The LHCb Detector and Triggers

BEACH 2006

2-8 July 2006
University of Lancaster (UK)

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(Bristol University)
On behalf of the LHCb Collaboration

Introduction
Detector and Trigger
Expected Offline Performance
Summary

Introduction

LHCb: dedicated 2nd generation B physics precision experiment at LHC

-study CP violation (precise determination of the CKM parameters)

-search rare B decays

B meson system:

-CPV expected to occur in many different decay channels

-ideal to test SM predictions and search for new physics

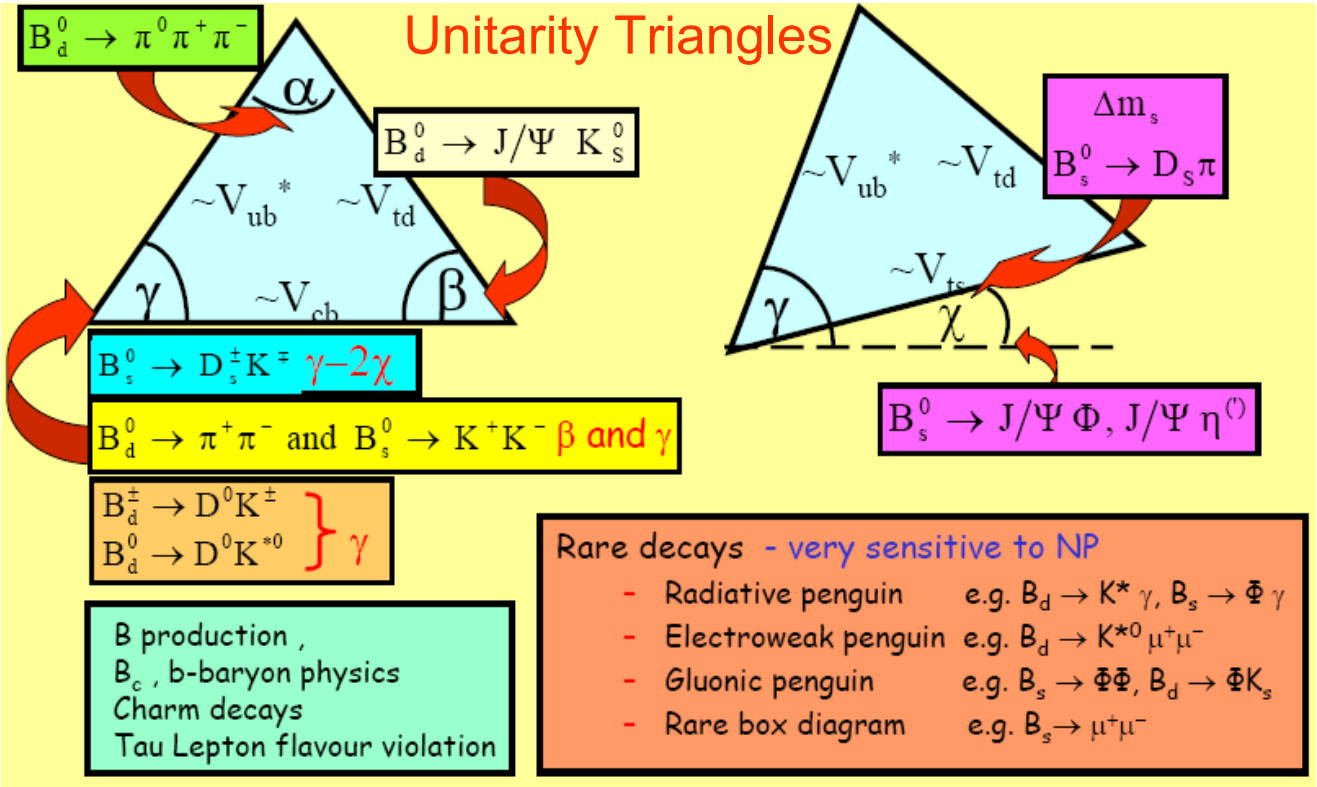
Aim to **over-constrain** the **Unitarity Triangles** ⇒ any inconsistencies are hint of new physics.

See talks by:

P. Koppenburg, LHC semileptonic and radioactive rare B decays program

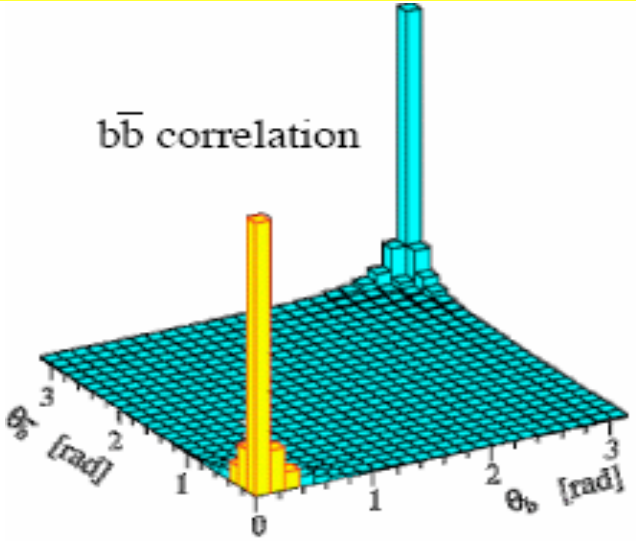
M. Musy, Potential for precise Unitarity Triangle angles measurements in LHC

V. Obratsov, LHCb – beyond the baseline



LHCb: b production

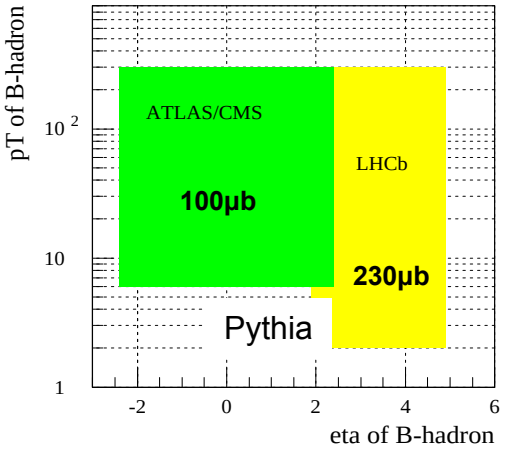
LHCb: single arm forward spectrometer (1.9<η<4.9)

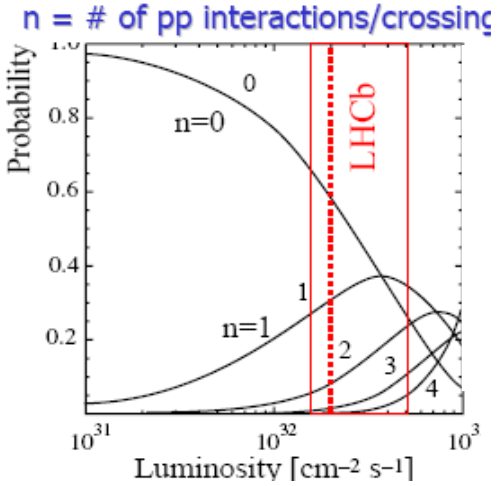


- **pp collisions at $\sqrt{s}$ = 14 TeV**
  - 25 ns bunch crossing
  - large cross section $\sigma_{b\bar{b}}$ ~500 μb, $\sigma_{inelastic}$ ~80mb
- **$b\bar{b}$ hadrons are produced in a forward cone, correlated**
  - single arm (cost and space reduction)

- **Copious source of B-hadrons⇒high statistics**
  - B_u, B_d, B_s, B_c, b-baryons
  - expect ~10^{12} $b\bar{b}$ pairs/year

- **Run at lower luminosity $\mathcal{L}$ ~ $2\times10^{32}cm^{-2}s^{-1}$**
  (LHC design $\mathcal{L}$= $10^{34}cm^{-2}s^{-1}$)
  - mostly single inelastic interactions
  - simpler event reconstruction
  - limit radiation damage
  - available form the start
  - 2 fb^{-1}/ year(10^7 s) nominal

