Cosmic Ray Study of the CMS Pixel Tracker

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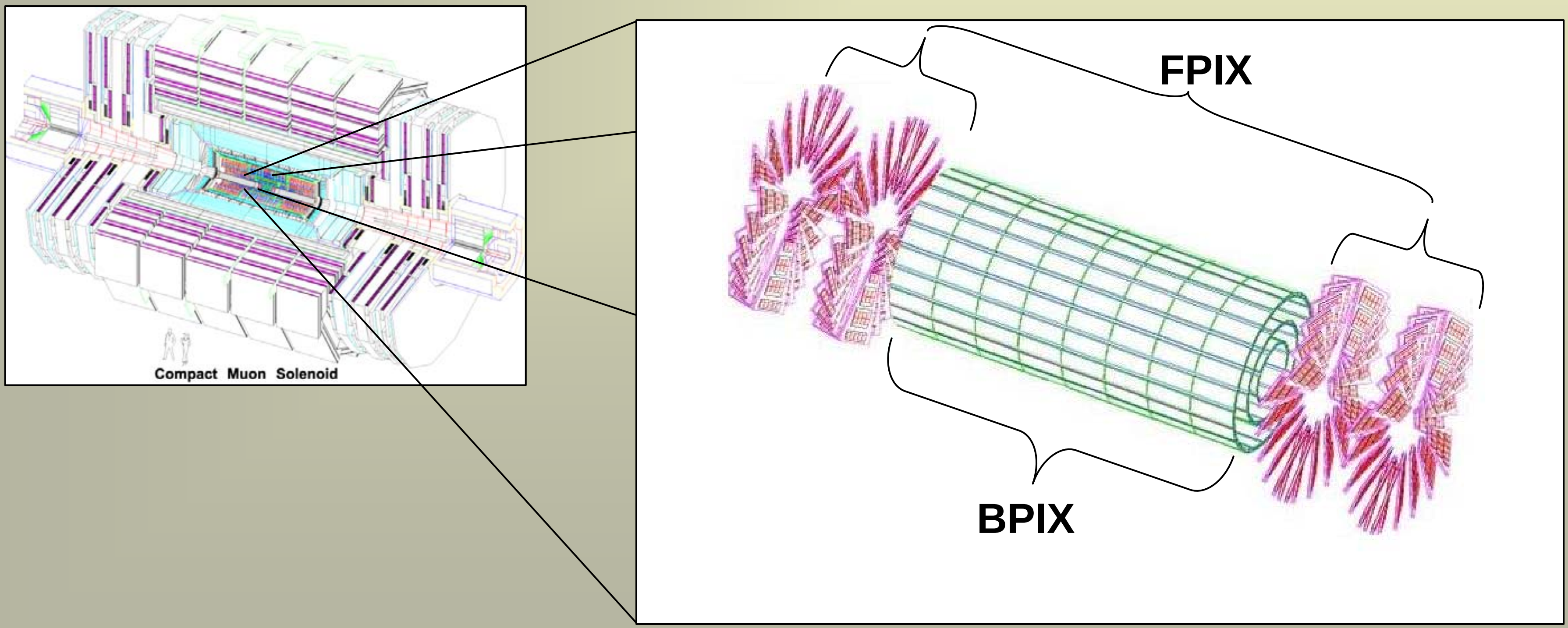
On behalf of the Tracker Project

EPS HEP 2009

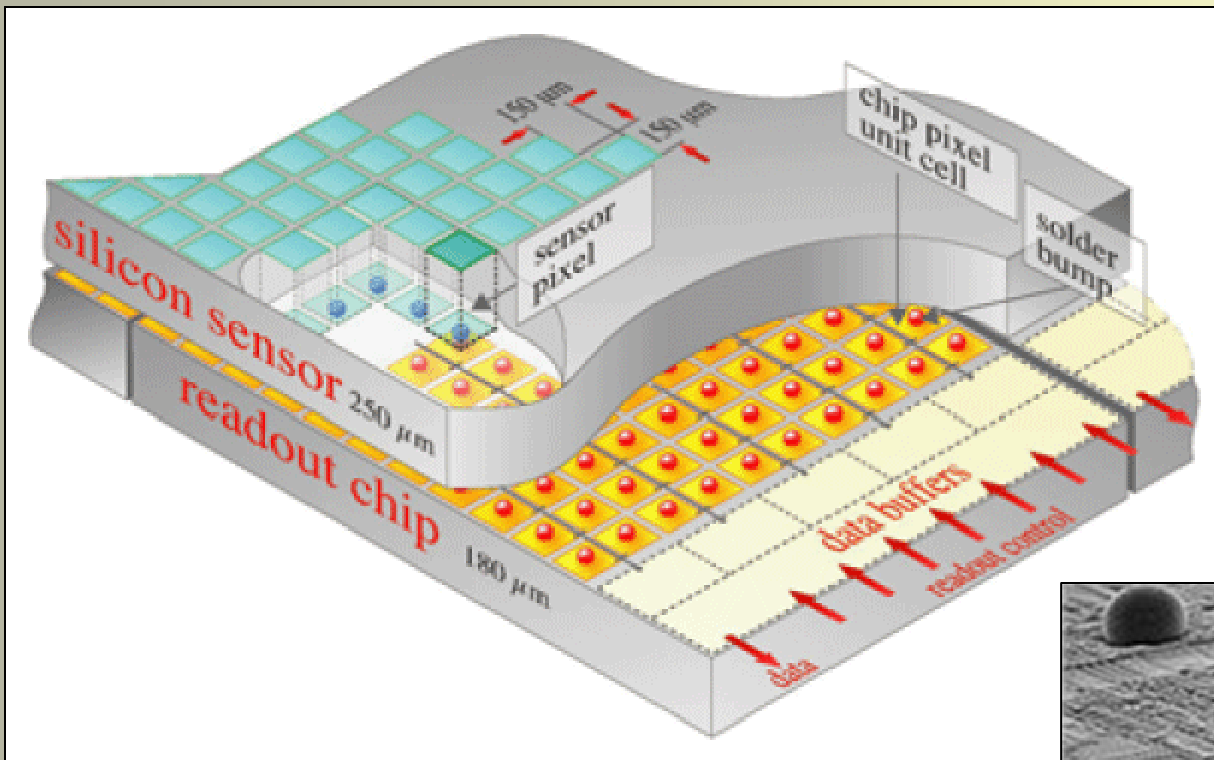
Outline

- The CMS Pixel Detector
- Results of various calibrations
- Cosmic Ray at Four Tesla (CRAFT) Results



The CMS Pixel Detector

Forward Pixel Detector (FPIX): 2 disks on each end (34.5 cm and 46.5 cm), 672 modules
Barrel Pixel Detector (BPIX): 3 layers of (radii 4.3 cm, 7.2 cm and 11.0 cm), 768 modules

