CCD output for full detector simulation in JAS

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Outline

- Brief overview of Oregon R&D in CCD vertex detector
- Justification for need of full CCD output simulation
- What CCD features have been simulated
- CCD signal processing simulation
- Software organization
- Comparison with VXD3 data
- Examples of application to LCD simulation
- Recommendation for CCD vertex detector design
- Conclusions

Oregon R&D in CCD Vertex Detector

University of Oregon: Jim Brau, Chris Potter, Olga Igonkina, Nikolai Sinev

- Radiation hardness study – started in 1997.
  - Published in J.E.Brau and N.Sinev “Operation of a CCD Particle Detector in the Presence of Bulk Neutron Damage” IEEE Trans.Nucl.Sci.,47,1898 (2000)
- Continued in 2003 – investigation on the nature of SLD VXD3 radiation damage and more details on the radiation damage effects
  - Reported in Vertex 2003 talk: http://hepwww.rl.ac.uk/Vertex03/Talks/NikolaiSinev.pdf
  - Reported in IEEE 2003 NSS talk. Will be published soon (for IEEE members available in conf. records)

Some results from radiation hardness studies

- CCD start seeing some loss of CTE at neutron fluence about 10^9 n/cm^2. However, sacrificial charge injection improves CTE, and normal CCD operation can be achieved up to 10^{10} n/cm^2, and with special design of CCD probably up to 10^{11} n/cm^2.
- SLD VXD3 suffered radiation damage not from neutrons, but from electromagnetic radiation. Extent of the damage corresponds to irradiation by about 10^{12} e/cm^2 with energy range within tens of MeV.
- Effect of radiation damage on CTE depends on readout speed. There is significant number of charge traps, created by irradiation, which are located in the zone of low charge density of traveling charge packet, and they absorb charge from the packet only if contact time is large enough (in milliseconds range).

Full CCD simulation - justification

- Idealized detector simulation can give wrong sense of confidence while real detector may encounter problems. Examples:
  - each track gives just one hit in current simulation. In reality, not one, but few pixels have signal from same track (occupancy underestimation). Also, background hits generate larger clusters of active pixels.
  - In idealized simulation we see separate hits for different tracks, even if they are very close, even in one pixel. Not so in reality.
- Understanding the impact of different design choices on detector performance is necessary for optimizing of detector design. Such understanding can be achieved with the full detector response simulation.

What CCD features have been simulated

- Charge diffusion in the CCD.

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

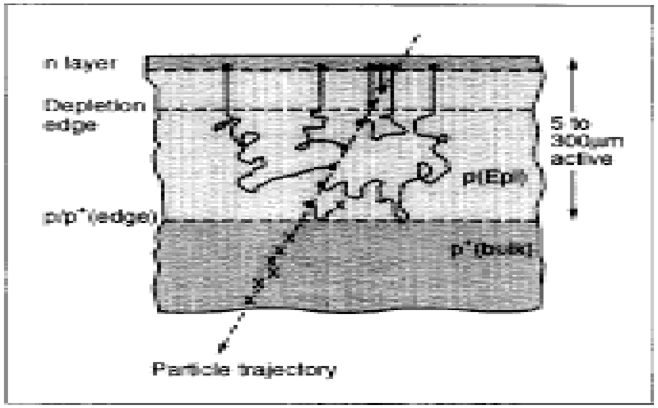


Fig. 24 Charge collection from a silicon structure as used in some pixel devices.

