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by

ARGUS Collaboration

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THE ARGUS COLLABORATION

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As an upgrade of the ARGUS detector, we propose the construction of a high precision vertex chamber, called a μVDC, and a thin beryllium beam pipe, in order to allow identification of vertices arising in B-meson decay. With this vertex chamber we expect to improve the significance of experiments with B-meson decays by as much as an order of magnitude. This proposal first describes the hardware to be constructed and then discusses the physics capabilities to be expected from such an instrument.

1 Design of a μVDC for ARGUS

1.1 Principles of operation

A detailed study has shown that the position of particle tracks projected to the interaction point must be measured with a precision of 15 μm, in both the r-ϕ plane and in z, in order to achieve reasonable vertex reconstruction and background suppression probabilities. Such precision could easily be obtained using silicon strip detectors. However, multiple scattering introduced by the substrate material would degrade the projected resolution at the vertex by an order of magnitude for particles with momenta less than 1 GeV/c, far too much for our purposes. A sufficiently small multiple scattering contribution can only be obtained with a drift chamber.

To achieve the required resolution, we propose the construction of a chamber exploiting recent, innovative advances in drift chamber technique. The pioneering work has already been done by Nygren et al. [1], referred to as a "radial time expansion chamber" and by Walenta et al. [2], called an "induction chamber". The basic operating principle is the same in both cases.

An example of a typical drift cell arrangement is shown in cross-section in Figure 1. The cell is bounded at one end by a negatively charged cathode layer, and at the other by a layer of field shaping wires. The measurement plane, consisting of alternating pickup and sense wires at 300 μm intervals, is located asymmetrically, 6 mm away from the cathode plane. The electric field is homogeneous throughout most of the drift volume, except in the vicinity of the anode plane. The relative potentials of the sense and pickup wires are chosen so that almost all field lines end on the sense wire.

Electron clusters produced by an ionizing track drift along field lines until reaching the high field near the surface of the sense wire, where an avalanche is created. A suitable choice of counter gas, such as propane, isobutane or dimethyl ether (DME), ensures that the avalanche does not spread over the surface of the signal wire, but remains localized and centred on the field line. Thereby, the mapping due to the electric field, between the lateral position of cluster origin and the angle, α, at which the avalanche reaches the sense wire, is preserved. The asymmetry in the amount of charge induced on the two neighbouring pickup wires can be used to determine α.

In practice, the concept is best applied to situations where tracks pass through the drift cells at small angles, λ. Landau fluctuations in the deposited ionization energy then occur along a line essentially perpendicular to the measurement axis. For a measurement which integrates over all collected charge, as in the induction chamber case [2], these fluctuations contribute to the resolution in proportion to the length of the track projected onto the measurement axis, and thus become significant as λ deviates from zero. If α of the incoming charge clusters is recorded as a function of time, as in the RDC design [1], the centre-of-gravity both along and perpendicular to the measurement axis can be measured, effectively allowing one to remove the dependence of the resolution on λ.

For tracks with small λ angles, because of the short drift lengths involved, the resolution is dominated not by diffusion, but by the precision with which α can be measured. The error on α depends on the ratio of signal to electronics noise, particularly for the small difference signal between the induced charge on the pickup wires, and on the intrinsic angular spread of the avalanche itself. The former can be reduced by high gas gain or higher fields near the sense wires. The latter is influenced by the choice of gas, and the diameter of the sense wires. Both fall with the square-root of the number of primary electrons, again a function of the chamber gas and operating pressure. It has been demonstrated [1, 2] that with suitable choices among these variables the ultimate resolution for the track coordinate measured over a few mm of track length is 10 μm or less. We consider 10 μm to be achievable in our full scale chamber, and comment on the sensitivity of physics applications to this assumption.

1.2 Application as a vertex detector

The detailed view of the proposed chamber is shown in Figure 2. Drift layers come in pairs, with a common negatively-charged cathode layer dividing the two. If the figure is seen as a cross-sectional view, with the beam tube towards the bottom, then it is clear that ionization electrons drift inward and outward from the cathode toward the two active layers. The complete chamber will consist of 4928 drift cells in 3 such superlayers (see Table 1), two close to the beam pipe and one just inside the main drift chamber, arranged in a hexagonal pattern around the beam pipe as in Figure 3. All 3 are contained within a common gas volume, with the inner and outer walls formed by the beam tube and a carbon fibre tube respectively. Thus, the distance between coordinate measurements without significant amounts of intervening material is over 10 cm. The track can then be projected to the interaction region with the desired precision. The only material introducing significant multiple scattering error into the vertex determination will be the beam tube wall.

In addition, the pairs of active wire layers are not parallel, but rotated and orthogonal to each other, in order that two track coordinates can be measured by each superlayer. This is accomplished by winding the wires over bridges at the corners of the hexagons with an inclination of 45°, in an approximately spiral pattern. The second active layer in the pair is wound with opposite inclination, such that the two layers are crossed at a 90° angle. This

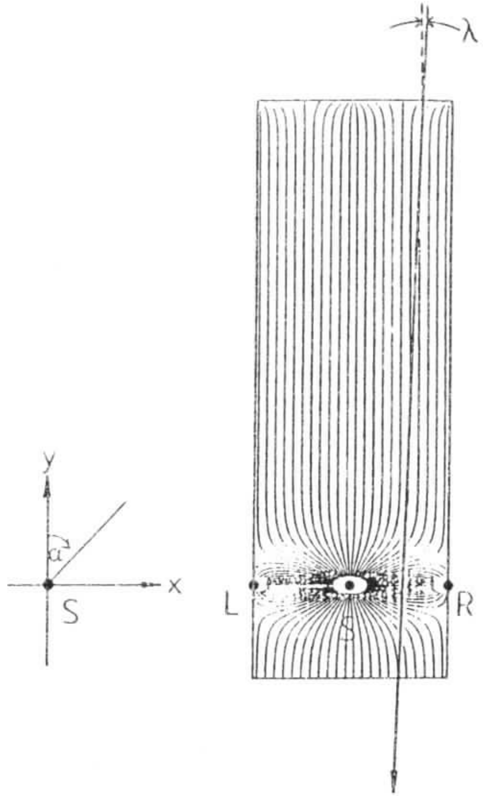

Figure 1: Typical drift cell, with cathode plane at top and the measurement plane consisting of pickup wires (L and R) and sense wire (S) 1 mm from bottom. The cell is 600 μm across and 7 mm long.