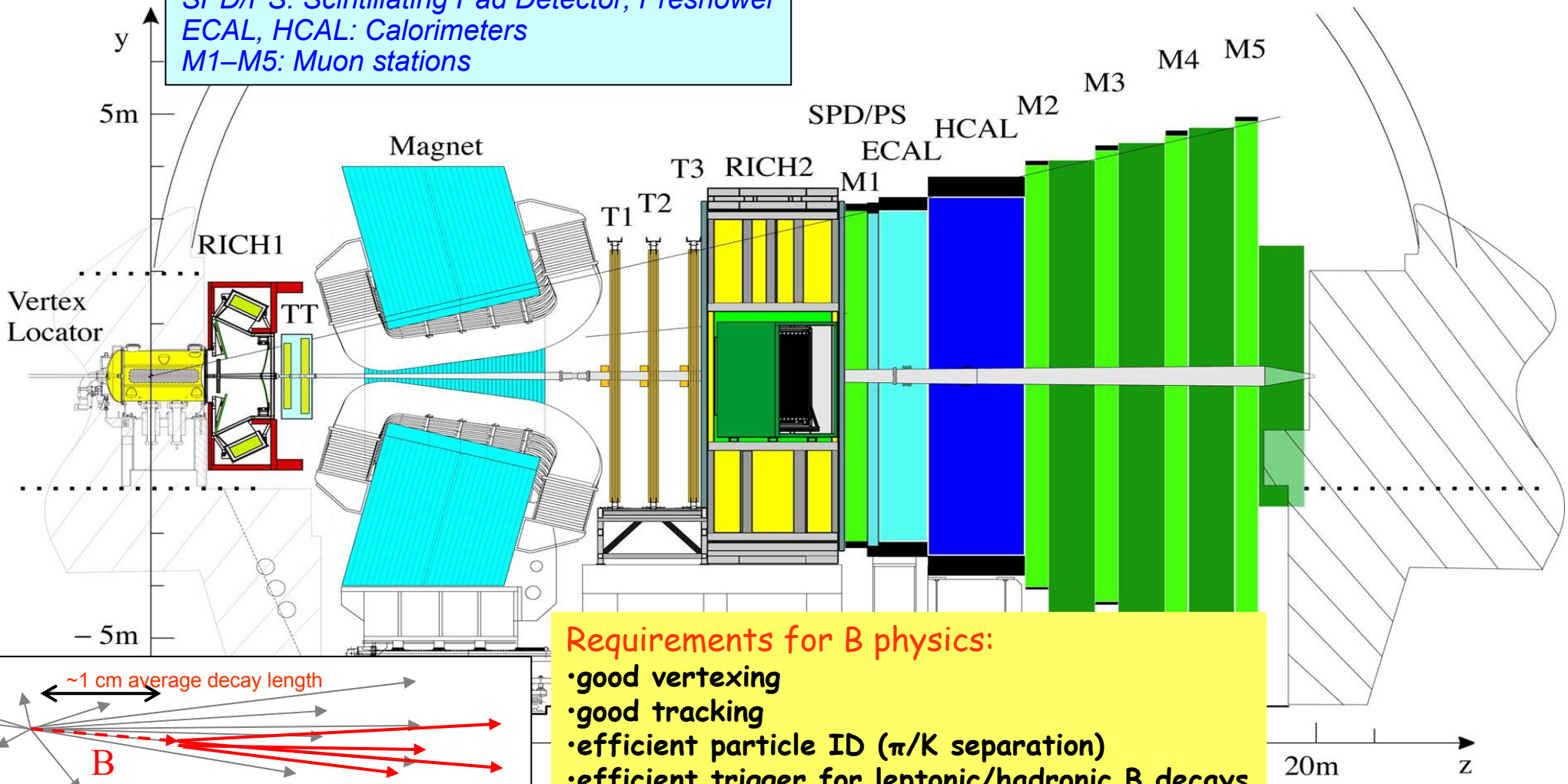


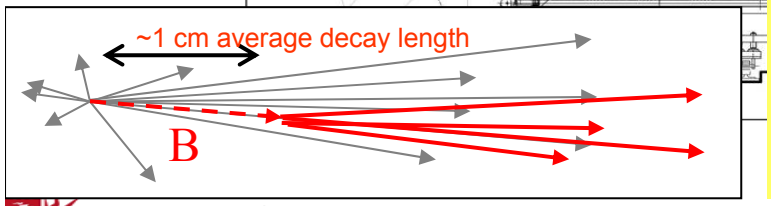


LHCb Detector Schematic

VELO: Vertex Locator
TT, T1, T2, T3: Tracking stations
RICH1-2: Ring Imaging Cherenkov detectors
SPD/PS: Scintillating Pad Detector, Preshower
ECAL, HCAL: Calorimeters
M1–M5: Muon stations

~10 mrad<θ< 300mrad bending plane (x-z)
~10 mrad<θ< 250 mrad non-bending plane (y-z)



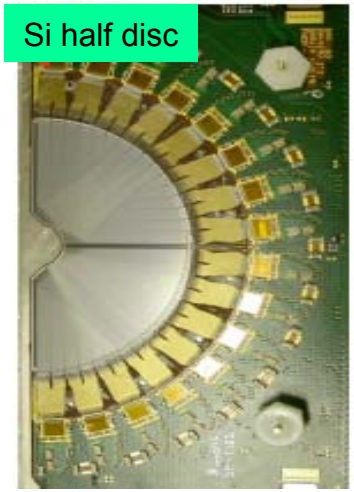


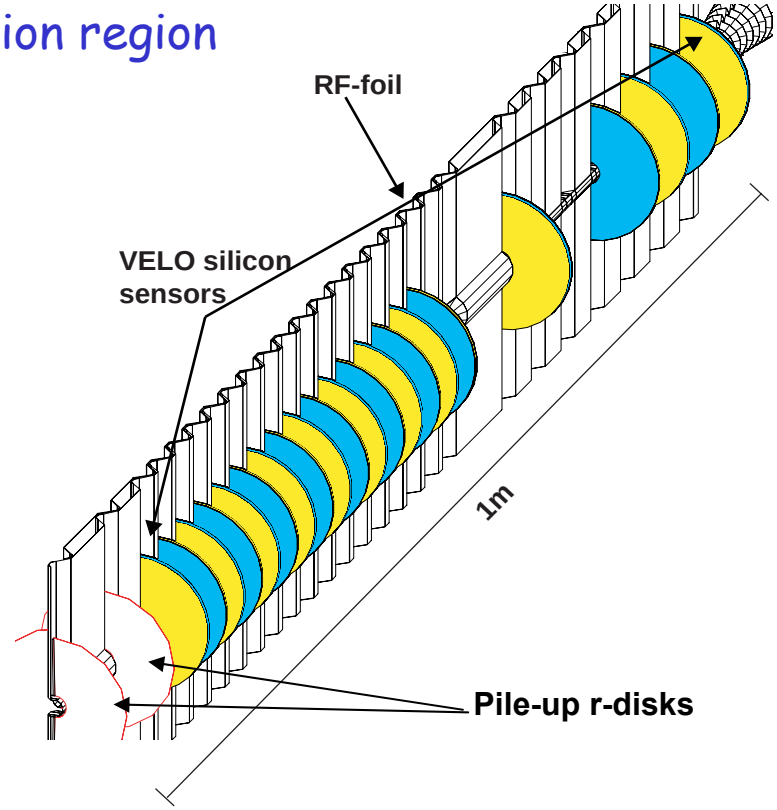
Requirements for B physics:
- **good vertexing**
- **good tracking**
- **efficient particle ID (π/K separation)**
- **efficient trigger for leptonic/hadronic B decays**

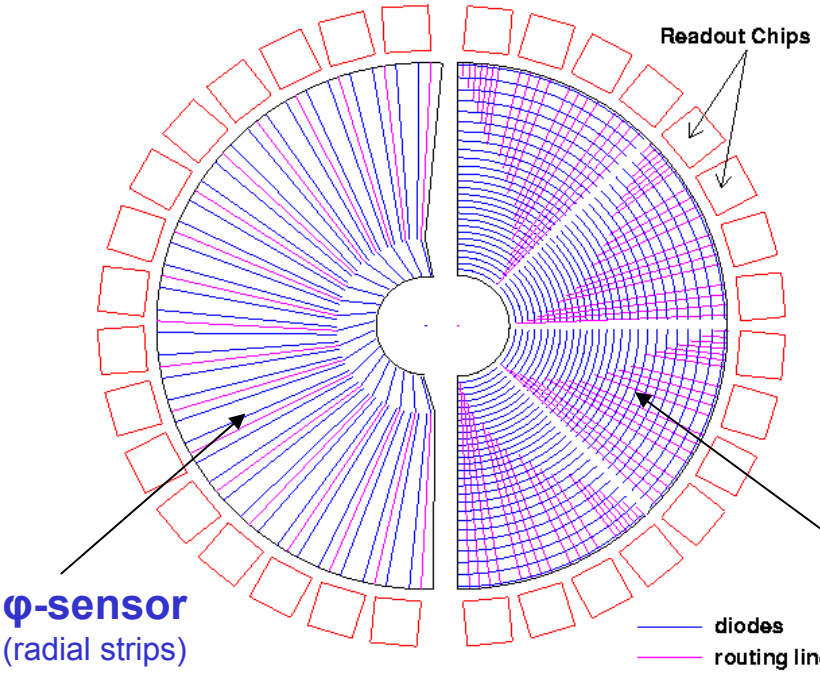
VELO-Vertex Locator

Measurement of track coordinates close to interaction region

- **21 stations:**
  - each station 2 pairs of Si half-discs: r,φ measurement
  - -positioned along beam line axis
  - -300 μm thick Si sensors
  - -35-100 μm pitch
  - -operated at -5 degrees (C02 cooling)





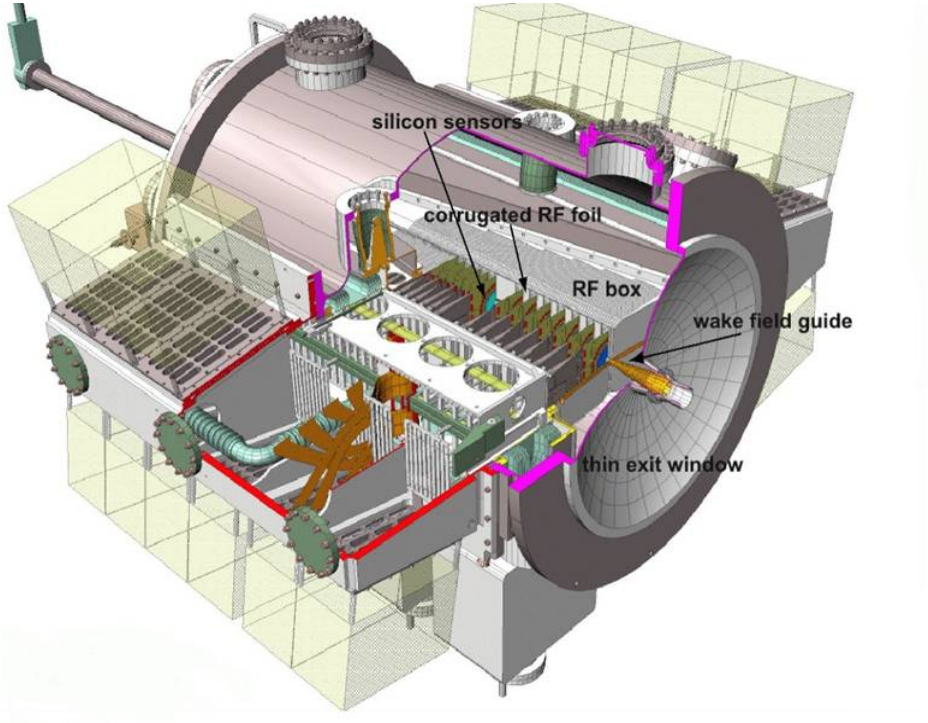


φ-sensor
(radial strips)

r-sensor
(circular strips)

•**Pile Up System:** two r-disks placed upstream to reject multiple interaction events (L0 trigger)

