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Illa da Toxa,
Pontevedra (Spain)

The HERA-B experiment

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Outline:

1. Brief history of HERA-B.
2. Physics Goals of HERA-B:
   CP violation in $\mathrm{B}^0 \to \mathrm{J}/\psi\,\mathrm{K}^0_\mathrm{S}$.
3. The HERA-B detector.
4. Actual status.
5. Results from 1996/1997 runs.
6. Summary and Conclusions.

A Brief History of HERA–B

October 92	Letter of Intent
March 93	Progress Report
May 94	Proposal
June 94	Conditional Approval
October 94	Open Collaboration meeting
January 95	Technical Design Report
February 95	Final Approval of HERA–B
April 96	HERA lattice modifications finished
1996/1997	Test runs in HERA proton beam
1998	Installation and commissioning of detectors
1999-2000	Physics measurements

$\boxed{\textbf{Objectives of HERA-B}}$

A) Observation of CP violation

- $\mathrm{B}^0 \longrightarrow \mathrm{J}/\psi K_s^0 \longrightarrow \ell^+\ell^-\pi^+\pi^-$
- $\mathrm{B}^0 \longrightarrow \pi^+\pi^-$
- Other channels ?

B) Observation of B_s^0 mixing

C) Test of experimental techniques for LHC

CKM matrix and $C\!\!\!/P$

Physical states (with defined mass) and weak eigenstates are not the same $\Longrightarrow$ quark mixing.

$$J_\mu^{cc} = \frac{e}{\sqrt{2}\sin\theta_w}(\bar{u},\bar{c},\bar{t})_L\gamma_\mu \mathbf{V}_{CKM}\begin{pmatrix} d \\ s \\ b \end{pmatrix}_L$$

$$\mathbf{V}_{\mathrm{CKM}} = \begin{pmatrix} \mathrm{V_{ud}} & \mathrm{V_{us}} & \mathrm{V_{ub}} \\ \mathrm{V_{cd}} & \mathrm{V_{cs}} & \mathrm{V_{cb}} \\ \mathrm{V_{td}} & \mathrm{V_{ts}} & \mathrm{V_{tb}} \end{pmatrix}$$

CKM Parameters: 3 angles, 1 Phase

$\rightarrow$ Wolfenstein Parametrization

$$\mathbf{V}_{\mathrm{CKM}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$(\lambda \approx \sin\theta_c = 0.22)$

$C\!\!\!/P$: $\quad \mathrm{Im(CKM)} \neq 0 \equiv \eta \neq 0$

Knowledge of the CKM parameters

Nuclear beta decay	$\Longrightarrow$	V_{ud}
Kaon/hyperon decays	$\Longrightarrow$	V_{us}
charm production from neutrions	$\Longrightarrow$	V_{cd}
D decays	$\Longrightarrow$	V_{cs}

$$\begin{array}{cc} \begin{pmatrix} 0.9744(10) & 0.2205(18) & V_{ub} \\ -0.204(17) & 1.01(18) & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \approx 1 \end{pmatrix} & \begin{array}{l} \text{B decays} \\ \\ \text{dominates t decays} \end{array} \end{array}$$

B mixing

Unitarity tests:

$$1 = \sum_i V_{ui} V_{ui}^* = 0.9980 \pm 0.0016$$

$$1 = \sum_i V_{ci} V_{ci}^* = 1.06 \pm 0.36$$

Unitarity Triangle

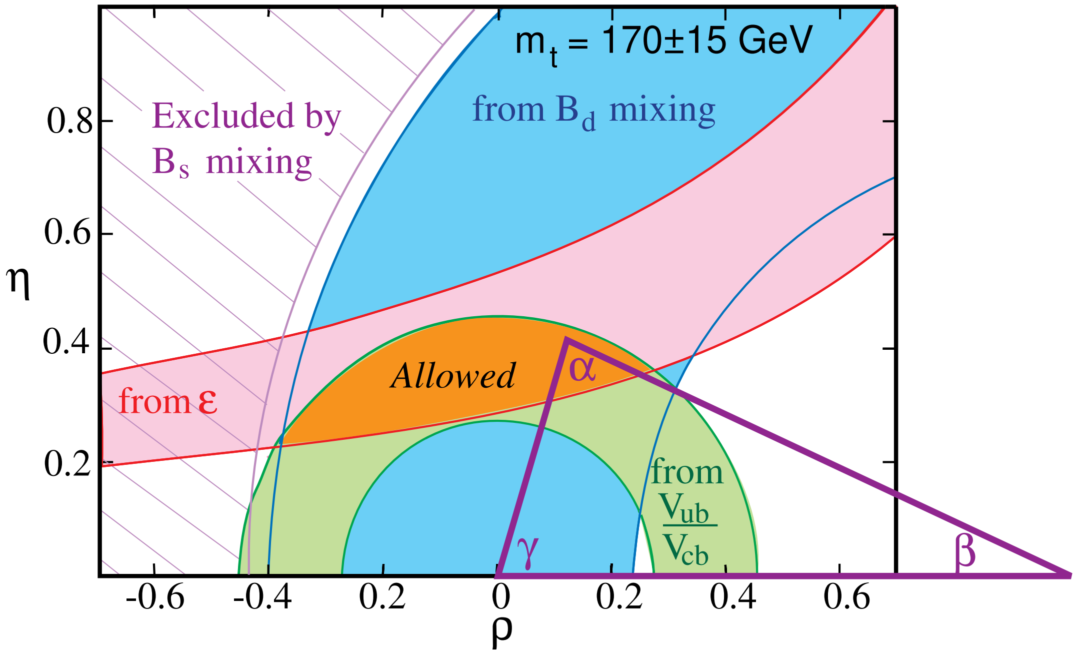
- One of the unitarity conditions $\Longrightarrow$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

Wolfenstein parametrization (neglecting $\mathcal{O}(\lambda^2\rho)$)

$$1 + (\rho - 1) - \rho + i(0 + \eta - \eta) = 0$$

$\Longrightarrow$ triangle in the (ρ, η) complex plane



- Constraints:

$$\mathrm{B\bar{B}-Oscillations} \quad \longrightarrow \frac{V_{td}}{|\lambda V_{cb}|} \sim \sqrt{(1-\rho)^2 + \eta^2}$$

$$\mathrm{B} \to \rho\ell\nu,\ \pi\ell\nu \quad \longrightarrow \frac{V_{ub}^*}{|\lambda V_{cb}|} \sim \sqrt{\rho^2 + \eta^2}$$

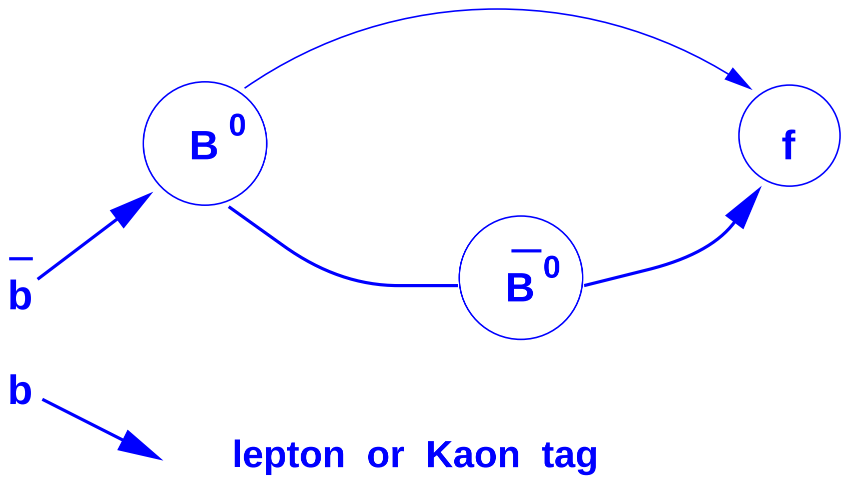
$$\mathrm{B} \to \mathrm{D}\ell\nu \quad \longrightarrow V_{cb}$$

$\not{C}\!\!\not{P}$ in K^0 $\longrightarrow \epsilon \longrightarrow$ tip of the triangle

OPAL ' 98 $\quad \sin 2\beta = 3.2^{+1.8}_{-2.0} \pm 0.5$

$\not{C}\not{P}$ in the B system

2 amplitudes for the process $B^0 \to f$:



The interference of both processes gives the information on the$\not{C}\not{P}$ phase:

$$A_f = \frac{\Gamma(B^0 \to f) - \Gamma(\bar{B}^0 \to f)}{\Gamma(B^0 \to f) + \Gamma(\bar{B}^0 \to f)} = \pm \sin(2\delta) \sin(xt)$$

$$x = \frac{\Delta m}{\Gamma} \text{ (Mixing parameter)}$$

$$\begin{aligned} \delta = \alpha: &\quad B^0 \to \pi\pi \\ \beta: &\quad B^0 \to J/\psi K_S^0 \\ \gamma: &\quad B^0 \to \rho K_S^0 \end{aligned}$$

Our Goal:
Measure CP Violation in B System

Quark Transitions in Standard Model:

$$\mathrm{CKM-Matrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

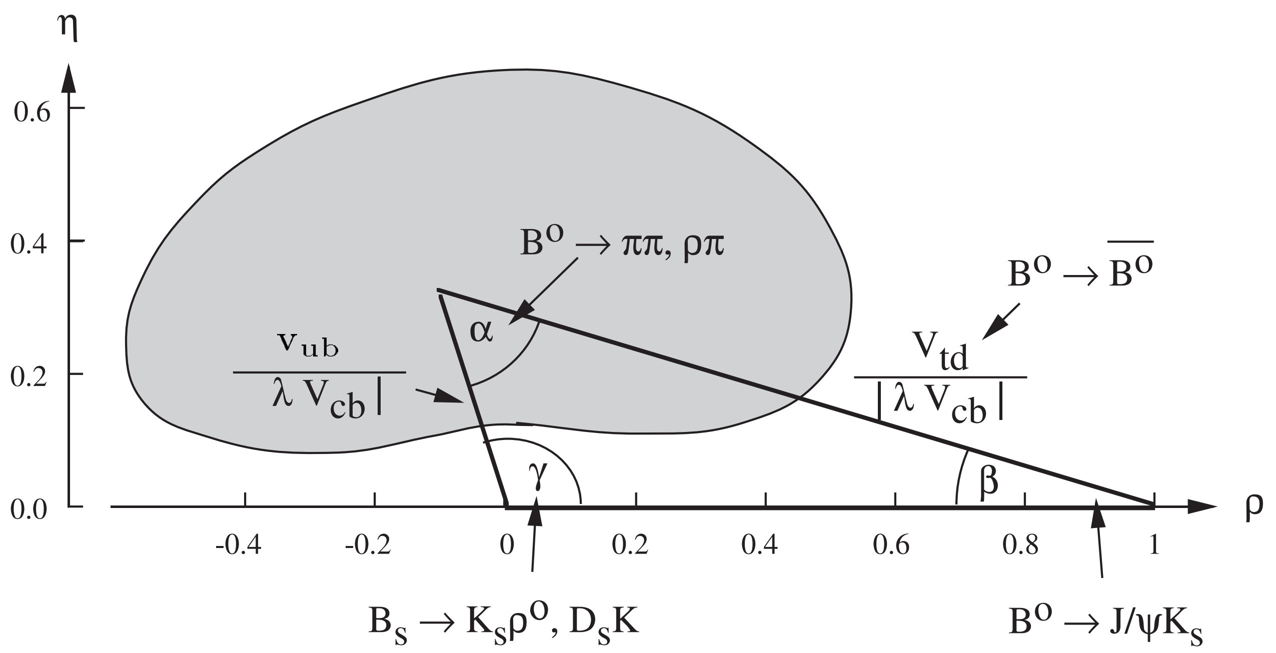
3 Mix. $\angle$

1 Phase

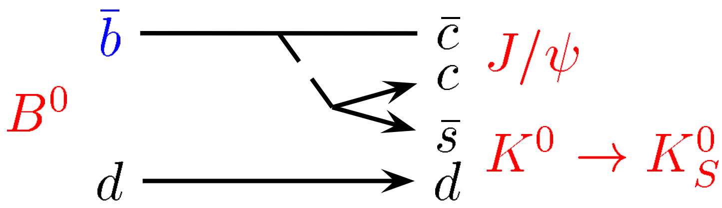
▷ unitarity: $V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$

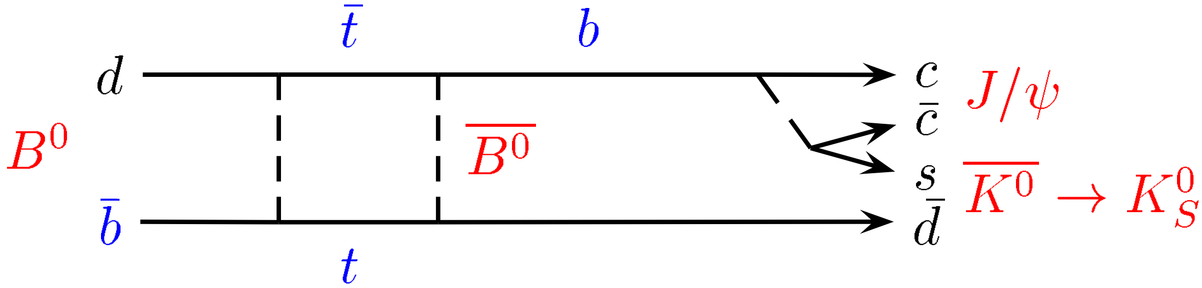
▷ $C\!\!\not{P}$: $\mathcal{I}(\mathrm{CKM}) \neq 0 \equiv \mathrm{Phase} \neq 0$

Wolfenstein Parameterization:



CP Violation in $\mathrm{B^0 \to J/\psi\, K^0_S}$





CP violation in the interference of
$\mathrm{B^0 \to J/\psi\, K^0_S}$ and $\mathrm{B^0 \to \overline{B^0} \to J/\psi\, K^0_S}$

Why looking at this system?

- only one dominating decay diagram
  $\Longrightarrow$ small hadronic amplitudes.
- small theoretical uncertainties.
- large CP asymmetry for $\mathrm{B^0 \to J/\psi\, K^0_S}$
- good trigger conditions.

Principle of Measurement

Pure B^0 beam: $n(t) \propto e^{-t}\,(1 + \sin 2\beta \;\sin xt)$

Pure $\overline{B^0}$ beam: $\bar{n}(t) \propto e^{-t}\,(1 - \sin 2\beta \;\sin xt)$

(mixing parameter $x = \Delta M/\Gamma \approx 0.67$)

$$\boxed{\text{Asymmetry} = C\not{P}}$$

$$a(t) = \frac{n(t) - \bar{n}(t)}{n(t) + \bar{n}(t)} = \sin 2\beta \;\sin xt$$

Time integrated asymmetry:

$$A_{int} = \frac{\int n(t)\,\mathrm{d}t - \int \bar{n}(t)\,\mathrm{d}t}{\int n(t)\,\mathrm{d}t + \int \bar{n}(t)\,\mathrm{d}t} = \sin 2\beta \;\frac{x}{1+x^2}$$

≈ 0.46

$$\boxed{\text{asymmetry proportional to } \sin 2\beta}$$

Experimental needs:

1. Count number of decays $B^0 \to J/\psi\, K^0_S$
2. Count number of decays $\overline{B^0} \to J/\psi\, K^0_S$

$\Longrightarrow$ Tag of the initial flavour (b or $\overline{\mathrm{b}}$) with the second B meson.

$\boxed{\textbf{Precision in } \sin 2\beta}$

Statistical error:

suppress background $\rightarrow$ require B vertex

($\equiv$ cut in proper decay time, $t > t_{cut}$)

$$A_{int}(t_{cut}) = \sin 2\beta \;\; M_{int}(t_{cut})$$

$$\text{with} \quad M_{int}(t_{cut}) = \frac{\sin xt_{cut} + x \;\; \cos xt_{cut}}{1 + x^2}$$

$$\boxed{\Delta \; \sin 2\beta = \frac{1}{M_{int}(t_{cut})} \cdot \frac{1}{\sqrt{N(t_{cut}) + \bar{N}(t_{cut})}}}$$

Mixing of the tagging B:

Probability of flavour change before tagging:

$$f_M = \frac{x^2}{2(1+x^2)}$$

$$n_{obs}(t) = n(t)(1 - f_M) + \bar{n}(t) f_M$$

$$\bar{n}_{obs}(t) = \bar{n}(t)(1 - f_M) + n(t) f_M$$

$$\boxed{A_{obs}(t_{cut}) = D_M \; M_{int}(t_{cut}) \;\; \sin 2\beta}$$

$$\text{with} \quad D_M = (1 - 2f_M) = \frac{1}{1+x^2} \approx 0.67$$

Precision in $\sin 2\beta$ contd.

Mistagging with a probability f_T:

Dilution factor $D_T = (1 - 2 f_T)$

$$\boxed{A_{obs}(t_{cut}) = D_T\, D_M\, M_{int}(t_{cut}) \sin 2\beta}$$

$\sin 2\beta \sim 0.5 \rightarrow A_{obs} \sim 0.15 - 0.2$

Total Error on $\sin 2\beta$:

$$\boxed{\Delta \sin 2\beta = \frac{1}{M_{int}(t_{cut})} \cdot \frac{1}{P} \cdot \frac{1}{\sqrt{N_{\mathrm{B}^0}}}}$$

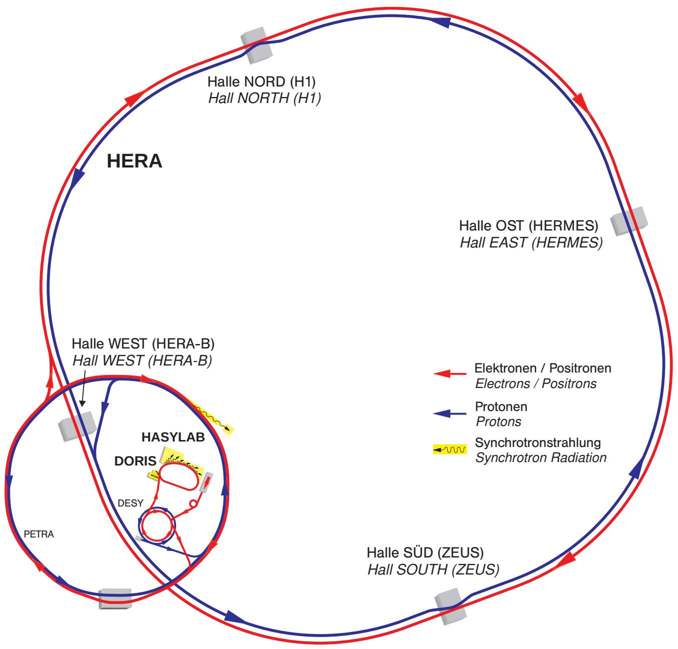
with tagging power $P = D_M D_T \sqrt{\epsilon_{tag}}$

N_{B^0} = Number of reconstructed B^0 mesons

$$\boxed{\Delta \sin 2\beta \approx 0.10 \Rightarrow N_{\mathrm{B}^0}\ \mathcal{O}(1500)}$$

The HERA machine

H1: $p \otimes e^-/e^+$



HERMES: $e \odot$ H,D polarized

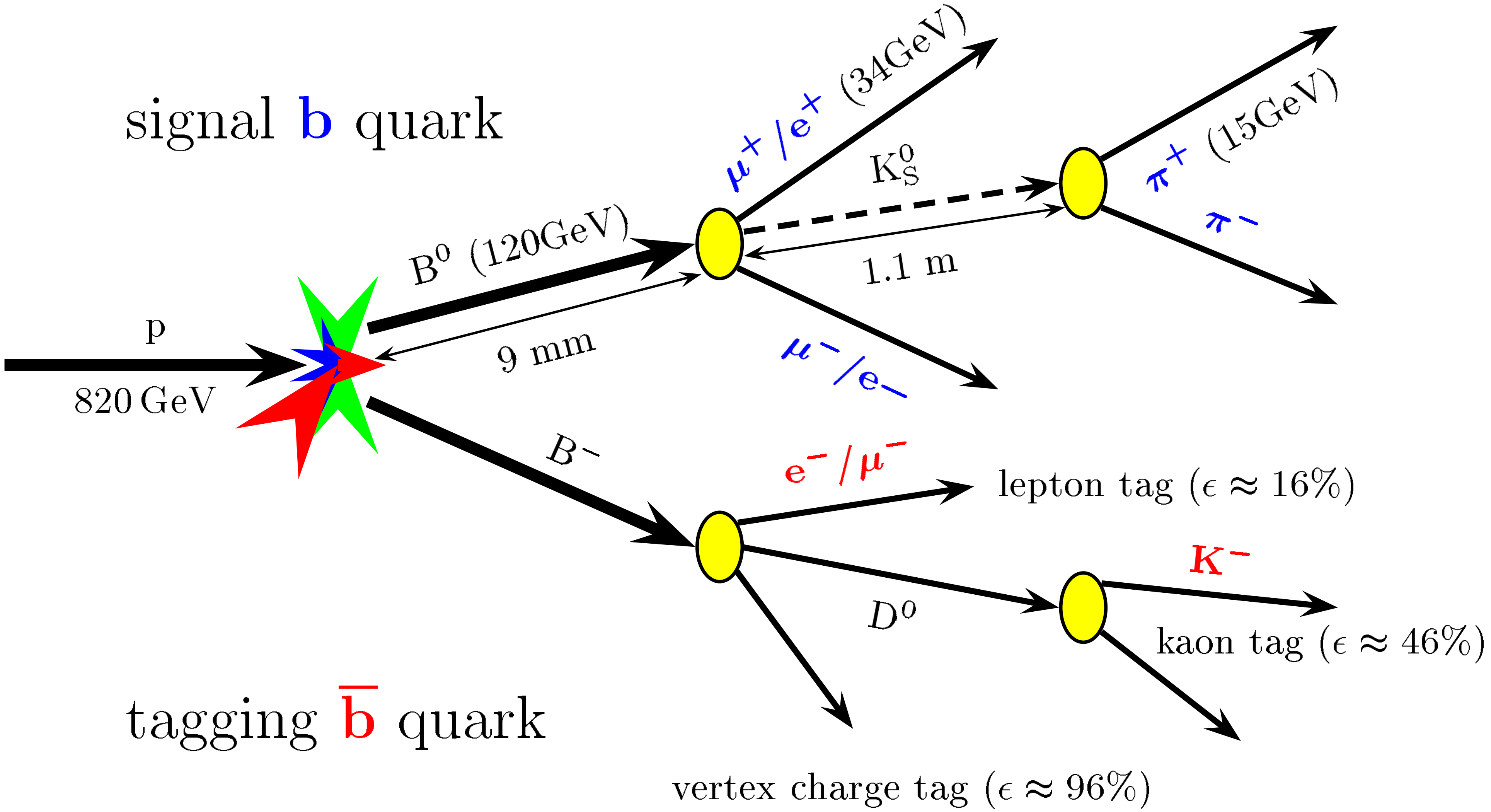
HERA-B: $p \odot Al/Cu$

ZEUS: $p \otimes e^-/e^+$

The HERA accelerator produces:

