Hybrid Photon Detectors for the LHCb RICH Counters

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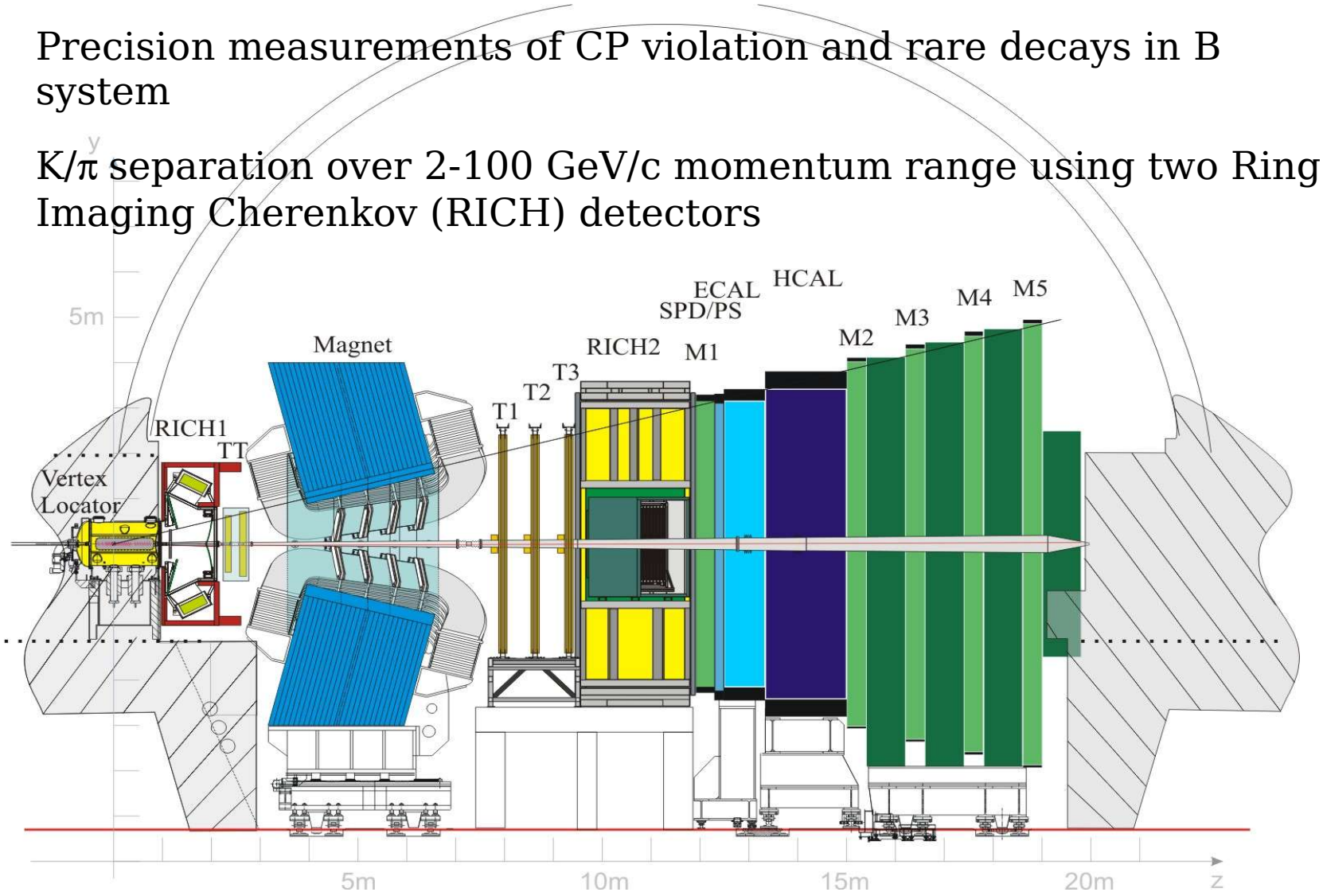
On behalf of the LHCb RICH Group

Outline

- The LHCb Experiment
- The RICH detectors
- Hybrid Photon Detector (HPD)
- Pre series tubes
- Conclusions

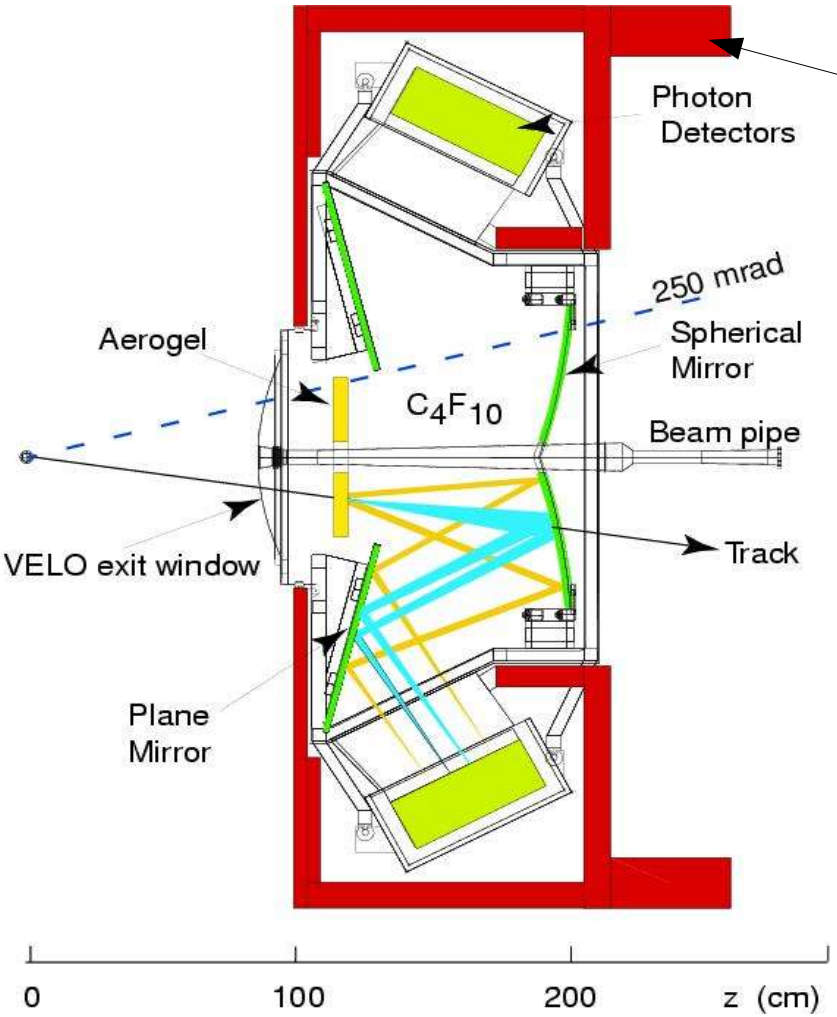
LHCb

- Single arm spectrometer
- Precision measurements of CP violation and rare decays in B system
- K/π separation over 2-100 GeV/c momentum range using two Ring Imaging Cherenkov (RICH) detectors

