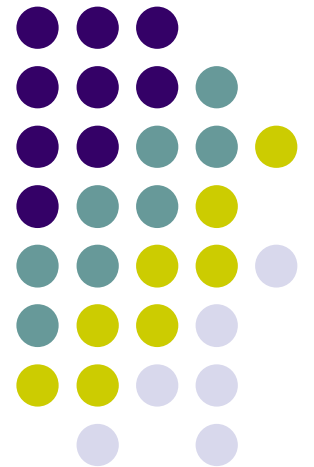# Realistic simulation of CCD response

By Nick Sinev (University of Oregon)
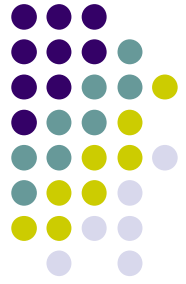
Plan

- Mechanism of CCD signal generation
- How to simulate it
- Some data from SLD VXD3
- Toy simulation – data comparison

Mechanism of CCD signal generation: basics of CCDs

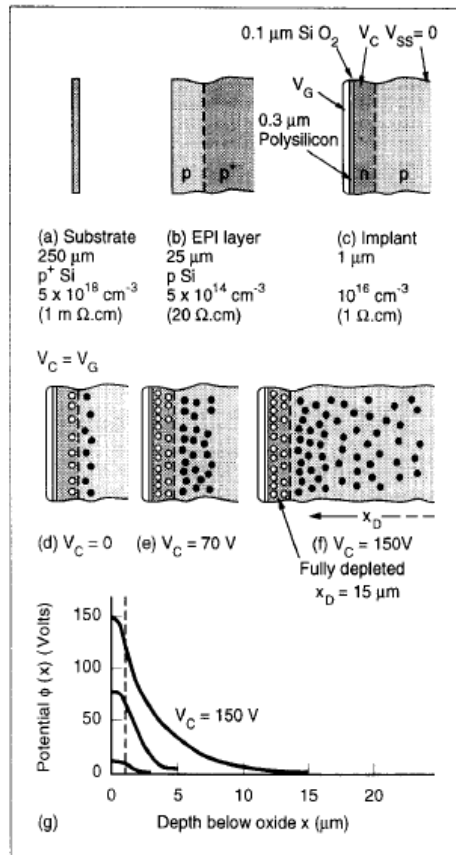- Just few pictures from Chris Damerrel review

Fig. 33 (a) - (c) The successive stages in making a CCD-like structure (shown with increasing magnification). (d) - (f) The depletion process which would apply if V_C and V_G were increased together. (g) The corresponding potential distributions as a function of depth in the silicon.
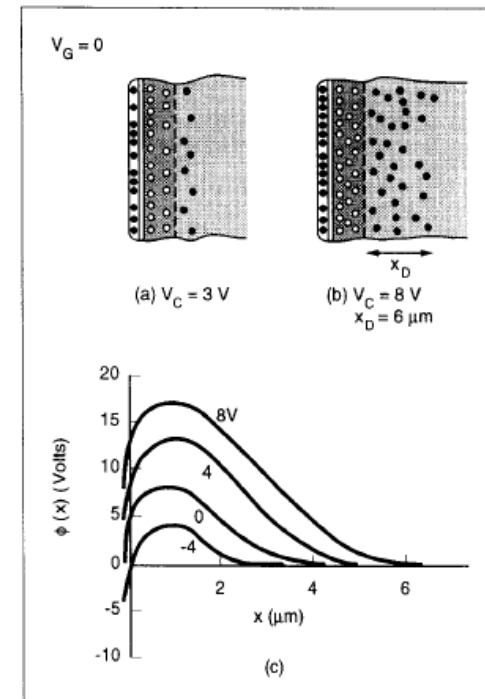
Fig. 34 (a) and (b) The depletion process in normally biased CCD operation with V_G negative with respect to V_c. (c) The corresponding potential distributions after channel pinch-off for various values of V_G.

Mechanism of CCD signal generation: diffusion

- Again from Chris:

Note:
Area of diffusion is defined entirely by the thickness of undepleted part of epitaxial layer. Charge transfer in depleted part happens so quickly that charge does not have chance to diffuse here
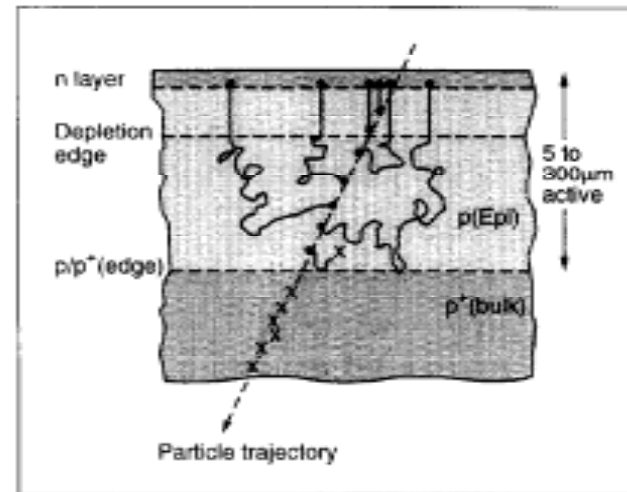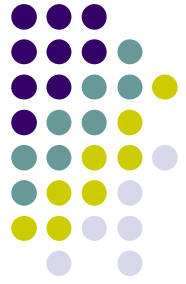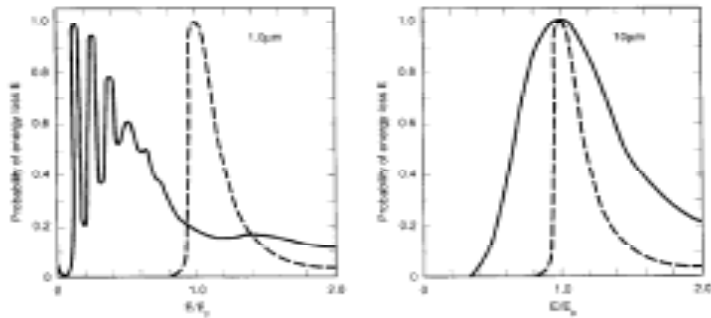

Fig. 24 Charge collection from a silicon structure as used in some pixel devices.

