Photon Detector Dark Tests for the LHCb RICH Detectors

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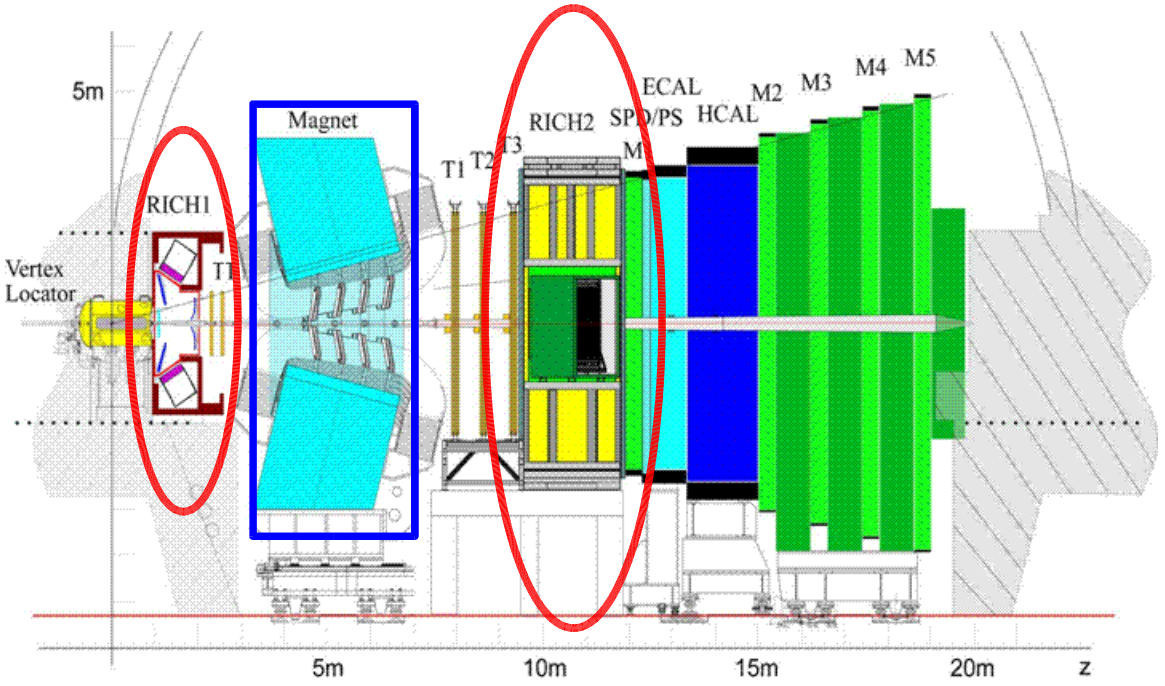
on behalf of the
LHCb experiment, CERN.

The LHCb Experiment

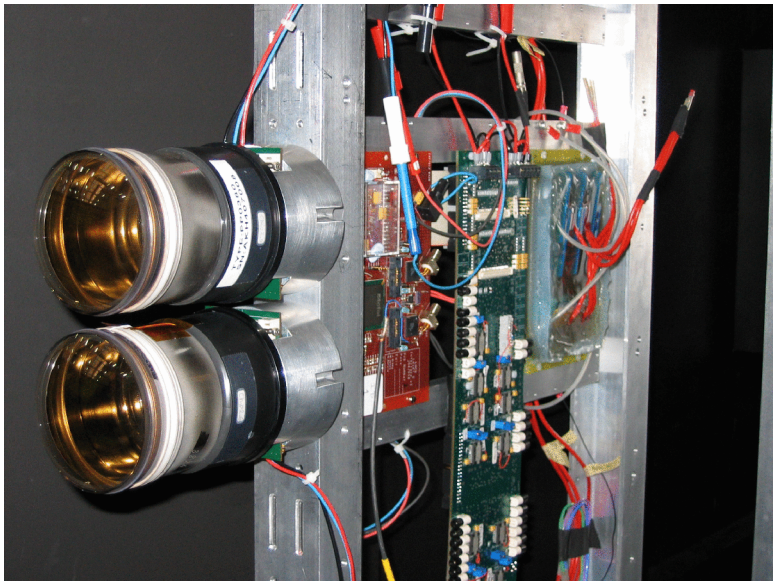
- LHCb is the CERN experiment dedicated to *b*-physics at the LHC.
- It is very important for us to be able to accurately differentiate between pions and kaons.

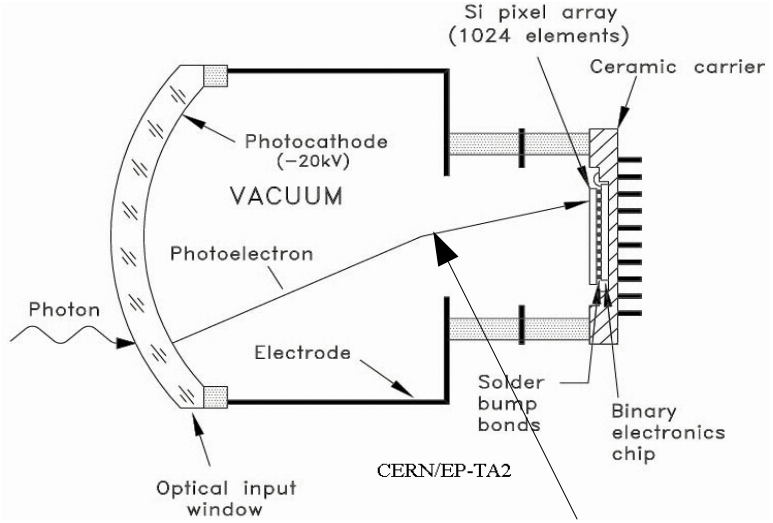


- We therefore have a particle ID capability provided by two Ring-Imaging CHerenkov radiation (RICH) detectors.
- Note the proximity to the magnet...

