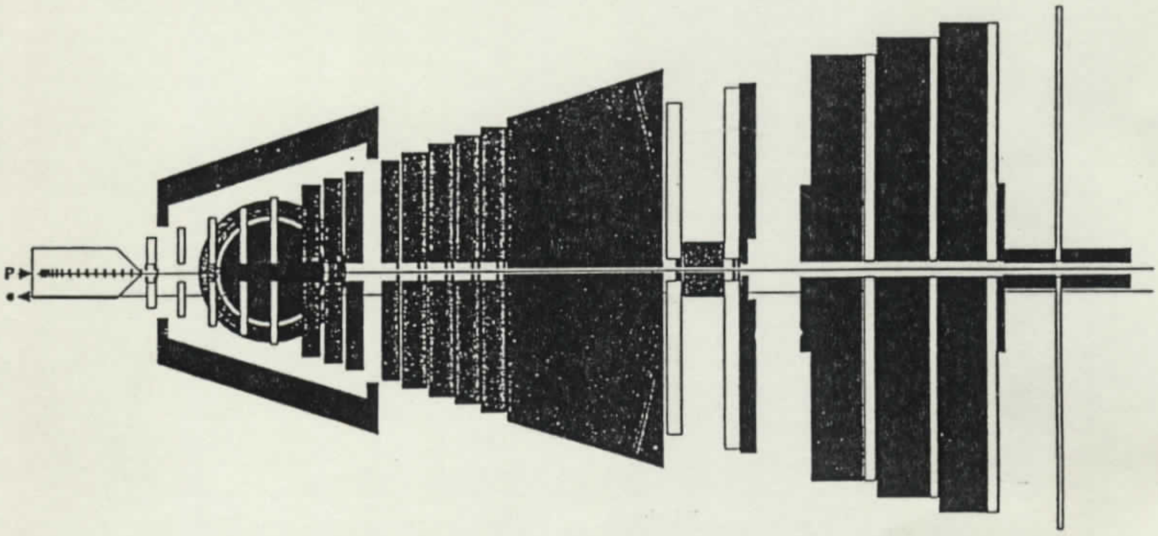
Internal Report
DESY F15-94-01
October 1994

HERA-B

An Experiment to Study CP Violation in the B System
Using an Internal Target at the HERA Proton Ring

Open Collaboration Meeting

October 4 - 6, 1994
DESY, Hamburg



Copies of Transparencies

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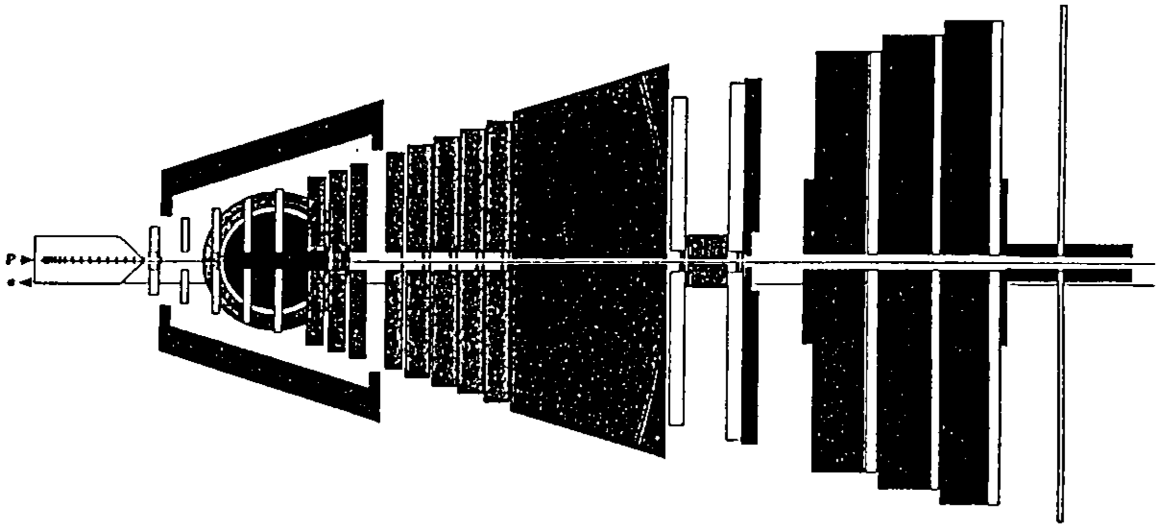


Copies of Transparencies

HERA-B Open Collaboration Meeting

October 4-6, 1994

Tuesday, October 4th, 1994

Morning Session — *DESY Auditorium* — *Chair: P. Söding*

9:15	Welcome	J. May	10 min
	Organizational Remarks	A. Schwarz	10 min A
	The HERA-*B* Detector	W. Schmidt-Parzefall	45 min B

10:30 Coffee Break

11:00	Physics with HERA-*B*	M. Danilov	30 min C
	CP Violation in $B^0 \rightarrow J/\psi K^0_S$	T. Lohse	30 min D
	B Physics Theory Talk	A. Buras	60 min E

Afternoon Session — *DESY Auditorium* — *Chair: D. Wegener*

14:00	Status of the HERA-*B* Project	W. Hofmann	30 min F
	Status and Prospects of HERA	F. Willeke	20 min G
	Beam Optics for HERA-*B*	B. Parker	20 min H
	Tests of the Internal Wire Target	K. Ehret	30 min I

15:50 Coffee Break

16:30	Spectrometer Magnet and		
	Impact on the HERA Electron Ring	R. Eckmann	20 min J
	Detector Challenges	S. Nowak	30 min K
	Vertex Detector	T. Knöpfle	30 min L

18:15 Welcome Drink - Foyer DESY Auditorium -

HERA-B Open Collaboration Meeting

October 4-6, 1994

Wednesday, October 5th, 1994

Morning Session — *DESY Auditorium* — *Chair: G. Carboni*

9:00	Inner Tracking System	F. Eisele	30 min M
	Outer Tracking System	H. Kapitza	30 min N
	Tracker Performance	R. Mankel	20 min O

10:30 Coffee Break

11:15	Electron Identification: Calorimeter	A. Golutvin	30 min P
	Electron Identification: TRD	B. Dolgoshein	30 min Q

Afternoon Session — *DESY Auditorium* — *Chair: R. Schwitters*

14:00	Muon Identification	Y. Zaitsev	30 min R
	Kaon Identification: RICH	P. Krizan	45 min S

15:25 Coffee Break

16:10	First Level Trigger (FLT):		
	FLT: Concept and Performance	D. Reßing	45 min T
	FLT: Implementation	J. Gläss	20 min U
17:25	Offline Software and Data Analysis	H. Albrecht	25 min V

19:00 Buffet Dinner - DESY Cafeteria -

HERA-B Open Collaboration Meeting

October 4-6, 1994

Thursday, October 6th, 1994

Morning Session - DESY Auditorium - Chair: P. Schlein

9:00	VLSI Frontend Architecture	M. Feuerstack	30 min	W
	Data Acquisition System	J. Zweizig	40 min	X
10:20	Coffee Break			
11:00	Second Level Trigger	M. Medinnis	40 min	Y
	Third Level Trigger and Analysis Farm	U. Gensch	30 min	Z
	Concluding Remarks	A. Wagner		

Afternoon: Informal discussions and Laboratory Visit

A. Schwarz
Oct. 4, 1994

Organisational Remarks

Prime Goal of the meeting:

Attract new groups to join this fascinating experiment

↓
- present the current status
- locate bottlenecks and critical path items
- discuss possible collaboration issues

↑ this has determined the agenda

Outline of agenda:

Tuesday:
- Overview and Status of experiment
- interface to HERA-machine
- introduction to detector challenges

Wednesday:
- detailled subsystem description
  - tracking devices
  - electron, muon, kaon } identification
  - First Level Trigger

Thursday:
- VLSI frontends
- data acquisition architecture
- level 2, 3, ...

In order to allow for detailled discussions:

- relatively long coffee breaks

- Tuesday 18:15 foyer auditorium
  Welcome Drink plus individual dinner arrangements

- Wednesday 19:00 DESY cafeteria
  Buffet Dinner

- Thursday afternoon ff. : reserved for further informal discussions

Miscellaneous Comments and Pleas

- all talks are in the DESY auditorium

- Lunch: visit the DESY cafeteria individually

- copies of the HERA-B proposal available in the foyer

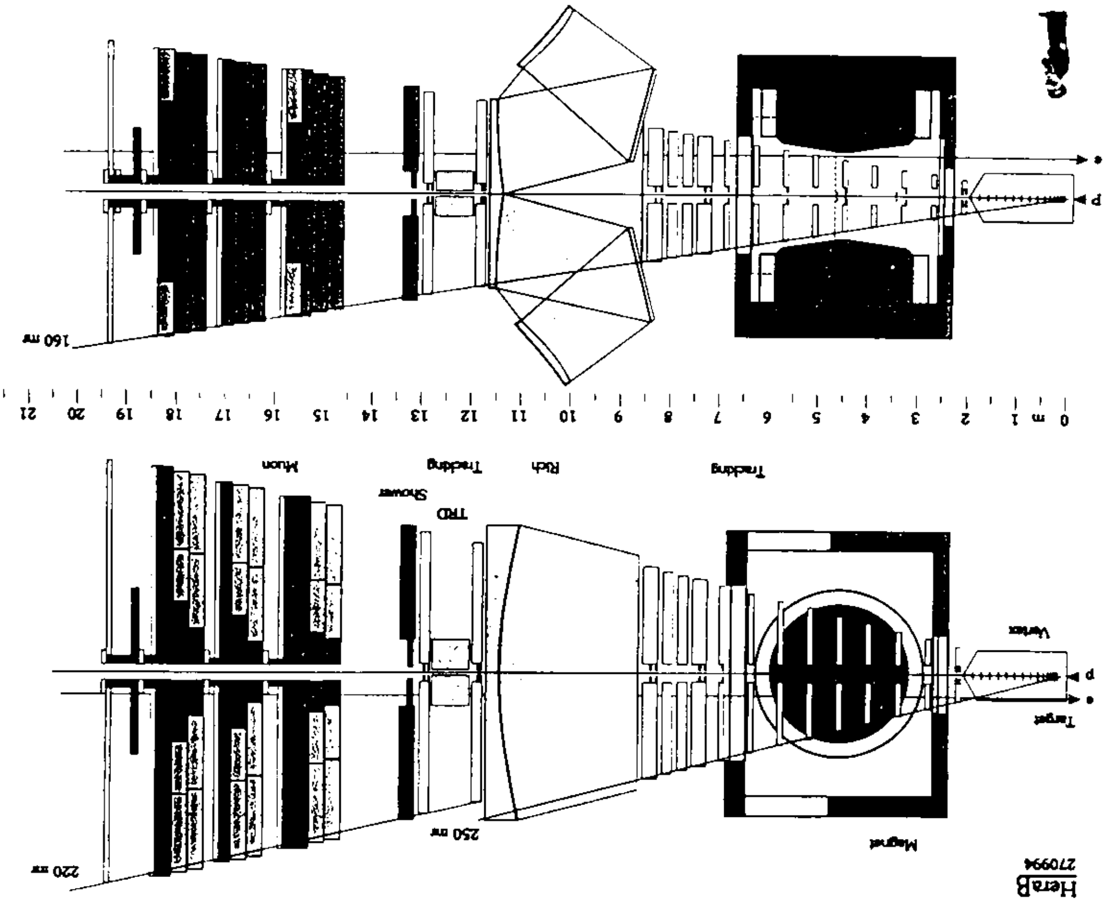
- Please wear the name tags
  (HERA-B people please add "HERA-B" to your name and institution)

- Please fill out the participants list
  - "head count" for the buffet dinner
  - mailing list for transparency copies

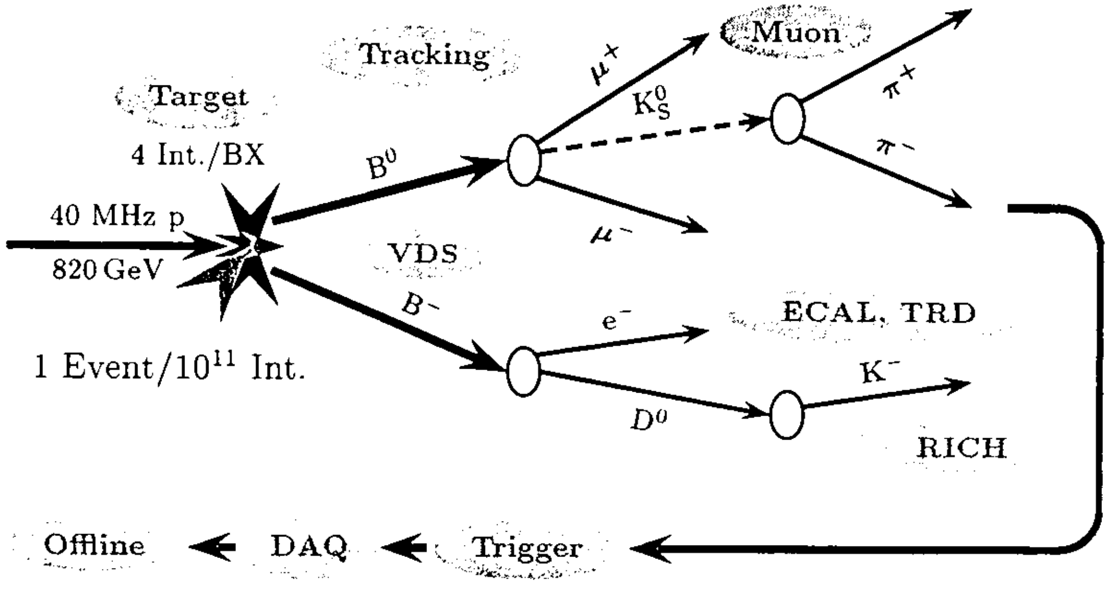
- To the speakers:
  - please hand in your transparencie
  - please stay "in time"

Welcome to the HERA-B meeting!

THE HERA-B DETECTOR
W. SCHMIDT-PARZEFALL
4.10.99



The Challenge: The HERA–B Detector



The Hera-B Detector

- Forward spectrometer 10 - 160 mrad
- Si vertex detector:
  - 1 - 6 cm from beam, retractable
  - exchange once per year
- High granularity tracker:
  - Silicon and gas microstrip at small radii
  - Straw- or honeycomb drift chambers
- Particle ID:
  - RICH ($K^{\pm}$)
  - TRD ($e^{\pm}$)
  - ECAL (Shashlik) ($e^{\pm}$)
  - Muon system (DC) ($\mu^{\pm}$)
- Three-level pipelined trigger and readout

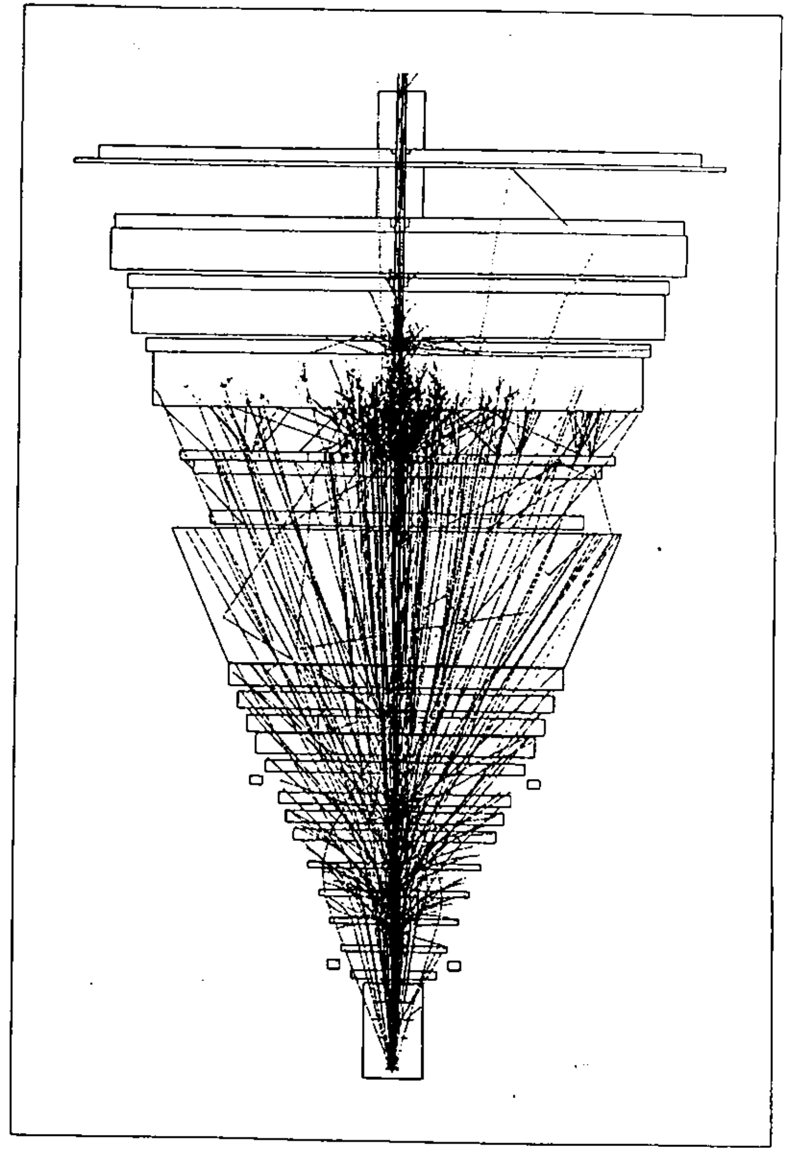
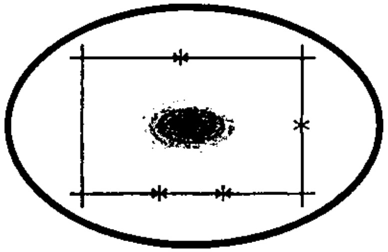


Figure 170: *A GEANT event consisting of multiple overlaying interactions.*

Internal Target

Introduce 8 thin wires (50 μm) into the beam halo to absorb protons leaving the beam core



Interaction Rate:

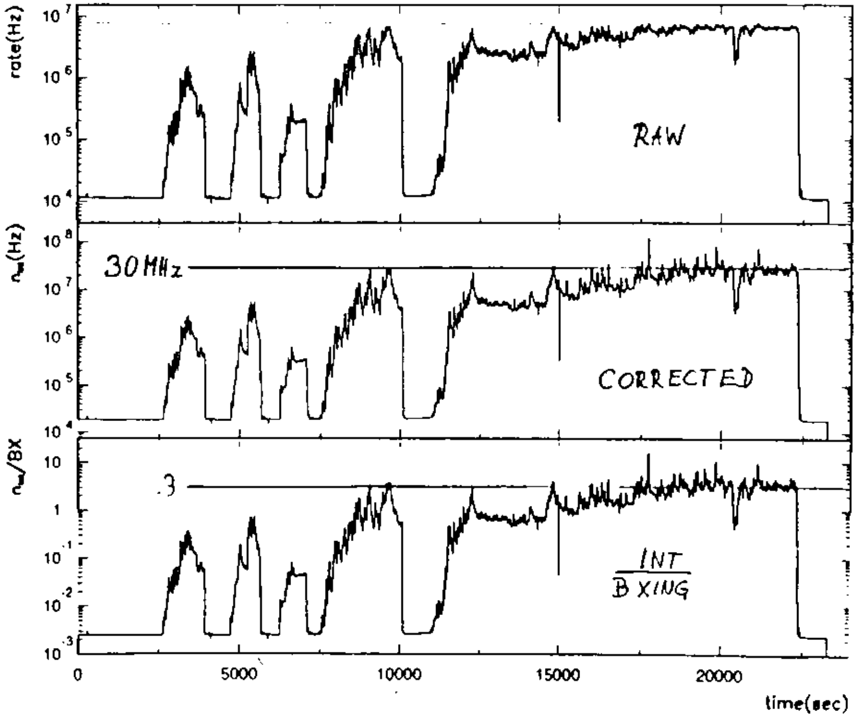
$$R \approx 60\ \text{MHz} \cdot \epsilon_T \cdot \frac{I}{I_{design}} \cdot \frac{100h}{\tau}$$
$$\epsilon_T = \text{target efficiency} \geq 50\%$$

Advantages:

- well localized main vertex
- multiple interactions distributed over several wires
- no interference with ep operation
- easy and reliable operation

B

1994 TARGET TEST



ONLY A FACTOR 1.5 MISSING

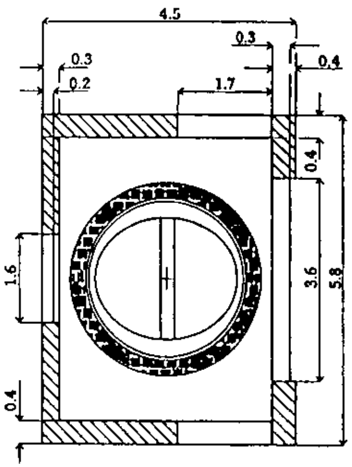
MACHINE IMPROVEMENTS :

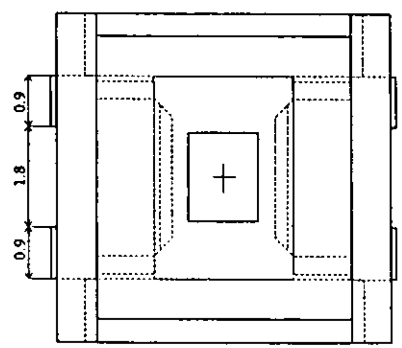
p - CURRENT x 2 EXPECTED

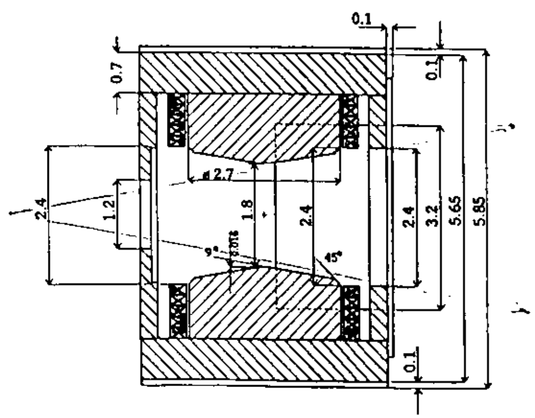
β - FUNCTION 40×30 → 20×20 m

MAGNET

USE ARGUS COIL







HeraB

270994

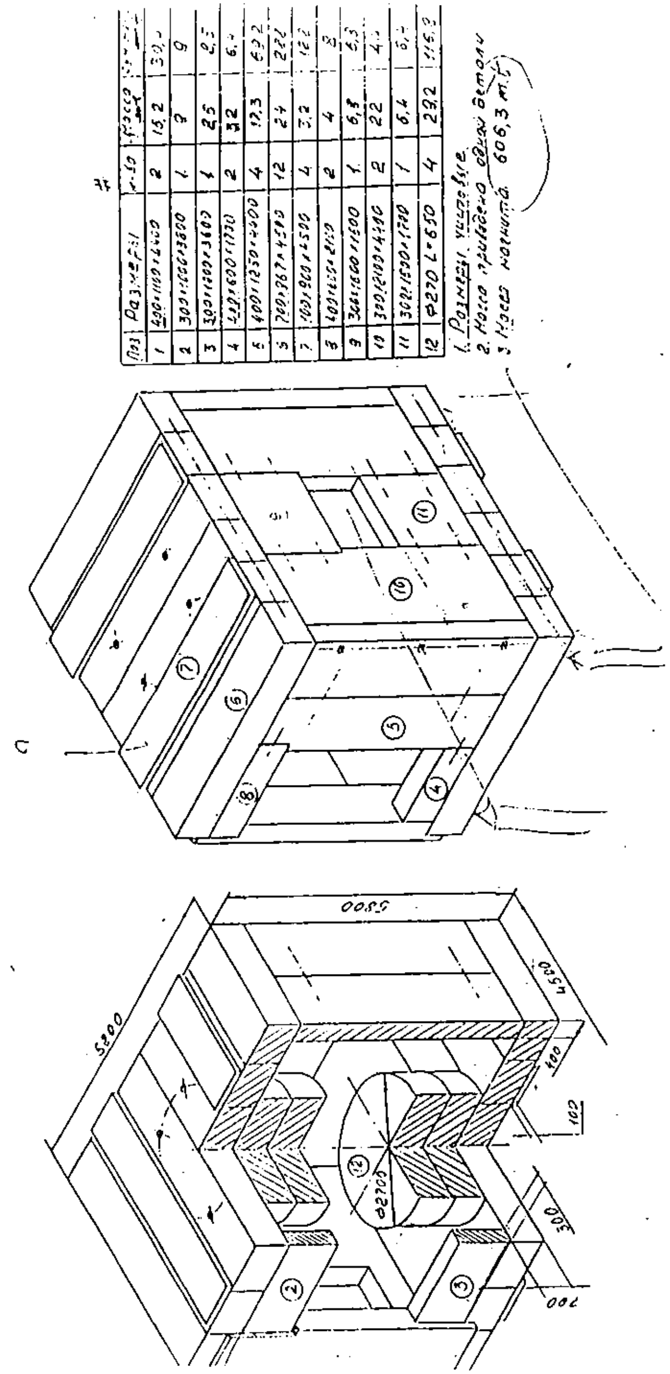
All parameters [m]

Iron yoke :
580 tons

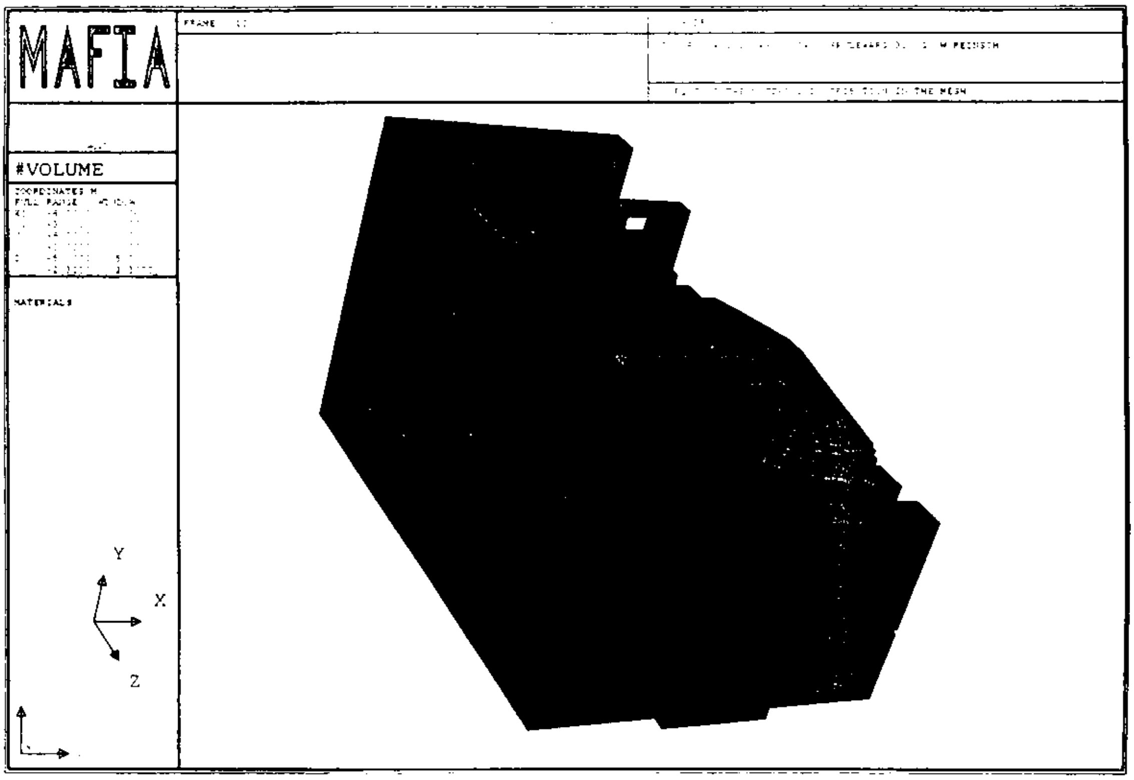
Coil :
Normalconducting
2 x 5 blocks
1.44 MA turns
1.06 MW
4.5 KA 5.0
33 tons
D = 3.40
d = 2.80
b = 0.185

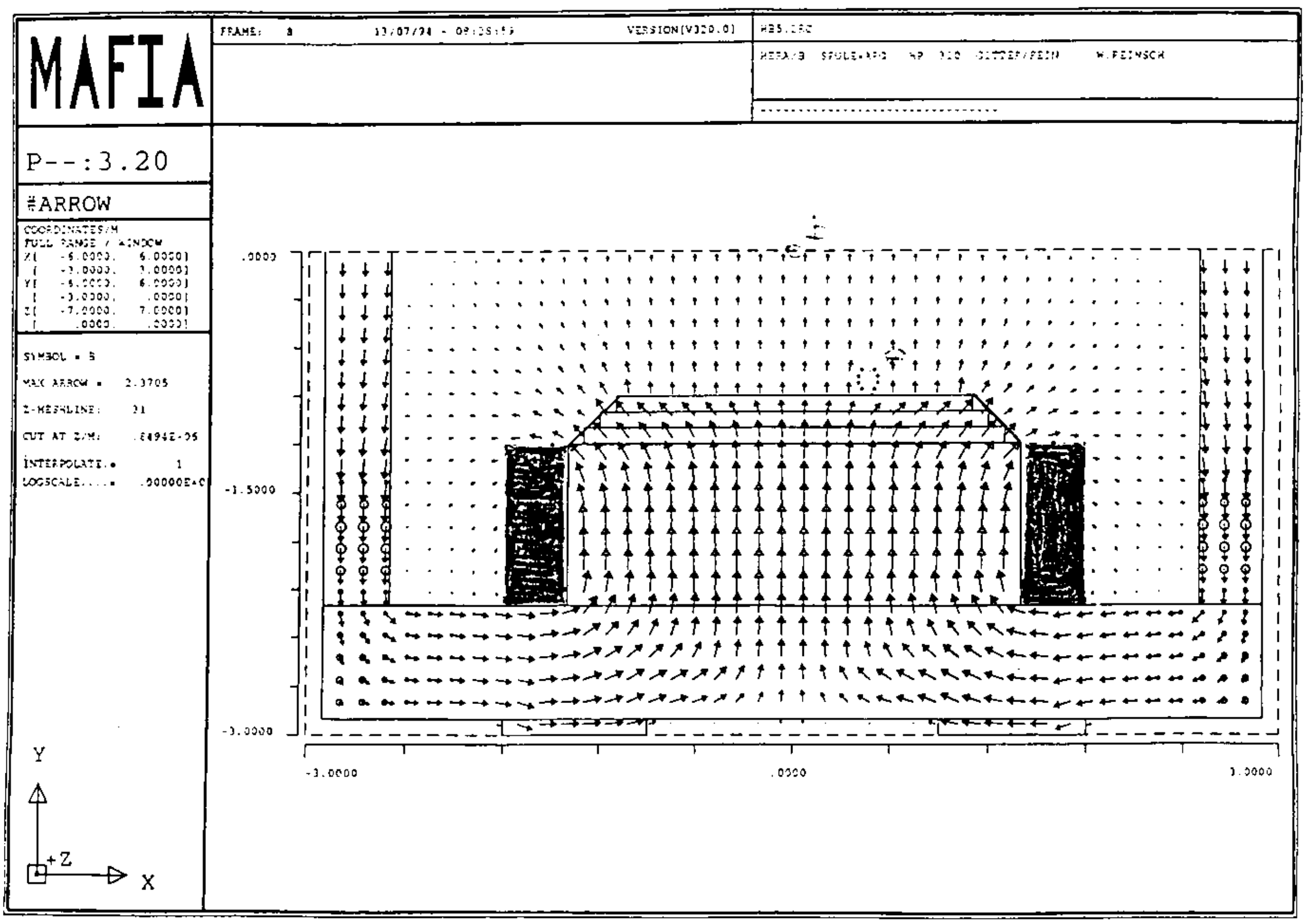
Magn. field :
B 0.75 T
Bdl 2.11 Tm 2.2

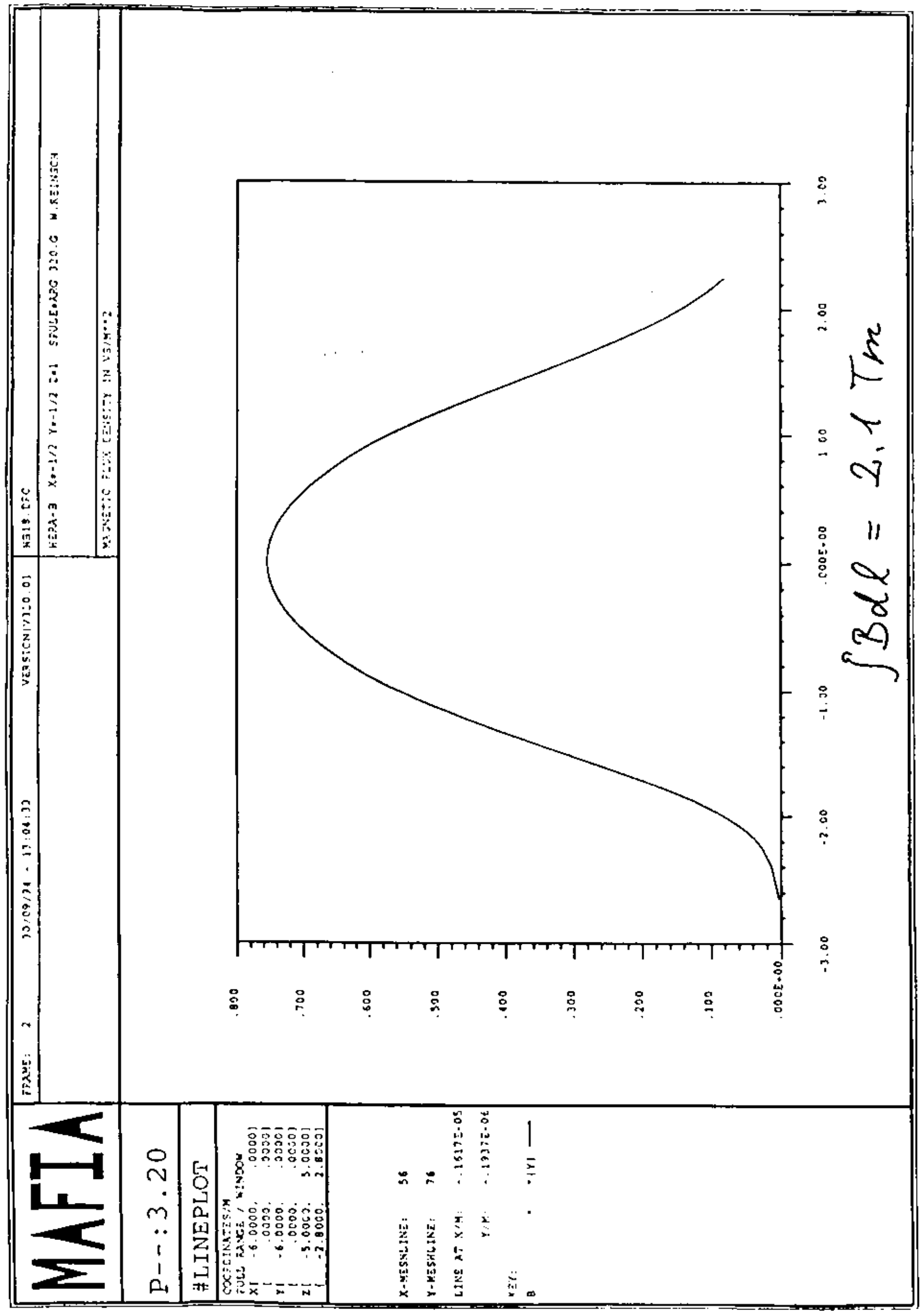
EFREMOV INSTITUTE ST. PETERSBURG



CONCEPTUAL DESIGN
OFFER


MAFIA
#VOLUME
COORDINATES/M
MATERIALS
Y
X
Z


MAFIA
FRAME: 8
13/07/94 - 09:28:59
VERSION(V320.0)
P--:3.20
#ARROW
COORDINATES/M
FULL RANGE / WINDOW
SYMBOL = B
MAX ARROW = 2.3705
Z-MESHLINE: 31
CUT AT Z/M: .64942-05
INTERPOLATE.= 1
LOGSCALE....= .00000E+0
.0000
-1.5000
-3.0000
-3.0000
.0000
3.0000
Y
+Z
X



FIELD REDUCTION

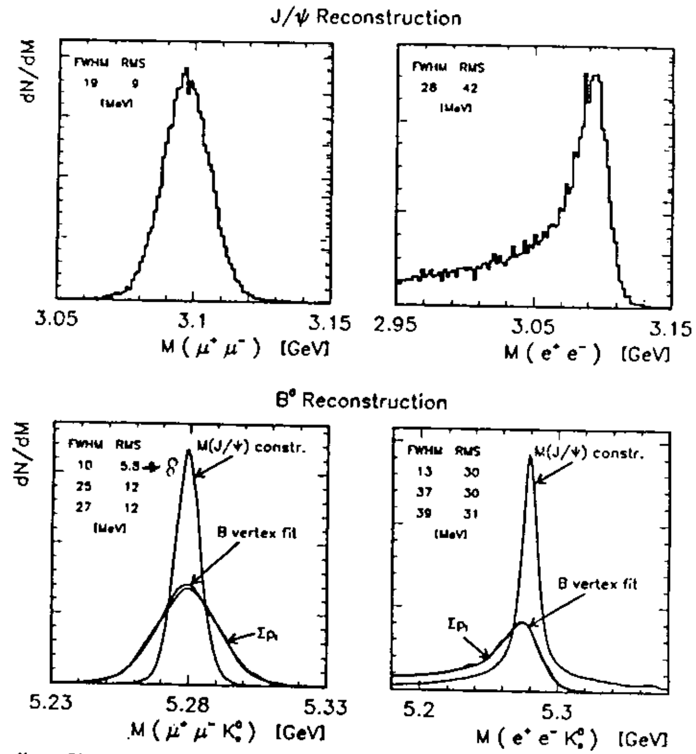


Figure 225: Upper Plots: Reconstructed $\mu^+\mu^-$ and e^+e^- mass spectra for simulated J/ψ decays after the vertex fit. Lower plots: Reconstructed $l^+l^- K^0_s$ mass for simulated B^0 decays without constraints, with common vertex constraint, and with additional J/ψ mass constraint.

3.3 Tm

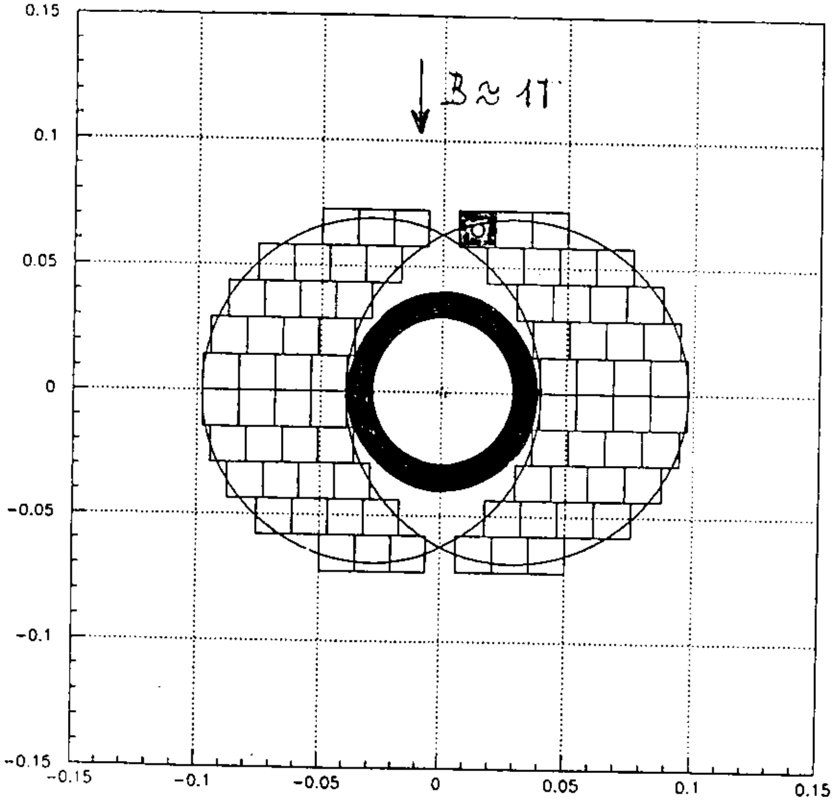
2.2. Tm

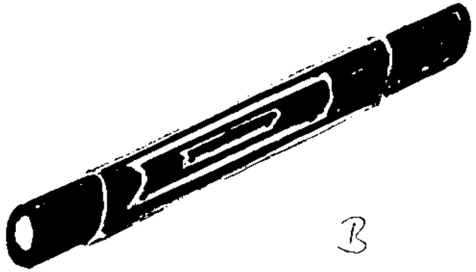
MAGNETIC SHIELD FOR THE e - BEAM

COIL → ± 5%

IRON TUBE → ± 0.2%

94/09/30 12.24





VERTEX

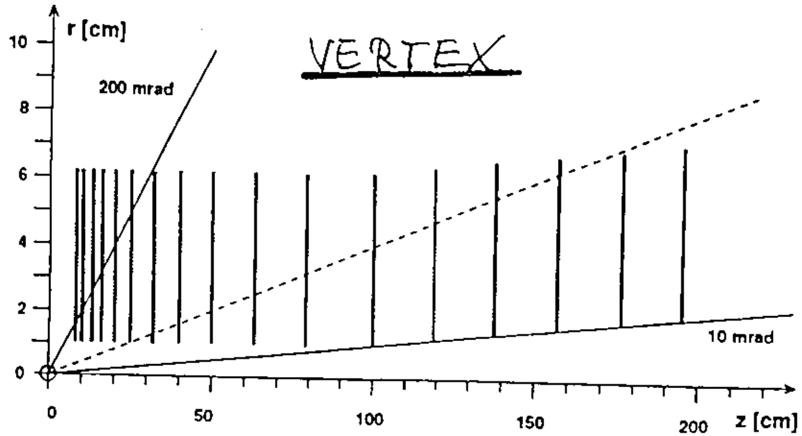


Figure 36: *Side view of the Vertex Detector System showing the detector positions. A track will never hit all but only a group of detector planes.*

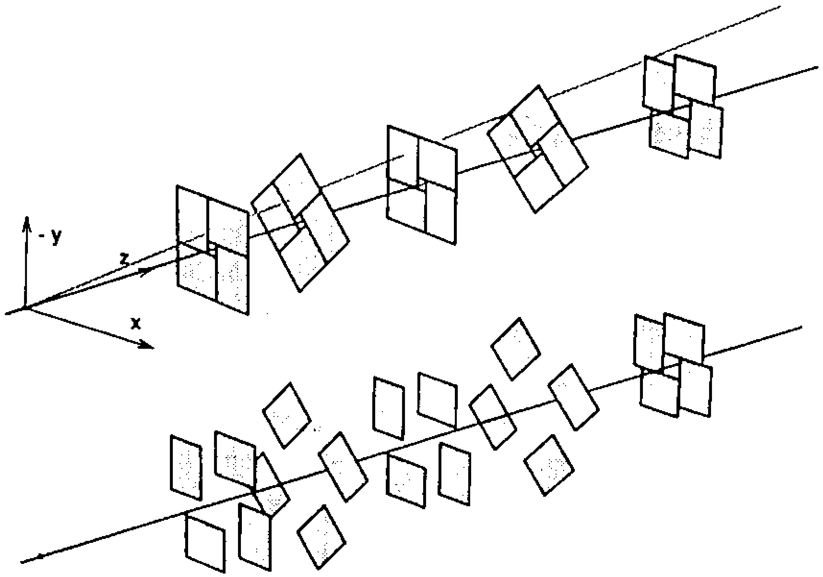


Figure 37: *Perspective view of the first four planes as well as of the last plane of the Vertex Detector System. During fills the detector elements of all but the last plane will be retracted to safe positions as shown in the lower part of the figure.*

CHANGES DISCUSSED

DOUBLE SIDED SI , SMALL ANGLE STEREO

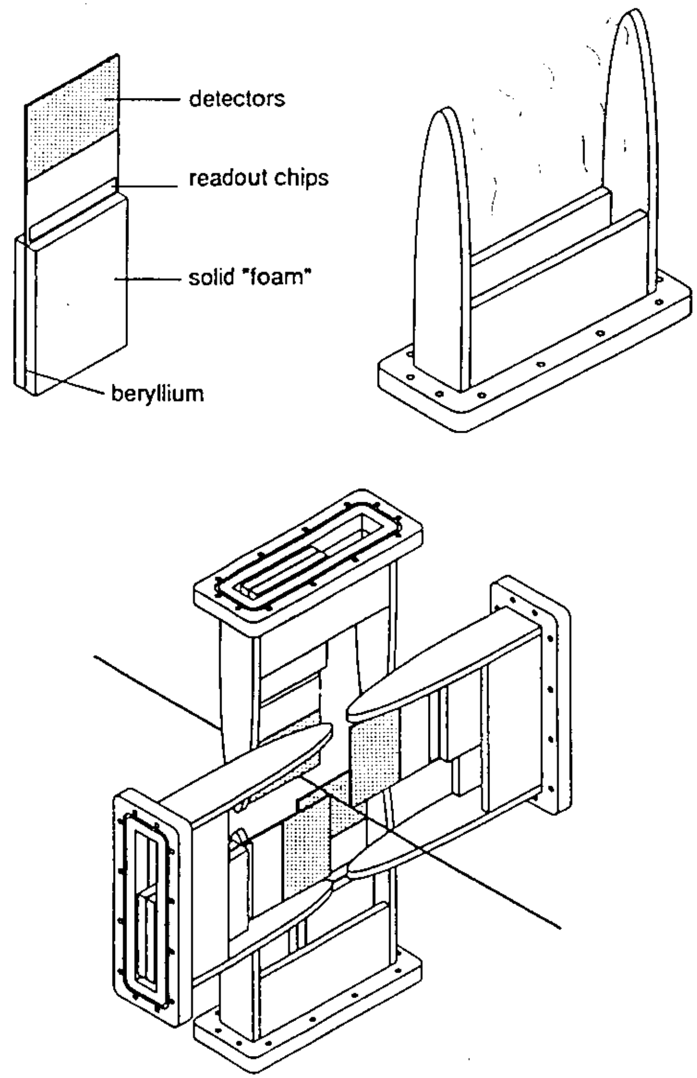


Figure 48: *Perspective views of a detector module with its shielding cap (top), and of the arrangement of the four detector modules including their caps within one layer. The thin aluminium foils covering the caps are not shown*

VERTEX RESOLUTION

ADEQUATE FOR ~~CP~~

WE CUT AWAY 50% OF B-MESONS,

IS ~NO LOSS IN CP-REACH

BUT

VERTEX RESOLUTION

NOT OPTIMAL FOR ADDITIONAL PHYSICS

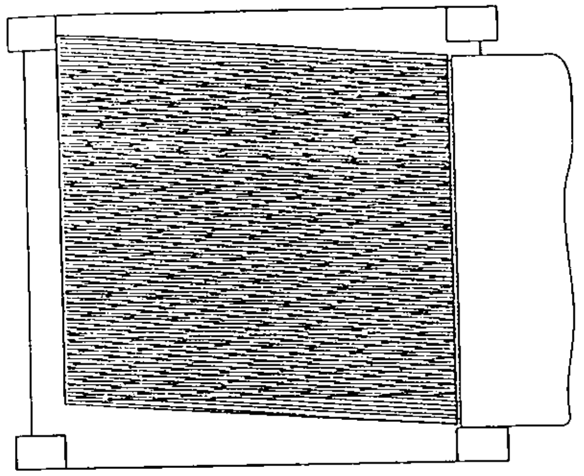
B_s - MIXING REQUIRES AN IMPROVEMENT OF A FACTOR **1.5**

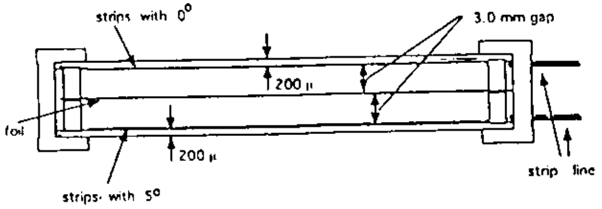
NOW ⟶

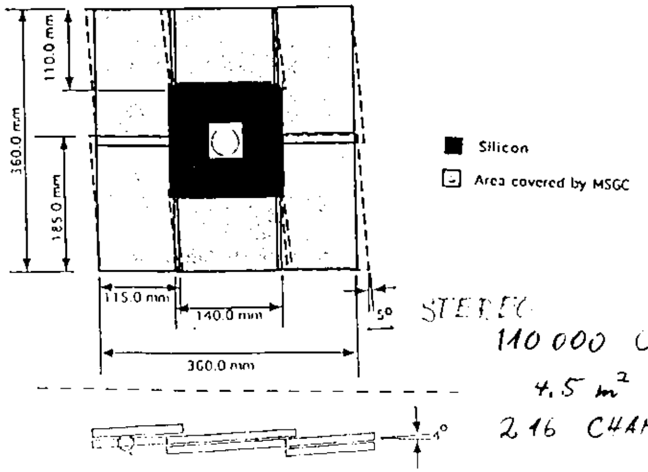
NO GOOD **GOOD**

THE MICRO STRIP GAS CHAMBERS

scetch of one MSGC double layer







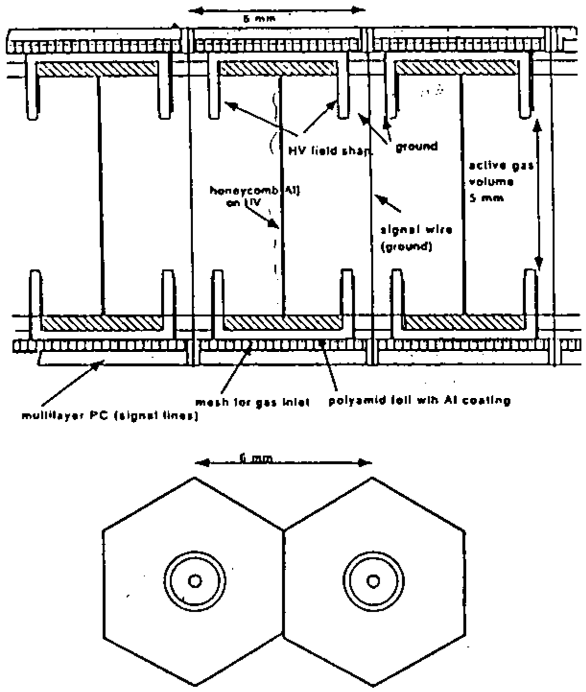
STEREO

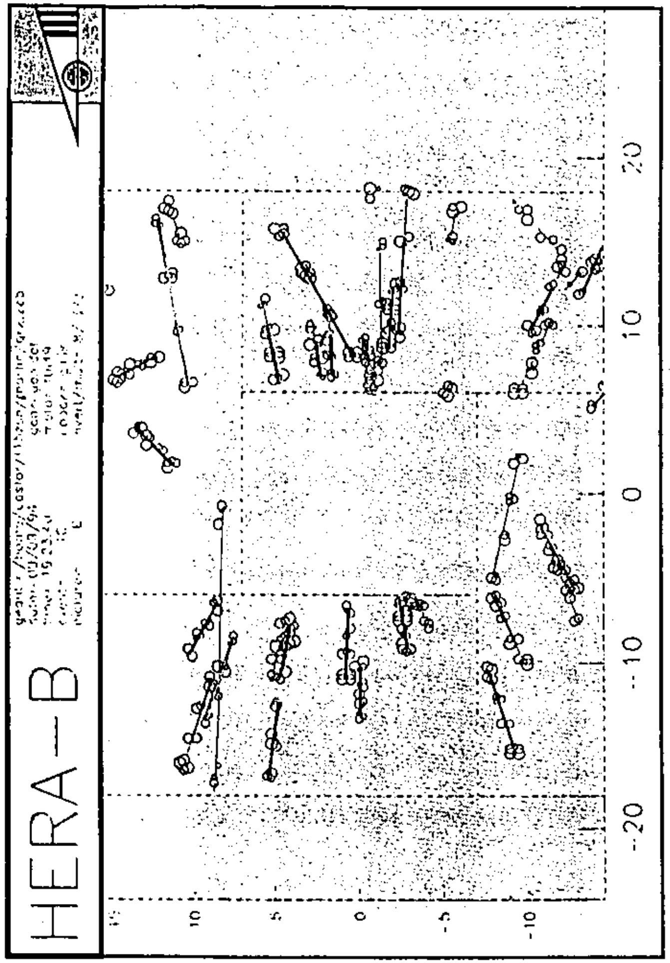
110 000 CHANNELS

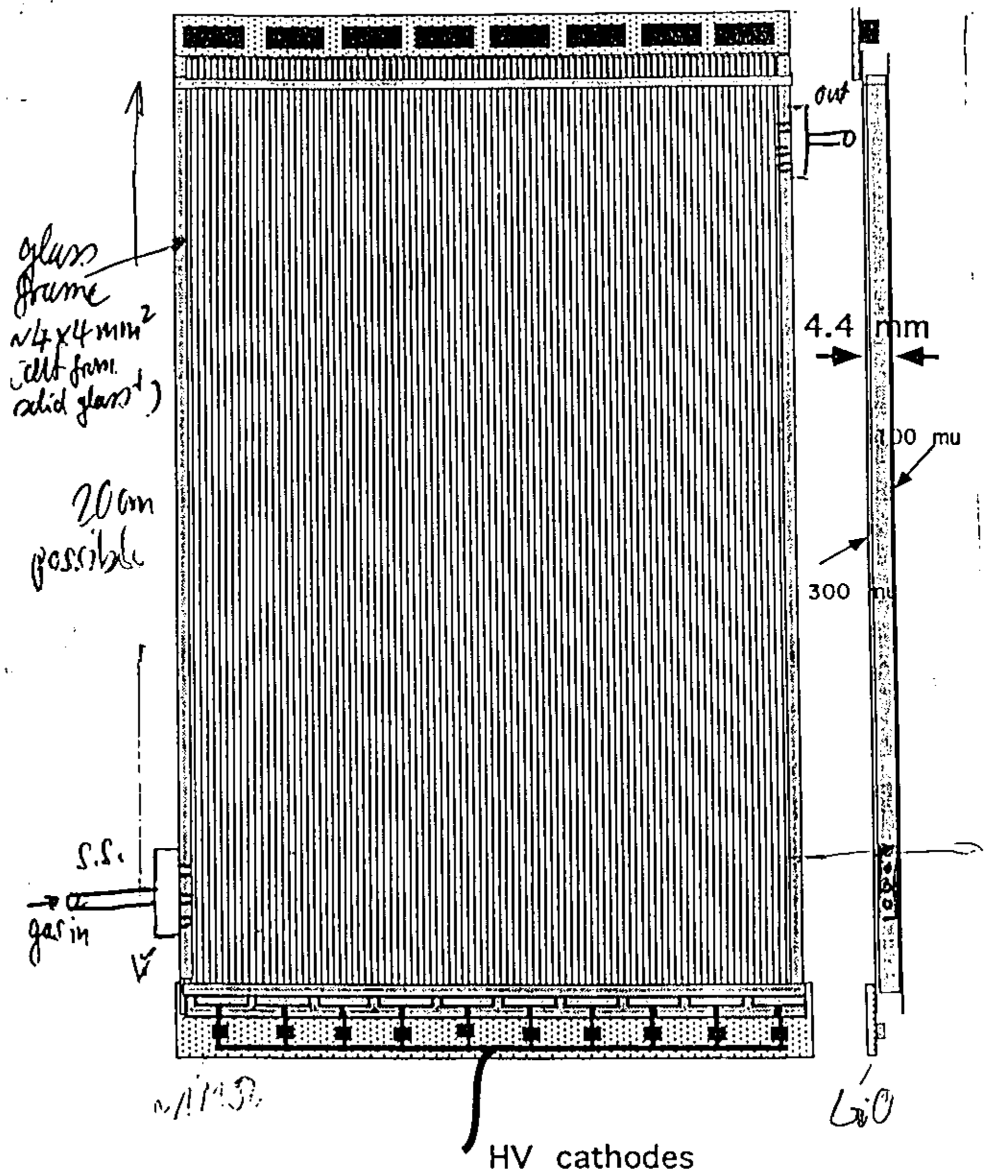
$4.5\ m^2$

216 CHAMBERS

INNER TRACKER







RECENT PROGRESS WITH MSGD

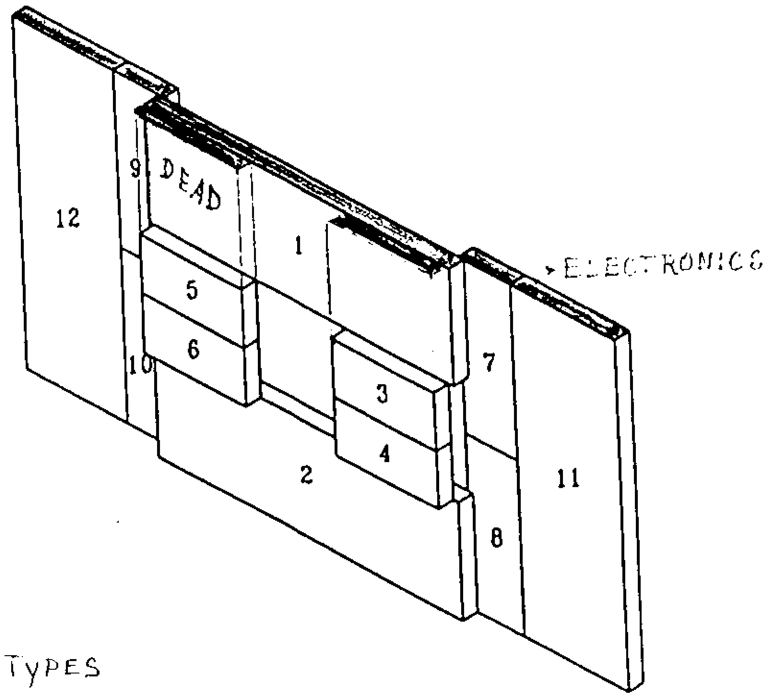
THE MAIN TRACKER

STRAW (HONNEYCOMB) CHAMBERS

OCCUPANCY < 10% FOR 5 EVENTS

SEGMENTATION OF A LAYER INTO 12 SECTIONS

Ø 5 mm FAR OUT Ø 8mm



4 TYPES

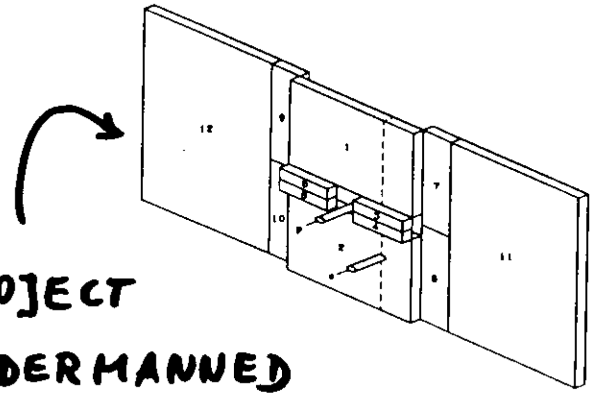
Tracker:

Particle flux = $3 \cdot 10^7/R(cm)^2/sec$

Trackers with different pitch required to limit the occupancy

radius (cm)	max. occup.(%)	detector
2 < R < 6	5%	Si-strip
6 < R < 19	3%	gas microstrip or pixel chamber
19 < R	≈ 15%	Straw or Honeycomb TRD/Tracker

Segmentation of a superlayer:



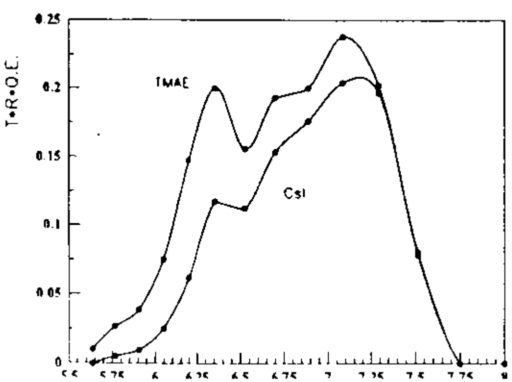
PROJECT UNDERMANNED

Čerenkov Counter

- C_4F_{10} Radiator
- Mirror à la OMEGA
- Photon detector (10 m^2, 64 modules, $8 \cdot 8$ mm^2 pads)
  - TMAE - CH_4 gas mixture
  - Pads covered with CsI
- Read-out system (160000 channels)

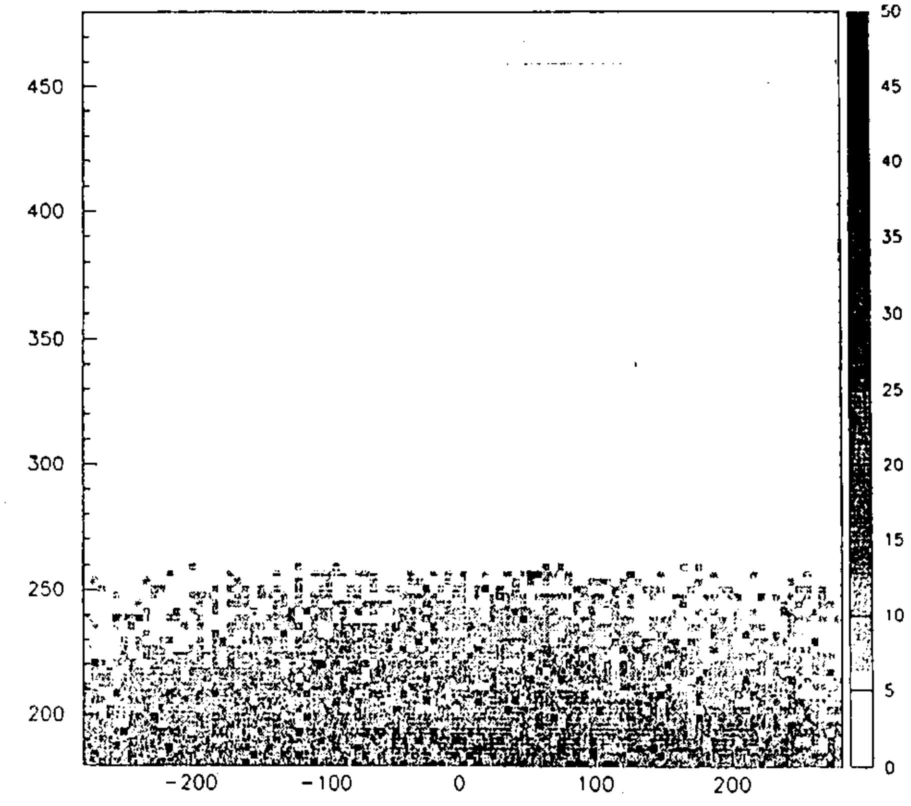
Photoelectron yield:

(Transmission · Reflectivity · Quantum Efficiency)



B

Particle density in RICH - phot detec region



Photon detector at 1100 cm, lower and upper plane folded!
particle density / 20 cm² for 3000 events (1+4) [charged + neutr.]
max. values 25 - 30 particles / 20 cm² = 0.00021 ÷ 0.00025 / cm² / event / side
24 ? at 170 cm [illegible]

Beam Tests

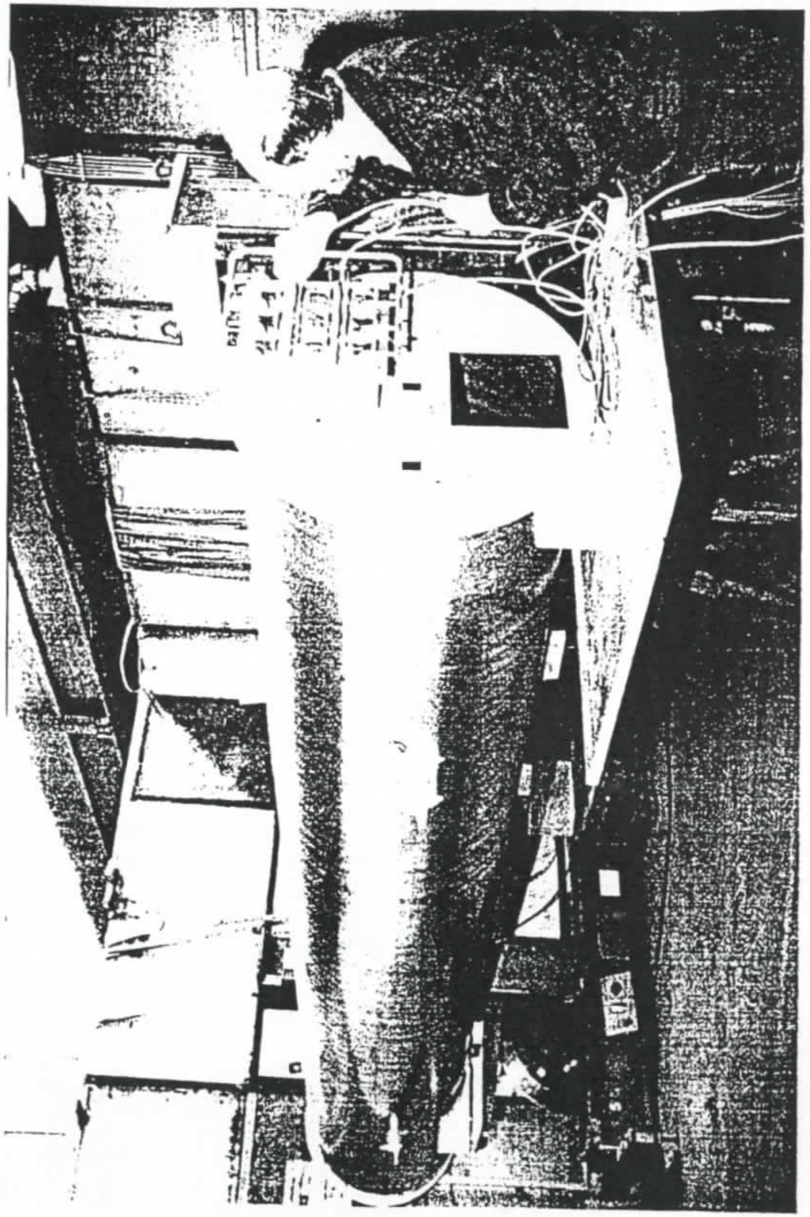
Rich with both photon detectors installed at DESY test beam. Radiator and mirror aligned, TMAE chamber operational.
Size of photon detector $25 \cdot 25\text{cm}^2$
Use Argon as radiator

	radius	# of photons
expected	11.4 cm	14.5
observed	$\approx$ 11.2 cm	$\approx$ 13

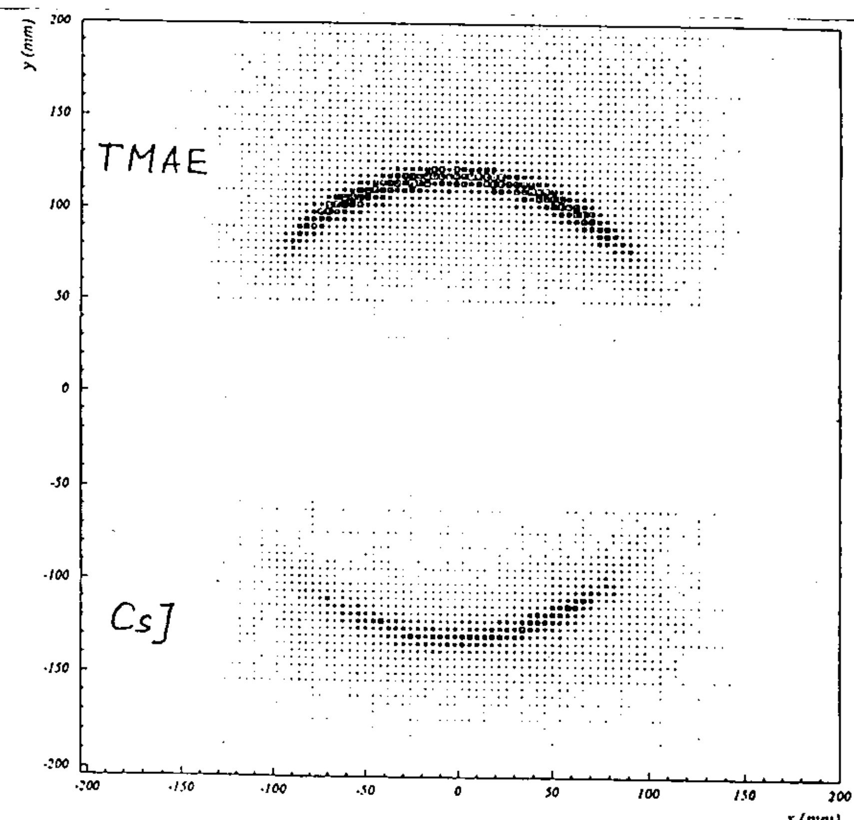
Expected number of 14.5 corresponds to 36 photons

Need 40 REACHED

RICH BEAM TEST



RICH BEAM TESTS



both chambers with track info

BOTH OPTIONS OPERATIONAL

CsJ PHOTON - SYSTEM EFFICIENCY ~3x LOWER

Decision on the detector type will be based upon:

- Number of photons
- Timing properties
- High rate capabilities
- Ageing
- Dead time of the detector
- Sensitivity to charged tracks (background)
- Cost
- Production
- Replacement, handling

TRD

ONLY THE FWD TRD REMAINS

WE SHOULD STUDY IF IT CAN BE USED FOR THE TRIGGER

MATERIAL

	PROPOSAL	NOW	THIN VERSION
X_0 %	80	56	≥ 40

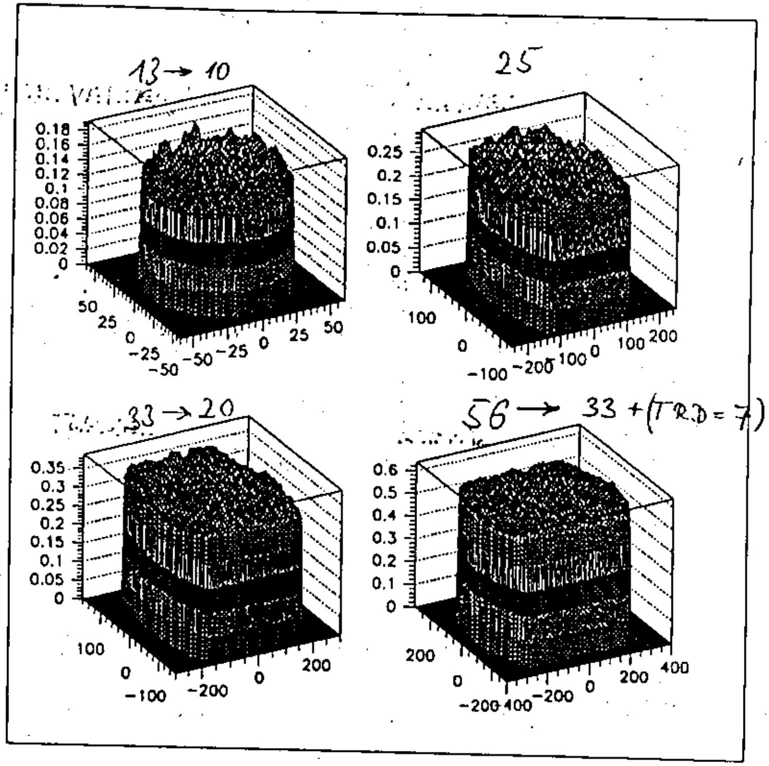


Figure 1: *Material distributions*

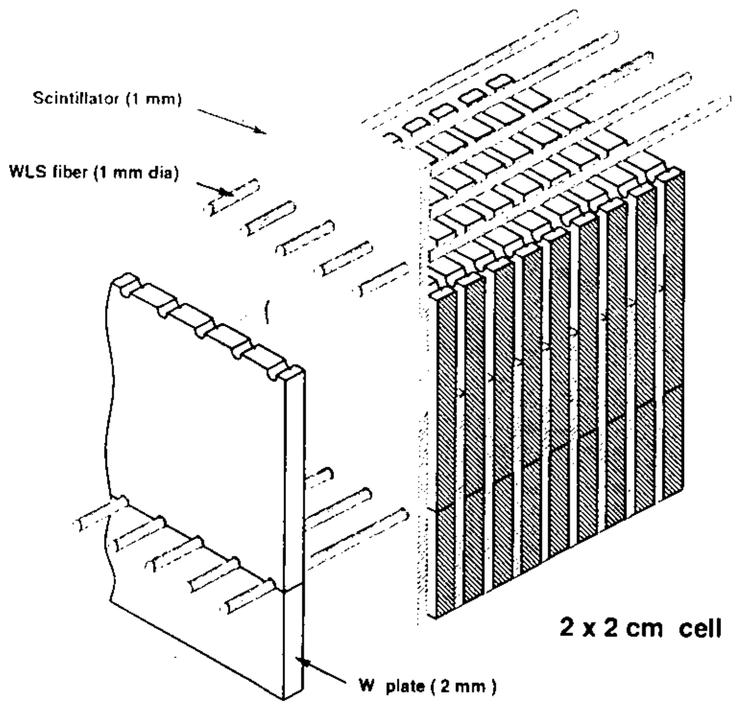
	WT01	WT02	WT03	WT04	WT05
n	6	4	4	4	4
RL cells %	.70	.47	.47	.47	.47
d of rohacel	2 cm	1.6 cm	1.6 cm	1.6 cm	1.6 cm
RL of rohacel%	.25	.20	.20	.20	.20
total RL %	.95	.67	.67	.67	.67

that no frames, electronics ... is implemented at the moment.

CHAMBER REGION

KonstrOption of the inner calorimeter:

SHASHLIK type calorimeter (need to be tested with prototype)



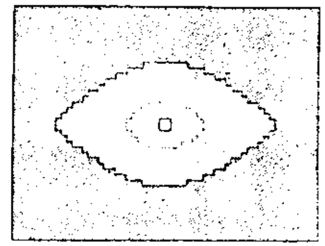
2 x 2 cm cell

Expected resolution ~ $\frac{14\%}{\sqrt{E}}$ (GEANT)

MOLIERE RADIUS 1 cm

B

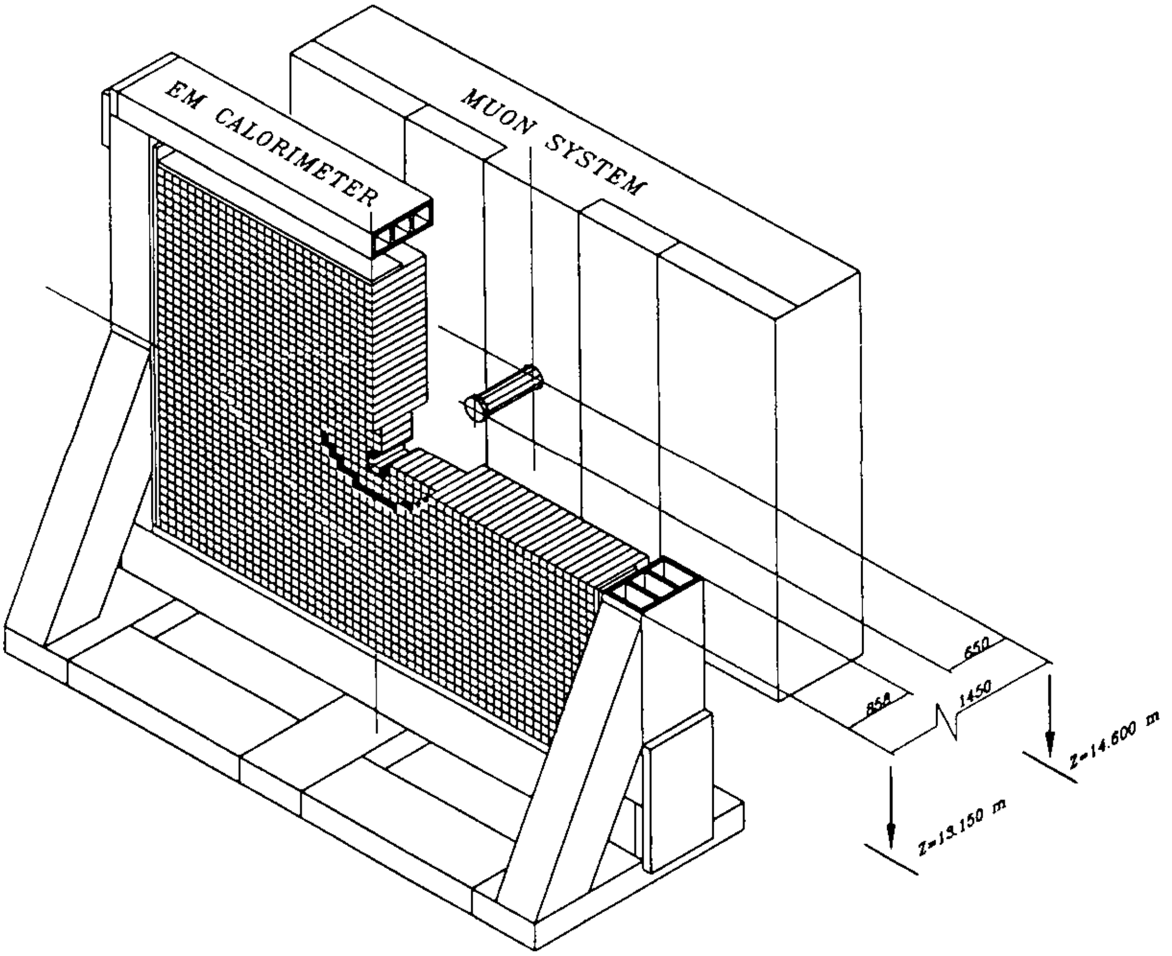
HERA – B calorimeter



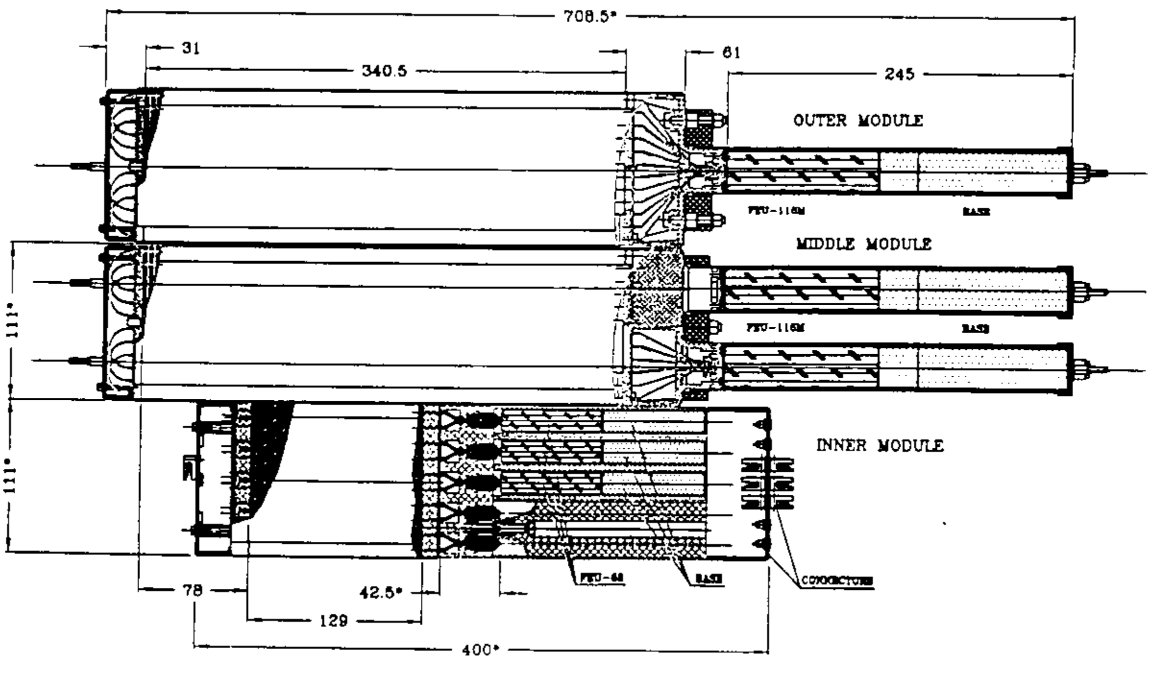
Distance from the target	1315 cm
Covered acceptance	220 mrad x 160 mrad
Size	624 cm x 468 cm
Weight	49.5 tons
Readout	5768 channels

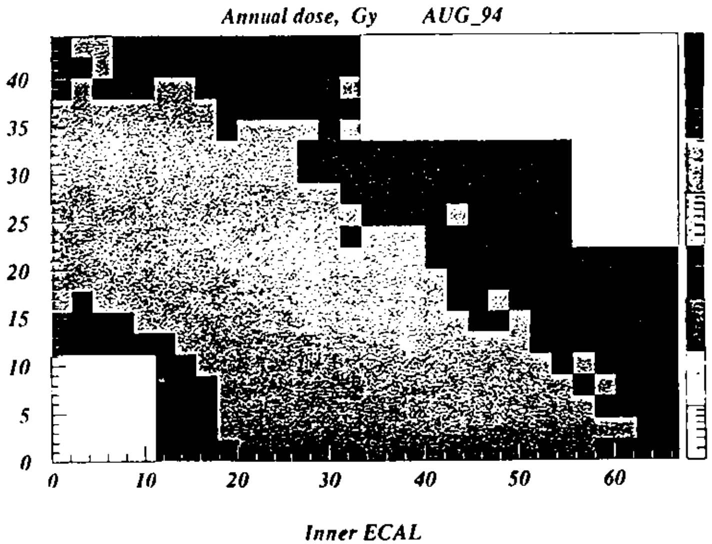
	Inner	Middle	Outer
Outer size	156 cm x 89 cm	446 cm x 245 cm	624 cm x 468 cm
Type	Shashlik	Shashlik	Shashlik
# of channels	2000	2000 *	1768
Absorber	Tungsten	Lead	Lead
Volume ratio	W : Scint = 2 : 1	Pb : Scint = 3 : 6	Pb : Scint = 3 : 6
Moliere radius	1.2 cm	3.5 cm	3.5 cm
Radiation length	0.52 cm	1.64 cm	1.64 cm
Cell size	2.23 cm x 2.23 cm	5.575 cm x 5.575 cm	11.15 cm x 11.15 cm
Depth	12 cm (23 Xo)	33 cm (20 Xo)	33 cm (20 Xo)
Weight	1.85 tons	11 tons	36 tons
Absorb. weight	1.52 tons	7.8 tons	27.5 tons
Scint. weight	42 kg (1 mm plates)	1450 kg (6 mm plates)	5126 kg (6 mm plates)
WLS fibres	1.6 km	36 km	127 km
PMT type	FEU – 68	FEU – 115M	FEU – 115M

B

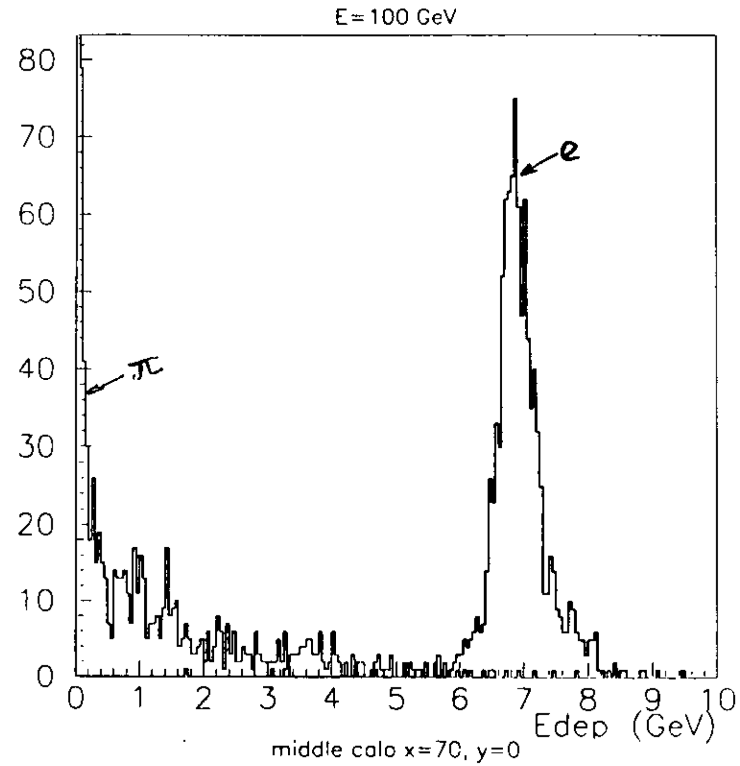

EM CALORIMETER
MUON SYSTEM
650
1450
858
Z=14.600 m
Z=13.150 m

34

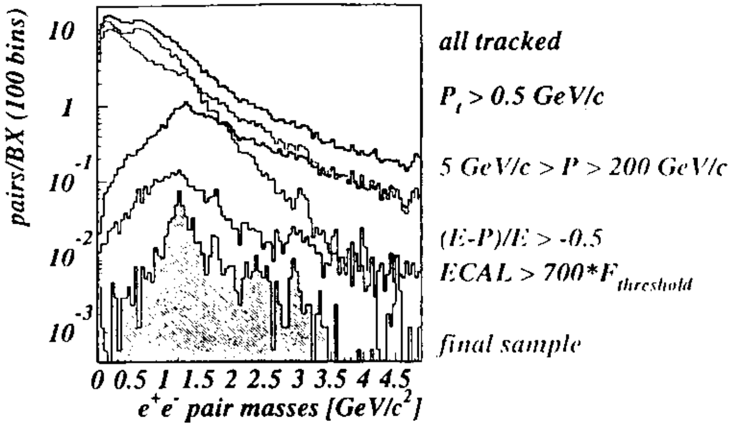

708.5*
31
340.5
61
245
OUTER MODULE
MIDDLE MODULE
INNER MODULE
111*
111*
78
42.5*
129
400*



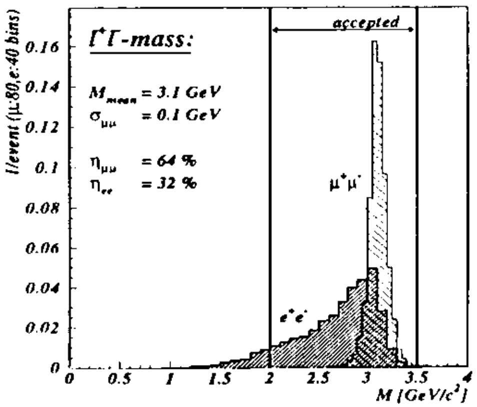
e – π SEPARATION OF THE CALORIMETER



Invariant mass distribution of e^+e^- pairs for minimum bias events



Invariant mass distribution of e^+e^- or $\mu^+\mu^-$ pairs for $B \rightarrow J/\psi$ events



THE EFFICIENCY FOR ELECTRONS MUST / CAN BE INCREASED → Andre
IMPORTANT FOR ~~CP~~ AND ADDITIONAL PHYSICS

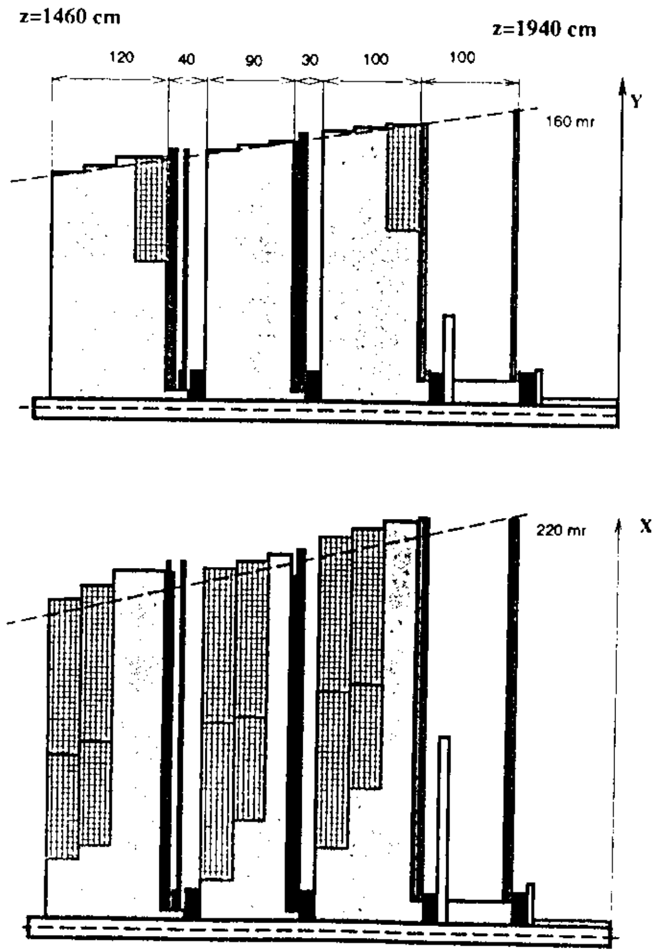
B

Yu.Zaitsev
14.09.94

Muon system layout

z_0 = 1460 cm

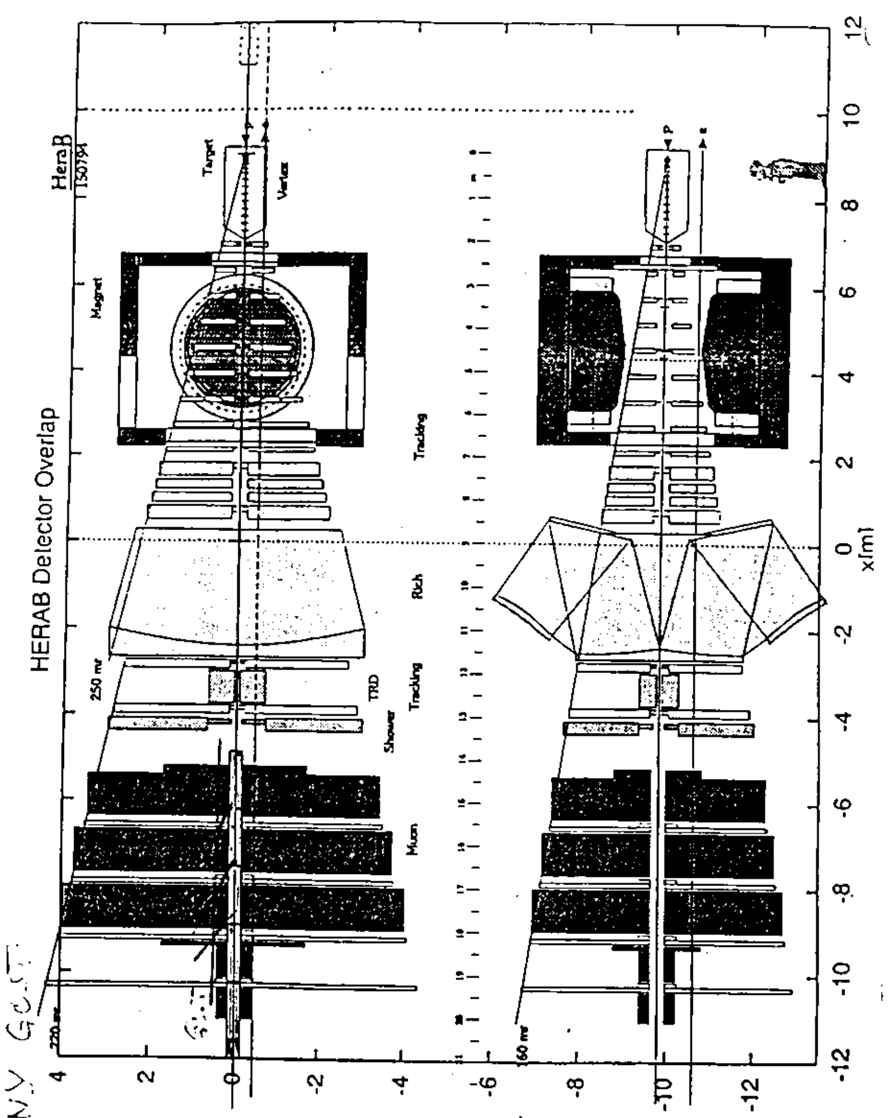
(preliminary)



B

DUMP KICKER IN THE MUON FILTER NOT ACCEPTABLE

TOO MANY GOST



KICKER

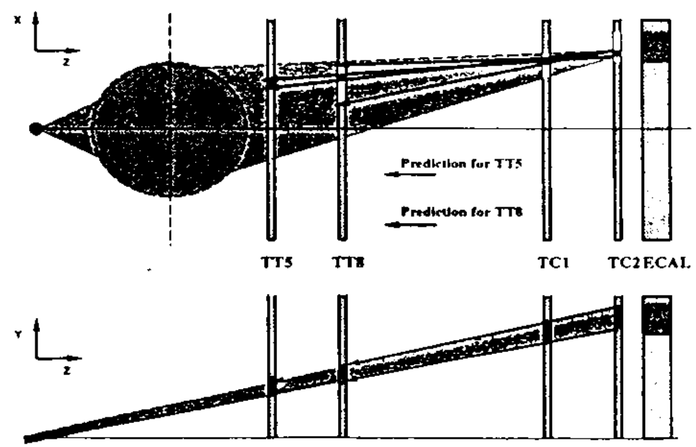
B

First Level Trigger

Trigger on J/ψ and $b\bar{b} \rightarrow l\,l\,X$
Reduction factor > 200

Principle (J/ψ trigger):

- Lepton pretrigger (ECAL, Muon)
- Follow track (Kalman filter) up to magnet
- Calculate momentum using main vertex
- Apply p, p_t and $(E-p)$ cuts
- $2.0(2.5) < M < 3.5$ GeV/c^2 for $e^+e^-(\mu^+\mu^-)$



B

FLT Performance

Extensive simulation and performance tests of FLT:

- Full GEANT simulation
- Lepton pretrigger
- Track finding using TFU's
- Flow of trigger information, messages between TFU's
- Complete time behaviour including mass calculation

Number of lepton candidates/BX (min. bias):

	$e^{\pm}$	$\mu^{\pm}$
pretrigger	1.7	1.0
tracking	1.1	0.6
p, p_t-cuts	0.36	0.18

WE MUST BE ABLE TO RUN WITH HIGHER RATES

Main Components of the HERA-B Detector

Detector	*Technology*	*Channels*	*In trigger level*
Vertex detector	Silicon microstrips (Resolution)	165000	2,3
Magnet	~~Sup~~Superconducting dipole		
Tracker	Si microstrips (r ≈ 2 - 6 cm)		2, 3
	MSGC or gas pixel ch. (r ≈ 6 - 20 cm)	135000	1,2,3
	Straw and honeycomb chambers (r > 20 cm)	15000	1,2,3
TRD/~~Tracker~~	Straws + foil radiator (ONLY FWD)	77000	2,3
RICH	CsI/chamber or TMAE/cellular chamber	120000	-
Trigger chambers	Honeycomb drift chambers	wires: 37000 ?	1,2,3
	# 2-LEVEL CANDIDATES	pads: 15000 ?	1
EM Calorimeter	W-Scint. (r ≈ 20 - 100 cm)	2000	1,2,3
	Pb-Sint (r > 100 cm)	4250	1,2,3
Muon System	Extruded drift chambers (Dump Kicker)	wires: 21500	1,2,3
		pads: 8000	1

LOTS OF WORK

M. Danilov

DESY 4.10.94

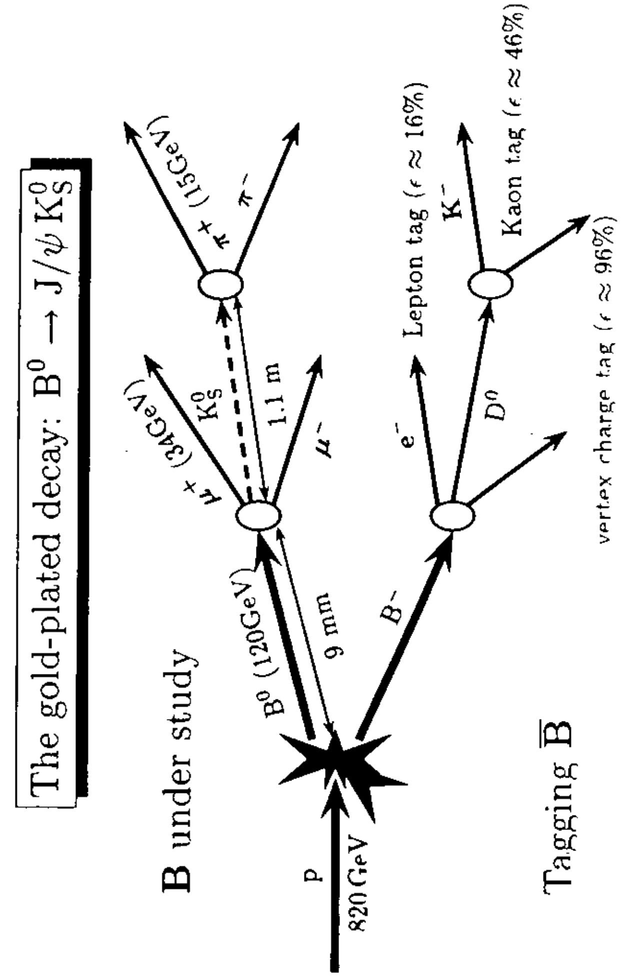
PHYSICS WITH HERA-B

INTRODUCTION

- Last 25 years – spectacular success of SM (t quark – the latest example)
- Nevertheless there are still problems
  - Origin of Mass ⇒ Build LHC
  - Origin of $\not{CP}$ ⇒ Build HERA-B, B factories, LHC
  - Too many parameters ⇒ Measure 4 of them using B
- b hadrons can be sensitive to New Physics
  - Long τ (still growing!)
  - Large M
  - 3[rd] family
- b physics is exiting
- HERA-B can do a lot of it

Outline

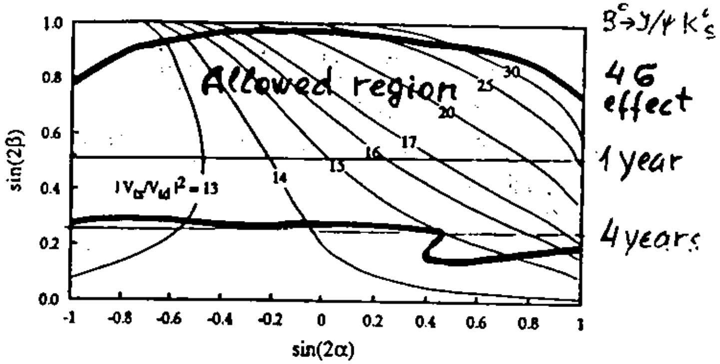
1. CP reach in β
2. Can HERA-B measure α ?
3. $B_s^0 \overline{B_s^0}$ Mixing
4. Measurement of $|V_{cb}|$
5. How to measure $|V_{ub}|$?
6. Search for $D^0 \overline{D^0}$ mixing
7. Additional triggers



CP Reach

(See talk by T. Lohse)

Assume $\sigma_{b\bar{b}} = 12$ nb



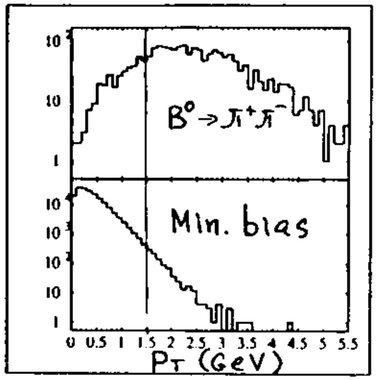
- Smaller $\sigma_{b\bar{b}}$ can reduce sensitivity
- Additional channels $B^0 \to D^{*+}D^{*-}$, $B^0 \to \rho^0 K^0_S$, ... can increase sensitivity

- Small $\sin(2\beta)$ ➡ Large $\sin(2\alpha)$
  Small x_s

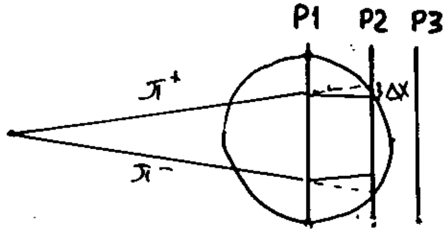
Can HERA-B measure α using $B^0 \to \pi^+\pi^-$?

- Assume $BR(B^0 \to \pi^+\pi^-) = 1.5 \cdot 10^{-5}$ ➡ 4500 ev./10^7s (produced)
- Comparable with $BR(B^0 \to J/\psi K^0_S) = 2 \cdot 10^{-5}$ ➡ 6200 ev./10^7s
  ($J/\psi \to \mu^+\mu^-$, $K^0_S \to \pi^+\pi^-$)

↳ Look for high p_T π



- Require two tracks with $P_T > 1.5$ GeV and $M > 4.5$ GeV
- Use normal HERA-B trigger processor to track π and calculate $M_{\pi^+\pi^-}$
- Add pad chamber coincidence to provide seed for trigger processor

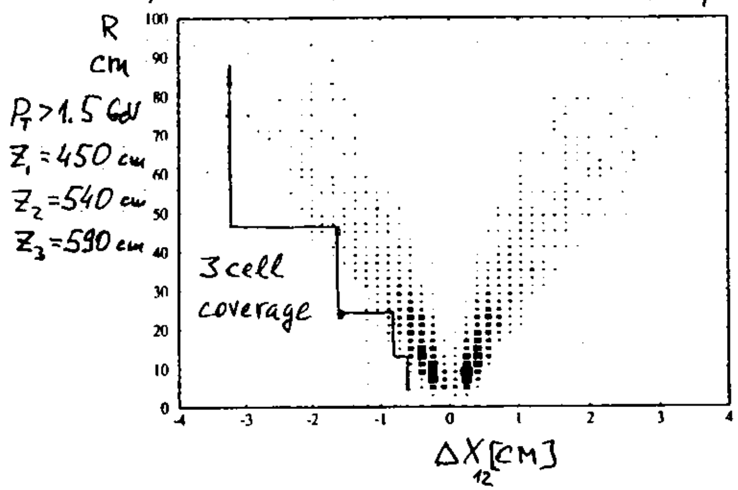


Δx small for high P_T tracks

PRETRIGGER

Idea: Large $P_T \Rightarrow$ Large $p \Rightarrow$ small ΔX

- X and Y projective.
- No deflection in Y allowed to reduce # of coincidences



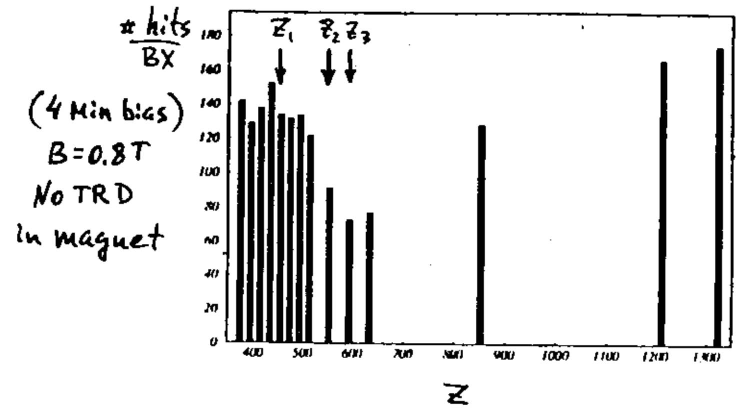
- The smaller the cell size – the better but it can not be too small because
  - a) Too large # of channels
  - b) Difficulty in making small size cells (in wire chamb.)
  - c) Non projective geometry on y

↳ 6×6 mm² the smallest cell

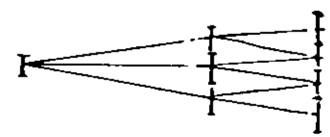
8 × 8
16 × 16

Position of the chambers

- At least one chamber in magnet in order to
  - reject converted γ (e_c have p=∞ after magnet)
  - have additional information for FLT (for e & μ triggers)
- Last chamber after the magnet – small occupancy
  – better extrapolation to TC2

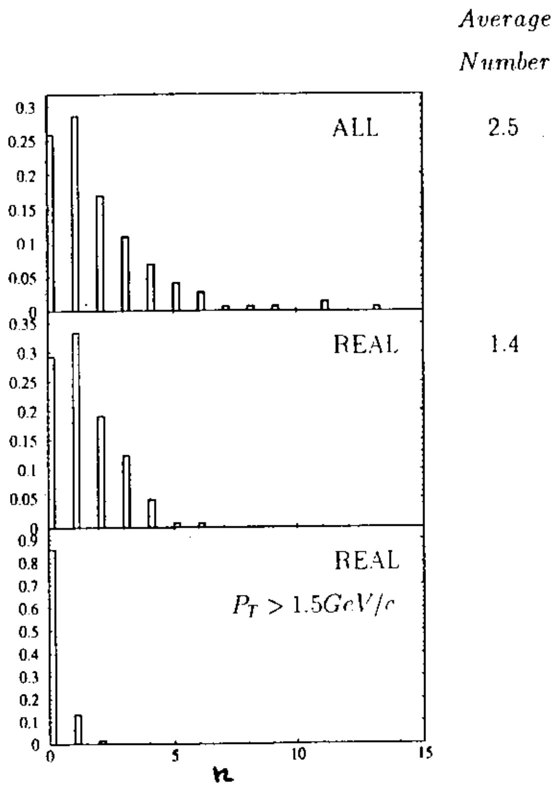


- Third chamber required to reduce random coincidences



$Z_2 - Z_1$ determined by ΔX_{12}
$Z_3 - Z_2$ determined by ΔX_{23}
$\Rightarrow$ $Z_1 = 450$, $Z_2 = 540$, $Z_3 = 590$

Number of pretriggers with three chambers



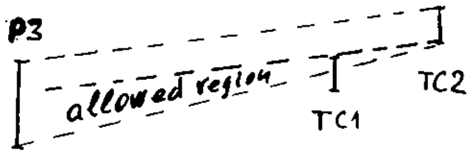
Cross talk between trigger cells is not included

Efficiency of Pretrigger for $B^0 \to \pi^+\pi^-$

Acceptance + $P_T > 1.5$ GeV	62%
Efficiency in Δy	90%
Efficiency in Δx_{12} ($r < 8$ cm)	94%
Efficiency in Δx_{12} ($r > 8$ cm)	98%
Efficiency in ΔX_{23}	97%
Extrapolation to TC2	98%
	48%

FLT

- Interpolation:

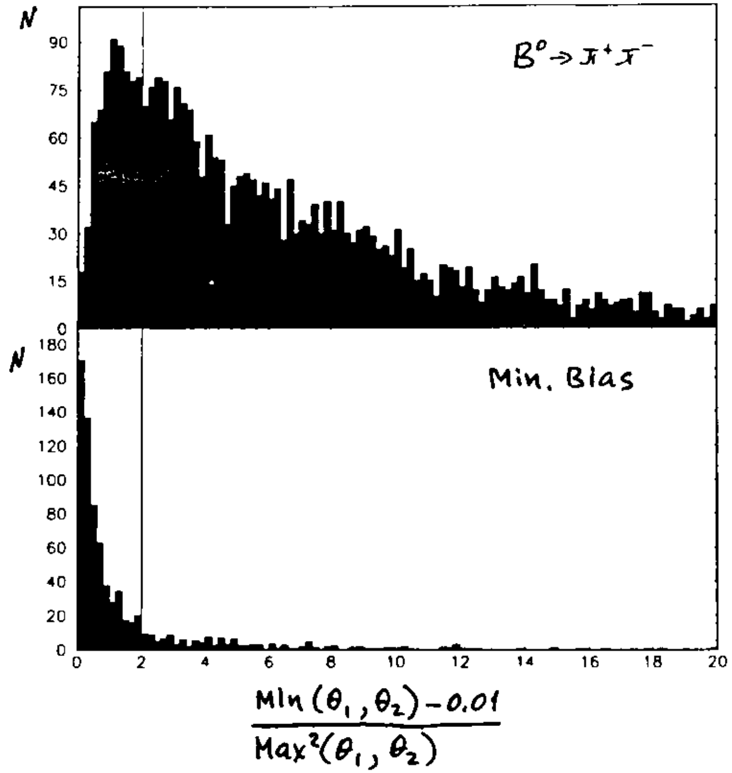


- Due to technical reasons FLT was simulated with slightly different pretrigger (different z_i)
- 500 Min bias events with 4 interactions, $p_T > 1.5$ GeV, $M > 4.5$ GeV (FULL GEANT) → 6 candidates:
  1 real - real
  2 ghost - ghost
  3 real - ghost
- Require $\frac{(\mathrm{Min}(\theta_1,\theta_2)-0.01)}{\mathrm{Max}^2(\theta_1,\theta_2)} > 2.5$ → 1 event left
- Requirement of opposite charge → suppression ×2

  ↳ FLT suppression ~ 10^3

- 2^{nd} level - vertex suppression ~ 25
- 3^{rd} level - only real tracks are left

  → suppression $2000 \times 2 \times 25 = 10^5$ (Lund, Eff, Vertex)

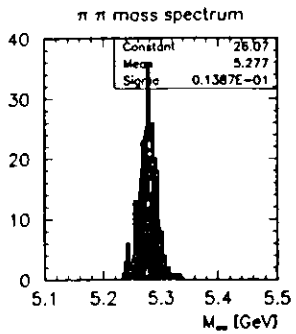


Efficiency for $B^0 \to \pi^+\pi^-$ = 75%

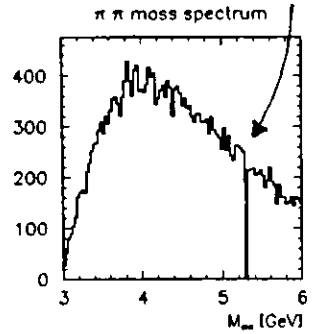
C C

Backgrounds (very prelim.)

Signal

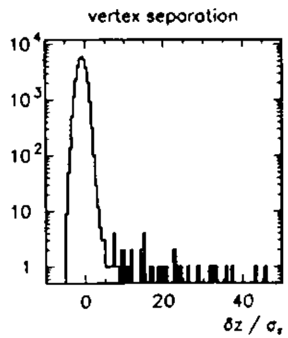


MB ≈ 10^5 x signal



Cuts:

- Vertex separation: > 10^3
- Lepton tag: 10 ... 100
- Event topology: ≈ 10



CP REACH

(Assume $\sigma_{b\bar{b}} = 12$ nb, $\sigma^{in}_{pCu} = 13$ mb per nucleon)

	$B^0 \to J/\psi K^0_S$ ($K^0_S \to \pi^+\pi^-$, $J/\psi \to \mu^+\mu^-$)	$B^0 \to \pi^+\pi^-$
BR	$2 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$
K^0_S reconstruction	0.61	—
Decay kinematics	0.8	0.75
TRIGGER	0.64	0.48
$\ell^+\ell^-/\pi^+\pi^-$ reconstr.	0.9	0.9
ℓ ID / π ID	0.94	0.94
B^0 reconstruction	0.95	0.95
Decay length cut	0.69	0.69
	$3.5 \cdot 10^{-6}$	$3.0 \cdot 10^{-6}$
$3 \cdot 10^8$ $B^0/\bar{B}^0$	→ 1050 ev.	900 ev./year

$$\Delta \sin(2\varphi) = \sqrt{\frac{K \cdot (1 + B/S)}{N \cdot P^2}}, \qquad P = D_M D_T \sqrt{\varepsilon_{Tag}} = 0.31$$

↳ $\Delta \sin(2\beta) = 0.15$ $\qquad \Delta \sin(2\alpha) = 0.16 \sqrt{1 + B/S}$

- $\Delta \sin(2\alpha)$ depends on (uncertain) background level
- Additional uncertainty due to penguin contribution can (in principle) be corrected

C C

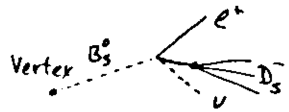
$B_s^0 \bar{B}_s^0$ MIXING

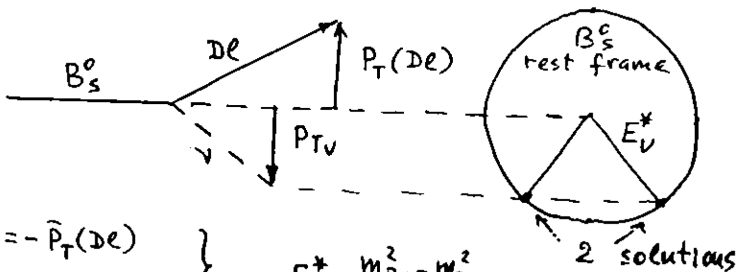
		BR
• Reconstruct	$\bar{B}_s^0 \to B_s^0 \to \ell^+ D_s^{(*)-} \nu$	$\sim 6\% \times 2$
	↳ $\phi \pi^+$	3.7%
	$\phi \pi^+ \pi^- \pi^+$	1.3%
	$K^{*0} K^-$	2.6%

Trigger

• Tag $\bar{b} \to \ell^+ \nu X$

• Direction of B_s^0 is known





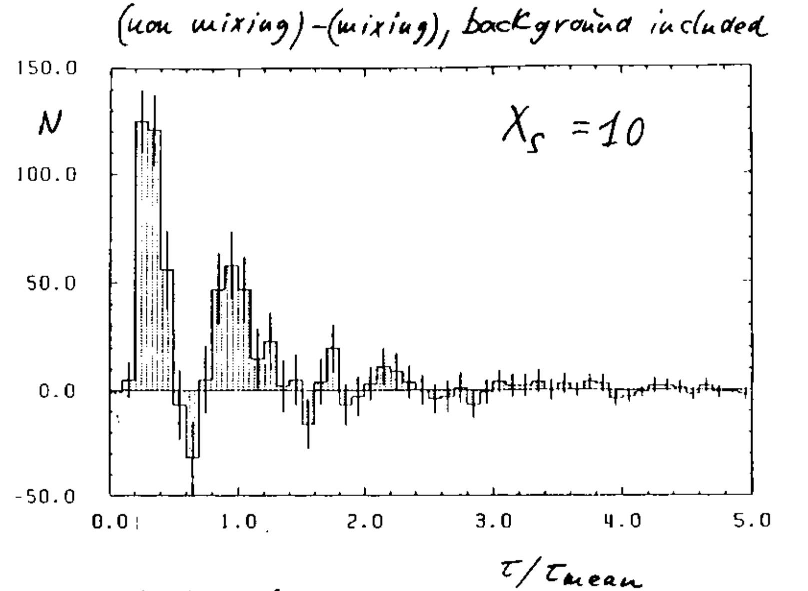
$$\left.\begin{array}{l} \vec{P}_{T\nu} = -\vec{P}_T(D\ell) \\ M(D_s \ell \nu) = M(B_s^0) \end{array}\right\} \quad E_\nu^* = \frac{m_{B_s}^2 - m_{D\ell}^2}{2 m_{B_s}}$$

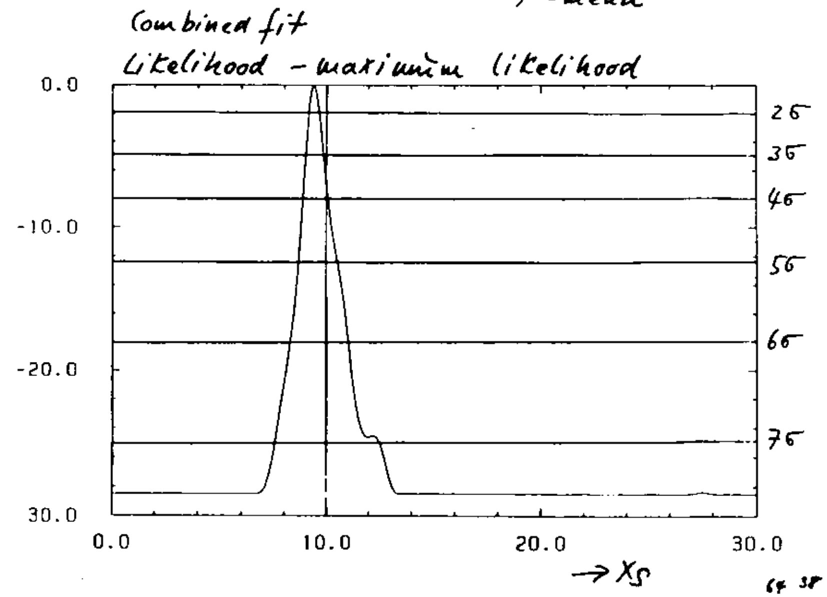
• Select $P(B_s^0)$ which is closer to $\frac{m_{B_s}}{m_{D\ell}} \cdot P_{D_s \ell}$

• Require $M_{D_s \ell} > 4$ GeV, $\sigma_\tau / \tau_m < 0.06$, $\Delta z > 4\sigma$

↳ 870 tagged B_s^0 decays per year

$x_s \leq 17$ can be measured



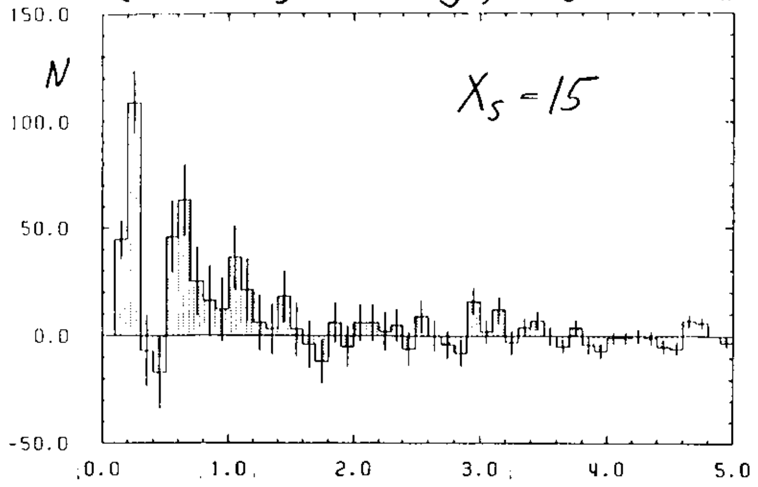


C

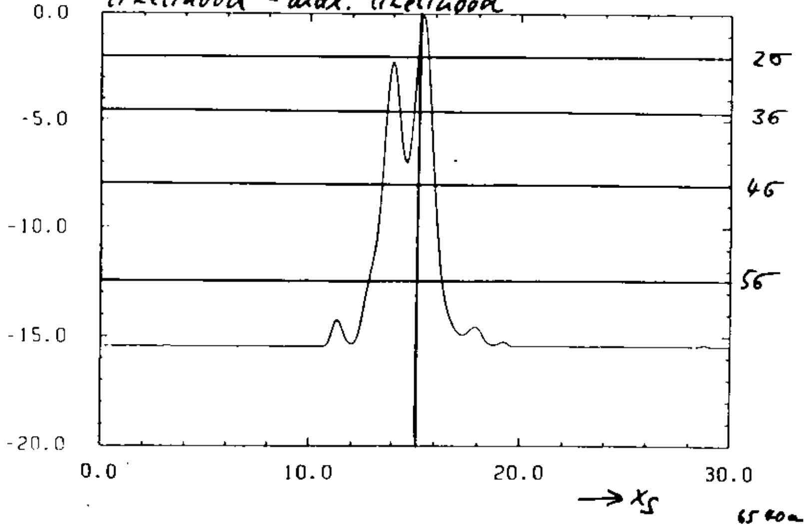
C

MEASUREMENT OF $|V_{cb}|$

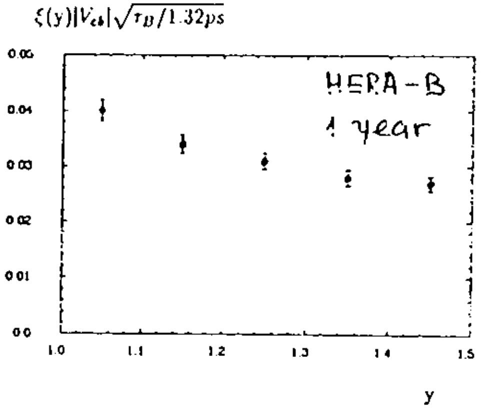
(non-mixing) - mixing, background included



combined fit
likelihood - max. likelihood



- Reconstruct $B^0 \to D^{*+} \ell^- \bar{\nu}$
- Require $|\cos\theta_V^*| < 0.4$
- Average two solutions for P_ν ➡ $\Delta y/y = 0.02$



↳ No extrapolation to y=1 required (practically)

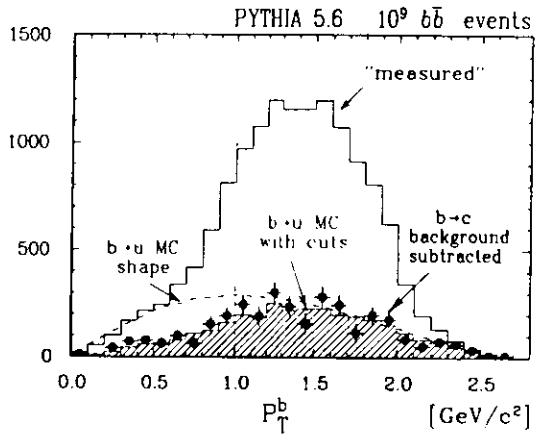
CAN WE MEASURE |Vub| ?

- Look for $\ell(n\pi^\pm)$ secondary vertices
- Suppress τ and charm by requirement

$\hat{p}_T^{\ell} > 1$ GeV

$\hat{p}_T^{had} > 1$ GeV

- Assume that D vertex can be separated for $Z_D - Z_B > 0.3$ mm



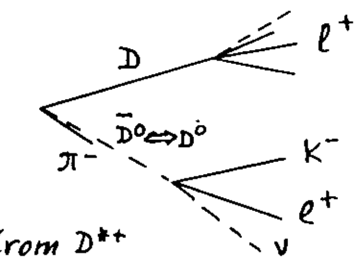
- Remaining backgr. from b→c can be subtracted using extrapolation to $\Delta Z = 0$
- Statistical error ~ 6–10% for $\Delta Z_{min} = 0.3$–2 mm
- Systematics ?
- Model dependence ? At least two charged track required.

C

SEARCH FOR $D^0\bar{D}^0$ MIXING

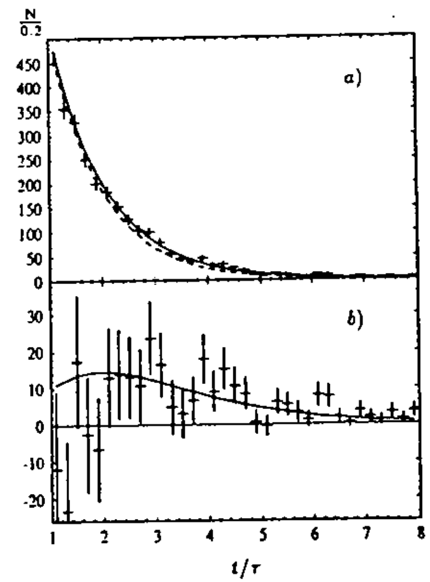
- Small in SM ($\chi_D \sim 10^{-4}$) → Sensitive to New Physics

Method



- Select D^0 from D^{*+}
- Tag and trigger with ℓ from second D

$\chi_D = 10^{-4}$ → 900 "MIXED" D^0/year



Separate double misidentification of ℓ and K by time dependence

⇓

$\Delta\chi_s \sim 2 \cdot 10^{-5}$

Systematics has to be studied

C

Other Physics Topics - Additional Triggers

Pretrigger → Filter & Momentum Det. → Decision

Trigger	$B \to J/\psi X \to l^+l^- X$ (CP Violation)	$B_1B_2 \to l_1l_2X$ (B Mixing, CKM...)	$B \to l_1CX \to l_1l_2X$ (Charm Mixing, CKM)	$B \to lX$ (Inclusive B)	$C_1C_2 \to l_1l_2X$ (Charm)
"J/ψ" (e^+e^-, $\mu^+\mu^-$, $M > 2.5$ GeV)	48%	9%	4%	–	0.05%
"Dilepton" ($\mu\mu$, $e\mu$, e^+e^-, $p_t > 1...1.2$ GeV)	25%	18%	2%	–	0.01%
"Single lepton" (e,μ, $p_t > 2.5...3$ GeV)	9%	7%	5%	4%	–
Total FLT Efficiency	50%	29%	9%	4%	0.06%
Events/year	260 k	1400 k	380 k	3200 k	>> M

$B \to J/\psi X$

260 k events per year

15000	reconstructed B decays	
1400	$B^0 \to J/\psi K_s$	
5500	$B^0 \to J/\psi K^{*0}$	
5900	$B^+ \to J/\psi K^+$	
1400	$B^+ \to J/\psi K^{*+}$	
1200	$B_s \to J/\psi \phi$	
400	$\Lambda_b \to J/\psi \Lambda$	

- other CP channels ($J/\psi \phi$, $J/\psi \rho$)
- lifetimes, V_{cb}
- B_c, Λ_b
- rare decays
- QCD ($gg \to b\bar{b}$)
- unbiased 2nd B

$B_1B_2 \to l_1l_2X$

1400 k events per year

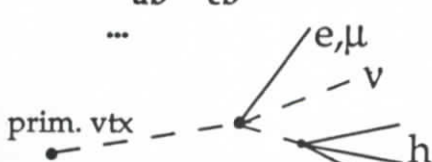
B^0 - $\overline{B^0}$ mixing

B_s - $\overline{B_s}$ mixing

rare decays

V_{ub}, V_{cb}

...



▶ **Reconstruction of semileptonic decays**

known:
- B direction of flight (vertex)
- ν p_t (p_t balance at decay vertex)
- ν energy in lh rest frame (B mass)

⇒ 2-fold ambiguity concerning sign of ν p_l (in lh rest frame)

CONCLUSIONS

- Detector optimized for $B \to J/\psi K^0_s$ can do many other things

⇓

Rich and balanced physics program

- With small modifications HERA-B can become even more powerful

↳ HERA-B has healthy design → long life

MORE WORK NEEDED

CP VIOLATION IN $B_d^0 \to J/\Psi K_s^0$

$\not{C}\not{P}$ REACH AT HERA-B

PRESENTED BY

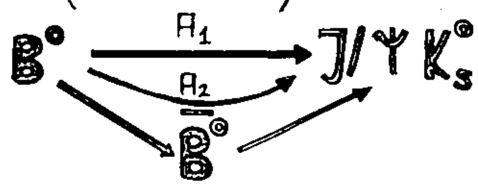
THOMAS LOHSE

HUMBOLDT-UNIVERSITY

$\not{C}\not{P}$ (B)

- IN STANDARD MODEL: Im(CKM-MATRIX) ≠ 0

$\Rightarrow$ $\not{C}\not{P}$ VIA INTERFERENCE



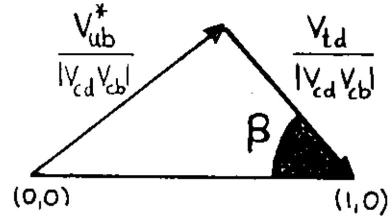
- MEASUREMENT:

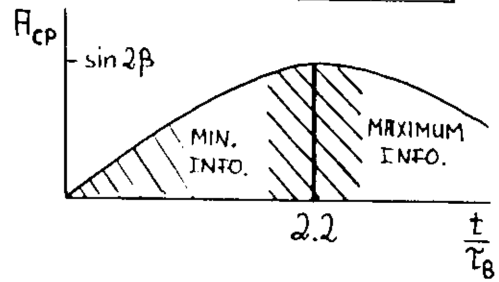
$$A_{CP}(t) \equiv \frac{N(B^0 \to J/\Psi K_s^0) - N(\bar{B}^0 \to J/\Psi K_s^0)}{N(B^0 \to J/\Psi K_s^0) + N(\bar{B}^0 \to J/\Psi K_s^0)} = \sin 2\beta \cdot \sin(x \cdot \frac{t}{\tau_B})$$

$\not{C}\not{P}$

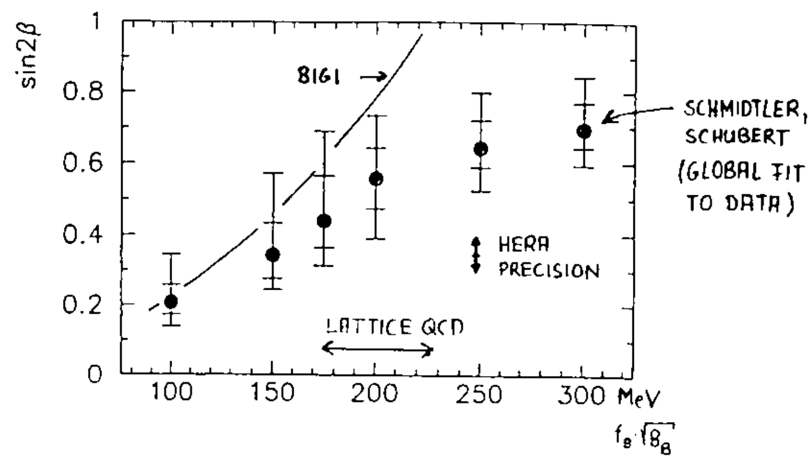
MIXING $x = \frac{\Delta M}{\Gamma} \approx 0.7$

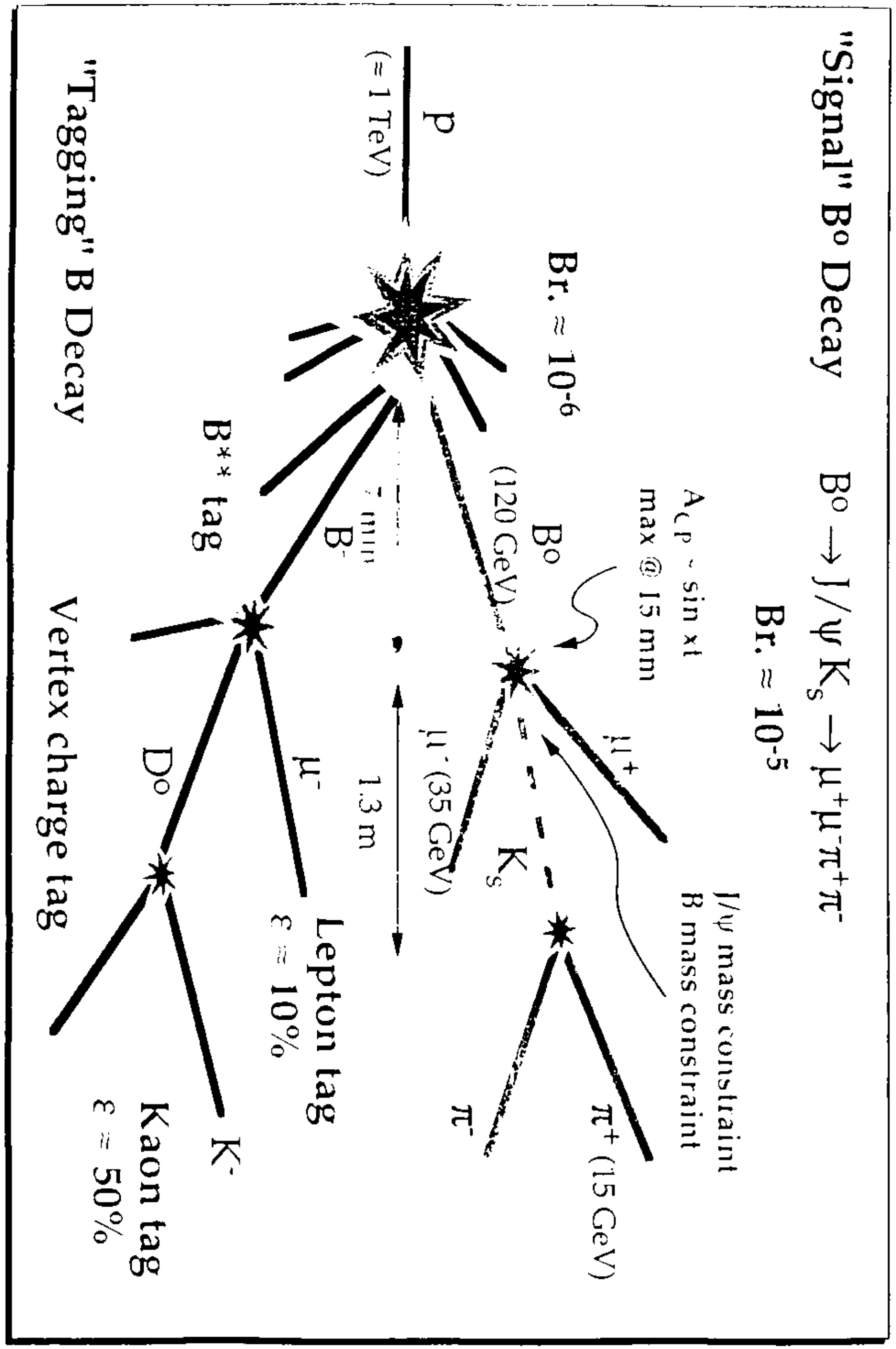
"UNITARITY TRIANGLE"





- EXPECTED SIZE:





~~CP~~ REACH FACTORS:

1) INTERACTION RATE	⟷	EFFICIENCY OF INTERNAL TARGET
2) $b\bar{b}$ CROSS SECT.	⟷	GENEROSITY OF THE LORD, + BEAM ENERGY
3) TRACK RECONSTR.	⟷	TRIGGER EFFICIENCY, PATTERN RECOGNITION EFFICIENCY, K^0_S RECONSTRUCTION EFFICIENCY
4) LEPTON / KAON ID.	⟷	MUON-FILTER PERFORMANCE, ECAL + TRD PERFORMANCE, RICH PERFORMANCE
5) B^0 RECONSTR.	⟷	VERTEX + MASS RESOLUTION
6) TAG DILUTION	⟷	PATTERN, PARTICLE ID, VERTEXING, ... CLEVER ALGORITHMS

7) BACKGROUNDS AND SYSTEMATIC ERRORS

CP Reach

Statistics

$a_{obs} = D_{Tag}\, D_{CP} \sin(2\beta)$ $\qquad D_{CP} \approx 0.6$

$\Delta a_{obs} = (1/N)^{1/2}$ $\qquad D_{Tag} \approx 0.4$

$\Delta \sin(2\beta) = 1/D_{Tag}\, D_{CP} \sqrt{N}$

for $\Delta\sin(2\beta) \approx 0.1$ need ≈ 1000 evts.

Event Rates

$\sigma_{bb}/\sigma_{inel}$	$\approx 5\cdot 10^{-7}$
$2P_{b \to B^o}$	≈ 0.8
$Br(B^o \to J/\Psi\, K_s)$	$\approx 5\cdot 10^{-4}$
$Br(J/\Psi \to e^+e^-/\mu^+\mu^-)$	≈ 0.12
$Br(K_s \to \pi^+\pi^-)$	≈ 0.69
	$\approx 10^{-11}$
trigger, reconstruction, tagging efficiency	$\approx 10^{-1}$
	$\approx 10^{-12}$

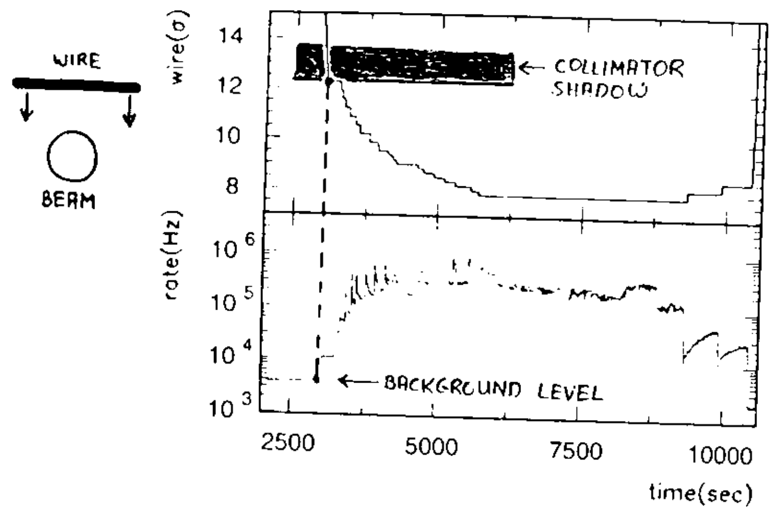
for 1000 tagged events, need 10^{15} interactions, or $3\cdot 10^{7}$ sec $\approx$ 30 MHz rate !

Machine

HERA BX $\approx$ 10 MHz
$\Rightarrow$ multiple interactions per BX !

Natural beam loss $\approx$ 100 MHz
$\Rightarrow$ rate ok with efficient target !

