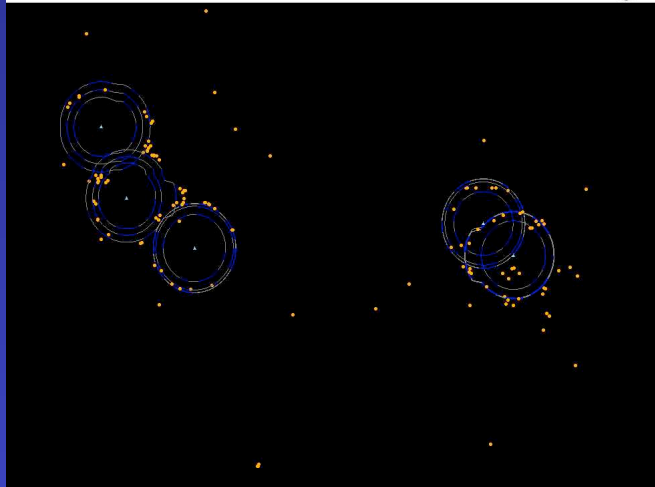




The Ring Imaging Cherenkov Detectors of the LHCb Experiment

RICH2 HPD Panels with Pixels and CK Rings



Franz Muheim
University of Edinburgh

On behalf of the
LHCb RICH collaboration



Outline



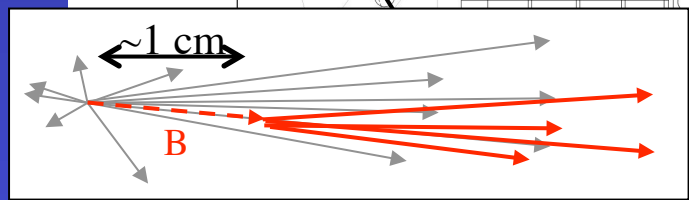
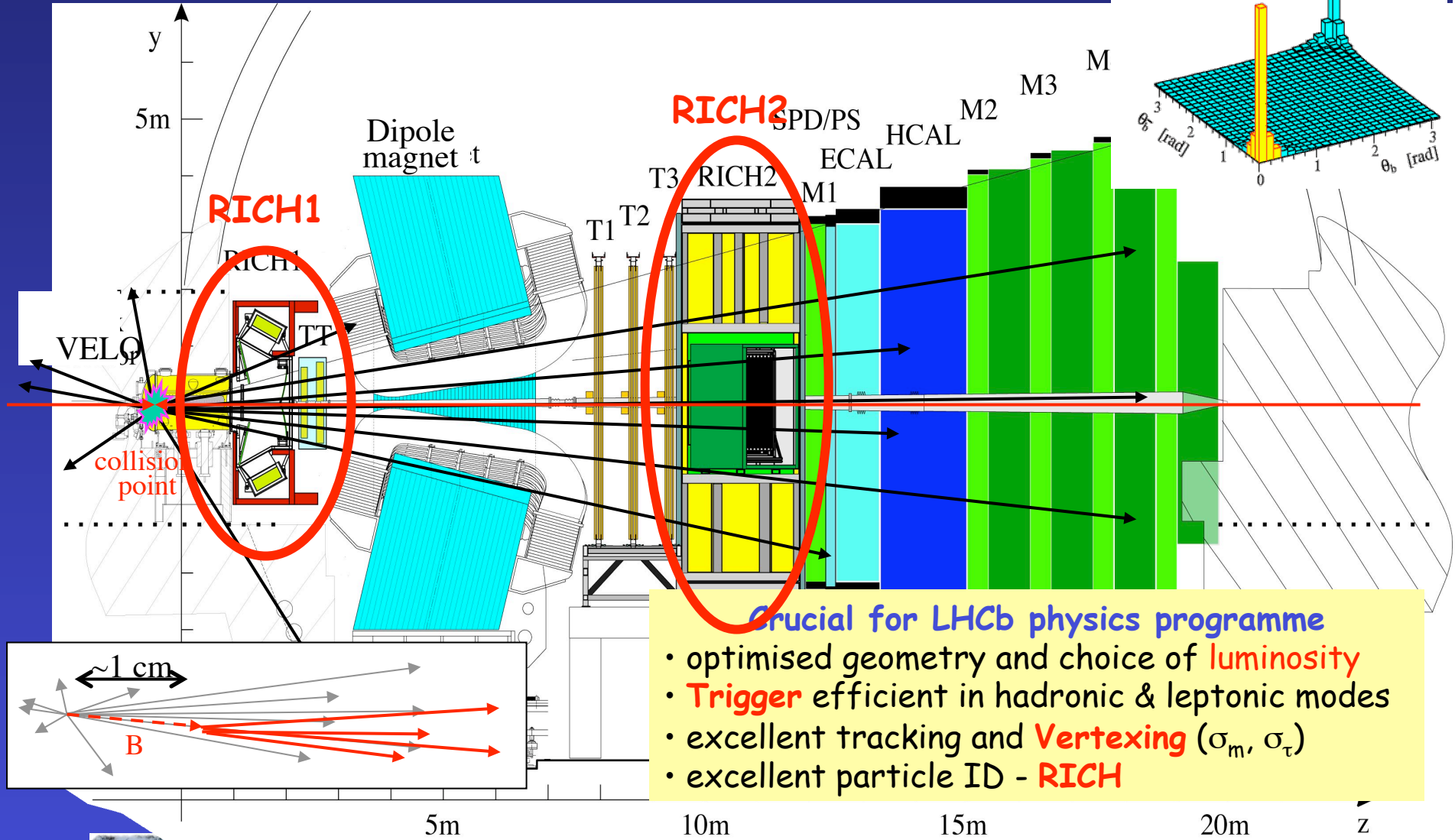
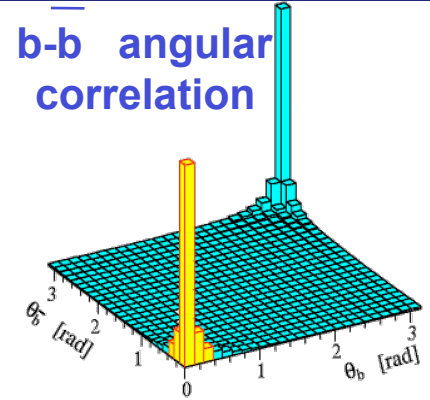
- LHCb Experiment
- Ring Imaging Cherenkov Detectors
- RICH Commissioning
- Preliminary Results with LHC Beam Data
- Outlook and Conclusions