- A beam of protons at 820 GeV
- A beam of e^- or e^+ at 30 GeV

The golden decay: $B^0 \to J/\psi K_S^0$



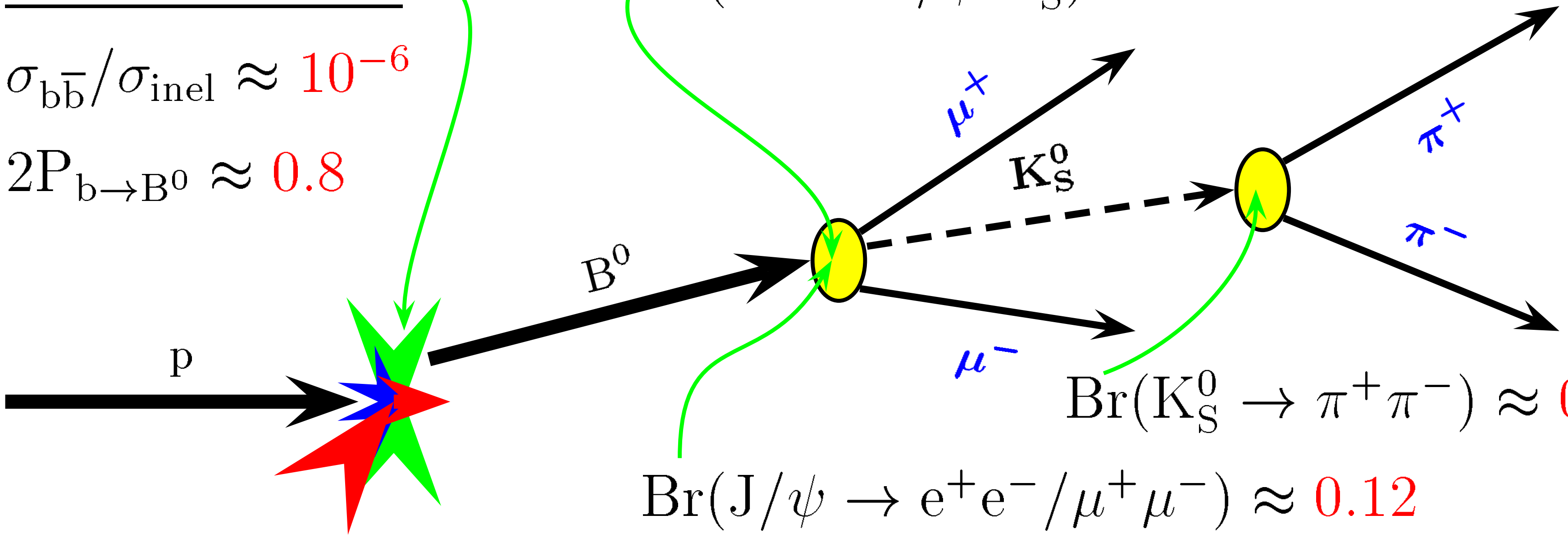
Production rate and efficiencies

<u>production rate</u>

$\sigma_{b\bar{b}}/\sigma_{\rm inel} \approx 10^{-6}$

$2P_{b\to B^0} \approx 0.8$

$\mathrm{Br}(B^0 \to J/\psi\, K^0_S) \approx 5\cdot 10^{-4}$



$\mathrm{Br}(K^0_S \to \pi^+\pi^-) \approx 0.69$

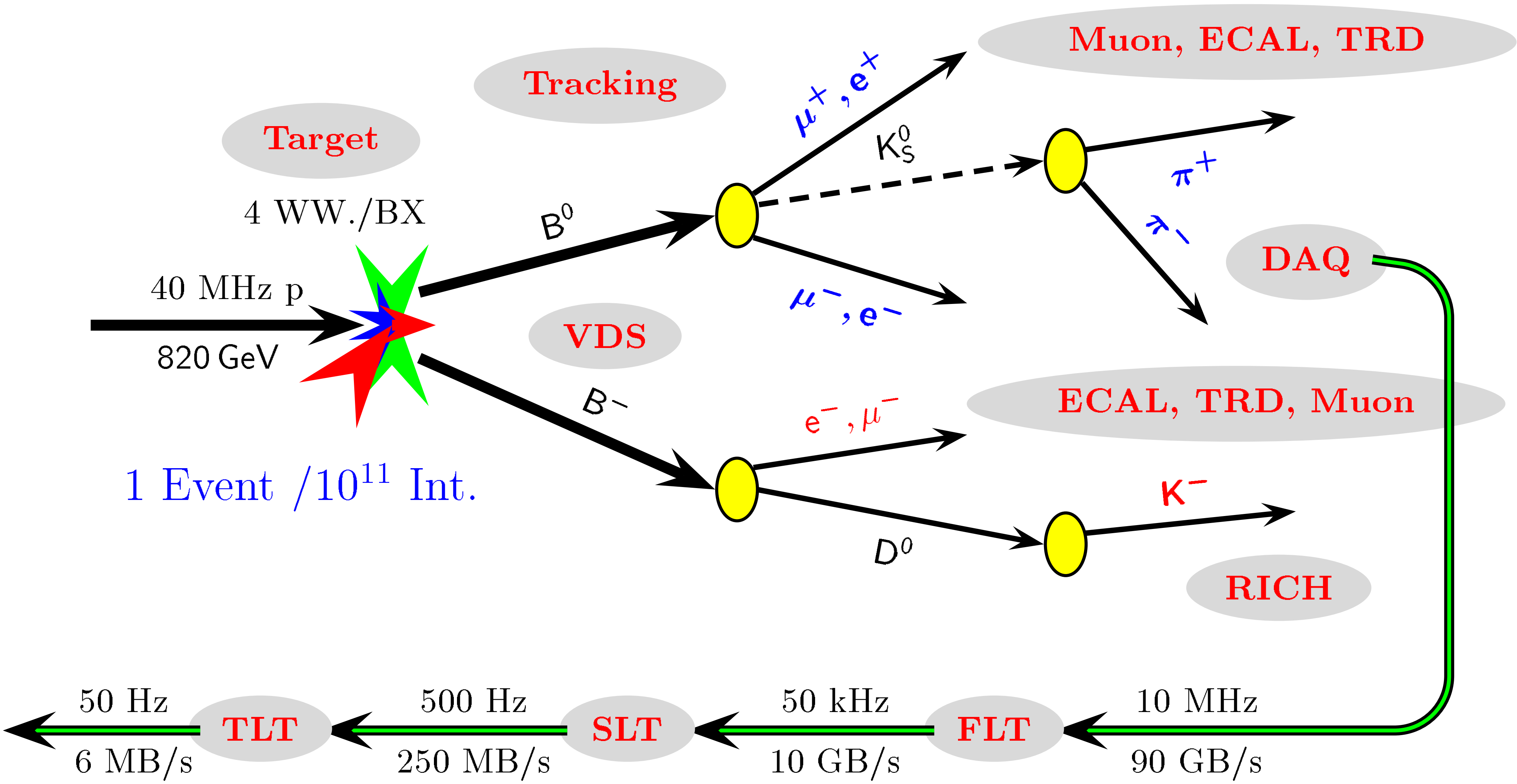
$\mathrm{Br}(J/\psi \to e^+e^-/\mu^+\mu^-) \approx 0.12$

$\mathrm{eff(trig, rec, vertex)} \approx 0.17; \quad \text{total Efficiency} \approx 4\cdot 10^{-12}$

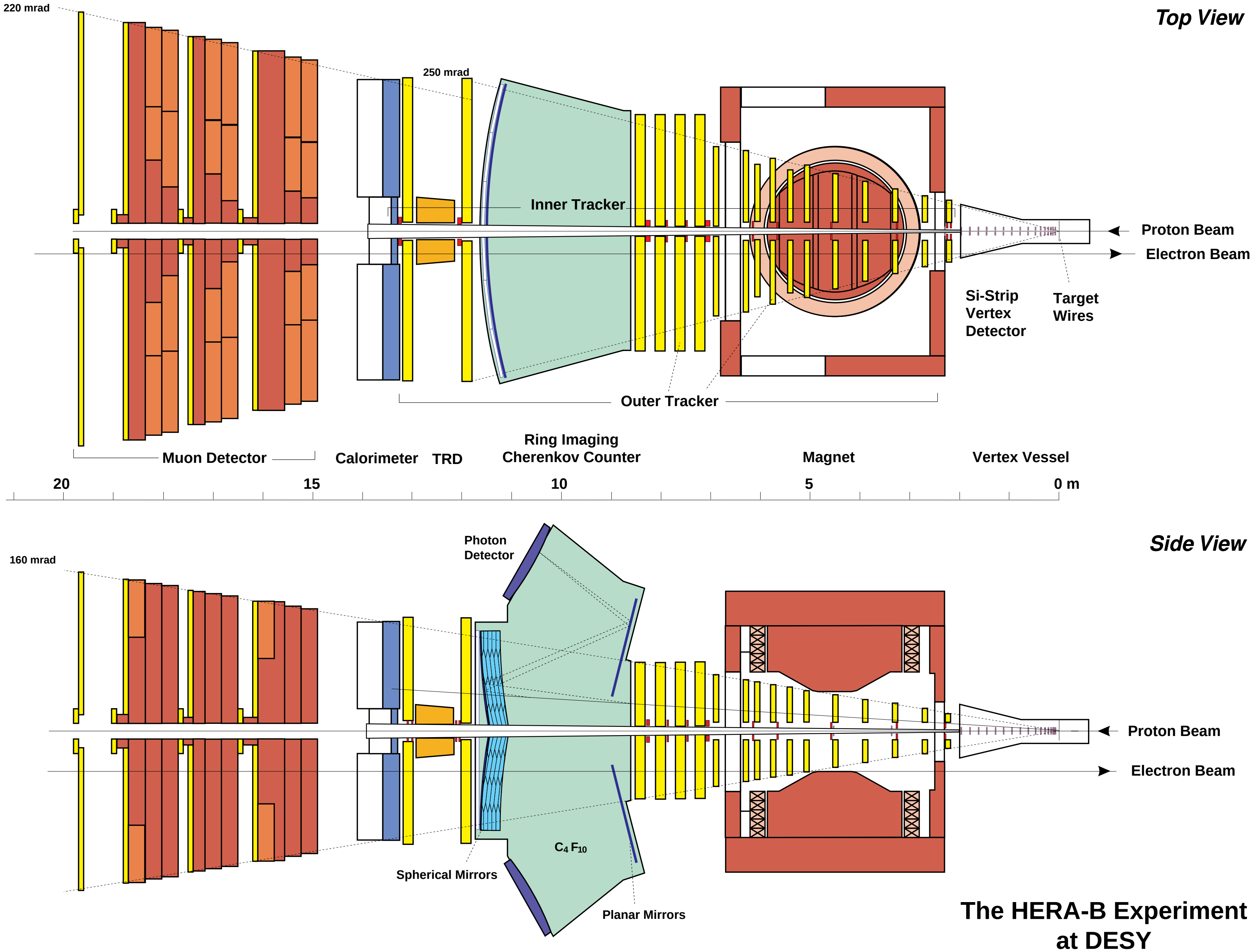
$\Delta \sin 2\beta = 0.13 \Longrightarrow 1500$ Events

Required interactions $\approx 4\cdot 10^{14}$ $(\sigma^{\rm tot}_{b\bar{b}} = 12\,\mathrm{nb},\ 1\,\mathrm{y} \,@\, 40\mathrm{MHz})$

Detector requirements



The HERA-B detector



The HERA-B Experiment at DESY

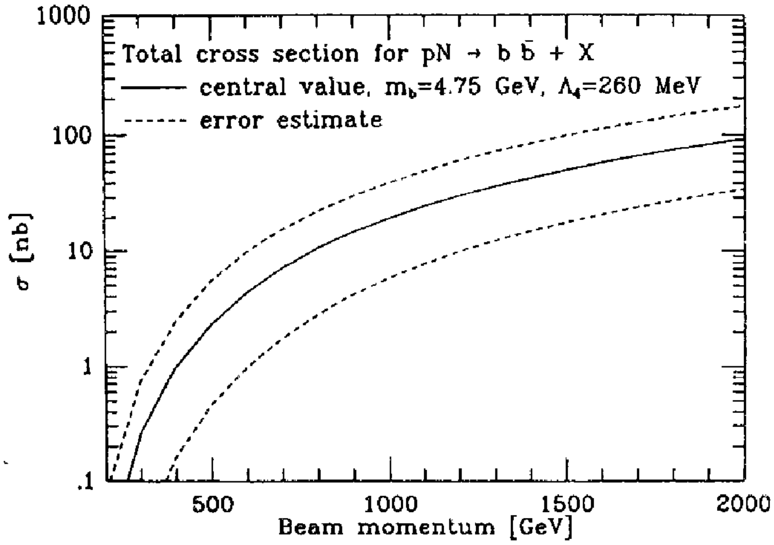
$b\overline{b}$ cross section

- QCD calculations up to α_s^3

$\sigma_{b\overline{b}}^{tot} =$

12 nb @ 820 GeV

20 nb @ 1000 GeV

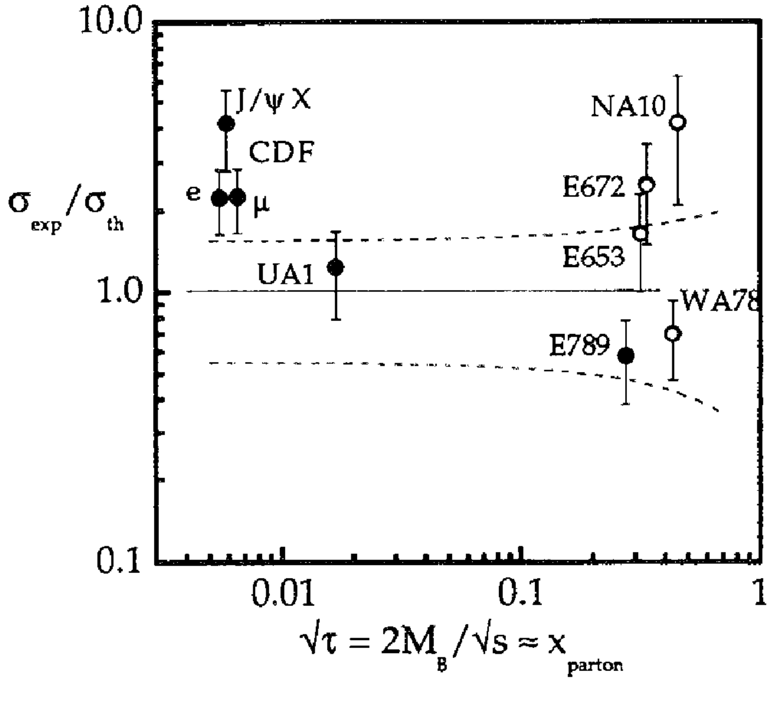


  - dependent on m_b (4.5–5 GeV)
  - dependent on scale of α_s calculation

- measurement of $\sigma_{b\overline{b}}$

E789:

$\sigma_{b\overline{b}}^{tot} = (7 \pm 2.5)\,\mathrm{nb}$



$\sigma_{b\overline{b}}^{tot} \approx 6 - 12\,\mathrm{nb}$

CP violation reach factors

1.	interaction rate	$\Longleftrightarrow$	efficiency of internal target
2.	$b\bar{b}$ cross section	$\Longleftrightarrow$	hope and beam energy
3.	track reconstruction	$\Longleftrightarrow$	trigger eff., pattern recognition eff., K_s^0 reconstruction eff.
4.	lepton/kaon ID	$\Longleftrightarrow$	MUON, ECAL, TRD and RICH performance
5.	J/ψ reconstruction	$\Longleftrightarrow$	vertex and mass resolution
6.	B^0 reconstruction	$\Longleftrightarrow$	vertex and mass resolution
7.	tagging dilution	$\Longleftrightarrow$	pattern recognition, particle ID, vertexing
8.	mixing dilution	$\Longleftrightarrow$	vertexing
9.	background	$\Longleftrightarrow$	vertex and mass resolution
10.	systematic errors	$\Longleftrightarrow$	scale errors, non-CP asymmetries

final observed asymmetry: $A_{obs} \approx sin\,2\beta \cdot M(t_0) \cdot D_T \cdot D_M \approx sin\,2\beta \cdot 0.3$

$$sin\,2\beta \approx 0.5 \Rightarrow A_{obs} \approx 0.15$$

CP reach

$\sigma_{b\bar{b}}$	6 nb	12 nb	17 nb
σ_{inel}	13 mb	13 mb	13 mb
$\sigma_{b\bar{b}}/\sigma_{inel}$	$4.6{\cdot}10^{-7}$	$9.2{\cdot}10^{-7}$	$1.3{\cdot}10^{-6}$
trigger rate	40 MHz	40 MHz	40 MHz
$\mathrm{b}\bar{\mathrm{b}}$ rate	18 Hz	37 Hz	52 Hz
fraction of det. $B^0 \to J/\psi K_S^0$	$4.2 \cdot 10^{-6}$	$4.2 \cdot 10^{-6}$	$4.2 \cdot 10^{-6}$
# $J/\psi K_S^0$ per 10^7 s	$\approx$ 800	$\approx$ 1500	$\approx$ 2200
statistical factor	2.3	2.3	2.3
tagging power P_{tag}	0.31	0.31	0.31
Δ sin 2β after 10^7 s	**0.18**	**0.13**	**0.11**

Efficiencies I

		$B^0 \to J/\psi K_S^0$ $J/\psi \to \mu^+\mu^-$	$B^0 \to J/\psi K_S^0$ $J/\psi \to e^+e^-$	$B^0 \to \pi^+\pi^-$
Physics	$\mathrm{b\bar{b}} \to \mathrm{b\bar{d}}$ $(\mathrm{d\bar{b}})$	0.8	0.8	0.8
	B^0 branching ratio	$5 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$1.5 \cdot 10^{-5}$
	$K_S^0 \to \pi^+\pi^-$	0.69	0.69	-
	$J/\psi \to \ell^+\ell^-$	0.06	0.06	-
Trigger	geometry, pre-trigger	0.69	0.50	0.61
	momentum cuts	0.90	≈ 0.95	0.78
	mass cuts	> 0.99	≈ 0.95	0.99
$\boldsymbol{\ell^+\ell^-/\pi^+\pi^-}$	geometry	0.99	0.99	0.99
Tracking	pattern	0.90	0.90	0.90
$\mathbf{K_S^0}$ Tracking	geometry	0.70	0.70	-
	pattern	0.90	0.90	-
	K_S^0 reconstruction	0.97	0.97	-

Efficiencies II

		$B^0 \to J/\psi K^0_S$ $J/\psi \to \mu^+\mu^-$	$B^0 \to J/\psi K^0_S$ $J/\psi \to e^+e^-$	$B^0 \to \pi^+\pi^-$
$\boldsymbol{\ell^+\ell^-/\pi^+\pi^-}$ **Identification**	efficiency	0.94	0.85	0.94
$\boldsymbol{J/\psi}$ **Reconstruction**	vertex fit, mass cut	> 0.99	> 0.99	-
B^0 Reconstruction	vertex fit, mass cut	0.95	≈ 0.75	0.95
	matching with target	> 0.99	0.98	0.98
Decay Kinematics	J/ψ decay angle cut	0.85	0.86	-
	B decay angle cut	0.94	0.93	0.75
Secondary vertex	decay length cut	0.69	0.69	0.69
Summary	**net yield per $b\bar{b}$**	$\mathbf{2.8 \cdot 10^{-6}}$	$\mathbf{1.4 \cdot 10^{-6}}$	$\mathbf{2.3 \cdot 10^{-6}}$

Tagging efficiencies and dilution

	Lepton tag	Kaon tag	Charge tag
Cuts:			
p	> 5 GeV/c	$\epsilon\,[5, 50]$ GeV/c	–
p_t	> 0.8 GeV/c	–	–
$\chi^2(v_B, t)$	–	> 2	> 2
$\delta(v_B, t)$	< 1 mm	< 1 mm	< 1 mm
$\chi^2(v_X, t)$	> 4	> 4	> 5
Tag: sign(x)	q_l	q_K	$\sum_i q_i \cdot p_i$
Efficiencies:			
ϵ (tag found)	16.1%	46.0%	96.4%
ϵ_c (correct)	11.5%	31.3%	56.0%
ϵ_w (wrong)	4.6%	14.7%	40.4%
Significance:			
Dilution $D = \frac{\epsilon_c - \epsilon_w}{\epsilon}$	0.43	0.36	0.16
Power $P = D \cdot \sqrt{\epsilon}$	0.17	0.24	0.16
Combined Power:	$P = 0.31 \pm 0.03$		

Background (MC studies)

Inv. mass plots:

$B^0 \to J/\psi\, K^{*0} \to \underbrace{J/\psi\, K^0_S}\, \pi^0$

fake B^0 decay

(inverted CP asymmetry)

$S/B > 1600 \quad \mu^+\mu^-$

$S/B > 170 \quad e^+e^-$

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

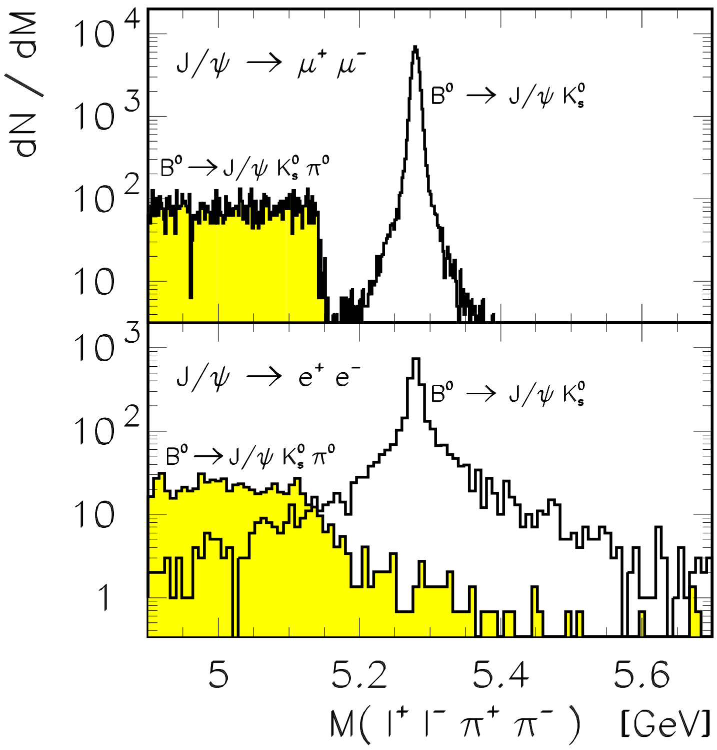
$S/B > 120 \quad \mu^+\mu^-$

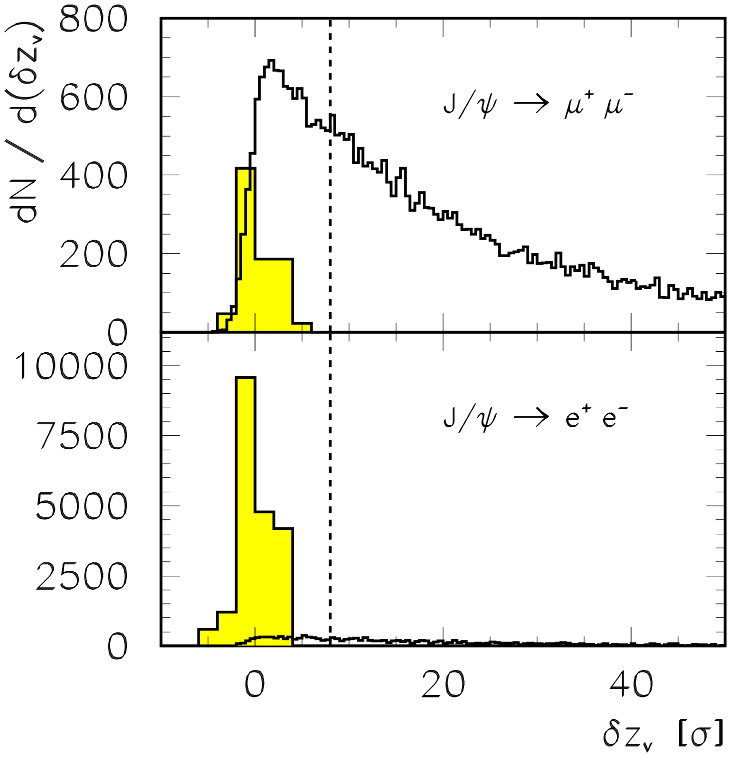
$S/B > 2 \quad e^+e^-$

min. bias $\Rightarrow$ fake lept.

