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Pixel Hybrid Photon Detector Magnetic Distortions Characterization and Compensation

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On behalf of the LHCb RICH collaboration

IEEE 2004 NSS N30-4

1. Introduction 2. Magnetic Distortions
3. Characterization and correction 4. Field estimation

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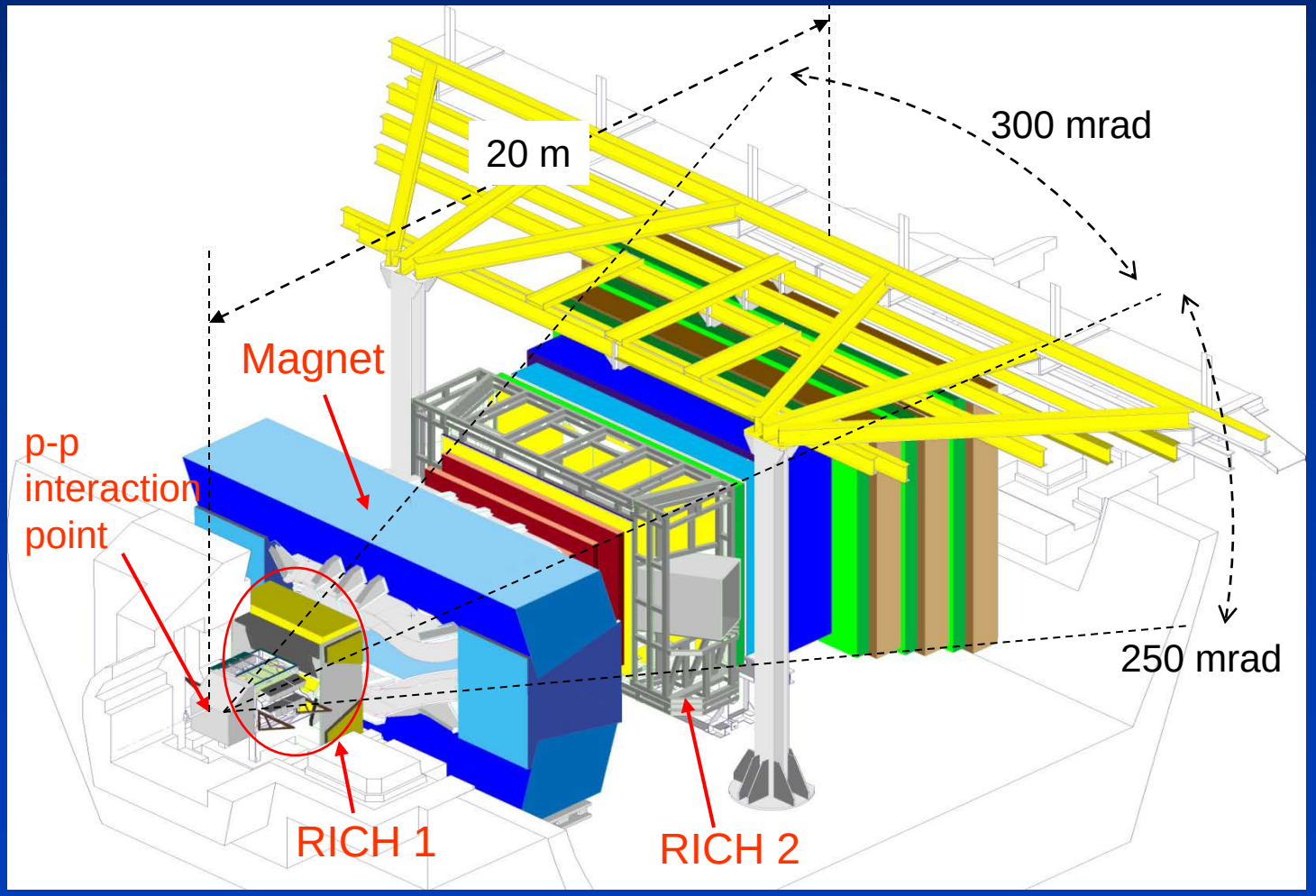
1954-2004 CERN 50

LHCb

The LHCb experiment

- b physics at the LHC p-p collider: CP violation, rare decays
- Single arm forward spectrometer (*W.Witzeling, IEEE NSS N21-8*)
- Hadrons identification -> Ring Imaging Cherenkov detectors RICH