Mechanism of CCD signal generation: fluctuations

- Energy loss fluctuations in thin layers can have significant impact on CCD single point resolution. Again, from Chris:

Energy loss distribution in thin
(1 and 10 microns) silicon layers.
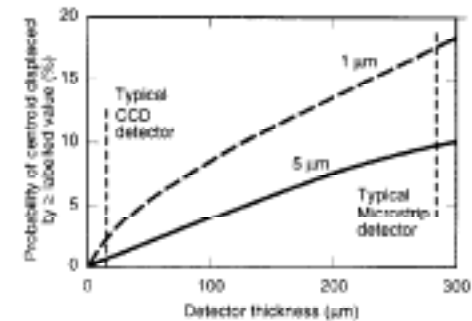Dashed line shows Landau function

Fig. 7 Detector precision limitations from δ-electrons for tracks of normal incidence, as a function of detector thickness.
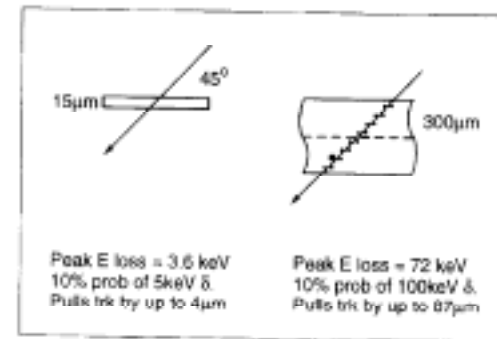

Peak E loss = 3.6 keV
10% prob of 5keV δ.
Pulls trk by up to 4µm

Peak E loss = 72 keV
10% prob of 100keV δ.
Pulls trk by up to 87µm

Fig. 8 Effect of energy loss fluctuations on detector precision for angled tracks.

How to simulate it

- We could simulate in details process of energy loss and charge diffusion in the CCD. However, it will take a lot of CPU time. It may be needed to understand resolution limits and affecting it factors, but for general tracking performance evaluation, we can employ simplified method:
  - Have parameterized charge distribution due to diffusion (with 1 or two gausians)
  - Have parameterized track pull due to delta-electrons as function of track incident angle
  - Simulate CCD response to charged track according to such parameterization.

Toy simulation algorithm

- Parameters: depletion depth, epitaxial layer thickness, electronic noise level, coefficient between distance from generation to collection and sigma of diffused distribution

- Assumptions: energy loss close to landau peak – uniform along track. Large excessive energy loss – delta electron generated in one point on the track. Charge generated within depleted layer is collected without diffusion. Charge in the undepleted layer undergo diffusion proportional to path traveled before collection. Half of the charge generated here reaches collection boundary after reflecting from epitaxial layer/substrate boundary.

