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Pixel hybrid photon detectors for the LHCb-RICH system

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Outline of the talk

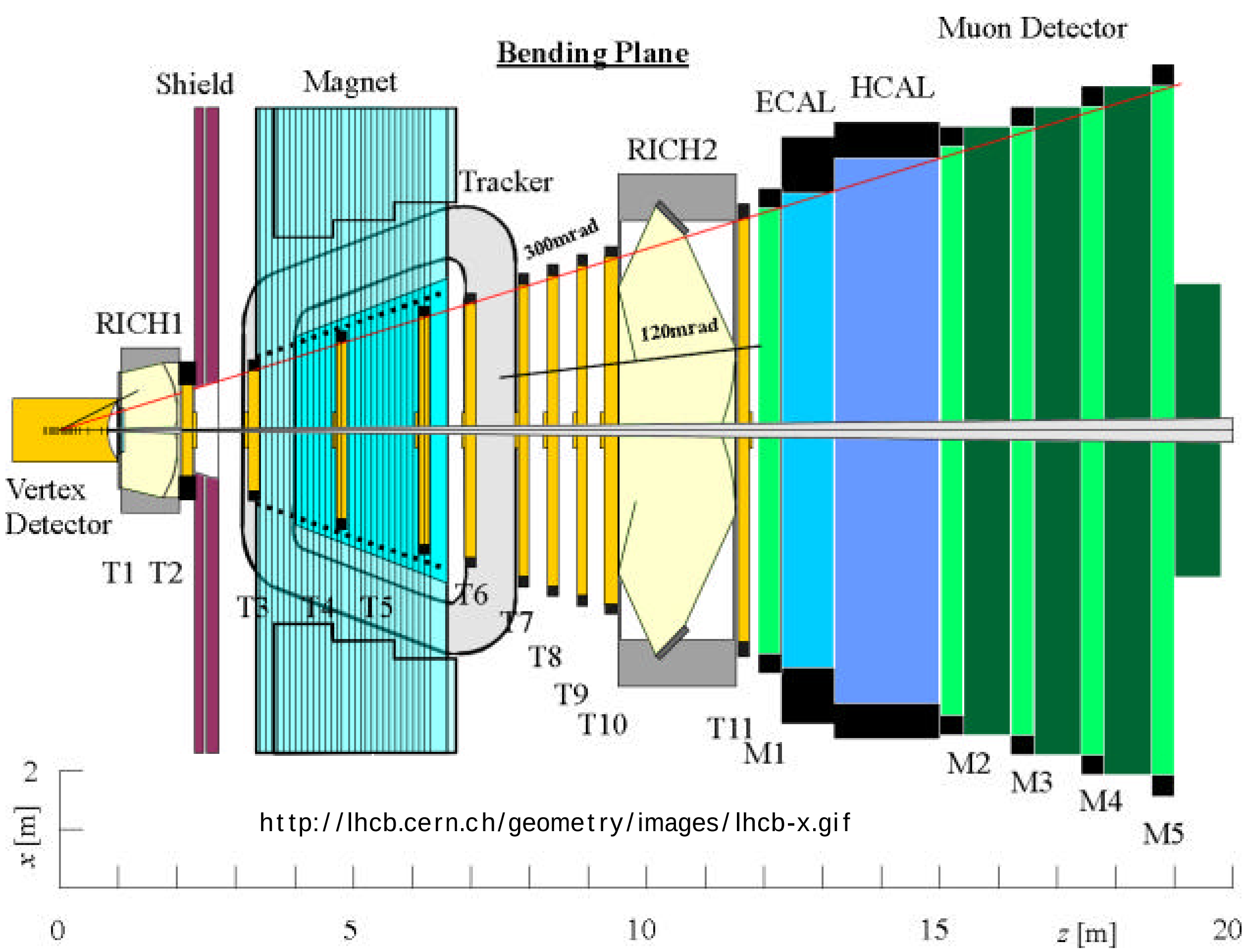
- Introduction
  - The LHCb detector
  - The RICH 2 counter
  - Overall RICH system requirements

- The pixel hybrid photon detector
  - Description
  - Binary front-end electronics
  - Full-scale HPD prototypes
  - Systematic tests

- Conclusions and perspectives

The LHCb detector (top view)

