Performance studies of Pixel Hybrid Photon Detectors for the LHCb RICH counters

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On behalf of the LHCb Collaboration - Pixel HPD group

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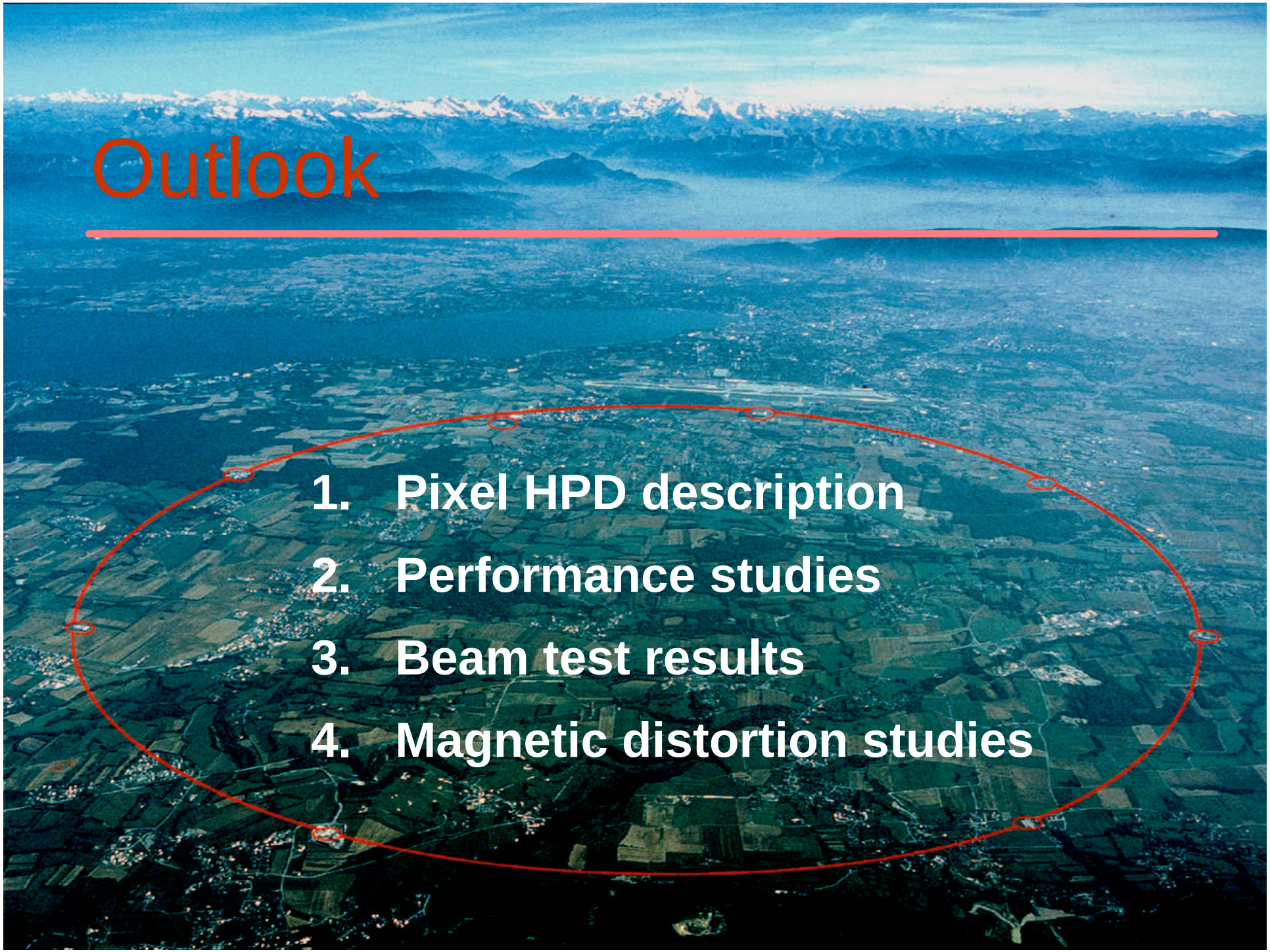

Outlook
1. Pixel HPD description
2. Performance studies
3. Beam test results
4. Magnetic distortion studies

The Pixel Hybrid Photon Detector

The photon detectors of the LHCb - RICHs

• Particle identification at LHCb experiment: kaon identification by Ring Imaging Cherenkov counters over 1-100 GeV/c momentum range

Photon detectors requirements:

• Efficient **single photon detection** in the 200-600 nm wavelength range

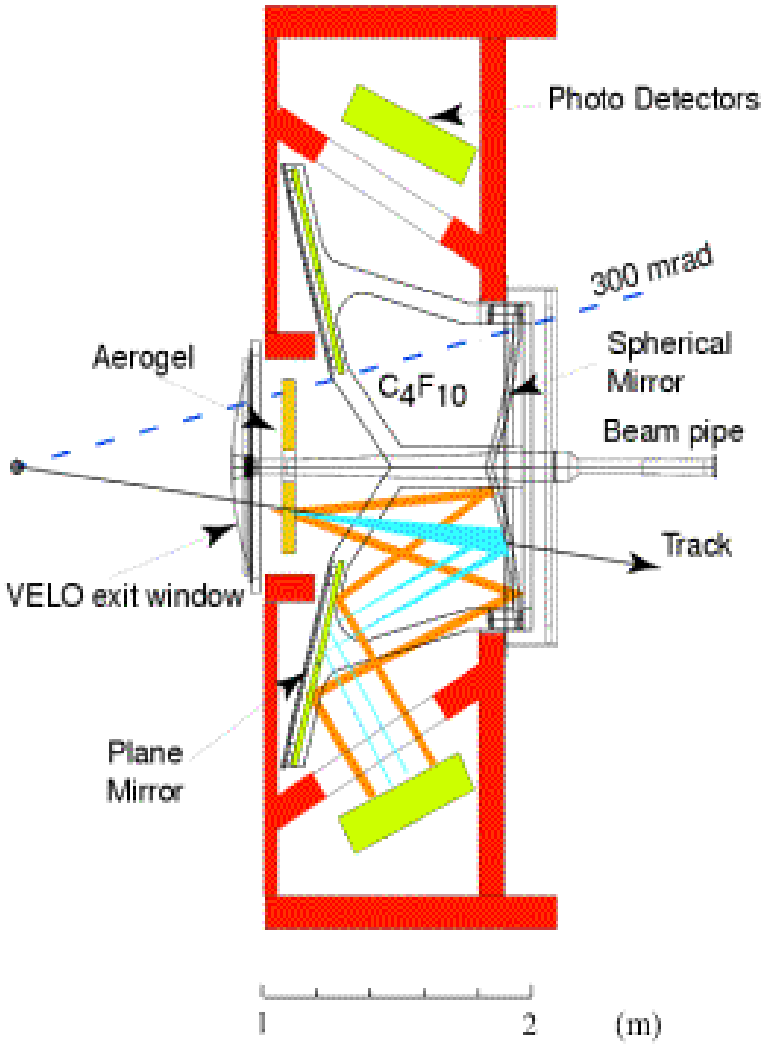
• Large area coverage: **2.8 m²**

• Active/Total area ratio > **70%**

• **2.5x2.5 mm²** granularity

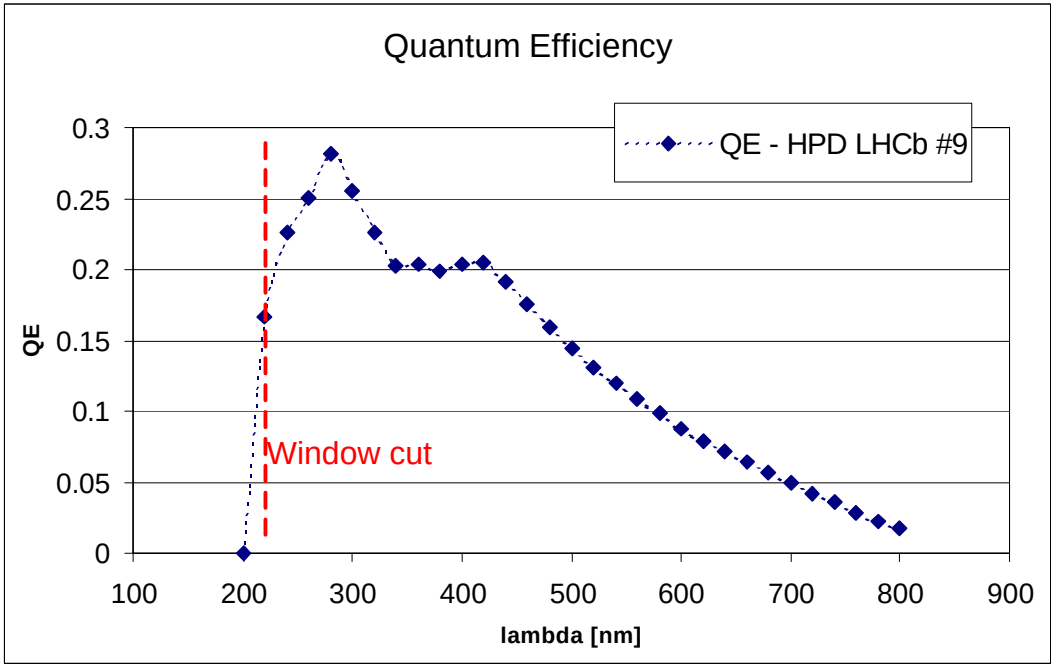
• Time resolution: **25 ns**

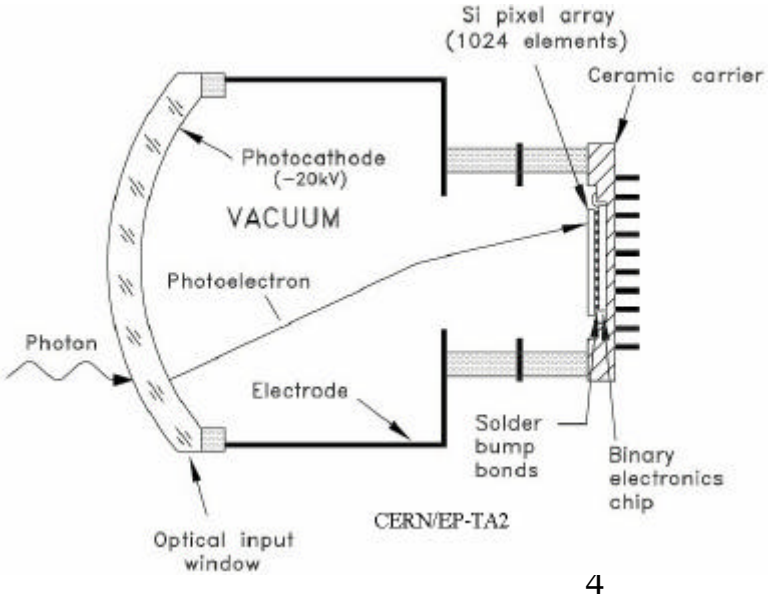
• Operation in fringe magnetic field of ~25 G



