Operating the Hybrid Photon Detectors in the LHCb RICH counters

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On behalf of the LHCb RICH Collaboration

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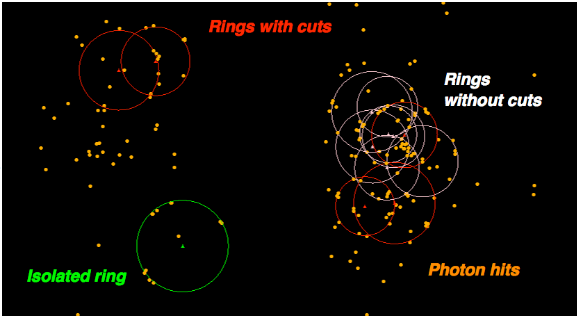
Outline

Requirements of a RICH photo-detector

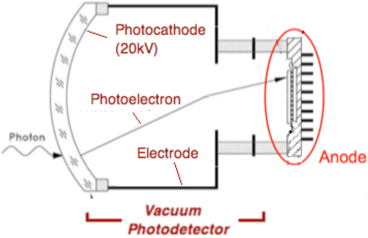
Single event snapshot of the RICH2 panels (450GeV proton beams)



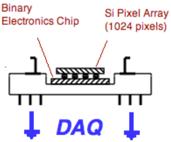
- Photodetector area: $3.3m^2$
- Single photon sensitivity: 200-600nm
- Quantum efficiency: >20%
- Good granularity: 2.5 x 2.5 mm^2
- Active area fraction: 65%
- # of electronic channels: 500k
- LHCb DAQ rate: 40MHz
- Radiation tolerance: 3kRad/year

What is a Hybrid Photon Detector?

- Photon detector:
  - Quartz-window, S20 Photocathode
    - Active diameter 75mm
  - Cross-focussing electrodes:
    - De-magnification by 5
  - 20 kV operating voltage ($5000e^-$)

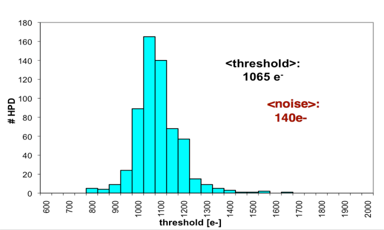


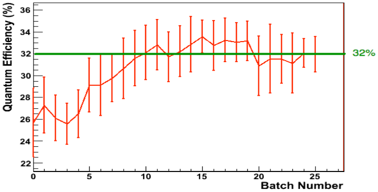
- Anode:
  - 256 x 32 pixel Si-sensor array
  - Bump-bonded to binary readout chip (low noise)
  - 8-fold binary OR -> effective 32 x 32 pixel array



Testing of Individual HPDs

- Every HPD is comprehensively tested for all the necessary parameters:
  - Signal over Noise
  - Photocathode voltage (High Voltage) stability
  - Dark count
  - Vacuum quality etc.
- Testing has yielded excellent results (>98% pass rate)
- We have tested 10% for quantum efficiency
  - Significant improvement seen over the course of production (25%→30%)
- HPDs installed by column into RICH detectors





Top: Pixel thresholds of an HPD

Bottom: Quantum efficiency by batch

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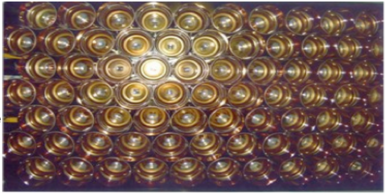

Top: HPDs mounted on RICH columns for testing

Bottom: Installed RICH1 columns

Front-End Interface Module

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Hybrid Photon Detector Specifications

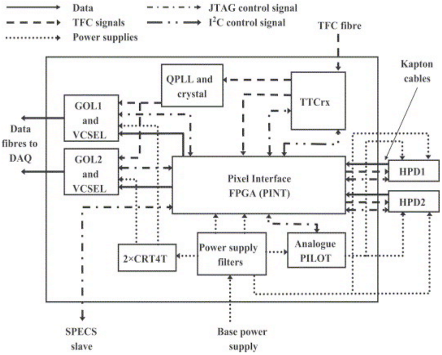
Dark runs

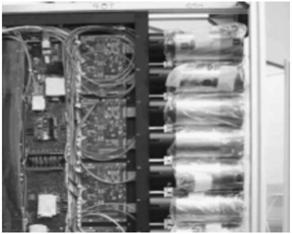
Continuous-wave laser runs

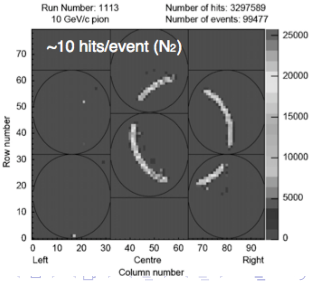
Pulsed laser runs

LHC Beam runs

Summary







Left: *Schematic of a front-end interface module*
Top-Right: *HPDs and interface boards on a RICH2 column*