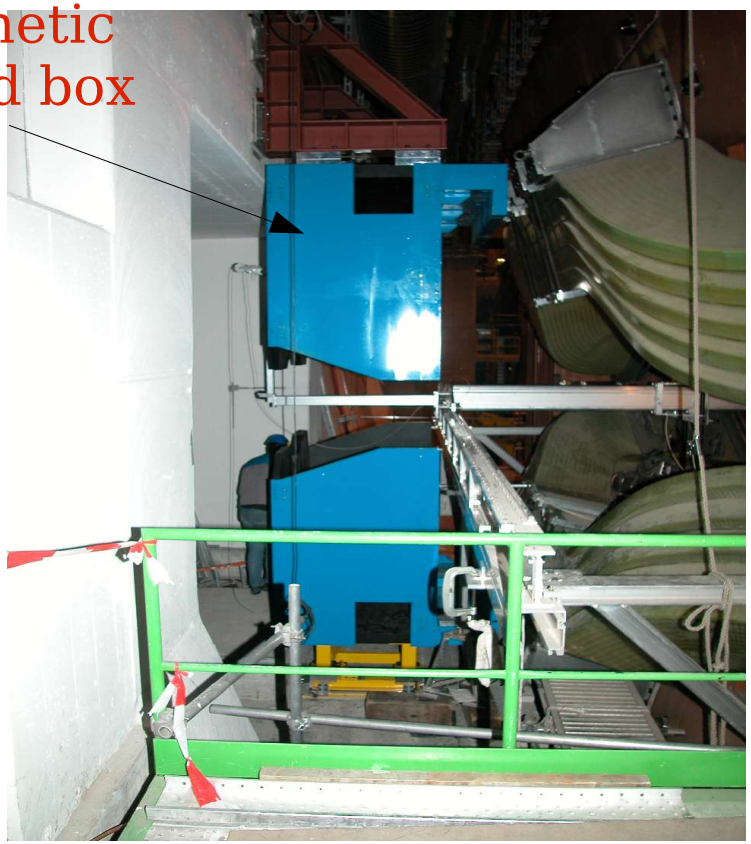


RICH 1

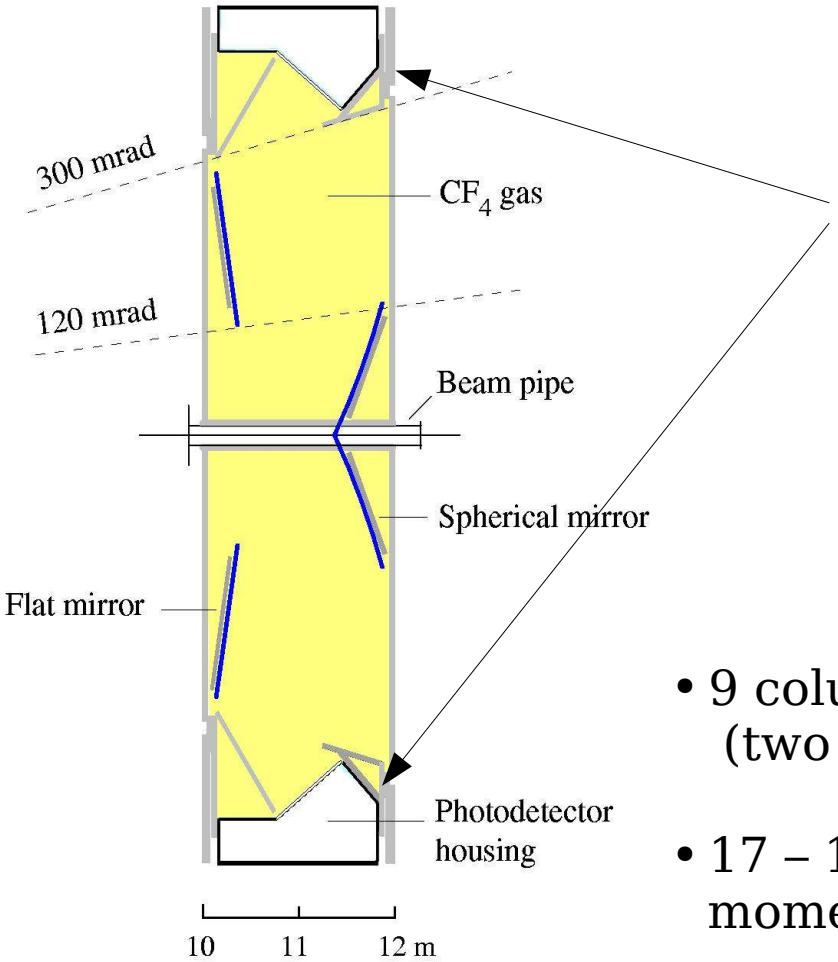
- 7 columns of 14 tubes each (2 planes of HPDs)
- 2-60 GeV/c momentum range

