# Tracking, Vertexing and Particle Identification in LHCb

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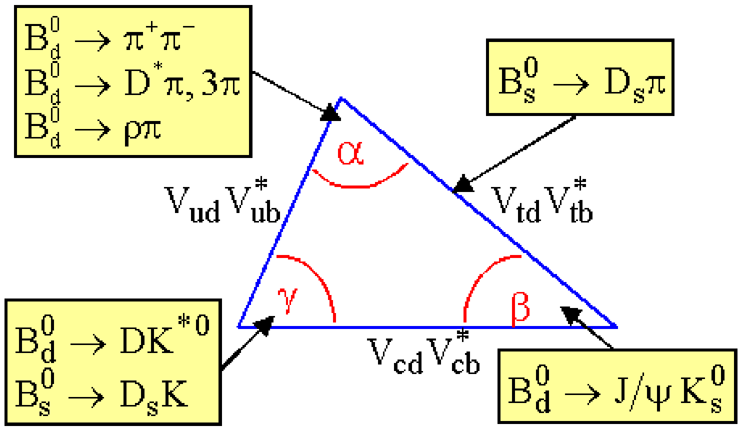
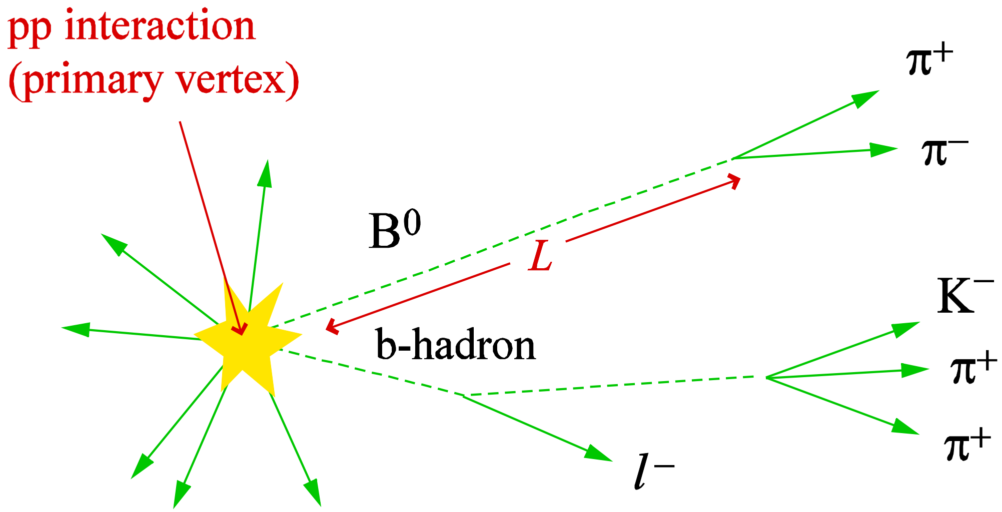
On behalf of the LHCb Collaboration

# Introduction

- **Precise CP measurements and rare physics studies in b decays**

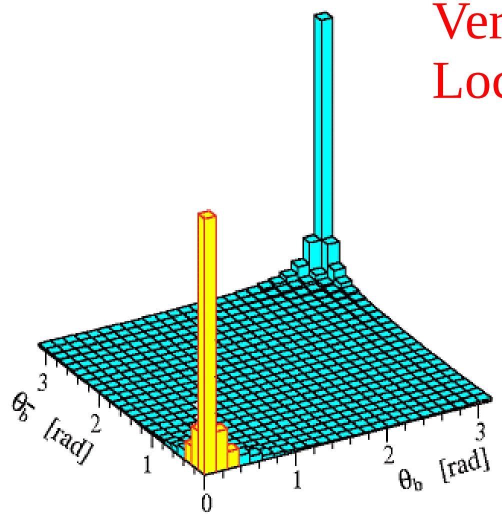


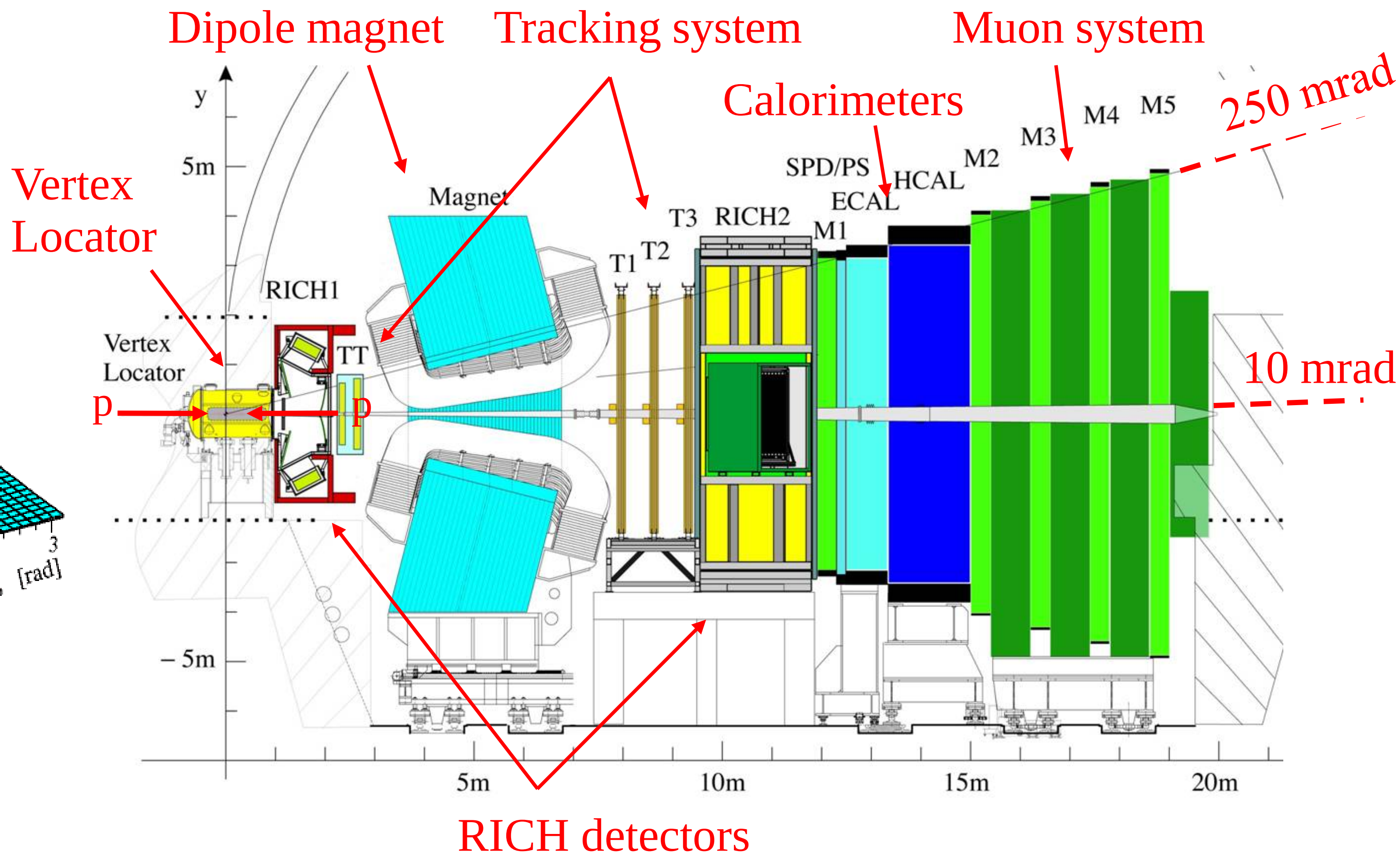




- **Main detector requirements**
  - Efficient trigger
  - Excellent vertex finding and tracking efficiency
  - Particle Identification
- **See presentations by C. Lazzeroni and B. Pietrzyk**

# LHCb Experiment

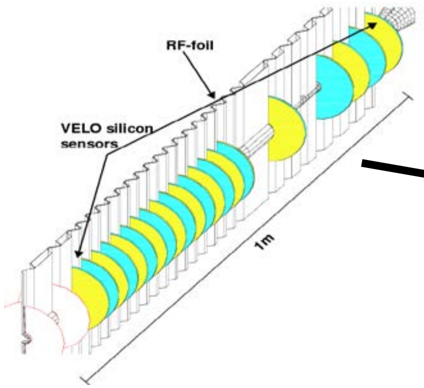
- **Large Samples of b decays**
  - B production predominately at small polar angles
  - LHCb optimized as single forward arm spectrometer

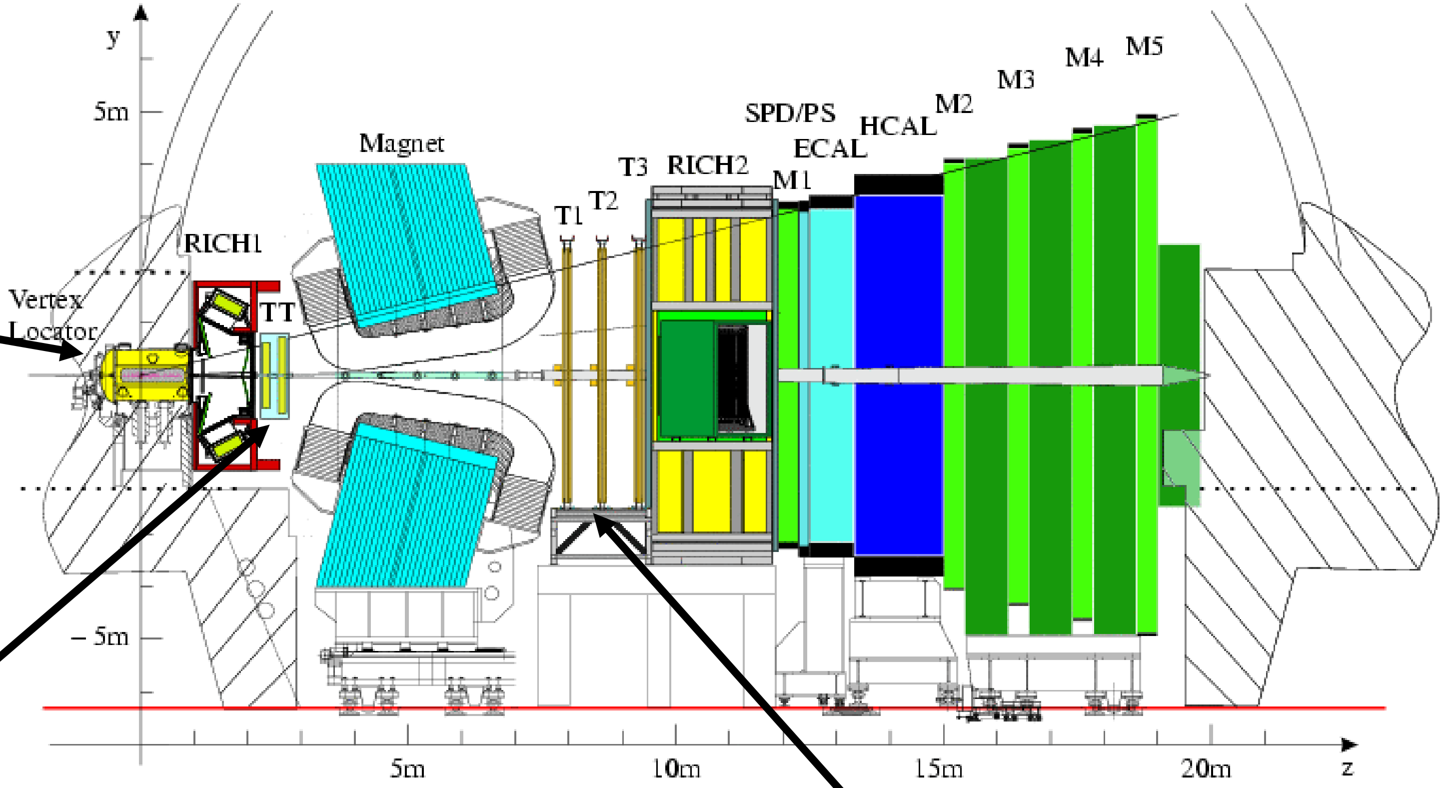


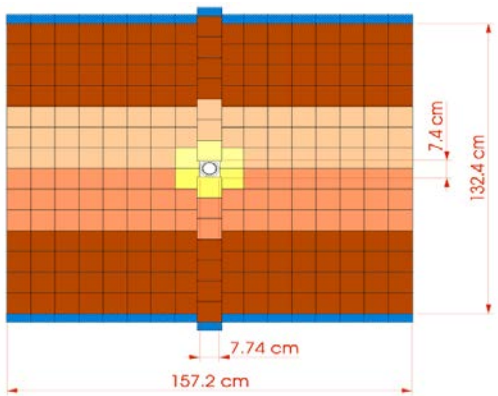



# The Vertexing and Tracking Systems

**V**e**L**o

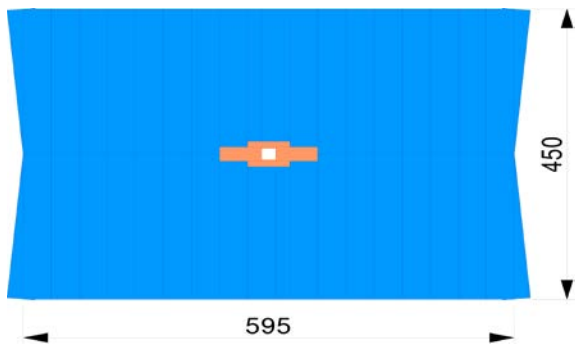


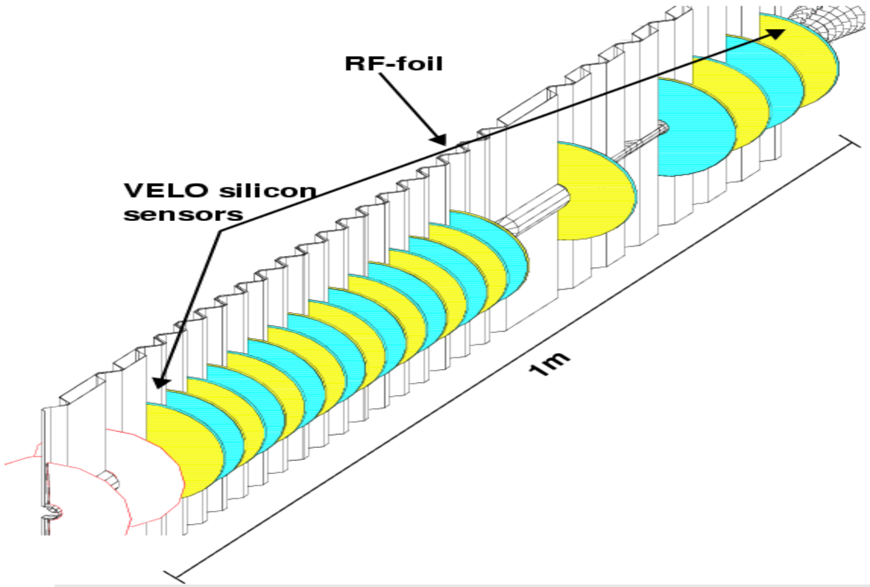




**T**rigger
**T**racker

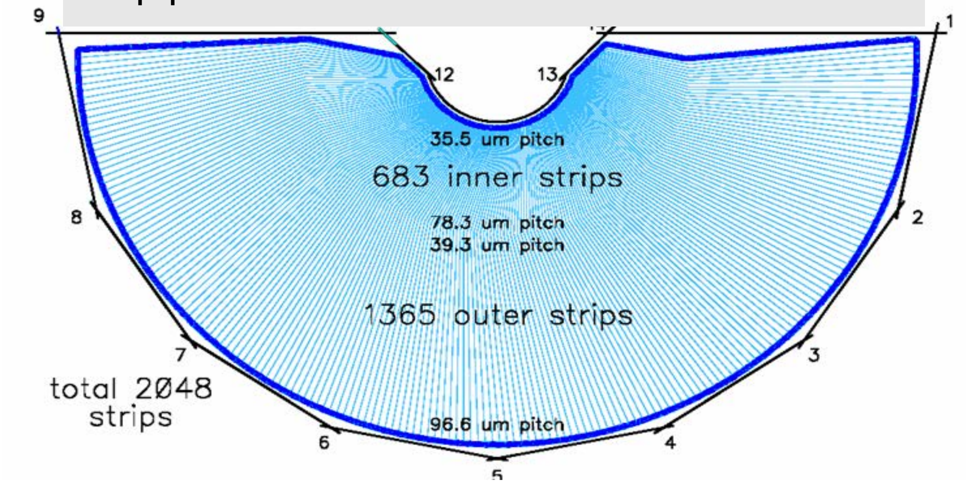
**T** Stations
**I**nner **T**racker
**O**uter **T**racker



