HPD Performance in the RICH Detectors of the LHCb

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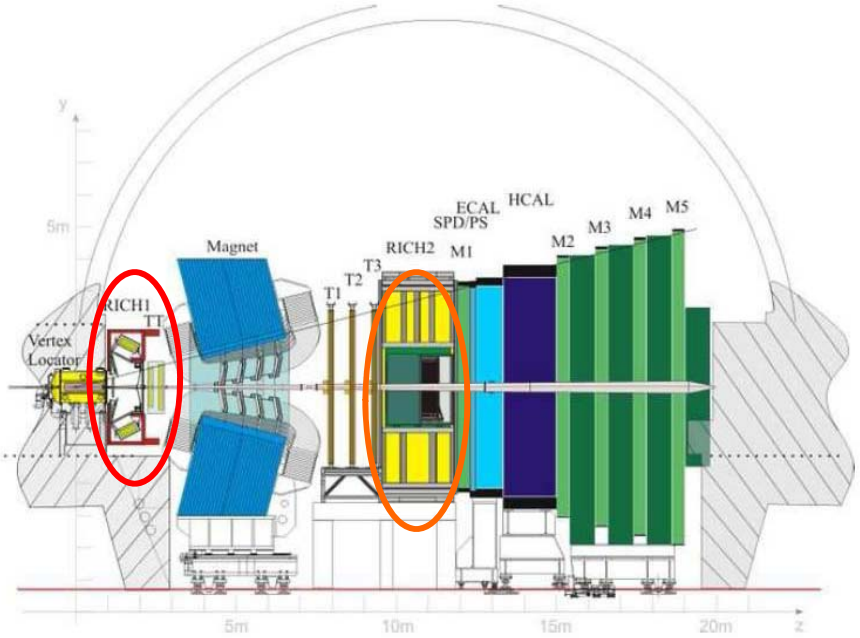
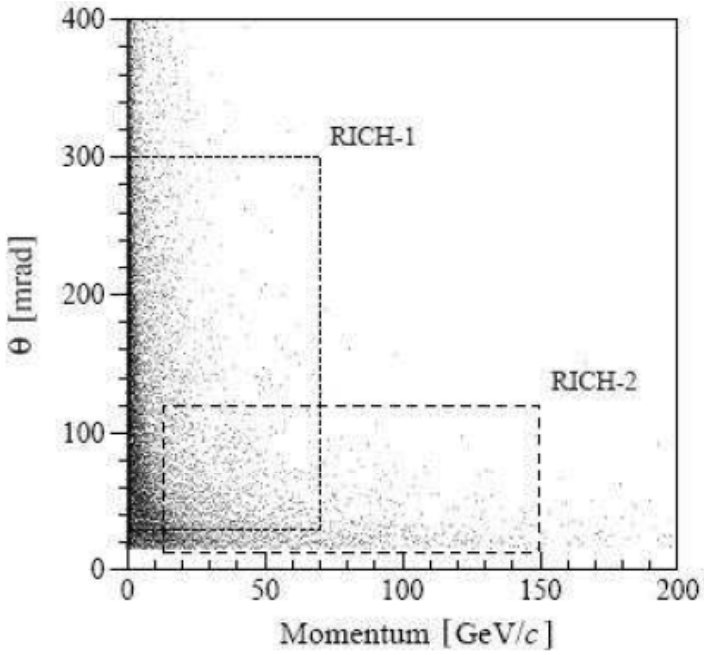
IoP HEPP Conference – April 2009