Bottom-Right: *Measured Cherenkov ring from 100k charged pion events*

HPD Response in Dark Conditions

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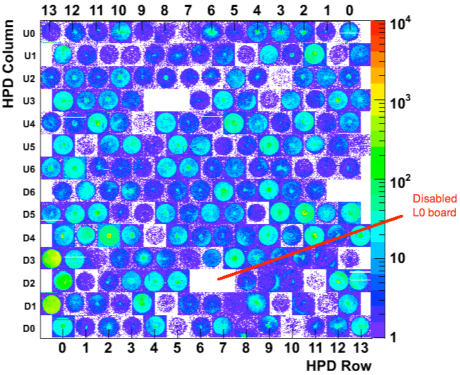
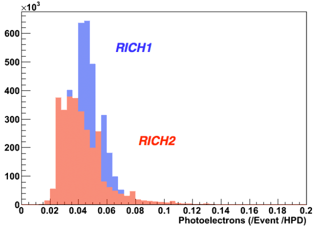
- Dark count is dependent on:
  - Temperature (thermo-ionic emission)
  - Stray Light
  - Other light sources (Laser Alignment Measurement System)
  - Hardware issues e.g. noisy pixels, disabled L0 boards



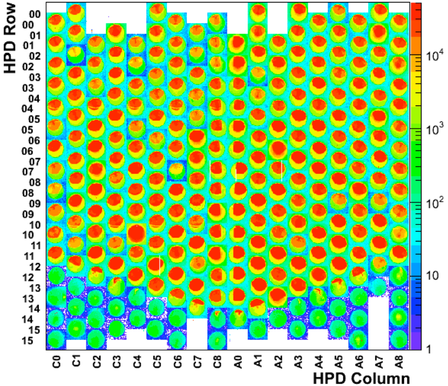


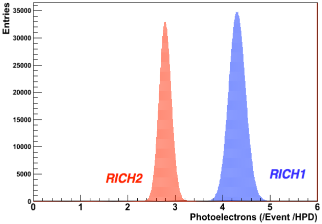
Left: *Photoelectron rate - each RICH HPD received, on average, 0.04 photoelectrons per event*

Above: *RICH1 Pixel hitmap*

HPD Response under Laser Light

- 635nm (red) 1mW continuous-wave laser.
  Used for:
  - Ion Feedback measurements
  - Photocathode Image Position measurements



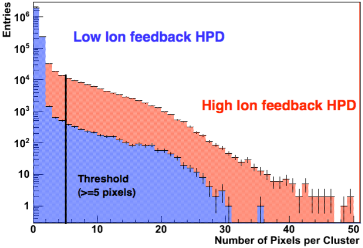


Left: Photoelectron rate - each RICH1 HPD received, on average, 4.3 p.e/event (2.8 for RICH2)

Above: RICH2 Pixel hitmap

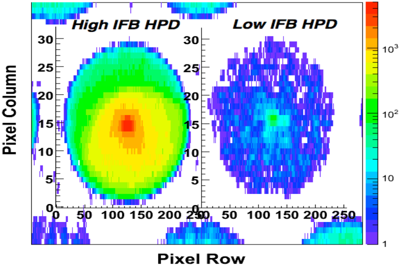
What is Ion Feedback?

- Ionisation of residual gas molecules.
- Shower of secondary photoelectrons.
  - Delayed by 200-300ns w.r.t. primary photoelectron.
  - Hits concentrated at centre of photocathode.
  - Detectable as large clusters of pixels.