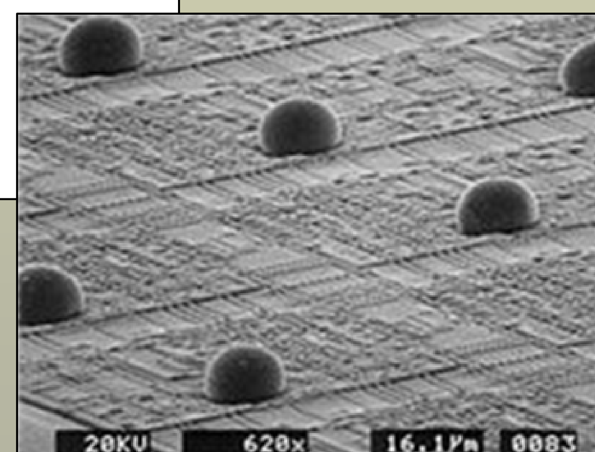


Each pixel is:
100 μm x 150 μm

52 × 80 = 4160 pixels per ROC

15,840 ROCs

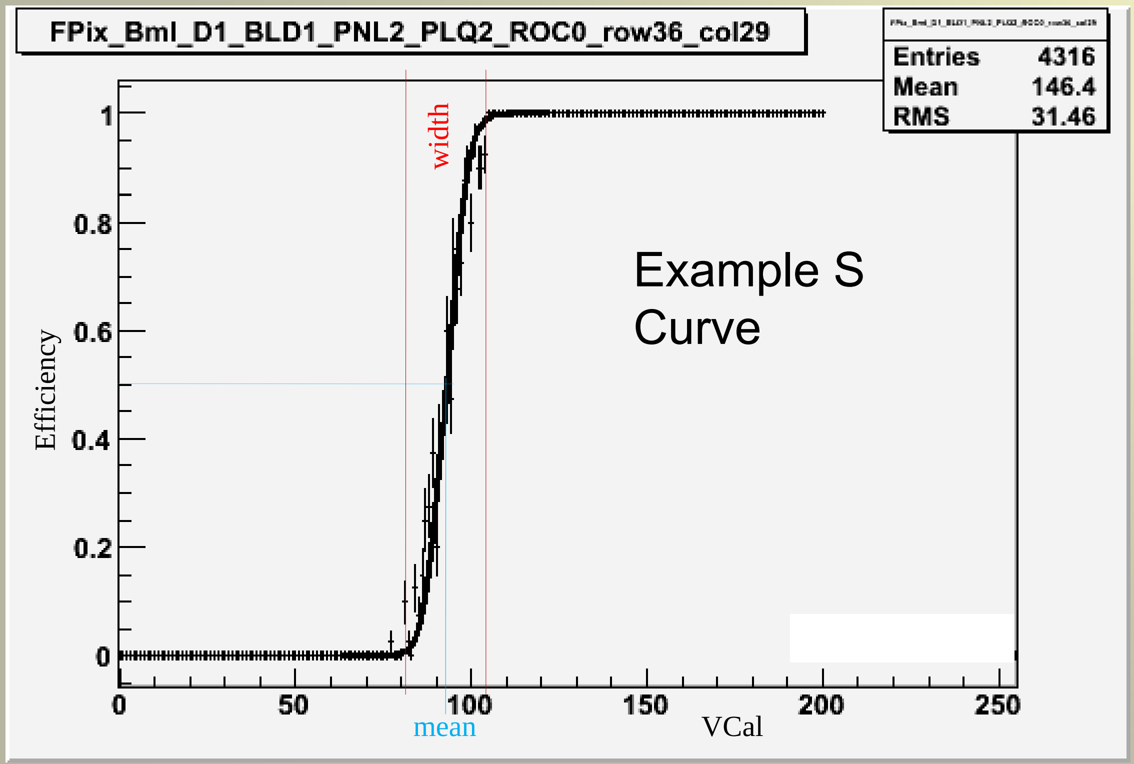
66 million pixels



- Each sensor pixel is bump bonded to the ROC
- Automatic zero-suppression
- Each pixel has a programmable threshold

Thresholds & Noise

Thresholds and noise are measured with an "S-Curve" scan (using injected charge – not cosmic rays). Due to time constraints, only 81 cells per ROC are measured.



The thresholds are an important parameter of the pixel detector since they influence hit position resolution.

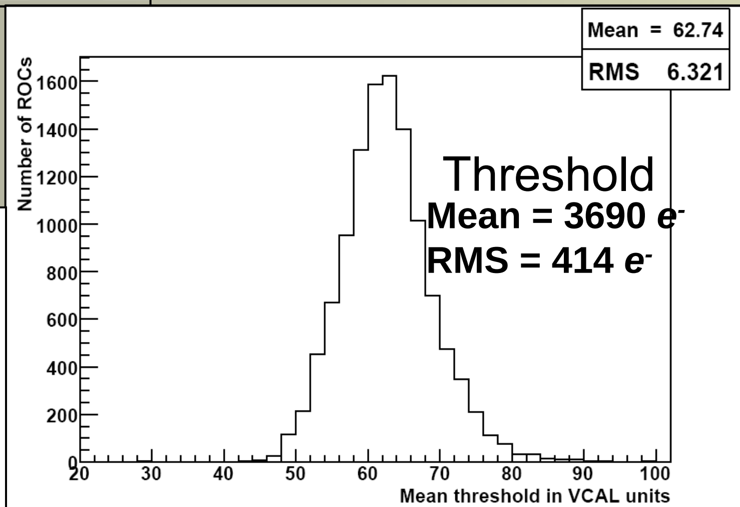
VCal = injected charge

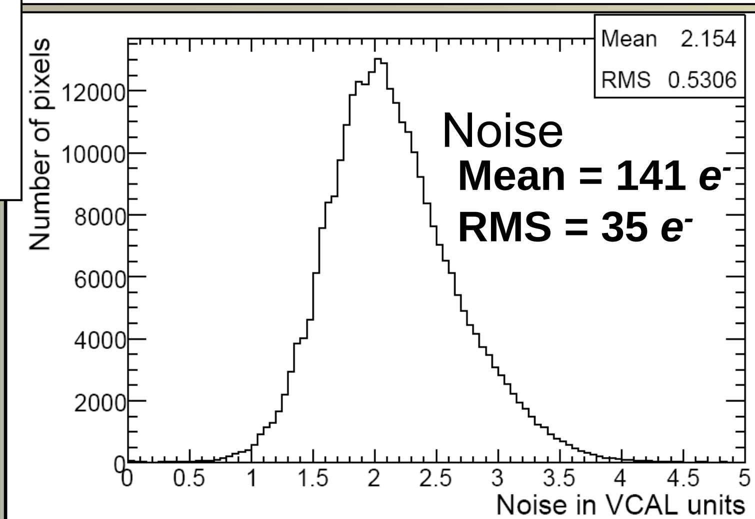
- The **threshold** is the VCal value where the signal shows 50% efficiency
- The **noise** is the width of the region where the signal efficiency switches from 0 to 100%
- VCal varies from pixel to pixel and ROC to ROC. On average, electrons = 65.5 * VCal - 410

Thresholds & Noise

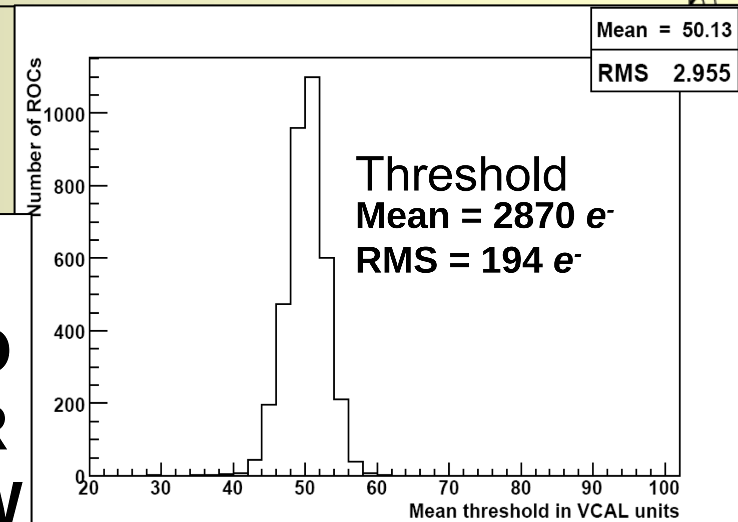
(D. Kotlinski)