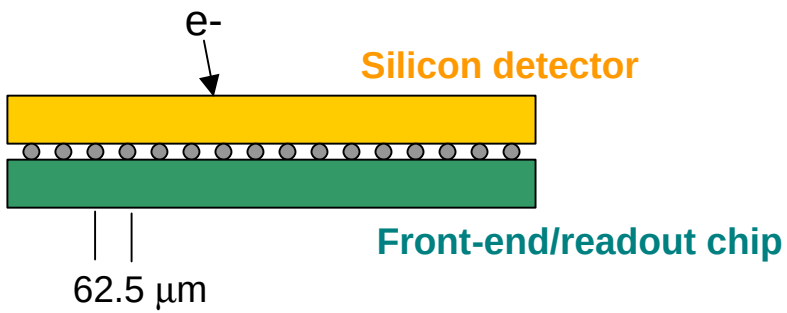
Pixel HPD

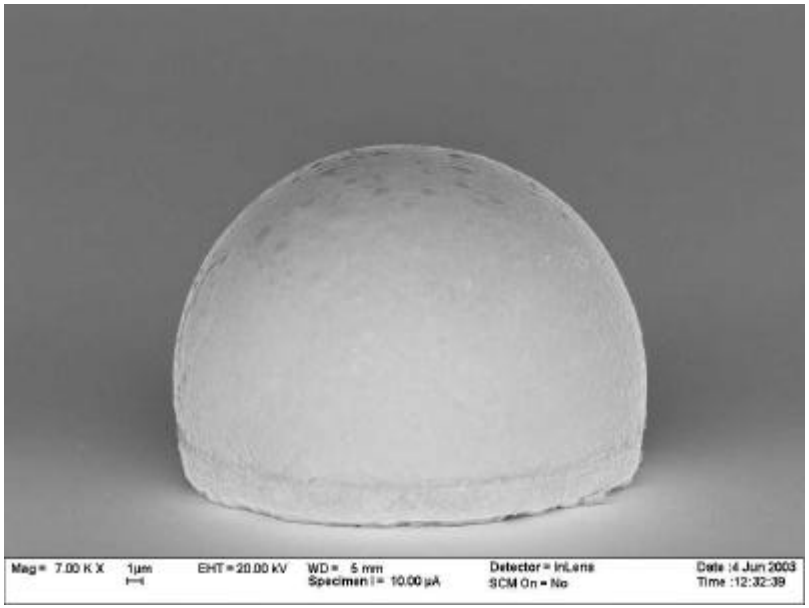
- Vacuum tube, diameter 80mm, height ~120mm
- S20 multi-alkali photocathode on inner surface of the entrance quartz window, 22-27 % QE
- Cross-focusing electron optics (~**20kV,** ~5000 e-h pairs in the silicon), demagnification factor of 5
- Photo-electrons focused on the anode assembly (16x16 mm^2), *fully encapsulated* in the vacuum enclosure



