RICH   Simulation in LHCb

LHC Detector Simulation Workshop

On   behalf of LHCb–RICH group

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RAL,
6-10-2011

Science & Technology
Facilities Council

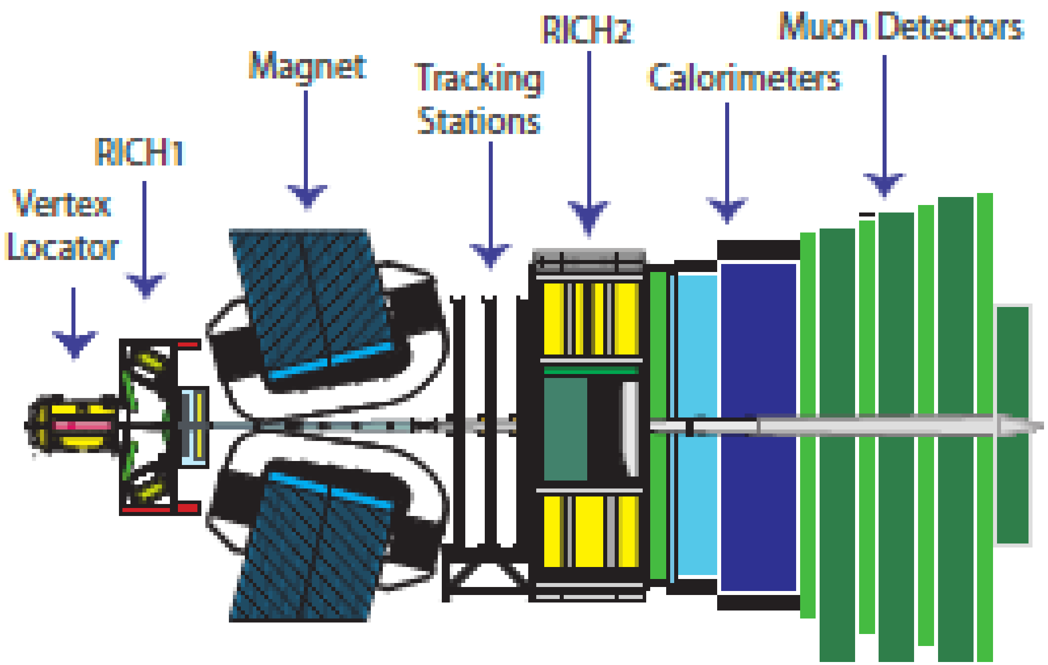
INTRODUCTION

- Simulating the RICH system in LHCb : Development → Maintenance phase
- Using GEANT4, within LHCb software framework (GAUDI)
- This presentation:
    - Brief description of the RICH system
    - Main features of the simulation
    - Validations using test beams in previous years
    - Comparisons with real data from LHCb , in 2011
    - Current status and plans

- Reference : *Simulation of LHCb RICH Detectors using GEANT4,* S.Easo et.al ., IEEE-Trans. Nucl. Sci. 52 (2005) 1665

LHCb and its RICH Detectors

LHCb: Forward arm spectrometer for
Precision Measurements of CP violation in B Meson System and search for New Physics.



- Particle Identification in LHCb
- Two RICH detectors
- Hybrid Photodiodes (HPD) as Photodetectors.

RICH1: Aerogel 2→10 GeV/c
C_4F_{10} < 70 GeV/c
RICH2 CF_4 < 100 GeV/c

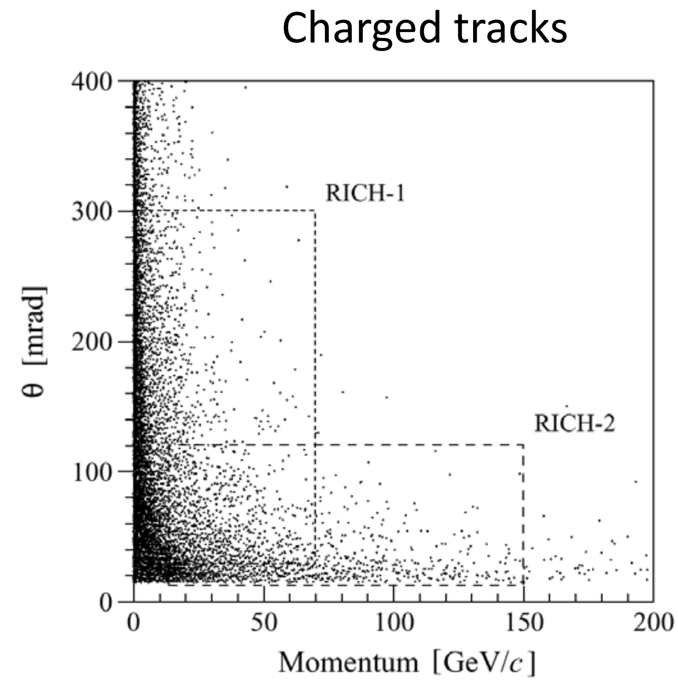
LHCb RICH Design

RICH1: Aerogel L=5cm p:2→10 GeV/c

C_4F_{10} L=85 cm p: < 70 GeV/c

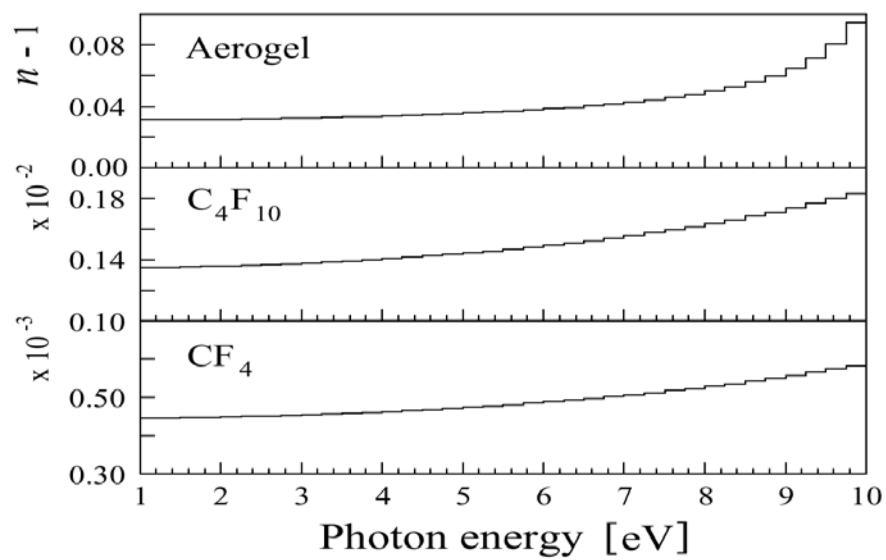
Upstream of LHCb Magnet
Acceptance: 25→250 mrad (vertical)
300 mrad (horizontal)
Gas vessel: 2 X 3 X 1 m^3