- Algorithm: first generate energy loss, from it determine if there was delta electron, simulate point of delta electron generation, simulate collection from depleted layer (geometry), simulate diffused charge collection. To speed the last one, I used pregenerated lookup tables.
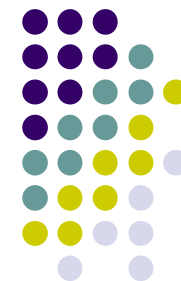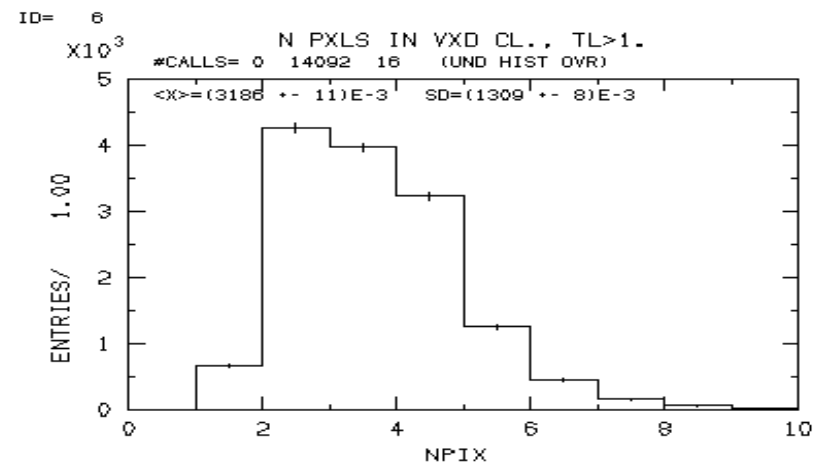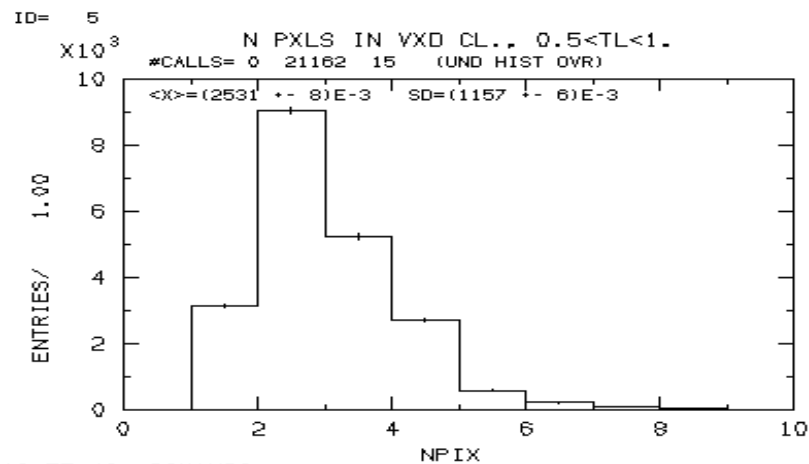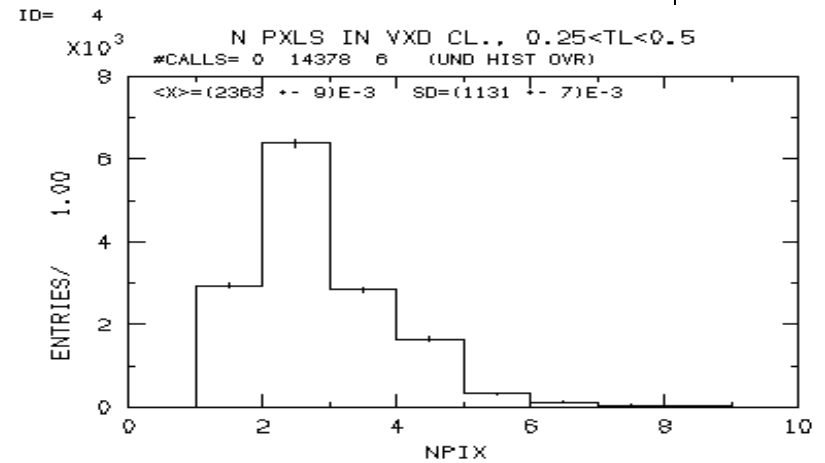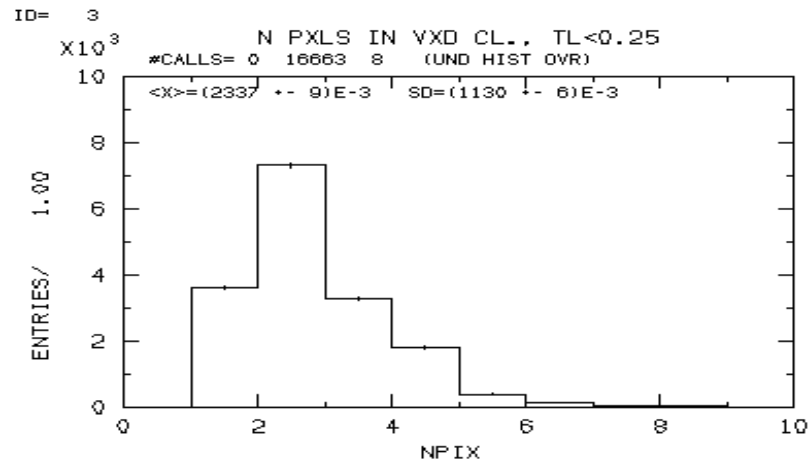
Some data from VXD3

- To be able to perform mentioned parameterization, we need data to compare. Here are some plots from VXD3 data:
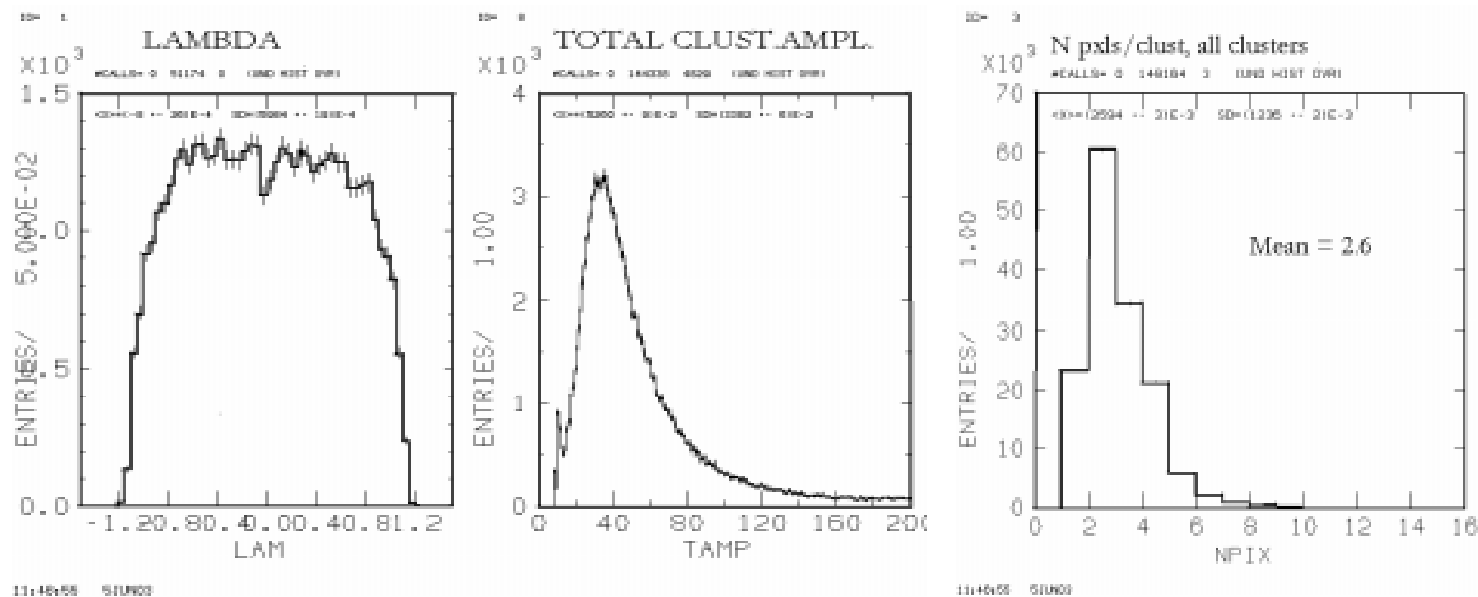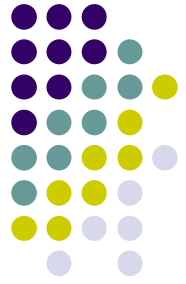