Superlayer		Number of cells
1	Inner	216
	Outer	312
2	Inner	312
	Outer	432
3	Inner	1736
	Outer	1920

Table 1: Number of drift cells in each layer of the proposed μVDC

structure is shown in Figure 4.

A side view of the complete setup, including the inner parts of the present detector, is shown in Figure 5. Note the different scales. The length of the chamber is chosen so as to cover 90% of the solid angle. The central part of the beam pipe is a thin (0.5 mm) beryllium tube, 36 mm in diameter. Multiple scattering in such a pipe introduces a 10 μm RMS error at the vertex position for 0.5 GeV/c pions. Also, 0.5 mm is sufficient to withstand overpressures of up to 15 atm, allowing us the option of improving μVDC resolution with increased gas pressure.

The beryllium tube is welded to an aluminum tube, which is shielded by lead against synchrotron radiation. A water-cooled tungsten collimator prevents direct synchrotron radiation from entering the detector. The collimator radius of 15 mm represents the smallest aperture acceptable for an undisturbed operation of the storage ring. The inner collimator surfaces, however, will backscatter synchrotron radiation into the detector. This potentially serious background problem can be reduced by an order of magnitude, if the collimator surfaces are covered by a sandwich of various materials, i.e. silver, copper and chromium [3]. With these provisions, synchrotron radiation should not pose a major problem.

Another potentially serious source of background is random tracks from beam gas, or beam wall events near the detector. One can estimate the expected rate by approximating the background as a line source along the beam axis. Integrating over the solid angle subtended by a drift cell viewing such a source, and over reasonable distances upstream and downstream of the detector, it can be concluded that the counting rate would be proportional to the area of the drift cell times the radius from the beam line. Given the small area of the drift cells in the proposed μVDC, we expect the counting rate in the innermost layer to be about 30 times smaller than that for the inner layer of the present vertex detector, clearly quite acceptable.

1.3 Readout electronics

There are two arguments which lead to the conclusion that it will not be sufficient to record only the integrated charge seen by sense and pickup wires. First, it should be recognized that most tracks passing through the drift cells will, in fact, not be at small λ angles. Also,

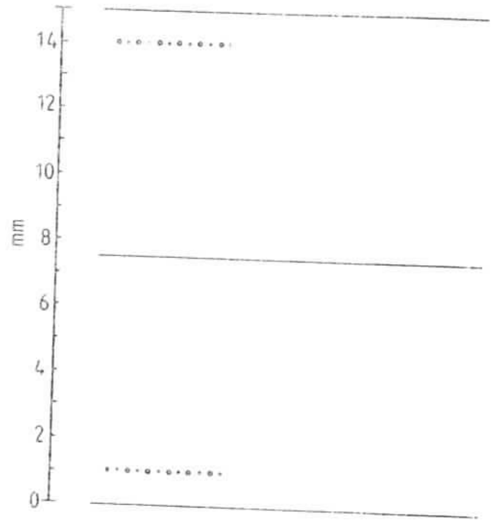

Figure 2: Detailed view of a superlayer, with cathode plane in the middle.

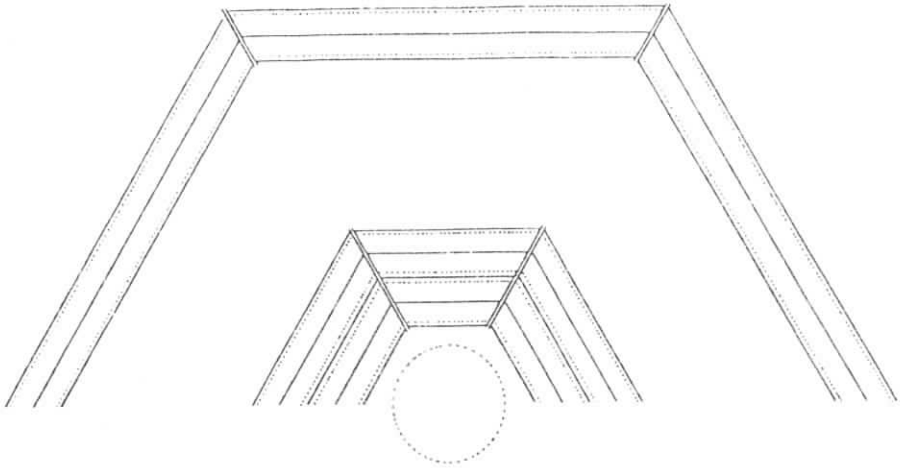

Figure 3: Cross-sectional view on the μVDC, showing hexagonal support structure for the 3 superlayers.