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3 – 7 May 2010

LHCb Experiment

b-b angular correlation

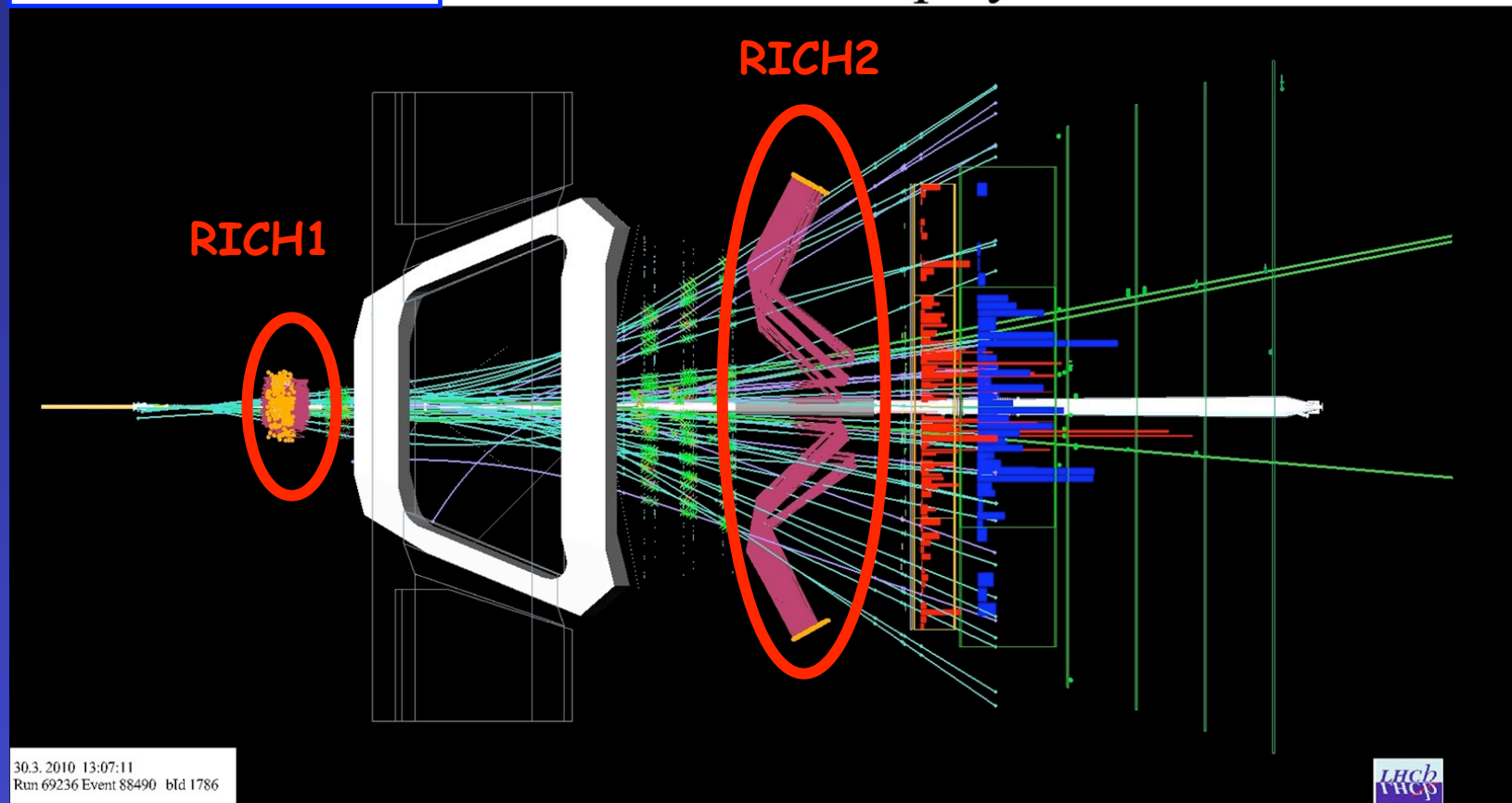


First LHCb Events at 7 TeV



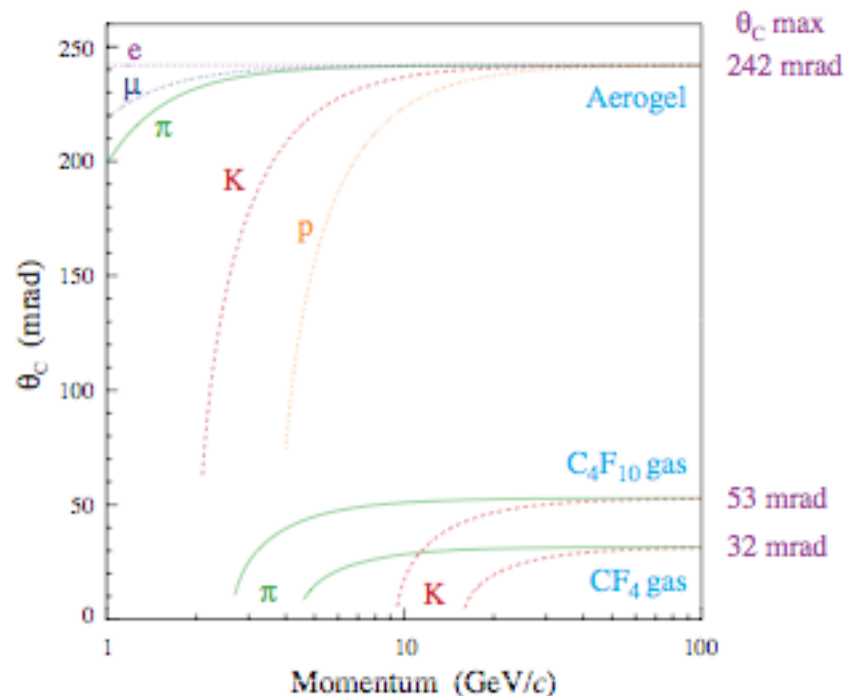
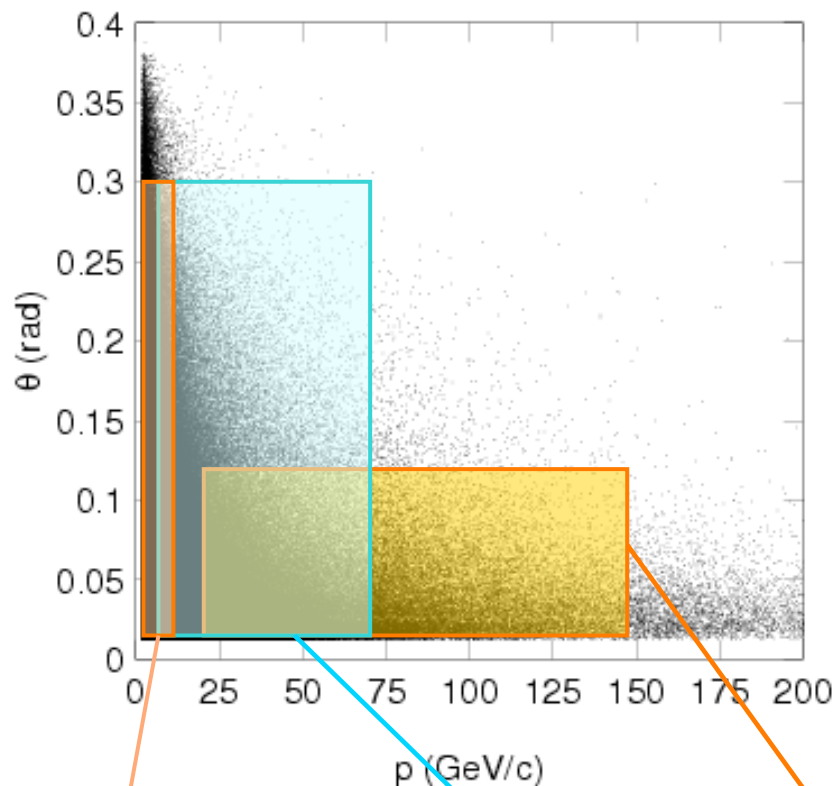
30th March 2010

LHCb Event Display



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The RICH Radiators



Silica Aerogel
 $n=1.03$
 2 to 10 GeV/c

C_4F_{10} gas
 $n=1.0014$
 Up to ~60 GeV/c

CF_4 gas
 $n=1.0005$
 Up to ~100 GeV/c

RICH1:

25 → 250 mrad vertical
 25 → 300 mrad horizontal

RICH2:

15 → 100 mrad vertical,
 15 → 120 mrad horizontal

Expected photon yields for isolated saturated particles

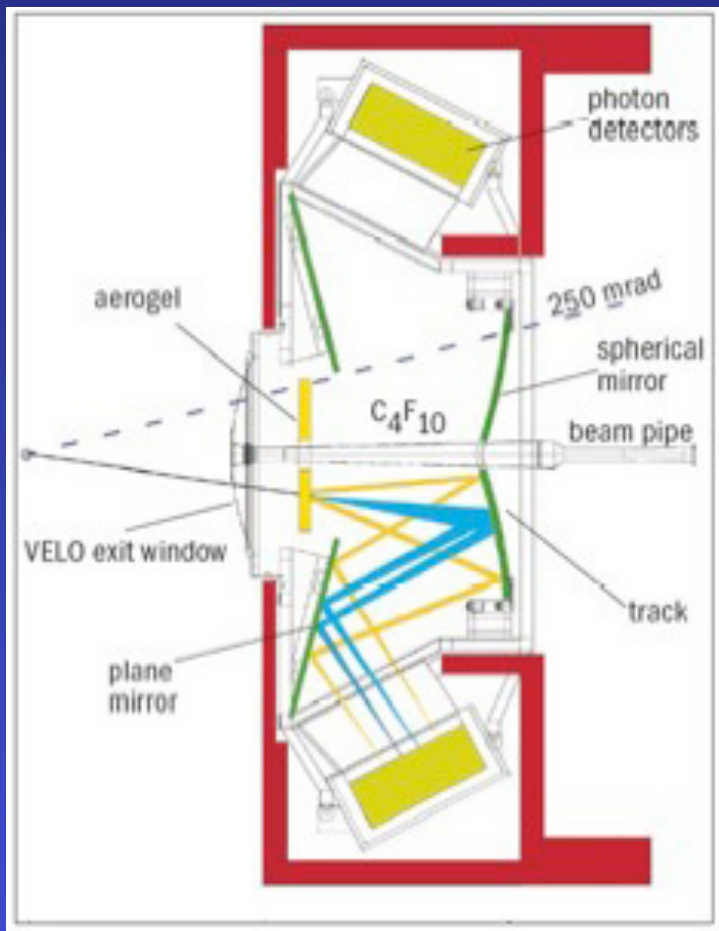
A. Alves et al., JINST 3:S08005,2008.

| Aerogel | C_4F_{10} | CF_4 |
|---------|-------------|--------|
| 6.7 | 30.3 | 21.9 |

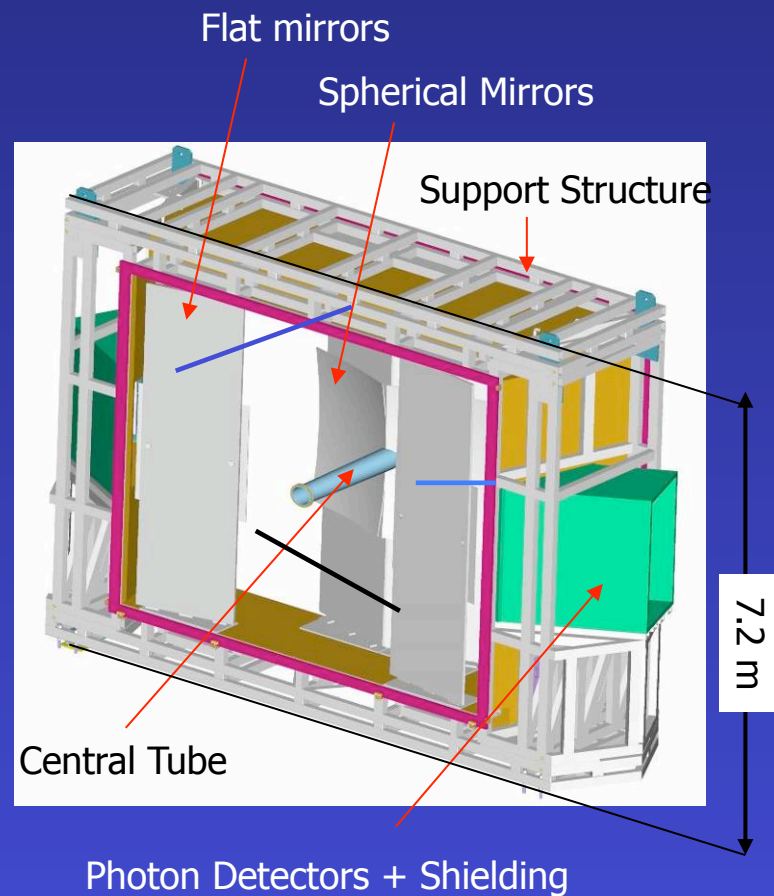
RICH1 and RICH2 Layout



RICH1



RICH2



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RICH Detectors - Pictures



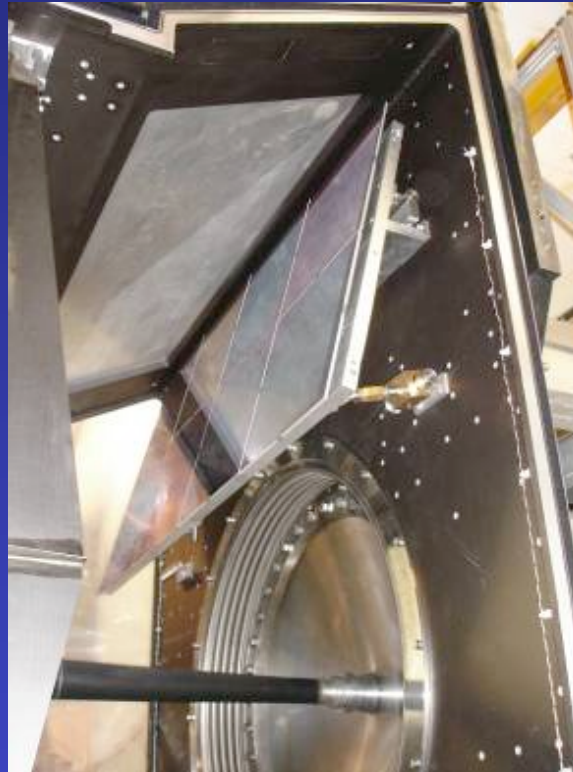
RICH 2 Detector
Support structure,
entrance window,
magnetic shielding



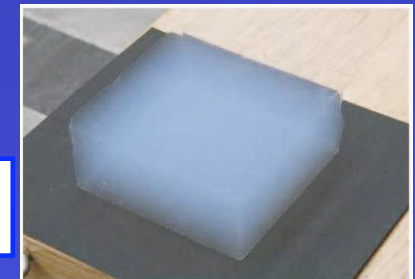
RICH 1 Inside gas enclosure with Aerogel and planar mirrors