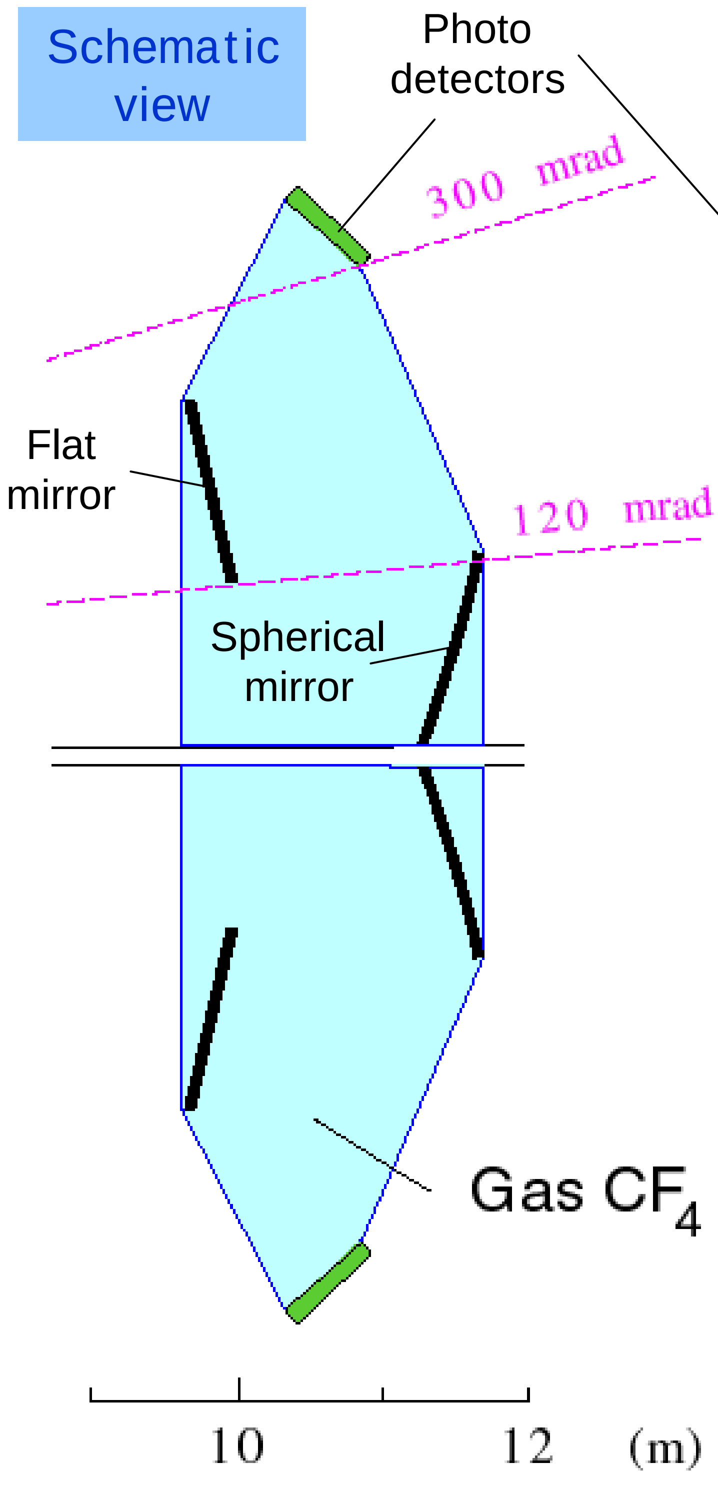
LHCb is a single-arm spectrometer with a forward angular coverage from 10 to 300 mrad, dedicated to precision studies of CP asymmetries and of rare decays in the B-meson system



Particle identification over the momentum range 1-150 GeV/c will be achieved by two Ring Imaging Cherenkov counters