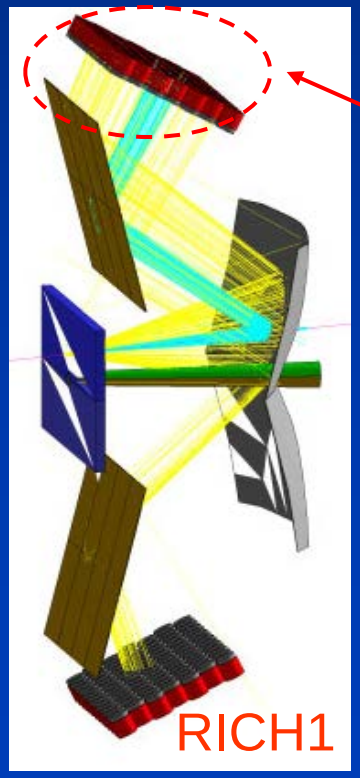
LHCb RICH detectors

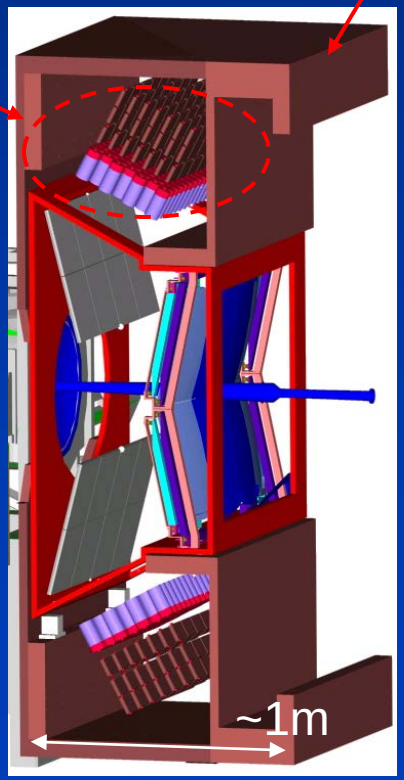
Particle ID by Cherenkov angle measurement from photon hits on detector planes

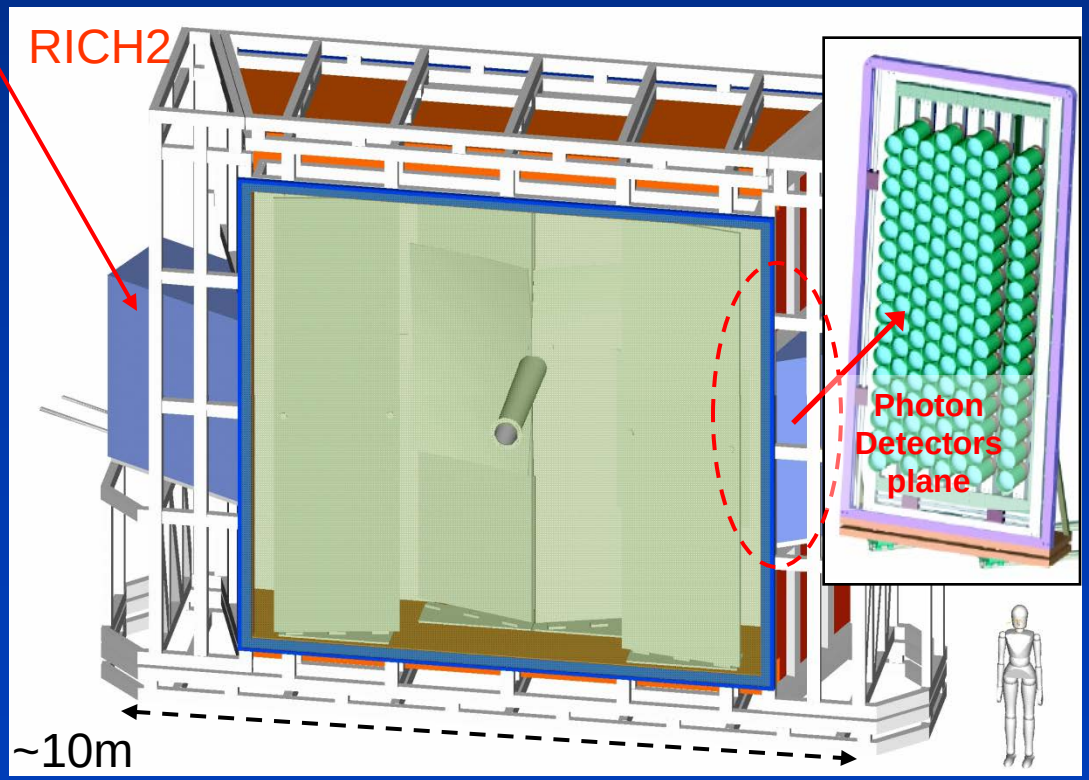
- **RICH1**
  - Aerogel (2 - ~10 GeV/c)
    D.Perego, IEEE NSS N21-7
  - C_4F_{10} (10 - ~60 GeV/c)

- **RICH2**
  - CF_4 (16 - ~100 GeV/c)