$S/B > 3 \quad \mu^+\mu^-$

$S/B > 0.6 \quad e^+e^-$

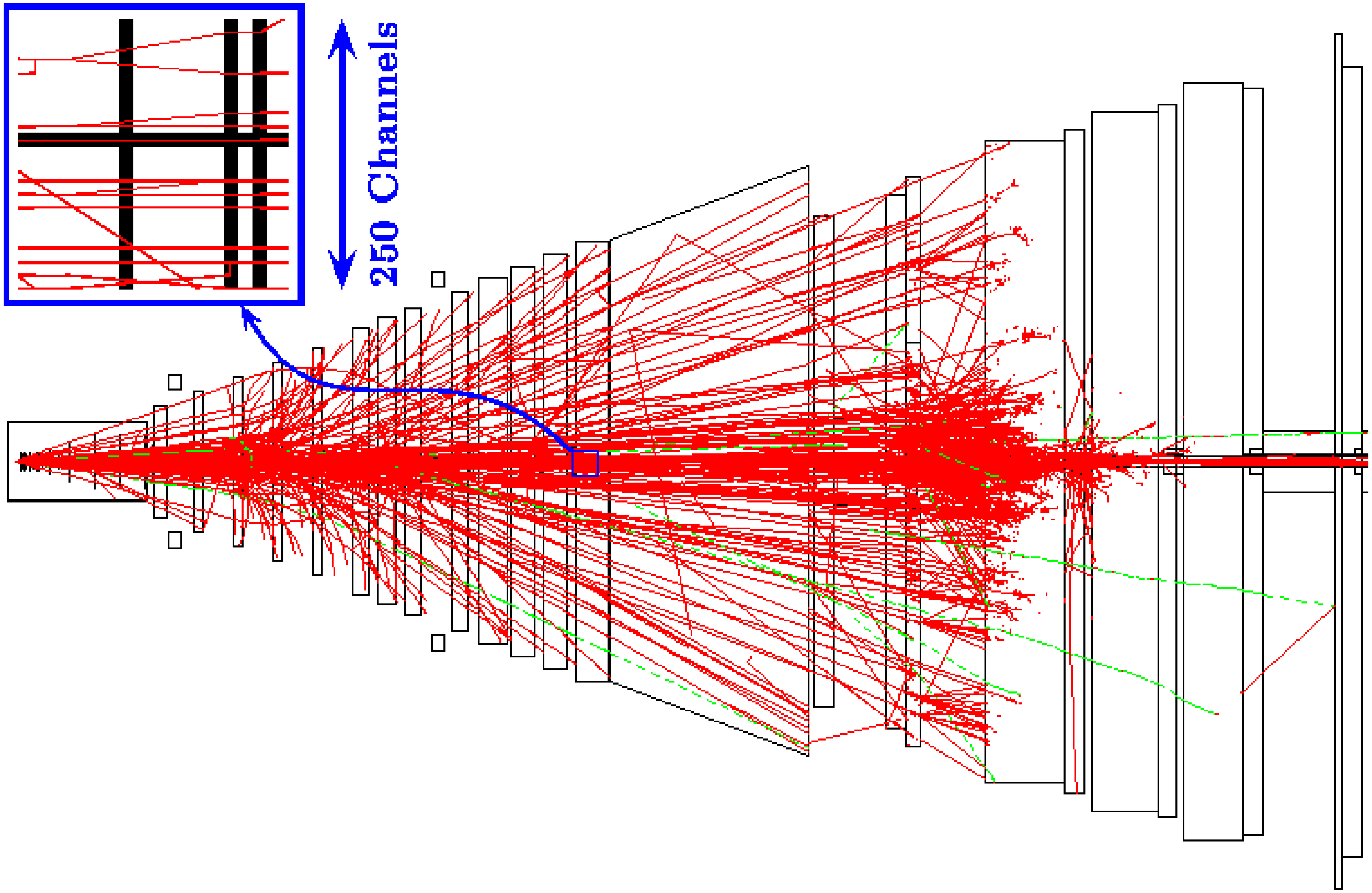




A typical event consisting of 4 interactions

60 primary tracks

200 tracks before ECAL

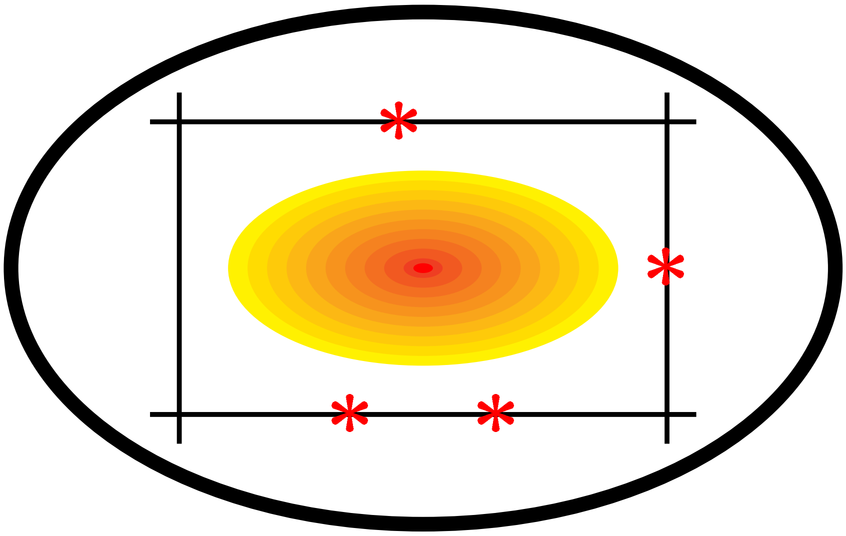


Main detector components

detector	*technology*	*number of channels*	*hits per BX*
Vertex detector	Si-strip	136 k	≈ 0.05
Tracker			
inner (2-6 cm)	Si-strip	40 k	≈ 0.02
inner (6-19 cm)	microstrip gas-chamber (GEM)	135 k	≈ 0.04
outer (>19 cm)	honeycomb-DC	120 k	≈ 0.15
High-p_T trigger $B^0 \to \pi^+\pi^-$	gas pixel/straw	26 k	≈ 0.05
RICH Kaon iden.	C_4F_{10} radiator PMT photon detector	32 k	≈ 0.1
Small-Angle TRD Electron iden.	fiber radiator straw chambers	15.7 k	≈ 0.1
EM calorimeter Electron iden.	W/Pb scint. shashlik	5.8 k	≈ 0.2
Muon system Muon iden.	gas pad + pixel prop. tubes	31.3 k	< 0.01
Total		$\approx$ 550 k	

HERA-B Target

Introduce 8 thin wires (50 μm) inside the beeam halo $\Rightarrow$ absorb protons leaving the beam core.



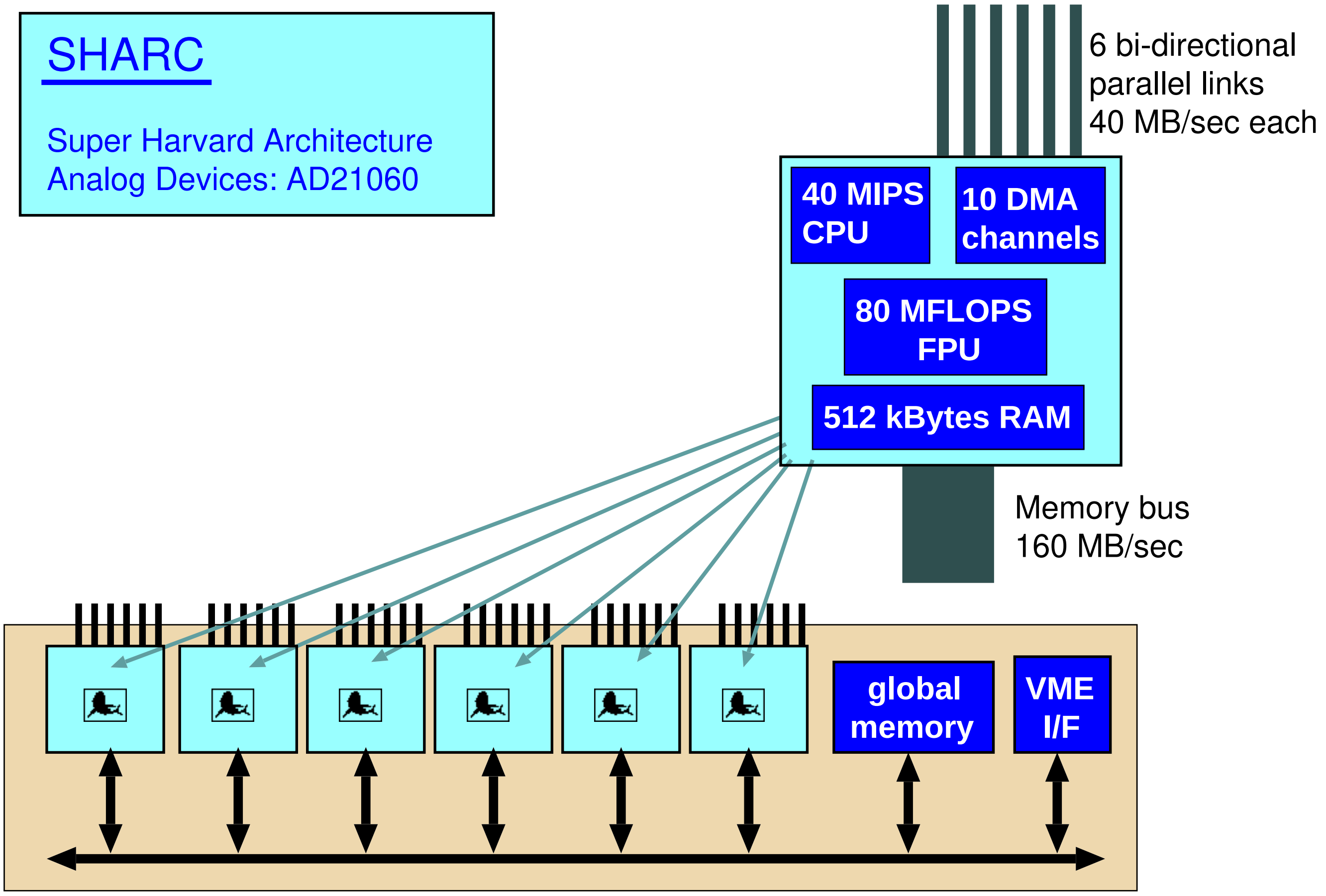
- Designed as halo target (leave beam core):
  $I_p = 100$mA, $\tau_p = 100$h, $\epsilon_T = 0.6$,
  BX rate $\approx$ 10 MHz.

- Beam scraping to reach IR$\approx$40 MHz

Advantages:

- Well localized primary vertex.
- Distribution of the multiple interactions over the 8 wires.
- No interaction with the ep beams.
- Reliable operation.

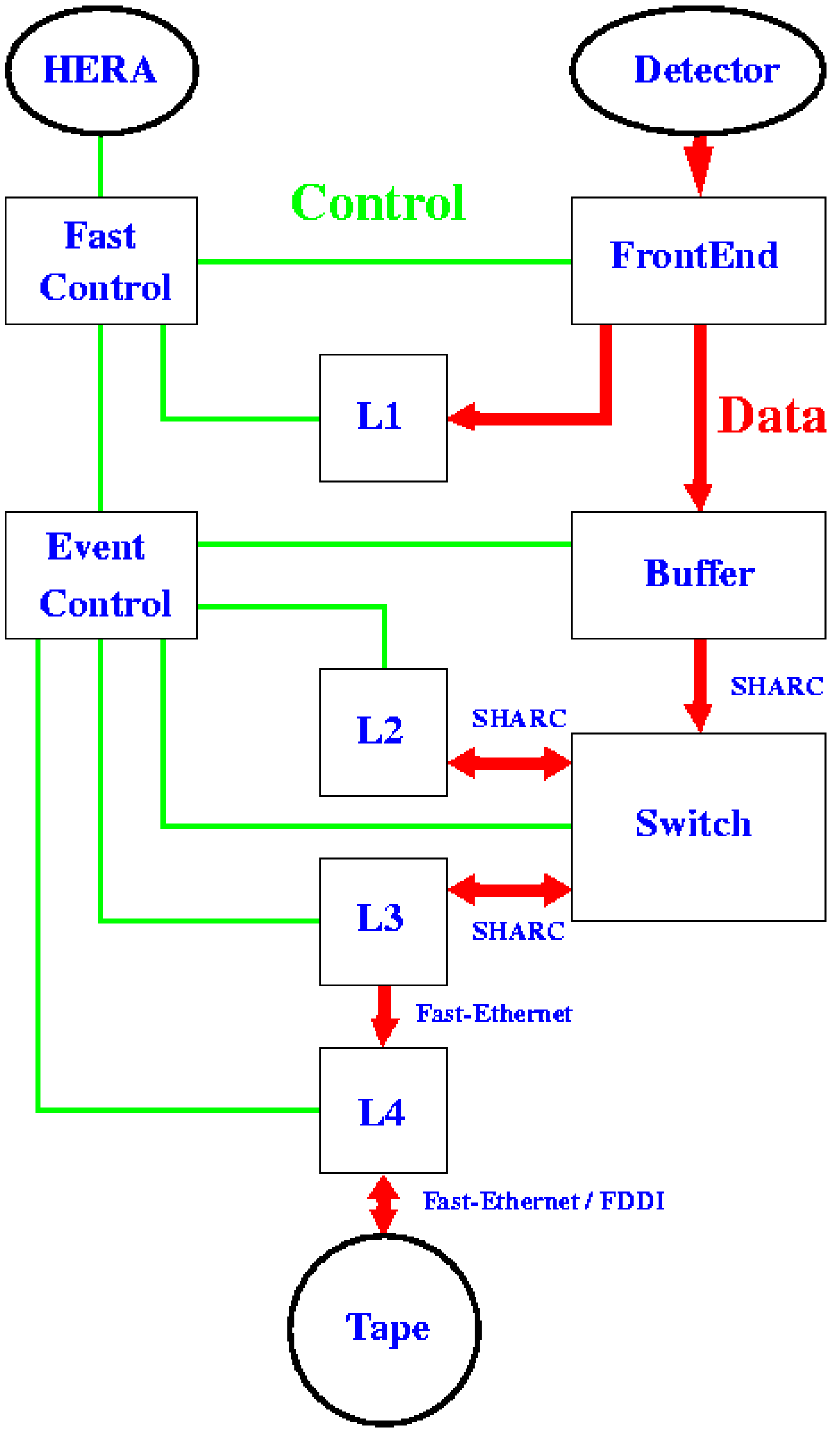
SHARC cluster board



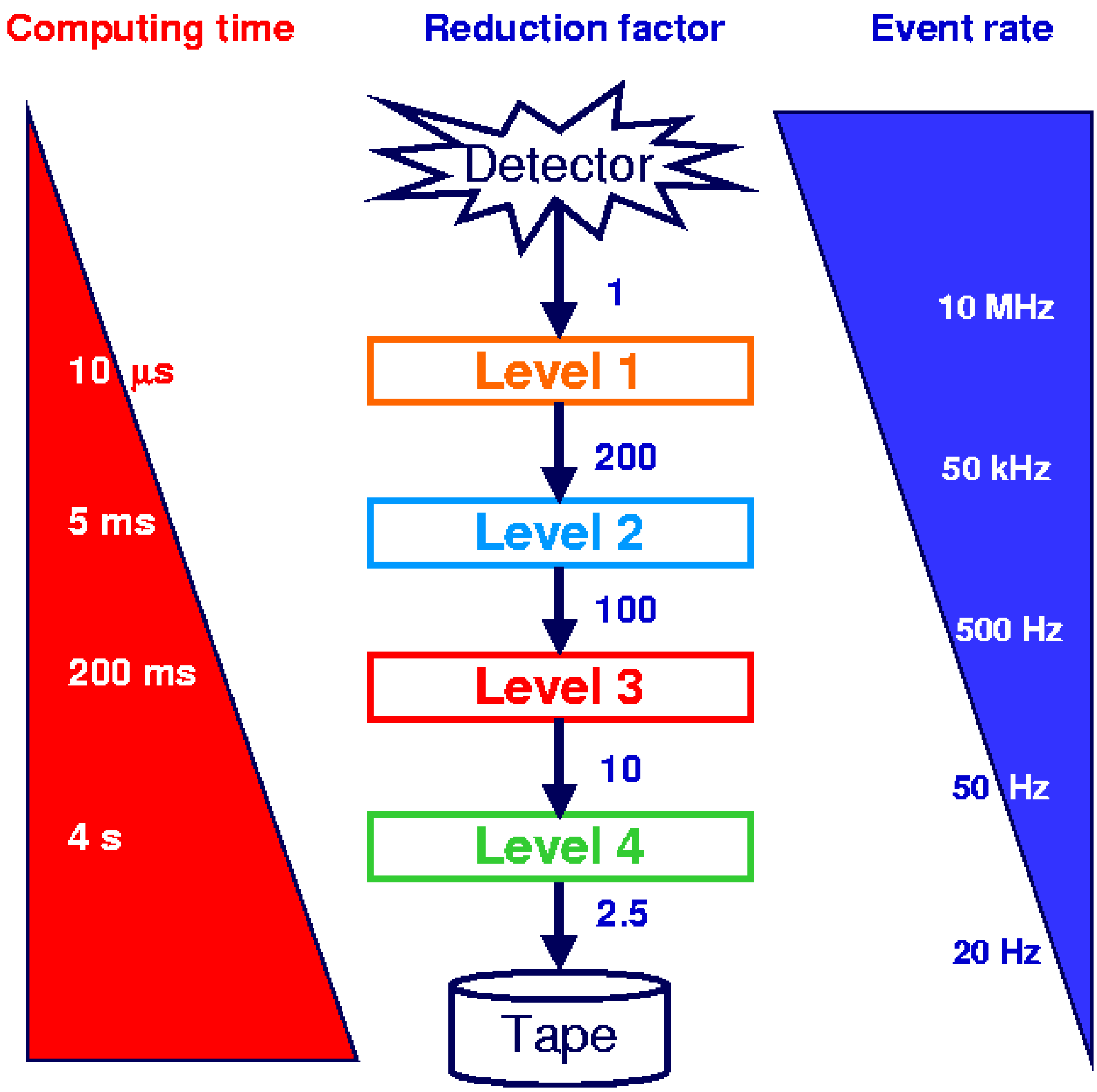
- 170 modules: 6u VME cards
- large I/O via 36 links / module
- Producer: MSC, Sutensee, Germany

DAQ and Trigger

DAQ Scheme



Trigger

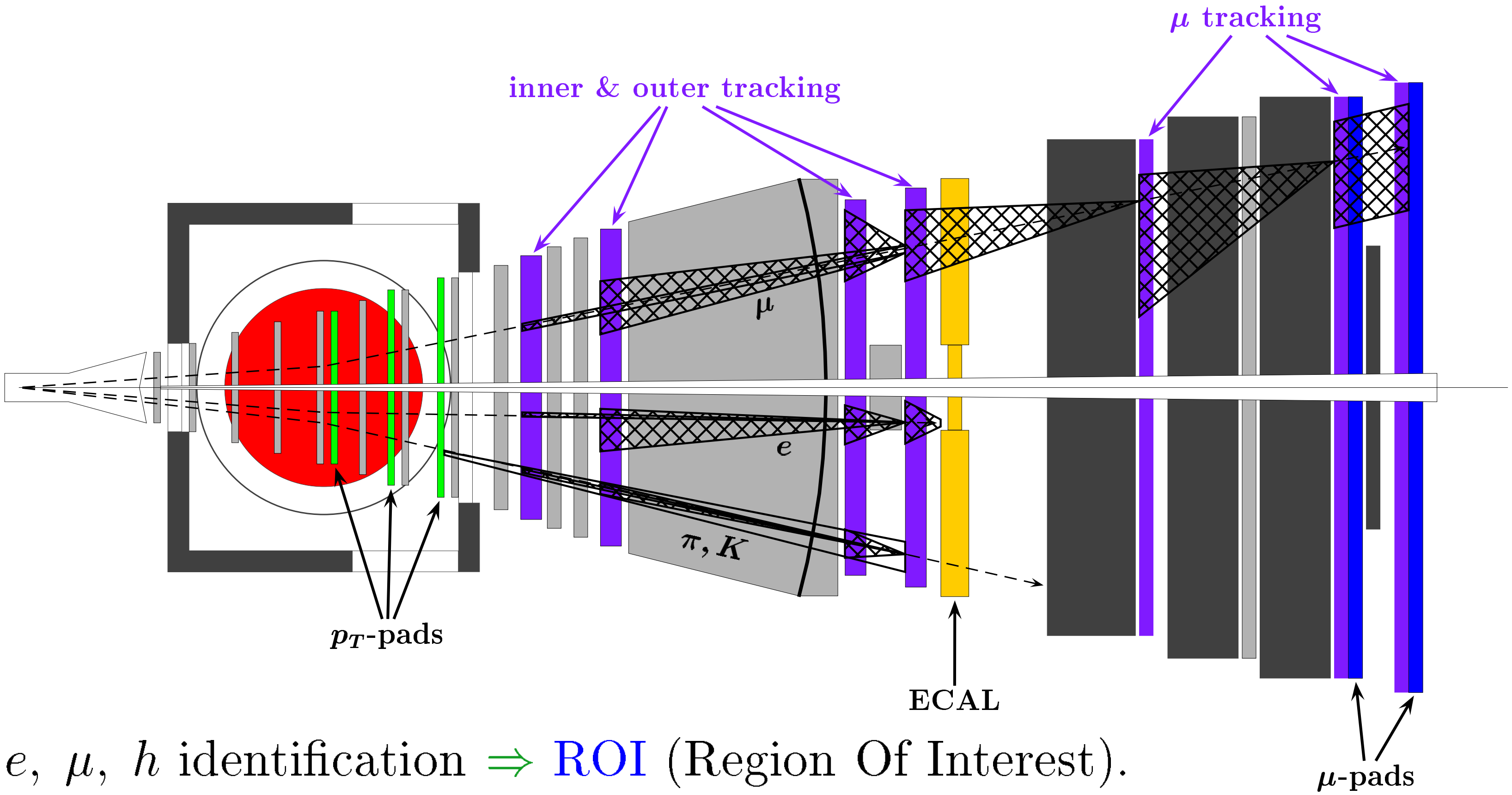


Level-1: Special Hardware Processors

Level-2/3/4: Farm of 2×200 PC/Workstation

100 PC for Level-2/3 in 1998

First Level Trigger



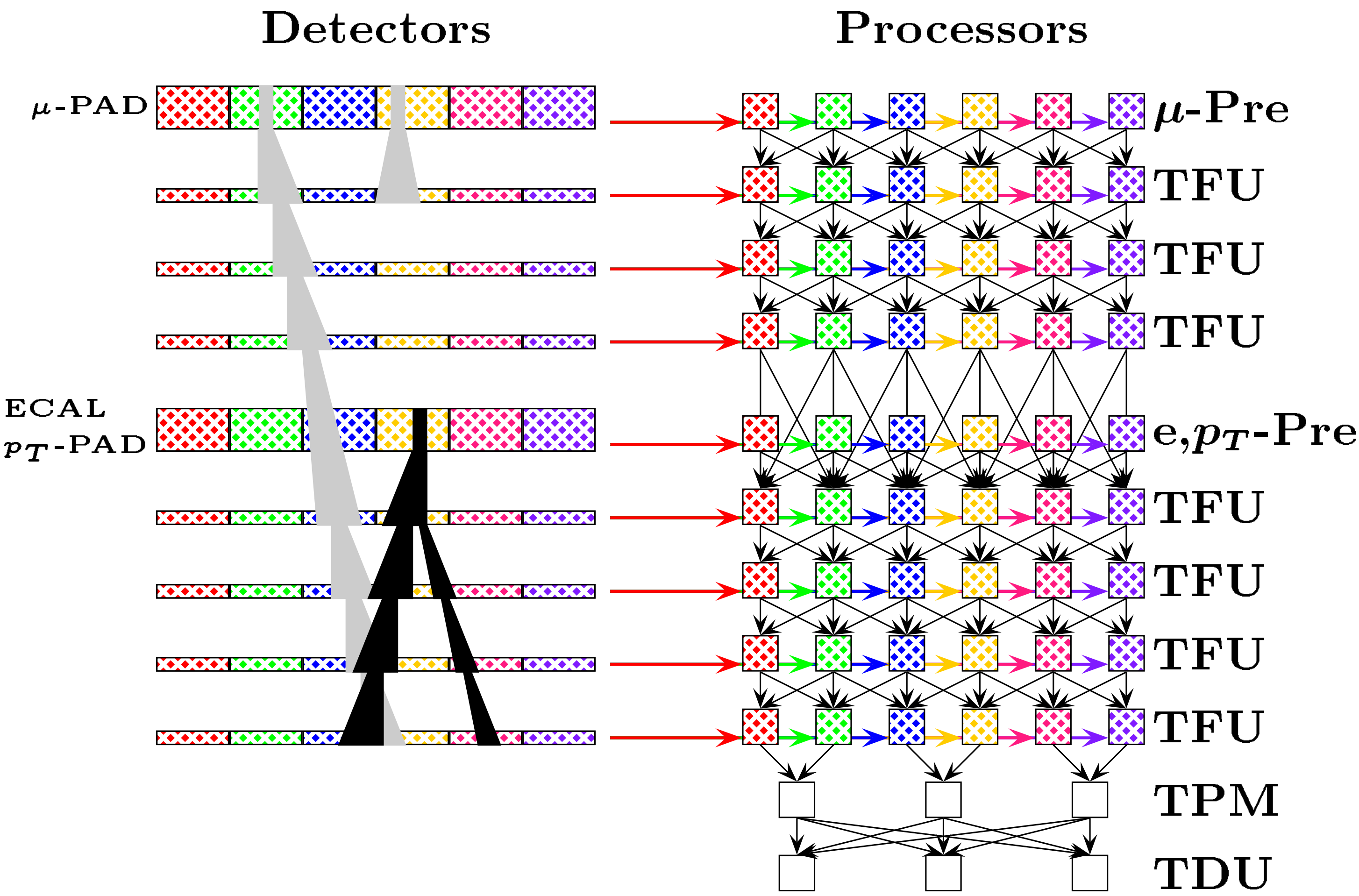
1) e, μ, h identification $\Rightarrow$ ROI (Region Of Interest).

2) Tracking towards the target.

3) Compute track parameters (P, $P_\perp$) $\Rightarrow$ accept or reject.

4) Trigger decission $\Rightarrow$ based on multiple track combinations.