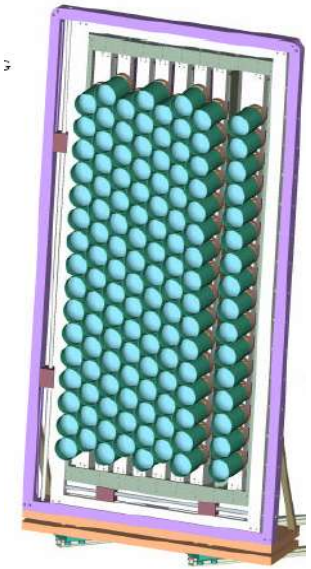


Magnetic shield box



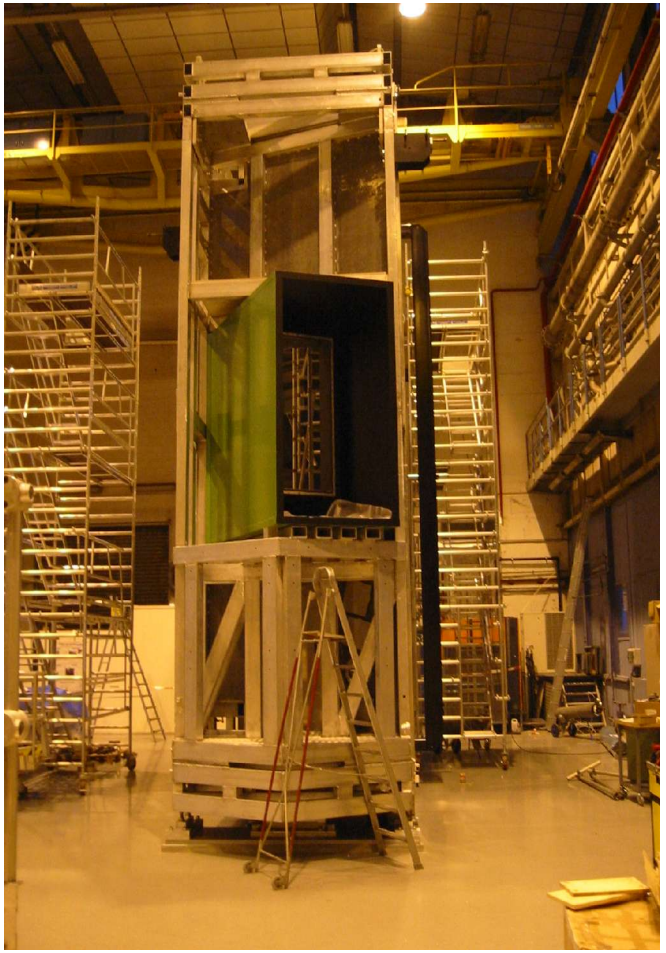
RICH 2





HPD Plane

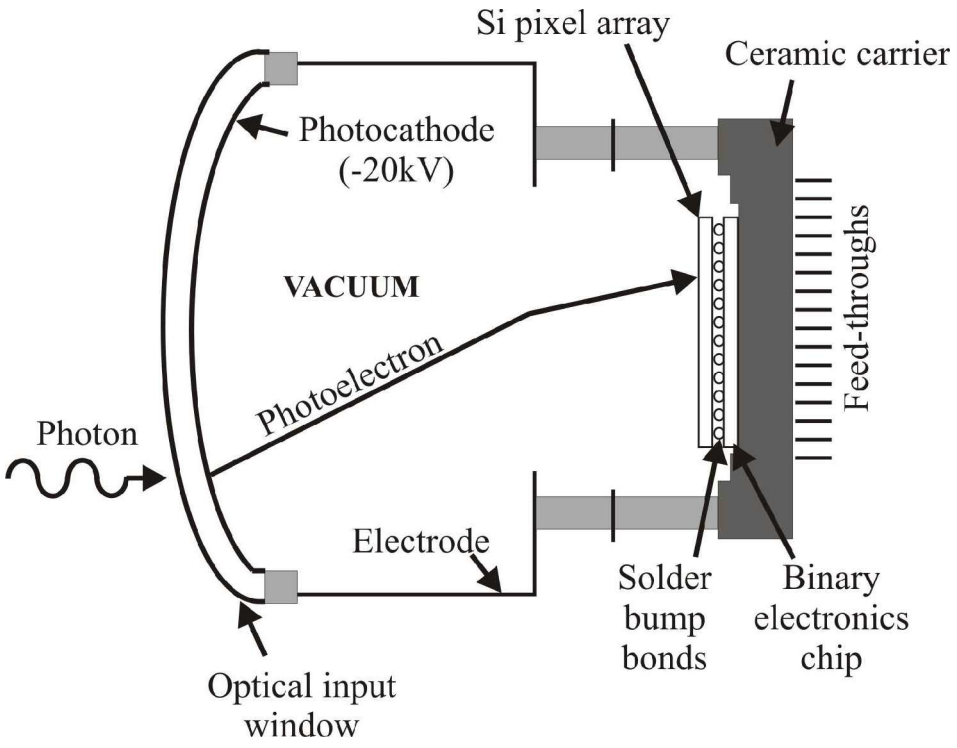
- 9 columns of 16 tubes (two planes of HPDs)
- 17 – 100 GeV/c momentum range



RICH Photon Detector Requirements

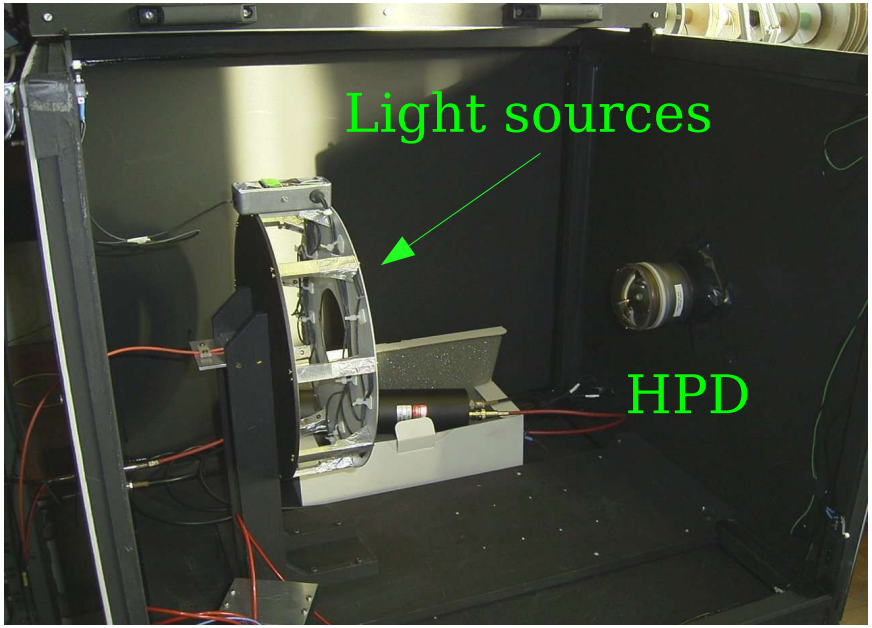
- Sensitive over the wavelength range 200nm to 600nm
- Large total area of 2.6m^2, active fraction ~65%
- Position sensitive, with granularity of 2.5mm x 2.5mm
- Single photon sensitivity
- Fast response for LHC bunch crossing rate of 40MHz
- Radiation tolerant (3krad per year)