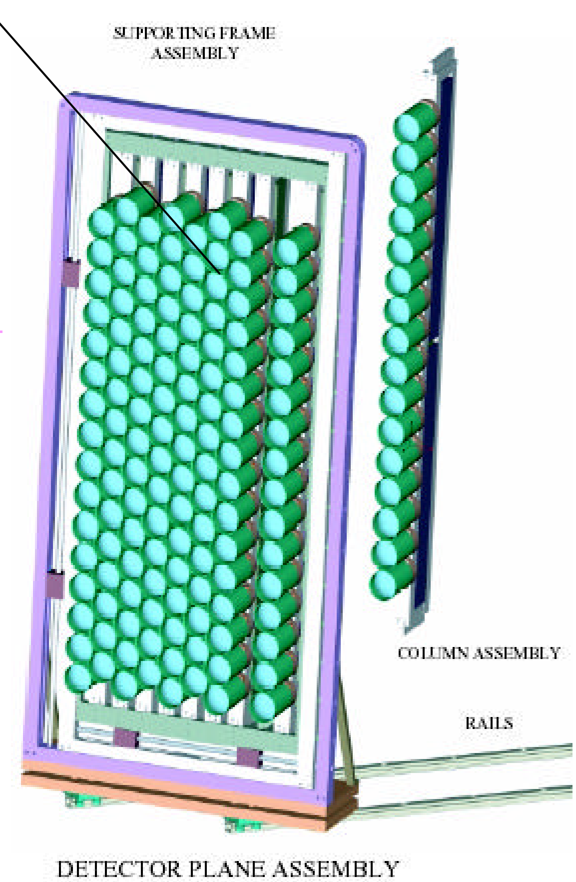
The RICH 2 counter

Schematic view



http://lhcb.cern.ch/rich/images/rich2_schematic.gif

Mechanical design studies



RICH2 EDR
LHCb EDR 2002-009
1 March 2002

Overall RICH system requirements

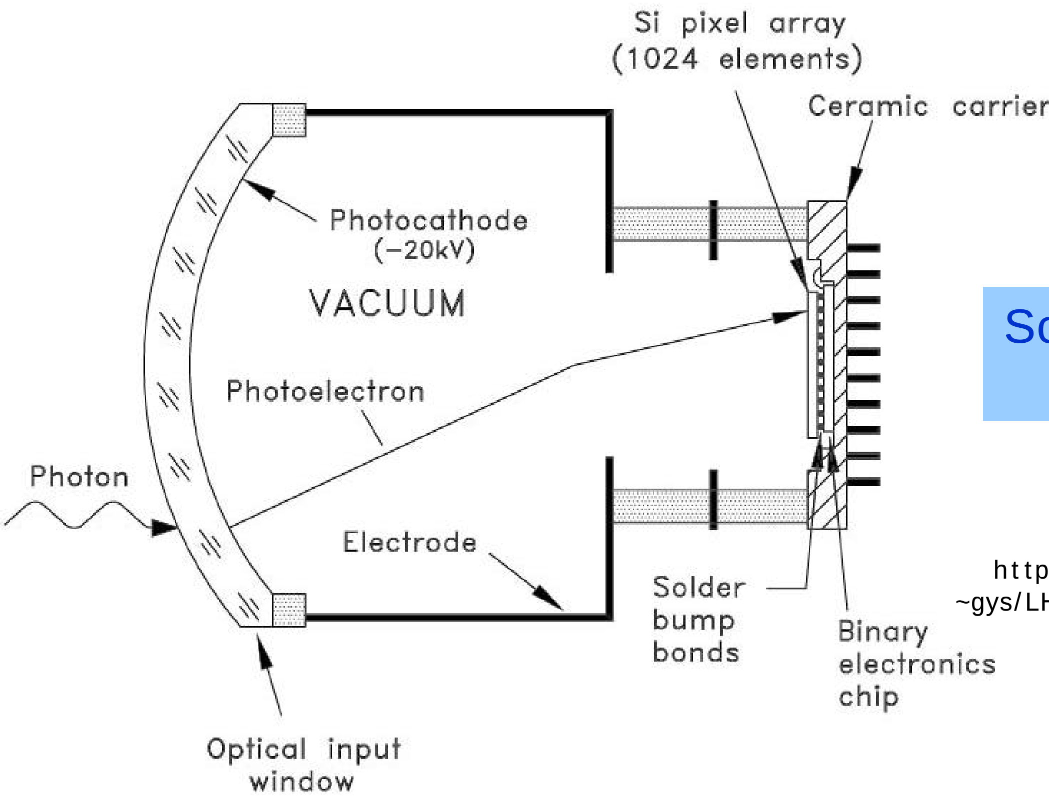
- **Photon detection**
  - ~2.9 m^2 total surface
  - Granularity: 2.5×2.5 mm^2
  - Active area coverage $\geq$ 70 % (~325'000 channels)
  - Single-photon sensitivity (λ = 200-600 nm)

- **Environment**
  - Magnetic stray field: $\leq$ 300 gauss (RICH1)
$\leq$ 100 gauss (RICH2)
  - Radiation dose: $\leq$ 3 kRad/year

- **Read-out**
  - Maximum occupancy: $\leq$ 10 %
  - BCO identification ($\tau_p \approx 25$ ns)
  - High L0-trigger rate (1 MHz)

- **Photo-detectors**
  - Pixel-HPDs: baseline solution
cross-focussing geometry
binary pixel readout (this talk)
  - Multi-anode PMTs: backup solution
metal channel dynodes
analogue readout

Pixel-HPD description



Schematic view

http://www.cern.ch/~gys/LHCb/PixelHPDs.htm

Main features:

Close collaboration with industry

Quartz window with thin S20 pK ($\int QE \bullet dE \approx 0.77eV$)

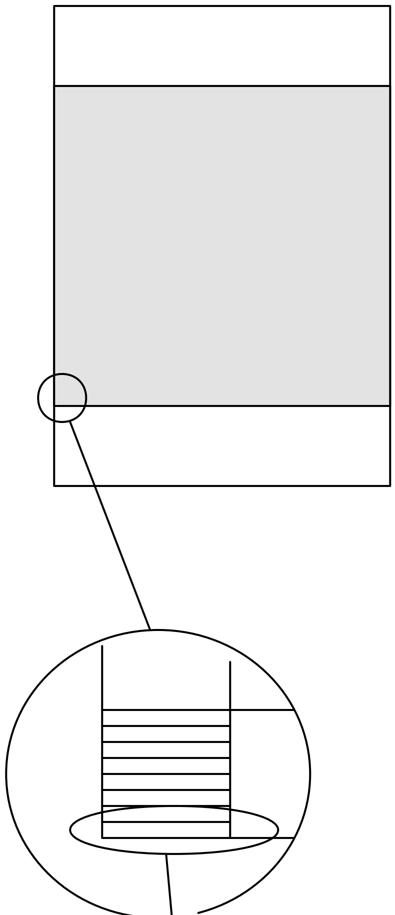
Cross-focussing optics (tetrode structure):

- De-magnification by ~5
- 50 μm PSF (~250 μm at window level)
- Active diameter 75 mm (81.7 % tube coverage)
  - ⇒ ~450 tubes for overall RICH system
- 20 kV operating voltage (~5000 e^- [eq. Si])

32×32 pixel sensor array (500 μm×500 μm each)

Encapsulated binary electronics readout chip

Binary front end electronics (baseline specifications)



Full readout chip

32 × 32 super-pixel array
16mm × 16mm active area
40MHz readout clock
⇒ ~800ns readout time complying with LHCb L0 trigger rate (1MHz)

