Pixel Clustering

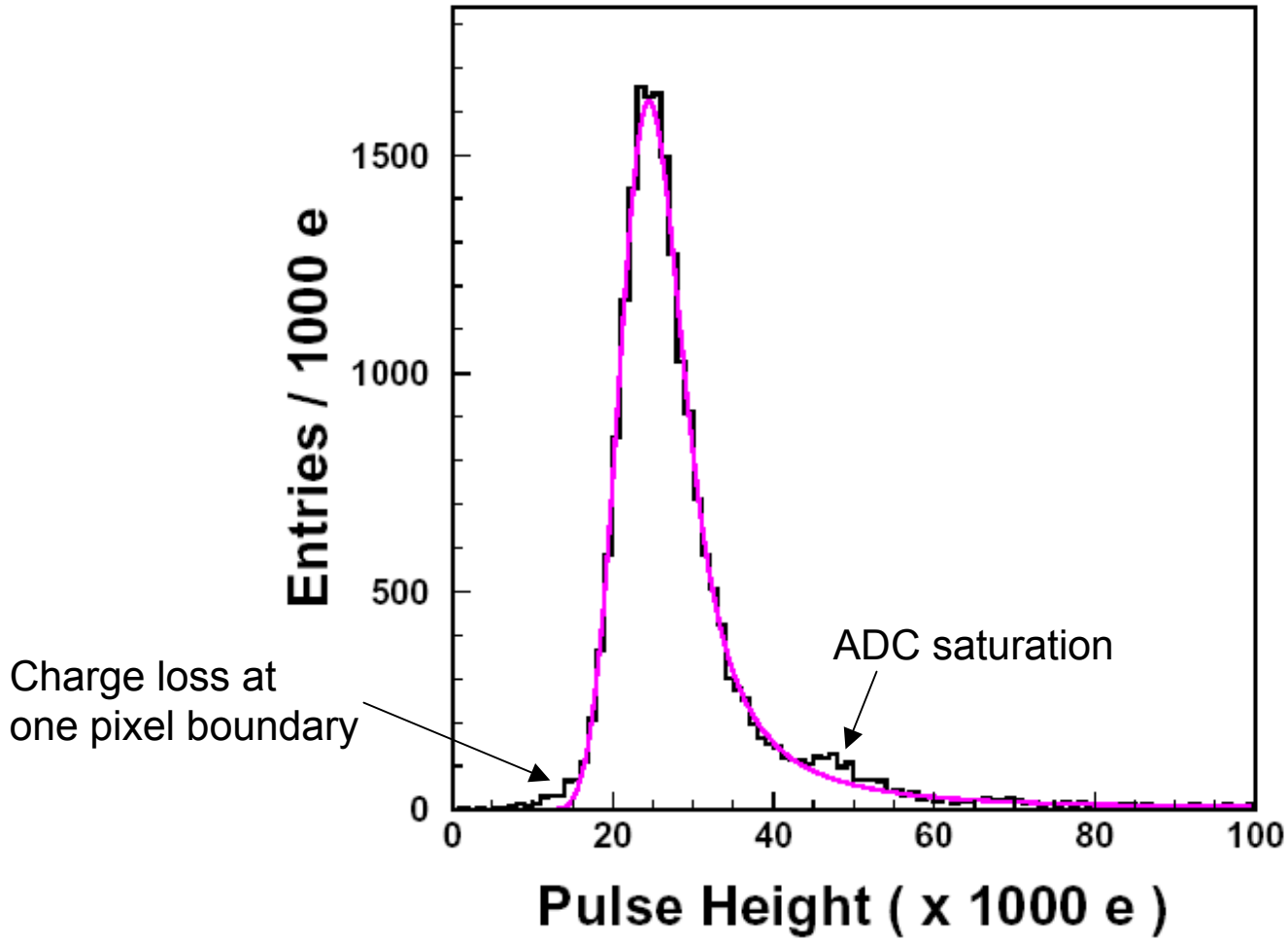
- Simplified presentation today ignores:
  - Cross column clustering
  - Magnetic field effects
  - Radiation damage effects

- Mobile charge creation
- Factors that determine cluster size:
  - Track Angle
  - Charge carrier diffusion
  - Discriminator threshold
  - Sensor bias voltage
- Optimal use of charge sharing information

