Hybrid Photon Detectors for the LHCb RICH Counters

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On behalf of the LHCb RICH Group

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- Test beam preliminary results
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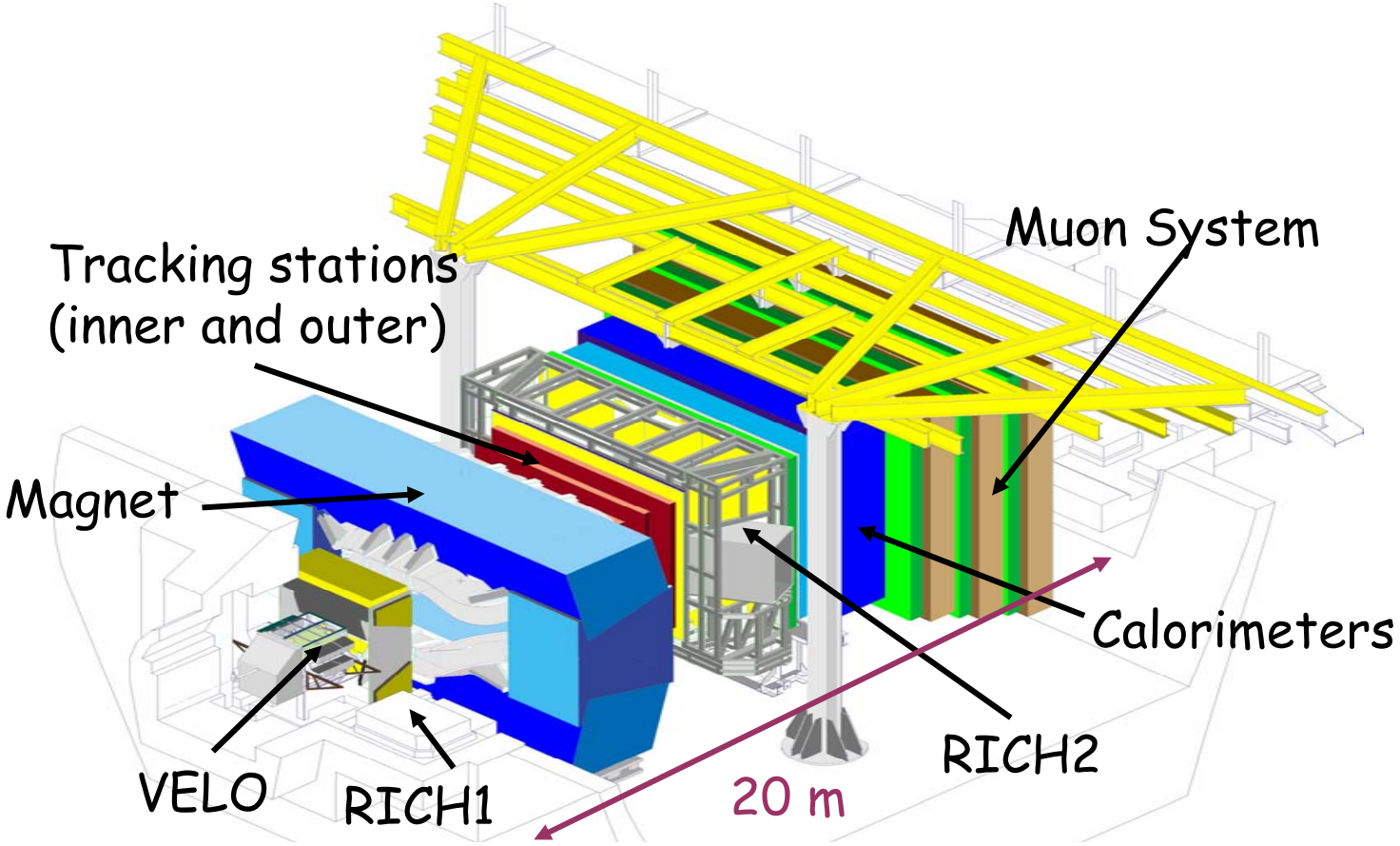
LHCb Detector

LHCb aims to make precision measurements of CP violation and rare decays from B mesons.



