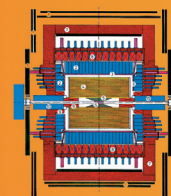
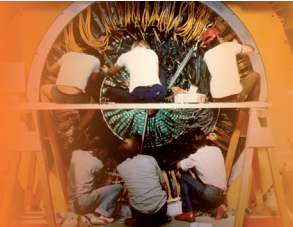
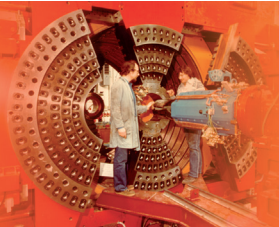


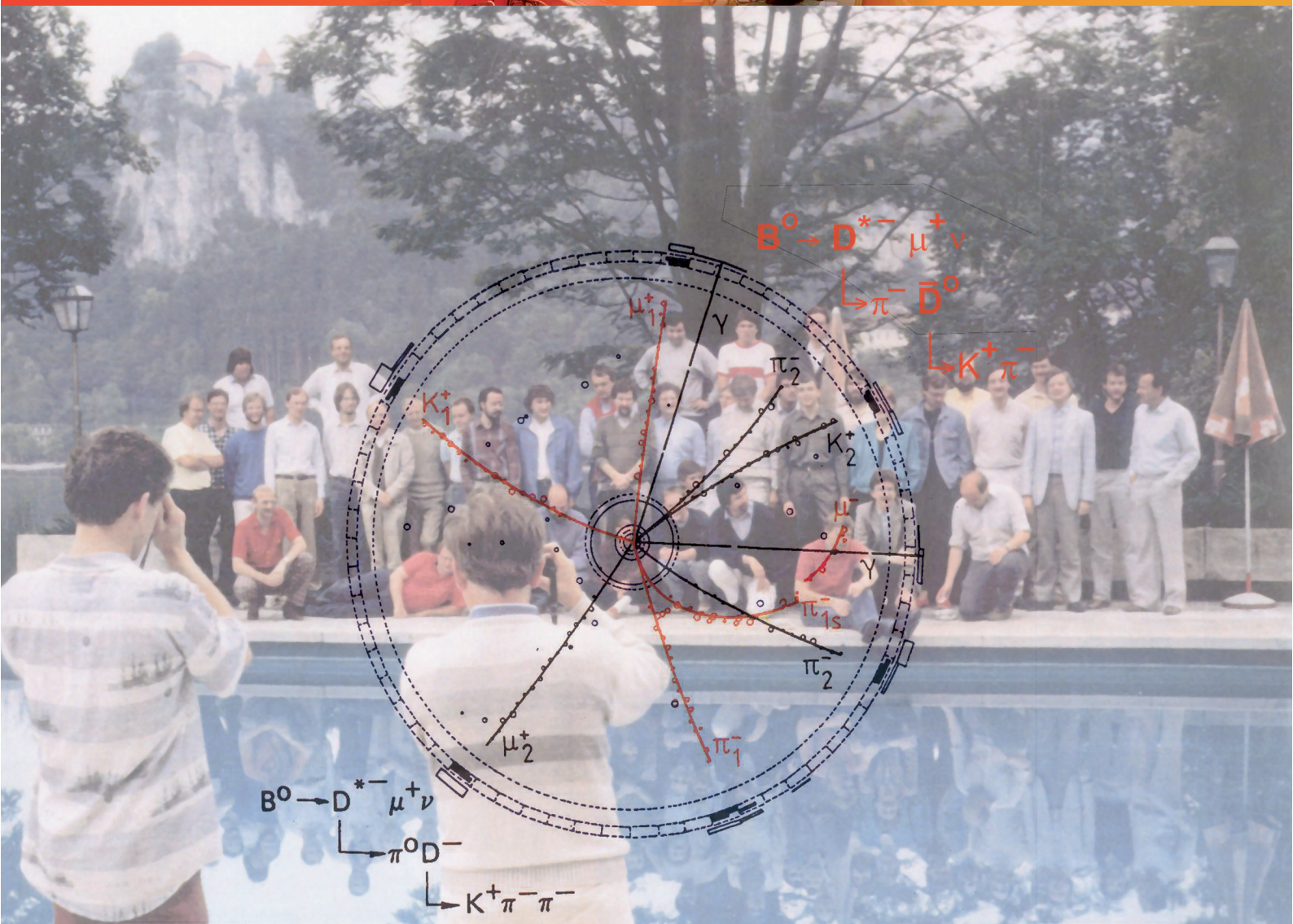
ARGUS

20 years of B meson mixing

Symposium, DESY



09
November
2007



ARGUS Fest

20 Years of B meson mixing

1987 - 2007

DESY Hamburg
09 November 2007

IMPRESSUM

Proceedings of the ARGUS – Symposium „20 Years of B Meson Mixing 1987 – 2007”

Workshop Homepage: <http://argus-fest.desy.de/>

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Editorial

Twenty years after the groundbreaking discovery of B meson mixing by the ARGUS experiment in 1987, around 150 physicists, among them many former ARGUS collaborators, gathered at DESY to celebrate the anniversary (<http://argus-fest.desy.de>) of this landmark for B physics.

The 1987 ARGUS observation was a big surprise to the community. Common belief at that time was that the top quark would be light, meaning that B mixing would be small if not negligible. However, ARGUS observed a substantial B meson mixing rate, indicating that the top quark must be much heavier than previously believed. The observed large mixing rate suddenly opened the door for CP-violating measurements in B physics and started to pave the way towards the design and construction of future B physics precision experiments that were then pursued at Babar/SLAC and Belle/KEK and will later be continued at LHCb.

The symposium opened with a talk by former DESY Director and CERN Director-General Professor Herwig Schopper, who had recognised the importance of heavy flavour physics very early on and established a B-physics programme at the DORIS storage ring at DESY immediately after the epochal b-quark discovery in 1977 by Leon Lederman at Fermilab. "At a time when most efforts at DESY were devoted to get PETRA in operation, DORIS and ARGUS were in the shadow of this large sister," remembered Professor Schopper. "To the surprise of most of us, ARGUS was able to open up a new domain of particle physics."

The story of ARGUS and the not always straight path that finally led to a clear signature of B meson mixing was presented by Walter Schmidt-Parzefall, the founding father and long-time spokesman of the experiment. Schmidt-Parzefall formed a team of young physicists to draft a concept for a new detector at DORIS. Officially, the chosen name ARGUS indicated the origin of the founding institutions: A Russian-German-United States-Swedish Collaboration. However, the founding fathers had also in mind that ARGUS was a legendary giant in Greek mythology, which was famous for having many eyes such that nothing in its vicinity could escape his view.

The ARGUS experiment took data from 1982 to 1992. In that decade the ARGUS collaboration contributed substantially to various fields of high-energy physics. Its 150 publications in high-energy physics are nearly cited 10'000-times.

Other speakers of the Symposium, including David Cassel, Professor at Cornell University and former member of the competing CLEO collaboration, stressed that the ARGUS discovery had "a profound effect on heavy quark physics and the CLEO programme".

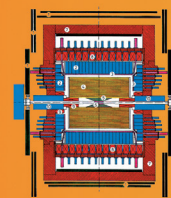
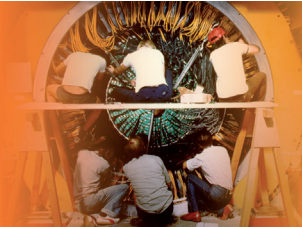
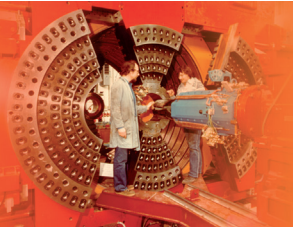
Talks did not only cover the physics but also the sociology of the experiment, and the slides were full of black-and-white photographs from the past and creative logbook entries made during ARGUS shifts.

With its large attendance the symposium was an excellent opportunity to meet old friends and to exchange pleasant remembrances of the good old time.

We are very grateful to all speakers at the symposium who did a wonderful job of recalling this exciting period in heavy flavour physics. With this Festschrift now at hand we have tried to capture this memorable event. We hope that many readers will enjoy it.

F. Lehner,
S. Faverot-Spengler
ARGUS Symposium Organization Team





Twenty years ago, in 1987, the ARGUS collaboration discovered the B meson mixing at the DORIS storage ring at DESY. Contrary to common belief at the time the observed mixing rate in the B meson system was substantial. The ARGUS observation opened a new chapter in B physics which is still being written by present day's experiments and will be continued well into the LHC era. It is my pleasure to welcome you to the ARGUS Symposium 'Twenty Years of B meson mixing'. I wish you an interesting symposium which recalls this exciting period in heavy flavour physics and a pleasant get together evoking cheerful memories of the good old times.



Prof. Dr. Albrecht Wagner,
Chair of the DESY Directorate

At the time when most of the efforts at DESY were devoted to get PETRA in operation, DORIS II and ARGUS were 'in the shadow' of this larger sister. To the surprise of most of us ARGUS was able to open up a new domain of particle physics by the first measurement of B meson mixing, a result that compares well with the other great achievements at DESY.

Celebrating this event after twenty years offers an excellent occasion to remember those times which appear even more glorious when looking back from our present knowledge. It will also be an opportunity to meet old friends and exchange pleasant reminiscences.



Prof. Dr. Herwig Schopper,
Former chair of the
DESY Directorate

Program

SESSION 1: Chair: Rolf-Dieter Heuer

- 14:00 Welcome**
Albrecht Wagner (DESY)
- 14:10 Launching of DORIS II and ARGUS**
Herwig Schopper (CERN)
- 14:30 B Physics: The past and present**
Zoltan Ligeti (LBL)
- 15:00 Discovery of B mixing 1987**
Walter Schmidt-Parzefall (Hamburg)
- 15:40 Coffee break**

SESSION 2: Chair: Henning Schröder

- 16:10 Sociology of ARGUS**
Dietrich Wegener (Dortmund)
- 16:30 B Physics at CLEO**
David Cassel (Cornell)
- 16:50 From ARGUS to B-Meson Factories**
Klaus Schubert (Dresden)

- 17:10 Results from Babar/Belle**
Jim Olsen (Princeton)

17:40 Coffee break

SESSION 3: Chair: David MacFarlane

- 18:10 B Physics Results from Tevatron**
Stephanie Hansmann-Menzemer (Heidelberg)
- 18:30 Future B Physics Programs**
Andrey Golutvin (ITEP)
- 18:50 Ceterum Censeo Fabricam Super Saporis Esse Faciendam – on the Future of Flavour Physics**
Ikaros Bigi (Notre Dame)
- 19:20 Group picture of all ARGUS members**

Afterwards Reception and Dinner (DESY-Bistro)

ARGUS Dates

W. Schmidt-Parzefall and D. Wegener

May 29, 2008

Spring 1977	H. Schopper initiates a high energy program at DORIS
30.6.1977	PLUTO proposal DESY #144 for high energy program at DORIS ($\leq 8.6\text{GeV}$)
30.6.1977	Announcement of $\Upsilon(1S)$ discovery by experiment E288 at FNAL
6.7.1977	First discussion to upgrade DORIS to 2x5 GeV (DORIS I) by PLUTO and maschine physicists
15.7.1977	279. meeting of DESY Forschungskollegium, strong support for upgrade
14.9.1977	W. Schmidt-Parzefall and D. Wegener decide to collaborate at DORIS
10./11.10.1977	Meeting on DORIS experiments. First version of ARGUS detector presented by W. Schmidt-Parzefall
16.12.1977	Proposal to upgrade DORIS to 2 x 5 GeV accepted
20.2.1978	Upgrade DORIS I \rightarrow DORIS II starts
15.4.1978	Scan of $\Upsilon(1S)$ region starts
30.4.1978	$\Upsilon(1S)$ observed at DESY by DASP 2 and PLUTO collaboration
August 1978	$\Upsilon(2S)$ observed at DESY by DASP II and LENA collaboration
October 1978	ARGUS proposal (DESY #148) submitted
4.12.1978	Support of ARGUS plans by Scientific Council
June 1979	Final discussion of ARGUS proposal in PRC
5.7.1979	ARGUS proposal approved by directorate
July 1979	Low-beta insertion to increase luminosity proposed by K. Wille
1979-1982	Building of ARGUS detector
March 1980	DORIS I stops running for high energy physics
February 1981	DORIS II (11.2 GeV machine) proposed
February 1981	Workshop on DORIS physics, Crystal Ball transfer from SLAC to DESY proposed
Autumn 1981	IPP Canada and University of Kansas join collaboration
November 1981	DORIS II upgrade started
Spring/Summer 1982	Assembly of ARGUS detector
May 1982	DORIS II starts running
6.10.1982	ARGUS rolled into interaction region and starts data taking
October 1983	First ARGUS publication submitted
1984	University of Ljubljana joins collaboration
1985	DORIS II run at $\Upsilon(4S)$ with priority
20.9.1985	ARGUS memorandum to PRC (PRC 85/05) emphasizing need to run also 1986 with priority at $\Upsilon(4S)$
25.9.1986	Evidence for $B^0\bar{B}^0$ mixing presented in group meeting by H. Schroeder
25.6.1987	Observation of $B^0\bar{B}^0$ mixing published
1988	University of Erlangen joins collaboration
1991	Upgrade of DORIS II (bypass) for synchrotron radiation
8.10.1992	ARGUS stops data taking
Spring 1993	Tests to increase DORIS II luminosity fail
17.6.1993	B. Wiik informs Scientific Council of decision to stop running of DORIS II for high energy physics
19.11.1993	ARGUS "End of the Run Party"
20.4.2000	Last ARGUS paper submitted

Launching DORIS II and ARGUS

Herwig Schopper, Geneva

It is a great pleasure and honor to be back at DESY and talk about one of the most important results obtained in this laboratory. My task will be to sketch the general historical background which will be filled in by more competent speakers.

Early days of DESY and DORIS

When DESY was founded in 1959 by W.Jentschke, the experience concerning high-energy accelerators was very limited in Germany. Nevertheless thanks to the help of American colleagues it became possible to put into operation already in 1964 an electron synchrotron with an energy of 6.3 GeV and experiments started quite fast. After this success DESY became more ambitious and a unique facility was envisaged.

DORIS (**Doppel-Ring-Speicher**, "double-ring storage") with a circumference of nearly 300 m was proposed in 1966, construction started in 1969 and operation began in 1974. The objective was to study both, collisions between electrons and their antiparticles, the positrons, but also between electrons and electrons. Whereas one ring is sufficient for the first purpose, two rings are needed for the second, since electrons cannot circulate in opposite directions in the same magnetic ring. With two rings also collisions of electrons with protons were considered, a possibility which became a reality only much later with HERA.

A difficult discussion concerned the maximum beam energy which this new facility should provide. Some famous theoreticians argued that it would not make sense to build such a machine with a beam energy of more than about 2 GeV. They had good arguments. The cross section for the collision of pointlike particles is predicted by quantum mechanics to decrease with the square of the collision energy and all form factors for extended particles (known or unknown) have to be smaller than 1. With the number of collisions per second (luminosity) expected for the new facility one could calculate that the number of observed events would be too small to obtain reasonable results.

After consulting many people at DESY and in other laboratories Jentschke took two brave decisions: the initial energy of the beams should be 3 GeV; the magnets keeping the particles on their circular orbits should be good for energies up to 4.3 GeV. The reason for these two different energies was due to the fact that in an electron storage ring the particles lose energy by synchrotron radiation which increases very rapidly with increasing energy. To compensate for this loss powerful radio frequency accelerating cavities have to be used

and the originally foreseen rf power was sufficient to store electrons at 3 GeV. If unexpected discoveries were made, it would be possible to boost the beam energies to 4.3 GeV by just adding rf cavities. Indeed this foresight made it possible that in 1978 DORIS could become a major player in the investigation of the b-quark (Fig.1).

In the two long straight sections of DORIS two experiments were installed, PLUTO and DASP, which were built and operated by international collaborations. Following the surprising discoveries of the J/ψ particle, (a bound state between a c-quark and its antiquark) and the superheavy electron (the τ particle) it became obvious that DORIS was an excellent facility to investigate this rich field of physics. Indeed several important contributions could be made by the DORIS experiments for the "excited charmonium states". The establishment of a new kind of excited state of the J/ψ (p-wave quark-antiquark state) and the discovery of semileptonic decays of the D-particle are only two examples. With these discoveries DORIS made important contributions to establishing the quark model and in particular to proving the existence of heavy quarks.

But DORIS became also a powerful source for synchrotron radiation experiments, although in the early phases they could use DORIS only 'parasitically'. HASYLAB was established and for EMBL the first outstation was created at DORIS. Among the many achievements I want to mention the first tests of X-ray lithography at DESY, a procedure which was later refined to X-ray depth lithography.

I had become the chairman of the DESY directorate early in 1973 and had the pleasure to live through this (and the following) productive and interesting period in an involved position.

The way to DORIS I

In 1977 discussions started to increase the energy of DORIS (upgrading to DORIS I). This upgrading was initiated by a PLUTO proposal which asked for energies up to $2 \times 4.3 = 8.6$ GeV, the highest energies planned in the original design. The objective was to measure the total cross section for e^+e^- annihilation in order to study excited charm states and to investigate the τ lepton. A search for the third quark generation was not mentioned, however.

This proposal was presented to the Forschungskollegium on 30 June 1977 which gave its full support. By chance, on this very same day a public seminar was organized at FNAL in the USA during which the $Y(9.46 \text{ GeV})$ resonance was announced. Of course, this became immediately known everywhere and already on 6 July 1977 PLUTO started discussions with machine people concerning a possible upgrade to 5GeV/beam (D.Degele, J.Bürger, L.Criegee, G.Flügge). Such an energy increase seemed feasible provided only one ring of DORIS would be operated and some accelerating cavities of PETRA and power supplies would be used. Also some changes to the DORIS magnetic lattice were envisaged to avoid saturation effects. This scheme was immediately supported by the Forschungskollegium on 15 July 1977. A possible physics program at 10 GeV was discussed at a DESY workshop in October 1977 where J. Bürger and H. Schröder presented the physics program of the PLUTO and DASP II collaborations (since the DASP group had moved to PETRA a new collaboration DASP II had been formed). The physics priorities from the theorists' point of view were discussed by T. Walsh. Astonishingly enough mainly the physics of the 2nd

generation of quarks was considered with the Υ decay into 3gluons only briefly mentioned. Both experimental groups, on the other hand, discussed in detail the possibility of learning about the properties of the 3. generation of quarks in only a few days of running.

DORIS I was approved by the Directorate on 16.12.1977. This was a difficult decision since the storage ring PETRA was supposed to start in 1978 and it enjoyed highest priority since it was in fierce competition with a similar project PEP at SLAC in California. It had also been foreseen to move PLUTO to PETRA and to dissolve the DASP collaboration. These plans were reconsidered, however, in view of the new situation.

On 20.2.1978, only a few months after this decision, DORIS I started to operate at the higher energy. This achievement was possible thanks to the initiative of Donatus Degele and the experience and dedication of the whole accelerator crew. The rapid energy upgrade of DORIS was unexpected to the outside. I remember a seminar given by A de Rujula at CERN in March 1978 where he discussed Υ physics and expected the first experimental results from CLEO at Cornell University early in 1979.

DORIS and the b-quark

The scan in the Υ (1S) region started at DESY on 15.April 1978. Both, the machine and the detectors, had problems in the beginning. A fluctuation observed by ARGUS and less prominently by PLUTO was convincing enough to motivate the DESY director to expend the first bottle of champagne. However, after a few days of running the peak vanished (its trace can still be found in the smaller step size of the scan around 9.38 GeV in the published resonance curve). Yet finally, on 30 April 1978 the resonance signal was established. The results obtained by PLUTO and DASP II proved that the resonance at 9.46 GeV was extremely narrow (Fig.2). In August 1978 DASPII could also find the narrow peak corresponding to the first excited state of the Υ at 9.9 GeV. These results were presented at the High Energy Physics Conference which took place at Hamburg in August 1978. A few months later DASP II and the LENA collaboration (which had replaced PLUTO) determined the parameters of the Υ (2S) state. I believe that only the DESY results by resolving the Υ peaks into narrow resonances and verifying the charge of the b-quark to be $1/3$ made the interpretation in terms of a bound state between a third quark and its antiquark credible. In my opinion DESY did not receive an appropriate credit for these measurements.

In 1979 DORIS was not much running since it had been decided to install a small intermediate positron accumulator PIA¹ to improve positron injection for PETRA. This freed DORIS for its own research programme. At the beginning of 1980 DASPII and LENA were continuing to take data for the Υ resonances but in March 1980 DORIS I stopped temporarily running for high energy physics in order to provide sufficient time for synchrotron radiation for EMBL and the Fraunhofer Society. This for DORIS was the beginning of a serious competition between high energy physics and the synchrotron radiation programme.

¹ Another girls' name for a facility. A liked this tradition at DESY of using nice easy to remember names. When I arrived many years ago at the airport of Hamburg and asked the taxi driver to take me to DESY he became angry and said he could not know all the addresses of the 'Daisies' at St.Pauli.

ARGUS

"A Russian-German-United States-Swedish Collaboration"². In summer 1977 I encouraged Schmidt-Parzefall whom I knew since our common time at Karlsruhe, to take over DASP (which became DASP II) and to consider the possibility for a new detector for DORIS. This I did since I was afraid of too little physics at DESY besides PETRA and that DORIS would not be used properly. I did it against the advice of many colleagues³. Initially the proposal for a new detector was not welcome since most people thought that all efforts should go to PETRA and its experiments. In the end, however, all the committees gave their blessings.

Schmidt-Parzefall accepted the challenge and contacted colleagues. For the formation of the new collaboration apparently a dinner at Dortmund in September 1977, the 'Wegener Dinner', was essential. Schmidt-Parzefall presented the ARGUS proposal at a meeting on DORIS experiments on 10/11 October 1977 (DESY F15/01, November 1977) which contained already the most important elements of the final design: large solid angle (hermeticity), particle identification, shower counter for detection of low energy photons inside the magnetic coil, muon chambers. The proposal 'ARGUS – a new detector for DESY', was presented to the Forschungskollegium (Proposal Nr. 146) in October 1978. The main actors among the 90 scientists participating in the collaboration were W. Schmidt-Parzefall and H.Schröder from DESY, D.Wegener from Dortmund, K.R.Schubert from Heidelberg, P.Böchmann and L.Jönsson from Lund, M.Danilov from Moscow and R.L.Childers and C.W.Darden from South Carolina.

The Scientific Council gave its approval on 4 December 1978 and it is stated in the Minutes: "Schopper reports further that the Forschungskollegium has positively evaluated the proposal of a new detector ARGUS. The cost will be DM 8 million with the use of several components of DASP". After clarifying all the resources the Directorate approved ARGUS in July 1979 with the target to be operational in 1981.

The final design followed in many details the original idea with only the layout of the drift chamber improved to account for the requirements of optimal pattern recognition. The physics benchmarks in the proposal were charm and τ physics. A detailed evaluation of a possible B- physics program was presented in April 1980. An expanded analysis of the possibilities of studying B physics with ARGUS followed in February 1981 when it became clear that DORIS I could be upgraded to an energy of 11.2 GeV. The ARGUS detector was built and it worked in a stable manner from 1982 to 1992 (Fig.3).

During a DORIS workshop in February 1981 the idea arose to transfer the Crystal Ball detector from SLAC to DESY. The proposal was soon presented and accepted in summer 1981. The Crystal Ball detector was transported to DESY in spring 1982 and started data taking August 1982 while ARGUS rolled in two months later. Both experiments were approved for running for 3 years, but Crystal Ball was given priority for one year. The competition between the two experiments delayed the B -physics program at DORIS for nearly 3 years because the Crystal Ball collaboration preferred to run at the energy of the Υ resonances being optimised for spectroscopic studies.

² One of the spouses knowing the senior members of the group too well interpreted the logo as 'Alle Richtigen Genies Unter Sich'.

³ The only other case where I took a decision neglecting advice and against the opinion of competent committees was the establishment of the heavy-ion programme at CERN during the construction of LEP.

DORIS II

A new chapter started at DESY on 1 January 1981 when V. Soergel took over the helm of DESY since I left to become Director General of CERN (Fig.4).

Early in 1981 discussions started to increase the energy of Doris further. G.-A. Voss presented to the Scientific Council the possibility to go to about 11 GeV requiring, however, a change of the magnetic lattice of DORIS. Consecutively K. Wille worked out a concrete scheme allowing 2×5.6 GeV with reduced considerably the power consumption. The essential differences of DORIS II with respect to DORIS I were the decrease of the magnetic gap width and the increase of the number of coil windings of the magnets thus reducing saturation effects and power consumption. The injection was improved by installing separator plates and a faster kicker magnet. A major increase in the luminosity was achieved by mounting special strong-focussing quadrupoles at a small distance from the interaction points. The cost of the upgrading was estimated at DM 2 million and 6 months of shut down were needed. The shut-down started on 2 November 1981 and after an incredible short time DORIS II started operation in May 1982. With these improvements DORIS II achieved a maximum integrated luminosity of $1.8 \text{ pb}^{-1}/\text{day}$ and an average luminosity of $0.5 \text{ pb}^{-1}/\text{day}$.

In the period 1983-85 DORIS II was running mainly for the Crystal Ball at the $\Upsilon(1S)$ resonance. For second part of 1986 ARGUS was declared to be the main user, but Schmidt-Parzefall had to complain to Scientific Council on 4 March 1986 asking for beam time (100 pb^{-1}) at the $\Upsilon(4S)$ in 1986 and sufficient luminosity in 1987 and indeed the great success came.

On 25 September 1986, H. Schroeder presented at an ARGUS group meeting the first results of an analysis of 50 events with reconstructed B^0 - B^0 bar. These events allowed the observation of ‘B-mixing’ which means the transformation of a B meson into its antiparticle, an anti-B meson. It was observed for the first time in the ARGUS detector and implies the discovery of a new fundamental property of the bottom quark. It is characterised by a mixing ratio and its value was found to be $r_d = 0.20 \pm 0.12$. The great news were for the first time communicated ‘publicly’ in a meeting of the Scientific Council on 16 March 1987 and were reported at the EPS Conference at Uppsala, 25 June 1987. They became the highlights at the International Lepton-Photon Symposium at Hamburg, 27/31 July 1987 and the CERN Courier⁴ reported about this event: “The session on the weak decays of quarks included the now famous result from the ARGUS experiment at DESY on particle mixing in the neutral B meson system”.

No doubt, the discovery of the B-mixing belongs to the most important discoveries made at DESY and hence it is fully justified to celebrate its 20 anniversary!

It should be mentioned that another important result reported at the Hamburg conference was the observation of the B-decay ‘without charm’, i.e. no particles containing a charm quark were observed in the final state of the decay.

ARGUS was one of the most successful detectors at DESY. Hence the leading physicists received a number of distinctions. W. Schmidt-Parzefall, spokesman of ARGUS for many years, received in 1995 the Gentner-Kastler Prize, a common prize of the German and

⁴ CERN Courier, 27, September, pg.4, 1987

French Physical Society. M. Danilov was honoured by the Max-Planck Research Prize in 1996 and the Karpinskij -Prize of the Töpfer Foundation in 1998. Finally H.Schröder and Y.Zaitsev were distinguished in 1997 by the Panofsky Prize of the American Physical Society.

A short Top excursion

I may be allowed to insert a short diversion concerning the top quark. My top story started when in 1977 a ‘sure’ theoretical prediction was made for the mass of the top $m_{\text{top}} \approx 44 \text{ GeV}/c^2$. Consequently a strong request was made that PETRA operating at beam energies around 19 GeV should be pushed to higher energies. The accelerating RF power was increased at quite some cost and 22 GeV/beam could be reached! The result: no top was found!! The lesson is that experiments do more than just confirm theories!

Nine years later the experimental situation was still unsatisfactory, the top had still not been observed and theorists were unable to make any predictions for its mass. In 1986 the UA1 experiment at CERN claimed⁵ to have observed a signal for the top with a mass of about 40 GeV/c^2 . Great enthusiasm! and I had the honour to baptise a newly born tiger in the zoo of Leipzig with the name Top (Fig.5).

What is the relation with ARGUS? For a top mass as observed by UA1 a small B-mixing parameter of about $r_d = 0.01$ was expected which was in disagreement with the final ARGUS result of $r_d = 0.171 \pm 0.048$. From the large mixing parameter measured by ARGUS one could infer that the top mass had to be large, $m_{\text{top}} > 50 \text{ GeV}/c^2$. It is now history that the top mass was indirectly determined at LEP and that the top was finally produced by the TEVATRON at FNAL with a mass of about 171 GeV/c^2 , much higher than ever expected. However, the ARGUS result was the first experimental indication for such a high top mass.

The last days of ARGUS

The year 1989 was another good year for ARGUS with 190 days of running with a total luminosity of 201 pb^{-1} and only 66 days for synchrotron radiation. During the first quarter of 1990 a new vertex detector and central drift chamber were installed in ARGUS and it was running until June, but with low total luminosity 17 pb^{-1} . In July a long shut-down started for the installation of a by-pass at DORIS to produce higher intensities for synchrotron radiation users. Also a silicon detector was installed for Argus. 1991 was the last good year for Argus with a luminosity of 300 pb^{-1} which allowed the production of many interesting data.

But 1992 became a fatal year for ARGUS. The bypass turned out to be very useful for synchrotron radiation but a catastrophe for high-energy physics. The previously reached high luminosities could never be achieved again. Only a total luminosity of 17 pb^{-1} could be obtained in 1992 and in October ARGUS stopped data taking after a mishap (damage of the silicon vertex detector by the beam) had occurred. V.Soergel asked the Extended

⁵ G. Arnison et al. (UA1), Phys. Lett. B147 (1987) 493

Scientific Council on 26 November 1992 for advice on the future DORIS programme. It was decided that the high-energy physics programme should be abandoned if the previously achieved luminosities could not be reproduced until spring 1993. This attempt failed and B.Wiik who had followed V.Soergel as chairman of the Directorate, had to inform the Extended Scientific Council on 17 June 1993 that in agreement with the ARGUS group the Directorate had decided to stop DORIS II for particle physics. The achievements of ARGUS were acknowledged in a colloquium on 22 November 1993 by D.Cassels and B.Stech.

This is the short story of ARGUS and how it contributed to the reputation of DESY. Looking back this seems to have been the Golden past when decisions could be taken and implemented at short notice. More details will be reported by other authors at this meeting.

DESY will remain an outstanding laboratory for particle physics, even with HERA having stopped to operate and PETRA being converted into a dedicated synchrotron radiation facility. Of course, emphasis will change but accelerator and detector development will remain a major part of the DESY programme. Participation in experiments at other laboratories will be another important objective in which case DESY should also have the task to support groups from other German universities or laboratories. Non-accelerator experiments will remain an essential activity of DESY – Zeuthen. Together with new facilities such as the free electron X-ray laser, DESY has, as I am certain, a bright future for which I transmit my best wishes.

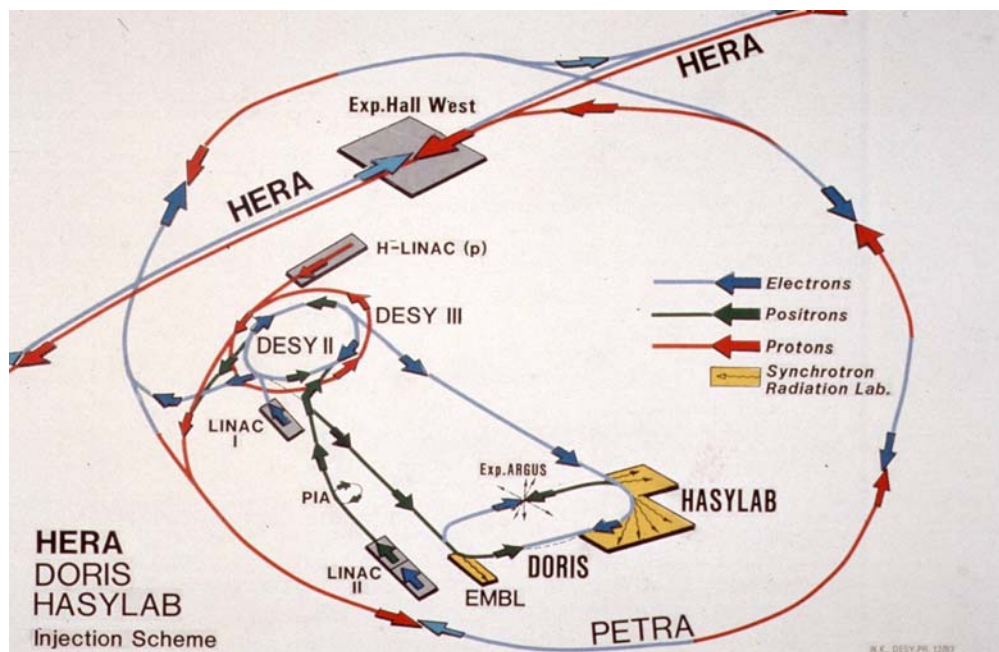


Fig.1. The plan of DESY

FNAL
First evidence of Upsilon

DASP
Upsilon resonances resolved

II

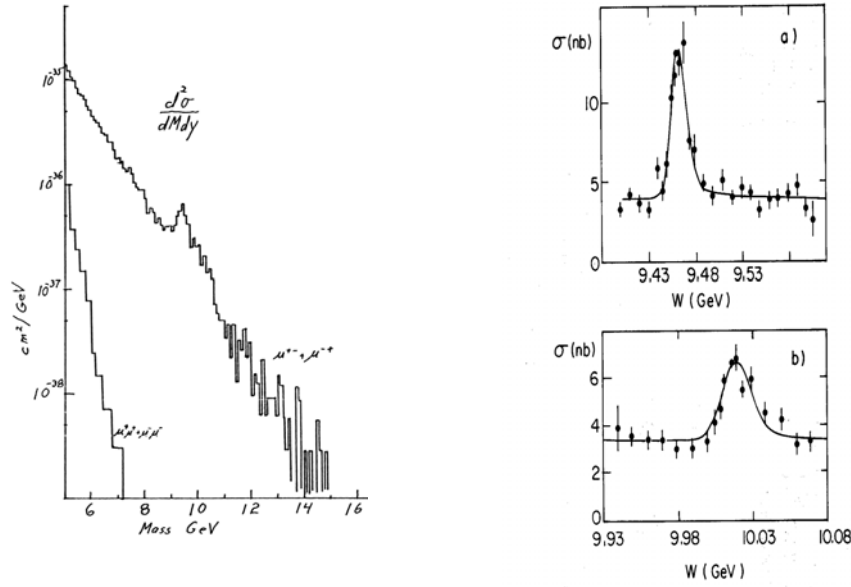


Fig.2. The discovery of the Upsilon



Fig.3. The ARGUS crew



Fig.4. Jentschke, Schopper and Soergel in 1980



Fig.5. Schopper baptises a new born tiger at the name TOP in the zoo of Leipzig with the director of the zoo watching

***B* Physics: Past and Present**

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Abstract

After recalling the significance of the discovery of B^0 – \bar{B}^0 mixing, we review the current status of flavor physics, starting with measurements pioneered by ARGUS and CLEO, followed by what we learned about CP violation from *BABAR* and Belle. We discuss the implications of the recent discoveries of B_s^0 – \bar{B}_s^0 and D^0 – \bar{D}^0 mixing, and conclude with a brief outlook for flavor physics in the LHC era.

1 Introduction: B^0 – \bar{B}^0 mixing in 1987

The discovery of B^0 – \bar{B}^0 mixing [1], which this symposium celebrates, is one of two major breakthroughs that occurred in 1987, which play prominent roles in particle physics to date (the other being Supernova 1987a and the detection of the neutrinos associated with it [2]).¹

The unexpectedly large value of Δm_B , i.e., the unexpectedly fast B^0 – \bar{B}^0 oscillation was surprising, because it indicated a much heavier top quark mass than the direct search limits at that time, which was $m_t > 23$ GeV. While the first announcement at DESY was in a seminar on February 24 [3], and the ARGUS paper [1] was received by Phys. Lett. B on April 9, the first theory paper analyzing the consequences of the discovery was received and published earlier [4], followed by a number of other studies [5, 6, 7, 8]. (Actually, it was pointed out in 1983 [but not taken too seriously] that if the B lifetime was large, the upper bound on $\Gamma(b \rightarrow u)/\Gamma(b \rightarrow c)$ and the measured value of ϵ_K implied a heavy top; for $\tau_B = 1.5$ ps, $m_t > 60$ GeV [9].)

In the standard model (SM), once $m_t \gg m_{u,d,s,c,b}$, the dominant contributions to Δm_B come from box diagrams with intermediate top quarks

¹A few minutes at the beginning of the talk were devoted to events unrelated to physics that also occurred in 1987, which are probably better not put in writing. And the Nobel Prize in physics in 1987 was shared by Bednorz and Müller for their discovery of high- T_c superconductivity, something which we still don't fully understand.

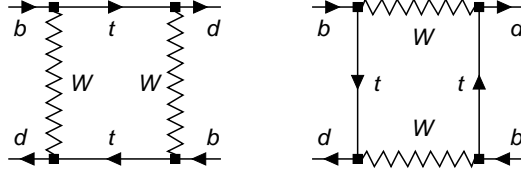


Figure 1: Dominant contributions to $B^0-\bar{B}^0$ mixing in the standard model.

shown in Fig. 1. Therefore, Δm_B is determined by short-distance physics,

$$\Delta m_B = |V_{tb}V_{td}^*|^2 \frac{G_F^2}{4\pi^2} \frac{m_W^2}{m_B} \times S\left(\frac{\bar{m}_t^2}{m_W^2}\right) \eta_B b_B(\mu) \times \langle B^0 | Q(\mu) | \bar{B}^0 \rangle, \quad (1)$$

except for the matrix element of $Q(\mu) = (\bar{b}_L \gamma_\nu d_L)(\bar{b}_L \gamma^\nu d_L)$ in the last term,

$$\langle B^0 | Q(\mu) | \bar{B}^0 \rangle = \frac{2}{3} m_B^2 f_B^2 \frac{\hat{B}_B}{b_B(\mu)}, \quad (2)$$

which is a nonperturbative quantity. In Eq. (1) $S(\bar{m}_t^2/m_W^2)$ is an Inami-Lim function [10], while $\eta_B \simeq 0.55$ and $b_B(\mu)$ contain the QCD corrections that occur in running the effective Hamiltonian down to a low scale and resum the potentially large logarithms of m_W/μ . Hadronic uncertainties enter via $f_B^2 \hat{B}_B$, which has to be determined from lattice QCD.

Using the available model predictions of f_B (which tended to be smaller than its currently favored value) and the upper bound on $|V_{td}|$ (which followed from $|V_{cb}|$ and the bound on $|V_{ub}/V_{cb}|$), the ARGUS discovery implied $m_t > 50 - 100$ GeV. This was the first indication that the top quark may not be observable at SLC and LEP. It also implied that there would be no top flavored hadrons, and that $B_s-\bar{B}_s^0$ mixing had to be maximal.

Of course, if there is beyond SM physics near the electroweak scale, it could modify the conclusions. Simply box diagrams with charged scalars in a two Higgs doublet model could have given rise to “A light top quark after all?” [11] (a scenario later excluded [12]). The lesson from this is that the interpretation of measurements of flavor-changing neutral-current (FCNC) processes in general — due to their sensitivity to physics at high scales — depend on whether one assumes the SM to be valid.

2 Flavor physics

In the standard model, the only interaction of quarks that distinguish between the three generations is their Yukawa couplings to the Higgs condensate, which gives rise to quark masses and all flavor changing phenomena

described by the Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix [13, 14]. We do not understand the hierarchy of the masses and mixing angles. Moreover, if there is new physics (NP) at the TeV scale, as suggested by the gauge hierarchy problem, it is puzzling why it has not shown up in flavor physics. For example, the four-quark operator, $(s\bar{d})^2/\Lambda_{\text{NP}}^2$, with $\mathcal{O}(1)$ coefficient would give a contribution exceeding the measured value of the CP violating parameter ϵ_K in the kaon sector [15], unless $\Lambda_{\text{NP}} \gtrsim 10^4$ TeV. In fact, most extensions of the SM aimed at solving the hierarchy problem contain new sources of CP and flavor violation. For example, generic SUSY models have 43 new CP violating phases [16, 17], and many of them have to be tiny in order not to contradict the experimental data. Finally, the observed baryon asymmetry of the Universe requires CP violation beyond the SM, however, it need not be in flavor changing processes (may affect electric dipole moments only) and it need not occur in the quark sector (could be in the lepton sector or between new particles only). In any case, flavor physics is an important probe of new physics — if there is new physics at the TeV scale, it has to have a very special structure to avoid violating the bounds imposed by the existing flavor physics data.

2.1 Testing the flavor sector

The flavor sector of the SM contains 10 physical quark flavor parameters, the 6 quark masses and the 4 parameters in the CKM matrix, 3 mixing angles and 1 CP violating phase. Therefore, the SM predicts intricate correlations between dozens of different decays of s , c , b , and t quarks, and in particular between CP violating observables. Possible deviations from the CKM paradigm may modify (i) correlations between different measurements (e.g., inconsistent constraints from B and K decays, or CP asymmetries not equal in $B \rightarrow \psi K$ and ϕK); (ii) predictions for FCNC transition (e.g., Δm_{B_s} incompatible with SM, enhanced $B_{(s)} \rightarrow \ell^+ \ell^-$); (iii) enhanced (or suppressed) CP violation, (e.g., in $B \rightarrow K^* \gamma$ or $B_s \rightarrow \psi \phi$).

The goal is not only to determine SM parameters as precisely as possible, but to test by many overconstraining measurements whether all observable flavor-changing interactions can be explained by the SM. It is convenient to use the Wolfenstein parameterization [18] of the CKM matrix,

$$V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\bar{\rho} - i\bar{\eta}) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \bar{\rho} - i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}, \quad (3)$$

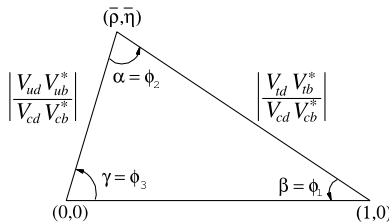


Figure 2: Sketch of the unitarity triangle.

which exhibits its hierarchical structure by expanding in $\lambda \simeq 0.23$, and is valid to order λ^4 . The unitarity of the CKM matrix implies $\sum_i V_{ij} V_{ik}^* = \delta_{jk}$ and $\sum_j V_{ij} V_{kj}^* = \delta_{ik}$, and the six vanishing combinations can be represented by triangles in a complex plane. The ones obtained by taking scalar products of neighboring rows or columns are nearly degenerate, so one usually considers

$$V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0. \quad (4)$$

A graphical representation is the unitarity triangle, obtained by rescaling the best-known side to unit length, see Fig. 2. The sides and angles can be determined in many “redundant” ways, by measuring CP violating and conserving observables. Considering the constraints on $\bar{\rho}$ and $\bar{\eta}$ is a convenient way to compare overconstraining measurements (however, some important ones cannot be represented on this plane in a useful way).

The CP violating parameter in the K system, ϵ_K , which has been precisely known for a long time, is at a level compatible with the SM; i.e., it can be accommodated with an $\mathcal{O}(1)$ value of the KM phase. The other observed CP violating quantity in kaon decay, ϵ'_K , is notoriously hard to interpret, because the electromagnetic and gluonic penguin contributions tend to cancel [19], significantly enhancing the hadronic uncertainties.² We cannot even rule out yet that NP is responsible for a large part of the measured value of ϵ'_K , so it does not provide a strong test of the KM mechanism. In the kaon sector, precise tests may come from measuring $K \rightarrow \pi \nu \bar{\nu}$ in the future.

3 The ARGUS and CLEO era

I focus here on a few semileptonic B decay measurements, for which many experimental techniques and theoretical tools were developed in the late 80's

²Amusingly, the Review of Particle Properties in 1986 [20], just before the ARGUS discovery, was the last edition in which ϵ'/ϵ was still within 1σ of 0. The first results of NA31 at CERN and E731 at Fermilab also appeared in 1987.

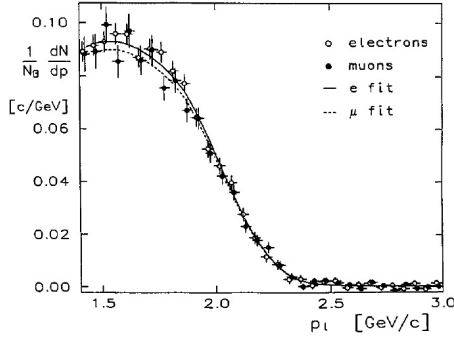


Fig. 3. Corrected momentum distribution of electrons and muons from $\Upsilon(4S)$ decays. The solid and dashed lines are the fits of the GISW model to the electron and muon data respectively.

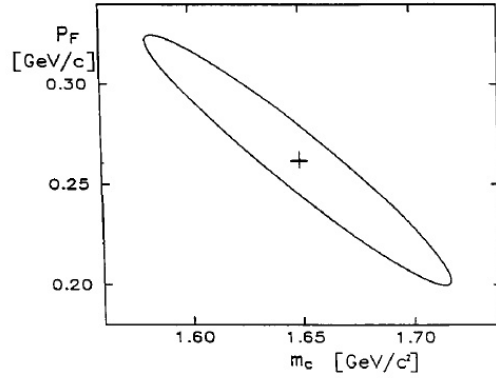


Fig. 4. Best fit and 1σ contour for p_F and m_c in the ACM model.

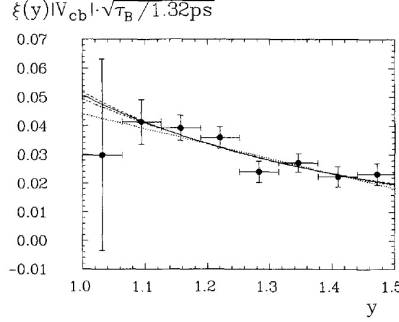
Figure 3: Semileptonic $B \rightarrow X_c \ell \bar{\nu}$ spectrum (left) and constraints on ACM model parameters (right) [21].

and early 90's. The successors of these yield the best measurements of $|V_{cb}|$ and $|V_{ub}|$ to date. They determine one side of the unitarity triangle and are crucial for the search for new physics, since these are tree-level measurements to which the loop processes sensitive to new physics can be compared.

3.1 Inclusive $B \rightarrow X_c \ell \bar{\nu}$ and $|V_{cb}|$

The inclusive semileptonic $B \rightarrow X_c \ell \bar{\nu}$ rate is obviously proportional to $|V_{cb}|^2$, and the “only” question was how to extract $|V_{cb}|$ without relying on models of the strong interaction. The state of the art around 1990 was to measure the charged lepton energy spectrum, and fit it to model predictions [21]; see the left plot in Fig. 3 (curiously, what is now known as the ISGW model was still called GISW [22] in the caption). It was already realized that the shape of the same spectrum can also be used to constrain the parameters of, say, the ACM [23] model, as shown in the right plot in Fig. 3.

Few years after these measurements, it was realized that the semileptonic decay spectra can be computed in a systematic, QCD based, operator product expansion (OPE) [24]. To make the perturbation series well behaved, instead of the pole mass an appropriate short distance mass scheme has to be used, e.g., the $1S$ mass [25]. By now the total rate, as well as moments of the lepton energy and the hadronic invariant mass spectra have been precisely measured and computed to order $\Lambda_{\text{QCD}}^3/m_b^3$ and α_s^2/β_0 [26] (very recently the full α_s^2 calculation is done [27]). These theoretical predictions are fit to about a hundred measurements from *BABAR*, *Belle*, and *CLEO*,



	$\xi(y)$	$ V_{cb} \times 10^3$	ρ	χ^2/dof
A	$1 - \rho^2(y - 1)$	$45 \pm 5 \pm 3$	$1.08 \pm 0.11 \pm 0.03$	5.1/6
B	$\frac{2}{y-1} \exp[-(2\rho^2 - 1)\frac{y-1}{y+1}]$	$53 \pm 8 \pm 3$	$1.52 \pm 0.21 \pm 0.10$	4.3/6
C	$(\frac{2}{y-1})^{2\rho^2}$	$51 \pm 8 \pm 3$	$1.45 \pm 0.19 \pm 0.09$	4.3/6
D	$\exp[-\rho^2(y - 1)]$	$50 \pm 8 \pm 2$	$1.37 \pm 0.19 \pm 0.08$	4.4/6

Table 5: Results on $|V_{cb}|$ and the “charge radius” ρ from various parametrizations of the Isgur-Wise function $\xi(y)$ [22] for fitting the q^2 -distribution

Figure 4: Semileptonic $B \rightarrow D^* \ell \bar{\nu}$ spectrum (left) and parameters of the fits with various functional forms to the $y = v \cdot v'$ distribution (right) [29].

and the fit determines simultaneously $|V_{cb}|$ and the hadronic parameters. Its consistency provides a powerful test of the theory. These fits have been performed in several schemes and give $|V_{cb}|$ and m_b with about 2% and 1% errors, respectively [26],

$$|V_{cb}| = (41.5 \pm 0.7) \times 10^{-3}, \quad m_b^{1S} = (4.68 \pm 0.04) \text{ GeV}. \quad (5)$$

The value of m_b is particularly important for the determination of $|V_{ub}|$ discussed below (this value corresponds to $\bar{m}_b(\bar{m}_b) = (4.18 \pm 0.04) \text{ GeV}$).

3.2 Exclusive $B \rightarrow D^* \ell \bar{\nu}$ and $|V_{cb}|$

Exclusive $B \rightarrow D^{(*)} \ell \bar{\nu}$ decays provide a determination of $|V_{cb}|$ complementary to inclusive decays, as both the theoretical and experimental uncertainties are different. The discovery of heavy quark symmetry [28] in 1989 opened the way for the model independent determination of $|V_{cb}|$, and the $B \rightarrow D^* \ell \bar{\nu}$ data was first analyzed by ARGUS [29] using the predictions of heavy quark symmetry.

In the $m_b, m_c \gg \Lambda_{\text{QCD}}$ limit, heavy quark symmetry relates all $B \rightarrow D^{(*)}$ form factors to a single Isgur-Wise function [28]. The relations hold at any value of the recoil parameter, $y = v \cdot v' = (m_B^2 + m_{D^{(*)}}^2 - q^2)/(2m_B m_{D^{(*)}})$, where v and v' are the four-velocities of the B and $D^{(*)}$, respectively. Moreover, the value of this function is known at zero recoil, $\xi(1) = 1$, and the measured form factor satisfies $F(y) = \xi(y) + \mathcal{O}(\alpha_s, \Lambda_{\text{QCD}}/m_{b,c})$. The left plot in Fig. 4 shows $|V_{cb}| \xi(y)$, which is how $|V_{cb}|$ is extracted from $B \rightarrow D^* \ell \bar{\nu}$ to date. The calculation of $F(1)$ is now dominated by lattice QCD [30].

As shown in the table in Fig. 4, already in the ARGUS analysis a dominant uncertainty was that from the functional form used to fit the data. This

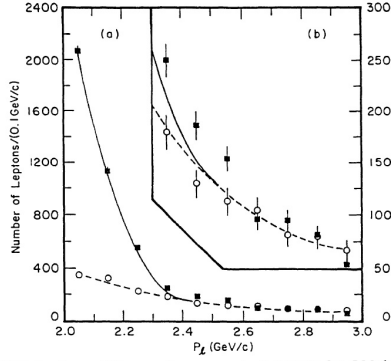


FIG. 1. Sum of the e and μ momentum spectra for ON data (filled squares), scaled OFF data (open circles), the fit to the OFF data (dashed line), and the fit to the OFF data plus the $b \rightarrow cl\nu$ yield (solid line). Note the different vertical scales in (a) and (b).

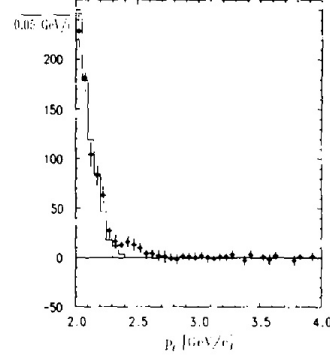


Fig. 5. Combined lepton momentum spectrum for direct $\Upsilon(4S)$ decays: the histogram is a $b \rightarrow c$ contribution normalized in the region 2.0–2.3 GeV/c.

Figure 5: First observation of semileptonic $B \rightarrow X_u \ell \bar{\nu}$ decay from CLEO [32] (left) and ARGUS [33] (right).

was largely reduced by the derivation of model independent constraints on the shape of the form factor [31], following from unitarity and analyticity.

3.3 Inclusive $B \rightarrow X_u \ell \bar{\nu}$ and $|V_{ub}|$

Before a nonzero value of $|V_{ub}|$ was established, it was not known whether the 3×3 CKM matrix contains CP violation, since its complex phase could be eliminated if any of the CKM elements vanished.