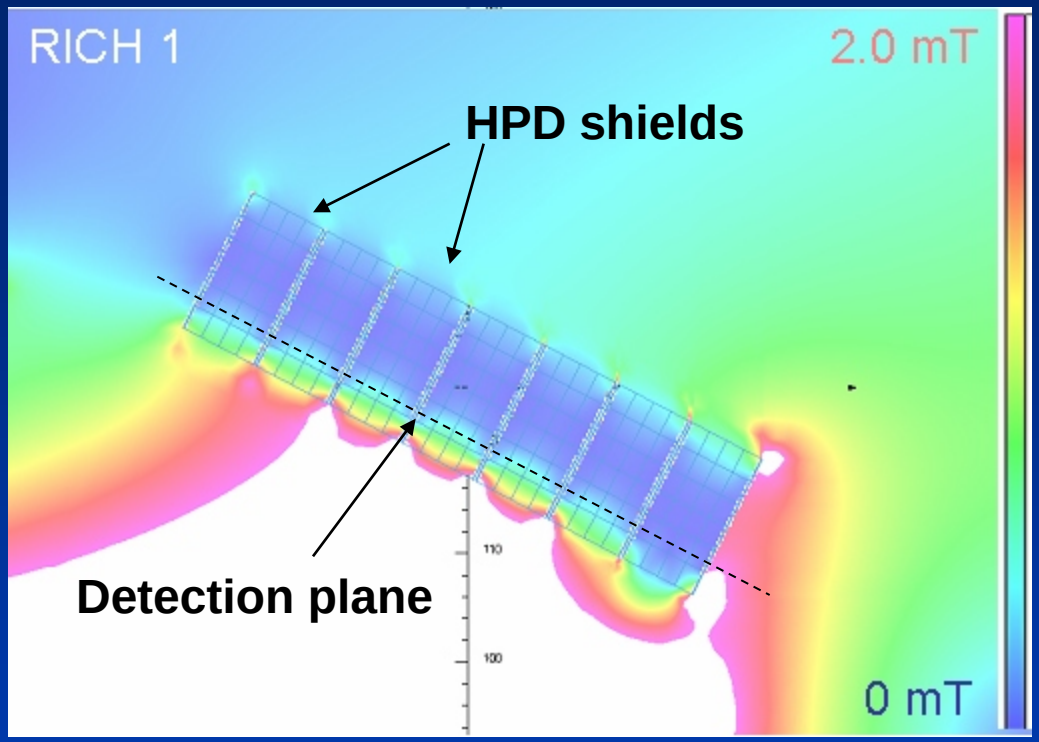
Magnet fringe field shielding boxes







Magnetic shielding and photon detector requirements



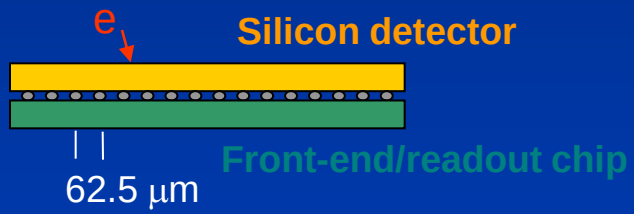
- Detectors planes inside iron shielding boxes
- Field below 2.5 mT inside shields
- Local shielding of photon detectors

Photon detectors requirements:

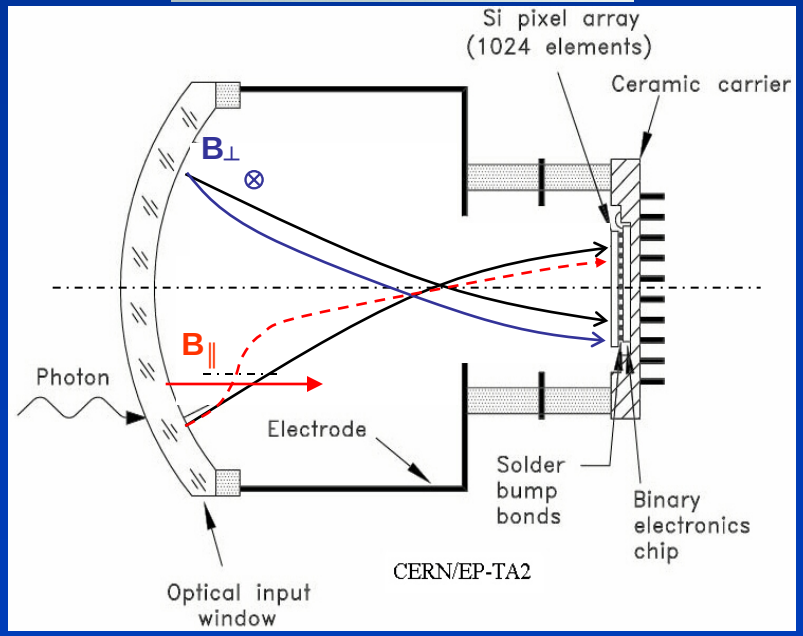
- Single photon detection in the 200-600 nm wavelength range
- 2.5x2.5 mm^2 spatial resolution on entrance window equivalent to $\sigma_{\theta c}$= 0.62 mrad error contribution to Cherenkov angle
- Operational in magnetic field of ~2.5 mT in RICH1 and ~1.0 mT in RICH2