HPD I



- Quartz window with S20 photocathode
- Cross-focusing optics
  - Demagnification by ~5
  - Active diameter 75mm
  - 20 kV operating voltage
- 32x256 pixel array
  - Digitally ORed to give a 32x32 array
  - Effective pixel size 500μm x 500μm
- Encapsulated binary electronics readout chip

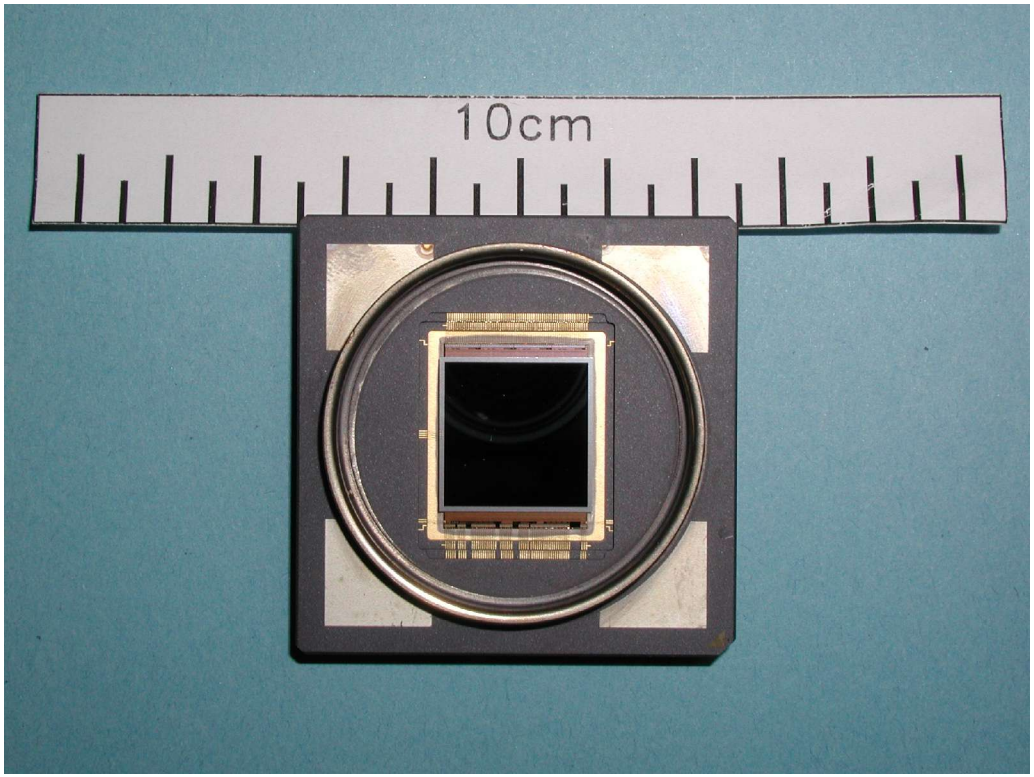
HPD II



HPD Test station

Pixel Chip

- Low noise ~ 100e^-
- Low threshold ~ 2000e^-
- 25 ns time precision
- Binary architecture
- 16mm x 16mm active area
- 500μm x 500μm channel size



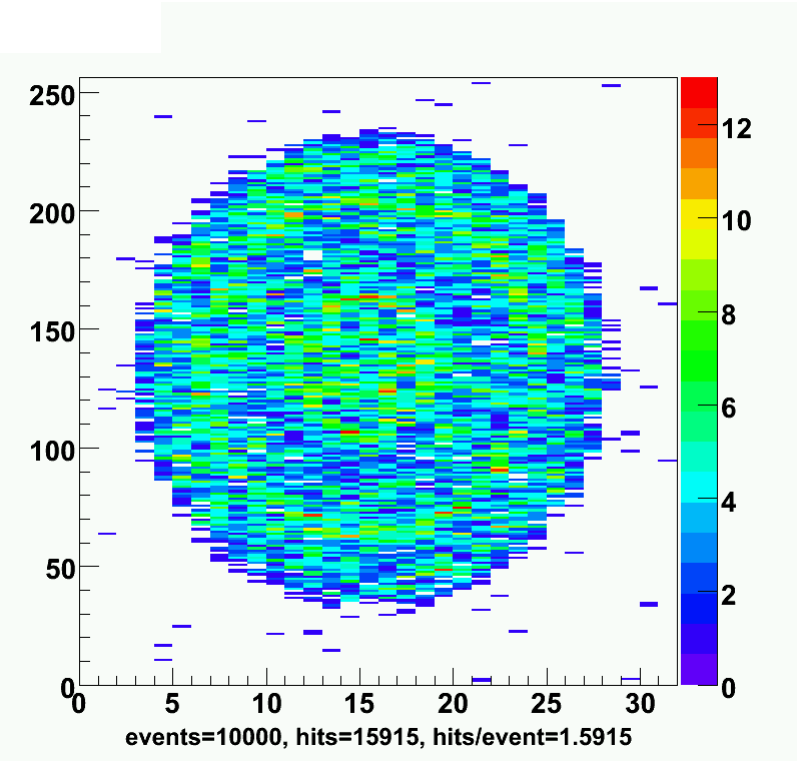
Pre Series Tubes

- Final tube mechanics
- 9 pre series tubes delivered
- Requirements
  - Pixel response > 95%
  - Min threshold < 2000e^-
  - Noise < 250e^-
  - Leakage current ~ 1μA @ 80V bias
  - Dark count rate < 5kHz/cm^2 (< 2 x 10^{-3})
  - Ion feedback rate < 10^{-3} of signal
  - Detection efficiency > 85%
  - Quantum efficiency > 20% @ 270 nm

Pixel Response

HPD	Dead Channels Test Pulse	LED	Working Fraction	
2_11	2	19	99.56	
4_3	0	4	99.9	
3_1	1	11	99.71	
4_1	256	211	94.82	*
2_6	20	27	99.31	
4_4	0	4	99.91	
3_2	5	12	99.7	
4_5	1	1	99.98	
2_7	3	10	99.77	

