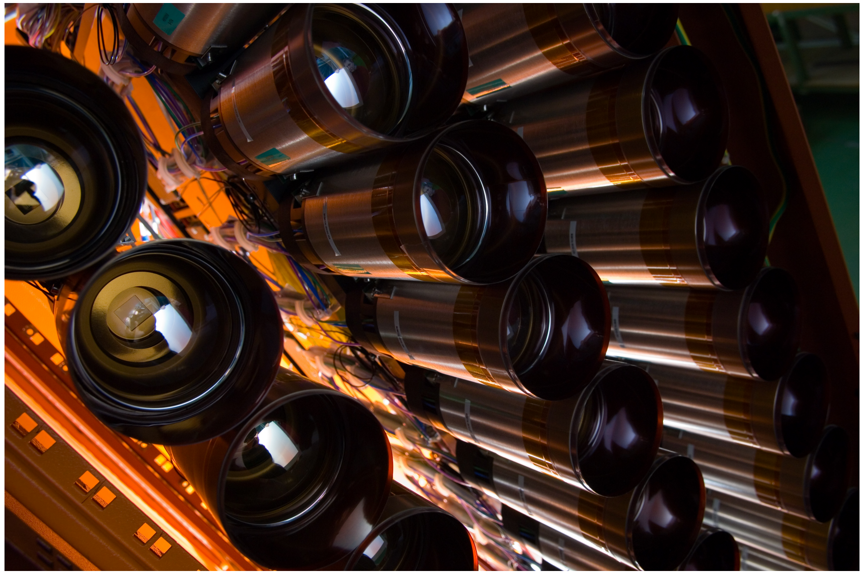
Reconstruction & PID Performance of the LHCb RICH Detectors



Andrew Powell

On behalf of the LHCb RICH Collaboration

RICH2010

Outline

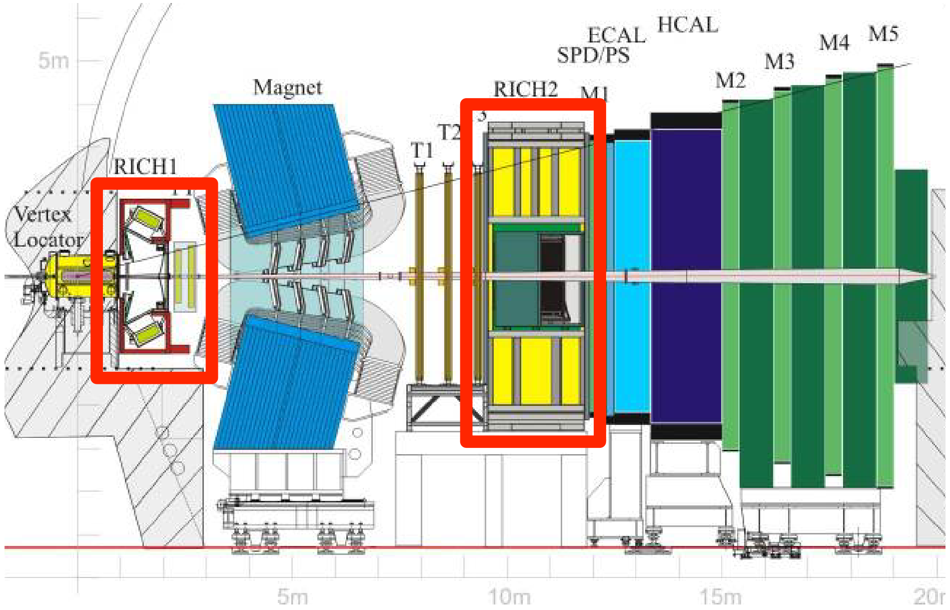
Reminder of the three previous LHCb talks:

LHCb RICH Overview	Franz Muheim
Operation of the LHCb RICH HPDs	Ross Young
RICH Detector Alignment with Data	Chris Blanks

Now the fourth chapter:

- Baseline RICH reconstruction strategy
- RICH dataflow and monitoring
- **PID Monitoring with $\sqrt{s}$= 7 TeV collisions**
  - Isolating charged track samples
  - Current performance w/ first data
  - Prospects at nominal luminosities

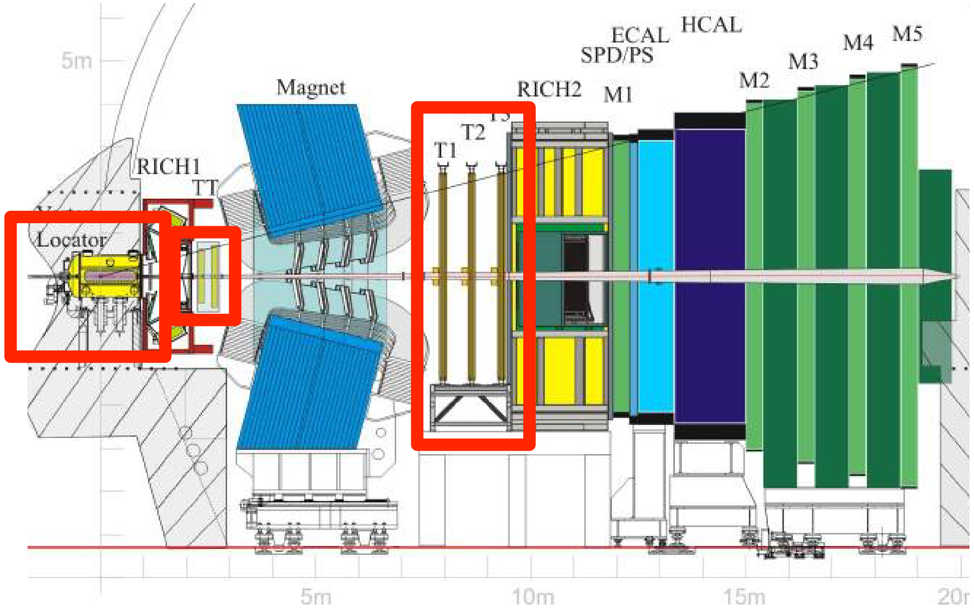
LHCb RICH (+Tracking) System



Two RICH sub-Detectors

- RICH 1 (PID: 2 GeV - 60 GeV)
- RICH 2 (PID: 30 GeV - 100+ GeV)

LHCb RICH (+Tracking) System



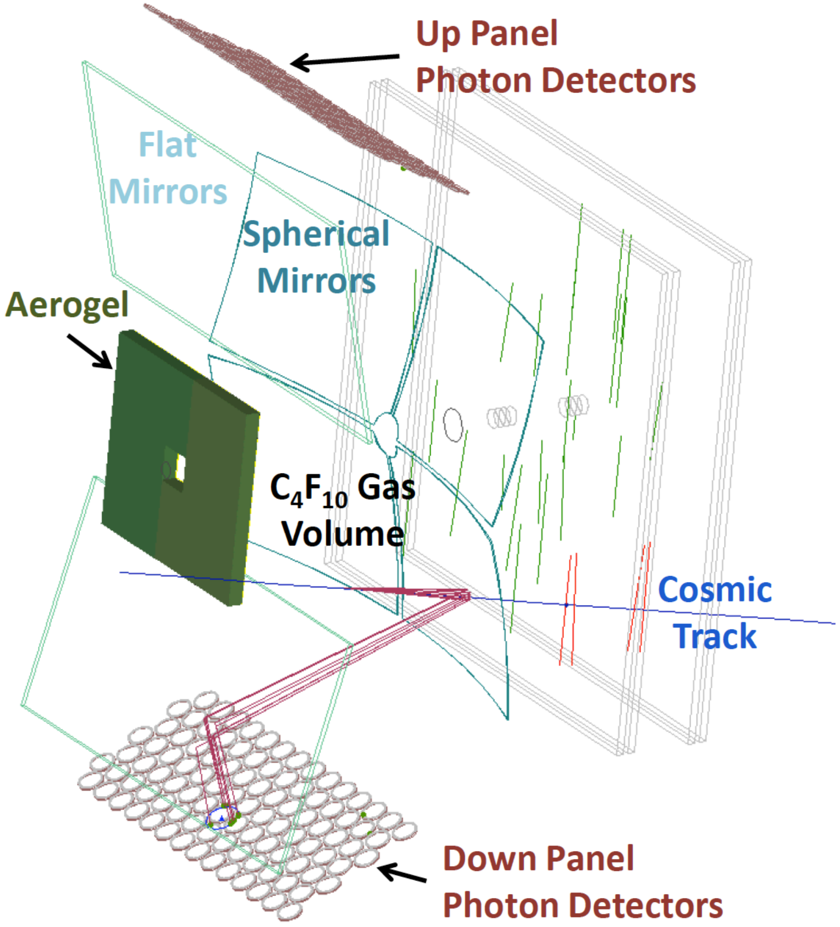
Two RICH sub-Detectors

- RICH 1 (PID: 2 GeV - 60 GeV)
- RICH 2 (PID: 30 GeV - 100+ GeV)

RICH performance also reliant on LHCb Tracking

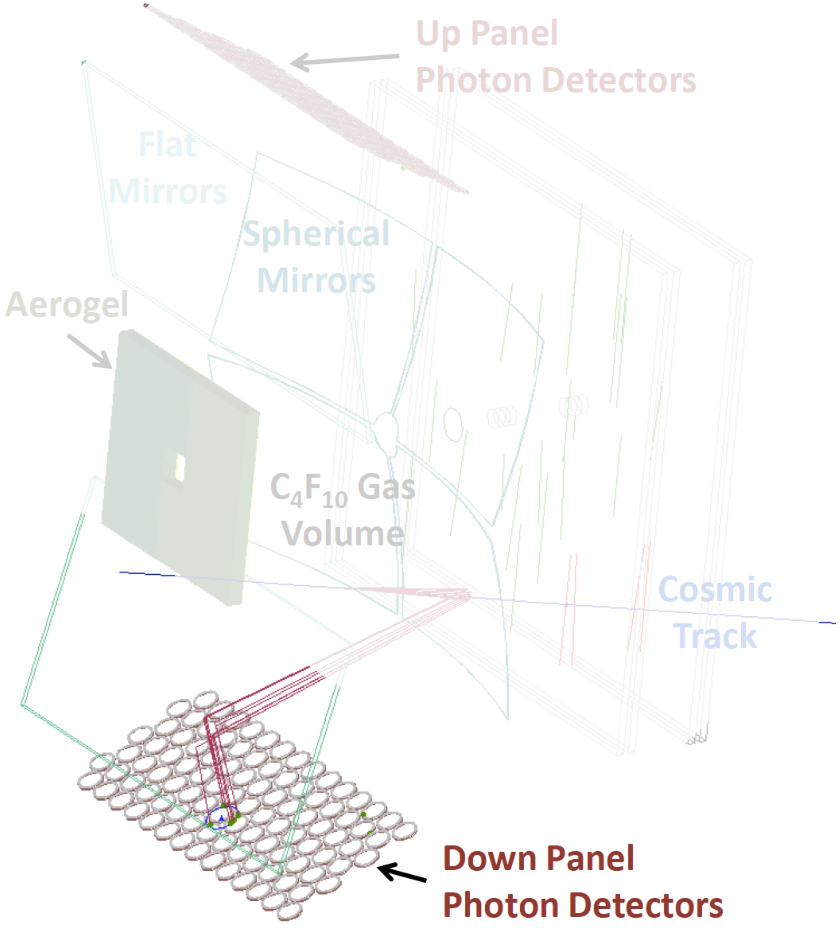
- Vertex detector (VELO)
- Series of tracking stations before & after magnet
  - Silicon strips for high occupancy close to beam pipe
  - Drift chambers at low η

