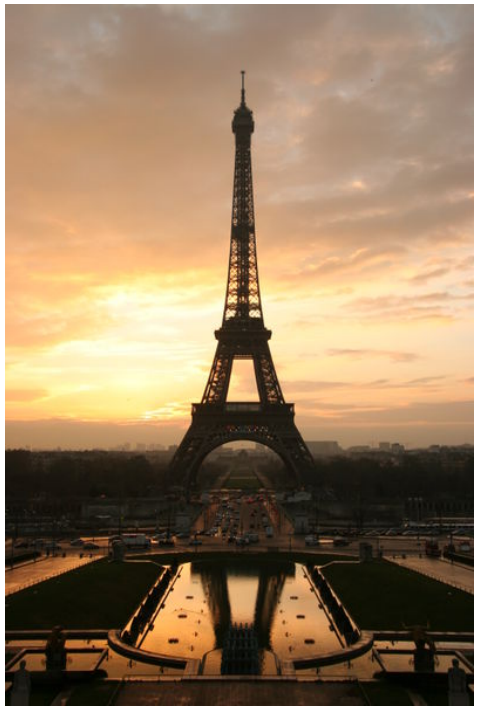
Particle ID at LHCb



Andrew Powell (University of Oxford)

On behalf of the LHCb Collaboration

35th International Conference on HEP, Paris, France - July 2010

LHCb

- **Broad physics program with emphasis on studies of CP Violation & Rare Decays**

- **Several key measurements** (arXiv:0912.4179)
  - All probing physics beyond the SM
  - Detailed presentations at this conference

- **To quote just three:**
  1) Tree-Level determination of CKM angle γ $B^+ \to D^0 K^+$
  2) CP Violation in B_S sector $B_S^0 \to J/\psi\phi$
  3) Radiative Penguin Decays $B_S^0 \to \phi\gamma$

LHCb

- **Broad physics program with emphasis on studies of CP Violation & Rare Decays**

- **Several key measurements** (arXiv:0912.4179)
  - All probing physics beyond the SM
  - Detailed presentations at this conference

Excellent Particle Identification is Vital!

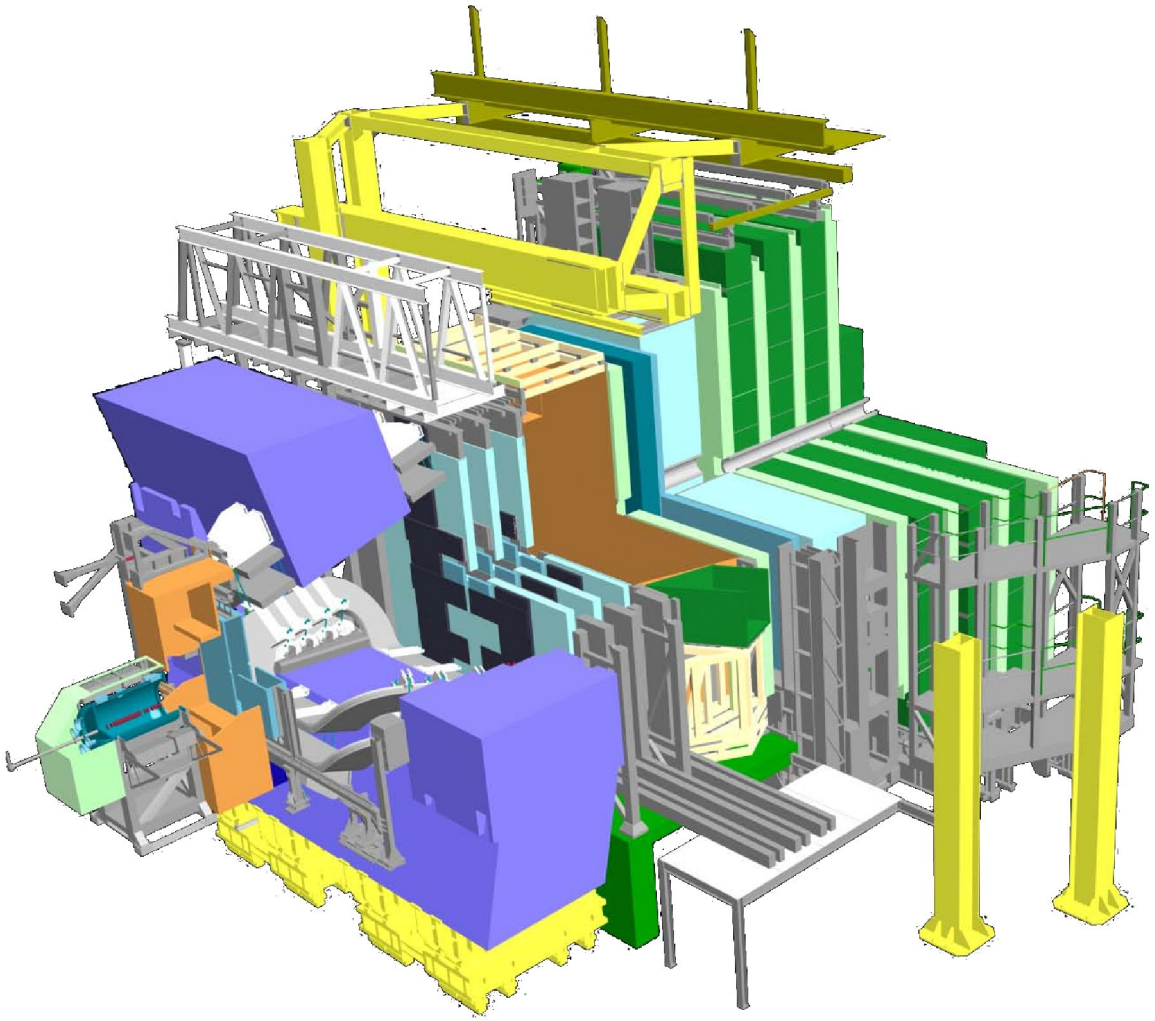
(as well as vertexing, proper-time resolution, triggering…)

$B^+ \to D^0 K^+$

$B_S^0 \to J/\psi\phi$

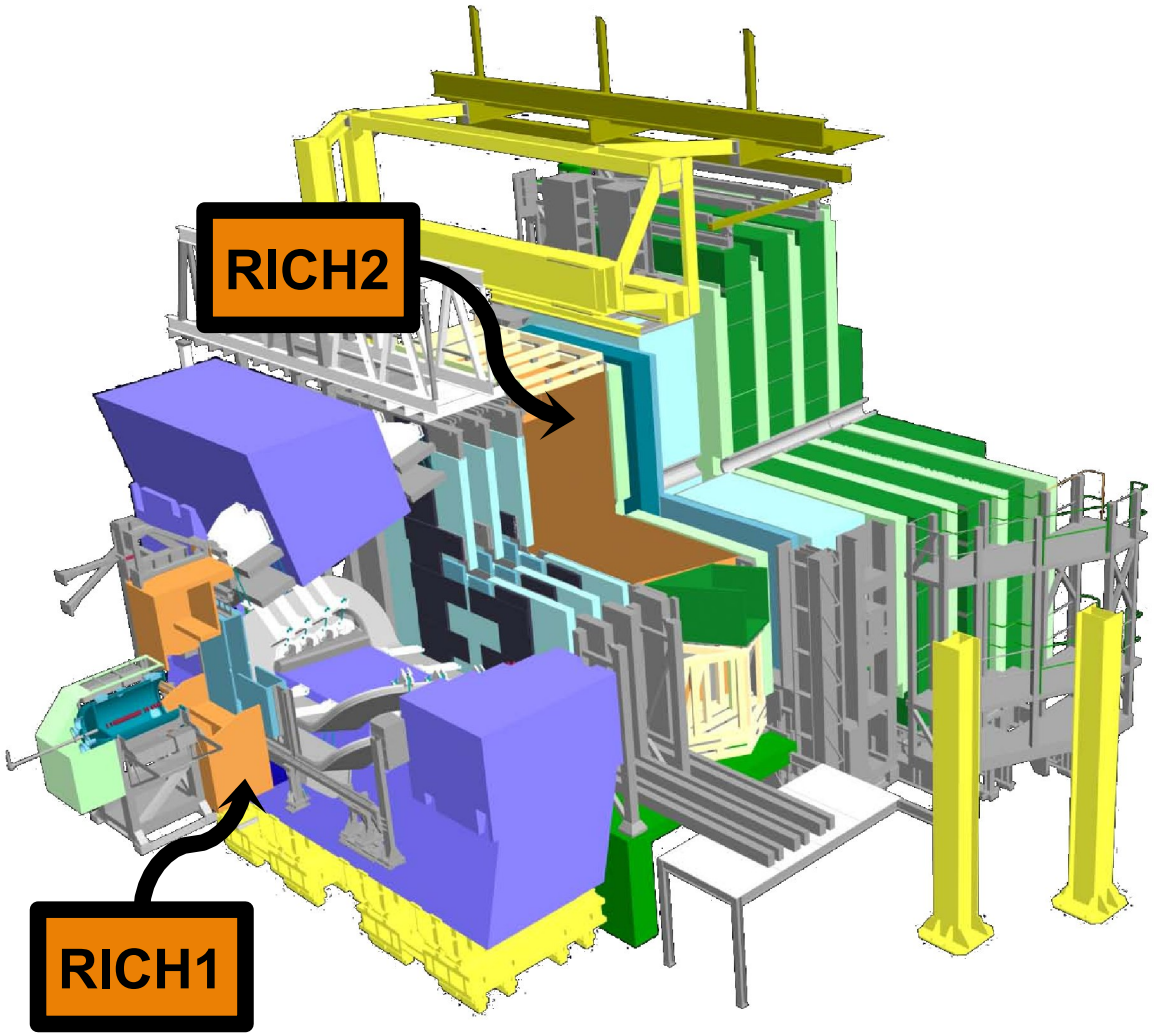
$B_S^0 \to \phi\gamma$

LHCb Detector



- Single-arm spectrometer
- Covering $2 < \eta < 5$
- PID provided by three groups of detectors:

LHCb - RICH



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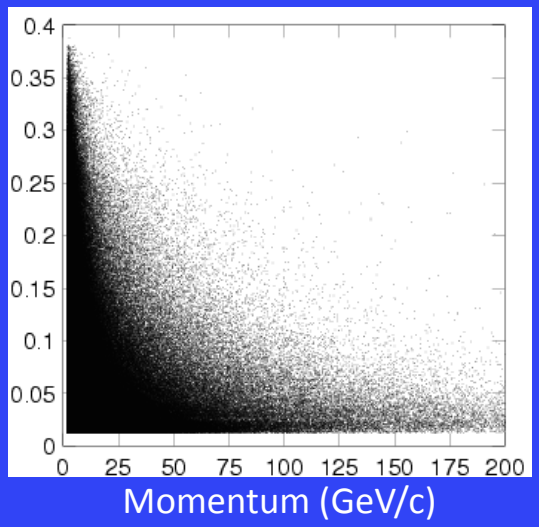
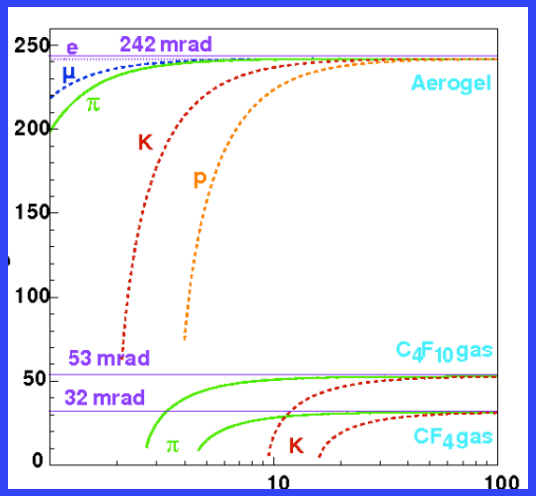
1. **Ring Imaging Cherenkov (RICH) detectors**

LHCb - RICH

- RICH unique to LHCb!



- Two detectors
- Three radiators



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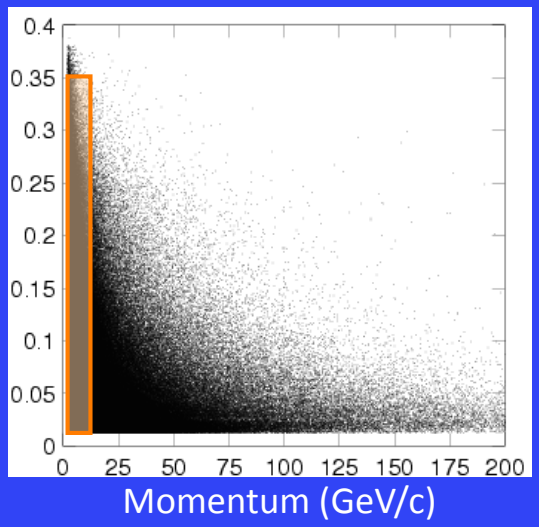
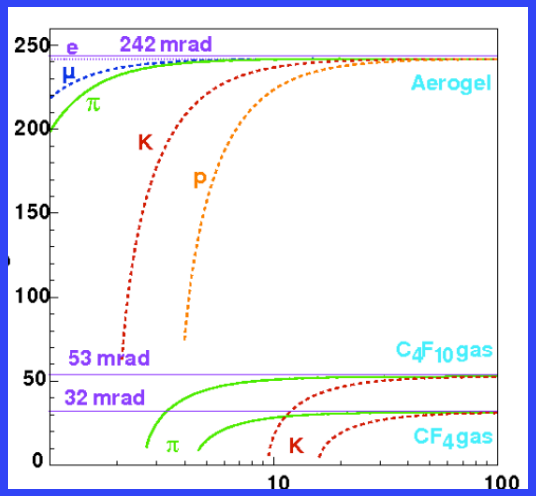


- Two detectors
- Three radiators
  - Silica Aerogel



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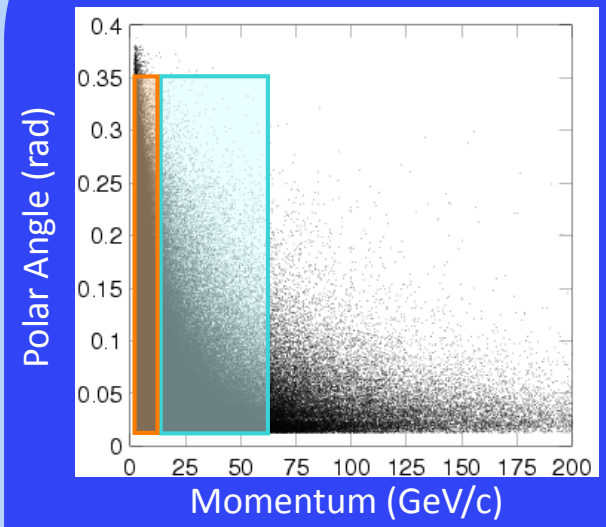
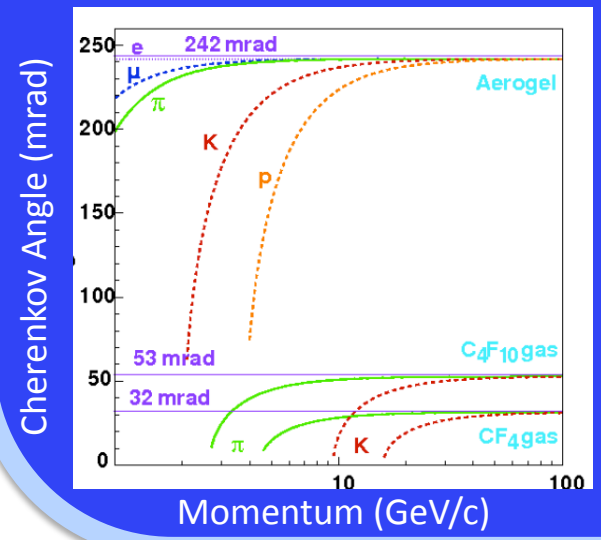


- Two detectors
- Three radiators
  - Silica Aerogel
  - C_4F_{10}



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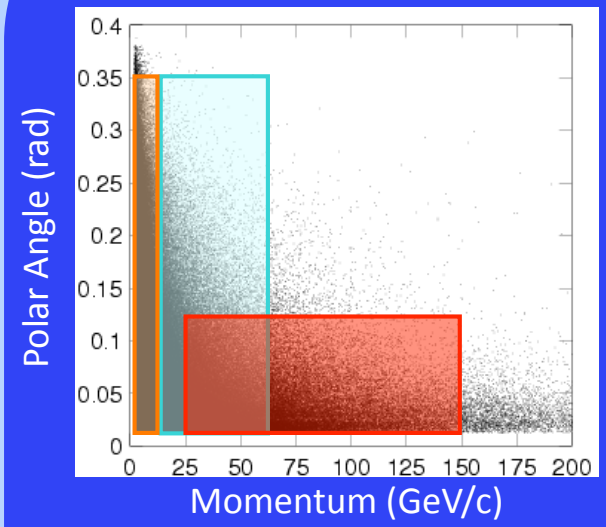
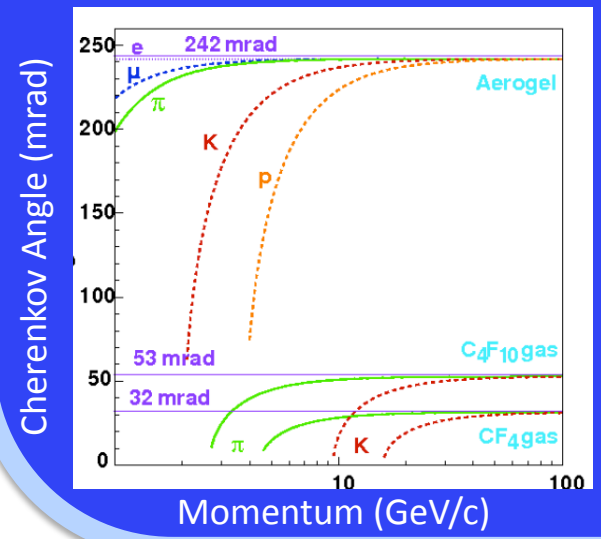


