Particle Identification at LHC

ALICE and LHCb

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Frédéric Machefert, on behalf of the LHCb Collaboration
Laboratoire de l'Accélérateur Linéaire, Orsay

Outline of the talk

- Introduction
  - The ALICE and LHCb detectors, focusing on the PID
- Particle identification methods
  - Energy Loss
  - Transition radiation
  - Time of flight
  - Cherenkov detectors
  - Calorimetry
  - Muon spectrometers
- Conclusions

Introduction

- Focus here on the 2 large dedicated experiments at the CERN LHC:
  - **A L**arge **I**on **C**ollider **E**xperiment is the experiment dedicated to heavy-ion physics
  - **LHCb** studies heavy flavours: charm, beauty, CP violation and rare decays

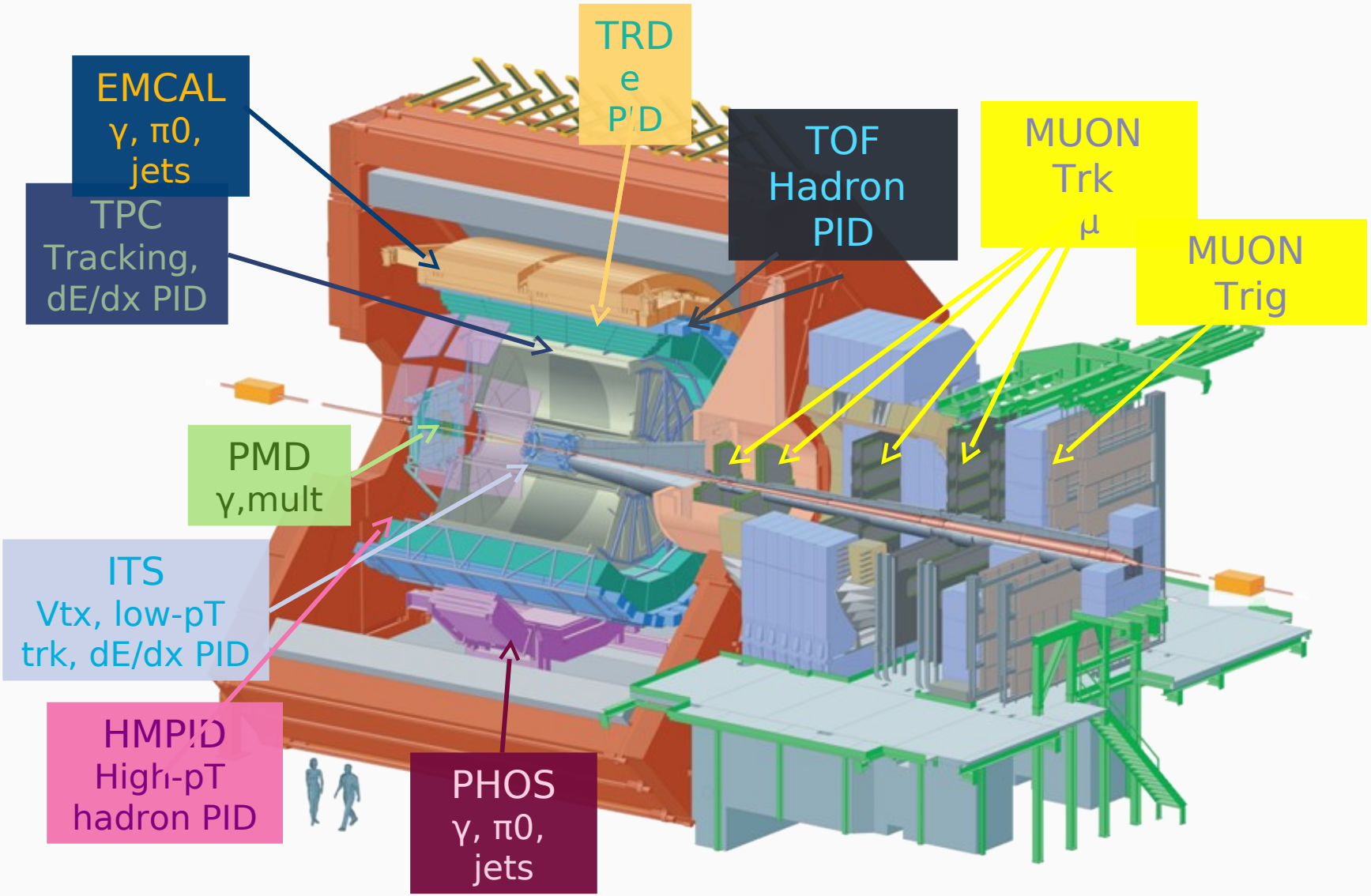
- The fields covered by those experiments require
  - A precise determination of many observables
    - Multiplicity,
    - Energy,
    - Angular distribution

      for specific types of particles
  - The exclusive reconstruction of specific final states (often hadronic decays)

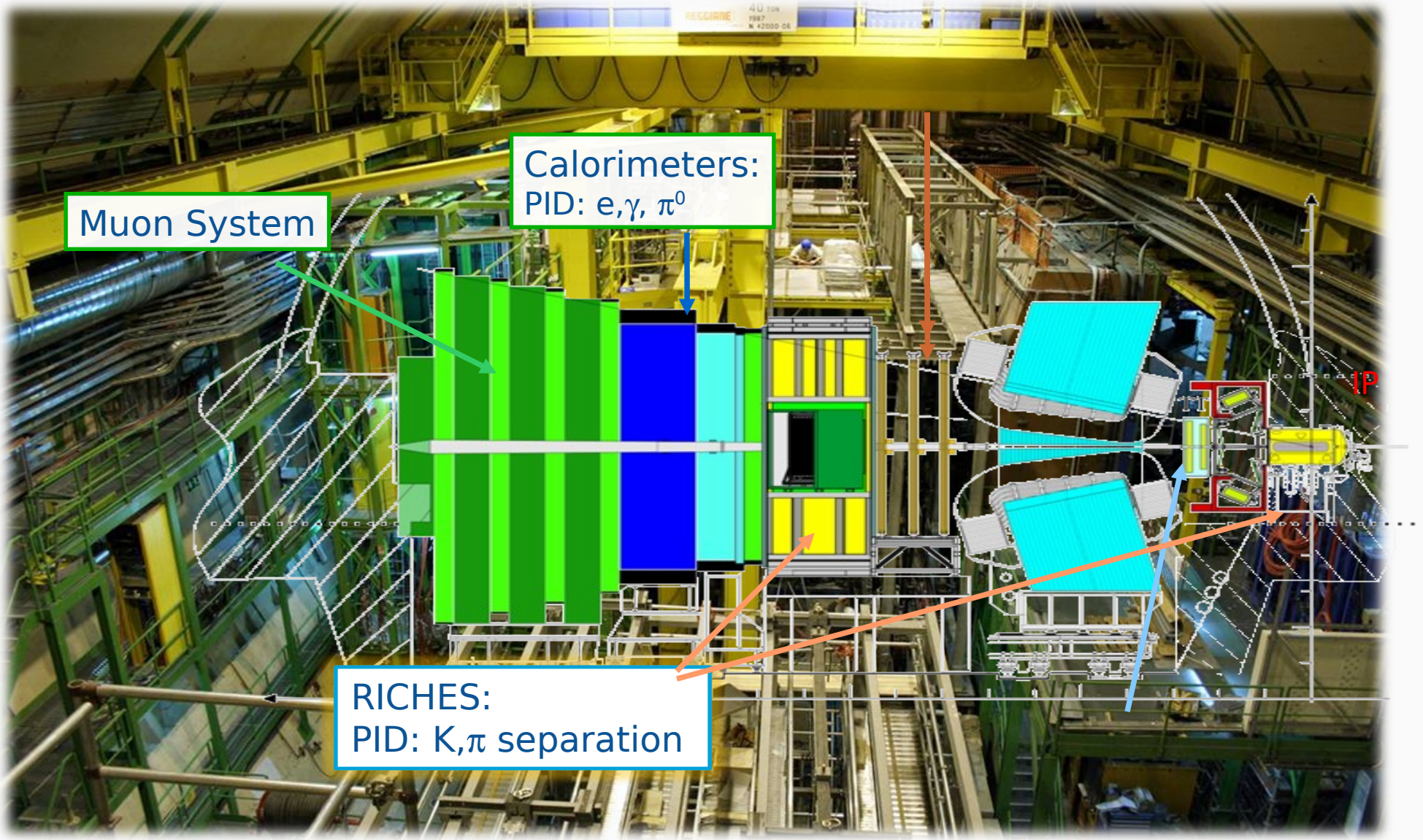
- Particle identification may be used at trigger level to select events

- They require
  - the usage of most of the particle identification techniques
  - the coverage of a large momentum range
    in the hard environment at LHC (occupancy, radiation, ...)

The ALICE detector



The LHCb detector

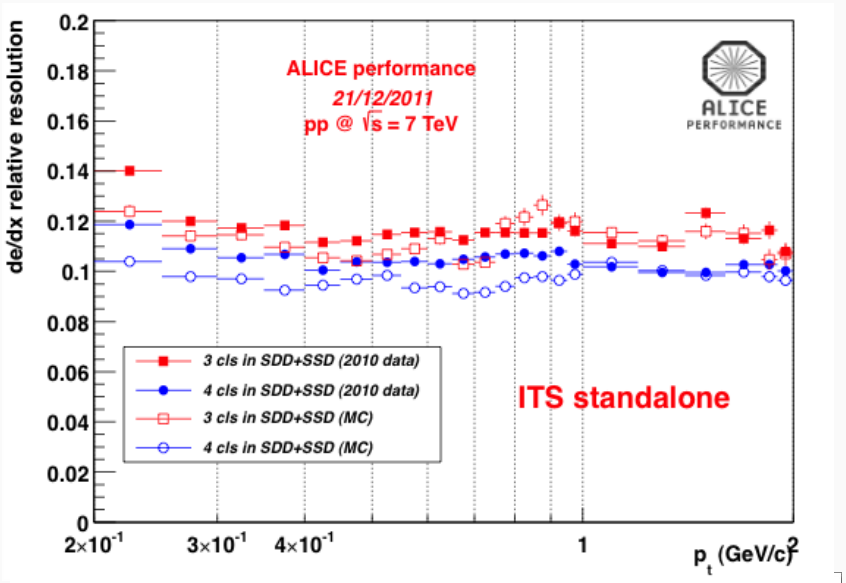


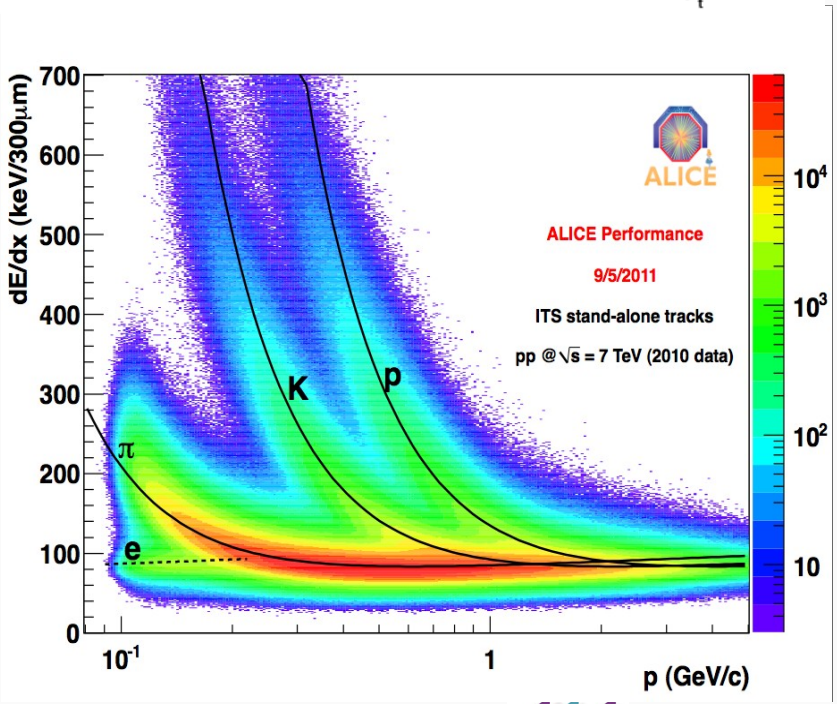
Particle identification in the Barrel

ALICE

Energy Loss: inner tracker system and TPC of ALICE

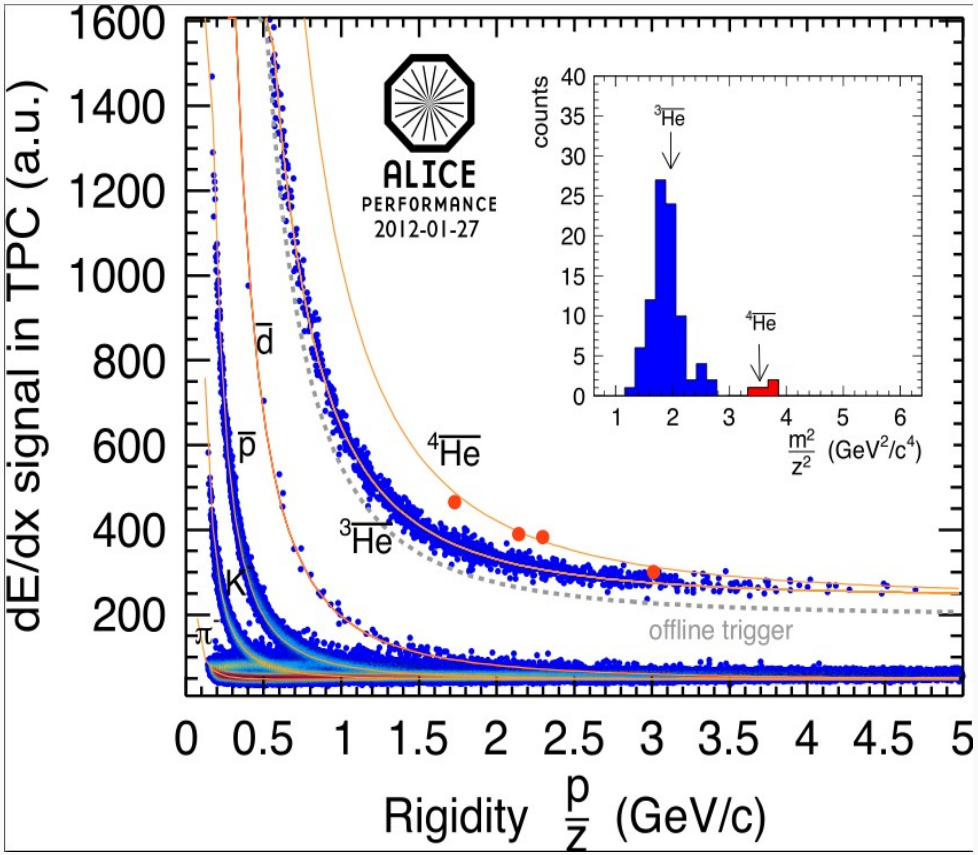
- ALICE uses two detectors for energy loss measurement in the barrel detector region $|\eta|<0.9$
  - 6 layers of tracker (Inner Tracker System)
  - A large TPC
- The ALICE ITS is made of 3 technologies
  - Silicon Pixel (SPD) from 3.9 cm of the beam
  - Silicon Drift Detector (SDD)
  - Silicon Strips (SSD) in the outermost layers
- Primary tasks
  - Localize the primary vertex, tracking
  - Identification of charged particles through dE/dx (SDD and SSD)
    - Measurement of the charge collected in the 4 layers
    - Energy resolution ~10/15%
      - K-p separation up to 1GeV/c
      - π-K up to 450MeV/c
    - Especially for low momentum particles
      - 100MeV/c region inaccessible to TPC

