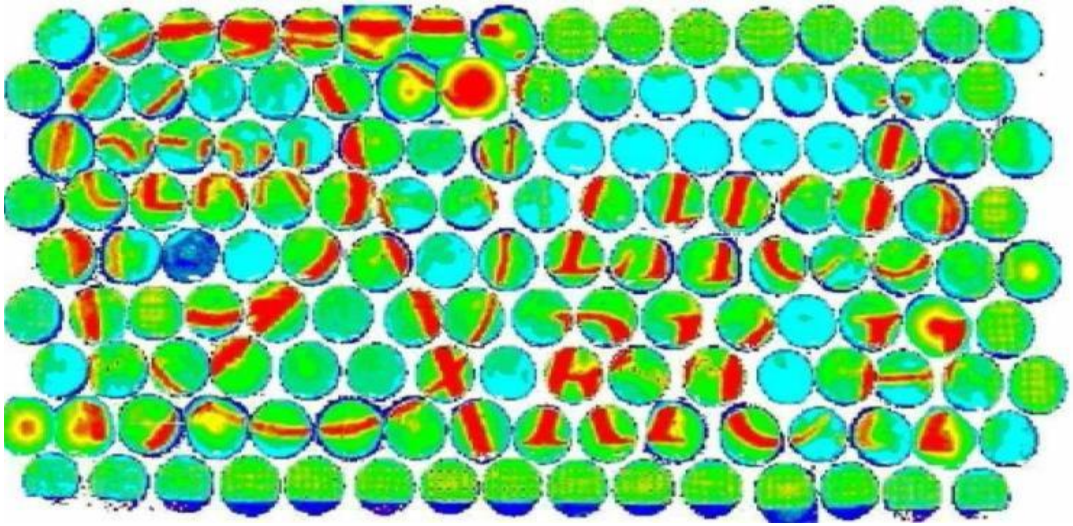
The RICH detectors of LHCb and the proposed upgrade



Antonis Papanestis

On behalf of the LHCb RICH collaboration

Science & Technology Facilities Council

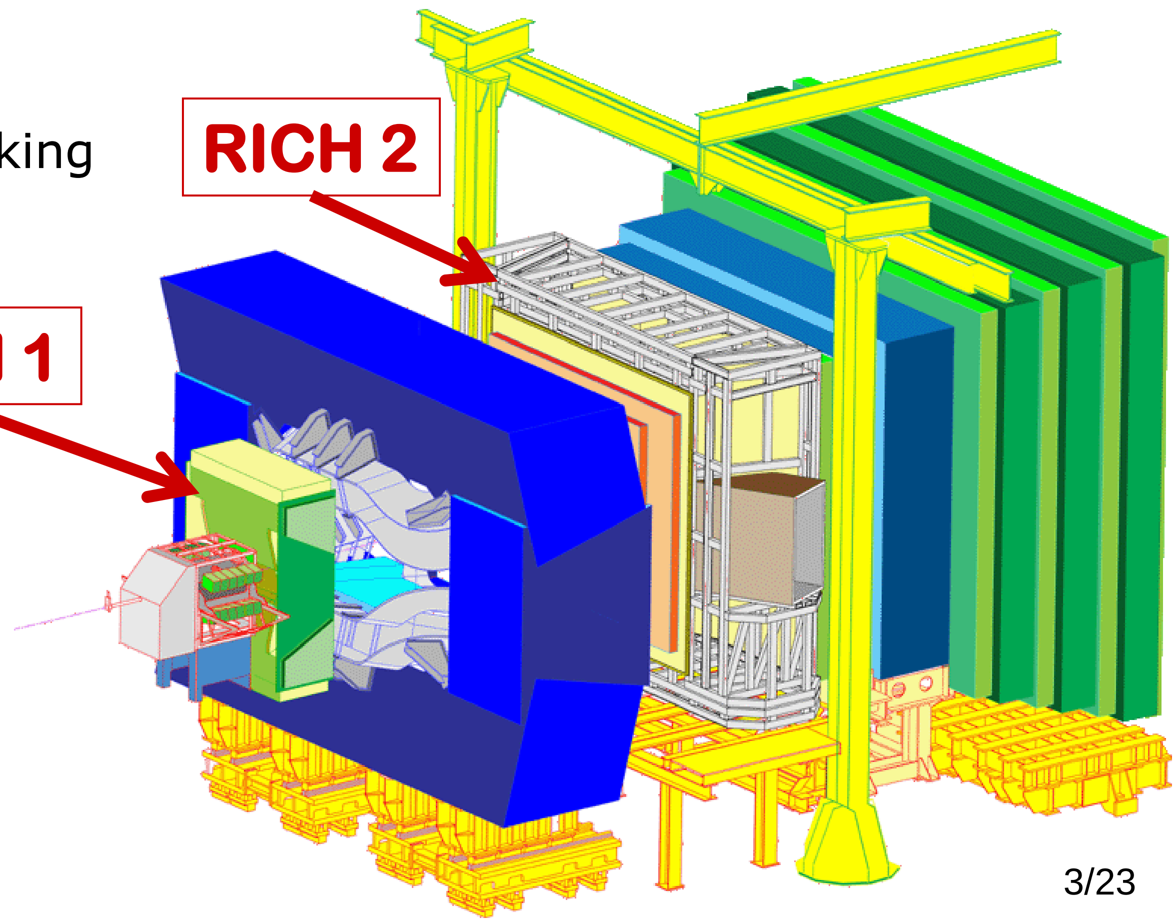
Outline

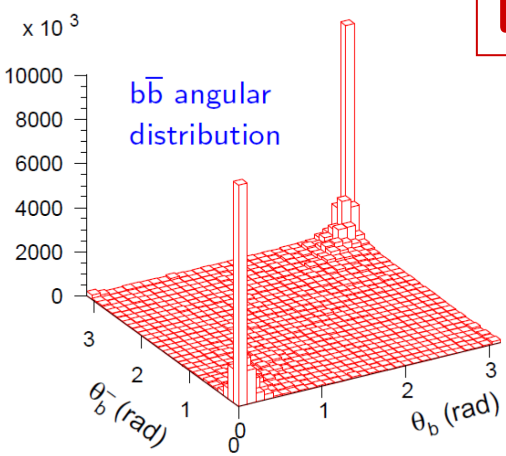
- The LHCb experiment
- The LHCb RICH detectors
  - Description
  - Operation
  - Alignment and Calibration
  - Performance
  - Physics examples
- LHCb Upgrade
- Conclusions

The LHCb experiment

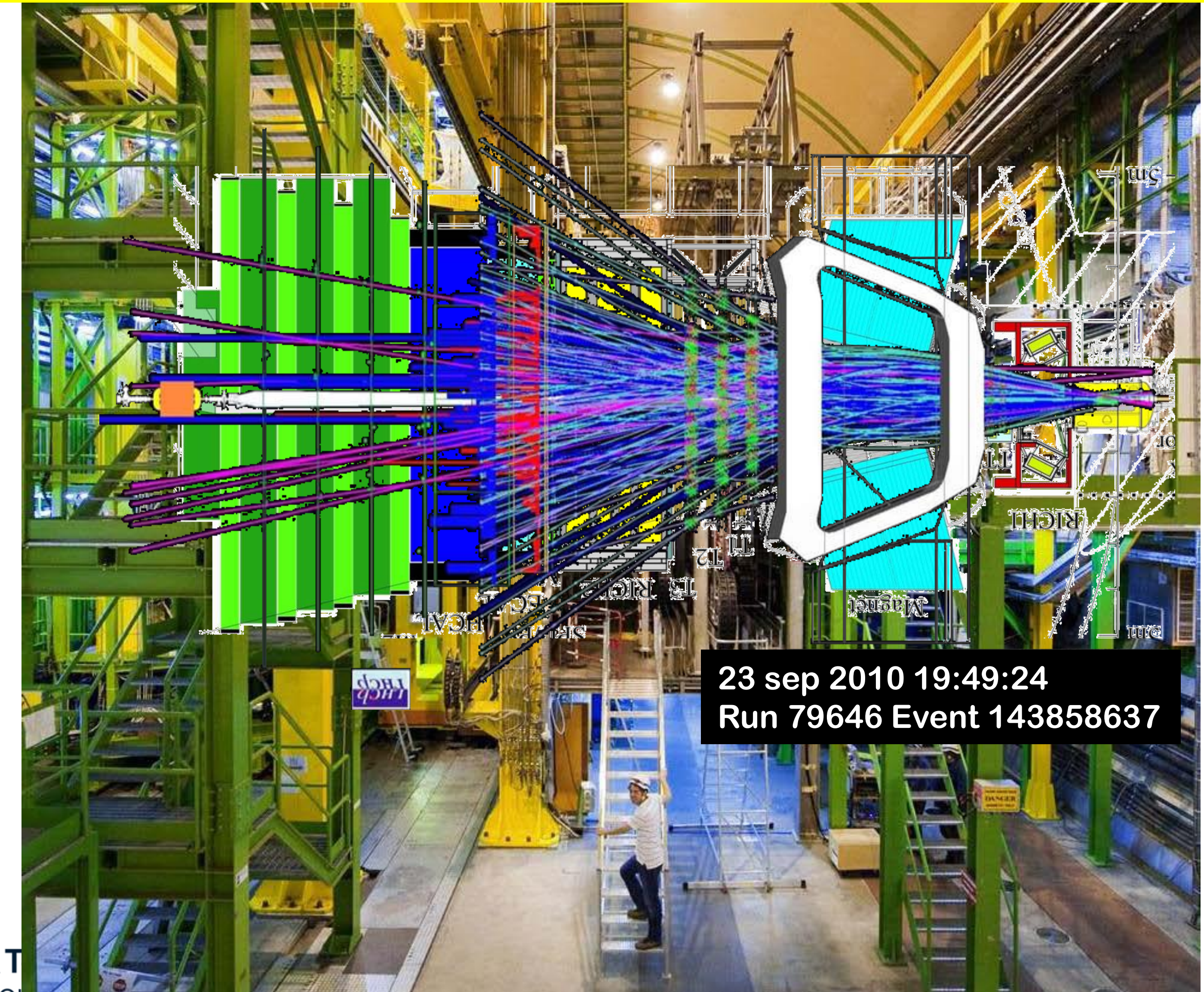
Probing New Physics in CP violation and rare decays of b and c quarks

Single arm spectrometer with:
- Excellent vertexing
- **Excellent PID**
- Efficient trigger and tracking