TARGET WIRE SCANS:

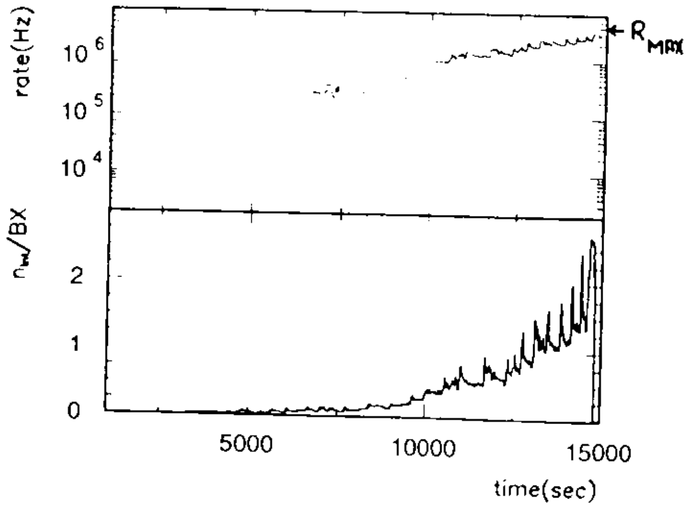


HIGH RATE SCAN:

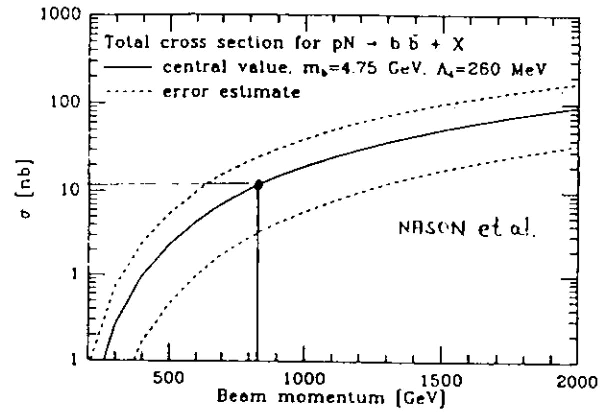
$R_{MAX} = \frac{1\ \text{TRIGGER}}{BX} \underset{84\ \text{BUNCHES}}{=} 4\,MHz$

$R_{TRIG} = R_{MAX} \cdot \left(1 - e^{-\epsilon \langle n_{Int} \rangle}\right)$

UP TO 2.5 INTERACTIONS PER BX ACHIEVED

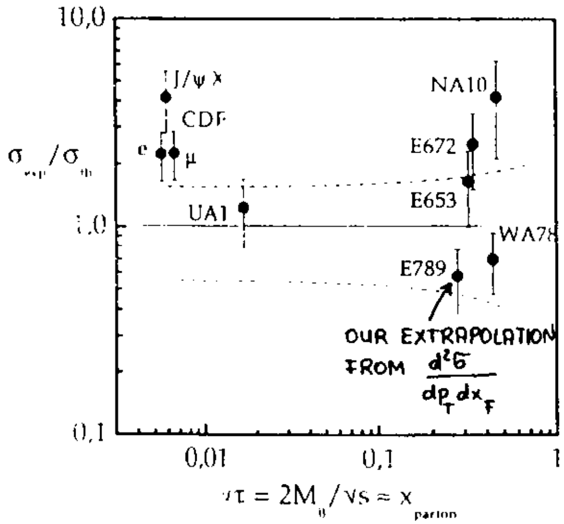


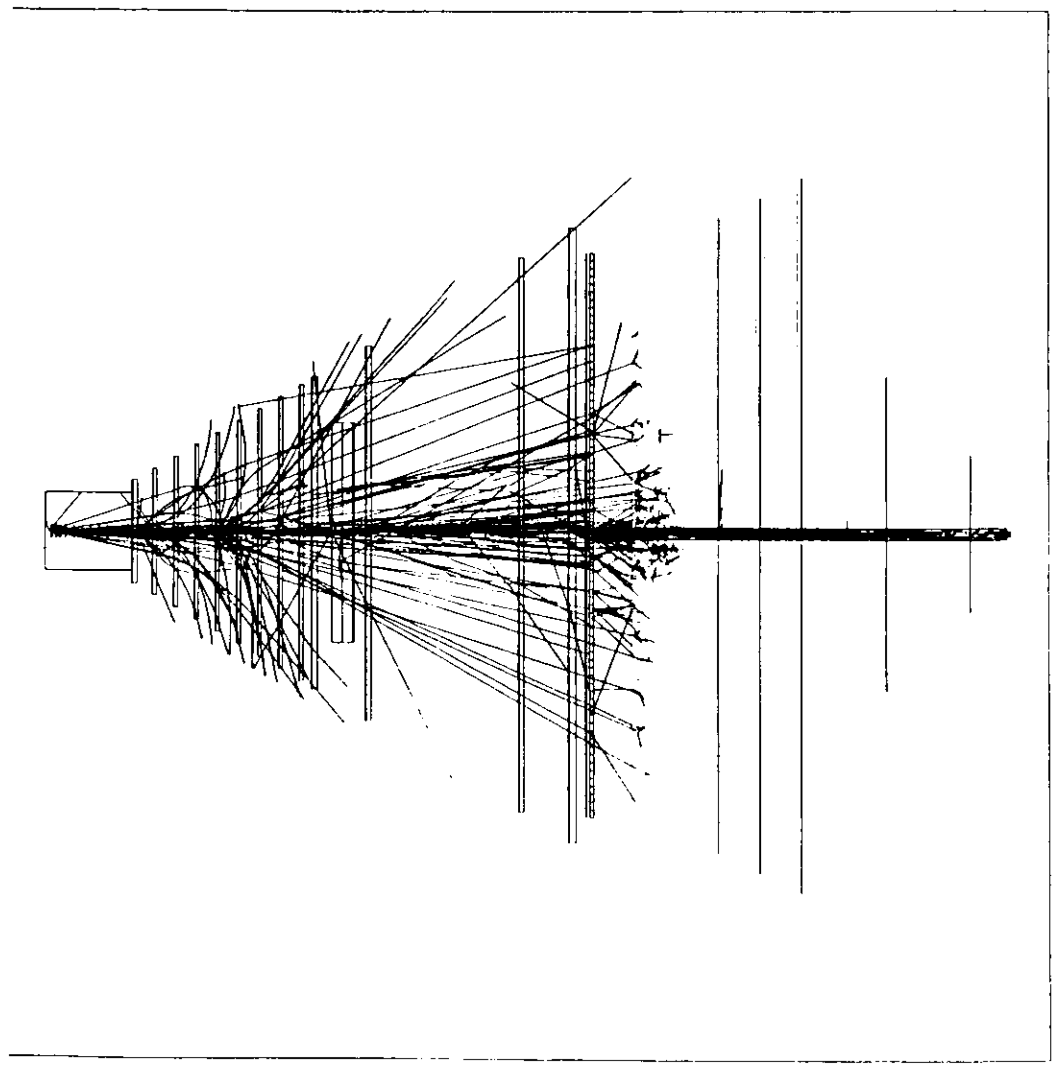
$b\bar{b}$ cross section



$\pi\ N$ cross section dominated by quark fusion

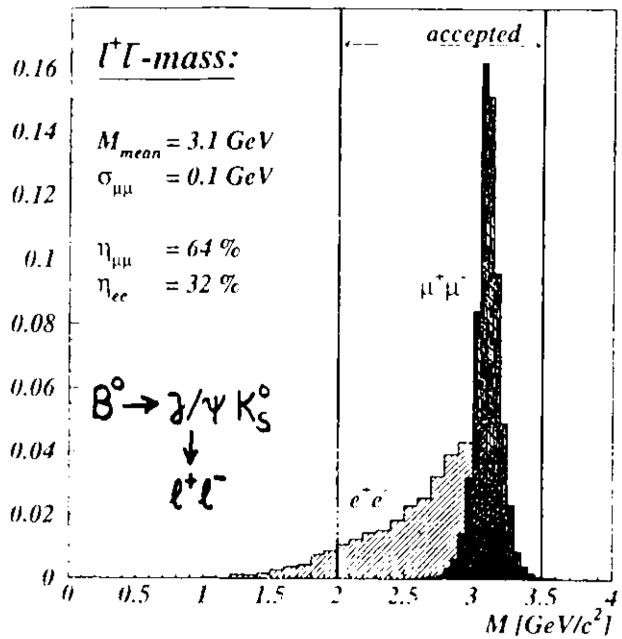
$p\ N$ cross section dominated by gluon fusion





TRIGGER PERFORMANCE

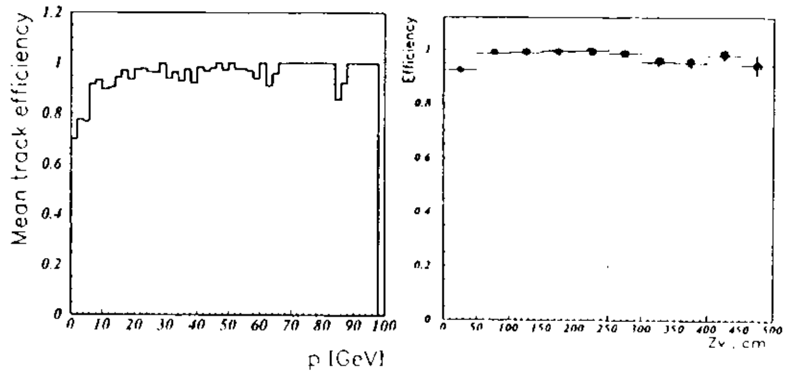
A. ACCEPTING SIGNAL – EFFICIENCY



	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
GEOMETRY	71%	70%
P, E-CUTS	90%	50%
$M(\ell^+\ell^-)$ CUTS	>99%	91%
EFFICIENCY	63%	32%

Pattern Recognition

Track efficiency: K_S^0 vertex efficiency:

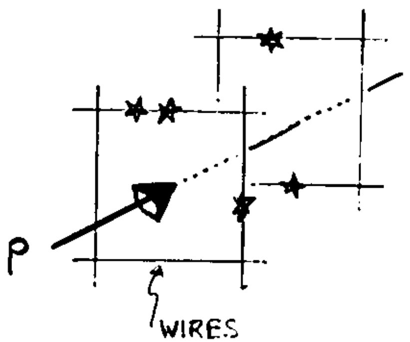


Combined multi-track efficiencies for $B \to J/\psi K_S^0$ decay products	
TRD/Tracker+MSGC ($\ell^+\ell^-\pi^+\pi^-$)	$\epsilon =$ [illegible]
Silicon ($\ell^+\ell^-$)	$\epsilon =$ [illegible]
K_S^0 reconstruction	$\epsilon =$ [illegible]

DECAY CHAIN RECONSTRUCTION

a) PRIMARY VERTICES

→ USE WIRE CONSTRAINT



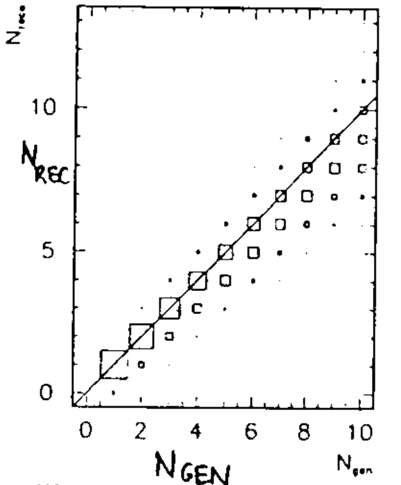
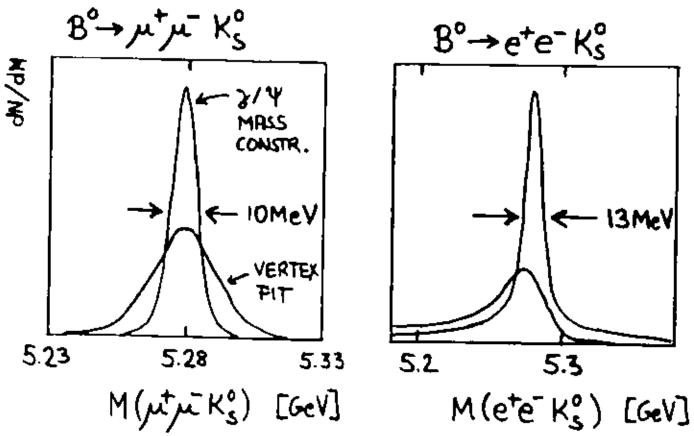


Figure 230 Number of reconstructed primary vertices versus the number of generated primary vertices

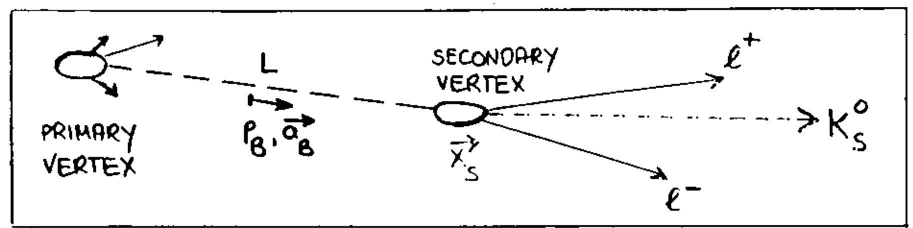
b) $J/\Psi + B^0$ RECONSTRUCTION



ELECTRONS RECOVERED BY J/Ψ-MASS-CONSTRAINT

c) MATCHING TO PRIMARY VERTEX

SIMULTANEOUS FITS OF PRIMARY + SECONDARY VERTICES



CONSTRAINTS:	PARAMETERS:	
o $M(\ell^+\ell^-) = M(J/\Psi)$	o L	$\sigma_L \sim 500\mu m$
o $M(\ell^+\ell^- K^0_S) = M(B^0)$	o $\vec{x}_S$	$\sigma_\perp \sim 20\mu m$
o ℓ^+, ℓ^-, K^0_S ON A VERTEX	o p_B	$\delta p_B/p_B \sim \mathcal{O}(10^{-3})$
o B^0 (+ TRACKS) ON A WIRE	o $\vec{a}_B$	$\sigma_a \sim 60\mu rad$

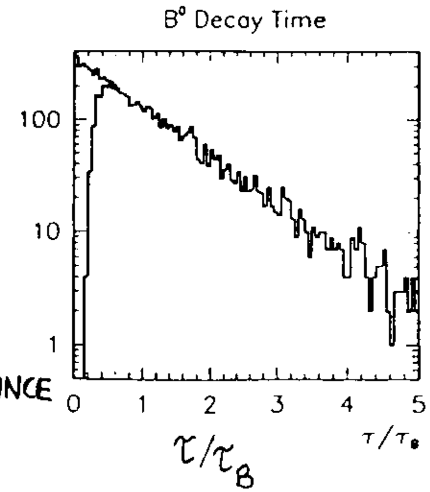
d) DECAY LENGTH CUT

$\frac{L}{\sigma_L} > 8$

⇕

$\tau \gtrsim 0.4\, \tau_B$

$\frac{L}{\sigma_L} > 12$ POSSIBLE WITHOUT LOSS IN ~~CP~~ SIGNIFICANCE



CP REACH

[ASSUME $\sigma_{b\bar{b}} = 12\,\mu b$/NUCLEON
$\sigma_{pCu} = 13\,mb$/NUCLEON]

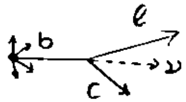
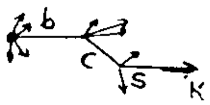
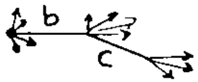
I. $B_d^0 \to J/\psi\, K_S^0$ STATISTICS

SUPPRESSION	$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
$\sigma_{b\bar{b}} / \sigma_{tot}$	$9.2 \cdot 10^{-7}$	$9.2 \cdot 10^{-7}$
BR	$1.7 \cdot 10^{-5}$	$1.7 \cdot 10^{-5}$
TRIGGER	0.63	0.32
TRACKING	0.54	0.54
LEPTON ID	0.94	0.85
J/ψ, B_d^0 REC.	0.95	0.66
KINEMATICS CUTS	0.86	0.80
VERTEX CUT	0.69	0.69
TOTAL SUPPR.	$2.6 \cdot 10^{-12}$	$0.6 \cdot 10^{-12}$
10^7s (~1YEAR) @ 40MHz	1030 EVENTS	330 EVENTS

$\delta \sin(2\beta)$ WITH PERFECT TAG 0.041

TAGGING DILUTION

[CUTS ON p, p_t, VERTEX DISTANCES]

TAG	LEPTON	KAON	CHARGE
			
	$\text{sign}(q_\ell)$	$\text{sign}(q_K)$	$\text{sign}(\sum_i q_i p_i)$
ϵ	16.1%	46.0%	96.4%
CORRECT	11.5%	31.3%	56.0%
WRONG	4.6%	14.7%	40.4%
DILUTION $D = \frac{C-W}{C+W}$	0.43	0.36	0.16
TAGGING POWER $P = D\sqrt{\epsilon}$	0.17	0.24	0.16
	0.31		

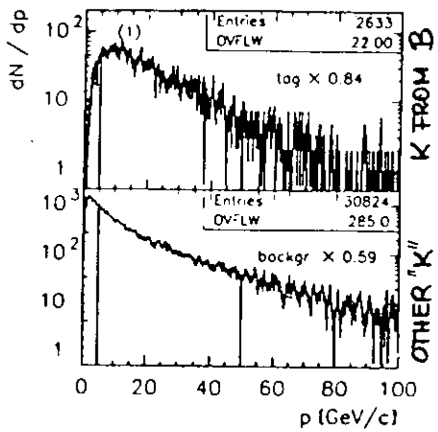
10^7s @ 40 MHz $\Longrightarrow$ $\delta \sin(2\beta) = 0.13$

EXAMPLE: THE KAON TAG

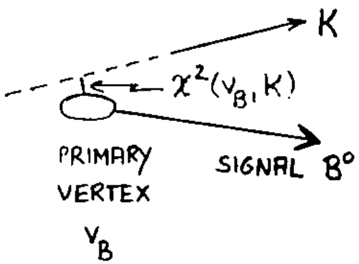
1) MOMENTUM CUT

$5\,GeV < p < 50\,GeV$

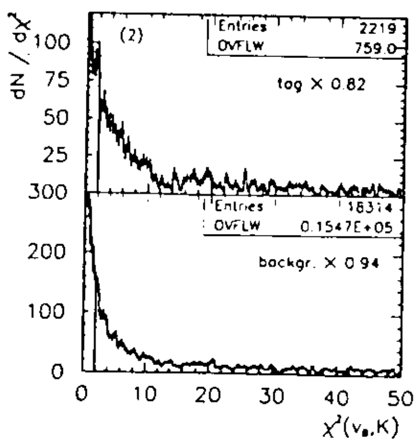
⇒ RICH RELIABLE



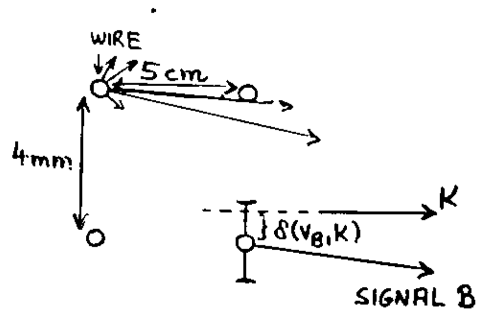
2) SOFT IMPACT PARAMETER CUT

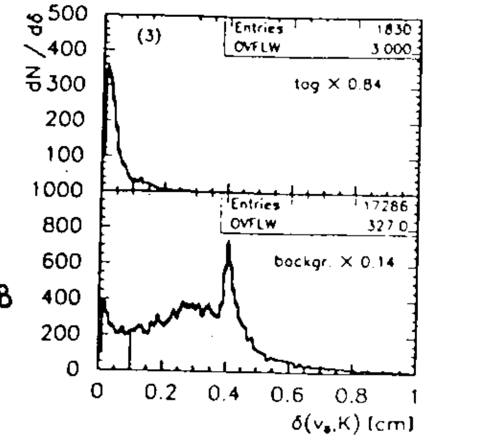


$\chi^2(v_B, K) > 2$



3) IMPACT PARAMETER CUT AGAINST OTHER PRIMARY VERTICES

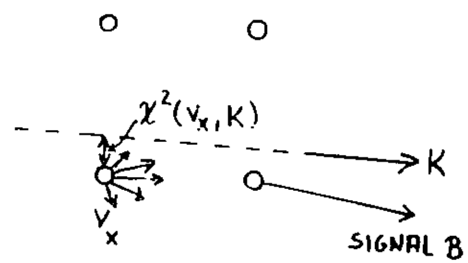




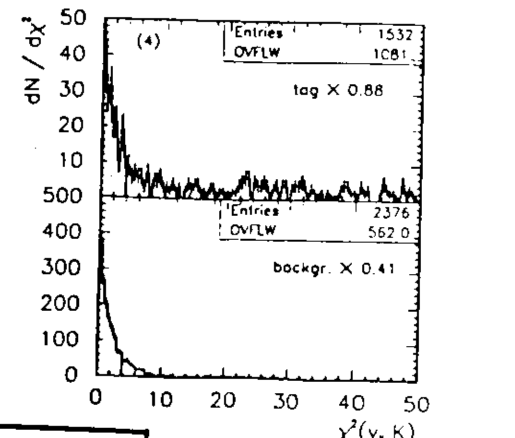
$\delta(v_B, K) < 1\,mm$

K-TAG IMPACT PARAMETER
RESOLUTION $\simeq 60\,\mu m$

4) INCOMPATIBILITY WITH OTHER PRIMARY VERTICES



$\chi^2(v_x, K) > 4$



IN TOTAL:	B → K-TAG	* 0.51
	FAKE K-TAG	* 0.03

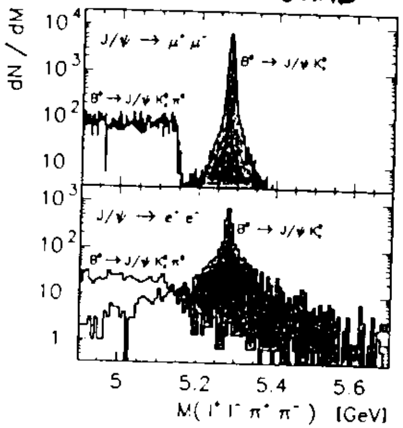
BACKGROUNDS:

a) MONTE CARLO STUDIES (LIMITED BY STATISTICS)

- $B_d^0 \to J/\Psi\, K^{0*} \to \underbrace{J/\Psi\, K_S^0}\, \pi^0$
  FAKE B_d^0 DECAY
  → HAS OPPOSITE CP ASYMMETRY

$$\frac{S}{B} \begin{array}{ll} > 1600 & ,\ \mu^+\mu^- \\ = 170 & ,\ e^+e^- \end{array}$$

K^{0*} BACKGROUND



- $b\bar{b} \to \ell^+\ell^- X$

$$\frac{S}{B} = \begin{array}{ll} 500 & ,\ \mu^+\mu^- \\ 11 & ,\ e^+e^- \end{array}$$

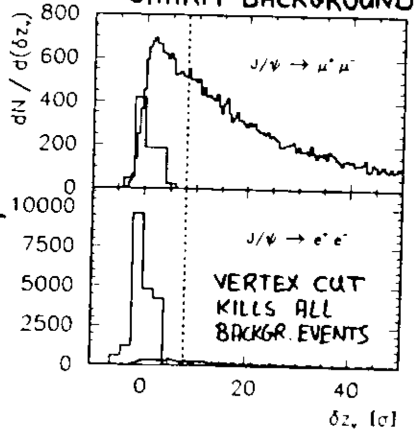
- $c\bar{c} \to \ell^+\ell^- X$

$$\frac{S}{B} \underset{\substack{90\% \\ c.l.}}{>} \begin{array}{ll} 120 & ,\ \mu^+\mu^- \\ 2 & ,\ e^+e^- \end{array}$$

- MIN. BIAS → FAKE LEPTONS

$$\frac{S}{B} \underset{\substack{90\% \\ c.l.}}{>} \begin{array}{ll} 3 & ,\ \mu^+\mu^- \\ 0.6 & ,\ e^+e^- \end{array}$$

CHARM BACKGROUND

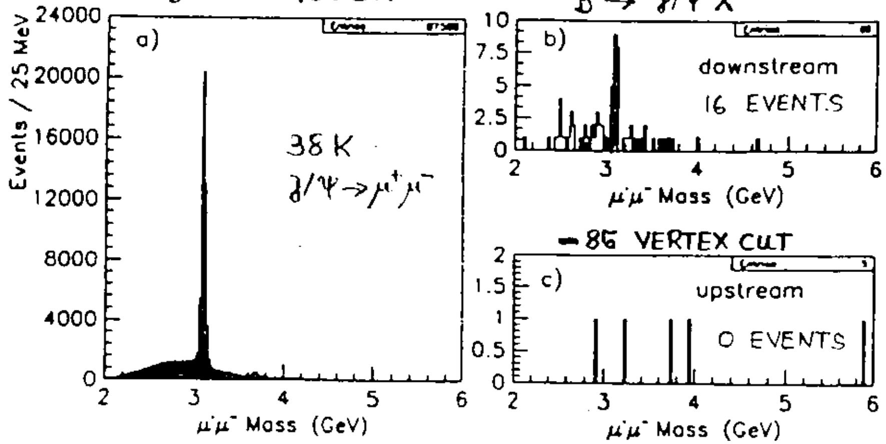


- OTHER, LESS IMPORTANT BACKGROUND

b) MEASUREMENT (E 789, FERMILAB)

J/Ψ TRIGGER

8σ VERTEX CUT
B → J/Ψ X



► VERY CLEAN $B \to J/\Psi\, X$

► $B \to J/\Psi\, K_S^0$ IS EXPECTED TO BE EVEN CLEANER

SYSTEMATIC ERRORS

TYPE 1: NON-CP ASYMMETRIES
SPOIL CP SIGNAL

TYPE 2: SCALE UNCERTAINTY IN $\sin(2\beta)$ ✓
CP SIGNIFICANCE UNAFFECTED

MEASUREMENT USING REFERENCE REACTIONS:

CHANNEL	$R = \frac{\# \text{REF.}}{\# B^0 \to J/\psi K^0_S}\Big\|_{\text{DETECTED}}$	
$B^0 \to J/\psi K^{*0}$ $\to \ell^+\ell^- K^+\pi^-$	3.8	SELF-TAG
$B^+ \to J/\psi K^+$ $\to \ell^+\ell^- K^+$	4.1	SELF-TAG
$B^+ \to J/\psi K^{*+}$ $\to \ell^+\ell^-\pi^+\pi^-\pi^+$	1.0	SELF-TAG
$B^0_s \to J/\psi \phi$ $\to \ell^+\ell^- K^+K^-$	0.8	NO CP
$\Lambda_b \to J/\psi \Lambda$ $\to \ell^+\ell^- p\pi^-$	0.3	SELF-TAG

MEASURING SCALE ERRORS

TAGGING DILUTION, MIXING DILUTION, STATISTICAL FACTOR (DECAY TIME CUT)

$$A_{OBS} = \underbrace{D_T \cdot D_M \cdot M(t_0)}_{\simeq 0.3} \cdot \sin(2\beta)$$

$M(t_0)$:

▷ SHAPE OF t_0 CUT-OFF → WELL MEASURED

▷ MIXING PARAMETER → $\frac{1}{M}\frac{dM}{dx} \simeq 0.5$, $\frac{\sigma_x}{x} \sim$ FEW %

⇒ ERRORS ON $M(t_0)$ NEGLIGIBLE

$D_T \cdot D_M$: MEASURED WITH SELF-TAGGING MODES (TRUE ASYMMETRY = 1)

$$\frac{\delta \sin(2\beta)_{SCALE}}{\delta \sin(2\beta)_{STAT}} \simeq \frac{A_{OBSERVED,CP}}{A_{OBSERVED,REF}} \cdot \frac{1}{\sqrt{R}}$$

$B^0 \to J/\psi K^{*0}$ ALONE ⇒ $\lesssim 0.3$

⇒ SCALE ERROR SMALL COMPARED TO STATISTICAL ERROR

MEASURING NON-CP ASYMMETRIES

- UNEQUAL $B, \bar{B}$ RATES
- UNEQUAL TAGGING PROBABILITIES FOR $B, \bar{B}$
- CHARGE ASYMMETRIC BACKGROUNDS
- CHARGE ASYMMETRIC DETECTOR ACCEPTANCE

METHOD 1: $N_{B^0}/N_{\bar{B}^0}$ AS FREE FIT-PARAMETER

$\Rightarrow$ SIGNIFICANT LOSS IN ACCURACY OF A_{CP}

METHOD 2: $B^0 \to J/\psi K^{*0}$ + TAG REFERENCE MODE ✓

$K^{*0} \to K^+\pi^-$

SELF TAGGING

$\bar{B}^0 \not\to J/\psi K^{*0}$ (NO CP̸)

} ALL SOURCES OF ASYMMETRIES MEASURED

$$R = 3.8 \rightarrow \quad \delta \sin(2\beta)_{stat} \to \delta \sin(2\beta)_{stat} \cdot 1.12$$

$$\delta A_{NON\text{-}CP} \lesssim 0.015, \quad \delta \sin(2\beta)_{syst} \lesssim 0.05$$

METHOD 3: FULL LIST OF REFERENCE MODES ✓

$\Rightarrow$ INDIVIDUAL ASYMMETRIES

$$\begin{matrix} \bar{B}^0 & B^- & \bar{B}^0_s & B_{BARYON} \\ \updownarrow & \updownarrow & \updownarrow & \updownarrow \\ B^0 & B^+ & B^0_s & \bar{B}_{BARYON} \end{matrix}$$

$\rightarrow$ MONTE CARLO PARAMETER TUNING

$\rightarrow$ PROBABLY ULTIMATE PRECISION

CONCLUSIONS

- DETAILED GEANT SIMULATIONS OF DETECTOR COMPONENTS AND TRIGGER
- PRELIMINARY VERSION OF EFFICIENT PATTERN RECOGNITION
- FULL ANALYSIS CHAIN OF $B^0 \to J/\psi K^0_S$ + TAG
- $\boxed{\delta \sin(2\beta) = 0.13}$ FOR 10^7 s RUNNING TIME AND $\sigma_{b\bar{b}} = 12$ nb
- BACKGROUNDS SMALL FOR $J/\psi \to \mu^+\mu^-$, OK FOR $J/\psi \to e^+e^-$
- SYSTEMATIC ERRORS SMALL COMPARED TO STATISTICAL ERRORS

The Role of B-Physics in Clean Determinations of the CKM Matrix

Andrzej J. Buras

(DESY, 4. October 1994)

PROGRAM

1. Grand View
   Theoretical Framework
   Motivations, Strategies
2. Express Review of CP Asymmetries
3. 2000 - 2011
4. Shopping Lists

An Important Target of Particle Physics

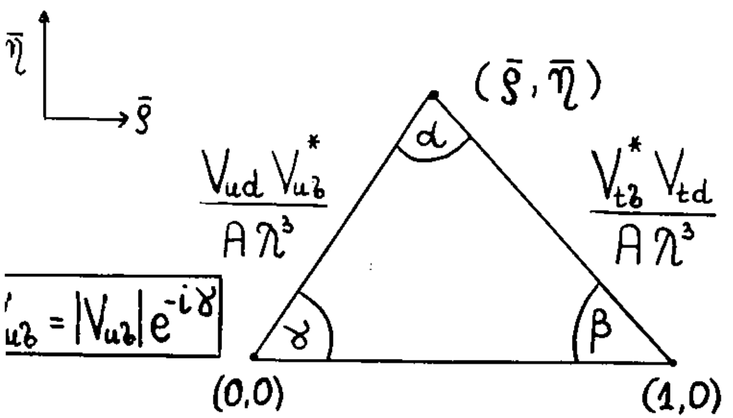
CKM:	V_{ud}	V_{us}	V_{ub}
	V_{cd}	V_{cs}	V_{cb}
	V_{td}	V_{ts}	V_{tb}

$$\lambda,\ A,\ \varrho,\ \eta$$

(Wolfenstein)

$$|V_{us}| \equiv \lambda \qquad |V_{cb}| \equiv A\lambda^2$$

$$V_{ub} = A\lambda^3(\varrho - i\eta) \qquad V_{td} = A\lambda^3(1-\bar\varrho - i\bar\eta)$$



$$V_{ub} = |V_{ub}|e^{-i\gamma} \qquad V_{td} = |V_{td}|e^{-i\beta}$$

(Unitarity Triangle)

$$\bar\varrho = \varrho(1-\lambda^2/2) \qquad \bar\eta = \eta(1-\lambda^2/2)$$

AJB
Lautenbache
Ostermaier
(94)

1989 - 1996

Electroweak Precision Studies

$$\alpha_{QED},\ G_F,\ M_Z,\ m_t,\ m_H$$

$(M_W,\ \sin^2\theta_W)$

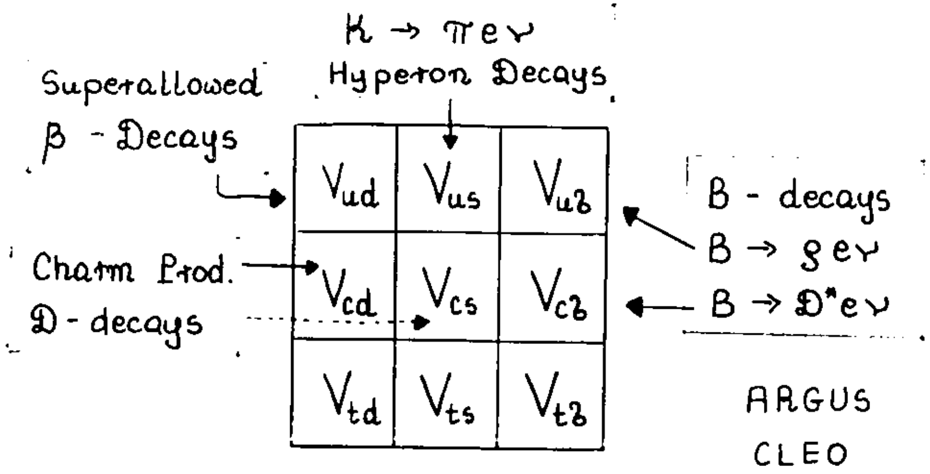
Spontaneous Symmetry Breakdown

2000 - 2011

CKM Precision Studies

$$\lambda,\ A,\ \varrho,\ \eta,\ m_t$$

$\hat{V}_{CKM}$ from Tree Level Decays + Unitarity



$$|V_{ud}| = 0.9744 \pm 0.0010$$
$$|V_{us}| = 0.2205 \pm 0.0018$$
$$|V_{cb}| = 0.040 \pm 0.005$$
$$|V_{ub}/V_{cb}| = 0.08 \pm 0.02$$

+ Unitarity

	d	s	b
u	0.975	0.22	$(2.-5.)10^{-3}$
c	0.22	0.974	$(4.0 \pm 0.5)\,10^{-2}$
t	$(2.-15)\cdot 10^{-3}$	$(3.9 \pm 0.6)\,10^{-2}$	0.999

Recent Messages from Heavy Quark Effective Theory

{ Luke, Savage; Shifman, Uraltsev, Vainshtein; Bigi; Ball, Nierste; Beneke, Braun; Mannel, Neubert. }

⇓

Because of hadronic uncertainties, difficult to imagine that

± 15%	$\Delta\,|V_{ub}/V_{cb}| \leqslant \pm 0.01$	from Tree - Level Decays
± 5%	$\Delta\,|V_{cb}| \leqslant \pm 0.002$	

even with improved data !

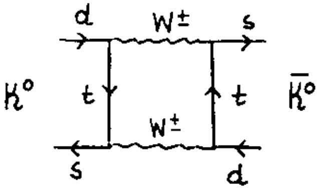
$|V_{td}|$ cannot be measured in TLD anyway !

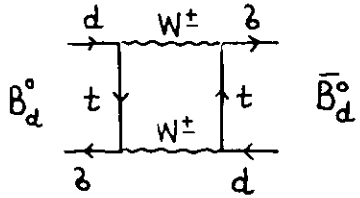
⇓

Go to **Loop Induced Decays**

\+ **CP Asymmetries in B**

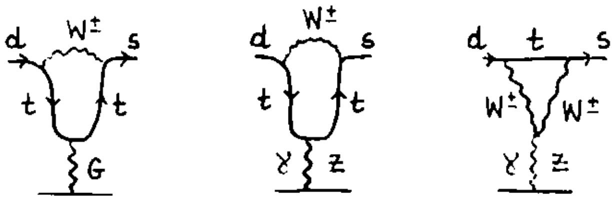
Loop Induced Decays

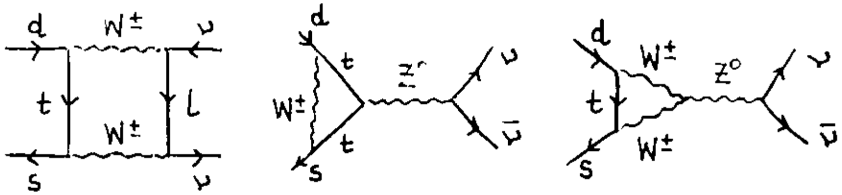




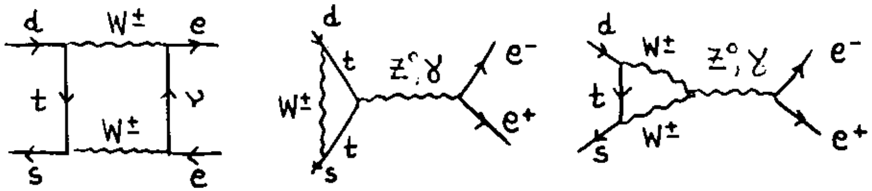
~~CP~~ ε - Parameter $B^0 - \bar{B}^0$ Mixing

ε'

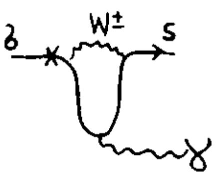




$K^+ \to \pi^+ \nu \bar{\nu}$ $K_L \to \pi^0 \nu \bar{\nu}$, $K_L \to \mu \bar{\mu}$, $B \to \mu \bar{\mu}$, $B \to X_s \nu \bar{\nu}$



$K_L \to \pi^0 e^+ e^-$ $B \to X_s e^+ e^-$



$B \to X_s \gamma$ $B \to K^* \gamma$

$B \to X_d \gamma$

General Structure

$$A(\text{Decay}) = B_{\text{Decay}} \cdot V_{CKM}\, \underbrace{\eta_{QCD}\, F(x_t)}_{} + \text{Internal Charm Contribut.}$$

{Non-Perturbative Parameter}
Can be calculated in QCD or extracted from Leading Decays

{Fully Calculable in RG improved PTh}
Short Distance

Example

$$x_c = \frac{m_c^2}{M_W^2} \qquad x_t = \frac{m_t^2}{M_W^2}$$

$$Br(K^+ \to \pi^+ \nu \bar{\nu}) = \left[\frac{\alpha^2_{QED}\, Br(K^+ \to \pi^0 e^+ \nu)}{V_{us}^2\, 2\pi^2 \sin^4 \Theta_W}\right] \cdot$$

$$\cdot \left| V_{ts}^* V_{td}\, \eta_t\, X(x_t) + V_{cs}^* V_{cd}\, \eta_c\, X(x_c) \right|^2$$

$$\eta_t \approx 1 \qquad \eta_c \approx \frac{2}{3}$$

$X(x_t)$, $X(x_c)$ } known Functions of m_t, m_c

Classification (1994) (AJB)

TUM - 64/94

Class I (TH very clean)

$K_L \to \pi^0 \nu \bar{\nu}$, $\not{C}\not{P}$ in B^0 decays.

Class II ($\Lambda_{\overline{MS}}$, m_c, μ_c, $SU(3)_F$)

$K^+ \to \pi^+ \nu \bar{\nu}$, x_d/x_s , Δ_{LR} ($K^+ \to \pi^+ \mu^+ \mu^-$)

$B \to X_{d,s} \nu \bar{\nu}$, $(b \to d\gamma)/(b \to s\gamma)$, $(B_d \to \mu\bar{\mu})/(B_s \to \mu\bar{\mu})$

Class III ("Moderate" TH Uncertainties)

$B^0 - \bar{B}^0$ mixing (x_d, x_s) ; $B_{d,s} \to \mu\bar{\mu}$

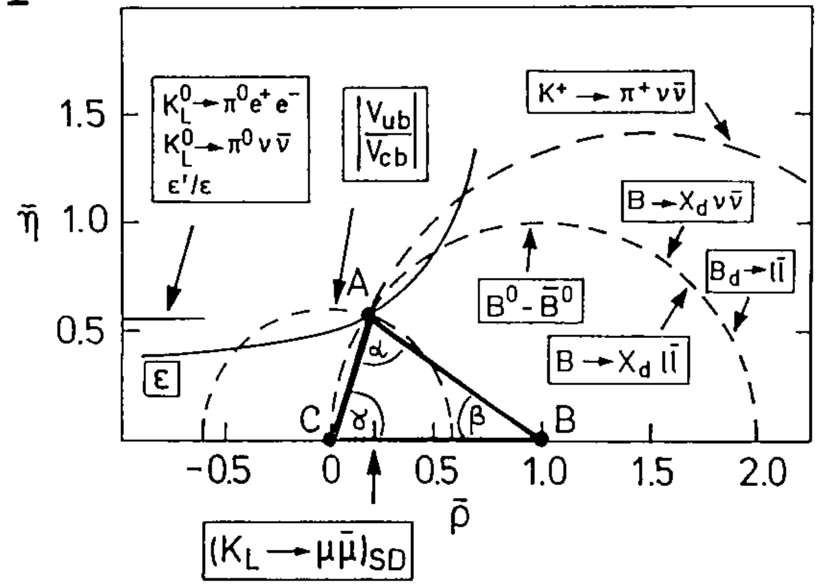
ε_K , $K_L \to \pi^0 e^+ e^-$; $B \to X_{d,s} \gamma$, $X_{d,s} e^+ e^-$

Class IV (Large TH Uncertainties)

$(\varepsilon'/\varepsilon)_K$, $K_L \to \mu\bar{\mu}$; $\not{C}\not{P}$ in $B^\pm, \Lambda, \Xi, \Sigma$.

Hunting Δ with Rare and $\not{C}\not{P}$ Decays

2011:



★ Quark Mixing and CP Violation closely related in the St. Model

★ $\left\{ \begin{array}{c} \text{CP Asymmetries} \\ \text{in} \\ \text{B - Decays} \end{array} \right\} \Rightarrow \left\{ \begin{array}{c} \sin 2\alpha \\ \sin 2\beta \\ \sin 2\gamma \end{array} \right\}$

Present Status of NLO η_{QCD}

$\Delta S = 1$, $\Delta C = 1$, $\Delta B = 1$ Hamiltonians

Current - Current — Altarelli, Curci, Martinelli, Petrarca (81); AJB + Weisz (89)

QCD Penguins — AJB, Jamin, Lautenbacher, Weisz (91); Ciuchini, Franco, Martinelli, Reina (93)

Electroweak Penguins — AJB, Jamin, Lautenbacher (93); Ciuchini, Franco, Martinelli, Reina (93)

Particle - Antiparticle Mixing + ε_K

Top Contributions (η_2) — AJB, Jamin, Weisz (90)

Charm Contributions ($\eta_{1,3}$) — Herrlich, Nierste (93) (94)

Rare K-, B- Decays

$K^+ \to \pi^+ \nu\bar{\nu}$, $K_L \to \mu^+\mu^-$, $K_L \to \pi^0 \nu\bar{\nu}$, $B \to l^+ l^-$, $B \to X_s \nu\bar{\nu}$, Δ_{LR} — Buchalla + AJB (93) (94)

$K_L \to \pi^0 e^+ e^-$ — AJB, Lautenbacher, Misiak, Münz (94)

CP - Asymmetries in B - Decays — Fleischer (92, 93)

Reduction of the μ-dependence

(Buchalla + AJB (93))

$$Br(B_s \to \mu\bar{\mu}) = F(m_t(\mu_t), V_{CKM}, F_B, \tau(B_s))$$

$$100\,\text{GeV} \lesssim \mu_t \lesssim 300\,\text{GeV}$$

Pure μ_t uncertainty:

$$Br(B_s \to \mu\bar{\mu}) = \begin{cases} (2.9 \pm 0.4)\, 10^{-9} & (LO) \\ (3.12 \pm 0.04)\, 10^{-9} & (NLO) \end{cases}$$

$\Downarrow$

After including NLO

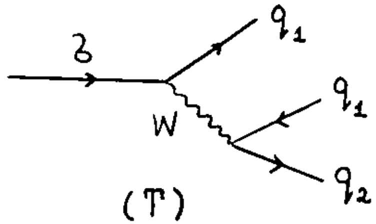
$$Br(B_s \to \mu\bar{\mu}) = \left[3.12 \cdot 10^{-9}\right] \left[\frac{\tau(B_s)}{1.6\,ps}\right] \left[\frac{F_B}{200\,MeV}\right]^2 \cdot \left[\frac{V_{ts}}{0.040}\right]^2 \cdot \left[\frac{\bar{m}_t(m_t)}{170\,GeV}\right]^{3.12}$$

Long Distance Problems in $K_L \to \mu\bar{\mu}$ and μ - Uncertainties in $B \to X_s \gamma$ — absent here!

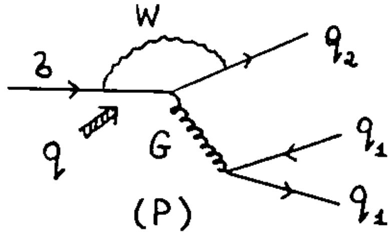
Express Review of CP Asymmetries

Basic Contributions

Class I : Decays with Trees (T) and Penguins (P)



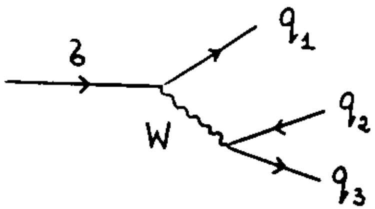
(T)



(P)

$q_1 \in \{u, c\}$ $\quad q_2 \in \{d, s\}$ $\quad q \in \{u, c, t\}$

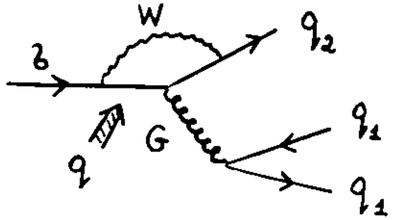
Class II : Decays with T only



$q_1 \neq q_2 \in \{u, c\}$

$q_3 \in \{d, s\}$

Class III : Decays with P only



$q_1, q_2 \in \{d, s\}$

$q \in \{u, c, t\}$

Direct CP Violation

Need two amplitudes (T, P) (T, T') (P, P') with <u>different</u> weak and strong phases
(φ_T, φ_P) (δ_T, δ_P)

$$\frac{\Gamma(B^+\to\pi^0K^+) - \Gamma(B^-\to\pi^0K^-)}{\Gamma(B^+\to\pi^0K^+) + \Gamma(B^-\to\pi^0K^-)} \sim \underset{(\gamma)}{\sin(\varphi_T - \varphi_P)}\,\sin(\delta_T - \delta_{P}$$

The presence of strong phases precludes a clean determination of CKM phases. (Gérard, Hou; Simma, Wyler; Fleischer; Kramer, Palmer ($B^\pm \to VV$))

Indirect (Mixing-Induced) $\not{C}\not{P}$

$B^0 \longrightarrow B^0 \searrow f$
$B^0 \longrightarrow \bar{B}^0 \nearrow f$
Mixing Decay

- If only single decay amplitude : clean determination of CKM (Particularly simple if f = CP eigenstate)

- Generally need 4 time dependent rates : $B^0(t) \to f$, $\bar{B}^0(t) \to f$, $B^0(t) \to \bar{f}$, $\bar{B}^0(t) \to \bar{f}$
- Tagging required : distinction between unmixed B^0 and $\bar{B}^0$ at t

Decays to CP Eigenstates

Single Tree Diagram :

$$A_{CP}(f) = \overbrace{\chi_{CP}(f)}^{\pm 1} \sin(2\varphi_D - \varphi_M)\, \frac{x_{d,s}}{1 + x_{d,s}^2}$$

$$\varphi_D = \begin{cases} \gamma & b \to u \\ 0 & b \to c \end{cases} \qquad \varphi_M = \begin{cases} -2\beta & B_d \\ 0 & B_s \end{cases}$$

(Decay) (Mixing)

⇓ $\sin(2\varphi_D - \varphi_M)$

- <u>B_d decays $(b \to c)$</u> : $\boxed{\sin 2\beta}$

  $B_d \to \psi K_S$ (very clean)

- <u>B_s decays $(b \to c)$</u> : $\boxed{2\lambda^2\eta}$

  $B_s \to \psi\varphi$ (clean but small)

- <u>B_d decays $(b \to u)$</u> : $\boxed{\sin 2\alpha}$

  $B_d \to \pi^+\pi^-$ (Need Isospin Analysis to remove P) (Gronau London)

- **B_s decays ($b \to u$) : $\sin 2\gamma$**

$B_s^0 \to \rho K_s$ ($Br \sim O(10^{-7})$, Penguin uncertainties)

$\Downarrow$

Other Strategies

- **$B_s \to D_s^+ K^-, D_s^- K^+$: $\boxed{\sin^2\gamma}$**
  - CP non-eigenstate
  - Full time-dependent analysis
  - $Br \sim 10^{-4}$
  - Pure tree diagram decay

  {Aleksan, Dunietz, Kayser}

- **$B^+ \to D^0_{CP} K^+$: $\boxed{\gamma}$**
  - Direct CP̸
  - No tagging
  - No time dependent measurements
  - Pure Tree's (T, T')
  - Need 6 decay rates to extract γ ($Br \sim 10^{-4} - 10^{-5}$)

  {Gronau, Wyler}

  ($B^+ \to D^0 K^+$, $\bar{D}^0 K^+$; $B^- \to \bar{D}^0 K^-$, $D^0 K^-$ etc.)

- **Using $SU(3)_F$** — Gronau, Hernandez, London, Rosner

$\boxed{B \to \pi\pi, \pi K, KK}$

- No tagging, No time dependent studies
- Plausible dynamical assumptions
- $SU(3)_F$?
- Top - Peguin Dominance

$\Rightarrow \boxed{\gamma, \beta}$

However:

(AJB, Fleischer) {u- and c- Penguins preclude a clean determination of β. γ unaffected. (including x_d/x_s solves "β - Problem")

(Fleischer, Deshpande, He) {Electroweak Penguins can have considerable impact on this approach

- **Electroweak Penguins and CP̸**

Play important role in

$\boxed{B_s \to \pi^0 \varphi, \; B^\pm \to K^\pm \varphi, \; B \to \rho\varphi}$ (Fleischer)

- $A_{CP}(B_d \to K^0 \bar{K}^0) \neq 0$ in SM (~30%)

(contrary to various statements)

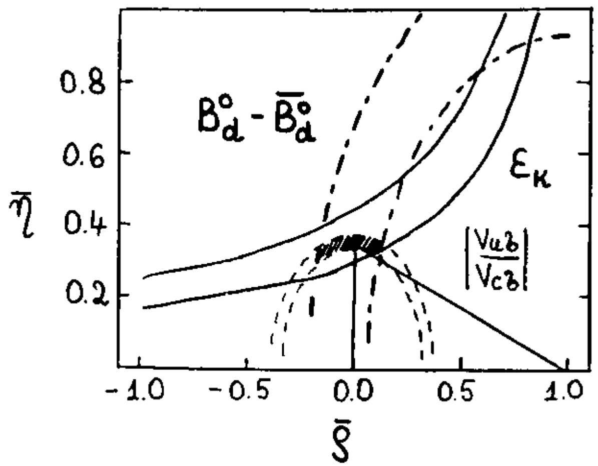
2000 - 2011
EXCURSIONS

- $\triangle$ from ε, B^0-$\bar{B}^0$, V_{cb}, $|V_{ub}/V_{cb}|$
- Impact of "B - Factories"
- $\sin 2\beta$ from $K \to \pi\nu\bar{\nu}$
- CKM without hadronic uncertainties.

Expectations from the "Standard" Analysis : ε_K, B_d^0-$\bar{B}_d^0$, $|V_{ub}/V_{cb}|$, V_{cb}

AJB Lautenbacher Ostermaier

"2000 - Picture"



Input

$|V_{cb}| = 0.040 \pm 0.001$
$\left|\frac{V_{ub}}{V_{cb}}\right| = 0.080 \pm 0.005$
$B_K = 0.75 \pm 0.05$
$m_t = 170 \pm 5$ GeV
$\sqrt{B_B} F_B = (180 \pm 10)$ MeV

Review of hadronic uncertainties Pich, Prades (94)

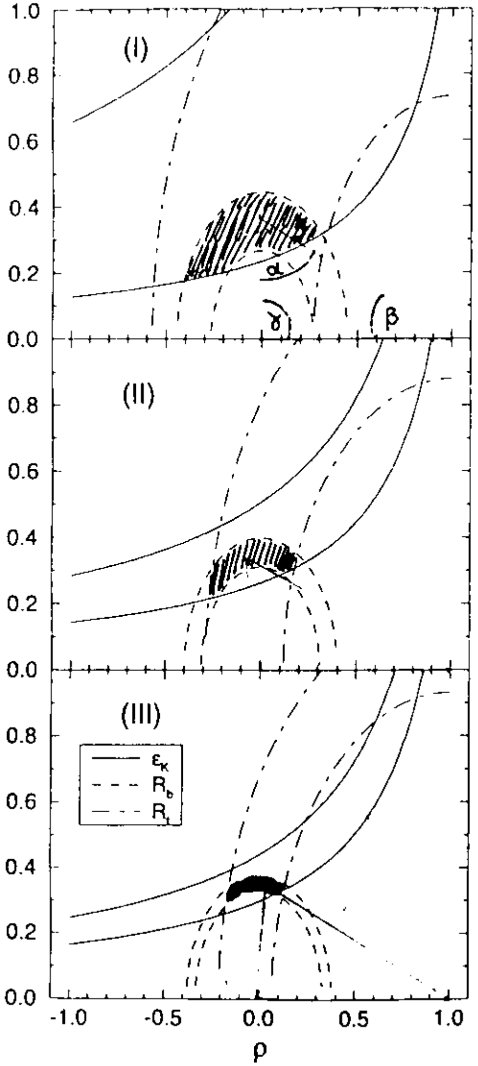
$\Delta\eta = \pm 0.05 \qquad \Delta\varrho = \pm 0.15$ (Optimistic)

Go to cleaner decays :

- to decrease $\Delta\eta$, $\Delta\varrho$
- to measure $|V_{ub}/V_{cb}|$, V_{cb}, $|V_{td}|$ without hadronic uncertainties

Impact of $\sin 2\varphi_i$ Measurements

(see also Ali, London)



⇑

$\Delta\eta = \pm\ 0.05$
$\Delta\rho = \pm\ 0.15$

1994

$0.38 \leq \sin 2\beta \leq 0.79$
$-0.67 \leq \sin 2\alpha \leq 1.0$
$-1.0 \leq \sin 2\gamma \leq 1.0$

1997

$0.46 \leq \sin 2\beta \leq 0.73$
$-0.30 \leq \sin 2\alpha \leq 1.0$
$-0.91 \leq \sin 2\gamma \leq 0.85$

2000 ✯

$0.52 \leq \sin 2\beta \leq 0.70$
$0.00 \leq \sin 2\alpha \leq 0.99$
$-0.74 \leq \sin 2\gamma \leq 0.67$

$\sin 2\beta = 0.61 \pm 0.09$

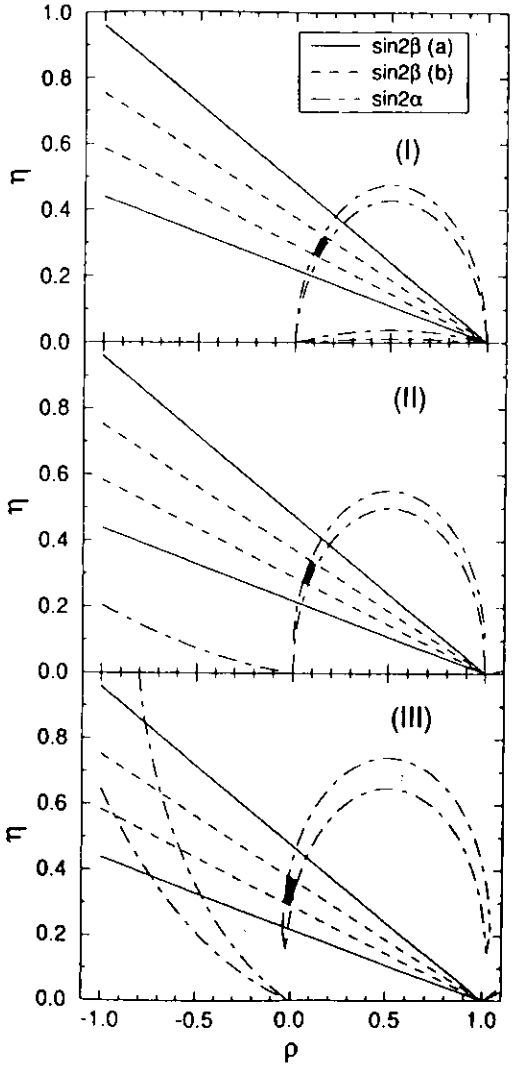
Huge uncertainties in $\sin 2\alpha$, $\sin 2\gamma$

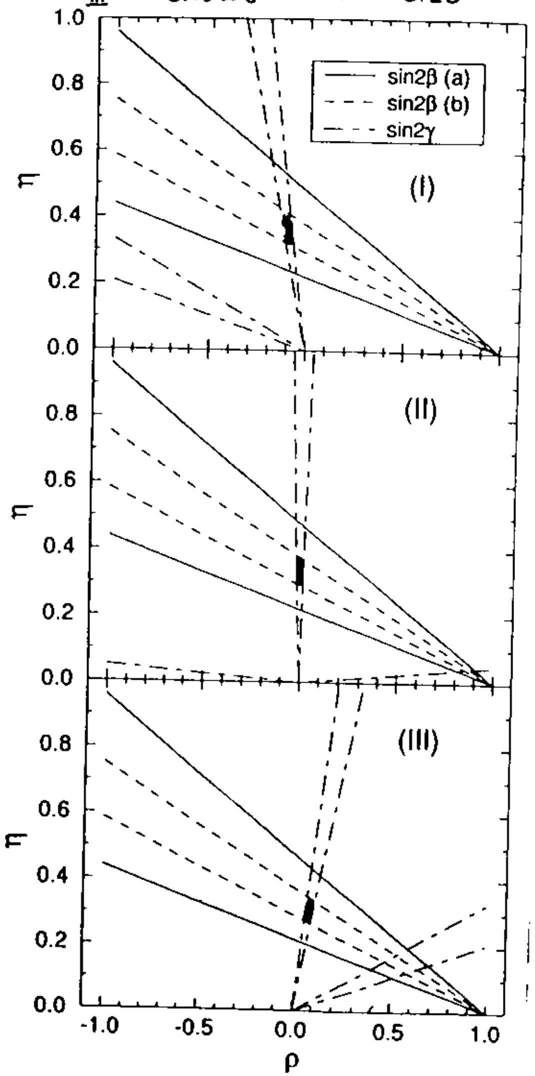
a) $\sin 2\beta = 0.60 \pm 0.06$

I : $\sin 2\alpha = -0.20 \pm 0.10$
II : $\sin 2\alpha = 0.10 \pm 0.10$
III : $\sin 2\alpha = 0.60 \pm 0.10$

b) $\sin 2\beta = 0.60 \pm 0.18$

I : $\sin 2\gamma = -0.50 \pm 0.10$
II : $\sin 2\gamma = 0.0 \pm 0.10$
III : $\sin 2\gamma = 0.50 \pm 0.10$





HERA-B , SLAC , KEK ~ 2000
B-FNAL

Finalists for a Clean Determination of CKM

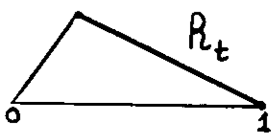
(AJB 94)

1. CP Asymmetries in B - Decays — $\boxed{\rho, \eta}$

2. $K_L \to \pi^0 \nu \bar{\nu}$ — $\boxed{A \text{ or } |V_{cb}|}$ } $\boxed{\beta}$

3. $K^+ \to \pi^+ \nu \bar{\nu}$ — $\boxed{A \text{ or } |V_{cb}|}$ }

4.* $(B_d^0 - \bar{B}_d^0)/(B_s^0 - \bar{B}_s^0)$



5.* $K^+ \to \pi^0 e^+ \nu$, $K_L \to \pi^- e^+ \nu$ } $\boxed{\eta}$

* Small hadronic uncertainties (under control in $\boxed{5}$)

CP - Asymmetries in B^0 Decays

$$A_{CP}(f) \equiv \frac{\Gamma(B^0 \to f) - \Gamma(\bar{B}^0 \to f)}{\Gamma(B^0 \to f) + \Gamma(\bar{B}^0 \to f)} \qquad f = \text{CP eigenstate}$$

e.g.

$\{ f = \psi K_s \} \Longrightarrow \sin 2\beta$ — Gronau, London, Rosner, Nir, Quinn, Wyler, Aleksan, Kayser, Dunietz, Fleischer ....

$\{ f = \pi^+ \pi^- \} \Longrightarrow \sin 2\alpha$ (after Isospin Analysis)

- No hadronic or $\Lambda_{\overline{MS}}$ uncertainties
- No dependence on m_t, V_{cb} (A)

$\boxed{(B_d^0 - \bar{B}_d^0)/(B_s^0 - \bar{B}_s^0) \text{ Mixing}}$

$\Downarrow$

$$R_t = \frac{1}{\sqrt{R_{ds}}} \frac{1}{\lambda} \sqrt{\frac{x_d}{x_s}} \qquad R_{ds} = \underbrace{\frac{\tau_{B_d} m_{B_d}}{\tau_{B_s} m_{B_s}}}_{\text{EXP}} \underbrace{\left[\frac{F_{B_d} \sqrt{B_{B_d}}}{F_{B_s} \sqrt{B_{B_s}}} \right]^2}_{\text{TH}}$$

- No $\Lambda_{\overline{MS}}$, m_t, V_{cb} (A) dependence
- Theoretical Uncertainty in $SU(3)_F$ Breaking ~ (5 - 10 %) ?

See also: $(b \to d \gamma)/(b \to s \gamma)$

$(B_d \to \mu \bar{\mu})/(B_s \to \bar{\mu} \mu)$

$K_L \to \pi^0 \nu\bar{\nu}$ (Direct CP̸)

$$Br(K_L \to \pi^0 \nu\bar{\nu}) = \kappa_L \, \eta^2 \, |V_{cb}|^4 \, X^2(m_t)$$

$$\kappa_L = \frac{3\alpha^2 \, Br(K^+ \to \pi^0 e^+ \nu)}{2\pi^2 \sin^4\theta_W} \, \frac{\tau(K_L)}{\tau(K^+)} = 3.54 \cdot 10^{-5}$$

$$X(m_t) = 0.65 \left(\frac{m_t}{M_W}\right)^{1.15} \qquad m_t \equiv \bar{m}_t(m_t)$$

- No hadronic uncertainties
- $\Lambda_{\overline{MS}}$ and μ_t uncertainties ~ 1% — $\bar{m}_t(\mu_t)$
- Strong m_t, V_{cb} (A) dependence

$K^+ \to \pi^+ \nu\bar{\nu}$ (CP Conserving)

(Additional Charm Contribution)

- Small hadronic Uncertainties* < 1%
- $\Lambda_{\overline{MS}}$, , $\bar{m}_c(\mu_c)$ Uncertainties** ~ 5-10%
- Strong m_t, V_{cb} (A) dependence

* Rein, Sehgal ; Hagelin, Littenberg ; Lu, Wise

** Perturbation Theory

E 25

$\sin 2\beta$ from $K \to \pi\nu\bar{\nu}$

(Buchalla, AJB) (94) (Phys. Lett. B)

★

$$B_+ = \frac{Br(K^+ \to \pi^+ \nu\bar{\nu})}{4.64 \cdot 10^{-11}} \qquad B_L = \frac{Br(K_L \to \pi^0 \nu\bar{\nu})}{1.94 \cdot 10^{-10}}$$

$$\sin 2\beta = \frac{2r}{1+r^2} \qquad r \equiv \frac{\sqrt{B_+ - B_L} - P_0(K^+)}{\sqrt{B_L}}$$

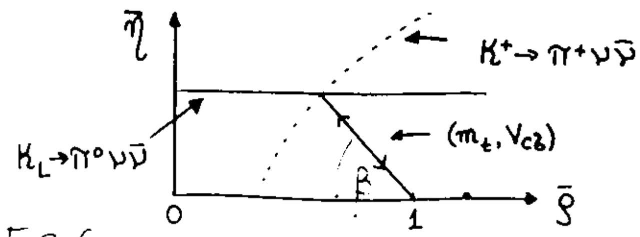
$$P_0(K^+) = 0.40 \pm 0.09 \quad \leftarrow (m_c, \Lambda_{\overline{MS}}, \mu_c)$$

No m_t, V_{cb} dependence in $\sin 2\beta$!

$$\left\{ \begin{aligned} Br(K^+ \to \pi^+ \nu\bar{\nu}) &= (1.0 \pm 0.1) \cdot 10^{-10} \\ Br(K_L \to \pi^0 \nu\bar{\nu}) &= (2.50 \pm 0.25) \cdot 10^{-11} \end{aligned} \right\}$$

⇓

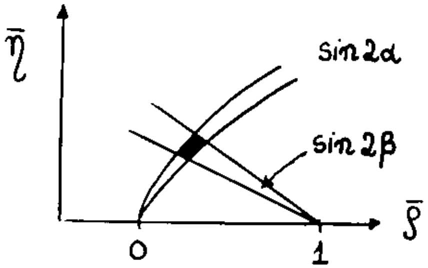
$$\sin 2\beta = 0.60 \pm \underbrace{0.06}_{Br} \pm \underbrace{0.03}_{m_c, \Lambda_{\overline{MS}}} \pm \underbrace{0.02}_{\mu\text{-dep}}$$



Comparision with $A_{CP}(\psi K_S)$ should give ... ★

E 26

(ρ, η) from $(\sin 2\alpha, \sin 2\beta)$



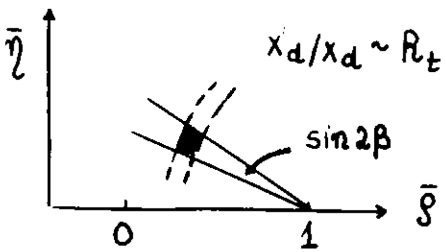
$a \equiv \sin 2\alpha$

$b \equiv \sin 2\beta$

$$\bar\rho = 1 - \bar\eta\, r_+(b) \qquad \bar\eta = \frac{r_-(a) + r_+(b)}{1 + r_+^2(b)}$$

$$r_\pm(z) = \frac{1}{z}\left[1 \pm \sqrt{1 - z^2}\right] \qquad z = a, b$$

(ρ, η) from $(R_t, \sin 2\beta)$



$$\bar\eta = \eta(1 - \lambda^2/2)$$
$$\bar\rho = \rho(1 - \lambda^2/2)$$

$$\bar\rho = 1 - \bar\eta\, r_+(b) \qquad \bar\eta = \frac{R_t}{\sqrt{2}} \sqrt{b\, r_-(b)}$$

First Look

Input	$\sin 2\alpha$	0.40	± 0.16	± 0.16
Input	$\sin 2\beta$	0.70	± 0.18	± 0.12
	ρ	0.09	± 0.11	± 0.08
	η	0.40	± 0.13	± 0.09
	$\lvert V_{ub}/V_{cb}\rvert$	0.090	± 0.030	± 0.020

Input	R_t	1.00	± 0.10	± 0.10
Input	$\sin 2\beta$	0.70	± 0.18	± 0.12
	ρ	0.09	± 0.15	± 0.13
	η	0.40	± 0.17	± 0.12
	$\lvert V_{ub}/V_{cb}\rvert$	0.092	± 0.033	± 0.023

Determination of CKM Matrix without hadronic Uncertainties

AJB (94) (Phys. Lett. B)

Input:

- $|V_{us}| = \lambda = 0.2205 \pm 0.0018$
- $a \equiv \sin 2\alpha \qquad b \equiv \sin 2\beta$
- $Br(K_L \to \pi^0 \nu \bar{\nu}) \equiv Br(K_L)$

Output:

$$\bar{\varrho} = 1 - \bar{\eta}\, r_+(b) \quad ; \quad \bar{\eta} = \frac{r_-(a) + r_+(b)}{1 + r_+^2(b)}$$

$$r_\pm(z) = \frac{1}{z}\left[1 \pm \sqrt{1-z^2}\right] \qquad z = a, b$$

$$|V_{cb}| = 39.1 \cdot 10^{-3} \sqrt{\frac{0.39}{\eta}} \left[\frac{170\,\mathrm{GeV}}{m_t}\right]^{0.58} \left[\frac{Br(K_L)}{3 \cdot 10^{-11}}\right]^{1/4}$$

$$\frac{\Delta |V_{cb}|}{|V_{cb}|} \cong \frac{1}{2}\frac{\Delta\eta}{\eta} + 0.58\,\frac{\Delta m_t}{m_t} + \frac{1}{4}\,\frac{\Delta Br(K_L)}{Br(K_L)}$$

$$\left(\bar{\eta} = \eta\,(1-\lambda^2/2), \quad \bar{\varrho} = \varrho\,(1-\lambda^2/2) \right)$$

		Central	I (2002)	II (2005)	III (2008)	"Standard" Analysis
Input	$\sin 2\alpha$	0.40	±0.08	±0.04	±0.02	
Input	$\sin 2\beta$	0.70	±0.06	±0.02	±0.01	
Input	m_t	170	± 5	± 3	± 3	
Input	$10^{11} \cdot Br(K_L)$	3	±0.30	±0.15	±0.15	
	ϱ	0.072	±0.040	±0.016	±0.008	±0.15
	η	0.389	±0.044	±0.016	±0.008	±0.05
$K_L \to \pi^0 \nu \bar{\nu}$	$10^3 \cdot \lvert V_{cb}\rvert$	39.2	± 3.9	± 1.7	± 1.3	± 2
$K_L \to \pi^0 \nu \bar{\nu}$	$10^3 \cdot \lvert V_{td}\rvert$	8.7	± 0.9	± 0.4	± 0.3	± 1.2
	$\lvert V_{ub}/V_{cb}\rvert$	0.087	±0.010	±0.003	±0.002	±0.01
$K^+ \to \pi^+ \nu \bar{\nu}$	$10^3 \cdot \lvert V_{cb}\rvert$	41.2	± 4.3	± 3.0	± 2.8	
$K^+ \to \pi^+ \nu \bar{\nu}$	$10^3 \cdot \lvert V_{td}\rvert$	9.1	± 0.9	± 0.6	± 0.6	

Other Implications

Tests of SM and Search for New Physics

$$\left(V_{cb}\right)_{\text{Loops}} \stackrel{?}{=} \left(V_{cb}\right)_{\text{Tree Decays}}$$

$$\left|\frac{V_{ub}}{V_{cb}}\right|_{\text{Loops}} \stackrel{?}{=} \left|\frac{V_{ub}}{V_{cb}}\right|_{\text{Tree Decays}}$$

Possible New Physics Contributions — Essentially Unaffected by New Physics

Tests of Non-Perturbative Methods

Determination through Loop Decays :

		I	II	III
B_K	0.83	± 0.17	± 0.07	± 0.06
$F_{B_d}\sqrt{B_{B_d}}$	200	± 19	± 8	± 6

Using R_t instead of $\sin 2\alpha$

		Central	I	II	III
Input	R_t	1.00	± 0.10	± 0.05	± 0.03
Input	$\sin 2\beta$	0.70	± 0.06	± 0.02	± 0.01
Input	m_t	170	± 5	± 3	± 3
Input	$10^{11}\cdot Br(K_L)$	3	± 0.30	± 0.15	± 0.15

		Central	I	II	III
	ϱ	0.076	± 0.111	± 0.053	± 0.031
	η	0.389	± 0.079	± 0.033	± 0.019
$K_L\to\pi^0\nu\bar\nu$	$10^3\,\lvert V_{cb}\rvert$	39.3	± 5.7	± 2.6	± 1.8
$K_L\to\pi^0\nu\bar\nu$	$10^3\cdot\lvert V_{td}\rvert$	8.7	± 1.2	± 0.6	± 0.4
	$\lvert V_{ub}/V_{cb}\rvert$	0.087	± 0.014	± 0.005	± 0.003
$K^+\to\pi^+\nu\bar\nu$	$10^3\,\lvert V_{cb}\rvert$	41.3	± 5.8	± 3.7	± 3.3
$K^+\to\pi^+\nu\bar\nu$	$10^3\,\lvert V_{td}\rvert$	9.1	± 1.3	± 0.8	± 0.7

HERA-B Topics

$$\left.\begin{array}{l}\sin 2\beta \\ B_s^0 - \bar{B}_s^0\end{array}\right\} \Rightarrow (\varrho, \eta)$$

$$B_s \to \psi\varphi \} \Rightarrow \eta$$

$$B^+ \to D^0_{CP} K^+ \} \Rightarrow \gamma \quad \left(\begin{array}{c}\text{Direct} \\ \not{CP}\end{array}\right)$$

$$B_{d,s} \to \mu\bar{\mu} \} \Rightarrow |V_{ts}|, |V_{td}| (?)$$

$\sin 2\alpha$???

$$x_s = \begin{cases} > 9 & \text{ALEPH} \\ 16 \pm 8 & \text{(AJB, Lautenbacher, Ostermaier)} \\ 19 \pm 13 & \text{(Ali, London)} \end{cases}$$

Shopping List 1994 - 1999

1. Improved Measurements of m_t
   CDF, DØ, LEP (94 - 96) (99)

2. Improved Determinations of V_{ub}, V_{cb}, $B_d^0 - \bar{B}_d^0$
   CLEO, LEP (94 - 99)

3. $B \to X_s \gamma$ and NLO (94-96)

4. $K^+ \to \pi^+ \nu \bar{\nu}$ at BNL (95-96) V_{td}

5. ε'/ε at $\Delta = 10^{-4}$ (96 - 98) (CERN, FNAL, Frascati)

6. Improved Calculations of B_i

7. $K_L \to \pi^0 e^+ e^-$, $K_S \to \pi^0 e^+ e^-$ (98?)

8. Discovery of $\not{CP}$ - B at HERA-B (99?)

Shopping List 2000 - 2008

1. $\not{CP}$ in B - decays
   (HERA-B , SLAC , KEK , FNAL)   2000 ↓ 2004

2. $B_s^0 - \bar{B}_s^0$, $B \to \mu\bar{\mu}$, $B \to X_s \mu\bar{\mu}$
   (HERA-B , FNAL)

3. $K_L \to \pi^0 \nu \bar{\nu}$ (200X)
   (KAMI , KEK)

4. $\Delta m_t \approx 3$ GeV
   (FNAL , LHC)

5. Precision Measurements of (α, β, γ) (LHC)   (2005 →)

6. Signals of New Physics

Hope : $X = 0$, $Y \leq 3$ (2 XYZ)

Status of HERA-B

W. Hofmann
MPI Heidelberg
Open Collab. Meeting
October 1994

- The HERA-B Collaboration
- History and
  Recent Developments
- Cost of the Experiment
- Installation and
  Running Scenarios
- Responsibilities
  and Opportunities
- Goals of this Meeting

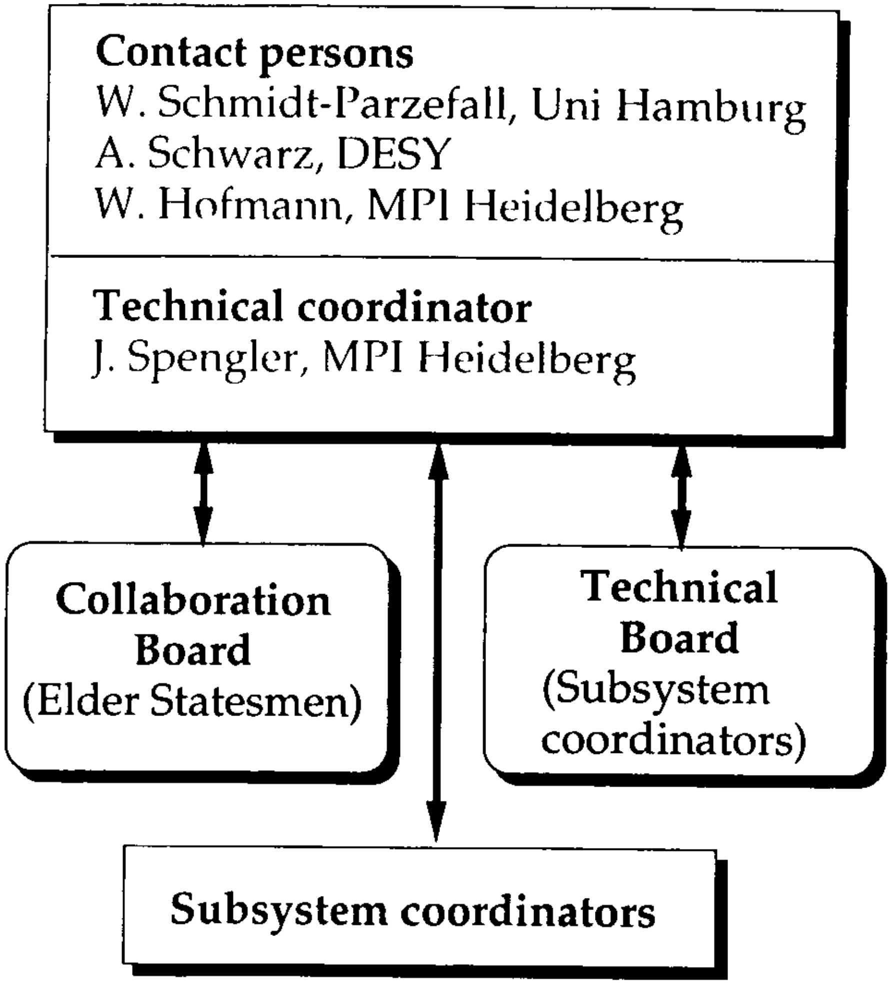
The HERA-B Collaboration

- Humboldt Univ., Berlin
- Univ. and INFN Bologna
- Univ. Dortmund
- DESY, Hamburg
- Univ. Hamburg
- MPI für Kernphysik, Heidelberg
- Univ. Heidelberg
- Inst. for Nuclear Research, Kiev
- Inst. J. Stefan and Univ. Ljubljana
- Univ. of California, Los Angeles
- Univ. Mannheim
- Univ. of Massachusetts, Amherst
- ITEP, Moscow
- Phys. Engineering Inst., Moscow
- MPI für Physik, München
- Univ. and INFN Rome
- Univ. Siegen
- Univ. of Texas, Austin
- DESY, Zeuthen

19 Institutions
132 Physicists

{"frozen" since late spring '94}

HERA-B Organization
(until fully approved)



to be reevaluated in January...

History

Letter of Intent (151 p):
DESY PRC 92/04 — **Oct. 92**
Progress Report (100 p):
DESY PRC 93/04 — **March 93**
Proposal (289 p):
DESY PRC 94/02 — **May 94**

CORE Review: — **May 94**

Conditional Approval: — **June 94**

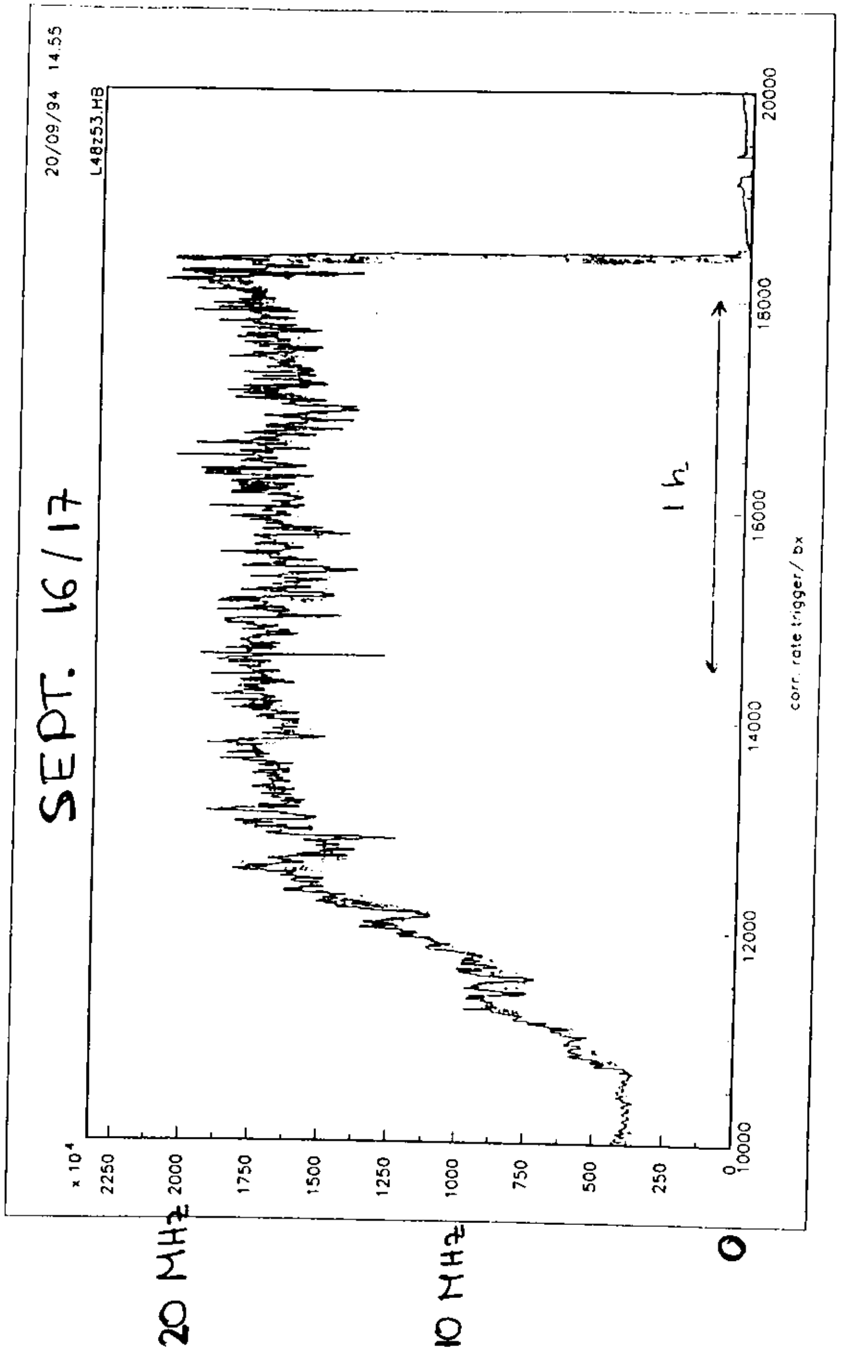
Conditions:
- Show that the experiment will be ready to take data on time
- Strenghten the collaboration
- Secure adequate funding
- Study options to simplify/stage
- Resolve accelerator issues

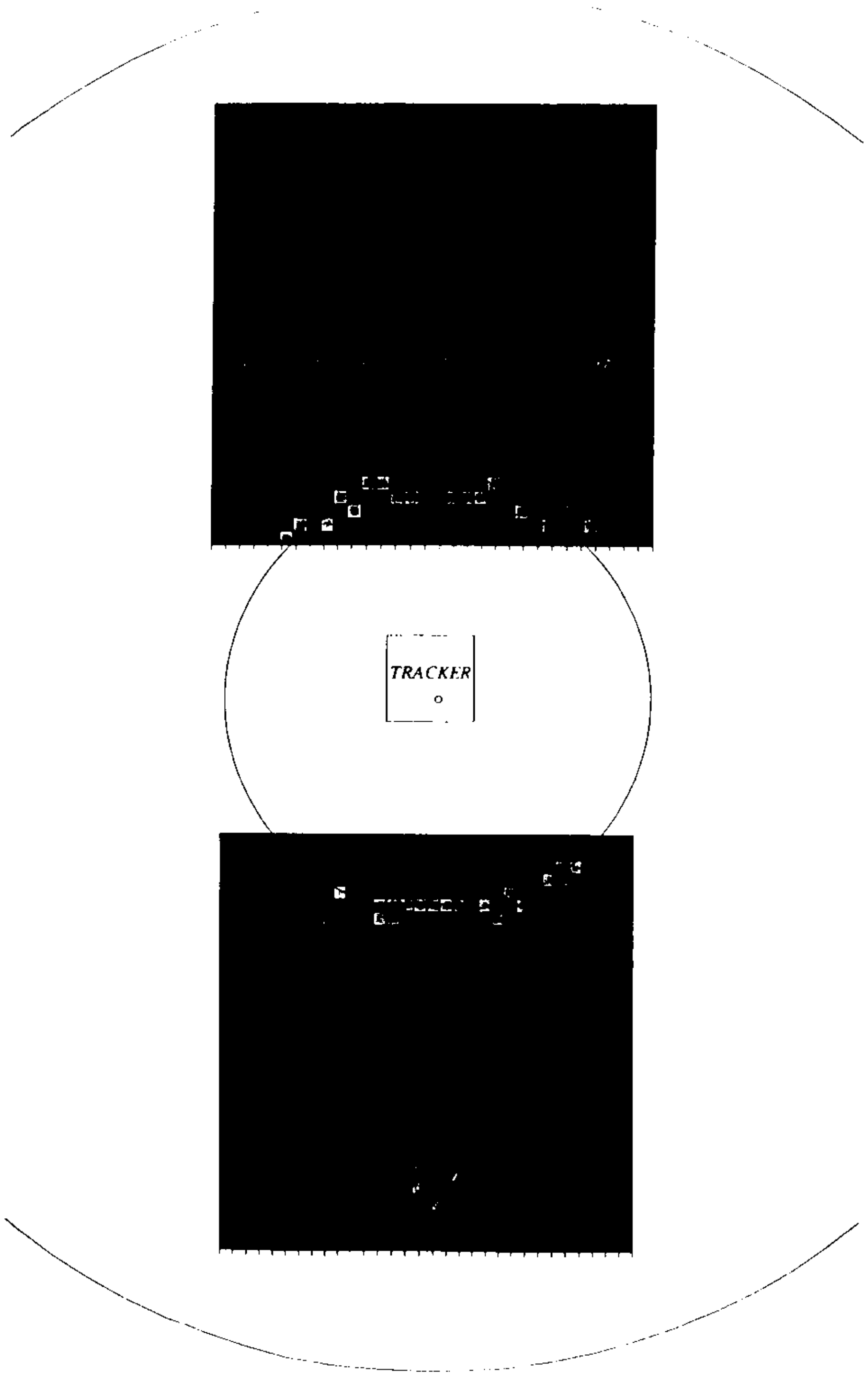
and Future ...

Open Collaboration Meeting: **Oct. 94**
Technical Design Report: **Dec. 94**
Final Approval: **Jan. 95 ?**

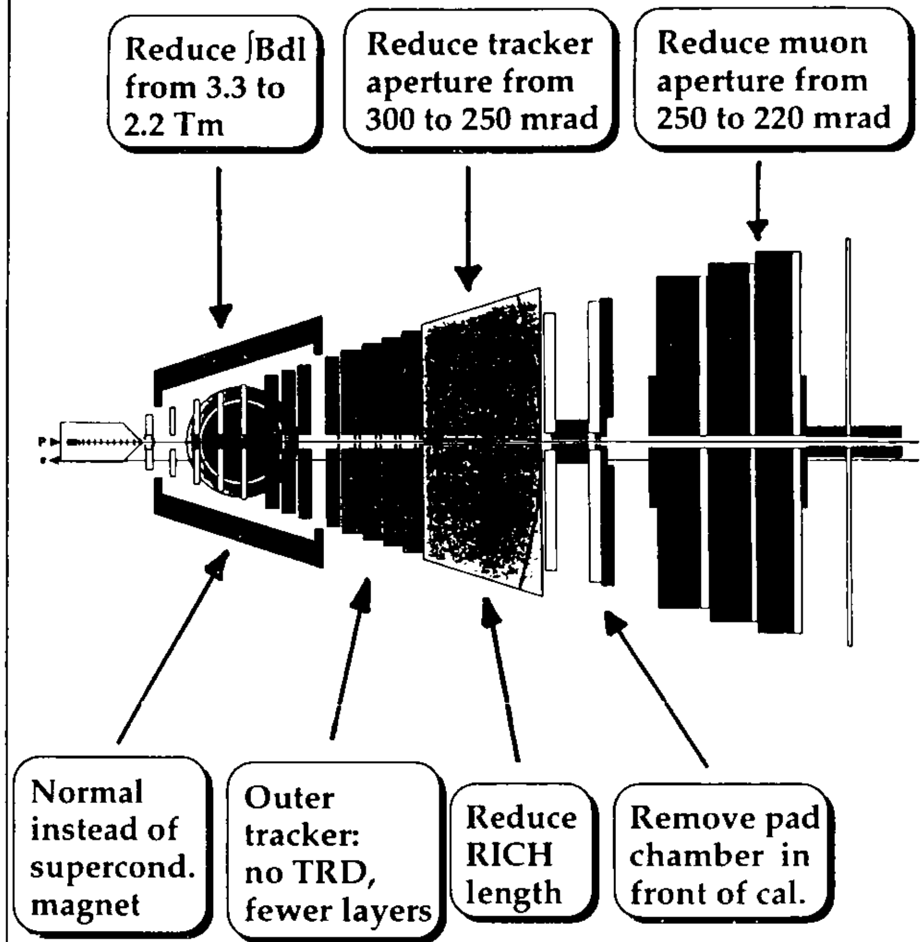
Detector Decisions: Milestones

Magnet: normal or superconducting?	**normal (time, cost)**
Inner tracker: MSGCs or gas pixels?	**open ... MSGCs look good (Pisa)**
Combined TRD/ Tracker: yes or no?	**no (main) TRD (material, cost)**
RICH readout: CsI cathode or TMAE cells?	**open... both work!**
Calorimeter: yes / no / staged?	**yes, maybe staged**
Electron trigger: yes / no /staged?	**open ... being reevaluated**





Slimming down the Detector



Material in front of calorimeter reduced significantly

Total length of detector slightly reduced

Cost Summary

	Proposal	CORE	Action taken
Magnet, cryogenics	3000	+2500	normal magnet
Beam pipe, target	250		
Vertex detector	4190		
Inner tracker	2440		
Outer tracker, TRD	5645	+200	no TDR
RICH	3200	+xxxx	
Calorimeter	4520		simplified constr.
Muon system	3080		
First level trigger	2975		
Second level trigger	1265		
DAQ, 3rd level	3600		
Detector platform	1500		
Misc. Infrastructure	3000	+3500	
Total	38665		

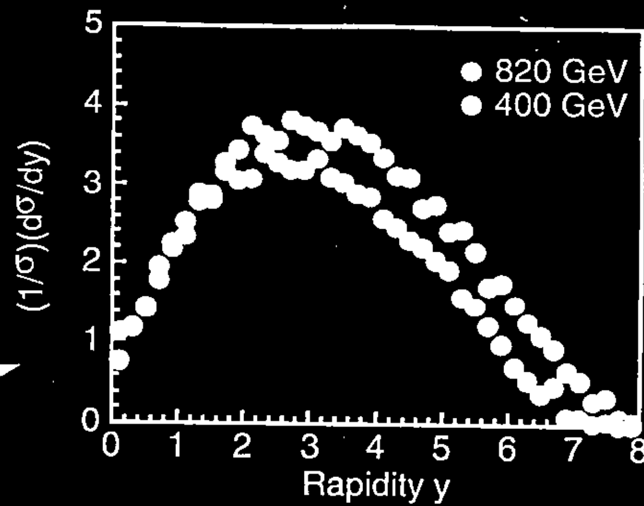
	1995	1996	1997	1998
	Test setup in tunnel			
	Target test	**R&D run**	**Technical test run**	**Physics run**
Machine	• Rates & rate control • Backgrounds & collimation • HOM & pickup	• HERA p ring operation w. magnet • HERA e ring operation w. shield • Optics tests & tuning • Rate & rate control • Backgrounds & collimation	• Fine-tuning & optimization of operation	
Detector	• Particle flux & radiation doses • Background hits & tracks in det.	• Occupancies & chamber loads • Si-vtxdet. operations and rad. damage • μ, CAL pretrigger rates & operation	• Test and tune - readout - pretriggers - trigger processor - 2nd level algorithm - online farm - detector operations procedure - calibration & control software	• Running in of - detector - triggers - DAQ • Tune-up of - calibration - on-line analysis • Routine running procdures
Physics		• μ-pair trigger and J/Psi • B -> J/Psi X possible	• μ-pair trigger and J/Psi • B -> J/Psi X likely	• Reconstr. B, lifetimes, tagging studies

W. Hofmann, Sept. 94

Machine Requirements

- Early optics modification
- Maximum p current
- Maximum # of bunches
- Maximum energy for physics data (900 GeV?)

- Lower energies ok for testing and running-in, but not for B-physics (x 0.5 in E = x 0.1 in σ_B)



1995	1996	1997	1998
Target test	R&D run	Technical test run	Physics run

High-Energy Running

W. Hofmann, Sept. 94

Why staged installation& test scenario?

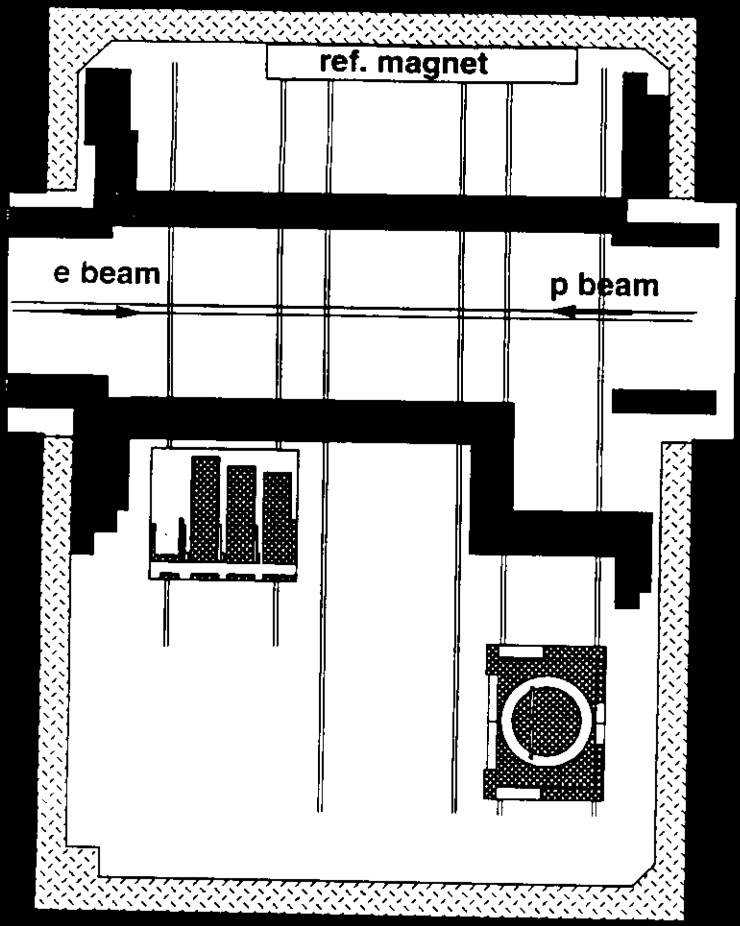
+ Early start on learning curve for machine and target operation
+ 96 run can still influence design details
+ 97 provides early operational experience with the detector
+ Real estate in West Hall does not permit simult. installation
+ Good for students

– Increased manpower demands

– Danger to get side-tracked

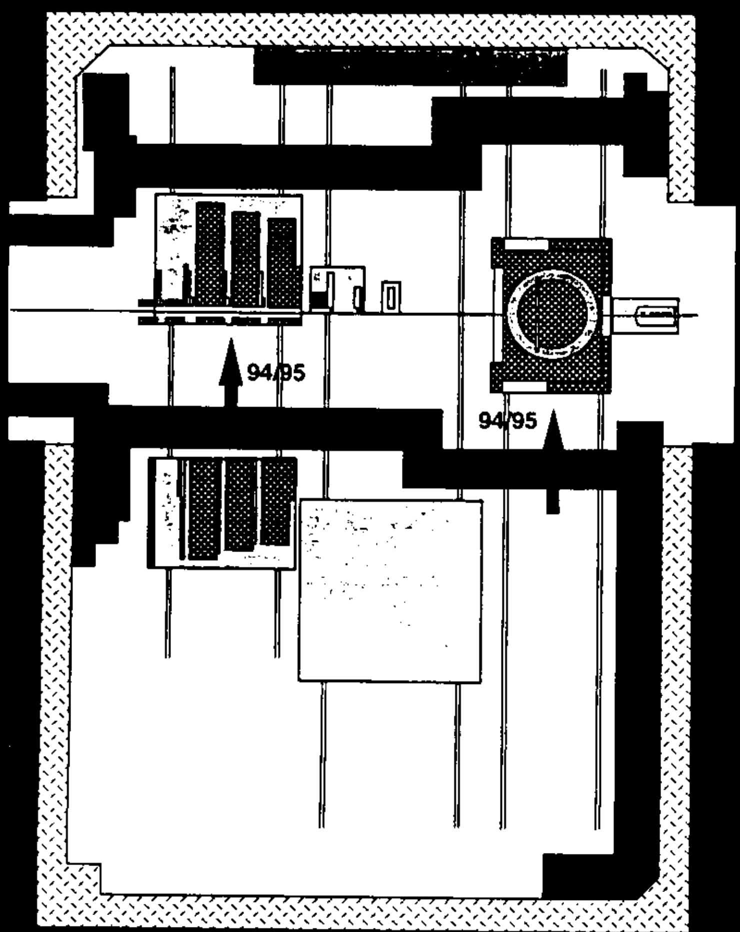
Beware !

W. Hofmann, Sept. 94



1994/1995 Shutdown
- Install rails
- Install utilities

1995
Prepare outside:
- Magnet
- Tracker prototypes
- Rear μ system
  (≈ 30% of chambers)



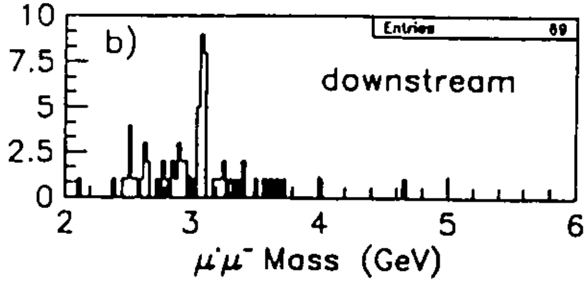
1995/1996 Shutdown
Modify:
- Beam optics
- HERMES laser pipe
- Shielding

Install
- Magnet and e,p comp.
- Rear μ platform, chambers
- Beam pipe
- Target prototype
- Silicon prototype
- Tracker prototypes
- Calorimeter prototype
- RICH chamber prototype

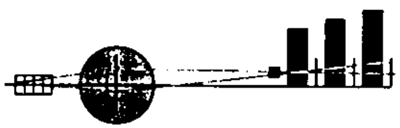
1996
Prepare outside:
- Front μ system
- Middle platform (?)

Measurement of the B Cross Section

E789 off-vertex dimuons
based on 2 (Fermilab-)months of data,
at 40 MHz peak rate, and 0.5% efficiency:



HERA-B R&D run:



- Si + 1 chamber + 20% μ-system
- Dimuon-eff. ≈ 2.5%
- Mass resolution ≈ 30 MeV
- Peak rate ≈ 10 MHz

☞ **about 30 reconstructed events after cuts, per 10^6 s of data**

Issues:

- **Trigger rejection (≈ 10^4 needed)**
- **DAQ /event builder**

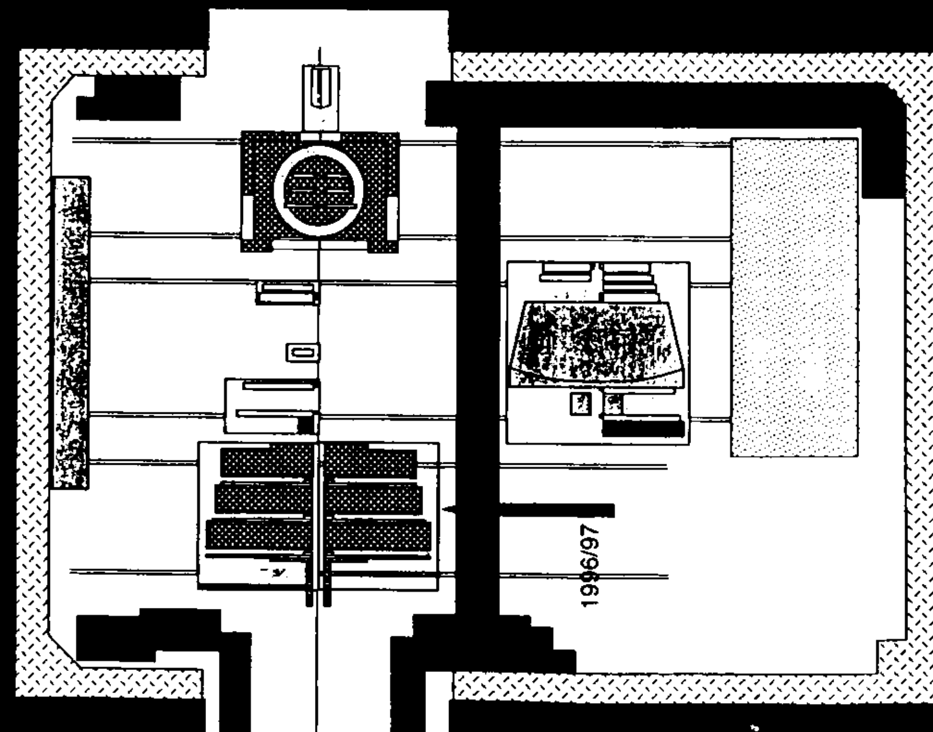
1996/1997 Shutdown

- Install front μ system
- Add tracking chambers

1997

Prepare outside:

- Middle platform with
  - Tracking chambers
  - RICH
  - TRD
  - Calorimeter;
- electronics hut



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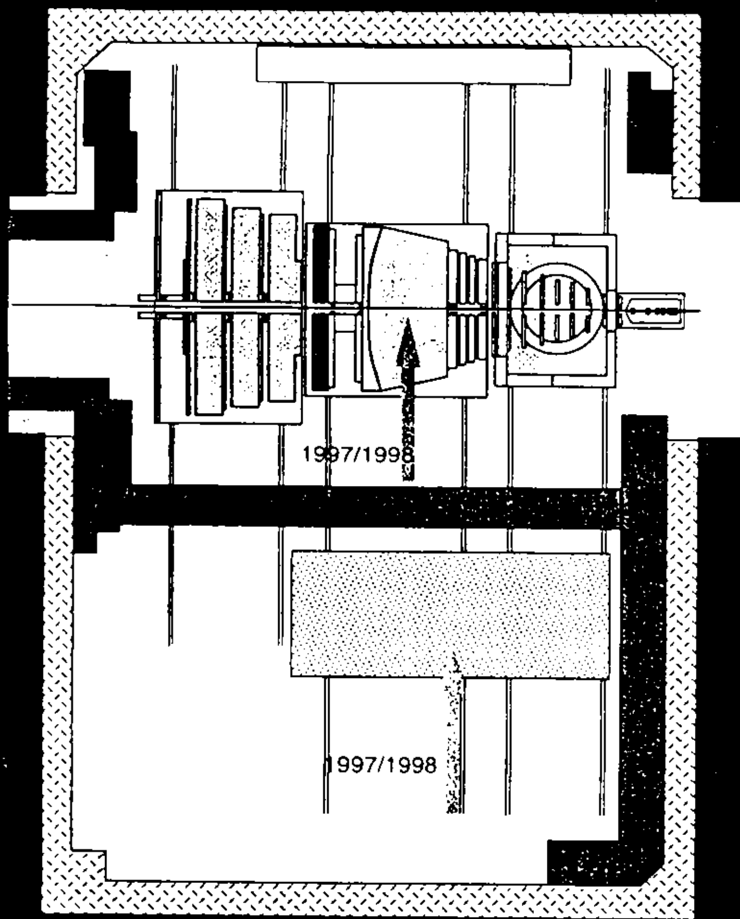
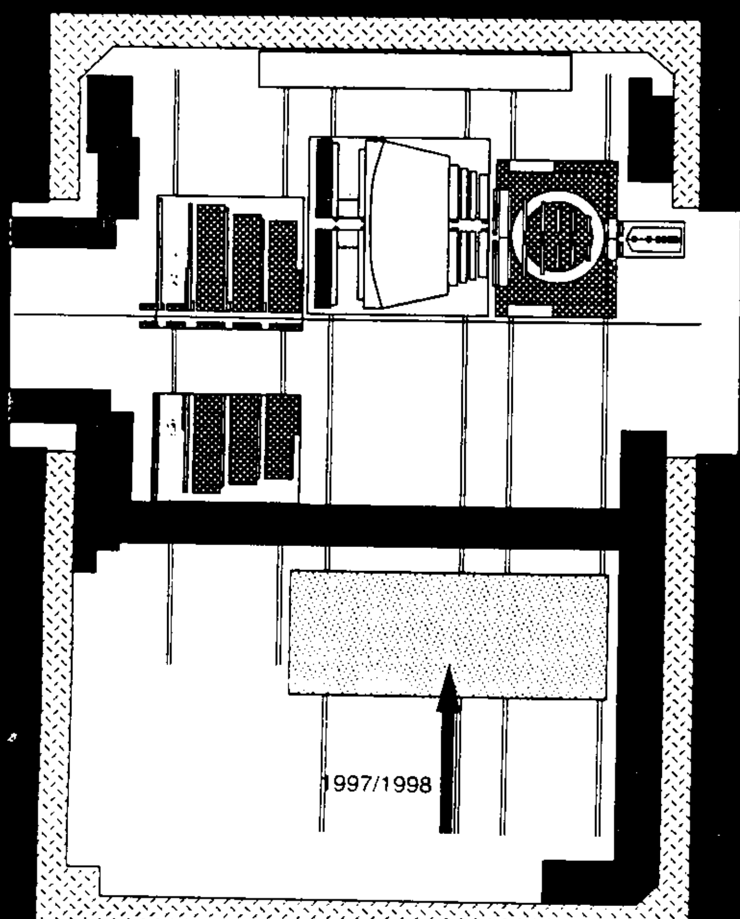


1997/1998
- Install middle platform
- Install final shielding

1998
- Complete electronics installation

W. Hofmann, Sept. 94



Access for HERA Tram

W. Hofmann, Sept. 94

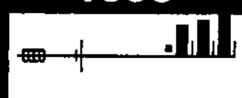
Past-1998

- steady running for 4 to 5 years
- $\tau_{beam} \approx \varepsilon_{target} (I / I_{design})$ *125 h ≈ (I / I_{design}) *100 h
- energy upgrade:
  900 GeV gains x 1.3
  1 TeV gains x 1.7
  tradeoff cross section ↔ running efficiency?
- p-only running is ok - refill every few days
  may need to enhance diffusion (RF)

What if ...

the magnet slips ?

1996



R&D run

Real estate in West Hall more problematic

Loose time in 1996/97 shutdown

• HERA p ring operation w. magnet	Impossible -> 1997
• HERA e ring operation w. shield	Impossible -> 1997
• Optics tests & tuning	ok
• Rate & rate control	ok
• Backgrounds & collimation	ok
• Occupancies & chamber loads	possible, but compromised
• Si-vtxdet. operations and rad. damage	ok
• μ, CAL pretrigger rates & operation	possible, but compromised
• μ-pair trigger	possible, but compromised
and J/Psi	impossible
• B -> J/Psi X possible	impossible

no physics until 1997

a pity, but no disaster !

W. Hofmann, Sept. 94

F-2.1-

What if ...

the optics mod. slips?

(p-beam & e-beam optics in West Hall, p beam dump)

very likely to prolong the startup phase and to delay physics output!

1996

R&D run

- HERA p ring operation w. magnet
- HERA e ring operation w. shield
- Optics tests & tuning
- Rates & rate control
- Backgrounds & collimation

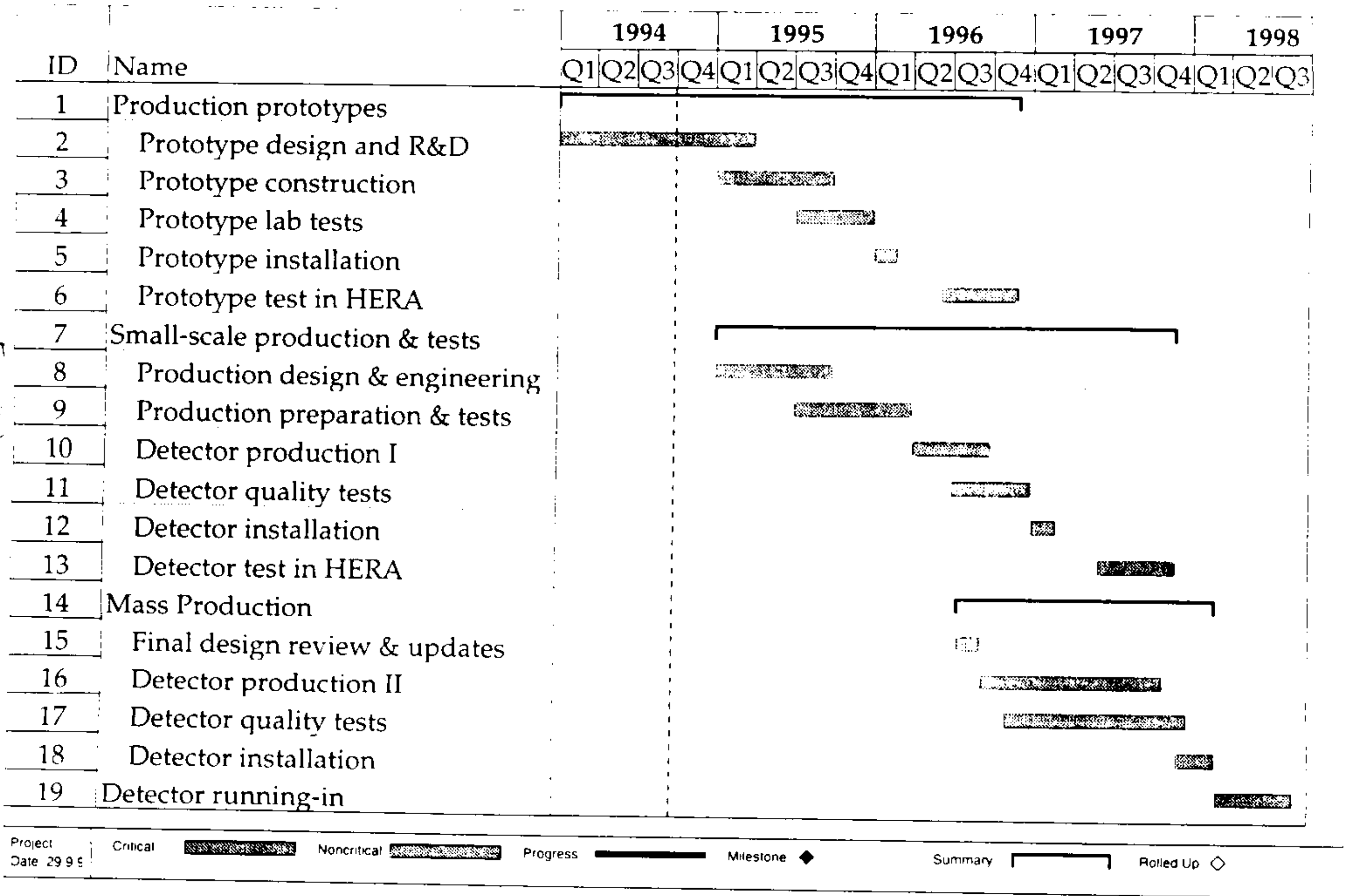
- Occupancies & chamber loads
- Si-vtxdet. operations and rad. damage
- μ, CAL pretrigger rates & operation

- μ-pair trigger and J/Psi
- B -> J/Psi X possible

- Cannot learn much more from target test station in tunnel
  - wrong optics
  - space too limited
  - readout complicated
- 1997: simultaneous test & tuning of both machine/target and detectors
- Tests cannot provide feedback for detector construction - too late
- Limited opportunity for longer-term tests (aging & rad. damage)
- 1996/97 shutdown overloaded, both concerning time and floor space

W. Hofmann, Sept. 94

F-2.2-

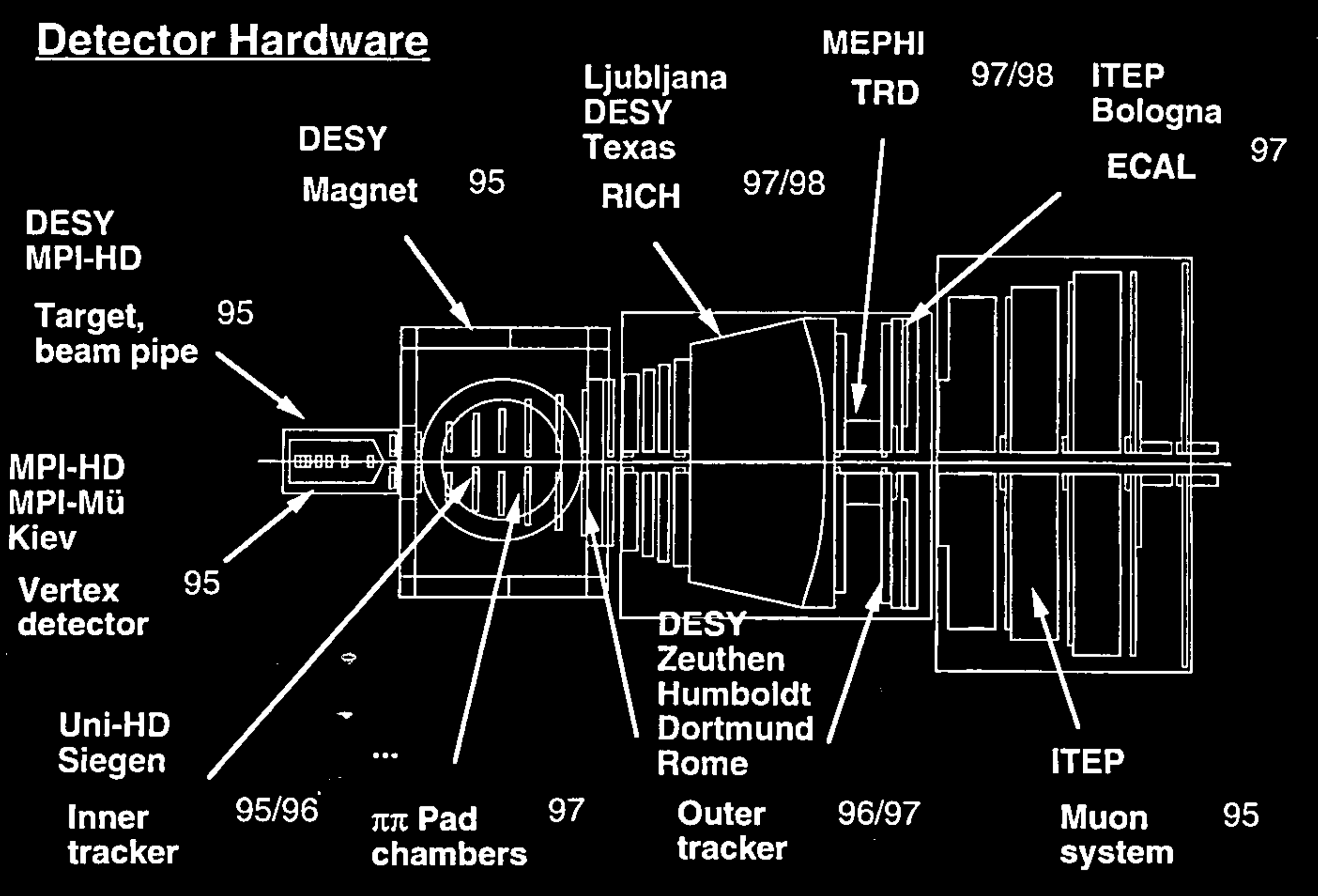


Responsibilities

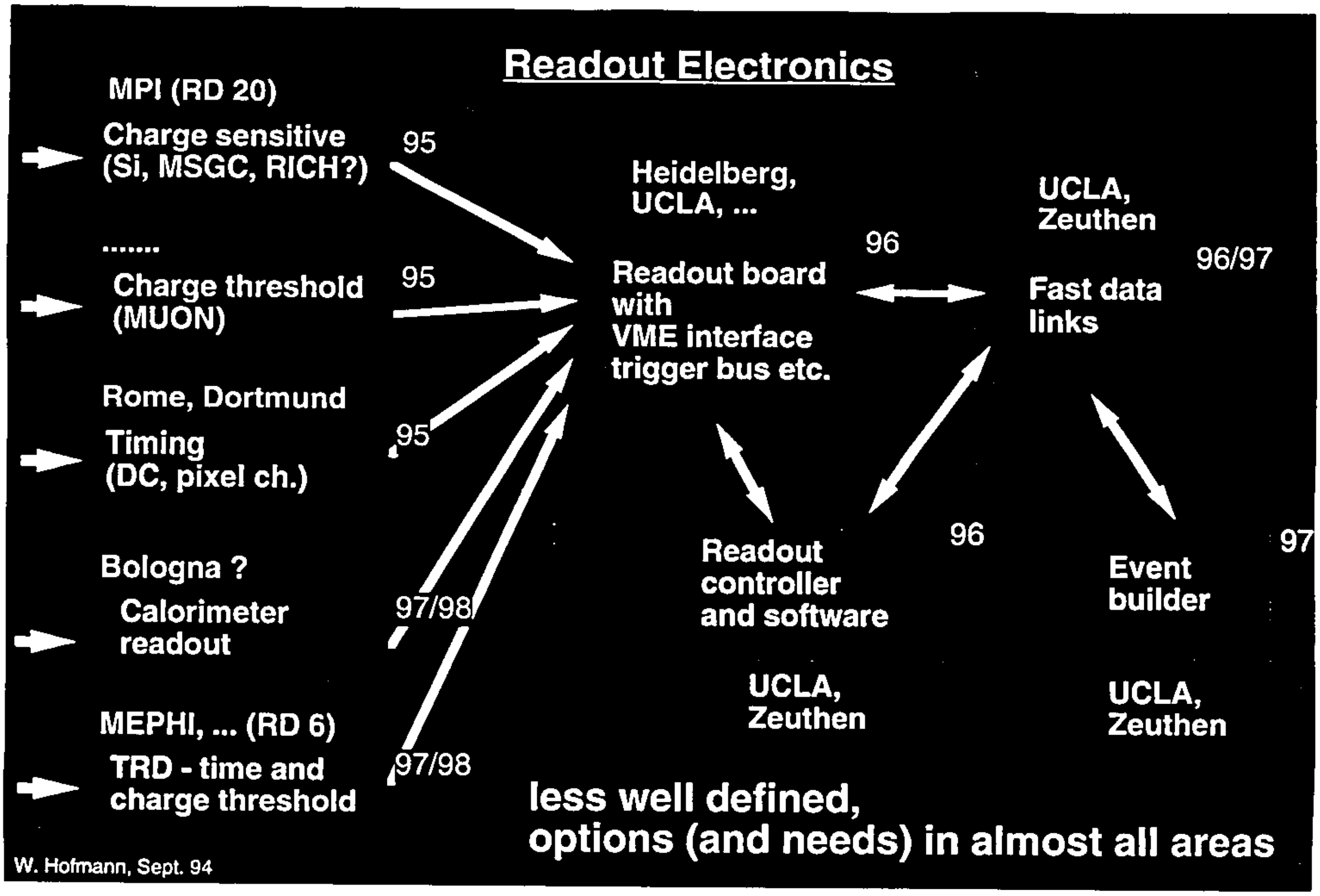
	Humboldt Berlin	INFN, Univ. Bologna	Univ. Dortmund	DESY, Univ. Hamburg	Univ. Heidelberg	MPI Heidelberg	INR Kiew	IJS, Univ. Ljubljana	UCLA	Univ. Mannheim	U.Mass., Amherst	ITEP Moscow	MEPHI Moscow	MPI München	INFN, Univ. Rome	Univ. Siegen	U. Texas, Austin	DESY Zeuthen
Beam pipe, target				●		●												
Silicon vtx						●	●							●				
Magnet				●														
Inner tracker					●											●		
Outer tracker	●		●	●											●			●
RICH				●				●									●	
TRD													●					
Calorimeter		●										●						
Muon system												●						
Level 1 trigger				●						●								
Level 2 trigger									●		●							●
DAQ					●				●									●
Farms																		●

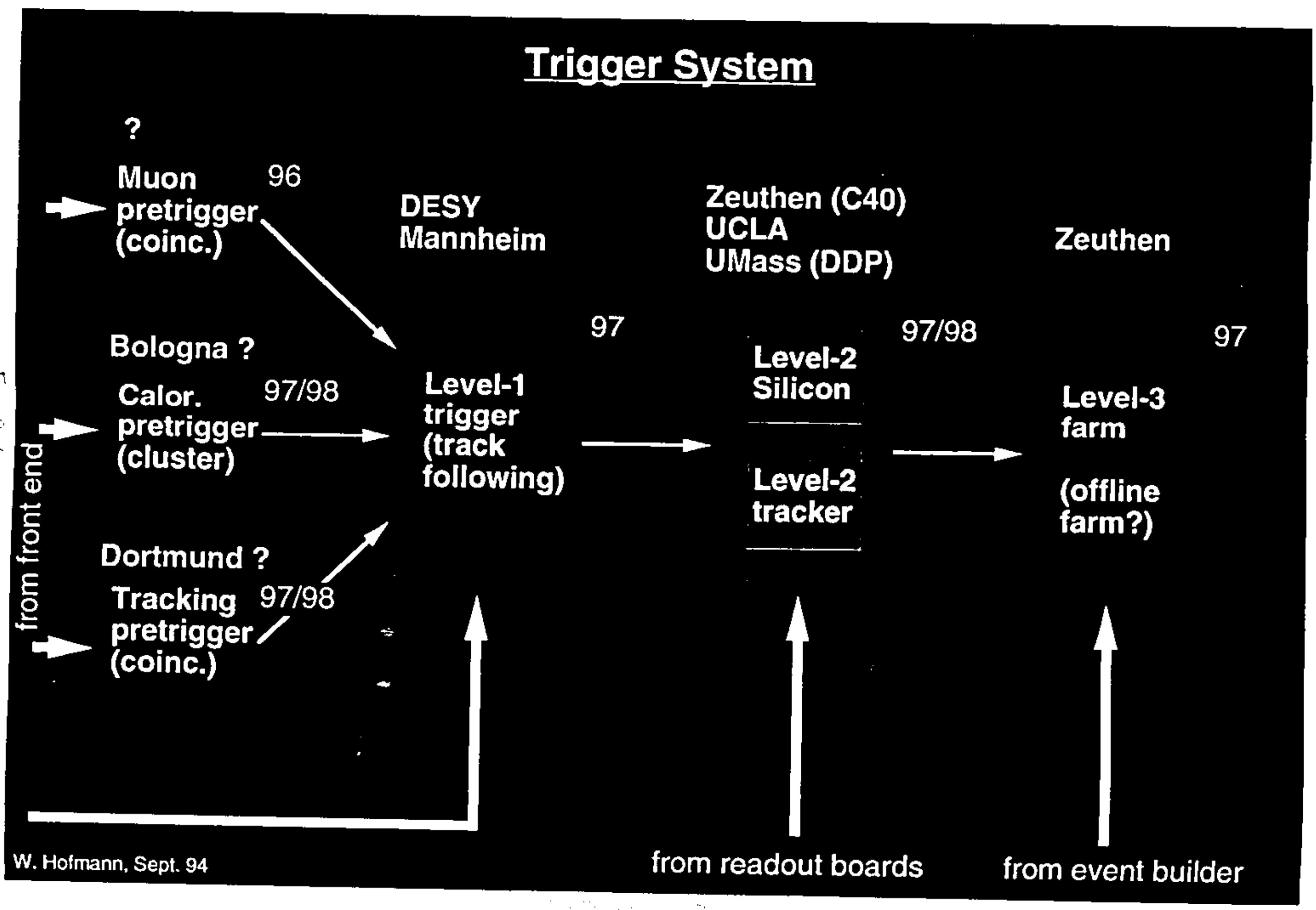
W. Hofmann, Sept. 94

Detector Hardware



W. Hofmann, Sept. 94


Readout Electronics
MPI (RD 20)
Charge sensitive (Si, MSGC, RICH?)
95
....
Charge threshold (MUON)
95
Rome, Dortmund
Timing (DC, pixel ch.)
95
Bologna ?
Calorimeter readout
97/98
MEPHI, ... (RD 6)
TRD - time and charge threshold
97/98
Heidelberg, UCLA, ...
Readout board with VME interface trigger bus etc.
96
UCLA, Zeuthen
Fast data links
96/97
Readout controller and software
96
UCLA, Zeuthen
Event builder
97
UCLA, Zeuthen
less well defined,
options (and needs) in almost all areas
W. Hofmann, Sept. 94


Trigger System
?
Muon pretrigger (coinc.)
96
Bologna ?
Calor. pretrigger (cluster)
97/98
Dortmund ?
Tracking pretrigger (coinc.)
97/98
from front end
DESY
Mannheim
Level-1 trigger (track following)
97
Zeuthen (C40)
UCLA
UMass (DDP)
Level-2 Silicon
Level-2 tracker
97/98
Zeuthen
Level-3 farm
(offline farm?)
97
from readout boards
from event builder
W. Hofmann, Sept. 94

- Components not covered
  - muon electronics
  - $\pi\pi$ trigger chambers

- Many areas, where additional
  - ideas
  - physicist manpower
  - engineering capacity
  - funds

  would be welcome

- In particular, even fairly general features of electronics and DAQ are still under discussion

- Detailed definition of the sharing of work among the interested groups is still open in many subprojects

- Large variety of smaller, but essential subprojects

target monitoring and control
magnet mapping
tracker alignment system
slow control systems
...

Software

Impressive progress so far
- full GEANT simulation
- cores of pattern recognition engines
- track and vertex fitting packages
- clock-level trigger simulation

Reliable software is crucial
- most of selection done on-line or quasi-online
- no chance to reprocess significant chunks of data

Detector calibration and data quality checks have to be done in real-time!

Installation in stages allows early tuning of DAQ and analysis software!

Software development not necessarily tied to hardware projects - many opportunities!

Goals for the Open Collaboration Meeting (and the following weeks)

- Present the status of the detector design
- Review the sharing of responsibilities in the detector construction, locate bottlenecks and critical path items
- Within subsystems, attempt for a more precise definition of work packets and interfaces
- Review the scenario for installation and running, aiming for the earliest possible start of efficient data taking
- Review funding scenarios, funding profiles, and staging options

and, most importantly

- Attract new groups to join this fascinating experiment!

F. Willeke, DESY

STATUS of HERA

HERA-B OPEN COLLABORATION MEETING

October 4-6 1994

THE HERA e-p Collider

6 km Circumference
10-20 m below Ground
5 m ϕ Tunnel
4 Exp. Halls

Protons:

Beam Energy 820 GeV
Beam Intensity 158 mA
200 Bunches
Superconducting Magnets 4.5 T

Electrons

Beam Energy 30 GeV
Beam Intensity 58 mA
200 Bunches
S.C. Rf Cavities

Luminosity $1.5 \cdot 10^{31}\ cm^{-2}s^{-1}$ (design)

4 Experiments

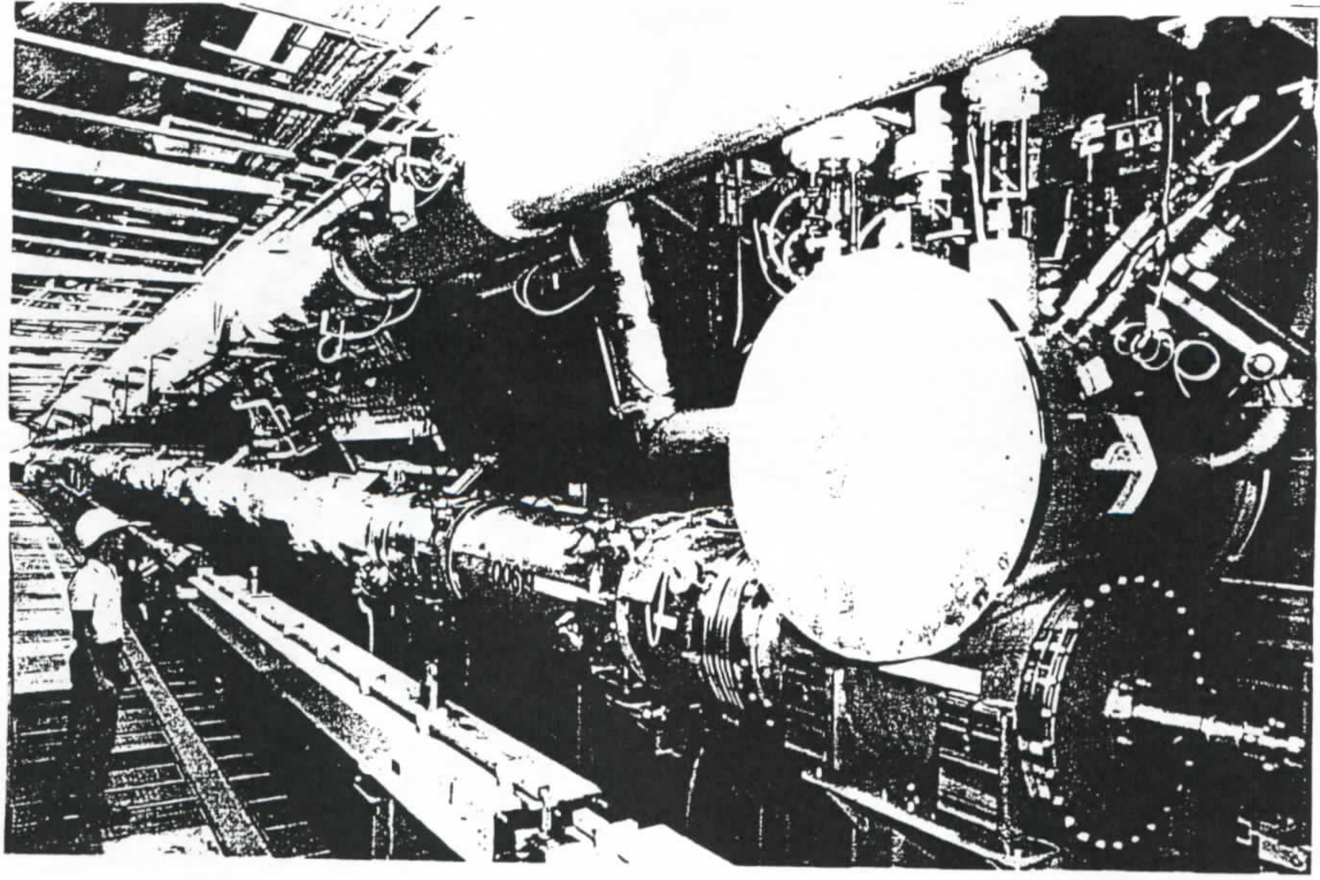
ZEUS	(ep)	
H1	(ep)	
HERMES	(e Fixed Target)	under construction
HERA-B	(p-Fixed Target)	conditionally approved

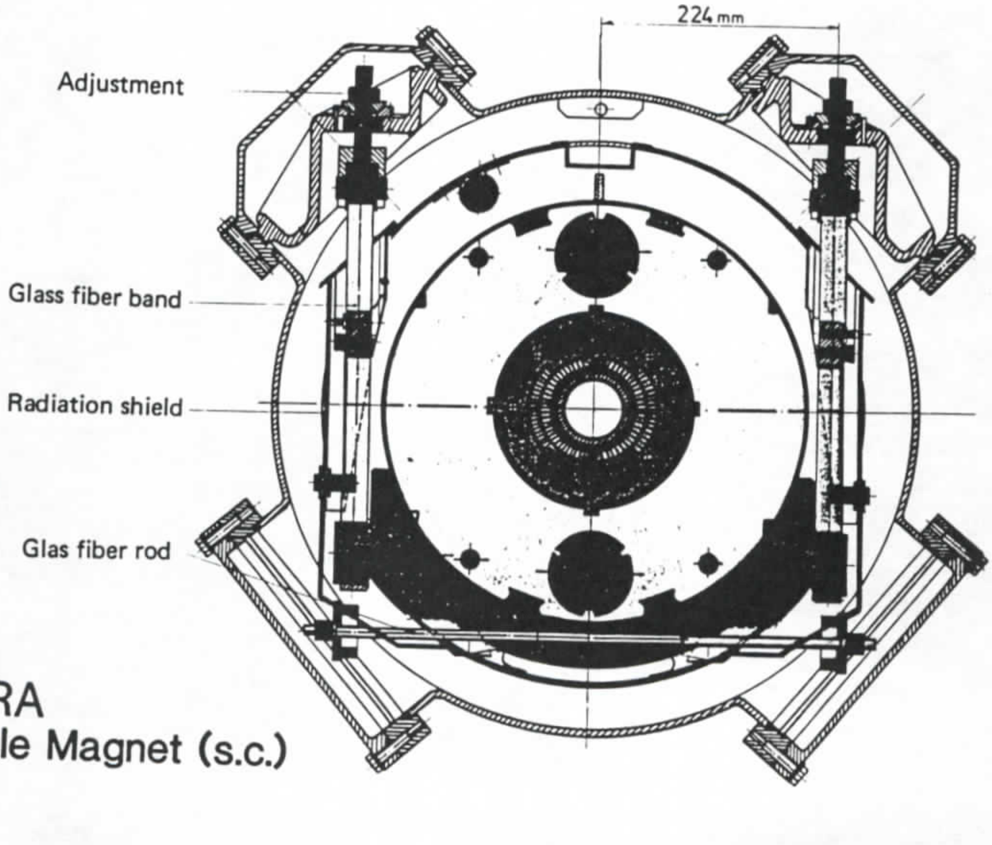
The HERA International Collaboration

Canada	*52Mhz Rf Systems for PETRA and HERA-p* *H- Beam Tranport System*
CFSR	*Magnet Measurement, Controls*
China	*Work on: H- Linac, Work on DESYIII rf System,* *Magnet Measurements, Vacuum, Cryogenics,* *p-Beam Dump, Quench Protection, Radiation Protect.*
France	*Design of S.C Quadrupoles,* *Production of 50% of S.C. Quadruypole Magnets*
Israel	*Current Lead for S. C. Magnets* *Work on Controls*
Italy	*Production of half of the S.C. Dipole Magnets*
Nederland:	*Design and Production of S.C. Correction Magnets*
Poland	*Work on Vacuum System, p-Beam Dump, Controls* *RF, DESYIII, H- Linac*
UK	*Design of rf Systems for Proton Beam* *Design Work on DESYIII*
USA	*Short Sample Measurements of S.C.Cable* *Cryogenic Equipment*

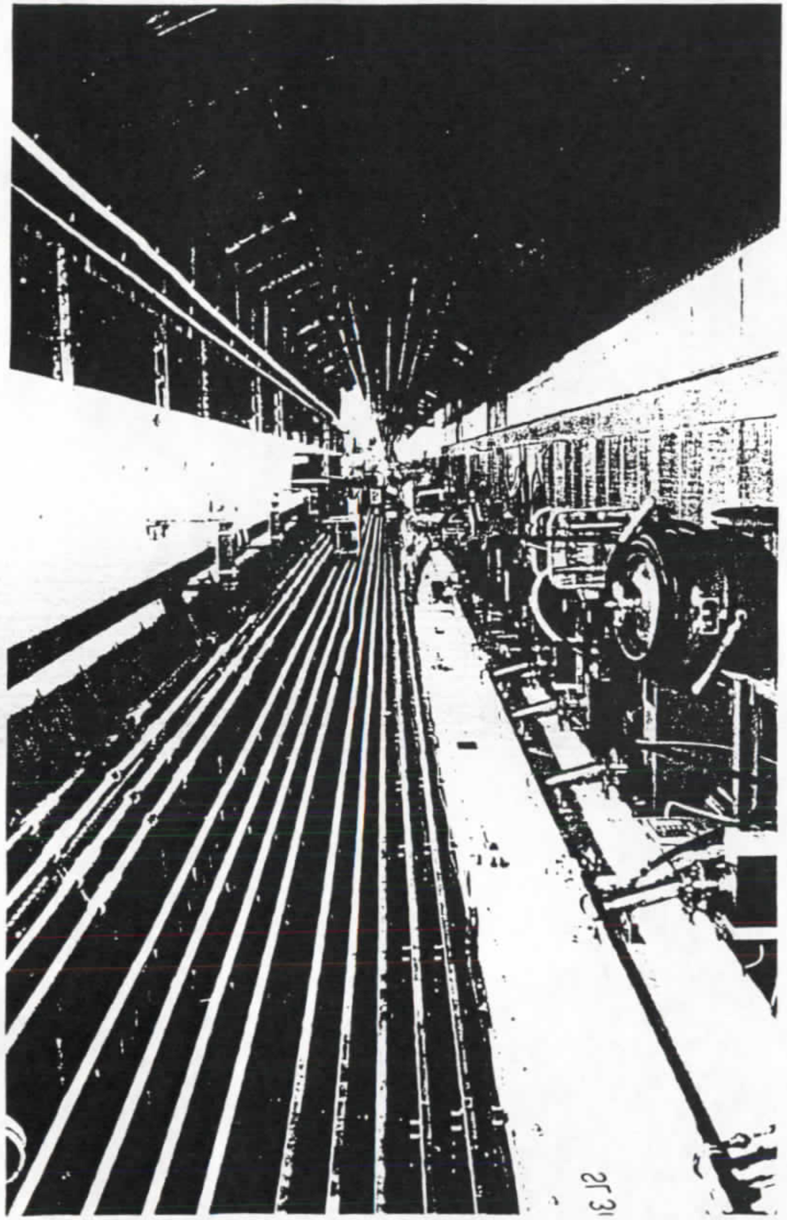
History of the HERA e-p Collider

1981	*Proposal*
1984	*Approval and Start of Construction*
1988	*Completion od e-Ring*
1990	*HERA was Completed*
1991	*Commissioning*
1992	*Luminosity Test Run (2X10 Bunches)*
1993	*Luminosity Operation*
1994	*Maschine Improvements and Luminosity Operation*

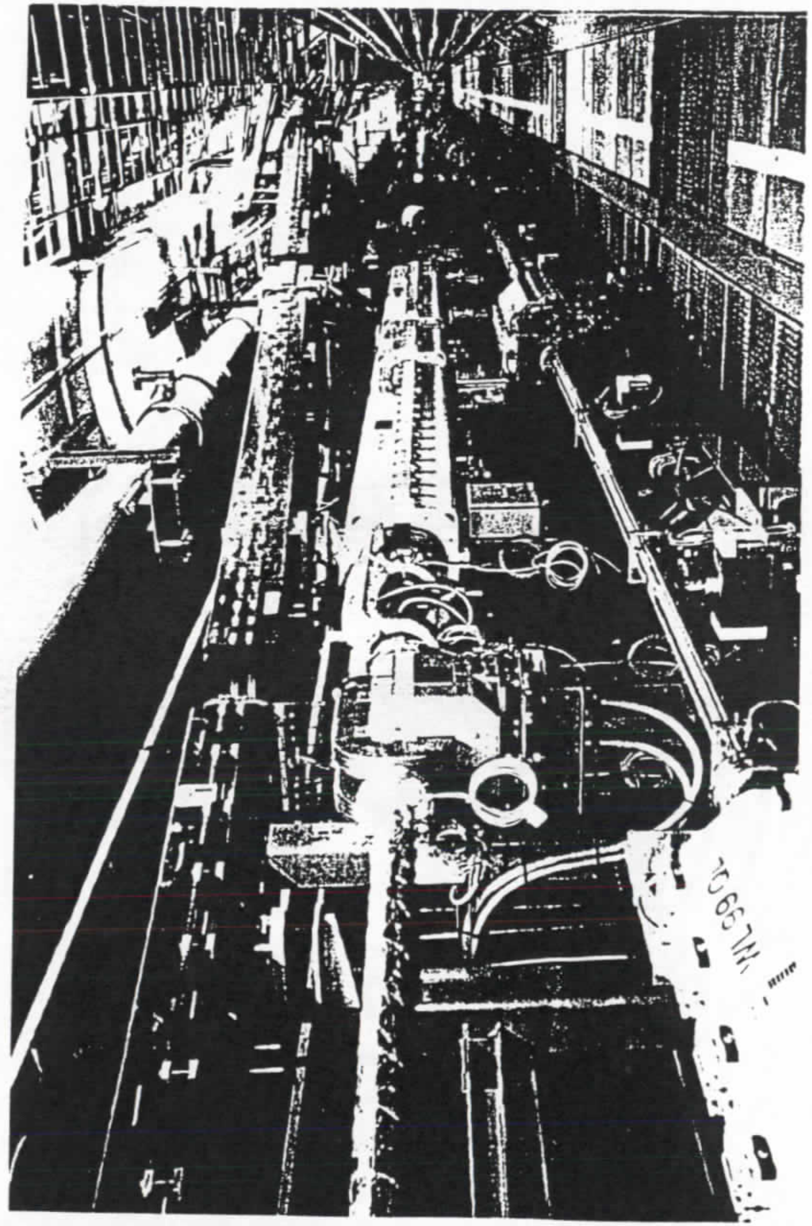




HERA
Dipole Magnet (s.c.)