Here is the SLD charge tracks labmda distribution (CCD cluster size depends on the angle) ,CCD cluster total pulse height (amplitude) and number of pixel in cluster (cluster size) distribution for ALL linked to track clusters.
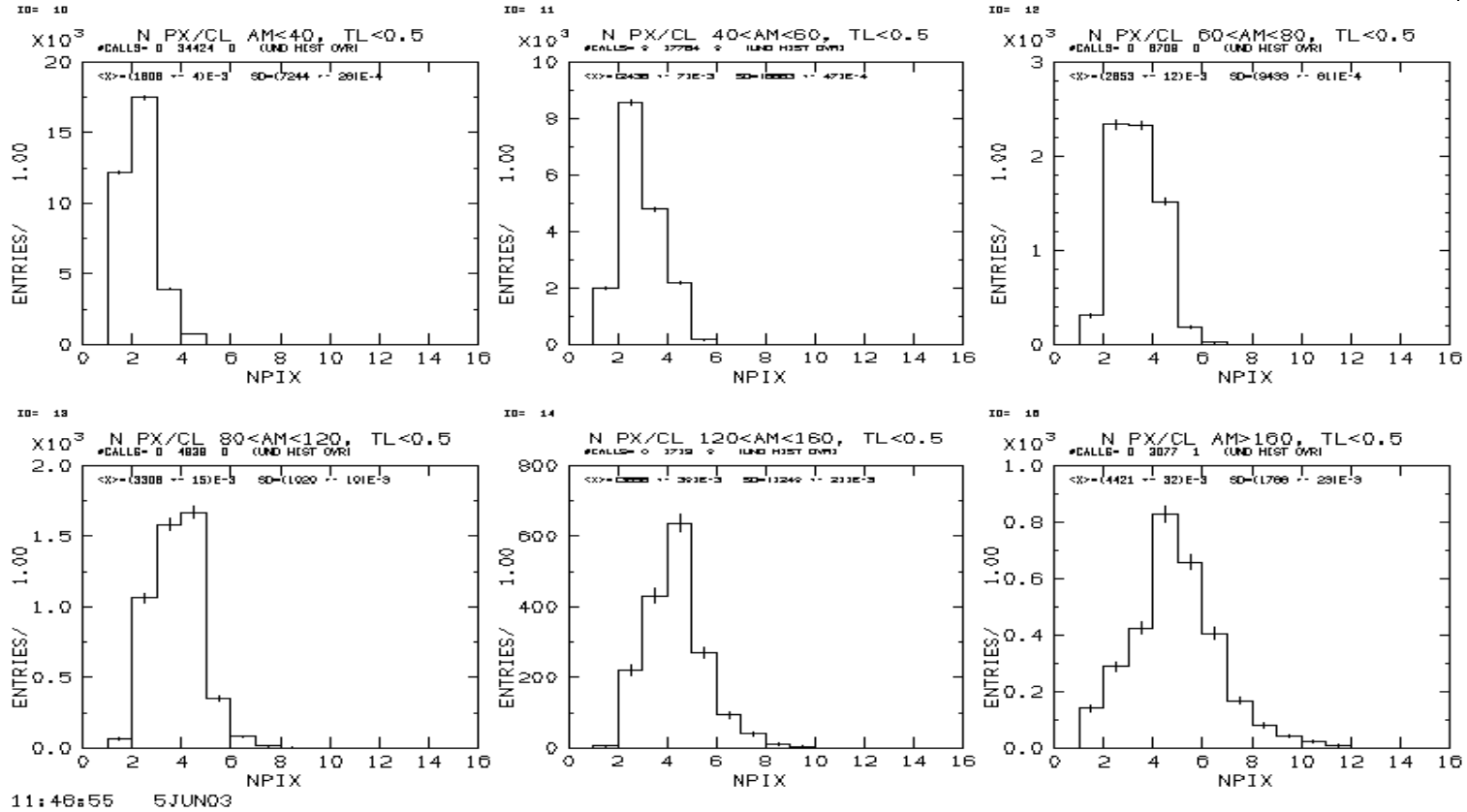
Some data from VXD3 – p.2

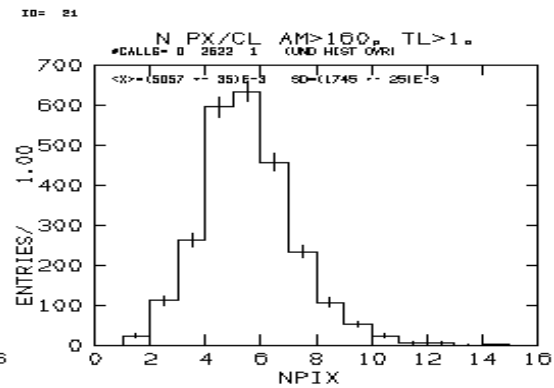- CCD cluster size for different ranges of tangent lambda (linked to tracks clusters)

