ECAL RESOLUTION STUDIES AND UPDATE

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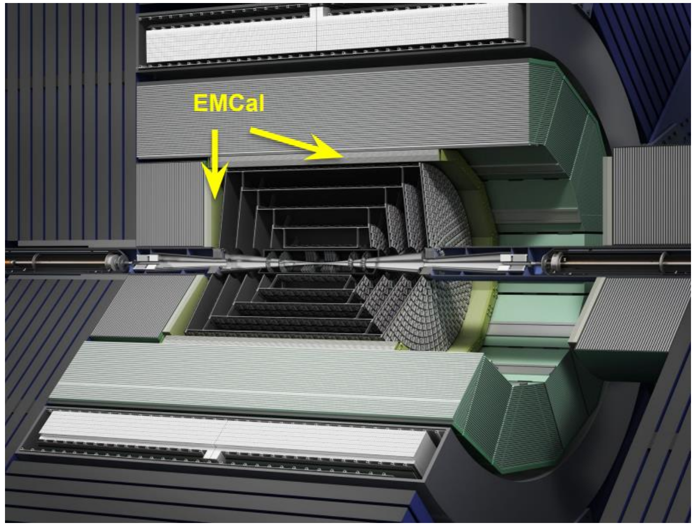
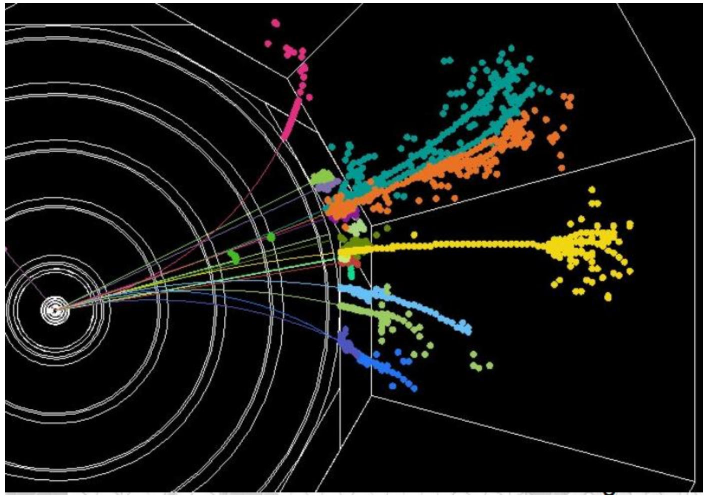
OUTLINE

- KPiX
- Reminder of What Has Been Done
  - Where I started on the project
    - Test Beam Simulation and Comparison to KPiX data
    - How we start applying these to the full detector model
- Current Geometry Studies
  - Effects on Resolution
- Beginning to Look at Simulated Events

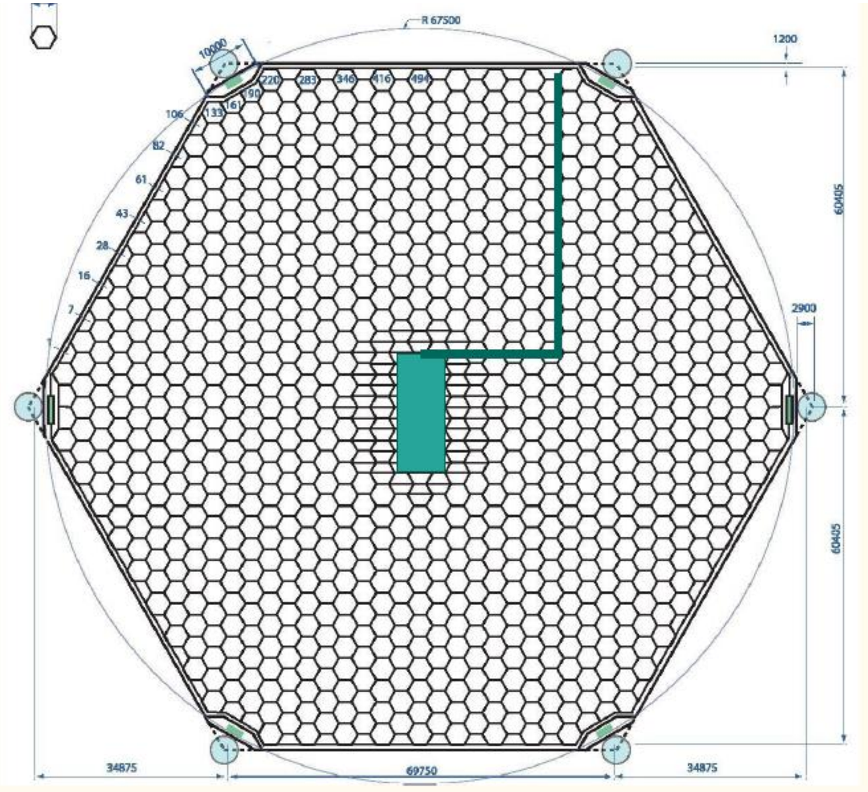
PARTICLE FLOW CALORIMETRY

- SiD has been designed to use Particle Flow Calorimetry to measure all final states with precision
- We expect excellent jet energy resolution
  - Measure charged momenta with tracker, neutral energies with calorimeters
  - Requires very fine segmentation
- An “Imaging ECAL” is a crucial part of the design
  - Silicon-Tungsten based calorimeter is being developed for a high granularity ECAL
  - KPiX ASIC for readout of silicon pixels





KPIX

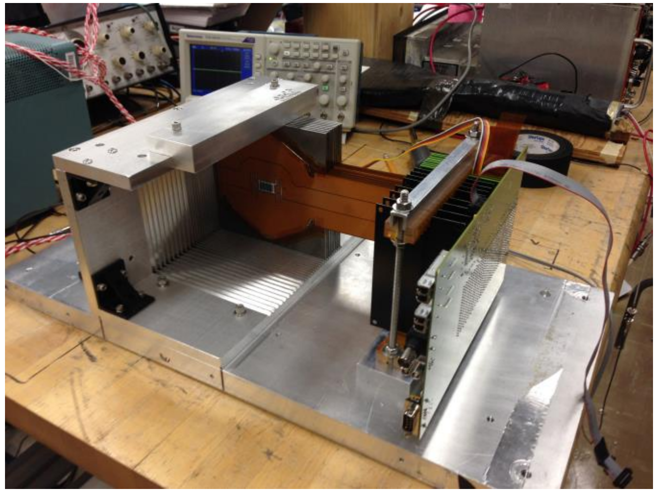


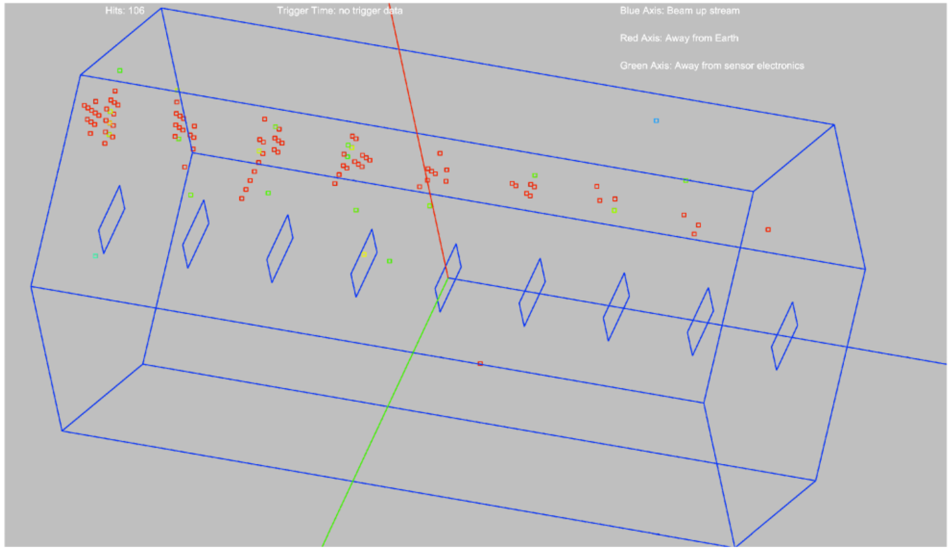
- 6 inch wafers
- 1024 13mm^2 pixels
- Readout and cable are bump-bonded directly to the sensor
- Test beam studies have happened with an initial version of this KPiX sensor design

- Will come back to the geometry and its effect on resolution measurements

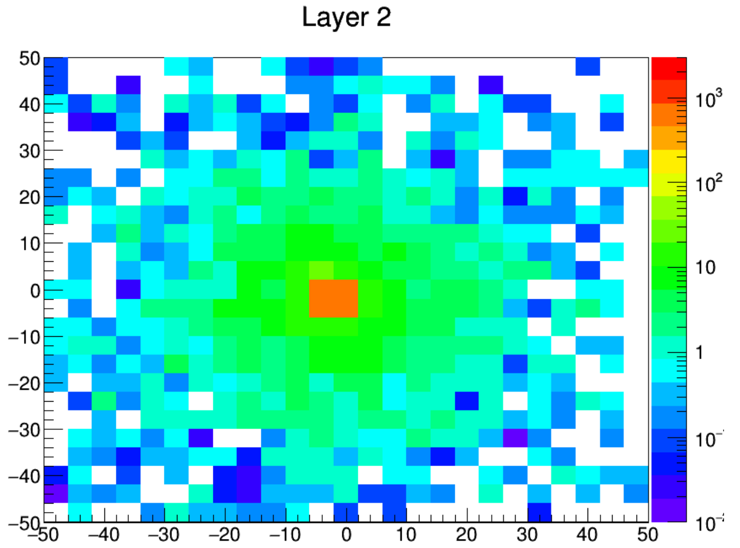
TEST BEAM STUDIES

- Small 9 layer stack was placed into SLAC test beam
- Sensor issues have been found and change the design going forward
  - Cross Talk, Dead Pixels, …
- Many electron events were seen that we can analyze and compare with simulation to improve understanding of the system
  - Resolution, Identification (how well we can tell how many electrons are in an event)





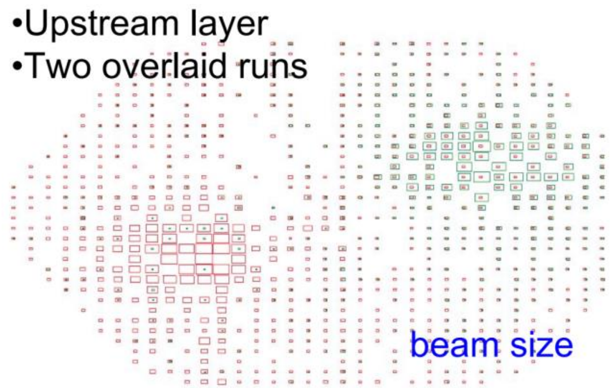
- Geant4 Simulation created of 40x40cm plane of alternating Si (320 µm) and W (2.5mm,5/7 χ_0)
  - 40 (thin W) layer detector simulated simulated, only include 9 to match test beam stack for comparisons sake
  - Electrons fired at origin of various energies (in particular 12.1 GeV, test beam energy)
  - Want to try to match test beam running conditions

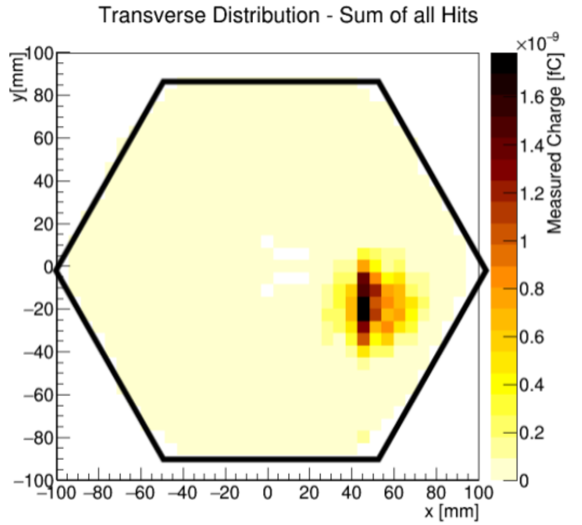


1000events, 10GeV. Energy in MeV deposited (all events summed) on the z-axis.