- Two detectors
- Three radiators
  - Silica Aerogel
  - C_4F_{10}
  - CF_4

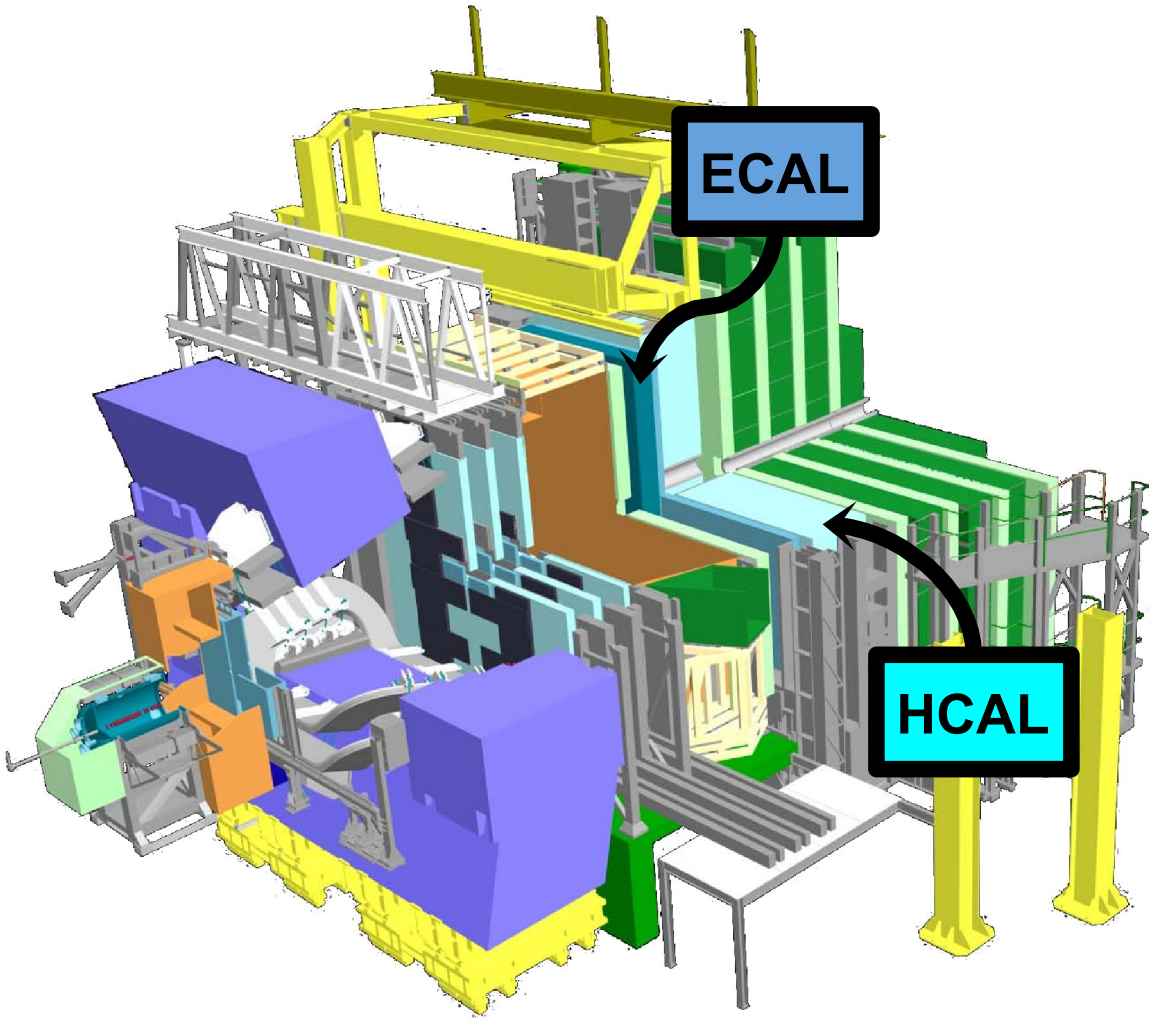


- Provides K/π separation between 2 – 100 GeV/c
- More later…

- Single-arm spectrometer
- Covering $2 < \eta < 5$
- PID provided by three groups of detectors:

1. **Ring Imaging Cherenkov (RICH) detectors**

LHCb - CALO

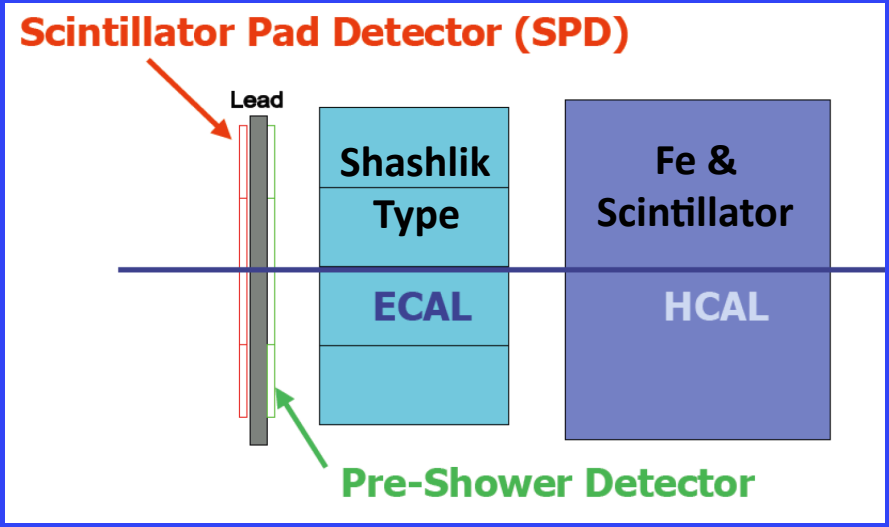


- Single-arm spectrometer
- Covering $2 < \eta < 5$
- PID provided by three groups of detectors:

1. Ring Imaging Cherenkov (RICH) detectors
2. **Calorimeters**

LHCb - CALO

- Provides PID for e^-, γ & neutrals
- Also measures energy and position
- Longitudinal separation of EM shower needed to identify e^- over $\pi^{\pm}/\pi^0$
- Use SPD & PSD detectors



- Single-arm spectrometer
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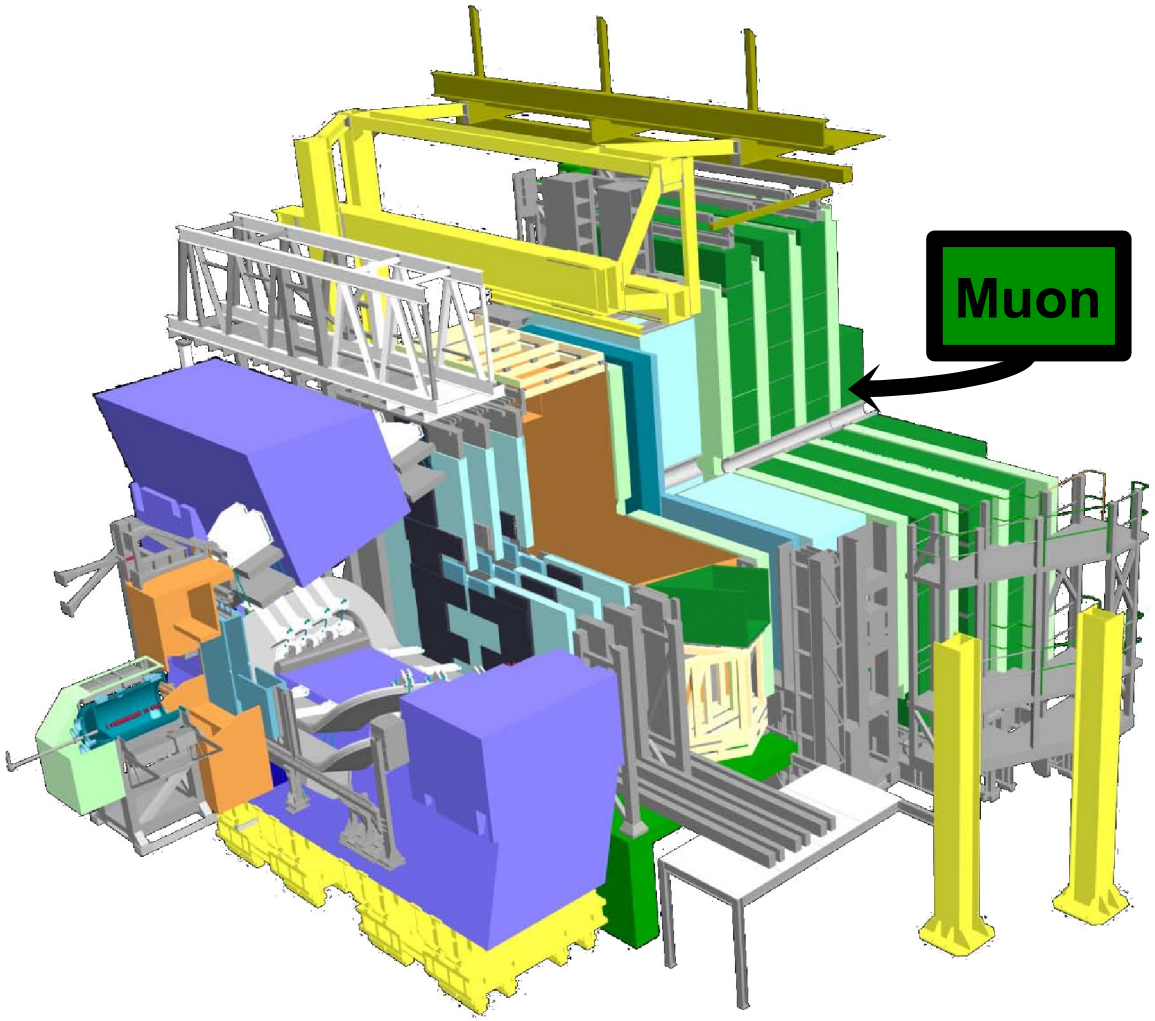
2. **Calorimeters**

LHCb – Muon Chambers

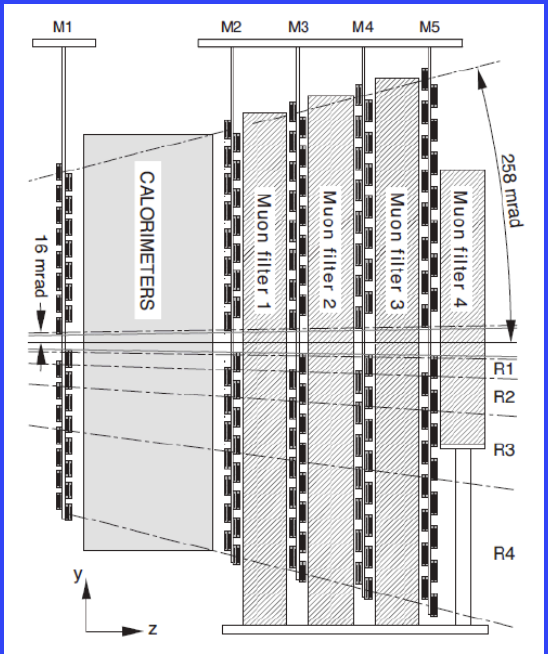


- Single-arm spectrometer
- Covering $2 < \eta < 5$
- PID provided by three groups of detectors:

1. Ring Imaging Cherenkov (RICH) detectors
2. Calorimeters
3. **Muon Chambers**

LHCb – Muon Chambers

- Provides μ-ID with high purity
- 5 tracking stations (M1 – M5) around hadron absorbers (~23λ)
- Two types of tracking technology:

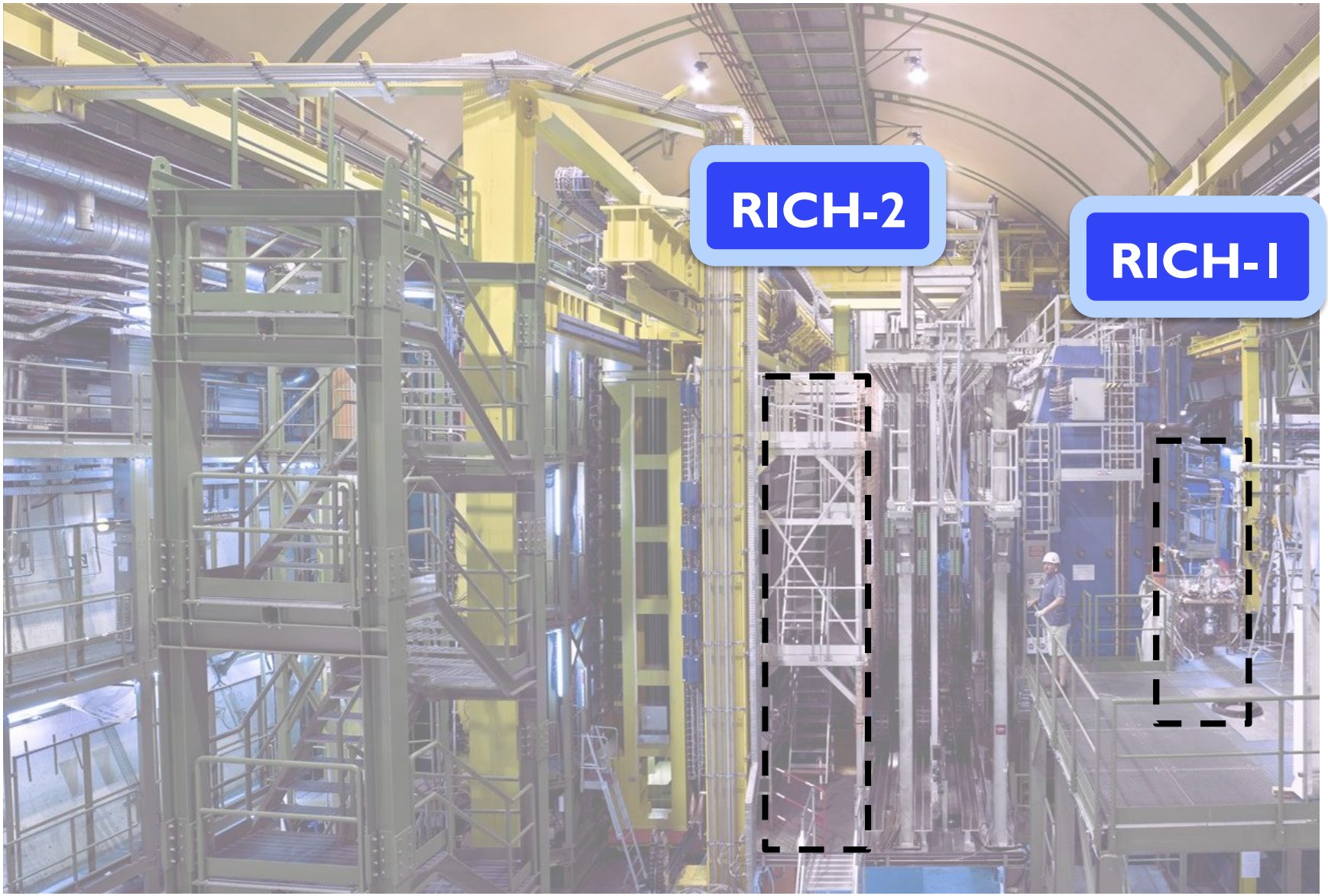


- Multi-wire Proportional Chambers (MWPCs)
- Gas Electron Multipliers (GEMs)

- Single-arm spectrometer
- Covering $2 < \eta < 5$
- PID provided by three groups of detectors:

1. Ring Imaging Cherenkov (RICH) detectors
2. Calorimeters
3. **Muon Chambers**

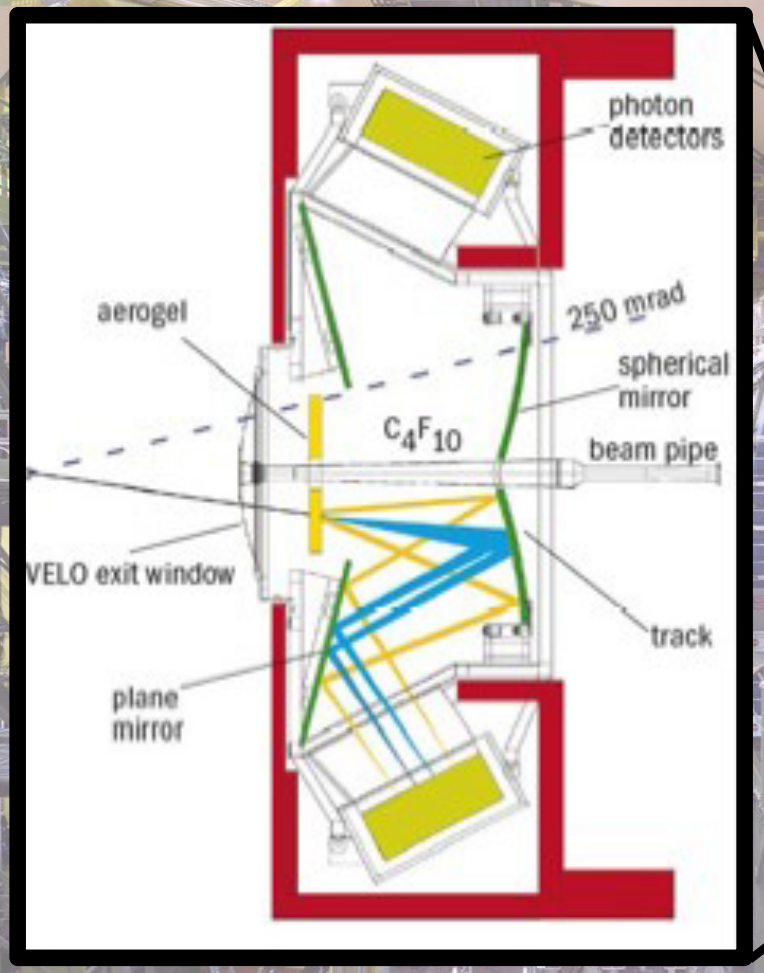
More on the RICH…



More on the RICH…

RICH-1

Arrangement of spherical & flat mirrors focus rings onto two photon detector arrays out of the LHCb acceptance



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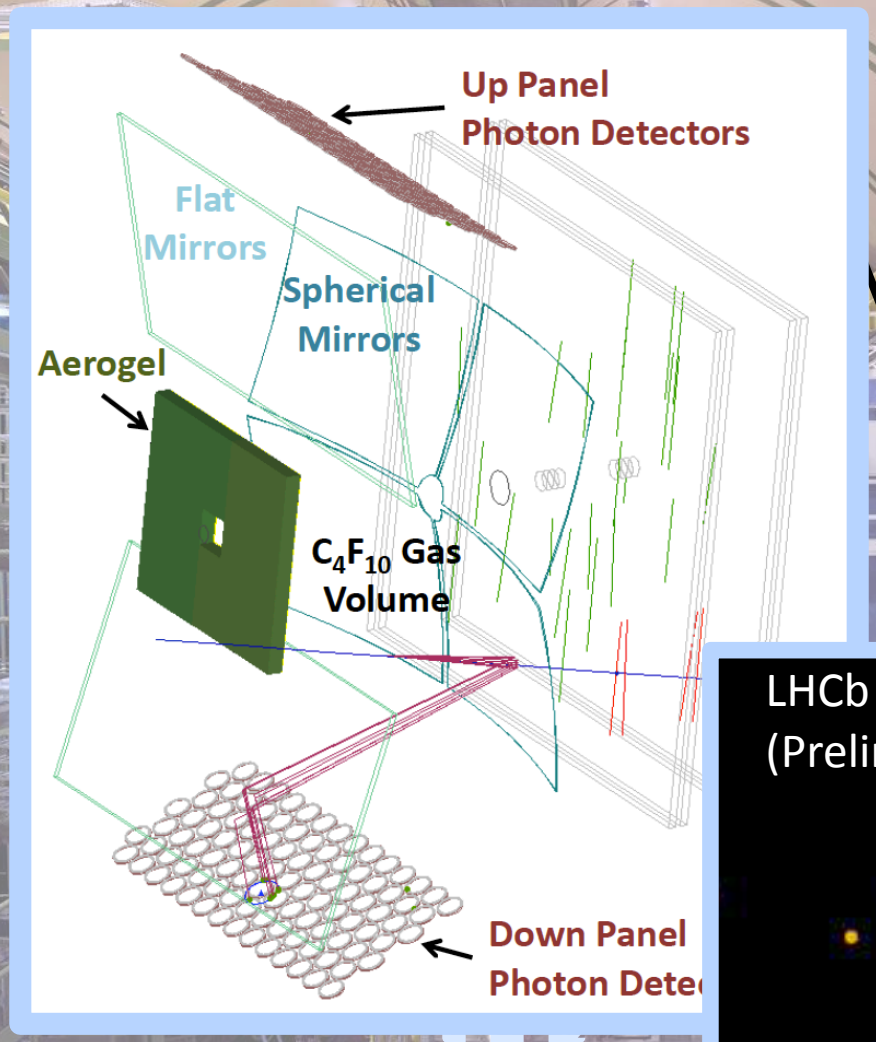
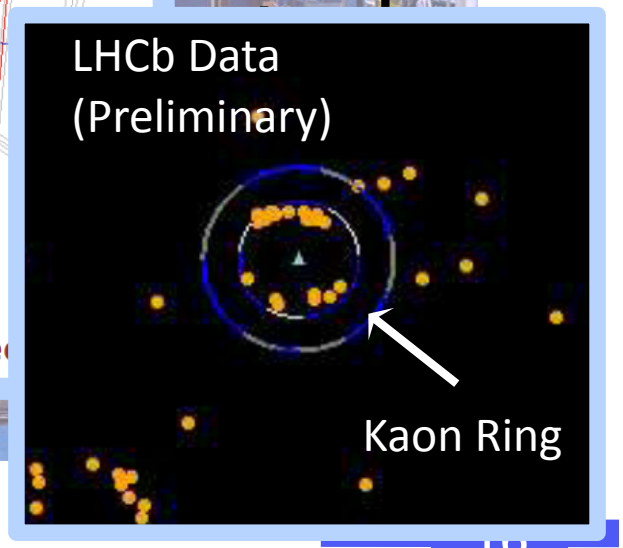




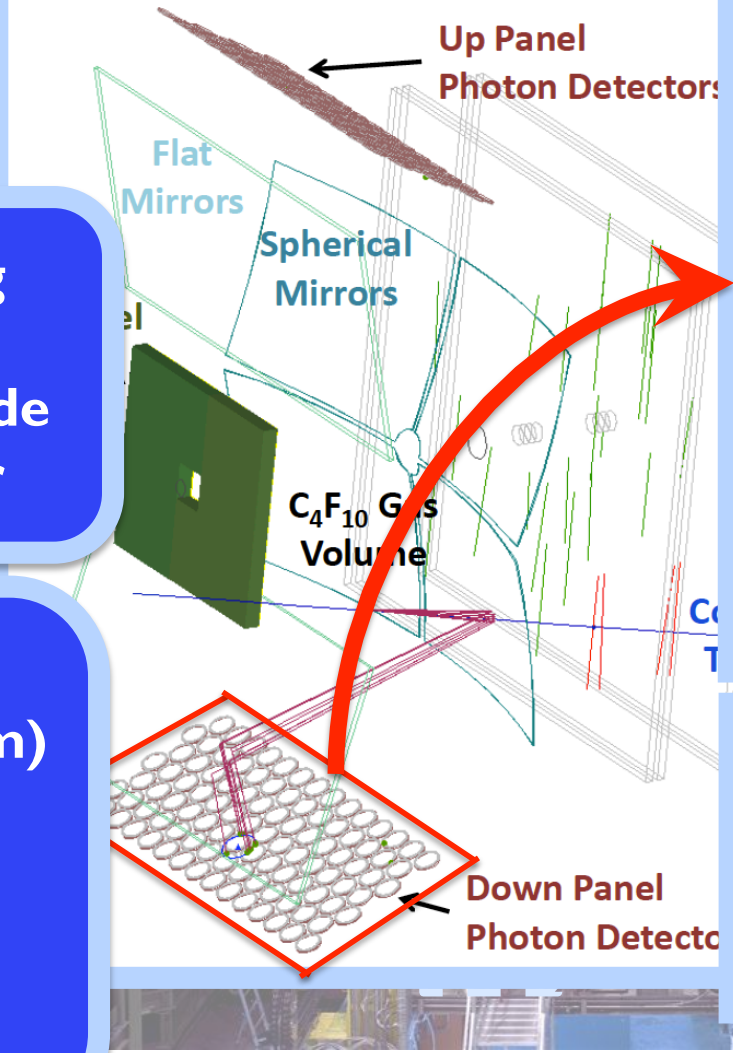
More on the RICH…

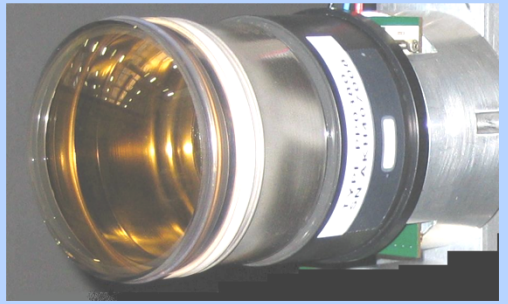
Pixel Hybrid Photon Detector

- Novel device combining two technologies:
- Vacuum Photo-cathode
- Silicon pixel detector

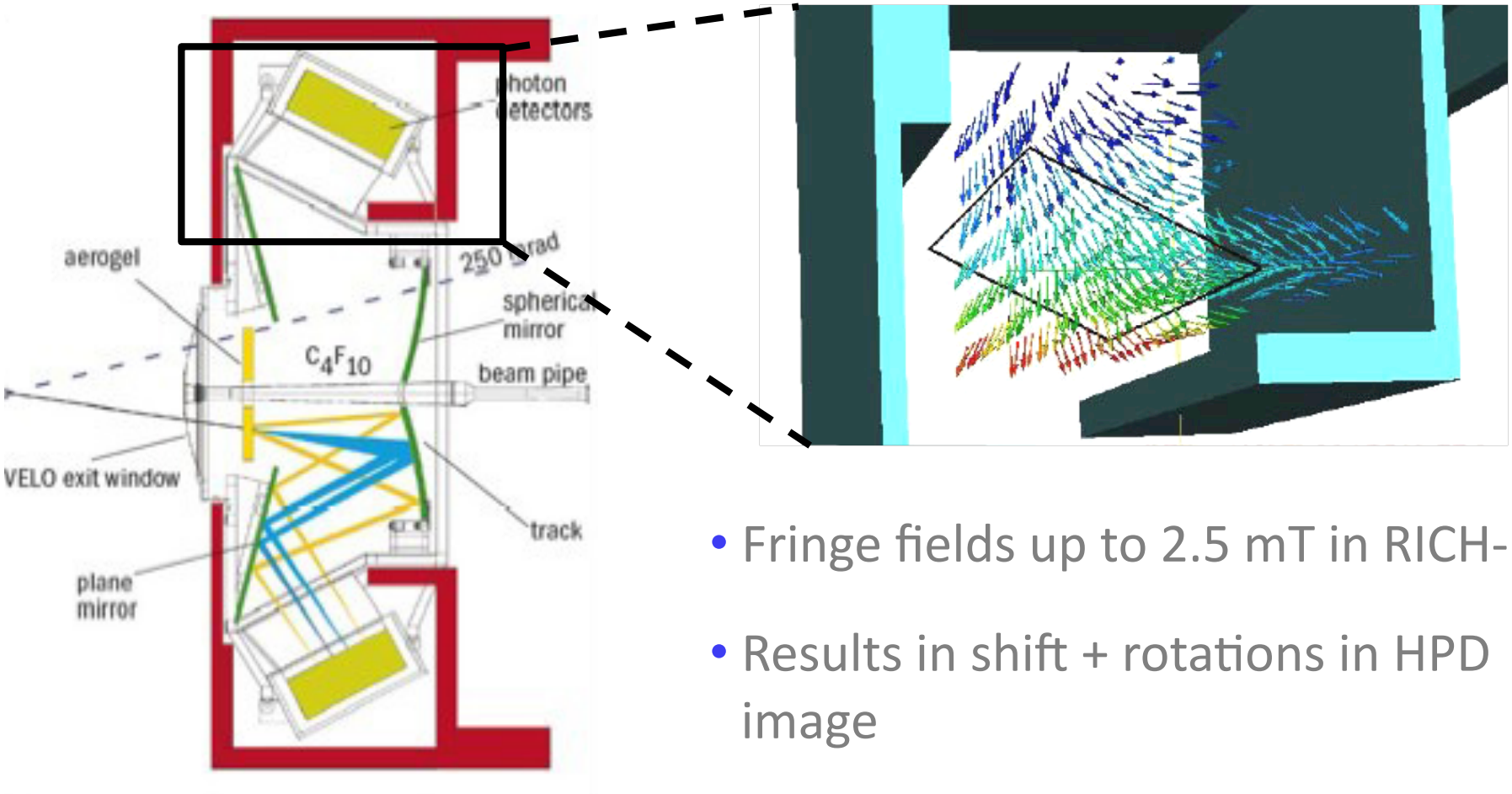
- Single photon sensitivity (200 – 600nm)
- Q.E. ε > 20%
- Granularity $(2.5\ mm)^2$

- Susceptible to fringe magnetic fields…



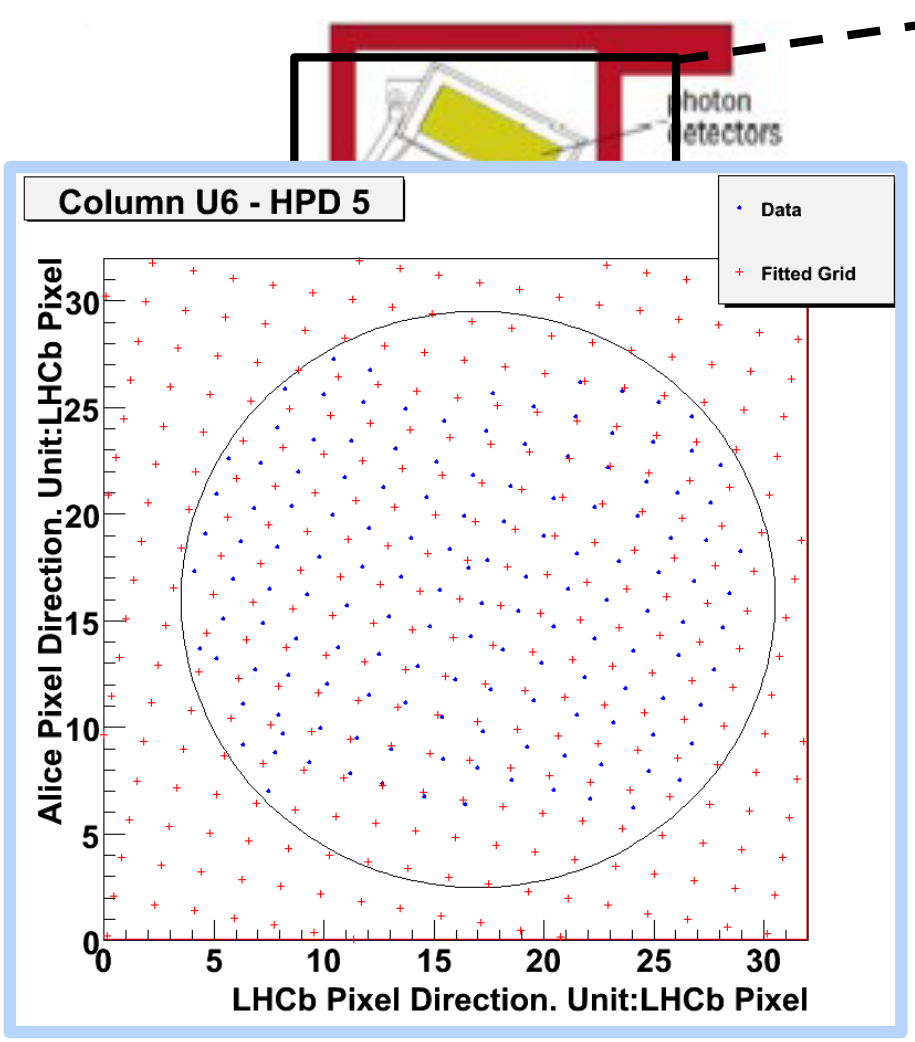


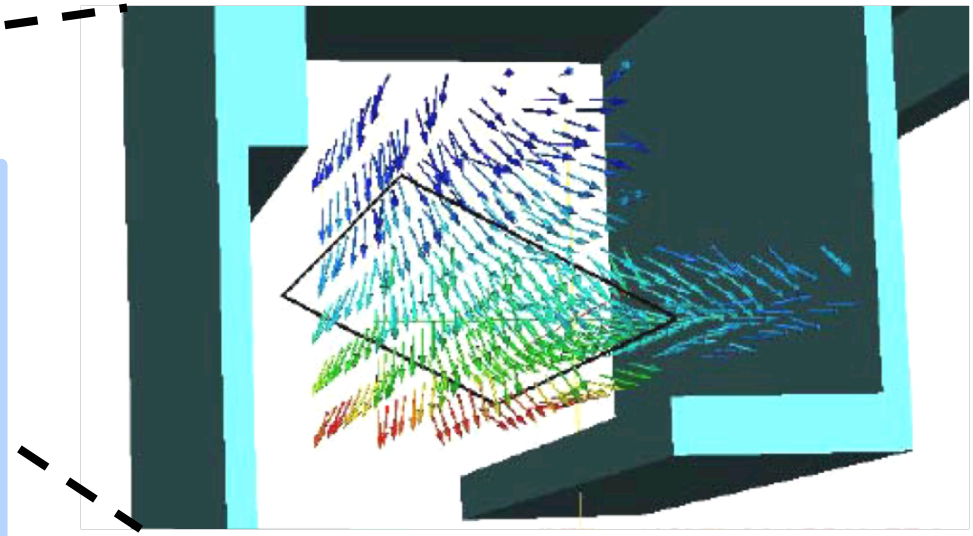
More on the RICH…



- Fringe fields up to 2.5 mT in RICH-1
- Results in shift + rotations in HPD image
- Dedicated Magnetic Distortion Calibration System (MDMS) to correct for the effect