FLT: hardware realization



- Execution time: 12 μs/BX
- # used channels : 150000
- Technique: asynchronous parallel pipelines $\Rightarrow$
  processor operates on local data
- Input rate : 10 MHz $<$ 4 int/BX $>$
- Output rate : 50 KHz

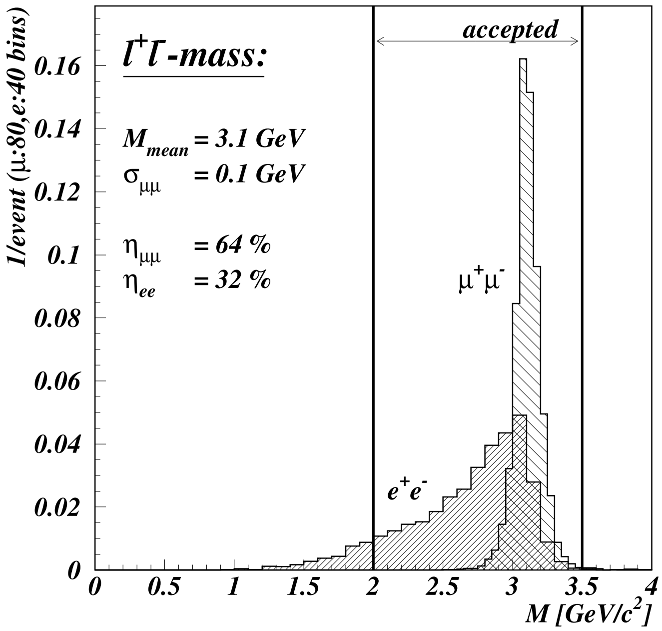
Efficiency

- Trigger Efficiency of $B^0 \rightarrow J/\psi\, K^0_S$

Reco. Masses of

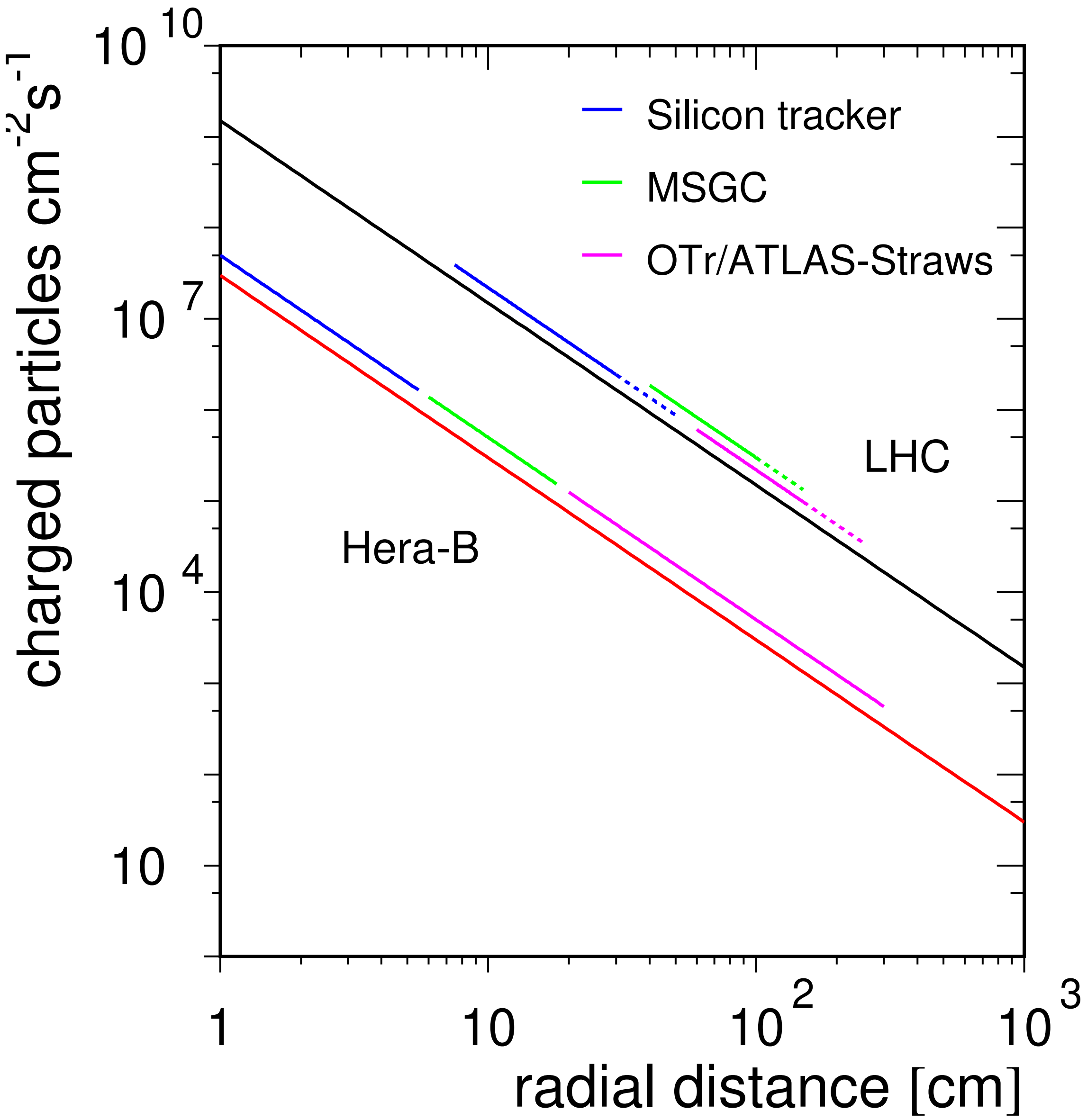
$J/\psi \rightarrow \mu^+\mu^-$

$J/\psi \rightarrow e^+e^-$



	$J/\psi \rightarrow \mu^+\mu^-$	$J/\psi \rightarrow e^+e^-$
Trigger	0.62	0.45
Tracking Leptons	0.89	0.89
Tracking K^0_S	0.61	0.61
Lepton–Identification	0.94	0.85
J/ψ / B^0 Reconstruction	0.95	0.73
Kinematical cuts	0.80	0.80
Vertex cut	0.69	0.69
Reco. Probability	≈ 0.17	≈ 0.09

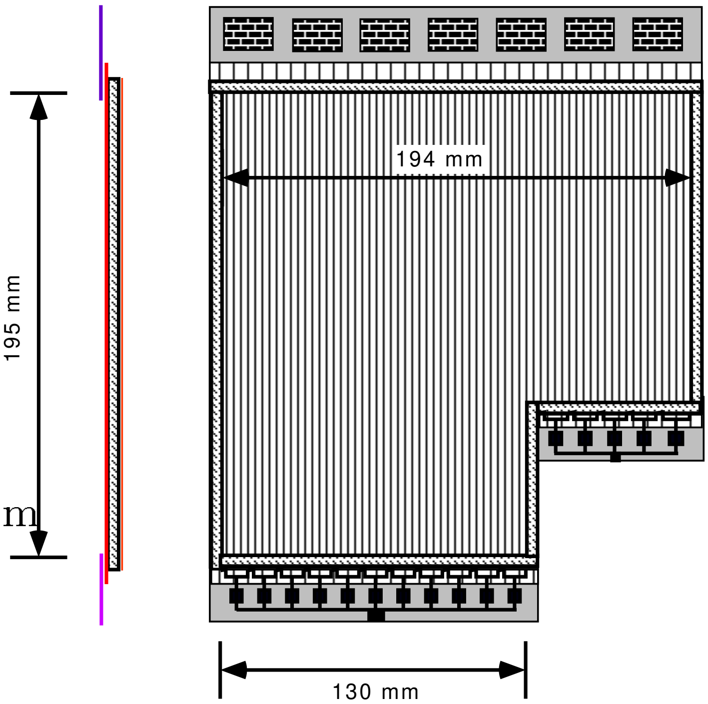
Radiation Level



(simple $1/R^2$ assumption)

→ Detector components see particle flux comparable to LHC

Inner Tracker: MSGC



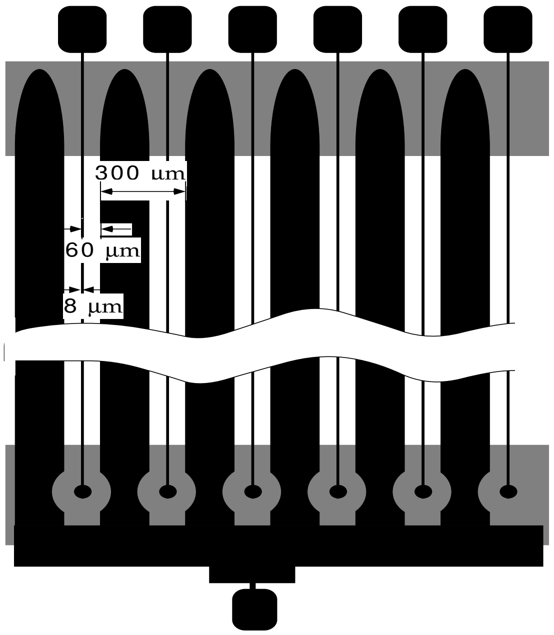
module geometry

Detector characteristics

- pitch : 300 μm
- lenght of a strip : $19 - 25$ cm
- Gap height 3.5 mm
- Gas : Ar : DME 50 : 50

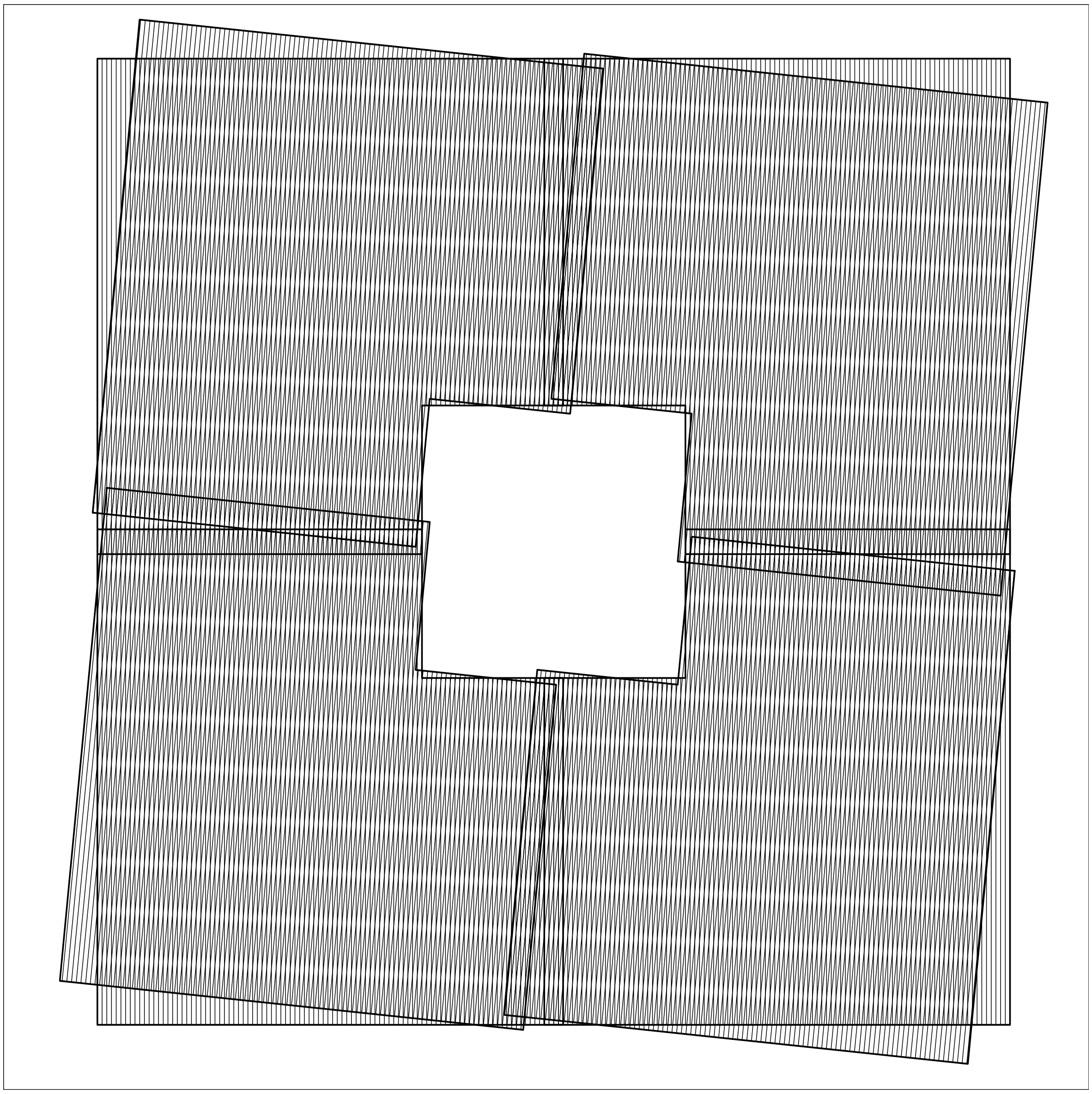
Performance:

- Counting rates : 10^4 mm^{-2}s^{-1}
- occupancy : $< 5\%$
- gas gain : ~ 1000
- electrons/mip : 50
- resolution : < 80 μm



Structure of the electrodes

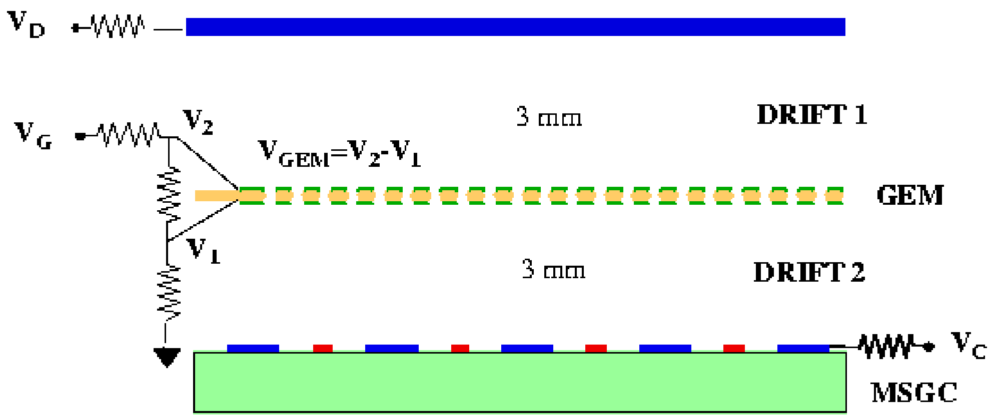
Inner Tracker



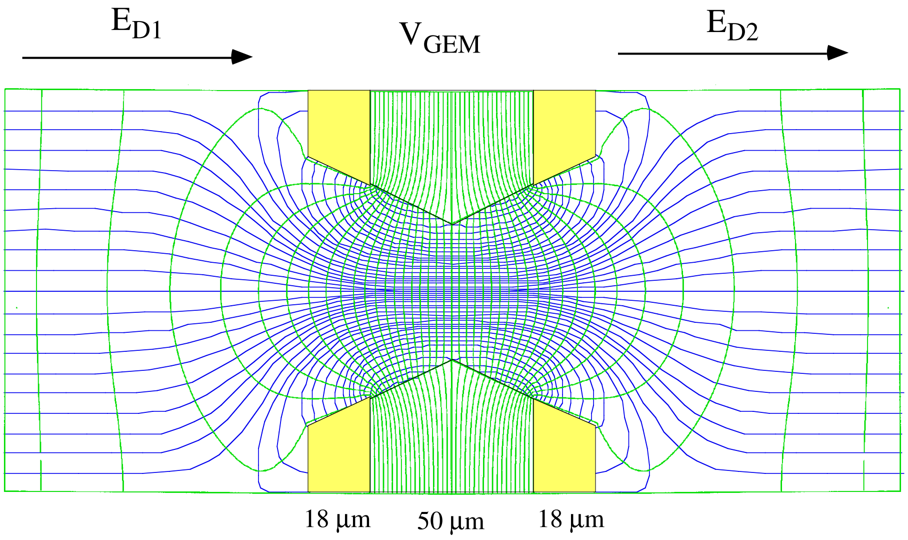
Sensitive surface of a super-layer

- ~ 136000 channels in 192 modules.
- Detectors show radiation damage in hadron beams: discharges triggered by HIP's destroy the electrode strips.

MSGC with GEM



Gas Electron Multiplier (GEM) F.Sauli et al.

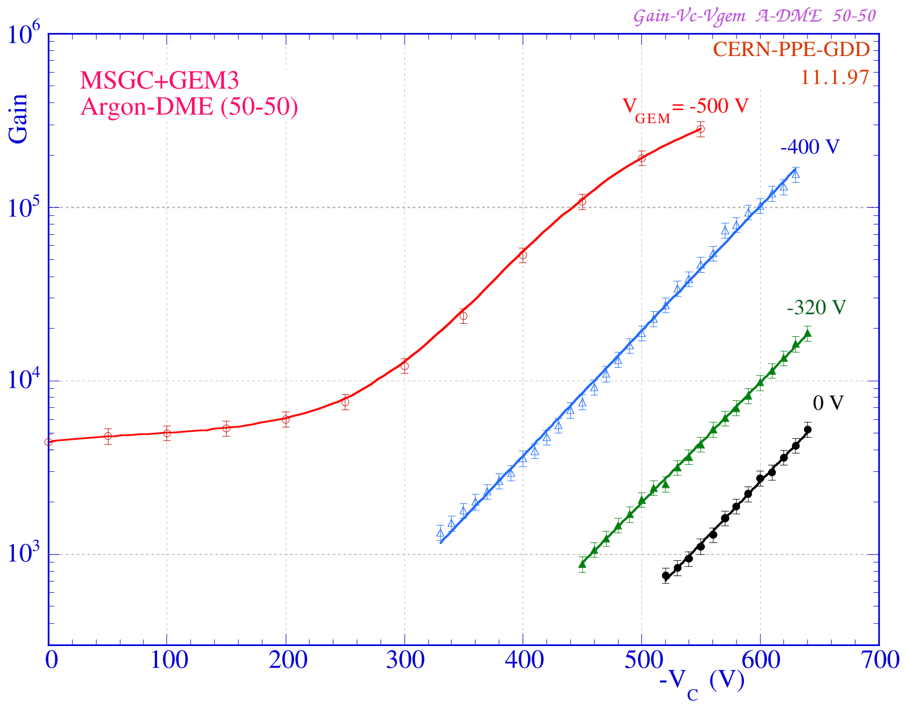


Thin insulating foil with metal-clad and matrix of holes ($\sim$ 100 μm).

$\longrightarrow$ gas amplification due to high field strength in holes.

Gas amplification in GEM

- With a pre-amplification factor ($\sim$ 50) the cathode voltage can be reduced.



F.Sauli et al.

- Gas amplification factors of 5000 can be reached without discharges.
- GEM has no significant influence on position resolution.
- The amplification is not affected inside a magnetic field.

Status of the HERA-B GEM-MSGC

- GEM foils from CERN workshop.

- Diamond-coated glass substract with gold electrodes.

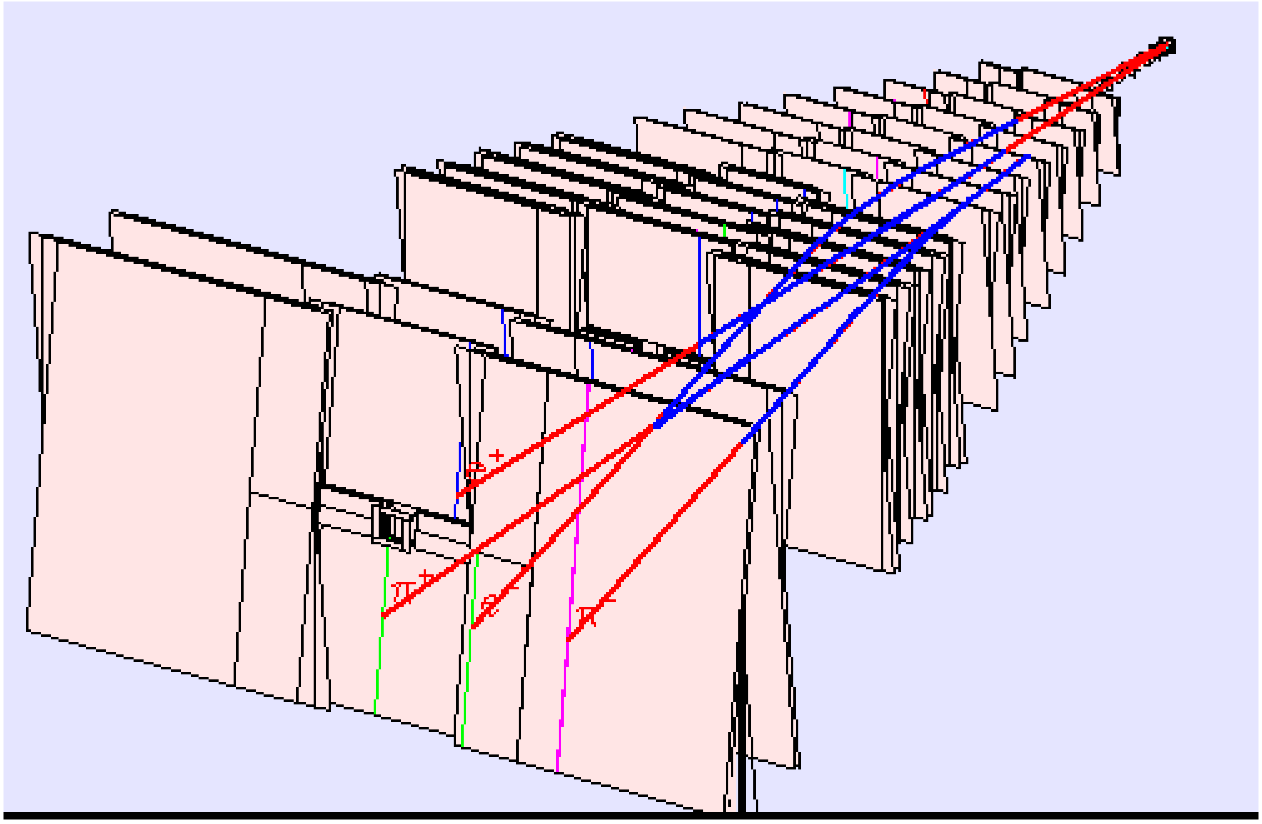
- Aging studies (with Ar/DME 50:50 gas mixture) so far satisfactory.

- Mass-production: 20 detectors produced every month.

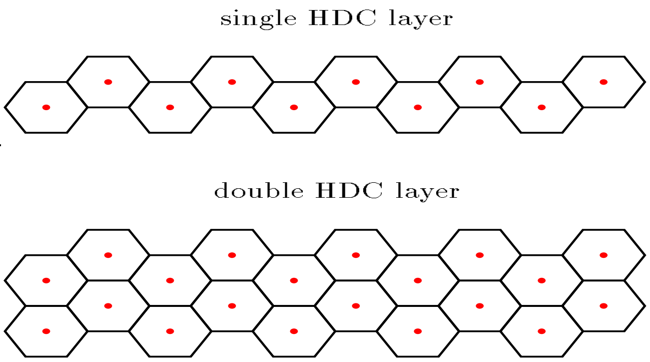
- 20 detectors to be installed during 1998 run.

Remark:
The alternative detector was scintillating-fibers, which was found to be possible but too expensive.

Outer Tracker



- # of superlayers: 13 (larger: ~ 4.5 m x 6 m)
- $R_{min} = 20$ cm $\rightarrow$ occupancy up to 20 %
- fast gas (CH_4 based) with drift velocity of $\sim 100\ \mu$m/ns
- spatial resolution : 150 μm
- tubes : 10 mm and 5 mm



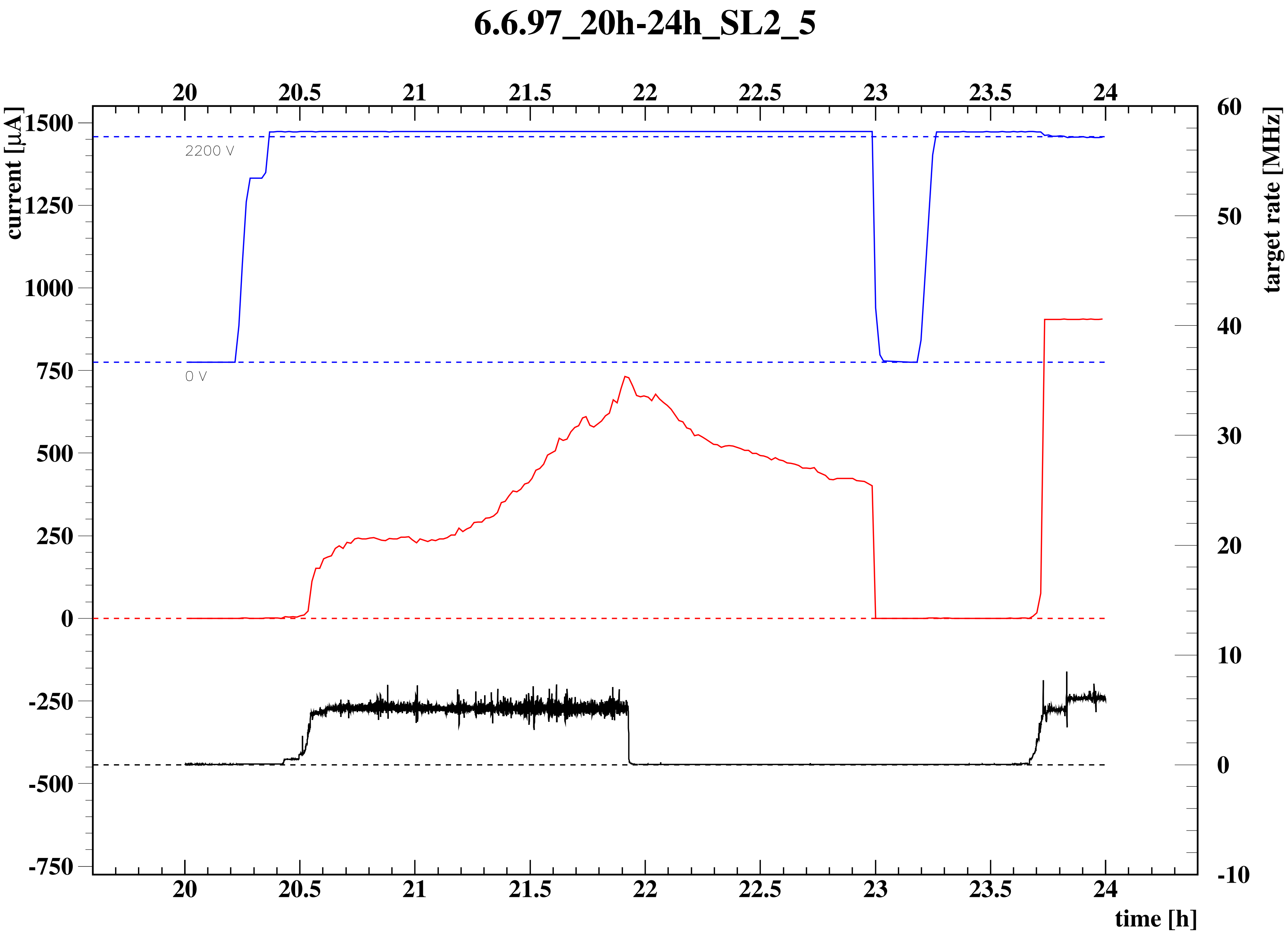
Structure : Honeycomb

OTR: Radiation damage

- Aging tests in the laboratory:
  X-ray tests showed no aging for a charge deposition up to 5 C/cm of wire (equivalent to 5 HERA-B running years).