RICH Reconstruction



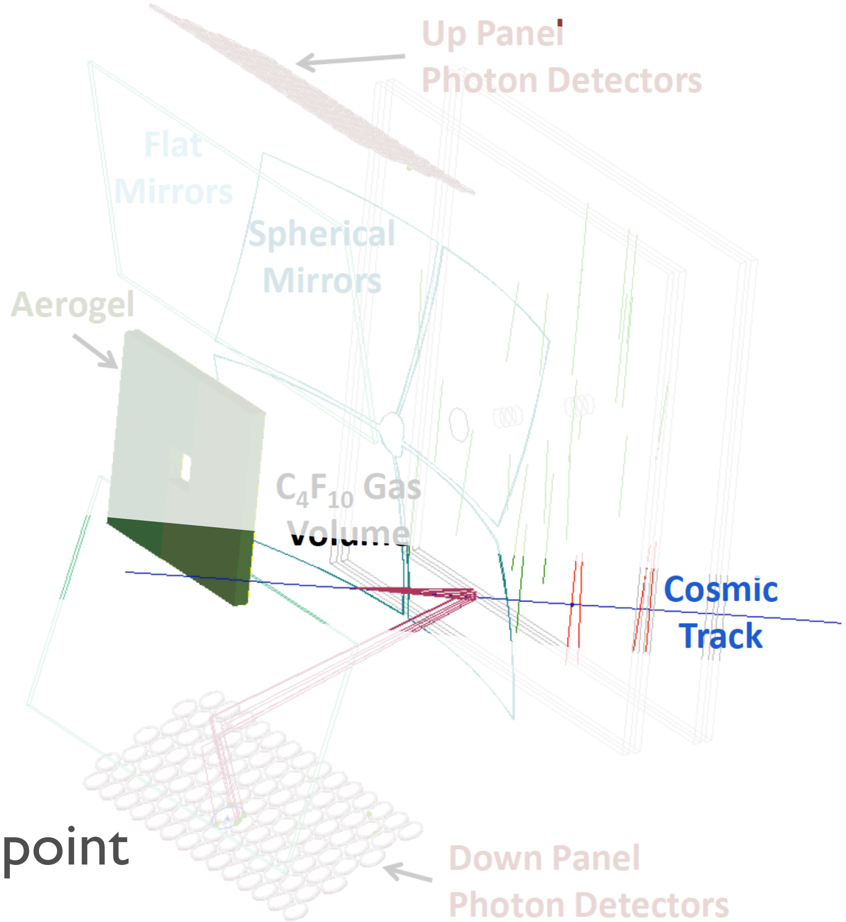
RICH Reconstruction

- **Interpret HPD info.**
  - Decode raw buffer data
  - Create pixels
  - Apply hit cleaning
  - Translate pixel hit into a spatial position



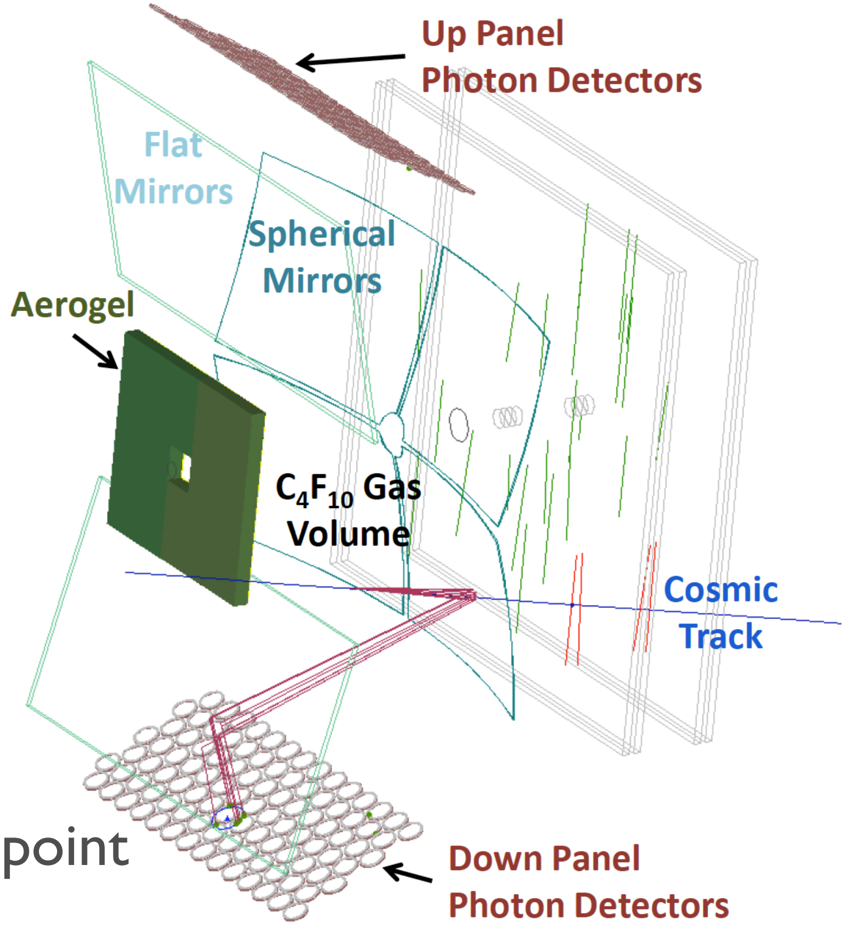
RICH Reconstruction

- **Interpret HPD info.**
  - Decode raw buffer data
  - Create pixels
  - Apply hit cleaning
  - Translate pixel hit into a spatial position
- **Select Tracks**
  - Identify good tracks
  - Reject those that don't transverse the RICH sub-detector
  - Determine radiator entry/middle/exit point



RICH Reconstruction

- **Interpret HPD info.**
  - Decode raw buffer data
  - Create pixels
  - Apply hit cleaning
  - Translate pixel hit into a spatial position



- **Select Tracks**
  - Identify good tracks
  - Reject those that don't transverse the RICH sub-detector
  - Determine radiator entry/middle/exit point
- **Reconstruct Photon Candidates**
  - Assume photon emission point to be the middle of the track
  - Pair-up photons and tracks and compute photon parameters
- **Determine PIDs with a Global Likelihood…**

Global Likelihood PID Algorithm

Consider

- **all** photons,
- **all** tracks and for
- **all** radiators…

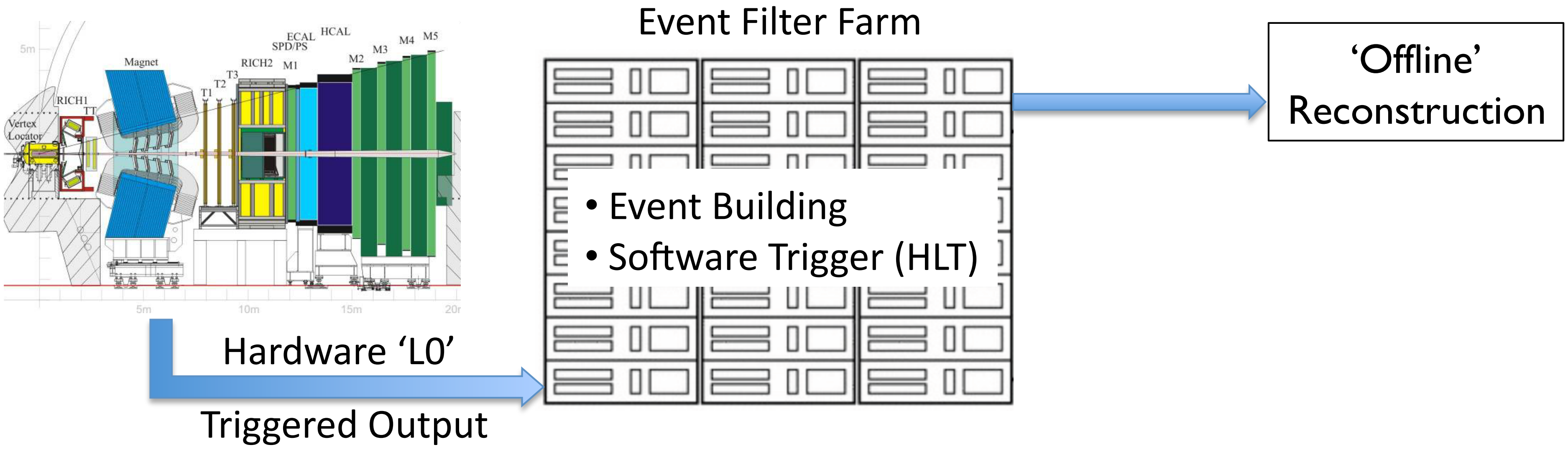
…and maximise the following:

$$\mathcal{L} = \mathcal{L}\left(n_{pixel},\ \sum_{track} a_{pixel,track},\ b_{pixel}\right)$$

1. Take all PIDs to be π (or seed with a previous iteration)
   - ○ Estimate background parameter b_{pixel} per HPD
2. Calculate likelihood of a given pixel distribution
3. Iterate (until no improvement is found):
   - ○ Change PID hypothesis for one track at a time
   - ○ Recalculate likelihood for each hypothesis
   - ○ Take the PID that maximises the likelihood
   - ○ Assign new PID to that track
4. With signal photons “identified”, update background estimate and iterate

For PID, cut on Δlog$\mathcal{L}$ per track and hypothesis

LHCb Data Flow & Monitoring



Event Filter Farm

- Event Building
- Software Trigger (HLT)

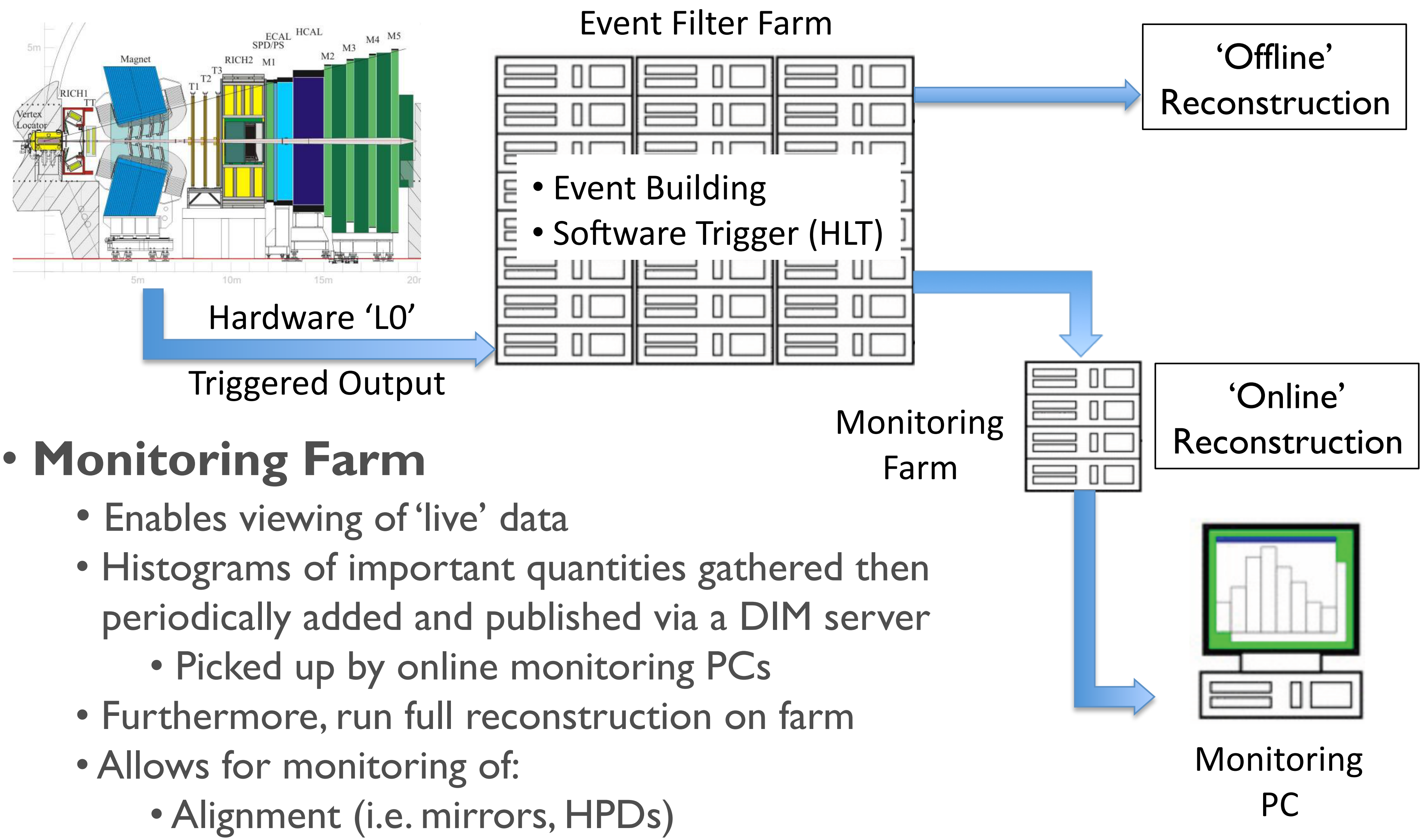
Hardware ‘L0’

Triggered Output

‘Offline’ Reconstruction

- **Path to Offline**
  - L0 triggered data sent to ‘Event Filter Farm’
  - Information from all sub-detectors gathered and ‘events’ are built and buffered
  - The Higher-Level software Trigger (HLT) process these events and selects only those of interest for ‘offline’ reconstruction

LHCb Data Flow & Monitoring



Event Filter Farm

- Event Building
- Software Trigger (HLT)

Hardware 'L0'

Triggered Output

'Offline' Reconstruction

Monitoring Farm

'Online' Reconstruction

Monitoring PC

- **Monitoring Farm**
  - Enables viewing of 'live' data
  - Histograms of important quantities gathered then periodically added and published via a DIM server
    - Picked up by online monitoring PCs
  - Furthermore, run full reconstruction on farm
  - Allows for monitoring of:
    - Alignment (i.e. mirrors, HPDs)
    - Physics performance (i.e. PID monitoring)

PID Monitoring

How well is the RICH operating during data taking?