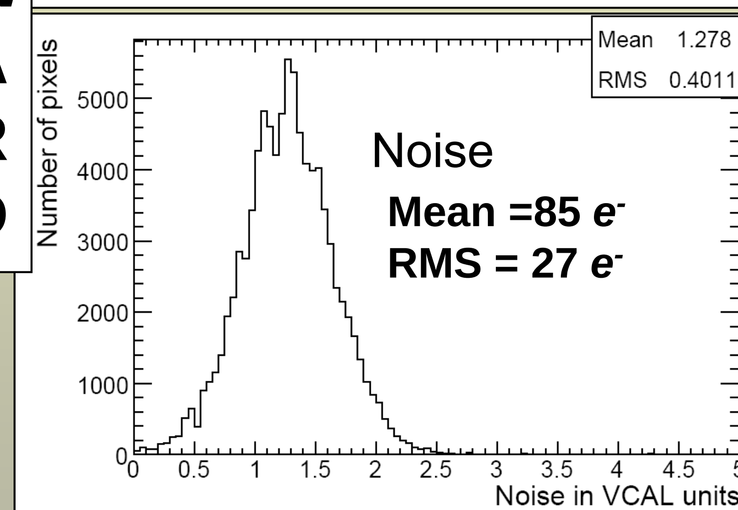
BARREL





FORWARD

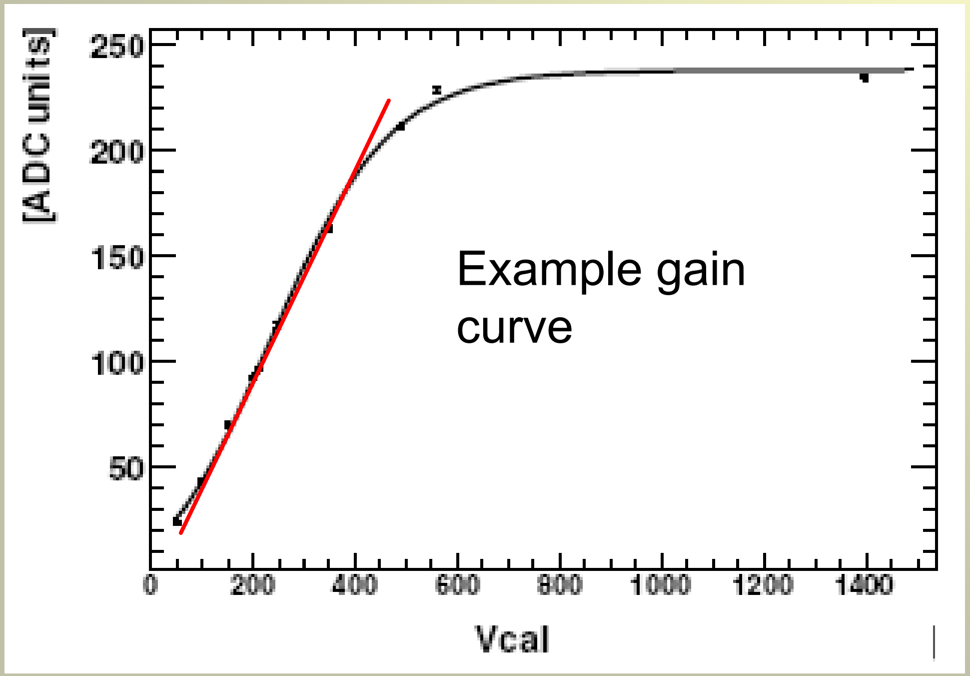




Minimum Ionizing Particle (MIP) = 22,000 e^-

Gain Calibration

The gain and pedestals are used to calculate the charge deposited in clusters.



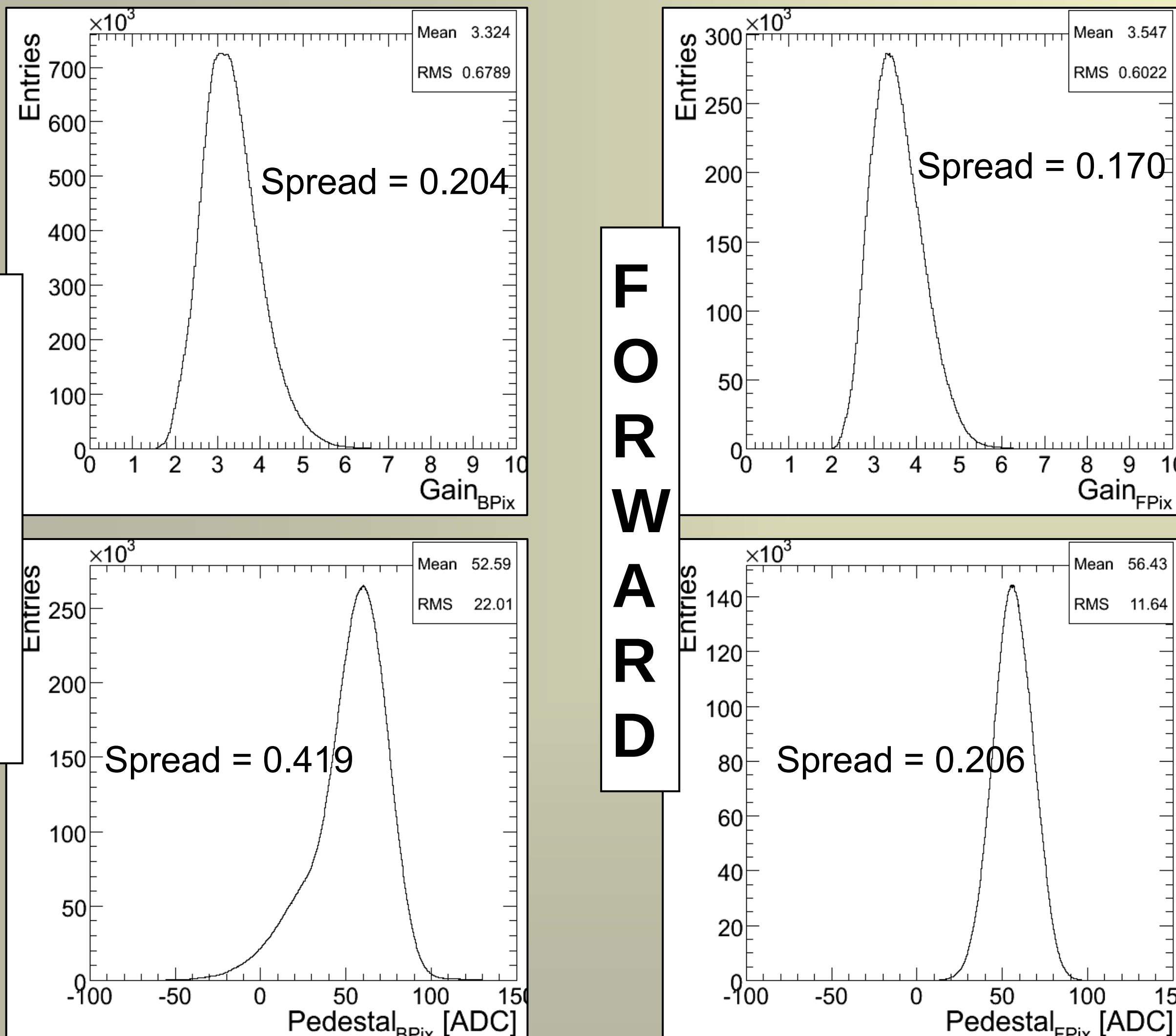
- Similarly to the S-Curve scan, for each pixel, the amplitude of the injected test charge (VCal) is varied and the ADC response is recorded.
- Gain = mean of slope (ADC/VCal) (linear fit)
- Pedestal = offset (ADC)

