IEEE NUCLEAR & PLASMA SCIENCES SOCIETY
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Medical Imaging Conference
13th International Workshop on Room-Temperature Semiconductor X- and Gamma-Ray Detectors
Symposium on Nuclear Power Systems
October 19-25, 2003 • Doubletree Hotel -- Hayden Complex • Portland, Oregon, U.S.A.

The LHCb Experiment

Matthias Moritz

On behalf of the LHCb collaboration

- Introduction and physics goals
- The LHCb detector and its components
- LHCb trigger
- Summary

Introduction

- **LHCb is designed to make precision measurement of CP violation and other rare phenomena in the b system**
  - **B mesons are a "laboratory" where theoretical predictions can be precisely compared with experimental results**
    - **Check consistency of Standard Model**
    - **Search for new physics**
- **Crucial to trigger and reconstruct many different decay modes (with small BR) to make independent and complementary measurements**

  $B_d \rightarrow J/\Psi$ ($\mu\mu$/ee) K_s, $D^*\pi$, D^0K^*, $\pi\pi$, $K\pi$, $\rho\pi$, $K^*\gamma$, $K^*\mu\mu$, . . .

  $B_s \rightarrow J/\Psi\ \phi$, D_sK, $D_s\pi$, KK, $\phi\phi$, $\phi\gamma$, . . .
  - **ParticleID**
  - **Excellent mass and decay time resolution**

CP violation in 2007

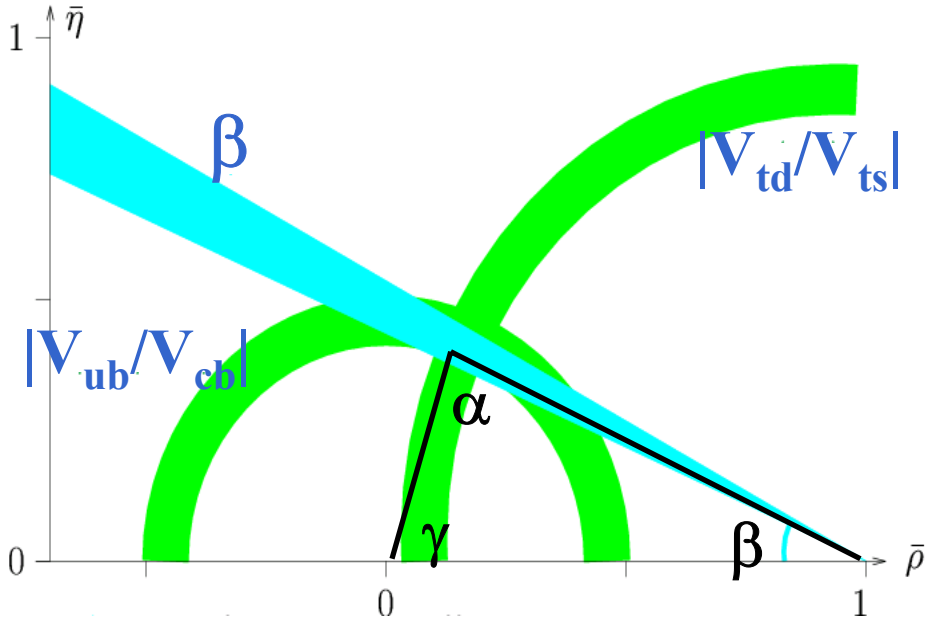
- σ_{world} (sin 2β) ~ 0.02
- σ(sin 2α) ~ 0.1
- σ (γ) ~ large ?
- |Vtd|/|Vts| from Δ m_S

  by CDF & D0 (UL so far)

  ~ 5-10% (for Δ m_S <40 ps-1)
- |Vub|/|Vcb| from b → u

  by BaBar & Belle

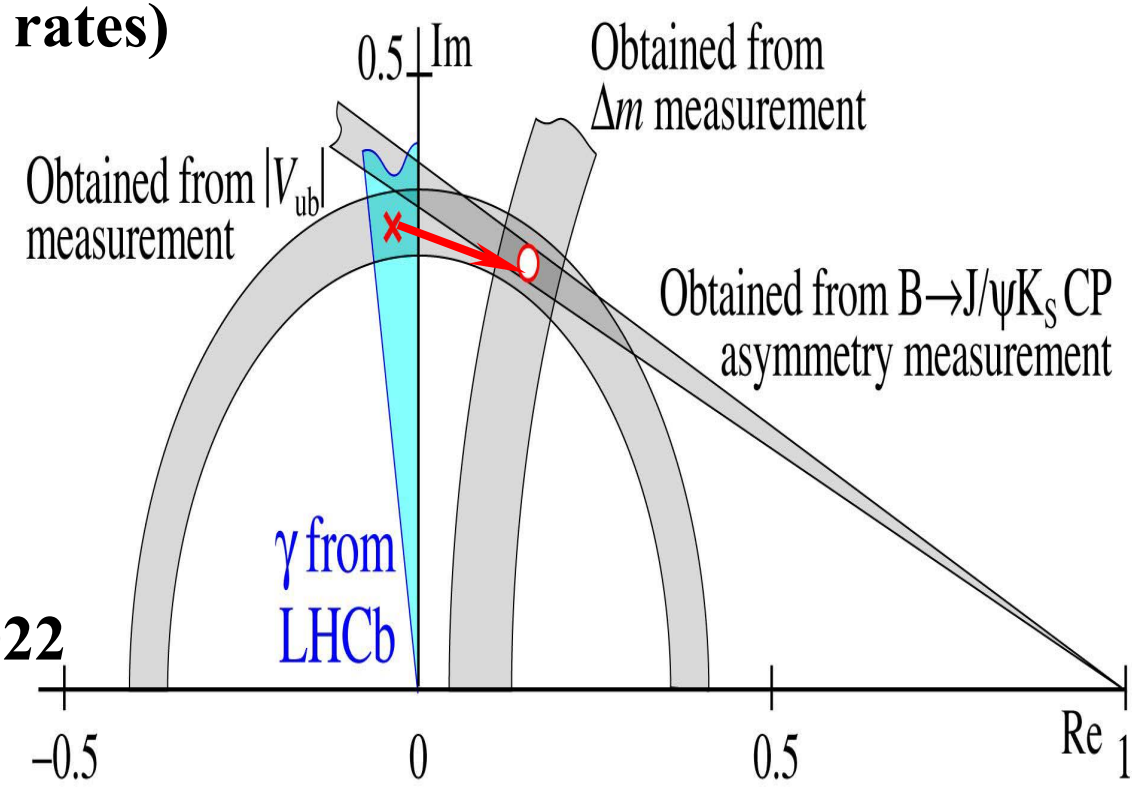
  (limited by theory)



γ from LHCb

γ from different channels:

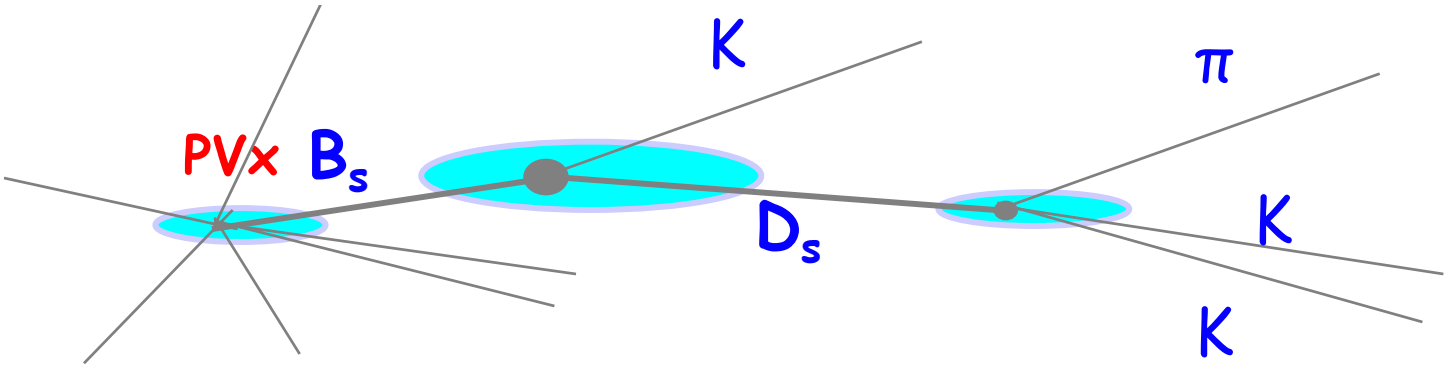
- **$B_s \rightarrow D_s K$ (annual yield ~5.4k events)**
- **$B \rightarrow \pi\pi$ (26k), $B_s \rightarrow KK$ (37k)**
- **$B \rightarrow DK^*$ (4.5k of 6 decay rates)**



- **high statistics: $\sigma(\sin 2\beta) = 0.022$**
- **Δm_s, rare decays**

Experimental Requirements

- Efficient trigger
- Good vertexing
- Kinematics measurement
- Particle identification
- Control of systematics

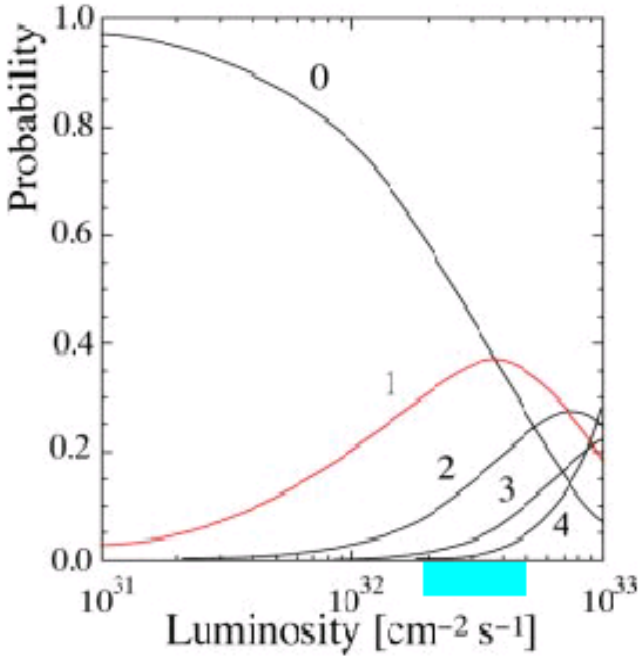


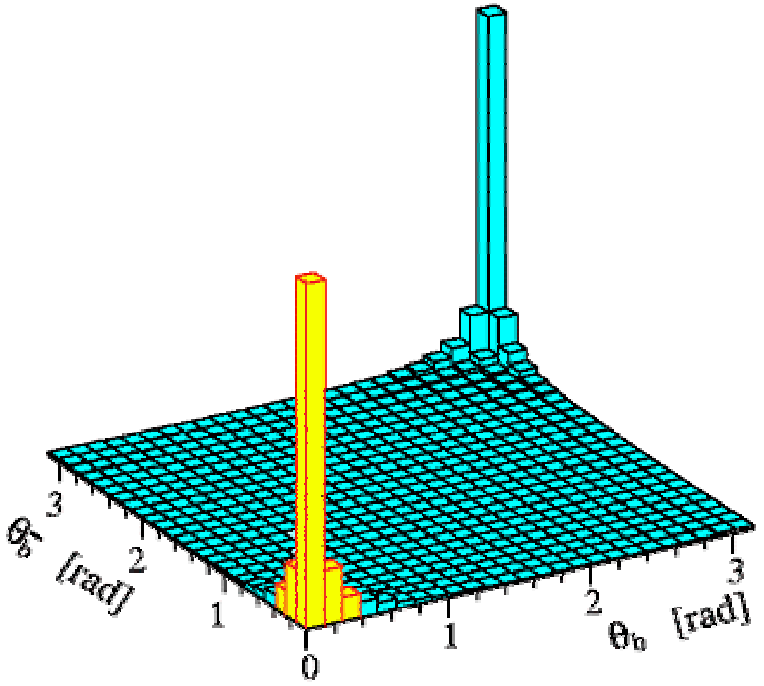
Forward spectrometer: LHCb

- **LHC Luminosity @ LHCb: 2×10^{32} cm^{-2} s^{-1}**
- **$\sigma_{bbar} = 500$ µb**
- **$\sigma_{inelastic} = 80$ mb**