More on the RICH…





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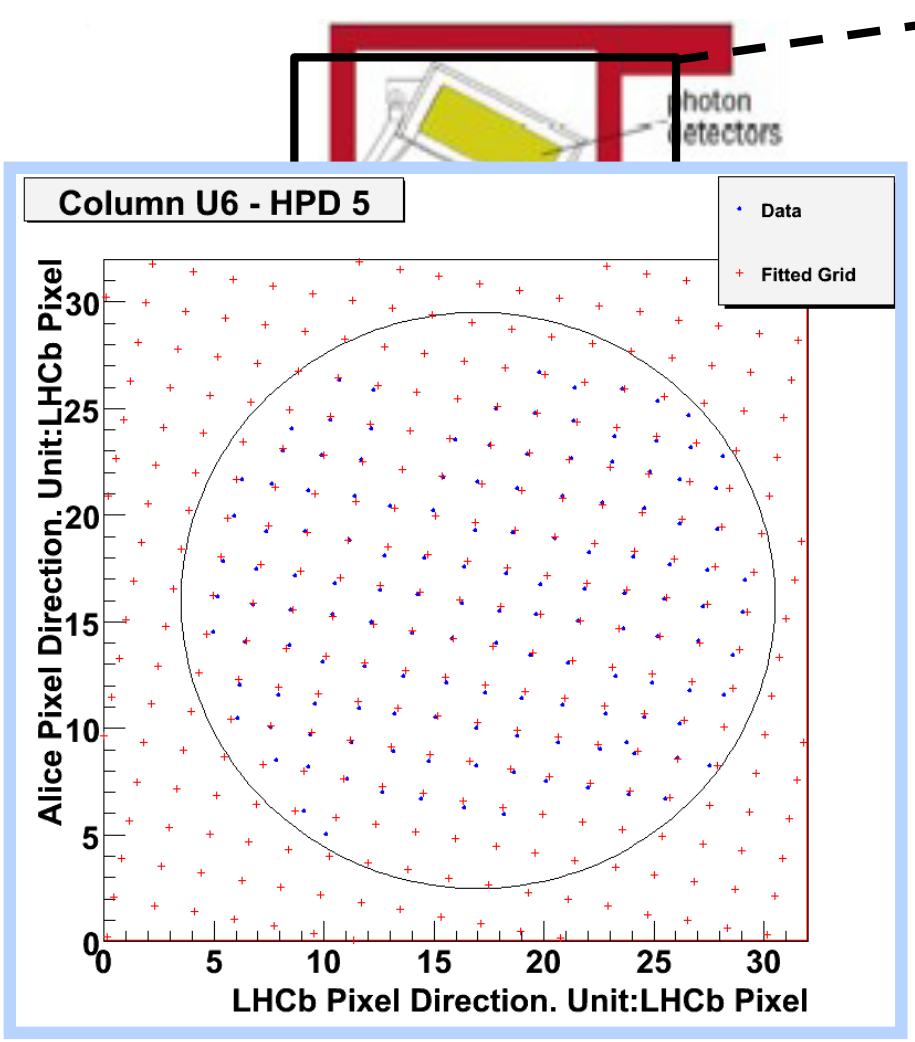
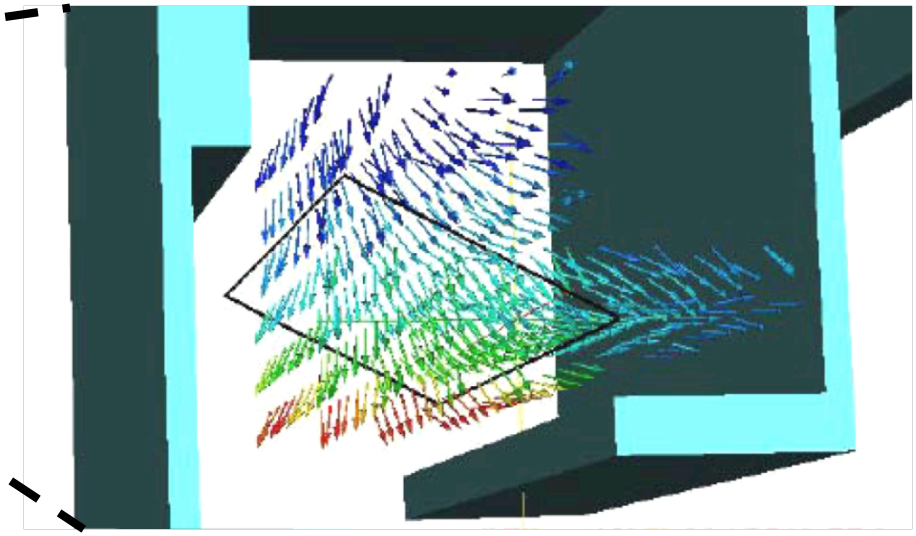
Before Corrections

More on the RICH…



After Corrections



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LHCb PID Performance at $\sqrt{s} = 7$ TeV

Methodology

- **To determine ID and mis-ID rates, need:**
  - pure samples of each particle type ($K^{\pm}, \pi^{\pm}, p, \bar{p}, \mu^{\pm}, e^{\pm}$)
  - identified without the use of *any* PID
- **Exploit an array of 'standard candle' decays:**

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  - **'V0-decays'**
    - $K^0_S \rightarrow \pi^- \pi^+$
    - $\Lambda^0 \rightarrow p\pi^-$

Selected via kinematics cuts alone

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    - $\phi(1020) \rightarrow K^+ K^-$
    - $J/\psi \rightarrow \mu^+ \mu^-$

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'Tag-and-Probe' : PID applied to 'tag' track, unbiased 'probe' used to assess K/μ performance

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  - pure samples of each particle type ($K^{\pm}, \pi^{\pm}, p, \bar{p}, \mu^{\pm}, e^{\pm}$)
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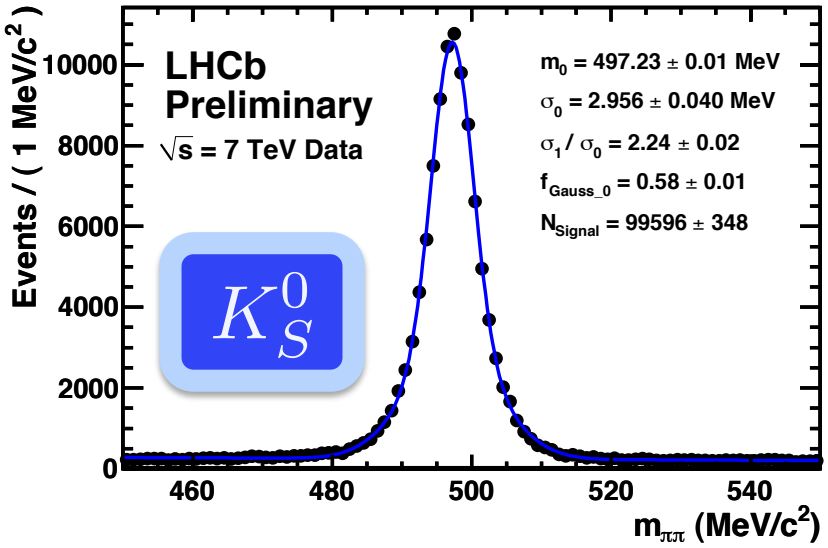
  - **Resonances**
    - $\phi(1020) \rightarrow K^+K^-$
    - $J/\psi \rightarrow \mu^+\mu^-$
  - **Photon Conversion**
    - $\gamma \rightarrow e^+e^-$

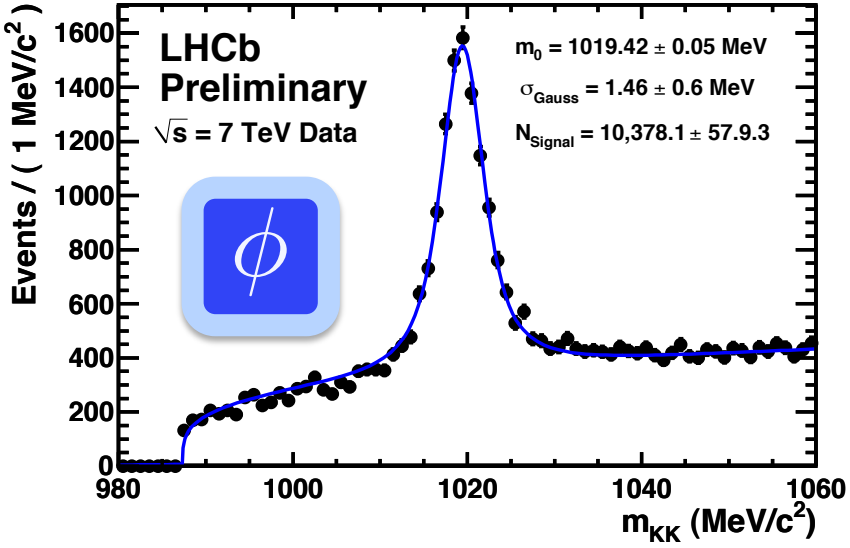
Selected via kinematics cuts alone

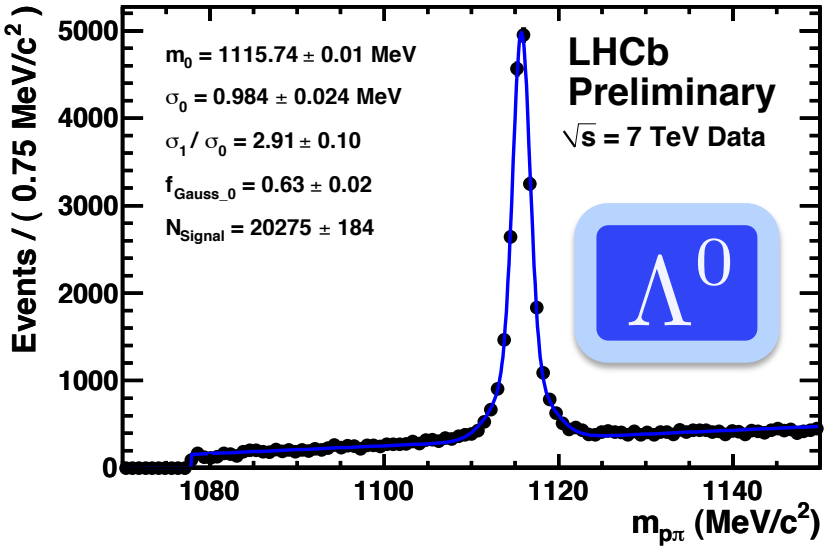
'Tag-and-Probe' : PID applied to 'tag' track, unbiased 'probe' used to assess K/μ performance

M_{ee} < 50 MeV → 99% purity

RICH Performance





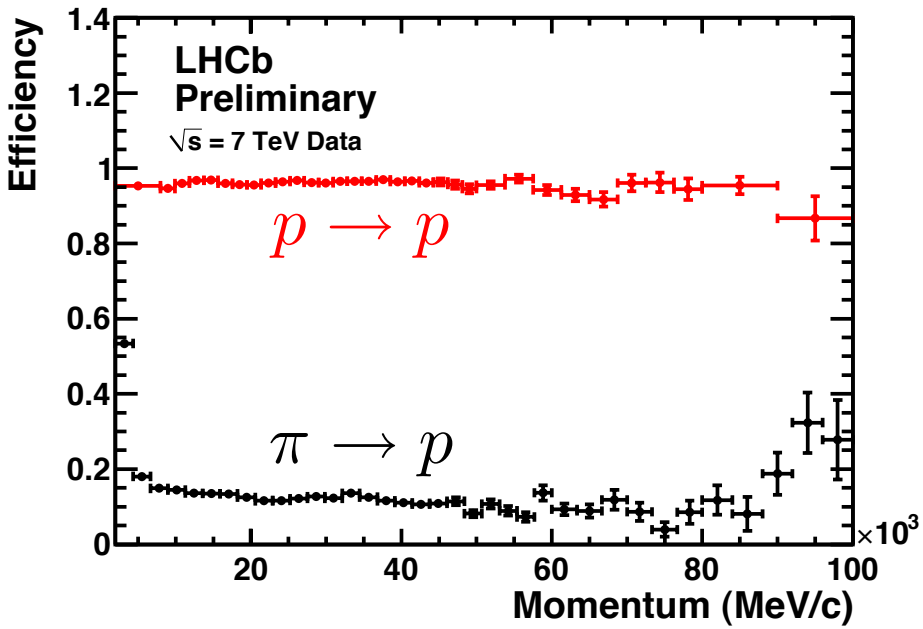


- High purity obtainable in V0's
- Dominant background present in Inclusive ϕ sample
- Extract true kaon distributions through 'sPlots' technique† (details in backups)

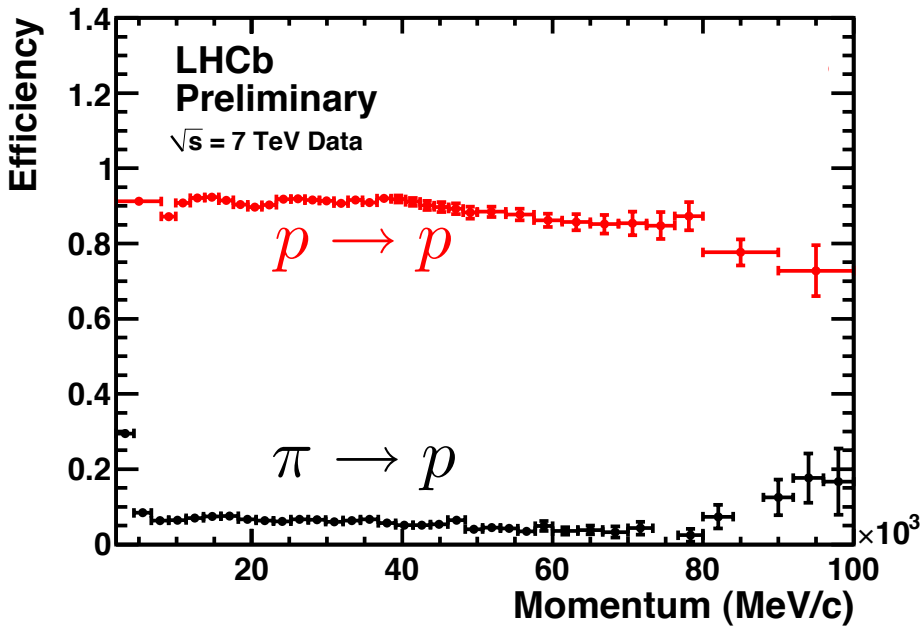
†Nucl. Inst. & Meth.A 555 (2005) 356-369

RICH Performance

$\Delta\log\mathcal{L}(\mathrm{p}-\pi) > 0$



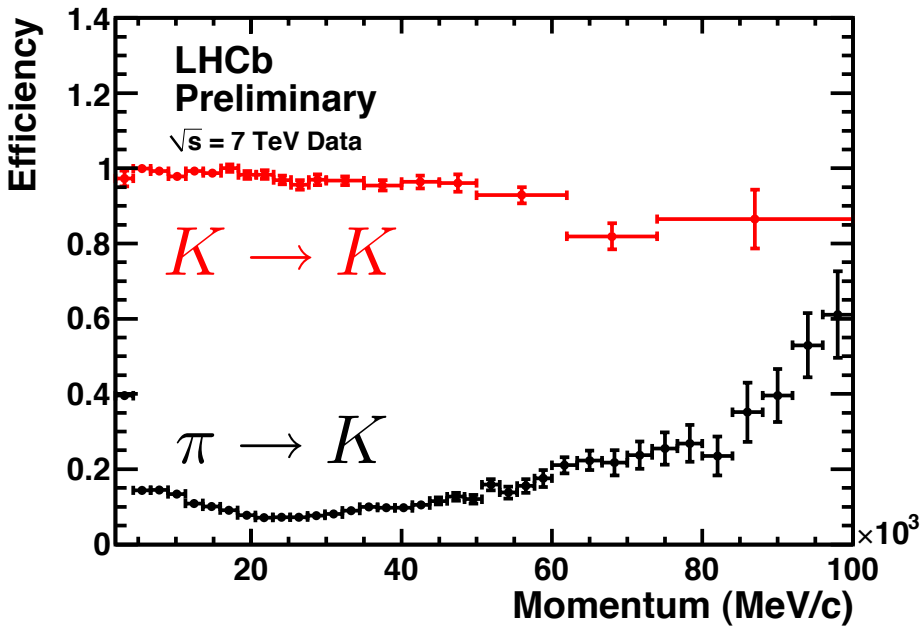
$\Delta\log\mathcal{L}(\mathrm{p}-\pi) > 5$