LHCb and the RICH Sub-Detectors



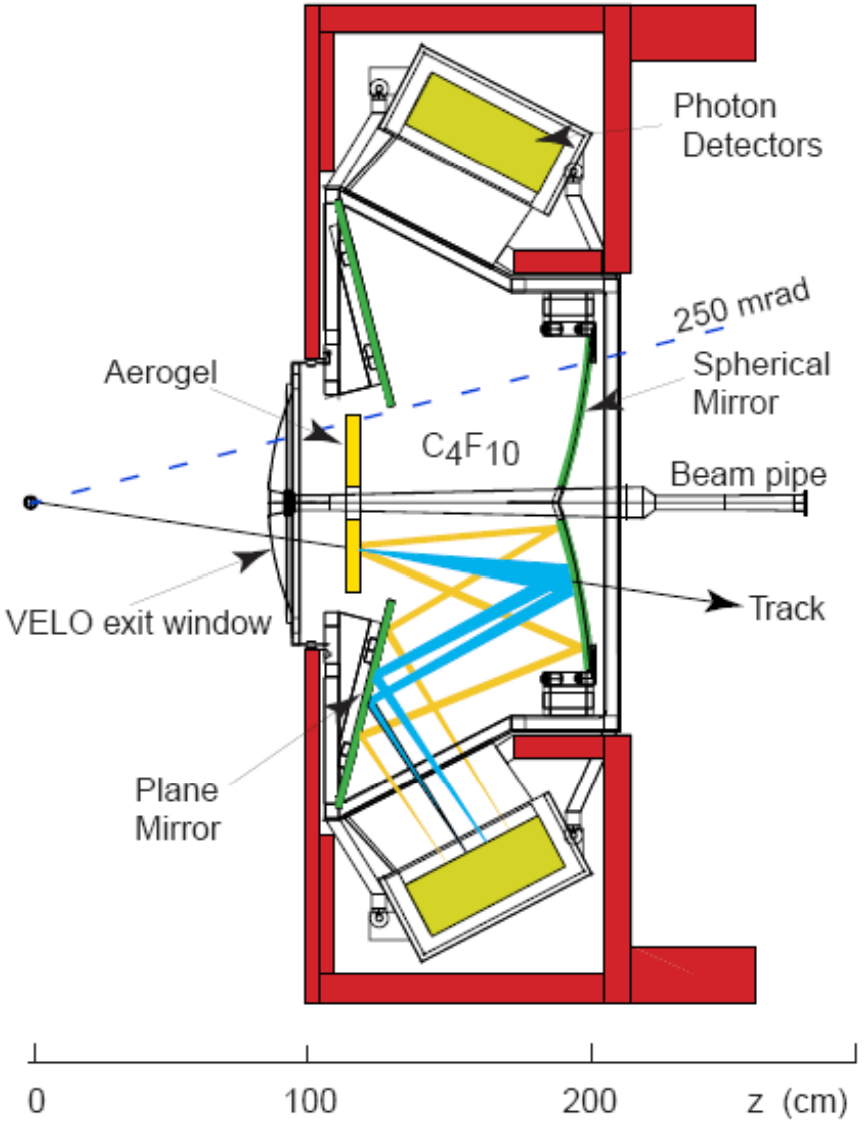
LHCb Sideview Schematic, with RICH1 and RICH2 circled in red and orange



Momentum-Polar Angle plot of simulated B_d->ππ events, showing regions that the RICH detectors will cover

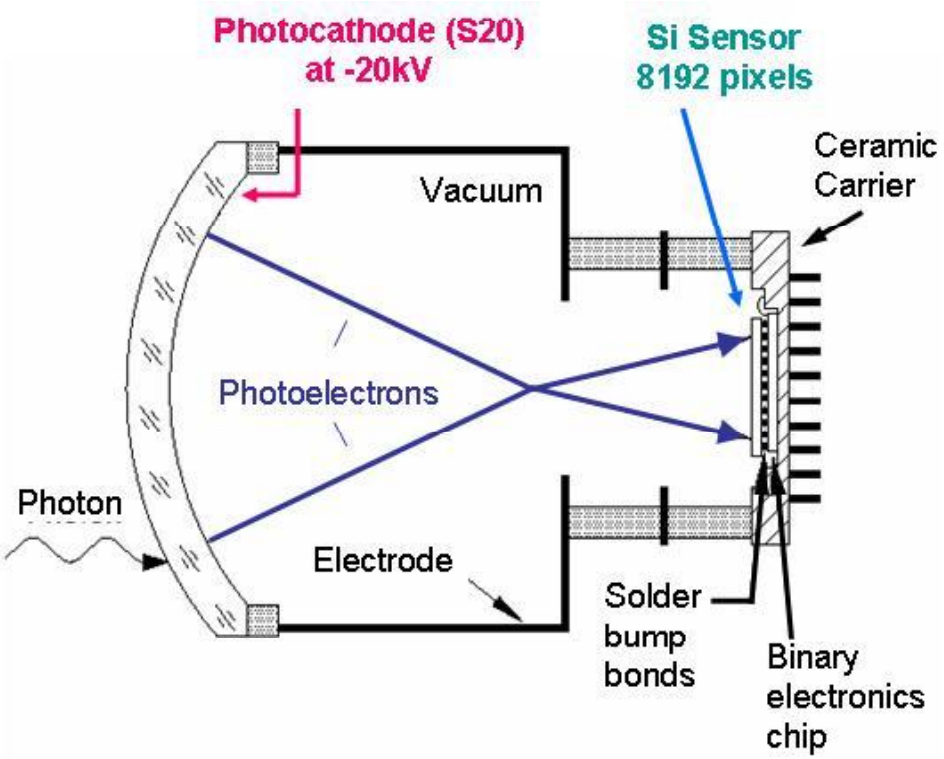
- Used for Particle Identification: the radius of the ring of Cherenkov photons created by charged particles can be used to infer its velocity.
- 2 Ring Imaging Cherenkov (RICH) detectors to cover different momentum and polar angle ranges.