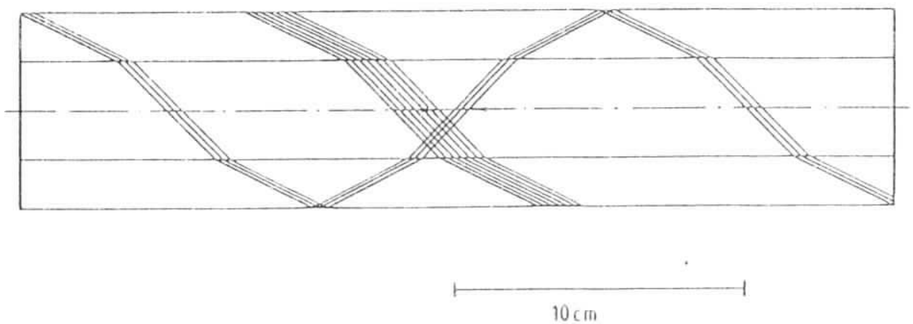

Figure 4: Side view on the μVDC, showing arrangement of drift cells at 45° to the support structure. The two layers of a superlayer cross at 90°.

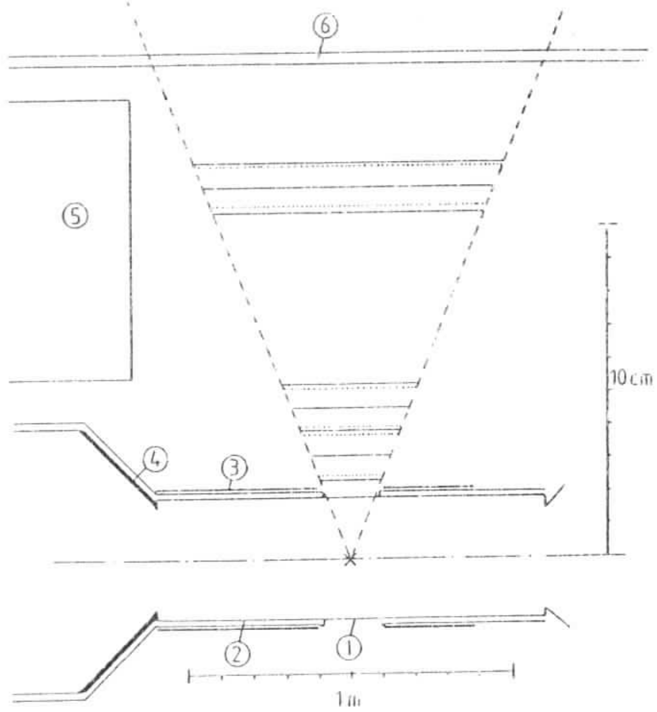

Figure 5: Side view of the inner part of the ARGUS detector showing the proposed layout of beam pipe and μVDC. Note the different vertical and horizontal scales. The numbers in the figure refer to: 1 - 0.5 mm beryllium beam pipe, 2 - 2 mm aluminum beam pipe, 3 - lead shield, 4 - tungsten absorber, 5 - compensation coil and 6 - inner wall of the main drift chamber.

the μVDC will operate in a magnetic field, causing the drift paths of ionization clusters to be effectively inclined with respect to the electric field lines. Therefore, in order to achieve the desired resolution for all tracks it will be necessary to measure α as a function of time, probably at about 20 ns intervals, depending on the choice of gas and operating pressure. Second, high angle tracks will hit not just a few cells, but many, because of the 45° stereo angle. This prevents us from ganging together ouput channels, and requires that we work towards good two-track separation through drift time differences.

Measurement of the time development of the signal can be accomplished using either Flash ADCs, or by taking advantage of new developments in CCD multiplexing [4]. Our preferred solution is the latter. Given the limited space between the inner compensation coils and the main drift chamber, there does not seem to be enough space to pass signal and high voltage cables for 4928 drift cells. If an eighteenfold reduction in the number of signal cables can be made using multiplexing technology, this would go a long way towards solving both this problem, and reducing the overall cost of this proposed project. The high density of signal channels seems to necessitate some form of custom made VLSI preamplifier for the chamber. Again, the design specifications for the CCD-based parallel-to-series registers calls for an integrated low-noise front-end [4], ideally suited to our needs. If the time scale for the development matches our needs, the CCD solution would likely be our choice for readout.

1.4 Cost estimate and schedule

The estimated cost for the project depends to some extent on the assumptions about our final choice for a readout system. If the CCD-multiplexing scheme is viable, we will only need Flash ADCs for every 18 channels, at considerable savings. On this basis, we estimate the total cost to be DM1.4 million, divided as follows:

	DM
Beryllium beam tube	150K
Mechanical construction of chamber	250K
Electronics	
10000 Preamplifiers	500K
600 Serial readout lines	500K
CCD registers (DM150/channel)	
Cables (DM50/channel)	
Flash ADCs (DM500/channel)	

If approved, we expect that about one year will be needed for development and testing of prototypes leading to a final design. The construction of the full-scale chamber will require an additional year. Therefore, we anticipate installing the μVDC in late spring of 1988.

2 Physics performance with a μVDC

2.1 Present approach to B physics

Although much progress has been made in determining properties of bound state b-quarks, measurements of the fundamental Kobayashi-Maskawa matrix elements relating to the weak decay of the b-quark are far from complete. This is a clear consequence of the high multiplicity of B-decays, which results in large combinatorial backgrounds and substantial geometric inefficiencies, even for e^+e^- detectors covering large solid angles. Furthermore, while the $\Upsilon(4S)$ resonance is a favourable source in terms of rate, the $B\bar{B}$ pairs are produced isotropically and nearly at rest. Thus, decay products from the two mesons are completely intermixed, allowing no simple kinematic reduction of the combinatorial problem. The charm mesons produced in B decays are also therefore relatively slow, leading to lower detection efficiencies. Finally, since many more channels are available for B decays than for lower mass states, branching ratios into any particular mode are expected, and observed, to be quite small.