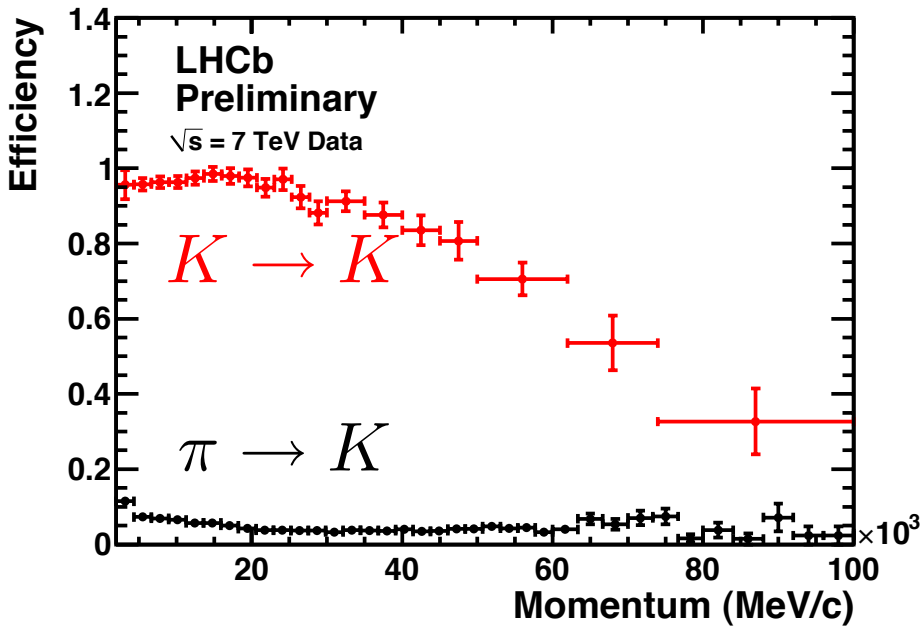
- Excellent performance over typical B/D track momentum range
- Pion background very small with tight PID cut

RICH Performance

$\Delta\log\mathcal{L}(\mathrm{K}-\pi) > 0$



$\Delta\log\mathcal{L}(\mathrm{K}-\pi) > 5$



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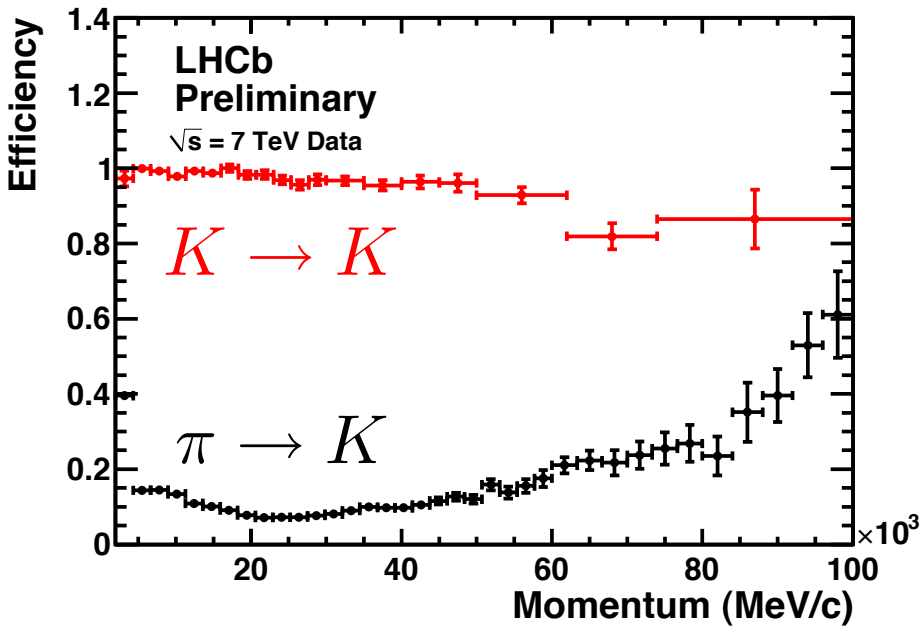

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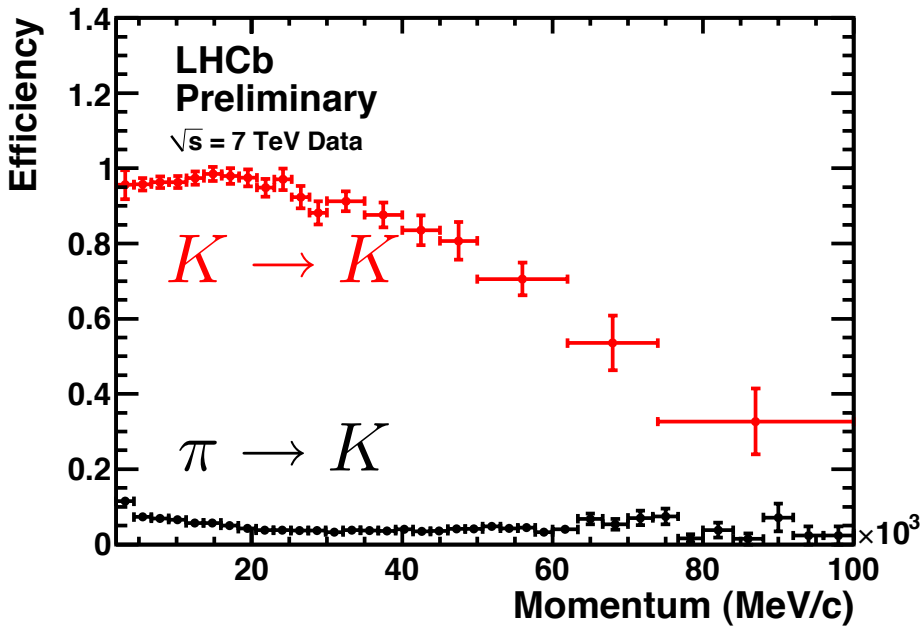
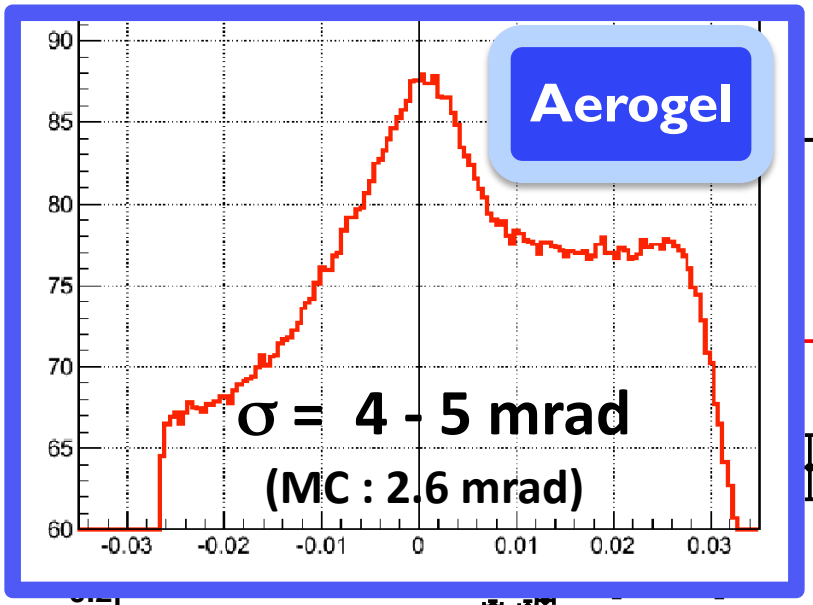
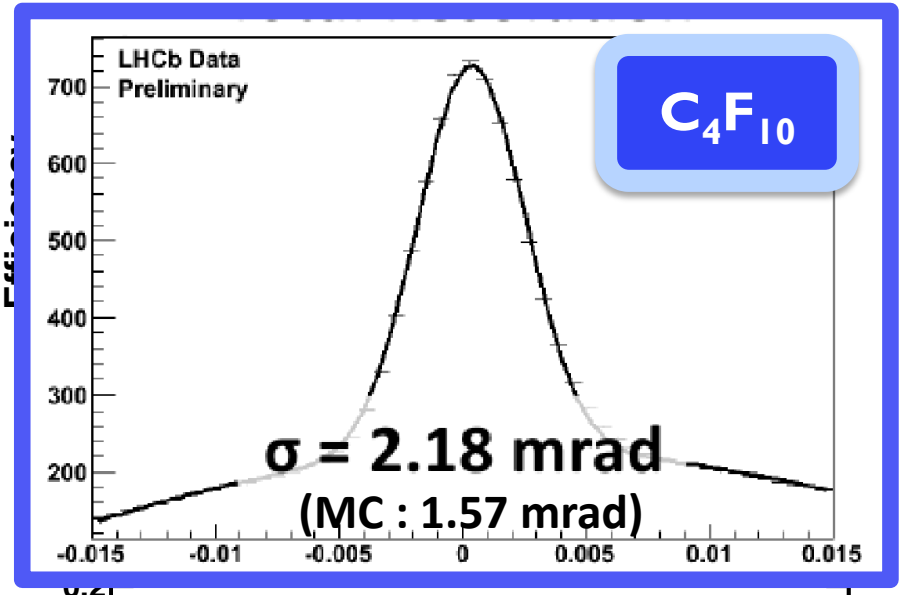


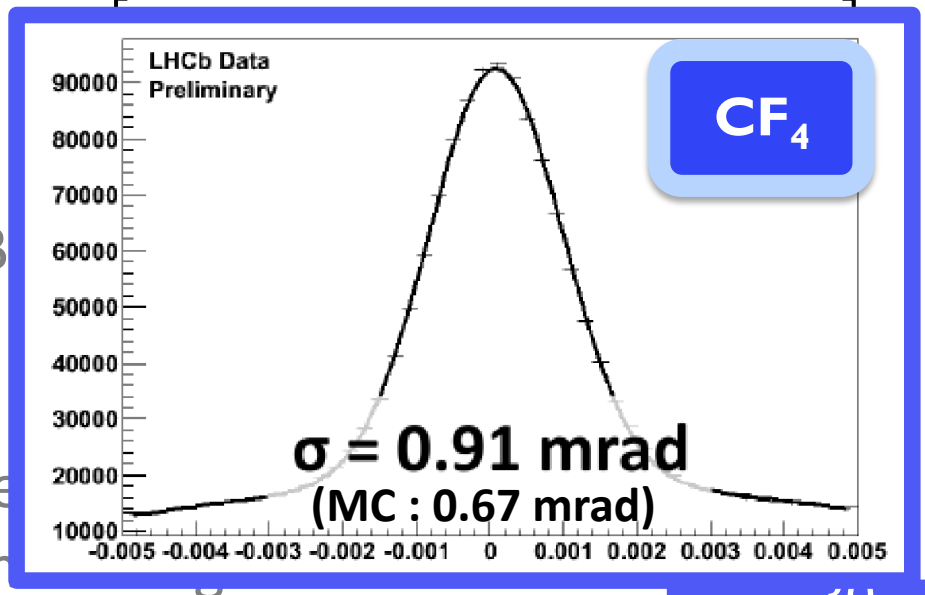
- Excellent performance over typical B/D track momentum range
- Pion background very small with tight PID cut
- Still room for improvement
  - Precision tuning of radiator refractive index
  - Targeting design spec. Cherenkov angle resolutions

Č Angle Resolutions



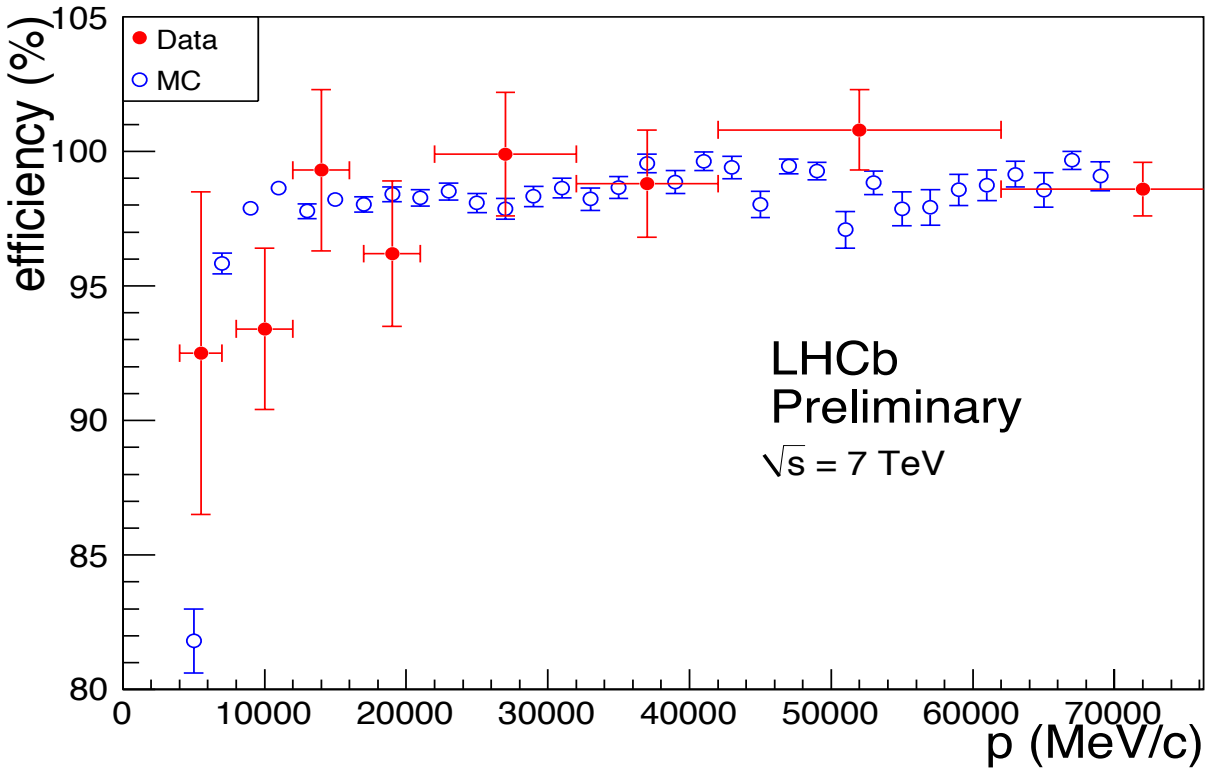


- Aerogel performance somewhat short of MC
- Understood due to C_4F_{10} contamination
- Program underway to recover performance



Muon ID Efficiency

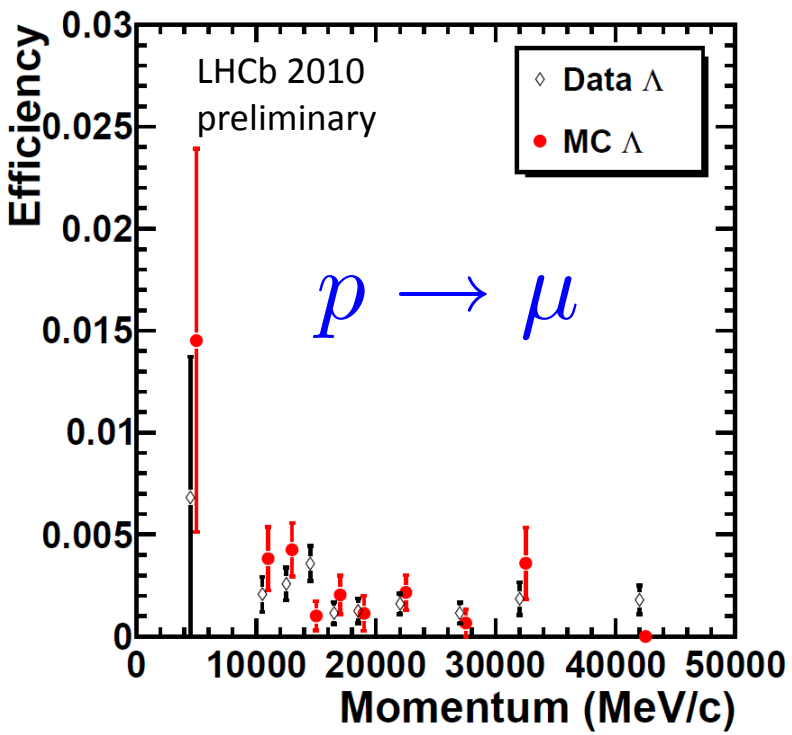
‘Loose’ Muon Selection

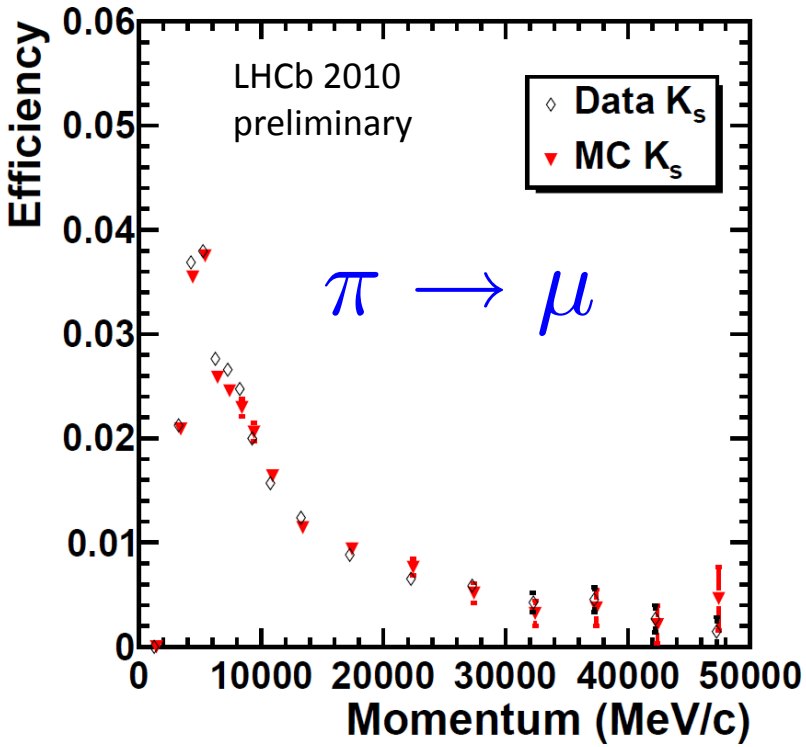


- Integrated efficiency over full spectrum, $\varepsilon(\mu) = 97.3 \pm 1.2$ %
- Good agreement with Monte Carlo performance

