Detailed Simulation of Track Ionization in CCDs

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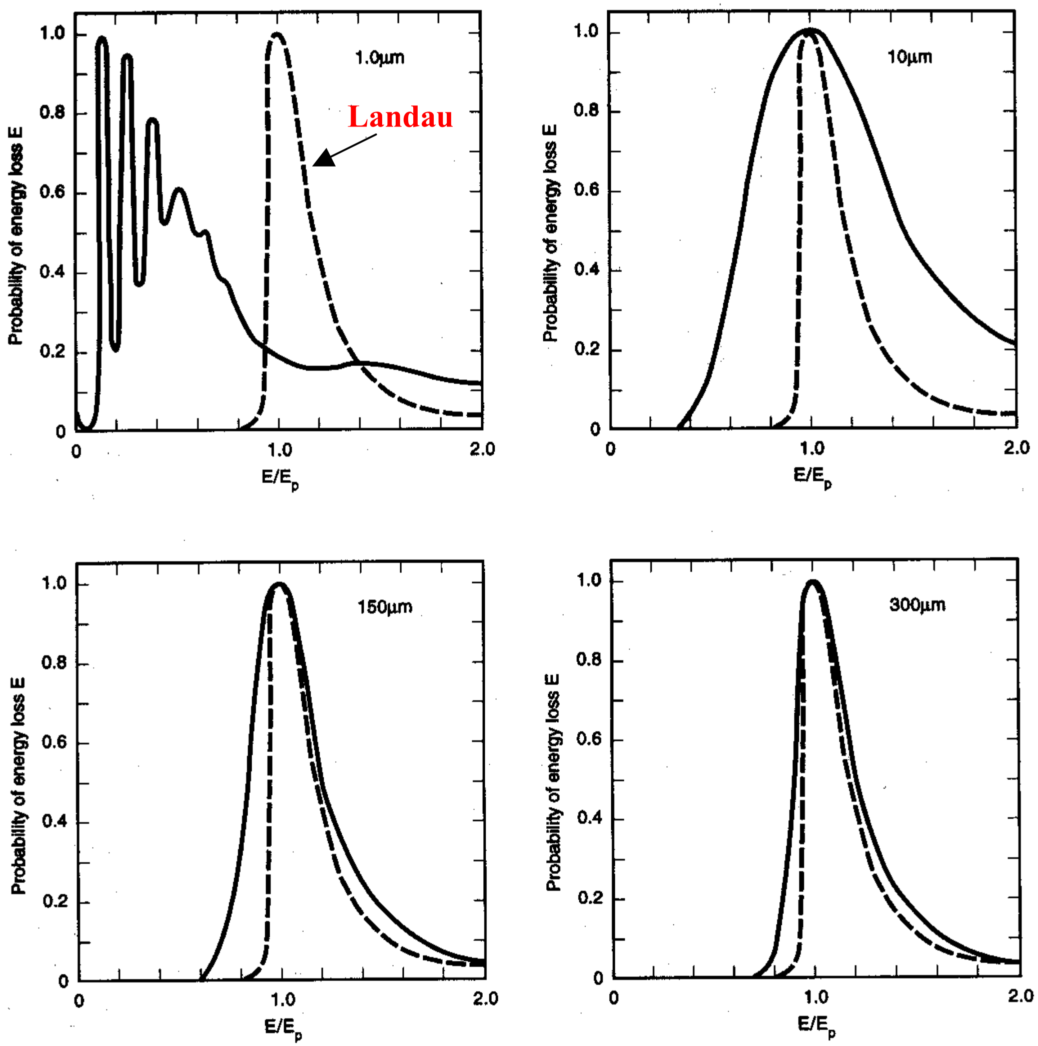
Vertex detector parallel session

Functionality of the CCD Simulation

- **A standalone tool for CCD vertex detector design optimization:**
  - Track ionization a la Hans Bichsel dE/dx scheme
  - Charge diffusion and collection simulation
  - Readout noise and charge transfer efficiency
  - Frontend cluster processing and offline cluster recon
- **Some tasks it might serve:**
  - Readout electronics noise effect on resolution
  - Pixel size and active silicon depth optimization for efficiency and resolution
  - Clustering centroid algorithm development

Much of the work was done 10 years ago for SLD VXD design and need to migrate to LC simulation framework

Track ionization is surely well understood ?