Charged tracks



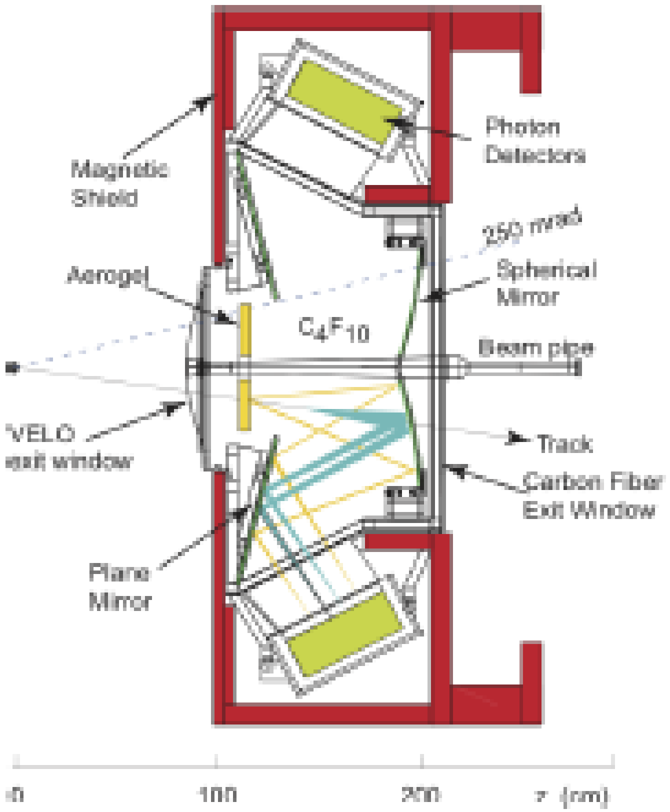
RICH2: CF_4 L=196 cm p: < 100 GeV/c

Downstream of LHCb Magnet
Acceptance: 15→100 mrad (vertical)
120 mrad (horizontal)
Gas vessel : 100 m^3