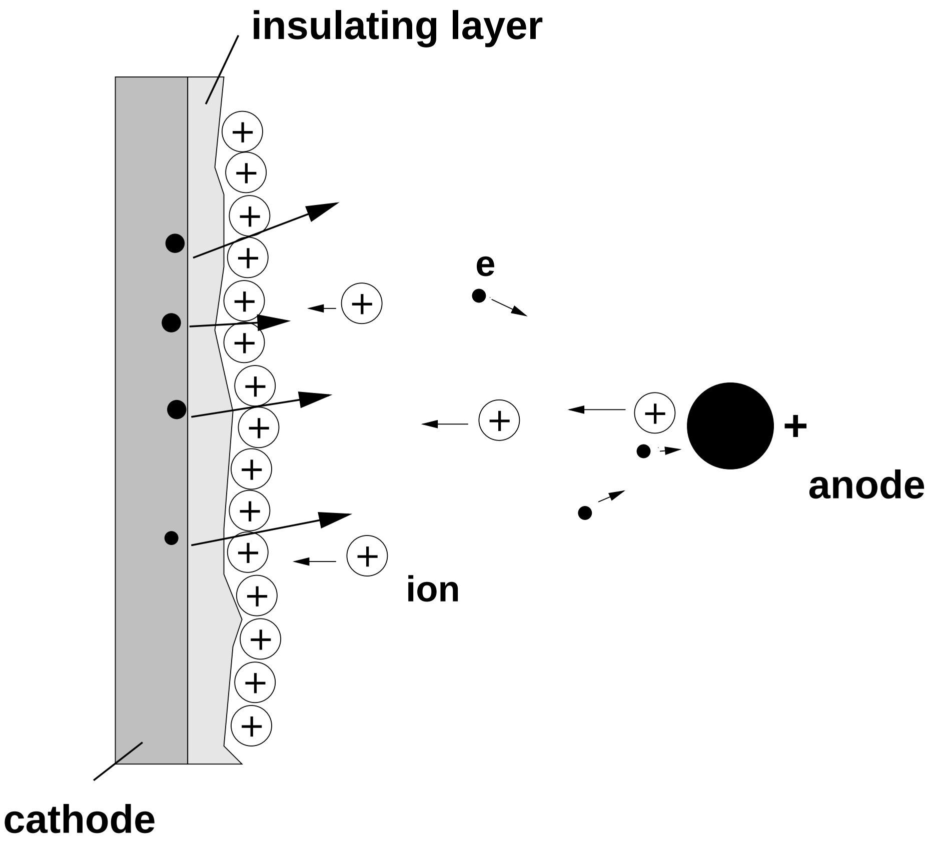
- Prototype chambers in HERA:
  radiation damage of chambers after only $\mathcal{O}(1\ \text{mC/cm})$.
  - ➢ Current increase during irradiation.
  - ➢ Persisting current after irradiation.

- Hadronic radiation with very high local ionization density damages the chambers.


6.6.97_20h-24h_SL2_5
current [µA]
target rate [MHz]
time [h]
2200 V
0 V
20
20.5
21
21.5
22
22.5
23
23.5
24
1500
1250
1000
750
500
250
0
-250
-500
-750
60
50
40
30
20
10
0
-10

Malter effect

- Malter effect induced by insulating layer.



→ Insulating deposits on the cathode.

→ Accumulation of ions.

→ Locally high electric field creates free electrons which lead to new ions.

Malter effect: Model

- Electron microscopy showed insulating layer in the cathode foil (Pokalon-C).
- Used foil showed deposits from plasma polimerization.

→ Highly ionizing particles lead to high local ionization densities that provoque plasma polimerization products.

→ Insulating layer on Pokalon-C facilitates its deposition.

→ Malter effect is created and the deposition on the foil continues.

⟹ Treatment of the foil to increase conductivity and avoid insulating deposits:
Coating with **Cu/Au** is proposed.

OTR: Status

- Mass production was stopped in summer 1997.
- A detailed R&D on foil treatment and aging studies was started.

  → Find environment outside HERA-B that reproduces the Malter effect.

  → Test different foil coatings.

→ Long term aging studies with different foil coatings is started (KFZ Karlsruhe).

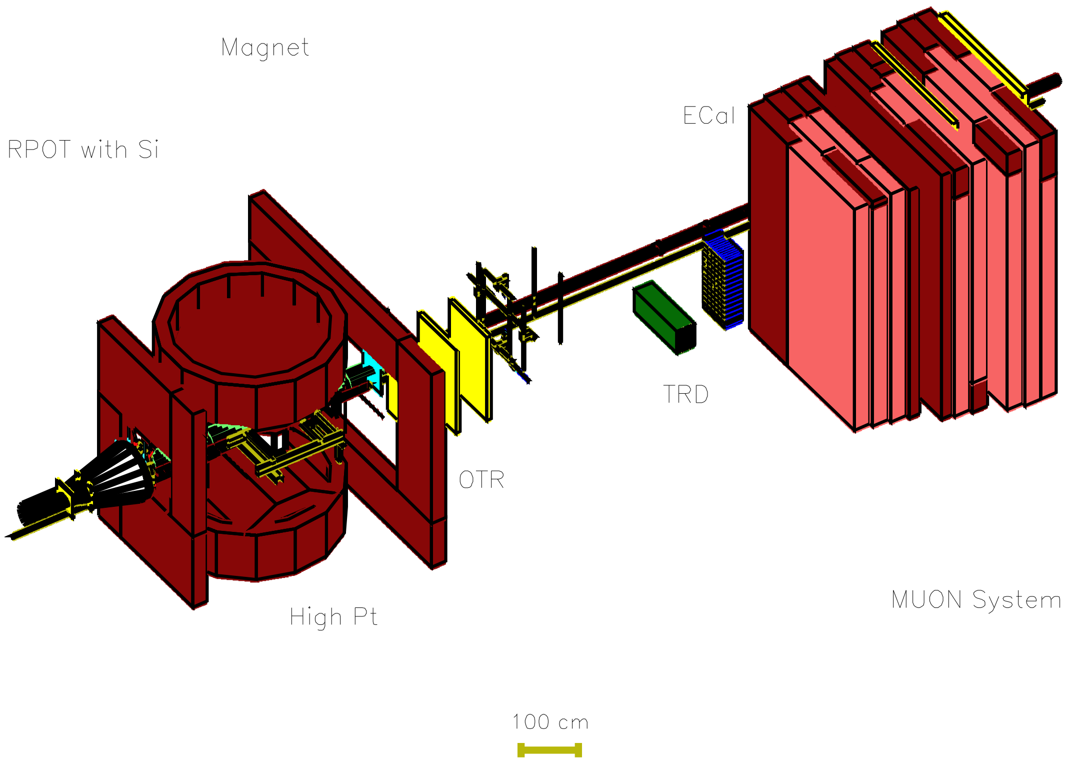
→ Resume mass-production in the following months.

- To be ready in early 1999: speed up by a factor of 2 or more from previous scheme.
- 6 institutes (NIKHEF, IHEP Beijing, Thsinghua Beijing, JINR Dubna, DESY HH, DESY Z) and several companies (e.g.: Lufthansa) involved.

$\Longrightarrow$ Logistic challenge

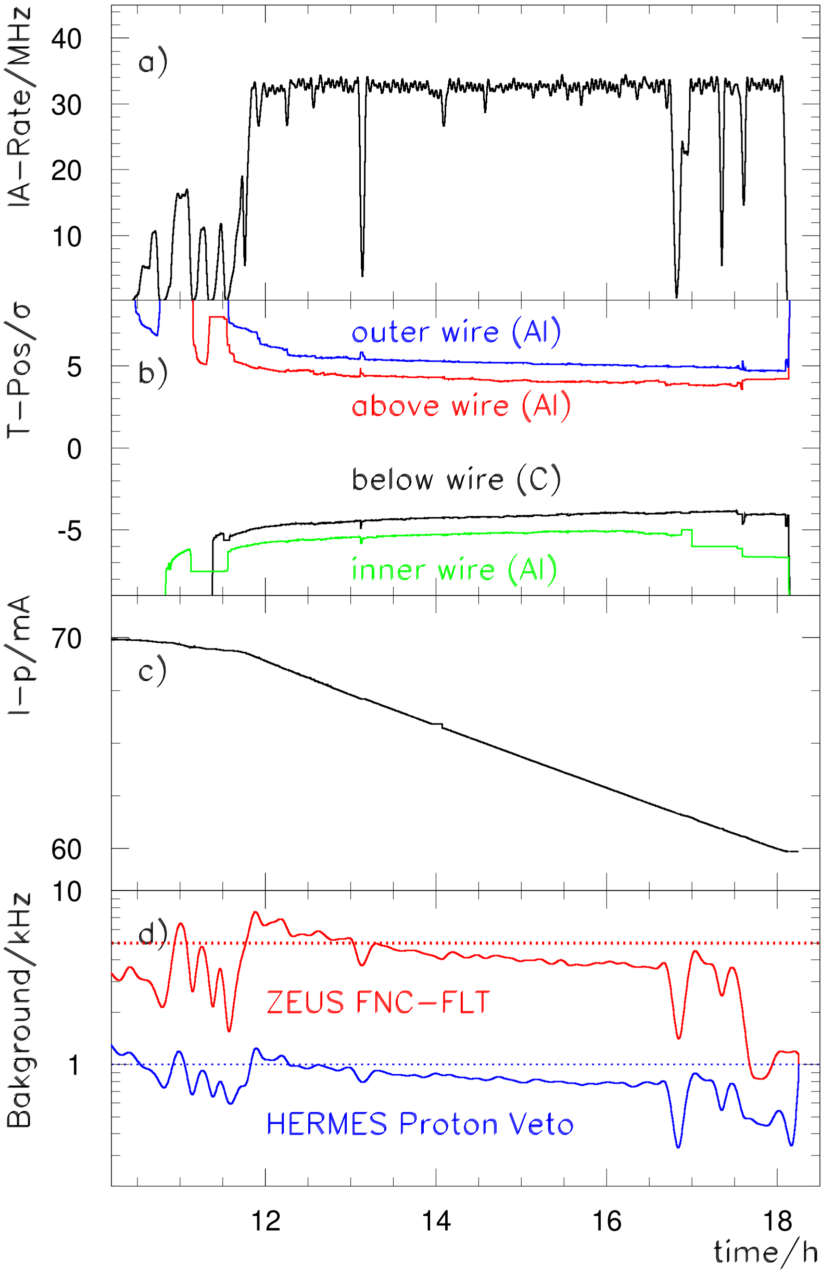
Backup solution is straw tracker which is successfully run in HERA-B (TRD).

Detector setup in 1996 (97)



- VDS-vessel with 3 double sided Si-strip detectors with 6000 channels and 8 targets.
- Al beam pipe 0.5 mm.
- Magnet and e-compensation coil.
- High-Pt gas pixel chambers.
- 3 superlayers of the OTR.
- MSGC (GEM) and Fiber test modules.
- ECAL with 320 channels.
- 1/12 TRD.
- MUON absorber with 24 tube and 7 pad chambers.

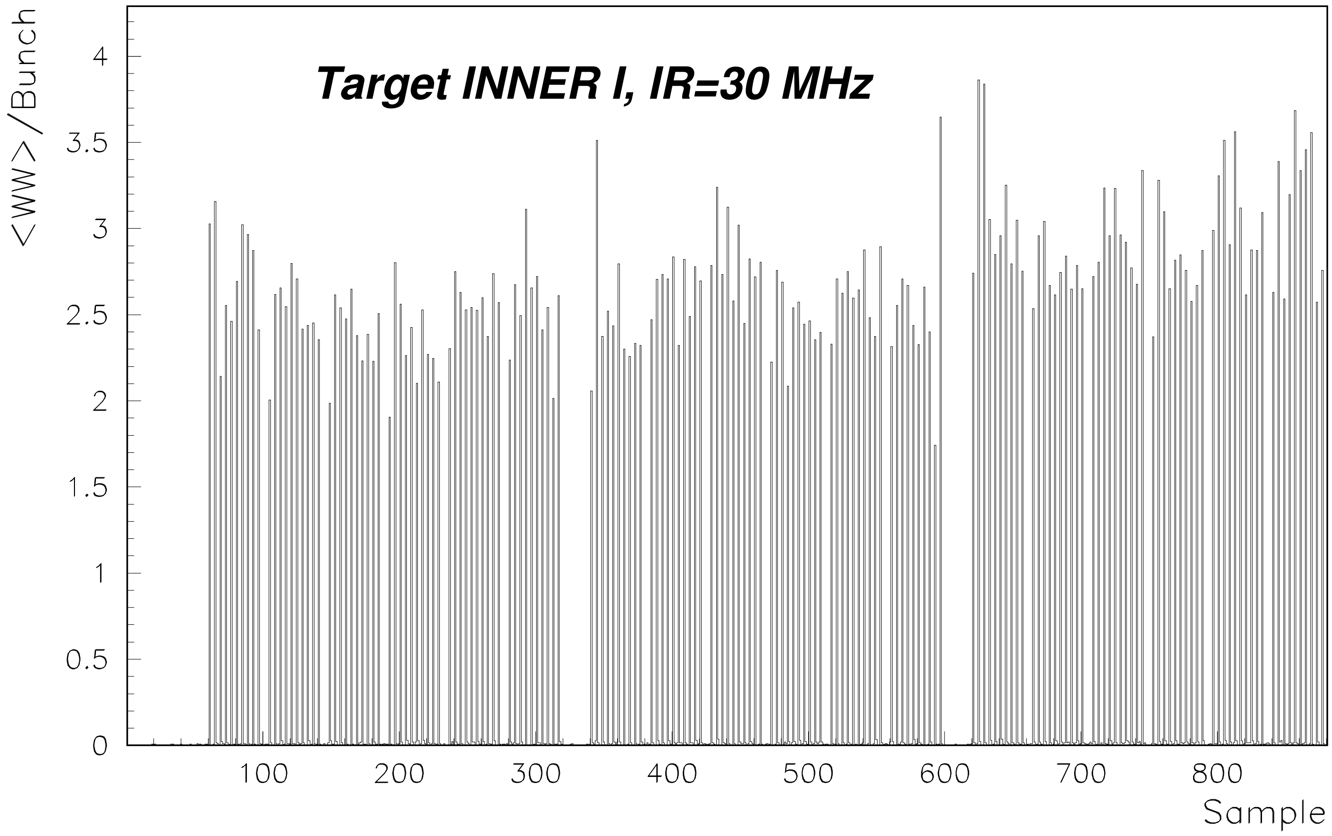
TARGET: Rates and Lifetime



- High rates with $\epsilon_T \geq 60\%$ achieved.
- Proton-beam lifetimes about 50 h.
- Low background for other HERA experiments.
- Little influence on luminosity.
- Automatic target steering established.

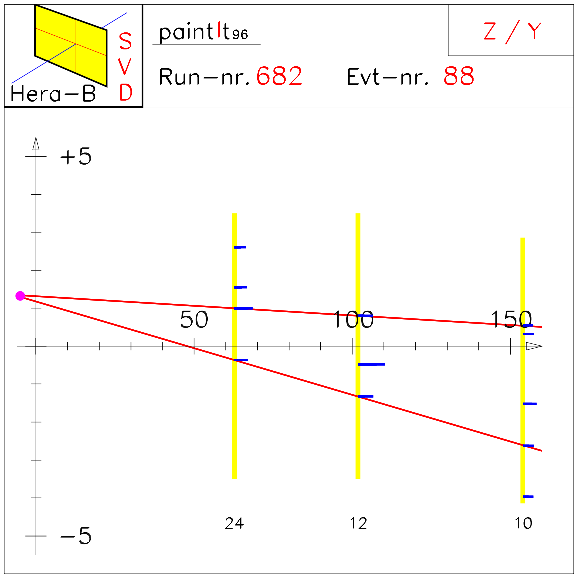
TARGET: Bunch contribution

FADC to resolve HERA bunch structure:
interaction rate contribution of bunches

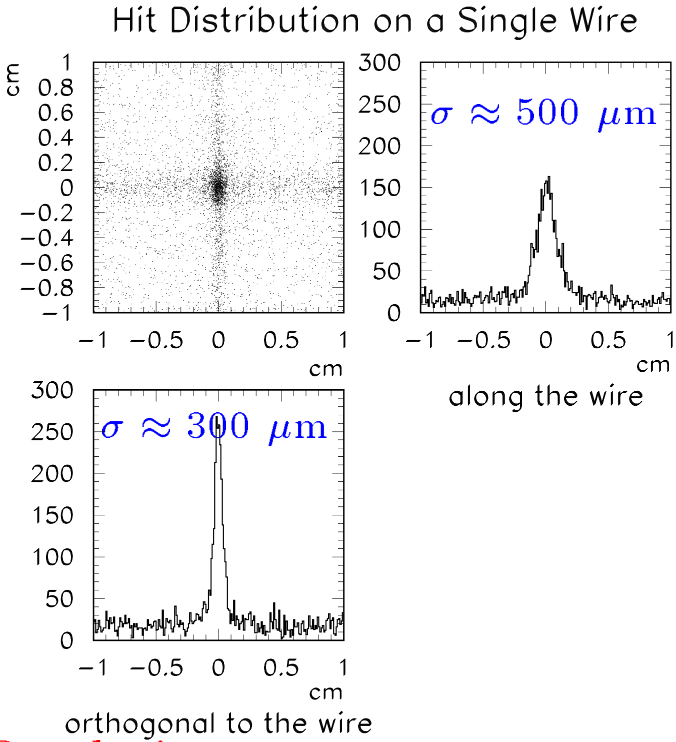


Bunch structure of HERA (1997):
$3 \times (6 \times 10)$ bunches $= 180$ bunches

Vertex Detector 1996



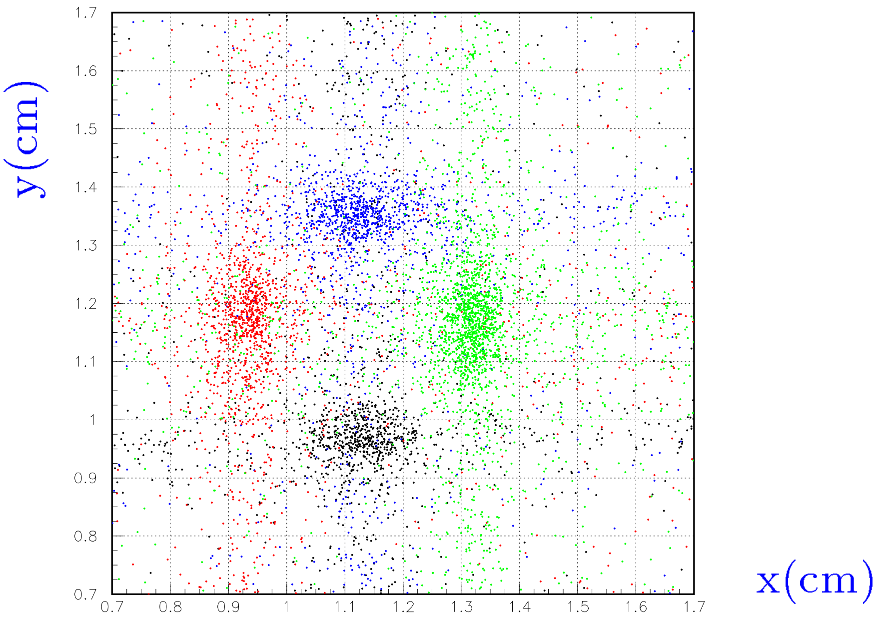
Tracks seen by the VDS



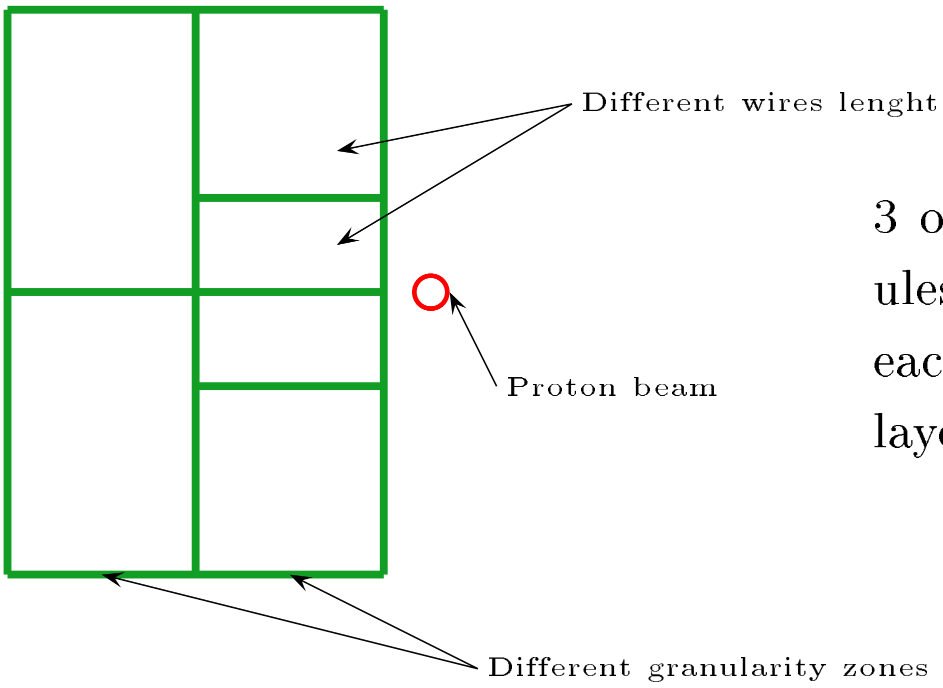
Resolution

The four target wires seen by the vertex detector.

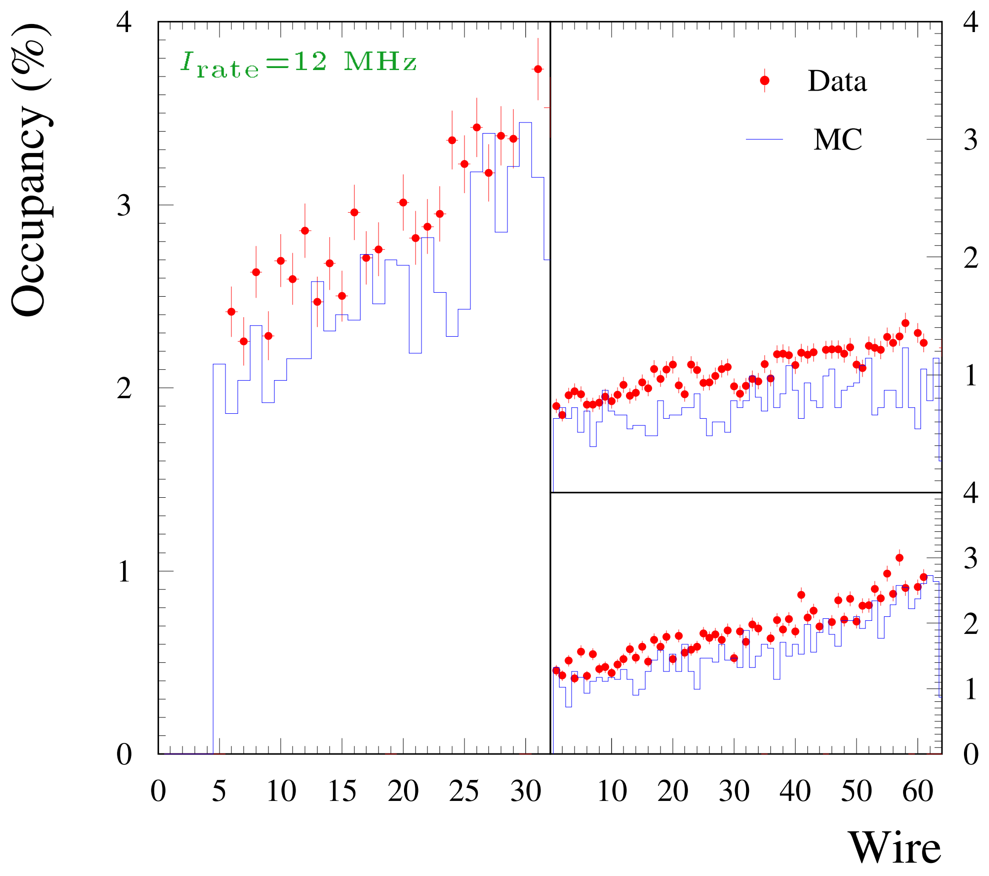
(x,y) coordinates of track candidates at z_{target}.