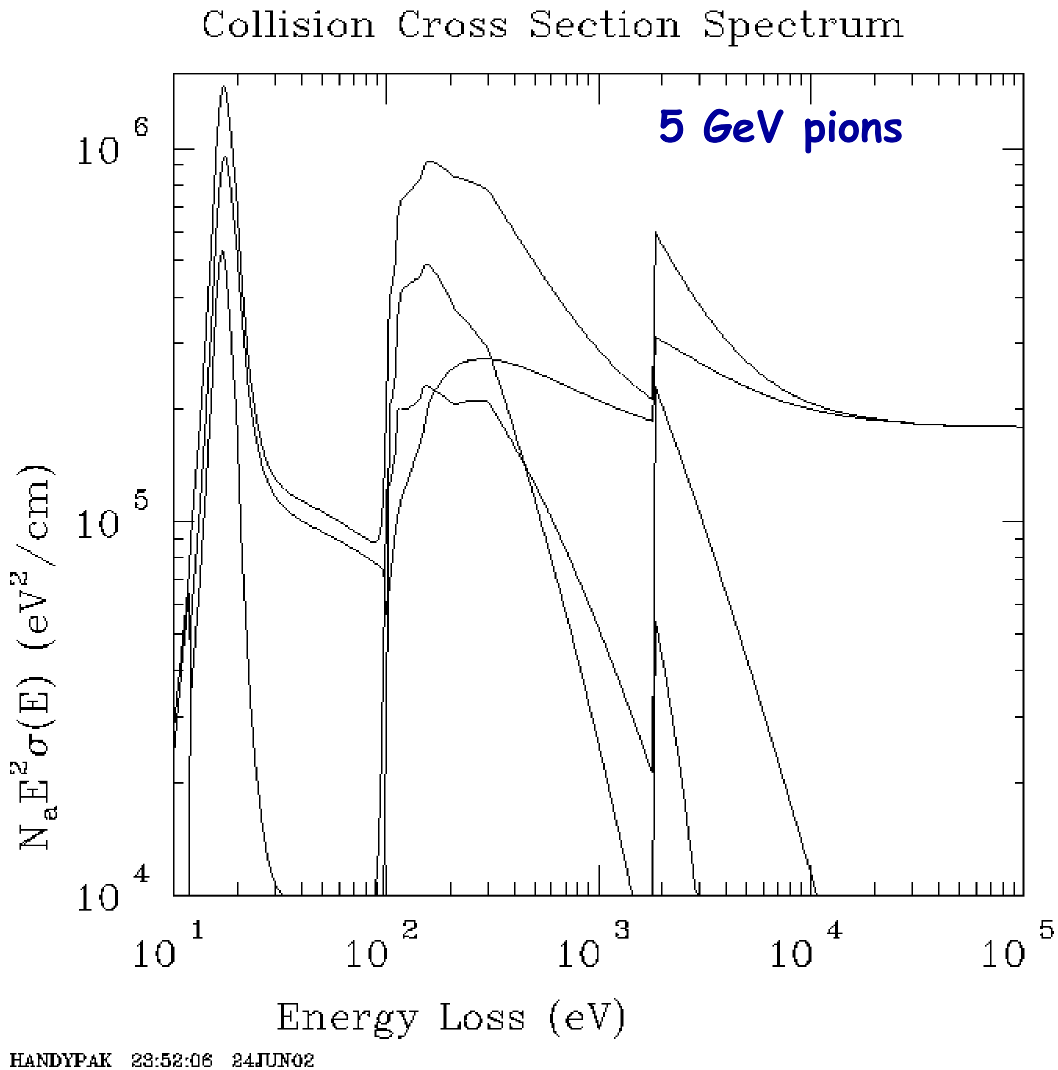


May be understood by a few, but not picked up by most simulation. Various kluges (e.g. Landau convoluted with Gaussian) help at limited thickness range and breakdown for very thin layers.

Not just a problem for silicon. Drift-chamber dE/dx for a single wire layer typically suffer similarly.

Can we do better than just "Smear it" ?