Muon mis-ID Efficiencies

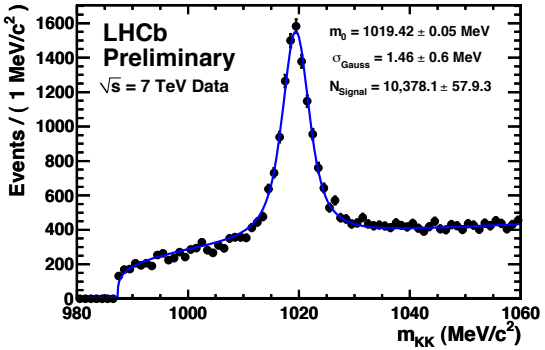
‘Loose’ Muon Selection

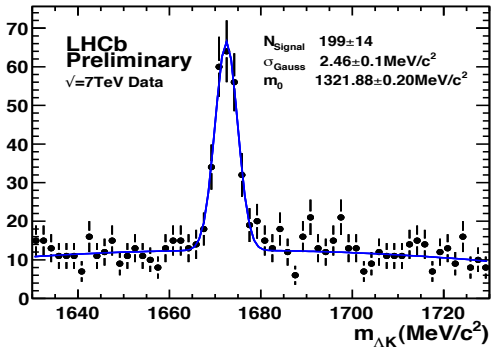


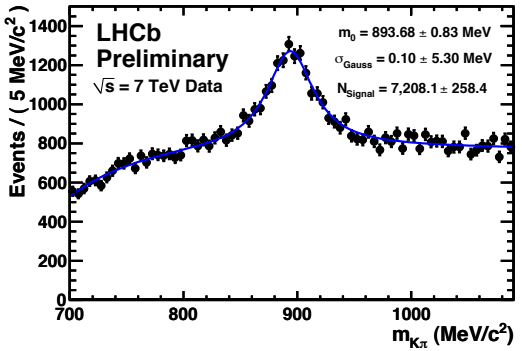


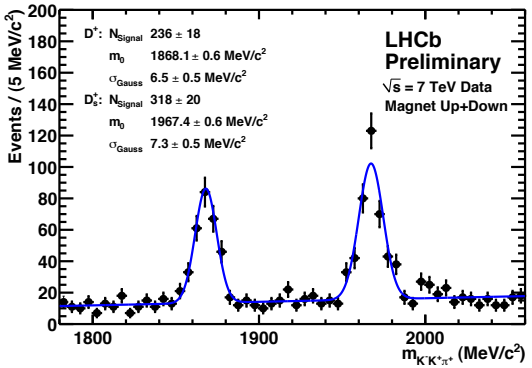
- Integrated efficiency over full spectrum, $\varepsilon(\mu) = 97.3 \pm 1.2$ %
- Good agreement with Monte Carlo performance
  - $\varepsilon(p \to \mu) = 0.21 \pm 0.05$ %
  - $\varepsilon(\pi \to \mu) = 2.35 \pm 0.04$ %
  - $\varepsilon(K \to \mu) = 1.67 \pm 0.06$ %

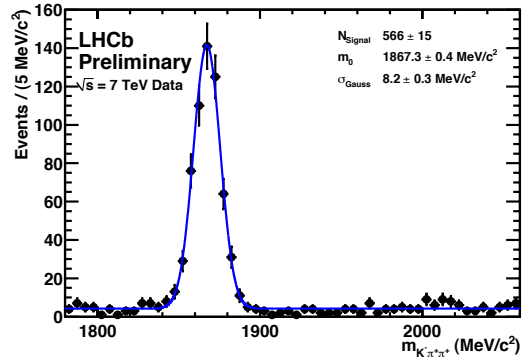
RICH- Particle Zoo

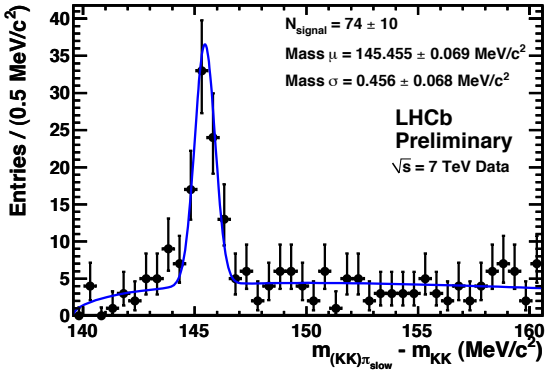












$$\phi \to K^+K^-$$

$$\Omega^- \to \Lambda K^-$$

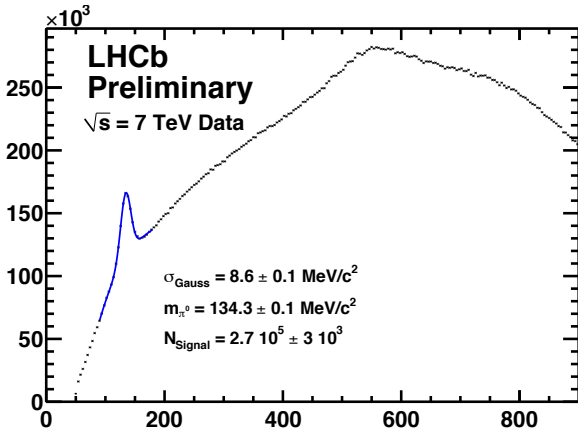
$$K^*(892) \to K^\pm\pi^\mp$$

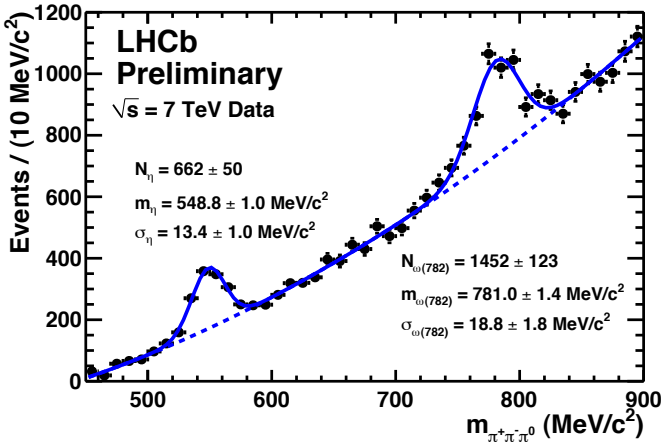
$$D^+ \to K^+K^-\pi^+$$

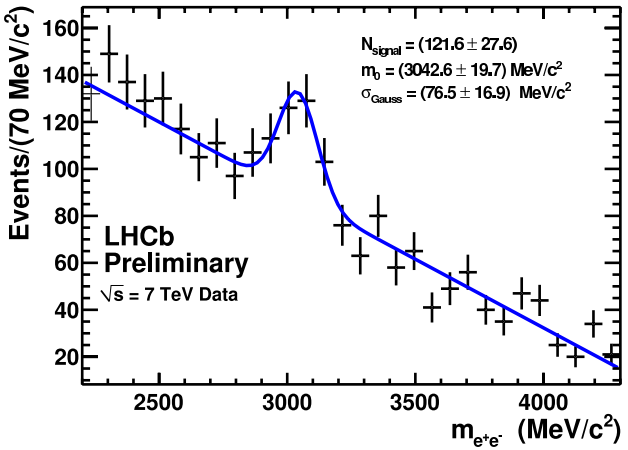
$$D^+ \to K^-\pi^-\pi^+$$

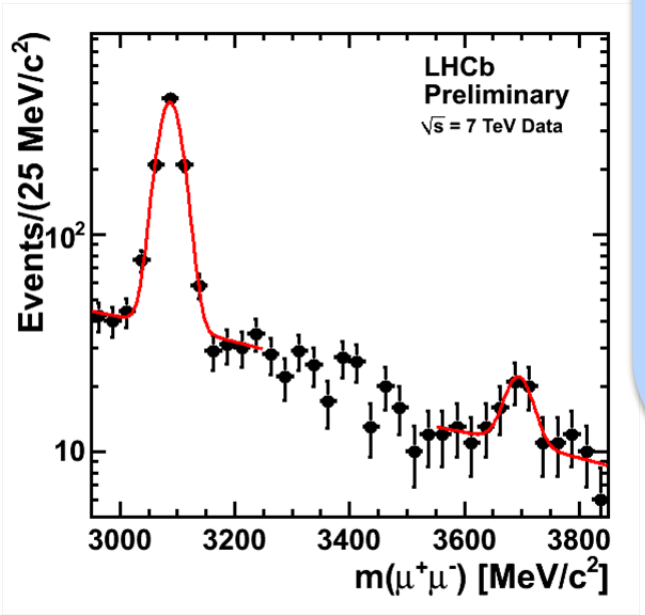
$$D^{*+} \to D(K\pi)\pi^+$$

Calo & Muon - Particle Zoo









$$\pi^0 \to \gamma\gamma$$

$$\eta \to \pi^+\pi^-\pi^0$$

$$\omega \to \pi^+\pi^-\pi^0$$

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

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

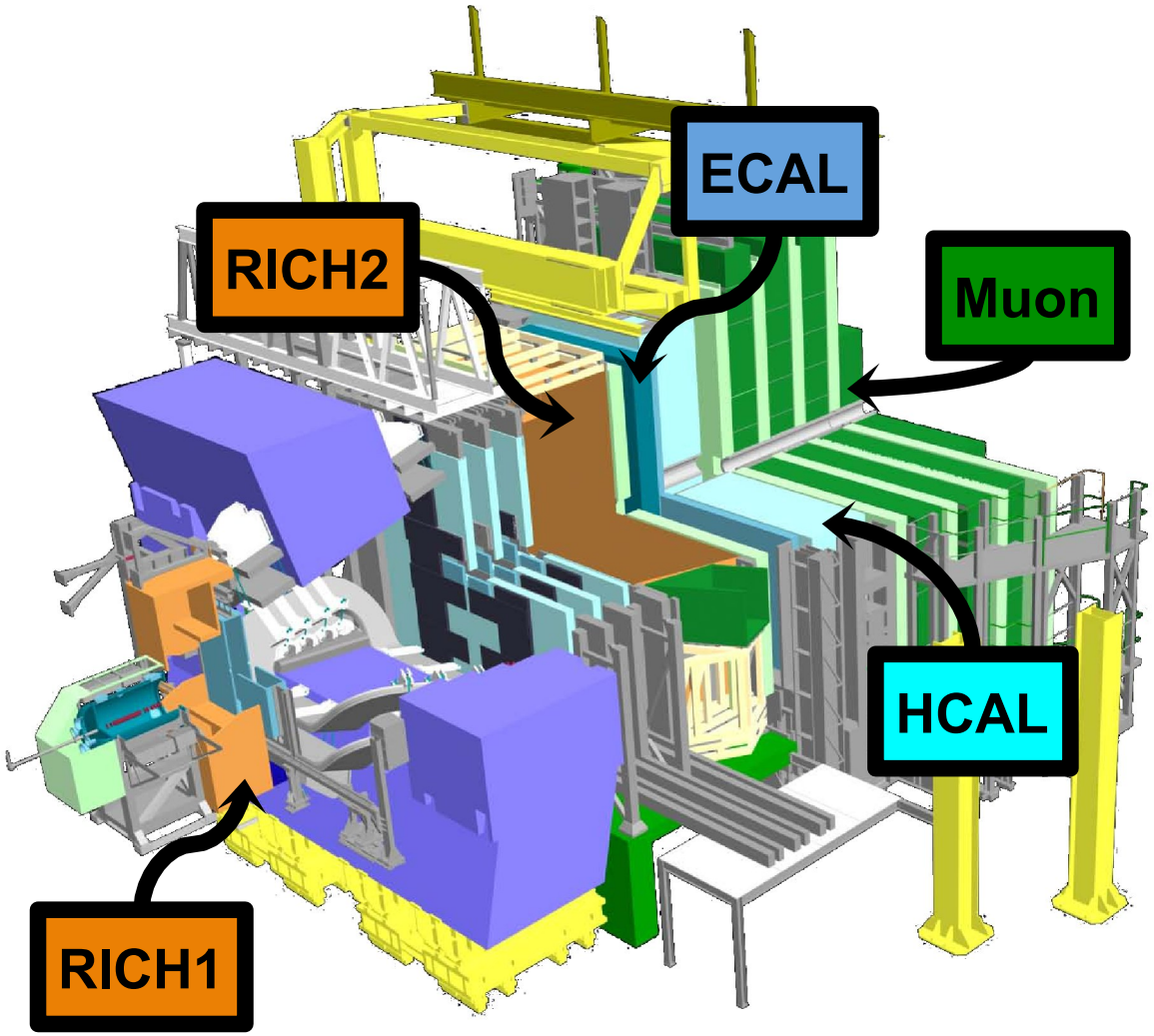
$$\psi(2s) \to \mu^+\mu^-$$

Summary

- PID at LHCb essential in order to achieve physics goals
- RICH, CALO & MUON systems all fully operational and already providing useful PID information
- Performance approaching Monte Carlo expectations with continuing calibration/alignment iterations
- Look out for the many physics presentations at this conference that exploit LHCb's excellent PID!

Backup Slides

LHCb Detector



- Single-arm spectrometer
- Covering $2 < \eta < 5$
- PID provided by three groups of detectors:

1. **Ring Imaging Cherenkov (RICH) detectors**
2. **Calorimeters**
3. **Muon Chambers**

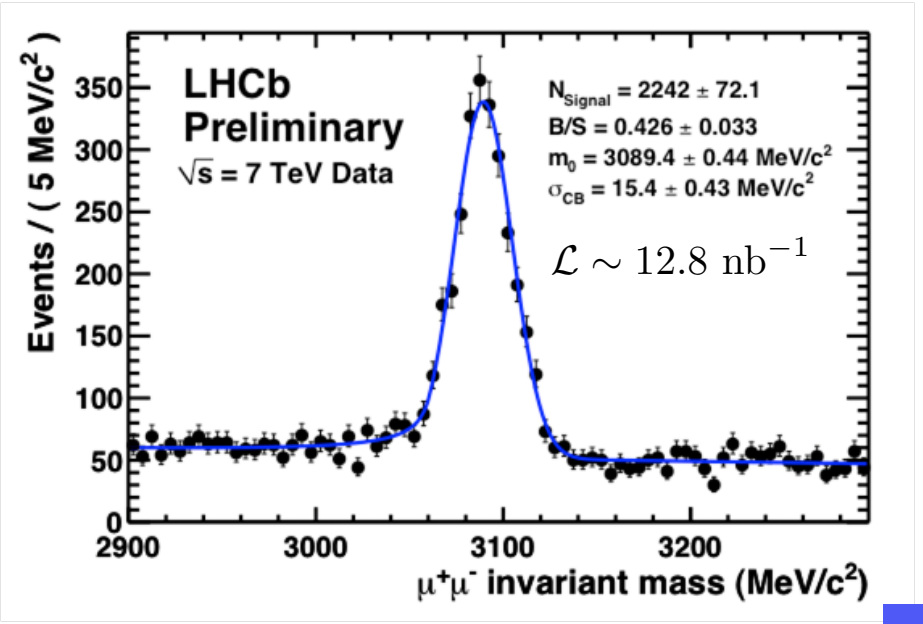
sPlots [Nucl. Inst. & Meth. A 555 (2005) 356-369]

- **Yes – sPlots and sWeights**
- The functional form describing the signal and background contributions to ϕ invariant-mass distributions are known (see fit on previous slide) – but not those in $\Delta\log\mathcal{L}$, momentum (p) etc.
- However, since $\Delta\log\mathcal{L}$ and p of a daughter track is uncorrelated to the mother invariant-mass, one can utilise **"sWeights"**
  - Following a fit to the invariant-mass distribution, can assign a weight (sWeight) to each candidate defining its probability to be signal or background
  - Can then use these weights to "unfold" the background and signal contributions to the daughter track $\Delta\log\mathcal{L}$ distributions
  - The "unfolded" distributions are then referred to as "sPlots"

LHCb – Muon Chambers

- **μ Identification**
  - Tracks extrapolated to Muon system
  - Search for hits in Muon Chambers within a Field-of-Interest (FOI)
  - μ candidate required to have deposited at least one hit in FOI in a number of Muon Chambers dependent on the track momentum
  - If satisfied, flag set:
    - `IsMuon` = 1