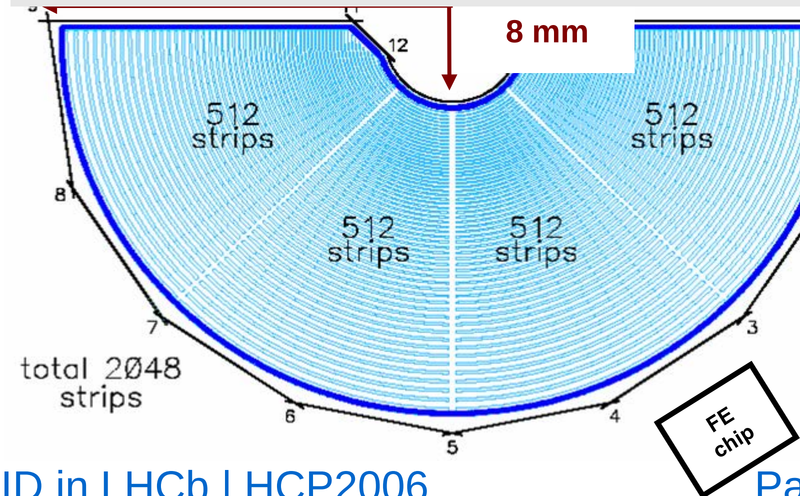
- **21 tracking stations**
  - 4 sensors per station with r/Φ geometry
  - Optimised for
    - Fast online 2D tracking
    - Vertex reconstruction
    - Offline track reconstruction



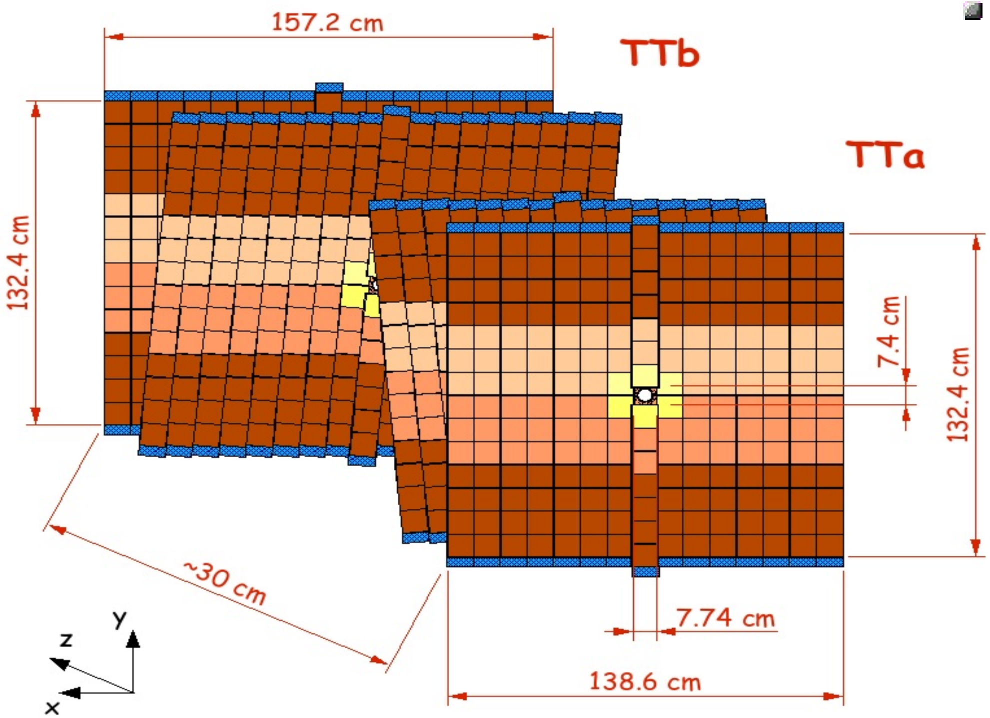

Φ-sensors
2048 strip in inner and outer regions
strip pitch increase with R : 36um->97um



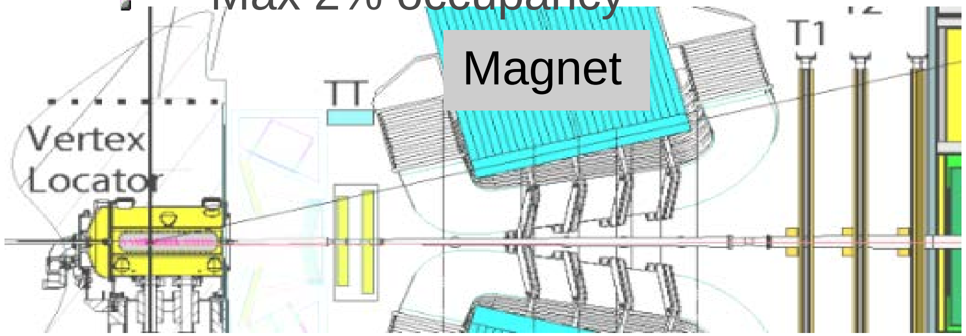

R-sensors
2048 strip in 45$^{o}$ sectors
strip pitch increase with R : 40um->100um



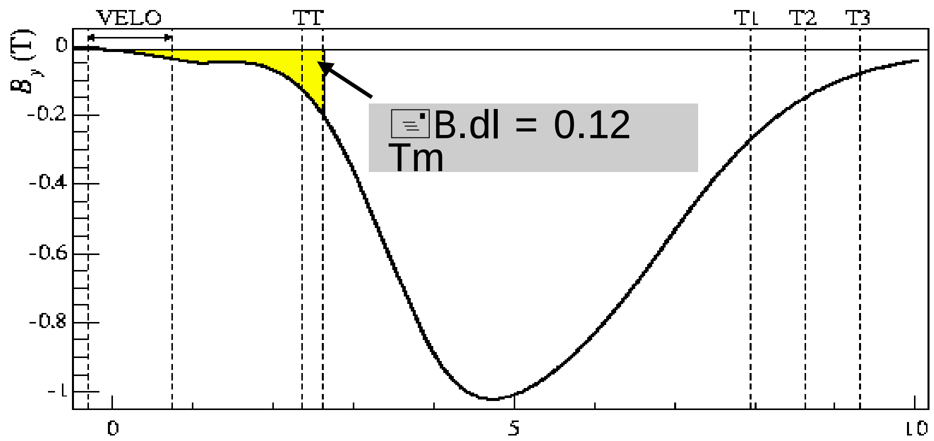
# Track Trigger



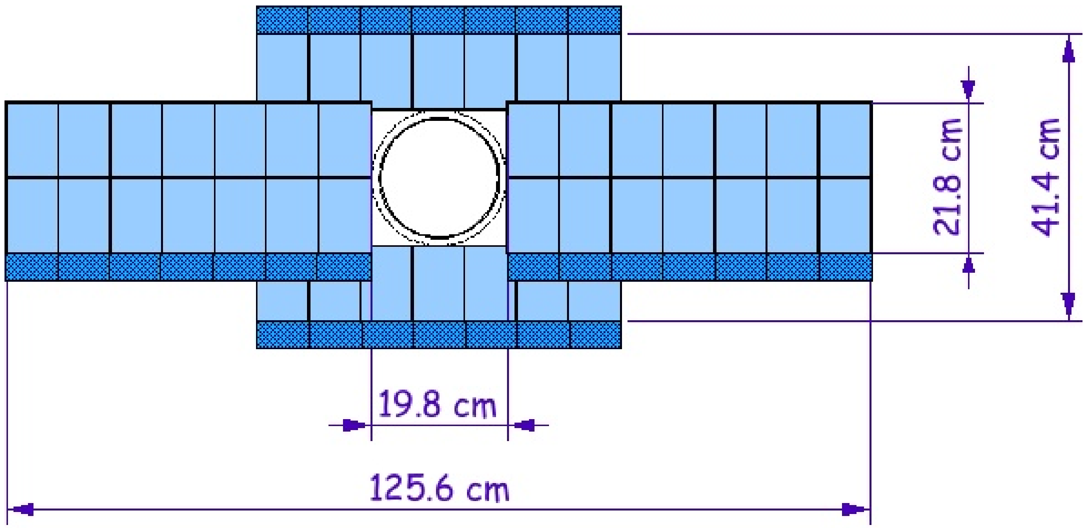

- **Silicon micro-strip detector**
  - Full LHCb acceptance
  - 4 layers, $0^o$, $-5^o$, $5^o$, $0^o$
  - 94.4mm x 96.4mm wafers
  - 183 um pitch
  - Max 2% occupancy



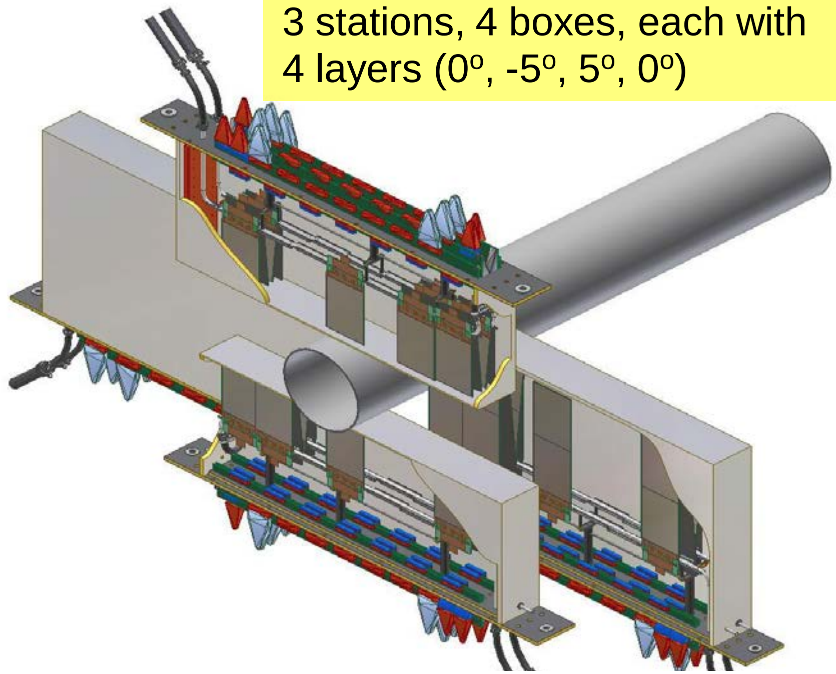

- **In fringe field of magnet**
  - **Fast track momentum measurement for trigger**
    - dP/P ~ 30% ($P_T$=3GeV)
  - **Offline reconstruction of long-lived and low momentum particles**



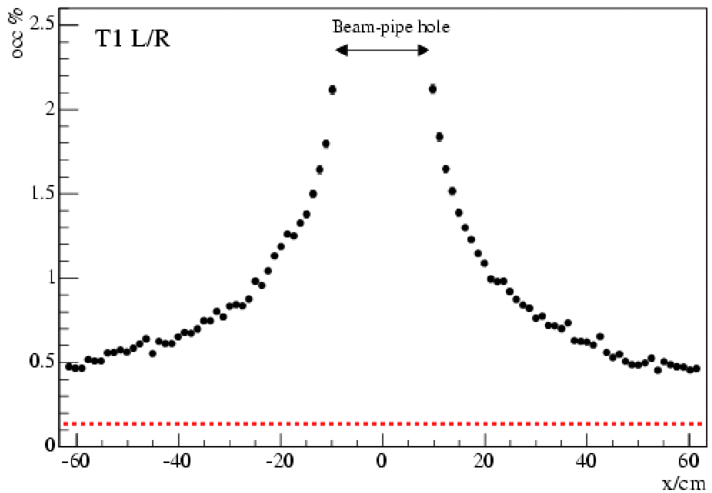
# T Stations : Inner Tracker



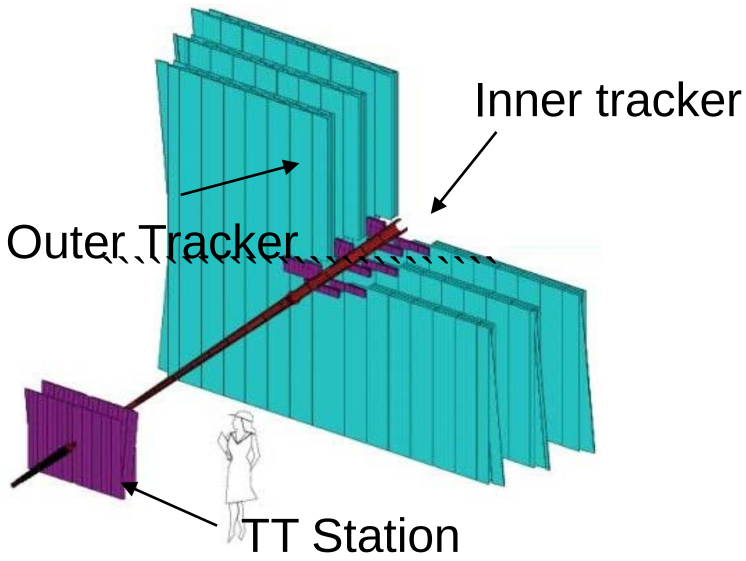

3 stations, 4 boxes, each with 4 layers (0°, -5°, 5°, 0°)

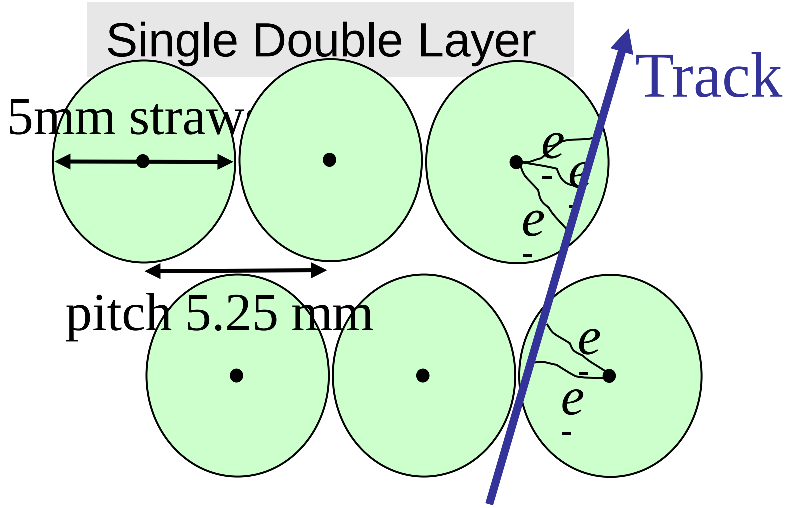


- **Inner regions of T stations**
  - High track density region
    - Silicon detector
      - Pitch 198 μm, implant width 50 μm
    - 2% of acceptance, 20% of tracks
    - Maximum occupancy 2.3%
- **Each station has four boxes**
  - Cooling, readout and infrastructure