Hans Bichsel `Fold' Technique

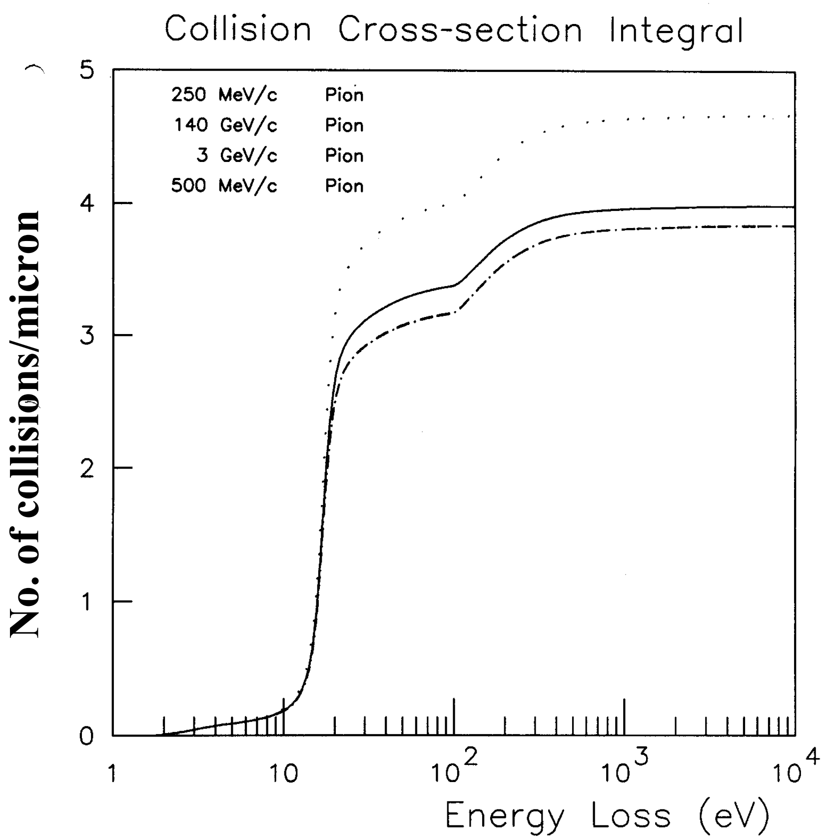


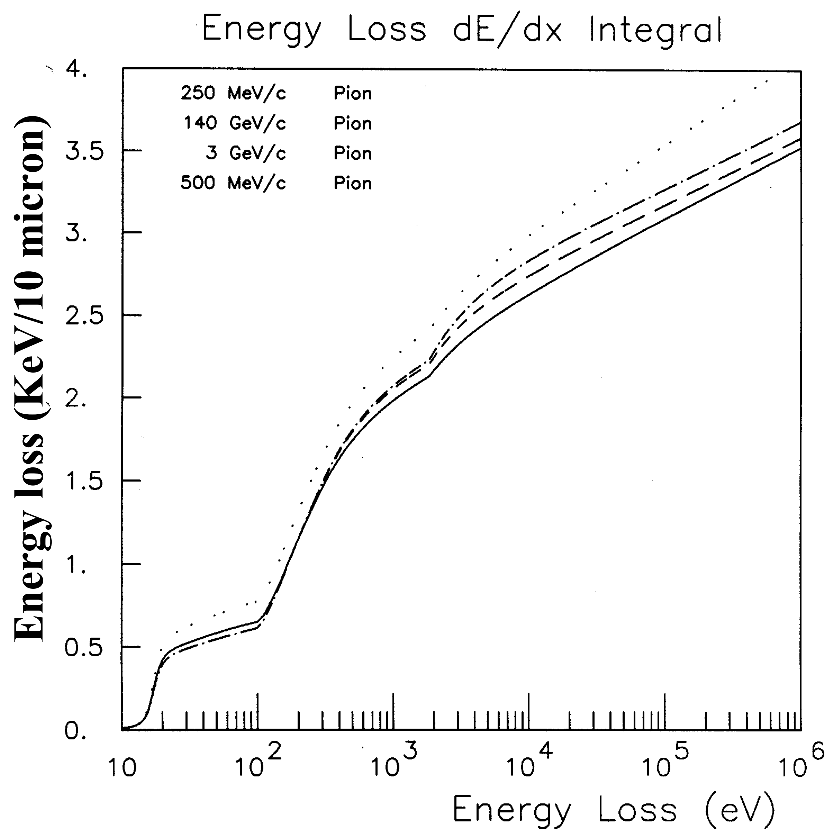
Detailed single atomic collision spectrum from a combination of atomic theory and data.