- Effect of δ-electrons
- Low energy electrons (compton from photons) behavior
- Electronics noise and signal digitization

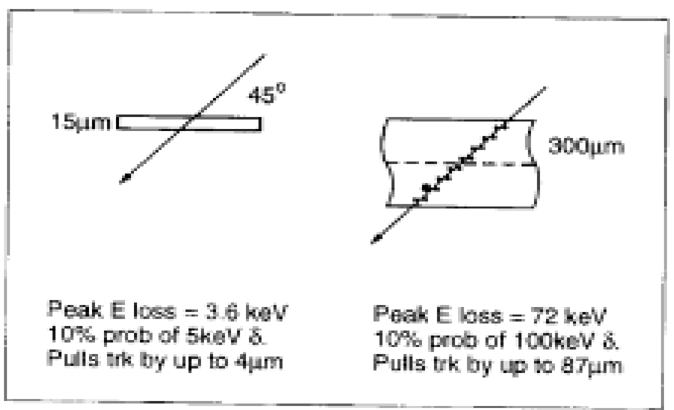


Fig. 8 Effect of energy loss fluctuations on detector precision for angled tracks.

How it was simulated

- Use pre-generated tables of the probability for the electron, generated at given point inside CCD active layer to be collected by given pixel.
- Simulate Landau distribution for total charge deposit, uniformly spread it along track length for small deposits, and generate single δ-electron if deposit exceeds preset threshold. δ-electron position on the track is random, and all ionization deposit from it to be in one point
- For compton (low energy) electrons use tabulated range in silicon (from US NIS). Energy deposition for the portion of the electron range inside CCD active layer is extracted from this table also. Used for up to 200 keV energy of electron (range 240 um).

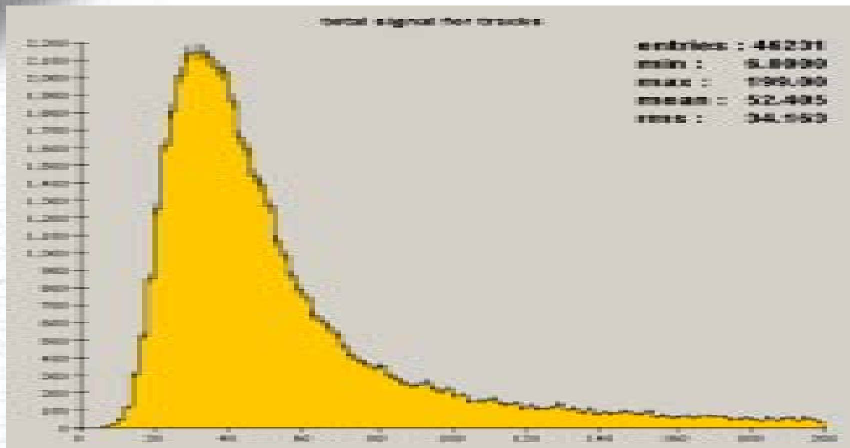
Simulation of CCD signal processing

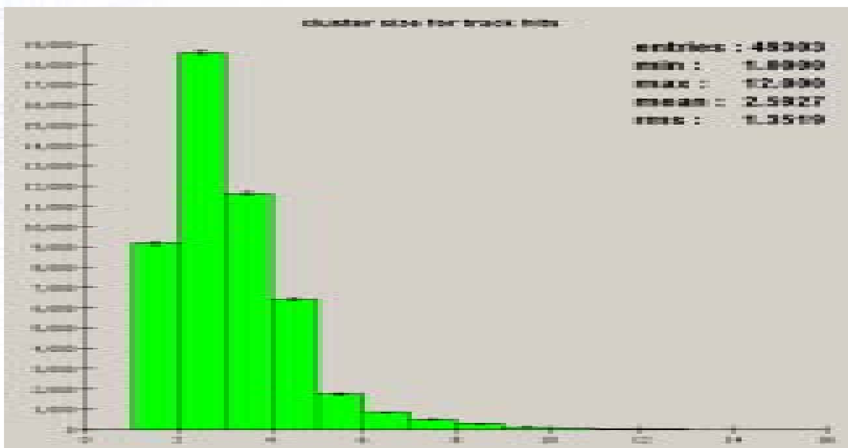
- CCD simulating program creates a list of active pixels in each CCD. It takes VXD hits from simulated events, finds charge deposited in each pixel, adds electronics noise and digitizes signal.
- CCD cluster finder finds active pixels clusters, defined as continuous region of touching active pixels
- Each cluster examined for the presence of multiple maxima, and is split into number of clusters according to number of maxima.
- Center of each cluster is found, using selected method (it can be just center of gravity, or modified center of gravity with reduced contribution of central pixel, or more elaborate algorithm).
- Coordinates of found centers are used to replace tracker hits in the simulated events. Further event processing (track finding, fitting, and so on) proceeds the same way as it was before.