COMPARISONS (CONT.)

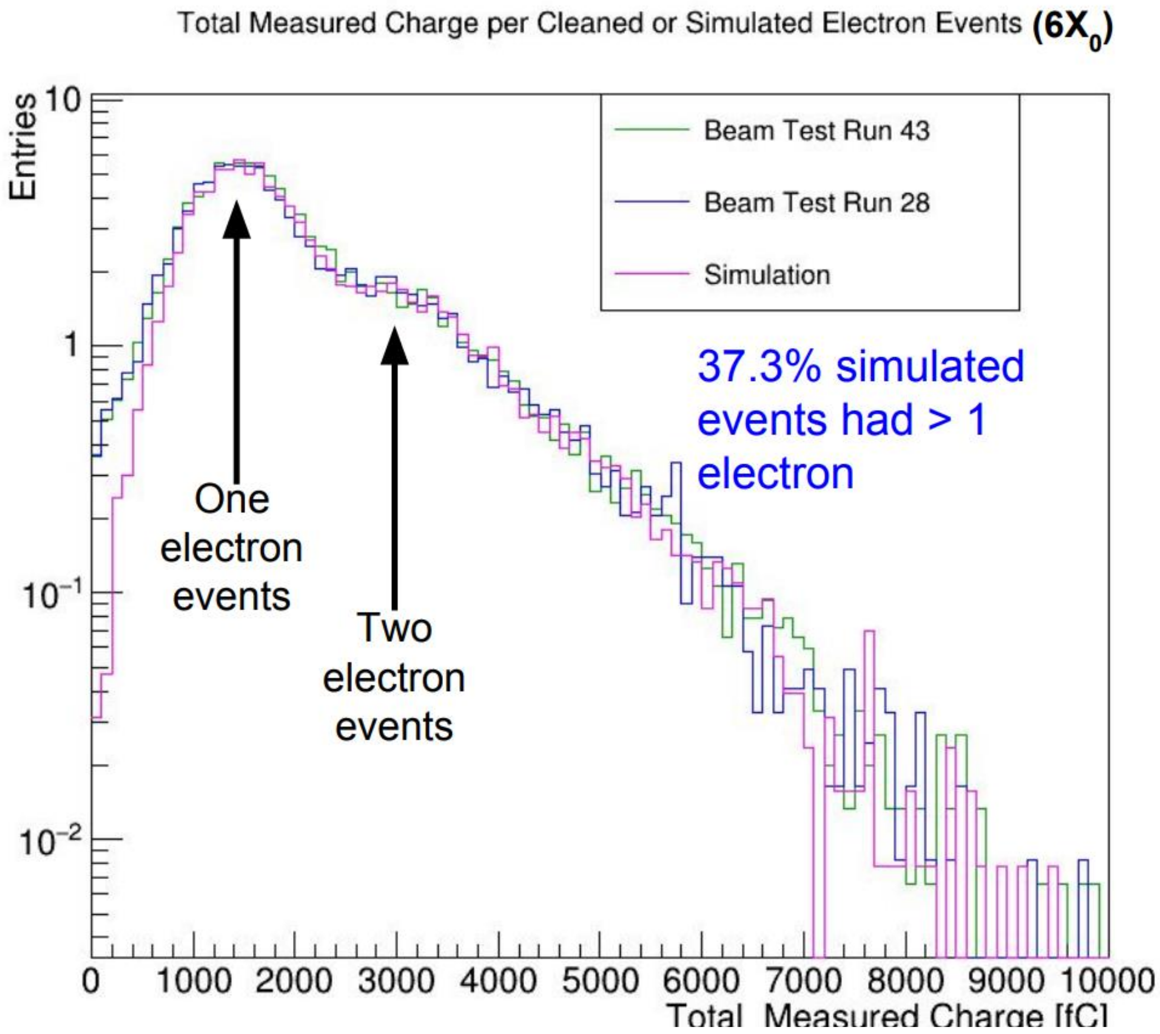
- Attempted to model distribution of electron multiplicity and errors in test beam
  - 10% pixels randomly removed from each layer
  - Poisson distribution of simultaneous electrons per event used <n>=0.8725
  - Shifted from central area (more densely pixelated, also test beam was shifted away)
  - Match hit to KPiX pixel location





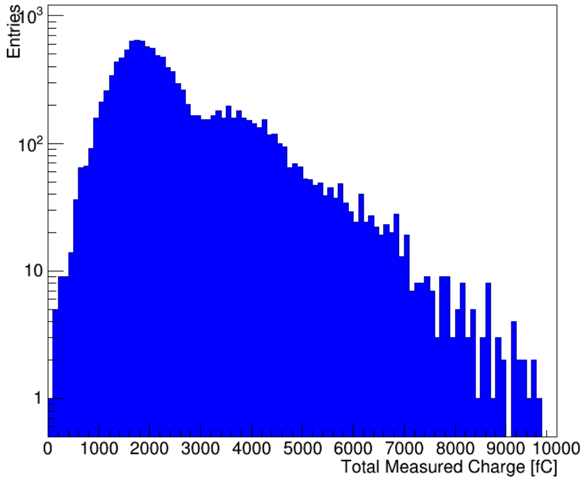
COMPARISONS (CONT.)

- Excellent agreement to test beam data.
- Couldn't remove all of the low E shoulder during test beam cleaning (lots of ~0fC hits)

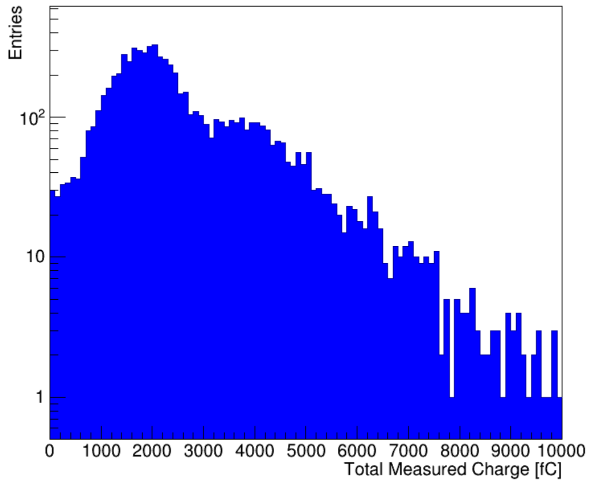


COUNTING ELECTRONS

Total Measured Charge per Simulated Electron Event

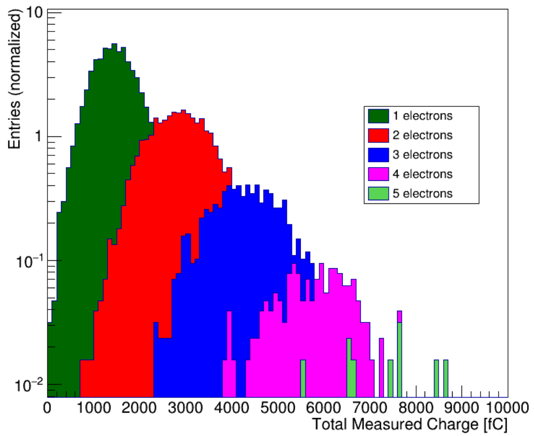


Total measured Charge After Cleaning

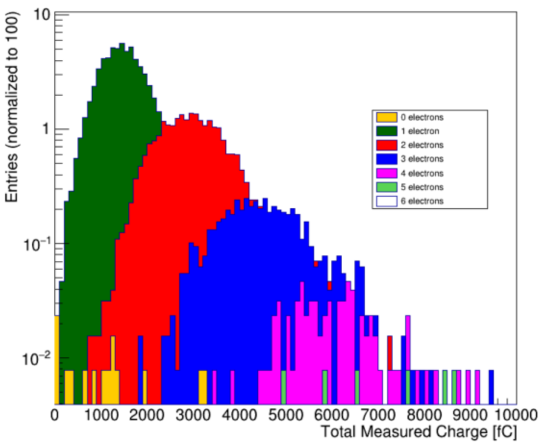


- Algorithm used to count the number of electrons in the even based on energy distributions throughout the detector.