Start with a very thin layer with <<1 collision on average. Convolute (fold) same distribution to double thickness. Repeat until reach desired thickness.

H. Bichsel, Rev. Mod. Phys. Vol 60, 663 (1988)

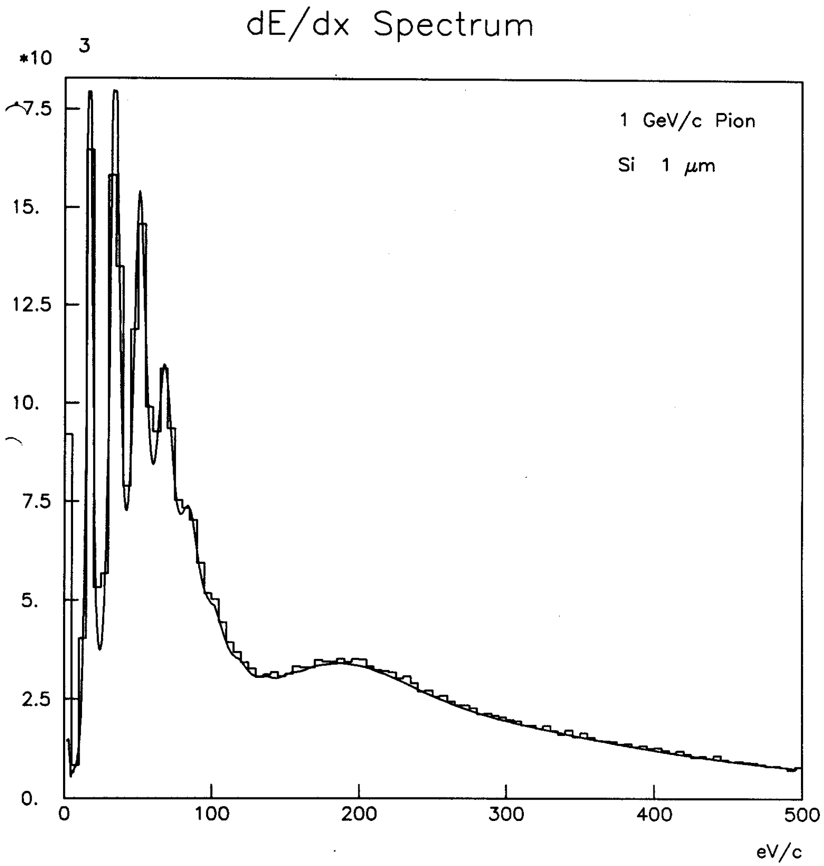
dE/dx atomic collision integral contributions





Interesting facts: ~4 collisions/micron and <1 collision/micron with E_{loss}>100eV, but ~ half the energy loss from >1 KeV collisions in 20 micron silicon.

