



# 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  $10^9 \text{ n/cm}^2$ . However, sacrificial charge injection improves CTE, and normal CCD operation can be achieved up to  $10^{10} \text{ n/cm}^2$ , and with special design of CCD probably up to  $10^{11} \text{ n/cm}^2$ .
- SLD VXD3 suffered **radiation damage** not from neutrons, but from **electromagnetic radiation**. Extent of the damage corresponds to irradiation by about  $10^{12} \text{ e/cm}^2$  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

- Effect of  **$\delta$ -electrons**
- Low energy electrons (**compton from photons**) behavior
- Electronics **noise** and signal digitization

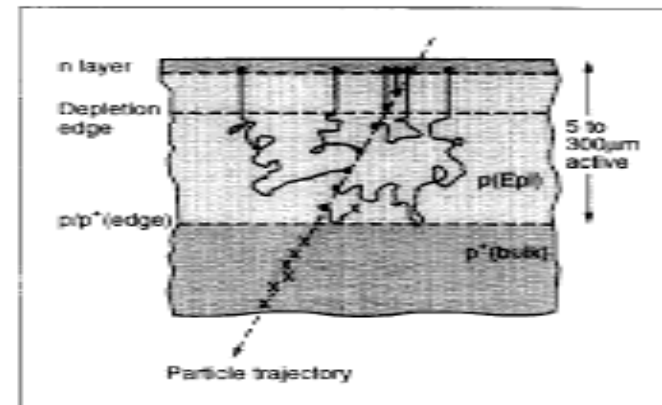


Fig. 24 Charge collection from a silicon structure as used in some pixel devices.

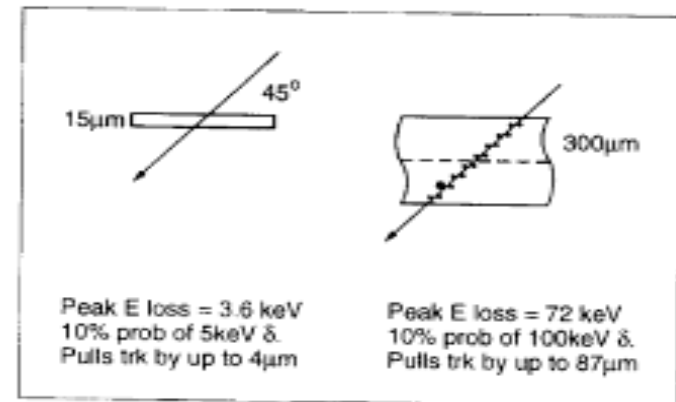


Fig. 8 Effect of energy loss fluctuations on detector precision for angled tracks.



# 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  **$\delta$ -electron** if deposit exceeds preset threshold.  **$\delta$ -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  $\mu\text{m}$ ).



# 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.

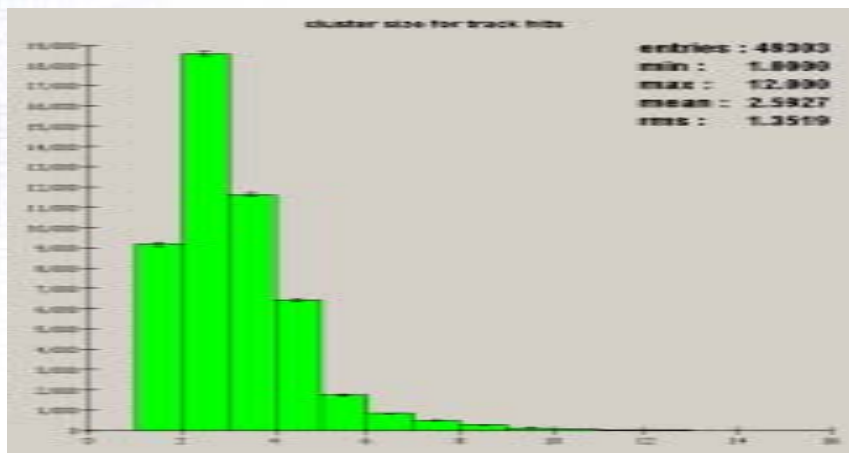
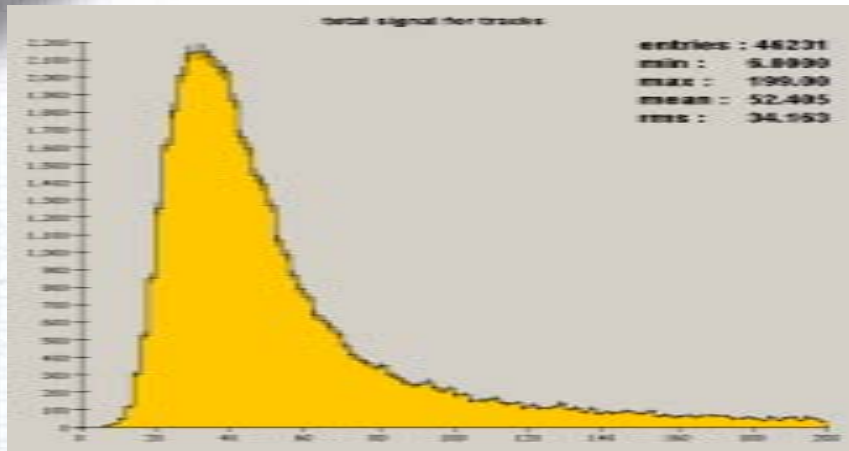