RICH1 Schematic



- Charged particle (e.g. π) passes through 2 different radiators
  - Different refractive indices for wider coverage of photon angles
- Cherenkov photons collected by mirrors onto photon detector panels
- Data from both panels put together to reconstruct the Cherenkov ring

Eyes of the RICH: the HPDs



- Hybrid Photon-Detectors (HPDs) are used in the RICH
- Uses the photo-electric effect
- Bi-alkali photocathode deposited on back of quartz window
- HPD is vacuum sealed
- Electric field focuses photoelectrons to silicon sensor
- Sensor is bump-bonded to readout chip
- Readout speed matched to 25ns clock
- 8192 pixels of size 500μm x 62.5μm

Photos of HPDs

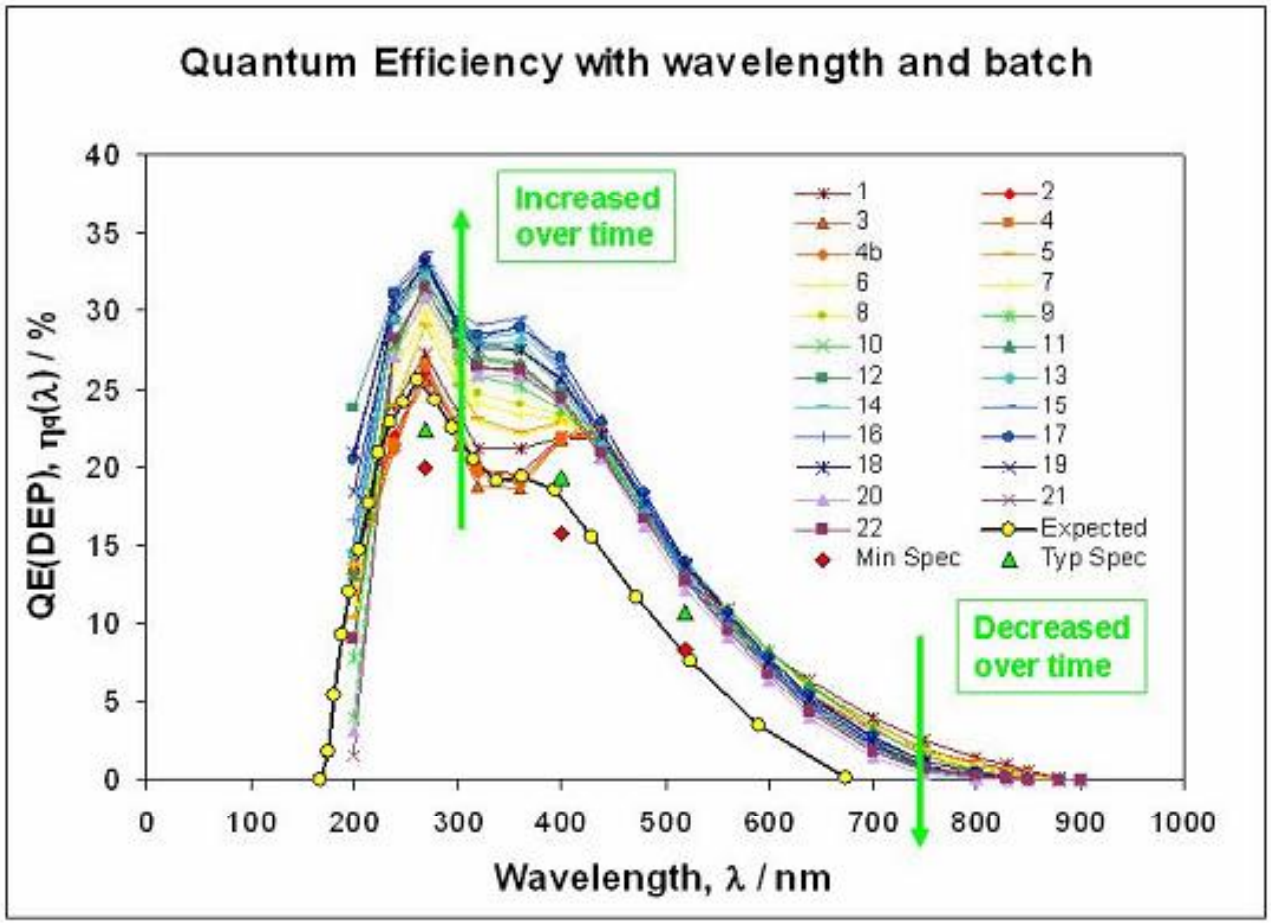
Single HPD. Ruler is 10cm long

Panel of HPDs inside RICH

HPD Testing

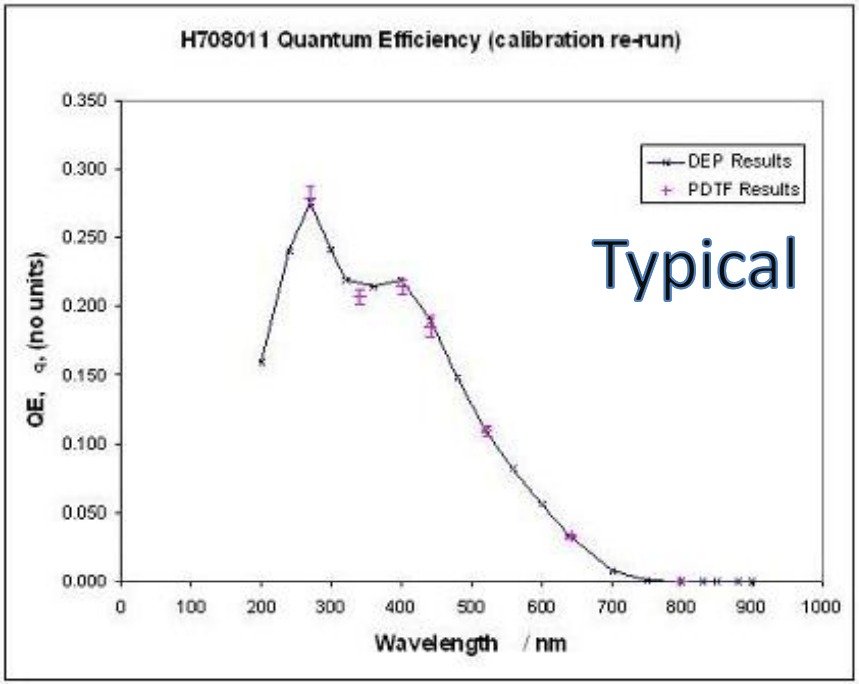
- 550 HPDs needed to be independently tested and categorised.
- Photon Detector Test Facilities (PDTF) were set up in Scotland to do this: 2 stations each at Edinburgh and Glasgow
- The Quantum Efficiency (QE) of a subsample of the HPDs were measured.
- QE = Overall probability an incoming photon produces a detected photoelectron.