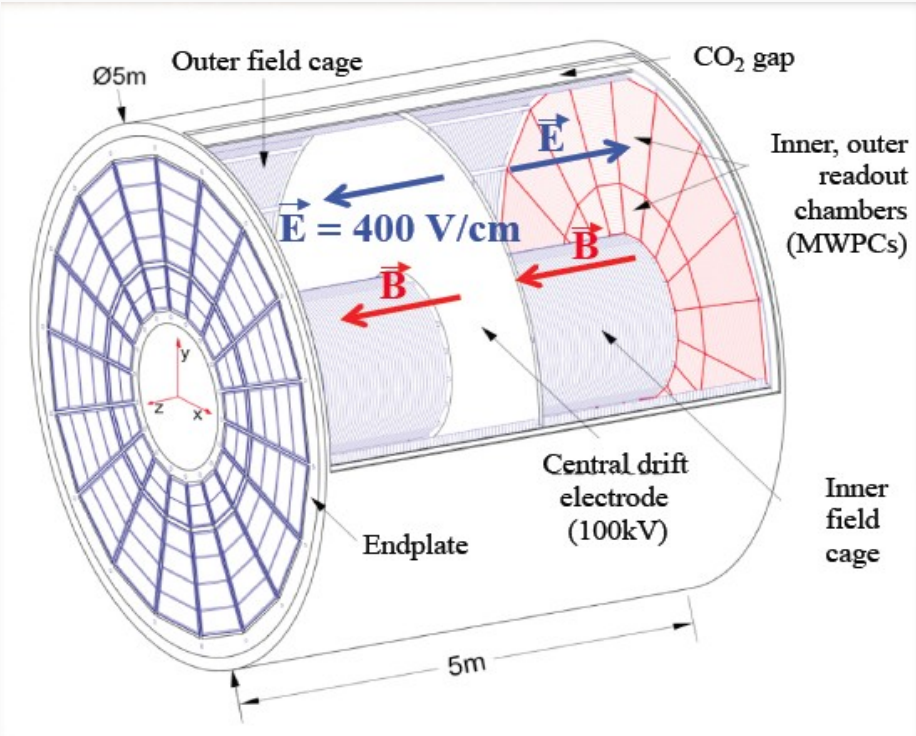


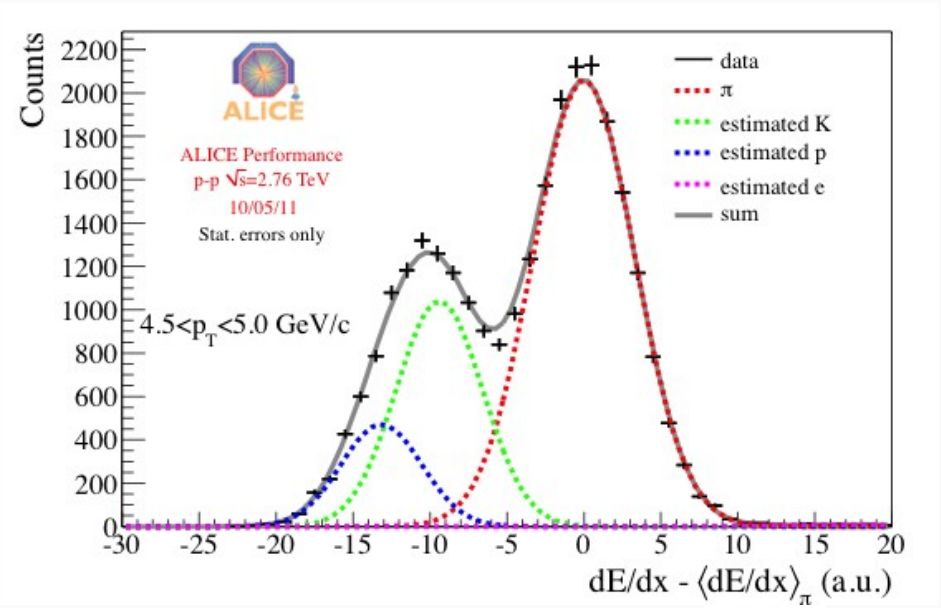


Energy loss: TPC of ALICE

- ALICE is famous also for its TPC
  - 5m diameter and long
    - 92 m^3 (inner radius ~80cm)
    - Only 3% X^0
    - Drift gas: $Ne/CO_2/N_2$
    - Drift time: 92μs
    - ~560k pads

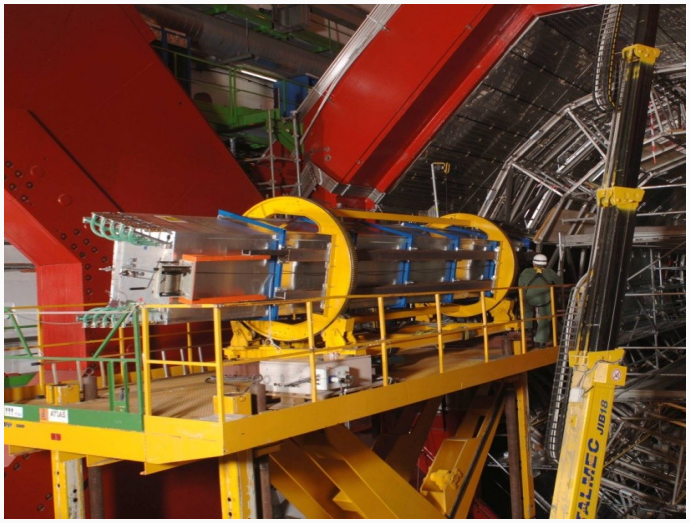


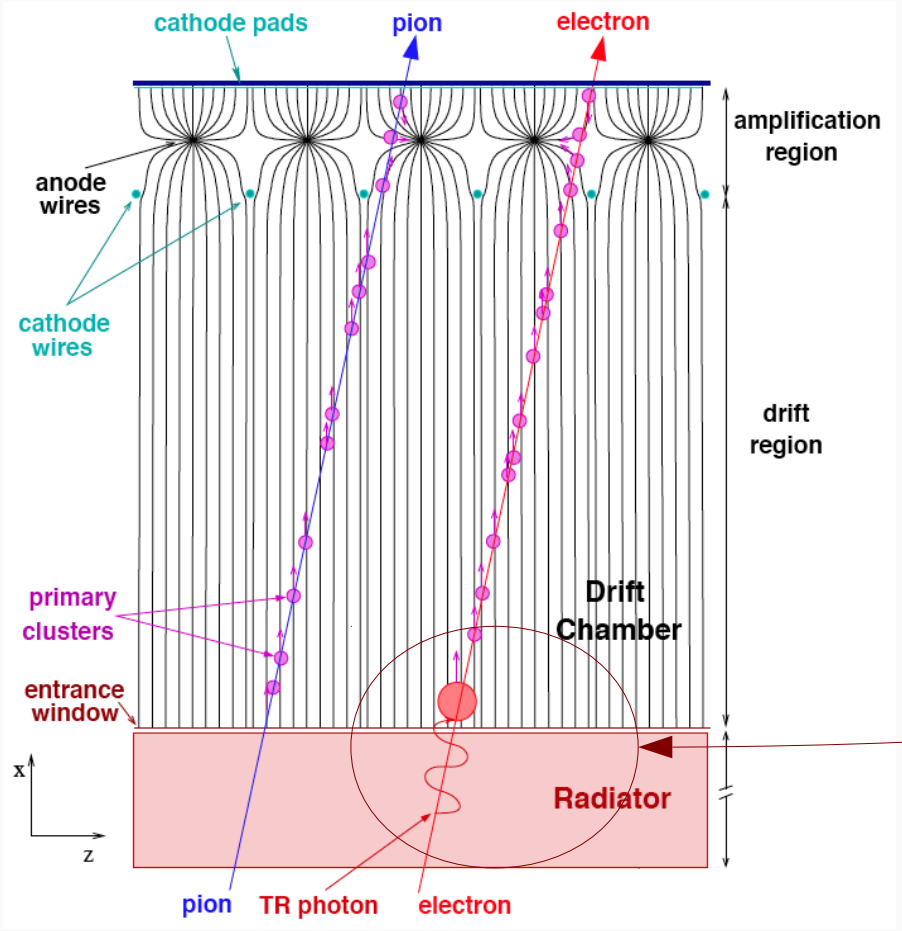


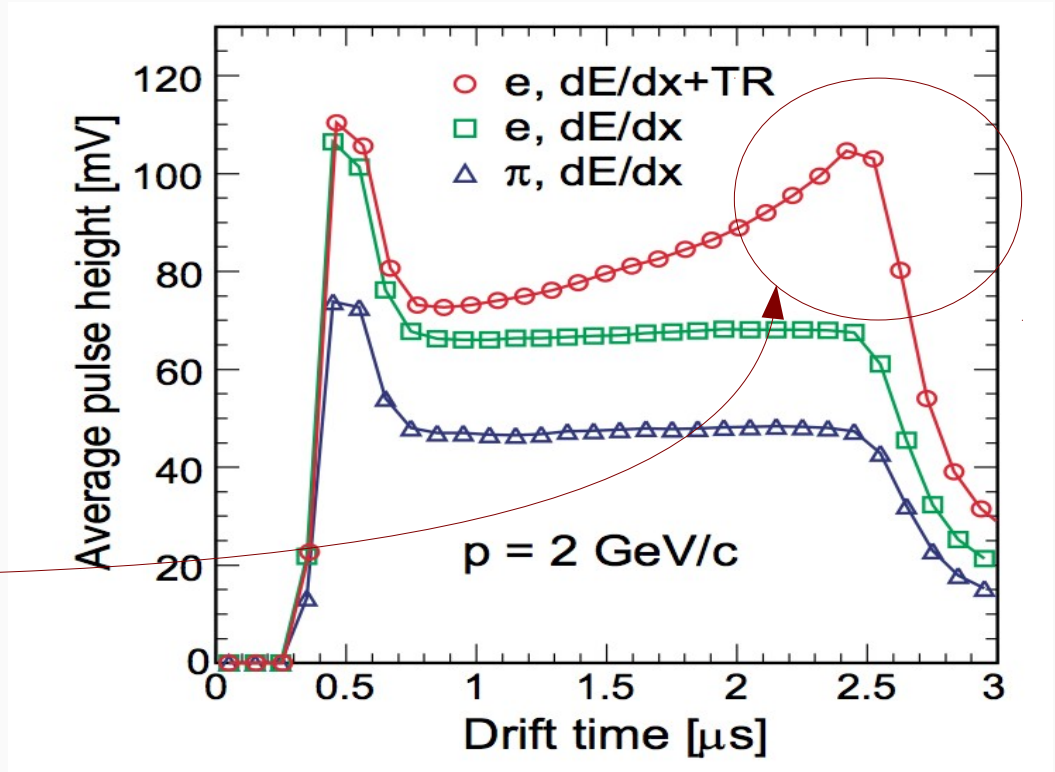


Transition radiation in ALICE

- Transition radiation from 6 layers
  - Permits to identify electrons (wrt pions)
  - At LHC energies only $e^{+/-}$ emit TR γ
    - Requires γ>1000
  - Rejection factor ~100 (p>1GeV/c)



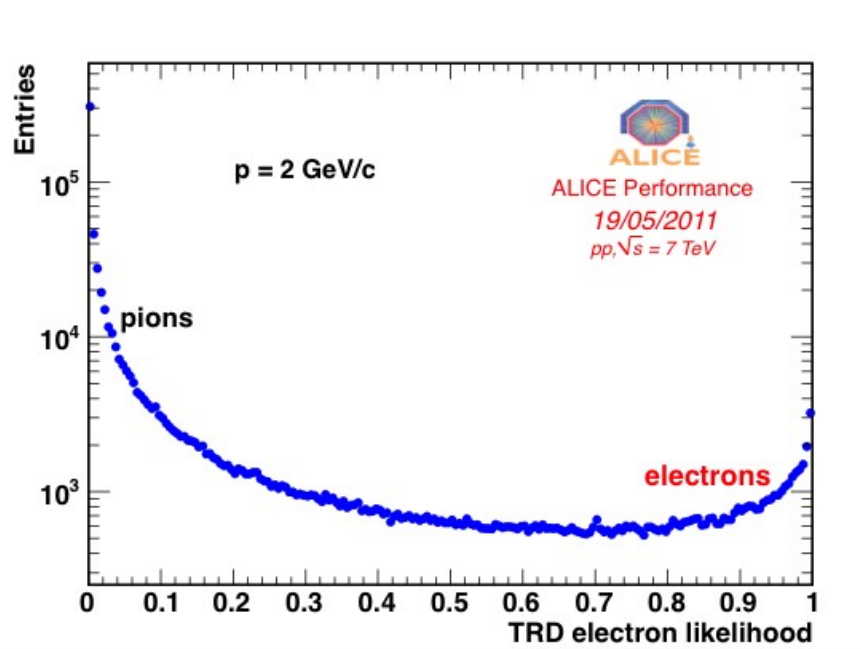


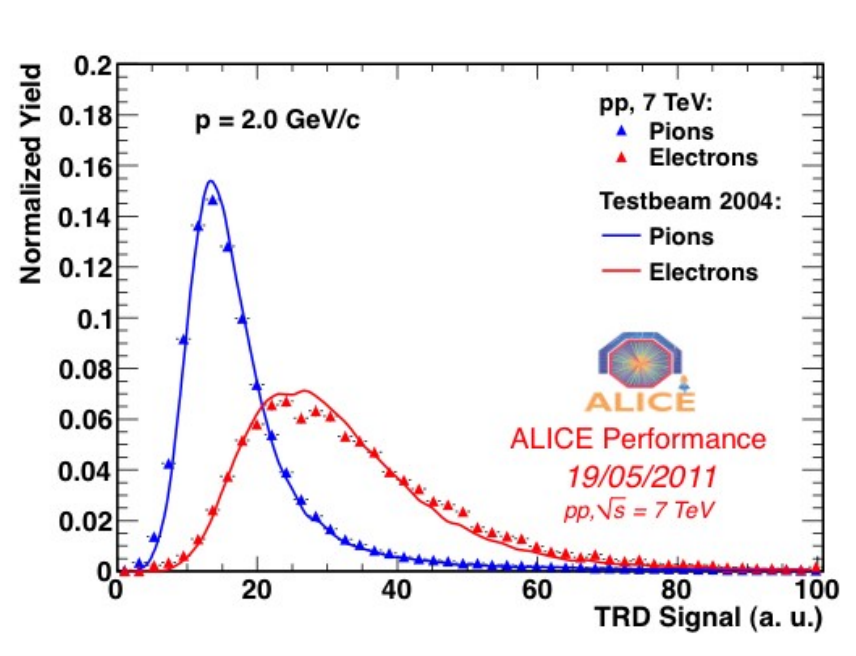


Peak at late time (electrons only) → Transition radiation

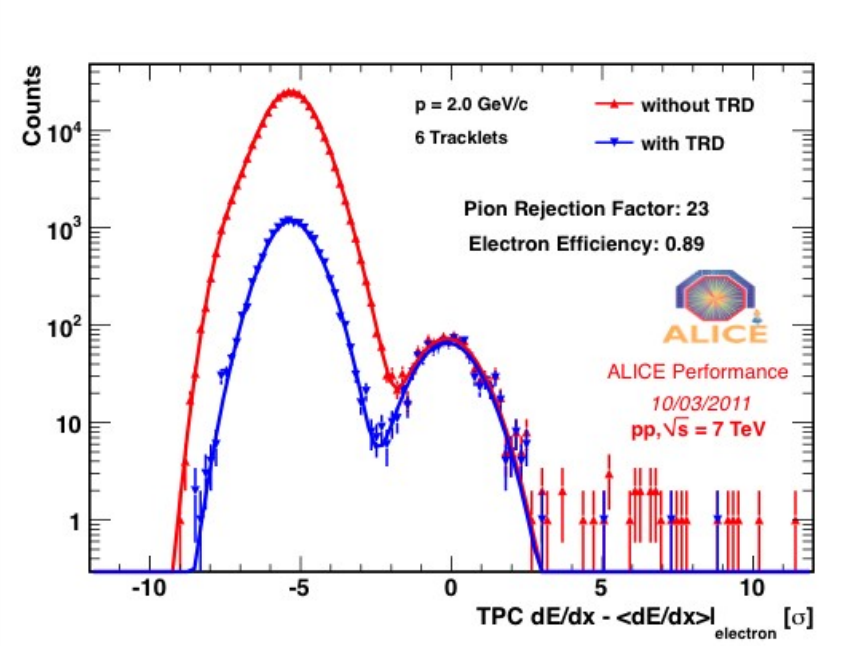
TRD /TPC identification methods

- Statistical methods based on likelihood or neural network to distinguish pions and electrons