RICH 1 Beryllium beampipe,
VELO exit window and seal
and planar mirrors

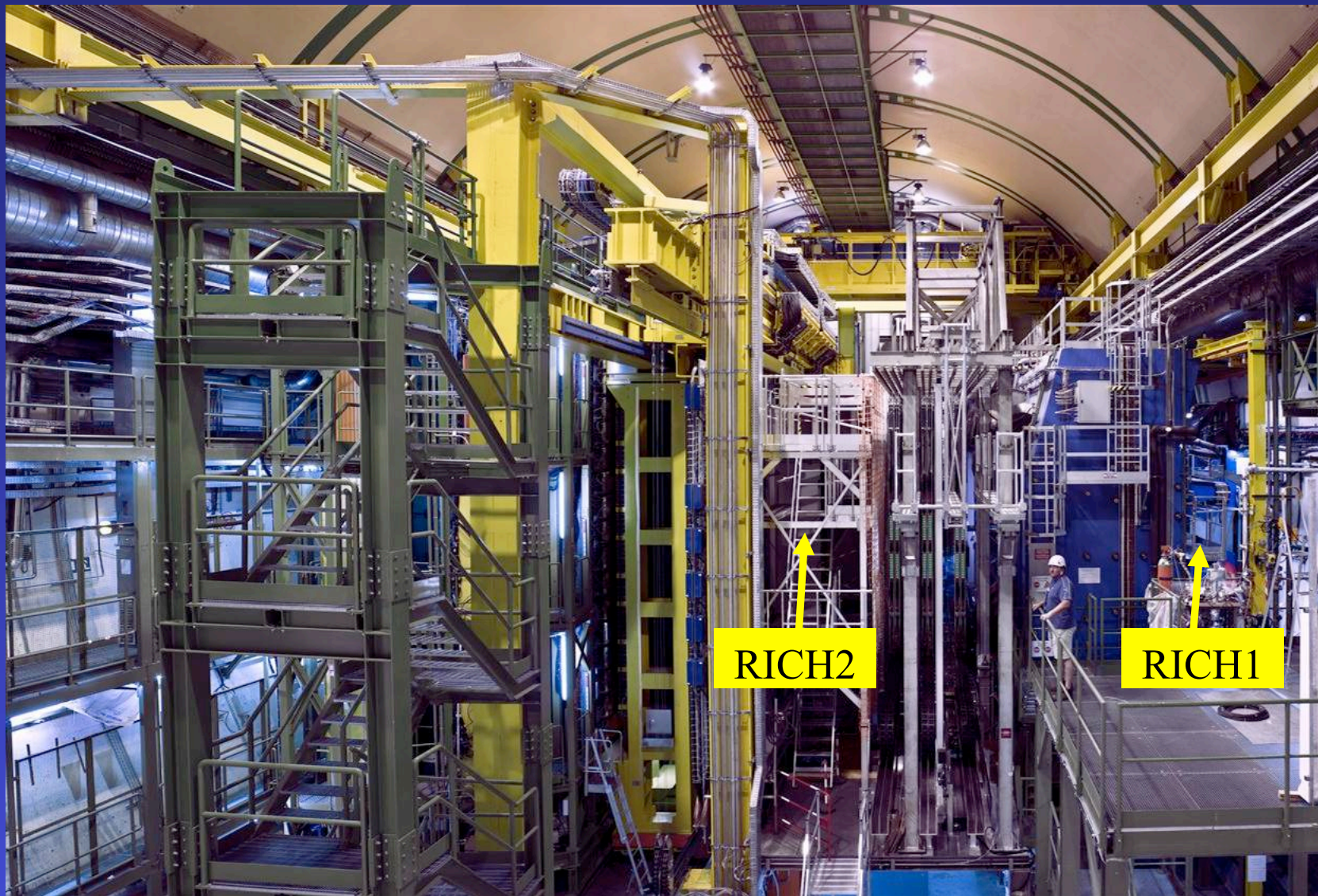


RICH 1
Aerogel tile



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LHCb Detector



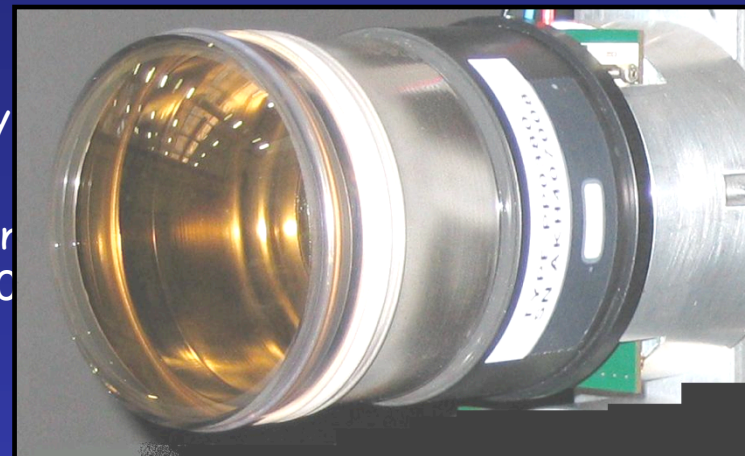
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Hybrid Photon Detectors



- **Pixel HPDs**

- developed in collaboration with industry (Photonis-DEP lead partner)
- Combines vacuum technology with silicon pixel readout - Quartz window with S20 photocathode
- 200-600 nm wavelength
- Factor 5 demagnification @ 20kV

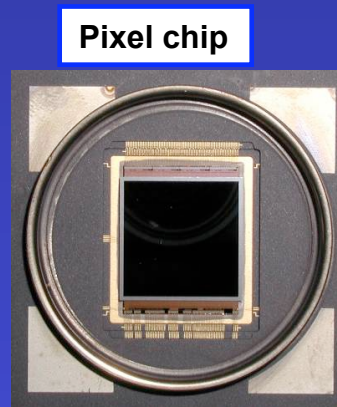


- **LHCb RICH - 484 HPDs**

- total area of 3.3m²
- with 2.5 x 2.5 mm² granularity

- **Readout**

- Encapsulated 32x32 pixel silicon sensor
- Bump-bonded binary readout chip
- Operates at the LHC bunch crossing frequency (40MHz)



Pixel chip



RICH1 HPD Panel



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RICH Commissioning



- LHCb RICH detectors have been commissioned extensively starting in autumn 2007
- Detector Control System and Monitoring
- Photon Detectors Properties
- Magnetic Distortion Monitoring System
- First Light
- Cosmic Rays
- Gas Systems

See talk by Ross Young

See poster by Funai Xing



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Experiment & Detector Control



- RICH Operation fully automated
- 1 piquet shift

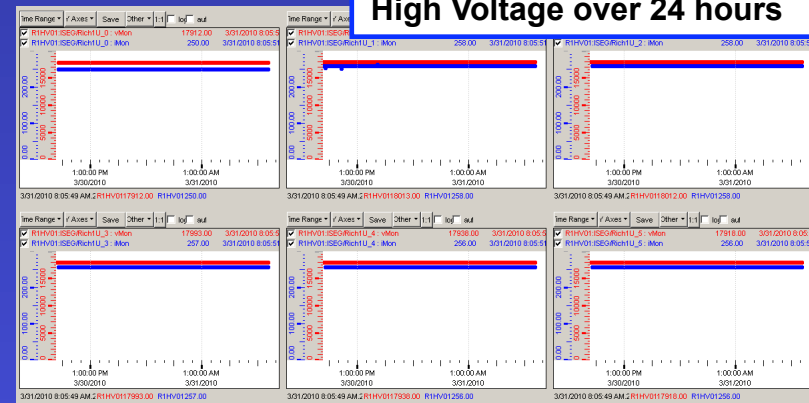
RICH Control Panel

High Voltage Status

RICH High Voltage Status

| | LV_LO | | LV_HI | | SiBias | | HV_20 (kV) | | Temperature State |
|--------|-------|------|-------|------|--------|-----|------------|-------|-------------------|
| | V | A | V | A | V | uA | Up | Down | |
| Col U0 | 0.04 | 0.23 | 0.05 | 0.23 | 0.00 | 0.0 | 0.00 | 0.00 | READY |
| Col U1 | 0.04 | 0.24 | 0.05 | 0.27 | 0.10 | 0.0 | 0.00 | -0.00 | READY |
| Col U2 | 0.05 | 0.23 | 0.05 | 0.21 | 0.00 | 0.0 | -0.01 | 0.01 | READY |
| Col U3 | 0.02 | 0.26 | 0.03 | 0.25 | 0.20 | 0.0 | -0.00 | 0.01 | READY |
| Col U4 | 0.03 | 0.23 | 0.04 | 0.23 | 0.10 | 0.0 | 0.01 | 0.01 | READY |
| Col U5 | 0.03 | 0.22 | 0.02 | 0.25 | 0.10 | 0.0 | 0.00 | 0.01 | READY |
| Col U6 | 0.04 | 0.29 | 0.05 | 0.27 | 0.00 | 0.0 | -0.00 | 0.00 | READY |
| Col D0 | 0.11 | 0.27 | 0.10 | 0.27 | 0.10 | 0.0 | 0.00 | 0.01 | READY |
| Col D1 | 0.07 | 0.29 | 0.01 | 0.29 | 0.00 | 0.0 | -0.00 | 0.02 | READY |
| Col D2 | 0.01 | 0.30 | 0.04 | 0.29 | 0.10 | 0.0 | 0.00 | -0.01 | READY |
| Col D3 | 0.04 | 0.30 | 0.00 | 0.30 | 0.10 | 0.0 | 0.01 | 0.01 | READY |
| Col D4 | 0.08 | 0.29 | 0.07 | 0.29 | 0.00 | 0.0 | 0.00 | 0.01 | READY |
| Col D5 | 0.00 | 0.30 | 0.02 | 0.30 | 0.00 | 0.0 | 0.01 | 0.00 | READY |
| Col D6 | 0.03 | 0.27 | 0.03 | 0.22 | 0.00 | 0.0 | -0.00 | -0.01 | READY |

High Voltage over 24 hours



RICH Commissioning



- **RICH 1 and RICH 2 fully commissioned**

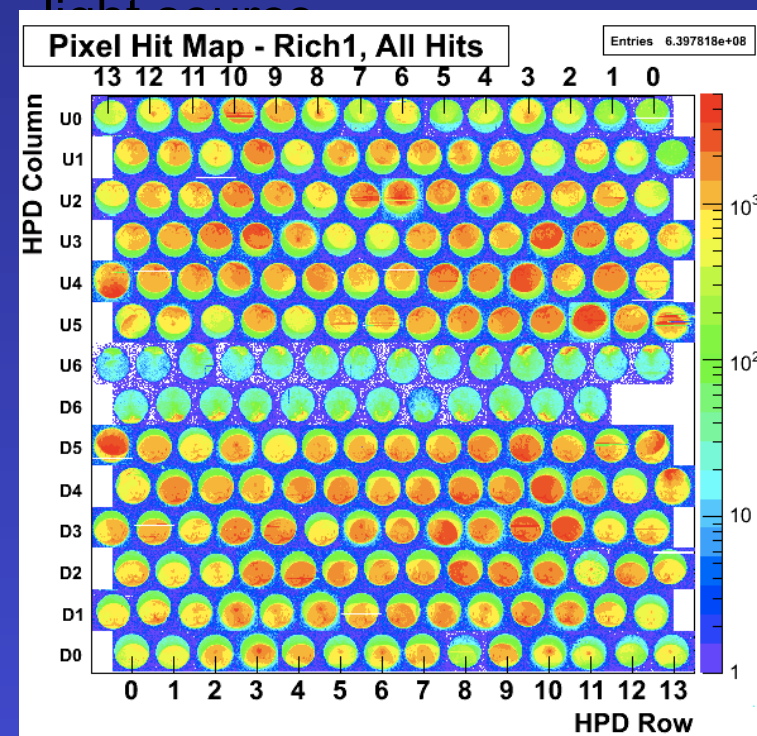
- Level-0 and Level-1 Electronics
- Detector control & safety systems (DCS/ ECS)
- Monitoring

- **HPD properties**

- Monitored with laser light source
- Dark count rate, ion feedback
- ~18% of HPDs have developed large ion feedback
- 73 HPDs replaced now
- ~13 HPD replacements/year expected