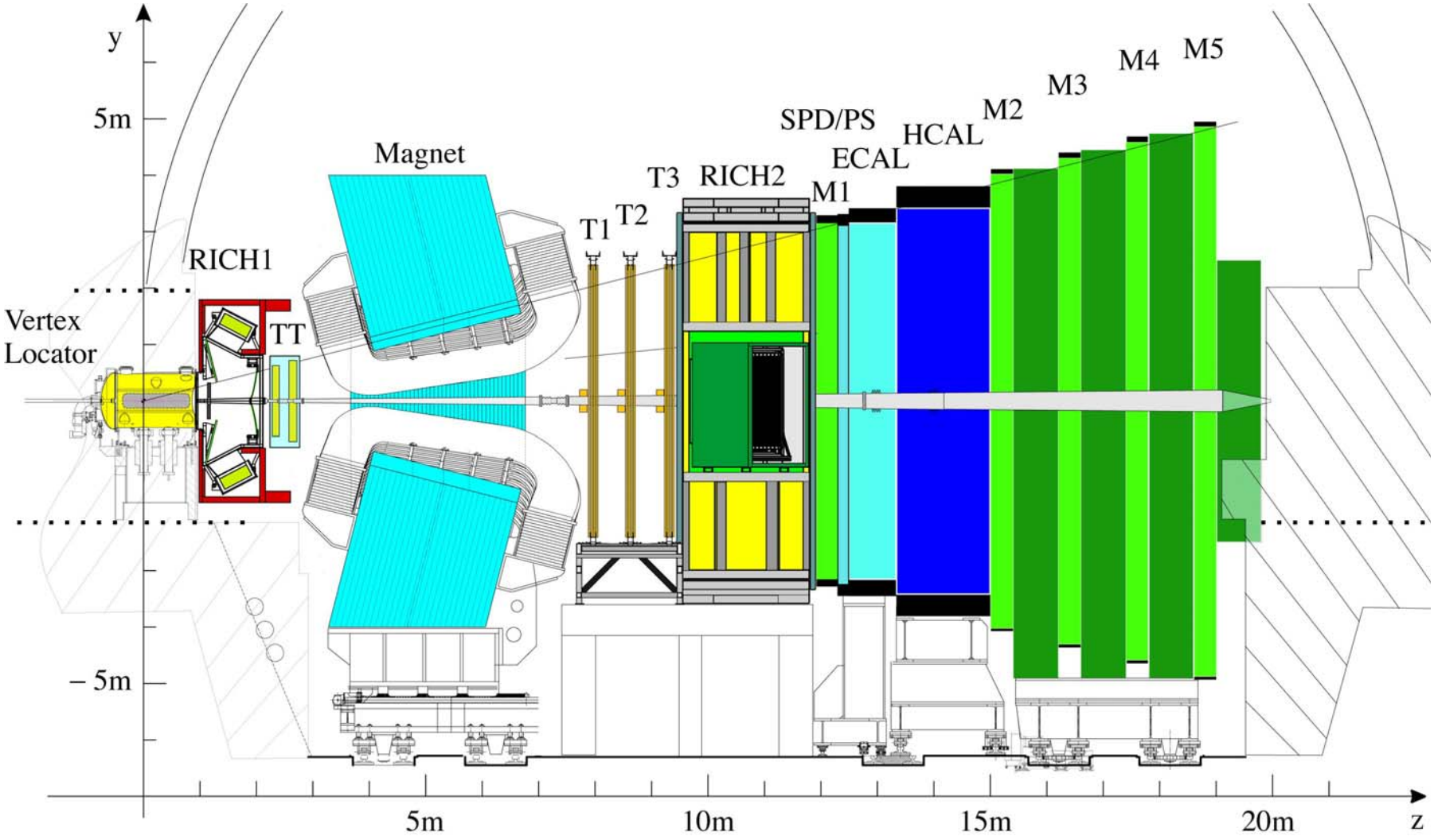
10^{12} bbar per 10^{7}s

$b\bar{b}$ angular distribution



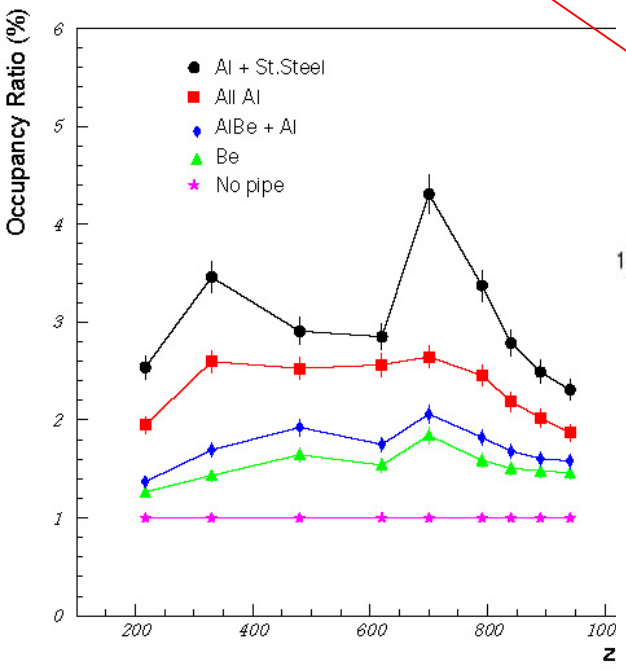


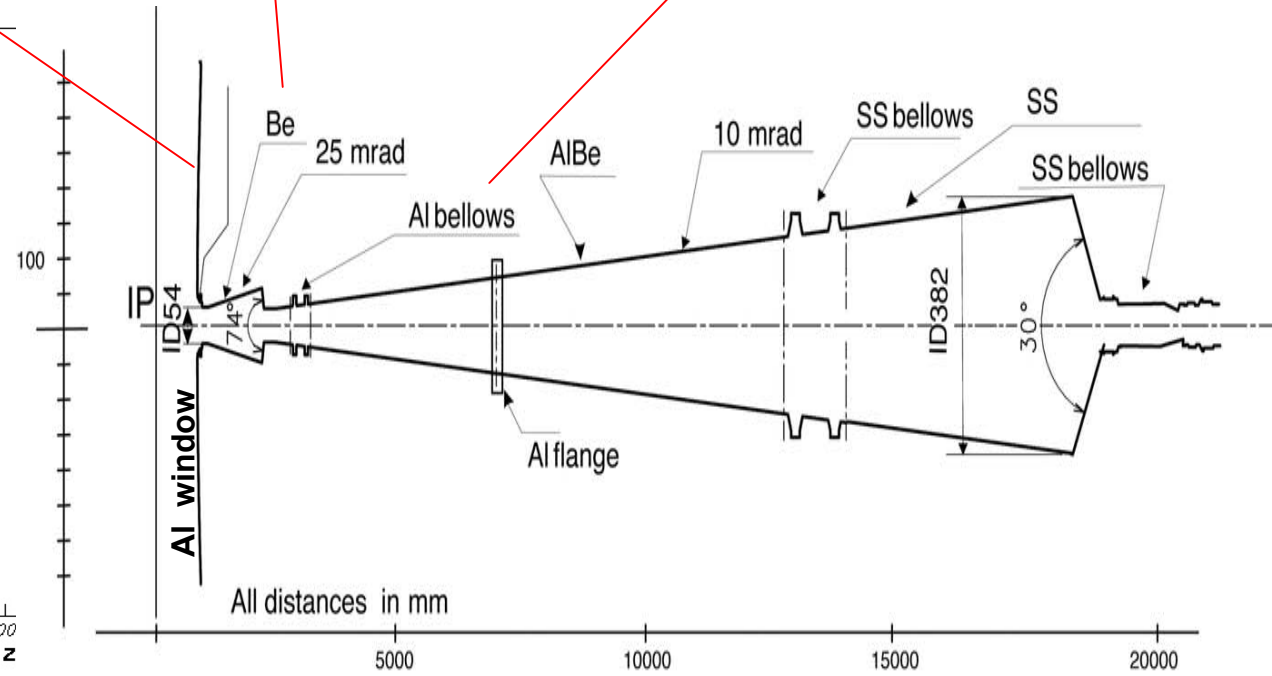
The LHCb Detector



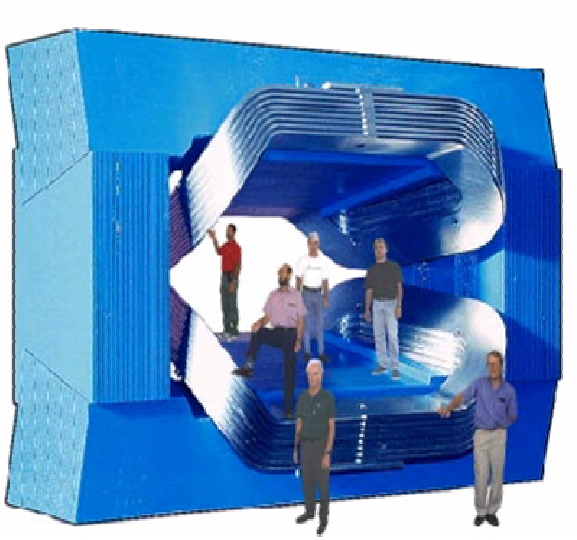
Acceptance 10...(250)300 mrad for (non)-bending plane

Beam Pipe


Occupancy Ratio (%)
Al + St.Steel
All Al
AlBe + Al
Be
No pipe
z

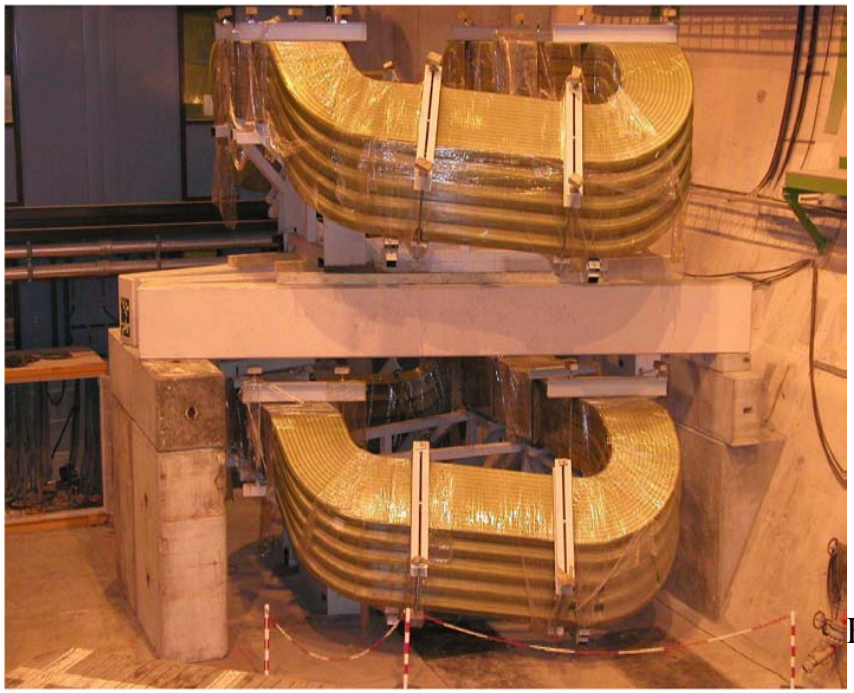

Be
25 mrad
AlBe
10 mrad
SS bellows
SS
SS bellows
Al bellows
IP
ID54
74°
ID382
30°
Al window
Al flange
All distances in mm
100
5000
10000
15000
20000

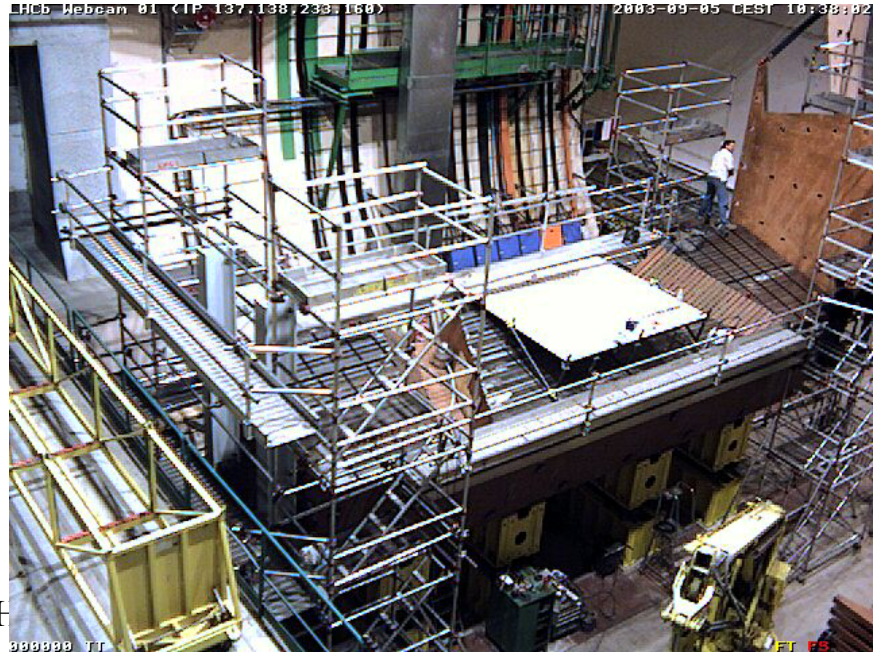
Magnet



- Warm magnet Al conductor
  - $\int B.dl = 4$ Tm
- Production well underway
- Power 4.2 MW
- Fe yoke 1600 t
- All the components delivered; assembly ongoing