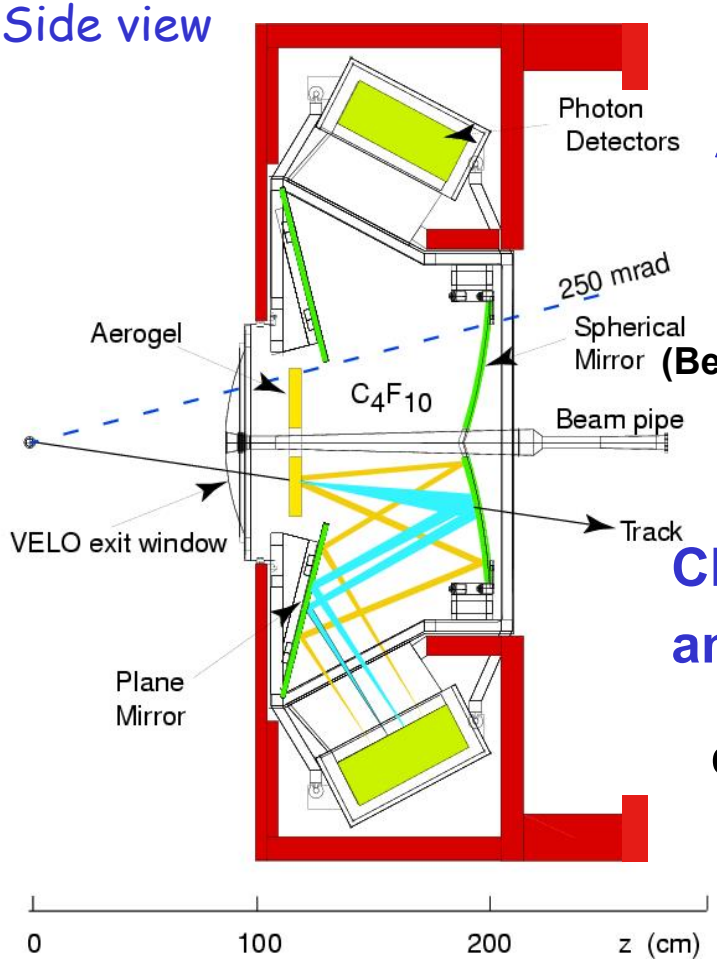
RICH Detectors

Particle Identification: Ring Imaging Cherenkov detectors

RICH1

Acceptance 25-300 mrad

Side view



Three radiators: aerogel, C_4F_{10} and CF_4

π/K separation: 2-100 GeV/c

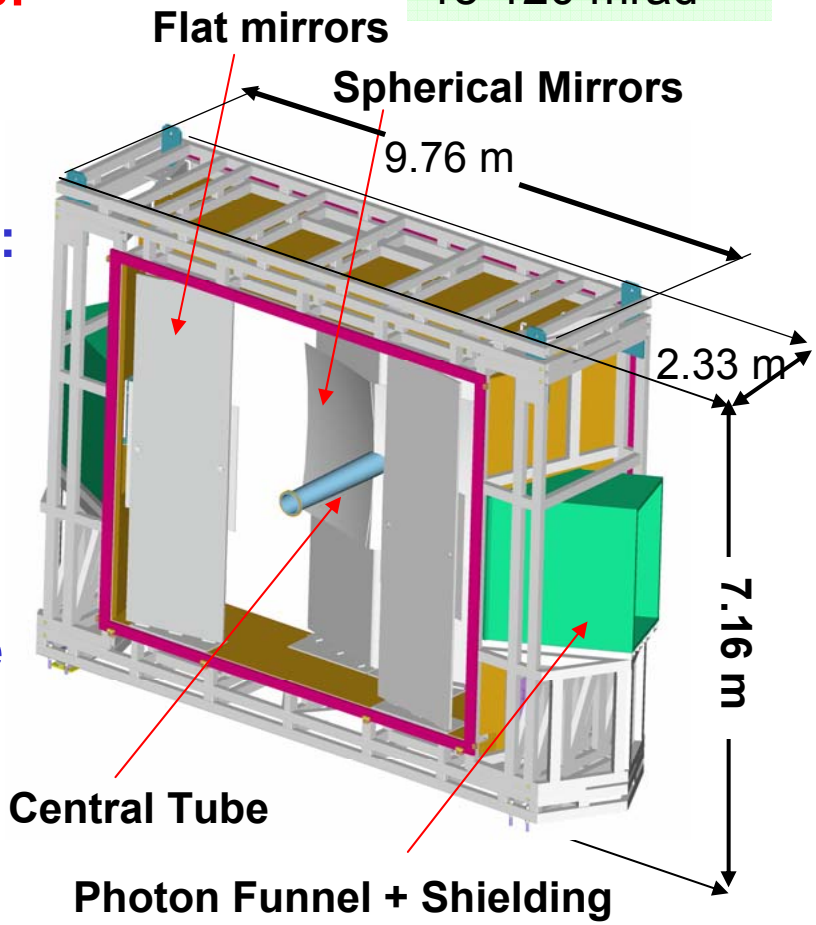
(Beryllium)

Cherenkov cone angle:

$$\cos(\theta_c) = \frac{1}{n \cdot \beta}$$

RICH2

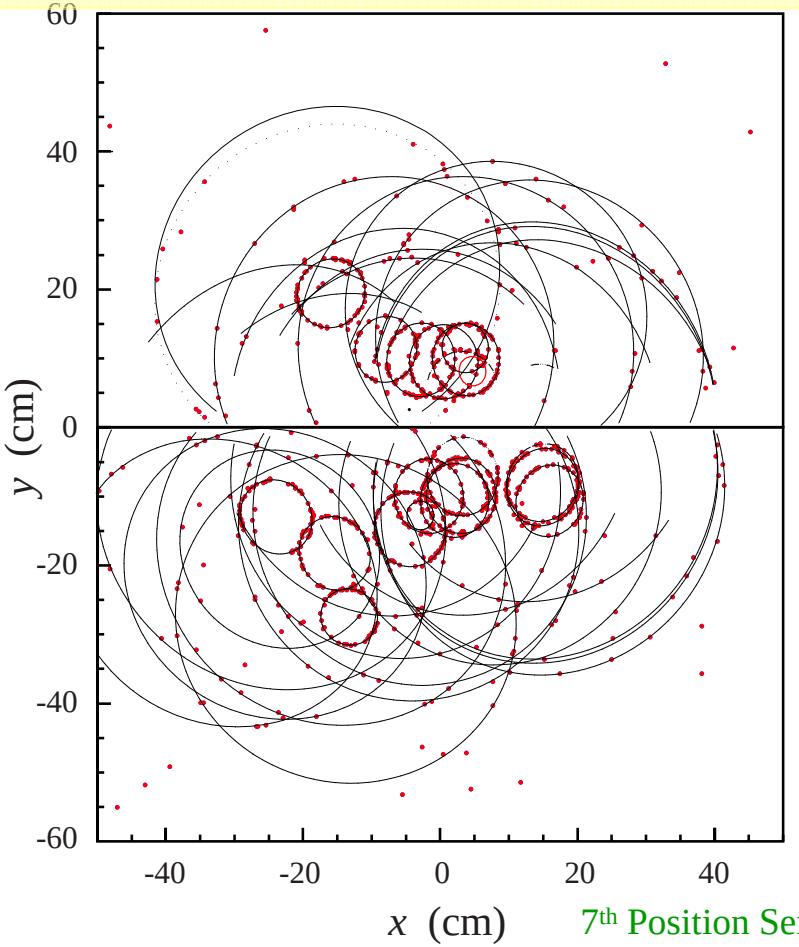
Acceptance 15-120 mrad

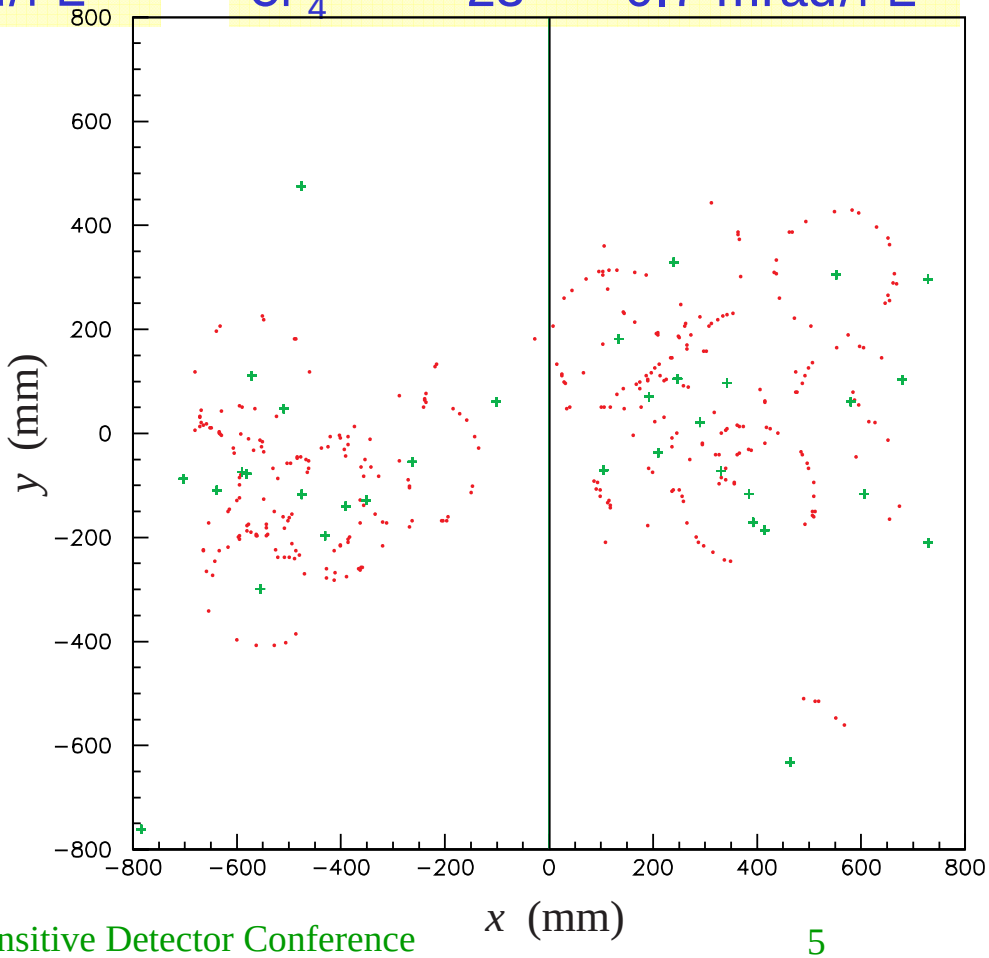


Reconstructed rings

RICH1	PE/track	$\sigma(\theta_c)$
C_4F_{10} (small)	– 31	1.6 mrad/PE
Aerogel (large)	– 6.8	2.6 mrad/PE