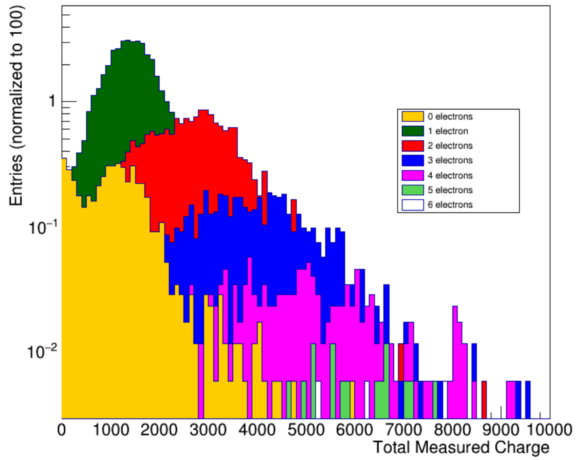
Electron Events - Simulation Truth



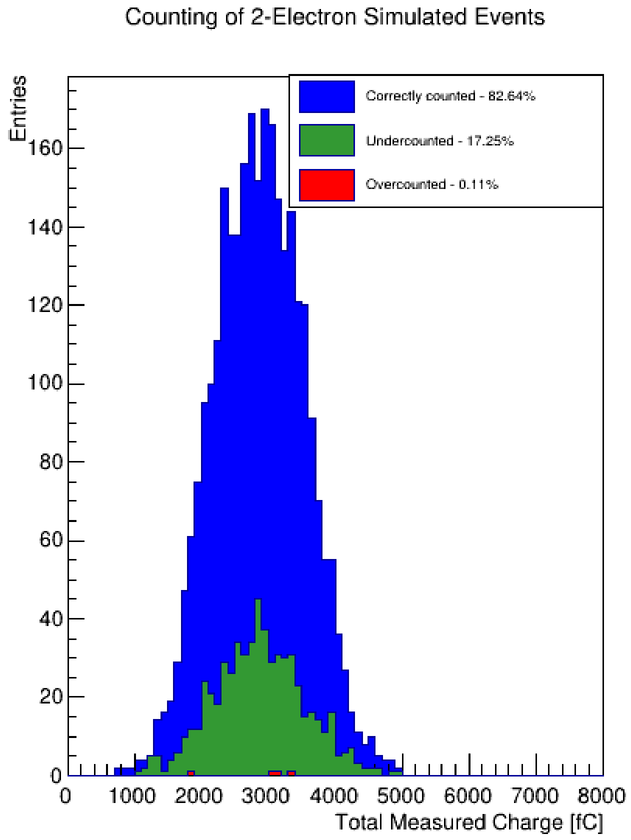
Electron Events - Simulation Counted

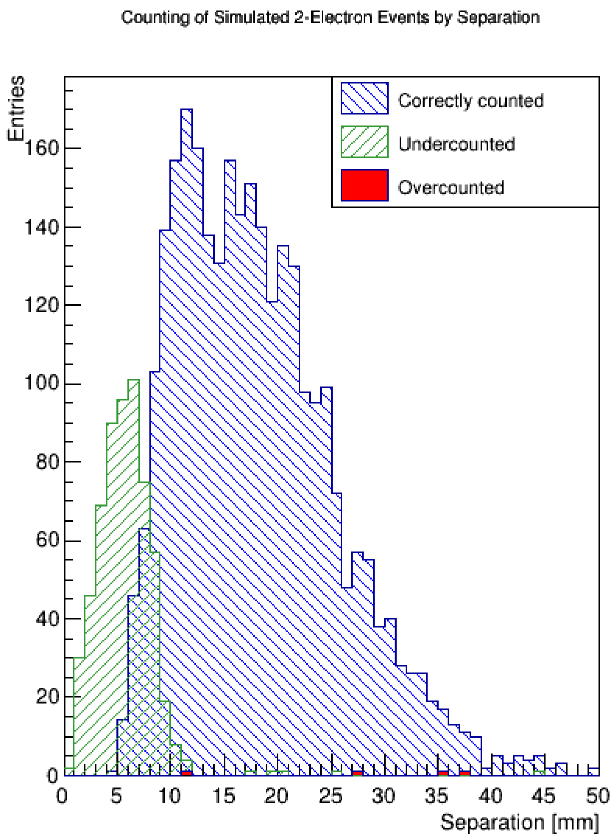


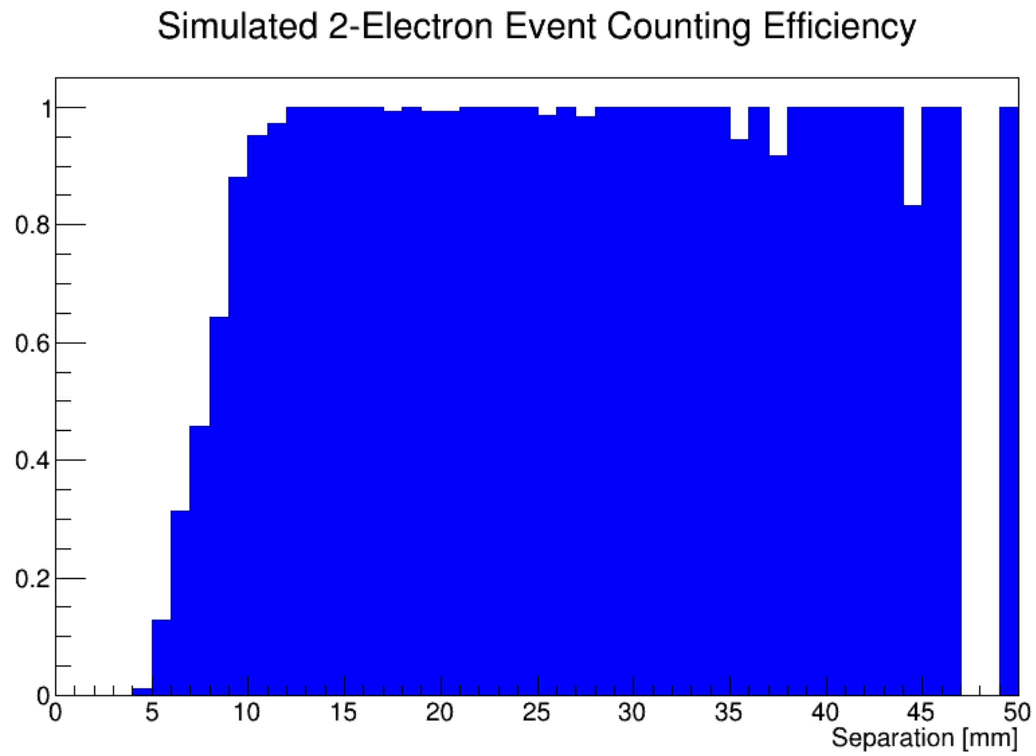
Electron Events - Test Beam Counted



COUNTING ELECTRONS (CONT.)