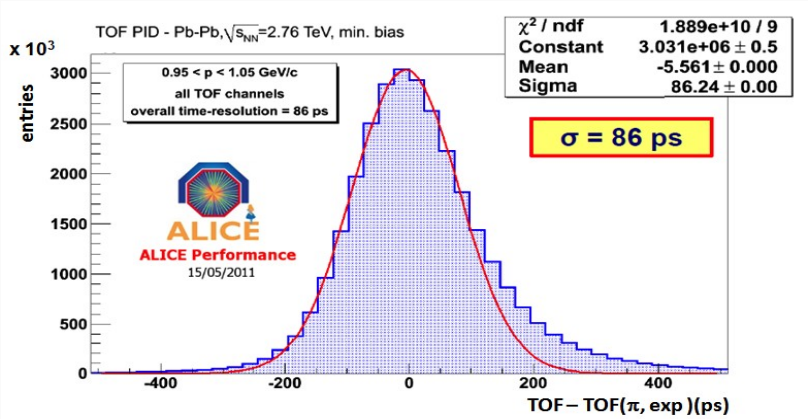
- Combination of TRD and TPC information
  - Rejection factor ~23 on pions
  - Electron efficiency ~90%

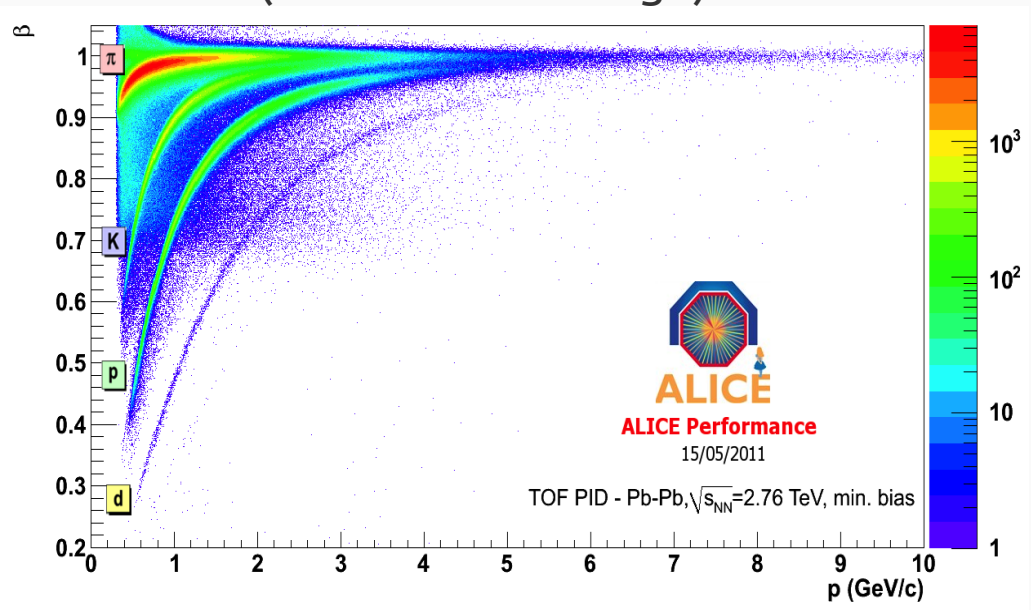


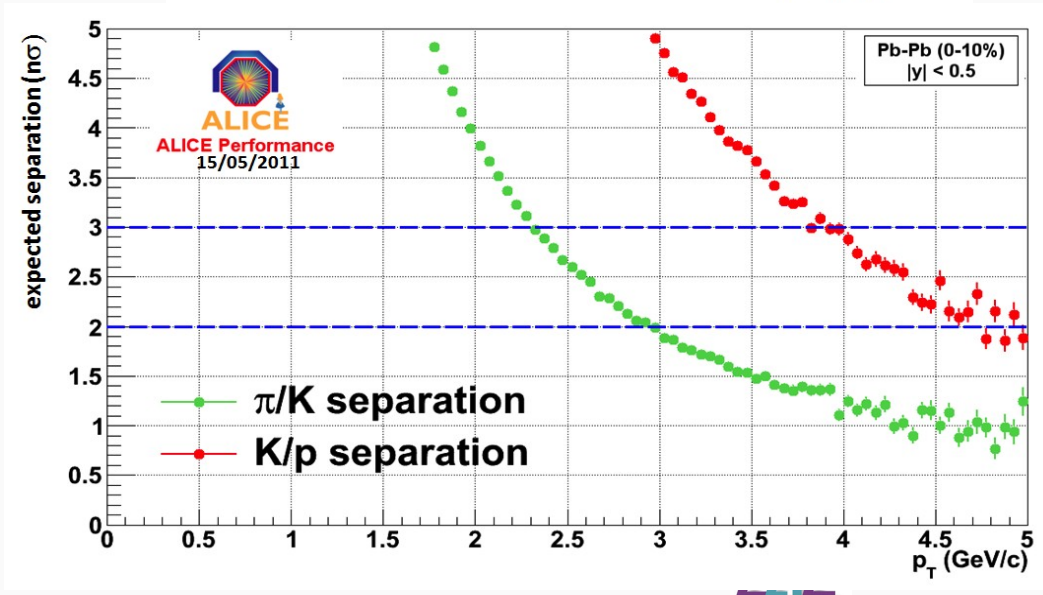
ALICE TOF detector

- Time Of Flight (TOF) measurement is based on Multigap Resistive Plate Chambers surrounding the barrel
  - $|\eta|<0.9$ at 3.7 m, full Φ coverage ($140 m^2$)
  - Intrinsic resolution ~40ps
    - Overall resolution ~90ps
  - Mass determined from momentum/time
  - Start time of the event determined either from the ALICE detector (T0) or an offline algorithm
  - Excellent Pion/Kaon and Kaon/proton separations up to 2 or 4GeV/c p_T

    (intermediate range)







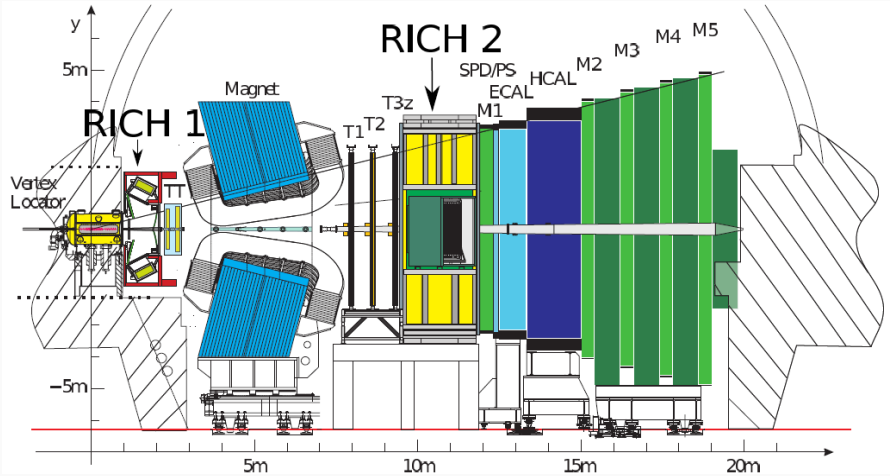
Particle Identification *with a single arm*

ALICE and LHCb

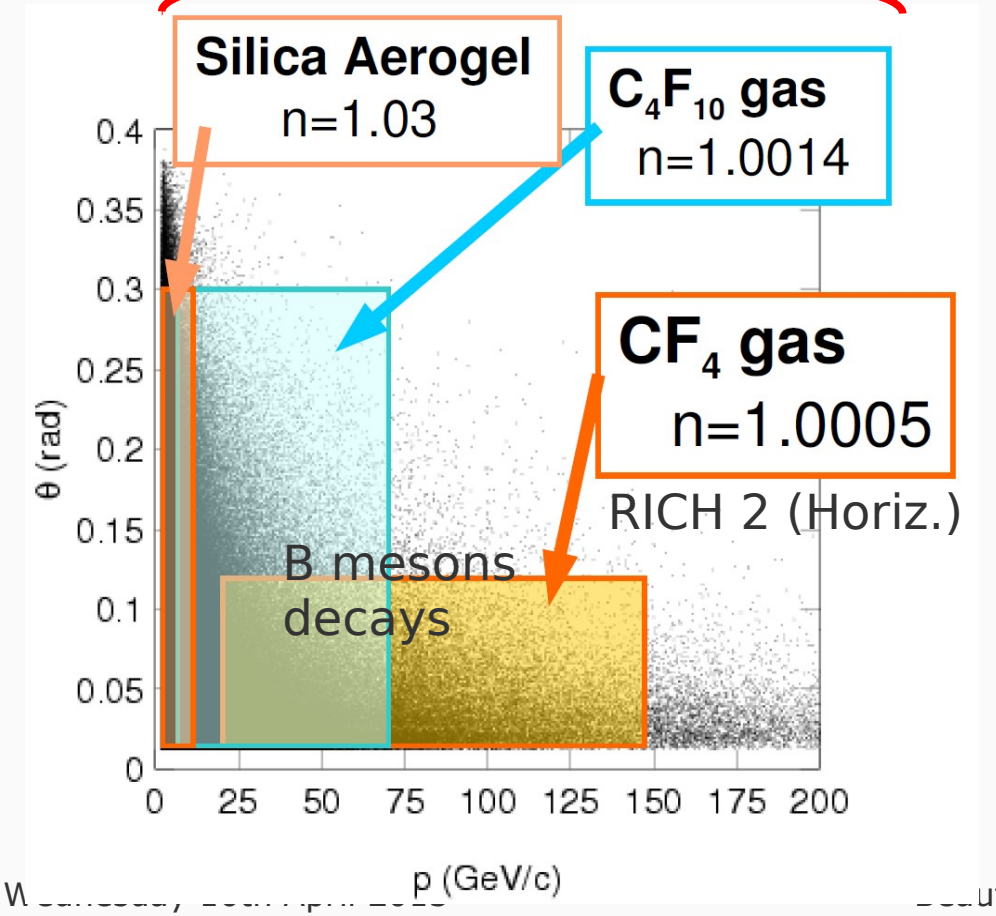
Cherenkov detectors

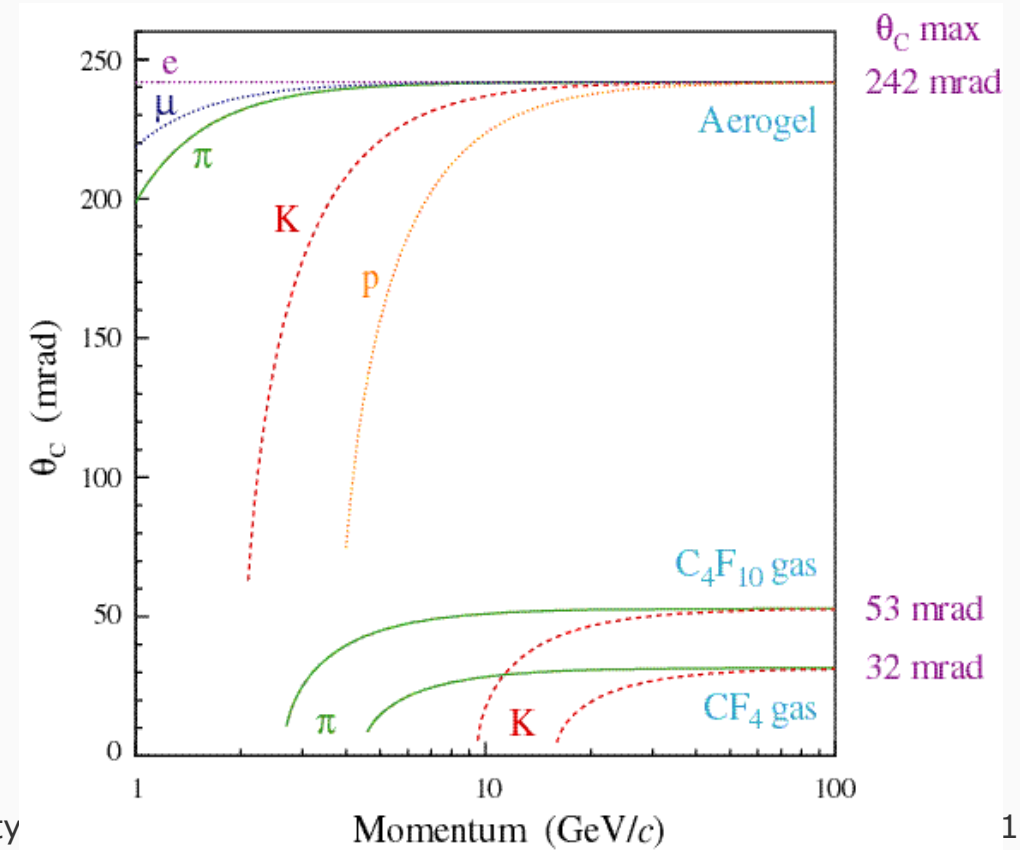
LHCb: RICH system

- LHCb needs a good π/K/proton separation on a wide momentum range
  - Typically between 1 and 100 GeV/c
  - Good coverage of the angular acceptance
- Usage of
  - 2 separate detectors and 3 different radiators



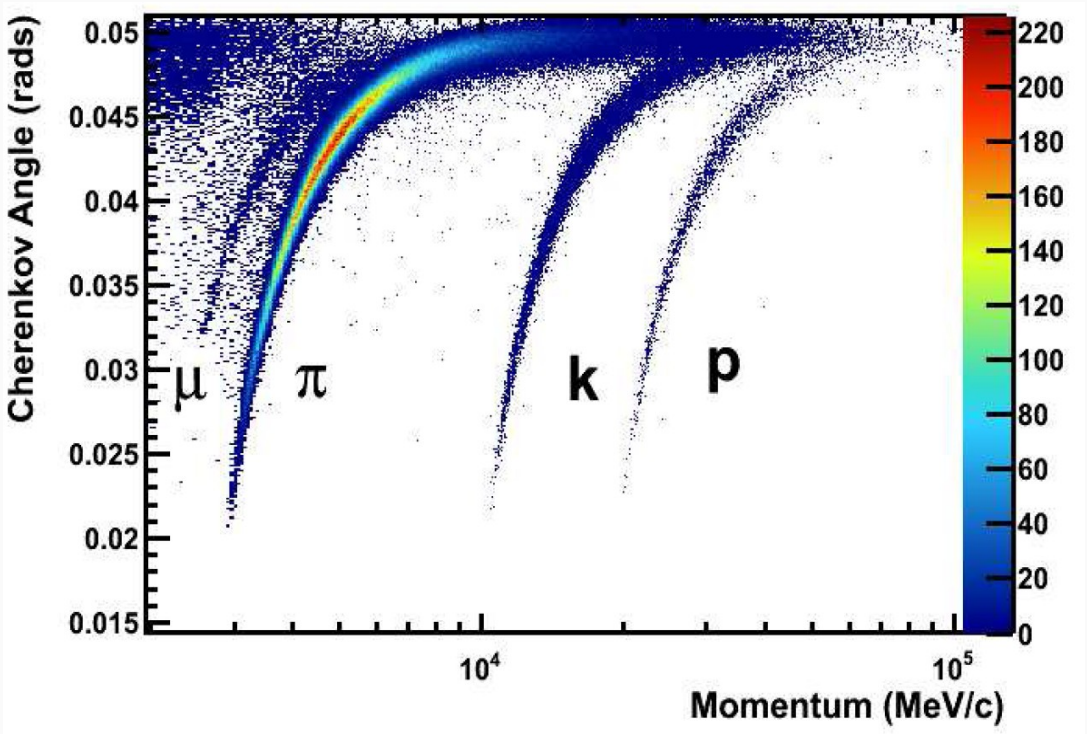
RICH 1 (Vertical)