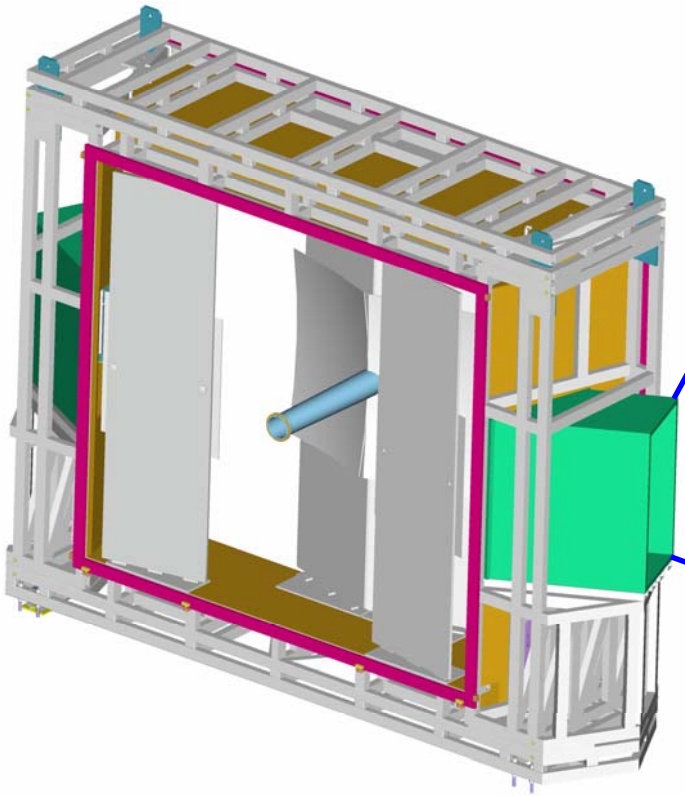
RICH2	PE/track	$\sigma(\theta_c)$
CF_4	– 23	0.7 mrad/PE



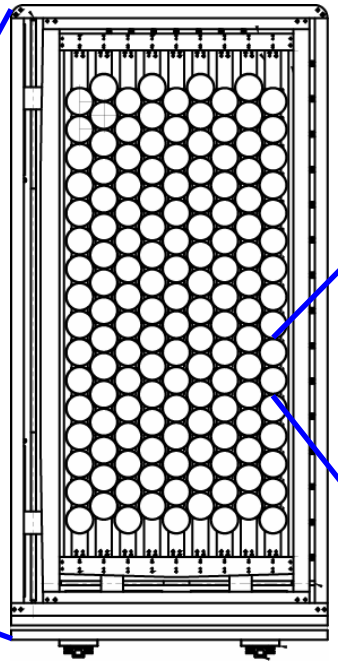


Photon Detector Planes

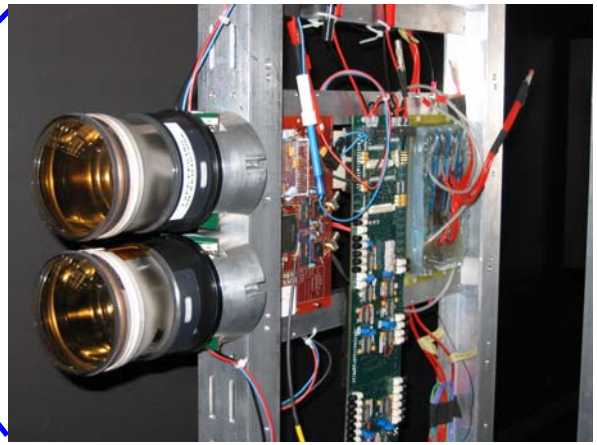
e.g. RICH2



Photon detector plane

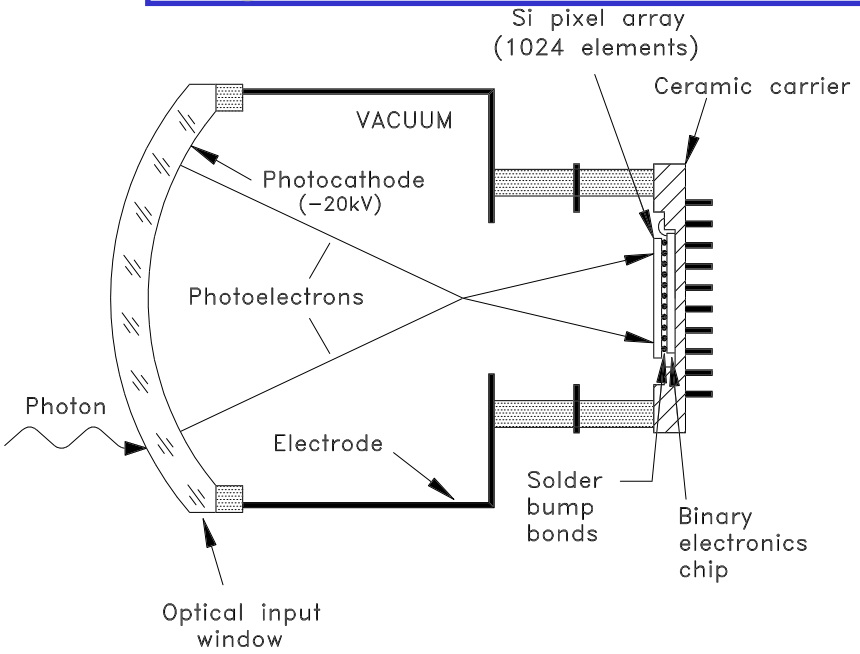


Hybrid Photon Detectors



RICH1: 7 columns of 14 HPDs (2 planes)
RICH2: 9 columns of 16 HPDs (2 planes)
} →484 HPDs (area =2.6 m^2)