Mobile charge creation in silicon

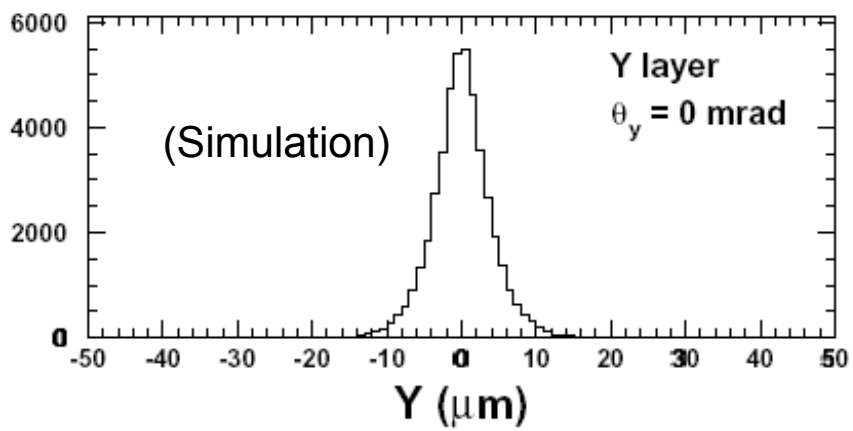
- One e-hole pair is created per 3.62 eV lost by a particle. On average, 24000 e-hole pairs are created per 300μ of track length for a minimum-ionizing particle (~87 keV lost by track).
- We have been using 300μ thick sensors so far; nominally expect to use 250μ thick sensors in BTeV.
- Pulse height distribution is well fit with a Landau function convoluted with a Gaussian.
  - Fluctuations are large: FHWM(300μ Si) $\approx$ 10000 e-.
  - Distribution is asymmetric (long high-energy tail).

Data from 1999 testbeam run



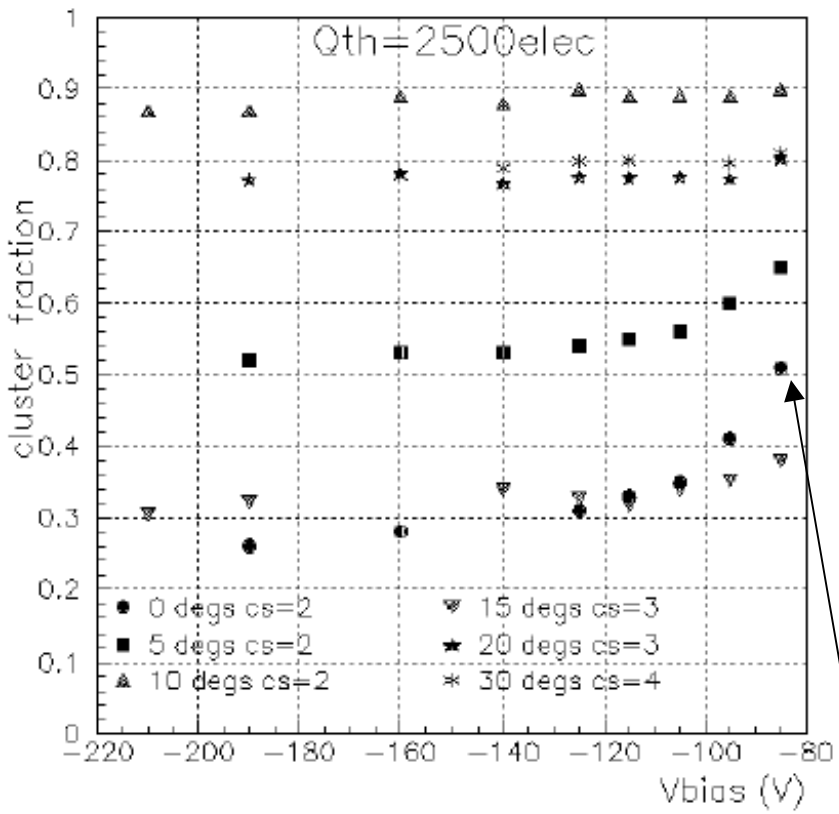
Charge creation & collection

- Most e-hole pairs are created within ~3μ of track.
  - Exceptions are due to "δ-rays" – electrons with energy of many 10's of KeV (up to MeV) – these are the cause of the long high energy tail in dE/dx.
  - δ-rays are produced nearly perpendicular to track (elastic scattering kinematics).
- Diffusion adds to "width" of track.
  - Depends on **<u>discriminator threshold</u>** and bias voltage.
  - Less diffusion at higher bias voltage.

