The Pixel Luminosity Telescope: a Dedicated Luminosity Monitor for CMS

Pixel 2010

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CMS PLT Group

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Importance of Luminosity Monitoring in CMS

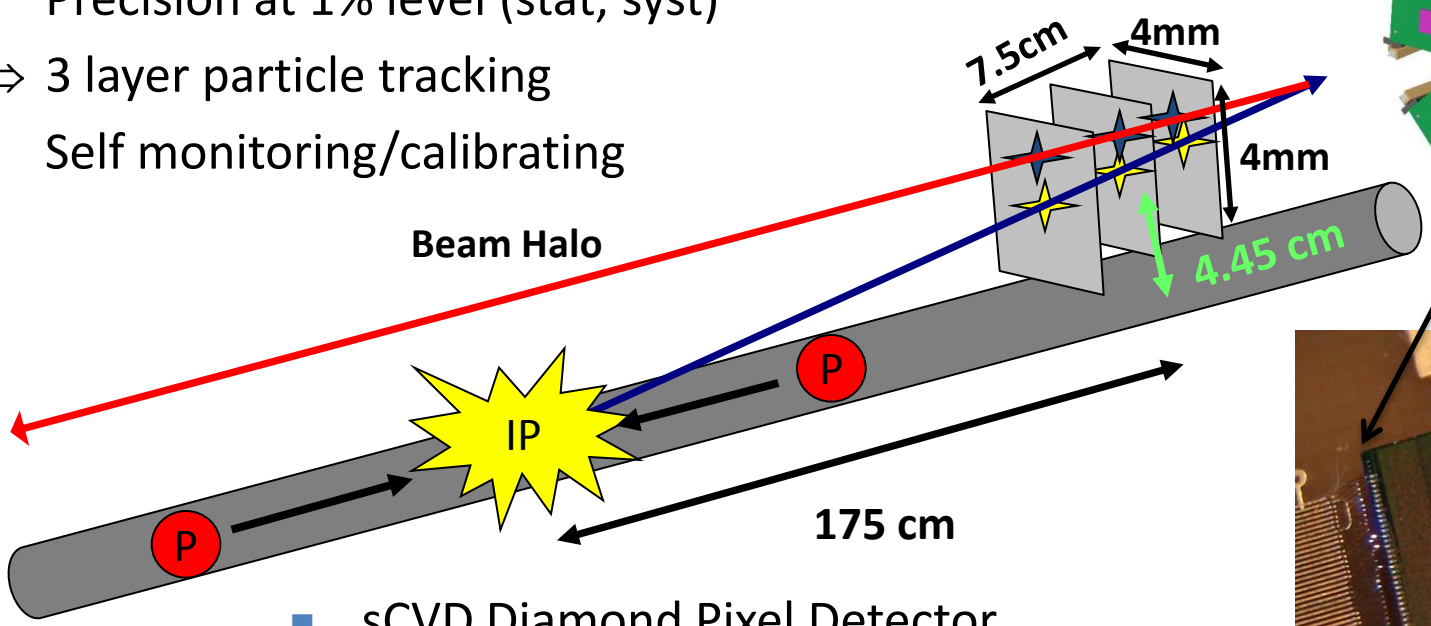
- Limiting systematic in many Tevatron measurements
- Production cross section -> Absolute mass of new particles
- Bunch-by-bunch uniformity
  - Trigger biases
- Instant feedback to accelerator control
  - Instantaneous luminosity
  - Beam quality
- Want to measure luminosity as well as possible ➔PLT

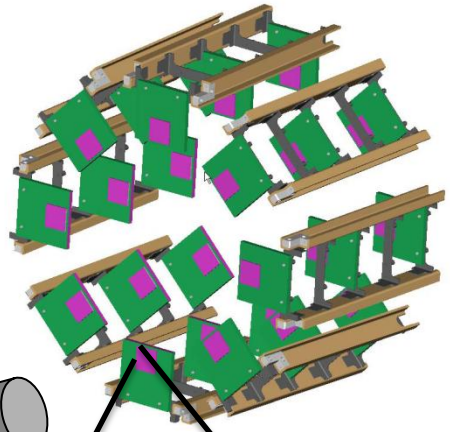
The Pixel Luminosity Telescope (PLT)

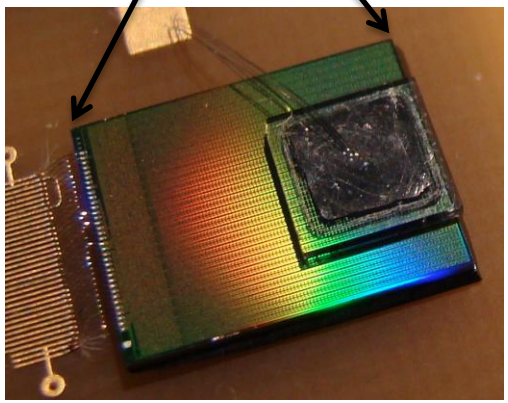
- Relative bunch-by-bunch luminosity measurement
- Independent of CMS (self-triggered)
- Precision at 1% level (stat, syst)

⇒ 3 layer particle tracking

Self monitoring/calibrating



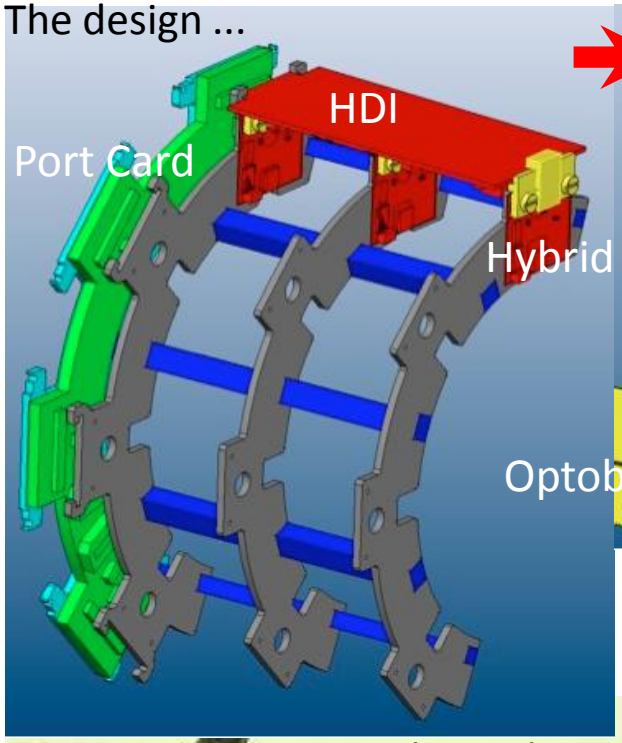


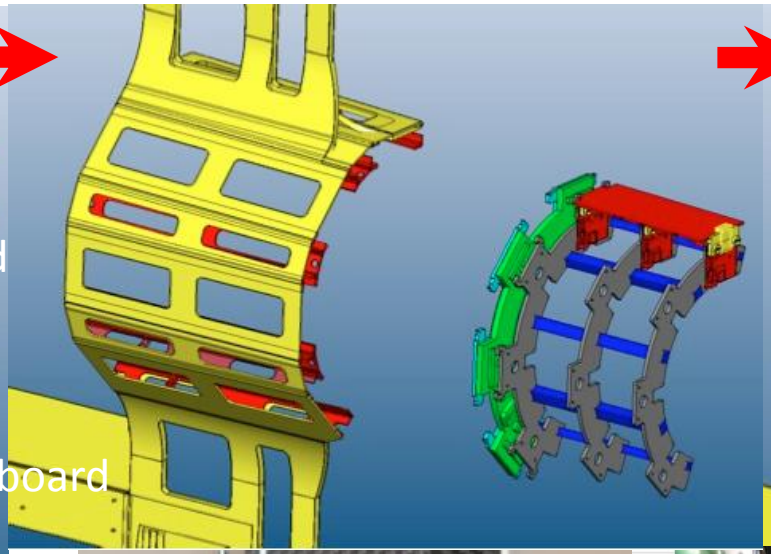


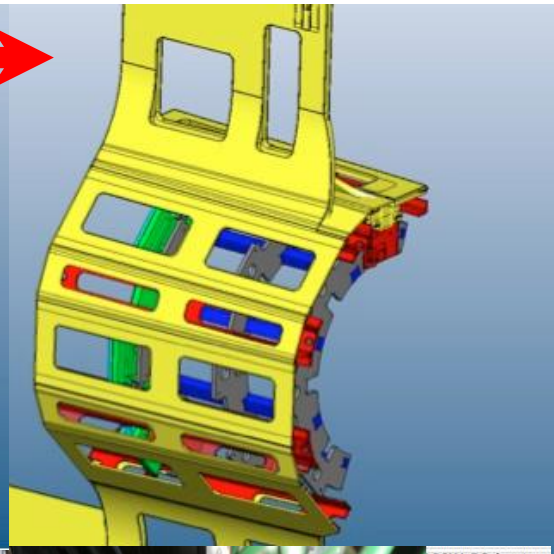
- sCVD Diamond Pixel Detector
  - Fast OR readout (3-layer coincidence): online luminosity information
  - Full pixel readout (1-10 kHz): alignment, luminous region, background studies, etc.

PLT Mechanics

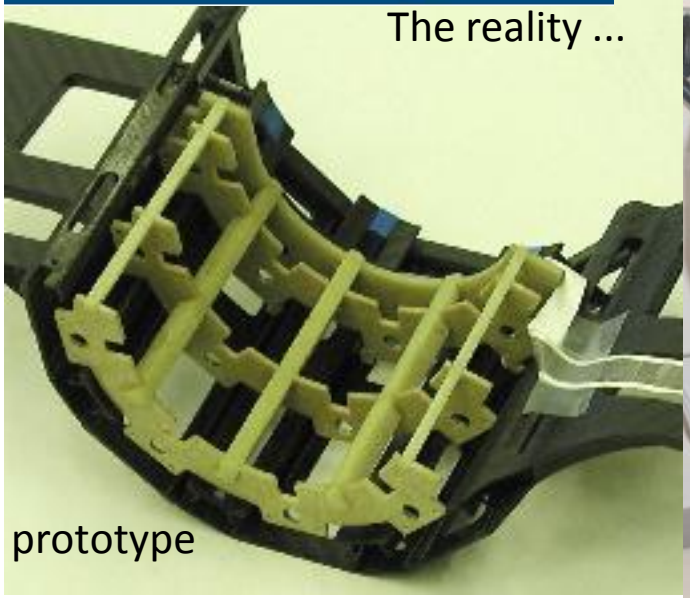
The design ...