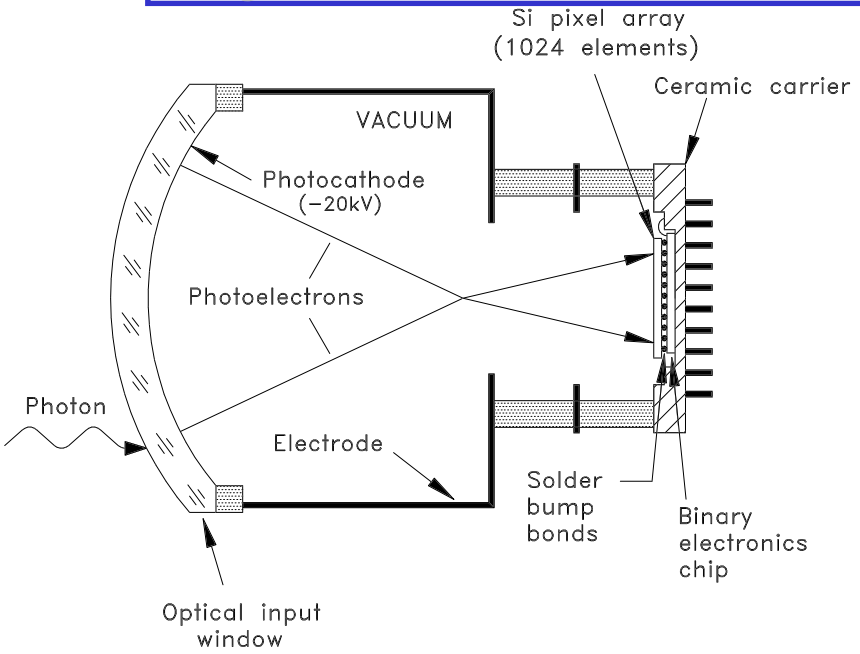
Hybrid Photon Detectors



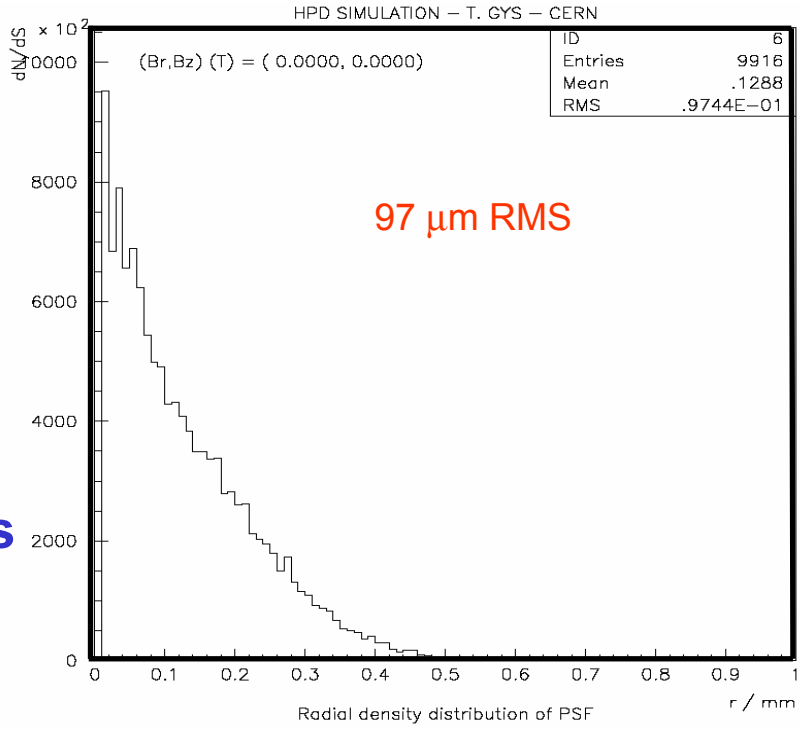
- Quartz window (S20 photocathode)
  - $\int$ QE dE > 0.7 eV
- 20 kV accelerating potential
  - 5000 e^- signal
- Cross-focussing optics
- Active diameter: 75 mm

- Encapsulated readout chip
- 32x256 (8192) pixel array (Canberra)
  - 62.5 μm x 500 μm
- Digital OR: 32x32 (1024) super-pixels
  - 0.5 mm x 0.5 mm
- Demagnification factor of ~5:
  - 2.5 mm x 2.5 mm effective size

Hybrid Photon Detectors



- **Simulation of Point Spread Function:**
  - **Shows that RMS in position of electron at the Si plane is 97 μm**
  - **Effectively, all points collected within one super-pixel**



- **Encapsulated readout chip**
- **32x256 (8192) pixel array (Canberra)**
  - **62.5 μm x 500 μm**
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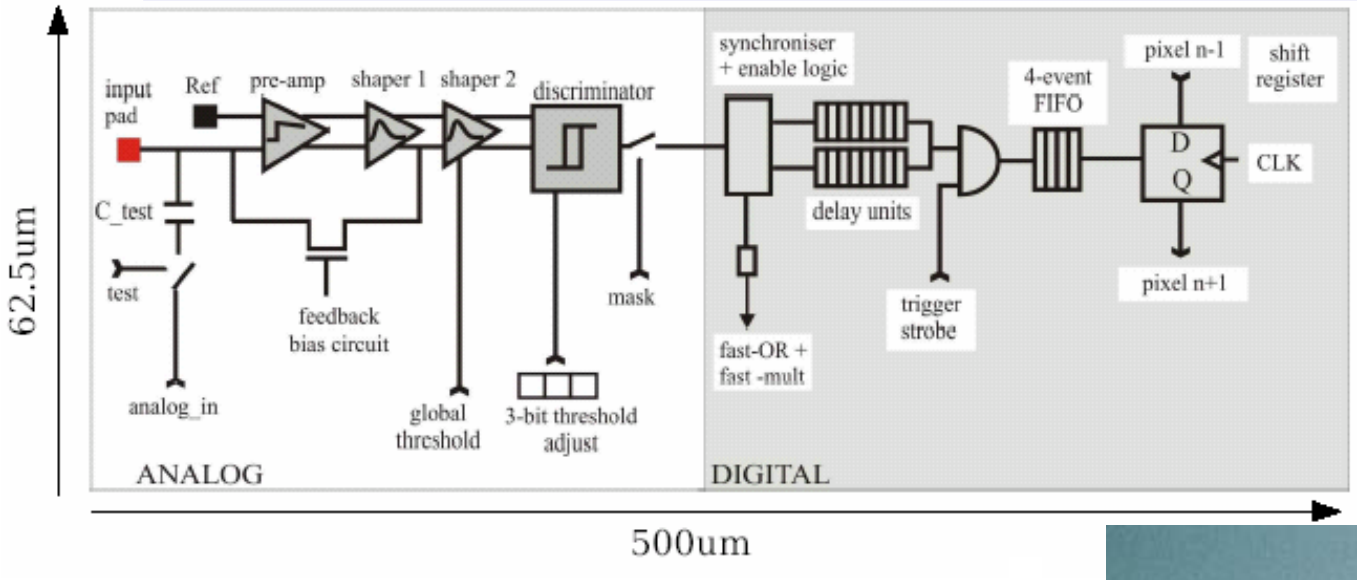
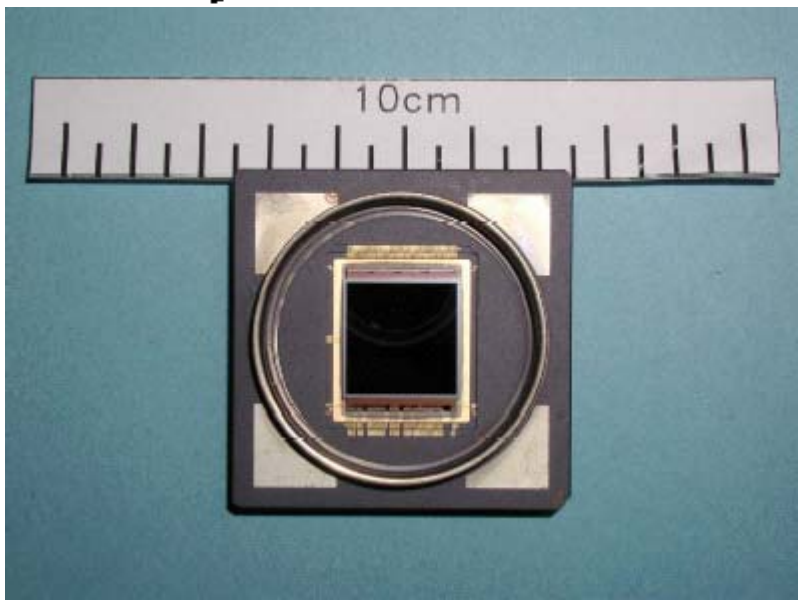
  - **0.5 mm x 0.5 mm**
- **Demagnification factor of ~5:**
  - **2.5 mm x 2.5 mm effective size**

Pixel chip (LHCBPIX1)



- 0.25 μm CMOS process
- Radiation tolerant (3 kRad/year)