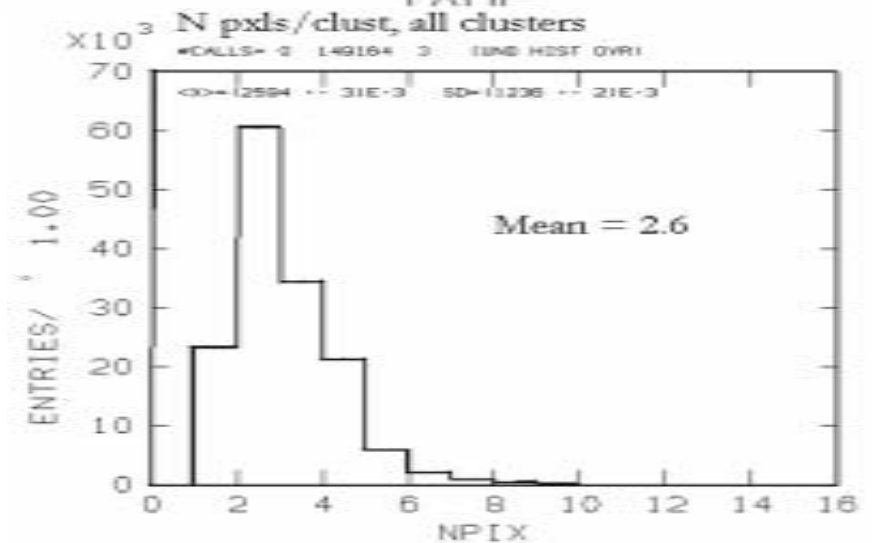
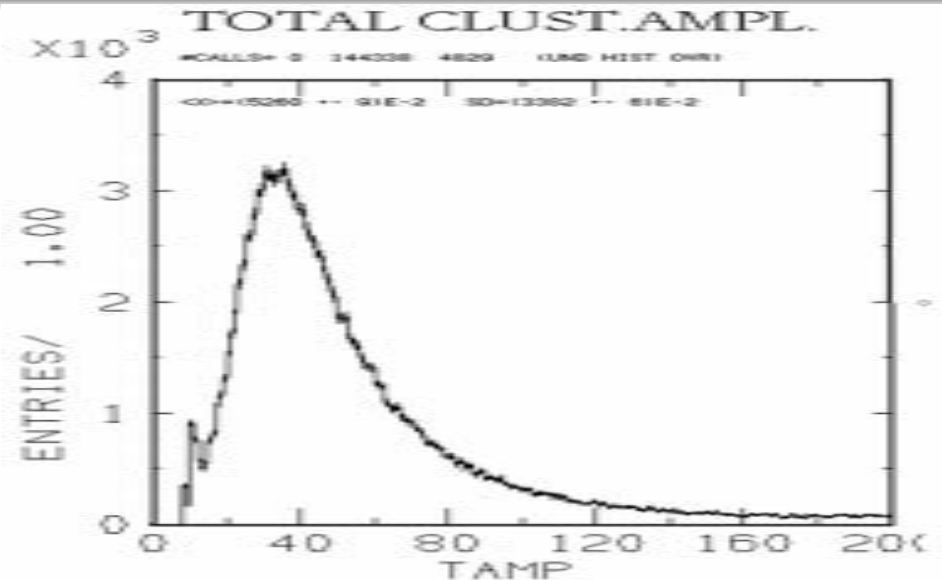
# Software organization