Good particle identification, as provided for example by the dE/dx and TOF systems of the ARGUS detector, helps enormously in reducing the background. However, this is still not sufficient. The approach which has brought some success to date is to first reconstruct intermediate charm states, to which up to 3 pions are added to complete the B reconstruction. It is comparatively easy to obtain clean charm signals, since decays are typically low multiplicity and include either a charged or neutral kaon. This is particularly so when the excellent resolution for the $D^{*+} - D^0$ mass difference is exploited. However, there is a penalty to pay: the reconstruction efficiency is less than 10^{-3}, since it is the product of already small B branching ratios with an also small efficiency times branching ratio for the charm meson.

As an example, consider one of the simplest channels[1]:

$$\bar{B}^0 \to D^{*+}\pi^- \qquad BR \sim 0.2\%$$

where [5]:

$$D^{*+} \to D^0\pi^+ \qquad BR = 49\%$$

The low momentum of the π^+, while leading to the excellent mass difference resolution, also results in efficiencies of only about 45% for its detection. Nor is it possible to use all D^0 decay channels. Currently, we are able to exploit only the following [6]:

	$\eta[D^0] \cdot BR[D^0]$
$K^-\pi^+$	4.5%
$K^-\pi^+\pi^0$	4.7%
$K^-\pi^+\pi^+\pi^-$	7.7%
$K^0_S\pi^+\pi^-$	1.3%

[1] References to a specific charged state are to be interpreted as implying the charge conjugate state also.

making a total of 18.2% of all D^0 decays. Ultimately, the product of efficiency times branching ratios into useable channels is:

$$\eta[D^{*+}] \cdot BR[D^{*+}] \sim 4.0\%$$

Thus, in our 50 pb^{-1} of $\Upsilon(4S)$ data, containing 1×10^5 $B\overline{B}$ pairs and representing the majority of the HEP beam time for 1985 at DORIS, we find 5 events in this particular $\overline{B}^0$ decay channel. The sum of all combinations of D^{*+} plus 1-3 pions, including up to one π^0, yields in the same data set 70 charged and neutral B candidates above background, as shown in Figure 6.

Actually, this is considerably fewer events than would have been expected on the basis of the early CLEO branching ratios [7, 8]. For example, as originally reported the branching ratio for $\overline{B}^0 \to D^{*+}\pi^-$ was $(1.7 \pm 0.5 \pm 0.5)\%$. More recent measurements are smaller by factors of 5-10 [9], consistent with our own observations.

2.2 What needs to be measured?

This is quite a success, considering the size of the world's sample to date [5]. However, the result should be placed in context with the important physics unknowns which we hope to measure in the B-system. These can be divided into the following areas:

1. Measure inclusive and exclusive branching ratios, including semi-leptonic rates for the charged and neutral B, and charged and neutral lifetimes, in order to sort out the QCD properties of the B meson as probed on the weak interaction distance scale, and confirm the spectator picture of B decays. As with the exploration of the charm system, it is probably the rare decay channels which will prove most important in understanding B decays. Our 70 events, while a beginning, belong only to the dominant decay channels through charm, and even then are too few to determine the resonant sub-channel contributions. It is also too small a tagged sample to measure separately the charged and neutral semi-leptonic branching ratios, so crucial to testing the spectator picture. Still under investigation is whether a B sample, tagged by a cleanly reconstructed D^{*+}, will prove useful for investigating these questions.

2. Determine the weak couplings between the b and u quark, either from leptonic spectra or by direct observation of hadronic decay channels. Only the endpoint region of the lepton spectrum is free from the dominant contribution of $(b \to c)$ transitions, and therefore sensitive to V_{bu}, without model assumptions about the $(b \to c)$ contribution. However, there is still considerable uncertainty about the shape expected in this region from $(b \to u)$ transitions, dominated by low mass, low multiplicity channels [10]. Searches for hadronic signals [11], on the other hand, are confined to low multiplicity channels, with correspondingly small branching ratios. A signal would, of course, be difficult to convert into an inclusive rate, for reasons similar to difficulties in predicting the leptonic spectrum near the endpoint.

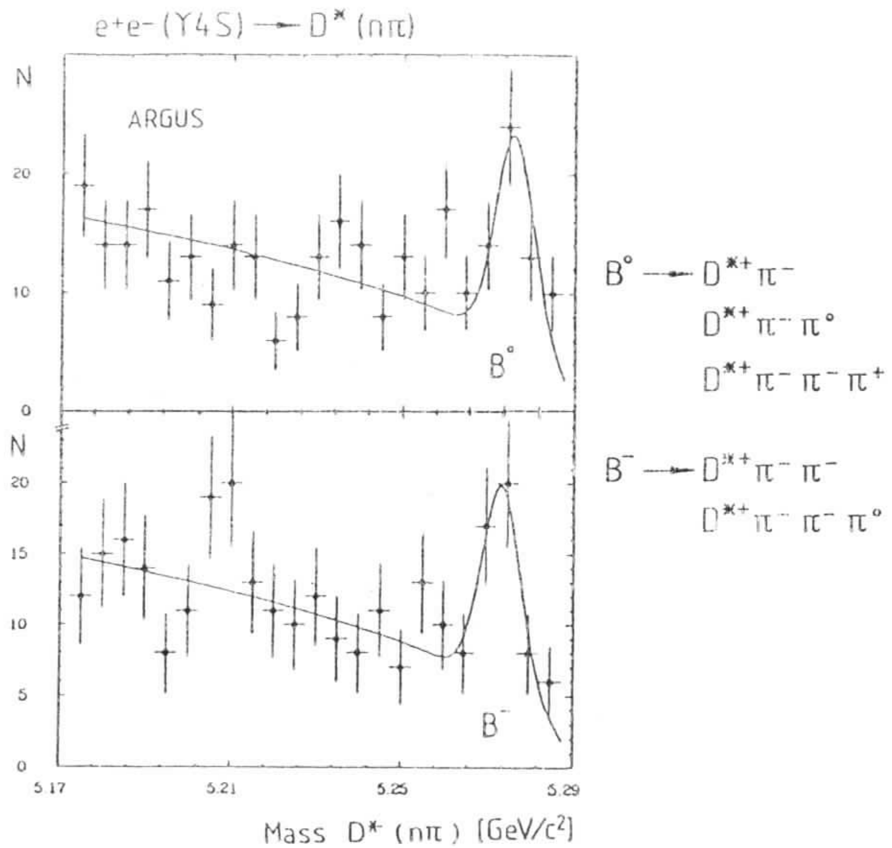

Figure 6: Reconstructed B mesons from our current sample of 50 pb^{-1} of $\Upsilon(4S)$ data.