Photon Detectors in the RICH Detectors

- Cherenkov radiation is reflected on to two planes in each detector; one above and one below the beam pipe.
- Each plane consist of a honeycomb arrangement of Hybrid Photon Detectors (HPDs) mounted on columns.





Note cross-focusing here.

- Photons hitting the circular photo-cathode cause the emission of photo-electrons.
- These photo-electrons are focused onto a square pixel chip, which is bump-bonded to a readout chip.

Magnetic Shielding of HPDs

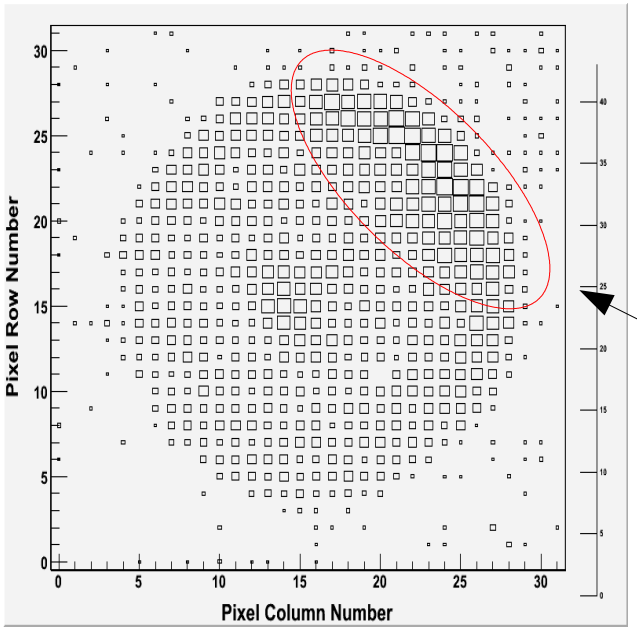
- The HPD arrays sit in the fringe field of the magnet – a magnetic field distorts the image of the HPD photo-cathode.
- We need to shield the HPDs from this field, by placing a mu-metal sheath around each HPD. This sheath protrudes a few centimeters proud of the photo-cathode.
- Problem: the mu-metal shielding is at ground, so there is a p.d. of 20 kV between the sheath and the nearby photo-cathode. There is an insulating sheath within this gap...
- We wish know the effect of the addition of mu-metal magnetic shielding to HPDs.

Possible Effects of HPD Shielding

- The worst case would be an arc that would damage the HPD photo-cathode and thus render a HPD useless.
- Another possibility is that we see micro-discharges, that would result in clusters of photo-electrons from the edge of the photo-cathode which could impact on our pattern recognition.
- We also want to know how many photo-electron hits we obtain which do not come from Cherenkov radiation and be sure that such hits do not reduce the effectiveness of our pattern recognition.
- I took 1,228,795 “dark count” triggers from four HPDs with **no** mu-metal shielding and have compared this to 477,899 triggers from the **same** HPDs **with** mu-metal shielding.