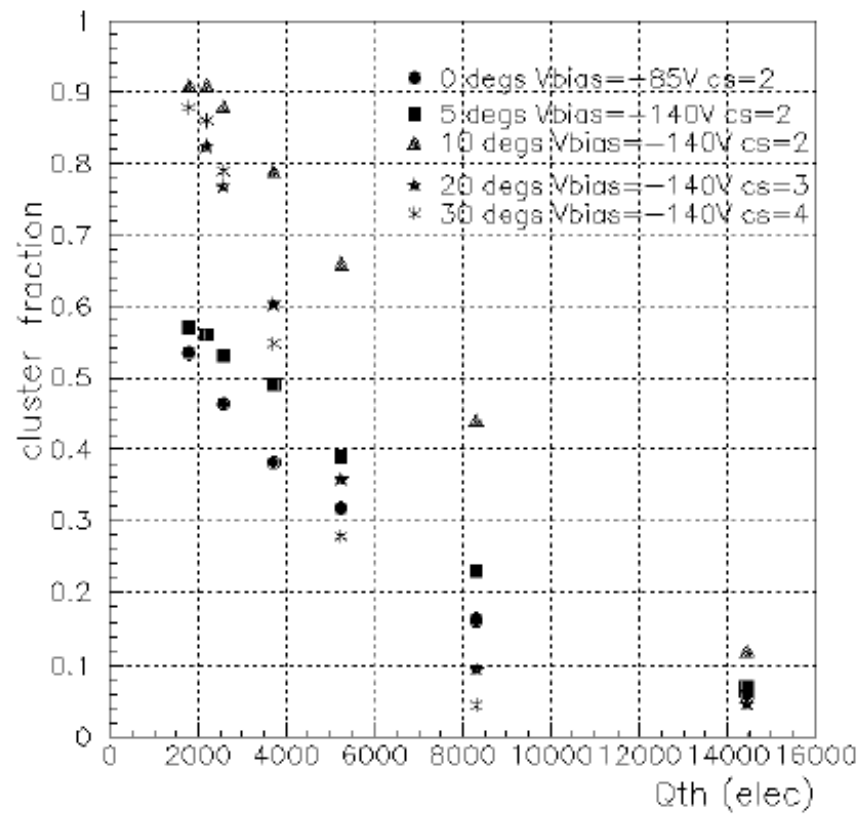


- Effective "width" of track ≈ ±10μ.