Gain Calibration

(F. Blekman, R. Rougny, B. Heyburn)

BARREL

FORWARD



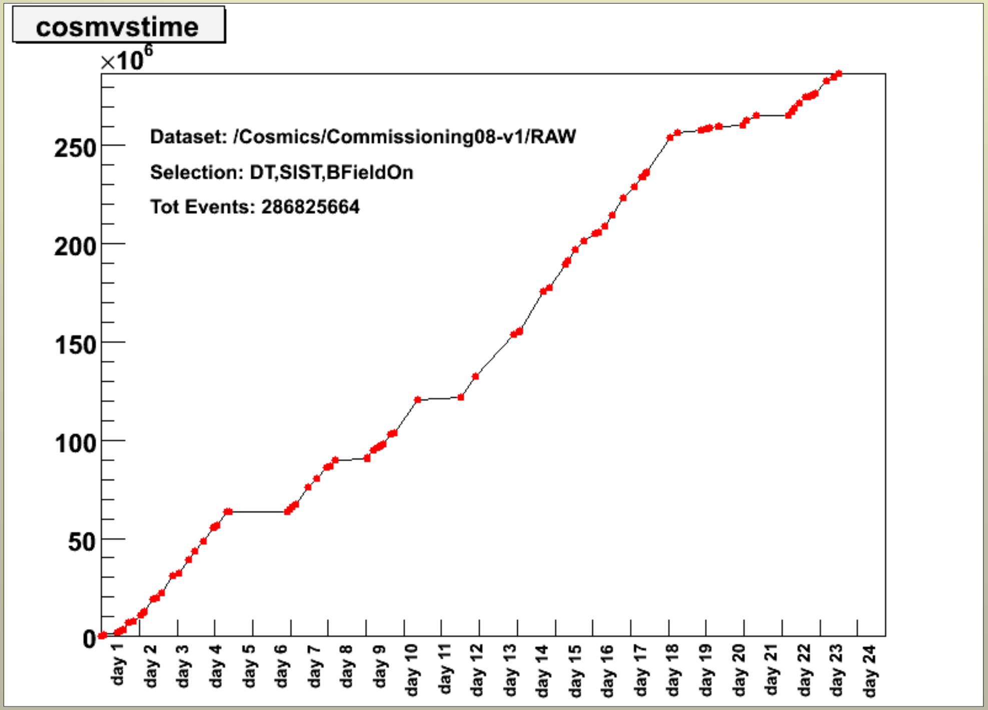
For each pixel, gain and pedestals are determined from a linear fit to the gain response function. There are dedicated gain calibration runs.

CRAFT

- During the Fall of 2008, CMS recorded ~370 million events during a Cosmic Run at Four Tesla (CRAFT) (3.8 T magnetic field)

•Number of pixel tracks: ~85000
•Mean number of pixel hits on a track: 3.01 (if any)
•Number of pixel clusters: 256800

Results of calibrations used for the final reprocessing of CRAFT data.



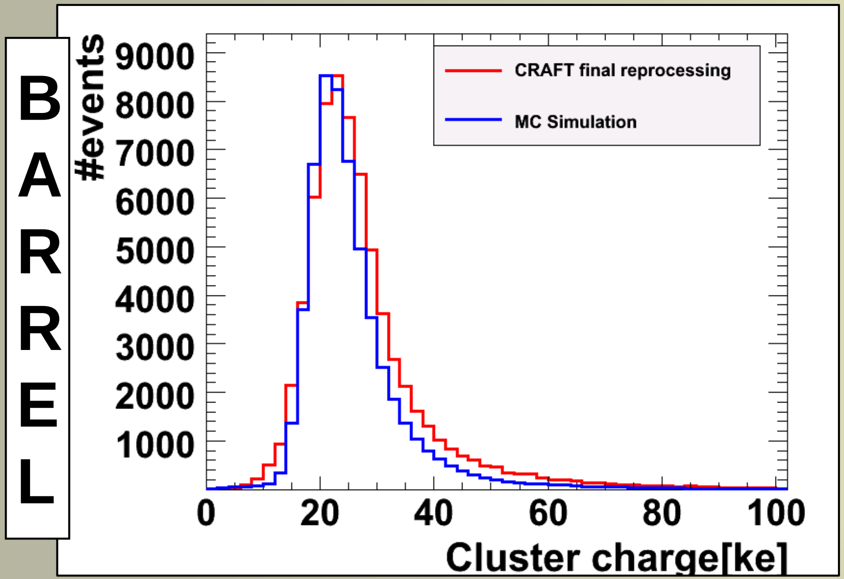
Noisy Pixels

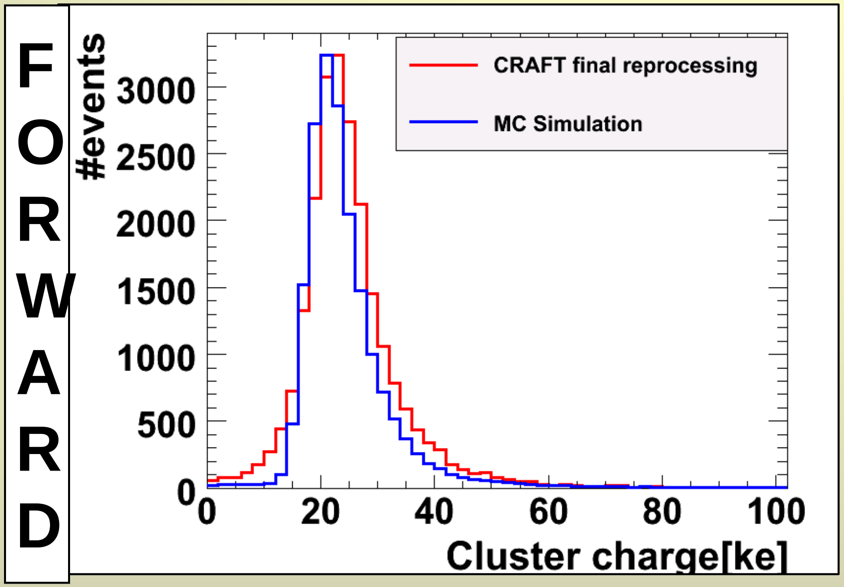
(P. Merkel)

- Noisy pixels are detected via the Pixel Data Quality Monitoring package
  - Can be done in real time or offline (running on reprocessed data)
  - Counts the number of events in which a pixel registers a charge above threshold, and divides by the total number of events – the "**event rate**"
- Cutoff: event rate > 0.001
  - Barrel: 235 noisy pixels
    - One full column
    - Two full rows
    - 51 individual, random pixels
  - Forward: 17 noisy pixels
    - All randomly distributed
- Noisy pixels were masked during CRAFT data taking
- If cutoff is tightened to 0.0001, only 13 additional pixels would be declared noisy (these are not currently masked)
- Number of noisy pixels is very small: **.00038% of total pixels**