- 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

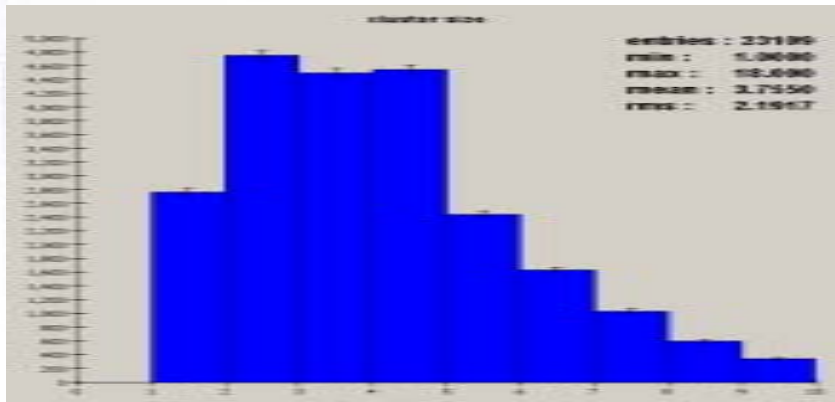
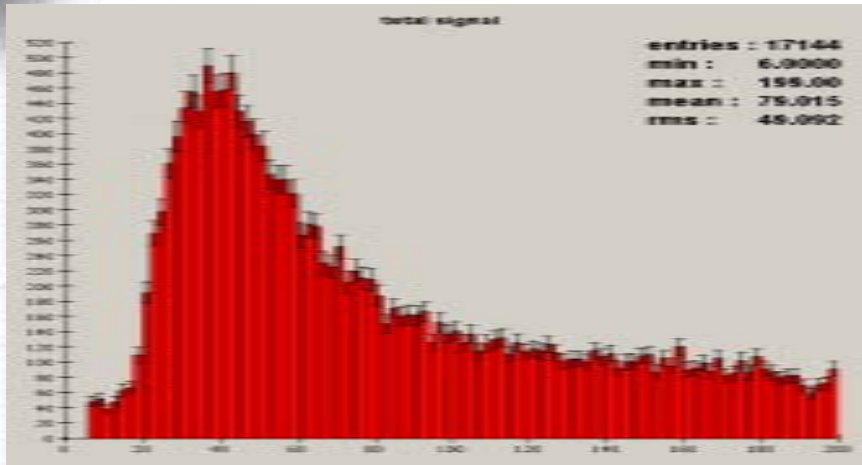


Simulation

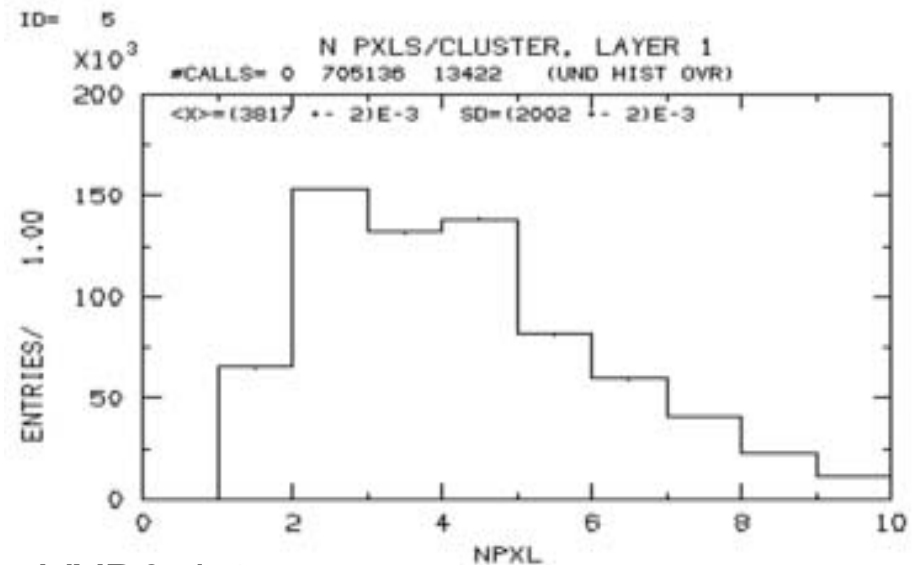
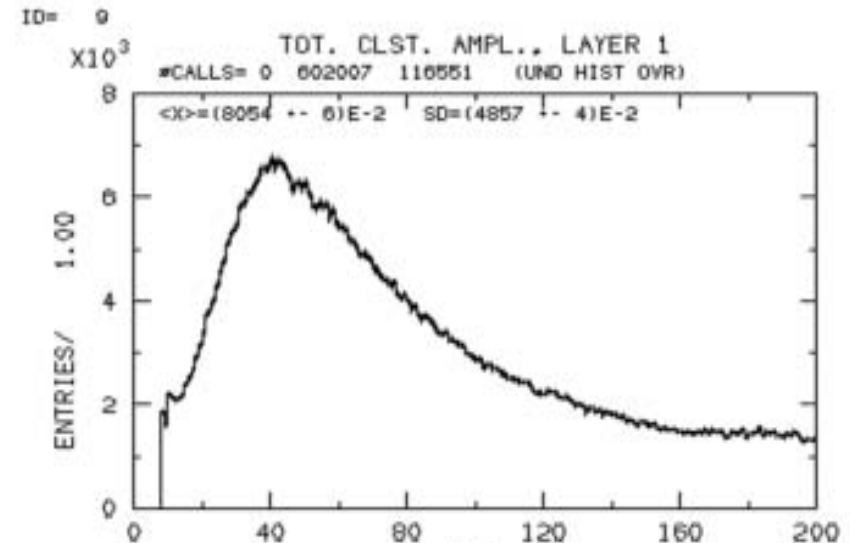