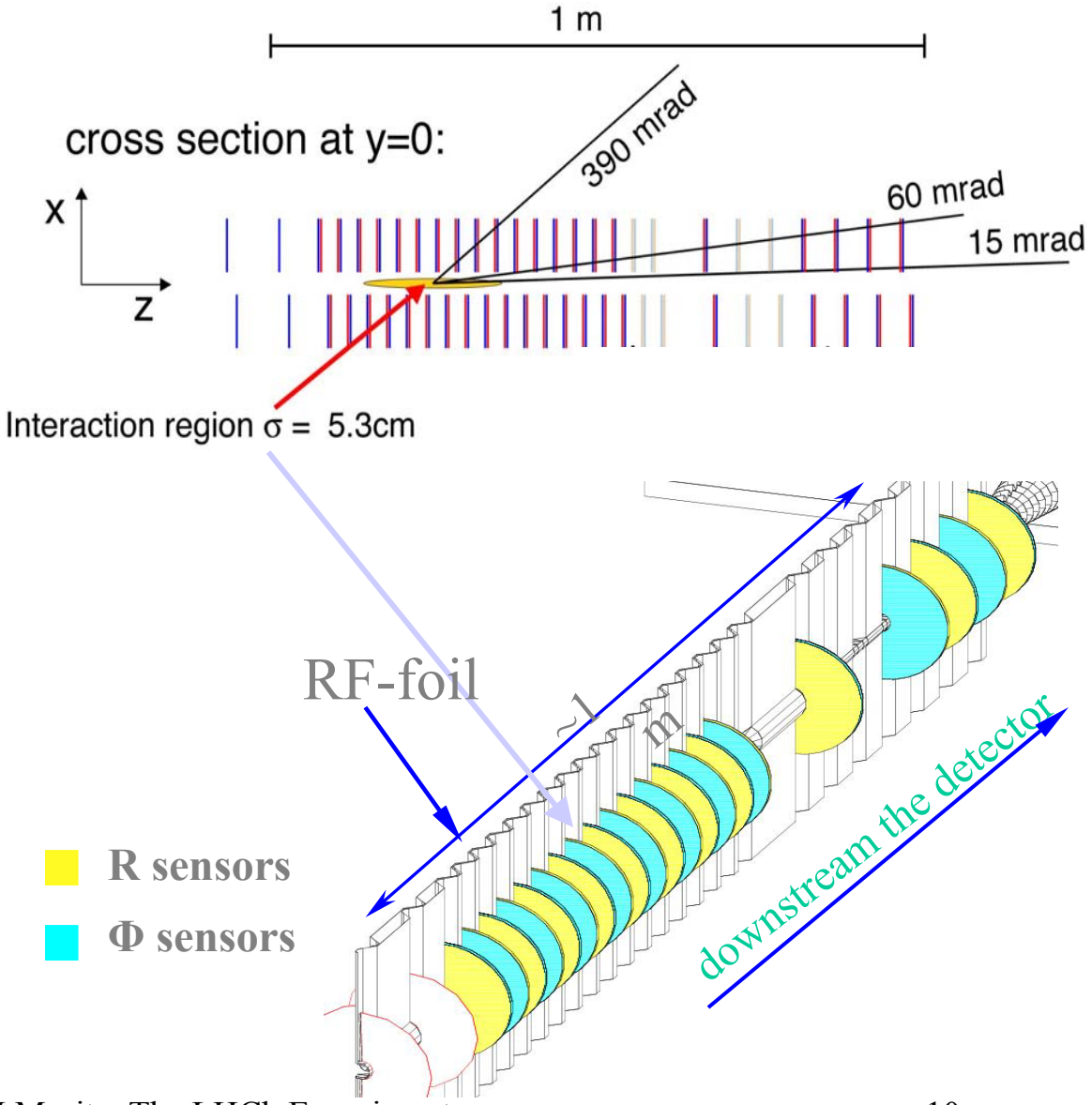
Magnet support at UX8



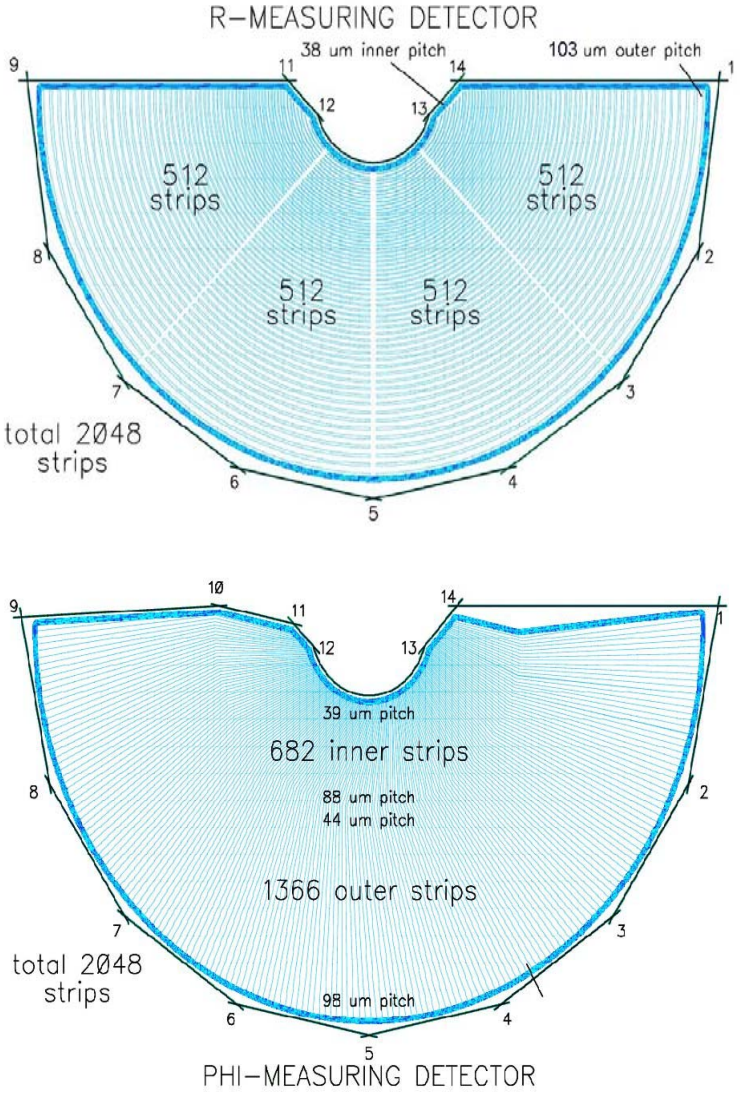


Vertex Locator

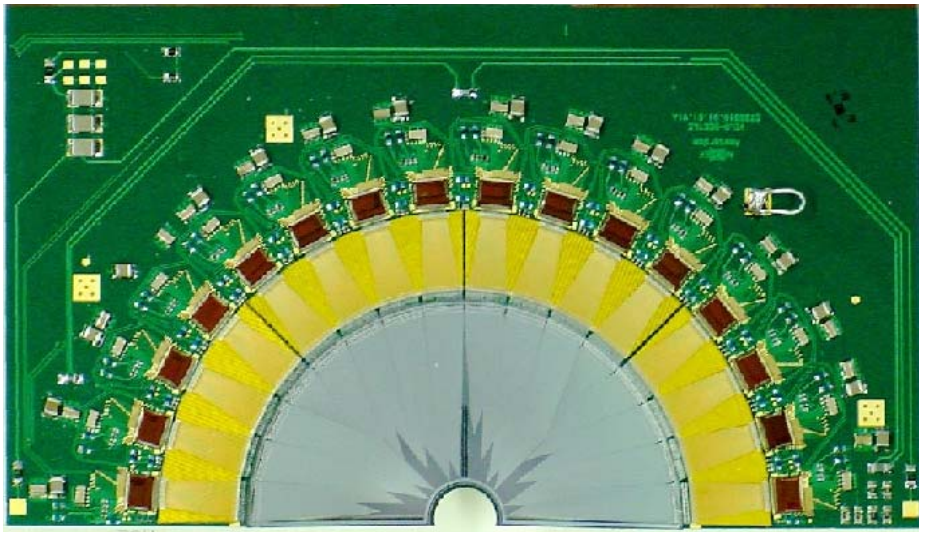
- **Single-sided Si strip detectors,220 μm thick, 180^0 wedges**
- **21 stations mounted inside the vacuum tank ~200 K R-O -channels**
- **Crucial in all time-dependent measurements**



Vertex Locator

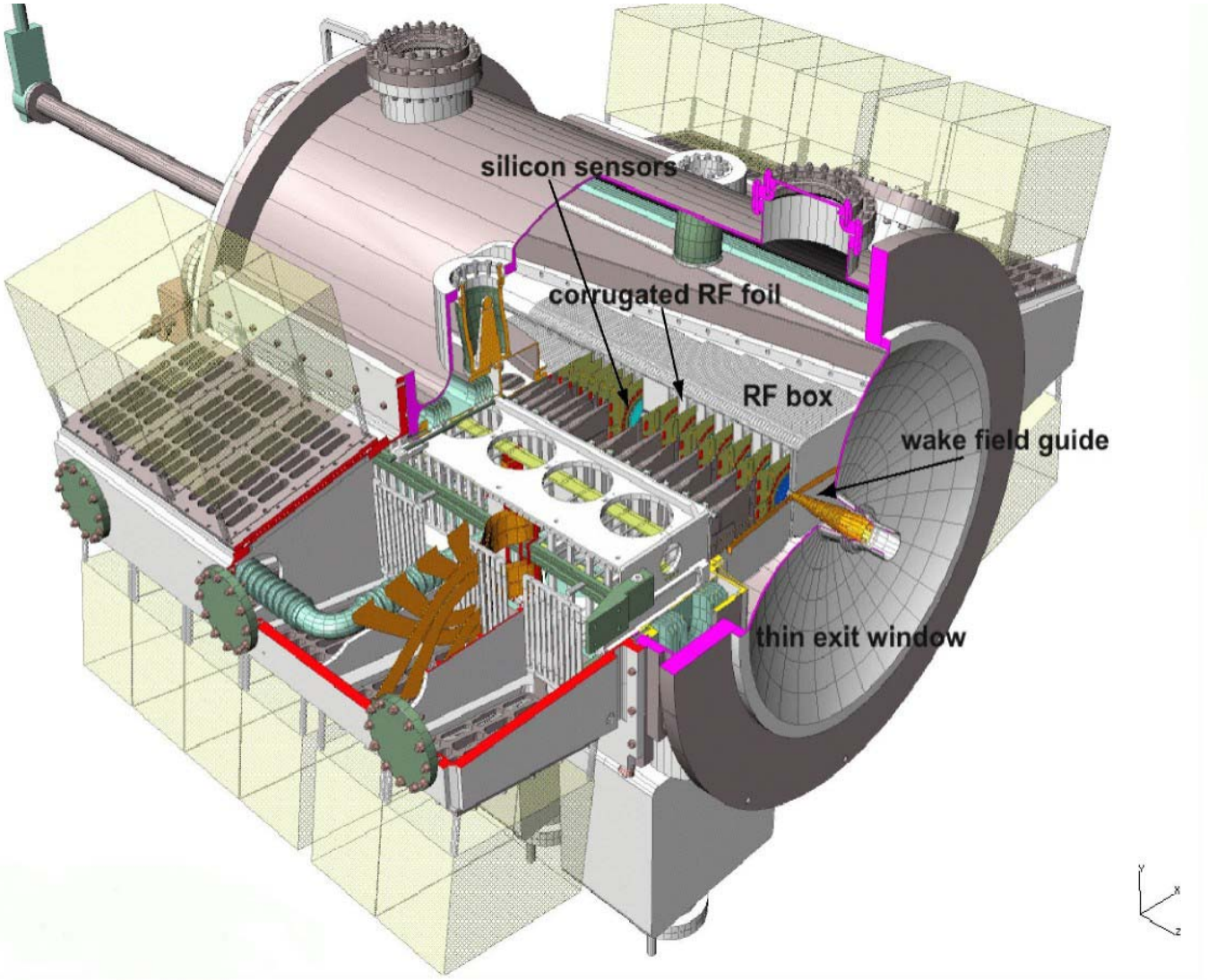


220 µm n-on-n Si short strips, double metal layer for R-O with LHCb Beetle chip (1/4 µm CMOS)



Sensors are to be placed in the secondary vacuum

Vertex Locator



Proper Position & Time Resolution

Primary vertex resolution:

~8μm (x,y) and ~40μm (z)

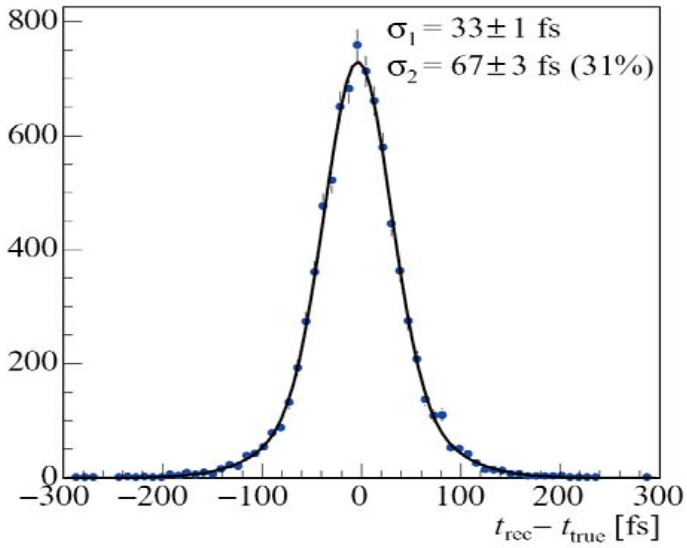
- **Observation of CP asymmetries with B_s decays (eg.$B_s \rightarrow D_s K$)**
- **Δm_s wih $B_s \rightarrow D_s^- \pi^+$**
- **If $\Delta m_s = 20\ ps^{-1}$**