LHCb event



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The LHCb RICH detectors

RICH 1

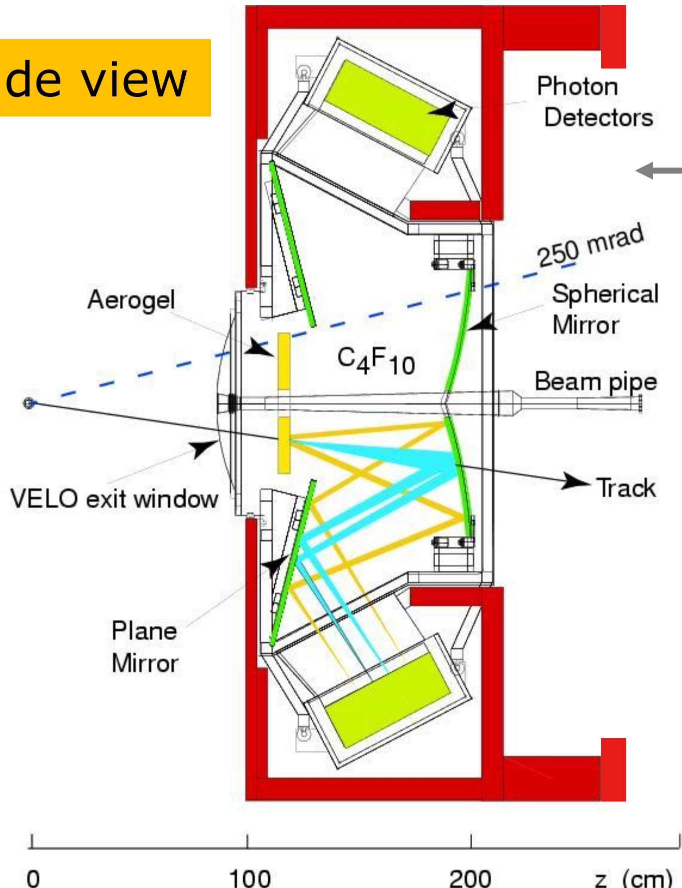
Acceptance 25-300 mrad

2 Detectors
3 Radiators

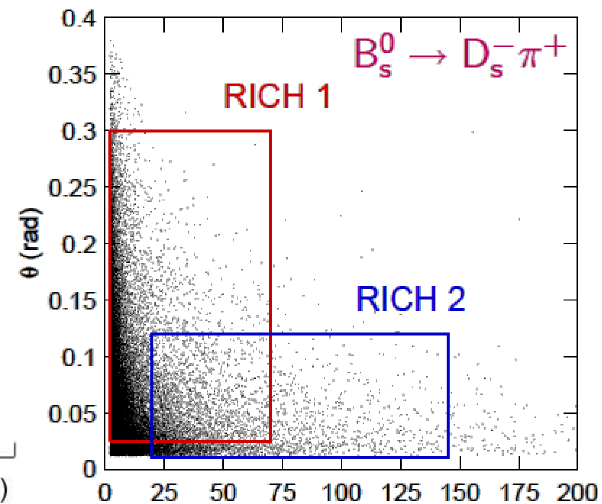
RICH 2

Acceptance 15-120 mrad

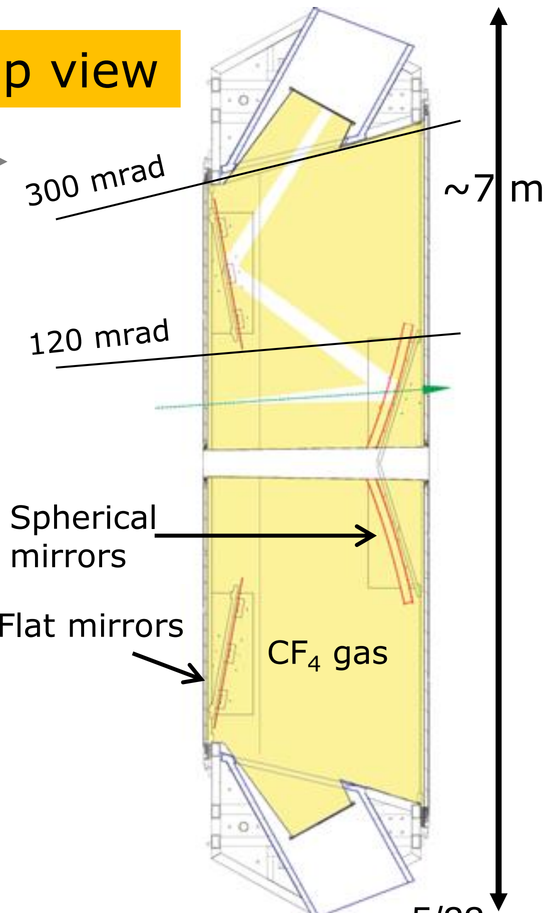
Side view



Note Scale Difference



Top view



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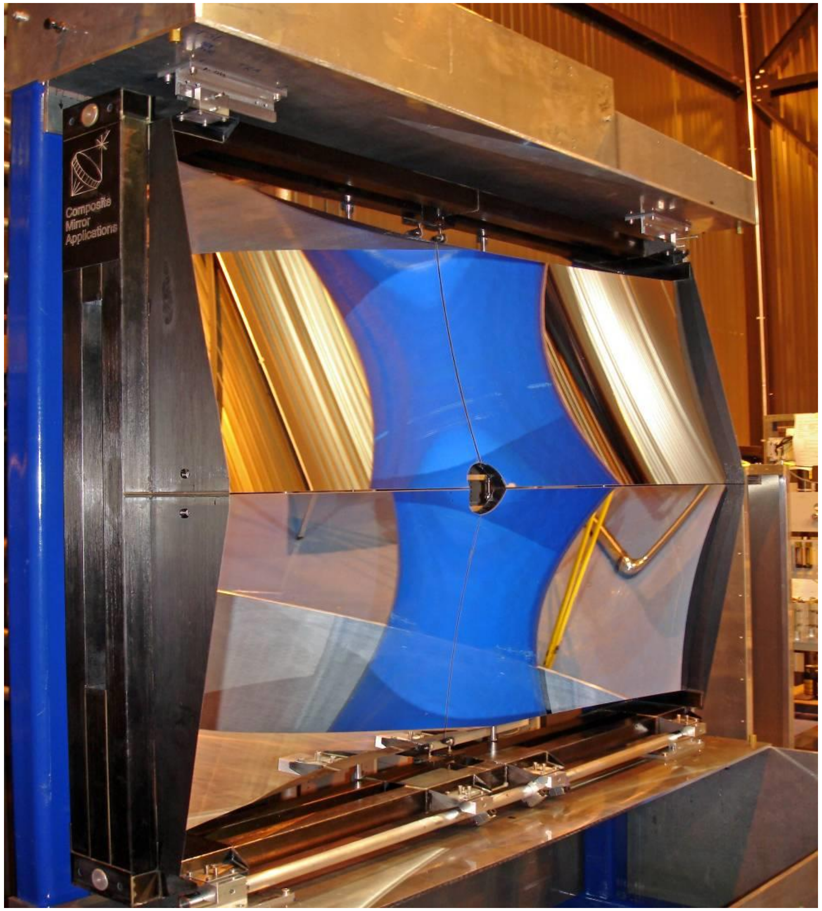
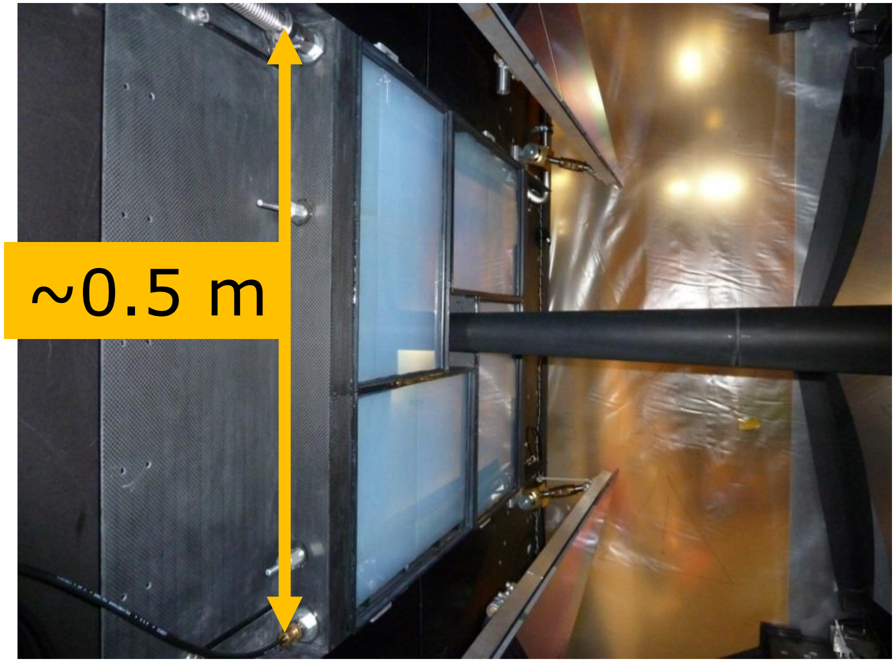
RICH1 Mirrors and Aerogel



Carbon fibre mirrors for low material budget

Aerogel is inside a gas tight box flushed with CO_2 to avoid performance degradation from exposure to C_4F_{10}



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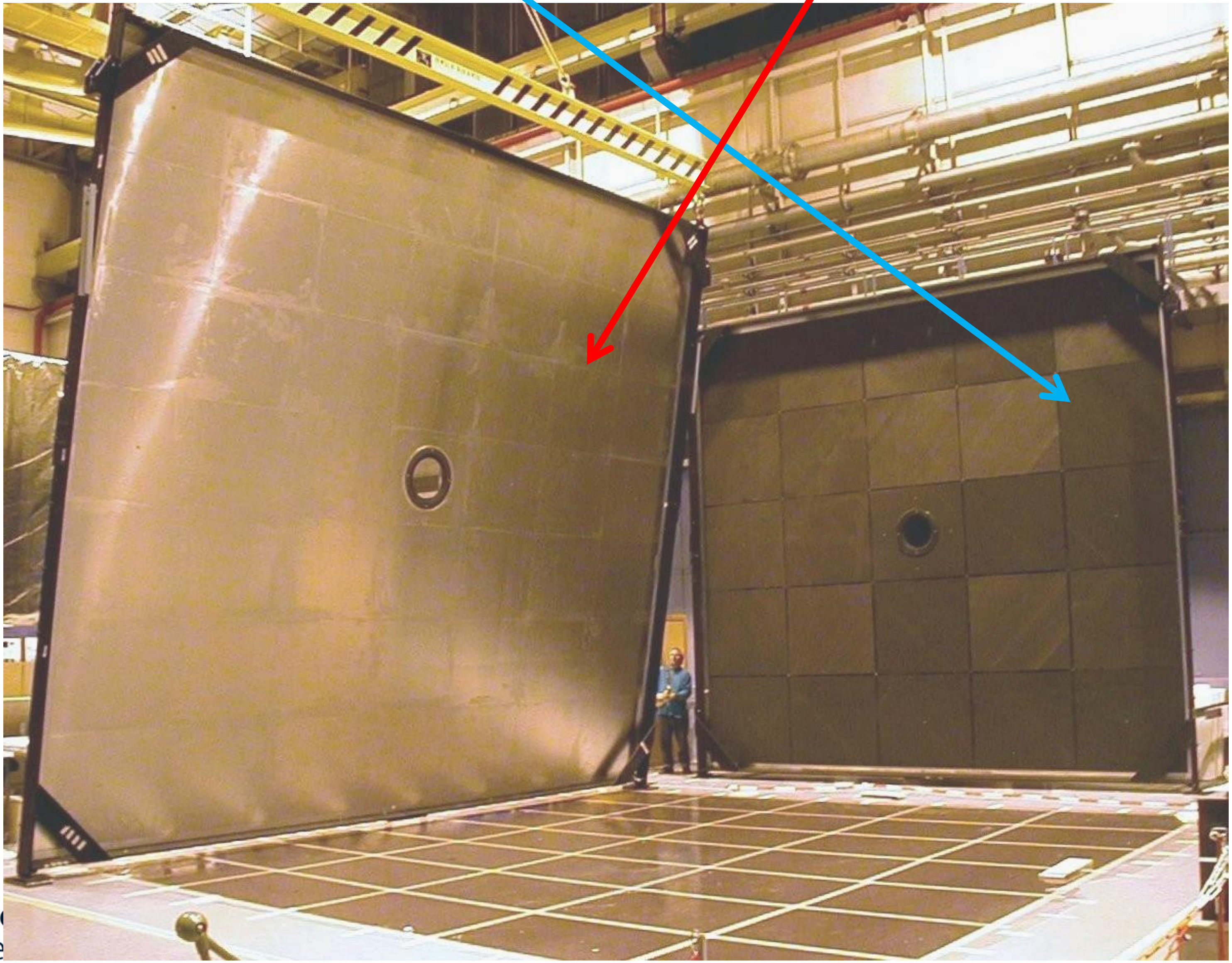
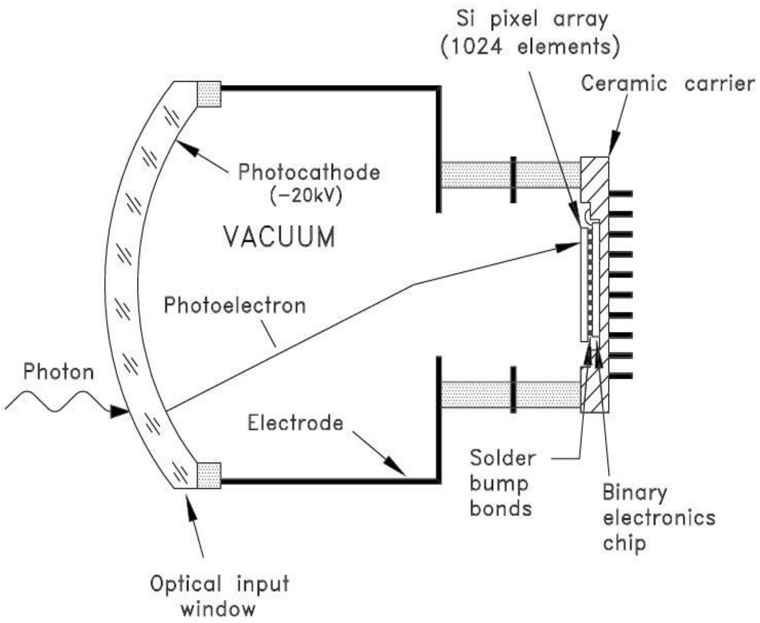
RICH 2 entry and exit windows



Photon Detectors



Main features of Pixel-HPD:

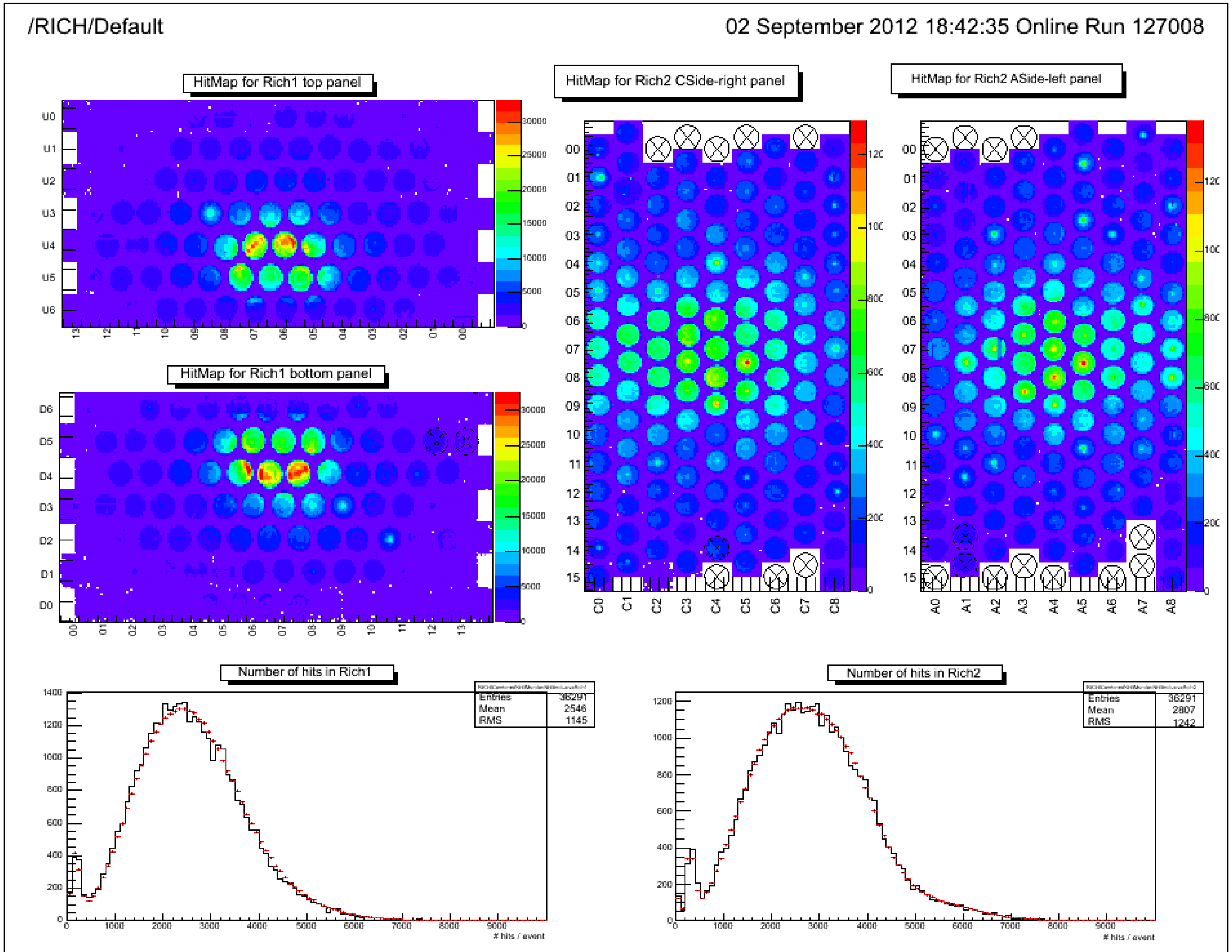
Quartz window with thin S20 pK
Cross-focussing optics (tetrode structure):

- De-magnification by ~5
- Active diameter 75mm
  ⇒ 484 tubes for overall RICH system
- Up to 20 kV operating voltage (~5000 e^- [eq. Si])
- Low noise (~140 e^- RMS)

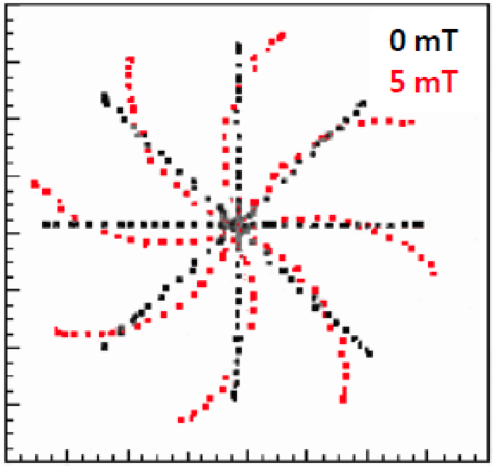
32×32 pixel sensor array (0.5mm×0.5mm each)
Encapsulated binary electronics readout chip