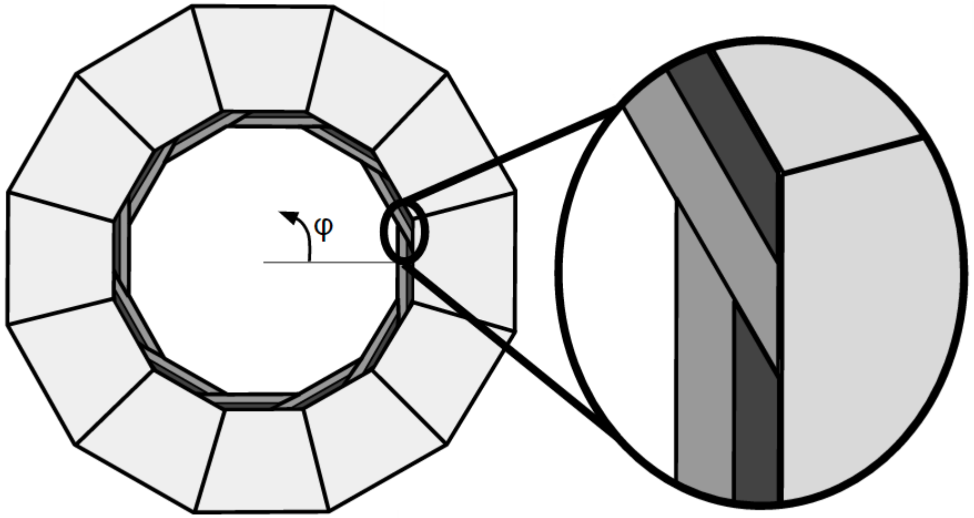


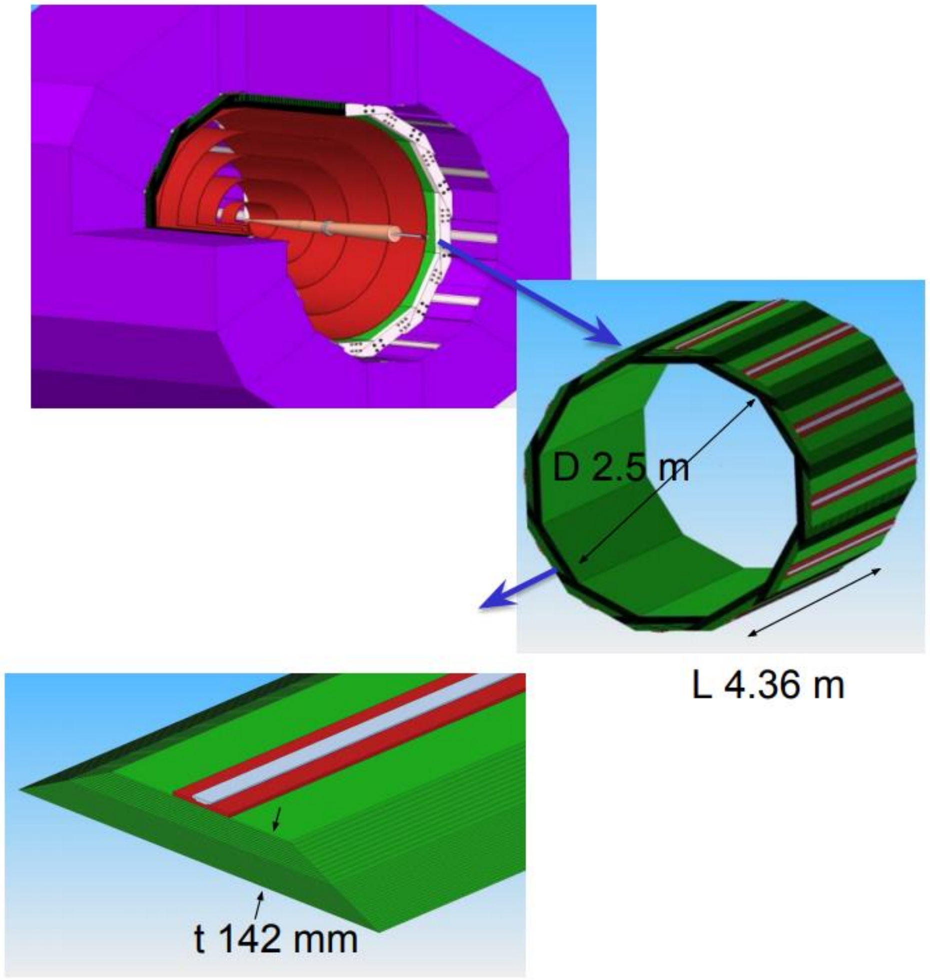




No field, just simple detector simulation

ECAL GEOMETRY AND ITS EFFECTS





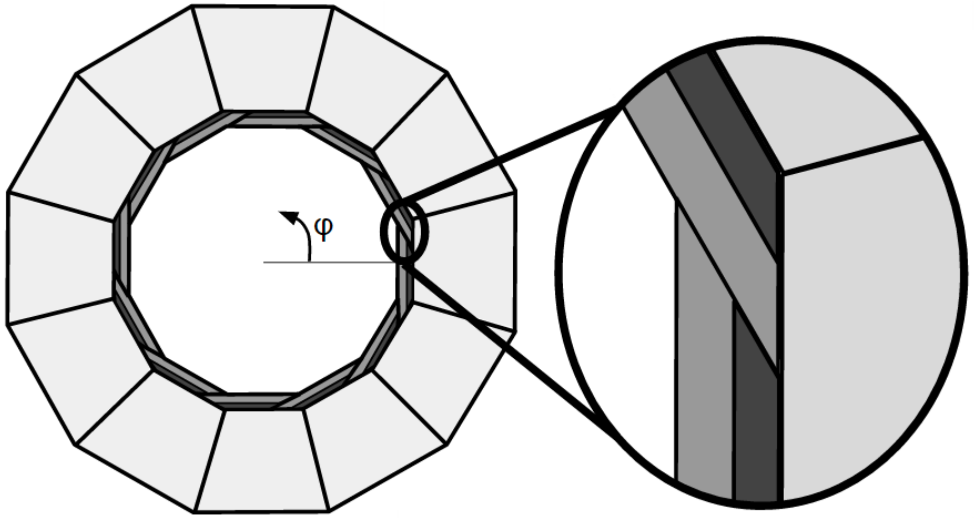
20 layers 2.5mm W

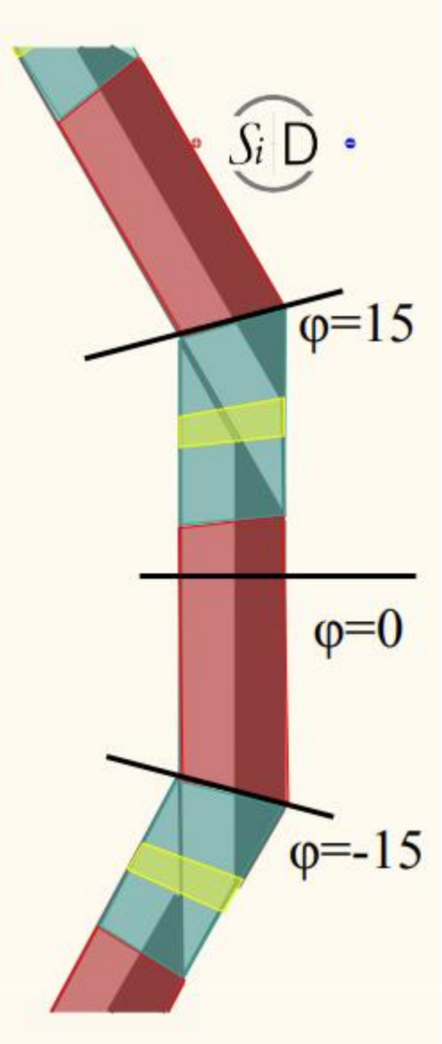
10 layers 5mm W

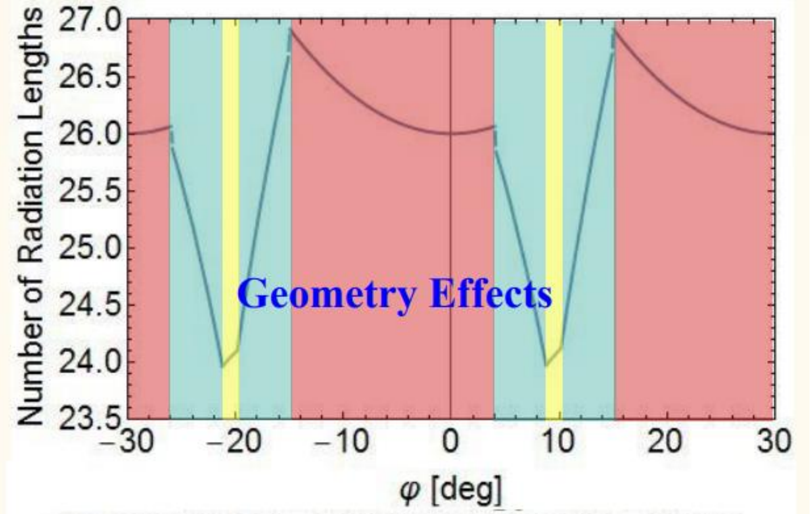
30 gaps 1.25mm w/pixel sensors

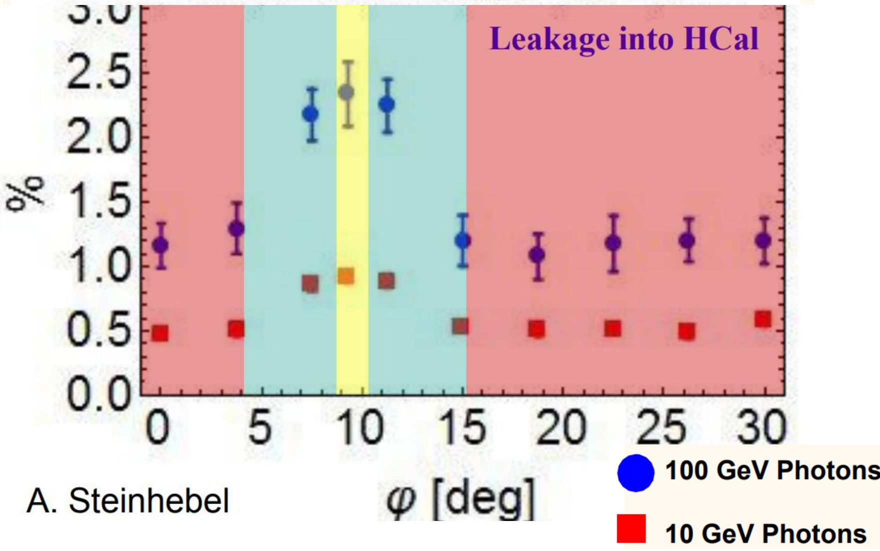
29 χ_0

GEOMETRY EFFECTS



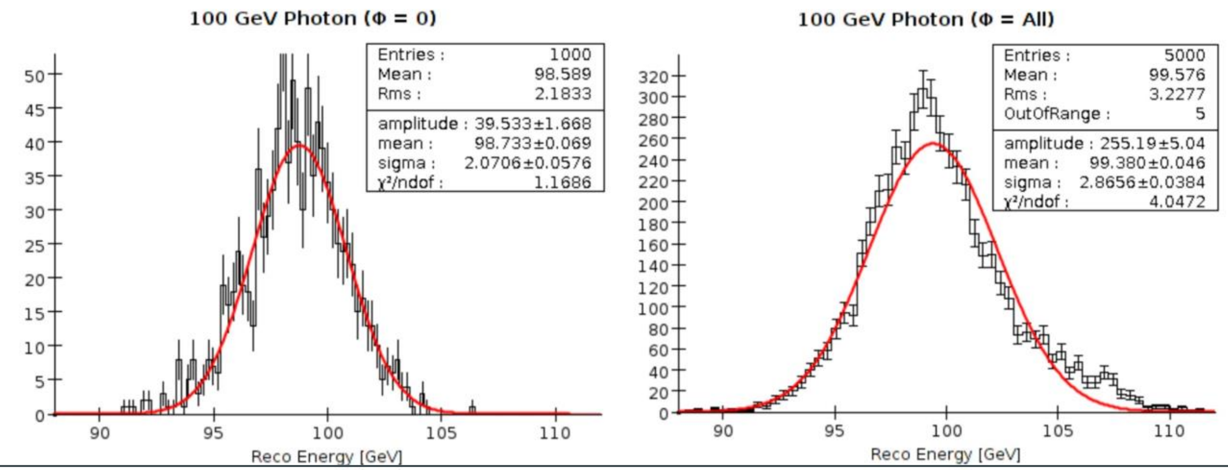






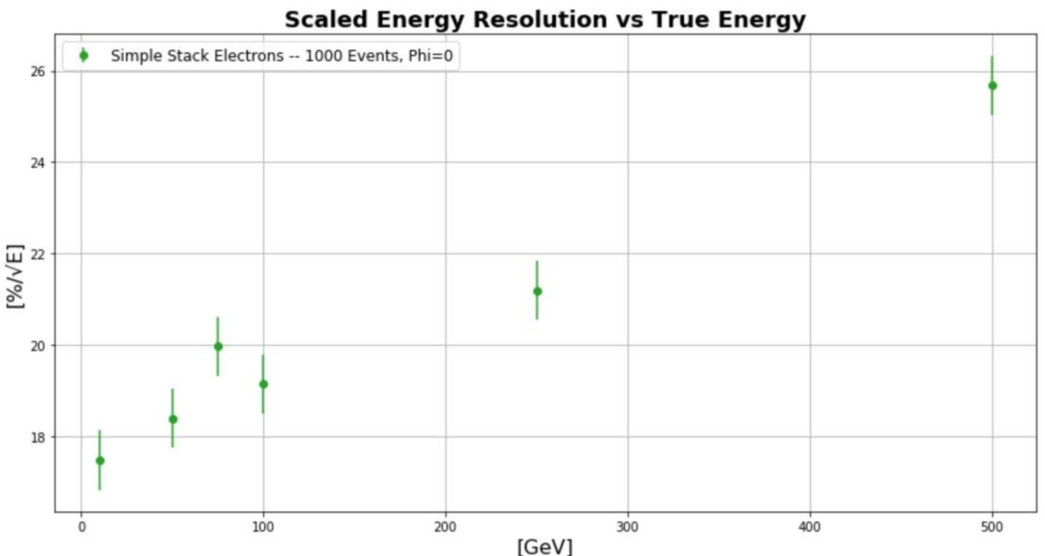
Leakage into HCAL in overlap region increases due to less material, phi dependent

RESOLUTION EFFECTS FROM GEOMETRY



Previous resolution study (Da An, et al. 2014) using 100 GeV photons in sidloi3.

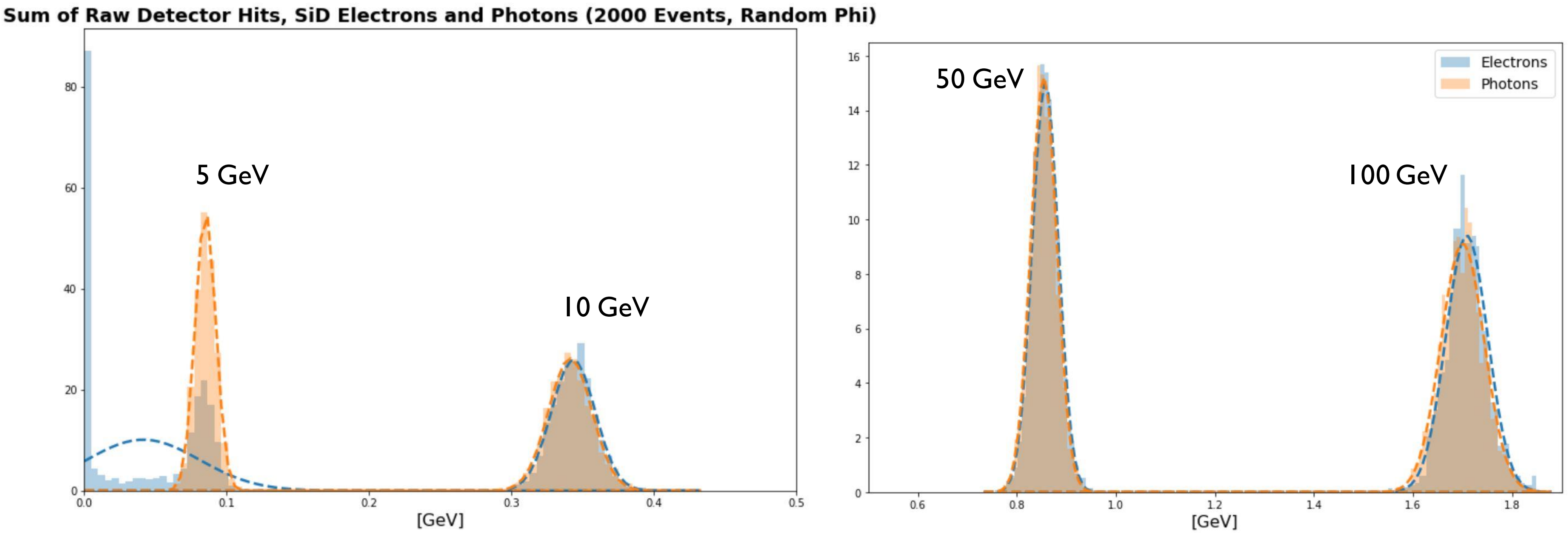
- $\phi = 0$ → Resolution ~ $21\%/\sqrt{E}$
- $\phi = All$ → Resolution ~ $29\%/\sqrt{E}$