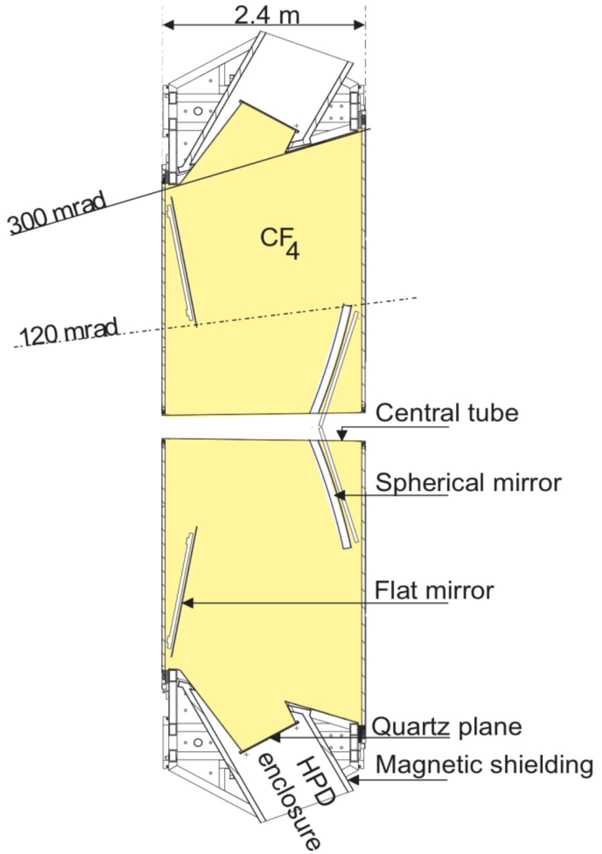
LHCb RICH system

Side View



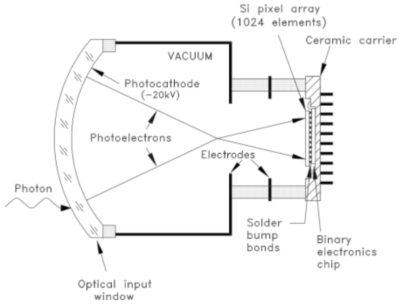
RICH1

TOP View



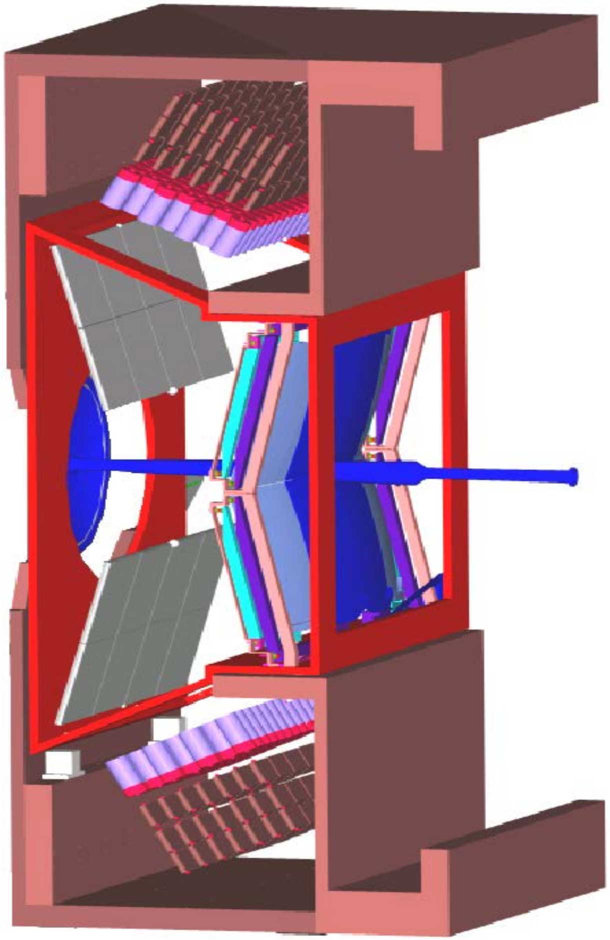
RICH2

HPD



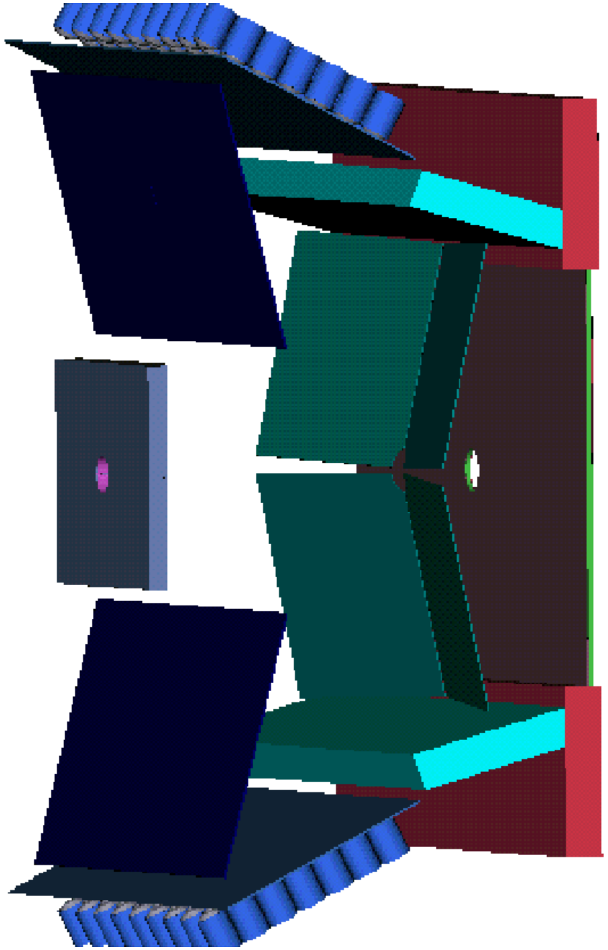
HPD

LHCb- RICH1 system



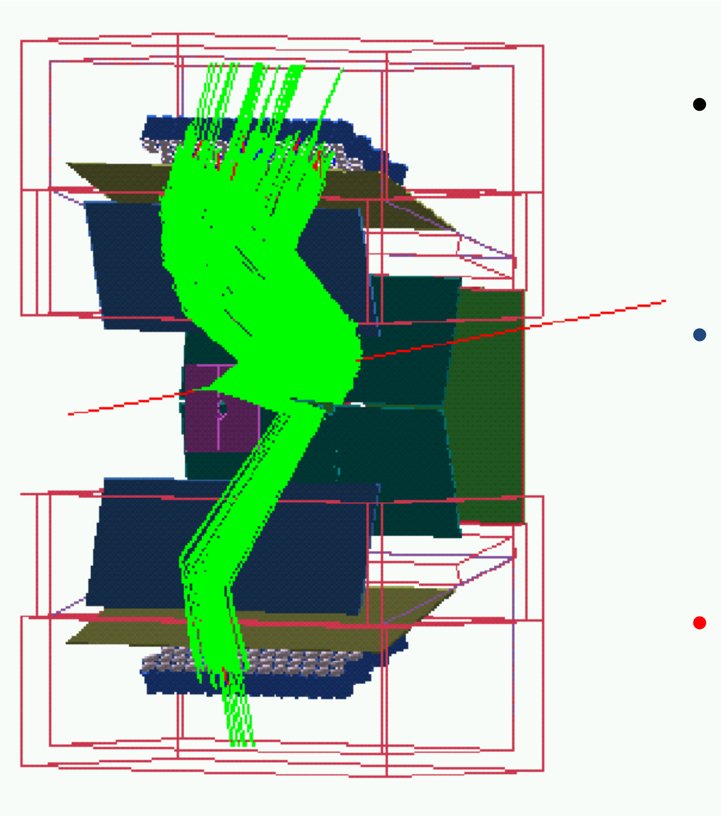
Engineering drawing

Similar case for RICH2



Simulation geometry.
Part of the iron shielding and
some other volumes not shown

Some features of the RICH Simulation



GEANT4 graphics
Charged track from particle gun
and Cherenkov photons

- Standard physics lists as used by LHCb, are used in the RICH .
- Few additions to GEANT4 optical photon processes to facilitate cpu optimization and data analysis in LHCb,
- The simulation has been working for several years in different production runs. Now being maintained and kept up-to-date with changes in LHCb and GEANT4 versions.

Few Additions to Processes with Optical photons

- Photon creation: Attach user parameters to G4Track, to tag things like the angle between photon and charged track for later analysis.
  Tag if a photon is created by Cherenkov process or scintillation.
  Refractive index tables with different wavelength ranges for photon creation and propagation, (to optimize CPU time).

- Photon propagation: Avoid things like quasi-infinite number of total internal reflections (in a rectangular block) or Rayleigh scattering.
  Tag if a photon is Rayleigh scattered in aerogel.

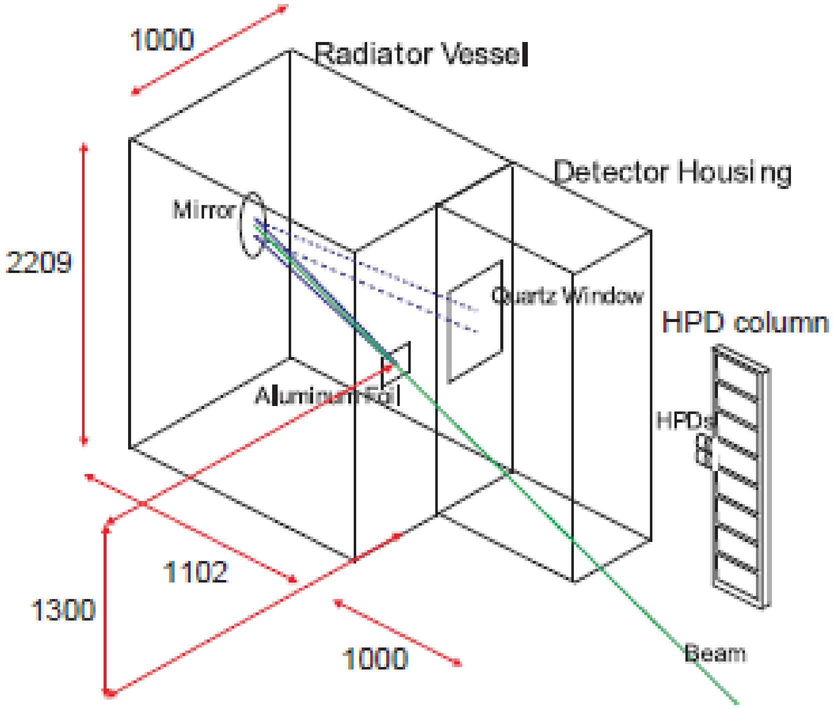
- HPD Simulation: Created two new processes:

  (a) Photo Electric Effect in HPD: Use the measured QE tables to create photoelectrons similar to G4PhotoElectric Process
  (b) Energy Loss in HPD Silicon: Simple and fast process to simulate this.

