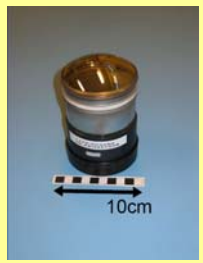
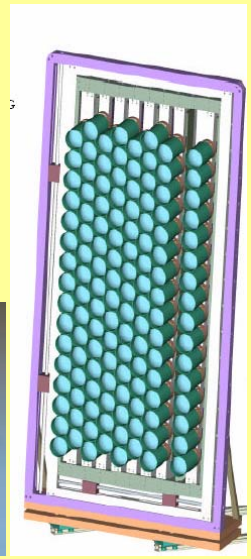
Production of HPDs for the LHCb RICH Detectors

- LHCb RICH Detectors
- Hybrid Photon Detector
- Production
- Photo Detector Test Facilities
- Test Results
- Conclusions

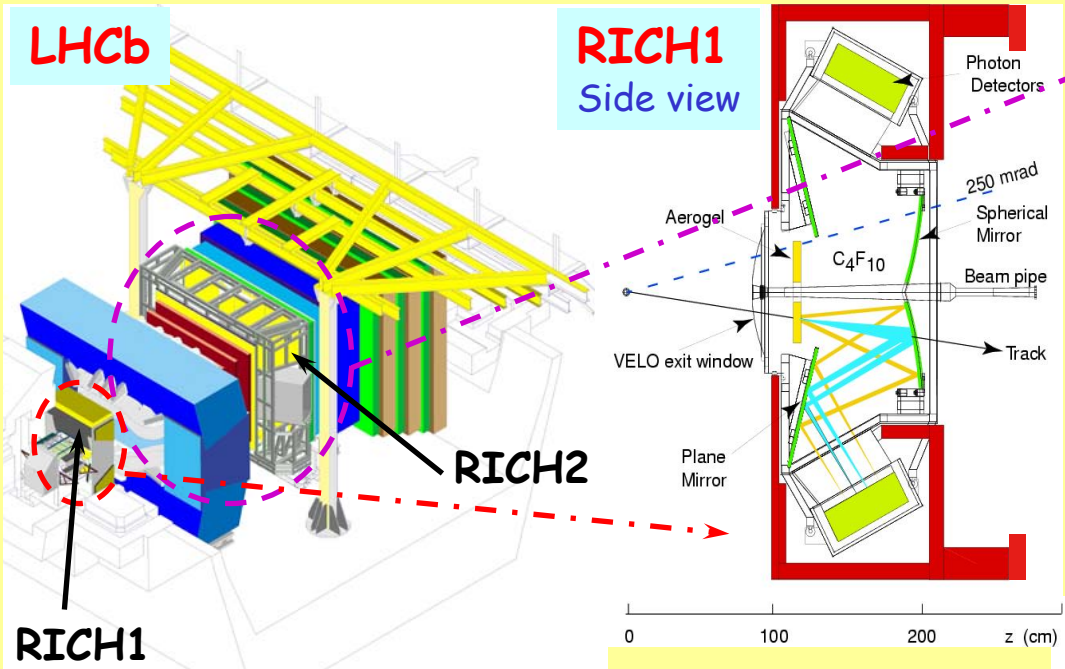


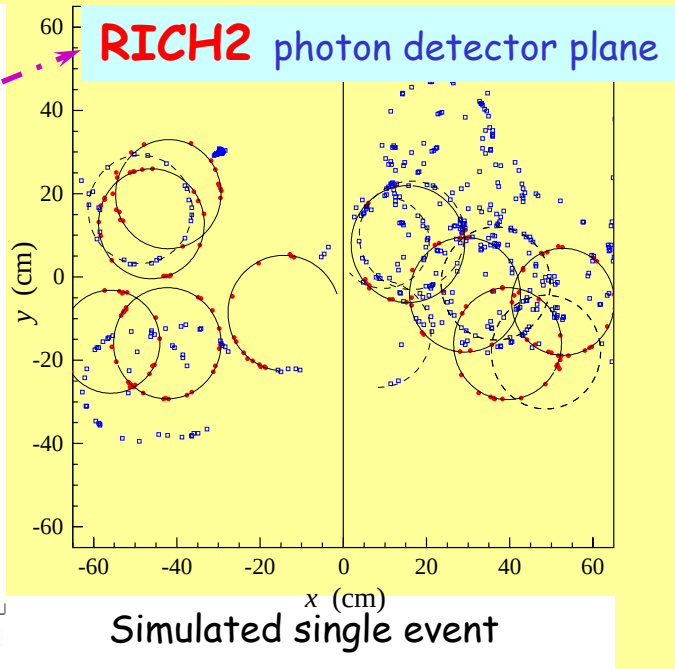


IEEE Nuclear Science Symposium
Wyndham, 24th - 26th October 2005

Franz Muheim
University of Edinburgh
for the LHCb RICH group

LHCb RICH Detectors

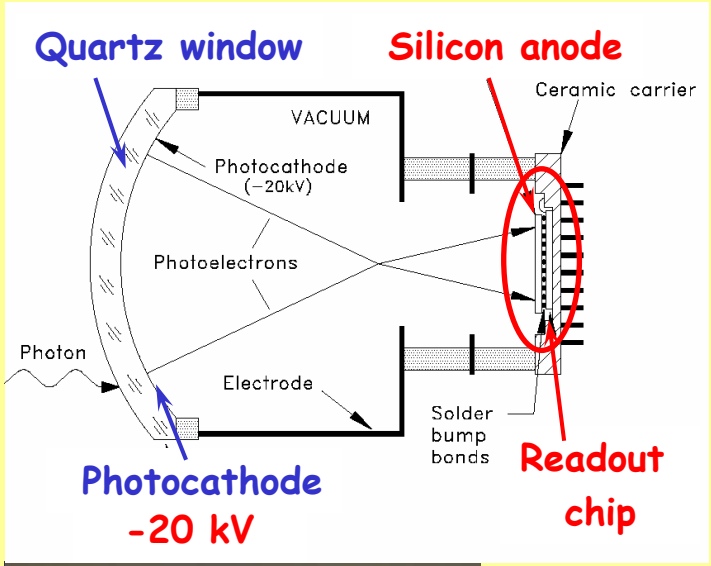


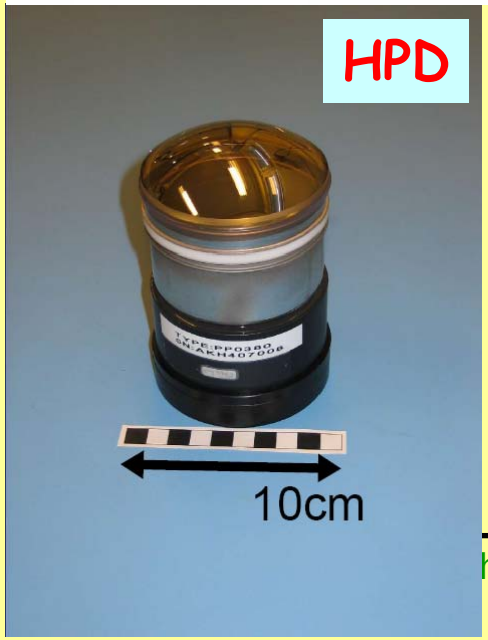


- **LHCb Experiment**
  - Precision measurements of CP violation in B meson decays, search for New Physics
- **Ring Imaging Cherenkov Detectors**
  - Charged particle identification
  - 2 RICH detectors - RICH1 and RICH2
  - 3 radiators - aerogel, C_4F_{10}, CF_4
- See talks in N25 - R Linder & C d'Ambrosio

- **RICH Photon Detector Requirements**
  - single photon sensitivity: 200 - 600 nm
  - quantum efficiency: >20%
  - photo detector area: 3.0 m^2
  - active area fraction: 65%
  - spatial resolution /pixel size: 2.5 x 2.5 mm^2