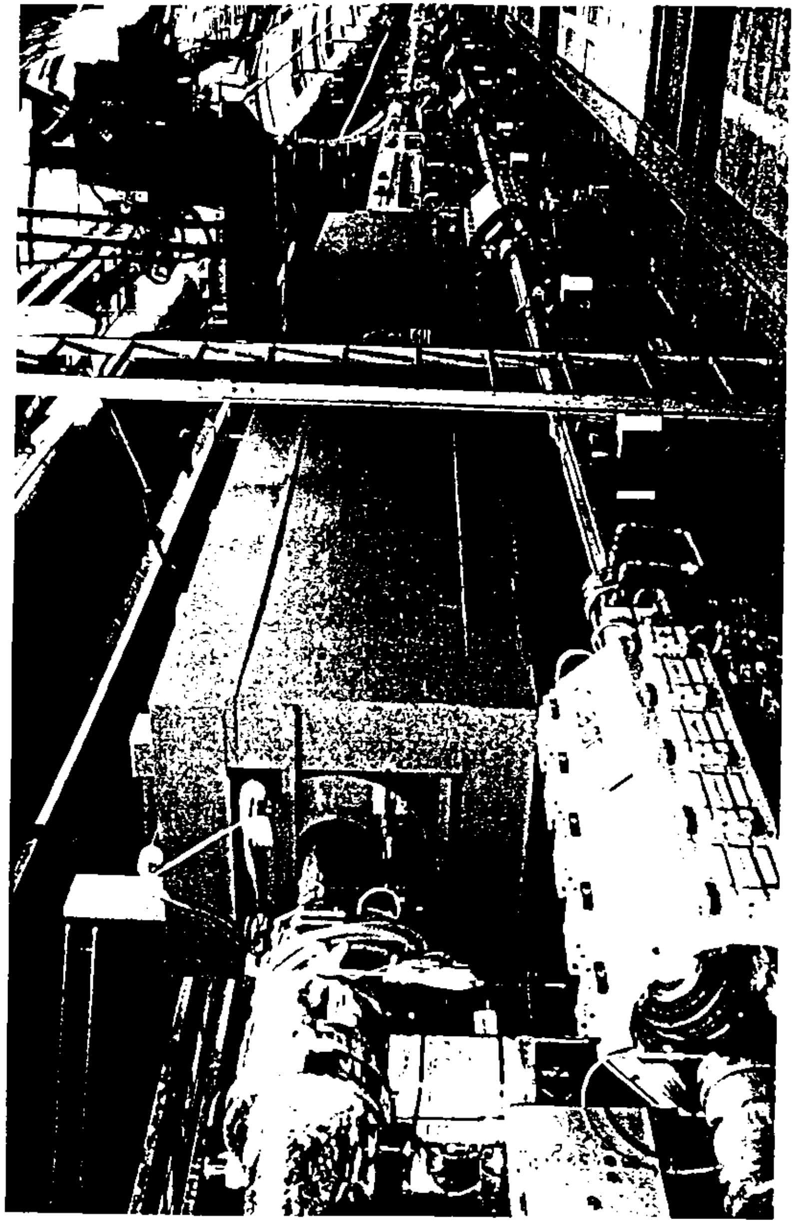


G-7-



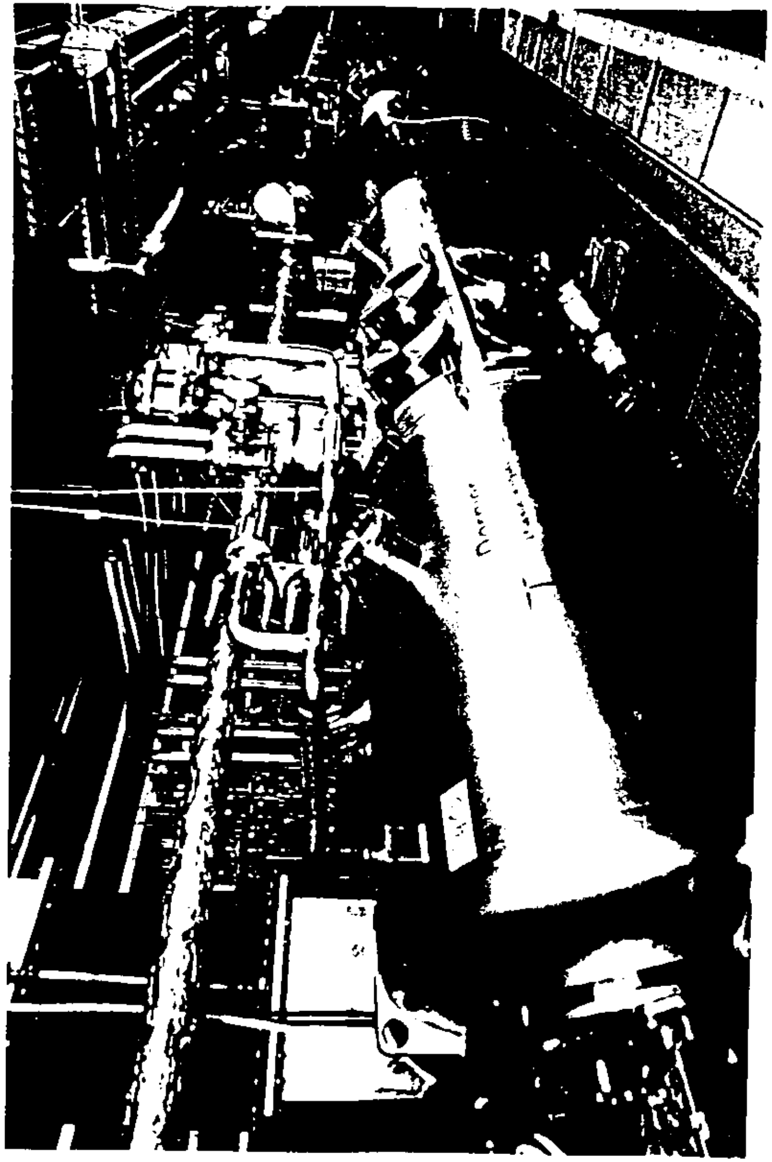
G-8-

UP SUPERIÉURE OBEN おもて



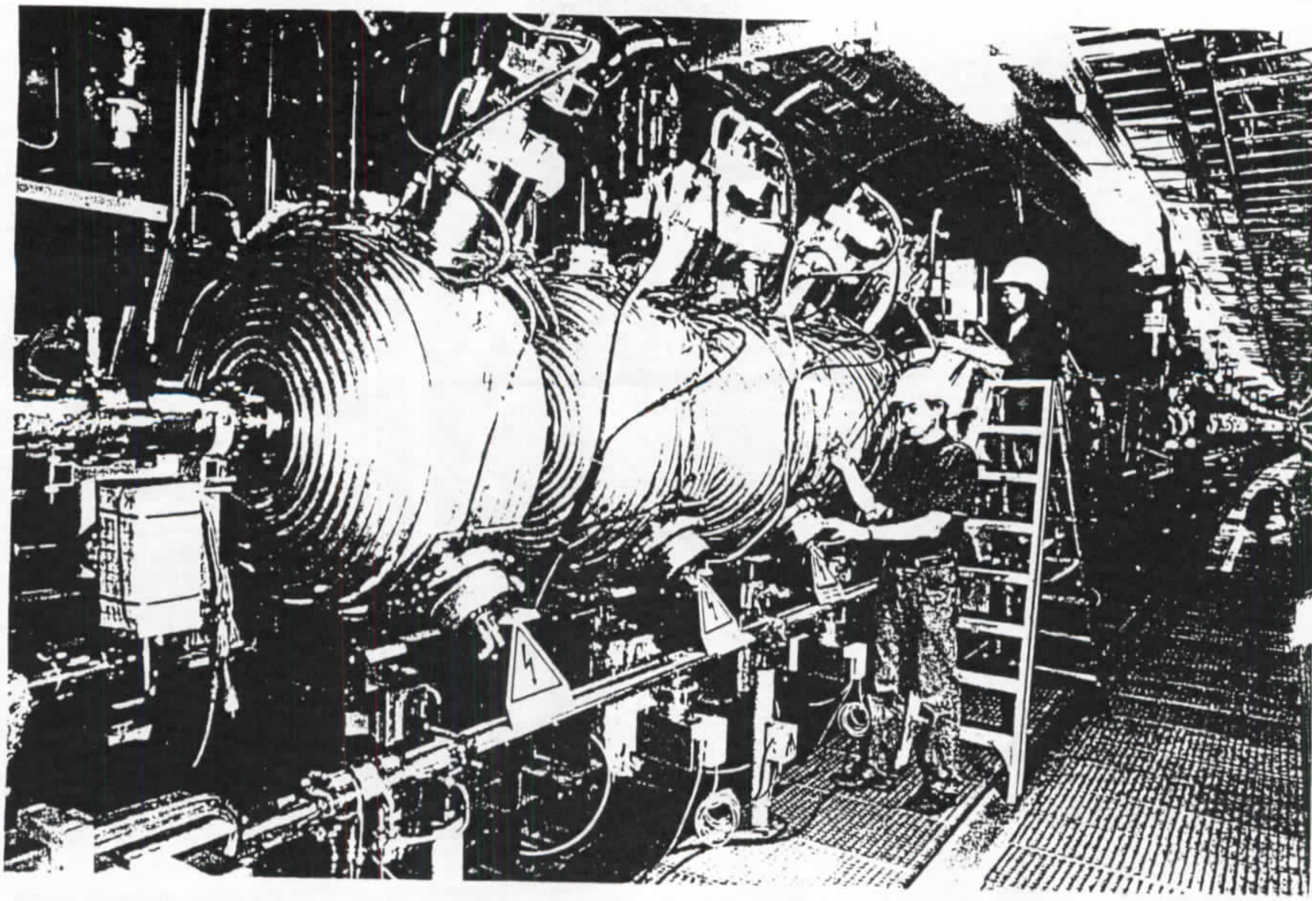
UP SUPERIÉURE OBEN おもて

G -9-



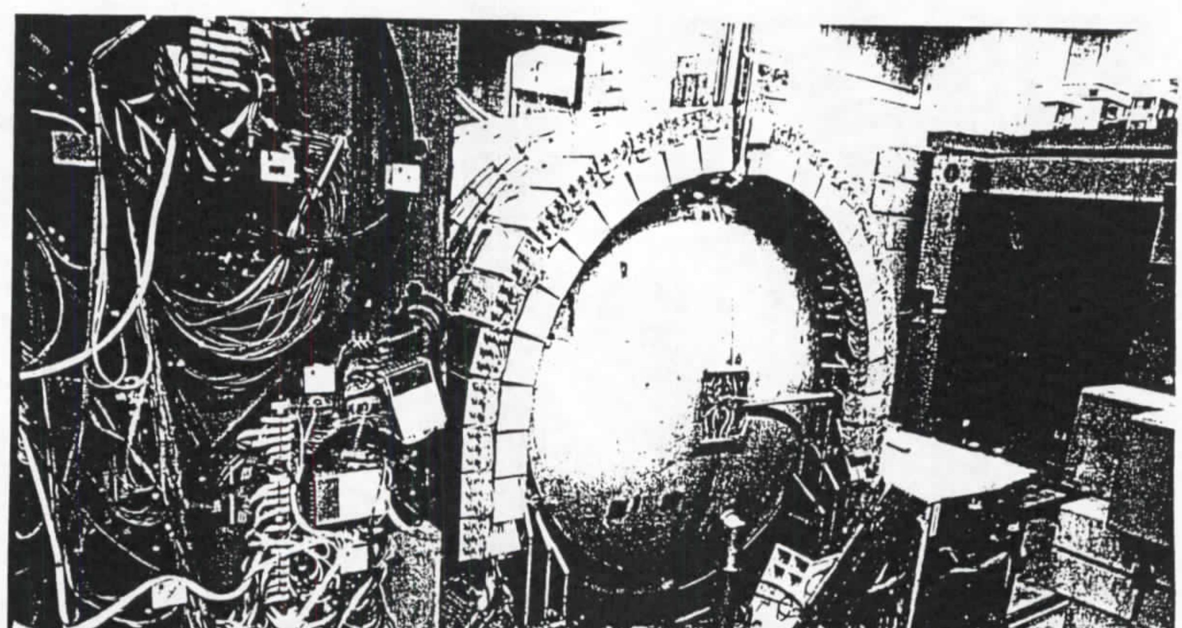
G -10-

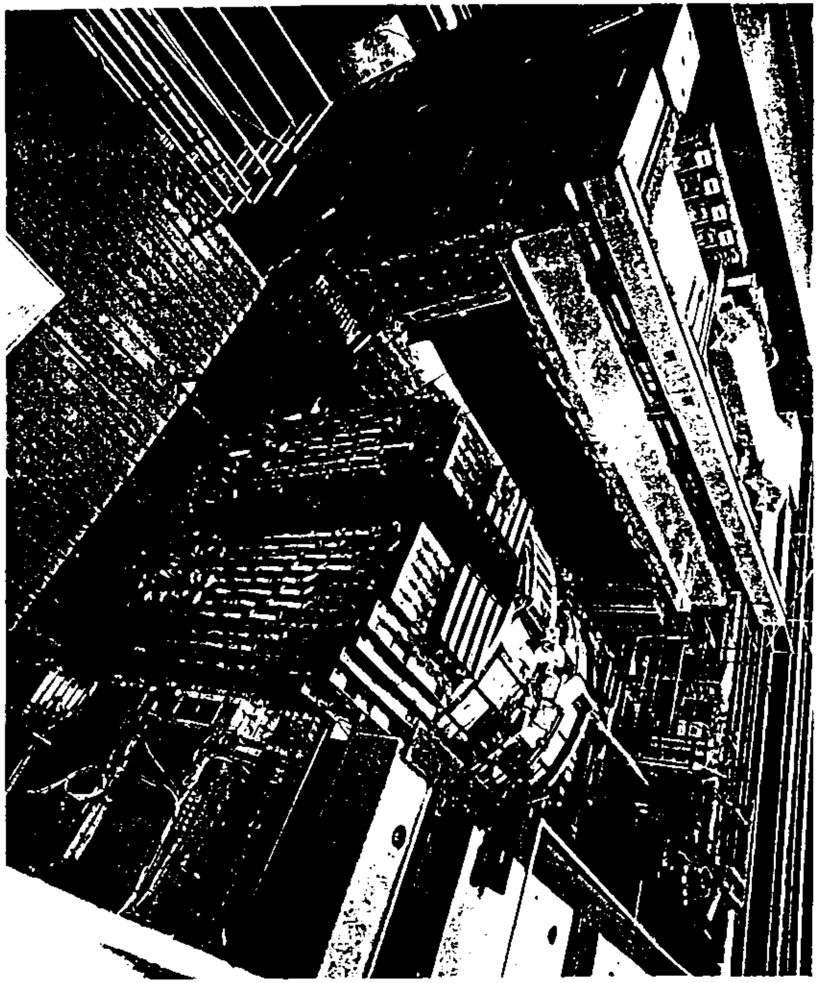
G-11



p cavities built by CRNL

G-12





1994 Luminosity Run

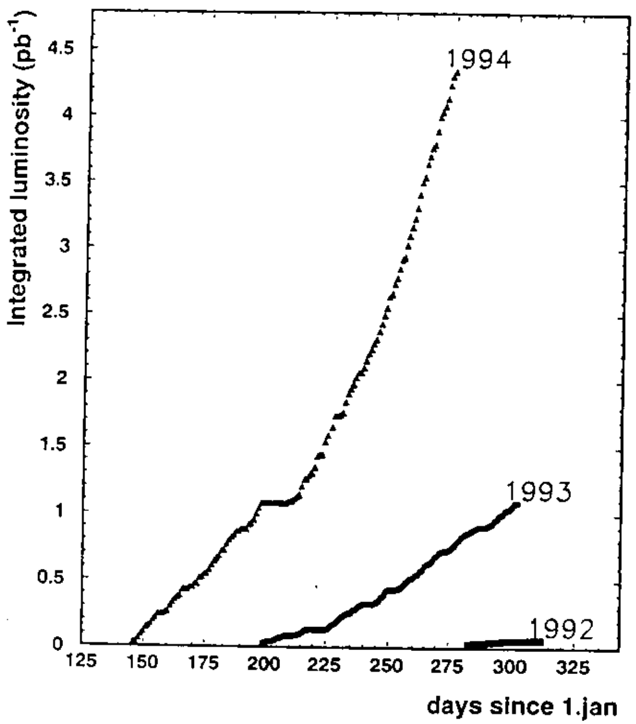
MAIN PARAMETERS

	Protons	Electrons / Positrons	
Beam Energy	820 GeV	27.5 GeV	
Beam Current	40 mA	28 mA	(average values)
# of Bunches	156+24	156+22	
Beam Lifetime	> 100 h	(8-12) h	
Emittance Growth	$1 \cdot 10^{-6}$ r·m·h^{-1}	–	

Specific Luminosity	$(4-5) \cdot 10^{29}$ cm^{-2}s^{-1}mA^{-2} (initial pol.)
Peak Luminosity	$3 \cdot 10^{30}$ cm^{-2}s^{-1}
Best Luminosity	$4.7 \cdot 10^{30}$ cm^{-2}s^{-1}
Integrated Luminosity	3.5 pb^{-1} (Sept. 20)

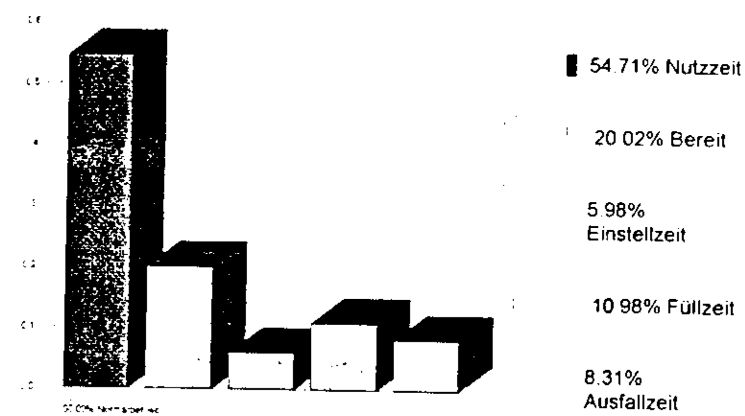
GENERAL:
- Long Stable Runs > 8 h
  Proton Beam very stable despite larger e-Int./bunch
  We can deliver 100 nb^{-1} day^{-1} 500 nb^{-1} per week
  Problem with proton Satellite Bunches reduced but not solved
- Luminosity Runs benefited from switching from e^- to e^+ by the end of July '94
  $\tau_L \approx 3$ h ⟶ $\tau_L \approx 8$ h

HERA luminosity 1992-94

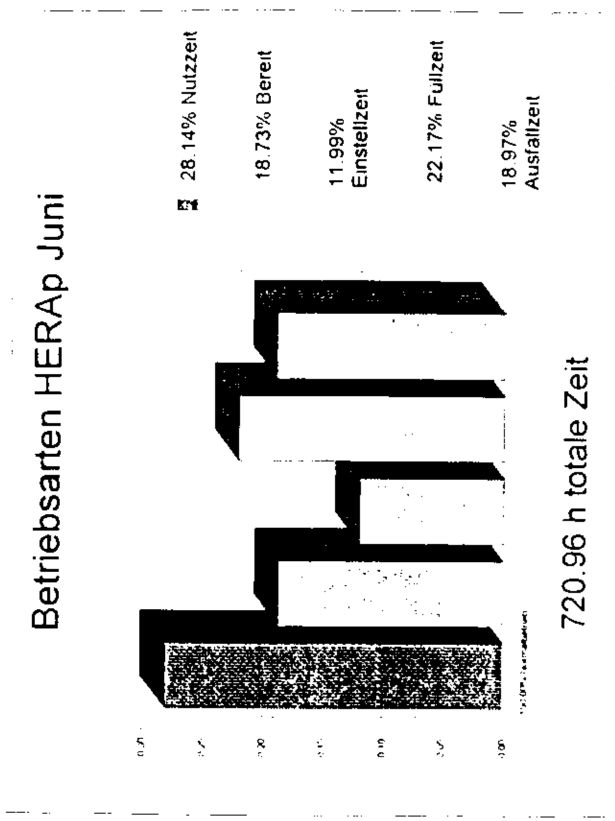


4.10.94

Betriebsarten HERAp September



715.21 h totale Zeit



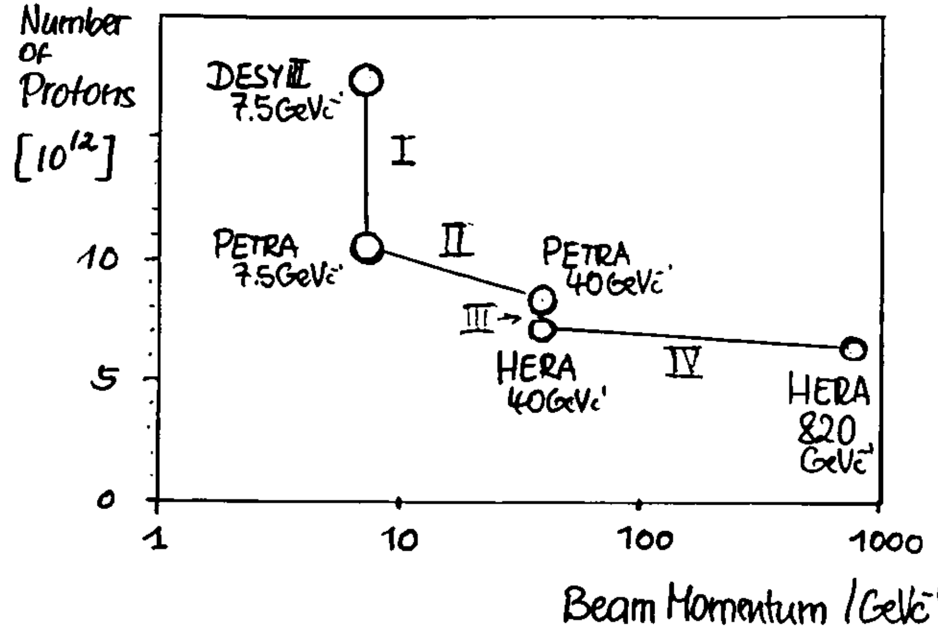
HERA-Performance

	1992 Parameters	1993 Parameters	1994 Goals	Design Values	
Protons					
Beam Energy/GeV	820	820	820	820	
Beam Current/mA	1.5	12.5	40	150	
Particles/Bunch	2	1.8	3	11	
Number of Bunches	10	90	170	210	
Beam Lifetime(coll)/h	100	100	100	10	
Rel. Emitt Growth*h	0.1	0.1	0.1		
Electrons					
Beam Energy/GeV	26.7	26.7	27.5	30	
Beam Current/mA	2	12.5	30	58	
Particles/Bunch	2.6	1.7	2	3.6	
Number of Bunches	10	54	168	210	
Lifetime at top Energy	5	10	10	10	
e-p					
Spec Luminosity	2.5	4	5	3.2	$cm^{-2} s^{-1} mA^{-2} \cdot 10^{29}$
Peak Luminosity	0.2	1.4	4	16	$cm^{-2} s^{-1} \cdot 10^{30}$
Integrated Lumi	0.06	1	5		pb^{-1}
Luminosity Lifetime	4	6	6		
OperationalEfficiency	10	27	40		

HERA - Proton Ring Parameters

	Average 93	Average 94	Best 94	Expected 95	Design Goal
Beam Energy /GeV	820	820	820	820	820
Beam Current /mA	12.5	40	60	60	159
# of Bunches	90	170	170	192	210
Particles per Bunch / 10^{10}	1.8	3.1	4.7	4.1	10
Transverse Emittance / 10^{-6} r·m (normalized, 2σ val)	12	15	10	15	20
Long. Emittance /eVs	0.08	0.073	0.059	0.069	0.143
Bunch Length	0.46	0.42	0.34	0.40	0.5

Proton Acceleration for HERA



	Beam Loss	Measures planned	
I 40%	DESY III Extr. Sept.	enlarge aperture	WSD 95/96
	P-Weg	enlarge aperture, impr. Instr.	WS 94/95
	PETRA Inj. Sept.	enlarge aperture	WSD 95/96
	PETRA Lifetime	improve controls	Nov 94
II 20%	PETRA ACCELERATION	improve controls, feedback	Nov 94
III 15%	PR-Weg Aperture	improve Instrument & controls	WSD 95/96
	HERA lifetime 40GeVc⁻¹	feedback	
IV	HERA Ramp	improved controls, feedback	

LUMINOSITY PROSPECTS

PROTON BEAM INTENSITY: 2year Programme improving the Injector Chain

for '95 expect 60mA (aver. current) in 192 bunches

ELECTRON / POSITRON BEAM INTENSITY

for e^+ in '95 expect design bunch intensity with 192 bunches

→ Expect Peak Luminosity of $\hat{\mathcal{L}} = 7.5 \cdot 10^{30}\,cm^{-2}s^{-1}$ @ 50% design goal

Operational Efficiency is slightly improving

(Septem. '93: Efficiency 43%
Septem. 94 Efficiency 54% sofar)

HERA IMPROVEMENT & DEVELOPMENT PROGRAMME

:

- Continous Improvements on Technical Systems such as
  - QUENCH PROTECTION
  - MAGNET POWER SUPPLIES
  - INFRA STRUCTURE
  - ⋮
- New Control Systems
- Preparing for New Experiment in West Straight
- Improvements in the eRing Vacuum System
- Study to Explore Bunched Beam Cooling (p-Beam)
  Study to Control p-Beam Emittance Growth
- Spin Rotator System for North & South IP

HERA-B OPEN COLLABORATION MEETING

Beam Optics for HERA-B:
Gibt es eine Latticemöglichkeit?

presented by
Brett Parker

For partial installation of the HERA-B detector in the Winter 95/96 shutdown, essentially all changes to the lattice must be completed at that time.

... aus der Not eine Tugend machen.

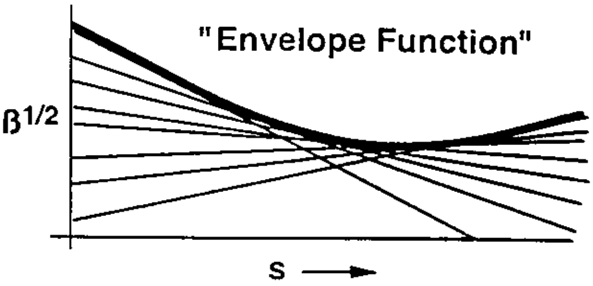
Acknowledgements

HERAe Optics:	R. Kose
HERAp Optics:	T. Sen F. Willeke
HERAp Abort:	M. Schmitz
Polarimeter:	D.P. Barber
HERAe Rf:	W. Möller

Accelerator Terminology & Useful Relations

For a given beam emittance (phase space area) the beam size goes as $\beta^{1/2}$

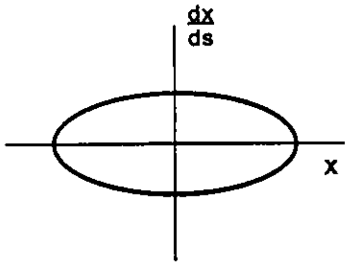
Therefore, one can scale the effect of an aperture limitation at point 1 to another point 2, somewhere else in the accelerator, by scaling the transverse dimension by the ratio $(\beta_2/\beta_1)^{1/2}$



Examples: 40 mm x sqrt(32 m / 80 m) -> 25 mm equiv. size
44 mm x sqrt(250 m / 980 m) -> 22 mm equiv. size

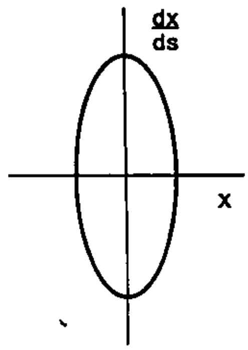
For complete description need amplitude, β, and phase, $\psi = \int ds/\beta(s)$

Accelerator Terminology & Useful Relations



At places where ß is "large"
transverse beam size, X, is large
angular spread, $^{dx}/_{ds}$, is small

F Quadrupole

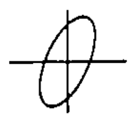


At places where ß is "small"
transverse beam size, X, is small
angular spread, $^{dx}/_{ds}$, is large

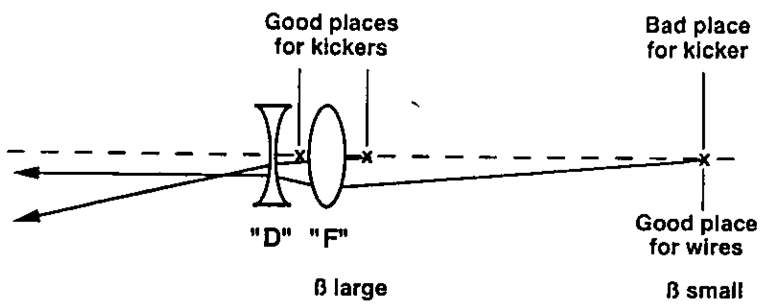
D Quadrupole

Rule of thumb: Effect of angular kick is minimized at locations with where ß is "small"

Caveat: $\alpha = -{}^1/_2 \, {}^{d\beta}/_{ds} \approx 0$

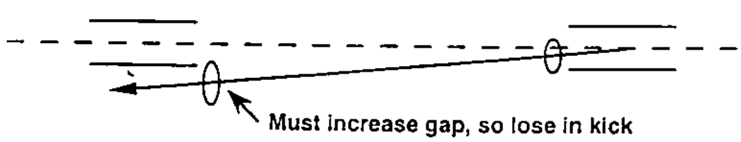


Accelerator Terminology & Useful Relations



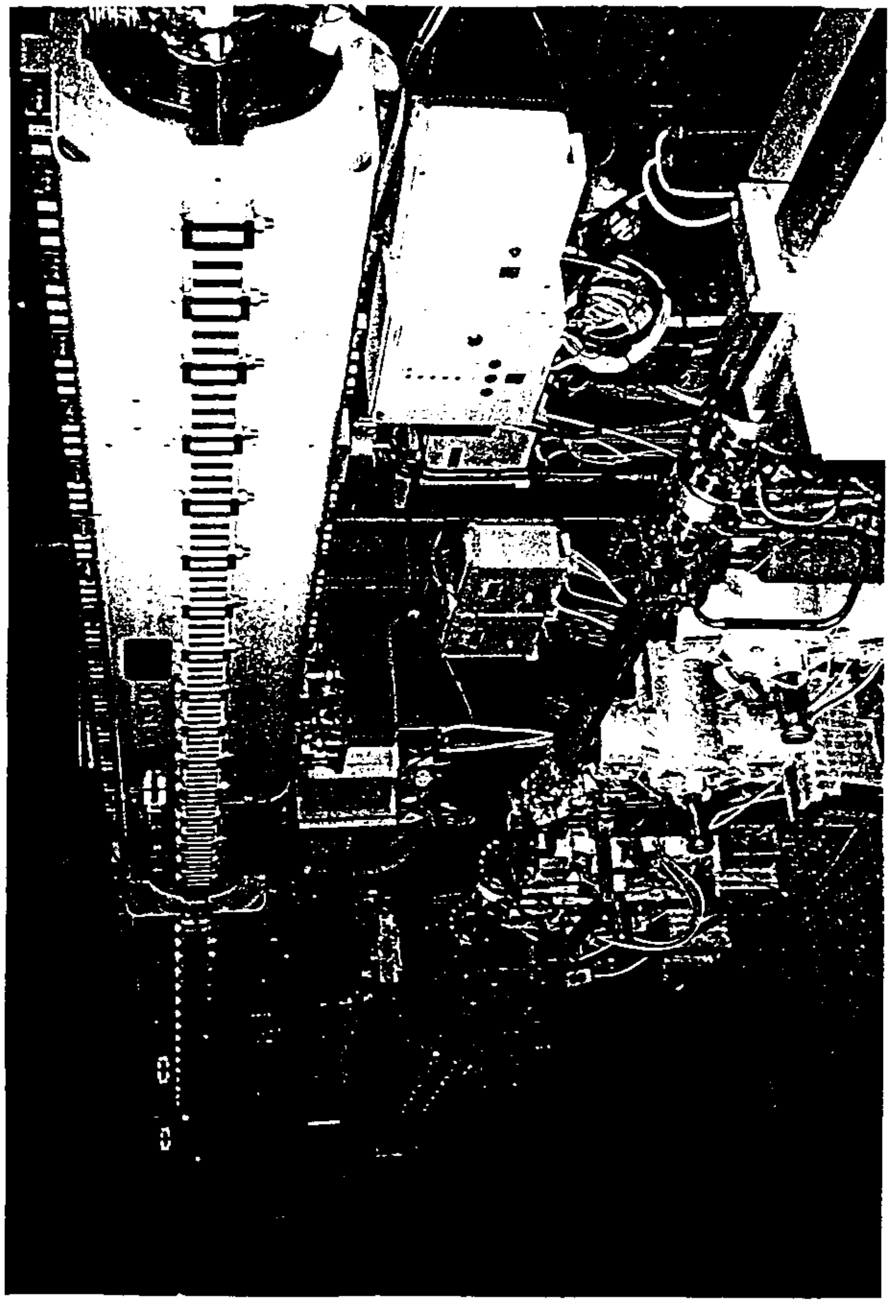
A quadrupole is focussing in one plane and defocussing in the other. Can get net focussing from quadrupole pair (i.e. if further off-axis in F than in D).

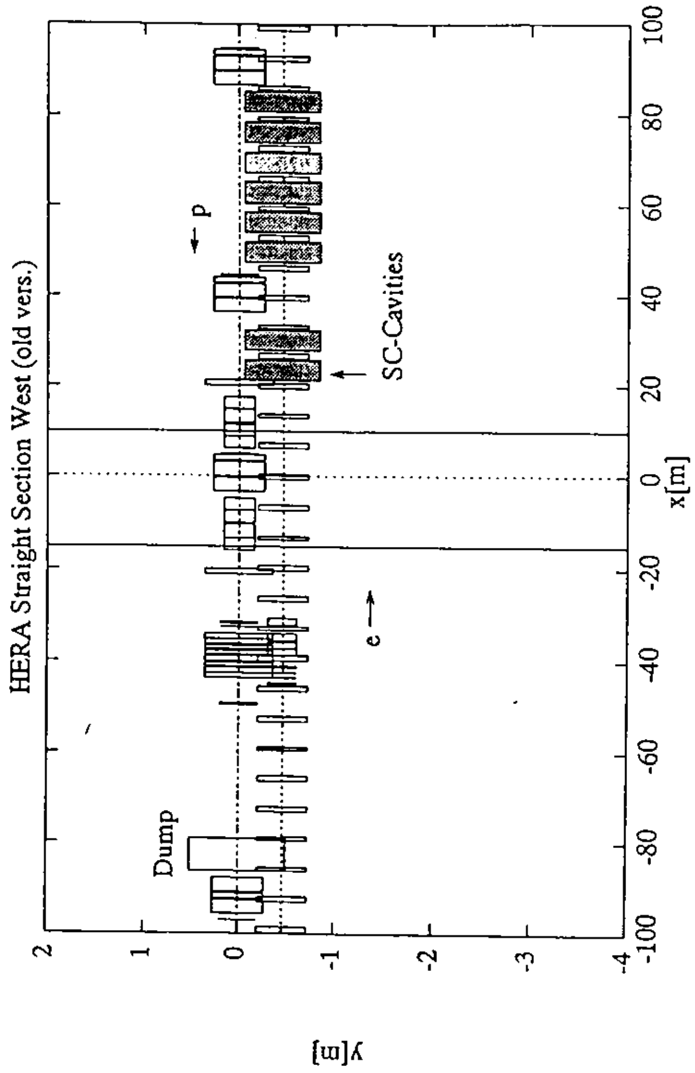
Rule 1: Don't let kickers get too far from quadrupole.

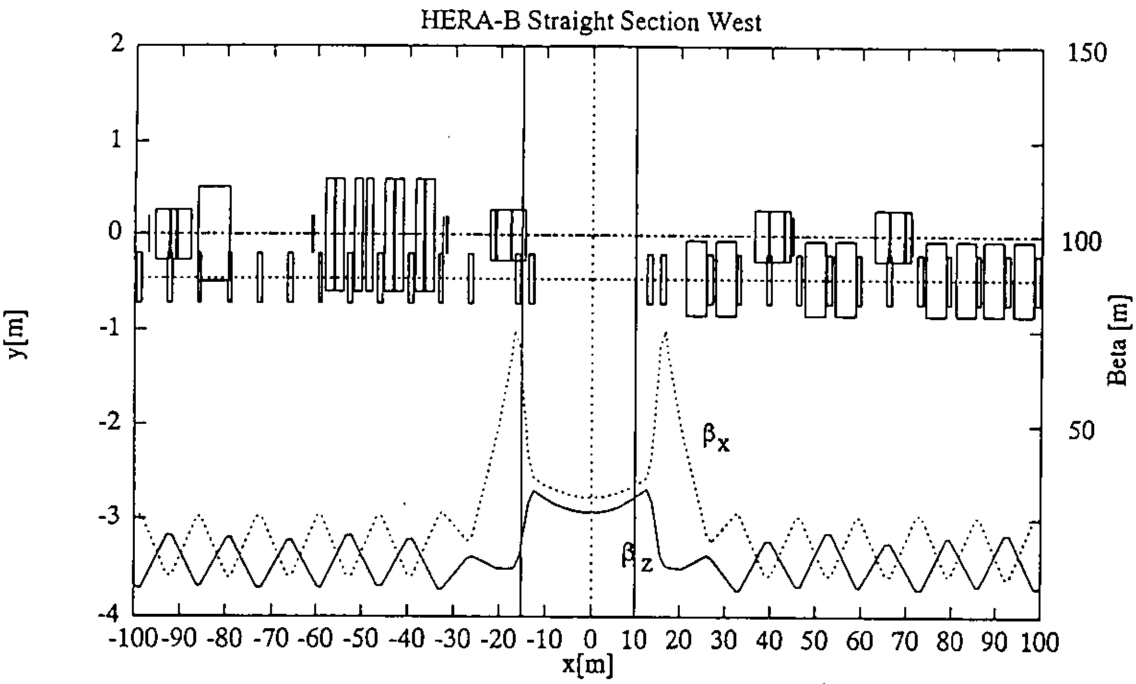


Kick Angle $\propto {}^1/_{\text{gap size}}$

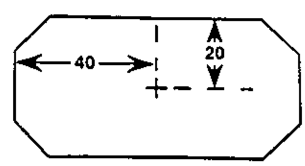
Rule 2: Don't let kickers get too far from each other.




HERA Straight Section West (old vers.)
Dump
p
e
SC-Cavities
x[m]
y[m]
2
1
0
-1
-2
-3
-4
-100
-80
-60
-40
-20
0
20
40
60
80
100

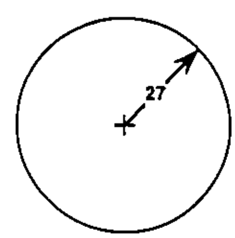


HERA-B Modified Optics



HERAe Standard Vacuum Chamber

For HERAe one has: $\beta_{x,y} \approx 32$ m across Halle West
$\beta_{x,y} \approx 80$ m maximum in arcs
& 40 by 20 mm half aperture in arcs.
sqrt (32 / 80) –> smaller 25 by 13 mm equiv. size at HERA-B location



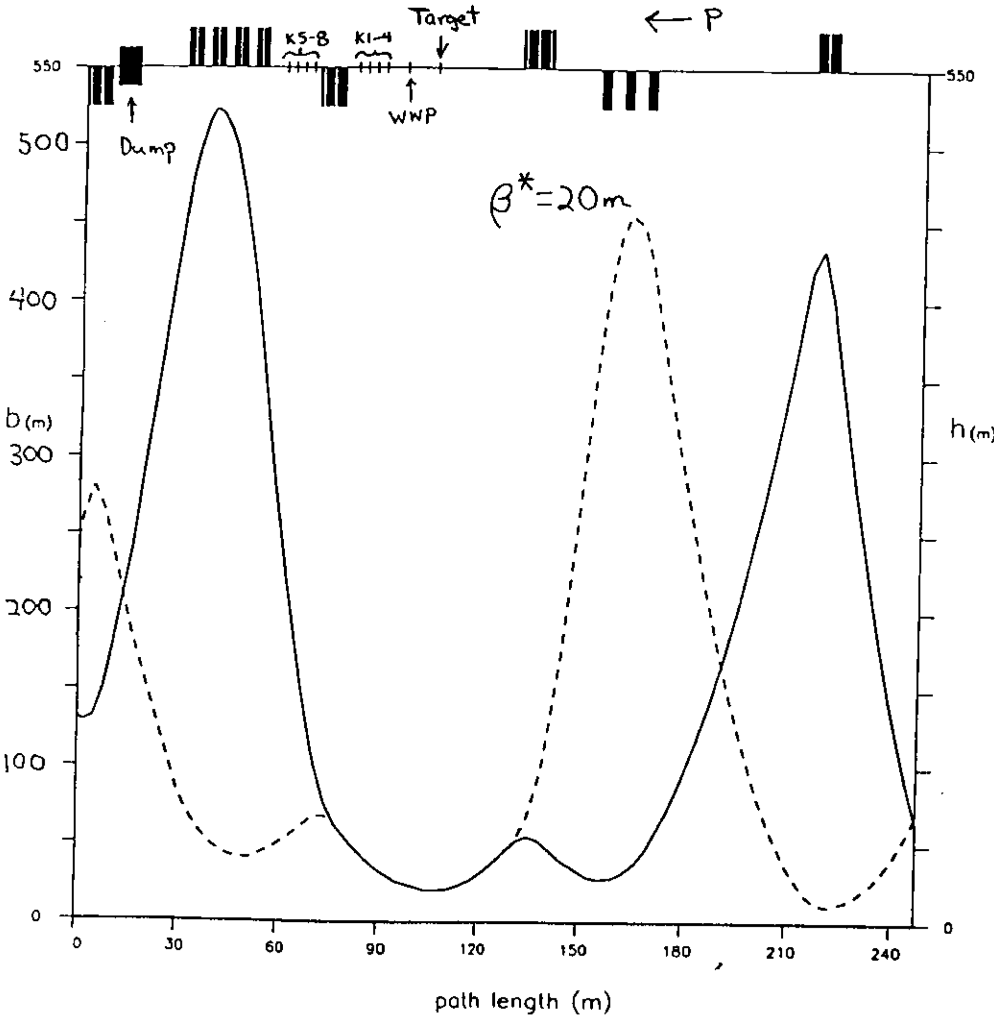
HERAp Vacuum Beampipe (limiting magnet & dump have the same inner dia.)

For HERAp the layout & optics from HERA-B Proposal† has:

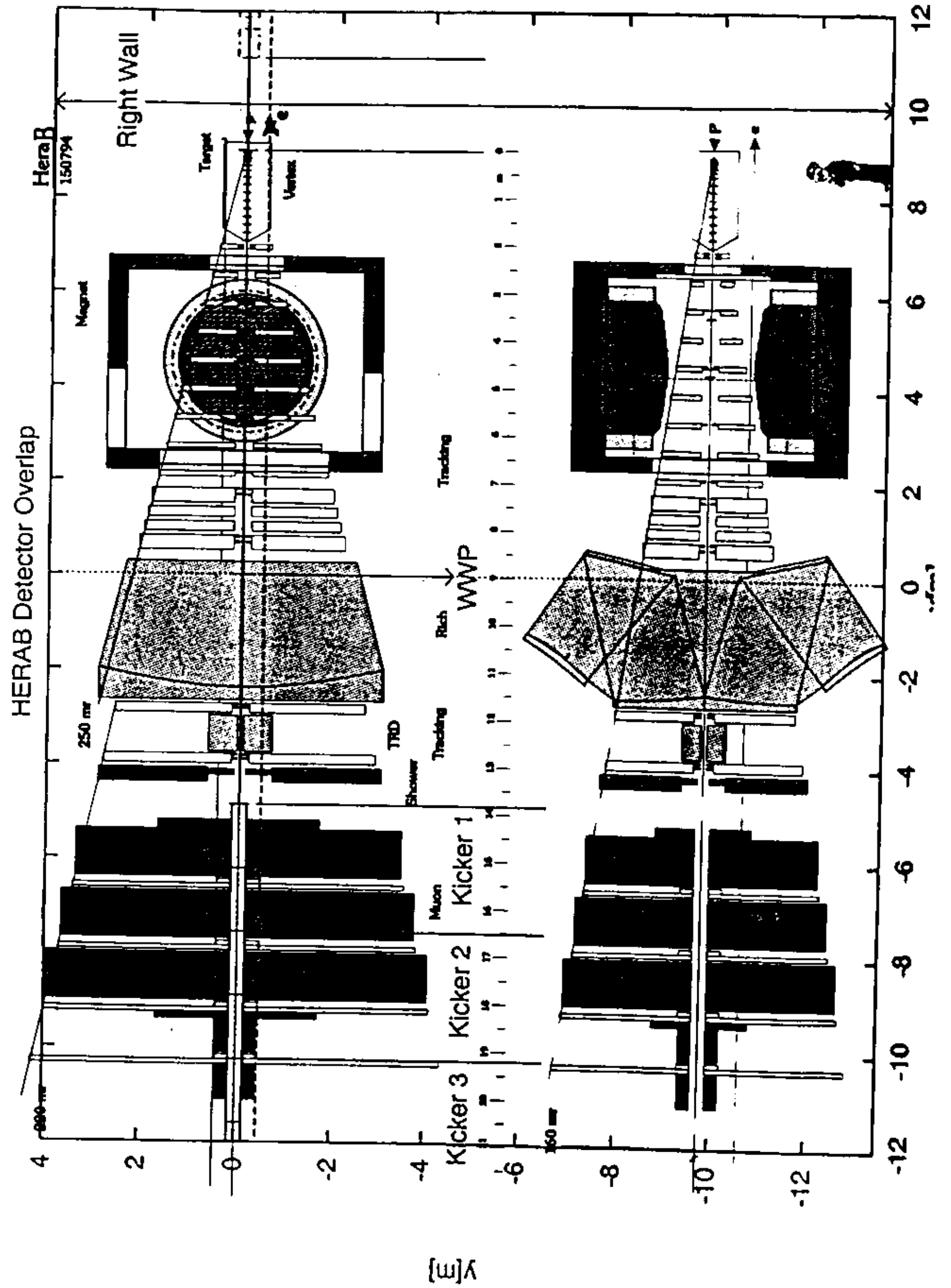
- Abort kickers overlaping Shower & TRD (almost to Rich)
- β too large at dump (i.e. reduced injection acceptance) by sqrt (320 m / 140 m) –> ≈ 33% admittance reduction.

∴ Optics revision is required.

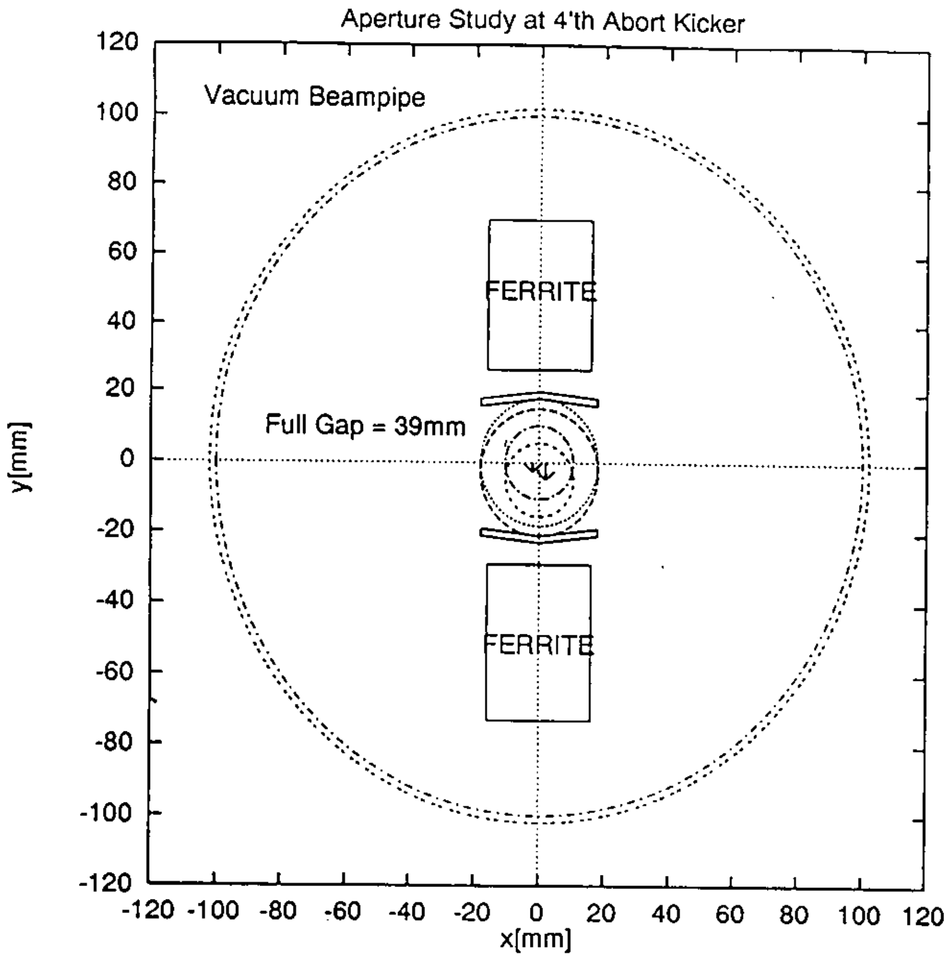
† See HERA-B Proposal, Fig. 23 pg. 42.



K5-8
K1-4
Target
← P
Dump
WWP
550
500
400
300
200
100
0
b (m)
h (m)
β* = 20 m
0
30
60
90
120
150
180
210
240
path length (m)

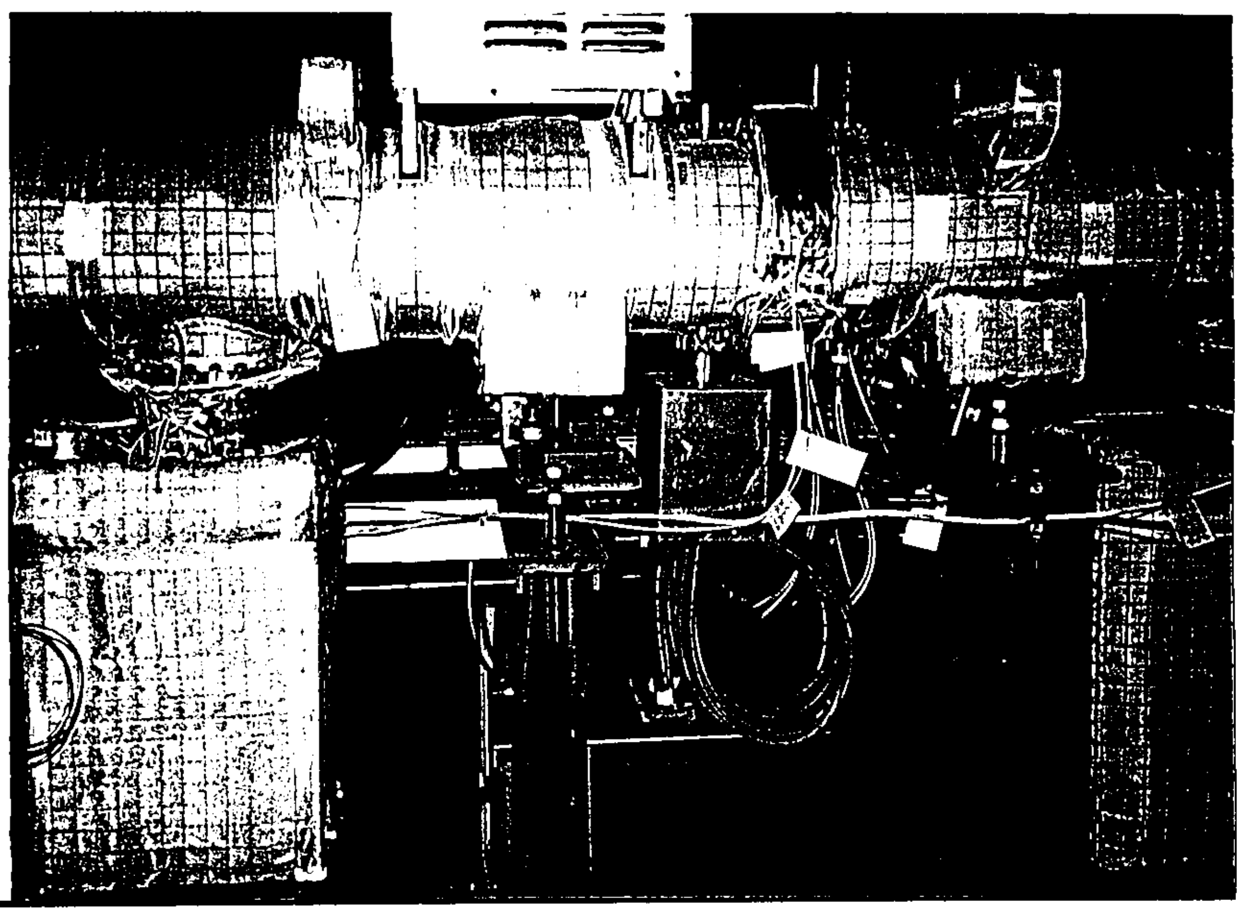


HERAB Detector Overlap
HeraB
150794
Right Wall
Target
Vertex
Magnet
Tracking
Rich
WWP
TRD
Shower
Muon
Kicker 1
Kicker 2
Kicker 3
250 mr
y[m]

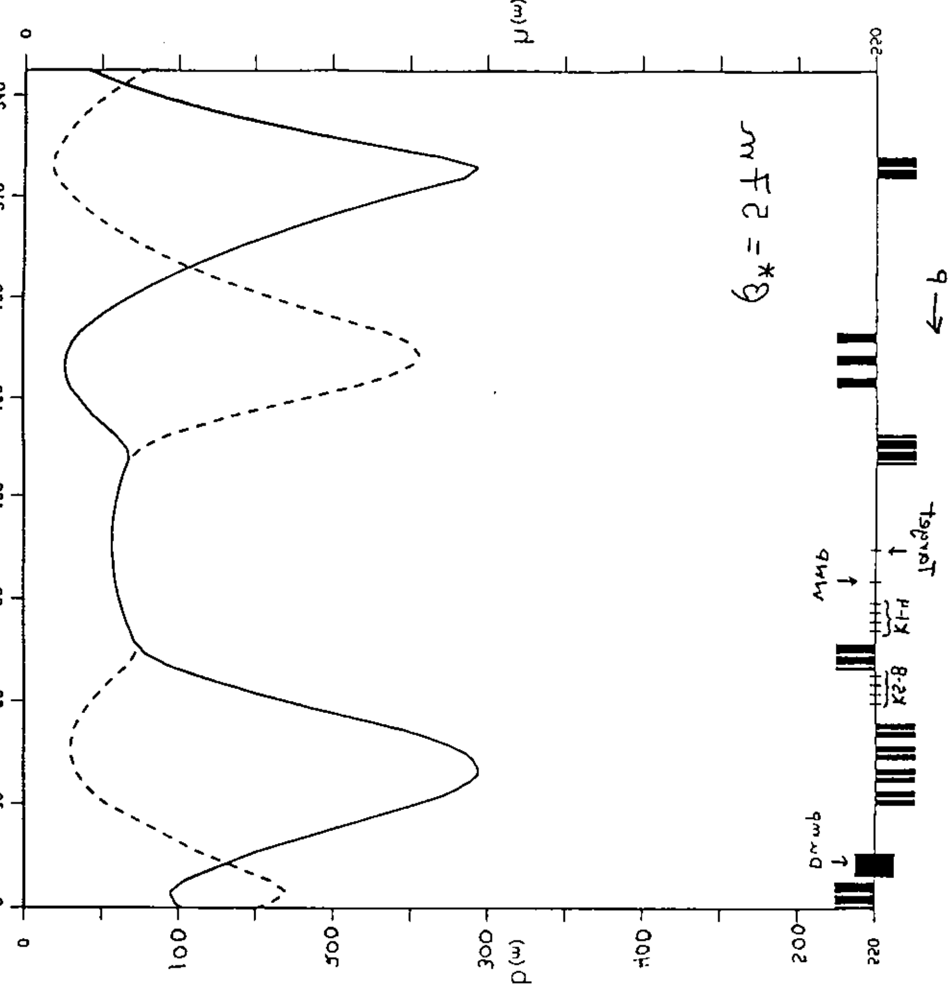


Aperture Study at 4'th Abort Kicker
Vacuum Beampipe
FERRITE
Full Gap = 39mm
FERRITE
y[mm]
x[mm]
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120

H - 11 -

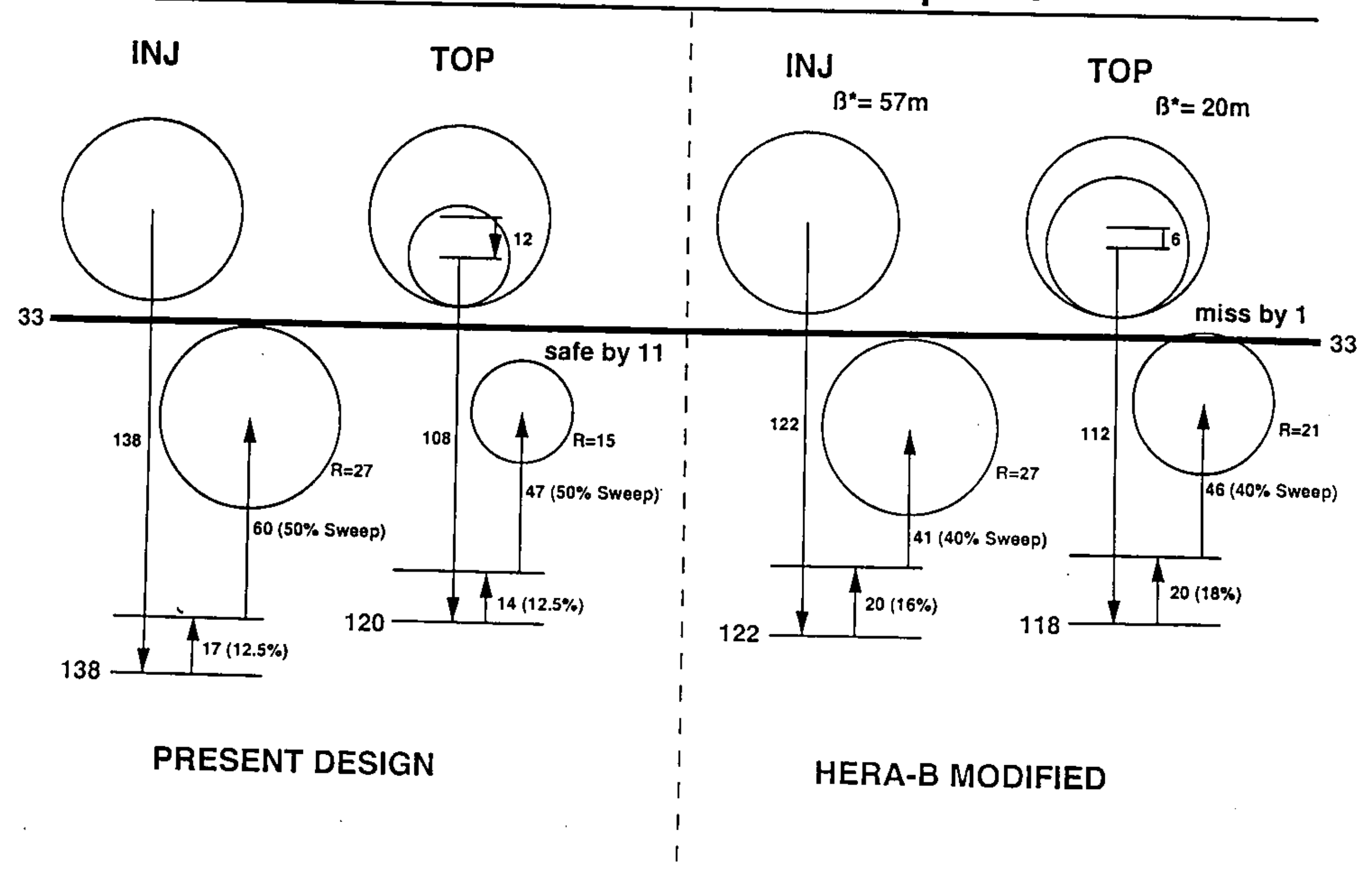


H - 12 -



HERA-B Collaboration Meeting 4.9.1994

Abort Parameter Comparison



HERA-B Modified Optics: Summary

- Kickers can move back & only overlap muon system.
- Optics are available with β^* variable over ≈ factor 3 (i.e. 70% in beam size –> knob for optimization)
- Viable injection optics, with $\beta^* = 57$ m, now exists (i.e. do β squeeze later, similar to H1 & ZEUS).

β(dump) as a function of β^*

β^* (m)	β(Dump) (m)
20	250
32	197
57	151

- Kickers must overlap muon system (only small ≈ 20 cm shifts can be considered)
- Abort system is now quite marginal at top energy (all parameters pushed to respective limits –> risk).

Note: Optics with higher β^* (i.e. $\beta^* > 30$ m) are more forgiving at top energy.

Conflicts, Changes & Challenges in HERA West

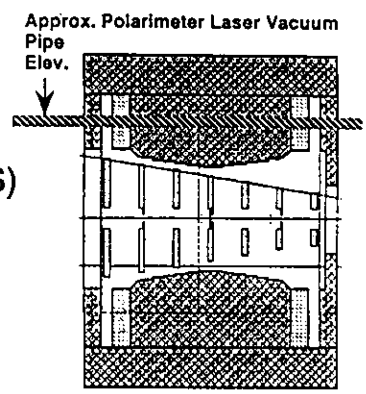
In addition to making new abort kickers, shifting/replacing main quadrupoles and adding new support infrastructure...

HERAp:

- Add detector field compensation (bump) dipoles (order new magnets)
- Collimation (scraper) system must move (phase advances marginal)
- Lopez monitor & other critical diagnostics must move
- Skew quadrupoles (decoupling) must move

HERAe:

- Polarimeter laser path intersects HERA-B magnet (move laser to surface, is difficult fix & impacts HERMES)
- Longitudinal feedback system displaced by QB quads
- Superconducting Rf displaced (DM 1 Mio & 15 weeks)
- Compensate detector field at electron beam location.



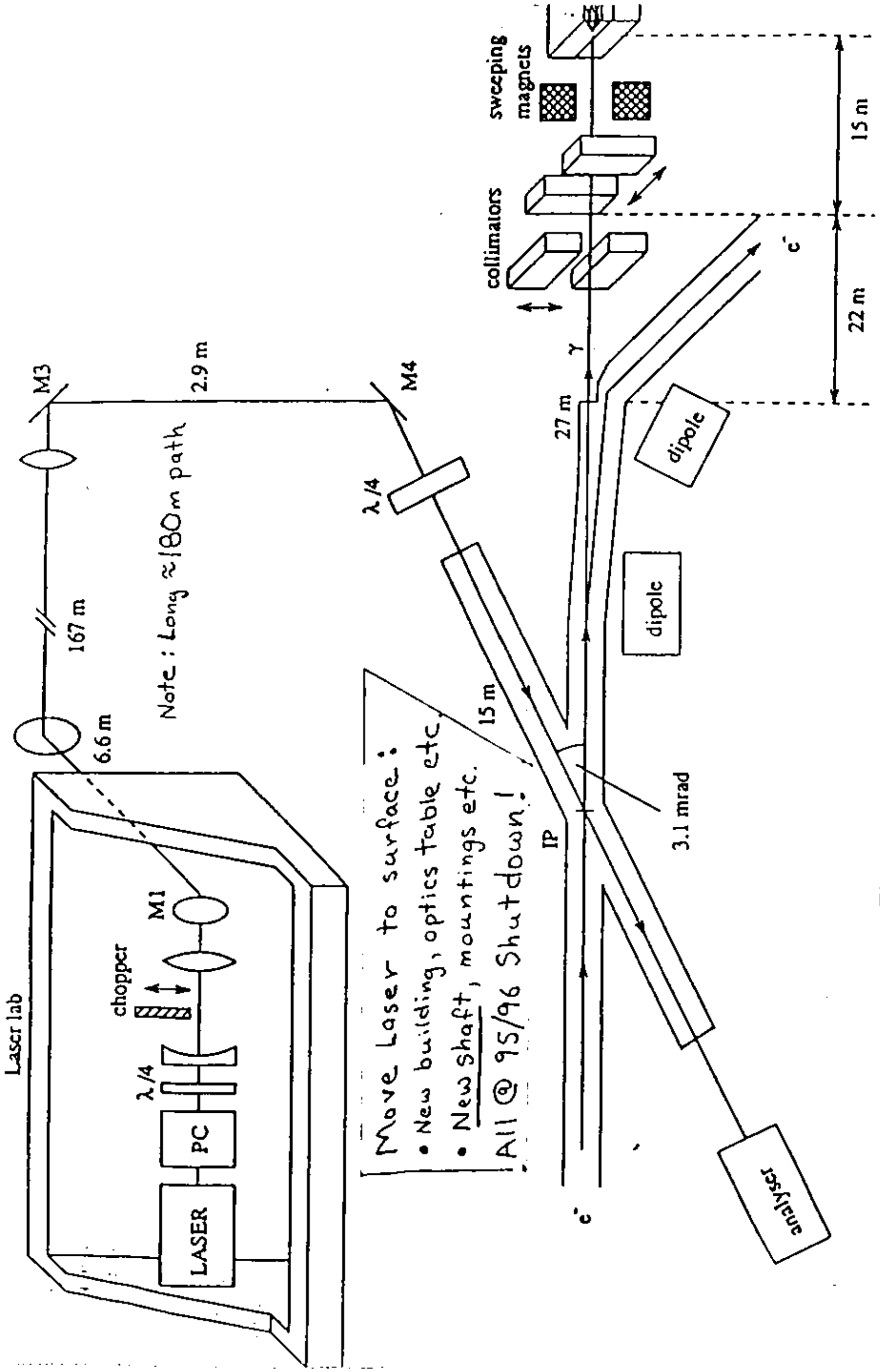
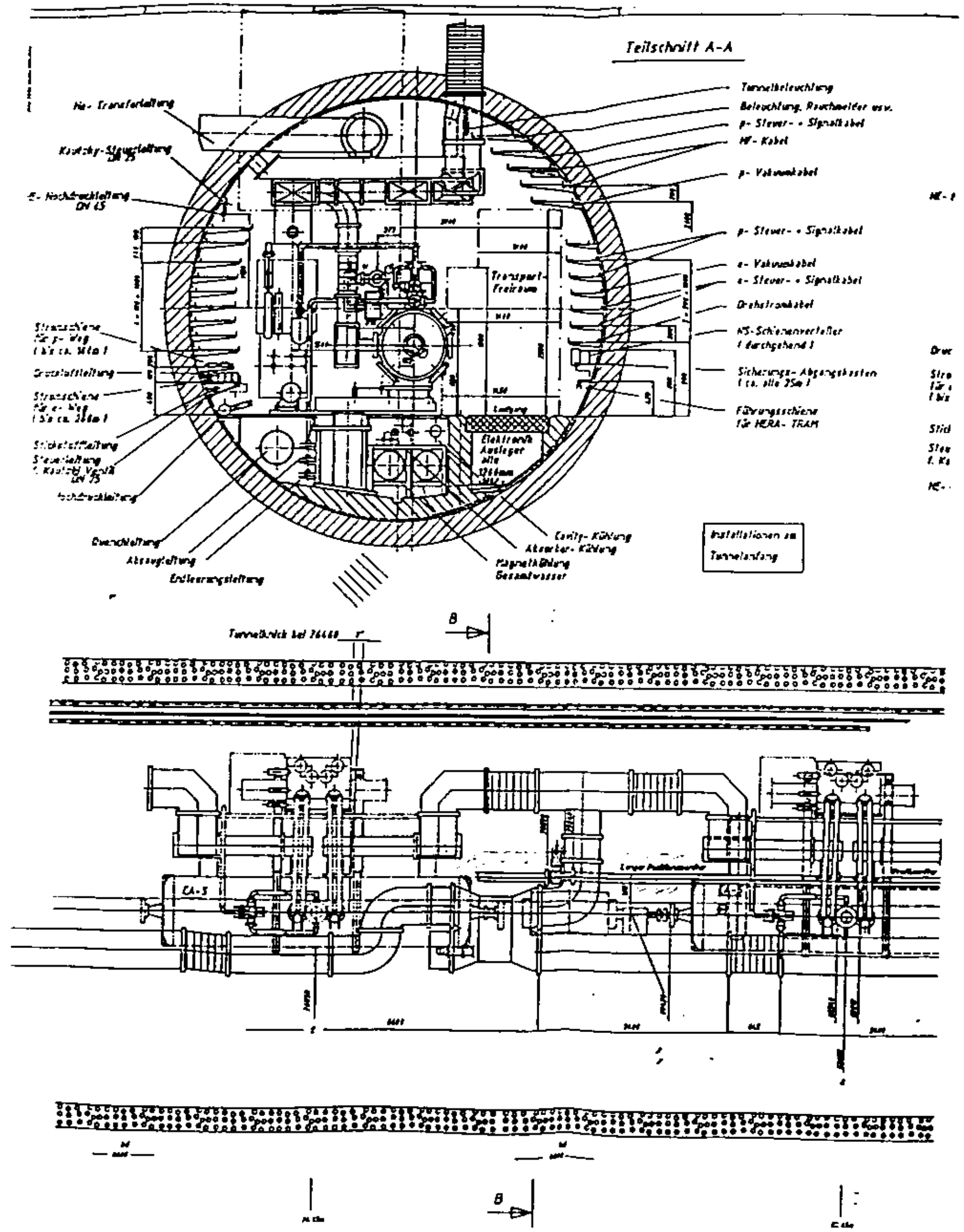
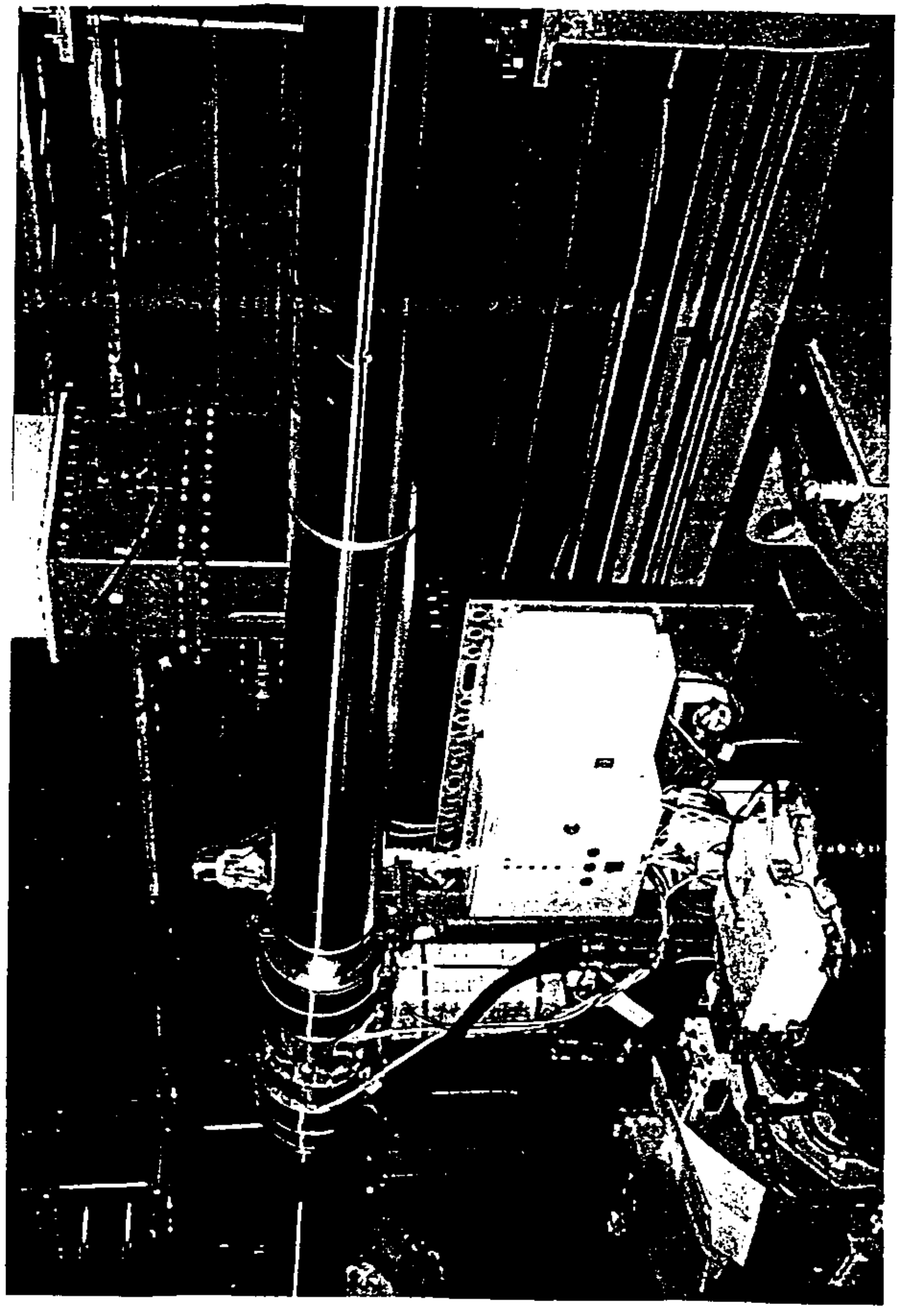
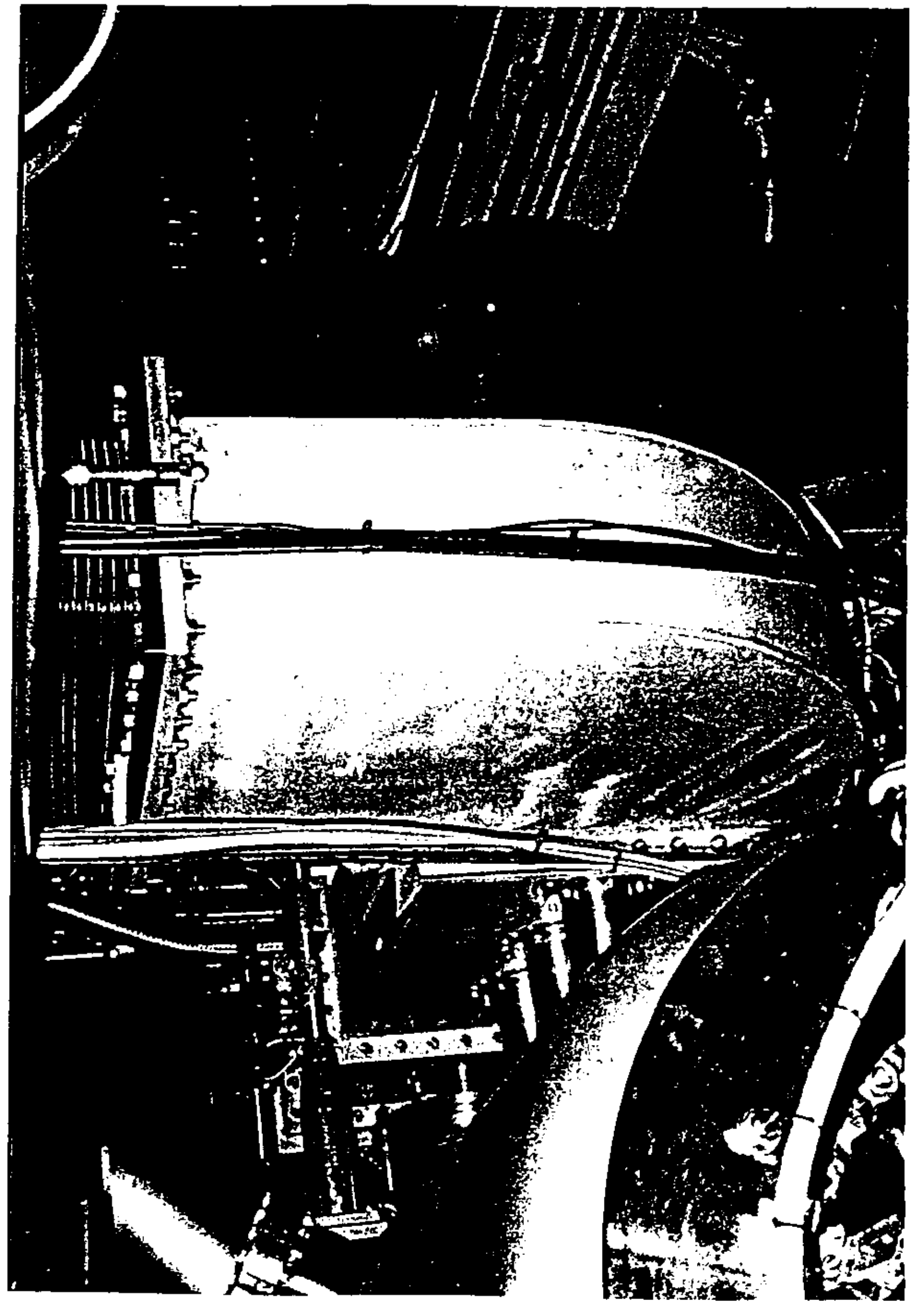


Fig. 9. An overview of the HERA polarimeter.

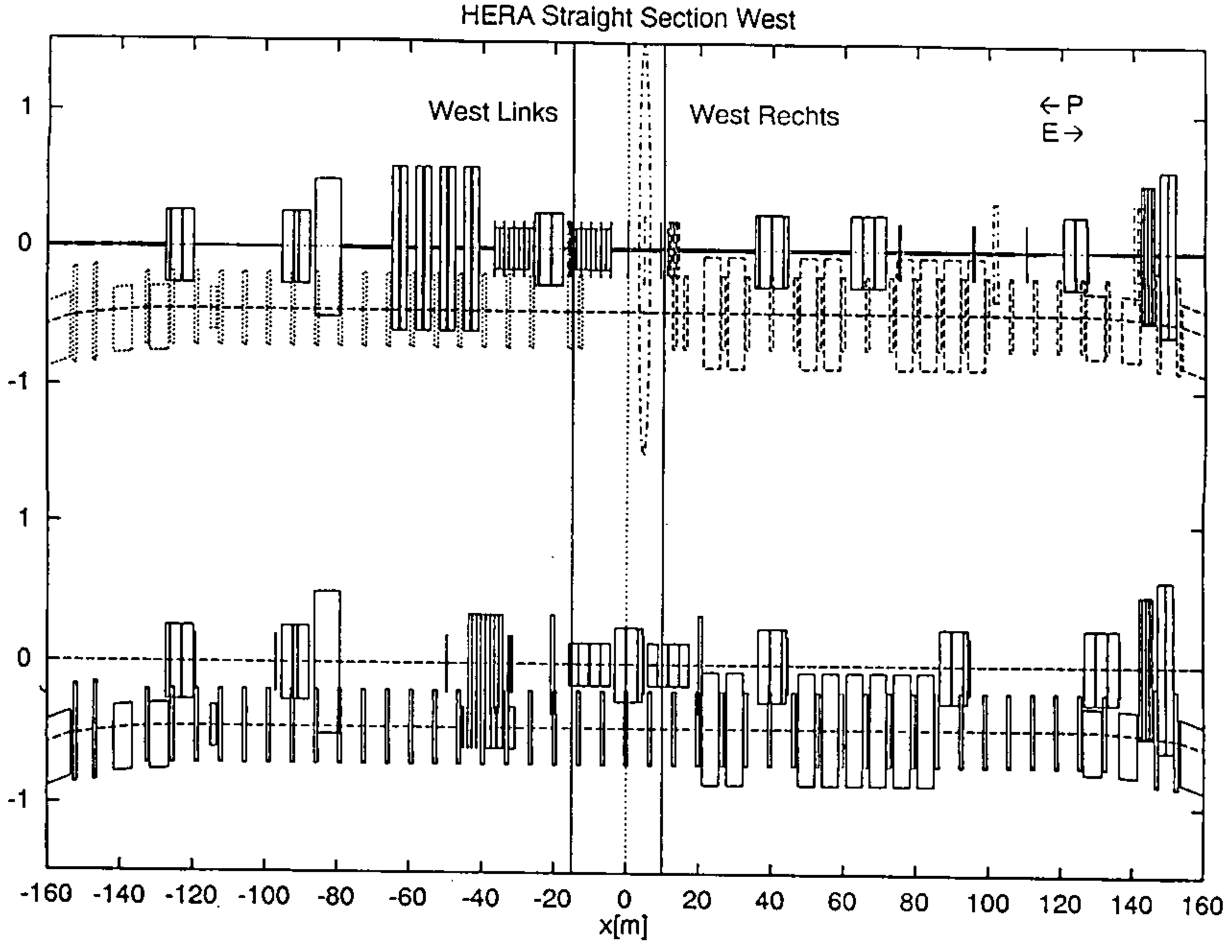




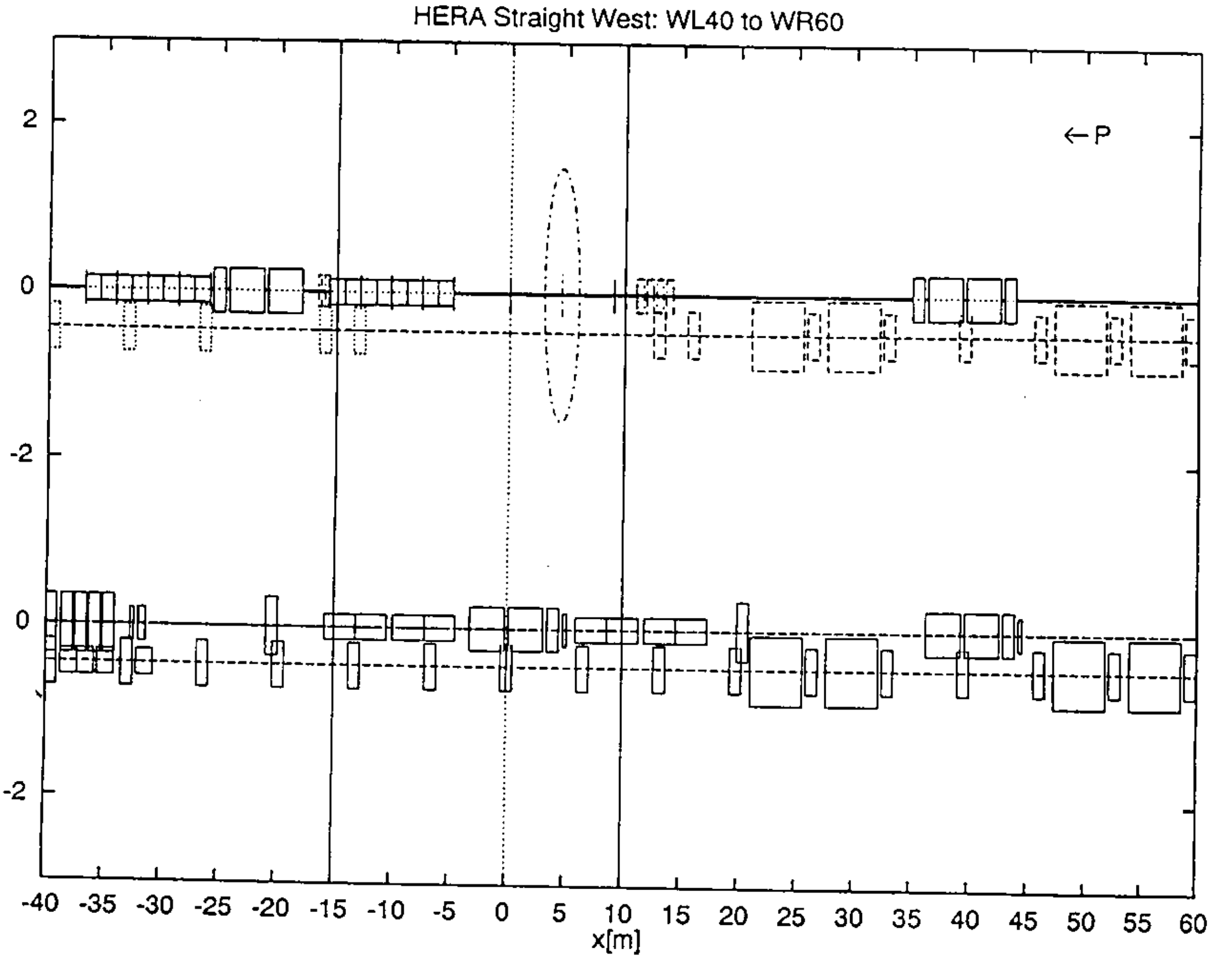
H - 19 -



H - 20 -

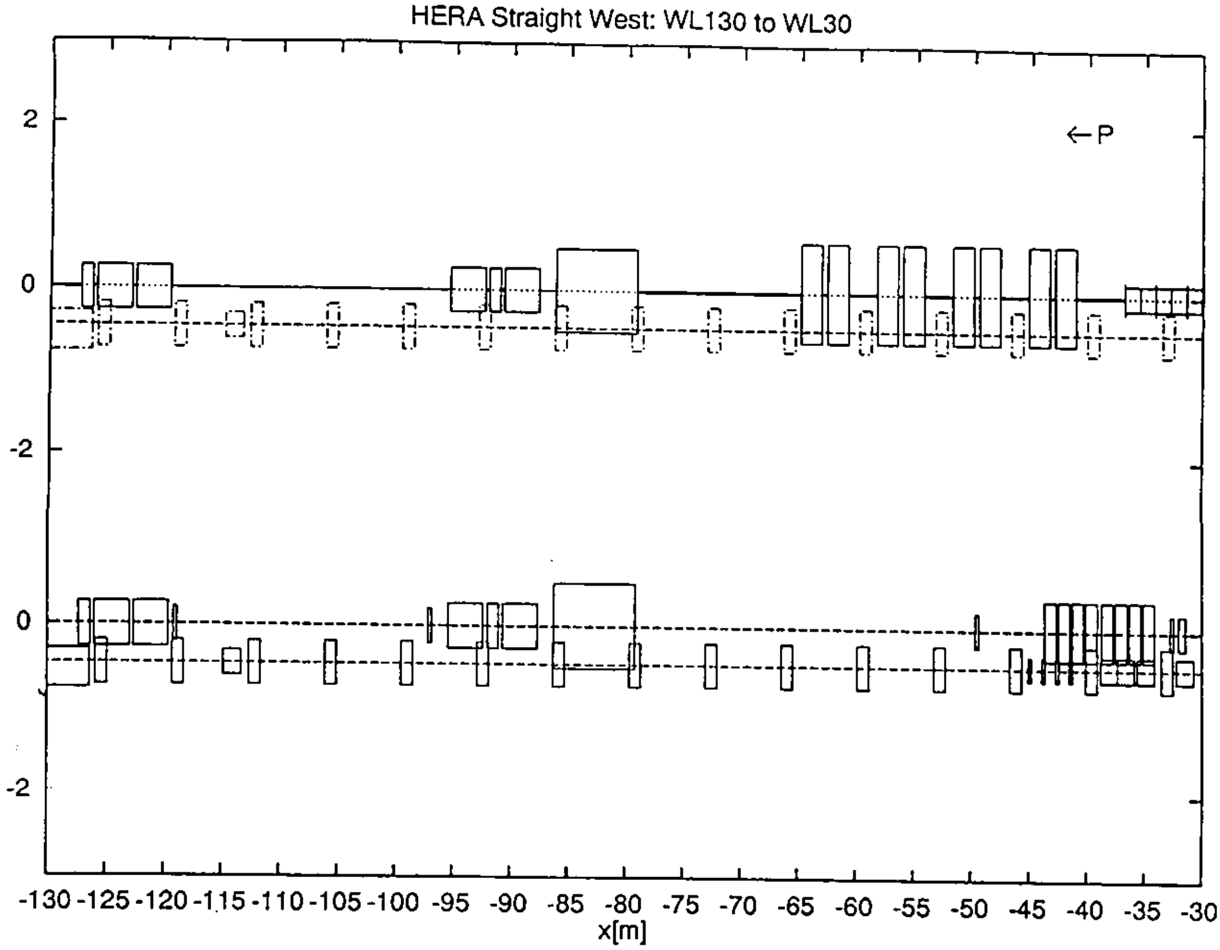

HERA Straight Section West
West Links
West Rechts
← P
E →
y[m]
x[m]
1
0
-1
-160
-140
-120
-100
-80
-60
-40
-20
20
40
60
80
100
120
140
160

H -21-


HERA Straight West: WL40 to WR60
← P
y[m]
x[m]
2
0
-2
-40
-35
-30
-25
-20
-15
-10
-5
5
10
15
20
25
30
35
40
45
50
55
60

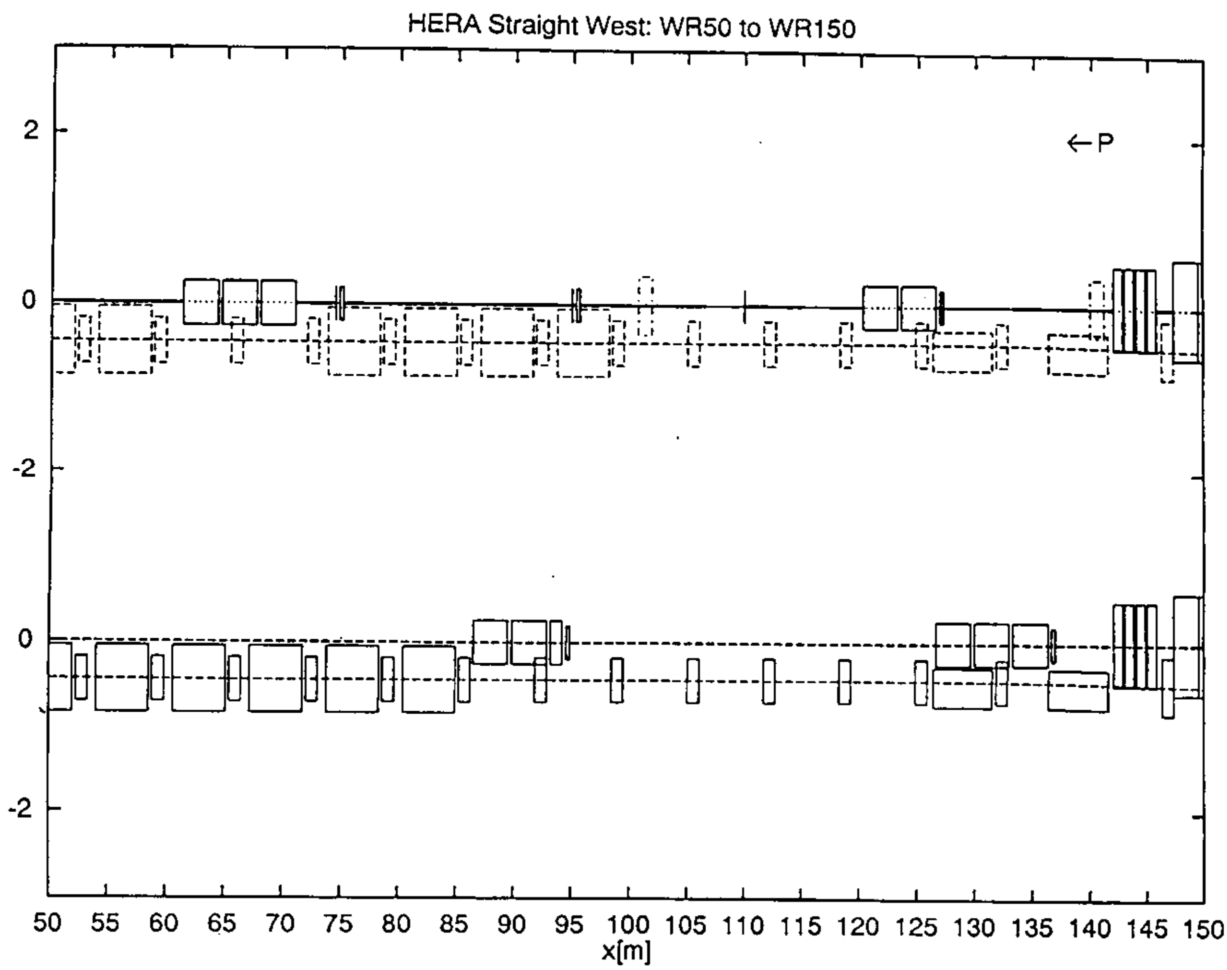
H -22-

H - 23 -

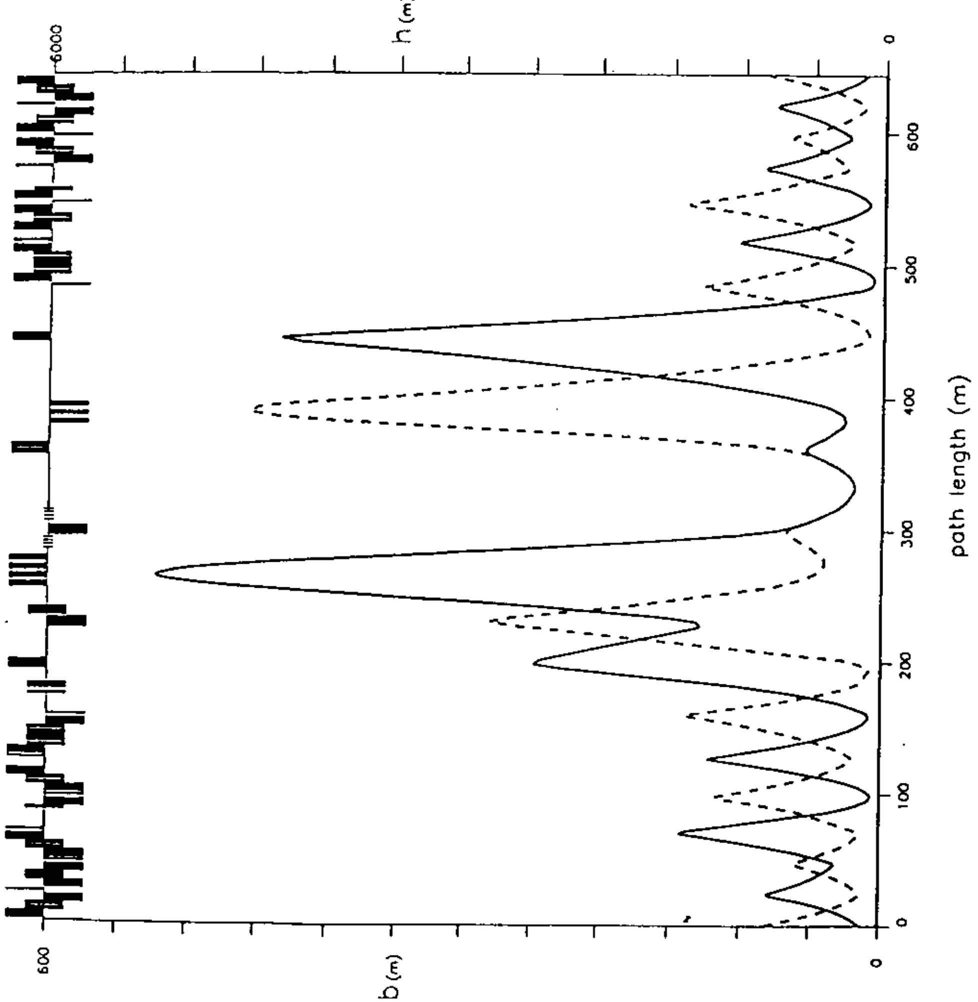


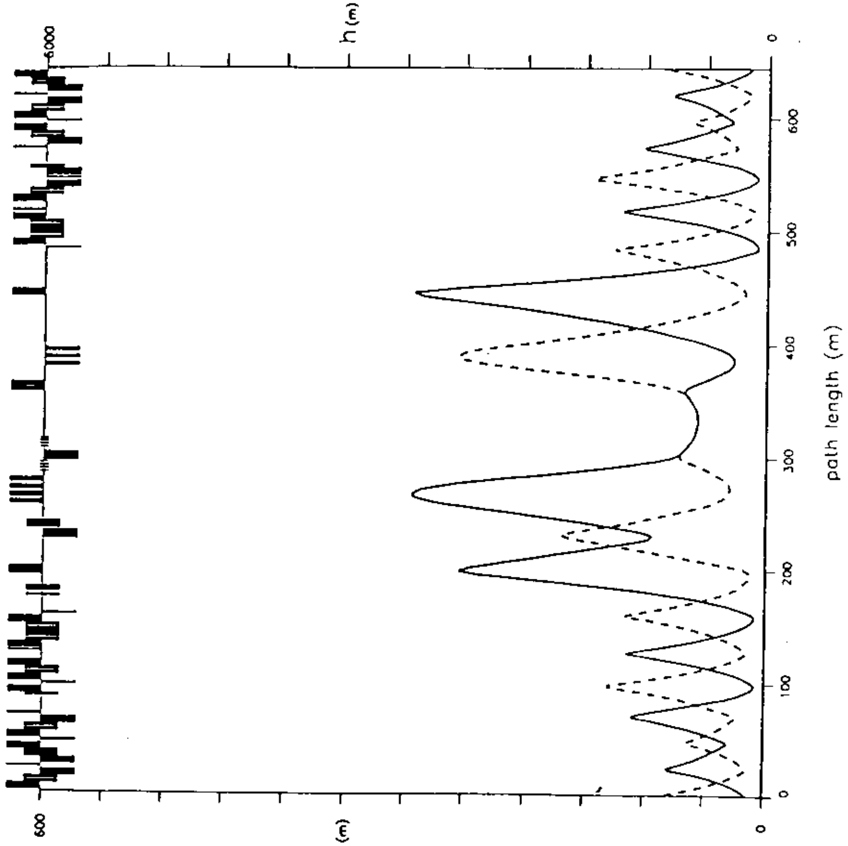
HERA Straight West: WL130 to WL30
←P
y[m]
2
0
-2
0
-2
-130 -125 -120 -115 -110 -105 -100 -95 -90 -85 -80 -75 -70 -65 -60 -55 -50 -45 -40 -35 -30
x[m]

H - 24 -



HERA Straight West: WR50 to WR150
←P
y[m]
2
0
-2
0
-2
50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150
x[m]


h (m)
6000
0
b (m)
600
0
path length (m)
0
100
200
300
400
500
600


h (m)
6000
0
b (m)
600
0
path length (m)
0
100
200
300
400
500
600

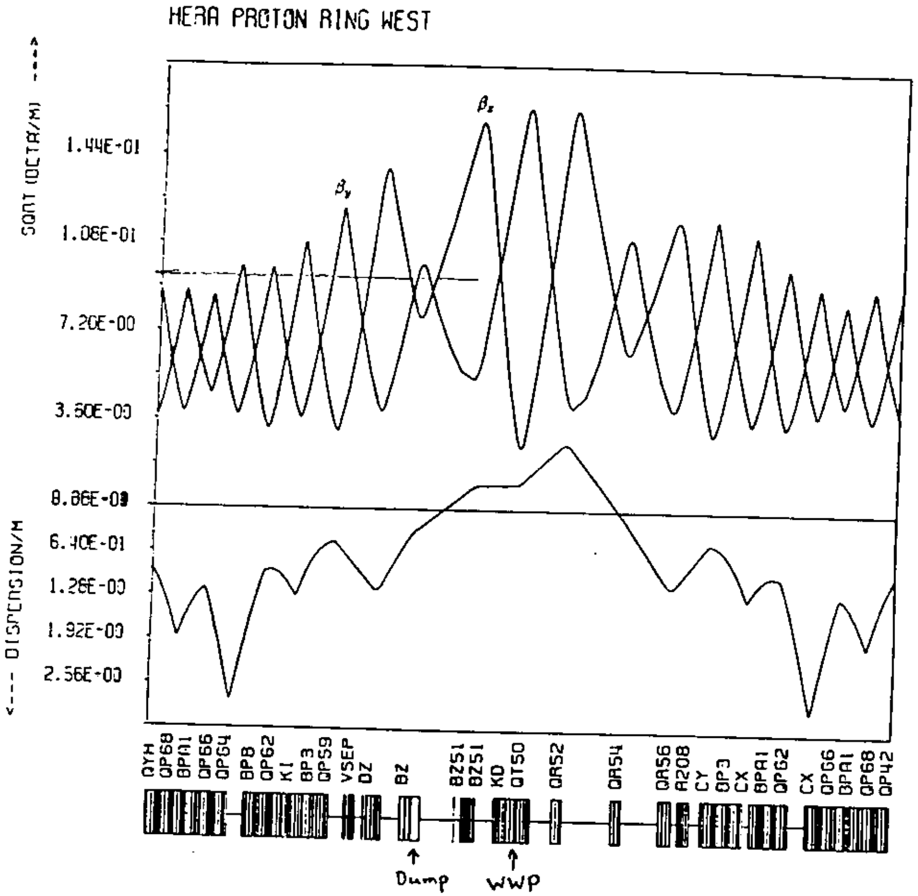


Figure 21: *Horizontal and vertical β function and horizontal dispersion function around the West Hall.*

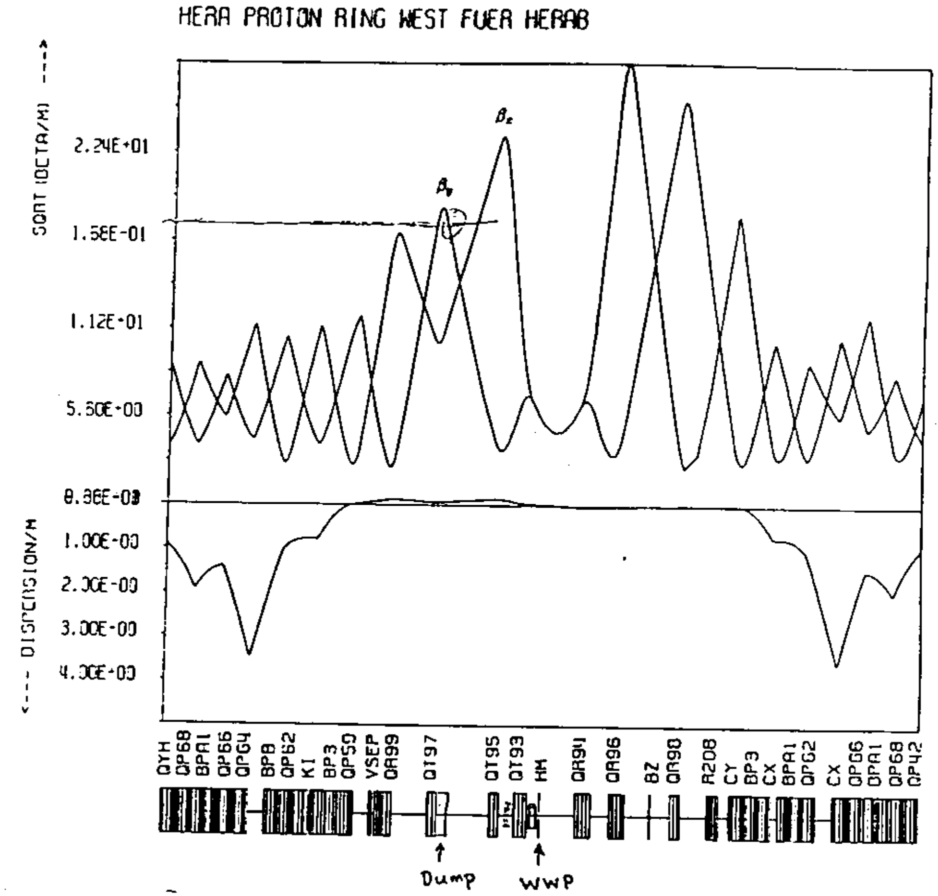


Figure 23: *Horizontal and vertical β function and horizontal dispersion function around the West Hall for the dump compatible redesigned optics.*

HERA-B

Klaus Ehret
MPI-K Heidelberg
HERA-B Meeting
DESY Hamburg
4-Oct-1994

Test of the Internal Wire Target

- Rate Requirements, Motivation
- Internal Halo Target
- Wire Test Measurements in 1993
  - Setup, Rates, Efficiencies
  - Fluctuations and Background
- Status and first Result of 1994
- Summary and Conclusions

Rate Requirements

- physics goal: $\delta[\sin 2\beta] \approx 0.1...0.15$ (1 year)
  $\Rightarrow$ requires: ≈ 1000 events/year
- $\sigma_{b\bar{b}}$, BR's and efficiencies:
  $\Rightarrow \quad \approx 4 \cdot 10^{14}$ i.a./year = 40 MHz
  (1 year = 10^7 sec)
- HERA - p:
  bunch frequency: 8 - 10 MHz
  design current - 160 mA: $N_p = 2 \cdot 10^{13}$ p
  (1993: 15 mA, 1994: 40 - 50 mA)
  lifetime: $\tau \approx 100$ h
  $\Rightarrow$ natural loss rate: ≈ 60 MHz

required target performance:
$< 4 >$ interactions per bx
$\text{eff}_{\text{Target}} \geq 60\%$

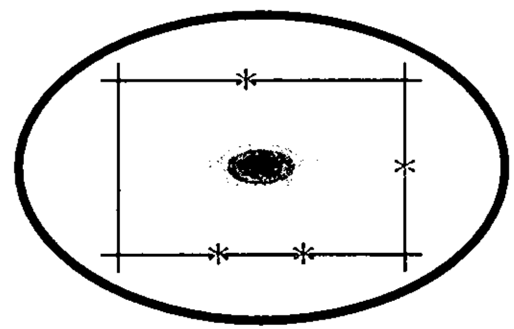
Motivation for Target Measurements

- Proof of principle:
  high efficient target, high rates
- Background at e-p experiments ?
- Stable rates over a long time:
  < 4 > i.a./bx distributed over different wires
- Efficient operation of the target requires:
  - experience with HERA machine
  - detailed understanding of the machine
- Study multiplicity, event topology etc.
  and compare with MC
- Experience at high rate enviroment:
  test of detector components, e.g. PM, chambers, silicon, electronics, and daq system
- Infrastructure for final experiment:
  BPM, target control, connection to HERA data server, etc.

Internal Target

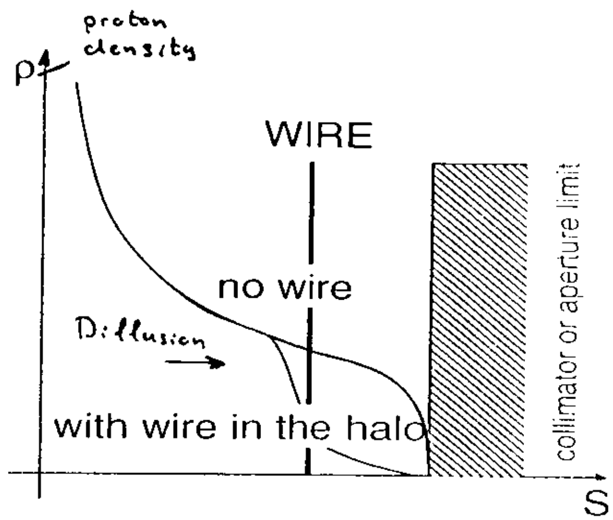
Introduce thin wires in the beam halo:

- Absorb protons leaving beam core
- Protons pass wire $\mathcal{O}(1000) \Rightarrow$ Interaction
- Well localized vertices distributed over different wires



Advantages:
mechanical stable, easy to operate

Principle of a Halo Wire Target



Efficient competition with collimators needed !

What is limiting the efficiency ?

Diffusion of Halo Protons

requires: small v_D and large Z (fast absorption)

Multiple Scattering in Target

$\Delta\epsilon = \Theta^2\beta, \quad \Theta = 14\ \mathrm{MeV/p}\sqrt{X_{int}/X_{rad}}$

requires: small β-function, low Z

Parameters of Proton Beam

- $\beta_{x/y} = 94/30\mathrm{m}$, $\epsilon_{x/y} \approx 3...6 \cdot 10^{-9}\mathrm{rad\ m}$
  $\longrightarrow \quad \sigma_{x/y} \approx 0.8/0.4$ mm
- typical collimator settings at $\approx 10\sigma$
- number of bunches and currents:

1992: 10 bunche à 150μA
$\tau \approx 100$ h

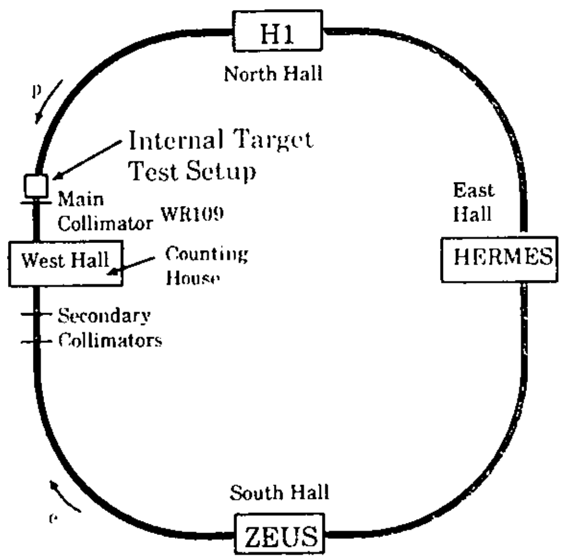
1993: 90 bunches à 150μA
$\tau \approx 20$ h...500 h

1994: 170 bunches à 250μA
$\tau = \mathcal{O}(1000\ \mathrm{h})$

design: ≈ 200 bunches à 800μA
$\Rightarrow$ 160 mA

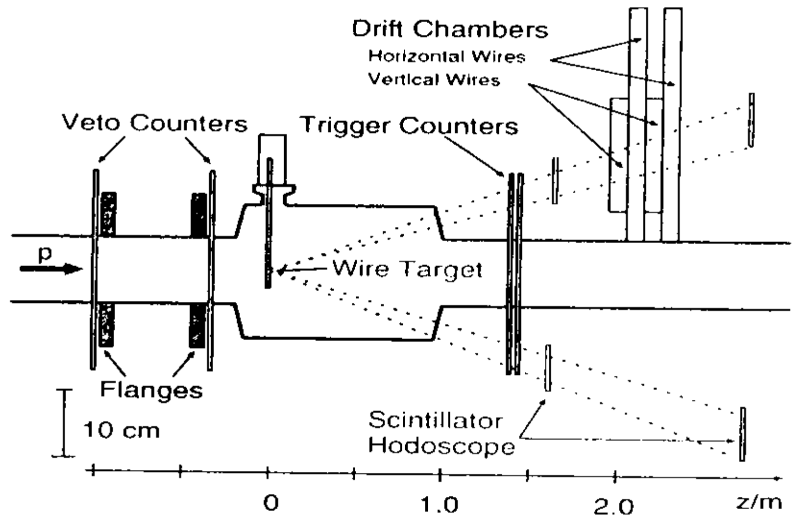
Location of Test Experiment

HERA West, 118 m upstream from West Hall
(long cable way and difficult access)

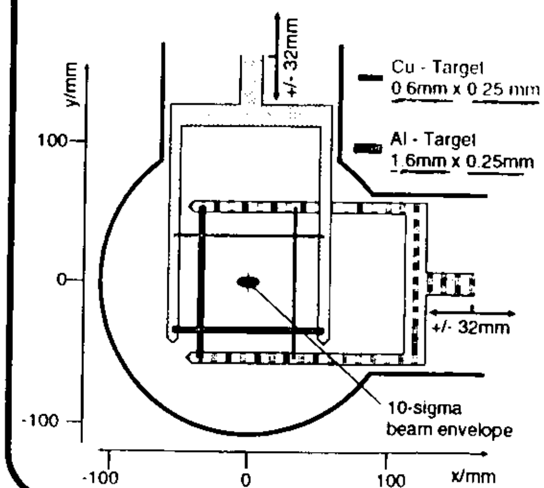


- first measurements in 1992
- improved and extended setups in 1993 and 1994
- measurements parallel to e – p Lumi operation

Target Test Setup 1993



acceptance: trigger ≈ 100%, hodoscope ≈ 50%



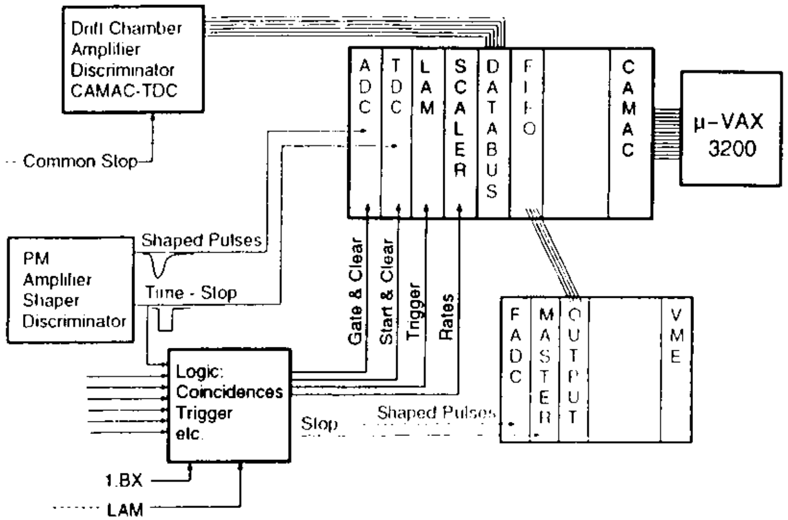
$l_z \cong 0.4\% X_{int}$

$\Rightarrow$ 250 turns $\cong X_{int}$

$\Delta_{x/y} \approx 0.5\ \sigma_{beam}$

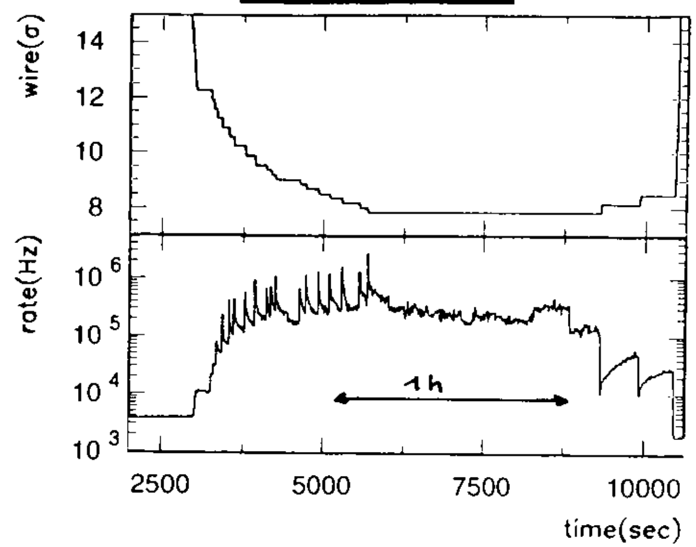
$\nu_D \approx 1 \ldots 10\ \sigma/\mathrm{sec}$

Electronics and DAQ 1993



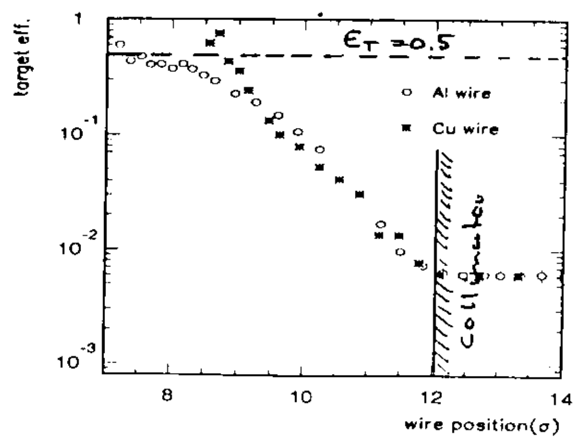
- rates (each second)
- tdc, adc, fadc's etc (with 10 ... 20 Hz)
- hera information
- typical measurements over one electron fill (~ 5h)

Wire Scans



Target Efficiency:

$$\epsilon_T = \frac{\text{interaction rate R}}{\text{loss Rate } N_p/\tau_p} = \frac{\tau_p}{N_p} R$$



achieved:

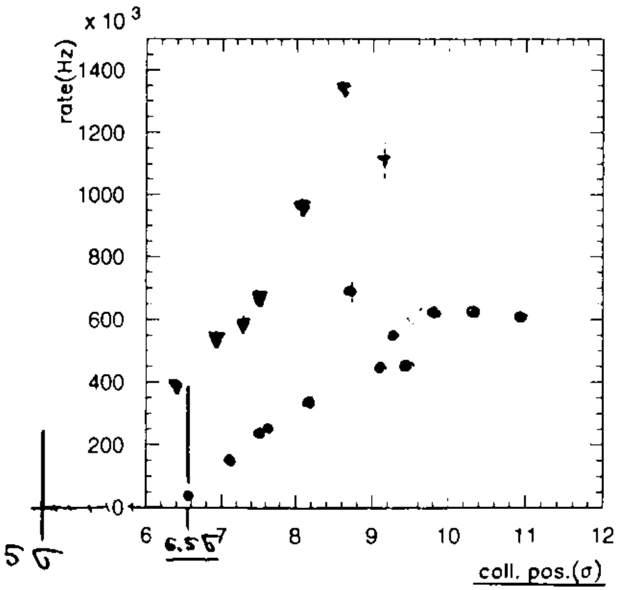
$\epsilon_T > 0.5$

Dependence on Collimator Position

Wire position fixed:

- ● $-6.5\ \sigma$ (dots)
- ▼ $-5\ \sigma$ (triangles)

move collimator



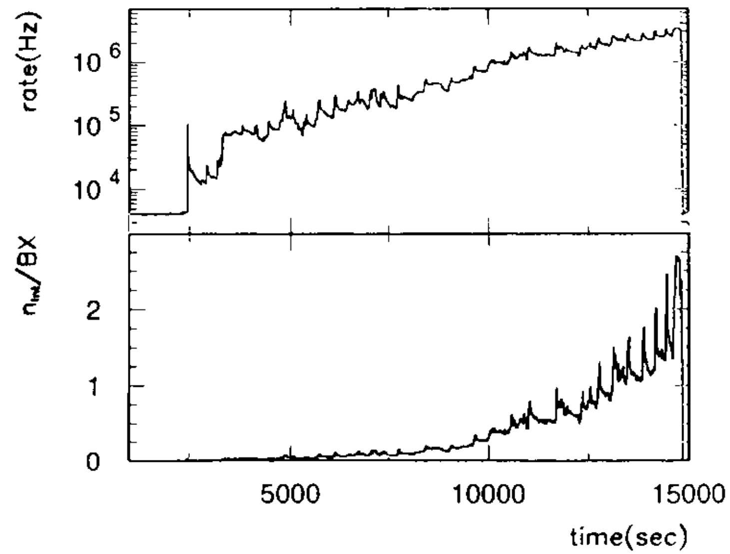
High Rate Wire Scan

we cannot directly resolve multiply i.a./bx
⇒ max. measured rate $r = 1/\mathrm{bx}$

- but the # of interaction/bx follows a poisson distribution

$$n_{int} = -\frac{1}{\epsilon}\log\left(1 - \frac{r}{f_{bx}}\right)$$

ϵ - accept., $f_{bx} \approx 4$ MHz

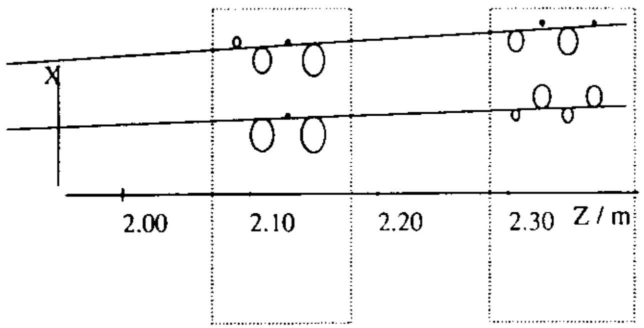


$n_{int} > 2$ @ 30% of design I_{bx}

Drift Chambers

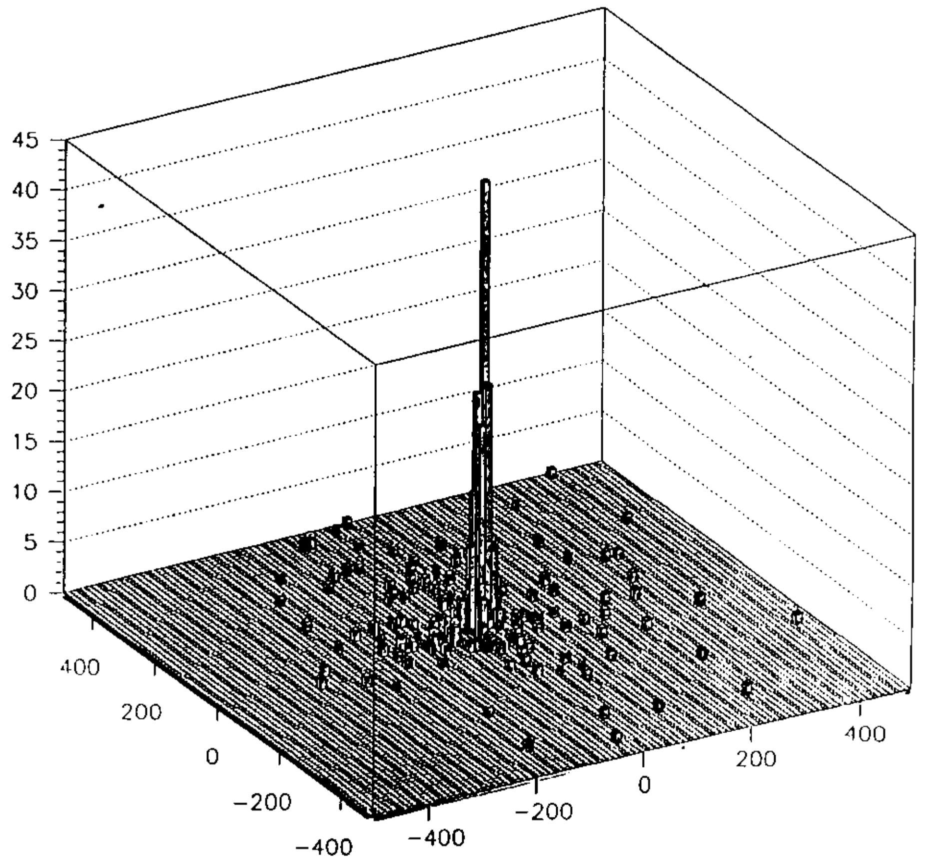
small setup of 4 drift chambers:

- two in each projection
- each consist of 4 layers with 8 wires
- using CF_4 at ≈ 3000 V
- operated at moderate rates

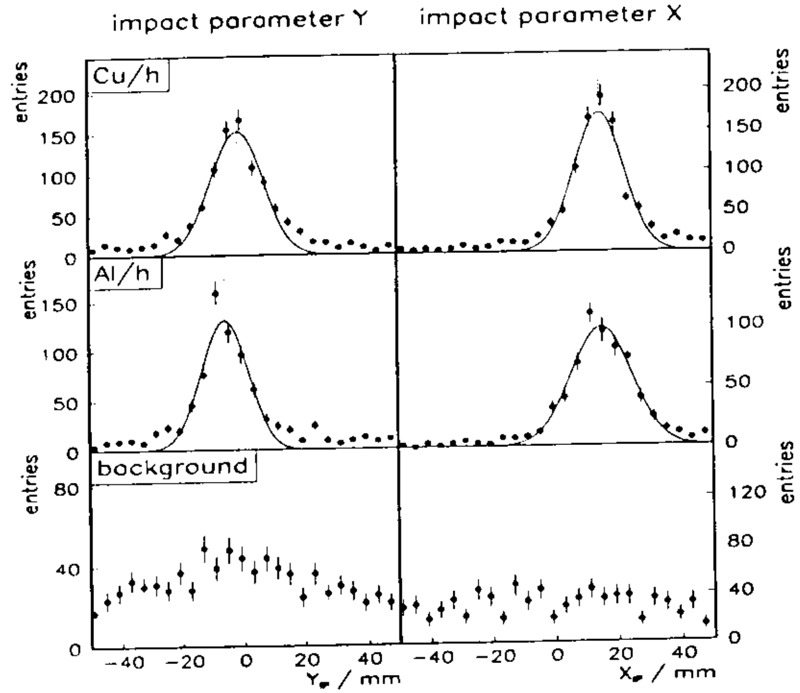


- drift velocity: ≈ 0.1 mm / ns
- impact parameter resolution @ target
  $\sigma_{x/y} \approx 8$ mm
  dominated by multiple scattering

Correlation of X_{IP} and Y_{IP}, 1 Track per Projection



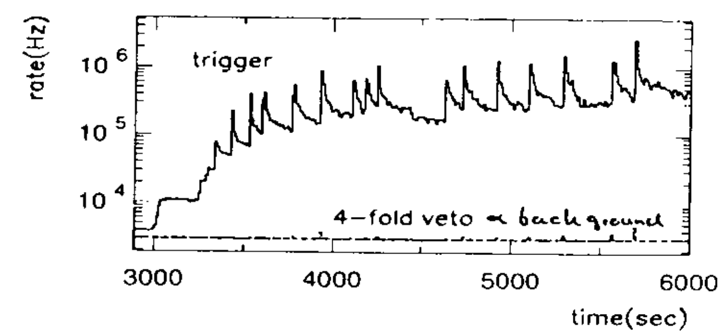
Tracks from Target



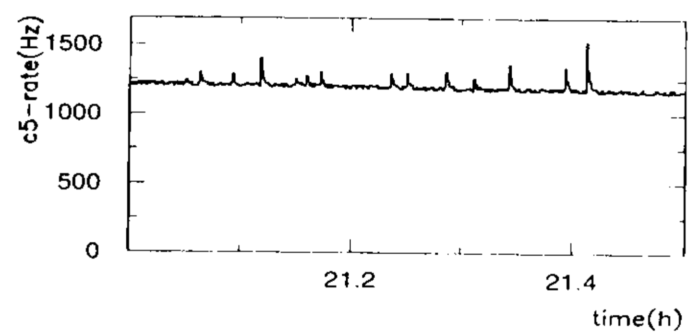
- obvious difference between background and target interactions
- clear evidence for interactions from target
- possible to distinguish two opposite wires:
  $\Delta y_{wire} = 6$ mm $\approx \Delta y_{tracks}$
  $\Delta x_{wire} = 0$ mm $\approx \Delta x_{tracks}$

Background

- 4-fold veto rate (~ background rate)



- ZEUS-background (@ ≈ same time)

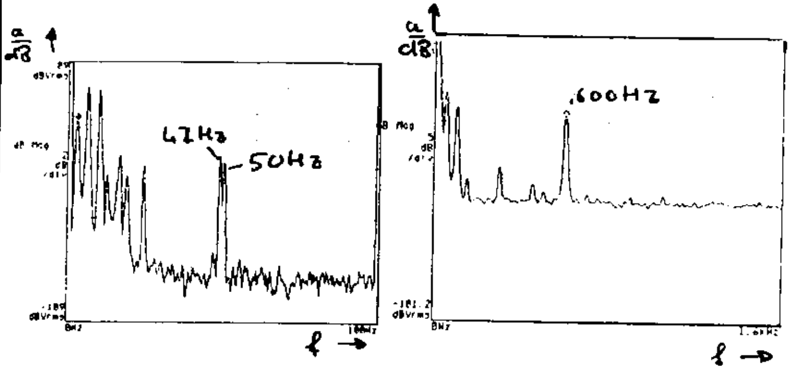


⇒ background stays stable, despite small spikes after large wire movements

Parallel running possible without problems

Long Term Fluctuations

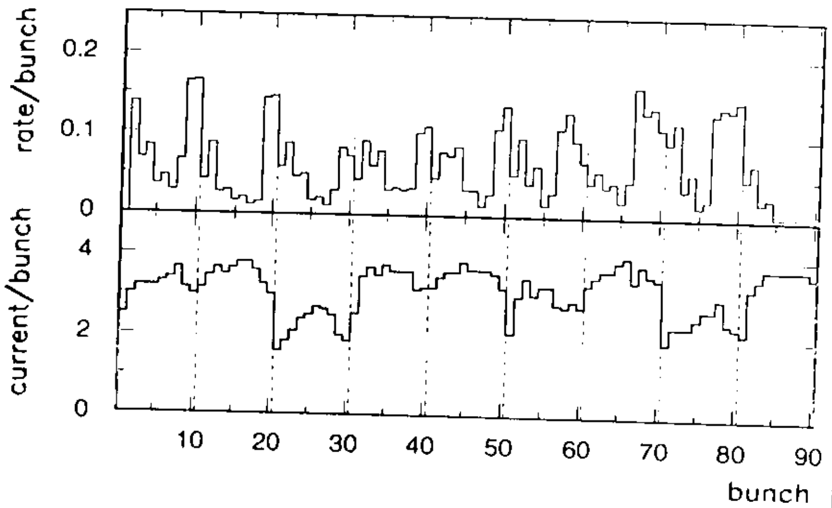
HERA-B requires stable interaction rates:
⇒ frequency analysis of counting rate



- Source well understood:
  - mechanical vibrations (below 50 Hz)
  - HERA power supplies (50 Hz to 600 Hz)
- Leads to rate modulation:
  $\boxed{\sigma_{rate} \approx 0.13 * < rate >}$
- Corresponds to a jitter in the beam position of 10 – 20 μm
- Didn't affect the efficiency of the experiment

Short Term Fluctuations

Measurement of individual bunch contribution with Flash-ADC's worst example (1993):

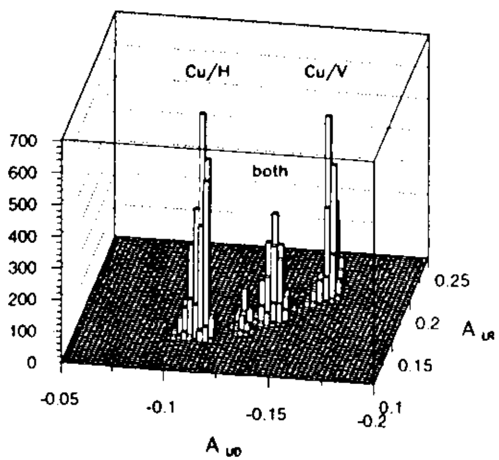


- timing problem while injection (under study)
- would affect efficiency of the experiment; we would lose up to 30% of interactions if the detector handles up to 6 i.a./bx

Asymmetries and Target Control

Important to distribute i.a. on different wires.

left-right / up-down asymmetries
for 4 hodoscopes



- Magnitude agrees with expectations (geometrical acceptance)
- Provides a sensitive and simple tool for automatic control

Improved Setup for 1994

Why continue with measurements?
Didn't look all questions solved?

- There are still open problems, questions ...
  - Experience at higher p-currents and higher rates
  - Event topology, multiplicity, vertex distribution on wire, etc.
  - Bunch to bunch variations, fluctuations
- Long term experience with HERA
- Develop target control

⇒ Requirements:

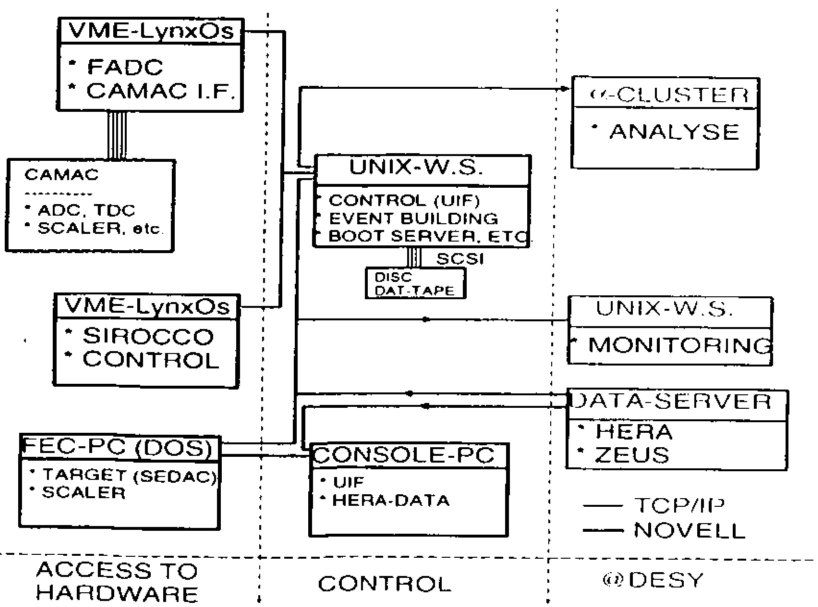
- Measure rates up to 40 MHz
  - finer granularity of counters (2 → 12)
  - improved base of PM:

    $I_{PM} \approx 30\ \mathrm{MHz} * 15\ \mathrm{nsec} * 10\ \mathrm{mV}/50\ \Omega = 100\ \mathrm{mA}$
- Measure individual bunch contributions

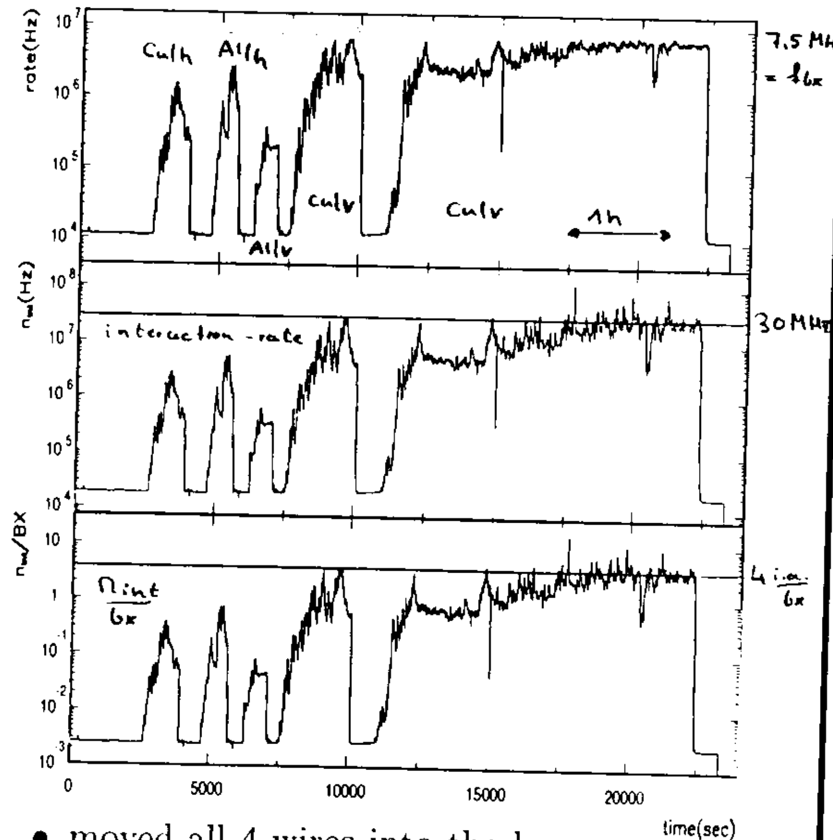
- Better track/vertex resolution:
  ⇒ set of 4 double sided silicon counters
- Improved target control
  ⇒ independent rate monitoring, access to HERA data, better user interface

⇒ new daq system neccessary
(higher data rate, several cpus and tasks):

Fully unix based vme readout

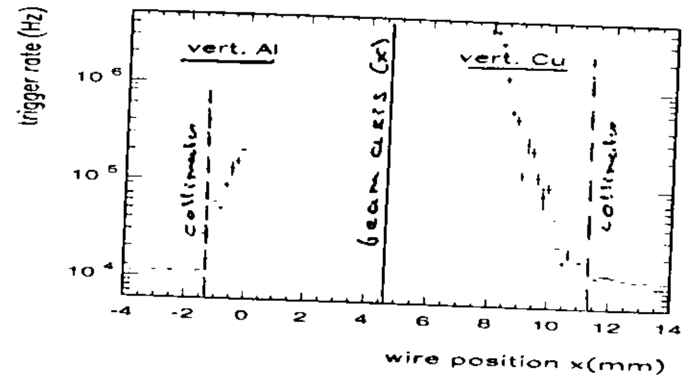


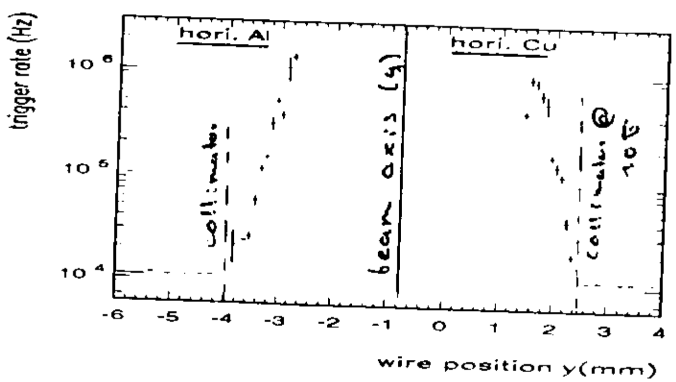
Scan with all 4 Target Wires



- moved all 4 wires into the beam
- countingrates up to $\approx f_{bx} = 7.5$ MHz
- rates up to ≈ 30 MHz (4 i.a./bx) @ 1/3 I_{Design} ⇒ $\tau_P \approx 30h$

Rates versus Targetposition





- beam position and collimator positions agrees well with different independent measurements

Determination of Interaction Rate

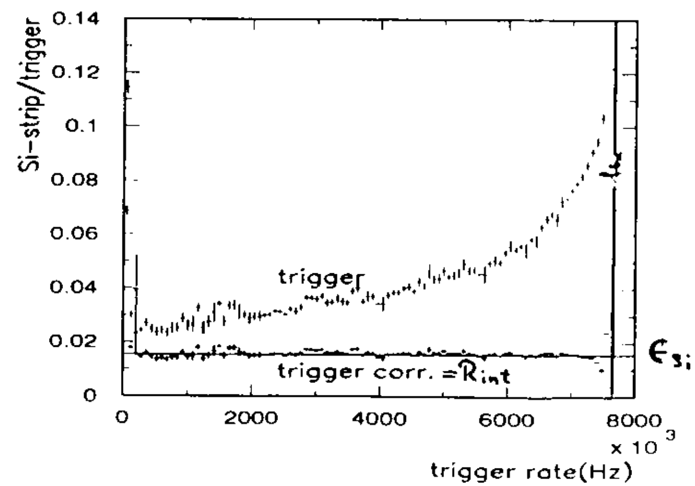
We cannot directly resolve multiple i.a./bx, maximal measured rate $R_{meas} = 1/bx = f_{bx}$

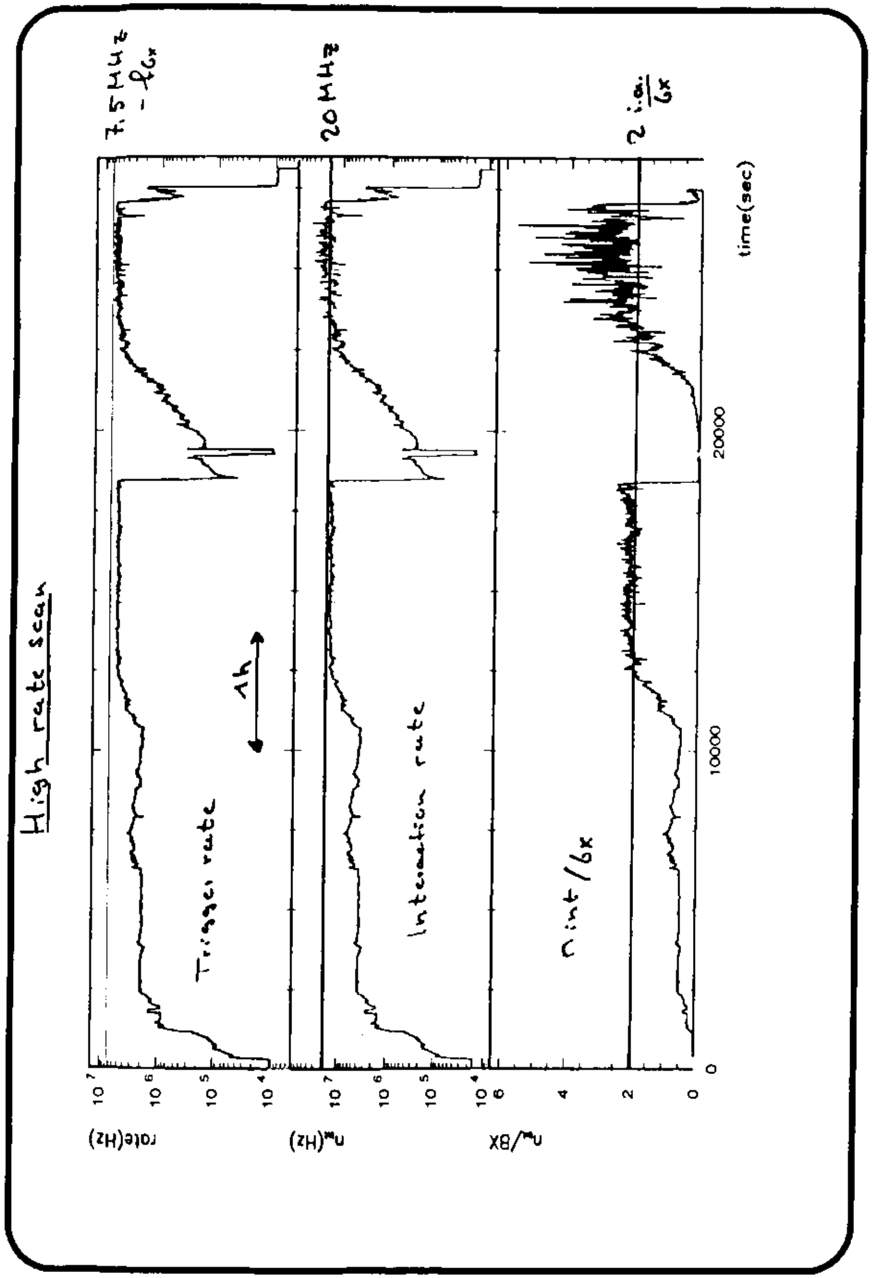
- n_{int}/bx follows a poisson distribution:

$$\frac{n_{int}}{bx} = -\frac{1}{\epsilon}\log\left(1 - \frac{R_{meas}}{f_{bx}}\right) \Rightarrow R_{int} = \frac{n_{int}}{bx} \cdot f_{bx}$$

ϵ = accept., $f_{bx} \approx 7.5$ MHz

- Counters with slow acceptance $\epsilon = \mathcal{O}(1\%)$:
  - no saturation: $R_{meas} = \epsilon\, R_{int}$
  - allows independent check

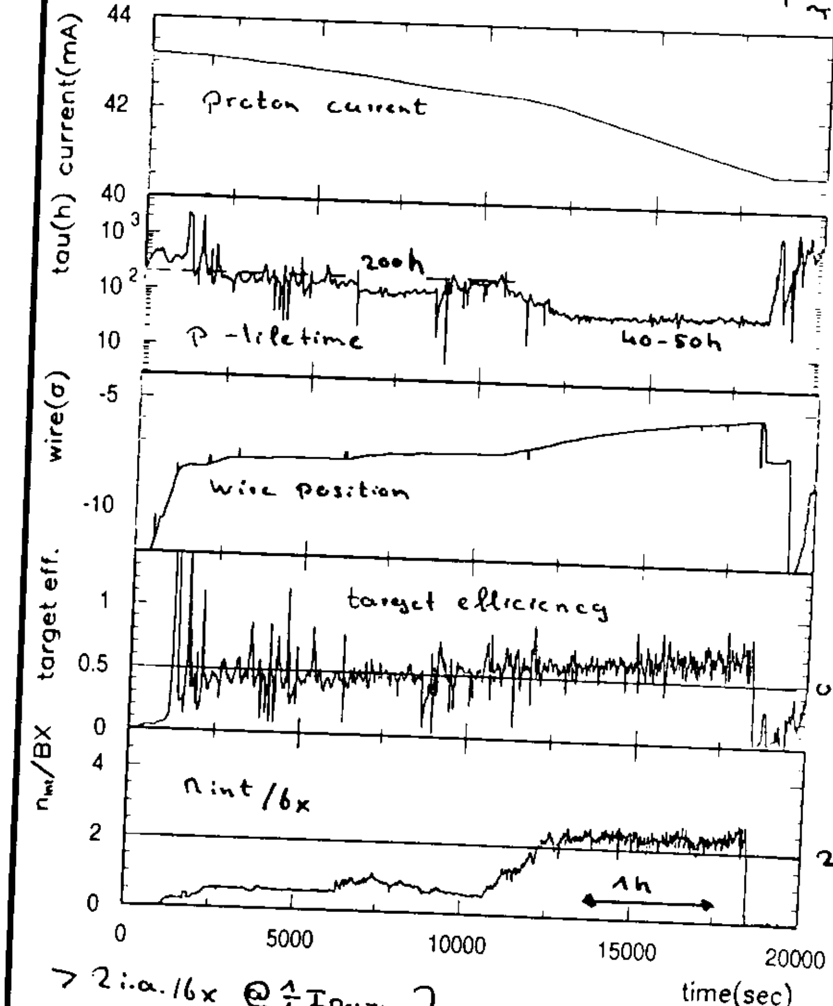




Influence on Machine Parameters

another measurement:

$R_{int} \simeq 40\,MHz \cdot \varepsilon_T \cdot \frac{I\,[mA]}{\tau\,[h]}$



> 2 i.a./bx @ $\frac{1}{4} I_{Design}$; $\varepsilon_T = 0.5 \ldots 0.6$ } $\tau_p \simeq 50h$

Conclusion

- $eff_{Target} > 60\%$
- $n_{int} > 3$ @ 30% of design I_{bx}
- Background:
  - H1: no problems
  - ZEUS: LPS and FNC sometimes sensitive

  Further Tests required
- Fluctuations:
  - long term: harmless
  - bx-to-bx variations: caused by injection
- Target Control with Assymetries: looks promising, needs further improvement and investigation
- Test Setup 94: allows detailed studies of multiplicity, bx-fluctuations and vertex distribution

Further Plans

Next Year (1995):

New Target: 4 independent wires
smaller stepsize of 0.1 μm

PM-Bases: active Cockcroft-Walton bases
(will be used for the HERA-B calorimeter)

Target Control: Silicon Counters (Pixel)

etc.: Standard Operation of DAQ System
with FADC's and silicon-strip detectors

1995/96: Move in West Hall

- new modified HERA-B optic
- vacuum tank with parts of silicon detector
- magnet
- parts of muon system
- prototype detector elements
- tracking chambers

Spectrometer Magnet and Impact on the HERA Electron Ring

4.10.94

Reinhard Eckmann ; Uni Hamburg

Contents:

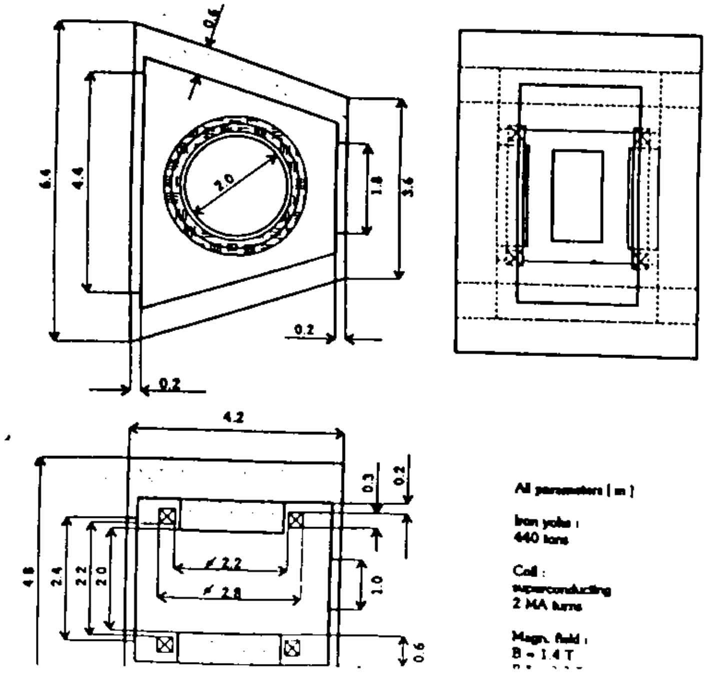
Review of the proposal design

$B \to J/\psi \, (\to \mu^+ \mu^-) \; K_s^0 \, (\to \pi^+ \pi^-)$

- **coil**
  - $\int dz\, B_y \sim 1\,\text{Tm} \Leftrightarrow \Delta m \sim 25\,\text{MeV} \Leftrightarrow$ minimal mass resolution
  - $\int dz\, B_y \sim 3.3\,\text{Tm} \Leftrightarrow \Delta m \sim 6\,\text{MeV}$ ↳ $S/N \to 10 \cdot S/N$

  ↳ superconduction coil suggested

- **iron yoke**
  - trapezoidal shape ↳ minimal amount of iron (440 to
    but: difficult access for detector installation



Normal conducting coil

- results of mc-studies are now available
  - $\int dz\, B_y \sim 2.2$ Tm leads to: $\Delta m \sim 8$ MeV
    $p_{t,kick} \sim 0.65$ GeV

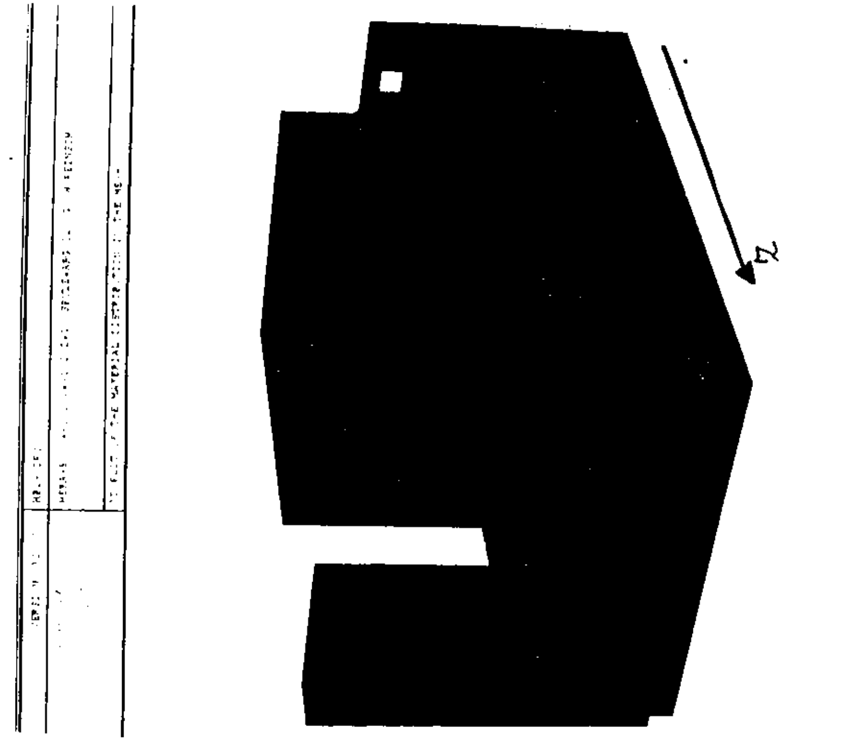
↳ a normal conducting coil is acceptable

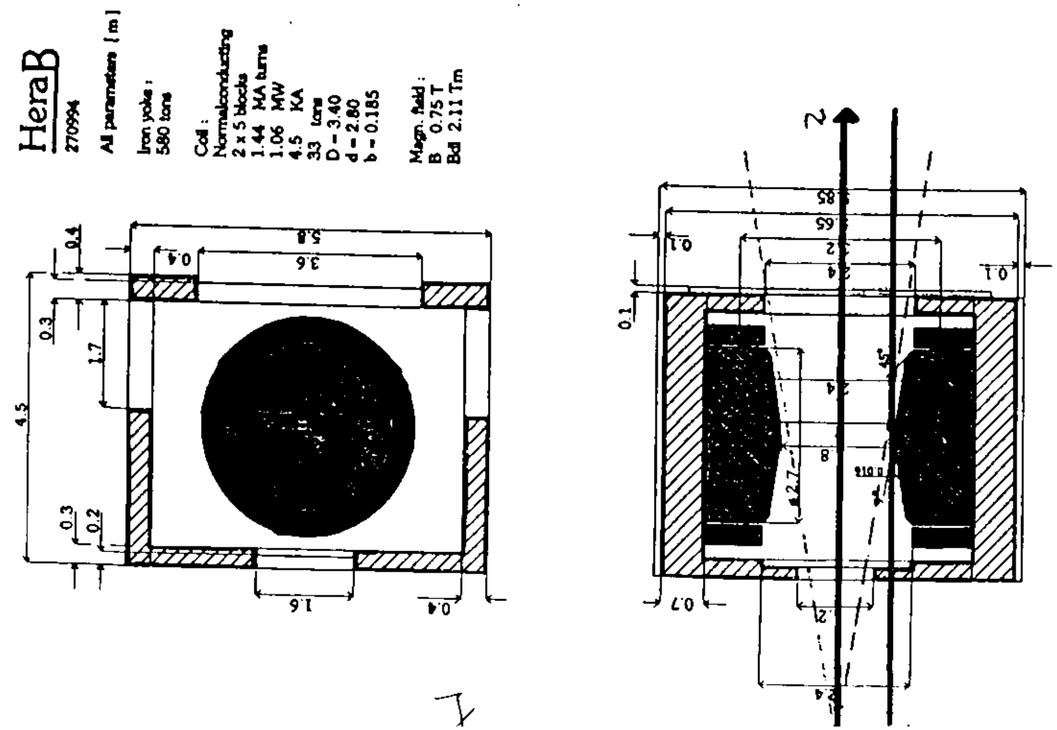
- cost reduction
  - take 2× 5 blocks from the ARGUS coil.
  - $I = 5000$ A → $I = 4500$ A

  ↳ $\int dz\, B_y \sim 2.2$ Tm → $\int dz\, B_y \sim 2.1$ Tm

  $P \sim 1.3$ MW → $P \sim 1.06$ MW

20% decrease of operating cost
for ~ 5% loss in Δm





The iron yoke

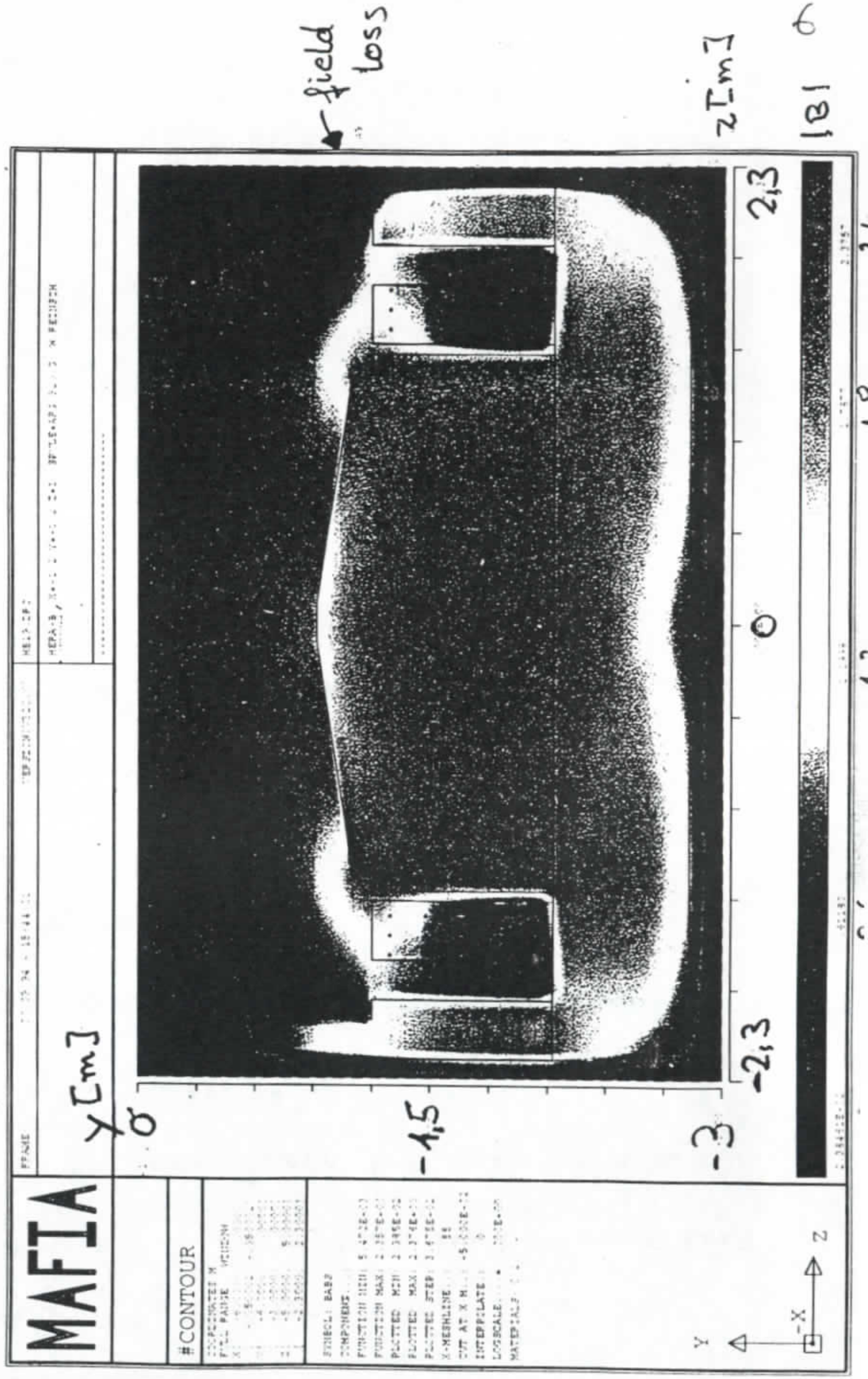
- simplified construction: cube-like shape (Quader)
- boundaries:
  - ARGUS - coil: 2.8 m < r < 3.4 m
  - aperature ......: 200 mrad
    <=> { 300 mrad bending plane; 160 mrad non-bending plane }

↳ 1. 1.6 m × 1.2 m hole in front plane
2. 2.4 m × 3.6 m hole in back plane
3. 1.8 m pol-distance
4. polshape parallel to aperature boundary in a distance of 15 cm (space for chamber construction)

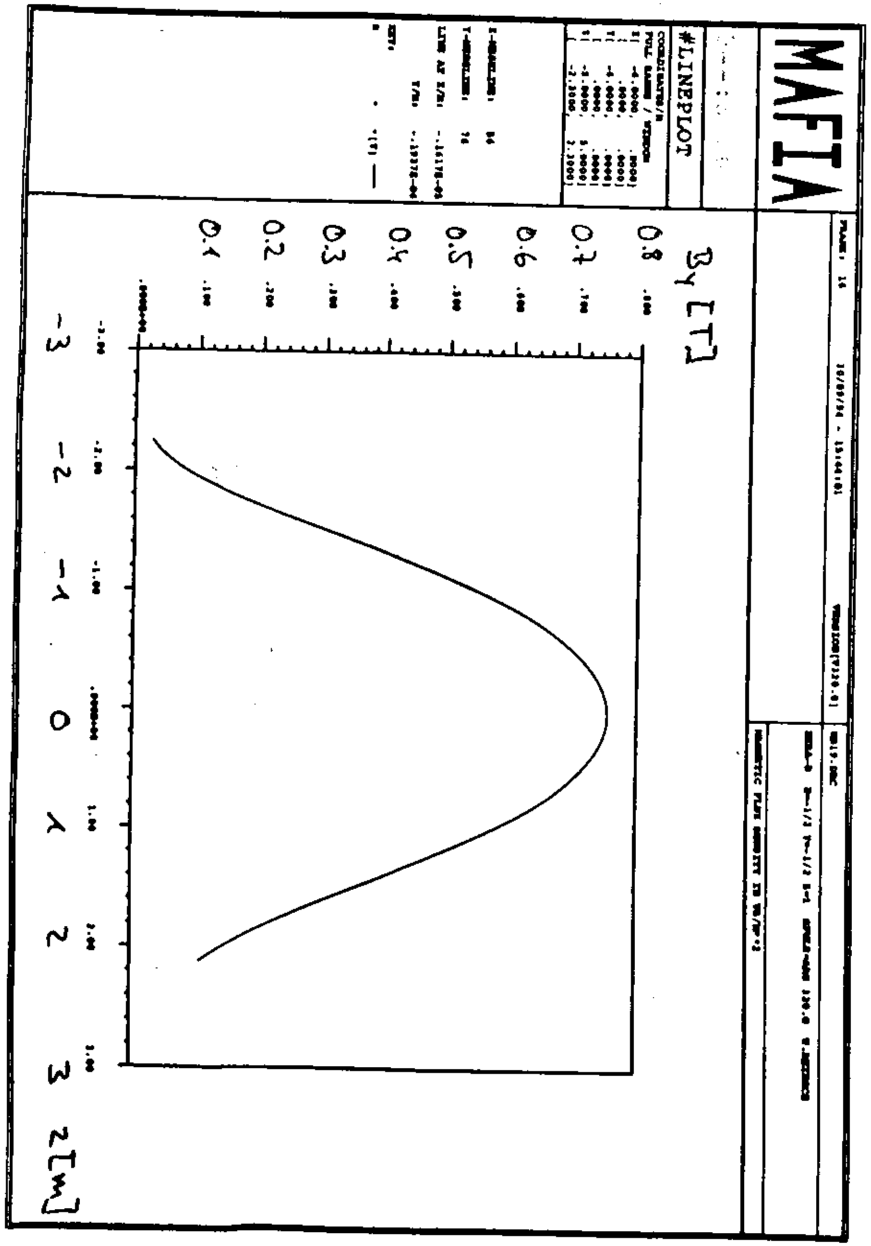
- tracking: little stray fields outside the magnet
  ↳ small in z-direction
  limited by loss of magnetic field

↳ width: 4.5 m
depth: 5.8 m (reduced loss)

- chamber installation: 2 doors 1.7 m × 3.2 m
- thickness of the walls: nowhere a greater flux than in the pole



Field distribution in central plane



Conclusions

- the magnet is one year earliers avaiable, but loss in S/N, since $\Delta m \sim 6\,MeV \rightarrow \Delta m \sim 8\,MeV$
- gain in the acceptance for soft particles
- cheaper in construction.
- greater technical reliability
- operating cost
  - 20% reduced power consumption than proposal versi
  - but more than superconducting coil
  - but no extra operating team necessary

Impact on the proton ring

done by Mrs. Wipf using the HERA-MAFIA simulation

RADIUS = 2.5cm, integrated from z = -2.1 to z = 5 m

relative multipole coefficients			
order	normal	skew	
1	1.00000000	.00000000	Dipol
2	.00000000	.00000000	Quadropol
3	-.00012719	.00000000	Sextupol
4	.00000000	.00000000	⋮
5	.00000269	.00000000	
6	.00000000	.00000000	
7	.00001020	.00000000	
8	.00000000	.00000000	
9	-.00000562	.00000000	
10	.00000000	.00000000	
11	-.00001113	.00000000	
12	.00000000	.00000000	
13	.00001355	.00000000	
14	.00000000	.00000000	
15	-.00000170	.00000000	
16	.00000000	.00000000	
17	-.00002273	.00000000	
18	.00000000	.00000000	
19	-.00004277	.00000000	
20	.00000000	.00000000	

- largest multipol: Sextupol $< 1.4 \cdot 10^{-4}$ of the dipol
- proton kick due to dipol field: 1 mrad

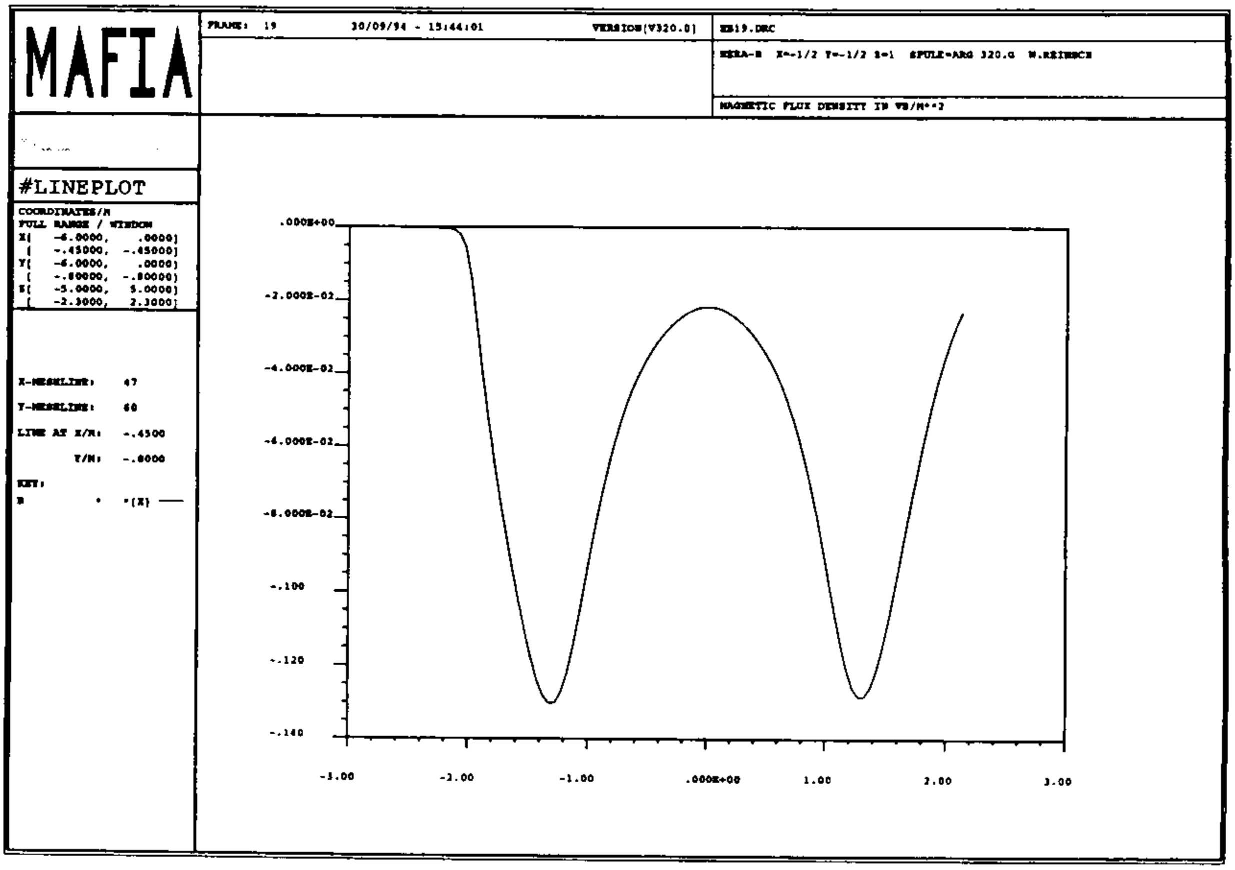
→ **neglectible field errors for the proton beam**

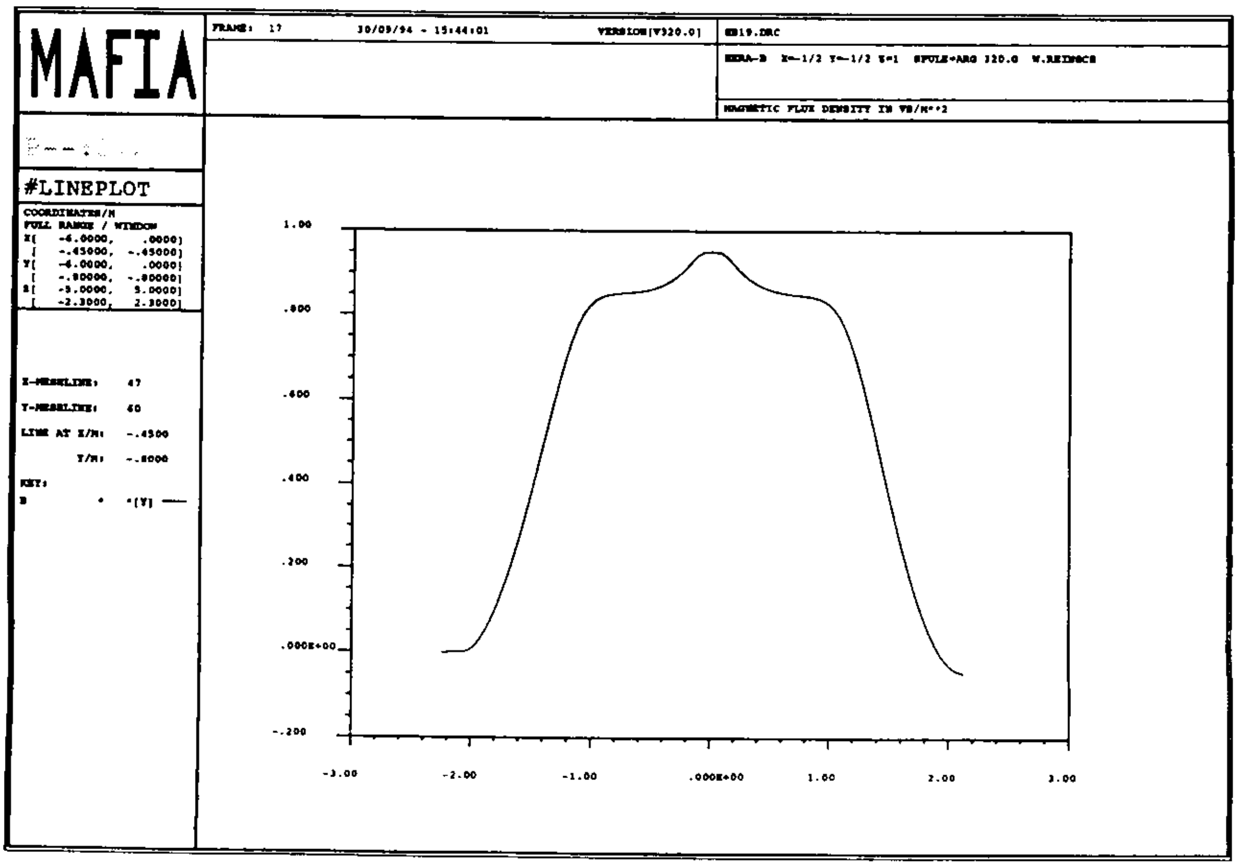
Field compensation for the electron beam

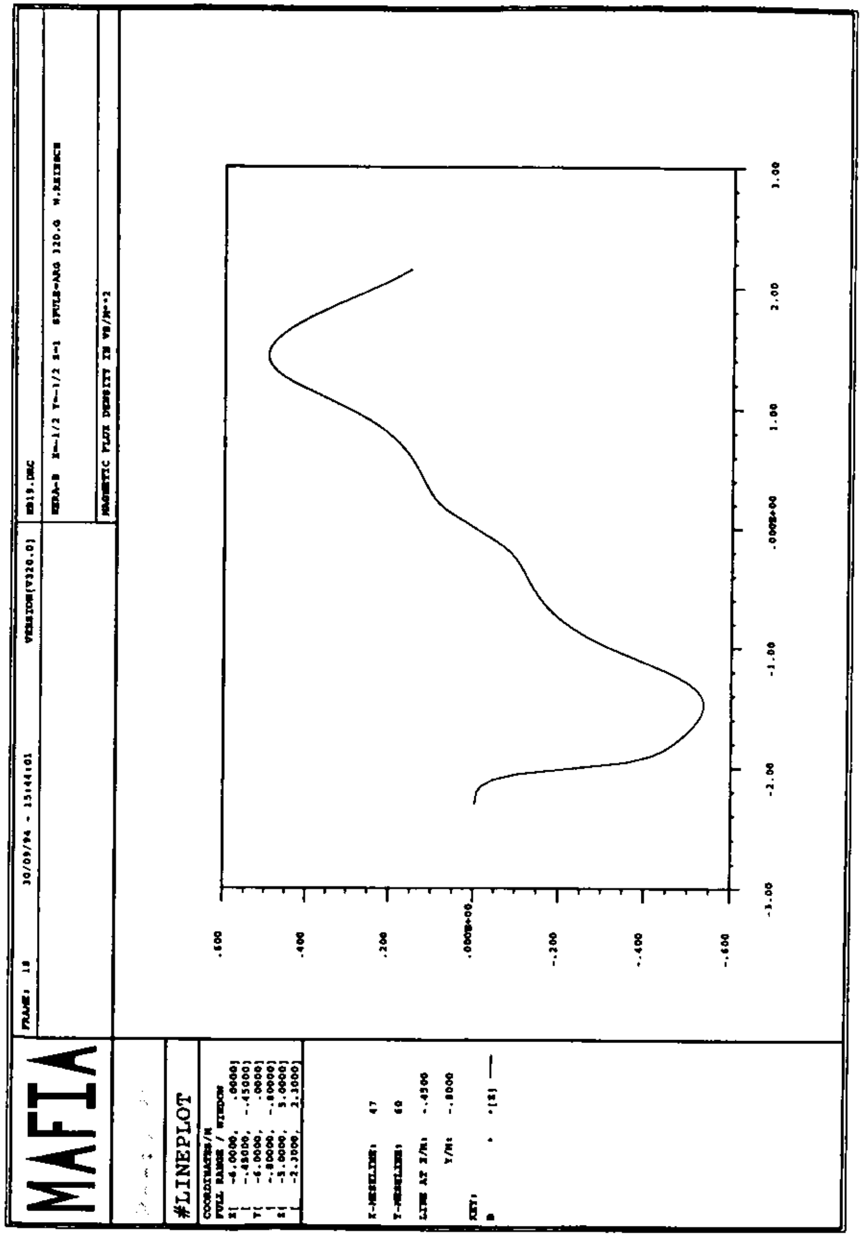
- consequently switched to normal conducting coil
  - no cyrogenics only for the compensation coil
  - no support team — " —
  - greater reliability

What follows is

- Introduction to the design ideas
- Presentation of the preliminary MAFIA calculatio


MAFIA
FRAME: 19
30/09/94 - 15:44:01
VERSION(V320.0)
#LINEPLOT
COORDINATES/M
FULL RANGE / WINDOW
X-MESHLINE: 47
Y-MESHLINE: 60
LINE AT X/M: -.4500
Y/M: -.8000
KEY:
MAGNETIC FLUX DENSITY IN VB/M**2
.000E+00
-2.000E-02
-4.000E-02
-6.000E-02
-8.000E-02
-.100
-.120
-.140
-3.00
-2.00
-1.00
.000E+00
1.00
2.00
3.00

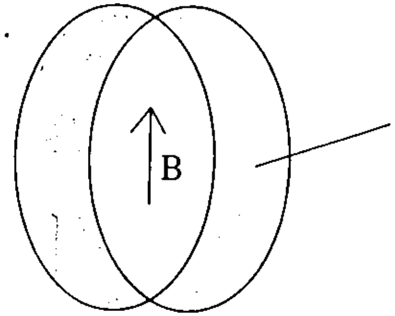

MAFIA
FRAME: 17
30/09/94 - 15:44:01
VERSION(V320.0)
#LINEPLOT
COORDINATES/M
FULL RANGE / WINDOW
X-MESHLINE: 47
Y-MESHLINE: 60
LINE AT X/M: -.4500
Y/M: -.8000
KEY:
MAGNETIC FLUX DENSITY IN VB/M**2
1.00
.800
.600
.400
.200
.000E+00
-.200
-3.00
-2.00
-1.00
.000E+00
1.00
2.00
3.00



The basic ideas

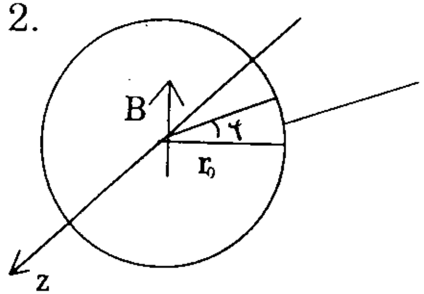
- current densities to generate a homogeneous transversal B (by Kaiser)

1.