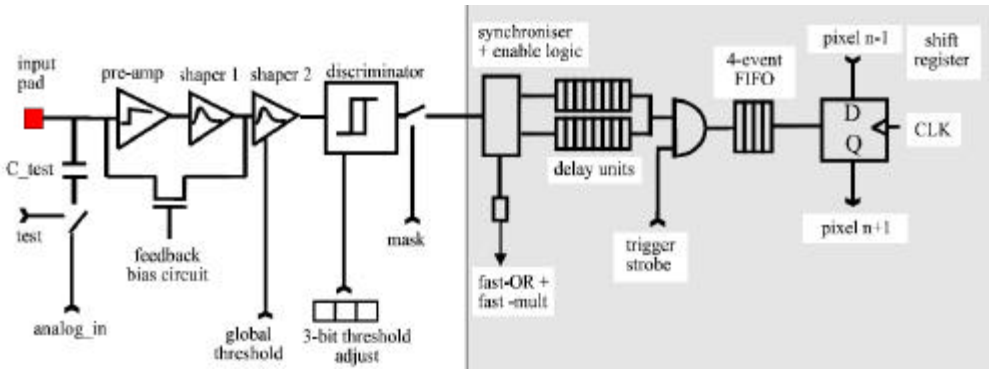


Pixel HPD Anode

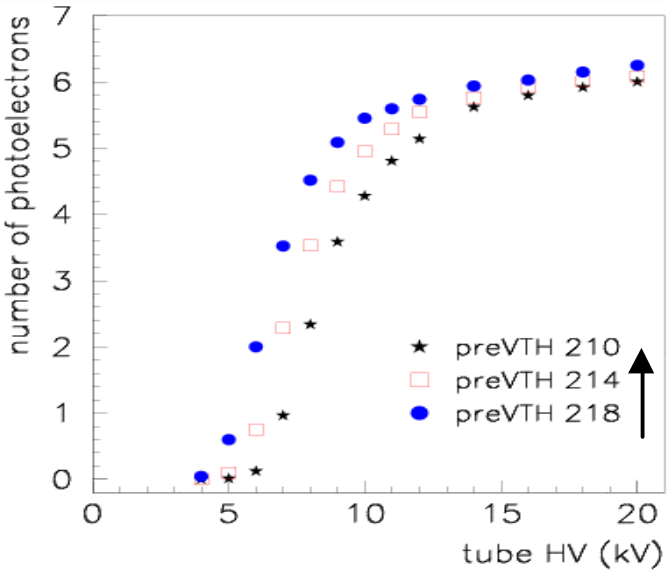


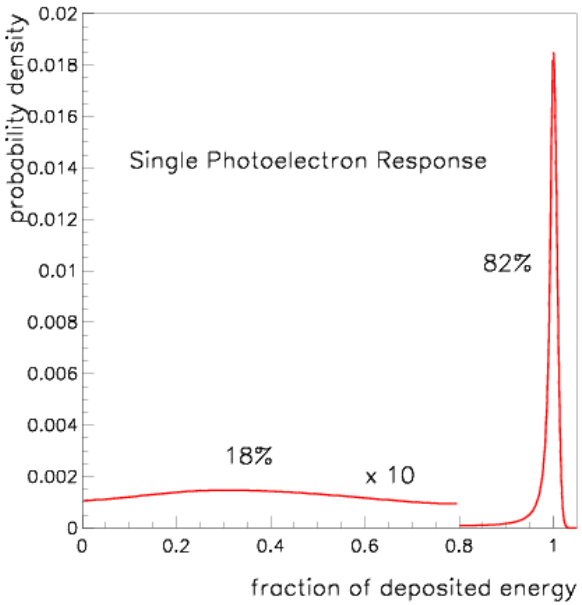


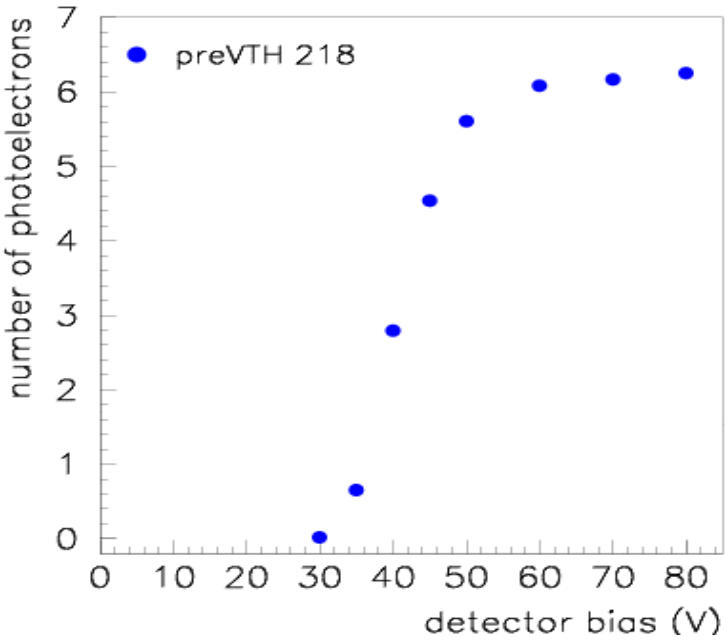
- **Assembly: silicon detector**, 32x256 matrix of 500x62.5 μm^2 pixels **bump-bonded** onto the LHCbPIX1 CMOS **readout chip**
- 8192 channels with charge pre-amp, 25ns peaking time, adjustable threshold discriminator, coincidence logic, memory, operating at 40 MHz clock
- Digital OR grouping of 8 pixels for the LHCb experiment gives 1024=32x32 sensitive areas of 2.5x2.5 mm^2 on the entrance window, fully read-out in 800 ns through 32 parallel lines



Tube H.V. scan and Detector Bias scan





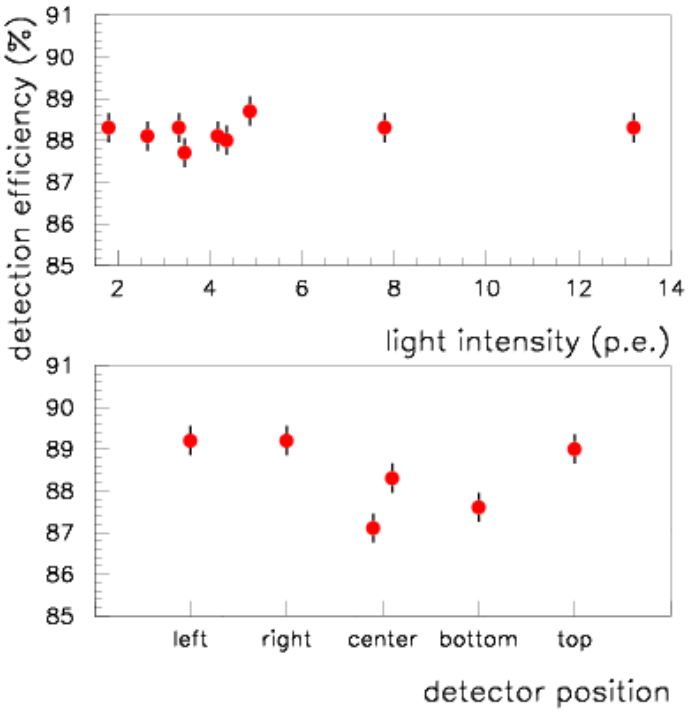


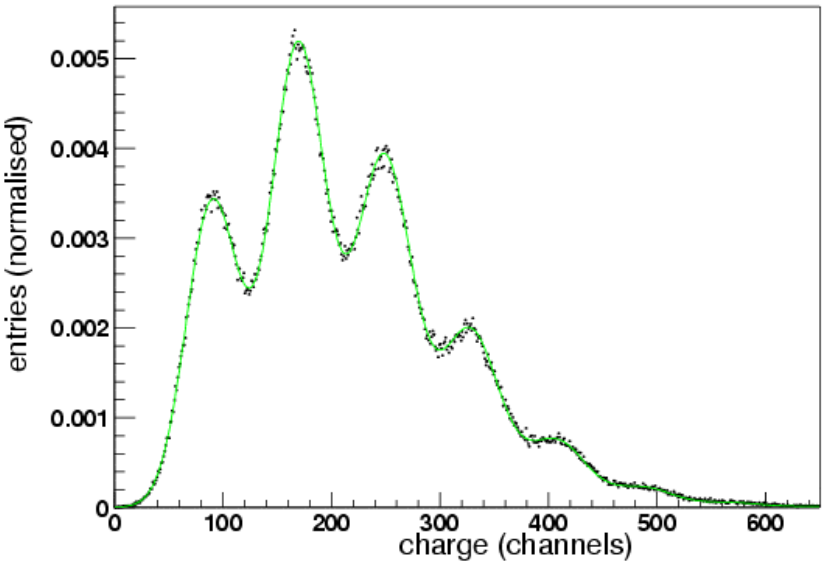
Over-depletion reduces *charge-sharing* (pixels-clusters)