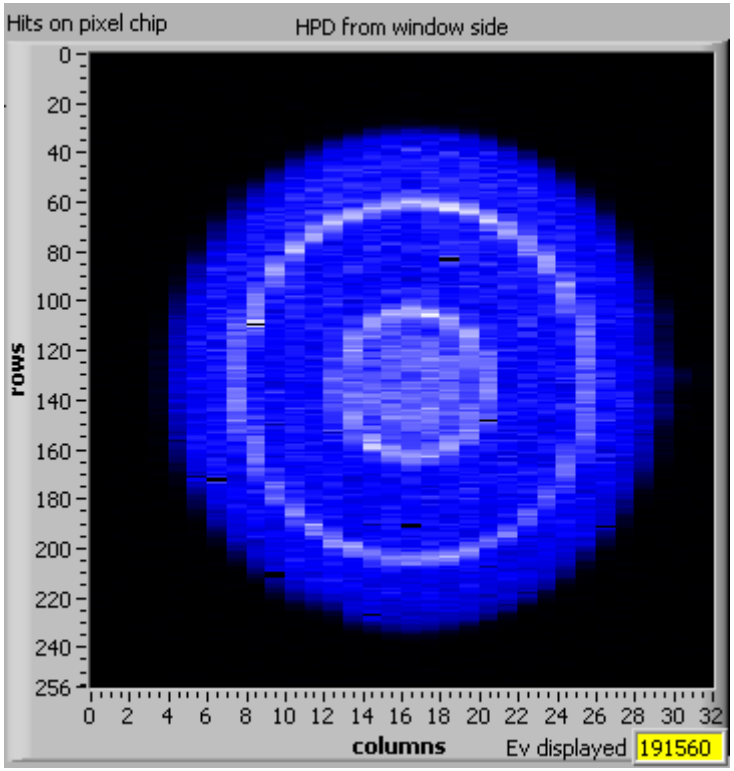
- Low noise (< 250 e^-)
- Low threshold (< 2000 e^-)
- 40 MHz (25 ns precison)
- Binary architecture
- 16 mm x 16 mm active area
- 62.5 μm x 500 μm pixel size
- Two modes of operation: 8192 pixels or 1024 pixels



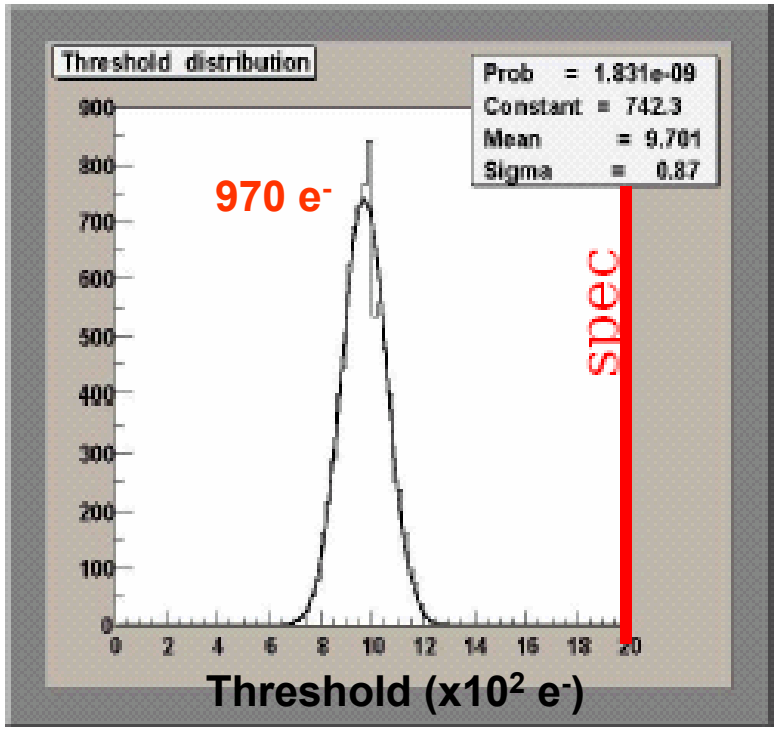
HPD pre-series performance

- Mass production of 484 HPDs has commenced at DEP (~30 /month)
- Quality assurance to be provided by two test facilities
- Pre-series of 9 tubes tested:

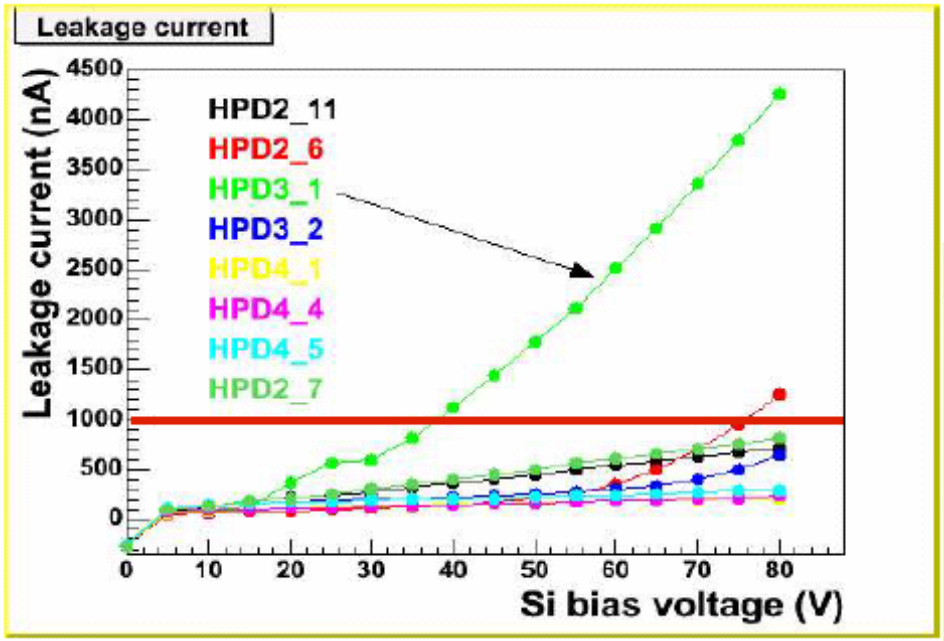
More than 99.3% good pixels
Threshold: 1100-1200 e- (< 2000 e^-)
Pixel-pixel variation ~ 90-100 e^-
Noise: 160-170 e^- (< 250 e^-)