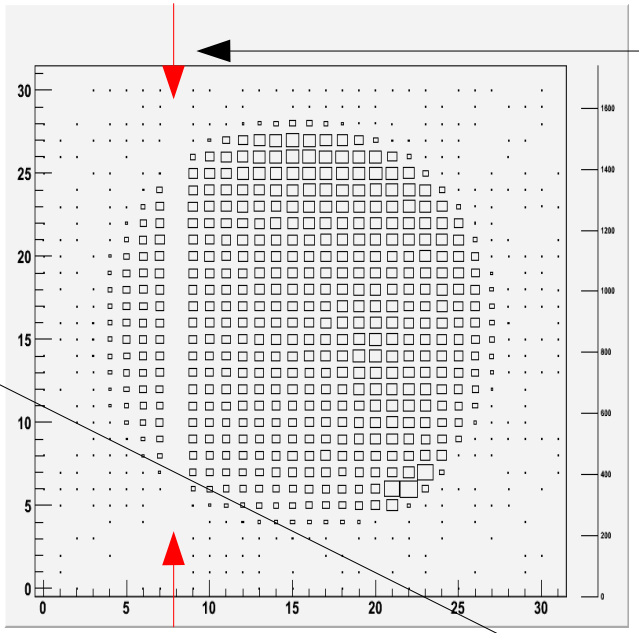
Some Raw Data - **No** Mu-metal

0



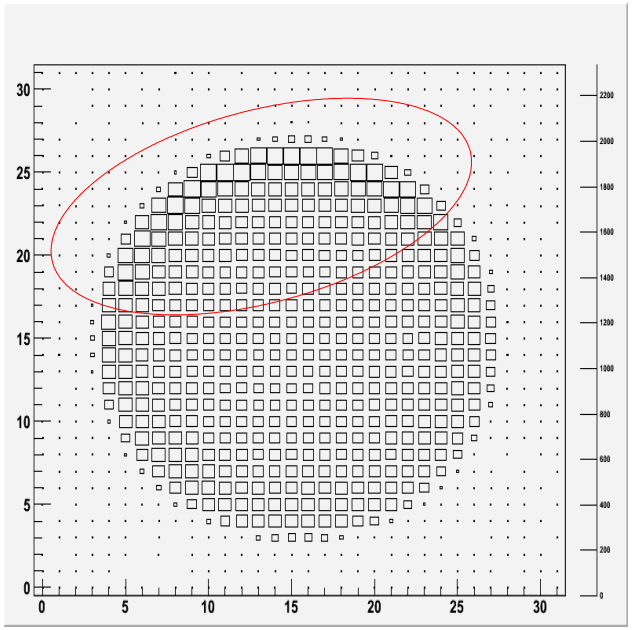
Pixel occupancy ($\times 10^{-6}$) = 6.99

1



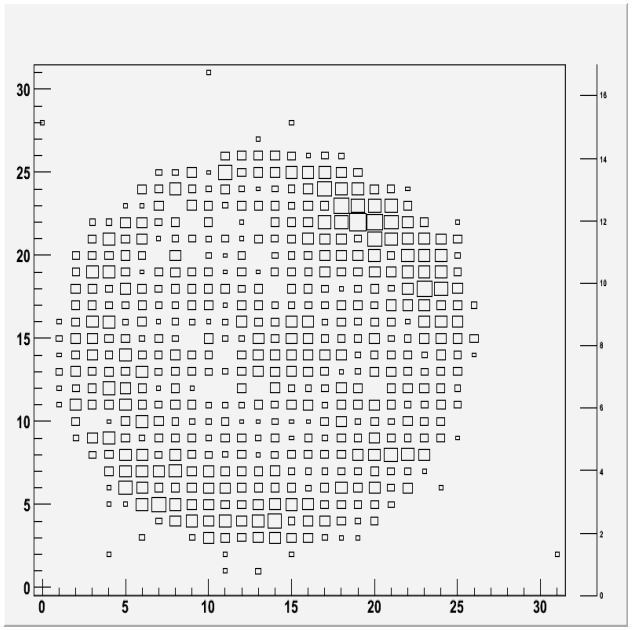
Occupancy = 227

2



Occupancy = 512

3

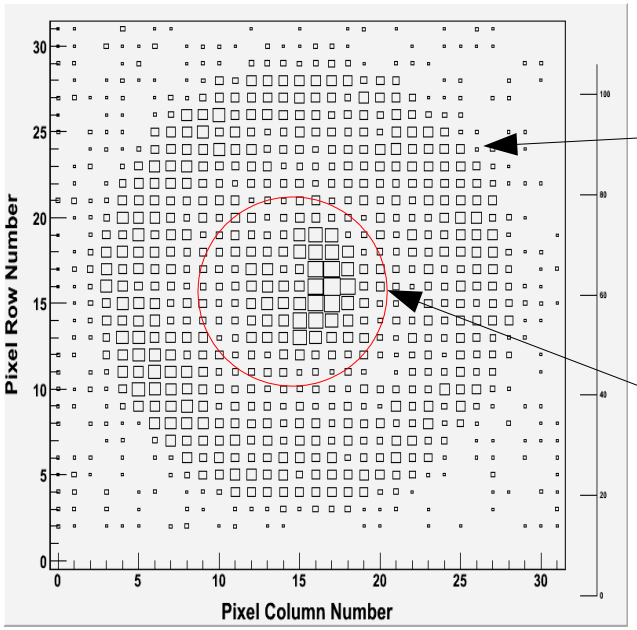


Occupancy = 2.47

- This empty column is simply due to a (one-off!) chip connection error.
- These plots show the cumulative distribution of hits over a run.
- Note crescent shape – possibly due to light leak.
- HPDs 1 & 2 are infra-red sensitive and pick up red light from the fiber optic data line.