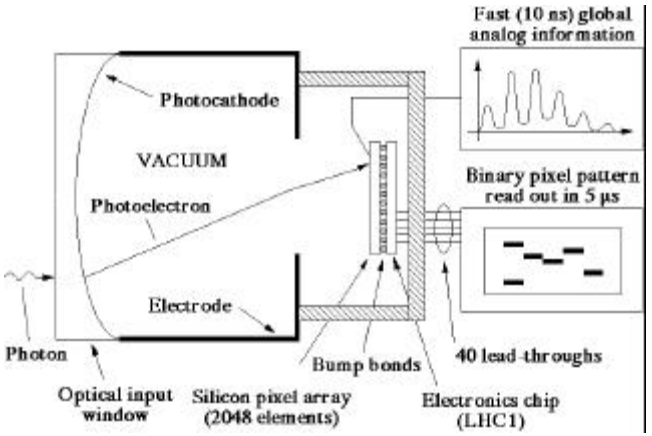
Detection Efficiency

$$\text{Detection Efficiency} = \frac{Number\ of\ clusters > Threshold}{Number\ of\ p.e.}$$

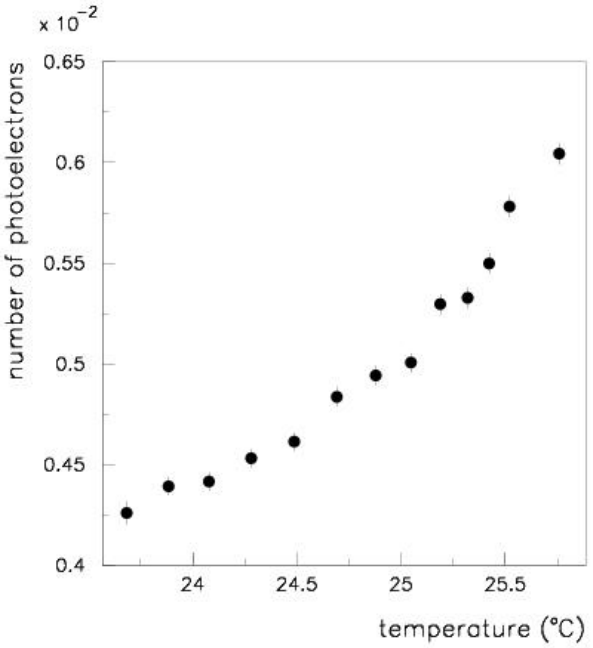
- Sources of losses: back-scattering (~18%), charge-sharing, threshold
- Silicon detector total current analog signal (***back-pulse***) sampled during run
- A fit of its spectrum allows for quantification of ***average number of incident p.e***
- Binary data analysis considered ***pixel clustering***
- **Detection Efficiency: ~ 88% (@ 20 kV)**







Background



1. Dark counts

- Thermo-ionic emission from the photocathode is a source of background
- Typical dark-counts rate in the 40MHz prototypes of

  ~ 1 KHz / cm^2

2. Ion feedback

- Ionisation of residual gas molecules and acceleration of ions towards cathode, where they cause emission of electrons
- Fingerprints: *time delayed* with respect to original signal hit of ~250 ns and *large clusters*
- *Probability of ion feedback: 0.5% per primary photoelectron*
- Well known in PMT: afterpulses

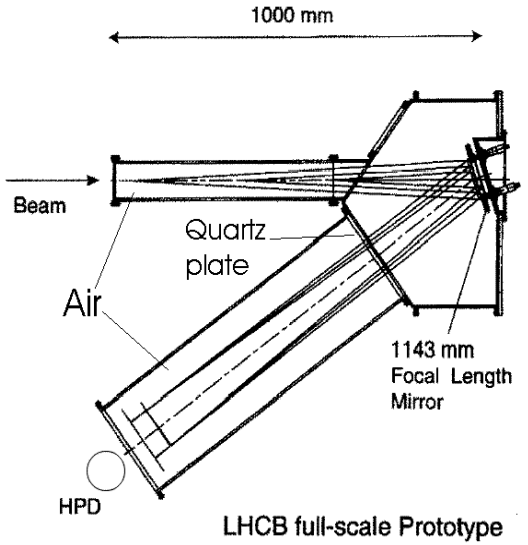
Test beams – HPD performance

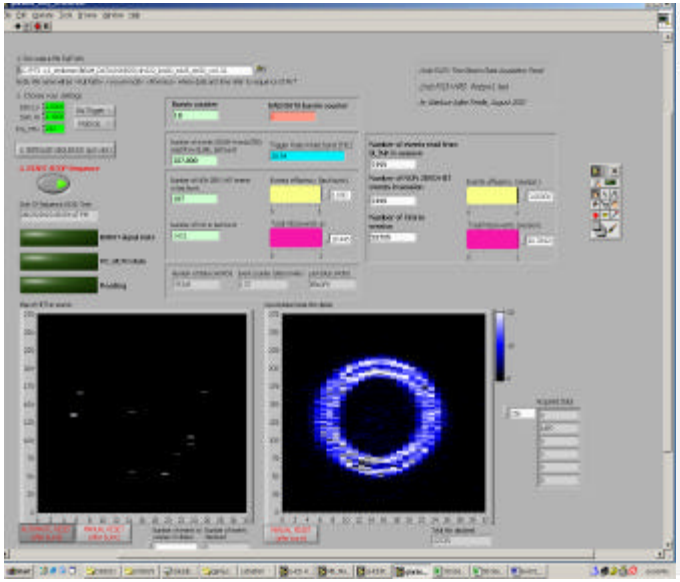
Prototype 40 MHz HPDs were tested and used in two beam tests at CERN, August 2003 and October 2003 in Cherenkov imaging vessels, with **air, N2** and **Aerogel** as radiators