- Need high purity samples of K, π and p
- Isolated without the use of RICH information

'Standard Candle' Decay Modes

- Harness the wealth of statistics from certain modes
- Reconstruct through kinematic requirements alone

$$\left.\begin{array}{l} K_S^0 \rightarrow \pi^- \pi^+ \\ \Lambda^0 \rightarrow p\pi^- \\ \phi(1020) \rightarrow K^+ K^- \end{array}\right\}$$

'strange' decays – ***bountiful*** and in first data

$$\left.\begin{array}{l} D^{*+} \rightarrow D^0(K^- \pi^+)\pi^+ \\ D_s^+ \rightarrow \phi(K^+ K^-)\pi^+ \end{array}\right\}$$

'charmed' decays – reduced production cross-sections, but plentiful when running at nominal luminosity

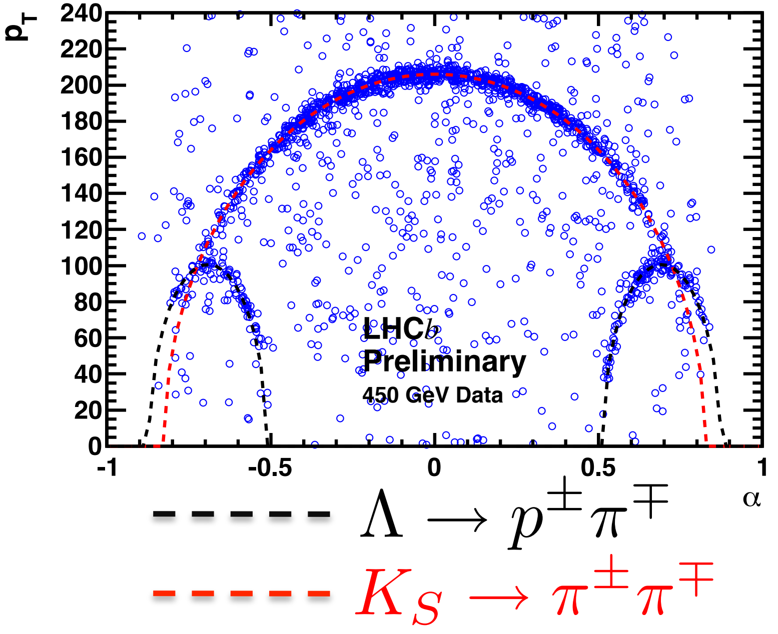
Selecting K_S & Λ (V^0) Decays

- **Kinematically equivalent decays**
  - Two-body weak decays (hence the 'V' in bubble chamber images)
  - Originating from PV (mainly) – small impact parameter
  - Daughter tracks with large impact parameters

- **Exploit these decay characteristics**
  - Utilise a single, multi-variant, selection requirement

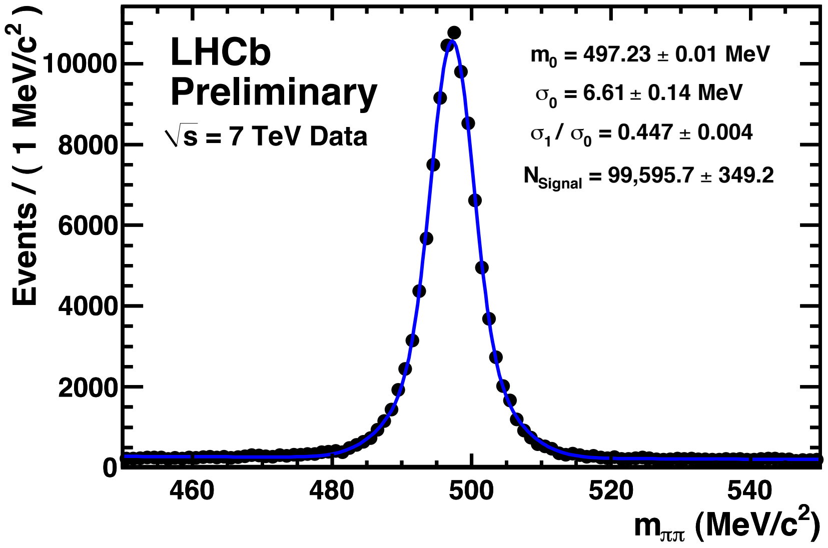
$$\nu = \log 10\left(\frac{IP_{+} \cdot IP_{-}}{IP_{V^0}}\right)$$

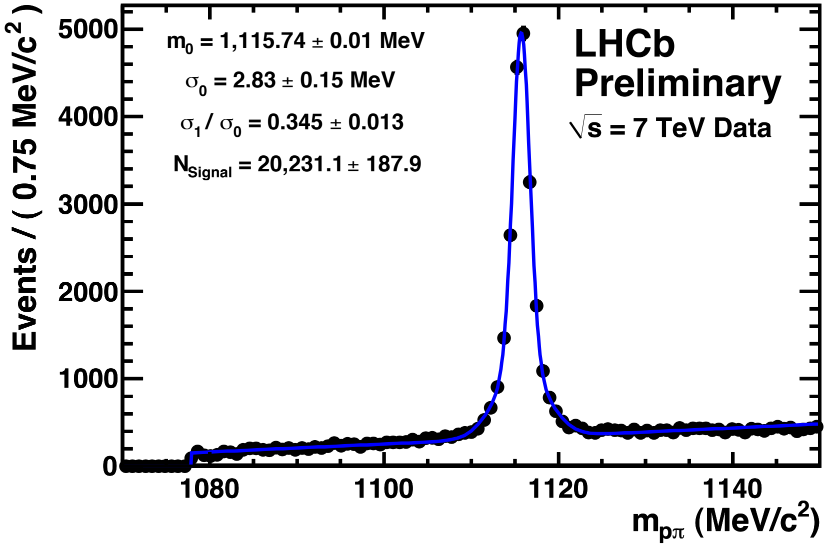
  - But no use of PID!
  - AP plot demonstrates:
    - Success of this cut
    - $K_S(\Lambda)$ are a background in $\Lambda(K_S)$
      - Utilise 'wrong mass' vetos
      - 98+ % purity obtainable


'Armenteros Podolanski' Plot

Philosophical Mag Series 7, Vol 45, Issue 360 Jan 1954 , (13 – 30)

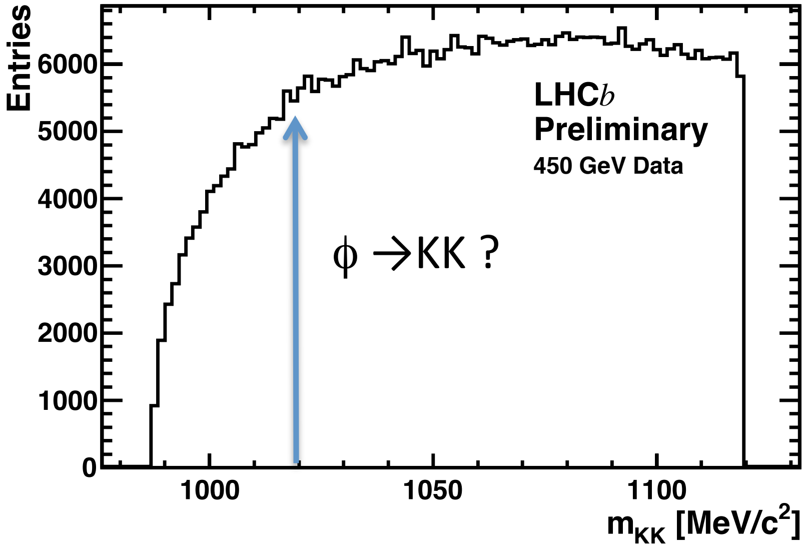
K_S & Λ Samples from ~65μb^{-1}

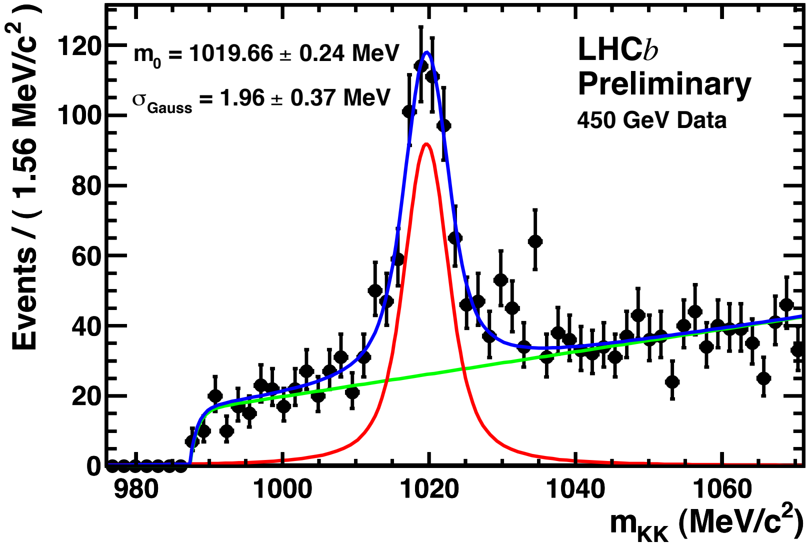




- **First 2 weeks of √s=7 TeV Data**
  - Accumulated from ~ 3 million L0 triggered events
  - In both cases, only high quality tracks have been used (that transverse the full tracking system)
  - And no PID used!
  - Provides high purity samples of pions and protons
  - What about kaons…?

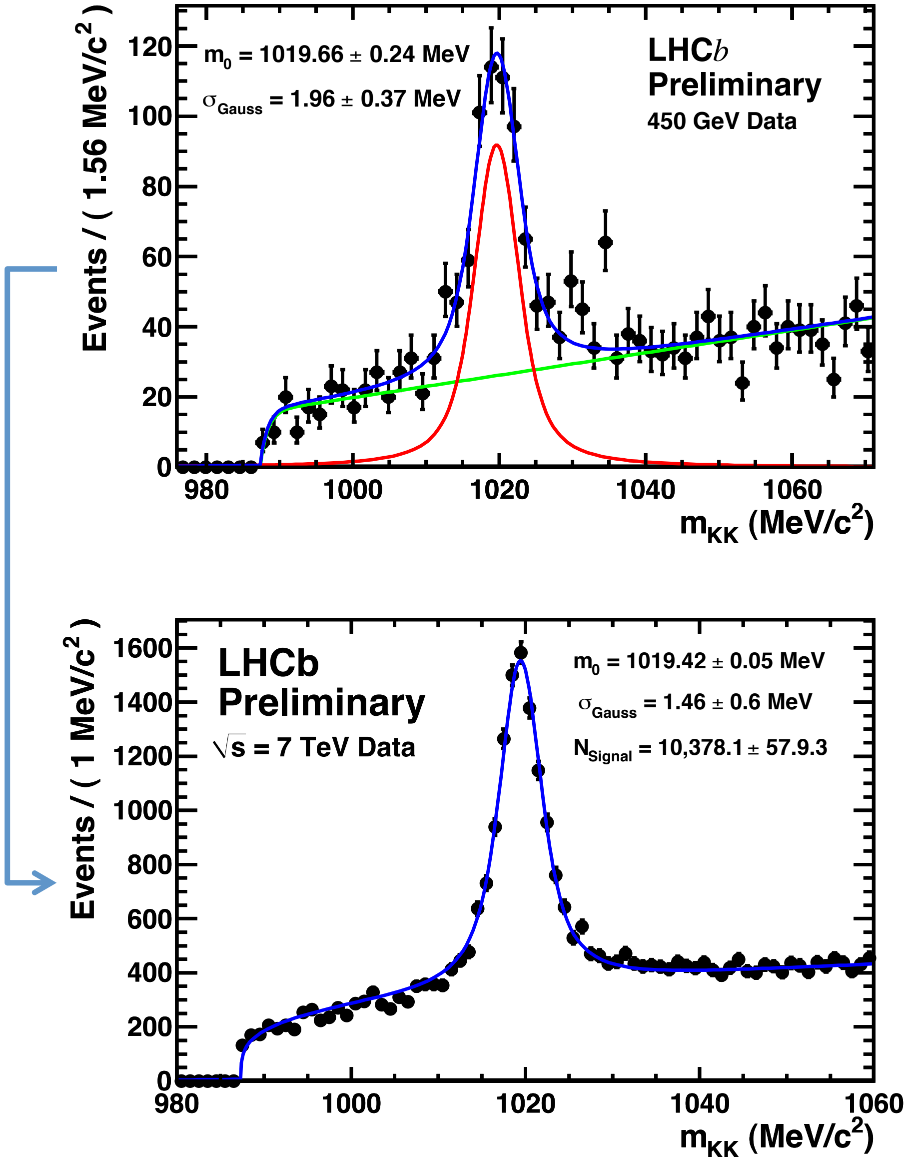
$\phi \rightarrow K^+K^-$ in $\sqrt{s}$ = 900 GeV Data