  - read-out at LHC int. rate 40MHz
  - radiation tolerant: 3kRad/year

Hybrid Photon Detector - HPD





LHCb RICH
484 HPDs
~500k channels

- **HPD = Hybrid Device**
  - Visible light photon detector
  - Pixelised silicon sensor and readout electronics
  - Encapsulated in vacuum tube
- **Photon detector**
  - Multi alkali photo cathode (S20), quartz window
  - 20 kV photo cathode high voltage
  - Cross-focusing optics - de-magnification: ~5
- **Silicon anode**
  - Si-sensor array with 256×32 pixels
  - bump-bonded to binary readout chip
  - Single photo electron (p.e) at 20 kV
    ~5000 e^- hole pairs in silicon
  - LHCb readout mode – 8-fold binary OR
    effective 32×32 pixel array
  - Pixel size - 500 μm × 500 μm

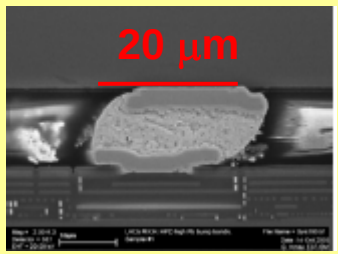
HPD Production - Anode

Silicon sensor
(Canberra - B)

Readout chip
(IBM - F)

High Temperature
bump-bonding
(VTT - FIN)

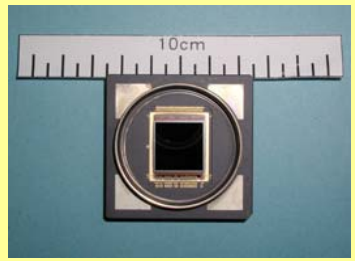
Wafer probing



Assembly probing

Packaging
(HCM - F)

Anode testing



Ceramic carrier
(Kyocera - JP)

Brazing (DEP - NL) and
gold-plating (CERN)