The $b \rightarrow u$ semileptonic decay was first observed by CLEO [32] and ARGUS [33]. Since one had to study the endpoint region of the $B \rightarrow X_u \ell \bar{\nu}$ spectrum to eliminate the much larger $B \rightarrow X_c \ell \bar{\nu}$ background (see Fig. 5), the hadronic model dependence was even greater than for $|V_{cb}|$, and was the dominant uncertainty. The CLEO paper concluded “ $|V_{ub}/V_{cb}| \dots$ is approximately 0.1; it is sensitive to the theoretical model” [32], while ARGUS was even more cautious, “If interpreted as a signal of $b \rightarrow u$ coupling the observed event rate leads to $\dots |V_{ub}/V_{cb}|$ of about 10%” [33].

The theoretical uncertainties became better controlled when it was realized [34] that the nonperturbative effects that lead to a breakdown of the OPE in the endpoint region of $B \rightarrow X_u \ell \bar{\nu}$ spectra can be related to the photon energy spectrum in $B \rightarrow X_s \gamma$, first measured by CLEO [35]. Thus, theoretical uncertainties are suppressed by $\mathcal{O}(\Lambda_{\text{QCD}}/m_b)$, but there are several unknown functions at that order, and it is hard to control them below the 10% level. Recently, with the full reconstruction method, the B facto-

ries could measure the neutrino momentum, which allowed access to wider kinematic regions and also to parts of phase space in which the $B \rightarrow X_c \ell \bar{\nu}$ decay is forbidden, but an OPE is still possible [36].

4 The *BABAR* and Belle era

An illustration that the B factories started a new era in the study of CP violation is the fact that for 35 years, from 1964 until 1999, there was only one CP violating quantity, ϵ_K , which was robustly measured. At the time of this Symposium, 19 CP violating quantities with different sensitivities to short distance physics are measured with at least 3σ significance (i.e., not counting $S_{\psi K_L}$ separately from $S_{\psi K_S}$, but considering $S_{\eta' K_S}$ as independent) [37]. Thus, the important measurements are those which are experimentally most precise and theoretically least uncertain, thereby providing the best sensitivity to constrain possible deviations from the SM. (The experimental techniques and more complete lists of references to the measurements can be found in J. Olsen's contribution.)

4.1 Mixing and CP violation (again)

The two neutral B meson states form a quantum mechanical two-level system, whose time evolution is described by

$$i \frac{d}{dt} \begin{pmatrix} |B^0(t)\rangle \\ |\bar{B}^0(t)\rangle \end{pmatrix} = \left(M - \frac{i}{2} \Gamma \right) \begin{pmatrix} |B^0(t)\rangle \\ |\bar{B}^0(t)\rangle \end{pmatrix}, \quad (6)$$

where M and Γ are 2×2 Hermitian matrices. The physical mass eigenstates (labelled heavy and light) are linear superpositions of the flavor eigenstates,

$$|B_{H,L}\rangle = p|B^0\rangle \mp q|\bar{B}^0\rangle. \quad (7)$$

The box diagrams in Fig. 1 (with t, c, u quarks) give rise to M_{12} and Γ_{12} . These in turn determine q/p (see, e.g., [38]), which plays an important role in CP violation,

$$q/p = e^{-2i\beta + (\xi_B + \xi_d - \xi_b)} + \mathcal{O}(10^{-3}), \quad (8)$$

where β is an angle of the unitarity triangle shown in Fig. 2, and $\xi_{B,d,b}$ are (unphysical) phase conventions for the meson and quark fields. In the SM, $|q/p|$ is very near unity, which means that CP violation in $B^0 - \bar{B}^0$ mixing is expected to be a small, $\mathcal{O}(10^{-3})$. (Recall that CP is violated in mixing

if and only if $\langle B_H | B_L \rangle = |p|^2 - |q|^2 \neq 0$, indicating that CP violation is an intrinsically quantum mechanical phenomenon.)

In some cases it is possible to obtain theoretically clean information on phases in the Lagrangian of the underlying theory from large CP violating phenomena. The simplest examples are CP violation in the interference of decay with and without mixing [39, 40], in particular, when the final state is a CP eigenstate. The interference between $\bar{B}^0 \rightarrow f_{CP}$ and $\bar{B}^0 \rightarrow B^0 \rightarrow f_{CP}$ is described by

$$\lambda_{f_{CP}} = \frac{q}{p} \frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}} = \eta_{f_{CP}} \frac{q}{p} \frac{\bar{A}_{\bar{f}_{CP}}}{A_{f_{CP}}}, \quad (9)$$

where $A_f = \langle f | \mathcal{H} | B \rangle$, $\bar{A}_f = \langle f | \mathcal{H} | \bar{B} \rangle$, and $\eta_{f_{CP}} = \pm 1$ is the CP eigenvalue of f_{CP} . Experimentally one can study the time dependent CP asymmetry,

$$a_{f_{CP}} = \frac{\Gamma[\bar{B}^0(t) \rightarrow f] - \Gamma[B^0(t) \rightarrow f]}{\Gamma[\bar{B}^0(t) \rightarrow f] + \Gamma[B^0(t) \rightarrow f]} = S_f \sin(\Delta m_B t) - C_f \cos(\Delta m_B t), \quad (10)$$

where t is the time difference between the flavor tag of the “other” B meson and the decay, and

$$S_f = \frac{2 \text{Im} \lambda_f}{1 + |\lambda_f|^2}, \quad C_f = \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2}. \quad (11)$$

If amplitudes with one weak phase dominate a decay, then $a_{f_{CP}}$ measures a phase in the Lagrangian theoretically cleanly. In this case $C_f = 0$ (no direct CP violation), and $S_{f_{CP}} = \text{Im} \lambda_{f_{CP}} = \sin(\arg \lambda_{f_{CP}})$, where $\arg \lambda_{f_{CP}}$ is the phase difference between the $\bar{B}^0 \rightarrow f_{CP}$ and $\bar{B}^0 \rightarrow B^0 \rightarrow f_{CP}$ amplitudes.

Equation (10) makes it clear that the unexpectedly large value of Δm_B discovered by ARGUS was very important to make the precision study of time dependent CP violation feasible.

4.2 Some key measurements

The theoretically cleanest CP violation measurement in B decays is $B \rightarrow \psi K^0$ (where $\psi = J/\psi, \psi'$). While there are tree and penguin contributions to the decay amplitude with different weak phases, the dominant part of the penguin amplitudes have the same weak phase as the tree. Therefore, contributions with the tree amplitude’s weak phase dominate, to an accuracy better than $\sim 1\%$. In the usual phase convention $S_{\psi K_{S,L}} = \mp \sin[(B\text{-mixing} = -2\beta) + (\text{decay} = 0) + (K\text{-mixing} = 0)]$, so we expect $S_{\psi K_{S,L}} = \pm \sin 2\beta$ and $C_{\psi K_{S,L}} = 0$ to a similar accuracy. The current world average is [37]

$$\sin 2\beta = 0.681 \pm 0.025. \quad (12)$$

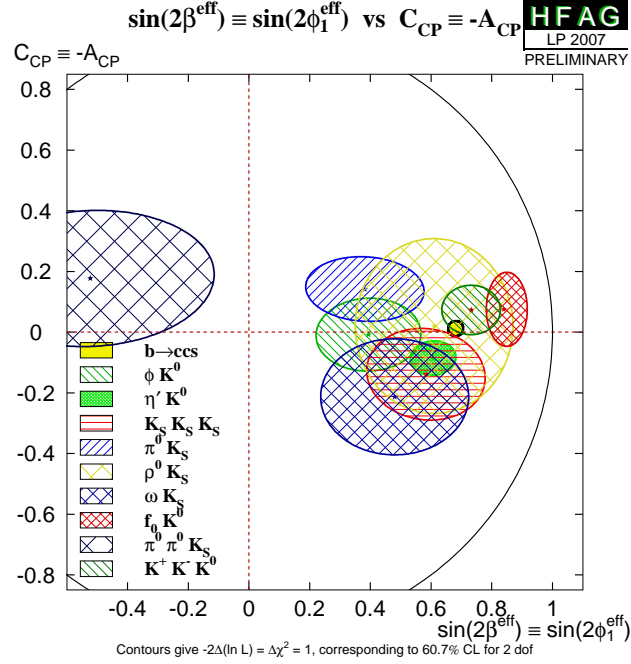


Figure 6: The CP asymmetries in $b \rightarrow s$ penguin dominated modes [37].

One of the most stringent tests of the SM flavor sector come from CP asymmetry measurements in $b \rightarrow s$ dominated transitions, such as $B \rightarrow \phi K^0$, $\eta' K^0$, $K^+ K^- K_S$, etc. These decays are dominated by one-loop (penguin) amplitudes in the SM, and therefore new physics could compete with the SM contributions [41]. Using CKM unitarity, one can write the contributions to such decays as a term proportional to $V_{cb}V_{cs}^*$ and another proportional to $V_{ub}V_{us}^*$. Since the ratio of these CKM elements is ~ 0.02 , we expect amplitudes with the $V_{cb}V_{cs}^*$ weak phase to dominate, similar to $B \rightarrow \psi K^0$. Thus, in the SM, the measurements of $-\eta_f S_f$ should agree with $\sin 2\beta$ (and C_f should vanish) to an accuracy of order a few times 0.02. Figure 6 shows the current measurements, with the tiny circle representing the tree-dominated $B \rightarrow \psi K^0$ mode. There is no significant evidence for deviations from the SM, e.g., $S_{\psi K} - S_{\phi K} = 0.29 \pm 0.17$.

The measurements of α and γ are less precise, although the results are better than they were foreseen a decade ago; the best modes to measure both are actually new since 2003. (I call a measurement of γ the determination of the phase difference between $b \rightarrow u$ and $b \rightarrow c$ transitions, and $\alpha (\equiv \pi - \beta - \gamma)$ refers to measurements of γ in the presence of $B^0 - \bar{B}^0$ mixing.)

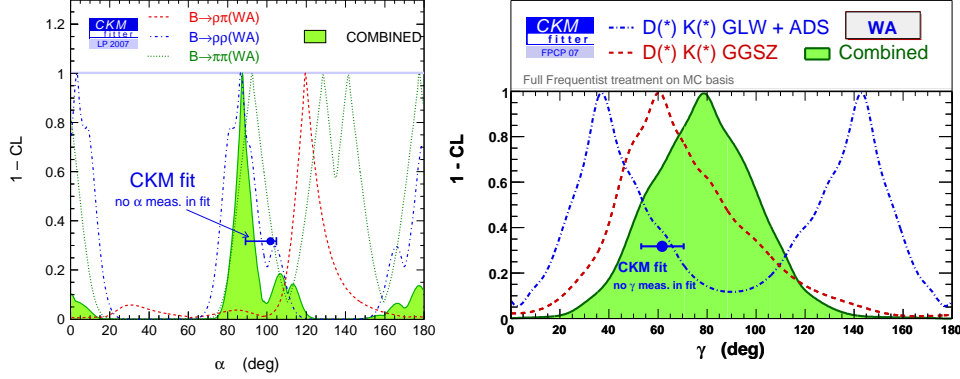


Figure 7: Measurements of the CKM angles α and γ [44].

In contrast to $B \rightarrow \psi K$, which is dominated by amplitudes with one weak phase, it is known since the CLEO observation of $B \rightarrow K\pi$ in 1997 [42] that in $B \rightarrow \pi^+\pi^-$ the penguin (P) amplitude is not much smaller than the tree (T). Before this measurement, one expected $S_{\pi^+\pi^-} = \sin[(B\text{-mixing} = -2\beta) + (\bar{A}/A = -2\gamma + \dots)] = \sin 2\alpha + \dots$. The ellipses denote $\mathcal{O}(P/T)$ terms, which are experimentally measured to be sizable. Therefore, to determine α model independently, an isospin analysis of all $B \rightarrow \pi\pi$ decay channels is needed [43]. The world average, including the $B \rightarrow \rho\rho$ and $\rho\pi$ modes, is shown in the left plot in Fig. 7. The $B \rightarrow \rho\rho$ mode dominates, because the data tell us that $|P/T|$ is relatively small in this mode.

The special feature of the measurements of γ compared to β and α is that γ is measured in entirely tree-level processes, in the interference of $b \rightarrow c\bar{u}s$ (e.g., $B^- \rightarrow D^0 K^-$) and $b \rightarrow u\bar{c}s$ (e.g., $B^- \rightarrow \bar{D}^0 K^-$) transitions, using common final states of D^0 and \bar{D}^0 . Since there are no two identical quarks in these decays, penguin diagrams cannot contribute, so new physics is very unlikely to effect these measurements. The world average, including several D decay modes is shown in the right plot in Fig. 7.

For all these angle measurements one would need much more data to approach the theoretical limitations, and the sensitivity to new physics would increase at least until when the experimental errors get ~ 10 times smaller.

4.3 Constraints on new physics in $B^0-\bar{B}^0$ mixing

In a large class of models the dominant NP effect in B physics is to modify the $B^0-\bar{B}^0$ mixing amplitude [45]. Assuming that the 3×3 CKM matrix is unitary and tree-level decays are SM dominated imply that there are two

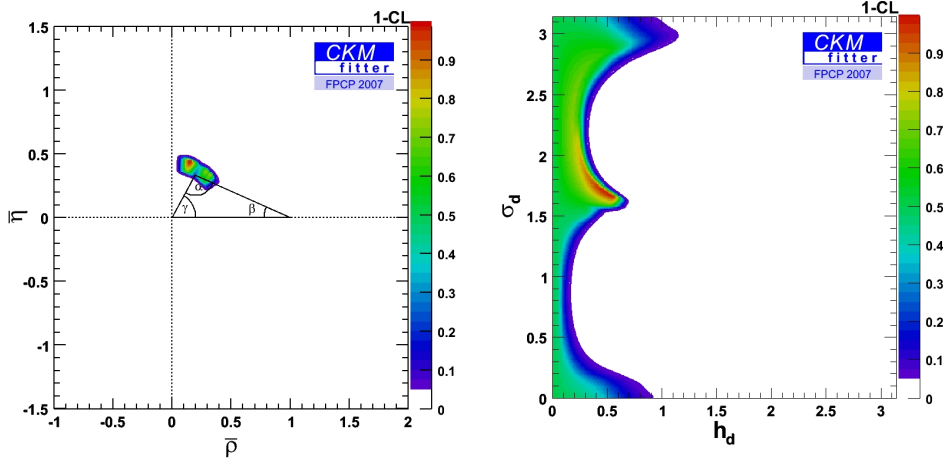


Figure 8: Allowed $\bar{\rho} - \bar{\eta}$ region in the presence of new physics in $B^0 - \bar{B}^0$ mixing (left), and the allowed $h_d - \sigma_d$ region (right) [44].

new parameters for each meson mixing amplitude,

$$M_{12} = M_{12}^{(\text{SM})} r^2 e^{2i\theta} = M_{12}^{\text{SM}} (1 + h e^{2i\sigma}). \quad (13)$$

The (h, σ) parameterization is more physical, since any new physics model gives an additive (and not a multiplicative) correction to M_{12} . To constrain new physics, it is crucial to have measurements of both new physics independent tree-level processes, such as $|V_{ub}/V_{cb}|$ and γ (or $\pi - \beta - \alpha$), and mixing dependent processes, which include Δm , S_{f_i} , A_{SL} [46].

It is a remarkable result of the B factories that the allowed $\bar{\rho} - \bar{\eta}$ region in the presence of new physics in mixing has become similarly small as it is in the SM, as shown in the left plot in Fig. 8. The right plot shows the allowed $h_d - \sigma_d$ region, indicating that new contributions to $B^0 - \bar{B}^0$ mixing at the level of 20 – 30% of the SM without a fine tuned phase are still allowed.

4.4 $B_s^0 - \bar{B}_s^0$ mixing

As mentioned in the introduction, the ARGUS discovery of $B^0 - \bar{B}^0$ mixing immediately implied that B_s mixing is near maximal in the SM, due to the hierarchical structure of the CKM matrix. [Eq. (1) applies for B_s mixing as well, replacing $V_{td} \rightarrow V_{ts}$, $m_{B_d} \rightarrow m_{B_s}$, $f_{B_d} \rightarrow f_{B_s}$, and $\hat{B}_{B_d} \rightarrow \hat{B}_{B_s}$.] This made resolving the oscillations very challenging. The CDF measurement [47]

$$\Delta m_{B_s} = (17.77 \pm 0.10 \pm 0.07) \text{ ps}^{-1}, \quad (14)$$

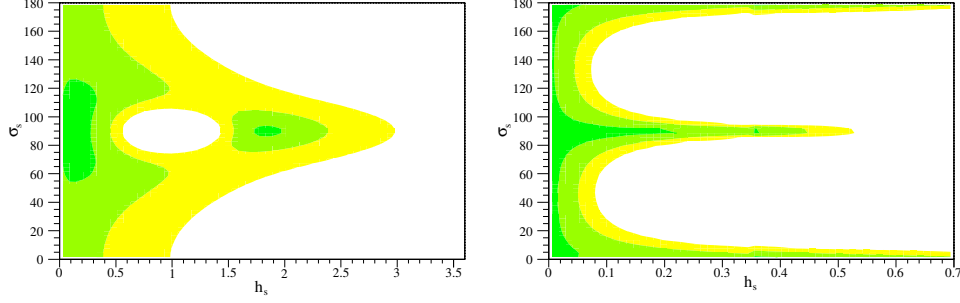


Figure 9: Constraints on the NP parameters (h_s , σ_s) in B_s mixing, after the measurement of Δm_{B_s} (left) and after a nominal year at LHCb (right) [48].

indicates that B_s^0 and \bar{B}_s^0 mesons oscillate about 25 times before they decay. Amusingly, once the oscillation could be resolved, the experimental uncertainty $\sigma(\Delta m_{B_s}) = 0.7\%$ is already smaller than $\sigma(\Delta m_{B_d}) = 0.8\%$. In the B_s system the lifetime difference is $1/\lambda^2$ enhanced compared to B_d , since decays to common final states of B_s^0 and \bar{B}_s^0 are Cabibbo allowed. Thus one expected $\Delta\Gamma_{B_s}/\Gamma_{B_s} \sim 0.1$, and the world average is $0.104^{+0.076}_{-0.084}$ [37].

With the measurement of Δm_{B_s} , the CKM picture passed another stringent test. Many models with TeV-scale new particles could have given rise to significant deviations from the SM prediction, without altering the agreement with data in the B_d sector. However, as shown in Fig. 9, even after the measurement of Δm_{B_s} (and initial data on $\Delta\Gamma_{B_s}$) new physics comparable to the SM contribution may still be present in $B_s^0-\bar{B}_s^0$ mixing. The next key measurement will come from the time dependent CP asymmetry in $B_s \rightarrow \psi\phi$ (i.e., that in the CP -even partial waves, the analog of measuring $\sin 2\beta$ in $B \rightarrow \psi K$), for which the SM predicts $\sin 2\beta_s = 0.0368^{+0.0017}_{-0.0018}$ [44]. As can be seen from the right plot in Fig. 9, the expected LHCb precision with even one year of nominal data, $\sigma(\sin 2\beta_s) = 0.03$, will make a huge improvement in the sensitivity to NP in $B_s^0-\bar{B}_s^0$ mixing. (While this writeup was in preparation, the first results from CDF and DØ appeared [49].)

4.5 $D^0-\bar{D}^0$ mixing

There are other fascinating developments in flavor physics. Just this past year, the observation for $D^0-\bar{D}^0$ mixing is becoming conclusive, which is discussed in detail in K. Schubert's contribution. The D^0 system is special in that it is the only neutral meson in which mixing is generated by box diagrams with down (rather than up) type quarks. Unfortunately, it is not

possible to rule out that the SM could account for the observed central values of $x_D = \Delta m_D/\Gamma_D$ and $y_D = \Delta\Gamma_D/2\Gamma_D$ [50]. The evidence for $(x_D, y_D) \neq (0, 0)$ is $\sim 5\sigma$, but their separate measurements are only at the $\sim 3\sigma$ level. However, the measurements viewed as an upper bound on Δm_D already provide strong constraints on new physics (similar to ϵ'/ϵ). For example, the smallness of Δm_D implies that quark-squark alignment models [51] without other suppression mechanisms are no longer viable (if $m_{\tilde{g}, \tilde{q}} \lesssim 1$ TeV). Thus, it is important to improve the constraints on both x_D and y_D , and to look for CP violation, for which there is no hint yet, but it remains a potentially robust signal of new physics.

5 Final comments

With the B_s^0 and D^0 mixing measurements, we now know a lot more about the correspondence between the lifetimes, CP eigenstates, and mass eigenstates of the neutral mesons. Neglecting CP violation in mixing [38]

$$\begin{aligned} K^0 &: \text{long-lived} = CP\text{-odd} = \text{heavy} , \\ D^0 &: \text{long-lived} = CP\text{-odd} (3.5\sigma) = \text{light} (2\sigma) , \\ B_s^0 &: \text{long-lived} = CP\text{-odd} (1.5\sigma) = \text{heavy in the SM} , \\ B_d^0 &: \text{yet unknown; same as } B_s \text{ in SM for } m_b \gg \Lambda_{\text{QCD}} . \end{aligned} \quad (15)$$

In all four systems the long-lived state seems to be the CP -odd, and it is also the heavier state with the exception of D mesons. Curiously, before 2006 we only knew experimentally the first line in Eq. (15), and it is only the B_d^0 system for which we still lack experimental evidence for the correspondence between the heavy-light, even-odd, long-short states. (It may be impossible to identify the CP -even and -odd B_d^0 states, since it may not have any decay to a CP eigenstate final state in which CP violation is negligible.)

With the imminent start of the LHC, we are at the verge of an exciting era. We will soon probe directly the mechanism of electroweak symmetry breaking. At the same time, the lack of deviations from the SM in flavor physics experiments poses a problem for many TeV-scale new physics scenarios. One possibility to avoid fine tuning in the presence of TeV-scale new physics is to assume minimal flavor violation (MFV), which is the assertion that Yukawa couplings are the only source of flavor and CP violation, even in the presence of new physics. In the context of SUSY, for example, MFV implies to a good approximation that the first two generation superpartners are degenerate and that the decays of new heavy particles are flavor diago-

nal. These can be probed at the LHC, so the spectra and decay channels of possible new particles will also teach us about flavor.

In conclusion, tremendous progress has been made in B physics over the last couple of decades. The SM flavor sector has been tested with increasing precision, and we now know that the CKM phase is the dominant source of CP violation in flavor changing processes. Deviations from the SM in $B_{d,s}$ mixing, in $b \rightarrow s$ and even $b \rightarrow d$ decays are being constrained. The scales probed by these measurements are at the hundreds of TeV level, so if there is new physics at the TeV scale, it must incorporate some mechanism(s) to suppress FCNC processes. If beyond SM flavor physics is seen at the B factories or at LHCb, then we will certainly want to study it in as many different processes as possible. In the absence of new discoveries, flavor physics will still provide important constraints, similar to the LEP tests of the gauge sector of the SM. In either case, flavor physics will give powerful constraints on model building in the LHC era.

Acknowledgments

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References

- [1] H. Albrecht *et al.* [ARGUS Collaboration], Phys. Lett. B **192**, 245 (1987).
- [2] K. Hirata *et al.* [KAMIOKANDE-II Collaboration], Phys. Rev. Lett. **58**, 1490 (1987); R. M. Bionta *et al.*, Phys. Rev. Lett. **58**, 1494 (1987).
- [3] H. Schröder, DESY seminar.
- [4] J. R. Ellis, J. S. Hagelin and S. Rudaz, Phys. Lett. B **192**, 201 (1987).
- [5] I. I. Y. Bigi and A. I. Sanda, Phys. Lett. B **194**, 307 (1987).
- [6] V. D. Barger, T. Han, D. V. Nanopoulos and R. J. N. Phillips, Phys. Lett. B **194**, 312 (1987).
- [7] G. Altarelli and P. J. Franzini, Z. Phys. C **37**, 271 (1988).
- [8] H. Harari and Y. Nir, Phys. Lett. B **195**, 586 (1987).
- [9] P. H. Ginsparg, S. L. Glashow and M. B. Wise, Phys. Rev. Lett. **50**, 1415 (1983) [Erratum-ibid. **51**, 1395 (1983)].

- [10] T. Inami and C. S. Lim, Prog. Theor. Phys. **65**, 297 (1981) [Erratum-
ibid. **65**, 1772 (1981)].
- [11] S. L. Glashow and E. E. Jenkins, Phys. Lett. B **196**, 233 (1987).
- [12] Y. Nir, Phys. Lett. B **236**, 471 (1990).
- [13] N. Cabibbo, Phys. Rev. Lett. **10** (1963) 531.
- [14] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49** (1973) 652.
- [15] J. H. Christenson, J. W. Cronin, V. L. Fitch and R. Turlay, Phys. Rev.
Lett. **13** (1964) 138.
- [16] H. E. Haber, Nucl. Phys. Proc. Suppl. **62** (1998) 469 [hep-ph/9709450];
- [17] Y. Nir, hep-ph/0109090.
- [18] L. Wolfenstein, Phys. Rev. Lett. **51**, 1945 (1983).
- [19] J. M. Flynn and L. Randall, Phys. Lett. B **224**, 221 (1989).
- [20] M. Aguilar-Benitez *et al.* [Particle Data Group], Phys. Lett. B **170**, 1
(1986).
- [21] H. Albrecht *et al.* [ARGUS Collaboration], Phys. Lett. B **249**, 359
(1990).
- [22] B. Grinstein, M. B. Wise and N. Isgur, Phys. Rev. Lett. **56**, 298 (1986);
N. Isgur, D. Scora, B. Grinstein and M. B. Wise, Phys. Rev. D **39**, 799
(1989).
- [23] G. Altarelli, N. Cabibbo, G. Corbo, L. Maiani and G. Martinelli, Nucl.
Phys. B **208**, 365 (1982).
- [24] J. Chay, H. Georgi and B. Grinstein, Phys. Lett. B **247** (1990) 399;
M.A. Shifman and M.B. Voloshin, Sov. J. Nucl. Phys. **41** (1985) 120;
I.I. Bigi, N.G. Uraltsev and A.I. Vainshtein, Phys. Lett. B **293** (1992)
430 [E. B **297** (1992) 477]; I.I. Bigi, M.A. Shifman, N.G. Uraltsev and
A.I. Vainshtein, Phys. Rev. Lett. **71** (1993) 496; A.V. Manohar and
M.B. Wise, Phys. Rev. D **49** (1994) 1310.
- [25] A. H. Hoang, Z. Ligeti and A. V. Manohar, Phys. Rev. Lett. **82** (1999)
277 [hep-ph/9809423]; Phys. Rev. D **59** (1999) 074017 [hep-ph/9811239];
A. H. Hoang and T. Teubner, Phys. Rev. D **60** (1999) 114027 [hep-
ph/9904468].
- [26] C. W. Bauer, Z. Ligeti, M. Luke, A. V. Manohar and M. Trott, Phys.
Rev. D **70**, 094017 (2004) [hep-ph/0408002]; C. W. Bauer, Z. Ligeti,
M. Luke and A. V. Manohar, Phys. Rev. D **67**, 054012 (2003) [hep-
ph/0210027]; and references therein.
- [27] K. Melnikov, arXiv:0803.0951; A. Pak and A. Czarnecki,
arXiv:0803.0960.

- [28] N. Isgur and M. B. Wise, Phys. Lett. B **232**, 113 (1989); Phys. Lett. B **237**, 527 (1990).
- [29] H. Albrecht *et al.* [ARGUS Collaboration], Z. Phys. C **57**, 533 (1993).
- [30] J. Laiho [Fermilab Lattice and MILC Collaborations], arXiv:0710.1111.
- [31] C. G. Boyd, B. Grinstein and R. F. Lebed, Phys. Lett. B **353**, 306 (1995) [hep-ph/9504235]; Phys. Rev. D **56**, 6895 (1997) [hep-ph/9705252].
- [32] R. Fulton *et al.* [CLEO Collaboration], Phys. Rev. Lett. **64**, 16 (1990).
- [33] H. Albrecht *et al.* [ARGUS Collaboration], Phys. Lett. B **234**, 409 (1990).
- [34] M. Neubert, Phys. Rev. D **49** (1994) 3392 [hep-ph/9311325]; *ibid.* 4623 [hep-ph/9312311]; I. I. Y. Bigi, M. A. Shifman, N. G. Uraltsev and A. I. Vainshtein, Int. J. Mod. Phys. A **9** (1994) 2467 [hep-ph/9312359].
- [35] M. S. Alam *et al.* [CLEO Collaboration], Phys. Rev. Lett. **74**, 2885 (1995).
- [36] C. W. Bauer, Z. Ligeti and M. E. Luke, Phys. Lett. B **479**, 395 (2000) [hep-ph/0002161]; Phys. Rev. D **64**, 113004 (2001) [hep-ph/0107074].
- [37] E. Barberio *et al.* [Heavy Flavor Averaging Group], arXiv:0704.3575; and updates at <http://www.slac.stanford.edu/xorg/hfag/>.
- [38] Z. Ligeti, arXiv:0706.0919; and references therein.
- [39] A. B. Carter and A. I. Sanda, Phys. Rev. D **23**, 1567 (1981).
- [40] I. I. Y. Bigi and A. I. Sanda, Nucl. Phys. B **193**, 85 (1981).
- [41] Y. Grossman and M. Worah, Phys. Lett. B **395** (1997) 241 [hep-ph/9612269]; D. London and A. Soni, Phys. Lett. B **407** (1997) 61 [hep-ph/9704277].
- [42] R. Godang *et al.* [CLEO Collaboration], Phys. Rev. Lett. **80**, 3456 (1998) [hep-ex/9711010].
- [43] M. Gronau and D. London, Phys. Rev. Lett. **65** (1990) 3381.
- [44] A. Höcker, H. Lacker, S. Laplace and F. Le Diberder, Eur. Phys. J. C **21** (2001) 225 [hep-ph/0104062]; J. Charles *et al.*, Eur. Phys. J. C **41** (2005) 1 [hep-ph/0406184]; and updates at <http://ckmfitter.in2p3.fr/>.
- [45] J. M. Soares and L. Wolfenstein, Phys. Rev. D **47**, 1021 (1993); T. Goto, N. Kitazawa, Y. Okada and M. Tanaka, Phys. Rev. D **53**, 6662 (1996) [hep-ph/9506311]; J. P. Silva and L. Wolfenstein, Phys. Rev. D **55**, 5331 (1997) [hep-ph/9610208]; Y. Grossman, Y. Nir and M. P. Worah, Phys. Lett. B **407**, 307 (1997) [hep-ph/9704287].
- [46] Z. Ligeti, Int. J. Mod. Phys. A **20**, 5105 (2005) [hep-ph/0408267].

- [47] A. Abulencia *et al.* [CDF Collaboration], Phys. Rev. Lett. **97**, 242003 (2006) [hep-ex/0609040].
- [48] Z. Ligeti, M. Papucci and G. Perez, Phys. Rev. Lett. **97**, 101801 (2006) [hep-ph/0604112].
- [49] T. Aaltonen *et al.* [CDF Collaboration], arXiv:0712.2397;
V. M. Abazov *et al.* [DØ Collaboration], arXiv:0802.2255.
- [50] A. F. Falk, Y. Grossman, Z. Ligeti and A. A. Petrov, Phys. Rev. D **65**, 054034 (2002) [hep-ph/0110317]; A. F. Falk, Y. Grossman, Z. Ligeti, Y. Nir and A. A. Petrov, Phys. Rev. D **69**, 114021 (2004) [hep-ph/0402204].
- [51] Y. Nir and N. Seiberg, Phys. Lett. B **309**, 337 (1993) [hep-ph/9304307].

The Discovery of $B\bar{B}$ mixing

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Welcome to the celebration of the 20th anniversary of the discovery of $B\bar{B}$ mixing, achieved by ARGUS in 1987. What made this discovery possible, D. Cassel explained in his talk on the occasion of the termination of the ARGUS experiment:

Have a better detector that can “see all”
Have excellent physics analysis software
Have excellent physics ideas and follow them
Have a little bit of luck.

This is also the outline of my talk.

1 The ARGUS Detector

Everything began in 1977. At DESY the new e^+e^- storage ring PETRA was successfully brought into operation. Moreover, the DESY director H. Schopper decided, that research at the old storage ring DORIS should be continued with a new detector. For this purpose he set up a new research group at DESY and invited for the formation of an international collaboration to work at DORIS.



Figure 1: H. Schopper

Also in 1977 the Υ and thus the 5th quark, the b -quark was discovered by L. Lederman and his group at FNAL. Consequently, it was decided to up-

grade the energy of DORIS in order to produce the Υ states by e^+e^- collisions. The new DORIS collaboration obtained the DASP detector, since its former owners had quit. The DASP detector gave very valuable experience on experimentation in the e^+e^- environment and it immediately provided important new physics results from the upgraded DORIS. The two lowest Υ states, the $\Upsilon(1S)$ and $\Upsilon(2S)$ were, together with PLUTO, found at DORIS and their parameters were precisely measured in 1978.

The main task, however, was to design a new detector for DORIS. It received the name ARGUS, the name of the hero of Greek mythology having many eyes so that he would see everything. But the actual meaning underlying this name was only found later, in a physicists wife point of view. She said:

“Alle Richtigen Genies Unter Sich”.

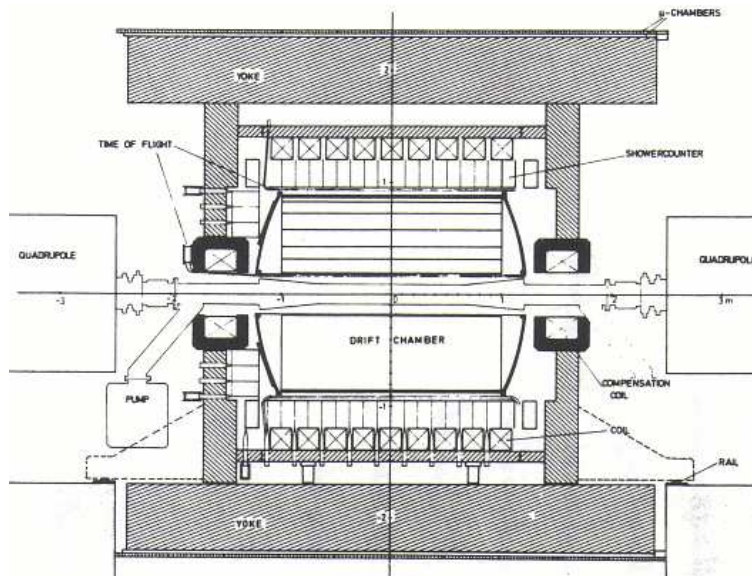


Figure 2: The first version of the ARGUS detector

H. Schopper fully supported the project. He emphasized: What counts is that the new detector is competitive. In order to reach this goal, money was not an issue. But then he left to become director general of CERN. Now we had to learn the art of getting hold of sufficient support.

For the design criteria of the new detector the recently constructed detectors at PETRA and PEP were very instructive and were studied in detail. In order to present my first detector design, a workshop was held at DESY on

10.11.1977. This first version of ARGUS shown in Fig.2 had already many features of the final design.

It has a homogenous structure over a large range of solid angle. Various magnetic field configurations had been studied, but it turned out that the classical solenoid field had the best properties. In order to avoid delays, a normal conducting magnet coil was chosen. Since the detector performance is improving by a high magnetic field, the magnetic field was made as high as achievable by a normal conducting coil. The magnetic field of the detector thus defined, was 0.8 T.

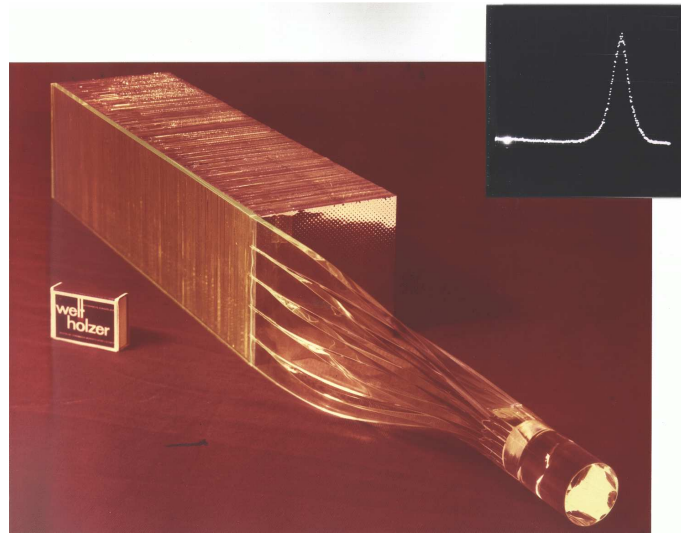


Figure 3: Prototype for the ARGUS shower counters, consisting of a lead scintillator sandwich read out by a wavelength shifter bar. Also shown the energy distribution for 1 GeV electrons

The copper coil producing this field is too thick so that no particles other than muons can be detected behind it. Thus the electromagnetic calorimeter for the detection of γ -rays and electrons had to be placed inside the magnetic field volume in front of the coil. Fortunately, a new type of shower counter suited for this purpose had been invented just recently by W.B. Atwood. It consists of a lead-scintillator sandwich read out by a wavelength shifter bar doted with BBQ. The light is concentrated into an area, which is small enough so that it can be transported by lightguides through slits between the coil segments to the field free region behind the coil, where photo-multipliers can work. A first prototype shown in Fig.3 was quickly made at DESY and tested at a test-beam. It showed an even better energy-resolution than obtained by

the inventor. In the final detector an energy resolution of

$$\sigma_E/E = \sqrt{7^2 + 8^2} \text{ GeV}/E \%$$

was obtained. No e^+e^- -detector at that time had a calorimeter with a better energy resolution.

This first design of ARGUS had as the central track detector a copy of the Jet-chamber of JADE. Since particle identification is essential for B -physics, its appealing feature was, that it combined momentum determination with a measurement of dE/dx for particle identification.

2 Forming the ARGUS collaboration

Building up the collaboration worked mainly by personal relations.

The first ally was D. Wegener of the Universität Dortmund. We had met many years before as students in the Göttingen Physics Institute and then worked together in Karlsruhe from where we did the DESY Experiment F23. Then we met again at CERN from where we made tours to the famous restaurants of Burgundy, enjoying life together.

Next, K. Schubert from the Universität Heidelberg joined. We had met at CERN and worked together in the CHOV collaboration at the ISR.

The director for research G. Weber knew G. von Dardel of Lund University in Sweden. Consequently, L. Jönsson joined the collaboration.

DESY director H. Schopper had worked in Russia before and by these contacts he arranged a collaboration with ITEP Moscow, which turned out very fruitful.

Finally, C. Darden from South Carolina University joined. He had just recently married a German wife and therefore spent his sabbatical at DESY, where he got interested in the project.

The formation of an efficient research group was strongly supported by G. Weber, who helped us a lot to get started.

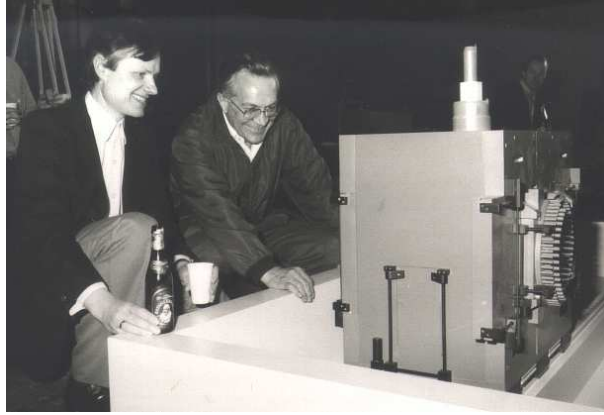


Figure 4: The author and G. Weber with a model of the ARGUS detector

3 The proposal version of ARGUS

Together with the new DESY group, these five groups worked out the proposal ARGUS, A New Detector for DORIS which was submitted in October 1978 and approved on 5. 7. 1979.

The proposal version of the detector [1] is shown in Fig.5 The performance of such a detector improves with increasing size. As a limit the existing pit around the interaction region of DORIS was taken. Thus no time was lost for enlarging the pit and changing the foundations of the storage ring.

The main new feature of the proposal version of ARGUS was a new central driftchamber. It had turned out that the charge division method used by JADE for the measurement of the longitudinal track coordinate, needed a gas-gain too high for good dE/dx resolution and had the disadvantage of doubling the front-end electronics.

In order to avoid these problems, I worked out a novel driftchamber design [2], which is capable of measuring dE/dx , but uses small angle stereo to measure the longitudinal coordinate. The driftchamber consists of 5940 drift-cells with an approximate quadratic shape, as Fig.6 shows. They are arranged in 36 layers. Every second layer is tilted by a stereo angle. In such a stereo layer the projection of a sense wire, seen from the side, forms a hyperbola. For a sufficiently constant gas-gain over the whole sense wire, the maximum deviation of the hyperbola from a straight line was set to 1 mm. The stereo angle of each layer was thus defined. It increases with radius and gives a good space-resolution. The size of the drift-cell of 18 mm was chosen because it fully

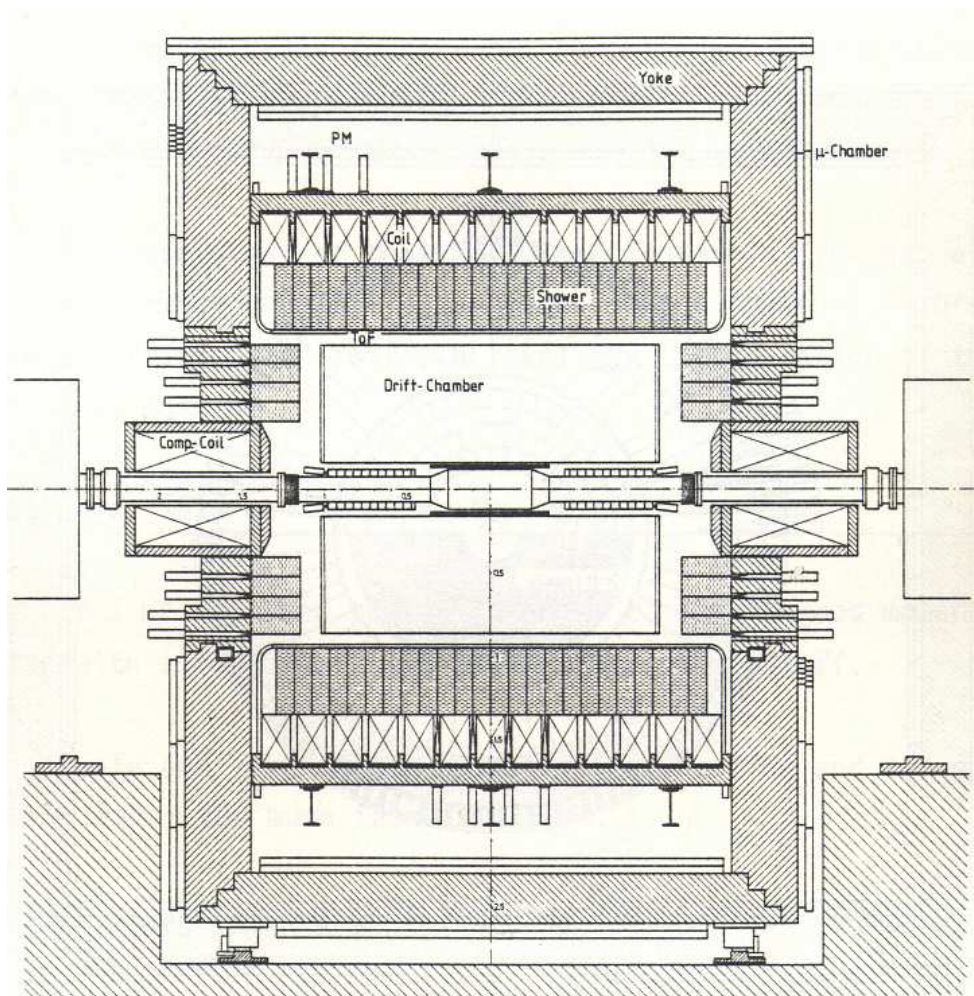


Figure 5: The proposal version of the ARGUS detector

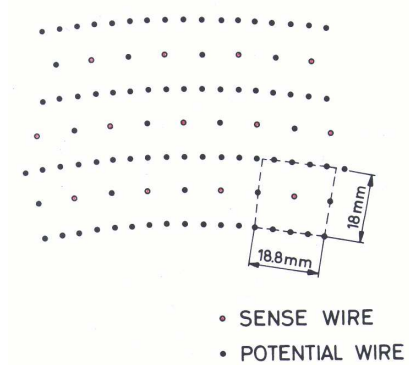


Figure 6: The cell structure of the ARGUS driftchamber

exploits the dE/dx information obtainable from the counting-gas. The price to pay for the excellent performance of this design was that 24588 potential wires had to be strung. The proposal version had even 30804 potential wires. But an optimisation performed at ITEP Moscow showed that this number could be reduced.

It was the opinion of many of the experts of that time, that it was crazy to try to build such a chamber. But finally it worked very well.

4 Enlarging the collaboration

The collaboration was not yet strong enough to manage. But it grew.

N. Kwak from Kansas University, who had already worked with us in CHOV at CERN joined together with R. Ammar and R. Davis.

Next a very strong team from the IPP Canada joined. It consisted of
P. Patel and T.S. Yoon, Montreal
J. Pentice and W. Frisken, Toronto
K. Edwards, Ottawa

Finally, the collaboration was completed by the teams of
G. Kernel, University of Ljubljana and
H. Wegener, Universität Erlangen.

In total the collaboration consisted of about 80 scientists. It had no committees, no boards, no panels. Nevertheless, the collaboration worked very well. Probably because it was an unusual collection of brilliant people.

5 The luminosity upgrade of DORIS

By 1980 a very important upgrade of DORIS [3] was initiated. H. Nesemann and K. Wille were made responsible for DORIS. It was their initiative to work out an upgrade project in order to make DORIS competitive with CESR, which was under construction at Cornell and was also planning to do B -physics. The basic idea of this upgrade was to increase the luminosity of DORIS by mini-beta quadrupoles positioned close to the interaction point. This appeared impossible, since the quadrupoles had to be placed inside the ARGUS detector, where the high magnetic detector field would prevent them from operating properly. But the expected luminosity increase by a factor of ten was an offer, which one



Figure 7: K. Wille

simply could not reject. Therefore, I came up with an arrangement of compensating coils to protect the mini-beta quads against the detector field. This scheme was checked by K. Wille and found to be satisfactory. Fortunately, the director of research at that time, E. Lohrmann strongly supported this idea, so that it was approved by DESY.



Figure 8: E. Lohrmann

The official decision to perform the luminosity upgrade of DORIS was prepared at a workshop on 10.02.1981. It was attended by E. Bloom, the spokesman of the Crystal Ball experiment at SLAC. He stated, that if this upgrade really were made as proposed, he would bring the Crystal Ball experiment to DESY. That a scientific team with such a high reputation from the United States would come to DESY, was sufficient motivation for DORIS to be essentially rebuilt at the highest standards of accelerator technology. The good thing for ARGUS was, that we got a marvelous machine. But since Crystal Ball was given priority, we had to wait for some years until their research programme was finished, before we could start with the ARGUS research programme.

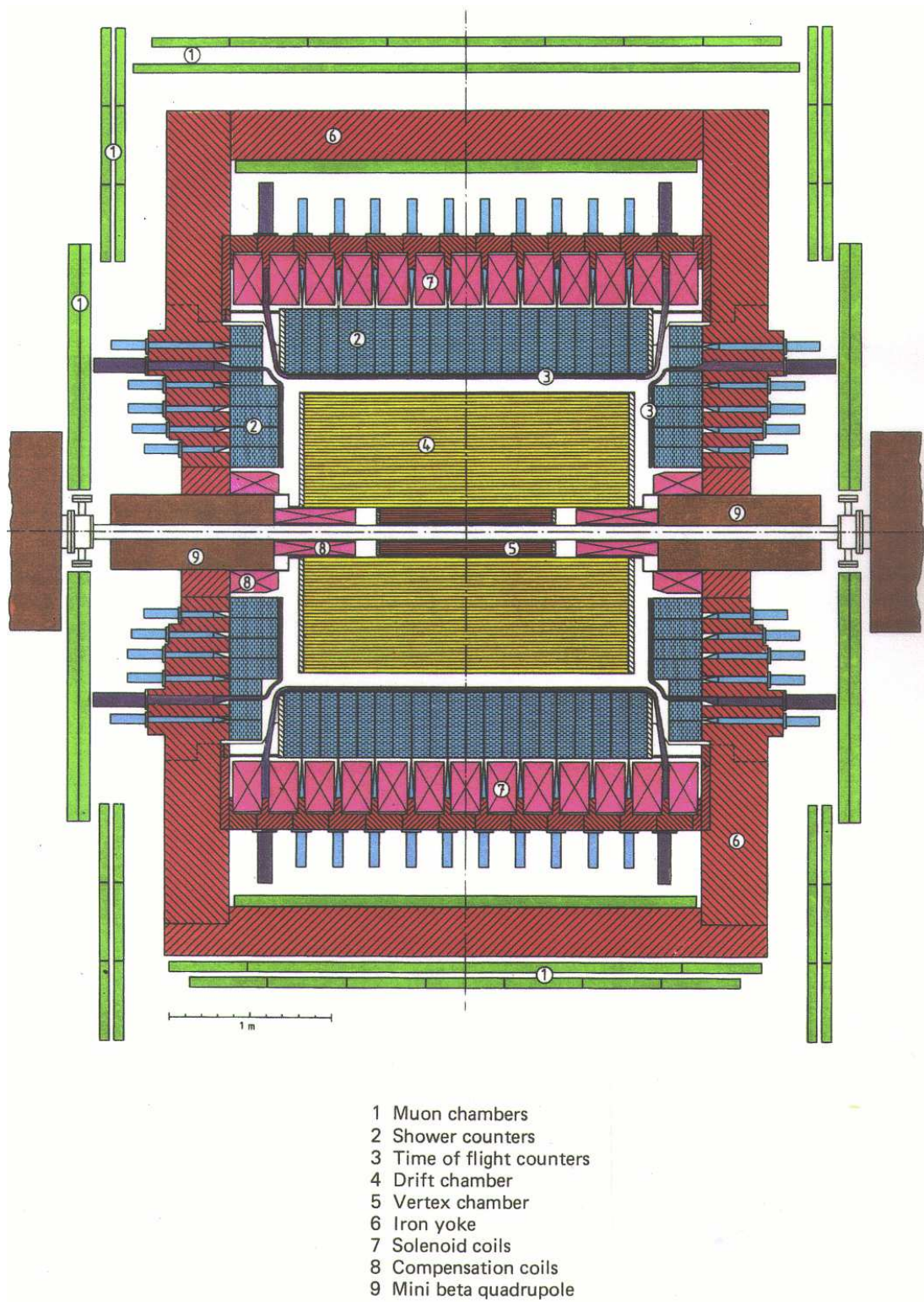


Figure 9: The final version of the ARGUS detector

The luminosity upgrade required a change of the detector design in order to accommodate the mini-beta quadrupoles. Thus, the layout of ARGUS was again modified and received its final shape [4] as displayed in Fig.9. This design turned out to be quite competitive.

6 Building the detector

Now the task of the participating institutes was to build the detector. In addition to the infrastructure and the magnet, the following components were contributed by the DESY group, listed together with the responsible persons: the driftchamber E. Michel, the track-finder trigger H.-D. Schulz and the data acquisition R. Wurth.



Figure 10: L. Jönsson

The driftchamber design really was at the edge of technical possibilities. No German company could be found, which was prepared to drill the 60000 precision holes into the end-plates of the driftchamber. Finally, L. Jönsson found a company in Sweden, which did the job under his supervision. A picture of the drift-chamber under construction, with light reflected from the wires is shown in Fig.11 .

D. Wegener and his team of the Universität Dortmund took the responsibility for the development and the production of the shower-counters [5]. The barrel consisted of 1280 and the two end-caps of 480 counters. Thus, an enormous job had to be managed. Part of the shower-counters ready for installation are shown in Fig.13 .

The time-of-flight system [6] was contributed by K. Schubert and his group from the Universität Heidelberg. It consisted of 64 barrel counters and 48

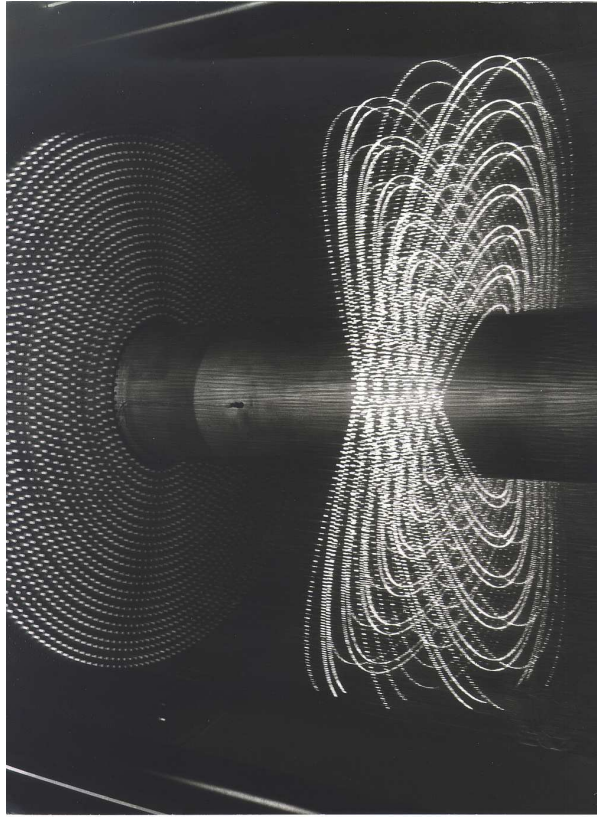


Figure 11: The central drift chamber under construction. The light reflected from the wires indicates the complex cell structure.