Resolution study using 10, 50, 75, 100, 250, and 500 GeV electrons using Simple Geant4 Stack Simulation

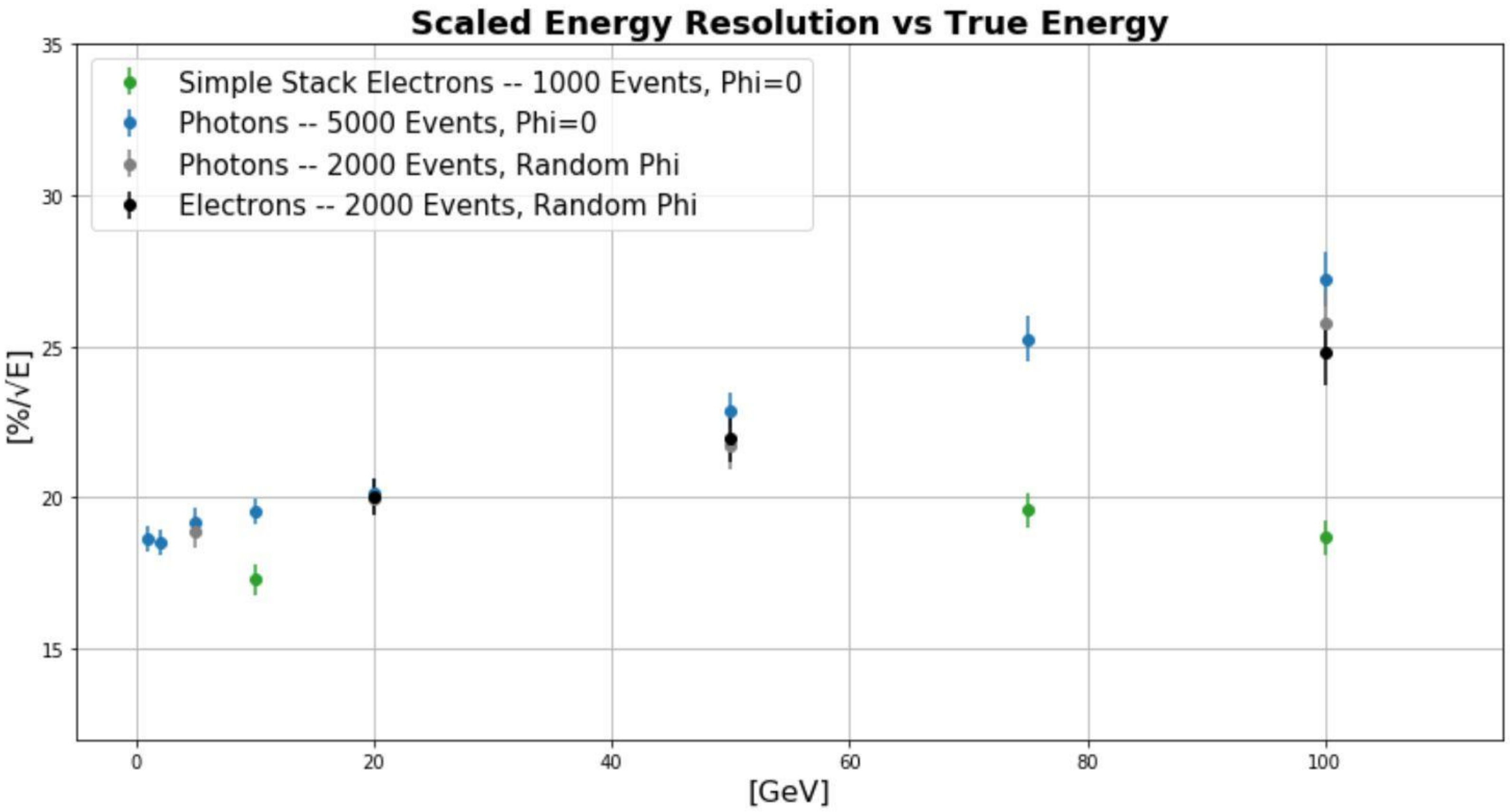
- For lower energy e- (<100 GeV), Resolution much closer to design expectation (17%/$\sqrt{E}$)

DISTRUBUTIONS



- Use cone width ϕ ± 0.2 rad constraint on hit locations (avoid backscatter)
  - ϕ determined from incident MC particle, not actual hits in detector
  - Ignore 5 GeV electrons in resolution plots, B-field effects → shower gets missed with ϕ constraint

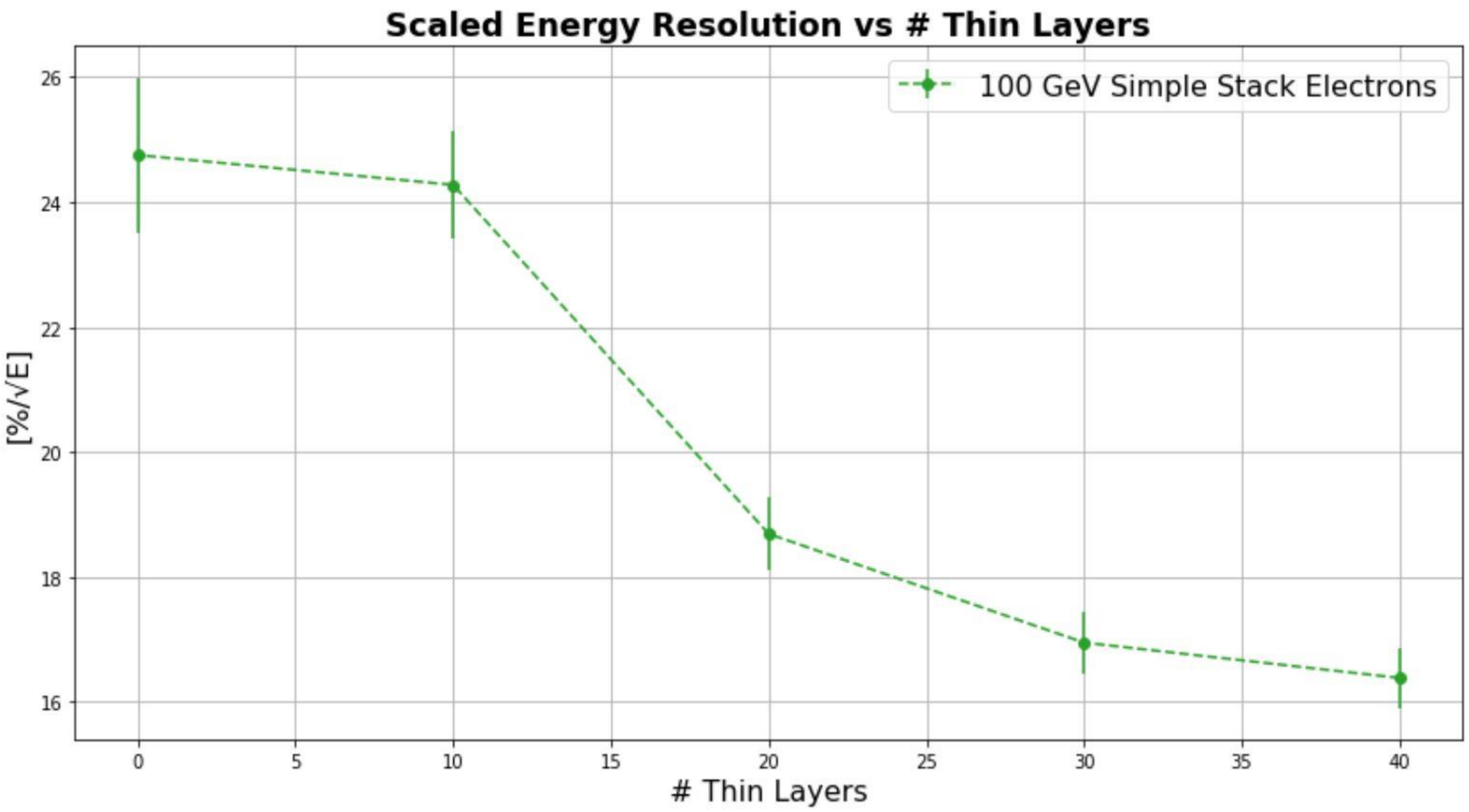
COMPARISONS



Discrepancies

- SiD resolution degrades much faster than the simple stack resolution
- 100 GeV SiD photons for $\phi = 0$ have Res ~ $28\%/\sqrt{E}$ compared to ~ $21\%/\sqrt{E}$ from previous sidloi3 study
- $\phi = All$ 100 GeV SiD photons have slightly better resolution than previous sidloi3 study; $\sim 26\%/\sqrt{E}$ compared to ~ $29\%/\sqrt{E}$

CONFIRM SIMPLE STACK BEHAVES AS EXPECTED

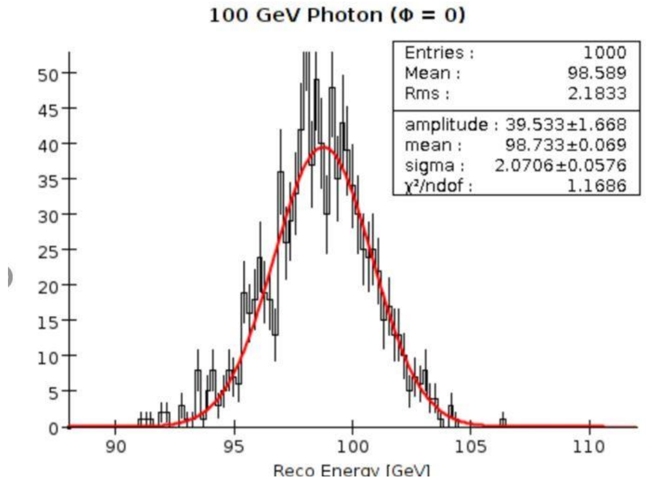


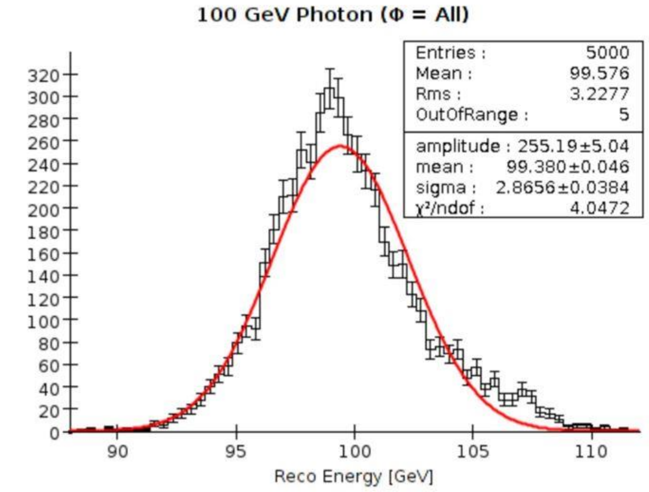
Vary the number of thin and thick layers for simple stack electrons