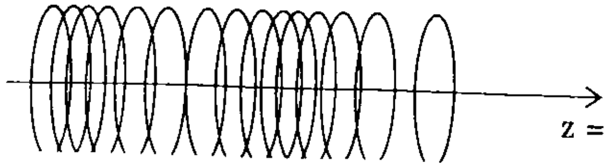
filled with a homogeneous current density

2.



current density proprortional to sin φ at $r = r_0$

- solonoid with variing density of windings for compensation of the longitudinal field



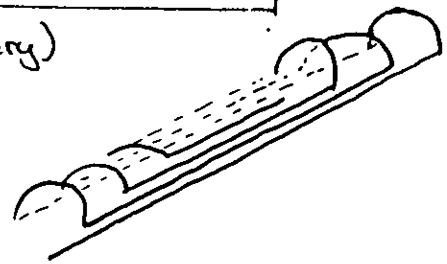
z = electron beam

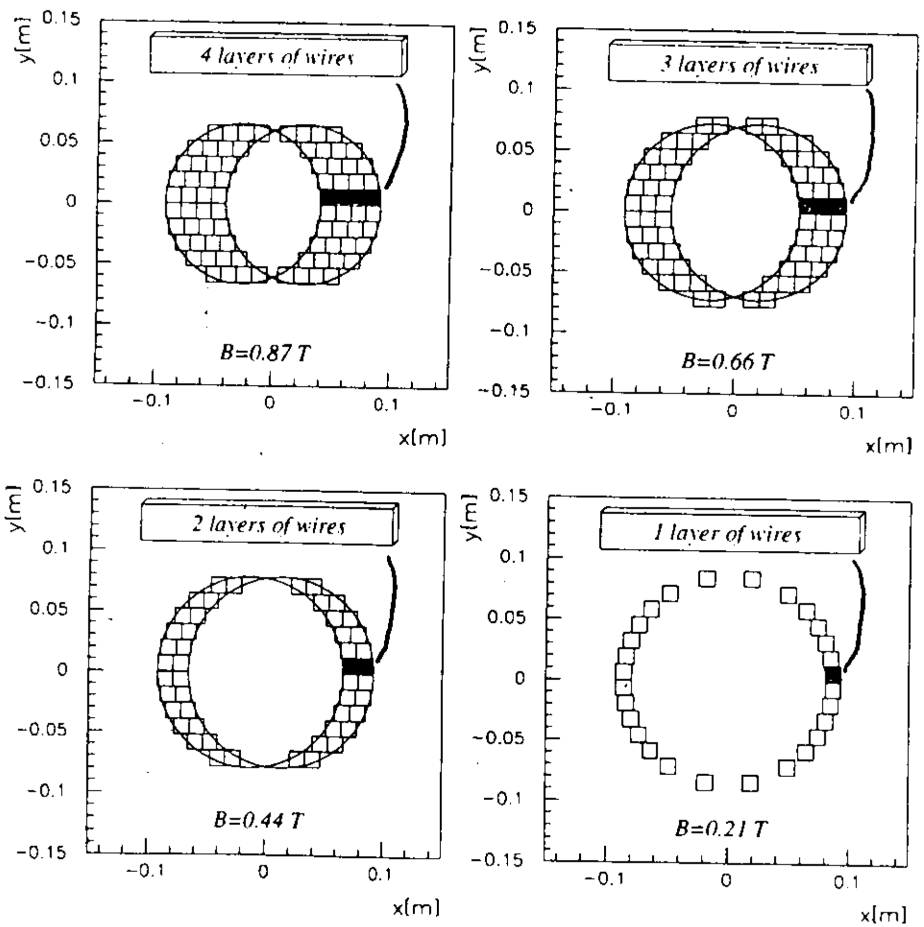
The compensation of the transversal field

wire size: 13 × 13 mm (preliminary)
current: 4500 A

$B = \sum_{wires} B_i$

Field of a long wire.





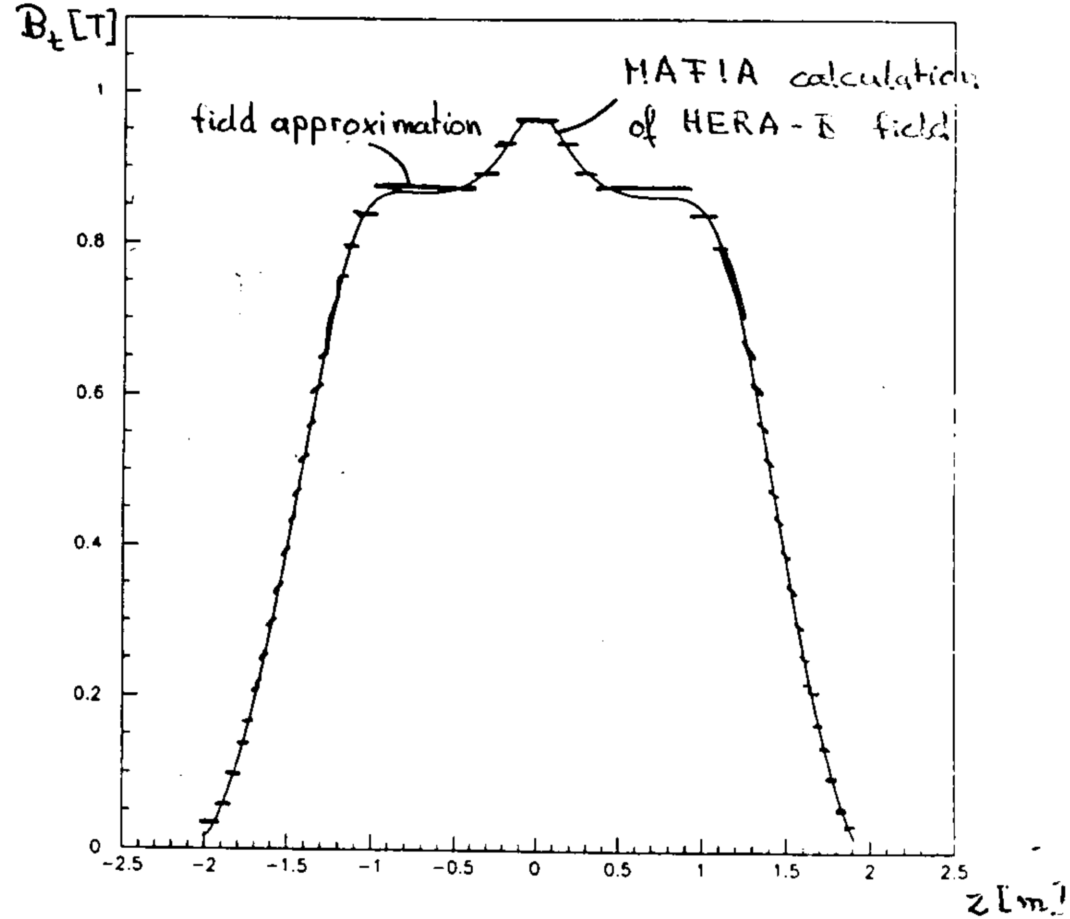
Design goal: B < 0.03 T in the beam region

↳ When closing a winding: No steps > 0.06 T

→ $r_{wire} > r_{min}$

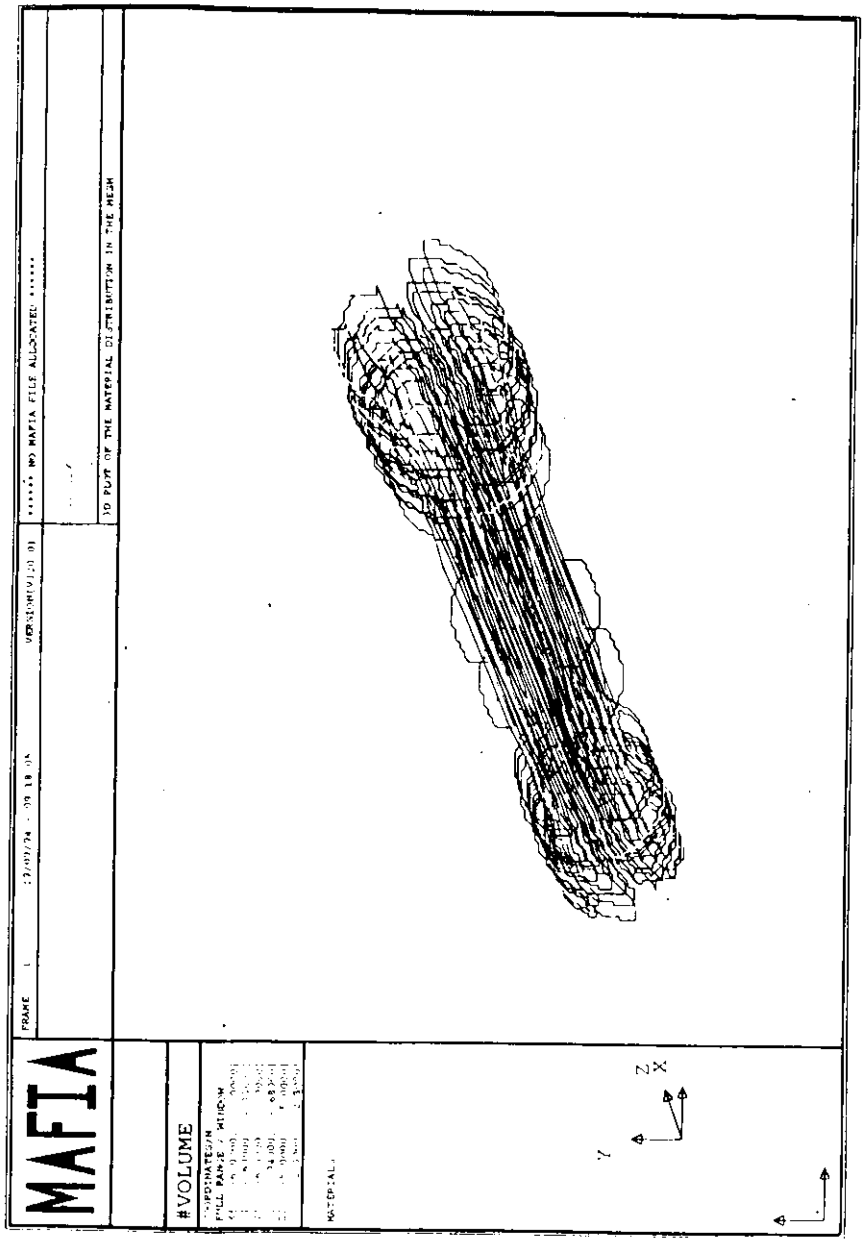
1. Approximation of the transversal field

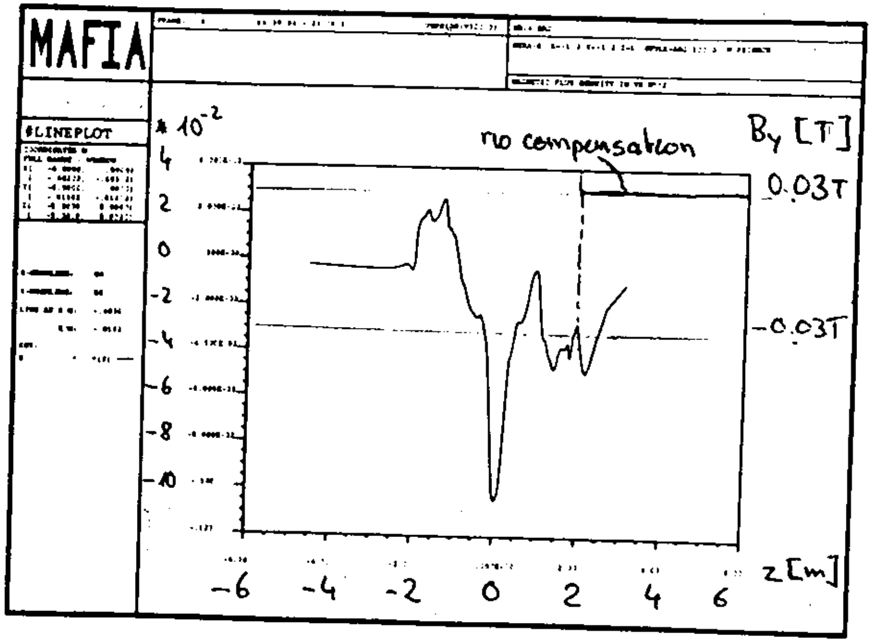
- take a twisted coil: ~ 0° - 35°
  to compensate the small B_x

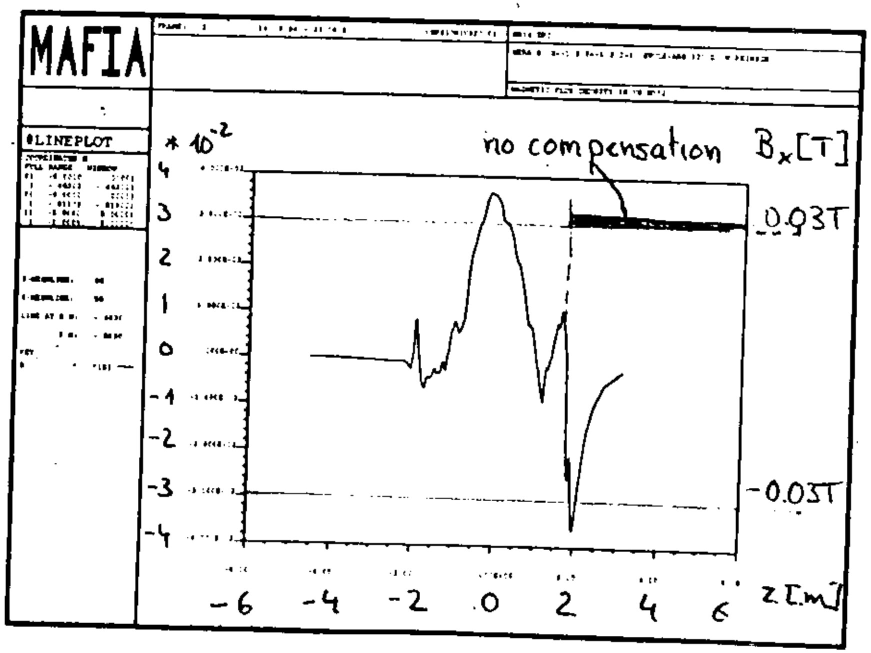


- In reality: The steps are reduced due to the finite length of the wires

Residual field after 1. Approximation







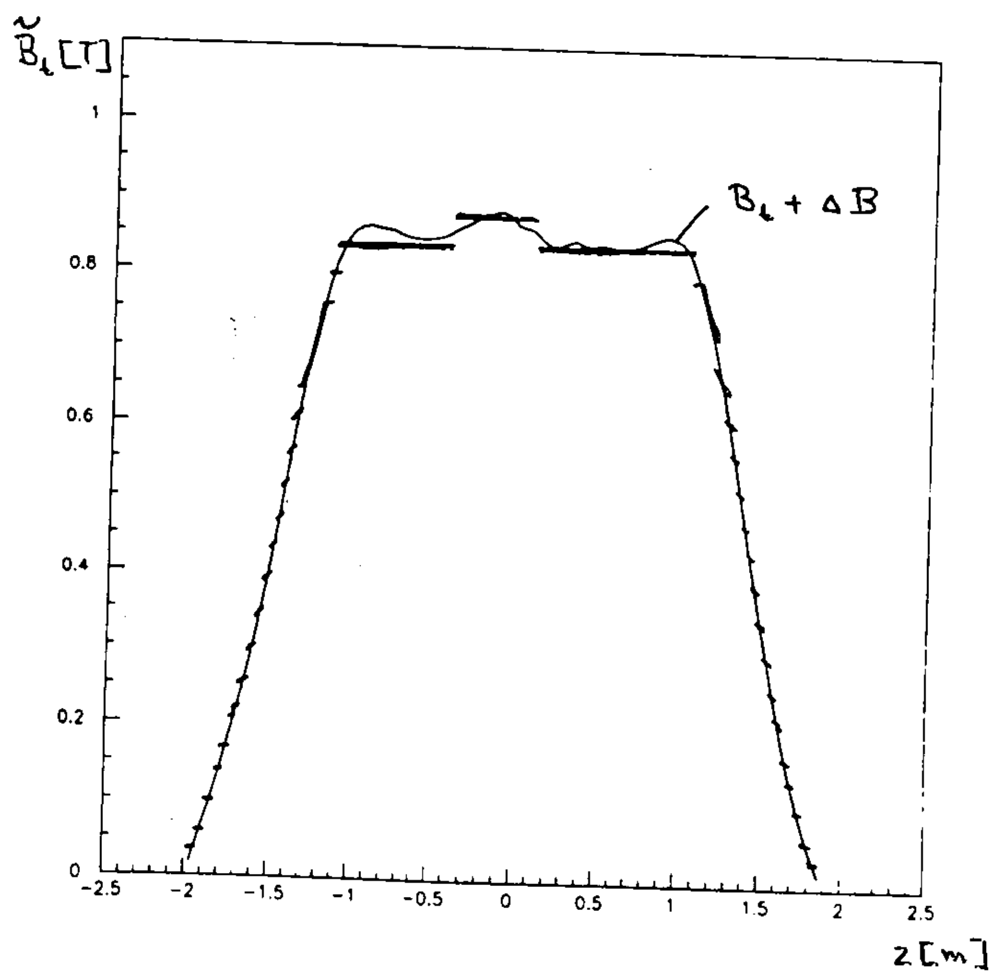
8

8

2. Approximation of the transversal field

- new field input:
  add the residual field to the original field
- add a coil with two windings between $1.85 < z < 2.$

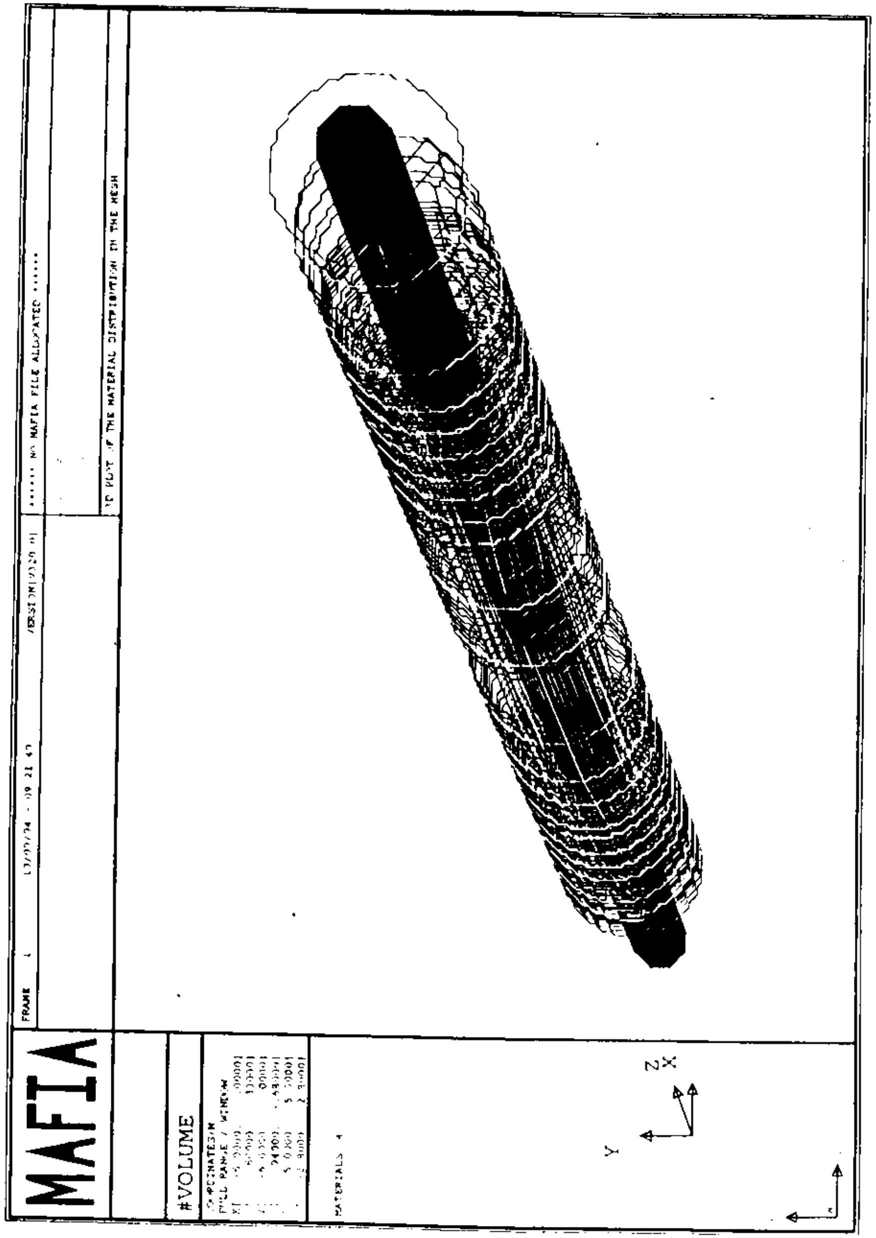
94/09/19 09.03



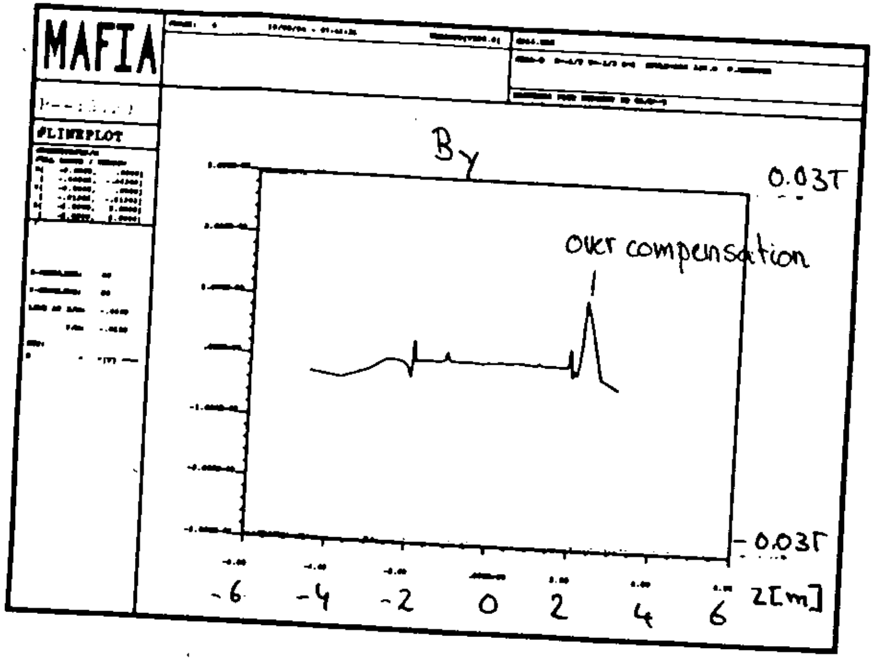
- add an inner iron tube:

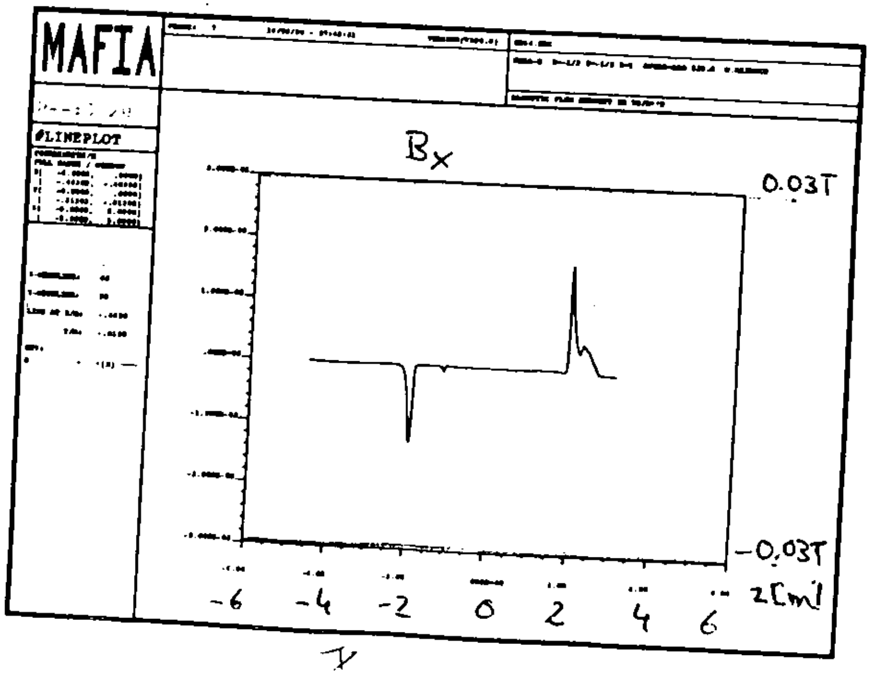
thickness $\begin{cases} 1\,cm & 1.8 < |z| < 2.4 \\ 0.5\,cm & else \end{cases}$

Compensation of the longitudinal field:
add outer solonoid + inner solonoid I = 4500 A

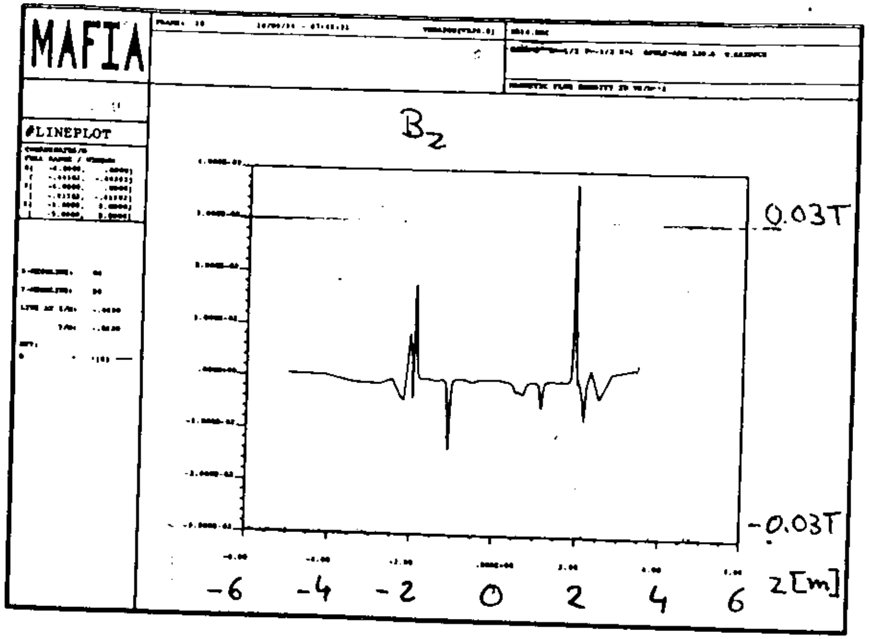


Residual field after 2. Approximation





Residual field after 2. Approximation



- influence on the electron polarisation:

  spin rotation < 6 mrad is nearly acceptable

- result of a bug search:

  There is no iron shielding, where the electron beam crosses the flux wall (|z| ~ 2m)

Outlook

- e^- compensation
  - some optimisation work necessary (already started)
    - choose industrial available wire sizes
    - minimisation of the cross section
  - forces on the wires
- p compensation ✓
- time table: magnet + compensation coil
  - order: end of october
    delivery: one year later
    set up: winter shutdown 95/96

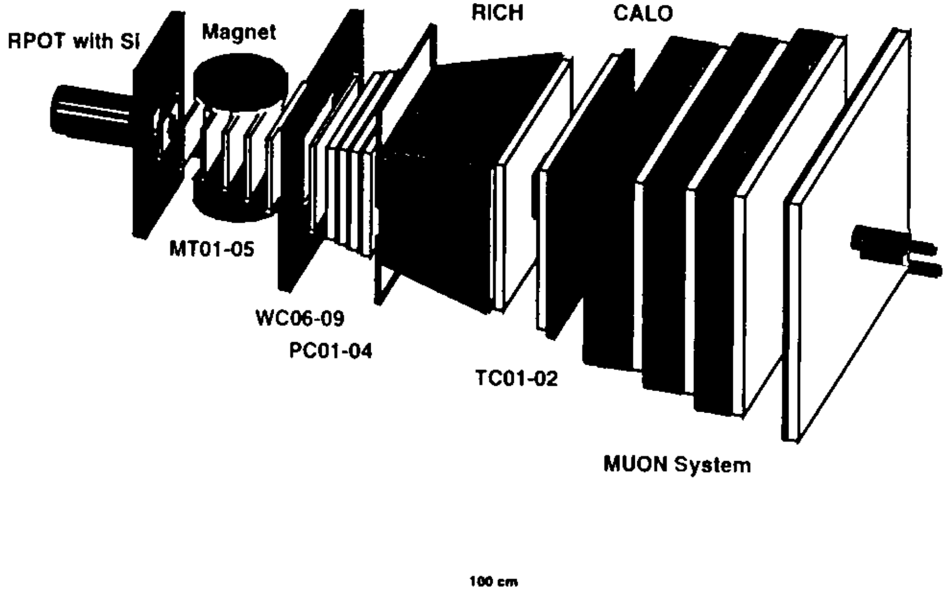
DETECTOR CHALLENGES FOR HERA-B

REQUESTS TO THE DETECTOR FROM GEANT STUDIES

S. NOWAK
DESY-IFH ZEUTHEN

HAMBURG, OCTOBER 94

HERA-B



MAIN EXPERIMENTAL CHALLENGES

- Interaction rates of more then 30 MHz: multiple interactions/bunch crossing
- High effiency and large Background rejection
- Capability to reconstruct B decays, especially

$$B^0\ \bar{B}^0 \rightarrow J/\psi\ K^0_S\ \text{tag}\ X$$

$J/\psi \rightarrow \mu^+\mu^-$ or e^+e^-; $K^0_S \rightarrow \pi^+\pi^-$; tag: $K^\pm$ or $\ell^\pm$

$\Longrightarrow$

- multiplicities and secondary interactions
- radiation thickness of the detector
- occupancies

HBGEAN

MAIN EXPERIMENTAL CHALLENGES

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$\Longrightarrow$

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- radiation thickness of the detector
- occupancies

HBGEAN

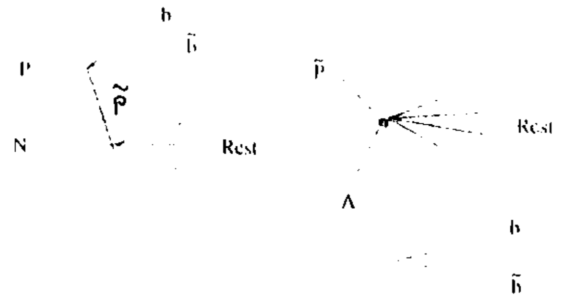
EVENT GENERATORS (LUND)

PYTHIA

heavy quark production
in p-nucleon
interactions

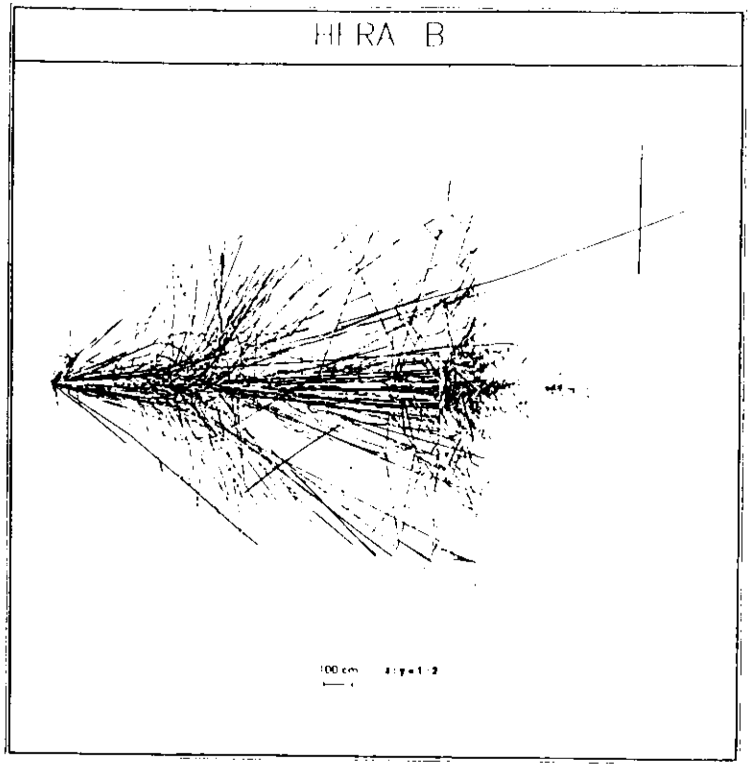
FRITIOF

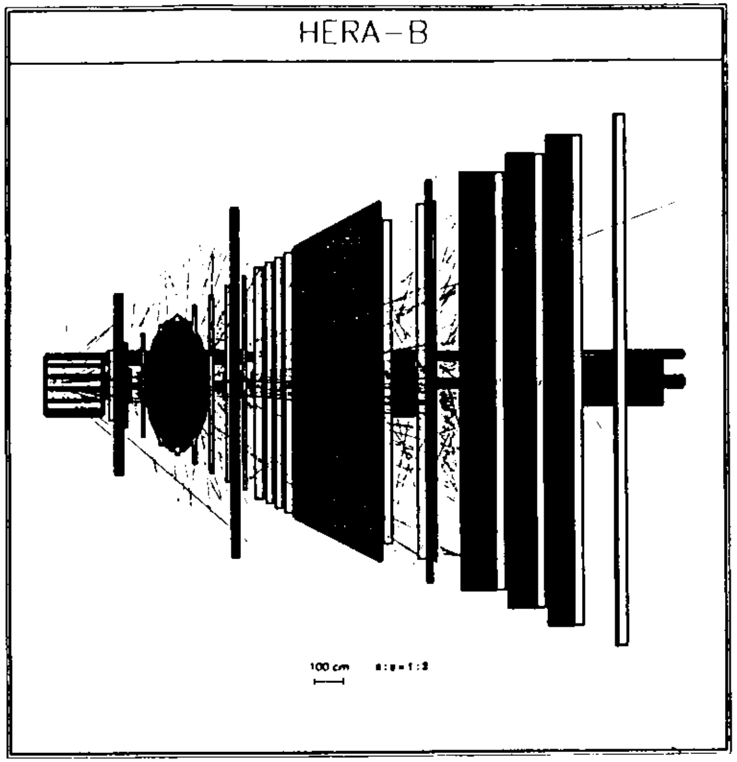
p-nucleus interactions
with light quarks
only

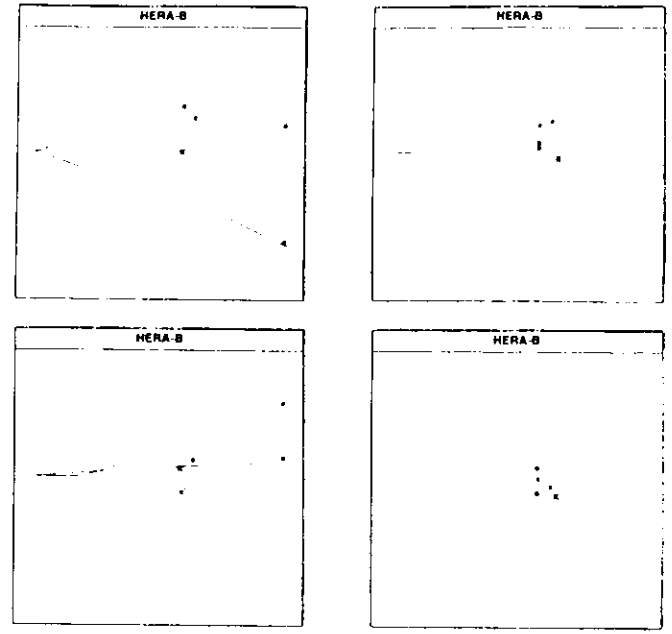


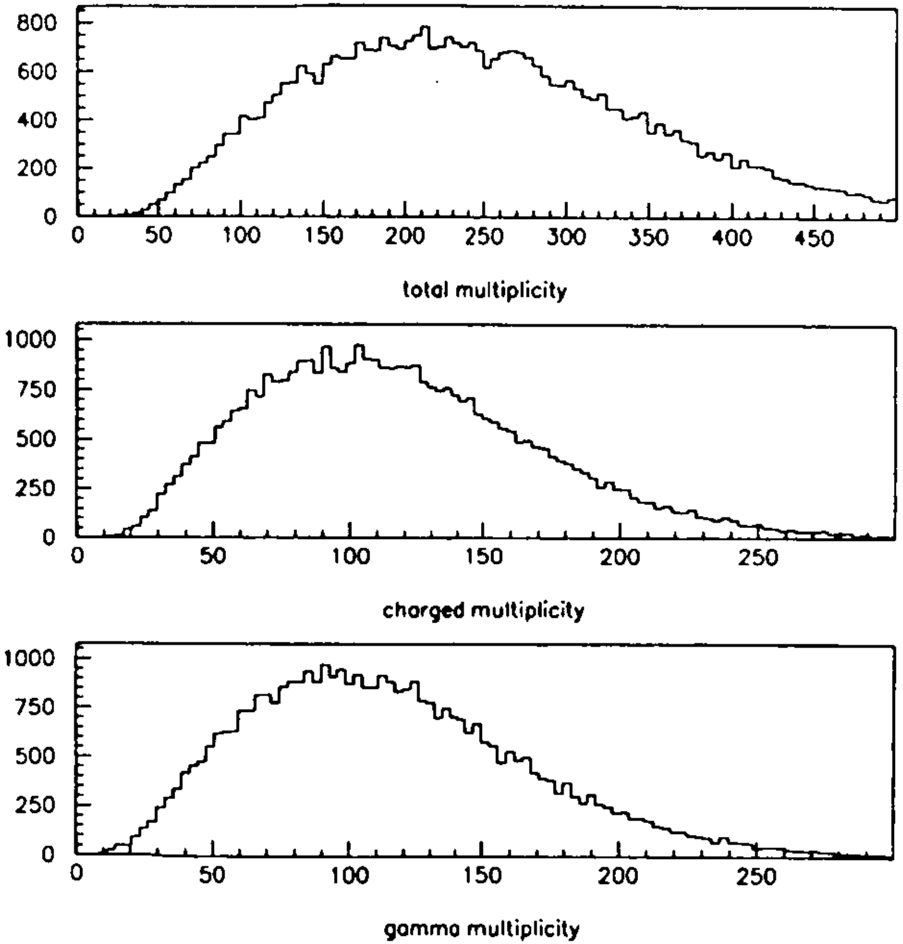
Minimum bias

TAKE one $b\bar{b}$ event	(Poisson distr.)
+	four minimum bias (Poisson distr.)
=	one Superevent / bunch crossing



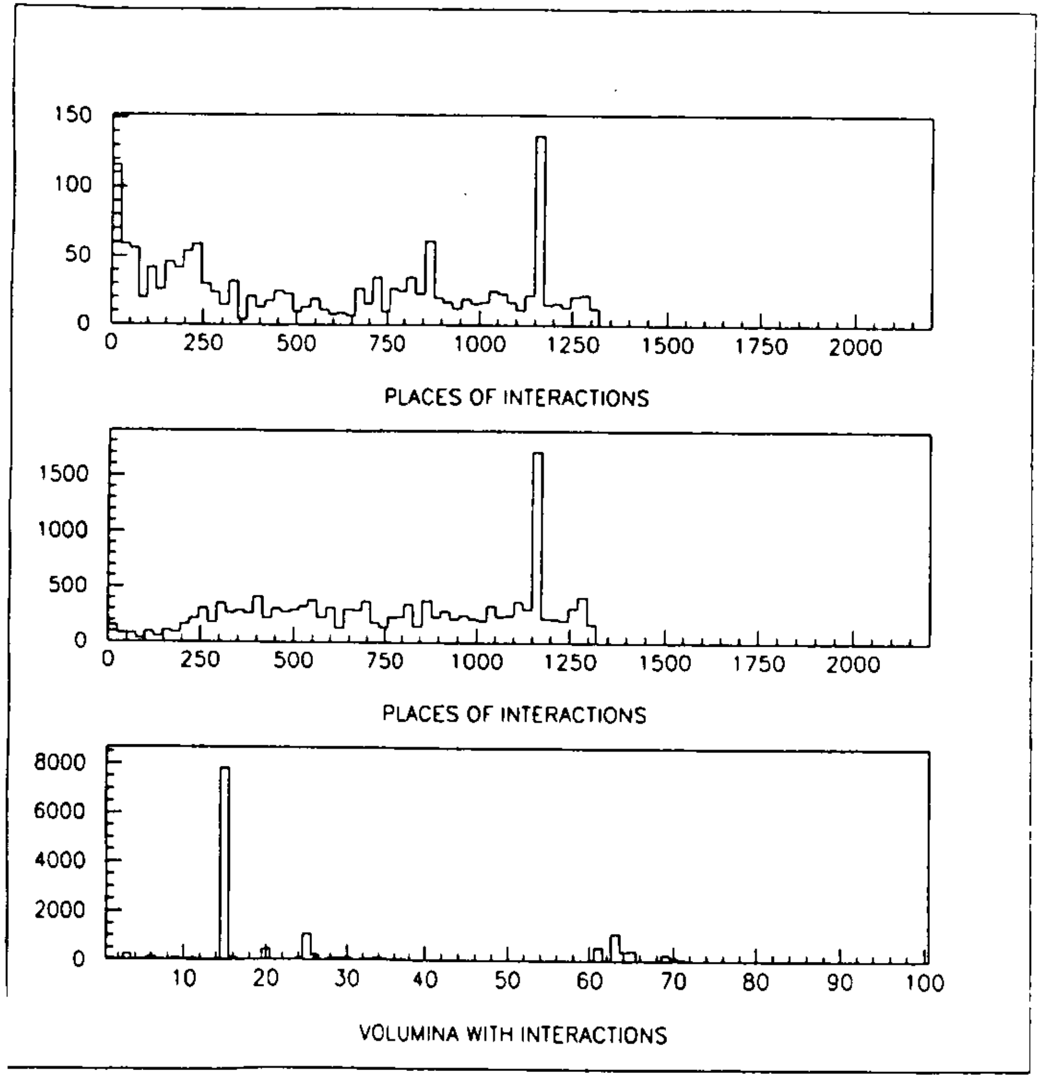

HERA-B
100 cm

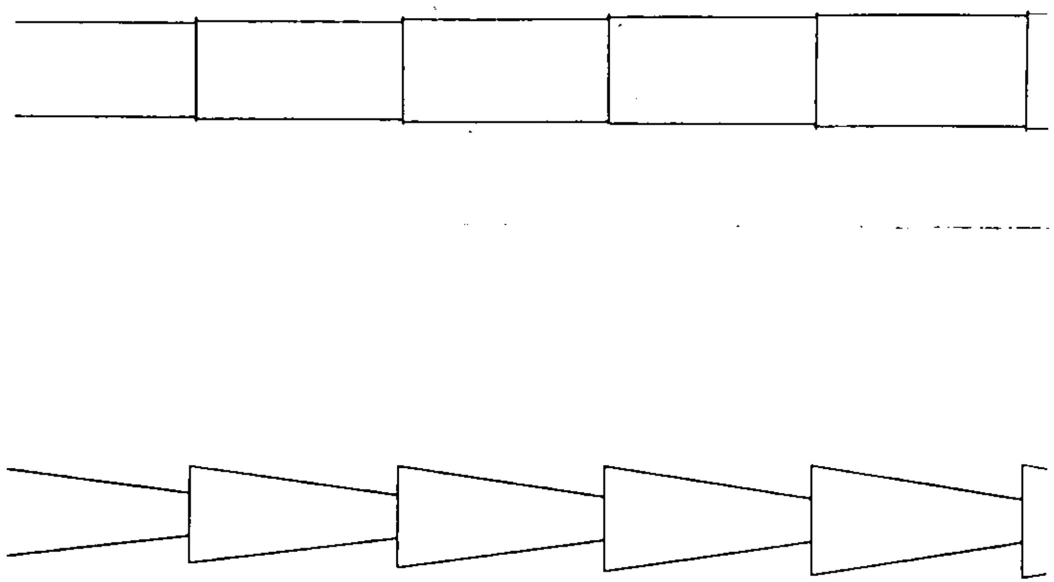

HERA-B
HERA-B
HERA-B
HERA-B



Mean multiplicities for long lived particles ($\tau > 10^{-12}$ sec):

at vertex		secondaries ($e^+/e^-, \gamma$ p > 10 MeV) (nucleons p > 50 MeV)	
total	250	total	725
charged	118	gammas	400
neutral	131	e^+/e^-	290
baryons	25	charged mesons	22
photons	116	protons	7
		neutron / deuterons...	7


150
100
50
0
0
250
500
750
1000
1250
1500
1750
2000
PLACES OF INTERACTIONS
1500
1000
500
0
0
250
500
750
1000
1250
1500
1750
2000
PLACES OF INTERACTIONS
8000
6000
4000
2000
0
10
20
30
40
50
60
70
80
90
100
VOLUMINA WITH INTERACTIONS



K -11-

K -12-

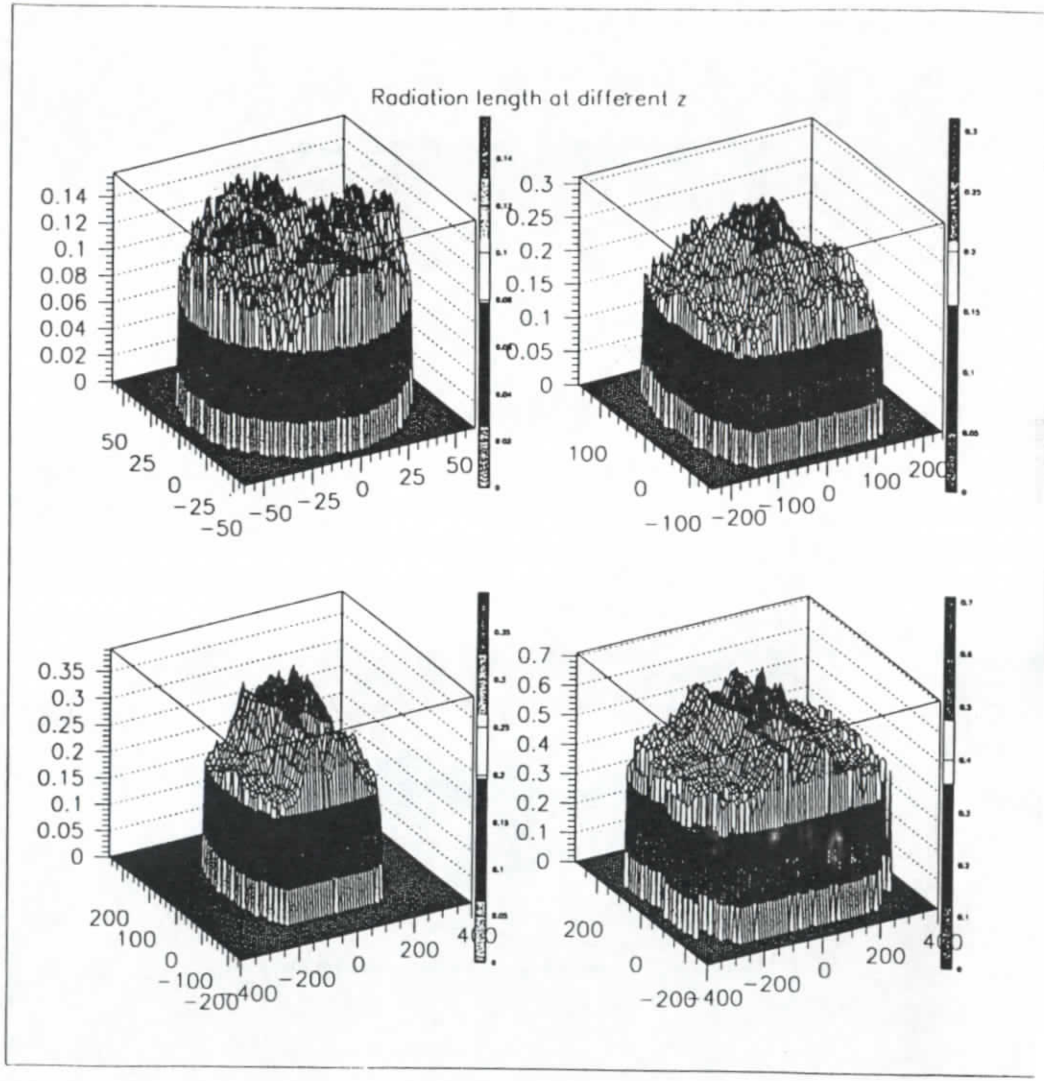
Radiation and hadronic absorption thickness

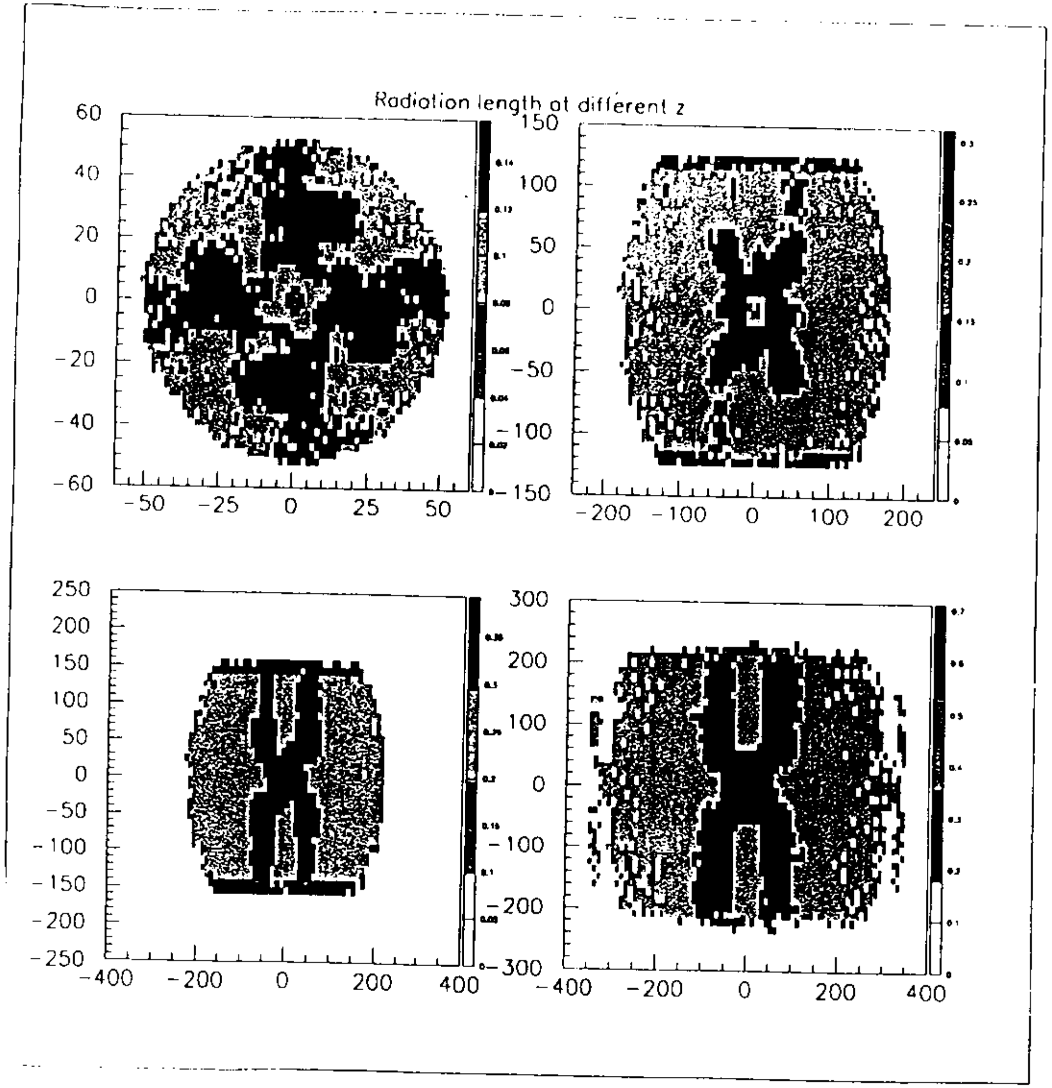
- take event tracks
- switch off magnetic field
- switch off any physical process in tracing
- add up the radiation / absorption length up to a plane at definite z and plot it as function (x, y)

Planes at definite z

z = 200 cm		entrance into the magnet
z = 700 cm		exit from magnet
z = 860 cm		entrance into RICH
z =1315 cm		entrance into CALORIMETER

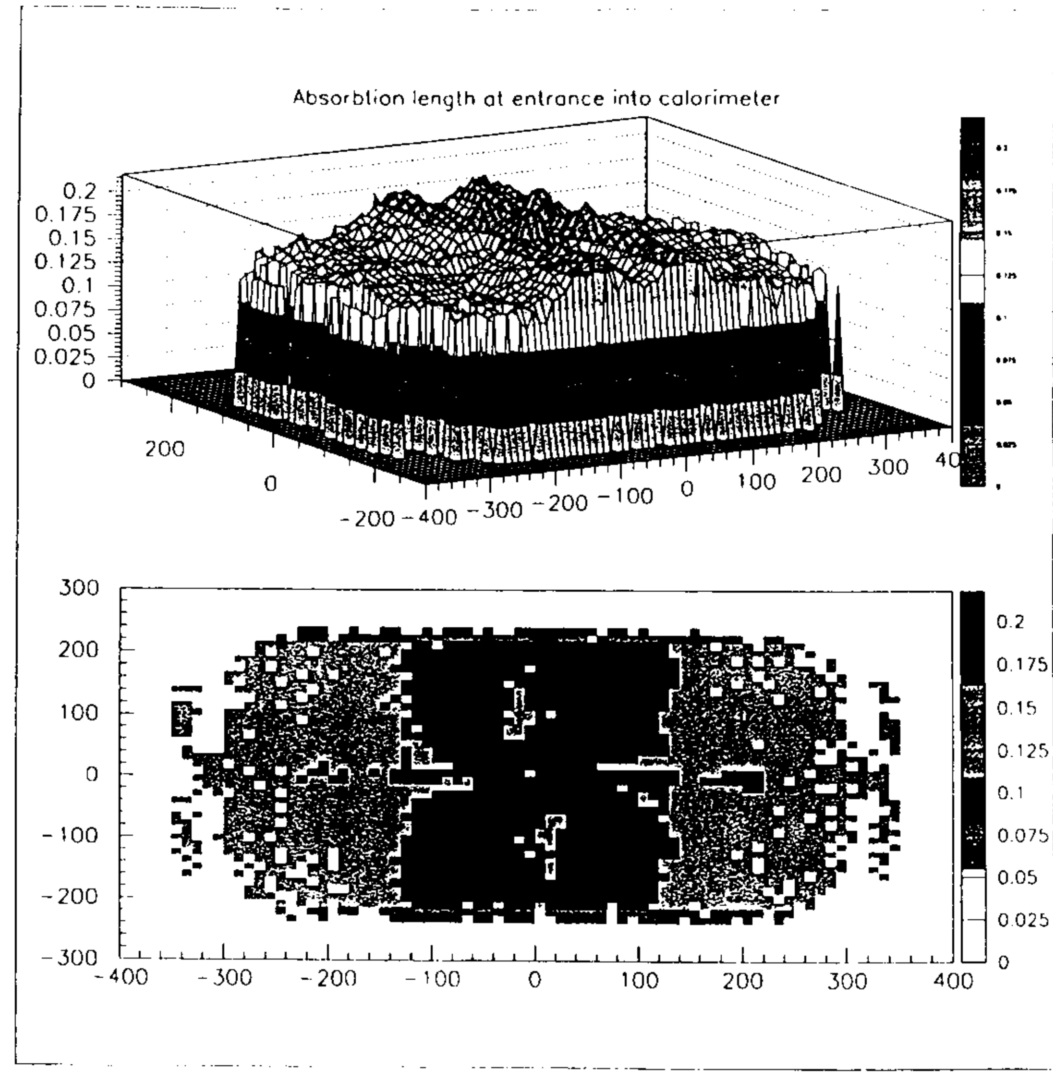
Mean values in %	Radiation length	absorption length
z = 200 cm	0.12	
z = 700 cm	0.20	
z = 860 cm	0.25	
z = 1315 cm	0.47	0.16





Radiation length at different z

K - 15 -



Absorbtion length at entrance into calorimeter

K - 16 -

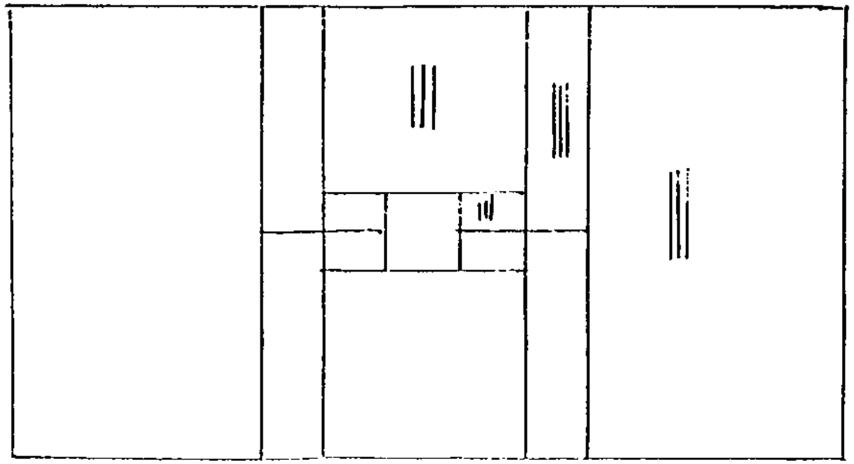
OCCUPANCIES:

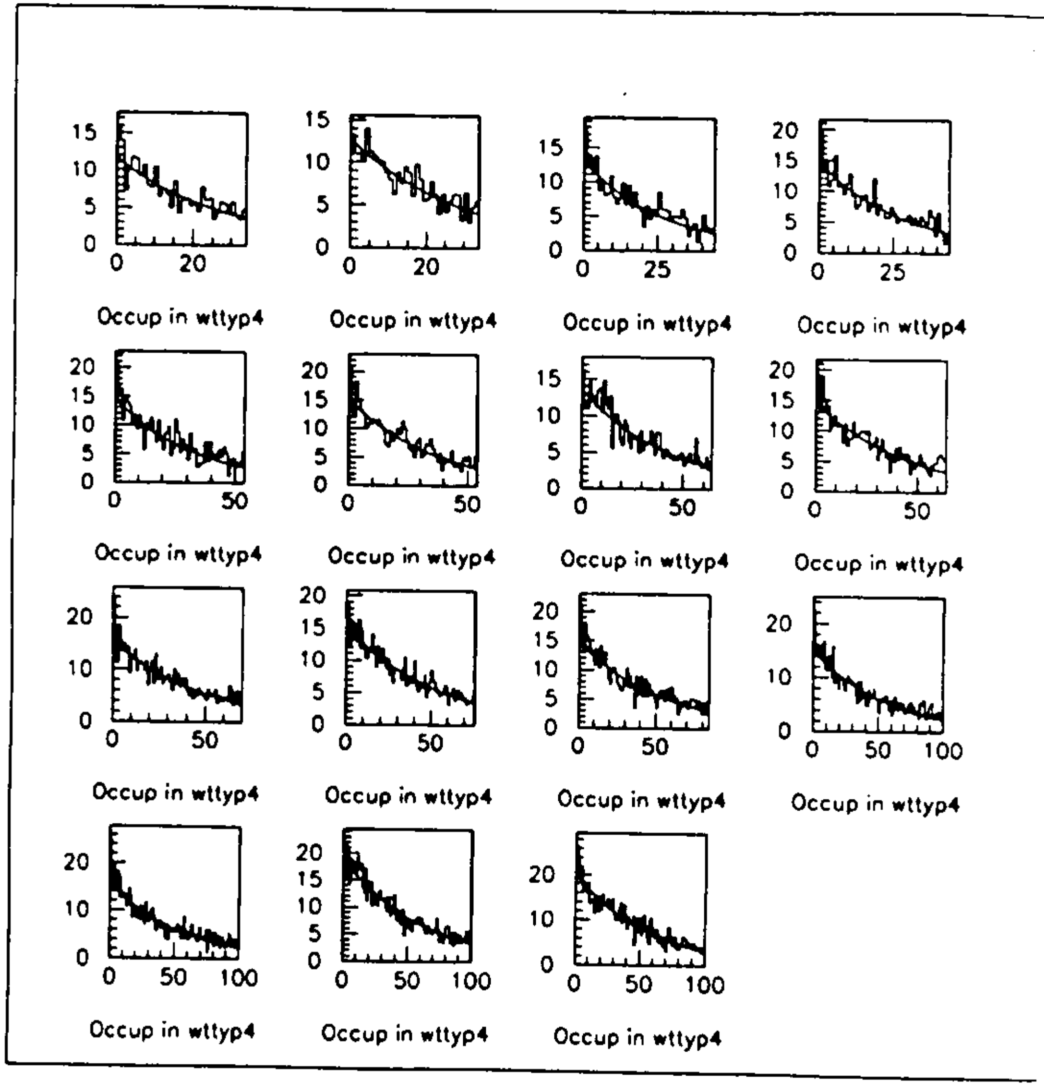
Occupancy = number of hits / channel

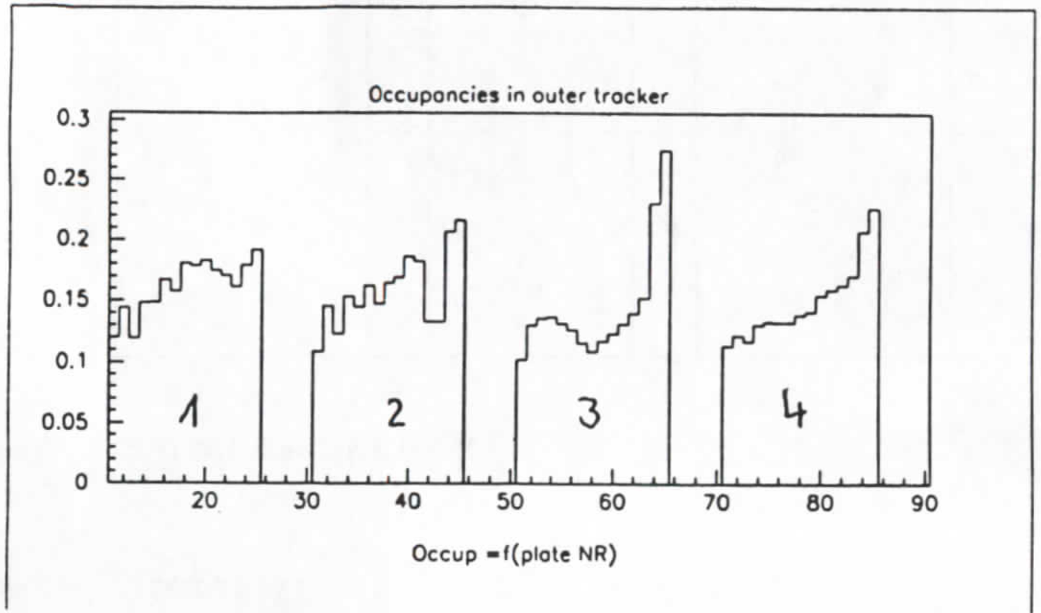
ie | drift cell
| MSGC - strip
| silicium strip

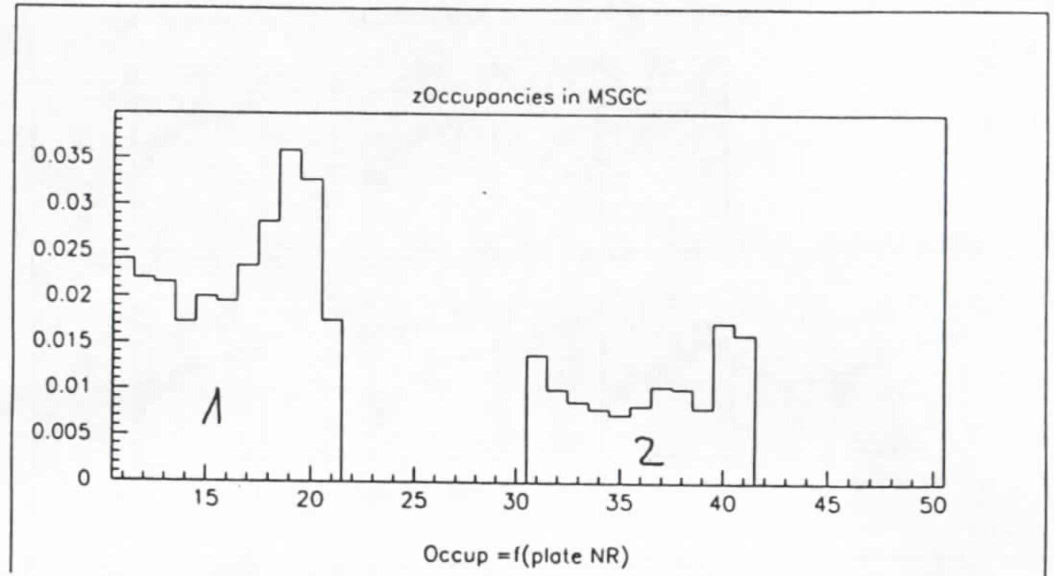
indirect measure for reconstruction capability - no definite relation

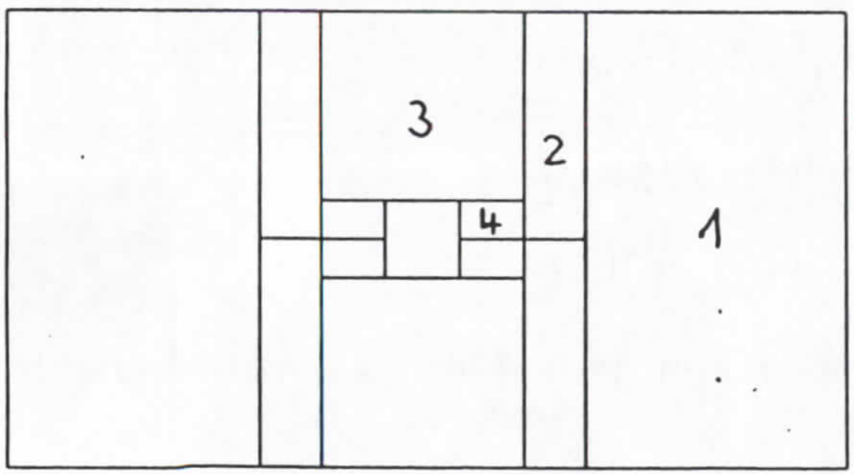
Outer tracker



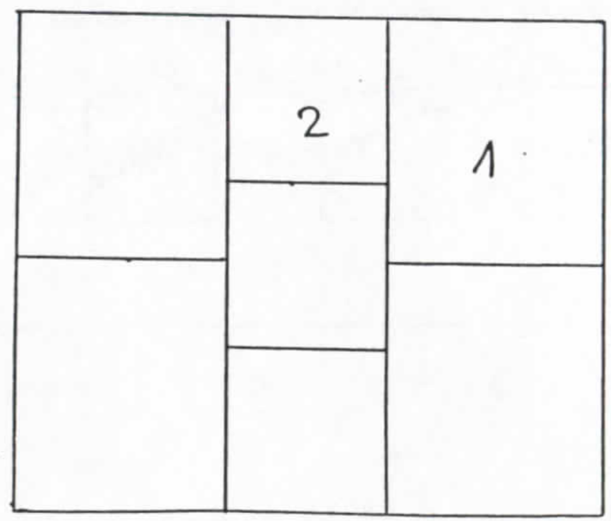



Occupancies in outer tracker
0.3
0.25
0.2
0.15
0.1
0.05
0
20 30 40 50 60 70 80 90
1
2
3
4
Occup =f(plate NR)

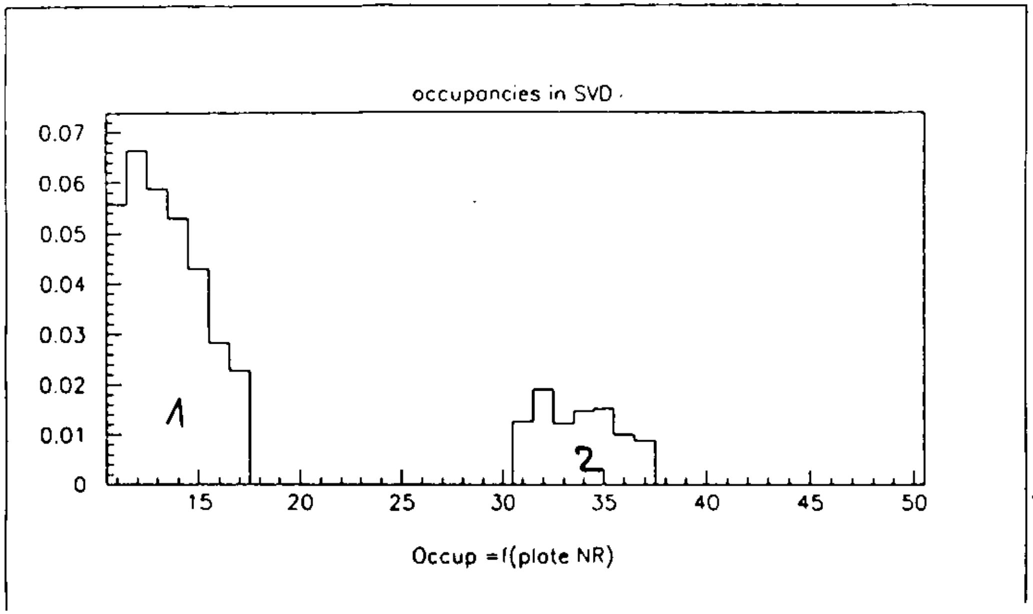

zOccupancies in MSGC
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
15 20 25 30 35 40 45 50
1
2
Occup =f(plate NR)

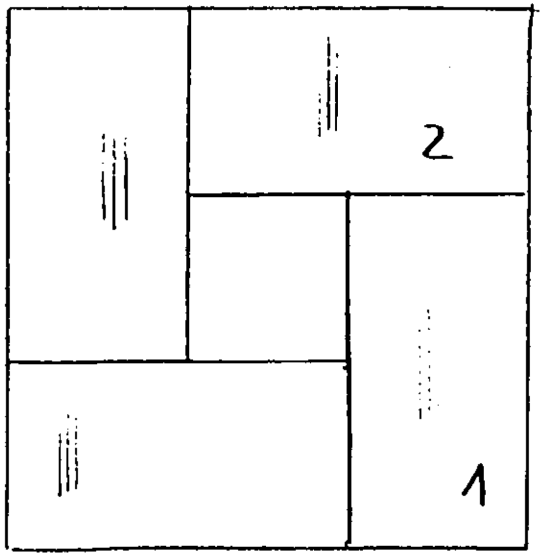

3
2
4
1

K – 19 –


2
1

K – 20 –



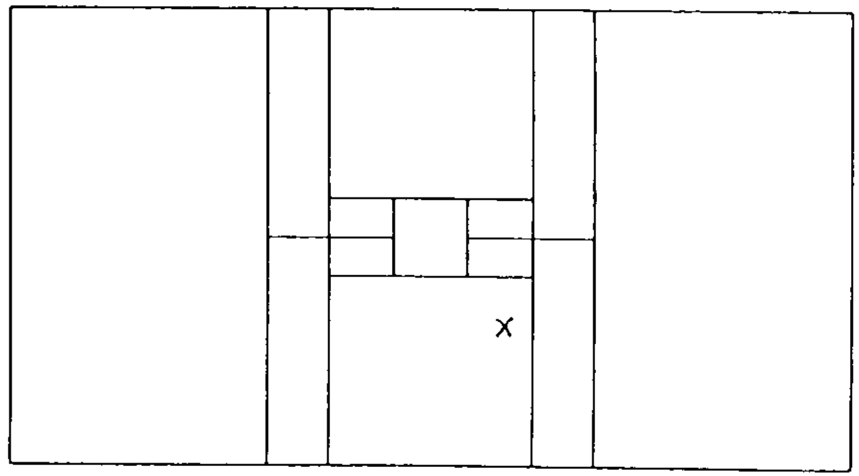


LEFT RIGHT ASYMMETRIES OF THE DETECTOR

AVOID (if possible) any left right asymmetry

Example: Electron beam pipe

x = 45.8 cm
y = -81 cm

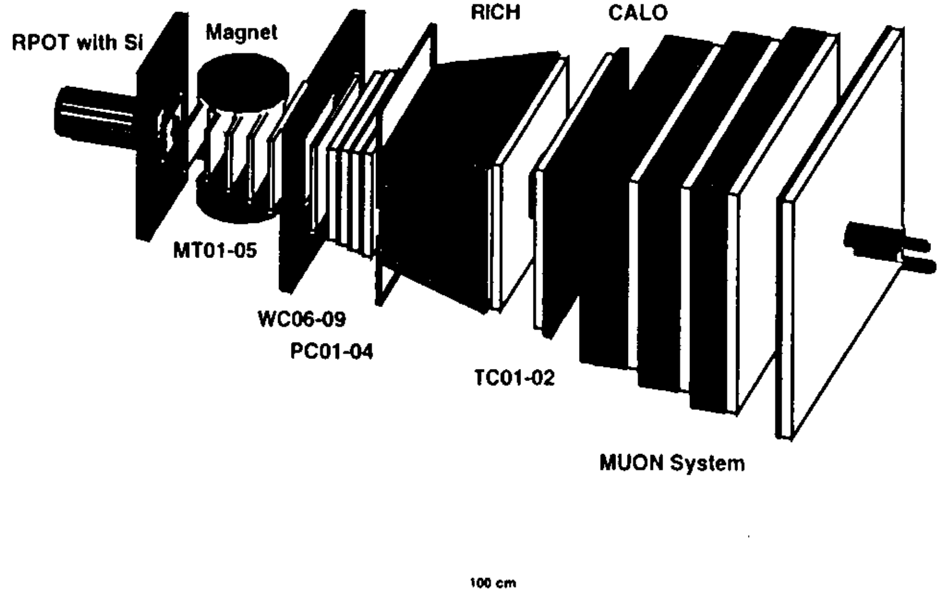


40 000 events $B\bar{B} \to J/\psi\ K^0_s$ + tag + X

For R = 9 cm:

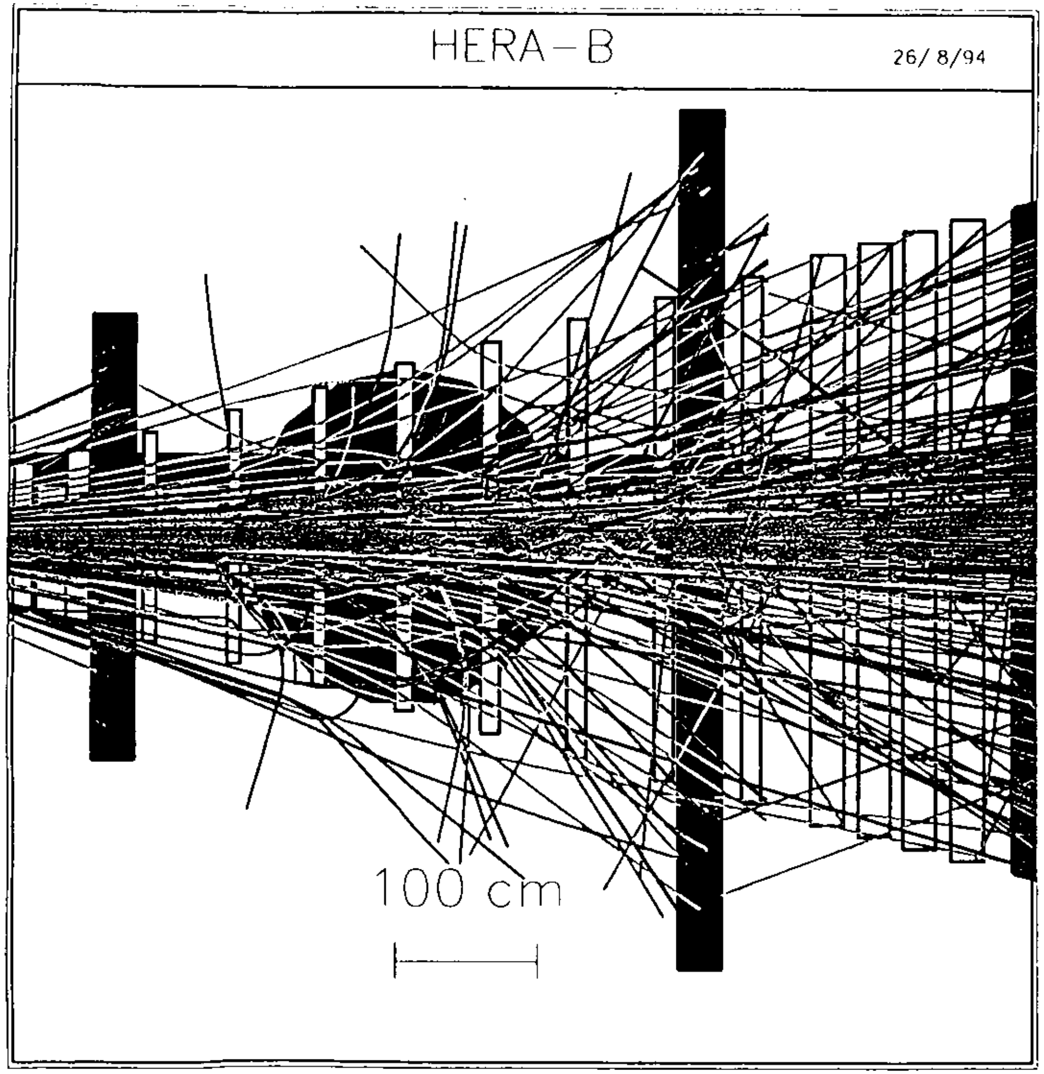
	N_{TOT} of particles	lost	percentage
L^+ from $J\Psi$	36212	282	0.78
L^- " "	36111	591	1.64
π^+ from K_s^0	25190	121 (94)	0.48 (0.37)
π^- " "	25190	335 (253)	1.32 (1.00)
K^+ tags	8249	10 (9)	0.12 (0.11)
K^- tags	7902	39 (29)	0.49 (0.37)
e^+ tags	728	4	0.54
e^- tags	813	7	0.86
μ^+ tags	779	11	1.41
μ^- tags	753	11	1.46

HERA-B



Conclusion:

You will find them in the talks about performance of the detector

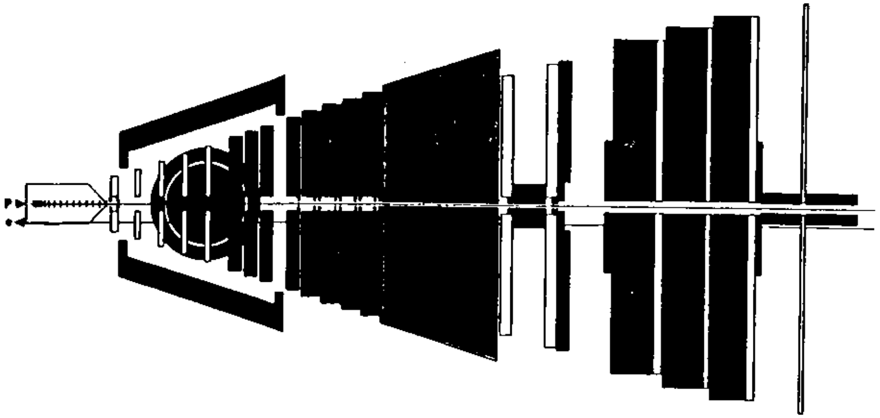


don't worry

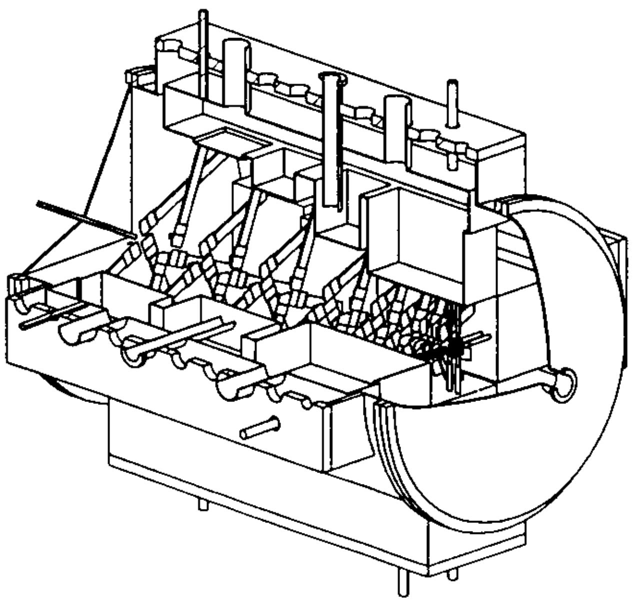
K -27-

K -28-

K.T.Knöpfle - DESY - 4/10/94
MPI Kernphysik Heidelberg
ktkno@enull.mpi-hd.mpg.de



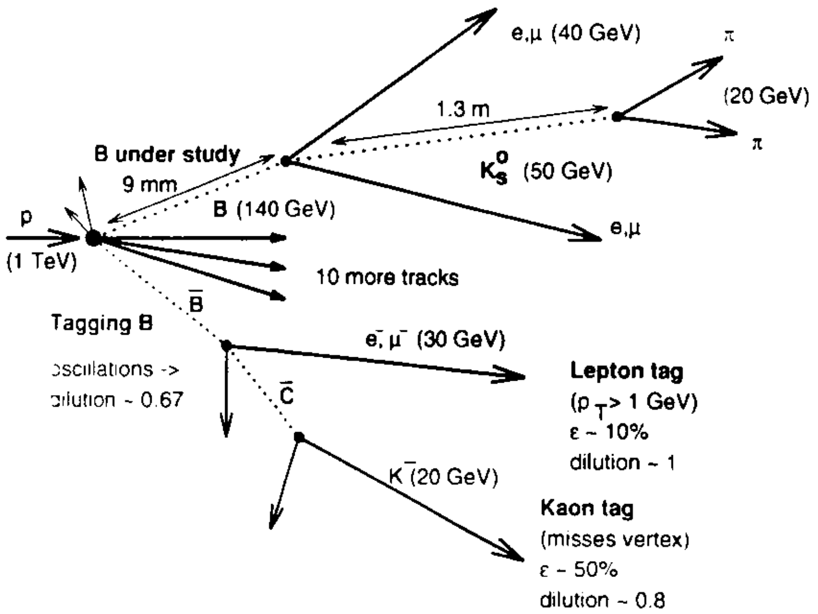
The HERA-*B* Vertex Detector System



Outline

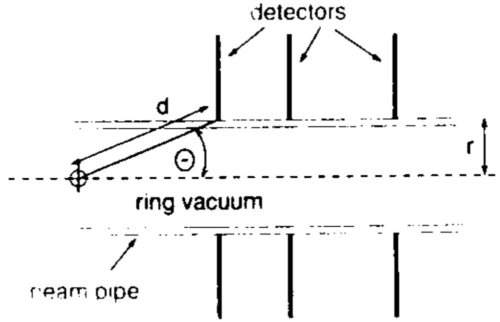
- Introduction
- Geometrical Layout
- Radiation Damage
- Readout Electronics
- Technical Realization
- Concluding Remarks

Purpose of Vertex Detector System



- Reconstruct $J/\Psi \rightarrow \ell^+\ell^-$ vertex (0.7 mm)
- Reconstruct impact parameters of all tagging particles (20-30 μm)
- Separate primary vertices of multiple overlaying events
- Reject backgrounds from charm and minimum bias events

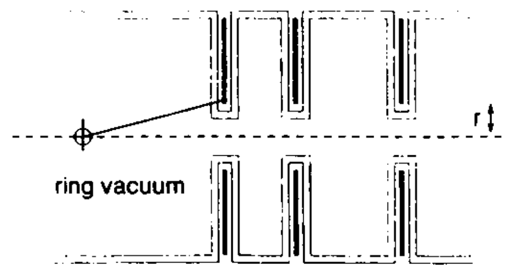
Conventional vs 'Folded' Beam Pipe



$$\sigma_{MS} = \theta_{MS} \cdot d = \frac{14\ MeV/c}{p_t}\sqrt{\frac{X}{X_0}} \cdot R_\perp \qquad p_t = p \cdot \sin\theta$$

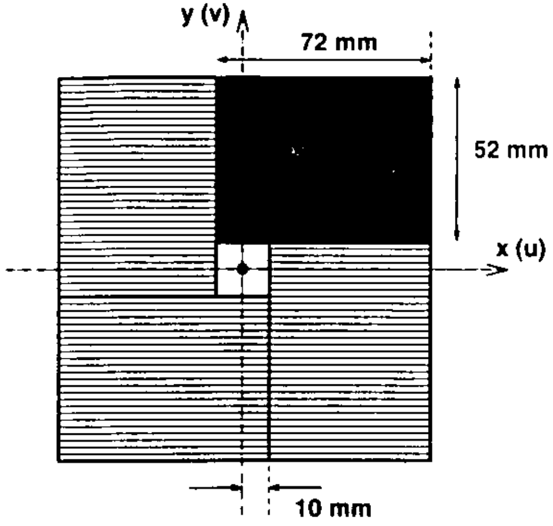
$$\sigma^2 = (\frac{14\ MeV/c}{p_t}\sqrt{\frac{X}{X_0 \cdot \sin\theta}} \cdot R_\perp)^2 + \sigma_{det}^2.$$

(1 GeV, 10 mrad; Be beam pipe, 350 μm thick, 1.5 cm radius → 66 μm)



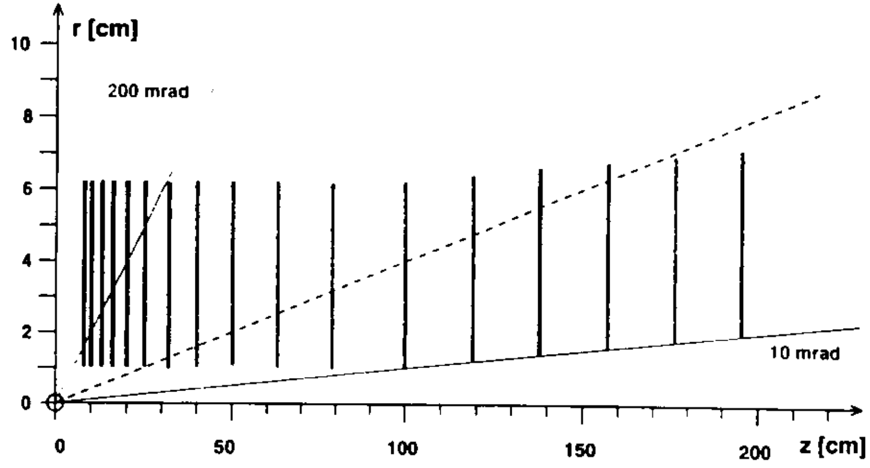
r ≈ 1cm

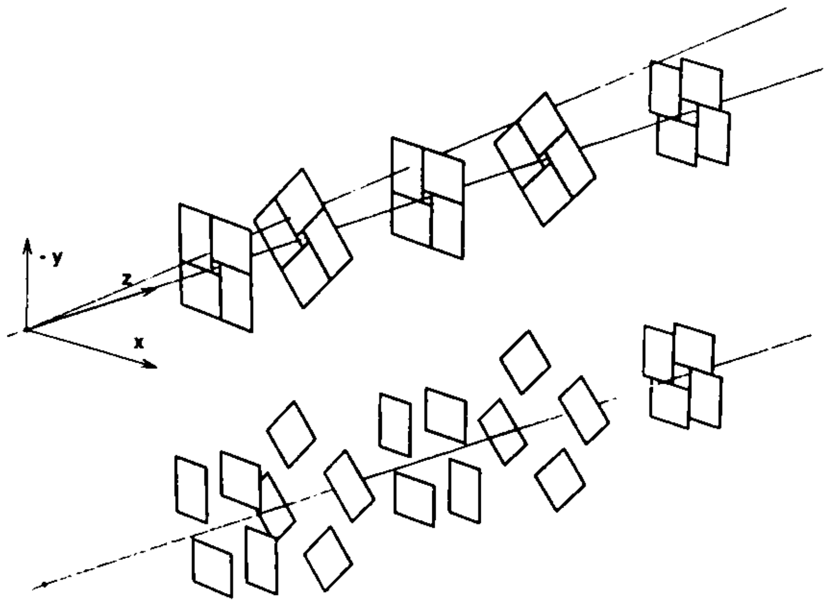
Baseline Design



- 17 planes between 8 cm and 2 m from target
- 10 to 200 mrad of polar angle coverage
- Constant inner and outer radii of 1 cm and 6.2 cm, respectively, up to the distance of 1 m from target; beyond, inner radii increase in accordance with 10 mrad wedge.
- Alternating stereo angles of either (0°,90°) or (45°,135°)
- Each plane is built out of 4×2 single-sided silicon detectors each of which can be cut from a 4" wafer; strip pitch 25 μm, readout pitch 50 μm.

Views of Vertex Detector System





Lean Vertex Detector Designs

(evaluated* resp. generated by Jörg Rieling)

Designs (x-y = (0°, 90°), u-v = (45°, 135°)) :

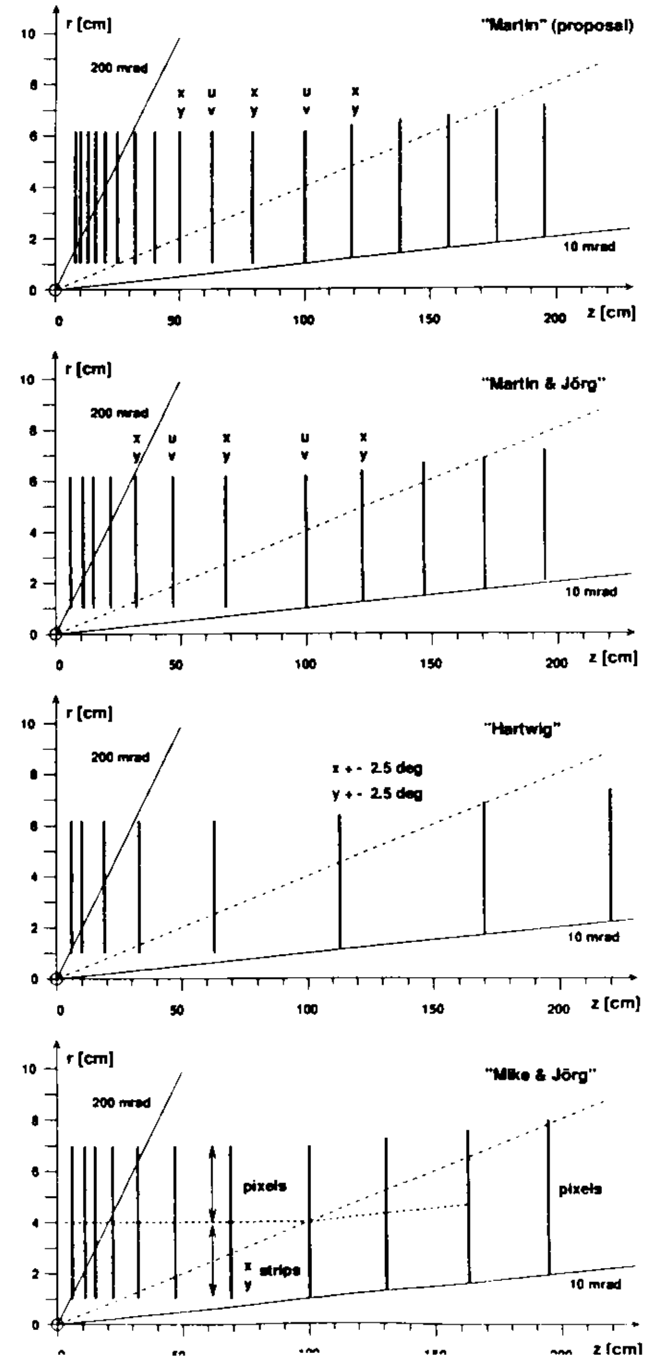
- 'Martin' (proposal) 17 SL : x-y & u-v views alternating
- 'Martin & Jörg' 12 SL : x-y & u-v views alternating
- 'Hartwig' 8 SL : x±2.5°, y±2.5°
- 'Mike' 15 SL* : x-y views & macro pixels
- 'Mike & Jörg' 10 SL* : x-y views & macro pixels
- 'M & H & J' 8 SL* : 2 x-y views & macro pixels

* plus one macro pixel plane

Many parameters evaluated – e.g. :

- radiation length
- impact parameter resolution
- number of hits per track
- azimuthal angle coverage
- ...
- ...
- ...
- wafer size

cap and mounting material included



Y-Detector Front View

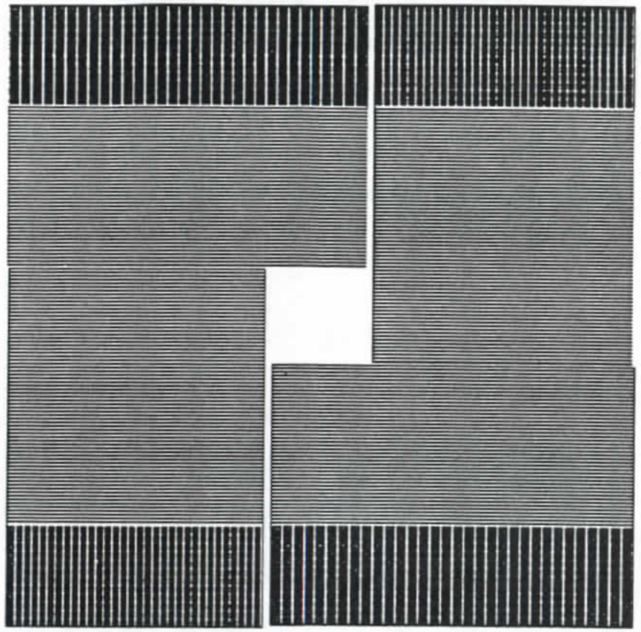


Figure 1: Front view of a y-view detector. The inner regions are covered with 50 micron strips. The outer ≈ 2 cm are covered with pads of area 3.6 mm^2 (2.6 mm^2) for the 72 mm (52 mm) detectors.

The last two planes are replaced by detectors containing only pads.

Geometry

For redundancy, the tracks should traverse at least two pads.

In the present 17-plane detector design, this can be accomplished if

- The outer ≈ 2.2 cm are covered with pads
- two planes, containing nothing but pads are added for the low-angle tracks.

This still leaves at least 5 microstrip measurements per view, and 7 (except in the outside corners) in an orthogonal view.

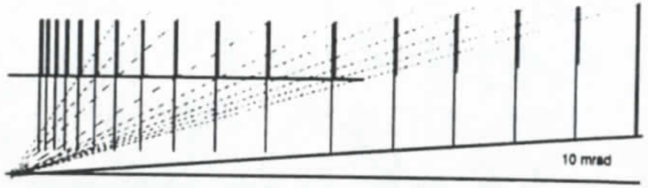
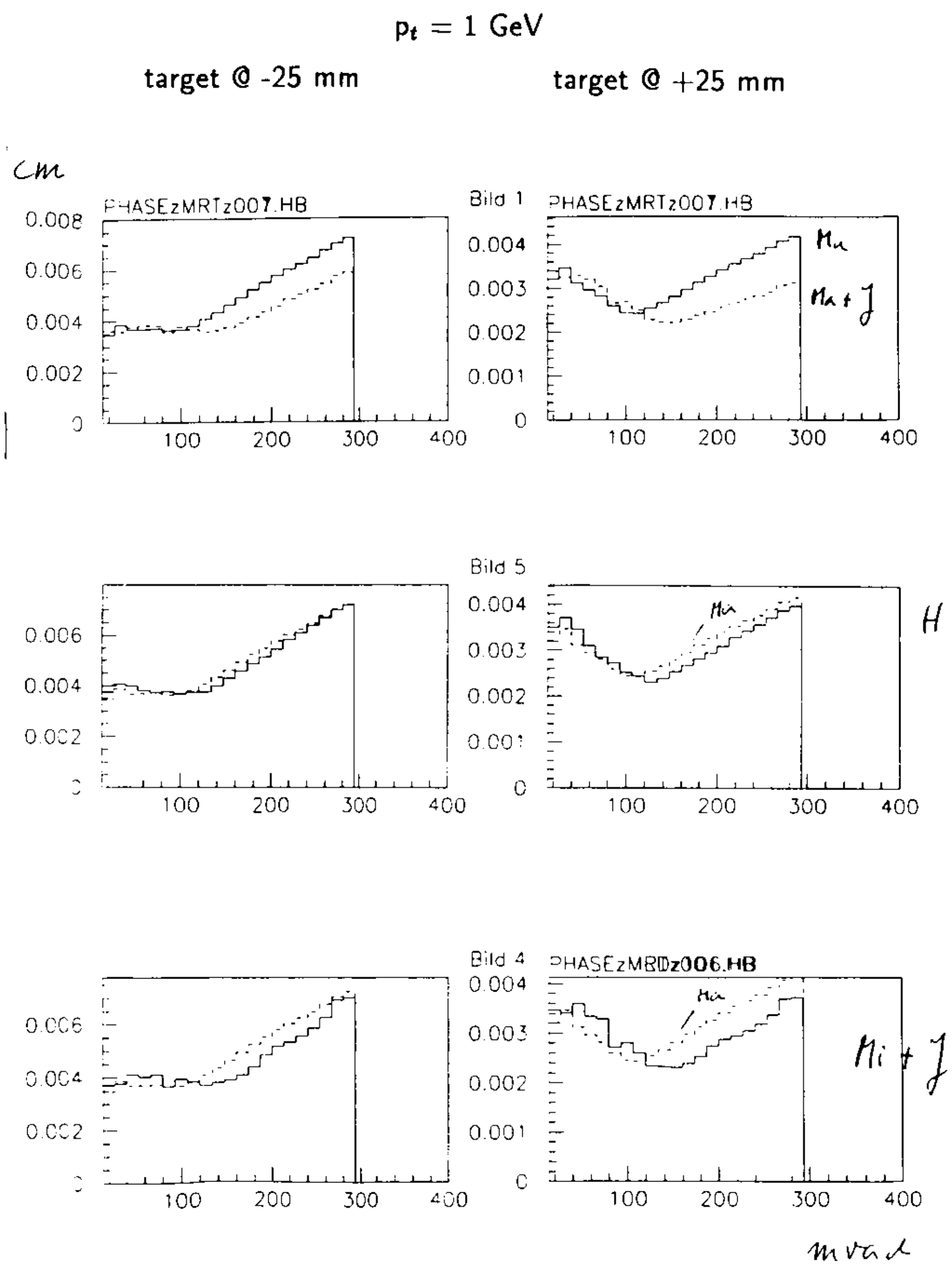
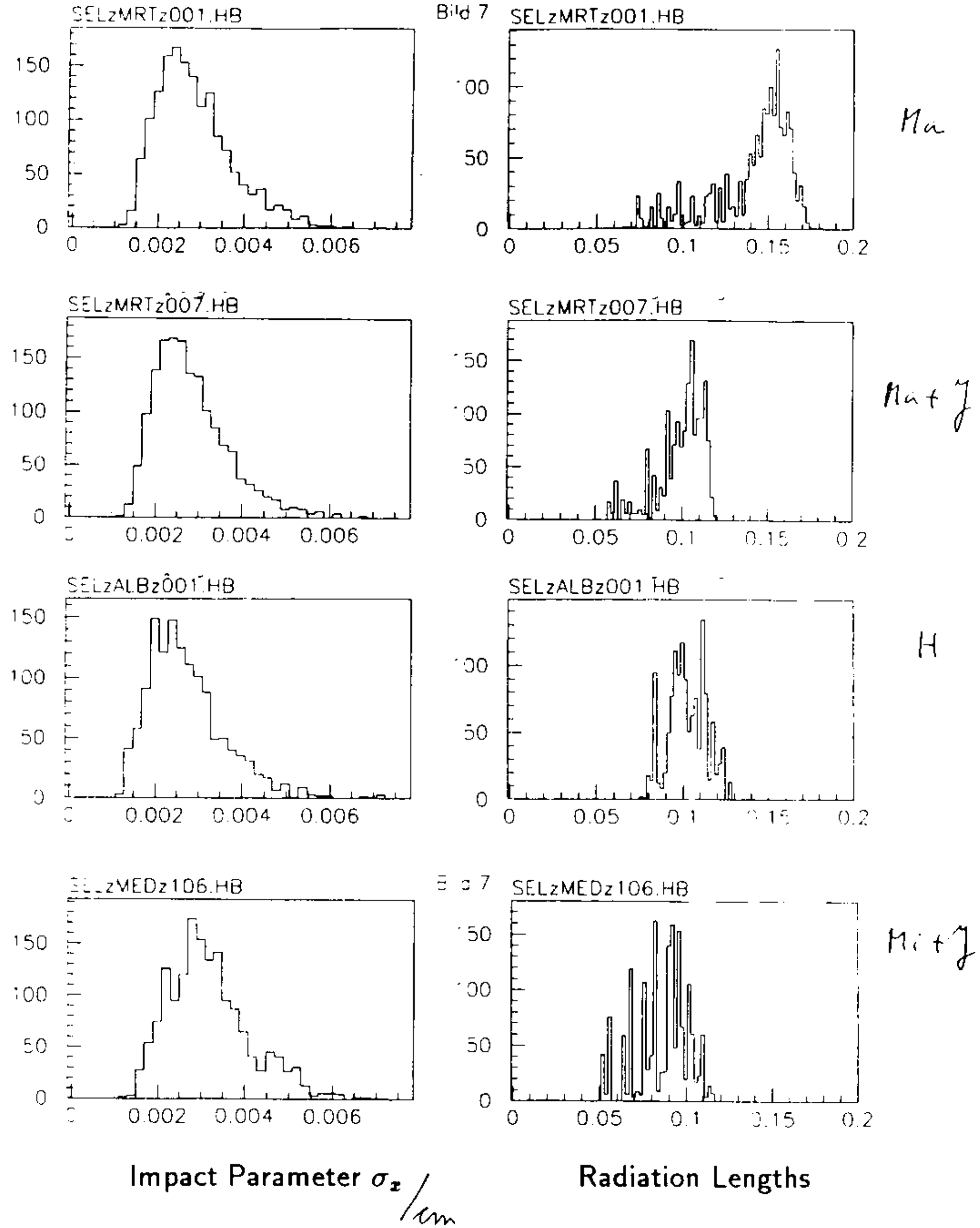


Figure 3: Side-view of the microvertex detector. Heavy lines indicate the regions covered with pads.

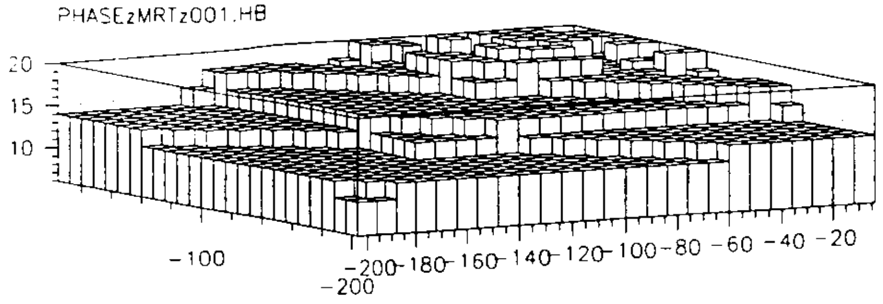
Impact Parameter Resolution σ_x vs Polar Angle

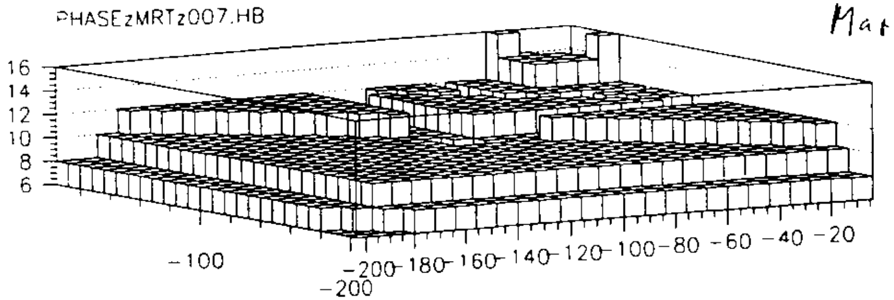


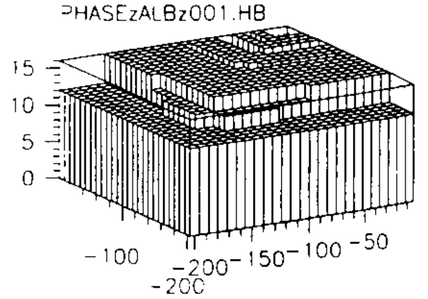
Resolution and Radiation Lengths for J/Ψ Signal Electrons

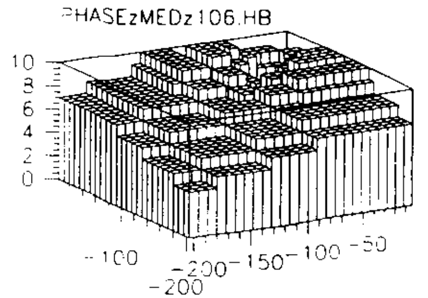


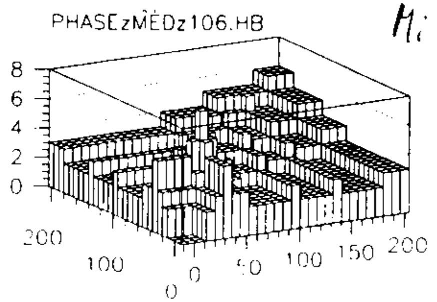
Number of Hits per Track











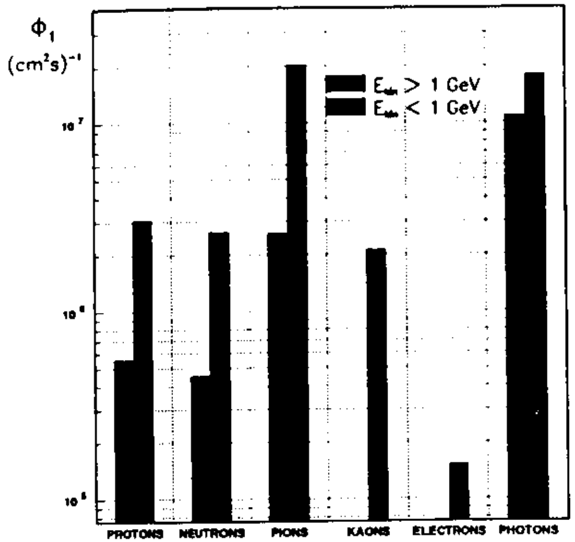
Very Schematic Summary of Designs

	'Martin'	'M & Jörg'	'Hartwig'	'Mike&Jörg'
I.P. Resolution	F	B	F	F
Hits per track	B	F	F	W, F with strips+pad
Radiation Length	W	F	B	F
Module Construction	B	B	F	W
Module Support	W	W	B	B
2nd Level Trigger	W	W	W	B
Coverage at $r \leq 14$ mm, $\phi = 45°$	B	B	W	W
Other features	B[1)]	B[1)]W[2)]	W[3)]	W[2,4)]

1) Highest symmetry in azimuthal angle
2) Detector size too big for 4" wafer
3) Shielding cap closer to beam axis
4) Non-standard detectors & pixel planes resolution in x-y views asymmetric

Radiation Environment

FRITIOF prediction for 900 GeV proton-copper interactions at 40 MHz



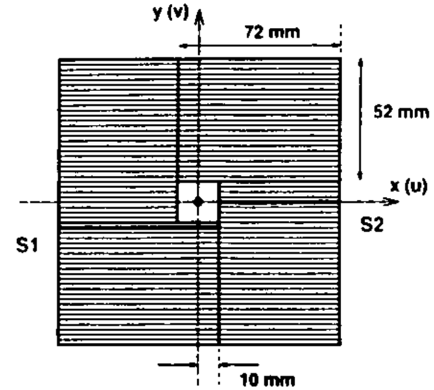
- At an interaction rate of 40 MHz the total flux is

  $\phi(R) = \phi_1 \cdot (1\ \text{cm}/R)^2$ where $\phi_1 = 3 \cdot 10^7\ \text{cm}^{-2}\text{s}^{-1}$

  is the flux at $R = 1$ cm;

  $\rightarrow$ 'annual' fluence at 1 cm : $\Phi_1 = 3 \cdot 10^{14}\ \text{cm}^{-2}$.

Leakage Current and Full Depletion Voltage



$$I_1(\Phi_1) = \alpha \cdot \Phi_1 \cdot W \cdot b \cdot r_1 \cdot (\arctan(\frac{\pi}{4}) + \arctan(L/r_1 - 1))$$

$$I_2(\Phi_1) = \alpha \cdot \Phi_1 \cdot W \cdot b \cdot r_1 \cdot (1 - \frac{1}{L/r_1 + 1})$$

T [C]	α [10^{-17} A/cm]	I_1 [μA]	I_2 [μA]
0°	0.6 ± 0.1	0.55	0.21
10°	1.3	1.19	0.46
20°	2.8 ± 0.3	2.58	0.99

T [C]	β [1/cm]	V_{FD}(280 μm) [V]	V_{FD} (250 μm) [V]
0°	0.037	348	278
20°	0.018	169	135

Leakage currents after exposure to $3 \cdot 10^{14}$ particles per cm^2;
Full depletion voltages after exposure to $1.5 \cdot 10^{14}$ particles per cm^2;
Damage parameters from 650 MeV proton irradiations (Los Alamos).

Full Depletion Voltage as Function of Flux ϕ, Irradiation Time t, and Temperature T

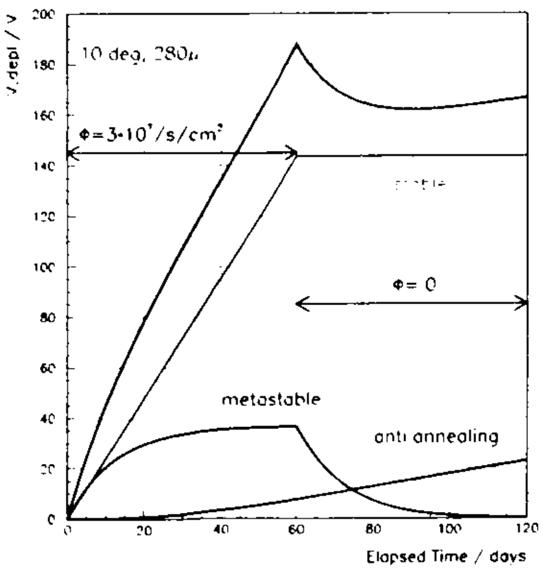
(Ziock et al., NIM A342 (94) 96-104)

Two counteracting (beneficial/detrimental) annealing processes :

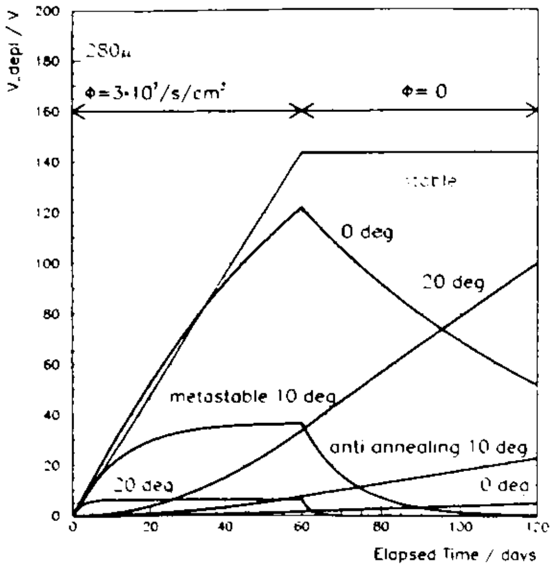
- $\tau_S = \quad 70 \cdot \exp(-0.175 \cdot T)$ days
- $\tau_L = 9140 \cdot \exp(-0.152 \cdot T)$ days

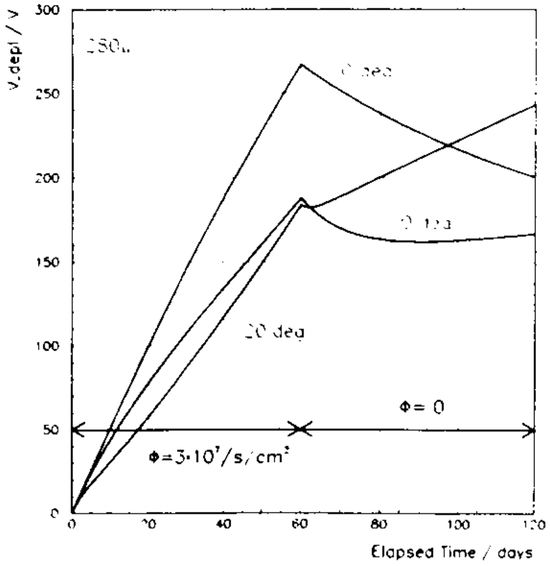
$$
\begin{aligned}
V_{FD} &= \nu_Z \cdot \phi \cdot t && \text{(stable acceptors)} \\
&+ \nu_S \cdot \phi \cdot \tau_s \cdot [\, 1 - \exp(-t/\tau_S) \,] && \text{(metastable acceptors)} \\
&+ \nu_A \cdot \phi \cdot (\, t + \tau_L \cdot [\, -1 + \exp(-t/\tau_L)]) && \text{(acceptors from r.a.)}
\end{aligned}
$$

$$(\nu_Z, \nu_S, \nu_a) \;=\; (1.06,\ 1.34,\ 3.80) \cdot (W/300\mu)^2 \cdot 10^{-12}\ \text{V cm}^2$$

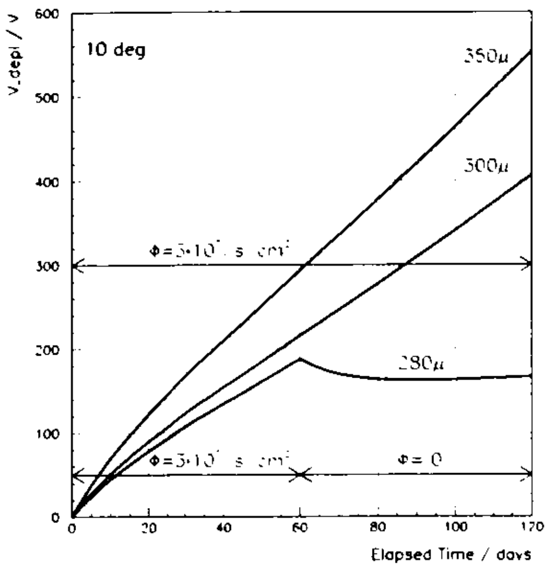


Effect of Operating Temperature



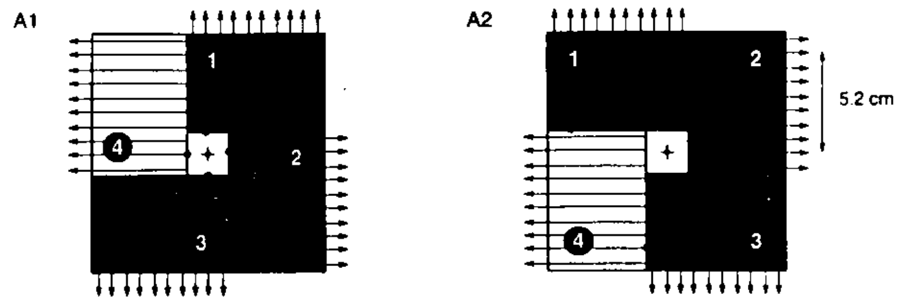


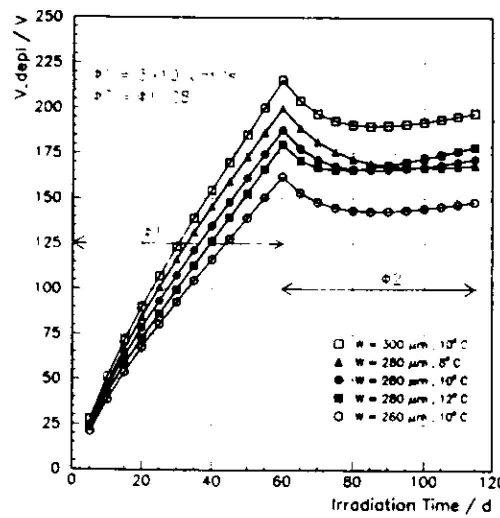
Effect of Detector Thickness

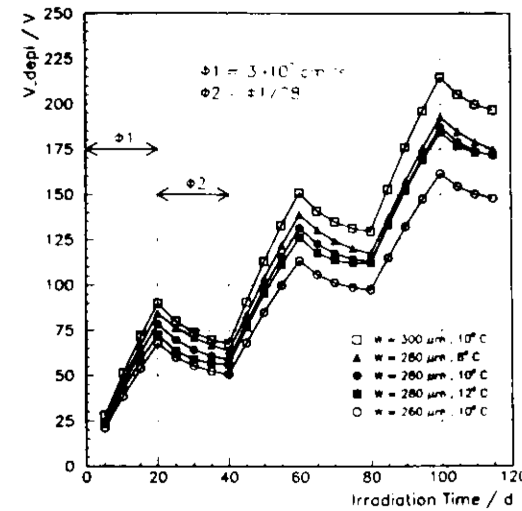


L -19-

Rotation of Detector Positions





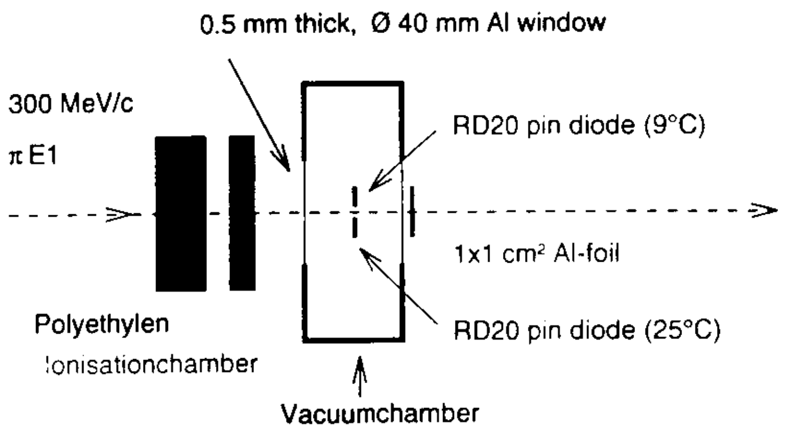


L -20-

Pion Irradiations with 190 MeV π^+ Beam at PSI

(K. Riechmann, V. Pugatch, K.T.K.)

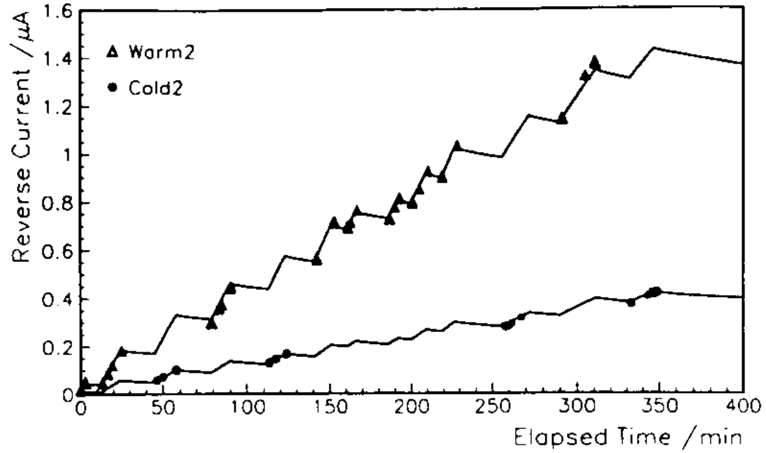
- IRRADIATED :
  Pairs of SI/RD20 Pin Diodes, 3×3 mm^2, 350 μm thick
- Biased at Full Depletion Voltage (FDV)
- Operating Temperatures of 10° and 25° C, respectively



- MEASURED during irradiations at 0.2 Hz :
- Leakage Currents
- Ionization Chamber Current, ...
- MEASURED after each irradiation step and after different annealing intervals :
- I-V Characteristics
- C-V Characteristics
- DEDUCED damage and annealing constants of
- Leakage Current
- Full Depletion Voltage

Increase of Leakage Currents

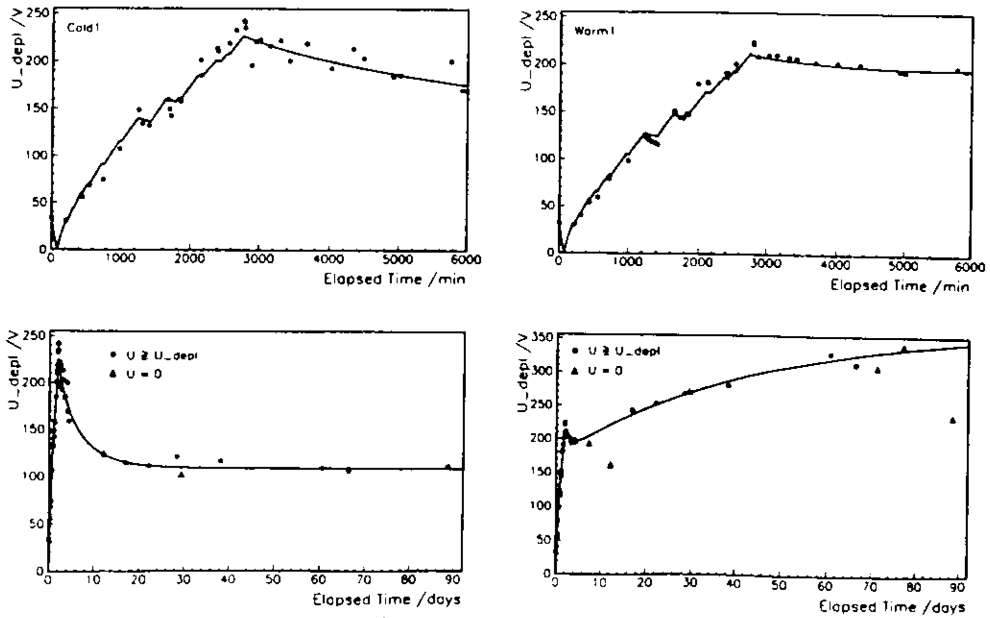
Flux ϕ_π typ. $7 \cdot 10^8/\mathrm{cm}^2 \cdot \mathrm{s}$ Fluence $\Phi_\pi \approx 4 \cdot 10^{12}/\mathrm{cm}^2$



Change of Full Depletion Voltages

$\phi_\pi^{cold} = 6 \cdot 10^8$ /cm^2·s
$\Phi_\pi^{cold} = 7.7 \cdot 10^{13}$ /cm^2

$\phi_\pi^{warm} = 1 \cdot 10^9$ /cm^2·s
$\Phi_\pi^{warm} = 1.3 \cdot 10^{14}$ /cm^2

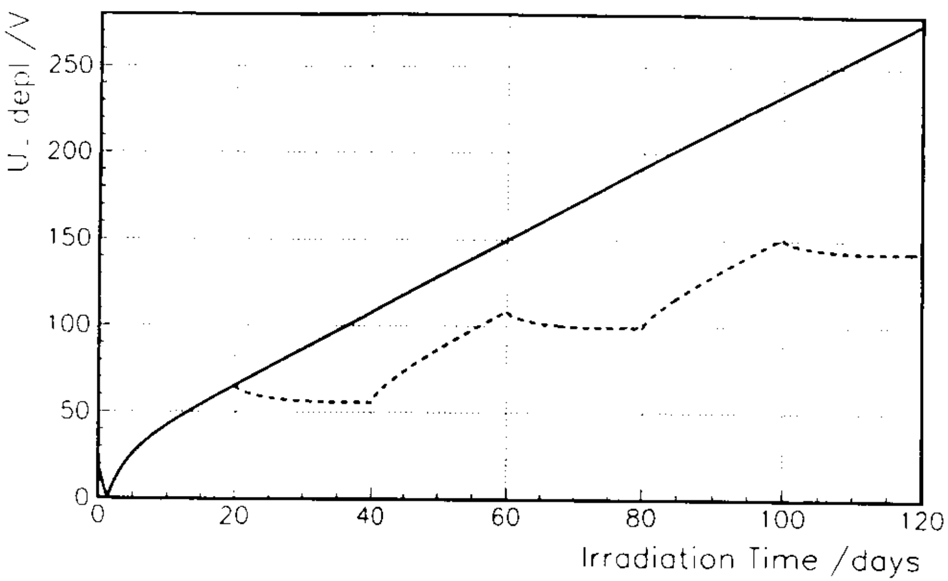


Preliminary Results

- Damage rates α scale with NIEL (similar to 1 MeV neutrons)
- Damage / Annealing parameters are of similar magnitude as those found for 650 MeV protons at Los Alamos.