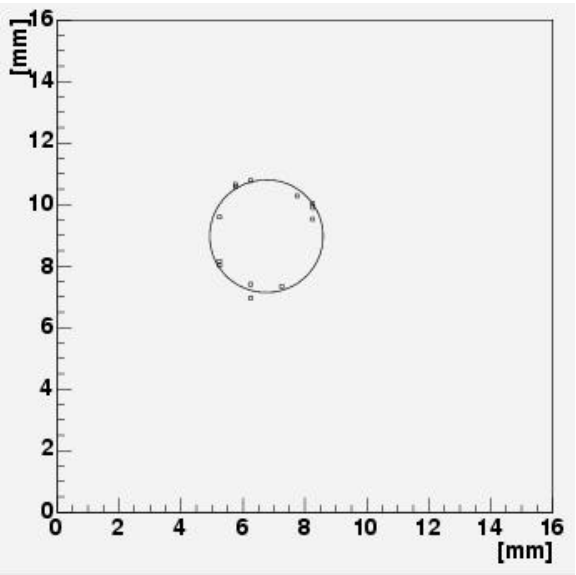
Cherenkov rings from 10 GeV/c pions and electrons were recorded

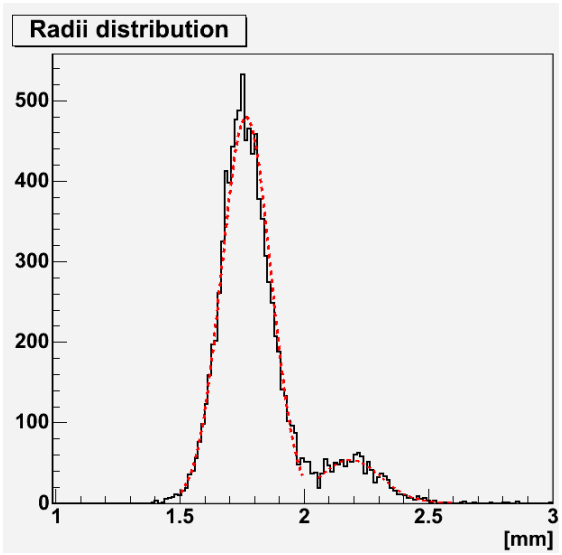
Measured Cherenkov angles: 20.6 ± 1.3 mrad and 25.6 ± 1.5 mrad

H.V. scan, detection efficiency measurements in agreement with laboratory measurements









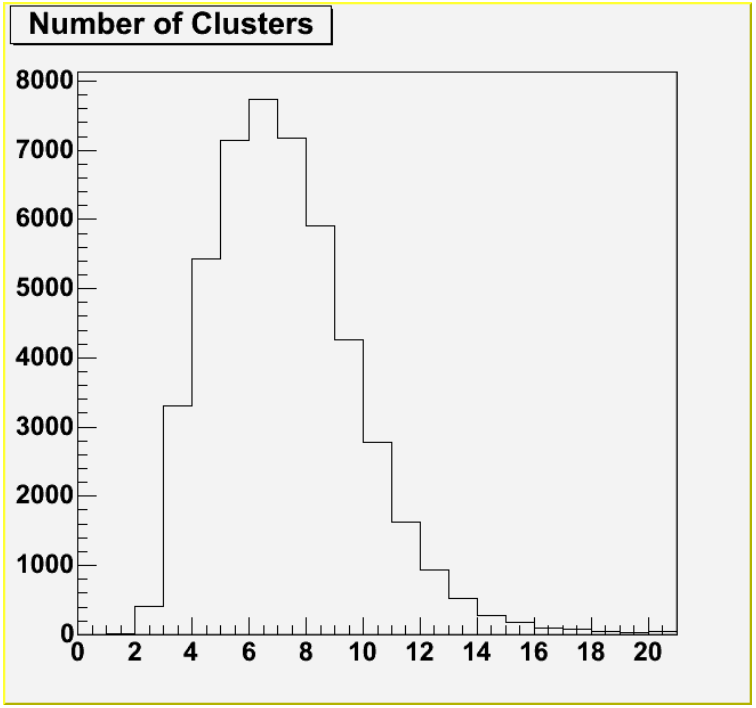
Test beams – HPD performance

Radiator (N2) refractive index curve, losses for reflections at interfaces, HPD cathode Q.E., are used for average photon yield calculation

Correction for multiple hits probability is applied

The result is to be compared with the measured average cluster number to give an independent measurement of the Detection Efficiency

$$N = \int_{\lambda} \frac{2\pi Z^2 \alpha L}{\lambda^2} \left[1 - \frac{1}{n^2(\lambda)\cdot\beta^2} \right] \cdot R_M(\lambda) \cdot T(\lambda) \cdot QE(\lambda)\, d\lambda$$



Tube	Expected number of p.e. (100% DE)	Measured average of p.e.	Detection Efficiency [%]
LHCb #8	11.6 (±0.7)	10.1	87.1 ±5.3
LHCb #9	12.8 (±0.8)	10.6	82.8 ±5.2

Magnetic distortions studies

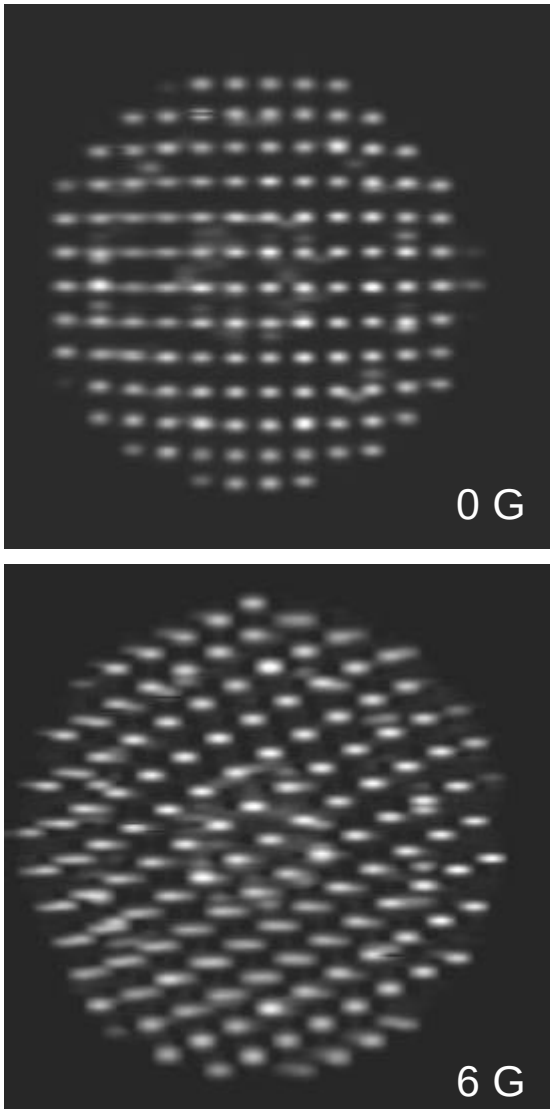
The HPDs have to be placed in the fringe field of the LHCb dipole magnet