Cluster Charge Data/MC Comparison

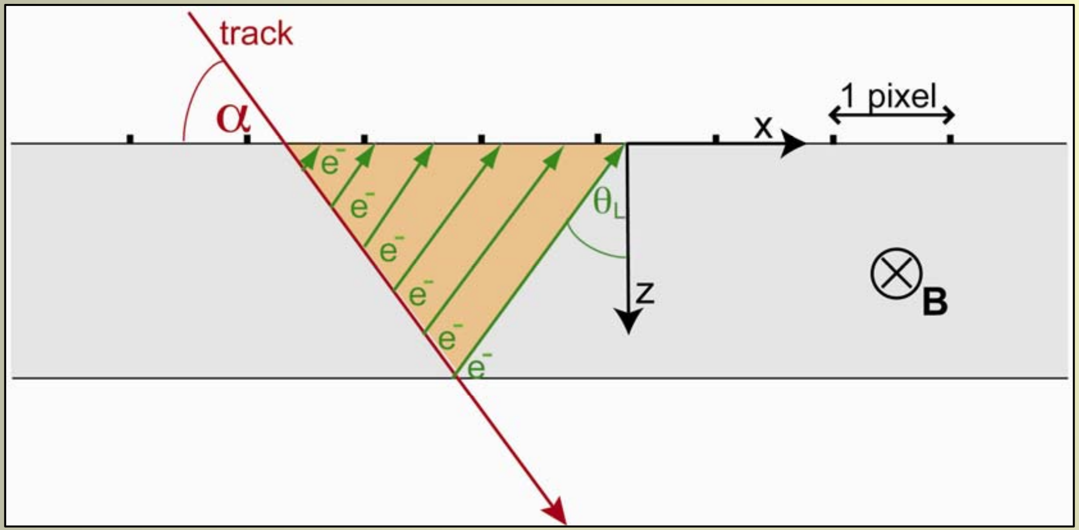
(T. Rommerskirchen, G. Giurgiu, V. Chiochia)





- Cluster charge is corrected for the way the particle travels in a module.
- MC has IDEAL gain calibration (no smearing of gain and pedestal values)
- Many cosmic ray effects (time-walk, broken clusters) not simulated in MC (and not needed for collisions).

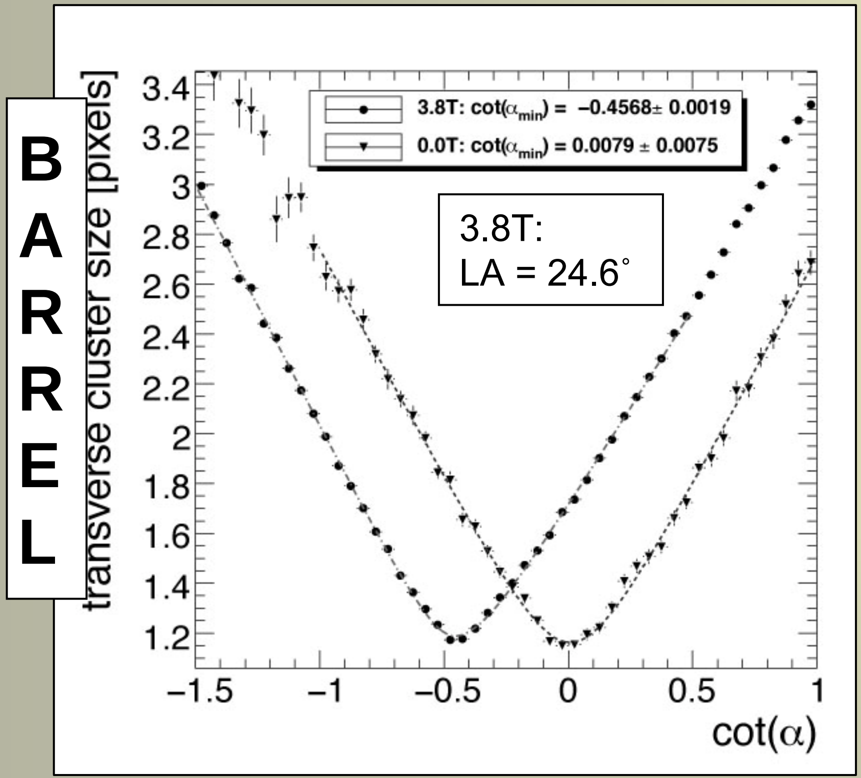
Extraction of the Lorentz Angle

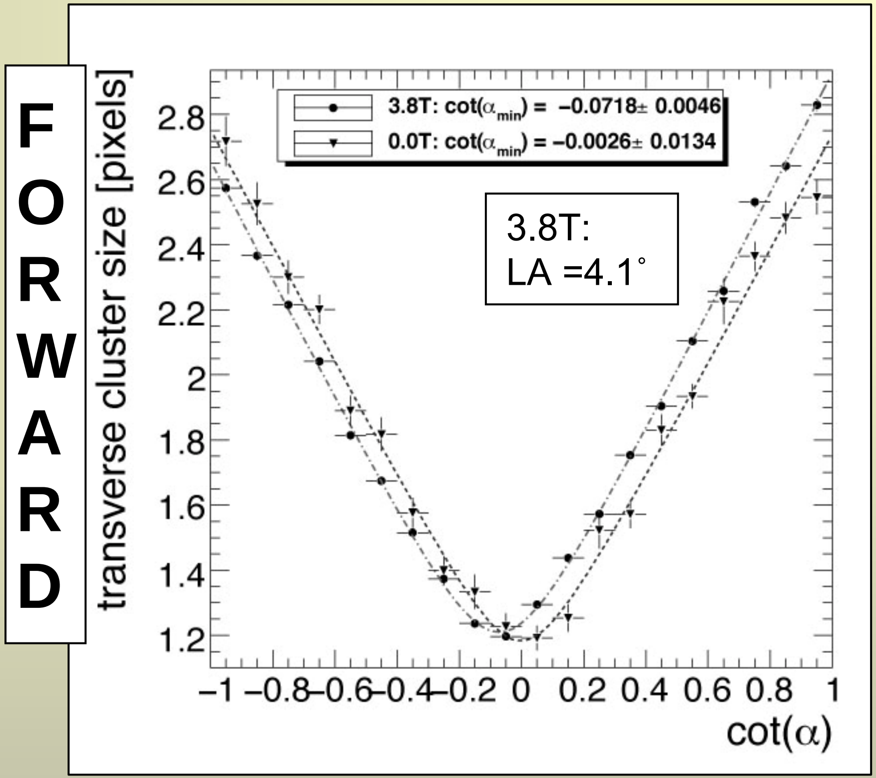


- In the presence of E and B fields, the charge carriers are affected by the Lorentz force and are deflected at a Lorentz angle with respect to the E field.
- To determine the value of the Lorentz Angle, the spread of the drifting charge distribution is measured as a function of the track incidence angle (minimized at the Lorentz Angle)

Extraction of the Lorentz Angle

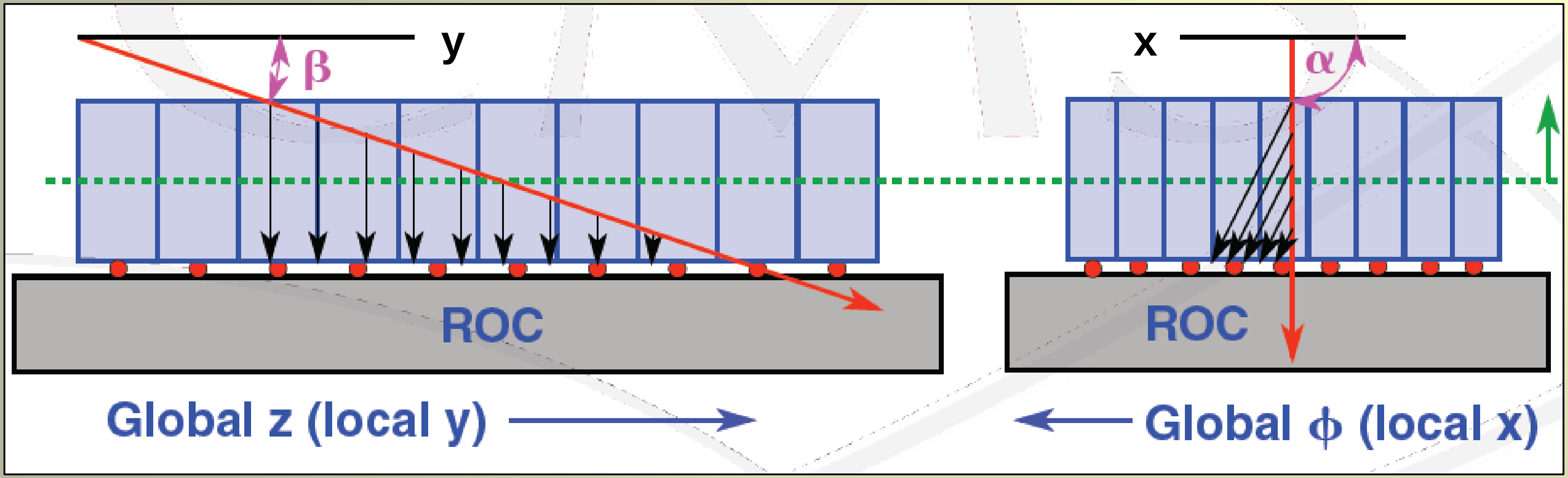
(L. Wilke, A. Kumar, M. Swartz)