Hybrid Photon Detectors

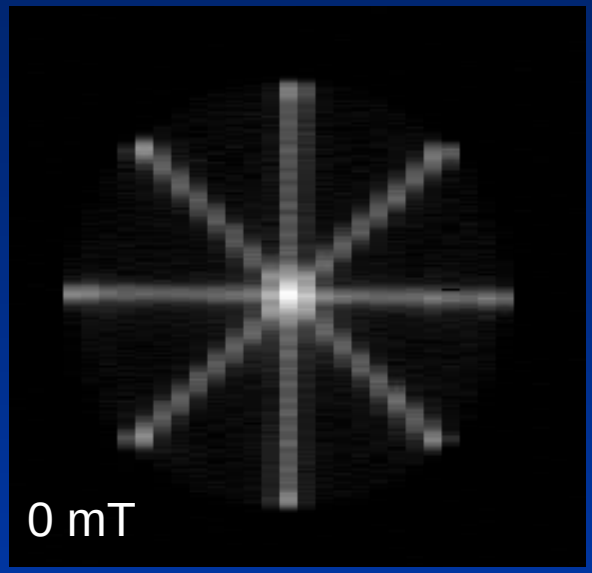
- Vacuum tube
- Quartz window, S20 photo-cathode, 25% peak QE
- Cross-focusing electron optics
- Anode assembly:
  - hybrid pixel detector (16x16 mm²) *fully encapsulated* in the vacuum tube
  - 32×256 pixel silicon detector bump-bonded onto the LHCbPIX1 CMOS readout chip
  - Analog and digital chain readout on chip

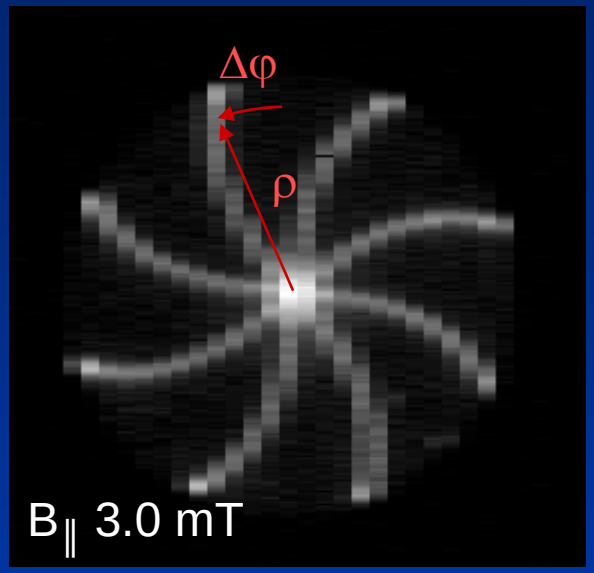


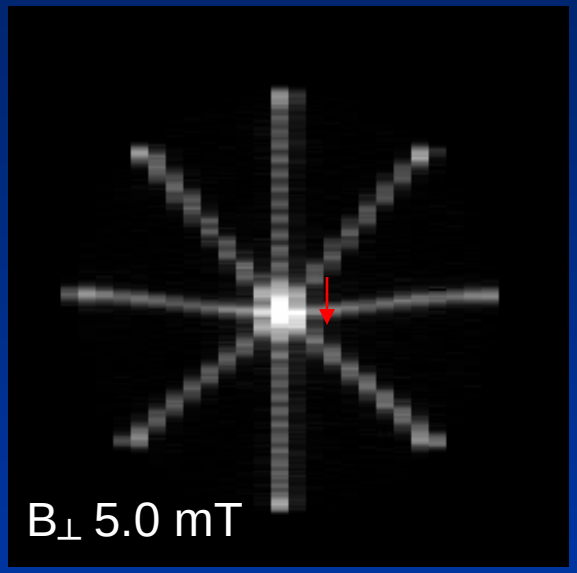
- Electron trajectories distorted by magnetic field like in Image Intensifiers for fluoroscopy
- Rotation (S-distortion) due to axial component
- Translation due to transverse component