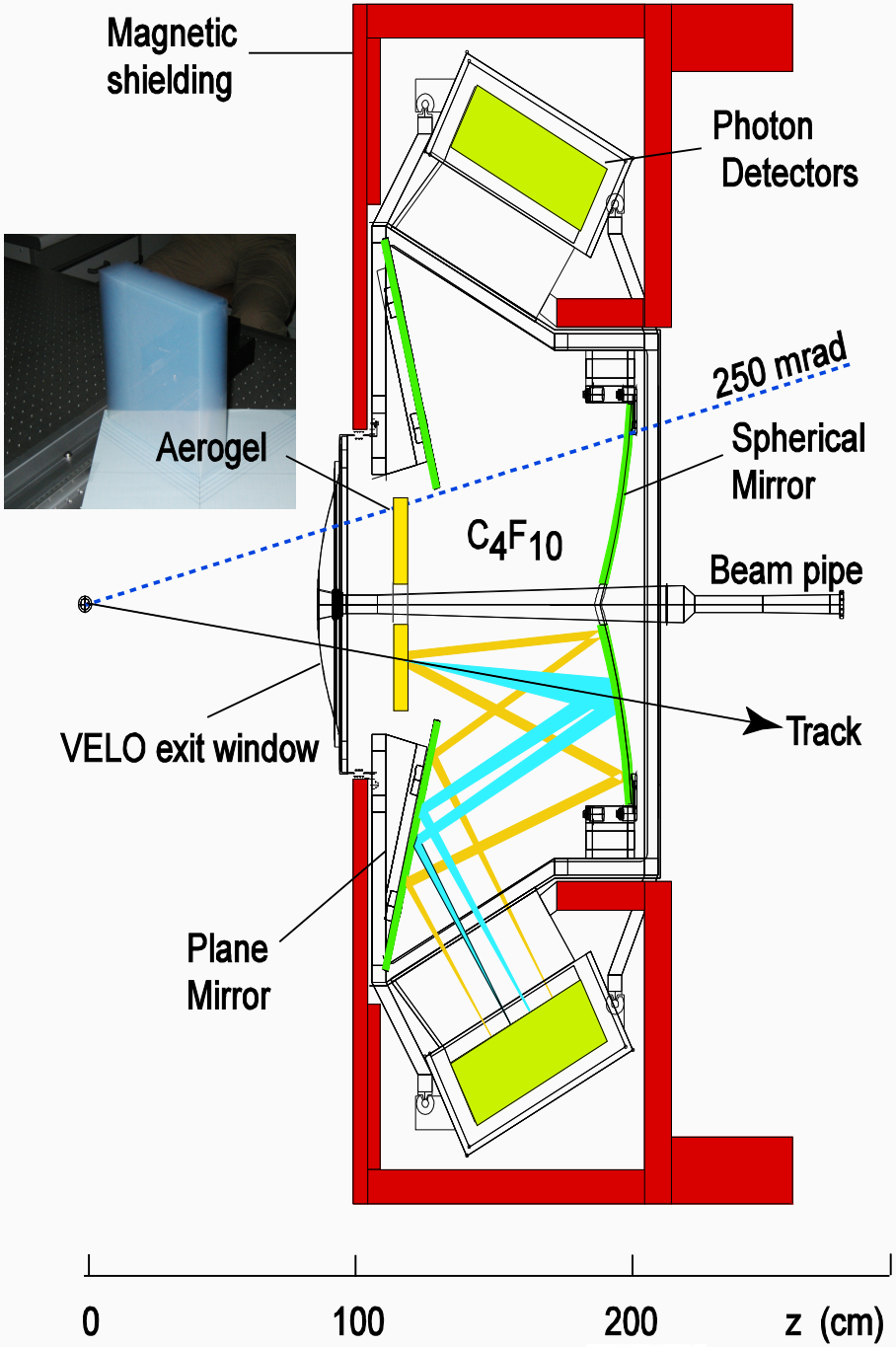




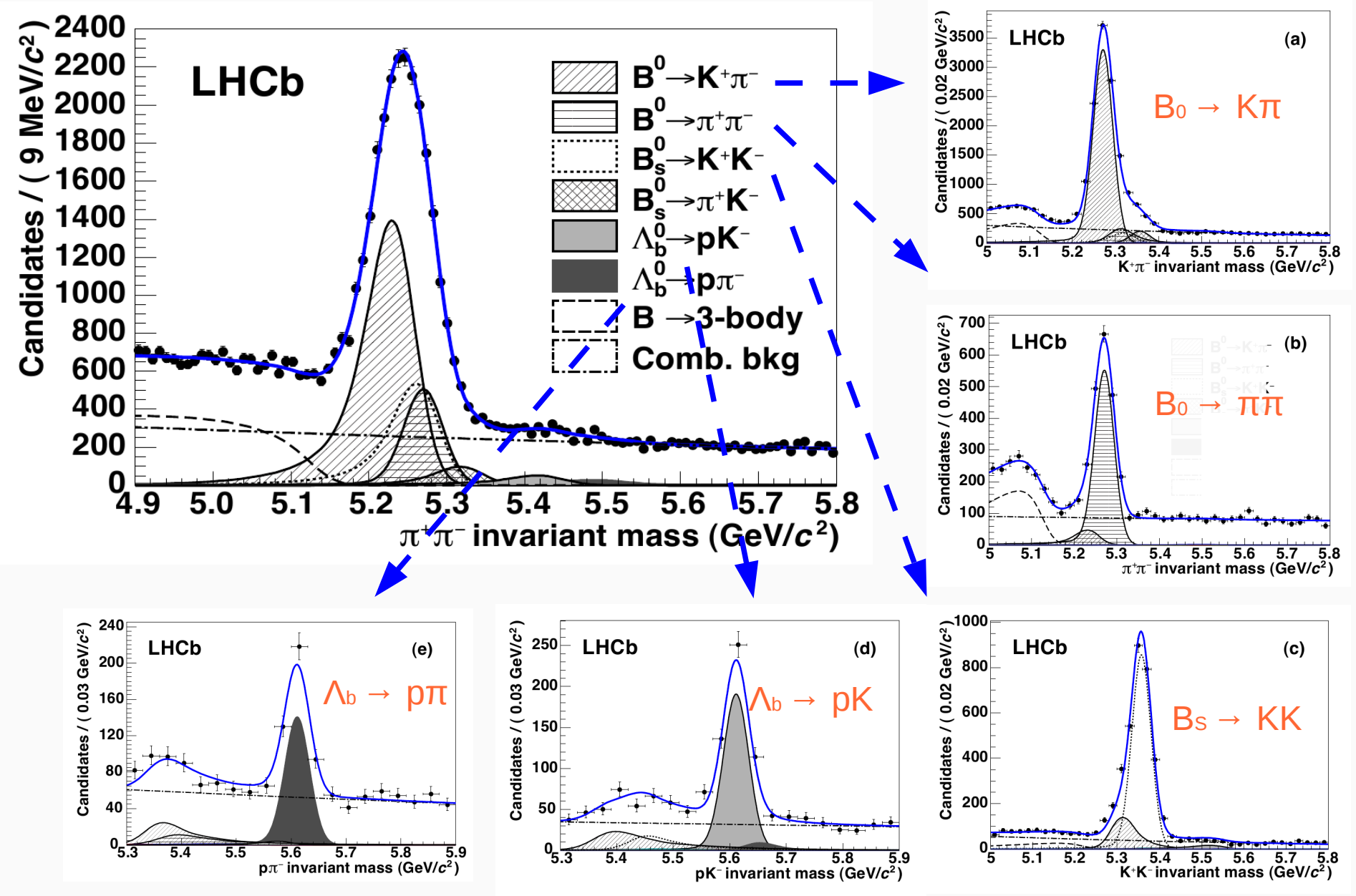
LHCb: RICH system

- The RICH are based on 1 or 2 radiators and produce light rings on an array of HPD located outside the LHCb acceptance
  - Usage of both spherical and flat mirrors
- Combine Photon rings (Cherenkov angle) and track momentum information
  - Log-likelihood re-computed for e, μ, π, K, p mass hypothesis
  - Resolutions: CF_4(RICH2)~0.68, C_4F_{10}(RICH1)~1.62 mrad





RICH: particle identification at work



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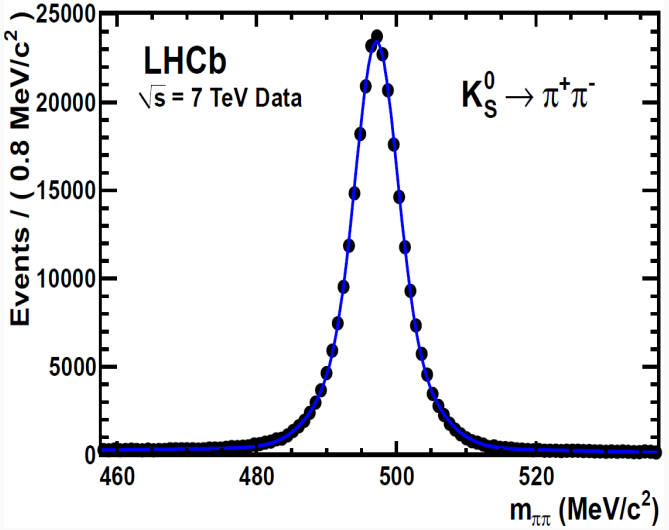
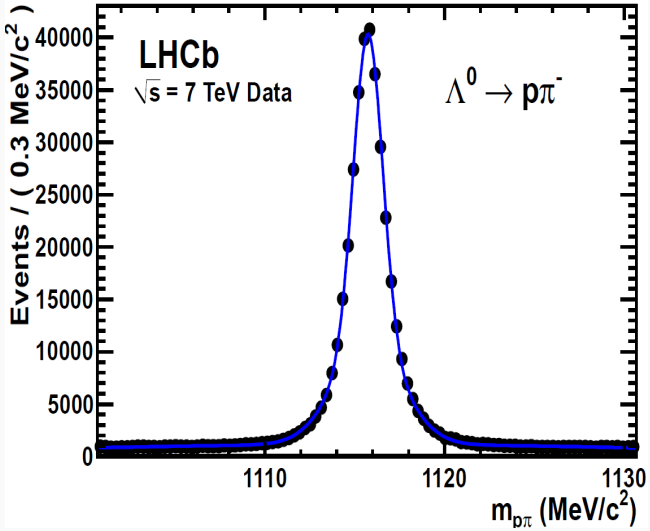
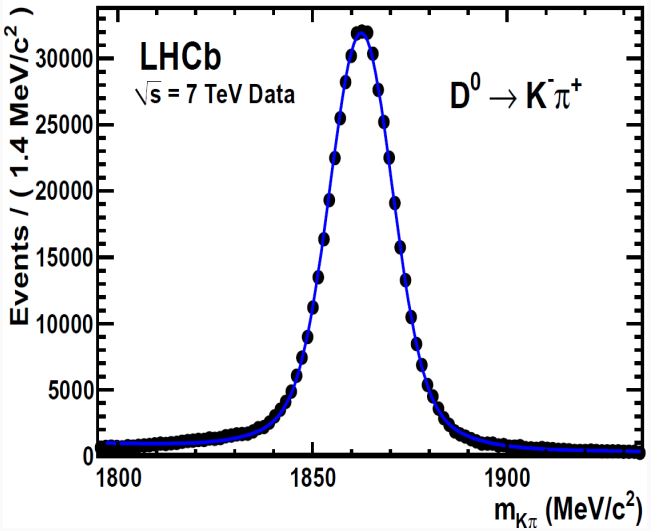
Pion - Kaon separation at LHCb: large clean calibration samples

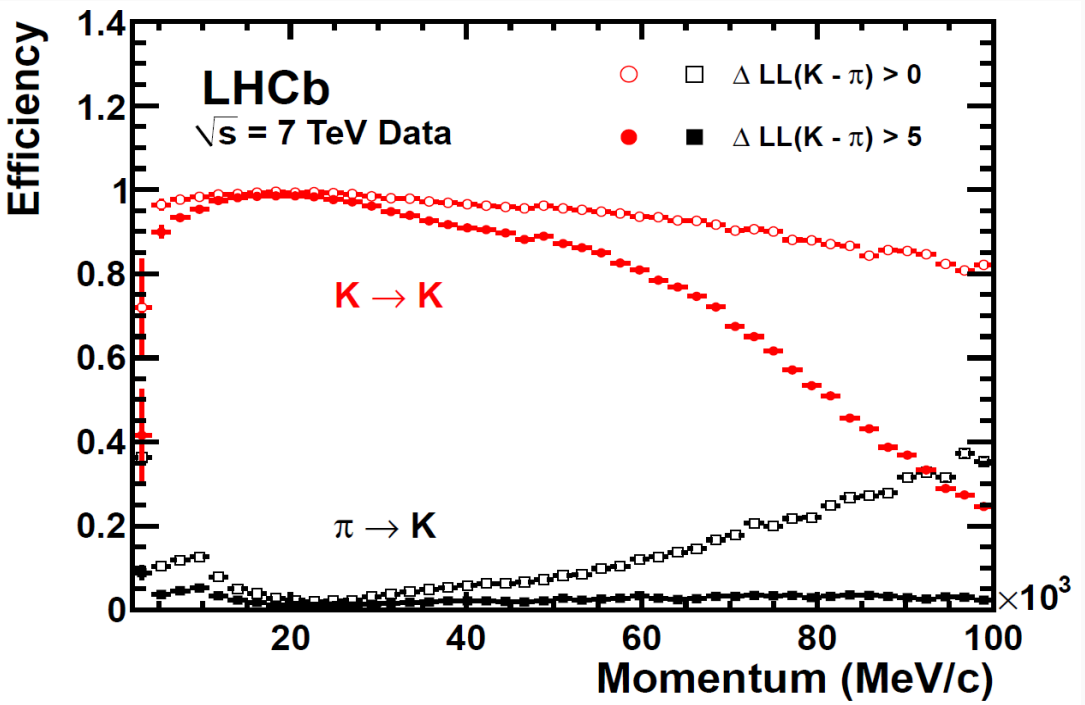
- Selection of high purity exclusive decays from kinematics only

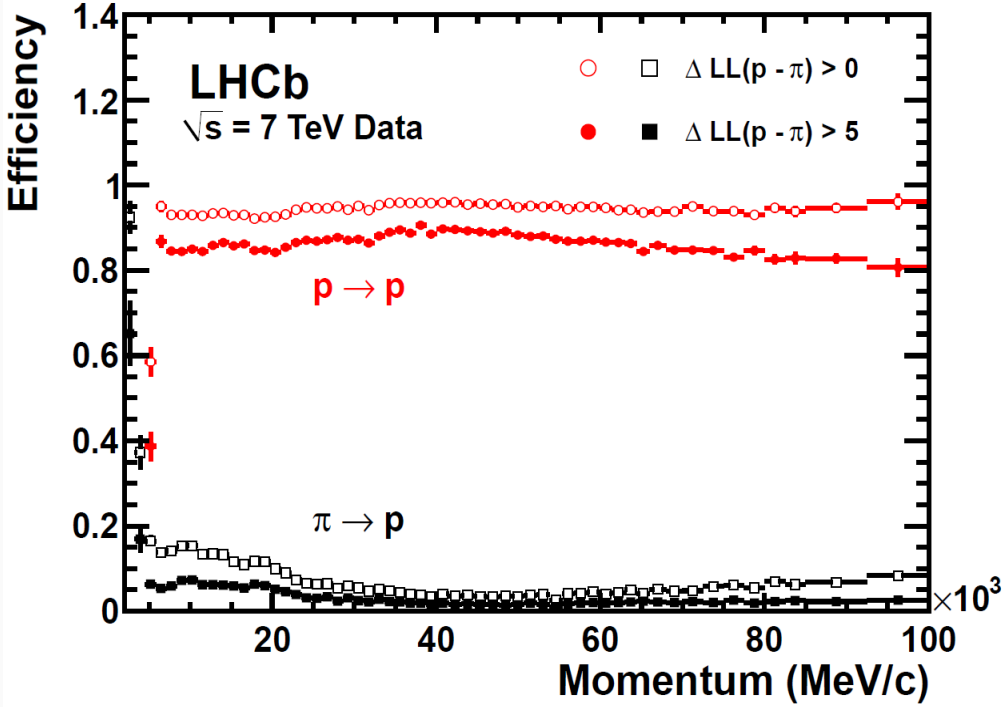






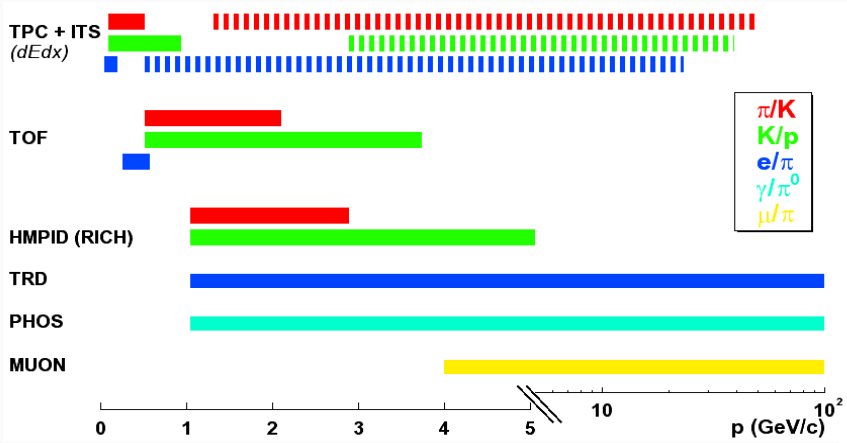
- Determination of the PID performances from the data samples