Above: Cluster-size distributions

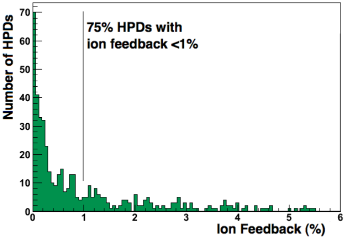
Below: HPD pixel hitmaps



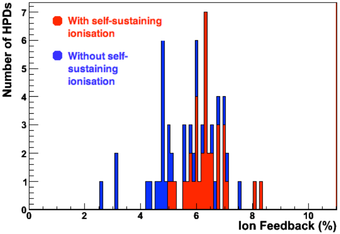
- We define minimum "Cluster-size" thresholds for ion feedback rates (>=5 adjacent pixels in picture)

Ion Feedback Distribution

- The majority of RICH HPDs retain an excellent vacuum quality.
- Residual gas ionisation may become self-sustaining for HPDs with large ion feedback:
  - Probability gas ionisation x Electron Multiplicity > 1
  - We define a threshold (5%) above which an HPD is considered at risk



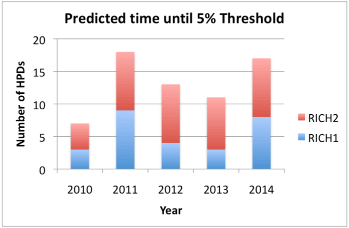
Above: Ion feedback distribution of all HPDs currently in RICH detectors



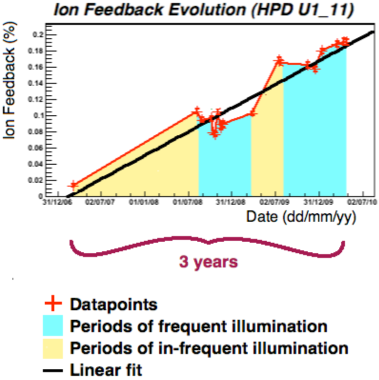
Above: Ion feedback distribution of HPDs removed from RICH detectors

Predicting HPD lifetime

- We observe a lower increase in ion feedback rate over periods of constant illumination.
- Fit linearly and extrapolate forward in time → HPD lifetime prediction.
- We have removed 86 out of 484 (18%) HPDs from the RICH.



Above: *Estimated time of 5% ion feedback pass (using linear fit)*

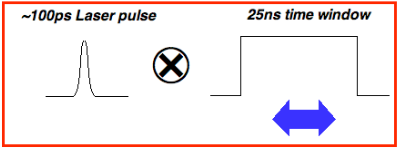


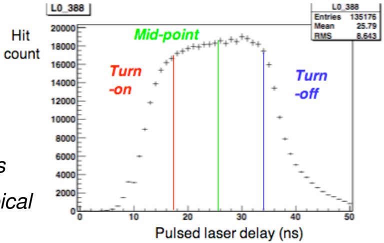
Above: *Ion feedback evolution of a typical HPD*

Time alignment of the HPDs

We want to ensure that the readout of our RICH HPDs occurs synchronously with the rest of LHCb.

- Time-align Level-0 boards (2 HPDs per board) individually:
  1. Pulsed laser light distributed to HPD panels
  2. Variable delay between laser and readout
  3. Board offset by average midpoint

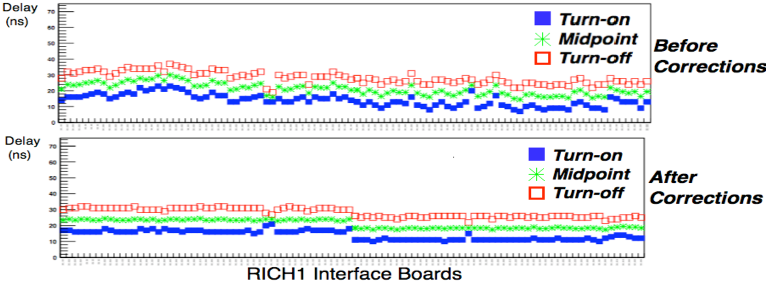




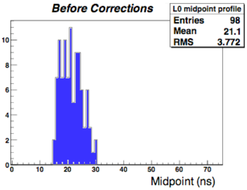
Top-Right: Simplified time profiles

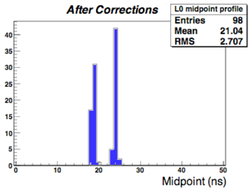
Bottom-Right: Time scan of a typical interface board

Time Alignment with Laser (RICH1)

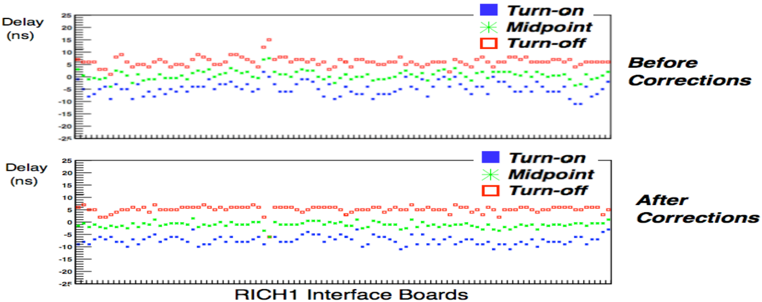


- Time spread of midpoints is reduced significantly after corrections in delay.
- Different delays due to fibre-length accounted for.