Magnetic distortions





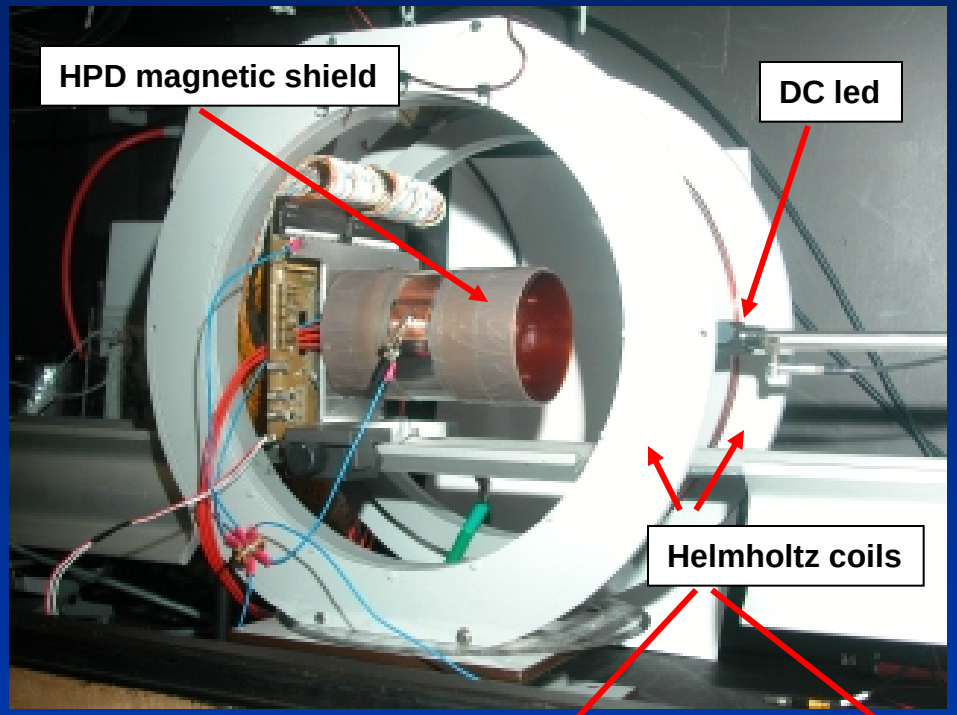


- **Individual magnetic shielding**
- **Smaller displacements for transverse component**
- **No losses due to magnetic effects unless image shifted out of anode (>> 5.0 mT)**

- **Reconstruct pixel hit – photon hit position correspondence for each HPD**
- **Magnetic field not uniform and varying tube-by-tube**