Dependence of Cluster Fraction on Bias Voltage and Discriminator Threshold



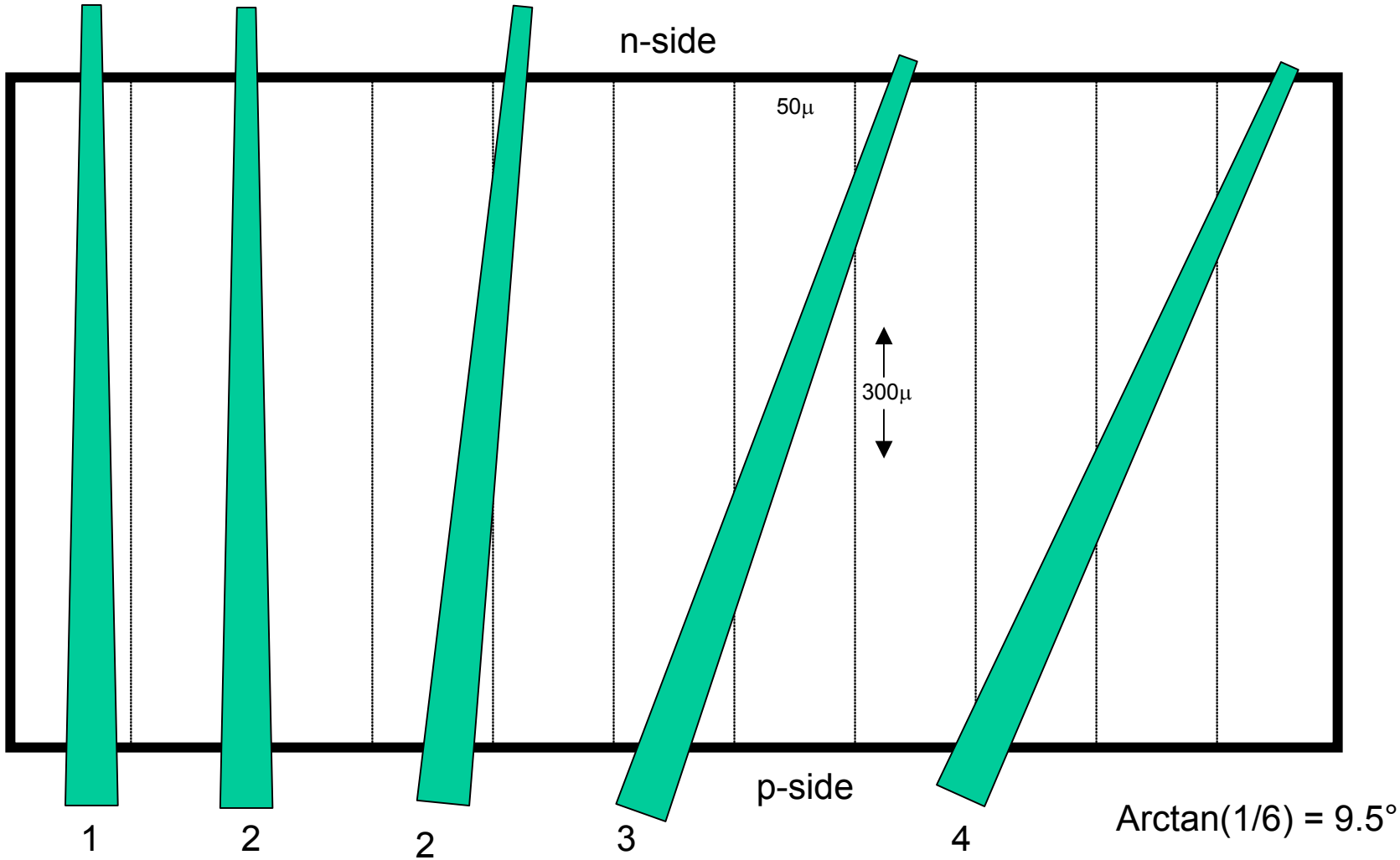
Bias Voltage



Discriminator Threshold

CAN get 50% charge sharing at normal incidence (50μ wide pixels) with sensor just depleted.