Outer Tracker: Occupancy

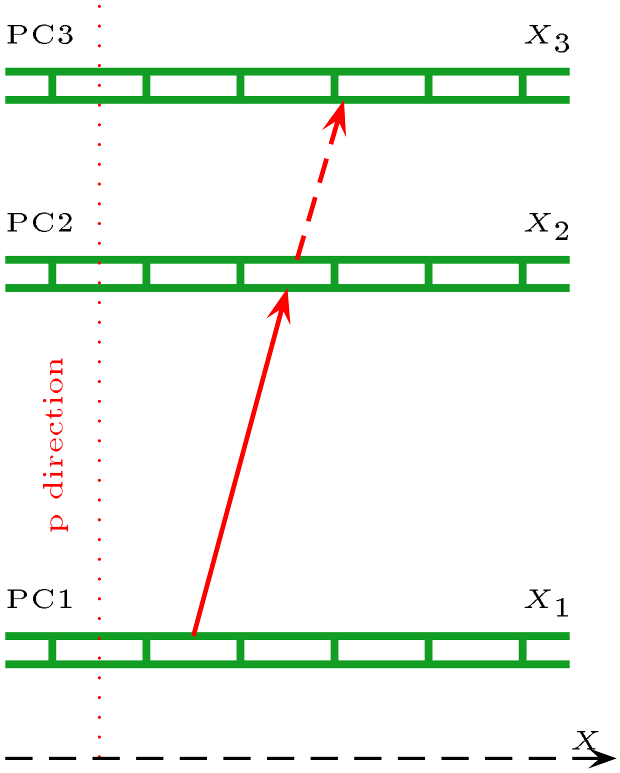


3 of such layer modules are installed in each of the 3 superlayers

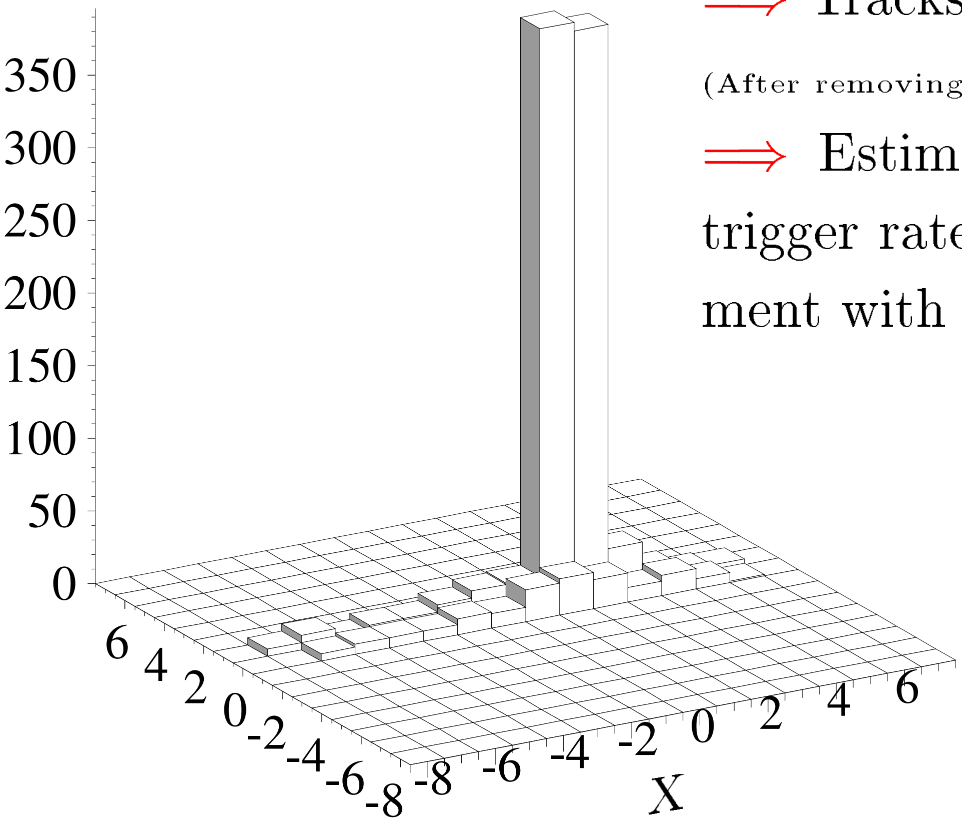


Reasonable agreement between data and MC

High-P$_T$: Track observation



Plot the difference between the extrapolated and hitted cell.

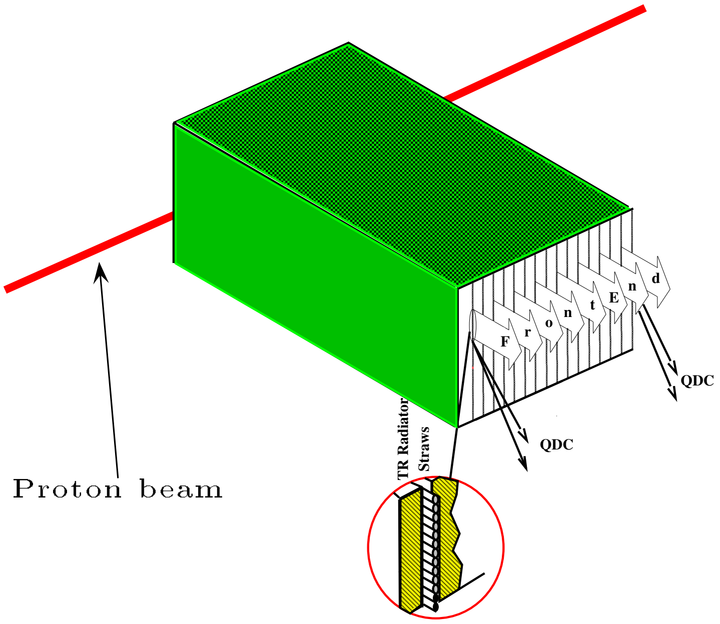


$\Longrightarrow$ Tracks observed.

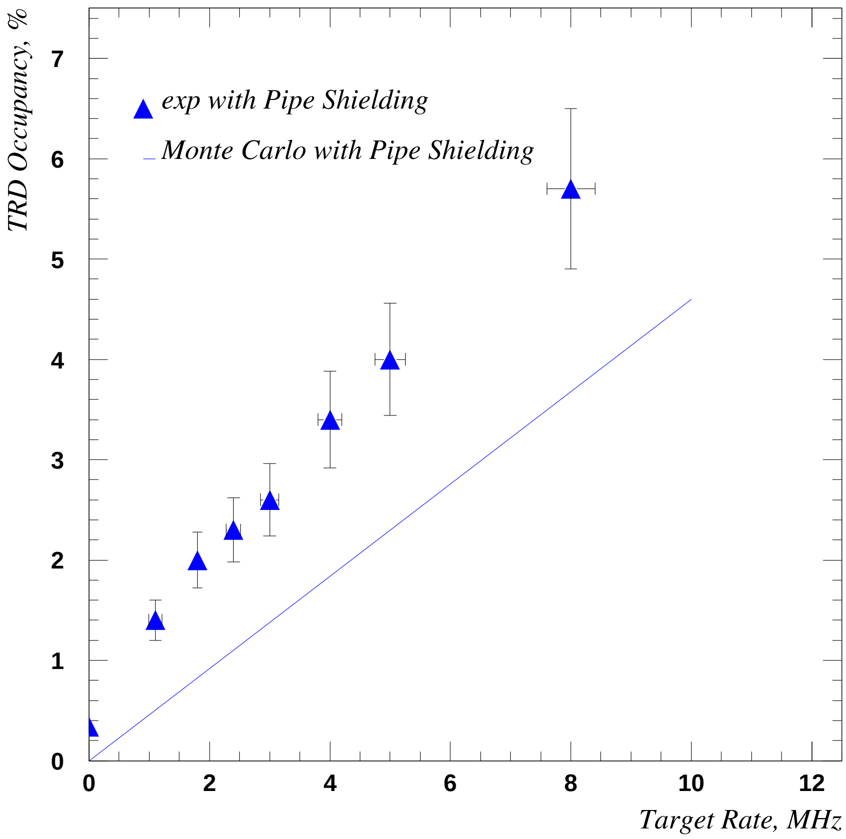
(After removing the beam pipe shielding)

$\Longrightarrow$ Estimations of the pre-trigger rate show good agreement with MC.

TRD: Occupancy



One block of final HERA-B design positioned at z=12 m from the target

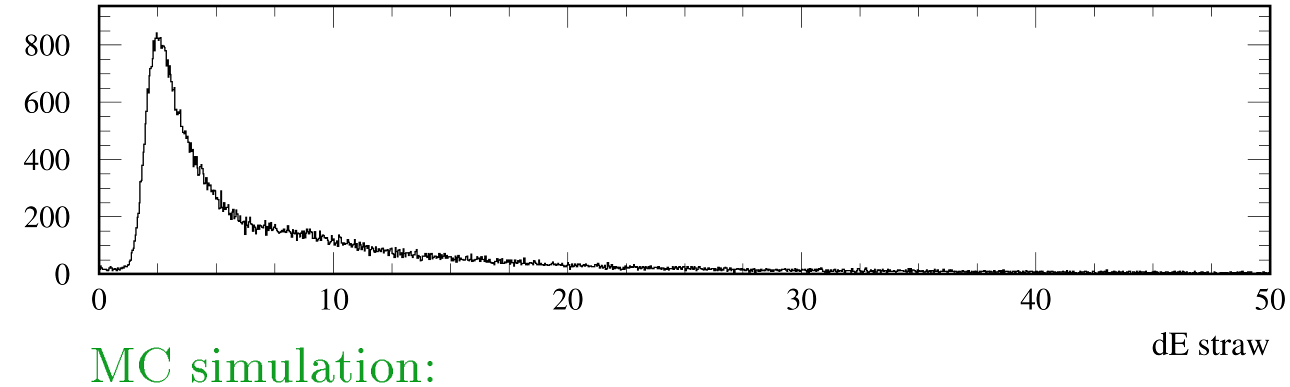


Data shows larger occupancy than MC.

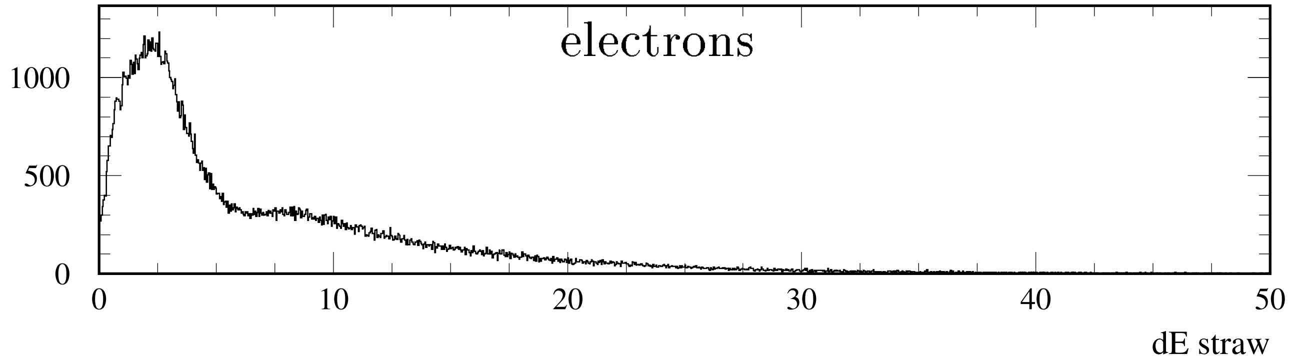
Tansition Radiation signal

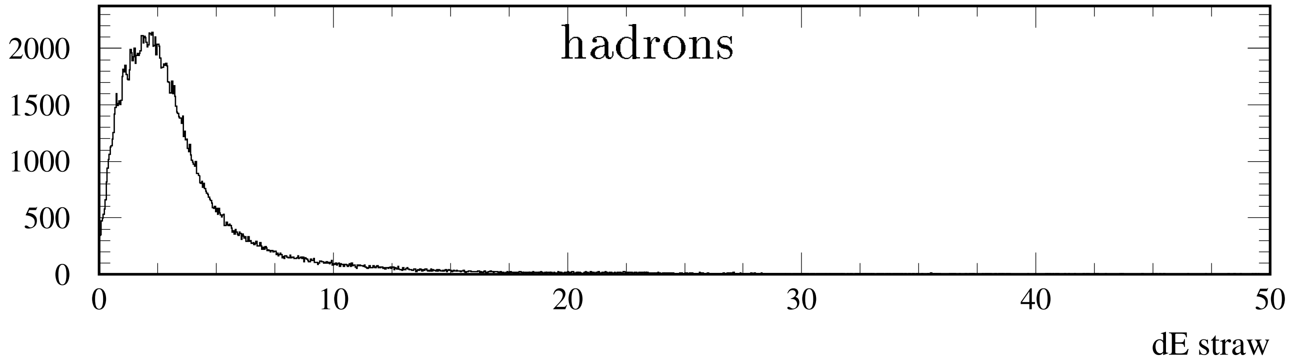
Spectrum of TR signal and MC simulation

Experimental data:



MC simulation:

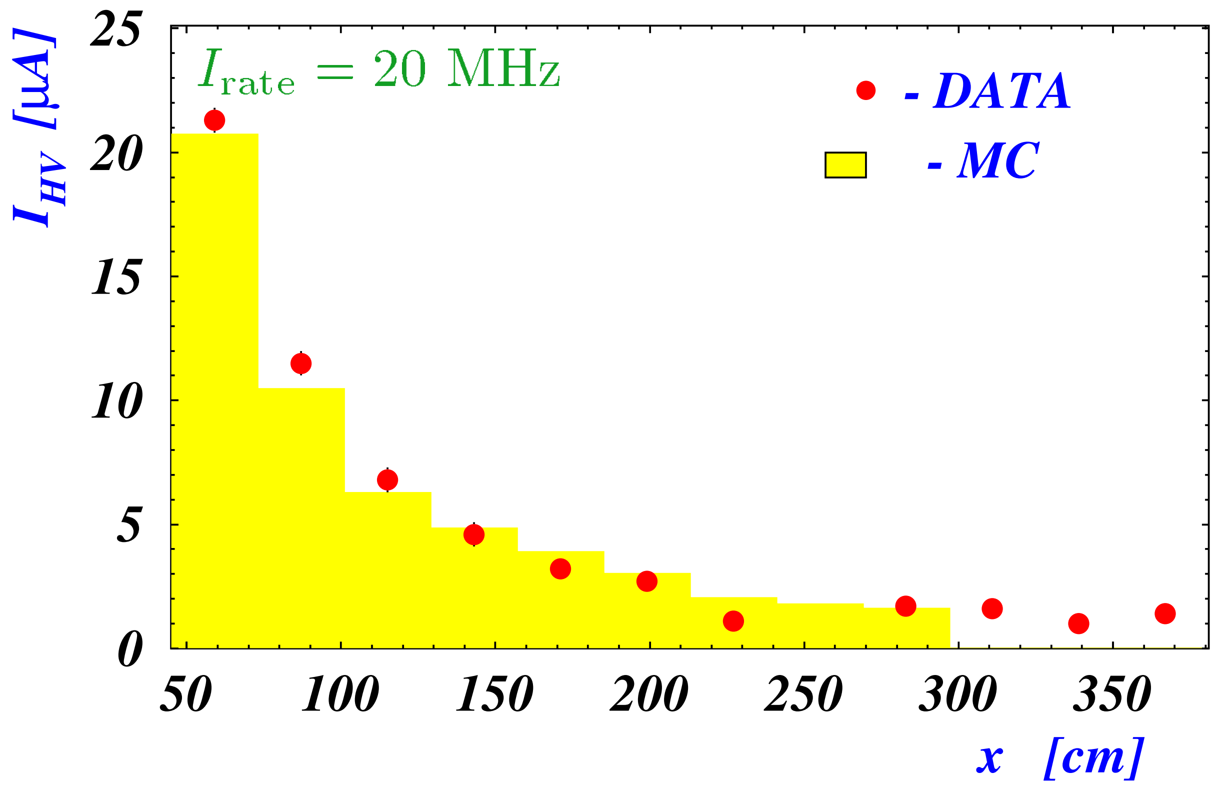




MUON: tube chambers

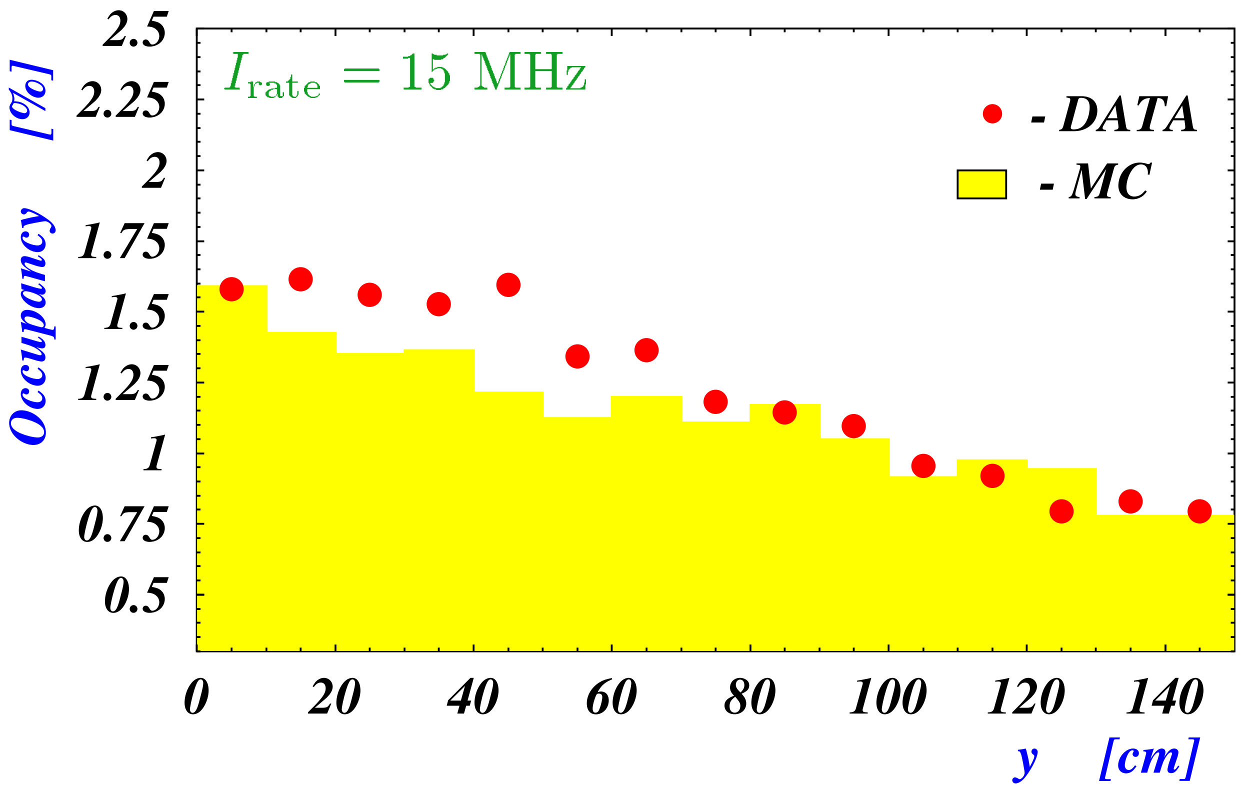
Comparison of the MC and Data shape distributions

MC is normalized to the area under 7 data points.



Good agreement between MC and data *radial* distributions.

MUON: Occupancy

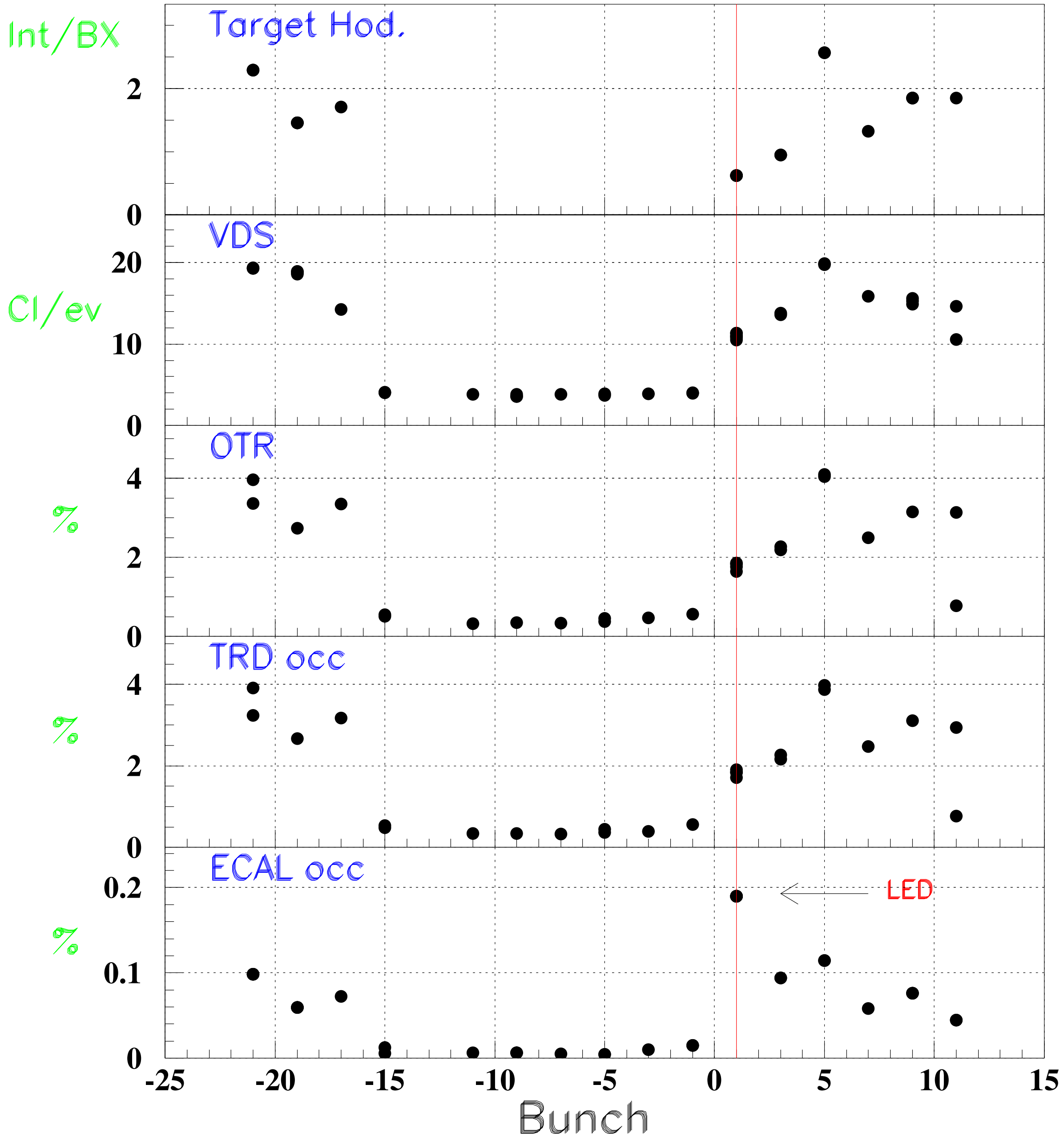


Already good agreement with MC.

Still missing the shielding around the beam pipe.

$\Longrightarrow$ Large background from the Lopez Monitor and the Dump kicker.