VELO-Vertex Locator



RF boxes

VELO TANK at IP8

Sensitive area ~ 8mm of the LHC beam

-two retractable halves

-Si disks housed in secondary vacuum (Roman Pot) separated from beampipe vacuum by Al RF foil(250 μm)

-3 cm retraction during injection

Commissioned in testbeam 2006
Final installation 2007

RICH: Ring Imaging Cherenkov Detectors

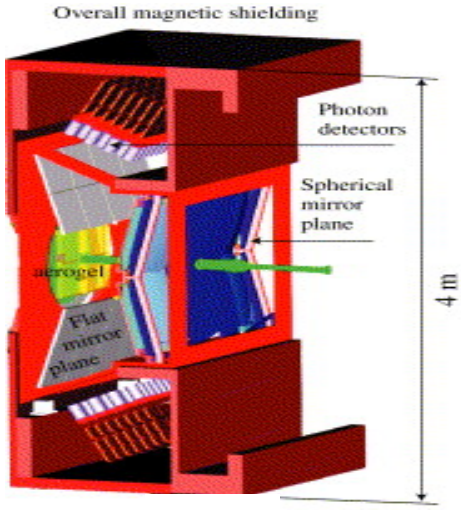
Charged particle identification in 2-100 GeV/c range: two RICH detectors, 3 radiators

RICH1

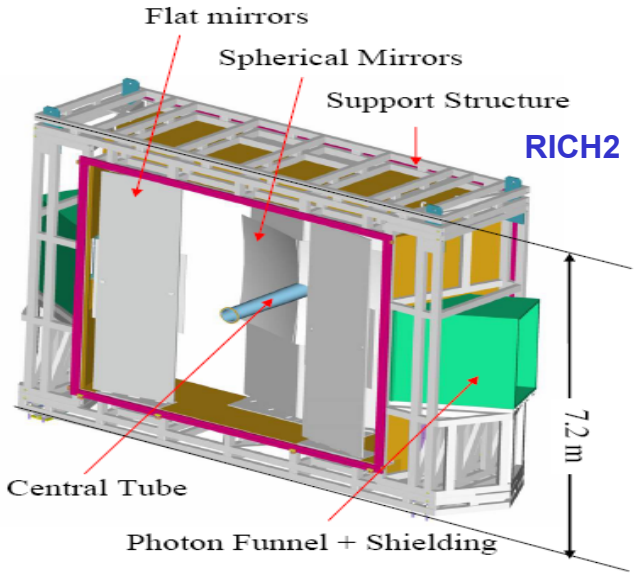
- **mirrors:** spherical (light-weight carbon fiber) and planar (glass)
- **radiator:** aerogel ⇒ ~2-10 GeV/c
  C4F10 gas ⇒ ~10-65 GeV/c
- **magnetic shielding**: shield photon detectors stray B-field
  funnels B-field for tracking
- **wide acceptance**: 25-300mrad (bending plane)
- installation completed by ~March07

RICH2

- **mirrors:** glass (spherical + planar)
- **radiator:** CF4 gas
- **momentum range** ~15-100 GeV/c
- **smaller acceptance:** 15-120 mrad (bending plane)
- installation completed by end 2006

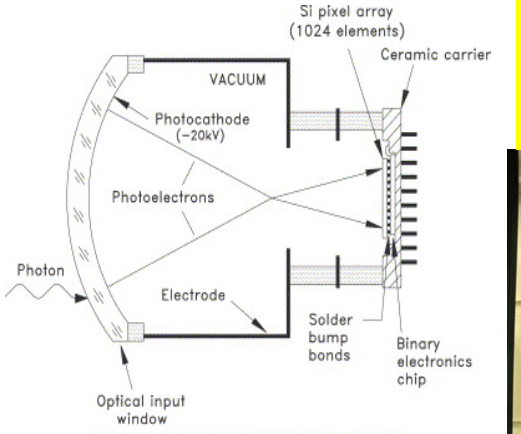


RICH1



RICH

hybrid photon detectors (HPD) : λ~200-600 nm

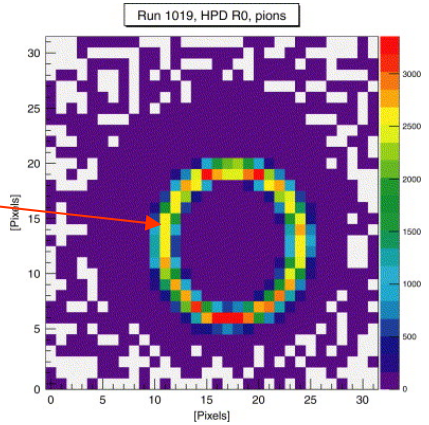


Si array of 1024 pixels
2.5mmx2.5mm granularity
~500 HPD

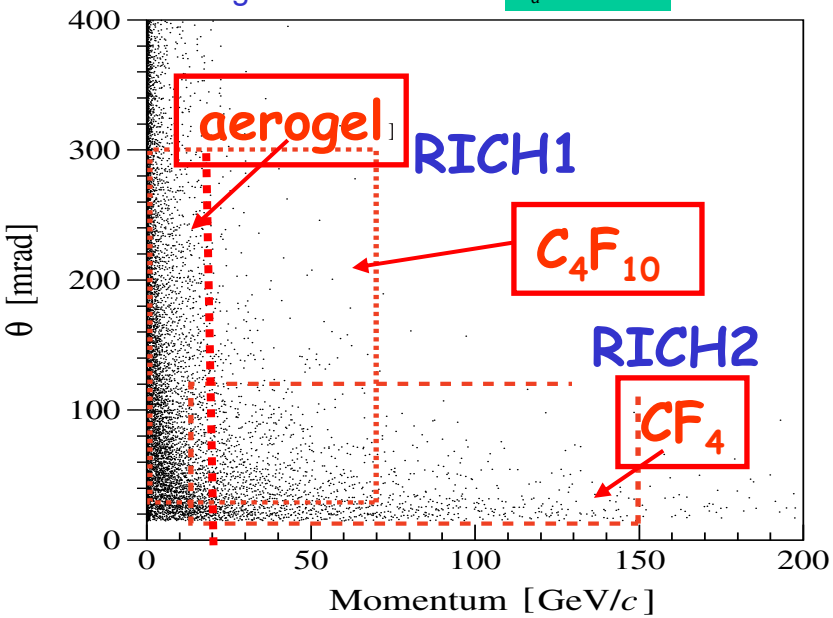
HPD

HPD Column

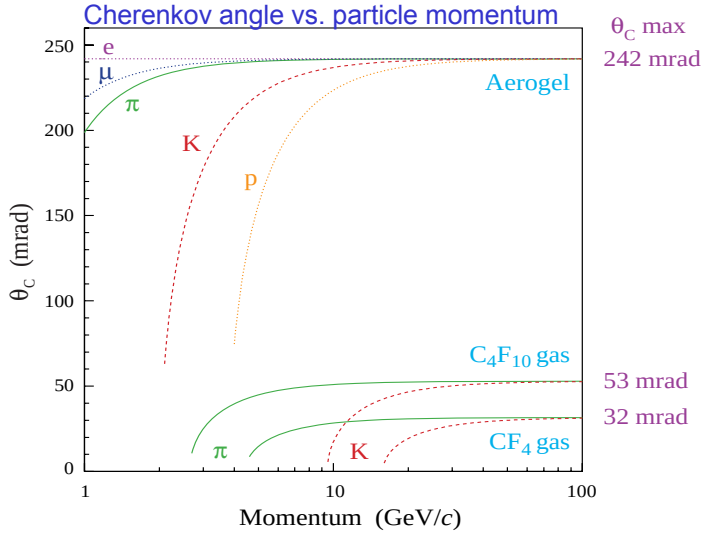
ring image ~30k events
N_2 radiator



Polar angle vs. momentum $B_d^0 \to \pi^+\pi^-$



Cherenkov angle vs. particle momentum



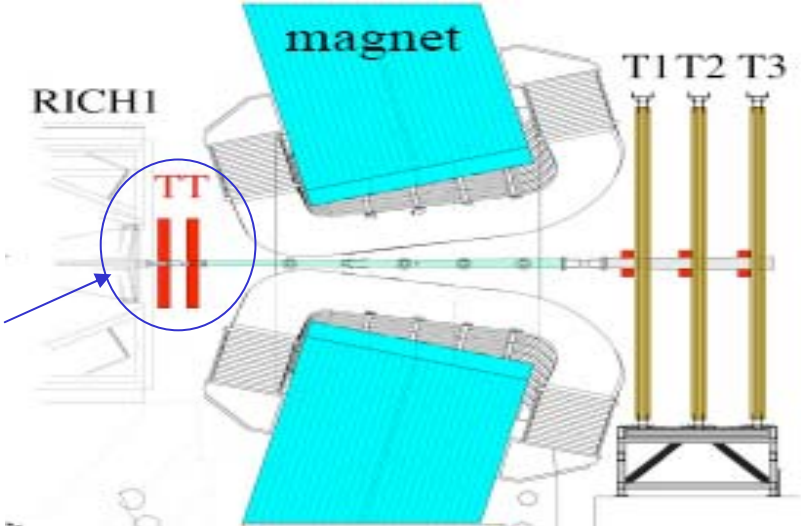
θ_C max
242 mrad
53 mrad
32 mrad

Tracking

Find charged particle tracks and measure momentum: VELO + 4 tracking stations

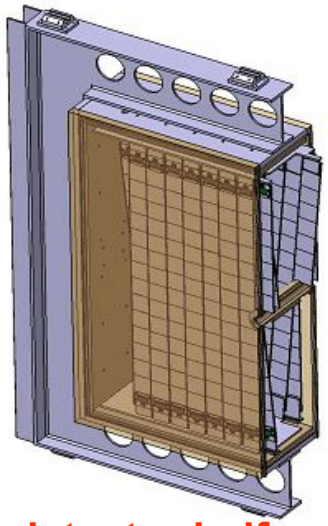
4 Tracking stations (TT,T1,T2,T3)

- 2 outer layers: vertical strips
- 2 inner layers: rotated by stereo angle $+5^0$,-5^0