RICH 1 & 2 Hitmap

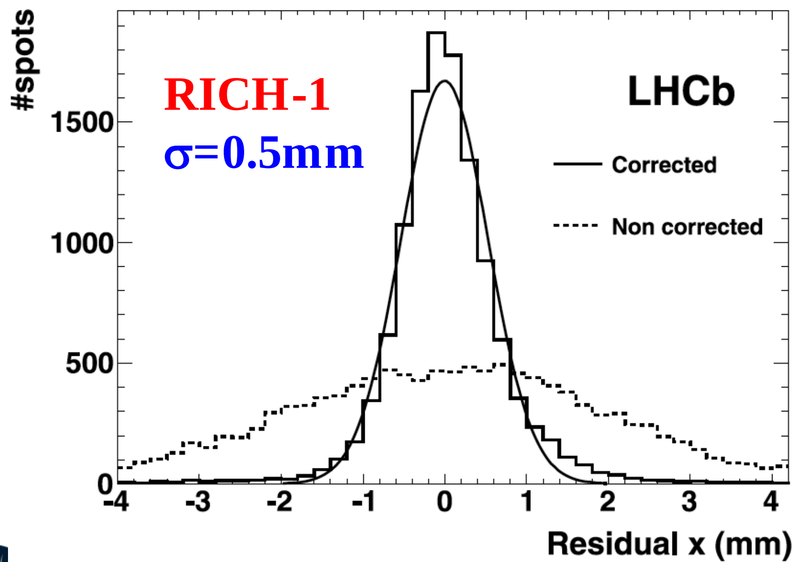
From Online Monitor. RED histograms for reference

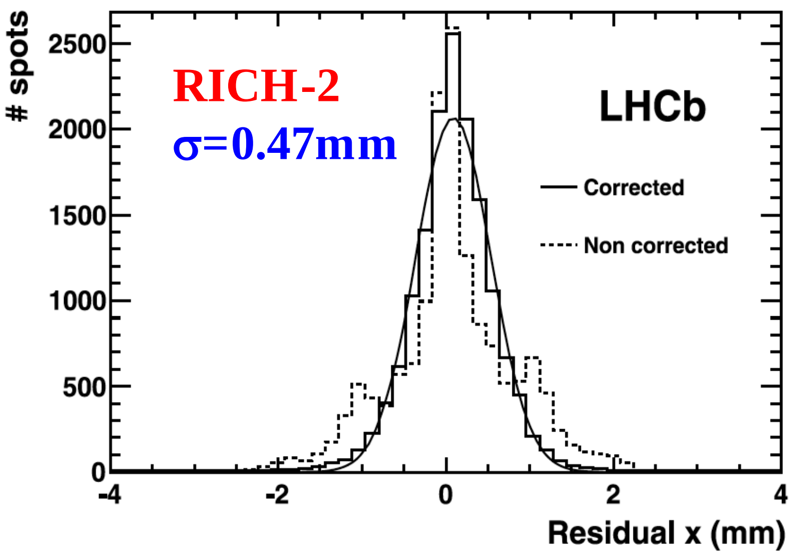


Magnetic field corrections



- HPD image distortion due to magnetic field
- Projection of test pattern with and without magnetic field to extract correction parameters





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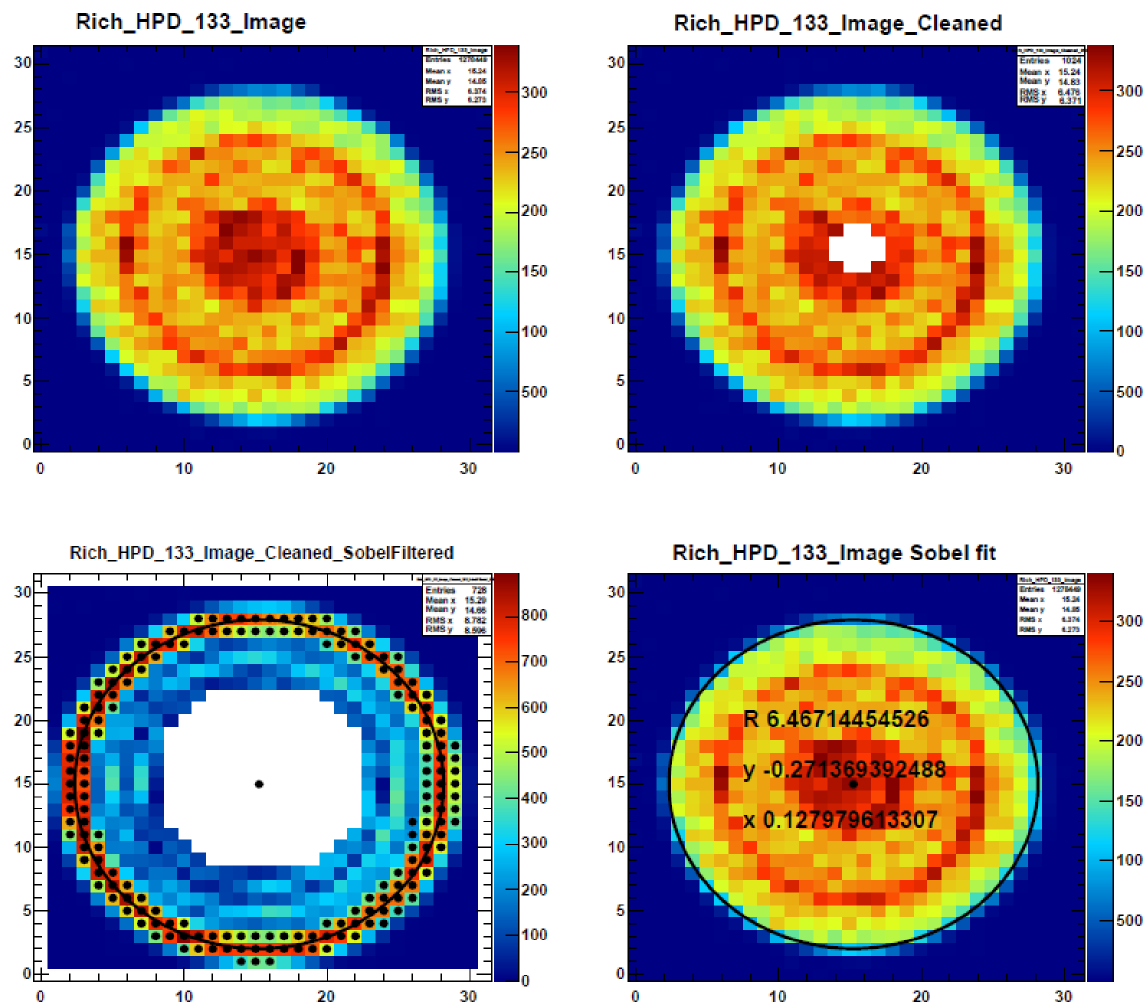
Anode image fitting

- Position of the photocathode image on the anode can change due to charging effects.
- Anode images are cleaned and a Sobel filter is used to detect the edge.
- Automated procedure, updates the position of the photo-cathode centre in Conditions Database



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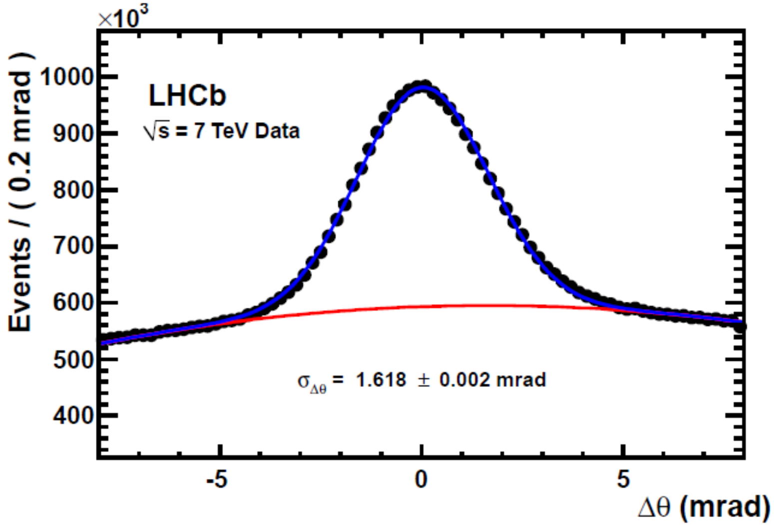
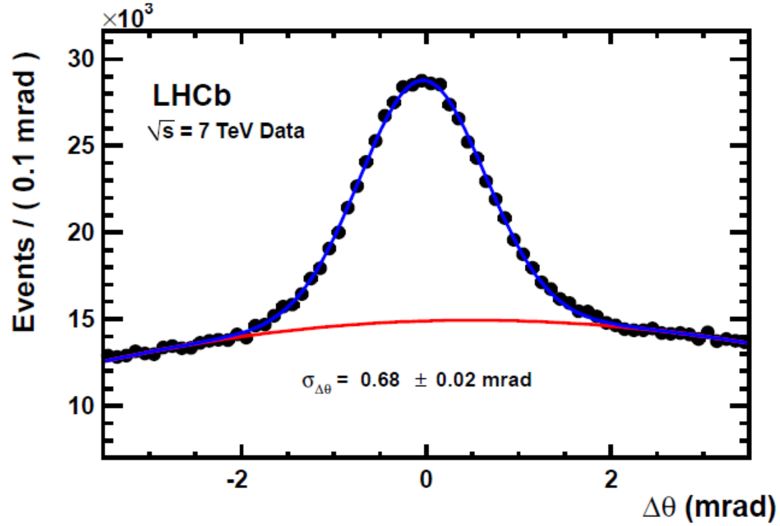
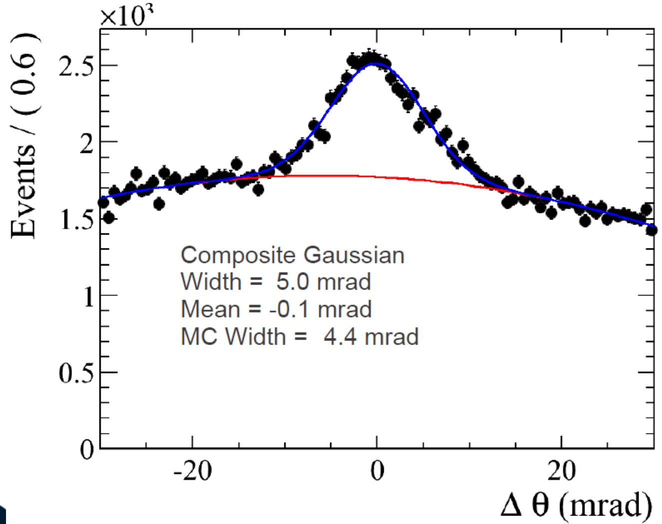
Cherenkov angle resolution



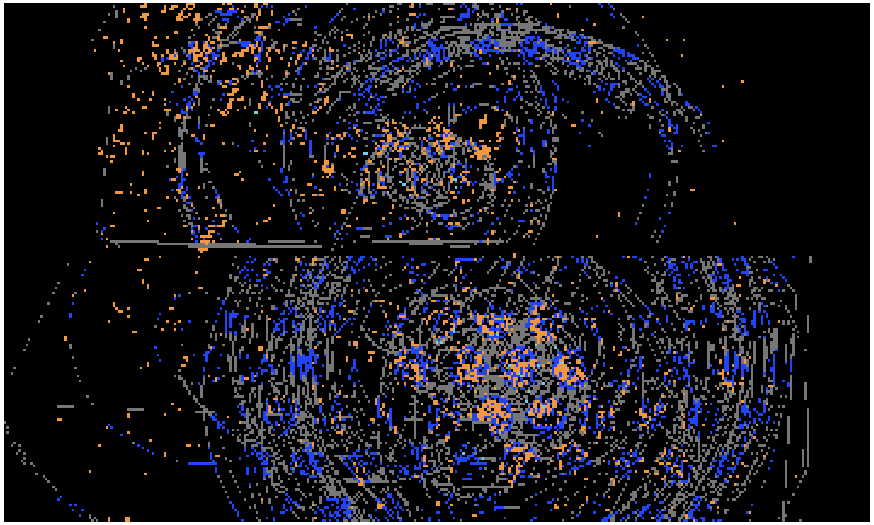




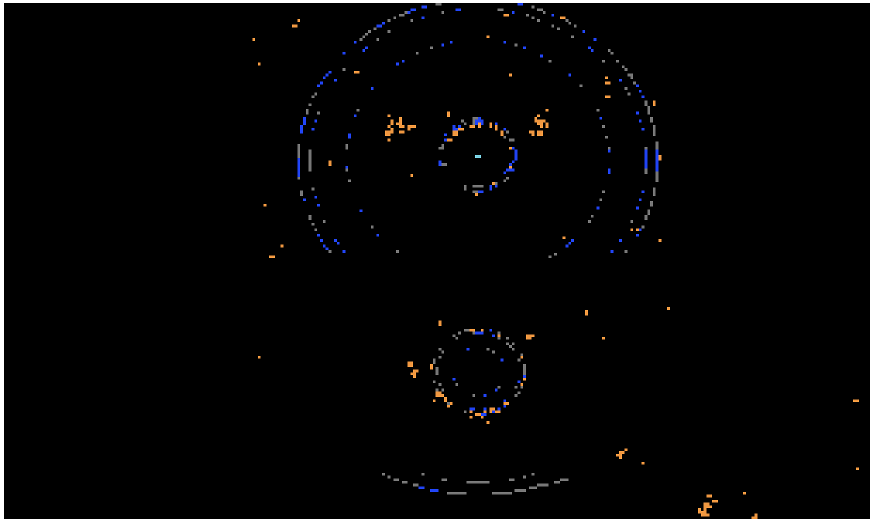
	Data	MC	Unit
Aerogel	5.0	4.4	mrad
C_4F_{10}	1.62	1.53	mrad
CF_4	0.68	0.68	mrad