- Comparison to simulation shows good agreement:
  - BPIX 3.8 T, 100 V, 20 C: $\cot(\alpha_{min}) = -0.452 \pm 0.002$
  - FPIX 3.8 T, 300 V, 20 C: $\cot(\alpha_{min}) = -0.080 \pm 0.005$

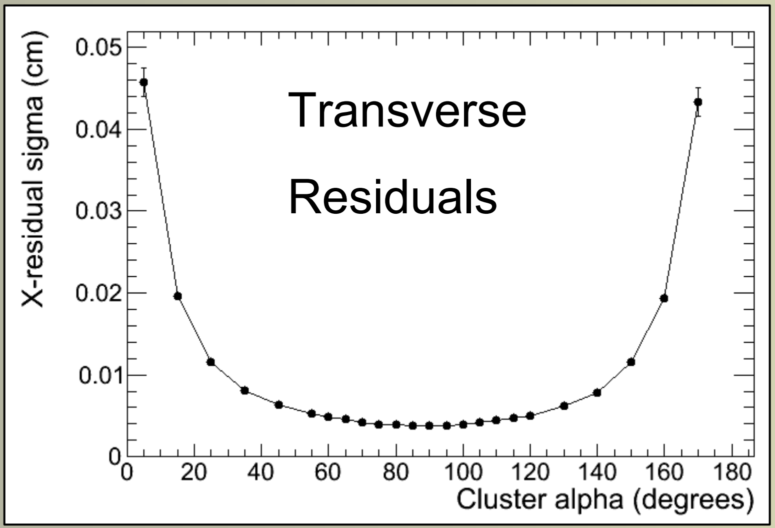
BARREL Hit Residuals

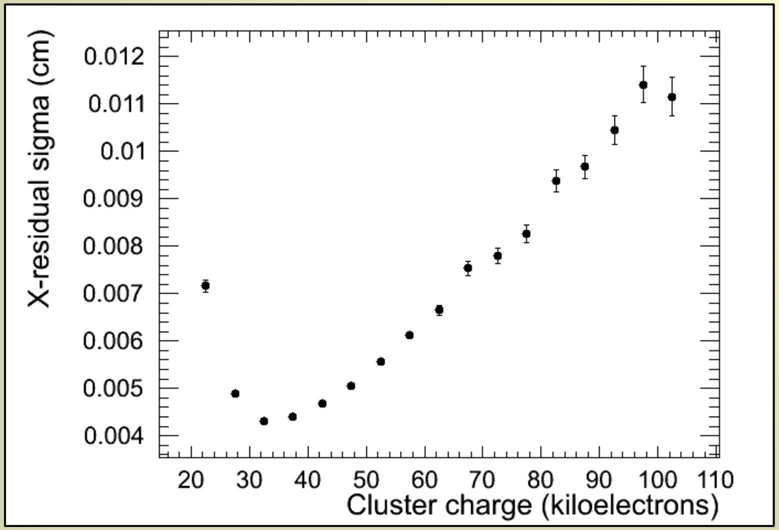


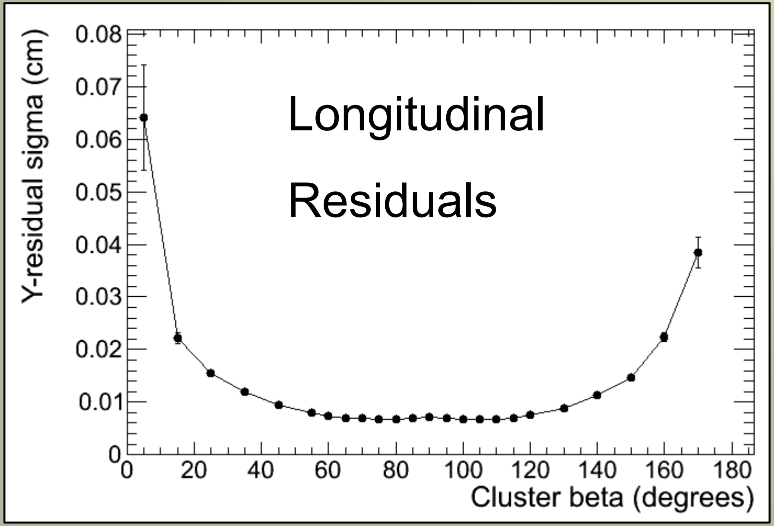
- A residual is the distance between where you expect a reconstructed hit (“rec hit”) to be and where it actually is.
- The residual is calculated by taking a track, removing the rec hit you are studying, refitting the track, and then subtracting the position at which the track intersects the module from the actual position of the rec hit.

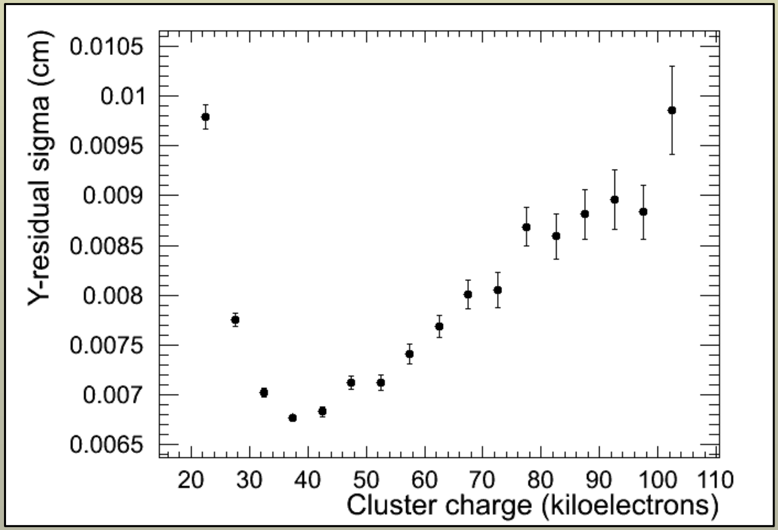
BARREL Hit Residuals

(A. York)









Momentum

> 10 GeV

Other Cuts:

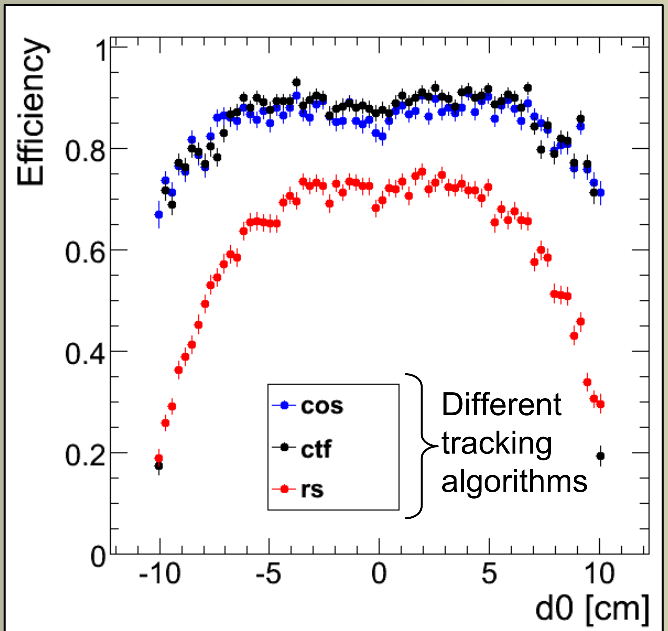
-Edge hits not included

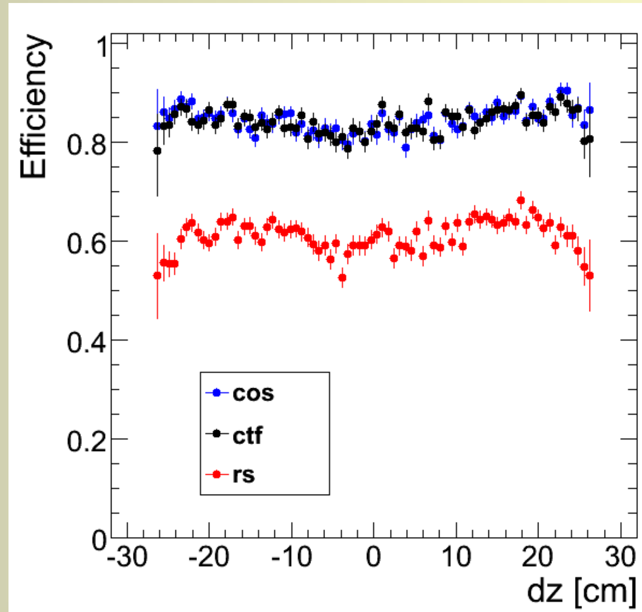
-1 pixel hits with < 10ke charge

This is the TOTAL residual – includes track extrapolation error

Barrel Pixel Track Efficiency

(M. Lebourgeois, B. Mangano)

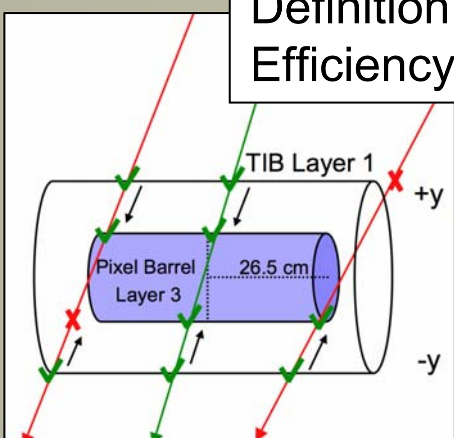




Important:

1) Pixel integration times = 25 ns, half of that of the strip tracker
2) Due to geometry (and nature of cosmic rays), only 3% of tracks through BPIX, 1.5% through FPIX

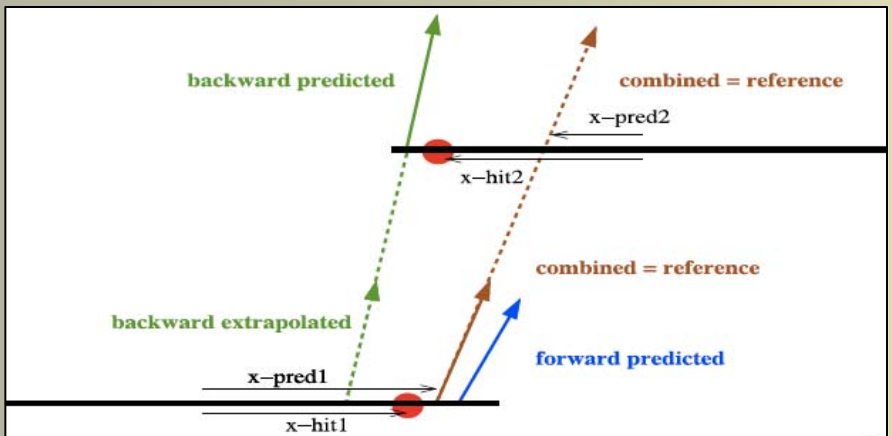
Definition of Efficiency



- If cut of pT > 20 GeV applied, RS similar to CTF/COS
- Comparison of CTF to MC gives similar results
- This is not a measurement of the sensor efficiency, but is rather a result of several factors: Tracking efficiency, alignment, detector performance, timing synchronization, etc.

Barrel Pixel Hit Resolution

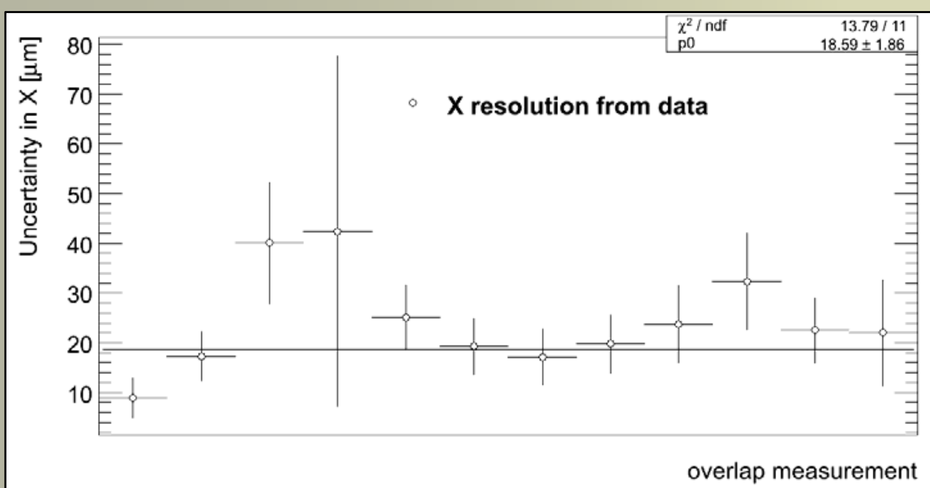
(K. Ulmer)

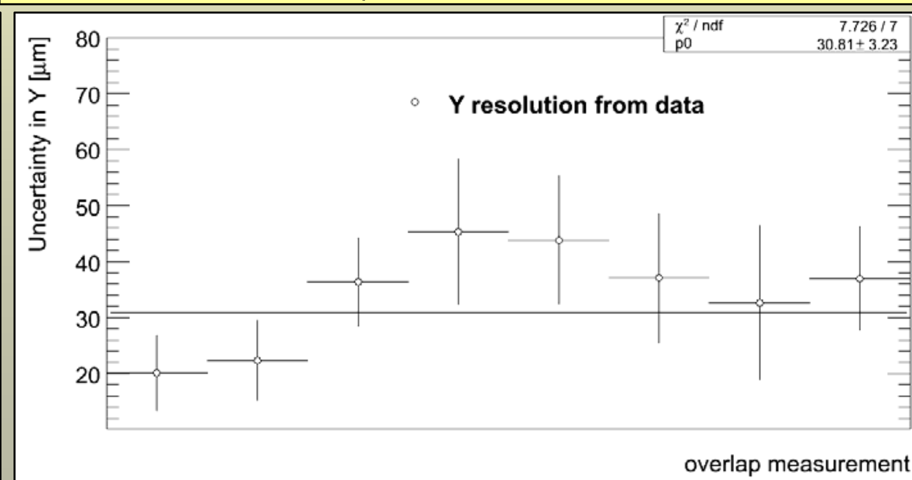


- Use tracks passing through two sensors in the same layer
- Find the “double difference”:
  - The difference in hit and predicted positions on the two overlap modules