Visual inspection and
plating control

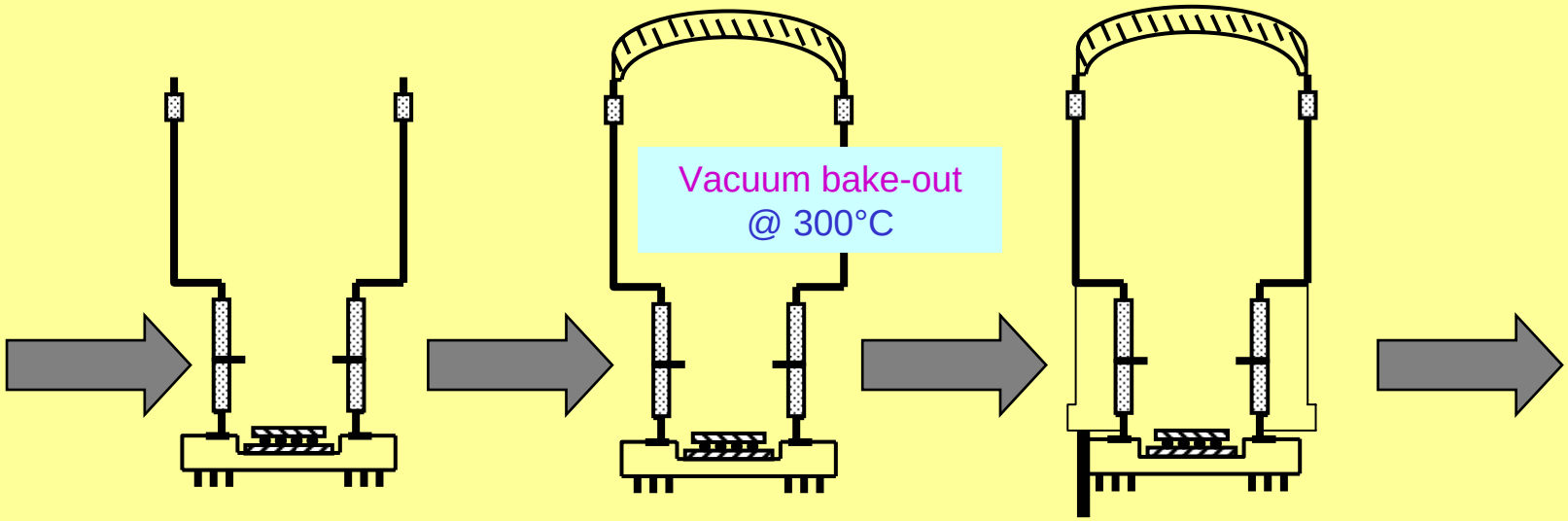
HPD Production – Photon Detector

Hybrid photon detector production
(Photonis DEP - NL)

Tube body assembly

Photo-cathode deposition and vacuum sealing

HPD cabling and potting



Anode incoming inspection and testing

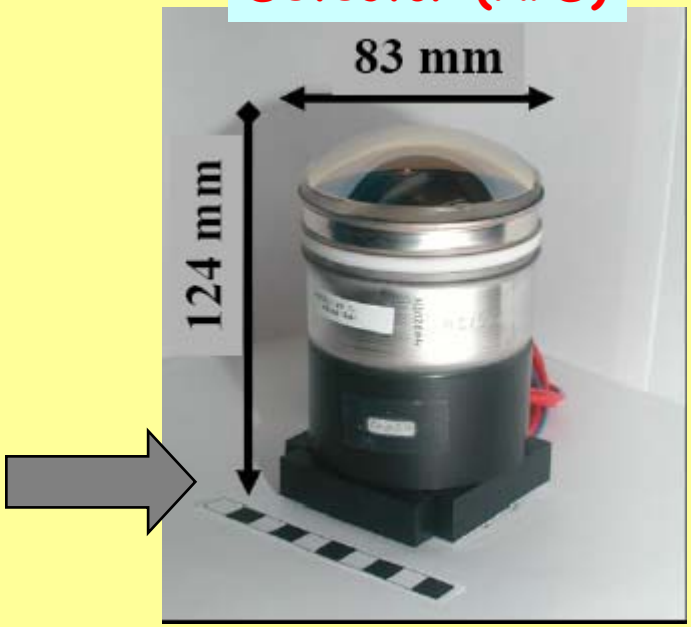
Anode testing

QE measurement and anode testing

HPD Q&A testing

HPD Quality Assurance

Hybrid Photon Detector (HPD)



- **HPD Production**
  - Series production of ~500 HPDs started
    21 (+9 pre-series) HPDs delivered
  - Production rate - 30 HPDs/month over 18 months
- **Photo Detector Test Facilities (PDTF)**
  - Provide quality assurance (QA) and verify/measure HPD specifications/properties
  - Two PDTF sites: at Edinburgh and Glasgow Univ. with two fully equipped test stations/ PDTF site
  - Automation wherever possible
  - Testing rate - one HPD / work day / site
  - Extended tests for subsample (~10%) of HPDs