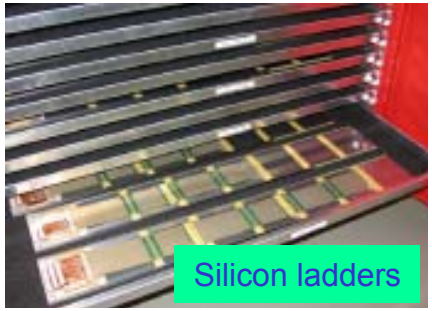


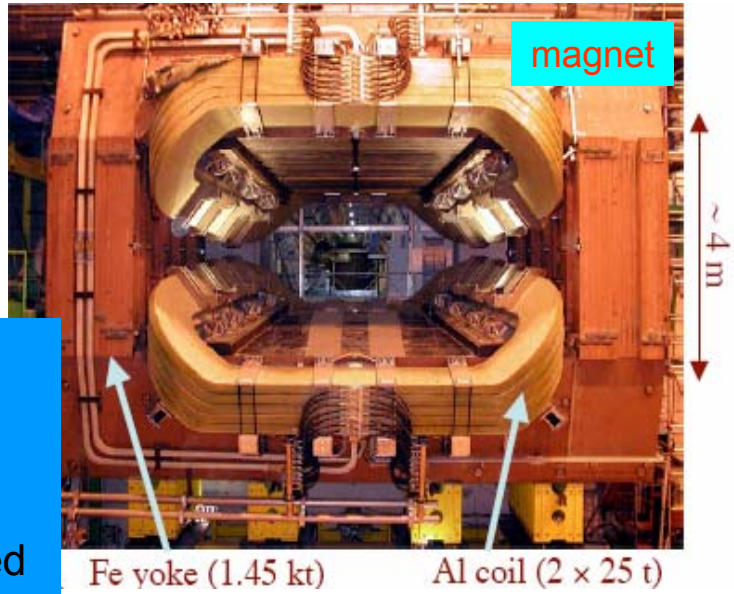
Trigger Tracker

- 4 Si μ-strip planes
- 500μm Si, pitch 183μm, up to 37 cm long strips
- operated at ~5^0C



TT detector half



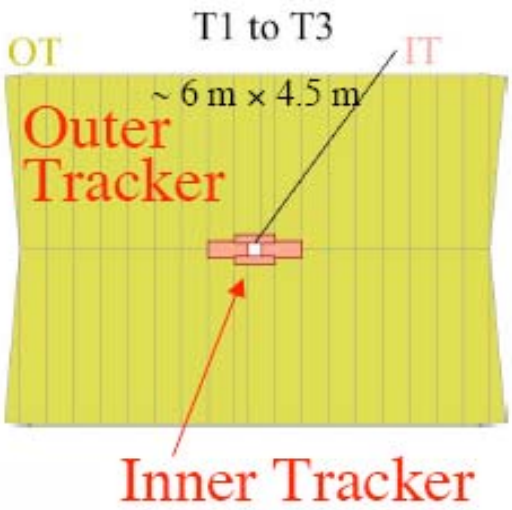


Magnet

- Warm dipole magnet
- ∫BdL=4Tm
- B field regularly reversed
- Installed and commissioned
- Field map completed

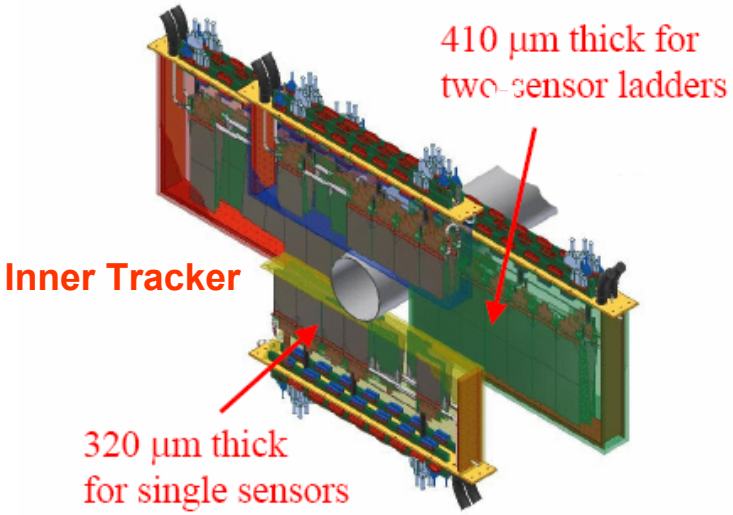
Tracking

High track occupancy close to beampipe
Area: IT~2%, OT~98%
Tracks: IT~20%,OT~80%

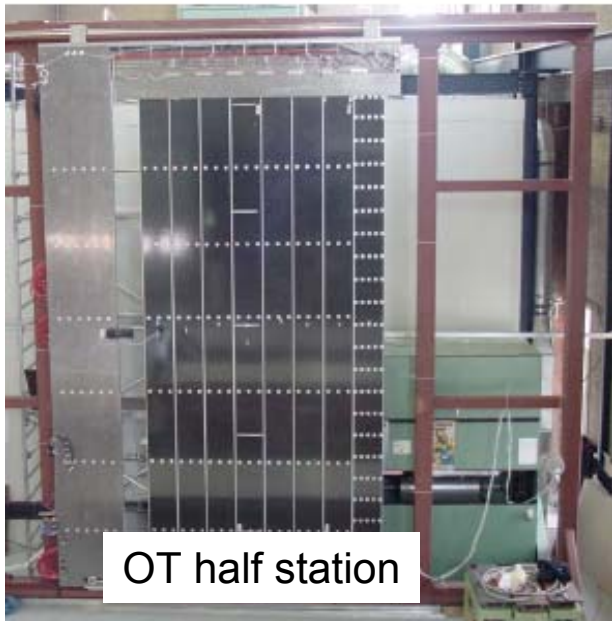


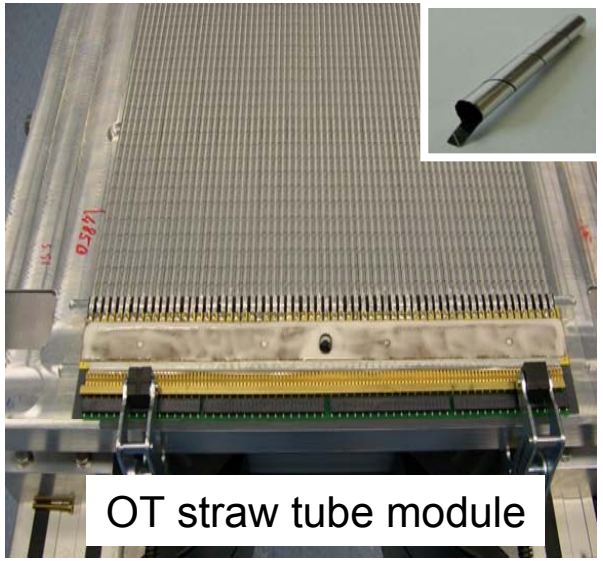
Inner Tracker:
- Si sensors
- Si μ-strip, pitch 198μm, lengths up to 22 cm
- Thickness: 320μm and 410 μm

Outer Tracker
- Kapton/Al straw tubes (5 mm *4.7 m)
- Ar-$C0_2$ gas



OT production completed
IT, TT chambers in production


OT half station


OT straw tube module

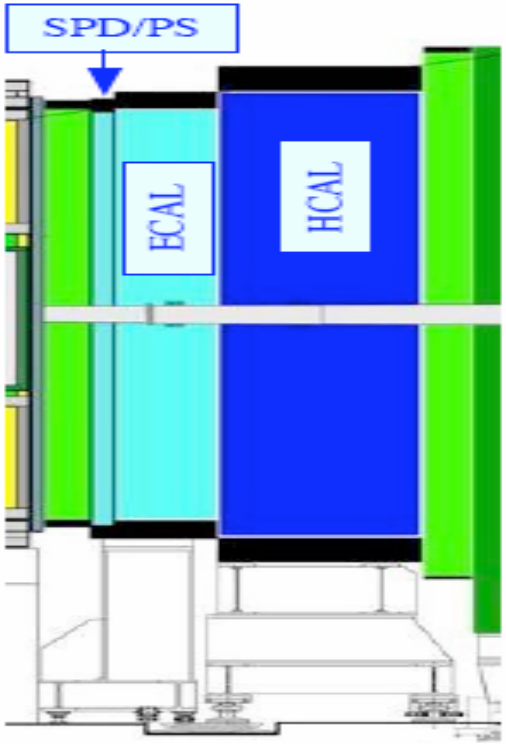
Calorimeters

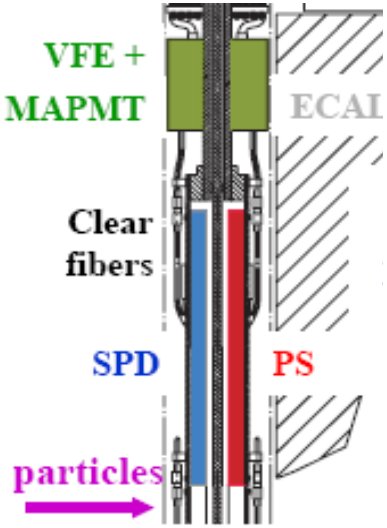
Energy measurement and e,γ,π^0, hadron identification

3 subdetectors

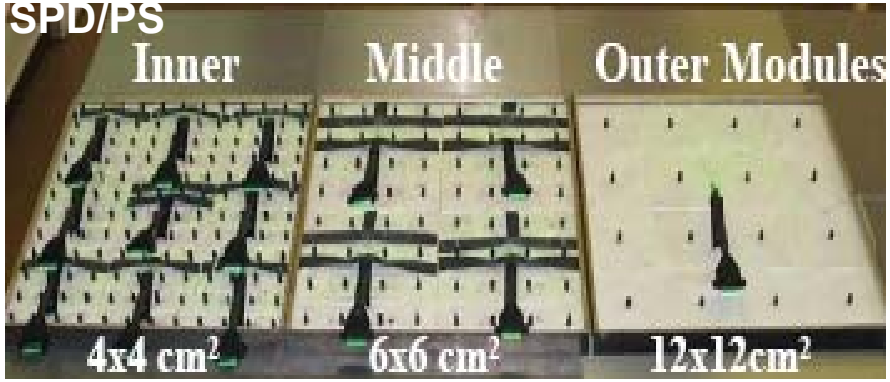
- **SPD/PS: 2 planes of scintillating pads with $2X_0$ Pb wall in between (e, γ separation)**
- **ECAL: Pb-scintillator Shashlik ($25\ X_0$, $1.1\lambda_I$)**
- **HCAL: Fe-scintillator tile ($5.6\ \lambda_I$)**