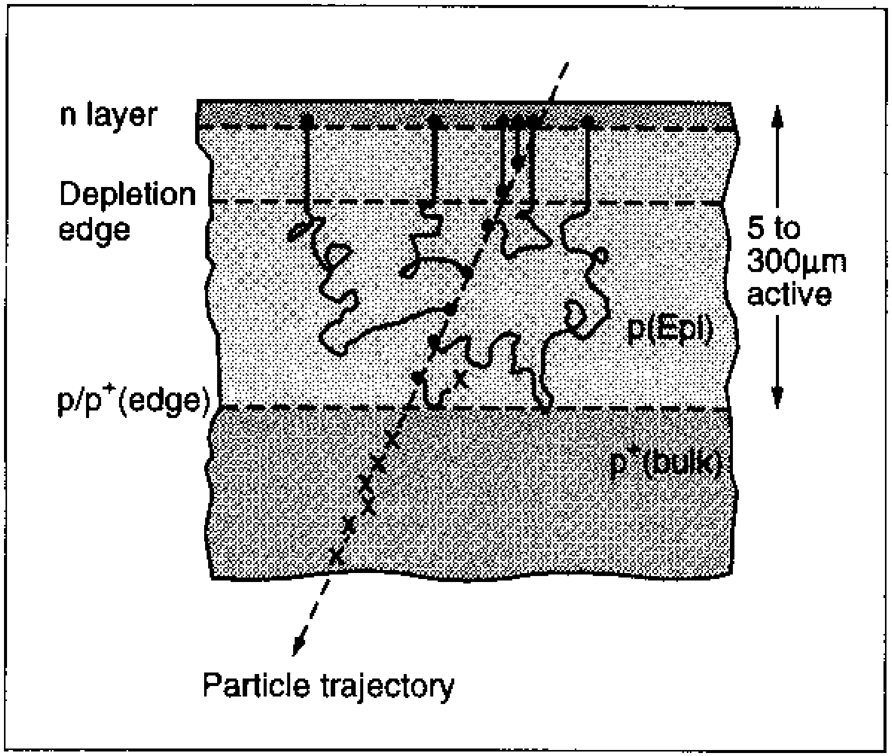
Simulation procedure

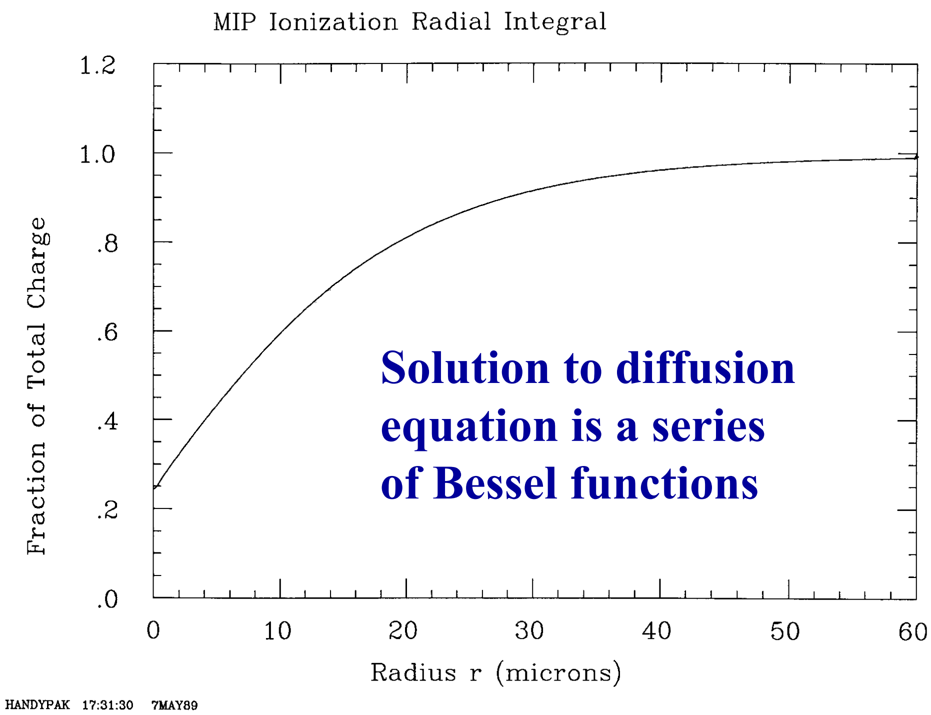


- Divide active silicon into 1μm depth slices. For given charged particle momentum (b) and entrance angle make initial calculation of dE/dx spectrum within slice (integral form)
- Each track loops over slices to generate E_{loss} per slice.
- Convert E_{loss} into ionization electrons and diffuse them (one or few at a time) to see which pixel they get collected.

After charge collection done for all hits, generate readout noise And do clustering simulation and cluster reconstruction.