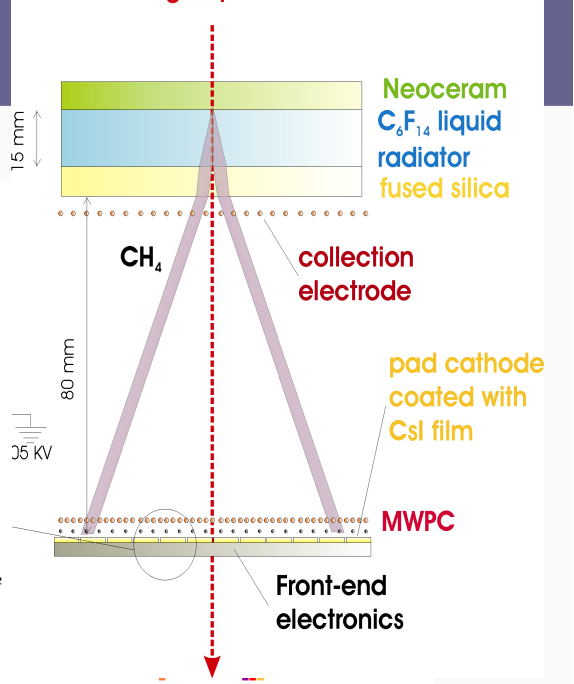


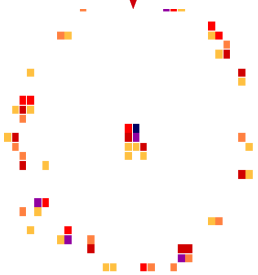


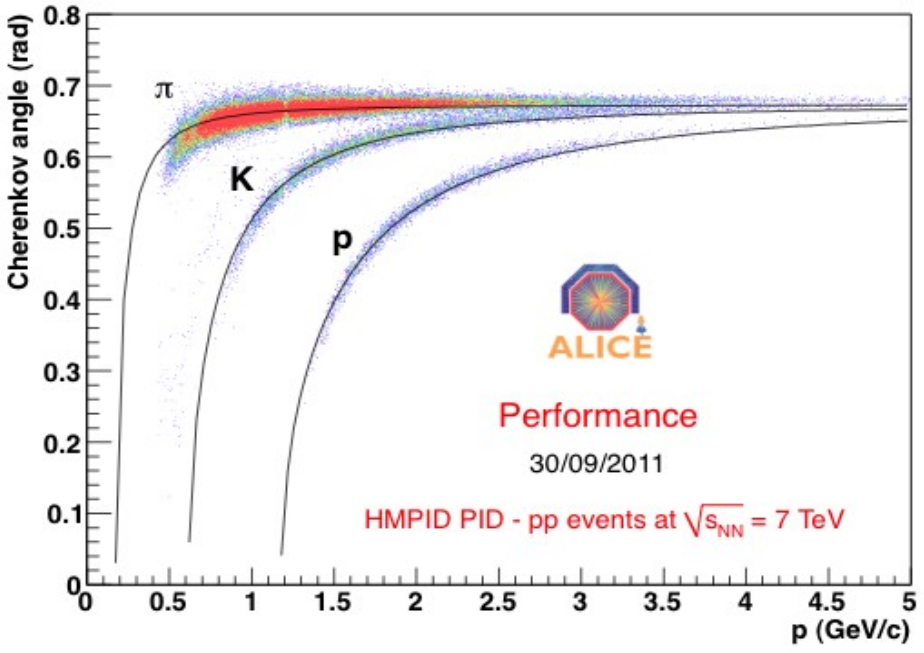
ALICE: HMPID

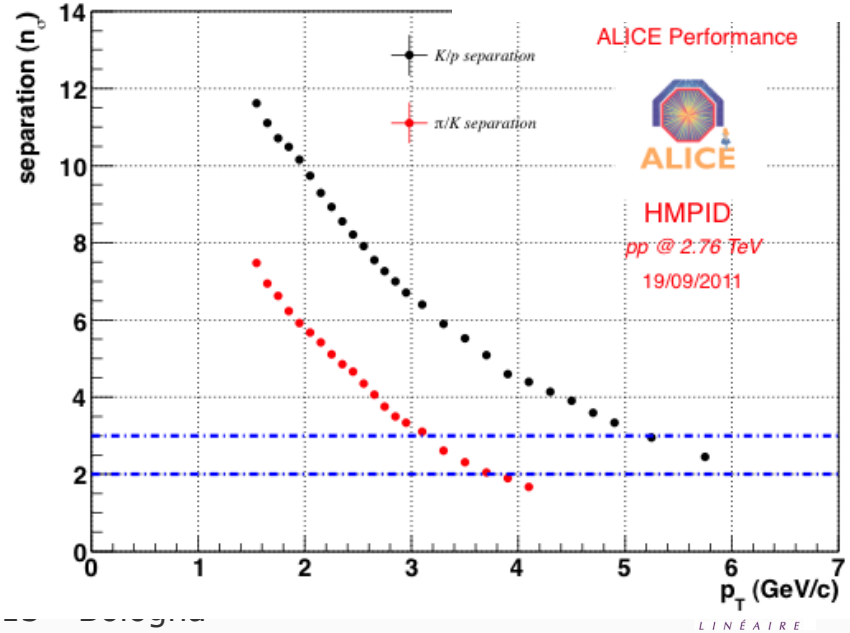
- High Momentum PID
- Single arm proximity focusing RICH
  - $|\eta|<0.6$,
  - $1.2°<\phi<58.8°$
- Liquid radiator
- Gaseous photon detector











LHCb calorimeter system: SPD, PRS, ECAL, HCAL

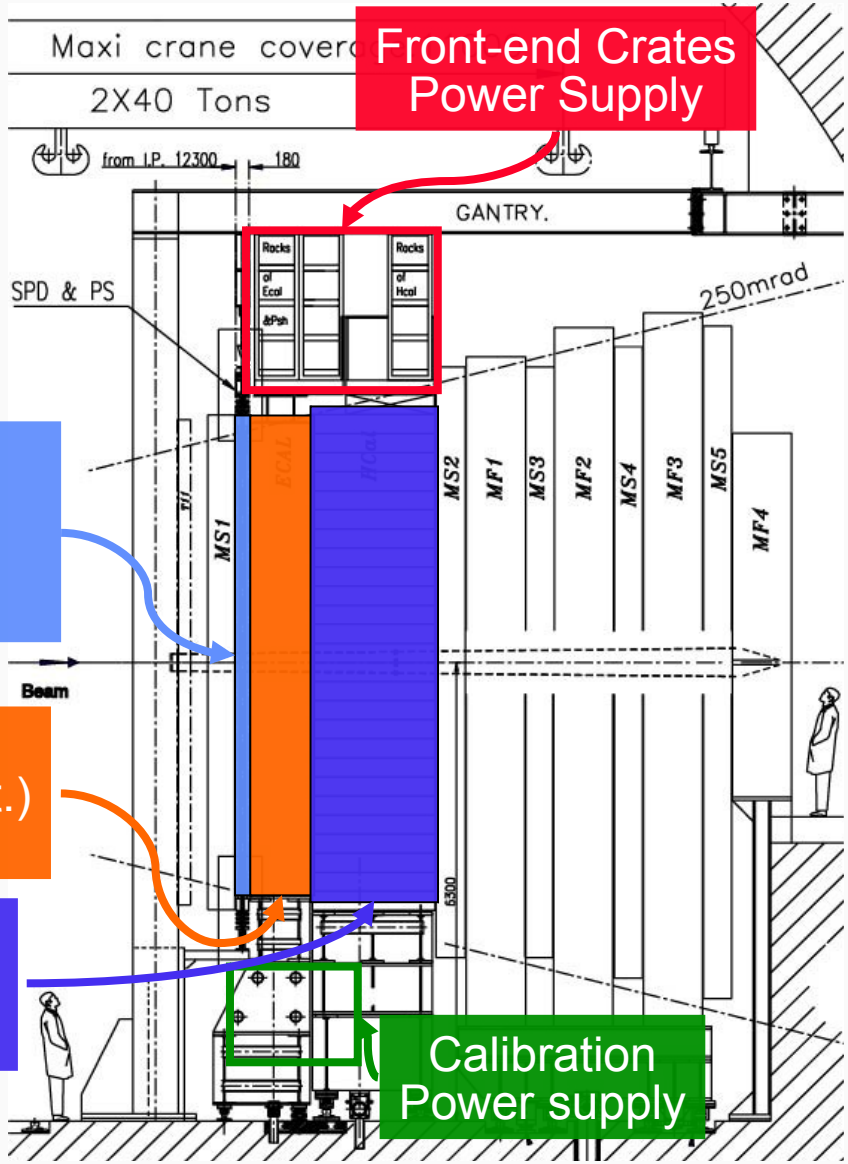
- Requirements:
  - Energy/position measurement
  - Identification of γ, electrons, hadrons
  - L0 trigger input:
    - High sensitivity
    - Fast response (40MHz)
  - Clean sampling in 25ns (no spill-over)

Front-end partly common

Scintillating Pad Det (SPD)
Preshower (PS)
Scint. Pad + Fibres+ MAPMT
6016 cells each

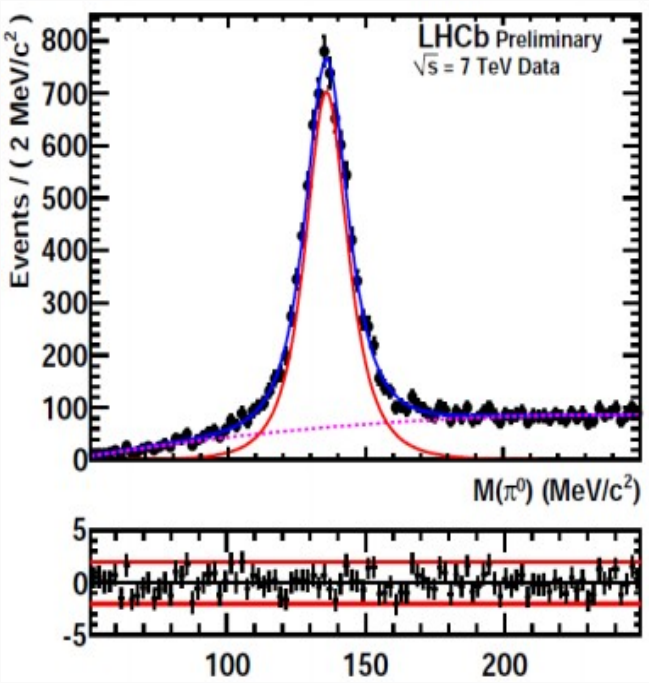
ECAL
Shashlik (Pb-scint.)
6016 cells

HCAL
Tiles (Iron-scint.)
1488 cells

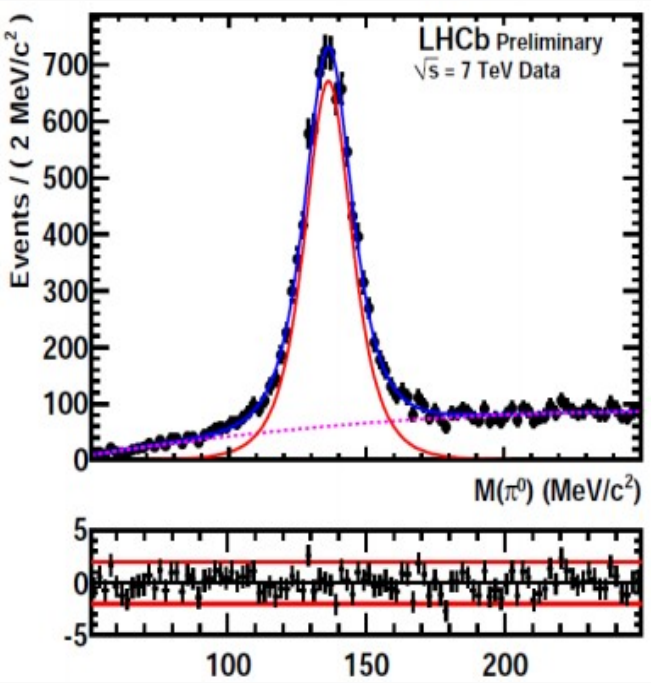


LHCb calorimeters: photon identification

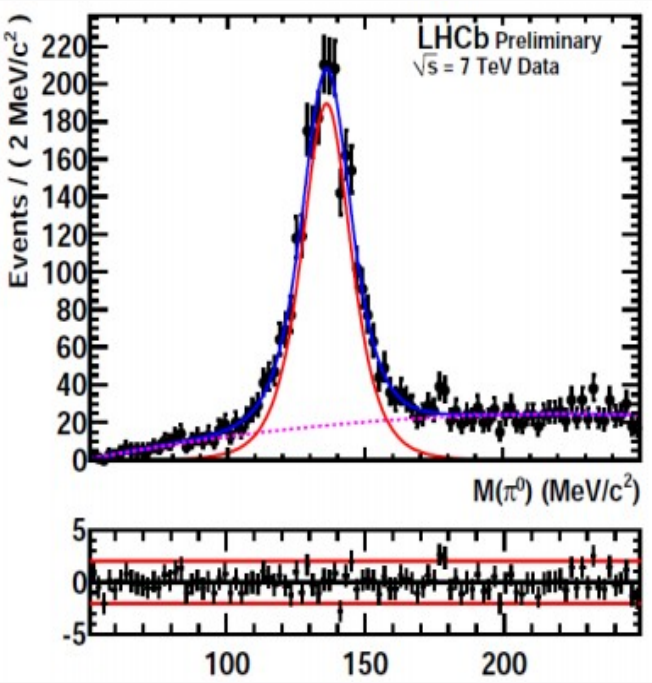
- Photon PID based on 2D PDF (variable, Energy) → ΔLog Likelihood method
  - Track – ECAL cluster position anti-coincidence
  - ECAL shower shape
  - Preshower energy
- Neutral pion selection
  - Cut on γ estimator (>0.8)
  - $P_t(\gamma)$>650MeV/c
- Typical neutral pion resolutions
  - $\pi^0 \to \gamma\gamma$: 7.2 +/- 0.1 MeV/c^2
  - $\pi^0 \to (e+e-)\gamma$: 8.2 +/- 0.1 MeV/c^2
  - $\pi^0 \to (e+e-)(e+e-)$: 9.5 +/- 0.1 MeV/c^2