Predicted Evolution of FDV at HERA-B
$(\phi = 3 \cdot 10^7$ /cm^2·s)

(K. Riechmann, Diplomarbeit, Heidelberg, 30/9/1994)



Radiation Damage - Conclusions

There is increasing evidence that the Vertex Detector System for the HERA-B experiment can be designed such that it will function during the desired operation period of one year (10^7 s) as specified:

- leakage current in each strip diode $\leq 1.5\ \mu$A,
- full depletion voltage in each detector cell ≤ 200 V.

Measures and Safety Margins

- Choice of detectors with a thickness of 280 μm or less
- Operation of detectors at about 10° C
- Rotation of detector positions

- Use of single-sided detectors which can operate at partial depletion
- Implementation of novel guard ring structures
- Operation of Vertex Detector System at slightly larger radius
- Theoretical evidence that bulk damage is about twice as large for 650 MeV protons than for relativistic pions.

New Development could change whole scenario !

HLL Pasing of MPI Munich is producing double sided strip detectors which can be operated at bias voltages up to 600 V. Irradiation tests of small prototypes will start at Heidelberg this month.

Alternatives to Si Detectors : GaAS & Diamond

- Higher Radiation Tolerance
- No Need for Detector Cooling
- Negligible Leakage Current

	GaAs	Diamond	Silicon
Band Gap [eV]	1.43	5.5	1.12
Radiation Length [mm]	23	122	93.6
Mip Signal / 100μm [e]	12900	3600	8800
Mip Signal / 0.1% X_0 [e]	3000	4500	8300

Status

- GaAs detectors of 200 μm thickness are yielding now more than 20000 e^- from minimum ionizing particles.

- Diamond strip detectors are existing and working
- 'Collection distance' still too small, typically 100 μm

DRDC recommends approval of diamond R&D poposal P56 in September 94:
'demonstrate radiation resistance of diamond detectors..'
'demonstrate significant increase in signal (about 8000 e^-).'

Systematic comparison of radiation hardness of Diamond, GaAs, and Si is still lacking.

CERN/DRDC 94-21
DRDC/P56
May 5, 1994

R & D Proposal

Development of Diamond Tracking Detectors for High Luminosity Experiments at the LHC

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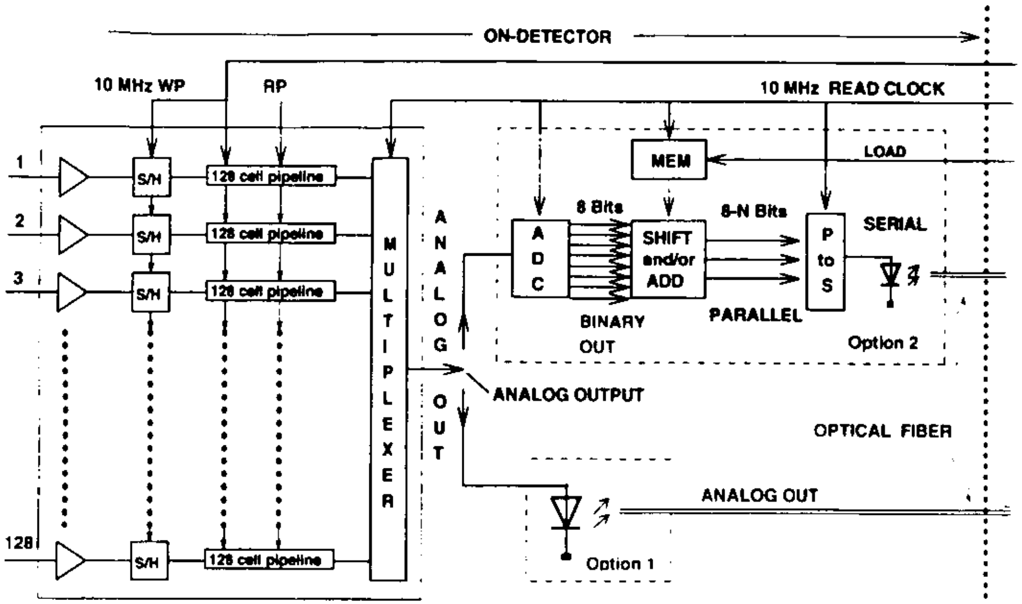
R. Frühwirth, J. Hrubec, M. Krammer, G. Leder, H. Pernegger, M. Pernicka
Institut für Hochenergiephysik, Österr. Akademie d. Wissenschaften, A-1050 Vienna, Austria

* Spokespersons.

Possible Configuration of a Readout Scheme



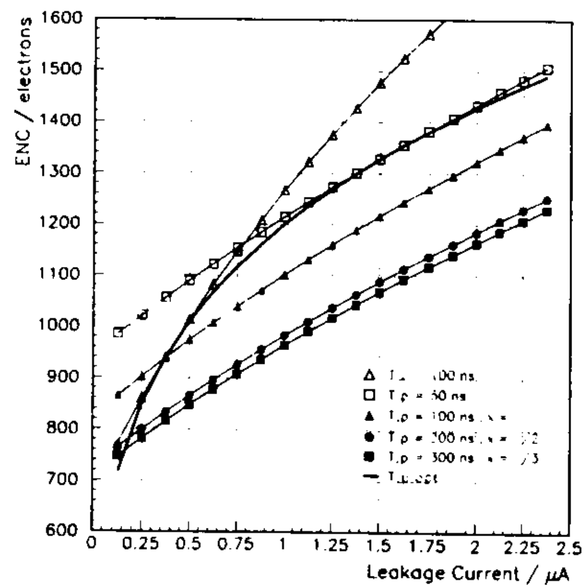
Specs for Silicon Vertex Detector Front-End

- Channel pitch of $\leq 50\ \mu m$
- Adequate signal processing for lowest possible noise at leakage currents up to 1.5 μA and input capacitance of 9 pF
- 128 cell deep 10 MHz pipeline
- Deadtimeless readout within about 10 μs
- Moderate radiation tolerance of $\leq$ 200 krad with the readout chips placed at $R \geq 7$ cm

Signal Processing

$$ENC^2 = a_1 \cdot \frac{C_{inp}^2}{T_p} + a_2 \cdot I_L \cdot T_p + \cdots$$

$$a_1 = (43\,e^-/pF)^2 \cdot 75\,ns, \quad a_2 = 1/4 \cdot \exp 2, \quad C_{inp} = 18\,pF$$



Deconvolution : S. Gadomski et al., NIM A320 (1992) 217.

Readout Chip Characteristics

Name	APC	AACC	ADAM	FElix	APV5
Source	PSI	St. Cruz	RD2	RD20	RD20
Pitch $\leq 50\ \mu m$	•			•	•
ENC ≤ 1500 e @ 20pF	•	•	o	•	•
128 cell pipeline		o	o	o	•
Indep. R/W		•	•	•	•
R.H. ≥ 1 Mrad	•	•	n/a	n/a	•
W-Freq. ≥ 10 MHz	•	•	•	•	•
R-Freq. ≥ 10 MHz		•		•	•
Peak Time 75 ± 25 ns	•	•	25 ns	•	•
128 ch version available	•	•	95	5/95?	1/95!

Status of RD20 Readout Chips

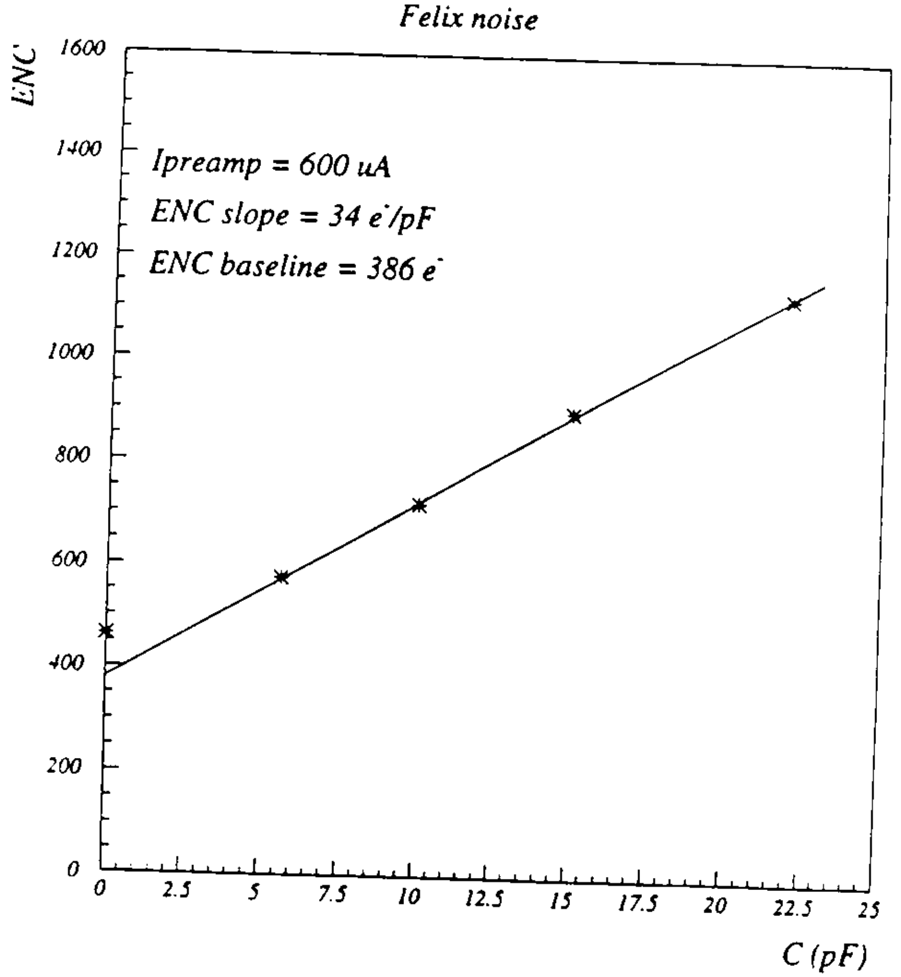
32 ch protoypes bonded to separate multiplexers under tests :

- FElix (AMS) : $t_p = 75$ ns, ENC/$e^- = 386 + 34$/pF
- APV5-RH (AVLSI-RA) :
  $t_p = 45$ ns, ENC/$e^- = 450 + 50$/pF
- 32 ch FElix multiplexer : 25 MHz clock rate
- APV5 multiplexer : designed for up to 40 MHz clock rate

- APV5-RH in production
- Bias control chip for APV5 in production

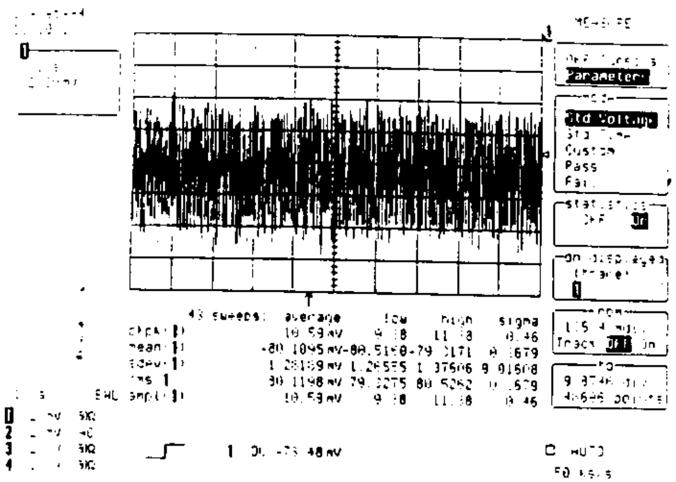
Next Steps

- Evaluation of 32 ch FElix
  - getting two chips mounted on testboards from RD20
  - getting VME sequencer from RAL
- Participation in APV5-RH hybrid/testboard designs (in collaboration with RD20/RAL)

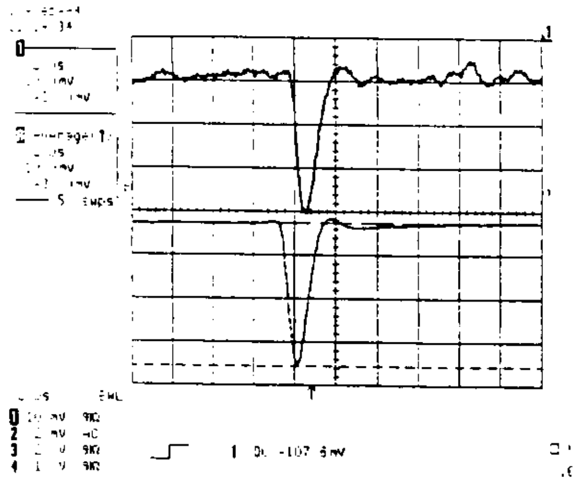


FELIX Chip Bonded to Single-Sided pn Junction Detector (CSEM)

Detector : 50 μm pitch
50 μm R.O. pitch
6 cm long strips
$V_B = 70$ V



Noise

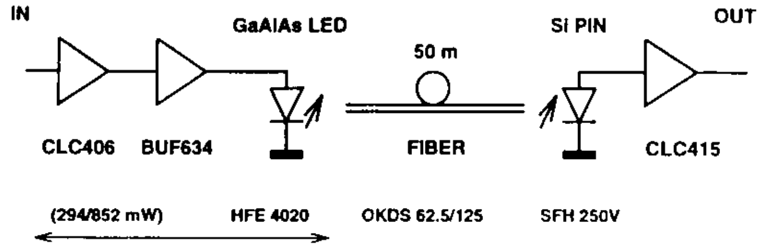


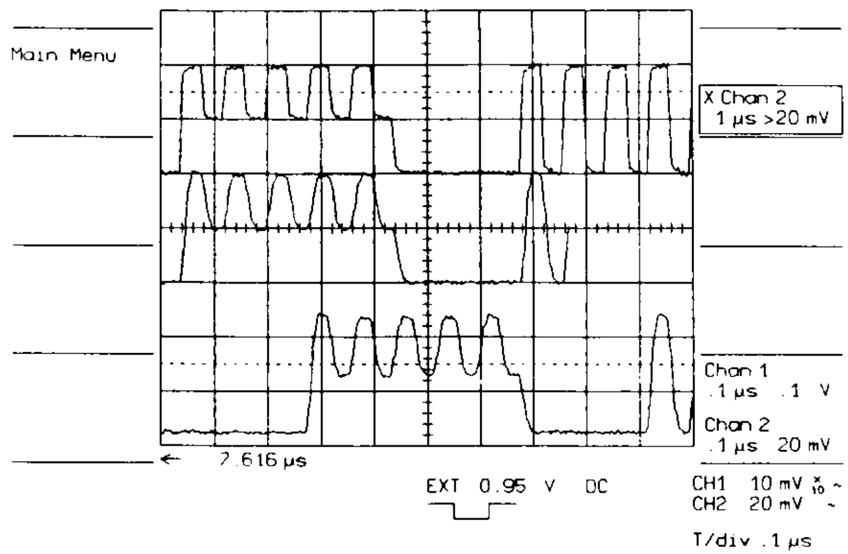
$I_d = 600$ μA

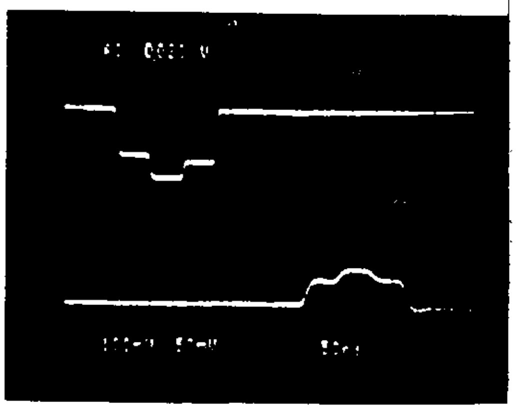
Am 60 keV γ

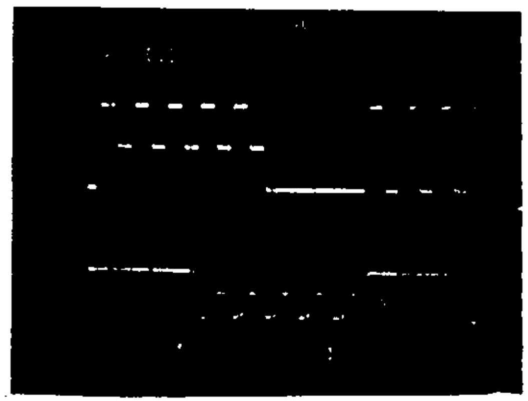
S/N = 36

Analog Signal Transmission by Optical Fiber Link at 25 MHz









Analog Signal Transmission by Optical Fiber Links

- Speed (Daisy chain of two 128 ch chips possible by now!)
- Dynamic Range
- Linearity
- Noise

? Ageing
? Radiation Hardness
? Match of Optical Couplings
? Power Reduction

! Evaluate alternatives like optical modulators,..., copper

Off-Detector Front End
(As much electronics off-detector as possible!)

Input: analog signals of all 165k channels

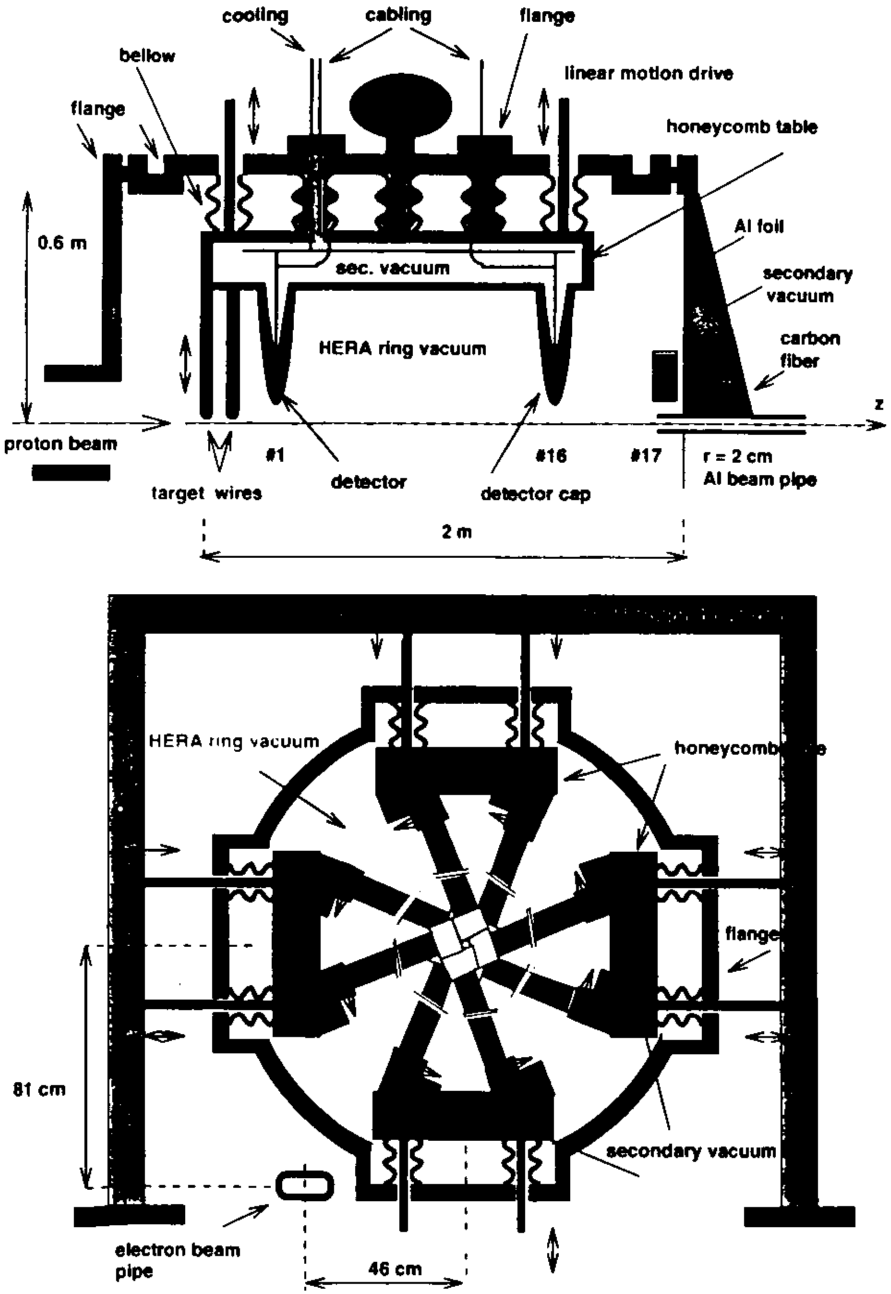
- Digitization
- Masking of Hot Channels
- Common Mode Correction
- Pedestal Subtraction
- Cluster Finding
- Sparsification

Output: formatted hit cluster data

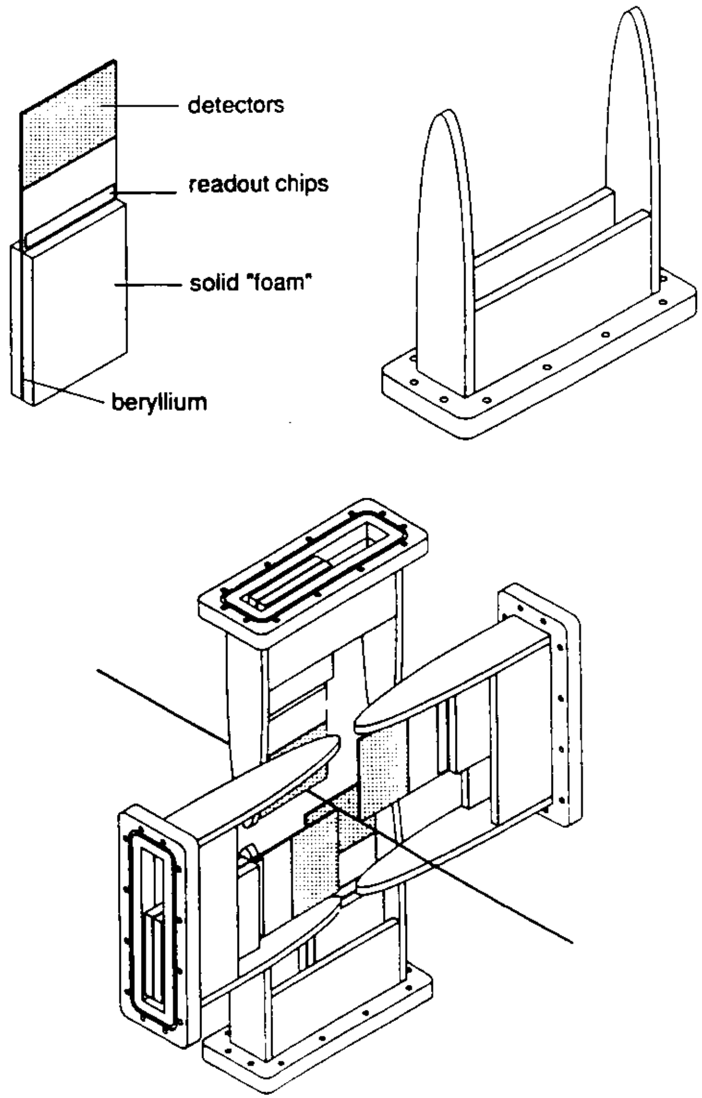
Mechanical Setup - Constraints

- Retractrable detector arrangement
- Invariant alignment of detectors within subgroups at least
- Little and low Z material within 250 mrad horizontal and 160 mrad vertical acceptance
- Shielding detectors against RF pickup due to passage of beam bunches
- No significant impact on HERA proton ring vacuum
- quick and easy replacement of detectors

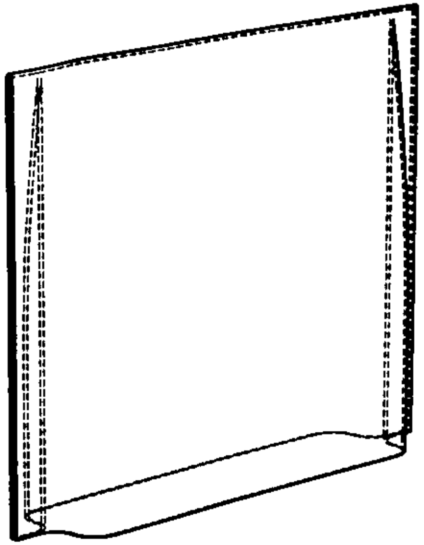
→ ROMAN POT SYSTEM

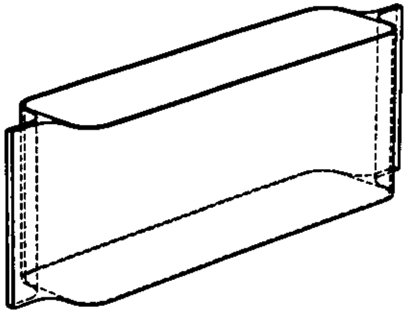


Arrangement of Detector Modules



Selfsupporting Detector Cap

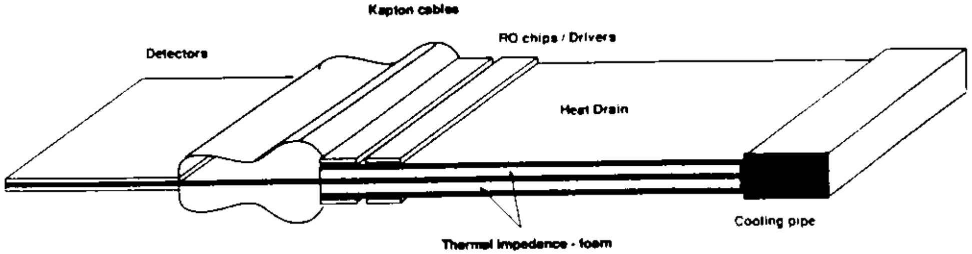




- Electron-beam welded 200 μm thick Al cap now available

100 μm possible

Alternative Cooling Scheme



Materials for Heat Drains

	ρ g/cm^3	α 10^{-6}/K	Heat Cond. W/m/K	X_0 mm	FoM	Cost DM/cm^2
Si	2.3	2.4-4.2	80-165	94	11	3
Al_2O_3	3.9	8.0	30	72	2	-
AlN	3.3	5.3	165	85	14	5
Al	2.7	24	237	89	21	-
BeO	2.9	8.7	280	144	40	16
Be	1.9	12	201	353	70	20
Thornell			1050			
Diamond	3.5	1-2	1500	122	180	$10^?$
H_2O	1			361		

Concluding Remarks

- Geometrical Layout
+ new designs featuring improved performance
+ basis for sensible final decision now available

- Radiation Damage
- severe
+ lifetime expectancy 1 year
+ promising new developments

- Readout Electronics
+ RD20 chips - Felix & APV5-RH - meet all our requirements
+ final version of APV5-RH in production
+ proof of principle for 25 MHz analog optical fiber link

- Technical Realization
+ six months contract with most experienced design team (engineer/technician) to provide mechanical and engineering design study of Vertex Detector System
+ prototypes of thin selfsupporting Al caps produced

- Less Developed but 'Straightforward?' Topics
- cooling
- pumping
- cabling
- off-detector frontend
- alignment
- out-of-tank detector modules

- Less Developed and Not 'Straightforward' Issue
- how to prevent resonant and transient power losses of proton beam in vacuum chamber

- Time Schedule, Costs
+ proposal outlines still valid

F. Eisele 5/10/94

HERAB Inner Tracking =

Tracking and triggering near the beam pipe with

→ very high rates

→ high radiation loads

~ LHC

radial area:	2 < r < 25 cm
angular range	> 10 mrad

specific challenges:

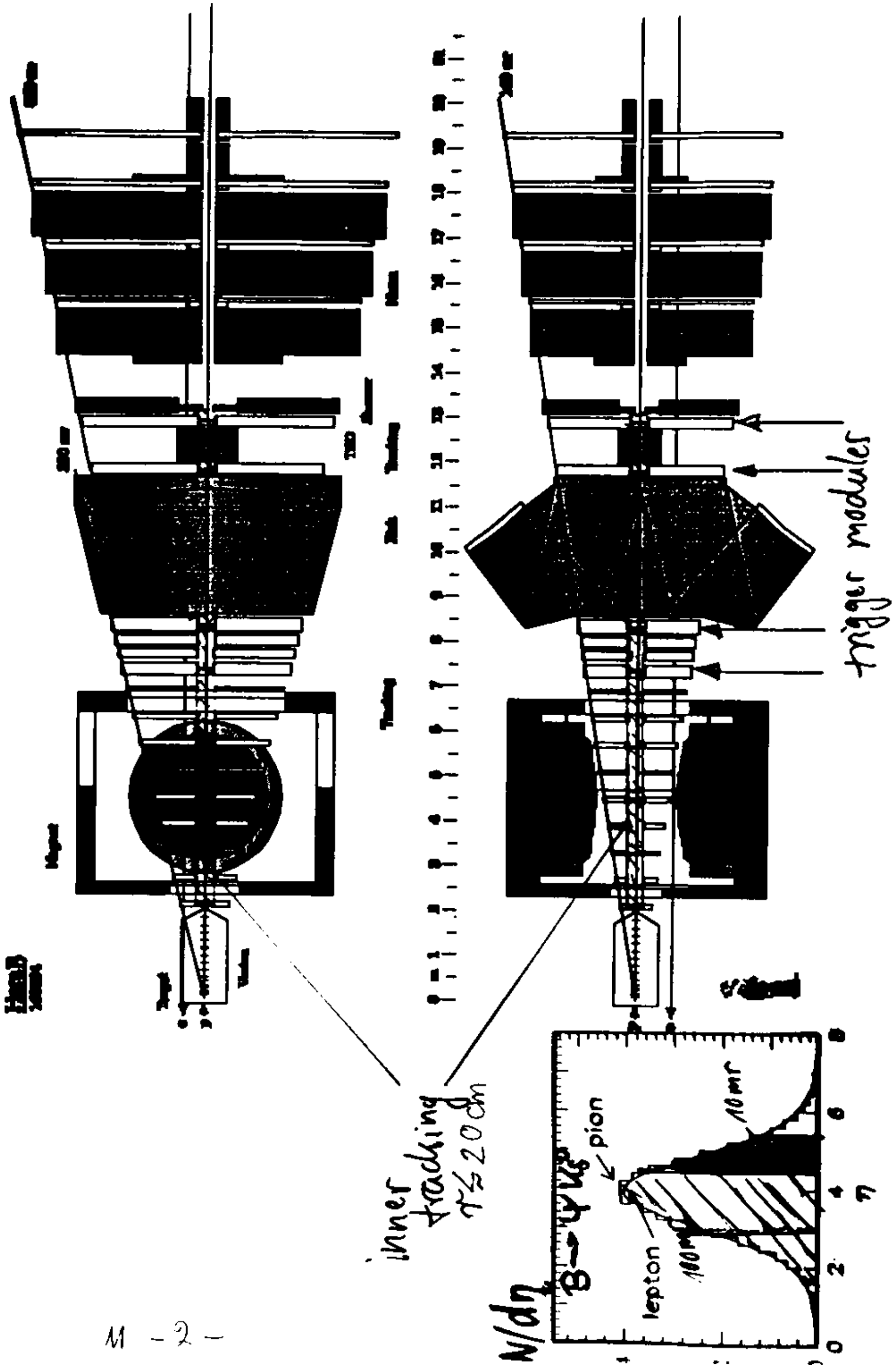
● charged particle flux:	r> 2 cm	$<10^5$ mm^{-2}s^{-1}
● ~ 1/r	r> 6 cm	$<10^4$ mm-2s^{-1}
● radiation load/year	r> 6 cm	0.5 Mrad

detector requirements:

- ● high rate tolerance
- ● occupancies small << 10 %
- ● spatial resolution < 120 μm
- ● robust against aging effects and high radiation dosis

→ area per detector element small <= 40 mm^{-2}

Si strip detectors for highest rates
MSGC's for r> 6 cm (baseline)
OR gas pixel detectors (backup)



Inner tracker:

1) innermost area $r < 6$ cm : for $z < 6$ m only
   rates go up to 10^5 mm^{-2} s^{-1}
   ⇒ use Si-strip detectors, only safe solution
   detectors similar to SVX, no detailed design yet

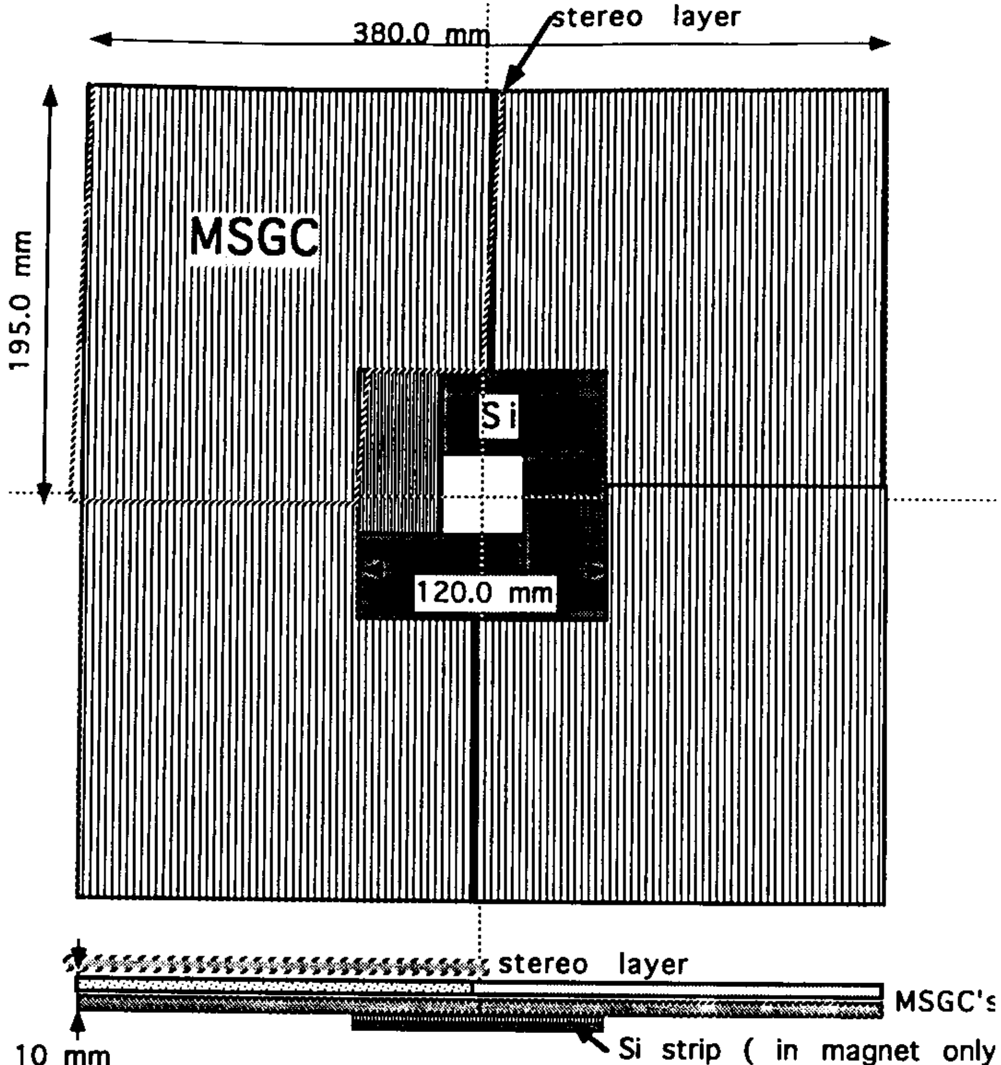
2) $r > 6$ cm   rates up to 10^4 mm^{-2} s^{-1}

MSGC's	gas pixels
• large area substrates with long strips l×25 cm and small pitch ~300 μm	• small hexagon drift cells with wires ∥ beam → same area ~30 mm² covered
• $\sigma < 80$ μm	• $\sigma \leq 100$ μm by drift time measurement
- 3 stereo layers (±75 mr, 0°) - same geometry for all layers - 48 layers along beam	- staggered cells ~45 layers along beam
4 detectors / layer	2 detectors / layer

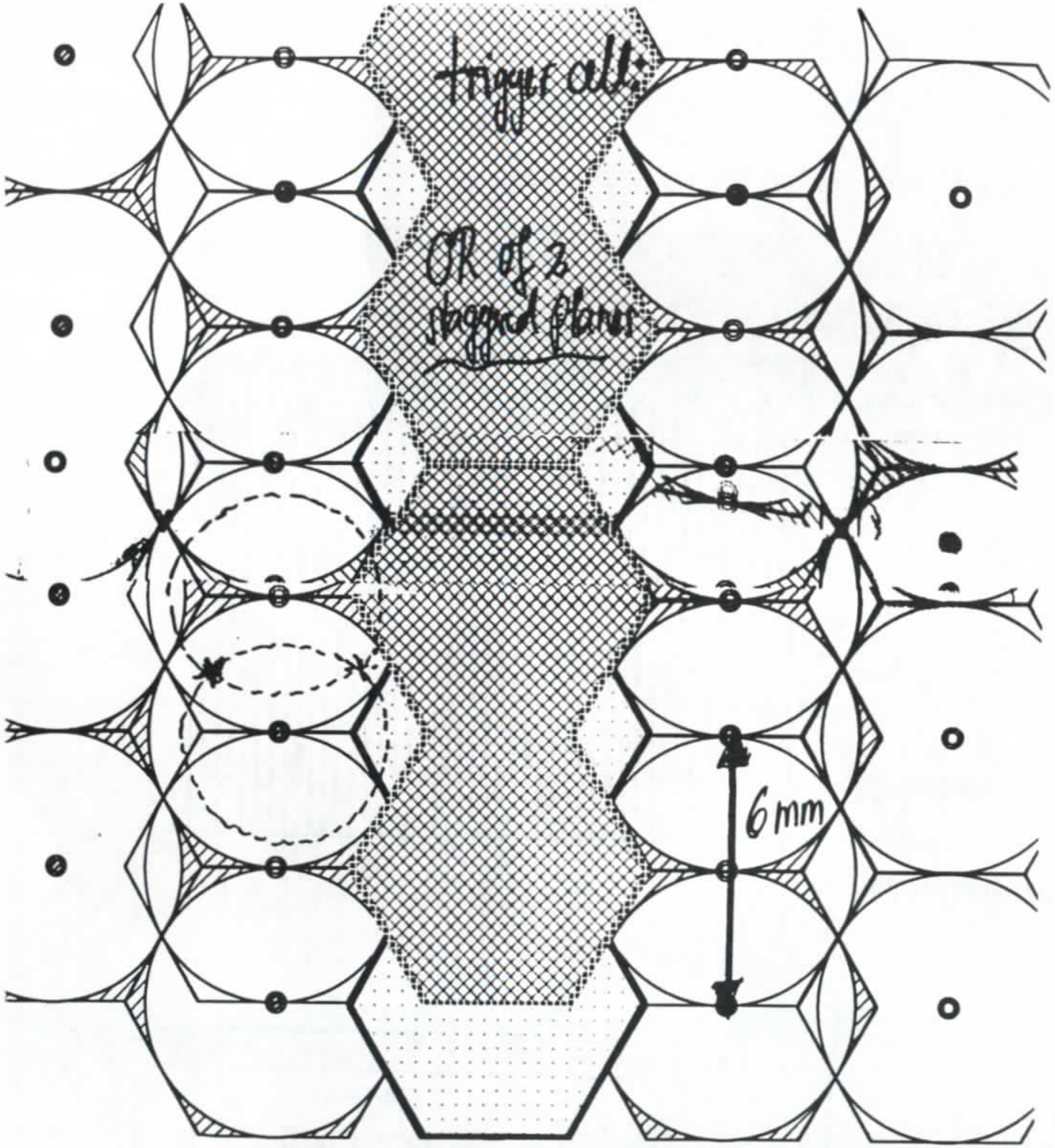
3 radiation thickness:

MSGC's	gas pixels
~.5 % X_0 / layer	~.6% X_0 / layer
⇒ 18% X_0 in front of RICH !	! 23% X_0 in front of RICH

note: number of layers not yet optimized, need full track reconstruction...



300 μm pitch
Trigger: 4-fold OR of strips
MSGC geometry in front of RICH: 36 layers
• Si-insert needed inside magnet (up to 6m z) (12 layers)
→ will use technique of Si-Vertex-Detector (not studied in detail)



'gas pixel' detectors: ~area/cell 31 mm² ~occupancy ≤ 3% drift time measurement (single shot)

Microstrip Gas Chambers for HERAB

for r > 6 cm

excellent high rate capabilities (very small space charge effect)	up to 10^6 $mm^{-2}s^{-1}$
natural strip granularity needed for HERAB	300 μm
occupancies	< 6 %
resolution	75 μm
large areas at reasonable prize	up to 25x25 cm^2

----> *this would be the the best choice*

but there are several serious questions:

We need a robust detector which can operate for > 7 years

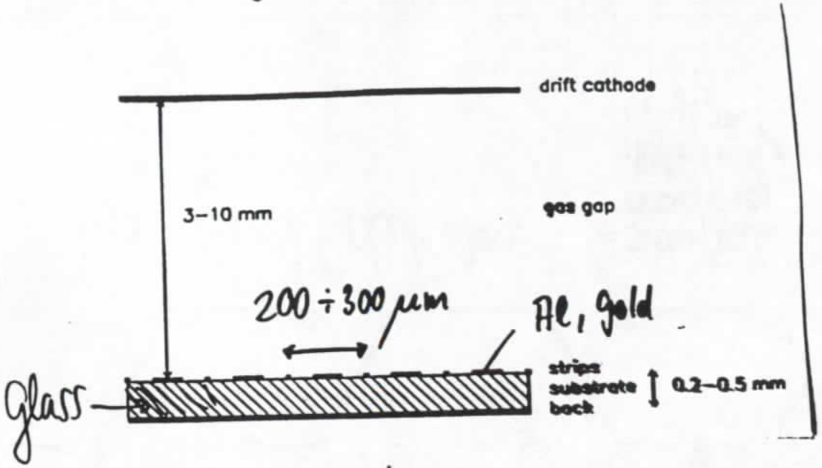
- tolerance against aging?? up to 30 mC/cm
- long term stability of substrates and electrodes in high radiation environment and under HV

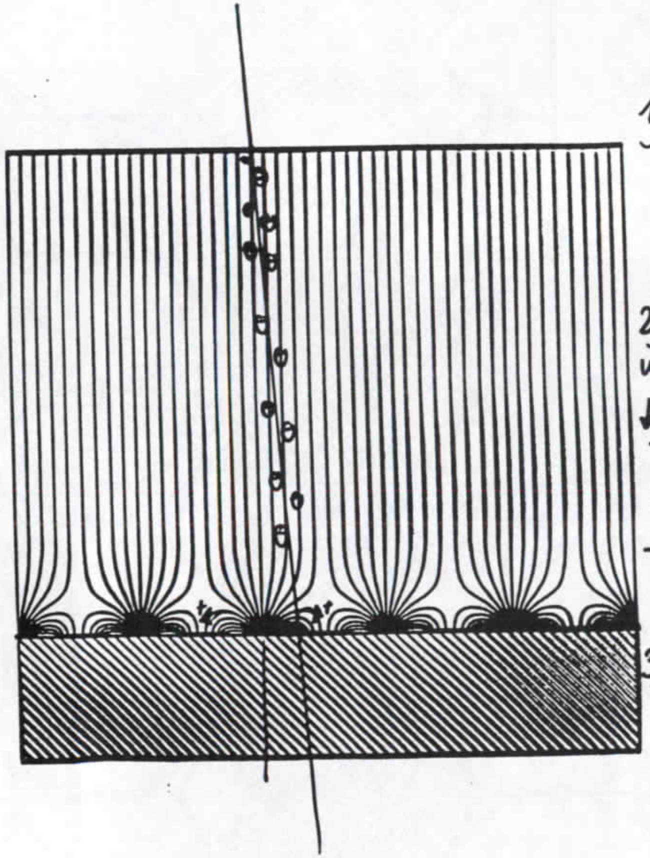
so far nobody has buildt or designed a system adequate for HERAB

note: accidentally HERAB requirements are almost identical to the requirements for the CMS MSGC tracker

→ ***we also work on a backup solution*** : gas Pixels

Microstrip Gas Chamber : MSGC





1) naturally v. good resolution

2) very fast: up to $10^6\,mm^{-2}s^{-1}$
↓ ions go mostly to cathode
→ small space charge effect

3) gas amplification $\sim 10^3$

- **aging of MSGC's:**

→ severe degradation of MSGC's + aging effects have been reported for chambers with high resistivity substrates (standard ionic glass)

- in june 94 first reports by CMS (Bellazzini et al.) that standard substrates (D263) + gold electrodes show very low aging effects !

→ a standard glass solution seems feasible for HERA B →

1) main improvement comes from gold electrodes + covers (Aluminium electrodes show strong aging)
2) clean gas conditions + assembly
→ individually sealed glass detectors

⇒ preliminary conclusions:

- MSGC's look promising based on available techniques
- every improvement in substrates e.g. coating or reduction of aging by gas admixtures increase safety margin

⇒ worth while to study production methods

- Long term stability of substrates

Siegen | migration of alkali ions clearly observed under HV
⇒ long term change of substrates
diffusion of gold into glass ??

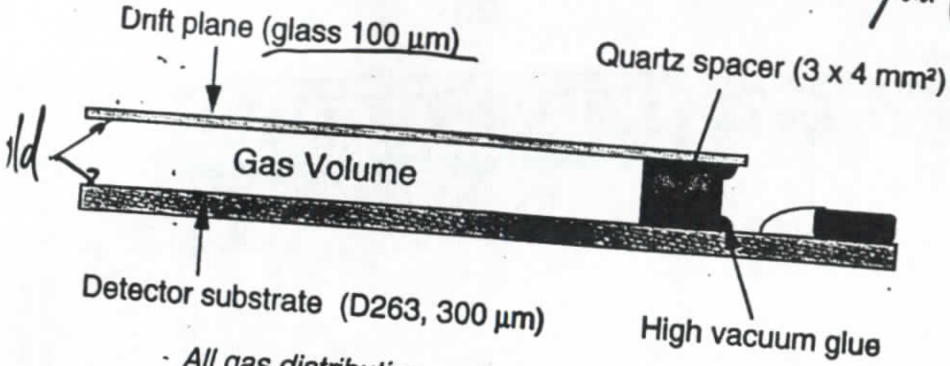
* effects are 'reversible', not necessarily fatal ...

MSGC: Aging

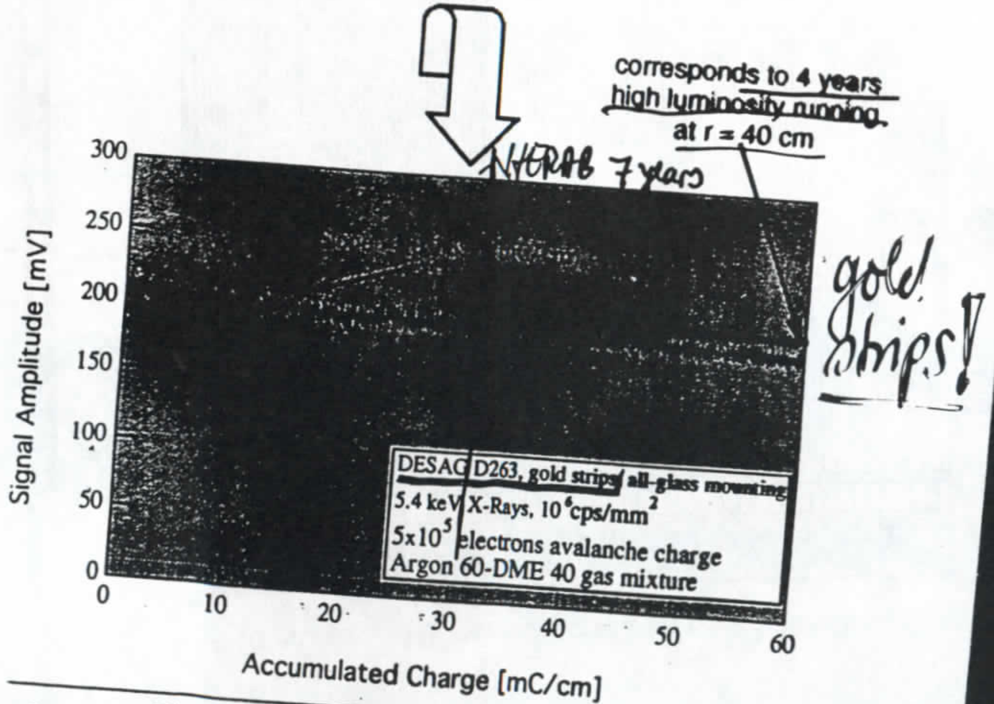
June 94 – CMS

Clean Detector Mounting:

size: 2.5cm x 10cm
200µm pitch



- *All gas distribution and tubing in stainless steel*



HERA-B: $10^7 s$, $\doteq 10^4 mm^{-2}s^{-1}$ → 4 mC/cm/a
Gain ≈ 2000

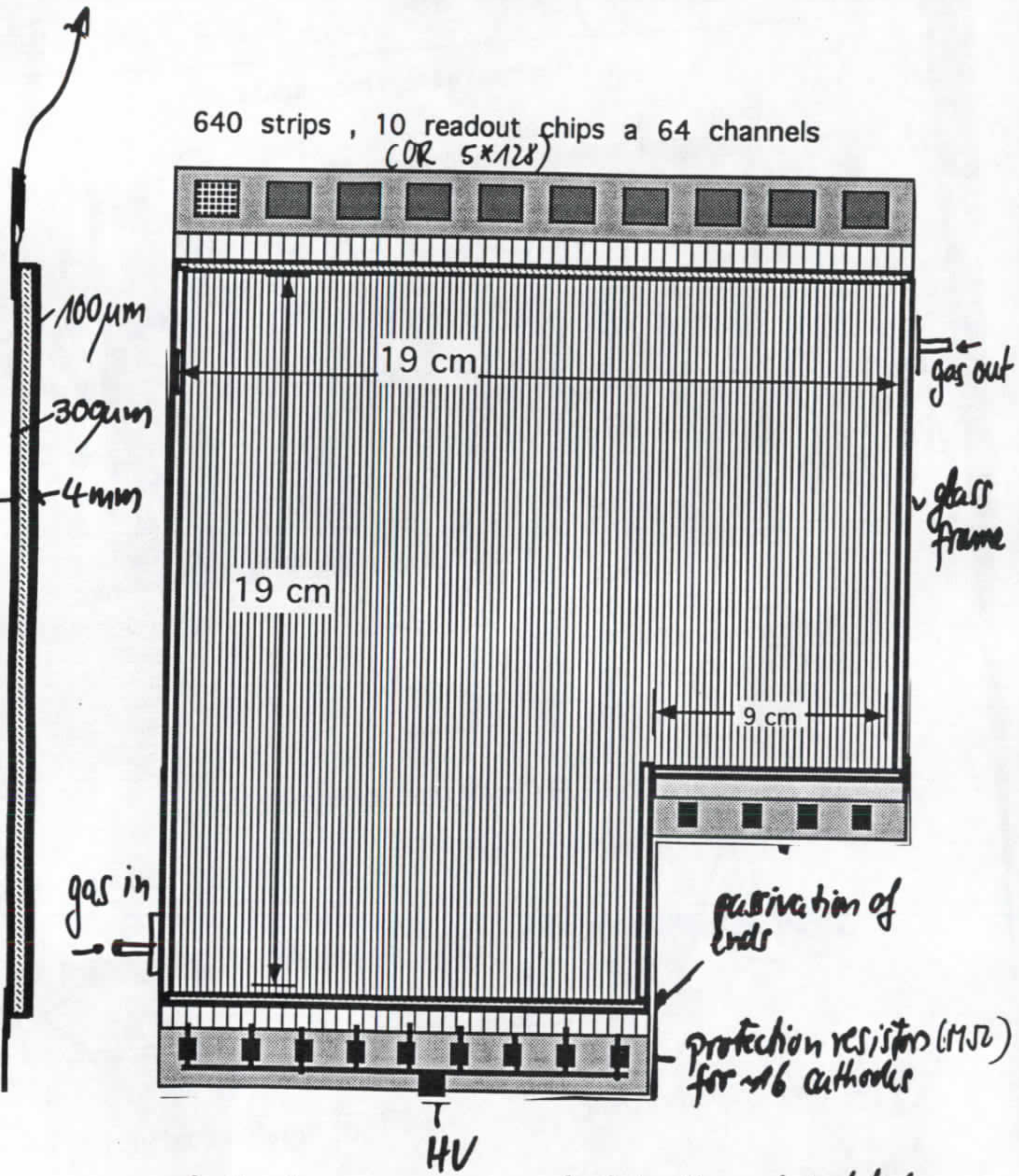
Operational problems: • HV discharges can destroy thin anode strips

biggest risk: at end of cathode strips:
- E-field esp. large
- gas amplification near cathode boundary possible → discharges

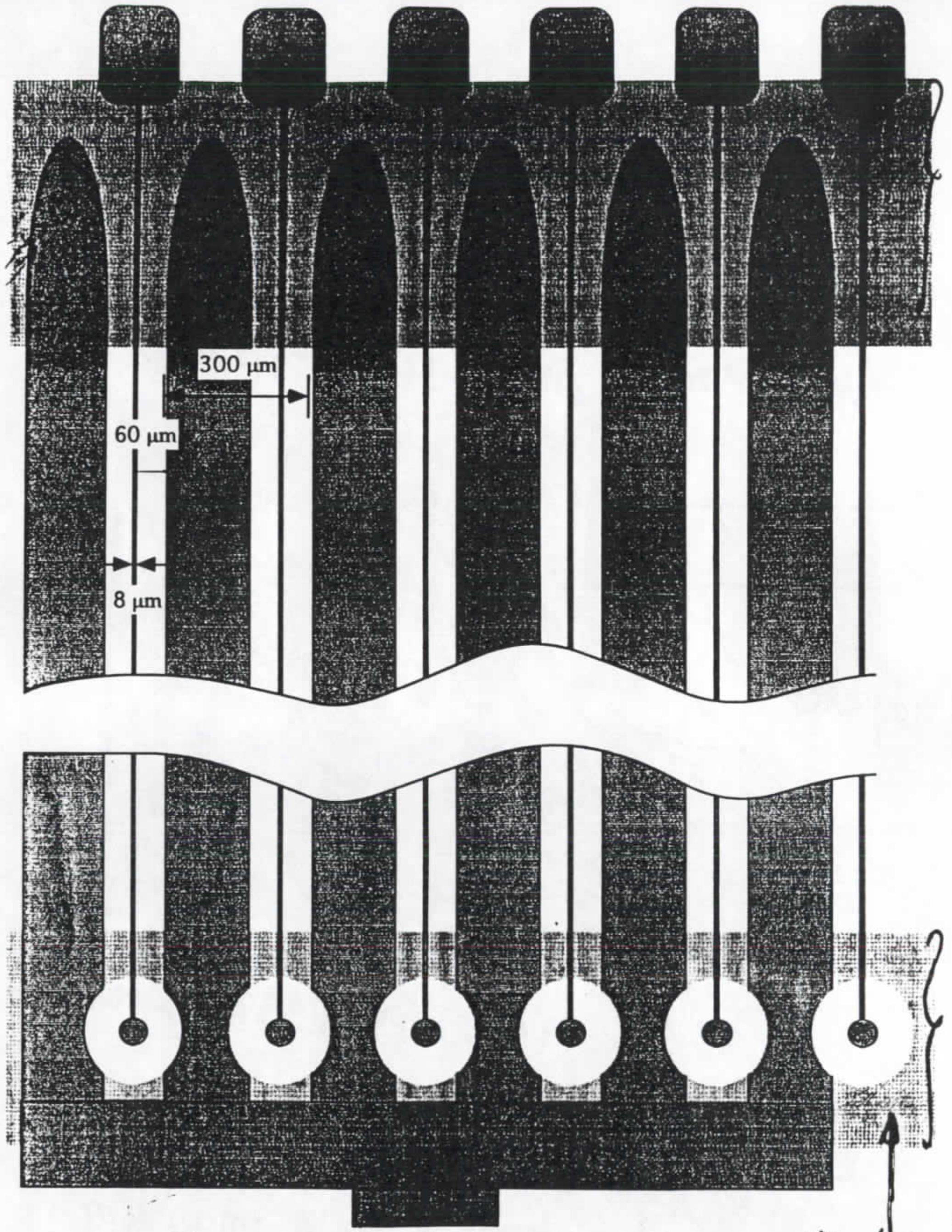
example: U. Werthenbach (Siegen)

Protection can be improved by passivation
- polyimid layer (very expensive..)
- passivation by UHV glue used to assemble detector box

conceptual design



- full glass assembly, individually sealed detectors
- full size substrate
  - looks feasible with small fault number based on present experience



in practice: glueing glass side walls on top of electrode ends.

Characteristical numbers for an MSGC solution

1) detector properties	
pitch	300 µm
strip length	19 to 25 cm
active area	19 x19 cm^2 and 25 x 25 cm^2 ✓
height of drift volume	4 mm
gas mixture	Ar: DME (50:50)
2) expected detector performance	
counting rates	10^4 $mm^{-2}s^{-1}$ ✓
occupancy	< 6 %
gas gain	1000 ✓
electrons per minimum ionizing particle	50 e^- ✓
average strip multiplicity	~ 1.8 ✓
resolution for primary tracks (for angles < 40 mr)	< 90 µm ✓
3) operation requirements	
charge accumulation (negligible aging over at least 7 years)	4 mC/year ?
radiation dosis	.2 Mrad/year ?

- what is the safety margin for MSGC long term operation?
  - aging + substrate changes
  - HV protection ..

MSGC inner tracking: summary

A) number of single strip detector layers:

before RICH: size 38x38 cm^2	36
before calorimeter: size 48x48 cm^2	12
total number of strip layers:	48
vertical strip layers:	22
u strip layers (+75 mr)	13
v strip layers (-75 mr)	13
trigger layers with digital & analog readout	24

B) number of individual detectors and strips:

in front of RICH:		
36 layers x 4 detectors	144	detectors
640 strips/ detector	92160	strips
detectors with trigger readout	12	
number of trigger signals (4 fold OR)	7680	signals
before calorimeter:		
12 layers x 4 detectors	48	detectors
896 strips/ detector	43008	strips
number of trigger signals (4 fold OR)	10752	signal

C) global numbers:

number of detectors	192	detectors
number of strips	135168	strips
number of trigger signals	14529	signals
active area of detectors	7.2	m^2
gas volume	30	liters

Cost estimate: ~2,2 MDM

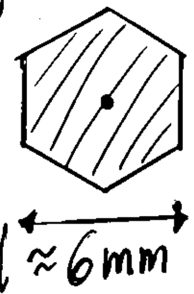
PISGC's: do list

- optimize – pitch, drift distance
  – electrode structure, parameters
- study further long term changes of substrates + particle ... (X-ray)
- aging tests by short term irradiation + long term tests (source)
  test additions to gas mixtures (Water, ...)
- get experience with detector assembly — HV, procurement of equipment underway
  – electrode layout
  – mechanical assembly
  – bonding ..
- test preamps + trigger chips .. *
- get experience with operation of large scale PISGC's : start with Pisa detector — start october 94

* relevant results needed for ≤ may 95
* readout almost identical to Si-detectors except trigger : needs 4-fold OR over anode strips
  → see M. Feuerstack .

Pixel gas detector (backup)

hexagon cell
wire parallel to beam!



- area seen by particle ~ 31 mm² !
  - occupancy ≤ 3 %
  - rates/wire ≤ 300 kHz !
  - max. drift time < 80 ns

→ large cell number ≈ 220 000 !
(maximal cell size : ~50 mm², d = 7.5 mm → 135000 wires
t_{max} < 96 ns — but high rates !)

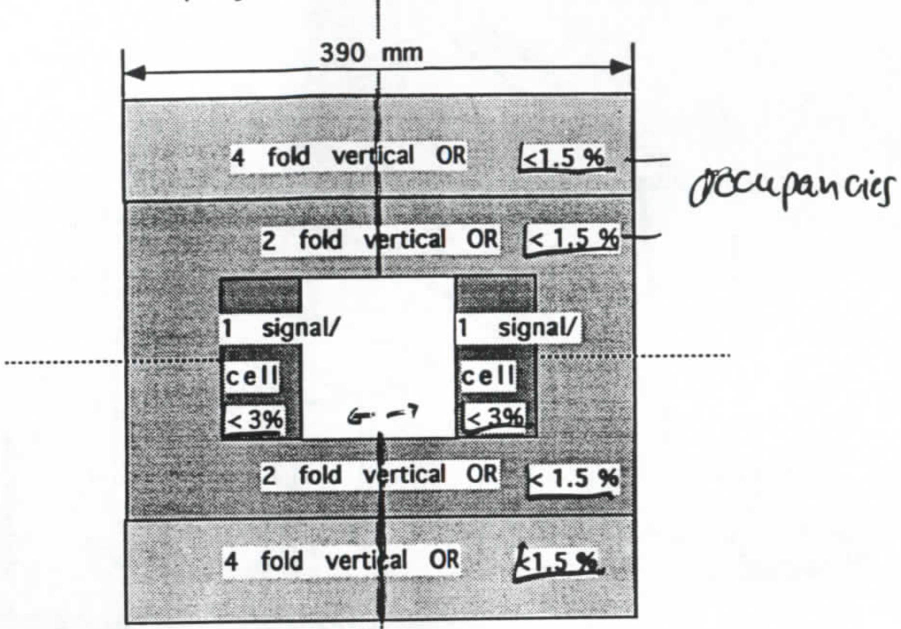
→ we are forced to measure drift time to get resolution ~ 100 µm
→ readout granularity has to be reduced to get acceptable electronic costs. → (~20.DM/TDC)

<u>basic problems:</u> (to be evaluated)
- rates are at the limit!
- space charge effects will affect resolution
- aging effects could (will) be serious

very labour intensive solution

Readout granularity for Pixel Detector (d=6mm)

occupancy / readout cell is kept below 1.5 %

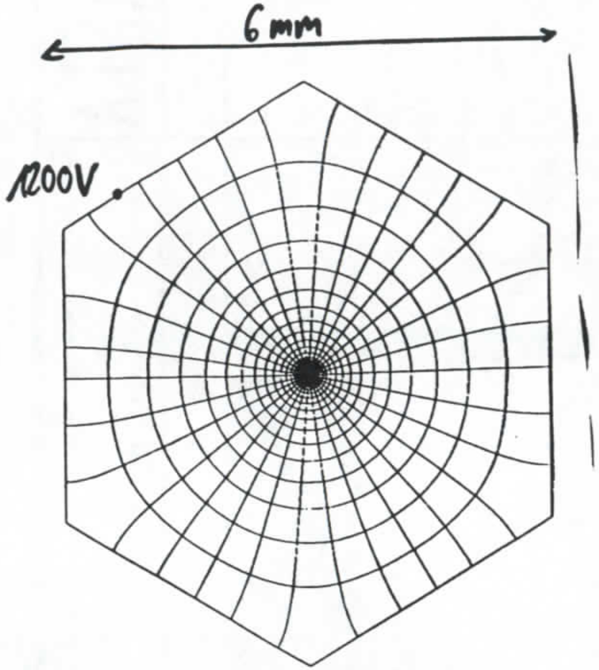


500 single cell readout channels
1000 double cell readout channels
500 4 cell readout channels

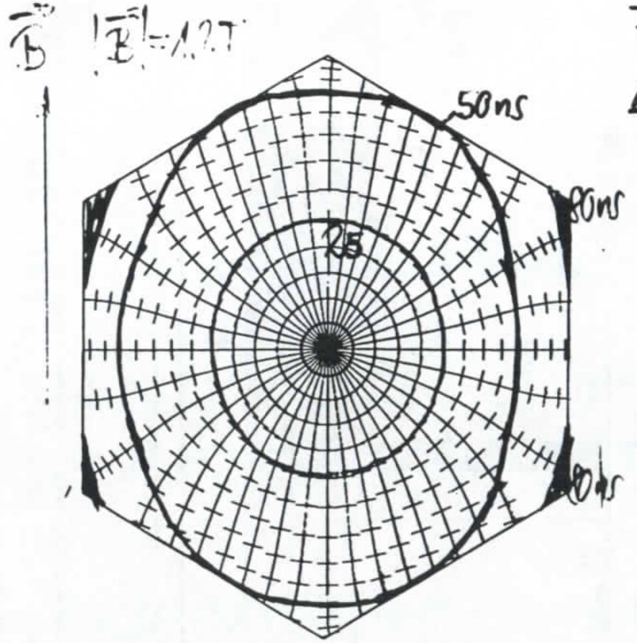
2000 readout channels/ plane

4500 pixels

Pixel Cells: field + isochrones



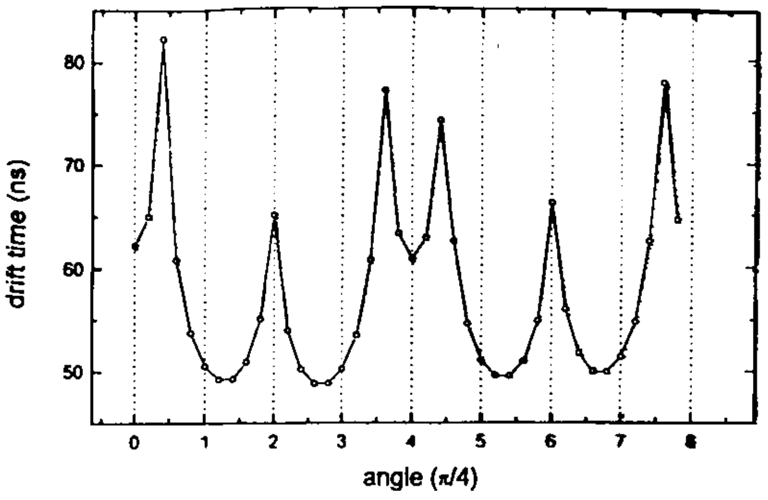
el. field lines
+ equipotentials ΔV = 50 V

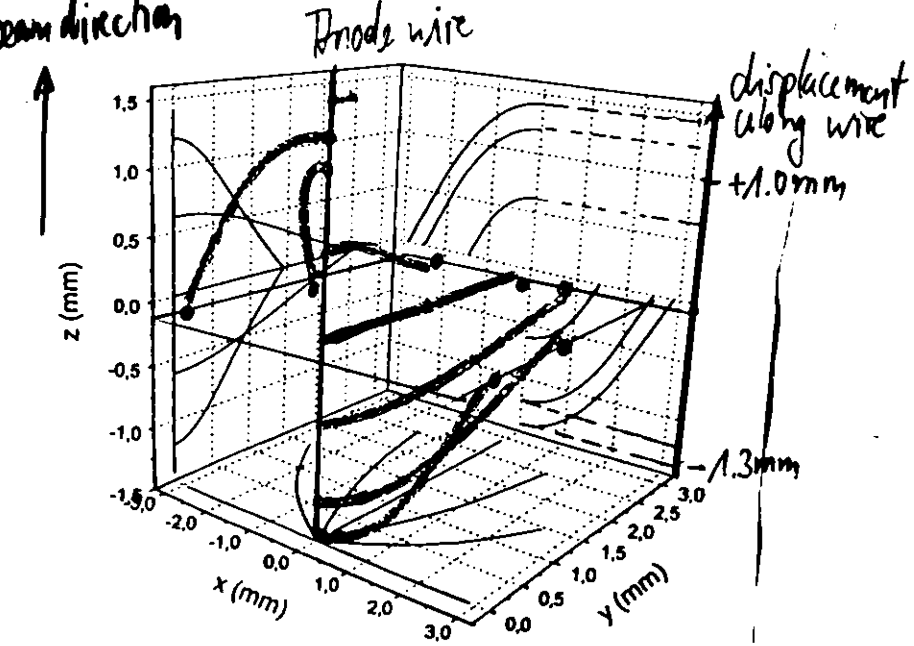


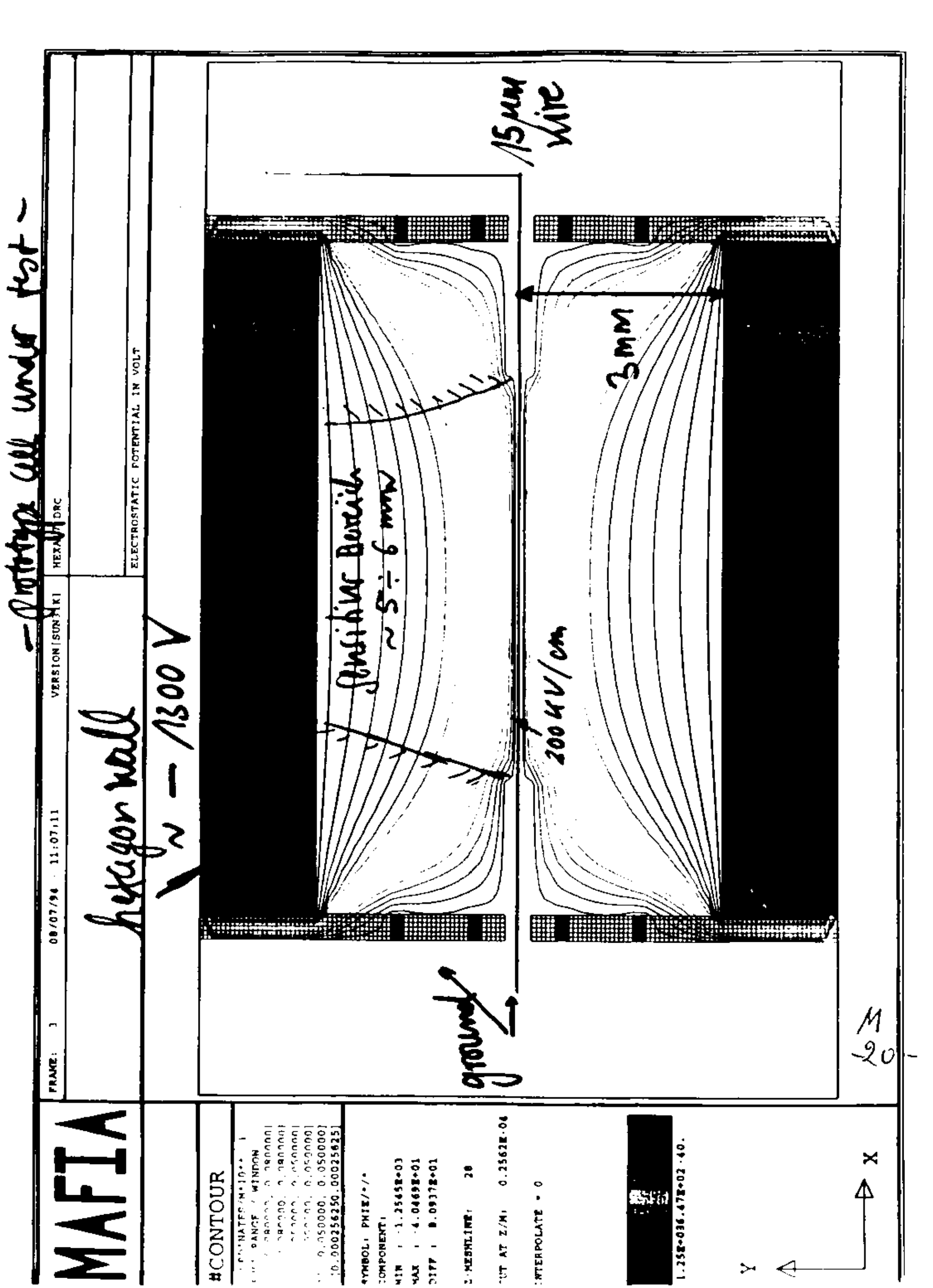
Ar : CO_2 : CF_4 (85 : 10 : 5)

$\Delta t = 5$ ns

- effective charge collection within 1 bunch crossing
- sizeable deformation of isochrones in B-field
- moderate displacement of track along wire (beam) by ≲ ±1mm


drift time (ns)
angle (π/4)


Anode wire
displacement along wire
+1.0mm
-1.3mm
z (mm)
x (mm)
y (mm)


MAFIA
#CONTOUR
ELECTROSTATIC POTENTIAL IN VOLT
hexagon wall
~ -1300 V
15 μm wire
3mm
200 kV/cm
ground

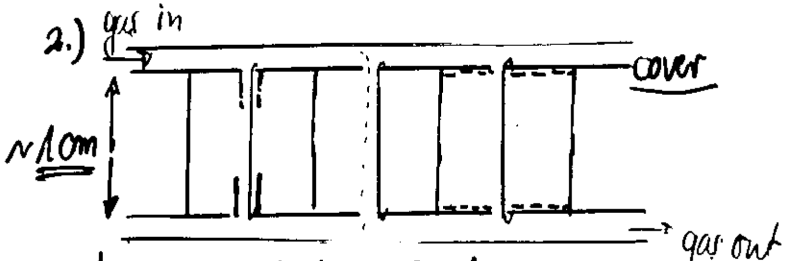
How to build pixel detector:

1) honeycomb structure: from carbon loaded polycarbonate foil (50 μm)

folding i) mechanically (Aachen) not too precise..

ii) thermoplastic folding in form ← technique developed at Aachen (Vormutti et. al.) (slow)

2.)

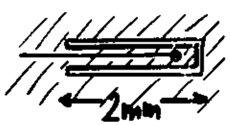


2) shaping of electrical field (cover)..

→ cell consist mainly of edge effect!

simple approach (HD)

G10 cover + shielding cylinders (passive shaping)
wire tension by G10 'spring'



ambitious approach (Si)

use of LiO ceramics + hybrid technique.
active field shaping by field electrodes on cover + resistor chain
(size limited to 10×10 cm^2)

3) readout:

i) strip lines to outer periphery (simplest)

preamplifier chip + OR-ing of channels on cover

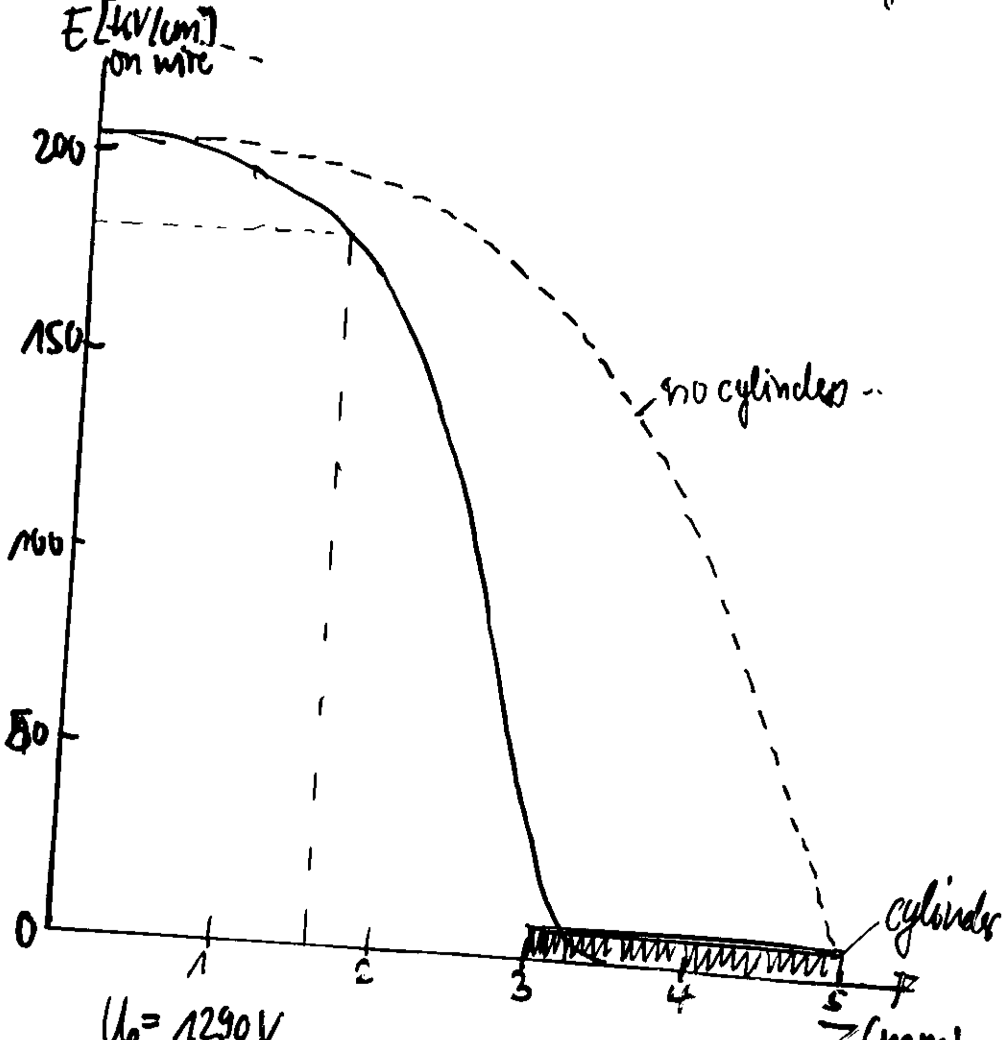
→ best S/N ratio

first test results (lab):

1) strongly varying pulse heights over sensitive volume → E-field varies along wire surface

2) 'average' gas gain at 'safe' operation voltage for Ar:CO_2:CF_4.. ≈ $6\cdot10^3 \div 10^4$

3) cells stand high rates, no gain variation yet..



$U_0 = 1290\,V$
$\phi = 15\,\mu m$

Do List Pixels:

1) single cell tests + simulations;
crucial !, ** – resolution at high rates? ⇒ beam tests
   can we tolerate 400 kHz? } also in $\vec{B}$ field
   space charge effects
2) study and test of readout structures
3.) assembly of small cell array with foils
** 4.) aging tests: crucial but difficult to get meaningful results..
5.) test of production methods
6.) trigger studies..

not yet clear how far we will go in this list
(depends on how fast we get confidence in MSGC's..

→ gas pixel solution has many drawbacks
and is by no means simple
very labour intensive

Cost: ~ 2.3 MDM (mostly electronics / 20 DM/channel)
for 7mm cells

comparison of both solutions

	MSGC's	gas Pixels
design: 1. low occupancy ≲5%	● { natural match	◎ small area ⬡ ~ [illegible]
2. resolution ≲ 100μm	● { with pitch ~ 300μm	◎ drift time measurement → space charge effects.. ◎ at the limit
3. high rate tolerance	** excellent	
4. pattern recognition	● looks good, fits well to outer tracker + Si	◉ looks feasible but problematic link to outer tra + Si
5. trigger	● 4-fold OR over strips ✓	◎ OR over subsequent plan cell overlaps, no choice in transverse granularity.
6. Robustness + long term survival? aging, long term changes of det.	◎ recent results look ?○ promising	○ will be problematic
7. mass production	● 'industrialized' to large extent. ⇑ baseline	● very labour intensive! (200 000 wires!!) ⇑ backup: pushes conven. technique to the limit

Time Planning and Milestones for Inner tracking

may 95	first milestone: decision on basic solution MSGC or Pixel

up to may 95

MSGC's:

in progress -optimisation of detector geometry and basic MSGC tests

-high rate tests (short and longterm) to study aging effects and detector deterioration

-further studies on ion migration...

-basic detector design and assembly of test

in progress detectors; preparation of assembly line

-tests of readout and trigger

Pixel detector

in progress - single cell tests and simulation gain and space charge effects at high rates and resolution (also in B-field)

- aging tests and radiation hardness

- design of detector mechanics and readout

in progress cell structure, covers, field shaping, integrated readout chip

---

95 start of mechanical construction
first full size prototype detector and tests
design of readout and trigger electronics

---

1. half 96 assembly of first layer; prototype of support structure
final mechanical design
prototypes of readout electronics

mid 96	2. milestone: test of prototype detectors at HERA

Open Collaboration Meeting
October 4–6, 1994
DESY Hamburg

The HERA-B Outer Tracking Detector

H. Kapitza, Universität Dortmund/DESY

Outline:

1. Design Goals
2. Boundary Conditions
3. Choice of Detector Type
4. OTD Design Status
5. System Alignment
6. Status of Tests
7. Project Development
8. Conclusions

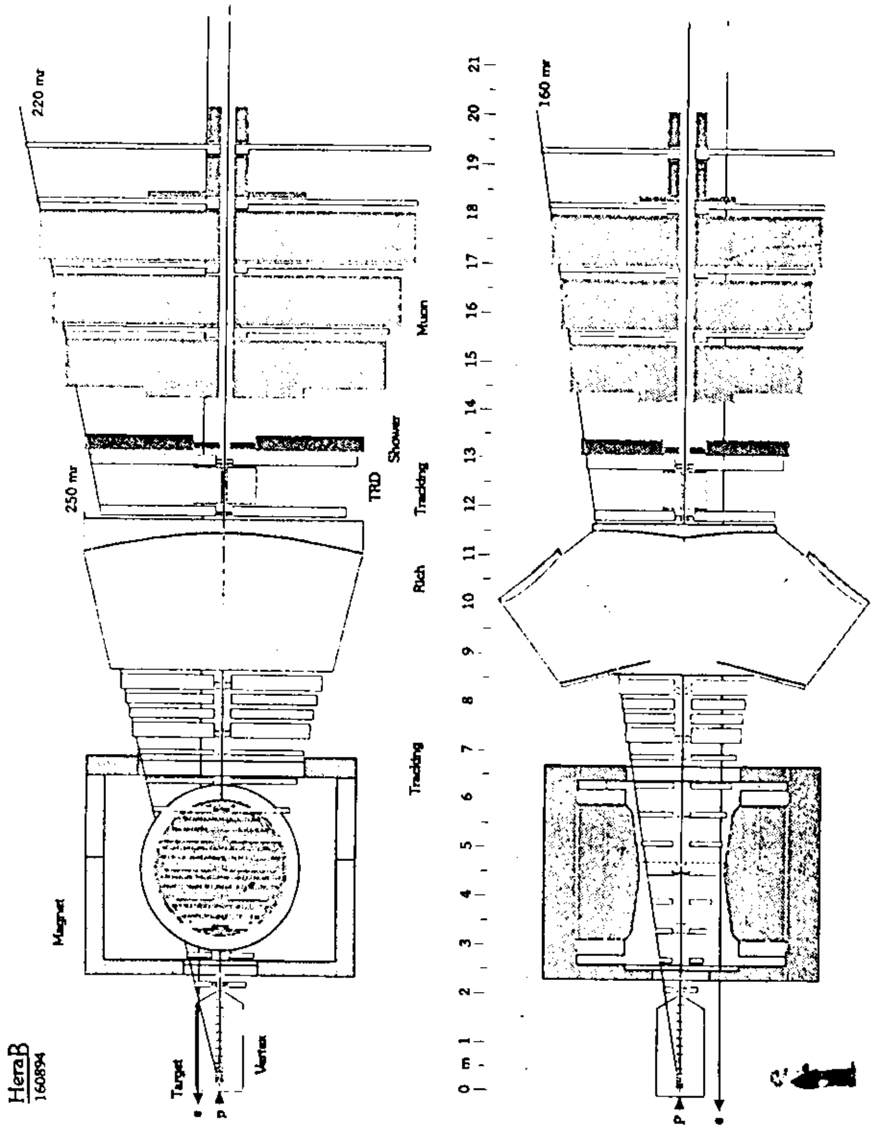
Design Goals

The Outer Tracking Detector (OTD) must provide

- $\vec{p}$ and $\vec{x}$ measurement in almost whole acceptance region, down to $r \approx 20\,\mathrm{cm}$
- sufficient impact parameter resolution to reliably link information from other subdetectors (SVX, RICH, ECAL, MUON)
- sufficient momentum resolution for narrow peaks in offline reconstruction of

$$\begin{aligned} J/\psi &\rightarrow \ell^+\ell^- \\ K_S^0 &\rightarrow \pi^+\pi^- \\ B^0 &\rightarrow J/\psi K_S^0 \end{aligned}$$

- a high single hit efficiency and sufficient cell granularity for J/ψ identification by First Level Trigger (using only hits)



N 3

Boundary Conditions

Most design aspects are governed by

high particle density in space and time

- $\mathcal{O}(100)$ charged multiplicity every 96 ns
- downstream increase due to secondary interactions
- radial dependence:

$$\frac{dn}{dA} \approx \frac{3}{r^2} \text{ per BUNX} = \frac{30\,\text{MHz}}{r^2} \quad (r \text{ in cm})$$

Consequences for tracking detector

demand	requires
low occupancy (< 15 %)	small drift cells (d and ℓ)
low surface fields (aging)	solid drift cell walls
few secondaries	thin low L_R materials
radiation hardness	proper materials
event separation	fast drift gas

Less severe, just annoying:

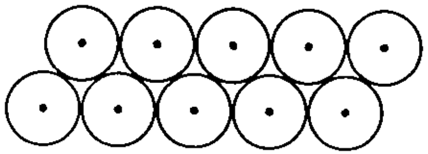
HERA beam pipe geometry in West Hall

N 4

Choice of Detector Type

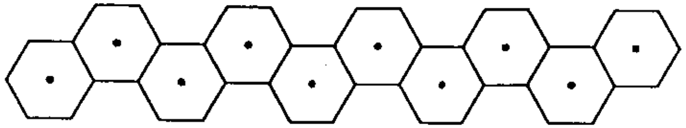
Rate-related requirements are fulfilled by two detector types (investigated for SSC/LHC):

Straw Drift Tubes (SDT)

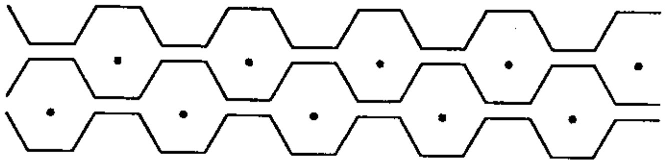


- Each straw must be separately prepared → time and manpower consuming
- Is the Dubna welding technique and infrastructure a cost-efficient alternative (feed-throughs to be provided)?
- Can handle small units → short development cycles.
- Stabilization and positioning of long straws requires additional support structures.
- Sense wire support/interruption complicated.

Honeycomb Drift Chambers (HDC)



- Self-supporting and open chamber production well suited for mass-producing many channels:



- Complex units must be produced already in R&D phase → large tooling overhead (but experience at NIKHEF)

A decision on the basic detector type must be made soon!

-- Strip Chambers (anode + cathode readout):

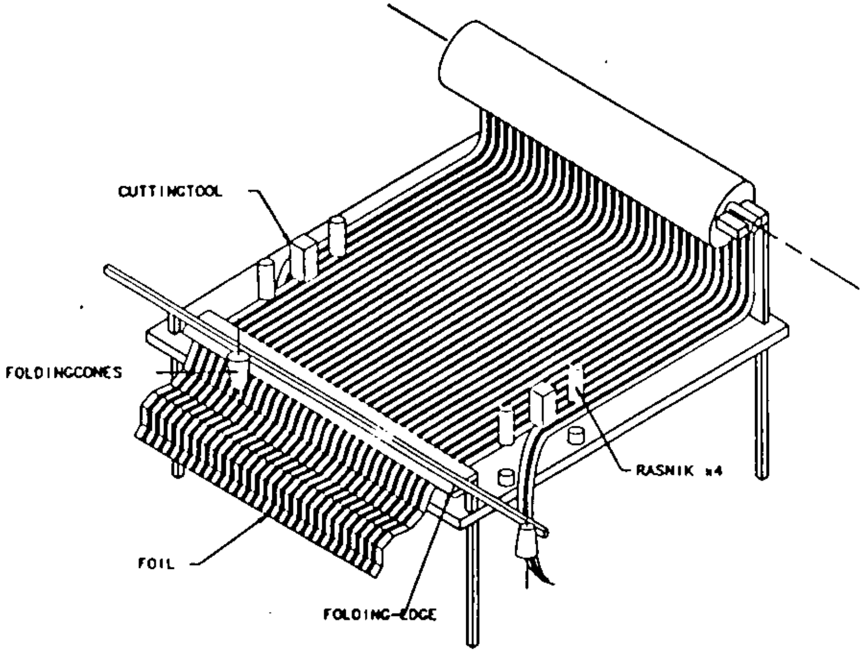
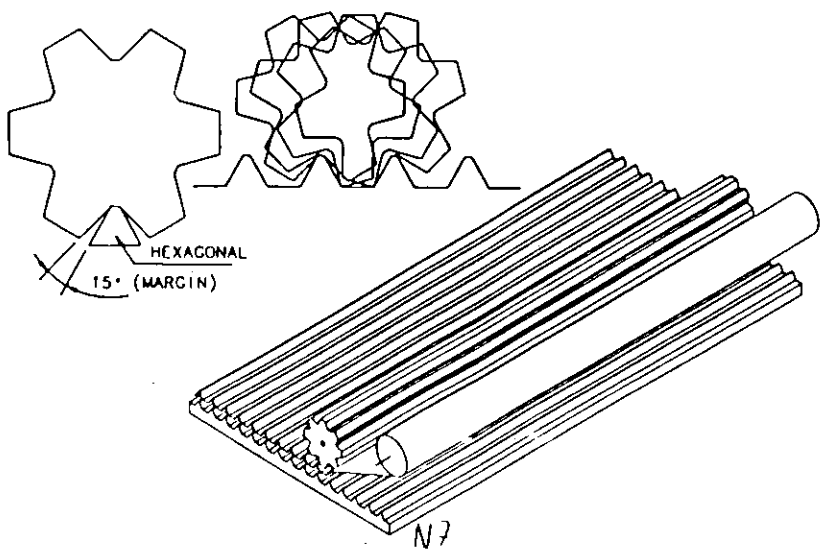


Figure 34: *Machine used to fold mylar foils.*

-- Aluminium Chambers :



N7

- vacuum between template and foil
-- plastic edge blocks glued at cell ends
-- mounting of wires
-- top foil in 2. template lowered on bottom f.
-- joining by glue, spot welding or ultrasonic w.

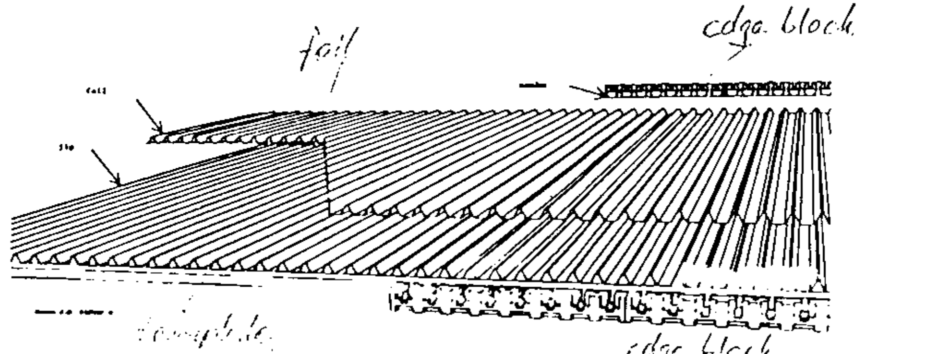


Figure 6: *Schematic assembly of monolayer: foil-template and end-combs are shown.*

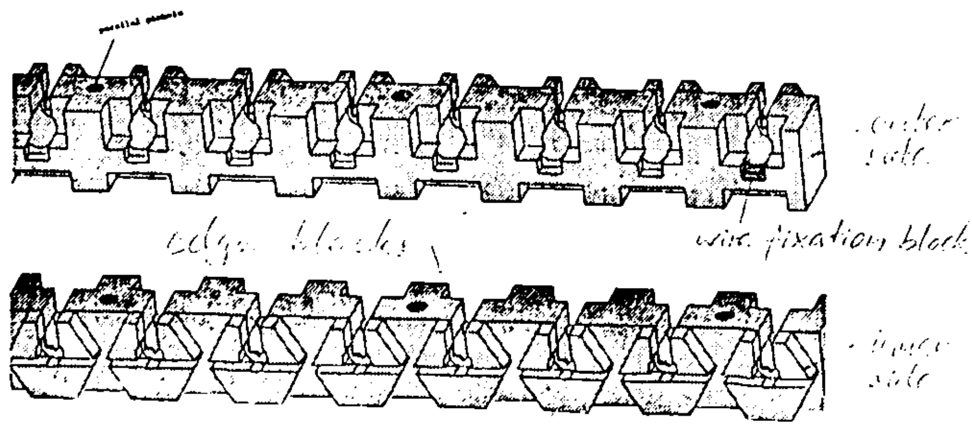


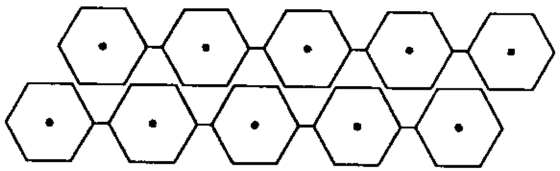
Figure 7: *The plastic mould-injected edge blocks. Top: outer side (the Cu/Te blocks with the slits for wire fixation are not in place). Bottom: inner side; the hexagonal shape of the individual cell is clearly visible.*

N8

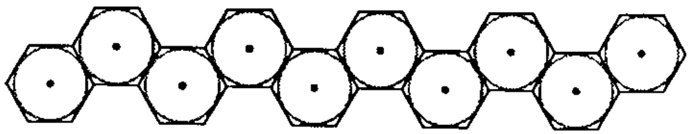
OTD Design Status

Our current design assumption are Honeycomb Drift Chambers which have been built at NIKHEF and Aachen.

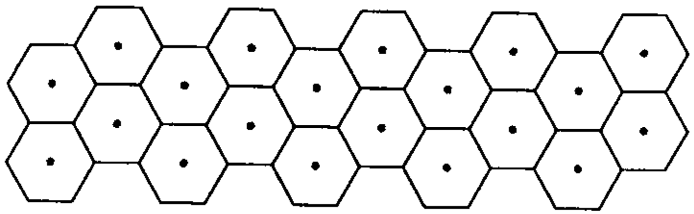
efficient NIKHEF layer



single Aachen layer



double Aachen layer (for FLT)



Aachen layers are our current design assumption.

Layer Materials

We consider various 50–70 μm thick polymer foils:

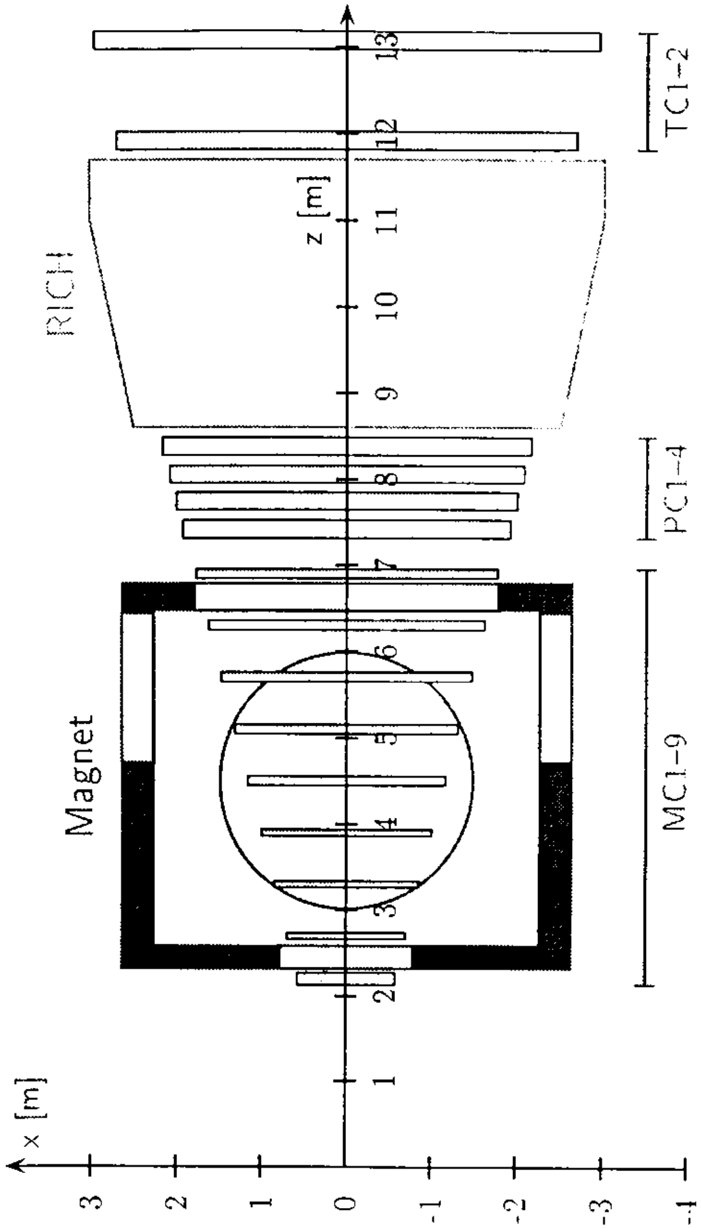
material	radiation hardness
Cu-coated Kapton	$> 2.2\,C/cm$
C-loaded Kapton	$> 5\,C/cm$
Polycarbonate	not tested

Avoid thin aluminum layers!

Drift Gas

- need a fast gas:
  → use CF_4 based mixture ($v_D \approx 100\,\mu m/ns$)
  → with 1 ns time resolution 150 μm spatial resolution achievable
- expect to collect 0.2 C/cm/y in cell closest to beam
  → no aging problem (3 %/C/cm gain reduction observed for CF_4/iC_4H_{10} (80/20) in SDC tests)

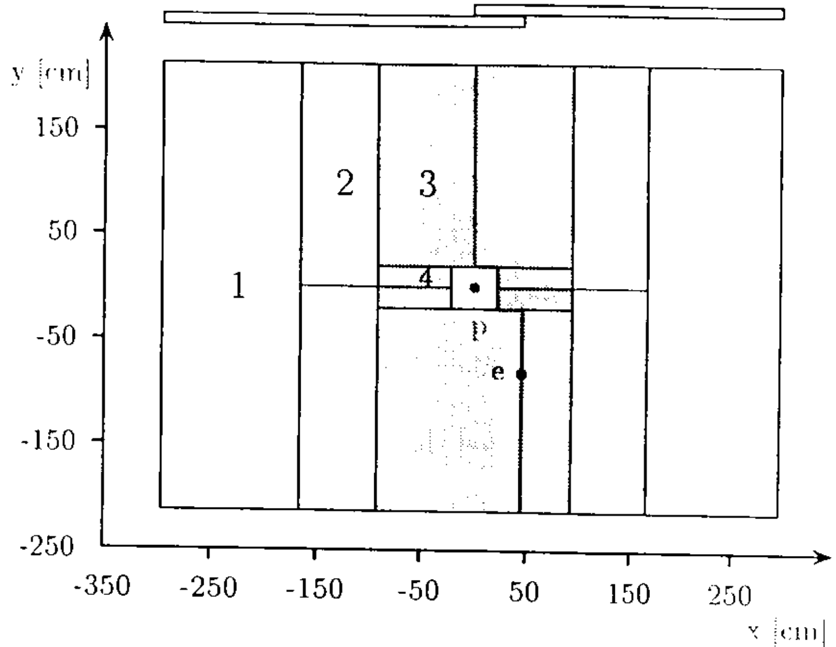
Detector Overview



N 11

Superlayer Structure

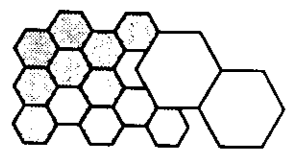
Low occupancy enforces segmentation of superlayers:



10 mm cells

5 mm cells

— wire separation

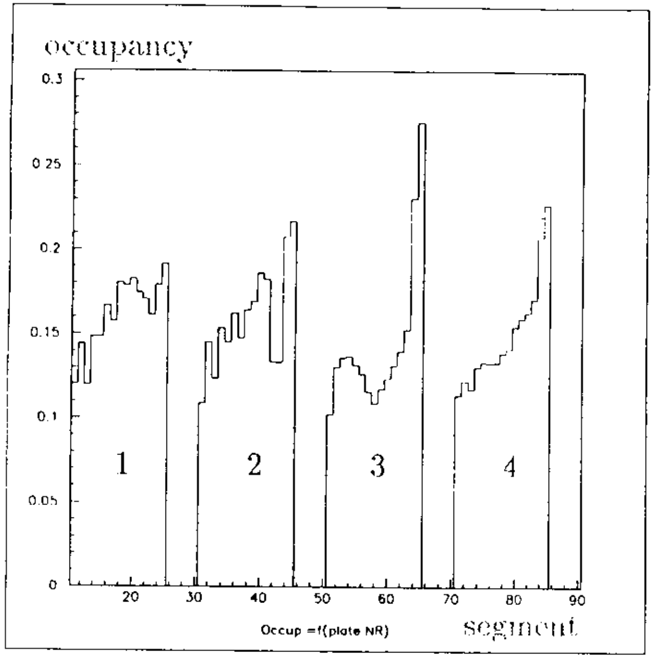


small/large cell transition

All wires are vertical and are read out at top or bottom.

N 12

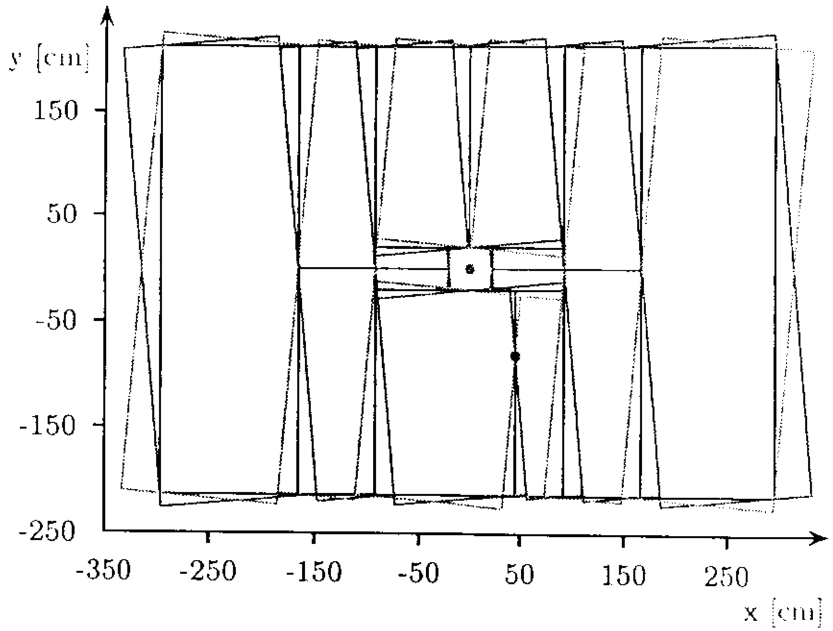
Occupancies in all Segments



- Only worst wire in each segment shown.
- Many secondaries after the RICH.
- Needs further optimization to stay below 15 %.

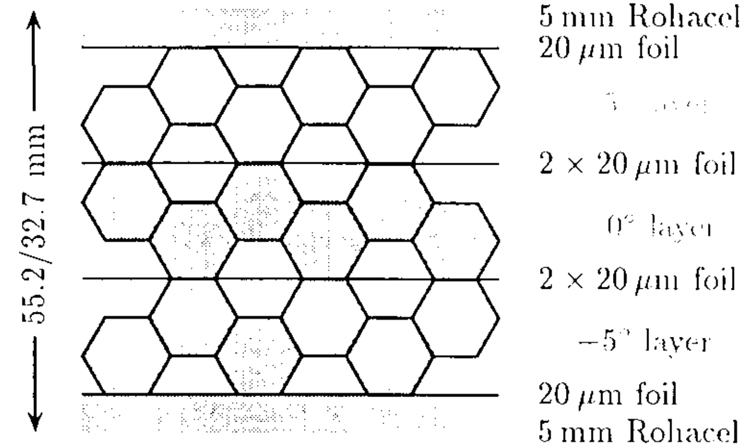
Stereo Layers

- 3D-information will be obtained from stereo wires.
- Small stereo angle (±5°) keeps # ambiguities low.
- Bad resolution in non-bending plane acceptable.
- Segmentation of superlayer TC2:



Constructional Details

• Superlayer segment of single HDC layers:



- Aim at 100 μm precision of wire positions (largely determined by end-pieces).
- Stabilize superlayer modules with Rohacel plates.
- Sandwiching with thin C-fibre plates allows for layer alignment in support frame (gauge holes).
- Chamber support on top and bottom (8 mrad tilt of p beam).

Detector Summary

Technical Summary:

total # channels:	97 000
total radiation length:	11.7 %
total volume:	5.6 m^3
total wire length:	105 km
total foil area:	1100 m^2

Performance Assumptions:

- 150 % design resolution = 225 μm
- 3.3 Tm magnet

Performance Results:

- momentum resolution:

$$\frac{\Delta p}{p} \approx 4.5 \cdot 10^{-5} p \oplus 2.5 \cdot 10^{-3}$$

- mass resolutions:

$$J/\psi \to \mu^+\mu^- \quad : \quad \sigma(m) \approx 9\,\mathrm{MeV}/c^2$$
$$B^0 \to J/\psi K^0_S \quad : \quad \sigma(m) \approx 6\,\mathrm{MeV}/c^2$$

System Alignment

Relative alignment of OTD modules will be a 3-step process:

- Rough optical alignment during installation to $\approx 500\,\mu$m (bad accessibility later)
- Regular operation of a dedicated alignment system ($< 50\,\mu$m) during data taking:
  - infra-red laser plus Si-strip detectors can align many modules (MPI Munich)
  - LED plus photodiode or CCD can also align z-position (NIKHEF)
- Final alignment from offline data analysis.

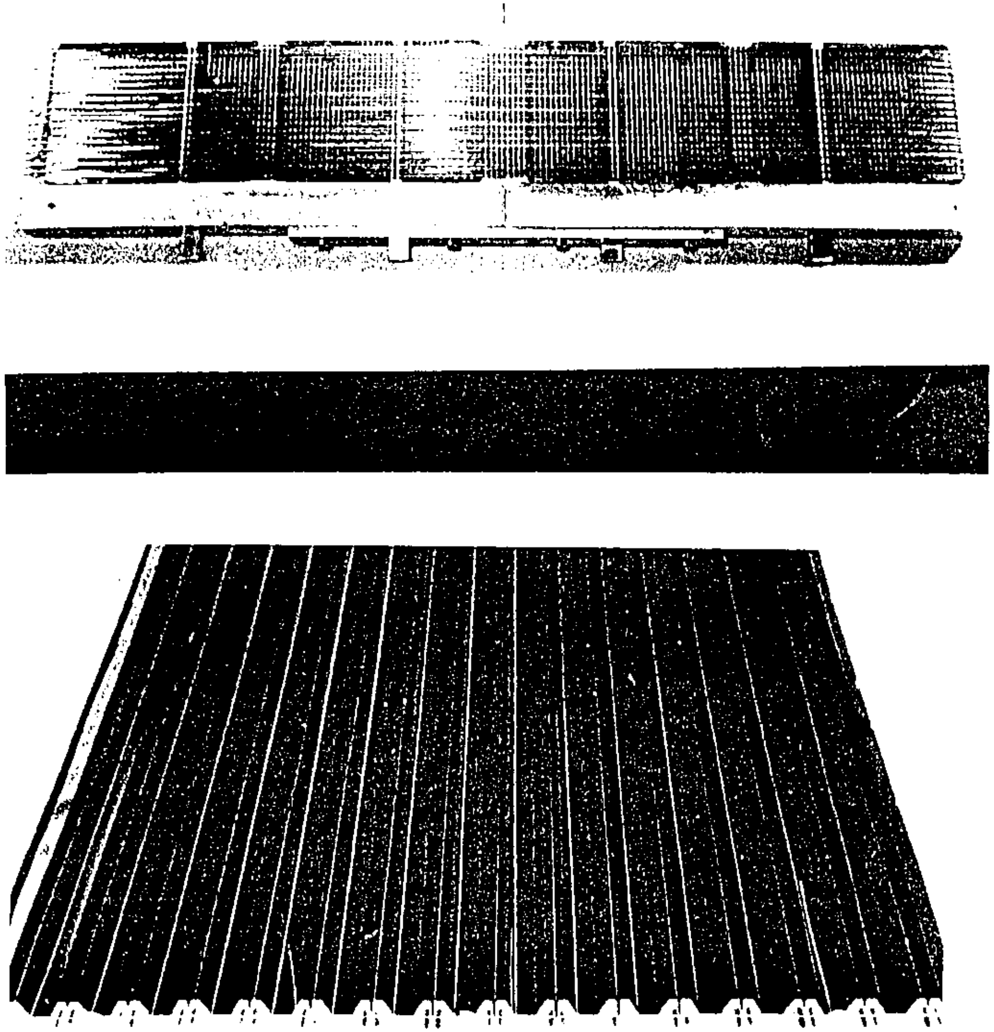
Status of Tests

ongoing:

- Assembly of HDC monolayers (18 5-mm-cells, 80 cm long) using foils folded at NIKHEF.
- Wire separation in large drift cells.
- Various gas mixtures.

planned:

- Need set of production tools if HDC's to be built.
- Foil treatment (folding plus tempering?)
- Performance and radiation hardness of polycarbonate foil (?)
- Assembly of HDC module (Aachen cells) showing all details in large — small cell transition region.
- Readout components.



Project Development

- Tentative time schedule:

decision on detector type	soon
finish material studies	Dec 94
start with prototypes	Mar 95
install prototypes	Dec 95
start mass production	Mar 96
installation of last modules	Dec 97

- Participating institutes:
  DESY Hamburg/Zeuthen
  Uni Hamburg
  Uni Dortmund
  Humboldt Berlin
  INFN Bologna
  INFN Roma

  Expressions of interest:
  Beijing
  JINR Dubna

  More are clearly welcome!

Conclusions

- We have a global design for the Outer Tracking Detector which satisfies the (known) boundary conditions, but essential design features are not fixed yet.
- Tests of single design aspects have started or are under preparation.
- Aim at installing first prototype in Dec 1995.
- The time schedule is tight — strengthen the team!

HERA-B

PERFORMANCE OF THE TRACKING SYSTEM

RAINER MANKEL
HUMBOLDT UNIVERSITÄT
BERLIN

OFFLINE RECONSTRUCTION

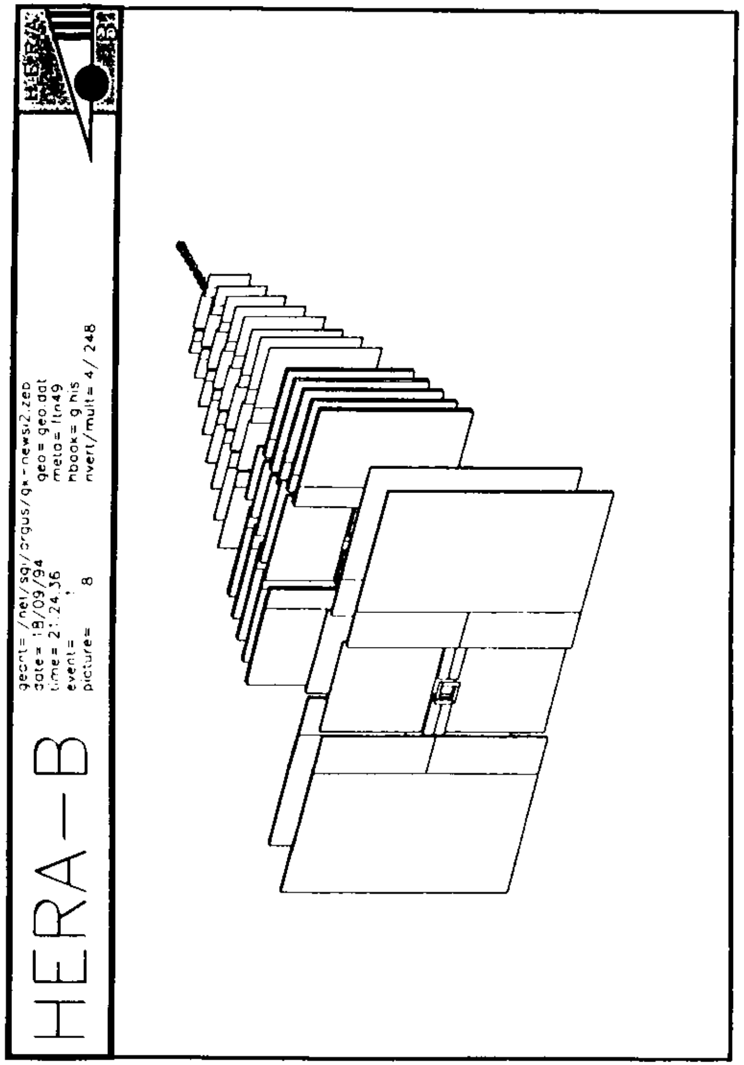
WHY NOW ?

- LARGE TRACK DENSITIES, SECONDARIES
- PATTERN RECOGNITION DEMANDS DETERMINE GRANULARITY
- GRANULARITY ⟷ EFFORT

▶ RECONSTRUCTION STUDIES AT THIS POINT CRUCIAL FOR DETECTOR DESIGN

NEED:

- EVENT GENERATION (PYTHIA + FRITIOF)
- REALISTIC DETECTOR MODEL(S) (MATERIAL + DIGITIZATION)
- FULL EVENT SIMULATION (GEANT)
- PROTOTYPE PATTERN RECOGNITION + TRACK / VERTEX FITTING
- RESOLUTION TRACING


HERA-B
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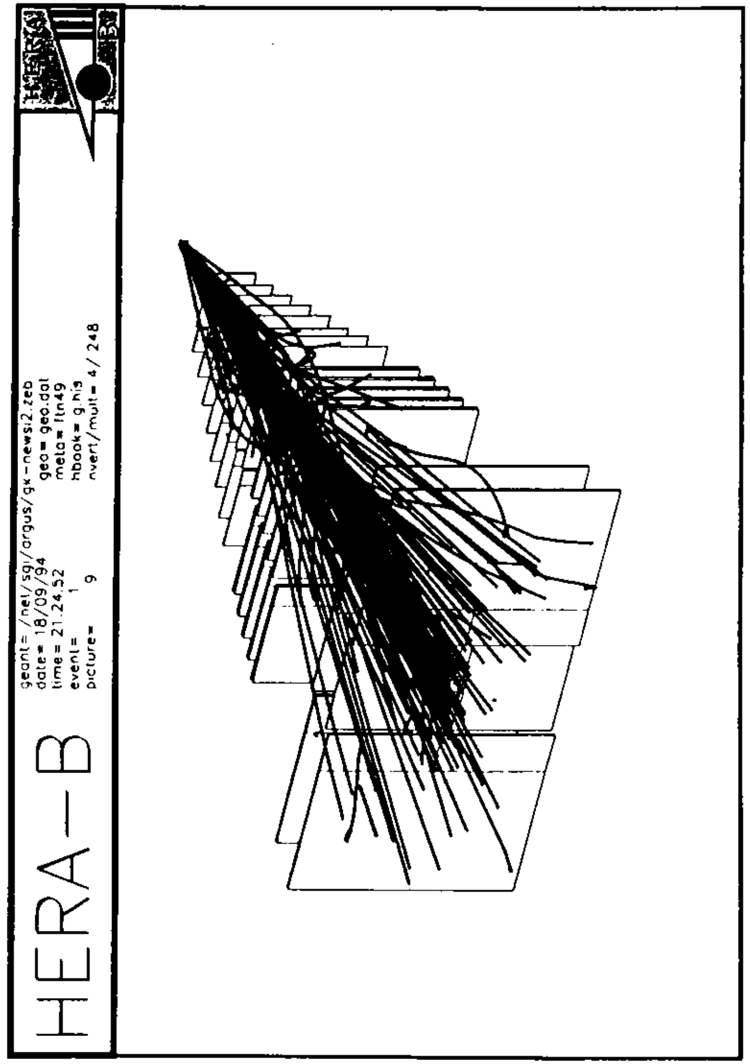
date= 18/09/94
time= 21.24.36
event= 1
picture= 8
geo= geo.dat
meta= ltn49
hbook= g.his
nvert/mult= 4/248

0 -3-


HERA-B
geant= /net/sgi/argus/gx-newsi2.zeb
date= 18/09/94
time= 21.24.52
event= 1
picture= 9
geo= geo.dat
meta= ltn49
hbook= g.his
nvert/mult= 4/248

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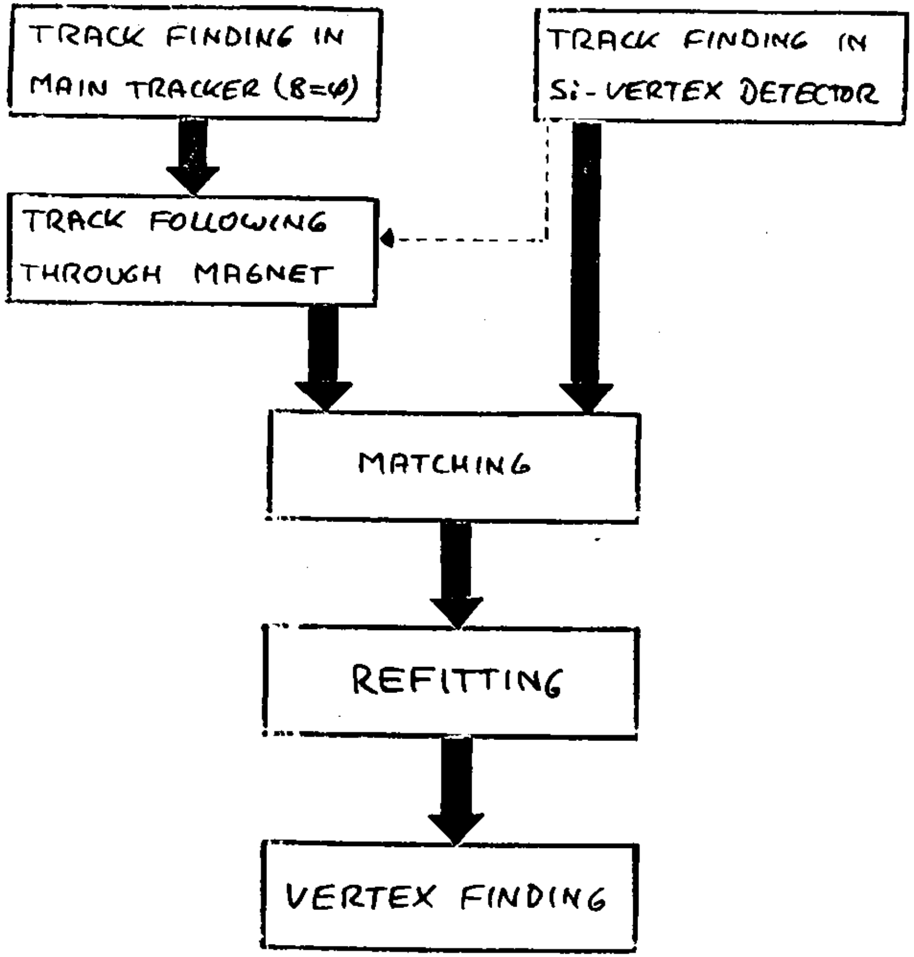
TRACK FINDING & TRACK RECONSTRUCTION

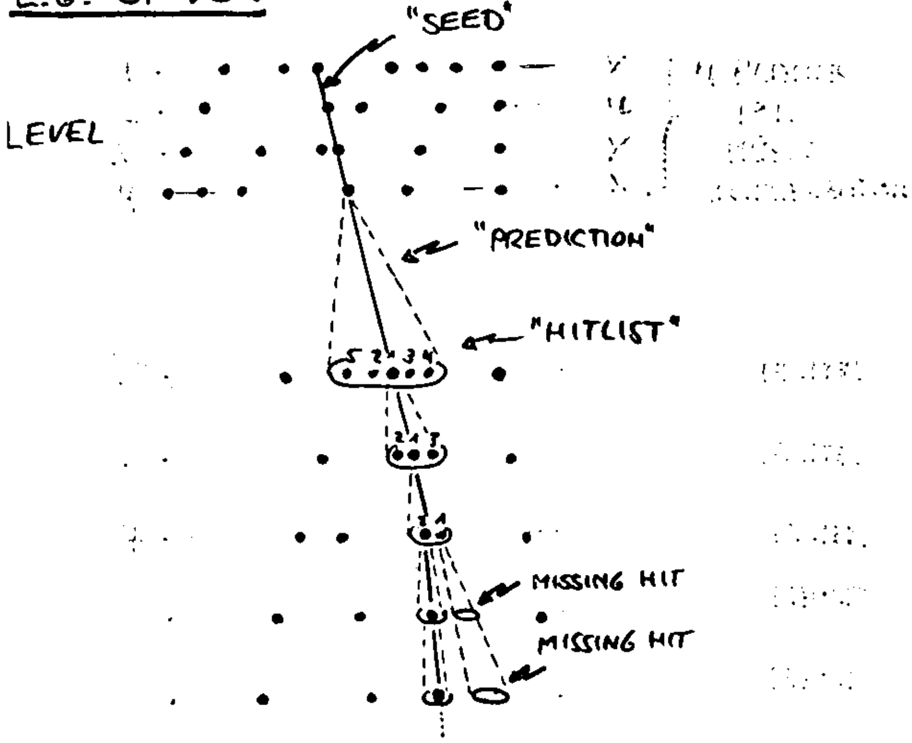
BASIC STRATEGY:



TRACK FINDING/TRACK FOLLOWING

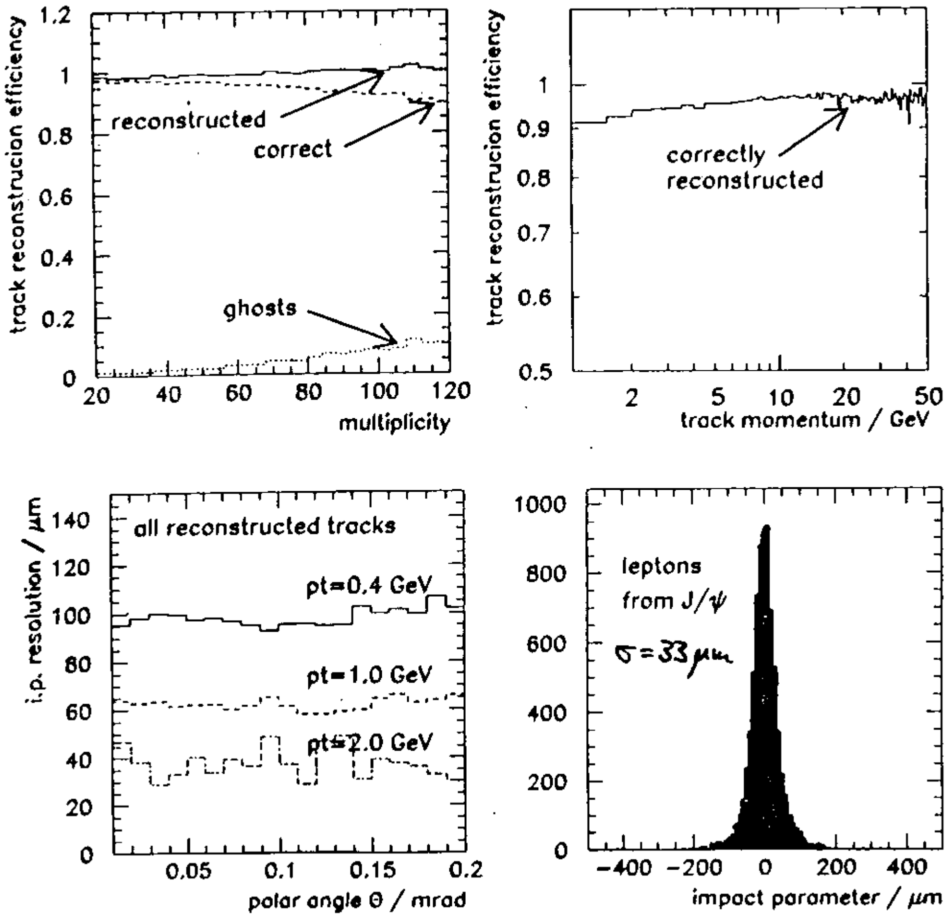
- 3D (VD, GPC) OR 2D (HONEYCOMBS, MSGC)
- "SEED" FROM NEARBY PLANES
- KALMAN FILTER TECHNIQUE

E.G. Si-VD:



- MULTIPLE SCATTERING ACCOUNTED FOR AS "PROCESS NOISE"
- TOLERATES MISSING HITS (FAULTS)

TRACK FINDING PERFORMANCE IN Si-VD



- $\langle \epsilon \rangle > 94\%$ FOR $P > 5$ GEV
- FOR LEPTON FROM GOLDEN B DECAY, $\langle \epsilon_\ell \rangle = 98\%$

TRACK FINDING IN MAIN TRACKING SYSTEM

- LARGER OCCUPANCY (HONEYCOMBS)
- ADDITIONAL L/R AMBIGUITY (HONEYCOMBS)
- OUTER (STRAWS) & INNER TRACKING (MSGC's) NOT INDEPENDENT

► TRACK FOLLOWING IN PROJECTIONS INSTEAD OF 3D. USE KALMAN-FILTERING

BASIC PRINCIPLE:

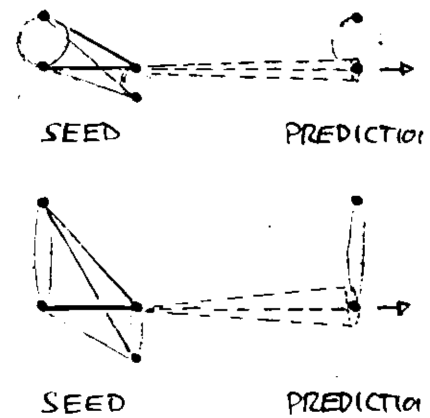
FIND XZ PROJECTION OF TRACK USING ϕ° LAYERS ONLY

↓

FIND YZ PROJECTION OF TRACK USING STEREO LAYERS

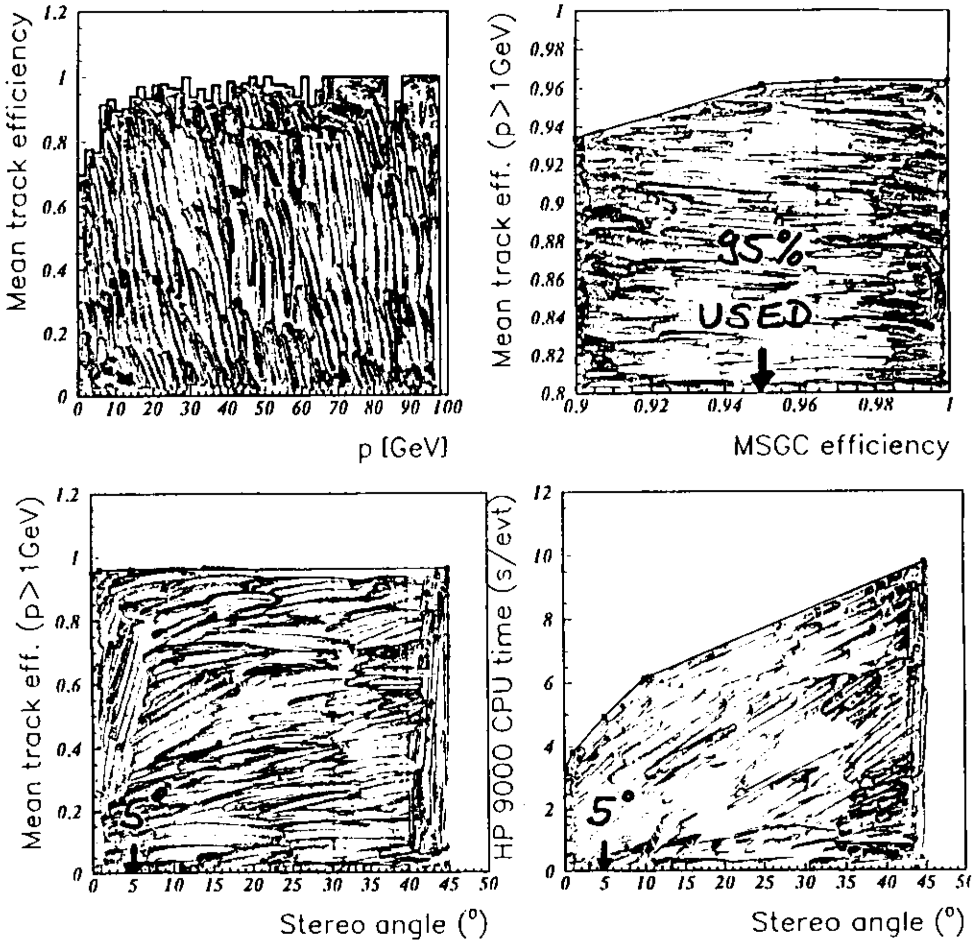
↓

FULL 3D RECONSTRUCTION OF TRACK USING ALL LAYERS

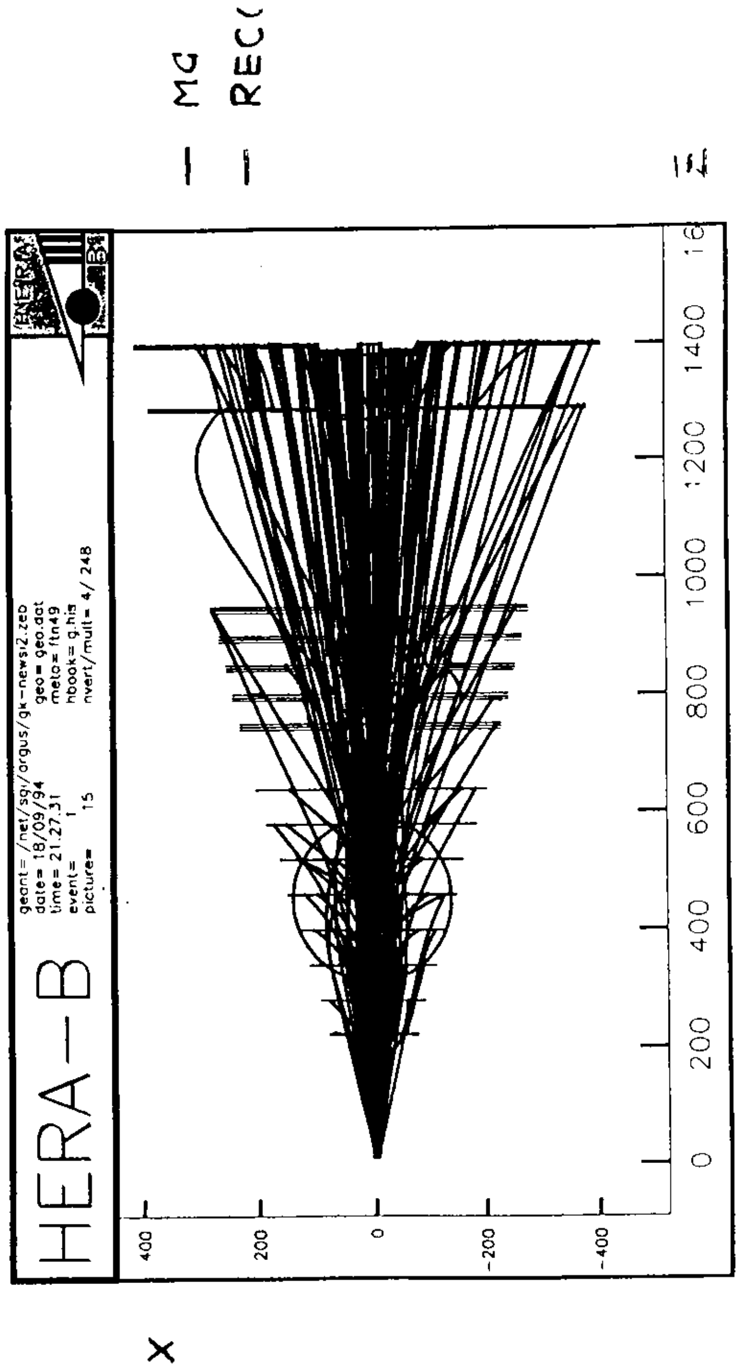


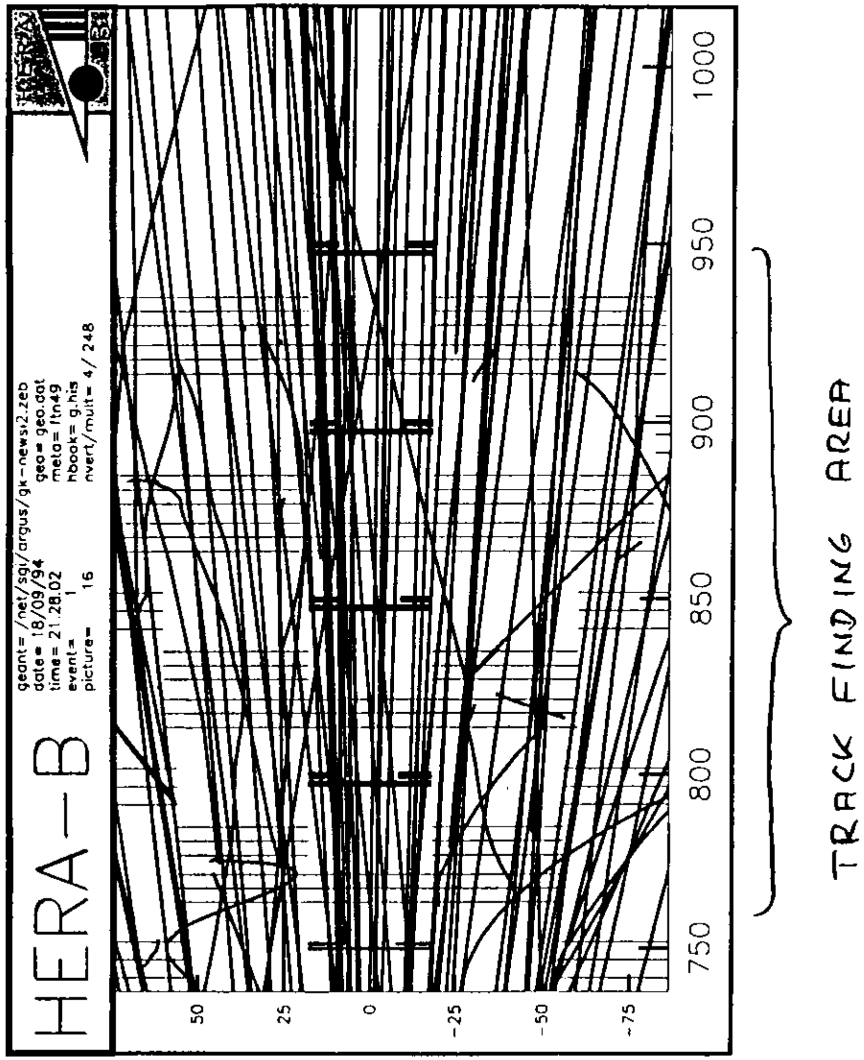
TRACK FINDING PERFORMANCE IN INNER MAIN TRACKING (MSGC's)

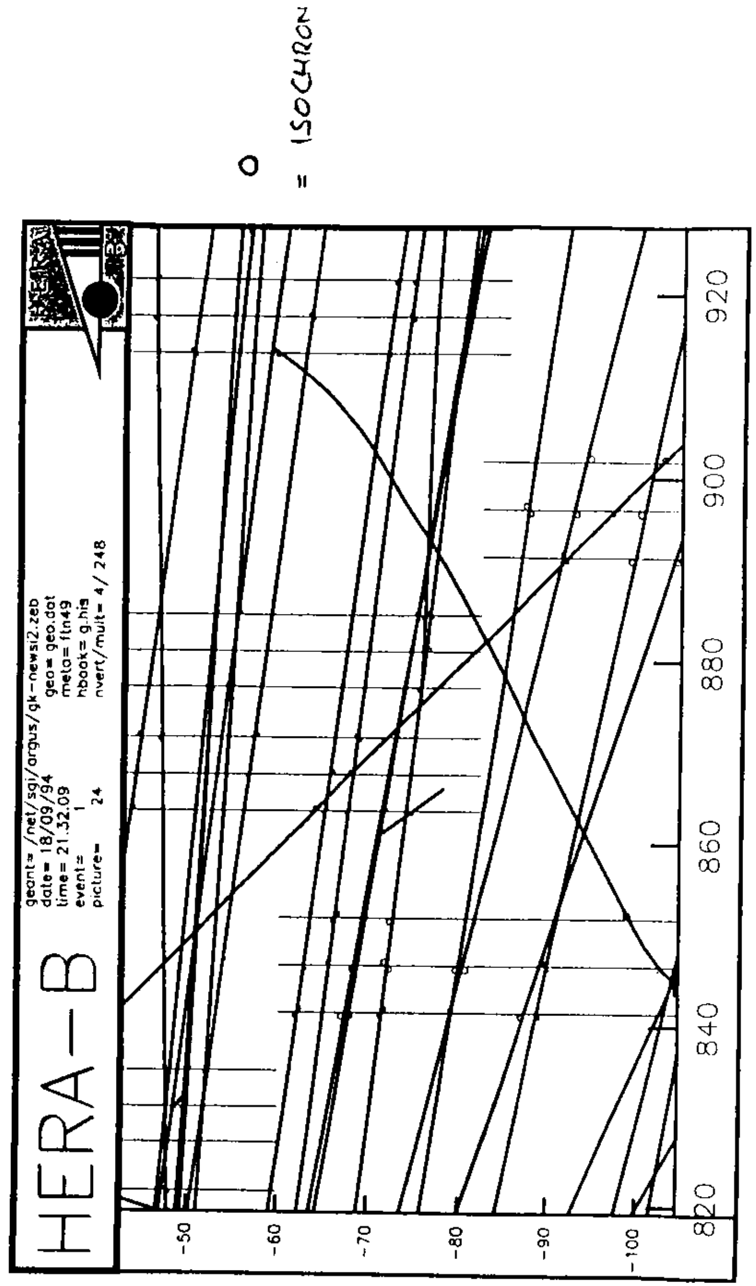
FOR CHARGED PARTICLES WITH $p > 1$ GeV



- FAULT TOLERANCE
- ε ALMOST INDEPENDENT OF STEREO ANGLE
- FASTER FOR SMALL STEREO ANGLE




HERA-B
geant= /net/sgi/argus/gk-newsi2.zeb
date= 18/09/94
time= 21.28.02
event= 1
picture= 16
geo= geo.dat
meta= ftn49
hbook= g.his
nvert/mult= 4/ 248
750
800
850
900
950
1000
50
25
0
-25
-50
-75
TRACK FINDING AREA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HERA-B
geant= /net/sgi/argus/gk-newsi2.zeb
date= 18/09/94
time= 21.32.09
event= 1
picture= 24
geo= geo.dat
meta= ftn49
hbook= g.his
nvert/mult= 4/ 248
820
840
860
880
900
920
-50
-60
-70
-80
-90
-100

TRACK FINDING EFFICIENCY FOR MAIN TRACKING SYSTEM

- FOR TRACKS WITHIN GEOM. ACCEPTANCE

	$\epsilon_{T.F.}$ INNER	OUTER	BOTH
$X^{\pm}$ $p > 1$ GeV	98%	94%	94%
$\{e, \mu, \pi\}_{GOLD}$	98%	96%	95%
B^0_{GOLD}	-	90%	90% ← 4 TRACKS!

► RELEVANT TRACKS HAVE $\epsilon > 95\%$

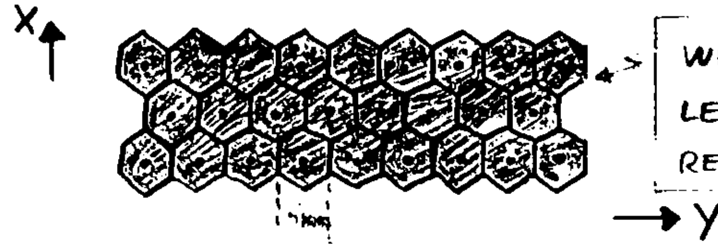
► REASONABLE EFFICIENCY FOR $B^0 \to J/\psi\, K^0_S$

► $\epsilon_{B^0} > \epsilon_{l^+} \epsilon_{l^-} \epsilon_{\pi^+} \epsilon_{\pi^-}$ DUE TO EFFICIENCY CORRELATIONS

► BEGINNING ONLY, EXPECT IMPROVEMENTS

GAS PIXEL CHAMBERS (GPC)

- "CONVENTIONAL" ALTERNATIVE TO MSGC's FOR INNER MAIN TRACKING



WIRES ∥ z
LENGTH 1 cm
RESOLUTION 100 μm

- TRACK FINDING POSSIBLE ?

▷ DEVELOP METHOD BASED ON 4-RINGLET SEEDS & 3D TRACK FOLLOWING

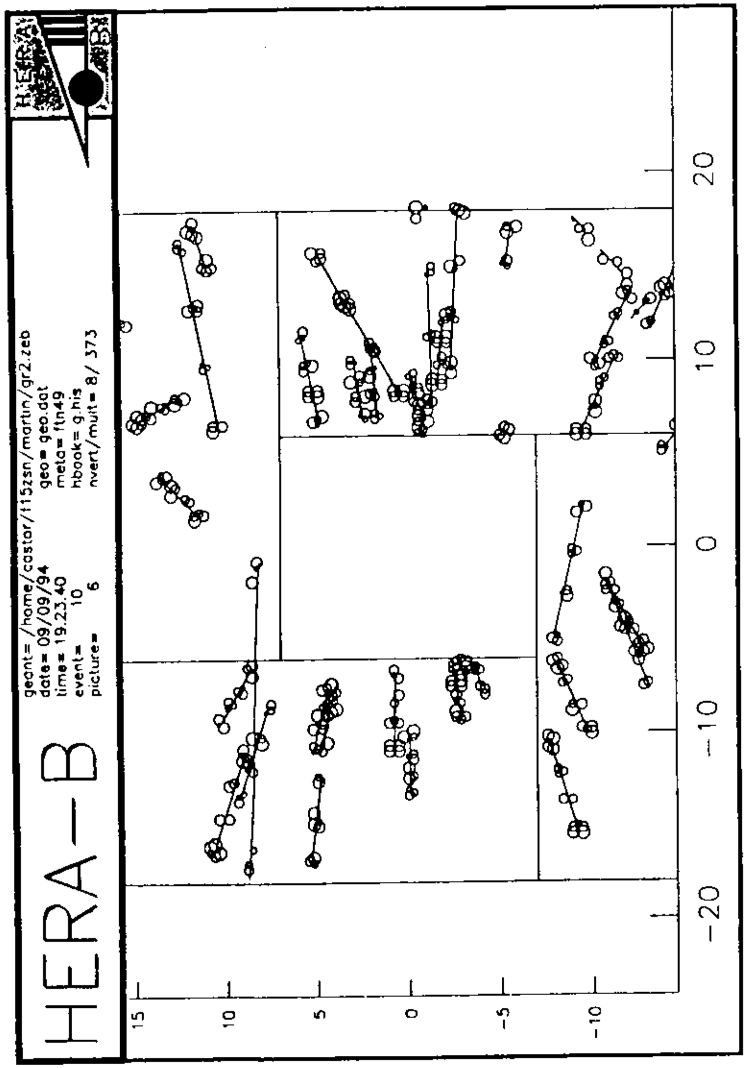
- KALMAN FILTER WITH LINEARIZED $H_i \to \frac{\partial h_i^{(i)}}{\partial x_k}$

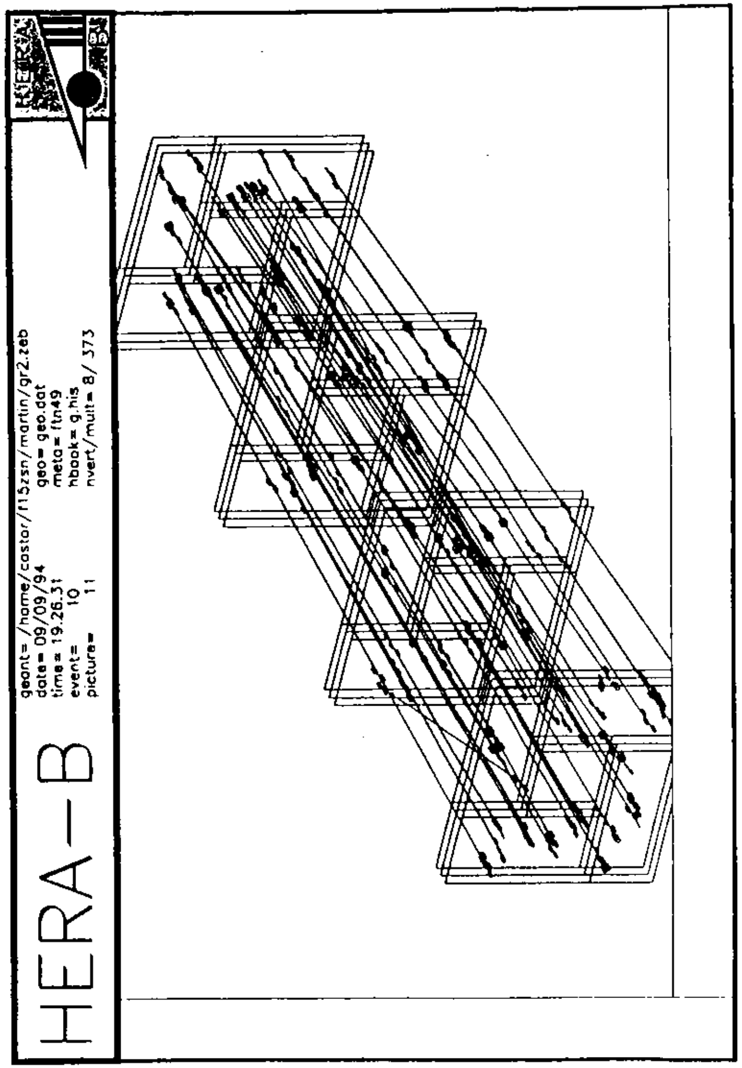
► SUCCESSFUL GPC-TRACK RECONSTRUCTION, $\epsilon_{T.F.} \sim 90\%$

► SLOWER THAN IN MSGC (ITERATIONS!)