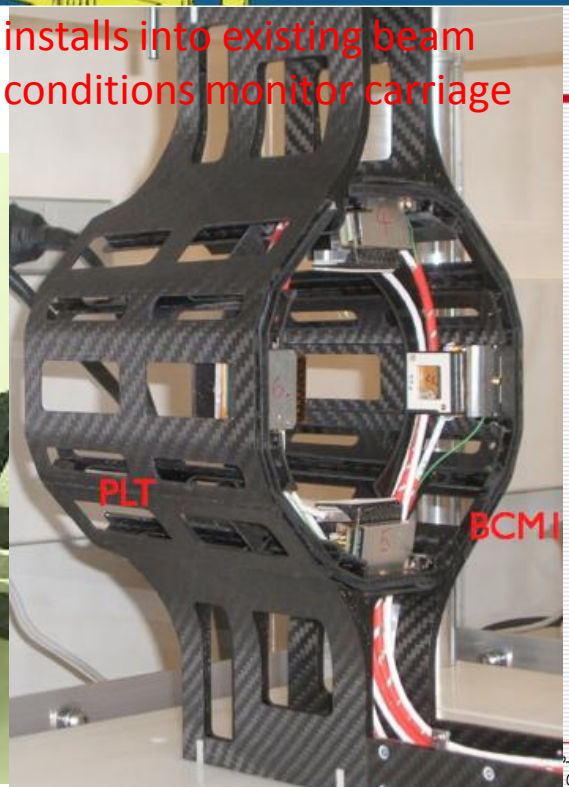


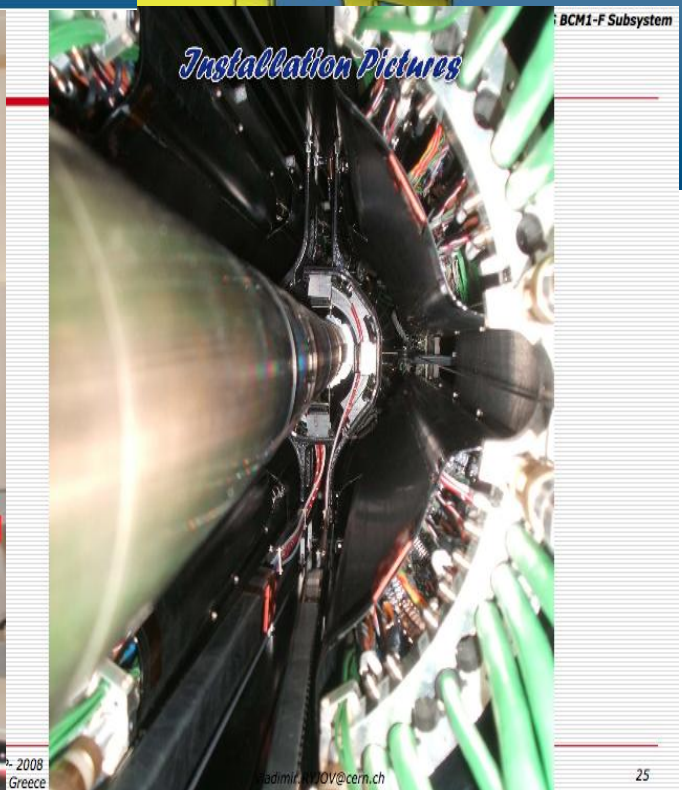


The reality ...



installs into existing beam conditions monitor carriage

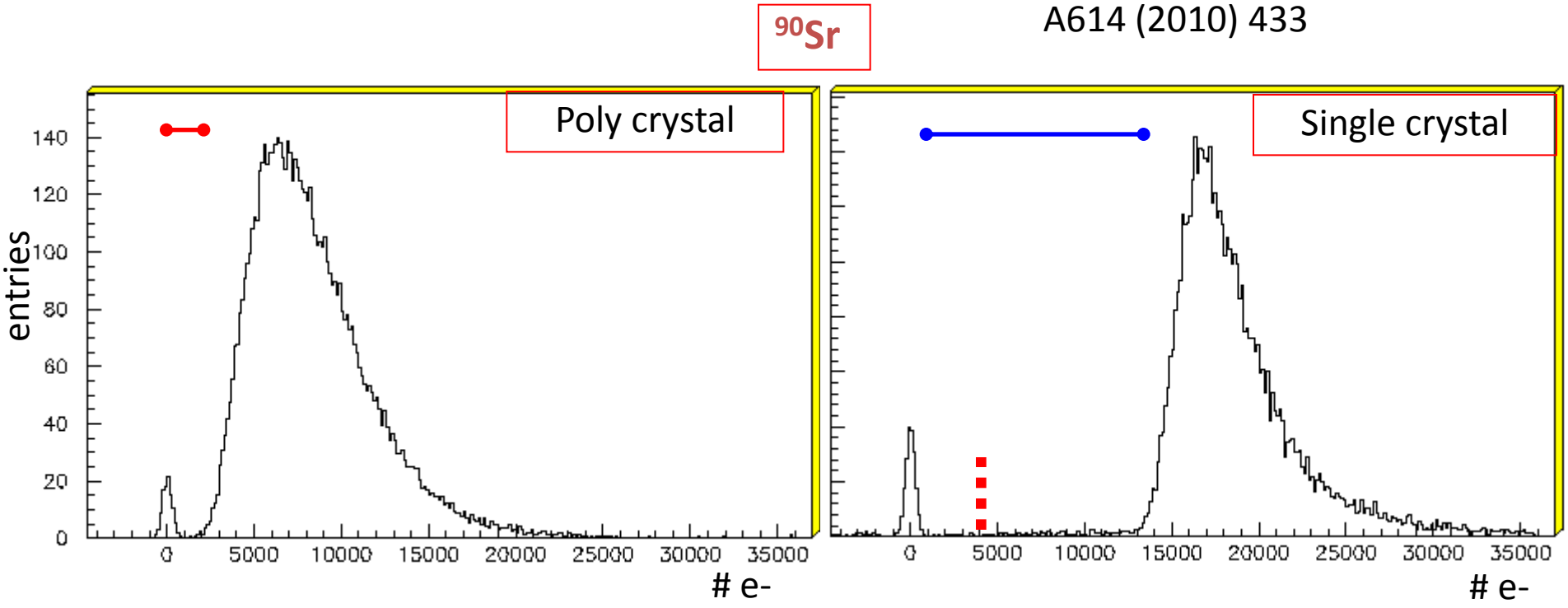




Single-Crystal Diamond Detector (sCVD)

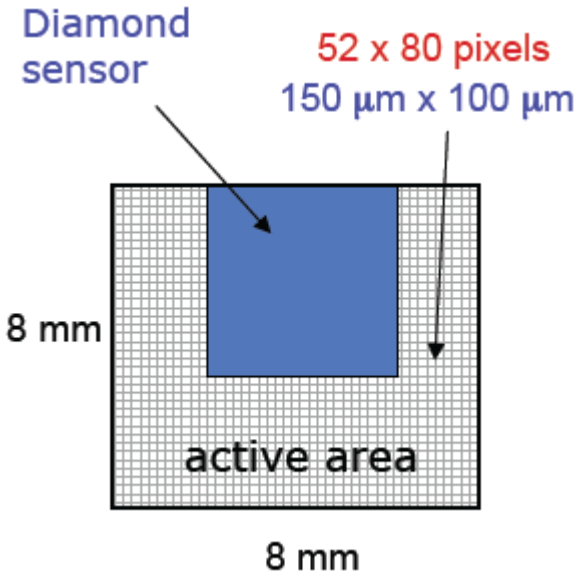
- Radiation hard (survives > 2 x 10^{15} p/cm^2)
- No need for cooling
- Full charge collection at E-field < 0.2V/um
- Fast signal collection (~1ns from 500 um)
- Pulse height well separated from pedestal

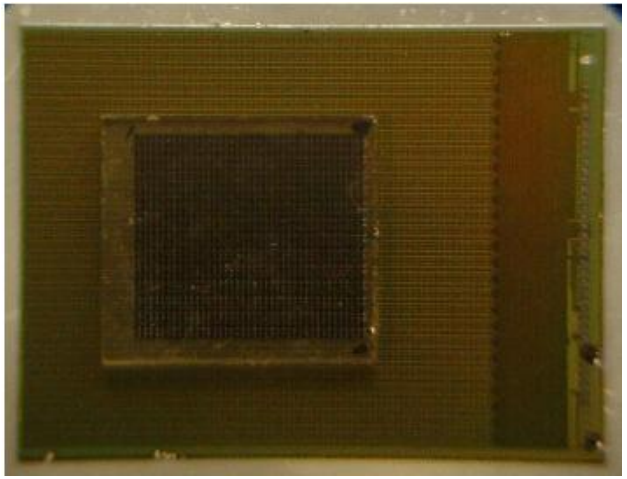
- BCM1F is currently the largest implementation of sCVD diamond
  - W. Lohmann et al., "Fast Beam Conditions Monitor BCM1F for the CMS Experiment", NIM A614 (2010) 433



Readout

- CMS Pixel chip (PSI46) bump-bonded to sCVD
- Has fast cluster counting in double-columns built in
- Individual pixel thresholds adjustable
- Individual pixels can be masked
- Self-triggered by Fast Or readout
- Full analog readout of
  - Hit address
  - Charge deposit
- Standard pixel readout (FEC, FED [ADC])
- FED has custom firmware for Fast Or



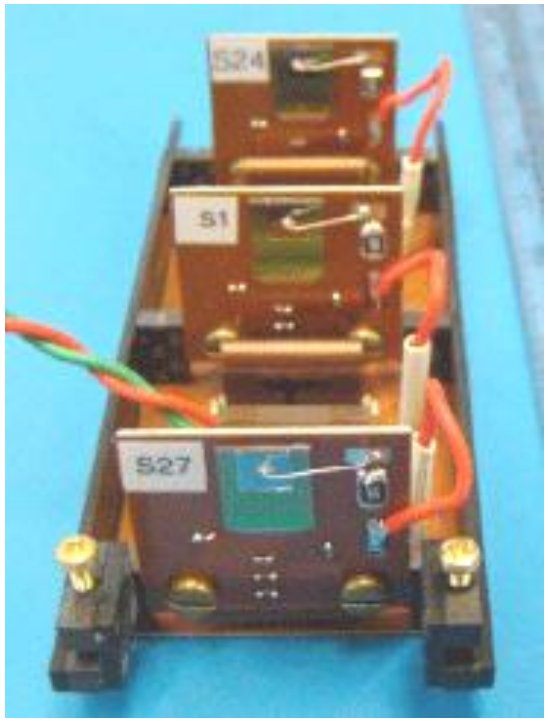


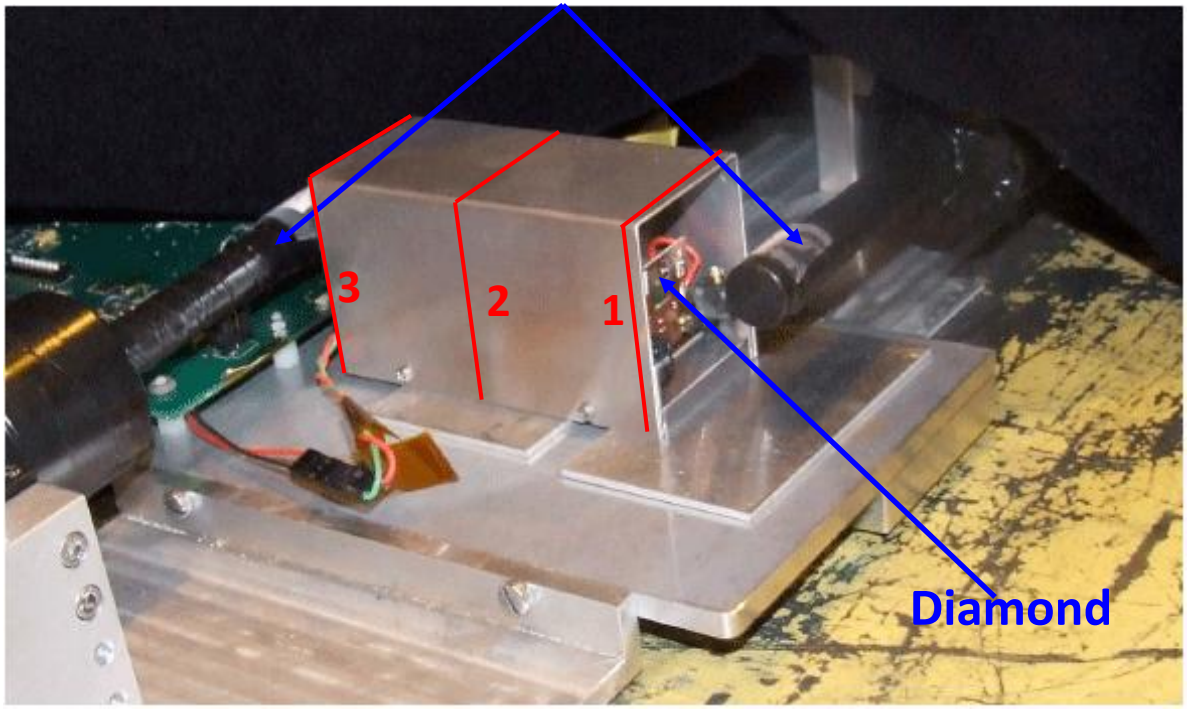
Bump bonded at Princeton micro-fab lab

CERN SPS – May 2009

- 150 GeV/c π+
- 2 days of beam time
- Used electrical FED and FEC

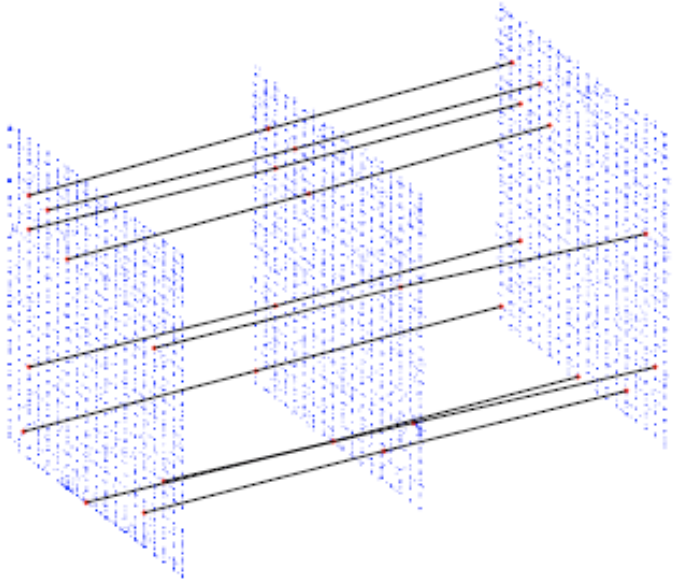
Small (6x6 mm) Scintillators
(used as triggers)