Number of detected photons

Two event types



Physics event: $D^0 \rightarrow K^- \pi^+$

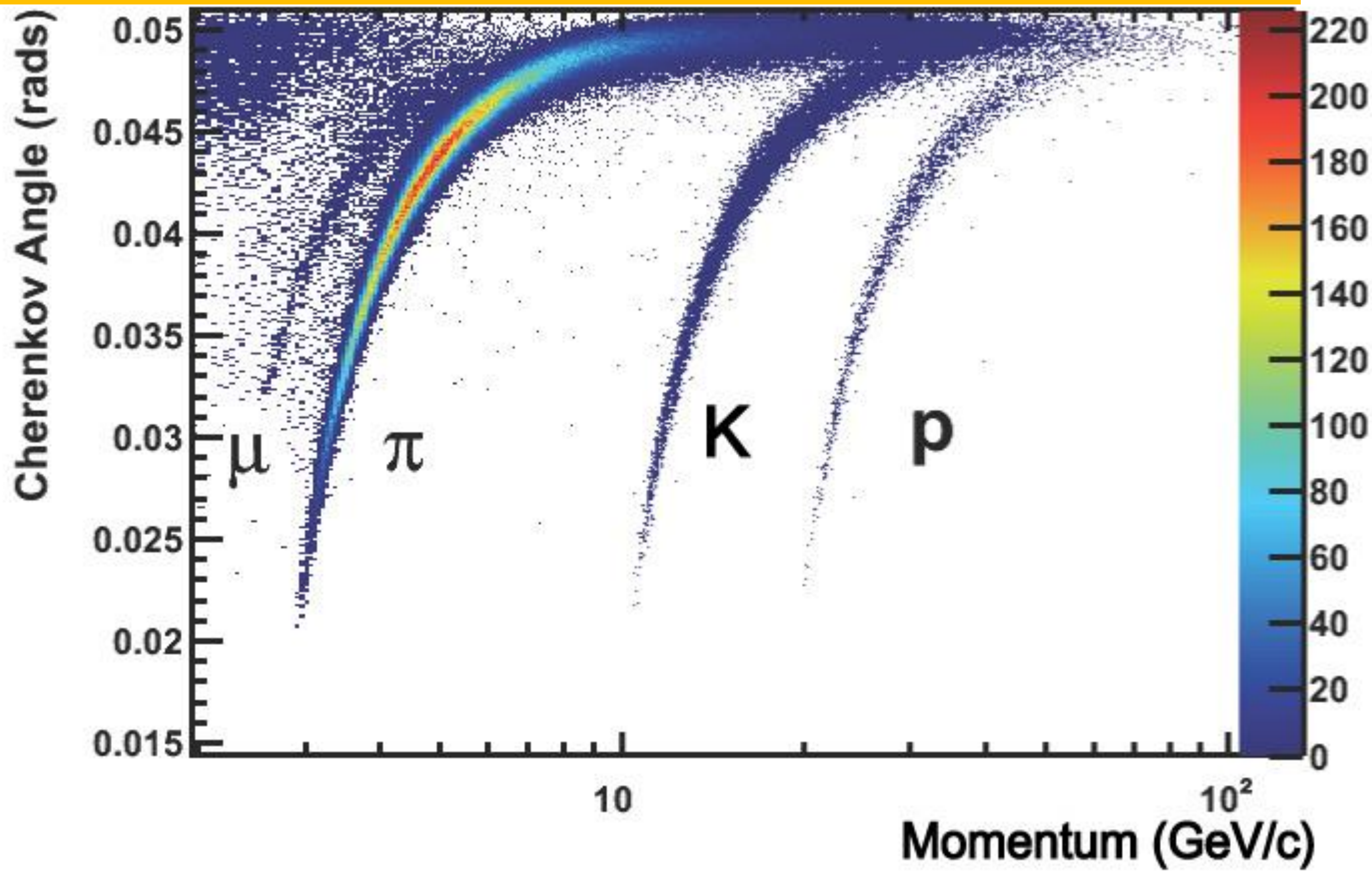


"Light" Event: $pp \rightarrow pp\mu^+\mu^-$

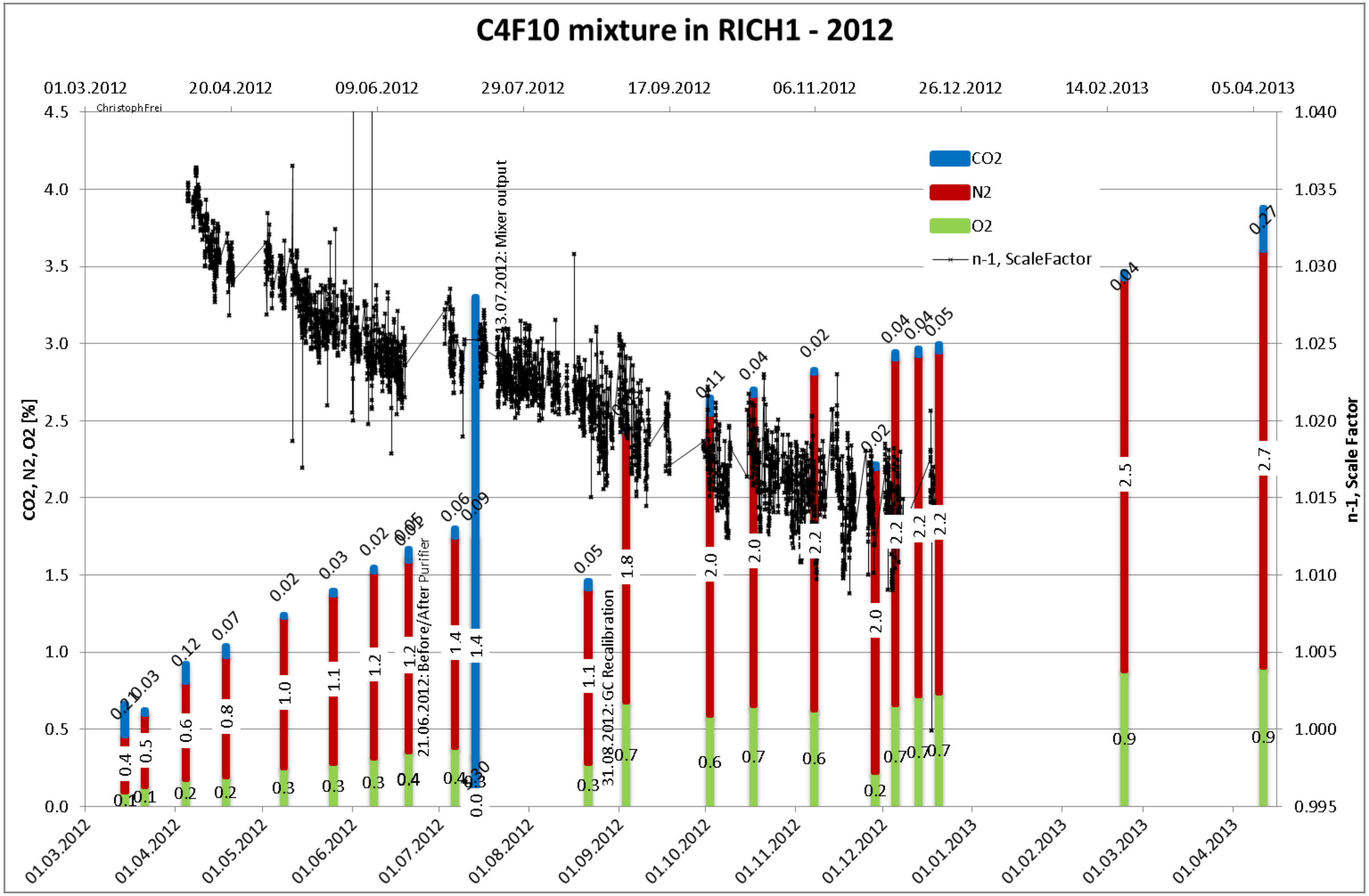
Radiator	N_{pe} from data		N_{pe} Simulation
	$D^0 \rightarrow K^- \pi^+$	$pp \rightarrow pp\mu^+\mu^-$	
Aerogel	5.0±3.0	4.3±0.9	6.8±0.3
C_4F_{10}	20.4±0.1	24.5±0.3	29.5±0.5
CF_4	15.8±0.1	17.6±0.2	23.3±0.5

Using isolated rings

Cherenkov angle vs momentum in RICH1



C_4F_{10} Gas Composition



PID algorithm

Consider all photons and all tracks and all radiators at once and maximise likelihood function:

$$L = L(n_{pixel}, \sum_{track} e_{pixel,track}, b_{pixel})$$

1. Take all PIDs to be pions

   Estimate background parameter b_{pixel} per HPD
2. Calculate likelihood of given pixel distribution.
3. Iterate
   1. Change PID hypothesis one track at a time
   2. Recalculate likelihood
   3. Choose change that had biggest impact
   4. Assign new PID to that track
4. Until no significant improvement is found

As signal photons are now identified better, update background estimate and start a 2^{nd} (and usually final) iteration.

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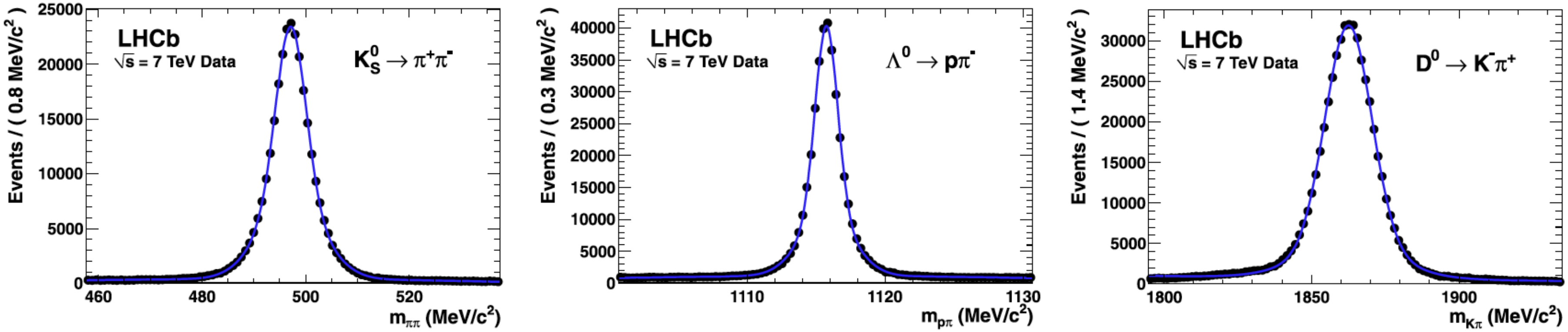
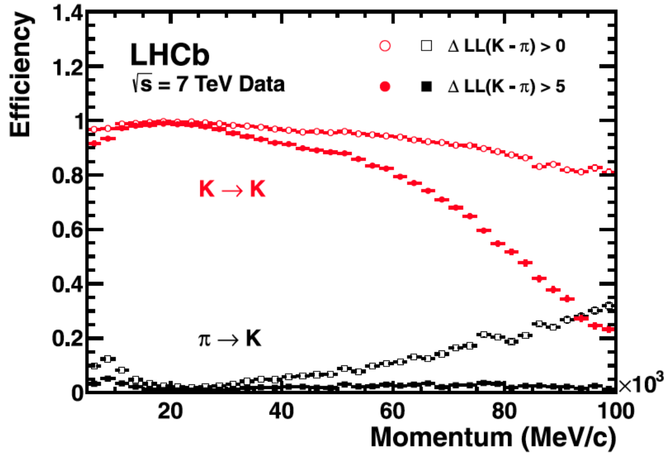
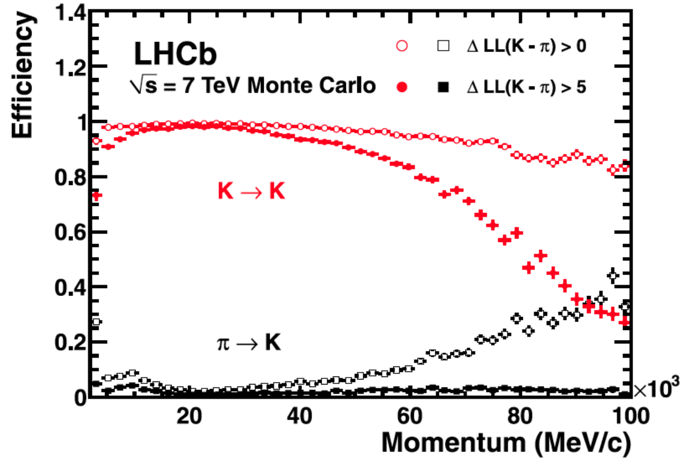
PID Performance



- PID performance evaluated from data
  - Genuine $\pi/K/p$ samples identified from kinematics only





Data

Monte-Carlo

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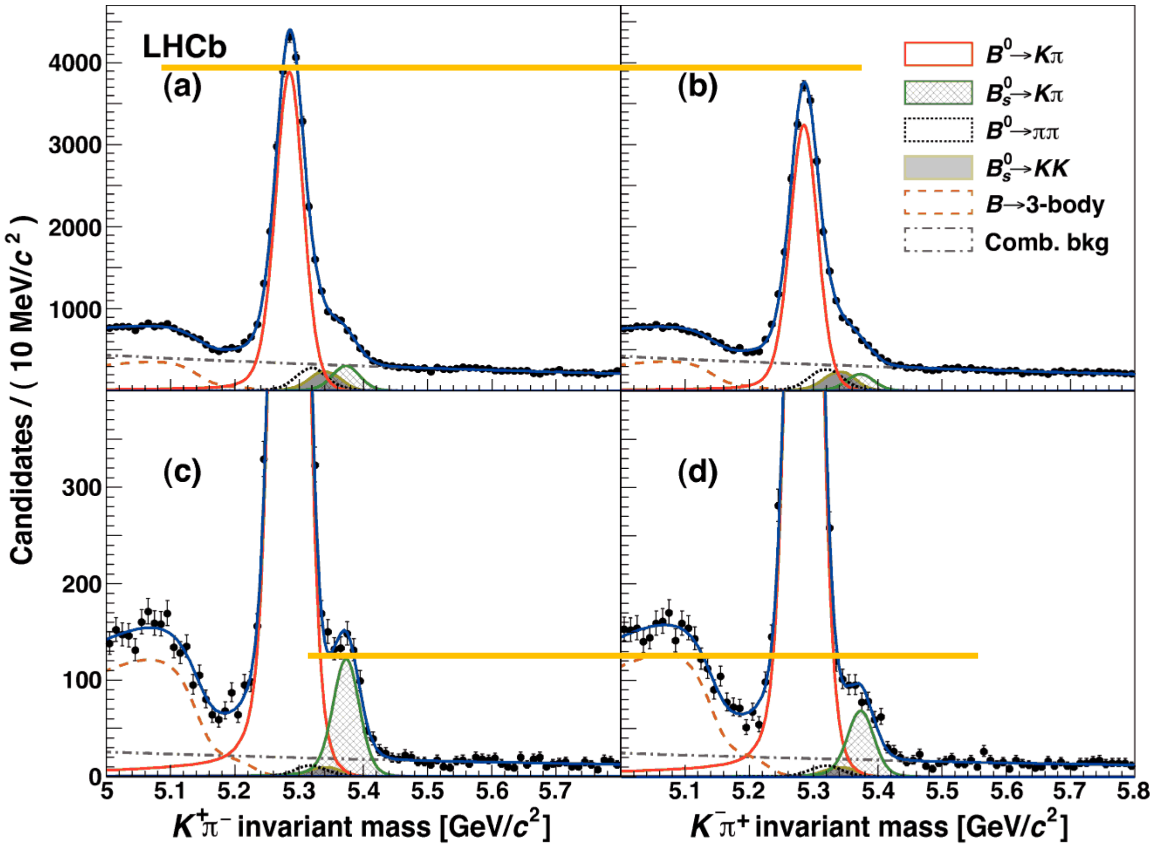
CP violation in $B^0_{(s)}$