Dependence of cluster size on track angle

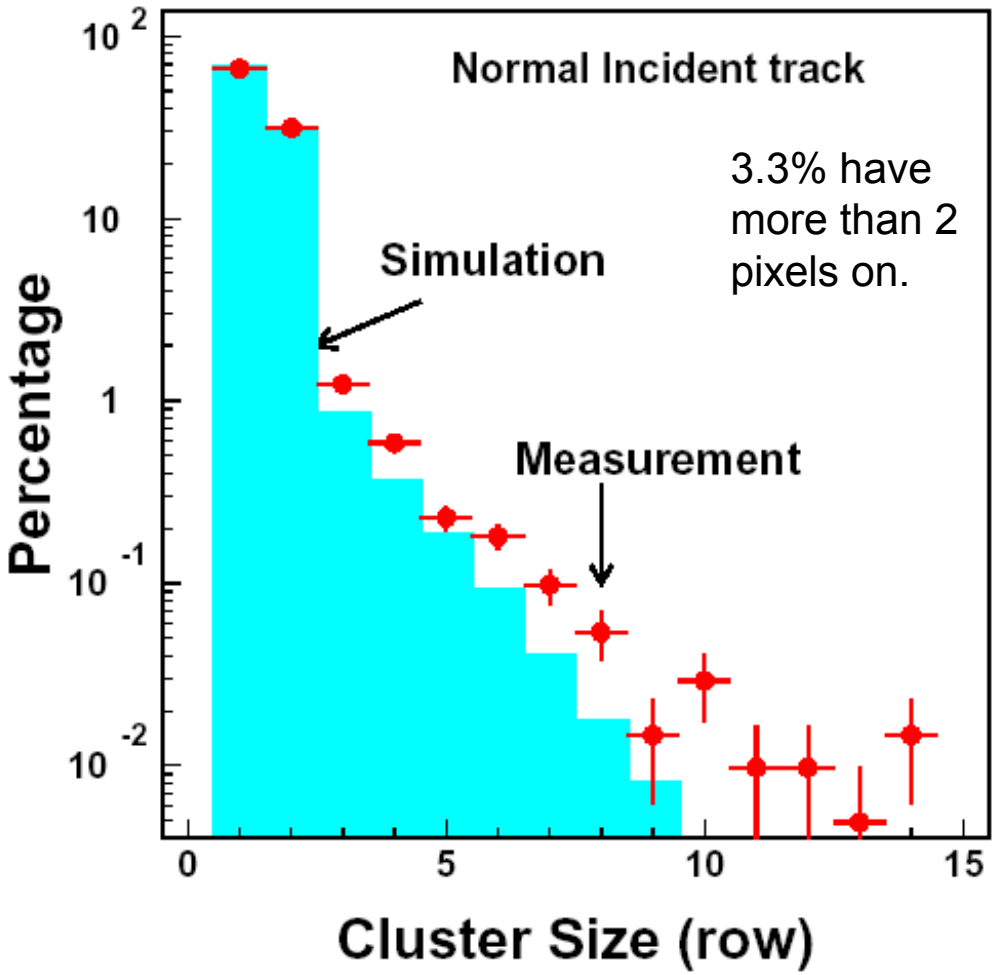


Dependence of cluster size on track angle (data from 1999 testbeam run)

[degs]	CS=1	CS=2	CS=3	CS=4	CS=5	$CS \geq 6$
0	.639±.0034	.328±.0033	.017±.0010	.009±.0019	.0034±.0004	.0025±.0004
5	.433±.0035	.527±.0035	.022±.0011	.010±.0011	.0041±.0004	.0028±.0004
10	.090±.0018	.846±.0025	.040±.0016	.015±.0009	.0055±.0005	.0029±.0005
15	-	.635±.0034	.332±.0034	.022±.0011	.0080±.0007	.0034±.0004
20	-	.209±.0027	.741±.0030	.031±.0014	.0124±.0009	.0060±.0006
30	-	-	.178±.0024	.769±.0029	.041 ±.0018	.0115±.0009

Table A.1: Cluster size fraction for various angles of incidence for FPIX0 p-stop regular gain cells. For each angle, the sample size is about 20000 tracks. These data were collected with a sensor bias voltage of -140 V, and a discriminator threshold of 2500 e^-.