3. Observe mixing in the neutral B system, and CP violation either as di-lepton or hadronic asymmetries. Through coherent use of all detector information, ARGUS has achieved high efficiencies for lepton detection [12]. Nevertheless, the like-sign di-lepton rates predicted by the standard model from mixing would not be seen in our 50 pb^{-1} sample because of the overwhelming background from parallel semi-leptonic B decays, with one primary and one secondary source lepton [13]. The large asymmetries predicted in some hadronic B decays due to CP violation [14, 15] will not be accessible either, until some efficient technique is found for reconstructing rare decay channels.

One can summarize this survey by remarking that there seems to be some discrepancy between what is needed to measure the fundamental properties of B decays, and what so far has been achieved, despite the state-of-the-art nature of the ARGUS detector and the efforts of the DORIS staff.

2.3 Improvements with a μVDC

How then will the proposed μVDC improve our ability to address these important questions? We wish to explore a few specific examples in detail, while others will only be outlined. Once operational, other instances where such a device would prove invaluable will undoubtedly be discovered.

2.3.1 Charm tagging

The first, and most obvious, use for a high precision vertex measurement is to exploit the finite flight paths of the charm mesons produced in B decay, and possibly even of the B mesons themselves. Using the world average for D and B lifetimes [16], and the B meson mass reported by CLEO [7], recently confirmed by our own measurement, it is expected that $\Upsilon(4S)$ decays into $B\bar{B}$ pairs will result in average flight distances, λ, of:

	$\lambda[\mu m]$	$\tau[ps]$
D^0	60	0.4
D^+	115	0.9
B^0	20	1.1
B^-	25	1.1

A μVDC, providing vertex resolutions of 15-20 μm, should be able to resolve many of the charm vertices, and even some of those from B decays. Nevertheless, since we are dealing with projections of tracks, the use of the improved vertex information is not trivial. A typical $\Upsilon(4S)$ decay consists of 4 or more low-multiplicity vertices, which may or may not be sufficiently separated in space to be resolved. If precise measurements were to be made only in the r-ϕ plane, every pair of projected tracks forms a possible vertex. Corresponding to the combinatorial problem for reconstructing a B meson from a large number of tracks, there is an insurmountable combinatorial problem for vertices. Adding the capability of precise

z measurements, as in the proposed design, eliminates many of these spurious crossings. However, we have concluded that the ratio of vertex resolution to average flight path distance is not large enough to allow the vertex problem to be untangled on the basis of topology alone.

Instead, the proposed strategy is to use information from the rest of the detector to first obtain a set of candidate tracks which should belong to a common vertex, then use the μVDC measurements to confirm or reject the hypothesis. Thereby, it is expected that backgrounds can be reduced to the point where D signals will be useful for B reconstruction.

Such an approach has been tested by Monte Carlo for two D decay channels of different decay vertex multiplicities:

$$D^0 \rightarrow K^-\pi^+$$
$$D^+ \rightarrow K^-\pi^+\pi^+$$

Hits were generated in the μVDC only. Two intercepts and two direction cosines for each track were reconstructed from these simulated measurements, which could then be input to a vertex fitting routine. It was assumed that multiple scattering in the inner wall of the main drift chamber would make the errors on position and direction determination from the rest of the detector too large to influence the precision vertex determination. Events were generated using a Field-Feynman independent fragmentation model. The branching ratios for D^0 and D^+ decays were obtained from the latest MARK III results [6]. The parameters of the spectator model for B decays were taken from Rückl [17].

Events were selected containing D^0 or D^+ candidates lying within ± 30 MeV/c^2 of the D mass. This corresponds to ± 2 sigma for the present detector. It should be noted that a precision z measurement would reduce the correlation between momentum and cot θ, which is present in current data because of the use of small angle stereo in the main drift chamber to obtain z information. Thereby, it is expected that the D mass resolution would be improved significantly. The selected events were then required to satisfy the following:

1. Tracks near the interaction region must not fit to a common vertex with a probability of more than 10% (for the D^+ channel only).
2. The D^0 or D^+ candidate tracks must fit to a common vertex with probability of more than 10%.
3. The D vertex must be isolated from the rest of the tracks in the event. This was achieved by requiring that no track with momentum greater than 750 MeV/c be closer than 3 sigma to the D vertex.
4. The momentum vector of the D candidate must point towards a primary vertex formed from the remaining tracks in the event. This primary vertex was obtained by iteratively fitting the non-D tracks to a vertex, removing the track with the worst χ^2 at each iteration, until the fit probability exceeded 10%. The vertex so obtained was found to track the interaction point with a sigma of 35 μm.

The last two cuts were found to be particularly effective in removing background combinations. In contrast, for a design using only measurements in r-ϕ, these same cuts could not be used: in projection, the vertices are much less likely to be isolated, and no algorithm could be devised which tracked the interaction point to better than 100 μm.