- #Thick Layers = (40 - #Thin) / 2
- Expected resolution of 40 thin ~$17\%/\sqrt{E}$
  - measured $16.6\%/\sqrt{E}$
- Expected resolution of 0 thin layers to degrade by $\sqrt{2}$ (~$24\%/\sqrt{E}$)
  - measured $25\%/\sqrt{E}$
- **Conclusion**: simple stack behaves as expected

*Note: Simple stack absorbers are pure W

SIDLOI3 RESULTS





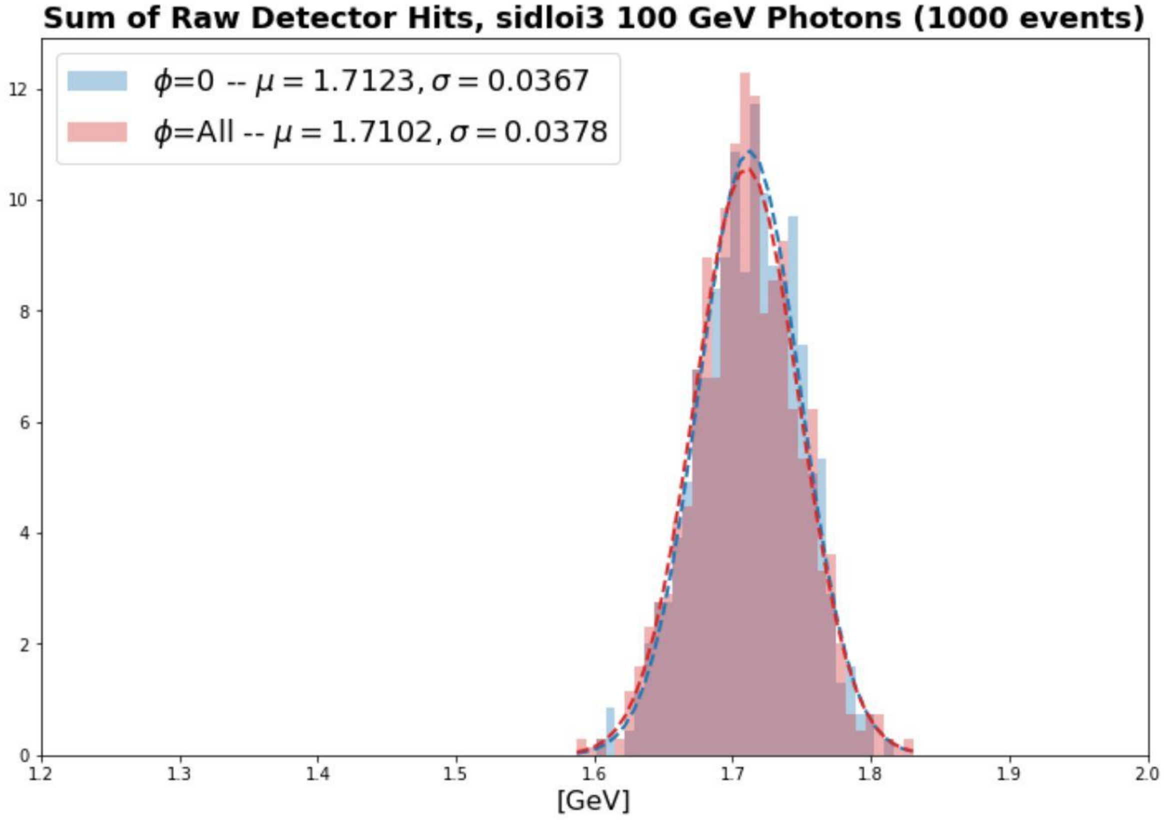
Large difference between $\phi = 0$ and $\phi = All$

← Previous study

(Da An, et al.)

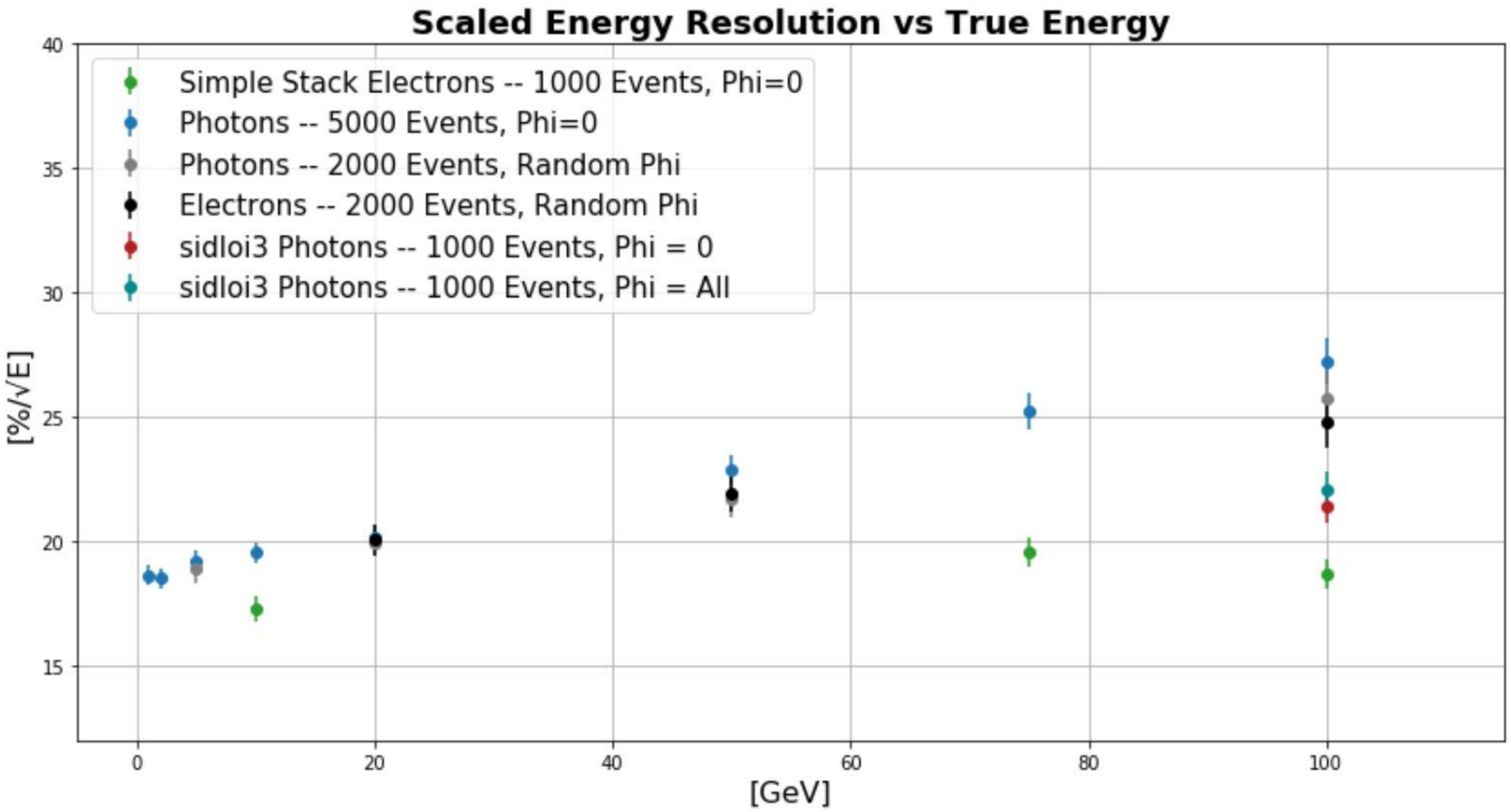
Current study →

(what is used on following resolution plot)



Small/negligible difference between $\phi = 0$ and $\phi = All$

SIDLOI3 RESULTS (CONT.)



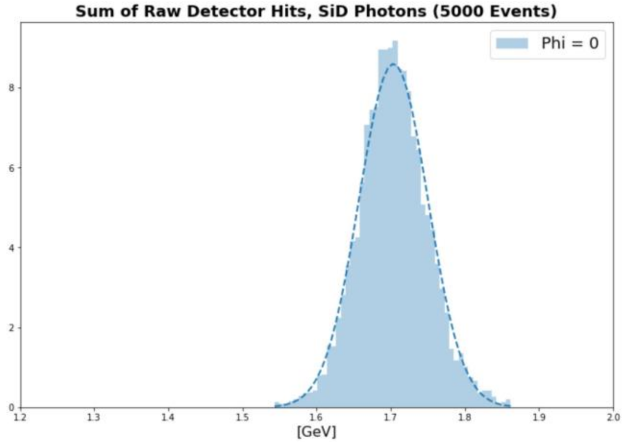
<u>Consistency</u>

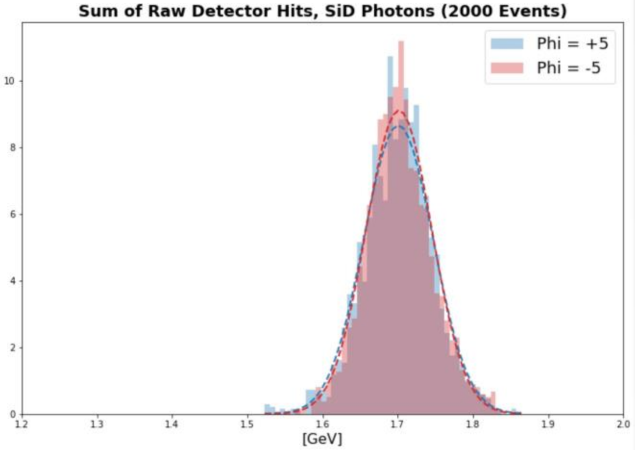
- Resolution at $\phi = 0$ for old and current sidloi3 studies match