Validation using test beams

- Test beam versions of this simulation was validated using test beam data taken few times during the last decade. Two examples :

HPDs mounted in columns on two testbeams



Schematic of a typical prototype RICH test beam setup

Validation using test beams

(A) Performance of the LHCb RICH photodetectors in a charged particle beam : M.Adinolfi et.al, NIM A 574(2007) 39-49

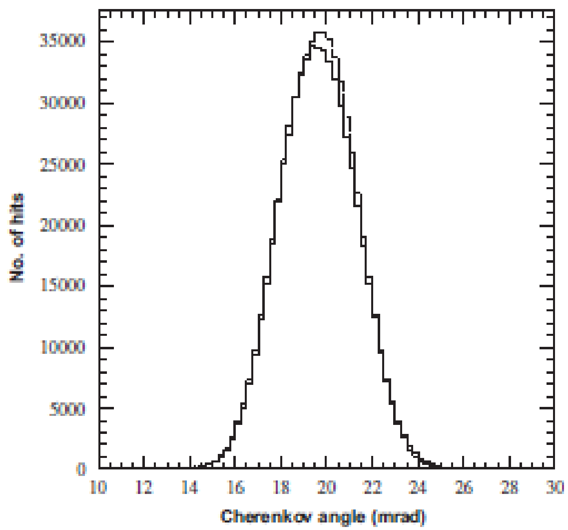


Fig. 12. Reconstructed Cherenkov angle for data (solid line) and MC simulation (dashed line) for HPD C1. There is one entry per photo-electron hit.

Table 3
The chromatic, photon reconstruction, beam reconstruction and charge sharing contributions to the MC Cherenkov angle resolution, compared to the Cherenkov angle resolution observed in the data

Effect	Contribution (mrad)
Chromatic	0.41
Photon reconstruction	1.28
Pixelisation	0.78
PSF	1.00
Emission point	0.19
Beam reconstruction	0.95
Charge sharing	0.12
MC simulation total	1.64
Data	1.66

The photon reconstruction is further broken down into sub-components from pixelisation, the PSF and the emission point effect.

With N_2 radiator

	Data	MC
Resolution mrad	1.66 ± 0.03	1.64
Yield in one of the HPDs	10.2 ± 0.1	10 .0 ± 0.4

Similar results for yields in other HPDs. Using LHCb software framework

Validation using Testbeams

(B) Performance of the LHCb RICH photo-detectors and readout in a system test using charged particles from a 25 ns- structured beam,
M.Adinolfi et.al. , NIM A 603 (2009) 287-293

Radiator	quantity	Data	MC
N_2	resolution mrad	$0.296 \pm 0.003 \pm 0.006$	0.29 ± 0.003
C_4F_{10}	resolution mrad	$0.166 \pm 0.002 \pm 0.002$	0.174 ± 0.005
N_2	yield	$12.44 \pm 0.04^{+0.08}_{-0.09}$	12.15 ± 0.61
C_4F_{10}	yield	8.9 ± 0.5	9.3 ± 0.5

Here, resolution: Single photon Cherenkov angle resolution
yield: Yield in a typical HPD. Similar yields in other HPDs

Using LHCb software framework and standard LHCb software chain

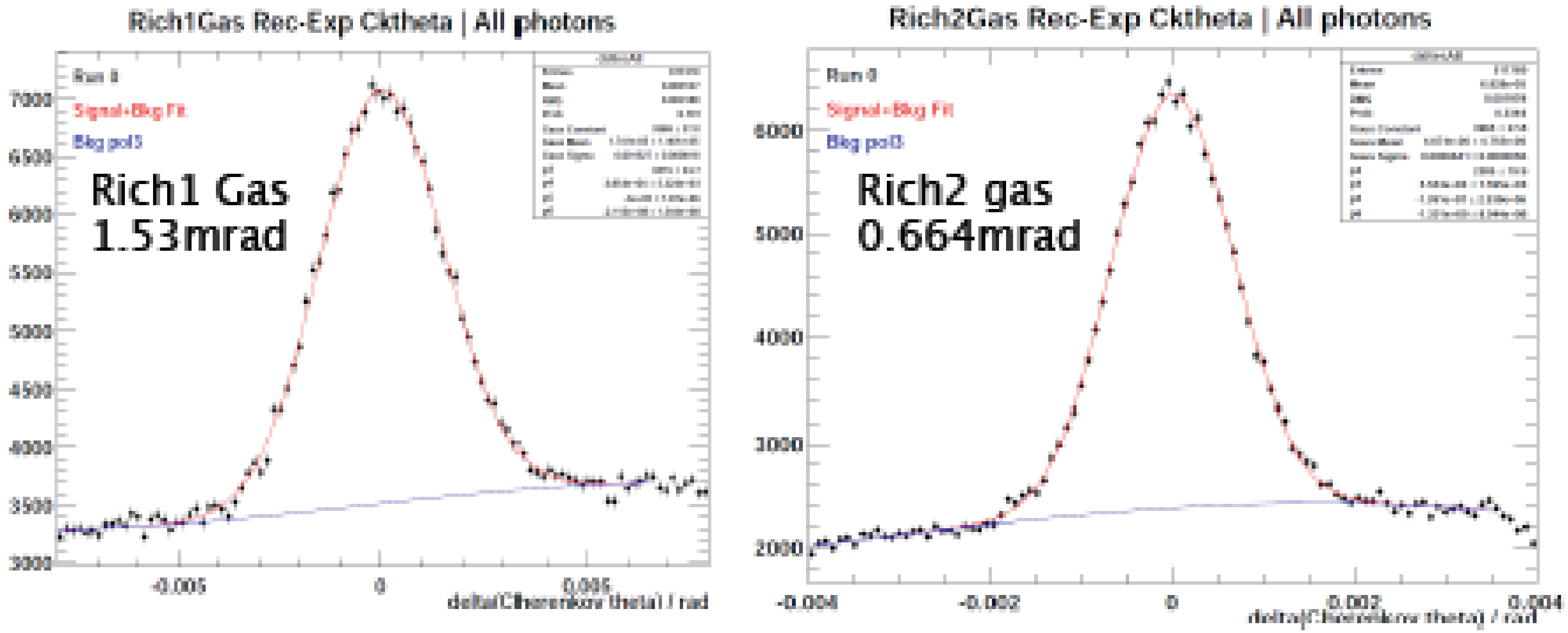
RICH Simulation : Past and Future

- A simplified version of one of this testbeam simulation programs , is a standard '*GEANT4 advanced example*' .