Deviations of the electrons from the designed electrostatic trajectories because of the magnetic field, result in distortions of the image of the cathode

A large magnetic shielding box surrounds the photon detectors: residual magnetic field ~ 25 G

HPDs could need *individual magnetic shielding*: cylindrical envelope of high permeability alloy for each tube

Residual distortions to be off line compensated restoring the excellent space resolution



Magnetic distortions studies

Distortions in a shielded tube in a transverse field of 50G equivalent to bare tube in 2.5G

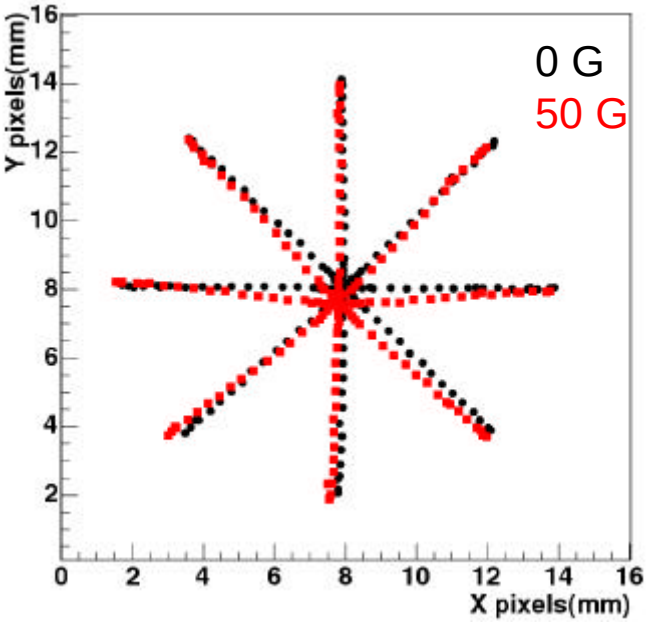
Distortions in a shielded tube in an axial field of 50G equivalent to bare tube in 15G

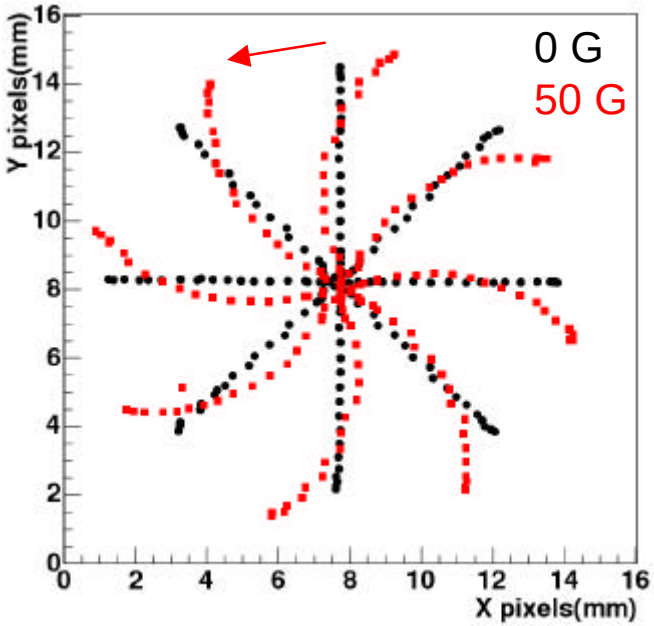
NO coverage losses with shielded tube up to 50G