Software organization

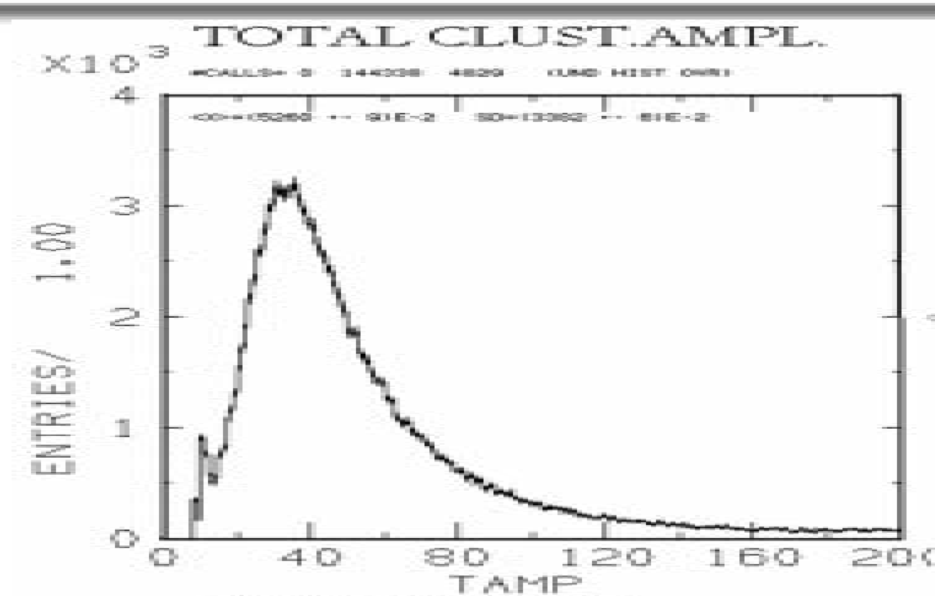
- The package hep.lcd.mc.CcdSim contains all java classes implementing described algorithm.
- To use it in the JAS event processing job with all default parameters (similar to CCDs used in VXD3), one needs only add 2 lines of code in his/her analysis:
  - FullCcdSimulation ccdsim = new FullCCDSimulation();
  - add(ccdsim);
- The class FullCcdSimulation includes many access functions to set CCD parameters (like thickness, depleted layer depth, epi layer thickness and so on), electronics parameters (noise, ADC conversion scale, pixel and cluster thresholds), processing parameters (like cluster center calculation method). By default, cylindrical CCDs (one per layer) are created with radius and length read from Detector.ini file for given detector geometry

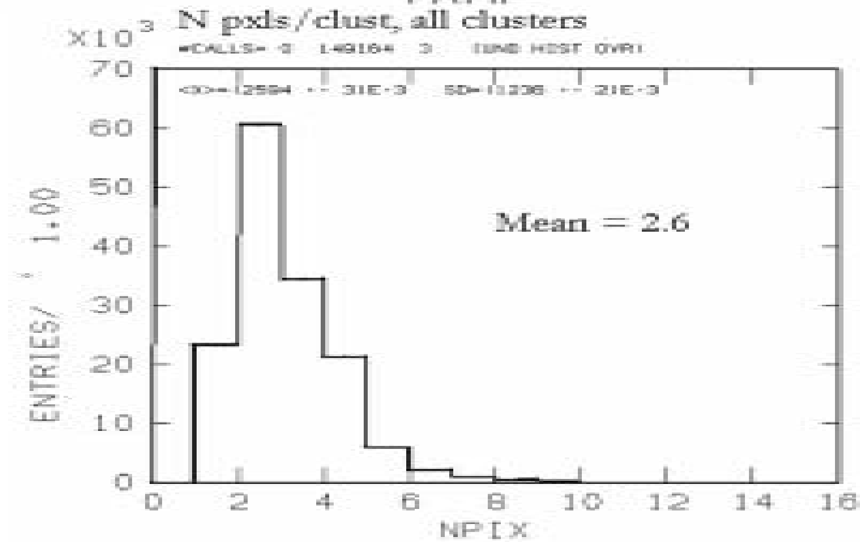
Comparison with SLD VXD3 data – clusters linked to tracks