Figure 12: D. Wegener

end-cap counters and reached the excellent time resolution of 220 ps.

The detector was surrounded by two layers of muon chambers, [7] which were contributed by ITEP Moscow. They consisted of 1744 aluminum tubes.



Figure 13: The shower counters ready for installation



Figure 14: K. Schubert

The outer layer covered a solid angle of $0.87 \times 4\pi$.

The vertex-driftchamber [8] located inside the central driftchamber was contributed by IPP Canada. Actually, during the data taking period of ARGUS three versions were built and installed, with gradually improving performance. The second version had 594 hexagonal driftcells. It provided a significant improvement of the momentum resolution. The combined momentum resolution of both driftchambers was very good and reached

$$\sigma(p_T)/p_T = \sqrt{0.01^2 + (0.006 p_T/(\text{GeV}/c))^2}.$$

In 1982 the commissioning of the detector took place. After the usual initial troubles, to our surprise, the detector worked perfectly. Each of the collaborating institutes had delivered its detector component, completely meeting the specifications.

It turned out, that the particle identification power of the time-of-flight sys-

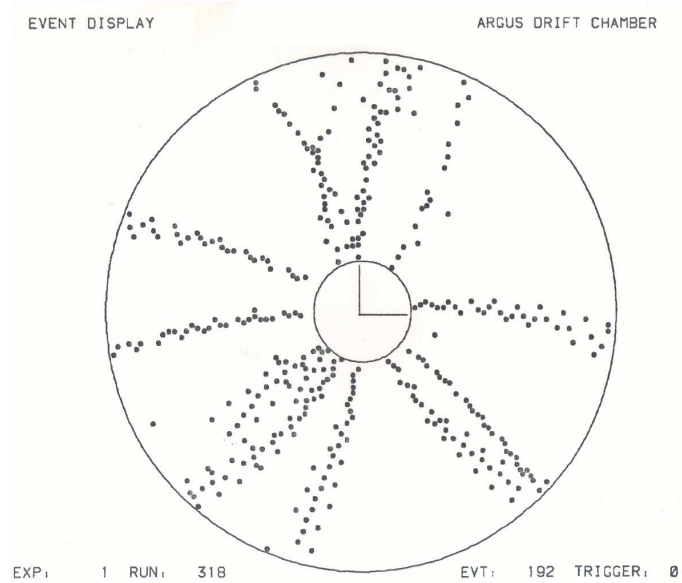


Figure 15: The online display of one of the first events recorded

tem and of the dE/dx measurement by the driftchamber were equally good. Both reached a π -K separation of 3σ up to 750 MeV. Thus, always both techniques were used, resulting in improved particle assignments.

7 Running the Experiment

Data taking started in fall 1982. The online display of one of the first events recorded is given in Fig.15. It shows the three stereo views of the central driftchamber. The data are remarkably clean and complete.

A reconstructed typical event, showing only the longitudinal wires is displayed in Fig.16. This picture shows the excellent pattern-recognition capabilities of the ARGUS driftchamber. Close tracks and crossing tracks are clearly recognized.

Most of the event-reconstruction software of ARGUS has been written by H. Albrecht. In addition, in close connection with H. Schröder, at that time the ARGUS physics coordinator, he developed an analysis language called KAL. This language served as a user interface to the reconstructed data. It was used by all people doing data analysis.

After some time it was free of bugs, so that ARGUS produced very re-

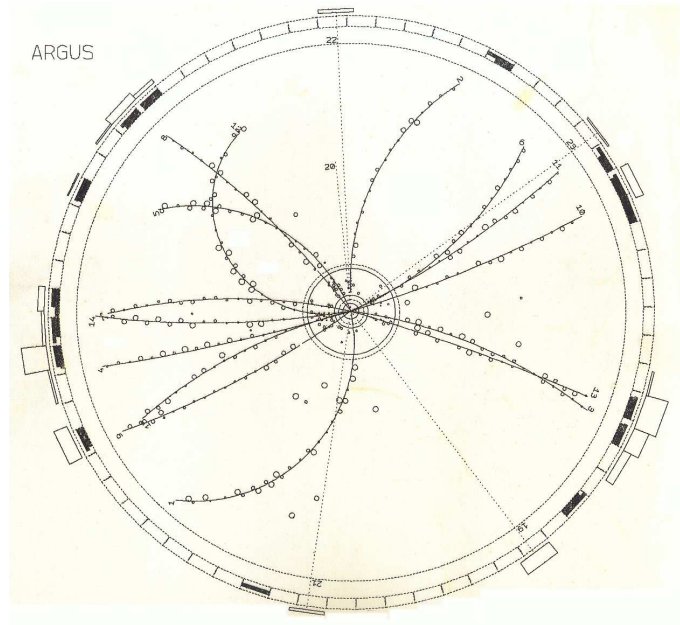


Figure 16: A typical event after reconstruction showing the excellent pattern-recognition capabilities of the ARGUS driftchamber



Figure 17: H. Albrecht

liable results. The large number of publications was only possible through this analysis language. It allowed to concentrate on the physics issues, not being distracted by the always repeating difficult technical aspects of data-calibration and data-reconstruction.

The responsibility for good data quality stayed over the whole running time of the experiment with the institute, which originally contributed the hardware. Due to this clear responsibility structure, the data quality was always close to perfect.

After the termination of the Crystal Ball experiment in 1985, ARGUS could begin with its own research programme. It concentrated on the weak interaction of the 5th quark, the b quark. Also the Υ states, the heavy lepton τ , the charmed quark and $\gamma - \gamma$ -physics were important research topics of ARGUS. But the most important topic was b -physics. Only CLEO at Cornell and ARGUS at DESY had the facilities to do this research. Both groups worked in a fruitful competition and in most cases confirmed each other.

By 1987 the number of B -mesons collected by ARGUS was 176 000, while CLEO had already collected 263 000 B -mesons. However, the overall efficiency of ARGUS was higher than the efficiency of CLEO, what compensated for the lower number of recorded events.

8 b -Physics

The starting point for the study of the weak interaction of the b -quark is the $\Upsilon(4S)$ state, which is a $b\bar{b}$ bound state. It is produced by e^+e^- annihilation as shown in Fig.18. Its mass is just high enough, that it can decay into a pair of B -mesons. The B -mesons produced are either neutral or charged. Their quark contents is $B^0 = \bar{b}d$ and $B^+ = \bar{b}u$.

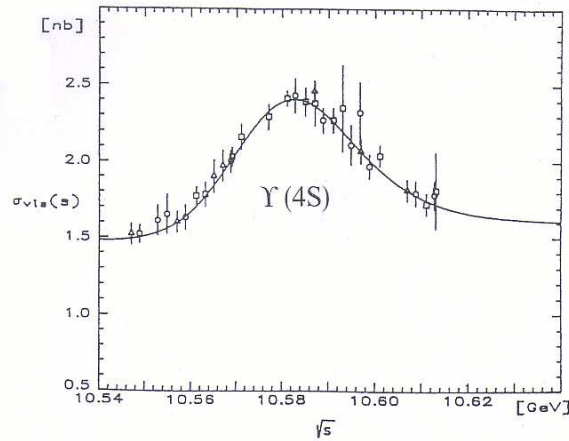


Figure 18: The $\Upsilon(4S)$ state produced by e^+e^- annihilations. It decays into a pair of B -mesons as a starting point for the study of the weak interaction of the b quark

Thus the starting reaction is, expressed by mesons

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0\bar{B}^0 \text{ or } B^+B^-$$

or expressed by quarks

$$e^+e^- \rightarrow \bar{b}b \rightarrow \bar{b}d\bar{d}b \text{ or } \bar{b}u\bar{u}b$$

The b -quarks thus produced allow to study their weak interaction. It proceeds by the transition of a quark i into a quark k via emission or absorption of a W^\pm boson.

$$q_i \rightarrow q_k + W^\pm$$

The couplings of any unlike charged pair of quarks i, k to the W^\pm boson

$$V_{ik} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{array}{l} \text{--- } b \rightarrow u \text{ Transition} \\ \text{--- } B \text{ Lifetime} \\ \text{--- } B^0 \bar{B}^0 \text{ } B_s \bar{B}_s \text{ --- Mixing} \end{array}$$

Figure 19: The CKM matrix. The elements involving the 3rd generation of quarks are subject of b -physics.

are proportional to amplitudes V_{ik} which form the elements of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. These parameters represent an arbitrary input into the Standard Model. They have to be determined experimentally.

The CKM matrix elements involving the 3rd generation of quarks are essentially the subject of B -meson physics as summarized in Fig.19.

$|V_{ub}|$ is given by the branching ratio for the transition $b \rightarrow u$.

It was discovered by CLEO and ARGUS in 1989.

$|V_{cb}|$ is derived from the lifetime of the B -mesons.

$|V_{td}|$ and $|V_{ts}|$ are accessible via $B^0\bar{B}^0$ and $B_s\bar{B}_s$ mixing.

$|V_{tb}|$ is close to unity.

9 $B\bar{B}$ Mixing

B^0 -mesons may transform into their antiparticles through the box diagrams as shown in Fig.20. Such a box diagram is of special interest, since it is dominated by the exchange of the heaviest particle, contributing to the loop.

A similar box diagram for the K^0 -meson played already a major role in particle physics. It lead to the prediction of the charm-quark, which was

required to make the loop integral finite.

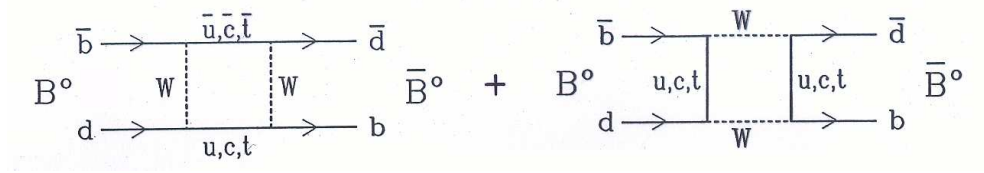


Figure 20: The box graphs implying the transition of a B^0 -meson into its antiparticle

Since B^0 -mesons transform into their antiparticles, the states

$$\langle B^0 \rangle \quad \text{and} \quad \langle \overline{B^0} \rangle$$

are not mass eigenstates. The two states mix and form the stationary mass eigenstates

$$\frac{1}{\sqrt{2}} \langle B^0 + \overline{B^0} \rangle \quad \text{and} \quad \frac{1}{\sqrt{2}} \langle B^0 - \overline{B^0} \rangle,$$

which differ in mass by an amount ΔM .

Assuming that the two mixed states have equal lifetime and total width Γ , the quantum mechanics of such a two state system leads to a simple formula for its time evolution. For a system which is entirely B^0 at time zero, the intensity to find it in a $\overline{B^0}$ state is

$$I_{\overline{B^0}}(t) = \frac{1}{2} e^{-\Gamma t} (1 - \cos \Delta M t), \quad I_{B^0}(0) = 1.$$

This relation shows an oscillation term, where ΔM is the oscillation frequency. There are two competing reactions: A B^0 -meson can either decay with decay width Γ or transform into its antiparticle with frequency ΔM . The mixing parameter x defined as

$$x = \frac{\Delta M}{\Gamma}$$

is the relative strength of the two reactions. In order to present the results of time integrated experiments, the mixing parameter r has been introduced, which is defined as the rate to find a particle originally produced as a B^0 -meson at the time of decay as a $\overline{B^0}$ -meson, over the rate to find it as a B^0 -meson. On the $\Upsilon(4S)$ where B -meson pairs are produced in a correlated state r is related to x by

$$r = \frac{BR(B \rightarrow \overline{B} \rightarrow \overline{X})}{BR(B \rightarrow X)} = \frac{x^2}{2 + x^2}.$$

Thus in essence, a measurement of r represents a determination of ΔM .

By 1987 the theoretical expectations predicted a substantial mixing, $r \approx 1$ for the $b\bar{s}$ -meson and a very small mixing for the $b\bar{d}$ -meson.

The experiments on $B\bar{B}$ mixing used reactions, where primarily $B\bar{B}$ pairs are created. Through mixing a B -meson transforms into its antiparticle, which leads to $B\bar{B}$ or $\bar{B}B$ pairs. Observation of such like-kind B -meson pairs is then taken as evidence for mixing. Instead of a complete reconstruction of B -mesons, semi-leptonic B decays can be used. This allows one to tag B -mesons with the lepton charge, which is correlated with the charge of the decaying b -quark.

$$B^0 \rightarrow \ell^+ X \quad \bar{B}^0 \rightarrow \ell^- \bar{X}.$$

Thus the observation of like-sign lepton pairs originating from B -meson decays is evidence for $B\bar{B}$ mixing. However, leptons also originate from charm and strange decays. Clearly this method requires a very good understanding of the background.

Upper limits on $B\bar{B}$ mixing were already reported by the collaborations CLEO, MARK II and JADE [9]. By 1986, the UA1 collaboration reported a 3 standard deviations excess of like-sign muon pairs [10], which was generally interpreted as $b\bar{s}$ mixing and no great surprise.

The major breakthrough for the observation of $B\bar{B}$ mixing was achieved by the ARGUS collaboration in 1987. For this discovery two independent lines of analysis were followed, the search for like-sign lepton pairs and the reconstruction of semi-leptonic B -meson decays.

Since ITEP Moscow had the experts on leptons, in early 1987 I asked a student from ITEP to look into like-sign lepton pairs. I told him: "Theorist say that it is very important, but you will see nothing." After some time, the student presented his result. He had found no like-sign lepton pairs. Actually, he had invented very innocently looking smart cuts and killed all candidates in order to arrive at the expectation.

I was content to learn that ARGUS had very little background and a high sensitivity for this reaction. But CLEO had just recently published a limit on $B\bar{B}$ mixing. Due to this competition, the ARGUS collaboration decided, that our much better limit should also be published. Thus a paper was quickly written and submitted to the Journal.

The other line of analysis proceeded via the reconstruction of B -mesons.



Figure 21: H. Schröder

H. Schröder had developed a method to reconstruct semi-leptonic B decays. The basic idea of this method was to compute the mass of the unseen neutrino from the kinematic variables of the other decay products of the B -meson, and require this mass to be close to zero.

For the decay $B^0 \rightarrow D^* \ell \nu$ the expression for the neutrino mass M_ν is

$$\begin{aligned} M_\nu^2 &= (E_B - E_{D^*} - E_\ell)^2 - (\mathbf{p}_B - \mathbf{p}_{D^*} - \mathbf{p}_\ell)^2 \\ &\approx (E_{\text{Beam}} - E_{D^*} - E_\ell)^2 - (\mathbf{p}_{D^*} + \mathbf{p}_\ell)^2, \end{aligned}$$

where Schröder's trick was, to exploit $E_B = E_{\text{Beam}}$ and $\mathbf{p}_B \approx 0$.

The distribution of neutrino masses thus obtained is shown in Fig.22.

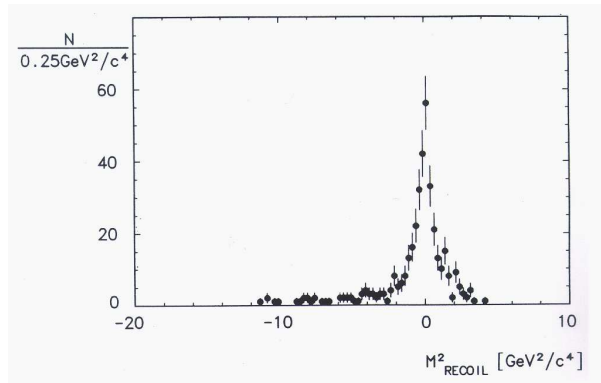


Figure 22: The distribution of the neutrino mass squared for reconstructed semi-leptonic decays $B \rightarrow D^* \ell \nu$

H. Schröder studied these reconstructed events in detail. By early 1987 he discovered a few events, having the signature of $B\bar{B}$ mixing and showed them

to me. However, at that time the statistics were still too small to arrive at a quantitative result.

About two weeks after our paper with the limit on $B\bar{B}$ mixing had been sent away, a big delegation of ARGUS people came into my office. Among the people entering were H. Schröder, Yu. Zaitsev, A. Golutvin and D. MacFarlane. They informed me, that after new data had become available and the old data had been reprocessed, many like-sign lepton pairs had been found.



Figure 23: Yu. Zaitsev and A. Golutvin

Thus our paper was definitely wrong. I agreed to write to the Journal and to withdraw the paper. In addition, the already printed DESY red reports were collected, just in time before they were mailed.

On this meeting everybody felt that very probably we had made a discovery. In order to work it out in detail, the necessary work was distributed. Yu. Zaitsev agreed to supervise the ITEP people around and to work on lepton pairs. H. Schröder agreed to continue his work on reconstructed B -mesons and D. MacFarlane agreed to work out the lepton background from other sources.



Figure 24: D. MacFarlane

Soon the final result was worked out. H. Schröder had found his golden event, shown in Fig.25. Instead of the usual $B\bar{B}$ -meson pair it contains two B^0 -mesons each decaying via $B^0 \rightarrow D^{*-}\mu^+\nu$ and demonstrates explicitly that $B^0\bar{B}^0$ mixing occurs.

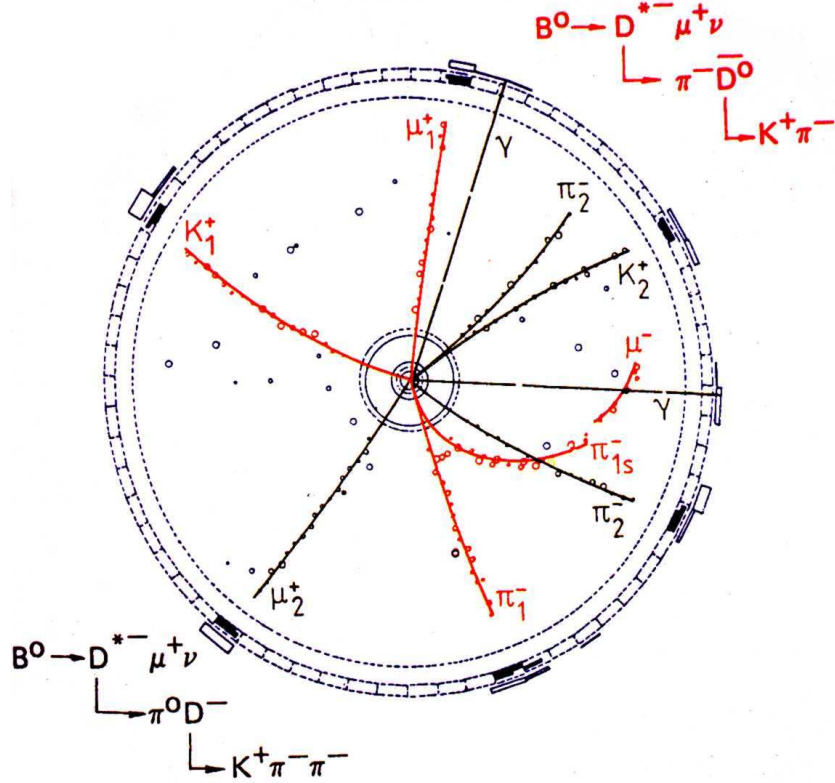


Figure 25: The golden event found by H. Schröder. It shows the reaction $\Upsilon(4S) \rightarrow B^0\bar{B}^0 \rightarrow B^0B^0$, which is evidence for $B\bar{B}$ mixing.

In addition, H. Schröder analysed events containing a B -meson and a lepton. Taking all reconstructed B^0 -mesons available, which decay like $B^0 \rightarrow D^*\ell\nu$ or $B^0 \rightarrow D^*n\pi$, and asking for an additional lepton with a momentum above $1.4\text{ GeV}/c$, he found 5 ± 0.9 candidates for mixing together with 23 ± 2.5 normal events. The advantage of this method is its low background rate. The mixing parameter r obtained was

$$r = \frac{N(B^0\ell^+) + N(\bar{B}^0\ell^-)}{N(B^0\ell^-) + N(\bar{B}^0\ell^+)} = 0.20 \pm 0.12.$$

Yu. Zaitsev presented his results on lepton pairs using leptons with momenta above $1.4\text{ GeV}/c$. He studied both electrons and muons and obtained

three mixing rates, which are consistent with each other.

$$r_{ee} = 0.17 \pm 0.19, \quad r_{\mu\mu} = 0.19 \pm 0.16, \quad r_{e\mu} = 0.28 \pm 0.14.$$

The combined like-sign lepton pair result is

$$r = 0.22 \pm 0.09.$$

This result together with the evidence from B^0 -meson lepton combinations gives the ARGUS result

$$r = 0.21 \pm 0.08.$$

Before publishing this result, the question was then raised whether this surprisingly large rate of $B^0\overline{B}^0$ mixing was consistent with the Standard Model and its parameters, or whether new physics was required to explain it. Since the Standard Model works so well, I would have felt uneasy to publish a result inconsistent with the Standard Model.

In the Standard Theory, $B^0\overline{B}^0$ mixing is described by the box graph, Fig.20. From an analysis of the corresponding box graph of the K^0 system, M.K. Gaillard and B.W. Lee [11] had successfully predicted the mass of the c quark. Similarly $B^0\overline{B}^0$ mixing is sensitive to the t quark mass.

The amplitude of a box graph is divergent, unless the contributions of the individual quark exchange amplitudes cancel each other at high momentum transfer. For this cancelation, called the GIM mechanism [12], to be realized, the CKM elements must fulfill

$$V_{bu}^*V_{ud} + V_{bc}^*V_{cd} + V_{bt}^*V_{td} = 0.$$

This relation is guaranteed by the unitarity of the CKM matrix.

The oscillation frequency ΔM is then given by

$$\begin{aligned} \Delta M &= \langle B | j_\mu j^\mu | B \rangle \\ &\times \int_0^\infty \frac{k^4}{8\pi^2} \left(\frac{V_{bu}^*V_{ud}}{k^2 - m_u^2} + \frac{V_{bc}^*V_{cd}}{k^2 - m_c^2} + \frac{V_{bt}^*V_{td}}{k^2 - m_t^2} \right)^2 \left(\frac{g^2}{k^2 - m_W^2} \right)^2 dk^2. \end{aligned}$$

Mixing can only occur, if the two quarks in the B^0 -meson come close together. This probability is contained in the term

$$\langle B | j_\mu j^\mu | B \rangle = \frac{4}{3} m_b B_B f_B^2.$$

Besides the b quark mass m_b , it depends on a bag factor B_B and the B^0 -meson decay-constant f_B .

The loop integral is easily evaluated, if the masses of the lighter quarks are set to zero, an approximation, which is well justified. The W -exchange term simply gives the Fermi coupling constant G_F^2 for $m_t^2 \ll m_W^2$. For a larger top quark mass a slowly varying correction function $A(z)$ has to be introduced

$$A(z) = \frac{1}{4} + \frac{9}{4(1-z)} - \frac{3}{2(1-z)^2} - \frac{3z^2 \ln z}{2(1-z)^3}.$$

Finally a small QCD correction η_{QCD} must be applied. Thus the mixing frequency is given by [13]

$$\Delta M = \frac{G_F^2}{6\pi^2} m_b B_B f_B^2 |V_{bt}^* V_{td}|^2 m_t^2 A\left(\frac{m_t^2}{m_W^2}\right) \eta_{QCD}.$$

Since the observed mixing rate r is related to ΔM by

$$r \approx \frac{1}{2} \left(\frac{\Delta M}{\Gamma} \right)^2,$$

the observed mixing rate r is proportional to the fourth power of the top quark mass which, however, was not known at that time. But our result on r allowed to obtain a lower limit for m_t .

In order to estimate the unknown parameters of the B -meson in the expression for ΔM , I assumed that the QCD of a B -meson is not much different from the QCD of the K -meson. In both cases there is a heavy quark surrounded by a light quark. Thus naively I set

$$\sqrt{B_B \eta_{QCD}} f_B = f_K = 160 \text{ MeV}.$$

The unknown CKM elements by 1987 were already constrained within

$$|V_{td}| = 0.002 \text{ to } 0.018, \quad |V_{tb}| = 0.9986 \text{ to } 0.9993.$$

Taking the upper limit for $|V_{td}|$ one obtains a lower limit for m_t . Inserting these numbers into ΔM led to the surprise

$$m_t > 50 \text{ GeV}.$$

By 1987 it was the general belief, that the top quark mass was much smaller than 50 GeV, but we found, that it is much larger. Meanwhile the top quark was discovered. Indeed, its mass is $174.3 \pm 5.1 \text{ GeV}$.

OBSERVATION OF B^0 - \bar{B}^0 MIXING

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Figure 26: The frontpage of the ARGUS paper on the observation of $B^0\bar{B}^0$ mixing



Figure 27: The author congratulating
at the 1987 ARGUS collaboration meeting held at Bled

Since our result on $B\bar{B}$ mixing was not in conflict with the Standard Model, we decided to publish [14]. The frontpage of the paper with the list of the authors is shown in Fig.26.

Due to the large mixing rate, it became clear that CP -violation is observable in B -meson decays, which represented the unique possibility to determine the imaginary part of the CKM matrix. Thus a new field of research was opened up, which was then pursued by Babar at SLAC and Belle at KEK.

The observation of $B^0\bar{B}^0$ mixing would have been the most important event in particle physics in 1987, had not the universe presented an even more spectacular event, the supernova explosion SN 1987A.

10 Acknowledgements

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11 References

- [1] H. Hasemann et al., DESY-Proposal No. 148 Oct. (1978)
- [2] The ARGUS drift chamber, M. Danilov et al. Nucl. Instr. Meth. 217 (1983) 153.
- [3] H. Nesemann et al., DESY preprint DESY M-80/89, (1980) in: Proc. Geneva Accel. Conf. (1980) 315.
- [4] ARGUS: A universal detector at DORIS-II, H. Albrecht et al., Nucl. Instr. Meth. A 275 (1989) 1.
- [5] The ARGUS electron-photon calorimeter
 - 1. Detection of low energy electromagnetic showers, A. Drescher et al., Nucl. Instr. Meth. 205 (1983) 125.
 - 2. Properties of the light collection system of the lead scintillator shower counters, A. Drescher et al., Nucl. Instr. Meth. 216 (1983) 35.
 - 3. Electron-hadron separation, A. Drescher et al., Nucl. Instr. Meth. 237 (1985) 464.
- [6] The ARGUS time-of-flight system, R. Heller et al., Nucl. Instr. Meth. A 235 (1985) 26.
- [7] Muon chambers of the ARGUS detector (in Russian), A.V. Arefiev et al., Prib. Tekh. Eksp. 2 (1986) 66.
- [8] The ARGUS vertex drift chamber, K.W. Edwards et al., Nucl. Instr. Meth. A 252 (1986) 384.
The ARGUS microvertex detector, E. Michel et al., Nucl. Instr. Meth. A 283 (1989) 554.
- [9] A. Bean et al., CLEO, Phys. Rev. Lett. 58 (1987) 183,
T. Schaad et al., MARK II, Phys. Lett. 160B (1985) 188,
W. Bartel et al., JADE, Phys. Lett. 146B (1984) 437.
- [10] C. Albajar et al., UA1, Phys. Lett. 186B (1987) 247.
- [11] M.K. Gaillard and B.W. Lee, Phys. Rev. 10D (1974) 897.
- [12] S.L. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev. D2 (1970) 1285.
- [13] A. Ali and Z.Z. Aydin, Nucl. Phys. 148 (1978) 165,
J.S. Hagelin, Phys. Rev. D 20 (1979) 2893;
J.S. Hagelin, Nucl. Phys. B 193 (1981) 123.
M.J. Vysotski, Sov. J. Nucl. Phys. 31 (1980) 797,
T. Inami and C.S. Lim, Prog. Theor. Phys. 65 (1981) 297.
- [14] H. Albrecht et al., ARGUS, Phys. Lett. B 192 (1987) 245.

Sociology of the ARGUS Collaboration

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What we call the beginning is often the end and to make an end is to make a beginning. The end is where we start.
ARGUS logbook 21.3.1989*

1. Introduction

Recently a growing number of sociologists and historians of science started to analyze the way physics in Big Science [1] is carried out. Specifically they are interested in the way how collaborations function in general [2]. On the contrary in this paper the ARGUS experiment is taken as an example to discuss the different steps in the development of an efficient collaboration which might provide a benchmark for professionals in the field for their more abstract studies. Moreover, the paper aims to remind people who worked over years in ARGUS of their hard work and stress but also of happy hours of success; fortunately the latter were not too rare.

The late D.R.O. Morrison summarized his experience with and observation of international collaborations in the paper ‘The Sociology of International Collaborations’ [3]. According to his insights a strong leadership is the necessary condition for a successful experiment, hence he postulated:

- The spokesman is an outstanding physicist and leader who is the dominant personality in the collaboration.

Since he noted a few cases where not enough critical potential was available in a collaboration to avoid publication of wrong results he qualified his requirement:

- It is important to have at least a second major personality in the collaboration.

On the other hand the key for a collaboration to miss its goals according to Morrison was the following organizational structure:

- A collaboration in which there are several major personalities and which is completely democratic does have a problem.

Though ARGUS was not really a democratic organized collaboration and had two successful spokesmen (fig.1) this third criterion formulated by Morrison describes its organization best. Hence the question arises if ARGUS had a problem as foreseen by Morrison.

This can be judged following the old advice ‘A fructibus eorum cognoscetis eos’ [4]. Referring to the citation statistics ARGUS was very successful. In fig.2 the citations of the DESY experiments are compared; even the first observation of the gluon is less often quoted than the discovery of $B^0\bar{B}^0$ -mixing by ARGUS. Moreover, the ARGUS result belongs to the top 20 list of the most influential experimental papers in particle physics. Concentrating to accelerator based experiments ARGUS ranks even at place 11 (table 1). If one trusts more in peer reviews one can quote the judgement of the director of the competing laboratory [5]: ‘In particular, the ARGUS collaboration, about 80 physicists from DESY,

*quoting T.S. Eliot



Figure 1: W. Schmidt-Parzefall (left) spokesman 1979 – 1989 and H. Schröder (right) spokesman 1990-2000

Table 1: Accelerator based particle physics experiments – TOP citation list [7]

Experiment	Topic	Publication	cit.
Aubert et al	Observation of J	PRL33(1974)1404	1546
MARKI(SLAC)	Observation of Ψ	PRL 33(1074)1406	1453
CDF(FNAL)	Obs. of Top Quark	PRL74(1995)2626	1408
Cristenson(BNL)	Obs. of CP Violation	PRL13(1964)138	1380
EMC(CERN)	Spin Asymmetry μ DIS	PLB206(1988)364	1354
D0(FNAL)	Obs. of Top Quark	PRL 74(1995)2632	1348
UA1(CERN)	Obs.of W	PLB122(1983)103	1209
EMC(CERN)	Spin Struct. of Proton	NPB328(1989)1	1176
UA1(CERN)	Obs. of Z^0	PLB126(1983)398	1129
HERB(FNAL)	Obs. of Υ	PRL39(1977)252	1109
ARGUS(DESY)	Obs. of $B^0 \bar{B}^0$ –Mixing	PLB192(1987)245	1097
UA2(CERN)	Evidence for Z^0	PLB129(1983)130	1049

several German universities and others in Canada, Russia and elsewhere has been one of the most productive collaborations in the history of experimental high energy physics’. Similar judgements by G. Altarelli [6] and the chairman of IUPAP, who ranked the observation of the supernova explosion SN1987a, the ARGUS result on $B\bar{B}$ –mixing and the observation of high temperature superconductivity as the most important physics results during his chairmanship underline the success of ARGUS. It follows from these judgements that Morrison must have missed essential characteristics of successful collaborations. The question ‘did Argus have a problem’ should be replaced by ‘why was ARGUS so successful’.

2. Conception, Birth and Growth of the ARGUS Collaboration

The details of the conception of the ARGUS experiment and its launching are described in these proceedings by the two main actors [8], [9]. The early stages of running DORIS in the Υ –region is discussed in [10] and therefore will not

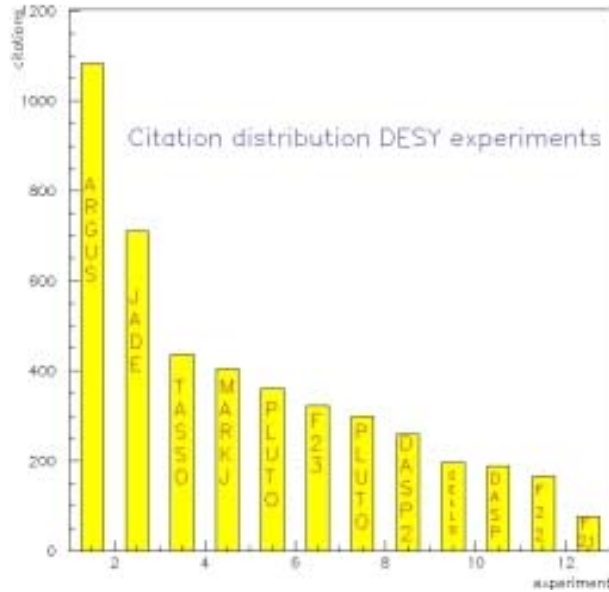


Figure 2: Citation statistics of DESY experiments [14]

be repeated here. Part of the conception phase was a dinner on September 14, 1977 which WSP, myself and our wives had shortly before we left Geneva and started to work at DESY and Dortmund respectively.

Only one month later at a DESY workshop [11] W. Schmidt-Parzefall presented the concept of ‘A New Detector at DORIS’ which already included the essential features of the final design. The list of physicists who participated in this study is given in fig.3. The arguments in favor of the possible physics program (fig.3) – fortunately not formulated too specifically – and the essential constraints of the detector design (fig.3) turned out to be farsighted. Only the last line of fig.3 demonstrates that no one in 1977 really could forecast the treasures hidden in the gold mine. Especially the theorists at that time underestimated the possibilities of a physics program at DORIS; characteristic is the table of priorities as seen by their representative [12] at the time of the workshop (fig.4).

The ARGUS proposal [13] was submitted October 1978 and presented to the PRC by two young members (fig.5) of the collaboration. Physicists from DESY (8), Dortmund (6), Heidelberg (3), Lund (2), ITEP Moscow (9) and South Carolina (2) signed it. Note that charm decays served as benchmark for the detector layout. The proposal was accepted after a long and cumbersome discussion in June 1979; this date can be identified as the birth of the ARGUS experiment.

2.1 Growth of the ARGUS Collaboration

In order to achieve enough strength and credibility a minimum number of scientists and institutes is necessary. ARGUS passed this threshold when IPP Toronto and Kansas University joined the common effort at the end of 1981.

<u>Detector Design Study</u>		
C. W. Darden		
H. Hasemann		
A. Krolzig		
W. Schmidt-Parzfall		
H. Schröder		
H.-D. Schulz		
F. Selonke		
R. Wirth		
F 15	F 51	R 2

Why

DORIS = gold mine

Charm Spectroscopy

Heavy lepton (non sequential?)

Upsilon region

Cornell, SPEAR

What

Solid angle

Resolution

Identification

Second Generation \approx Last Generation

Figure 3: List of physicists who participated in the detector study (left) and arguments in favor of a research program at DORIS (right) [11]

PRIORITIES		
ISSUES	PARADIGM	TOPIC
NEW INTERACTIONS	GAUGE GLUON THEORIES + QUARKS	T { CP UNIVERSALITY RARE DECAYS D { C ² ISM D ⁰ D ⁰ MIXING NONLEPTONIC
STRUCTURE INTERACTIONS	GAUGE GLUON THEORIES + QUARKS	NONSCALING JETS GLUE SPECTROSCOPY
EM INTERACTIONS	QUARKS, OLD IDEAS	$\Upsilon\Upsilon$ { $\Upsilon' \rightarrow \Upsilon\Upsilon$ $\Upsilon^0 \rightarrow \Upsilon\Upsilon$ $\sigma_{\Upsilon\Upsilon}$
1. T : $\rightarrow e\Upsilon, \mu\Upsilon$ + CP UNIVERSALITY 2. D : $\rightarrow e\Upsilon, \mu\Upsilon$ + D ⁰ D ⁰ MIXING 3. QCD: $\Upsilon \rightarrow 3 \text{ JETS}$, $\sigma_{\text{TOT}} (10^{-30})$ 4. SPECTROSCOPY: C ² , MOLECULES, C ² ATOM 5. $\Upsilon\Upsilon$: $\rightarrow \eta'$, $\rightarrow \Upsilon^0$ $E_{\text{cm}} < 2 \text{ GeV}$ 1. "NEW" MIXING 2. NEW DETECTOR		
	5. OLD MIXING BONAUZA

Figure 4: Priority list for the DORIS program as seen by a theoretician in 1977 [12]



Figure 5: W. Hofmann and H. Schröder who presented the ARGUS proposal

At this moment not only the typical number of collaborators for experiments was achieved (Fig.6), but even more important enough experienced groups had joined the experiment who had the expertise and capacity to build the major detector components. Also enough manpower was available to develop the necessary online and analysis software. In retrospect it was especially fortunate that each major component could be developed and built by one of the participating institutes. The necessary technical coordination among other things was minimized by this fact.

Fig.7a shows a typical example of the mass production; as demonstrated by fig.7b during the development phase a few problems were met, but they turned out to be solvable. As shown in fig.8 the final installation was again a common effort of all members. It should be stressed that the detector was built in a very short time; three years after the proposal was accepted the detector was installed in the interaction region. Less than one month was needed to tune the detector and the data collection could start. The necessary diplomatic skills to convince the machine group to reduce the background are described in [9].

A first and essential answer why ARGUS was so successful is based on the facts described above:

- One institute was responsible to develop, build, calibrate and run the major components of the detector;
- during the whole lifetime of the experiment this responsibility did not change;
- each institute took care that their PhD students achieved hardware experience participating in the running and calibration of the detector;
- each member of the collaboration got the chance to contribute to the general work and most of them made use of it.

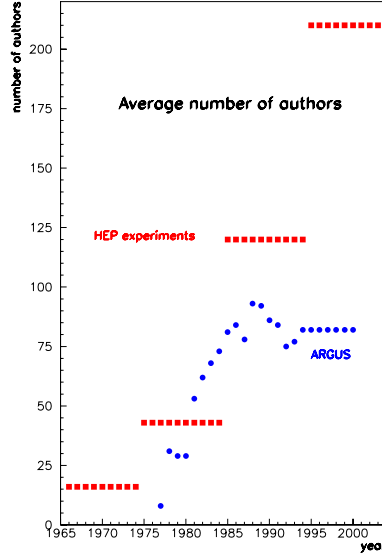


Figure 6: Number of authors signing ARGUS papers compared to average collaboration size [14] as a function of time

3. The Collaboration in its Maturity

The data taking of the ARGUS experiment started on October 6, 1982 and ended on October 8, 1992 (fig.9); during these 10 years less than 30% of the time DORIS II was available for high energy physics (fig.10). In principle 2/3 of the running time was scheduled for high energy physics and 1/3 for synchrotron radiation. But in 1987 DORIS II was switched off for most of the time because of HERA preparations, the short running time available was then scheduled for synchrotron radiation. In 1990 DORIS II was upgraded for synchrotron radiation (Bypass), only a short test run for ARGUS was foreseen. Also in 1991 and 1992 nearly no luminosity for ARGUS was delivered. Only in the years 1985, 1986, 1988 and 1989 the ARGUS collaboration could collect luminosity for its physics program.

The first paper was submitted end of October 1983 [15]. It was followed by the only paper where ARGUS and Crystal Ball [16] combined their data to achieve a precision measurement in this case of the $\Upsilon(2S)$ -mass. The last publication [17] appeared in 2000, eight years after the end of data collection. In total 151 journal papers were published by the ARGUS collaboration. It is worth noting that after 1989 six results were only submitted as preprints because the statistics available was too small to arrive at conclusive results.

3.1 Organization

Actually the organization of collaborations due to the complexity of the experiment and the large number of physicists and institutes participating is extremely elaborate with many boards and committees. Already the sheer number of co-

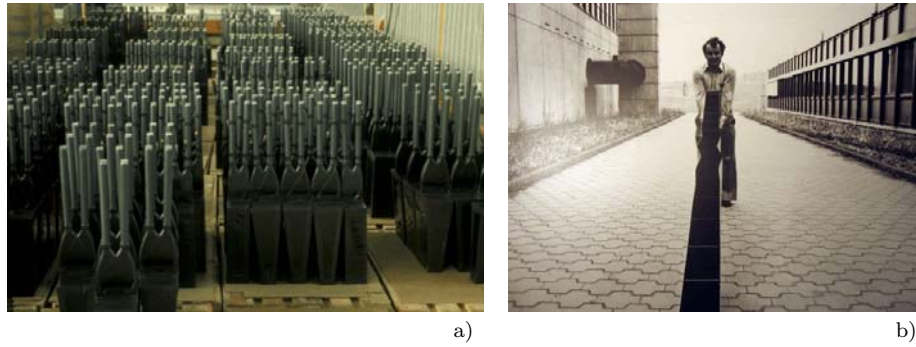


Figure 7: Shower counter modules prepared for calibration run (a) and model of support structure (b) of the shower counters

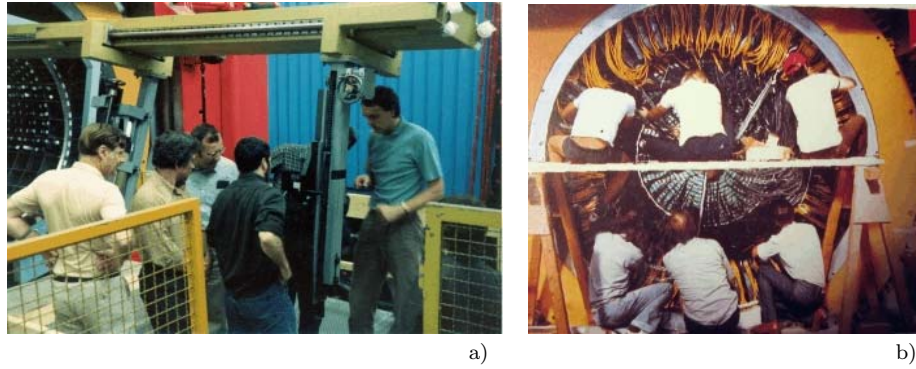


Figure 8: Installation of detector components: insertion of shower counters (a) and cabling of drift chamber (b)

ordinators and deputies in one of the LHC experiments exceeds the number of ARGUS members. Hence much simpler ways to organize the work of the ARGUS collaboration were necessary and possible: Decisions were taken by the spokesman who used his telephone and the daily meeting of the senior coffee club to make sure that essential arguments were considered. The decisions were clear and problem orientated and could immediately be realized (fig.11a). The spokesman and other members of the ARGUS collaboration were not forced to attend unnumerable meetings but had time for real work as demonstrated by fig.11b. Outsiders sometimes received the impression of chaotic conditions to prevail in the ARGUS collaboration but the principle of selforganization proved to be very effective. This is exemplified in a symbolic way by fig.12; while fig.12a symbolizes the chaotic phase, fig.12b recorded a few minutes later, proves the effectiveness of ARGUS selforganization.

The daily work was discussed once a week in the group meeting on Thursday morning where the running status and new results from data analysis were presented. Here for the first time the observation of $B^0\bar{B}^0$ -mixing (fig.22) was discussed and I remember the talk of M. Danilov where he showed why ARGUS was a factor of 7 better than CLEO at that time. Of course, information was also exchanged by telephone and quite early e-mail was used. The first e-mail I found in my folders dates from 1988. Of special importance were collaboration

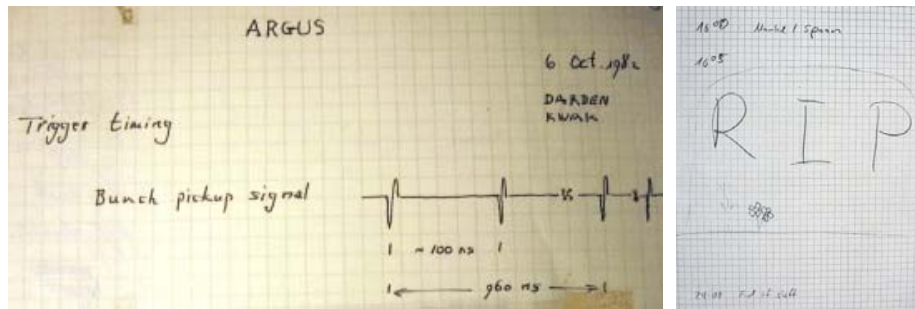


Figure 9: First entrance 6.10.1982 (left) and last one 8.10.1992 (right) in the ARGUS logbook

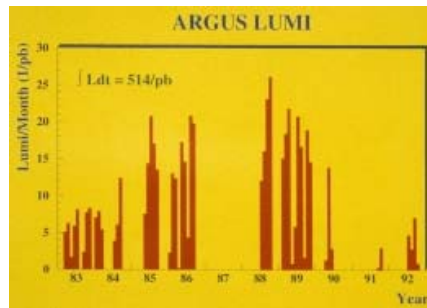


Figure 10: Integrated luminosity collected by ARGUS as function of time

meetings which took place twice a year. Each year one of these meetings was held at one of the outside institutions (Dortmund, Heidelberg, Moskau, Ljubljana, Montreal) before the summer conferences and the second in December usually in Stade. Parallel sessions which nowadays dominate the agenda of collaboration meetings were avoided; thus every member was able to follow the full program. No one was tempted to skip a session in order to do computer work since WWW was in its infancy.

None of the ARGUS physicists belonged to the DESY establishment; this fact turned out to be a major disadvantage, especially when priorities in the lab were defined. ARGUS' output for sure suffered from this fact.

One might get the impression that the young postdocs and PhD students were decoupled from the decisions taken in the experiment. This was not true on the contrary they were able to influence the priorities in the experiment to a large extend. This is best demonstrated [18] by the so called "Zwergenaufstand" (fig.13,14). At the end of the first long running period of the ARGUS experiment a series of possible improvements of the hardware as well as of the software were identified. Since no immediate reaction of the ARGUS management followed, a group of engaged young postdocs and PhD students took the initiative after a discussion with the spokesman and seized his suggestion to elaborate their ideas for an improvement program. They not only collected in a brainstorming session 'many unordered ideas regardless of the smallest chances of realization'. In a paper [19] they summarized in detail their 'ideas in a structured manner'.

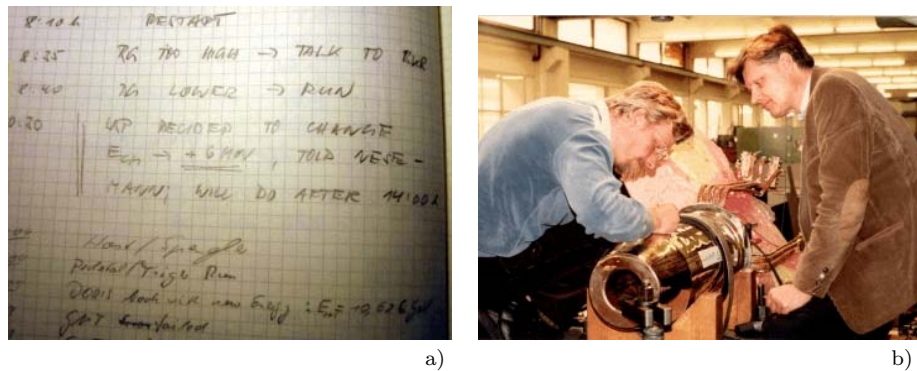


Figure 11: Note in the logbook 6.4.1989 (a) and preparation of the mini-quadrupoles (b)

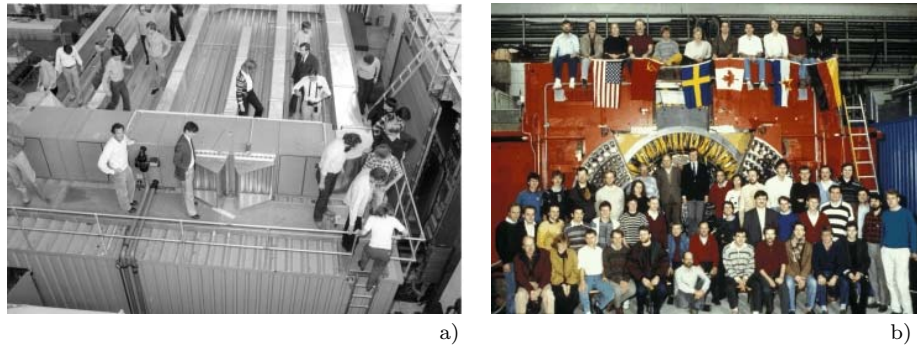


Figure 12: Demonstration of effective selforganization

They even made a step further: a priority list and an estimate of the necessary manpower were compiled. Fig.14 gives an impression of their work. Moreover, they found those people in the collaboration who were willing to take over the work to be done. This initiative turned out to be extremely successful and is an example of the power of selforganization. The results of these efforts were an essential ingredient of the ARGUS success.

3.2 Data taking

As discussed in the beginning of this chapter luminosity was delivered only part of the time. Even worse in the first years priority was given to the Crystal Ball experiment, only in the year 1985 ARGUS physics program got priority. In retrospect this decision of the DESY directorate needs some explanation. In 1983 priority for the Crystal Ball experiment was a natural decision and even for the year 1984 a rational argument exists:

- Crystal Ball had a running detector;
- it was an established and successful collaboration with a respectable record of discoveries;

Zwergenaufstand Teil I

Anwesend waren :
Uwe B., Gernod H., Dietmar K., Herbert K.,
Ulf M., Klaus S. und Siegfried W.
Nicht anwesend war:
Andreas D.
2.11.86, 20:00
in der "Blauen Blume"

Figure 13: Postdocs and PhD students of the ‘Zwergenaufstand’ [18]

- the ARGUS senior members were youngsters at that time and not every one at DESY was convinced that we could compete successfully with the CLEO experiment;
- Crystal Ball observed [20] an unexpected signal in the decay channel $\Upsilon(1S) \rightarrow \gamma\zeta$. Hopes were running high for a short time at DESY that a light Higgs boson had been observed.

The signal observed in the 1983 data could not be reproduced by Crystal Ball [21] in the data collected in 1984. In agreement with this result ARGUS derived from its data a limit of the branching ratio [22] which was a factor 3 below the value originally claimed by Crystal Ball [20]. A ‘model which might explain the disappearances’ [23] seems to have been a strong enough argument for the directorate to schedule in 1986 50% of the running time available for high energy physics to collect data ± 12 MeV below and above the $\Upsilon(1S)$. This model seems to be described in ref.[24]; its explanative power had been analyzed with a negative result [25] already in spring 1985 by a senior member of the Crystal Ball collaboration. When discussing the DORIS II program for 1986, the PRC did not formulate an explicit recommendation for the 1986 running period, the minutes simply state ‘the directorate will take a wise decision’ [26]. No signal was observed either [23]; unfortunately these data could only be used for studies of $\gamma\gamma$ —physics and not for the really interesting physics questions. As the final resumé of the Crystal Ball collaboration after three years of hard work one finds in [23] the statement ‘the observation of ζ has to be interpreted as a statistical fluctuation’.

How can the observation of the ζ by Crystal Ball be explained? A convincing explanation may be the guidelines for searches formulated by J. W. Goethe, a critical observer of our field [27]. However, in addition the group dynamical explanation by Morrison [3] in his essay has to be considered for research performed by large collaborations: ‘... there are a number of published results which seem exciting and caused great activity, but are finally found to be wrong. It is not easy to say precisely how this occurs, may be by constantly repeating it to one another a surprisingly result becomes acceptable. The problem is when it becomes an article of faith for members of the collaboration to believe the result’.

4 Man power estimates	
We tried to set up a rough estimate how many people are needed for all tasks mentioned above under the assumption that all this has to be done as full time job over 6 months.	
$\frac{dE}{dz}$ calibration	1 PhD student (plus one "active responsible" post doc / senior in background)
Drifttime-space-relation	1 PhD student (plus one active post doc / senior in background)
SH calibration and tuning of the program	1 diploma student (plus one active PhD student / post doc in the background)
TOF-calibration	1 PhD student
MU-analysis	1 (wo)man
VX-Fit	1 PhD student (plus one very active senior in background)
trackfit/superfit	1 (wo)man
constant- and other files	1-2 PhD students
luminosity	1 diploma / PhD student

Figure 14: List of tasks to improve the ARGUS detector as presented by the dwarfs in their memo [19]

There were of course for ARGUS as in every other high energy physics experiment some problems due to external influences. The machine had to be switched off in the late afternoon because of energy costs. Moreover, DORIS II was sometimes not running smoothly and for long periods no data could be taken due to machine problems (fig.15a). Also the cooperation of the operators was not optimal as demonstrated by records in ARGUS logbook (fig.15b).