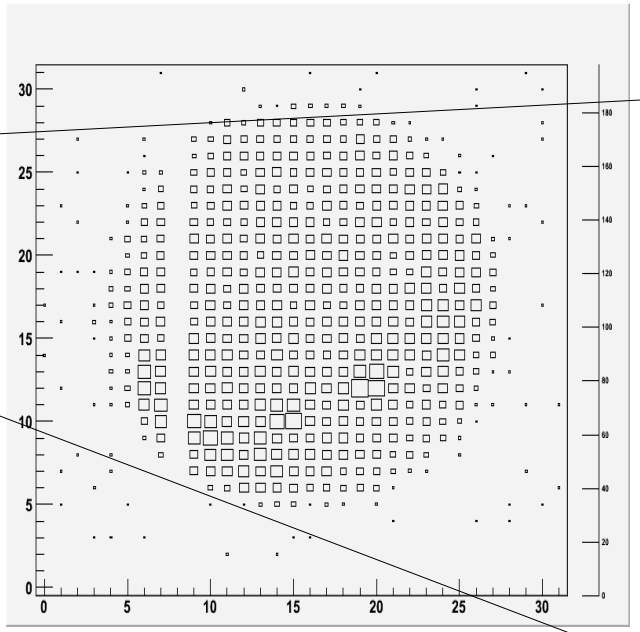
More Raw Data - **With** Mu-metal

0



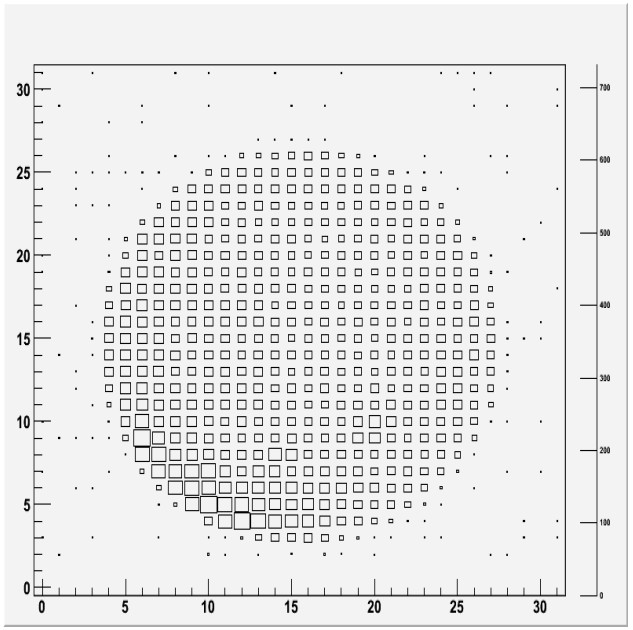
Pixel occupancy ($\times 10^{-6}$) = 15.1

1



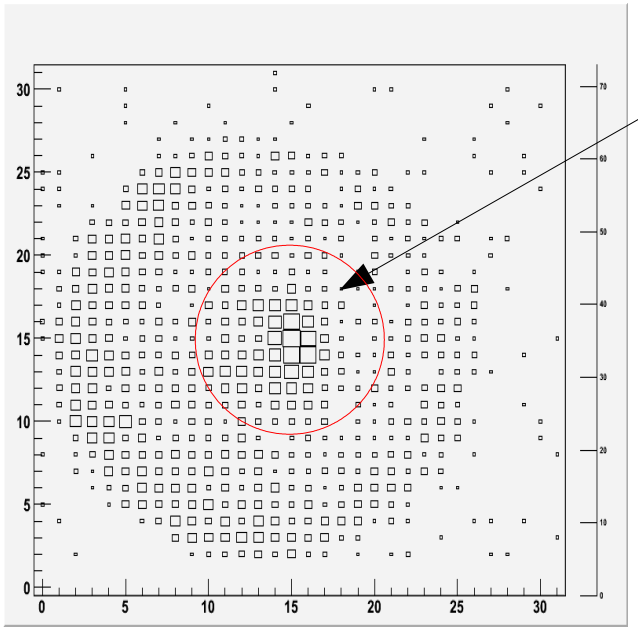
Occupancy = 21.1

2



Occupancy = 83.2

3



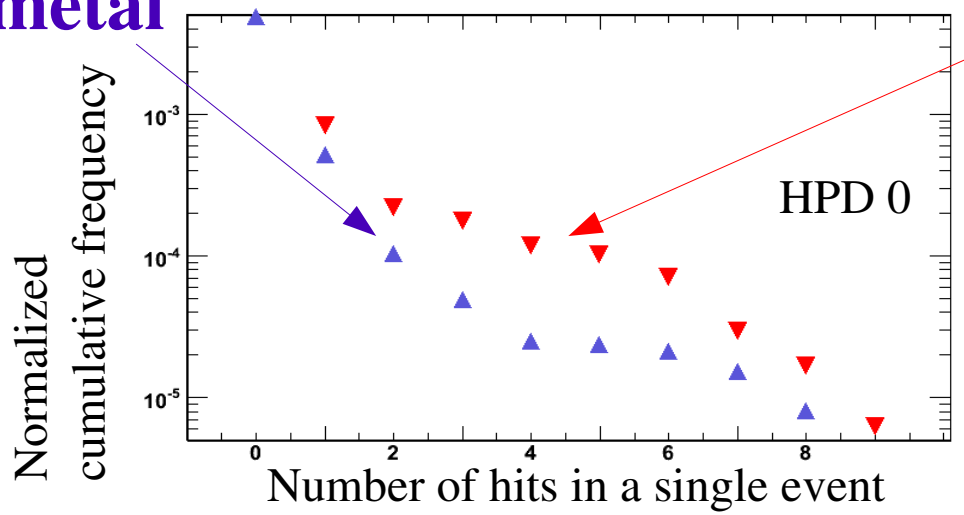
Occupancy = 5.67

- The shielding (proud of the photo-cathode plane) reduces red light detected from the fiber optic data link, leading to an reduction of crescent hits. Can't draw conclusions on edge effects yet...
- Although we can now see a collection of hits in the center.
- For HPDs 0 & 3, occupancy increase ~ ×2.
- For IR sensitive 1 & 2, occupancy decrease ~ ×7.