LED scan

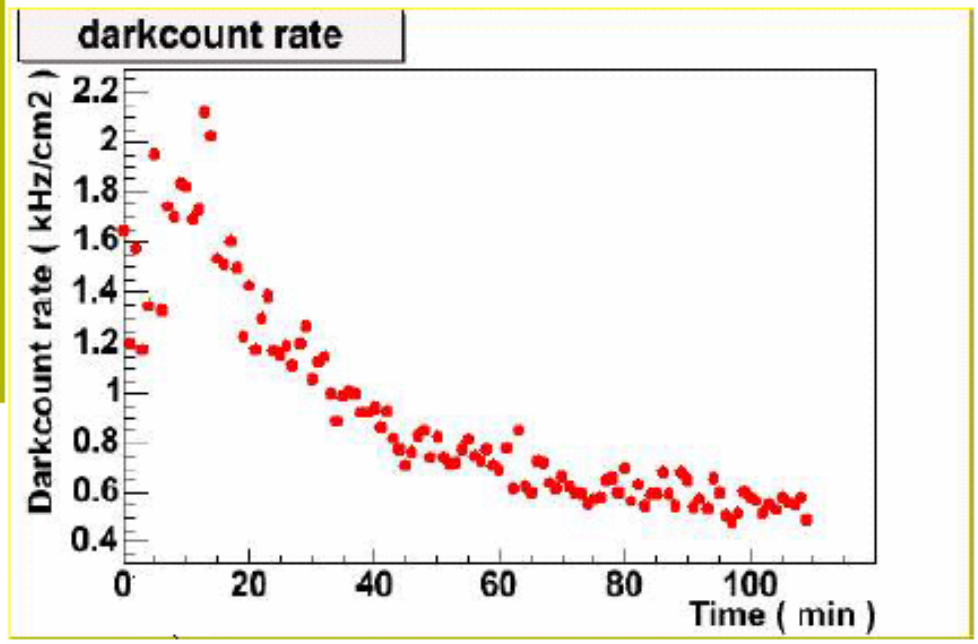


Leakage current and dark count

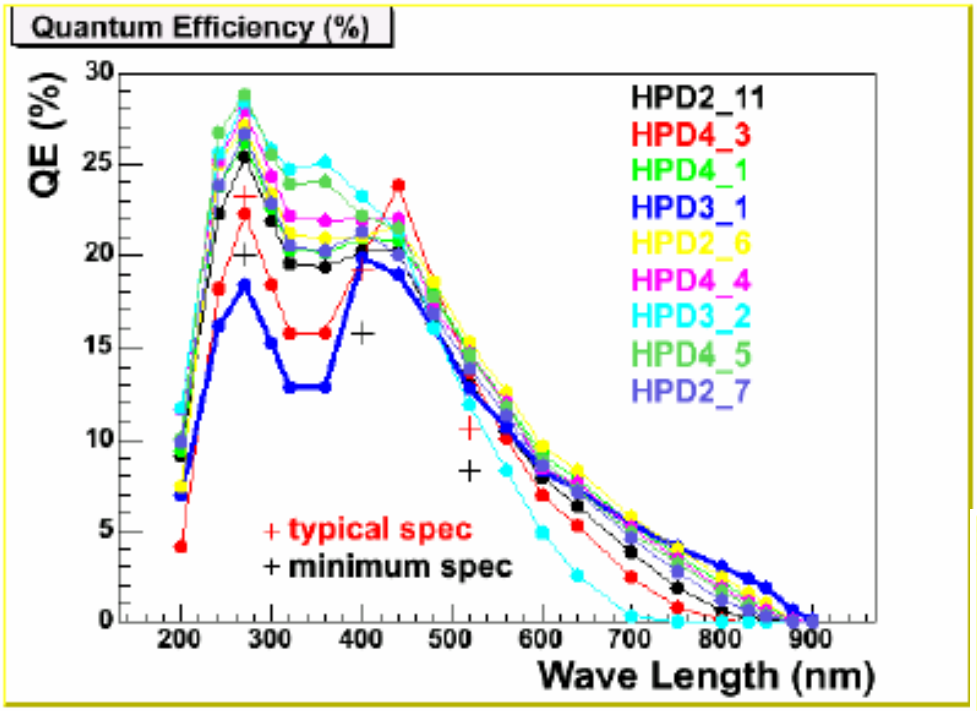


Leakage current: < 1 μA @ 80 V
8 out of 9 HPDs satisfy requirement
(but tube still operational)

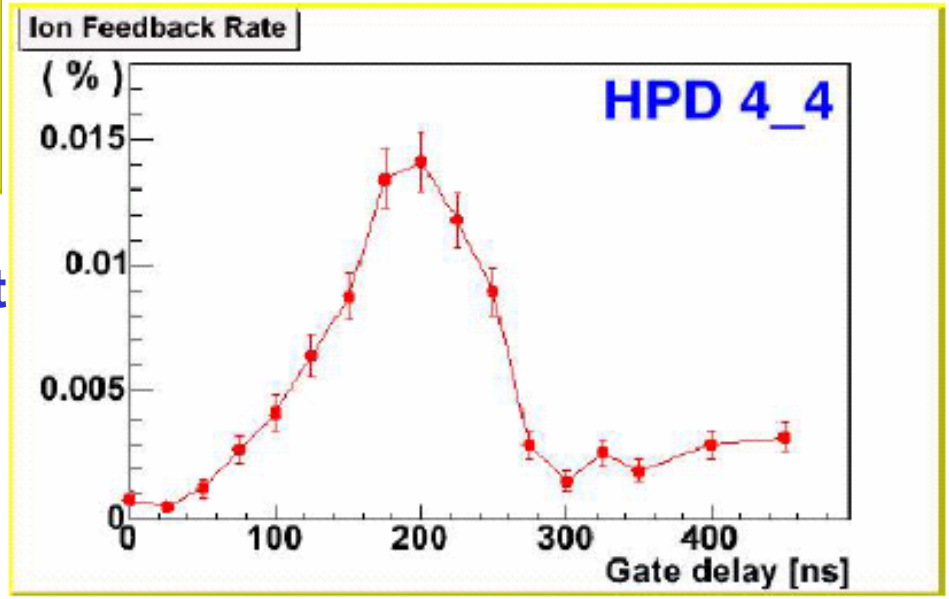
Dark count rate (< 5 kHz/cm²):
Measured rates between 0.03 and 3.0 kHz/cm².
Stabilises after 90-100 mins.



Quantum eff. and ion feedback



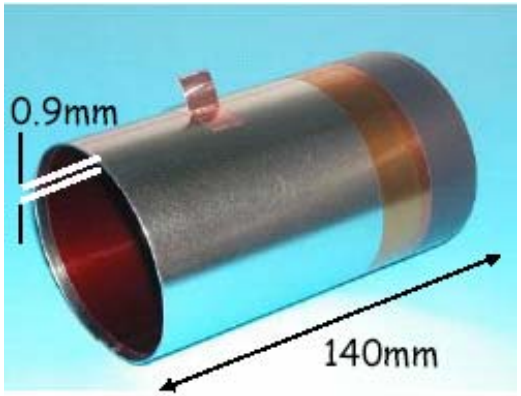
- Ion feedback:
  - Photoelectron ionises residual gas molecule
  - Ion travels back to cathode ejecting PE 200 ns after first electron pulse
- Test of gas quality
- Requirement < 1% signal
- Results < 0.1% signal

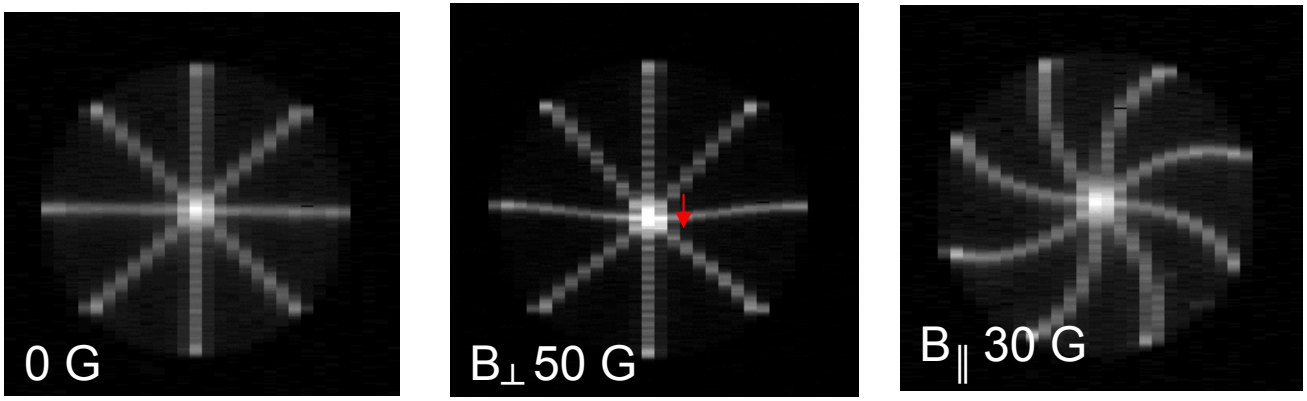


8 out of 9 satisfy QE min. requirement
QE > 20% @ 270 nm
(smaller QE in UV but higher
QE in red→tube can also be used)