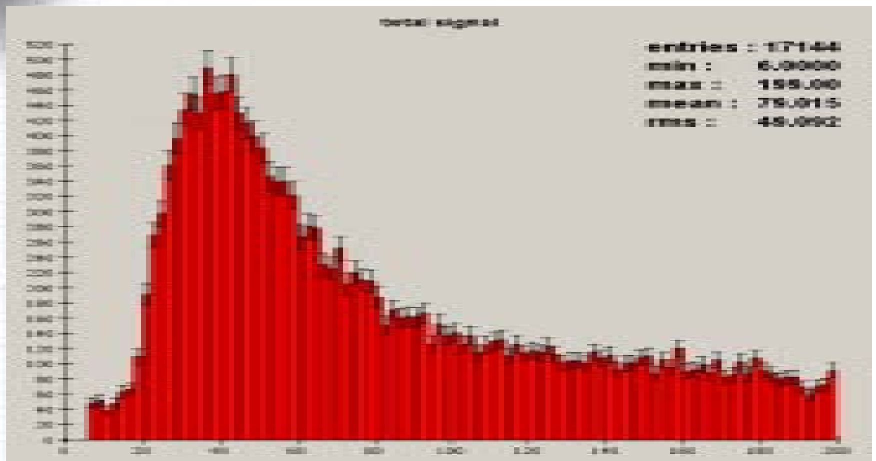
Simulation

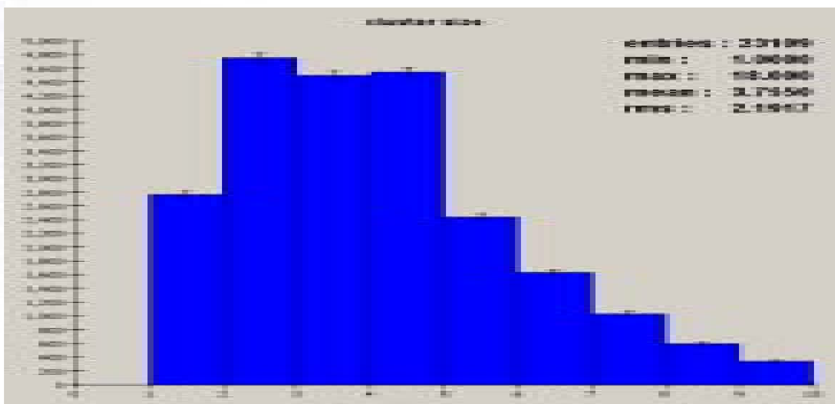




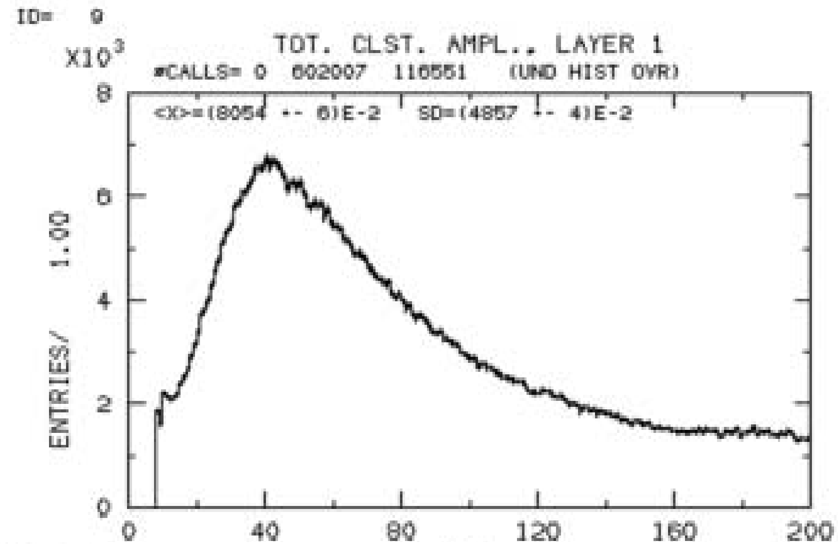