0 conversion



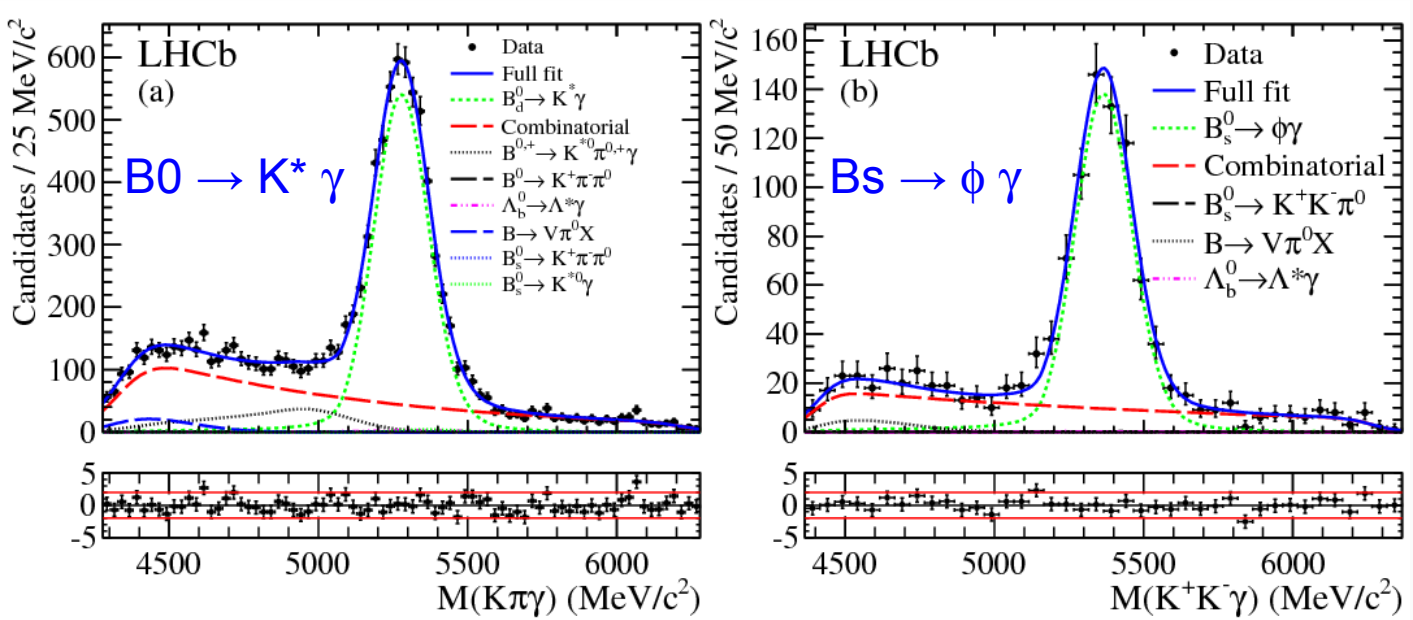
1 conversion



2 conversions

LHCb calorimeter: example of the radiative decays

- BR of radiative decays of B^0 and B_s suffer from large uncertainties (form factors)
  - $BR(B^0 \to K^*\gamma) = (4.3 \pm 1.4)\times10^{-5}$ – $BR(B_s \to \phi\gamma) = (4.3 \pm 1.4)\times10^{-5}$
- LHCb measurement (2011 data, $1.0 fb^{-1}$) (Nucl. Phys. B 867 (2012) 1)
  - $N(B^0 \to K^*\gamma) = 5279 \pm 93$ – $N(B_s \to \phi\gamma) = 691 \pm 36$
  - Ratio of BR ~ $1.23 \pm 0.06 \pm 0.04 \pm 0.10$ (fs/fd) [th : 1.0 ± 0.2]
- ACP $(B^0 \to K^*\gamma) = (0.8 \pm 1.7 \pm 0.9)\%$ [th : -0.61 ± 0.43]
- World best measurement :
  - $BR(B_s \to \phi\gamma) = (0.5 \pm 0.4)\times10^{-5}$ → in agreement with SM...

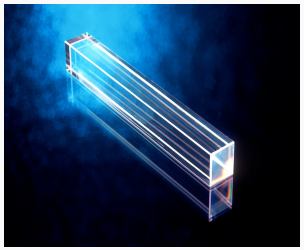


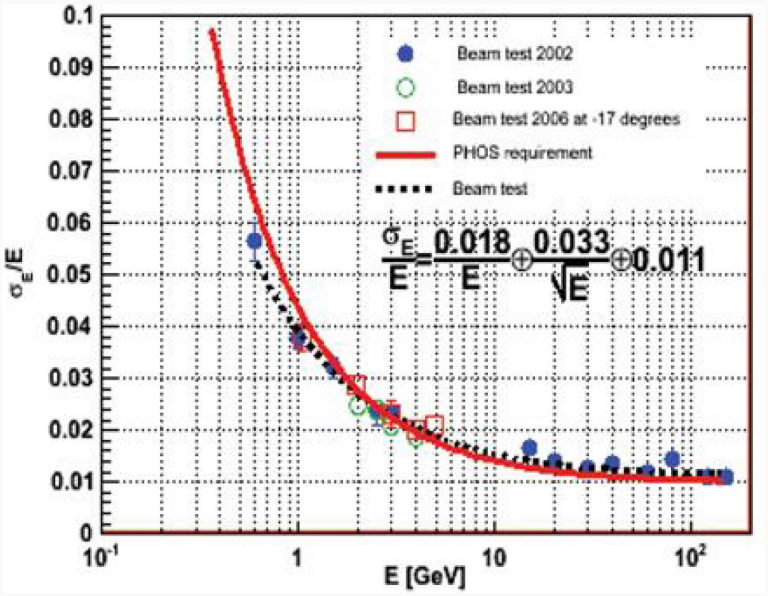
Invariant mass resolution: ~92 MeV/c2

ALICE calorimeter system

- ALICE calorimeter mainly based on 2 calorimeters : PHOS and EMCAL

- PHOS
  - Homogeneous EM Calorimeter
    - At 4.6m
    - $|\eta|<0.13$, $\Delta\phi\sim0.6\pi$
    - $PbW0_4$ crystals
    - Avalanche PhotoDiode
    - γ identification in the energy range $0<E<100$GeV
      - Upgrade planned up to 200GeV

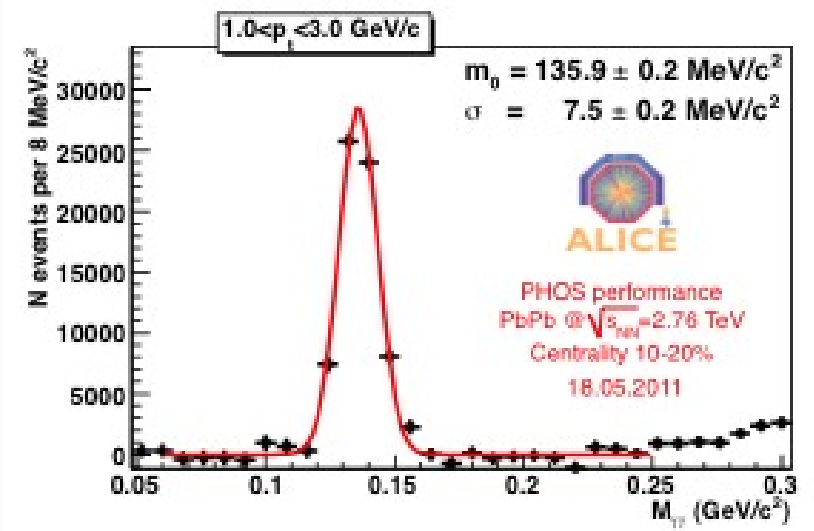


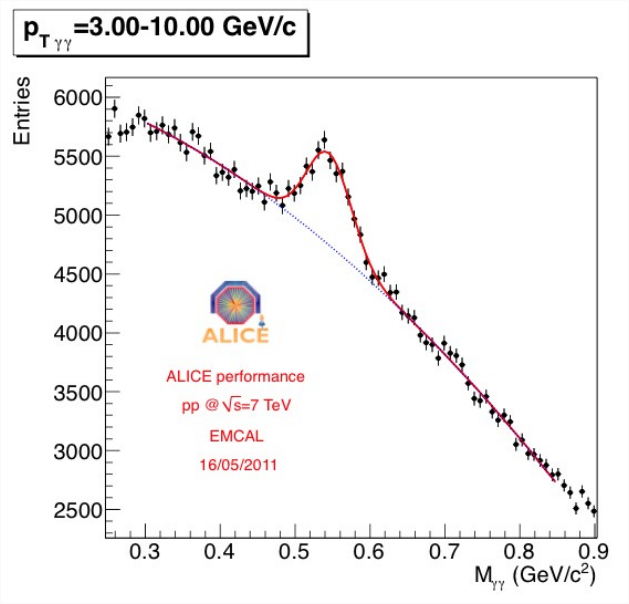


- EMCAL
  - Sampling EM Calorimeter
    - Located inside the large ALICE magnet, at 4.6m
    - $|\eta|<0.7$, $\Delta\phi\sim110°$
    - 77 layers Pb/scintillating
    - 12672 towers
    - Readout with WLS fibers
    - γ identification in the energy range $0<E<250$GeV

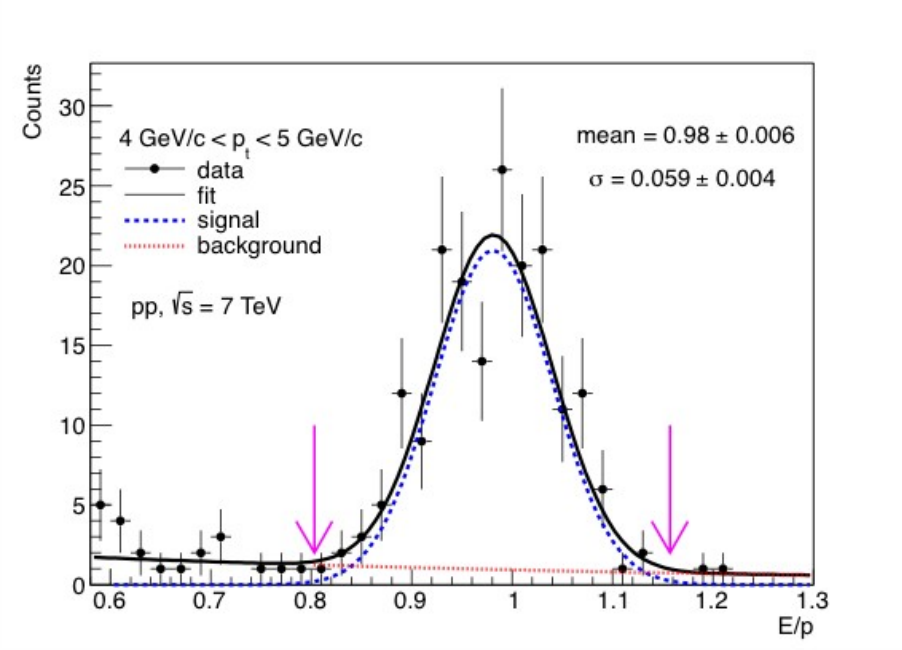
ALICE calorimeter system: photon and electron identification