ARGUS itself produced also problems causing serious losses during data taking. The computing system was unstable quite often producing desperation to the people on shift; the note in the logbook (fig.16) expresses the frustration of a shift. Sometimes detector components were running unstable; fortunately seniors knew the basic tricks to solve the problems (fig.17). Some of the youngsters soon developed a stoic attitude (fig.18a); moreover, as observed also in other collaborations the experiment not always benefitted from the presence of active experts (fig.18b).

ARGUS was confronted with one real hardware problem already at an early stage of the experiment. Not totally unexpected [28] a serious aging of the driftchamber due to deposits on the wires was observed in February 1984. Experts all over the world were contacted (fig.19a), unfortunately no unambiguous advice was given. Finally the spokesman, after discussing the problem with his friends at CERN, decided that water admixture should solve the problem (fig.19b) as it indeed did. After the successful operation, we could send a telegram to the spokesman who had gone for skiing, reporting the success of the procedure. The simple organizational structure of ARGUS (see ch.3.1) was in this case a real advantage to arrive at a quick decision.

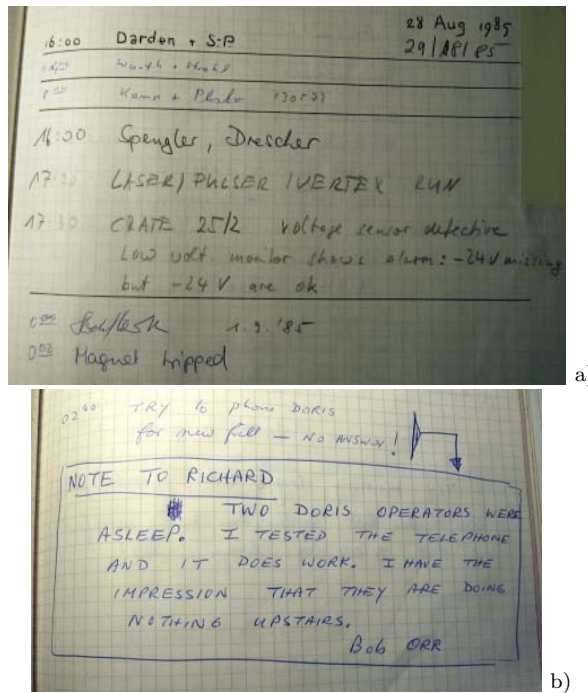


Figure 15: Notes in ARGUS logbook demonstrating external problems (a) 28.8.1985 and (b) 24.6.1984

Despite of these problems a successful data taking was possible and on some days unexpected high luminosities were collected (fig.20) followed by a spontaneous party of the shift crew. As explanation for this successful luminosity run the acknowledgement in the logbook might serve: ‘The result would not have been possible without the help of a nice bottle of Manatirka Slivovic (ARGUS logbook VII p.103). It is not clear from the notes if the bottle was provided to the DORIS operators (following the example of WSP and Micha Danilov in 1982 [9]) or to the ARGUS shift team.

Enough data for a successful physics program including the first observation of $B^0 - \bar{B}^0$ -mixing and the establishment of the $b \rightarrow u$ transition was available to mention only the highlights in B-physics program. One might wonder, if a schedule of DORIS II considering the ARGUS wishes with higher priority would have allowed to observe in addition Penguin transition $b \rightarrow \gamma$ for the first time. The later CLEO result [29] for the branching ratio excludes this in retrospect; a factor of 4 to 5 higher luminosity would have been needed.

3.3 Physics

DORIS II turned out to be a gold mine as emphasized by W. Schmidt-Parzefall at the first presentation (fig.3b) of the physics program [11]. It covered such different topics as:

- B-physics

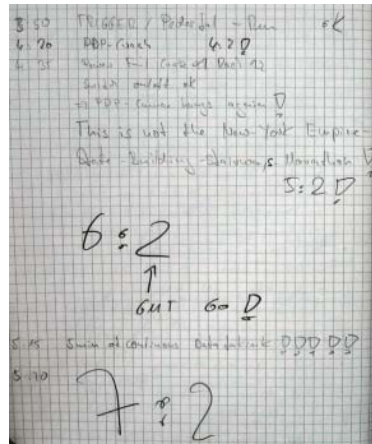


Figure 16: Frustration of a shift team due to computer crashes, ARGUS logbook 3.5.1990

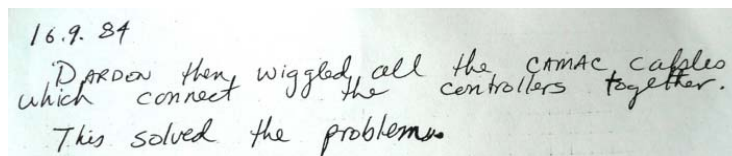


Figure 17: Note from the ARGUS logbook 16.9.1984

- Charm–physics
- τ –physics
- Spectroscopy of $b\bar{b}$ bound states
- Quark and gluon fragmentation
- $\gamma\gamma$ –physics
- Searches for new physics

In all these fields papers were published starting with ‘First observation of ...’. More than 50% of the publications were based on PhD thesis (fig.21).

There existed a plethora of physics problems which could be attacked. This fact made life easy since every one could find problems whose solution promised reward. Comparing the number of PhD thesis with the number of publications and the time distribution of diploma and PhD thesis a characteristic time shift is observed which also shows up in other experiments. It can easily be explained by the fact that publications were often based on results of PhD while diploma thesis very often covering technical developments.

Why was ARGUS so successful to exploit the rich physics accessible? We had an excellent detector and optimally designed software, but of course most

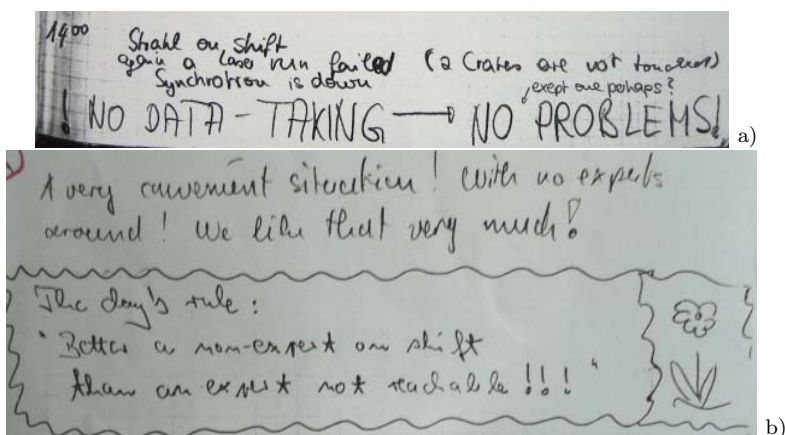


Figure 18: Notes in the ARGUS logbook (a) 22.5.1985 and (b) 17.4.1989

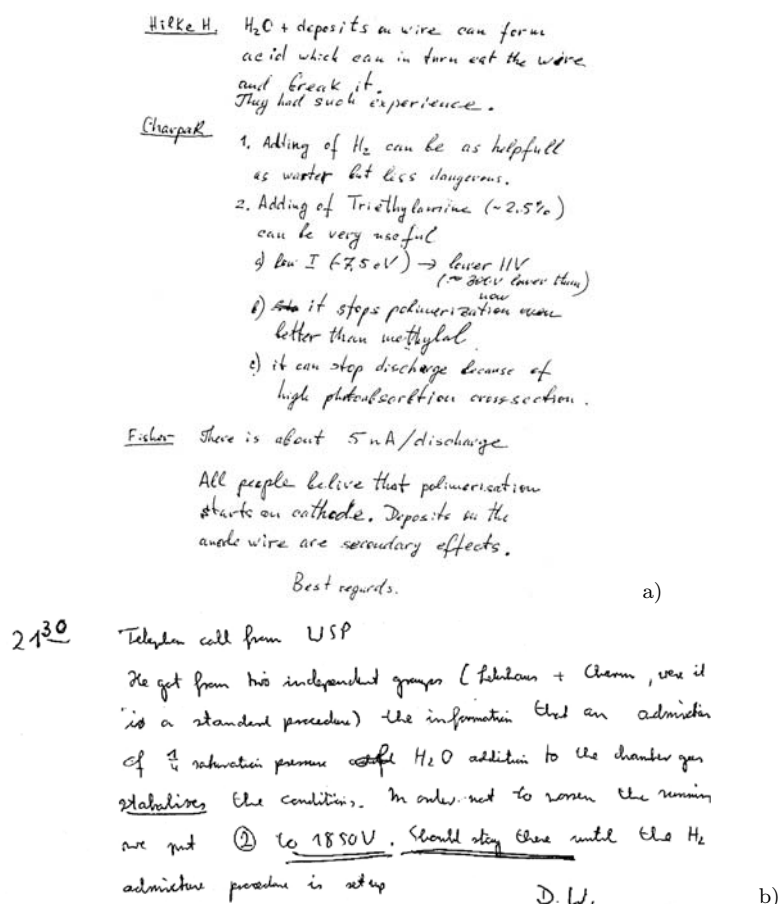


Figure 19: (a) Proposed actions to cure aging effects and (b) method applied successfully, logbook 8.3.1984

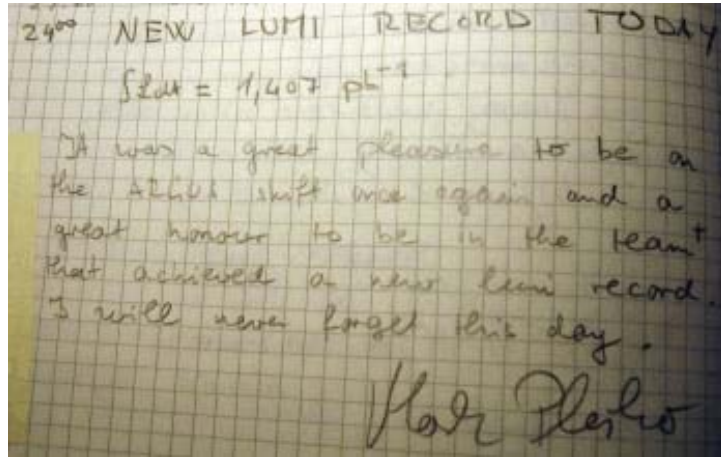


Figure 20: Record of very successful data taking day 5.8.1989

important was the quality of the physicists using them. A colleague from US once pointed out to me the importance of the nearly ideal mixture of experienced competent senior physicists from DESY and the excellent PhD students and postdocs of the participating universities. Their close cooperation turned out to be extremely effective and allowed to exploit the goldmine and successfully compete for many years with our colleagues from CLEO.

Twice the publication of wrong results was avoided in the last moment. The delivery of the DESY preprint concerning D_s -meson observation was delayed by 8 month: the DESY preprint number is DESY 84-043 (May 1984), while the paper [30] was finally submitted January 7, 1985. In ref.[31] the reason for the delay is discussed. The first version of the preprint was collected in the last moment by K. Schubert and eco-friendly disposed [31].

A first preliminary limit on $B^0\bar{B}^0$ -mixing was presented at Berkeley conference, it amounted to $r_d = \frac{N(B^0B^0)+N(\bar{B}^0\bar{B}^0)}{N(B^0\bar{B}^0)} \leq 0.11$. Returning from this conference H. Schröder started in August 1986 an analysis using an increased data sample of the exclusive decay $\bar{B}^0 \rightarrow D^{*+}l^-\bar{\nu}_l$. For this purpose he developed a new selection method exploiting the excellent particle identification capabilities, the hermiticity and the large efficiency of the ARGUS detector. Along with 23 candidates for unmixed events he observed 2 B^0e^+ , 2 \bar{B}^0e^- , and 1 $\bar{B}^0\mu^-$ and 1 fully reconstructed B^0B^0 -event. The results were presented at the weekly ARGUS group meeting September 25, 1986 (fig.22). The delivery of the paper, prepared immediately after the Berkeley conference, was stopped in the last moment; the final results were published in June 1987 [32]

In one case the quality assurance methods of ARGUS did not prove successful [33]. A peak showed up in the $p\bar{p}\pi^+$ channel which is an allowed decay channel of the B^+ -meson. Unfortunately, also the signal of one negative hadron in the shower counters was compatible with a \bar{p} [34]. This decay channel meanwhile has been observed [35] with a branching ratio a factor of 100 smaller than the value

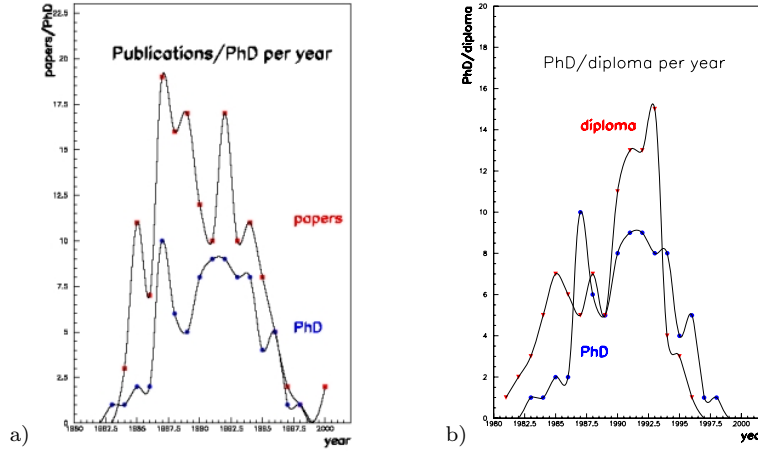


Figure 21: (a) Number of PhD thesis and publications per year, (b) comparison of ARGUS PhD and diploma thesis per year as function of time

derived from the ARGUS ‘signal’ which has to be interpreted as a fluctuation. This analysis suffered from the fact that no realistic model of $\Upsilon(4S)$ –decays existed at that time and the cuts applied to select the ‘signal’ were tuned on the data. The bias introduced by this procedure was not realistically estimated at this time and thus the significance of the two fluctuations overestimated. Also the group dynamics [3] mentioned in ch.3.2 seems to have been important. In a later publication [36] the withdrawal of this result was indicated in an indirect way. The procedure proposed by L. Meitner to O. Hahn [37] when they were forced to withdraw their previous results on n –capture in U after the observation of nuclear fission would have been more elegant; ARGUS had the chance for such an approach when they observed for the first time $b \rightarrow u$ transitions in inclusive semileptonic B–decays [38]; this opportunity was not used.

In consequence of this mishap a formal referee system was introduced where a critical expert of the collaboration, not involved in details of the analysis, was asked to check the different steps leading to the result. This procedure established a very effective control mechanism.

3.4 Social life

Good personal relations between the members of a collaboration are of high importance and in the ARGUS collaboration they were indeed usually very good. The many important discoveries from the beginning of the experiment on made the work rewarding and hence satisfying. The friendly competition with CLEO [39] enforced the feeling of solidarity and the work towards a common goal. People made friends and supported each other if necessary. Disagreements on technical and scientific matters were expressed clearly but usually in a polite way. Scanning the notes in the logbook one finds only one (fig.23) where the opposing opinions clashed; fortunately a senior was around to rise the discussion to the usual level.

$\underline{D^{*+} - LEPTON^- - CORRELATIONS}$
 OR
 $\underline{RECONSTRUCTION OF}$
 $\underline{\bar{B}^0 \rightarrow D^{*+} e^- \nu}$
 OR
 $\underline{HOW CAN WE OBSERVE}$
 $\underline{B^0 - \bar{B}^0 - MIXING}$
 H. SCHRÖDER, DESY 25.11.86

Figure 22: Front transparency of H. Schröder's talk announcing first observation of $B^0 \bar{B}^0$ -mixing

1 Dec '82 this note is deliberately misleading RSD
 IN RESPONSE TO THE REMARK ON P. 193
 BY JDP (~~SEE DRIVER DESCRIPTION~~) PLEASE READ
 YOUR OWN DRIVER DESCRIPTION ^{which refers}
 ↓ to an irrelevant problem
 See below JDP
 *TITLE XADRV
 *IDENT /VI.8/
 XADRV → A DMS11-M DIRECT MEMORY INTERFACE MODULE DRIVER
 OKAY ⇒ PEACE! etc.

Figure 23: Notes from ARGUS logbook (1.12.1982) expressing controversial opinions

The collaboration meetings usually included social events which are documented in figs.24–26. The first meeting dedicated to the preparation of the proposal was held in 1978 at Geneva enforced by political reasons. In 1981 the group had grown (fig.24), but it was still small enough that all group members could be invited to the home of a senior. This changed later on; the highlight for sure was the collaboration meeting 1987 in Bled. Figs.25 prove the good spirit characteristic for the ARGUS collaboration. Usually a half-day excursion was planned during the outside collaboration meetings (fig.26a,b). Also these activities helped to improve solidarity within the collaboration. On long term these undertakings payed off. At DESY the social contacts were more on a personal level, only a few times on special events like finishing calibration runs or starting data taking Booze-ups took place. In these cases the training of our spokesman during student days as a 'Blauer Sänger' made him an ideal barkeeper (fig.27).



Figure 24: Documents of collaboration meetings 1978 at CERN and 1981 at Dortmund



Figure 25: Collaboration dinner at Bled 1987



Figure 26: Collaboration meeting in Moscow and Bled



Figure 27: The spokesman in full action

3.5 Careers

Besides the publication and citation statistics the future careers of the collaboration members reflects the success of an experiment. 81 PhD and 101 Diploma/Master students prepared their thesis in the ARGUS collaboration. As shown in fig.28 most of the German graduates work nowadays in industry, some of them in leading positions. About 50% of the ARGUS students from outside Germany are still active in high energy physics.



Figure 28: Position in science and industry of german (left) and non-german ARGUS members (right)

Many of the seniors and postdocs of the ARGUS collaboration are nowadays in leading research positions (table 2). Three of the former postdocs are now spokesmen of one of the present day large international collaborations; as far as I can see no other collaboration has been as successful. The list of former PhD students which now have an influential position at universities and research centers is also long (table 2).

Finally the list of honors and prizes awarded to ARGUS members is impressive:

- 1989 B. Spaan Benno-Orenstein-Preis
- 1991 D.B. MacFarlane Herzberg Medal and
1995 Rutherford Medal

Table 2: ARGUS members who achieved leading positions in research institutions

Seniors	Postdocs	PhD
M. Danilov H. Kolanoski W. Schmidt-Parzefall K.R. Schubert	A. Golutvin W. Hofmann P. Krizan D.B. MacFarlane H. Schröder	S. Ball D.J. Britton D.M. Gingrich G. Herrera S. Khan J.A. McKenna J. Parsons M. Paulini T. Ruf S. Schael B. Spaan J.D. Swain G. Tsipolitis S. Westerhoff

- 1995 W. Schmidt-Parzefall Gentner–Kastler Preis
- 1996 M. Danilov Max–Planck–Forschungspreis
- 1997 H. Schröder W.K.H. Panofsky Prize of APS
- 1997 Y.M. Zaitsev W.K.H. Panofsky Prize of APS
- 2001 G. Herrera Premio de Investigación 2001 de AMC
- 2004 C. Darden Russell Research Award
- 2007 D. Wegener Bundesverdienstkreuz 1. Klasse

Summary

The success of the ARGUS collaboration had different sources. First of all the physics in the $\Upsilon(4S)$ region turned out to be extremely multivarious and many fundamental problems could be attacked and solved. This was not expected when the ARGUS collaboration started. A powerful detector was necessary to exploit the goldmine and indeed the ARGUS detector fulfilled all conditions: charged and neutral particles were detected in nearly the full phase space, its hermiticity could be exploited in the analysis by innovative ideas. It had excellent particle identification possibilities. The fact that one institute was responsible for a component and this did not change during the lifetime of the experiment was essential for the optimal exploitation of the detector. All components achieved their design values and some even surpassed them. The design of the detector was optimized for pattern recognition and special effective analysis software was developed. ARGUS had excellent PhD students whose contribution was essential to develop and exploit original ideas in the analysis. Of

course a little bit of luck was also necessary and the friendly competition with CLEO should not be underestimated [39].

Last but not least ARGUS was so successful because of the enthusiasm of its members and since the spirit in the collaboration was unique. It is best characterized by the introductory remarks of the report written by the “dwarfs” (fig.13,14): ‘Please note that some of the “dwarfs” very probably will not have the opportunity to profit by the future of ARGUS. So account for their participation in our meetings as an expression of responsibility’.

Acknowledgement

I thank J. Bürger, M. Danilov, H. Kapitza, W. Schmidt-Parzefall, H. Schröder, B. Spaan and K. Wille for discussions, unpublished material and copies of ARGUS notes. All my colleagues of the ARGUS experiment made the 22 years of collaboration a wonderful experience.

Bibliography

- [1] D. Price, Little Science, Big Science Suhrkamp 1982
- [2] W. Shrum et al., Structures of Scientific Collaboration MIT Press 2007
- [3] D.R.O. Morrison in R. Armenteros, A. Burger, Y. Goldschmidt-Clermont, J. Prentki (ed.): Physics from Friends – Papers dedicated to C. Peyrou on his 60th birthday, Geneva 1978
- [4] Novum Testamentum Vulgatae Editionis, Ev. Matthaei VII,16
- [5] K. Berkelmann, Cornell University 1992
- [6] G. Altarelli, Proc. Intern.Conf. High Energy Physics, Uppsala 1987, p.1002
- [7] Spires data bank October 2007
- [8] H. Schopper, Launching of DORIS II and ARGUS, these proceedings
- [9] W. Schmidt-Parzefall, Discovery of B–Mixing 1987, these proceedings
- [10] D. Wegener, B–Quark studies at DESY, Poceedings Twenty Beautiful Years of Bottom Physics, Chicago 1977 AIP Confrence Series 424(1998)50
- [11] W. Schmidt-Parzefall, Meeting on DORIS Experiments, Int.Rep. F15/01 (Nov.1977)
- [12] T. Walsh Meeting on DORIS Experiments, Int.Rep. F15/1 (Nov.1977)
- [13] ARGUS A New Detector for DORIS DESY F12/Pro 148 (Oct. 1978)
- [14] K. Yunkewicz, Author growth, Symmetry 01(2004) issue01
- [15] H. Albrecht et al. (ARGUS), Phys.Lett. 134B(1984)137, submitted 26.10.1983
- [16] D. P. Barber et al. (ARGUS, Crystal Ball), Phys.Lett. B135(1984)498
- [17] H. Albrecht et al. (ARGUS), Phys.Lett. B485(2000)37 subm. 24.4.2000, A search for the electric dipole moment of the τ –lepton
- [18] Zwergenaufstand, ARGUS internal report 2.11.1986
- [19] The dwarfs: U. Binder et al., The uprising of the dwarfs, ARGUS internal note 1986

- [20] H.J. Trost et al. (Crystal Ball), Proc. XXII Int. Conf. High Energy Physics Leipzig 1984, p. 201
- [21] DESY Annual Report 1984 p. 120
- [22] H. Albrecht et al. (ARGUS), Z.Phys. C29(1985)167
- [23] DESY Annual Report 1986 p.116
- [24] S.-H.H. Tye and C. Rosenfeld, Phys.Rev.Lett. 53(1984)2215
- [25] E. D. Bloom SLAC-PUB-3686 (1985)
- [26] Minutes, DESY Physics Research Committee (PRC) October 2–3,1985
- [27] J.W. Goethe, Hamburger Ausgabe Vol.XIII p.10, Der Versuch als Vermittler von Subjekt und Objekt; for a translation see ref.[10] footnote 2
- [28] DESY Annual Report 1982, p.107
- [29] T.E. Coan et al. (CLEO2), Phys.Rev.Lett. 85(2000)525
- [30] H. Albrecht et al. (ARGUS), Phys.Lett. B153(1985)343
- [31] K.R. Schubert, Pioneering work on beauty: The CLEO/ARGUS era (1978–1993), Sheldon Fest, Syracuse 20.5.2006
- [32] H. Albrecht et al. (ARGUS), Phys.Lett. B192(1987)245
- [33] H. Albrecht et al. (ARGUS), Phys.Lett. B209(1988)119
- [34] D. Wegener, Proc. Ringberg Workshop on Hadronic Matrixelements, Ringberg April 17–22 1988, p.337
- [35] Particle data group, J.Phys.G 33(2006)1
- [36] H. Albrecht et al. (ARGUS), Phys.Lett. B241(1990)278
- [37] Letter of L. Meitner to O. Hahn, January 1, 1939, in O. Hahn Erlebnisse und Erkenntnisse, Econ 1975 p.76
- [38] H. Albrecht et al. (ARGUS), Phys.Lett. B234(1990)409
- [39] D. Cassel, talk at the ‘ARGUS End of the Run Party’, DESY 9.11.1993

CLEO B Physics

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Active and friendly competition with the ARGUS Collaboration was an important chapter in the history of the CLEO Collaboration. In this talk, I will discuss some of my impressions of the CLEO B physics program, which – not only for the purpose of the ARGUS Symposium – can conveniently be divided into three periods or efforts: before $B^0\bar{B}^0$ mixing, studying $B^0\bar{B}^0$ mixing, and after $B^0\bar{B}^0$ mixing. My emphasis is on CLEO's insights, turning points, interactions with ARGUS, and measurements that are still competitive in the B Factory era.

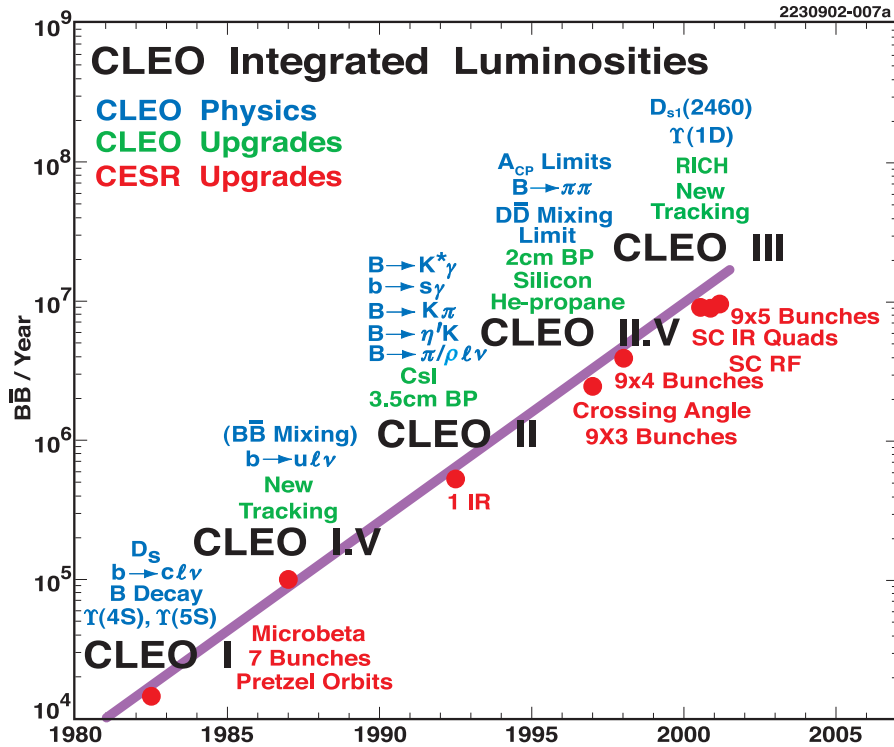


FIGURE 1. Graphical history of CLEO integrated luminosity, detectors, and the results of the CLEO B physics program. The physics results were all discoveries or co-discoveries except for ($B^0\bar{B}^0$ Mixing) which – as everyone at this symposium knows – was a confirmation following the discovery by ARGUS.

1 Overview

The CLEO Collaboration took data in the Υ energy region at the CESR storage ring from 1979 to 2003. Many of the important discoveries and measurements of CLEO during that period are illustrated in Fig. 1, which emphasizes the CLEO B physics program. The CUSB collaboration took data simultaneously with CLEO from the beginning through the early CLEO II period. CUSB published results simultaneously with CLEO for several of the earliest discoveries and measurements. Other important CLEO results from the Υ period include Υ , D , τ , and QCD measurements, as well as the first observation of about 2/3 of the known charmed

baryons. From 2003 to 2008, CLEO took data in the charm threshold region. Results of the CLEO-c physics program include: first observations of $h_c(1P_1)$ and f_{D^+} ; confirmations of $\eta_c(2S)$ and $Y(4260)$; and precision measurements of f_{D_s} , M_{D^0} , and M_η ; precision absolute hadronic branching fractions of D^0 , D^+ , and D_s^+ ; precision measurement of η branching fractions; and precision measurements of D^0 and D^+ semileptonic branching fractions. To date (March 2008) CLEO has published or submitted for publication 468 articles in refereed journals. A total of 211 graduate students completed Ph.D. theses with CLEO data and 30 Cornell graduate students in accelerator physics based their theses on work they did at CESR. Much more information on the history of CLEO and the CLEO physics program is available in a monograph by Karl Berkelman [1].

The CESR storage ring is illustrated in Fig. 2 along with two Cornell accelerator innovations that contributed significantly to the almost exponential increase in integrated luminosity for CLEO illustrated in Fig. 1. These innovations were pretzel orbits, invented by Raphael Littauer (1983), and bunch trains, invented by Robert Meller (1990). These innovations involved separating the electron and positron orbits at the points where parasitic collisions of multiple bunches would otherwise occur and beam-beam interactions would limit luminosity. Electrostatic separators introduced horizontal betatron oscillations that – of course – were of opposite sign for the two beams. LEP and LEP II also utilized these inventions, which contributed to the success of the LEP physics programs.

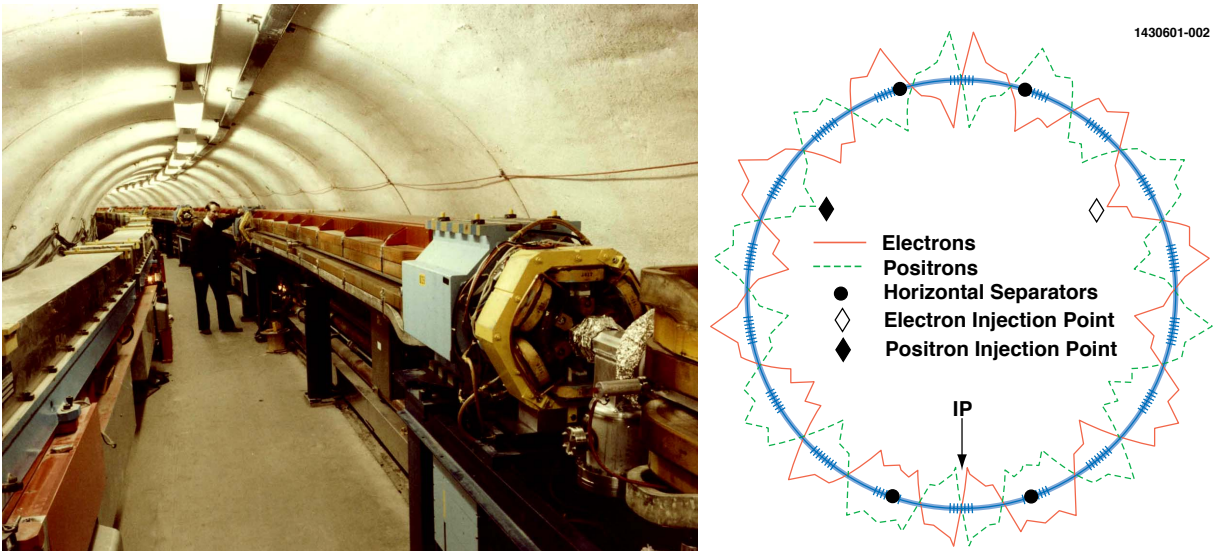


FIGURE 2. (Left) the CESR tunnel with CESR on the right and the 10 GeV synchrotron, which is used as an injector for CESR, on the left. Boyce McDaniel, the director of the Cornell laboratory during the construction and early operation of CESR and CLEO, is standing next to CESR. (Right) an illustration of pretzel orbits and bunch trains in CESR, with betatron oscillations greatly exaggerated. The locations of the bunch trains are illustrated by the small tick marks at the maxima of the betatron oscillations.

The CLEO I [2] and CLEO II [3] detectors are illustrated in Fig. 3. The CLEO I detector was a first-generation detector with particle identification (dE/dx measurements or Cherenkov radiation detectors) and electromagnetic calorimetry outside of the solenoidal magnet coil. The ARGUS detector [4] was superior to the CLEO I detector, which provided several advantages for the ARGUS physics program. With the CLEO II detector, CLEO pioneered the utilization of CsI for electromagnetic calorimetry, a technique that BaBar and BELLE now use.

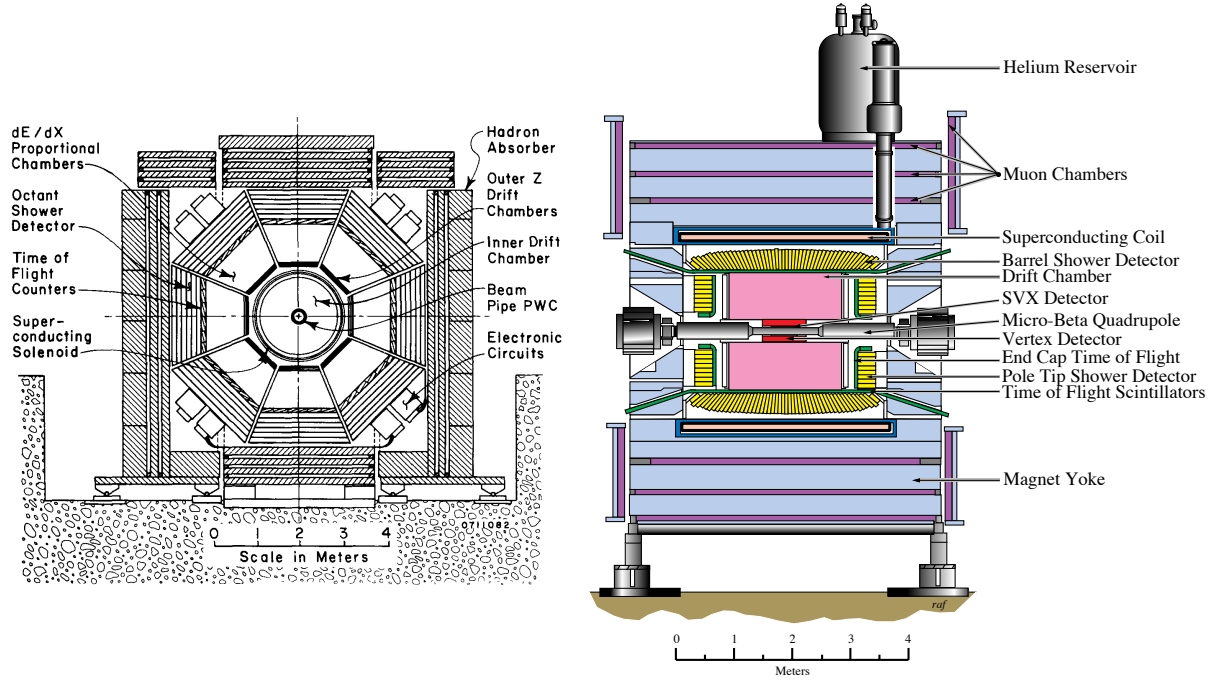


FIGURE 3. (Left) the CLEO I and I.V detectors 1979 – 1989, and (right) the CLEO II and II.V detectors 1989 – 1999. In the CLEO I.V configuration, the CLEO II drift chamber replaced the original CLEO I drift chamber. The CLEO II.V detector included the silicon vertex (SVX) detector indicated in the figure, which was not part of the original CLEO II configuration.

2 Before $B^0\bar{B}^0$ Mixing

The first physics results of the CLEO Collaboration (simultaneously with the CUSB Collaboration) were the confirmation that the $\Upsilon(3S)$ was a narrow resonance [5,6]. DESY contributed significantly to these first CLEO and CUSB observations of Υ states, because the LENA [7] collaboration at DORIS had measured the mass difference, $M_{\Upsilon(2S)} - M_{\Upsilon(1S)}$, accurately. Once CLEO and CUSB found the $\Upsilon(1S)$, finding the $\Upsilon(2S)$ was relatively quick and easy. This is illustrated in Fig. 4, which shows the 1979 holiday card that was sent by Cornell to colleagues and laboratories, and also shows the data that were published by CLEO [5]. These figures show that the $\Upsilon(1S)$ state was found with a few outlying points in the scan. The $\Upsilon(1S)$ position determined the energy scale of CESR relative to that of DORIS. Then using the LENA measurement of the mass difference, $M_{\Upsilon(2S)} - M_{\Upsilon(1S)}$, CLEO and CUSB found the $\Upsilon(2S)$ state with essentially no wasted effort. However, since the DORIS energy was too low to enable LENA to observe the $\Upsilon(3S)$, finding it required more time and effort as illustrated by the many data points taken above that resonance. The energy scan of the $\Upsilon(3S)$ by CLEO and CUSB was the first demonstration that this resonance was narrow. This symposium is a good opportunity to thank members of the LENA collaboration for their contribution to the earliest CLEO and CUSB measurements!

CLEO and CUSB followed their observations of the first three Υ states with the discovery of the $\Upsilon(4S)$ state and the observation that this state is broad, suggesting that it is above the threshold for $B\bar{B}$ production [8,9]. The CLEO data for this discovery are illustrated in Fig. 5. The upper figure on the left illustrates the cross section in the neighborhood of the $\Upsilon(4S)$, while the lower figure on the left illustrates the cross section in that region with a requirement that selects events with relatively spherical shapes. Fig. 5 also illustrates CUSB data for the first four Υ states and CLEO data for the later discovery with CUSB of the $\Upsilon(5S)$ and $\Upsilon(6S)$

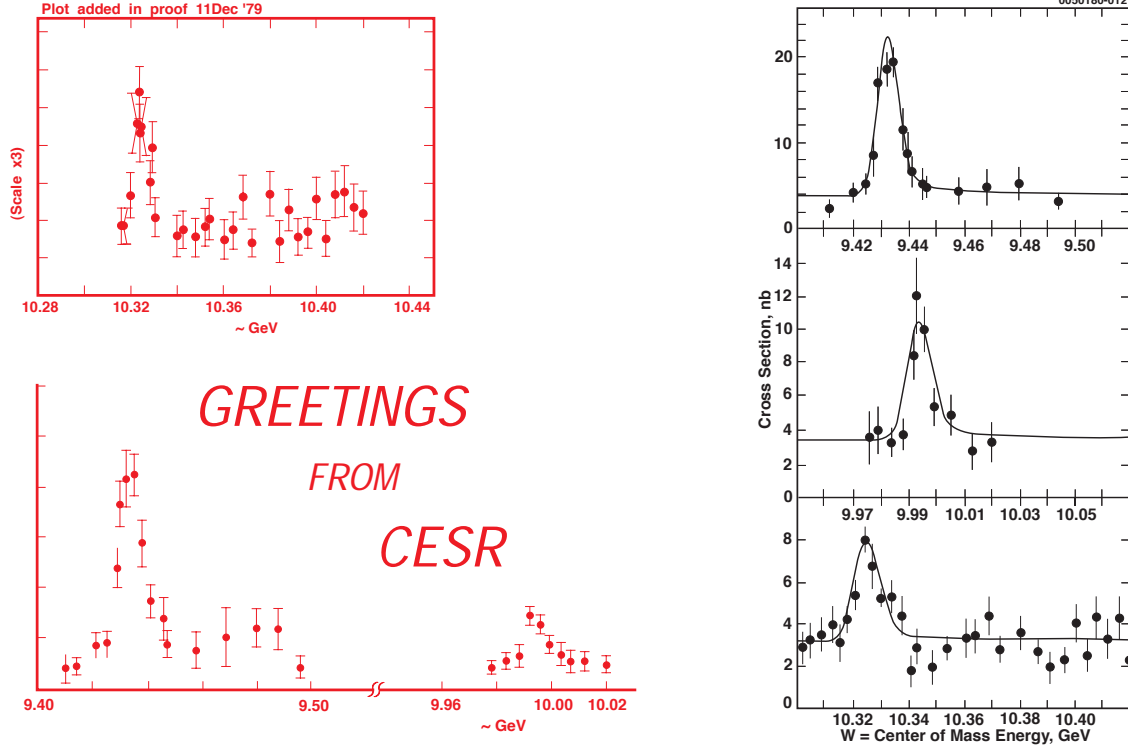


FIGURE 4. (Left) the 1979 Cornell holiday card illustrating the CLEO confirmation of the $\Upsilon(1S)$ and $\Upsilon(2S)$, and demonstration that the $\Upsilon(3S)$ is narrow. (Right) the same data when published. At the time of the holiday card, the analysis of the data was in an early stage, so the horizontal and vertical scales were purposefully left vague.

states [10,11]. These states complete the list of known 3S_1 Υ states.

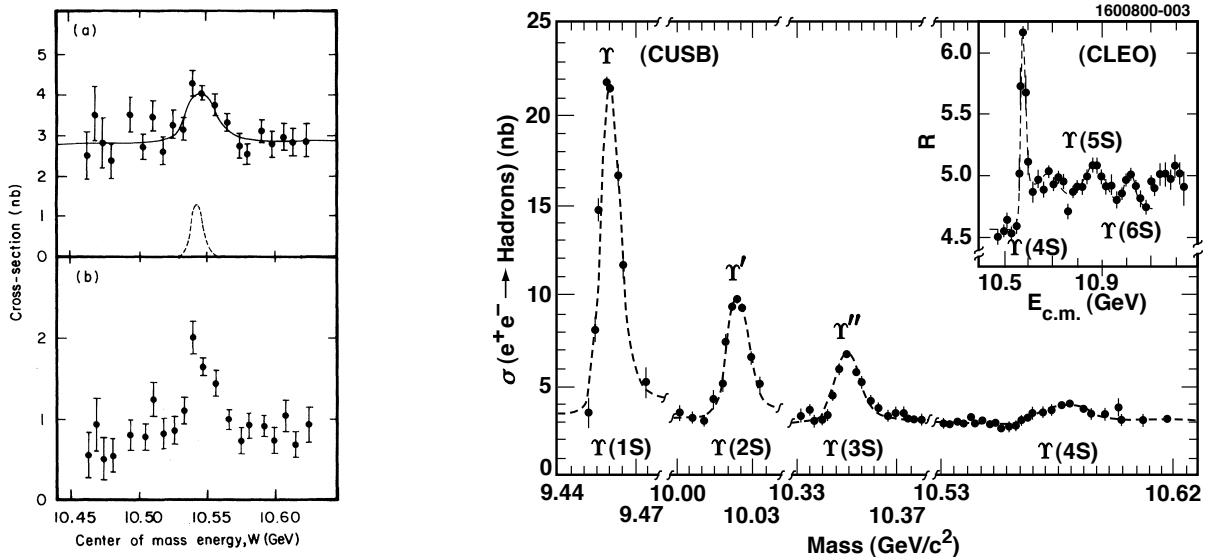


FIGURE 5. (Left) the CLEO observation of the $\Upsilon(4S)$ resonance. The top figure illustrates the measured cross section, while the bottom figure illustrates the cross section with an additional requirement that selects events with a relatively spherical shape. (Right) CUSB data illustrating the $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$, and $\Upsilon(4S)$ states with an insert of CLEO data illustrating the $\Upsilon(5S)$ and $\Upsilon(6S)$ states.

The discovery of the $\Upsilon(4S)$ was soon followed by convincing, but indirect, evidence for the existence of B mesons and of the decay $\Upsilon(4S) \rightarrow B\bar{B}$. It was well known (and indeed verified by the discovery of D mesons) that leptons produced in e^+e^- annihilation experiments can come from two principle sources: from scattering or annihilations, which produce leptons with a cross section that varies smoothly with energy, and from semileptonic decays of mesons containing heavy quarks. The cross sections of leptons from heavy mesons have thresholds at the production of these mesons. As illustrated in Fig. 6, CLEO saw evidence for the enhancement of electron [12] and muon [13] yields at the $\Upsilon(4S)$ state. The leptonic branching fractions measured in these papers $\mathcal{B}(B \rightarrow Xe\nu) = (13 \pm 3 \pm 3)\%$ and $\mathcal{B}(B \rightarrow X\mu\nu) = (9.4 \pm 3.6)\%$ are consistent with current measurements, which are much more precise.

The period 1981-1986 was an exciting time in B physics; since essentially nothing about B mesons had been known, everything was new. ARGUS [14] entered the arena during this period, so three experiments actively studied B mesons produced at the $\Upsilon(4S)$ and competed with each other. During this period, ARGUS, CLEO, and CUSB discovered many B decay modes and measured their branching fractions; now the 2007 Particle Data Group (PDG) summary [15] lists 347 B^0 and 300 B^+ modes and submodes (including upper limits). Among these many decay modes, it is hard to single out any one hadronic decay as being particularly significant. However, inclusive and exclusive semileptonic decays played a substantial role in measurements of the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$ [16]. I will not discuss exclusive semileptonic decays further in this talk, although ARGUS and CLEO were active in measuring branching fractions of these modes and determining the two B decay CKM matrix elements from the measurements.

Progress was impeded by the existence of so many decay modes, which implies that essentially all exclusive branching fractions are rather small. Fully reconstructing B decay modes was further hindered because nearly all B decays lead to D mesons in the final state, and fully reconstructing D meson decays was difficult because D branching fractions are also small. At

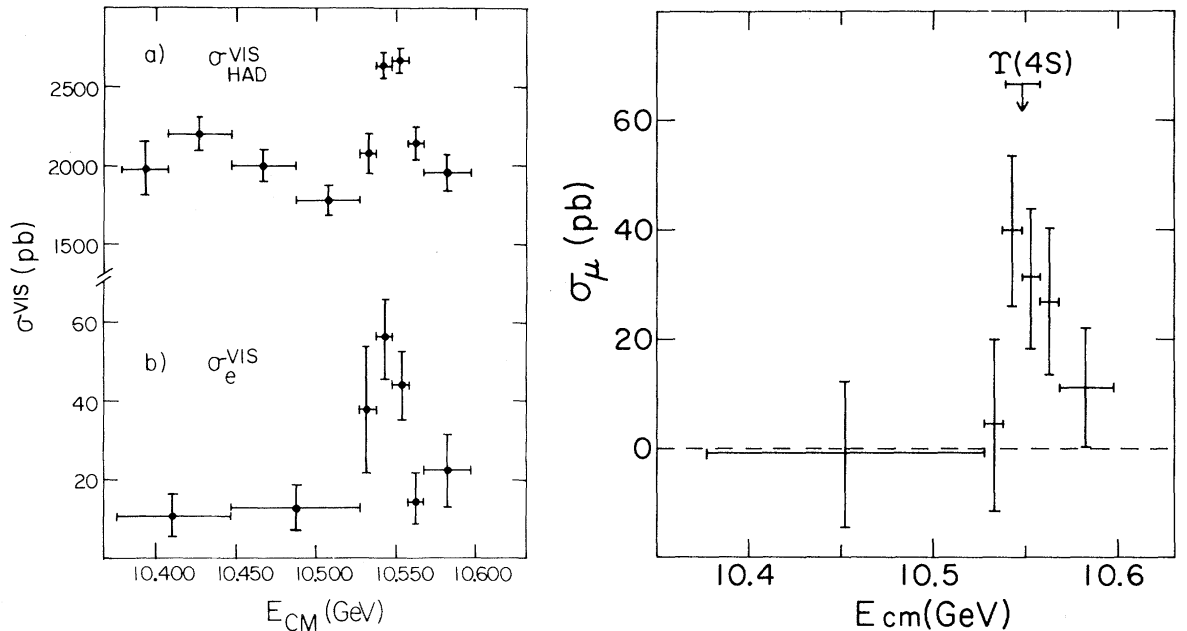


FIGURE 6. Data from CLEO's observation of leptons produced at the $\Upsilon(4S)$ from the semileptonic decays of B mesons. (Left) the visible cross section for production of electrons and (right) the visible cross section for production of muons in the $\Upsilon(4S)$ region. The hadron production cross section included in the figure on the left indicates that the increase in lepton production cross section in both figures is more noticeable than the increase in the hadron production cross section.

least one technique to sidestep the reconstruction of D mesons is worth mentioning. In 1984 CLEO developed a method of partially reconstructing D^{*+} decays to measure $\bar{B}^0 \rightarrow D^{*+}\pi^-$ [17]. This technique uses the momentum p_h of the hard π^- from the \bar{B}^0 decay and the momentum p_s of the soft π^+ from $D^{*+} \rightarrow D^0\pi^+$ decay. With these two momenta, the beam energy, and the known magnitude of the momentum of the B , it is possible to determine the mass of the B reasonably well without reconstructing the D . This technique substantially increases efficiency for reconstructing \bar{B}^0 decays because the branching fractions for D^0 decays to a few hadrons are small. Since then many other techniques for partially reconstructing B mesons have been developed and successfully employed.

The large ($\gtrsim 1$ ps) lifetime of B mesons [15], observed at PEP and confirmed at Petra, was the big surprise and perhaps the most important single discovery of that era. This large lifetime implied that the CKM parameter $|V_{cb}|$ was small compared to $\sin\theta_C$, and inspired Wolfenstein's [18] parameterization of the CKM matrix. The long B meson lifetime was one of the ingredients that made the ARGUS discovery of $B^0\bar{B}^0$ mixing particularly important.

3 Studying $B^0\bar{B}^0$ Mixing

ARGUS's discovery of $B^0\bar{B}^0$ mixing [19] in 1987 came as a surprise to CLEO and – I dare say – to nearly all of the elementary particle physics community. As we all know, it was a very important result because the large value of $B^0\bar{B}^0$ mixing and the long B^0 meson lifetime opened the door to observation of CP violation in B decay. Study of CP violation is the principal *raison d'être* for the current very high interest in B physics and the justification for the community and agency support for most B meson programs subsequent to ARGUS's discovery.

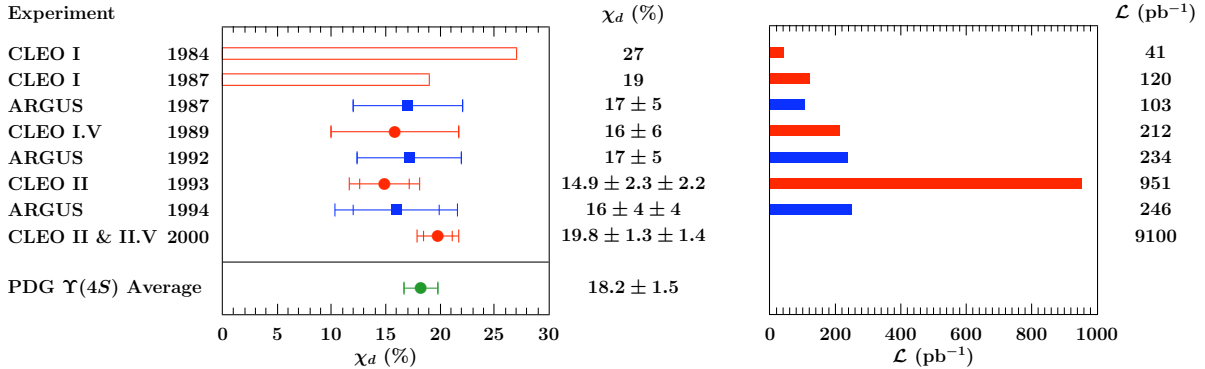


FIGURE 7. (Left) ARGUS and CLEO measurements of the $B^0\bar{B}^0$ mixing parameter χ_d and (right) the luminosities on which these measurements were based. Note that the 9.1 fb $^{-1}$ of luminosity utilized in the CLEO 2000 measurement was much larger than any of the others, going well beyond the scale of the figure, so there is no bar illustrating that luminosity.

CLEO was interested in the possibility of observing $B^0\bar{B}^0$ mixing well before the ARGUS discovery. In fact, CLEO published two upper limits on $B^0\bar{B}^0$ mixing [20,21] before the ARGUS announcement. Although CLEO had slightly more luminosity than ARGUS at that time, the (next generation) ARGUS detector was much better suited for the measurement. Furthermore, CLEO's upper limits were based only on searches for like-sign dilepton events, while ARGUS also utilized leptons in events with one fully reconstructed B meson, and – of course – the well known fully reconstructed event [19]. In fact, CLEO [22] required two more years and a new detector to confirm the ARGUS result. Measurement of $B^0\bar{B}^0$ mixing by ARGUS [19,23,24] and CLEO [20,21,22,25,26] are illustrated in Fig. 7. The χ_d average in the figure is taken from the Heavy Flavor Averaging Group (HFAG) [27]. The values of Δm_d obtained from these measurements of χ_d have been superseded by BaBar and Belle [15].

Since most of the reports in this symposium concern ARGUS's discovery of $B^0\bar{B}^0$ mixing and the consequences of that discovery, I will now turn to a description of some of the other ARGUS and CLEO observations and measurements in B physics.