Light collection: WLS fibers to PM; MaPMT for **SPD/PS**
Contributes to L0 trigger



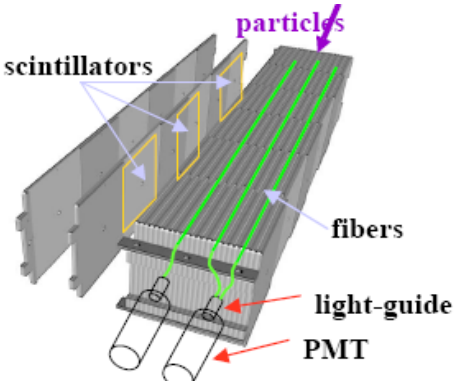


SPD/PS: 16 super modules, each consisting of 26 modules mounted in two columns

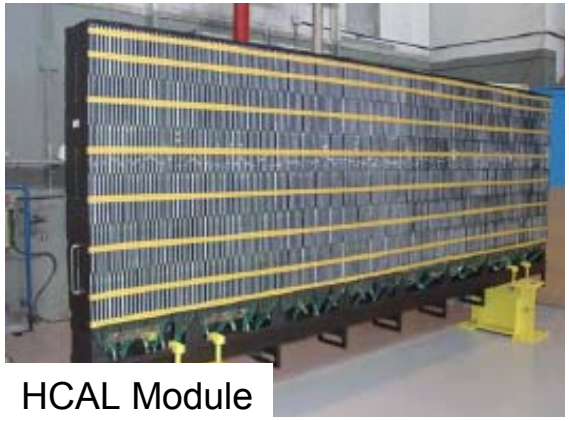


Calorimeters

HCAL
- 52 modules
- Each half: 26 stacked modules
- Each module: 8 sub modules



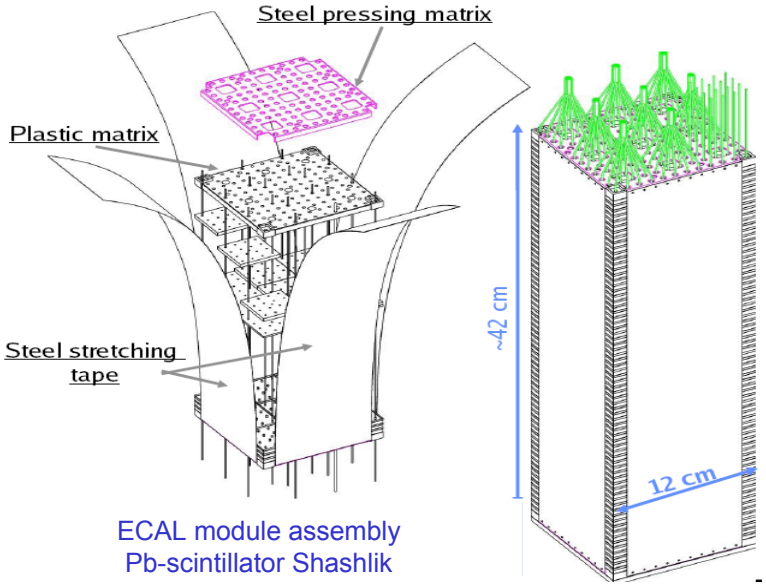
HCAL structure



HCAL Module

ECAL modules

ECAL
- ~3300 modules, stacked ~6m high
- 3 module types of different segmentation



ECAL module assembly
Pb-scintillator Shashlik

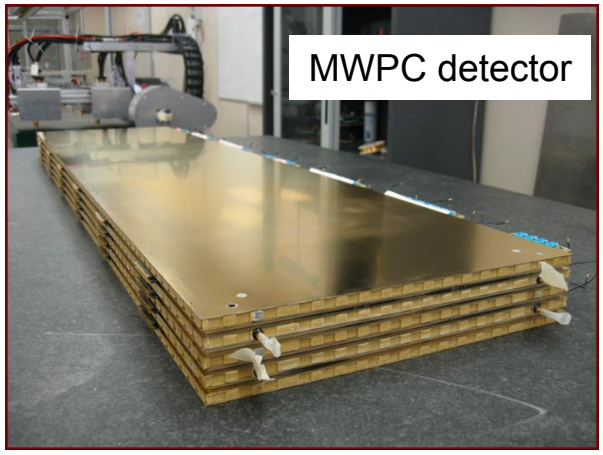
- ECAL: $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1.5\%$
- HCAL: $\sigma(E)/E \sim 80\%/\sqrt{E} \oplus 10\%$
- $\varepsilon(e \to e) \sim 95\%, \quad \varepsilon(\pi \to e) \sim 0.7\%$

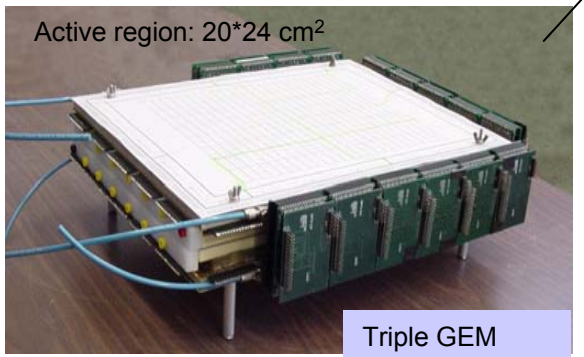
ECAL, HCAL installed
SPD/PS installation summer 2006

Muon System

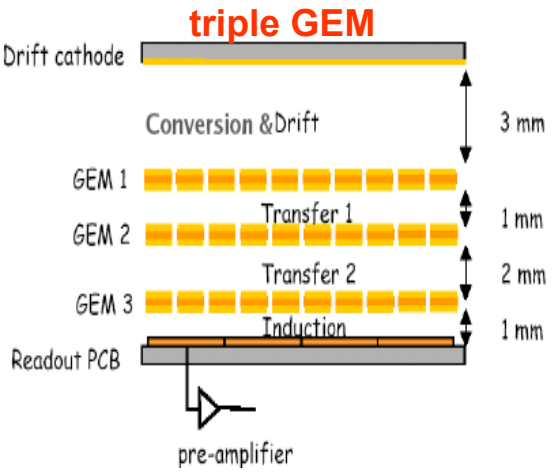
High Pt Muon triggering (L0) and Muon identification

- 5 muon stations
  - -1380 MWPC
  - -24 Triple-GEMS in M1 inner part were high rate (>100kHz/cm2)
- 3 iron muon filters

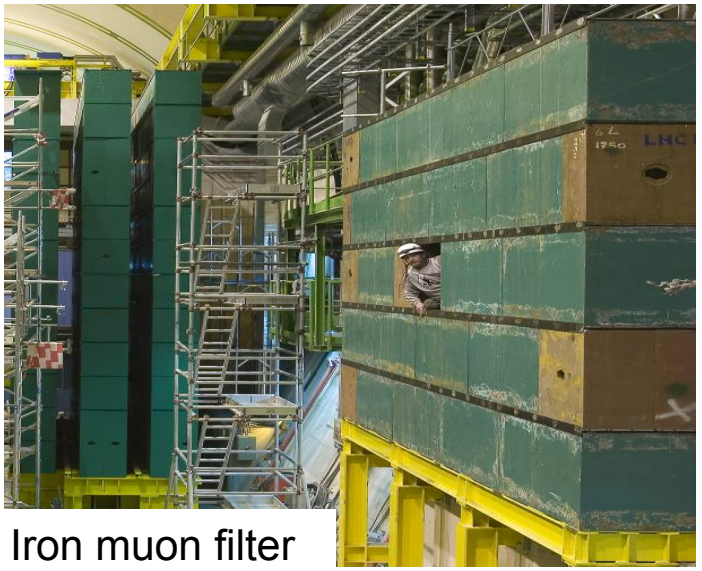




Muon Identification efficiency ~94%
Pion misidentification ~1.5%
δp/p ~ 20% for b-decays



Muon filter installed
Muon chambers completed by end 2006
Installation completed ~April 2007



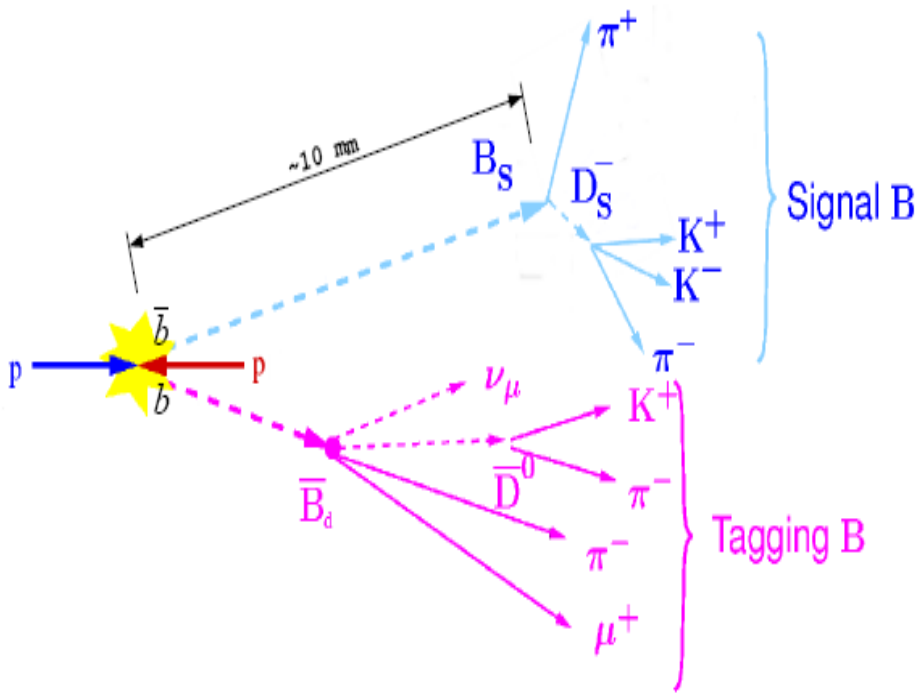
Iron muon filter

Trigger

Select interesting B-meson decays

- large background/signal ratio $\sigma_{inelastic}/\sigma_{b\bar{b}}$ ~160
- small branching ratios (<10^{-3})
- limited detector acceptance