- Few years ago one of the testbeams with aerogel radiator showed a discrepancy in resolutions between data and MC. (LHCb Note 2006-006), although the yields were similar.
  One possible reason, contributing to this was , lack of MIE scattering process.
  In the future, we may try use the MIE scattering process available in recent versions of GEANT4.

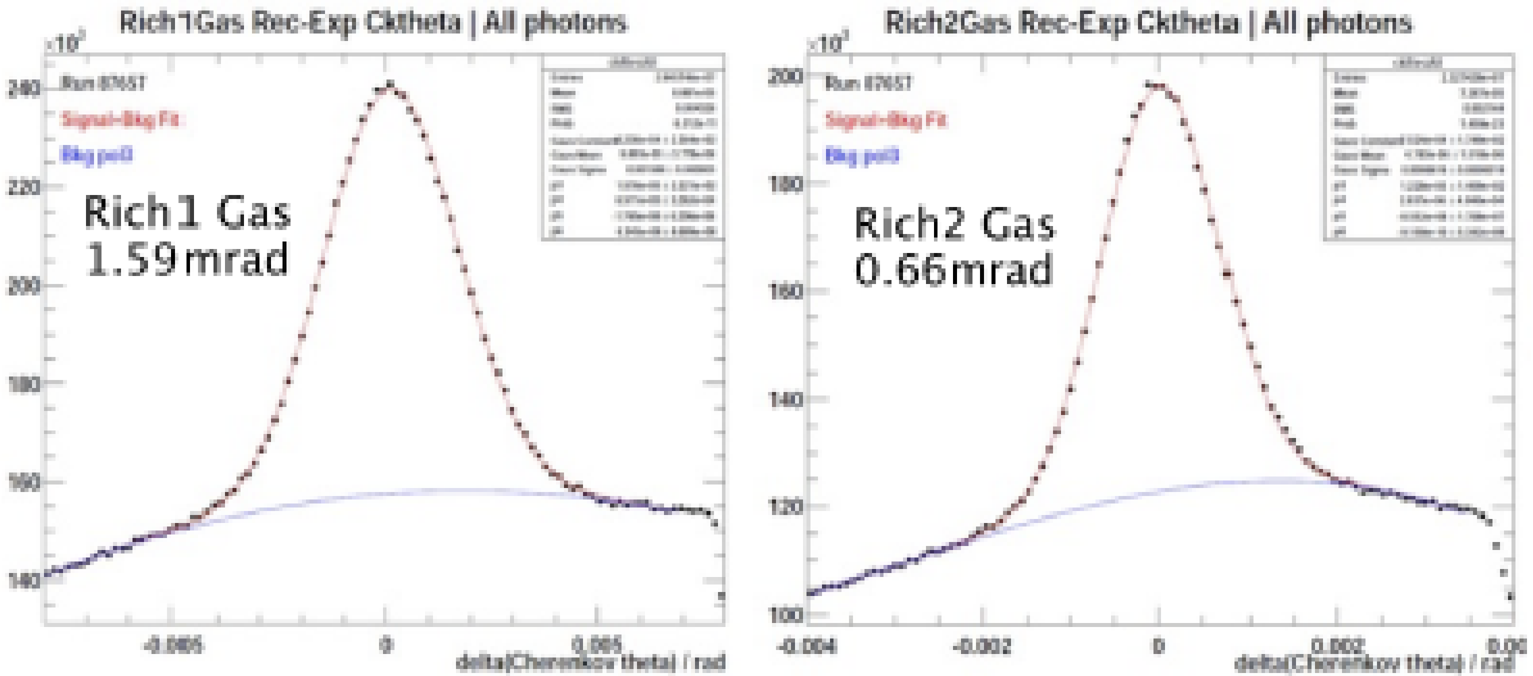
- More RICH testbeams expected in the coming years as part PID upgrade in LHCb.

Performance of LHCb RICH Simulation: Resolutions



Data reconstructed from LHCb MC10 production run

Resolutions in LHCb Real Data



Monte Carlo →

	C_4F_{10}	CF_4
$\sigma(\theta_c)$	1.53mrad	0.66mrad

- RICH1: Residual misalignments causing
  the minor difference between MC and real data.

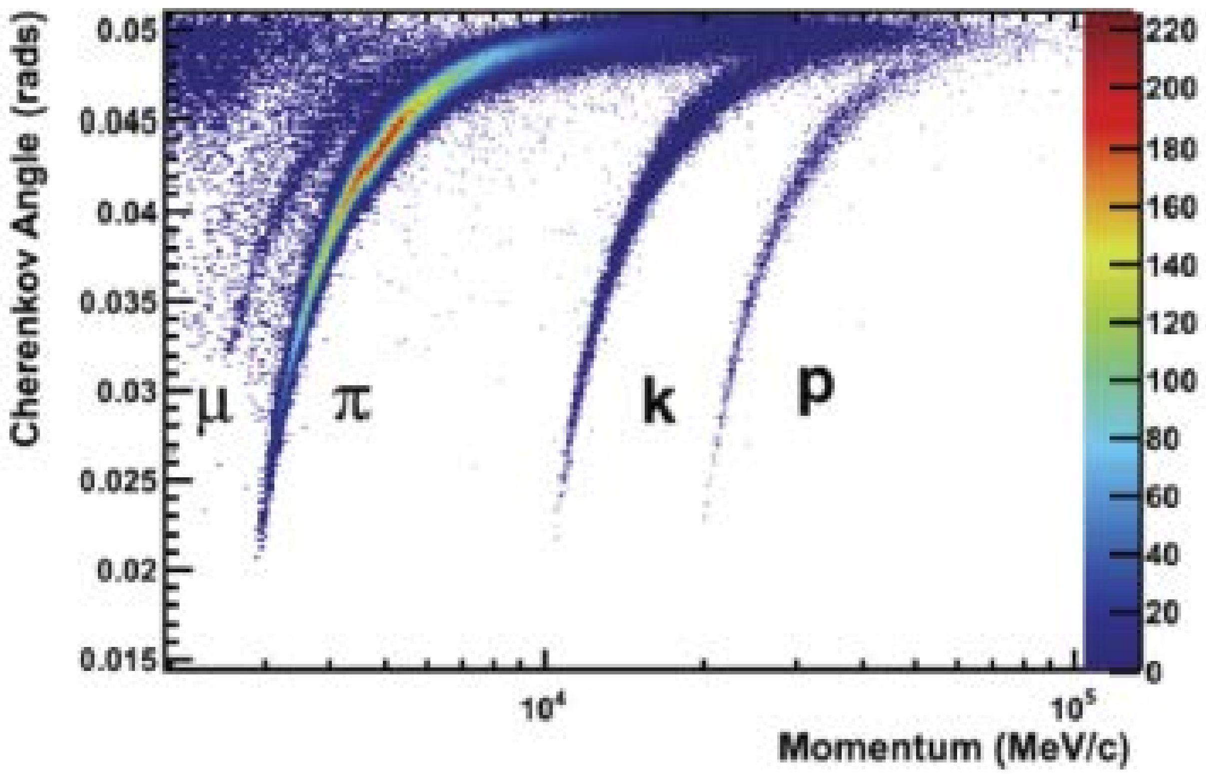
More on Resolutions and Yields: Work in progress

