Simulating Inside Detector Physics for the Nab Experiment

Tom Shelton
for the Nab Collaboration

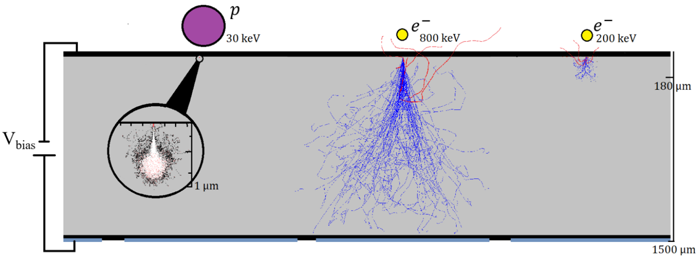
University of Kentucky

APS DNP, 17 October 2019

Motivation and goal

To determine the proton momentum from time-of-flight using the difference in decay electron/proton arrival times, the average timing response bias needs to be within 0.3 ns to meet Nab's precision goals for finding the *a* parameter.

Trajectories and energies of these decay pairs change the deposition of energy resulting in discrepant pulse shapes and timings.

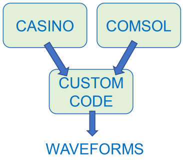


Motivation and goal cont.

- Particle depth affects the drift times of created e^-/h pairs and thus the charge collection times.
- We know there are serious implications for timing resolution, but more study is needed to see the severity on electron energy (e.g undepleted regions).
- An immediate application is if this needs to be taken into account for the Fierz interference term search in the ^{45}Ca experiment from 2017.
- We have created a simulation framework that can be benchmarked with detector studies such as discussed by Glenn.

Outline

1. CASINO (monte CArlo SImulation of electroN trajectory in sOlids)[1]
    - Calculates trajectories of primary electrons.
    - Use to classify trajectories and find functional forms to perform a data reduction.
2. COMSOL®[2]
    - Model geometry and solve by finite element analysis Poisson/Laplace eq.'s for potentials.
    - Output a grid of electric/weighting fields.
3. Custom Code
    - Determine induced current of ions with Shockley-Ramo Thm.
    - Find integrated charge of incident particles.



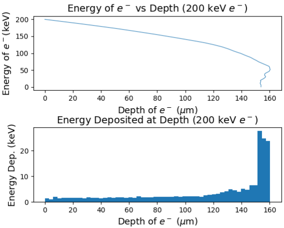
[1] D. Drouin, *et al.*, Scanning 29, 92–101(2007).

[2] COMSOL Multiphysics® v. 5.1. www.comsol.com.

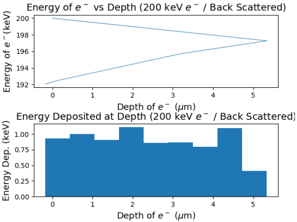
CASINO results

- Instead of single electrons, build a table of classifications to use in other steps of simulation.
- 60 – 70%, trajectories look like (a), but others need to be handled as well.

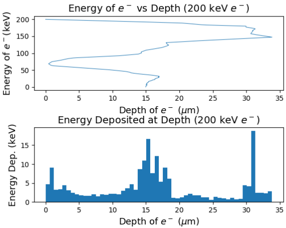
Examples of electron tracks and energy deposition depths:



(a) Generally forward depositing in the z direction.



(b) An electron that back scattered out.



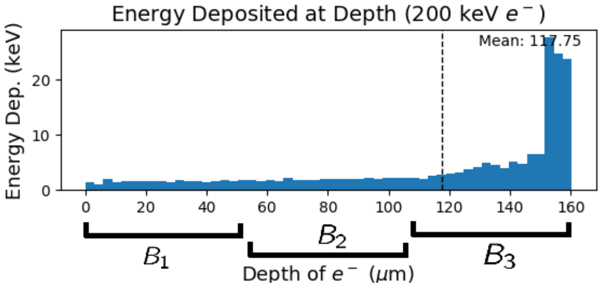
(c) Some take more varied paths.