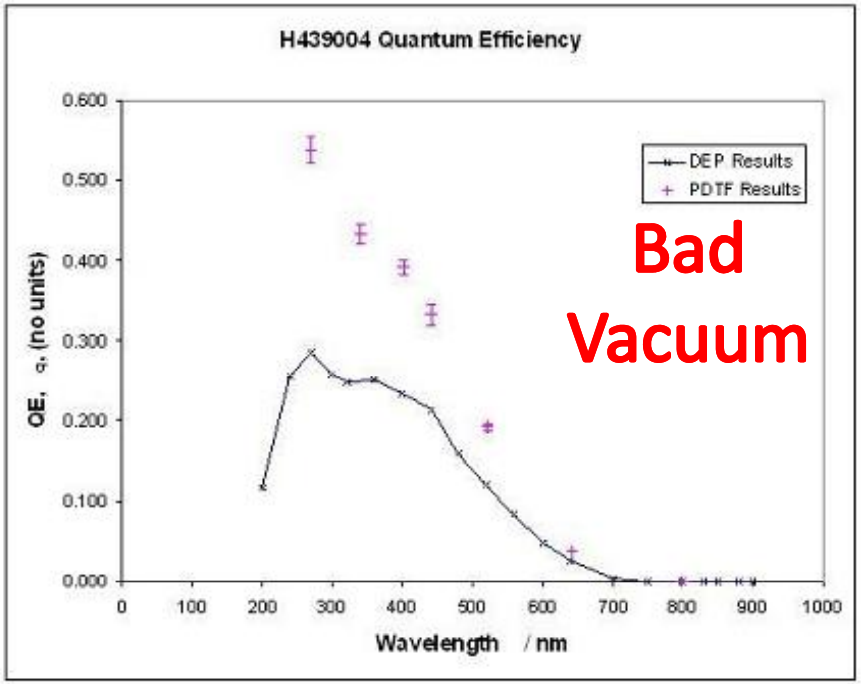
QE Results



- Quantum Efficiency (QE) improved over the manufacturing process:
  - improve S/B ratio from QE

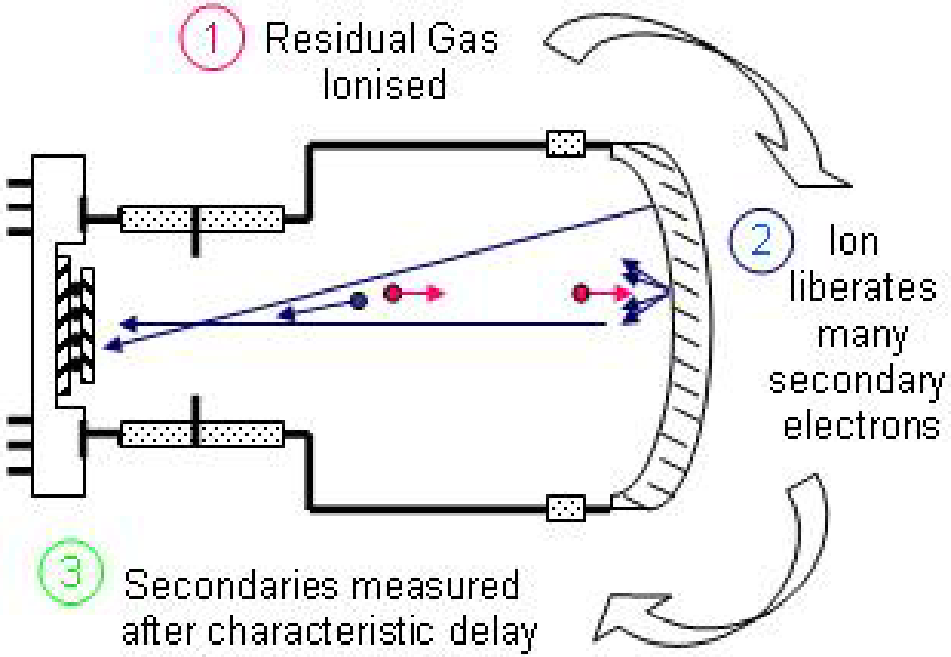
QE Results II





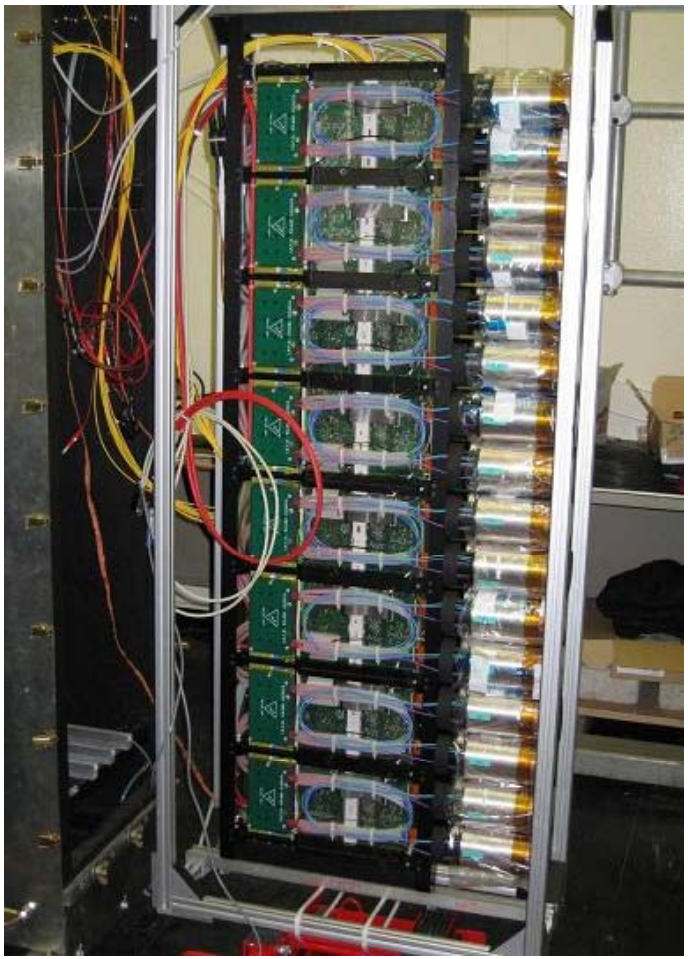
- Left: a typical HPD's QE results. Close agreement with manufacturer's measurements
- Right: an early prototype HPD which shows Ion Feedback due to degraded vacuum