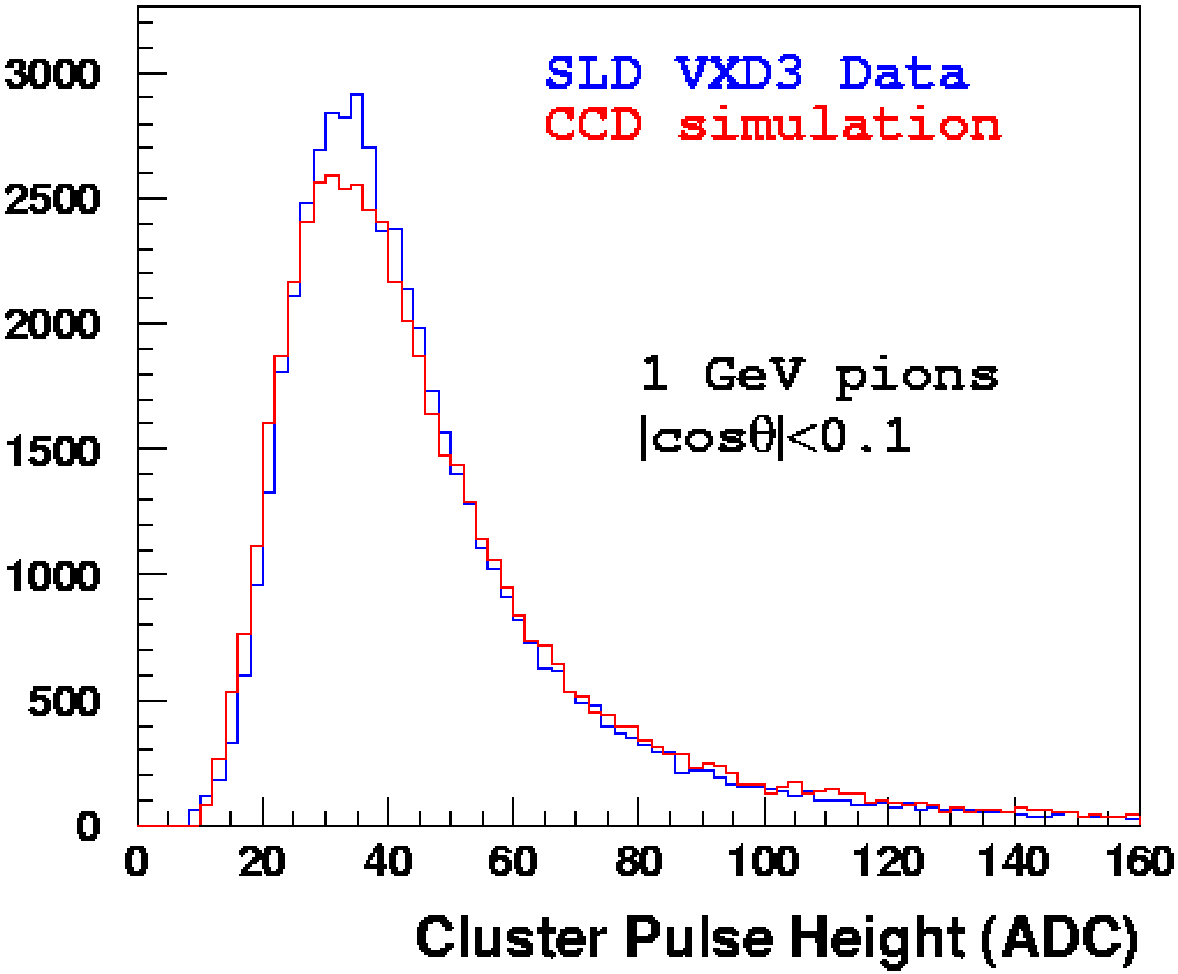
Charge Diffusion





e.g. SLD VXD3 CCD has total 20μm EPI silicon. Only top 3-4μm is depleted. The diffusion in undepleted region and reflective P+ substrate are very helpful to spread out charge for better cluster centroid reconstruction.

Performance compared to data ?



More detailed tests on cluster shapes to follow…

Spatial resolution prediction: 3.9μm
SLD achieved data resolution: 3.8μm

(caveat: this simulation is using an older crude cluster centroid algorithm ! Data had max pixel charge corr. And pixel position dep. Corr.)

What can be looked at with this simulation ?

- Pixel size, EPI / depletion depth optimization.
- Track entrance angle effects.
- Frontend clustering noise suppression technique.
- Cluster centroid algorithm tests.
- Readout noise effects:

  A quick test for SLD VXD3 CCDs:

raw mode noise (e)	resolution (μm)
32	3.9
64	4.5
16	3.2

- Probably many other tests too…

Simulation code status

- Still only have VMS fortran version. Conversion to run on UNIX is in progress. Bichsel code very difficult to convert to C++. Other code can be migrated to C++. (Valerie Halyo interested in helping on this).
- Some work is needed to skim some SLD data for validating the simulation.
- Will make documentation and make the package publicly available.
- Plugging into GEANT ?
  - Initial dE/dx spectrum need to be parameterized for various particle boost β.
  - Need to examine code efficiency for speed and cut down unnecessary fine divisions.