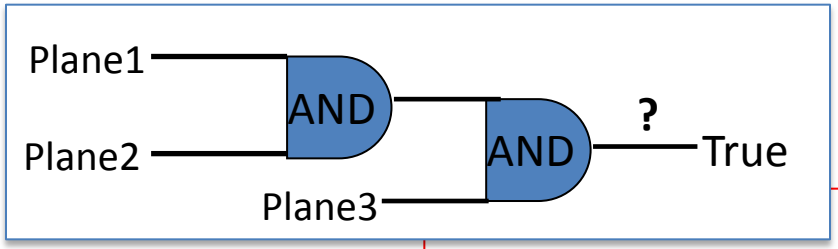




Efficiencies

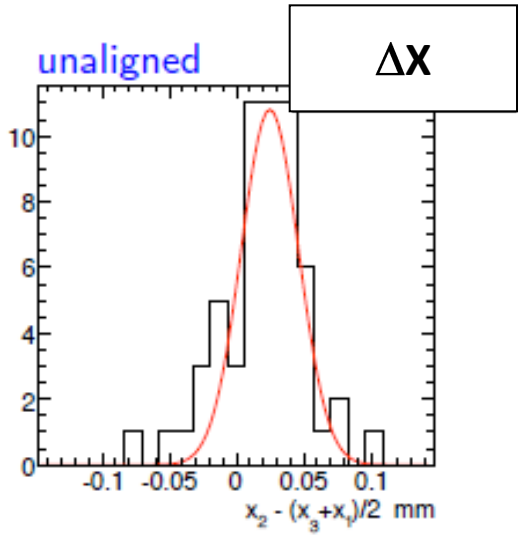
- Fiducial area
  - Masked border rows/columns
  - Removed columns in the shadow of the entrance counter
- Dead pixels
  - Plane 1: 1.8%
  - Plane 2: 2.2%
  - Plane 3: 0.1%
- Bump bonding efficiency
- Fast Or Efficiency:

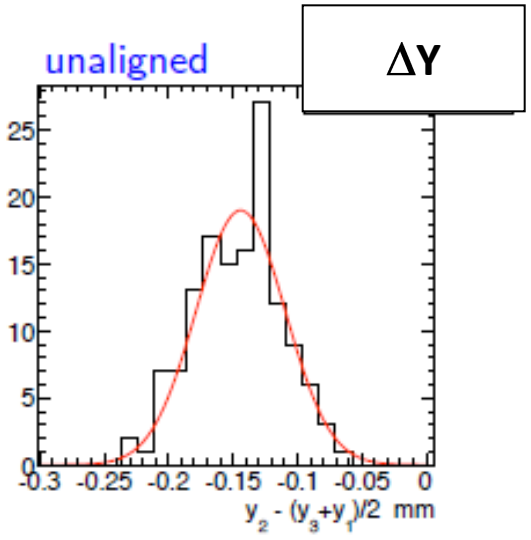


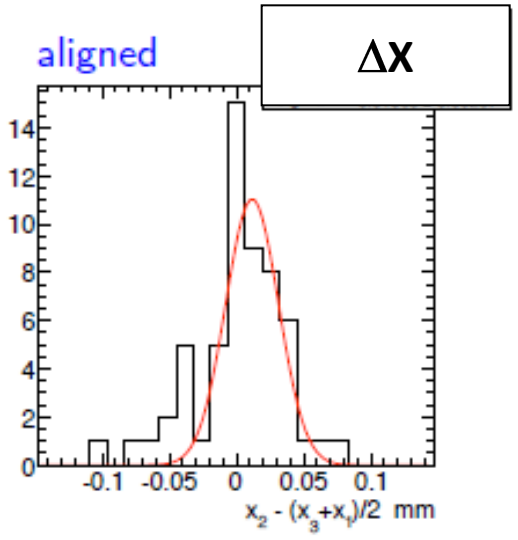


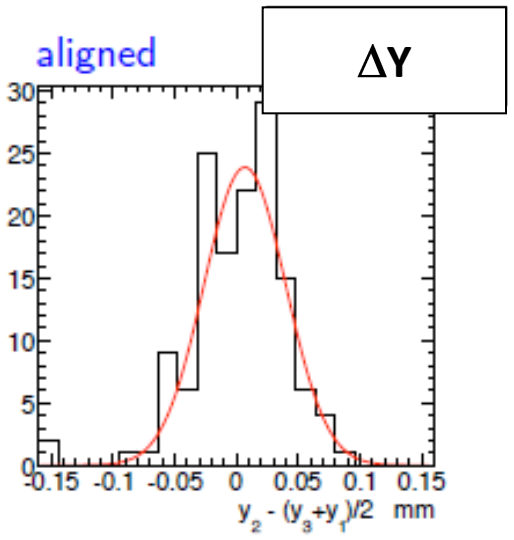
	Plane 1	Plane 2	Plane 3
Measured Efficiencies	99.3%	99.6%	99.9%

Alignment





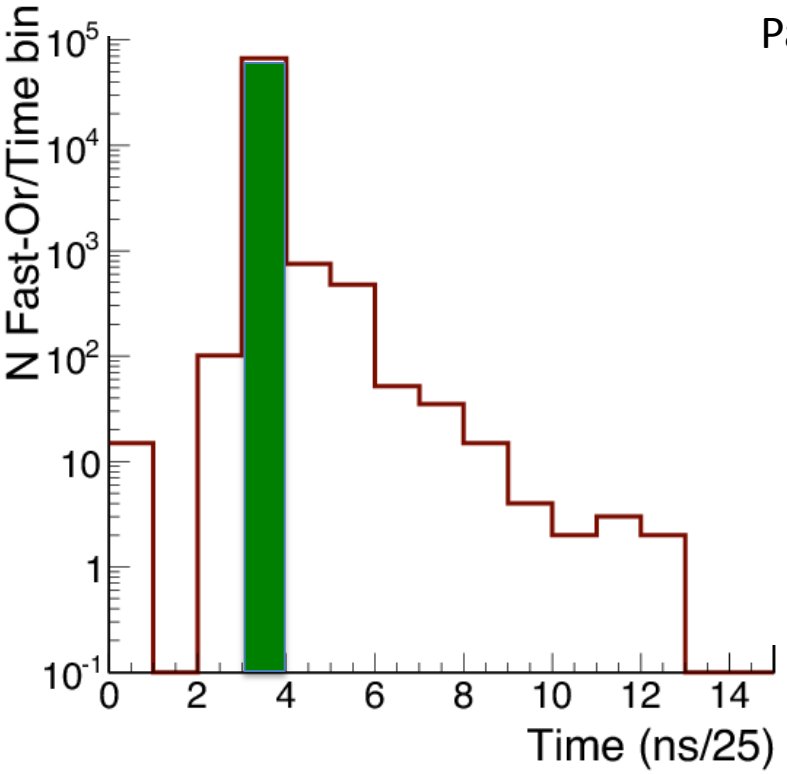


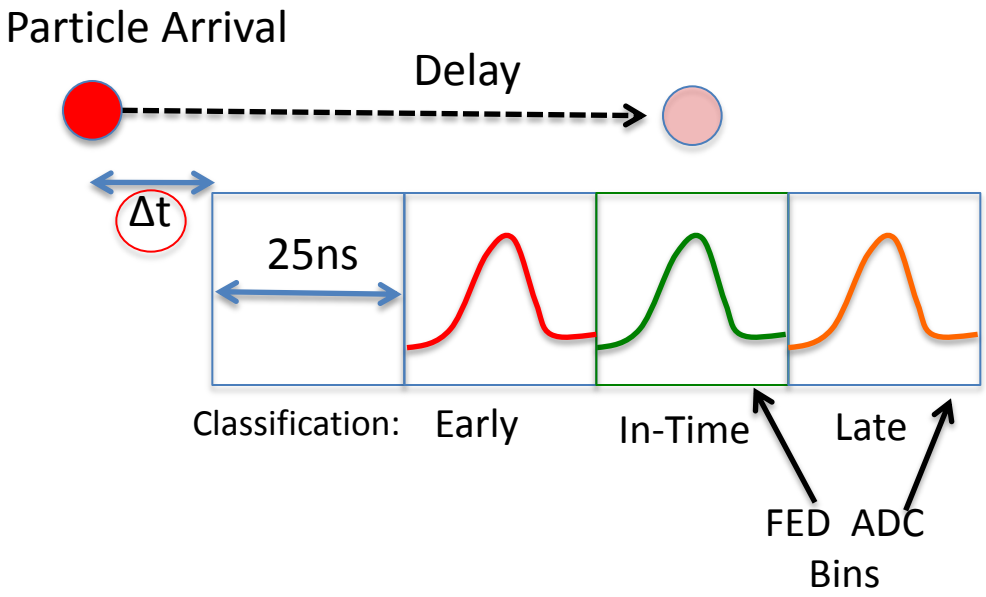


- Successfully reconstructed tracks
  - Hit position defined as the "center of charge" (charge sharing)
- Define residual: $x_2 - (x_3-x_1)/2$
- Alignment
  - X offset: 25 ± 5 um
  - Y offset: 144 ± 3 um
- Even with only a few tracks, a successful alignment was achieved
  - X alignment: 57 tracks
  - Y alignment: 140 tracks

Fast Or

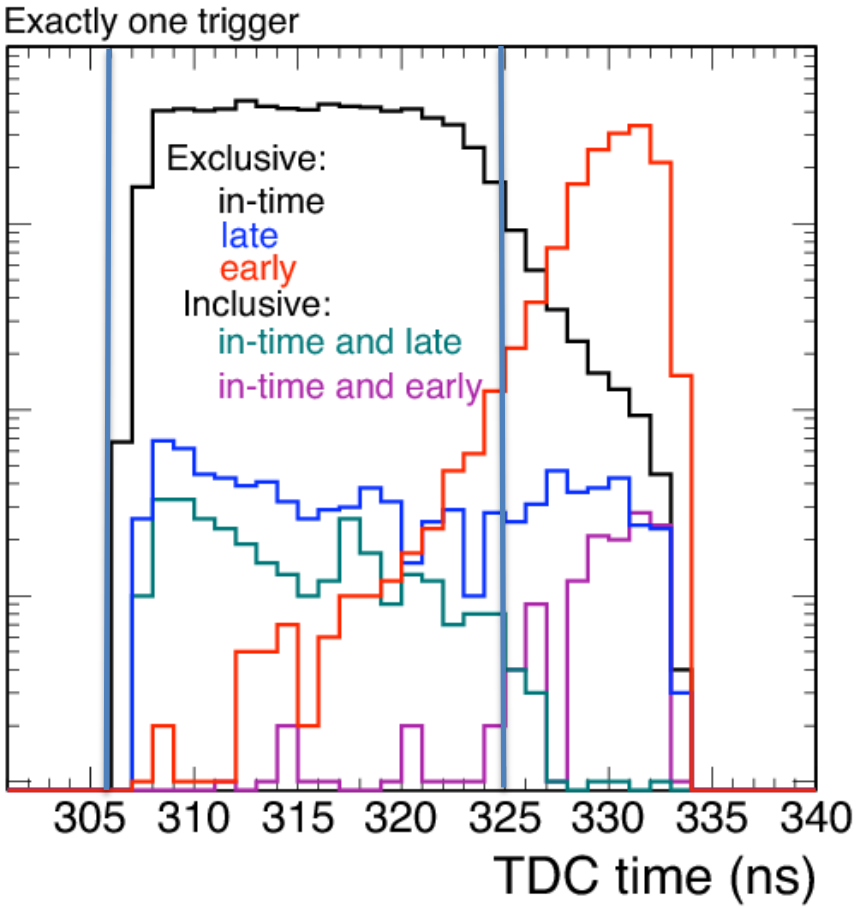
- FNAL Mtest – March 2010, 80 GeV pions
- Full optical readout used (including Fast Or)
- Studied timing of Fast Or with a Multi-Hit TDC
- Triggered on scintillator coincidence