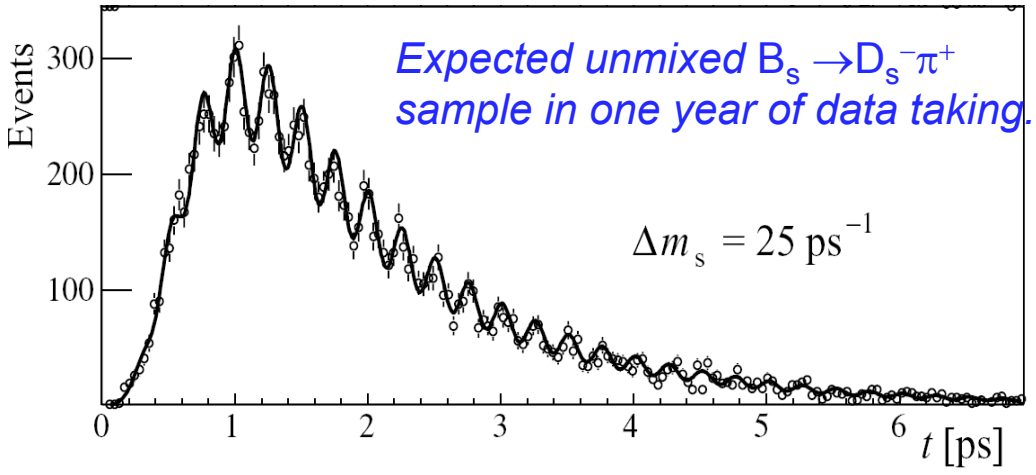
$\sigma(\Delta m_s) = 0.011\ ps^{-1}$

- **Can observe >5σ oscillation signal if**

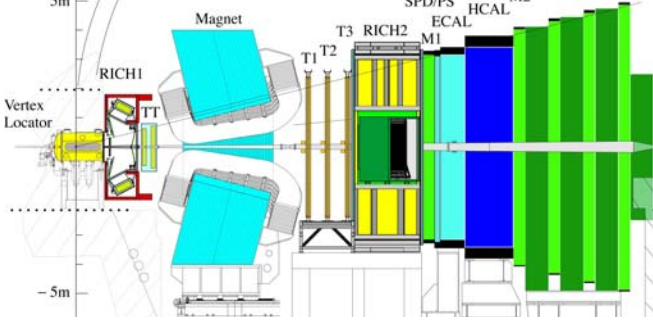
$\Delta m_s < 68\ ps^{-1}$

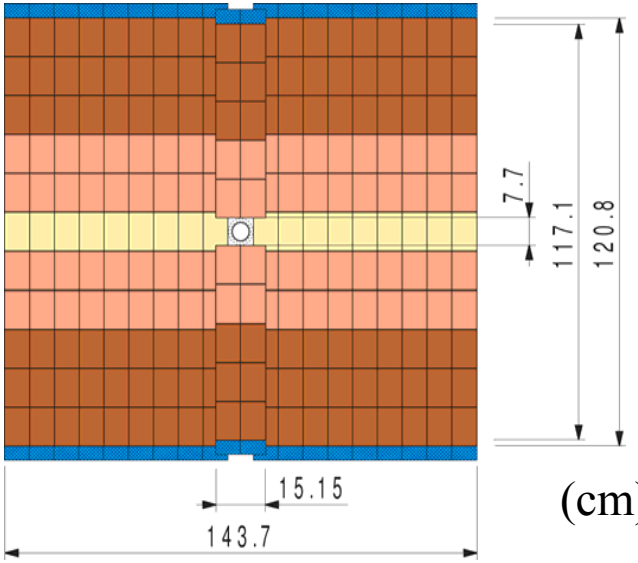
- **well beyond SM prediction**



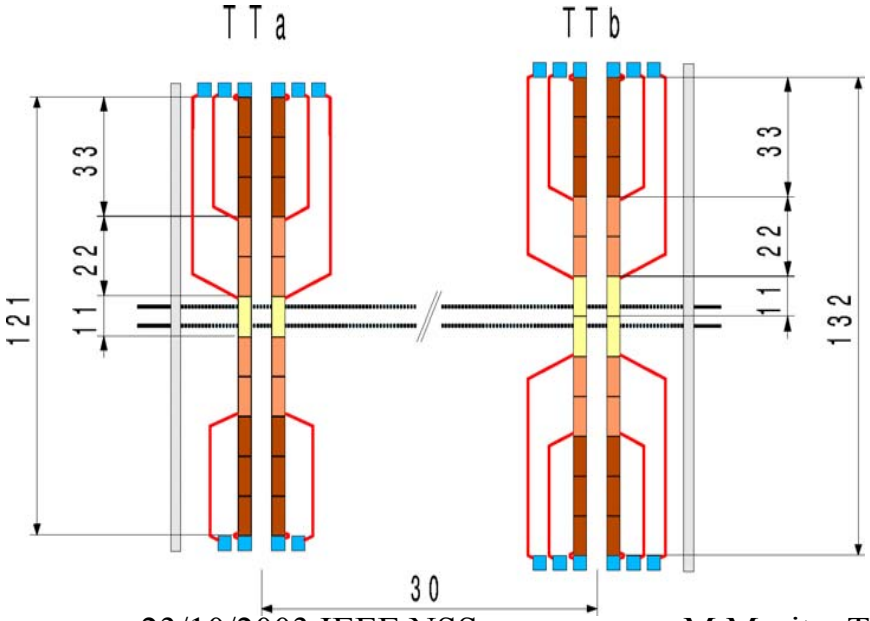


Trigger Tracker





(cm)



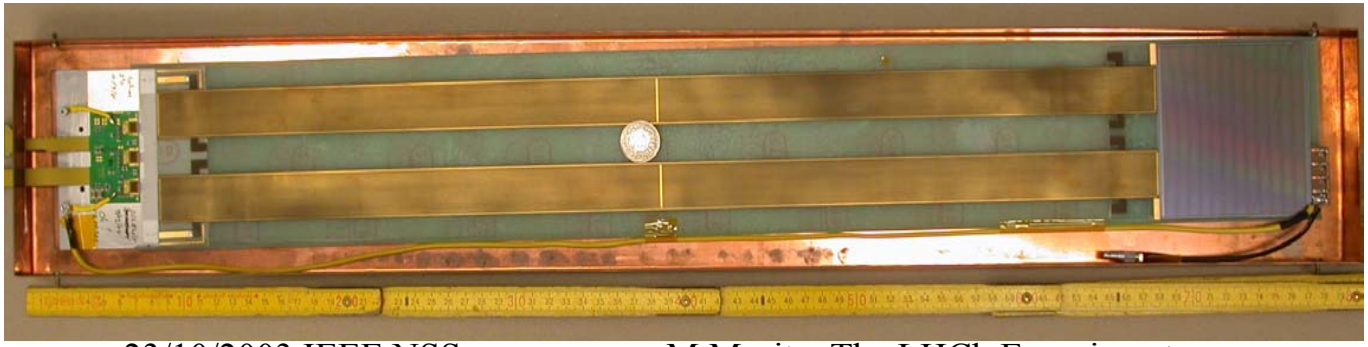
- Provides P_T for L1 trigger
- Reconstruction of low-P particles bent out of Tracker acceptance, and long-lived neutrals
  - Si strip detectors covering LHCb acceptance, total surface > 8 m²
  - Two stations: X-U — V-X planes structure
  - Cooling system ($C_6 F_{14}$) to operate the sensors below 5 °C
  - R/O with Beetle chip
  - In total: ~1k sensors, ~0.5k ladders, ~1.4k FE-chips, ~180k R/O channels

Trigger Tracker

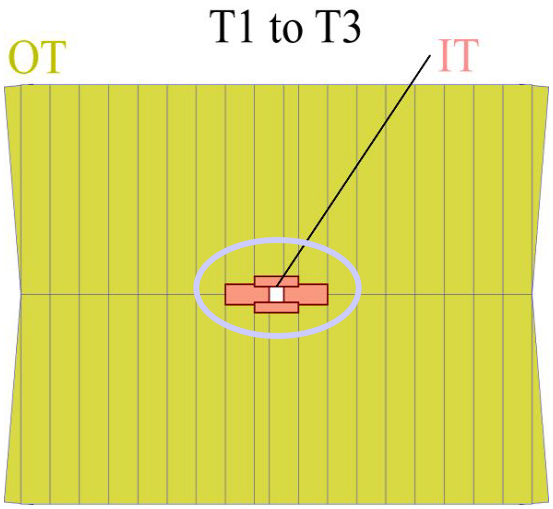
Baseline sensor design:

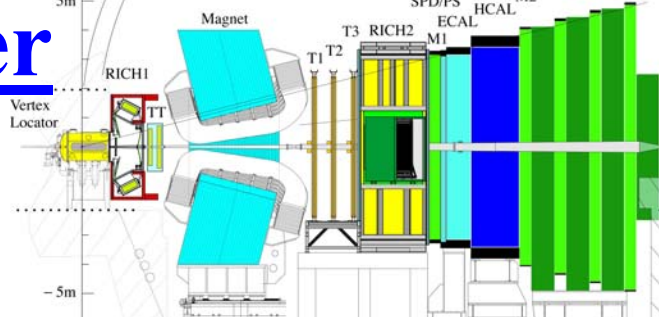
- **Wafer thickness 410 µm**
- **p-on-n silicon with AC coupled R/O**
- **108 mm x 76 mm active area**
- **110 mm x 78 mm total area per sensor**
- **Strip pitch 198 µm, implant width 70 µm**

Prototype of Kapton interconnect cables



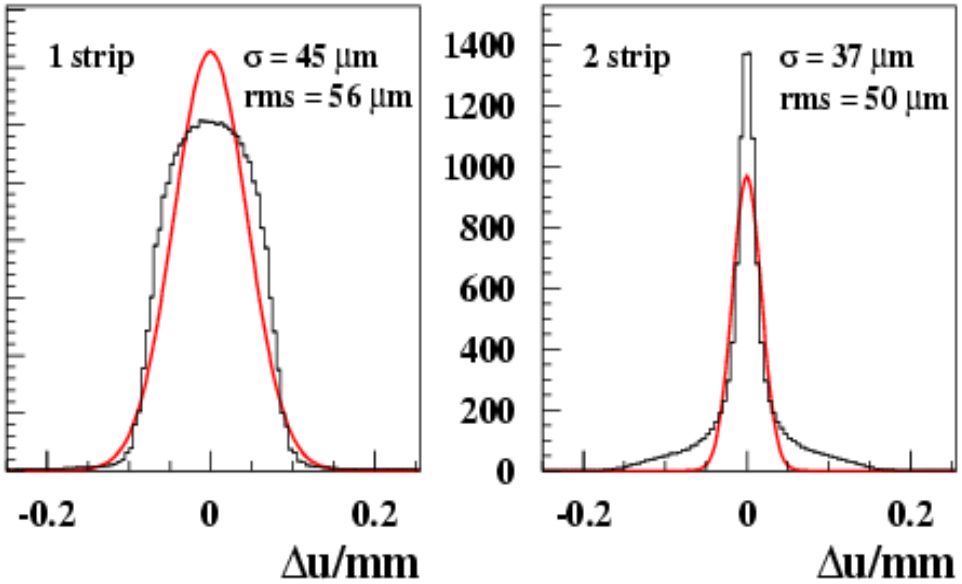
Main Tracker: Inner Tracker

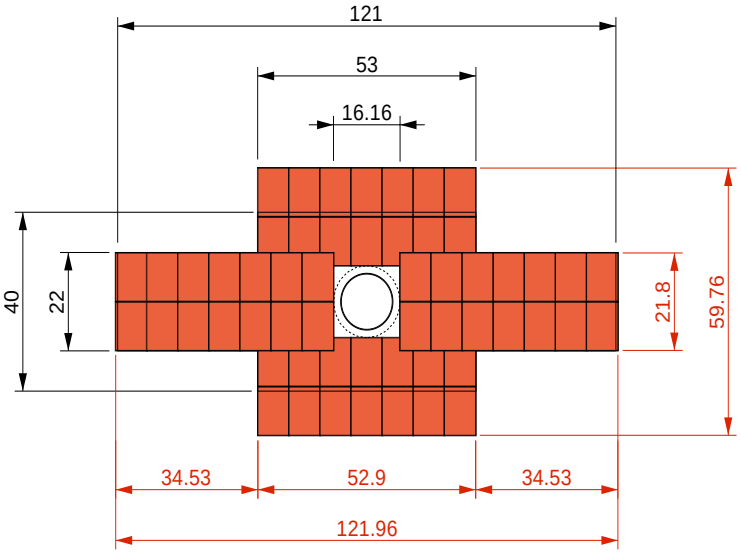




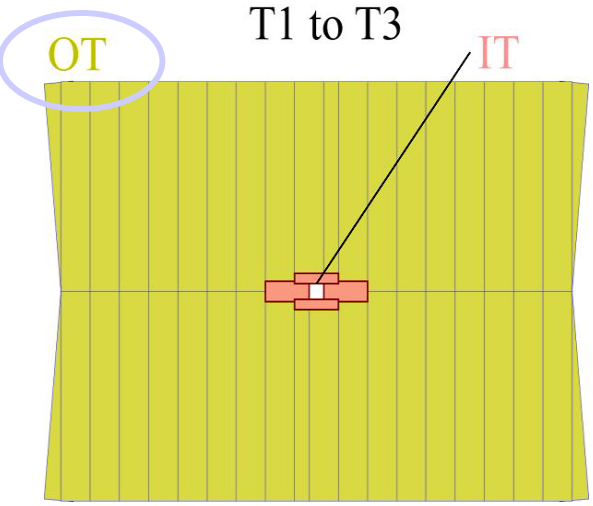
- Fully Si detector
- T1-T3 stations with 0°,+5°,-5°,0° layers each
- Silicon 320 µm thin
- R/O pitch 198 µm
- 130k R/O channels

After clustering:

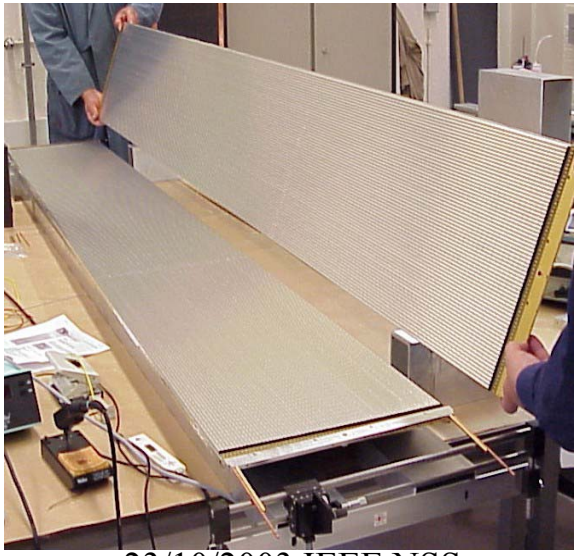




Main Tracker: Outer Tracker

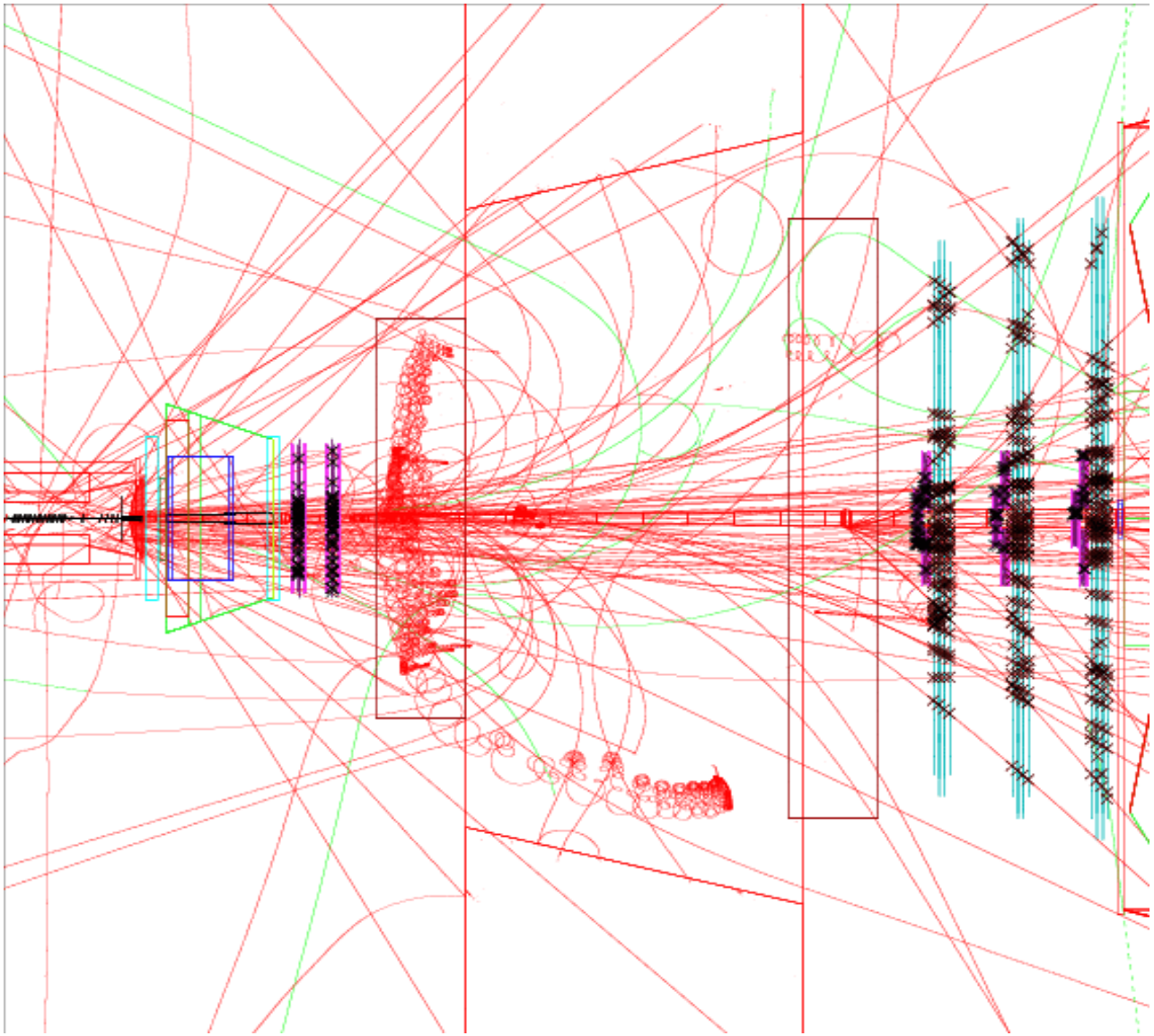


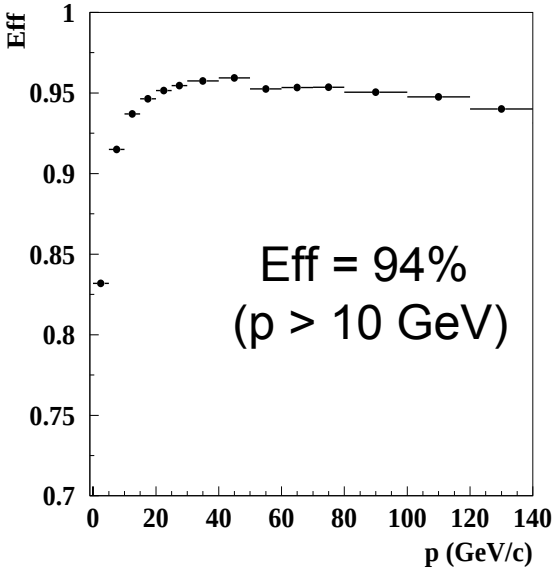
2.5 m prototype module

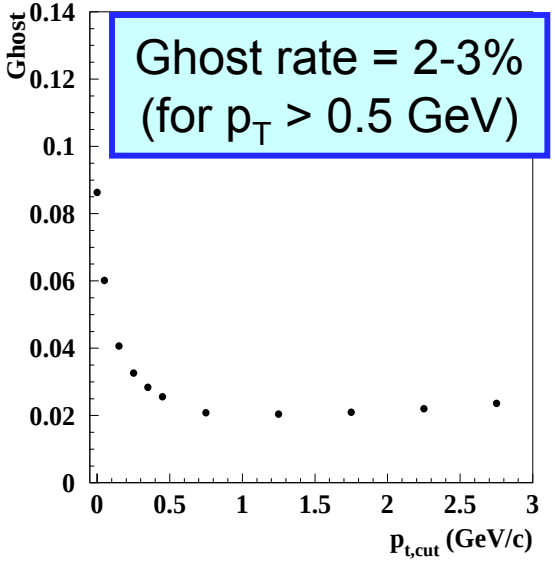


- Straw tubes: 5mm diameter, pitch 5.25 mm
- T1-T3 stations with 0°,+5°,-5°,0° double layers each
- Average occupancy ~4%, hottest region ~7%
- Fast gas mixture $Ar(75)/CF_4(15)/CO_2(10)$: signal collection < 50 ns
- Straws 4.7 m with R/O on top and below (long modules)
- 50k R/O channels