Event Sizes

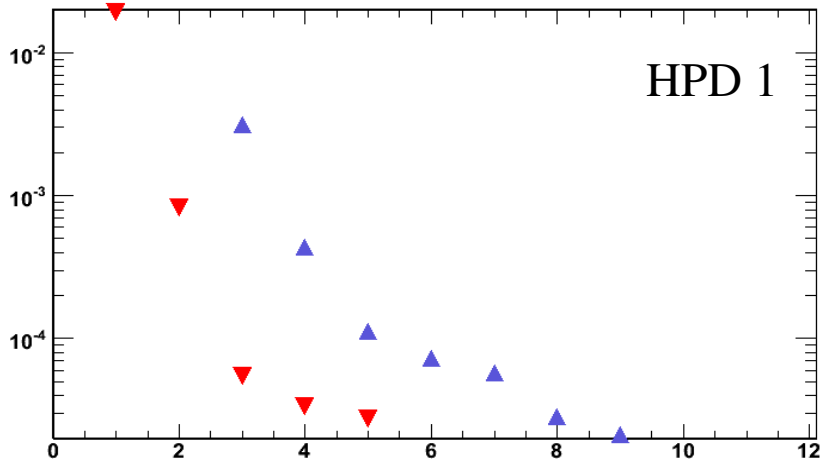
No mu-metal

With mu-metal



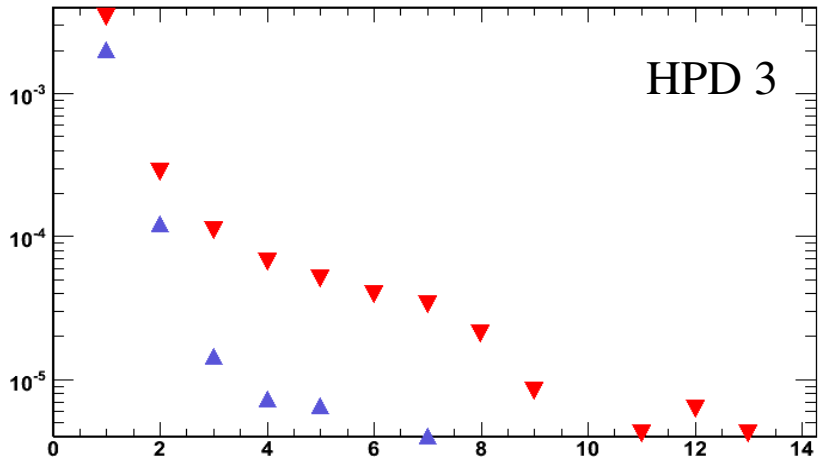
Mean event size = 0.00716

Mean event size = 0.0155



Mean event size = 0.232

Mean event size = 0.0215



Mean event size = 0.00252

Mean event size = 0.00581

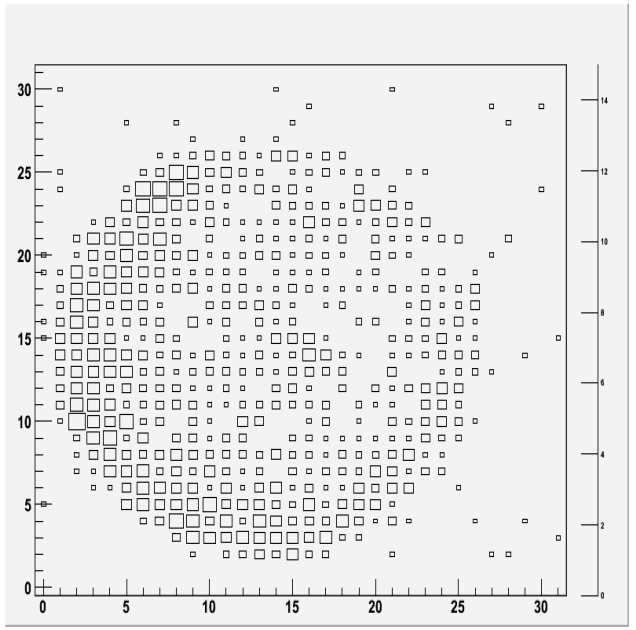
The plot for HPD 1 looks like the plot for HPD 2.

- Note logarithmic scale.
- Looks like two different distributions, one for inside the photo-cathode image, one for the entire silicon plane.
- However there are large events, and for HPDs 0 & 3 we see an increased mean event size...

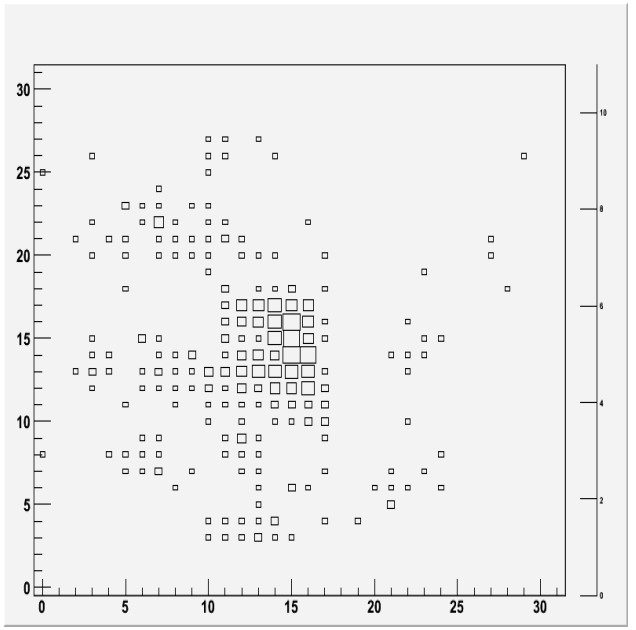
Sources of Clusters

- Randomly large events.
- Ion clustering. This is the result of ionization within the HPD vacuum. This causes a shower of photo-electrons from the photo-cathode. These photo-electrons tend to produce a cluster of hits near the center of the photo-cathode since photo-electrons are focused through a small point on the HPD axis. We could see this in the raw data.
- Micro-discharges from the mu-metal shielding could give clusters of hits on the edge of the photo-cathode image.