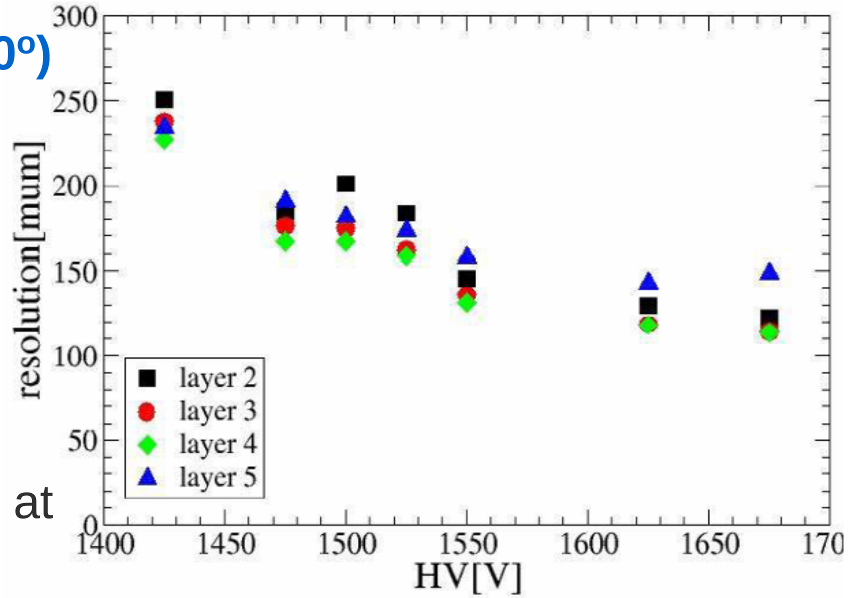


# T Stations : Outer Tracker



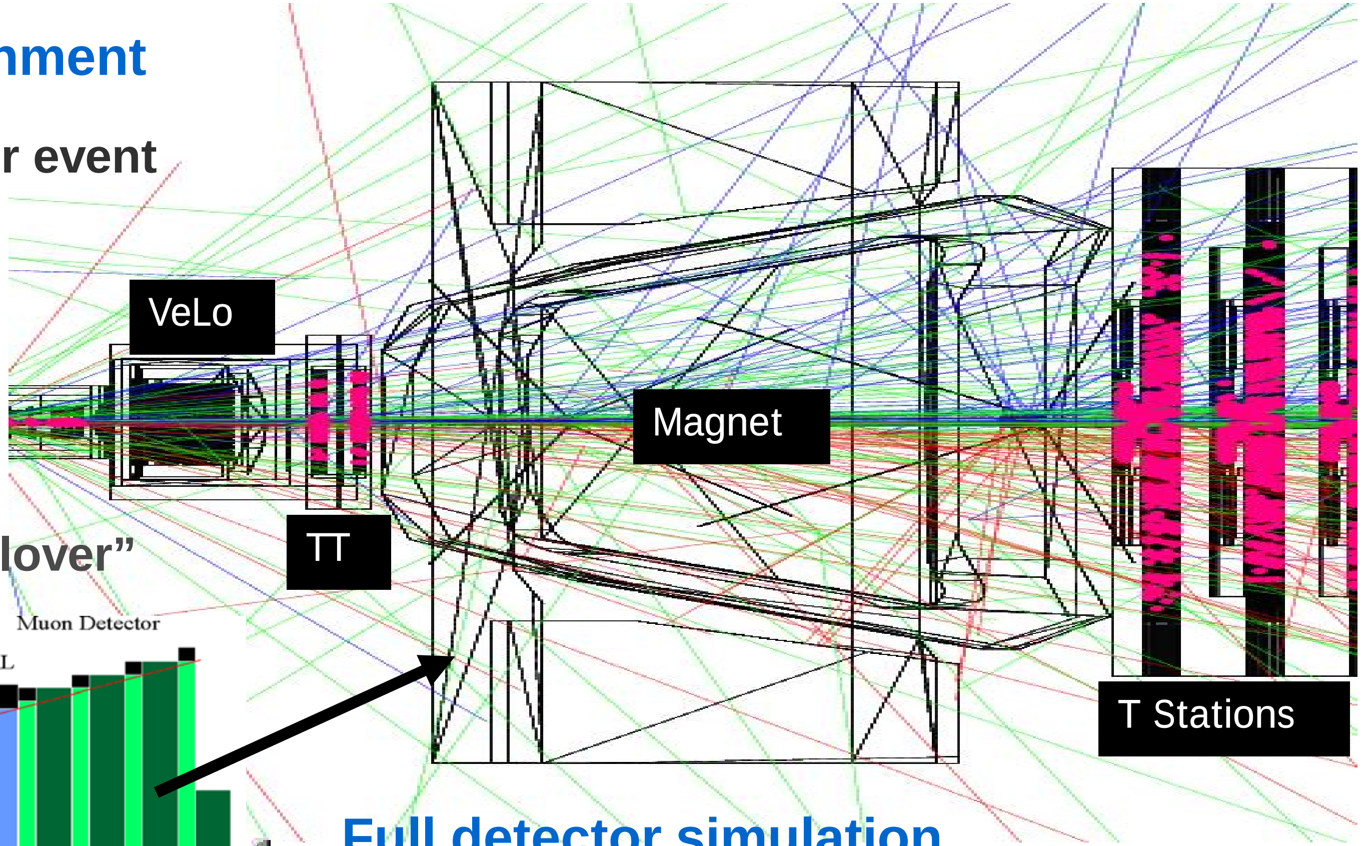



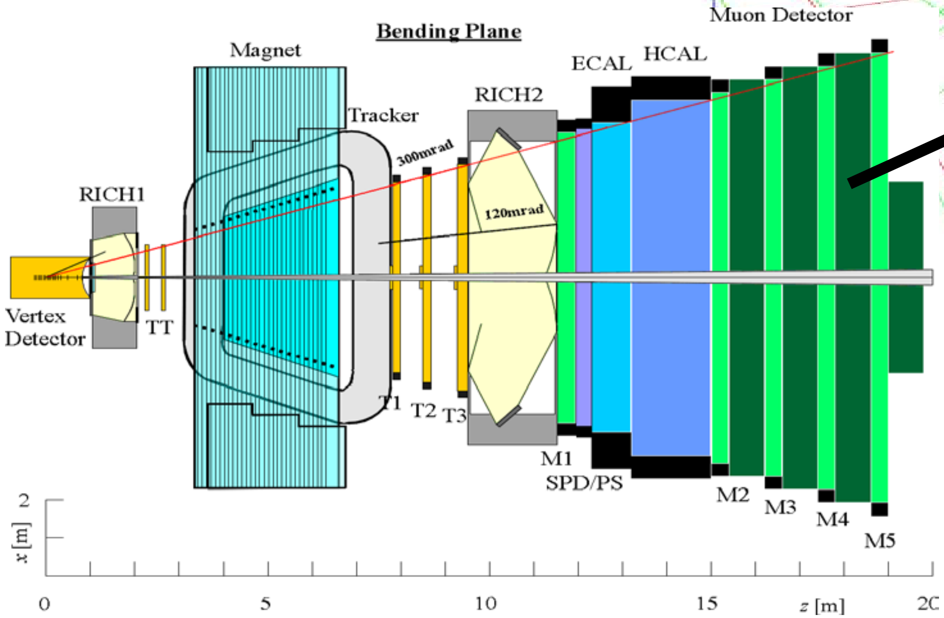

- **3 Stations with 4 "Double Layers" ( 0º, -5º, 5º, 0º)**
  - 5 mm Kapton/Al straw tubes
  - Drift gas 70:30 Ar:$CO_2$ mixture
  - Longest straws 4.7m, dual readout
- **6 GeV electron testbeam (DESY)**
  - Efficiency 98%, 5% cross-talk, 200um resolution at 1550 V



# Tracking in LHCb

- **High Track density Environment**
  - **~50 primary particles per event**
  - **~ 50% $X_0$ to up RICH2**
    - **Multiple scattering**
    - **Secondary particles**
  - **40MHz bunch rate**
    - **10-20% detector “spillover”**

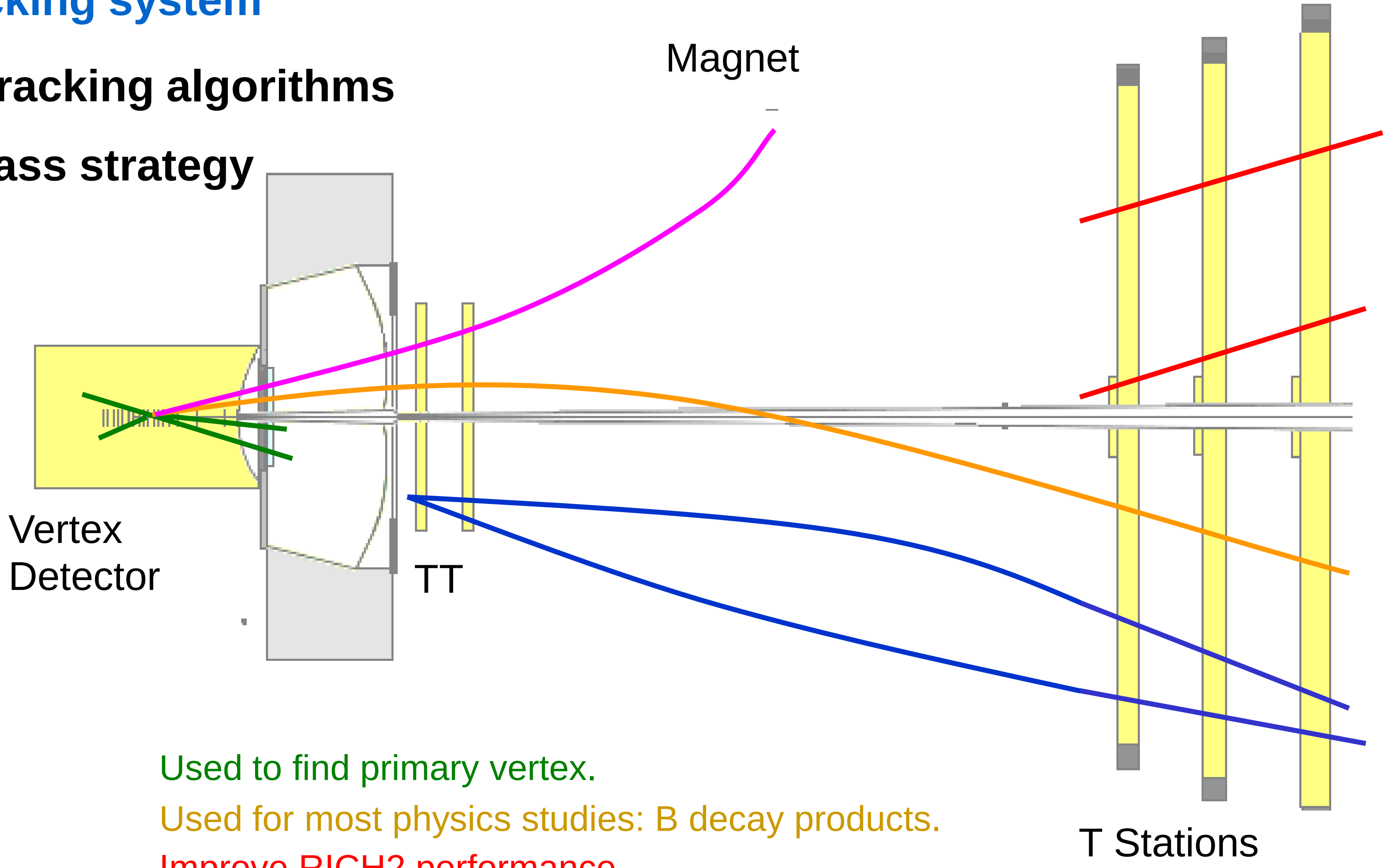



- **Full detector simulation**
  - **Event generation** (Pythia,Herwig etc.)
  - **Geant4**
  - **Detector electronics simulation**

# Tracking Strategy

- **Discrete tracking system**
  - **Different tracking algorithms**
  - **Multiple pass strategy**




Velo tracks: Used to find primary vertex.

Long tracks: Used for most physics studies: B decay products.

T tracks: Improve RICH2 performance.

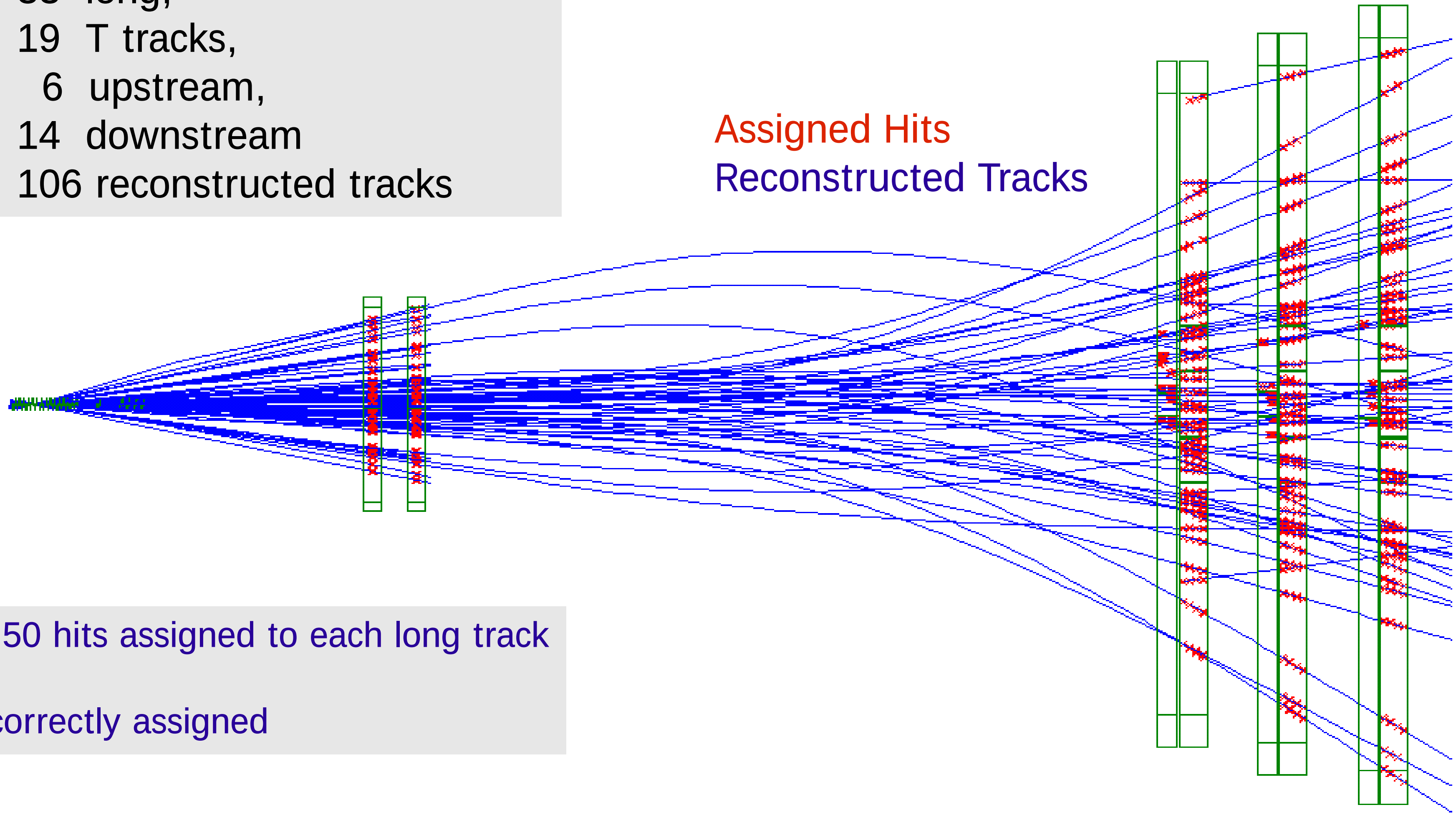
Upstream tracks: Improve RICH1 performance, moderate *p* estimate.

Downstream tracks: Enhance $K_S$ finding.

# Track Event Display

Average # of tracks in b-events:

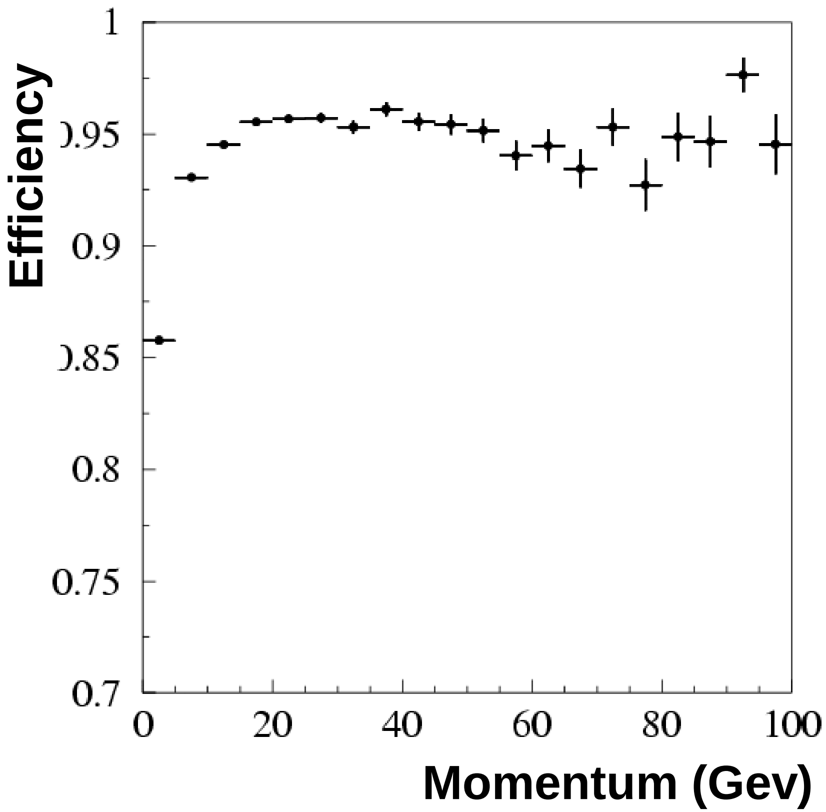
| | | |
|---|---|---|
| | 34 | VELO, |
| | 33 | long, |
| | 19 | T tracks, |
| | 6 | upstream, |
| | 14 | downstream |
| Total | 106 | reconstructed tracks |