Result of Bad HPD Vacuum: Ion Feedback (IFB)



- Vacuum degradation: gas particles inside HPD body
- Photoelectrons ionise these gas particles
- Gas ions drift back to photocathode by electric fields
- Many secondary electrons released when gas ions reach photocathode
- These secondary electrons reach the silicon sensor after a delay, typically 250ns after the primary photoelectron
- In very bad cases, chain reaction occurs as these secondary electrons also ionise gas particles

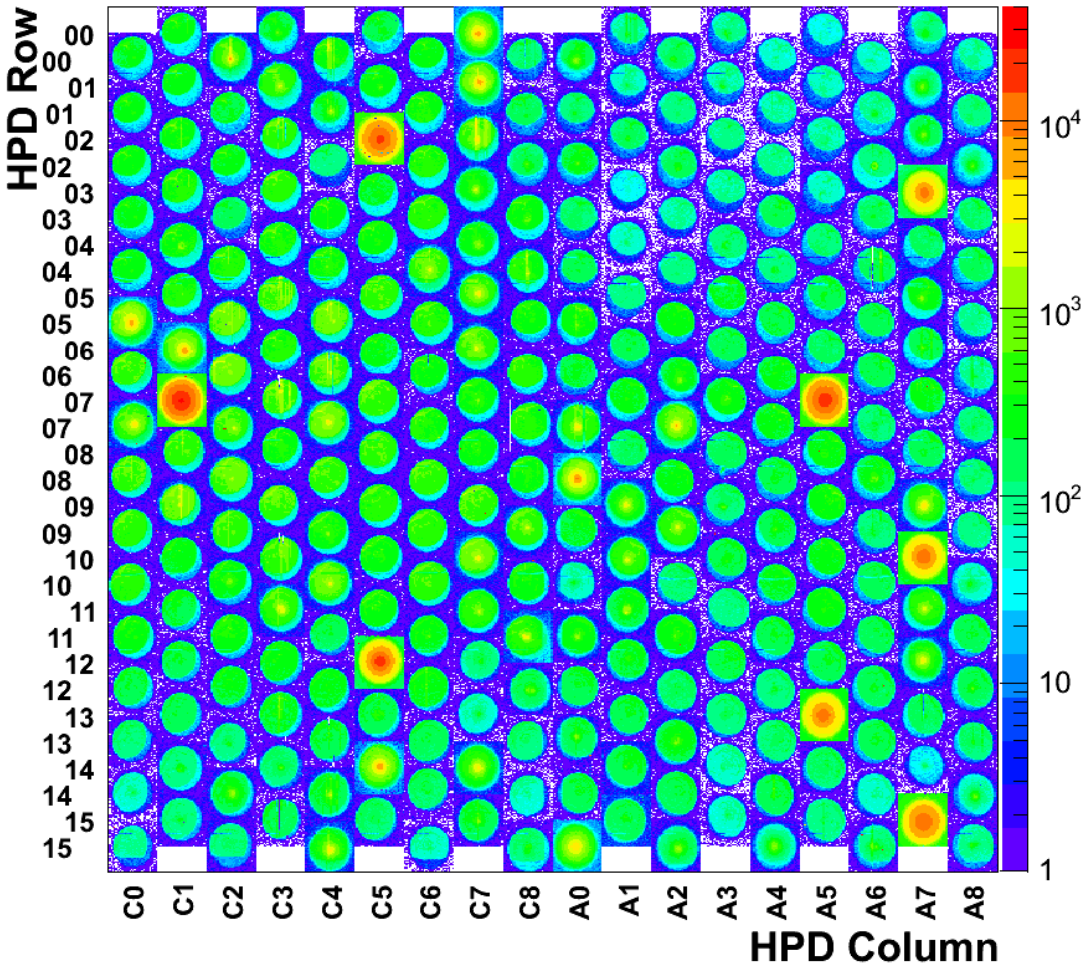
Monitoring HPDs Mounted in RICH



RICH2 Column, fitted with 16 HPDs

- Once shipped to CERN, HPDs mounted into columns and installed in RICH
  - RICH1 has 196 HPDs
  - RICH2 has 288 HPDs
- The commissioned RICH detectors go through test runs, with a laser light source