First observation of CP violation in the decays of B_s mesons (arXIV 1304.6173; Phys.Rev.Lett 110 ,221601(2013))



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CP violation in $B^0_{(s)}$

$$A_{CP}(B^0_{(s)}) = \frac{\Gamma(\bar{B}^0_{(s)} \to \bar{f}_{(s)}) - \Gamma(B^0_{(s)} \to f_{(s)})}{\Gamma(\bar{B}^0_{(s)} \to \bar{f}_{(s)}) + \Gamma(B^0_{(s)} \to f_{(s)})}$$

Where $f = K^+\pi^-$ and $f_s = K^-\pi^+$

$A_{raw}(B^0 \to K\pi) = -0.091 \pm 0.006$ 41420±300 events

$A_{raw}(B^0_s \to K\pi) = 0.28 \pm 0.04$ 1065±55 events

$$A_{CP} = A_{raw} - A_{\Delta}$$

Correction for production and detection asymmetries

$A_{CP}(B^0 \to K\pi) = -0.080 \pm 0.007 \pm 0.003$

10.5 σ

World's best

$A_{CP}(B^0_s \to K\pi) = 0.27 \pm 0.04 \pm 0.01$

6.5 σ

First observation

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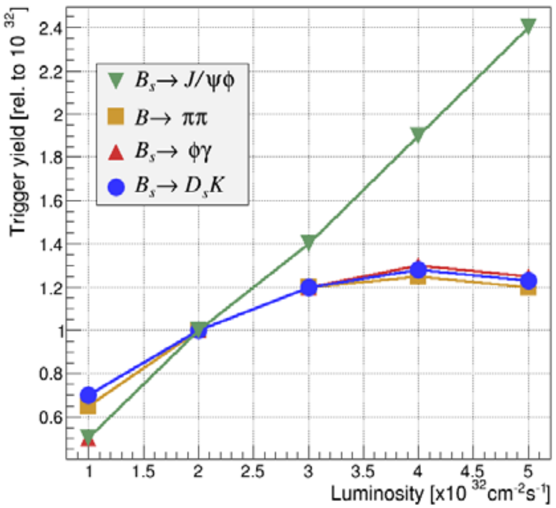
LHCb Upgrade

- Goal: collect 50 fb^{-1}
- Consequence: run at L_{inst} up to $2\times10^{33}cm^{-2}s^{-1}$
- Approach: remove trigger limitations and readout detector @ 40 MHz
  - Current max trigger rate of 1.1 MHz limits the efficiency of hadronic channels



40 MHz readout rate @ up to $2\times10^{33}cm^{-2}s^{-1}$

- Change opto-electronic chain:
- Photon detectors
- Front-end electronics
- DAQ

- RICH optics and mechanics:
- Modify RICH1 optics
- Optimise for available space.
- Remove aerogel radiator

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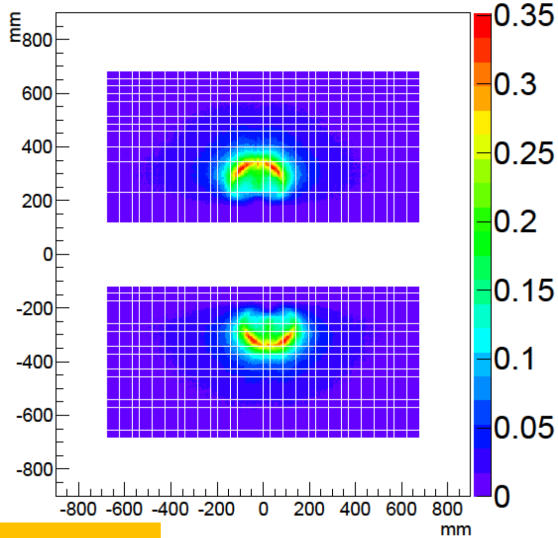
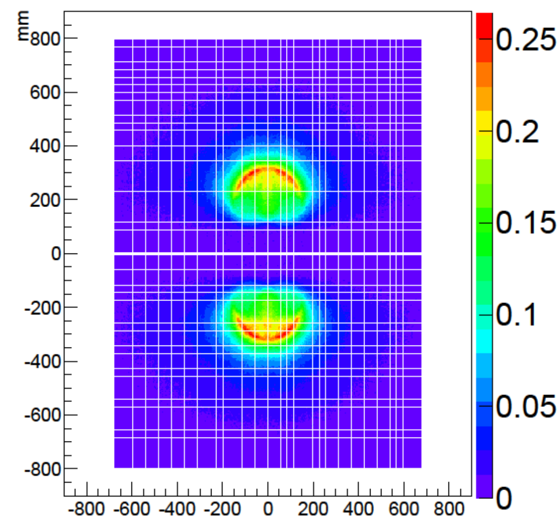
New RICH 1 layout

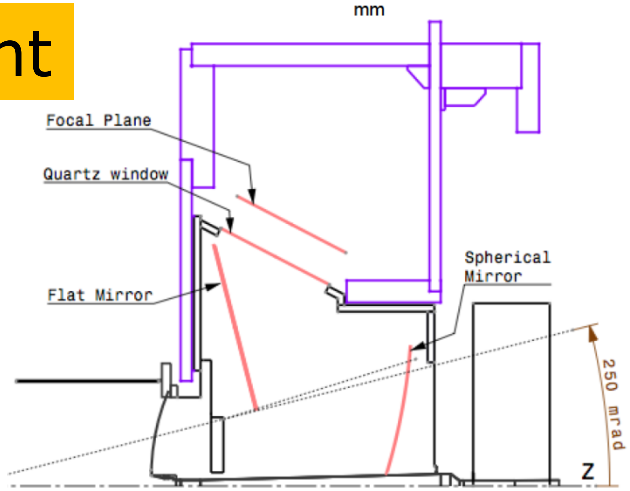


Hit distribution on photon detectors.

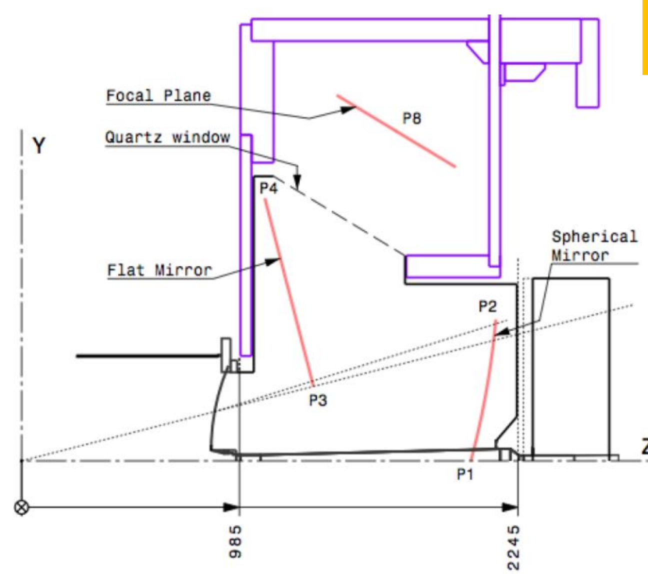
Reduced peak occupancy for upgrade geometry



Present



Upgraded



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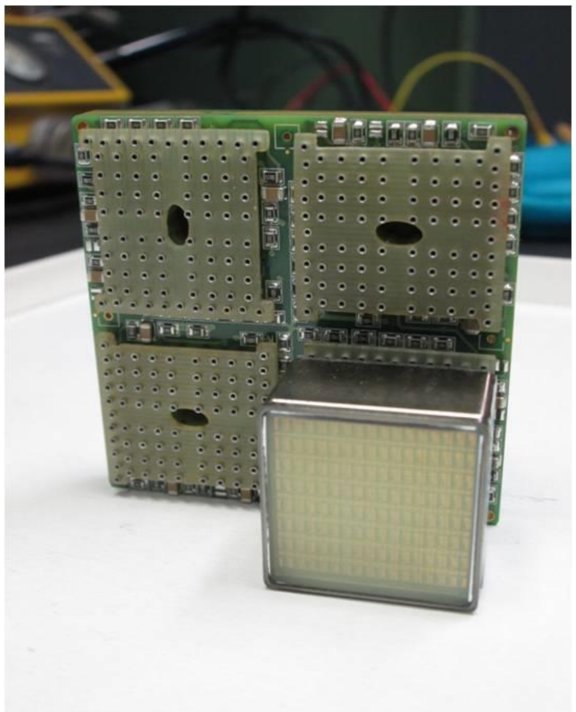
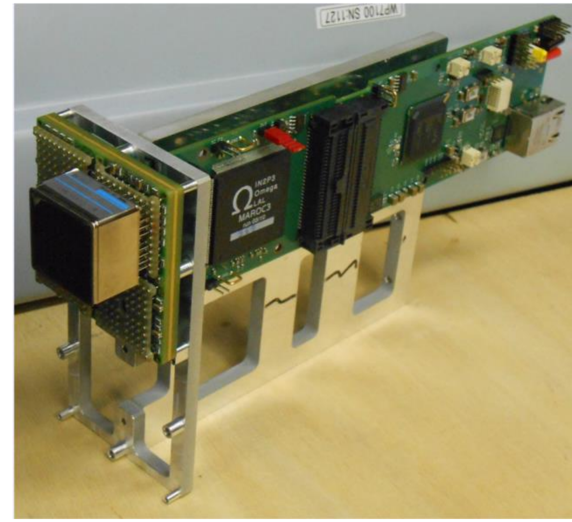
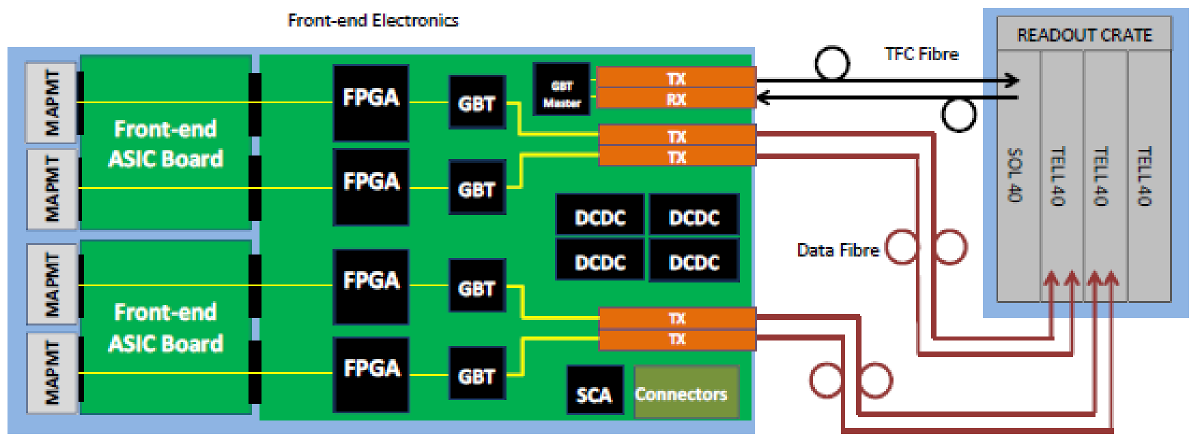
New photo-electronic chain

Baseline option: 64 pixels MaPMT
+ custom FE chip (CLARO8)
+ digital board + GBTs







TORCH - a Cherenkov based Time-of-Flight Detector
by Euan Cowie (Thu 17:10)

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Conclusions

- LHCb has recorded 3 fb^{-1} in 2010-2012, running in conditions well above the original specifications, at 90% efficiency, producing a number of world first and world best measurements.
- The LHCb RICH detectors have been operating in a difficult environment of high track multiplicity and form an essential part of the experiment. There are advanced plans to use the RICH detector in the LHCb trigger for the LHC Run2.
- After careful alignment and calibration, the performance of the RICH detectors has reached the levels expected from MC simulations. This is due to:
  - Excellent photo-detectors.
  - Very stable optical system.
  - Well controlled gas radiators.
- The LHCb RICH upgrade is progressing well and is on schedule for installation in 2018.