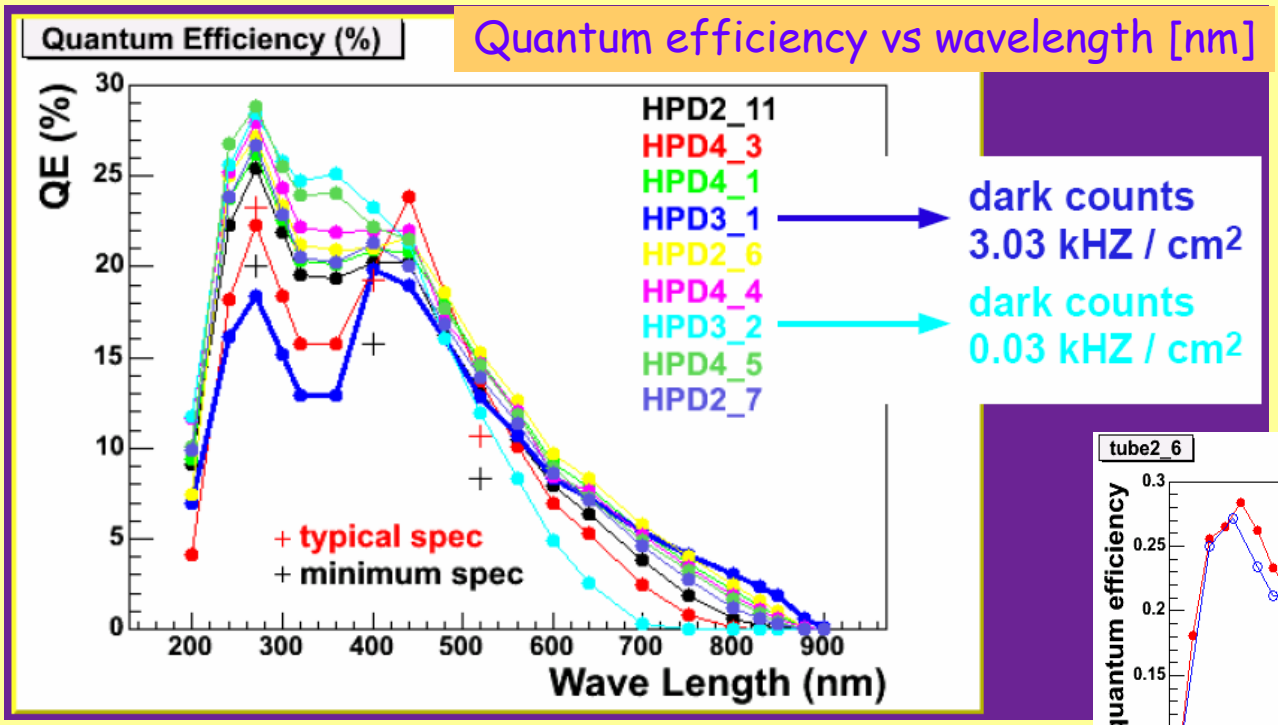
PDTF Test Programme

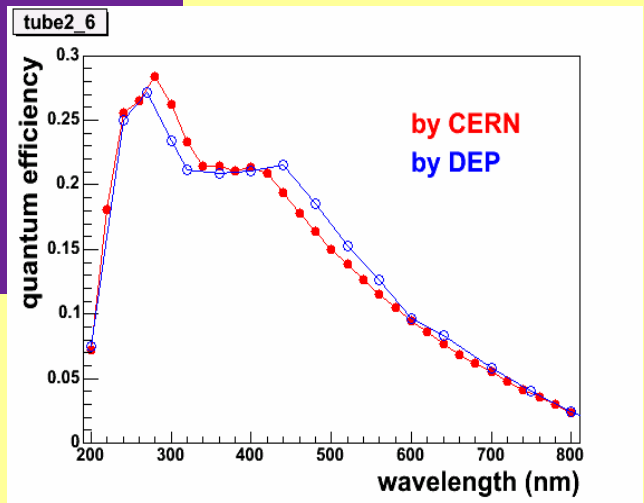
Mandatory for all HPDs		
Max. threshold:	<2000 e^-	threshold scans
Noise:	<250 e^-	
Chip leakage current:	typ. 1μA @ 80V bias	IV scan & Bias V scan
HV operation:	stable @ 20kV	High voltage scan
Pixel response:	>95% for light	long LED run
Tube intrinsic coverage:	>80%	
Ion feedback rate:	<10^{-2} rel. to signal	time delay scan
Dark Count Rate:	<5kHz/cm^2	Dark count runs
for 10% sub-sample of HPDs		
Ph.e. detection eff.:	typ. 85%	Backpulse measurement
Quantum Efficiency:	at 270, 400, 520 nm	QE measurement

Measurements of 9 pre-series HPDs tested at CERN
Results generally well within specification

Quantum Efficiency

- QE measurements
  - 9 pre-series HPDs at CERN
- QE specifications
  - based on HPD prototype results

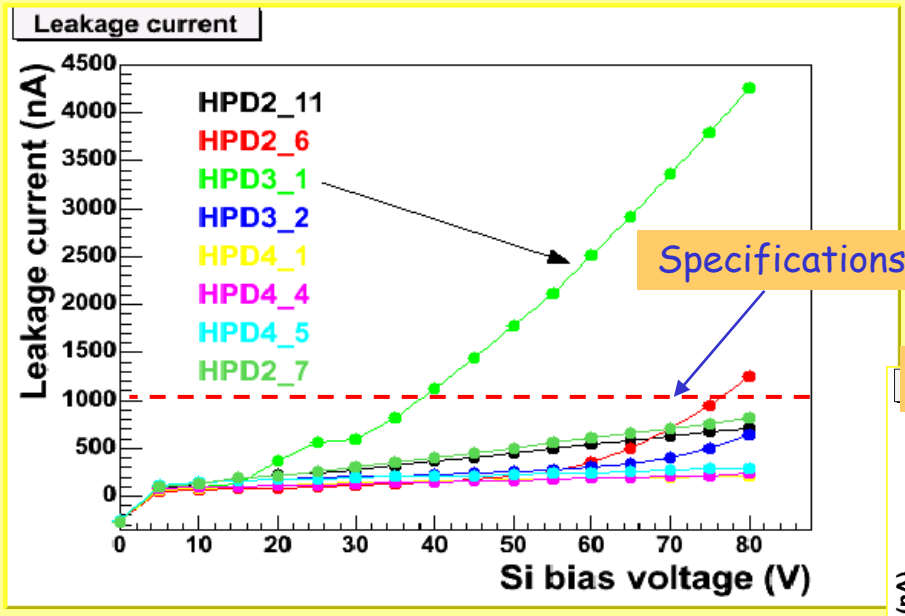




- Dark count rare correlated with QE red response
- Measurements consistent between CERN and DEP