Clean signals in both channels can be achieved, with efficiencies for tagging the D from a B decay ranging from 25 to 50%, depending on the desired signal-to-noise ratio. For comparison, the present signal for $D^0 \to K^-\pi^+$ sits above a background 10 times larger than the signal and higher multiplicity channels are, of course, considerably worse. For purposes of fully reconstructing B decays, we assume that a signal-to-noise ratio of 1:2 is sufficient, and therefore take 50% as the tagging efficiency.

One of the principle components of the CLEO II upgrade [18] is a new CsI calorimeter, located inside the magnet coil. This will allow reconstruction of B channels into a D^{*+} plus charged and neutral pions, already possible with the current ARGUS detector. It will also permit the detection of the soft π^0 or γ emitted in the transition between a D^* and a D. Effectively, the number of cleanly reconstructed D^* candidates, and hence B mesons, will thereby increased. This goal is quite analogous to our use of the μVDC to directly improve the available D^0 and D^+ signals.

2.3.2 B meson reconstruction efficiency

In order to predict the efficiency for B reconstruction, we compare the inclusive rates for D^{*+} and D reconstruction. This assumes that once the charm decay is identified, the probability for reconstructing a B is the same, no matter which particular charm state was found. Implicitly, one assumes that the slow π^0 or π^+, or low energy photon from the D^* to D transition is not needed to complete the B reconstruction. We expect that the vertex finding algorithm can be applied not just to the 3 examples studied, but to any D decay channel with 2 or more charged tracks from the charm vertex, and up to one π^0. For the D^0, these are [6]:

	$\eta[D^0] \cdot BR[D^0]$
$K^-\pi^+$	4.5%
$K^-\pi^+\pi^0$	4.7%
$K^0_S\pi^+\pi^-\pi^0$	1.1%
$K^-\pi^+\pi^+\pi^-$	7.7%
$K^0_S\pi^+\pi^-$	1.3%

making a total of 19.8% for D^0 decays. Likewise, for D^+ we take [6]:

	$\eta[D^+] \cdot BR[D^+]$
$K^-\pi^+\pi^+$	8.5%
$K^0_S\pi^+\pi^+\pi^-$	1.8%
$K^-\pi^+\pi^+\pi^0$	1.5%

for a total of 11.8% for D^+ decays. Folding in the tagging efficiency noted above, we predict that 9.9% of D^0 and 5.9% of D^+ decays can be used for B reconstruction: the comparable

number for the D^{*+} was, as described earlier, 10%. Finally, to compute the inclusive reconstruction rate per B decay, the rate of D and D^* production per B decay is needed. The D^{*+} rate is well measured and found to be 27% [9, 19]. The D^0 and D^- rates can be inferred by assuming a 1:3 ratio for psuedo-scalar to vector production: this yields 47% for D^0 and 20% for D^+. Thus, we expect:

$$
\begin{aligned}
N[B \to D^0 X]/N[B] &= 4.7\% \\
N[B \to D^+ X]/N[B] &= 1.2\% \\
N[B \to D^{*+} X]/N[B] &= 1.1\%
\end{aligned}
$$

where geometric acceptances are not included. By this argument, the μVDC will improve our ability to fully reconstruct B decays proceeding through charm by more than a factor of 5. If instead, one assumes a 1:1 ratio for direct D^0 to D^{*+} production, then the inclusive D reconstruction rate will be more than 8 times that for the D^{*+}. While there are aspects of the design which will tend to reduce this number, such as geometric losses due to the hexagonal supports, or failure to achieve the design resolution, there are also a number of other factors not included so far, which will work in a positive direction. For example, it will be possible to further reduce background by requiring that the charged tracks from the B decay vertex also form a common vertex, and the subtle, but difficult, problem of double counting is essentially eliminated by the μVDC solution.

2.3.3 B lifetimes and branching ratios

Clearly, the μVDC puts us within reach of several important results. If we assume that 1 year of DORIS operation is dedicated to $\Upsilon(4S)$ running, or equivalently 100 pb^{-1} is accumulated, then we will have a sample of over 800 fully reconstructed B decays. This is sufficient, given the lepton efficiency of ARGUS, to allow a 10% measurement of the $\overline{B}^0$ and B^- semi-leptonic branching ratios. $\overline{B}^0$ and B^- lifetime measurements will likewise be possible, either by the usual impact parameter technique, or directly, since approximately 25% of the B vertices will be separated by more than 2 sigma. The actual rate is sensitive to details of the design of the chamber, and is therefore one of the processes used to set the values of design parameters. In particular, moving the inner chambers outward by 1 cm, degrading the measurement resolution by 50% or increasing the beam tube thickness by 50%, all cause a 20% loss in the rate of separable B vertices.

For many decay channels, we are not necessarily interested in the B which decays through charm. In this case, the D can be used as a tag, signaling that a particular event is a BB pair, and not continuum. Again, we can expect a factor of 5 improvement in the number of tagged events. A 100 pb^{-1} sample would yield not 2160 tagged B events, as would be true at present, but 11700, meaning that branching ratios as low as 2×10^{-4} would be accessible. One particularly interesting channel in this range is the decay $B^- \to \tau\nu$, allowing a measurement of the B meson form factor, f_B, if V_{ub} is known [17]. Another example is the search for hadronic decays via ($b \to u$) transitions. As already noted, such searches are now limited to low multiplicity channels; the μVDC will allow access to high multiplicity channels, with presumably larger branching ratios.

2.3.4 Semi-leptonic spectra

An interesting, and much less model dependent, approach to measuring V_{bu} from the lepton spectrum can also be foreseen. The tagged B sample will contain about 780(400) events with an additional electron(muon) of momentum greater than 0.5(1.0) GeV/c. The vertex topology of these events will naturally divide them into two categories:

	Topology	Contributing events
Class I	Tag vertex plus one additional vertex	$B \rightarrow X_u \ell \nu$ and $B \rightarrow X_c \ell \nu$ where X_c is short lived
Class II	Tag vertex plus more than one vertex	$B \rightarrow X_c \ell \nu$ where X_c is long lived

Class II can be used to either study the semi-leptonic $(b \rightarrow c)$ decays to determine the parameters of the models for that sector, or, via Monte Carlo calculation of the separation probability, to subtract the $(b \rightarrow c)$ component of Class I.