Performance of the LHCb RICH detector at LHCb; Eur. Phys. J. C (2013) 73:2431

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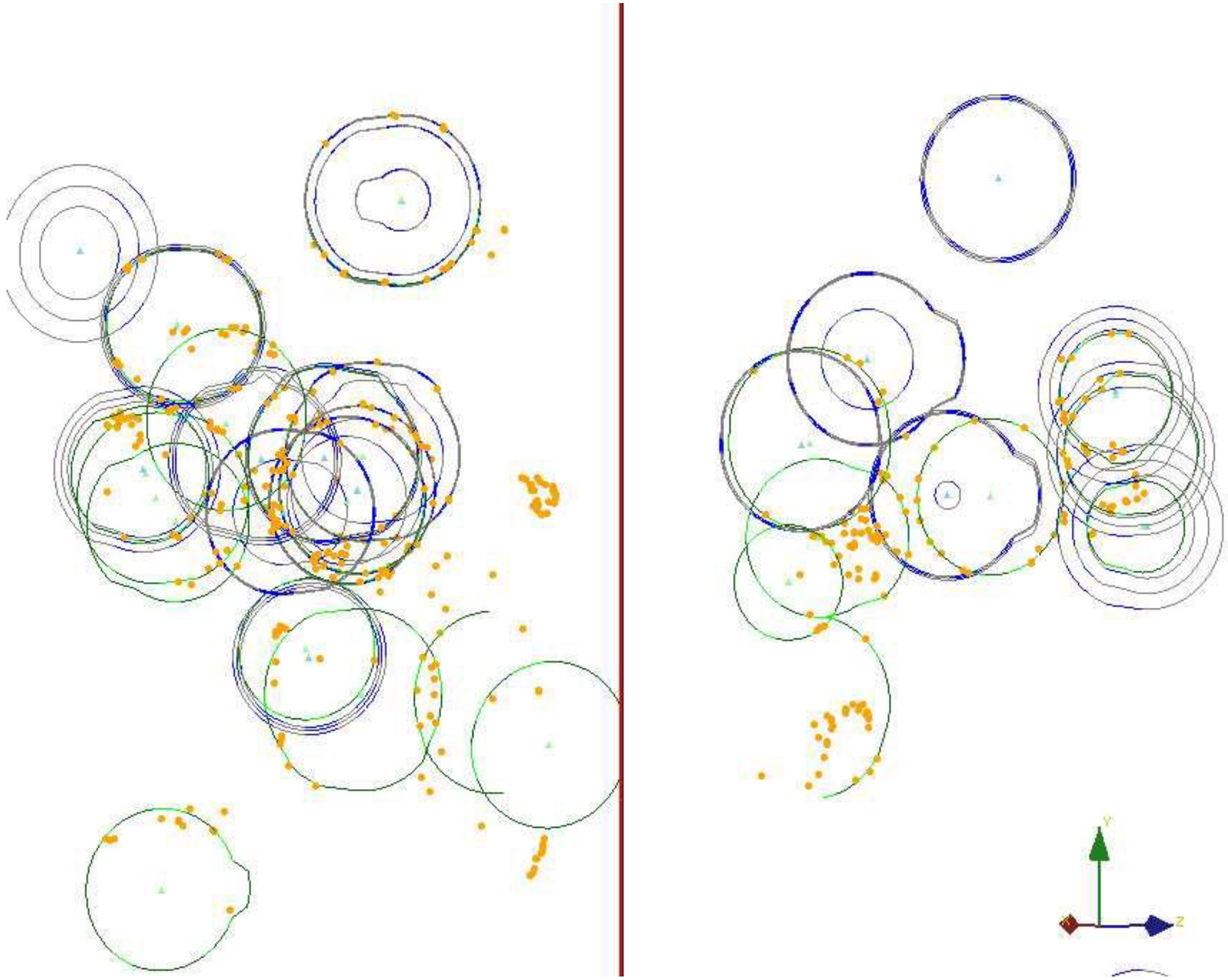
The END



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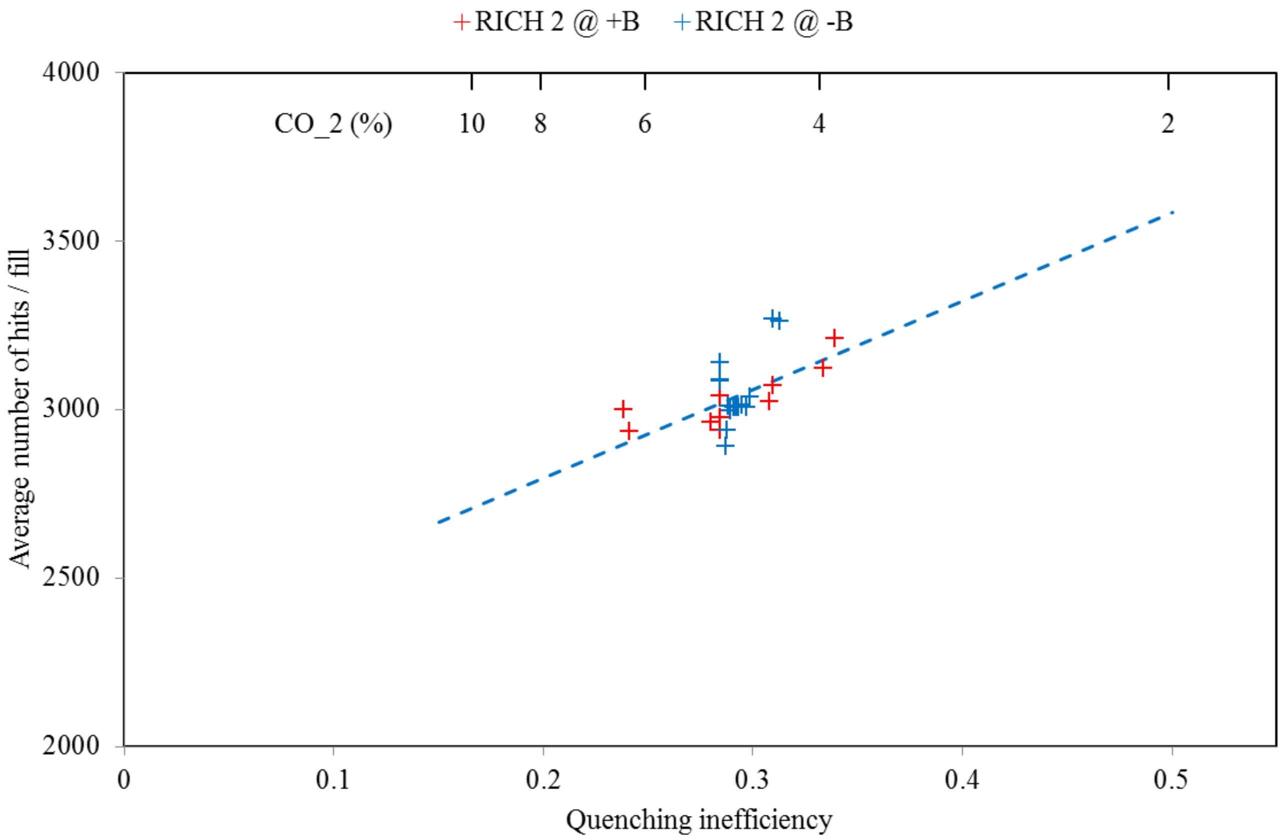
CF_4 Scintillation

Quenched using CO_2

"Extra" photons from scintillation were saturating data bandwidth



Inefficiency is calculated from lab measurements

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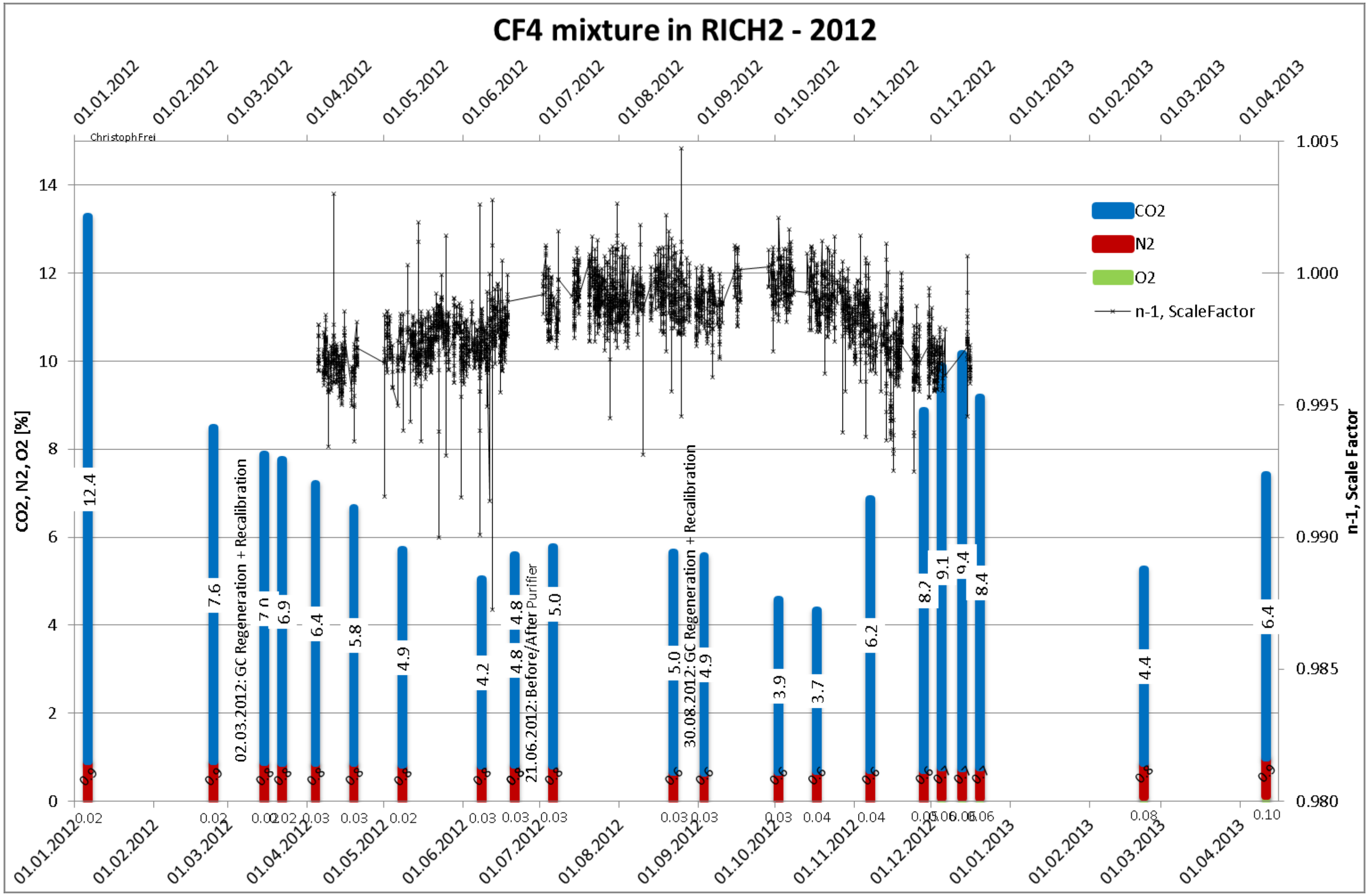
CF_4 Ref Index calibration



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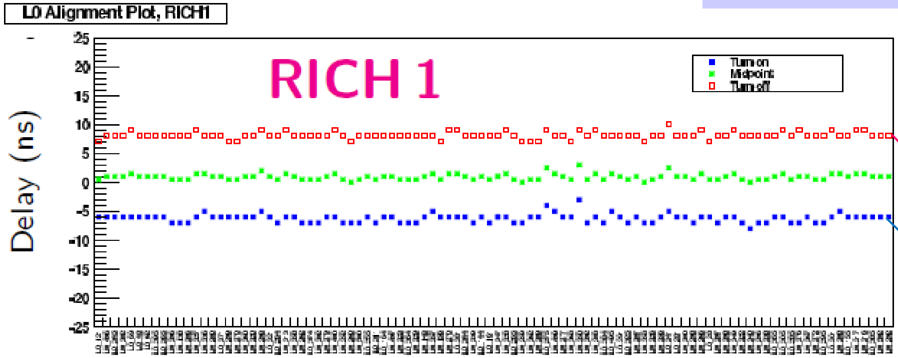
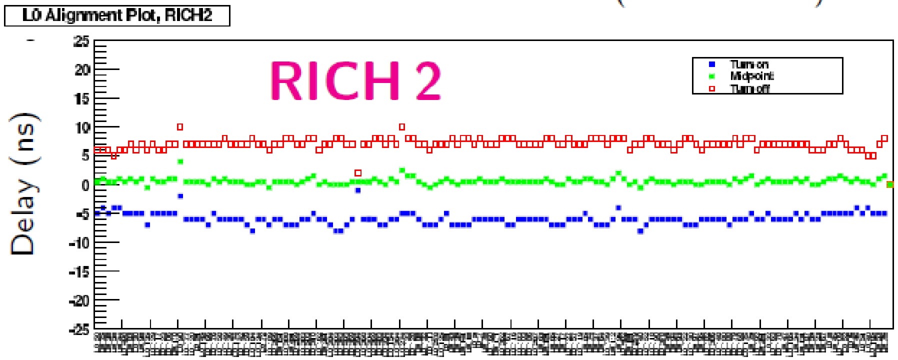
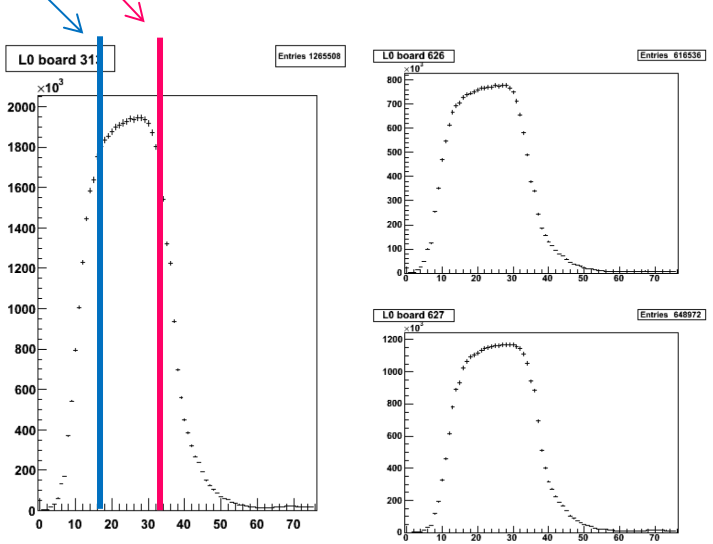
Time alignment

Both RICH detectors are time aligned to less than 1 ns





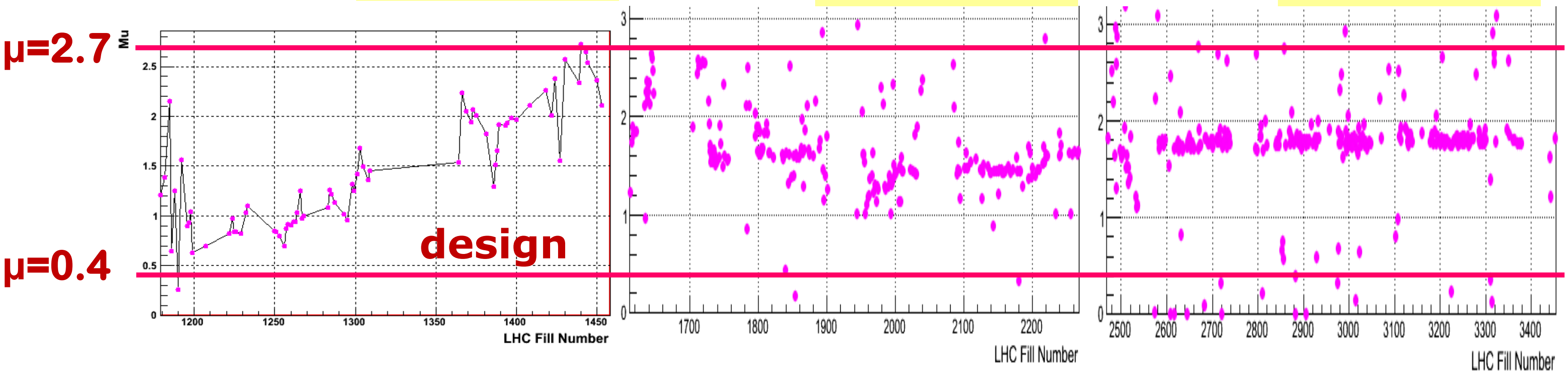
	Delay	RMS
RICH 1	0.93 ns	0.52 ns
RICH 2	0.59 ns	0.54 ns