4 After $B^0\bar{B}^0$ Mixing

For more than a decade following ARGUS's discovery of $B^0\bar{B}^0$ mixing, CLEO enjoyed a rich program of studying B meson physics. Many of the earlier results of this program were obtained in intense and fruitful competition with ARGUS. After ARGUS left the field, CLEO became the source of most results in B physics until BaBar and Belle took over the field. I will describe two measurements from the period of competition between ARGUS and CLEO: measuring $|V_{cb}|$ with inclusive $B \rightarrow X_c \ell \nu$ decay and measuring $|V_{ub}|$ with inclusive $B \rightarrow X_u \ell \nu$ decay. I will follow this with discussion of CLEO's discovery of $B \rightarrow K^* \gamma$ decays, which are dominated by radiative penguin diagrams, and of CLEO's measurements of the branching fraction for $B \rightarrow X_s \gamma$ decay, which imposes rather stringent limits on new physics in the heavy quark sector and enables theoretically sound (model-independent) measurements of $|V_{cb}|$ and $|V_{ub}|$.

4.1 Measuring $|V_{cb}|$ with Inclusive $\bar{B} \rightarrow X_c \ell \nu$ Decay

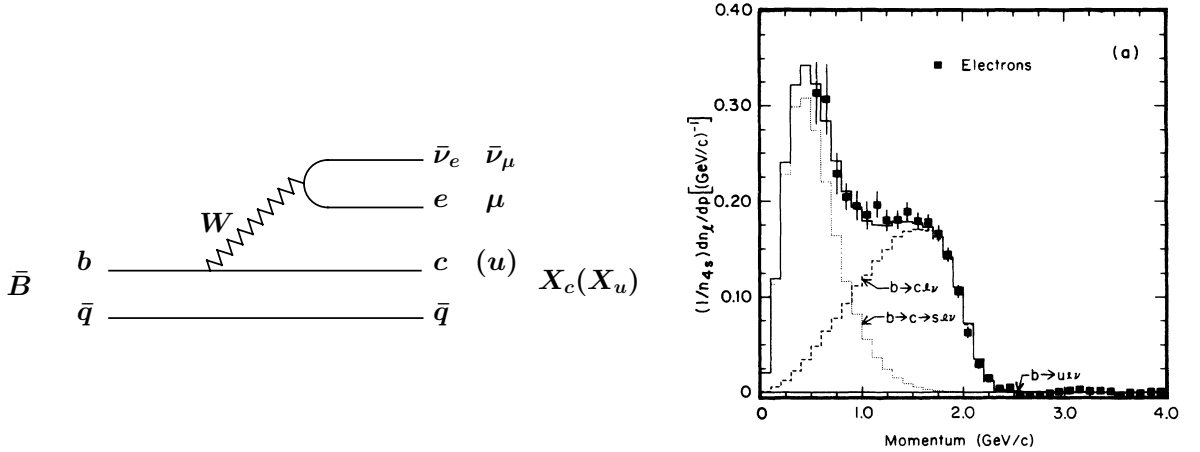


FIGURE 8. (Left) the Feynman diagram for semileptonic B decay to states X_c containing a charm quark or to states X_u without a charm quark. (Right) the inclusive electron momentum spectrum observed from B meson decays. The spectrum labeled $b \rightarrow c \ell \nu$ is from semileptonic B decay, while the spectrum labeled $b \rightarrow c \rightarrow s \ell \nu$ is from the semileptonic decays of D meson daughters produced in B decay.

The Feynman diagram for semileptonic B decay is illustrated in Fig. 8. The CKM matrix $|V_{cb}|$ can be determined from

$$\Gamma_{SL}^c \equiv \Gamma(\bar{B} \rightarrow X_c \ell \nu) = \frac{\mathcal{B}(\bar{B} \rightarrow X_c \ell \nu)}{\tau_B} = \gamma_c |V_{cb}|^2,$$

where $\mathcal{B}(\bar{B} \rightarrow X_c \ell \nu)$ is the branching fraction for $\bar{B} \rightarrow X_c \ell \nu$ decay, τ_B is the B meson lifetime, and γ_c is a constant that must be provided by theory. The chief experimental challenge [28] in measuring $\mathcal{B}(\bar{B} \rightarrow X_c \ell \nu)$ is also illustrated in Fig. 8. Below $p_\ell \sim 1.2$ GeV/c there is a large contribution from semileptonic decays of D meson daughters produced in B decays. Initially, theoretical models were used to extrapolate the $\bar{B} \rightarrow X_c \ell \nu$ momentum spectrum through the region dominated by semileptonic D decay down to $p_\ell = 0$ GeV/c. Hence, theoretical models

were required to obtain $\mathcal{B}(\bar{B} \rightarrow X_c \ell \nu)$, as well as to obtain $|V_{cb}|$ from $\mathcal{B}(\bar{B} \rightarrow X_c \ell \nu)$. The ACCMM [29] and ISGW [30] models were frequently used for both purposes.

ARGUS [31] revolutionized this subject by developing a tagging technique to separate the lepton spectrum quite reliably into a $\bar{B} \rightarrow X_c \ell \nu$ component and the sequential decay $\bar{B} \rightarrow DX$ followed by $D \rightarrow \bar{X}_s \ell \nu$. ARGUS's key idea was to use leptons in the momentum range $1.4 \leq p_\ell \leq 2.3$ GeV/c to tag a B decay. When ARGUS found an electron in the same event, with momentum in the range $0.6 \leq p_\ell \leq 2.3$ GeV/c, they attributed the electron to $\bar{B} \rightarrow X_c \ell \nu$ decay if the leptons had opposite sign, or attributed it to sequential semileptonic D decay if the leptons had the same sign.

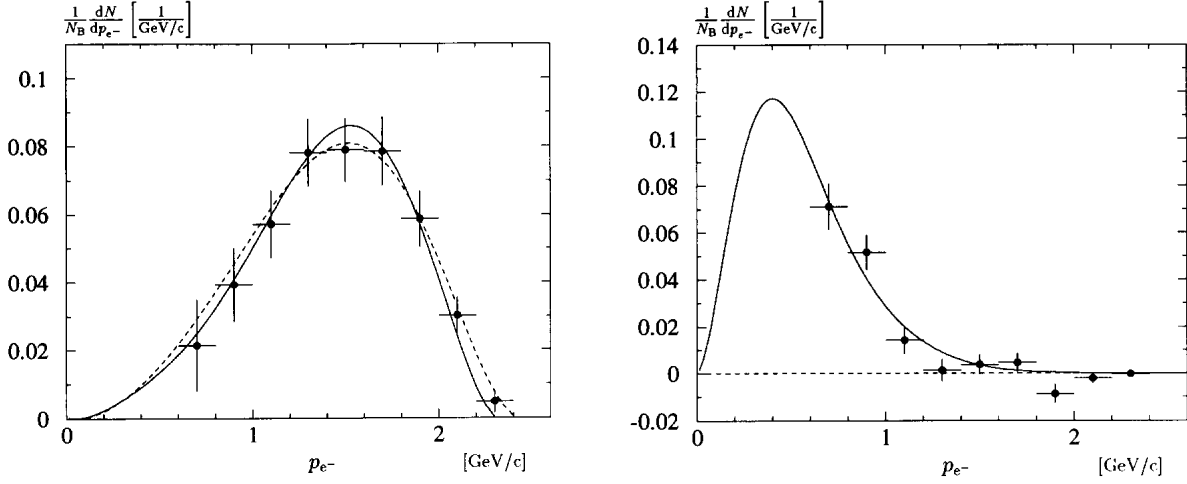


FIGURE 9. (Left) the electron spectrum from $\bar{B} \rightarrow X_c \ell \nu$ decay that ARGUS obtained with the tagging technique. (Right) the corresponding electron spectrum that ARGUS obtained for sequential semileptonic D decay.

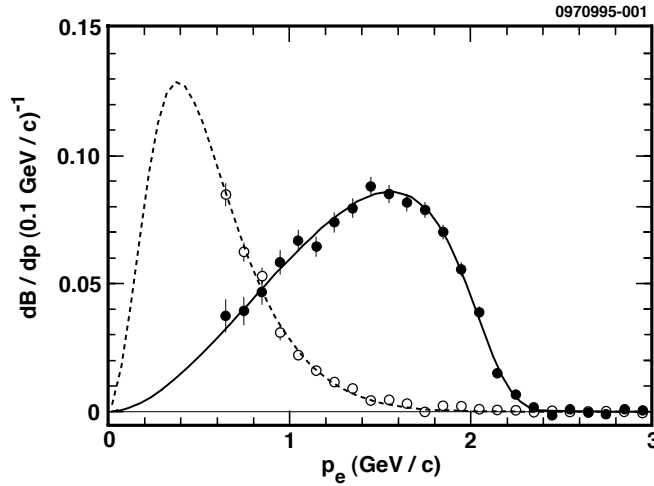


FIGURE 10. The p_ℓ spectra that CLEO obtained for $\bar{B} \rightarrow X_c \ell \nu$ decay (solid circles) and sequential semileptonic D decay (open circles), by using a tag technique similar to the ARGUS tag technique.

Figure 9 illustrates the success of ARGUS's tagging technique in separating the two components in the lepton momentum spectrum. This technique was used down to lepton momenta $p_\ell \approx 0.6$ GeV/ c . Extrapolating the p_ℓ spectrum the rest of the way to $p_\ell = 0$ GeV/ c can be accomplished with relatively little model dependence, making the measurement of the branching fraction $\bar{B} \rightarrow X_c \ell \nu$ almost independent of models. Model calculations were still required to determine $|V_{cb}|$ from the branching fraction, but the overall model dependence was substantially reduced by this method. CLEO [32] refined and successfully employed the ARGUS tagging technique to measure the lepton momentum spectrum from $\bar{B} \rightarrow X_c \ell \nu$ decay; the resulting spectra are illustrated in Fig. 10.

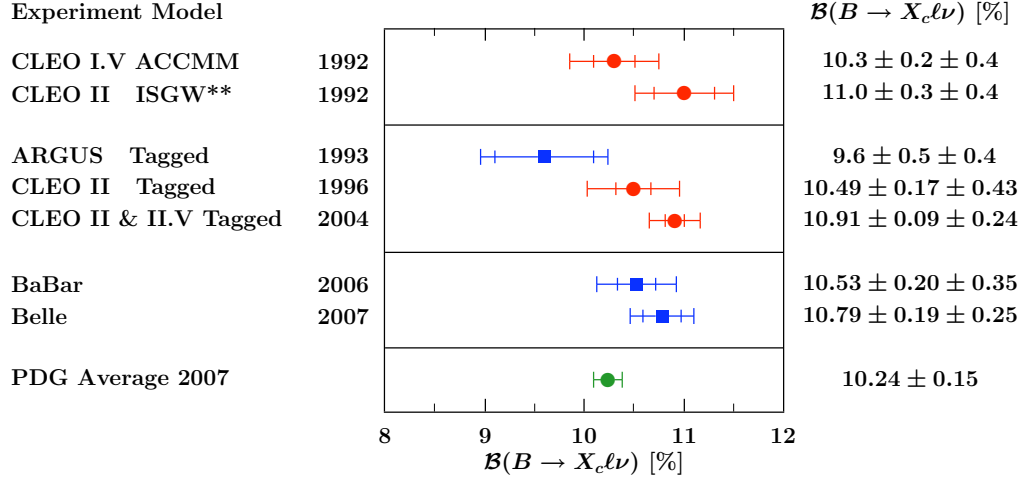


FIGURE 11. Measurements of $\mathcal{B}(\bar{B} \rightarrow X_c \ell \nu)$ by ARGUS, CLEO, BaBar, and Belle. The 1992 measurements utilized the ACCMM and ISGW** theoretical models to separate the $\bar{B} \rightarrow X_c \ell \nu$ component in the lepton momentum spectrum from the leptons from sequential semileptonic D decay. The rest of the measurements utilized tagging techniques based on the original ARGUS tagged measurement.

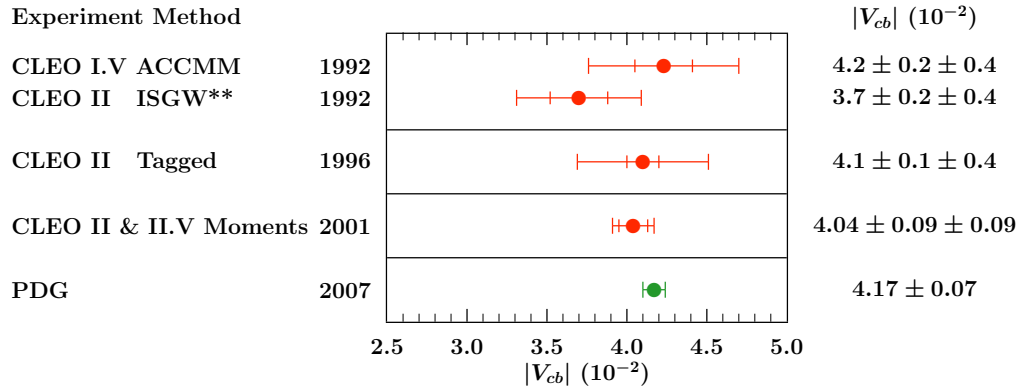


FIGURE 12. CLEO measurements of $|V_{cb}|$. The 1992 and 1996 measurements used the parameter γ_c from the ACCMM and ISGW** theoretical models to determine $|V_{cb}|$ from $\mathcal{B}(\bar{B} \rightarrow X_c \ell \nu)$. The theoretical basis for the 2001 measurement is substantially more sound.

The results of ARGUS [31] and CLEO [32,33] measurements of $\mathcal{B}(\bar{B} \rightarrow X_c \ell \nu)$ are illustrated in Fig. 11. The CLEO measurements [28] labeled ACCMM [29] and ISGW** [30] are model-dependent untagged measurements, in which the shapes of the momenta spectra were determined using these models. (The ** in ISGW** indicates that one component of the ISGW spectrum

was allowed to float in order to obtain a better fit in the crossover region between the electrons from semileptonic B decay and those from semileptonic D decay.) More recent measurements from BaBar [34] and Belle [35] (corrected for the portion of the $\bar{B} \rightarrow X_c \ell \nu$ spectrum below $p_\ell = 0.6$ GeV/ c using the correction factor 1.0495 given in HFAG 2007 [27]) and the PDG 2007 average [15] are included for comparison. BaBar and Belle used fully reconstructed B decays for their tags, rather than the lepton tags used by ARGUS and CLEO, so the experimental errors are larger than they might otherwise be, given the huge luminosities obtained by these two collaborations. In any event, this method is a descendent of the ARGUS technique.

Values of $|V_{cb}|$ obtained from the CLEO measurements [28,32,36] of $\bar{B} \rightarrow X_c \ell \nu$ are illustrated in Fig. 12. The measurement labeled CLEO II & II.V Moments 2001 utilized measurements of the moments of hadronic mass distributions to eliminate the model-dependence in the earlier measurements. The moment technique, based on Heavy Quark Effective Theory (HQET) has a much more secure theoretical foundation, resulting in the substantial reduction of the theory error compared to the other measurements. Recent measurements utilize HQET moments to extract $|V_{cb}|$ from the $\bar{B} \rightarrow X_c \ell \nu$ decays [16].

4.2 Measuring $|V_{ub}|$ with Inclusive $\bar{B} \rightarrow X_u \ell \nu$ Decay

CLEO and ARGUS detected inclusive $\bar{B} \rightarrow X_u \ell \nu$ decays in the p_ℓ spectrum above the endpoint for $\bar{B} \rightarrow X_c \ell \nu$ decays. Observing and measuring inclusive $\bar{B} \rightarrow X_u \ell \nu$ decays is even more challenging than measuring $\bar{B} \rightarrow X_c \ell \nu$ decays because: the branching fraction is very small $\mathcal{O}(10^{-4})$, only a very narrow window in p_ℓ is useful, the background from $\bar{B} \rightarrow X_c \ell \nu$ decays is significant, and continuum events can produce charged particles in this narrow p_ℓ range. These challenges are illustrated in Fig. 13, where the contribution of $\bar{B} \rightarrow X_u \ell \nu$ decays to the p_ℓ spectrum is increased by a factor of 10 to make it visible. Despite these difficulties, CLEO [37] and ARGUS [38] both reported $\bar{B} \rightarrow X_u \ell \nu$ signals in 1990. Fig. 14 illustrates measurements of the $\bar{B} \rightarrow X_u \ell \nu$ spectrum from ARGUS [39] in 1991 and later from CLEO [40] in 2002 with much larger luminosity. ARGUS [39] also fully reconstructed two events with $\bar{B} \rightarrow X_u \ell \nu$ decays, providing convincing evidence that there were actually $\bar{B} \rightarrow X_u \ell \nu$ decays in the endpoint region of the p_ℓ spectrum.

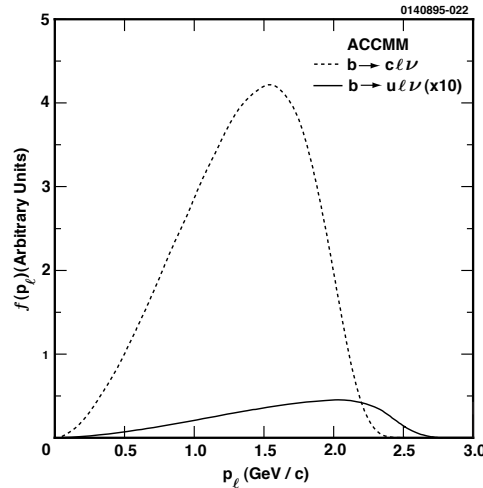


FIGURE 13. The ACCMM prediction for the lepton momentum spectrum for $\bar{B} \rightarrow X_c \ell \nu$ decays and the spectrum for $\bar{B} \rightarrow X_u \ell \nu$ decays. The height of the latter spectrum is increased by a factor of 10 to make it visible.

The $|V_{ub}|$ measurements from ARGUS [38] and CLEO [37,40,41] are illustrated in Fig. 15,

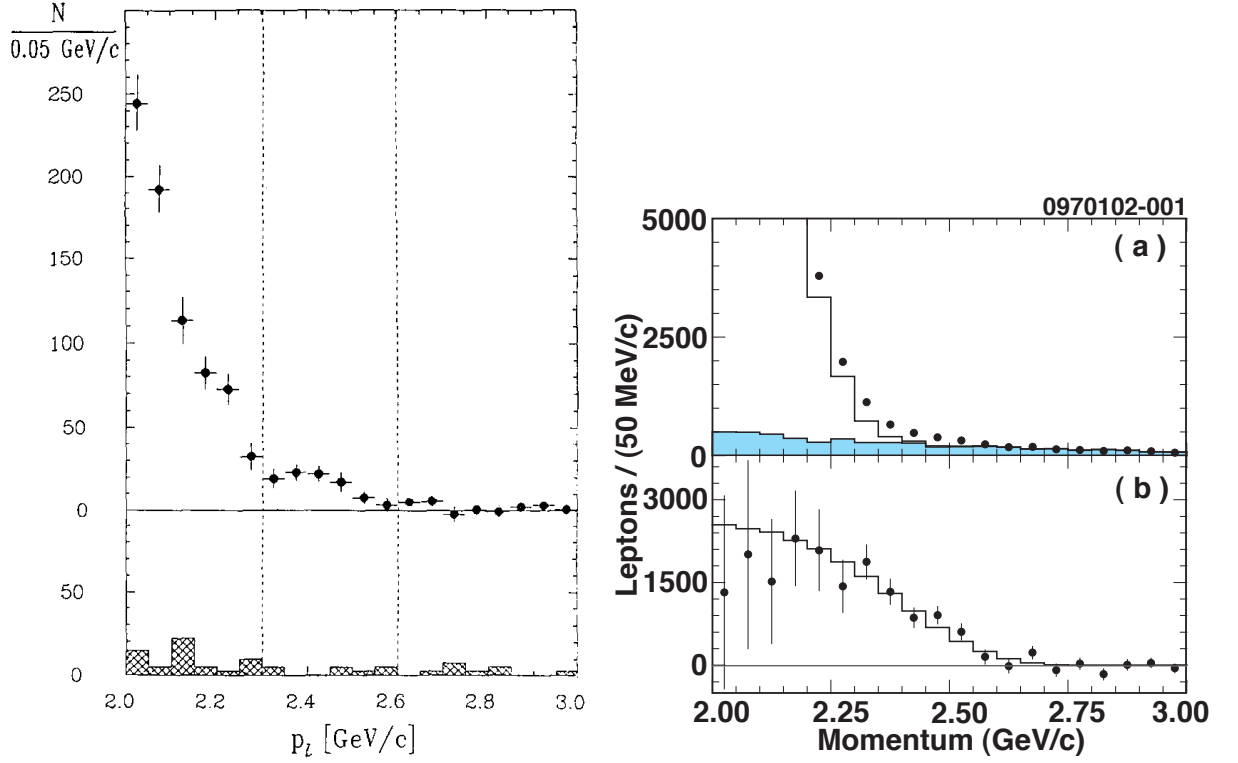


FIGURE 14. (Left) the ARGUS p_ℓ spectrum for charmless semileptonic B decay from 1991 and (right) the corresponding CLEO spectrum from 2002. ARGUS illustrates the spectrum observed at the $\Upsilon(4S)$ (points) and the scaled spectrum from the continuum (hatched histogram), which must be subtracted. CLEO illustrates the observed $\Upsilon(4S)$ spectrum along with the continuum spectrum (shaded histogram), and the net $\bar{B} \rightarrow X_u \ell \nu$ spectrum (points with error bars) with the prediction (histogram) from the measured value of $|V_{ub}|$.

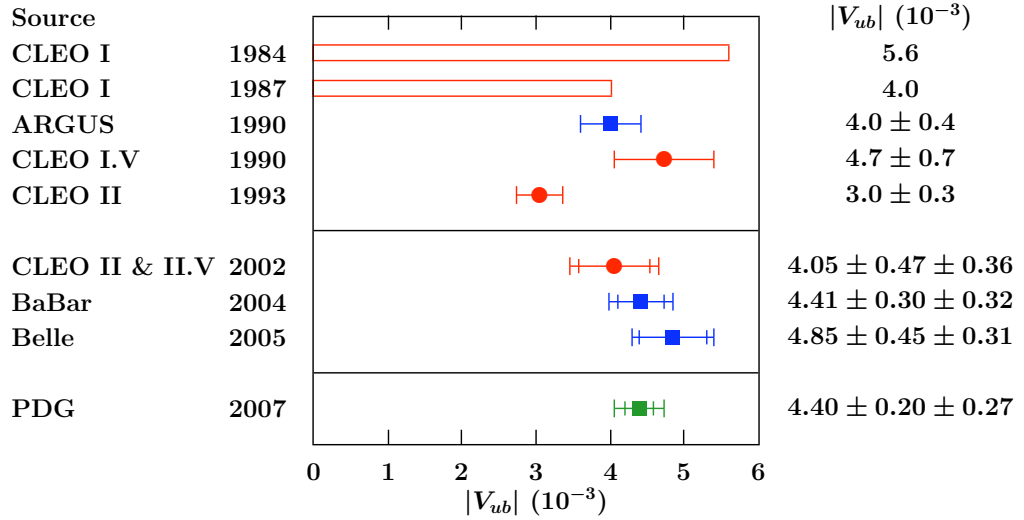


FIGURE 15. Measurements of $|V_{ub}|$ from ARGUS, CLEO, BaBar, and Belle and the PDG 2007 average.

along with two earlier upper limits from CLEO [42,43] and more recent measurements from BaBar [44] and Belle [45]. CLEO used the ACCMM [29] model to obtain the upper limits and

values of $|V_{ub}|$ in the 1984 to 1993 analyses. However, this use of models is even less satisfactory than it is for measurements of $|V_{cb}|$ because model dependence for $|V_{ub}|$ is much more serious than it is for $|V_{cb}|$. For the CLEO 2002, BaBar, and Belle results, these collaborations utilized more rigorous HQET techniques to extract $|V_{ub}|$ from moments of the $\bar{B} \rightarrow X_u \ell \nu$ and $B \rightarrow X_s \gamma$ spectra. The results given in Fig. 15 are rescaled from the original measurements to a common value of τ_B and – in the case of the more recent measurements – derived from a common HQET analysis [16].

Many of us in CLEO noticed that the two upper limits had not decreased much even though the 1987 limit was based on substantially more luminosity than the 1984 limit. Due to our experience with upper limits for $B^0 \bar{B}^0$ mixing, we felt that we were near an observation of $\bar{B} \rightarrow X_u \ell \nu$ decays, and this hunch turned out to be correct.

4.3 Discovery of Radiative Penguin Processes

The discovery of exclusive radiative penguin processes and measurements of the corresponding inclusive processes were the most challenging and important CLEO results that were not shared with ARGUS or other collaborations until Belle and BaBar entered the field.

Penguin diagrams, illustrated in Fig. 16, were initially proposed to explain the $\Delta I = \frac{1}{2}$ rule in K decay (see Ref. [46] for references to the early theoretical literature). The penguin diagram introduces a large $\Delta I = \frac{1}{2}$ enhancement, in contrast to a picture in which the $\Delta I = \frac{3}{2}$ is suppressed somehow. However, there was no incontrovertible experimental evidence for the existence of penguin decays for nearly 20 years, until CLEO observed $B \rightarrow K^* \gamma$ decays [46].

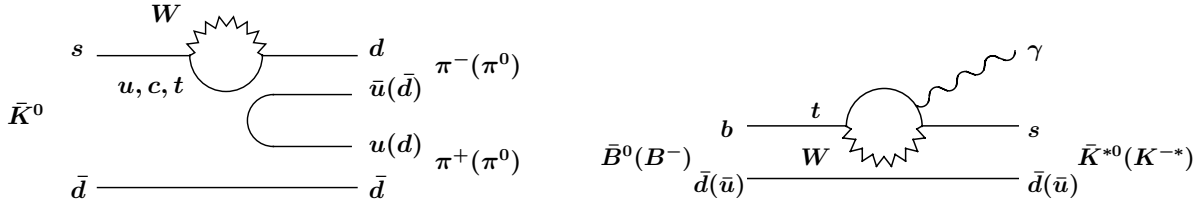


FIGURE 16. (Left) the penguin diagram proposed to explain the $\Delta I = \frac{1}{2}$ rule in K decay and (right) the diagram for exclusive radiative penguin decays.

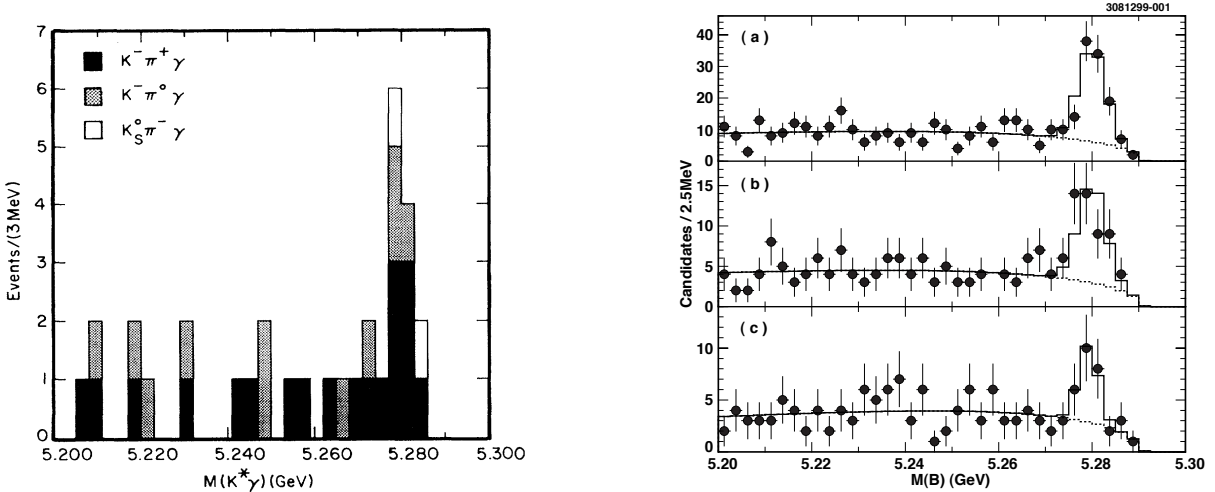


FIGURE 17. The B mass distributions for $B \rightarrow K^* \gamma$ candidates from the CLEO 1993 (left) and CLEO 2000 (right) analyses. For the CLEO 2000 analysis, the K^* candidates are (a) $K^{*+}(892)$, (b) $K^{*0}(892)$, and (c) $K_2^*(1430)$ candidates.

CLEO searched for the decay modes $\bar{B}^0 \rightarrow \bar{K}^{*0}\gamma$ with $\bar{K}^{*0} \rightarrow K^-\pi^+$, and $B^- \rightarrow K^{*-}$ with $K^{*-} \rightarrow K^-\pi^0$ or $K^{*-} \rightarrow K_S^0\pi^-$. Reducing the backgrounds, particularly the backgrounds from continuum events, was the principal experimental challenge. CLEO had devoted approximately $\frac{1}{3}$ of its luminosity to taking data on the continuum below the $\Upsilon(4S)$, and these data were crucial for exclusive and inclusive $B \rightarrow X_s\gamma$ analyses. Figure 17 illustrates the B mass distributions for $\bar{B} \rightarrow \bar{K}^*\gamma$ candidates from discovery of these decays in 1993 [46] and from the 2000 [47] analysis with a significantly larger data sample.

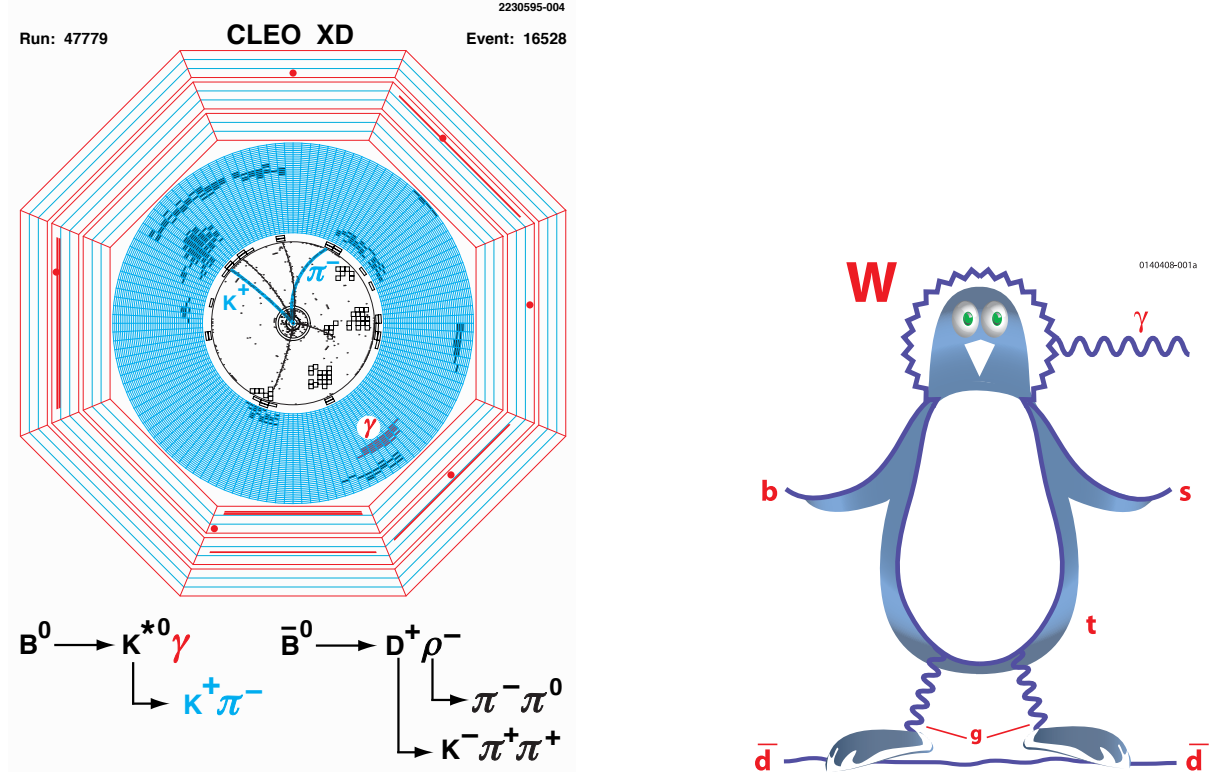


FIGURE 18. (Left) a fully reconstructed $B^0\bar{B}^0$ event with the decays $\bar{B}^0 \rightarrow D^+\rho^-$ and $B^0 \rightarrow K^{*0}\gamma$. (Right) an artist's view of the radiative penguin diagram.

Following ARGUS's lead in presenting fully reconstructed events, CLEO displays a fully reconstructed $B^0\bar{B}^0$ event with the decays $\bar{B}^0 \rightarrow D^+\rho^-$ and $B^0 \rightarrow K^{*0}\gamma$. Figure 18 illustrates this event along with an artist's view of the penguin Feynman diagram. All decay daughters (except one soft photon from π^0 decay) in the event were detected and measured. Figure 19 illustrates the branching fractions for $B \rightarrow K^*\gamma$ decays measured by CLEO [46,47], BaBar [48,49] and Belle [50]. Since individual $B \rightarrow K^*\gamma$ branching fractions depend on how the X_s final state hadronizes, there are no secure theoretical predictions with which to compare these experimental results.

4.4 Measurement of $\mathcal{B}(B \rightarrow X_s\gamma)$

The inclusive branching fraction $\mathcal{B}(B \rightarrow X_s\gamma)$ is much more important than the exclusive branching fractions $\mathcal{B}(B^0 \rightarrow K^*(890)\gamma)$ described in the previous section, because the Standard Model (SM) rate for the inclusive decays can be calculated with some precision. Furthermore, the SM rate is sensitive to Beyond SM effects in the loop.

The experimental challenges involved in measuring the inclusive branching fraction are much more severe than they are for measuring exclusive branching fractions, because reconstruction of K^* candidates and imposition of a K^* mass cut are very useful in reducing background in

exclusive analyses. Figure 20 illustrates the expected signal and backgrounds. The backgrounds from photons in continuum events are approximately a factor of 100 above the SM signal.

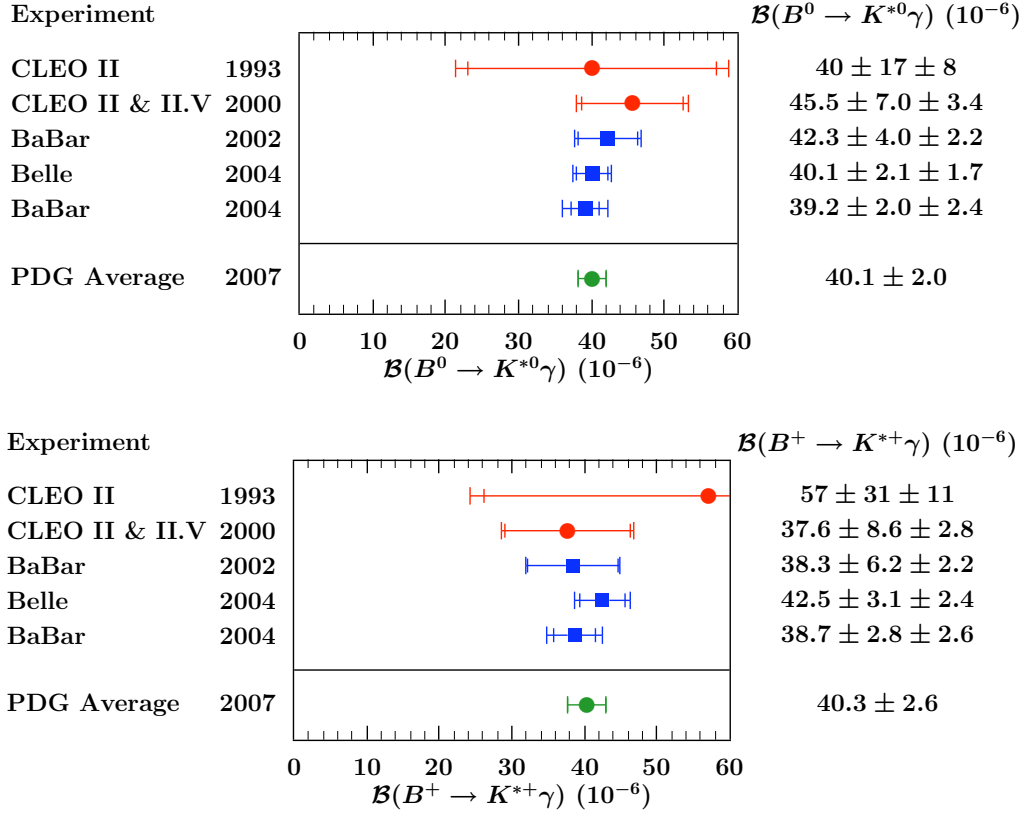


FIGURE 19. (Top) branching fractions for $B^0 \rightarrow K^{*0}\gamma$ and (bottom) $B^+ \rightarrow K^{*+}\gamma$ decays measured by CLEO, BaBar, and Belle. The PDG 2007 average utilizes the CLEO 2000, BaBar 2004, and Belle 2004 measurements only.

In an 1995 analysis, CLEO eliminated photons that could be paired with any other photon to produce a $\gamma\gamma$ pair with an invariant mass consistent with either the π^0 or η mass. CLEO also developed a neural network that utilized several event-shape variables and the energies detected in cones parallel and antiparallel to the candidate photon direction. CLEO's large sample of continuum events was crucial for training the neural net and demonstrating that it was effective in picking out continuum background. CLEO also reconstructed events that were consistent with $B \rightarrow X_s\gamma$ decays with $0.6 < M(X_s) < 1.8 \text{ GeV}/c^2$. The results of the two techniques are consistent and only mildly correlated. CLEO's publication of this 1995 result [51] was based on 2.0 fb^{-1} of $\Upsilon(4S)$ data. The photon energy spectrum from an updated analysis in 2001 [52] that utilized 9.1 fb^{-1} of $\Upsilon(4S)$ data is illustrated in Fig. 20.

Measurements of $B \rightarrow X_s\gamma$ from CLEO [51,52], Belle [53,54], and Babar [55,56], are illustrated in Fig. 21, along with the PDG 2007 [15] average and a recent theoretical calculation of the branching fraction in next-to-next-to-leading order (NNLO) [57]. It is clear that there is not much room for physics beyond the SM between this theoretical calculation and the experimental average. The fact that the CLEO result remains competitive (so far) with results from BaBar and Belle is due, in part, to CLEO's enormous investment in continuum data.

The importance of these measurements of $B \rightarrow X_s\gamma$ decay go well beyond the search for new physics. Moments of the photon energy spectrum are sensitive to HQET parameters that also appear in moments of the electron energy or hadronic mass spectrum in $\bar{B} \rightarrow X_c\ell\nu$ and

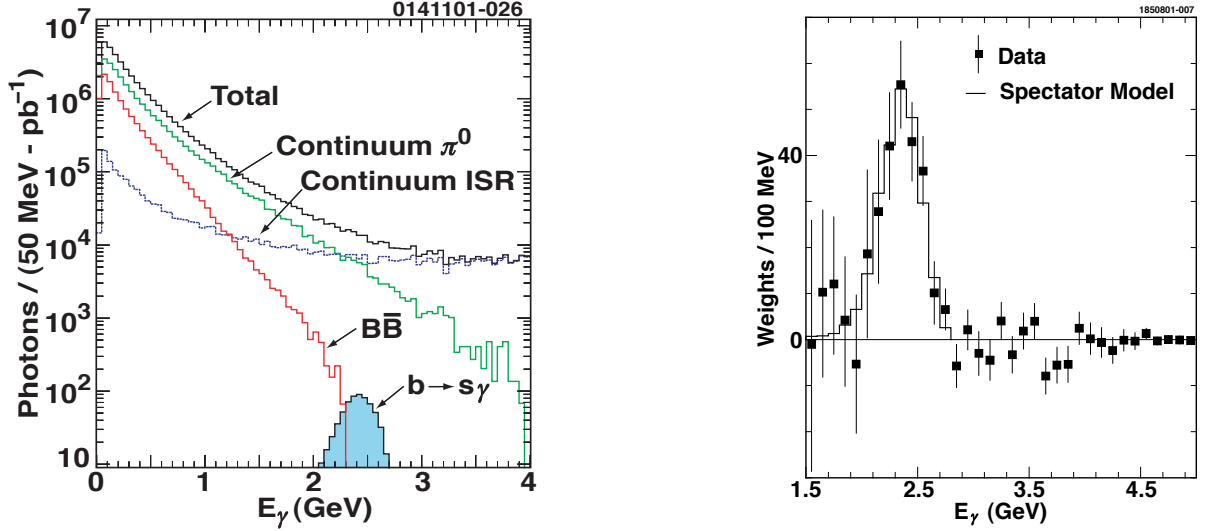


FIGURE 20. (Left) the $B \rightarrow X_s \gamma$ signal expected from SM predictions and the backgrounds anticipated from photons and π^0 s in continuum events, and from photons in other $B\bar{B}$ decays. Note the logarithmic scale on the vertical axis. (Right) CLEO's 2001 photon energy spectrum for $B \rightarrow X_s \gamma$ decays.

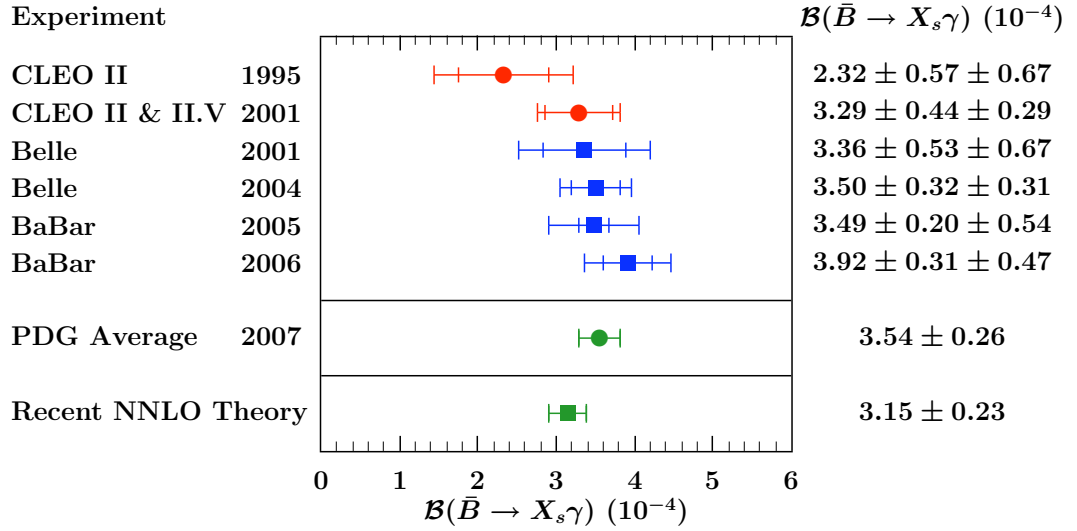


FIGURE 21. A summary of measurements of the inclusive $B \rightarrow X_s \gamma$ branching fraction and a recent SM theoretical calculation in next-to-next-to-leading order. The PDG 2007 average utilizes the CLEO 2001, Belle 2004, and BaBar 2005 and 2006 measurements.

$\bar{B} \rightarrow X_u \ell \nu$ decays. In fact, the most precise inclusive semileptonic measurements of $|V_{cb}|$ and $|V_{ub}|$ with the least theoretical uncertainty are obtained from these moments [16].

5 Concluding Remarks

First, I am delighted to congratulate ARGUS for discovering $B^0 \bar{B}^0$ mixing! Obviously I would have been pleased if this had been a CLEO discovery, but ARGUS was definitely first with a better detector and a better method of analyzing the data.

Beyond this, I wish to express a few personal thoughts about ARGUS, CLEO, and my experience in CLEO. It is clear that large $B^0 \bar{B}^0$ mixing and the resulting promise of observable CP violation in B meson decay were crucial for mustering the community and agency support

necessary for the last 20 years of the CLEO program! I believe that the competition between ARGUS and CLEO was very healthy for both collaborations and for the advancement of elementary particle physics. This competition kept all of us on our toes and (as I have described in this report) we often learned something from each other.

Our experience in CLEO with $B^0\bar{B}^0$ mixing and $B \rightarrow X_u\ell\nu$ decays taught me that converging upper limits may indicate that a discovery is near. On the other hand, in some instances we also learned that the first observation of a phenomenon may be an upward fluctuation. We found that developing a new field requires substantial time and creative effort because even experienced physicists have a lot to learn if the field is largely unexplored. Furthermore, sustaining an experiment over several decades requires frequent detector and/or luminosity upgrades. This lesson is also understood by other collaborations, including the LHC collaborations, which have not even taken data so far. These upgrades are expensive and disruptive because they require substantial time and effort, but they are necessary.

Finally, heavy quark physics with CLEO was (and still is) a wonderful experience! Now it's time for CLEO members to finish CLEO-c and move on to other experiments.

Acknowledgements

I wish to express my sincere appreciation to members of the ARGUS collaboration and to the DESY administration for inviting me to include a report on CLEO in the ARGUS Symposium. Special thanks are due to Dr. Frank Lehner for his help with all aspects of my participation. Of course I wish to thank my colleagues in the CLEO collaboration and CESR operations group whose heroic effort over the past 3 decades led to the results and insights that I am able to describe. Over the years, the NSF has supported the Cornell effort in CLEO and CESR with a succession of grants and cooperative agreements. At the time of this symposium, NSF-PY 0202078 provided this support.

References

1. Karl Berkelman, *A Personal History of CESR and CLEO*, World Scientific (2004), Cornell Report No. CLNS02-1784 (2002)
<http://www.lns.cornell.edu/public/CLNS/2002/CLNS02-1784/history.pdf>
2. (CLEO Collaboration) D. Andrews *et al.* Nucl. Instrum. Methods **211**, 47 (1983).
3. (CLEO Collaboration) Y. Kubota *et al.* Nucl. Instrum. Methods A **320**, 66 (1992).
4. (ARGUS Collaboration) H. Albrecht *et al.*, Nucl. Instrum. Meth. A **275**, 1 (1989).
5. (CLEO Collaboration) D. Andrews *et al.* Phys. Rev. Lett. **44**, 1108 (1980).
6. (CUSB Collaboration) T. Bohringer *et al.*, Phys. Rev. Lett. **44**, 1111 (1980).
7. (LENA Collaboration) J.K. Bienlein *et al.*, Phys. Lett. B **78**, 360 (1978).
8. (CLEO Collaboration) D. Andrews *et al.* Phys. Rev. Lett. **45**, 219 (1980).
9. (CUSB Collaboration) G. Finocchiaro *et al.*, Phys. Rev. Lett. **45**, 222 (1980).
10. (CUSB Collaboration) D.M.J. Lovelock *et al.* Phys. Rev. Lett. **54**, 377 (1985).
11. (CLEO Collaboration) D. Besson *et al.* Phys. Rev. Lett. **54**, 381 (1985).
12. (CLEO Collaboration) C. Bebek *et al.* Phys. Rev. Lett. **46**, 84 (1981).
13. (CLEO Collaboration) K. Chadwick *et al.* Phys. Rev. Lett. **46**, 88 (1981).
14. (ARGUS Collaboration), D. P. Barber *et al.*, Phys. Lett. B **135**, 498 (1984).
15. (Particle Data Group) W.-M. Yao *et al.*, J. Phys. G **33**, 1 (2006) and the 2007 partial update, available at <http://pdg.lbl.gov/>.

16. R. Kowalewski and T. Mannel in Ref. [15].
17. (CLEO Collaboration) R. Giles *et al.*, Phys. Rev. D **30**, 2279 (1984).
18. L. Wolfenstein, Phys. Rev. Lett. **51**, 1945 (1983).
19. (ARGUS Collaboration) H. Albrecht *et al.*, Phys. Lett. B **192**, 245 (1987).
20. (CLEO Collaboration) P. Avery *et al.*, Phys. Rev. Lett. **53**, 1309 (1984).
21. (CLEO Collaboration) A. Bean *et al.*, Phys. Rev. Lett. **58**, 183 (1987).
22. (CLEO Collaboration) M. Artuso *et al.*, Phys. Rev. Lett. **62**, 2233 (1989).
23. (ARGUS Collaboration) H. Albrecht *et al.*, Z. Phys. C **55**, 357 (1992).
24. (ARGUS Collaboration) H. Albrecht *et al.*, Phys. Lett. B **324**, 249 (1994).
25. (CLEO Collaboration) J. Bartelt *et al.*, Phys. Rev. Lett. **71**, 1680 (1993)..
26. (CLEO Collaboration) B.H. Behrens *et al.* Phys. Lett. B **490**, 36 (2000).
27. Heavy Flavor Averaging Group, [arXiv:0704.3575].
28. (CLEO Collaboration) S. Henderson *et al.*, Phys. Rev. D **45**, 2212 (1992).
29. G. Altarelli, N. Cabibbo, G. Corbo, L. Maini, and G. Martinelli, Nucl. Phys. B **208**, 365 (1989).
30. N. Isgur, D. Scora, B. Grinstein, and M.B. Wise, Phys. Rev. D **39**, 799 (1989).
31. (ARGUS Collaboration) H. Albrecht *et al.*, Phys. Lett. B **318**, 397 (1993).
32. (CLEO Collaboration) B. Barish *et al.*, Phys. Rev. Lett. **76**, 1570 (1996).
33. (CLEO Collaboration) A.H. Mahmood *et al.*, Phys. Rev. D **70**, 032003 (2004).
34. (BaBar Collaboration) B. Aubert *et al.*, Phys. Rev. D **74**, 091105R (2006).
35. (Belle Collaboration) P. Urquijo *et al.*, Phys. Rev. D **75**, 032001 (2007).
36. (CLEO Collaboration) D. Cronin-Hennessy *et al.*, Phys. Rev. Lett. **87**, 251808 (2001).
37. (CLEO Collaboration) R. Fulton *et al.* Phys. Rev. Lett. **64**, 16 (1990).
38. (ARGUS Collaboration) H. Albrecht *et al.*, Phys. Lett. B **234**, 409 (1990).
39. (ARGUS Collaboration) H. Albrecht *et al.*, Phys. Lett. B **255**, 297 (1991).
40. (CLEO Collaboration) A. Bornheim *et al.*, Phys. Rev. Lett. **88**, 231803 (2002).
41. (CLEO Collaboration) J. Bartelt *et al.*, Phys. Rev. Lett. **71**, 4111 (1993).
42. (CLEO Collaboration) A. Chen *et al.*, Phys. Rev. Lett. **52**, 1084 (1984).
43. (CLEO Collaboration) S. Behrends *et al.*, Phys. Rev. Lett. **59**, 407 (1987).
44. (BaBar Collaboration) B. Aubert *et al.*, Phys. Rev. Lett. **95**, 111801 (2005).
45. (Belle Collaboration) A. Limosani *et al.*, Phys. Lett. B **621**, 28 (2005).
46. (CLEO Collaboration) R. Ammar *et al.* Phys. Rev. Lett. **71**, 674 (1993).
47. (CLEO Collaboration) T.E. Coan *et al.* Phys. Rev. Lett. **84**, 5283 (2000).
48. (BaBar Collaboration) Aubert *et al.*, Phys. Rev. Lett. **88**, 101805 (2002).
49. (BaBar Collaboration) Aubert *et al.*, Phys. Rev. D **69**, 011102 (2004).
50. (Belle Collaboration) M. Nakao *et al.*, Phys. Rev. D **69**, 112001 (2004).
51. (CLEO Collaboration) M.S. Alam *et al.* Phys. Rev. Lett. **74**, 2885 (1995).
52. (CLEO Collaboration) S. Chen *et al.* Phys. Rev. Lett. **87**, 251807 (2001).
53. (Belle Collaboration) K. Abe *et al.*, Phys. Lett. B **511**, 151 (2001).
54. (Belle Collaboration) P. Koppenburg *et al.*, Phys. Rev. Lett. **93**, 061803 (2004).
55. (Babar Collaboration) B. Aubert *et al.*, Phys. Rev. D **72**, 052004 (2005).
56. (Babar Collaboration) B. Aubert *et al.*, Phys. Rev. Lett. **97**, 171803 (2006).
57. M. Misiak and M. Steinhauser, Nucl. Phys. B **764**, 62 (2007).

From ARGUS to B-Meson Factories

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The writeup of my presentation at the ARGUS Fest consists of three parts: my recollections of the history of B-Meson Factories from 1987 to 1993, the discovery of $D^0\bar{D}^0$ mixing in 2007 at the Factories PEP-II and KEKB, and a short view into the Future.