Leakage Current

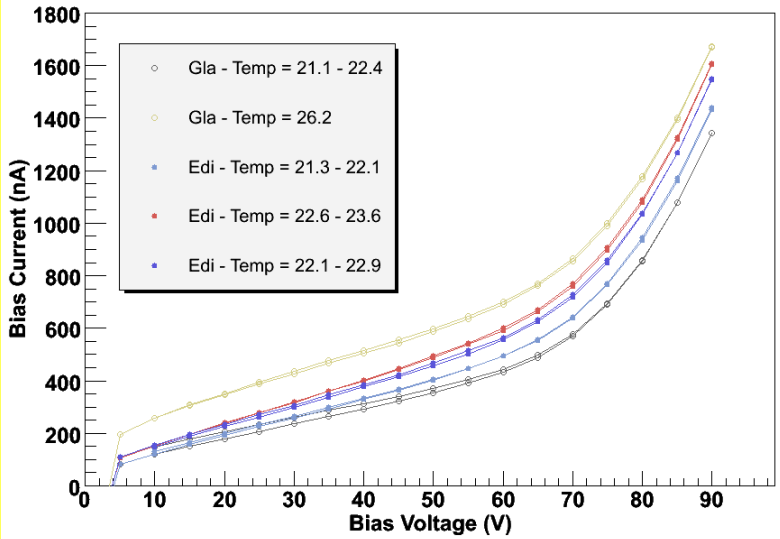
- Measurements
  - 9 pre-series HPDs



  - 8 HPDs <1μA - typ. 1μA @ 80V
  - 1 HPD 4.3μA - OK
- Leakage Current
  - Dependent on chip temperature
  - Not correlated with ambient temperature

- Measure "Chip" Temperature
  - PT sensor at HPD read-out board
- Photo detector test facilities
  - Cross-calibration of 2 PDTF sites
  - Measure leakage current increases with "chip" temperature

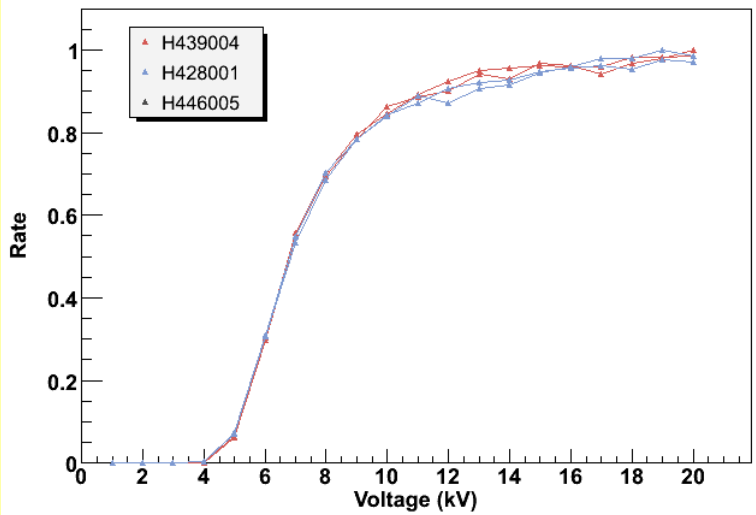
Leakage current vs Si bias voltage



Bias & High Voltage Scans

- High Voltage Scans

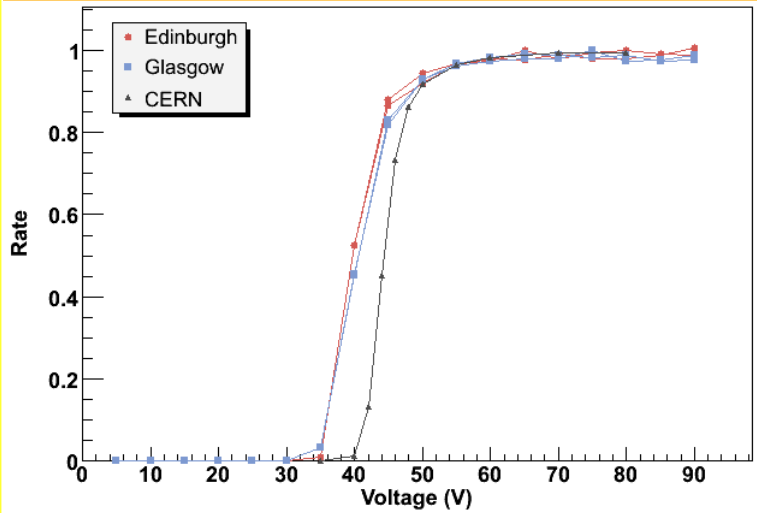
# of photo electrons vs high voltage



- PDTF Results
  - HV curves are very similar
  - >90% relative efficiency > 10kV
  - large stable operating range
  - LED light yields vary between typ. 2 - 4 p.e./event