- Missing column on one tube (*)
- Otherwise > 99% working pixels on photocathode image area



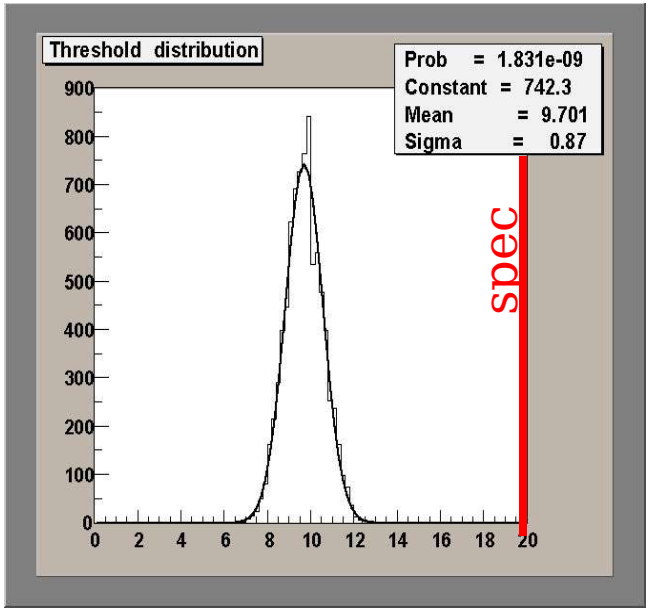
Photocathode image on pixel sensor (tube 3_2)

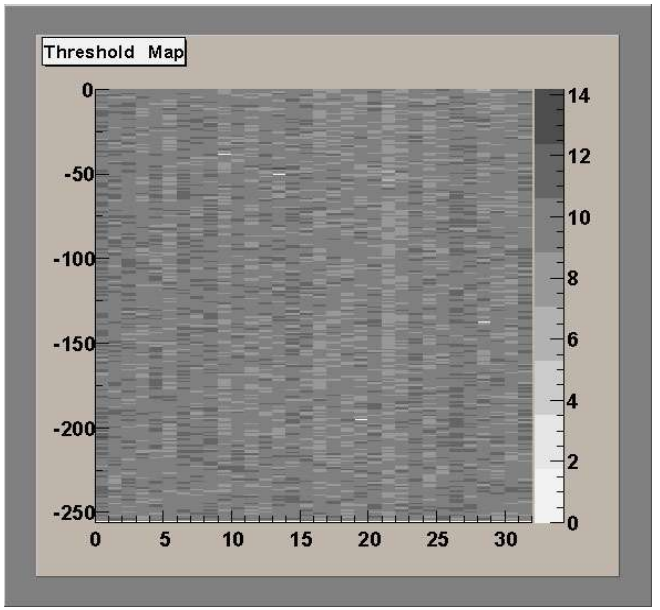
Threshold/Noise

	Threshold (e-)		
HPD	Mean	Sigma	Noise (e-)
2_11	1145	92	163
4_3	1287	99	164
3_1	1233	92	168
4_1	1201	91	161
2_6	1090	93	158
4_4	1235	93	165
3_2	1103	88	154
4_5	1217	91	174
2_7	1083	99	156

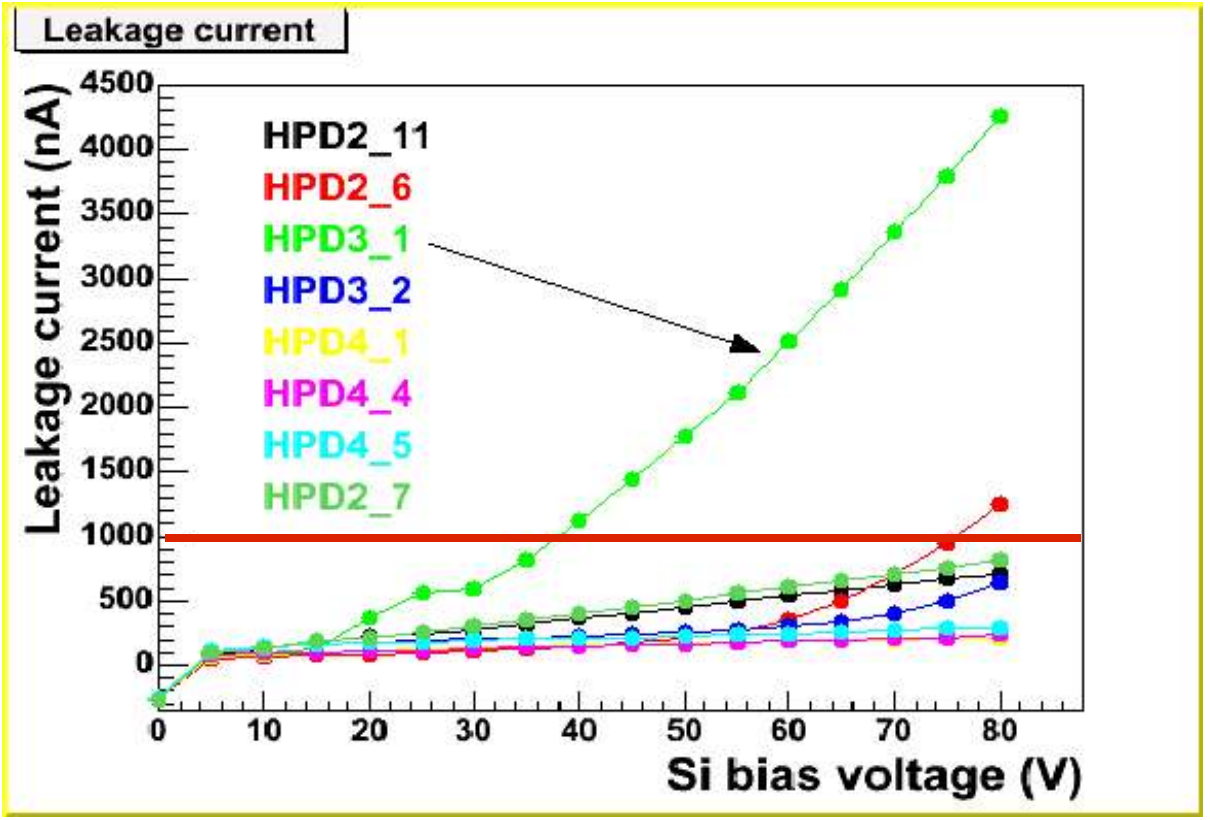
Threshold 1100 - 1300 e^- (< 2000 e^-)
Pixel to pixel variation ~ 100e-