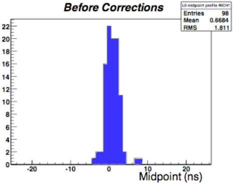


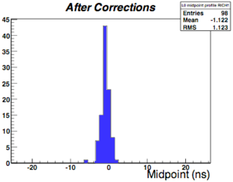


Time Alignment with LHC Beam (RICH1)



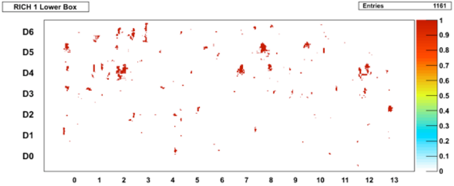
- Time spread of midpoints is reduced significantly after corrections in delay.
- April'10:
  - RICH1 time-aligned to within 1.1ns.
  - RICH2 time-aligned to within 0.8ns.



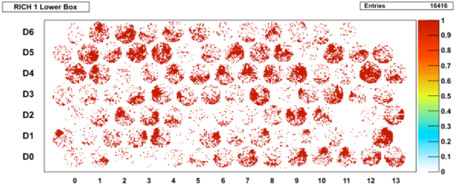


September ’08: First Sight of Beam

RICH detected particles from an LHC beam coming from the "wrong" side of the detector



- Readout out of time:
  - "Strips" of pixel hits, perpendicular to pixel columns.
  - Particles passing directly through silicon detectors.

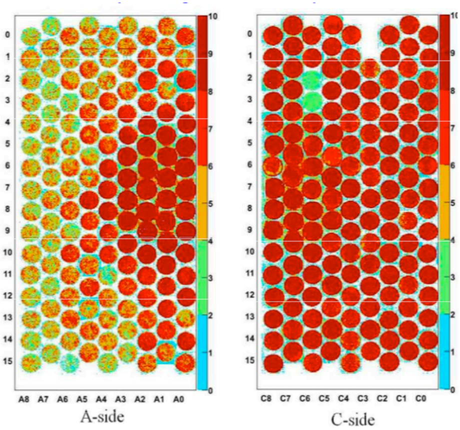


- Readout in time:
  - Large clusters of pixel hits.
  - Particles hitting the photocathode.

September ’08: Beam-Splash events

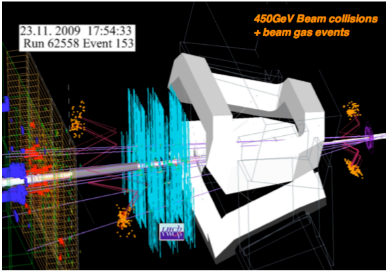
- Recorded picture of LHC beam hitting collimator
  - >2000 hits per tube (C-side)
  - All HPDs operational
  - Photocathode surface clearly defined

Below: RICH2 hitmap from accumulated events



November ’09: Beam Collisions at 450GeV

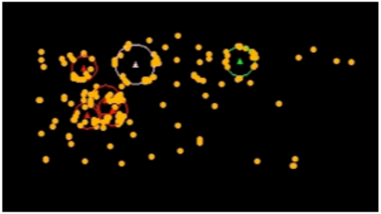
Below: *LHCb Event Snapshot*



- RICH1 detected >200 hits/event
- RICH2 detected >100 hits/event

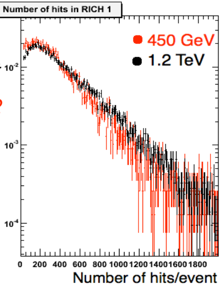
- Run the trackless ring-finder on some rings.
- Look for isolated rings with quality criterion applied.