- Reconstruction of neutral π and η



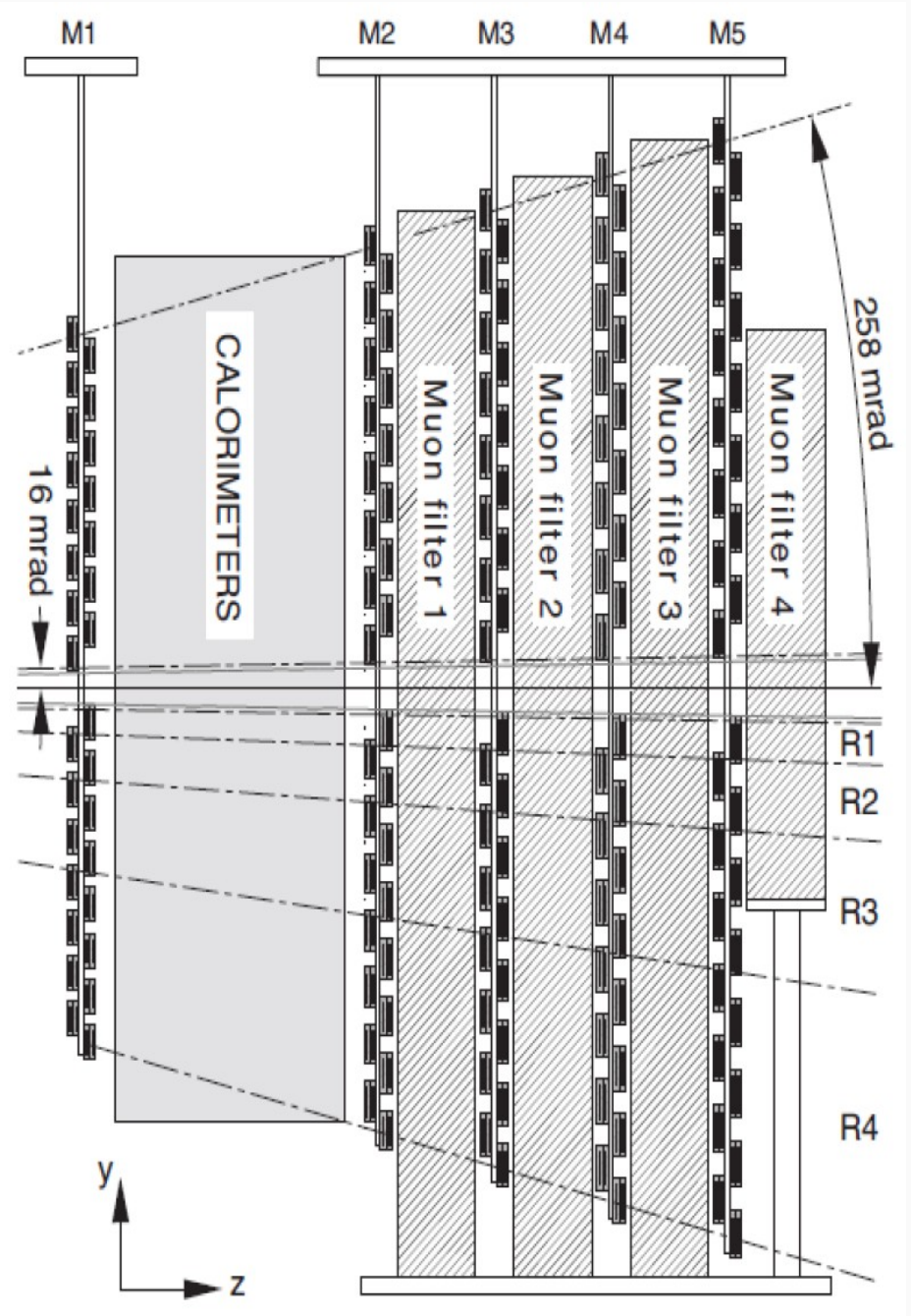


- Hadron rejection and Electron identification using E/p distribution

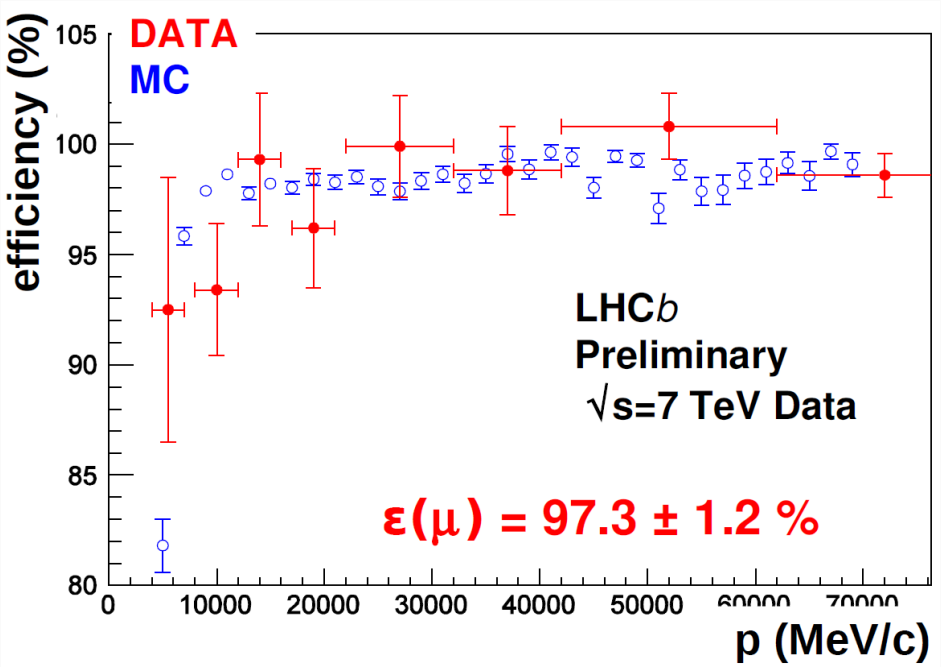


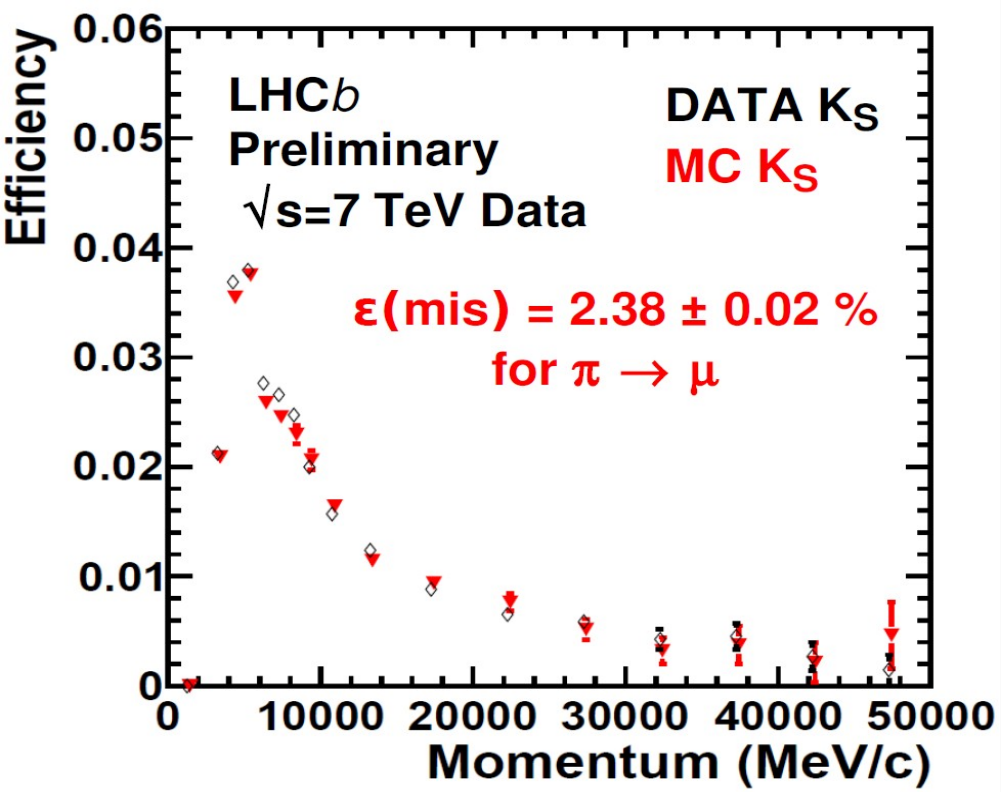
LHCb: muon identification

- 5 tracking stations alternating with hadron absorbers (~23λ)
  - M1 before the calorimeter
  - Level-arm to point towards the IP
- Technology
  - MWPC
  - 3-GEM in M1 (central region)
- Method based on
  - Track extrapolation to the μ-system
  - Look for hits in the region of trak impact point
  - Calculate probability from hit distribution in μ-stations
- Performance studied with
  - J/Ψ for μ-id
  - Use π/K/p from exclusive decays for mis-id



LHCb: muon identification

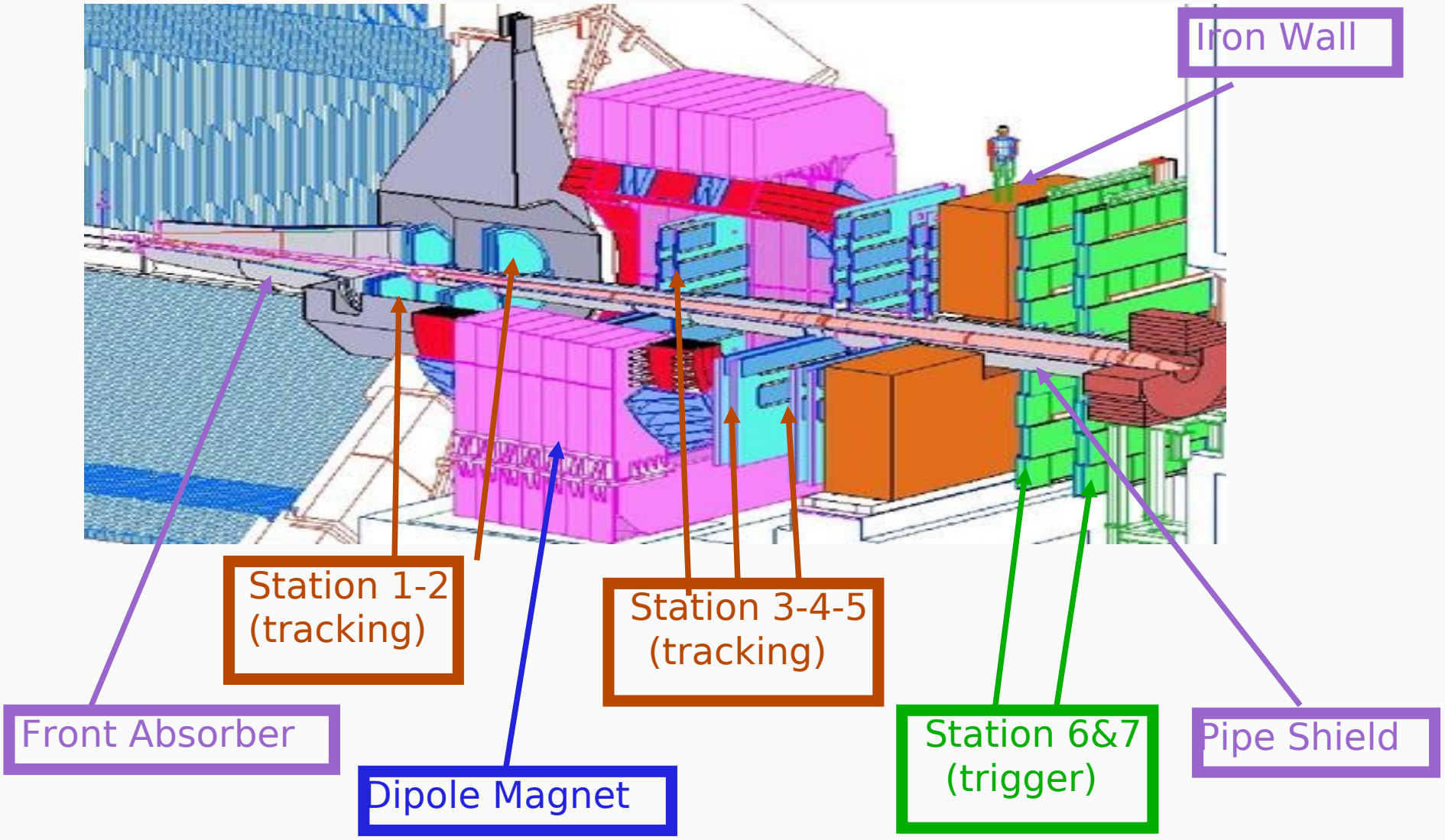




- Integrated efficiency over full spectrum ε(μ) = (97.3 ± 1.2)%
- Mis-id rates
  - ε(p → μ) = (0.21 ± 0.05)%
  - ε(π → μ) = (2.38 ± 0.02)%
  - ε(K → μ) = (1.67 ± 0.06)%
- Good agreement with MC estimated performances

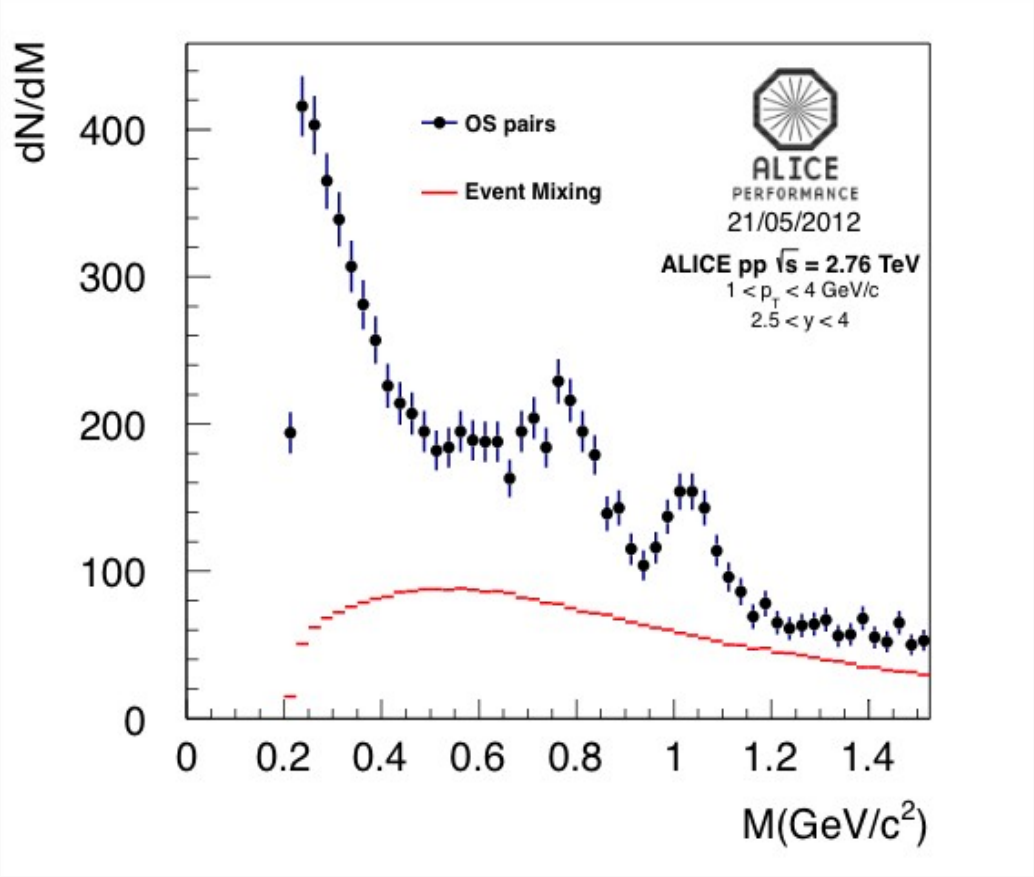
ALICE: muon identification

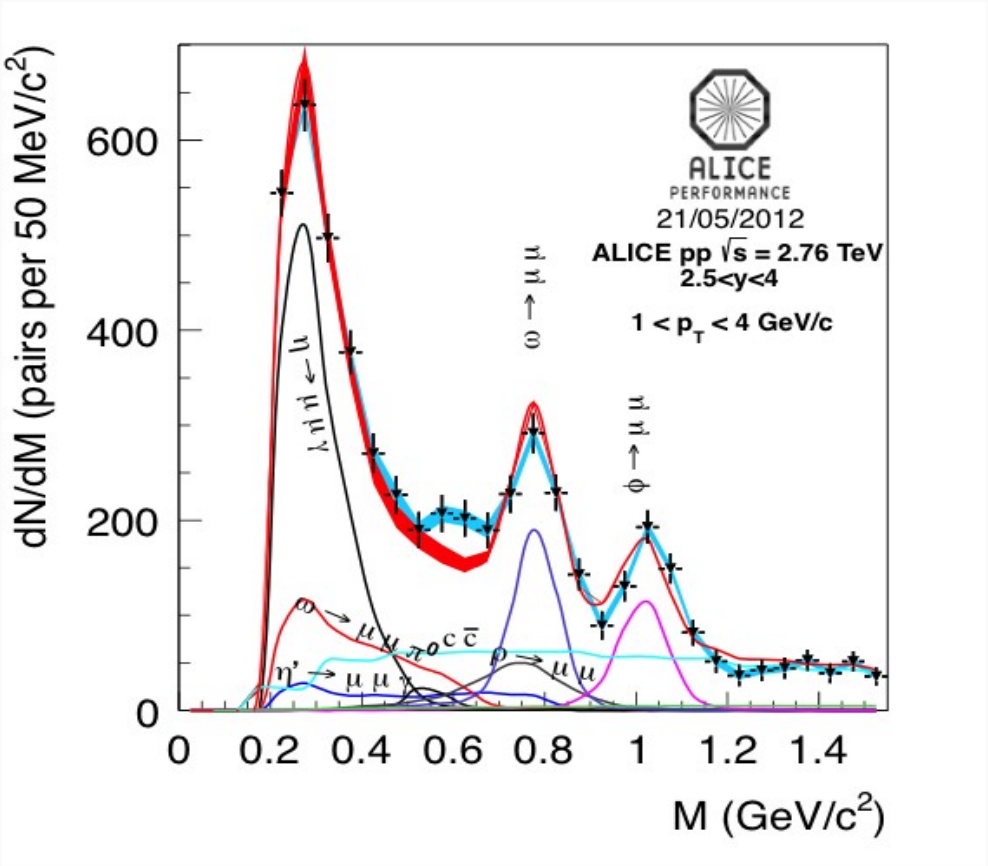
- 2 stations for trigger (RPC)
- 5 stations for muon tracking (MWPC)



ALICE: muon identification

- Muon spectrometer
  - located in a dipole magnetic field (3Tm)
  - At -2.5>η<-4
  - μ-identification for p>4GeV/c





Conclusions

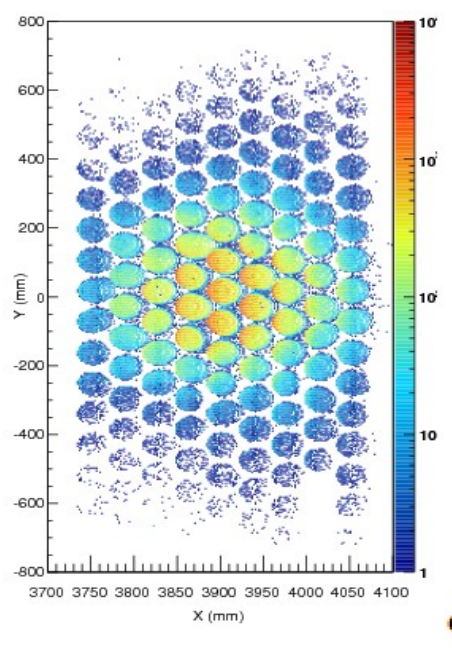
- ALICE and LHCb collaborations have designed, commissioned and run very powerful and sophisticated detectors
  - Covering a large momentum range
  - Using all the known techniques
  - With a high level of technology
- This was needed by the specificity of the physics of those experiments
- The performances are in the specifications
- The long shutdowns are foreseen to be used for upgrades
  - Particle identification is heavily concerned by this upgrade
    - ALICE
      - Improvement of its ITS for tracking
      - Extension of the muon system
      - PID with the RICH up to high Pt
      - Finer calorimetry up to high rapidity
    - LHCb
      - Improvement of the tracking
      - Review of the RICH
        - 1 single RICH with 2 radiators ?
      - Project of a TOF detector