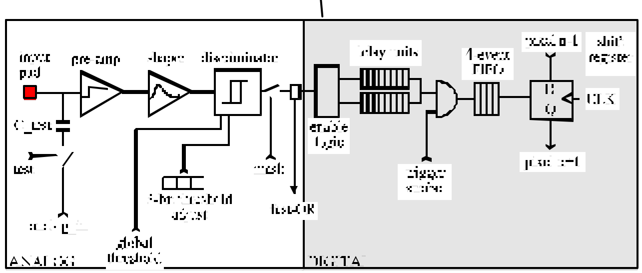
Super-pixel

500µm × 500µm area
8 sub-pixels ORed together
Digital FE electronics:

- 16 delay lines (4µs)
- 16-deep FIFO de-randomizing buffer

⇒ reduced occupancy seen by analogue FE and lower noise

Sub-pixel



62.5µm × 500µm area
Analogue FE electronics:

- Differential amplifier (250 e^- noise)
- Shaper (25 ns peaking time)
- Discriminator (2000 e^- aver.)

See also another contribution of K. Wyllie (this workshop)

Full-scale pixel-HPD prototypes (1)

Manufactured by *DEP B.V.* (The Netherlands)

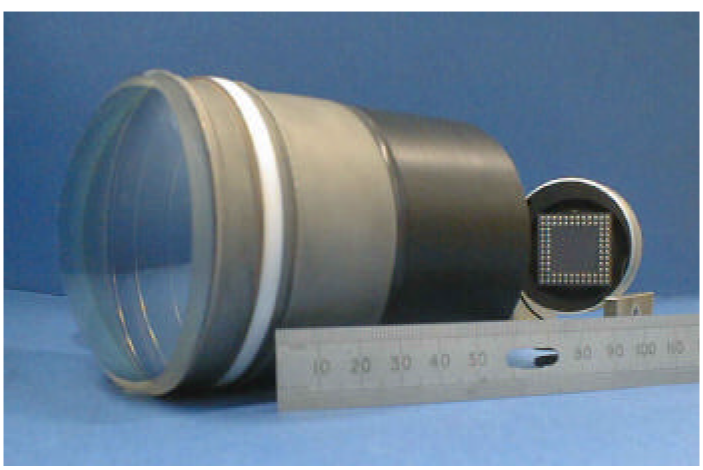
- **First prototype (completed in 1999)**
  - Phosphor screen anode
  - CCD readout

  $\Rightarrow$ check of active area, electron-optics, photo-cathode uniformity, magnetic field sensitivity and shielding options.

  M. Alemi et al., IEEE Trans. Nucl. Sc. 46,6 (1999) 1901.

- **Second prototype (completed in 1999)**
  - 61-pixels anode
  - External analogue VA2 readout

  $\Rightarrow$ check of response to Cherenkov light, installation of a cluster in the RICH prototype.

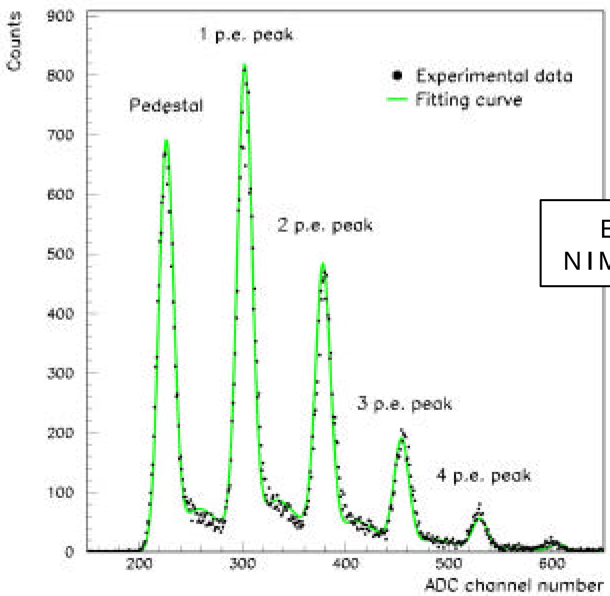


61-pixel HPD prototype

http://www.cern.ch/~gys/LHCb/PixelHPDs.htm

Full-scale pixel-HPD prototypes (2)