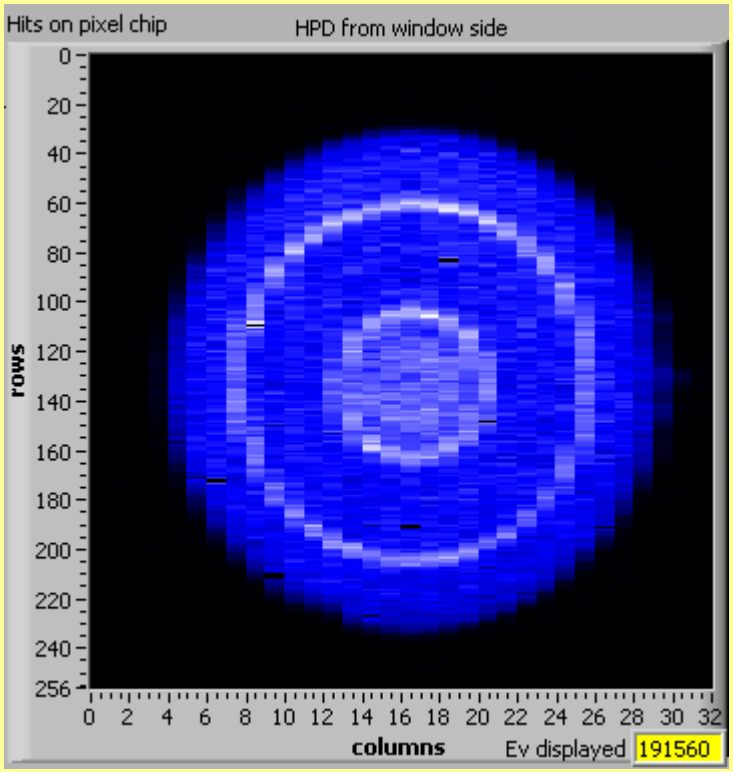
- Bias Voltage Scans
  - Strobe Timing is critical
  - drift velocity increases with V_{Bias}
  - depletion voltage and saturation yield depend on drift velocity
- PDTF measurements
  - Excellent agreement between PDTF sites
  - difference to CERN due to timing

# of photo electrons vs bias voltage

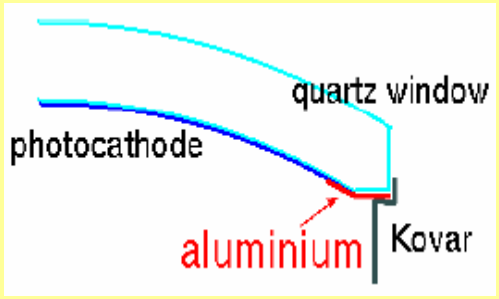


Long LED Run

High statistics LED run
(200k events, ~3 npe/event)



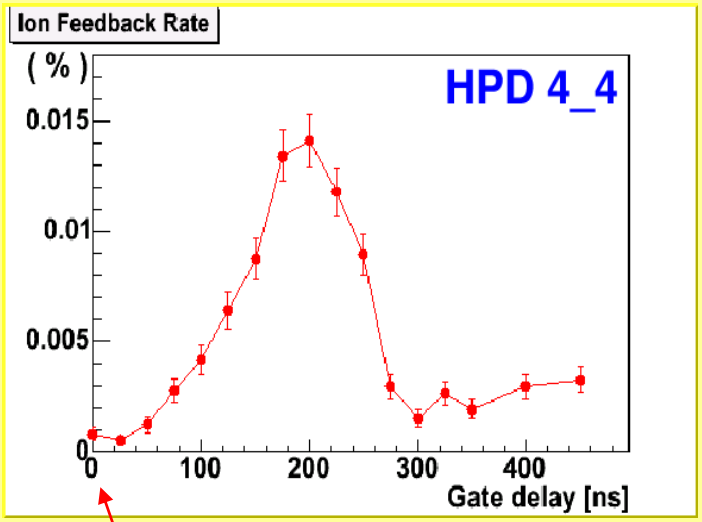
- HPD response
  - Full photo cathode area active
  - measure sensor positions
  - measure demagnification
  - cylindrical structures due to reflection on Al coating at edge



  - HPD edges will be shadowed mu-metal shielding
- 9 pre-series HPD results
  - uniform response over full active area (apart from reflections)
  - pixel response:
  - 8 HPDs >99%
  - 1 HPD > 94.8% (1 missing column)
  - Specifications: >95%