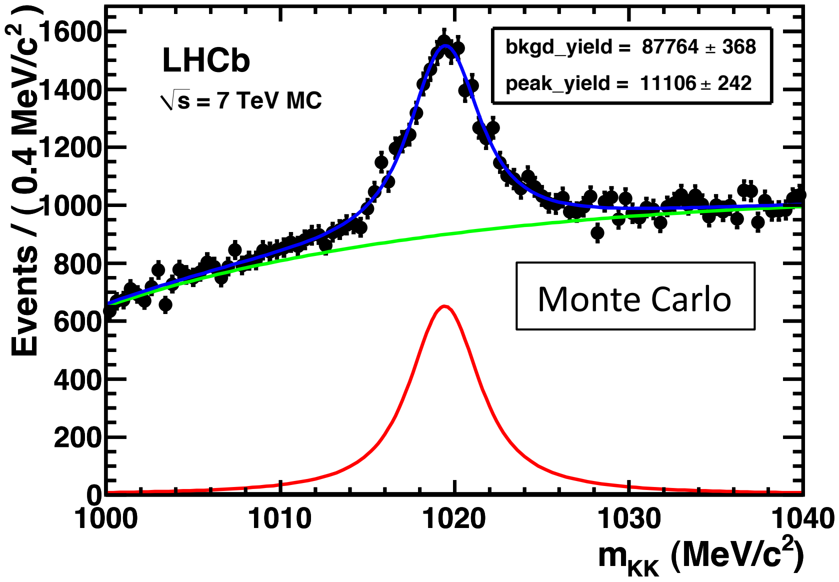
- **As show by Franz on Monday**
  - The first physics success from exploiting the RICH with 1st data!
  - **Top**: KK invariant mass before PID (kinematic cuts only)
  - **Bottom**: After applying PID to both tracks (N_{signal} ~ 600 events)
  - And the situation with $\sqrt{s}$ = 7 TeV?

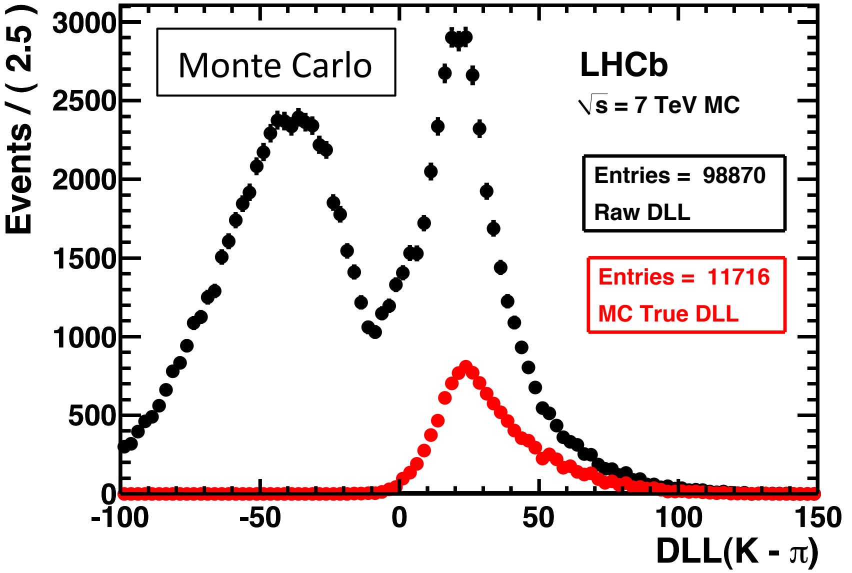
$\phi \rightarrow K^+K^-$ in $\sqrt{s} = 7$ TeV Data



- **Now a real throbbing peak!**
  - $\mathcal{L}_{int} \sim 60\ \mu b^{-1}$
  - N_{signal} ~10,000 events
- **Is it not possible to utilise these events to ascertain RICH performance with kaons?**
  - In theory, only applying a RICH PID cut to one of the kaons would leave the 'opposite' track as an unbiased kaon

Extracting Kaon Info. from $\phi \rightarrow KK$



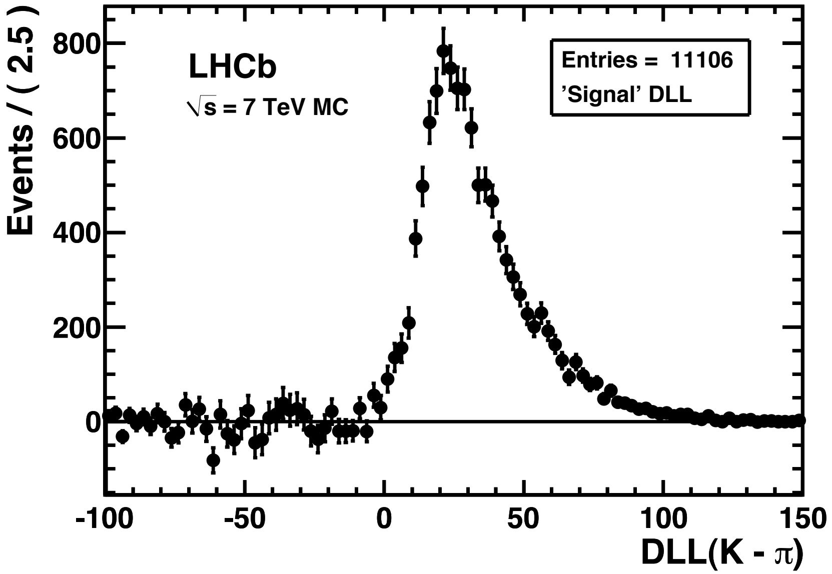


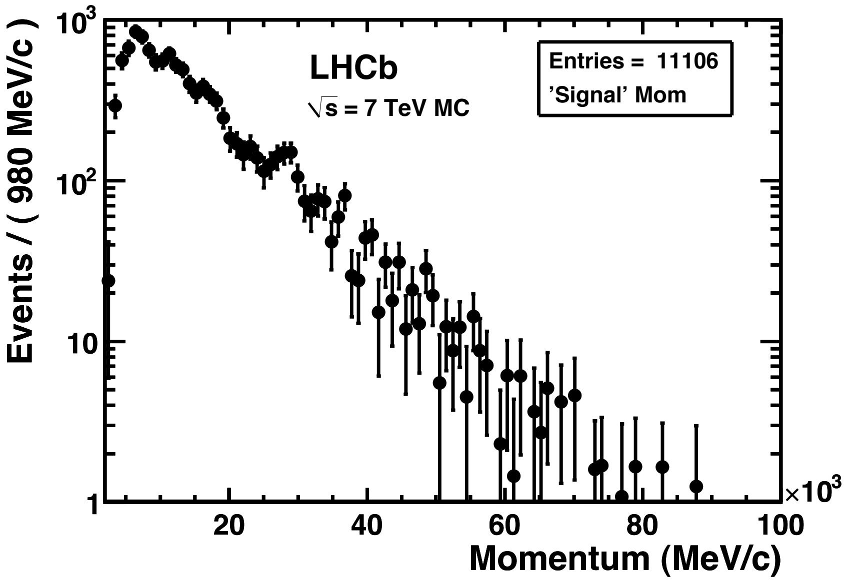
- **The issue is how to deal with the background**
  - Perform MC study
  - Top, invariant mass plot from applying PID to the K^- track only
    - Dominated by background
    - Unbiased K^+
  - Quantities we'd like to extract are:
    - RICH $\Delta\log\mathcal{L}$
    - Track momentum
  - Bottom, the **raw** and **MC true** kaon $\Delta\log\mathcal{L}$ distributions for the unbiased K^+
  - Is there a technique to 'unfold' one from the other?

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

- **Yes – sPlots and sWeights**
- The functional form describing the signal and background contributions of ϕ invariant-mass distributions are known (see fit on previous slide) – but not those in Δlog$\mathcal{L}$, momentum (p) etc.
- However, since Δlog$\mathcal{L}$ and p of a daughter track are 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 Δlog$\mathcal{L}$ distributions
  - The “unfolded” distributions are then referred to as “sPlots”

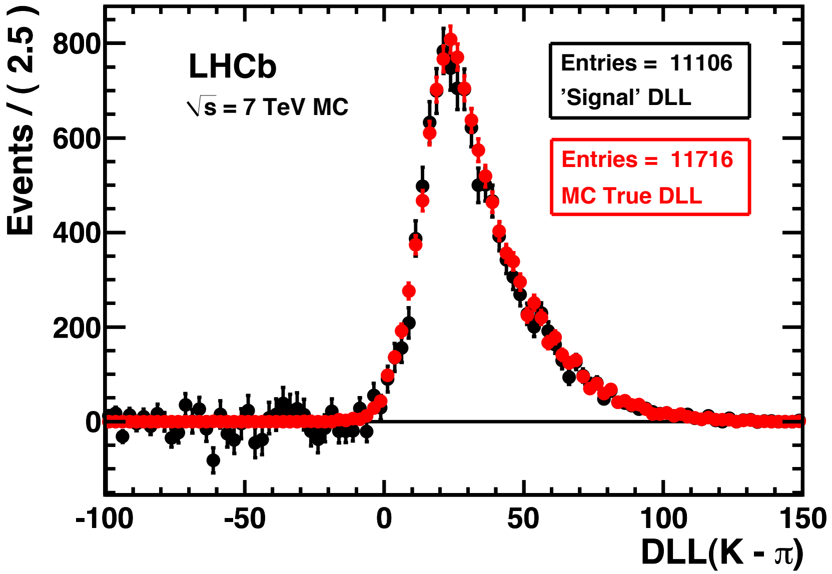
Unfolding Kaon Distributions

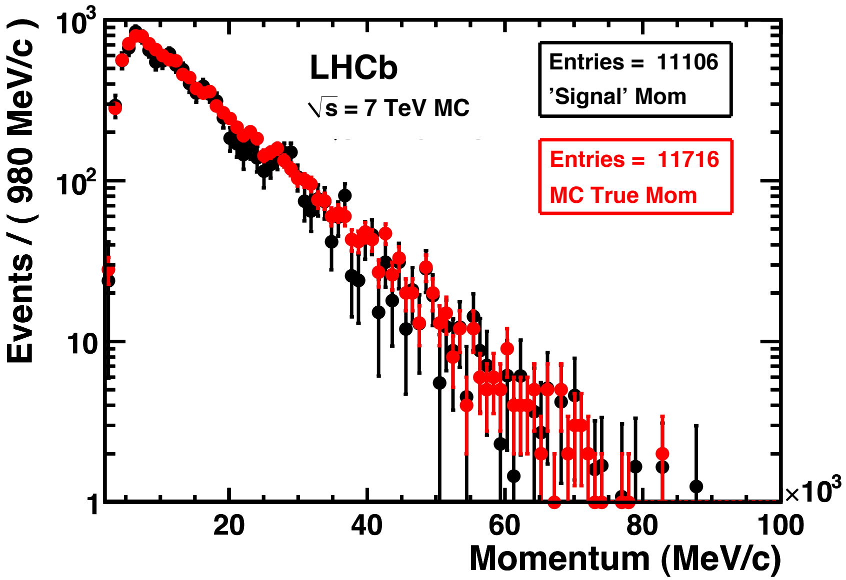




- **Test method on Monte Carlo**
  - Top, unfolded Δlog$\mathcal{L}$ distribution
  - Bottom, unfolded momentum distribution
  - How do these compare with the **MC true** distributions?