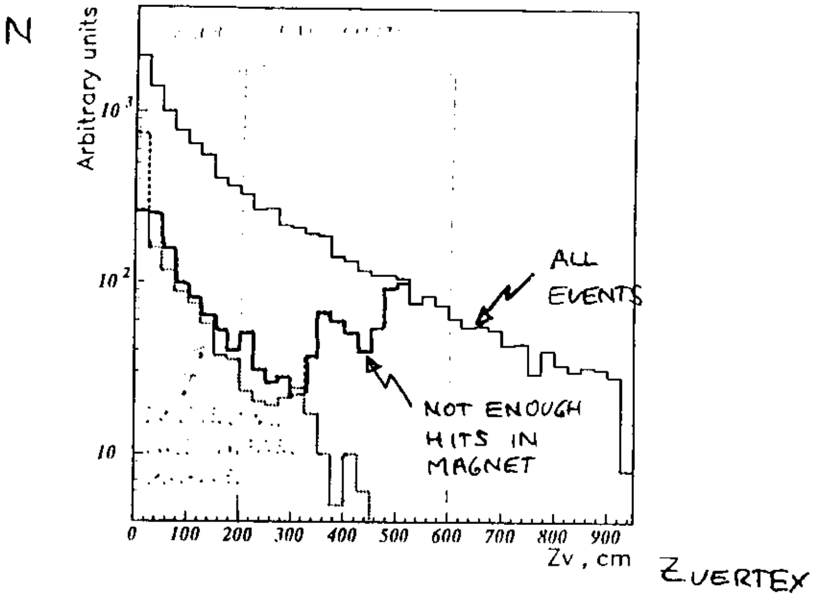
► INCOMPATIBLE WITH OUTER TRACKING

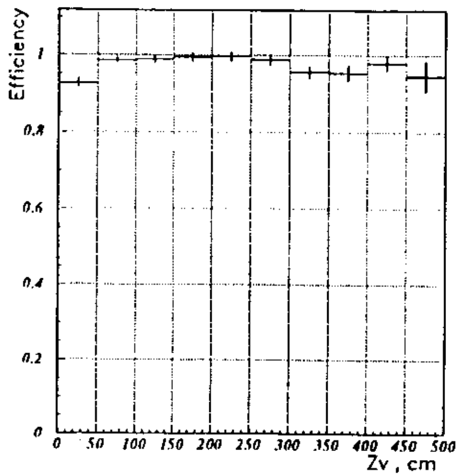
► VIABLE FALL-BACK SOLUTION

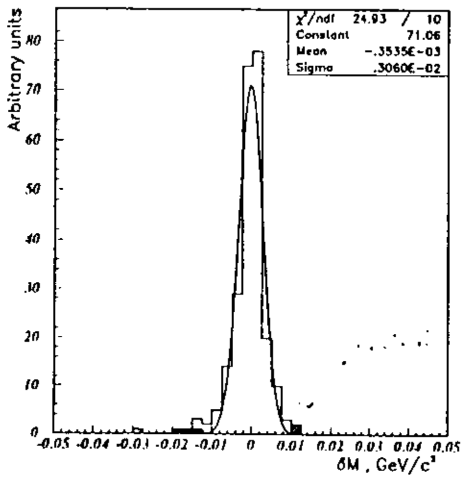

HERA-B
geant= /home/castor/f15zsn/martin/gr2.zeb
date= 09/09/94
time= 19.23.40
event= 10
picture= 6
geo= geo.dat
meta= ftn49
hbook= g.his
nvert/mult= 8/ 373
20
10
0
-10
-20
15
10
5
0
-5
-10


HERA-B
geant= /home/castor/f15zsn/martin/gr2.zeb
date= 09/09/94
time= 19.26.31
event= 10
picture= 11
geo= geo.dat
meta= ftn49
hbook= g.his
nvert/mult= 8/ 373

K_S^0 RECONSTRUCTION







- $\epsilon^{RECO}_{K_S^0} = 97\%$, $r_{GHOST} = 2\%$

TRACKING RESOLUTION

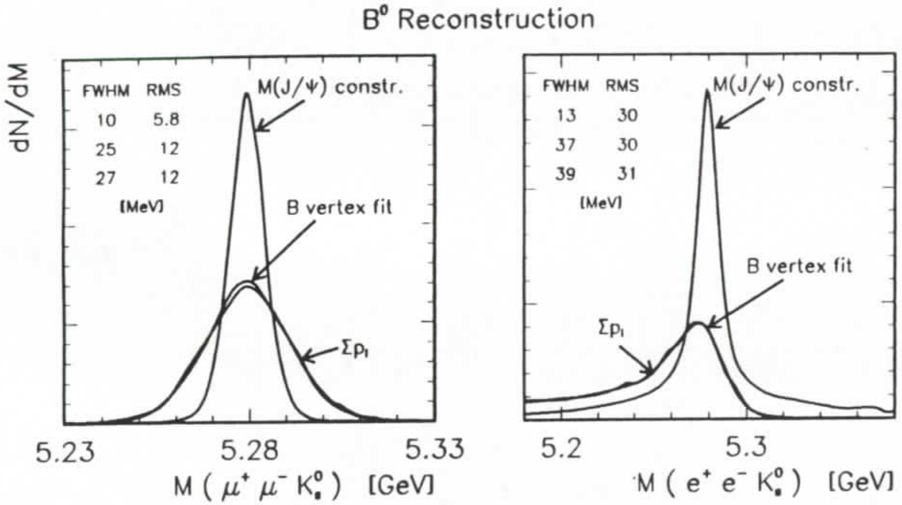
- OBTAINED BY ANALYTICAL TRACING OF ERROR MATRICES THROUGH TRACKER
- USES DETAILED POSITIONS & RESOLUTIONS OF ALL TRACKING DEVICES

RESULTS :

- $dp/p^2 \lesssim 10^{-4}/GEV$ IN FULL REGION FOR $P > 40$ GEV
- IMPACT PARAMETER RESOLUTION $\delta b_x < 40\,\mu m$ FOR $P_T = 1.5$ GEV
- MASS RESOLUTION FOR J/ψ $\delta(m_{J/\psi}) < 10$ MEV
- MASS RESOLUTION FOR $B^0 \to J/\psi K_S^0$ $\delta(m_B) \sim$ ~~4.5~~ 5...6 MEV

B° RECONSTRUCTION

MASS RESOLUTION:



- J/Ψ MASS CONSTRAINT FIT COMPENSATES $e^{\pm}$ RADIATION TAIL
- TIGHT MASS CUTS POSSIBLE

SUMMARY

- PROTOTYPE CONCEPTS FOR EVENT RECONSTRUCTION EXIST
- IMPACT ON DETECTOR DESIGN
- PATTERN RECOGNITION CAN BE HANDLED
- TRACKING RESOLUTION MEETS/ EXCEEDS HERA-B DEMANDS
- HERA-B TRACKING PHILOSOPHY PROVES REASONABLE

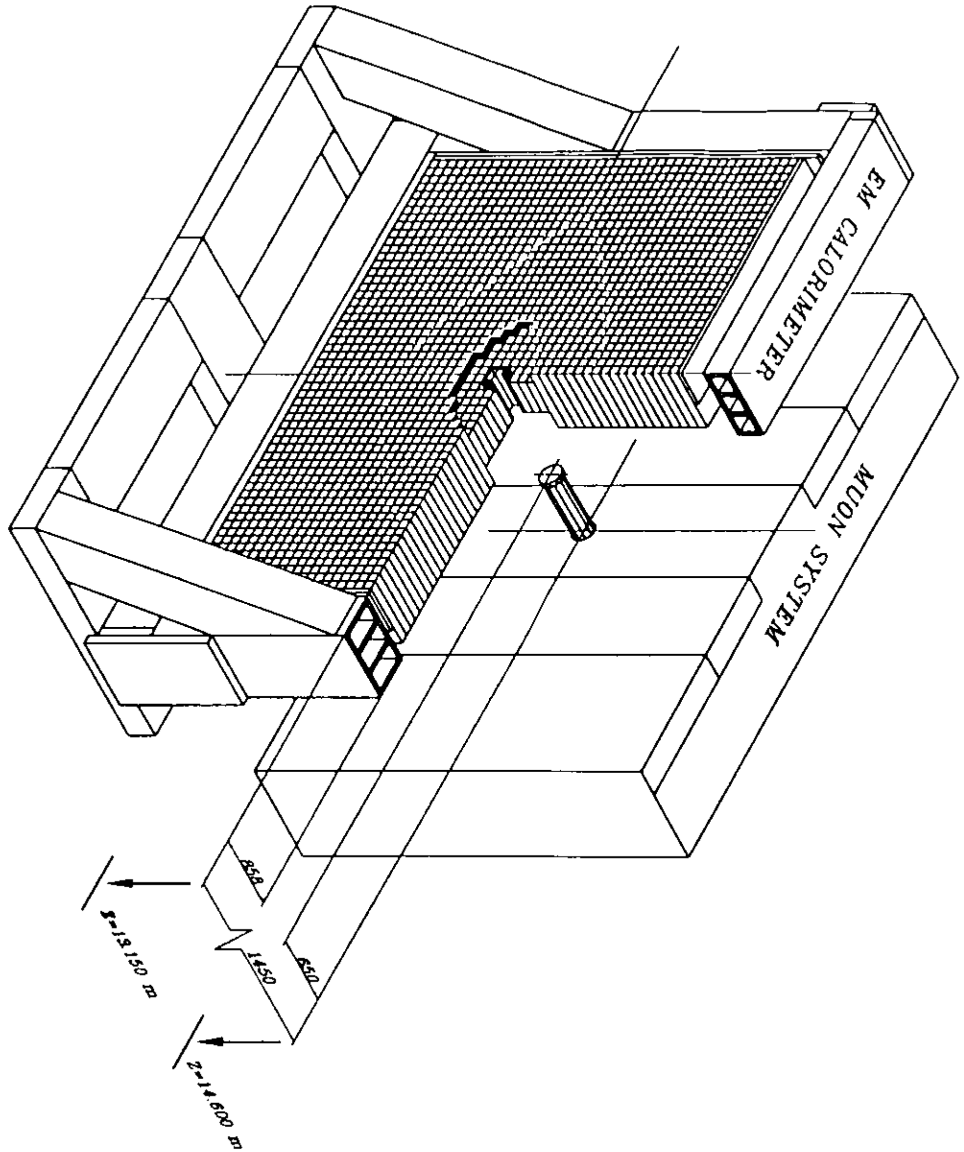
FURTHER OPTIMIZATION OF HARDWARE / SOFTWARE IS NECESSARY & POSSIBLE

Andrei Golutvin (ITEP, Moscow)
HERA-B Open Collaboration Meeting, October 4-6, 1994

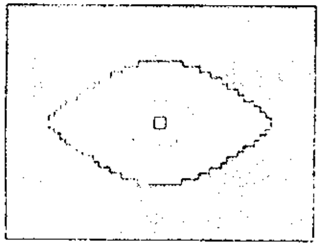
ELECTROMAGNETIC SHASHLIK CALORIMETER FOR THE HERA-B EXPERIMENT (Changes since the Proposal)

(1) General overview of ECAL

(2) Improvement of the performance for the $J/\psi \to e^+e^-$ channel

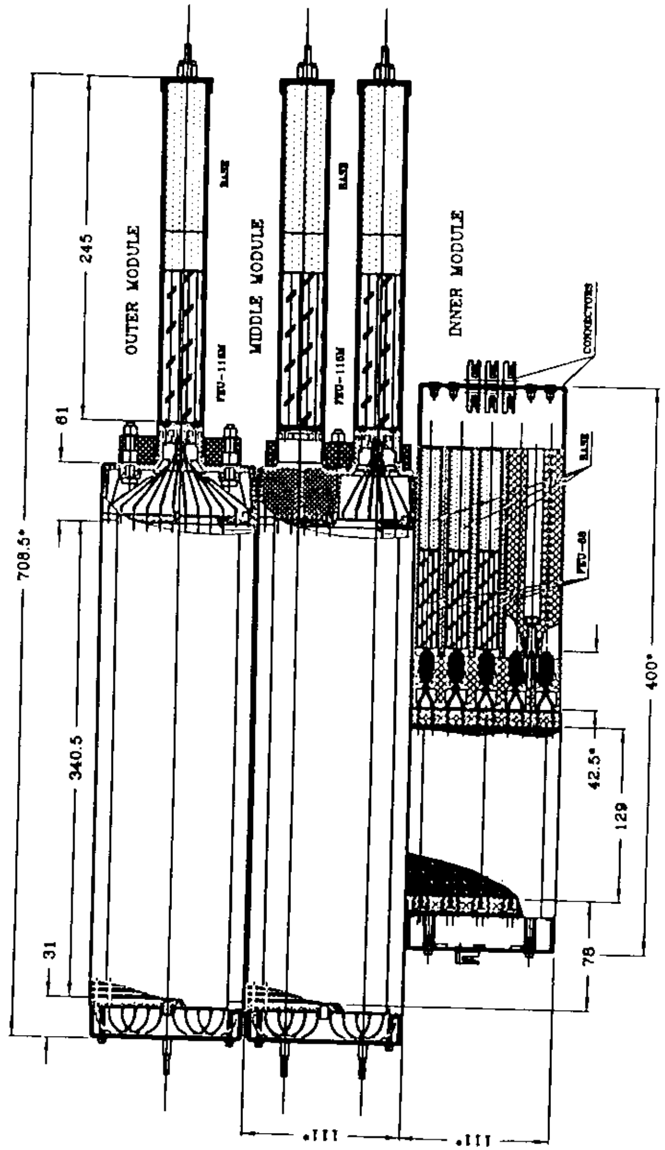


HERA – B calorimeter



Distance from the target	1315 cm
Covered acceptance	220 mrad x 160 mrad
Size	624 cm x 468 cm
Weight	49.5 tons
Readout	5768 channels

	Inner	Middle	Outer
Outer size	156 cm x 89 cm	446 cm x 245 cm	624 cm x 468 cm
Type	Shashlik	Shashlik	Shashlik
# of channels	2000	2000 *	1768
Absorber	Tungsten	Lead	Lead
Volume ratio	W : Scint = 2 : 1	Pb : Scint = 3 : 6	Pb : Scint = 3 : 6
Moliere radius	1.2 cm	3.5 cm	3.5 cm
Radiation length	0.52 cm	1.64 cm	1.64 cm
Cell size	2.23 cm x 2.23 cm	5.575 cm x 5.575 cm	11.15 cm x 11.15 cm
Depth	12 cm (23 Xo)	33 cm (20 Xo)	33 cm (20 Xo)
Weight	1.85 tons	11 tons	36 tons
Absorb. weight	1.52 tons	7.8 tons	27.5 tons
Scint. weight	42 kg (1 mm plates)	1450 kg (6 mm plates)	5126 kg (6 mm plates)
WLS fibres	1.6 km	36 km	127 km
PMT type	FEU – 68	FEU – 115M	FEU – 115M



Major changes in the calorimeter design

(1) Decreased ECAL dimension in the new HERA-B configuration

- Reduction in the cost by ~260 kDM in the outer section

(2) Supermodular $\Longrightarrow$ Modular construction

- Advantages:
  - Better optimization of the shape
  - Simplified construction $\Longrightarrow$ Some reduction in the cost
- Disadvantages:
  - More time for the installation is needed during HERA-B assembly
  - More complicated replacement procedure of the innermost modules damaged by radiation (if needed) Possible solution is found

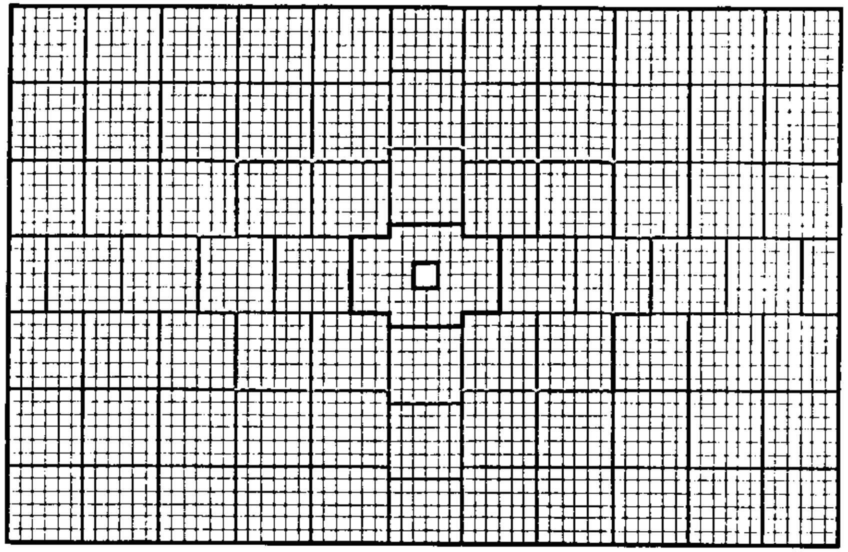
(3) Increase of the scintillator plates thickness for the middle and outer sections: 4 $mm \Longrightarrow$ 6 mm

- Improved spatial resolution and e/π-separation

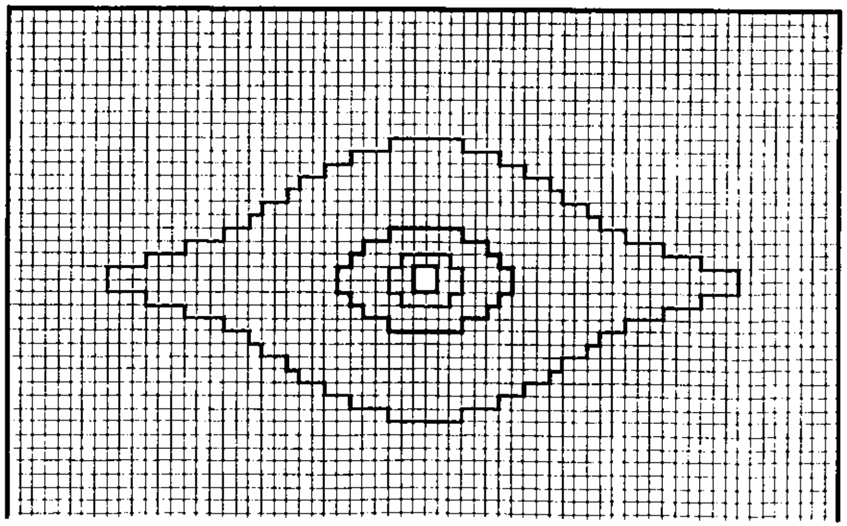
(4) Possible use of Russian produced FEU-68 photomultipliers (85 DM per unit) instead of expensive R647-01 (510 DM per unit). Preliminary tests look promissing.

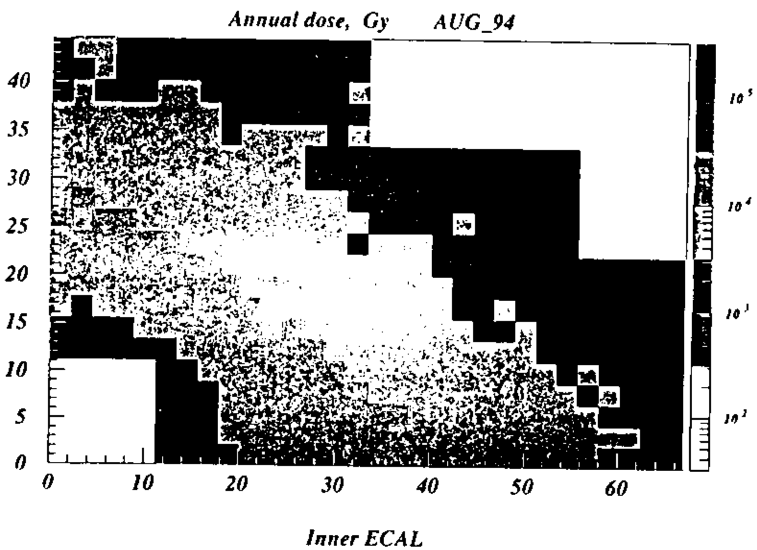
- **Substantial reduction in the cost by 850 kDM if ordered now !**

HERA-B Calorimeter – Supermodule structrure



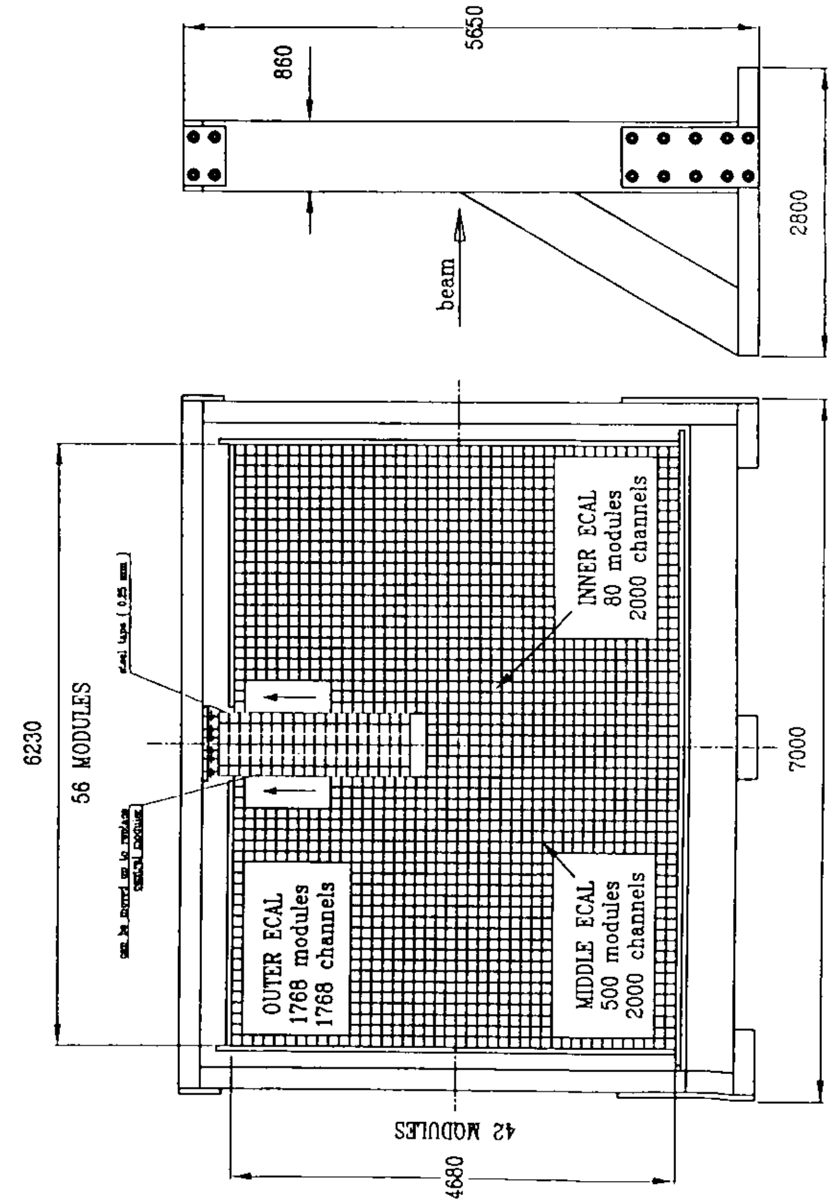
Module structure of ECAL





Annual dose, Gy AUG_94
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
10^5
10^4
10^3
10^2
Inner ECAL

F 7



5650
860
2800
beam
6230
56 MODULES
7000
INNER ECAL
80 modules
2000 channels
MIDDLE ECAL
500 modules
2000 channels
OUTER ECAL
1768 modules
1768 channels
42 MODULES
4680

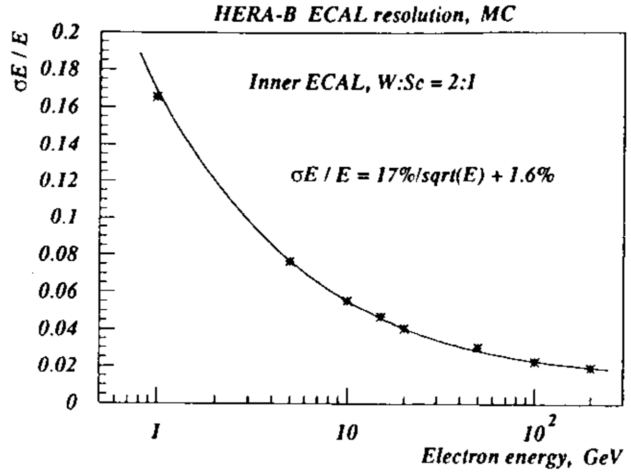
P 8

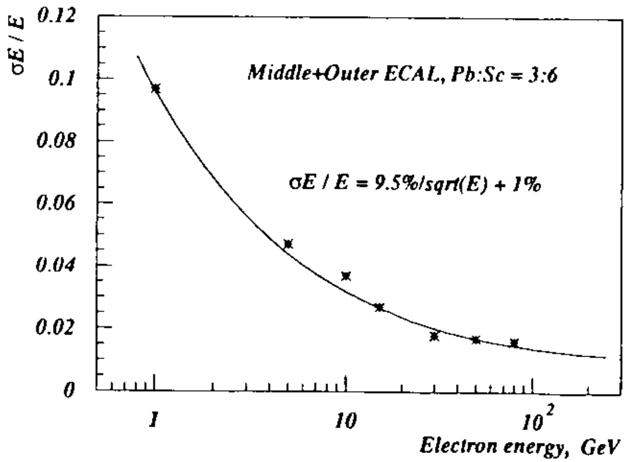
Test results of phototubes for ECAL

Item	Description: Middle and Outer	Description: Inner
PM type	FEU-115M	FEU-68
Manufacturer	MELZ, Moscow, Russian Federation	
Photocathode	SB-K-Na-Cs	Sb-K-Na-Cs
Photocathode diameter	25 mm	10 mm
External PM diameter	30 mm	15 mm
PM length	90 mm	64 mm

Mean measured characteristics:

QE at BCF-92 fibre fluorescence spectra	13%	
Nonuniformity of central region	Diameter 10 mm:	Square 3 mm side:
	sigma = 5%	sigma = 6%
Linearity at 2% level	>50 mA - 100%	3 mA
	>100 mA - 50%	
Gain	1.8 kV - $5 \cdot 10^5$	1.0 kV - $5 \cdot 10^3$
	2.0 kV - 10^6	1.8 kV - 10^5
Dark current (U at anode sensitivity 100 A/Lm)	4 nA	





Estimate of the fraction of reconstructed $B^0 \to J/\psi K^0_S$ events per $b\bar{b}$ event

		$J/\psi \to \mu^+\mu^-$	$J/\psi \to e^+e^-$
Physics	$bb \to b\bar{d}$ $(d\bar{b})$ $B^0 \to J/\psi K^0_S$ $K^0_S \to \pi^+\pi^-$ $J/\psi \to \ell^+\ell^-$	0.8 $5 \cdot 10^{-4}$ 0.69 0.06	0.8 $5 \cdot 10^{-4}$ 0.69 0.06
Trigger	geometry, pre-trigger momentum cuts mass cuts	0.70 0.9[illegible] 0.99	0.70 0.51 0.91
Lepton Tracking	geometry pattern	0.99 0.90	0.99 0.90
K^0_S Tracking:	geometry pattern K^0_S reconstruction	0.70 0.90 0.97	0.70 0.90 0.97
Lepton Identification	efficiency	0.91	0.85
J/ψ Reconstruction	vertex fit, mass cut	> 0.99	> 0.99
B^0 Reconstruction	vertex fit, mass cut matching with target	0.95 > 0.99	0.67 0.98
Decay Kinematics	J/ψ decay angle cut B decay angle cut	0.85 0.94	0.86 0.93
Secondary vertex	decay length cut	0.69	0.69
Summary	suppression statistical factor K	$2.8 \cdot 10^{-[illegible]}$ 2.3	$0.9 \cdot 10^{-[illegible]}$ 2.3

Improvement of CP violation performance for the $J/\psi \to e^+e^-$ channel (preliminary)

(1) Improvement of the FLT efficiency

- Reduction of the material in front of the calorimeter
- Using the shower shape information to minimize the Region of Interest for the FLT
- Using the information from the PAD chamber proposed for the $\pi\pi$-trigger (see talk of M.Danilov)
- Using the information from the TRD for the electron pretrigger (will be covered by B.Dolgoshein)
- Correcting P_t (measured in the tracker) for the energy of bremsstrahlung photons (measured in the calorimeter) at the FLT

(2) Improvement of the B reconstruction efficiency

- Recovery of the low mass tail (resulted from bremsstrahlung) in the electron pair mass spectrum

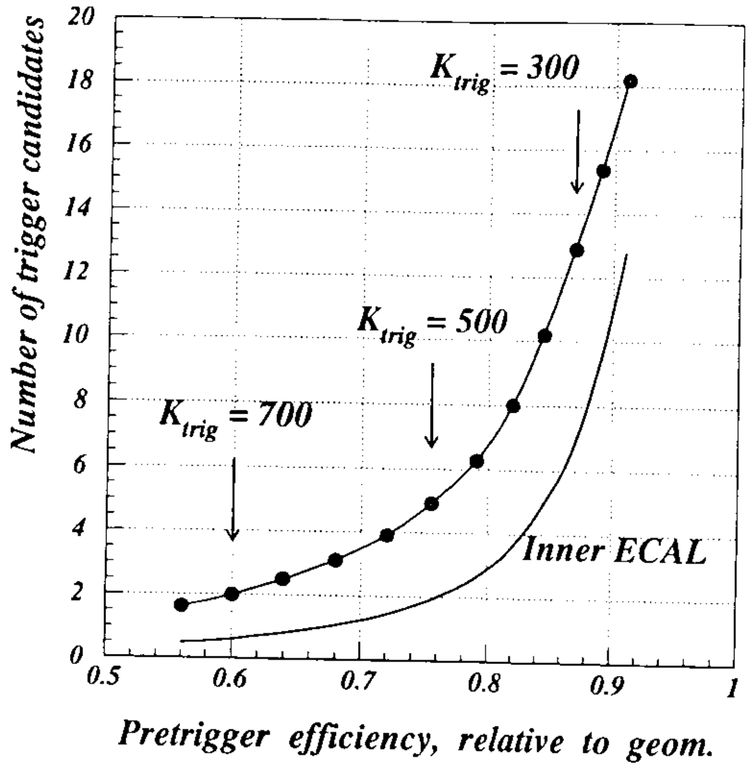
FLT acceptance

HERA-B Proposal

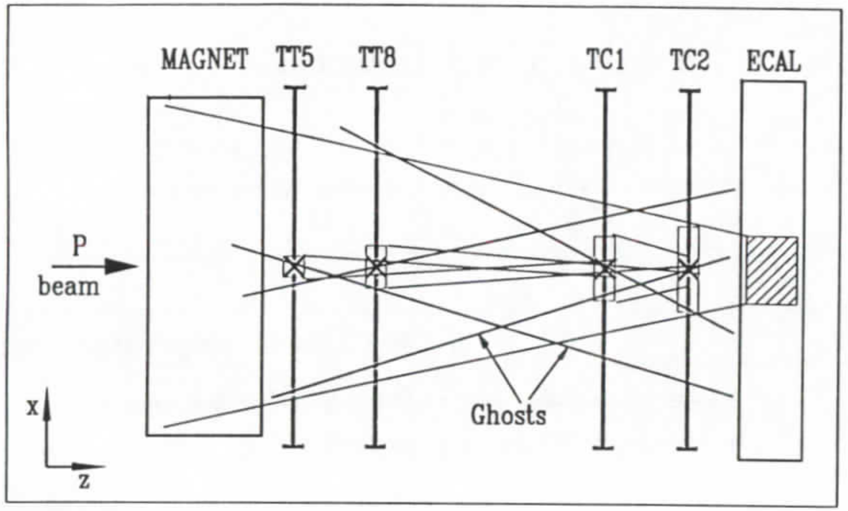
- **FLT performance was limited by the high trigger rate for electrons rather than the TFU capacity !**
- The dominant fraction (72%) of the FLT candidates is resulted from faked tracks (Ghosts)
- The FLT rate is proportional to the number of electron candidates generated by the ECAL pretrigger
- In order to reduce the number of electron candidates high ECAL treshold was applied: $K_{trig} = 700 \iff \langle N_e \rangle = 2$
- **Unavoidable loss of efficiency !**

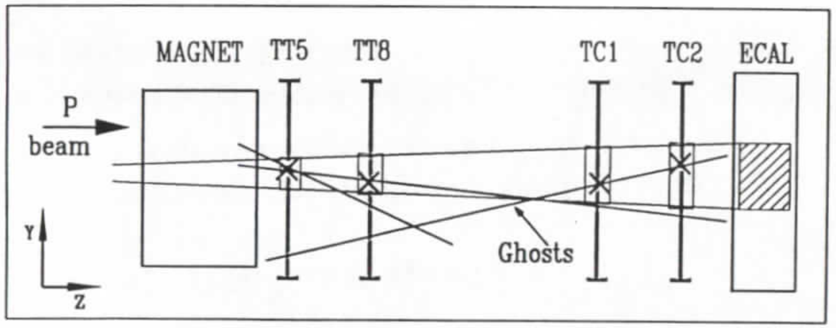
	e^+e^-	$\mu^+\mu^-$
Geometrical acceptance	70%	70%
Single track cuts	51%	92%
Pair mass cut	91%	99%
Total FLT acceptance	32%	64%

ECAL THRESHOLD = $F(K_{trig})$



TRACK FINDING ALGORITHM AT THE FLT

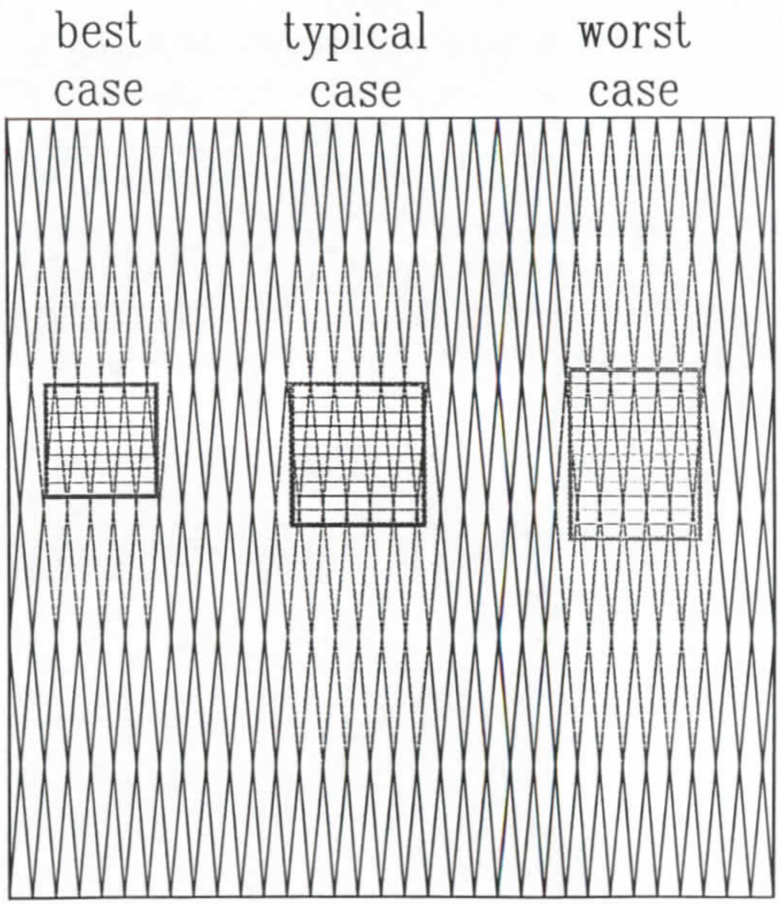




$$N_{Ghosts} = (O_{ccupancy} * S_{eff.})^n * (N_{electron\ cand.})$$

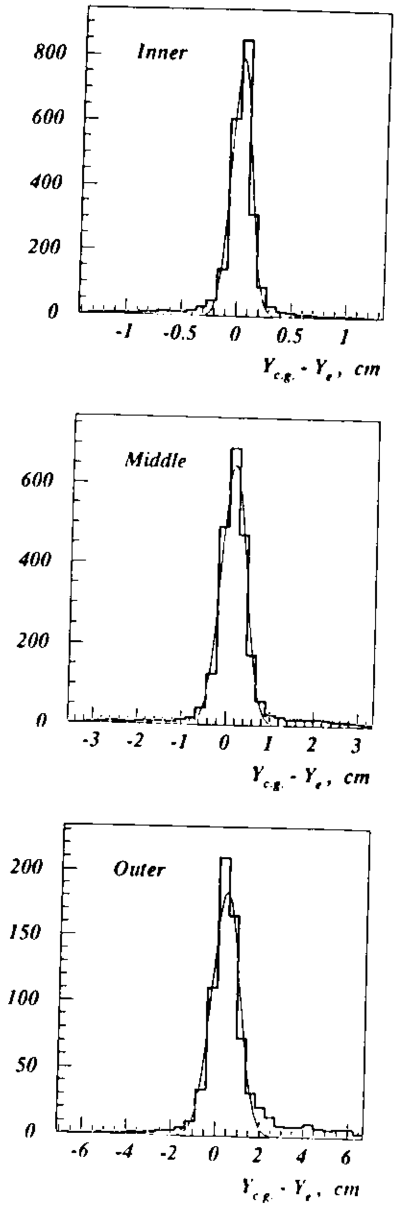
(n = 2 - 4)

ACTUAL REGION OF INTEREST IS LARGER DUE TO STEREO STRUCTURE OF THE FLT PLANES



→ THE DECREASE OF Y-DIMENSION OF THE ECAL CLUSTER BY A FACTOR OF ~2 IS OPTIMAL FOR THE PRESENT CONFIGURATION

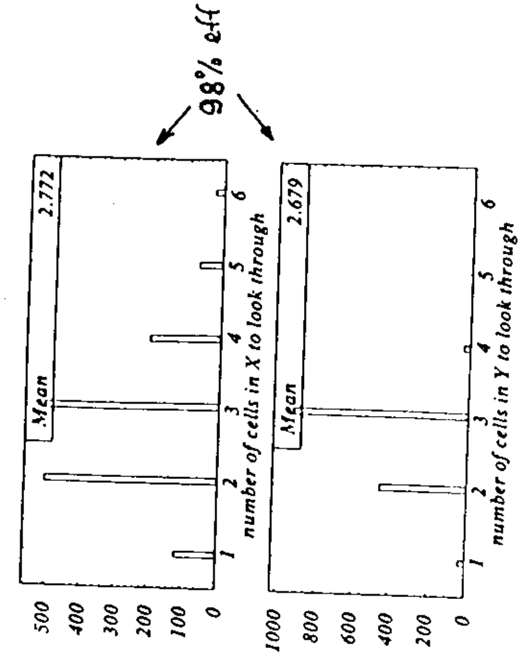
Spatial resolution at the Calorimeter pretrigger
(corrected center of gravity)

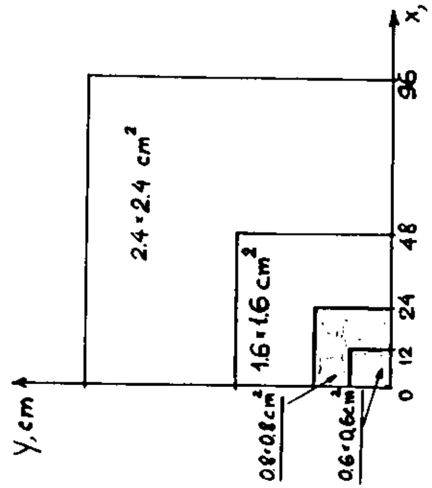


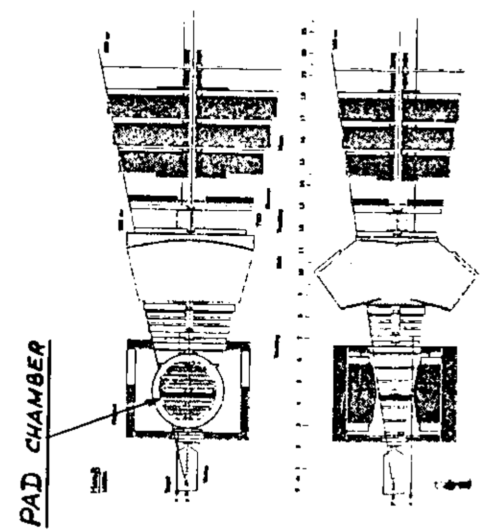
- y-dimension of the ECAL cluster size can be efficiently reduced (95% efficiency for the single candidate) by a factor of 2 at the pretrigger stage
- Expected reduction in the Ghost rate: > 4
- Lower ECAL threshold is possible: $K_{trig} = 400$ corresponding to $< N_e >=8$
- **Pretrigger efficiency: 82% (46% more than in Proposal) FLT rate** $\sim$ **50KHz**

USE THE PAD CHAMBER ($\pi\pi$ trigger) FOR ELECTRON FLT

REGION OF INTEREST IN THE PAD CHAMBER (Full MC: J/ψ + 4 mbe)





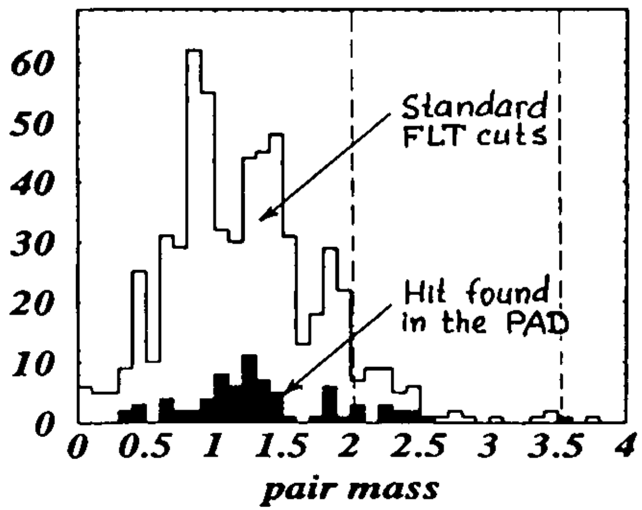


$K_{trig} = 300 \Longleftrightarrow$ **Pretrigger efficiency = 87%**

Generated (J/ψ + 4 mbe)	2100 events
Standard FLT cuts: P > 5 GeV/c P_t > 0.5 GeV/c (P-E)/E < 1/2 2 < pair mass < 3.5 GeV/c^2	20 events
Hit in the ROI of the PAD chamber	5 events

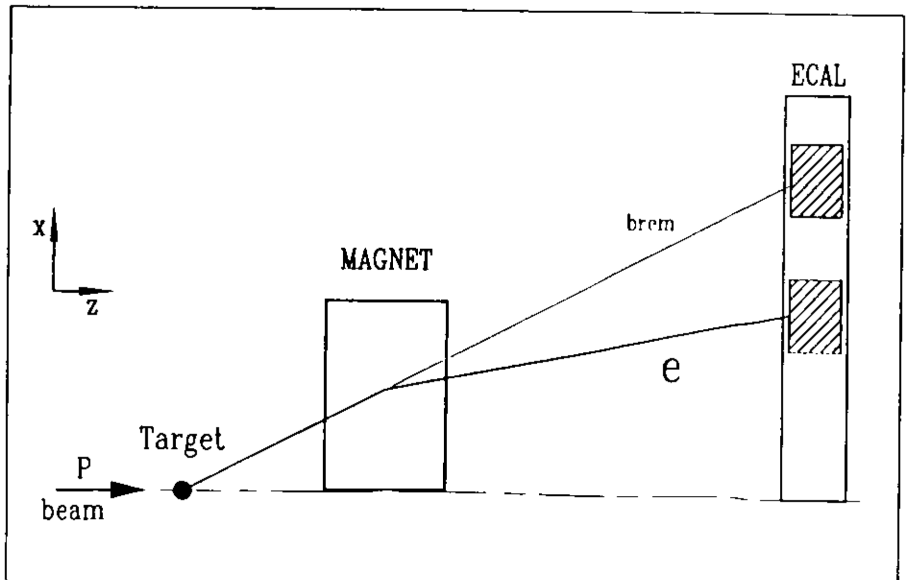
Total suppression: > 250
Gain in Pretrigger efficiency by 55% (compare to the Proposal) at the same FLT rate

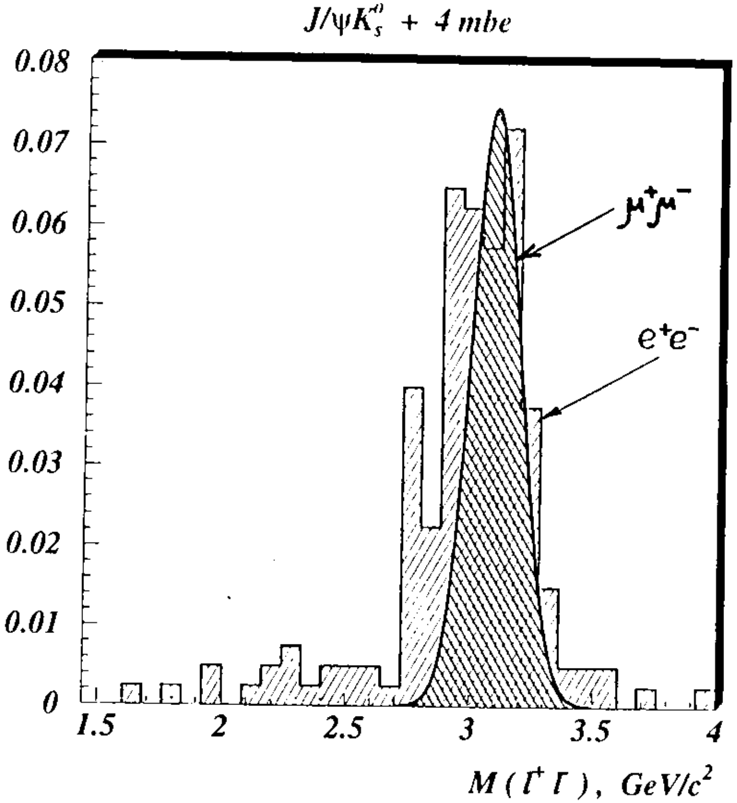
Pretrigger efficiency: 87%
FLT rate: <40KHz



Expected FLT efficiency for $J/\psi \rightarrow e^+e^-$

- **Eff(FLT) is determined by the product: Eff(geometry)×Eff(pretrigger)× Eff(FLT cuts)**
- Eff(pretrigger)=87% for K_{trig}=300
- Standard FLT cuts have been optimized for the high ECAL threshold K_{trig}=700
- Eff(FLT cuts) is only 62% for K_{trig}=300. In order to increase this efficiency the FLT cuts could be further optimized
- The loss in Eff(FLT cuts) is caused mainly by bremsstrahlung photons emitted in front of the magnet. Partial recovery is possible by:
  - **Reduction of the material in front of the magnet**
  - **Measuring the energy of bremsstrahlung photons in the calorimeter**





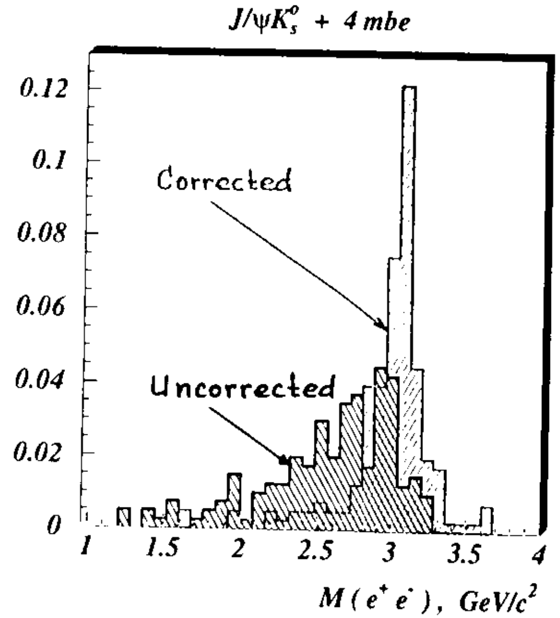
Correction for the energy of bremsstrahlung photons leads to:

Eff(FLT cuts) = 72%

(very preliminary)
Total FLT acceptance for electrons $\sim 43\%$ could be achieved at the FLT rate ~ 50 kHz

Improvement of the B mass reconstruction efficiency

- At the stage of B mass reconstruction some losses in case of electronic decays are unavoidable due to radiative tails which persist even after mass constraint fit (see talk of T. Lohse).
- The electron momentum measured in the tracker can be corrected by measuring the energy of bremsstrahlung photons in the calorimeter.
- The position of the bremsstrahlung photons (emitted in front of the magnet) at the calorimeter face is precisely known from the electron momentum measured in the tracker. Therefore the energy of bremsstrahlung photons has to be measured in the well defined and small region of $ECAL$.



- The mass distribution of electron pairs looks promissing
- The actual improvement of efficiency at the B^0 reconstruction has to be studied

CONCLUSIONS

(DEVELOPMENT SINSE THE PROPOSAL)

() THE DESIGN OF THE CALORIMETER HAS BEEN OPTIMIZED BOTH IN TERMS OF PERFORMANCE AND COST
(COST REDUCTION BY ~ 1,000 KDM LOOKS POSSIBLE IF FEU-68 PHOTOTUBES WILL BE ORDERED SOON)

() THE FLT PERFORMANCE CAN BE IMPROVED FOR ELECTRONS
- STRAIGHTFORWARD USE OF THE PAD CHAMBER FOR $\pi\pi$ - TRIGGER OR SHOWER SHAPE ANALYSIS ALLOWS TO INCREASE THE FLT ACCEPTANCE ABOVE 38% !
- FURTHER OPTIMIZATION COULD IMPROVE THE FLT ACCEPTANCE UP TO ~45% AT THE FLT RATE BELOW 50 kHz

() AN IMPROVEMENT IN B^0 RECONSTRUCTION EFFICIENCY FOR ELECTRONS LOOKS PROMISSING — HAS TO BE STUDIED IN DETAIL

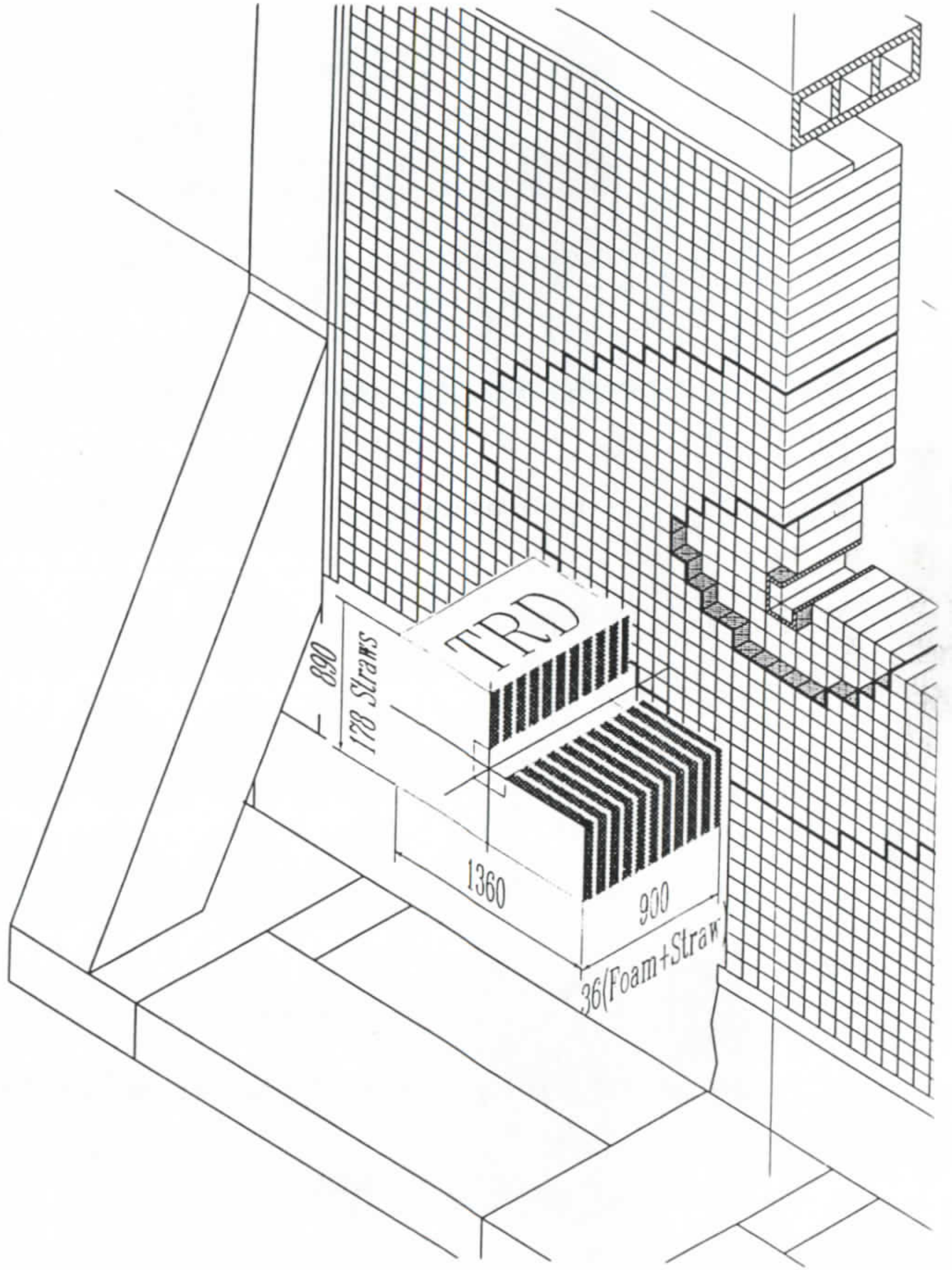
() THE HARDWARE IMPLEMENTATION FOR THE ECAL PRETRIGGER HAS TO BE FOUND

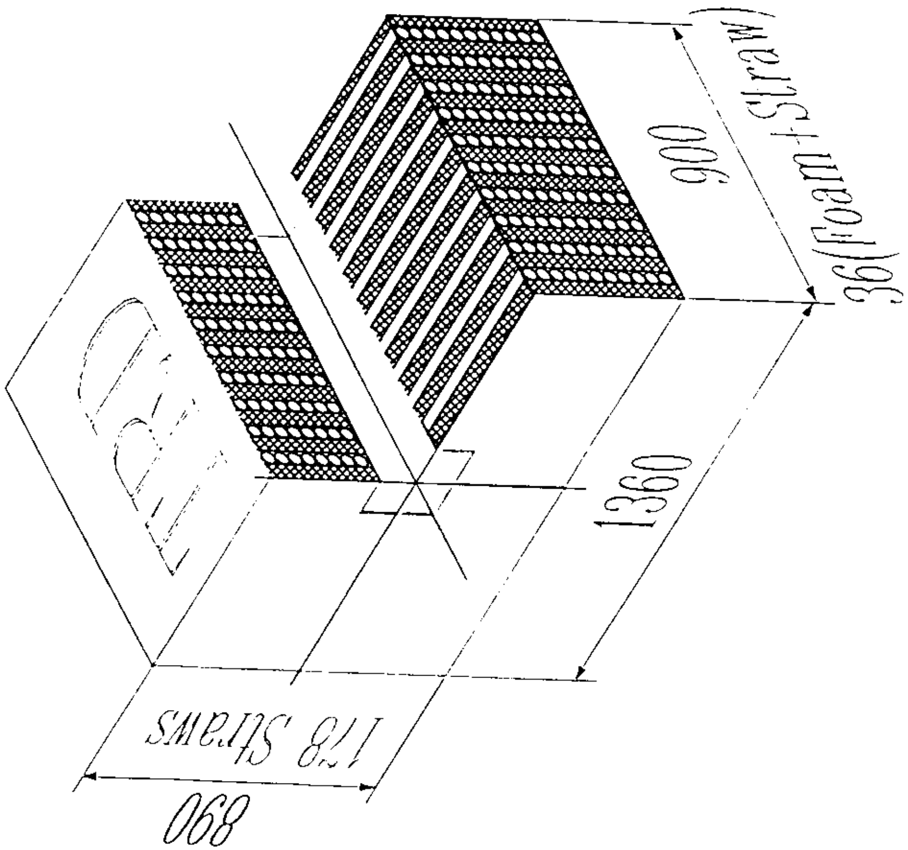
ROME — BOLOGNA GROUP IS WORKING ON THAT
FERMI - READOUT SEEMS TO BE AN ADEQUATE SOLUTION ?

Boris DOLGOSHEIN(MEPhI ,Moscow)
HERA-B Open Collaboration Meeting, DESY, 4-6.Oct.1994

Transition Radiation Detector for HERA-B Status Report

- Introduction. TRD description.
- TRD performance list.
- TRD function in HERA-B and efficiency of $J/\psi - e^+e^-$ detection.
- Conclusions.





HERA-B TRD Parameters

- Z position Jast in between of TC1 and TC2, in front of INNER part of the ECAL.

  Δ Z = 90 cm

- Δ X = ± 67 cm. Δ Y = ± 44.5 cm. Beam Hole 12 cm. x 12 cm.

- TRD is made of O 5 mm kapton straws (Gas: Xe / CF4 / CO2)

  with 20 mm polyethilen foam sheets (TR – radiator in between)

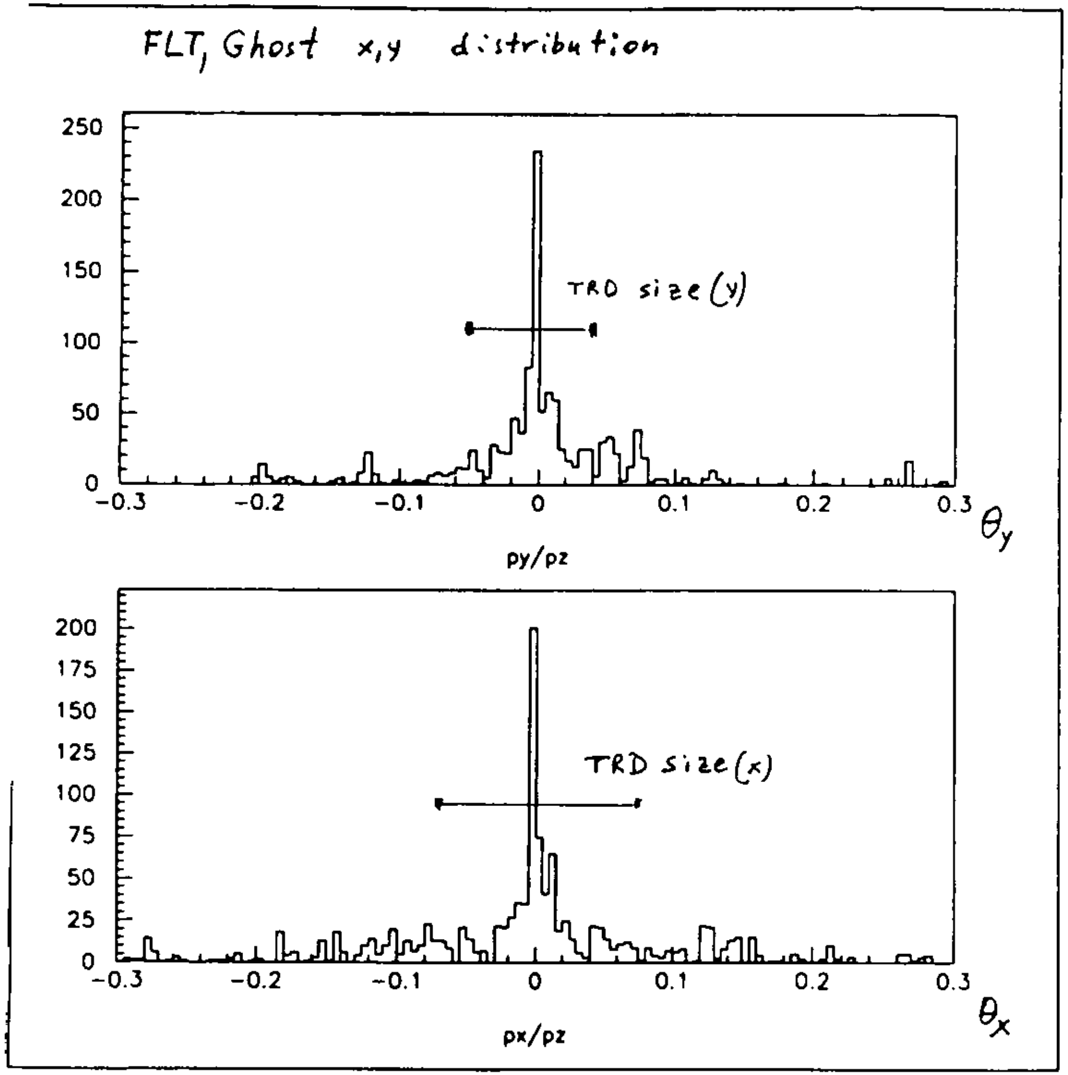
- the straw length 134 / 2 cm.

- the straws are positioned horizontally (along x)

- and staggered (3 / 8 Q straw) from layer to layer

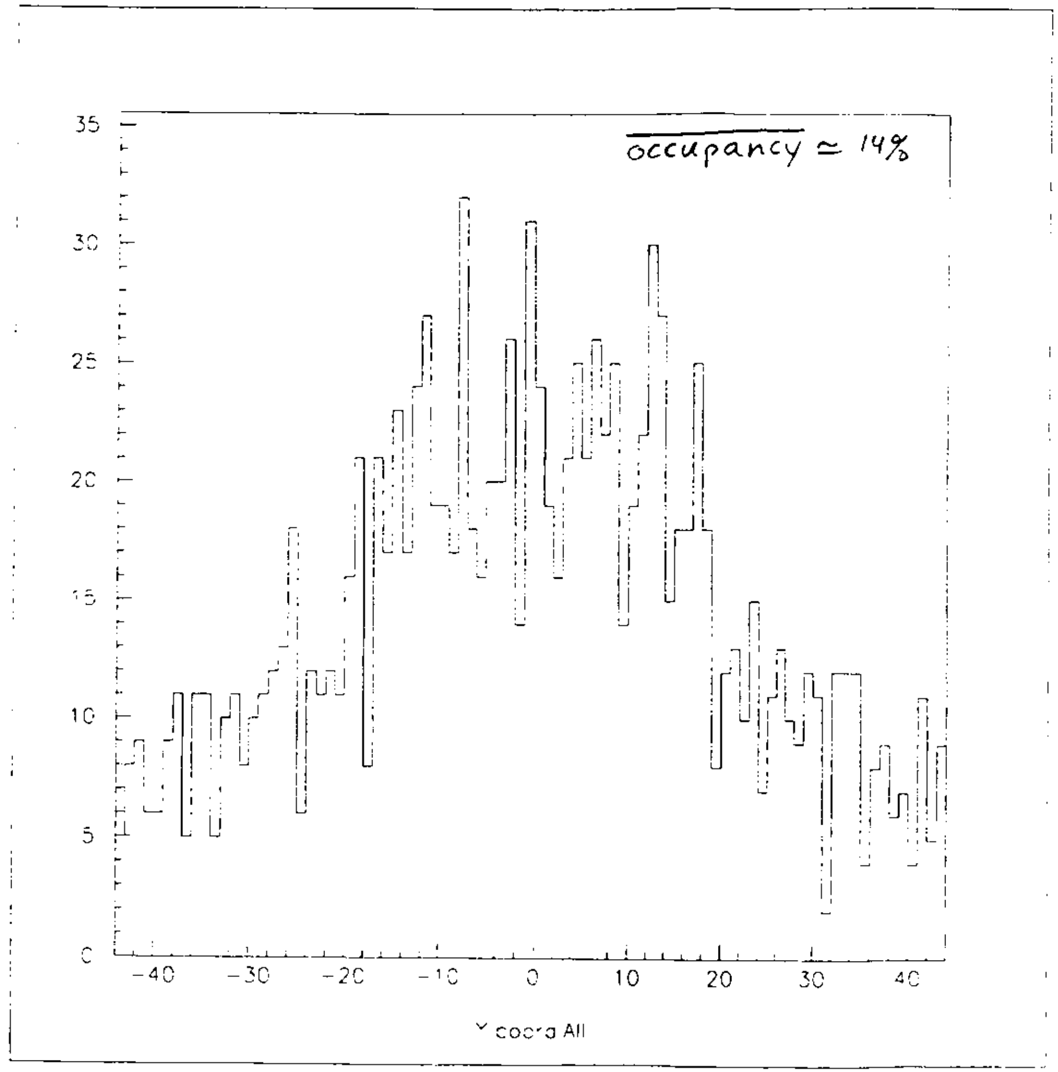
- total number of straws is 6500 (36 layers x 352)

  of electronics channels is 13000



FLT, Ghost x,y distribution
TRD size(y)
py/pz
θ_y
TRD size(x)
px/pz
θ_x

Q -5-



occupancy ≃ 14%
Y coord All

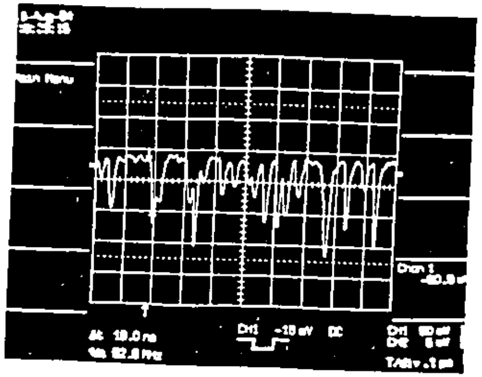
Q -6-

TRD performance list

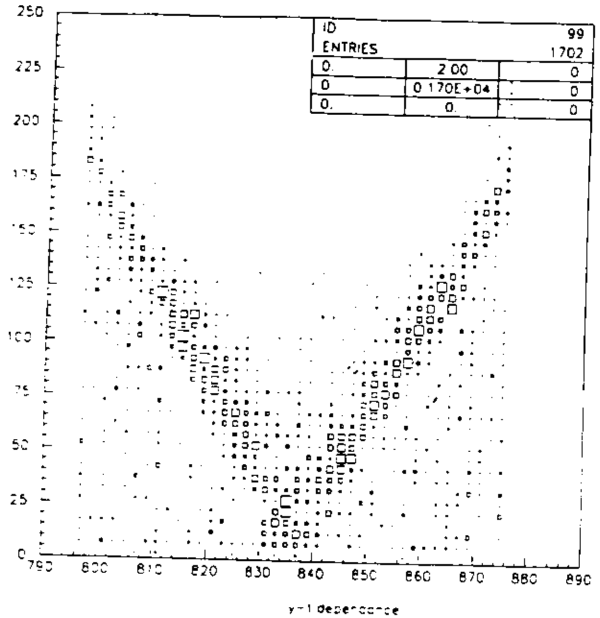
TRD Properties	Confirmed by ATLAS TRT(RD6) experience (data)	Expected for HERA-B TRD
1. Particle ID	$Eff_e = 90\%$	$Eff_e = 95\%$
R hadrons (pion,20GeV)	300 (isolated particles) 50 (occupancy 0.2)	200 (isolated particles) ~10 (occupancy 0.2)
R gamma–conversions	10–30 (isolated particles)	2 (due to material in front of TRD)
[illegible]		
intrinsic straw resolution	150 μm	Drift time not used
residuals distribution	170 μm	
relative track fit angular resolution	0.17 mrad	
track position	40 μm	
[illegible]		
straw resolution	$4\ mm/\sqrt{12} = 1.15$ mm	$5\ mm/\sqrt{12} = 1.44$ mm
angular resolution	4 mrad	5 mrad
track position resolution	180 μm	230 μm
4 High rate performance	$\sigma = 150$ μm up to $6 \cdot 10^5$ part/cm $\sigma = 150$ μm to $\sigma = 170$ μm for 18 MHz rate (special high rate electronics: ion tail concellation + baseline restoration)	max flux: ~ $6 \cdot 10^4$ max rate : ~ 3 MHz

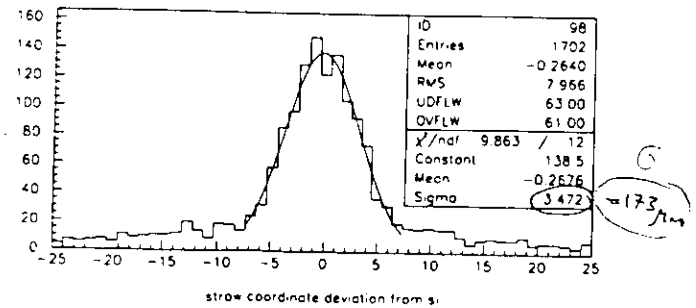
TRD performance list

TRD Properties	Confirmed by ATLAS TRT(RD6) experience (data)	Expected for HERA-B TRD
5 Ageing and rad hardness	Integrated charge > 5 C/cm neutrons: $4 \cdot 10^{14}$ charged particles : 80 MRad	5 C/cm ~30 years HERA-B ~ 20 years HERA-B
[illegible]	FE: preamp+shaper +iontail cancellation+restorer +discr (2 THResholds: high 6 Kev (TR) Low 0.2 KeV (dE/dx) +DTM +ROC local logic [illegible]	6 Kev (TR)
[illegible]	P1: 864 straws P2: 2500 straws tested on the beam P3 9600 straws assembled	6500 straws

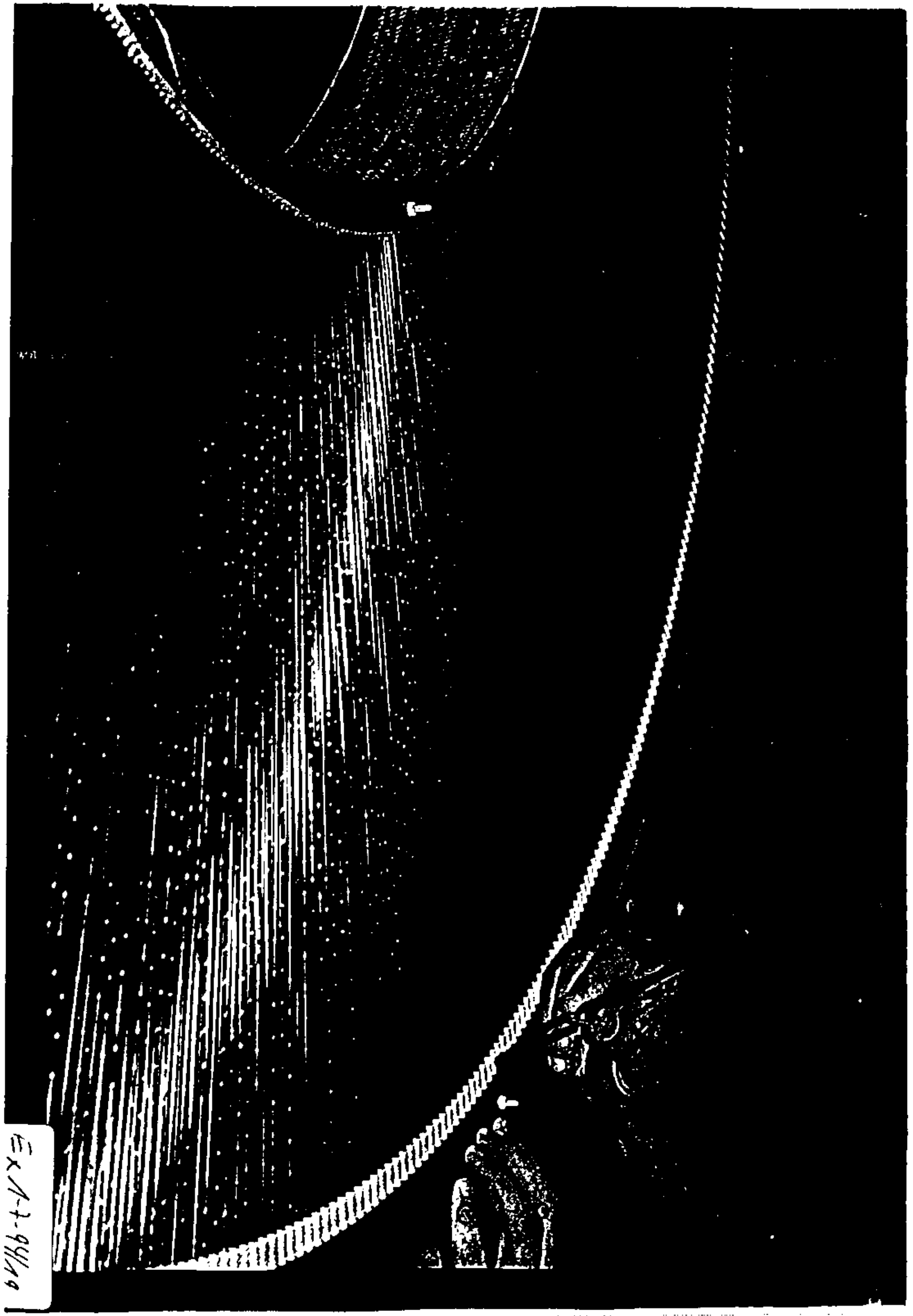


18 MHz

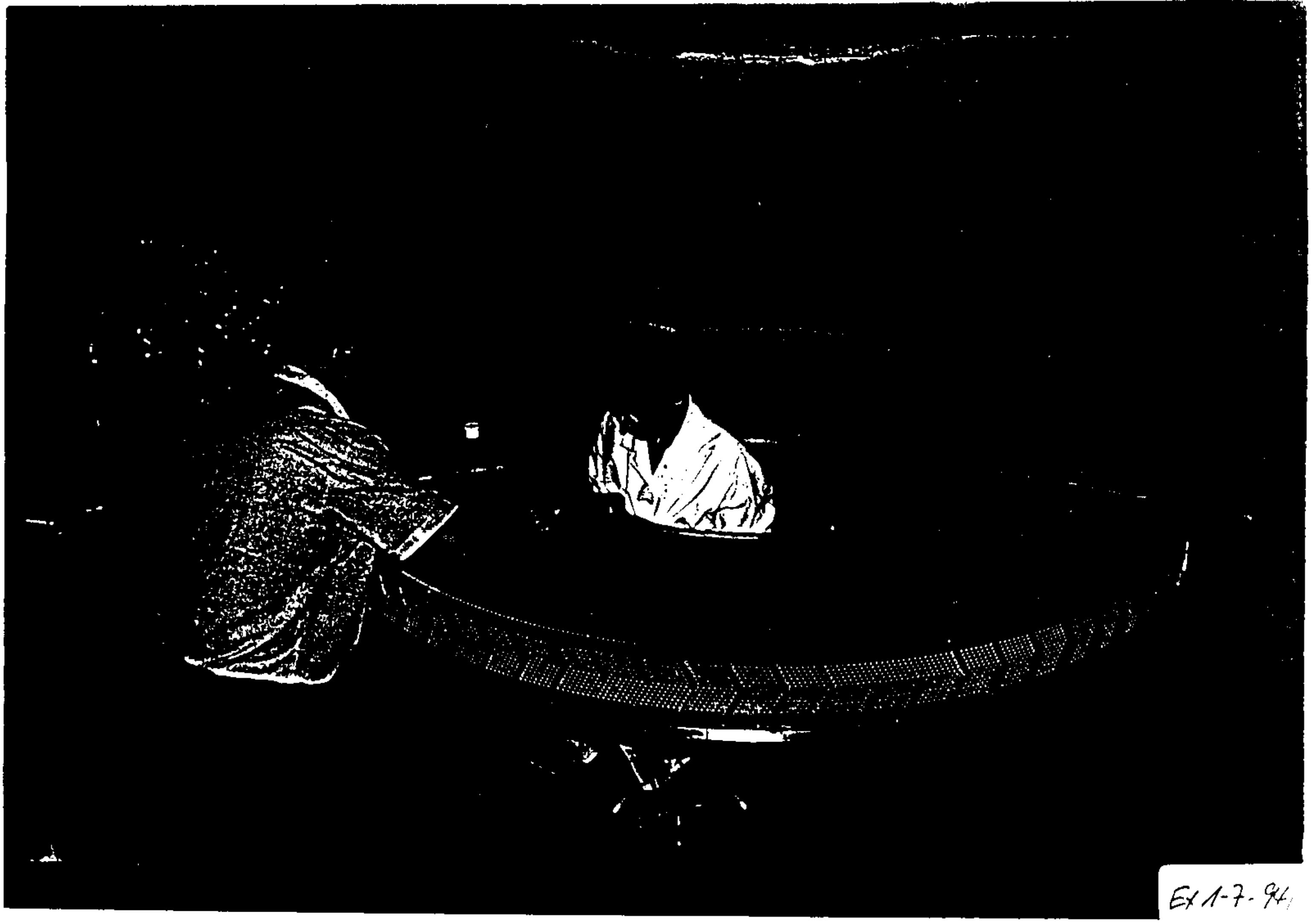




Q – 9 –



Ex A-1-94/19

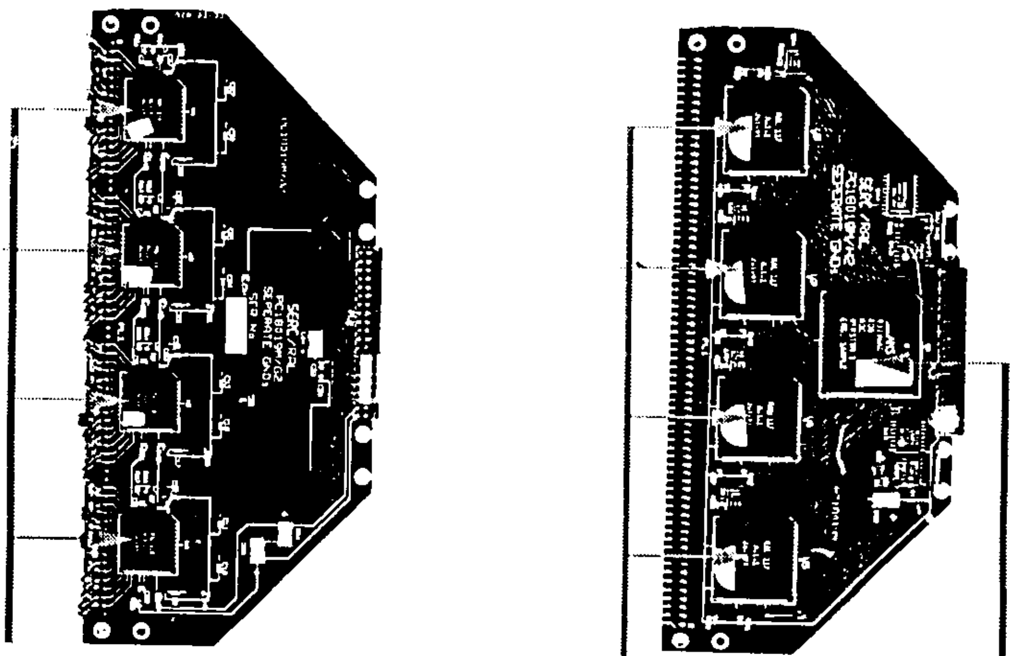


Ex 1-7-94

Beam test prototype: Electronics

Daughter board
Analogue side

Daughter board
Digital side



8 channel bipolar preamplifier, shaper and discriminator

8 channel CMOS control circuit and current to CMOS level converter

32 channel, digital pipeline, derandomizer and serial output

Q -12-

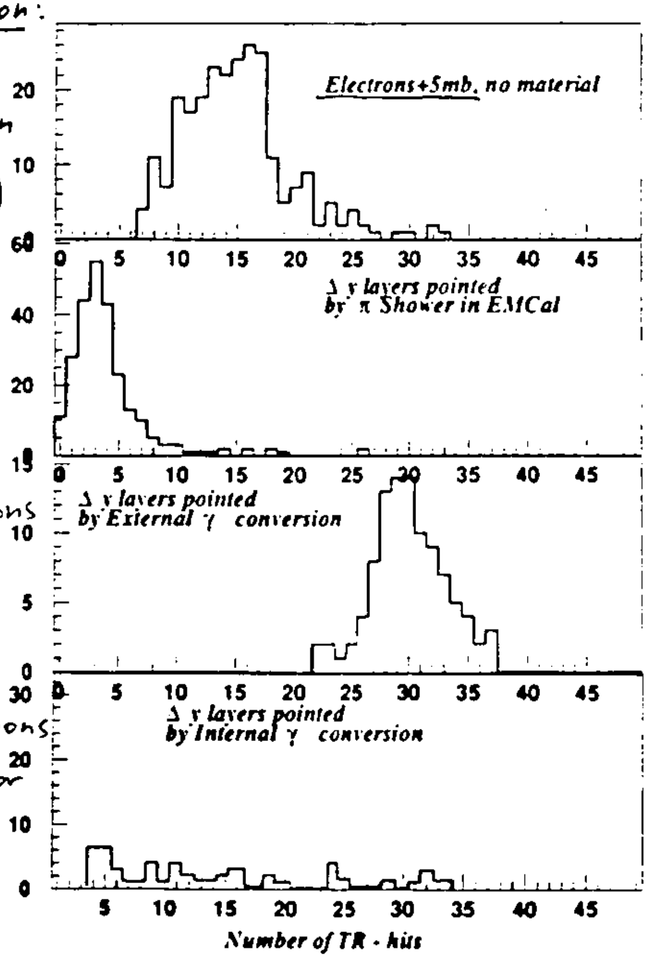
The ECAL Pretrigger composition:

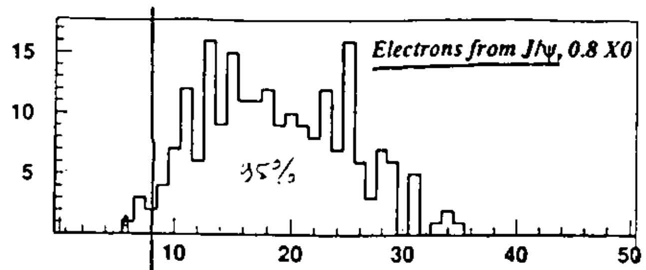
electrons (conversion upstream and in $\vec{B}$) ~15%

hadrons ~45%

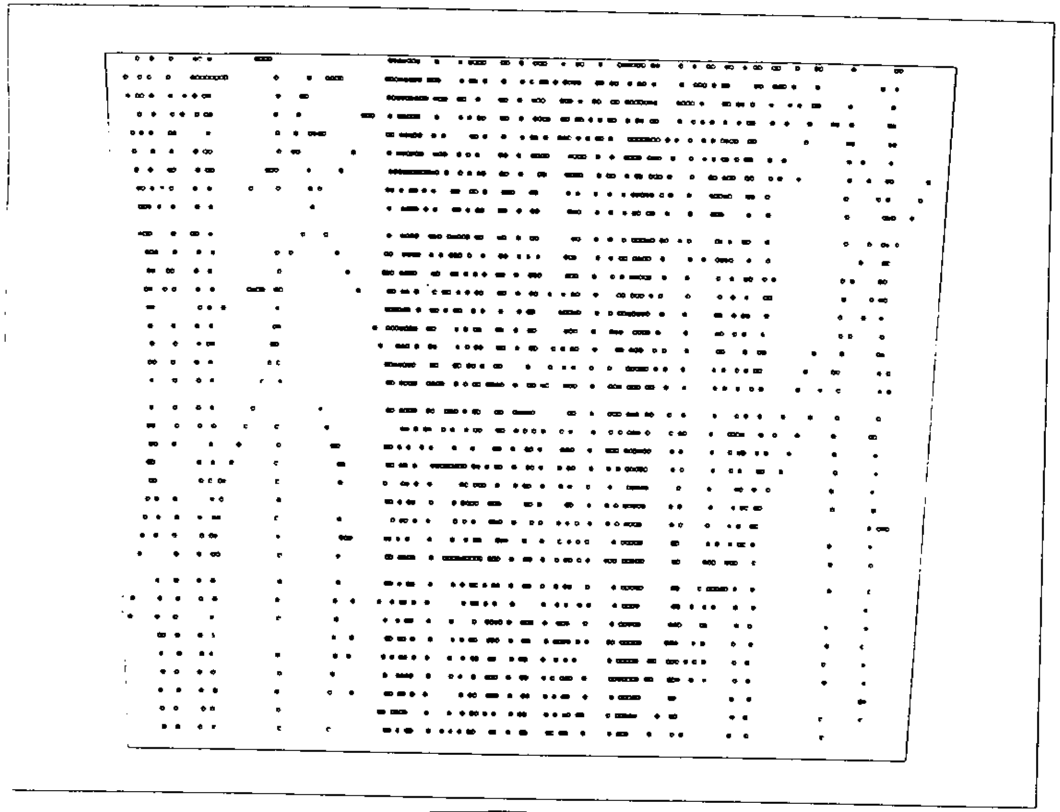
γ-conversions after $\vec{B}$ ~35%

γ conversions in Radiator ~5%

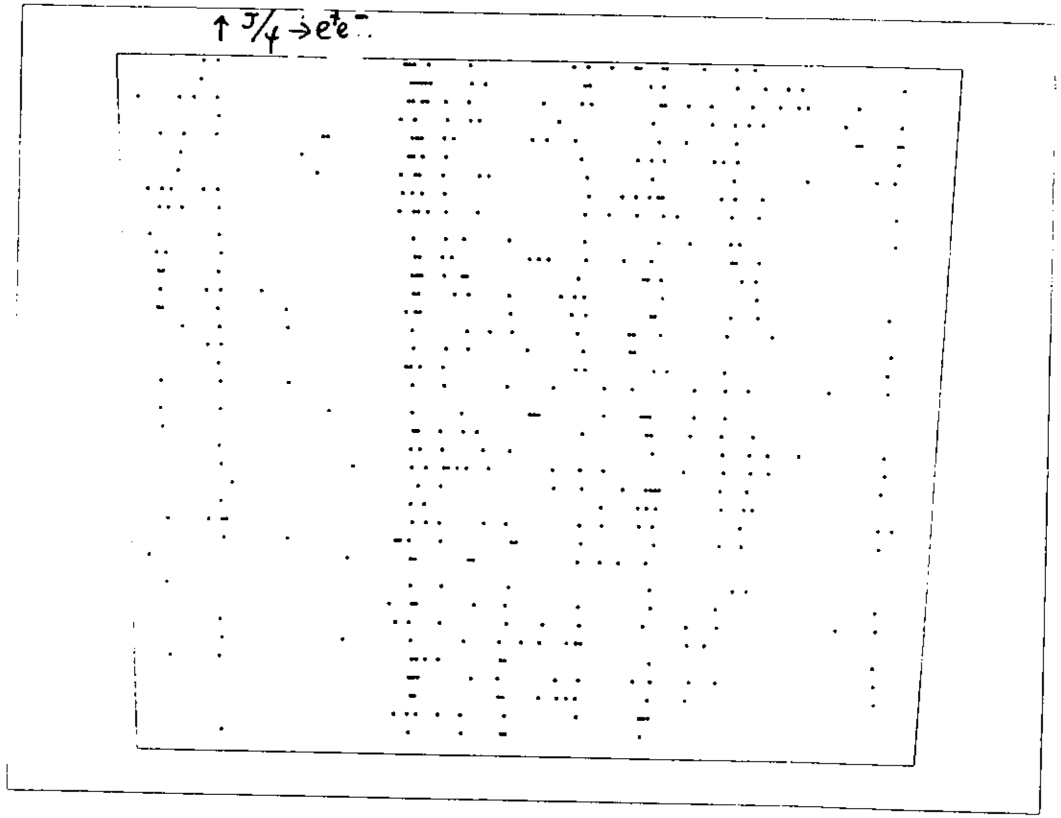




1

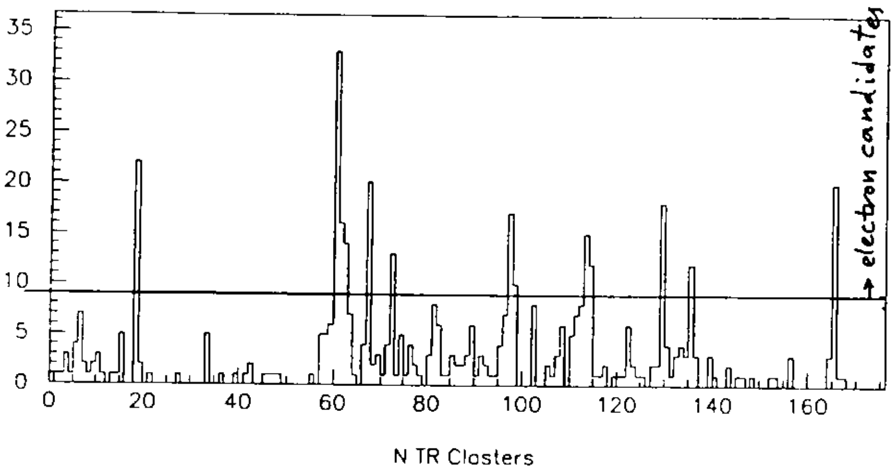


$\overline{\text{Occupancy}}$ = 28%



Q -15-

Q -16-



HERA-B TRD functions and possibility to increase the $J/\psi - e^+e^-$ trigger efficiency.

· TRD Functions:

⊙ To reduce the number e-candidates at the level of the ECAL + TRD pretrigger

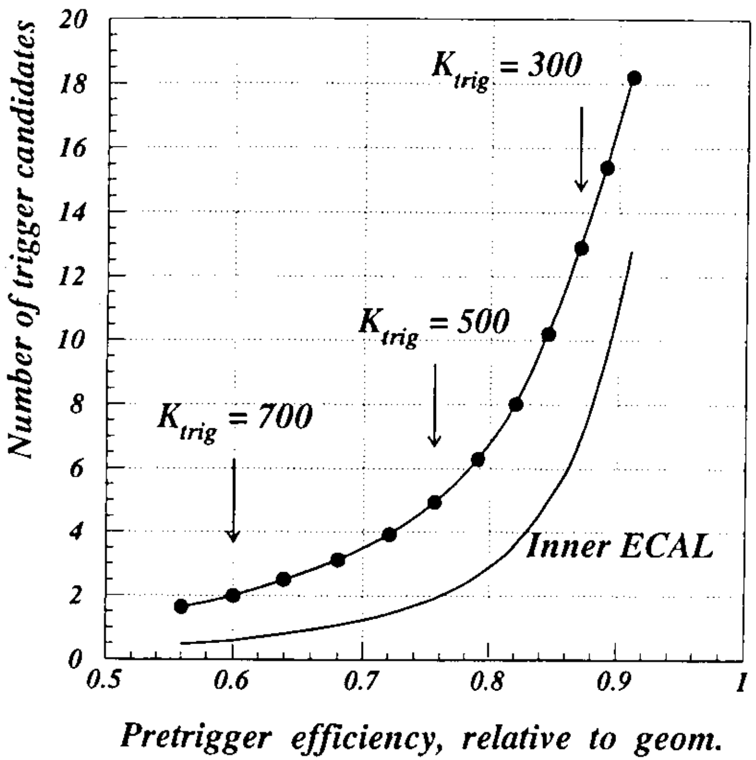
⊙ To reduce of number of accepted FLT events/pretrigger The composition of FLT accepted events (D.Ressing):

	% events	
$e^+(\mu^+)e^-(\mu^-)$	4.5 %	
$e(\mu)h, hh$	23%	⇓ by TR
ghost-ghost	72%	⇓ by decrease of ROI size (Δ Y)

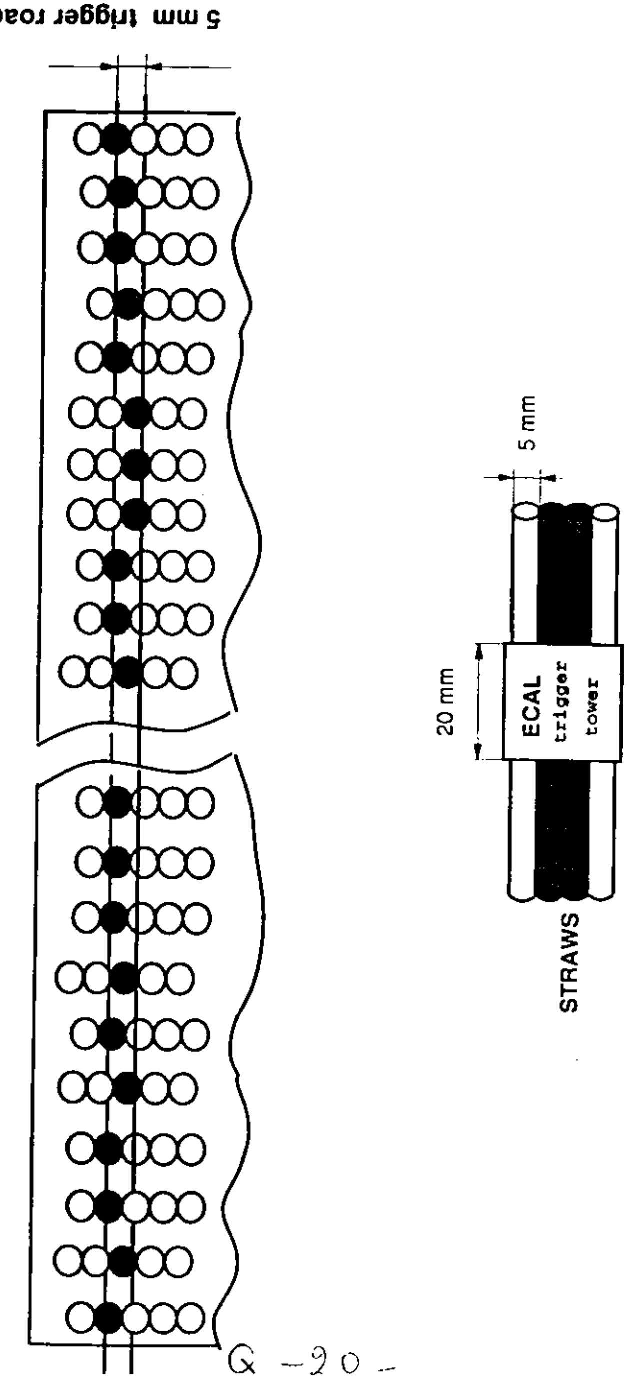
⊙ Level 2 (3) trigger: hadron/electron rejection

· Implementation of ECAL+TRD pretrigger (Hardware):

⊙ Projective ECAL tower + straw Y-layer (5 - 10 mm)


Number of trigger candidates
Pretrigger efficiency, relative to geom.
K_{trig} = 300
K_{trig} = 500
K_{trig} = 700
Inner ECAL
0
2
4
6
8
10
12
14
16
18
20
0.5
0.6
0.7
0.8
0.9
1

Q -19-


5 mm trigger road
5 mm
20 mm
ECAL
trigger
tower
STRAWS

Q -20-

· The reduction of the number of pretrigger e-candidates.

⊙ Due to relatively high occupancy of the Δ Y-straw layer (20% for Δ Y = 5 mm.) see event display, the hadron rejection expected at the pre-trigger level is about of a factor 3 for the electron efficiency 95%.
This gives a reduction of the the number of e-candidates by a factor of about 2.

· The reduction of the number of FLT accepted events/pretrigger.

- ghost-ghost events (72 %)
  $N_{ghost}/pretrigger$ is proportional Δ (ROI), because $\frac{\Delta Y(TRD)}{\Delta Y(TC1.2)} = \frac{few mm}{few cm} = 0.1$ and ghost radial distribution (see fig) we get a suppression of ghost-ghost events by factor of 3. (72% ⇒ 24%)
- eh,hh -events (23%.
  due to hadron rejection by factor of about 3 the expected reduction of eh.hh events is about of 2 (23% ⇒ 11%).

So, total FLT rate reduction is estimated as:
$\frac{1}{2}(4.5\% + 11\% + 24\%) \simeq 20\%$.
That is the reduction of FLT rate by factor of 5

· RESULT:
The possibility to reduce the ECAL threshould and increase the $J/\psi - e^+e^-$ detection efficiency by 30 -40 %.

· LEVEL 2(3)trigger: hadron rejection Expected hadron rejection along the reconstructed by FLT track is about 10-15 for electron efficiency 95% :
The possibility to reduce the ECAL threshould

Conclusions

⊙ HERA-B Straw TRD is well advanced detector (RD-6) with well known properties and quite suitable for HERA-B conditions. It can be built relatively soon.

⊙ The use of the straw TRD in HERA-B provides:

- The reduction of e-pretrigger rate .
- The reduction of FLT rate due to reduction of ROI for electrons and hadron rejection. this gives the possibility to decrease the ECAL treshoulds
  As a result: the J/ψ - e^+e^- detection efficiency has to be increased by factor of about 1.3 (32% ⇒∼ 42%)

⊙ The additional degree of the flexibility and redundancy for J/ψ - e^+e^- detection because the sensitivity of MC predicted pretrigger and FLT rates on the detail of the simulation (the model of simulation, exact geometry, detector material distribution), long term detector performance etc

⊙ We need more detail combine ECAL + TRD parameters and cuts optimization.

Yu.Zaitsev
05.10.94

Muon Identification

- Introduction
- Muon system layout
- Muon chambers
- Structure of superlayers
- Influence of the kicker
- Muon pretrigger
- Acceptance & efficiencies
- Muon identification
- Conclusions

Performance requirements

Muon identification plays a key role in the detection and tagging of the $B^0 \to J/\Psi K^0_S$ mode.

⊙ **muon pairs with an invariant mass consistent with $M(J/\Psi)$ provide the signal for FLT**

⊙ **additional single muon is used for tagging**

⊙ **in off-line analysis - rejection of backgrounds**

Muons identification relies on the tracks met the tracker requirements associated with the hits in muon chambers.

Requirements

⊙ **muon momentum range between a few GeV/c up to about 200 GeV/c**

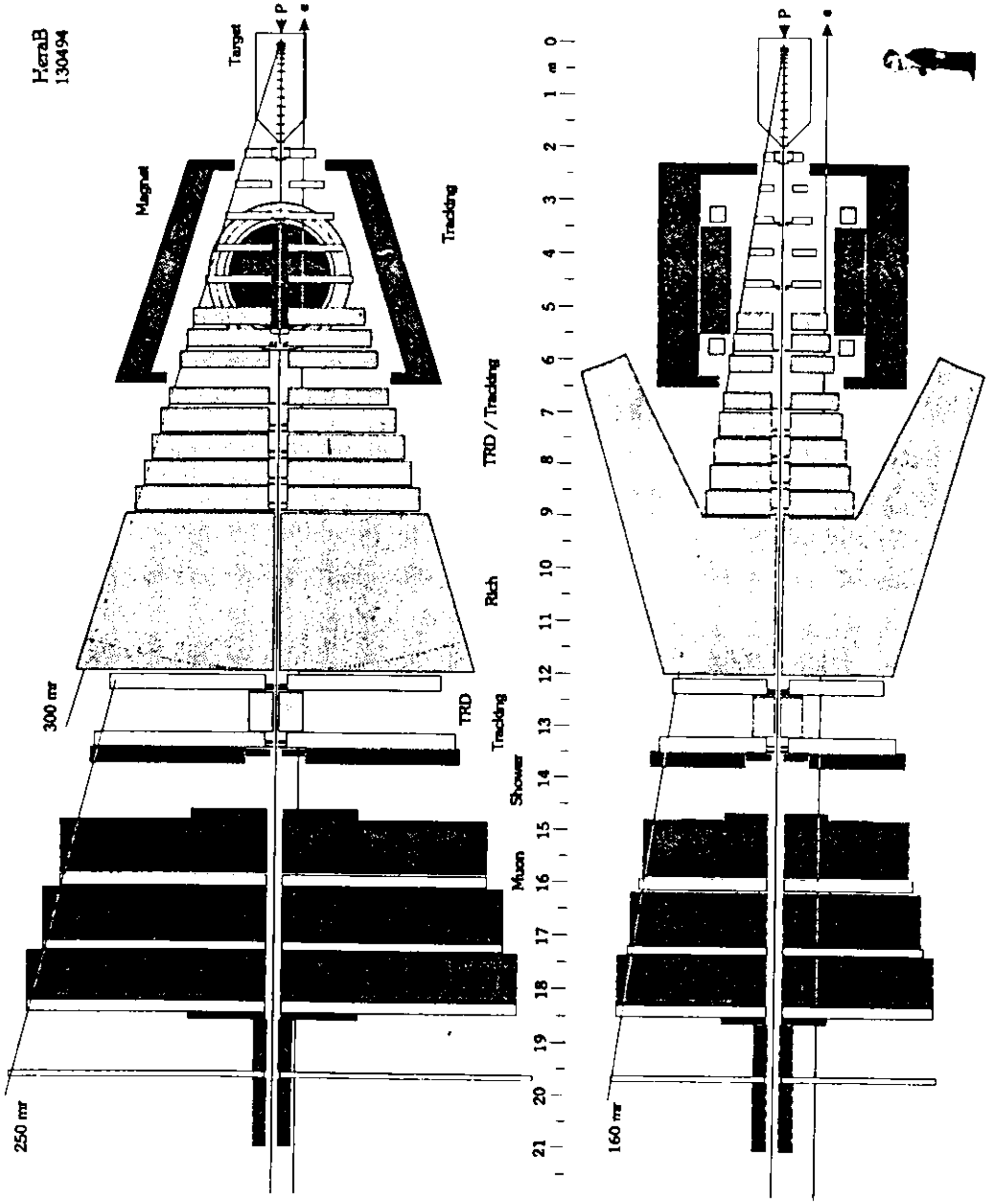
⊙ **high intrinsic efficiency for single muon**

⊙ **response of the muon chambers has to be faster than 96 ns**

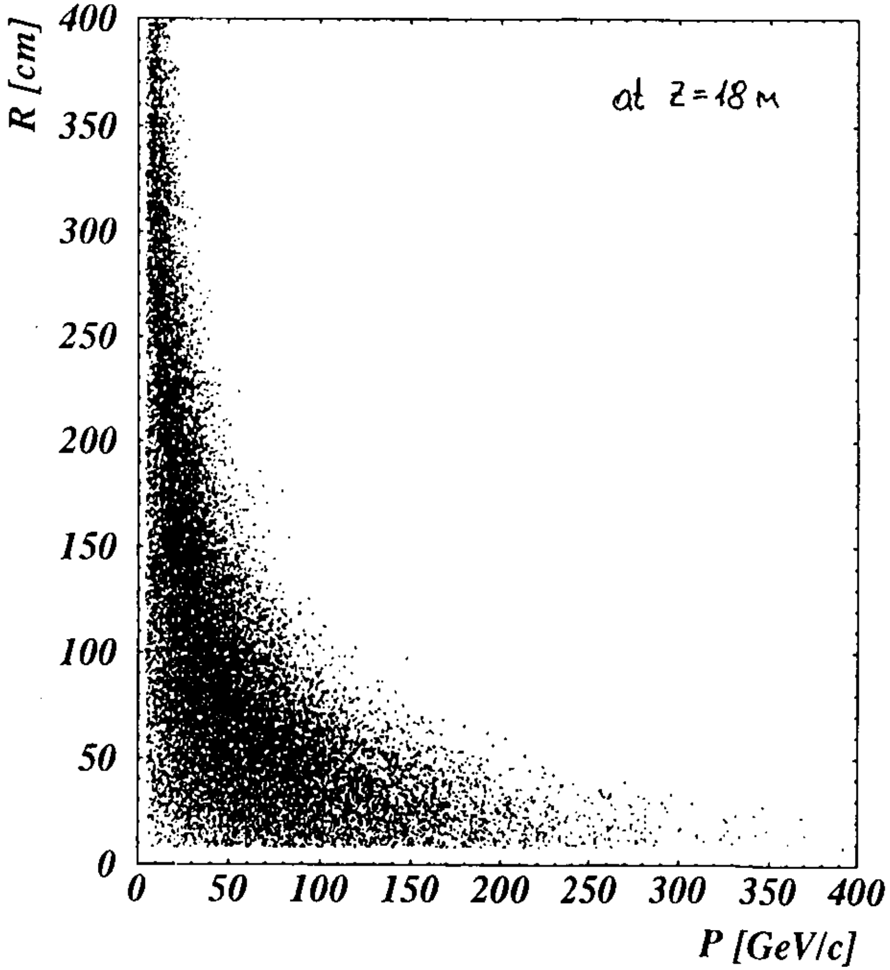
⊙ **transverse segmentation of chambers should ensure low occupancy**

⊙ **muon system has to have sufficient absorber material to keep an average punch-through probability at a level of $4 * 10^{-3}$**

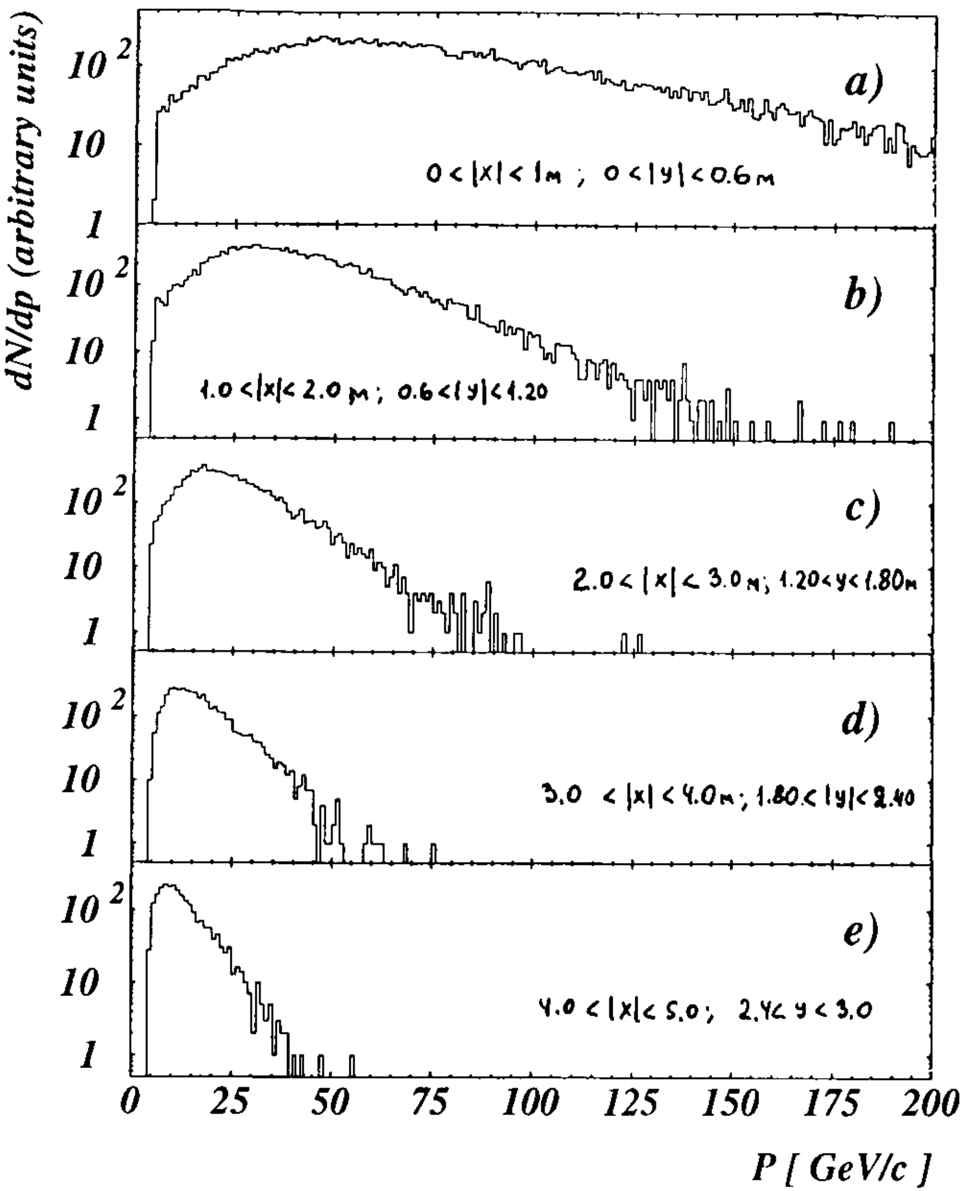
⊙ **space resolution has to be at least of the same order with multiple scattering in absorber to allow the efficient link between muon hits and track found in the tracker**



Muons from $B \to J/\psi K_s^0 \to \mu^+\mu^- K_s^0$

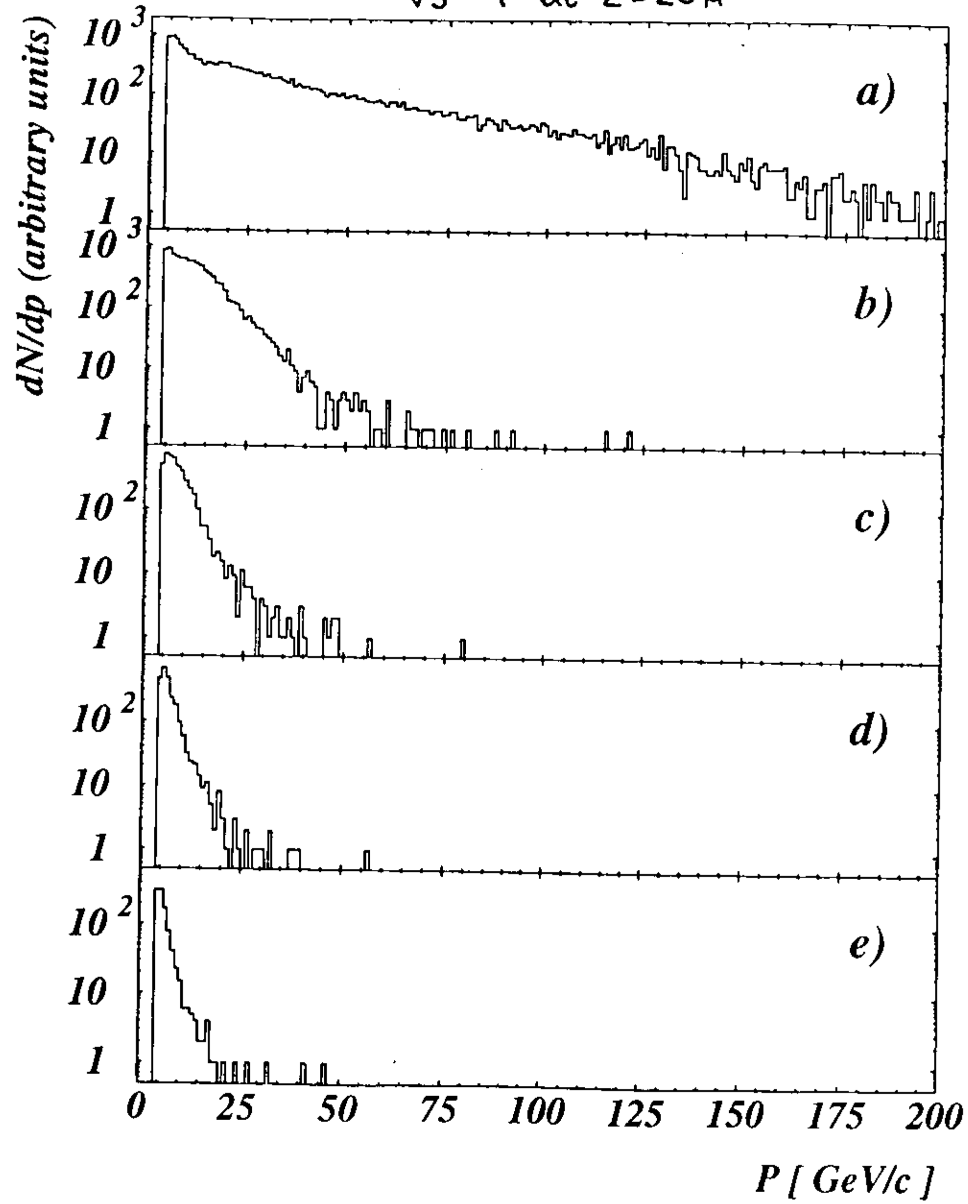


Muon spectra from $B \to J/\psi K^0_s \to \mu^+\mu^- K^0_s$



R -5-

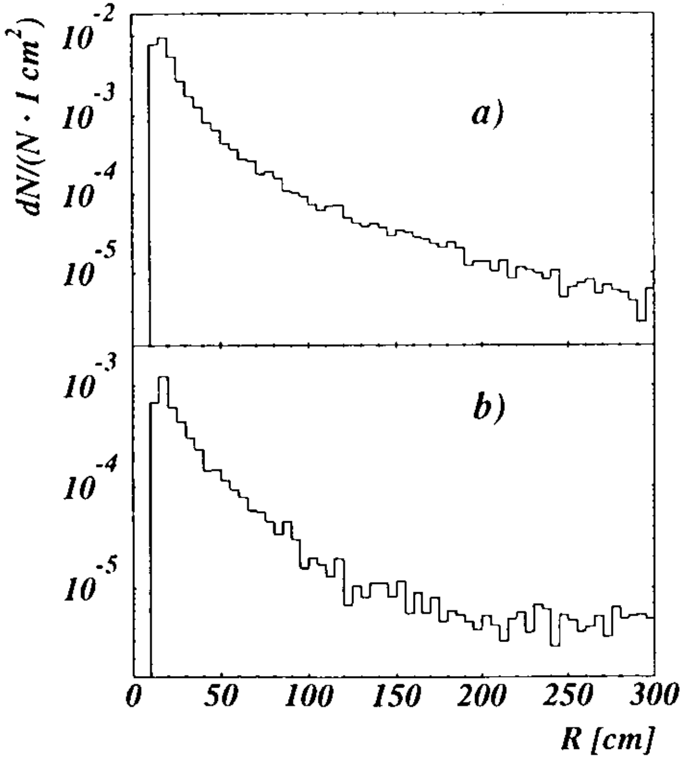
Pions spectra from min-bias events vs r at Z = 20m



R 6-

Track density at the planes MU_1 (a) and MU_1 (b) as a function of radius

- 5 Min Bias interactions per BX data have been used
- No kicker was assumed in the geometry layout

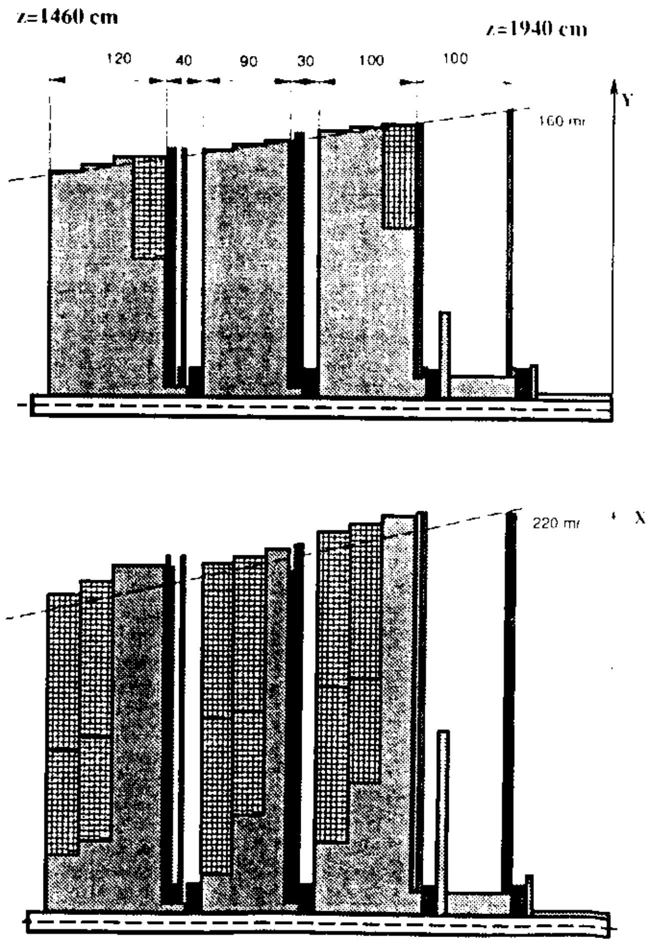


Yu.Zaitsev
14.09.94

Muon system layout

$z_0 \doteq 1460$ cm

(preliminary)



Muon System

○ *ABSORBER* - steel ⊕ steel-loaded concrete ($5.2 g/cm^3$)

$120\ m^3 \Longleftrightarrow 1000\ t$ steel(300 t concrete +550 t steel)
JADE muon filter → 100 t available

○ MU_1 and MU_2

3 double layers (0^o, $\pm 26.6^o$), wire readout (only hits)	$174 + 186 = 360$ chambers - 11160 wires
Central chamber (pixels)	$\approx 2 * 4400 = 8800$ pixels

○ MU_3 and MU_4

1 double layer (0^o) with pads and wire readout (only hits) pad size $10.0 * 13.5 cm^2$	$66 + 70 = 136$ chambers - 4216 wires
	$2 * (1947 + 2100) = 8094$ pads after "or" of each 2 ⇝ 4047 outputs
Central chambers with pixel and "pads" readout pad size $\approx 24 cm^2$	$\approx 2 * 4400 = 8800$ pixels $1612 + 1824 = 3436$ channels
	$\approx 240 + 260 = 500$ pads
	in total ≈ 27600 channels

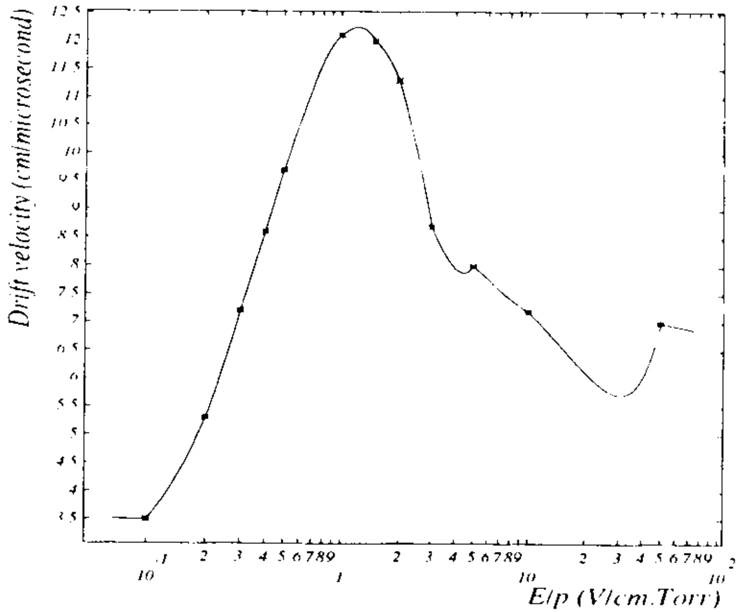
GARFIELD simulation of tube and pixel chambers

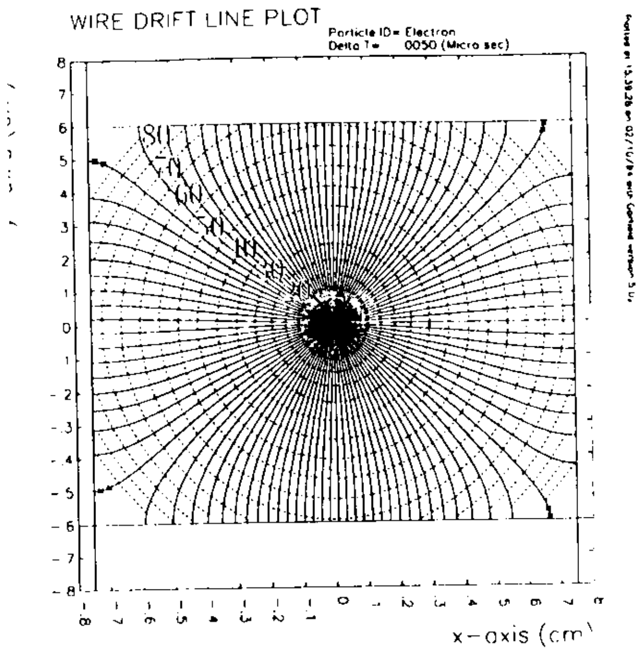
gas : $20\%\ CF_4\ 80\%\ Ar$

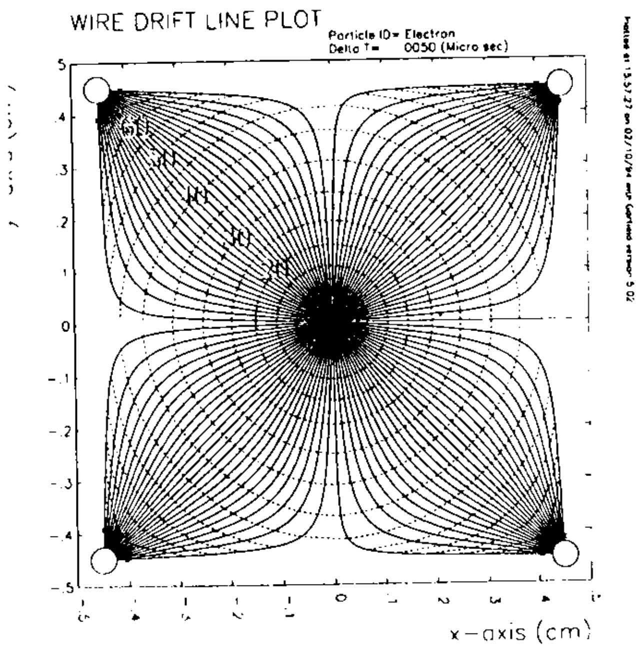
high voltage : $2500\ V$

sensitive wire : $D = 20\ \mu m$

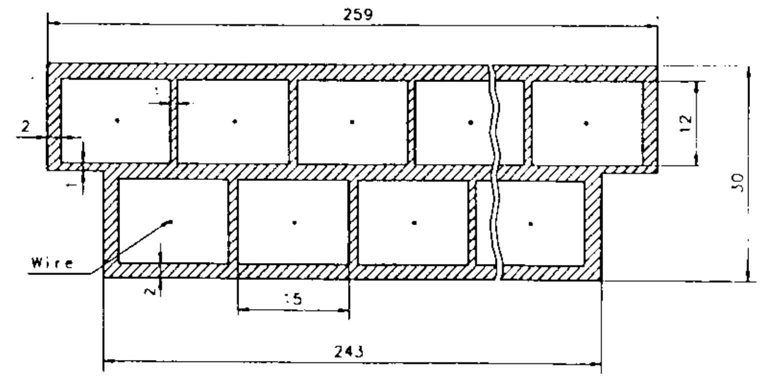
potential wire : $D = 200\ \mu m$



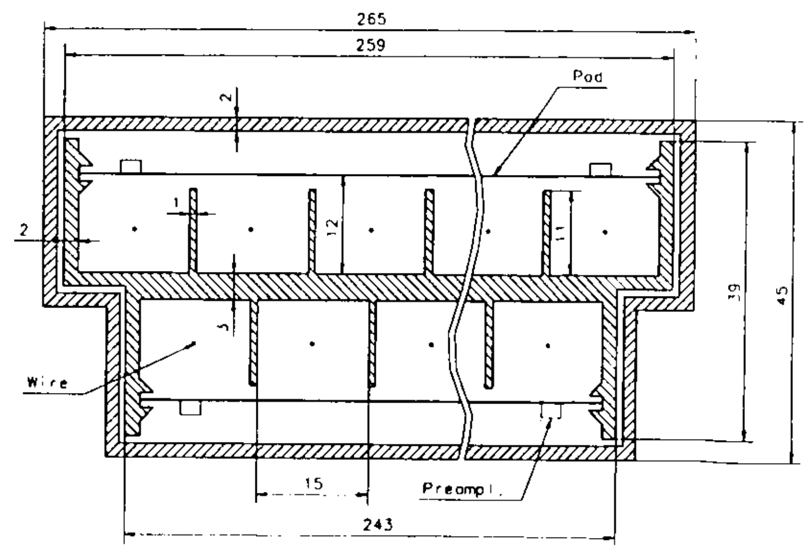




Tube chambers module



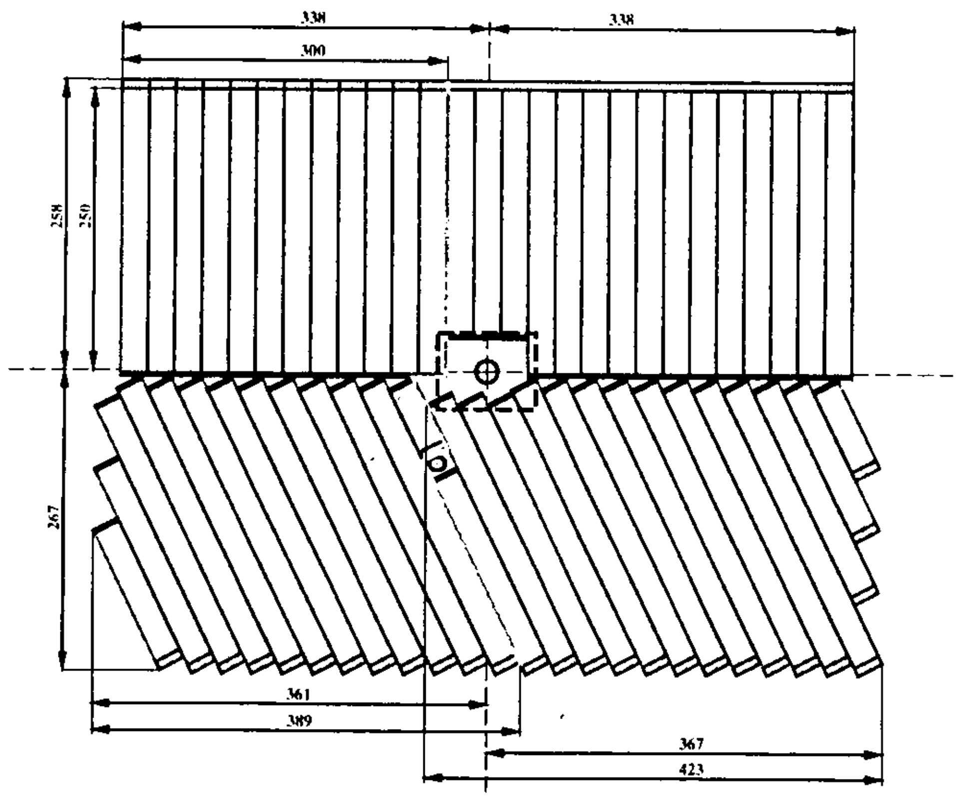
Pad chambers module



12.09.94

Structure of the 1–st layer of MU1

z = 1574 cm

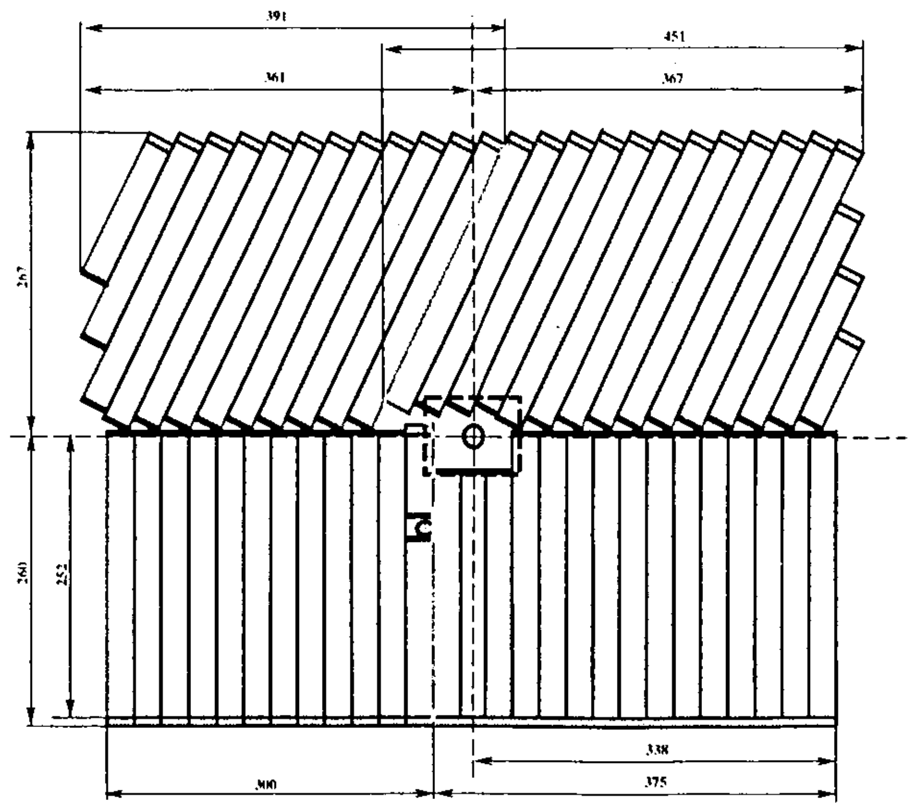


R -13-

Yu.Zaitsev
12.09.94

Structure of the 2–nd layer of MU1

z = 1578 cm

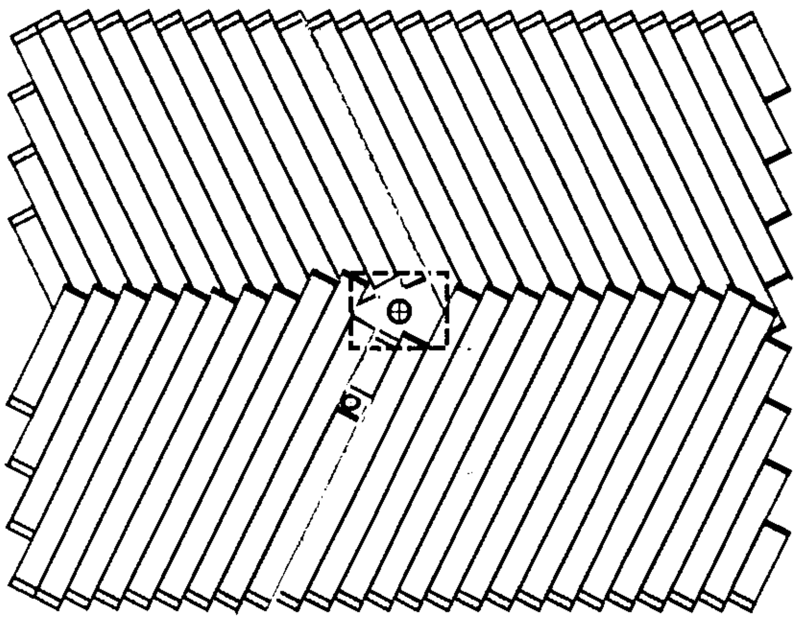


R -14-

Yu.Zaitsev
12.09.94

Structure of the 3–rd layer of MU1

z = 1584 cm

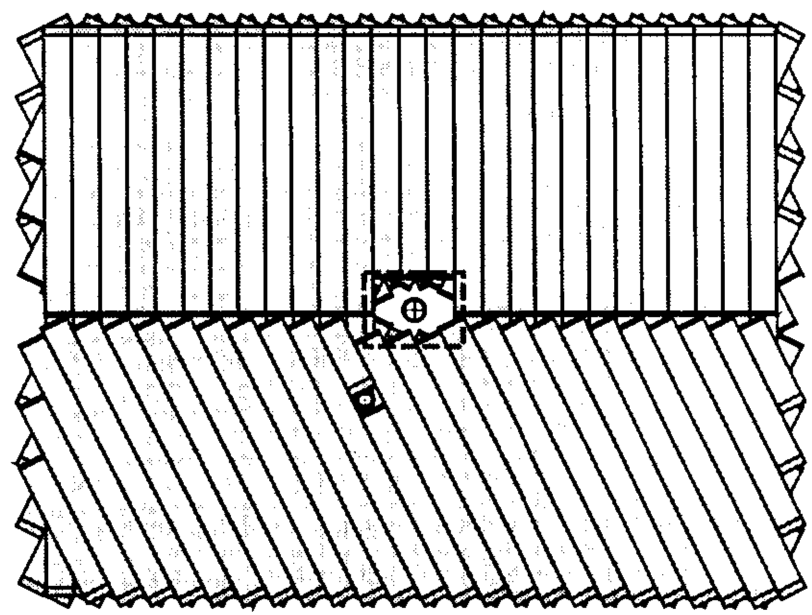


Yu.Zaitsev
12.09.94

Overlay view of the superlayer MU1

z_0= 1460 cm

(preliminary !)



Central pixel chamber in the superlayer MU3

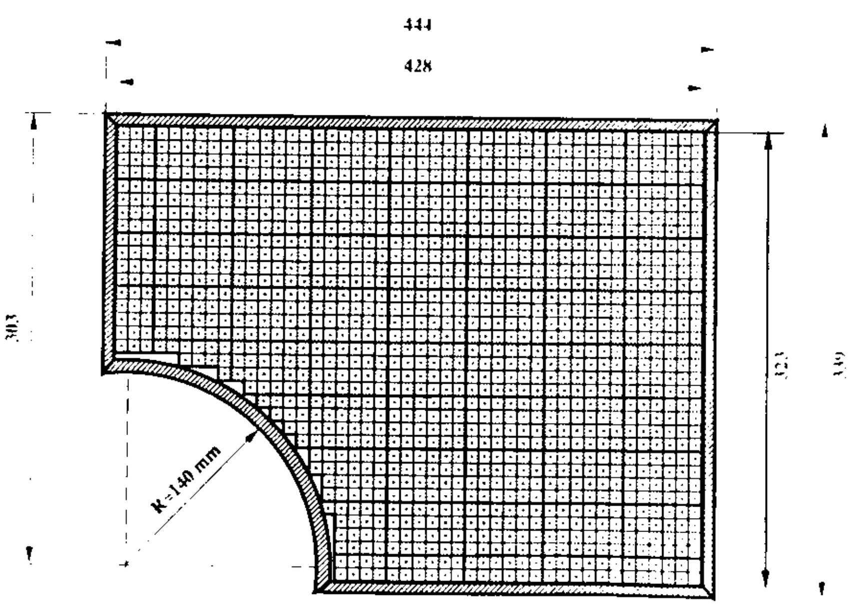
square cell 0.95*0.95 cm^2 1102 cells

60 pads   pad size 5.7*3.8 cm^2 (24 cells connected in OR)

60 pad readout channels

343 combined cells readout channel

(four cells in Y-direction inside one pad combined in one readout channel)



R - 17 -

Central pixel chamber in the superlayer MU4

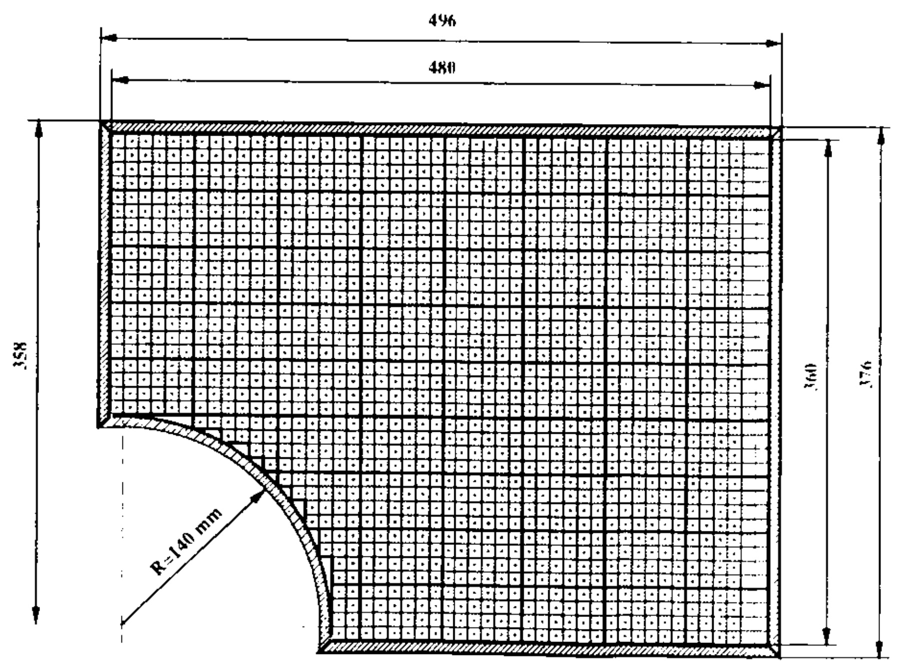
square cell 1*1 cm^2 1514 cells

65 pads   pad size 6*4 cm^2 (24 cells connected in OR)

65 pad readout channels

391 combined cells readout channels

(four cells in Y-direction inside one pad combined in one readout channel)

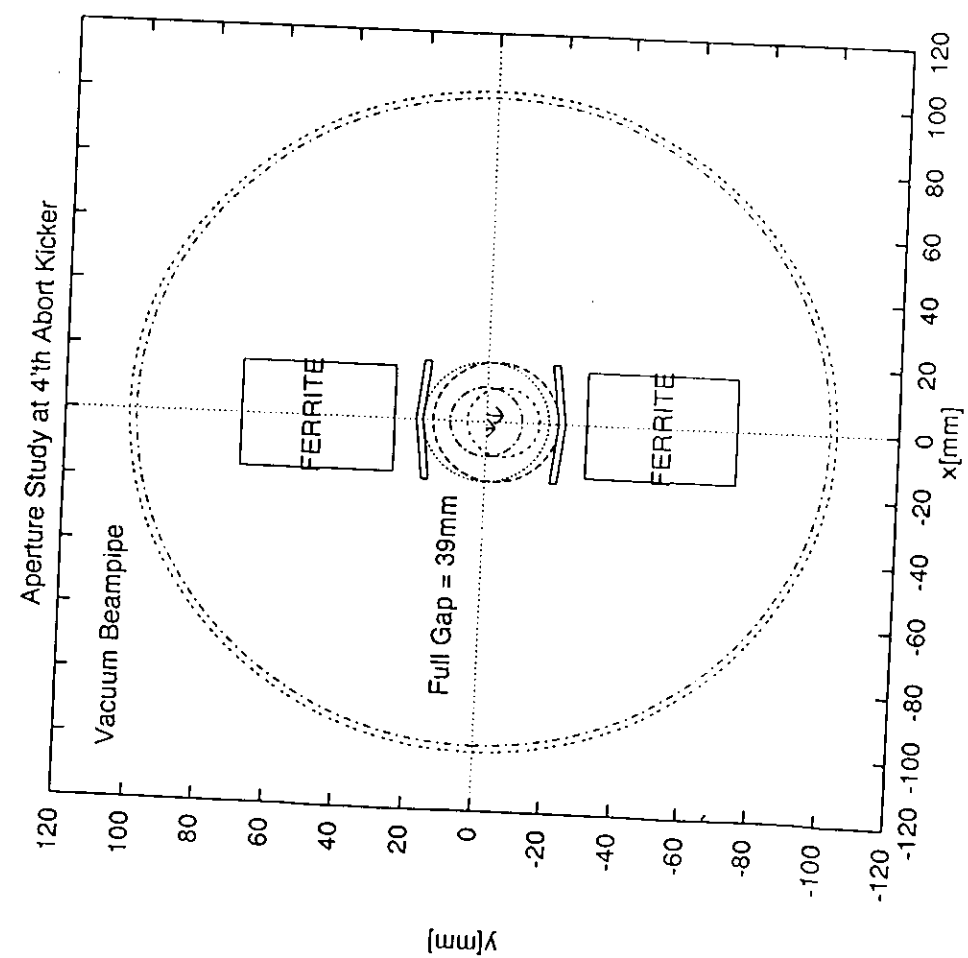


R - 13 -

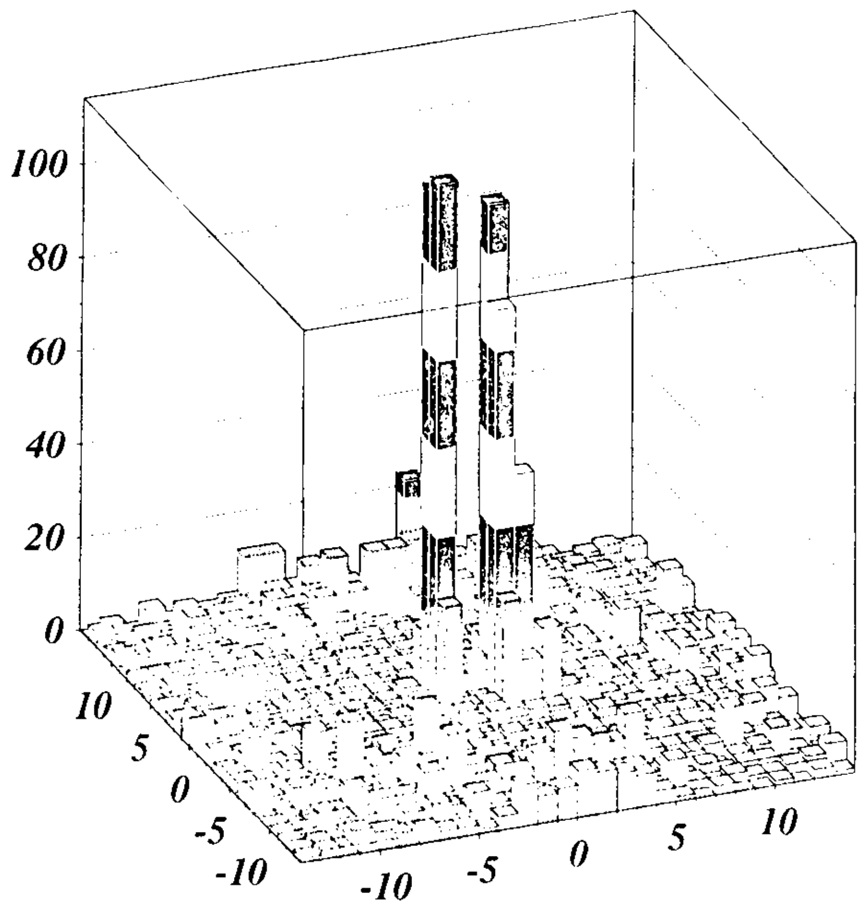
Numbers of wires, pads and electronic channels of the muon system

	function	type	nmbr of cham	nmbr of pads	nmbr of wires	nmbr of chan
MU_1	trigger ⊕ off-line	CC	4	–	4408	4408
		0° TC	58	–	1798	1798
		26.6° TC	116	–	3596	3596
MU_2	off-line	CC	4	–	4408	4408
		0° TC	62	–	1922	1922
		±26.6° TC	124	–	3844	3844
MU_3	pretr.⊕tr.	CC	4	240	4408	1612
	⊕off-line	0° PC	66	1980	2046	2046
MU_4	pretr.⊕tr.	CC	4	260	6056	1824
	⊕off-line	0° PC	70	1980	2170	2170
Total			512	5162	34648	27628

CC - central pixel chambers
TC - tube chambers only hits readout
PC - pad chambers



The kicker influence

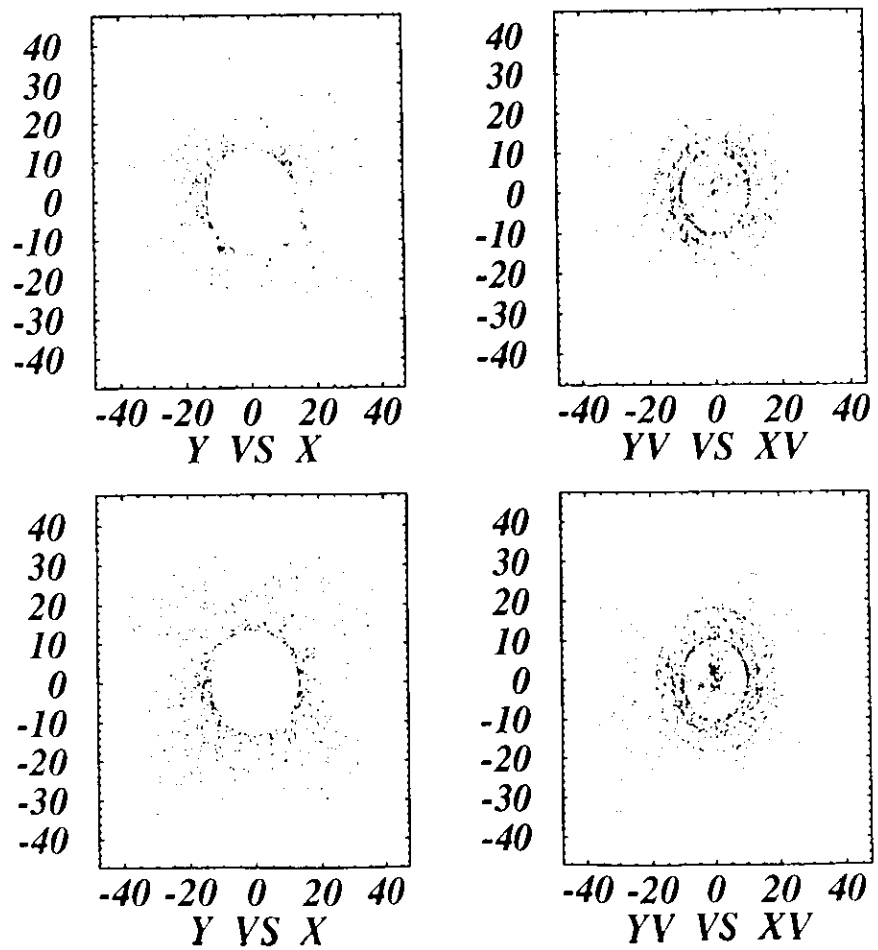


Verteces of the particles crossing MU_3 superlayer

Hits in MU3 and verteces these hits originate from

Without (top) and with (bottom) the kicker

(200 events * 5 Min Bias, Poisson)



The background from kicker

	region	MU_1	MU_2	MU_3	MU_4
Optimized	all	1.	1.	1.	1.
tube	inner			1.	1.
Beam pipe	all	1.1	1.7	2.8	2.4
$R = 10\ cm$	inner			4.0	3.9
Beam pipe	all	1.2	2.9	4.0	3.2
$\oplus$ Kicker	inner			6.5 !!!	5 !!!