Track Finding

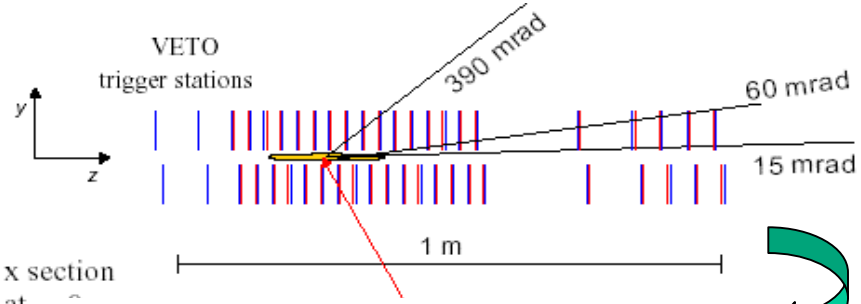


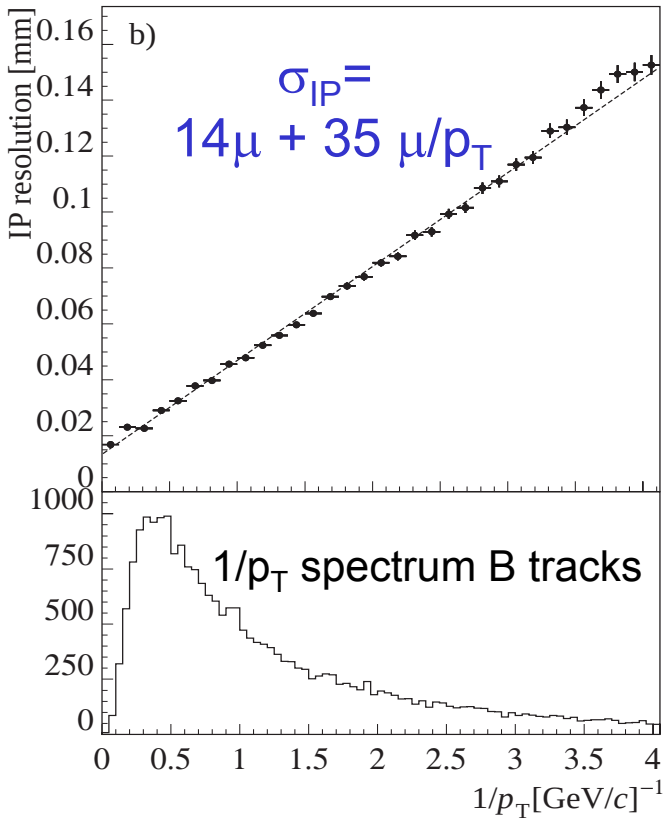




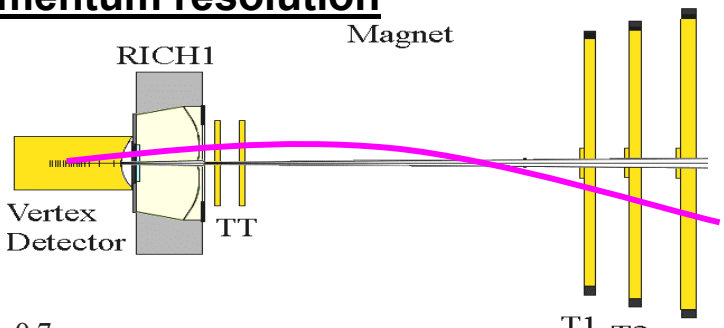
Track Resolution

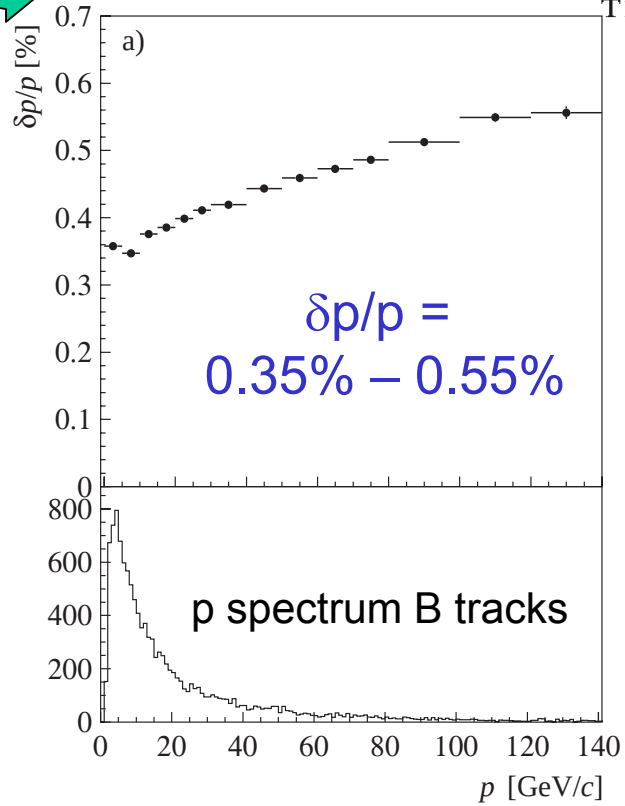
Impact parameter resolution



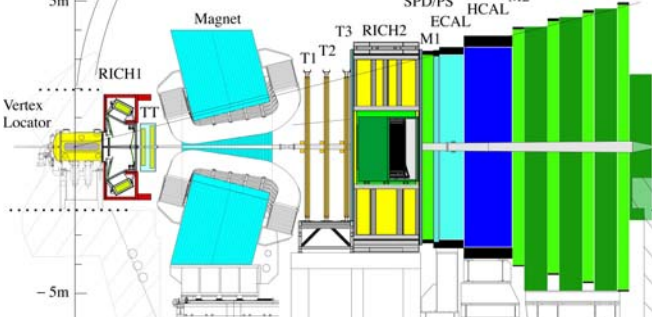


Momentum resolution

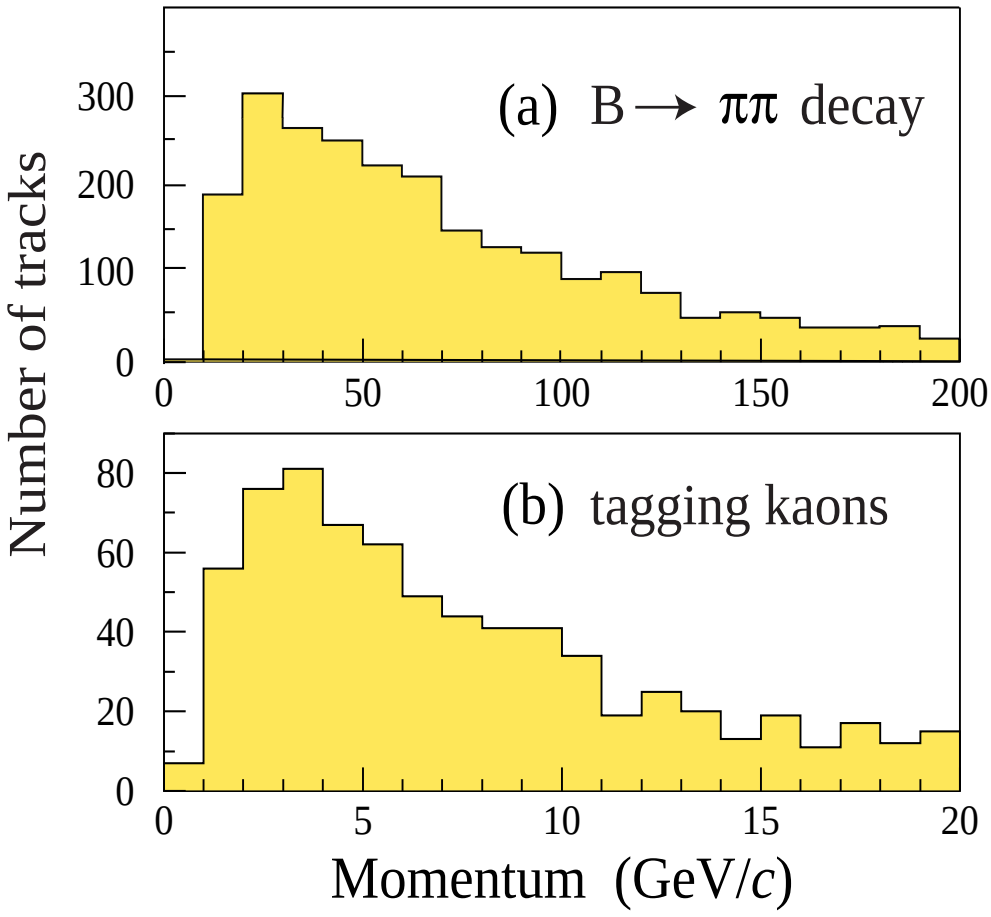




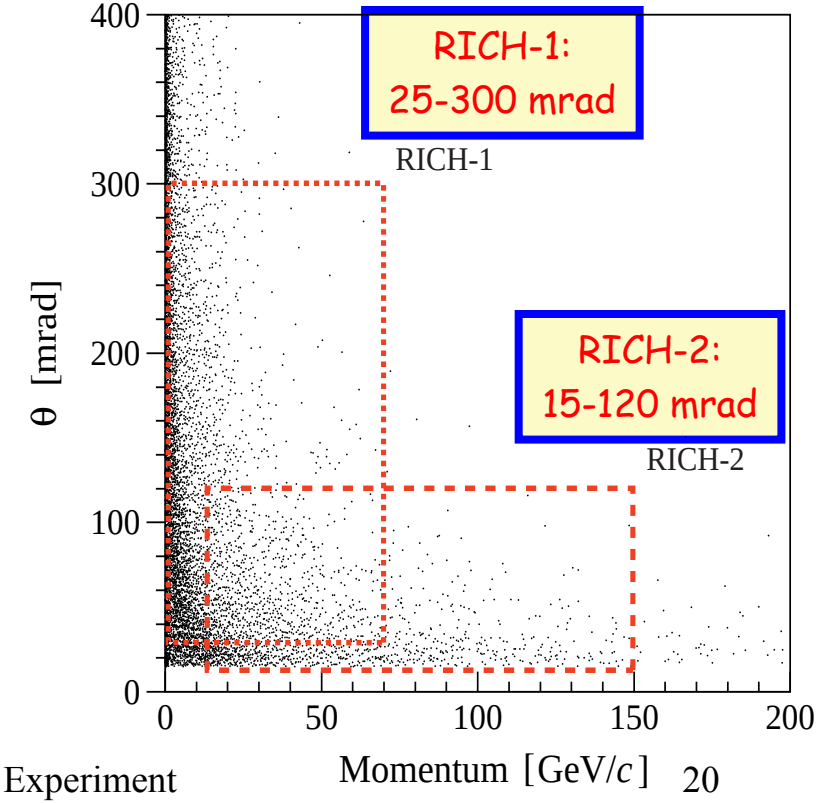
RICH System



Goal: π/K separation in 1-100 GeV/c range



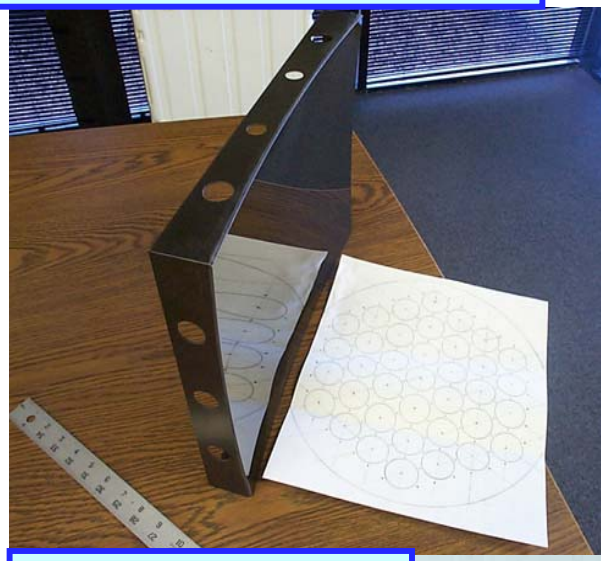
- **RICH1: Aerogel (n=1.03) and C_4F_{10} (n=1.0014)**
- **RICH2: CF_4 (n=1.0005)**



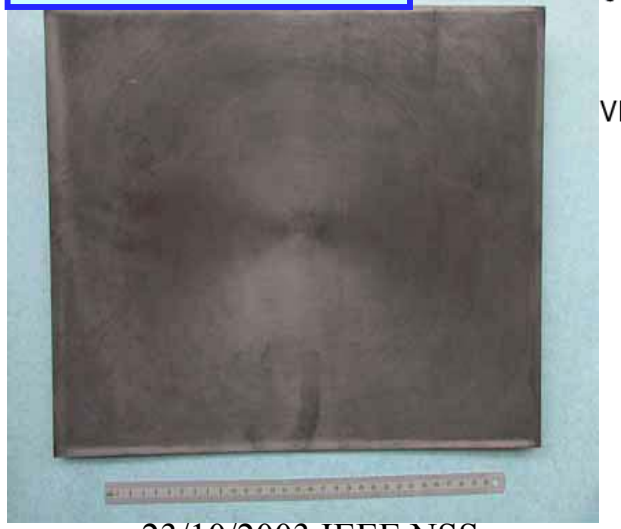
RICH System

RICH1 mirrors

carbon-fibre/epoxy composite

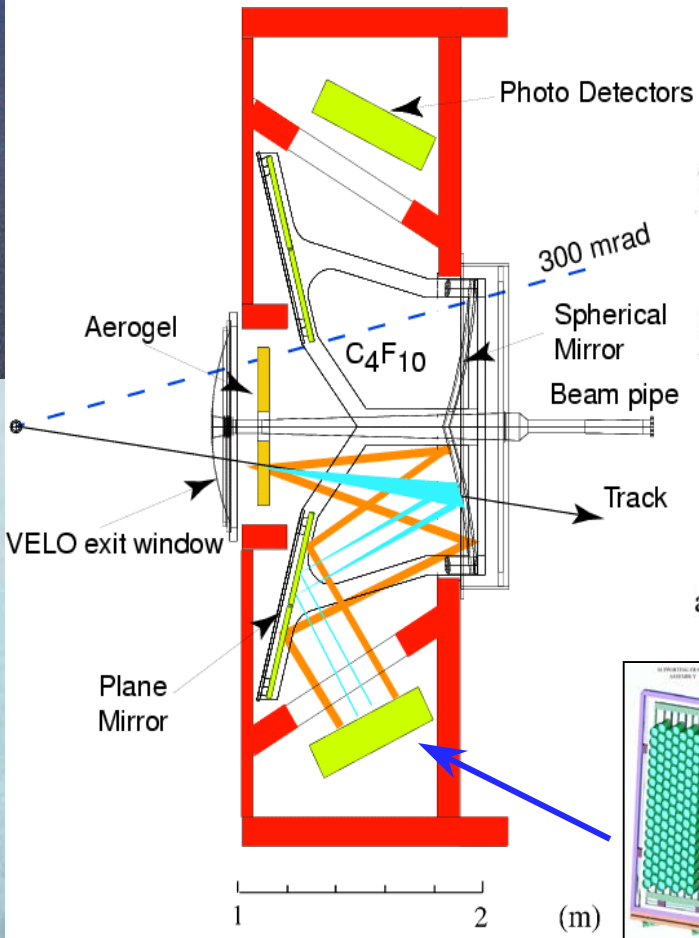


glass-coated beryllium



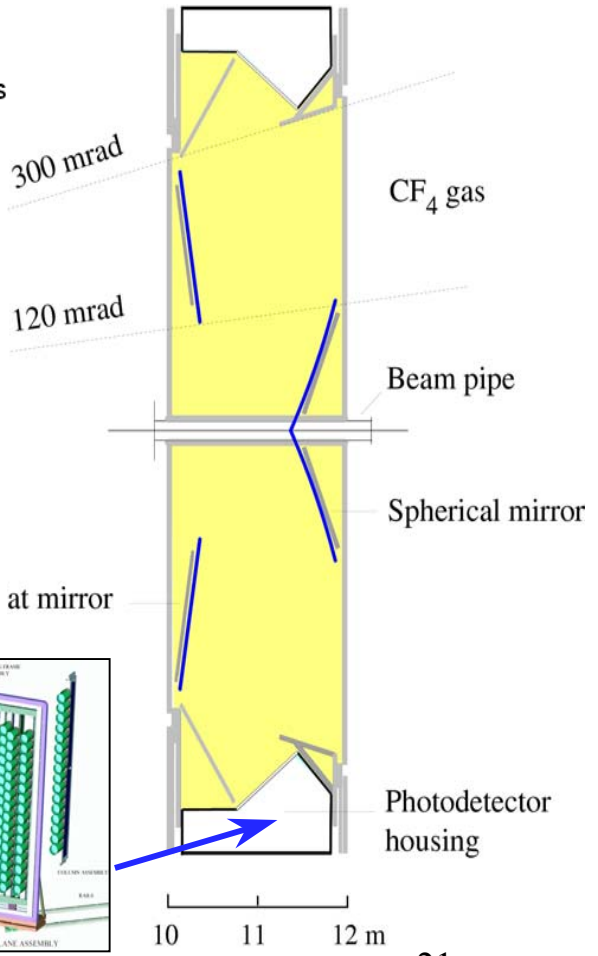
RICH-1:

y-z view

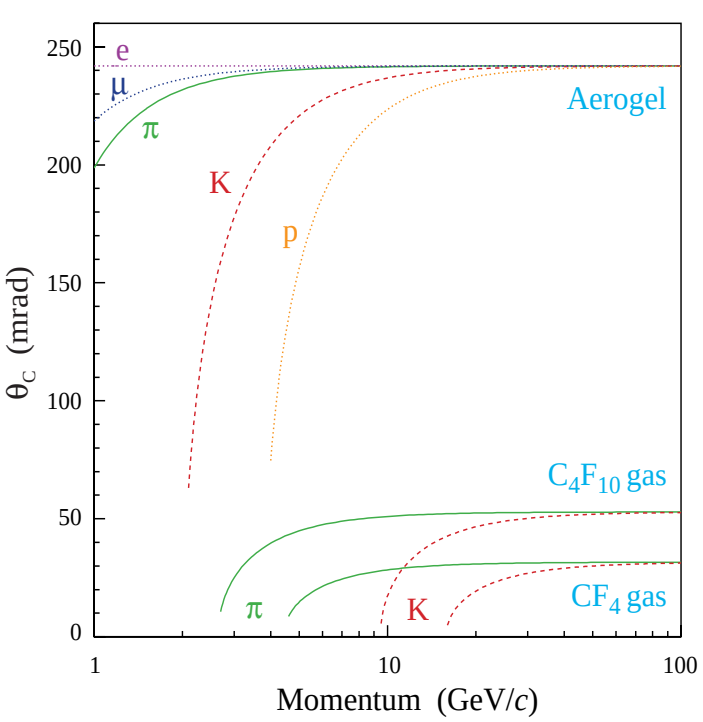


RICH-2: construction started

x-z view



RICH System: Radiators



θ_C max
242 mrad

53 mrad

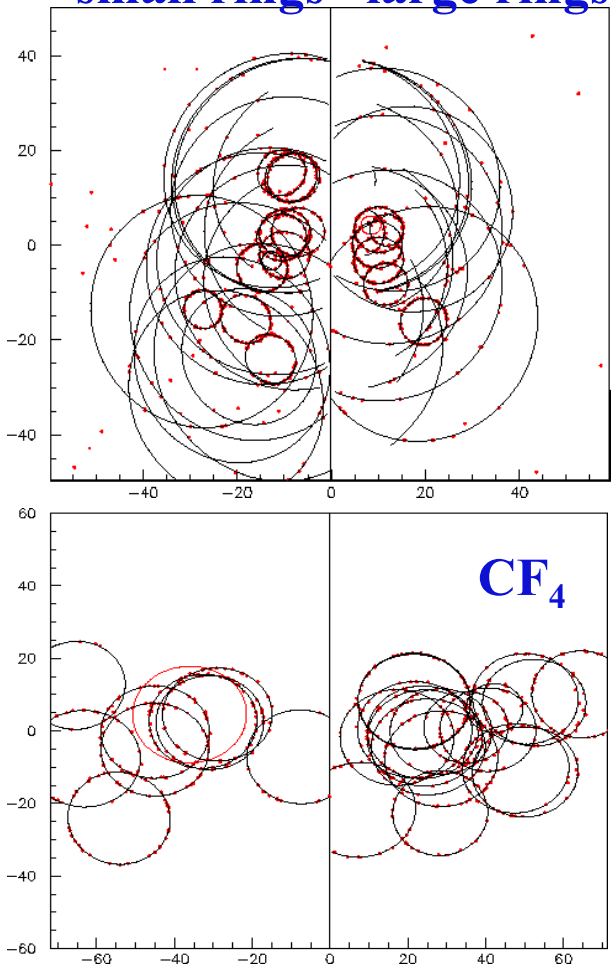
32 mrad

gas radiators:

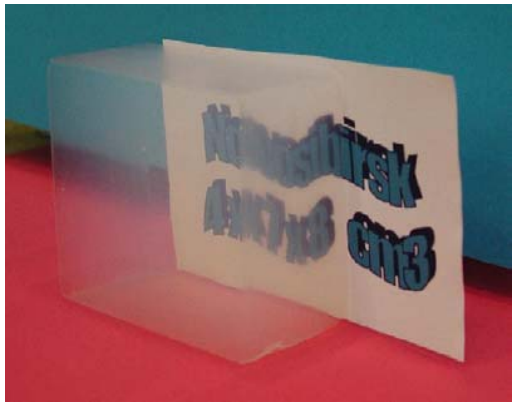
C_4F_{10}(RICH1)

CF_4 (RICH2)

C_4F_{10} small rings **Aerogel large rings**



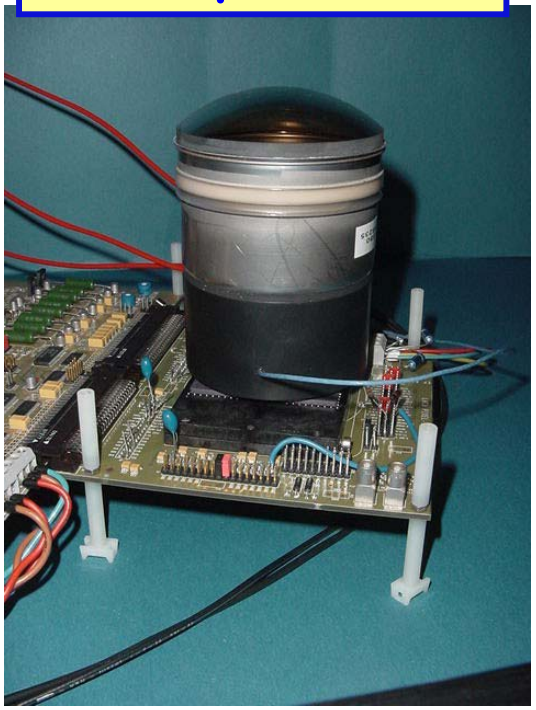
Aerogel:



RICH System: Photon Detectors

- Coverage of 2.6 m^2 with max. acceptance
- Granularity of 2.5 x 2.5 mm^2
- Single photon sensitivity for λ=200-600 nm
- R/O at 40 MHz

1024 pixel HPD



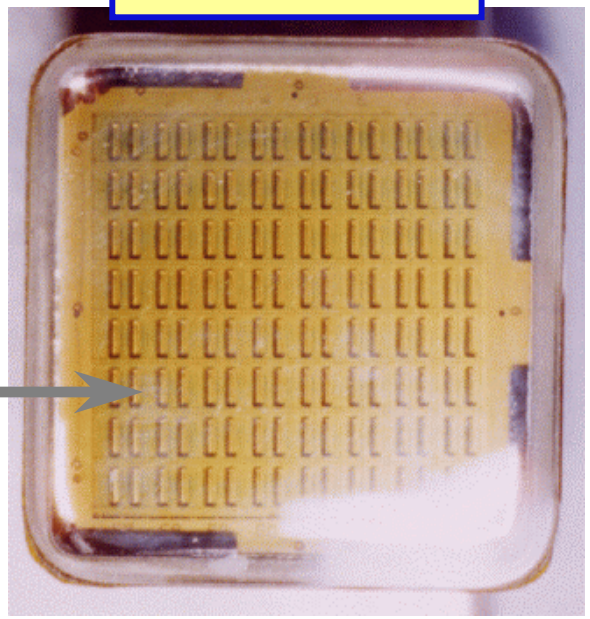
Hybrid Photon Detectors
(coll. CERN, DEP)

(talk on this conference)

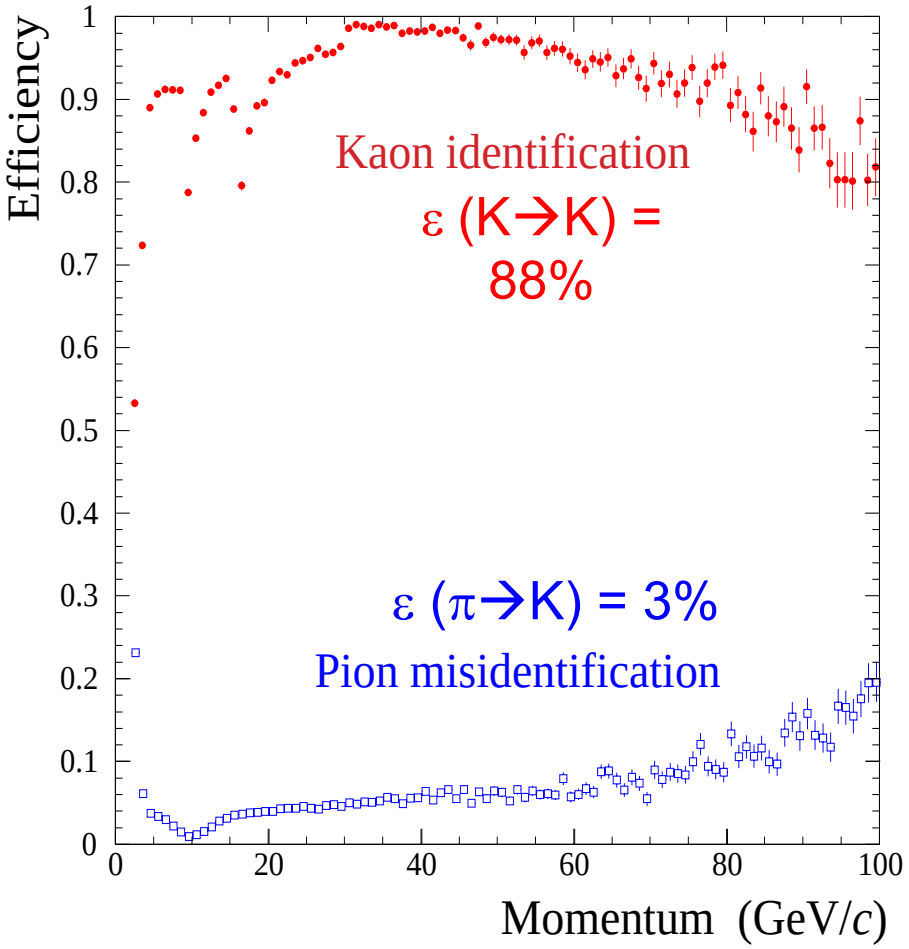
OR

Multi-Anode
PhotoMultiplier
(Hamamatsu)

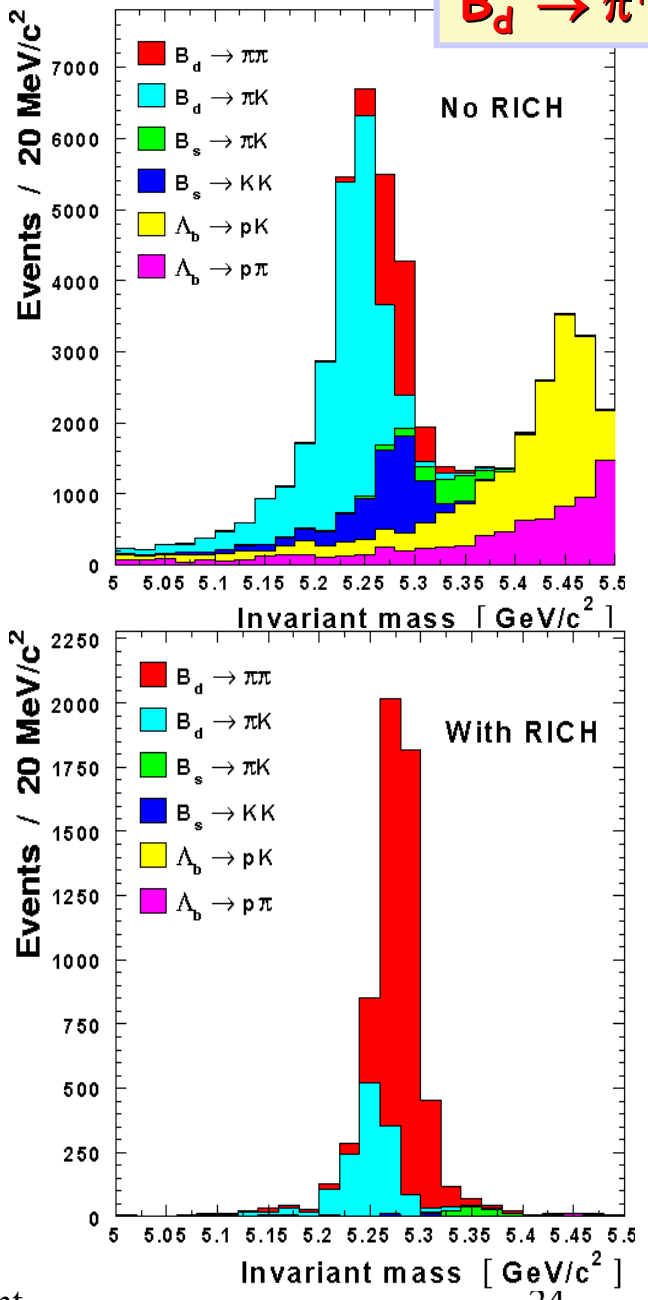
MAPMT



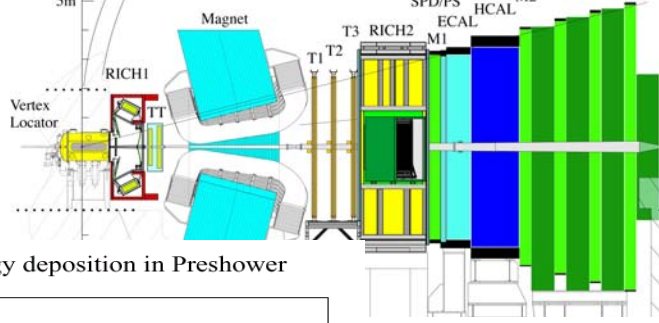
Particle ID



$B_d \rightarrow \pi^+\pi^-$

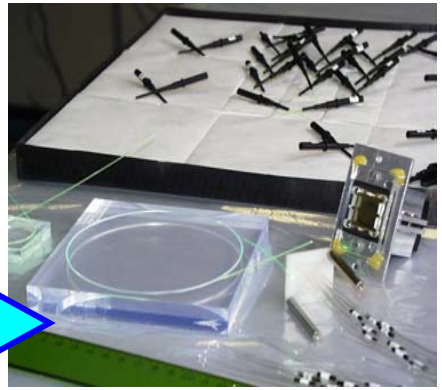


Calorimeters

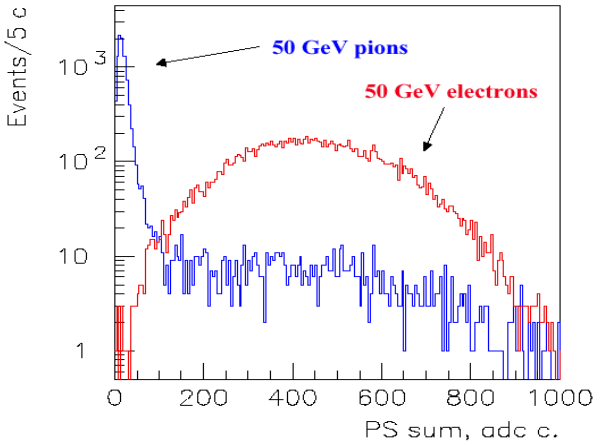


SPD/PS

- 15mm – 12mm – 15mm
- Sc – Pb – Sc structure
- 16 supermodules,
- 6k x 2 R-O channels
- Deep-groove design of SPD/PS cell
- Readout with MAPMTs



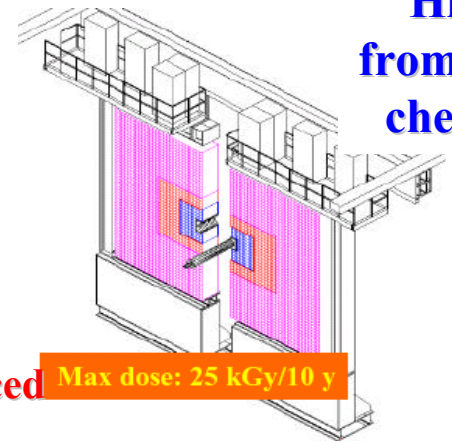
Energy deposition in Preshower



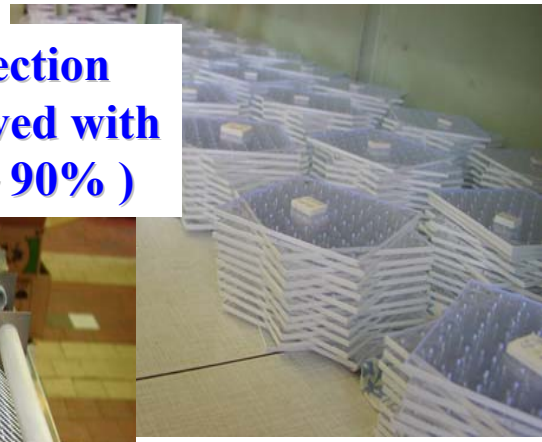
Test Beam data: e/π separation with PS

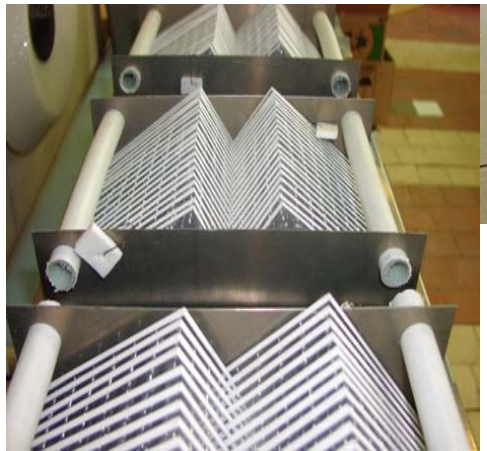
ECAL

- Shashlyk type technology
- 3.5k modules, 6k electronics channels
- $\sigma_E/E = 0.10/\sqrt{E} \oplus 0.01$
- 100% modules produced

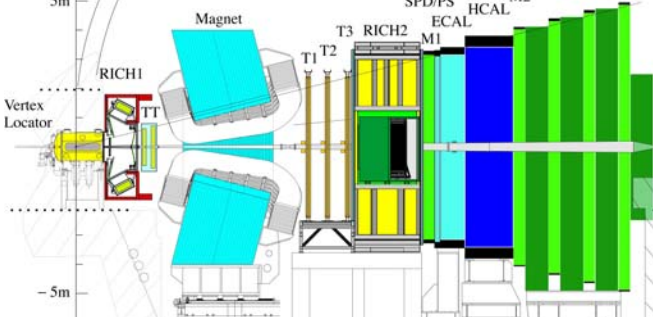


High quality light reflection from the tile edges achieved with chemical treatment (ε~ 90%)