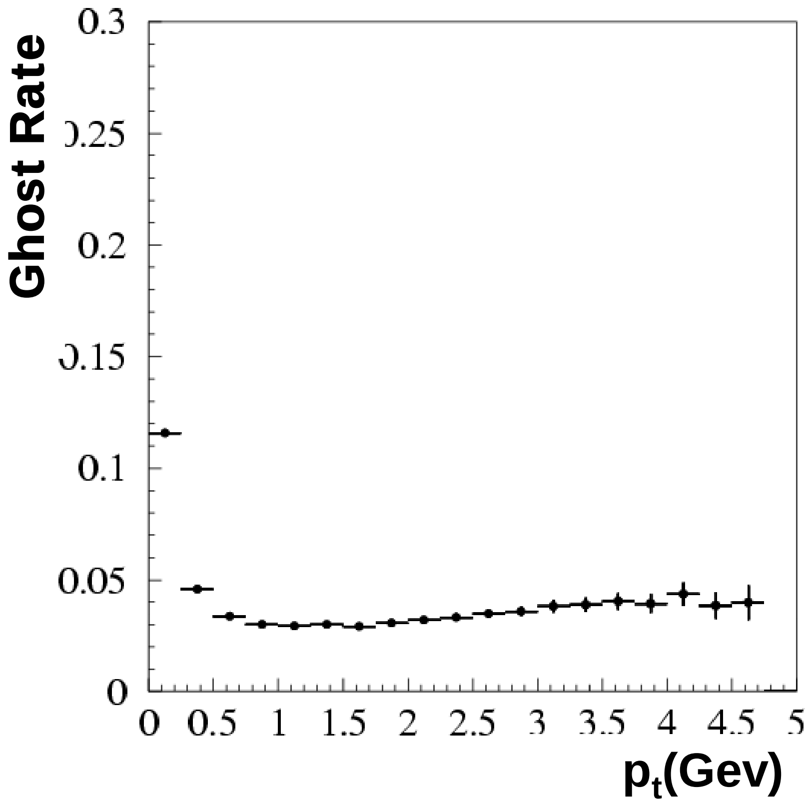



~ 20 to 50 hits assigned to each long track

98.7% correctly assigned

# Track Finding Efficiency

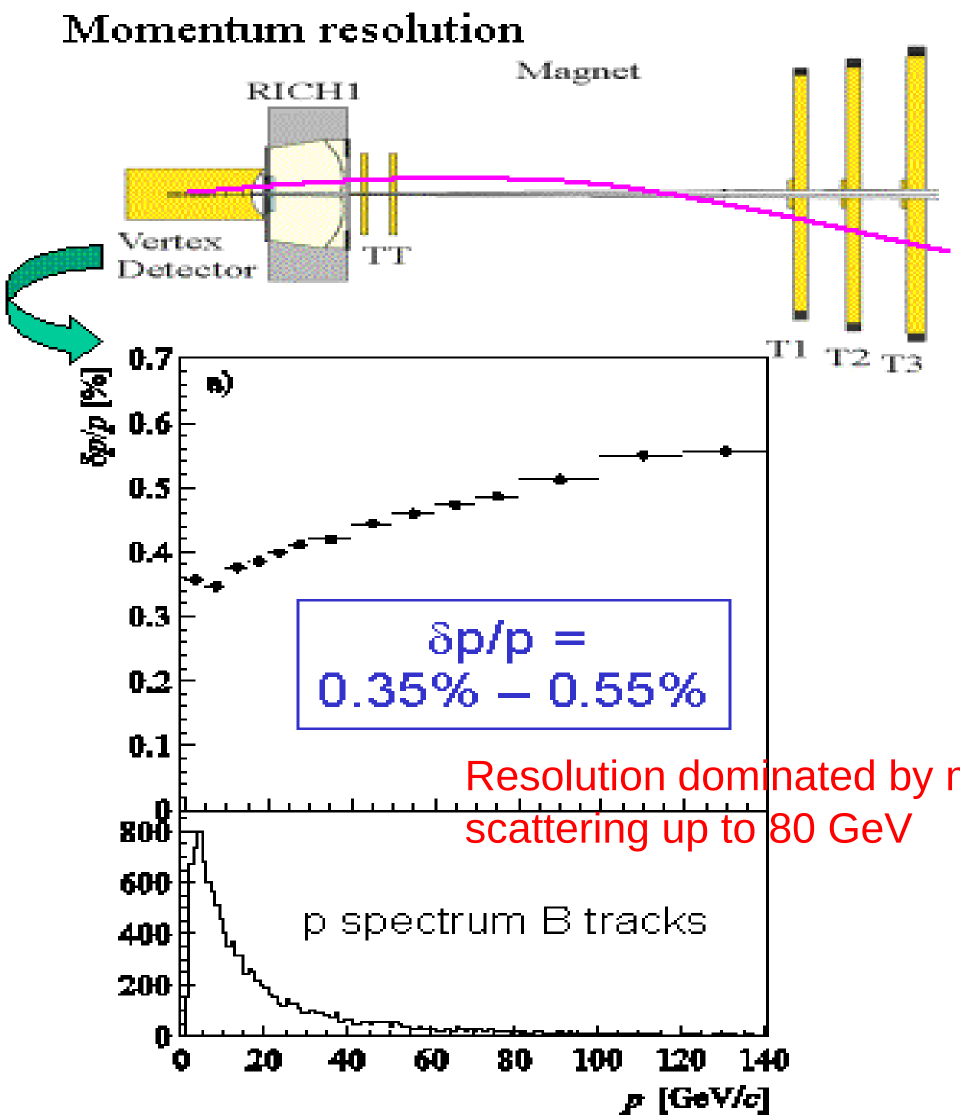


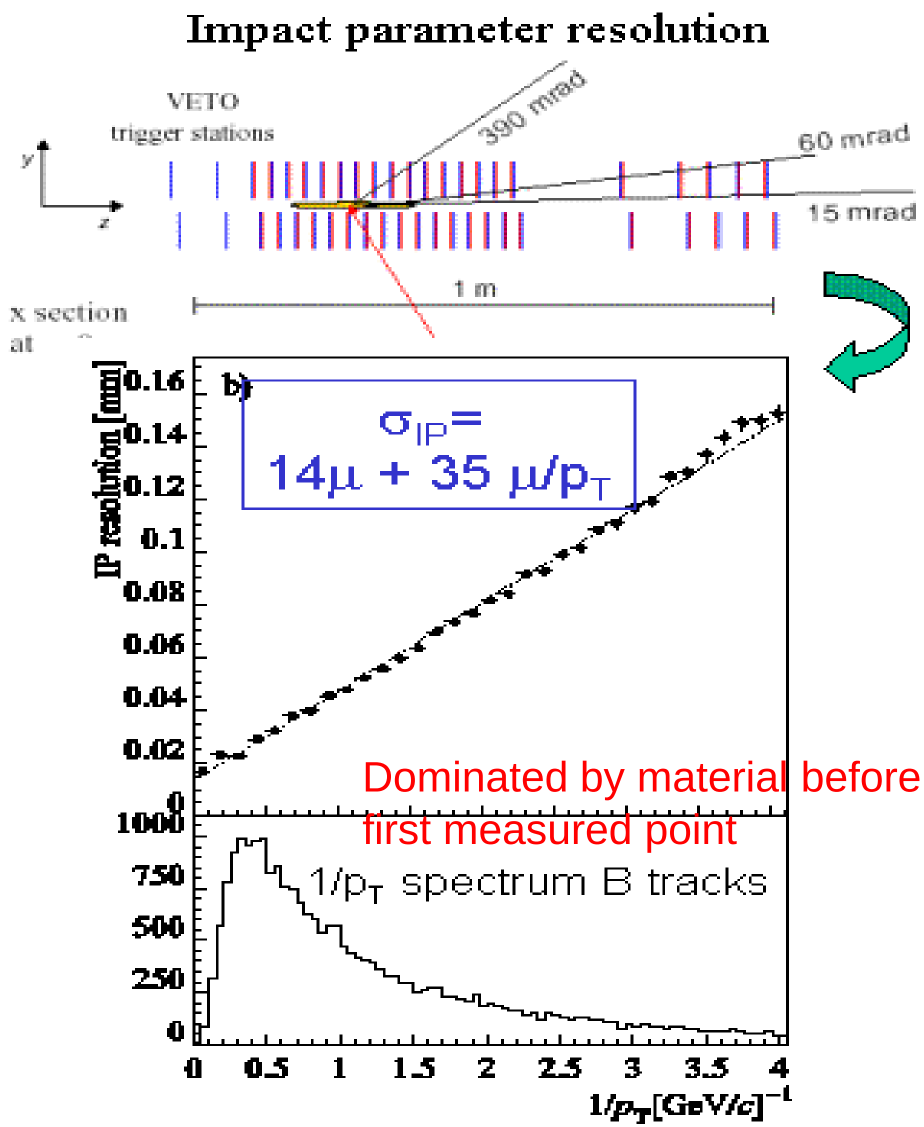




- Average Long track efficiency 90 %
- B decay products 95 % (higher p)

- Ghosts mainly at low pt
- Ghost rate 4 % for pt cut > 0.5 GeV

# Tracking Resolutions

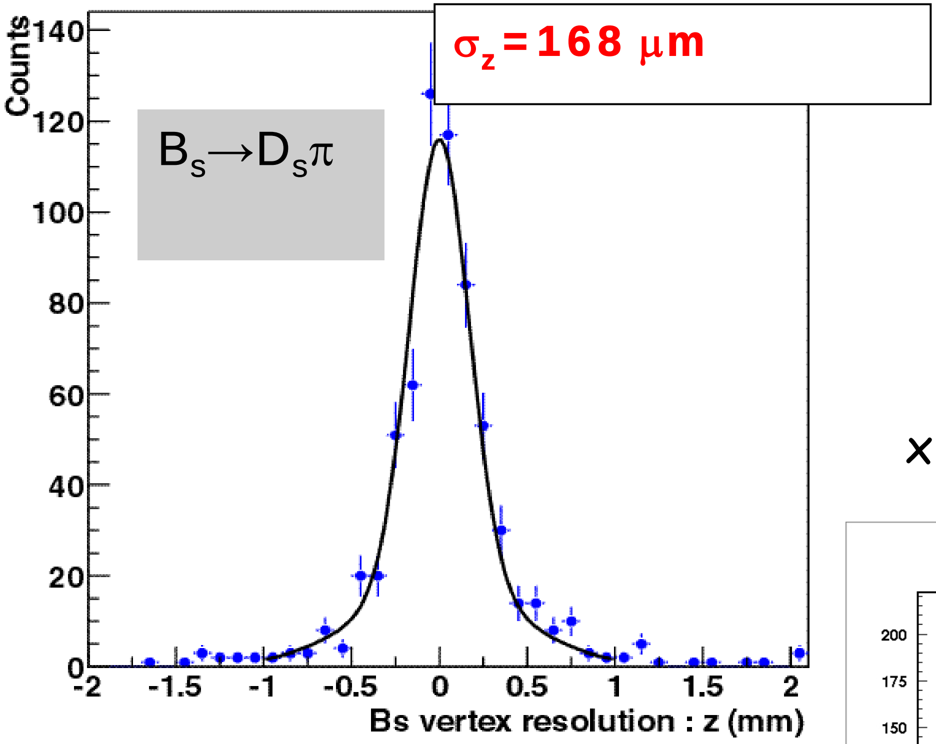


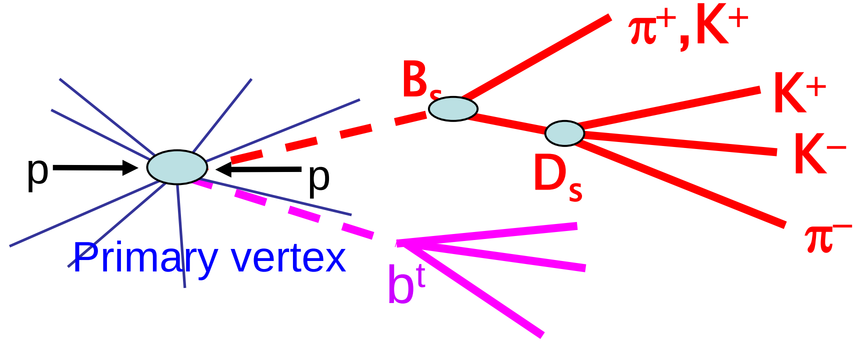




Resolution dominated by multiple scattering up to 80 GeV

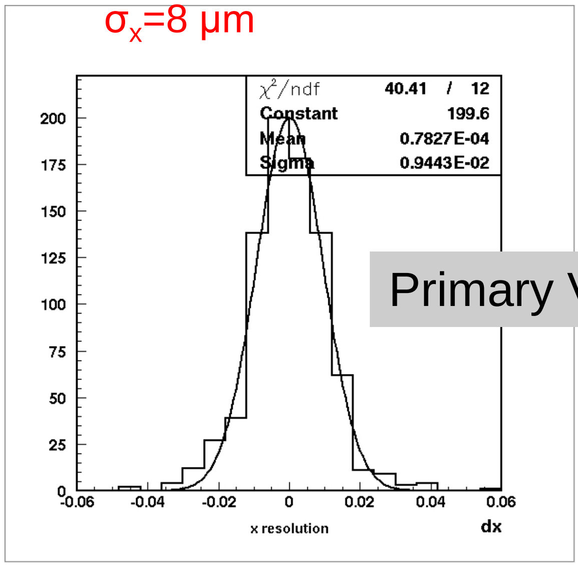
Dominated by material before first measured point