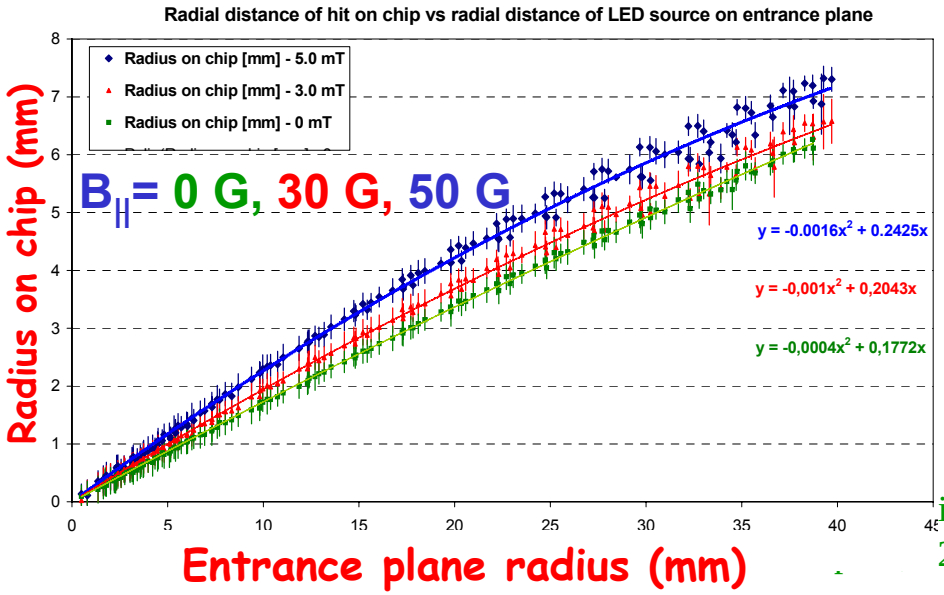
Magnetic field

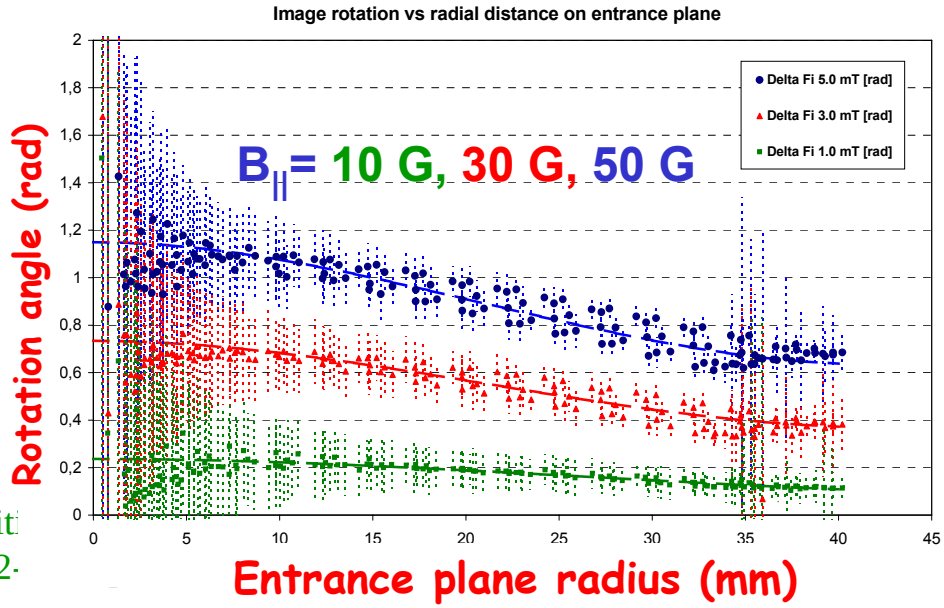
- Max field in RICH1 25 G, in RICH2 8 G
- Mu-metal shielding for each of the HPDs
- Distortions due to axial and transverse fields:



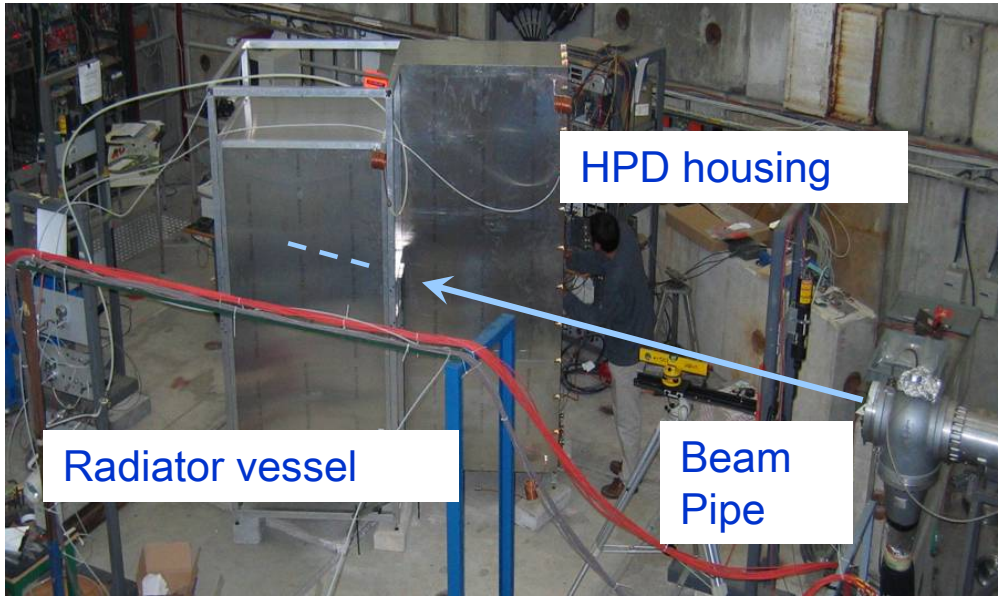


Need to correct for B-field distortions by use of test patterns.