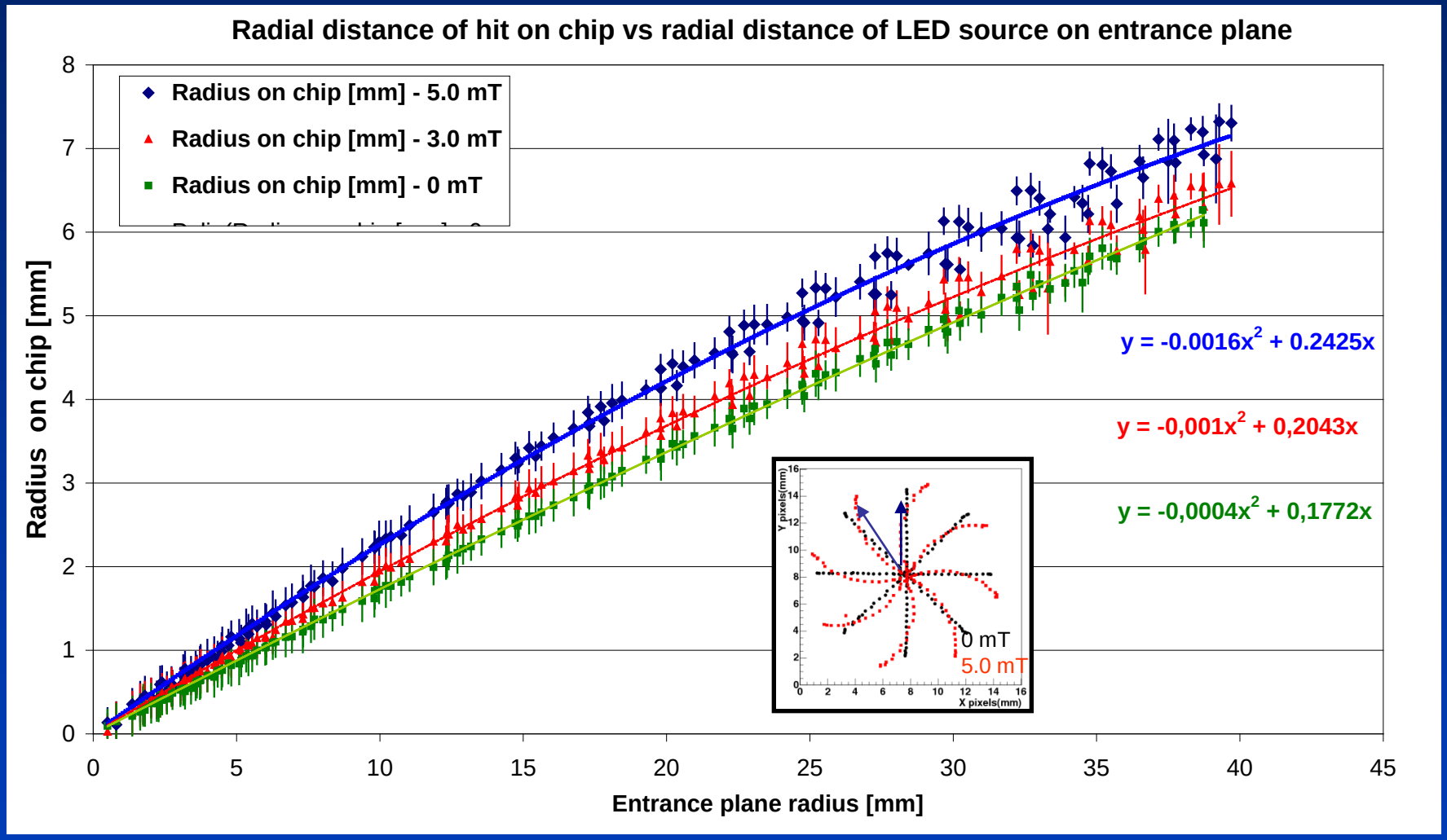
Set-up description

- Projection of collimated light on known positions on the HPD entrance window
- Magnetic field generated by Helmholtz coils
  - B field value is the one in the region when HPD and shield are not there
- Cylindrical Mumetal® magnetic shield



- 160 points Double Cross pattern to position the LED
- Characterization for axial magnetic field $B_{\parallel}$
- Rotational symmetry
- *Not too restrictive*
  - local shielding very effective on transverse component
  - Smaller displacement due to transverse field

Demagnification law

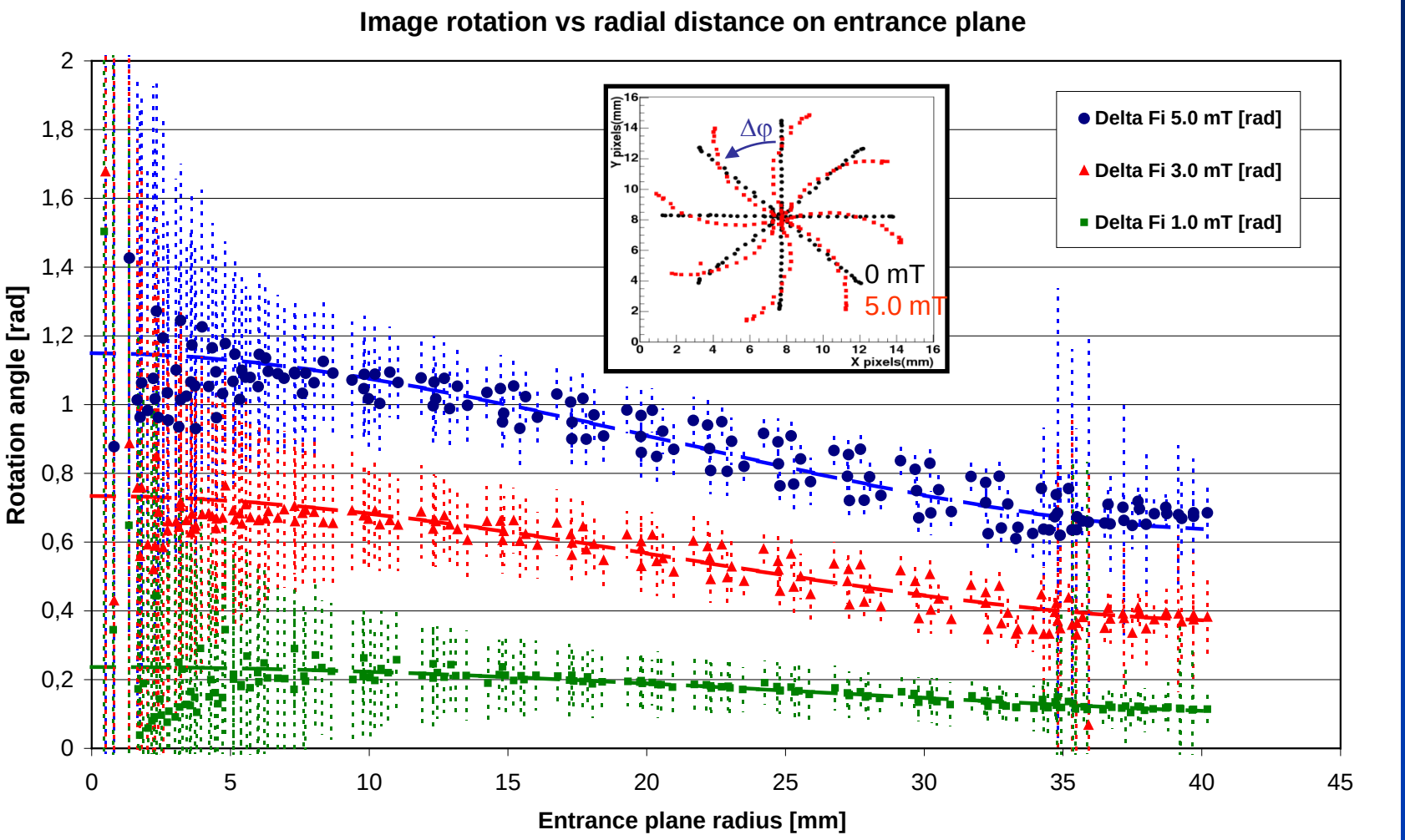


- Non uniform radial dilation
- Second order polynomial fit

$$\rho = \rho_1(B)\, r + \rho_2(B)\, r^2$$

$$\rho_i(B) = \sum_j \rho_{i,j}\, B^j$$

Rotation law



- Non uniform rotation (S-distortion)
- Third order polynomial fit, first order coefficient zero