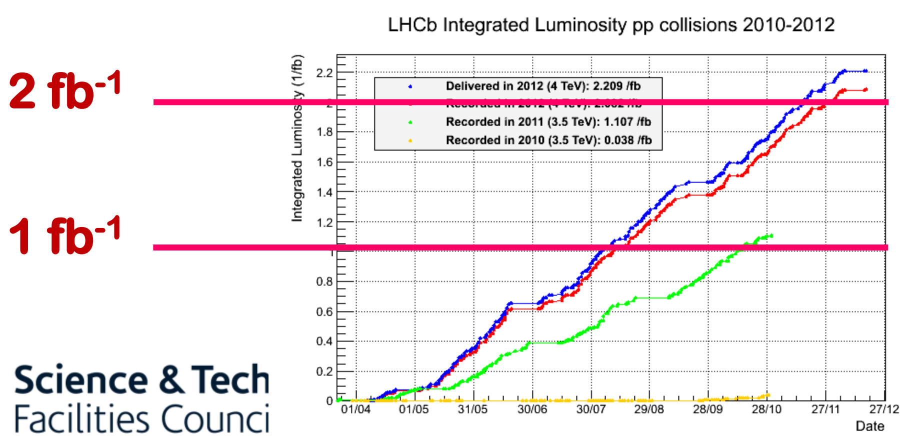


LHCb luminosity

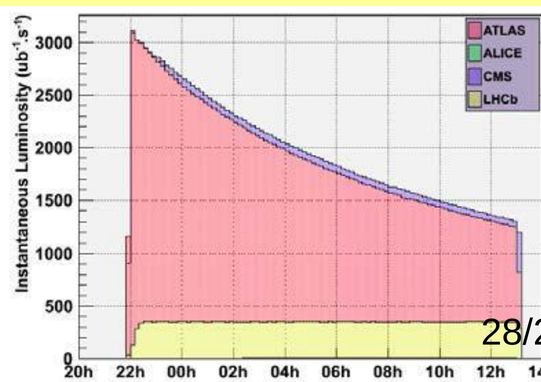
LHCb was designed to run at μ~0.5 and n_b~2600 ⇒ L_{inst}~$2\times10^{32}cm^{-2}s^{-1}$
In 2012 LHCb runs with μ~1.7 and n_b~1300 ⇒ L_{inst}~$4\times10^{32}cm^{-2}s^{-1}$

2010 data | 2011 data | 2012 data





Automatic luminosity levelling



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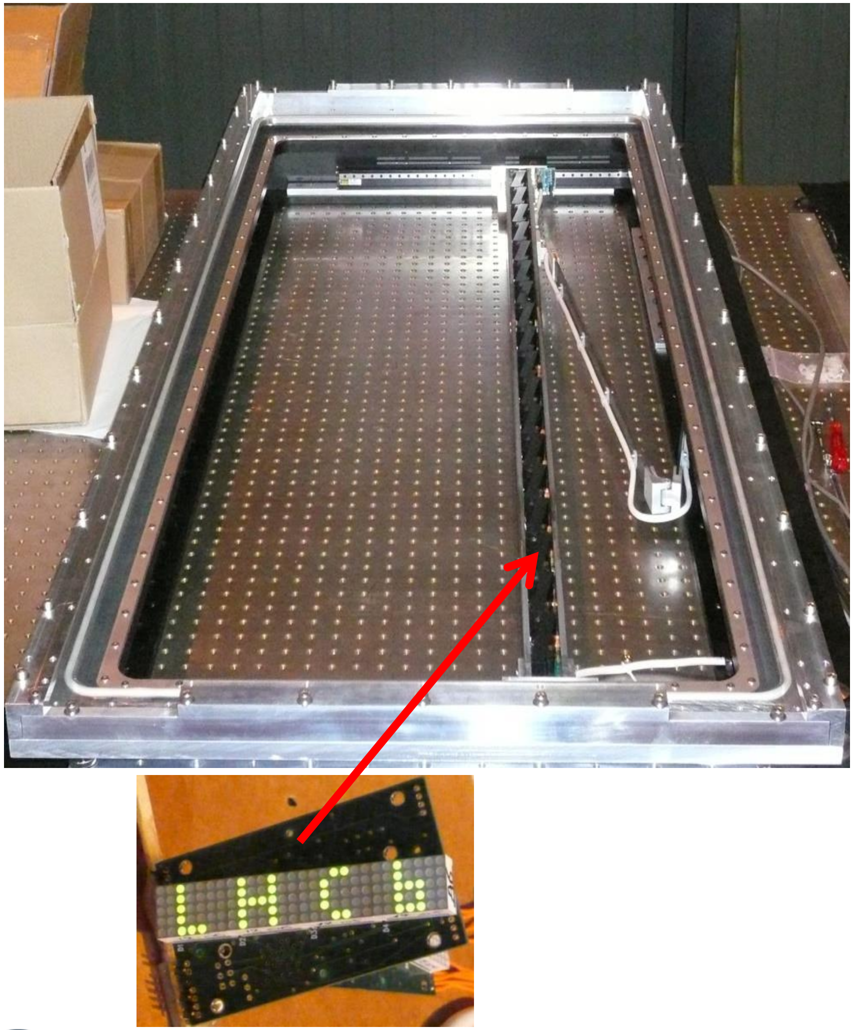
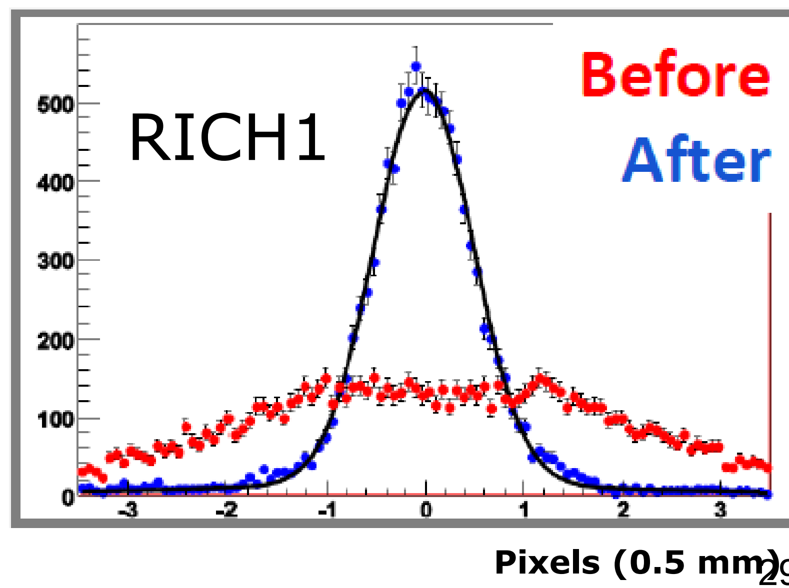
RICH 1 MDCS



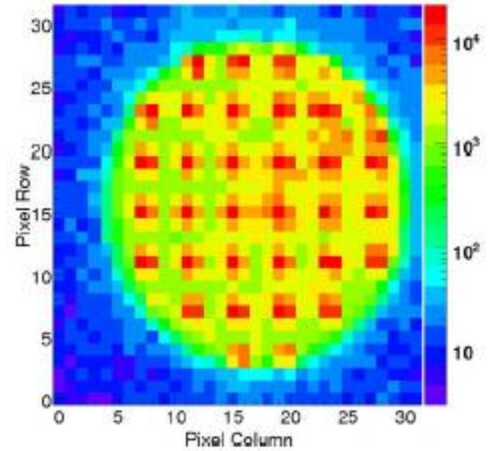
Correcting for the magnetic distortions



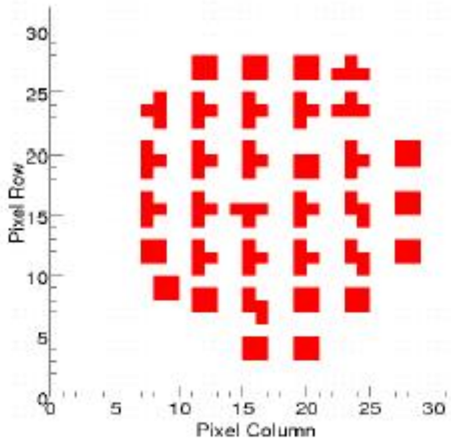
RICH 2 MDCS

A temporary setup, using commercial projector was used in 2008 to project a static, reproducible grid of light spots onto the photon detector plane,
The raw spot images were analysed to calculate the centre of gravity for precision comparison between measurements:

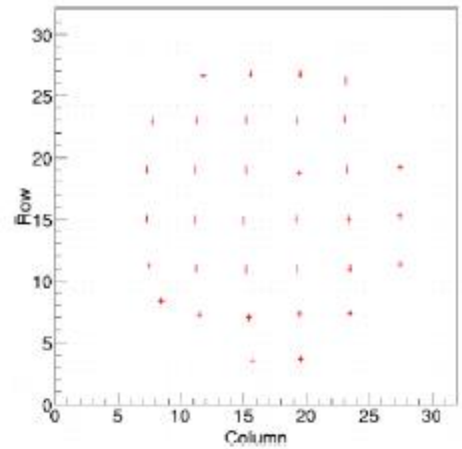
1. Accumulated HPD Image



2. Applied Thresholds

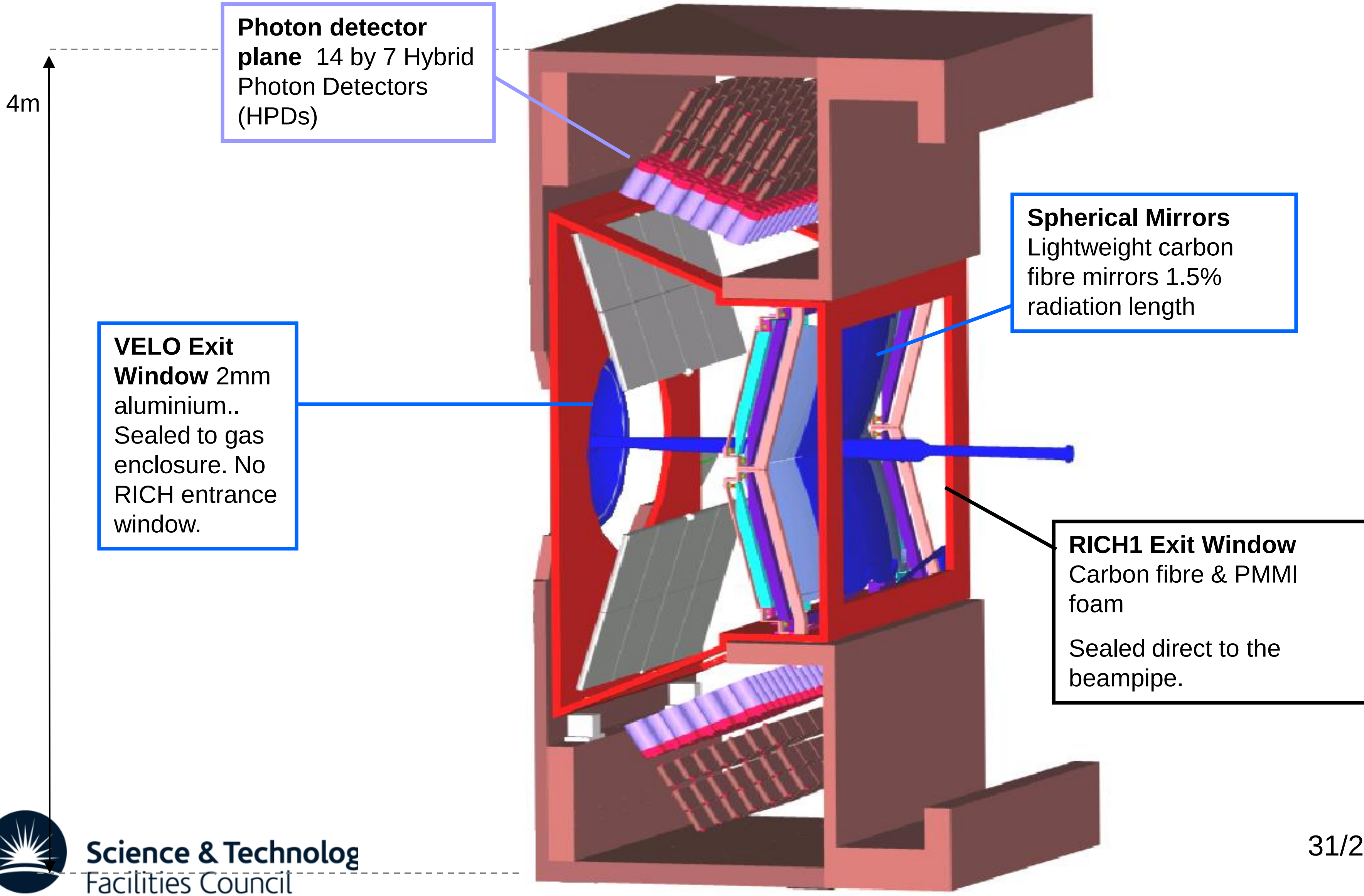


3. Centre of Gravity



RICH 1

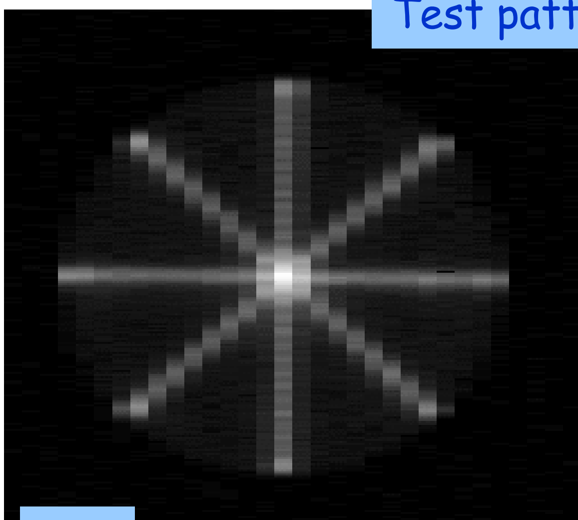
Tight space, low mass



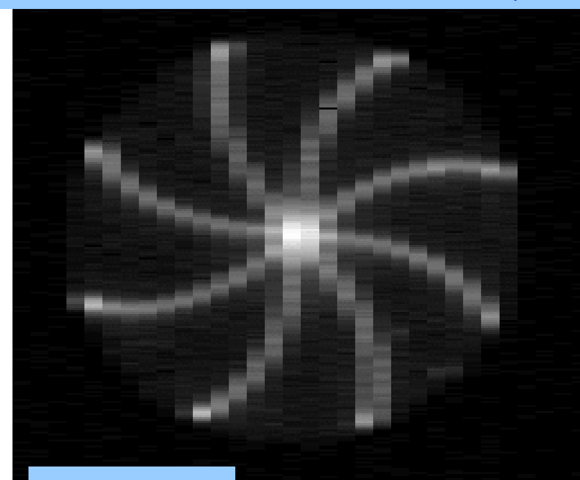
HPDs in magnetic field

Magnetic distortions

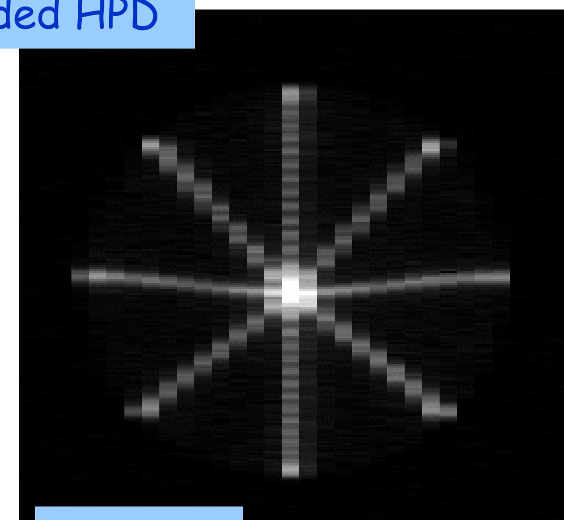
Test pattern measurements with locally shielded HPD