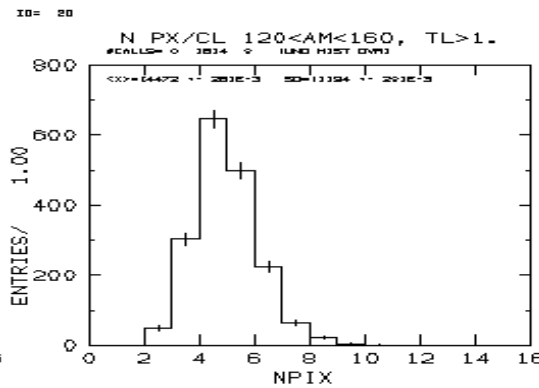# Some data from VXD3 – p.3

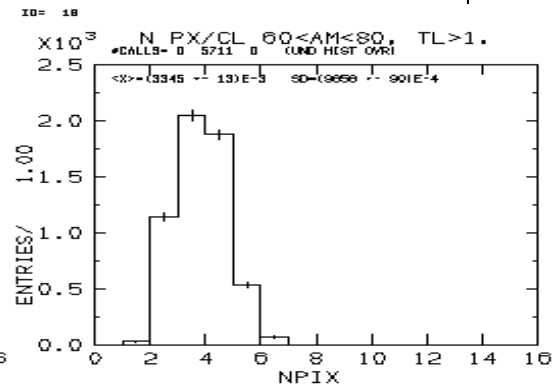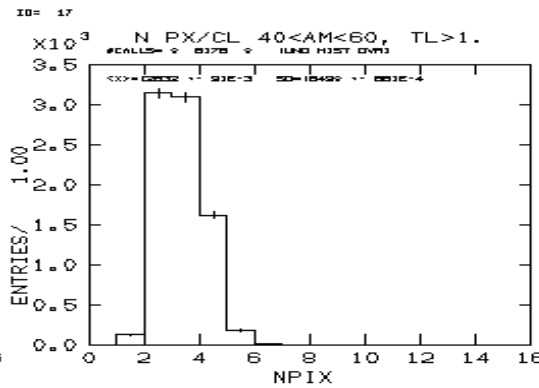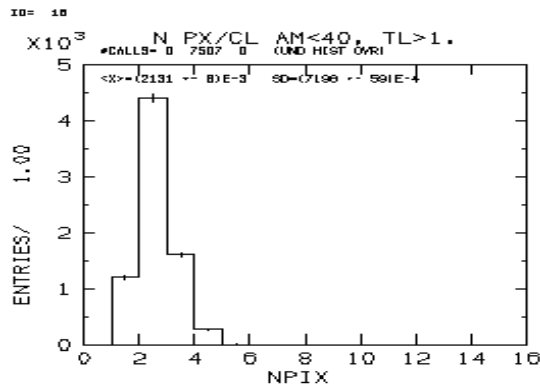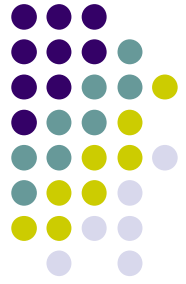- Cluster size (number of pixels) for different values of total cluster amplitude (some of all pulse heights in cluster), for small angles .
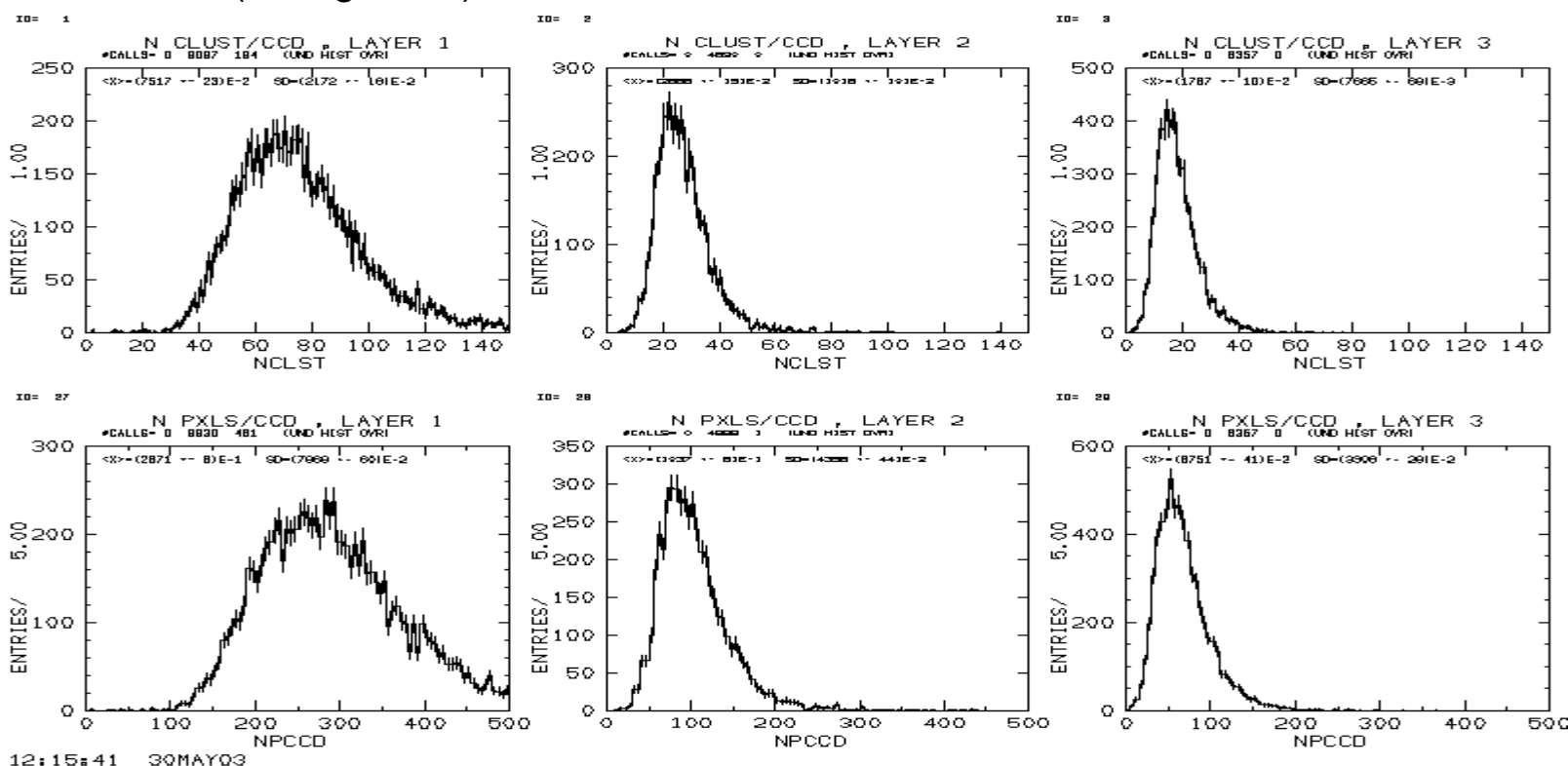
Some data from VXD3 – p.4
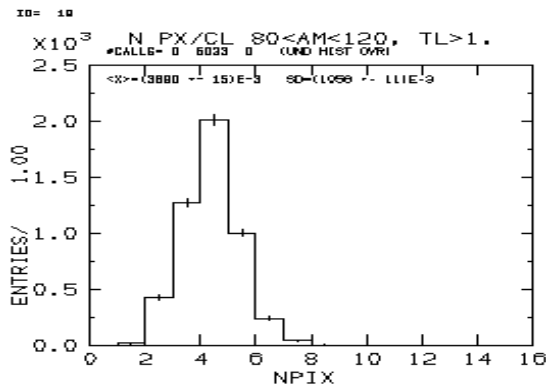
- Cluster size (number of pixels) for different values of total cluster amplitude (some of all pulse heights in cluster), for large angles .