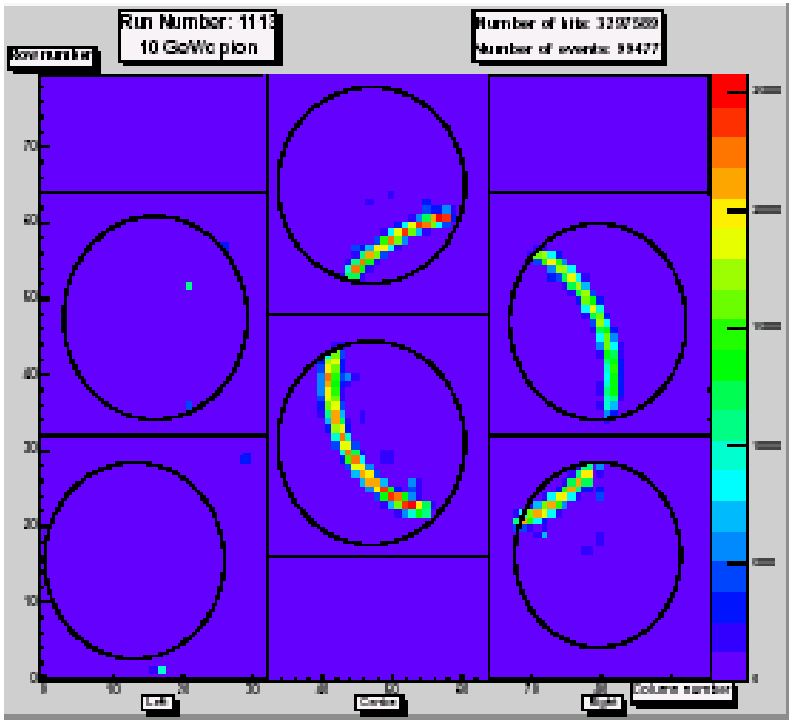


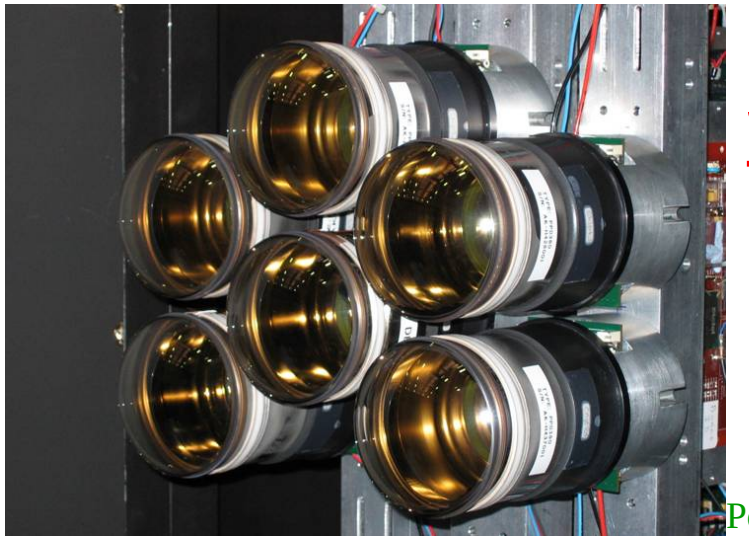
Test beam



Test beam at CERN PS:
10 GeV/c electrons and pions

Observation of aggregate Cherenkov rings in C_4F_{10} gas.

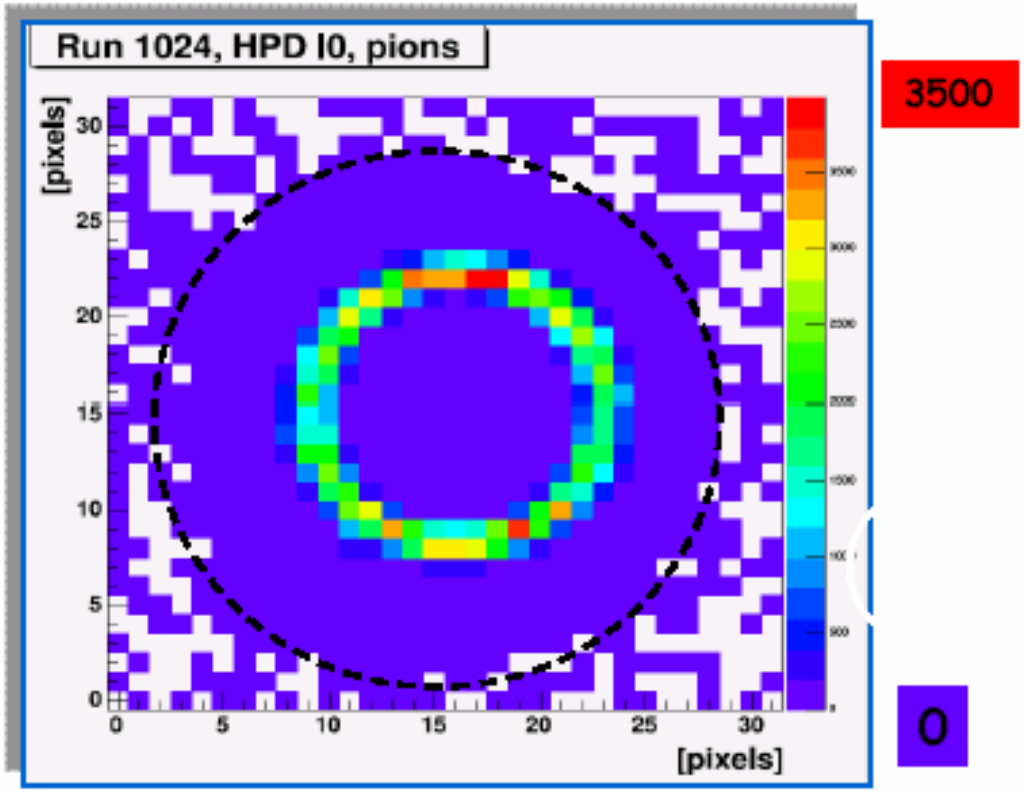




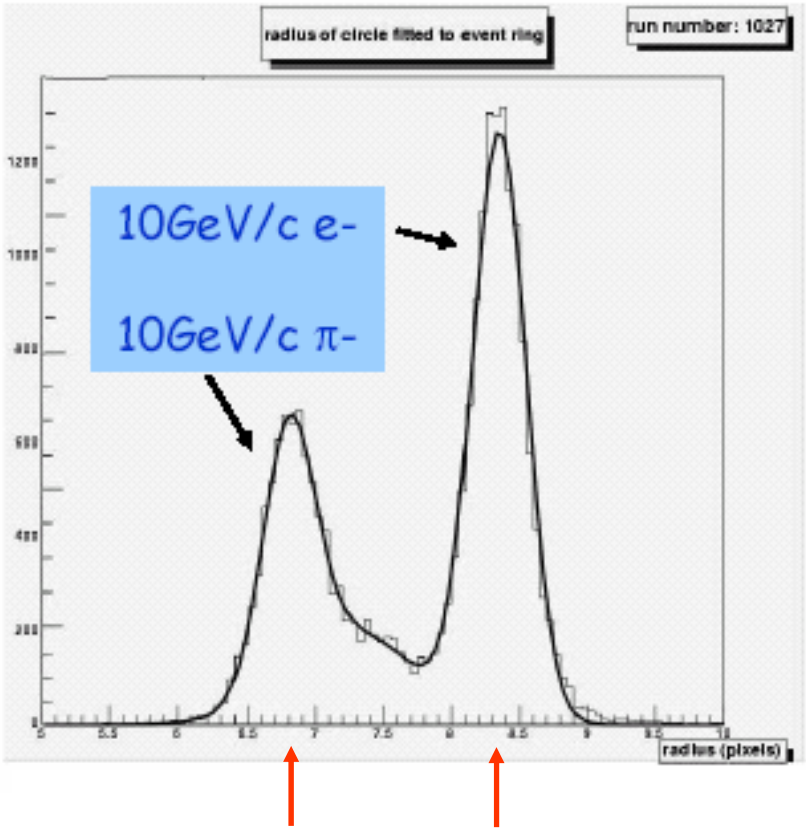
Six HPDs tested in beam test

Test beam (II)

Cherenkov rings in N_2 radiator focussed on one HPD



Electron/pion separation at 10 GeV/c clearly observed



Expectation: 19.1 mrad 23.7 mrad

Conclusions

- Hybrid Photon Detectors (HPD) will be used for the RICH counters of LHCb
- HPDs performing as expected
- Production of ~500 HPDs underway
- Quality assurance of production (~ 30 /month) to be provided by two test facilities.
- Test beam validates test results obtained in the laboratory

Backup slides

Bump bonding and HPD assembly

- **Bump-bonding: high melting point solder (Sn/Pb = 10/90) at VTT (Finland)**

- **HPD assembly at DEP:**