See talk by Ross Young

RICH1 cont. wave laser



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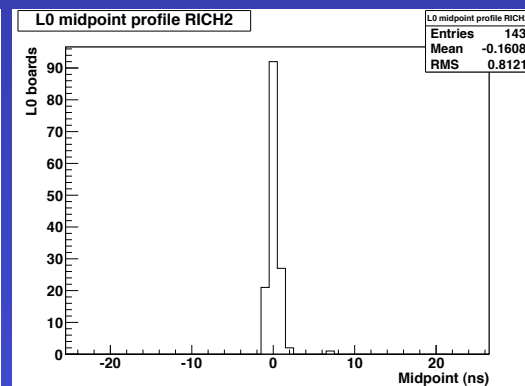
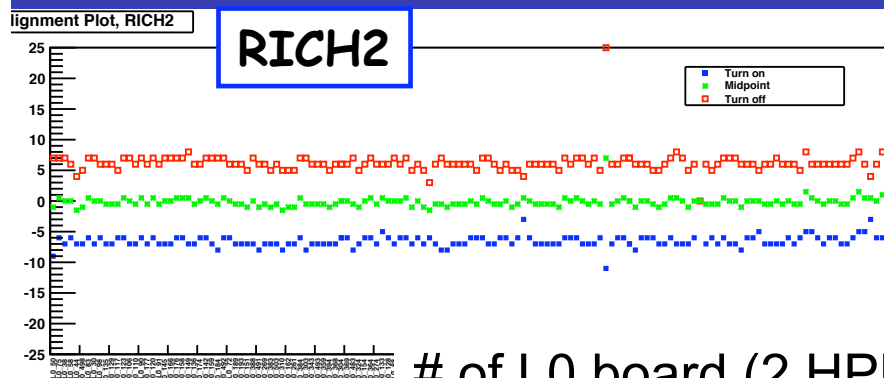
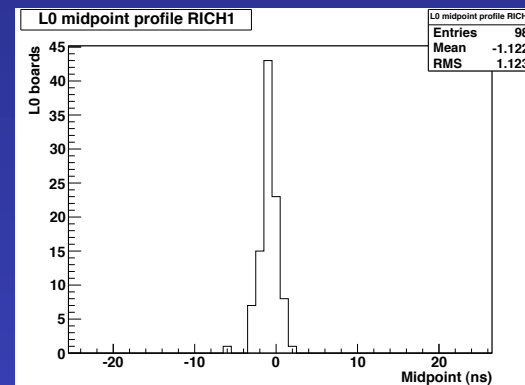
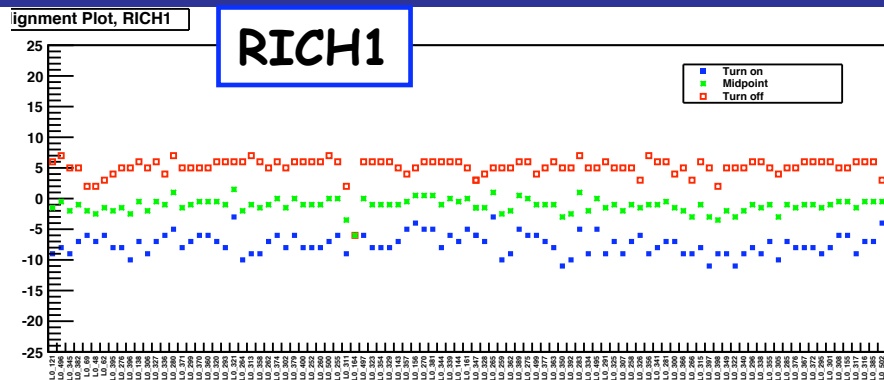
HPD Time Alignment

- Alignment methods
 - With laser light and beam data
 - From 7 TeV data - Resolution ~ 1 ns

See talk by Ross Young

Middle points

Lower, Middle, Upper points



of L0 board (2 HPDs)



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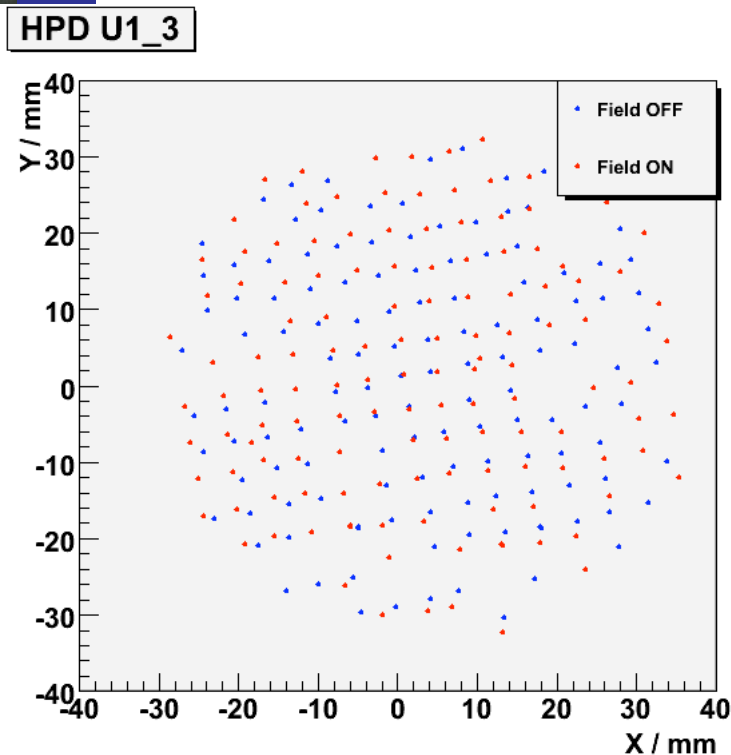
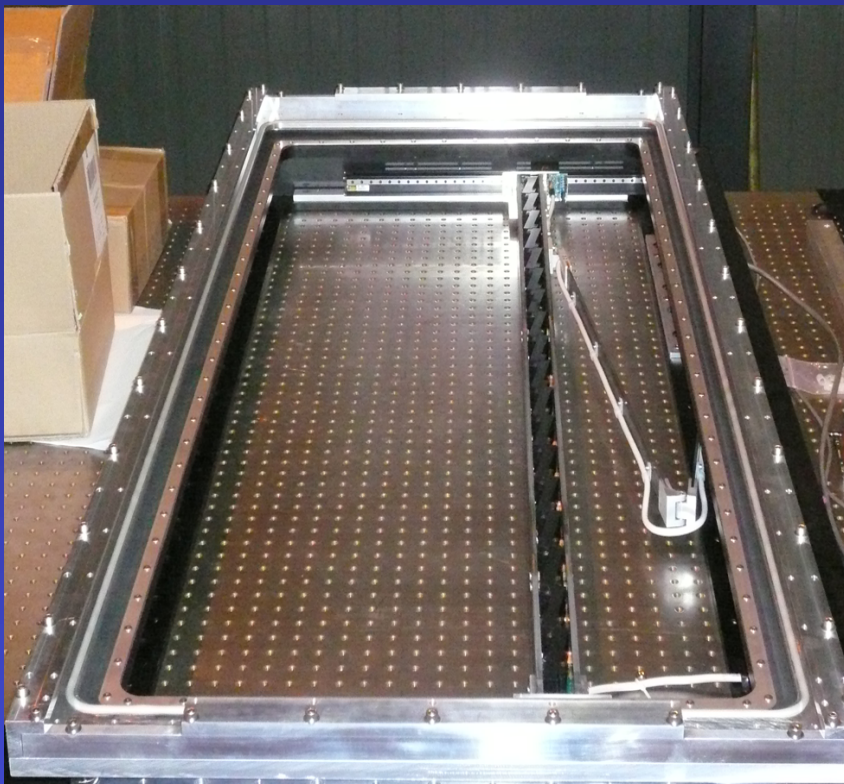
Magnetic Field Calibration

- **RICH1**

- Collimated LEDs on movable bar
- Retracted during collisions

See poster by Funai Xing

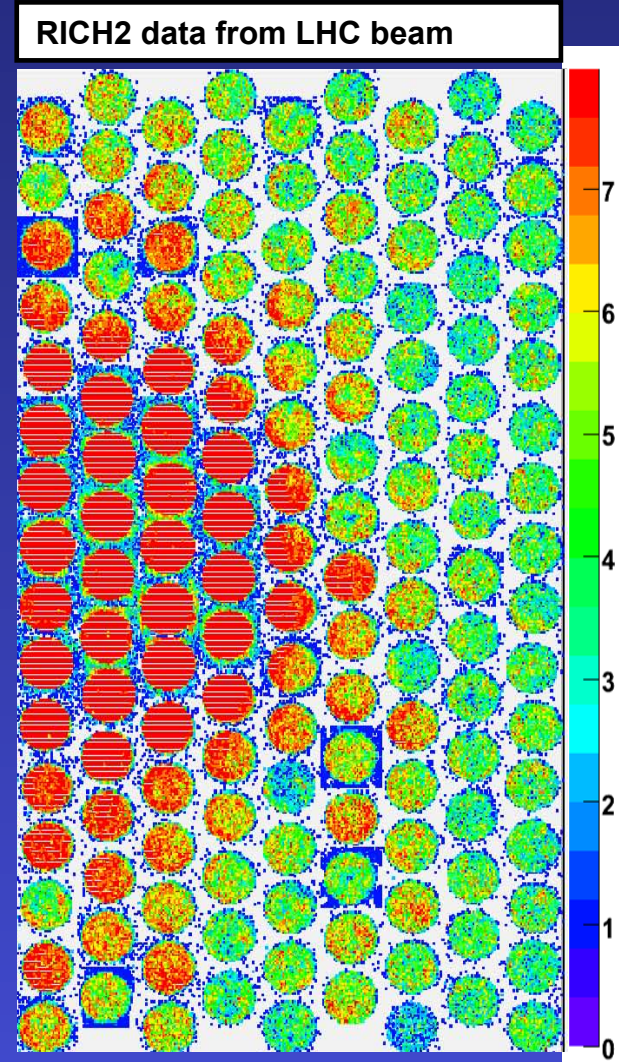
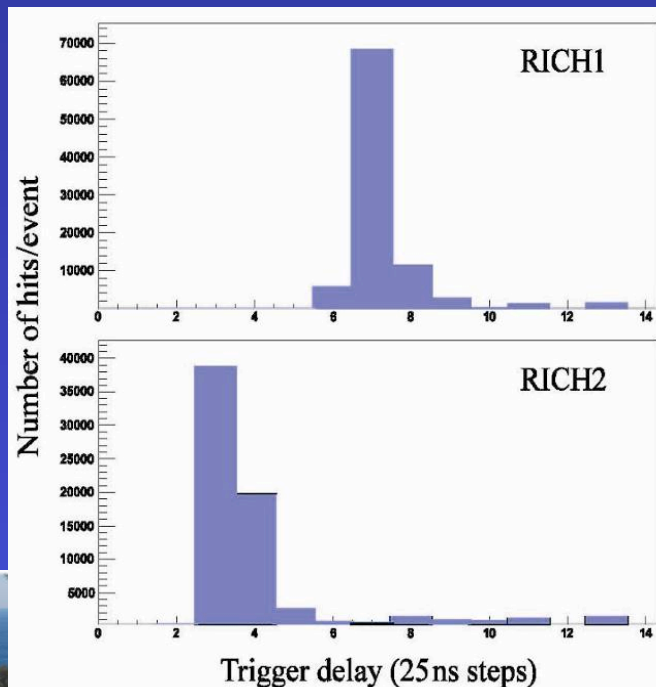
RICH1 fringe magnetic field
after shielding ~ 14 G