Aerogel: Resolutions in data significantly worse than that from MC.
It is understood to be due to the change in properties
of Aerogel in C_4F_{10} environment.
This is being fixed in hardware.
More information in a backup slide

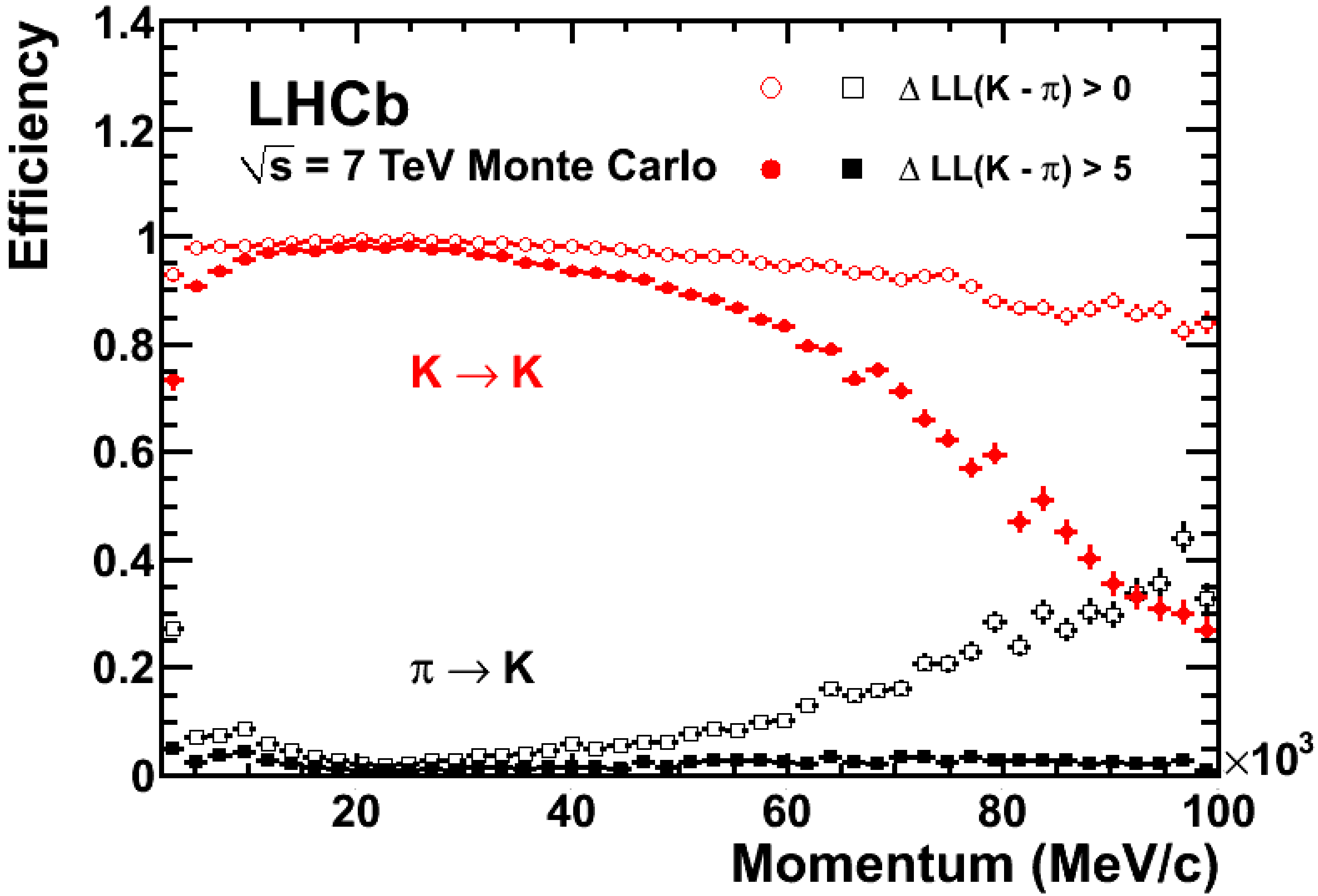
Yields : Difficult to estimate due to overlapping Cherenkov rings.
Recently estimated using S-Weights method.
Differences between data and MC being studied.
More information in a backup slide