Very clean J/ψ signal obtainable



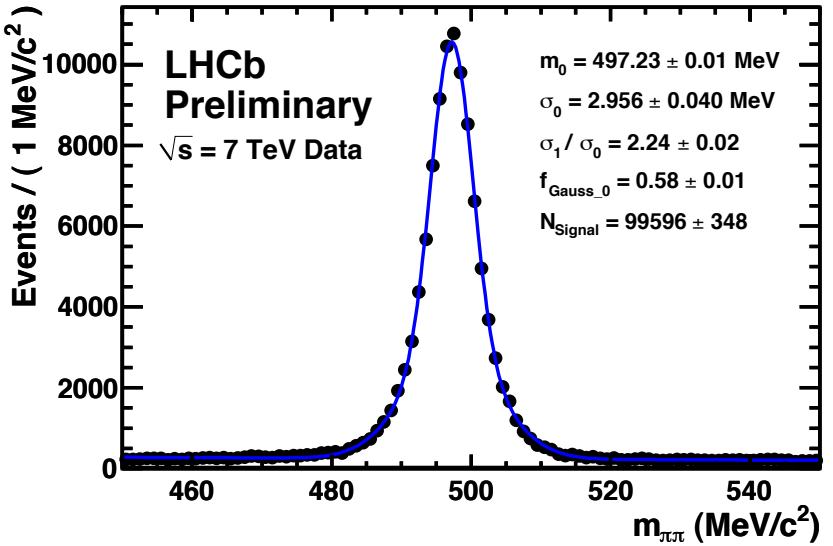
K_S & Λ (V0) Selections

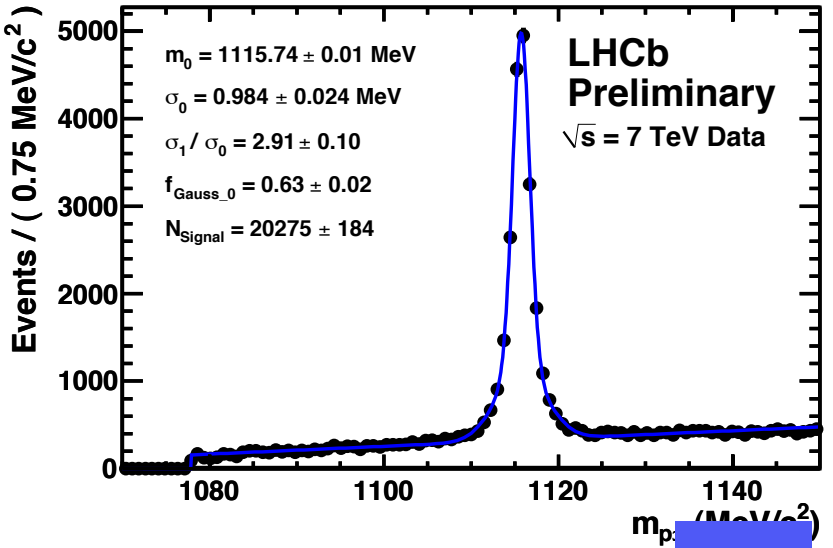
- **Kinematically Equivalent Decays**
  - Two-body weak
  - Originating from PV (mainly)
    - Small impact parameter (IP)
  - Daughter tracks with large IP

- **Exploit Decay Characteristics**
  - Utilise a single, multi-variant, requirement

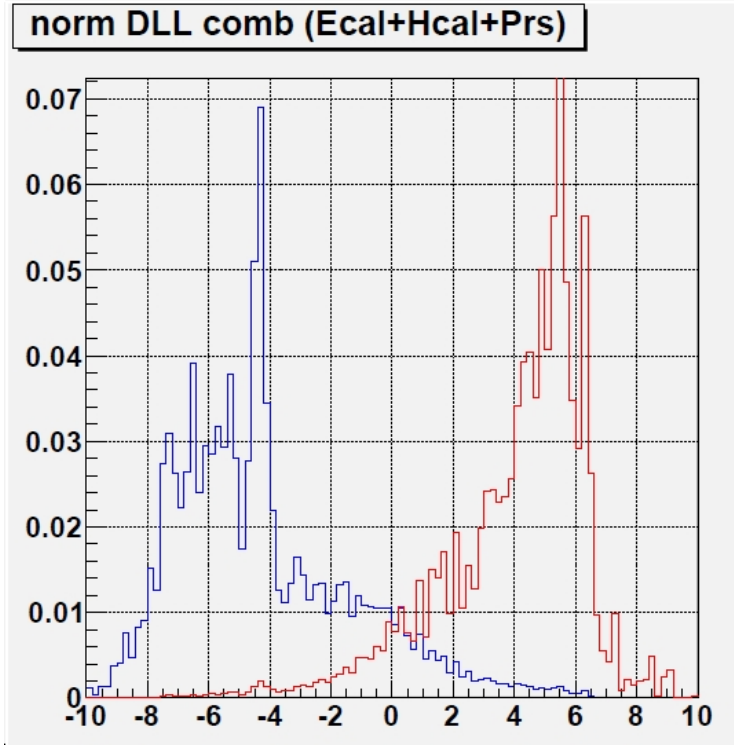
$$\nu = \ln\left(\frac{IP_+ \cdot IP_-}{IP_{V^0}}\right)$$

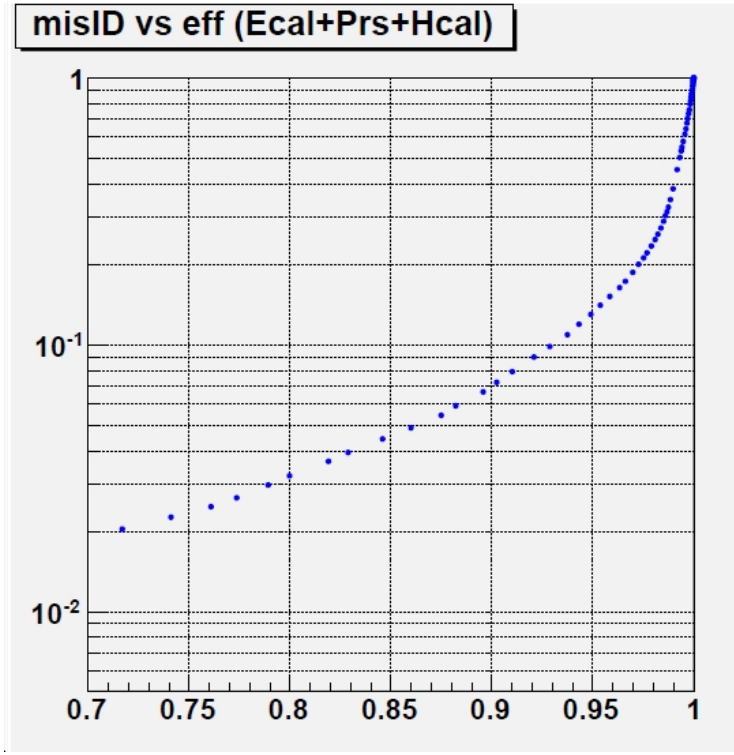
- $K_S(\Lambda)$ are a background in $\Lambda(K_S)$
  - Utilise 'wrong mass' vetos
  - Very high purity obtainable





Electron ID Efficiency





- Left, $\Delta\log\mathcal{L}(e-\pi)$ distributions for electrons and pions
- Right, pion mis-ID vs electron efficiency

Backgrounds in ϕ & J/ψ

- **Background contamination in both calibration ϕ and J/ψ selections must be accounted for**

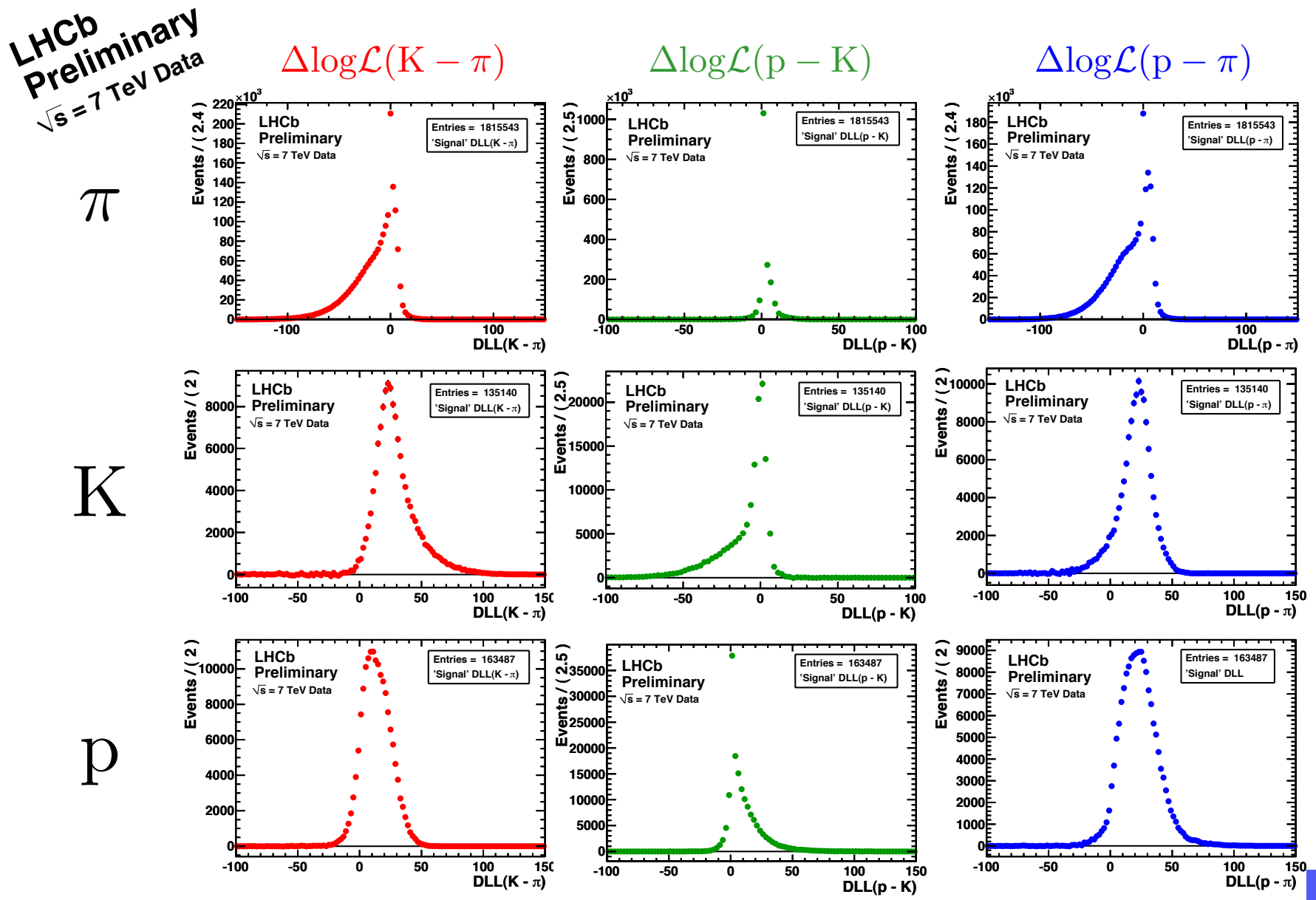
- **Two separate (but similar) techniques performed:**

1. Extended likelihood invariant-mass fits to determine signal/ background yields before PID cut applied to the 'probe' track
2. PID requirement applied to 'probe' track, either
   - RICH $\Delta\log\mathcal{L}$(A – B)
   - or, `IsMuon`
3. Re-fit invariant-mass to determine new signal/background yields

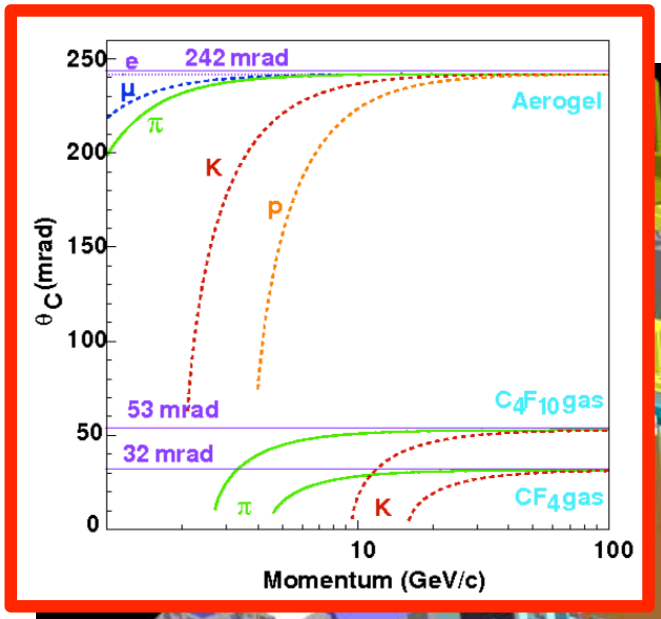
- To determine shapes of RICH $\Delta\log\mathcal{L}$ distributions, sWeights[†] are calculated

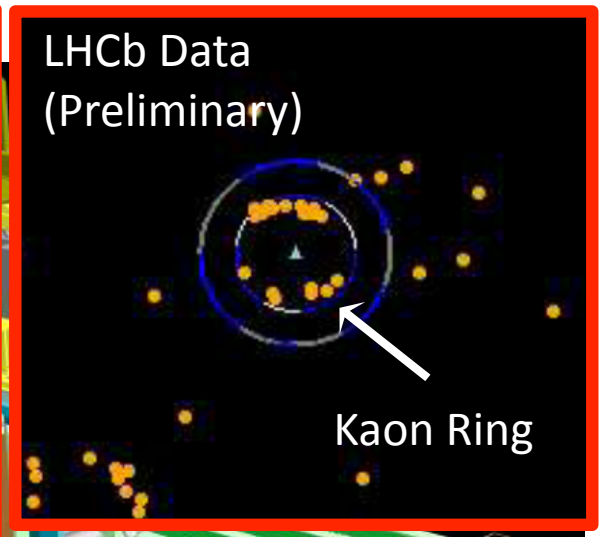
[†]Nucl. Inst. & Meth. A 555 (2005) 356-369

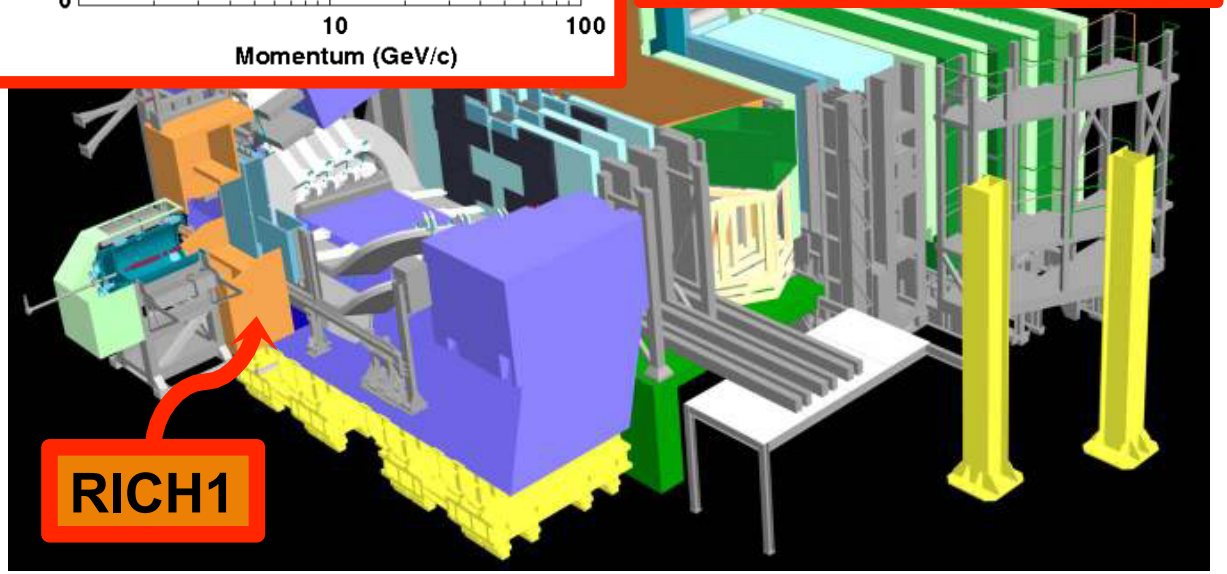
RICH $\Delta\log\mathcal{L}$ Distributions