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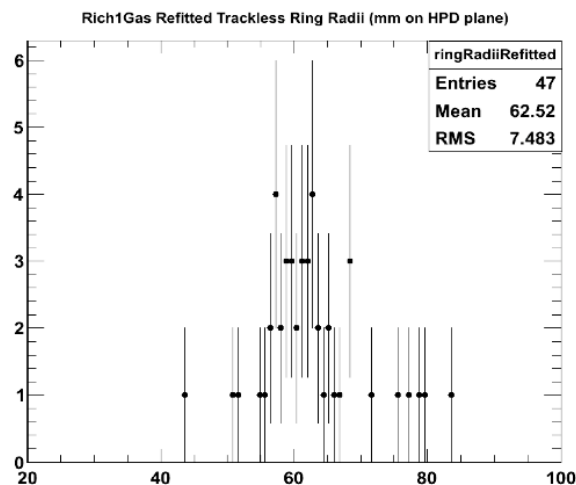
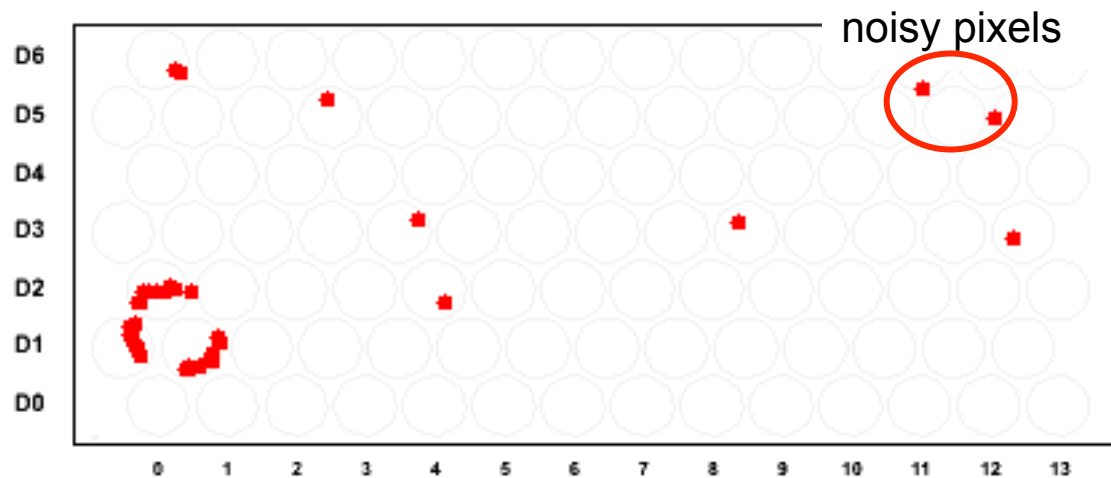
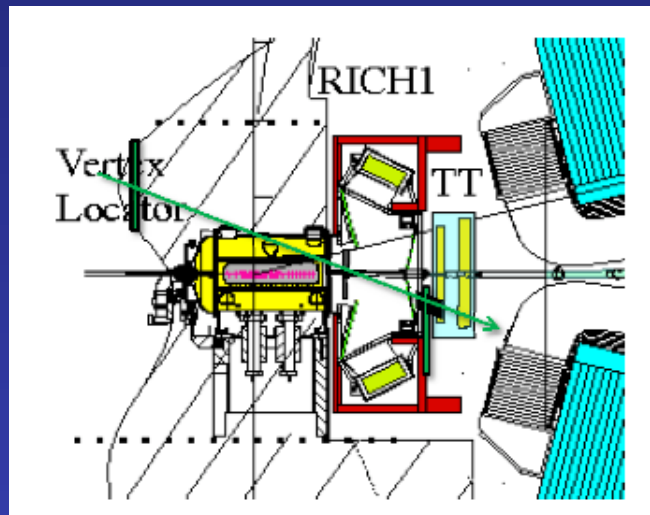
First Light - LHC beams

- **LHC injection beam tests**
 - in Aug/Sept 2008
 - Tracks passed through LHCb in "wrong" direction
high density $\sim 10/\text{cm}^2$
- **Cherenkov light in the HPD windows**
 - Used for time alignment



Cosmic Rays

- **Trigger - Scintillator planes**
 - 2x2 m², on Wall (VELO) and between RICH1 and TT
- **Low rate**
 - A few cosmic rays/hour
- **First RICH rings**
 - August 2009
 - Well isolated



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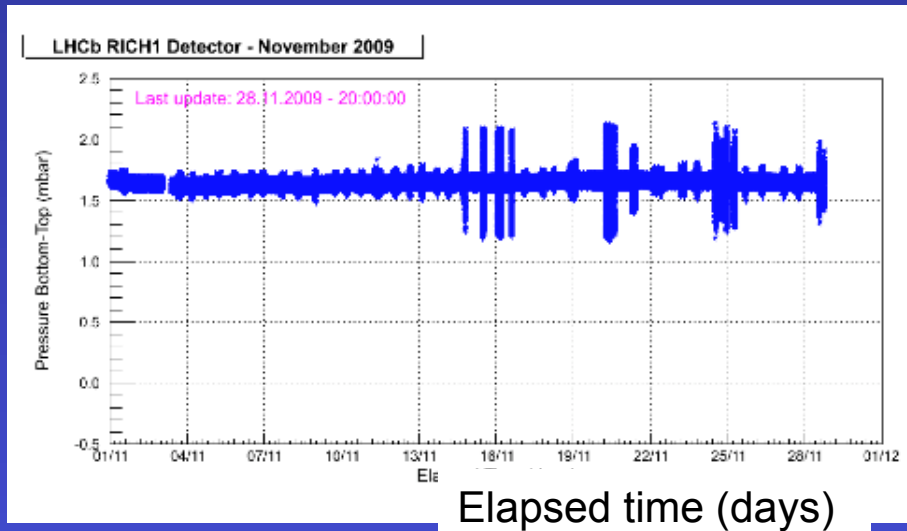
Ring radius [mm]

Gas Systems



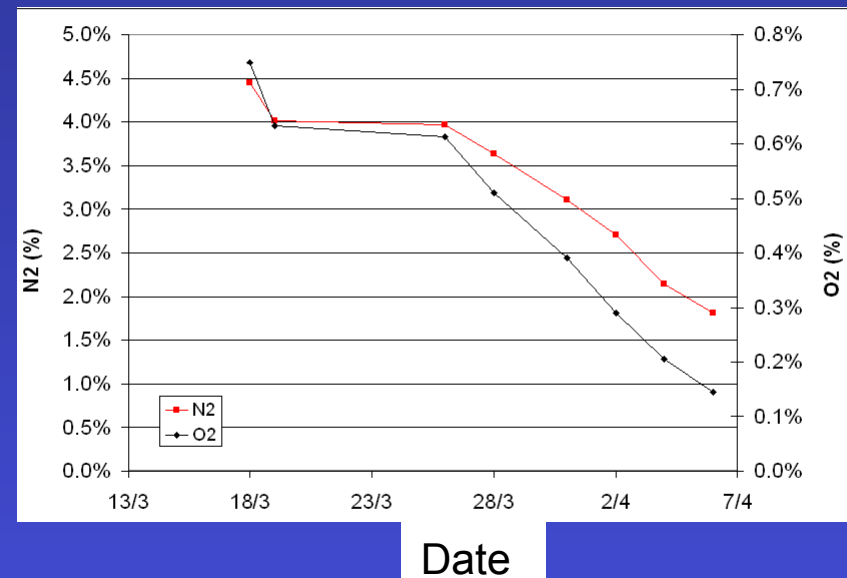
RICH1

- Gas chromatography
 - 98% C_4F_{10} ,
 - 0.8% CO_2 , 1% N_2 , 0.2% O_2
 - Monitoring with hydrostatic pressure difference top - bottom



RICH2

- Gas chromatography
 - CF_4 98%
 - N_2 1.8%,
 - O_2 0.2%,



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First Results with LHC Beams



- Event Displays & Monitoring
- Angular Resolution,
Mirror Alignment,
Photon Yield
- Aerogel Performance
- Particle Identification
- Charmed and Strange Hadrons

See talk by Chris Blanks

See poster by Davide Perego

See talk by Andrew Powell



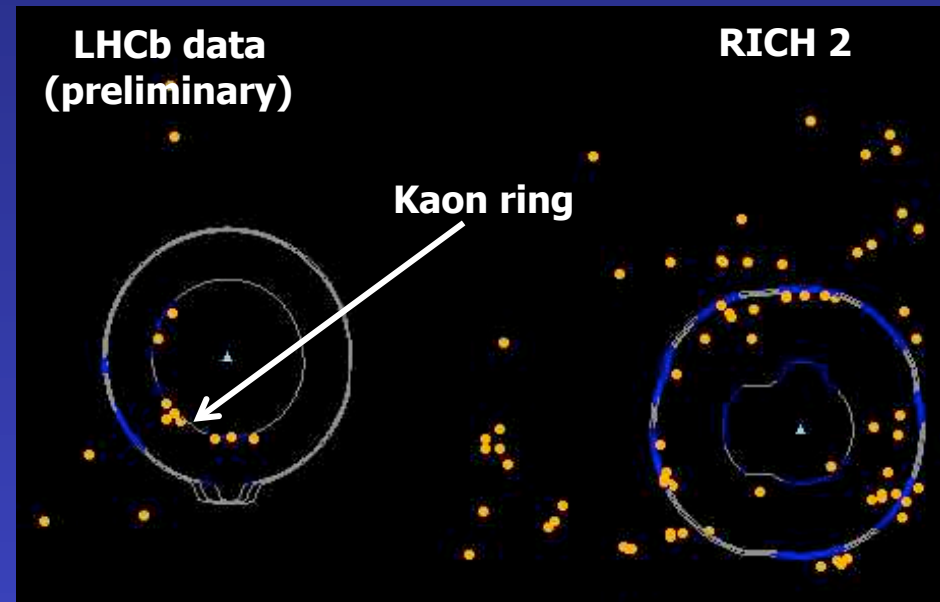
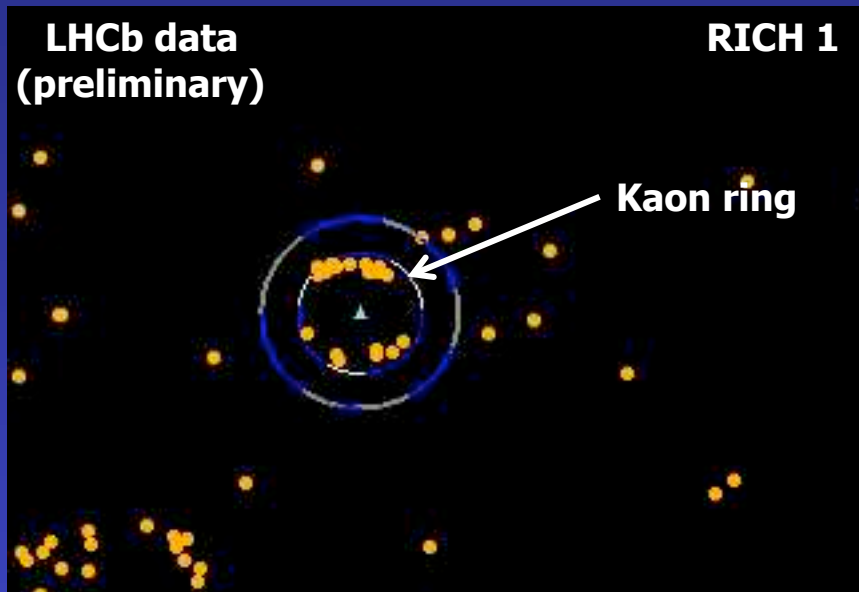
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Event Display

