# Pixel Hybrid Photon Detectors for the RICH Detectors of LHCb

**IWORID**
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**Glasgow**

- The RICH detectors of LHCb
- pixel-HPD Design
- pixel-HPD Laboratory & Testbeam Results

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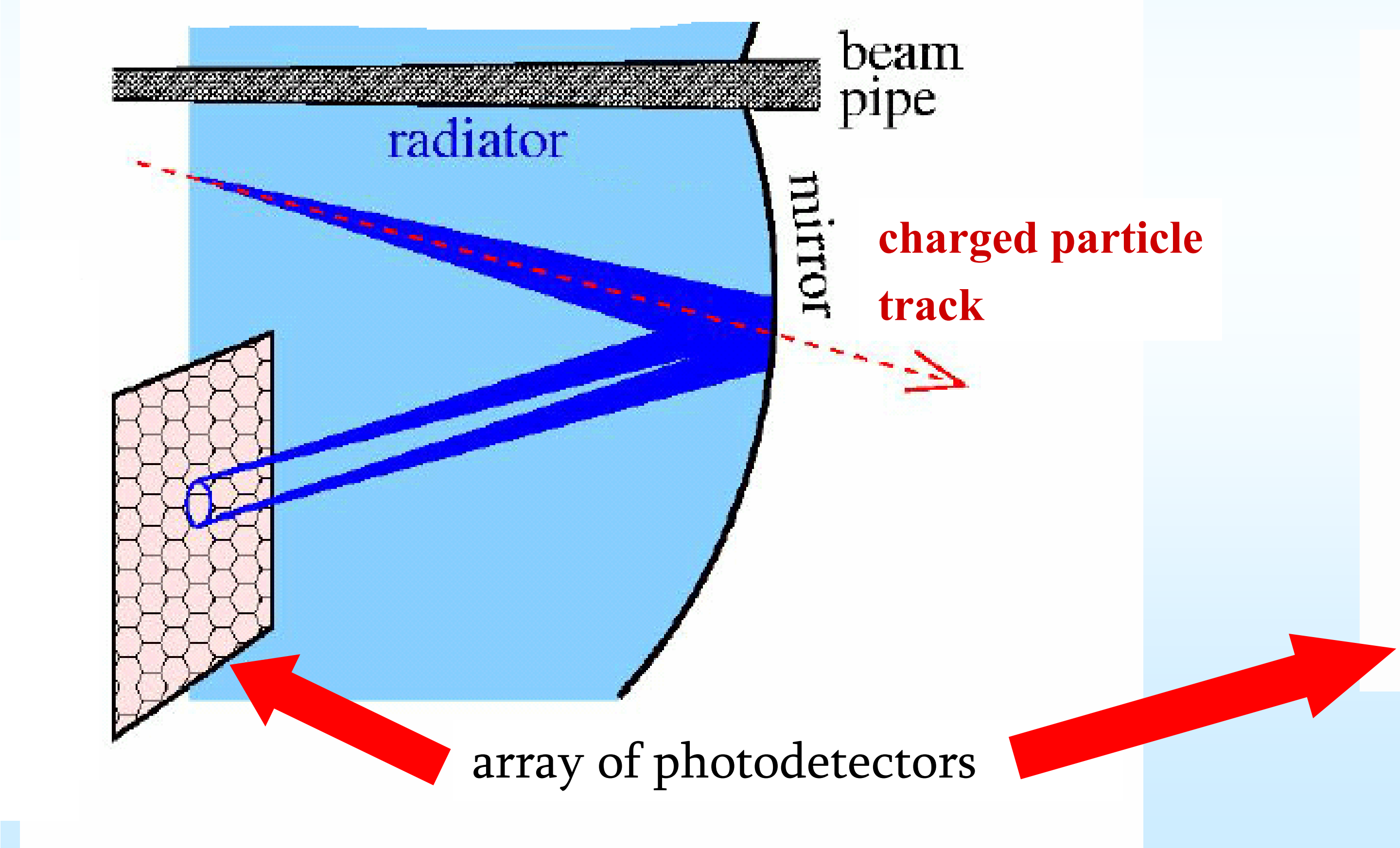
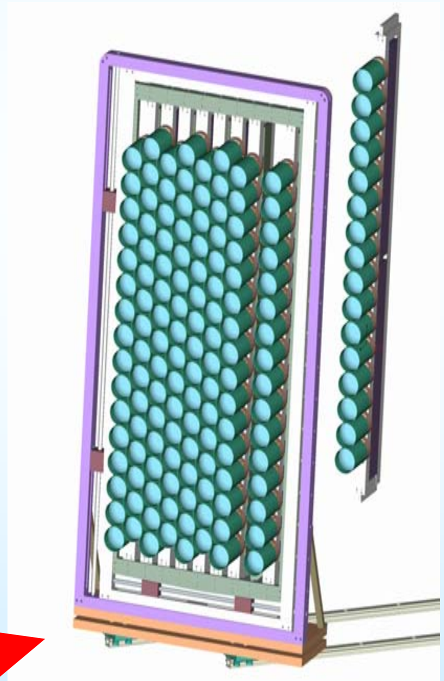
**on behalf of the LHCb collaboration**