δ-rays

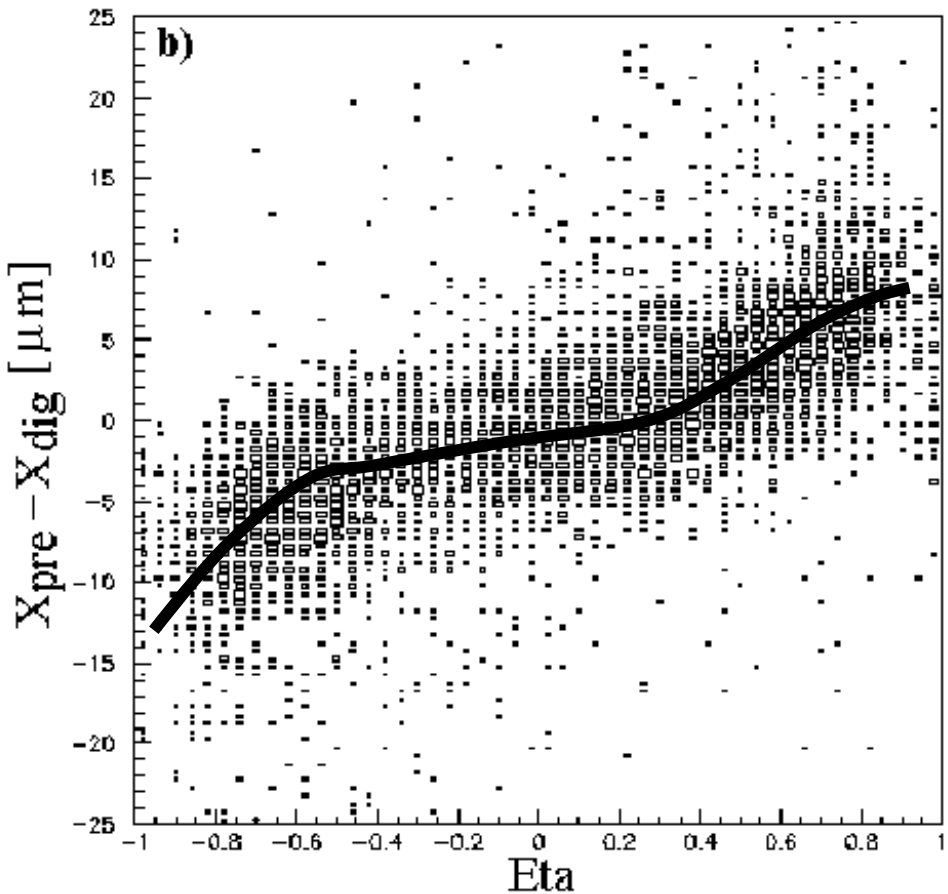

Normal Incident track
3.3% have more than 2 pixels on.
Simulation
Measurement
Percentage
Cluster Size (row)
10 2
10
1
10 -1
10 -2
0
5
10
15

Use of pulse height information

- Without knowledge of track angle, the best estimate of track position is given by the digital center of cluster (ignoring pulse height) $\equiv x_0$.
- Once the track angle is known, the best estimate of track position is given by $x_0 + f(\theta, N, PH_L, PH_R)$.
- For each angle θ, there are 2-3 possible values of N (others arise from δ-rays).
- PH_L,PH_R are the pulse heights on the left and right edges of the cluster.
- The pulse heights in the center of the cluster contain NO INFORMATION.
  - Knowing the track angle means knowing the track length in the central pixels!
- The function f is determined from data & simulation.

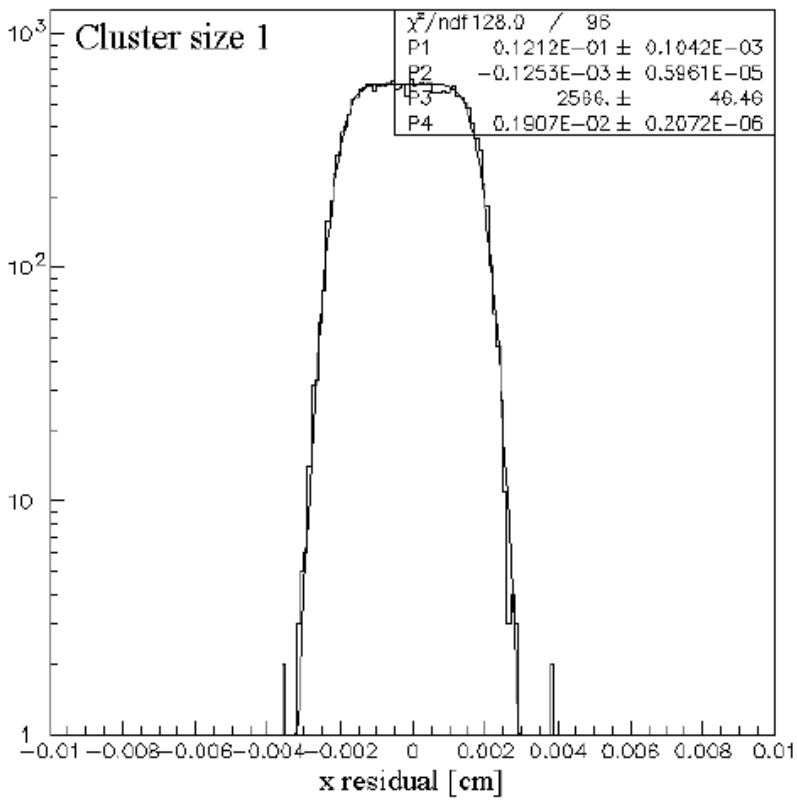
Determination of $f(\theta, N, PH_L, PH_R)$