Require selective and efficient trigger



B-meson signatures:

- leptons, hadrons with large Pt
- secondary vertices
- tracks with large impact parameter

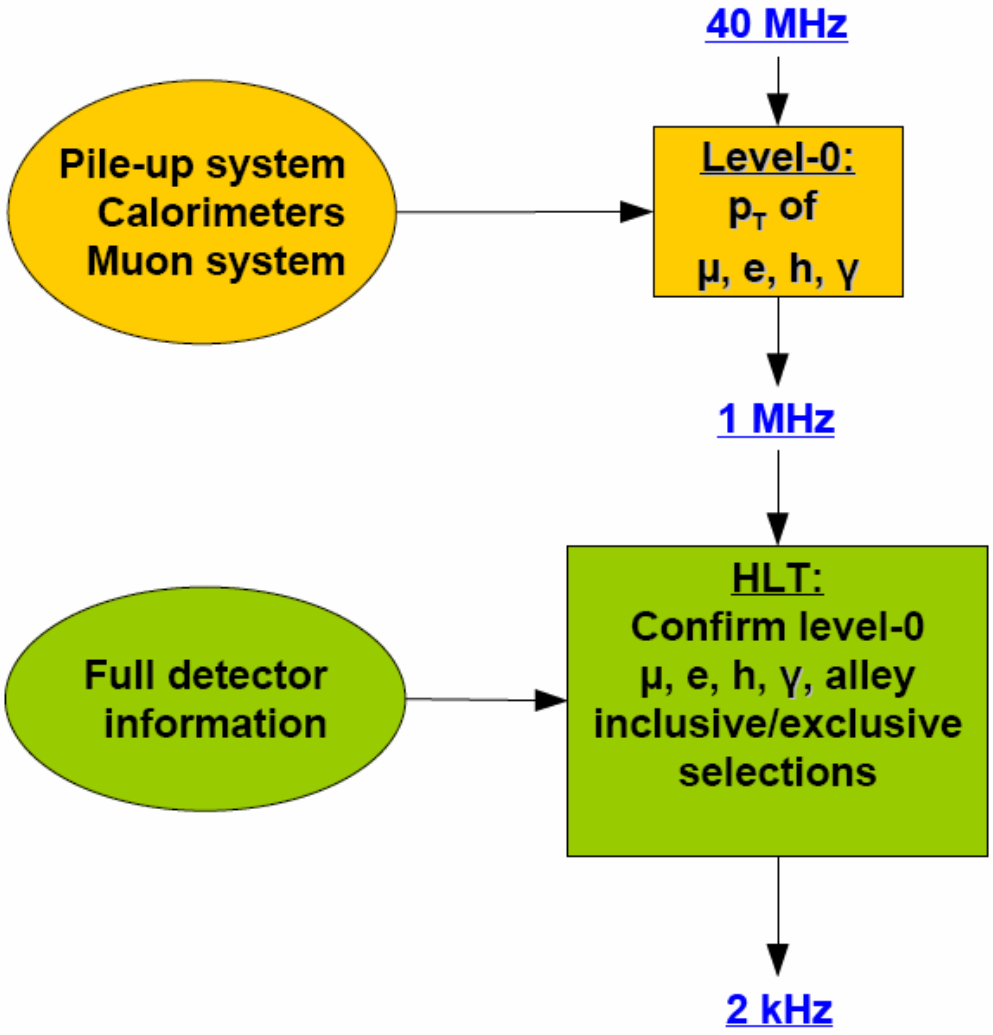
Trigger: Two levels

Level 0

- reduce rate from 40MHz (bunch crossing) to 1MHz
- fixed latency 4μs
- hardware trigger
- custom electronics

HLT (High Level Trigger)

- reduce rate from 1MHz to ~2kHz
- full detector info available
- software trigger
- CPU farm (~1800 nodes)
- latency dependant on number of CPUs