# Particle Identification for LHCb - Cherenkov Radiation

- LHCb is a B physics detector planned for the Large Hadron Collider, currently being built at CERN
- Particle identification is important for planned physics studies at LHCb
- Two **R**ing **I**maging **CH**erenkov detectors are needed for particle identification



# Photodetector Specifications

Need to detect single photons with a wavelength from 200-600 nm

The **photodetector** must combine:

- single photon sensitivity
  - single photoelectron detection efficiency better than 85%
- granularity of 2.5mm **x** 2.5mm
- high active-to-total area ratio ~70%
- high signal-to-noise ratio
- fast readout – time resolution better than 25ns

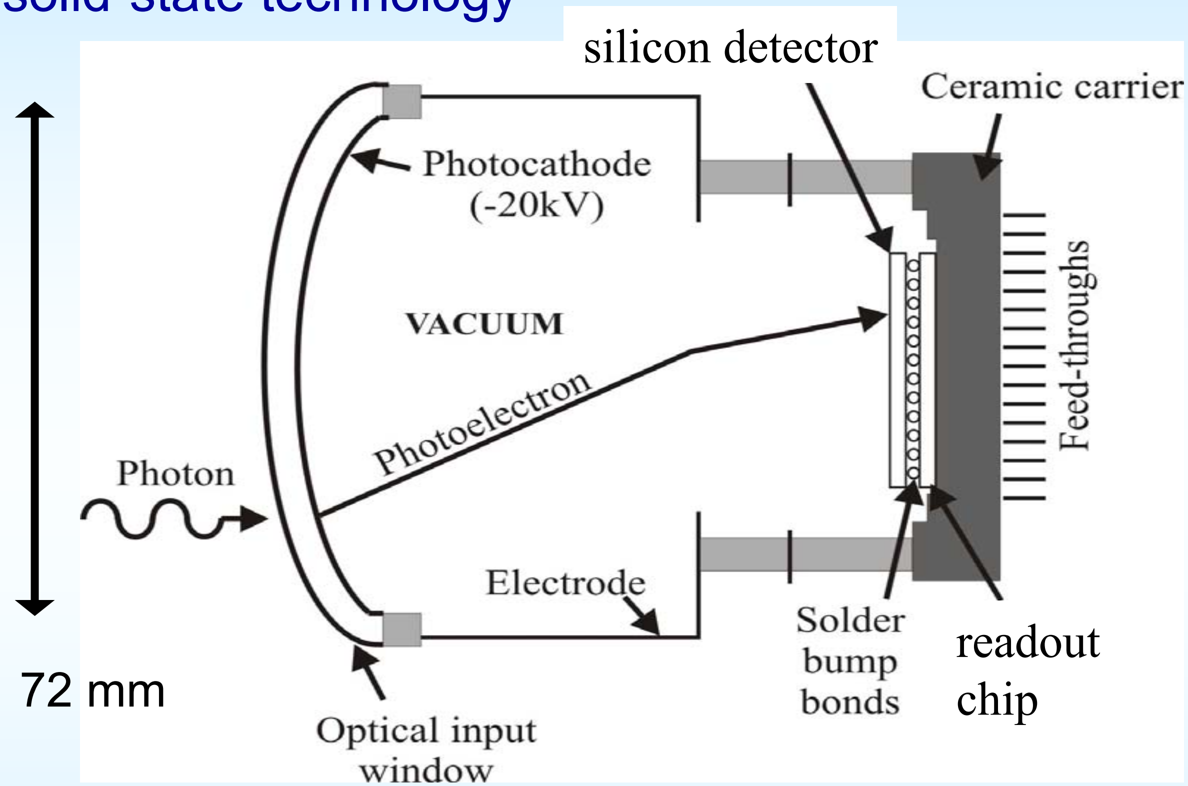
and survive:

- a radiation dose of 3krad per year
- a magnetic field of < 2.5 milliTesla

solution – development of pixel **<u>H</u>**ybrid **<u>P</u>**hoton **<u>D</u>**etector

# Pixel **H**ybrid **P**hoton **D**etectors – Principles & Design

pixel-HPDs combine in a single device vacuum photo-cathode technology and solid-state technology