Noise 150 – 180 e^- (< 250 e^-)



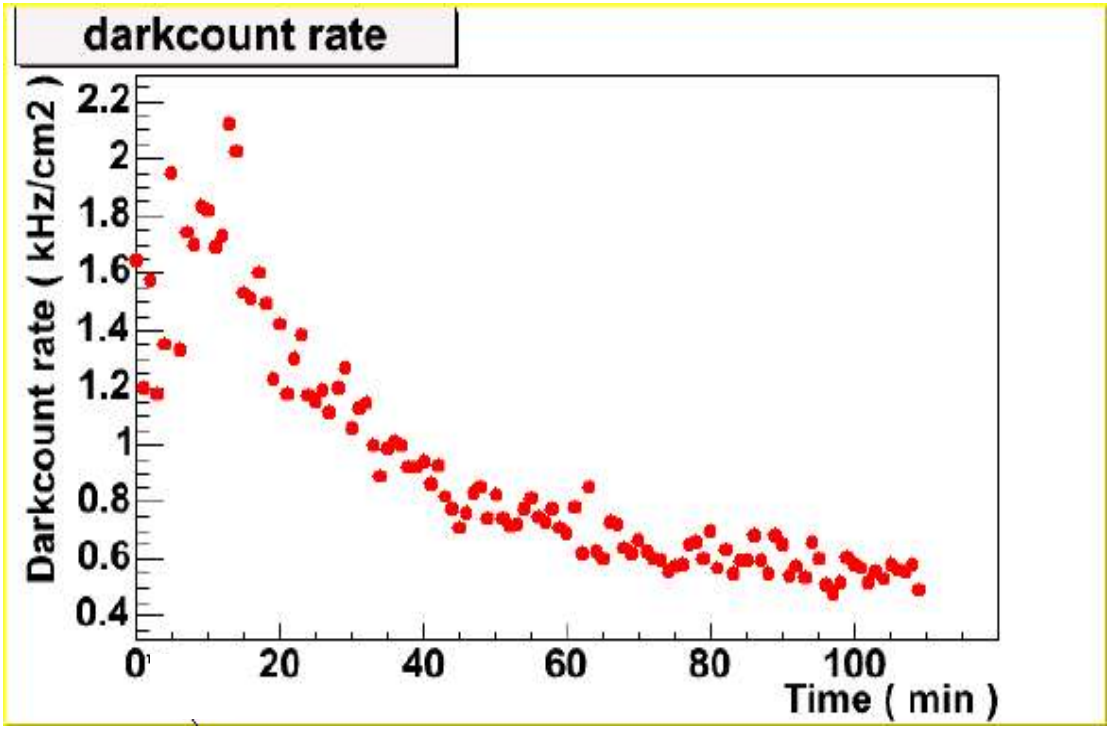


Leakage Current



Requirement of < ~1 μA @ 80V
Typical value of 200-500 nA @ 80V
8/9 pre series tubes with acceptable leak current

Dark Count Rate



HPD	DC (kHz/cm2)
2_11	0.95
4_3	0.27
3_1	3.03
4_1	0.53
2_6	0.94
4_4	1.87
3_2	0.03
4_5	0.61
2_7	0.24

- Main sources:
  - Thermionic electron emission (temperature)
  - Field emission (electric field)
  - Ion feedback (vacuum quality)