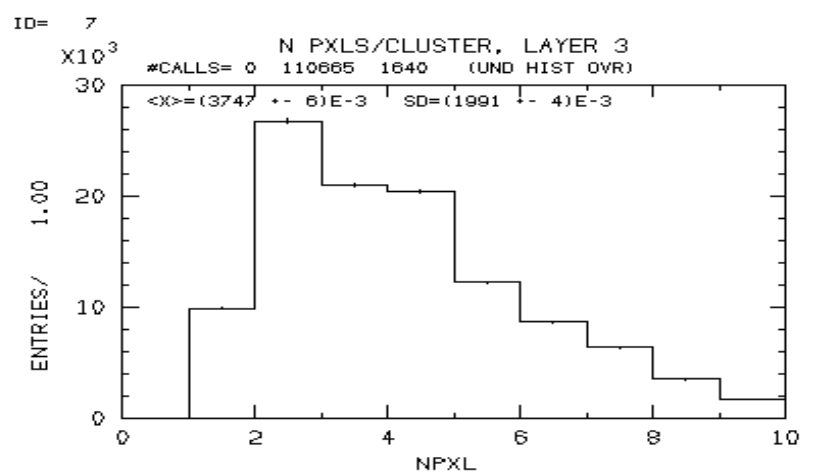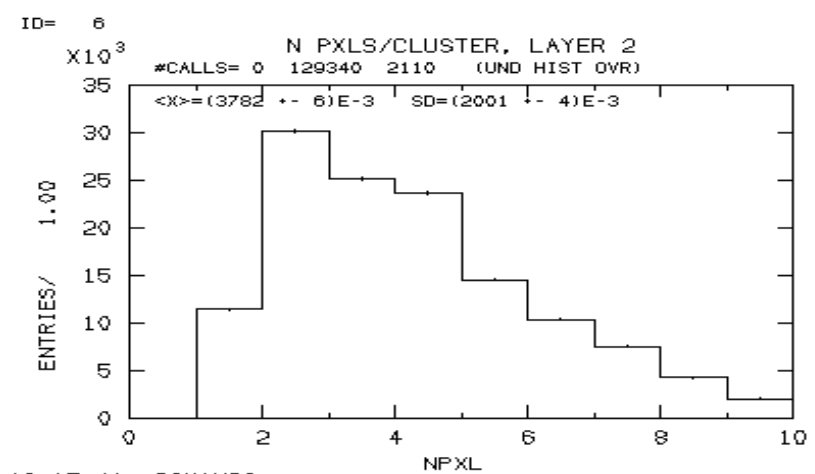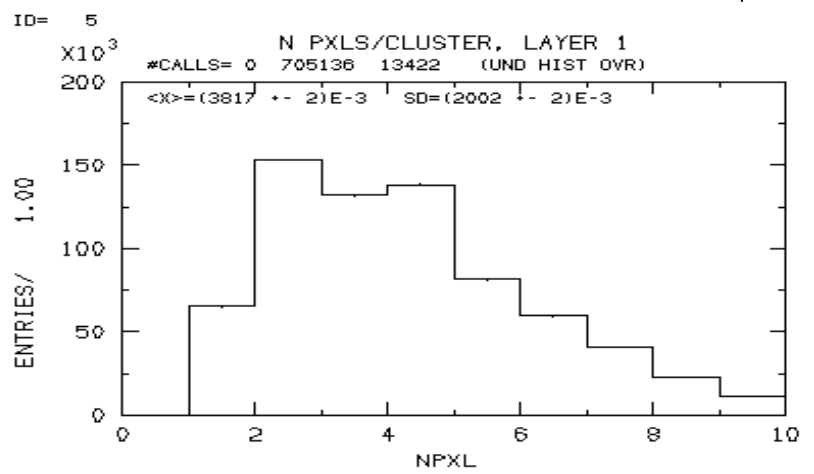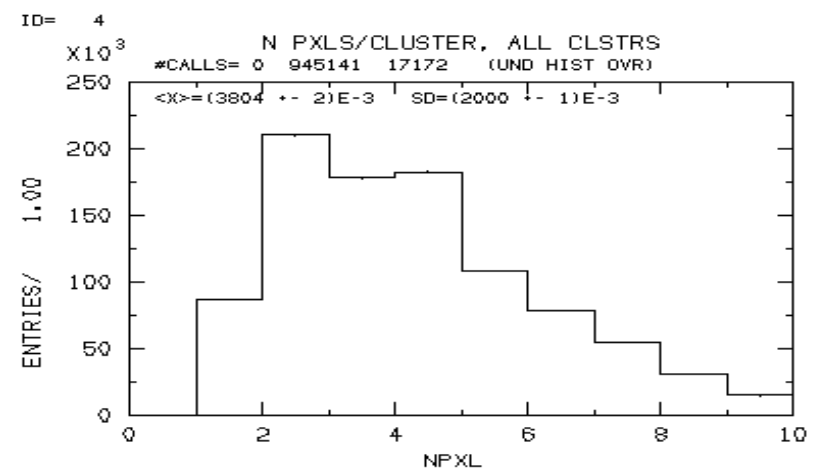# Some data from VXD3 – background clusters CCD occupancy
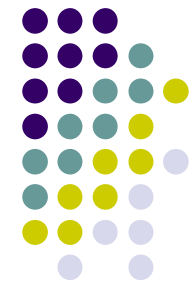
- Here are some plots to demonstrate difference between linked to track clusters and unlinked (background) ones