Laboratory measurements

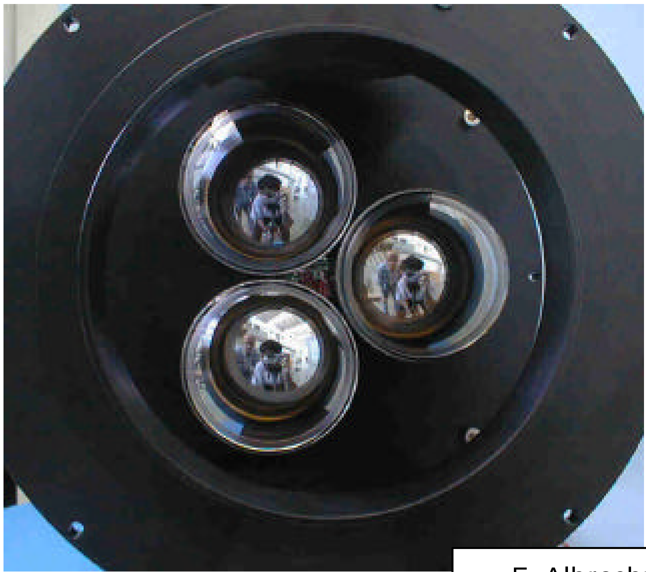


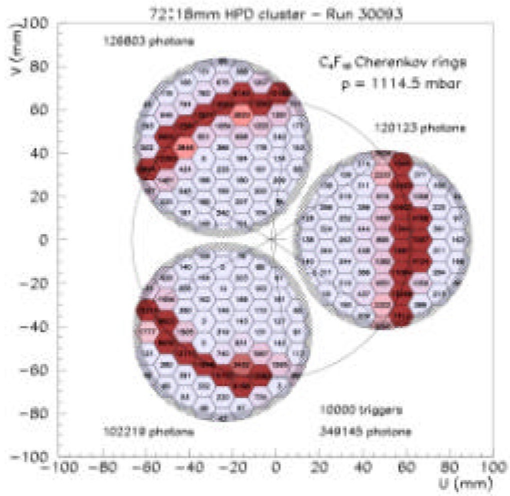
Pulsed LED spectrum

E. Albrecht et al.
NIM A 442 (2000) 164

Signal-to-noise ratio ≈ 11 @ 20kV with external analogue VA2 readout (τ_p=1.2 μs)

Beam tests in LHCb RICH 1 prototype





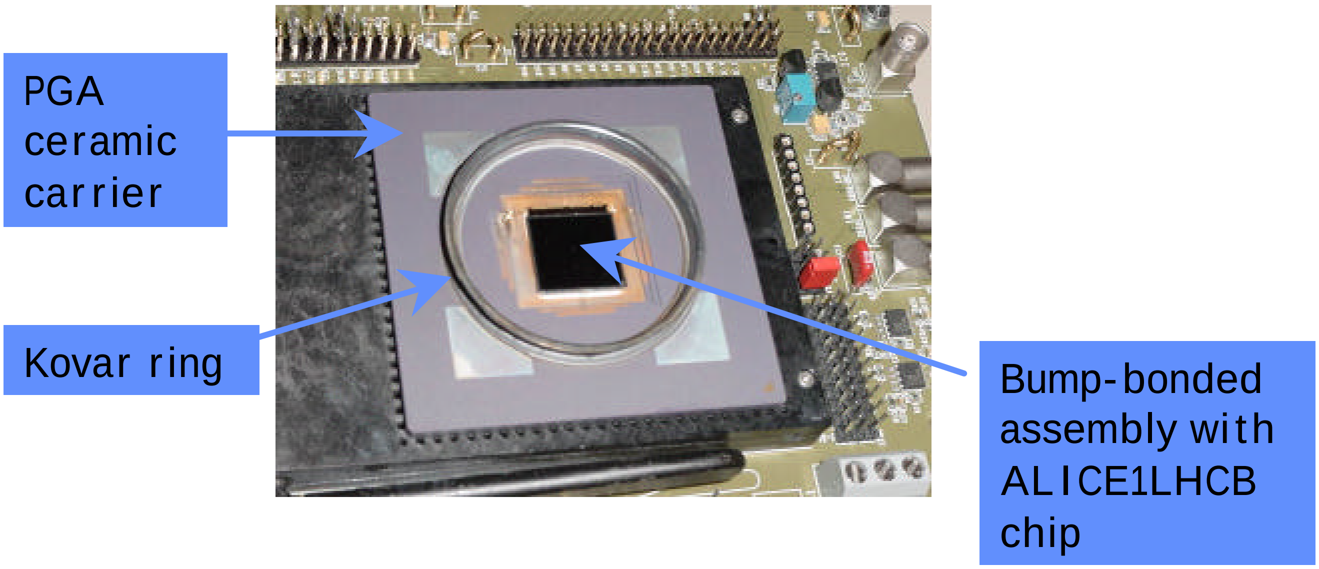
HPD cluster

E. Albrecht et al.
NIM A 442 (2000) 164

Tube figure of merit:
$N_0 \approx$ 225-250 cm^{-1}

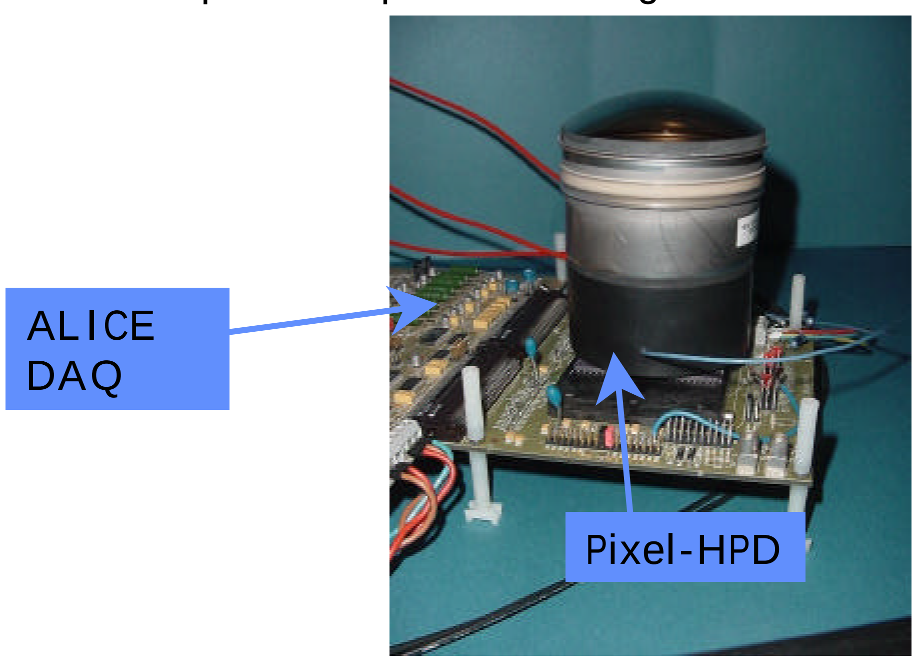
Full-scale pixel-HPD prototype (3)