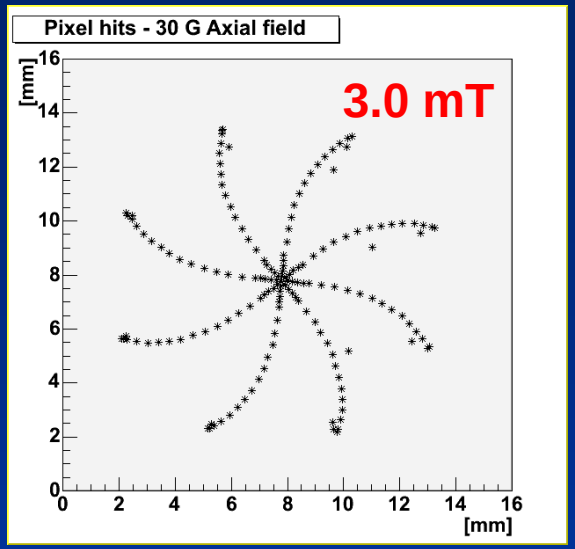
$$\Delta\varphi = \Delta\varphi_0(B) + \Delta\varphi_2(B)\, r^2 + \Delta\varphi_3(B)\, r^3$$

$$\Delta\varphi_i(B) = \sum_j \Delta\varphi_{i,j}\, B^j$$

Photon hit reconstruction

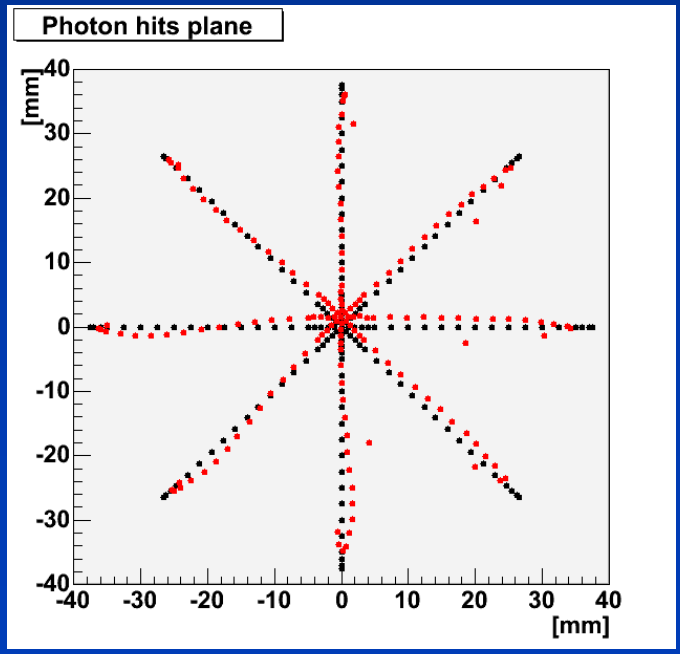
Parameterization obtained is used to

- **Reconstruct photon hit position from pixel hit position given the magnetic field**
- **Develop an estimator of $B_{//}$ with a test pattern**



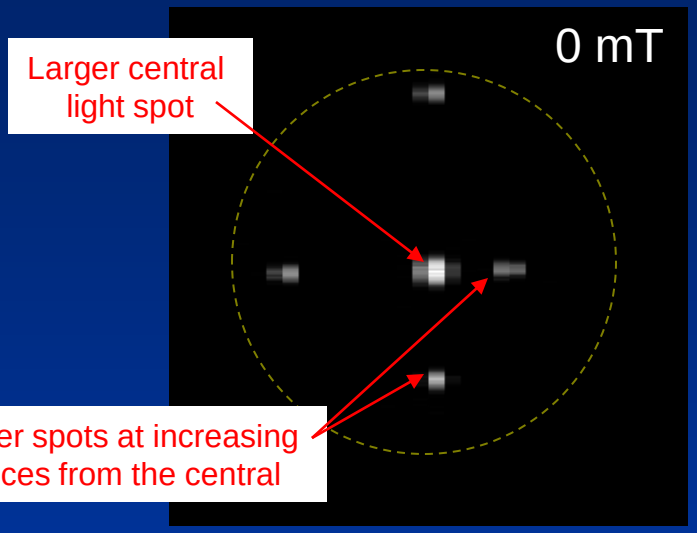
- **Distorted images of double cross processed to calculate the photon hit position**
- **Reconstruction error at 2.5 mT larger than intrinsic resolution of the HPD ($2.5/\sqrt{12} = 0.72$ mm)**
- **First trial, on-going study**