# Vertexing Performance



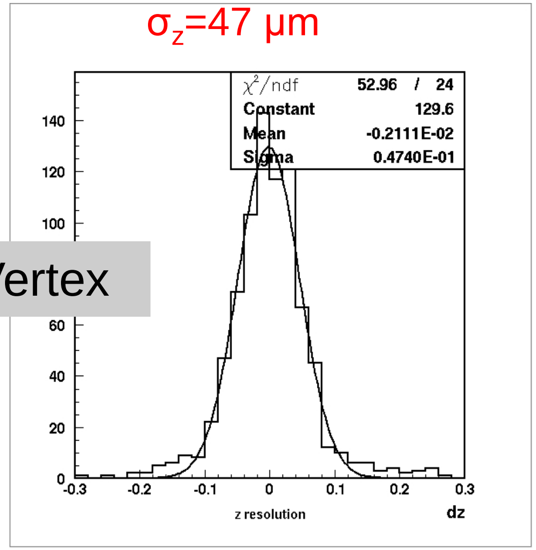




x resolution




Primary Vertex

z resolution



# Hadron Identification

**RICH1**

Z ~ 1.0 – 2.2 m

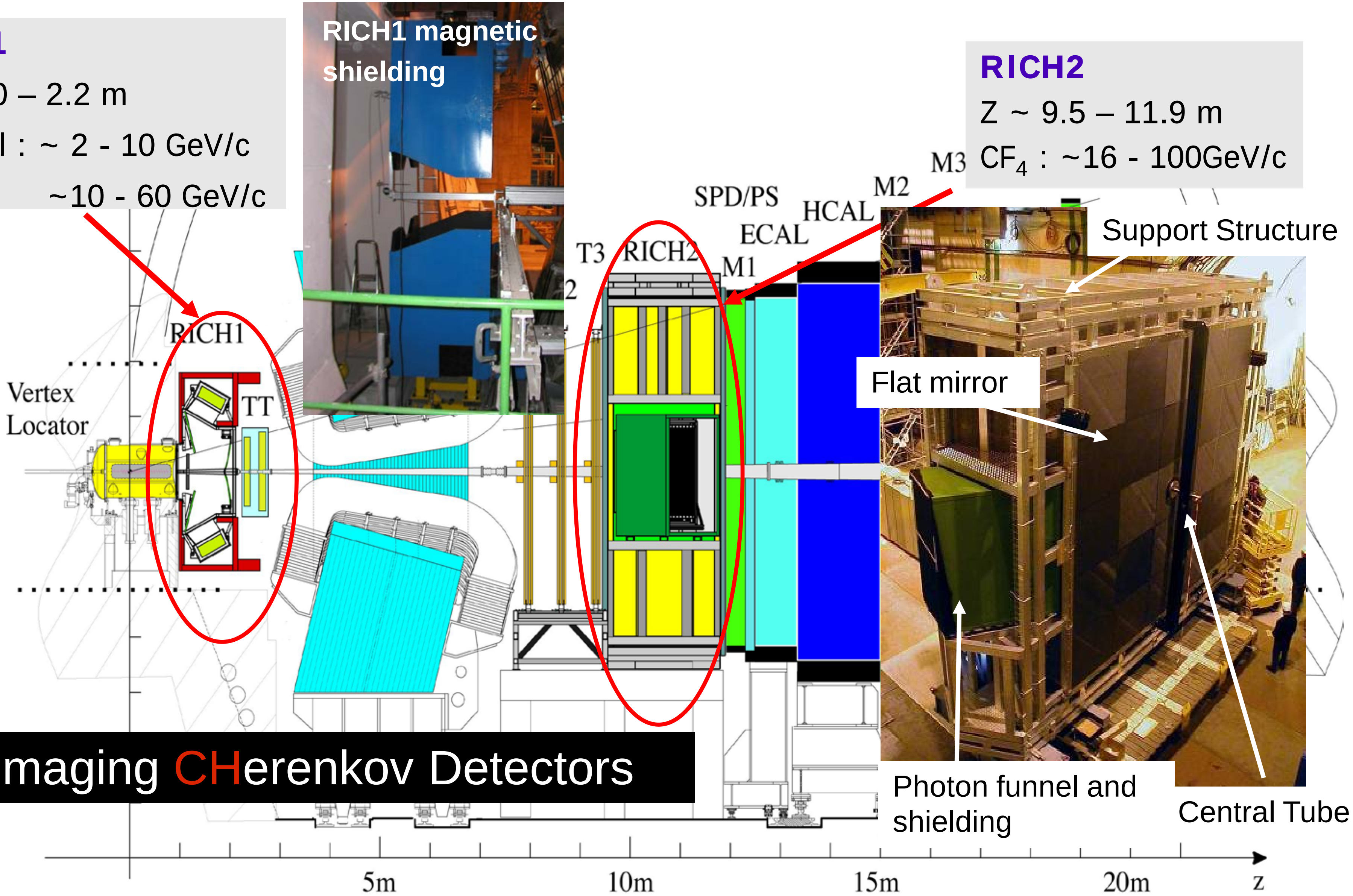
aerogel : ~ 2 - 10 GeV/c

$C_4F_{10}$ : ~10 - 60 GeV/c

**RICH2**

Z ~ 9.5 – 11.9 m

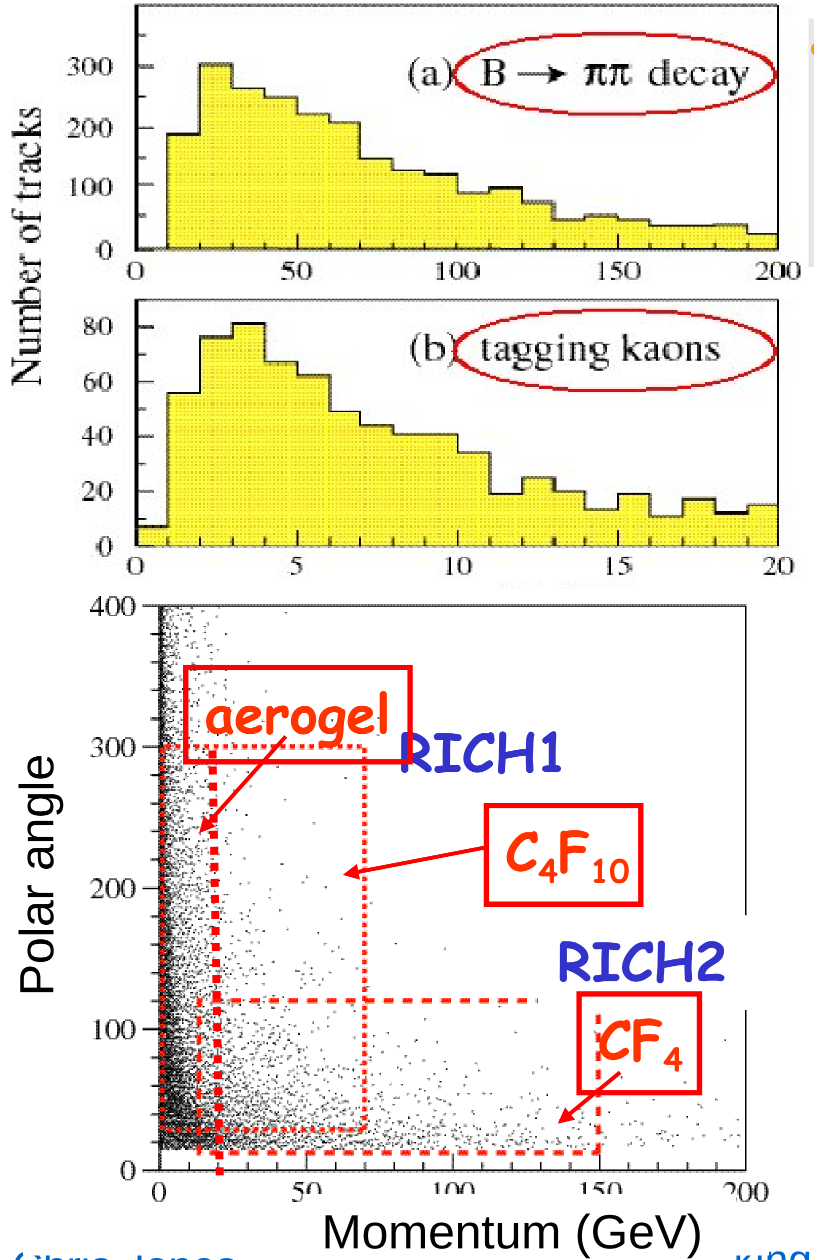
$CF_4$ : ~16 - 100GeV/c

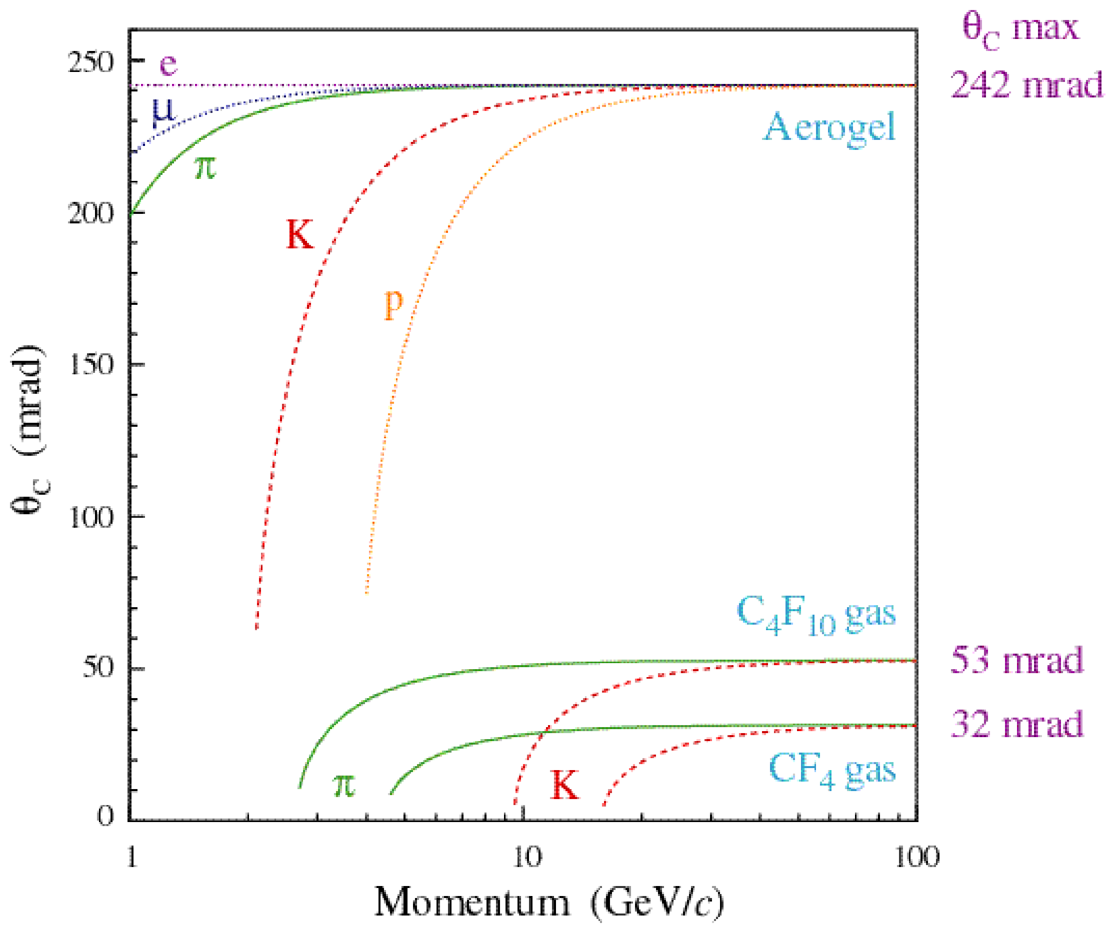



Ring Imaging CHerenkov Detectors

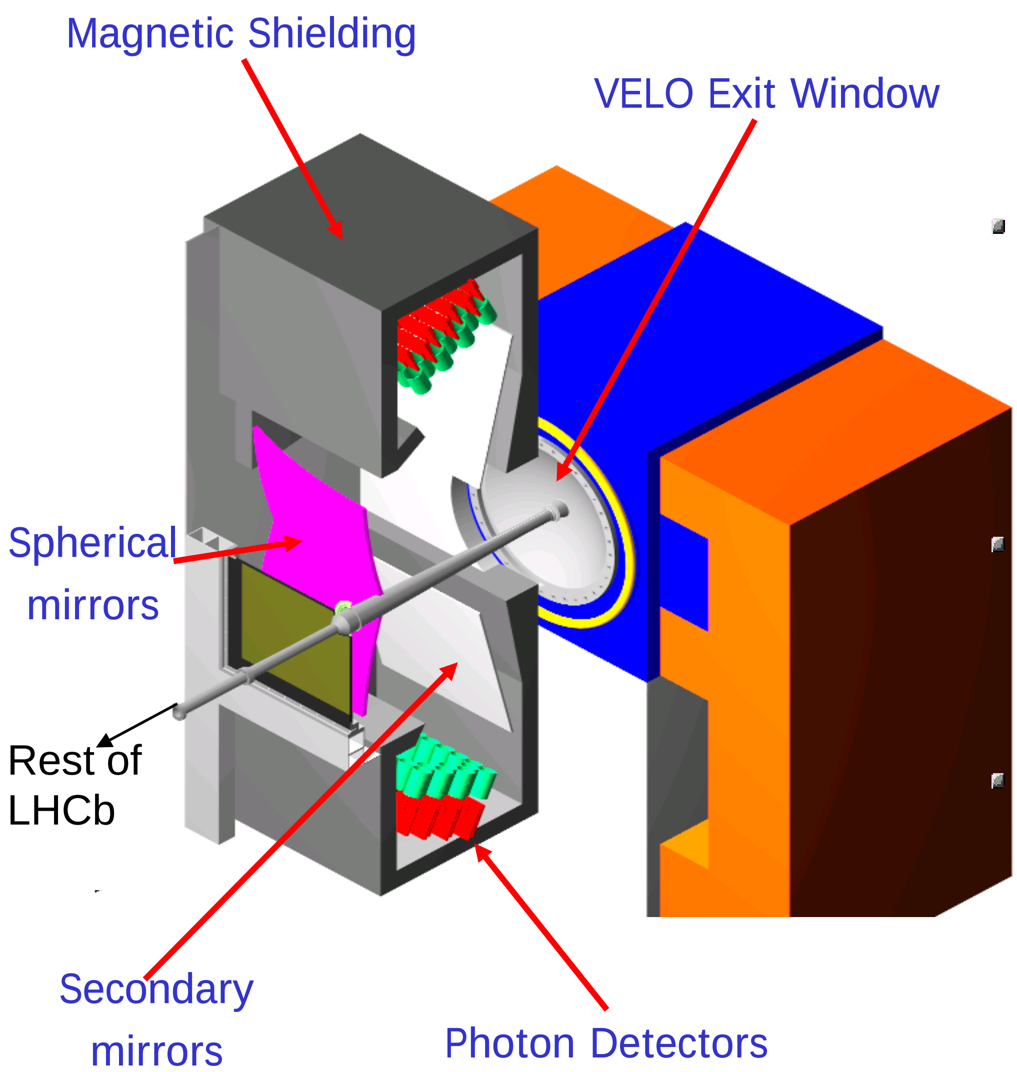
# RICH Detector Requirements

- Requires π/K separation over momentum range ~ 1 – 100 GeV/c
  - Two RICH detectors with three Cherenkov radiators

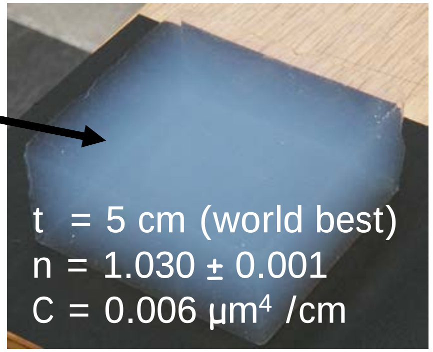


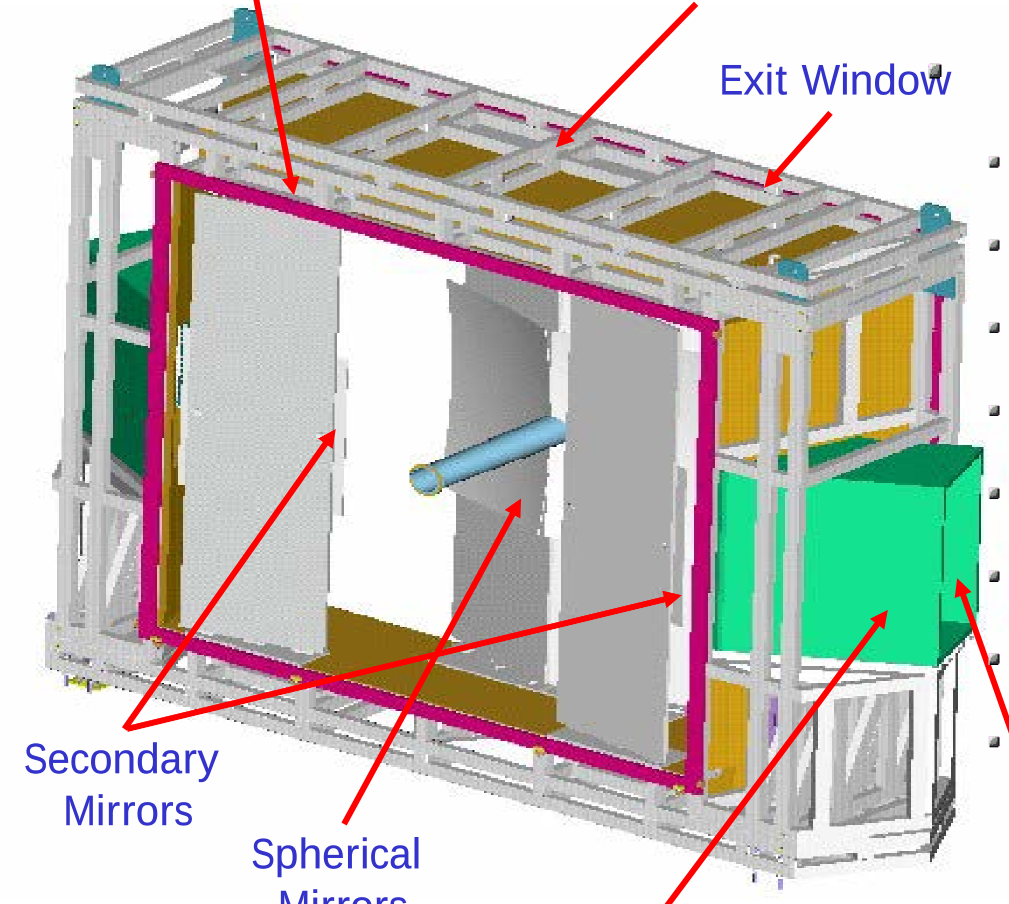
# RICH1 Detector



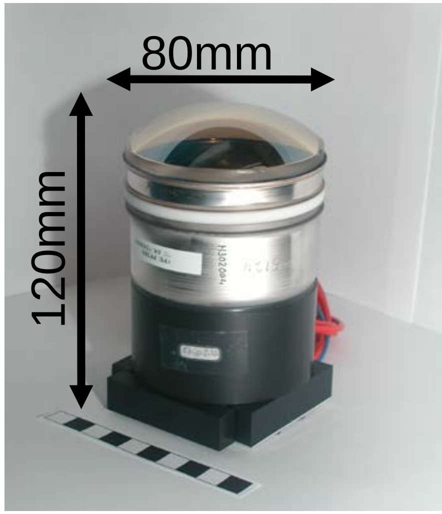

- **Spherical Mirrors**
  - Focus Cherenkov radiation
  - Tilted to move detectors outside acceptance
- **Secondary Mirrors**
  - Minimise detector length
  - Move photon detectors further out acceptance
- **Magnetic Shielding**
  - B-field on axis for TT momentum measurement
- **Radiator Media**
  - $C_4F_{10}$ and Aerogel
  - ~ 1-60 GeV/c