0 G

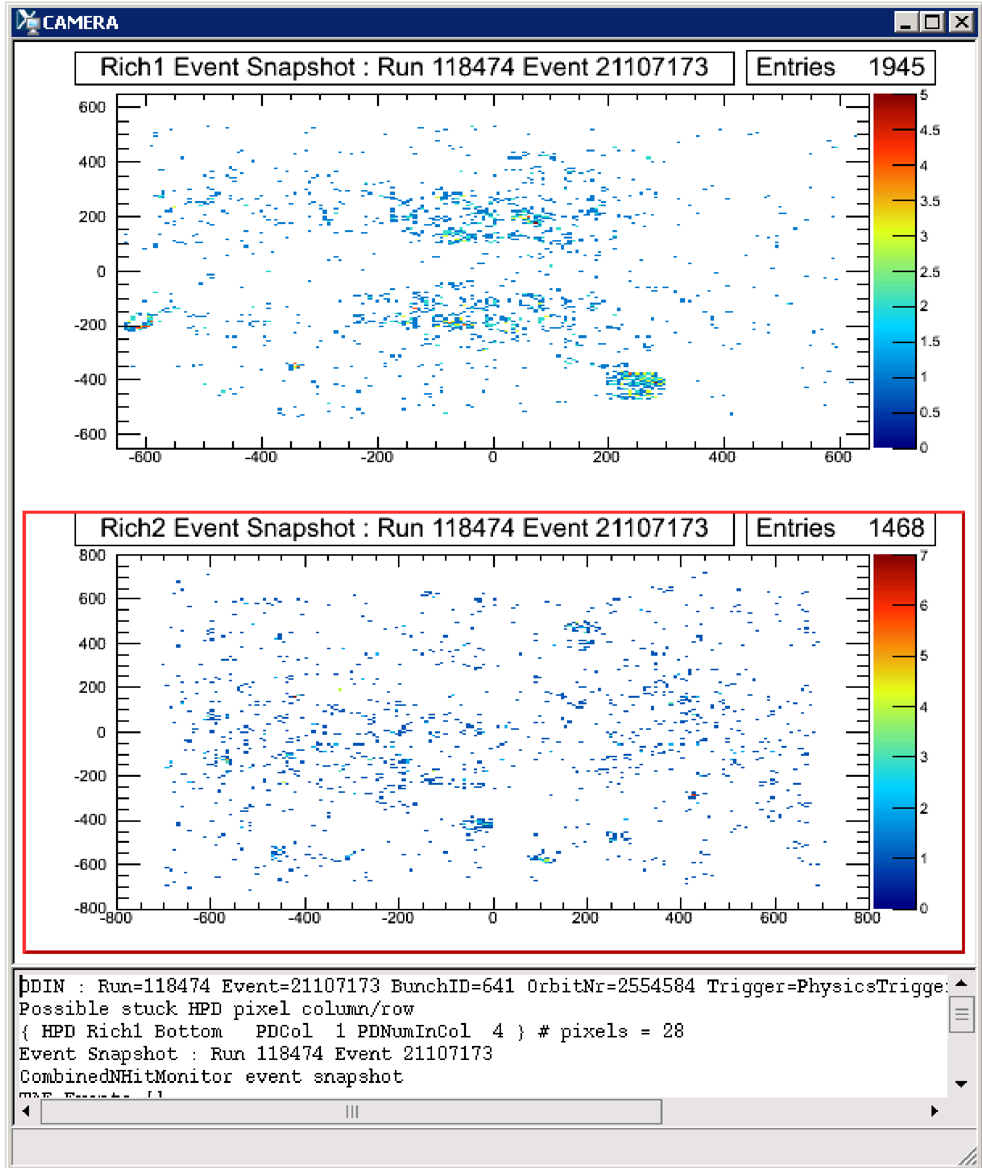


$B_{\parallel}$ 30 G



$B_{\perp}$ 50 G

Event snapshot 1



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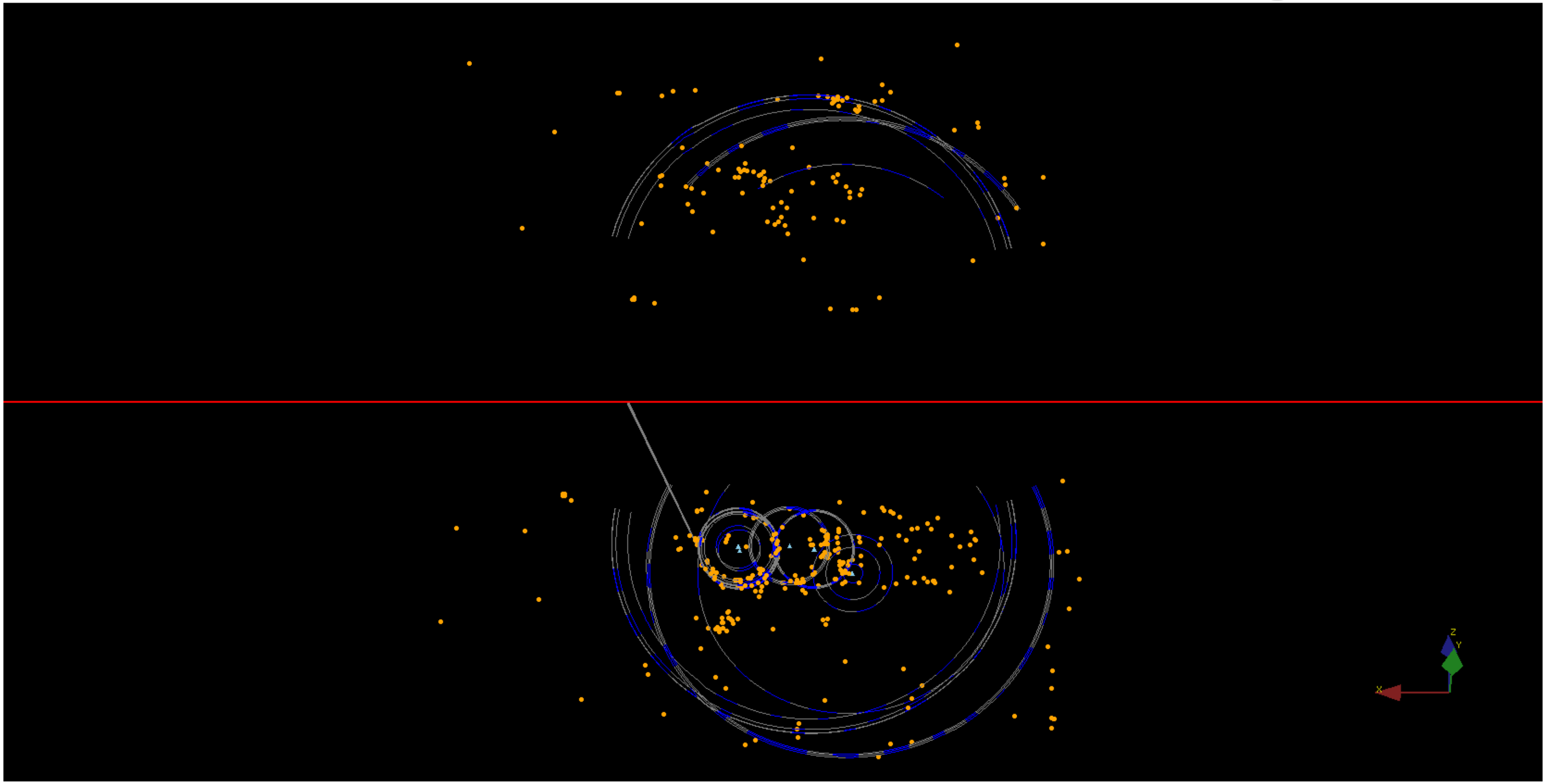
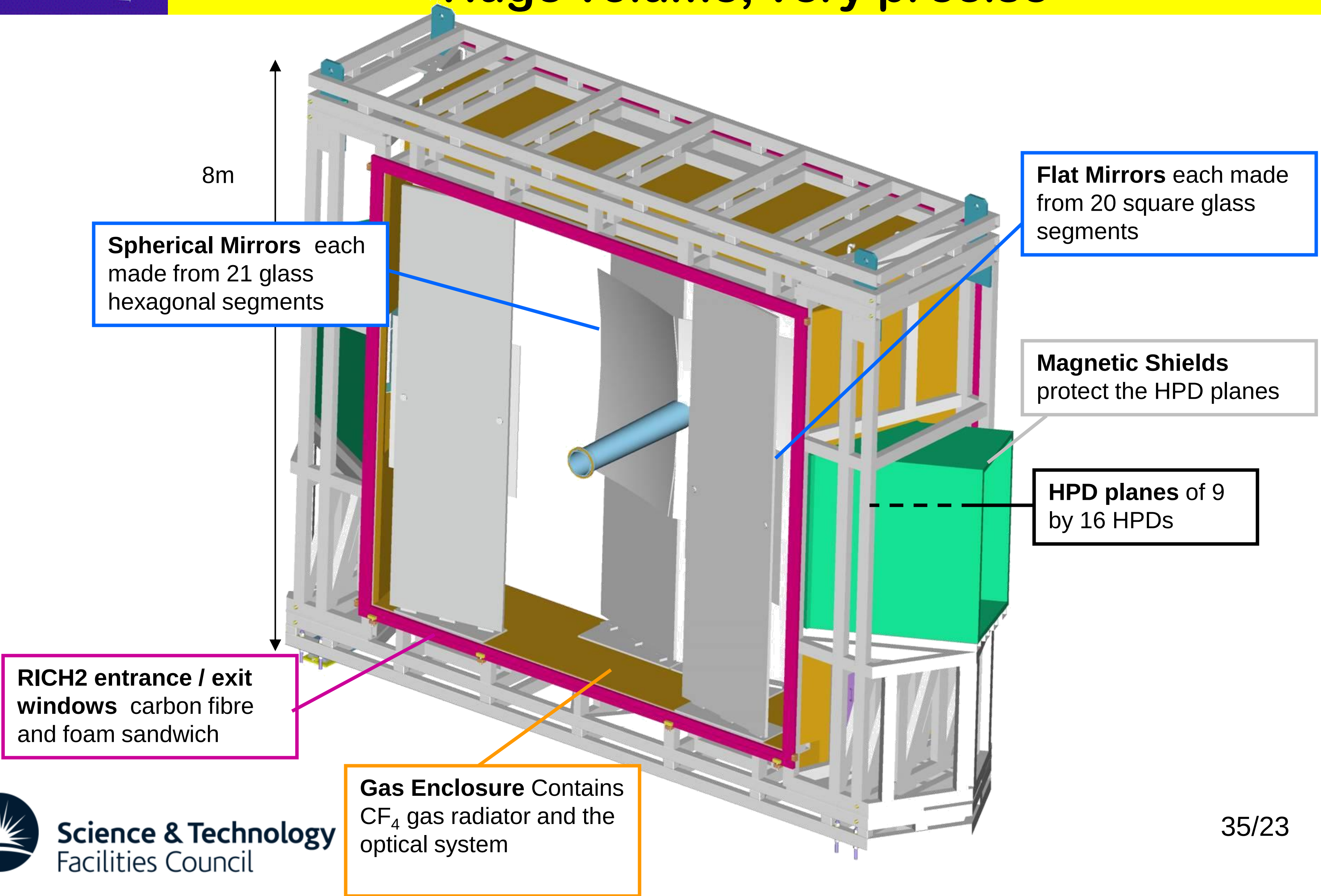
Event snapshot 2

RICH1 HPD Panels with Pixels and CK Rings



RICH 2

Huge volume, very precise



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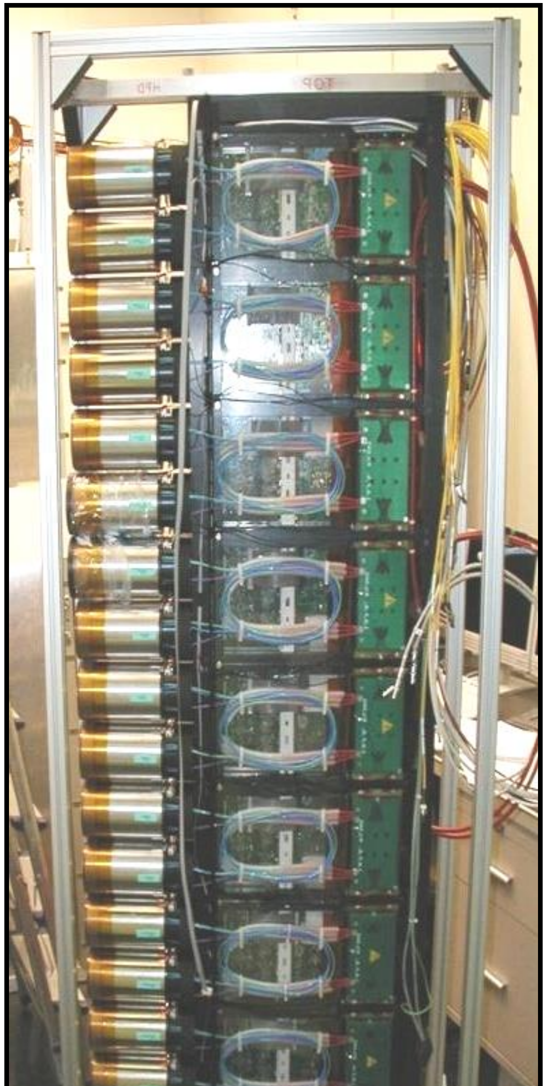
The readout chain



HPD column assembly

- All HPDs arranged in columns with ancillary front-end electronics
- LV & HV boards power the HPDs
- "Level-0" board passes triggered data to the "Level-1" off-detector board via an ~100m optical link
- Level-1 board receives and zero-suppresses the data and passes to the DAQ