Ion Feedback

Ion Feedback signal



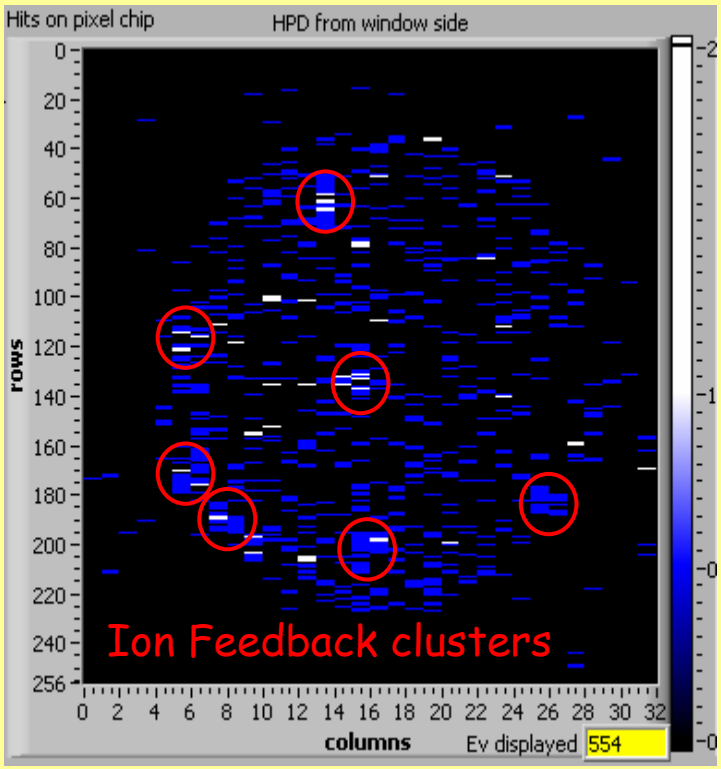
LED light pulse at ~0 ns

- Ion Feedback
  - photo electron ionises residual gas molecule
  - → travels back to the photo cathode
  - → releases cluster of photoelectrons
  - Delayed signal of clustered photo electrons
  - → peaks ~200ns after direct photon signal
  - indicator of vacuum quality

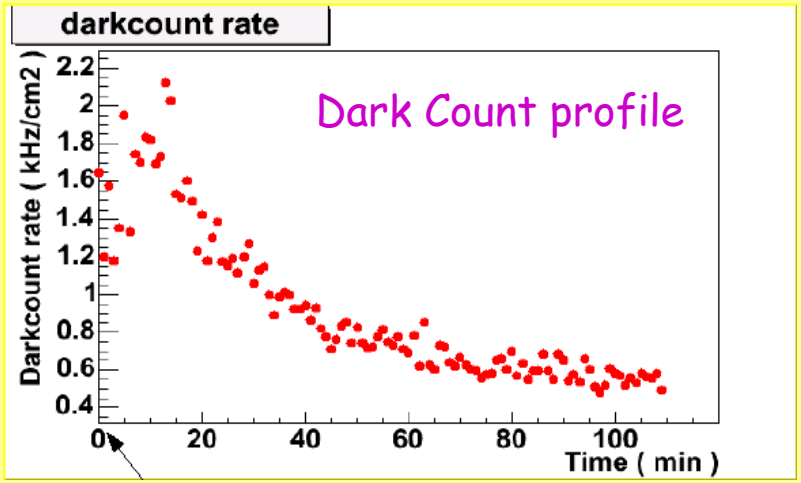
- 9 pre-series HPD results
  - ion feedback rate $<10^{-3}$ x direct photon signal
  - consistent with specifications ($<10^{-2}$)

Dark Counts

High statistics Dark Count run (5M events)



- Sources of dark counts
  - Thermionic electron emission (temperature)
  - Field emission (electric field)
  - Ion feedback (vacuum quality)



- 9 pre-series HPD:
  - dark count rate
  - 0.03-3.0kHz/cm^2 (<5kHz/cm^2) related to red response in QE

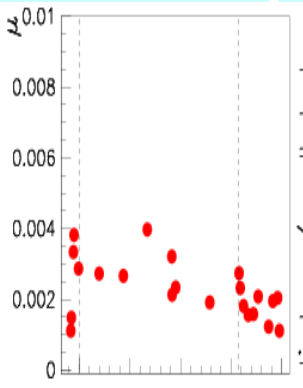
Long Term Performance - Ageing

- Aging Test Method
  - Illuminate HPD with intense LED light source
  - 40% occupancy at 50°C for 1 month
    normal LHCb occupancy ~1%
  - equivalent to 10 years of LHCb running

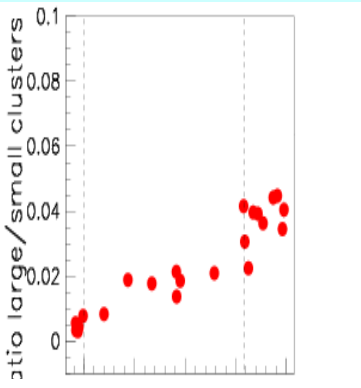
- Measurements
  - Dark current – slight decrease with time
  - Ion feedback - increases from 1 to 3%
    rate recovers
  - Light yield
  - Photocathode
    quantum efficiency
    unchanged