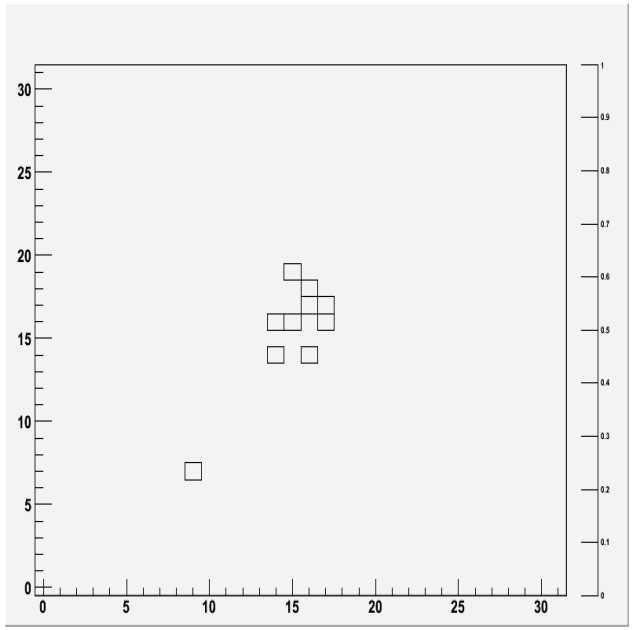
All with mu-metal, all HPD ref. 3.



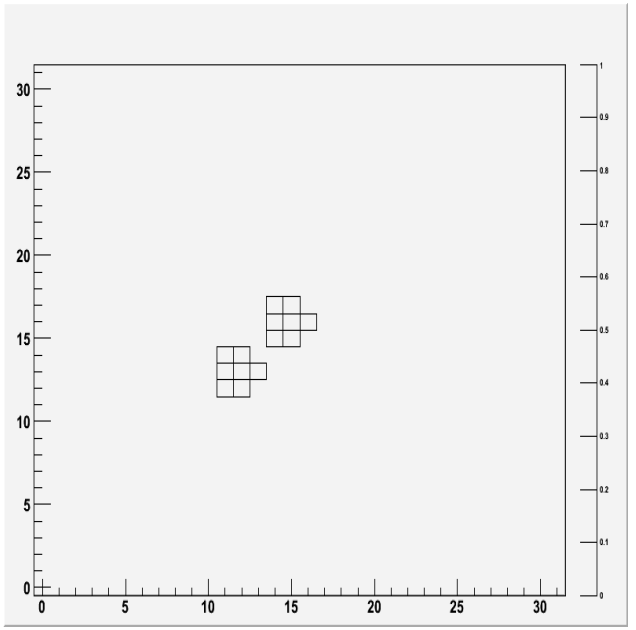
Event sizes = 1



Event sizes = 5, 6 & 7



Event size = 10

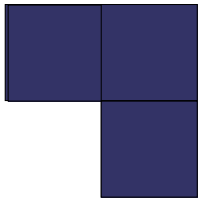


Event size = 14

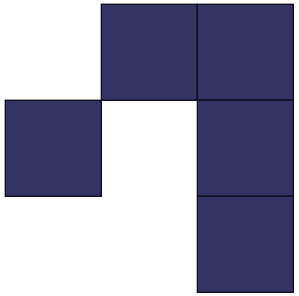
Some Cumulative Events

- These plots are cumulative displays over a run for one HPD of events, each event containing a particular number of hits.
- Ion feed-back always gives a cluster.
- No evidence of large clusters at HPD edge.

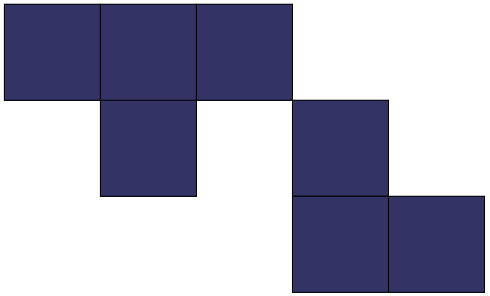
Clustering Algorithm



A cluster of 3 hits.



A cluster of 4 hits and
a cluster of 1 hit (i.e. a single hit).