Applied B field [mT]	Average reconstruction error [mm]
0	0.82
1.0	1.24
2.0	1.40
3.0	1.78



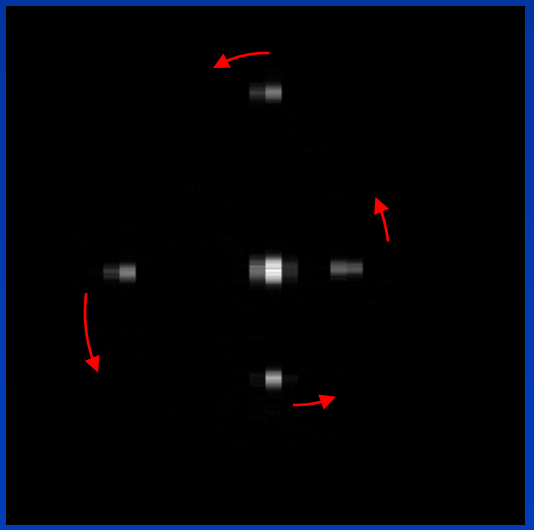
Test Pattern

- **Test pattern features:**
  - **Allows easy automatic search and identification of clusters (correspondence problem)**
  - **Spots averaged centers as coordinates for the analysis**
  - **Sample rotation of the image at various radii**
  - **Estimate the B field axial component by best fit of the model**



Applied B field [mT]	Estimated field [mT]	Bias [mT]
1.0	**0.90** 0.20	-0.10
2.0	**2.05** 0.27	0.05
3.0	**3.24** 0.27	0.24
4.0	**4.08** 0.24	0.08
5.0	**5.07** 0.19	0.07

Estimator average bias: 0.07 mT



- **Projection of a static pattern on the detectors plane in the experiment**
- **Automated calibration procedure on the full set of HPDs determining field in each tube**

Conclusion

- Innovative Hybrid Photon Detectors developed by the LHCb collaboration and industrial partners fulfil the LHCb RICH detectors requirements
- Shielded HPDs are fully operational in the residual magnetic field (2.5 mT) inside the shielding boxes
- Characterization and parameterization of ExB distortions of the image
- Strong S-distortion correction possible given $B_{||}$ value, recovering spatial resolution
- $B_{||}$ estimation with test pattern
- Automated calibration procedure for the LHCb RICH to estimate the axial field applied on each of the 484 HPDs installed in the experiment has been proposed

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Spares

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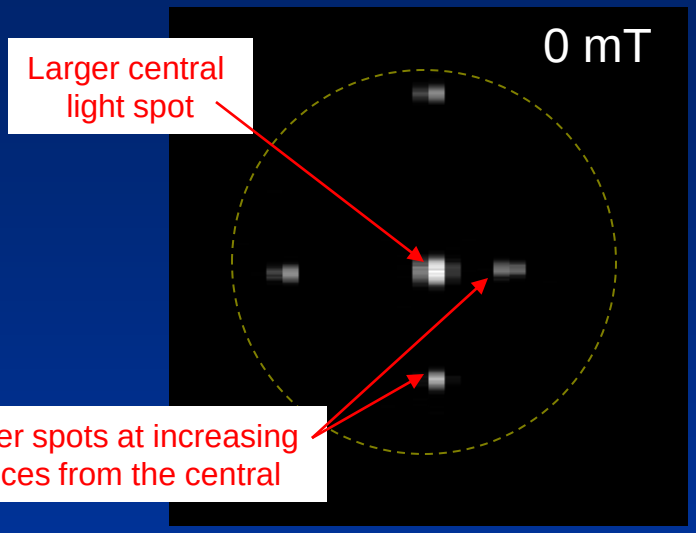

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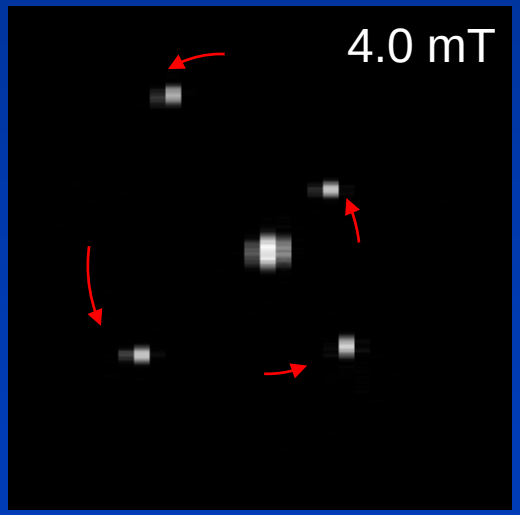

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