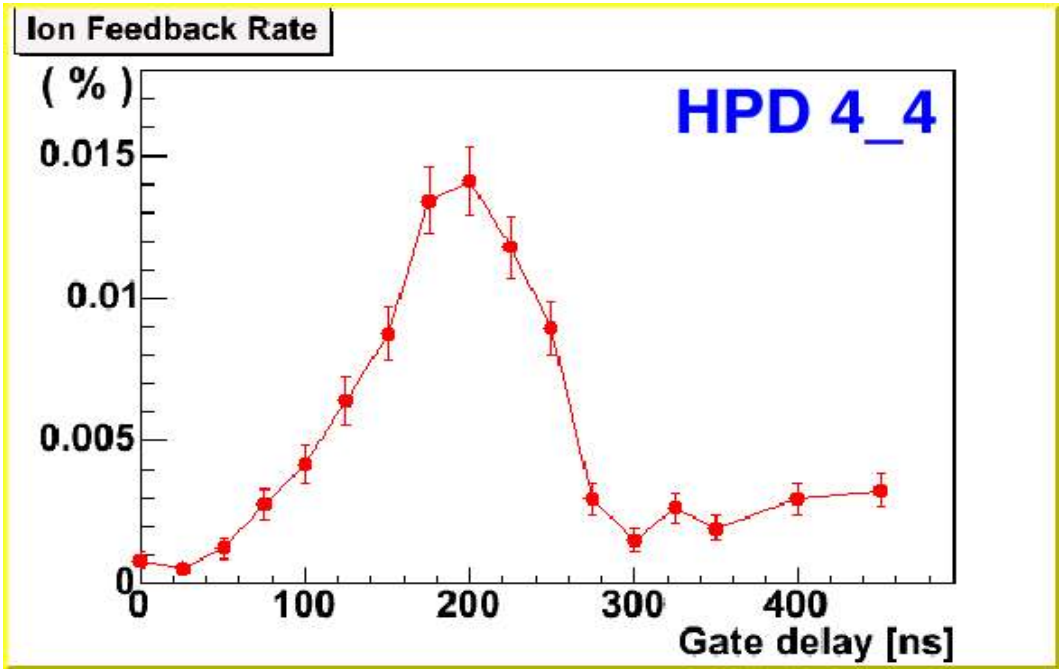
- All tubes < 5 kHz/cm^2 requirement

Ion Feedback

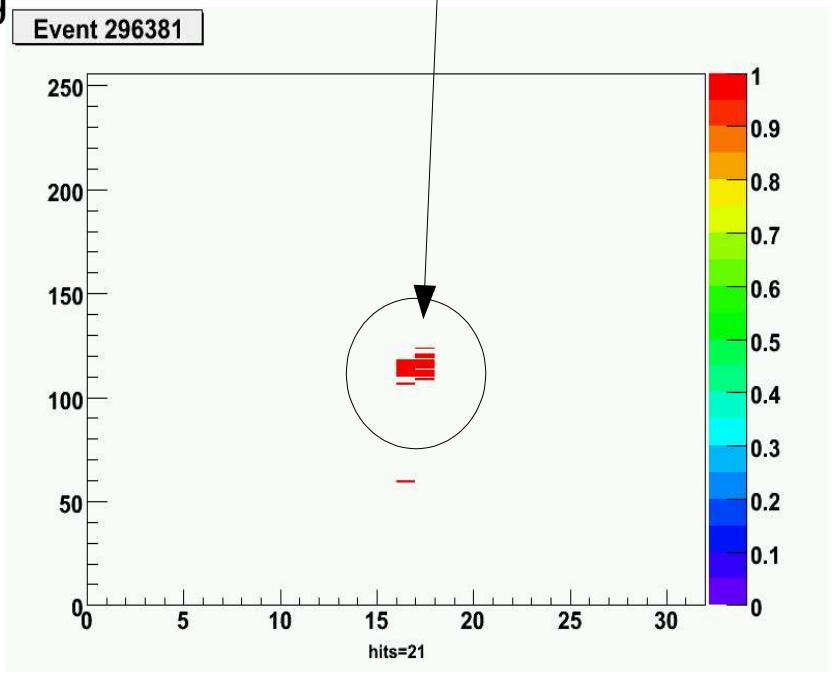
Photoelectron ionizes residual gas molecule

Ion accelerated back to photocathode liberating large number of electrons

Peak ion feedback rate ~200ns after standard photoelectron detection (ion travel time)

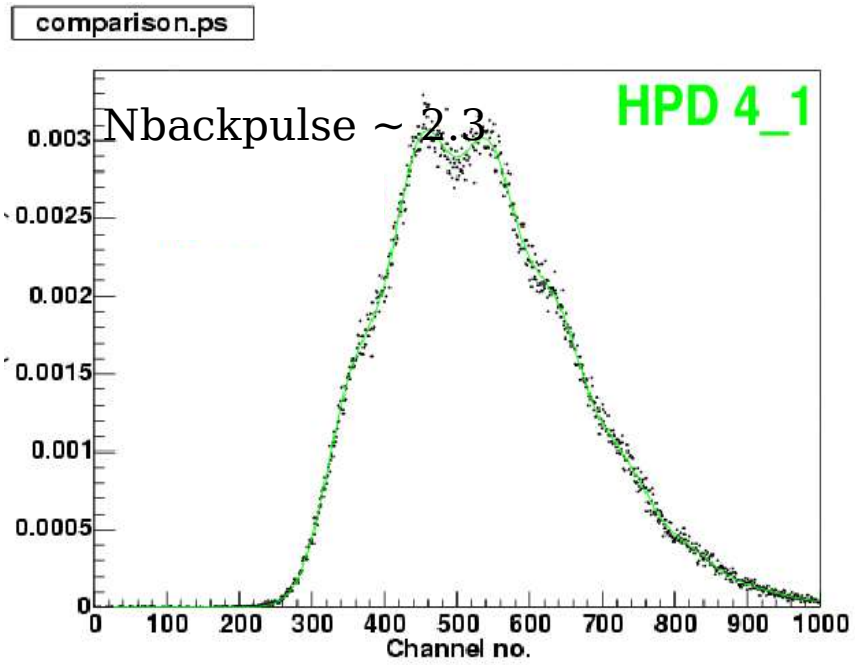


Ion feedback cluster



Efficiency

- Measure number of photo electrons using analogue backpulse signal
- Efficiency = $\frac{N_{binary}}{N_{backpulse}}$



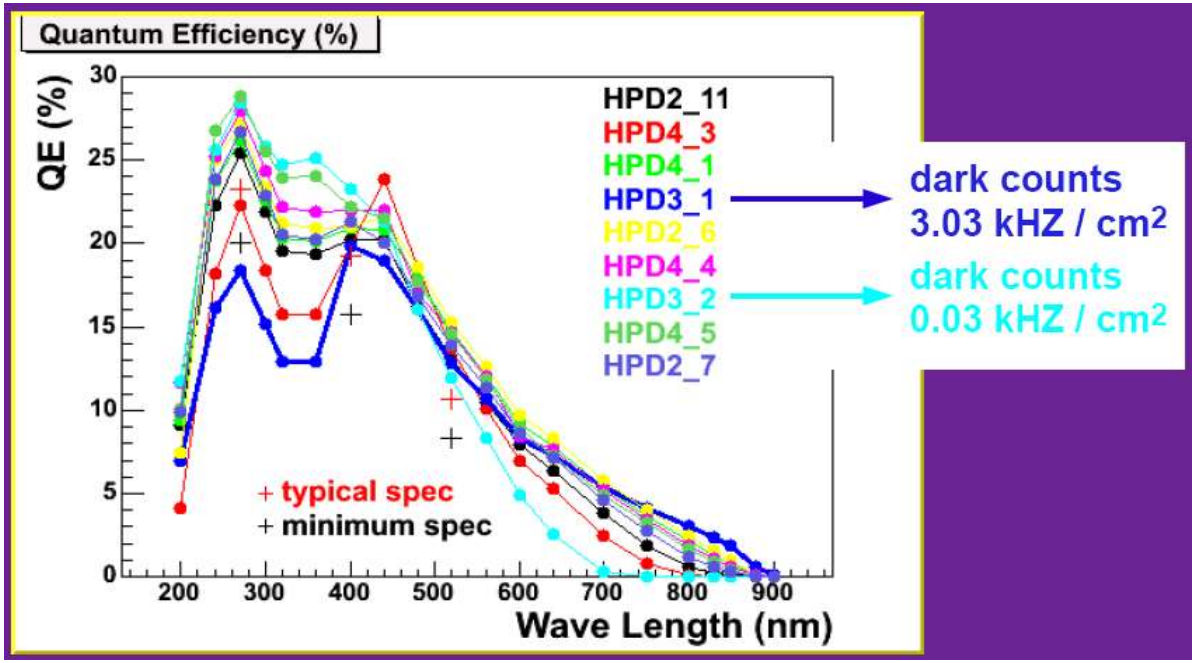
HPD	Efficiency
2_11	88
4_3	89
3_1	
4_1	79
2_6	82
4_4	84
3_2	89
4_5	
2_7	