- Observe no degradation
  - Due to aging

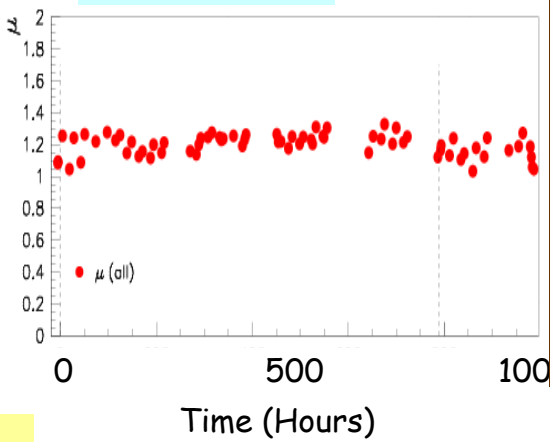
Dark count rate



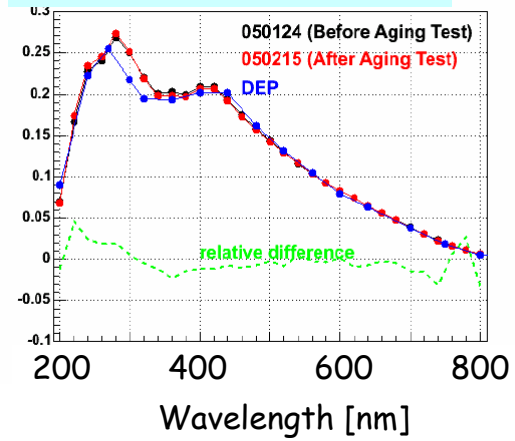
Ion feedback rate



Light yield

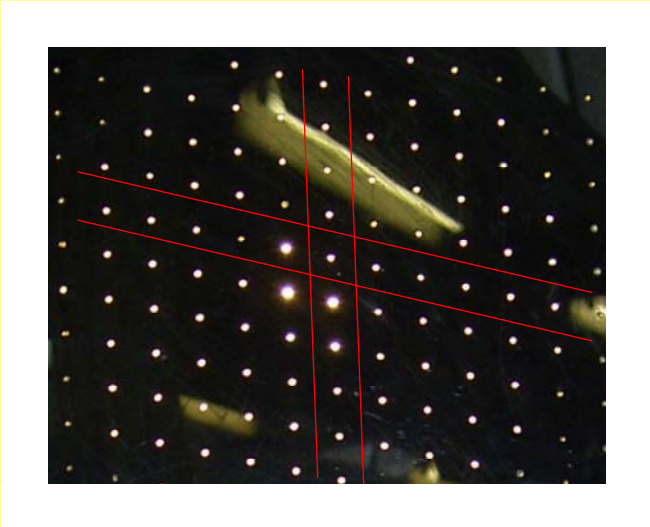


Quantum efficiency



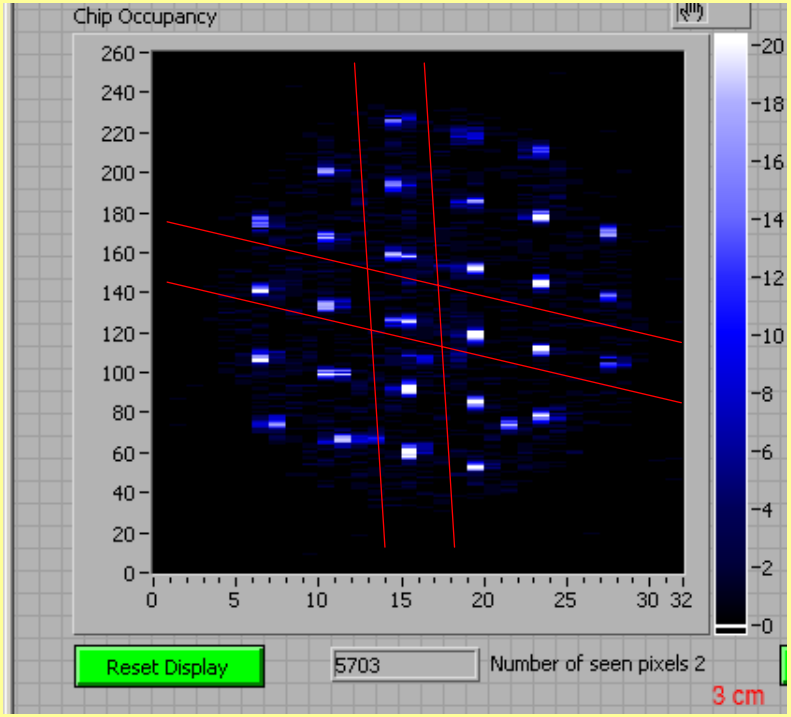
Pixel Mask Measurement

- Prototype pin-hole mask
  - hole diameter: 1 mm
  - hole separation: ~11 mm



- Method
  - Mask placed at 3 cm distance to HPD
  - Illuminate mask & HPD with point-like light source (fibre)
  - Fit light spot positions

Response to LED light with pin-hole mask (200k events)



- Goals
  - Compare spots to hole positions
  - Test for image distortion

Conclusions

- Hybrid Photon Detectors meet requirements for LHCb RICH detectors
- Pre-series HPDs have been tested extensively and their performance is within specifications
- Production of ~500 HPDs has started
  21 HPDs have been delivered
- Photo detector test facilities built and commissioned
- Automated test procedures are in place
- Series testing of HPDs has started

Backup Slides

HPD Performance

Results of 9 pre-series HPDs tested at CERN

Item	Specification	Results	Note
Pixel response	>95%	>99%	missing column in 1 HPD
Min. threshold Noise	<2000e- <250e-	Typ. 1200e- Typ. 160e-	
Leakage current	Typ. 1uA @ 80V bias	< 1uA	4.3uA for 1 HPD see page 10
Dark count rate	Max. 5kHz/cm^2	0.03-3kHz/cm^2	Correlated to red response
Ion feedback rate	Max. 10^{-2} rel. to signal	<10^{-3}	
P.e. detection efficiency	Typ. 85%	79-89%	No dead channel correction
Quantum efficiency	see page 9	Generally well above specs	1 HPD below specs in UV