VXD3 Data

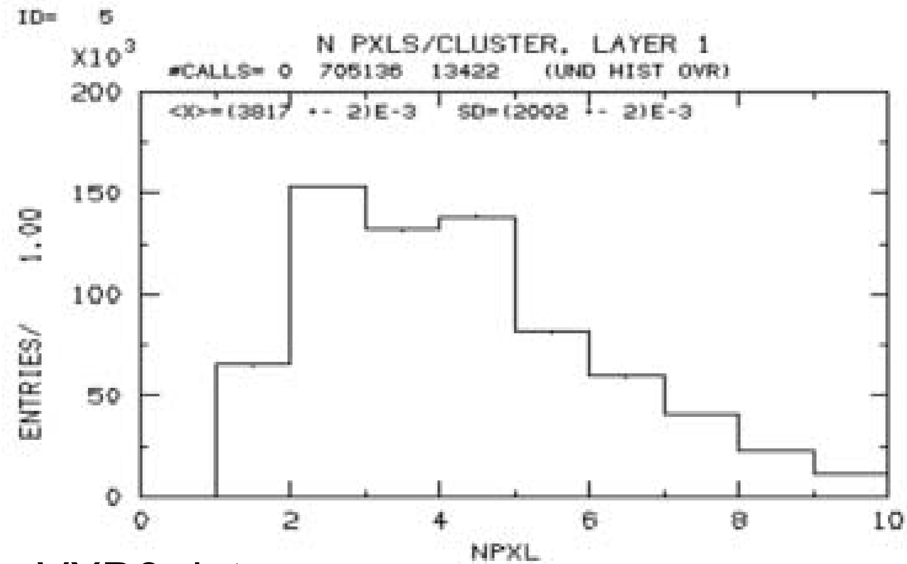
Comparison with SLD VXD3 data – not linked (background) clusters