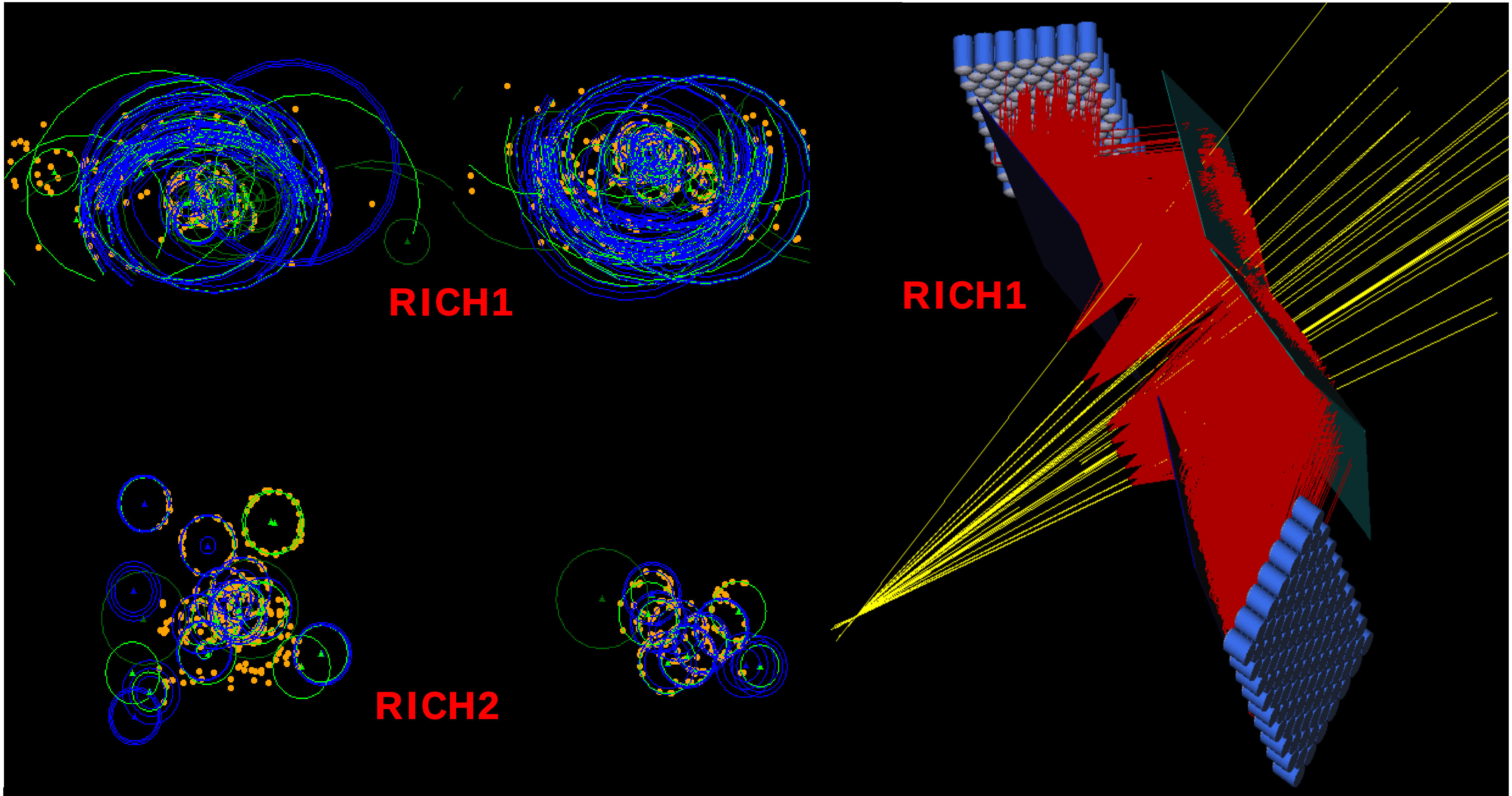
# RICH2 Detector




- **Optics follow similar principle to RICH1**
  - Primary and secondary mirror
  - Single $CF_4$ radiator covers ~ 20-100 GeV/c
- **RICH1 and RICH2 both use HPDs**
  - Total coverage 2.6 $m^2$
  - 196(RICH1) + 288(RICH2)
  - $\lambda$=200-600nm photon sensitivity
  - 70% active area coverage
  - 83mm cathode
  - 20 KV
  - 5 x demagnification
  - 0.5mm x 0.5mm pixels



# Geant4 Based Simulation

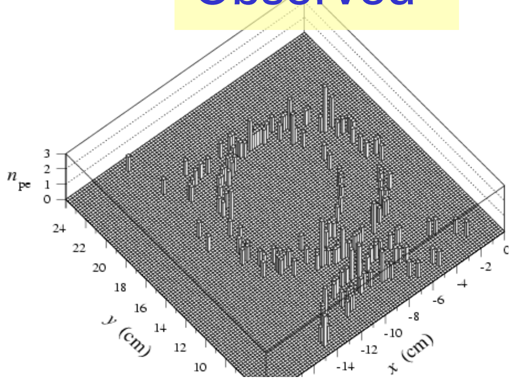



The Challenge : To reconstruct individual Cherenkov Rings

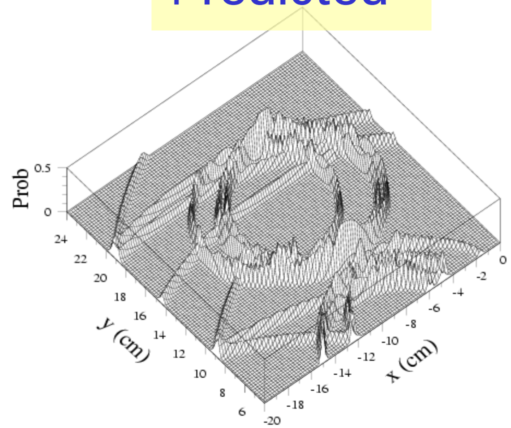
# RICH Pattern Recognition

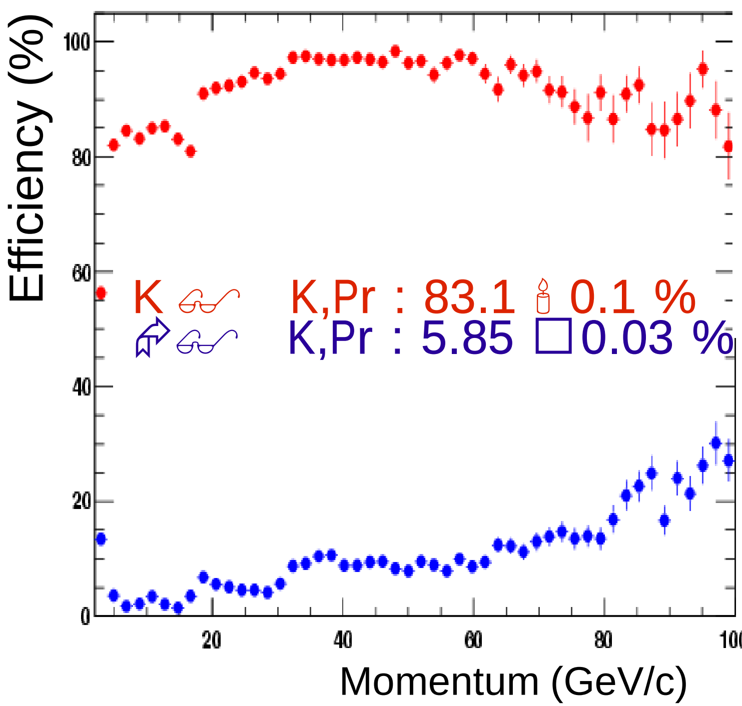
- **Pattern recognition approaches**
  - **Track based : Global**
    - Precise treatment of overall event
    - Requires full tracking information
  - **Track based : Local**
    - Fast single track approach
  - **Other approaches also under study**
    - E.g Trackless Ring Finders

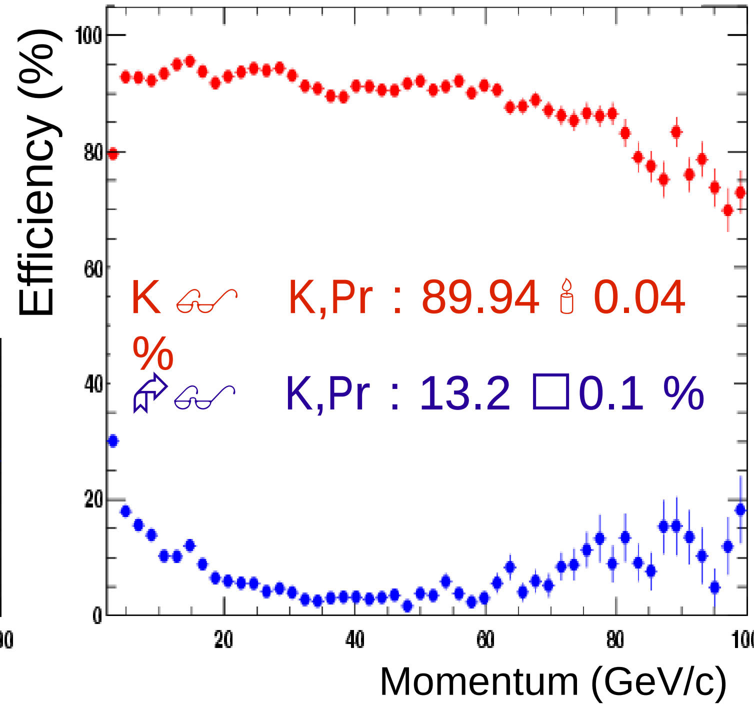
Observed




Predicted




Cherenkov Angle resolution (mrad)

- Aerogel 1.82
- $C_4F_{10}$ 1.26
- $CF_4$ 0.59

Detected Photons

- Aerogel 7
- $C_4F_{10}$ 30
- $CF_4$ 23

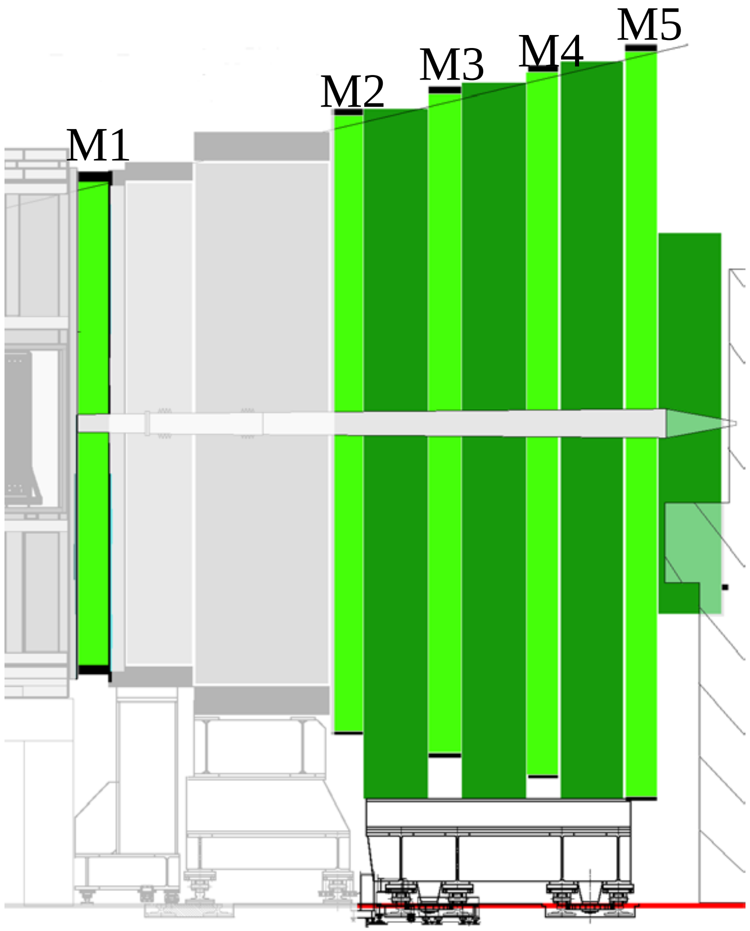
# MUON System

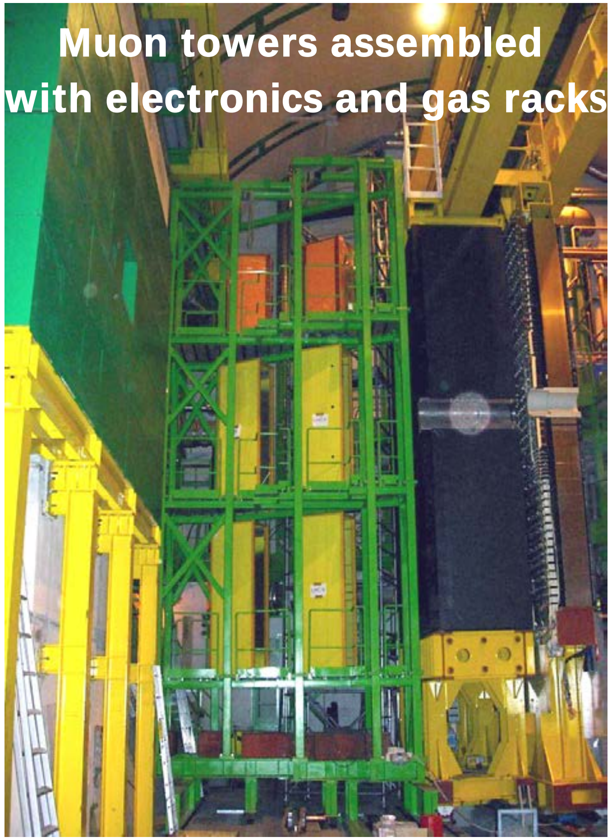
MUON Systems

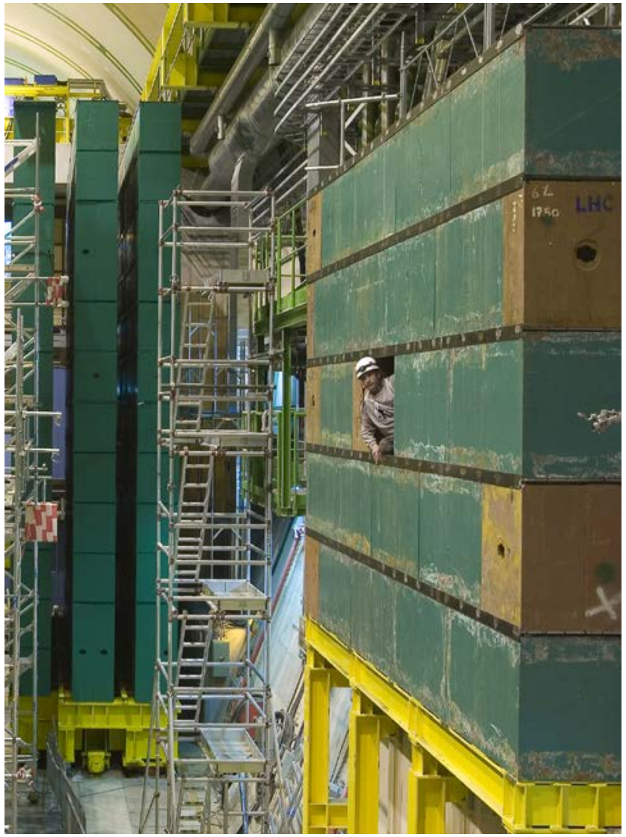
5 Stations

1368 MWPCs

24 triple GEMs (high occupancy M1 regions)