- Third prototype (to be completed in 2001)
  - ALICE1LHCB single assembly anode on custom ceramic carrier



  - ALICE DAQ (software+hardware) readout

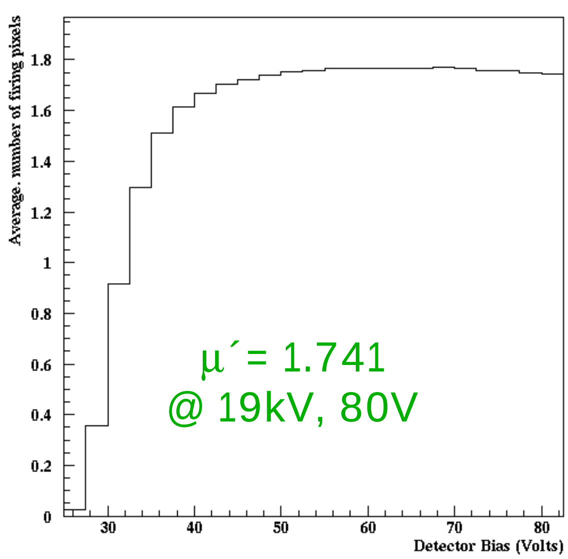
    ⇒ check of response to pulsed LED light.



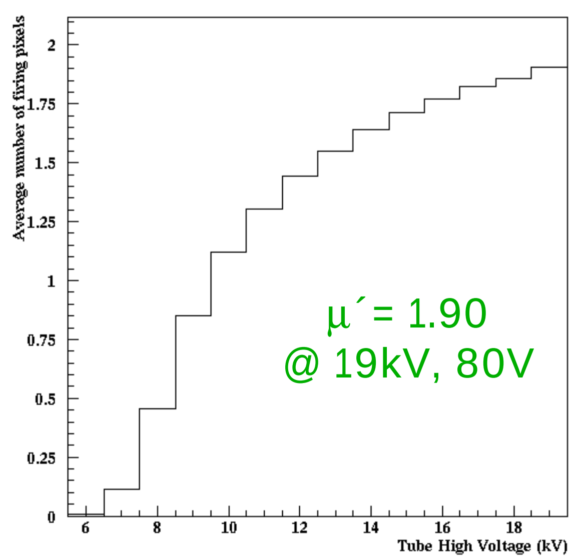
Systematic tests of pixel-HPD prototype (1)

- Operating conditions
  - HPD high voltage = 0 ⇒ 19kV
  - Silicon detector bias 0 ⇒ 80V
  - Back-pulse spectrum recorded at end of data taking
  - Temperature and HV remotely controlled and monitored
  - Noisy pixels masked
  - Missing bump-bonds in central part, due to HPD bake-out cycle
    ⇒ LED shining window edge