Parameterization of distortions

Distortion compensation algorithms (*un-warping*) to be developed

Detector calibration with a projected test pattern

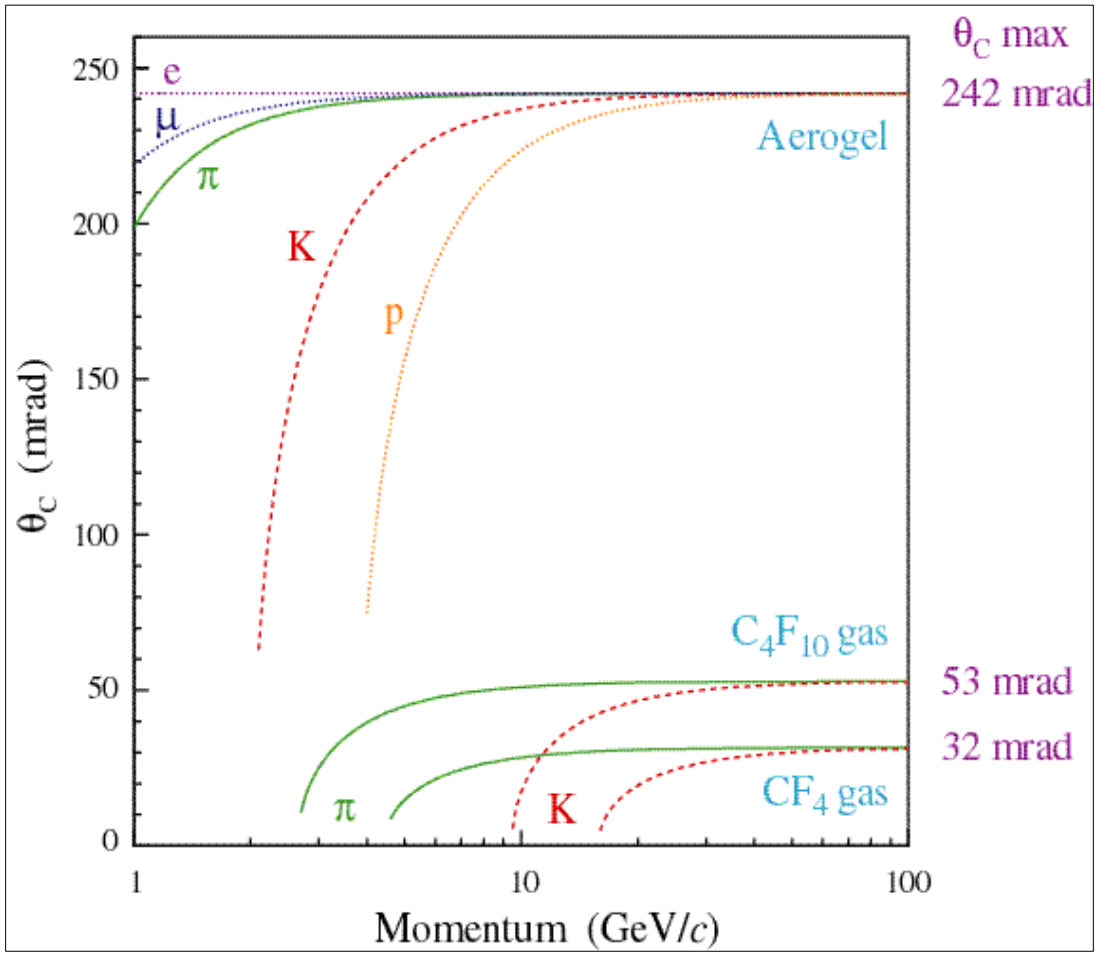




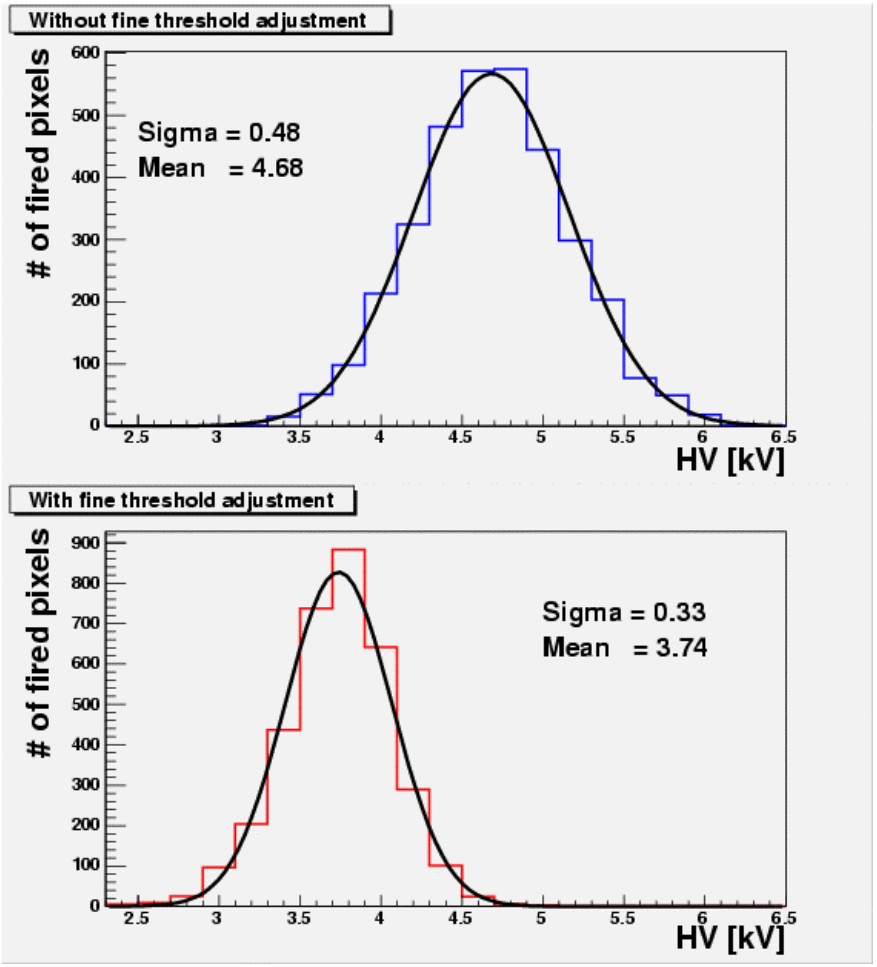
Summary

- Pixel Hybrid Photon detectors: **single photon sensitive, large active area, fast, imaging** detectors developed for the LHCb RICH detectors
- Prototypes performance determined in laboratory measurements
- Final 6 prototypes fulfill experiment requirements
- HPDs used in two beam tests at CERN in a RICH vessel
- Detection efficiency **88%**
- Magnetic distortion compensation
- Production phase entered with 550 tubes to be produced

Spares


θC max
242 mrad
e
μ
π
K
p
Aerogel
C4F10 gas
53 mrad
32 mrad
CF4 gas
π
K
θC (mrad)
Momentum (GeV/c)
250
200
150
100
50
0
1
10
100

Pixels' thresholds distribution



- Measurements with pulsed LED source in the laboratory
- Threshold distribution:
  - avg: 4.68 kV ~ **1300e** (spec. < 2000e)
  - rms: 0.48 kV ~ **134e** (spec. < 300e)

- 3-bit individual threshold adjustment allows for average threshold reduction and 1% improvement of detection efficiency at operational HV