Fast Or Timing Studies

- Beam out of sync with the system clock -> time walk effects exaggerated
- Select out in-time particle arrivals with TDC -> measure early, late, and on-time Fast Ors in LHC operating conditions

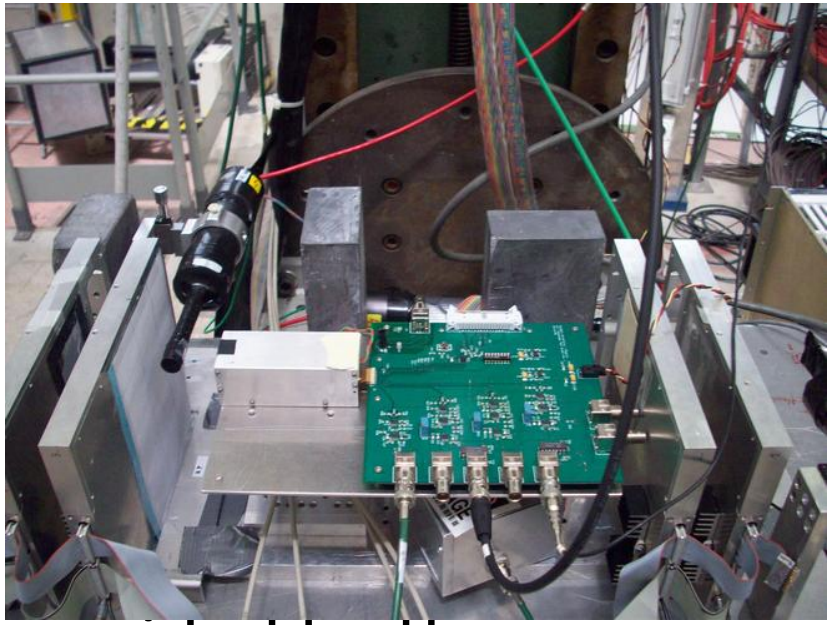


- Exclusive: only one Fast Or
- Inclusive: in-time + early or late

	Exclusive	Inclusive
Early	0.13%	0.01%
Late	0.84%	0.38%

- Exclusive events -> errors in relative bunch-by-bunch luminosity measurement
- Inclusive events-> errors in overall luminosity measurement (overcount)
- Meets goal of 1% systematic error

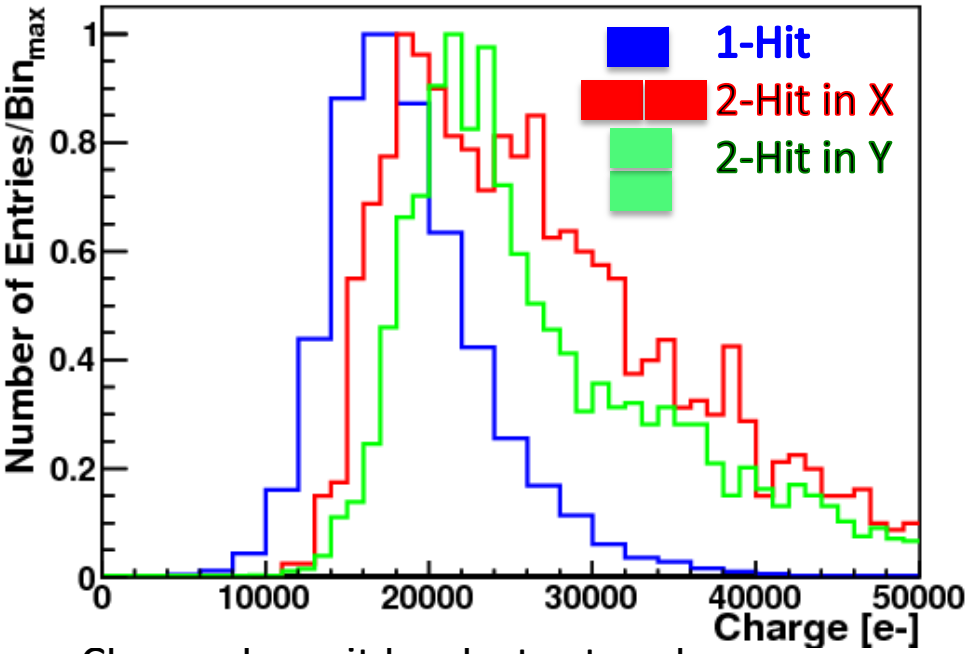
CERN PS T9 – May 2010



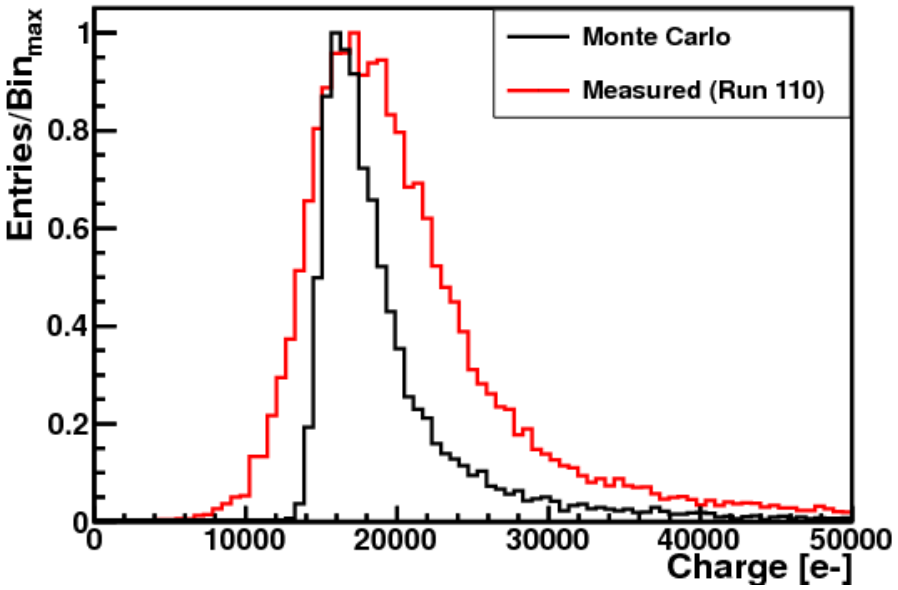
- Beam composition
  - 60% protons
  - 35% pions
  - 10 GeV
- 3 weeks of beam
  - 90% time running
- Included Si Strip tracker, provided by the University of Zurich
  - Intrinsic resolution of 2 um per plane
  - Resolution limited by multiple scattering

Charge Deposit

- Signal/Threshold = ~16000/3000 =5.3
- Broadening effects
  - Calibration Error
  - Beam out of time with system clock
  - Broken clusters



Charge deposit by cluster topology

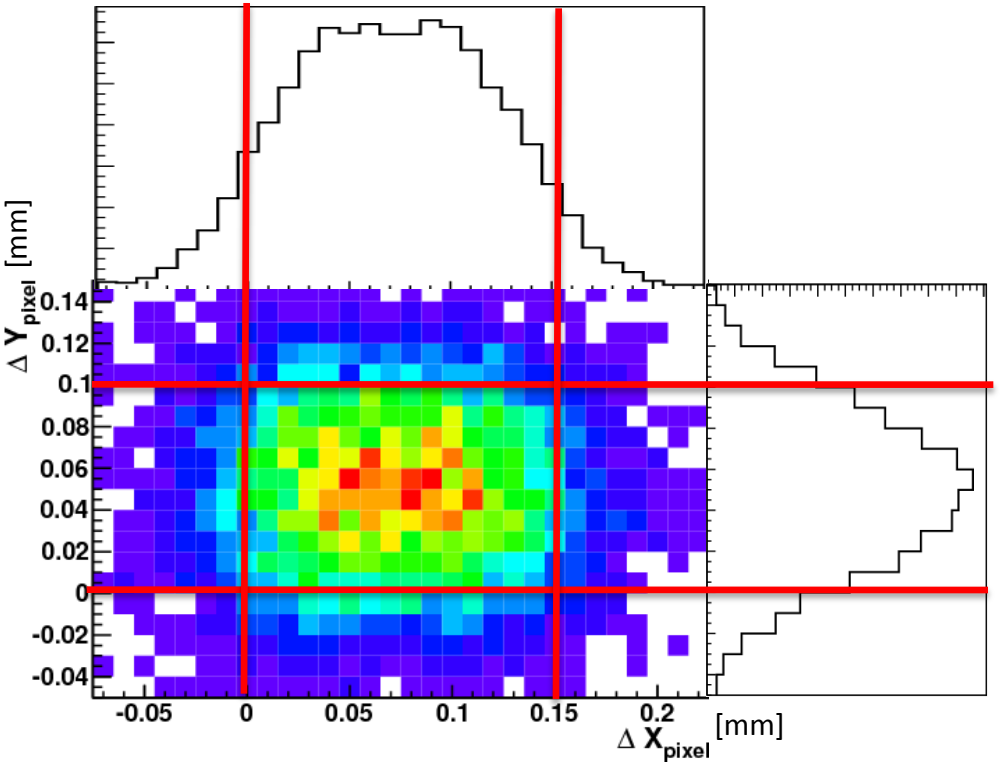


Charge deposit for all 1-cluster events (all cluster topologies included)
Normalized to the maximum point

In-Pixel Occupancy: 1 Hit Events

- Position in the pixel is calculated with respect to the lower left corner
- $\Delta x_{pixel} = x_{track} - col*(150\ [\mu m])$, $\Delta y_{pixel} = y_{track} - row*(100\ [\mu m])$

- The red box corresponds to the pixel area
  - 150 µm x 100 µm

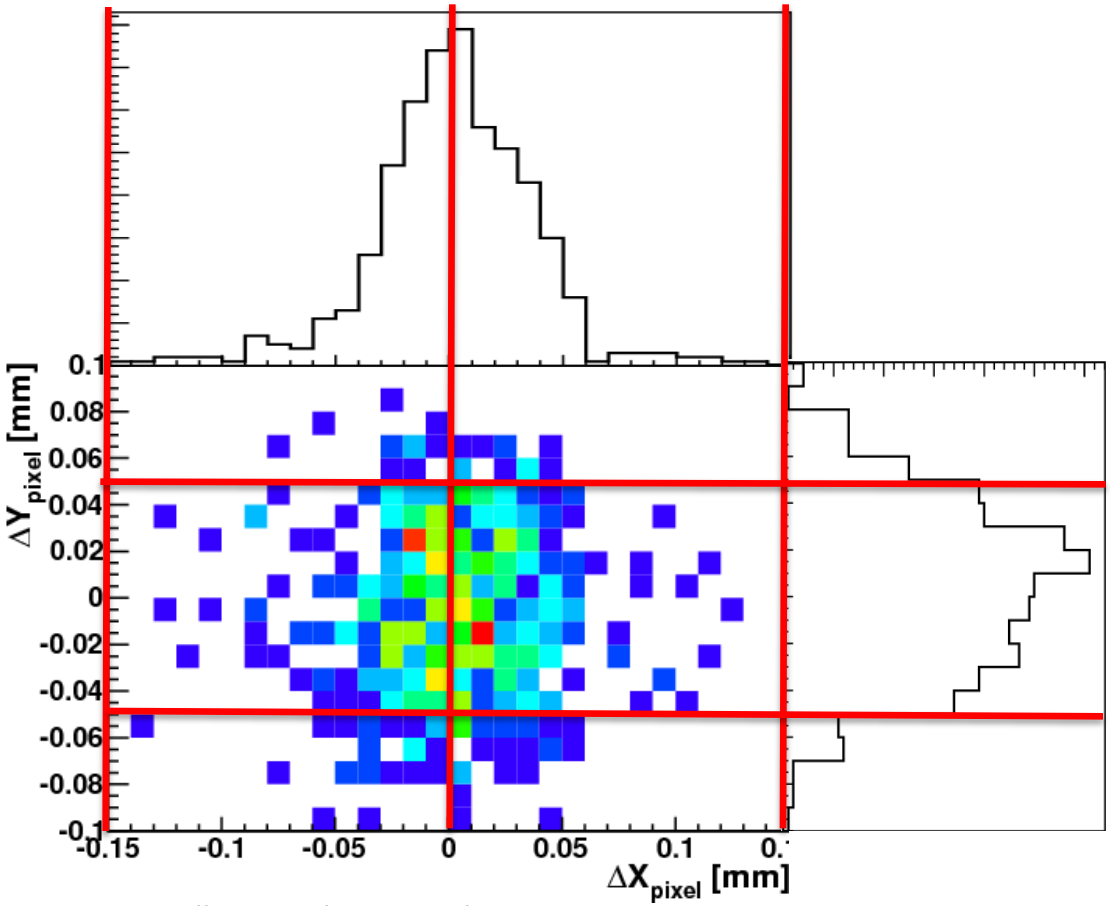


In Pixel Occupancy: 2 Hit "XX" Clusters

- $\Delta X_{border} = (x_{track} \% d_x - \delta)$
  - δ is a phase factor used to adjust border position to 0
- 0 corresponds to the border between the pixels