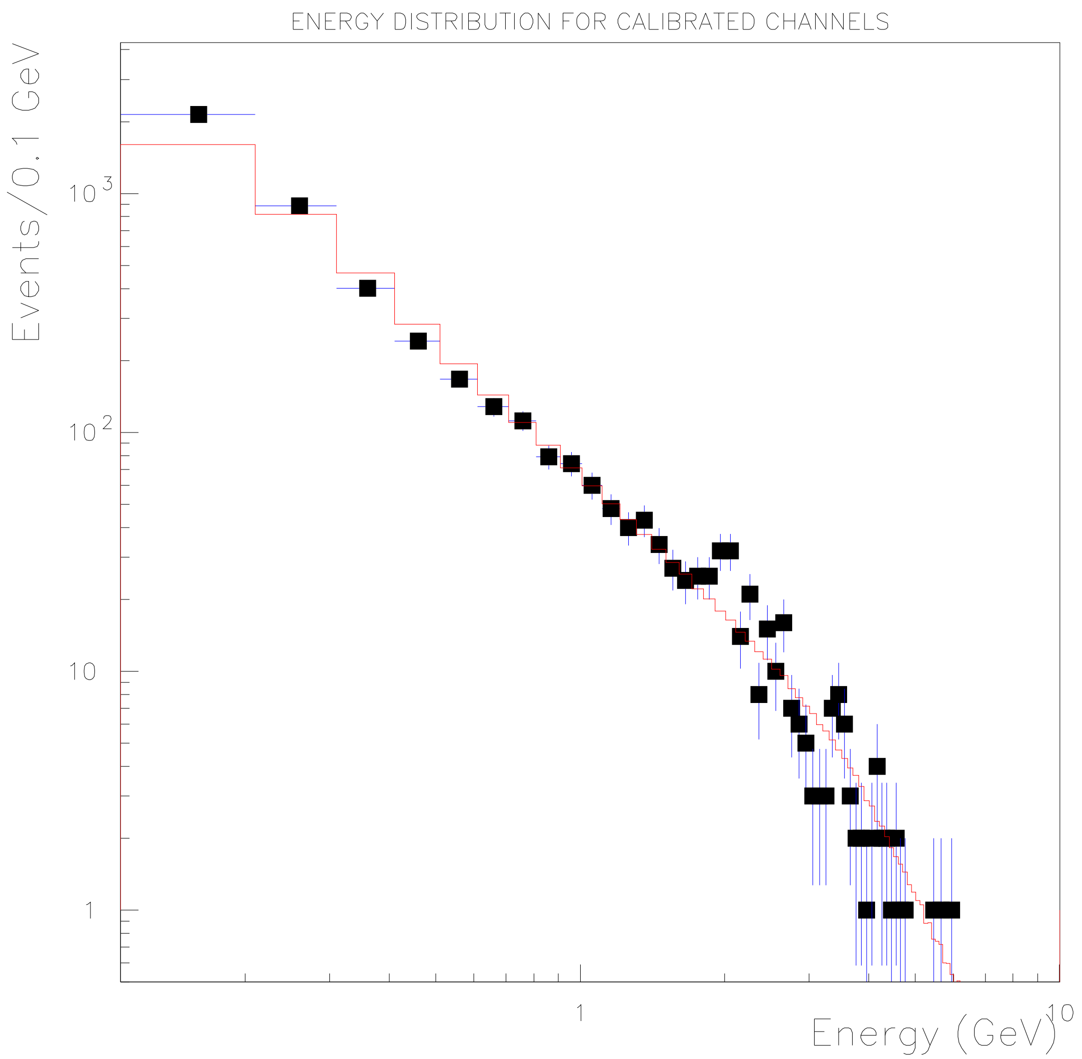
FCS: Synchronization



$\longrightarrow$ Synchronization with "empth bunches"

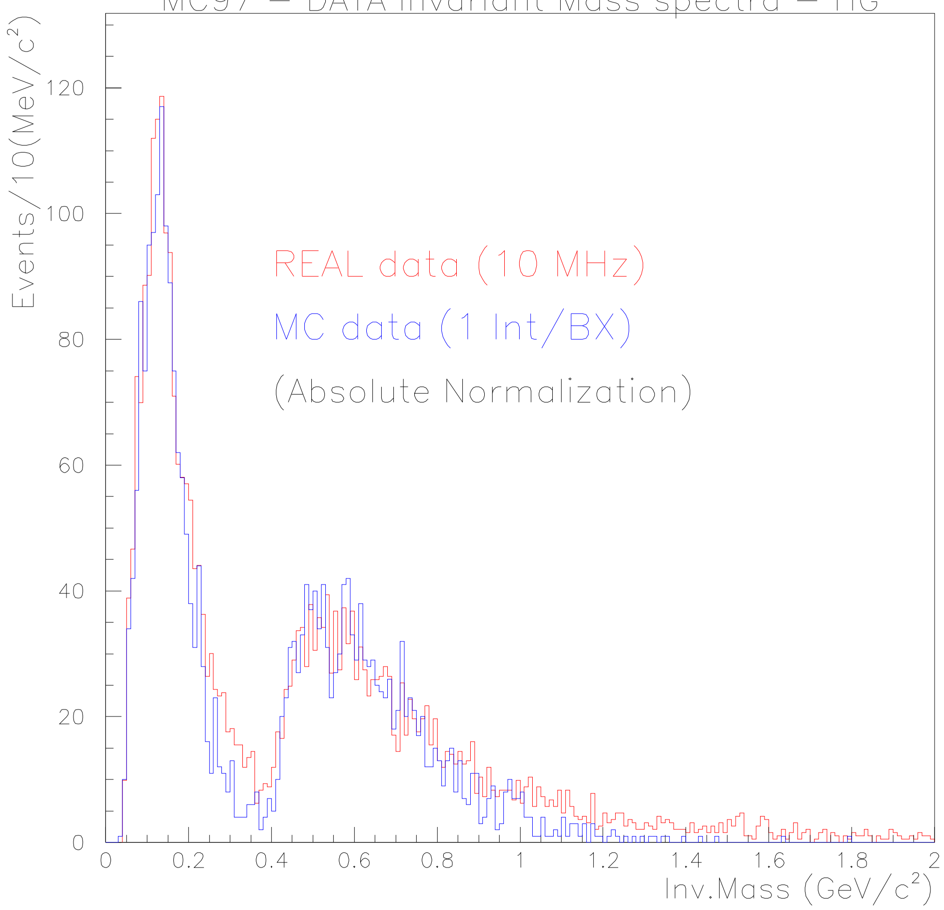
ECAL: Energy spectrum

- Callibration of towers using VDS tracks in association with ECAL clusters.



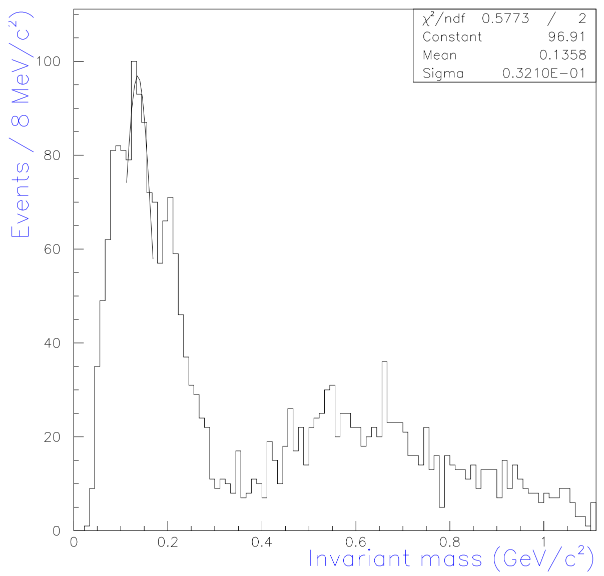
Invariant mass spectrum

$p_{T_{1,2}} > 200$ MeV



$\Longrightarrow$ Reasonable agreement between MC and data

π^0 peak? $\longrightarrow$



Results of the 1996/1997 Run

- Successful Target operation: reliable, secure, long term, multiwire, high rates, efficient, no disturbance of other HERA experiments.
- Tracks reconstructed by the VDS and OTR.
- Occupancies in all detectors in reasonable agreement with GEANT MC calculations.
- High-Pt tracks observed.
- Transition Radiation signals observed.
- ECAL calibration procedures tested.
- Readout of several detectors synchronized.
- essential parts of DAQ system operational:
  FED, FCS, Sharcs ...
- Track and vertex reconstruction software tested.
- '97 run: Inner Tracker proved to work.

successful operation of prototypes

Installation in 1998

- Middle platform finished.
- Electronics hut assembled.
- Muon system: One layer of tube chambers (MU1) and 2 half layers of pad chambers (MU3 and MU4).
- Calorimeter: Fully assembled. Equipped during the year.
- RICH: Completed.
- TRD: 80% ready. Front End electronics to be installed during the year.
- Inner Tracker: One superlayer to be installed.
- Outer Tracker: One superlayer (MC2) and 3 minisuperlayers to be installed in the Pattern Recognition area.
- high-P_T chambers: One layer installed.
- VDS: 12 detectors installed in 3 layers.
- Target: 2 stations (total of 8 wires) installed.
- DAQ: To be commissioned during the year.
- FARM: 100 PC nodes for triggering.

$\Longrightarrow$ Test and commission the maximum number of components.

$\Longrightarrow$ observe J/ψ observe $B \to J/\psi X$?).

Expected number of events

Mode	Trigger	Events/year
$B^0 \to J/\psi K^0_S$	J/ψ	$\approx$ 1500
$B^0 \to J/\psi K^{*0}$	J/ψ	$\approx$ 5500
$B^+ \to J/\psi K^+$	J/ψ	$\approx$ 7000
$B^+ \to J/\psi K^{*+}$	J/ψ	$\approx$ 1500
$B^0_s \to J/\psi \phi$	J/ψ	$\approx$ 1500
$\Lambda_b \to J/\psi \Lambda$	J/ψ	$\approx$ 500
$B^0_s \to D_s^{(*)} \ell^+ \nu$	$\ell\ell$	$\approx$ 900
$B^0_s \to D_s^{(*)} \pi^+$	ℓh	$\approx$ 200
$B^0_s \to D_s^{(*)} \pi^+ \pi^+ \pi^-$	ℓh	$\approx$ 200
$B^0 \to \pi^+ \pi^-$	hh	$\approx$ 800
$B^0 \to \pi^\pm a_1^\mp$	hh	$\approx$ 300
$B^+ \to \rho^0 K^+$	hh	$\approx$ 500

$$\sigma^{\mathrm{tot}}_{\mathrm{b\bar{b}}} = 12\,\mathrm{nb} \ @ \ 40\,\mathrm{MHz}$$

	# events per year	**HERA–*B* physics**
$B \to J/\psi\, X$	$\approx 2.6 \cdot 10^5$	$\approx$ 17 000 reconstructed B decays $\left.\begin{array}{l} 1500\ \ J/\psi\, K^0_S \\ 5500\ \ J/\psi\, K^{*0} \end{array}\right\}\ B^0$ $\left.\begin{array}{l} 7000\ \ J/\psi\, K^{+} \\ 1500\ \ J/\psi\, K^{*+} \end{array}\right\}\ B^+$ $\left.1500\ \ J/\psi\, \phi\ \right\}\ B_s$ $\left.500\ \ J\psi\, \Lambda\ \right\}\ \Lambda_B$ – lifetimes $\Rightarrow \lvert v_{cb}\rvert$ – unbiased B sample – CP violation – B_c, Λ_b – rare decays – QCD ($gg \to b\overline{b}$) – other CP decays – $B \to ll$
$B_1 B_2 \to l_1 l_2\, X$	$\approx 1.4 \cdot 10^6$	– $B^0\overline{B^0}$ mixing – $B^0_s\overline{B^0_s}$ mixing ($l_1\, l_2\, D_s^{(*)}\, \nu\nu$)
$B \to l_1\, C\, X$	$\approx 3.8 \cdot 10^5$	– $D^0\overline{D^0}$ mixing ($B \to [D^0 \leftrightarrow \overline{D^0}]\, l\, \nu \to l^\pm\, l^\pm\, X$) – v_{cb} – v_{ub}, B_c, $B \to ll$, rare decays – source for unbiased B mesons
$B \to l\, X$	$\approx 3.2 \cdot 10^6$	– unbiased tag of the second B meson

Other channels are not so detailed studied as $B^0 \to J/\psi\, K^0_S$

Other CP experiments

	Hera-B	BaBar	Belle	CDF
Start	1999	1999	1999	99/2000
$\mathcal{L}(\mathrm{fb}^{-}1)$	(50) 40MHz/12nb	30	100	1 $(100\mu b)$
$\mathrm{N(B}\rightarrow J/\Psi K_s^0)$	1400	1100	2000	7.5k
$\Delta\sin 2\beta$	0.13	0.10	0.08	0.14
all channels $\Delta\sin 2\beta$	0.12	0.06	0.06	0.14
$\mathrm{N(B}\rightarrow\pi^+\pi^-)$ $\Delta\sin 2\alpha$	850 $0.14\times$ $(1+B/S)^{0.5}$	350 0.20	650 0.15	5k 0.14

All numbers assume running during one year (10^7 s)

Summary and Conclusions

- CP reach of HERA-B:

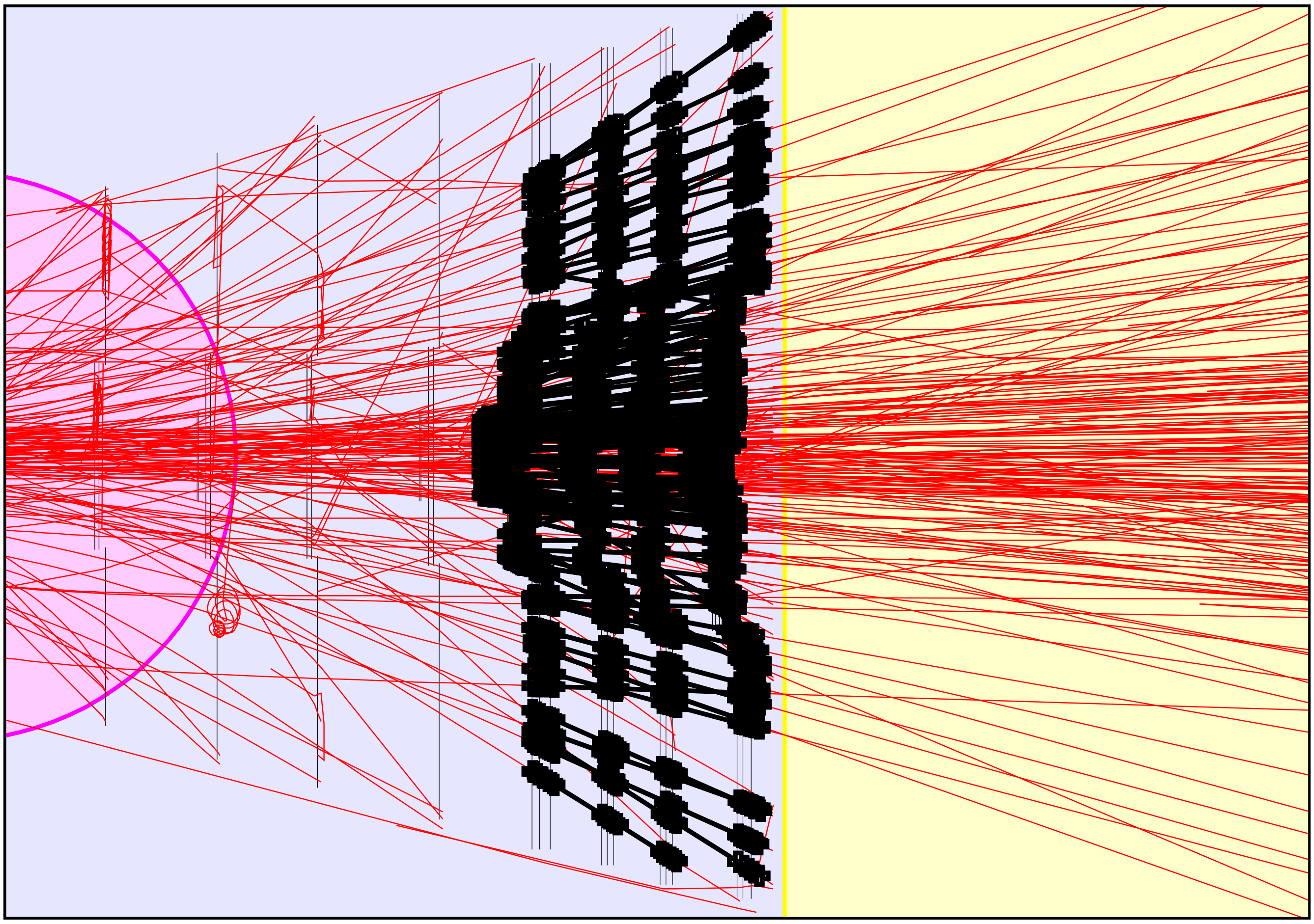
$$\begin{array}{lll} \Delta \sin 2\beta \approx & 0.11 \ldots 0.18 & 1 \text{ year} \\ & 0.07 \ldots 0.10 & 3 \text{ years} \end{array}$$

- HERA-B tests techniques for the LHC experiments.
  - → Need GEM-MSGC.
  - → Radiation damage in OTR ⇒ Foil coating.
- Very fruitful test runs in 1996/1997:
  - → Successful target operation.
  - → Prototypes of Vertex Detector, Outer Tracker, ECAL, TRD and Muon chambers operated.
  - → New DAQ techniques tested.
  - → Analysis of data shows good agreements with MC.
- Only small parts of the tracking system installed in 1998.
- The goal: Physics Run in 1999 is tough but still reachable.

Pattern Recongnition ?

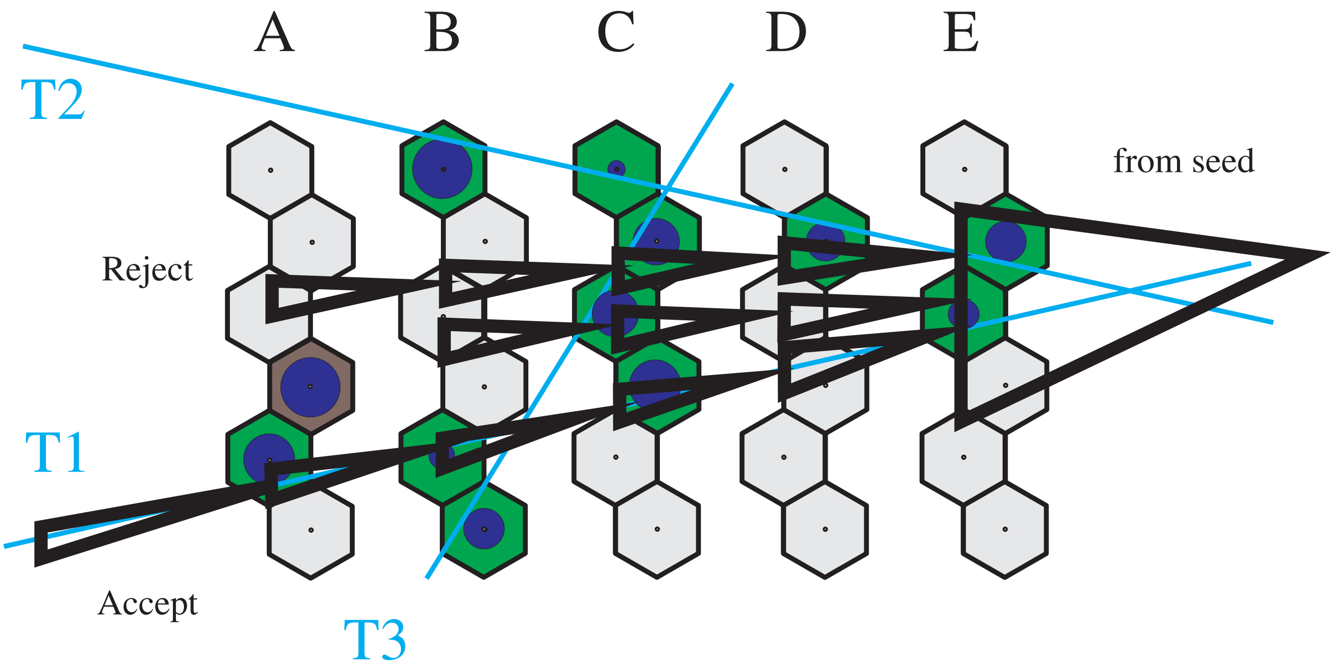
Large Occupancy and l/r-ambiguity.

→ An example of challenging pattern recognition.



Pattern Recognition

Local methode for Pattern Recognition:
Concurrent Track Evolution



- Initial seeds define a triplet.
- Too many faults → Eliminate.
- Tracks with maximum quality survive

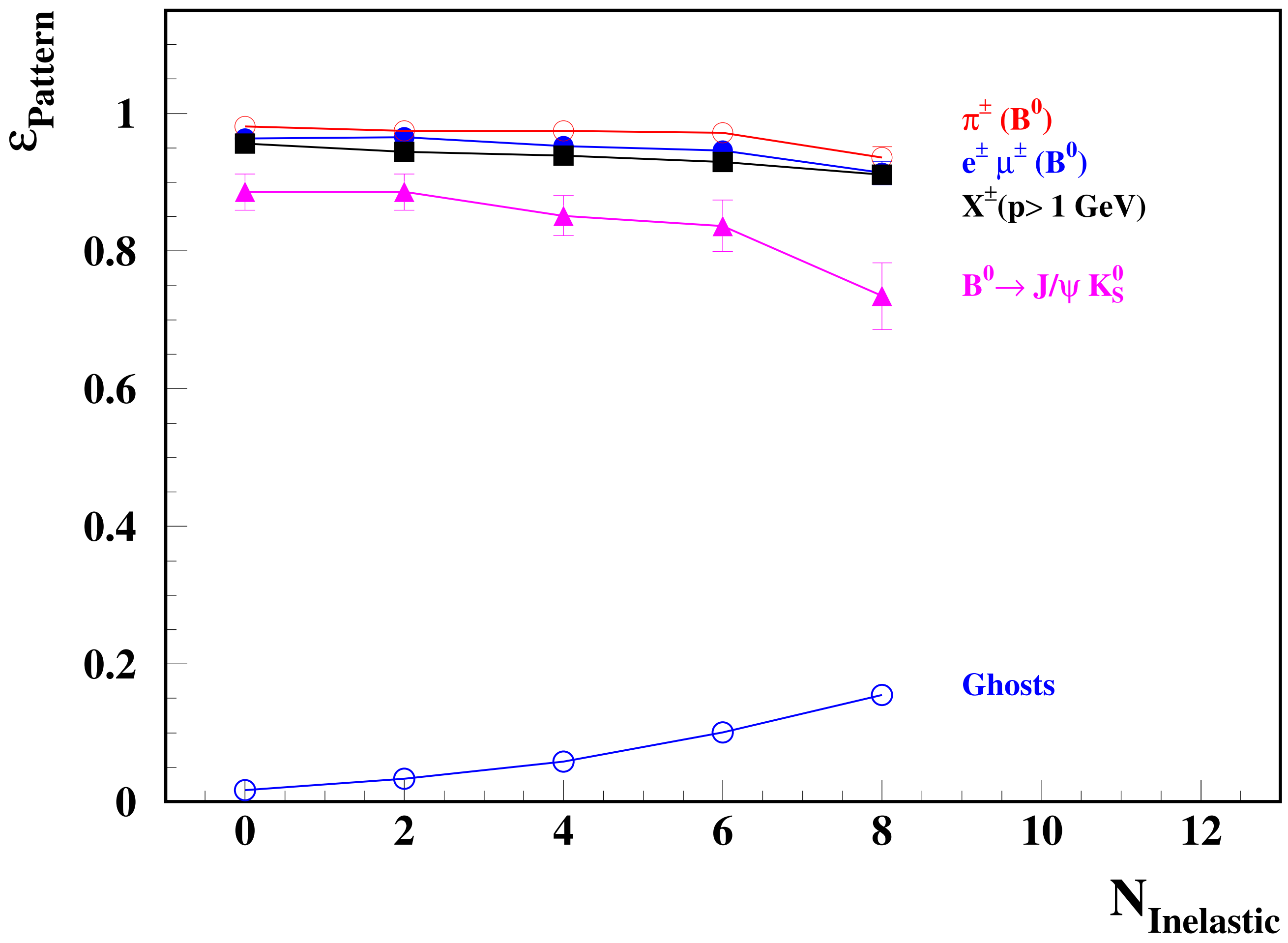
$$Q = N_{\mathrm{Steps}} - N_{\mathrm{Faults}} - w_{\chi^2} \sum \chi_i^2$$