Simulation

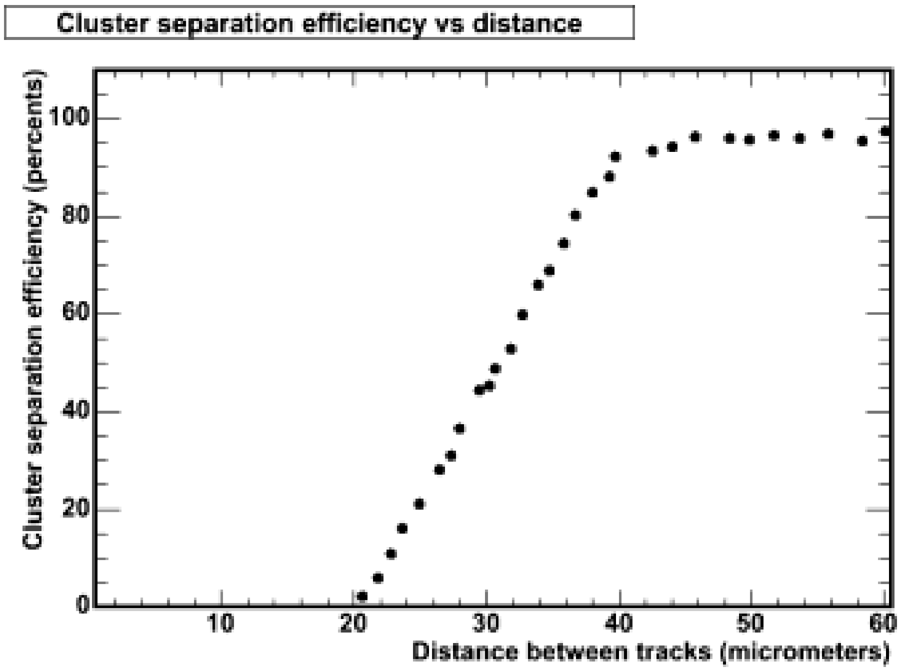




VXD3 data

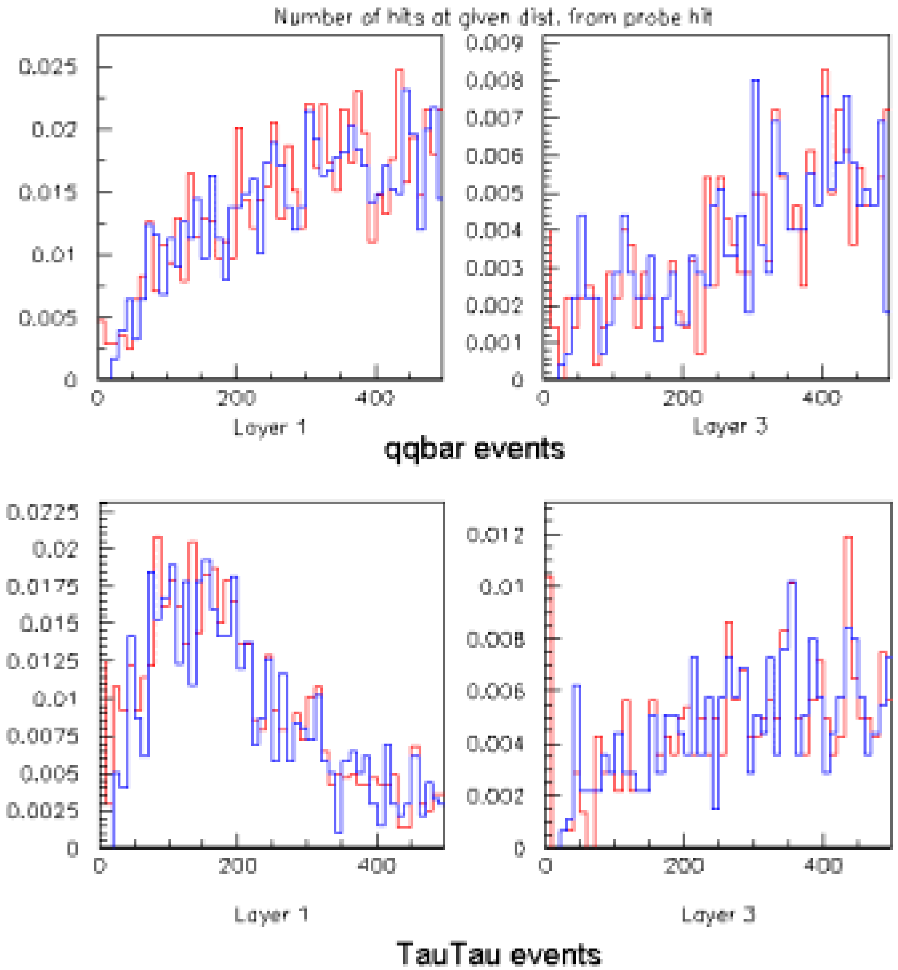
Examples of applications to full LCD simulation