VXD3 Data

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



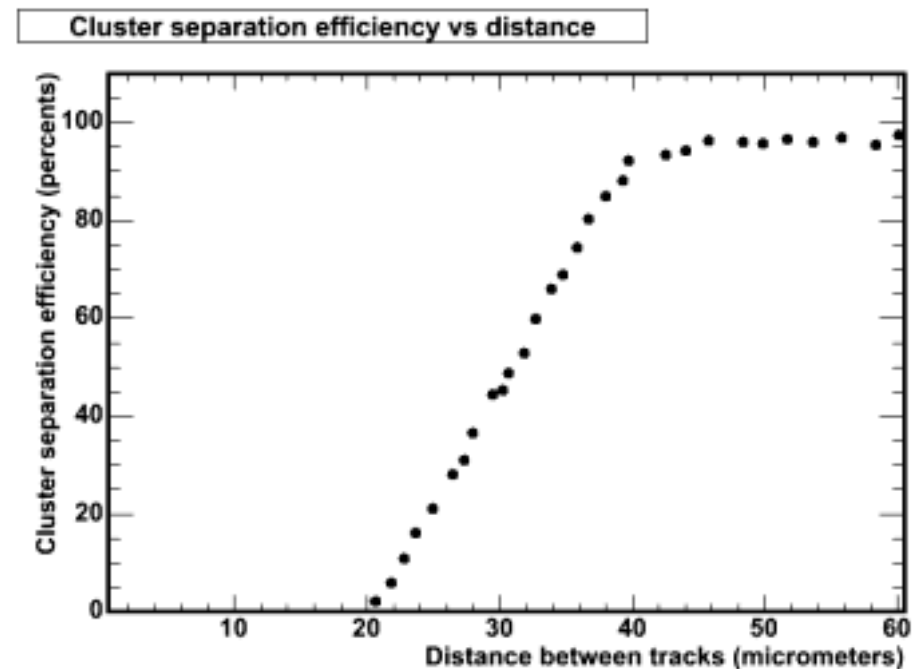
Simulation



VXD3 data

# Examples of applications to full LCD simulation

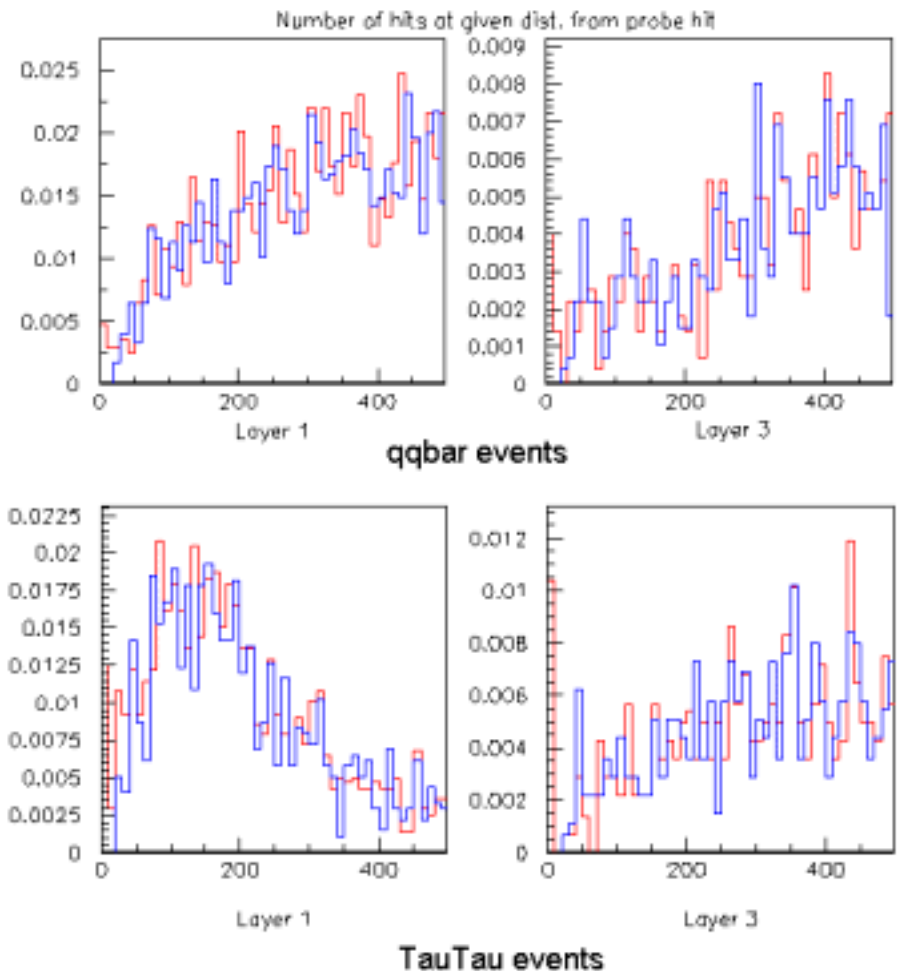
- Here is the **example** of the **efficiency** of the simulated CCD clusters **separation** as function of **distance** between tracks CCD hit points. **Direction** of the vector between points was **along** pixel width. For **random** direction efficiency **plateau** apparently will begin at **larger**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