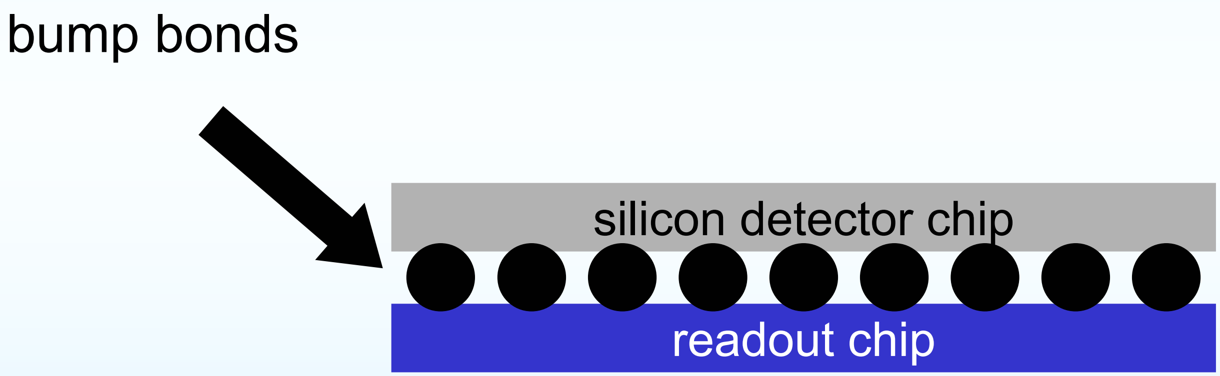

The readout chip is fully encapsulated in the device

- Peak quantum efficiencies reach 25 % at ~270 nm wavelength
- pixellated silicon detector
  - each pixel bump-bonded to individual channel on readout chip

All parts of the pixel-HPD are compatible with the demanding bake-out cycle required to produce the high quality photocathode