Performance of LHCb RICH Real Data

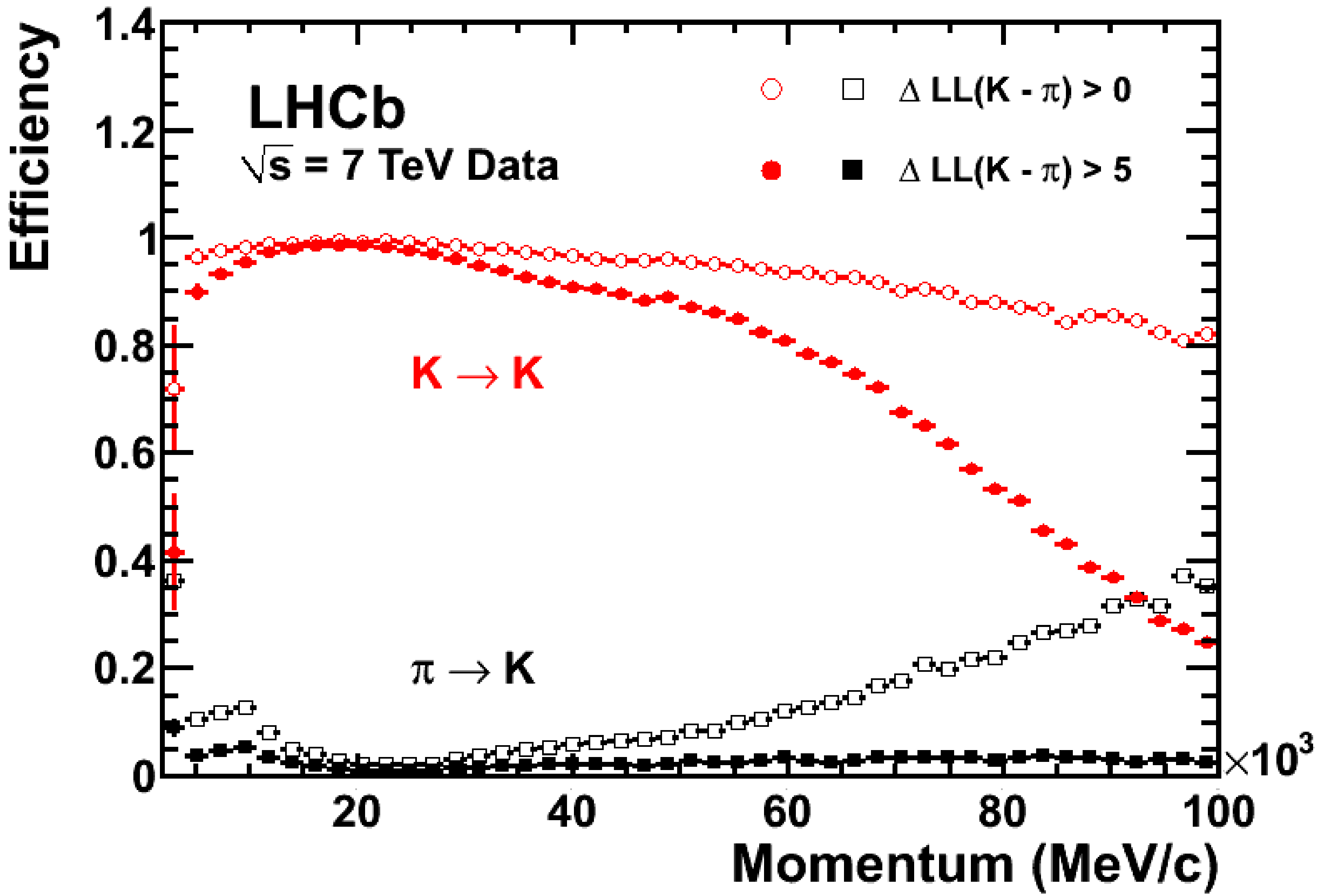
- From isolated Cherenkov rings in Real Data