RICH2 HPD Pixel Hitmap



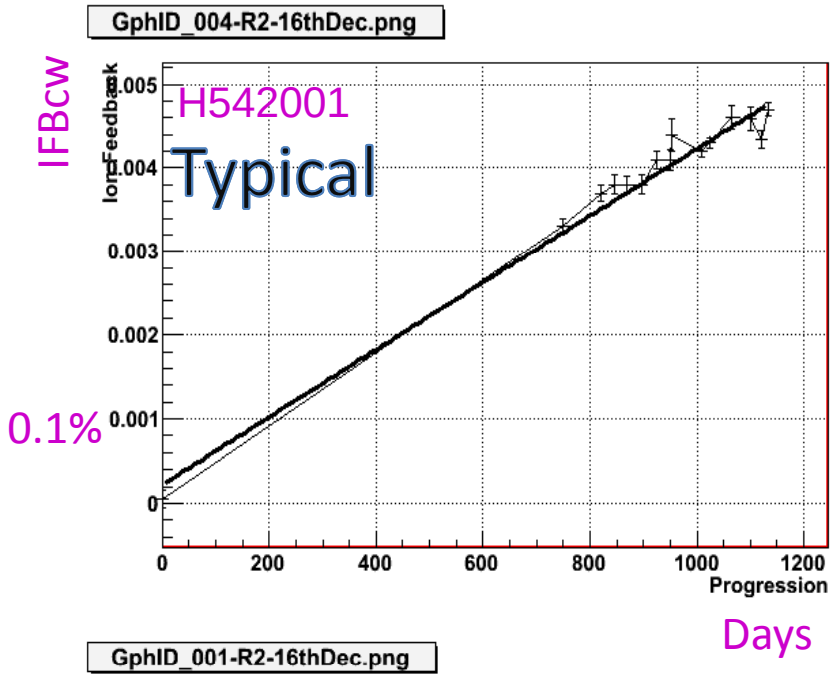
RICH2 Detector Plane

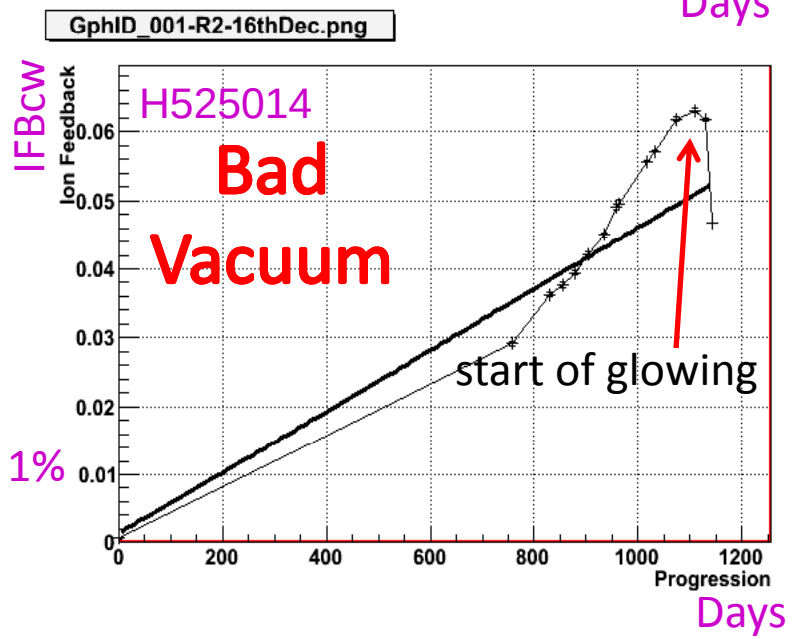
- Many test runs carried out over the months
- Continuous Wave (CW) Laser used
- This hitmap is for RICH2's 288 HPDs
  - 2.36 million pixels
- 3 million data readout events
- Hitmap shows how many hits each individual pixel received
- Most HPDs read out fine, but some are bad due to vacuum degradation