# Examples – cluster separation

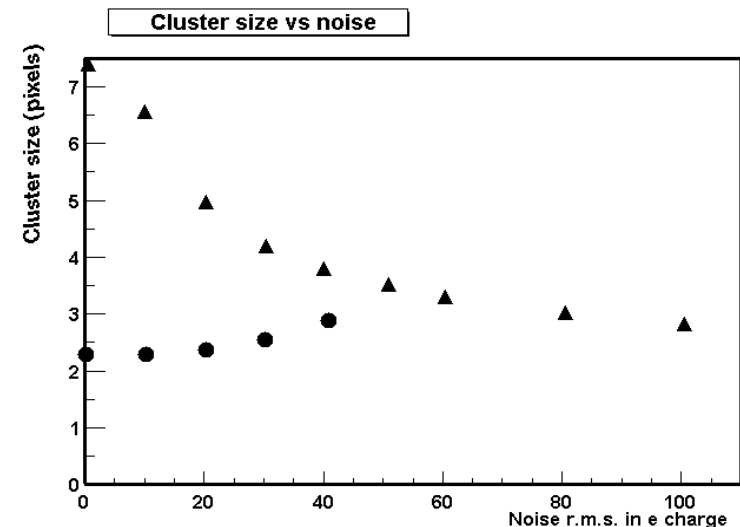
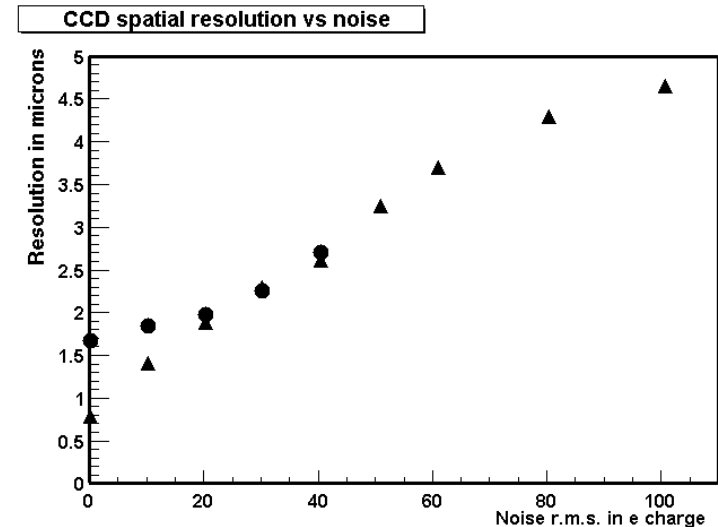
- Separation of track hits in simulated **events** with high density **jets**. **Red** lines show distributions **without** CCD simulation (ideal detector), **blue** – for reconstructed hits after **full** CCD simulation. 1 bin is 10  $\mu\text{m}$ , and we can see that **first 2** bins are **empty**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