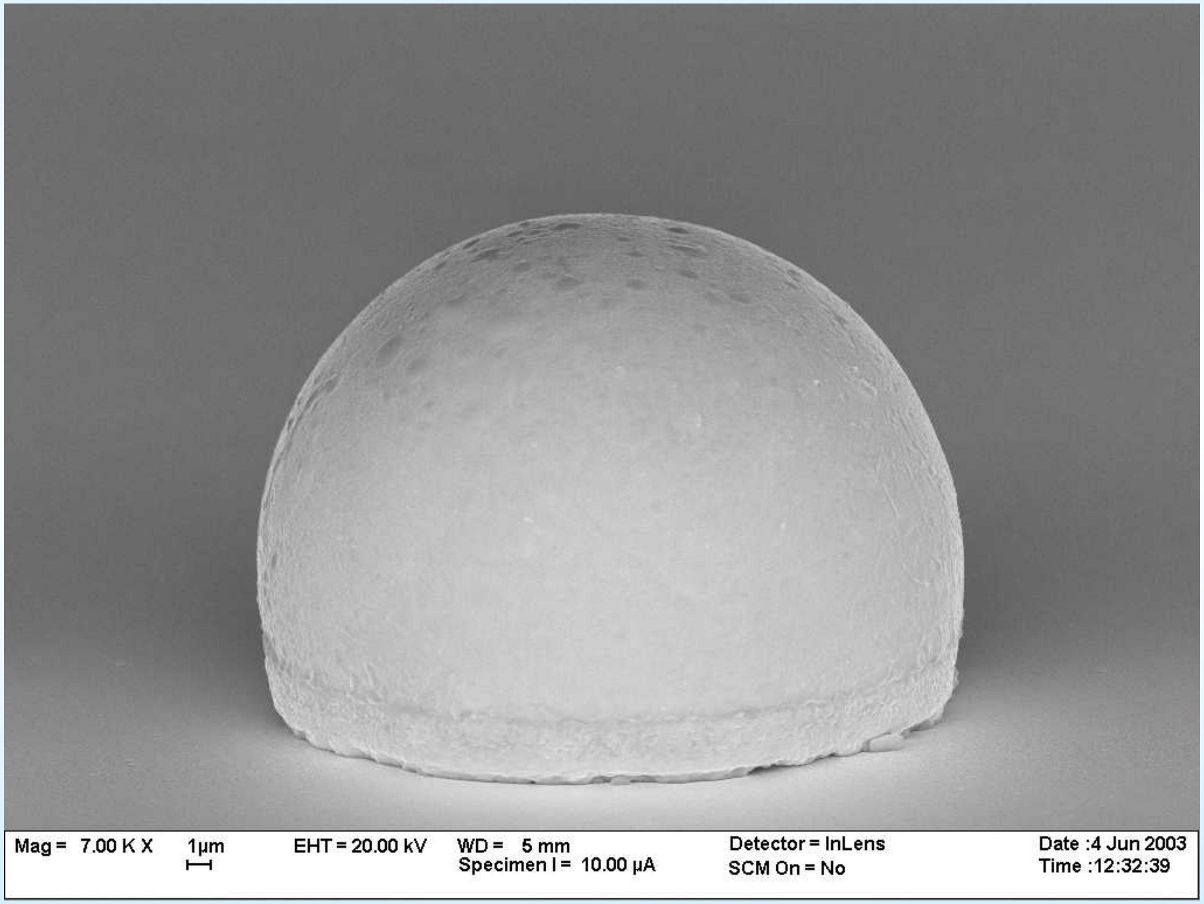
# Pixel-HPD Construction Process

1. silicon detector bump bonded to readout chip - anode



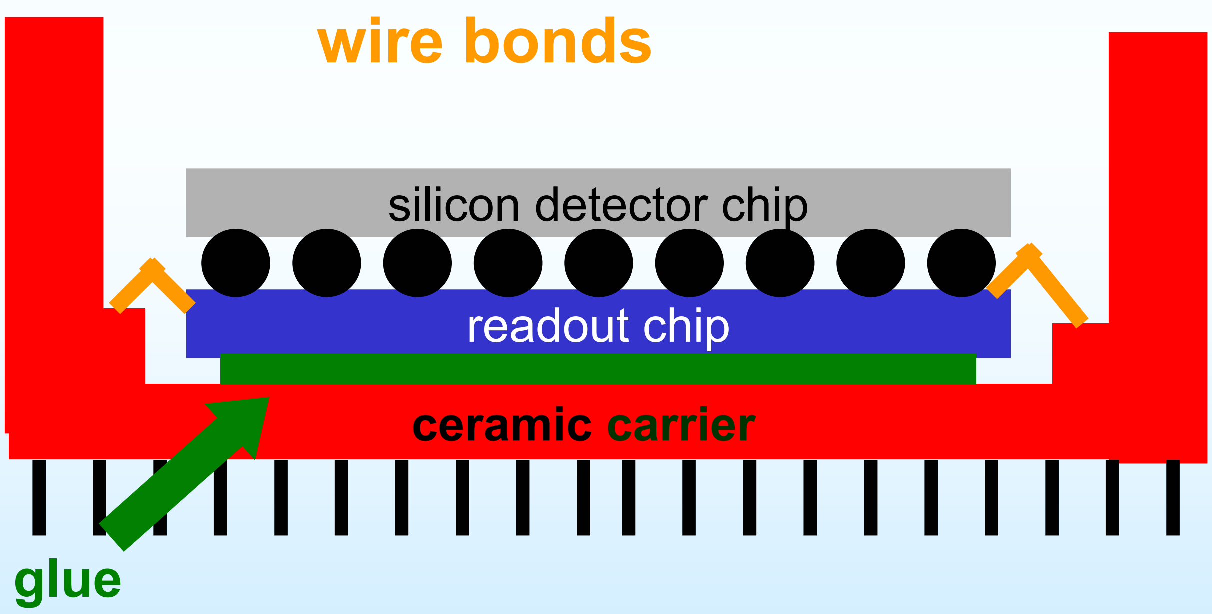
# Pixel-HPD Construction Process

1. silicon detector bump bonded to readout chip - anode



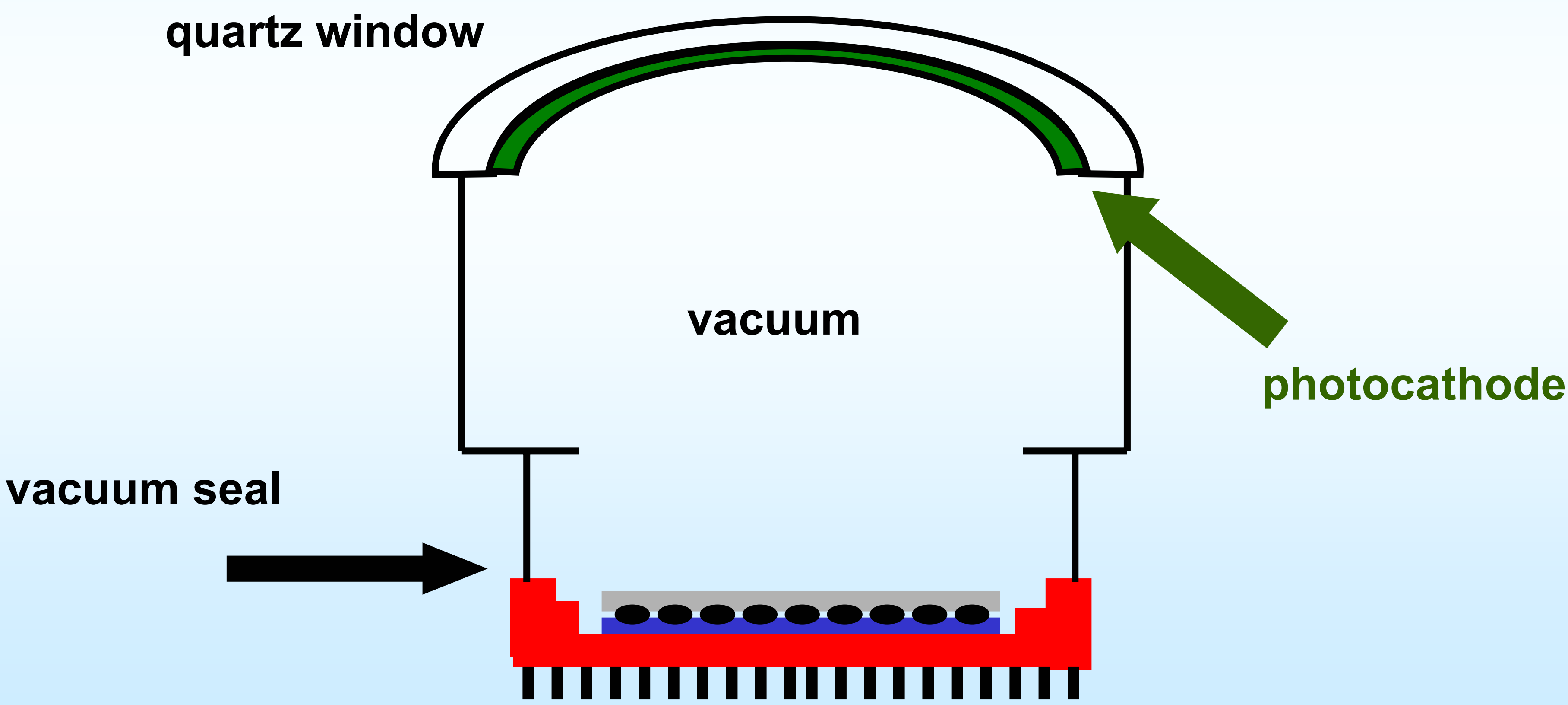
# Pixel-HPD Construction Process

1. silicon detector bump bonded to readout chip - anode