Unfolding Kaon Distributions





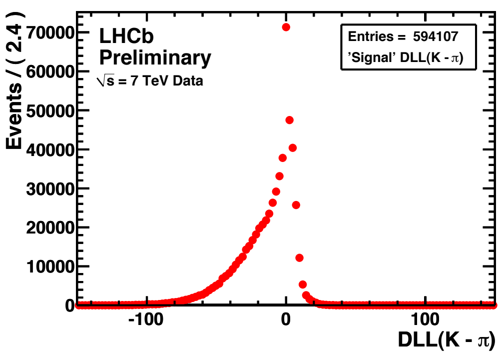
- **Test method on Monte Carlo**
  - Top, unfolded $\Delta\log\mathcal{L}$ distribution
  - Bottom, unfolded momentum distribution
  - How do these compare with the **MC true** distributions?
  - Excellent agreement
  - Method therefore applied to data
  - Used for both:
    - Kaons from ϕ
    - protons from Λ

$\Delta\log\mathcal{L}$ Distributions in Data

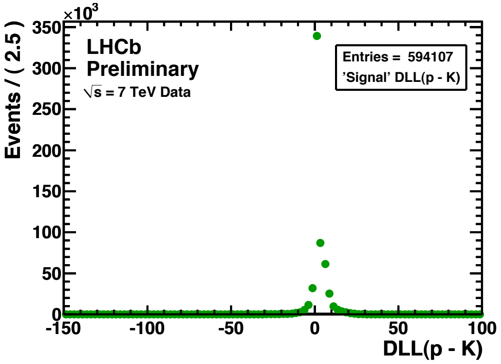
LHCb Preliminary
$\sqrt{s}$ = 7 TeV Data

π

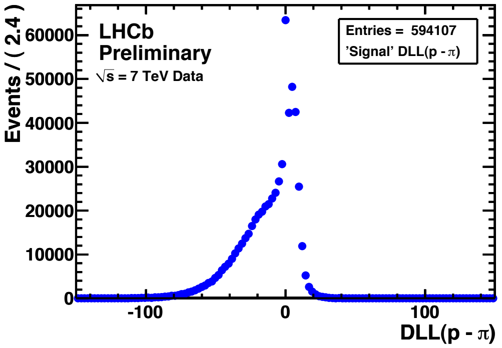
$\Delta\log\mathcal{L}(\mathrm{K}-\pi)$



$\Delta\log\mathcal{L}(\mathrm{p}-\mathrm{K})$



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



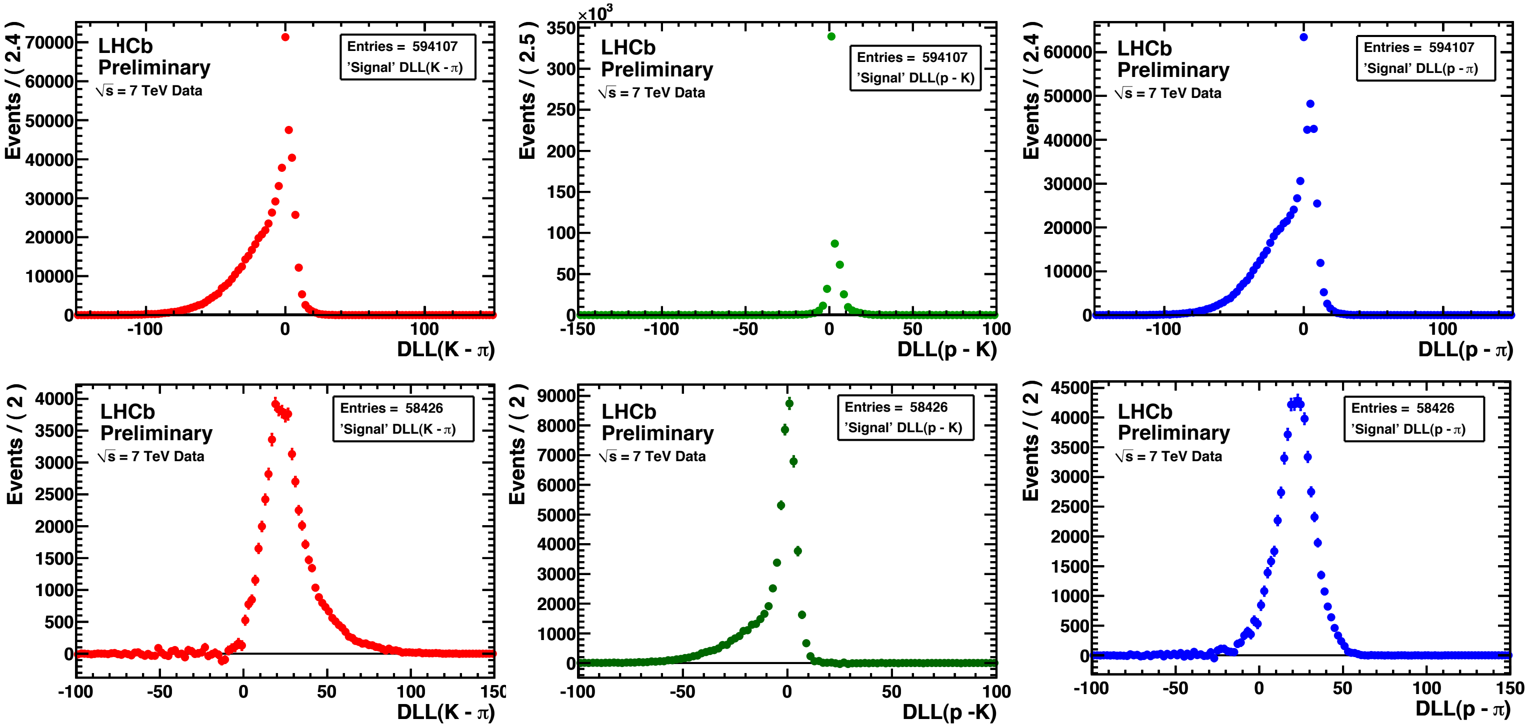
$\Delta\log\mathcal{L}$ Distributions in Data

LHCb
Preliminary
$\sqrt{s} = 7$ TeV Data

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

π

K



$\Delta\log\mathcal{L}$ Distributions in Data

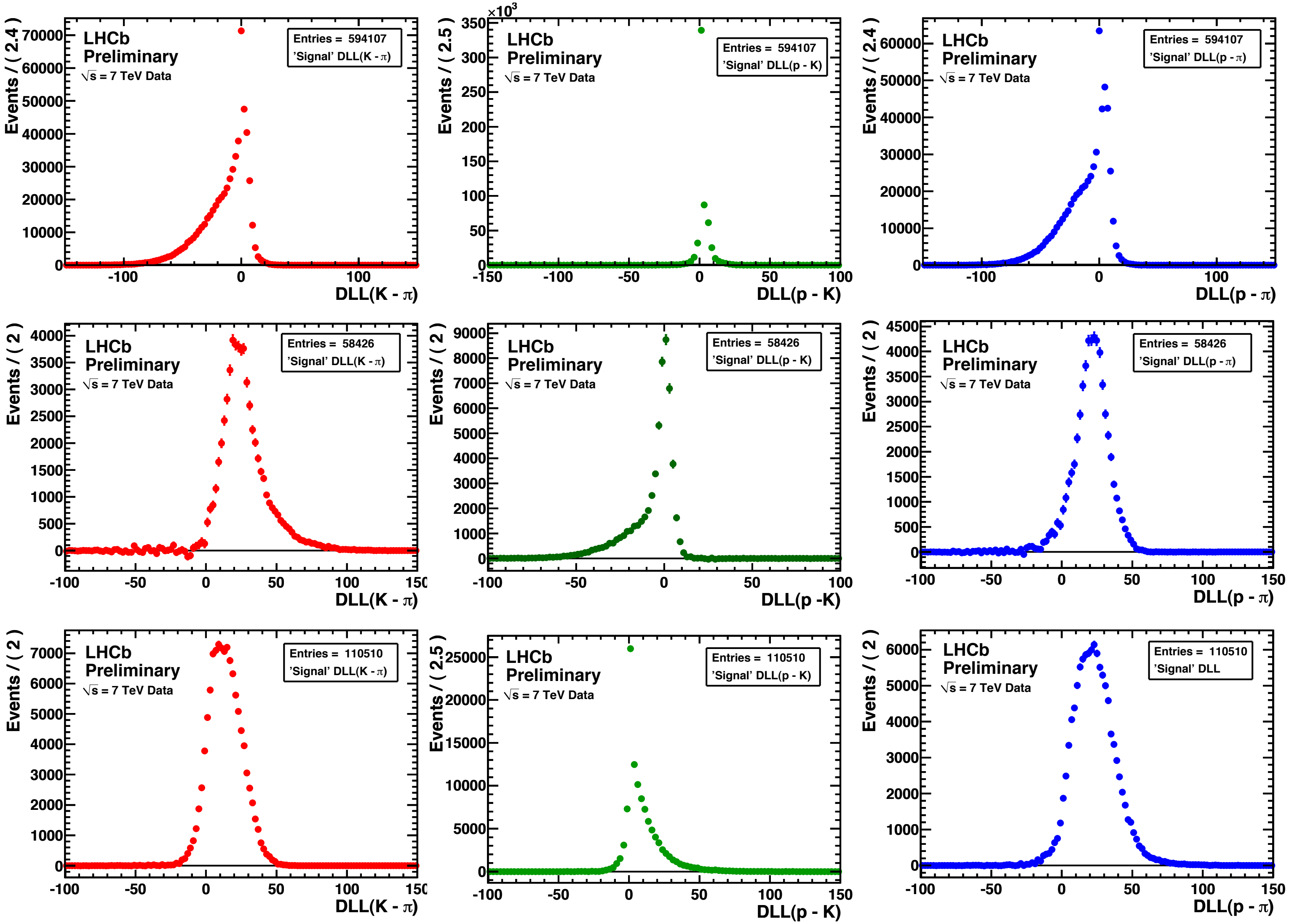
LHCb Preliminary
$\sqrt{s}$ = 7 TeV Data

$\Delta\log\mathcal{L}(\mathrm{K}-\pi)$ | $\Delta\log\mathcal{L}(\mathrm{p}-\mathrm{K})$ | $\Delta\log\mathcal{L}(\mathrm{p}-\pi)$