- Background in MU_3 and MU_4 is a factor of 4 – 6 larger with kicker compared to the geometry with the optimized beam pipe shape
- Remarkable part of this increase is due to we have to use non-optimized beam pipe shape within the muon system
- Still we underestimate the kicker influence for :
  - not all constructive elements of the kicker have been implemented in GEANT
  - additional constructive elements of kicker and vacuum pumps need the holes in the iron absorber. This will inevitably lead to the further occupancy growth around the beam pipe
  - the well-known GEANT underestimation of the particle production at large angles

⟹ Therefore we can expect a total increase in the background by a factor of 6 – 8 for both superlayers.

Muon pretrigger

Muon pretrigger will be used in order to decrease the number of muon candidates for the first level trigger with respect to the number of hits in the last layer of muon system

Each pad of the superlayer MU3 is put in coincidence with several pads in the superlayer MU4 which is placed about 1 m behind MU3

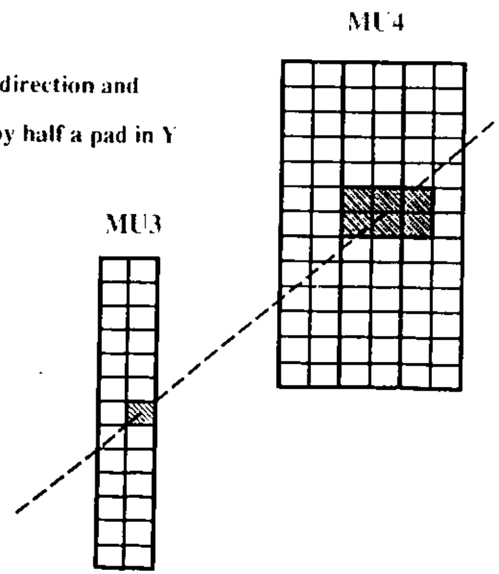
This gives position and direction information and start the algorithm of track finding in MU1 using wire information from MU3 and MU4

For outer region – projective geometry in Y–direction and pads in MU4 are shifted by half a pad in Y

There are three options under concideration:

in MU4

- 4 pads in X and 2 rows in Y = 8 pads
- 3 pads in X and 2 rows in Y = 6 pads
- 6 pads for middle part and 8 pads for outer part

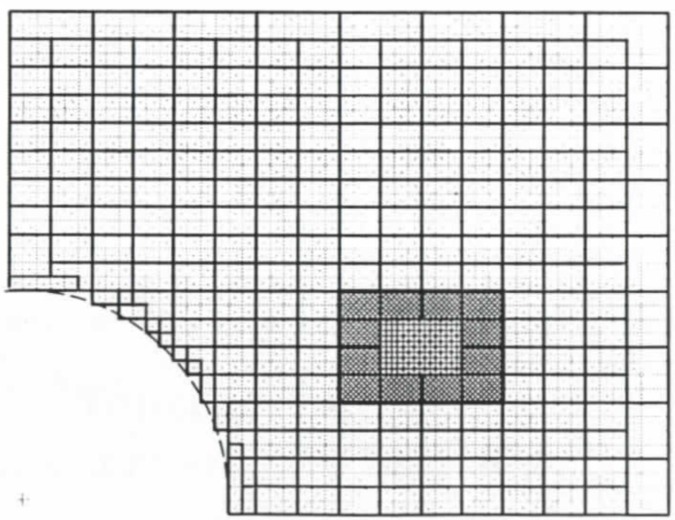


Pad connection in central chambers for muon pretrigger

$$\text{Pretrigger} = \text{pad}_{ij}(\text{MU3}) \text{ .AND. } \sum_{k=i,\, l=j}^{k=i+1,\, l=j+1} \text{pad}_{kl}(\text{MU4})$$

— projection of MU3 pads on the plane MU4

— pads in the superlayer MU4

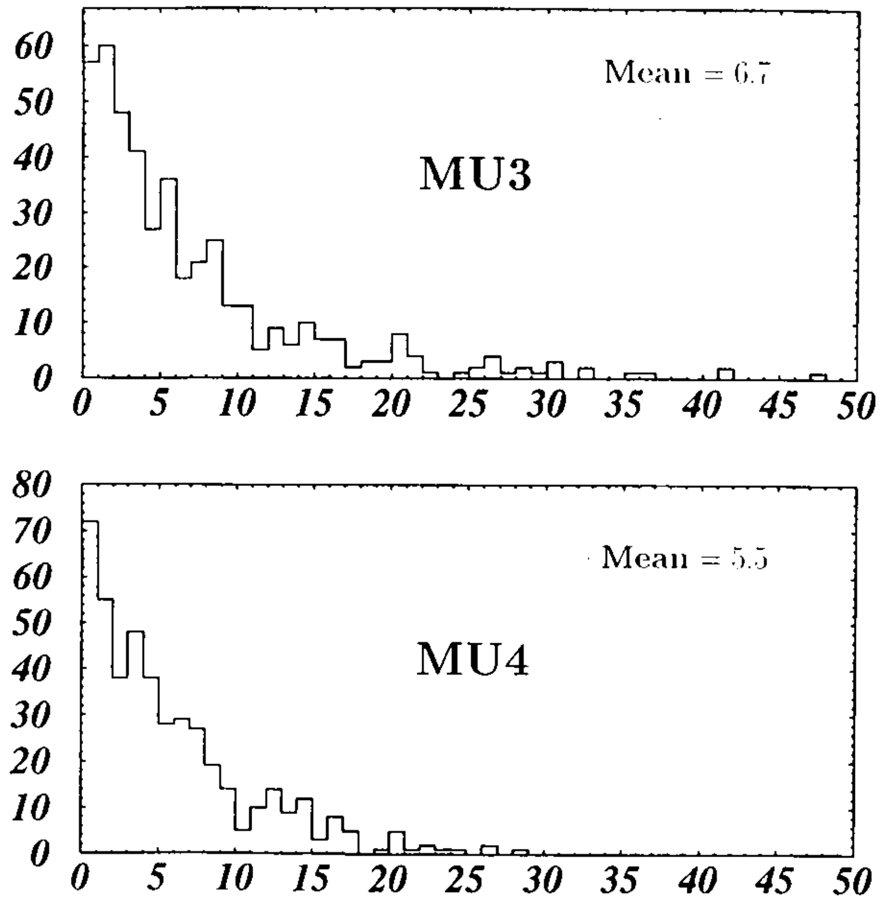


The changes influenced the pretrigger rate

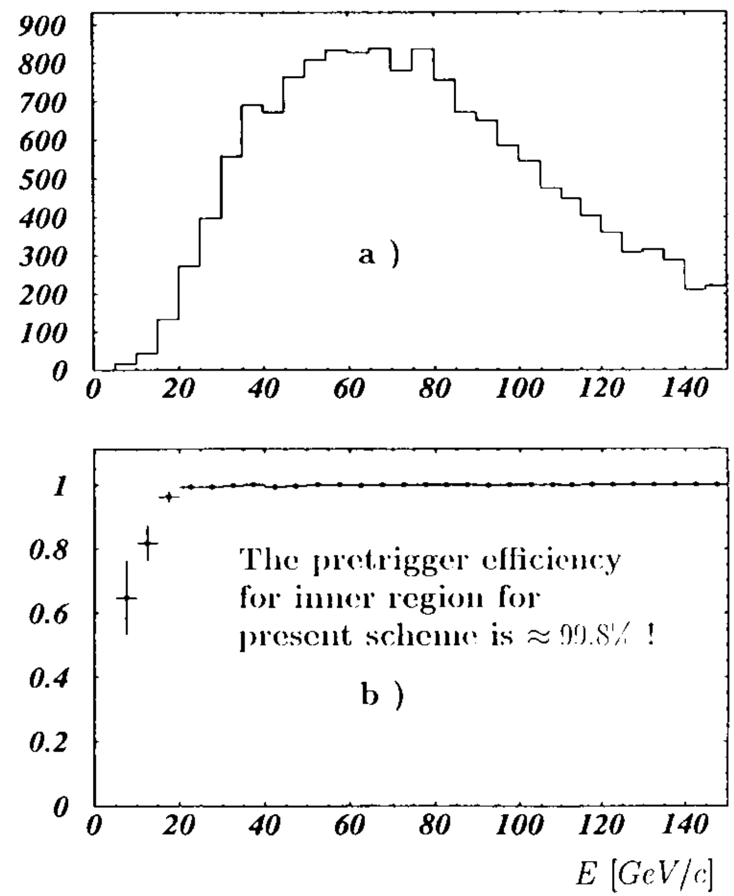
- The kicker was introduced
- → We have to use "non-optimised tube"
- → We have to increase the tube radius to 10 cm
- The tube is now surrounded by a 3.5 cm width absorber
- The present radius of inner chamber is 15 cm (efficiency went down from 68.6% (for 12 cm) to 68.1%)
- We use the projective geometry for inner region (90 cm * 68 cm) in X - direction either
- → **This allowed us to use 1 (in MU_3) to 6 (in MU_4) pad coincidences for inner region (the consequent decrease of pretrigger rate is up to 16%)**
- The promising option to use 1 (in MU_3) to even 4 (in MU_4) pad coincidences for the inner region is under detailed study

Pads occupancy in pretrigger superlayers

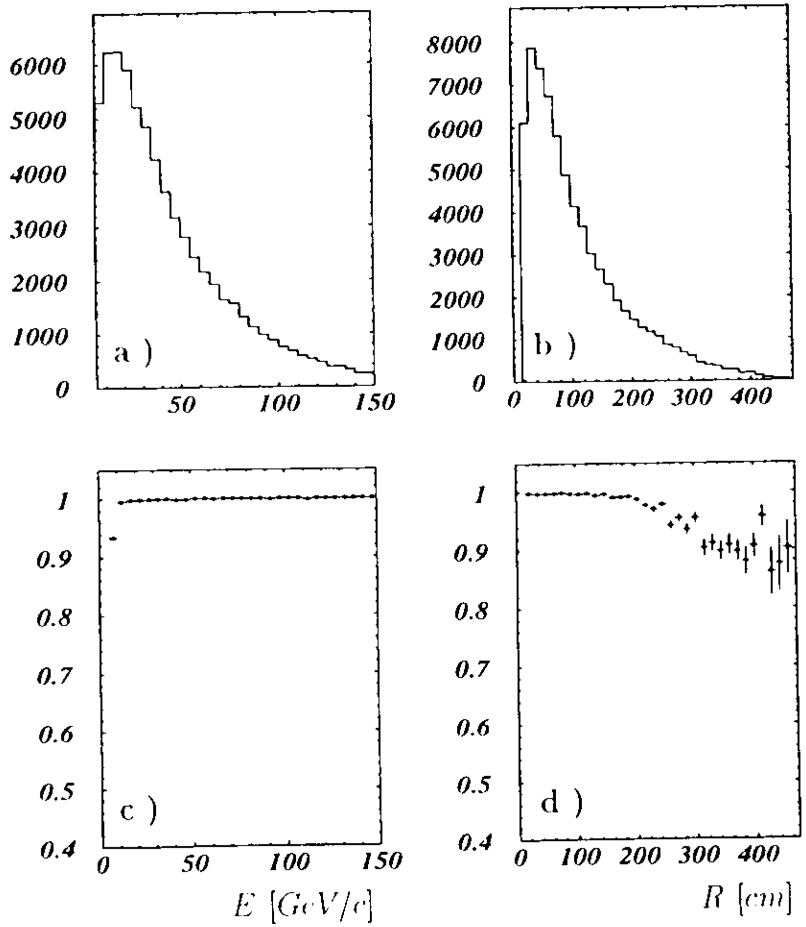
(450 events * 5 Min Bias, Poisson)



Muon energy spectrum (a) and pretrigger efficiency dependence on the energy (b) for muons from J/ψ decays crossing the inner region of MU_3 superlayer



Muon energy E spectrum (a), distance R from the beam axis distribution (b) and energy (c) and distance (d) pretrigger efficiency dependences for muons from J/ψ decays crossing the MU_1 superlayer



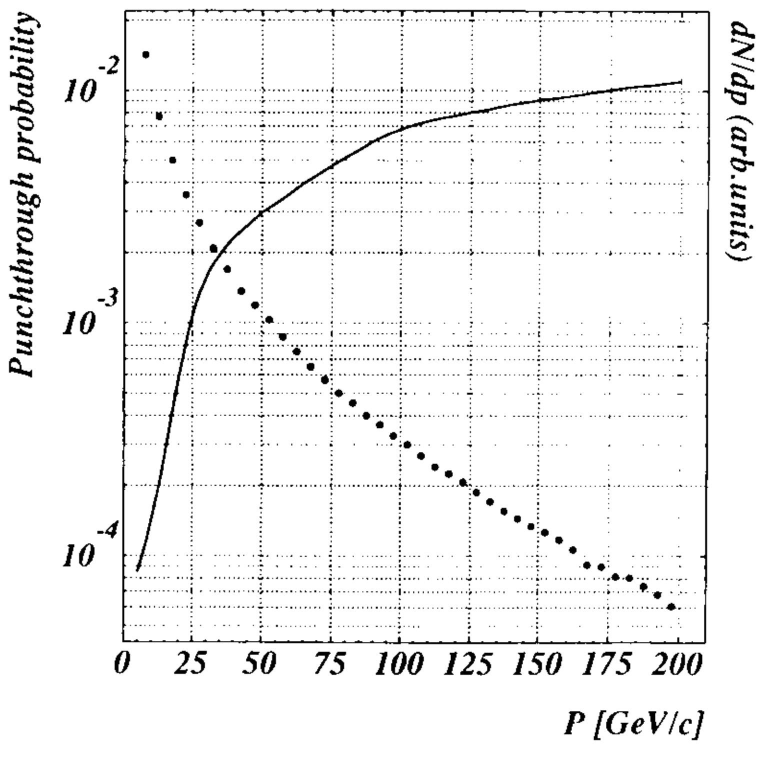
pretrigger efficiency = 99.0%

Backgrounds for muons identification

- ⊙ hadron punch-through
- ⊙ muons from $\pi(K)$ decays in the tracker and before the absorber
- ⊙ secondary particles interections with the beam wall in the muon chambers region
- ⊙ the muon hallo of proton beam
- ⊙ possible background from the electron beam
- ⊙ neutrons and neutron-induced photons in the hall
- ⊙ muon associated background, such as δ-electrons and muon-generated showers from the last few radiation lengths of the absorber
- ⊙ hits in chambers due to the electronic noise

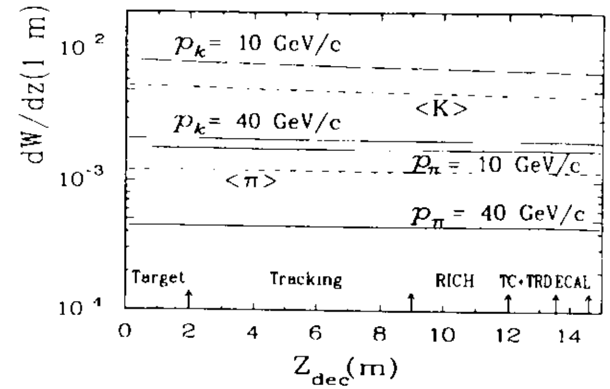
Punch-through probability estimation for HERA-B muon system

- momentum distribution of π mesons from MinBias events

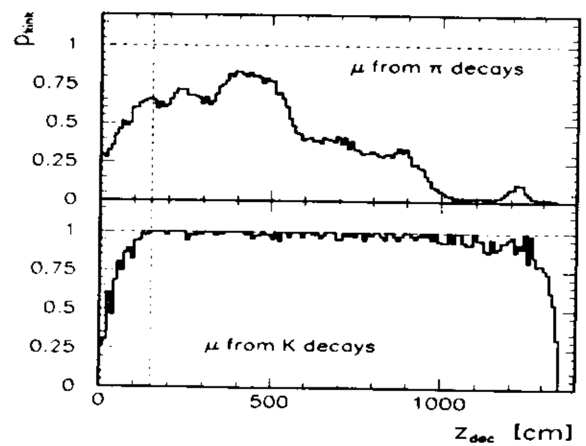


Hadrons decay in flight

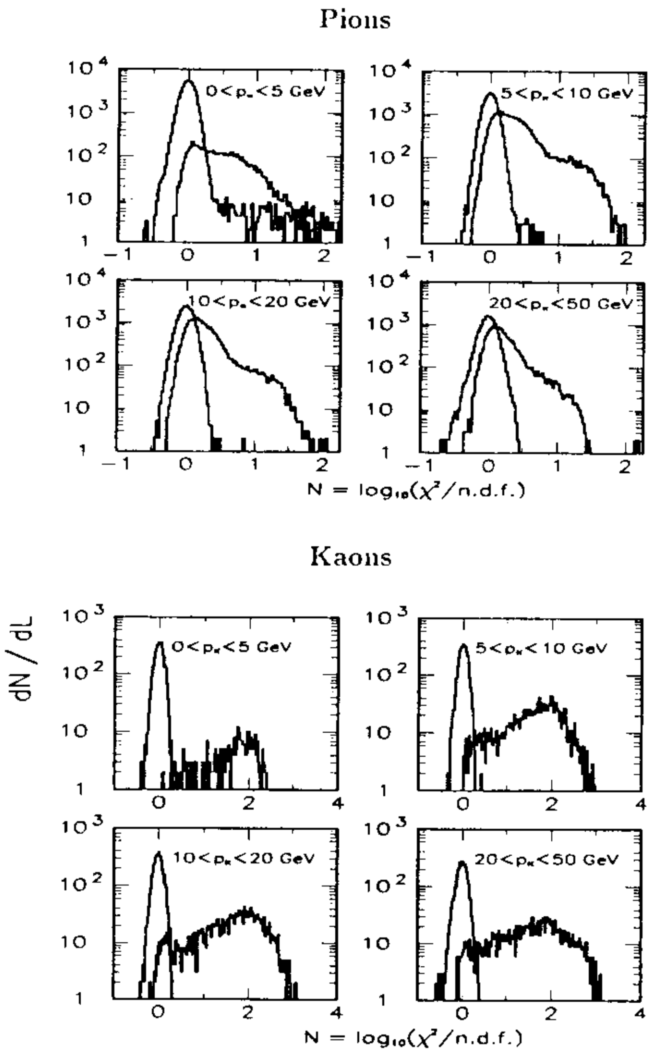
Decay probability



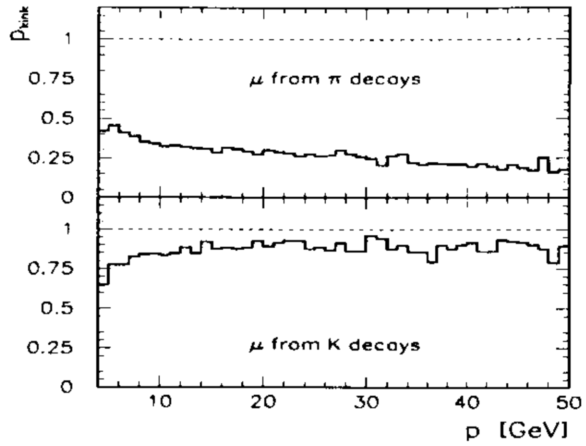
Probability to identify in the track fit a decaying pion or kaon as a function of the location of the decay point



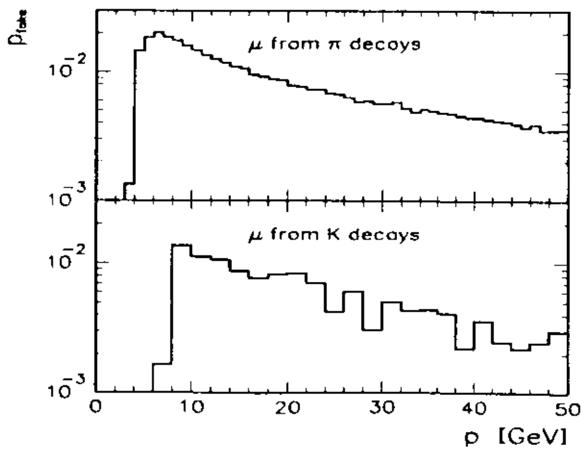
The χ^2 distribution of the track fit inside the tracker system



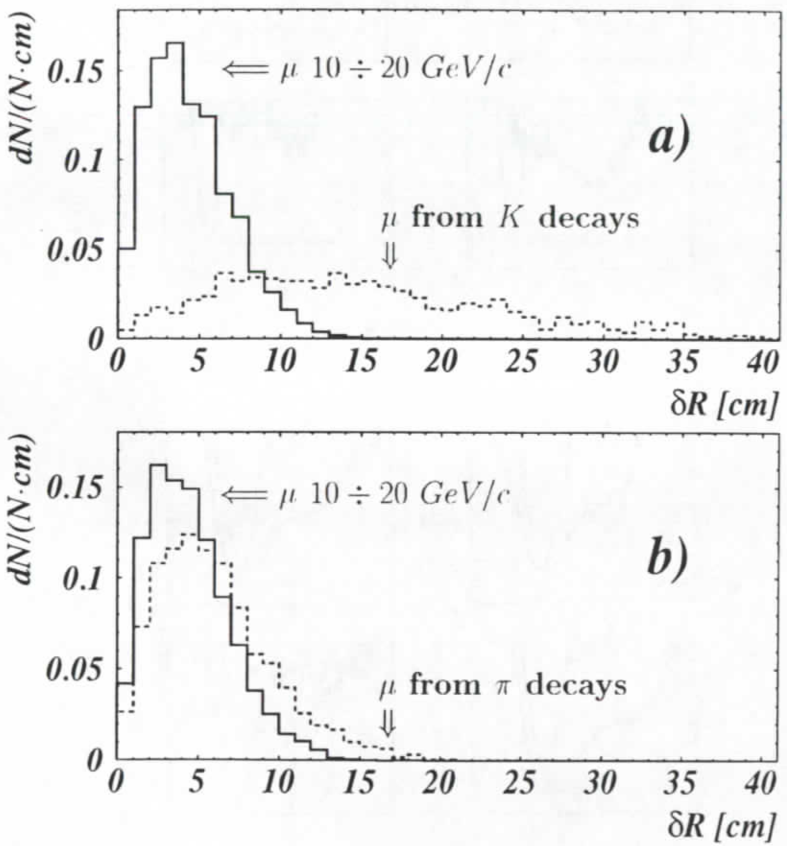
Probability to identify a kink as a function of the reconstructed pion (kaon) momentum



Fake rate of muons from the decay in flight of pions and kaons as a function of reconstructed momentum



Distance of expected impact point of particle in the MU_3 from extrapolation of real track found in the tracker system



Time table

Muon platforms	design is started now at DESY
Absorber	partly available, we are still looking for cheapest steel
Frames for chambers	design has to be started soon if we are going to use them in 1996
Central chambers	intensive R&D in progress, the decision - the beginning of 1995
Tube and Pad chambers	all profiles have to be ordered in January - February, 1995, start of mass production - May, 1995
Gas system	hope to update old ARGUS gas system, problems have to be discussed
Front - end electronics and Muon pretrigger	electronic channels test and pretrigger prototype are under study. We need collaborators !!

- ◇ Test set-up in ITEP ∼ will be ready in early 1995
- ◇ Preparation for mass production ∼ in progress
- & MC - study
- & Off - line analysis
- && On - line, second and third level triggers

Kaon identification - the HERA-B RICH

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J.Stefan Institute and Department of Physics,
University of Ljubljana, Ljubljana, Slovenia

1. Motivation
2. Expected Performance
3. The Prototype
4. Performance of the prototype
5. Conclusions

People involved

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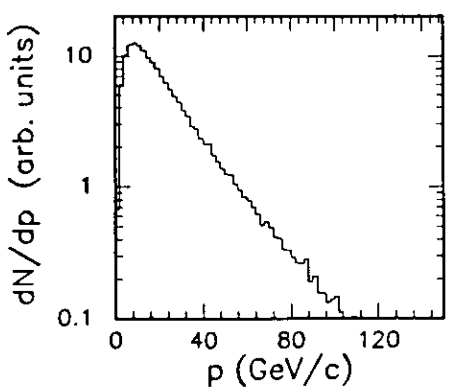
A. Bulla, T. Hamacher, E. Michel,
W. Schmidt-Parzefall, P. Weyers
DESY, Hamburg, Germany

R. Schwitters
Department of Physics, University of Texas, Austin,
USA

Motivation

In the HERA-B experiment the tagging of B meson flavour by the charge of kaon is an essential feature.

RICH has to be designed and build to match the requirements, high efficiency up to approx. 50 GeV/c.



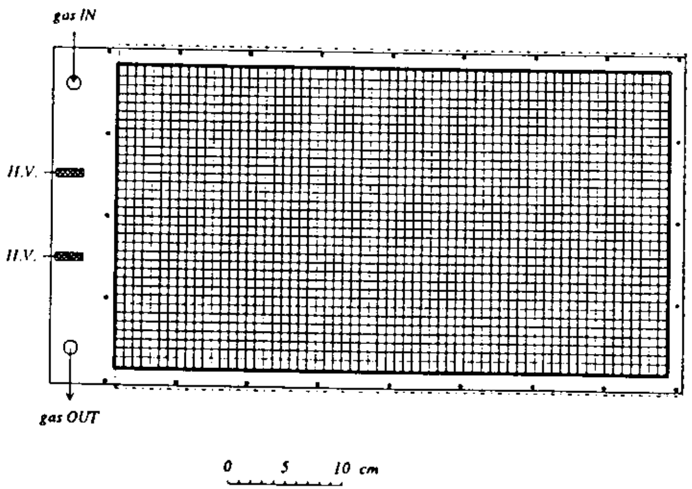
Design Criteria

The design choices are governed by the following criteria:

- To achieve the necessary performance, enough photons (more than 10) have to be detected for each ring image. This requirement fixes the length of the a gas radiator to a few meters.
- A high rate capability of the photon detector requires some kind of chamber with pads, and therefore limits the resolution to a few milimeters (assuming that only digital information is read out, rather than pulse height).
- The required high resolution in the measurement of the Čerenkov angle with such a photon detector is only achievable if the focal length is kept at several meters.
- The delicacy of the photon detector with a very low threshold, necessary to detect single photoelectrons, requires the photon detector to be kept out of the solid angle for charge particles and conversion products.

Our choice

- Radiator C_4F_{10}
- Mirror: like OMEGA
- Photon detector (10 m^2, 64 modules, $8 \cdot 8$ mm^2 pads)
  - TMAE - CH_4 gas mixture
  - Pads covered with CsI
- Read-out system (160000 channels)



Size of chamber $50 \cdot 30$ cm^2, 85% active area

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CHANGES IN DETECTOR DESIGN

- THE WHOLE DETECTOR HAS BEEN SHORTENED → PUSHED THE PHOTON DETECTOR CLOSE TO THE MAGNET
- THIS DECIDED THE "1 MIRROR" VS "2 MIRRORS" DISCUSSION
- GEANT SIMULATION STUDY OF BACKGROUNDS SET THE PHOTON DETECTOR POSITION TO $|y| > 2,5$ m

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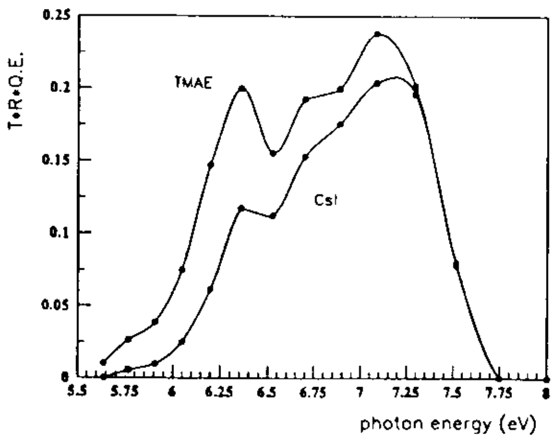
Expected Performance

Resolution:
$\sigma_\beta = 3.6 \cdot 10^{-5}$
$\sigma_\theta = 65 \cdot 10^{-3}$

photon detector	CsI	TMAE
ϵ_e	0.80	0.80
ϵ_a	0.85	0.85
absorption in chamber gas	1.0	0.85
number of photons	44	50



(Transmission · Reflectivity · Quantum Efficiency)

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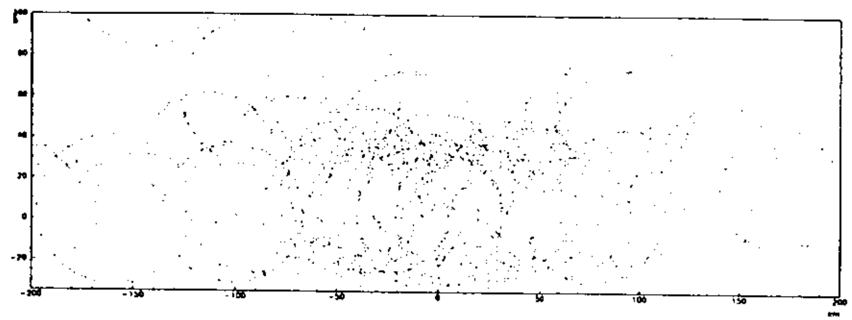
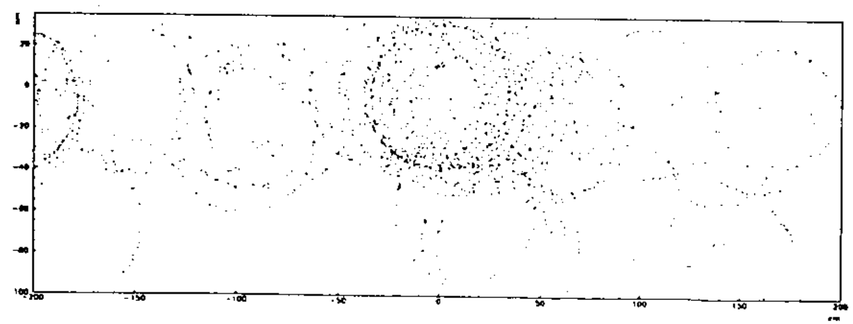
Performance studies:
Full GEANT simulation of events. Čerenkov photons generated and tracked to photon detector.





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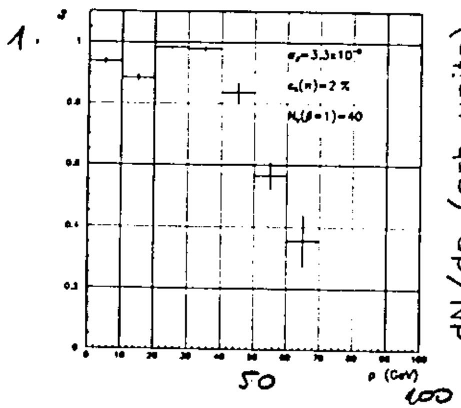
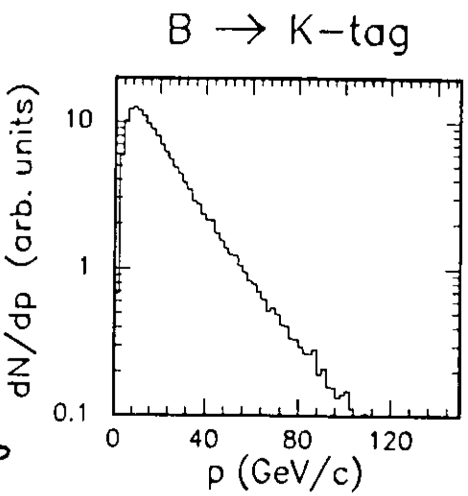
Match detected photons with charged tracks. Calculate for each track likelihoods of π and K-hypothesis taking into account background.

Kaon efficiency:



Kaon momentum:



π /K separation ($N_\gamma = 40$):

$$\epsilon(K) \approx 95\%$$
$$\epsilon(\pi) < 5\%$$

Photon detector: beam tests

The environment of the HERA-B experiment requires several additional checks of the techiques employed:

- high event rate capability
- rate per pad of the photon detector: few times 100 kHz
- ageing

Two photon detectors are tested in the beam test:

- TMAE chamber with cells
- CsI chamber with pads

The TMAE chamber

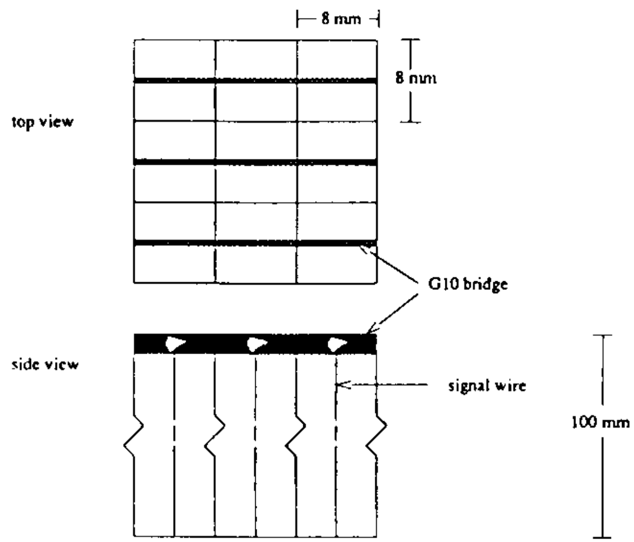
structure: 32x32 channels

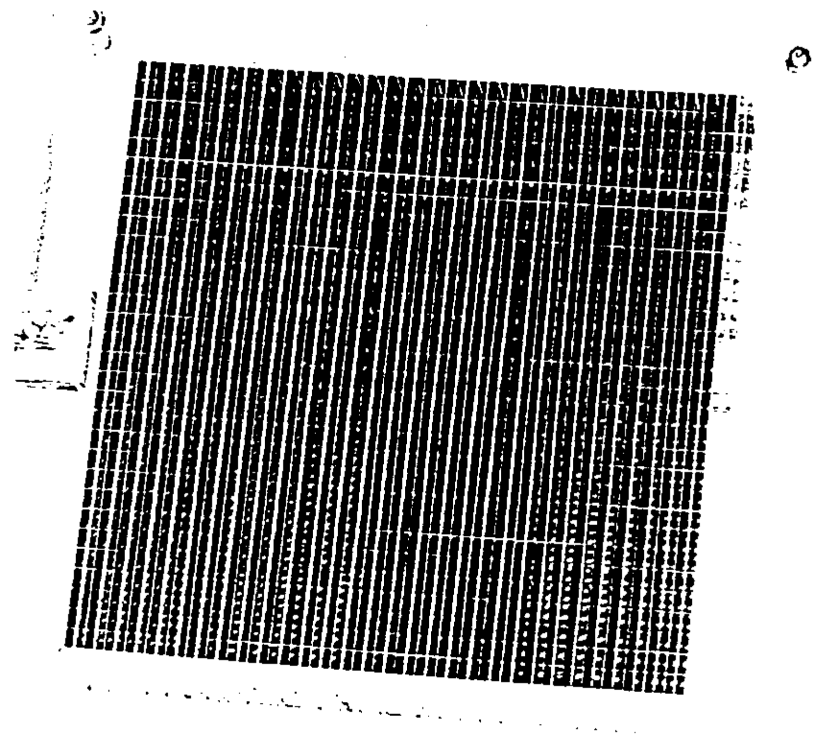
cell size: 8x8 mm^2, 100 mm long

window: 5 mm quartz

chamber gas: methane with TMAE

TMAE bubbler: at room temperature, concentration varied by mixing with pure methane





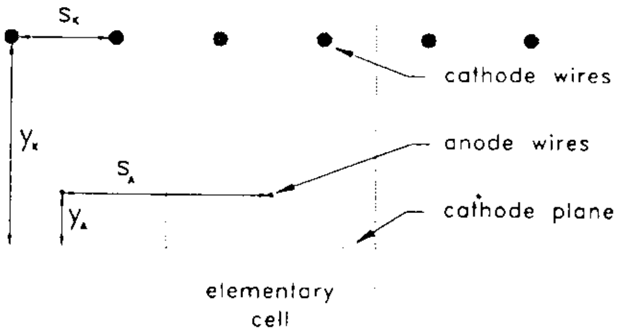
CsI chamber

32x32 channels

pad size 7.5x7.5 mm^2

5 mm quartz window

approx. 1 μm thick CsI layer on a polished Cu surface covered by solder



Geometry of anode and cathode wires with respect to the CsI cathode plane. In the present design these dimensions were optimized to $y_K = 2.1$ *mm,* $y_A = 0.66$ *mm,* $s_A = 2.5$ *mm and* $s_K = 1.25$ *mm.*

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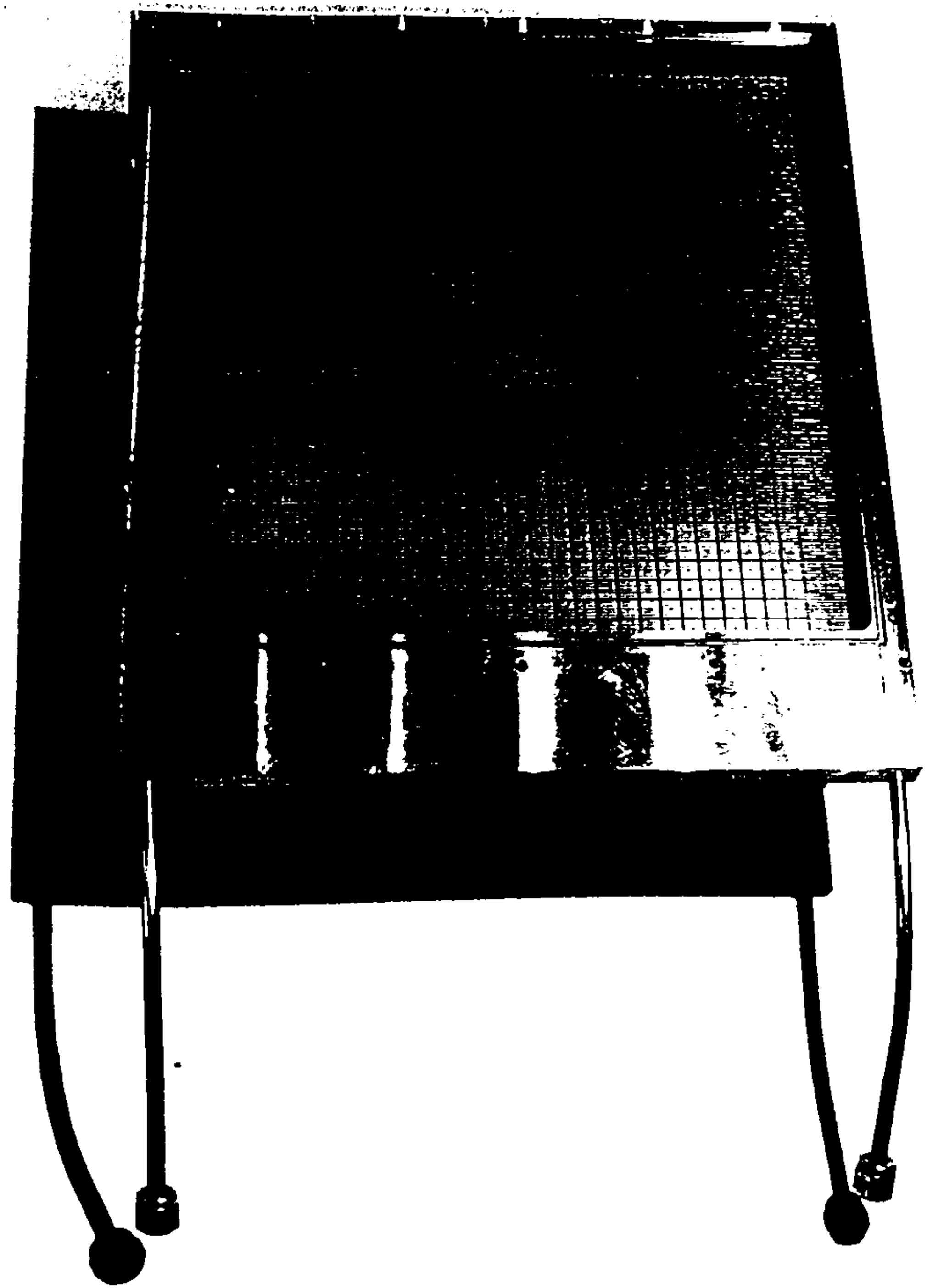

13a

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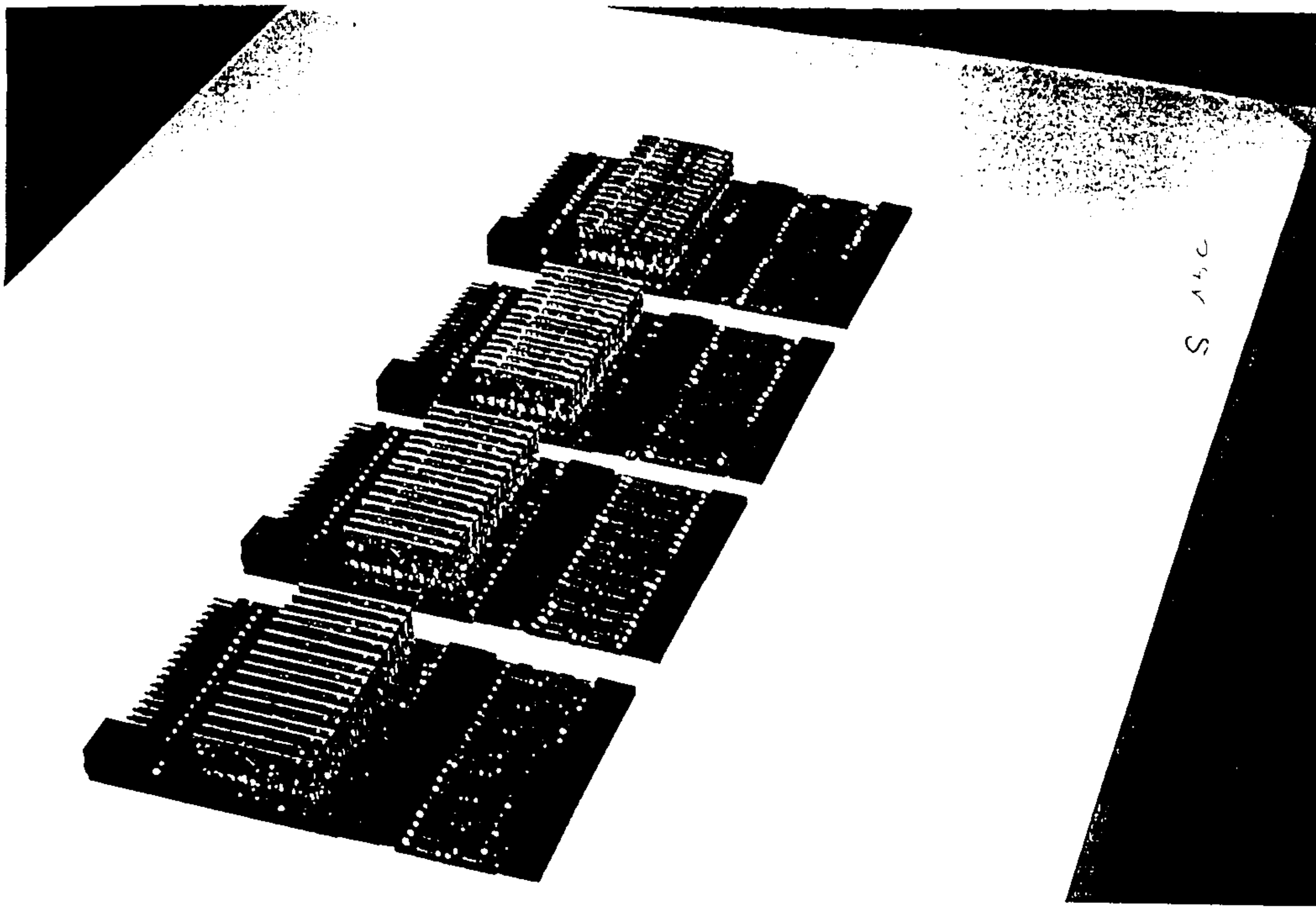
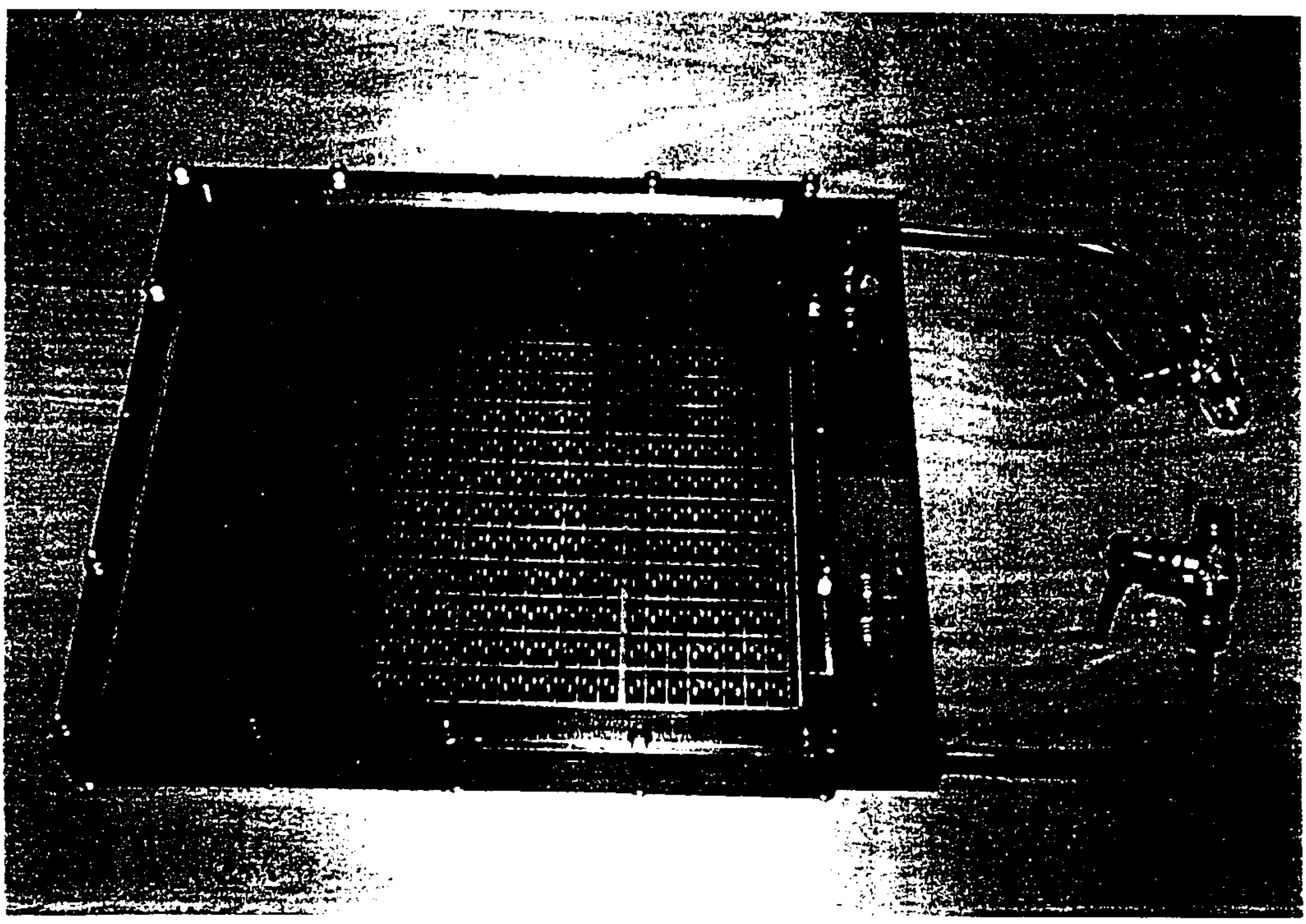
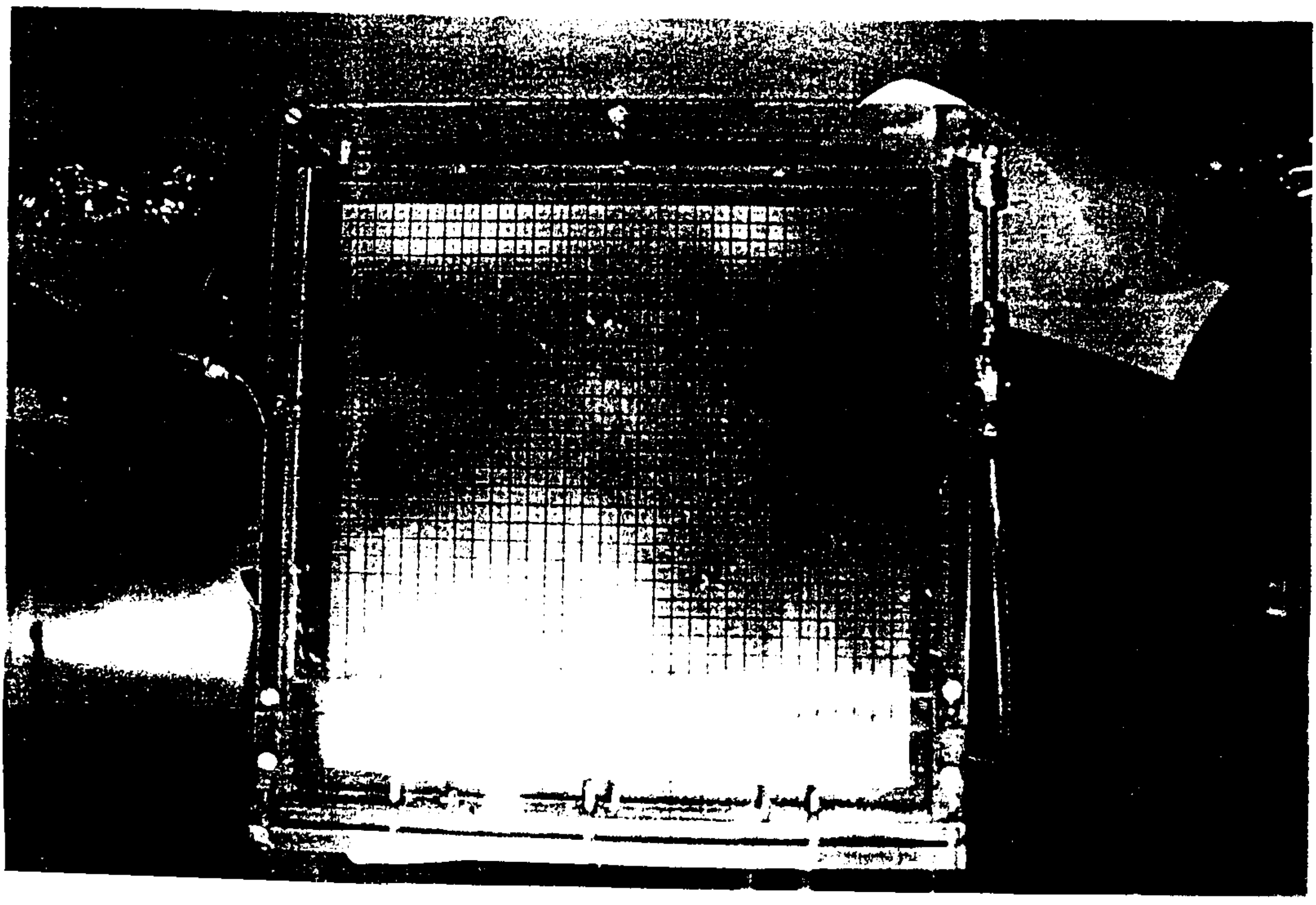
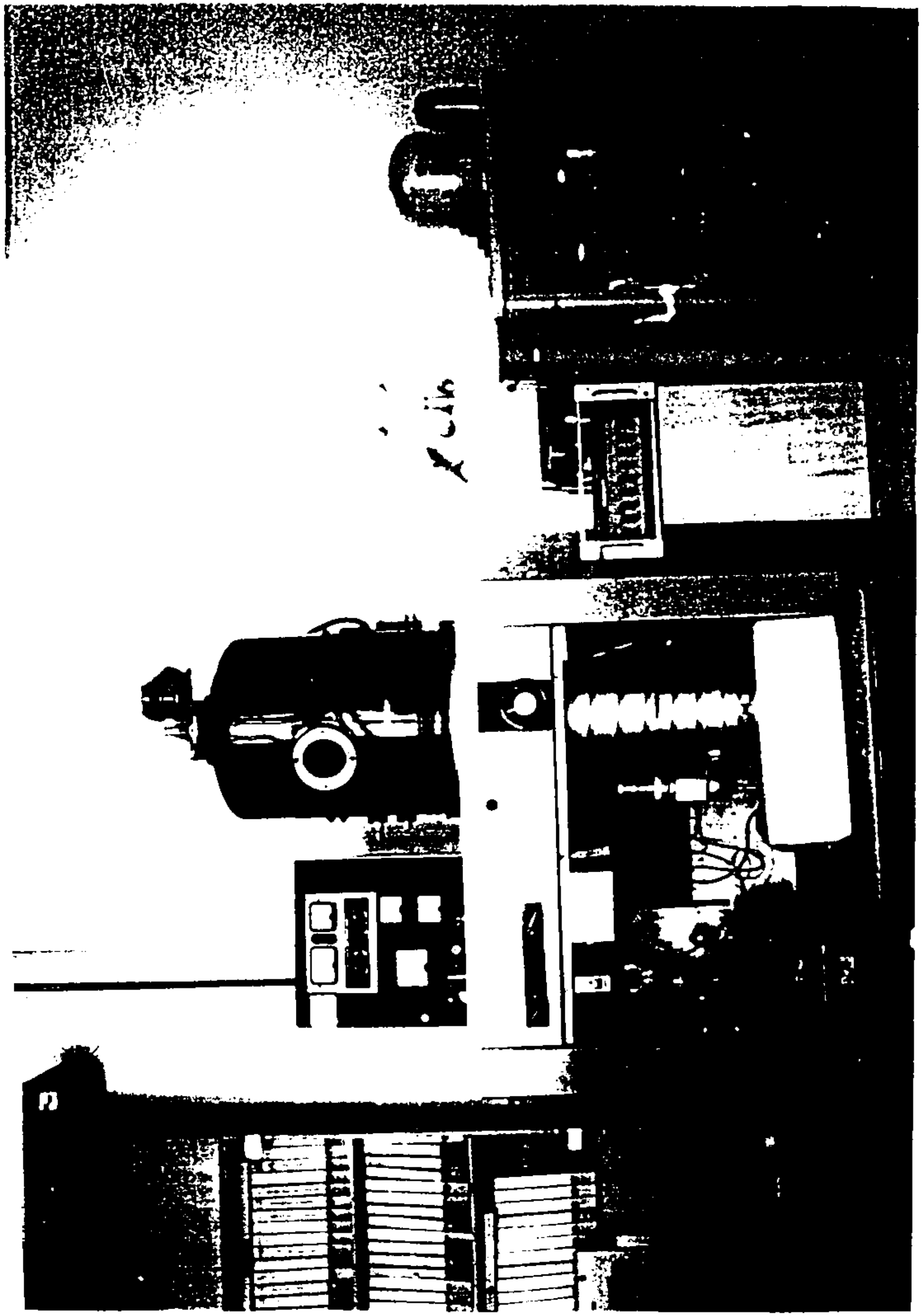


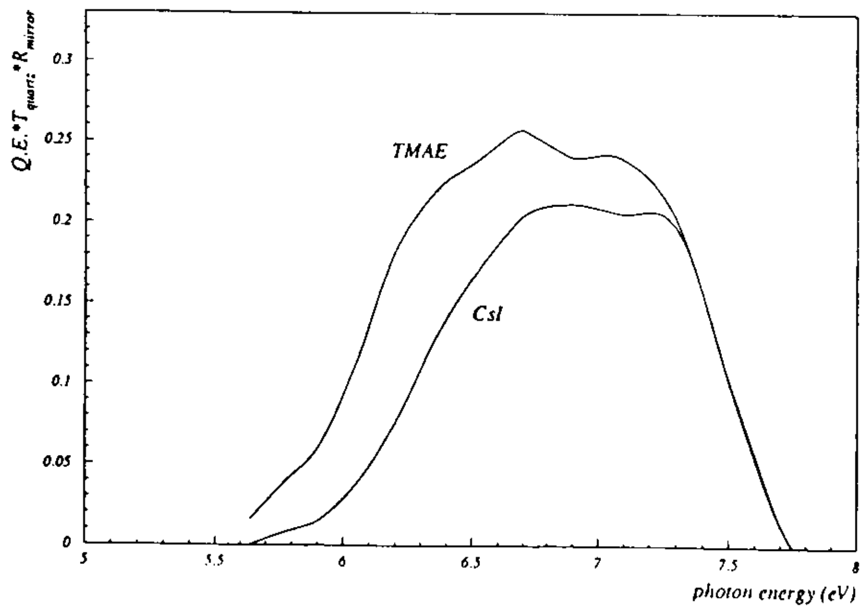






Expected prototype performance

photon detector	CsI	TMAE (40% at 21^0)
single electron counting efficiency	0.90	0.90
screening, absorption	0.92	0.64
expected number of photons	22	21



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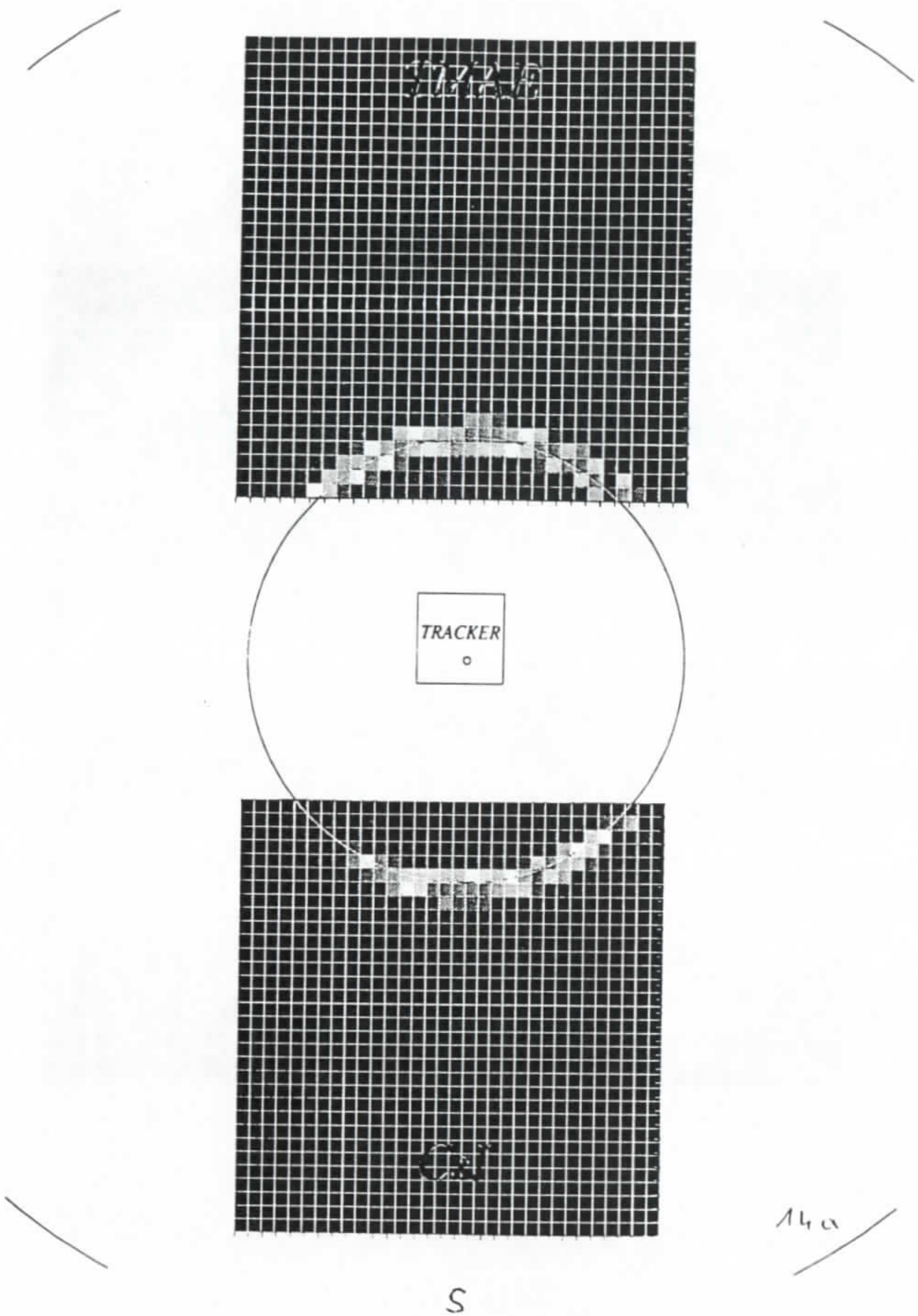

14a

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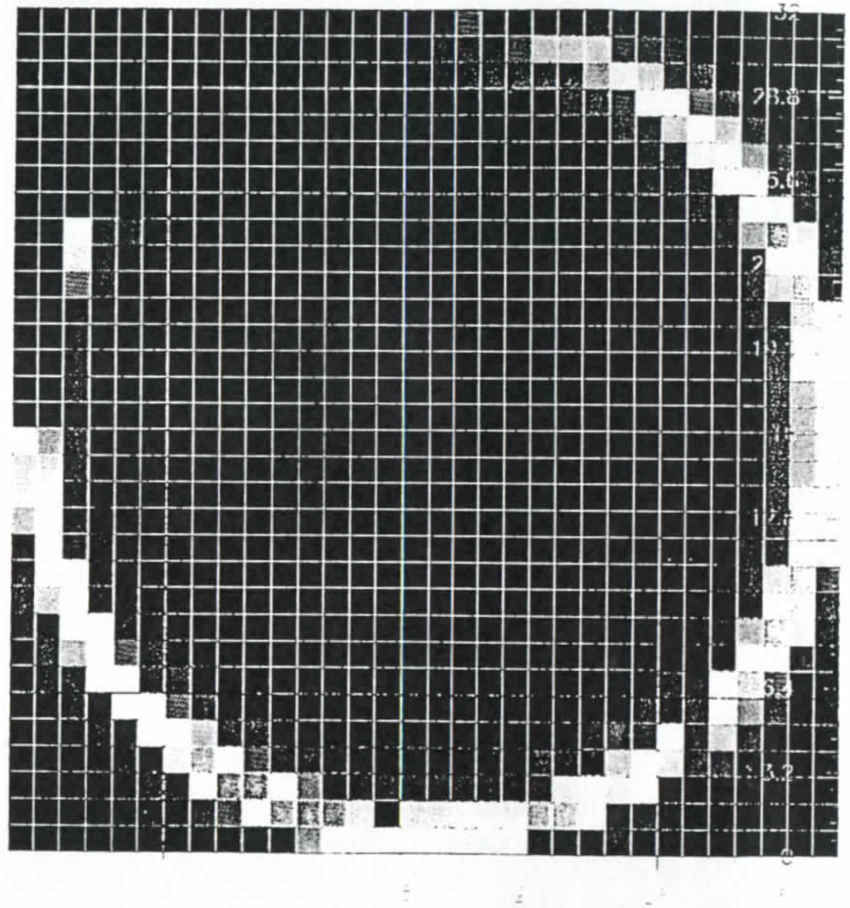

14 b

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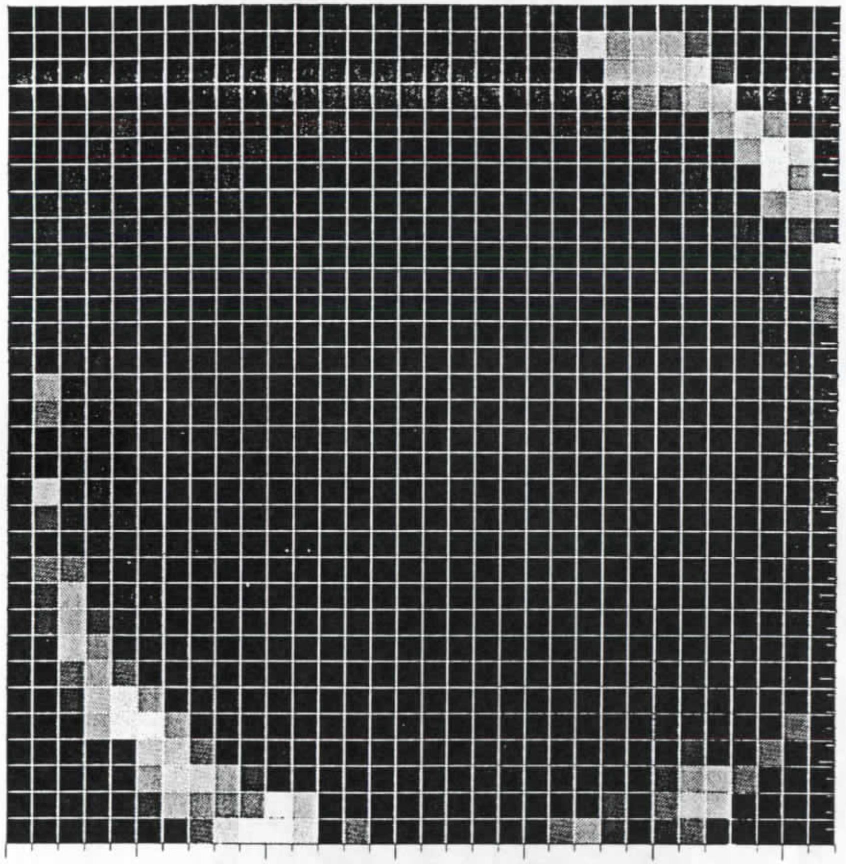
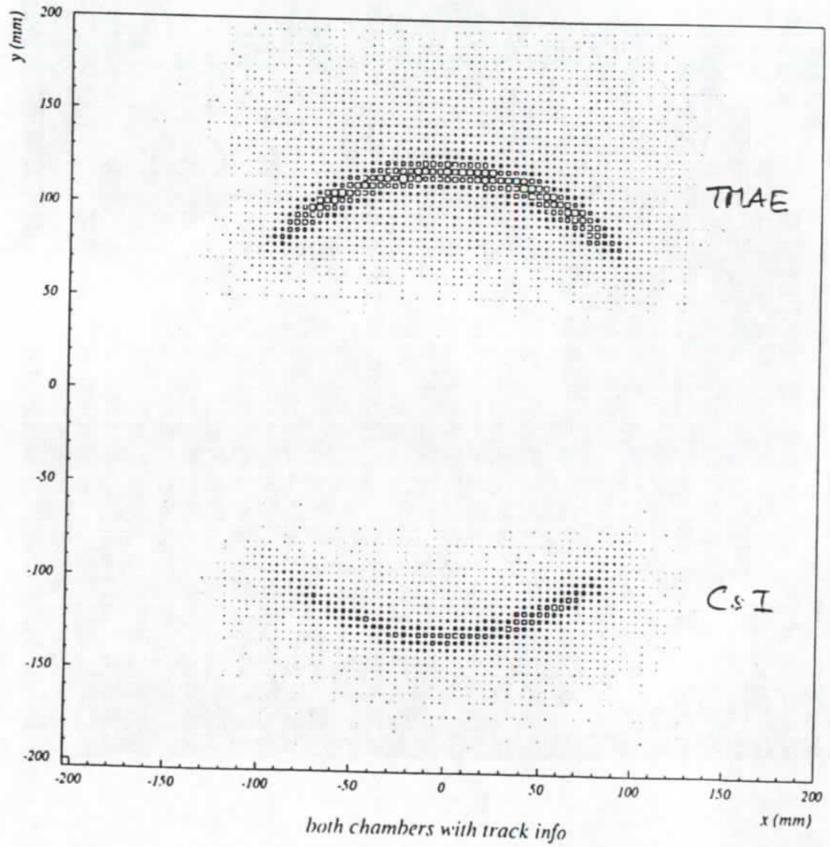


csi

S 14 c

Sharpening the image

Use tracking system data on an event by event basis to correct for finite beam divergence:



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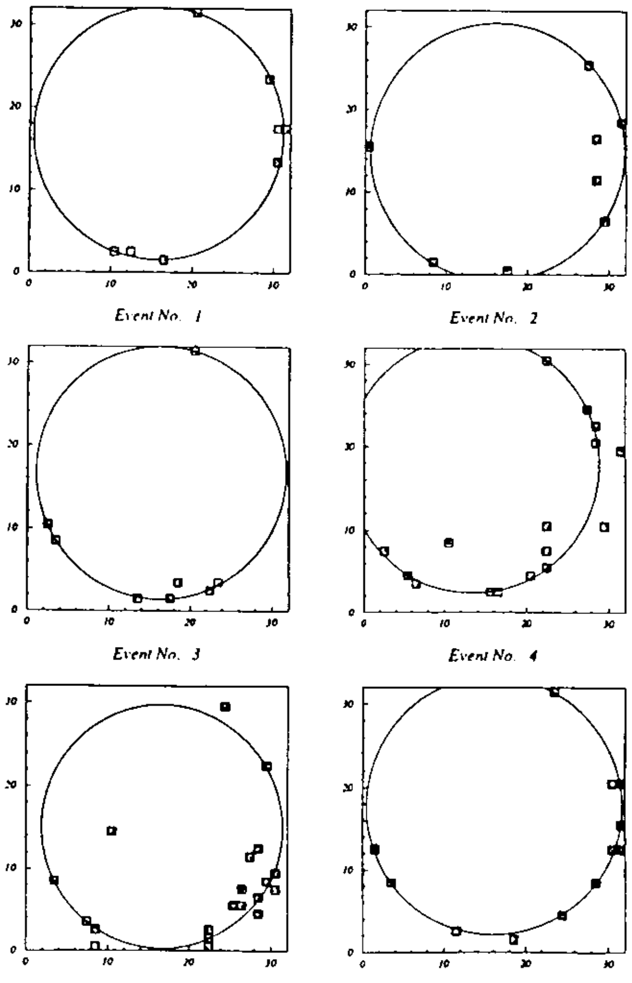
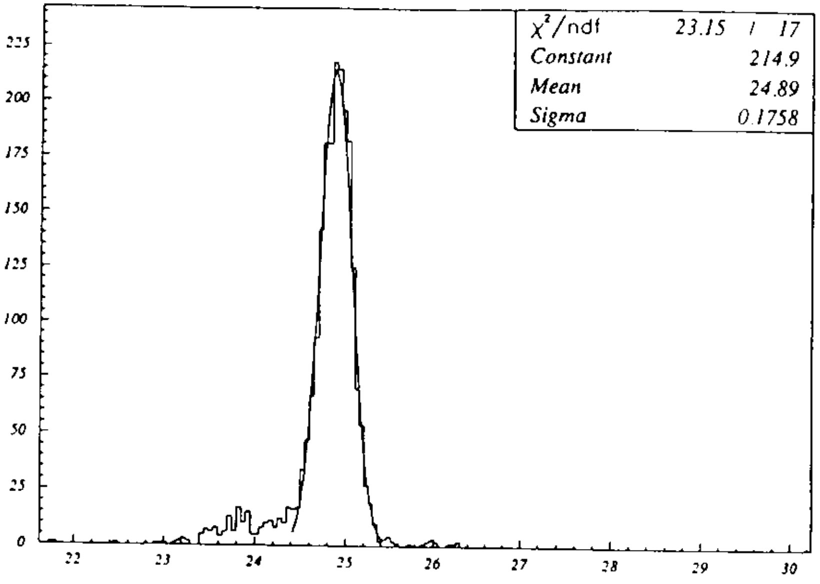
Fitting rings

Fitting the rings in the TMAE chamber on an event by event basis.



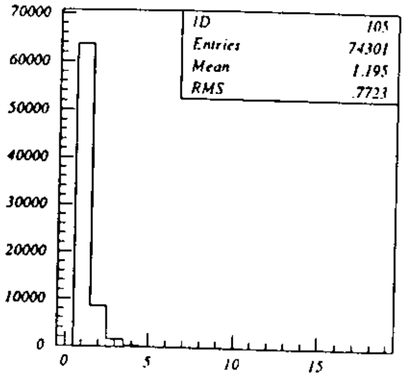
Prototype resolution



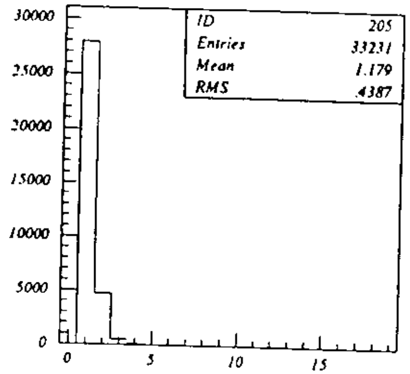
N.B. Such a counter would allow for a 3 σ separation of pions and kaons up to 92 GeV/c!

Hit multiplicity

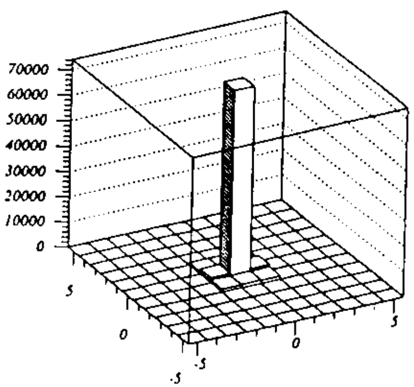
About 20% of photons produce a double hit.



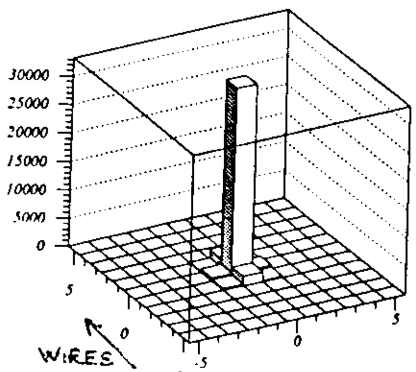
TMAE groups



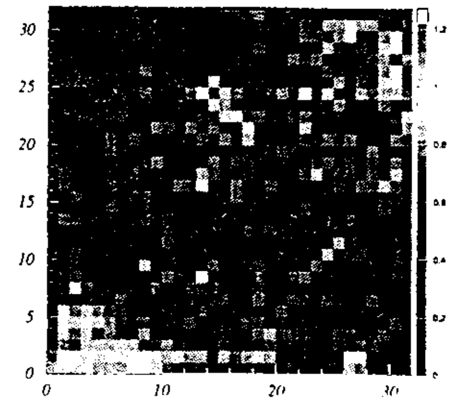
CsI groups



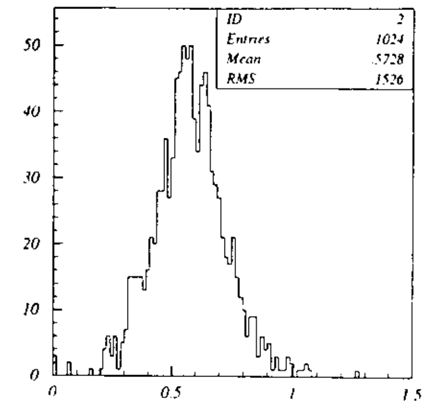
TMAE groups 2D



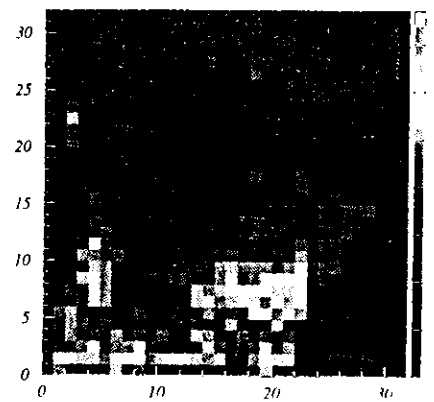
CsI groups 2D



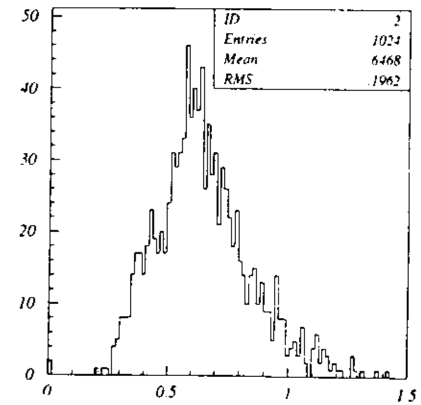
CsI No. 2



RQE distribution



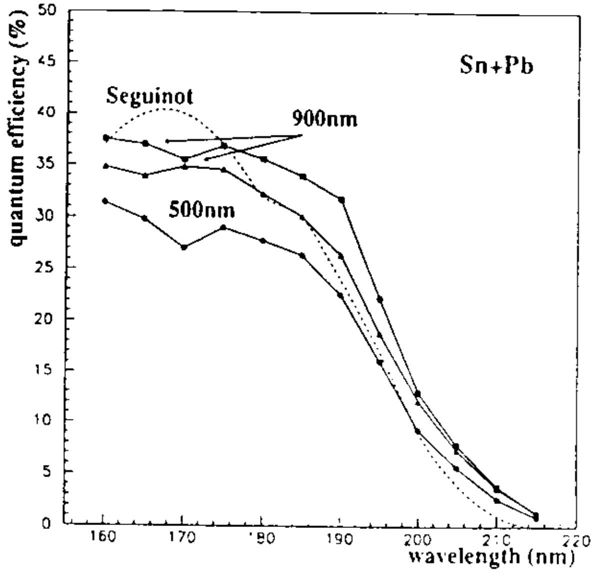
CsI No. 3

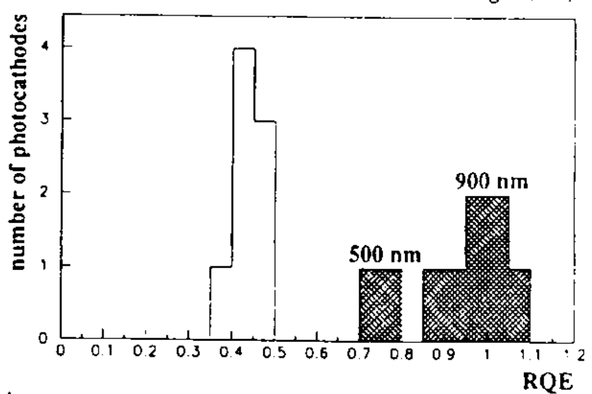


RQE distribution

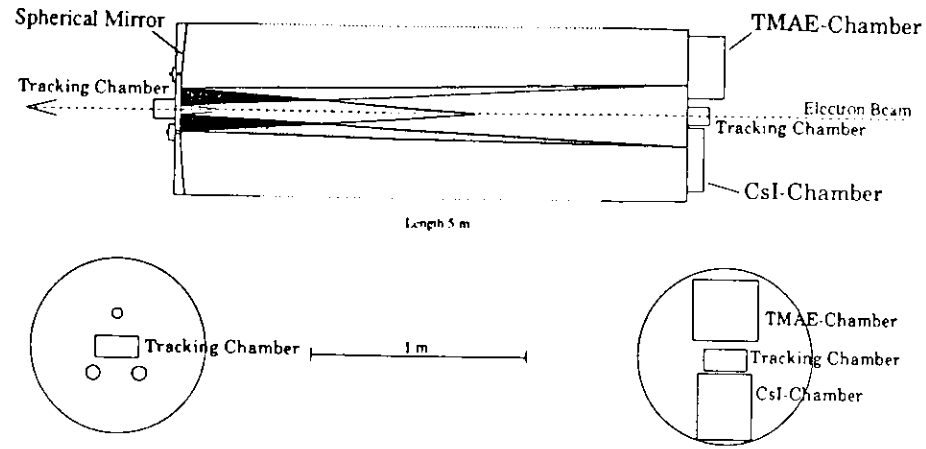
Quantum efficiency of CsI

The CsI photocathode response in the lab environment.





Test set-up



Mirror: OMEGA (5m focal length)

Radiator: argon

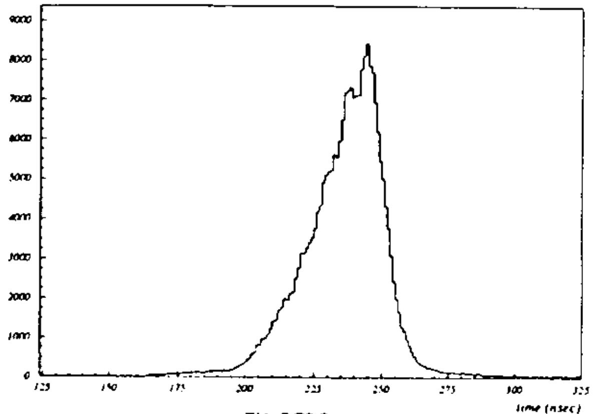
Tracking chambers: MWPC's with delay line read-out

Beam: 3 GeV electrons (test beam T24 at DESY)

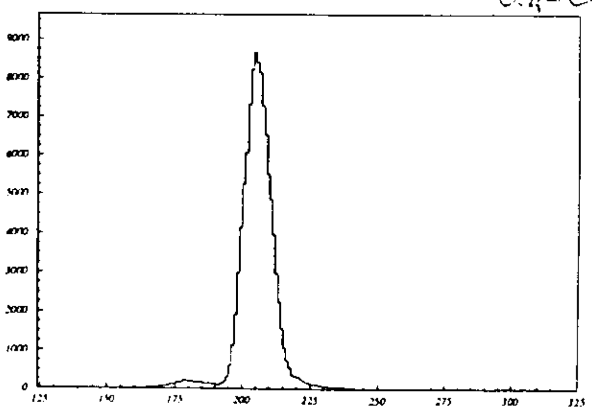
Read-out: ARGUS μVDC read-out chain, except for the PA of the CsI chamber (low noise hybrid, ENC 1200 e)

Timing

Drift time spread for both chambers:
TMAE: 65 ns
CsI: 25 ns.



NO IMPROVEMENT WITH $CF_4 - CH_4$ MIXTURE



Number of photons

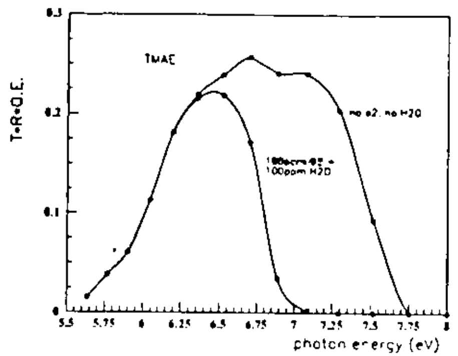
photon detector	CsI	TMAE (40% at 21^0)
hits/ring	7.3	12.2
hits/photon	1.179	1.195
photons/ring	6.2	10.2

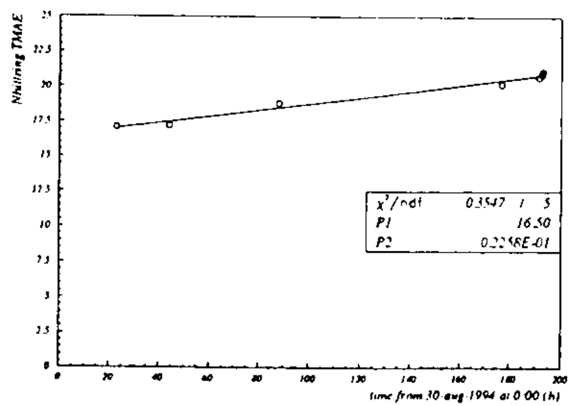
Expect about equal number of photons on both detectors. CsI photocathode gives about 0.6 of the TMAE chamber response
- most probably due to a complicated transportation (evaporated in Ljubljana, put in an argon filled box, transported to Hamburg - few days between evaporation and mounting in the chamber).

The TMAE chamber gives about half the hits expected: under investigation (radiator gas transmission, effects of cleaning the mirror).

Radiator purity

Impurities (water) in the radiator could be a reason for the discrepancy in the absolute normalisation.





A slight improvement in the performance over time: due to improved gas purity or something else? Under study.

Beam test: Conclusions

- Both photon detectors performed very well.
- Both chambers were very stable at gas gains as high as 10^5.
- The CsI photocathode response was about 0.6 of the quantum efficiency acheived in lab conditions.
- Further tests will concentrate on high rate capability and ageing issues, absolute calibration, improvement of the transfer of the CsI cathode.

Decision on the detector type will be based upon:

- Number of photons
- Timing properties
- High rate capabilities
- Ageing
- Dead time of the detector
- Sensitivity to charged tracks (background)
- Cost
- Production
- Replacement, handling

S

THE READ-OUT

THREE CHOICES

(1.) RD20 : TO BE TESTED SOON

(2.) RAL RICH CHIP ("YPSILANTIS" CHIP)
TAKE THE ANALOG PART, HAVE RAL DESIGN THE DIGITAL PART ANEW.
→ M. FRENCH "IS INTERESTED"

(3.) IF THE ANALOG PART MAKES PROBLEMS, TAKE OUR (EXCELLENT) P.A. → CHIP

S

CONCLUSIONS

1. WE HAVE TWO WORKING PHOTON DETECTORS.
   BOTH NEED MORE WORK TO BE DONE.

2. THE MECHANICAL ISSUSES + MIRROR ARE VOW SHIFTING IN THE FOCUS

S

HERA-B Open Collaboration Meeting
Hamburg, 5.10.94

First Level Trigger

Overview and Performance

Dominik Ressing (DESY)

- Definition of the task (mainly: J/ψ trigger)
- Choice of the variables
- The trigger algorithm
- Trigger performance
  - filtering steps
  - rate limitations
  - optimization
- additional triggers

T -1-

HERA-B is aiming on CP violation in the $B^0\overline{B^0}$-system using the B-decays:

$$B \to J/\psi K^0_S, \quad J/\psi \to l^+l^-, \quad K^0_S \to \pi^+\pi^-$$

signal/minimum-bias rate: $3 \cdot 10^{-11}$

The trigger must also accept events like:

mode	$\frac{\text{signal}}{\text{minbias}}$
$B \to J/\psi X \to llX$	$3 \cdot 10^{-9}$
$b\bar{b} \to llX$	$4 \cdot 10^{-8}$
$b \to clX \to llX$	$6.4 \cdot 10^{-8}$
...	

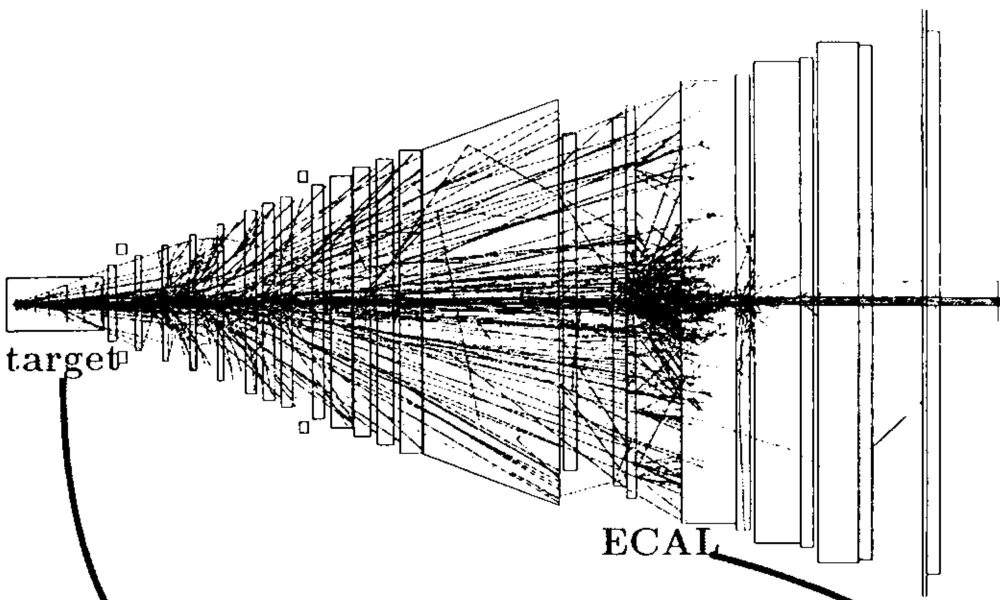
input rate : 40 MHz
detector channels : 500 000
lots of information to manage

FLT specifications

signal/minbias ratio improvment : $\mathcal{O}(10^3)$
available time (pipeline length): $12\,\mu s$

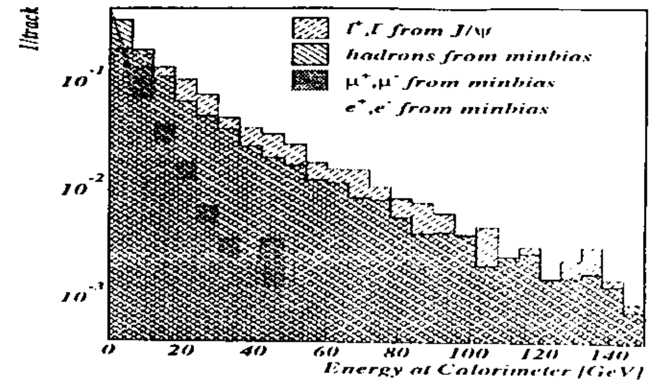
T -2-

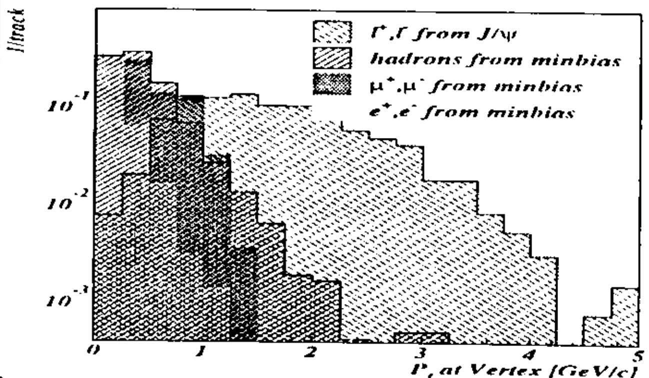
A detailed GEANT simulation is used to develope the FLT algorithm. A *typical* event in the HERA–B detector.



	mean # of charged tracks
primary (at target)	60/BX
in front of ECAL	210/BX

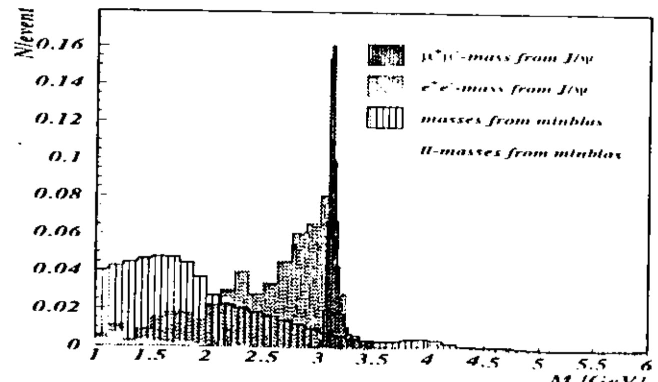
momentum of tracks at the surface of the ECAL





transverse momentum of tracks as reconstructed using only cell hit information

Invariant mass of track pairs as reconstructed using only cell hit information



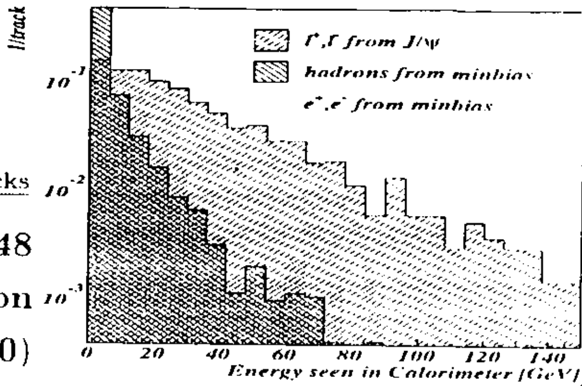
ECAL

occupancy:

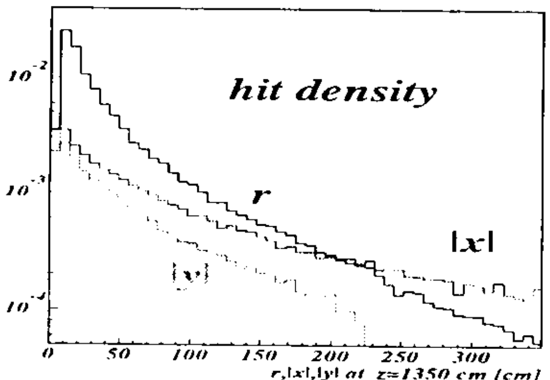
$\leq 0.1 \frac{\text{charged-tracks}}{\text{BX}}$

# of cells : 6248

offline hadron/electron seperation: $\mathcal{O}(100)$



Tracker



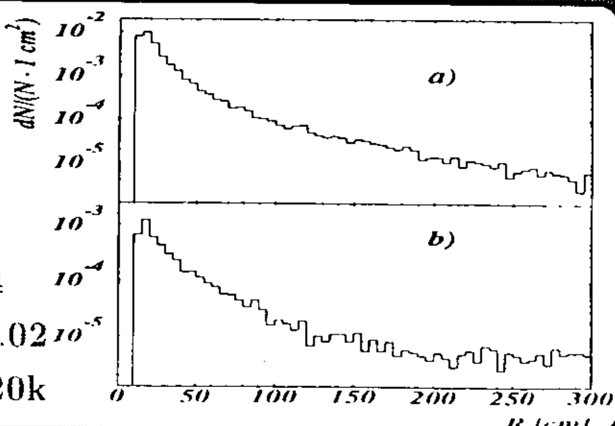
plots for TC2

mean occupancy: ≈ 0.10

peak occupancy: ≈ 0.15

# of channels: $\approx$ 100k

MUON system



(a): MU1; (b): MU4

mean occupancy: ≤ 0.02

# of channels: $\approx$ 20k

Outline of the trigger strategy

Identify lepton in MUON or ECAL

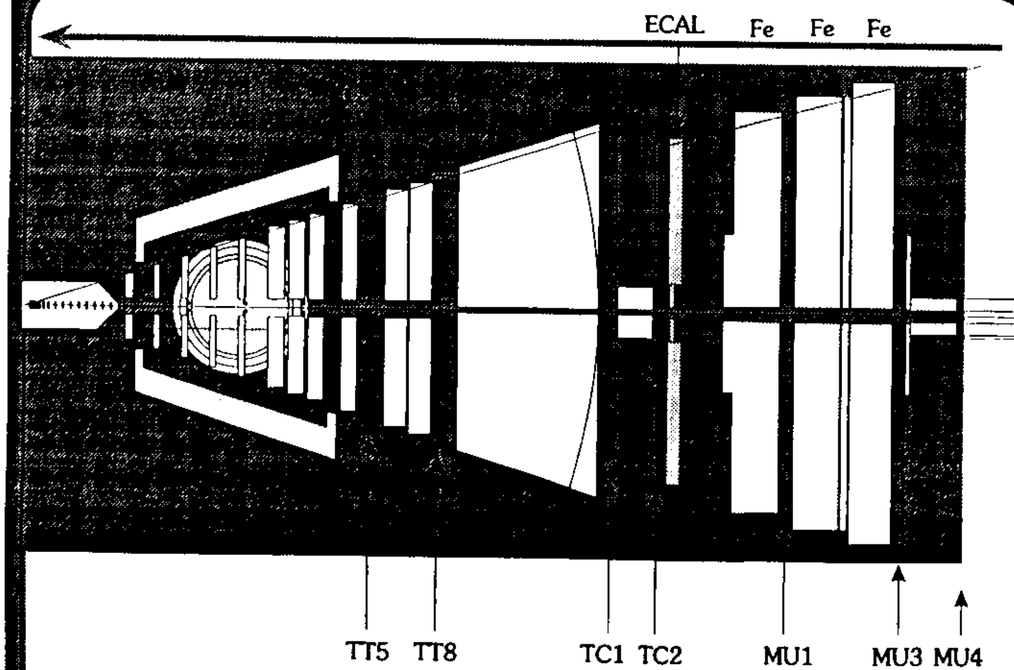
⟶ track seed

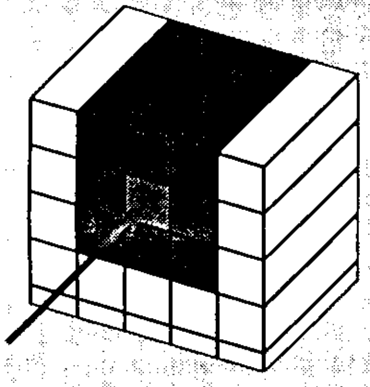
follow track from back to front in TRACKING

⟶ Kalman filtering

calculate track parameters using a VERTEX constraint, apply cuts and calculate invariant mass of track pairs

⟶ trigger decision





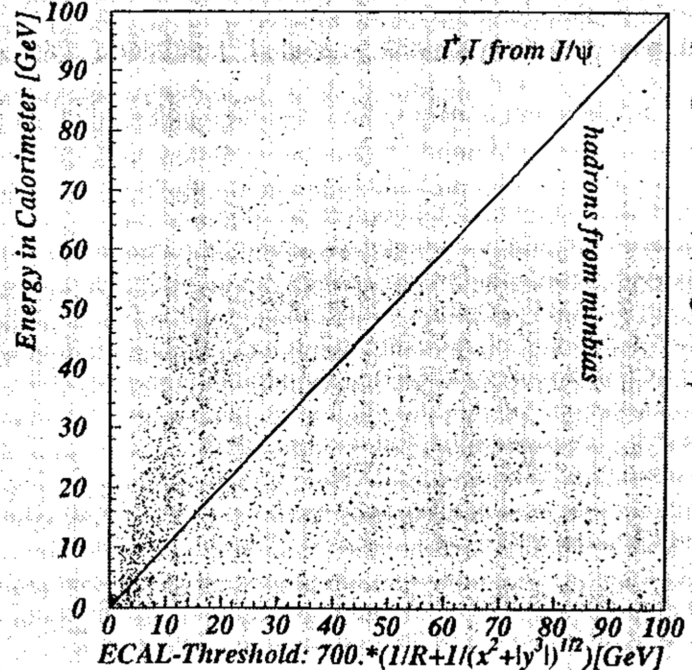
track seed = pretrigger

Electron track seeds:

$E_{min} = K_{Trig} \cdot \left(\frac{1}{R} + \frac{1}{x^2+|y^3|}\right)$

$E_9 > E_{min} \quad E_{center} > E_{min}/2$

mean # of seeds: 2/BX



$\eta(J/\psi \rightarrow e^+e^-)$:

$0.55 \cdot 0.70 = 0.38$

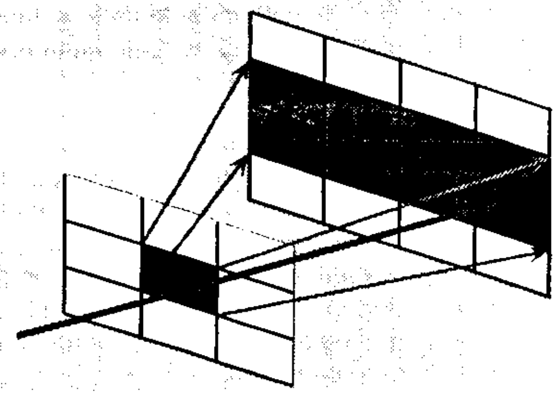
Decomposition of track-seeds:

	[%]
e^-, e^+	21
γ	43
hadr.	36

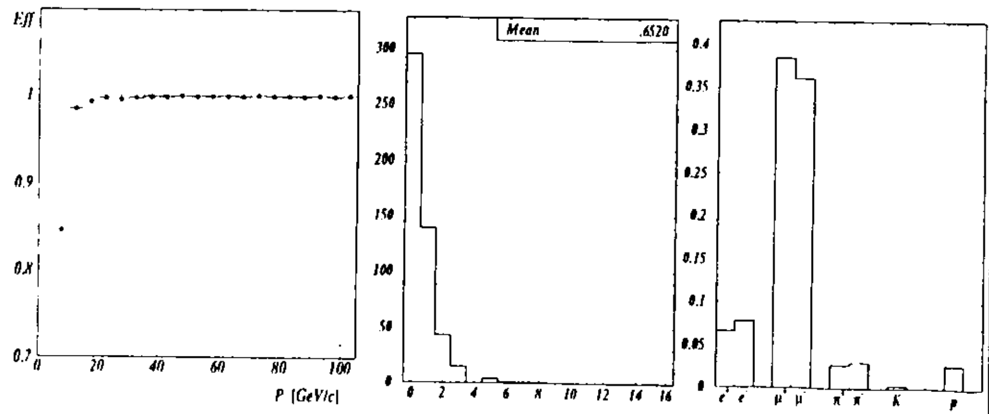
Muon track seeds:

require 1-8 concidence in "projective" arrangement

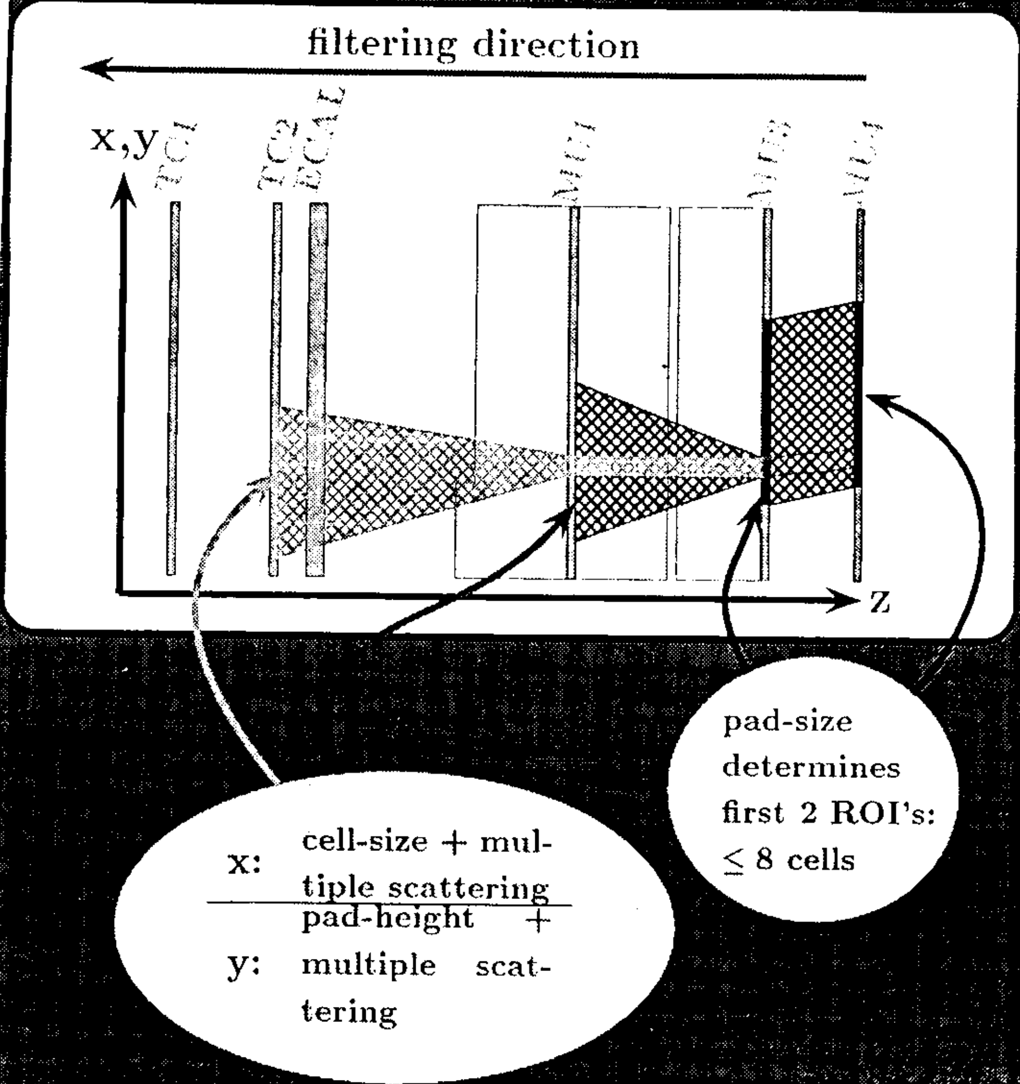
mean # of seeds: 0.65/BX



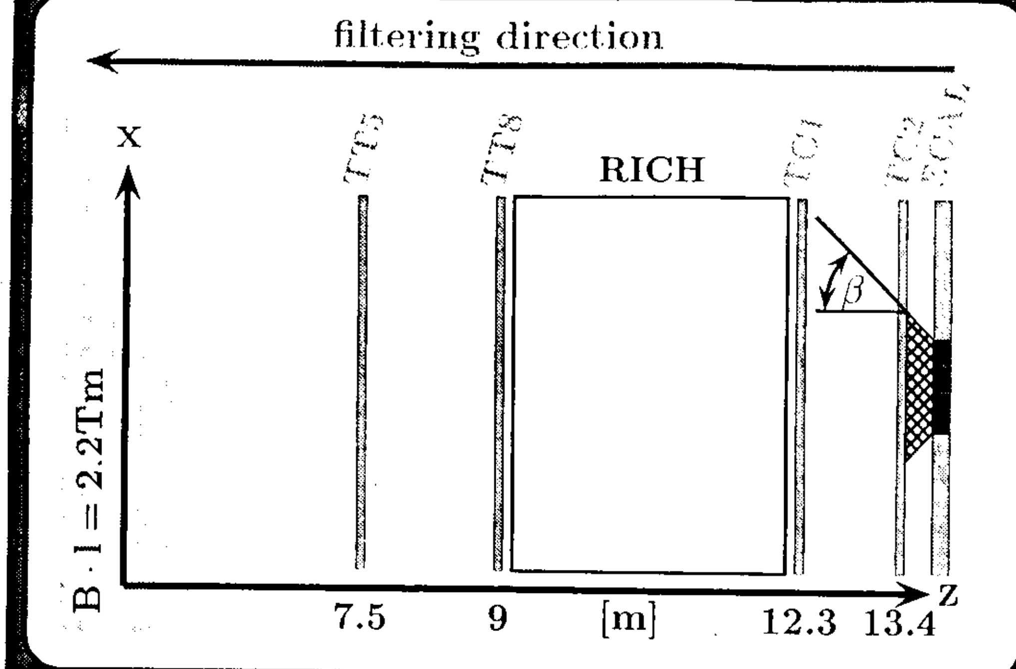
$\eta(J/\psi \rightarrow \mu^+\mu^-) = 0.985 \cdot 0.7 = 0.69$



Muon filter steps (3 steps)



Filter step 1



ROI in TC2:

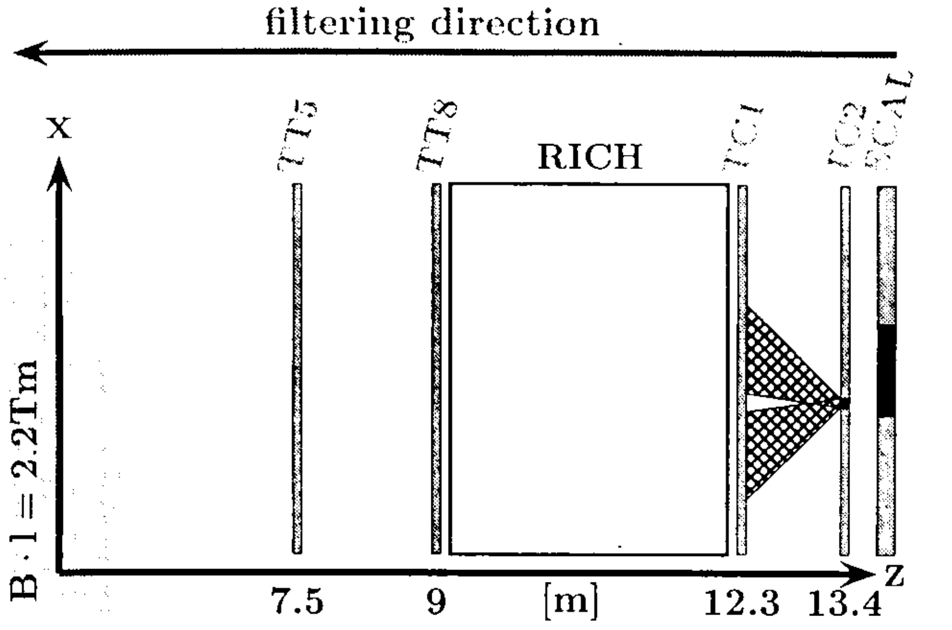
$$(\Delta x)_{TC2} = (\Delta x)_{ECAL} + 2 \cdot \beta_{max} \cdot 40\,cm = 2.9 \ldots 20\,cm$$

$$E_{min} = 5 \ldots 80\,GeV$$

$$\beta_{max} = 8 \ldots 132\,mrad$$

$$(\Delta y)_{TC2} = (\Delta y)_{ECAL} \cdot 0.97 = 2.2 \ldots 10\,cm$$

Filter step 2



ROI in TC1:

$(\Delta x)_{TC1} = 2\,(d_{TC1} + (\beta_{max} - \beta_{min}) \cdot 1.1\,m) = 0.6...29\,cm$

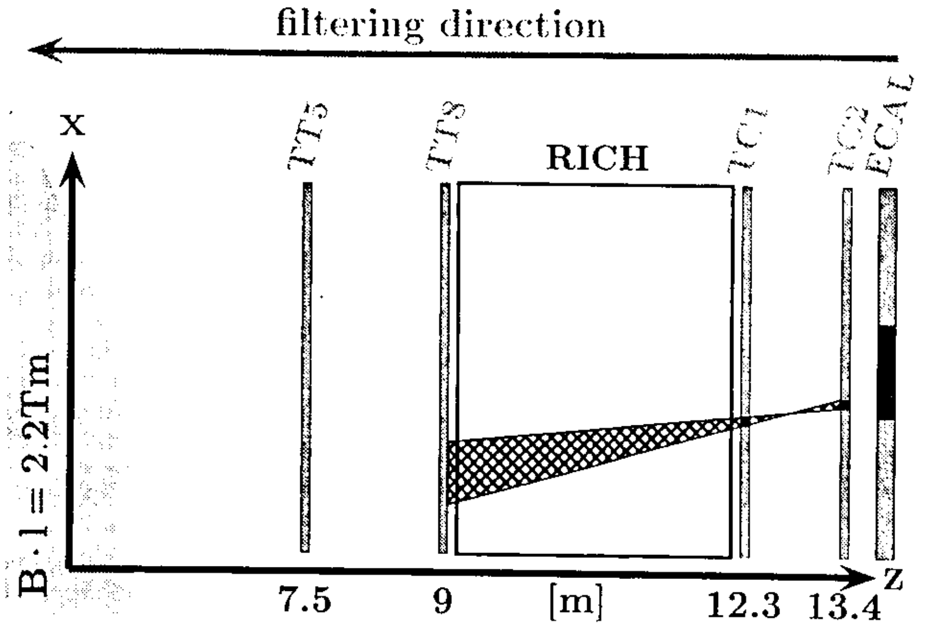
$E_{min} = 5...80\,GeV$

$\beta_{max} = 8...132\,mrad$

$\beta_{min} = \frac{0.66}{E} = 3...132\,mrad$

$(\Delta y)_{TC1} = (\Delta y)_{ECAL} \cdot 0.89 = 2...9\,cm$

Filter step 3

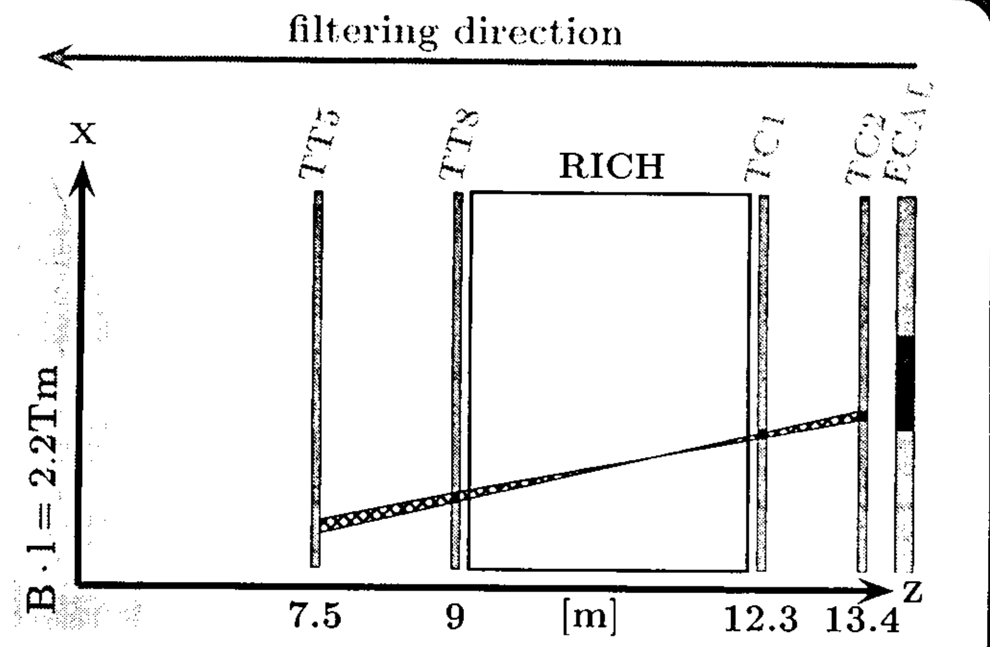


ROI in TT8:

$(\Delta x)_{TT8} = (d_{TC1} + d_{TC2}) \cdot (1 + 3.3/1.1) = 0.8...8\,cm$

$(\Delta y)_{TT8} = (\Delta y)_{ECAL} \cdot 0.65 = 1.4...6.5\,cm$

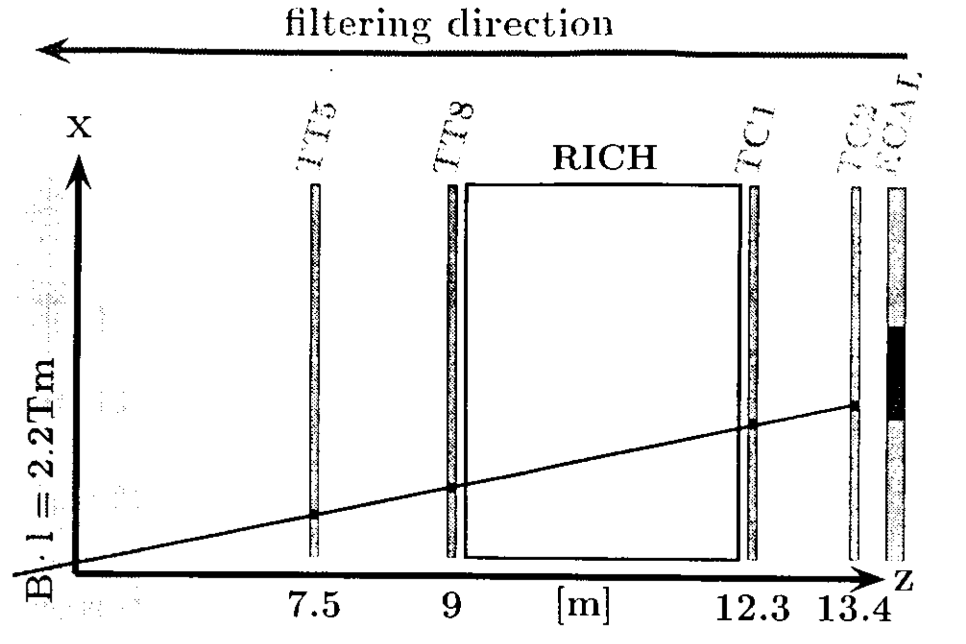
Filter step 4



ROI in TT5:

$$(\Delta x)_{TT5} = (d_{TC1} + d_{TT8}) \cdot (1 + 1.5/4.4) = 0.27...2.7\,\text{cm}$$
$$(\Delta y)_{TT5} = (\Delta y)_{ECAL} \cdot 0.54 = 1.2...5.4\,\text{cm}$$

Filter step 5



Calculate track parameters:

Assuming a homogeneous magnetic field in the circle and utilzating a vertex constraint all track parameters may be obtained: (x_M, z_M: x,z coordinates of track in magnet)

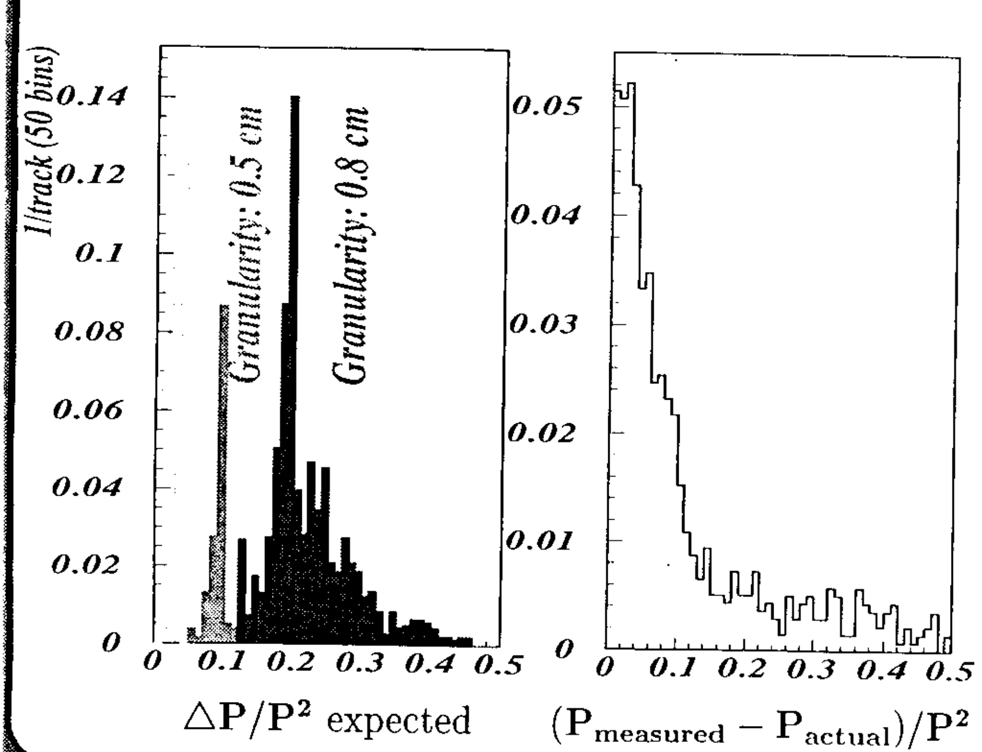
bending angle: $\alpha \approx \frac{P'_x}{P'_z} - \frac{x_M}{z_M}$

momentum(in bending plane): $P \approx \frac{0.66}{\tan \alpha}$

Momentum resolution:

$\Delta\alpha = \frac{d_{TC2}+d_{TT5}}{5.9m} \qquad \Delta P = P^2 \cdot \frac{\Delta\alpha}{0.66} = \frac{d_{TC2}+d_{TT5}}{3.9m}$

detector type	cell width	$\Delta P/P^2$
large cells	10 mm	0.5 %
small cells	5 mm	0.25 %
ORed micro-strips	1 mm	0.05 %

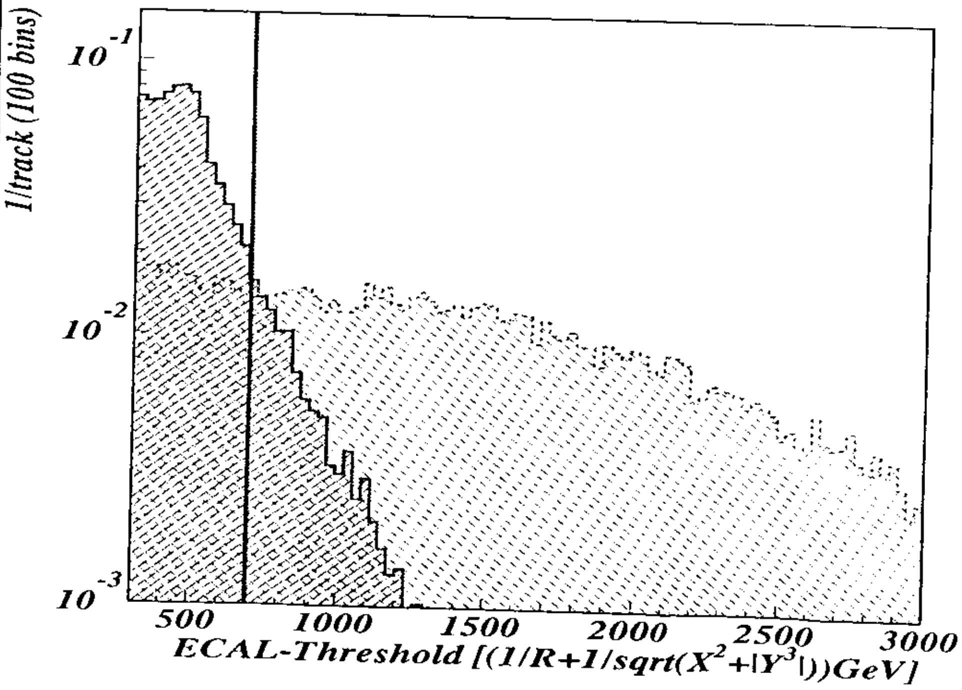


Cut on ECAL energy for electron ID

Standard cut: $700 \cdot \left(1/R + 1/\sqrt{x^2+|y^3|}\right)$

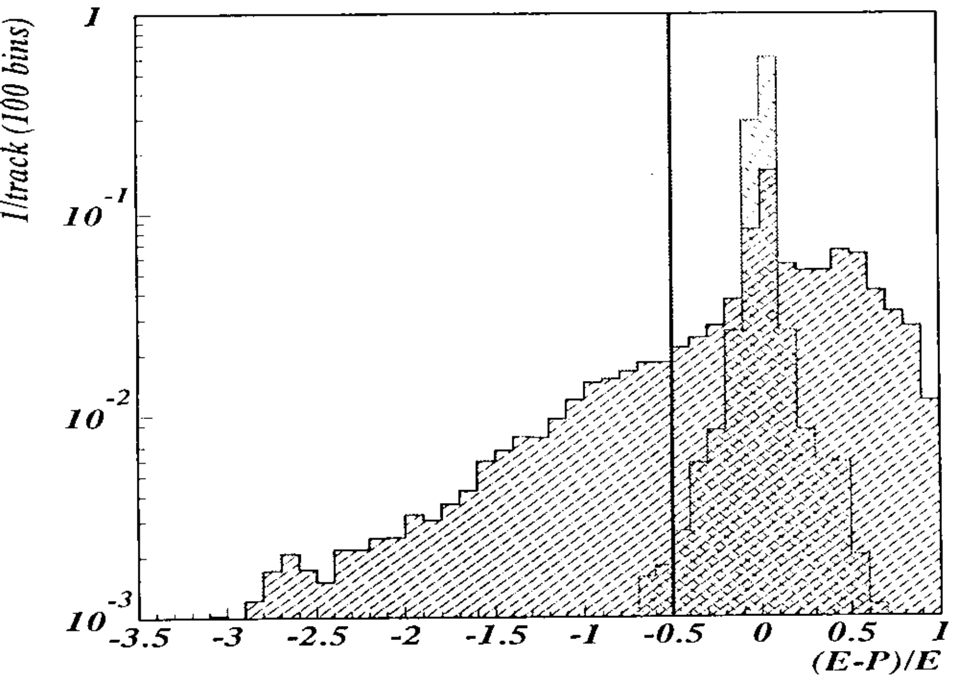
# of track-seeds: 1.7/BX

$\eta(J/\psi \rightarrow e^+e^-)$: 35 %



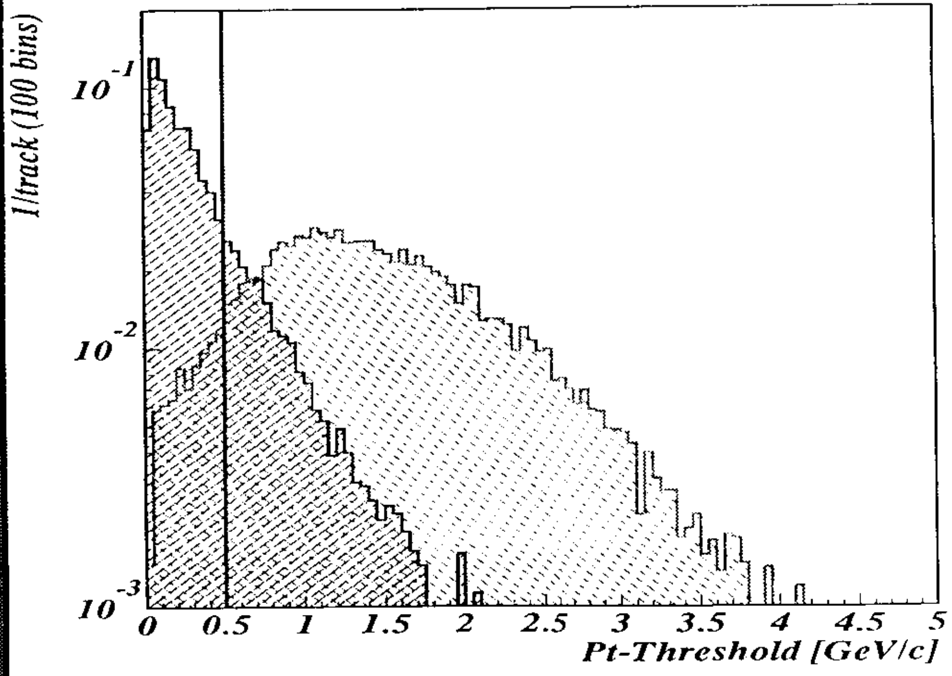
$P - E$ comparison: electron ID

Standard cut:	$(P - E)/E < 0.5$
suppression factor for hadrons:	2
$\eta(J/\psi \rightarrow e^+e^-)$:	99 %



Cut on transverse momentum

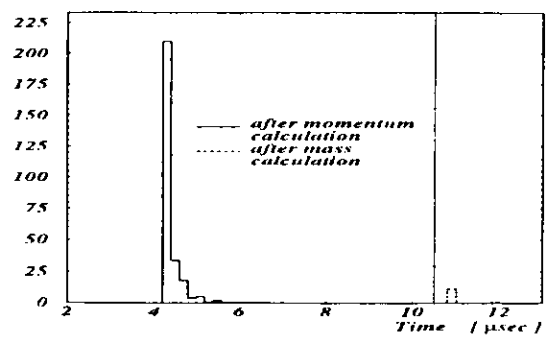
Standard cut:	$P_T > 0.5$ GeV/c
suppression factor for BG tracks:	4
$\eta(J/\psi \rightarrow e^+e^-)$:	95 %



Realization in hardware

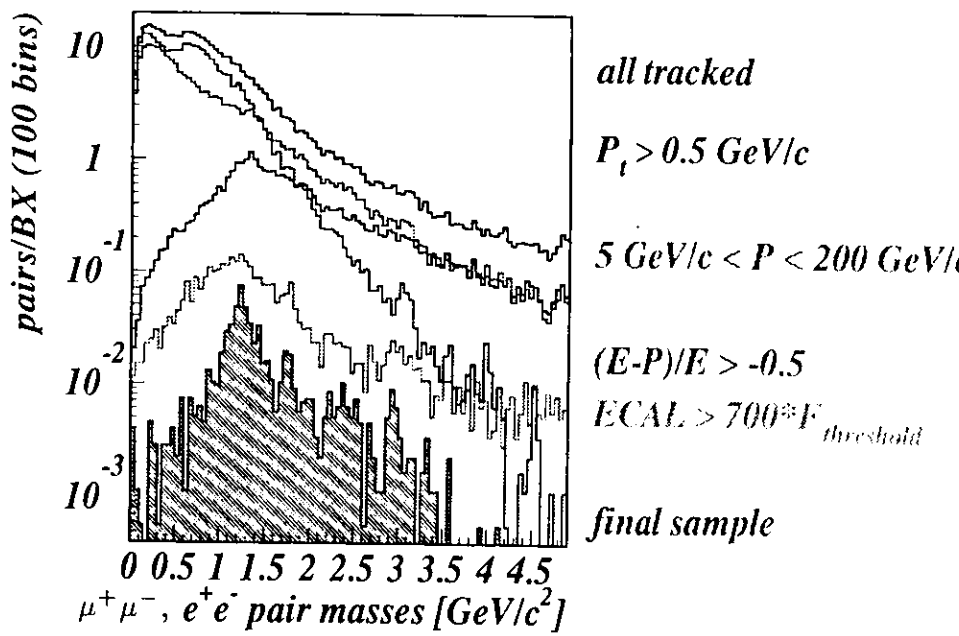
- track seeds are obtained by dedicated Pretrigger units
- track updates are prerformed by so-called track-finding-units (TFU)
- track parametrs are calculated by track-parameter-modules (TPM)
- invariant mass calculation is done in mass-calculation-units (MCU)
- due to multiple hits in ROI's the needed tracking time is uncertain !!

The timing result of our clock-level simulation:



Influence of cuts on mass-spectrum

Standard mass range: $M_{l^+l^-} = 2.0 \ldots 3.5\,\mathrm{GeV}/c^2$
Uppermost histogramm contains all tracks with $P > 5\,\mathrm{GeV/c}$.
Only single cuts applied!
Hatched histogramm shows data after all cuts.



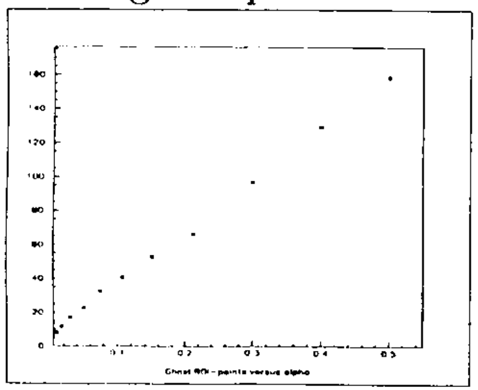
Decomposition of accepted events

	combinations	# of events	% of all
muons	μ^+, μ^-	1	1.4
electrons	e^+e^-, μ^+, μ^-	2	2.8
hadrons	$eh, \mu h, hh$	16	32
ghosts	$ge, g\mu, gh, gg$	50	72

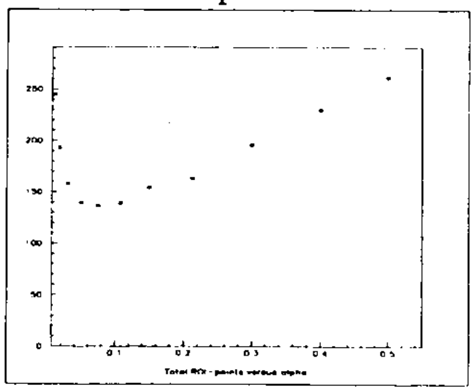
Kinds of "ghosts"

Ghost point	$\sim$ (# of crossings in ROI) $\cdot$ (occupancy)^3
Ghost track	$\sim$ (area of ROI) $\cdot$ (hit-density)

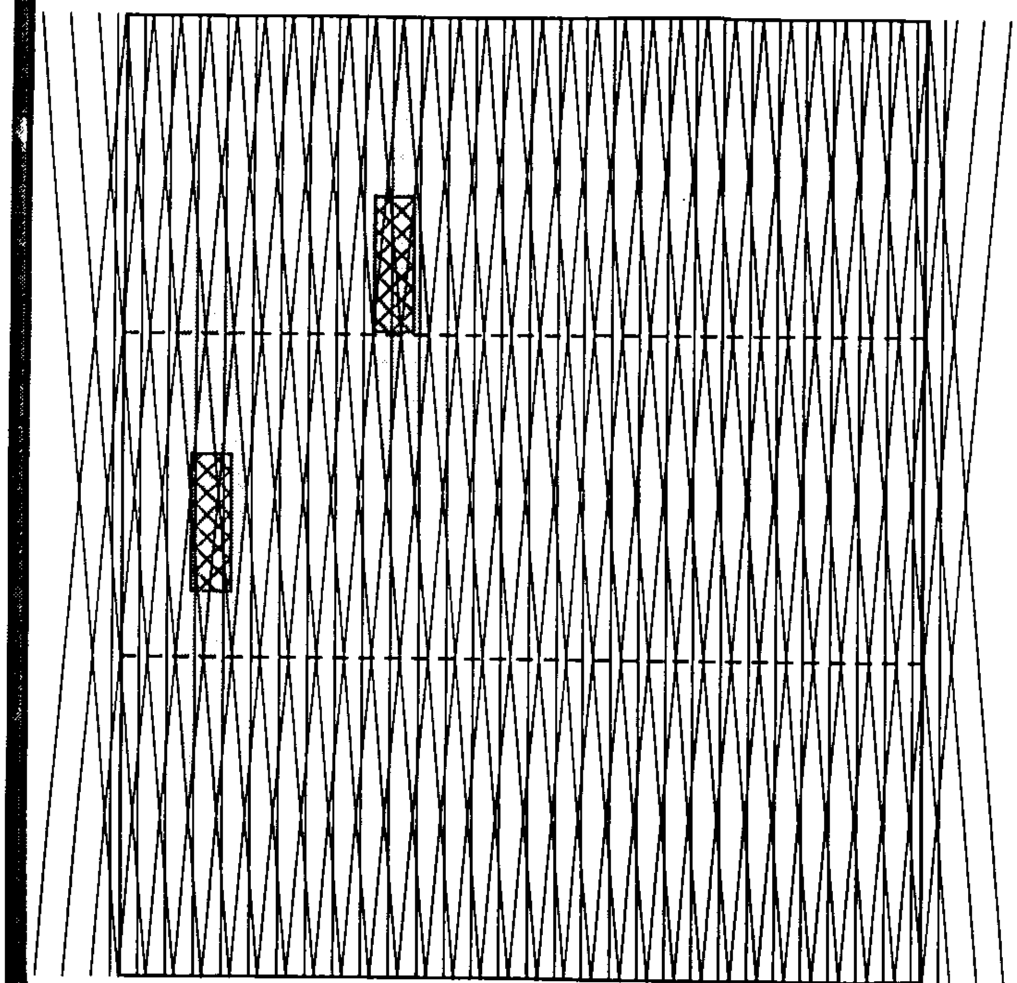
ghost points



all points



What a ROI looks like

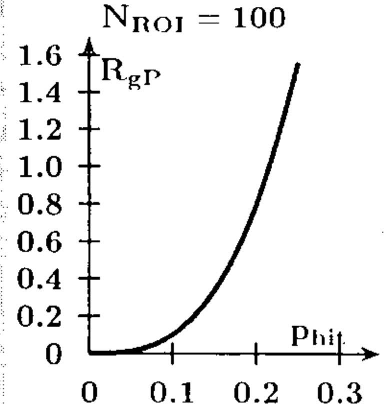


Small ghost-ology

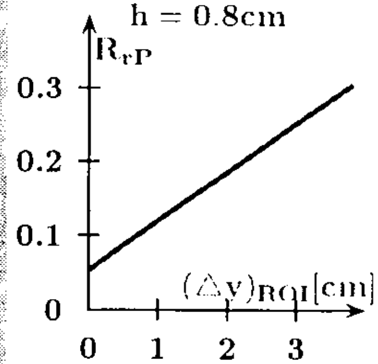
Rate of ghost points:
$R_{gP} \sim N_{ROI} * p_{hit}^3$

Rate of real points:
$R_{rP} \sim A_{ROI} * \rho_{track}$
$A_{ROI} = (\Delta x)_{ROI} \cdot ((\Delta y)_{ROI} + h)$
h: height of a rhombus

Rate of ghost tracks:
$R_{track} \sim R_{seeds} (R_{gP} + R_{rP})^i$
for a ghost: $i = 2...4$



$(\Delta x)_{ROI} = 2.2$cm
$\rho = 0.03/cm^2$
h = 0.8cm

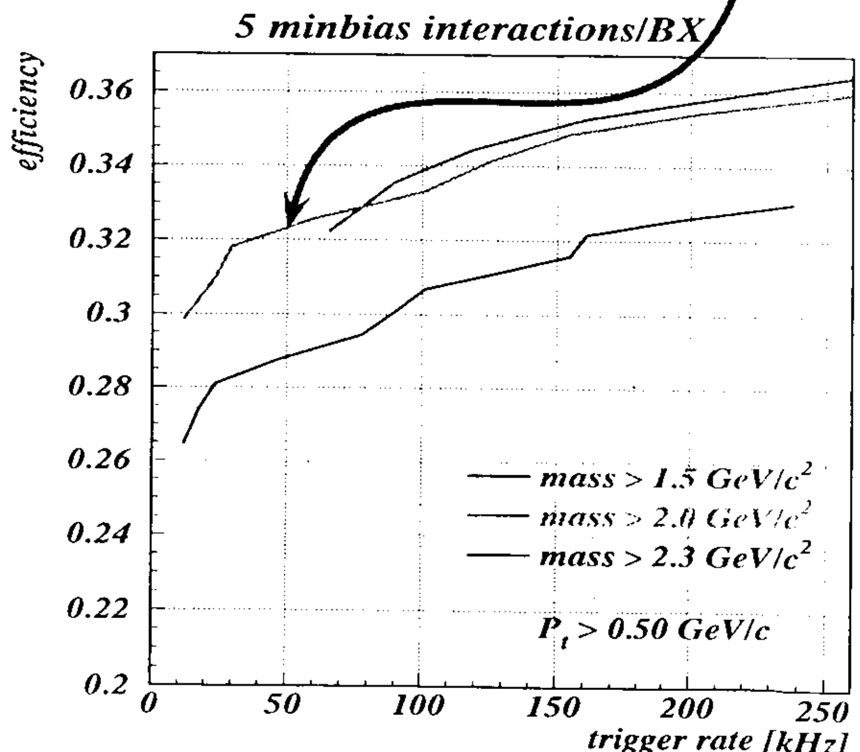


Optimization of working point

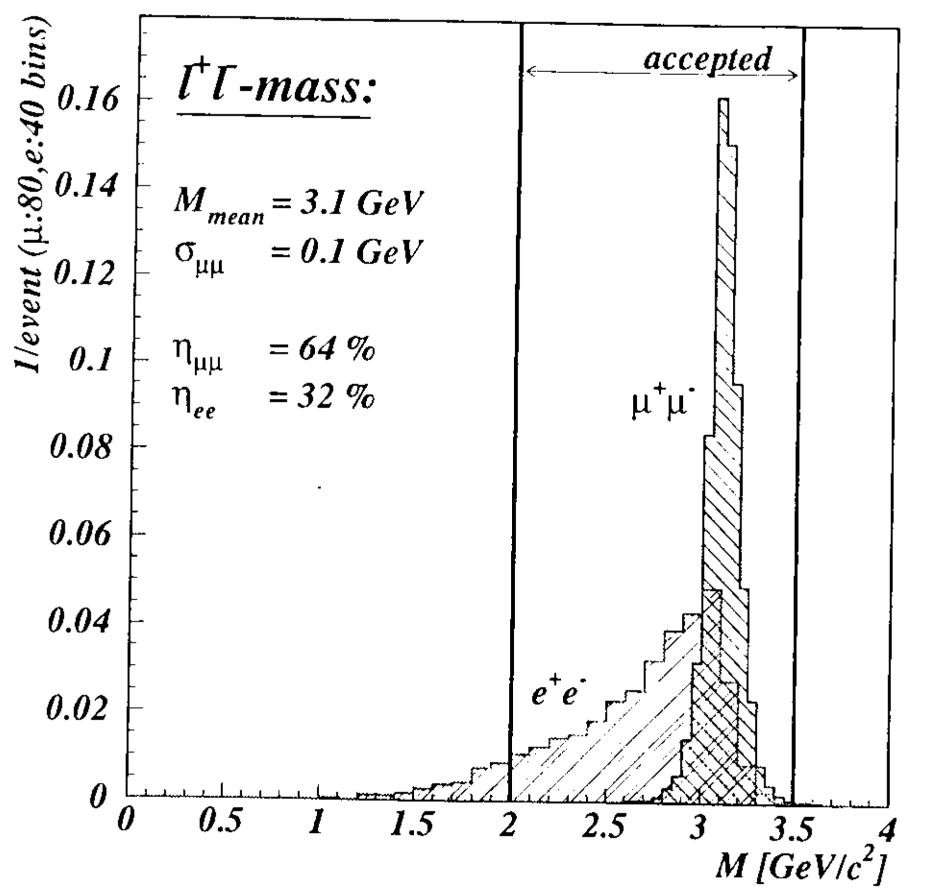
How to get the largest efficiency at a rate of 50 kHz?

alter the track-seed threshold K_{Trig}

$2 < M_{l+l-} < 3.5\,\mathrm{GeV}/c^2$ $K_{Trig} = 700\,\mathrm{GeV} \cdot cm$



The final mass-spectra



Improvment possibilities

efficiency for electrons: 32 %

efficiency for muons: 64 %

Difference due to fake-rate/track-seed
Efficiency limit is the number of found points→ghosts

Improve ECAL pretrigger !

- Improve shape of threshold function
- Collect "Bremsstrahlung" into cluster

Improve tracking: reduce ghosts !

- Reduce ROI sizes
  (i.e. Δy in ECAL track-seeds).
- Implement fifth superlayer
  (reduces rate by a factor of 3)

Additional triggers

By applying different cuts in the mass calculation step:

name	cuts	rate [kHz]
J/ψ	all muon combinations	52
Dilepton	both leptons (no ee): $P_{T_e} > 1.2\,\mathrm{GeV/c}$, $P_{T_\mu} > 1\,\mathrm{GeV/c}$	12
single lepton	$P_{T_e} > 3\,\mathrm{GeV/c}$, $P_{T_\mu} > 2.5\,\mathrm{GeV/c}$	12
all		70

η	J/ψ	Dilepton	single lepton	all
$b \to J/\psi \to l^+l^-$	0.48	0.25	0.09	0.5
$b \to lX$	0	0	0.035	0.035
$b\bar{b} \to llX$	11	18	0.07	0.29
$c\bar{c} \to llX$	0.05	0.014	0.05	0.06

Also under study: $b \to \pi^+\pi^-$ trigger.
efficiency is about 40 %!