    $\Delta x_{hit} = x_{hit1} - x_{hit2}$

    $\Delta x_{pred} = x_{pred1} - x_{pred2}$
  - For each overlap site, the width of the double difference is determined.
    $width^2 - \sigma(\Delta x_{pred})^2 = \sigma(\Delta x_{hit})^2$





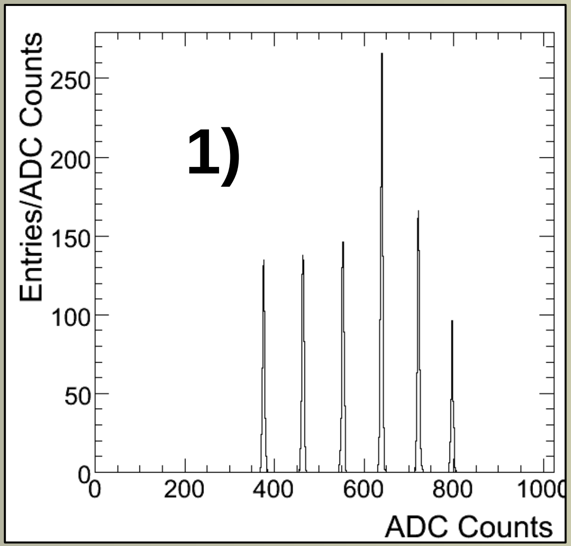
X resolution: 19±2 μm
Y resolution: 31±3 μm

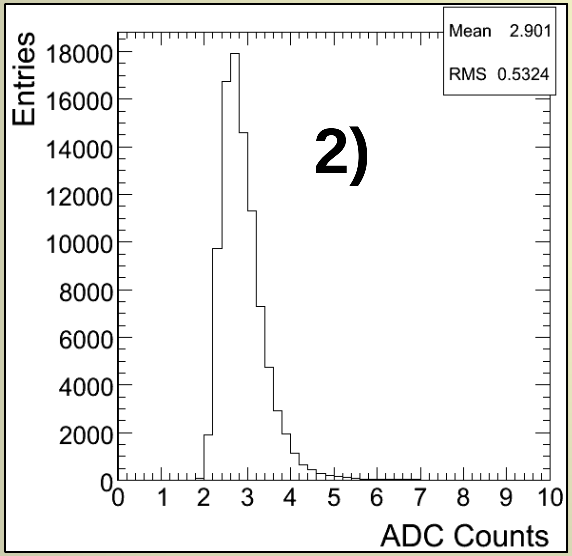
Summary

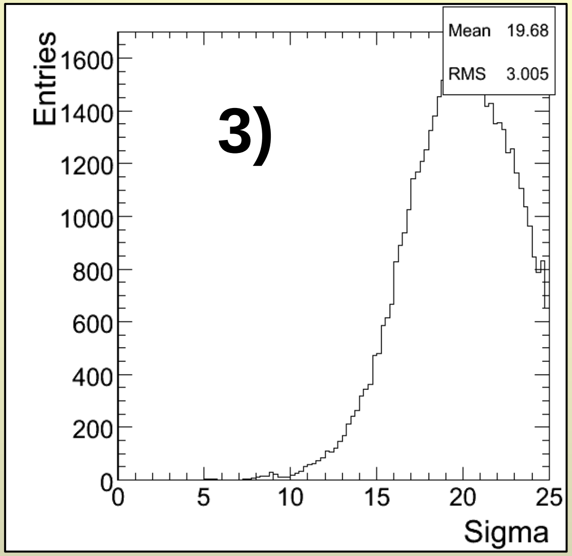
- There has been lots of remarkable work in calibration analyses, alignment analyses, and pixel CRAFT data analysis
- Resolutions and tracking efficiencies can only improve with collision data
- Expect more exciting results with CRAFT 2009 (starting July 22) and collisions (hopefully November)!

BACKUP

Address Level Calibration







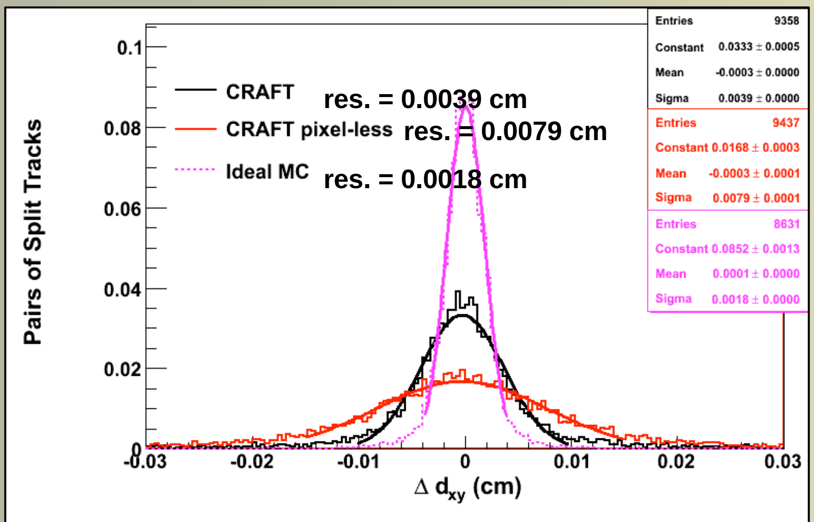
For each hit (above threshold), the pixel address is encoded with six analogue levels over five clock cycles (the sixth cycle gives the pixel charge). The histograms above show:

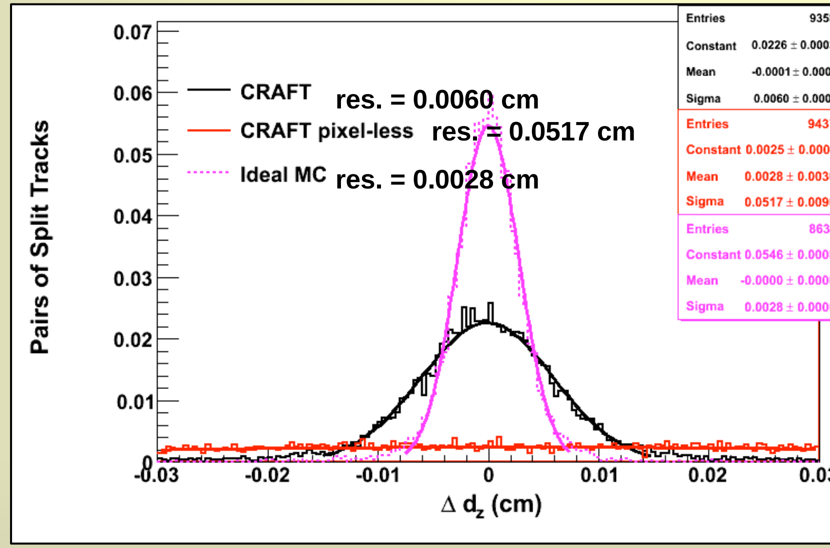
1) A sample set of six address level peaks from one ROC (of ~16000 ROCs)
2) RMS of all peaks for all ROCs
3) Address separation in units of RMS.

The levels are well-defined and well-separated.

Impact Parameter Resolution

(A. Bonato, N. Trahn)





- Based on track-splitting method
- Cuts:
  - At least 3 Pixel Barrel hits
  - Momentum >= 10 GeV
  - In "pixel-less" scenario, Alignment Parameter Errors (APEs) inflated by 100
- APEs affect parameter resolution: inclusion of pixels improves impact parameter resolution
  - Ongoing studies to find optimal APEs