This page shows CCD occupancy in SLD VXD3 in number of clusters and number of pixels per CCD in 3 VXD3 layers for hadronic events (readout time is 25 beam crossings)

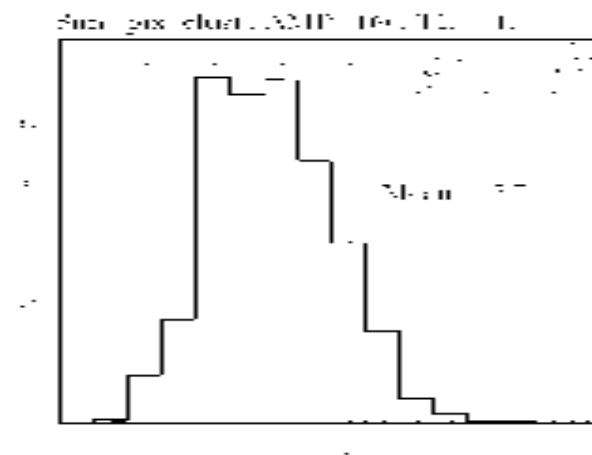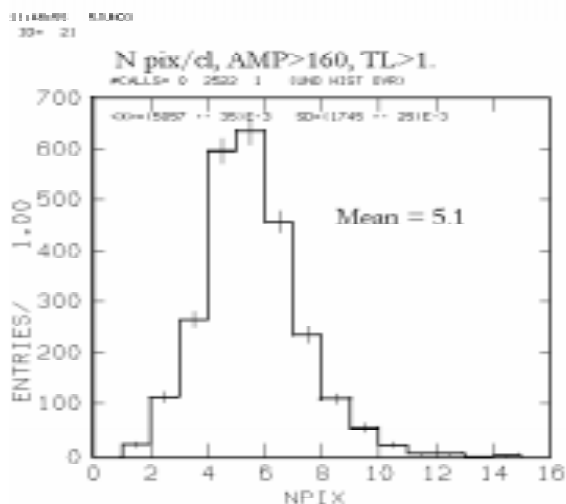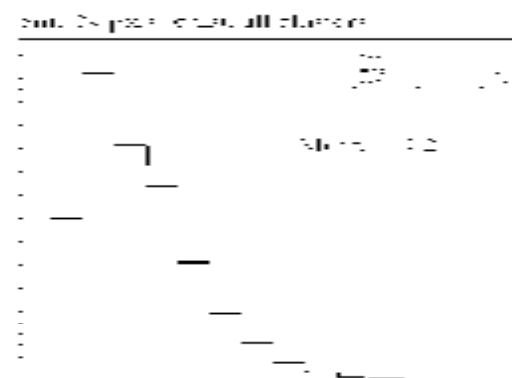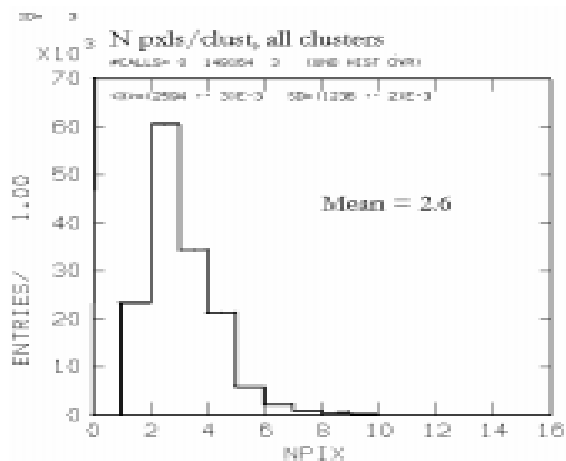# Some data from VXD3 – background clusters size