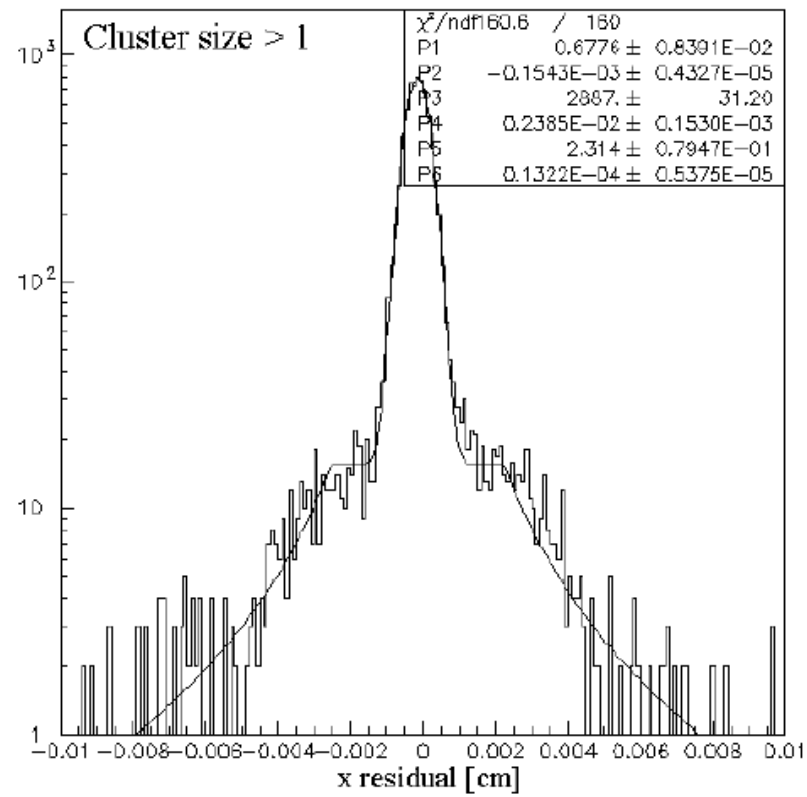
Example from 1999 test beam (θ = 0°)



Eta = $(PH_L - PH_R)/(PH_L + PH_R)$ … really would create a lookup table; 3 bits of pulse height → only 64 possibilities.

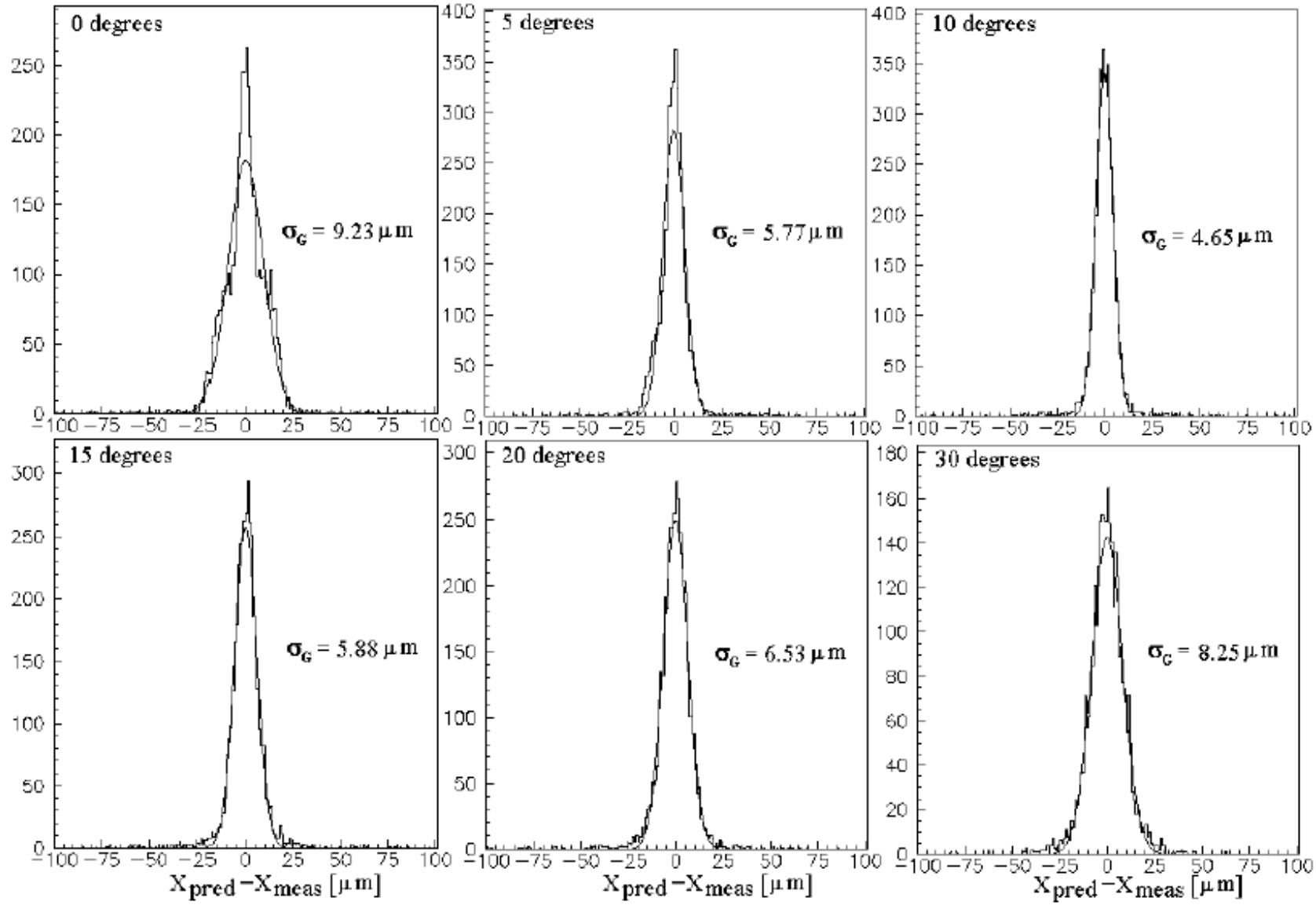
Residual distributions for tracks at normal incidence