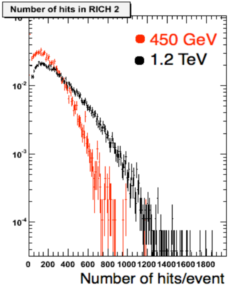
Below: *Trackless Ring-finding*



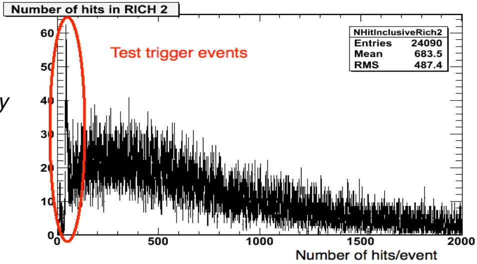
Occupancy Comparison

Right: *Occupancy comparison at different beam energies.* *RICH2 (1.2TeV) > RICH2 (450GeV)*

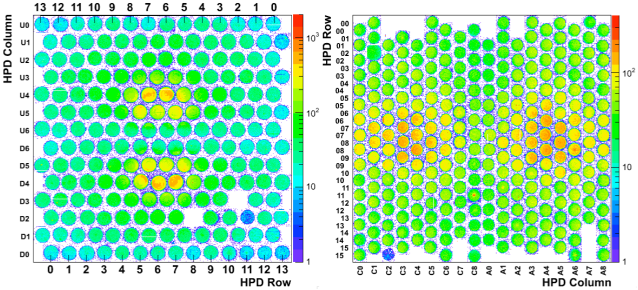




Right: *Occupancy of RICH2 at beam energy 7TeV.*



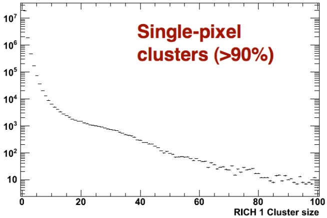
March ’10: Beam Collisions at 7TeV



Left: *RICH pixel hitmaps*

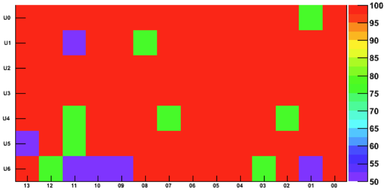
Bottom: *RICH1 cluster-sizes*

- Minimum bias events (First-level trigger rate = 55Hz)
- RICH1 occupancy spread = 0.24 $\rightarrow$ 5.42 p.e/event
- RICH2 occupancy spread = 0.47 $\rightarrow$ 2.76 p.e/event

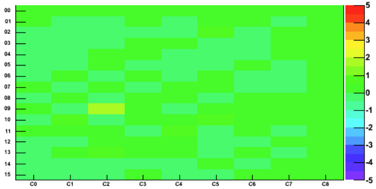


Online Monitoring

- ## Corner-pixel Test Pattern
  - Triggers sent at the LHC abort gap.
  - Efficiency of HPD data output.



Above: Efficiency map of RICH1 Upper-panel



Above: Hit pull of RICH1 Upper-panel

- ## Hit pull
  - *(Expected - Observed)/Expected* - uses a moving average.
  - Large changes in output.

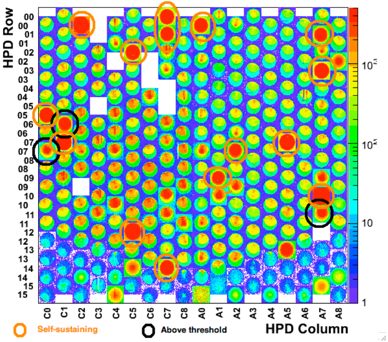
Summary

- Low noise, high efficiency Hybrid Photon Detectors are now being utilised, via interface boards, in the RICH detectors.
- RICH HPDs show a good response to light under a variety of different run environments.
- Through the ion feedback of an HPD, laser runs provide us with accurate lifetime predictions.
- Pulsed laser runs have been used to time-align the RICH detectors.
- LHCb-RICH detectors have already been operated successfully during beam start-up.

Backup Slides

HPD Repair Campaign (1)

- RICH2 contains (from manufacture date) older HPDs than RICH1.
- A higher proportion of HPDs have developed a self-sustaining ionisation.



HPD Repair Campaign (2)

Operating the Hybrid Photon Detectors in the LHCb RICH counters

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Hybrid Photon Detector Specifications

Dark runs

Continuous-wave laser runs

Pulsed laser runs

LHC Beam runs

Summary

- RICH2 contains (from manufacture date) older HPDs than RICH1.
- A higher proportion of HPDs have developed a self-sustaining ionisation.
- We prioritise the removal of certain HPDs according to:
  - Predicted lifetime
  - Effect on physics performance