The Past

1986 and 1988 were the years with the highest luminosities in ARGUS, slightly above 20/pb/month. During the year in between, where the DORIS machine physicists [1] were at the maximum of their possibilities, we had zero because of a long shutdown. This break forced us to fully concentrate on analysis. We published 19 papers in 1987, the top three being those on Full B-Meson Reconstruction [2] with now 151 citations, on $B^0\bar{B}^0$ mixing [3] with 1089, and on $B^0 \rightarrow D^{*-}\ell^+\nu$ [4] with 172. These results, together with many others from 1980 to 1987 at CESR and DORIS made widely visible that e^+e^- annihilation is the cleanest and most promising way to discover and to study CP violation in B-meson decays [5]. 1987 was the breakthrough year of the B-Meson Factory idea.

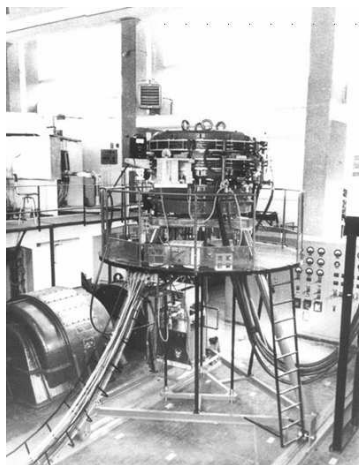


Figure 1: The original e^+e^- storage ring AdA at Frascati.

Storage rings with colliding beams were invented by R. Wideröe around 1942 [6]. After discussions with B. Touschek, he submitted his idea to the German Patentamt in 1943 [7]. The first e^-e^- storage-ring collider was built in 1959 by G. K. O'Neill et al. at Stanford [8], with first experimental results on Moeller scattering in 1965 [9] by W. C. Barber et al. The first e^+e^- collider ring AdA with $2 \cdot 0.25$ GeV was built in 1961 by B. Touschek et al. at Frascati [10]; first collisions were observed mid 1964 at Orsay [11] with a luminosity in the order of $10^{25}/\text{cm}^2/\text{s}$. The original AdA ring, as shown in Fig. 1, is still presented today at Frascati. A list of the e^+e^- rings which have produced important particle physics results and were in operation or planned before 1987 is given in Table 1. All these colliders with the exception of DORIS were single rings with e^+ and e^- in the same vacuum tube. (The double

Table 1: List of e^+e^- storage rings with a selection of their main results.

	location	active	energy	results
ACO, DCI	Orsay	1965-75	$2 \cdot 0.8$ GeV	ρ , ω , Φ
VEPP2	Novosibirsk	1965-75	$2 \cdot 0.5$ GeV	multi- π production
ADONE	Frascati	1969-93	$2 \cdot 1.5$ GeV	
SPEAR	SLAC	1972-90	$2 \cdot 4$ GeV	jets, ψ , ψ' , D, τ
DORIS	DESY	1973-77	$2 \cdot 3.5$ GeV	
DORIS2	DESY	1978-92	$2 \cdot 5.5$ GeV	$\chi(B^0)$, V_{ub}
VEPP4	Novosibirsk	1975-	$2 \cdot 6$ GeV	$m(c\bar{c})$, $m(b\bar{b})$
PETRA	DESY	1978-90	$2 \cdot 17$ GeV	gluon
CESR	Cornell	79-2007	$2 \cdot 6$ GeV	$\Upsilon(4S)$, B, V_{ub}
PEP	SLAC	1980-90	$2 \cdot 14$ GeV	$\tau(b)$
TRISTAN	KEK	1987-90	$2 \cdot 32$ GeV	
BEPC	Beijing	1989-	$2 \cdot 2.2$ GeV	$m(\tau)$
LEP	CERN	89-2002	$2 \cdot 90$ GeV	$m(Z)$, $N(\nu)$, $m(W)$

ring DORIS operated with a non-zero beam-crossing angle and, therefore, did not reach the planned high luminosity.)

Dreams, I mean my dreams, that Europe urgently needs a Cornell-like laboratory where B mesons and the search for CP violation in their decays have highest priority started in spring 1985. My first public talk on this subject was given 28 November 1985 at Zurich University. In May 1986, B. Stech and I organized a “Heavy Hadron” Symposium with 130 participants at Heidelberg with the main goal of collecting and spreading arguments for a B-Meson Factory. The proceedings [12] include the presentations of E. Lorenz on a realistic detector and of K. Wille on a double-storage-ring design with 5.3 GeV for both e^+ and e^- , 480 m circumference, 24 bunches in each ring, and a luminosity of $L = 5 \cdot 10^{32}/\text{cm}^2/\text{s}$. DORIS2 had 300 m and $\approx 2 \cdot 10^{31}/\text{cm}^2/\text{s}$.

These ideas resulted in a letter of intent [13] with five authors in November 1986 and a proposal [14] with about 50 authors from Switzerland, Germany, France, and Poland in July 1988. The proposal studies were funded by the Swiss national laboratory PSI at Villigen (the proposed Factory location), BMBF, and IN2P3. An appendix in the proposal expressed the interest of the Crystal Barrel Collaboration for the 2nd interaction region. The machine proposal included a synchrotron injector and an energy-symmetric double ring of 648 m circumference and 20 bunches in each ring, electrostatic beam separation in the interaction regions, and $L = (1 - 3) \cdot 10^{33}/\text{cm}^2/\text{s}$. The 1988-state-of-the-art detector was designed to consist of a silicon-strip vertex detector, a precision tracking chamber, a main drift chamber, a Cesium-Iodide calorimeter, a 1.5 Tesla superconducting coil, and an iron return yoke

with interleaved muon chambers. In July 1986, KEK presented a “Letter of Intent for Upgrading the TRISTAN Accumulation Ring for B Physics” [15], a storage ring idea with $4 \cdot 10^{32}/\text{cm}^2/\text{s}$. In January 1987, D. Cline organized a “Linear-Collider $B\bar{B}$ -Factory Design Workshop” at UC Los Angeles [16] under the motto “We need a $B\bar{B}$ -Factory in the 1990s with $L \geq 10^{34}$; this can only be done with a new type of machine and we will establish a working group”. In addition to the PSI and KEK intentions, the following three studies were presented at the workshop:

- a Linear Collider with 10^{33} on the $\Upsilon(4S)$ by J. Wurtele and A. Sessler,
- a superconducting Linear Collider with 10^{33} on the $\Upsilon(4S)$ and 10^{34} in the $b\bar{b}$ continuum by U. Amaldi and G. Coignet, and
- NPEP with two energy-symmetric rings in the PEP tunnel at SLAC with 10^{33} by E. Bloom.

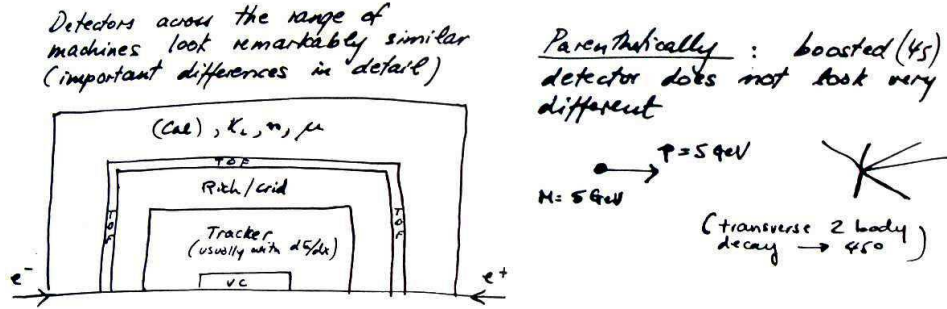


Figure 2: First presentation [17] of the boosted- $\Upsilon(4S)$ idea in 1987.

In the Detector Physics Group summary talk, P. Oddone [17] presented his idea of energy-asymmetric e^+e^- collisions without elaborating the physics motivation. To my knowledge, and as shown in Fig. 2, this is the first publication of the asymmetry idea.

Strong motivation for energy asymmetry appeared in the 1987 paper of I. Bigi and A. Sanda [18] with now 333 citations. (Parts of the arguments can be found already in the 1981 paper [19] of the same authors.) The time dependence of a CP-violating B decay into a CP eigenstate at time t_2 after the decay $\Upsilon(4S) \rightarrow B^0\bar{B}^0$ and a flavour-specific decay of the other B at time t_1 , which is necessary for distinguishing if the CP-eigenstate decay came from a B or a \bar{B} , is a function of only $t_2 - t_1$. Detectors at a storage ring where the $\Upsilon(4S)$ is produced at rest, and where the e^+e^- interaction region is much longer than the typical B-decay lengths, can only measure $t_2 + t_1$ and, therefore, cannot detect this type of CP violation. With a sufficiently large boost of the $\Upsilon(4S)$ in the detector frame, the distance between the two B-decay vertices measures $t_2 - t_1$ in very good approximation because of the small Q value of the $\Upsilon(4S) \rightarrow B\bar{B}$ decay. This consequence of the C- and P-conserving strong $\Upsilon(4S)$ decay, of the Einstein-Podolsky-Rosen paradoxon

in two-particle-state quantum mechanics, and of the longitudinal interaction-region size of all realistic e^+e^- colliders requires energy-asymmetric $\Upsilon(4S)$ production for observing CP violation in decays like $B^0 \rightarrow J/\psi K^0$. With this in mind, with the known value of $\text{Re}(\epsilon)$ in CP-violating K^0 decays, and with the 1987 values of $B^0\bar{B}^0$ mixing and $\mathcal{B}(B \rightarrow J/\psi K)$, it was clear that a few years with $10^{33}/\text{cm}^2/\text{s}$ are needed for answering the question with 5σ significance if the CP asymmetry in $B^0 \rightarrow J/\psi K_S^0$ decays has a value around 0.7 as predicted by Standard-Model CP violation or a value near zero.

In September 1987, E. Bloom and A. Fridman held a B-Meson Factory workshop at SLAC, where K. Wille presented the (still energy-symmetric) PSI plan, E. Bloom the transition NPEP \rightarrow SBF, a double-ring collider for the three options resting and boosted $\Upsilon(4S)$ and B production in the continuum, D. Cline and U. Amaldi linear colliders, and K. Berkelman a CESR-upgrade plan at Cornell. Starting in the summer of 1988, a series of further workshops at Snowmass, SLAC, and Caltech led to the SLAC proposal of an asymmetric B Factory with 9 GeV e^- on 3.1 GeV e^+ with 40 authors, appearing in October 1989 [20]. The machine paper [21] appeared in October 1989 as well. In the meanwhile, the PSI group had also adopted the boosted- $\Upsilon(4S)$ argument, and the calculations of T. Ruf and T. Nakada for the boost optimization led to K. Wille's energy-asymmetric design [22] with 7 on 4 GeV, published in December 1988.

Asymmetry had a big technical advantage. In symmetric double storage rings, the beam separation in the interaction regions had to be done by electrostatic separators with lengths in the order of 10 m. Energy asymmetry works with magnetic-field separation, e. g. with a tilted detector solenoid, which allows smaller bunch distances and, therefore, larger luminosity.

After the PSI proposal in July 1988 (asymmetry in December 1988) and the SLAC proposal in October 1989, the KEKB proposal [23] for a B-Meson Factory with e^- of 8 GeV, e^+ of 3.5 GeV, and $L \geq 10^{34}/\text{cm}^2/\text{s}$ appeared in

Table 2: The seven high-luminosity e^+e^- storage-ring proposals for B-meson production in 1991. C is the circumference, d_B the bunch distance.

Location	Ref.	E in GeV	L in $\text{cm}^{-2}\text{s}^{-1}$	C in m	d_B in m
PSI	[14]	$7.0 + 4.0$	$(1 - 3) \cdot 10^{33}$	648	32
SLAC	[21]	$9.0 + 3.1$	$3 \cdot 10^{33}$	2200	1.3
KEK	[23]	$8.0 + 3.5$	$1 \cdot 10^{34}$	3020	0.6
CERN	[24]	$8.0 + 3.5$	$1 \cdot 10^{34}$	963	3.0
Novosibirsk	[25]	$6.5 + 4.3$	$5 \cdot 10^{33}$	714	4.2
DESY	[26]	$9.3 + 3.0$	$3 \cdot 10^{33}$	2300	3.6
Cornell	[27]	$8.0 + 3.5$	$3 \cdot 10^{33}$	765	3.3

March 1991. The PSI proposal did not find approval in Switzerland and was moved into CERN's ISR tunnel [24]. In addition to CERN, also Novosibirsk, DESY, and Cornell proposed B-Meson Factories around the same time. In 1991, we had seven completed proposals for asymmetric e^+e^- double storage rings operating on the $\Upsilon(4S)$; Table 2 lists their main parameters. Only two of them were finally approved, PEP-II at SLAC in October 1993 and KEKB at KEK a few months later in 1994. The machines were ready to collide beams in July 1998 (PEP-II) and in March 1999 (KEKB). The first events were recorded by BABAR in May 1999 and by BELLE some days later in June 1999. The unexpected great successes of the two Factories and the two detectors are summarized by J. Olsen in this Symposium.

The Present

B-Meson Factories do not only produce B mesons. From the very beginning of Factory plans, D-meson, τ -lepton, and other questions have been part of the experimental proposals. This chapter of my presentation deals with D mesons. J. Olsen kindly agreed that I discuss here the “Discovery of the Year”, $D^0\bar{D}^0$ mixing. Different aspects of it have been observed by BABAR and BELLE in 2007 with sufficiently large significance. The discovery completes a long history in particle physics; all four meson systems which are allowed to mix have now been observed to mix.

The phenomenology is the same for all four systems. Mesons $M = K^0, D^0, B^0$ (also called B_d^0), and B_s (also called B_s^0) change with time into superpositions $\psi(t) = a(t) \cdot M + b(t) \cdot \bar{M}$, where a and b , owing to the weakness of the weak interaction, obey a linear differential equation

$$i \partial_t \begin{pmatrix} a \\ b \end{pmatrix} = (m_{ij} - i\Gamma_{ij}/2) \begin{pmatrix} a \\ b \end{pmatrix} \quad (1)$$

with Hermitean matrices m and Γ . The equation has two eigenstate solutions

$$\begin{aligned} M_h(t) &= (pM + q\bar{M}) \cdot \exp[-i(m + \Delta m/2)t - (\Gamma/2 + \Delta\Gamma/4)t] , \\ M_l(t) &= (pM - q\bar{M}) \cdot \exp[-i(m - \Delta m/2)t - (\Gamma/2 - \Delta\Gamma/4)t] , \end{aligned} \quad (2)$$

the only states which do not change their flavour composition with time. The subscript h means “heavy”, l means “light”, and the mass difference $\Delta m = m(M_h) - m(M_l)$ is positive per definition. The eigenstates have two more properties; they differ in their mean life $1/\Gamma$ (S = short-living, L = long-living) and they are approximate CP eigenstates if $|q/p| \approx 1$, i. e. if CP asymmetry in mixing is small ($+$ = CP-even, $-$ = CP-odd). CP asymmetry in K^0 mixing is known to be on the 10^{-3} level; in the other three systems it is expected to be of similar order or smaller. Any combination of the three properties (h,l) , (S,L) , $(+,-)$ is possible [28]. Therefore, in addition to

$$\Delta m/\Gamma = x , \quad \Delta\Gamma/2\Gamma = y \quad (3)$$

phenomenology needs a third parameter. The first one, $x > 0$, is positive per definition. Measurements of the sign of y determine the pairing of mean life and mass, $y > 0$ means $S = h$. The third parameter $\cos \phi$ determines the pairing of CP eigenvalue and mass. In the D^0 system, it is defined by the amplitude ratio

$$\lambda = \frac{A(D_h^0 \rightarrow K^+K^-) - A(D_l^0 \rightarrow K^+K^-)}{A(D_h^0 \rightarrow K^+K^-) + A(D_l^0 \rightarrow K^+K^-)} , \quad (4)$$

leading to $\cos \phi = +1$ for the pairing $+ = h$ and $\cos \phi = -1$ for $- = h$ if CP is conserved. (The above definition is more general; it allows CP violation in mixing, in decays, and in mixing-decay interference.)

Table 3: Summary of mixing-eigenstate properties.

Discovery				
K^0	1958	Long	= CP-odd	= heavy
D^0	2007	Long	= CP-odd (4σ)	= light (2σ)
B_s	Δm in 2006	Long	= CP-odd (1.5σ)	= ?
B^0	1987	Long	= ?	= ?

$K^0\bar{K}^0$ mixing was discovered in 1958 [29]; today we know well the CP assignments, Δm , and $\Delta\Gamma$. The mixing probability

$$\chi = \frac{x^2 + y^2}{2 + 2x^2} \quad (5)$$

has the value $\chi(K^0) = 0.498$, i. e. 49.8% of all produced K^0 mesons decay from the \bar{K}^0 state. $B^0\bar{B}^0$ mixing is celebrated in this Symposium, we know only Δm , and $\chi(B^0) = 19\%$ of all produced B^0 mesons decay as a \bar{B}^0 . $B_s\bar{B}_s$ mixing has been observed since long time, its Δm value was measured in 2006 [30], $|\Delta\Gamma| \neq 0$ has a significance of only 1.5σ , and $\chi(B_s) = 49.9\%$ of all produced B_s mesons decay as a \bar{B}_s .

$D^0\bar{D}^0$ mixing has been searched by many groups. In the celebrated year 1987, ARGUS [31] published a search for $D^{*+} \rightarrow \pi^+(D^0 \rightarrow \bar{D}^0 \rightarrow K^+\pi^-)$ decays and obtained $\chi(D^0) < 0.014$ (90% CL), one of the best limits at that time. From the results of BABAR and BELLE we have now obtained $\chi(D^0) \approx 1 \cdot 10^{-4}$ with 5σ from zero. Table 3 summarizes the relations between the three eigenstate properties in the sequence of decreasing knowledge level. Our birthday child is the rear-end light in the Table. The three major indications for $D^0\bar{D}^0$ mixing are presented in the following where all formulae are only valid in the limit of no CP violation:

1.) BELLE [32] has studied the lifetime distributions of 1.2 M $D^0 \rightarrow K^-\pi^+$, 110 k $D^0 \rightarrow K^-K^+$, and 50 k $D^0 \rightarrow \pi^-\pi^+$ decays and found a

difference as shown in Fig. 3. A fit to the data points gives the ratio

$$\tau(D^0 \rightarrow K^- \pi^+)/\tau(D^0 \rightarrow K^- K^+) = y \cdot \cos \phi = (1.31 \pm 0.32 \pm 0.25) 10^{-2} \quad (6)$$

which is 3.2σ from zero. BABAR has presented a preliminary result for the lifetime difference [33] and finds $y \cdot \cos \phi = (1.24 \pm 0.39 \pm 0.13) 10^{-2}$ by combining $K^+ K^-$ and $\pi^+ \pi^-$ decays. My average of the two results is $y \cdot \cos \phi = (1.28 \pm 0.29) 10^{-2}$ which is different from zero with 4.4σ . The sign of the measurement fixes the pairing $S = +$.

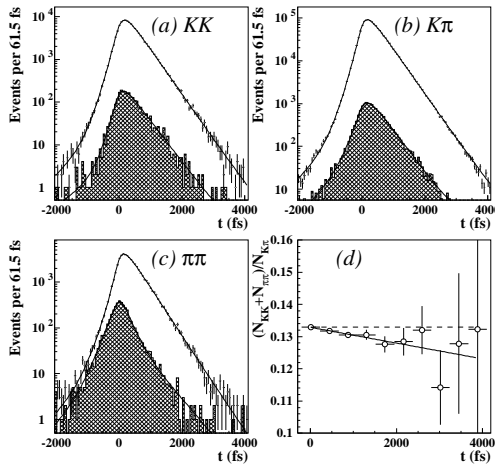


Figure 3: BELLE results [32] for the time dependence of $D^0 \rightarrow KK$, $K\pi$, $\pi\pi$. Part (d) shows the ratio $(KK+\pi\pi)/K\pi$.

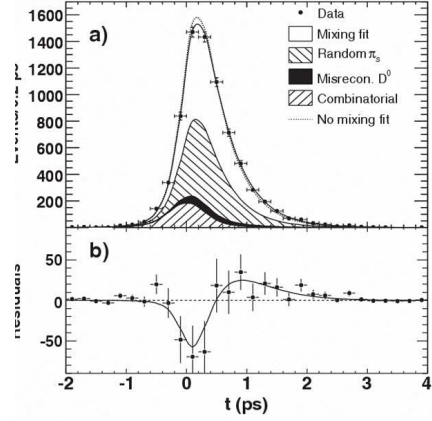


Figure 4: BABAR results [34] for (a) the time dependence of $D^0 \rightarrow K^+ \pi^-$ decays. In part (b), the points show the differences between data and the no-mixing fit, the line shows the difference between the best fit and the no-mixing fit.

2.) BABAR has reported direct evidence [34] for the transition $D^0 \rightarrow \bar{D}^0$ by observing $D^{*+} \rightarrow \pi^+ D^0$ decays with time-dependent sequential decays $D^0 \rightarrow a(t) D^0 + b(t) \bar{D}^0 \rightarrow K^+ \pi^-$. The observed time dependence is shown in Fig. 4(a). It is described by the expression

$$N_{+-}(t) = N_{+-}(0) \cdot e^{-\Gamma t} \cdot \left[R_D + \sqrt{R_D} y' \cos \phi \Gamma t + (x'^2 + y'^2)(\Gamma t)^2/4 \right], \quad (7)$$

where N_{+-} and N_{-+} are the numbers of $K^+ \pi^-$ and $K^- \pi^+$ decays.

$$R_D = \Gamma(D^0 \rightarrow K^+ \pi^-)/\Gamma(D^0 \rightarrow K^- \pi^+) \quad (8)$$

is the Double-Cabibbo-suppressed decay ratio, and x' , y' are related [35] to x , y through

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos \delta & \sin \delta \\ -\sin \delta & \cos \delta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \quad (9)$$

with the difference δ of final-state-interaction phase shifts between $D^0 \rightarrow K^+\pi^-$ and $D^0 \rightarrow K^-\pi^+$.

The two fits with free parameters x' , $y' \cos \phi$ and with no mixing ($x' = y' = 0$) differ by 3.9σ as shown in Fig. 4(b). The best-fit parameters are

$$R_D = (3.03 \pm 0.16 \pm 0.10) 10^{-3},$$

$$x'^2 = (-0.22 \pm 0.30 \pm 0.21) 10^{-3}, \quad y' \cos \phi = (9.7 \pm 4.4 \pm 3.1) 10^{-3}. \quad (10)$$

Fig. 5 shows the pertinent likelihood contours. BELLE [36] had an earlier evidence for mixing of this type, but with a significance of only 2.0σ .

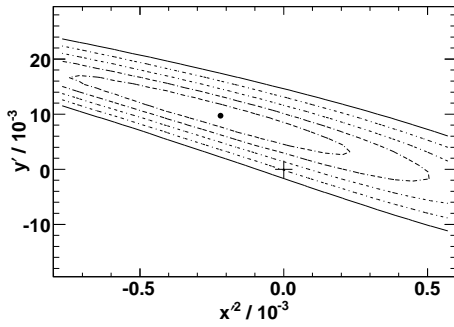


Figure 5: Fit results for $y' \cos \phi$ and x'^2 from the BABAR observation [34] of $D^0 \rightarrow K^+\pi^-$ decays. The dot shows the best fit, the five contours represent one to five standard deviations, and the cross shows the no-mixing point.

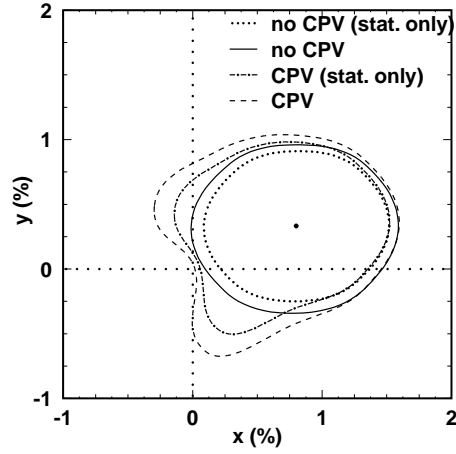


Figure 6: Fit results for x and y from the Dalitz analysis of BELLE [37] in D decays to $K_S^0 \pi^+ \pi^-$. The four contours correspond to two standard deviations.

3.) A time-dependent Dalitz-plot analysis of the three-body decays $a(t)D^0 + b(t)\bar{D}^0 \rightarrow K_S^0 \pi^+ \pi^-$ by BELLE [37] in 2007 led to the third evidence for mixing. The analysis is sensitive to x and y if a model for the Dalitz-plot population is used. With their expertise for such a population model, as used for determining the angle γ of the CKM-matrix unitarity triangle [38], BELLE finds

$$x = \left(0.80 \pm 0.29 \begin{smallmatrix} +0.13 \\ -0.16 \end{smallmatrix} \right) 10^{-2}, \quad y = \left(0.33 \pm 0.24 \begin{smallmatrix} +0.10 \\ -0.14 \end{smallmatrix} \right) 10^{-2} \quad (11)$$

with the 2σ likelihood contours in Fig. 6. The central point is 2σ away from the no-mixing point $x = y = 0$, but there may be an additional systematic uncertainty from the Dalitz-plot model.

A final HFAG fit [39] to all observations in Summer 2007, including also less significant results on $x^2 + y^2$ leads to the likelihood contours for x

and y in Fig. 7. They are very close to ellipses for one and two standard deviations. The pronounced non-Gaussian shapes for 4 and 5 σ have their origin in the non-linear transformation of (y', x'^2) from the $D^0 \rightarrow \bar{D}^0 \rightarrow K^+\pi^-$ measurement to (x, y) . The central point of the fit is

$$x = (8.8 \pm 3.3) 10^{-3}, \quad y = (6.8 \pm 2.1) 10^{-3}, \quad \chi(D^0) = (0.7 \pm 0.3) 10^{-4}. \quad (12)$$

The fit result for the mixing probability $\chi(D^0)$ is different from zero with a significance of five standard deviations. The fit result for x and y without the restriction of CP conservation in mixing looks nearly identical.

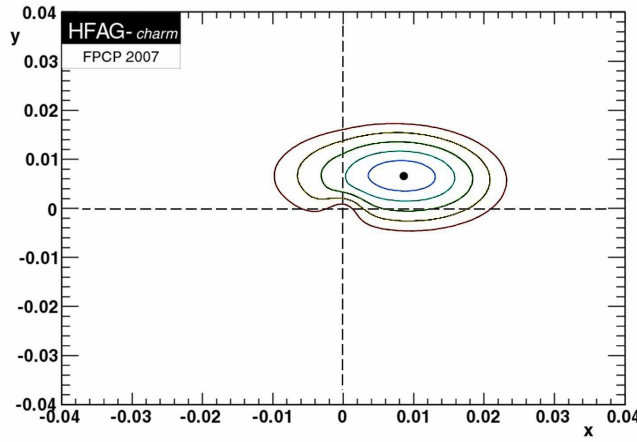


Figure 7: Combined fit to all $D^0\bar{D}^0$ mixing results with contours corresponding to 1 to 5 standard deviations [39]. The dashed lines correspond to $x = y = 0$.

One final comment on $\cos\phi$: There is strong evidence for $\Delta\Gamma \cos\phi > 0$, weak evidence for $\Delta\Gamma > 0$, and consequently for $\cos\phi = +1$. Until we have stronger evidence, the parameter $\cos\phi$ should be kept in the mixing phenomenology. We can completely forget it when the signs of both $\Delta\Gamma$ and $\Delta\Gamma \cos\phi$ will be well measured.

The Future

BABAR will finish data taking in September 2008¹, BELLE around half a year later. There are at present two major activities for a continuation of the B-Meson-Factory successes.

The present KEK roadmap [40] foresees a three-year KEKB shutdown after the end of BELLE's present data taking in the spring of 2009. During this shutdown, KEKB shall be upgraded to a luminosity of some $10^{35}/\text{cm}^2/\text{s}$

¹when writing these lines, there is already sad evidence for an earlier end in March.

and BELLE shall be replaced by an upgraded detector, to be built by a new international Collaboration.

The SuperB initiative [41] was started around 2002 by BABAR physicists, mainly from the US, Italy, France, and UK. At the end of 2005, INFN in Italy promoted the formation of an international study group on a Conceptual Design Report (CDR) for an e^+e^- double storage ring, a “Super Flavour Factory” containing

- the physics case in the era of LHC,
- a machine and detector design able to integrate $(15 - 65)/\text{ab/year}$ on the $\Upsilon(4S)$,
- the possibility of running at $\sqrt{s} = 4 \text{ GeV}$ with a peak luminosity of $10^{35}/\text{cm}^2/\text{s}$, and
- at least one polarized beam for τ -lepton physics.

The CDR was published in April 2007 [42] by 320 authors (experimentalists, theorists, and accelerator physicists) from 85 institutions in 15 countries, including 65 non-BABAR experimentalists. The luminosity goal is $1 \cdot 10^{36}/\text{cm}^2/\text{s}$ [with an option for doubling this goal]. The main luminosity gain comes from the bunch size in the interaction region with $\sigma_y^* = 35 \text{ nm}$, $\sigma_x^* = 5 \mu\text{m}$, $\sigma_z^* = 6 \text{ mm}$ and from a crab-crossing-like beam-crossing scheme called “crab-waist”. The main other machine parameters are 2000 m circumference, $E(e^-) = 7 \text{ GeV}$, $E(e^+) = 4 \text{ GeV}$, 30 mrad beam-crossing angle, 1.3 m [0.65 m] bunch distance, $I(e^-) = 1.3 \text{ A}$ [2.2 A], $I(e^+) = 2.3 \text{ A}$ [4.0 A], and $P = 17 \text{ MW}$ [35 MW], where the values in brackets are for the double-luminosity option. The smaller boost than in PEP-II requires better vertex resolution. This shall be achieved with an interaction-region beam tube radius of 1 cm and a pixel Silicon vertex detector with the first layer having the diameter of a one-Euro coin. The detector could be based on BABAR but needs new components for at least the calorimeter endcap, the vertex detector, the drift chamber, the DIRC readout and in the areas of trigger, data acquisition, and computing.

An International Review Committee has been appointed by INFN earlier this year. The members are: J. Dainton (Daresbury, chair), J. Lefrançois (Orsay), A. Masiero (Padova), R. Heuer (DESY), D. Schulte (CERN), A. Seiden (UC Santa Cruz), Y.-K. Kim (FNAL), and H. Aihara (Tokyo). The review is scheduled for November 2007 in Frascati. The report of the Committee is expected in spring 2008, after results from the DAΦNE test of the “crab-waist” scheme. Later in 2008, a presentation to the CERN strategy group is foreseen.

A possible site for the international SuperB project is on the campus of the Tor Vergata University south-east of Rome in 3 km distance from the LNF laboratory at Frascati, the place where the first e^+e^- storage ring had been built by B. Touschek and his collaborators.

References

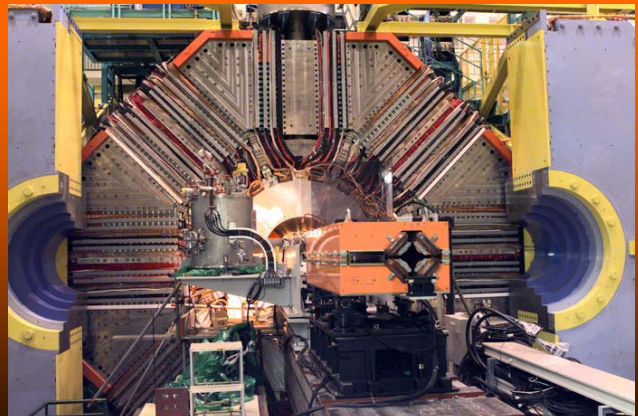
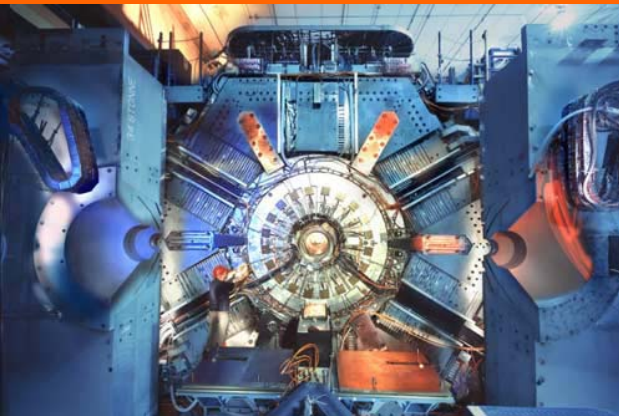
- [1] I gratefully remember the collaboration with H. Nesemann and K. Wille.
- [2] H. Albrecht et al. (ARGUS), Phys. Lett. B 185, 218 (1987)
- [3] H. Albrecht et al. (ARGUS), Phys. Lett. B 192, 245 (1987)
- [4] H. Albrecht et al. (ARGUS), Phys. Lett. B 197, 452 (1987)
- [5] I learnt the exciting CP-violation prospects after the Υ discovery 1977 from M. K. Gaillard.
- [6] R. Wideröe's autobiographic notes, in "The Infancy of Particle Accelerators", ed. by P. Waloschek, DESY report 94-039 (1994)
- [7] R. Wideröe, Deutsches Patentamt, Patentschrift Nr. 876279, submitted September 1943, published 1953
- [8] W. C. Barber, B. Gittelman, G. K. O'Neill, W. K. H. Panofsky, and B. Richter, Stanford University Report HEPL 170 (June 1959)
- [9] W. C. Barber, B. Gittelman, G. K. O'Neill, and B. Richter, Phys. Rev. Lett. 16, 1127 (1966)
- [10] C. Bernardini, G. F. Corazza, G. Ghigo, and B. Touschek, Nuovo Cimento 18, 1293 (1960)
- [11] C. Bernardini, G. F. Corazza, G. Di Giugno, J. Haïssinski, P. Marin, R. Querzoli, and B. Touschek, Nuovo Cimento 34, 1473 (1964)
- [12] Proc. Int. Symp. on Production and Decay of Heavy Hadrons, Heidelberg 1987, ed. by K. R. Schubert and R. Waldi
- [13] R. Eichler, T. Nakada, K. R. Schubert, S. Weseler, and K. Wille, SIN report PR-86-13 (1986)
- [14] Paul Scherrer Institute (formerly SIN), PSI Report PR-88-09 (1988)
- [15] H. Aihara et al., KEK internal, July 1986, presented in ref. [16]
- [16] Proc. Linear Collider $B\bar{B}$ Factory Conceptual Design Workshop, UC Los Angeles 1987, ed. by D. Stork
- [17] P. Oddone, in ref. [16]
- [18] I. I. Bigi and A. I. Sanda, Nucl. Phys. B 281, 41 (1987)
- [19] I. I. Bigi and A. I. Sanda, Nucl. Phys. B 193, 85 (1981)

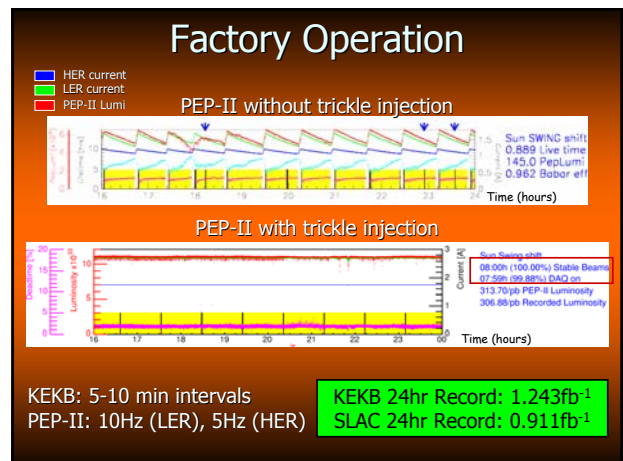
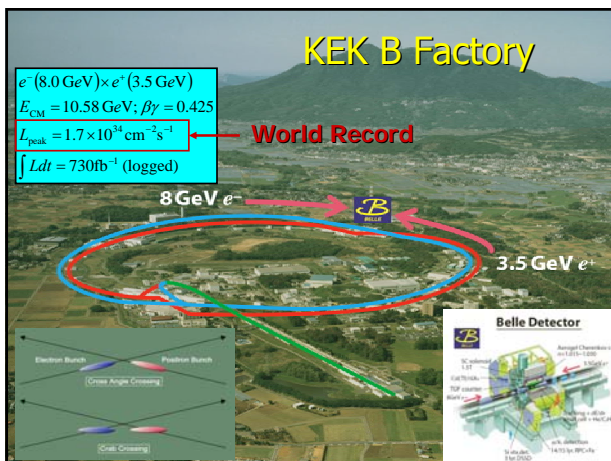
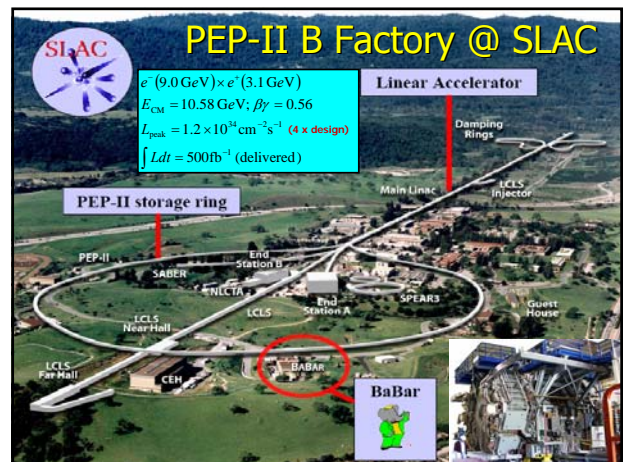
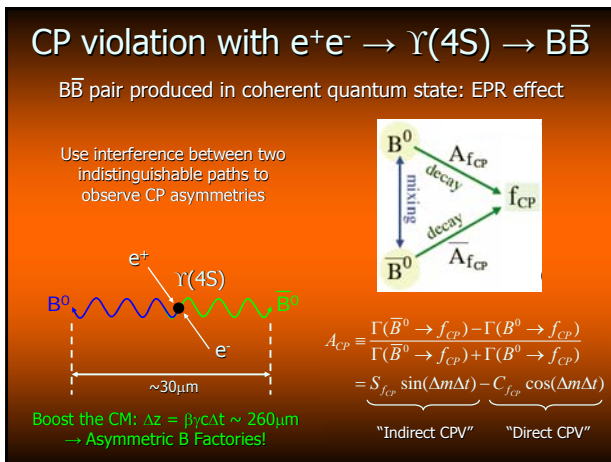
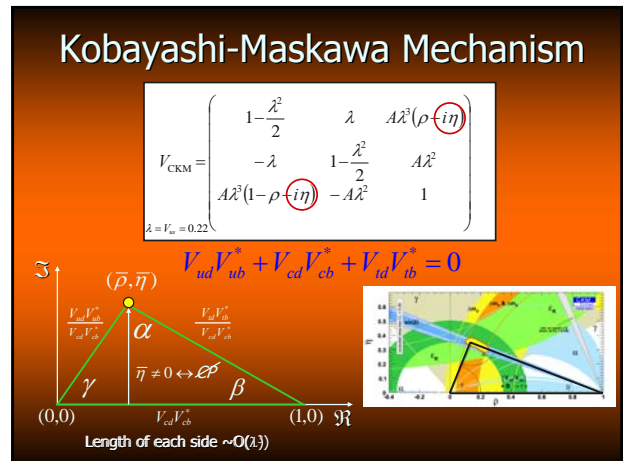
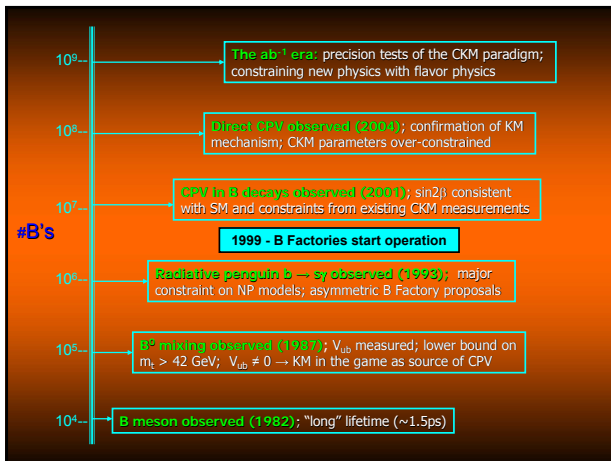
- [20] A. Eisner et al., SLAC-353 (1989), ed. by D. Hitlin
- [21] D. Hitlin et al., SLAC-352 (1989)
- [22] R. Eichler et al., PSI Report PR-88-22 (1988)
- [23] S. Kurokawa et al., KEK Report 90-24 (March 1991).
- [24] G. Coignet et al., CERN 90-02 (March 1990), ed. by T. Nakada
- [25] A. N. Dubrovin et al. (Budker Inst. Novosibirsk), submitted paper to the EPAC Accelerator Conf., Rome, 1988
- [26] H. Nesemann et al., DESY Report 89-080 (1989)
- [27] J. Alexander et al., Cornell Report CLNS 89/962 (1989)
- [28] I acknowledge discussions with Z. Ligeti on this subject.
- [29] M. Baldo-Ceolin et al., *Nuovo Cimento* 6, 130 (1957)
E. Boldt, D. O. Caldwell, and Y. Pal, *Phys. Rev. Lett.* 1, 150 (1958)
F. S. Crawford et al., *Phys. Rev.* 113, 1601 (1959)
- [30] A. Abulencia et al. (CDF), *Phys. Rev. Lett.* 97, 242003 (2006)
- [31] H. Albrecht et al. (ARGUS), *Phys. Lett. B* 199, 447 (1987)
- [32] M. Starič et al. (BELLE), *Phys. Rev. Lett.* 98, 211803 (2007)
- [33] W. Lockman (BABAR), presented at the Lepton-Photon Conference, Daegu, 2007
- [34] B. Aubert et al. (BABAR), *Phys. Rev. Lett.* 98, 211802 (2007)
- [35] K. R. Schubert, *Progress in Particle and Nuclear Physics* 21, 3 (1988)
- [36] L. M. Zhang et al. (BELLE), *Phys. Rev. Lett.* 96, 151801 (2006)
- [37] L. M. Zhang et al. (BELLE), *Phys. Rev. Lett.* 99, 131803 (2007)
- [38] A. Poluektov et al. (BELLE), *Phys. Rev. D* 73, 112009 (2006)
- [39] Heavy Flavour Averaging Group, FPCP07 part of
<http://www.slac.stanford.edu/xorg/hfag/charm>, 2007
- [40] M. Yamauchi and K. Oide, private communication
- [41] I thank M. Giorgi and F. Forti for their up-to-date informations on SuperB.
- [42] Report INFN/AE-07/02, SLAC-R-856, LAL 07-15,
arXiv.org/abs/0709.0451

The B Factory Era

ARGUS Symposium: 20 years of B meson mixing

James D. Olsen
Princeton University
November 9, 2007





Data in, physics out...

BaBar

PEP-II Delivered Luminosity: 498.65/fb
 Belle Recorded Luminosity: 477.45/fb
 Off Peak Luminosity: 45.35/fb

Integrated Luminosity (fb⁻¹)

Delivered Luminosity
 Recorded Luminosity
 Off Peak

477fb⁻¹

Belle

732fb⁻¹

Integrated Luminosity (fb⁻¹)

Belle log total: 732.12 fb⁻¹

B Factory Publications

Belle
 BaBar
 Total

> 1200fb⁻¹
 > 550 pubs

Physics Analysis with a Boosted $\Upsilon(4S)$

Instructions: 1) boost back to CM
2) use techniques developed by ARGUS & CLEO!

Kinematics:

$B^0 \rightarrow J/\psi K_S^0$

m_{ES}

ΔE

signal region

sidebands

Topology:

spherical $B\bar{B}$ events

jetty $q\bar{q}$ events

Important difference

For two-body decays: momentum of B daughters can be $> 4 \text{ GeV}/c$:

- 1) Affects resolution in ΔE , $E(\gamma, \pi^0)$, etc
- 2) Higher fraction of merged π^0
- 3) K/π separation more difficult

Establishing the KM Mechanism

[illegible]

Precision CP Violation

BaBar (384M)

$\sin 2\beta = 0.697 \pm 0.035 \pm 0.016$

Raw asymmetry
Events / (0.4 ps)

B^0 tags
 \bar{B}^0 tags

Δt [ps]

Belle (534M)

$\sin 2\beta = 0.642 \pm 0.031 \pm 0.017$

$B^0 \rightarrow D^+ D^-$

CP asymmetry

Δt (ps)

$\sin 2\beta_{WA} = 0.68 \pm 0.03$

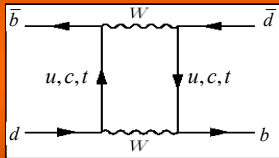
Is it the right answer?

The plot shows the parameter space for CP violation in the K system. The horizontal axis is $\bar{\rho}$ (ranging from -0.4 to 1) and the vertical axis is η (ranging from 0 to 0.6). Various regions are shaded in different colors: green for ϵ_K , yellow for Δm_d , orange for Δm_s and Δm_d , blue for α , light blue for β , and grey for γ . A red dashed line indicates the CKM unitarity triangle. A box labeled "CKM fit (PDG 2008)" is shown in the top right corner. A label "sin 2 β " is present near the origin. A label " $|V_{us}/V_{ub}| + B \rightarrow \tau\gamma$ " is also visible.

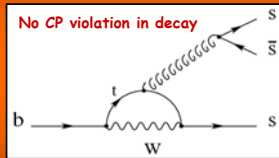
Yes! Large O(1) CP violation consistent with
a single source: phase of the CKM matrix

Is KM the only answer?

Superweak ansatz: CP-violating phenomena arise from $|\Delta F| = 2$ transitions



$$|\Delta B| = 2$$



$$|\Delta B| = 1$$

To disprove Superweak theories we needed to observe CP violation *in decay* (repeat of K system)

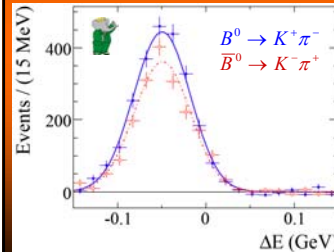
Direct CP Violation in $B^0 \rightarrow K^+\pi^-$

Established by BaBar and Belle in 2004

$$\text{Asymmetry} \equiv \frac{N_{K^-\pi^+} - N_{K^+\pi^-}}{N_{K^-\pi^+} + N_{K^+\pi^-}} \propto \frac{T}{P} \sin \gamma \sin \delta$$

strong phase

weak phase



BaBar + Belle + CDF + CLEO:

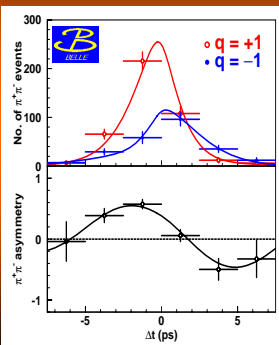
$$A_{\text{WA}}^{2007} = -0.097 \pm 0.012$$

Consequences:

- 1) ~~Superweak~~
- 2) First evidence for $\gamma \neq 0, \pi$
- 3) Large strong phase δ

CP Violation in $B^0 \rightarrow \pi^+\pi^-$

Observed by Belle (2004) and BaBar (2007)



Belle + BaBar:

$$S_{\pi\pi}^{\text{WA}} = -0.68 \pm 0.08 \quad (\text{Indirect CPV})$$

$$C_{\pi\pi}^{\text{WA}} = -0.38 \pm 0.07 \quad (\text{Direct CPV})$$

Superweak prediction:

$$S_{\pi\pi} = -\sin 2\beta \quad (\text{true within errors!})$$

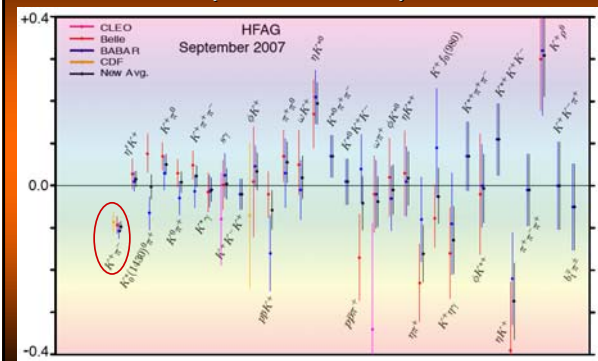
$$C = 0 \quad (\text{not true})$$

$C_{\pi\pi} \neq 0 \rightarrow$ critical confirmation of KM

SU(3) prediction:

$$C_{\pi\pi} = \frac{\Gamma_{K\pi}}{\Gamma_{\pi\pi}} A_{K\pi} = -0.34 \pm 0.02$$

Direct CP Asymmetry Measurements (charmless modes)



Over-constraining CP Violation

Measuring $\sin 2\alpha$

$A_{CP} = \overbrace{\sin 2\alpha}^{S_{\pi\pi}} \sin(\Delta m \Delta t)$

$S_{\pi\pi}^{\text{WA}} = -0.61 \pm 0.08 \rightarrow \alpha = 109^\circ \pm 3^\circ$

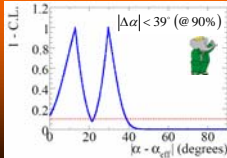
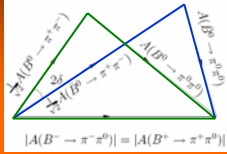
Compare with Global CKM Fits:

UT Fit: $(91 \pm 6)^\circ$

CKM Fitter: $(102^{+3}_{-13})^\circ$

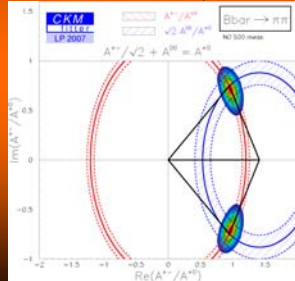
The problem with α ...

$$S_{\pi\pi} \propto \sin 2\alpha_{\text{eff}}; \alpha_{\text{eff}} = \alpha + \delta$$



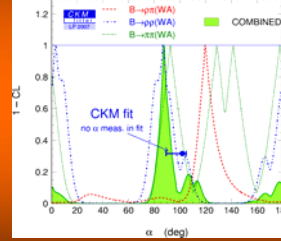
$$\text{Optimal Case: } A_{\pi^0\pi^0} \ll A_{\pi^+\pi^-} + A_{\pi^+\pi^0}$$

Not true for $\pi\pi$ system!

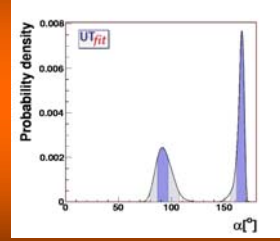


Combined Results for α

Penguin "pollution" much smaller in $\rho\rho$
 $\rho\pi$ Dalitz analysis removes mirror solutions

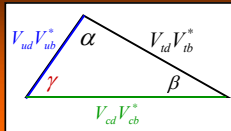


$$\alpha = (87 \pm 6)^\circ$$

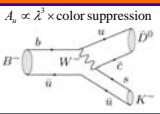
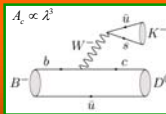


$$\alpha = (91 \pm 8)^\circ$$

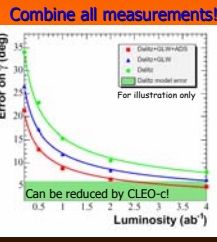
Measuring γ



Method	Modes	Adv.	Disadv.
GLW	$D^0(\text{CP})$	Constraints	Low stats, small interf.
ADS	$D^0(K_S)$	Large interf.	Low stats
GSZ	$D^0(K_S\pi\pi)$	Dalitz info	Dalitz model

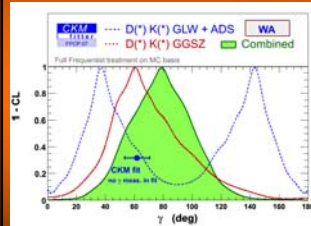


$$A_{CP} \equiv \frac{\Gamma(B^- \rightarrow DK^-) - \Gamma(B^+ \rightarrow DK^+)}{\Gamma(B^- \rightarrow DK^-) + \Gamma(B^+ \rightarrow DK^+)} \propto r_B \sin \gamma \sin \delta$$

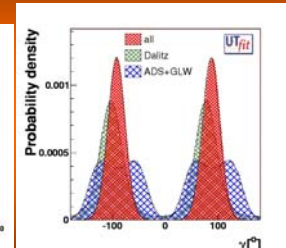


Combined Measurements of γ

Best method (Dalitz) was invented only in 2003!