Some data from VXD3 – background clusters amplitude
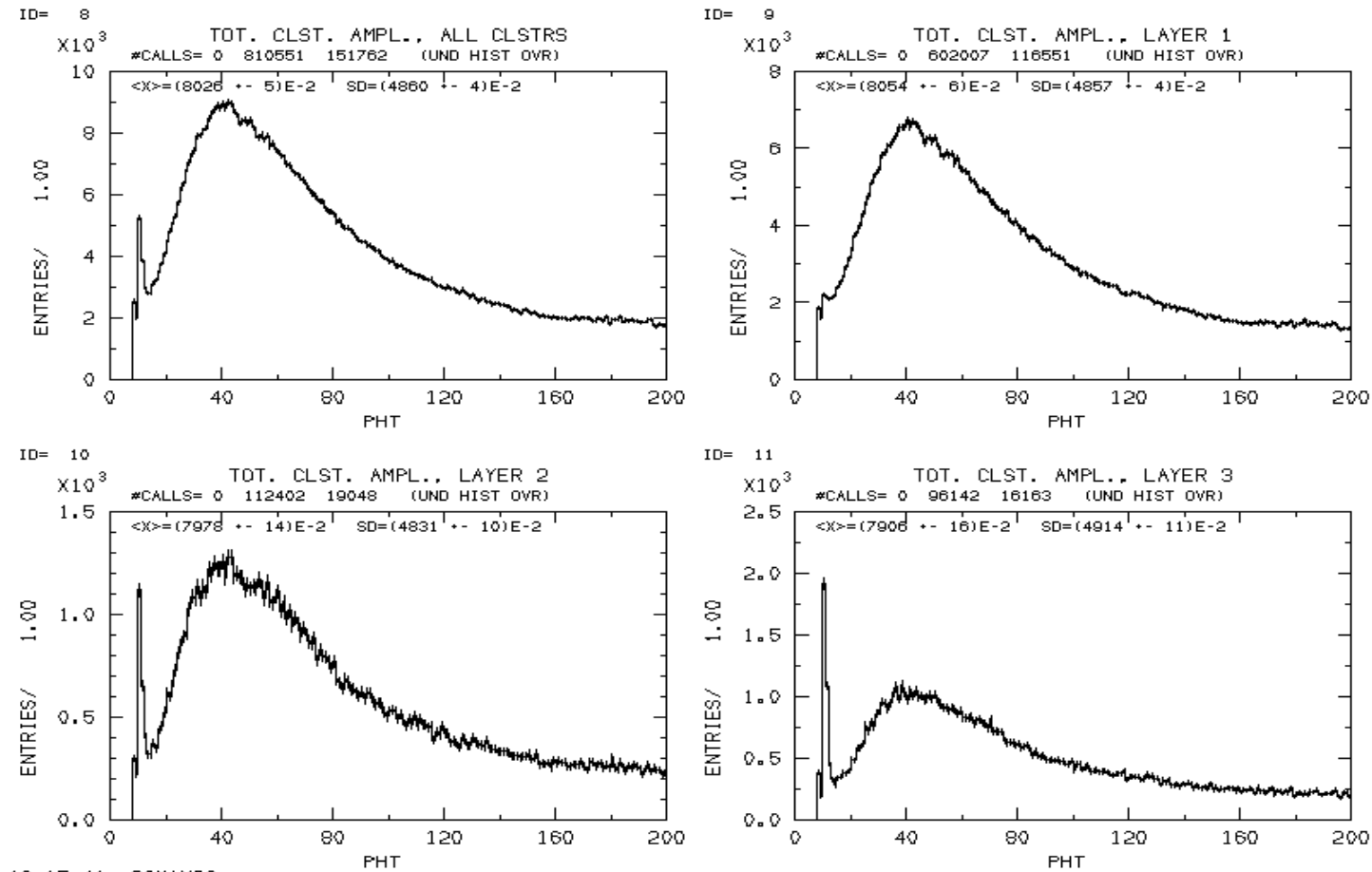
Comparison with toy simulation

Data

Simulation

Parameters used in simulation

- As seen from simulation – data comparison, the parameters I used still are not providing perfect match. It's a hard job to find right set. Though there are not much freedom – parameters should be sensible from physics point of view. The most difficult is to achieve cluster size distribution as sharp as is seen in data. It strongly depends on the single pixel threshold, as soon as this threshold is comparable with noise level. It probably would imply, that it depends on noise distribution also. In real life we have very different noise levels in different CCDs. This may be the source of thetrouble with simulation – data comparison. Anyway, I used following parameters:

  - Depletion depth 4 microns
  - Epitaxial layer thickness 16 micron
  - Travel distance – diffusion sigma coefficient 0.5
  - Noise level – 70 e
  - Single pixel threshold : > 4 ADC counts
  - Charge-ADC conversion : 1 ADC count = 27 e

Conclusion

- After some work with parameters adjustment suggested method of CCD response simulation can be used for most of tracking performance study

- More detailed simulation of CCD signal formation may be needed if we want to better understand resolution limits.