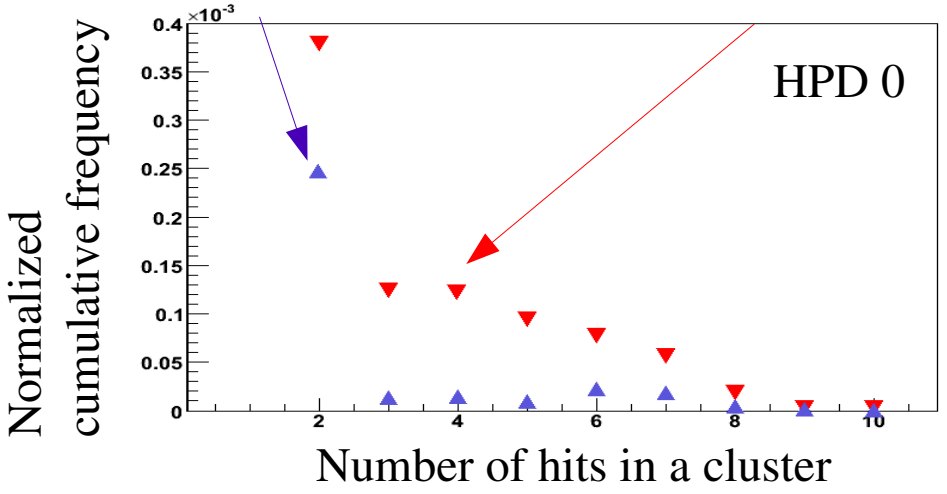


A cluster of 4 hits and a
separate cluster of 3 hits.