RICH1

Nov/Dec 2009
LHC beams $\sqrt{s} = 900 \text{ GeV}$

RICH2



- Orange points → photon hits
- Continuous lines → expected distribution for each particle hypothesis



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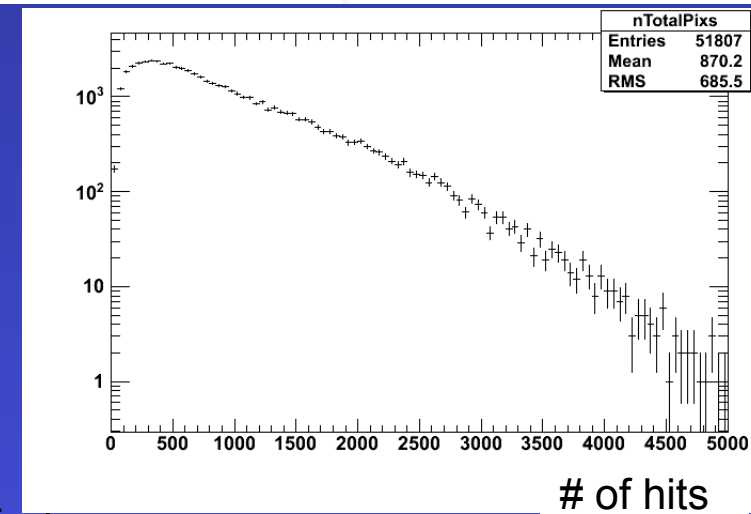
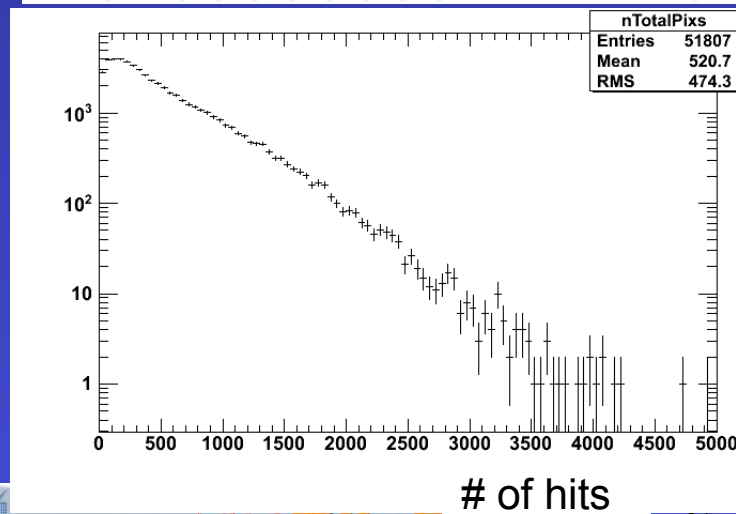
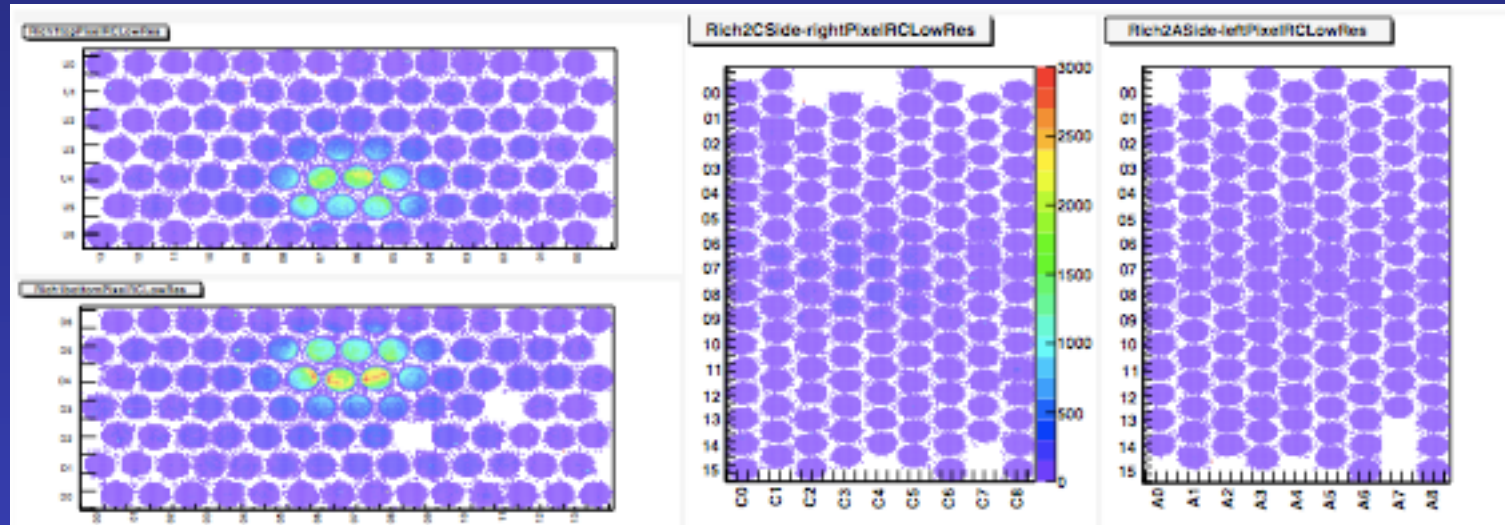
Monitoring

Since 30 March 2010

LHC beams at $\sqrt{s} = 7$ TeV

RICH1

RICH2



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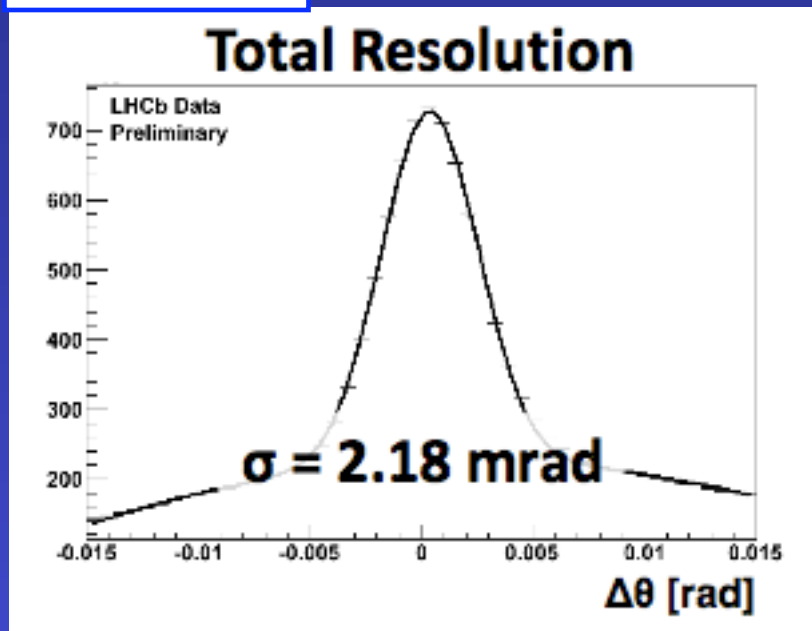
Angular Resolution