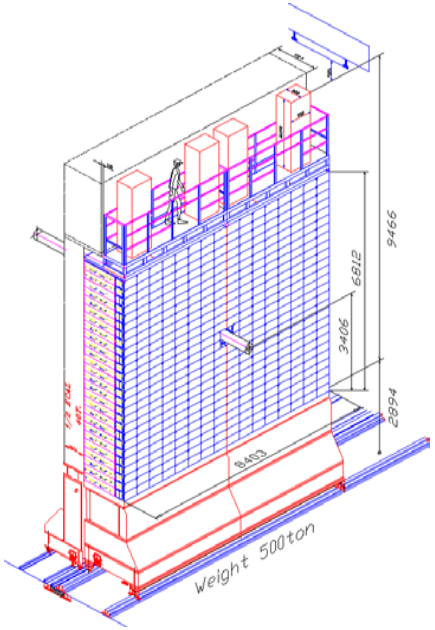


Calorimeters



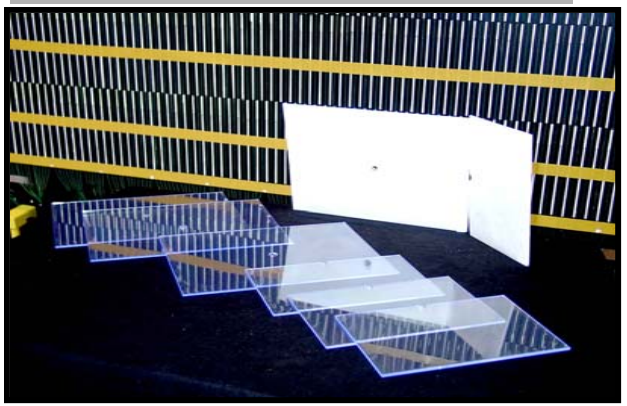
HCAL

- Tile calorimeter
- 52 modules, 1.5k electronics channels
- $\sigma_E/E = 0.80/\sqrt{E} \oplus 0.1$
- 4% modules produced

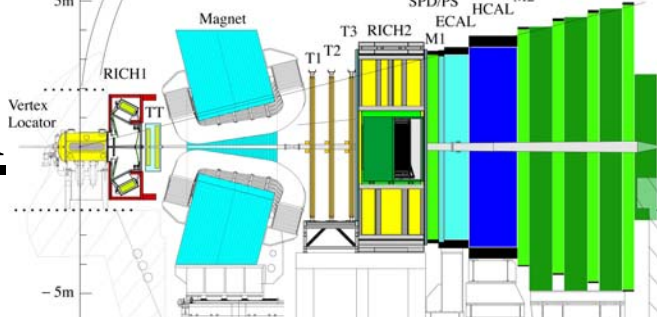


- Trigger on high p_T hadrons

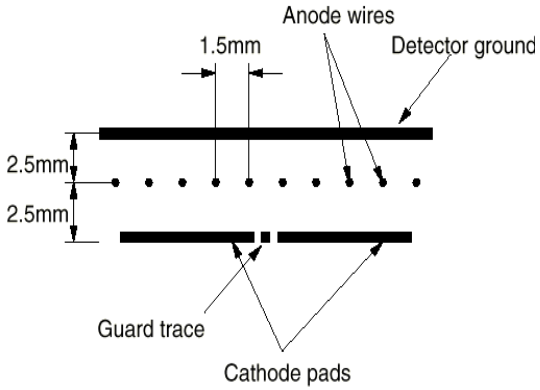
Assembly of HCAL module



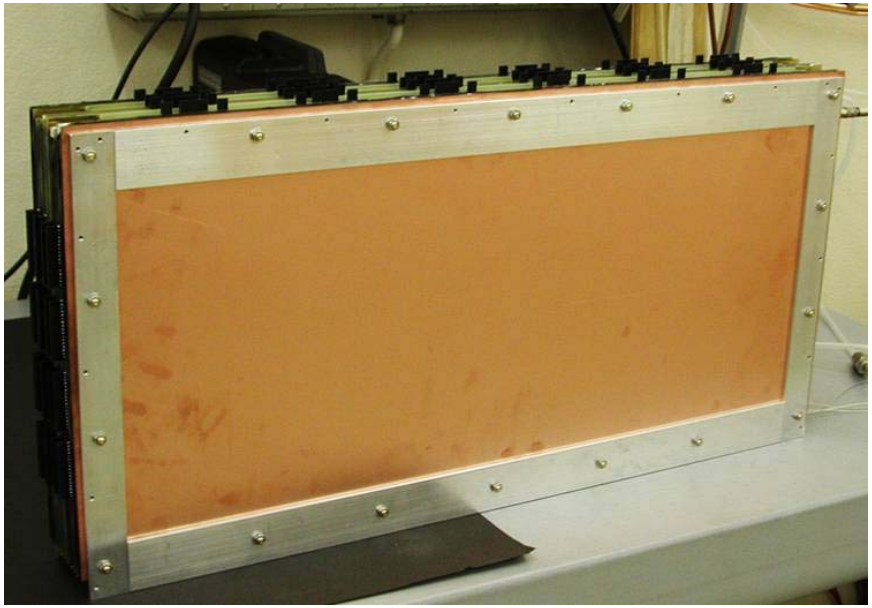
Muon System

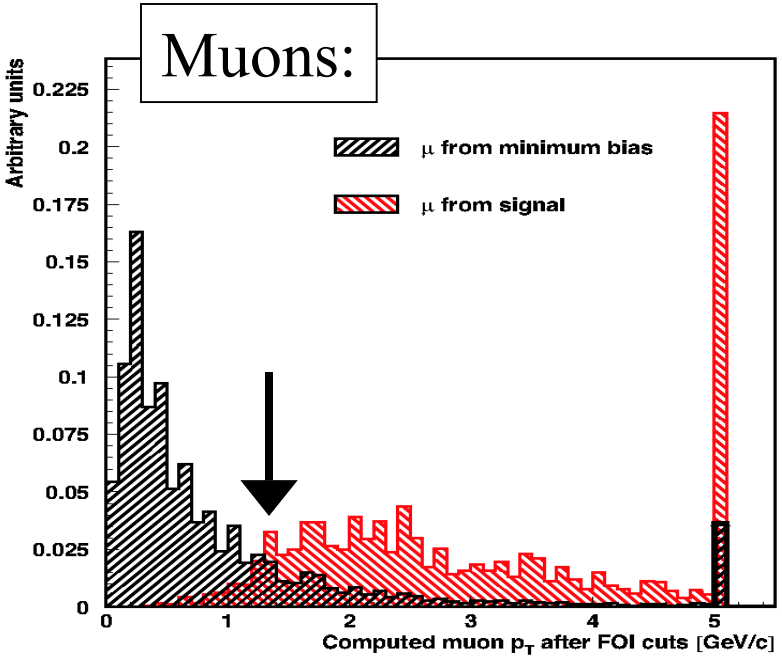


- ✓ 5 stations
- ✓ 1350 MWPCs



Talk by B. Schmidt at this conference





LHCb Trigger

40 MHz

Level-0:
p_T of
μ, e, h, γ

Calorimeter
Muon system
Pile-up system

1 MHz

Level-1:
Impact parameter
Rough p_T ~ 20%

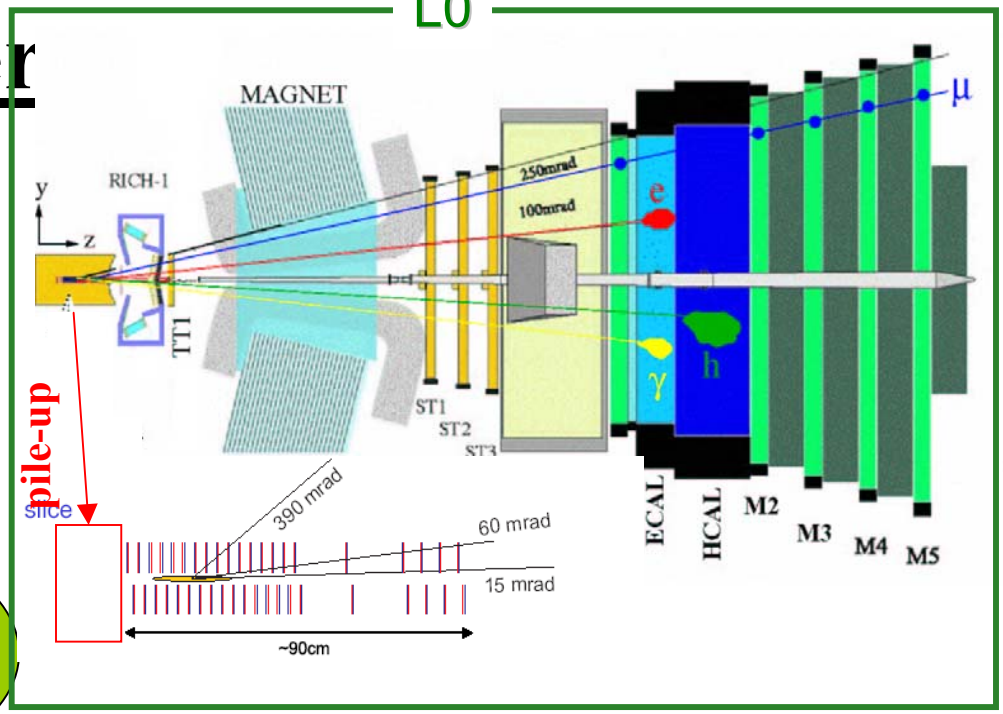
Vertex Locator
Trigger Tracker
Level 0 objects

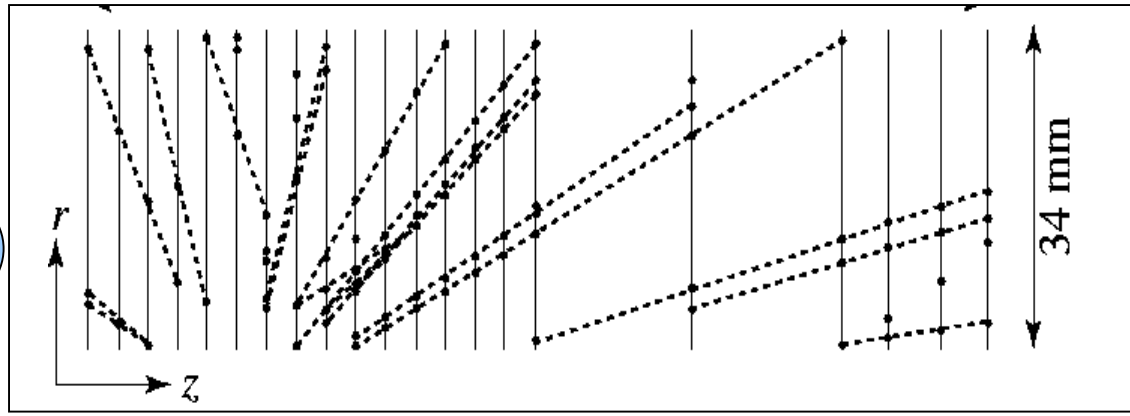
40 kHz

HLT:
Final state
reconstruction

Full detector
information

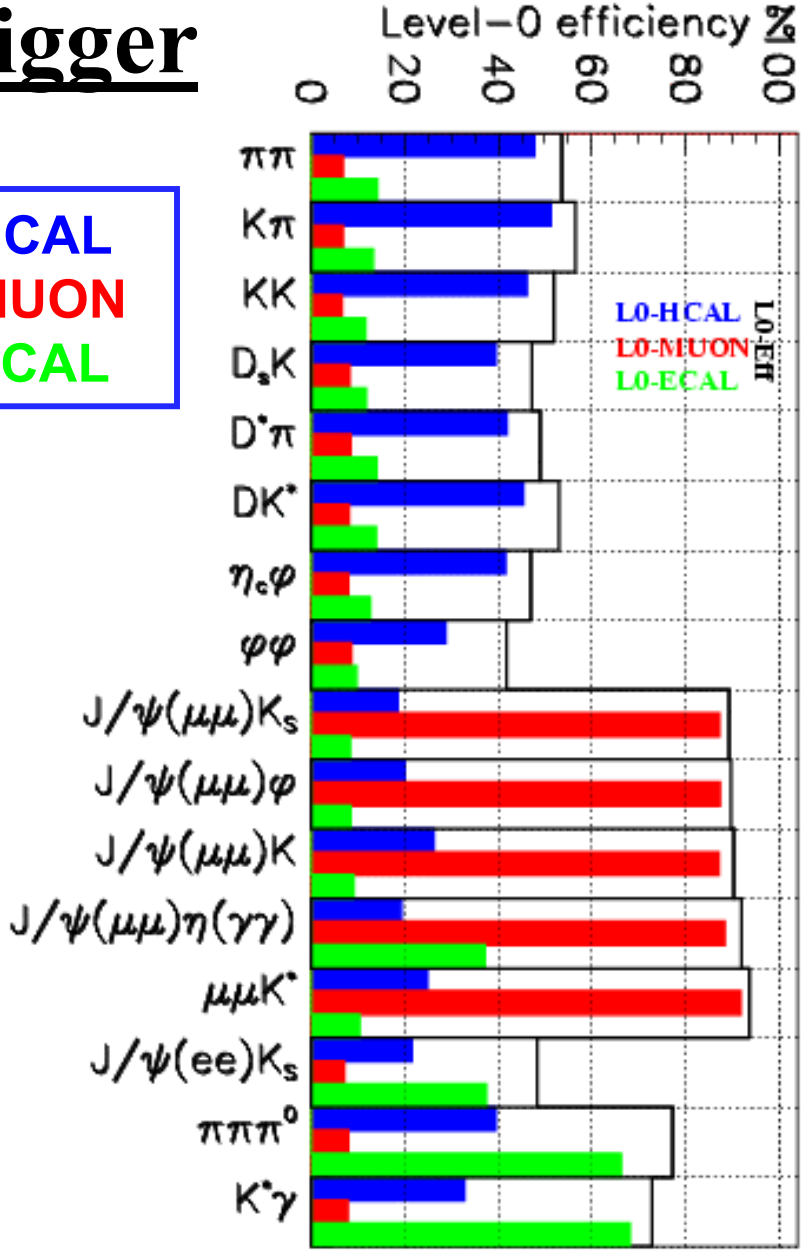
200 Hz output





LHCb Trigger

L0	HCAL
L0	MUON
L0	ECAL



- Measured on selected events
- Minimum bias retention adjusted
  - 1 MHz at L0
  - 40 kHz at L1

  L0xL1 efficiency:

  ~30% for hadronic channels

  ~60-70 % with di-muons

  ~30% for e/γ/π^0 channels

Summary

- **The LHCb experiment is expected to take data from LHC day 1, detector production well on schedule, installation starts end of next year**
- **Performance of chosen technologies:**

  excellent tracking and efficient particle identification
- **Physics potential: high statistics in B samples: precision studies of CP violating effects, CKM parameters will be precisely determined, New Physics may appear by over-constraining the Unitarity triangles**