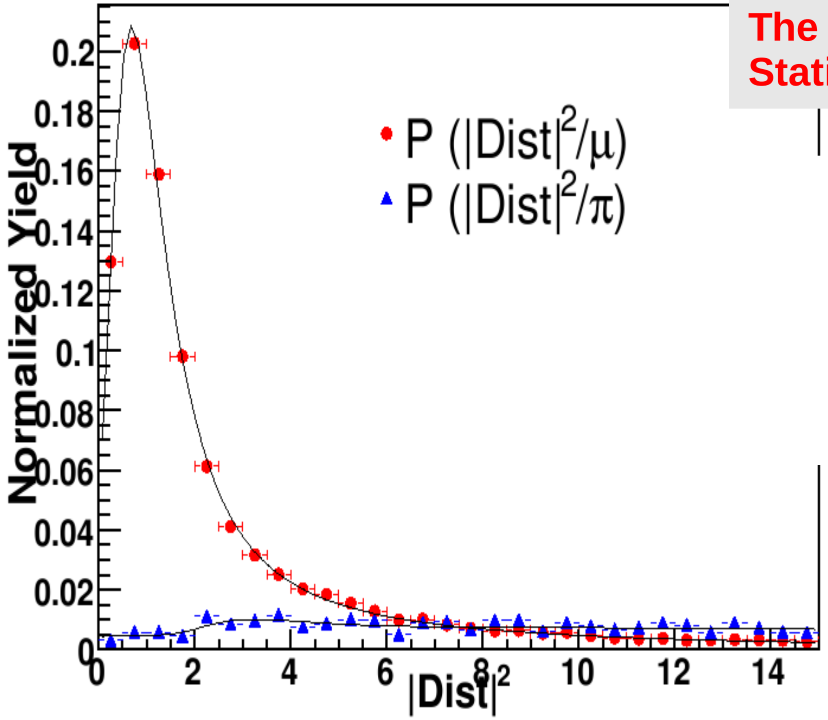



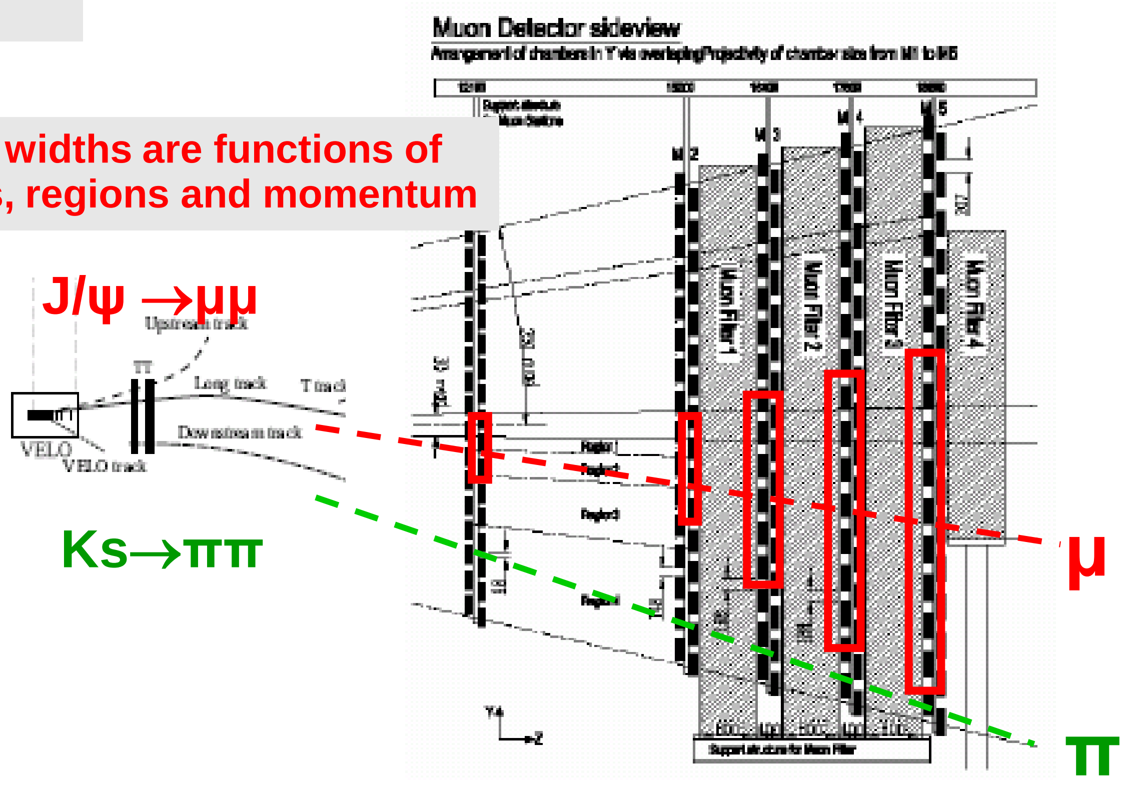
# Muon Identification

- Extrapolate well reconstructed tracks from tracking system to the Muon detector
- Look for hits in Field Of Interest (FOI) around the extrapolated track

| *FOI pool: hit found in* | *track momentum* |
|---|---|
| M2 and M3 | $p < 6$ GeV$/c$ |
| M2 and M3 and (M4 or M5) | $6 < p < 10$ GeV$/c$ |
| M2 and M3 and M4 and M5 | $p > 10$ GeV$/c$ |

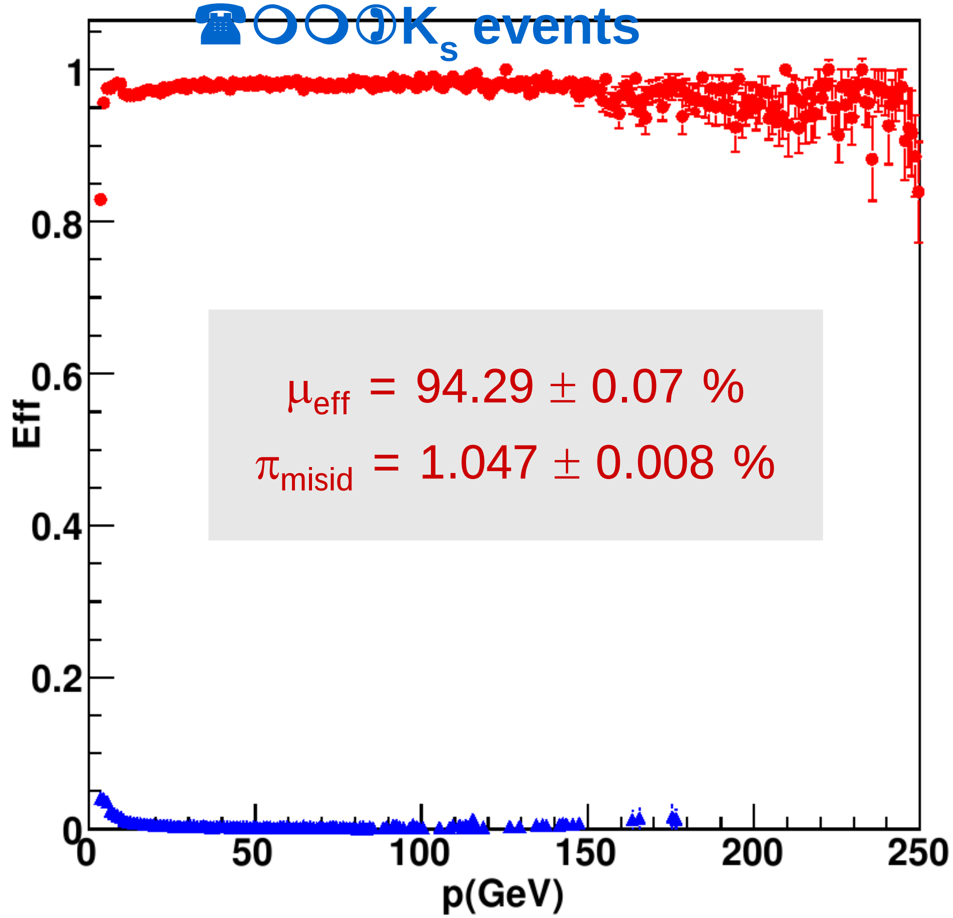
**The FOI widths are functions of Stations, regions and momentum**



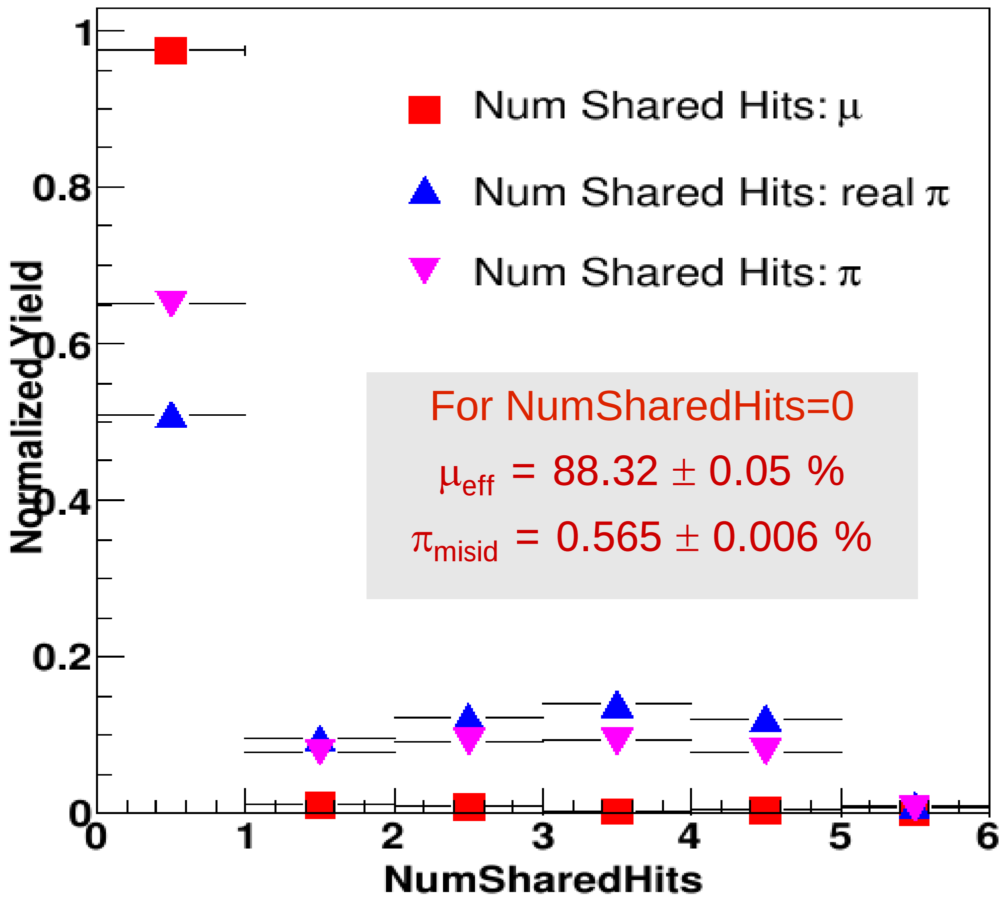
# Muon ID Performance

- Muon ID in B❼J/⍄ ☎❍❍➂$K_s$ events

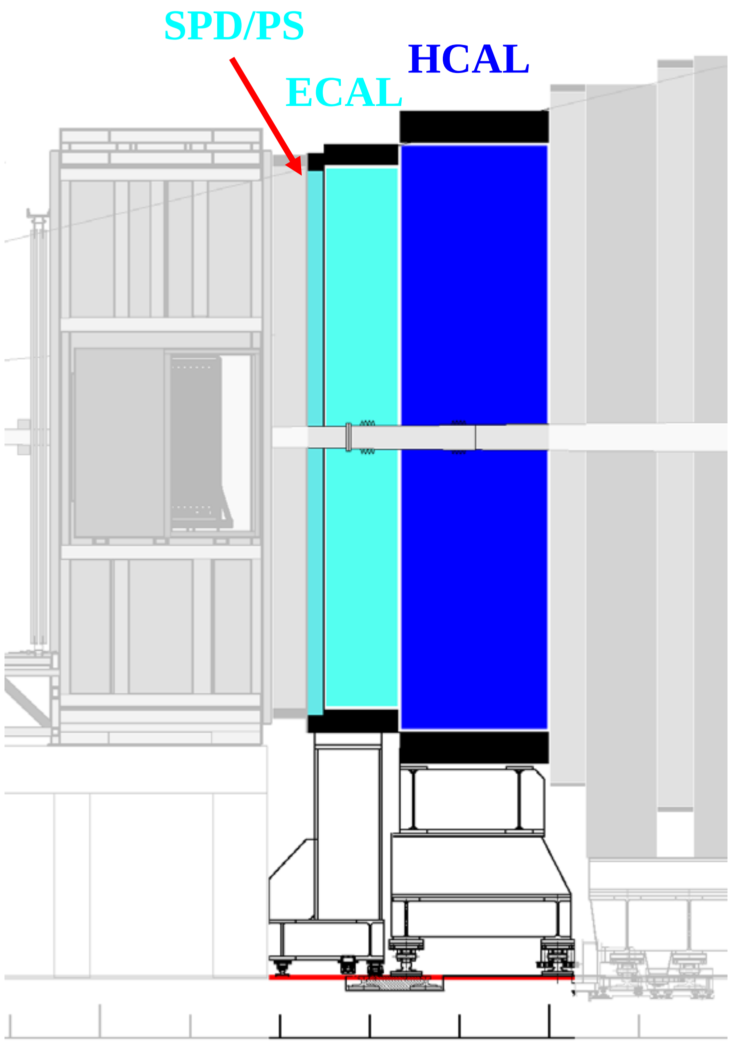



**Number of hits shared between tracks**

**Increase purity at expense of efficiency**



# Calorimeter System




## SPD / PS

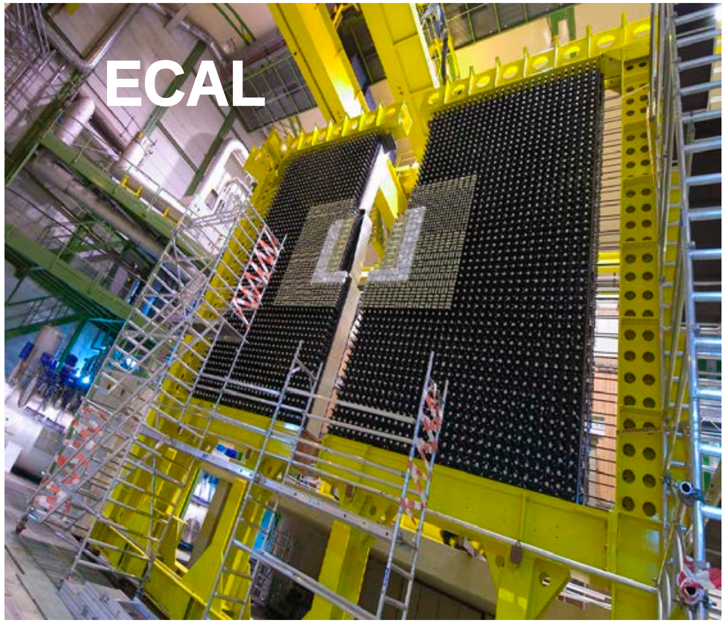
2 planes of Scintillating Pads,
Pb (1.5 cm) $2\ X_{0;}$;$0.1\lambda_I$

## ECAL

Pb – scintillator Shashlik calorimeter
66 layers 2mm Pb/4mm scintillator
$25\ X_0$; $1.1\ \lambda_I$ $\sigma/E \sim 10\%/\sqrt{E}$

## HCAL

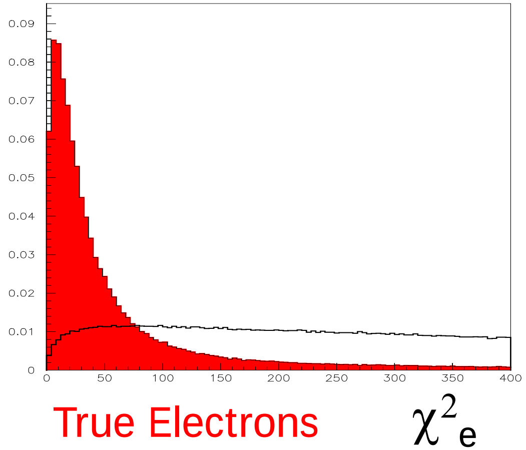
Fe – scintillator tile calorimeter $5.6\ \lambda_I$
$\sigma/E \sim 80\% /\sqrt{E} \oplus 10\%$

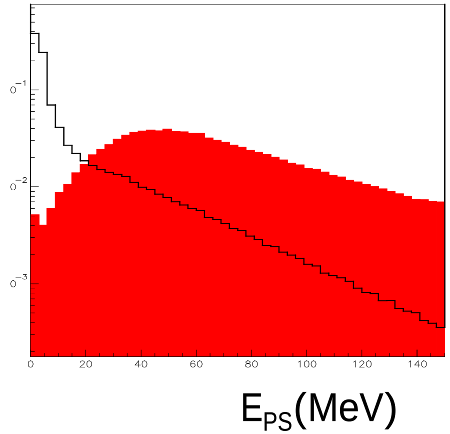


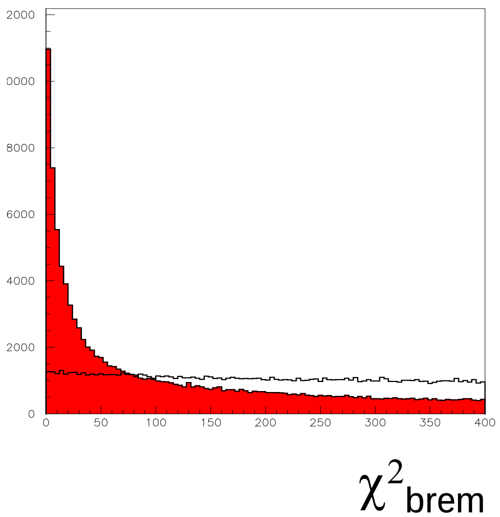

# Electron Identification

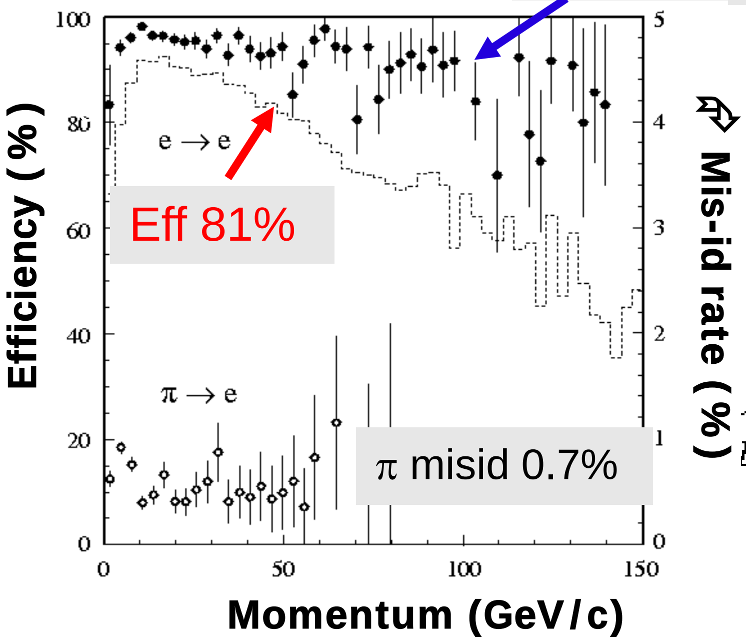
## Based on four discriminating variables