π

K

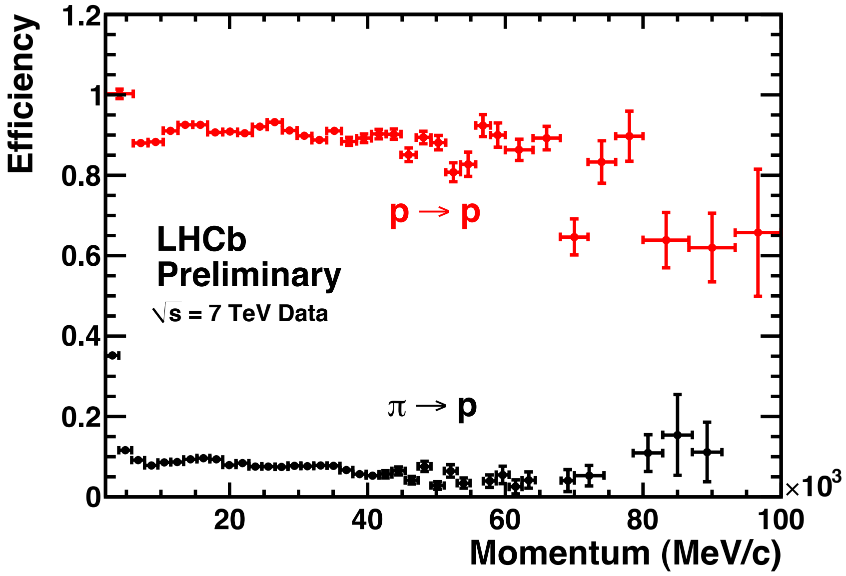
p



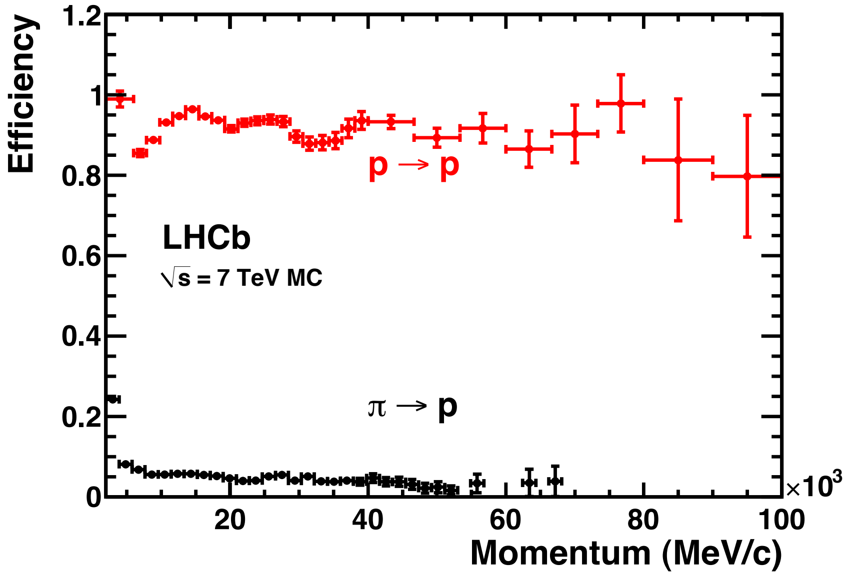
PID Performance

Example of performance: p-π discrimination

Data



Monte Carlo

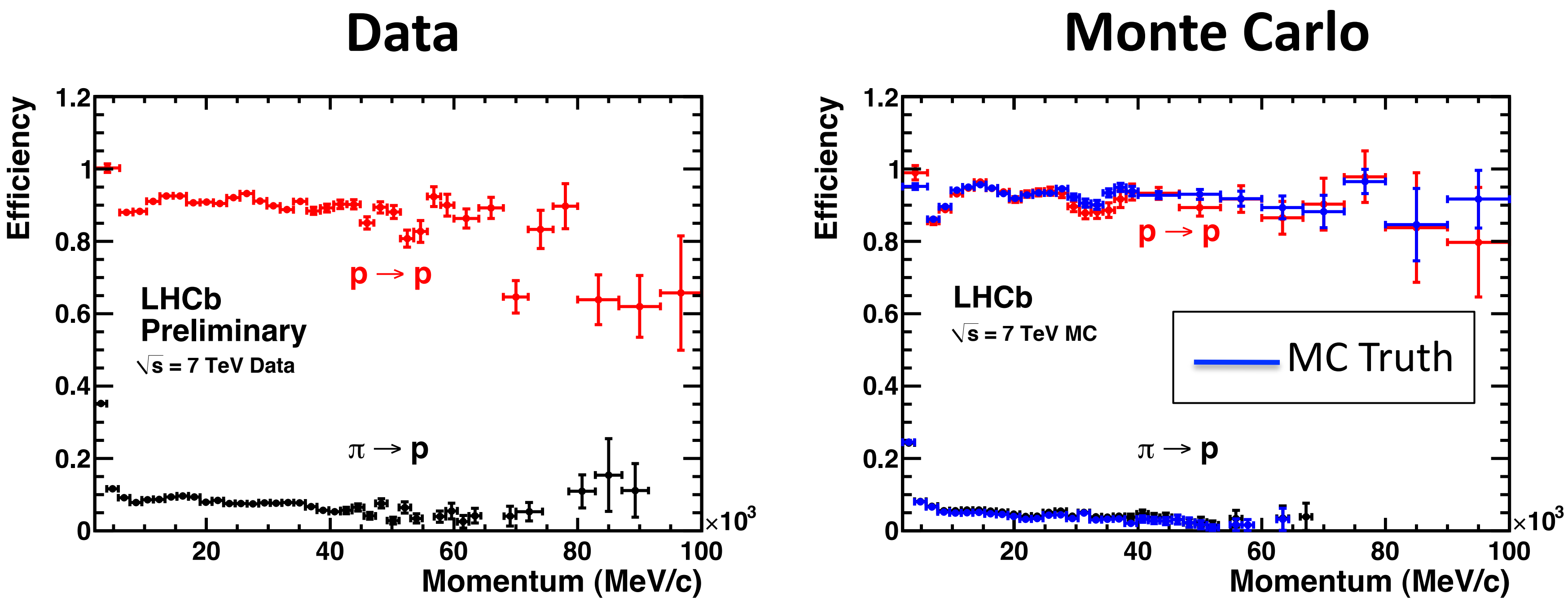


$$\Delta\log\mathcal{L}(\mathrm{p}-\pi) > 5$$

- Alignment and calibration still in early stages (see C. Blanks' talk)
- Thus, impressive to have such reasonable agreement between MC and data so soon!
- Expect marked improvements in the coming weeks

PID Performance

Example of performance: p-π discrimination


Data

Monte Carlo

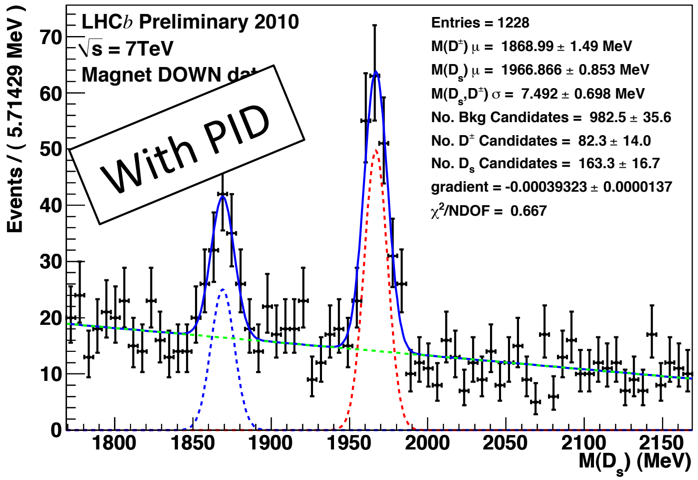
$$\Delta \log \mathcal{L}(\mathrm{p}-\pi) > 5$$

- Alignment and calibration still in early stages (see C. Blanks' talk)
- Thus, impressive to have such reasonable agreement between MC and data so soon!
- Expect marked improvements in the coming weeks

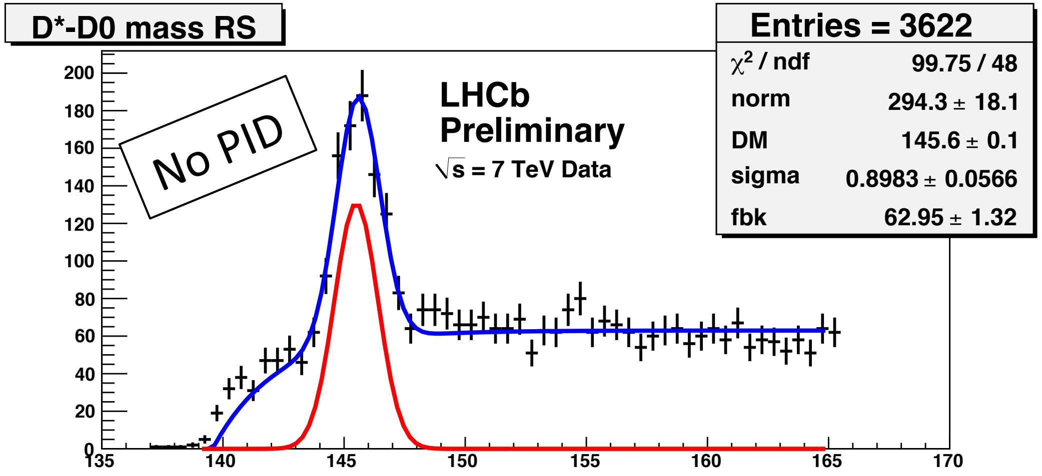
Prospects with Charm Modes

- High purity samples of kaons, via charm decays, just around the corner…

$D_s^+ \rightarrow \phi(K^+K^-)\pi^+$



$D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+$

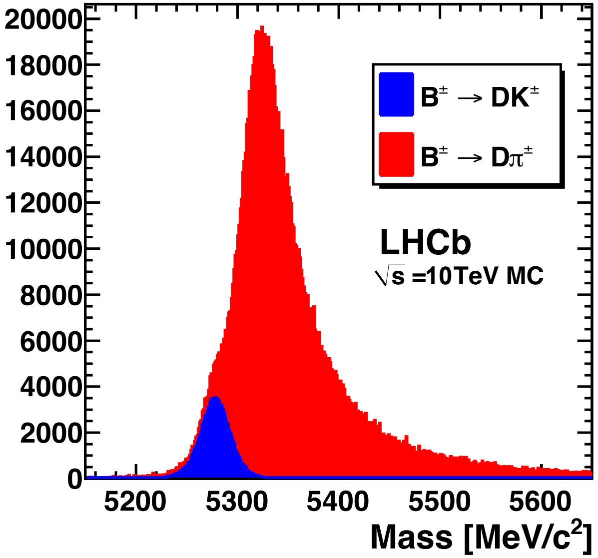


- Once running at nominal luminosities, can expect these to be our principal channels for kaon performance monitoring

And in the very near future…

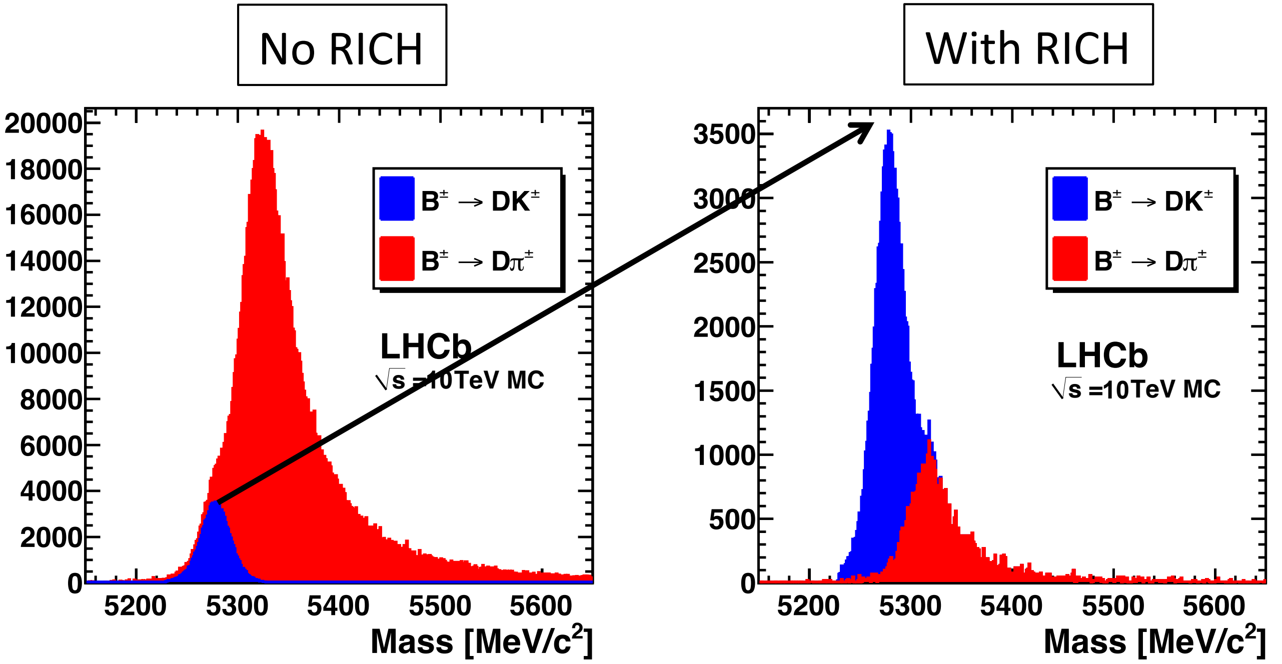
- **RICH will play a pivotal role in LHCb's key CP violation and rare decay analyses**
  - e,g. measurement of the CKM angle γ (CP violating phase)
  - Requires high statistic samples of **B → DK** decays
  - Difficulty comes from **B →Dπ** decays (x30 large BR)

No RICH



And in the very near future…

- **RICH will play a pivotal role in LHCb's key CP violation and rare decay analyses**
  - e,g. measurement of the CKM angle γ (CP violating phase)
  - Requires high statistic samples of **B → DK** decays
  - Difficulty comes from **B →Dπ** decays (x30 large BR)

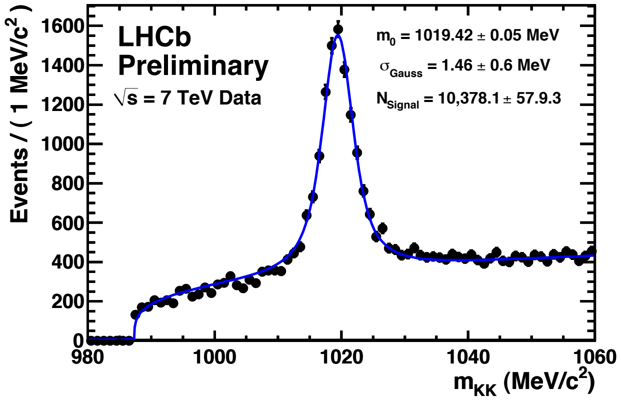


RICH enables such analysis to be performed!