L0 Trigger

- **Pile-up system**

  -reject events with multiple interactions per bunch crossing

- **Calorimeter trigger (high E_T clusters)**

  -find and select (h, e,γ,π^0) candidates with highest E_T : ECAL/HCAL

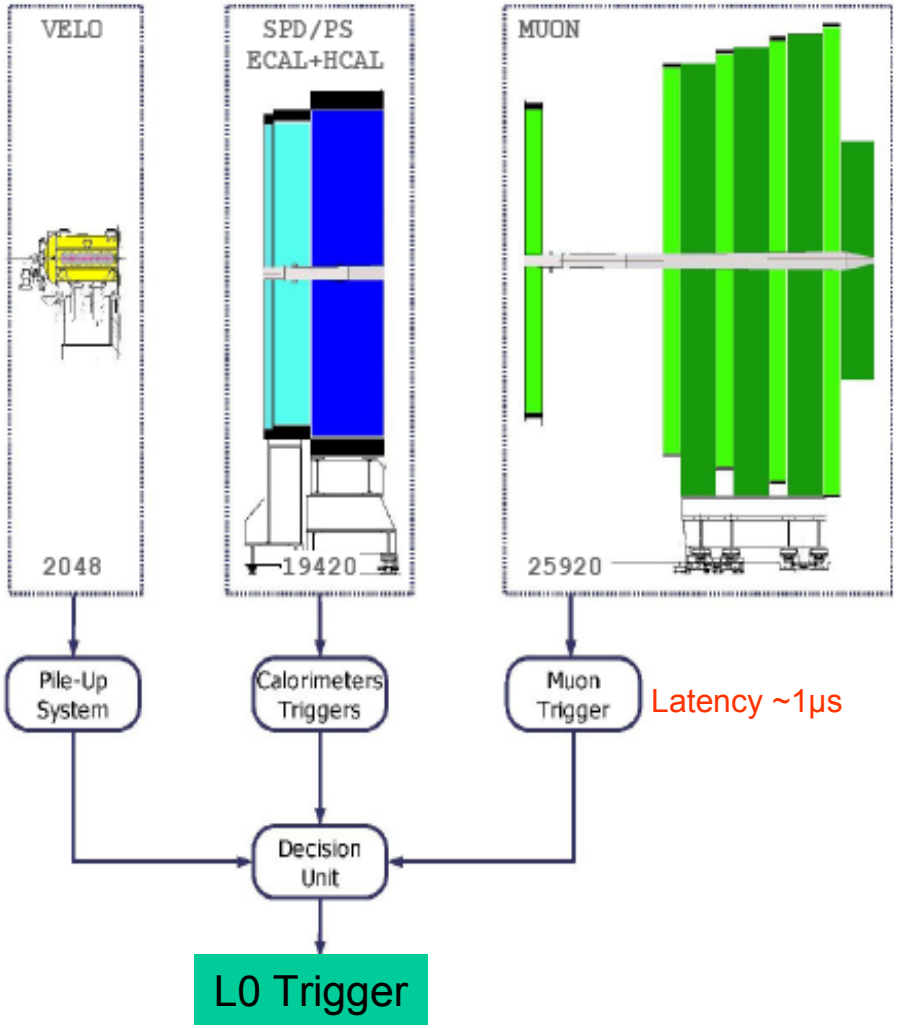
- **Muon Trigger (high P_T muons)**

  -select 2 muons with the highest P_T in each quadrant

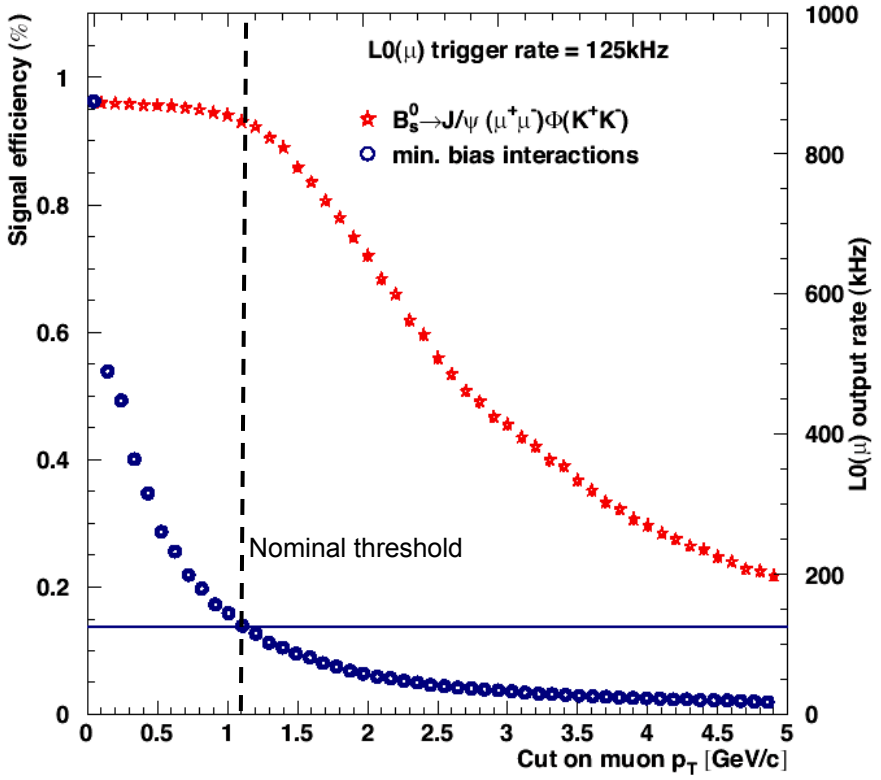
Decision Unit

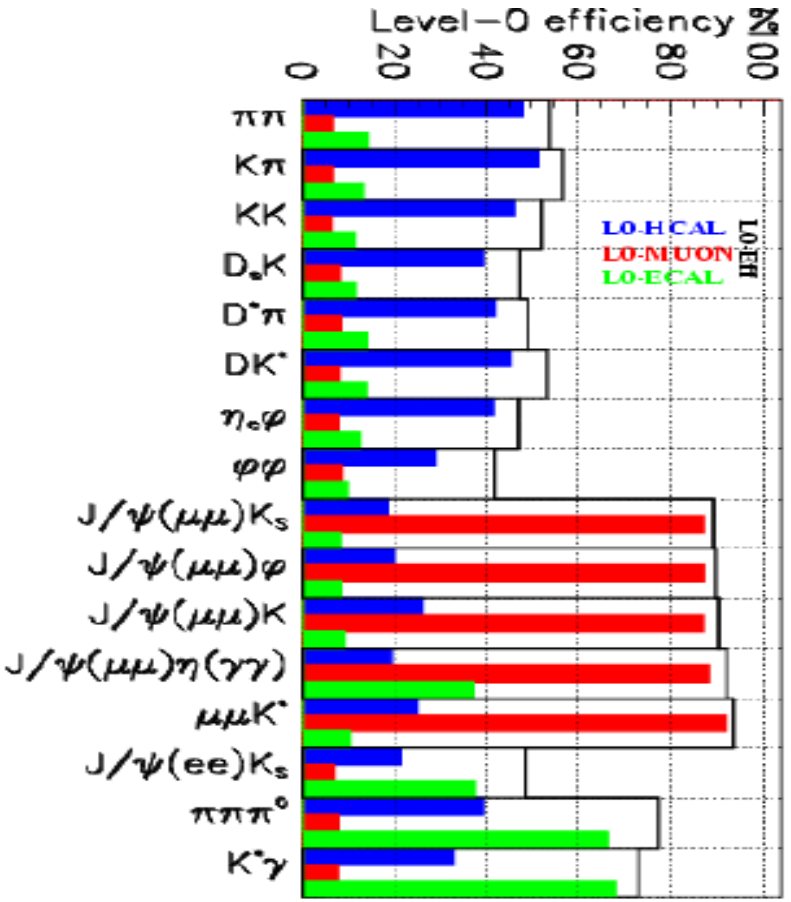
-trigger conditions evaluated

-L0 decision formed



L0 Trigger





L0 Efficiency:

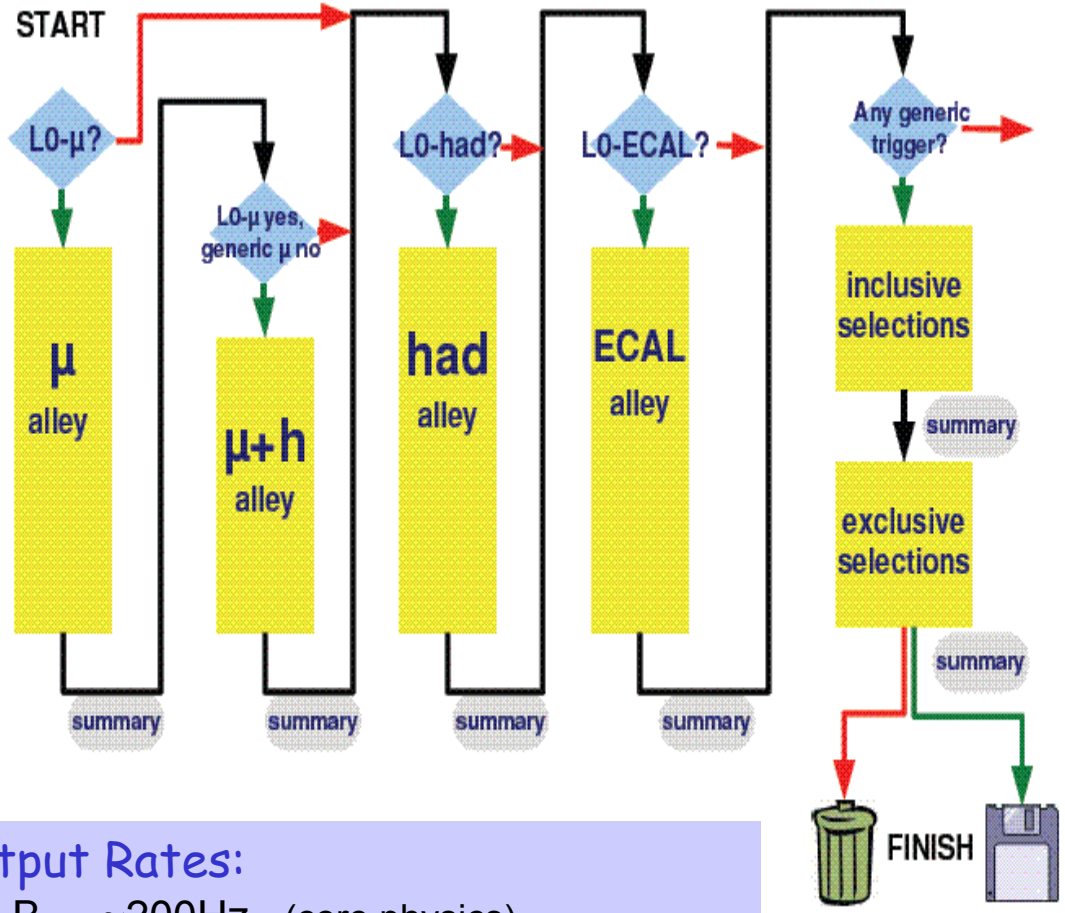
~50% for hadronic channels

~90% for μ channels

~70% for radiative channels

HLT Trigger

- **Use all detector info**
- **Starting point is the L0 decision**
- **4 alleys**
  - **alley chosen depends on L0**
  - **alleys are independent**
  - **alleys produce a summary (monitoring):**
    - *decision*
    - *type of trigger*
    - *quantities used*
    - *reconstructed objects*
  - **each alley consists of 3 main steps:**
    - -Level-0 trigger confirmation
    - -Fast rejection using reconstructed quantities
    - -Alley-dependent trigger algorithm
- **Inclusive selection**
  - -systematic studies
  - -inclusive B or D*
- **Exclusive selection**
  - -reconstructed B decays

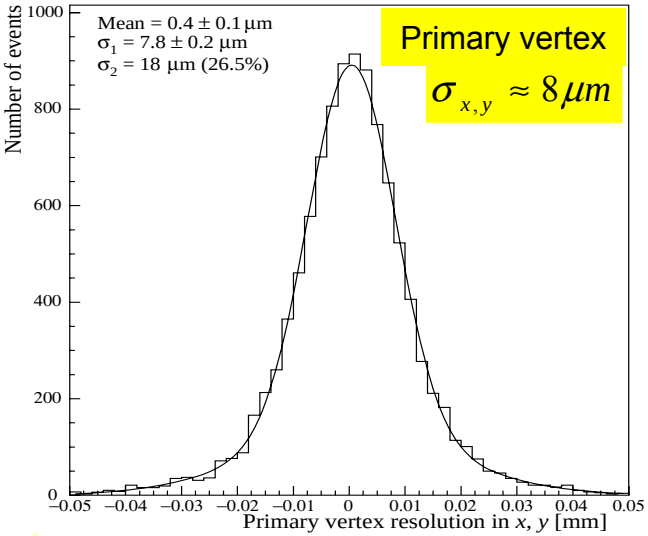


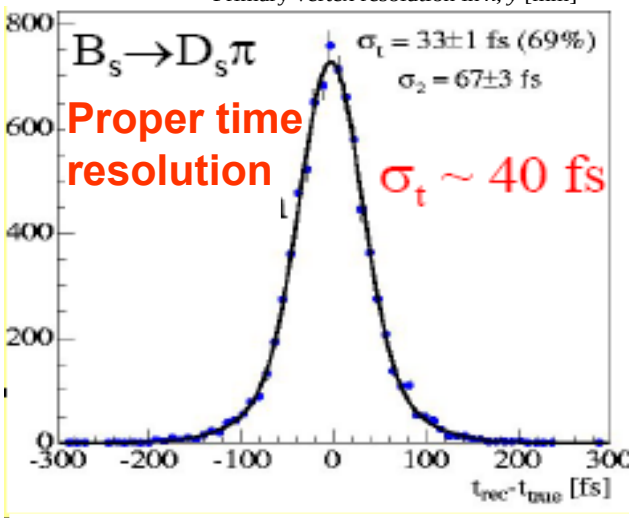
HLT Output Rates:

Exclusive B	~200Hz	(core physics)
D*	~300Hz	(PID eff., D decays)
Dimuon	~600Hz	(tracking, $\Delta\Gamma$)
Inclusive $b\to\mu$	~900Hz	(trigger eff., data mining)