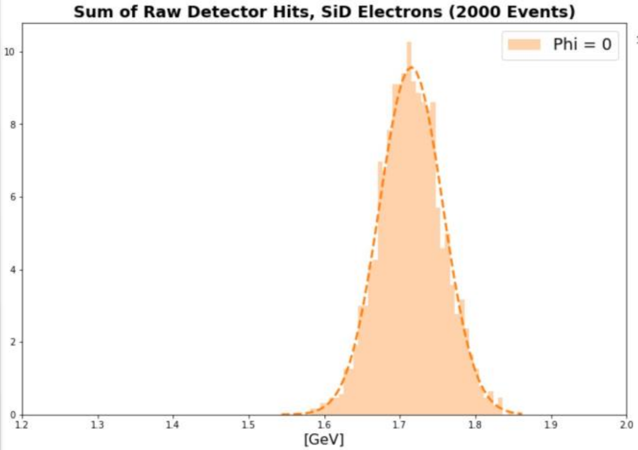
<u>Discrepancy</u>

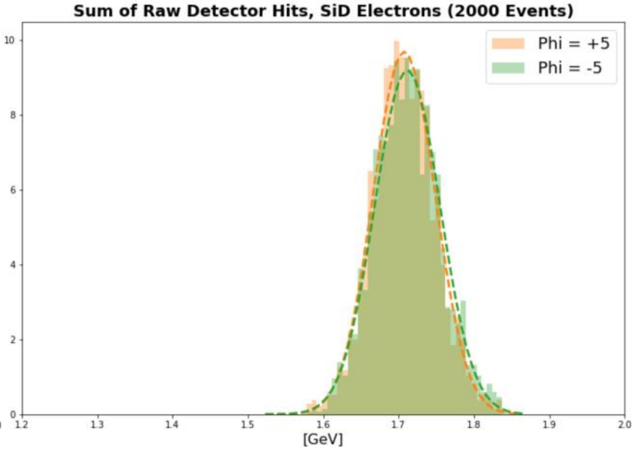
- For $\phi = All$, old and current studies do not match ($\sim 29\%/\sqrt{E}$ compared to $\sim 22\%/\sqrt{E}$)

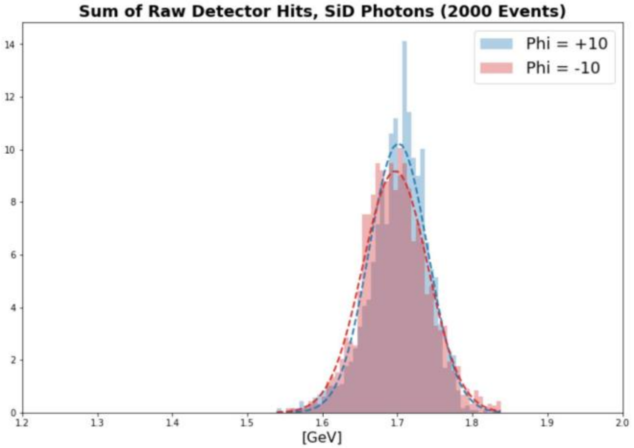
HOW DOES INCIDENT HIT LOCATION IN MODULE AFFECT RESOLUTION?