Cluster configuration

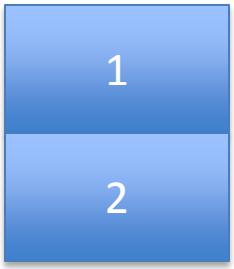
- The red boxes represent the area of the component pixels



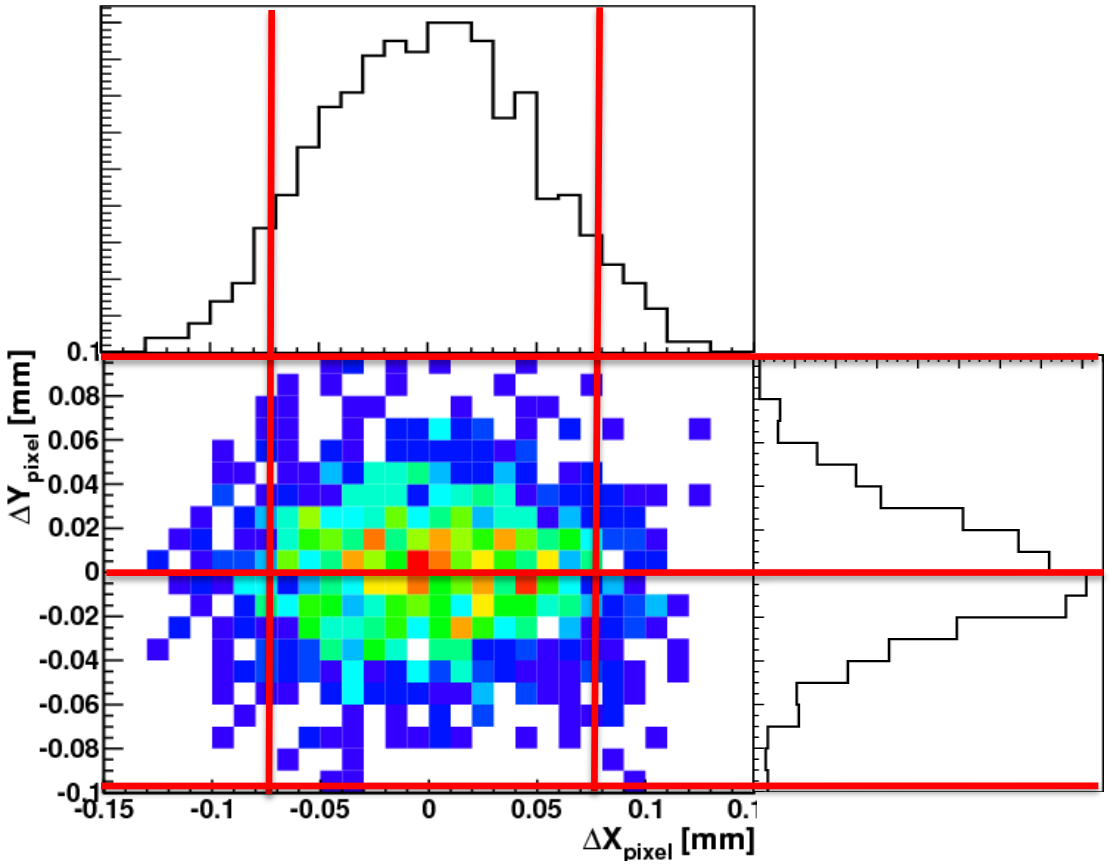
In Pixel Occupancy: 2 Hit "YY" Clusters

- $\Delta Y_{border} = (y_{track} \% d_x - \delta)$
  - δ is a phase factor used to adjust border position to 0
- 0 corresponds to the border between the pixels

Cluster configuration



- The red boxes represent the area of the component pixels

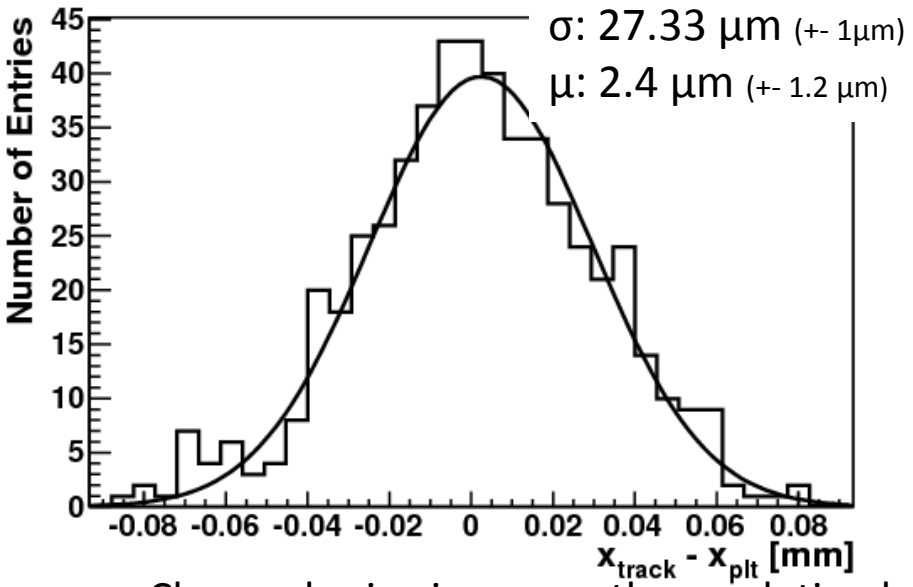


2-Hit residuals with η-based correction

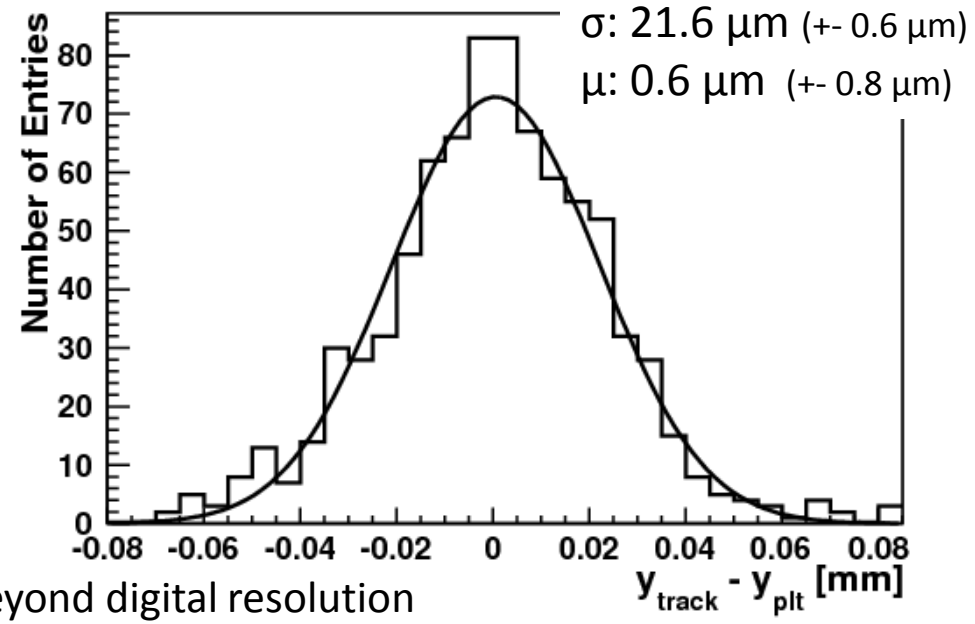
- Residuals: $\Delta_x = x_{track} - x_{plt}$, $\Delta_y = y_{track} - y_{plt}$
- Required that there is exactly 1 hit in the PLT
- Includes $\eta = Q_r/(Q_r+Q_l)$ correction

Perpendicular Tracks

Entries: 588
σ: 27.33 μm (+- 1μm)
μ: 2.4 μm (+- 1.2 μm)



Entries: 823
σ: 21.6 μm (+- 0.6 μm)
μ: 0.6 μm (+- 0.8 μm)

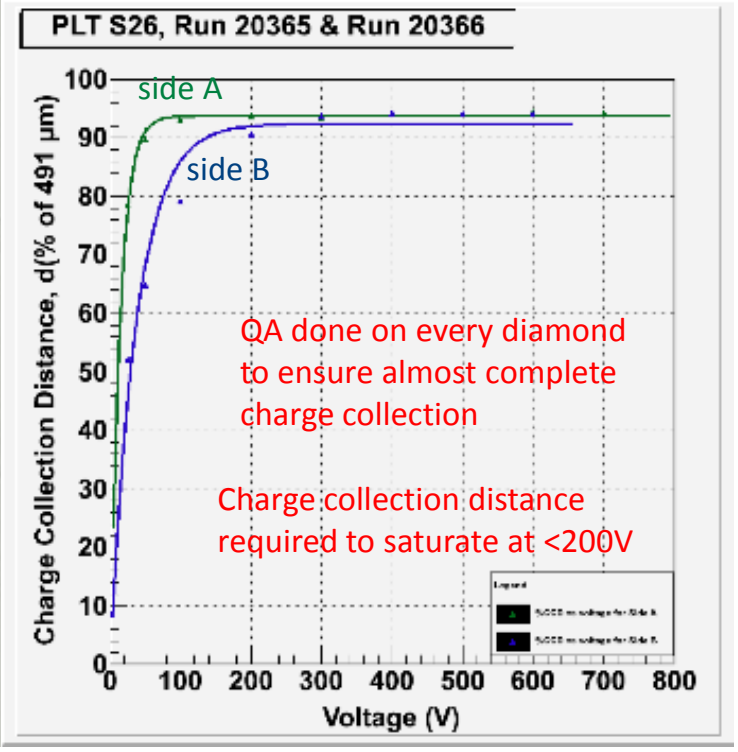


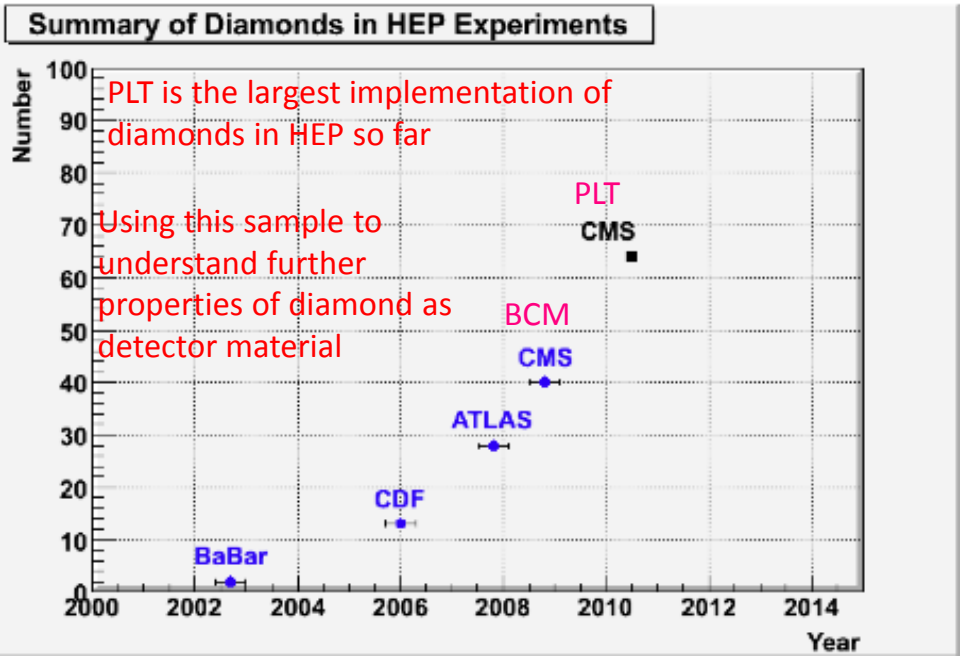
- Charge sharing improves the resolution beyond digital resolution
- Efficiency goes down significantly (90% drop for perpendicular tracks) when requiring 2-hit clusters