Glowing HPDs

- HPDs producing light at high vacuum degradation
- 5% Ion Feedback (IFB) threshold used as warning flag for HPDs that may start glowing

IFB Development Over Time

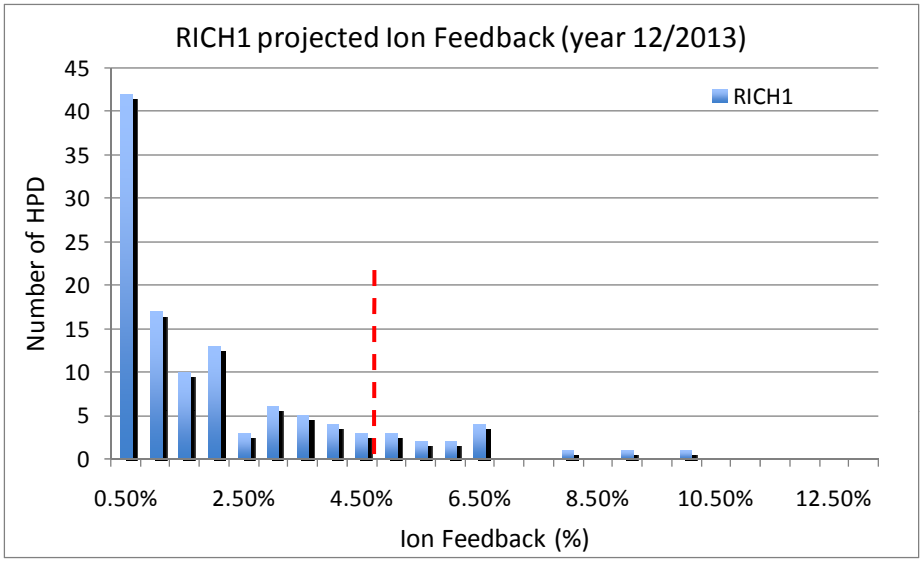




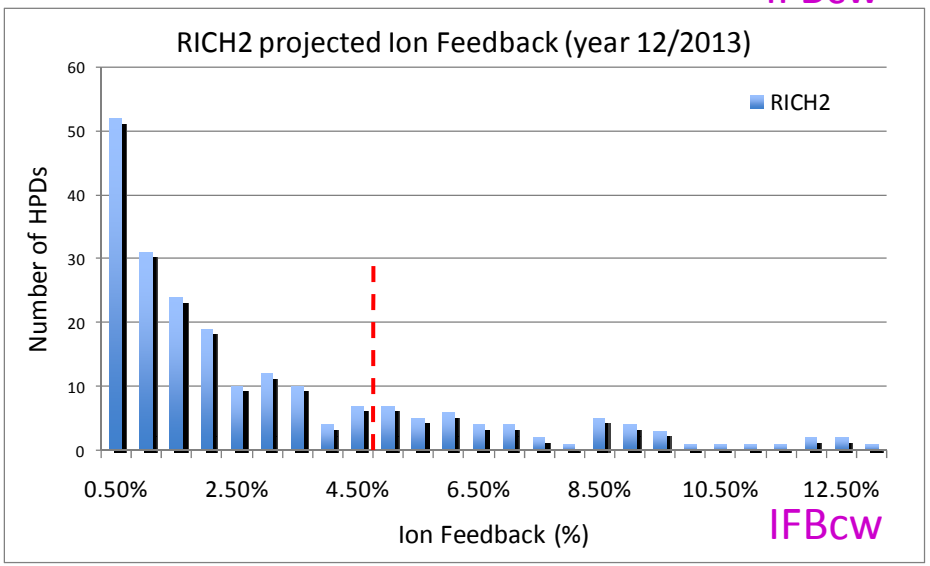
- We needed to know when to expect HPDs to start glowing so we can prepare replacements in advance
- IFB was monitored over several months
- The IFB development of the majority fit a linear model. This made IFB extrapolations possible

Projected IFB in 5 Years' Time

RICH1



IFBcw



RICH2

- RICH detectors need good HPDs until 2015
- Extrapolated IFB shows only a minority of HPDs will be at risk of glowing
- Glowing HPDs are replaced by spares while they get repaired

Conclusions

- We have commissioned both RICH detectors and most of our HPDs are working fine
- Quantum Efficiencies of HPDs exceeded specifications and gradually improved during manufacturing process
- HPDs have good performance in RICH detector test runs with laser light source
- Causes of higher rates of vacuum degradation in a minority of HPDs currently being investigated