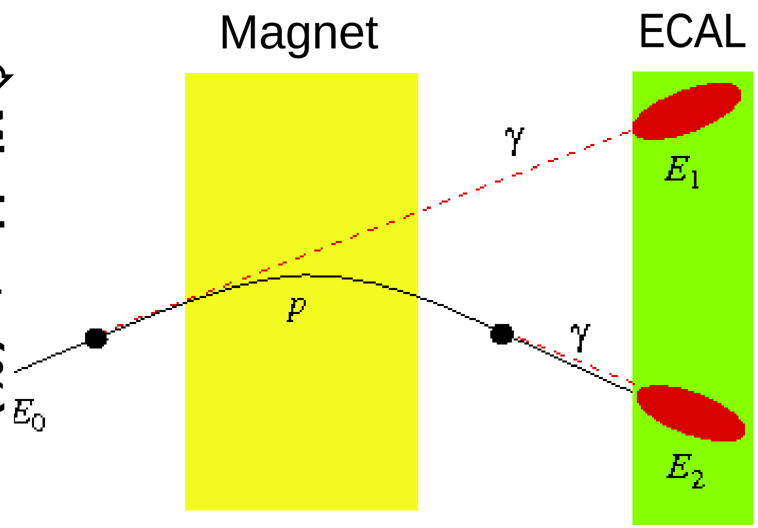
- $\chi^2$ of energy-position match for charged track
- Energy deposited in Preshower
- Bremstrahlung Correction
- Energy deposited in HCAL



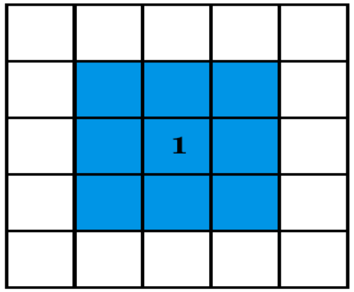



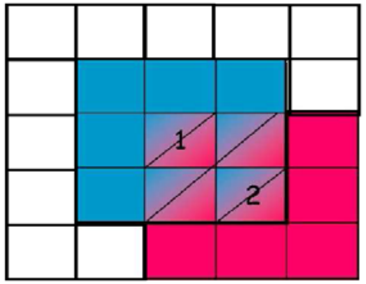



# Reconstruction of $\pi^0$

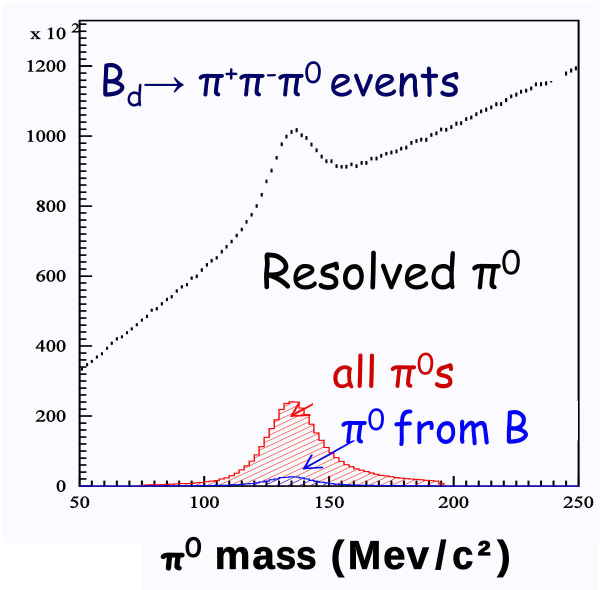
Resolved cluster

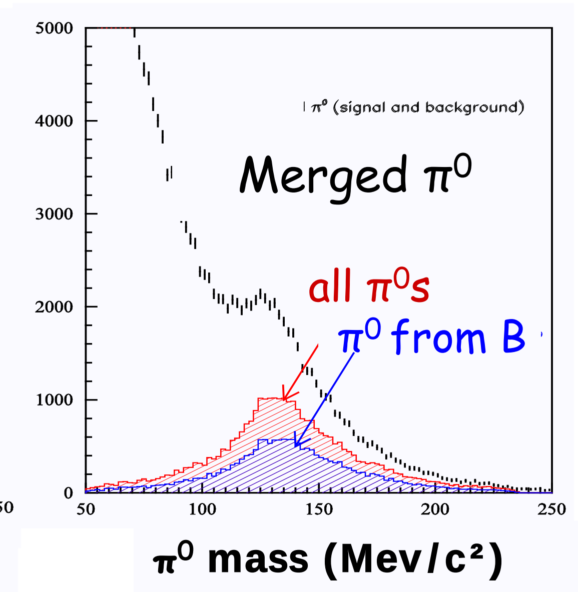


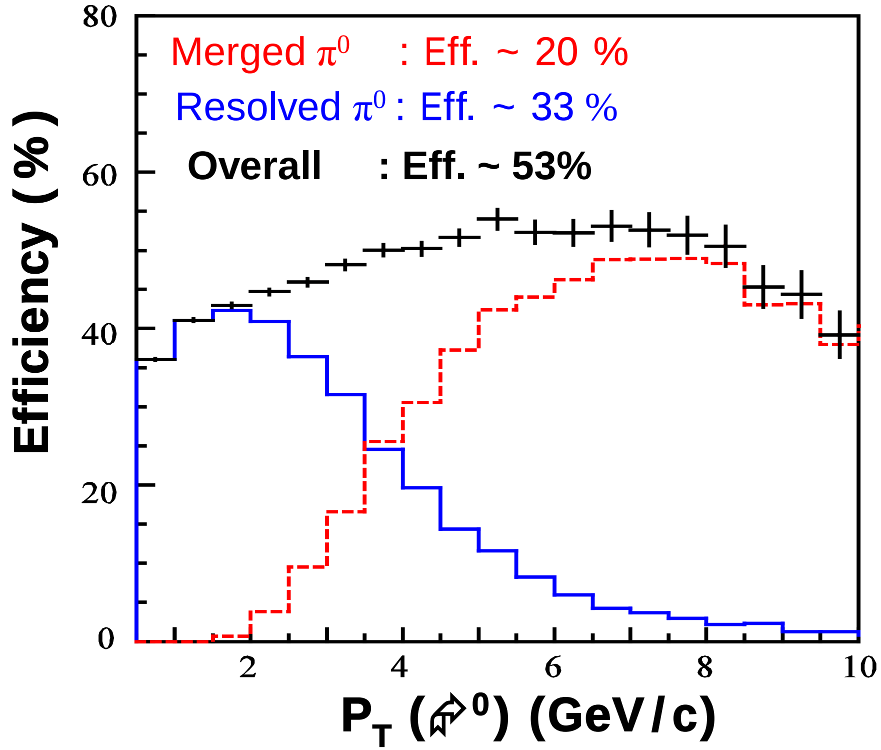

Merged cluster




- Resolved $\pi^0$
  - Reconstructed from isolated photon clusters
  - Mass resolution ~ 10 MeV/c$^2$
- Merged $\pi^0$
  - High energy □0 forms single merged cluster
  - Dedicated shower shape algorithm
  - Mass resolution ~ 15 MeV/c$^2$



# Conclusions

**Tracking and Particle ID using is essential for the LHCb physics program**

- **Tracking detectors**
  - **Velo, IT, TT and OT Production and commissioning ongoing**
- **Hadron Identification**
  - **RICH2 mirrors installed. RICH1 magnetic shields**
- **Muon Identification**
  - **MUON installation continuing**
- **Electron and Neutral Identification**
  - **ECAL/HCAL installation and commissioning well underway**

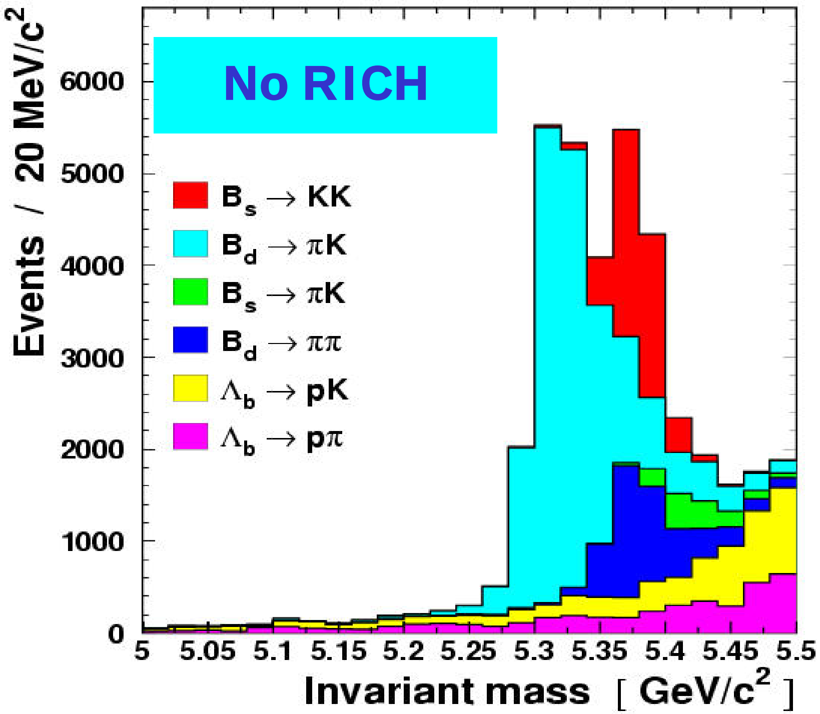
**LHCb on schedule for first data at the LHC startup in 2007**

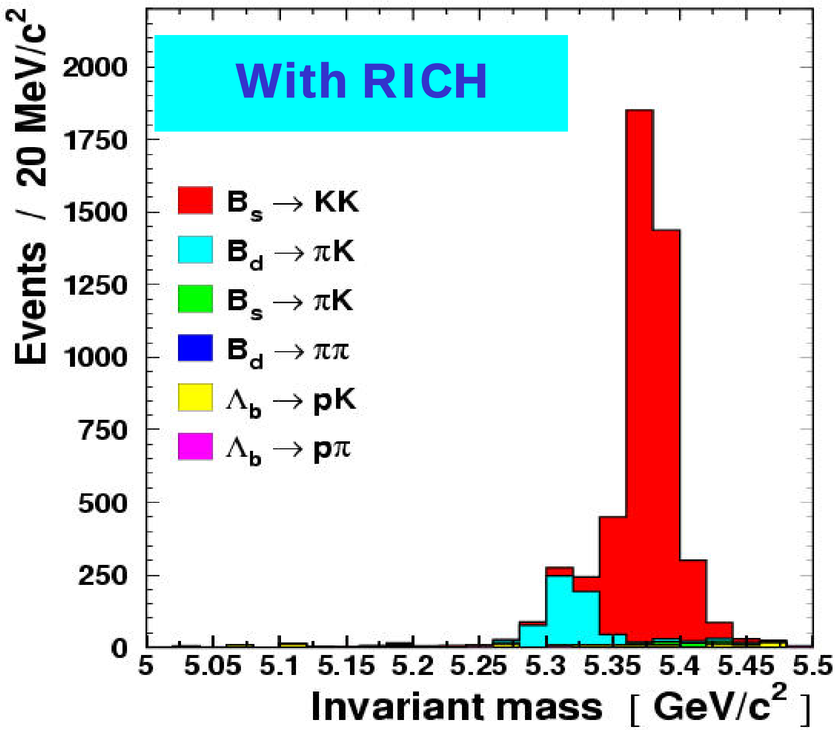
# backups

# Hadron ID : Physics Performance

- **RICH essential for hadronic decays**
- Example : $B_s \to K^+K^-$
- Sensitive to CKM angle $\gamma$

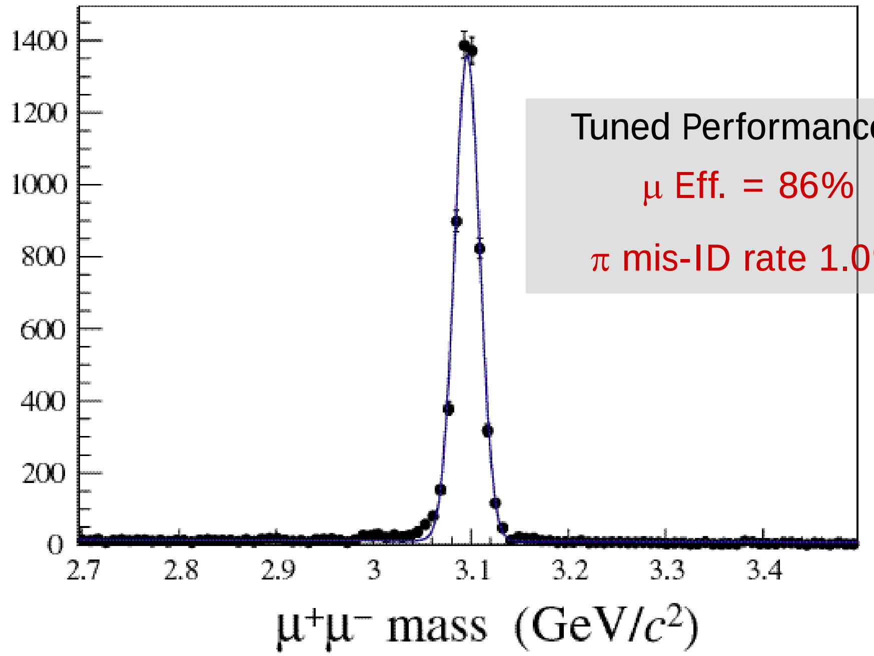
- Signal Purity improved from 13% to 84% with RICH
- Signal Efficiency 79%



# Lepton ID : $B_s \rightarrow (J/\psi \rightarrow l^+l^-)\ \phi$

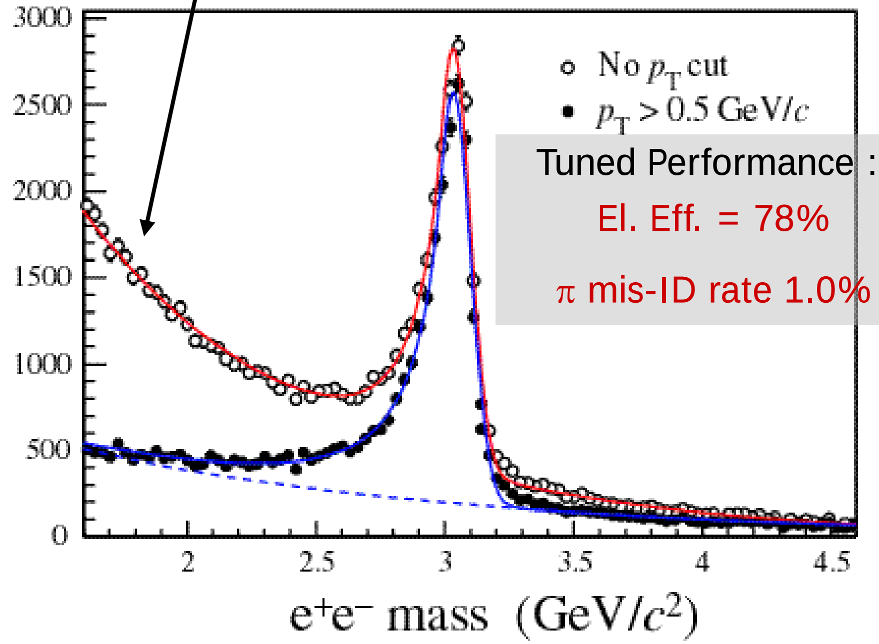
- Electron background predominately secondary electrons and ghosts
- Rejected efficiently with $P_T$ cut




Tuned Performance :-

μ Eff. = 86%

π mis-ID rate 1.0%




Tuned Performance :-

El. Eff. = 78%

π mis-ID rate 1.0%

- **RICH detectors can also discriminate leptons**
  - RICH alone has too high background
  - Combine with CALO/MUON using likelihood approach

RICH Electron ID