Digital Resolution
X : 43. 3 μm
Y : 28.9 μm

Production

- sCVD diamonds from Diamond Detectors
- Diamond Characterization done at Rutgers
- Bump bonding at PRISM





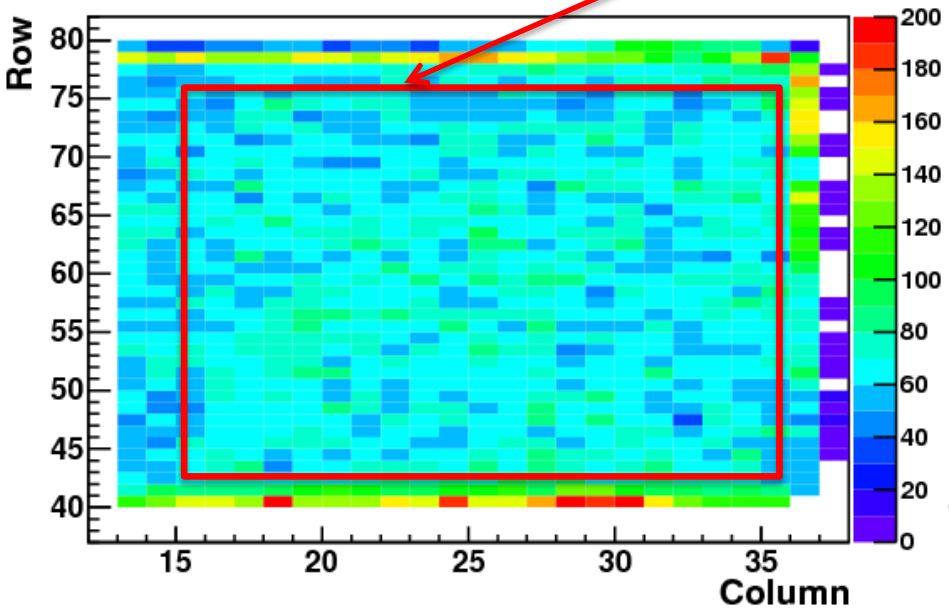
Conclusions

- PLT is a dedicated luminosity monitor for CMS based on sCVD diamond detectors
  - 1% statistical precision on bunch-by-bunch luminosity in ~1s
  - Precision realtime monitoring of IP centroid
  - Monitoring of beam halo and beam abort gap
- Will provide information on operation of diamond detectors
  - Diamond tracking performance and efficiency
  - Long-term high radiation environment
- E. Bartz et al., “Results from a beam test of a prototype PLT diamond pixel telescope”, NIM A (2010)

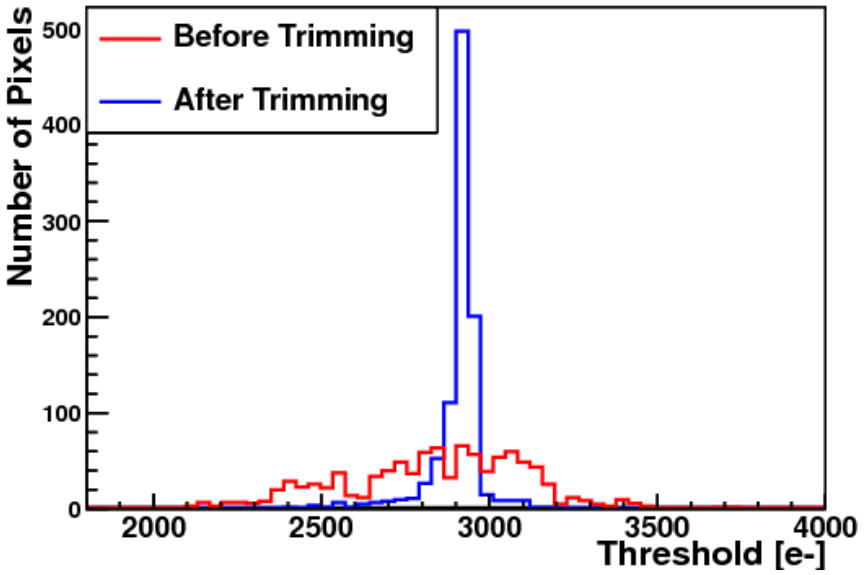
Backup

Event Selection/Characterization

- Trimmed per-pixel thresholds to 3000 e-
- ADC -> Charge conversion done using PSI46 charge injection facility
- The border region was excluded



Red box indicates analyzed region



Pixel thresholds before and after trimming

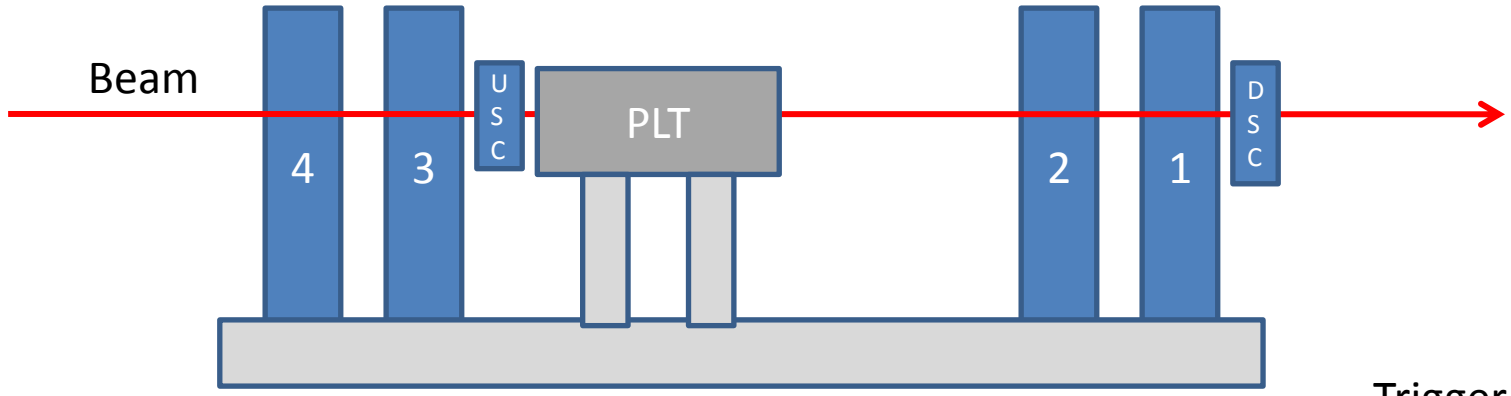
- Exactly one cluster, defined as a collection of adjacent hits, also required

PLT Performance – Test Beams

- Test beams
  - 2009 : CERN SPS
    - Efficiency
  - 2010 : FNAL Mtest
    - Optical Readout Characterization
    - Fast Or signal timing studies with TDC
  - 2010 : CERN PS
    - Long-running systematics
    - In-pixel occupancy
    - Spatial Resolution

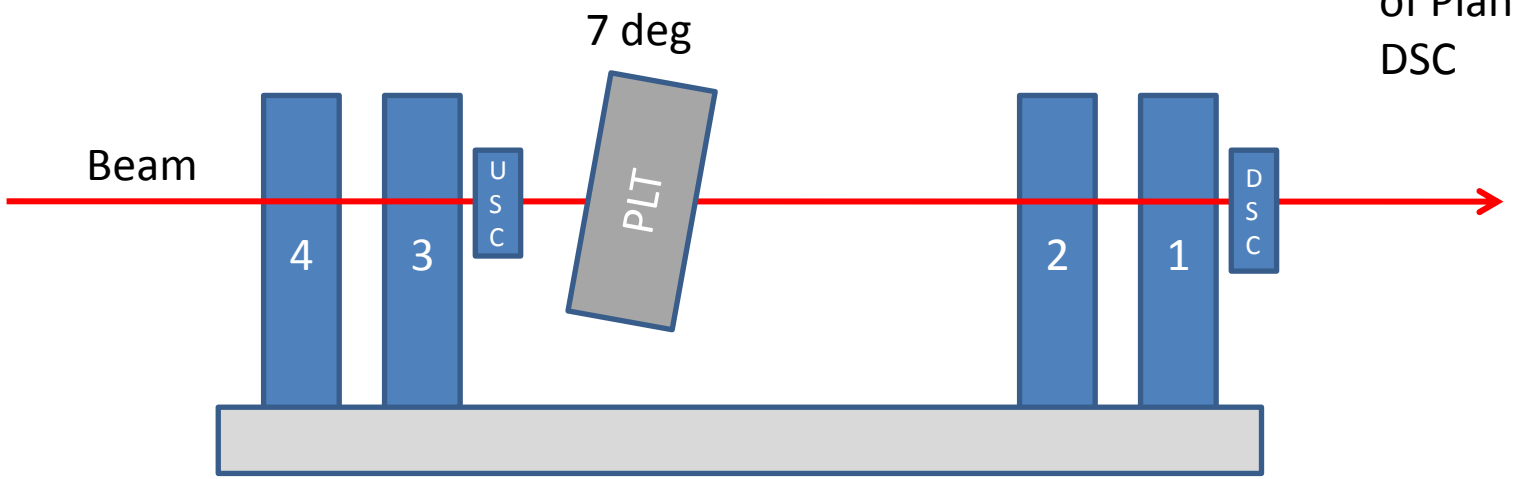
Setup

Configuration 1



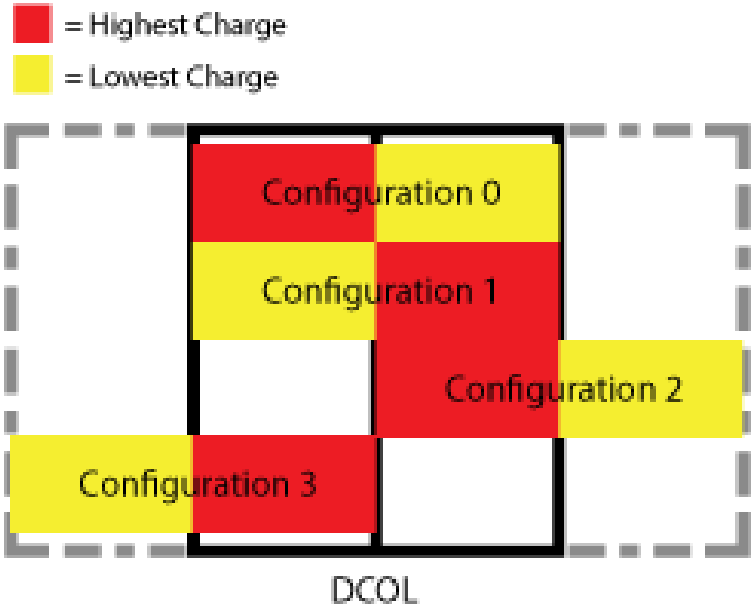
Trigger for most of the runs: Fastout of Plane 2 + DSC