LHCb - RICH

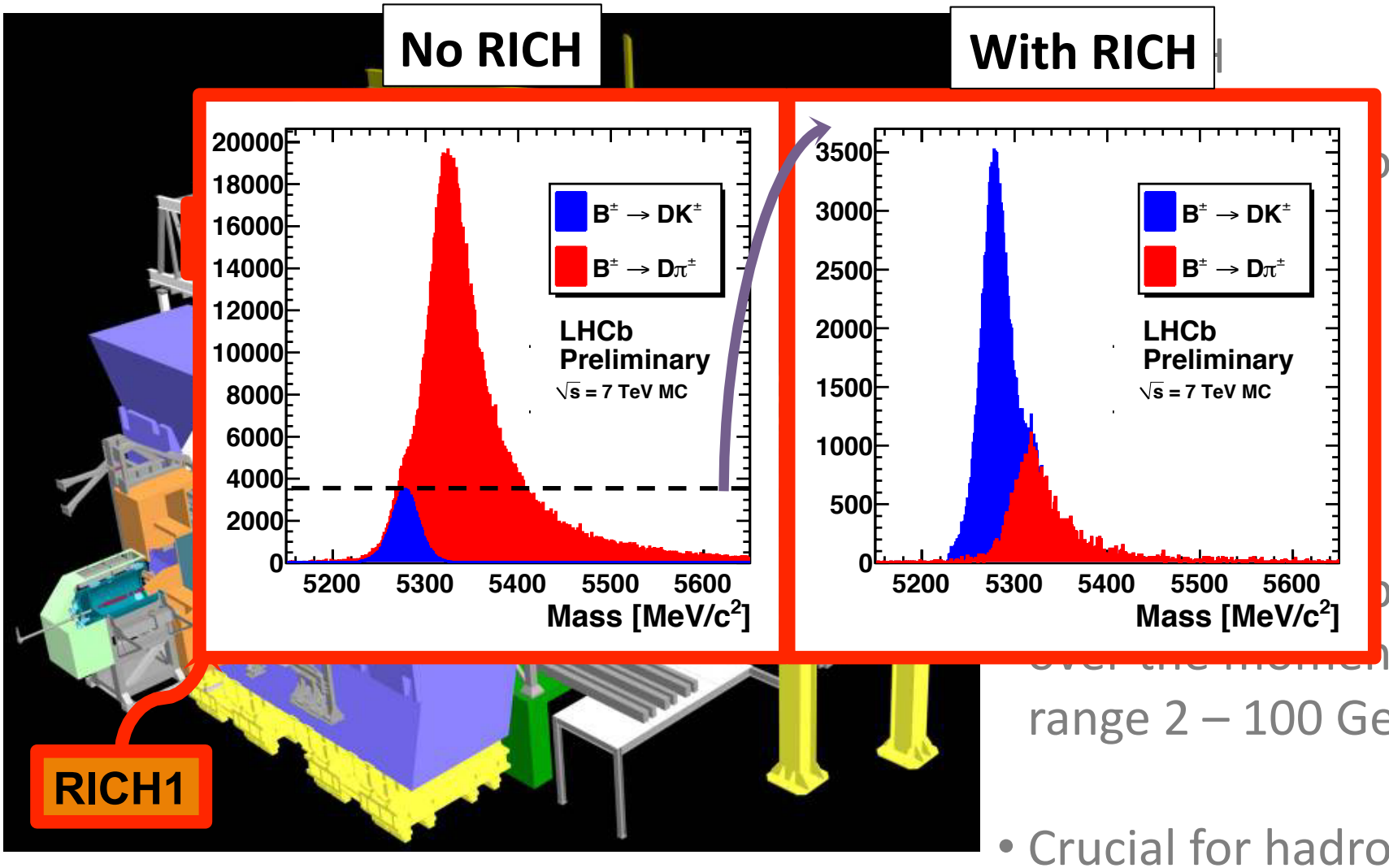






- The RICH
- Two sub-detectors:
  - RICH-1
    - Aerogel
    - C_4F_{10}
  - RICH-2
    - CF_4
- Provides K/π separation over the momentum range 2 – 100 GeV/c
- Crucial for hadronic modes

LHCb - RICH



ors:

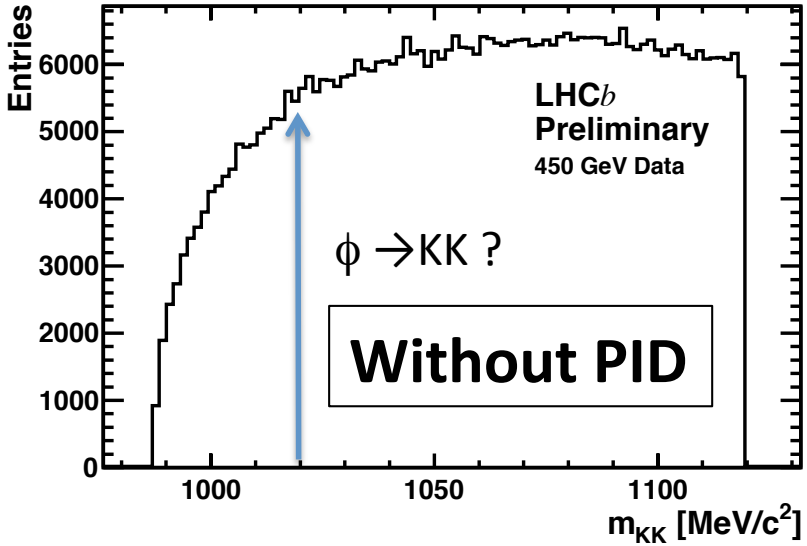
paration
ntum
range 2 – 100 GeV/c

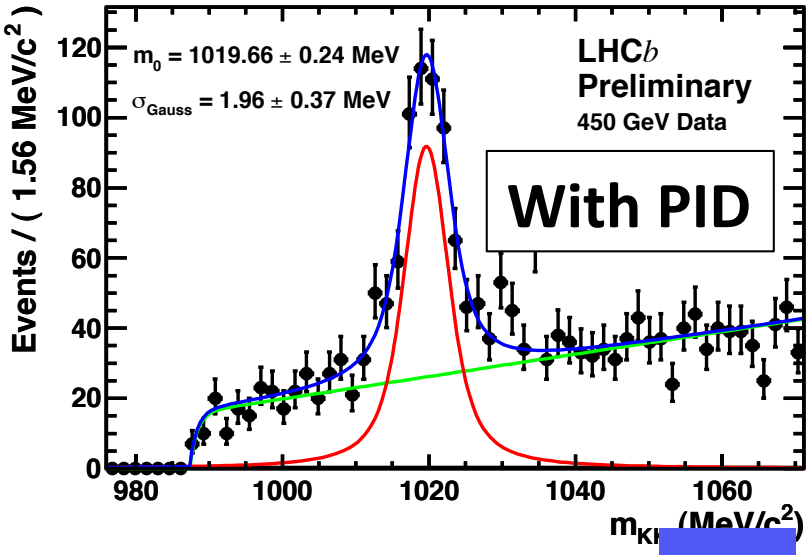
- Crucial for hadronic modes…

LHCb - RICH

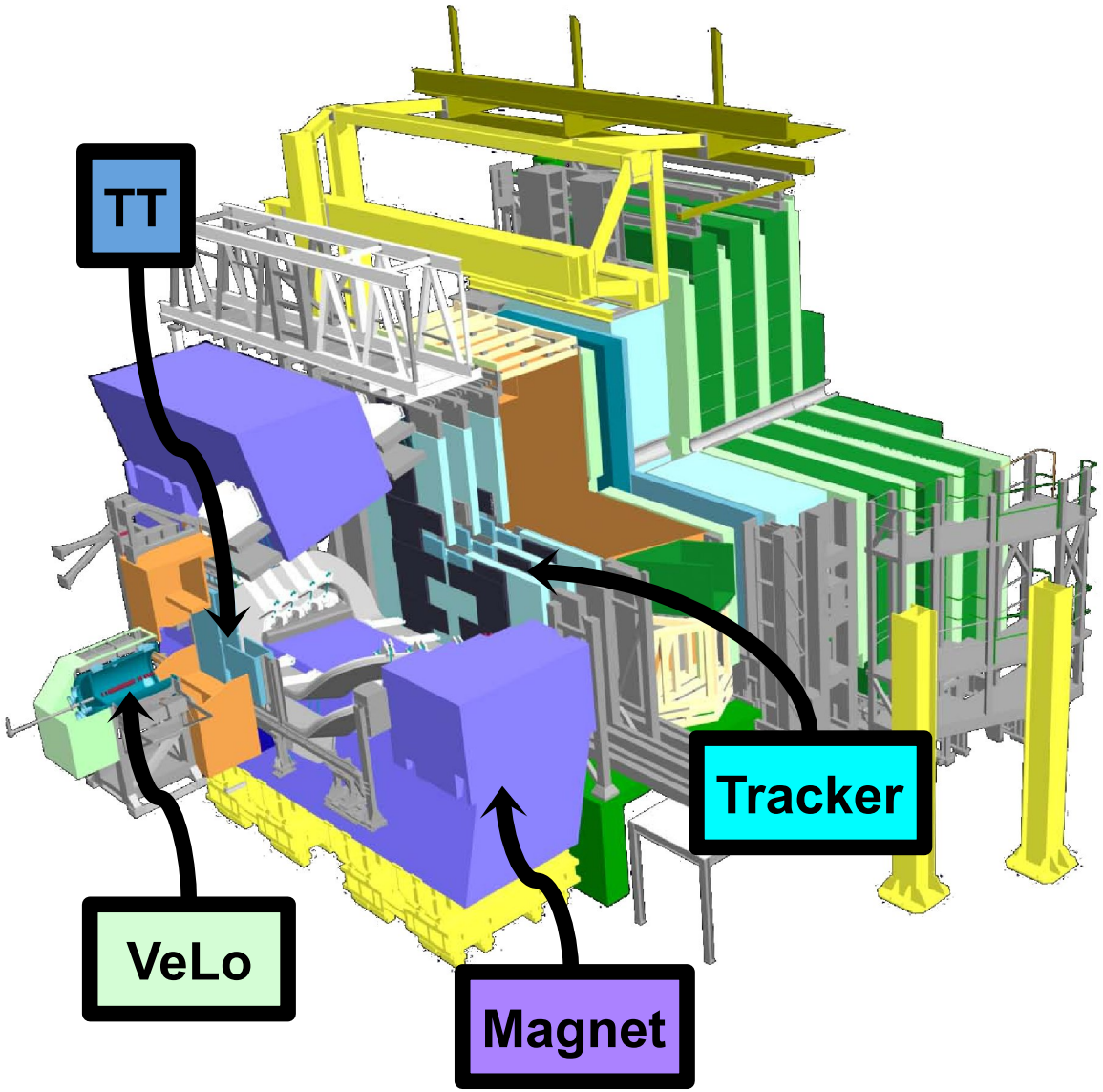
- **RICH Reconstruction**
  - Consider all tracks and photons within all radiators simultaneously (Global Likelihood)
  - Maximise event likelihood for photon distribution by changing mass hypothesis for each track
  - Likelihood for each track determined

- **RICH PID**
  - Cut on likelihood difference between mass hypotheses A,B: $\Delta \log \mathcal{L}$ (A – B)





LHCb Detector



- Single-arm spectrometer
- Covering $2 < \eta < 5$

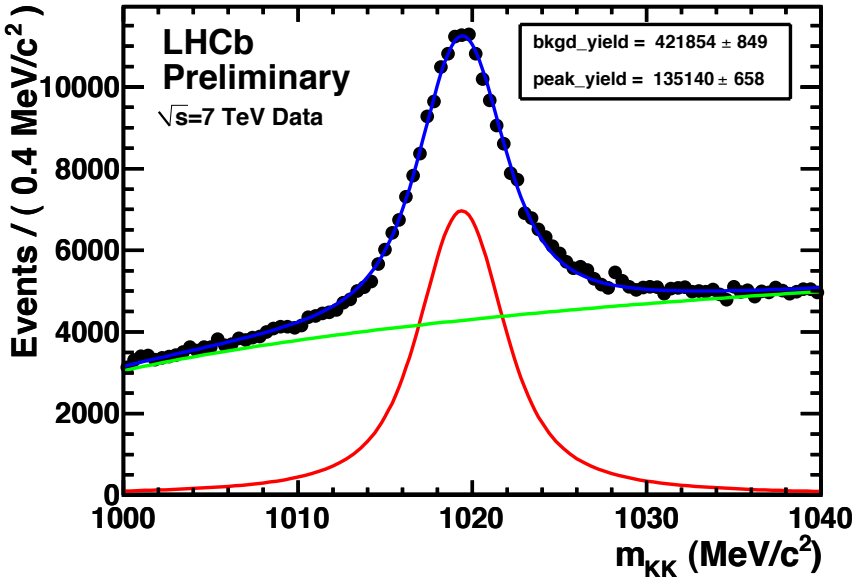
Siliva Borghi

Performance of the Tracking System at the LHCb Experiment

ϕ & J/ψ Selections

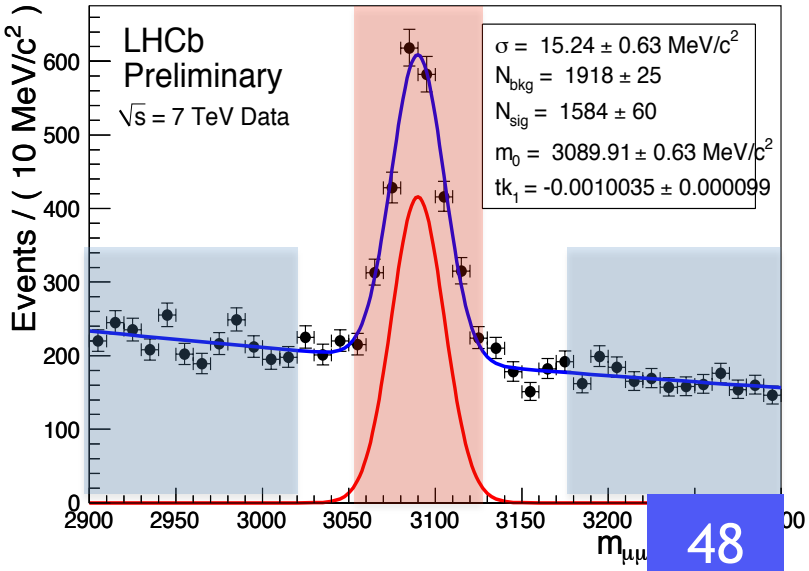
$\phi(1020) \rightarrow K^+K^-$

- Good 'Tag' Kaon:
  - $\Delta\log\mathcal{L}(K-\pi) > 15$
- Other track forms good vertex with 'Tag' track

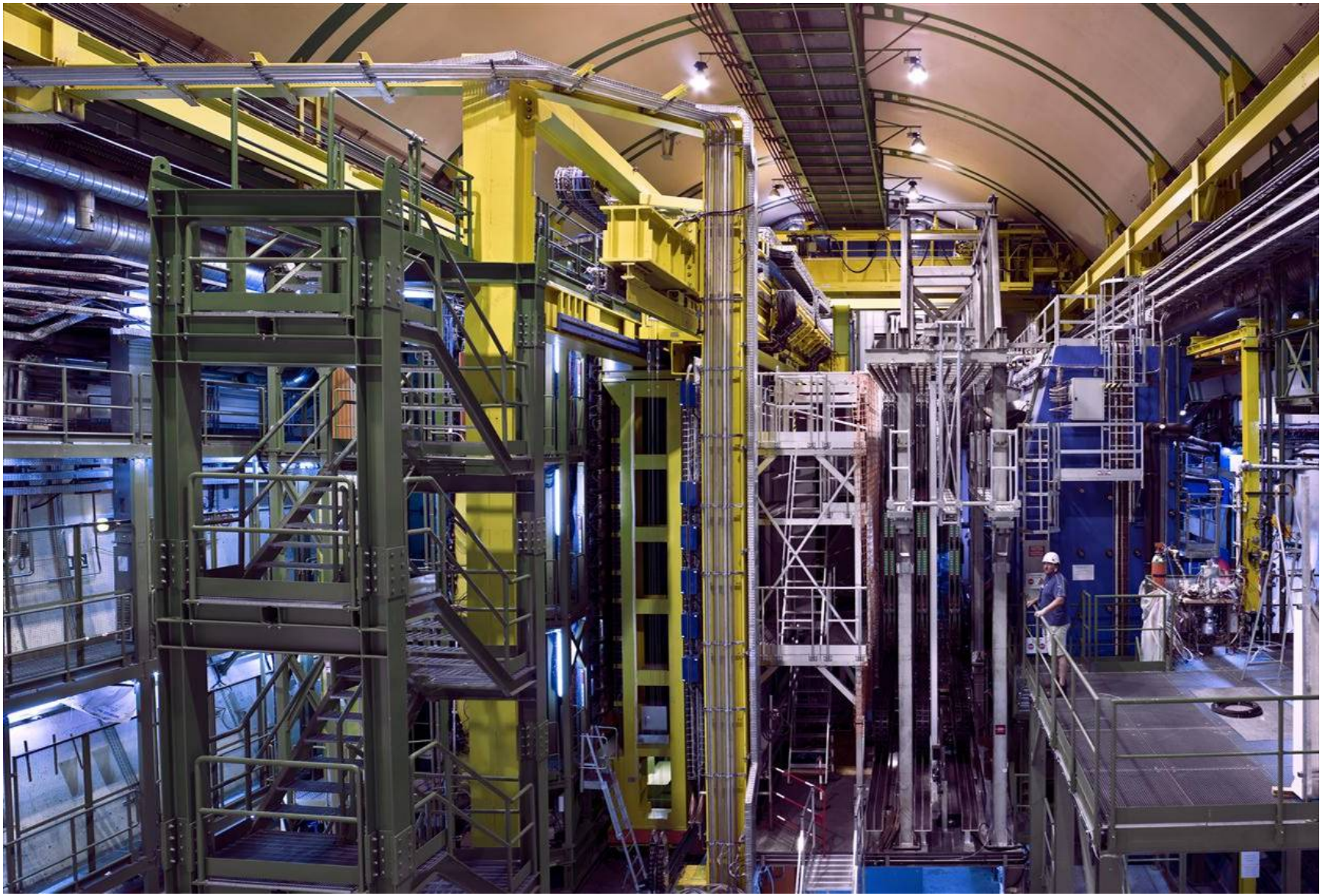


$J/\psi \rightarrow \mu^+\mu^-$

- Good 'Tag' μ:
  - **`IsMuon`** $\equiv 1$
- Other μ identified as a MIP in calorimeters



More on the RICH…



More on the RICH…