Triggering the rare ones

- The FLT has to reconstruct J/ψ masses
- A fast and flexible realization has been developed
- Simulations show that the algorithm works
- The remaining background is made by ghosts
- The mean efficiency to find a gold plated event is 48 %
- further improvments are possible

Implementation of the HERA *B* First Level Trigger

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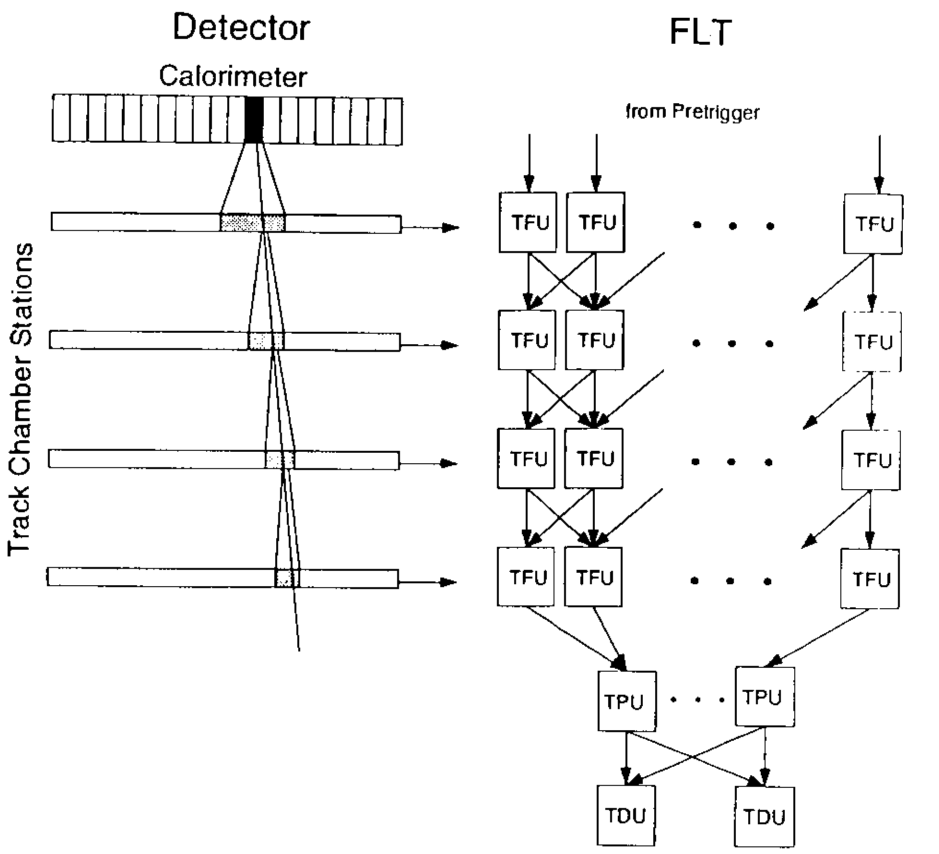
First-Level-Trigger System Overview

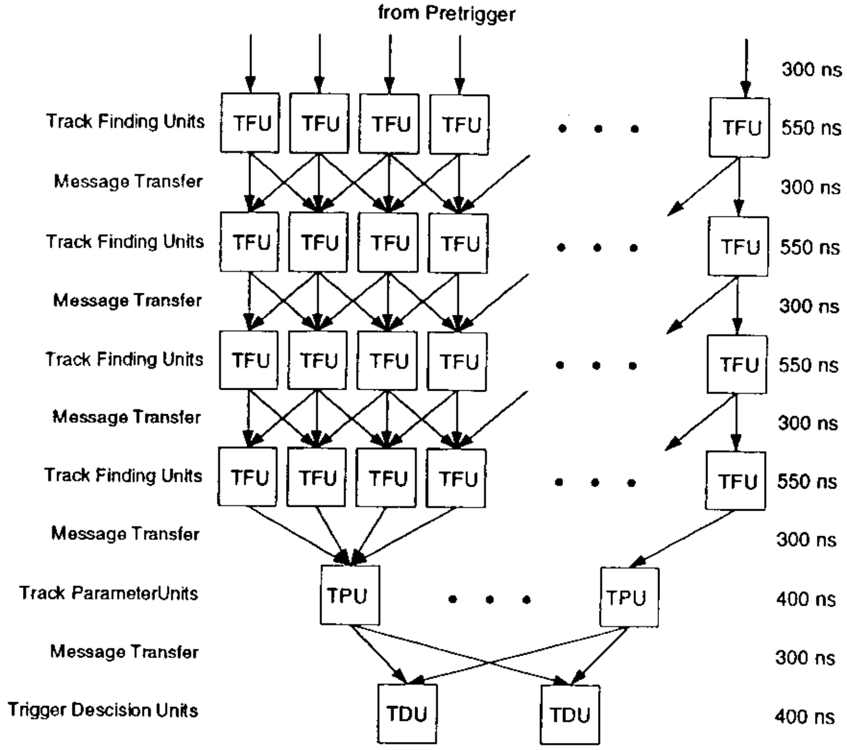


Track Finding Unit: wire memory
track finding processor

Track Parameter Unit: calculate kinematical parameters
apply momentum cuts

Trigger Descision Unit: calculate invariant mass
output trigger descision

First-Level-Trigger System Overview

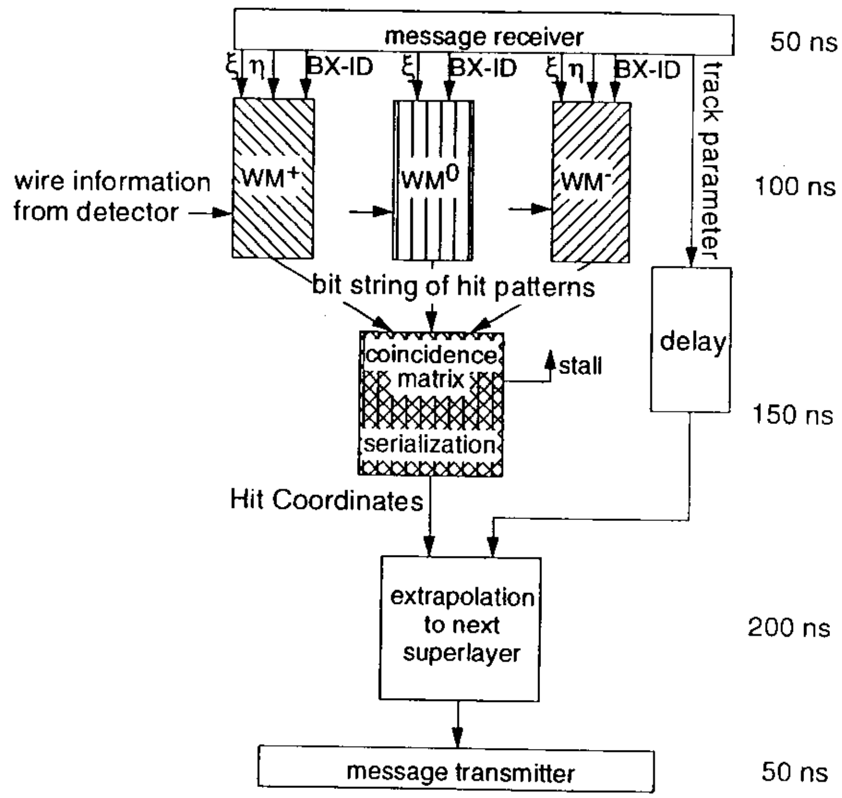


Track Finding Unit: wire memory
track finding processor

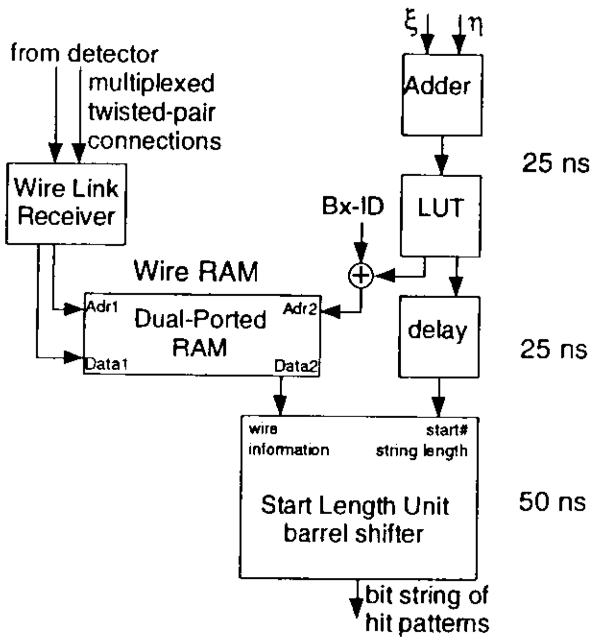
Track Parameter Unit: calculate kinematical parameters
apply momentum cuts

Trigger Descision Unit: calculate invariant mass
output trigger descision

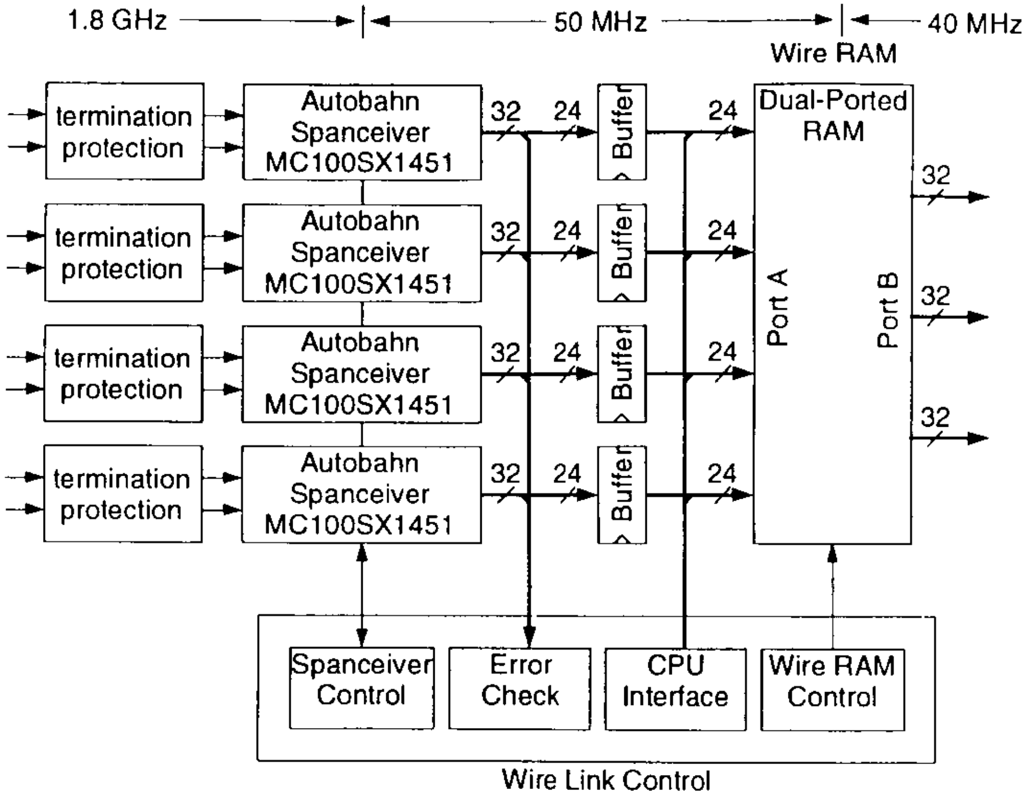
Track-Finding-Unit



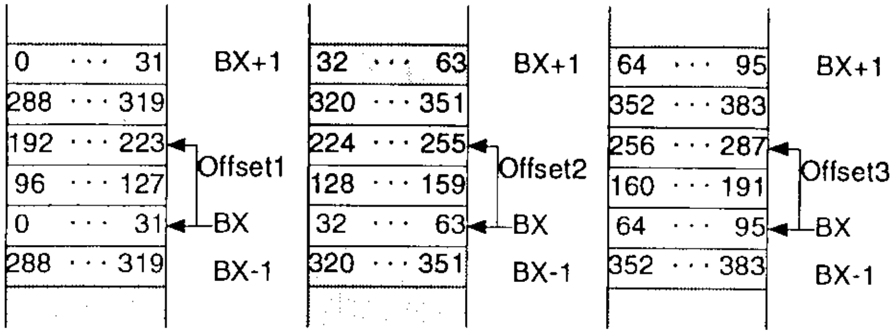
Wire Memory



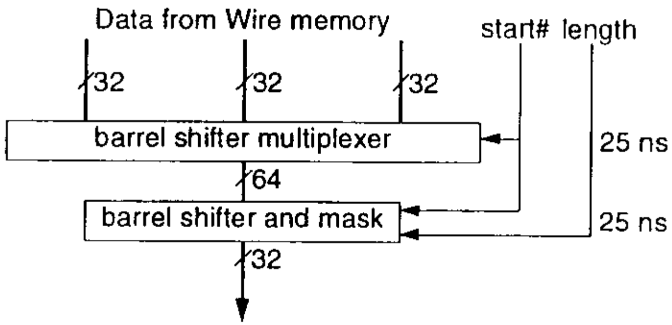
Wire Link Receiver



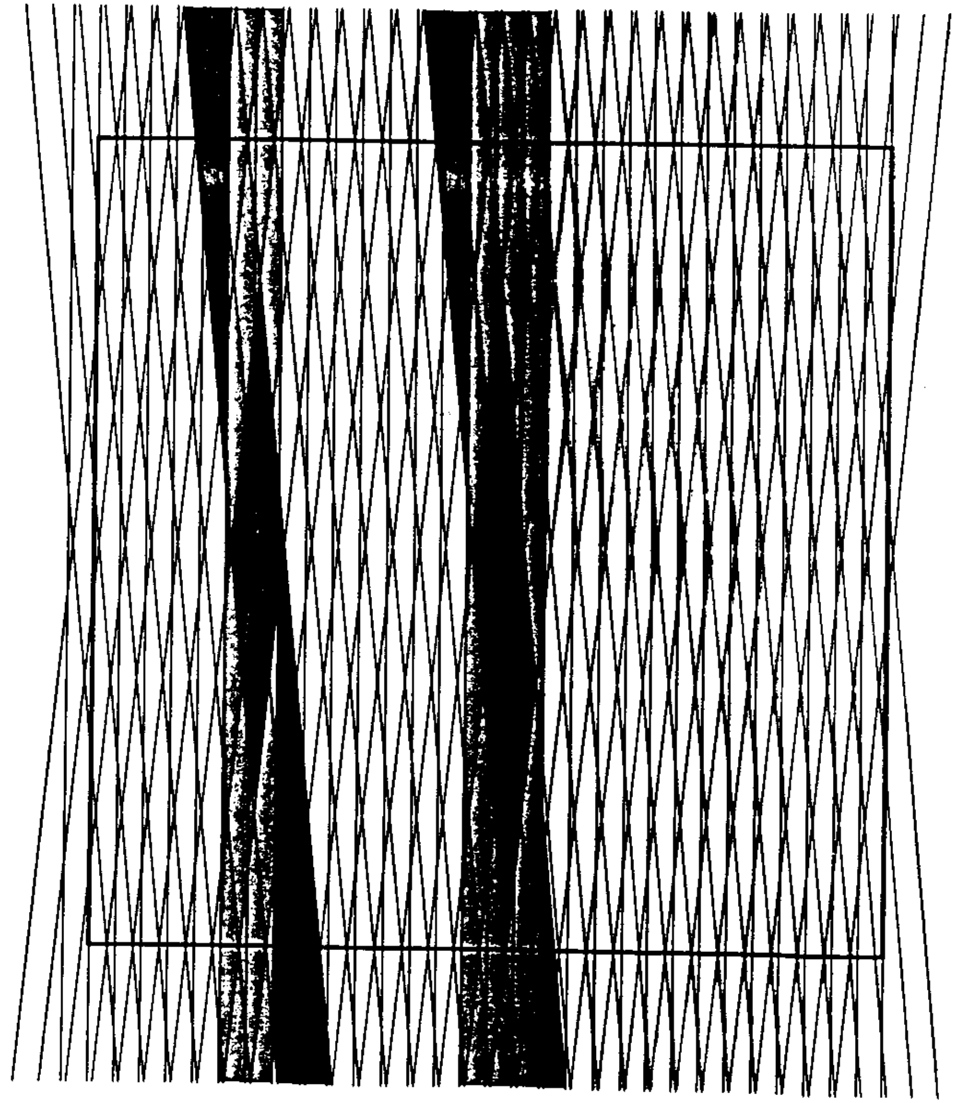
Wire-Memory Addressing Scheme

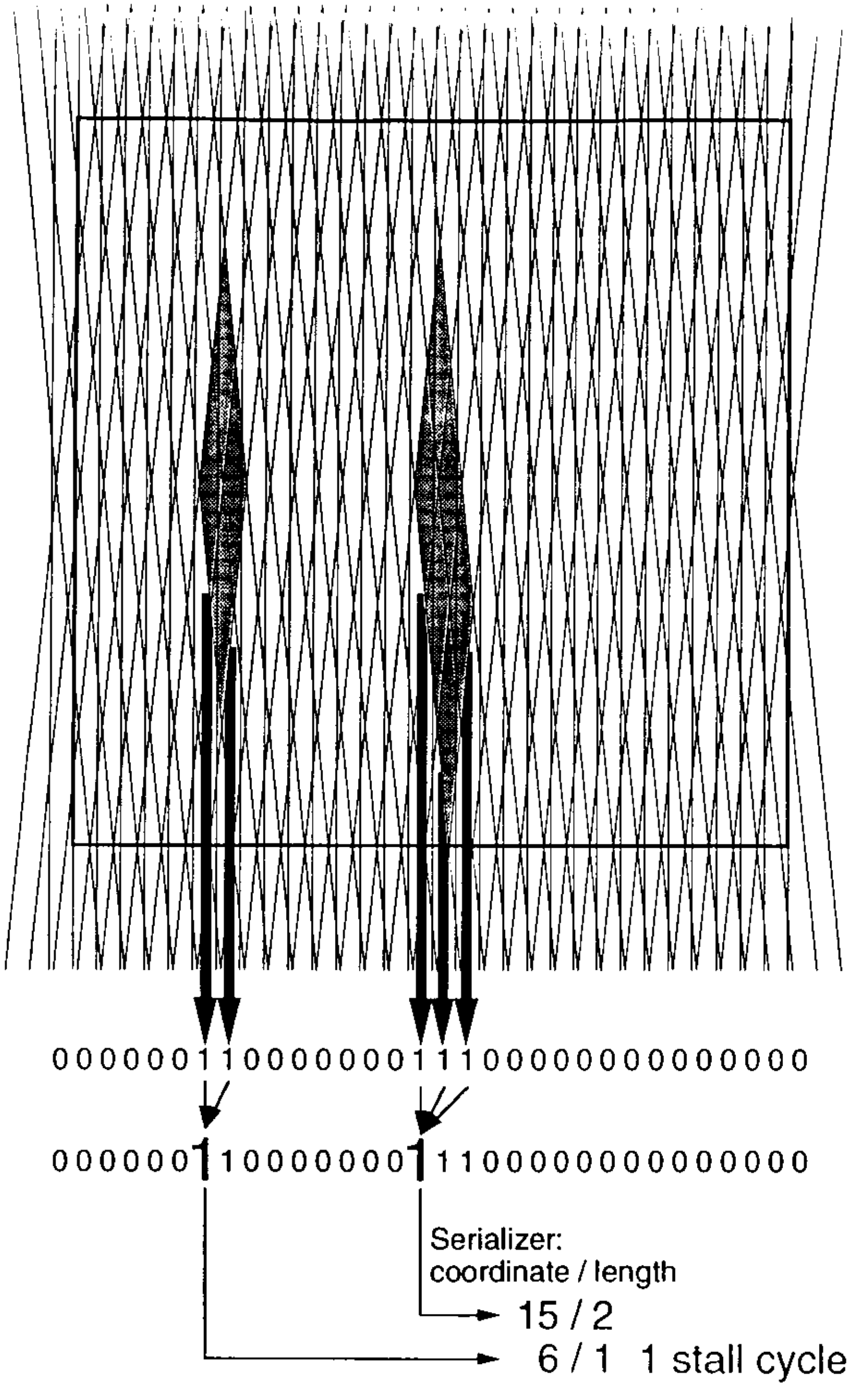


Start-Length-Unit

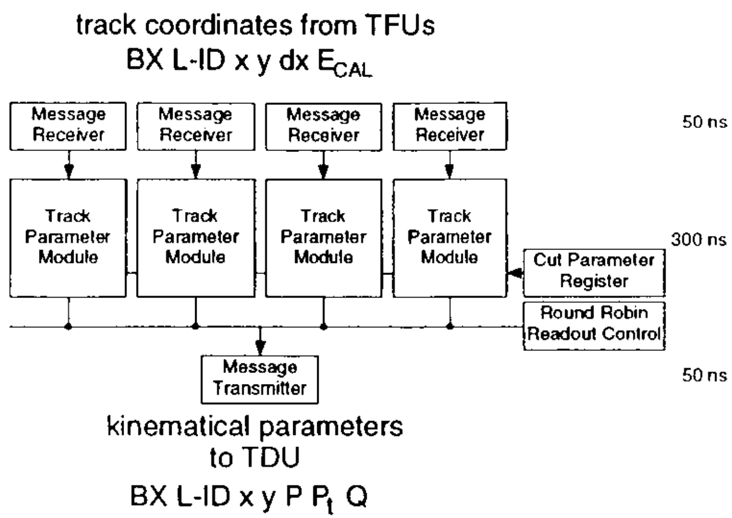


Hit Cluster

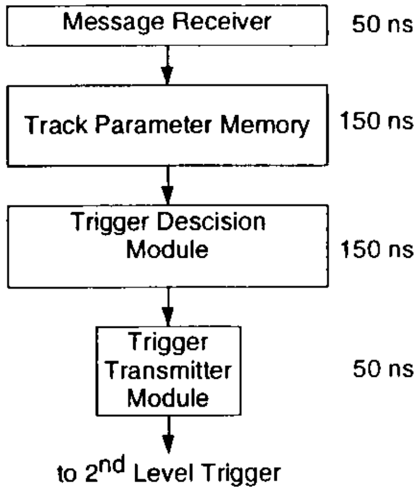




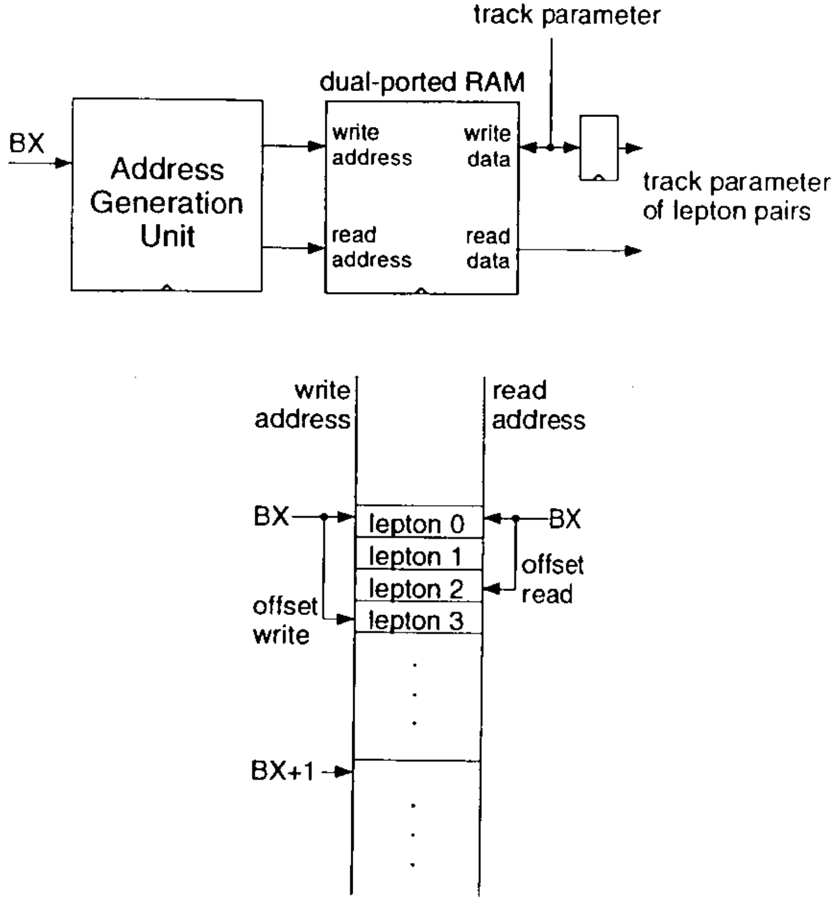
Track-Parameter-Unit



Trigger-Descision-Unit

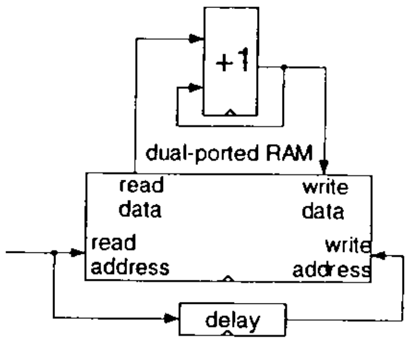


Track Parameter Memory



Address Generation Unit

BX RD ADD WB

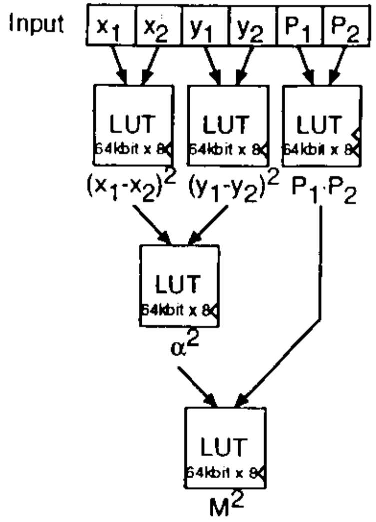


BX	RD	ADD	WB		
	BX	RD	ADD	WB	
		BX	RD	ADD	WB
		. . .			

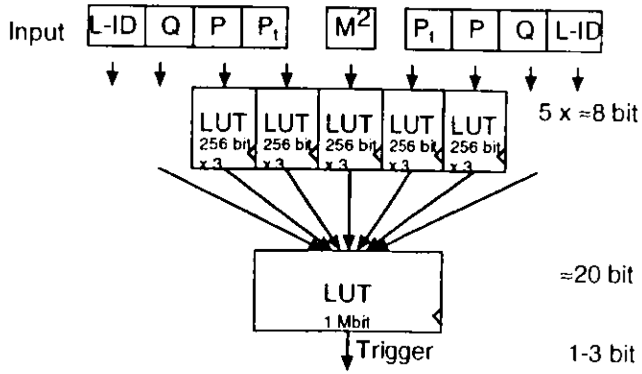
Pair Mass Calculation

$$M^2 = P_1 \cdot P_2 \cdot \alpha^2$$

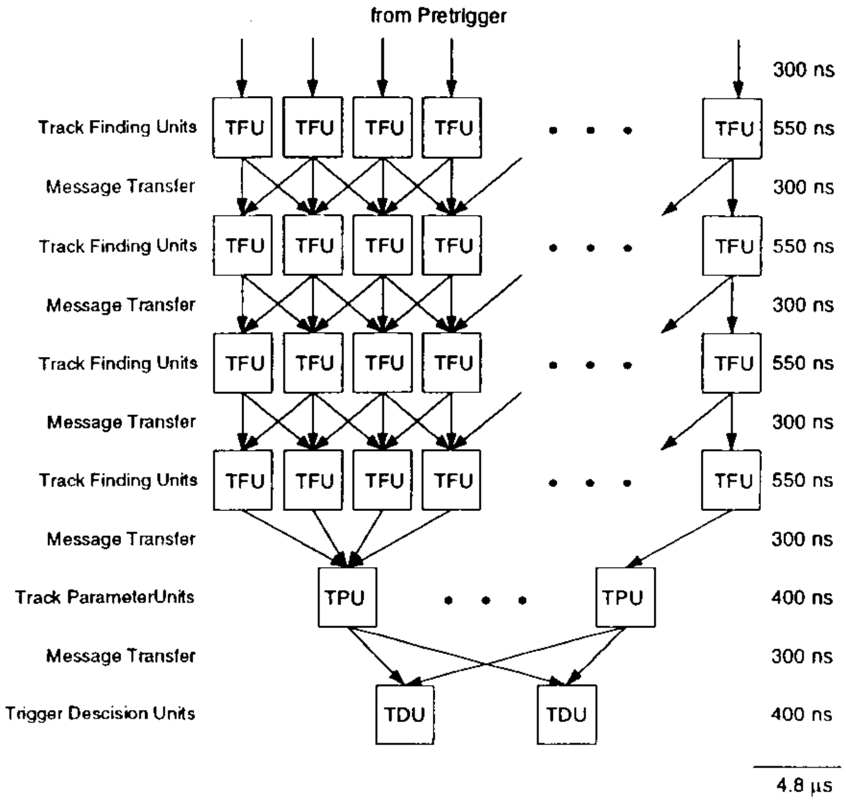
$$\alpha^2 = \frac{(x_1-x_2)^2+(y_1-y_2)^2}{z^2}$$



Trigger Descision Module



First-Level-Trigger System Overview



Systemsize:

3 Crates

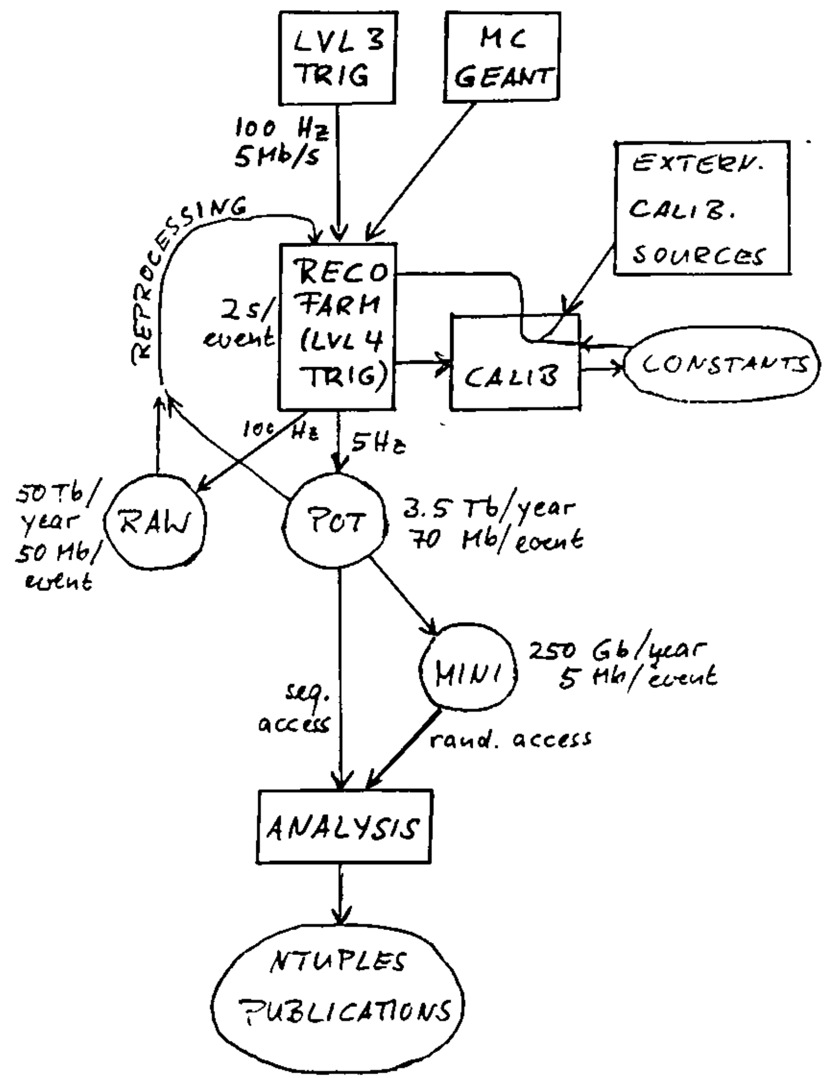
50 - 60 Boards
Boardsize 36 x 39 cm^2

OFFLINE SOFTWARE AND DATA ANALYSIS

H. ALBRECHT
DESY

- ANALYSIS CHAIN
- DATA SETS
- CALIBRATION ISSUES

ANALYSIS CHAIN



RAW DATA

CONTENT: DETECTOR HITS

EVENT RATE: 100 Hz ← crucial!
10^9 /year

EVENT SIZE: 50 kb opt. compressed.
(where does compr. takes place?)

DATA TRANSFER
TO RECO FARM: 5 Mb/s (manageable)

RAW DATA FILE

PURPOSE:
- EVENT REPROCESSING
- TRIGGER STUDIES
- NOT FOR PHYSICS ANALYSIS

AMOUNT OF DATA: 50 Tb / year
CAN BE STORED FOR ≳ 1 year.

POT: PRODUCTION OUTPUT TAPE

CONTENT: RAW DATA + RECONSTR. (tracks, vertices, part. ident.) } FOR EVENTS SELECTED BY THE 4^{th} LVL TRIG.

PURPOSE:
- PHYSICS ANALYSIS
- EVENT DISPLAY
- EVENT REPROCESSING

EVENT RATE:
$b\bar{b}$ events: 0.2 Hz (mainly from single-lepton trigger)
$c\bar{c}$, background: 5 Hz ? (depends crucially on "additional physics")

EVENT SIZE: 70 kb = 50 kb (RAW) + 20 kB (RECO)

TOTAL DATA RATE: 3.5 Tb/year
(not frightening - but cannot be stored on random access media)

MINI

CONTENT:
- TRACKS (momenta, part. ident.)
- VERTICES
- COVARIANCE MATRICES
- NO RAW DATA → event display imposs.

PURPOSE:
- RESTRICTED ANALYSIS
- EVENT SELECTION FOR LATER ANALYSIS WITH THE "POT".

EVENT SIZE: 5 kb

TOTAL DATA RATE: 250 Gb / year → random access.

EDIR: EVENT DIRECTORIES

CONTENT:
- EVENT FLAGS FOR PRESELECTION
- ADDRESSES FOR ACCESS ON "POT", "MINI"

DATA AVAILABILITY

RAW DATA:
- DESY ONLY
- SLOW ACCESS
- CANNOT BE KEPT FOR THE LIFETIME OF HERA-B (?)

POT:
- DESY ONLY (3.5 Tb cannot be easily transfered to other labs!)

CONSEQUENCE: all analysis programs using POT have to run at DESY!
- MASS STORAGE (fast; but rel. slow access to specific events)
- SELECTED SAMPLES CAN BE...
  - TRANSFERED TO OTHER LABS
  - STORED ON RANDOM ACCESS MEDIA

(but private copies are not desirable)
- BEWARE OF THE TIME CONSUMPTION OF A RUN THROUGH ALL DATA (WEEKS!)

MINI, EDIR:
- DISTRIBUTED TO ALL LABS
- RANDOM ACCESS

RECONSTRUCTION FARM

RECONSTRUCTION TIME / EVENT: 2 s ON SGI OR SIMILAR (ESTIMATION; SAME AS H1)

INPUT RATE: 100 Hz

→ 200 PROCESSORS à la SGI (20 times H1, ZEUS)

CANNOT BE REALIZED WITH SGI's (> 8 MDM)

NECESSARY: PROCESSOR FARM, SEE TALK OF U. GENSCH

CRUCIAL: KEEP THE INPUT RATE UNDER CONTROL!

CALIBRATION CONSTANTS

THE COMPLEXITY OF THE OFFLINE RECONSTRUCTION DEPENDS CRUCIALLY ON THE AVAILABILITY OF CALIBRATION DATA!

CALIBRATION:	USED BY
• DETECTOR GEOMETRY	
• GENERAL DETECTOR DESCRIPTION "CONSTANT" for long periods	TRIG, RECO
• FINE ADJUSTMENT OF PLANE POSITIONS "VARYING" within short periods	RECO
• CALORIMETER CALIBRATION "VARYING"	TRIG, RECO
• LIST OF DEAD AND HOT COUNTERS "VARYING"	RECO
• DRIFT TIME - SPACE RELATION "CONSTANT"	TRIG 2-3, RECO
• RUN FLAGS, SUMMARIES "CONSTANT"	ANALYSIS

CALIBRATION CONSTANTS

ORIGIN:

- HARDWARE, e.g. geometry: surveying
  ECAL: light flasher
- SOFTWARE: e.g. geometry: residuals of track fit
  ECAL: reconst. π, e

SOFTWARE CALIBRATION:

AVAILABLE AFTER RECONSTRUCTION

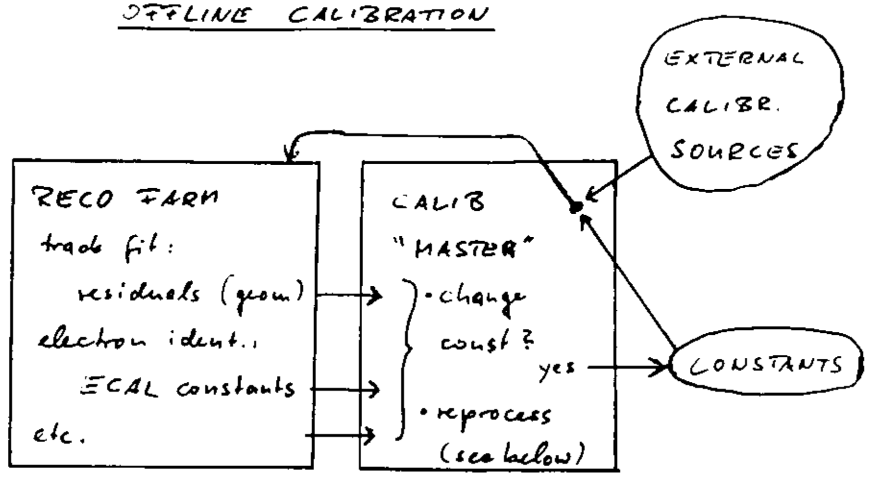
(thus, "quasi-online" reconst. is necessary!)

NEVERTHELESS: DELAYS OCCUR!

TRIGGER: BEWARE OF EVENT LOSS DUE TO CHANGES OF THE CALIBRATION DANGEROUS.

- ECAL CALIB → RELY ON HARDWARE CALIB. DURING TRIGGER.
- FINE ADJUSTMENT OF GEOMETRY
  → LARGE TOLERANCES IN THE TRIGGER.

OFFLINE CALIBRATION



CALIB "MASTER" PROCESSOR:

- THE ONLY PROCESSOR ALLOWED TO MODIFY THE CONSTANTS' FILE (disaster if hundreds of processors of the farm would do it simultaneously!)
- SHOULD WORK WITH (ALMOST) NO HUMAN INTERFERENCE.

CALIBRATION CONSTANTS

WHAT TO DO IF THE "CONSTANTS" CHANGE?

- CHANGES KNOWN FROM ONLINE MONITORING / HARDWARE DEVICES:

  THE OPTIMUM CASE: CAN BE TAKEN INTO ACCOUNT IMMEDIATELY.

- SLOW CHANGES:

  UPDATE CONSTANTS CONTINUOUSLY

- ABRUPT CHANGES

  EVENT <u>REPROCESSING</u> NECESSARY

  - WHICH EVENTS ARE TO BE REPROC.?
  - WHEN? (during data taking
    next filling
    next shutdown?)

MAJOR BOOKKEEPING PROBLEM!
CAN BE SOLVED ONLY WITH
AUTOMATIC DATA MANAGEMENT
(human interference → untolerable delay).

CONCLUSIONS

CPU POWER

- CHALLENGING (20 · H1, ZEUS)

SIZE OF DATA FILES

- MANAGEABLE (in near future)

DATA MANAGEMENT

- INVOLVES A LOT OF WORK!

VLSI Front end electronics for HERA-B An overview

M. FEUERSTACK

What is needed?

Detector	Quantity	#Channels	Occup.
Silicon Vertex	Charge	≈170.000	≈4%
Inner Tracker MSGC	Charge	≈135.000	<3%
Inner Tracker HPXL	Time	≈135.000	<3%
Outer Tracker	Time	≈90.000	<15%
Forward TRD	~~Time~~/State	≈13.000	<15%
Trigger chamber wires	Time	≈37.000	<15%
Trigger chamber pads	Charge	≈15.000	<15%
RICH	Charge	≈140.000	≈2%
ECAL	Charge(!)	≈7.000	large
MUON chamber wires	~~Time~~ Hits	≈22.000	≈1%
MUON chamber pads	Charge	≈13.000	<1%

Detectors that need to measure time:
Resolution: 0.5ns - 1ns, Range: 96ns, no double hits
Discriminator threshold ≥10^4electrons
=> chips most likely will be two pieces:
analogue Amp./Disc & digital TDC (w. pipeline)

Detectors that need to measure charge:
Resolution: Si-vertex 4bit, others 1bit
Range ≈10fC
=> One chip solution possible:
Amp./Shaper/Analogue pipeline or
Amp./Shaper/Disc./Digital pipeline

What is available?

Amplifier, Shaper, Discriminator (1)

Name	RAL 110 Amplifier Disc.	ASD-8 Amplifier, Shaper, Dicriminator
Reference	Ypsilantis	SDC
Number of readout chan.	8	8
Technologie	bipolar	Tektronix SHPi analog bipolar
Pitch size	?	≈ 470μm (due to differential input)
Chip size	?	packed in 44pin J-LEAD (PLCC) 2.8mm x 4.7mm
Peaking time	≈10ns	7ns
Input imped.	≈100Ω	≈125Ω
Gain	19uV/nA	2.5mV/fC
Noise	≈2000e-	78e-/pF + 850e-
Threshold	?	> 10mV
Supply volt.	+3V, -3V, GND	+3V, GND, -3V
Power/chan.	10mW	18mW
Costs/chan.	?	3,--DM - 4,--DM
Availability	Now	100 chips tested
Note	- Needs support chip for thresh. adj. (RAL111 TDC) - Includes analogue OR of 8 channels - Accepts positive RAL110 or negative input RAL110N depending on bonding scheme	Separate threshold for each channel

What is available?

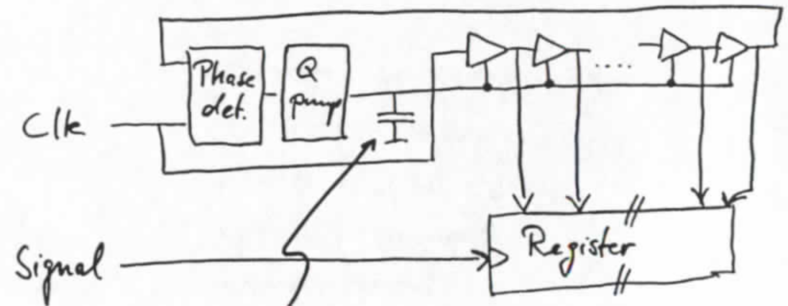
Amplifier, Shaper, Discriminator (2)

Name	IDE03 amplifier chip incl. OR of 4 chan.	RAL 118 TRDA Amp. & 2 threshold disc.
Reference	W. Lange/Zeuthen	RD-6
Num. of chan.	n x 4 channels/chip	8
Technologie	AMS 1.2µm n-well CMOS	Bipolar
Pitch size	200µm	
Chip size	4mm x (n x 1)mm	
Peaking time	45ns	8-10ns
Input impedance		
Gain	> 25mV/fC	
Noise	≤ 3000e- at 50pF	2000e- at 15pF
Threshold	< 0.3fC input charge	low: adj. 200eV - 1550eV (5bit DAC) high: adj. 1keV - 7,5keV (5bit DAC)
Supply voltage	-2V, GND, +2V	+3.6V, +1.2V, GND
Power/chan.	10mW	13mW
Costs/channel	2,--DM - 3,--DM (naked chips, wafer tested)	
Availability	W. Lange has 64 chips running, will produce 64 hybrids w. 8 chips each this year.	Now Output signal is differential current pulse
Note		Needs support chip RAL 117 TRDS/C

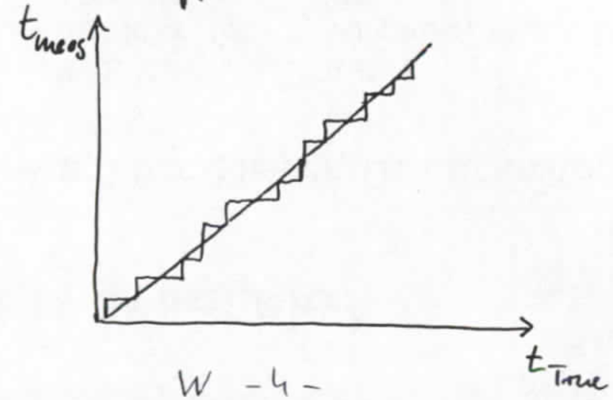
Conclusion:
Amplifier, Shaper, Discriminator chips are available

Need to get some and test them at the detector.
Work to be done by the subdetector groups.
Might need to develop new support chips for slow ctrl.

TDC - Principle



- Controls length of each delay step Is adjusted by phase detector at each clock cycle
  ⇒ Time jitter
- Short time disturbance due to switching within the chip is not controllable this way
  → Additional errors ("Differential nonlinearity)



What is available?

TDC with pipeline (1)

Name	DTM ROC	The RD-12 (NA48) TDC chip
Reference	RD-6	NA48
Number of chan.	32	16
Time resolution	3,125ns	1.6ns
Range	3bit	4bit fine time, 13bit coarse time clocked at 40MHz
Double pulse res.	No	?
Pipeline depth	128 stages	128 stages deep FIFO for 16 channels
Write clock freq.	≤ ~~40MHz~~ 20MHz	40MHz
Readout freq.	~~50kHz – 100kHz~~	40MHz/word => 150kHz
Technologie	AMS 1µm CZB	ES2 1µm CMOS
Pitch size	?	?
Chip size		$25mm^2$
Supply voltage	+5V, GND	?
Power/chan.	3.5mW	
Costs/channel		
Availability	~~Now (May 1994)~~	Now
Note	Each trigger reads out 3 time slices => Time between 2 triggers > 75ns	several channels have hits on the chip, data is not neces-serarily ordered by time. => Difficult to select events from FLT enable. FIFO for all channels makes storage time occupancy dependant

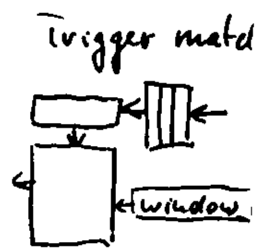
◯ k.o. criteria

W -5-

Follow an development

32 channels, 21bit, 0.5us

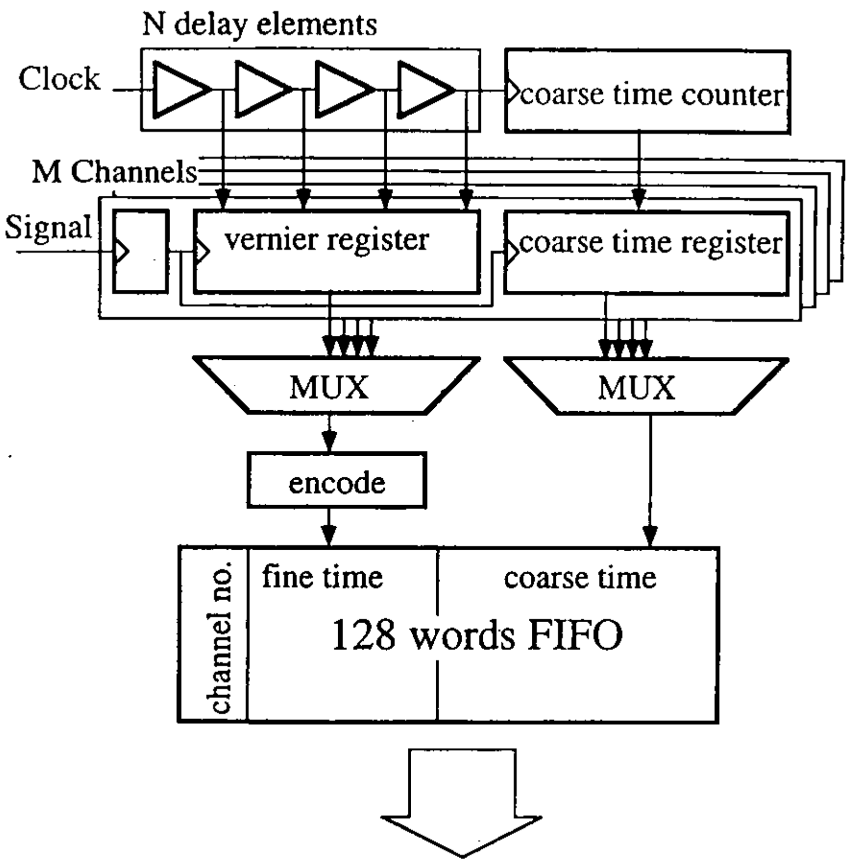
~~X~~ 256



32 word FIFO

W -6-

TDC(NA48) principle



Remark on follow-on development to NA48 chip

Looks promising:

- 32 channel, 21bit, 0.5ns bin size
- Increased FIFO length (256 words for all channels)
- Trigger matching circuitry simplifies readout of events residing in a programmable time interval

But:

- Architecture makes storageable number of events dependant on occupancy.
  Need at least 128 events
  256words/128 events => 2chan./event may have hit
  2chan./32 chan. => **<u><6.25% occupancy allowed!</u>**

=> Security?

Conclusion:
Need to contact Marchioro(CERN) to investigate status of project and try to increase length of FIFO

What is available?

TDC with pipeline
(SDC developments and follow-ons)

Name	TMC1004	TMC-SSC	TMCTEG3 Toshiba
Reference	SDC Tracker	SDC Tracker	ATLAS KEK
Number of chan.	4	4	4
Time resolution	1ns	2ns	<1ns
Range	11bit	11bit	3.2 - 4.1μs
Double pulse res.			<25-35ns
Pipeline depth	1-4μs	2-8μs	3~4μs (128 stages)
Write clock freq.	4ch. 1ch.		30 - 40MHz
Readout frequency			7.5 - 10MHz ×4mode
Technologie			0,5μm CMOS Sea of gates
Pitch size			0,5mm
Chip size	5mm×5.6mm = 28mm^2	6mm×7mm = 42mm^2	
Supply voltage	3V, GND	3V, GND	3.3V, GND
Power consumpt./ch.	7mW	8mW	10mW
Costs/channel	8,--DM	?	8,--DM
Availability	Now	In develop.	In development

Conclusion:
No chip fits our requirements yet.
Need to talk with Toshiba about redesign of TMCTEG3 with longer pipeline
(R. Wurth, A. Hölscher already trying to get into contact with Toshiba).

What is available?

TDC with pipeline
(New development by MSC, Wiesbaden)

Name	MSC Wiesbaden Neuentwicklung
Reference	Rainer Wurth, DESY
Number of chan.	8
Time resolution	0,5ns
Range	8bit
Double pulse res.	No
Pipeline depth	128 stages (may be a separate chip)
Write clock freq.	10.4MHz
Readout frequency	50kHz
Technologie	1μm CMOS Sea of gates
Pitch size	?
Chip size	?
Supply voltage	?
Power consumpt./ch.	?
Costs/channel	13,--DM with integrated pipeline 10,--DM w/o integrated pipeline
Availability	8.000 channels until Mid 95

Yet to develop.
- 14 man weeks development time required,
- prototypes 8 weeks after masks,
- mass production 16-20 weeks after order
- If specification is available within this year 8.000 channels could be ready until mid of 1995.

Conclusion:
Need to specify the design in more detail.
(**Rainer Wurth**, John Zweizig, Martin Feuerstack, Andreas Hölscher,…)

Latest news (at least for me)

Other TDCs:

- Development from C.A.E.N
  - 16 or 32 channels ?
  - 0.5ns LSB
  - 24 bit dynamic Range
  - 32 hits / channel FIFO
  - ~ 12,- DM / channel
- Development from Rome (Carboni)
  - 32 channels
  - 1 ns LSB
  - 16 bit dynamic Range ?
  - 32 hits / channel
  - ~ 6,- to 8,- DM / channel

Will be evaluated

Maybe adaption to our requirements is possible within our timescale

⇒ Stay tuned!

What is available?

Analogue pipeline

Name	Felix	APV-5
Reference	RD-20, K. T. Knoepfle	RD-20, K. T. Knoepfle
Number of chan.	32 now, later 128	32 now, later 128
Technologie	AMS 1,2μm CMOS (non rad-hard)	Harris AVLSIRA (10Mrad rad. hard CMOS)
Pitch size		
Chip size		
Peaking time	45ns	45ns
Input impedance		
Write clock freq.	10MHz	10MHz
Pipeline depth	67 stages now, design target 10μs => 128 stages	128 stages now design target 10μs => 128 stages
Readout freq.	50kHz = 20μs => < 10μs (deadtimeless)	50kHz = 20μs => < 10μs (deadtimeless)
Supply voltage		
Power/channel	1-2mW	1-2mW
Costs/channel		
Availability	now 32 channel, 67 stages delay pipeline	
Note	K. T. Knoepfle will receive a 32 channel version with multiplexor in late september, to test it.	

Conclusion:
K. T. Knoepfle: Very promising.
Wait for tests. Since chip is quite complex and integrates the analogue part, we need to distribute chips to the different subdetectors for testing (Si-Vertex ✓, MSGC, RICH)

What is available?

Digital pipeline

Name	FASTPLEX
Reference	NIKHEF
Number of channels	32
Technologie	
Pitch size	
Chip size	
Peaking time	<20ns rise time, 500ns fall time
Input impedance	
Write clock frequency	
Pipeline depth	128
Readout frequency	
Supply voltage	
Power/channel	
Costs/channel	
Availability	> June '95
Note	

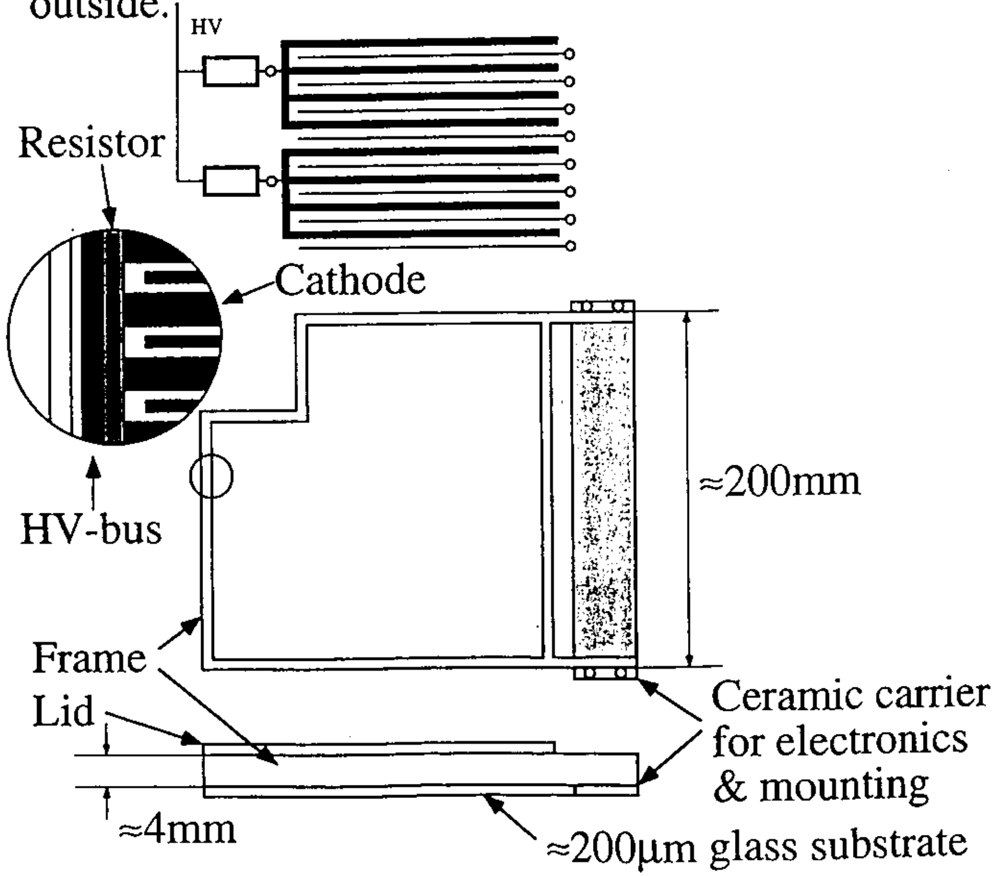
Could be fall-back solution for MSGC and RICH

Conclusion:
Clearly need to contact developers to get more information. ✓
Evaluate possibility to integrate a trigger facility into the chip for MSGC. Fall back solution for MSGC and RICH if RD-20 fails?

The problem with the MSGC trigger

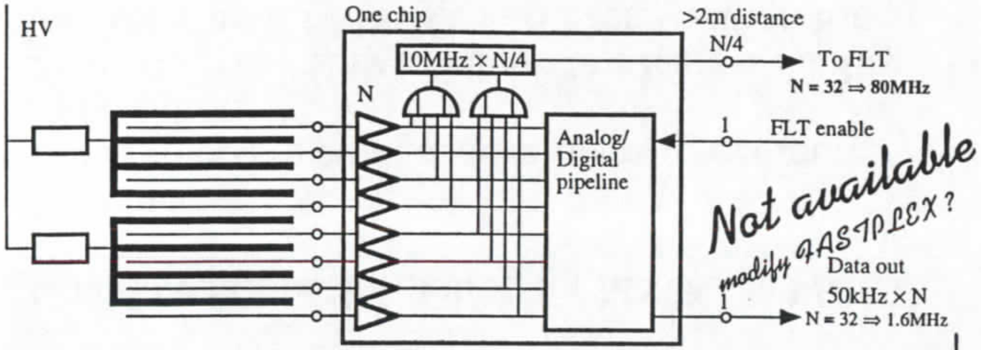
Need to:

- put data into SLT buffer for all channels (135.000)
- provide trigger signal (OR of 4 adjacent strips) for some signals (4 Superlayers: MT15-MT18, 7, 8, 13, 14 3 stereo angles ≈ 40.000 strips => 10.000 channels)
- Would like to have access to analogue data for monitoring purposes
- Must place at least amplifiers within the detector at < 20cm distance from beam to transport signal outside.

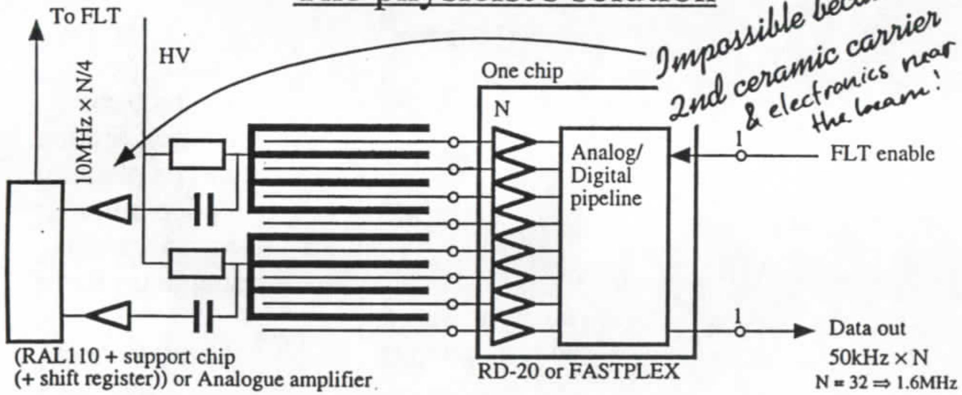


How to derive 10.000 trigger signals from the inner detector

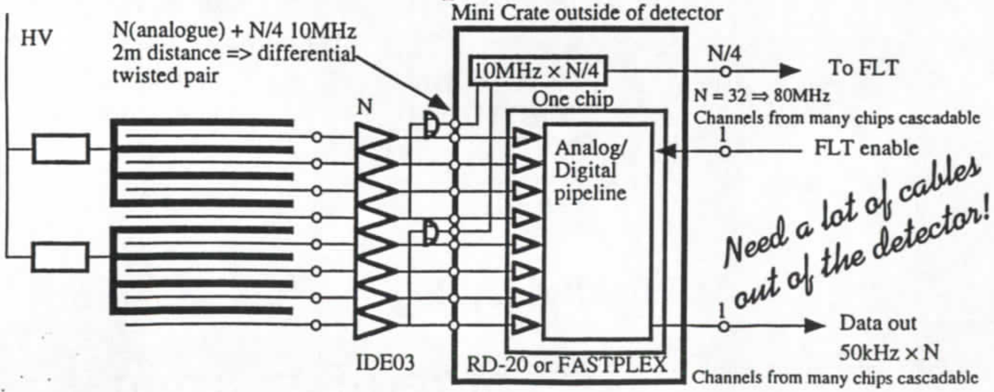
The All-in one solution



The physicist's solution



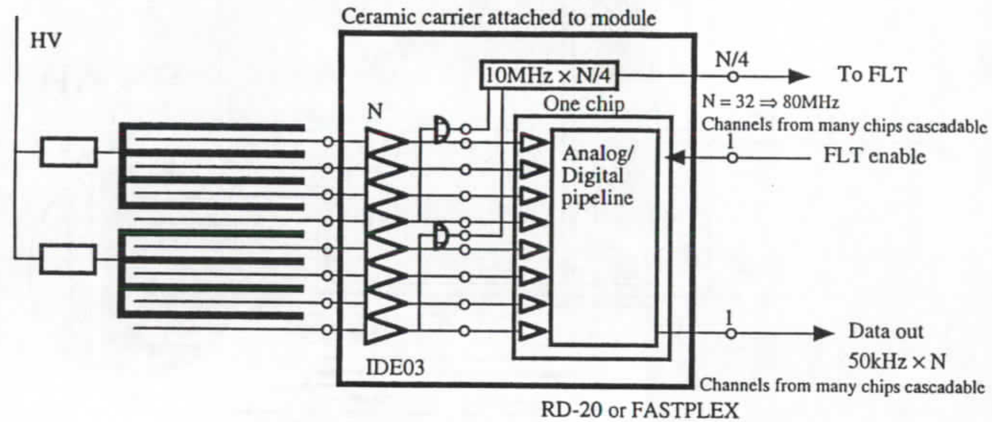
The "shift the problem" solution



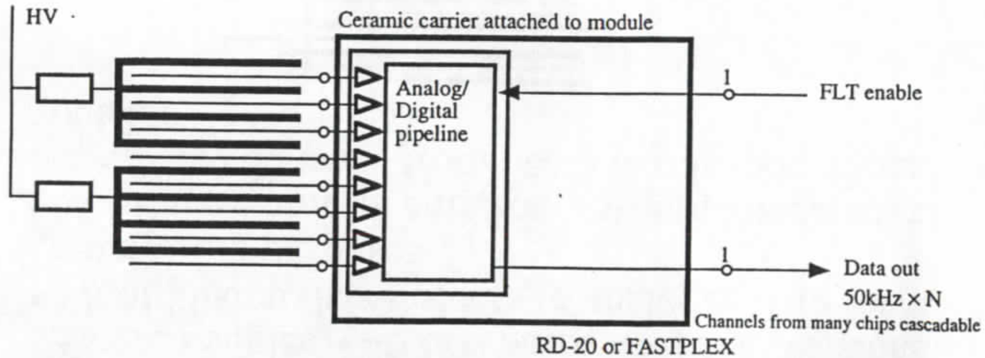
How to derive 10.000 trigger signals from the inner detector

The modular solution

MT15-18, 7,8,13,14



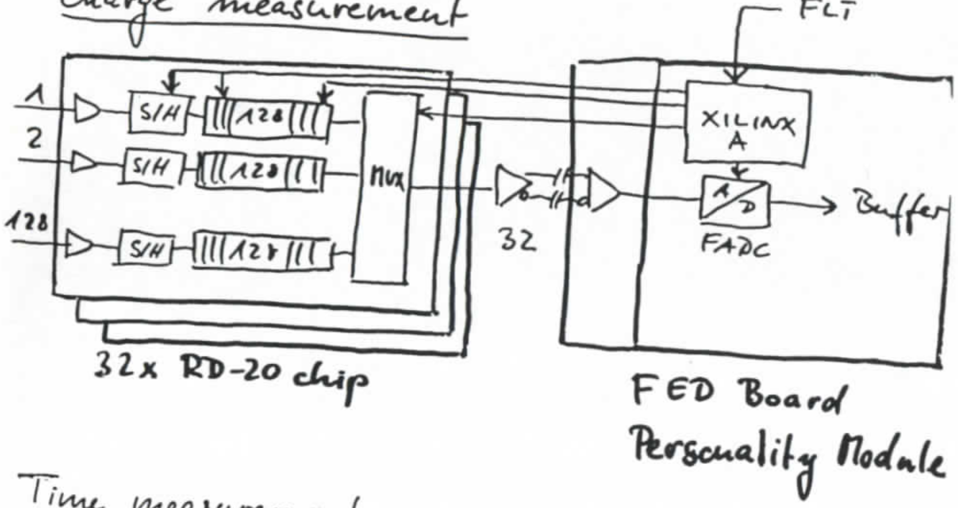
All others



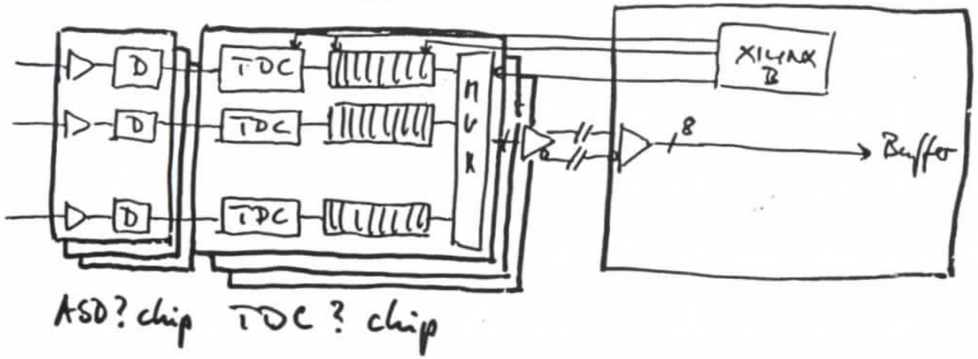
- Can be realized with currently available components,
- minimizes material for non-trigger planes.

The HERA-B front-end electronics architecture

Charge measurement



Time measurement



Conclusion:

Detector	Quantity	Possible chips
Silicon Vertex	Charge	RD-20
Inner Tracker MSGC	Charge	RD-20 (/FASTPLEX)
Inner Tracker HPXL	Time	ASD? & TDC to develop
Outer Tracker	Time	ASD? & TDC to develop
Forward TRD	Time/State	TRDA & TDC to develop
Trigger chamber wires	Time	ASD? & TDC to develop
Trigger chamber pads	Charge	ASD? (no pipeline needed)
RICH	Charge	RD-20(/FASTPLEX)
ECAL	Charge(!)	Discrete electronics FERMI ?
MUON chamber wires	~~Time~~	ASD?& TDC to develop
MUON chamber pads	Charge	

- TDC is still open
- Get Amplifier/Diskriminator chips and test them at detector
- Try to get RD20 chip run at Si-V, MSGC, RICH
- ECAL electronics still open (FERMI ?)
- MUON electronics ?

Hera-B Data Acquisition System

J. ZWEIZIG
UCLA

HERA-B OPEN COLLABORATION MEETING

OCTOBER 6, 1994

DAQ Functions

The Data Acquisition system must provide the following

- ***Event Readout:*** Readout sequencing, event building, data routing, etc.
- ***Run Control:*** Start/Stop acquisition; Enable/Disable detector sets; Specify run parameters (e.g. data routing to L3/Tape), etc.
- ***Initialization:*** downline loading programs and run-time constants (e.g. pedestals, threshholds, t_0s)
- ***Monitoring:*** Keep an eye on device status (e.g. currents, temperatures), detector performance, data integrity, etc.
- ***User Interface:*** Control interface, status display, error reporting, etc.
- ***Slow Control:*** Control of HV, target position, silicon detector position, etc.
- Online Database

HERA-B DAQ

Standards

We will attempt to adhere to commercial standards, and to use uniform hardware wherever possible.

- VME Bus
- Cern VSC 'Recommended practices'
- Uniform processor architecture (Power PC?)
- Uniform readout board kernal configuration.
- Uniform user interface
- Unix (Lynx O/S) and TCP-IP.

HERA-B DAQ

Data Acquisition Parameters

detector	channels	R/O boards/ crates	event size	event bldr. b/w
Si vertex	170,000 (4%)	42 / 3	13.6 kby	27.2 Mby/s
inner tracker	135,000 (3%)	66 / 4	8.1	16.2
outer tracker	97,000 (10%)	96 / 6	20.0	40.0
RICH	200,000 (2%)	49 / 3	8.0	16.0
TRD	13,000 (20%)	26 / 2	3.25	6.5
μ wires	22,000 (1%)	22 / 2	0.4	0.8
μ pads	13,000 (1%)	13 / 1	0.3	0.6
ECal	6250 (100%)	100 / 6	12.5	25.0
Total	656 250	414 / 27	66.2 kby	132.3 Mby/s

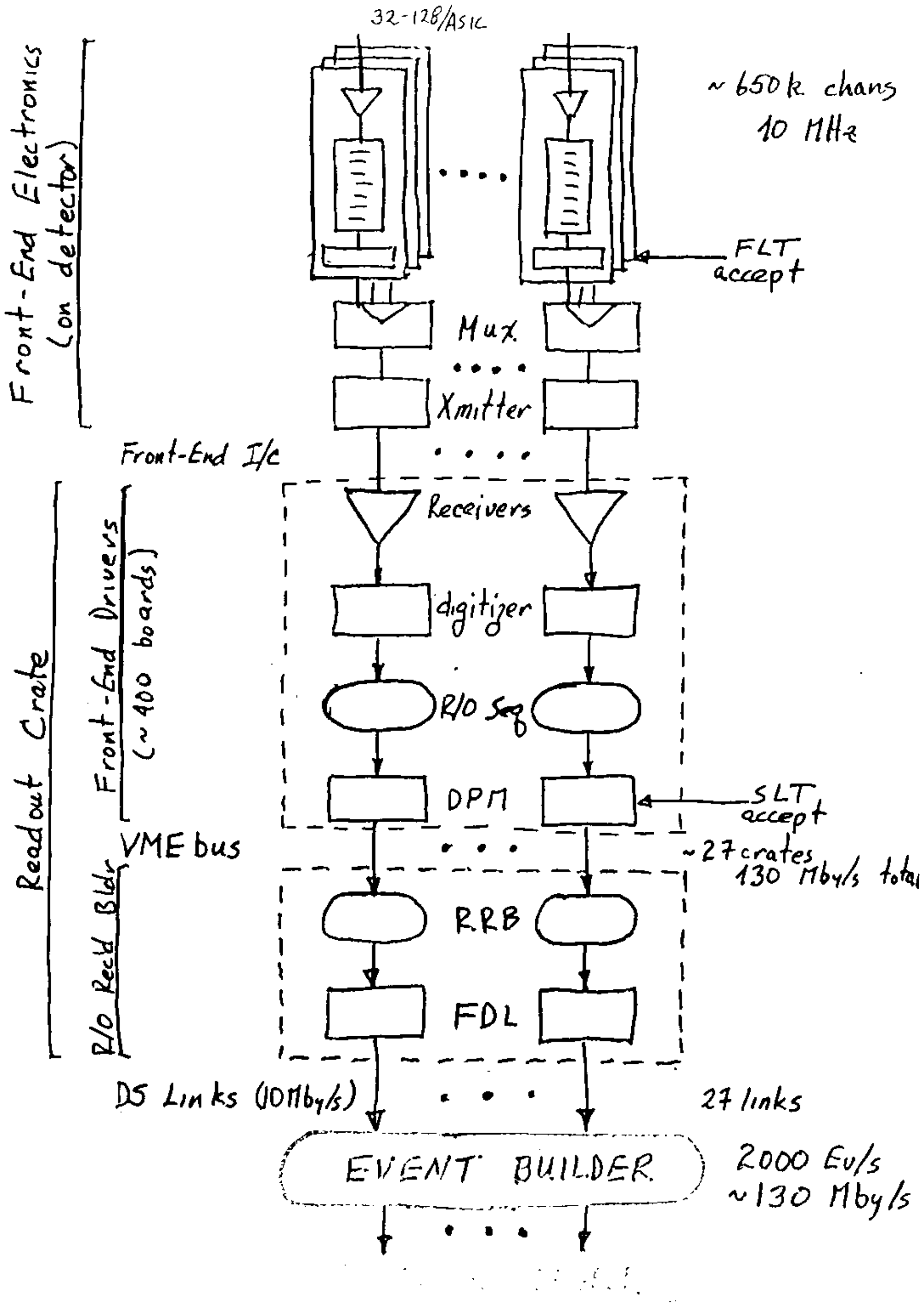
Assumptions

- 4096 chan / board for low precision ADCs used in calculation of Si, inner tracker (MSGC), RICH.
- 1024 chan / board for TDCs e.g. outer tracker, μ wires.
- TRD readout 2 bits / chan, no sparsification.
- ECal has 64 chans / board, no sparsification.

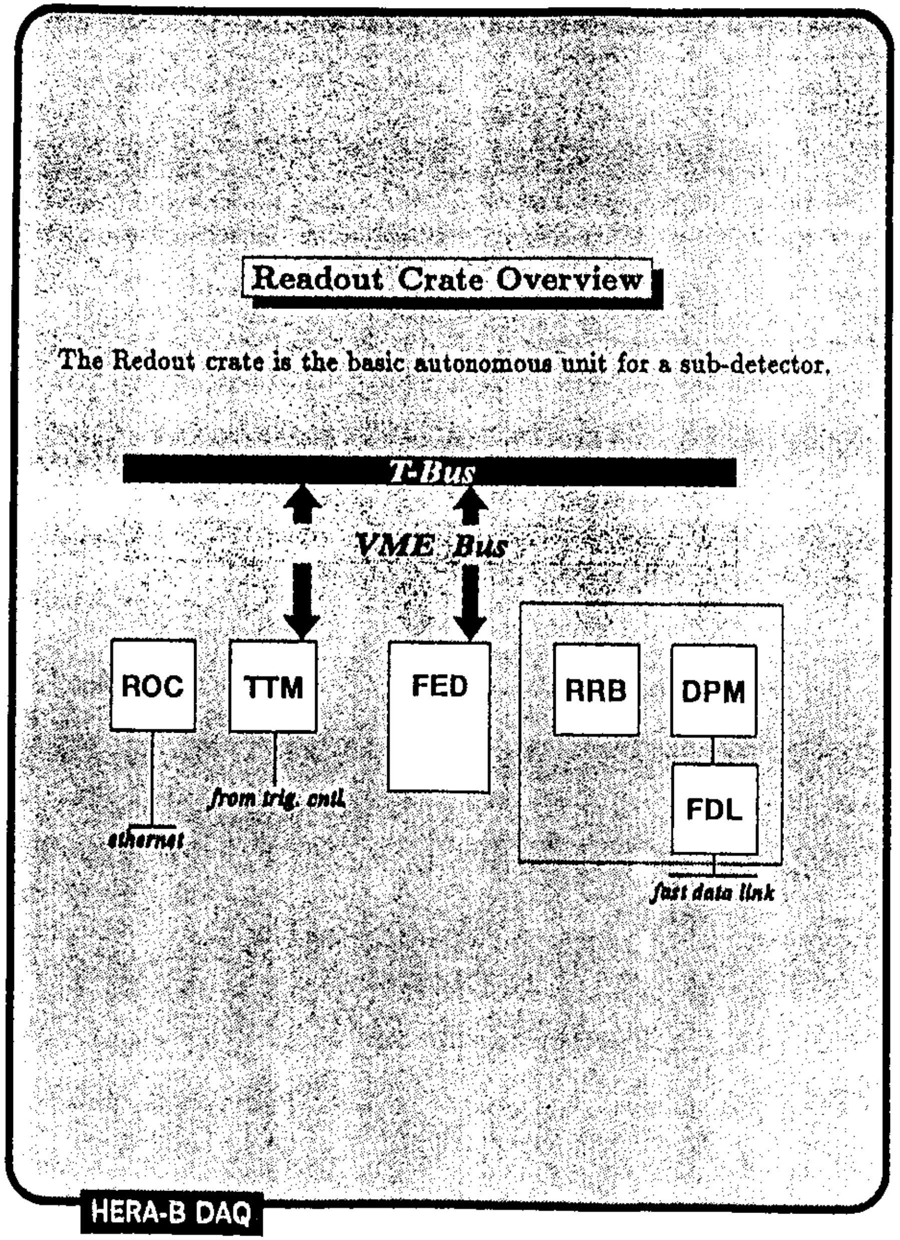
Noteworthy Rates

- digitize ~ 660,000 chans. in < 20 μsec
- Front-end readout rate of ~3.3 Gby/s
- Event Builder rate of > 130 Mby/s

⇒ Highly parallel data flow (4.9 Mby / readout crate)


32-128/ASIC
~650k chans
10 MHz
FLT accept
Front-End Electronics (on detector)
Mux
Xmitter
Front-End I/c
Receivers
digitizer
R/O Seq
DPM
SLT accept
Front-End Drivers (~400 boards)
Readout Crate
VME bus
~27 crates
130 Mby/s total
RRB
FDL
R/O Rec'd Bldr
DS Links (10Mby/s)
27 links
EVENT BUILDER
2000 Ev/s
~130 Mby/s

X -5-


Readout Crate Overview
The Redout crate is the basic autonomous unit for a sub-detector.
T-Bus
VME Bus
ROC
TTM
FED
RRB
DPM
FDL
ethernet
from trig. cntl.
fast data link
HERA-B DAQ

X -6-

Front-End Driver

Front-End Drivers link front-end electronics to the Readout System

- Readout sequencing
- Data sparsification (zero suppression)
- Event buffering during Level-2 decision.
- Standard I/F to readout system

High Density - Optional large format VME card

Common Readout Section:

- VME slave I/F with sparse data scanning
- Dual-ported event memory
- Buffer management
- I/F to detector specific section (e.g. PCI bus)
- I/F to trigger/timing bus

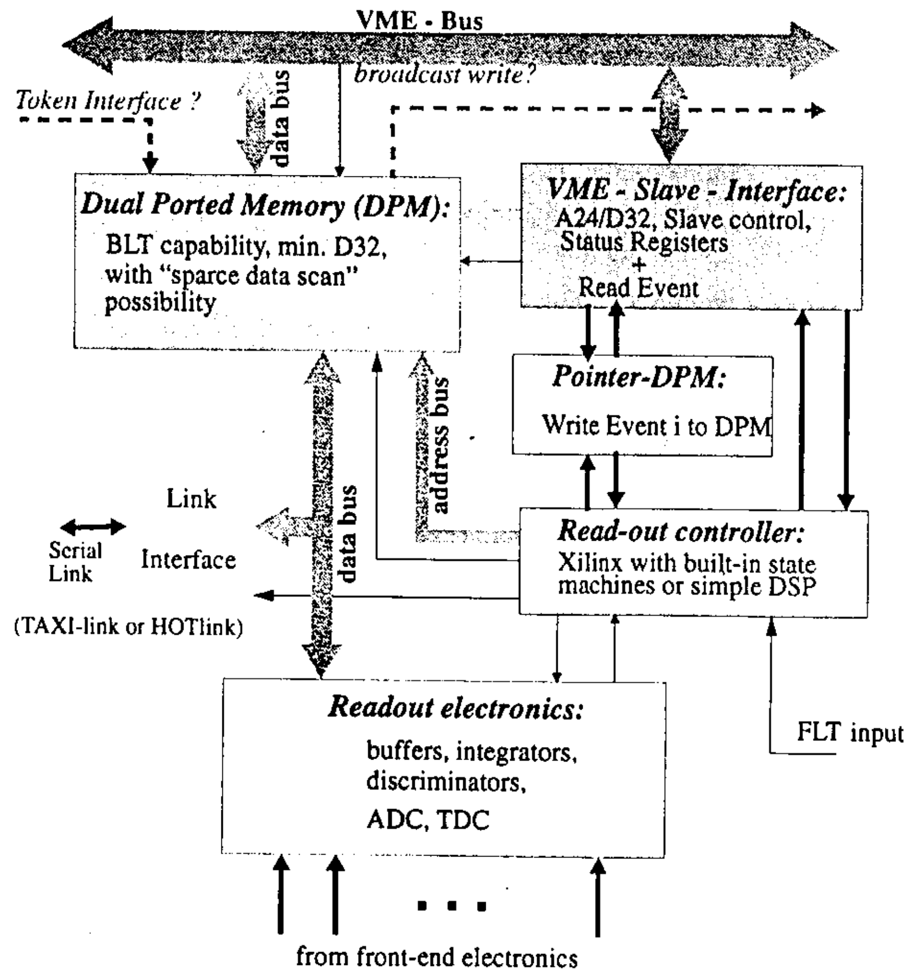
Detector specific section "personality module"

- Analog (digital) receiver
- Digitizer (if analog input)
- Readout sequencer / Control bus drivers.
- Data sparsification

HERA-B DAQ

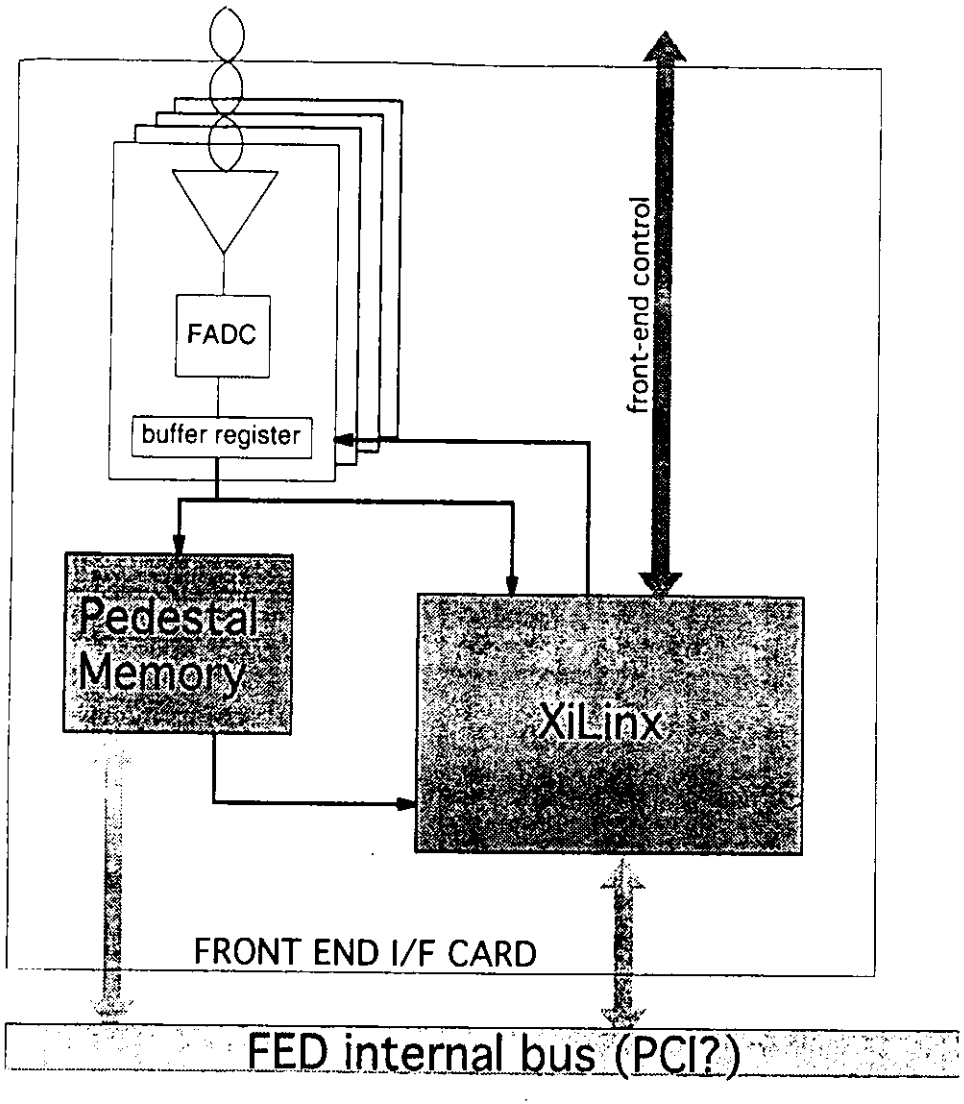
X -7-

Read-out Module Architecture II



H. Leich

X -8-

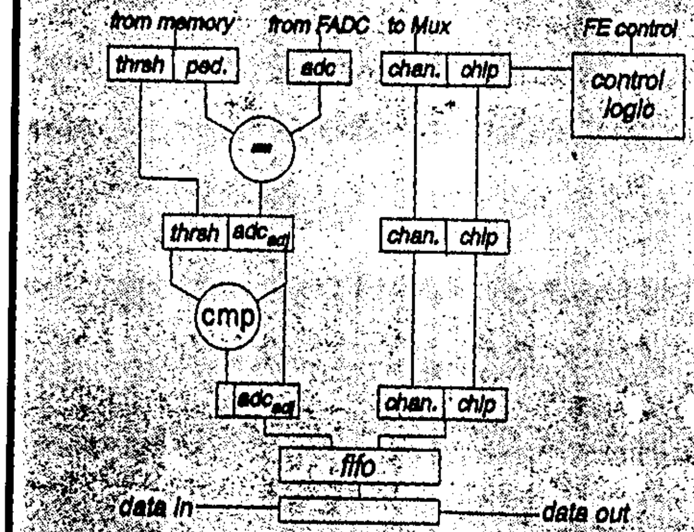


X -9-

XiLinx Readout Controller

Detector specific control logic can be implemented using a Xilinx chip configured for pipelined computation with external digitizers and storage.

A sample XiLinx readout sequencer configuration for the SVD



HERA-B DAQ

Readout Control Module

Functions:

- Run Control
- Communications
- Calibration and Diagnostic Runs
- Initialization
  - Load run-time constants (pedestals, threshholds, t_0s)
  - Load programs in modules without O/S
- Data Monitoring
- Detector Monitoring

Hardware:

- General purpose RISC processor
- VME Master I/F
- Ethernet controller
- Implementation : CES RTPC8067

Software:

- Lynx-OS
- TCP-IP
- Communications / Run Control process
- Detector specific monitoring processes

HERA-B DAQ

Readout Record Builder / Fast Data Link

Functions:

- Initiate sparse data readout
- DPM buffer management
- Transfer requested events to Event Builder

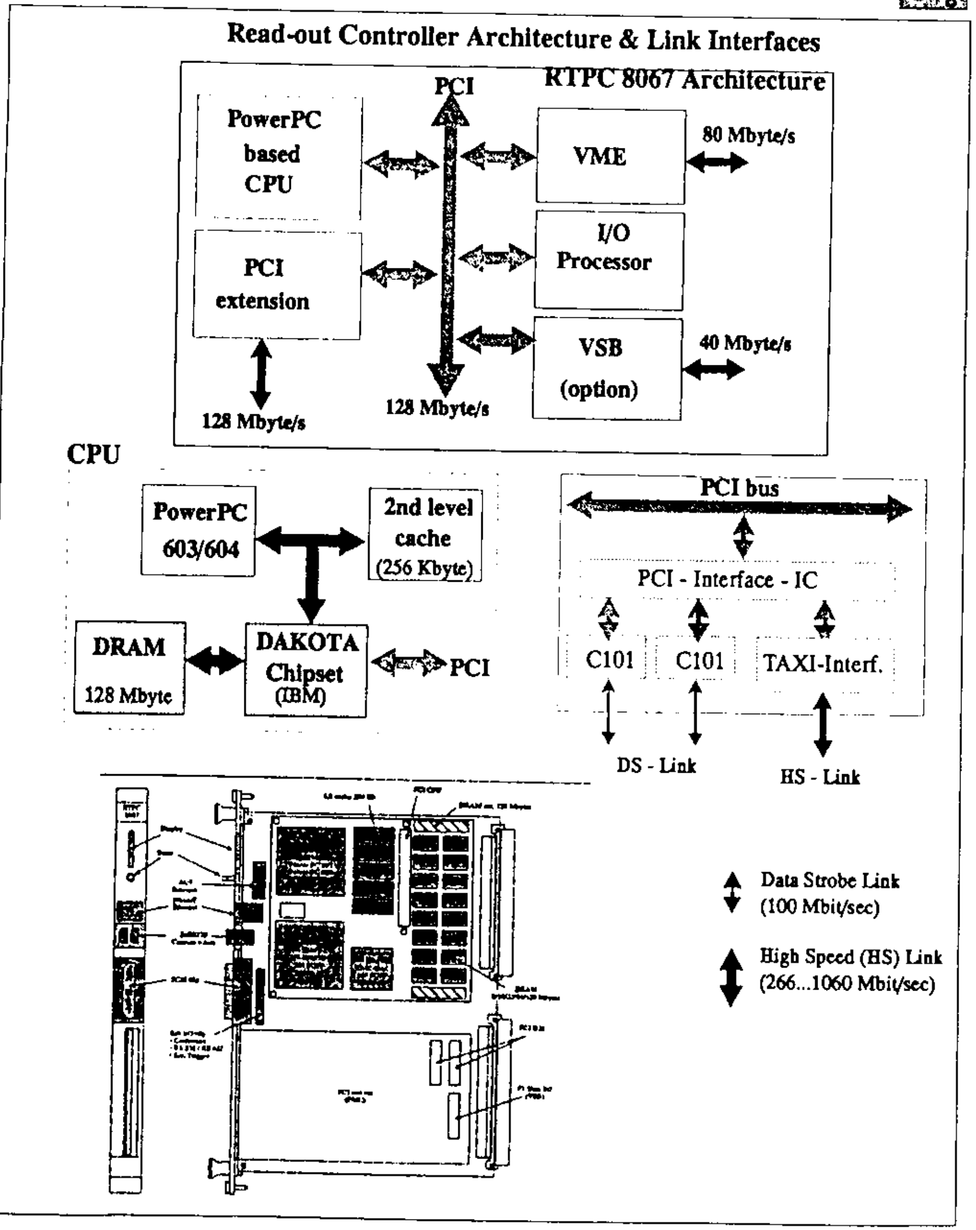
Hardware:

- Readout control processor
- VME Master I/F
- Dual Port (or shared) Memory (> 8Mby)
- Data Link control processor
- Data Link I/F
- Implementation: CES RTPC8067 + Purpose built data link, or CES FDL8050.

Software:

- Interrupt driven, stand-alone programs (no O/S)
- Interrupt driven readout process
- Data link process

HERA-B DAQ



H. Leich, U. Gensch, P. Wegner

X -13-

Distribution of Trigger and Timing Signals

A Trigger & Timing Bus (TBus) must be defined to

- Distribute Bx, FLT, and control signals from trigger controller to readout crates.
- Have synchronous architecture, simple interface.
- SLT distribution?

A Trigger & Timing Module in each crate will

- Distribute TBus signals to all FEDs
- Pass readout-busy signals to TBus/Trigger Controller
- Distribute SLT, initiate readout of events passing SLT?
- Generate fake FLT & SLT signals for diagnostic/calibration runs

HERA-B DAQ

X -14-

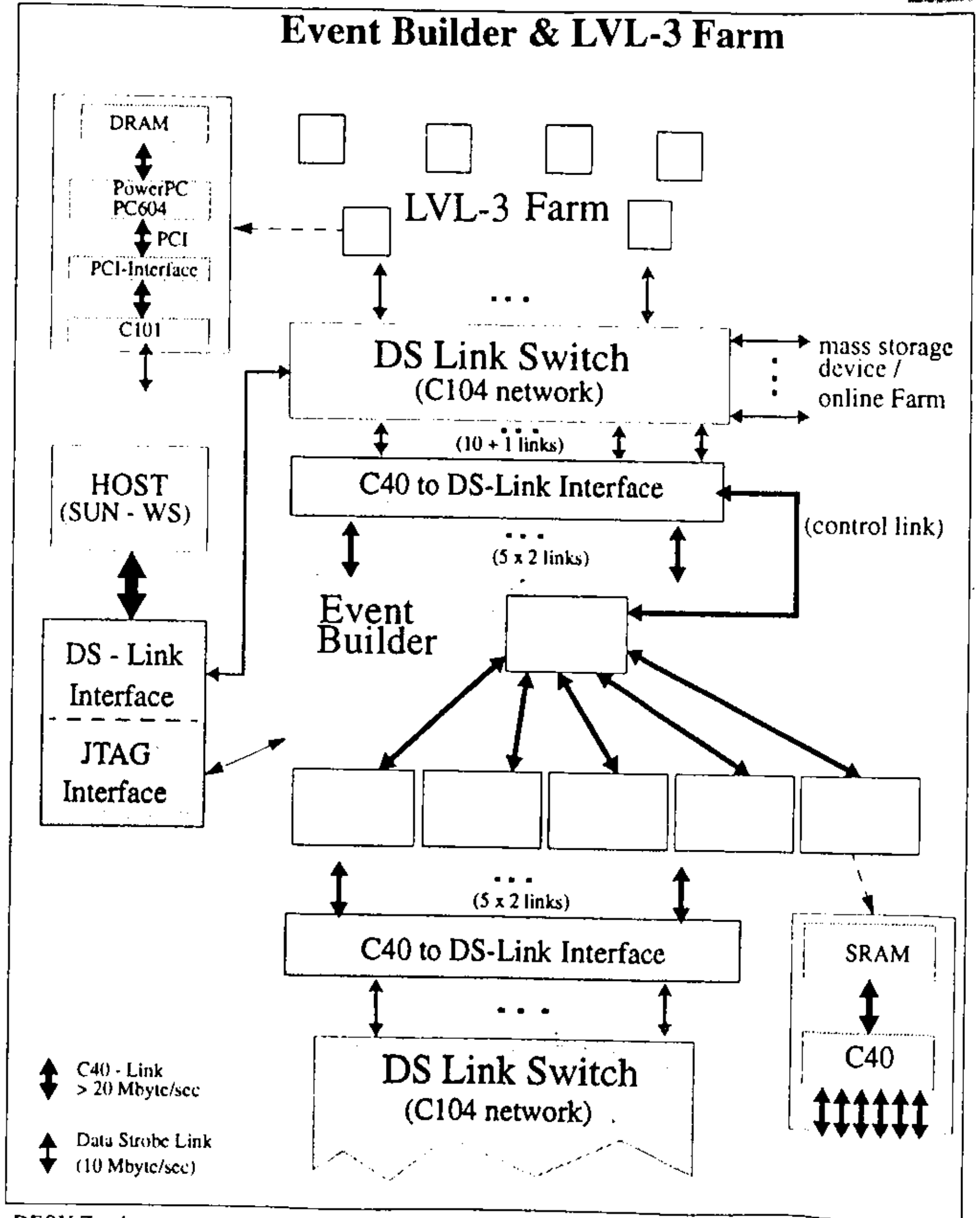
Event Builder

The event builder must

- Accept data from ~ 20 readout crates or strings of readout crates.
- Route all the data from a given event to one of several L3 farms.
- Data must arrive in the correct order.
- Combined throughput of >170 Mby/s.

HERA-B DAQ

X -15-



H. Leich, U. Gensch, P. Wegner

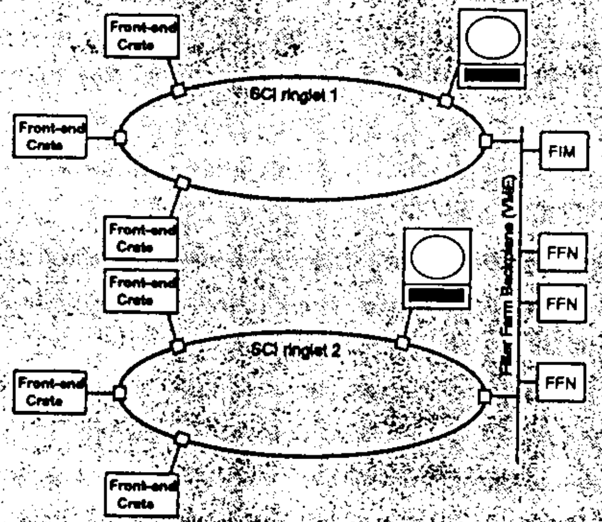
X -16-

Other Event Builder Architectures

Other event builder architectures may be available before the Hera-B system integration deadline. Promising architectures which are under development by CERN R&D projects are:

ATM: Asynchronous Transfer Mode will be used in telecommunicatons network applications. RD-31 is investgating the construction of a Data Driven Event builder from commercial ATM switches.

SCI (RD-24) is a high bandwidth data bus technology built from nodes organized in ringlets and connected by point-to-point links.



Other implementations of the ring structure are possible (e.g. FDL, VMETaxi).

HERA-B DAQ

DAQ Software

Architectural Considerations

- Distributed multi-process environment
- Control and communication by message passing (low bandwidth, global) or common storage areas (lots of data, within a crate).
- Uniform environment supplied by DAQ library.
- O/S not used in time-critical applications.

DAQ Library will contain packages for

- Interprocess communication (message passing)
- Process synchronization and control
- Buffer and Data management
- User Interface
- VME I/O
- File access

HERA-B DAQ

MIKE McDINNIS
UCLA

Level-2 Trigger

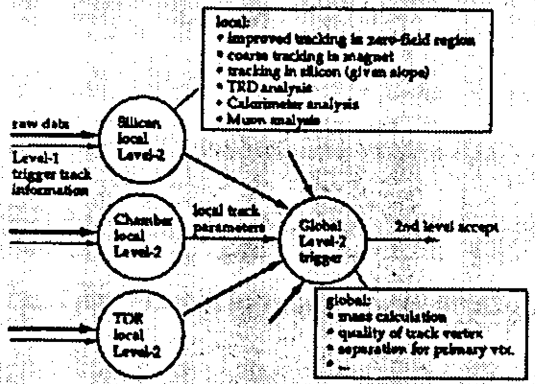
Goal: achieve a rejection factor of at least 25 by processing subsets of data from one or more detector types.

Peak input trigger rate: 50 kHz

Maximum latency ≈ 1 msec

Concept:

- Local processors produce partial trigger decisions based on data from individual detectors (e.g. silicon, tracking chambers etc.)
- Results from local processors are combined to form a global Level-2 trigger decision.

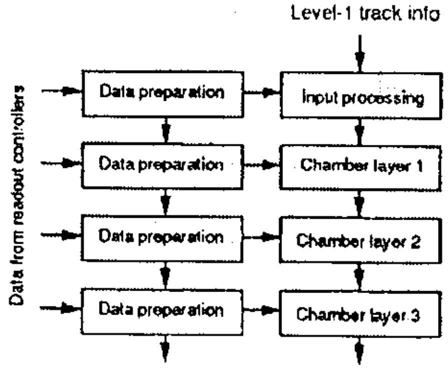


The set of detectors used by Level-2 could be as small as one, (the vertex detector) but the framework should allow input from most detectors.

HERA-B

Lepton track refit in trigger chambers:

Zeuthen Benchmark, of a Kalman filter using a DSP pipeline:



- use 40 MHz C40 DSPs for "chamber layers".
- full "offline" Kalman filter algorithm.
- hit conditioning not included (no "data preparation" module)

Result: 60 μsec per Kalman filter step.

- Using 80 MHz C40s (announced for 1995), six pipelines operating in parallel could keep up with the required rate.
- Further optimization may be possible.
- But suppression is not well-known, particularly when coupled with a silicon trigger.
- Decision to build awaits a full Level-2 simulation.

HERA-B

Track reconstruction in silicon

Suppression estimates from proposal:

Based on simple arguments (not a complete GEANT simulation):

1. factor of 3 from matching Level-1 leptons to silicon tracks by comparing slopes.
2. factor of 4 from requiring a common vertex of tracks matching the two Level-1 leptons.
3. factor of 8 from requiring the lepton vertex to be away from wires with weak vertex cuts.

$\Longrightarrow$ Most or all the minimum suppression ($\times 25$) can be obtained with the silicon detector. Given uncertainty in the numbers, it may even be possible to obtain the required suppression using only cuts 1 and 2, and defer the finite decay path cut to Level-3.

But these numbers must still be verified by GEANT simulation. A Level-2 simulation effort is underway by the UCLA group, using the Zeuthen Monte Carlo. The Zeuthen group will start work in this area as well.

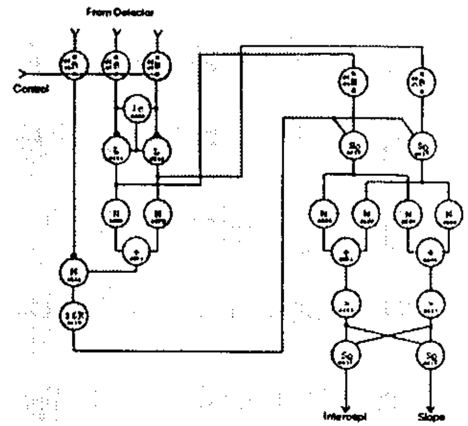
More reliable numbers also require a sample of Level-1 triggered events, for each trigger type.

$\Longrightarrow$ Treating the silicon detector is the highest priority item for the Level-2 group.

HERA-B

An implementation using the Nevis Processor

Full track reconstruction using a "traditional" Nevis processor approach, as discussed in the proposal.



- Find all tracks in silicon detector (road width criterion only)
- Identify lepton tracks using L1 information
- Find lepton vertex

All tracks in the silicon would then be available for processing at Level-3.

Appears do-able but module & cable count is very high (> 1000)

Better approach: Exploit the region-of-interest information from Level-1. Look specifically for the lepton tracks. Such a Nevis based approach is under study at UMass as a backup solution.

HERA-B

Other Techniques

Track Finding Algorithms:

- Kalman filter à la Level-1
- Histogramming techniques:
  - Hough transform: extensively studied by RD-11 for an LHC TRD trigger.
  - Fourier transform: use to isolate tracks with slopes matching Level-1 leptons, follow with a track fitter.
- 2-d Image processing techniques such as used in the Contiguity processor of WA-92 (BEATRICE)

Available Technologies:

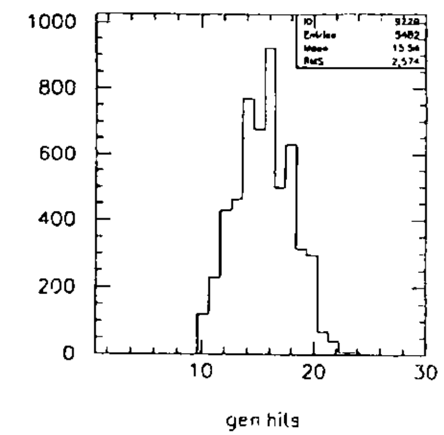
- DSPs
- RISCs
- commercial image processors, e.g. Datawave
- Logic Cell Arrays (LCA) e.g. Xilinx (DecPerle, Enable)
- Libraries of specialized modules e.g. Nevis, MAXVIDEO

The BEST solution is not yet known. One possibility which may do the whole job or function as a piece of the processor is a Kalman filter algorithm operating on a pipelined array of TMS32C40 DSPs.

HERA-B

Implications of Number of views and Stereo Angle

Number of Hits on Tracks (all views), baseline detector (M.Spahn)



Baseline design: 4 views, 45° stereo angle (x, y, u, v)

⟹ An average of 16 hits (4 per view) and as few as 10 (e.g. $3x, 3y, 2u, 2v$).

- Even moderate (order 5%) inefficiency in the silicon detectors will result in significant track finding losses.

⟹ Probably forced to track finding in 3-dimensions, leading to a 4-dimensional parameter space (2 slopes, 2 intercepts).

HERA-B

Implications of Number of views and Stereo Angle II

Small angle stereo design (Hartwig Albrecht): 4 views $\approx 1^\circ$ stereo angle (x, x', y, y')

- May be possible to find tracks separately in x, x' views and y, y' views. (e.g. Using Level-1 estimate for slope in the orthogonal view: $\sigma \approx 1cm \cdot .02 = 200\mu$m)
- A Kalman filter algorithm in 2-views is probably a workable solution.
- Might also allow application of methods which make use of histogramming or associative memory. Although, a track-fitting step is probably needed after track-finding to obtain acceptable vertex resolution.

Two orthogonal views with pads for matching (M. Medinnis):

- For same number of hits, the number of hits per view is doubled.
- The 4-d parameter space separates into two 2-dimensional spaces. This would allow application of methods using histogramming or associative memory. (In principle no refit needed...practice may be different.)

HERA-B

Kalman Filter in a C40 Pipe?

Advantages:

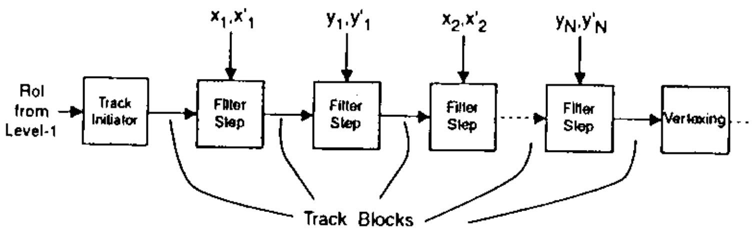
- Lends itself to pipelining, which simplifies data distribution.
- Capable of following tracks in a detector with stereo views (at least small angle stereo).
- The technique is well-known to the group (variants used for Level-1 and for offline analysis).
- Only a small amount of hardware needs to be designed and built in-house.
- The implementation of a Kalman filter at Level-2 has already been studied (for tracking in the chambers). $\Longrightarrow$ Resources and experience already exists.
- the C40 has been on the market for years: development systems exist, bugs worked out.

Constraints imposed by pipelined architecture:

- Total time per step $(t_{step}) < 20\ \mu$sec
- Must have less than 1 msec / $t_{step} \approx 50$ steps
- High reliability is required. (If an element of a 50 unit farm fails, the total processing power is decreased by 2% whereas if an element of a pipeline fails, processing stops.)

HERA-B

Kalman Filter Processor

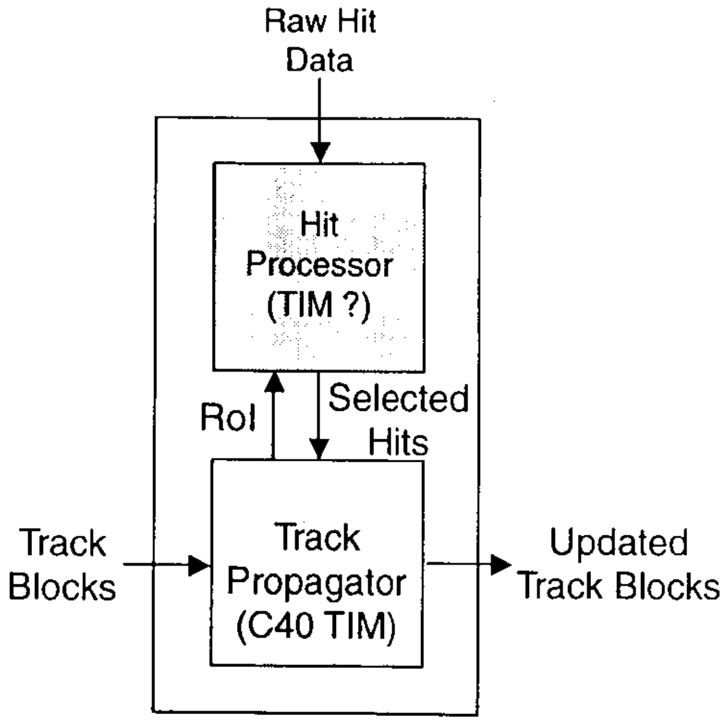


In this scheme, the number of filter steps = number of detector planes $\times\ 2 \approx 30$. Some adjustment of this is possible: e.g. it may be possible to handle more than one plane/view in a single processor for planes located far from the detector and closer in, to divide the x and x' into separate filter steps.

Assuming H. Leich's number of 600 MBytes / sec total data rate from the detector, the rate per x, x' plane $\approx$ 18 MBytes / sec. This could be reduced if clustering is performed before transmission to Level-2. (HS link bandwidth in the range 25 – 41 MByte / sec.)

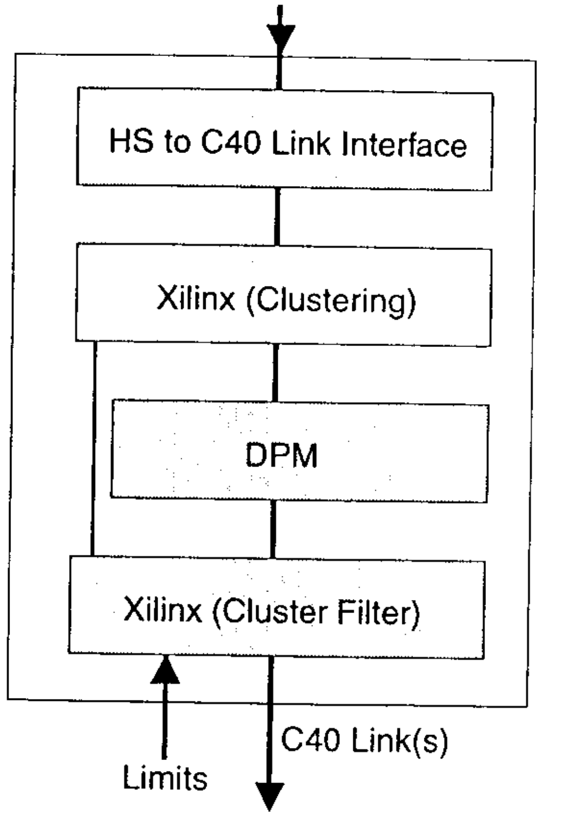
HERA-B

Filter Step



HERA-B

Hit Processor



HERA-B

Silicon Track-Finding Kalman Filter approach

Is Level-1 like algorithm feasible?

Paramatrize tracks as:

$$\begin{aligned} x &= d_x + s_x \cdot z \\ y &= d_y + s_y \cdot z \end{aligned}$$

The χ^2 at the $k+1$th iteration:

$$\chi^2_{k+1} = \chi^2_k + \frac{[(d_{x(k)} + s_{x(k)} \cdot z_{k+1})\cos(\theta_{k+1}) + (d_{y(k)} + s_{y(k)} \cdot z_{k+1})\sin(\theta_{k+1}) - m_{k+1}]^2}{\sigma^2_{k+1}}$$

m_k is the measured hit coordinate in the kth plane. θ_k is the rotation angle into the measurement direction of plane k.

- Minimizing leads to a 4×4 matrix.
- Since matrix inversion is an N^3 problem, factoring into two 2×2 matrices would save a factor of ≈ 4 in operation count.

HERA-B

The small angle detector variant

Going to either a small stereo angle detector as proposed by Hartwig Albrecht or x- and y-view only supplemented with pads for track matching would allow decomposition into two 2×2 matrices.

For the small angle stereo variant, one could (for example) use the result of the previous iteration in the orthogonal view to estimate position in the current iteration:

$$x_{k+1} = m_{k+1} + (d_y(k) + s_y(k) \cdot z_{k+1}) \cdot \theta_{k+1}$$

for x-view measurements and

$$y_{k+1} = m_{k+1} + (d_x(k) + s_x(k) \cdot z_{k+1}) \cdot (\pi/2 - \theta_{k+1})$$

for y-view measurements.

(Alternatively, use the Level-1 slope to estimate track slope in orthogonal view $\Longrightarrow$ poorer resolution but complete decoupling of x- and y-view filters. This would alleviate combinatoric problems but force a track refit.)

HERA-B

Operations Count

Minimizing gives a pair of 2×2 matrices. For the x-view:

$$\begin{pmatrix} s_x(k) \\ d_x(k) \end{pmatrix} = \frac{1}{S_x(k) \cdot S_x^{z^2}(k) - (S_x^z(k))^2} \begin{pmatrix} S_x^{z^2}(k) & -S_x^z(k) \\ -S_x^z(k) & S_x(k) \end{pmatrix} \begin{pmatrix} R_x^x(k) \\ R_x^{xz}(k) \end{pmatrix}$$

where

$$S_x(k) = \sum_{i=1}^k \frac{1}{\sigma_i^2} \quad S_x^z = \sum_{i=1}^k \frac{z_i}{\sigma_i^2} \quad S_x^{z^2} = \sum_{i=1}^k \frac{z_i^2}{\sigma_i^2}$$

$$R_x^x(k) = \sum_{i=1}^k \frac{x_i}{\sigma_i^2} \quad R_x^{xz} = \sum_{i=1}^k \frac{x_i \cdot z_i}{\sigma_i^2}$$

operation	×	+	÷
small angle correction	2	2	
road calculation	1	3	
hit retrieval			
sum update	2	5	
$s_x(k)$, $d_x(k)$ calculation	7	3	1
χ^2 calculation	3	2	
Total	15	15	1

HERA-B

Execution Time on a C40 DSP

For purely serial operation:

30 multiplies & adds $\Longrightarrow$ 30 instructions

1 divide $\Longrightarrow \approx 5$ instructions

With an 80 MHz clock, the instruction execution time is 25 nsec $\Longrightarrow$ 875 nsec to perform mathematics for one predict/filter step.

The C40 is capable of executing some instructions in parallel (e.g. one addition and one multiplication) $\Longrightarrow$ with careful coding, the real calculation time of these 35 instructions will be substantially less.

To this must be added overhead from:

- register $\longleftrightarrow$ memory transfers
- input/output operations (DMA available)
- synchronization with other processors
- other code needed for control and decisions to keep or discard tracks

(Hit searching is done in parallel in a separate processor.)

A full evaluation is not yet available but it seems likely that a single Kalman Filter step for one track can be performed in order 1 - 2 μsec.

HERA-B

Track candidates per event

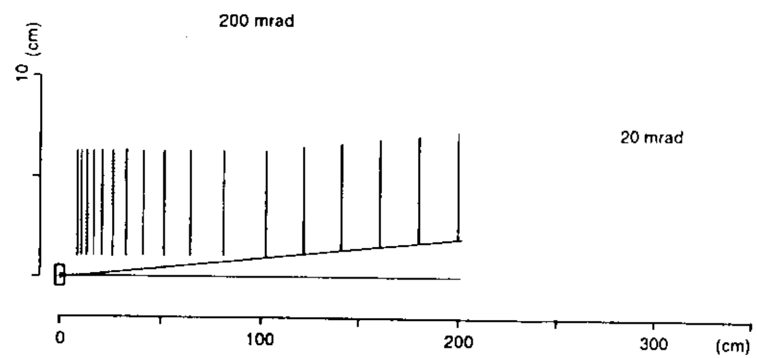
Almost always one and only one lepton-pair per event.

Per lepton candidate, the number of track initiators is the number of hits in the initial Region of Interest.

Tracks enter and exit the vertex detector on different planes depending on slope and intercept:

The RoI is determined by the point given by Level-1 and the target dimensions (1 cm × 5 cm) with an additional 5 cm added in z to allow for decay of the B.

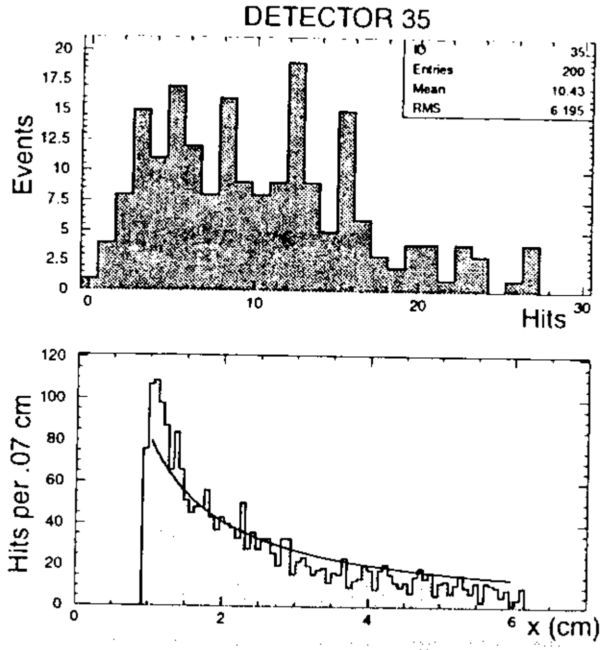
Regions of Interest



$\Longrightarrow$ the size of the Region of Interest depends on angle.

HERA-B

Detector Cluster Distribution



Generated using the HERA-B GEANT simulation.

The number of (minimum bias) interactions is Poisson-distributed with a mean of 5.

No noise is included.

HERA-B

plane	z (cm)	200 mrad		100 mrad		20 mrad	
		road width (mm)	num. hits	road width (mm)	num. hits	road width (mm)	num. hits
1	8.0	15.7	5.7	5.3	2.6		
2	10.0	19.6	6.6	7.2	3.3		
3	12.7	25.0	7.6	9.9	4.2		
4	15.9	29.0	7.4	13.0	5.1		
5	20.0	28.6	5.3	17.0	6.1		
6	25.2	28.2	3.9	18.8	5.3	0.1	0.1
7	31.7	17.2	2.0	18.4	4.0	1.3	0.7
8	39.9	0.3		17.9	3.0	2.8	1.5
9	50.2			17.3	2.2	4.7	2.4
10	63.2			9.3	1.0	7.1	3.3
11	79.5					9.4	3.8
12	100.0					8.6	2.7
13	119.0					8.0	2.1
14	138.0					7.3	1.6
15	157.0					6.7	1.3
16	176.0					6.0	1.1
17	195.0					5.4	0.8

Road width and average number of hits for three trajectories in baseline detector. (Assumes $dN/dx \propto 1/x$ and $\langle N \rangle = 10$.)

HERA-B

Combinatorics

Short of a full Monte Carlo, the average number of combinations per plane, per event is difficult to predict.

Some observations:

- From the table, we expect between 1 (low angle) and 16 (high angle) initial 3-d track candidates, depending on angle. With an average near 5.
- For a given Level-1 candidate, the number of combinations can at first increase (to account for inefficiencies) but then decreases as the track is followed through the detector.
- The rate of change is unknown and depends on how the algorithm handles inefficiencies.

If the execution time per Kalman filter step is between 1 μsec and 2μsec, the average number of candidates per lepton track must be less than 5 to 10.

Combinatorics could be a problem.

HERA-B

Cost Guesstimates

Price per C40 TIM board	$\approx$ 5,000 DM
Price per hit processor (pure guess)	2,000 DM
Number of units	$\approx$ 30
Total	210,000 DM

Not included: cost of vertex processor, input stage, crates, power, cables.

HERA-B

Conclusions

The general framework of Level-2 remains as stated in the proposal.

The main component of Level-2 will be the silicon tracker, vertexer.

Simulation work using the HERA-B GEANT Monte Carlo on the Level-2 silicon trigger has begun. Results should soon be available.

A Level-2 Silicon Tracker based on a Kalman filter algorithm implemented on a pipeline of C40-based track propagators and Xilinx based hit-processors is under study.

- Such a solution probably requires either the small-angle stereo variant or the 2-view + pads variant of the microvertex detector.
- The time needed per Kalman filter step is (roughly) estimated to be of order 1μsec. A benchmark is needed.
- The combinatoric background may be a problem.

The performance estimates of the Kalman filter approach are encouraging but the approach is not yet proven to work. Other technologies and algorithms should be explored in parallel.

Fuller understanding of the implications for Level-2 of the vertex detector geometry and view structure is needed.

HERA-B

Third Level Trigger and ReconstructionFarm(s)

tasks

rates, bandwidths

tasks (L3/L4)
- trigger tasks, filter
- complete reconstruction, calibration
- consecutive selection procedure to obtain rejection power?

discussion of concepts

feasibility, performance, costs, scalability

hard- and software effort

software
- OS (?), standard compiler, debugger
- farm scheduler

L3, L4 - separated or combined?
- buy, wait for purely commercial solution
- do it yourself
- find coll. partner (software & hardware)
- avoid vendor dependence (define architecture)
- use "standard components" (HERA-B)

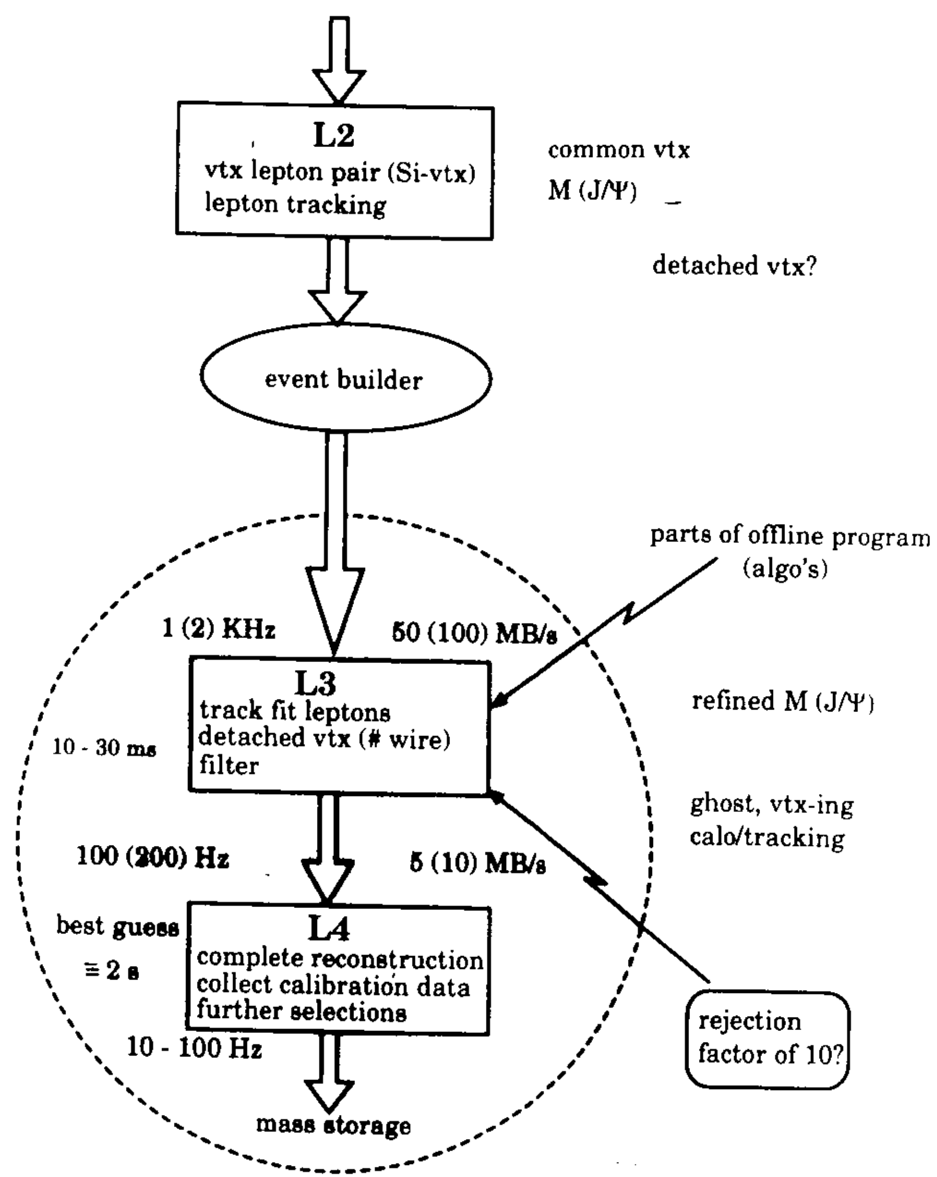
summary

in 95:
develop and test L3/L4 algo's, decide on concept
prototyping
perform benchmark tests

optimisation (speed) of the rec. program

Rates, Bandwidth — Tasks

40 MHz interaction rate
~ 600.000 channels
eventsize ~ 50 KB



discussion of concepts

any proposed solution
- should be considered only as "snapshot" demonstrating that it will be feasible to build L3/L4 farm(s) for HERA-B (in time)
- no anticipation of a technical realisation)

data driven architecture
DS,ATM (FDDI,futurebus,SCI,fibre channel...)

L3

trigger & filter tasks ---> O (10ms) ----> 30-50 proc. ?
C - code (O(100) lines)

VME-board with RISC-proc. (e.g. PowerPC 603/604...) ➔
(solution like H1)

several vendors

DS, Switch(128 ch, C104 network),PCI-DS(C101)
scheduling of the farm : C40/event builder ➔

advantages of dedicated L3 farm

hardware configuration according " HERA-B standard "
easy handling - further trigger algo's
- suprises (rates..)
- testing (no conflict with L4-softw & hardw)
reconstruction farm less demanding (input rate)

L4 (L3 & L4)

(biased) guess --> 2 s /event reconstruction time
increasing processing power (*5 up to 97/98 ?)
might be needed to fulfil the exp. constraints
assume, farm will consists of 100 proc.

1) commercial solution

SGI, SP2, SPP1000

(SGI, SP2, SP1000 ---> 50.000 DM/proc. incl. infrastructure)
> 5 MDM !

advantages : standard software, tools to schedule the "farm"

(interface with L3 ?)

2) WS-cluster

simple solution ? ➔

low cost WS (10.000 DM ?)
UNIX, scheduling with PVM/MPI
without L3 more complicated

3) "farm II"

(GMD project)

fast link 50 MB/s
OS - UNIX-compatible (PEACE)
ftn, debugger
PVM adapted

- such approach has been already realised (architecture,software)
but using intel´s i860 instead of the PowerPC-proc.)
- announced : board with 2*powerPC spring 95

should we follow this line ?

4) "farm III"

PARSYTEC (MSC)
L3 & L4 possible
fast link ~ 100 MB/s
OS - PARIX ("UNIX"), μ kernel on nodes, PVM
boards with 604 exists, 620 will come (?)
mid of 95 : testsystem available (?)

5) "farm IV"

similar to L3 architecture
boards : CES, Motorola, IBM
DS - link switch - available in 1/2 y --- 10.000 DM (?)
price per board ~ 10.000 DM (?)

software : ftn ---> cross system , compiler ?, libraries (CERN)
C ---> LynxOS

farm project at CERN :

similar boards
similar problems
should watch it (and collaborate)

summary

(see first page)

It seems feasible to build a farm (ready in 98) using components available already now. The technological progress (processing power vs price) expected could be necessary to reach the performance needed to run HERA-B.
It should be possible to assemble a dedicated farm consisting of ~100 processors (powerpc ...) for about .... MDM .
(warning : it is easy to underestimate the manpower needed for the software development - farm, reconstruction -...!)

---

separation L3 from L4 favoured
trigger group : software, algo´s
simulation

commercial solution (L4) : wait and collect money (???)
WS-cluster : still time
but start with interfaces, switches ...(for DAQ anyway)
bench marking in 95

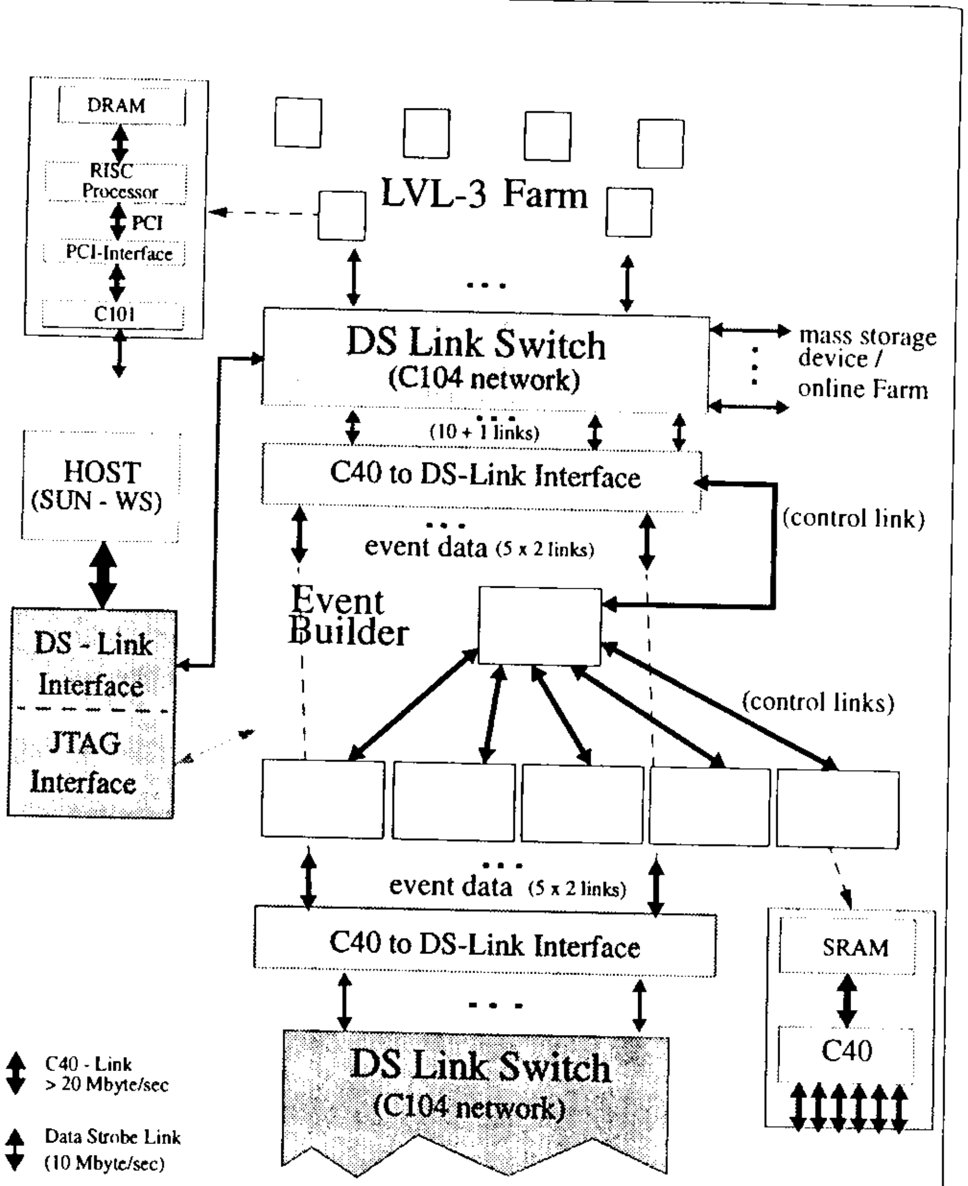
any other solution : get a test system, start with bench marking as soon as possible

software
trigger algo´s
large effort to get reconstruction fast
L3+L4 - will save hardware components, but
add. will cause other problems
adapting CERN software on "home made comp."

HERA-B: Online-Farm: Processor Overview

Proc. chip/ Manufact.	# of chips	Clock rate, MHz	SPEC int92	SPEC fp92	Power, W	Data bus width, bits
Alpha 21064/ DEC	1	200	130	195	30	64
Alpha 21164/ DEC	1	300	330	500	?	64
Pentium/ INTEL	1	100	100	81	16 ?	32
PA7100/ HP	?	90	98	170	23	32
SuperSparc UltraSparc	1 1	60 140...200	80 200...350	100 250...500	14	32 64
R4600/ MIPS	1	150	96	85	5	64
T5/ MIPS	1	?	295 ?	445 ?	?	64 ?
PowerPC 604 IBM, Motor.	1	100	160	165	13	32
PowerPC 620 IBM, Motor.	1					64
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Event Builder & LVL-3 Farm



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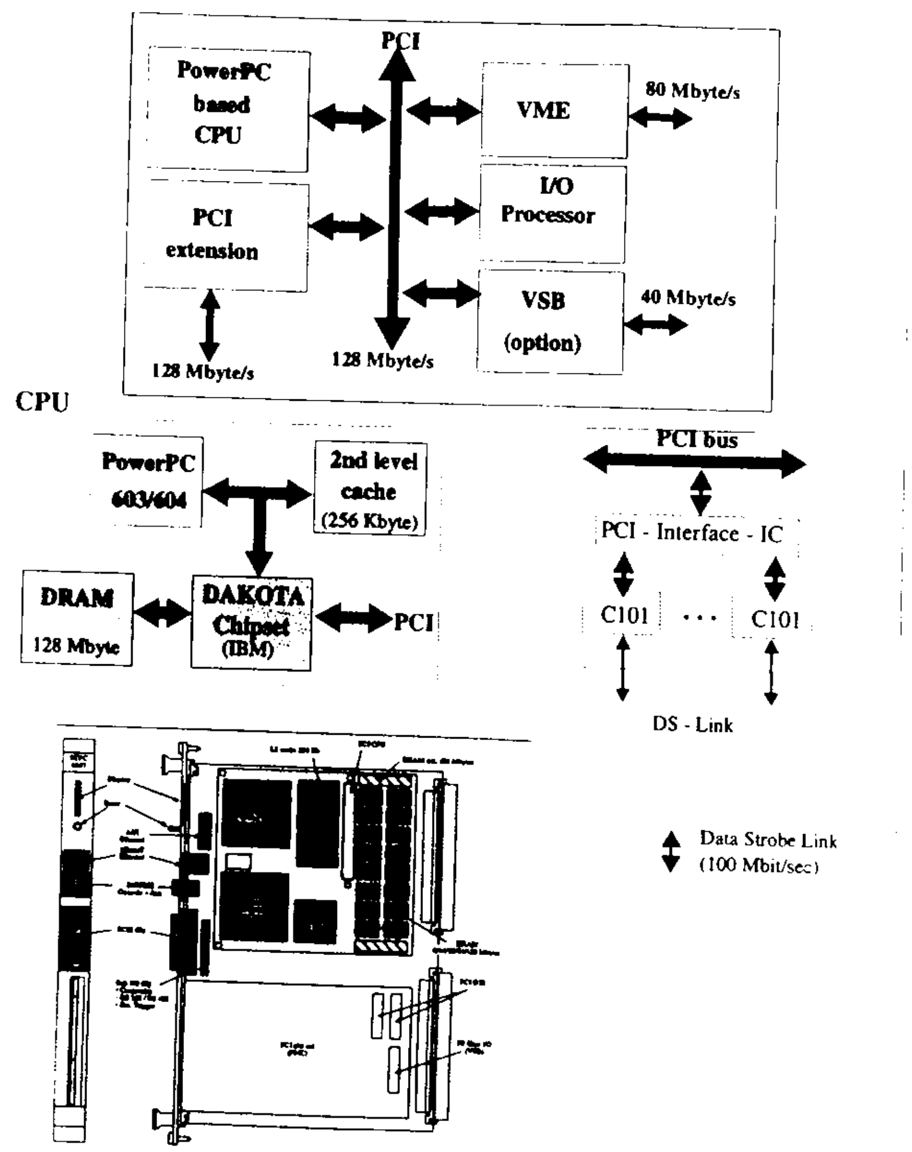
Z -9-

RTPC 8067 Architecture & Link Interfaces



DESY Zeuthen

H. Leich, U. Gensch, P. Wegner

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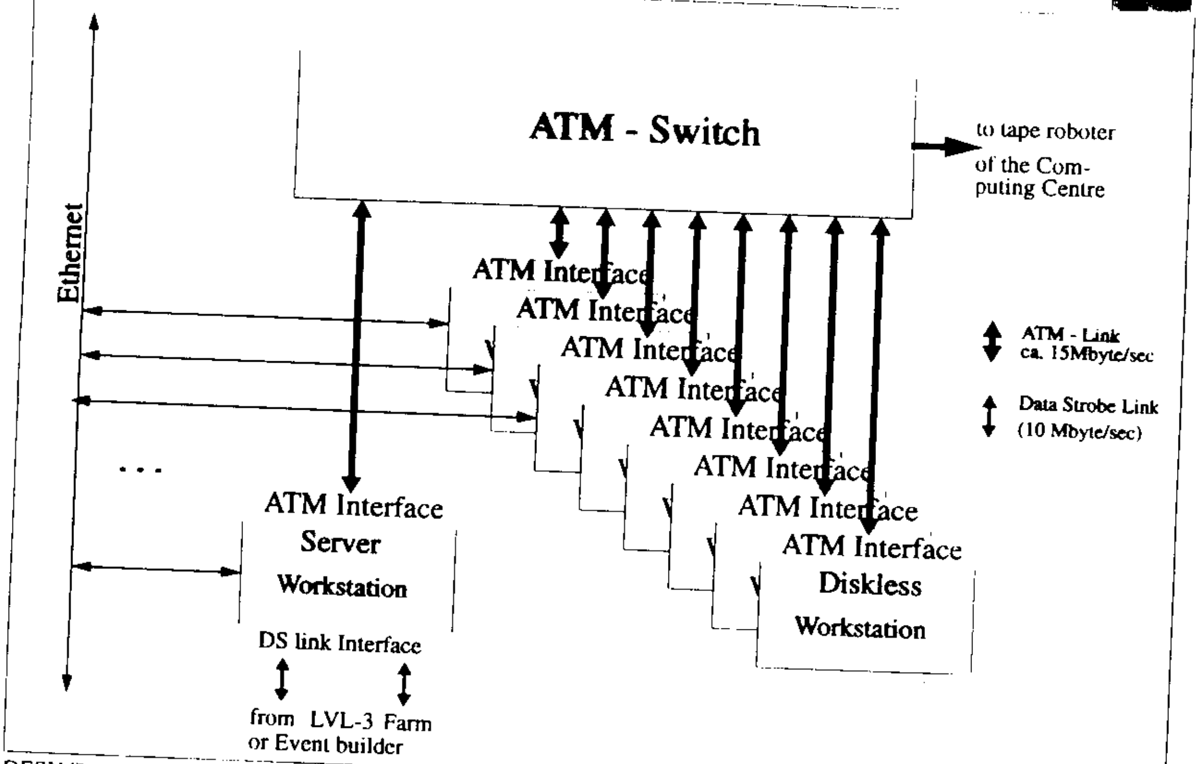
HERA-B: On-line Reconstruction Farm I

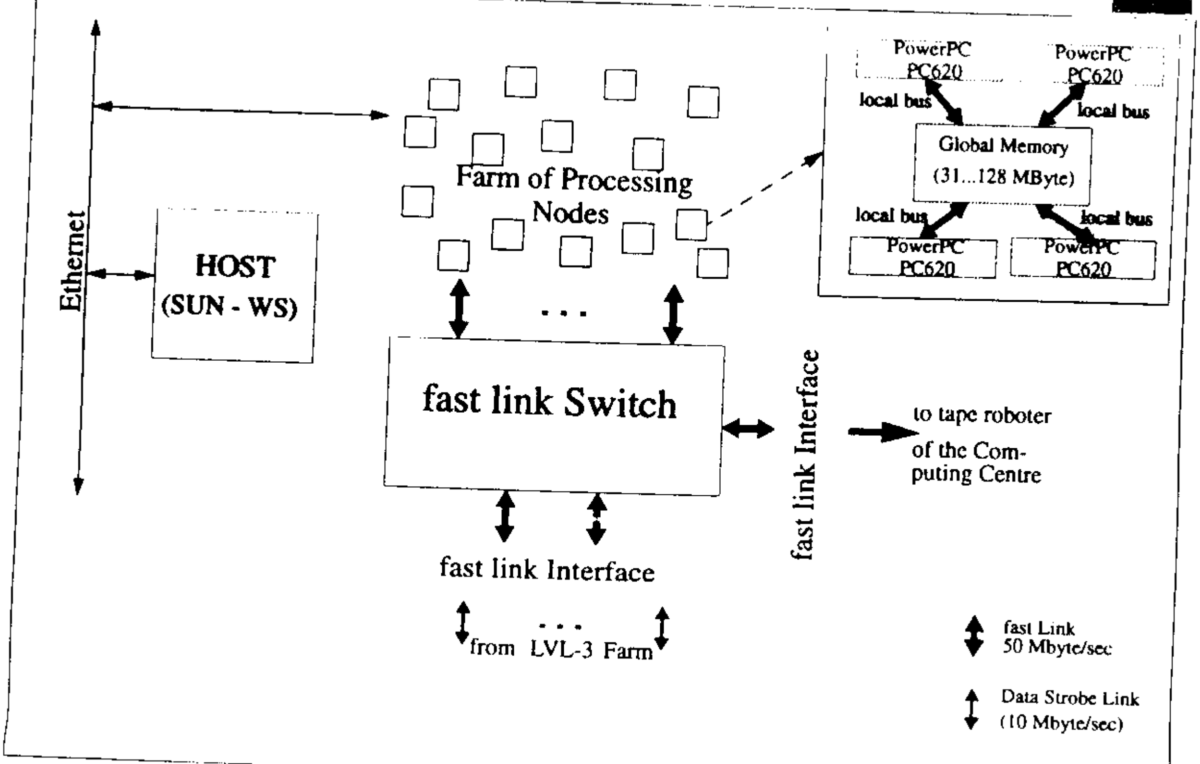


DESY Zeuthen

H. Leich, U. Gensch, P. Wegner

Z - 11 -

HERA-B: On-line Reconstruction Farm II

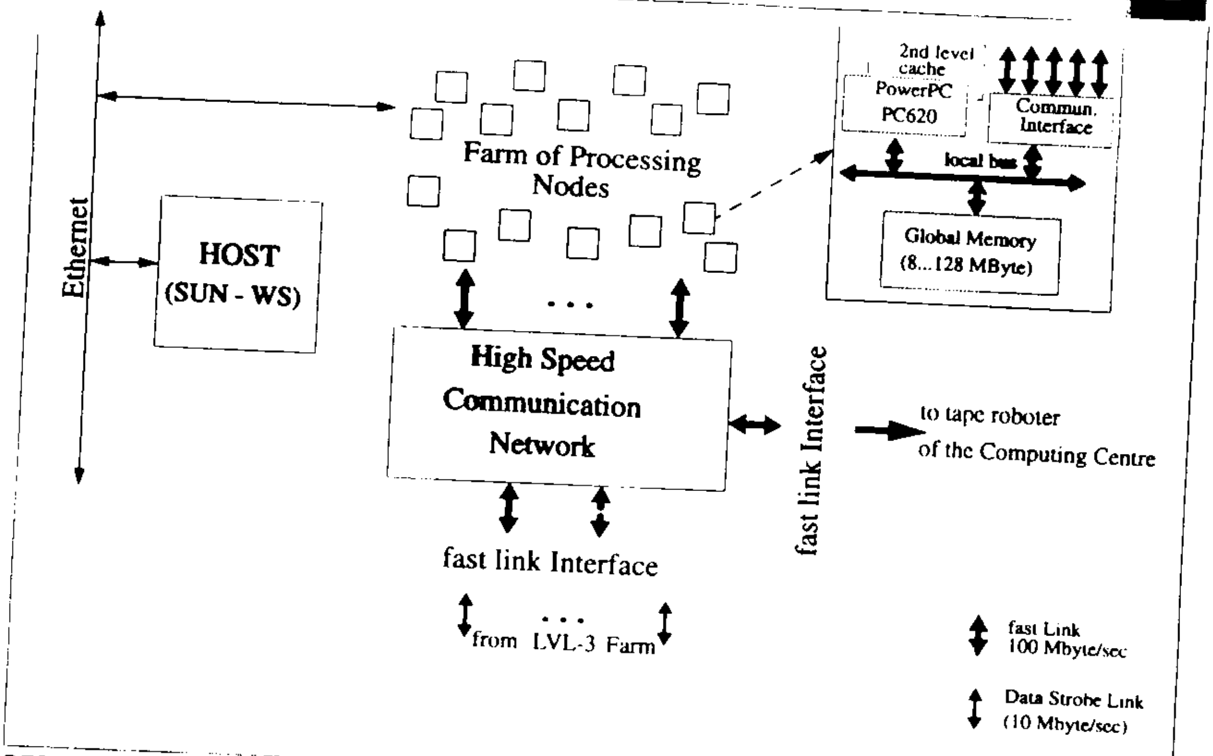


DESY Zeuthen

H. Leich, U. Gensch, P. Wegner

Z - 12 -

HERA-B: On-line Reconstruction Farm III

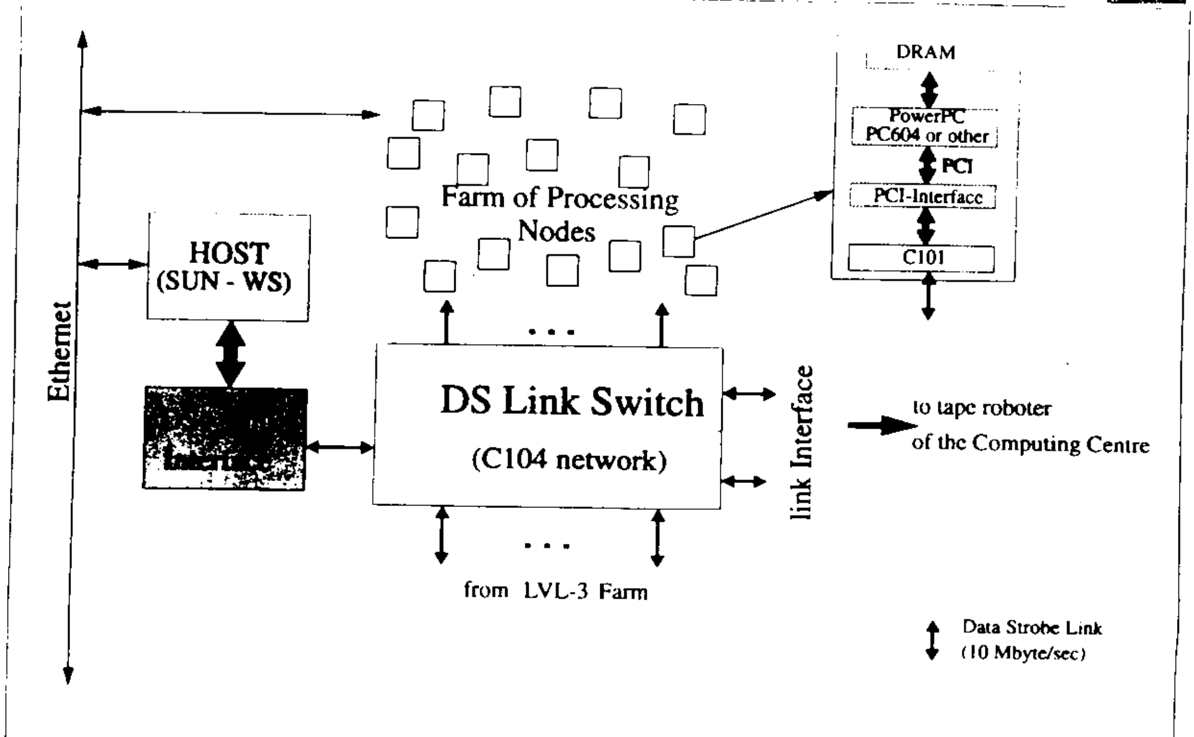


DESY Zeuthen

H. Leich, U. Gensch, P. Wegner

Z-13-

HERA-B: On-line Reconstruction Farm IV



DESY Zeuthen

H. Leich, U. Gensch, P. Wegner

Z-14-