Configuration 2



DCOL Configurations

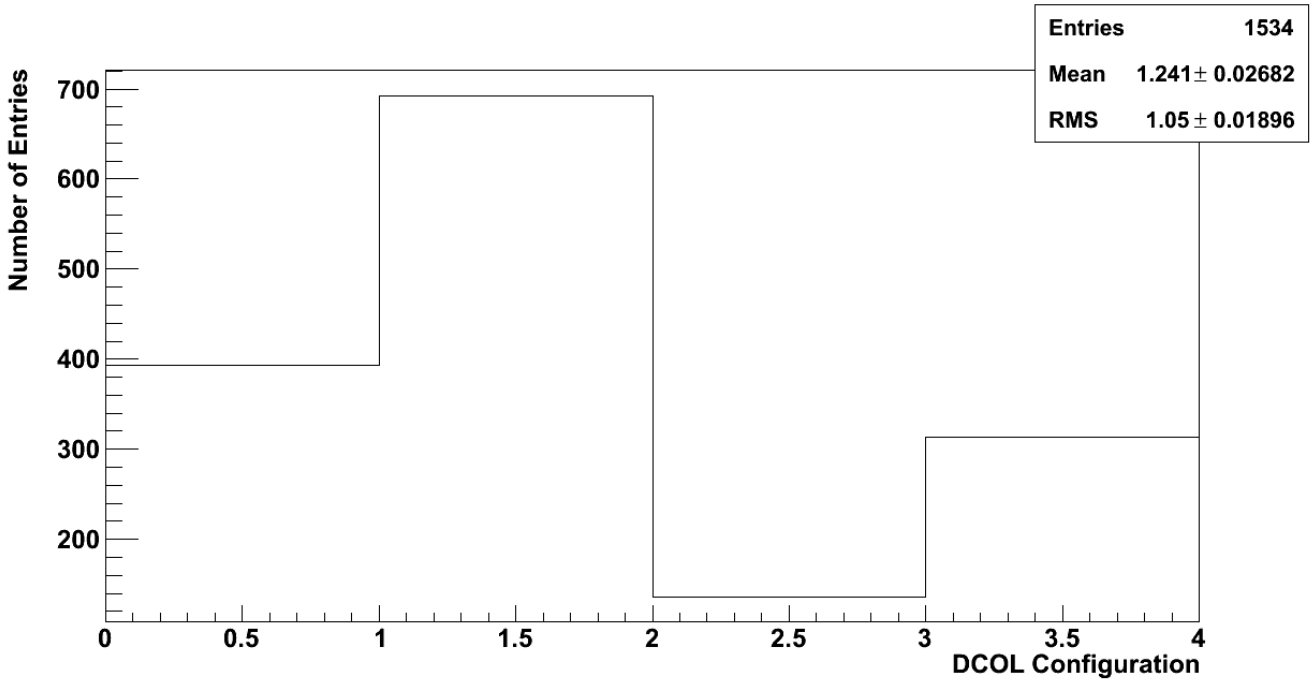
- Divided clusters with a length of 1 in X and 0 in Y into 4 separate types (“XX” clusters)



- Configuration 0 and 1 are referred to as “inside DCOL” clusters while 2 and 3 are referred to as “mixed DCOL” clusters

DCOL Asymmetries

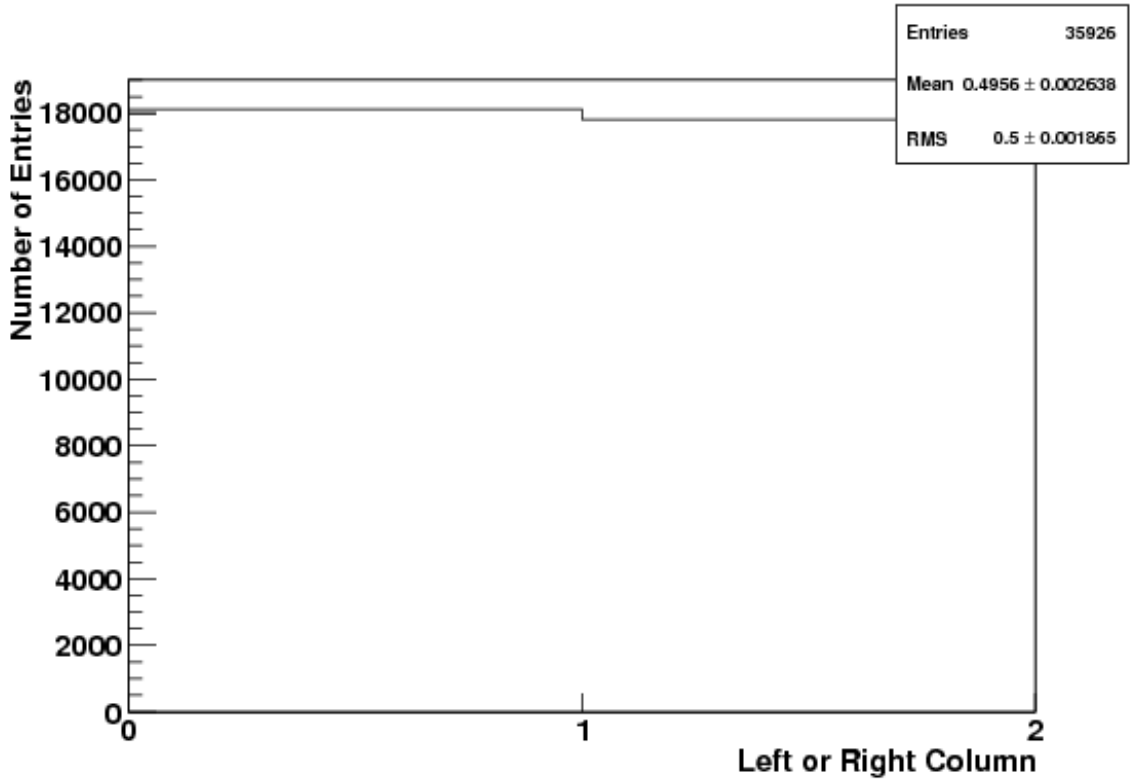
- More asymmetries can be found if I divide the sample into the 4 configurations described earlier



DCOL Configurations for XX clusters. A preference is seen for the charge to be higher in the right pixel (configuration 1 and 3) than the left pixel (0 and 2).

Left/Right Column Occupancy for Single-Hit Events

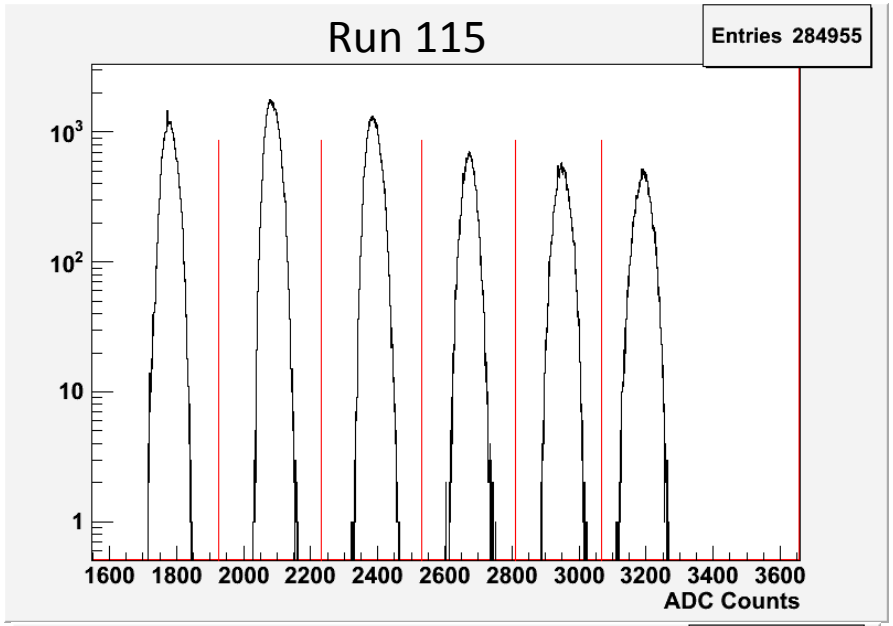
- Same plot as on previous slide, except for 1-hit events: asymmetry much less significant



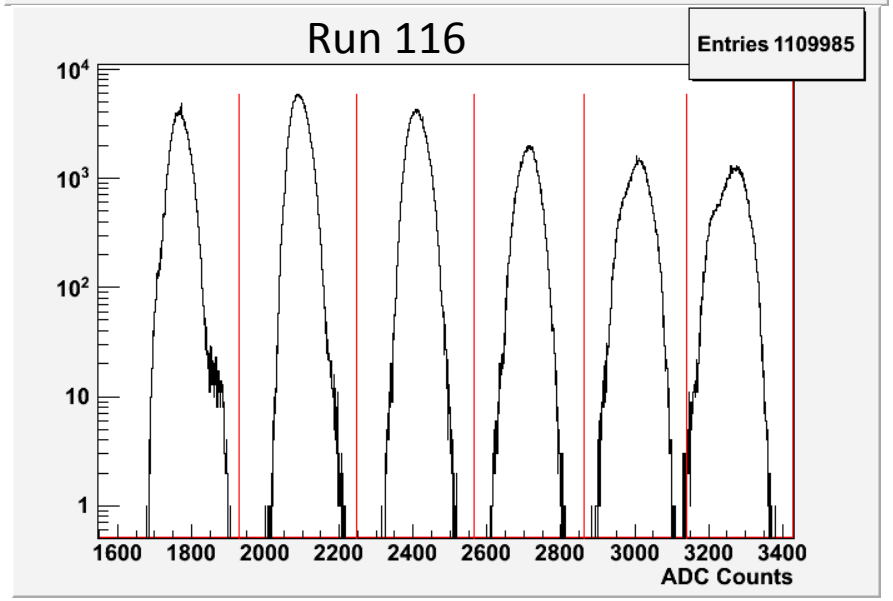
Column % 2. 0 corresponds to a hit in the left column of a DCOL, while 1 corresponds to a hit in the right

Address Levels

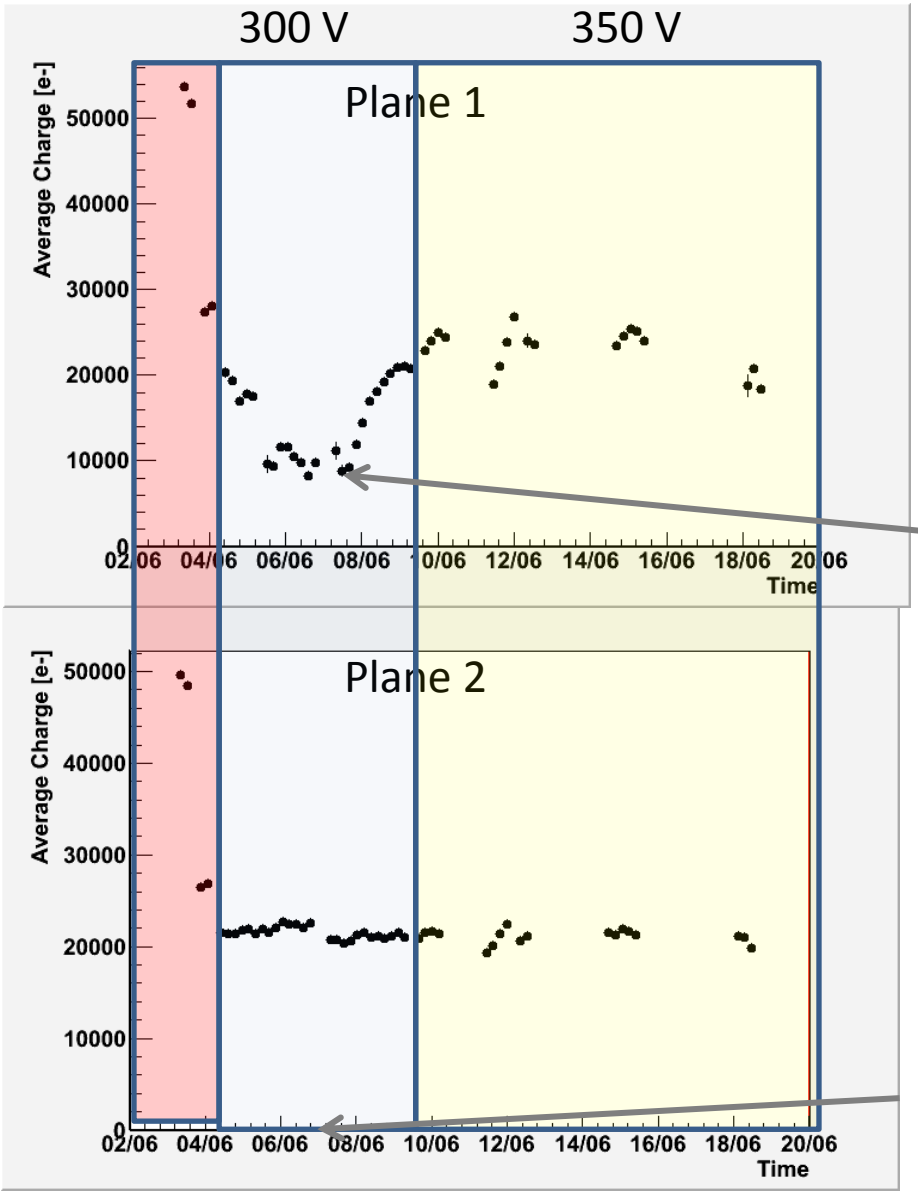
- Have an algorithm for automatically detecting address levels
- Peak detection -> Defines address levels as the center of each peak pair
- Results in plots like that ->
- Would probably be worthwhile to make this an online calibration that sweeps over all pixel to get the ringing that comes from larger level drops