→ Any number of Track-candidates possible

Reconstruction efficiency

ITr: $\epsilon_{\mathrm{Hit}} = 95\%$ und $\sigma = 80\mu\mathrm{m}$

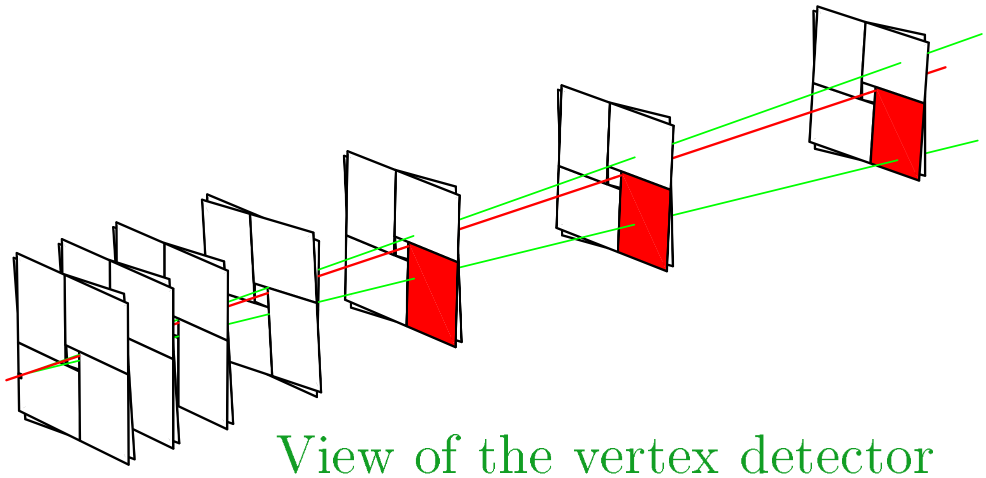
OTr: $\epsilon_{\mathrm{Hit}} = 98\%$ und $\sigma = 200\mu\mathrm{m}$



for 1+4 Events: Reconst-Efficiency for

$B \rightarrow J/\psi K^0_S \approx 85\%$

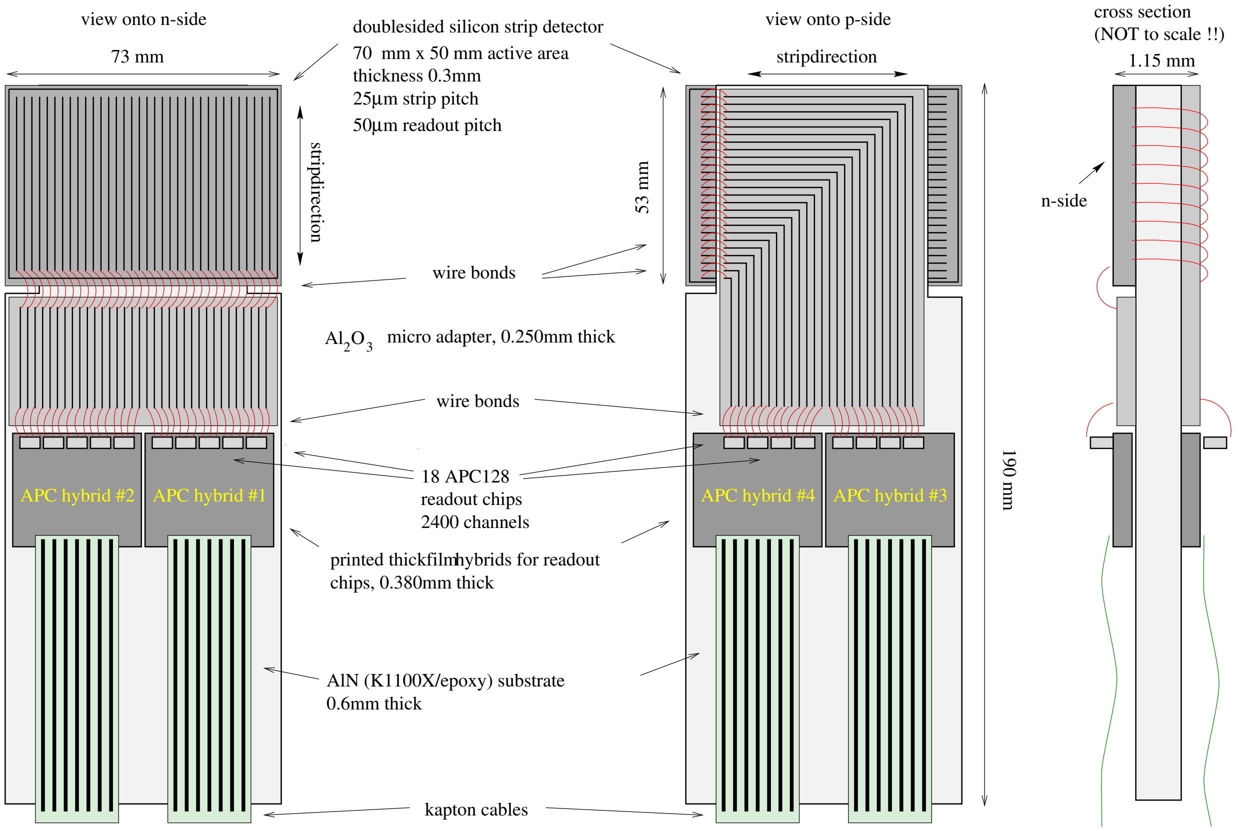
The vertex detector



View of the vertex detector

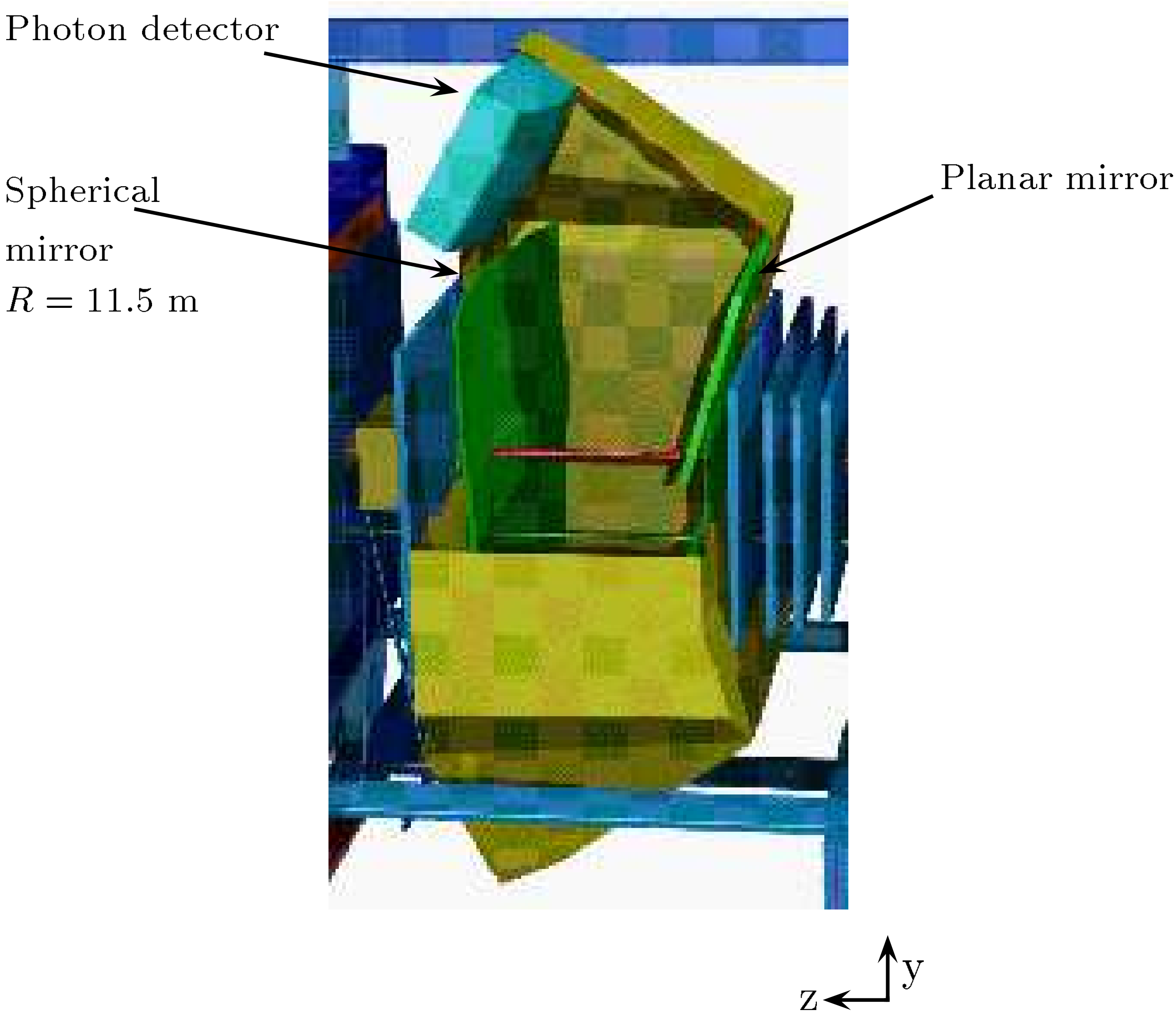
- technology. : Silicon microstrips
- # of channels : ~ 165000
- angular acceptance : 10 to 250 mrad
- # of super-layers : 7
- strip orientation : 0 ± 2.5^o, 90 ± 2.5^o.
- sensitive surface : 50×70 mm^2
- instalation : Roman-Pot system
- resolution : ~ 30 μm

The vertex detector



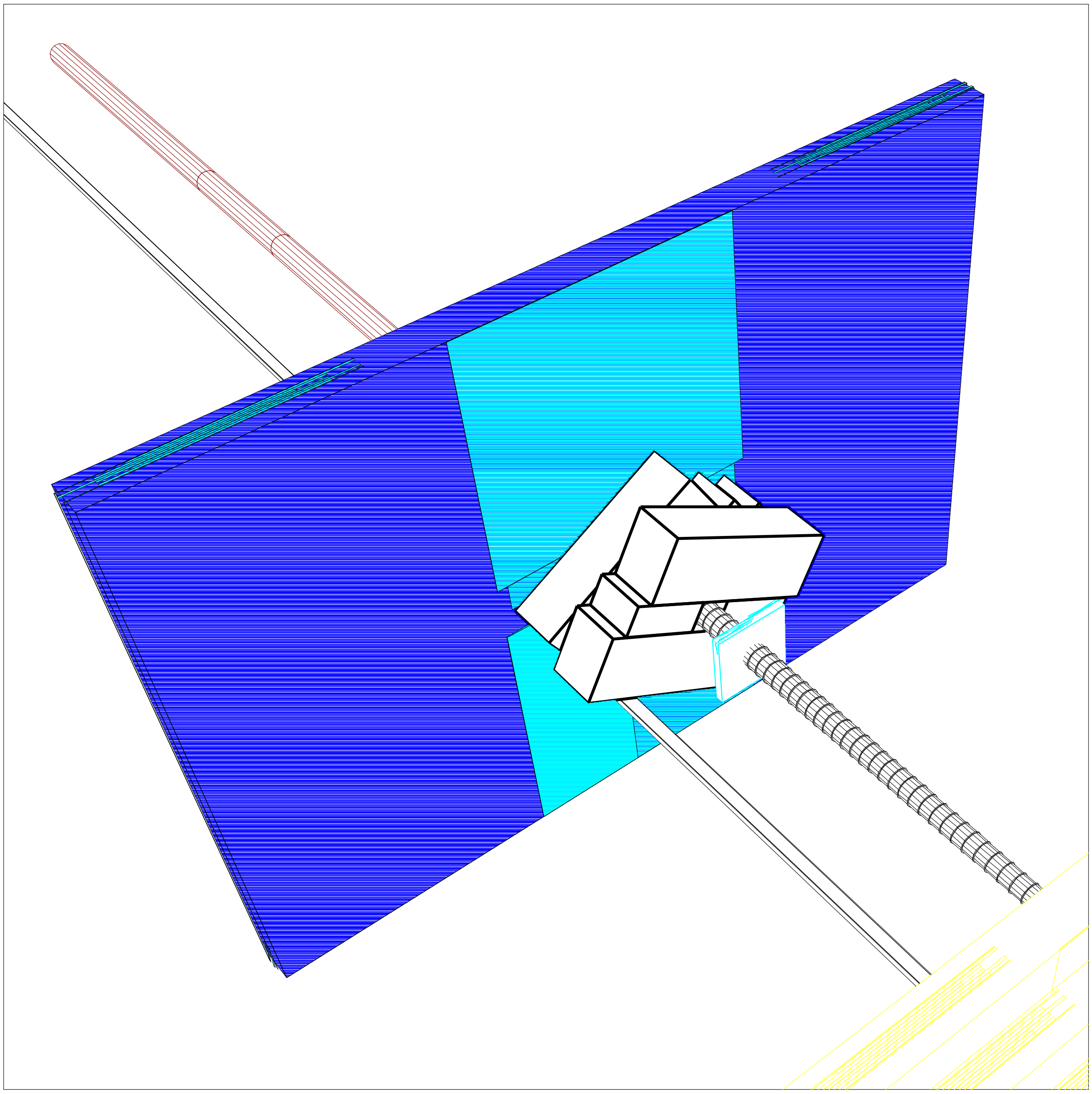
Detail of a module of the vertex detector

Ring Image CHerenkov



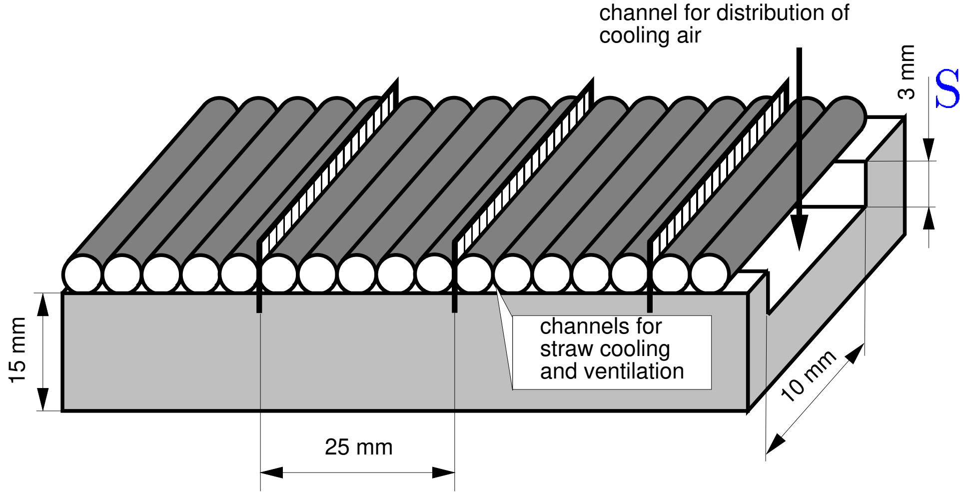
- Radiator : C_4F_{10}
- Radiator lenght : 2.7 m
- Photon detectors : 16(4) multianode PMT.
- $\#\ \gamma/\text{particle} \sim 20$
- K/π separation : $3\ \sigma$ $(10 - 75$ GeV$)$

Transition Radiation Detector

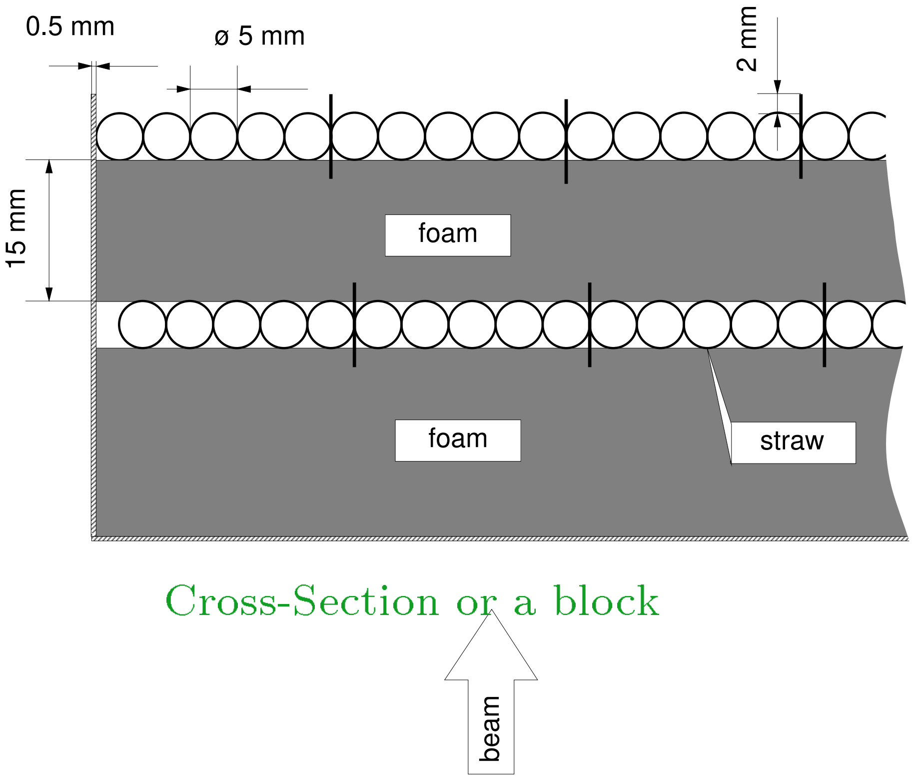


- TRD for electron identification
- # of layers: 32 (Radiator + straw tubes)
- Two views: $+30^o$ and -30^o
- Electron identification efficiency: $\sim$ 98%
- hadron/e missidentification 7% ($1 - 90$ GeV)

Transition Radiation Detector



TRD detail



Cross-Section or a block

Straws :

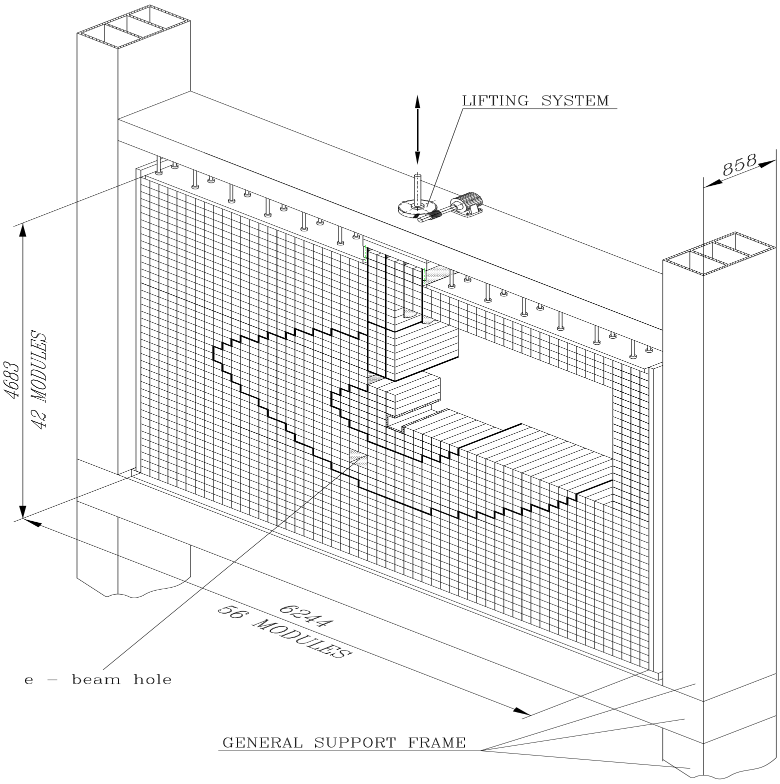
- Proportional tubes
- Lenght: 35 cm, 60 cm
- Gas : $70\%\mathrm{Xe} + 20\%\mathrm{CF}_4 + 10\%\mathrm{CO}_2$

Radiator :

- NEOPOLEN-P foam
- Density : 65 g/l
- Absorption length : 1.5 cm
- Used also as mechanical support

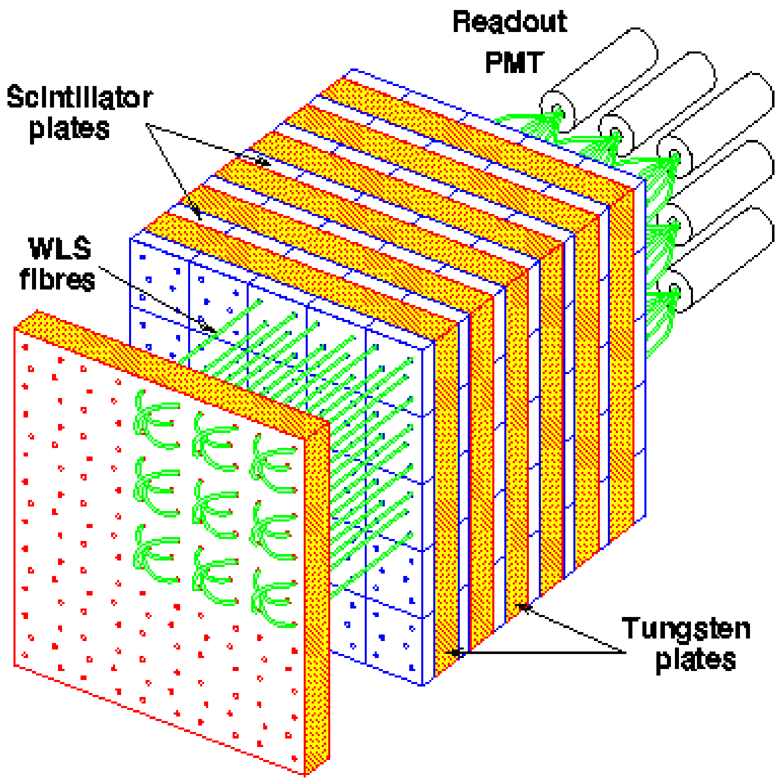
Electromagnetic CALorimeter

Technique: Shashlik
3 sections :
inner: $2.23 \cdot 2.23\ \mathrm{cm}^2,\ 22\ X_0$
mid.: $5.575 \cdot 5.575\ \mathrm{cm}^2,\ 20\ X_0$
Outer: $11.15 \cdot 11.15\ \mathrm{cm}^2,\ 20\ X_0$



Inner module

absorber: W-Ni-Fe
WLS: Kuraray Y-7
PM : FEU-68



$$\boxed{\sigma(E)/E = 15\%/\sqrt{E} + 1.3\%}$$

MUON system

Technique:

Tubes

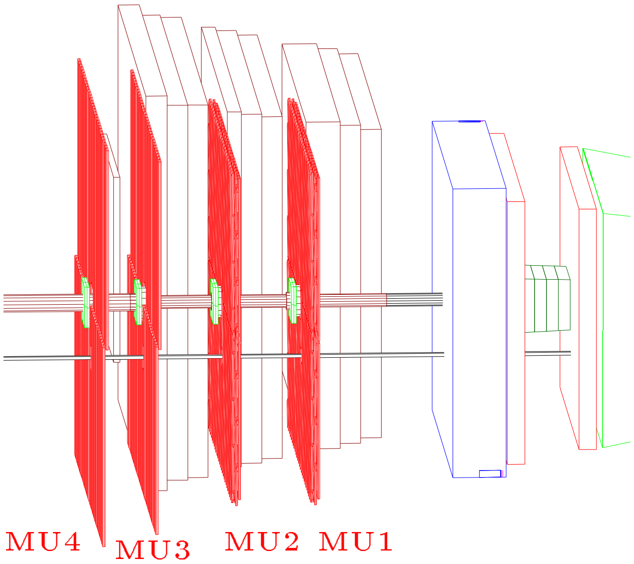
Pads

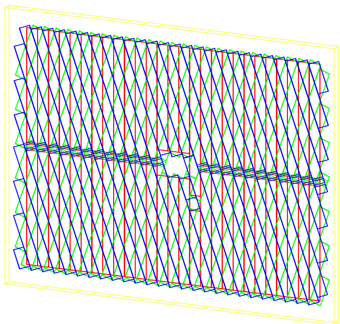
Pixels

channels: ~31500

Surface.: 340 m^2

Gas : CF_4 based

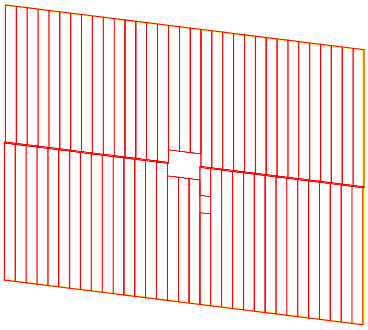




MU1-2: Tube chambers

Double layers : 0^o, $\pm 20^o$

signal : 40 μm Au-W wires



MU3-4: Pads

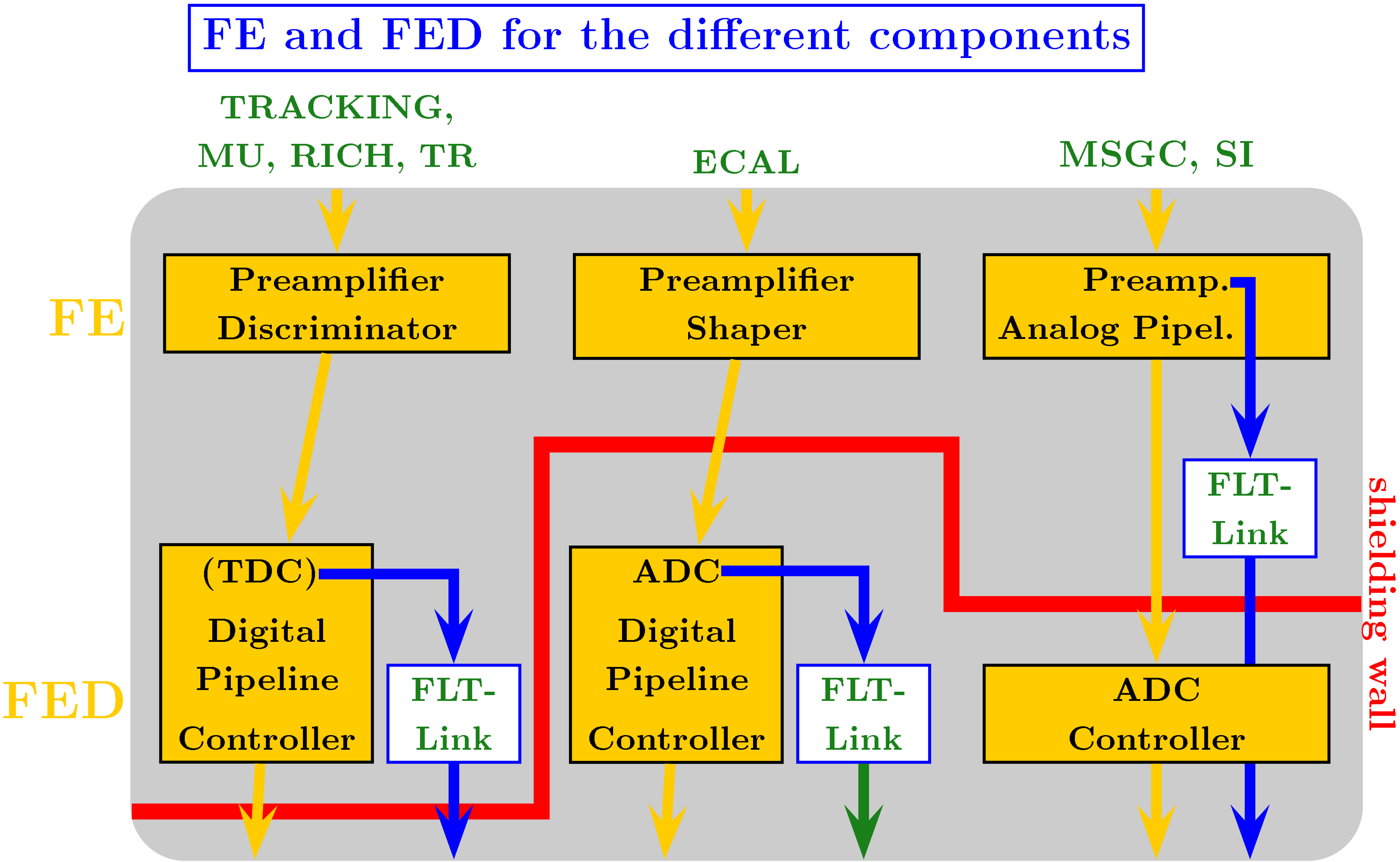
projective arrangement

signal : Pads and wires

Inner chambers: Gas pixel

cell size (x,y,z)MU1-3: 9 x 9 x 30 mm^3

cell size (x,y,z)MU4 : 9.4 x 9.4 x 30 mm^3


FE and FED for the different components
TRACKING,
MU, RICH, TR
ECAL
MSGC, SI
FE
FED
Preamplifier
Discriminator
Preamplifier
Shaper
Preamp.
Analog Pipel.
FLT-
Link
(TDC)
Digital
Pipeline
Controller
FLT-
Link
ADC
Digital
Pipeline
Controller
FLT-
Link
ADC
Controller
shielding wall