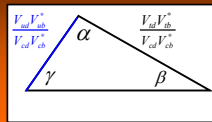
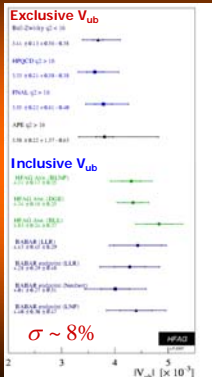


$$\gamma = (77 \pm 31)^\circ$$

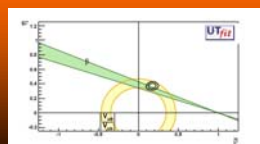


$$\gamma = (88 \pm 16)^\circ$$

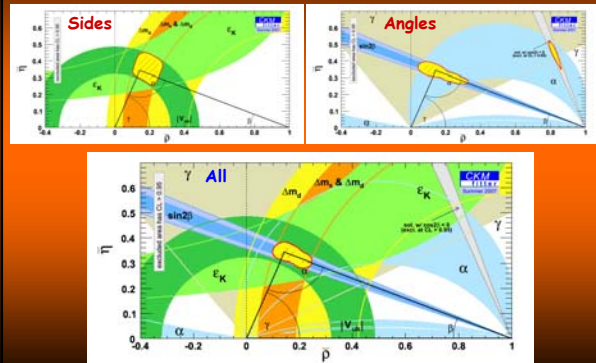
Measurements of V_{ub}



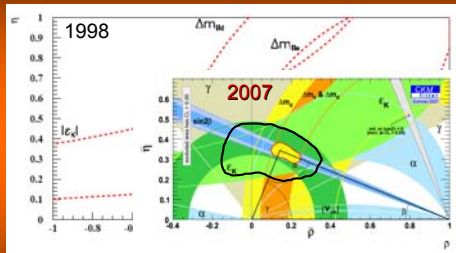
Critical KM test: does $\sin 2\beta$ intersect the V_{ub}/V_{cb} ring?



Over-constraining CP Violation



Impact of B Factories and Tevatron



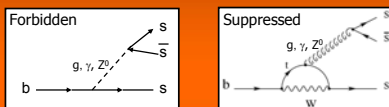
Enormous progress in the past decade has led to a paradigm change:
Use precision CKM measurements to search for New Physics (NP)

Constraining New Physics with Flavor Physics

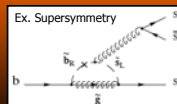
"Tasting" New Physics

Standard Model Flavor Transition Rule:

No 1st-order flavor-changing neutral currents



If the new physics has a generic flavor structure, we should see large non-SM effects in decays mediated by flavor-changing neutral currents:



MSSM Constraints from $b \rightarrow s\gamma$

"Most effective New Physics killer"

Experiment:

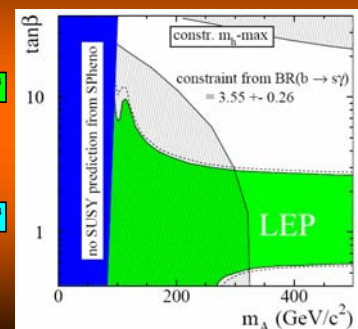
$$B(b \rightarrow s\gamma) = (3.55 \pm 0.26) \times 10^{-4}$$

$$A_{CP} = (0.4 \pm 3.6)\%$$

Theory:

$$B(b \rightarrow s\gamma) = (3.57 \pm 0.30) \times 10^{-4}$$

$$A_{CP} = (0.42^{+0.17}_{-0.12})\%$$



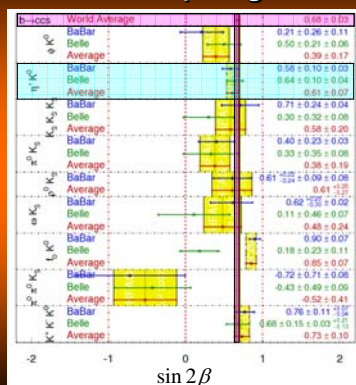
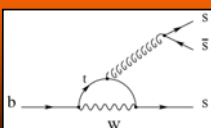
CP Violation in $b \rightarrow s$ penguins

First observation of indirect CP violation in $b \rightarrow s$ (2006)

$$S_{\eta K} = 0.61 \pm 0.07$$

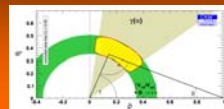
In the Standard Model :

$$|S| \approx \sin 2\beta \text{ for all } b \rightarrow sq\bar{q}$$

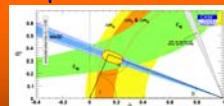


Constraining NP with Flavor Physics

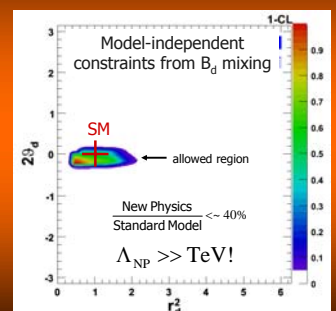
Trees



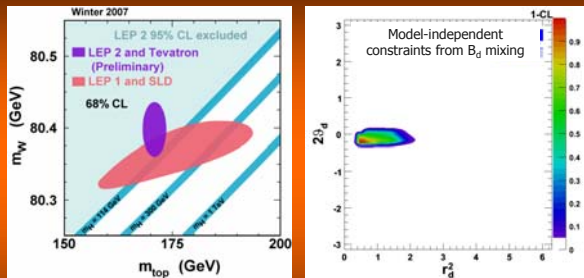
Loops



$$r_d^2 e^{i2\theta_d} \equiv \frac{A_{SM} + A_{NP}}{A_{SM}}$$



"New Physics Flavor Problem"

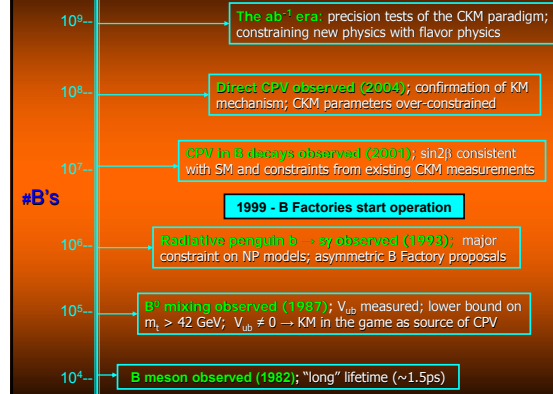


$\Lambda \sim 1 \text{ TeV}$

$\Lambda \gg \text{TeV}$

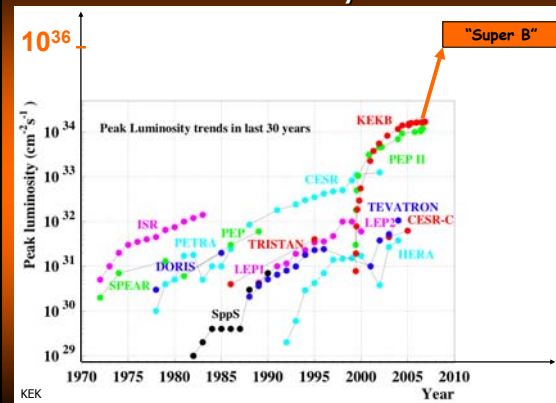
If new physics lives at the TeV scale it cannot have a generic flavor structure \rightarrow Minimal Flavor Violation!

Testing Minimal Flavor Violation



The Super B Factory Era

The Luminosity Frontier



Super B Factory Proposals



"Ultra-high currents"
 $L = 0.8 \times 10^{36} \text{ cm}^{-2} \text{ s}^{-1}$
 @ KEK

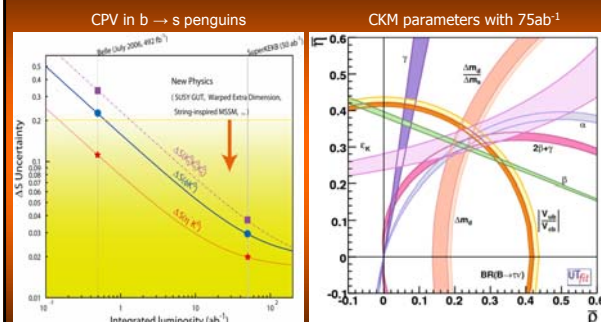


"Ultra-low emittance"
 $L \geq 1.0 \times 10^{36} \text{ cm}^{-2} \text{ s}^{-1}$
 @ ~Frascati (Tor Vergata)

		SuperB (2006/2007)	SuperKEKB (2006)	
Emittance	ϵ_x	1.6	9	nm
Horizontal beta	β_x^*	20	200	mm
Vertical beta	β_y^*	0.3	3	mm
Horizontal beam size	σ_x^*	5.7	42	μm
Vertical beam size	σ_y^*	35	367	nm
Bunch length	σ_z	6	3	mm
Half crossing angle	ϕ_x	17	15	mrad
Piwiński angle	ϕ	18	1	rad
Current (LER/HER)	I_b	2.28/1.30	9.4/4.1	A
Luminosity ($\times 10^{36}$)	L	10	8	$\text{cm}^{-2} \text{ s}^{-1}$
AC Plug Power	P	34	83	MW

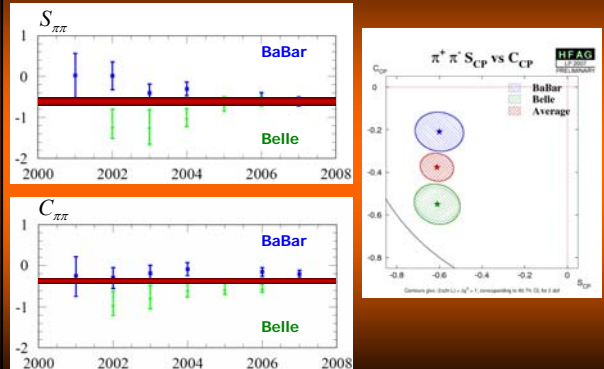
Y. Ohnishi

CKM in 201x?

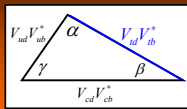


Backup

History of CP Violation in $B^0 \rightarrow \pi^+ \pi^-$

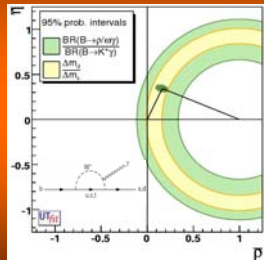
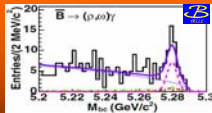


V_{td}/V_{ts} from $b \rightarrow (s,d) \gamma$

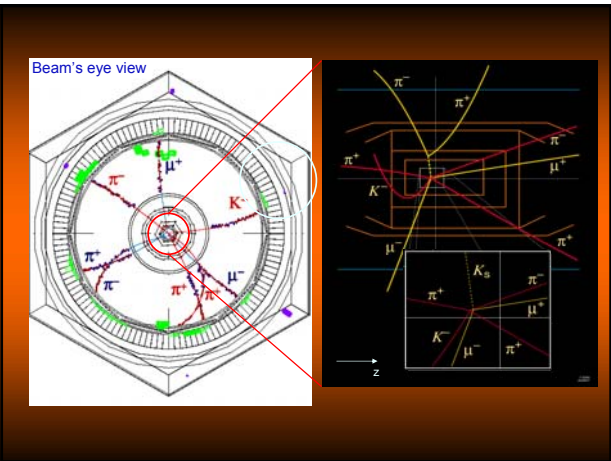


Observation of $B \rightarrow \rho \gamma$ by Belle and BaBar allows a complementary constraint on V_{td}/V_{ts}

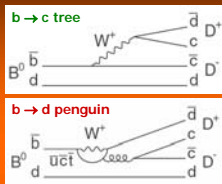
BF x 10 ⁶	Belle (386M _{BB})	BaBar (347M _{BB})
$B \rightarrow (\rho, \omega) \gamma$	$1.32^{+0.10}_{-0.09} \pm 0.08$ (5.1 σ)	$1.25^{+0.10}_{-0.09} \pm 0.08$ (6.4 σ)



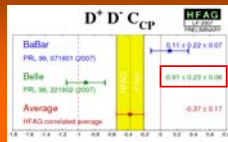
$\rho \gamma / K^* \gamma \rightarrow |V_{td}/V_{ts}| = 0.200 \pm 0.021$ (exp) ± 0.015 (thy)
 mixing $\rightarrow |V_{td}/V_{ts}| = 0.2060 \pm 0.0007$ (exp) ± 0.0081 (thy)



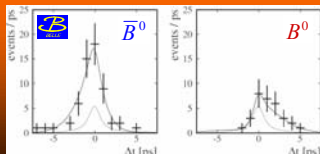
Direct CP Violation in $B^0 \rightarrow D^+ D^-$?



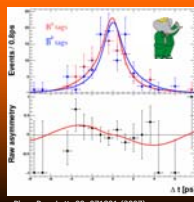
SM predicts $S \sim -\sin 2b$ and $C \sim 0$



3.2 σ

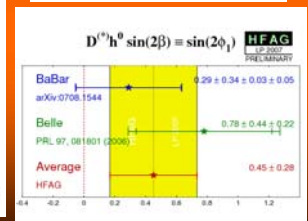
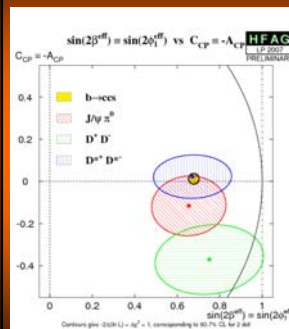


Phys. Rev. Lett. 98, 221802 (2007)



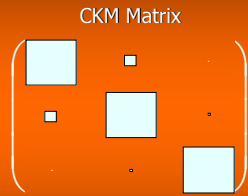
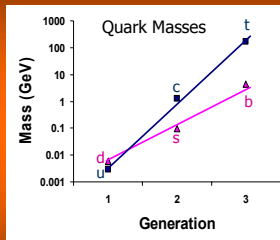
Phys. Rev. Lett. 99, 071801 (2007)

Additional Measurements of β



Known Unknowns: Mass and Flavor

What is the origin of the quark mass and mixing hierarchies?

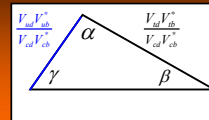


$$(m_u, m_d) < (m_c, m_s) < (m_t, m_b)$$

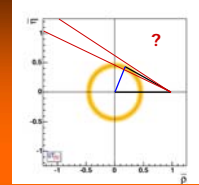
$$\theta_{13} \ll \theta_{23} \ll \theta_{12} \ll 1$$

The answer lies beyond the Standard Model!

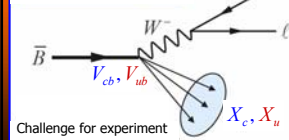
Measuring V_{ub} and V_{cb}



Critical KM test: does $\sin 2\beta$ intersect the V_{ub}/V_{cb} ring?

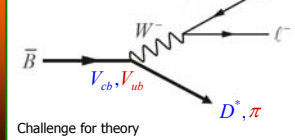


Inclusive V_{xb}



Challenge for experiment

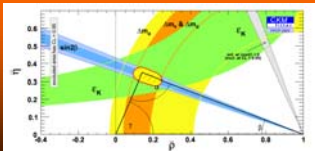
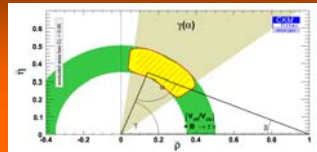
Exclusive V_{xb}



Challenge for theory

Constraining NP with Flavor Physics

Standard Model Reference:
decays allowed at 1st order



Search in loop-dominated
decays for inconsistencies:

$$r_d^2 e^{i2\theta_d} \equiv \frac{A_{SM} + A_{NP}}{A_{SM}}$$

***B* Physics @ the Tevatron**

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1 Introduction

The Tevatron collider at Fermilab, operating at a center-of-mass energy of $\sqrt{s} = 1.96$ TeV has a huge $b\bar{b}$ production cross section (≈ 1 nb), which is about five orders of magnitude larger than the $b\bar{b}$ production rate at the B factories PEP and KEK, e^+e^- colliders running on the $Y(4S)$ resonance. In addition, only B^+ and B_d mesons are produced at $Y(4S)$, while higher mass b hadrons such as B_s , B_c , b baryons, B^* and p-wave B mesons are currently produced only at the Tevatron. In order to exploit the possibility to study those variety of heavy b hadrons in a busy hadronic environment, dedicated detector systems, triggers and reconstruction are crucial.

Both D0 and CDF are multipurpose detectors featuring high resolution tracking in a magnetic field and lepton identification. These detectors are symmetrical in polar and azimuthal angles around the interaction point, with approximate 4π coverage [1, 2]. The CDF and D0 experiments are able to trigger at hardware level on large track impact parameters. CDF exploits this trigger to collect a sample of fully reconstructed B mesons, substantially enhancing the potential of its B physics program. At D0 the displaced track trigger is for the time being only used at lower bandwidth, e.g. for b tagging of potential Higgs candidates. CDF has a dedicated particle identification system composed of a time-of-flight detector and dE/dx measurements in the drift-chamber, which allows kaon-pion separation of at least 1.5σ throughout the whole momentum range. D0 has an excellent muon system and a tracking coverage in the forward region up to a pseudo-rapidity of $\eta = 2.5$.

About 3 fb^{-1} of data has been collected in the meantime by each of the both experiments. About $6\text{--}8\text{ fb}^{-1}$ are expected till the shutdown of the Tevatron end of 2009.

2 B Physics @ the Tevatron

The Tevatron has a rich B physics program, including several observations of heavy B hadrons and measurements of their branching ratios and lifetimes, such as Σ_b , B_s^{**} , Ξ_b , B_c and λ_b . Measurement of CP asymmetries in various decay channels, precision mass measurements and searches for rare decays such as $B_s \rightarrow \mu^+\mu^-$ and $B_s \rightarrow \phi\phi$ have been performed. Many analysis are for the moment still statistically

limited. However for most of them about a factor 4-6 more data is expected. Thus many more exciting results are to come soon.

At the Argus Symposium only a small selection of these results was presented. Within the context of the 20th anniversary of the discovery of B_d mixing, the focus was put on the mixing in the B_s system.

3 Observation of B_s Mixing

The probability \mathcal{P} for a B_s meson produced at time $t = 0$ to decay as a B_s (\overline{B}_s) at proper time $t > 0$ is, neglecting effects from CP violation as well as possible lifetime difference between the heavy and light B_s^0 mass eigenstates, given by

$$\mathcal{P}_{\pm}(t) = \frac{\Gamma_s}{2} e^{-\Gamma_s t} [1 \pm \cos \Delta m_s t], \quad (1)$$

where the subscript “+” (“-”) indicates that the meson decays as B_s (\overline{B}_s). Γ_s is the average B_s decay width and Δm_s the mass difference of the heavy and light B_s mass eigenstates.

Oscillation has been observed and well established in the B_d system. The mass difference Δm_d is measured to be [3]

$$\Delta m_d = 0.505 \pm 0.005 \text{ ps}^{-1}. \quad (2)$$

In the B_s system oscillation has been observed, too. However till winter 2006 all attempts to measure Δm_s have only yielded a combined lower limit on the mixing frequency of $\Delta m_s > 14.5 \text{ ps}^{-1}$ @ 95 % confidence level (C.L.). Indirect fits constraint Δm_s to be below 24 ps^{-1} @ 95 % C.L. within the Standard Model (SM). In March 2006 the D0 collaboration presented the first double sided 90 % C.L. limit [4] and CDF shortly afterwards presented the first precision measurement of Δm_s , with a significance of the signal of about 3σ at that time [5]. Just a few months later the CDF collaboration updated their result using the very same data, but improved analysis technics and announced the observation of the $B_s - \overline{B}_s$ mixing frequency [6]. In this chapter we will focus on this analysis, which is based on 1 fb^{-1} of data.

The canonical B mixing analysis proceeds as follows. The flavor of the B_s meson at decay time is determined from the charges of the reconstructed decay products in the final state. The proper is determined from the displacement of the B_s decay vertex with respect to the primary vertex, and the B_s transverse momentum. The transverse plane is here defined with respect to the proton beam. Finally, the so-called tagging algorithms deduce the B_s production flavor, in order to classify the meson as mixed or unmixed. Then the asymmetry can be measured:

$$\mathcal{A}(t) \equiv \frac{N(t)_{unmixed} - N(t)_{mixed}}{N(t)_{unmixed} + N(t)_{mixed}} = \mathcal{D} \cos(\Delta m_s t), \quad (3)$$

where $N(t)$ are the time-dependent rates for mixed and unmixed B_s decays. \mathcal{D} is the so-called dilution, a damping term which is related to imperfect tagging. It is

defined as $\mathcal{D} = 1 - P_w$, where P_w is the probability for a wrong tag. The significance \mathcal{S} of a mixing signal is given by:

$$\mathcal{S} = \sqrt{\frac{\epsilon \mathcal{D}^2}{2}} \sqrt{\frac{S}{S+B}} e^{-\frac{(\Delta m_s \sigma_{ct})^2}{2}} \quad (4)$$

S and B are the rates of signal and background events respectively. $\epsilon \mathcal{D}^2$ is the figure of merit for the flavor tagging, where ϵ is the efficiency to actually apply a tag to a given B_s candidate. σ_{ct} is the proper decay time resolution. Especially at large Δm_s values a high proper time resolution is crucial for this analysis.

3.1 Signal Yields

CDF studied fully and partial reconstructed hadronic and semileptonic B_s candidates in events collected by the displaced track trigger. About 2000 candidates are fully reconstructed in the cleanest, so-called golden mode $B_s \rightarrow D_s(\phi\pi)\pi$. About 3200 partially reconstructed B_s candidates coming from $B_s \rightarrow D_s^*(\phi\pi)\pi$ and $B_s \rightarrow D_s(\phi\pi)\rho$ are reconstructed with the same signal signature. Those events have slightly worse proper decay time resolution, due to γ or π^0 , which escaped reconstruction. 3600 B_s candidates are fully reconstructed in additional modes. Neural network technics have been used to enhance signal yield and to improve signal/background ratio.

A large sample of 61.500 semileptonic $B_s \rightarrow \ell D_s X$ candidates has been studied. Due to missing momentum of the non reconstructed particles in this decay a correction factor derived in Monte Carlo, has been applied to scale the ℓD_s momentum:

$$ct = \frac{L_{xy} M(B_s)}{p_T(B_s)} = \frac{L_{xy} M(B)}{p_T(\ell D_s)} * k. \quad (5)$$

The spread of the k factor distribution limits the proper time resolution. The invariant ℓD_s mass is a good variable, to split the data set in samples of different k factor distributions and thus to enhance the significance of the analysis. (Fig. 1).

3.2 Decay Length Resolution

One of the critical input to the analysis is the proper decay time resolution. It is the limiting factor of the sensitivity at large Δm_s values. σ_{ct} has been measured directly on data. CDF exploits prompt D decays plus tracks from the primary vertex to mimic all B decay topologies studied in this analysis. On an event-by-event basis, the decay time resolution is predicted, taking into account dependences on several variables, such as isolation, vertex χ^2 etc. The mean σ_{ct} for hadronic events is 26 μm and for semileptonic events about 45 μm .

3.3 Flavor Tagging

Two type of flavor tags can be applied: opposite-side and same-side tags. Opposite-side tags infer the production flavor of the B_s from the decay products of the B

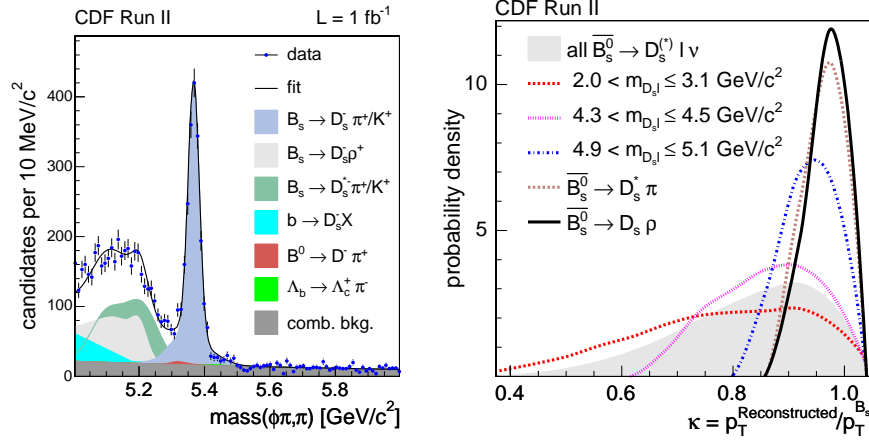


Figure 1: Left: Invariant mass of $B_s \rightarrow D_s(\phi\pi)\pi$ candidates. Right: k factor distribution for several ℓD_s mass values for semileptonic and partially reconstructed hadronic decays.

hadron produced from the other b quark in the event. A tagging performance of $\epsilon\mathcal{D}^2 = 1.8\%$ has been calibrated on kinematically similar B^+ and B_d decays. This value has to be compared to $\epsilon\mathcal{D}^2$ of about 30% at the B factories.

Same-side flavor tags are based on the charge of kaons produced in the fragmentation of the signal B_s meson. Contrary to the opposite-side tagging algorithms, its performance can not be calibrated on data. One has to rely on Monte Carlo samples till a significant B_s mixing signal has been established. Exploiting the particle identification system of the CDF detector, the same-side tagging algorithm yields a performance of $\epsilon\mathcal{D}^2 = 3.7/4.8\%$ for hadronic and semileptonic modes respectively. Thus the same-side tags enlarge the tagging power by a factor of 3-4!

3.4 Fit and Results

An unbinned maximum likelihood fit is utilized to search for $B_s - \overline{B}_s$ oscillations. The likelihood combines mass, proper decay time, proper decay time resolution and flavor tagging information for each candidate. Separate probability density functions are used to describe signal and each type of background. The amplitude scan method [7] was used to search for oscillations. This procedure corresponds to a Fourier transformation of the proper time space into the frequency space. In the case of infinite statistics and perfect resolution, it is expected to find an amplitude $\mathcal{A} = 1$ for the true value of Δm and $\mathcal{A} = 0$ otherwise.

The amplitude scan of the CDF data is consistent with unity around $\Delta m_s = 17.75 \text{ ps}^{-1}$ (Fig. 2). For all other Δm_s values, it is consistent with zero. Toy experiments evaluated the probability of tagged data to produce a maximum likelihood value higher than the one in data at any value of Δm_s . It was found to be smaller than $8 \times$

10^{-8} , which corresponds to a 5.4σ signal. The fit for Δm_s results in

$$\Delta m_s = 17.77 \pm 0.10 \text{ (stat.)} \pm 0.07 \text{ (syst)} \text{ ps}^{-1}. \quad (6)$$

The dominant contributions to the systematic uncertainties come from uncertainties on the absolute scale of the decay time measurement.

The $B_s - \bar{B}_s$ oscillations are displayed in Fig. 2. Candidates in the hadronic sample are collected in five bins of proper decay time modulo $2\pi/\Delta m_s$. The curve corresponds to a cosine wave with amplitude equal to 1.28, which is the fitted value in the hadronic sample.

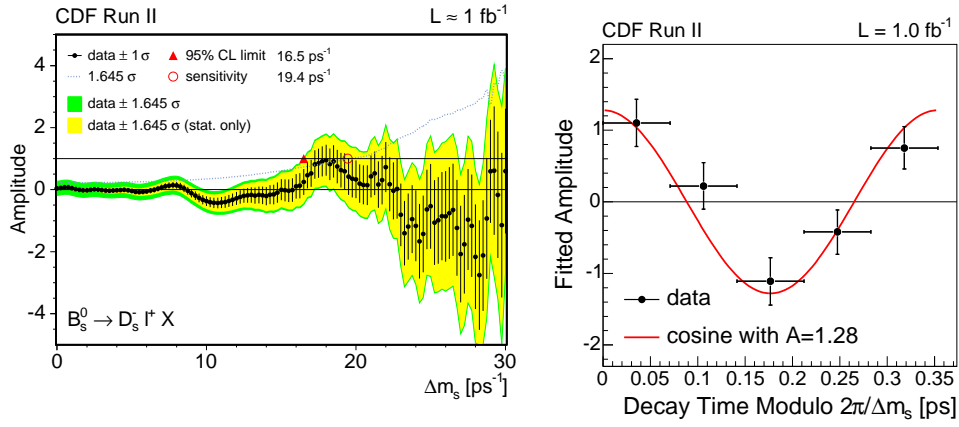


Figure 2: Left: Combined amplitude scan of hadronic and semileptonic modes. Right: The $B_s - \bar{B}_s$ oscillation signal (only hadronic modes) measured in five bins of proper decay time modulo the measured oscillation period $2\pi/\Delta m_s$. This plot does not contain the full statistic of this analysis.

4 B_s Lifetime Difference & Mixing Phase

Beside the mass difference Δm_s , there are two more parameters which determine the B_s system. Those are the decay width difference of the heavy and light B_s mass eigenstates $\Delta\Gamma_s = \Gamma_L - \Gamma_H$ and the mixing phase ϕ_s . While the first one is expected to be sizeable with in the SM ($\Delta\Gamma_s/\Gamma_s \approx 15\%$) the phase ϕ_s^{SM} is predicted to be small [8]. Thus to a good approximation the two mass eigenstates are CP eigenstates. New phenomena may introduce a non-vanishing mixing phase ϕ_s^{NP} , leading to a reduction of the observed $\Delta\Gamma_s$ compared to the SM prediction: $\Delta\Gamma_s = \Delta\Gamma_s^{SM} \times |\cos(\phi_s^{SM} + \phi_s^{NP})|$.

Several analysis have been performed at the Tevatron, to access $\Delta\Gamma_s$ and/or ϕ_s :

$B_s \rightarrow K^+ K^-$ is a pure CP even state. Assuming a small CP violating phase, the measurement of the lifetime in this final state directly corresponds to the measurement of the lifetime of the $B_s(\text{light})$, which can then be compared to measurements of lifetimes in flavor specific eigenstates [3].

The untagged decay rate asymmetry in semileptonic B_s decays (A_{SL}^s) is another handle on the mixing parameters of the B_s system [9]:

$$A_{SL}^s = \frac{\Delta\Gamma_s}{\Delta m_s} \tan(\phi_s) \quad (7)$$

A third approach is the measurement of the branching ration of $B_s \rightarrow D_s^{(*)} D_s^{(*)}$. This decay is predominantly CP even [10] and gives the largest contribution in the lifetime difference between the $B_s(\text{heavy})$ and $B_s(\text{light})$. The following relation can be obtained [8]:

$$2 * BR(B_s \rightarrow D_s^{(*)} D_s^{(*)}) \approx \frac{\Delta\Gamma_s}{\cos(\phi_s)\Gamma_s} [1 + O(\frac{\Delta\Gamma}{\Gamma_s})]. \quad (8)$$

The decay $B_s \rightarrow J/\Psi \phi$, through the quark process $b \rightarrow c\bar{c}s$, gives rise to both CP even and CP odd final states. It is possible to separate the two CP components of this decay, and thus to measure the lifetime difference, through a simultaneous study of the time evolution and the angular distributions of the decay products of the J/Ψ and the ϕ meson. Moreover, with a sizeable lifetime difference, there is a sensitivity to the mixing phase through the interference terms between the CP even and CP odd waves. This later analysis is rather complex, however it is a very promising approach. The relatively high branching ratio of the decay $B_s \rightarrow J/\Psi \phi$ will allow a significant simultaneous measurement of $\Delta\Gamma_s$ and ϕ_s .

Both the CDF and D0 collaboration presented preliminary results of this analysis.

Figure 3 shows the projection of the fit result onto the proper decay time distribution and onto $\cos\theta$, one of the transversity angles¹ for the D0 analysis.

Both experiments demonstrated the capability to perform this analysis, however

¹For a detailed definition of the transversity angles see [11]

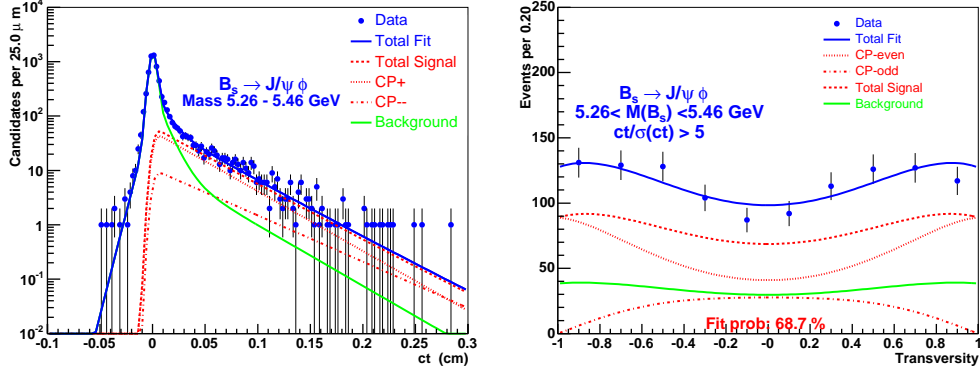


Figure 3: Lifetime and transversity angle distribution for CP even and CP odd $B_s \rightarrow J/\Psi \Phi$ decays of the D0 analysis.

sensitivity is still statistical limited by. While D0 performed a simultaneous fit of $\Delta\Gamma_s$ and ϕ_s , CDF quote only $\Delta\Gamma_s$ results with ϕ_s fixed to SM expectations:

$$\Delta\Gamma_s = 0.17 \pm 0.09 \text{ (stat.)} \pm 0.02 \text{ (syst.) ps}^{-1} \text{ (D0)} \quad (9)$$

$$\phi_s = -0.79 \pm 0.56 \text{ (stat.)}^{+0.14}_{-0.01} \text{ (syst.) (D0)} \quad (10)$$

$$\Delta\Gamma_s = 0.076^{+0.059}_{-0.063} \text{ (stat.)} \pm 0.006 \text{ (syst.) ps}^{-1} \text{ (CDF)} \quad (11)$$

The analysis are based on 1.7 and 1.0 fb^{-1} of data respectively. Figure 4 shows the allowed ranges in $\Delta\Gamma_s/\phi_s$ space. Improvement in this analysis will come from additional data and the use of flavour tagging. Performing the analysis separately for B_s and \bar{B}_s candidates with the given flavour tagging performance will reduce the statistical uncertainties of the analysis by an additional factor of 1.5. If $\Delta\Gamma_s/\Gamma_s$ is around the expected value of 15%, the Tevatron experiments have a good chance to establish a significant non-zero $\Delta\Gamma_s$ before the LHCb will take over. However the first significant measurement of ϕ_s is most likely to be performed at LHCb.

5 Summary

The Tevatron has a rich and exciting B physics program. The key to select interesting events out of the huge background in an hadronic environment is the trigger system.

CDF and D0 have proven the capability to perform high precision measurements at a hadron collider. Among those are the observation of the B_s mixing frequency:

$$\Delta m_s = 17.77 \pm 0.10 \text{ (stat.)} \pm 0.07 \text{ (syst) ps}^{-1} \quad (12)$$

and the discovery of several B hadrons, such as Σ_b , Ξ_b and B_s^{**} .

Only a fifth of the data expected from the Tevatron has been analyzed sofar. Thus

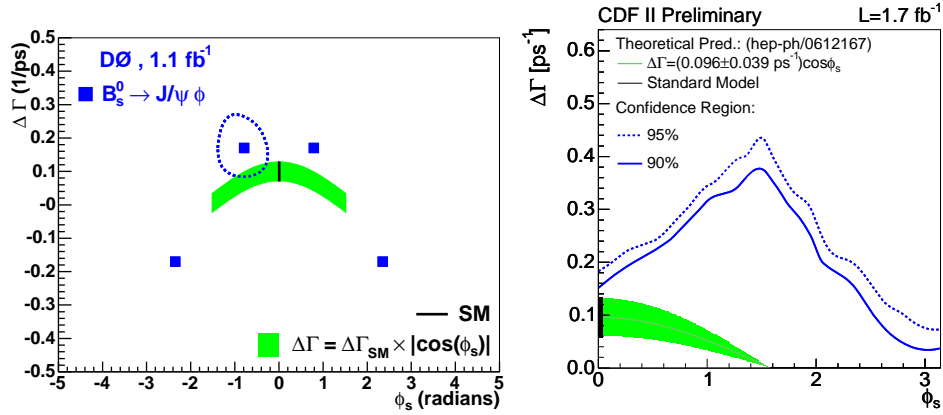


Figure 4: Allowed region for $\Delta\Gamma_s/\phi_s$ for the D0 (left) and CDF (right) analysis. In the left plot the contour corresponds to a 68% confidence region. The right plot shows only one solution of the four-folded ambiguity.

significant improvement in many statistical limited analysis, such as the measurement of $\Delta\Gamma_s$ are expected to come. For others such as the measurement of ϕ_s the Tevatron has proven their feasibility, however will pass over the field to the next generation of B physics experiments.

References

- [1] A. Abachi *et al.*, FERMILAB-PUB-96-357-E.
- [2] R. Blair *et al.*, FERMILAB-PUB-96-390-E.
- [3] S. Eidelmann *et al.*, Phys. Lett **B592**, 1.
- [4] Direct Limits on the B_s Oscillation Frequency, V. M. Abazov *et al.*, The D0 Collaboration, Phys. Rev. Lett **97** (2006) 021802
- [5] First precision measurement of Δm_s , A. Abulencia *et al.*, The CDF Collaboration, Phys. Rev. Lett. **97**, (2006) 062003
- [6] Observation of $B_s - \bar{B}_s$ Oscillations, A. Abulencia *et al.*, The CDF Collaboration, Phys. Rev. Lett **97** 242003 (2006)
- [7] H. G. Moser and A. Roussarie, Nucl. Instrum. Methods Phys. Res., Sect. A **384**, 491 (1997)
- [8] I. Dunietz, R. Fleischer and U. Nierste, hep-ph/0012219
- [9] M. Beneke, G. Buchalla, a. Lenz and U. Nierste, Phys. Lett. B **576** (2003) 173, hep-ph/0307344
- [10] R. Alexan *et al.*, Phys. Rev. Lett. **95** 171801 (2005)
- [11] T. Affolder *et al.*, Phys. Rev. Lett. **85**, 4668; V. M. Abazov *et al.*, Phys. Rev. Lett **95**, 171801

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New Physics & Future B Physics Programs



CP violation

Rare Decays

Experimental Facilities

- ❑ **LHCb** – forward spectrometer (running in pp – collider mode)
Data taking starts next year
Expect $\sim 10 \text{ fb}^{-1}$ by 2013
B physics is also a part of the ATLAS and CMS early program
- ❑ **Super Flavor Factory (SFF)** following either SuperKEKB or Super B proposal with an integrated luminosity of $50 - 75 \text{ ab}^{-1}$
Start data taking > 2014
(T.Browder et al. arXiv:0710.3799v1)
- ❑ **Upgraded LHCb (SLHCb)** where they would run at 10 times the initial design luminosity with twice more efficient trigger and record data sample of $> 100 \text{ fb}^{-1}$
Start data taking after 2014

2

LHCb

- ❑ Large bb cross section ($\sim 230 \mu\text{b}$)
- ❑ Forward geometry
- ❑ Low luminosity is sufficient
At $2 \times 10^{32} \text{ } 10^{12} \text{ } bb$ pairs are produced per year



3

Experimental Facilities

- ❑ **LHCb** – forward spectrometer (running in pp – collider mode)
Data taking starts next year
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Start data taking after 2014

4

UT as a standard approach to test the consistency of SM

Mean values of angles and sides of UT are consistent with SM predictions

Accuracy of sides is limited by theory:

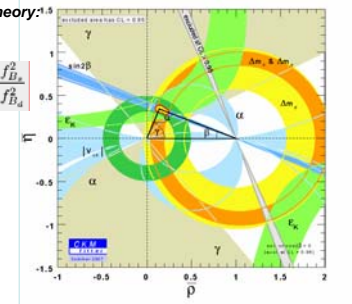
- Extraction of $|V_{ub}|$

- Lattice calculation of

$$\xi^2 = \frac{\tilde{B}_{B_s} f_{B_s}^2}{\tilde{B}_{B_d} f_{B_d}^2}$$

Accuracy of angles is limited by experiment:

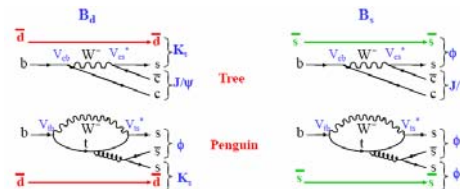
$$\begin{aligned} \alpha &= \pm 13^\circ \\ \beta &= \pm 1^\circ \\ \gamma &= \pm 25^\circ \end{aligned}$$



5

Search for NP comparing observables measured in tree and loop topologies

$\beta(\text{tree+box})$ in $B \rightarrow J/\psi K_s$
 $\chi(\text{tree})$ in many channels
 $\chi(\text{tree+box})$ in $B_s \rightarrow J/\psi \phi$



New heavy particles, which may contribute to d- and s- penguins, could lead to some phase shifts in all three angles:

$$\begin{aligned} \delta\gamma(\text{NP}) &= \gamma(\text{peng+tree}) - \gamma(\text{tree}) \\ \delta\beta(\text{NP}) &= \beta(B \rightarrow \psi K_s) - \beta(B \rightarrow J/\psi K_s) \neq 0 \\ \delta\chi(\text{NP}) &= \chi(B_s \rightarrow \psi \phi) - \chi(B_s \rightarrow J/\psi \phi) \end{aligned}$$

6

Search for NP comparing observables measured in tree and loop topologies

Contribution of NP to processes mediated by loops (present status)

❑ to boxes:

β vs $|V_{ub}| / |V_{cb}|$ is limited by theory ($\sim 10\%$ precision in $|V_{ub}|$) (d-box)
 χ not measured with any accuracy (s-box)

❑ to penguins:

$$\begin{aligned} \sigma(\delta\gamma(\text{NP})) &\sim 30^\circ & (\text{d-penguin}) \\ \sigma(\delta\beta(\text{NP})) &\sim 8^\circ & (\text{s-penguin}) \\ \sigma(\delta\chi(\text{NP})) &\text{not measured} & (\text{s-penguin}) \end{aligned}$$

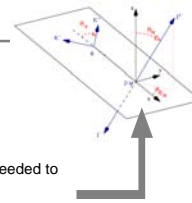
PS $\delta\beta(\text{NP}) = \delta\chi(\text{NP})$
 $\delta\chi(\text{NP})$ measured in $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$ decays may differ depending on penguin contribution to $\pi\pi$ and $\rho\rho$ final states

7

χ : LHC prospects

$B_s \rightarrow J/\psi \phi$ is the B_s counterpart of $B^0 \rightarrow J/\psi K_S$

- In SM $\phi_S = -2\arg(V_{ts}) = -2\lambda^2\eta \sim -0.04$
- Sensitive to New Physics effects in the B_s - B_s system mixing $\rightarrow \phi_S = \phi_S(\text{SM}) + \phi_S(\text{NP})$
- 2 CP-even, 1 CP-odd amplitudes, angular analysis needed to separate, then fit to ϕ_S , $\Delta\Gamma_S$, CP-odd fraction
- LHCb yield in 2 fb^{-1} 131k, B/S = 0.12



Channels	$\sigma(\phi_S)$ [rad]	Weight $(\sigma/\sigma_1)^2$ [%]
$B_s \rightarrow J/\psi \eta(\pi^+ \pi^- \pi^0)$	0.142	2.3
$B_s \rightarrow D_s D_s$	0.133	2.6
$B_s \rightarrow J/\psi \eta(\gamma \gamma)$	0.109	3.9
$B_s \rightarrow \eta \phi$	0.108	3.9
Combined (pure CP eigenstates)	0.060	12.7
$B_s \rightarrow J/\psi \phi$	0.021	87.3
Combined (all CP eigenstates)	0.021	100.0

LHCb

ATLAS will reach $s(\phi_S) \sim 0.08$ (10/fb, $\Delta m_s = 20/\text{ps}$, 90k $J/\psi \phi$ evts)

UT angle γ : LHCb (BaBar & BELLE & Tevatron $\sim 12^\circ$ precision for γ at best)

Interference between tree-level decays

Favored: $V_{cb} V_{us}^*$

Common final state

$K^{(*)-}$ $D^{(*)0}$

$V_{cs}^* V_{ub}$: suppressed

Parameters: γ , (r_B, δ_B) per mode

$\frac{A(B^- \rightarrow D^0 K^-)}{A(B^- \rightarrow D^0 K^-)} = r_B e^{i\delta_B} e^{-i\gamma}$

Three methods for exploiting interference (choice of D^0 decay modes):

- (GLW): Use CP eigenstates of $D^{(*)0}$ decay, e.g. $D^0 \rightarrow K^+ K^- / \pi^+ \pi^-$, $K_S \pi^0$
- (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \rightarrow K^+ \pi^-$
- (Dalitz): Use Dalitz plot analysis of 3-body D^0 decays, e.g. $K_S \pi^+ \pi^-$

Mixing induced CPV measurement in $B_s \rightarrow D_s K$ decays

Specific for LHCb

UT angle γ : LHCb summary table

B mode	D mode	Method	$\sigma(\gamma)$ with 2 fb^{-1}
$B^+ \rightarrow DK^+$	$K\pi$ + $KK/\pi\pi$ + $K3\pi$	ADS+GLW	$5^\circ - 13^\circ$
$B^+ \rightarrow D^* K^+$	$K\pi$ ($D^* \rightarrow D^+ \pi$, γ)	ADS+GLW	Under study
$B^+ \rightarrow DK^+$	$K_S \pi\pi$	Dalitz	$\sim 8 - 12^\circ$
$B^+ \rightarrow DK^+$	$KK\pi\pi$	4-body "Dalitz"	18°
$B^+ \rightarrow DK^+$	$K\pi\pi\pi$	4-body "Dalitz"	Under study
$B^0 \rightarrow DK^{*0}$	$K\pi$ + KK + $\pi\pi$	ADS+GLW	$\sim 6 - 12^\circ$
$B^0 \rightarrow DK^{*0}$	$K_S \pi\pi$	Dalitz	Under study
$B_s \rightarrow D_s K$	$KK(\phi)\pi$	tagged, $A(\dagger)$	$\sim 10^\circ$
$B^0 \rightarrow \pi^+ \pi^-$, $B_s \rightarrow K^+ K^-$	N/A	U-spin symmetry	$5^\circ - 10^\circ$

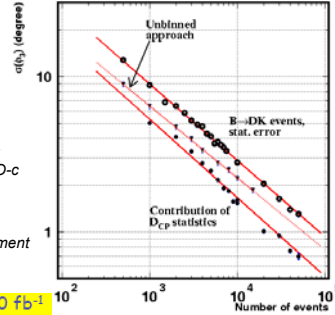
Combined precision after 2 fb^{-1} $\sigma(\gamma) \sim 5^\circ$ (from tree only)

angle $\gamma(\phi_3)$ at SFF

Model-independent approach

A. Bondar, A. Poluektov Eur.Phys.J C47,347(2006) hep-ph/0510246

- 50 ab^{-1} at SFF factory should be enough for model-independent γ/ϕ_3 measurement with accuracy below 2°
- 1 fb^{-1} at $\psi(3770)$ corresponds 2100 CP-tagged $K_S \pi^+ \pi^-$ events (first estimation based on CLEO-c data by David Asner)
- $\sim 10\text{ fb}^{-1}$ at $\psi(3770)$ needed to accompany SuperB measurement



BESIII: 20 fb^{-1} $\Rightarrow 1^\circ$ systematic

LHCb (10fb^{-1}) and SFF ($50\text{-}75\text{ ab}^{-1}$) & SLHCb ($>100\text{ fb}^{-1}$) sensitivities

Channel	Yield	Precision
γ From tree channels		$\sigma(\gamma) < 3^\circ$
α $B_s \rightarrow \pi^+ \pi^- \pi^0$	70k	$\sigma(\alpha) < 4^\circ$
β $B_s \rightarrow \rho^+ \rho^-$, $\rho^+ \rho^- \rho^0$	45k, 10k, 5k	
ϕ $B_s \rightarrow J/\psi(\mu\mu) K_S$	1200k	$\sigma(\sin 2\beta) < 0.01$
ϕ_S $B_s \rightarrow \phi K_S$	4k	$\sigma(\sin 2\beta) \sim 0.1$
ϕ_S $B_s \rightarrow J/\psi(\mu\mu) \phi$	750k	$\sigma(\phi_S) \sim 0.01$
ϕ_S $B_s \rightarrow \phi \phi$	20k	$\sigma(\phi_S) \sim 0.05$

SFF & SLHCb

Observable	Super Flavour Factory sensitivity	SLHCb (stat. only)
$\sin(2\beta)$ ($J/\psi K^0$)	0.005-0.012	~ 0.003
γ ($B \rightarrow D^{(*)} K^{(*)}$)	$1-2^\circ$	$< 1^\circ$ ($B_s \rightarrow D_s K$)
α ($B \rightarrow \pi^+ \rho^0 \rho^0$)	$1-2^\circ$	-
$ V_{ub} $ (exclusive)	3-5%	-
$ V_{ub} $ (inclusive)	2-6%	-
$\bar{\eta}$	1.7-3.4%	-
$\bar{\eta}$	0.7-1.7%	-
$S(\phi K^0)$	0.02-0.03	$S(\phi K^0)$ 0.02-0.03
$S(\eta K^0)$	0.01-0.02	$S(\phi \phi)$ 0.01
$S(K_S^0 K_S^0 K_S^0)$	0.02-0.04	-

> 2014

Search for New Physics in Rare Decays

LHCb


- Exclusive $b \rightarrow s \gamma$
- $B \rightarrow K^* \mu \mu$
- $B_s \rightarrow \mu \mu$

SFF

- $B \rightarrow \tau \nu$, $h \nu \nu$, ...
- $B \rightarrow s \gamma$, sll inclusive

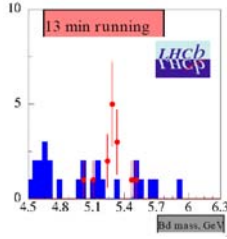
We are just approaching sensitivity promising for discovery...

Experimental challenge: keep backgrounds under control

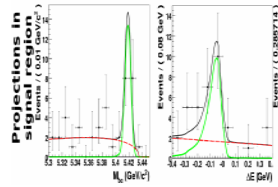


$b \rightarrow s\gamma$ exclusive

LHCb control channel: $B_d \rightarrow K^* \gamma$
~75k signal events per 2fb^{-1}



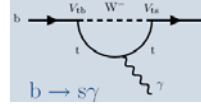
$B_s \rightarrow \phi \gamma$
BELLE observed 16 ± 8 events
2 weeks run at $\Upsilon(5S)$; no TDCPV
First observation of a B_s radiative penguin decay!



LHCb annual yield ~11k
with $B/S < 0.6$

14

$b \rightarrow s\gamma$ exclusive



$$b \rightarrow \gamma(L) + (m_s/m_b) \times \gamma(R)$$

Measurement of the photon helicity is very sensitive test of SM

Methods:

- Mixing induced CP asymmetries in $B_s \rightarrow \phi \gamma$, $B \rightarrow K_s \pi^0 \gamma$
- Photon helicity can be measured directly in radiative B decays to final state with ≥ 3 hadrons.