- **Mirror Alignment**

- Spherical and planar mirrors
- Well underway for gas radiators

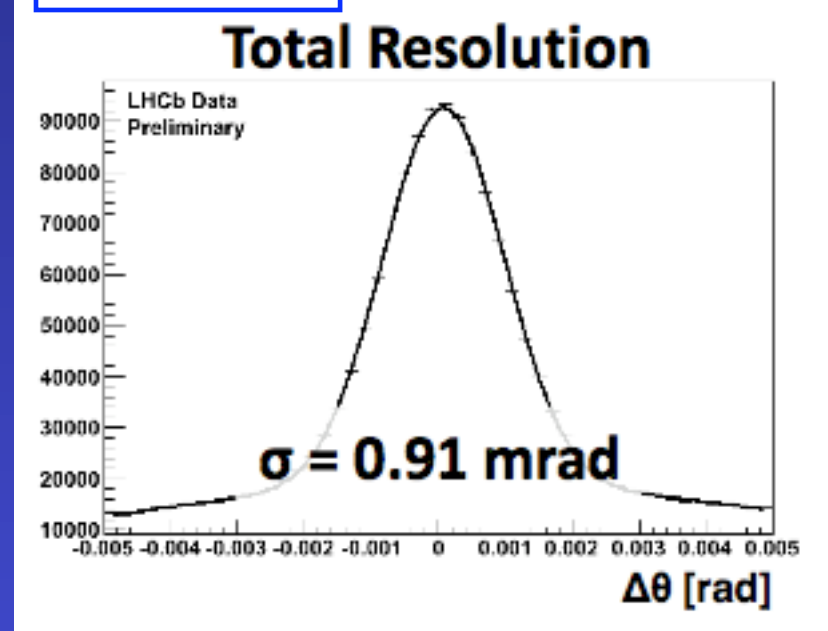
See talk by Chris Blanks

RICH1 Gas



MC expectation: 1.57 mrad

RICH2 Gas



MC expectation: 0.67 mrad



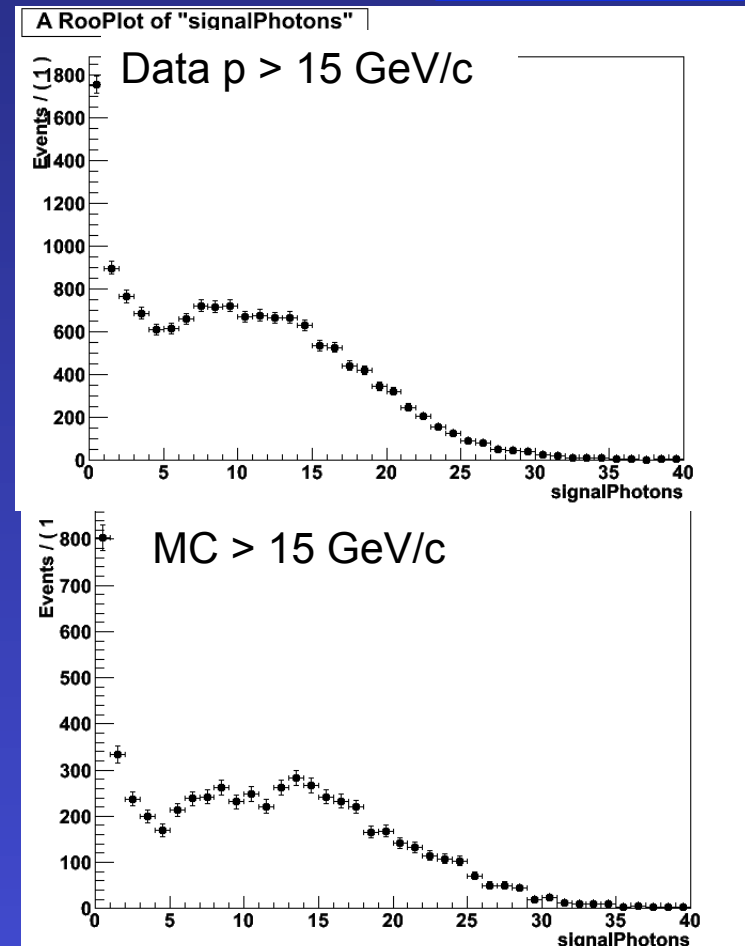
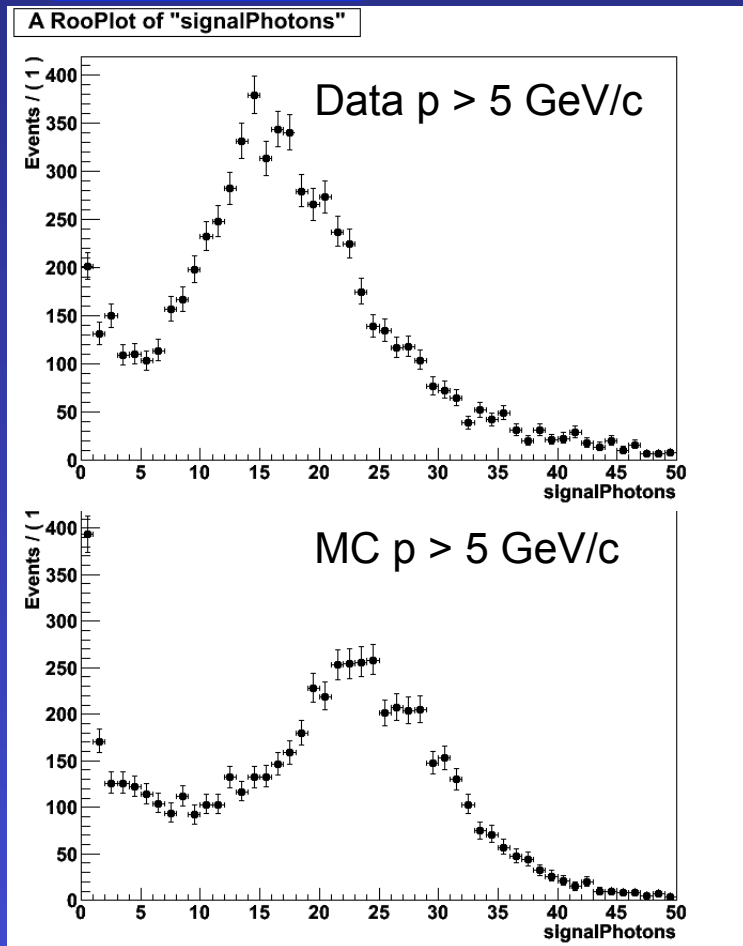
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Photon Yield

Data from Nov/Dec 2009
LHC beams $\sqrt{s} = 900 \text{ GeV}$

RICH1 Gas

RICH2 Gas



Aerogel Radiator

- **Geometry**

- 16 large tiles of silica aerogel
- 5 cm thick

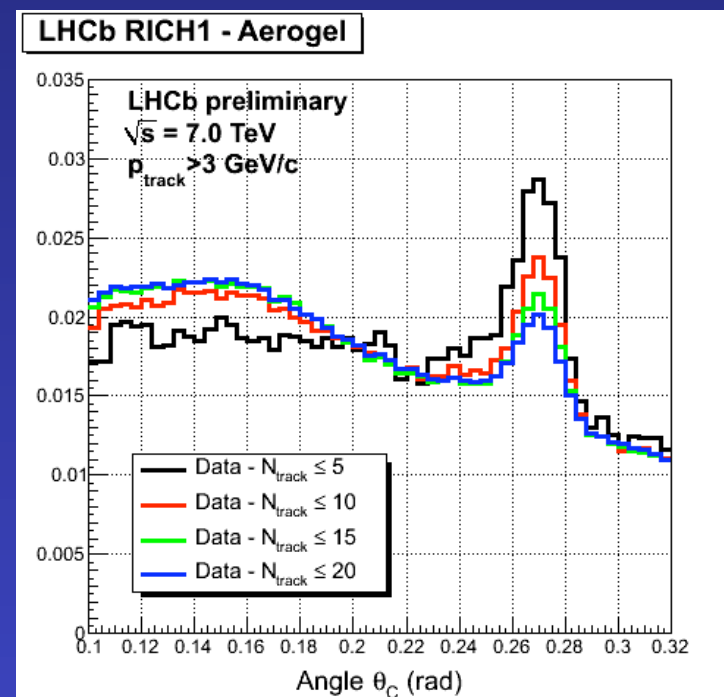
- **Properties**

- Refractive index ~ 1.03
- Excellent homogeneity
- Clarity $C < 0.006$
- 300 μm UV filter

- **Not sealed from gas volume**

- Changes due to C_4F_{10} absorption
- Refractive index increased to 1.037

See poster by Davide Perego



- **Photon yield and angular resolution**

- Worse than expected
- Under investigation

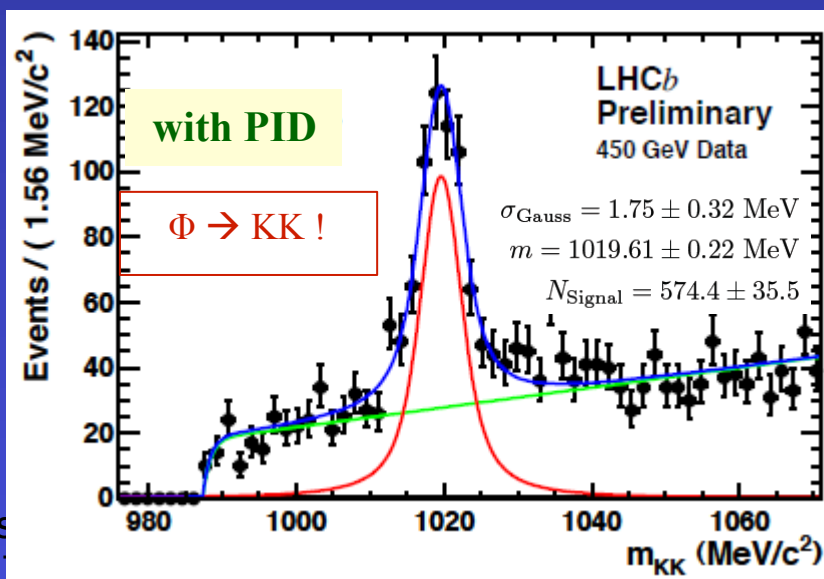
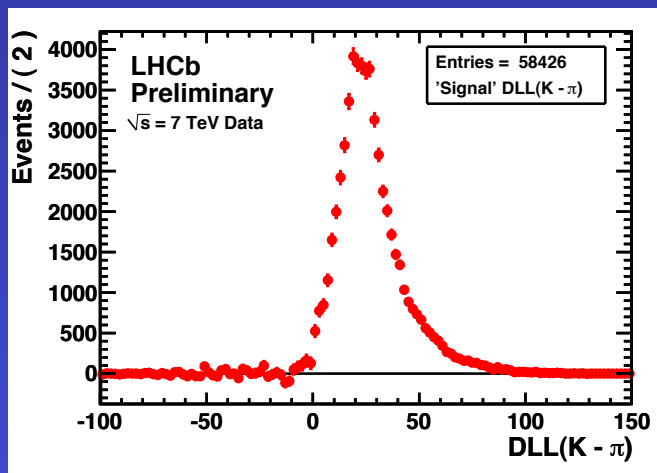
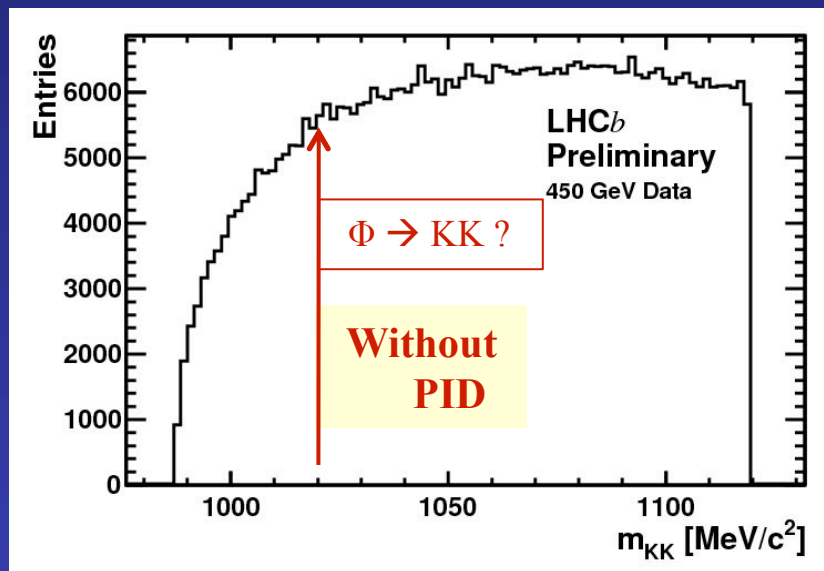


Particle Identification



See talk by Andrew Powell

- **Reconstruction**
 - Maximises likelihood of particle identification (PID) hypothesis
- **Selection**
 - Delta log likelihood between different hypotheses

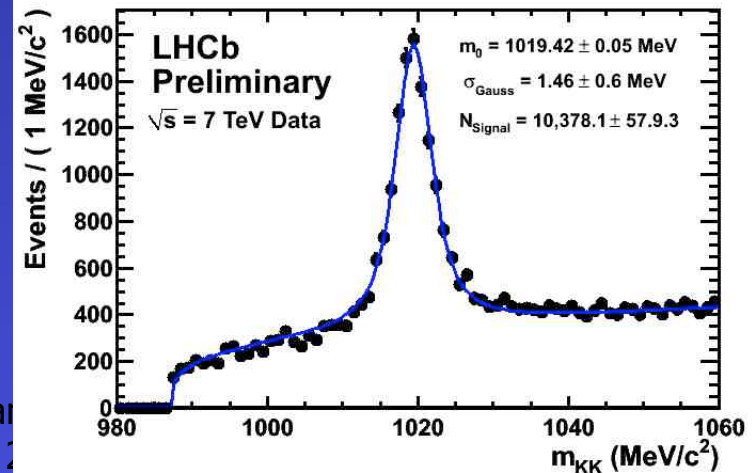
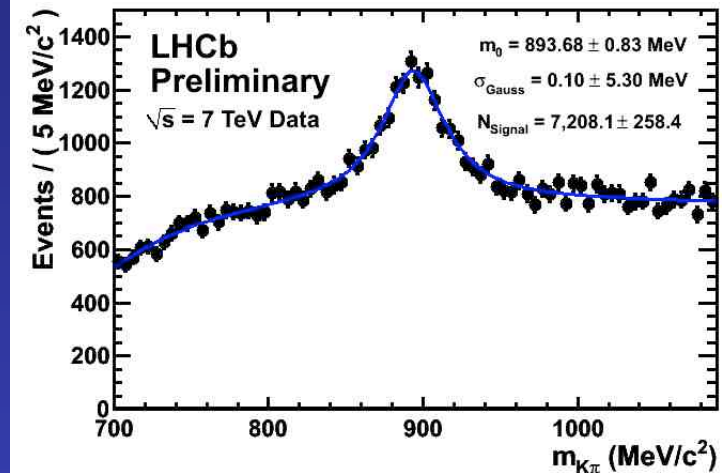
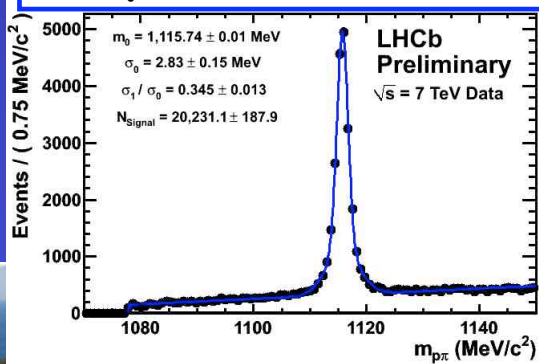
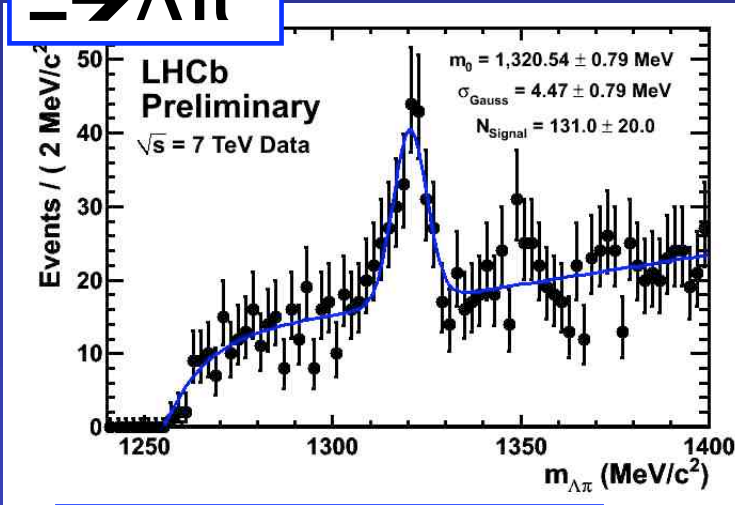