Cluster Sizes

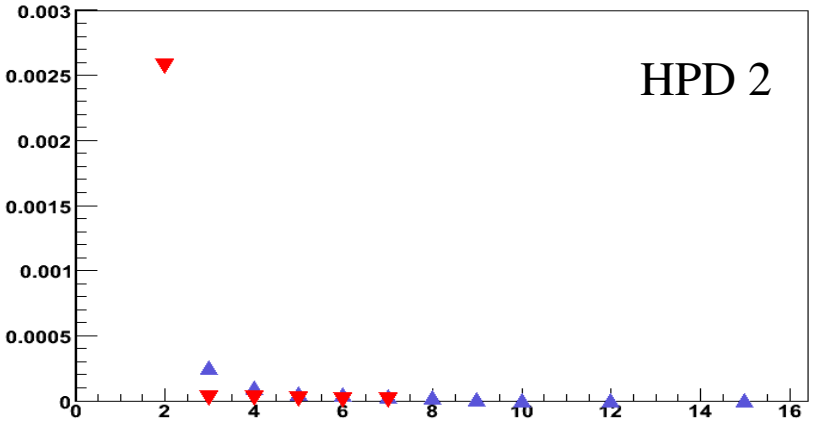
No mu-metal **With mu-metal**

Mean cluster size = 2.93



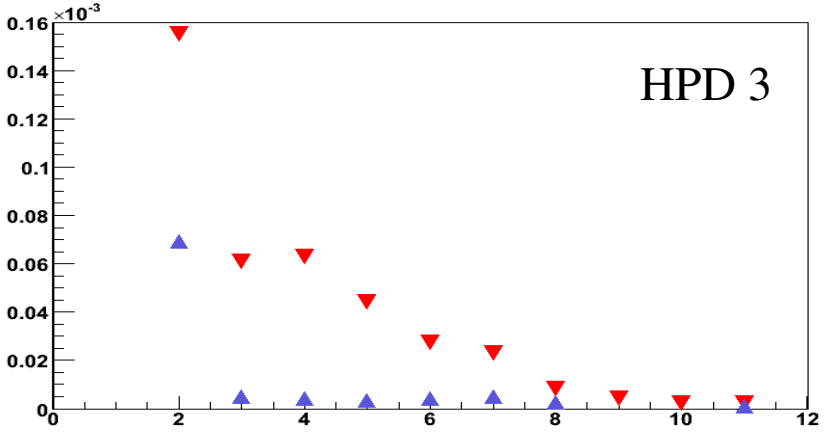
Mean cluster size = 3.58

Mean cluster size = 2.05



Mean cluster size = 2.05

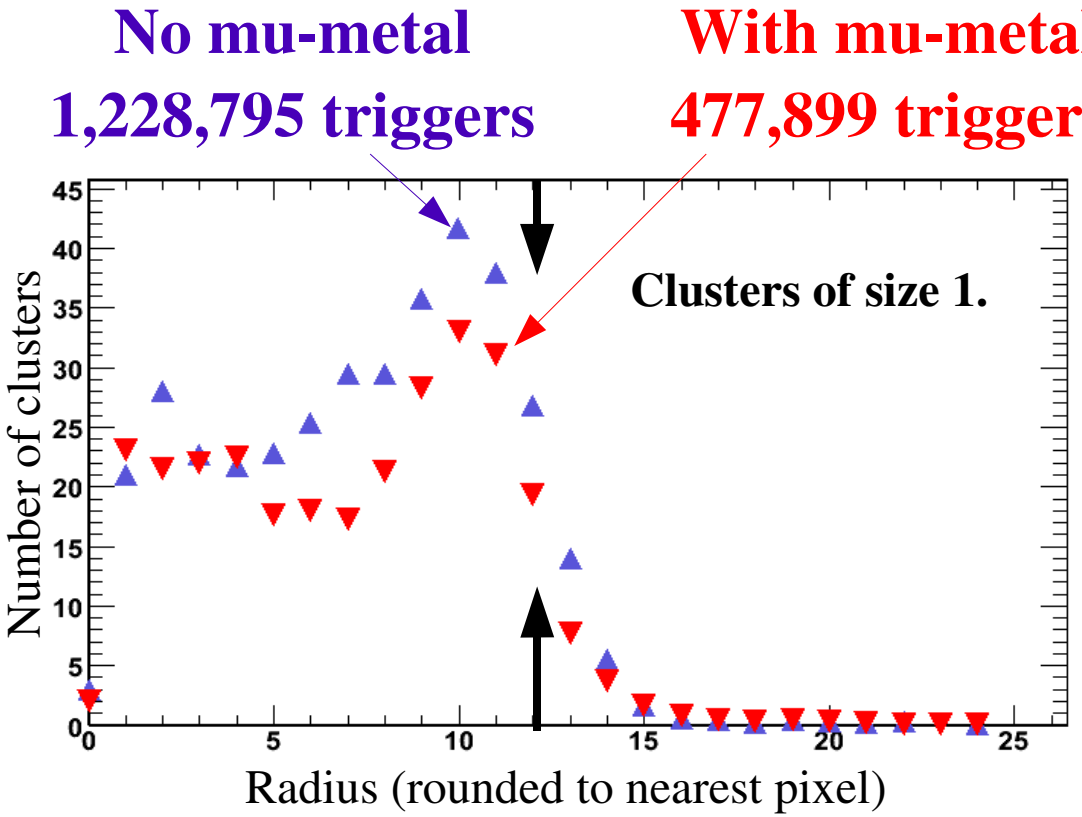
Mean cluster size = 3.00

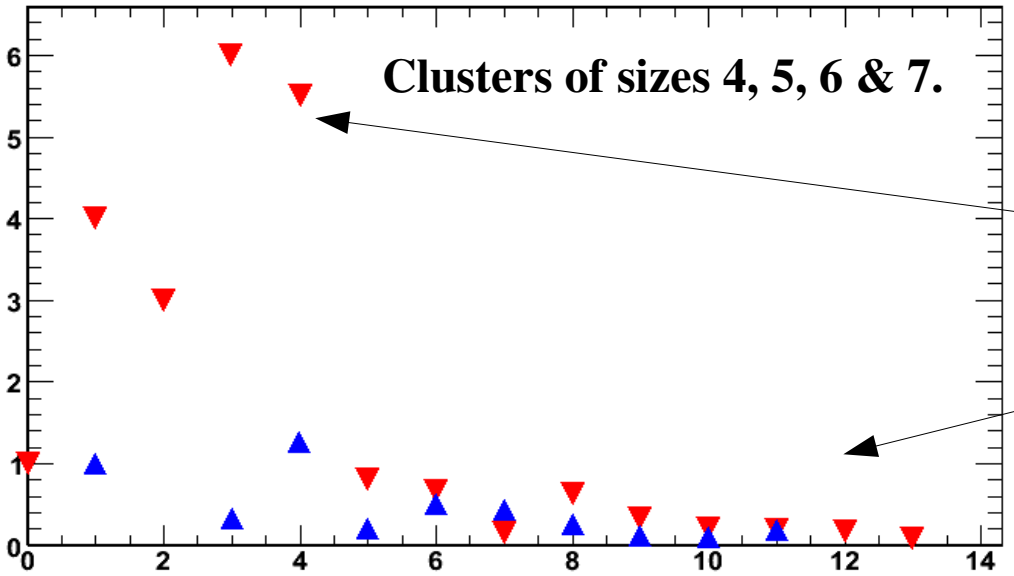


Mean cluster size = 3.69

- The mean here is a truncated mean – does not include clusters of size 1.
- General increase in mean cluster size – more ion feed-back may be occurring...
- To draw conclusions we need to know the position of these clusters from the center of the HPD.

Radial Cluster Position





- Black vertical arrows denote approximate edge of photo-cathode image on pixel chip.
- Note peaks of singletons at edge of HPD. This is due to the visible crescents resulting from red light leaking from the fiber optics. These are single photos, not a result of any discharge.
- Note spikes here due to ion feed-back. These are off center...
- No evidence of micro-discharges at edge due to shielding.

These plots all show HPD ref. 3. The Jacobian is accounted for.

Summary

All numbers in this table are in units of $\times 10^{-6}$.

HPD	No Mu-Metal		With Mu-Metal	
	Occupancy	Clustering Factor	Occupancy	Clustering Factor
0	6.99	16.3	11.5	87.4
1	277	80.4	21.1	18.3
2	512	57.6	83.2	9.94
3	2.47	4.07	5.67	39.2

Occupancy ≡ (total number of hits in a run) / ((number of triggers) * (32 × 32)†)
Clustering factor ≡ (number of clusters of size 4,5,6 & 7) / (number of triggers)

- In HPDs 0 & 3 on addition of mu-metal occupancy increases and clustering increases.
- In HPDs 1 & 2 on addition of mu-metal occupancy decreases and clustering decreases.

Note: our pattern recognition requires a "dark count" occupancy below 10,000 in these units, so we are fine adding mu-metal from this point of view.

† Number of pixels on chip = 32×32 = 1024.

Conclusions

- The noise increases by a factor ~2-3 on adding mu-metal shielding. This is observed in lab tests. This could be due to the increase in temperature when data was taken from HPDs in these runs. This is still (more than) fine for our pattern recognition.
- Ion feed-back always gives a cluster of hits.
- There is no evidence of micro-discharges at the edge of HPDs due to the mu-metal shielding in an array of HPDs.