Monte Carlo studies indicate that the probability for a semi-leptonic $(b \rightarrow c)$ transition to appear in Classes I and II is 40% and 60% respectively. Thus, Class II will contain a reasonably pure sample of about 700 tagged $(b \rightarrow c)$ semi-leptonic decays. The subtraction technique will be able to reach upper limits on $(b \rightarrow u)/(b \rightarrow c)$ of under 4% (90% CL). Using only the region above $p|\ell| > 2.4$ GeV/c^2, where no model assumption about the $(b \rightarrow c)$ sector is needed, the present limits are only 8% [11], but could be as much as twice as large given the considerable uncertainty about the $(b \rightarrow u)$ endpoint region [10]. The proposed approach, allowing one to measure the spectrum outside the endpoint region, would not suffer from such model limitations. If the $(b \rightarrow c)$ transitions of Class II are used to fit the parameters of a model for the charm sector, then a limit near 1% should be attainable.

Although the Monte Carlo study has not been made, in principle it should be possible to do the whole analysis without the charm tag. A first vertex could be reconstructed around the lepton, and then the topology of the rest of the event examined as before. This has the potential of increasing the available sample by a factor of nearly 20. The improvement would allow the subtraction technique to also reach the 1% level.

2.3.5 Mixing and CP violation

Some improvement in our ability to search for a di-lepton mixing signal will also be made possible by the μVDC. At present, the dominant source of like-sign di-leptons is the cascade

process:

$$B \rightarrow X \ell_p^+ \nu$$
$$\overline{B} \rightarrow X_c \rightarrow X \ell_s^+ \nu$$

Recent estimates [13, 20], based on the standard model, predict that for a lepton momentum cut of 1.0 GeV/c, the expected mixing signal in a 100 pb^{-1} sample is 24 events, while the cascade background is around 235.

With a precision vertex measurement, we could examine whether the di-lepton pair formed a common vertex, as is likely for two primary leptons, or not, as for a cascade source event, where the charm meson carries the secondary lepton further from the interaction region. Monte Carlo studies indicate that about 70% of the mixing signal would be retained if we required the lepton pair to form a common vertex with probability greater than 5%. The cascade background is accepted only 40% of the time under the same conditions. Thus, we can expect a gain of almost a factor of two in the ratio of signal-to-background just from this simple topological requirement. More sophisticated use of the precision vertex information should lead to further improvement.

Observation of asymmetry in the like-sign di-lepton rate due to CP violation effects seems unlikely. In the conventional picture, the effect is expected to be in the range 10^{-2} to 10^{-3} [20]. There have been a number of suggestions in the literature concerning searches for CP violation manifested as asymmetries in hadronic decay channels [14, 15]. The technique exploits inclusive or exclusive decay channels with final states common to both the B and $\overline{B}$. CP violation is brought about by interference between the phases of competing diagrams. The predicted asymmetries can be quite large, and therefore more favourable to observation.

A possibly accessible example of this type [14] would be:

$$B^- \rightarrow D^0 K_S^0 X$$
$$D^0 \rightarrow K_S^0 X'$$

A tag is required to identify whether the final state resulted from a B^- or B^+ decay. One could use a lepton, with $\eta|\ell| \cdot BR|\ell| \sim 10\%$, but with only a 60% chance that the lepton came from a B^+ rather than a B^0. An alternative would be tagging the B^+ with a $\overline{D}^0$ reconstructed using the μVDC. Backgrounds arise from B decays where the species of D meson is altered by adding extra quark loops. The number of expected events depends on the fraction of $B^+ \rightarrow \overline{D}^0 X$ with X containing a K^0. In a 100 pb^{-1} sample of $\Upsilon(4S)$ decays, we would expect about 100 signal events, with a background of 16, if this fraction is 30%. A limit approaching 15% could therefore be placed on the asymmetry, a level not uninteresting for theory.

On the $\Upsilon(4S)$ this technique only works for the charged B. For the neutral B, produced in a C – odd state, the requirement of a tag, when combined with the mixing phenomenon, results in no expected asymmetry for hadronic channels. Instead, one must move above the $B\overline{B}^*$ threshold, where the $B\overline{B}$ pair will be in a C – even state, and large asymmetries are again expected. From an experimental point of view, this means a reduction by 1/3 in $b\overline{b}$ cross-section, making most tests difficult.

One option which we believe should be seriously considered is running on the $\Upsilon(5S)$ [21]. This lies above the threshold for production of $B_S^0\overline{B}_S^0$ pairs, which are predicted to be completely mixed. The μVDC would tag B_S^0 decays by reconstruction of an F, rather than a D meson. Furthermore, the $b\bar{b}$ cross-section at this energy is approximately 1/2 that on the $\Upsilon(4S)$. A year of running could prove quite important for observation of mixing and CP violation phenomenon outside the neutral kaon system.

2.3.6 Continuum physics

Before concluding, we would like to point out that a μVDC would not only enhance our capability to make contributions to the physics of the b-quark. There are still open questions in the charm field which could be easily answered by an extended run in the continuum. In many ways, the vertex topology of charm decays would be far simpler than that for the $\Upsilon(4S)$: the hard charm fragmentation function results in considerably longer average flight paths (185 μm for the D^0 and 370 μm for the D^+). While D branching ratios and lifetimes are relatively well known, the F and the charmed baryons are not well understood. Both the F and Λ_c have been seen at substantial rates by ARGUS [22]. Lifetimes, searches for W-annihilation channels in F decay, measurements of absolute branching ratios by double tagging, to name a few examples, all seem within reach with the μVDC. Although somewhat outside the main thrust for building the chamber, this enrichment of physics possibilities from our continuum running is an important benefit to be kept in mind.