CASINO results

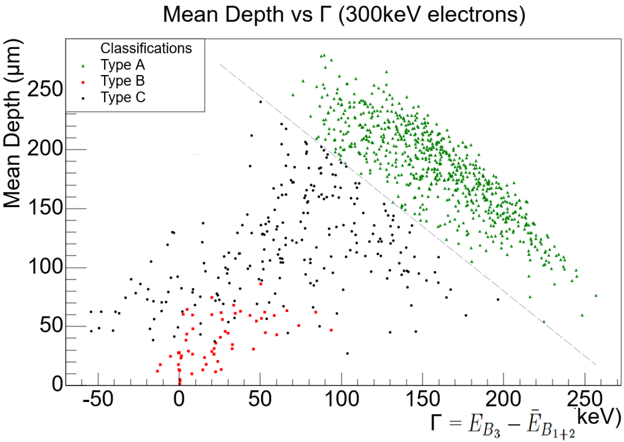
Type a classification:

$$\Gamma = E_{B_3} - \bar{E}_{B_{1+2}}$$

- Looking at how much energy is deposited in the deepest third of an electron's track, compared to in shallower depths.



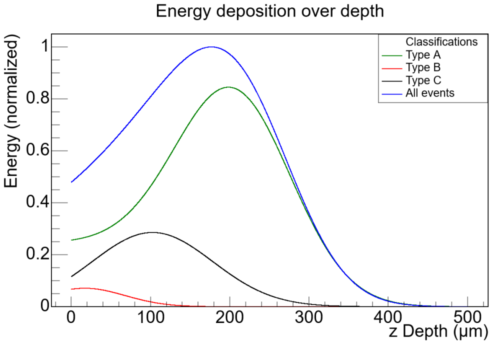
CASINO results



- Rough division of trajectories into forward (a), back scattered (b), other (c)

CASINO results

For each classification, empirically find functional forms[3] for the probability distribution of any electron energy along z depth.



$$D(i) = \frac{1}{2} H_D \exp\left(\frac{i - i_0}{\beta}\right) \operatorname{erfc}\left(\frac{i - i_0}{\sigma\sqrt{2}} + \frac{\sigma}{\beta\sqrt{2}}\right).$$

[3] J.L Campbell & J.A. Maxwell, NIM B 129 (1997) 297-299

COMSOL results

1. Electric potential found from

$$\Delta V = -\rho/\varepsilon,$$

where ρ is the average net impurity density in the detector, currently taken as uniform.

2. Weighting potential found from

$$\Delta V_i = 0,$$

where the central pixel set to unity, else set to ground.

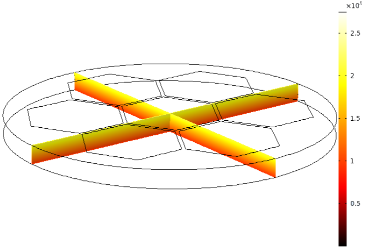


Figure: Electric Field

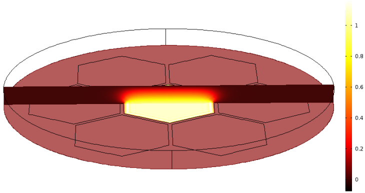


Figure: Weighting Potential

Methods: custom code

- Take field grids from COMSOL.
- Determines induced current i from a e^-/h pair given some creation point using Shockley-Ramo Thm.

$$i = q\langle v_d, E_0 \rangle,$$

  where q is the charge of the carrier, v_d is the drift velocity, and E_0 is the weighting field.
- This E_0 is a field determined by the geometry of our detector. As such, where the ions are created with respect to the edge of the unity pixel leads to different energy deposition.
- Combine with average deposition distributions from CASINO to get the energy deposited by an incident electron.

Custom code results

We can generate the induced signals of primary electrons on the detector.

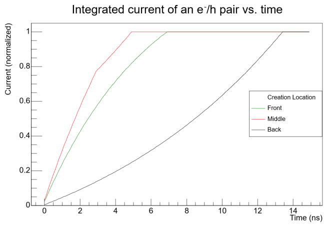


Figure: Induced current from single e^-/h pair created at detector center.

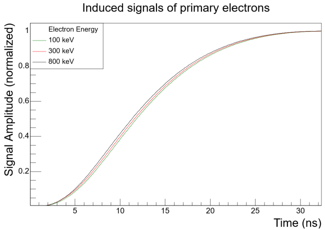


Figure: Integrated charge run through electronics simulation to get a signal.

[3] Li, S. S. and W. R. Thurber, Solid State Electron. 20, 7 (1977) 609-616.

Summary

- We have created a framework for waveform simulation that we can expand and benchmark.
- Use to investigate the edge effects and further studies on systematics.
- David Mathews with discuss the different algorithms we can use to determine bias in these waveforms.