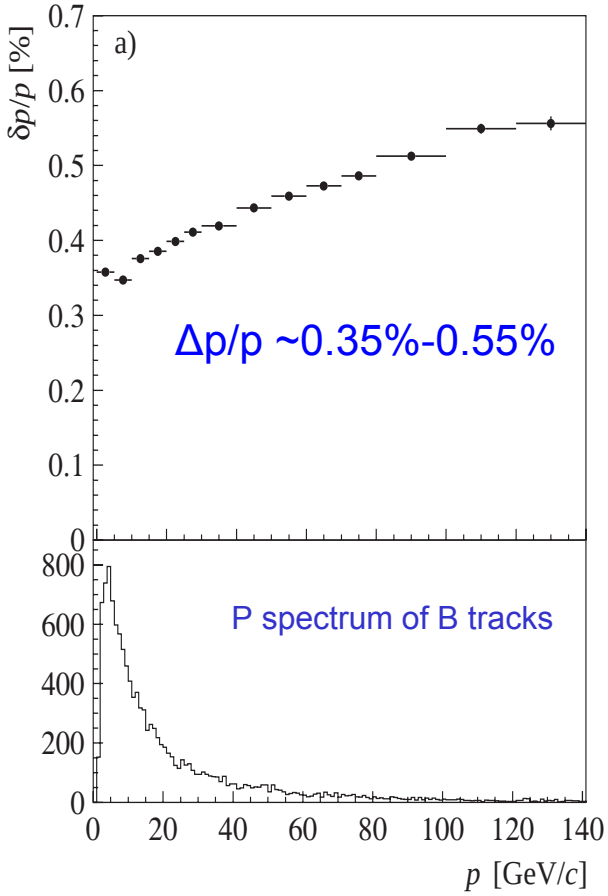
Expected Tracking Performance

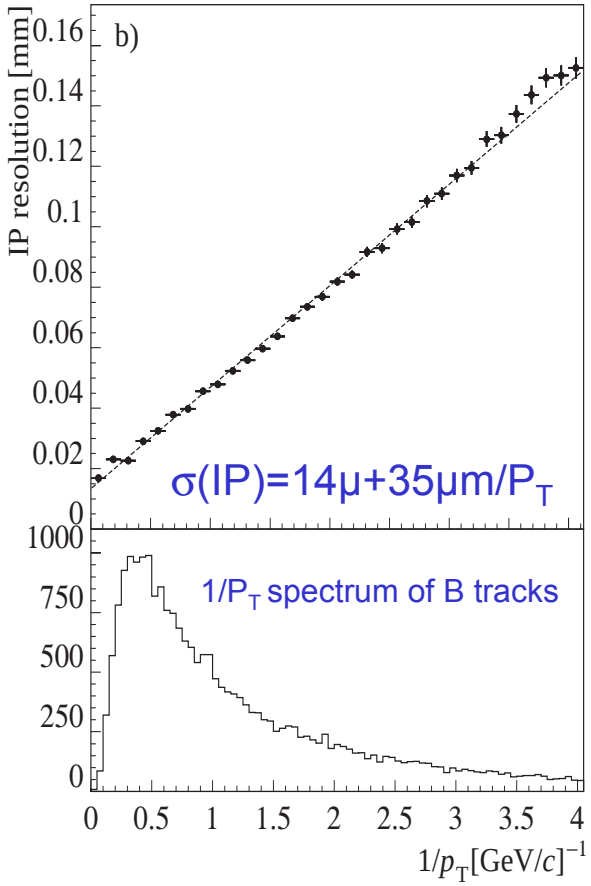
Primary vertex resolution: ~8 μm (x,y)
~44 μm (z)





Long tracks (from VELO to T stations):
- Efficiency: ~94% (p>10 GeV/c)
- Ghost rate: ~3% (p_T>0.5 GeV/c)
- Momentum resolution: ~0.4%
- Impact parameter resolution: ~40 μm

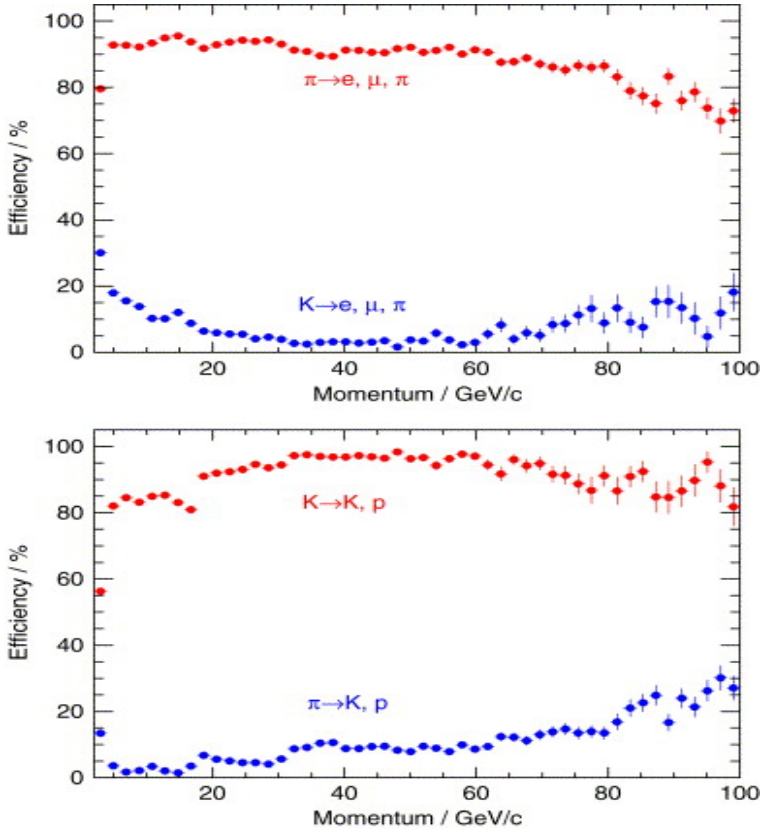


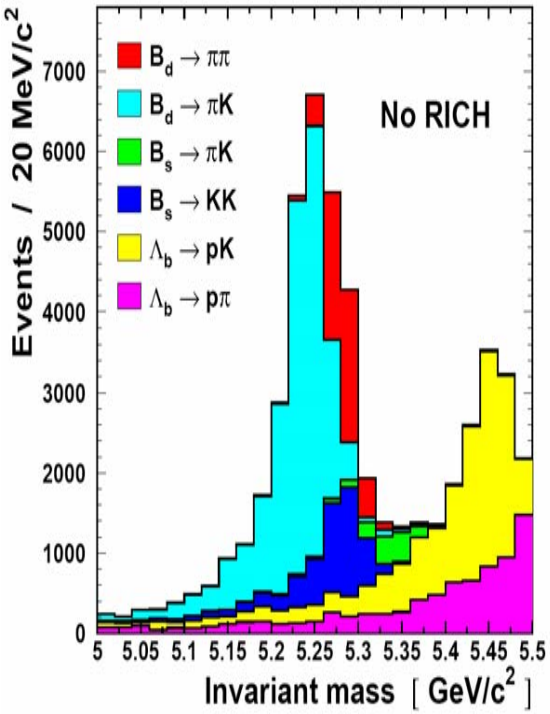


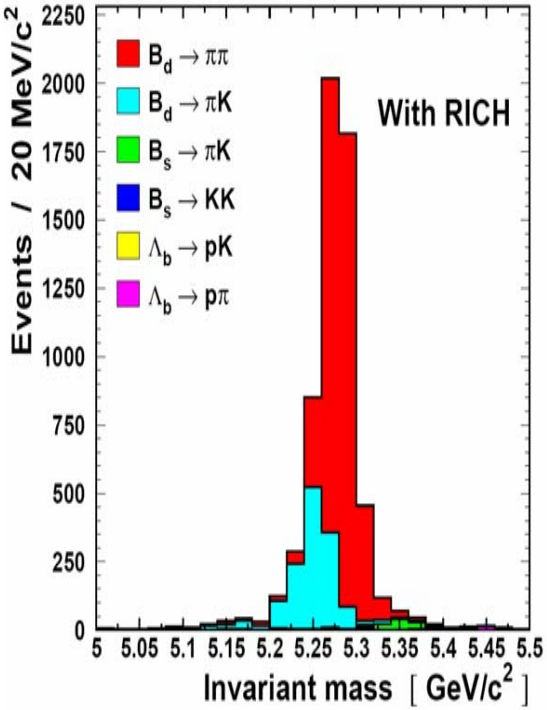
Expected Particle ID

•Efficient (K,π) separation with RICH

K,π id efficiency ~90%
K,π misidentification <10%



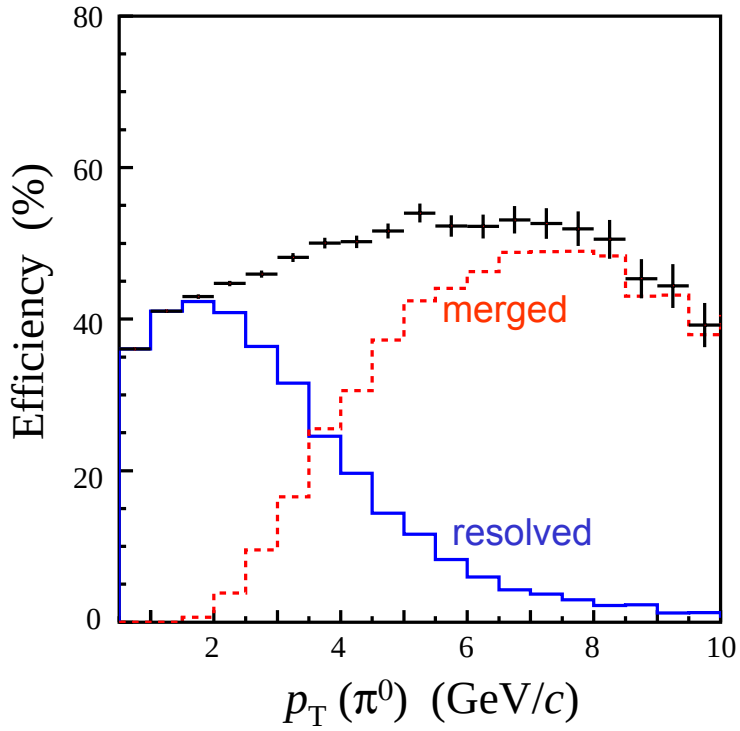




•With ECAL and Muon e,μ id efficiency ~ 95% , π misID ~1%

Expected Neutral Reconstruction

- π^0 ~50% reconstruction efficiency ($B^0 \to \pi^+\pi^-\pi^0$)
  -use CALO clusters not associated to tracks
  -reconstruct π^0 from two separate clusters (resolved) or single merged cluster (use cluster shape)



- $K_S \to \pi^+\pi^-$ reconstruction efficiency ~ 75% if decay in VELO, lower otherwise.

Summary

- LHCb detector is a dedicated B-physics experiment.
  - precise vertexing and tracking
  - excellent PID
  - excellent proper time resolution
  - efficient and selective trigger

- Construction and installation of the subdetectors is progressing on schedule.

- L0 trigger hardware is under construction and the commissioning is in early 2007, while the HLT trigger is in its final stage of development.

- LHCb will be ready for the LHC pilot run second half 2007.

- Aim to get physics results early from the LHC.