3 Conclusions

The μVDC represents a pioneering effort to apply new techniques in drift chamber design to the problem of precision vertex determination from low-momentum tracks in a high-rate, high-background environment. The physics potential realizable with vertex resolutions at the level of 15 μm is large and varied. The most direct benefit would be an increase by at least a factor of 5, and perhaps by as much as an order of magnitude, in our ability to reconstruct charm, and by implication, B decays with manageable backgrounds. This is sufficient to allow us to extract from a 100 pb^{-1} sample of $\Upsilon(4S)$ decays:

1. Over 800 fully reconstructed B decays.
2. $\overline{B}^0$ and B^- lifetimes and semi-leptonic branching ratios.
3. In a tagged sample of around 12000 B decays, search for important rare decay channels, such as $B \to \tau\nu$, or high multiplicity non-strange decays.
4. Search for CP induced asymmetries in charged B hadronic decays.

Furthermore, the vertex topology of $B\overline{B}$ events can be exploited to improve limits on ($b \to u$) transitions in semi-leptonic decays, and for $B^0\overline{B}^0$ mixing. Consideration will also be given to requesting extensive running on the $\Upsilon(5S)$, which would probably lead to further important results on $B_S^0\overline{B}_S^0$ mixing and CP violation. Thus, the μVDC, while a thrust in a new direction, will maintain the viability of the ARGUS detector as a competitor in the difficult field of B-physics.

References

[1] J.Huth and D.Nygren, "Feasibility tests of a high resolution sampling radial drift chamber", Berkeley preprint LBL-19462 (1985).

[2] E.Roderburg et al., "The induction drift chamber", Siegen preprint SI-86-01 (1986).

[3] W.Bartel et al., H1-ZEUS internal report (1986).

[4] H.Anders et al., "Feasibility study for a charge coupled device (CCD) as a multiplexing signal processor for microstrip and other particle detectors", CERN preprint CERN/EF 85-10 (1985).

[5] Particle Data Group, Rev.Mod.Phys. **56** (1984), S203 and Erratum. [6] : Branching ratios for D decays were taken from:
J.Hauser (MARK III collaboration), "A systematic study of the decays of charmed D mesons", Ph.D. Thesis, Caltech (1985);
R.M.Baltrusaitis et al. (MARK III collaboration), SLAC preprint SLAC-PUB-3861 (1985).

[7] S.Behrends et al. (CLEO collaboration), Phys.Rev.Lett. **50** (1983) 881.

[8] R.Giles et al. (CLEO collaboration), Phys.Rev. **D30** (1984) 2279;
A.Chen et al. (CLEO collaboration), CLEO preprint 85/636 (1985)

[9] M.S.Alam (CLEO collaboration), as reported at the Lake Louise Conference (1986).

[10] B.Grinstein, M.B.Wise and N.Isgur, Phys.Rev.Lett. **56** (1986) 298;
B.Grinstein, M.B.Wise and N.Isgur, "Quark model predictions for the electron energy spectrum in semileptonic D and B decays", Caltech preprint CALT-68-1311 (1986).

[11] E.H.Thorndike (CLEO collaboration), "Weak decays of heavy fermions", Rochester preprint UR-935 (1985).

[12] D.B.MacFarlane (ARGUS collaboration), "Recent results from ARGUS", Proceedings of the XXth Rencontre de Moriond on Electroweak Interactions, Les Arcs-Savoie (1985) vol.2, 207-218.

[13] A.Fridman and A.Schwarz, Phys.Rev. **D32** (1985) 1650.

[14] A.B.Carter and A.I.Sanda, Phys.Rev.Lett. **45** (1980) 952;
Phys.Rev. **D23** (1981) 1567

[15] I.I.Bigi and A.I.Sanda, Nucl.Phys. **B193** (1981) 85;
Phys.Rev. **D29** (1984) 1393;
L.L.Chau and H.Y.Cheng, Phys.Rev.Lett. **53** (1984) 1037;
R.G.Sachs, "$D^{\pm}$ interference in hadronic B^0, $\bar{B}^0$ as a test of CP-violation" Chicago preprint EFI 85-22 (1985).

[16] V.Lüth, Proceedings of the Vth Conference on Physics in Collision, Autun (1985) 191.

[17] R.Rückl, Habilitationsshrift, University of Munich (1983).

[18] "CLEO II: Updated proposal for improvements to the CLEO detector for the study of e^+e^- interactions at CESR", CLEO preprint CLNS-85/634 (1985).

[19] P.Avery (CLEO collaboration), CLEO preprint CLNS 84/608 (1984);
J.Green et al. (CLEO collaboration) Phys.Rev.Lett. **51** (1983) 347;
S.E.Csorna al. (CLEO collaboration) CLEO preprint CLNS 85/640 (1985).

[20] A.J.Buras, W.Slominski and H.Steger, Nucl.Phys. **B 245** (1984) 369;
L.L.Chau and W.Y.Keung, Phys.Rev. **D 29** (1984) 592.

[21] D.M.J.lovelock al. (CUSB collaboration), Phys.Rev.Lett. **54** (1985) 377;
D.Besson et al. (CLEO collaboration), Phys.Rev.Lett. **54** (1985) 381.

[22] H.Albrecht et al. (ARGUS collaboration), Phys.Lett. **153B** (1985) 343;
R.S.Orr (ARGUS collaboration), to appear in the Proceedings of the European Physical Society meeting, Bari (1985).