Promising channels for LHCb are $B \rightarrow \phi K \gamma$ and $B \rightarrow K \pi \pi \gamma$ decays

Expected yield per 2fb^{-1}
 $BR(B^+ \rightarrow K^+ \pi^+ \pi^+ \gamma) \sim 2.5 \times 10^{-5}$ rich pattern of resonances ~60k
 $BR(B^+ \rightarrow K^+ \phi \gamma) \sim 3 \times 10^{-6}$ highly distinctive final state ~7k

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$b \rightarrow s\gamma$ exclusive

Mixing induced CP asymmetries

$B \rightarrow K_s \pi^0 \gamma$ (B-factories)

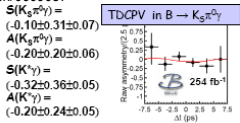
$$A_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0(t) \rightarrow K_s^0 \pi^0 \gamma) - \Gamma(B^0(t) \rightarrow K_s^0 \pi^0 \gamma)}{\Gamma(\bar{B}^0(t) \rightarrow K_s^0 \pi^0 \gamma) + \Gamma(B^0(t) \rightarrow K_s^0 \pi^0 \gamma)} = S \sin \Delta m \Delta t + A \cos \Delta m \Delta t$$

$S = -(2 + O(\alpha_s)) \sin(2\beta) m_s/m_b + (\text{possible contribution from } b \rightarrow s_1 g) = -0.022 \pm 0.015$
P.Ball and R.Zwicky hep-ph/0609037

Present accuracy:

$$S = -0.21 \pm 0.40 \text{ (BaBar : 232M BB)}$$

$$S = -0.10 \pm 0.31 \text{ (BELLE : 535M BB)}$$



Phys.Rev. D74, 111104 (2006)

$B_s \rightarrow \phi \gamma$ (LHCb)

$$A_{CP}(\Delta t) = \frac{S \sin \Delta m_s \Delta t + A \cos \Delta m_s \Delta t}{\cosh \frac{\Delta \Gamma \Delta t}{2} - A \Delta \sinh \frac{\Delta \Gamma \Delta t}{2}}$$

$$S = \sin 2\psi \sin \phi_s \approx 0$$

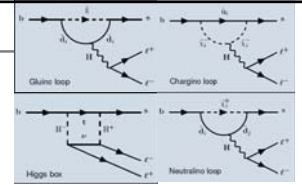
$$A^\Delta = \sin 2\psi \cos \phi_s \approx \frac{2m_s}{m_b}$$

LHCb sensitivity with 10fb^{-1} :
 $\alpha(A^\Delta) = 0.09$

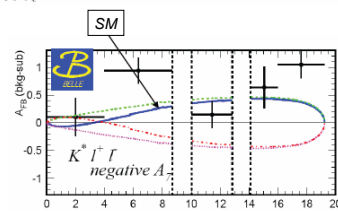
16

$B \rightarrow K^* \mu \mu$

In SM this $b \rightarrow s$ penguin decay contains right-handed calculable contribution but this could be added to by NP resulting in modified angular distributions



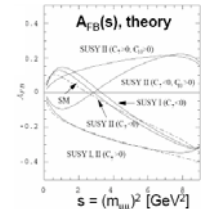
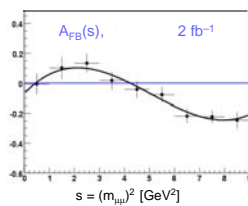
$$\frac{1}{\Gamma} \frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4} F_0 \sin^2 \theta_\ell + \frac{3}{8} F_T (1 + \cos^2 \theta_\ell) + A_{FB} \cos \theta_\ell$$



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$B \rightarrow K^* \mu \mu$: LHCb prospects

- Forward-backward asymmetry A_{FB} in $\mu\mu$ -rest frame is a sensitive NP probe
- Predicted zero of $A_{FB}(s)$ depends on Wilson coefficients $C_7^{\text{eff}}/C_9^{\text{eff}}$



- 7.2 k events / 2fb^{-1} with $B/S \sim 0.4$
- After 10fb^{-1} zero of A_{FB} located to $\pm 0.28\text{ GeV}^2$ providing 7% stat. error on $C_7^{\text{eff}}/C_9^{\text{eff}}$
- Full angular analysis gives better discrimination between models. Looks promising

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$B_s \rightarrow \mu \mu$

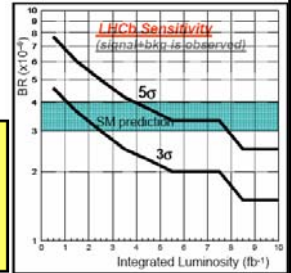
Very small BR in SM
 $(3.4 \pm 0.5) \times 10^{-9}$

This decay could be strongly enhanced in some SUSY models. Example: CMSSM

Current limit from CDF
 $BR(B_s \rightarrow \mu \mu) < 5.8 \times 10^{-8}$

LHCb

- $0.05\text{fb}^{-1} \Rightarrow$ overtake CDF+D0
- $0.5\text{fb}^{-1} \Rightarrow$ exclude BR values down to SM
- $2\text{fb}^{-1} \Rightarrow$ 3σ evidence of SM signal
- $10\text{fb}^{-1} \Rightarrow$ $>5\sigma$ observation of SM signal



\rightarrow 90% CL exclusion down to SM BR requires: 0.5fb^{-1} for LHCb, $\sim 10\text{fb}^{-1}$ for ATLAS/CMS
 \rightarrow 3σ sensitivity if BR(SM) requires: 2fb^{-1} for LHCb and $> 30\text{fb}^{-1}$ for ATLAS/CMS

SFF sensitivities for Rare Decays	
Channels complementary to LHCb / SLHCb	
$\mathcal{B}(B \rightarrow \tau \nu)$	3–4%
$\mathcal{B}(B \rightarrow \mu \nu)$	5–6%
$\mathcal{B}(B \rightarrow D \tau \nu)$	2–2.5%
$\mathcal{B}(B \rightarrow \rho \gamma) / \mathcal{B}(B \rightarrow K^* \gamma)$	3–4%
$A_{CP}(b \rightarrow s \gamma)$	0.004–0.005
$A_{CP}(b \rightarrow (s + d) \gamma)$	0.01
$S(K_s^0 \pi^0 \gamma)$	0.02–0.03
$S(\rho^0 \gamma)$	0.08–0.12
$A^{\text{FB}}(B \rightarrow X_s \ell^+ \ell^-) s_0$	4–6%
$\mathcal{B}(B \rightarrow K \nu \bar{\nu})$	16–20%

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OUTLOOK

Clean experimental signature of NP is unlikely at currently operating experiments

From now to 2014

A lot of opportunities (LHCb will start data taking next year)

Important measurements to search for NP and test SM in CP violation

- χ : if non-zero \rightarrow NP in boxes < 2010
- β vs R_b and γ vs R_t (Input from theory !)
- $\delta\beta(\text{NP})$ and $\delta\chi(\text{NP})$: if non-zero \rightarrow NP in penguins

in Rare decays

- $BR(B_s \rightarrow \mu \mu)$ down to SM prediction < 2010
- Photon helicity in exclusive $b \rightarrow s \gamma$ decays
- FBA & transversity amplitudes in exclusive $b \rightarrow s l l$ decays < 2010

After 2014

ATLAS and CMS might or might not discovered New Particles. At the same time LHCb might or might not see NP phenomena beyond SM.

In either case it is important to go on with B physics at SFF & Upgraded LHCb

high p_T \longleftrightarrow B's

Need much improved precision because any measurement in b-system constrains NP models

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"Ceterum Censeo Fabricam Super Saporis Esse Faciendam" (**"Moreover I Advise a Super-Flavour Factory has to be Built"**) ¹

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Abstract

The discovery of $B_d - \bar{B}_d$ oscillations twenty years ago by the ARGUS collaboration marked a watershed event. It persuaded a significant part of the HEP community that the large time dependent **CP** asymmetries predicted for some B_d decays might be within the reach of specially designed experiments. This opened the successful era of the B factories, which has a great future still ahead. After sketching the status of heavy flavour physics I describe why we need to continue a comprehensive heavy flavour program not only for its intrinsic reasons – it is even mandated as an integral part of the LHC program. Notwithstanding the great success anticipated for the LHCb experiment I explain why a Super-Flavour Factory is an essential complement to the LHC program.

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¹Lecture given at ARGUS-Fest, Nov. 9, 2007, DESY, Hamburg, Germany

Prologue

Earlier this afternoon we heard from Prof. Schopper how on his first visit here his request to be taken to DESY was misconstrued by the taxi driver. My experience this time was fundamentally different: when I told my taxi driver in Altona that I have to go to DESY, he immediately understood the nature of my destination. He perked up and said: "Oh, I am just reading a book on quantum chemistry – can we talk about it?" I take my experience as re-assuring evidence for a growing appreciation of scientific culture. Yet the reality-based among you – i.e. the experimentalists – will probably think: "Typical theorist!" For looking at me you will realize that I am much older now than Prof. Schopper was *then*: therefore I – unlike him – was above suspicion.

Allow me another brief look back. When I was invited before 1987 to give a talk and I suggested my topic – you can easily guess, what it was [2] – I heard the following reaction: "Yes, yes, we know, Ikaros ..., but could you not talk about something relevant?" After ARGUS' discovery of $B_d - \bar{B}_d$ oscillations twenty years ago [1], I never heard that again. Tony Sanda and I benefitted more from this discovery than most high energy physicists, and I can state an emphatic: "Thank you, thank you, ARGUS!"

At the time of ARGUS' discovery B_d oscillations had been expected to proceed rather slowly. The main reason for that prediction was that the UA1 experiment had reported strong evidence for having discovered top quarks with a mass of 40 ± 10 GeV. Almost all theorists accepted those findings. Peter Zerwas, however, did not, and he explained the reasons for his skepticism to me at the time. I should have listened to Peter – it is the only time I did not, and I have been kicking myself for it ever since!

Our knowledge of B meson dynamics has been expanded greatly over the last twenty years in a process accelerated by the success of the B factories. This development has been helped by theorists in a way nicely expressed by the cartoon of Fig.1, which I found last spring reading the In-flight journal of United Airlines: The chap in the middle, obviously an experimentalist, graciously – if with a slightly patronizing flavour – gives some credit to the theorist on his left by declaring: "To be honest, I never would have invented the wheel if not for Urg's groundbreaking theoretical work with the circle."

I have given the first title of my talk in Latin based on a fundamental Catholic tenet recently re-confirmed by the new church leadership: *If it can be expressed in Latin, it must be true*. Since Hamburg is not exactly a hotbed of Catholicism, I will use a less august language, while fully aware that the elegance and cogency of the argument will suffer from this drawback.

The talk will be organized as follows: In Act I I will sketch the role and status of studies of flavour dynamics; in Act II I will gaze into my crystal ball concerning the future of flavour physics as carried out for certain by LHCb and hopefully Super-Flavour Factories; in Act III I will present my conclusions before finishing with an Epilogue.

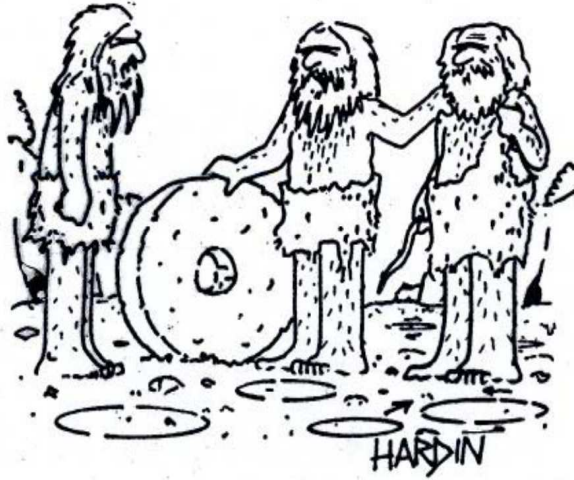


Figure 1: ” To be honest, I never would have invented the wheel if not for Urg’s groundbreaking theoretical work with the circle.”

1 Act I – On the Role and Status of Flavour Physics

Allow me to go ”medias in res” rather than beat around the bushes. While the detailed study of strangeness changing processes was instrumental for the creation of the Standard Model (SM), that of charm changing ones was central for its acceptance, and that of beauty changing ones has almost completed the SM’s validation (with only the Higgs boson not having been discovered yet).

As explained in previous talks [3, 4], the unitarity of the 3×3 CKM matrix V_{CKM} implies among others the following relation among its (complex) elements:

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0 , \quad (1)$$

which can be represented as a triangle in the complex plane. It is usually referred to as ‘the’ CKM unitarity triangle. While the sides of the triangle reflect transition rates for K and B mesons (including pure quantum effects like oscillations), the angles determine **CP** asymmetries. Accordingly the area of the triangle is a measure for those asymmetries. Since re-scaling the triangle leaves the angles unchanged, one conveniently normalizes the base line to unit length. Our knowledge of flavour dynamics is sketched in a highly condensed form in Fig.2 by showing constraints from data – most importantly from ΔM_{B_d} , ΔM_{B_s} [5], $|V_{ub}/V_{cb}|$ [6] and the **CP** sensitive observables ϵ_K and ϕ_1 (a.k.a. β). The latter is the angle extracted from the time dependent **CP** asymmetry in $B_d \rightarrow \psi K_S$. These constraints are inferred from a very heterogeneous set of transitions occurring on vastly different time scales. Yet they do overlap in a smallish domain indicated by the two ellipses for the apex of the triangle – a highly non-trivial success for the SM!

Fig.2 containing all constraints is very busy and thus obscures some of the relevant findings. Let me illuminate this by a highly topical example, namely the profound impact resolving $B_s - \bar{B}_s$ oscillations has had. Look at the left plot in Fig.3. The triangle there is constructed from its three sides: the unit length baseline, and the other two sides as

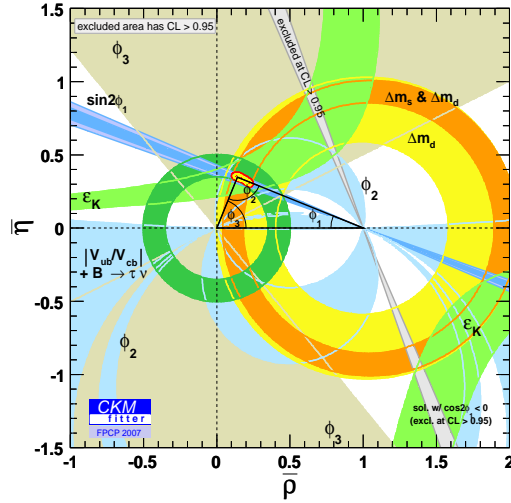


Figure 2: The CKM Unitarity Triangle fit (courtesy CKM fitter collab.).

inferred from $|V_{ub}/V_{cb}|$ [6] and $\Delta M_{B_d}/\Delta M_{B_s}$ [5], respectively, with the widths of the bands denoting the uncertainties (mainly of a theoretical nature). The two bands overlap in a small domain, where the apex has to lie. The resulting triangle clearly has a non-zero area: from two **CP** insensitive observables – i.e., two quantities that can be non-zero, even when **CP** invariance holds – we can thus infer that the SM has to contain **CP** violation. Yet the situation is even more intriguing, as the right plot in Fig.3 shows: the amount of **CP** violation inferred from $|V_{ub}/V_{cb}|$ and $\Delta M_{B_d}/\Delta M_{B_s}$ is completely consistent with the observed **CP** asymmetries as expressed through ϵ_K and ϕ_1 (a.k.a. β)! This marks another triumph for KM theory: From the observed values of two **CP** insensitive observables one infers the size of **CP** asymmetries in even quantitative agreement with the data.

So why not declare victory and close (the heavy flavour) shop? There are two sets of reasons against it:

1. We have experimental evidence of mostly heavenly origin that the SM is incomplete: neutrino oscillations, dark matter and dark energy.
2. The novel successes the SM has scored since the turn of the millenium – having the predictions of truly large **CP** asymmetries in B decays confirmed – do not illuminate any of its mysterious features; if anything, they deepen the mysteries:
 - (a) Theoretical arguments centered on the ‘gauge hierarchy problem’ strongly suggest that the electroweak symmetry breaking is driven by something beyond the SM’s $SU(2)_L \times U(1)$ gauge theory with that something entering around the TeV energy scale. Those arguments have been sufficiently persuasive as to motivate the construction of the LHC complex at CERN, and I will refer to

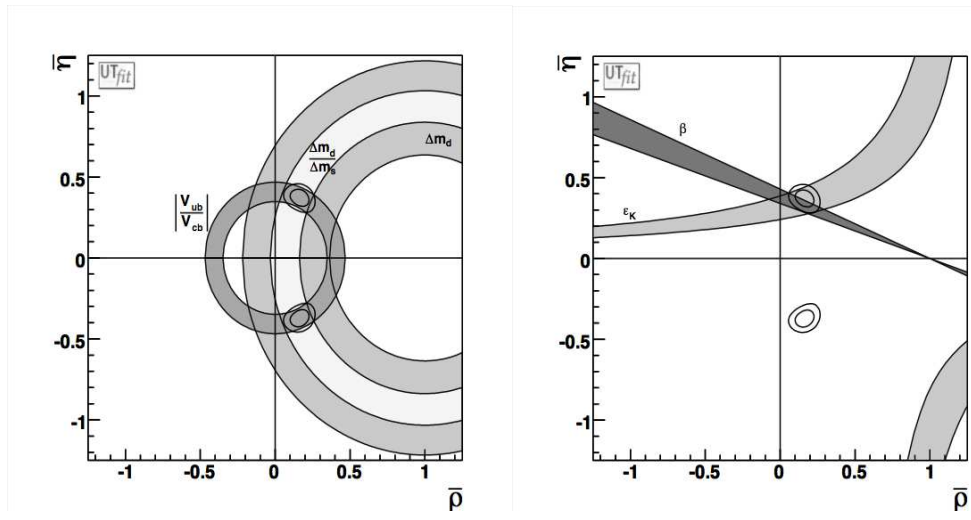


Figure 3: CKM unitarity triangle from $|V(ub)/V(cb)|$ and $\Delta M_{B_d}/\Delta M_{B_s}$ on the left and compared to constraints from ϵ_K and $\sin 2\phi_1$ on the right (courtesy V. Sordini).

it as the "confidently predicted New Physics" (*cpNP*). A popular candidate is provided by SUSY.

- (b) We have no structural explanation for charge quantization and the lepton-quark connection; i.e., why is the electric charge of the electron exactly three times that for d quarks? A natural resolution of this puzzle arises in Grand Unified Theories, which place quarks and leptons into the same multiplets. I will refer to it as the "guaranteed New Physics" (*gNP*) characterized by scales of the order of about 10^{14} GeV; an $SO(10)$ gauge theory provides an attractive scenario.
- (c) It seems likely that family replication and the hierarchical pattern in the CKM parameters is created by some fundamental dynamics operating at some high scale. I will call it "strongly suspected New Physics" (*ssNP*). We do not know what that scale is, and expressing the hope that M theory will resolve this puzzle is a polite way of saying that we have hardly a clue about it.

Detailed and comprehensive heavy flavour studies might – just might – provide insights into the *gNP* and *ssNP* – i.e., items (b) and (c) above – although we cannot count on it. Yet they are likely to be essential for identifying the *cpNP*, item (a)!

Let me explain the last point in some detail:

- I am confident the LHC will reveal the presence of New Physics directly by the production of new quanta.
- Yet we should aim higher than 'merely' establishing the existence of such New Physics. The goal must be to identify its salient features. I am a big fan of SUSY, yet we should remember that SUSY per se is not a theory or even class of theories – it is an organizing principle.

- TeV scale dynamics is likely to have some impact on B , D and τ decays. We need to probe the discovery potential in those processes in order to identify the New Physics. *A dedicated heavy flavour program is not a luxury – it is integral to the core mission of the LHC program.*
- We should already have seen, say, the impact of a ‘generic SUSY’ [7] – i.e., a version of SUSY picked at random out of the multitude of SUSY implementations. On the other hand past experience shows that Nature has not exhibited much taste for generic dynamics. Furthermore the one aspect of SUSY that is beyond dispute, namely that it is broken, is also the least understood one.
- The often heard term of ‘minimal flavour violation’ is a classification scheme [8], not a theory – analogous to the case of the ‘superweak model’ of **CP** violation. We have to ask to which degree do dynamics implement such a scenario: does it represent a strict or – more likely – an approximate one?

To summarize: we need to continue a comprehensive program of experimental heavy flavour studies, not to shed light on the flavour mystery of the SM – although that might happen – but as a high sensitivity instrument for probing more fully the dynamics behind the electroweak phase transition. We have learnt (and some of us had actually predicted it several years ago [10]) that heavy flavour transitions typically will *not* be affected in a *numerically massive* fashion by the anticipated New Physics. Yet this should make us strive for higher sensitivity in our searches, not to abandon them.

2 Act II: On the Future – LHCb and Super-Flavour Factories

Looking at the next few years I am pleased to say that the state of heavy flavour studies is promising and strong. The contributions from the CDF and D0 experiments studying hadronic collisions have greatly exceeded expectations with respect to B physics. The latest example – and a spectacular one – was the measurement of $B_s - \bar{B}_s$ oscillations [5]. More than a decade ago LHCb with its focus on B physics was approved as an experiment to take data from day one of LHC’s operation. The European HEP community deserves credit for this visionary decision. I am confident that LHCb will make truly seminal contributions in particular in the exploration of B_s decays – most notably the time dependent **CP** asymmetries in $B_s \rightarrow \psi\phi, \phi\phi$. Since B_d and B_s transitions a priori represent different chapters in Nature’s book of dynamics, we better analyze both with high accuracy. There is no doubt in my mind that the HEP community will reap great benefits from the support it gives to LHCb.

2.1 The “Second Renaissance” of Charm Physics

The case for a continuing experimental program of heavy flavour physics has been strengthened considerably by the strong evidence presented by Belle and BaBar in the spring of

2007 [11, 12, 13]. Analogous to the B_d case $D^0 - \bar{D}^0$ oscillation rates can be expressed in terms of the calibrated mass and width differences between the two mass eigenstates: $x_D \equiv \Delta M_D/\bar{\Gamma}_D$, $y_D \equiv \Delta\Gamma_D/2\bar{\Gamma}_D$. Averaging over all relevant data – an intriguing enterprise, yet one that is not without risk at present – one obtains [6]

$$x_D = (0.87_{-0.34}^{+0.30}) \cdot 10^{-2} \quad , \quad y_D = (0.66_{-0.20}^{+0.21}) \cdot 10^{-2} \quad , \quad (2)$$

which represents 5 σ evidence for $(x_D, y_D) \neq (0, 0)$.

If we had observed $x_D > 1\% \gg y_D$, we would have a strong *prima facie* case for New Physics – but such a scenario has been basically ruled out now. For the data point to $x_D \sim y_D \sim 0.5 - 1\%$.

1. Effects of that size could be due ‘merely’ to SM dynamics [14, 15]. Even then it would be a seminal discovery and should be measured accurately; for it can help to validate the observation of time dependent **CP** asymmetries as discussed below.
2. At the same time $D^0 - \bar{D}^0$ oscillations can still receive sizable contributions from New Physics.

How can we resolve this conundrum?

- We might be just one theoretical breakthrough away from a more accurate SM prediction. Maybe.
- Rather than wait for that to happen, since it might take a while, the experimentalists might follow the Calvinist tradition of demonstrating heavenly favour by achieving earthly success. For they can search for **CP** violation in charm transitions. It is most appropriate to emphasize this option at this ARGUS-Fest. Will history repeat itself in the sense that the discovery of oscillations will prompt a program of **CP** studies? There are obvious challenges involved: We are dealing with a ‘centi-ARGUS’ scenario, since x_D is about a factor of hundred smaller than x_{B_d} . I think our experimental colleagues will learn to deal with that. Another difference is that KM theory does not predict sizable, let alone large effects in the charm system. I submit this is actually an advantage, since the ratio of signal to ‘theoretical noise’ (from SM contributions) might well be large. Furthermore we are not engaging in a ‘wild goose chase’ here, since baryogenesis requires New Physics with **CP** violation.

The decay channels being analyzed for oscillations [16] – $D^0 \rightarrow K^+K^-/\pi^+\pi^-/K_S\pi^+\pi^-$ – are also excellent targets for such searches. For oscillations can generate *time dependent* **CP** asymmetries there. No such effects have been seen so far – but the experimental sensitivity has only recently reached a domain, where one could hope for a signal [17, 18]. Consider

$$D^0 \rightarrow K^+K^- \quad (3)$$

In qualitative analogy to $B_d \rightarrow \psi K_S$ the oscillation induced **CP** asymmetry is given by

$$\frac{\text{rate}(D^0(t) \rightarrow K^+K^-) - \text{rate}(\bar{D}^0(t) \rightarrow K^+K^-)}{\text{rate}(D^0(t) \rightarrow K^+K^-) + \text{rate}(\bar{D}^0(t) \rightarrow K^+K^-)} \sim x_D [\text{or } y_D] \cdot \frac{t}{\tau_D} \cdot \sin\phi_{\text{weak}} ; \quad (4)$$

i.e., it is by and large bounded by the value of x_D [or y_D]. If those do not exceed the 1% level, nor can the asymmetry, and that is about the experimental sensitivity at present. Having seen a signal would hardly have been credible. Yet now it is getting interesting; for any improvement in experimental sensitivity might reveal an effect.

2.2 The Case for a Super-Flavour Factory

I count on LHCb to become a highly successful experiment in heavy flavour studies – benchmark transitions like $B_s \rightarrow \psi\phi$, $\phi\phi$ or $D^0 \rightarrow K^+K^-$, $K^+\pi^-$ are optimal for LHCb's consumption – yet it will *not* complete the program!

As indicated above we can typically expect at most moderate deviations from SM predictions. Precision is therefore required both on the experimental and the theoretical side. The latter requires ‘flanking measures’; i.e., in order to calibrate our theoretical tools for interpreting decay rates, we want to analyze final states with (multi)neutral hadrons like $B^0 \rightarrow \pi^+\pi^-\pi^0/3\pi^0$, $B^- \rightarrow \pi^-\pi^0\pi^0$. We need to study $B_d \rightarrow \phi K_S$, $\eta^{(\prime)} K_S$ with precision, since those lessons are complementary rather than repetitive to those inferred from $B_s \rightarrow \phi\phi$. *Inclusive* reactions can be described more reliably than *exclusive* ones – a valuable asset when searching for smallish effects. We want to measure also semileptonic B decays – $B \rightarrow \tau\nu D/\tau\nu X$ – as a probe for the exchange of charged Higgs bosons with a mass in the several hundred GeV range. Comprehensive **CP** studies in charm transitions are mandated now more than ever before due to the strong evidence for $D^0 - \bar{D}^0$ oscillations. Last, but most certainly not least we have to search for both lepton flavour and **CP** violation in τ decays.

A Super-Flavour Factory – a low-energy e^+e^- machine with a luminosity of $10^{36} \text{ cm}^{-2} \text{ s}^{-1}$ is needed to take on these challenges [20]. In this context let me express a warning: a Super-Flavour Factory requires a very different kind of justification than the original B factories at KEK and SLAC did. For those we had so-called ‘killer applications’ [2]; i.e., effects that *individually* would have an immediate and profound impact on the SM, if they were observed or ruled out. Those were the time dependent **CP** asymmetries in $B_d \rightarrow \psi K_S/\pi^+\pi^-$; for they were predicted – *with no plausible deniability* – to reach the several $\times 10$ % range; this was inferred from the only known **CP** violation in the early 1990's, namely $K_L \rightarrow \pi\pi$, which is characterized by $|\epsilon_K| \simeq 0.22\%$. Furthermore the domain of quantitative heavy flavour dynamics was still largely ‘virgin’ territory. The success of the B factories has greatly exceeded our expectations: they have promoted the KM paradigm from an ansatz to a *tested theory*. As far as **CP** violation in the decays of hadrons is concerned, we no longer look for alternatives to KM theory, only to corrections to it. However, the very success of the B factories has raised the bar for a Super-Flavour Factory. Rather than exploring uncharted territory, we want to revisit it, albeit with greatly enhanced sensitivity. It is like going back into a heavily mined gold mine.

To say it slightly differently. There are two types of research programs, namely ‘hypothesis driven’ and ‘hypothesis generating’ research. While the former tests an existing paradigm (and thus is favoured by funding agencies), the latter aims at developing a new paradigm. The program at the B factories belonged to the former variety – and repre-

sents a most successful one – yet a Super-Flavour Factory aims at the latter by searching mainly for the anticipated ‘New **CP** Paradigm’.

The top priority at a Super-Flavour Factory has to be assigned to studies of B physics, which still has a rich agenda as explained in the talks by Ligeti [3] and Golutvin [9]; for more details see Ref.[20]. I will not repeat their discussion here and instead sketch the agenda of two other areas accessible at a Super-Flavour Factory, namely charm and τ physics.

2.2.1 2nd Priority: CP Studies in Charm Transitions

I had mentioned before that the observed rate of $B_s - \bar{B}_s$ oscillations is consistent with the SM prediction within the latter’s significant uncertainty. The potential New Physics hiding behind the uncertainty can be revealed in the time dependent **CP** asymmetry in $B_s \rightarrow \psi\phi$, since the latter is small in the SM for reasons germane to it [2].

The same strategy can and should be pursued in charm transitions. While the observed oscillation rate is not clearly inconsistent with the SM, the uncertainties are quite large. Yet decisive tests can be provided by **CP** studies in $D^0 \rightarrow K^+K^-/\pi^+\pi^-/K^+\pi^-/K_S\pi^+\pi^-$ as mentioned before, since the ‘signal to theoretical noise’ ratio is very likely higher in **CP** asymmetries than in pure oscillation phenomena. For the former are shaped to a higher degree by short-distance dynamics, over which we have better theoretical control than over the non-perturbative long-distance dynamics. Furthermore KM theory allows for only small asymmetries to arise in a rather restricted set of channels [16].

I want to add two examples of a bit unorthodox nature.

The ‘Dark Horse’: Semileptonic D^0 Decays

In analogy to the B_d case, the emergence of ‘wrong-sign’ leptons – $D^0 \rightarrow l^-\bar{\nu}K^+$ or $\bar{D}^0 \rightarrow l^+\nu K^-$ – signals oscillations have taken place. We already know that unlike for B_d mesons it is a rare process for neutral charm mesons. Once we have accumulated such wrong-sign events, we can ask whether this rate is different for the meson and anti-meson transition:

$$a_{SL}(D^0) \equiv \frac{\Gamma(D^0 \rightarrow l^-\bar{\nu}K^+) - \Gamma(\bar{D}^0 \rightarrow l^+\nu K^-)}{\Gamma(D^0 \rightarrow l^-\bar{\nu}K^+) + \Gamma(\bar{D}^0 \rightarrow l^+\nu K^-)} \quad (5)$$

Such differences have been and are being searched for in the semileptonic decays of neutral K and B mesons. For K_L decays the expected rate has been found – $a_{SL}(K_L) \simeq 3.3 \cdot 10^{-3}$; the experimental upper bounds for neutral B mesons have not yet reached the SM predictions: $a_{SL}(B_d) \simeq 4 \cdot 10^{-4}$, $a_{SL}(B_s) \simeq 2 \cdot 10^{-5}$ [21]. We understand why these numbers are so tiny. For a_{SL} is given very roughly by

$$a_{SL} \sim \frac{\Delta\Gamma}{\Delta M} \cdot \sin\phi_{\text{weak}} \quad (6)$$

While $\Delta\Gamma/\Delta M \simeq 1$ for kaons, we have $\sin\phi_{\text{weak}} \ll 1$ due to the third quark family being almost decoupled from the first two. For B_d it is the other way around: $\Delta\Gamma/\Delta M \ll 1$, yet $\sin\phi_{\text{weak}} \sim \mathcal{O}(0.1)$. For B_s mesons we have furthermore $\sin\phi_{\text{weak}} \ll 1$, since on the leading level only the second and third quark family contribute.

A rough estimate yields $a_{SL}(D^0)|_{SM} \leq 10^{-3}$. Present data suggest $\Delta\Gamma/\Delta M$ to be about unity. With New Physics inducing a weak phase we could conceivably obtain a relatively large value: $a_{SL}(D^0) \sim \text{few} \times 10^{-2}$; i.e., while we know that semileptonic D^0 decays produce few wrong-sign leptons, they might exhibit a large **CP** asymmetry – in marked contrast to K_L , B_d and B_s mesons.

Final State Distributions, T odd Moments

So far all **CP** violation has been found in partial widths – except for one, the forward-backward asymmetry in the orientation of the $\pi^+\pi^-$ and e^+e^- planes in $K_L \rightarrow \pi^+\pi^-e^+e^-$. It had been predicted [22] and subsequently found that the expectation value for this angular asymmetry is about 14% [19] – yet driven by $|\epsilon_K| \simeq 0.23\%$. How can that be? This puzzle is resolved, when one realizes that both amplitudes that generate the asymmetry through their interference – $K_L \xrightarrow{CPV} \pi^+\pi^- \xrightarrow{E1} \pi^+\pi^-\gamma^* \rightarrow \pi^+\pi^-e^+e^-$ and $K_L \xrightarrow{M1} \pi^+\pi^-\gamma^* \rightarrow \pi^+\pi^-e^+e^-$ – are greatly suppressed, albeit for different reasons: it is the **CP** violation in the first and the $M1$ feature in the second amplitude. Such a dramatic enhancement of the asymmetry does not come for free, of course: the price one pays is a tiny branching ratio of about $3 \cdot 10^{-7}$; i.e., one trades branching ratio for size of the asymmetry. This is a very desirable trade – if one has a copious production source.

There might be a close analogy in the charm complex, namely in the angular distribution of the K^+K^- relative to the $\mu^+\mu^-$ plane in

$$D_L \rightarrow K^+K^-\mu^+\mu^-, \quad (7)$$

where a **CP** violating $E1$ amplitude interferes with a **CP** conserving $M1$ amplitude to generate a forward-backward asymmetry. The latter could exhibit an enhancement of the underlying **CP** violation leading to $D_L \rightarrow K^+K^-$ by an order of magnitude depending on details of the strong dynamics. This radiative decay has not been observed yet; its branching ratio could be as ‘large’ as about 10^{-6} .

The reader might view this discussion as completely academic, since it requires a pure sample of long-lived neutral D mesons in qualitative analogy to K_L . Yet since the lifetime difference between D_L and D_S can hardly reach even the 1% level, ‘patience’ – waiting for the D_S component to decay away – is insufficient. Yet there is a unique capability of a Super-Flavour Factory that can be harnessed here through the use of EPR correlations [23] or ‘entanglement’. Consider running at charm production threshold:

$$e^+e^- \rightarrow \psi''(3770) \rightarrow D_S D_L. \quad (8)$$

Once one of the neutral D mesons decays as $D \rightarrow K^+K^-$, we know unambiguously that the other meson has to be a D_L , as long as **CP** is conserved. We can then track its decays into the $K^+K^-\mu^+\mu^-$ final state.

2.2.2 3rd Priority: τ Physics

Lepton Flavour Violating Decays (LFV)

Finding a transition of the type $\tau \rightarrow l\gamma$ or $\tau \rightarrow 3l$ establishes the existence of New Physics, since lepton flavour is violated. The B factories have established upper bounds

of $\text{few} \times 10^{-8}$. The range $10^{-8} - 10^{-10}$ is a very promising search domain rather than an ad hoc one. For several classes of New Physics scenarios – in particular of the GUT variety with their connections to $\mu \rightarrow e\gamma/3e$ – point to that range [20]. The radiative transition $\tau \rightarrow l\gamma$ seems to be clearly beyond the reach of LHC experiments; this might well turn out to be true for $\tau \rightarrow 3l$ as well. Yet a Super-Flavour factory can push into this domain and possibly sweep it out.

CP Violation in τ Physics

The next great challenge in **CP** studies is to find **CP** violation in leptodynamics. The leading contenders are the electron EDM, **CP** asymmetries in neutrino oscillations and in semi-hadronic τ decays like $\tau \rightarrow K\pi(\pi)\nu$ [24, 25]. If found, it would ‘de-mystify’ **CP** violation as a phenomenon present both in the quark and lepton sectors. Maybe more importantly it would provide us with a potential benchmark for leptogenesis that can subsequently induce baryogenesis in our Universe. There will not be any competition from LHC experiments for probing **CP** symmetry in τ decays. At a Super-Flavour Factory one can also employ a unique and powerful tool, namely longitudinal beam polarization: it will lead to the production of polarized τ leptons, which provides another handle on **CP** invariance [26, 25].

For proper perspective one should note that while a LFV rate has to be *quadratic* in a New Physics amplitude, a **CP** asymmetry (in a SM mode) is linear only:

$$\text{CP odd} \sim |T_{\text{SM}}^* T_{\text{NP}}| \quad \text{vs.} \quad \text{LFV} \sim |T_{\text{NP}}|^2. \quad (9)$$

Observing a 10^{-3} [10^{-4}] **CP** asymmetry in $\tau \rightarrow K\pi\nu$ then corresponds very roughly to discovering $\tau \rightarrow \mu\gamma$ with a branching ratio of about 10^{-8} [10^{-10}].

2.3 Design Criteria for a Super-Flavour Factory

The preceding discussion leads to the following strategic goals when designing a Super-Flavour Factory:

- *You cannot overdesign a Super-Flavour Factory.* If what we know now about the size of the **CP** asymmetry in $B_d \rightarrow \psi K_S$ had been known when the B factories were proposed, a less ambitious target for the luminosity would most likely have been chosen. In retrospect both B factories had been over-designed – yet that is exactly what was a cornerstone of their spectacular success! What is true for a ‘hypothesis driven’ research program, is even more true for a ‘hypothesis generating’ one. Tony Sanda’s dictum “We need a luminosity of $10^{43} \text{ cm}^{-2} \text{ s}^{-1}$ ” is certainly ‘tongue-in-cheek’, but not frivolous in that sense. If you must stage the construction, do *not* compromise on final performance. To be more down to earth: a data sample of 10 ab^{-1} – an increase by an order of magnitude over the existing set – should be targeted as an intermediate step; in the end one should aim for at least 50 ab^{-1} .
- Keep the background as low as possible.
- Make the detector as *hermetic* as possible. This is essential when aiming for $B \rightarrow \nu\bar{\nu}K^{(*)}\dots$, $B \rightarrow \tau\nu D\dots$, $D_{(s)} \rightarrow \tau\nu$ modes.

- Keep the flexibility to eventually have quality runs on the $\Upsilon(5S)$ resonance, be it for calibrating *absolute* rates for B_s transitions or analyzing some of their features that could not be settled by LHCb.
- It might turn out to be even more important to be able to run in the charm threshold region with good luminosity to reduce systematic uncertainties when searching for tiny **CP** asymmetries in charm decays. For the background is lowest there; furthermore quantum correlations can be harnessed to obtain unique information [16]. I have mentioned just one example, namely the ability to prepare a ‘beam’ of D_L mesons.
- Make a reasonably strong effort to obtain at least one longitudinally polarized beam. This is an essential tool in probing **CP** invariance in the production and decay of τ leptons. It would also be valuable in dealing with the background when searching for LFV τ decays (and for some **CP** asymmetries in charm baryon decays).

3 Conclusions and Outlook

We are about to embark on a most exciting adventure: we stand at the beginning of an era that promises to reveal the dynamics behind electroweak symmetry breaking. The central stage for this adventure will be the LHC, where quanta signaling New Physics are expected to be produced. Since failure of the LHC program would have disastrous consequences for the future of fundamental physics, it just cannot be tolerated! Yet heavy flavour studies probing the family structure and **CP** symmetry in the K , D , B and τ sectors will be central players in the evolving drama.

- Such studies are and will remain of fundamental importance in our efforts of revealing ‘Nature’s Grand Design’;
- their lessons cannot be obtained any other way;
- they cannot become obsolete.

At the same time comprehensive studies of **CP** violation, oscillations and rare decays can be *instrumentalized* to analyze the anticipated TeV scale New Physics. I see three scenarios play out over the next several years:

1. The ‘optimal’ one: New Physics has been discovered in high p_\perp collisions at the LHC. Then we must determine its salient features, and this cannot be done without analyzing its impact on flavour dynamics – even if there is none! With the mass scale of the New Physics revealed directly, lessons from heavy flavour rates can be interpreted with more quantitative rigour.
2. The ‘intriguing’ one: deviations from SM predictions have been established in heavy flavour decays.
3. The ‘frustrating’ one: no deviations from SM predictions have been identified anywhere.

I bet it will be the first scenario with some elements of the second one. We should not overlook that heavy flavour studies can realistically have sensitivities up to the about 10 - 100 TeV scale – well beyond the direct reach of the LHC. But in any case none of these scenarios weaken the essential role of flavour studies. For even the ‘frustrating’ scenario does not resolve any of the central mysteries of the SM.²

The LHCb experiment will be a worthy and successful standard bearer of heavy flavour physics, yet it will not complete the program. The era of the heavy flavour factories inaugurated by ARGUS’ discovery twenty years ago has not run its profitable course yet – the best might actually still be ahead. A Super-Flavour Factory provides unique capabilities in searching for LFV and **CP** violation in τ decays, unmatched access to **CP** studies in charm transitions and measurements of B decays that are highly complementary to the LHCb program. The HEP community is fortunate to have a battle tested and enthusiastic ‘army’ to embark on a Super-Flavour Factory campaign and will benefit greatly from the results of the latter.

Epilogue

When we look back over the last thirty years – i.e. including the period leading up to ARGUS’ discovery of $B_d - \bar{B}_d$ oscillations – we see several strands of developments: from the ‘heavy flavour sweatshops’ – ARGUS, CLEO and MARKIII – to the present B and tau-charm factories – Belle, BaBar, CLEO-c and BESIII – hopefully to a Super-Flavour Factory; accelerators pushing the high energy frontier – the SPS, Tevatron, LEP I/II and SLC – leading to the LHC and hopefully to the ILC; last (and presumably least for some of the readers) theory. These strands are not isolated from each other, but substantially intertwined. The generational challenge facing us is to understand the electroweak phase transition. This will be tackled in a dedicated way at the high energy frontier by the LHC experiments Atlas and CMS and at the high sensitivity frontier by LHCb. Yet they are unlikely to complete the task – we will need more precise and more comprehensive data. This is where the ILC, which is also a top factory, and a Super-Flavour Factory come in as essential parts of the adventure.

Let me allow a very personal look back as well: Fig.4 shows me giving a talk at the Heidelberg Heavy Quark Symposium in 1986. Fig.5 on the other hand might be closer to how some see me now. It actually shows the person whose most famous quote I adapted for the title.

It has been said: ”All roads lead to Rome.” Personally I think Rome is never a bad destination. When I said before we are at the beginning of an exciting journey into the unknown I was incorrect, as shown by celebrating ARGUS’ seminal achievements: For it is actually the continuation of an age-long adventure, and we are most privileged to be able to participate in it.

²This is of course a purely scientific-intellectual argument – the political one would play out very differently.



Figure 4: Giving a talk in Heidelberg in 1986

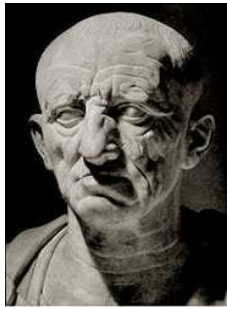


Figure 5: Cato the Elder

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References

- [1] ARGUS Collab., H. Albrecht *et al.*, *Phys.Lett.***B192** (1987) 245.
- [2] I.I. Bigi, A.I. Sanda, *Nucl.Phys.***B 193** (1981) 85.
- [3] Z. Ligeti, these Proceedings.
- [4] K. Schubert, these Proceedings.

- [5] CDF Collab., A. Abulencia *et al.*, hep-ex/0609040, which updates the earlier *Phys.Rev.Lett.* **97** (2006) 062003; D0 Collab., V.M. Abazov *et al.*, *Phys.Rev.Lett.* **97** (2006) 021802.
- [6] The Heavy Flavour Averaging Group provides continuously updated experimental numbers on their web site: <http://www.slac.stanford.edu/xorg/hfag/>
- [7] For a concise discussion see: H. Murayama, arXiv:0709.3041[hep-ph]; H. Murayama, Y. Nomura, D. Poland, arXiv:0709.0775 [hep-ph].
- [8] G. D'Ambrosio *et al.*, *Nucl.Phys.* **B645** (2002) 155.
- [9] A. Golutvin, these Proceedings.
- [10] See, e.g.: I.I. Bigi, A.I. Sanda, "CP Violation", *Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology* (Cambridge University Press) 2000; a second thoroughly updated edition will appear in late 2008.
- [11] BELLE Collab., M. Staric *et al.*, *Phys.Rev.Lett.* **98** (2007) 211803.
- [12] BABAR Collab., B. Aubert *et al.*, hep-ex/0703020.
- [13] BELLE Collab., L.M. Zhang *et al.*, *Phys.Rev.Lett.* **99** (2007) 131803.
- [14] I.I. Bigi, N.G. Uraltsev, *Nucl.Phys.***B592** (2001) 92.
- [15] A. Falk *et al.*, *Phys.Rev.* **D65** (2002) 054034; *Phys.Rev.* **D69** (2004) 114021.
- [16] See, e.g.: S. Bianco *et al.*, *La Rivista del Nuov. Cim.* **26**, # 7 - 8 (2003).
- [17] Y. Grossman, A. Kagan, Y. Nir, *Phys.Rev.* **D75** (2007) 036008.
- [18] I.I. Bigi, *Chin.Journ. of Physics* **45** # 3 (2007) 283; arXiv:hep-ph/0701273.
- [19] PDG, *Review of Particle Physics, Journal of Physics G* **33** (2006) 1.
- [20] T. Browder *et al.*, arXiv:0710.3799.
- [21] For a recent update see: A. Lenz, U. Nierste, hep-ph/0612167.
- [22] L.M. Sehgal, M. Wanninger, *Phys.Rev.* **D46** (1992) 1035; *ibid.* **D46** (1992) 5209 (E).
- [23] A. Einstein, B. Podolsky, N. Rosen, *Phys.Rev.* **47** (1935) 777.
- [24] J.H. Kühn, E. Mirkes, *Z.Phys.* **C56** (1992); Erratum, *ibid.* **C67** 364; J.H. Kühn, E. Mirkes, *Phys. Lett.* **B398** 407 (1997).
- [25] I.I. Bigi, A.I. Sanda, *Phys. Lett.* **B625** 47 (2005).
- [26] Y.S. Tsai, in: Stanford Tau Charm 1989:0387-393 (QCD183:T3:1989); Y.S. Tsai, *Phys.Rev.* **D51** 3172 (1995).

After Dinner Speech

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Dear friends, dear colleagues:

As the last speaker at the ARGUS Symposium I would like to thank DESY for the support. I also would like to thank all the people who worked hard to make this Symposium a success, in particular Frank Lehner and Sylvie Faverot-Spengler.

I was asked to analyze in my talk the reasons for the great ARGUS achievements. Collaborations are very similar to people. And their fates and successes depend on similar factors. It is well known that genes determine the future to a large extent. Therefore let us look at the ARGUS parents. ARGUS's mother is unknown. On the other hand many men claim that they are ARGUS's fathers. Some of them provide documents supporting this claim. Here you see a restaurant bill for the dinner at which ARGUS was conceived according to the claim by Walter Schmidt-Parzefall and Dietrich Wegener. A bottle of good wine was drunk to celebrate this event. Wine played a very important role in the ARGUS fate as we will see later. Therefore I consider this claim well justified. The bill can be considered as the ARGUS birth certificate. So genes were obviously good and it was possible already at that time to anticipate the great ARGUS future.

The childhood period is also extremely important for the fate. During childhood girls usually fall in love with their fathers. The ARGUS Collaboration was obviously female since it was so tiny, gentle, and smart. So the ARGUS Collaboration fell in love with her father, the first ARGUS spokesman Walter Schmidt-Parzefall. He deserved this love. He was young, handsome, clever and brave. Let me give you just one example of his boldness. Walter visited ITEP to discuss our contribution to ARGUS. At that time Russia was like another planet for people from the West. We proposed to change the JADE type drift chamber, which was the baseline at that time, to the ARGUS type drift chamber and to fill it with isobutane. Walter was bold enough to agree with this proposal from foreign planet people whom he even did not know. We were only recommended to him by Professor Schopper who happened to work for some time in Russia. The ARGUS performance demonstrated that this was not only bold but also a wise decision. Such a decision in a modern collaboration would require years of discussions, voting, endorsements, and so on. At ARGUS it could be made immediately and this was one of the reasons for the effectiveness of the collaboration.

It is important to learn foreign languages during childhood. The ARGUS native language was German. When I first came to DESY in 1979 I immediately went to a Collaboration meeting. It was in German. For 15 minutes I tried to learn German on spot but failed. So I asked to switch to English. After the meeting Richard Childers came to me and said:

“I am so glad that you came”.

I was surprised and he explained:

“I am already at DESY for half a year and did not understand a word during the collaboration meetings”.

Since that time English became more popular in the Collaboration. However the real ARGUS working language was a Kinematics Analysis Language (KAL). This language was written by Hartwig Albrecht and it played an extremely important role in the ARGUS data analysis. It was very simple and very efficient. It was possible to learn it in one day and to start the analysis.

The ability for social communication should be also developed during childhood. In ARGUS we developed a tradition of weekly ARGUS parties. They were excellent. I still remember the first ARGUS Russian party. I was impressed by the amount of vodka consumed by our not well trained western colleagues. When they returned home their families were impressed as well....

When childhood is over it becomes **time to fulfill your dreams**, i.e. to construct the detector. During the construction period the role of the spokesman is extremely important. Walter had his own strategic view on his task. According to him there are only two important tasks for the spokesman. The spokesman should not disturb good people when they are working and should defend them from bad people. Since there were no bad guys in ARGUS Walter concentrated on the first part of his task. He did it so perfectly that nobody had an illusion that something would be coordinated in ARGUS. Therefore each group took care itself that the part it built would fit with other parts of the detector. The success of this approach was tremendous. In half a year we assembled ARGUS without any problem. This was an excellent proof of a statement by the famous Russian anarchist Kropotkin:

“Anarchy is the mother of the order”.

Later on Walter and I derived a theory for the dependence of the collaboration efficiency on the organizational level. There are two obvious limits. With perfect organization the efficiency is zero. In Russia such a situation is called an Italian strike. When people fulfill all instructions everything stops to work. Another limit of zero organization has a reasonable efficiency as was demonstrated by the first ARGUS years. Since the behavior of the efficiency at intermediate values of the organizational level was unknown we tried to be close to the familiar point of zero organization. ARGUS had no constitution, no Collaboration Board, no elections. Instead of

Collaboration board meetings we had regular Collaboration parties and the result was excellent.

I'll not discuss **the period of maturity and glory**. It was already well covered in the talks today. I would like to remind you only that the BBbar mixing paper is the most famous paper at DESY with more than 1000 citations. For quite some time it was among 10 most cited experimental papers in particle physics. Twenty ARGUS papers have been cited more than 100 times. Taking into account the small size of the collaboration this is really a remarkable achievement. Initially we had a better detector than our competitors from CLEO. It was even possible to quantify the difference.

Once I gave an internal ARGUS seminar with a title "Is ARGUS 5 times better than CLEO?". At the beginning of the seminar I asked Walter and Dietrich to guess the answer. Dietrich said "Yes", Walter said "No". They were both right. ARGUS was 7 times better than CLEO. We reconstructed 7 times more B decays into J/psi than CLEO. However the biggest ARGUS advantage was excellent people. We continued to compete efficiently with CLEO even when they upgraded their detector and collected an order of magnitude more luminosity.

I must say that many ARGUS discoveries look so natural today that that they even do not look like discoveries. Some theorists even claim that they predicted them. Anticipating such a development I had asked one well known theorist to write a clear statement and to sign it. He wrote: "ARGUS will never observe BBbar mixing" and signed. Three months later we announced the discovery of BBbar mixing. After that theorists refuse to sign clear statements for me.

ARGUS is famous not only among physicists. Taking into account great scientific achievements and amount of consumed alcohol, our Azerbaijanian friends decided to name their best cognac after ARGUS. You can see here this bottle. I would like to present this bottle to Walter.

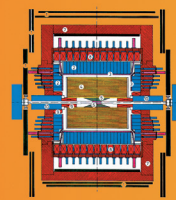
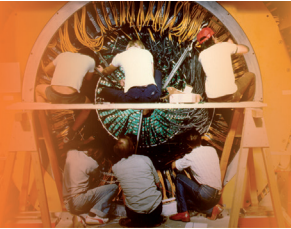
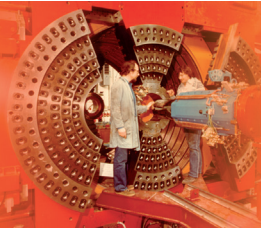
Unfortunately **the retirement age** comes inevitably at some time. It came to ARGUS as well. However there are pleasant moments during this period as well. It is still possible to recall the past discoveries and to have parties to celebrate them. It is also pleasant to witness the successes of ARGUS children and grandchildren. David MacFarlane was the spokesman of BaBar and Andrey Golutvin has been just elected to be the spokesman of LHCb. So we can say that ARGUS is still dominating the field of beauty and charm physics.

I propose to raise the glasses for future ARGUS successes. I tried to show that the good atmosphere and the good human relations were the main ARGUS achievements. This was the basis of all other achievements. I raise my glass for friendship, for ARGUS, for future!

ARGUS

20 years of B meson mixing

Symposium, DESY



09
November
2007

It is great to celebrate the important accomplishments of the ARGUS collaboration and to emphasize their significance. These achievements opened a novel and exceptionally fruitful domain in particle physics. Despite my enthusiasm for B physics I regret that I can not participate in the Symposium.
Berthold Stech, Heidelberg

I wish you and the organizers the best for successful symposium, and for the recalling of many fond memories of that exciting time at DESY
Elliot Bloom, SLAC

When I was a postdoc at DESY (1985-88) ARGUS always threw the best parties. So it is a real pity that I can not be there for this one. Have a great celebration!
Andreas Kronfeld, FNAL

It is good to hear that the ARGUS-Fest comes.
Bernhard Spaan, Dortmund

I wish the organisers a successful preparation and all participants a pleasant reunion.
Siegmond Nowak, DESY

I am delighted by your kind invitation to the ARGUS symposium. The observation of the large mixing in B physics was truly an important landmark in flavor physics and I would be delighted to attend the Symposium, but alas, I cannot.
Albert Silverman, Cornell

I regret that I will not be able to participate. Please give my best regards to all my good old ARGUS scientific friends.
Cecilia Jarlskog, Lund

Since it was indeed a pioneering discovery and one from which I have benefitted more than most other people, I gladly accept the invitation.
Ikaros Bigi, Notre Dame

Thank you for the gracious invitation to speak on CLEO's contributions to B physics at the ARGUS Symposium. I am delighted to accept the invitation. I appreciate being able to make a contribution to the celebration of ARGUS's discovery of B mixing, which had a such a profound effect on heavy quark physics and the CLEO program.
David Cassel, Cornell

IMPRESSIONS







**And
the
speakers**



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Zoltan Ligeti



Walter Schmidt-Parzefall



Dietrich Wegener



David Cassel



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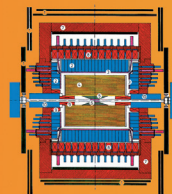
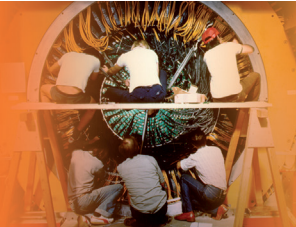
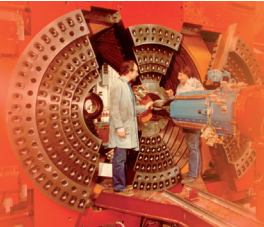
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