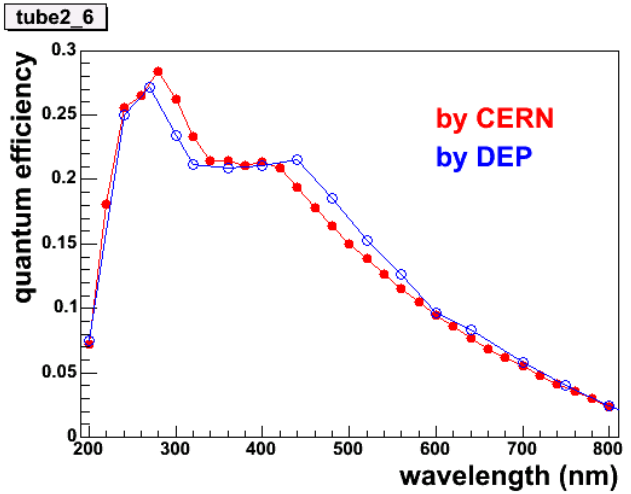
Very poor peak separation (high leakage current)

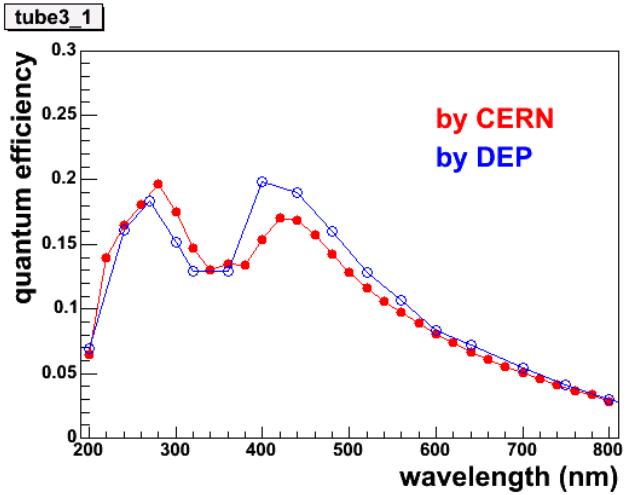
Not corrected for dead channels

Poor peak separation

QE Curves







QE specification established from prototype results

Dark count rate correlated to red sensitivity of tube

Conclusion

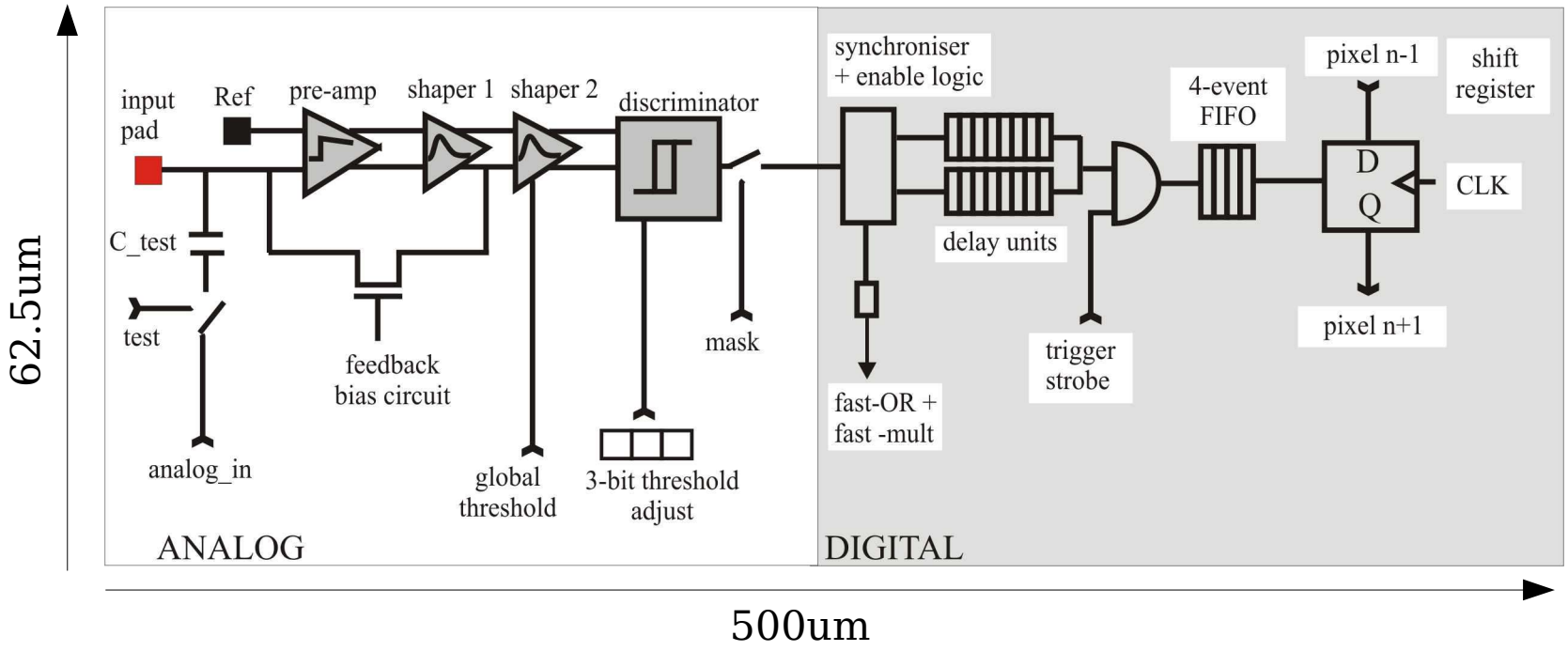
- Pixel chip meets HPD requirements
- HPD pre series performance ok
- Production of ~500 HPDs on going

Extra slides

Testing

- Production rate of 30 HPDs per month, over production period of ~18 months
- Two HPD test facilities (Glasgow, Edinburgh)
  - 1 HPD per work day per facility

HPD Pixel Chip II



One super pixel (500um x 500um) = 8 mini pixels (62.5um x 500um)

Internal logic makes logical OR of hits

Specifications

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 (OK)
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 next picture	Generally well above specs	1 HPD below specs in UV