2. anode glued to ceramic carrier and wire bonded – packaged anode

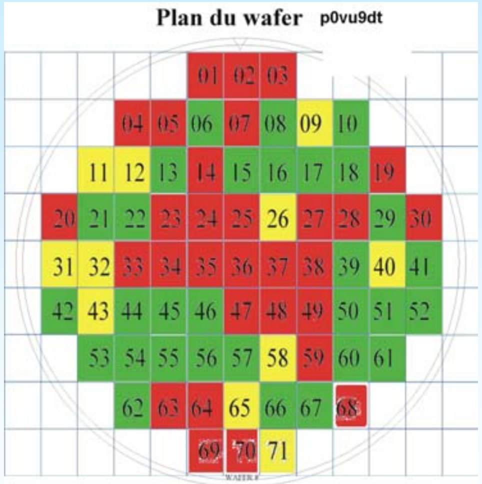


# Pixel-HPD Construction Process

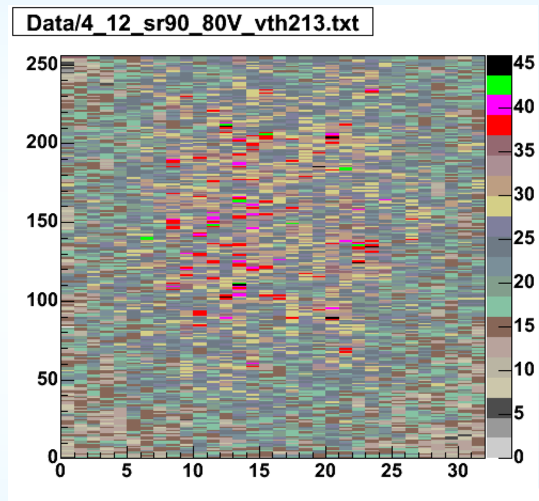
1. silicon detector bump bonded to readout chip - anode
2. anode glued to ceramic carrier and wire bonded – packaged anode
3. Vacuum bakeout cycle – temperature reaches ~300°C
4. Photocathode processing and sealing of pixel-HPD tube to carrier