$x_{predicted} - x_0$

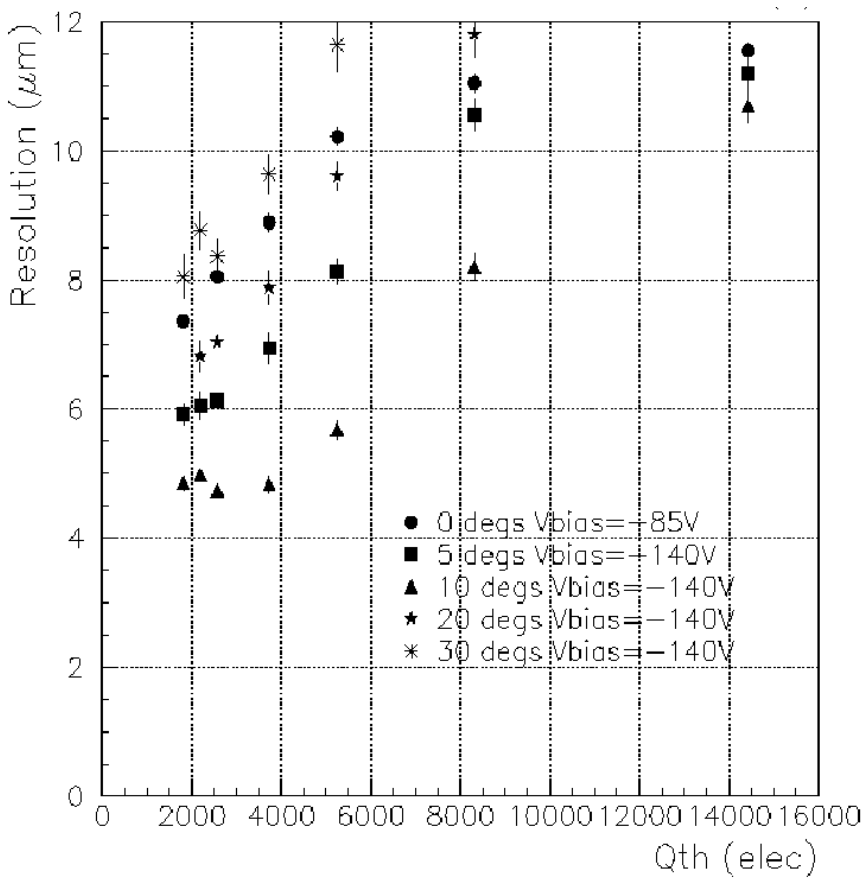
Resolution as a function of track angle



σ_G = standard deviation of Gaussian fit.

Comments on pulse height measurement

1. When more than one pixel is hit, either
   - Most of the information is in the small pulse height.
   - No pulse height is more than ~1/2 MIP.
2. No need for fine binning of pulse height (fluctuations in dE/dx are large).

- 1+2 → We use only 3 bits for pulse height.
- Dynamic range still not finally decided.
  - Probably >1/2 MIP, but <1 MIP.

Small pulse height measurements on cluster edges have large information content --- Low discriminator threshold is important!