- Here is the example of the efficiency of the simulated CCD clusters separation as function of distance between tracks CCD hit points. Direction of the vector between points was along pixel width. For random direction efficiency plateau apparently will begin at larger distance



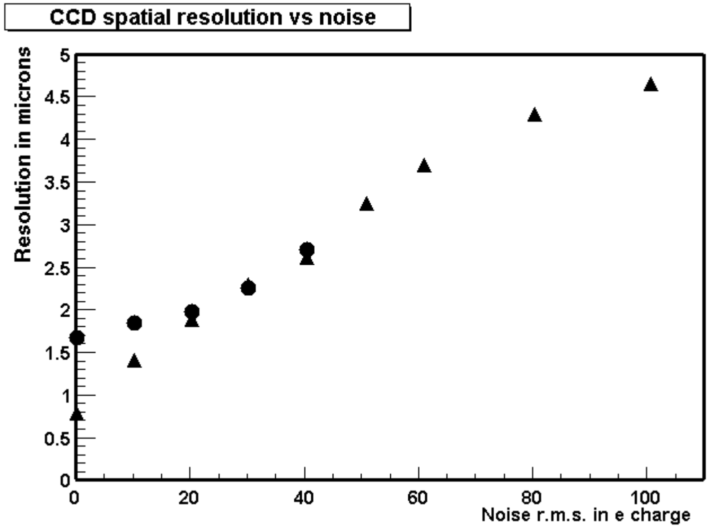
Examples – cluster separation

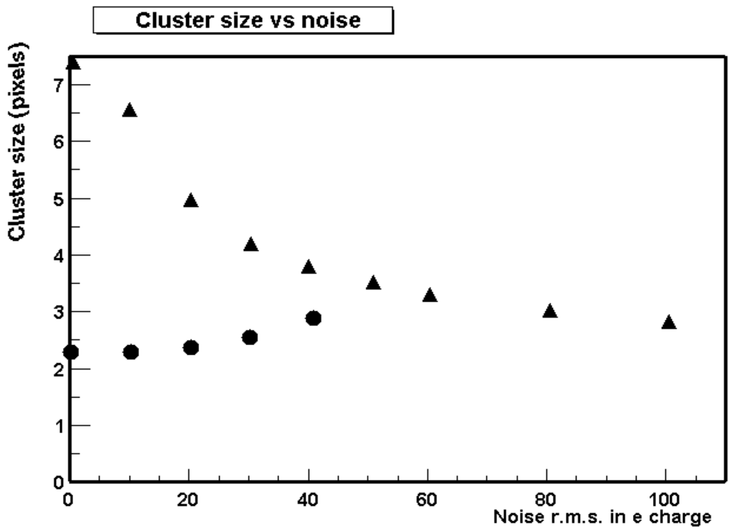
- Separation of track hits in simulated events with high density jets. Red lines show distributions without CCD simulation (ideal detector), blue – for reconstructed hits after full CCD simulation. 1 bin is 10 um, and we can see that first 2 bins are empty when full CCD simulation employed



Recommendations for CCD design: optimization of spatial resolution

- CCD spatial resolution as function of electronics noise:
  - a) keeping same cluster size by having same pixel threshold for low noise level (circles)
  - b) adjusting pixel threshold to 1.5 of noise level (triangles)





Optimization of spatial resolution

- If we want better spatial resolution we need better signal/noise ratio (as seen from previous page). To increase signal – increase epitaxial layer thickness, reduce output node capacitance. To reduce noise – better electronics or slower readout. Because readout speed depends on number of pixels in CCD and number of output channels per CCD, reduction of pixel size does not improve resolution, if we do not increase number of output channels.

Conclusions

- Software for full simulation of CCD signal is ready for release in the JAS environment
- Comparison of full simulation results with VXD3 data shows good agreement
- Software is extremely user-friendly, and can be easily tuned for large variety of CCD, electronics and processing parameters
- Software will be useful for verification of LC detector real life performance and for optimization of CCD and CCD readout electronics design for better physics reach.