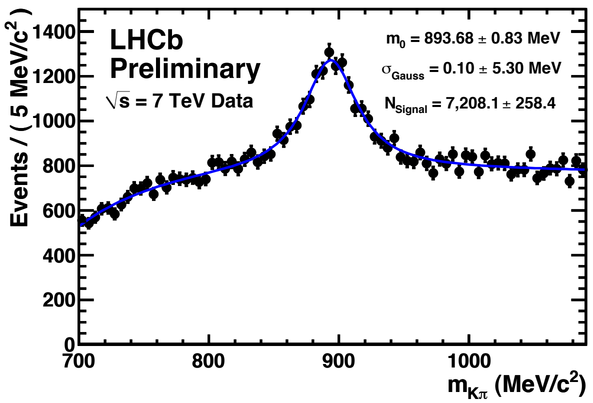
Conclusions

- **The LHCb RICH detectors are up and operational**
  - First order alignment & calibration performed
    - Many further corrections currently being determined
  - Despite this, RICH already providing useful discrimination power
    - Peaks visible from using RICH info.:

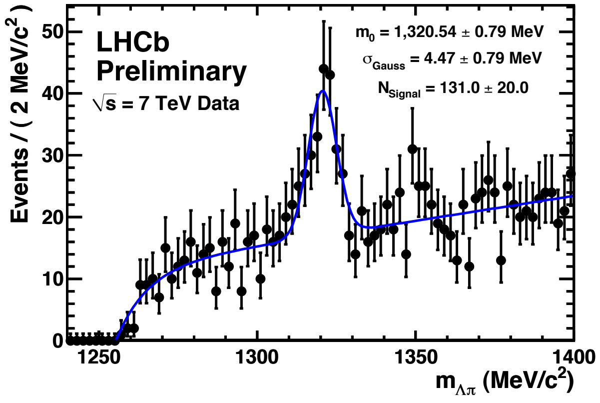
ϕ



$K^*(892)$



Ξ^-



- And signatures of other peaks around the corner (Λ_c, Ω^-, …)
- **A very "RICH" physics program ahead of us!**

Backup

Global Likelihood

Consider

- **all** photons,
- **all** tracks and for
- **all** radiators…

…in a given event and maximise the following:

$$\ln\mathcal{L} = -\sum_{track\ j} \mu_j + \sum_{pixel\ i} n_i \ln\Big(\sum_{track\ j} a_{ij} + b_i\Big)$$

a_{ij} = number of expected photons from track j in pixel i (for a given PID)

b_i = background in pixel i (photons not associated to any track)

n_i = number of photons in pixel i

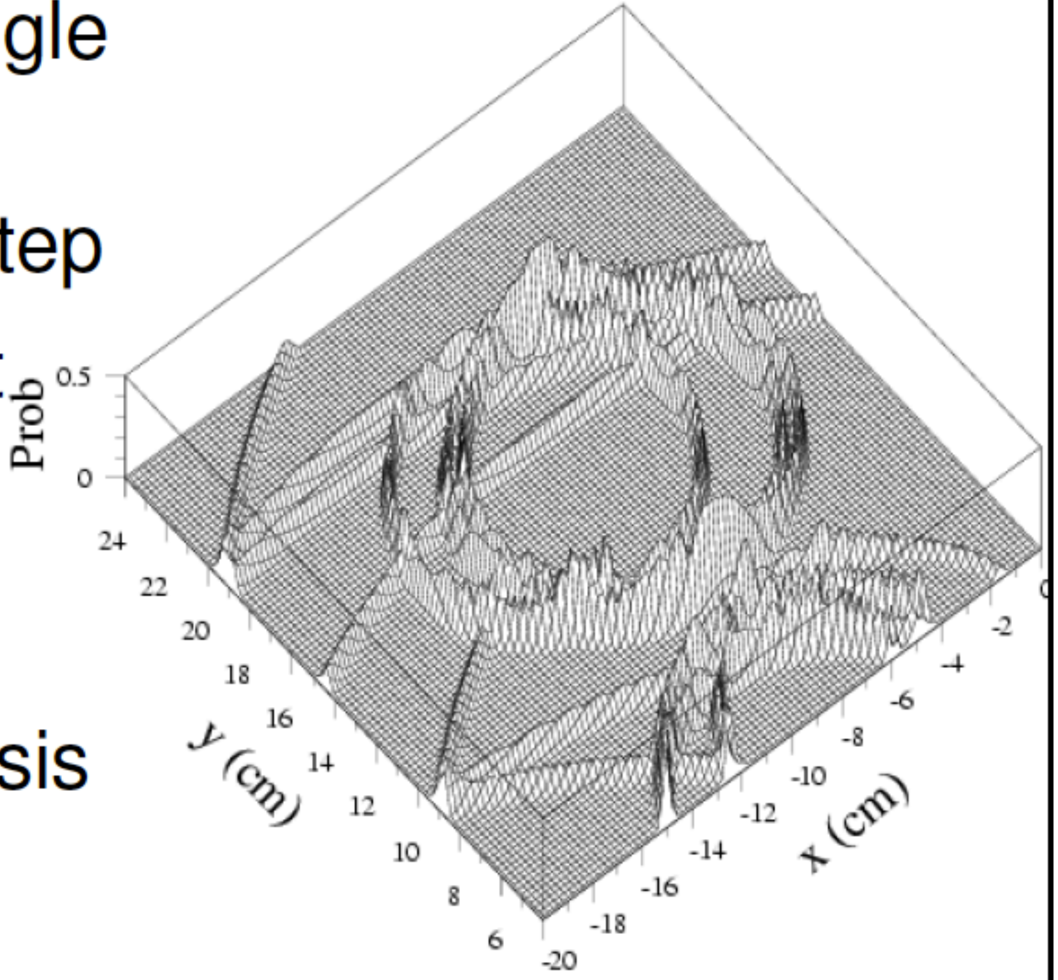
$\mu_j = \sum_i a_{ij}$ (expected number of photons associated with track j)

- Digital readout $\Rightarrow n_i = 1$ or 0

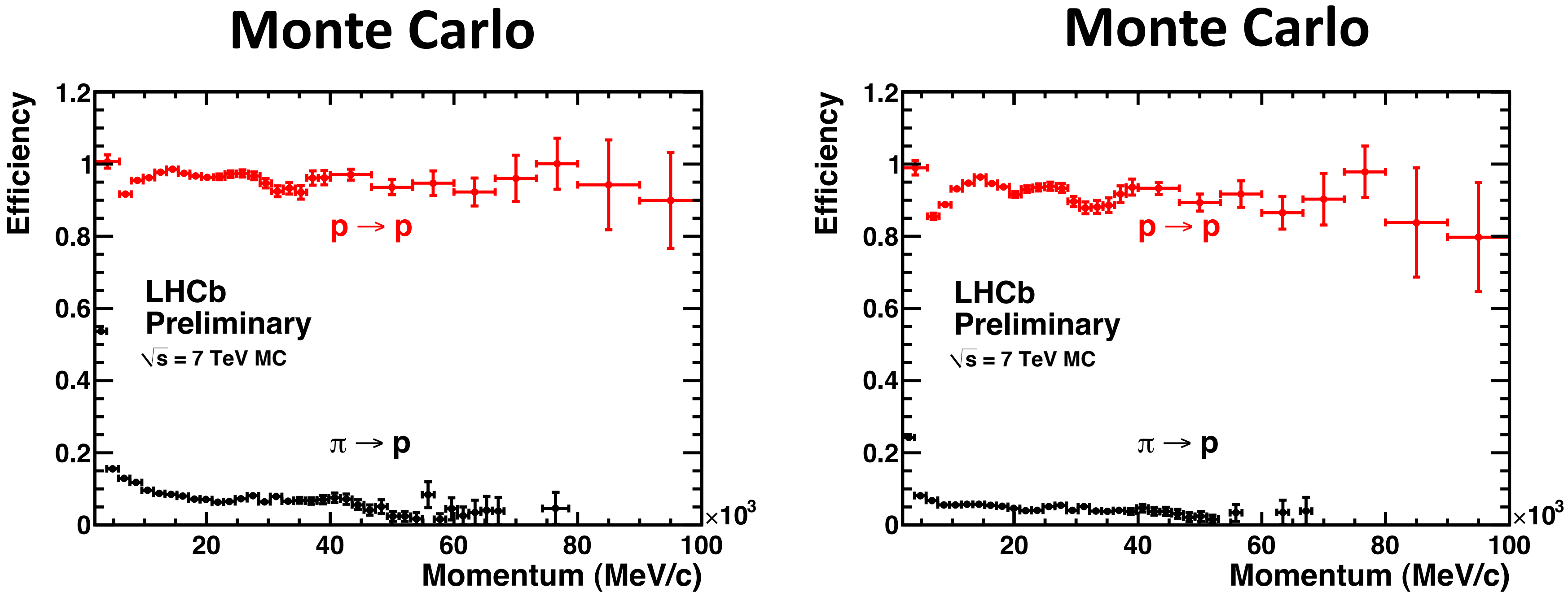
$$\boxed{\ln\mathcal{L} = -\sum_{track\ j} \mu_j + \sum_{pixel\ i} \ln\Big(\exp\Big(\sum_{track\ j} a_{ij} + b_i\Big) - 1\Big)}$$

Global likelihood - Remarks

- Operates in cerenkov angle space
- PDF is a gaussian on a "circle" at the expected cerenkov angle
- Try not to discard all knowledge at every step
- Don't recalculate what hasn't changed.
- For PID cut on Delta-Log-Likelihood per track and hypothesis



PID Performance



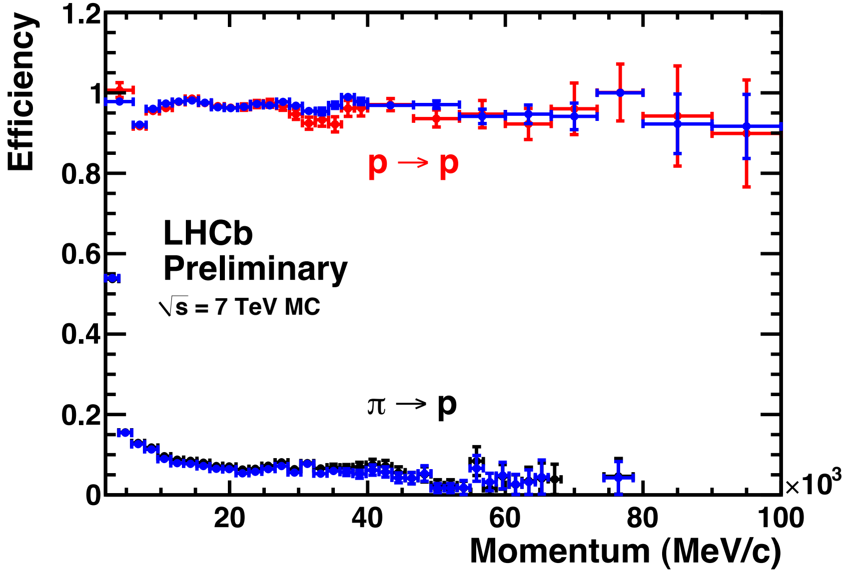
$\Delta \log \mathcal{L}(\mathrm{p} - \pi) > 0$