- Levels are not necessarily stable!
- Nothing was touched from run 115 (top) to run 116 (bottom), but at some point the address levels started fluctuating
- Could have been from a brownout or some sort of electrical failure… run 116 was the only time that the bt/plt scalers lost sync also



Pulse Height Stability

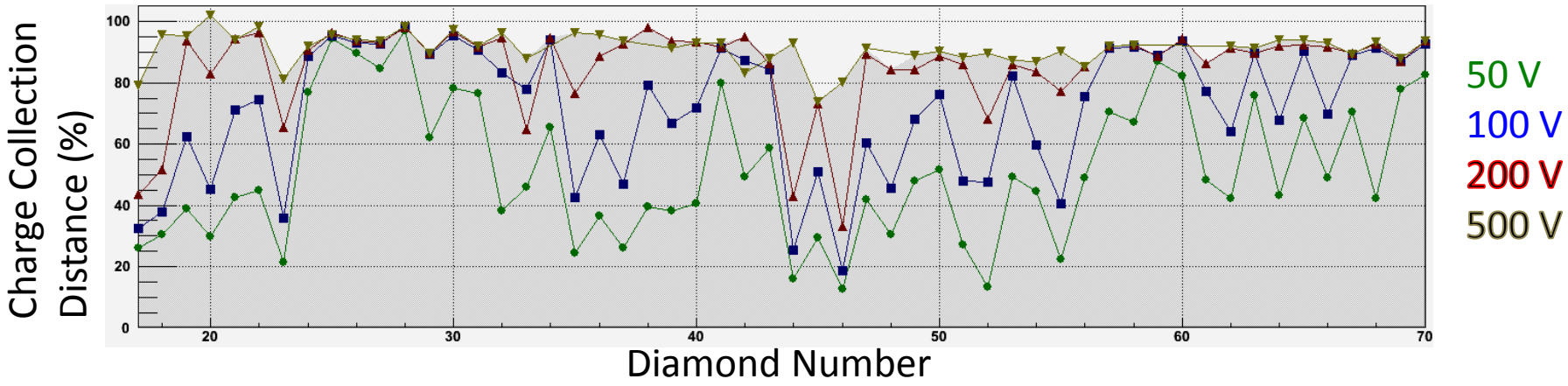


Covered front hole with tape

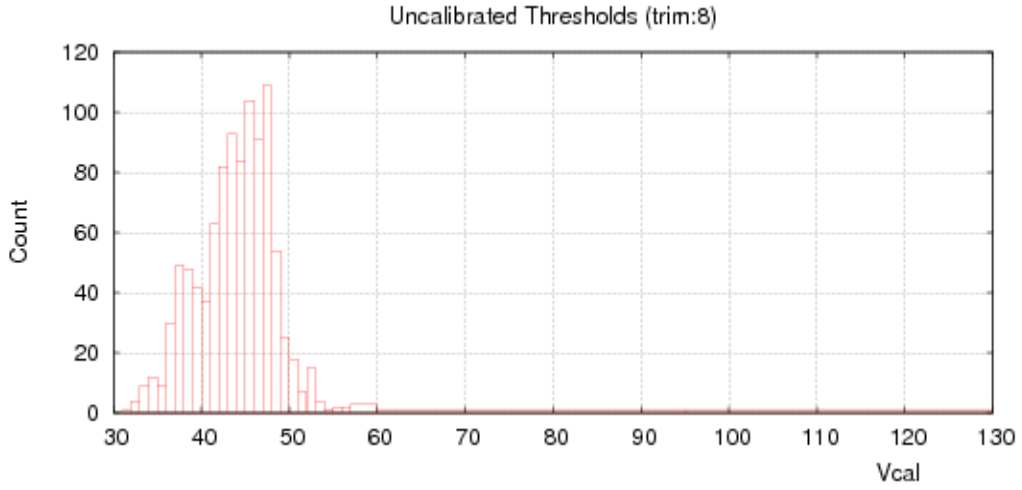
Trimming, 7th @ 8:00 am

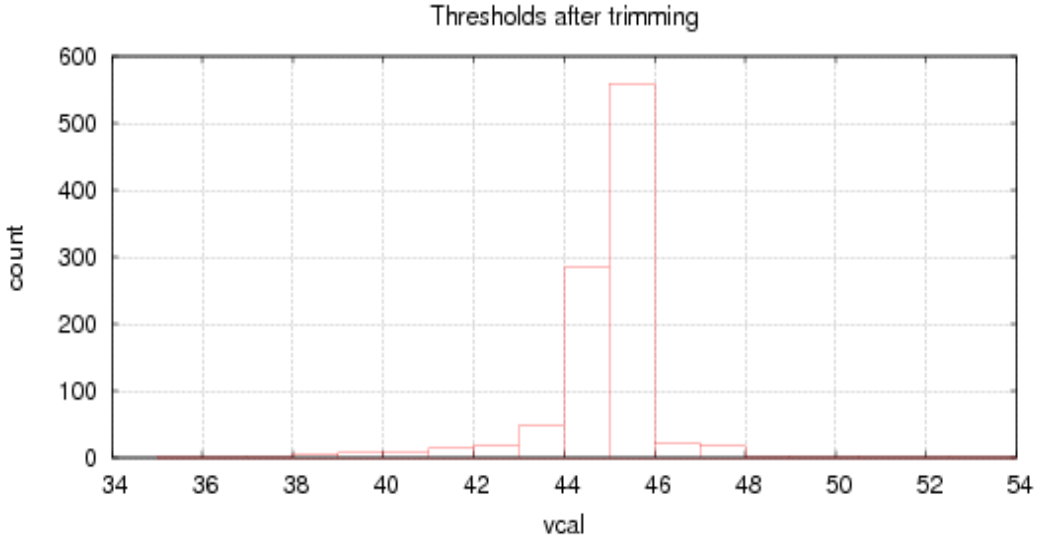
- Area marked in red is untrustworthy (gain calibration isn't appropriate)
- Plane 1's pulse heights stabilized after enclosure was made to be light-tight
- Plane 2's pulse heights were stable during the entire run

PLT Diamond CCD Summary



Trimming





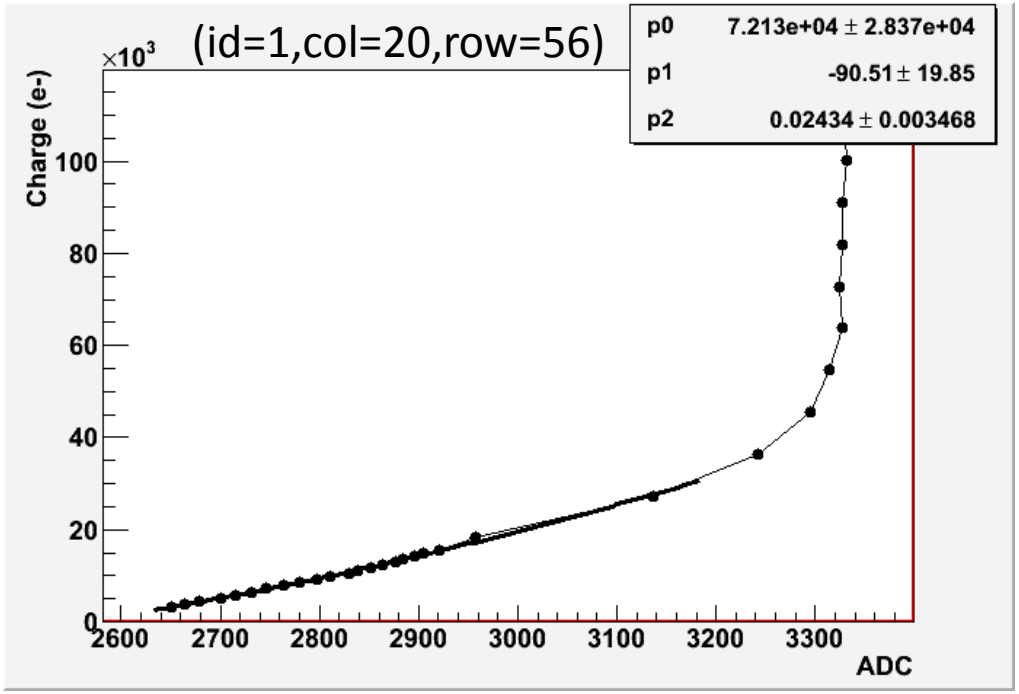
- ROCs were individually trimmed
- Took 15 minutes/ROC
- First 2 ROCs were trimmed, never trimmed the last one
- In electrons: ~3000 e-

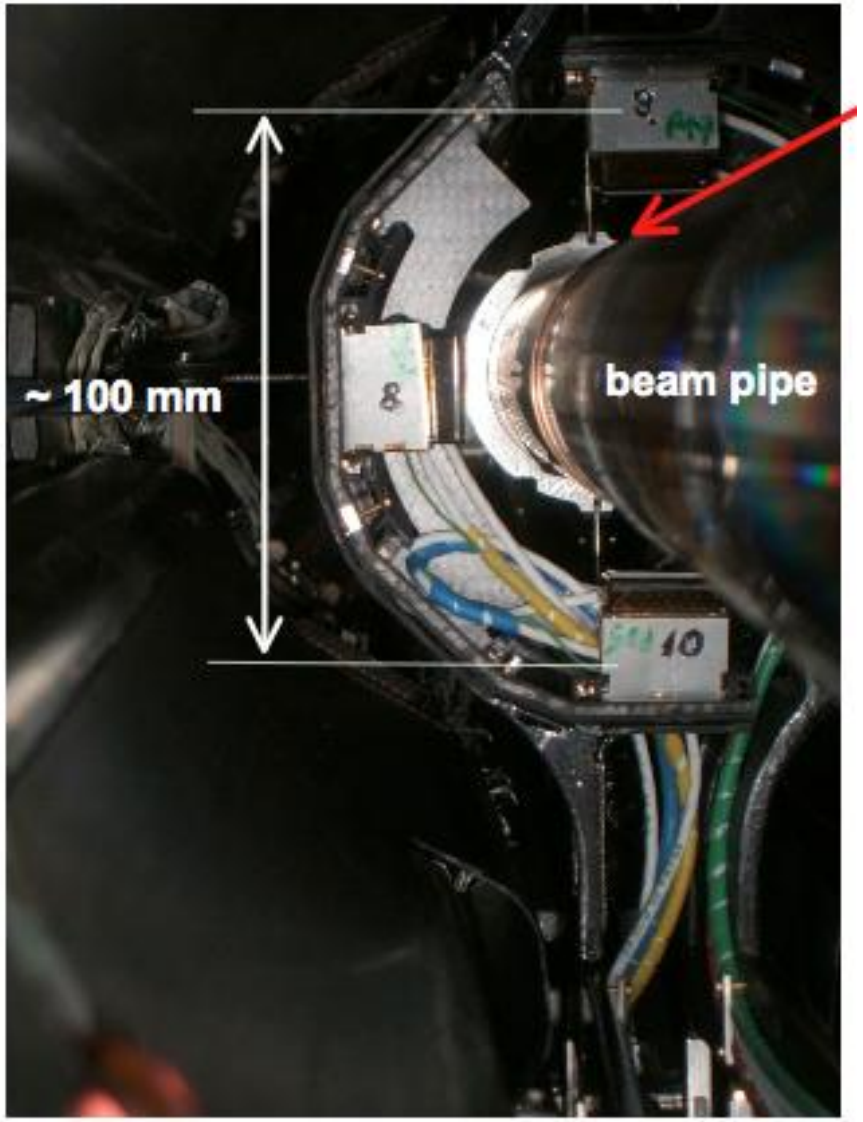
- Expected Charge Deposit
  - Perpendicular tracks: 36*513*1.05=19391
  - Grazing angle tracks: 36*100*1.05=3780

Gain Calibration

- Took 4 different gain calibration runs, ~6 days apart (run 101,102,103,104)
- First run seems to be unusable for plane

Run	Time
101	Jun 4 13:13
102	Jun 7 09:08
103	Jun 12 17:40
104	Jun 18 16:12





Installation Pictures