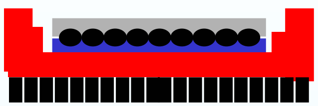
# Testing at each stage of process



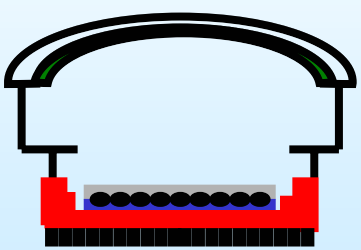

Bare readout chip on wafer of 71 chips



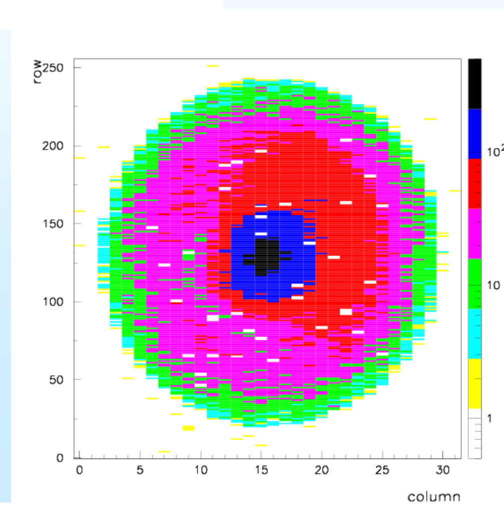

Anode



Packaged anode

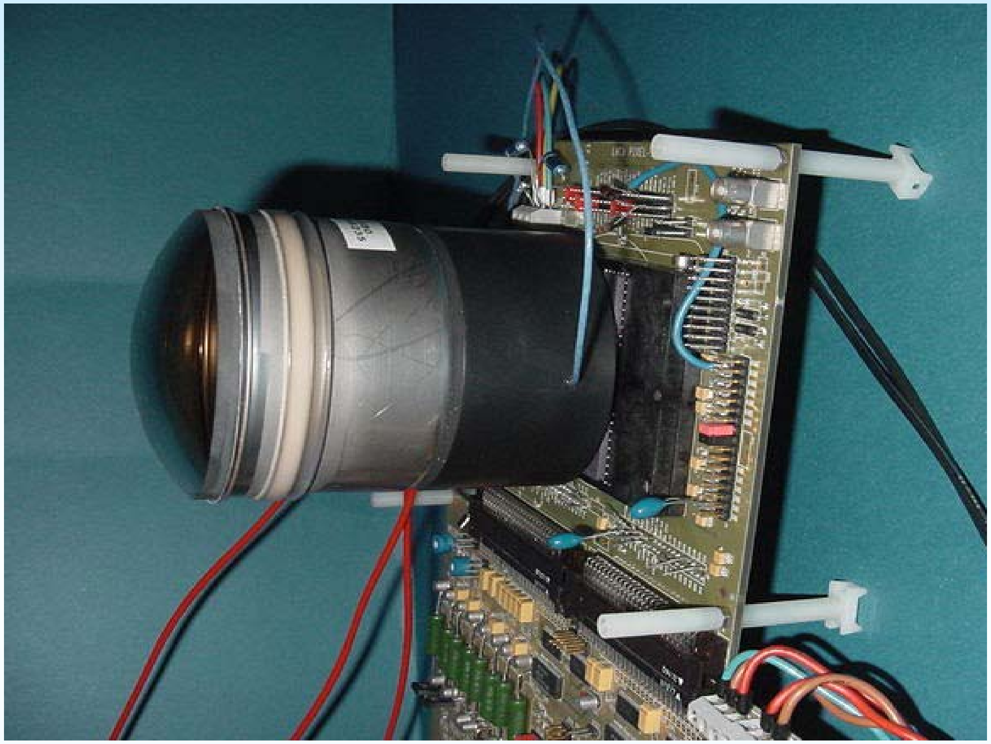


pixel-HPD after bakeout
& vacuum encapsulation



# Laboratory Testing of Pixel-HPD prototypes

Pulsed low intensity LED used to determine tube characteristics some important numbers:



**Single photoelectron detection efficiency**

- measured to be ~88%
- LHCb specification 85%

**Discriminator Threshold**

- Threshold scan performed by varying size of test pulse – hence amount of charge injected
- Provides information on threshold and noise distribution across pixels
- Typical results: mean threshold ~1250 e-, sigma ~ 100 e-
- Specifications – minimum threshold 2000 e-, sigma 300 e-

# Testbeam

- 10 GeV pion/electron beam
- air filled RICH vessel prototype
- Cherenkov rings focused on a pixel-HPD
- Two 40MHz prototypes found to be fully functional – confirmed more precise lab measurements