Detector bias scan



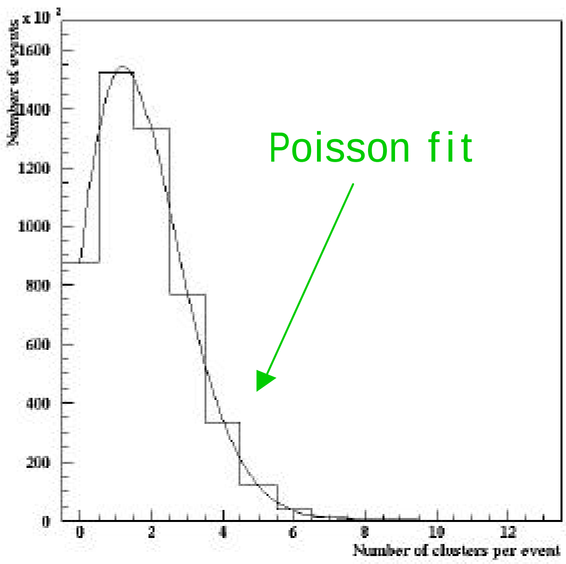
HV scan



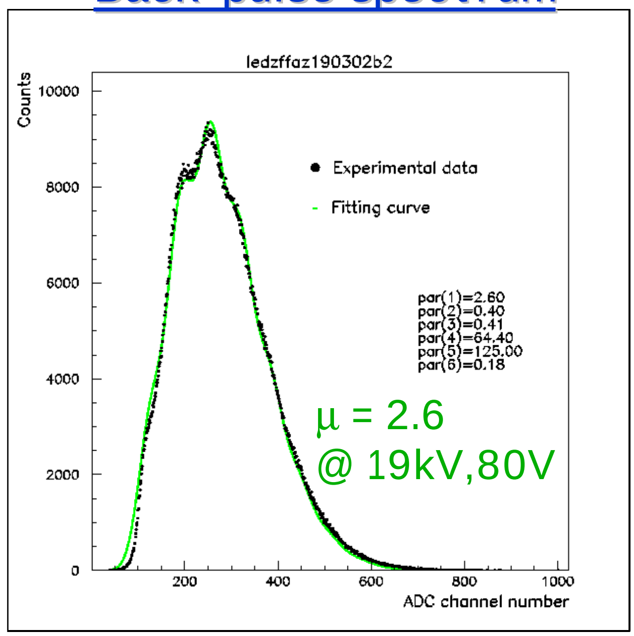
μ´ = average number of firing pixels
(*Poisson statistics*)

Systematic tests of pixel-HPD prototype (2)

Firing pixels per LED pulse

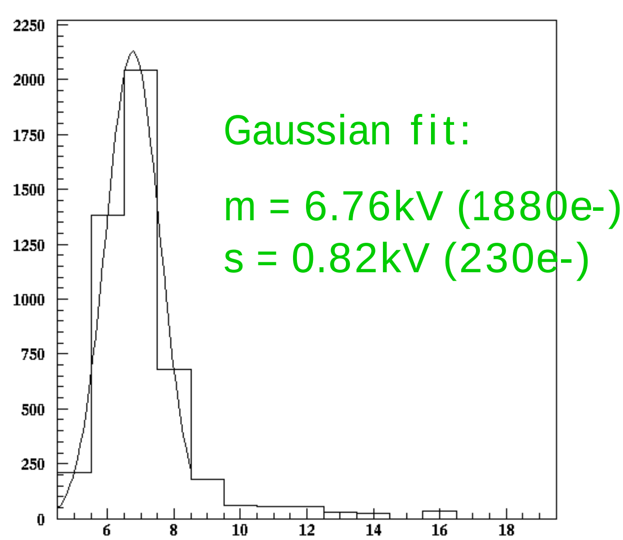


Back-pulse spectrum



μ = average number of photoelectrons per LED pulse inferred from back-pulse fit

Differential number of firing pixels as a function of HPD HV (detector bias 80V)

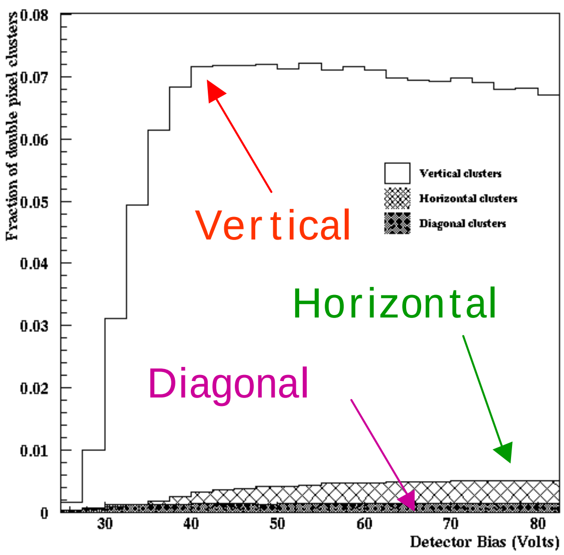


This distribution reflects the comparator threshold distribution of the ALICE1LHCb chip (without threshold adjust)

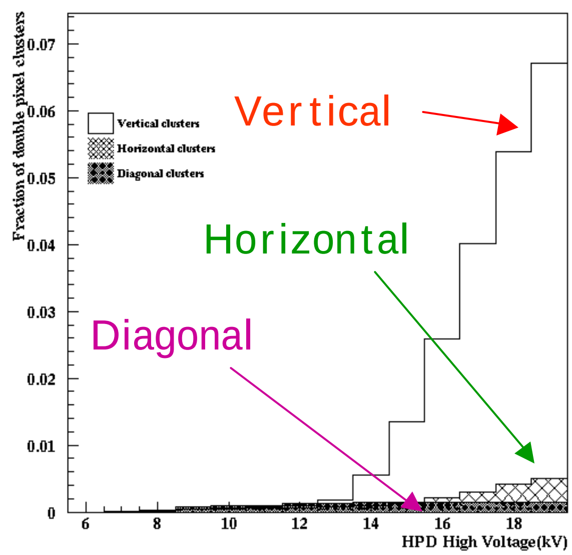
Systematic tests of pixel-HPD prototype (3)

Fraction of double pixel clusters as a function of:

Detector bias voltage



HPD high voltage

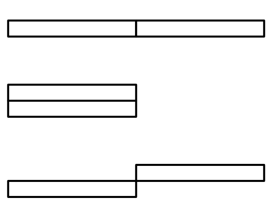


- 1 p.e can cause more than one pixel to fire
- *2-pixel cluster* : two adjacent pixels respond to 1 p.e.:

Horizontal

Vertical

Diagonal



- Vertical 2-pixel clusters are most common due to larger probability of charge sharing along long pixel side