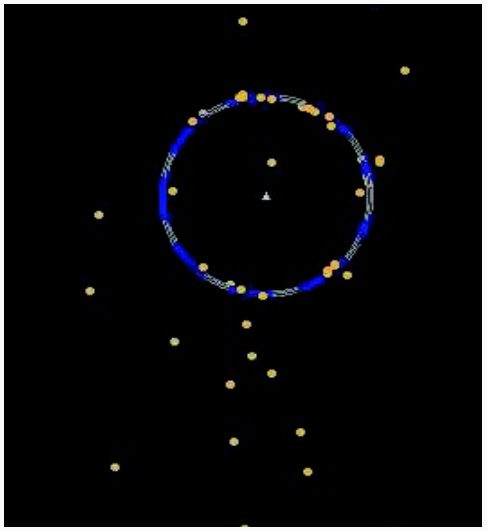
Backup

LHCb RICH System

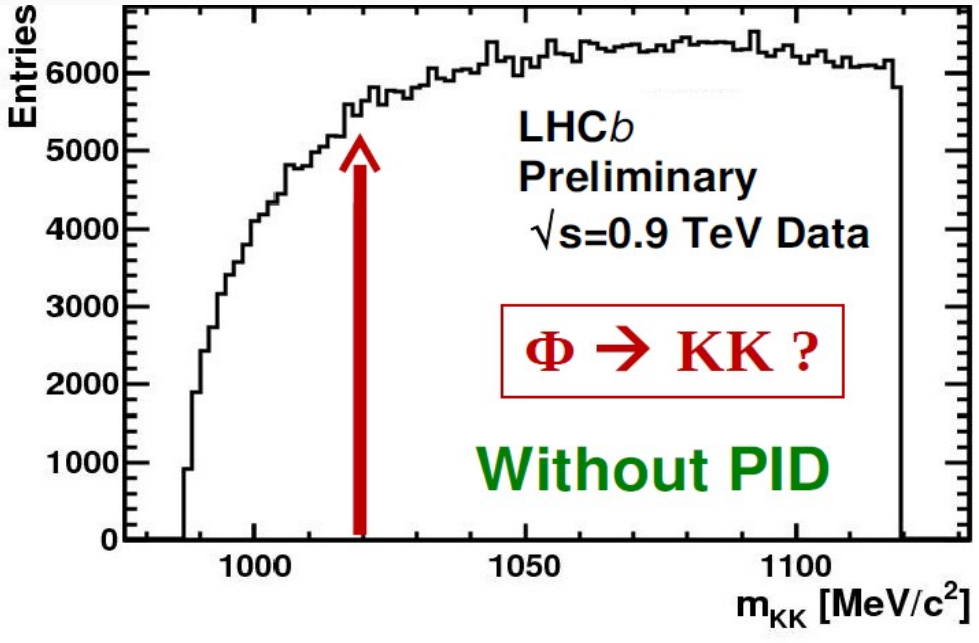
Installed HPDs

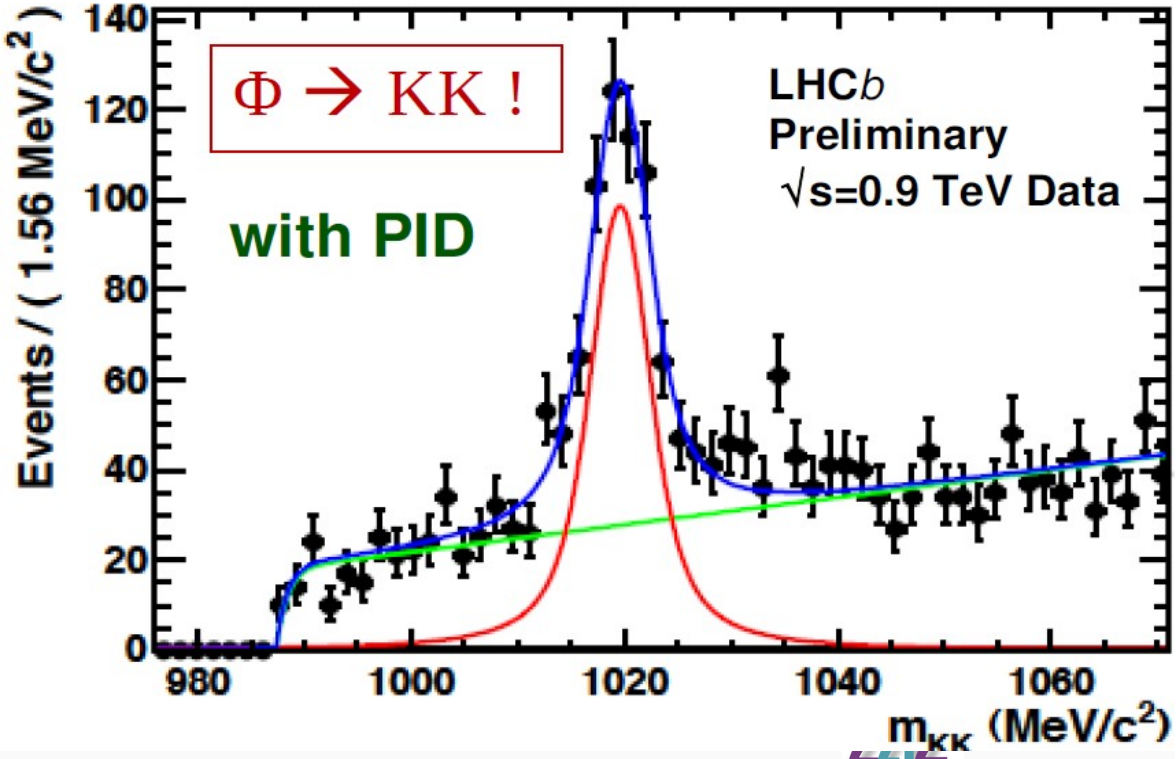
Data from LHC run





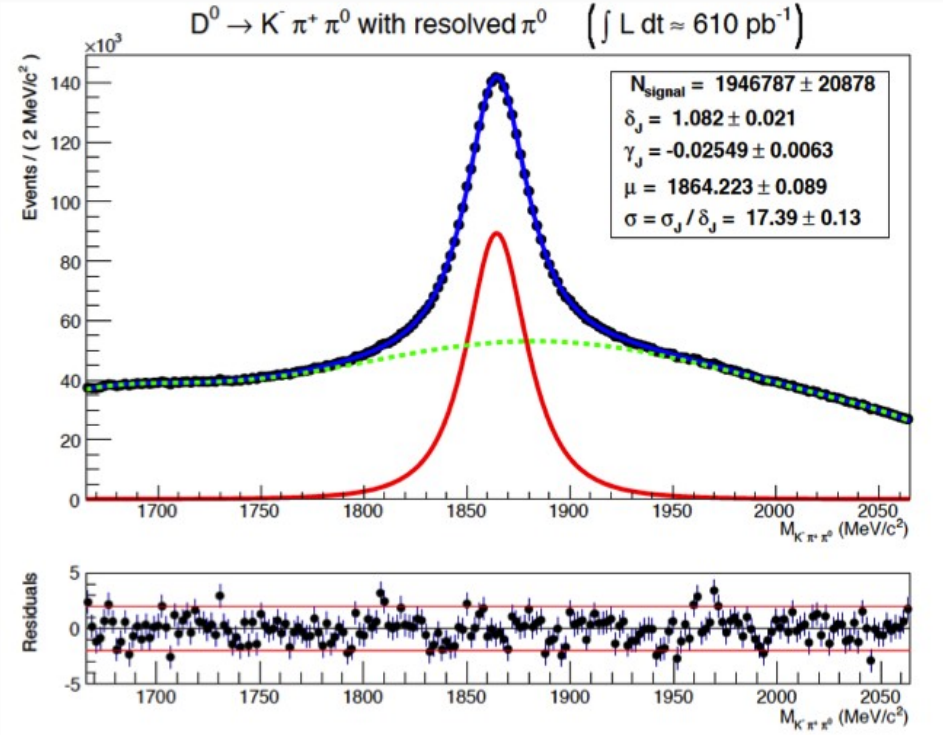
Hits from single event



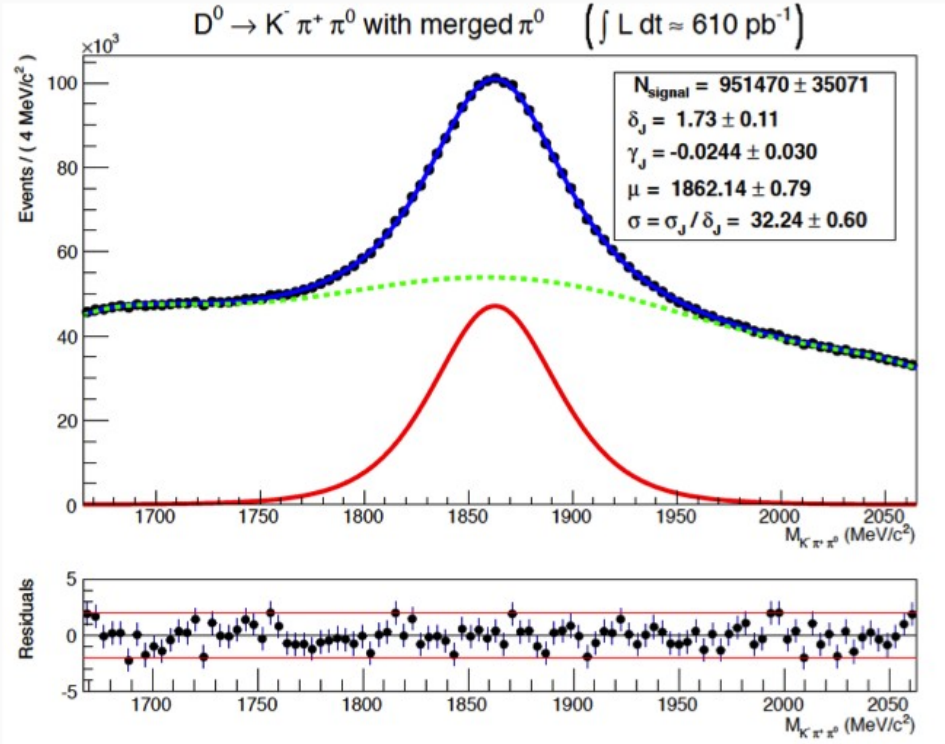


LHCb Calorimeters: neutral pions

- Neutral pions are selected either as 2 photons (photon identification) or as a single (broad) cluster
  - Merged pion algorithm based on cluster shape criteria



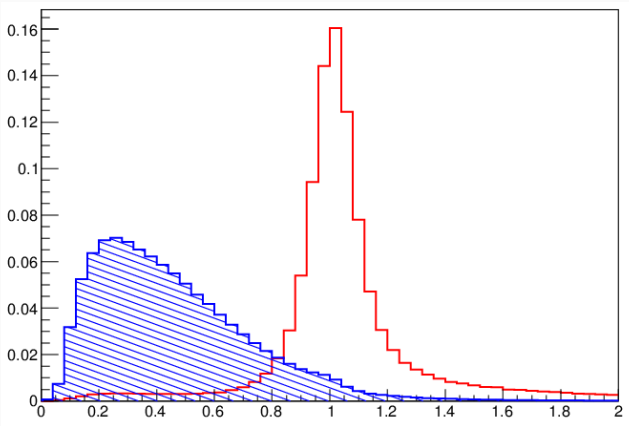
σ=17.4 MeV/c



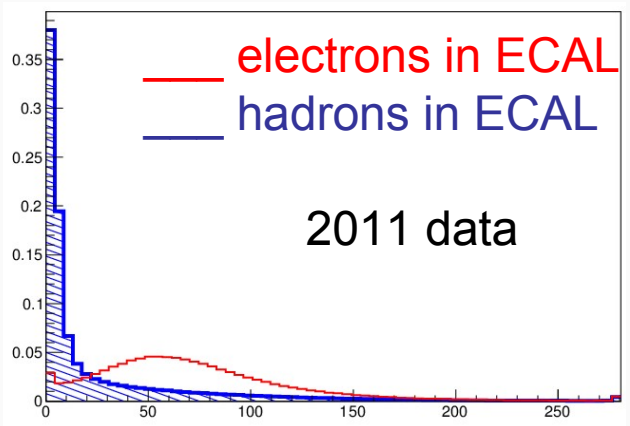
σ=32.2 MeV/c

LHCb Calorimeter: electron PID

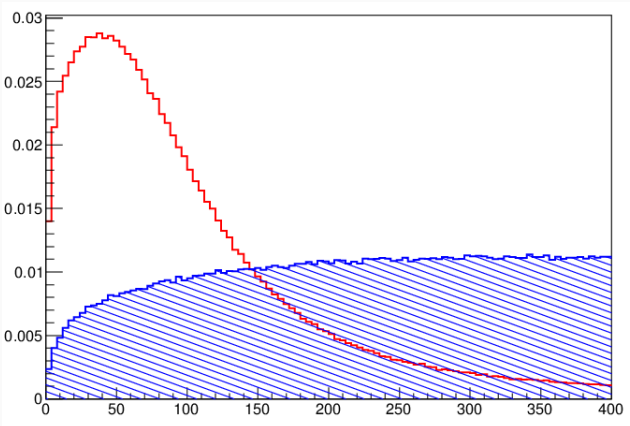
- Based on likelihood difference for signal(electron) and background
  - Fully based on data distributions
    - Signal: electrons/positrons from γ conversions
    - Background: hadrons from $D^0 \rightarrow K\pi$



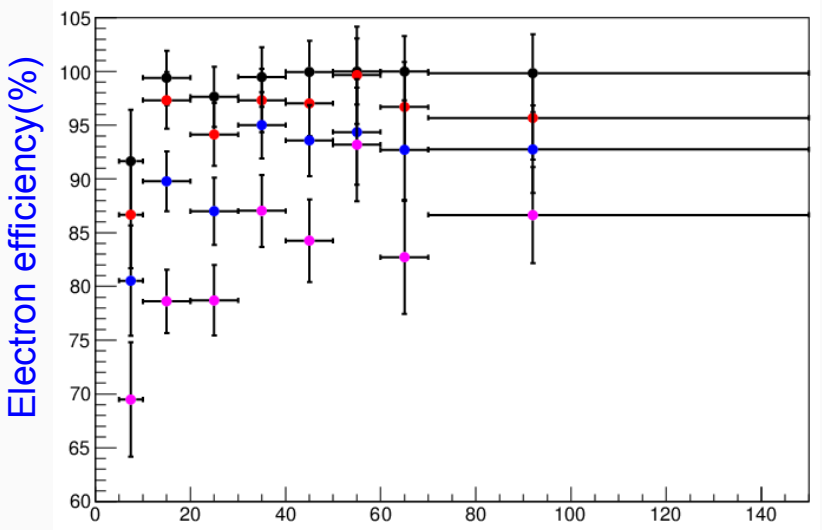
E/p

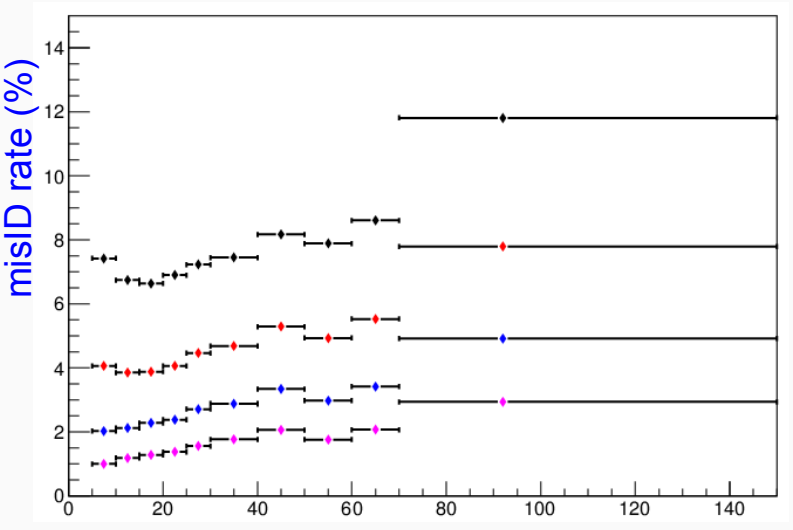


EPS(MeV)



Track – ECAL cluster matching





- Combined with RICH
  - E >97%
  - Mis-id~2%