snapshot of online DAQ

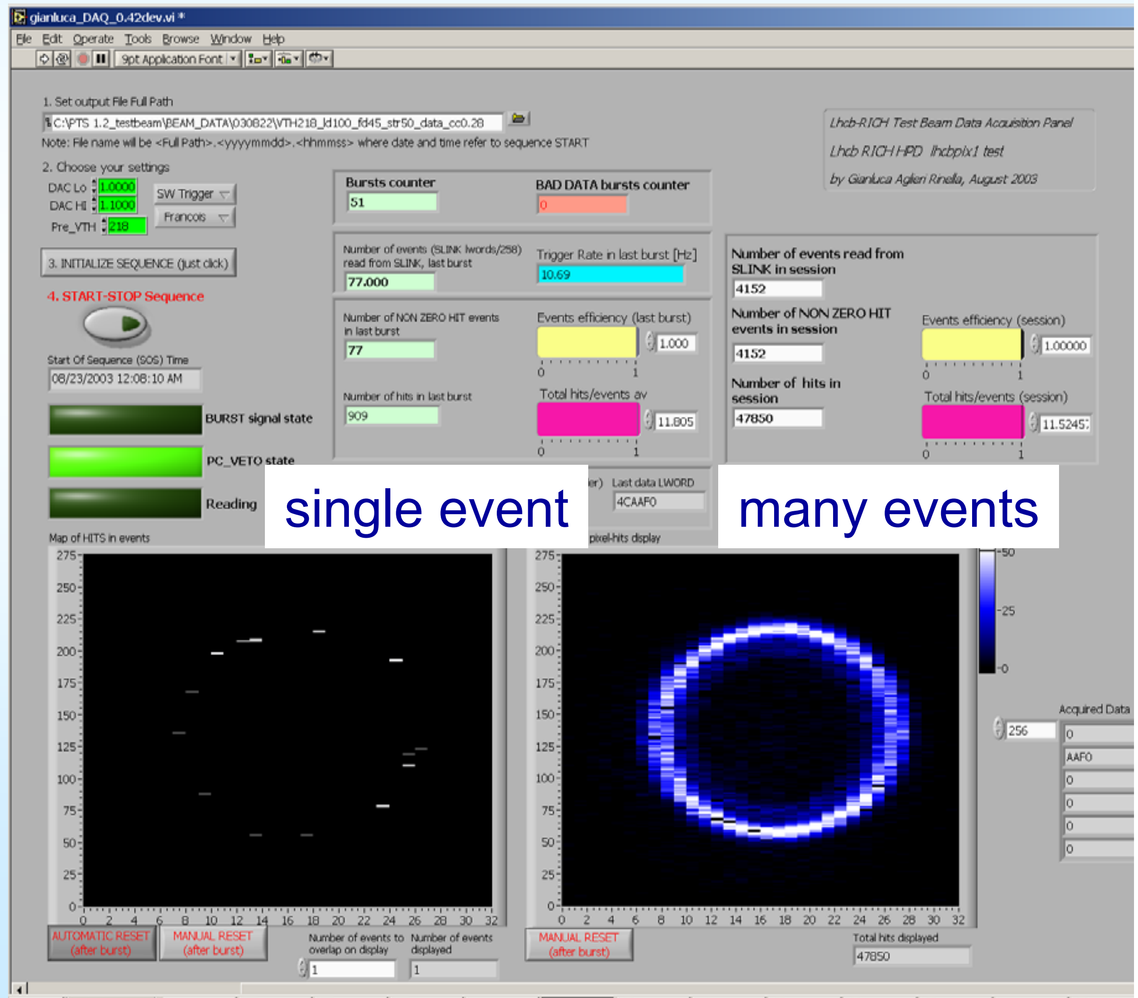
Beam restricted
to electrons

**Cherenkov angle resolution**

and

**photon detection efficiency**

measured



# Testbeam Results

**Cherenkov Angle Resolution**

- Fit to hits from all events from single run – electrons only
- error mainly due to uncertainty on individual electron tracks in beam

| tube | **Cherenkov angle** (mrad) | |
|---|---|---|
| | Expected | observed |
| HPD#1 | 23.7 | 23.6 (± 1.0) |
| HPD#2 | 23.7 | 22.8 (± 1.2) |

**Detection efficiency**

- Confirms lab measurements
  - lab result ~88%
- error contributions – mirror reflectivity, pixel-HPD quantum efficiency, refractive index and absorption curve of air

| tube | **Detection efficiency** (%) |
|---|---|
| HPD#1 | 87 ± 5.3 |
| HPD#2 | 83 ± 5.2 |