Strange Hadrons at $\sqrt{s} = 7$ TeV



- RICH PID**

- Makes finding peaks easy

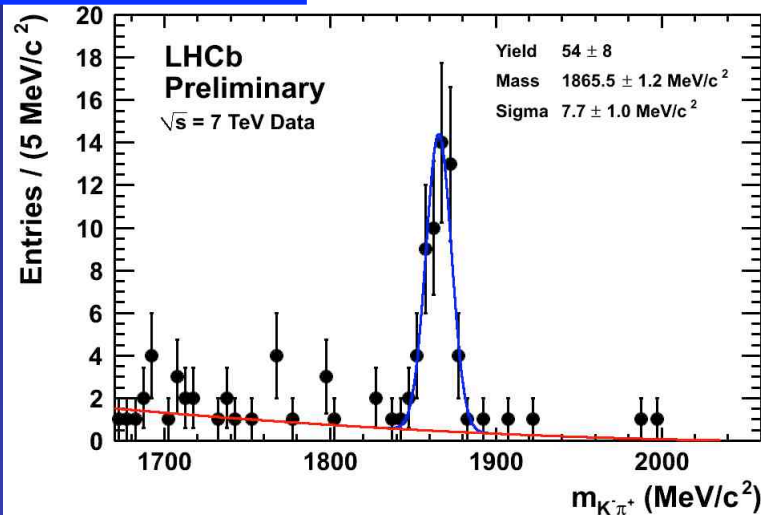


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Charmed Mesons at $\sqrt{s} = 7$ TeV



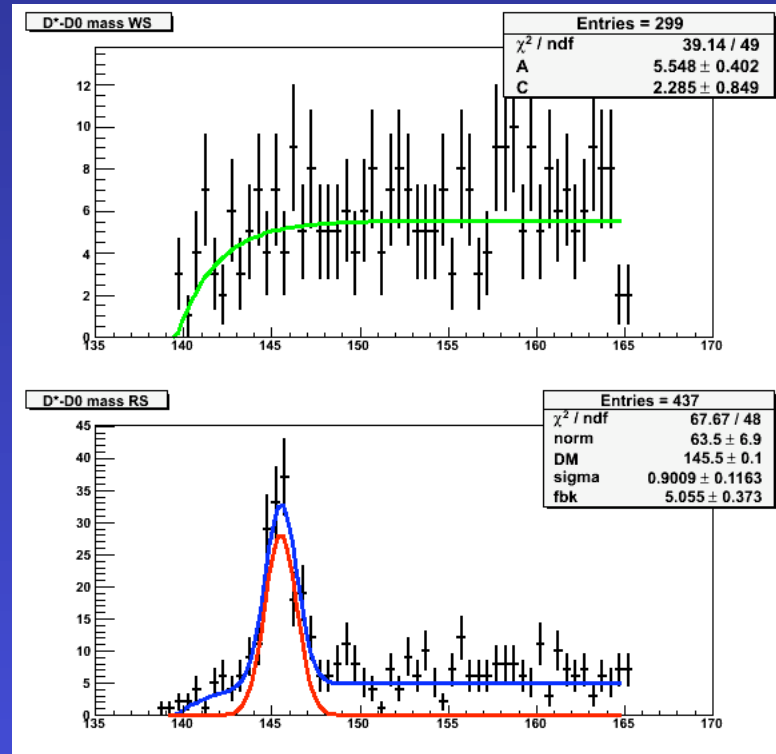
$D^0 \rightarrow K\pi$



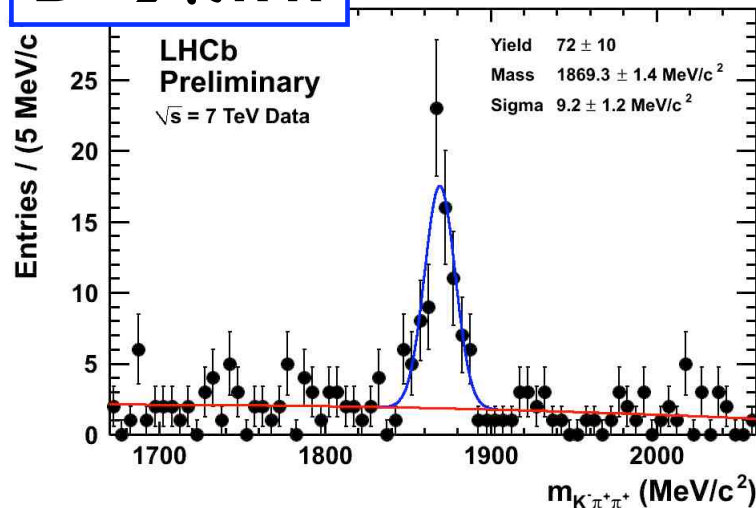
• RICH PID

- Essential for D^0 and D^+

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



$D^+ \rightarrow K\pi\pi$



$D_s \rightarrow \phi\pi$ $\sqrt{s} = 7$ TeV data



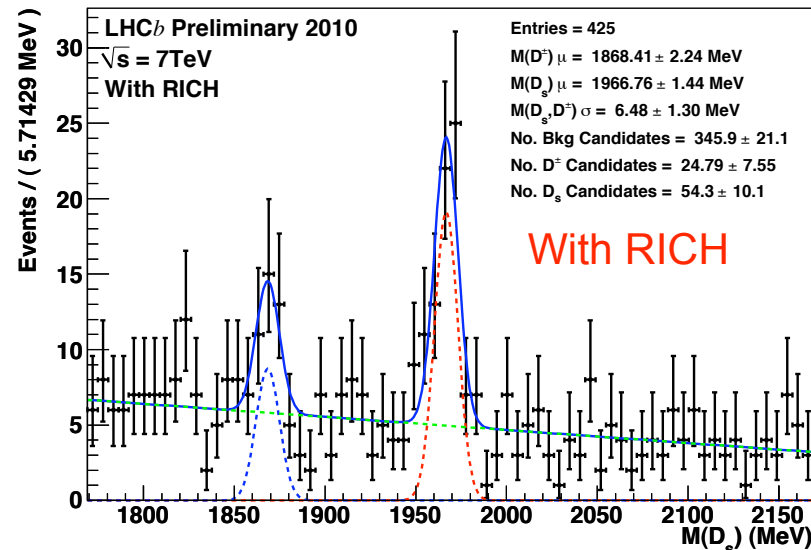
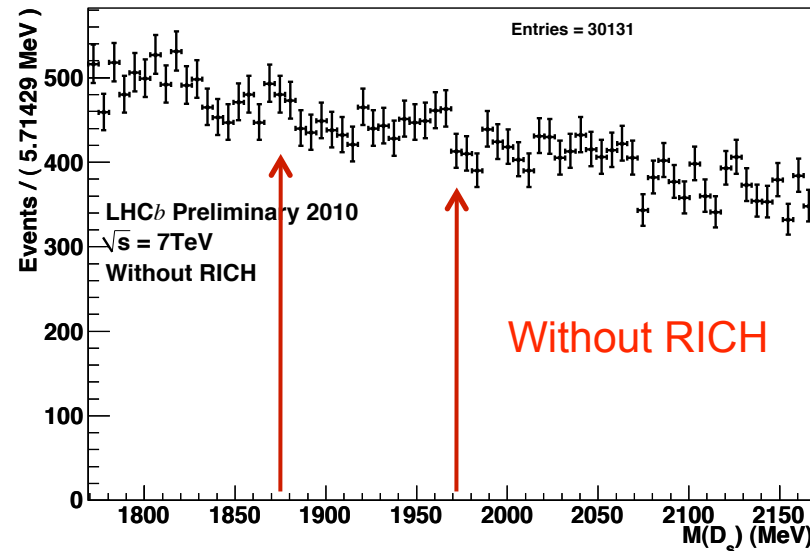
$$D_{(s)}^+ \rightarrow \phi\pi^+, \phi \rightarrow KK$$

RICH PID

- Crucial for D_s
- Facilitated finding first B candidate $B^+ \rightarrow J/\psi K^+$
- Particle zoo is increasing each day: $\Lambda_c, \Omega^-, \dots$
- PID performance results will appear soon

Exciting Outlook

- After a few weeks of data taking, RICH is running very well and used to produce first results
- Looking forward to increasing data sets for physics analysis



RICH Upgrade Plans



- **LHCb plans to upgrade detector**
 - Following first data taking phase
 - Expected at ~ 2016
 - Collaboration plans to submit Letter of Intent at end of 2010
- **LHCb upgrade strategy**
 - is running at 10 times design luminosity, i.e. at $\sim 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
 - read out full experiment at 40 MHz, currently at 1 MHz
 - → RICH photon detector needs to be replaced

See poster by Young Min Kim

- **TORCH - Novel Detector concept**
 - Time-of-flight for $p < 10 \text{ GeV}$
 - Quartz plate with focusing system to correct for photon time-of-propagation in plate
 - Requires time resolution of $O(20 \text{ ps})$

See talk by Mat Charles



Conclusions



- **LHCb RICH detectors are fully commissioned**
 - All systems are working
- **Data taking with LHC beams has commenced**
 - Fully time aligned
 - Magnetic field calibrated
 - Mirror alignments well underway for RICH2 and RICH1 gas
 - Aerogel performance under investigation
 - Particle Identification performance studies have started
- **RICH Detector Performance is excellent**
 - Rings have been observed immediately after switching on beams in a RICH detector at a hadron collider in the forward region
 - Many strange and charm hadrons already observed
- **Looking forward to analyse 2010/11 LHC data set**
- **R&D for LHCb upgrade has started**



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Backup Slides



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The End



Muheim