Typical PID Performance in MC Data



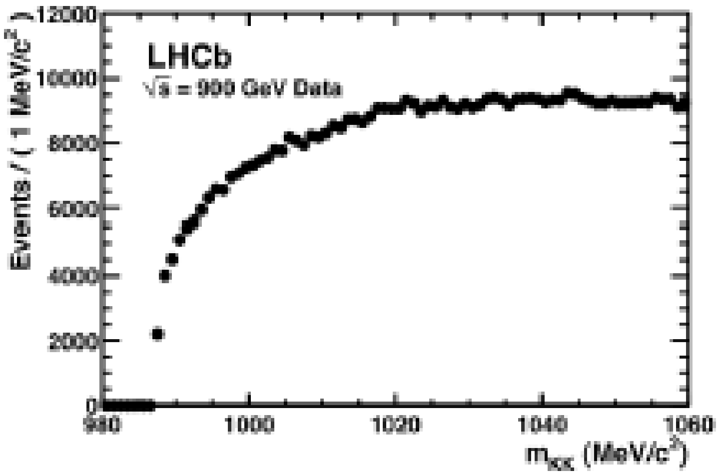
Typical PID Performance in Real Data



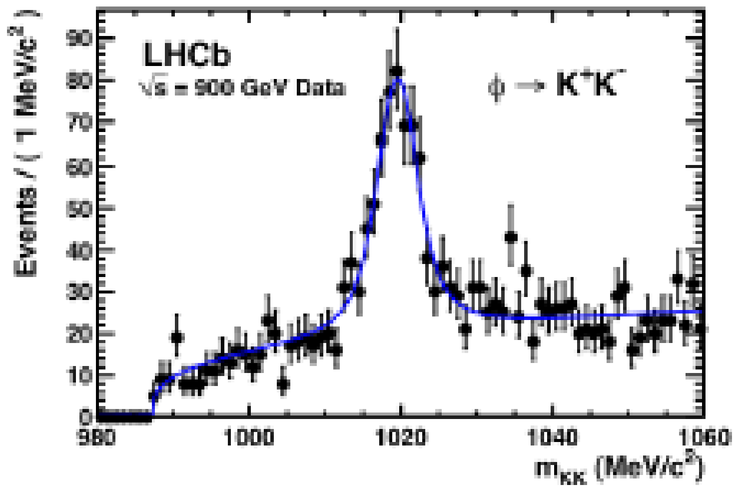
From RICH Calibration samples

RICH Data in Physics Analysis

Without RICH data

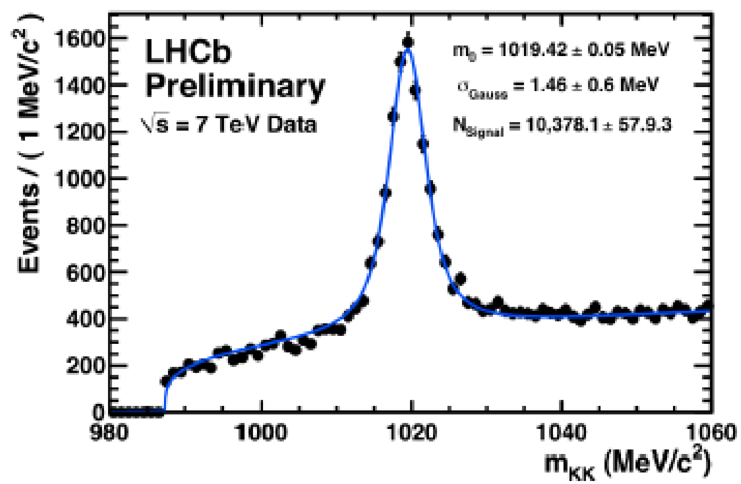


With RICH data



$\phi \rightarrow K^+K^-$

Current status
using RICH data



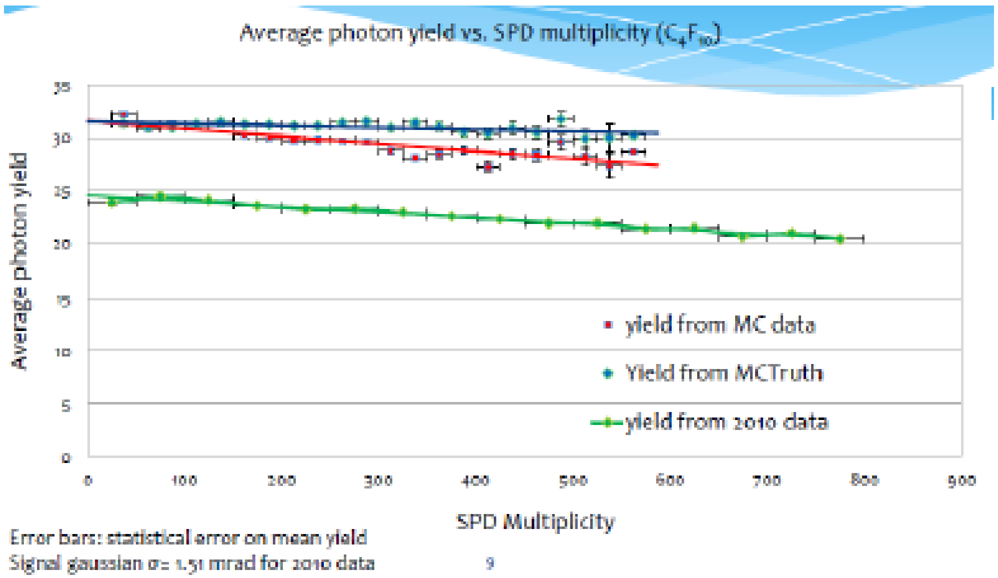
RICH data has been used in Physics analysis

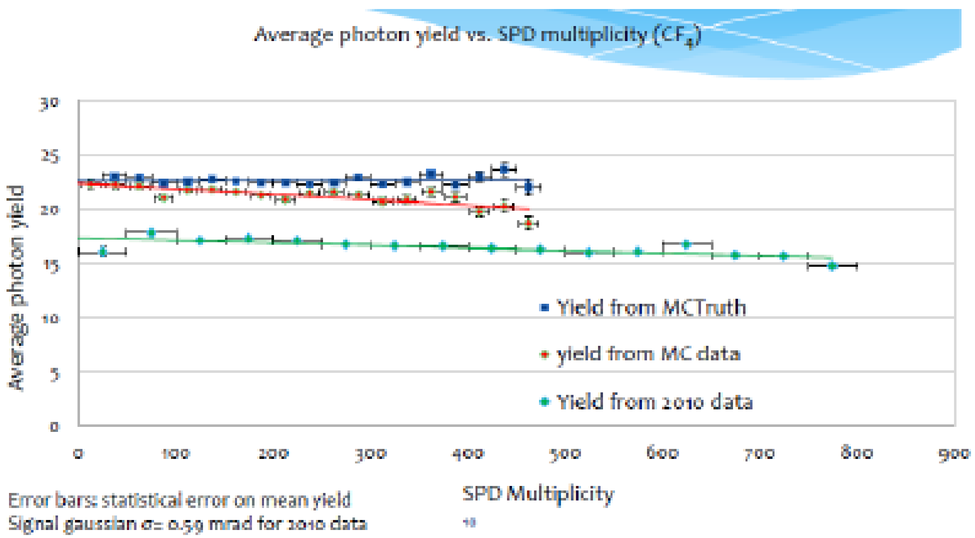
Current Status and Plans

- The real data from RICH gives similar performance to that from MC data.
- Work on alignment and further understanding of the data are in progress.
- The simulated data has been in useful in analysing the real data from LHCb.
- Work on RICH upgrade simulations has started.

BACKUP SLIDES

Yields : Work in progress

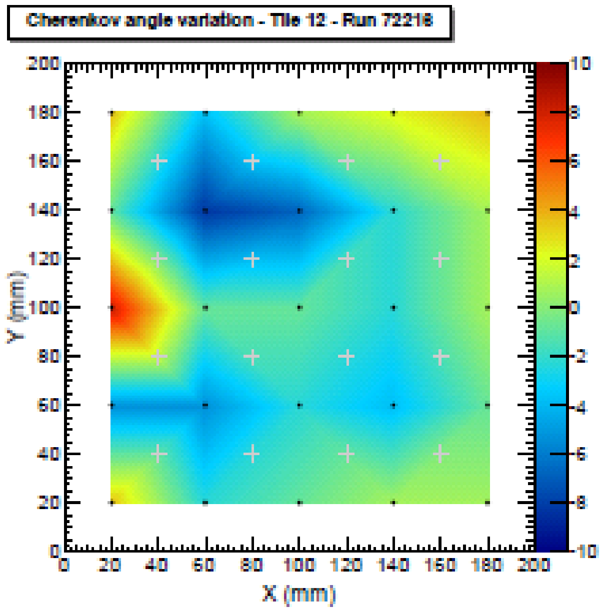


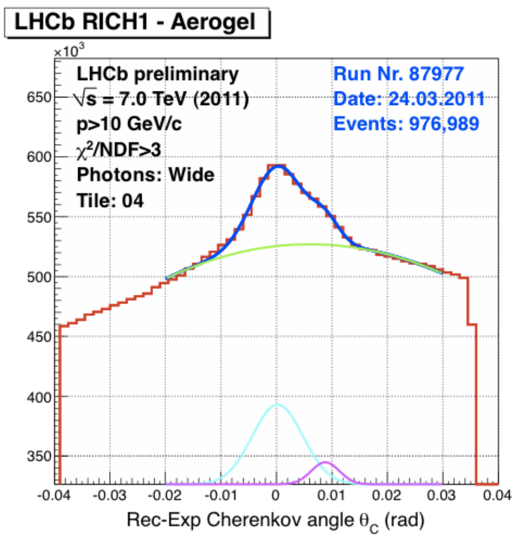


- Difference in the yields between MC and real data under study. Probable reasons: Binary readout, readout inefficiency, degradation of some components.

Aerogel Resolutions : Work in progress

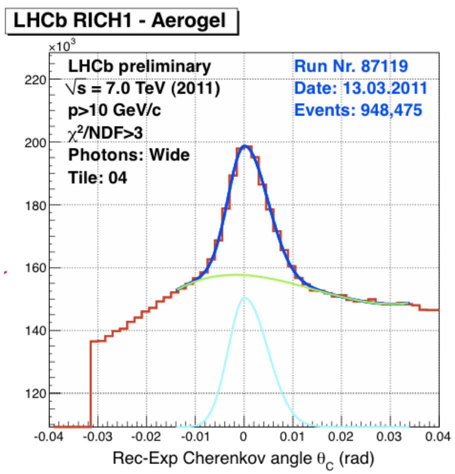
- Aerogel properties changed as it absorbed C_4F_{10}. So performance from simulation not same as that from real data. Hardware changes to keep aerogel in CO_2 enviornment is expected to be installed in the next shutdown.





In C_4F_{10}

Width ~ 4.7 mrad



In CO_2

Width ~2.8 mrad

closer to MC expectation