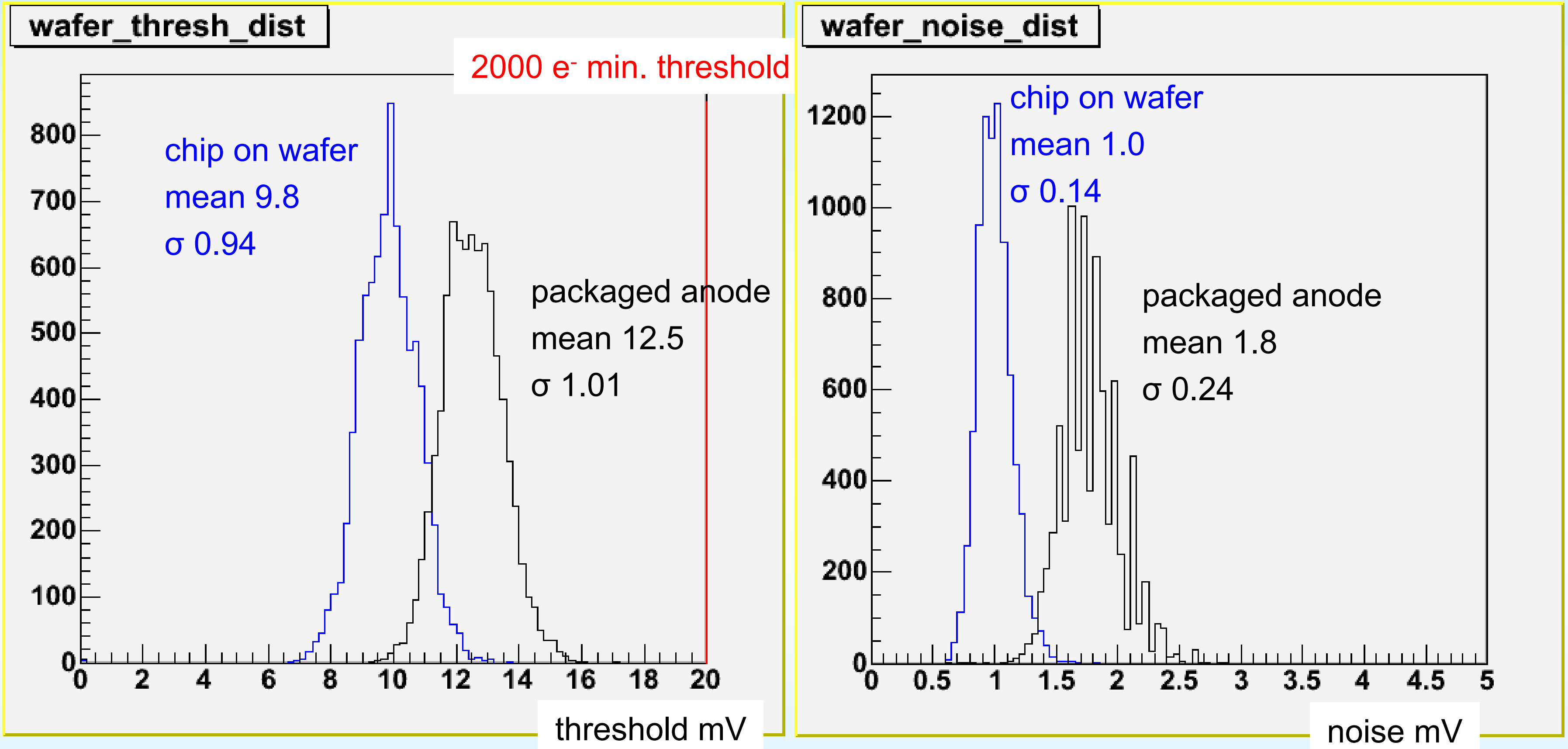
Fulfils LHCb requirement of 85%

# Conclusions & Future Plans

- A pixel **H**ybrid **P**hoton **D**etector has been developed that satisfies the stringent requirements of the LHCb **R**ing **I**maging **CH**erenkov detectors
- Single photon sensitivity, a high active-to-total area ratio and 25ns time resolution have been achieved
- Laboratory tests combined with test beam results have proven the performance of the pixel-HPDs
- High occupancy and ageing tests carried out – no degradation in performance
  - more tests planned
- Sucessful recent testbeam, closer to final RICH system
  - aerogel radiator and array of three pixel-HPDs
  - paper will be published with results
- Testbeam planned for the end of the year
  - close packed array of preproduction pixel-HPDs
  - DAQ based on prototype of LHCb readout electronics chain
- Production of ~500 pixel-HPDs underway

# reserve slides

# Testing – results for threshold scan
# bare chip vs bump boned anode assembly




Average threshold has moved to higher value

- since more noise with packaged anode

Threshold still below specification limit of 2000 $e^-$

Threshold spread specification limit is 300 $e^-$

# Ion Feedback & Dark Counts

example of test beam measurement

**Ion Feedback**

- Ionisation of residual gas molecules in pixel-HPD tube can cause background
- ionised molecule accelerated to cathode – releases bunch of e**-** which are accelerated to anode
- ion feedback rate measured in testbeam to be less than 0.5%

  => excellent vacuum quality

**Dark Counts**

- Thermal emission from cathode produces background signal
- average rate at 25 °C measured to be ~1kHz/cm²

# Aerogel Testbeam – details of set-up

- The furthest upstream RICH detector will have both a $CF_4$ and an aerogel radiator
- The performance of aerogel was invesigated in a testbeam, using three HPDs as photodetectors
- Analysis of the results is ongoing – paper in preparation