Systematic tests of pixel-HPD prototype (4)

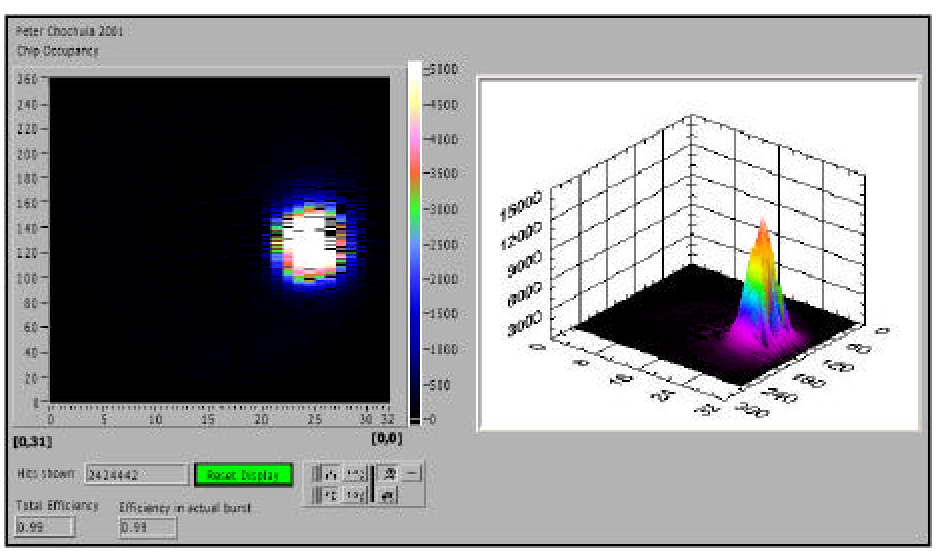
- Photoelectron detection efficiency estimate
  - Efficiency estimate from baseline specifications:
    - Pedestal: 250 e^- RMS noise
    - Threshold: 2000 e- aver.
    - Signal: 5000 e^- @ 20kV

    18% back-scattering probability, <E> = $E_0/2$, reduced effect if low cut

    Charge sharing, 7μm RMS lateral spread (300 μm-thickness, 90 V bias) not significant if $E_{cut}<E_0/2$

⇒ ~90 % expected detection efficiency

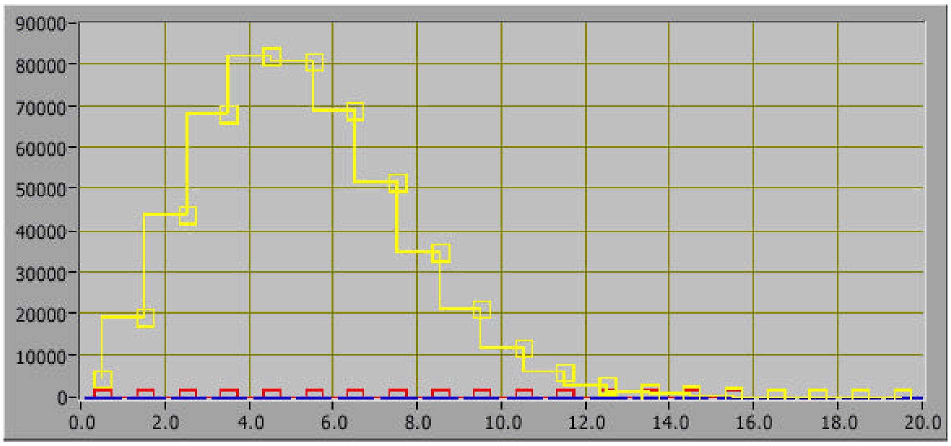
- Experimental procedure
  - LED shining smaller pixel area, where bump-bonds are generally good:



Systematic tests of pixel-HPD prototype (5)

- Experimental procedure (cont'd)

  - Analyze event size, correct for double pixel clusters, infer μ':



  - Record back-pulse spectrum, infer μ from fit

  - Compare values of μ' and μ; present estimates range from 81% to 83%; not corrected for LED drift with time, LED tail, missing bump-bonds, masked pixels, photoelectron pile-up

  - Error estimates:
    - LED drift: 5-10%
    - Fit parameters: 5%
    - LED tail: a few %

Conclusions and perspectives

- Conclusions
  - Pixel-HPD with ALICE1LHCB chip operational
  - General behaviour nominal:
    - Good QE: >23% @ 270nm
    - HV operation OK
    - Chip electrical response: same as before encapsulation
    - Detector leakage current: same as before encapsulation
    - Heat dissipation: 15 °C temperature increase for ~0.85W power consumption
  - Photoelectron response: nominal (missing bump-bonds excluded)
    - Preliminary photoelectron efficiency estimates range from 81% to 83%; not corrected for LED drift with time, LED tail, missing bump-bonds, masked pixels, photoelectron pile-up
  - Improved bump-bonding process survive bake-out cycle, new HPD prototypes under manufacturing
  - New LHCBPIX1 chip fully operational at 40MHz
- Perspectives
  - New silicon pixel detector and ceramic carrier designed, expected for the end of 2002
  - New bump-bonded assemblies to be manufactured early 2003