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

Comparing reconstructed MC distributions with MC truth

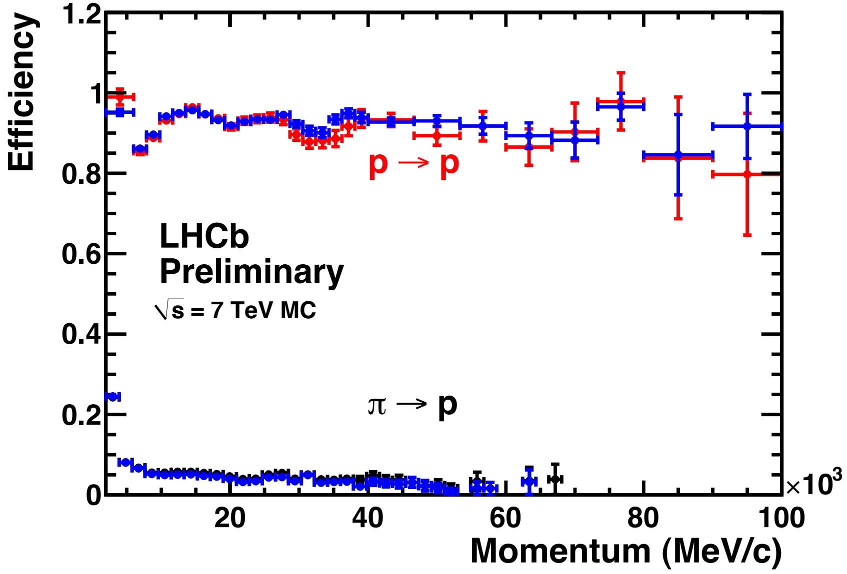
PID Performance

Monte Carlo



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

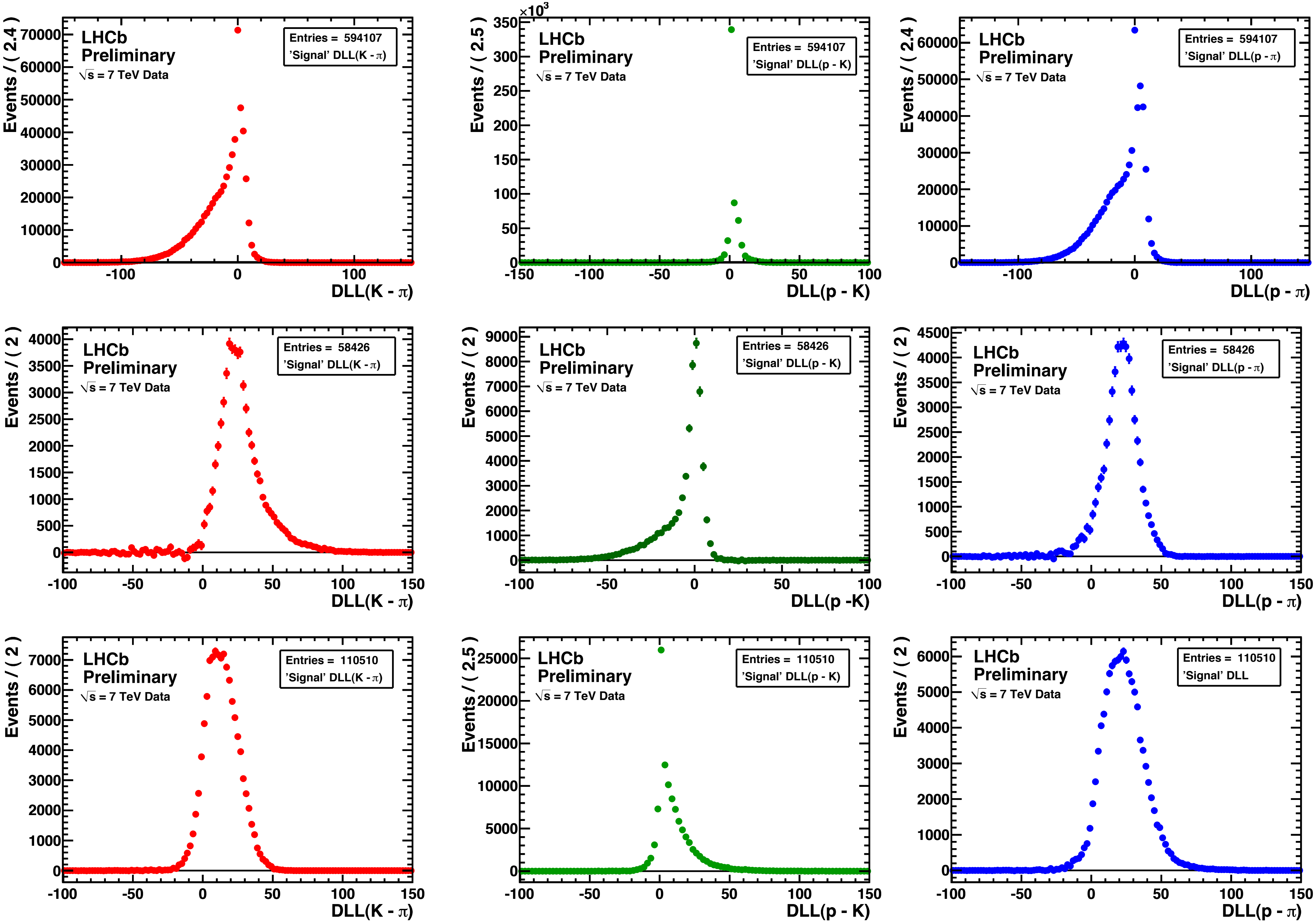
Monte Carlo



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

Comparing reconstructed MC distributions with MC truth

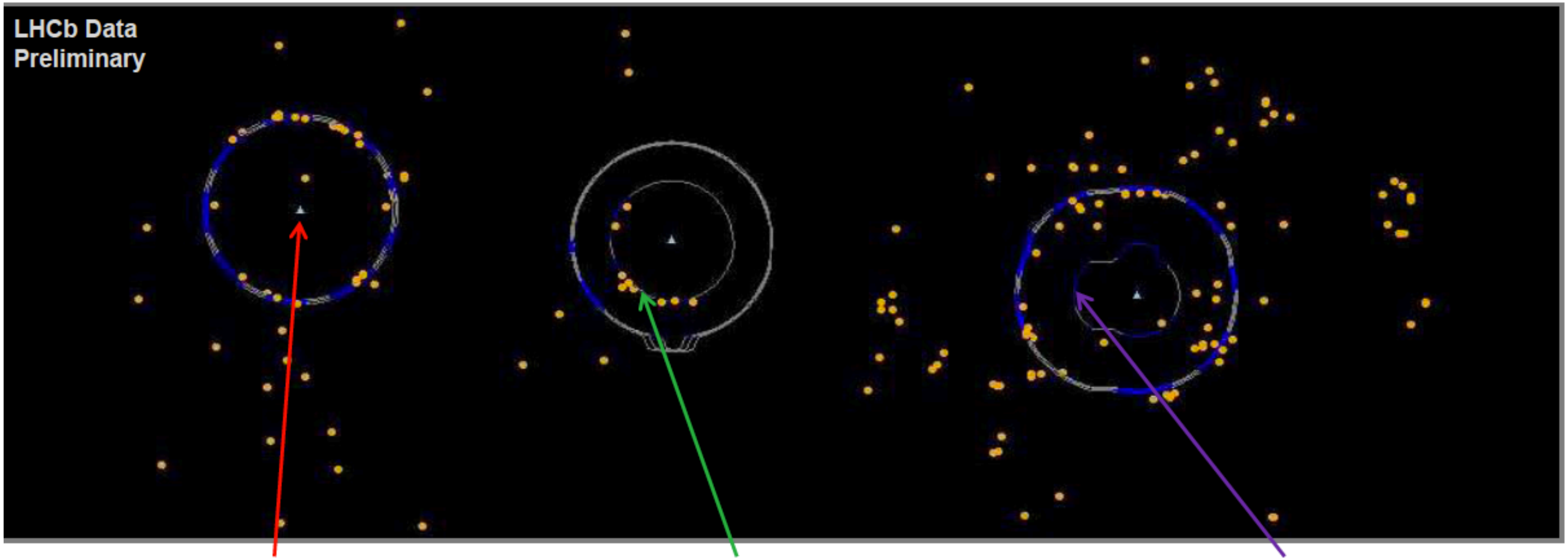
— MC Truth


LHCb
Preliminary
√s = 7 TeV Data
Entries = 594107
'Signal' DLL(K - π)
Events / (2.4)
DLL(K - π)
×10³
Entries = 594107
'Signal' DLL(p - K)
Events / (2.5)
DLL(p - K)
Entries = 594107
'Signal' DLL(p - π)
Events / (2.4)
DLL(p - π)
Entries = 58426
'Signal' DLL(K - π)
Events / (2)
Entries = 58426
'Signal' DLL(p - K)
DLL(p -K)
Entries = 58426
'Signal' DLL(p - π)
Entries = 110510
'Signal' DLL(K - π)
Entries = 110510
'Signal' DLL(p - K)
Events / (2.5)
Entries = 110510
'Signal' DLL

Particle Identification

An event display from real data show "rings" projected on to RICH1's photon detector plane:

Detector acceptance



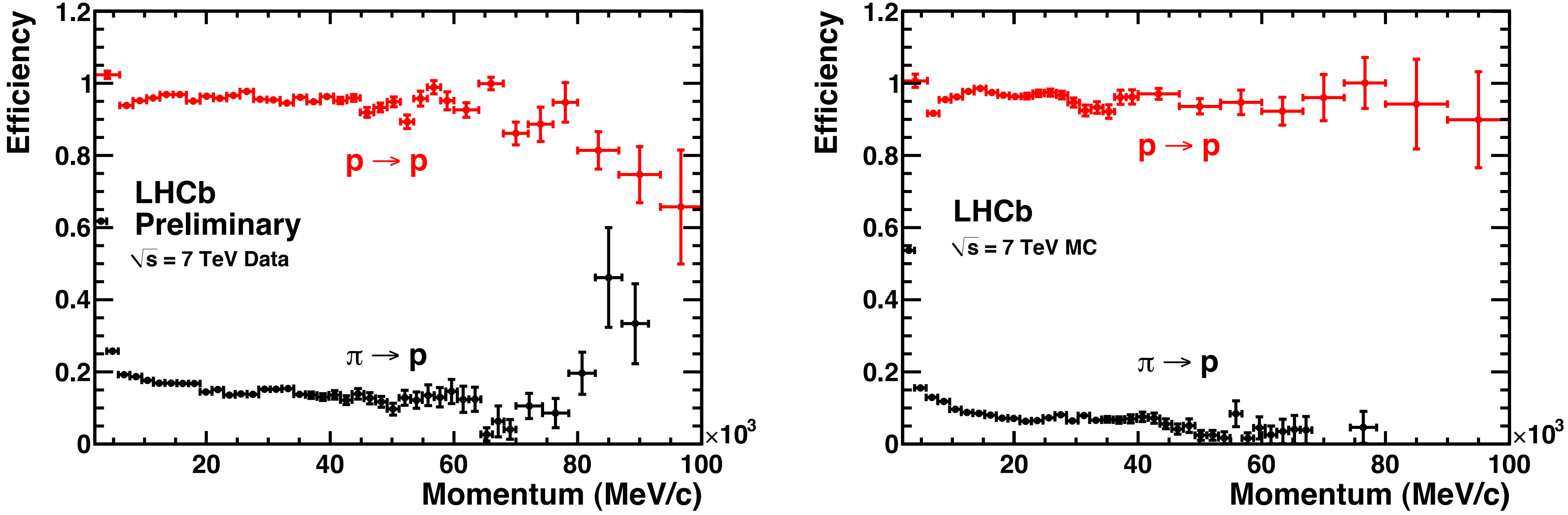
Saturated track: particle hypotheses indistinguishable

Photons clearly favour the Kaon ring hypothesis

Ring distortions due to detector geometry

PID Performance

Example of performance: p-π discrimination


Data

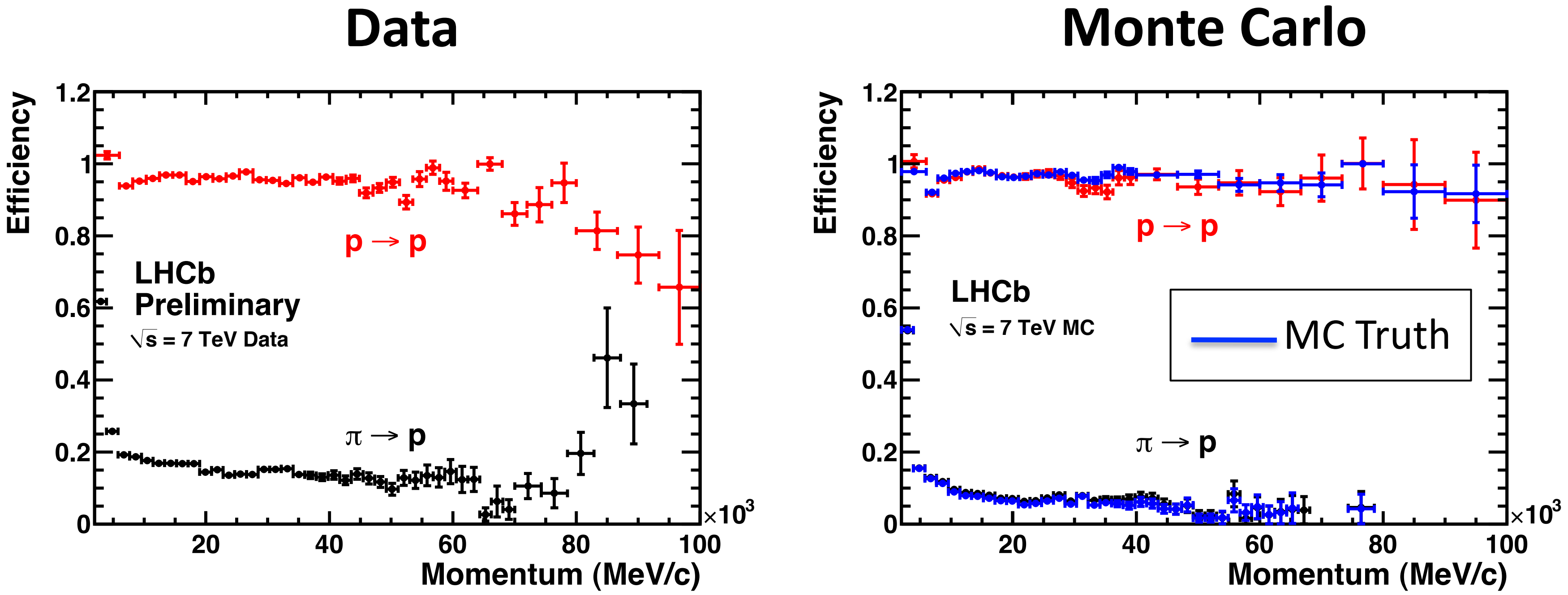
Monte Carlo

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

- Alignment and calibration still in early stages (see C. Blanks' talk)
- Thus, impressive to have such reasonable agreement between MC and data so soon!
- Expect marked improvements in the coming weeks

PID Performance

Example of performance: p-π discrimination



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

- Alignment and calibration still in early stages (see C. Blanks' talk)
- Thus, impressive to have such reasonable agreement between MC and data so soon!
- Expect marked improvements in the coming weeks