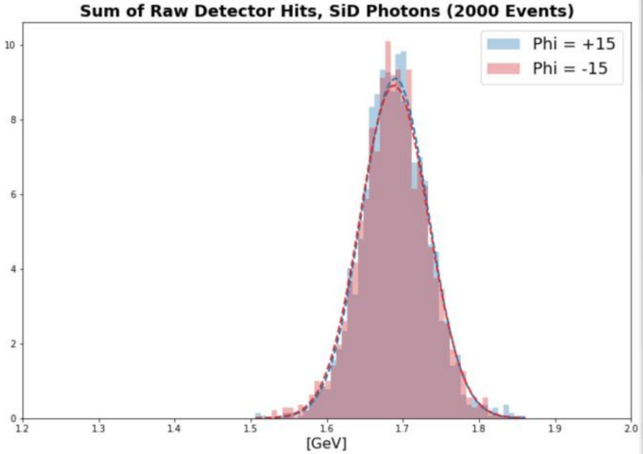


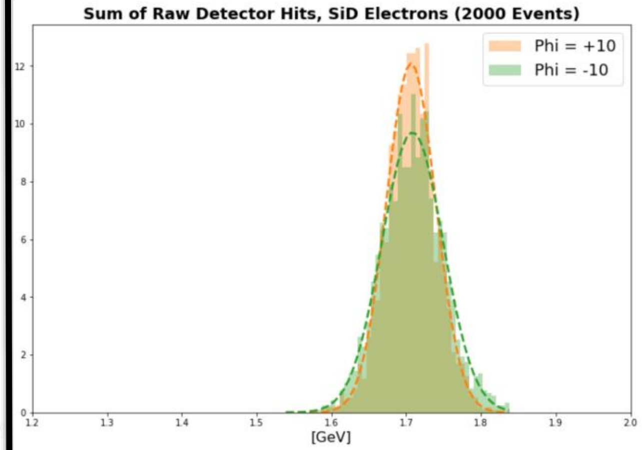


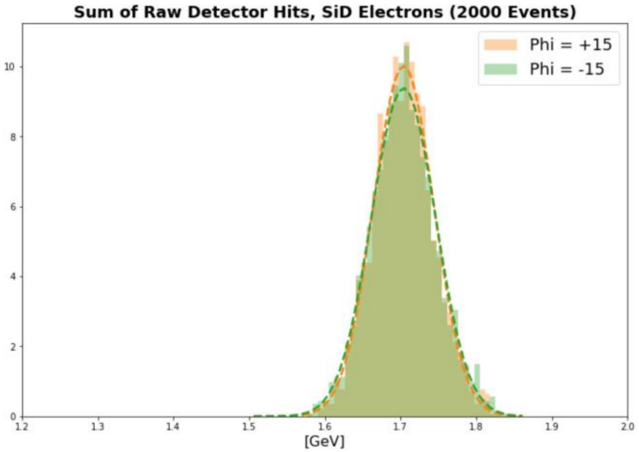




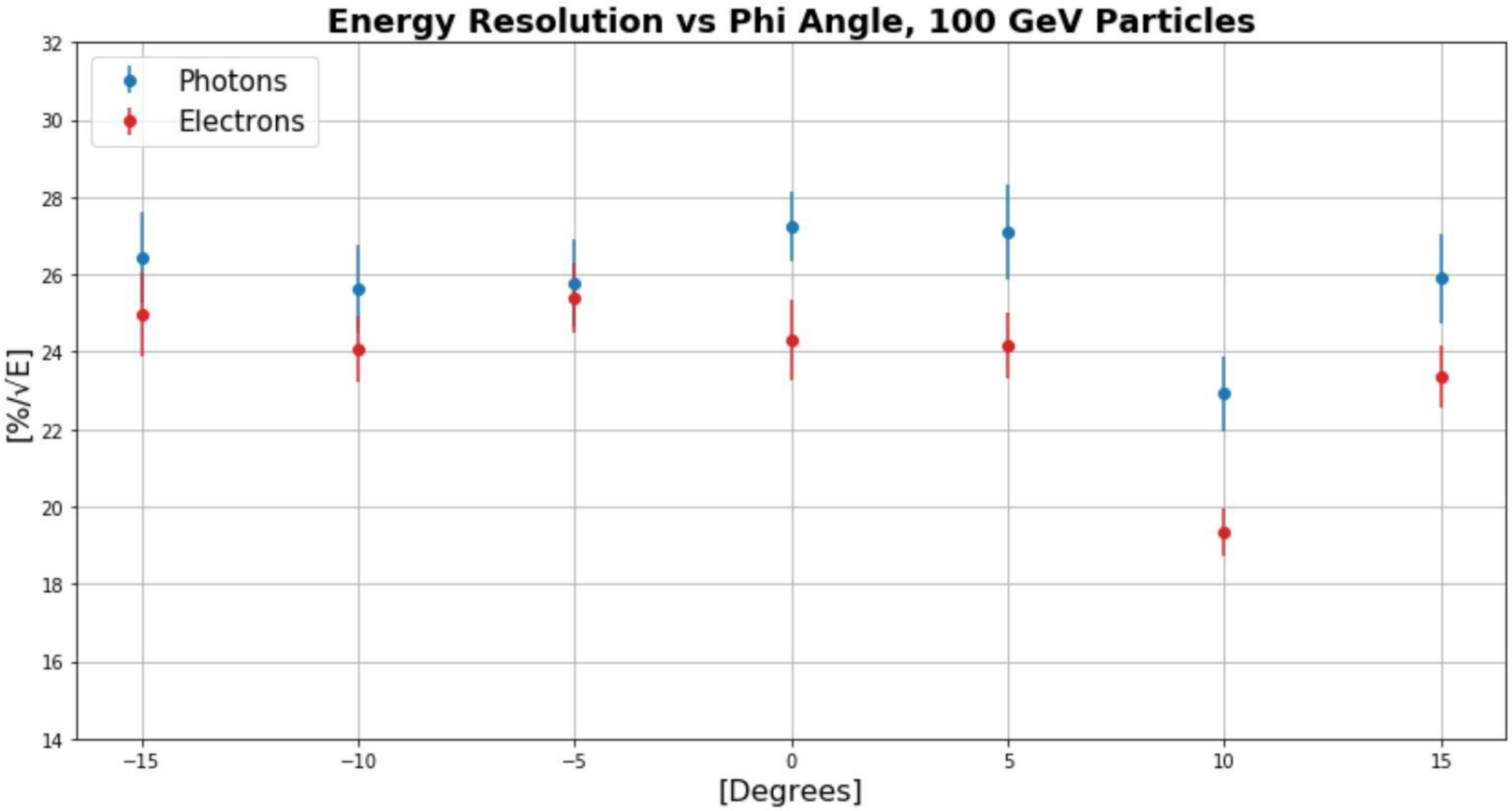








RESOLUTION DEPENDENCE ON PHI

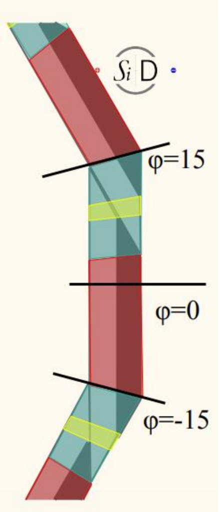


Closest overlap region to normal incidence: $\sim -4^{\circ}$

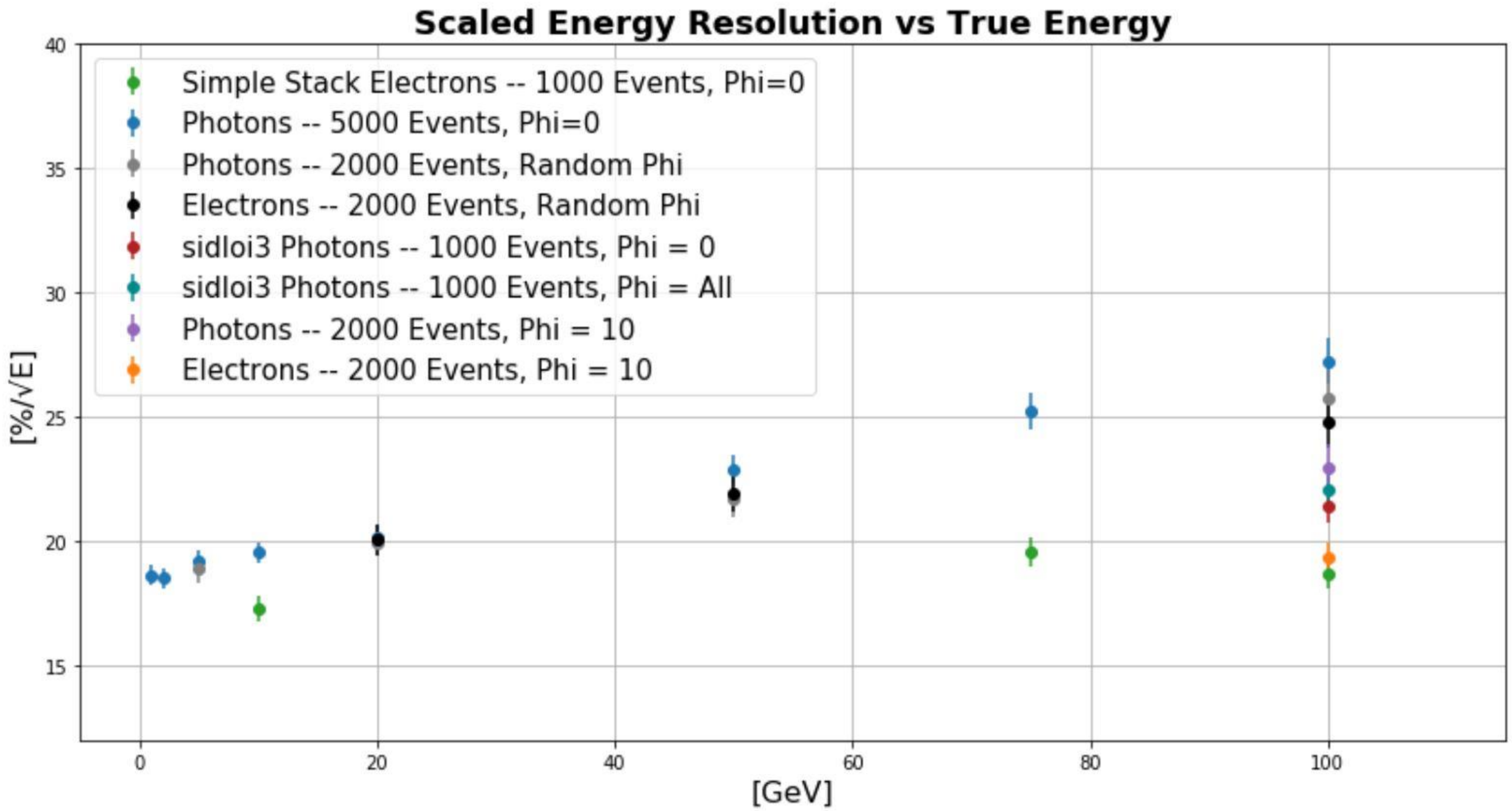
$\phi = 10°$ ensures entire shower goes through center of module

100 GeV e- at $\phi = 10°$ is comparable to simple stack

ϕ flipped from diagram on the right

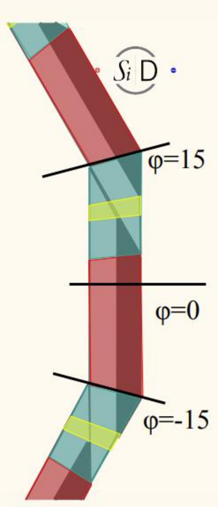


SUMMARY OF CURRENT RESOLUTION RESULTS

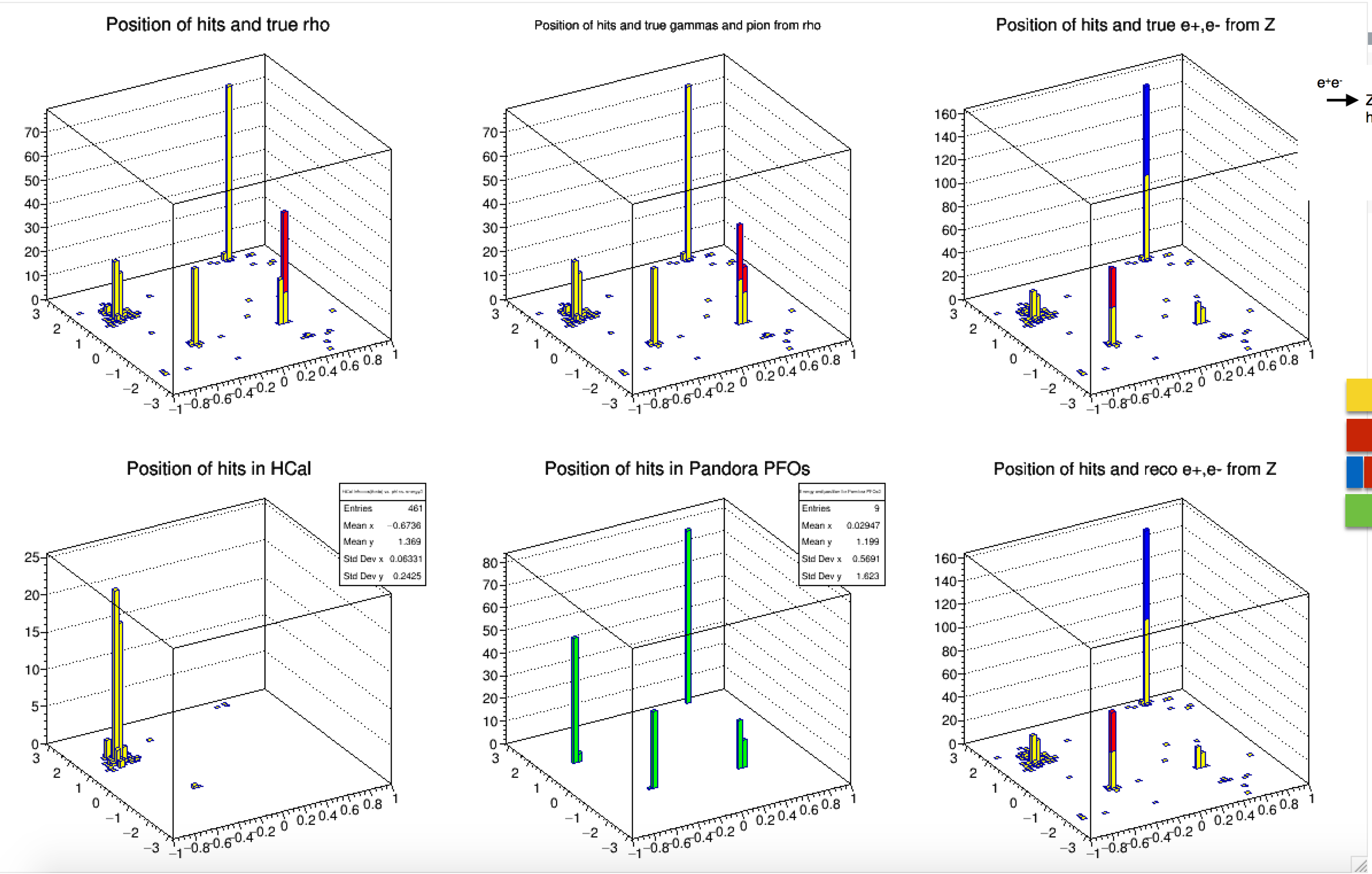


Current SiD compares better to previous studies when incident particles are fired at $\phi = 10°$ instead of normal incidence

Shower mostly contained in nonoverlapping region



Next: What about real events?!



$e^+e^- \rightarrow Zh$

$h \rightarrow \tau^+\tau^-$

$\tau^{+/-} \rightarrow \rho^{+/-}\nu_\tau$

$\rho^{+/-} \rightarrow \pi^{+/-}\pi^0$

$\pi^0 \rightarrow \gamma\gamma$

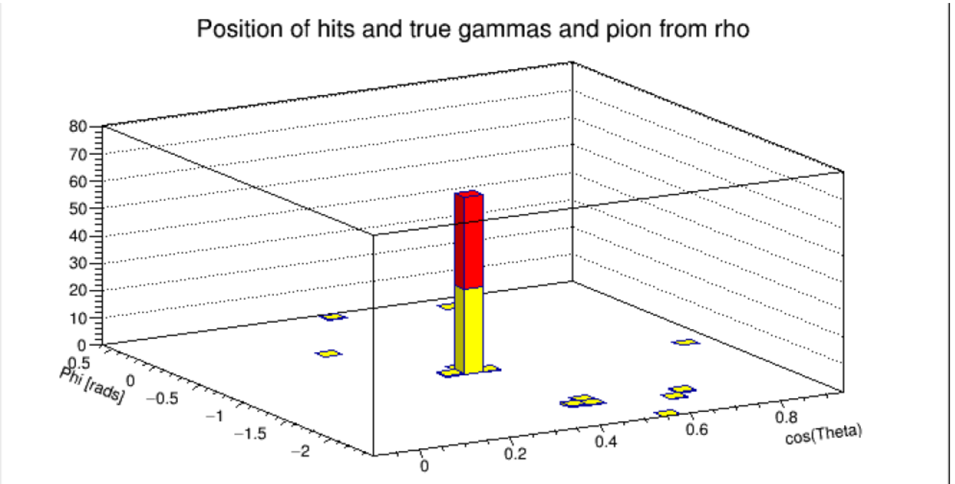
Calo hits

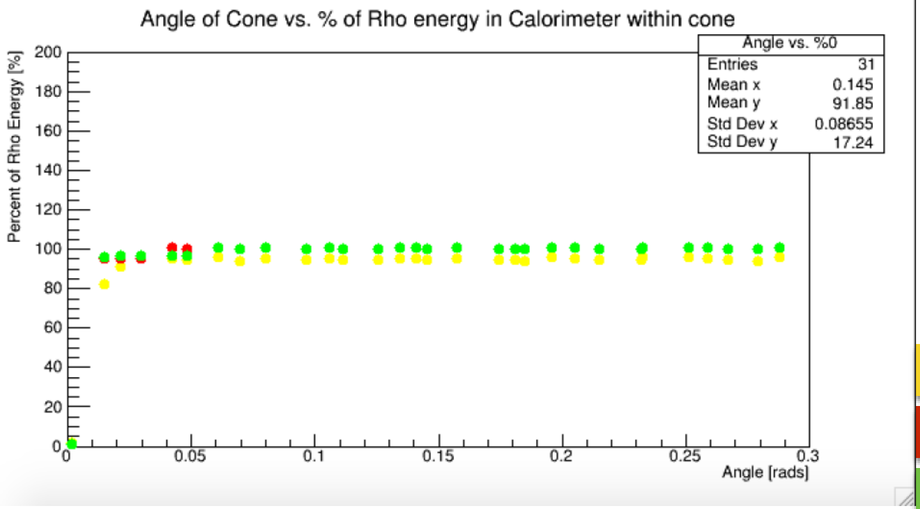
Truth MCParticle

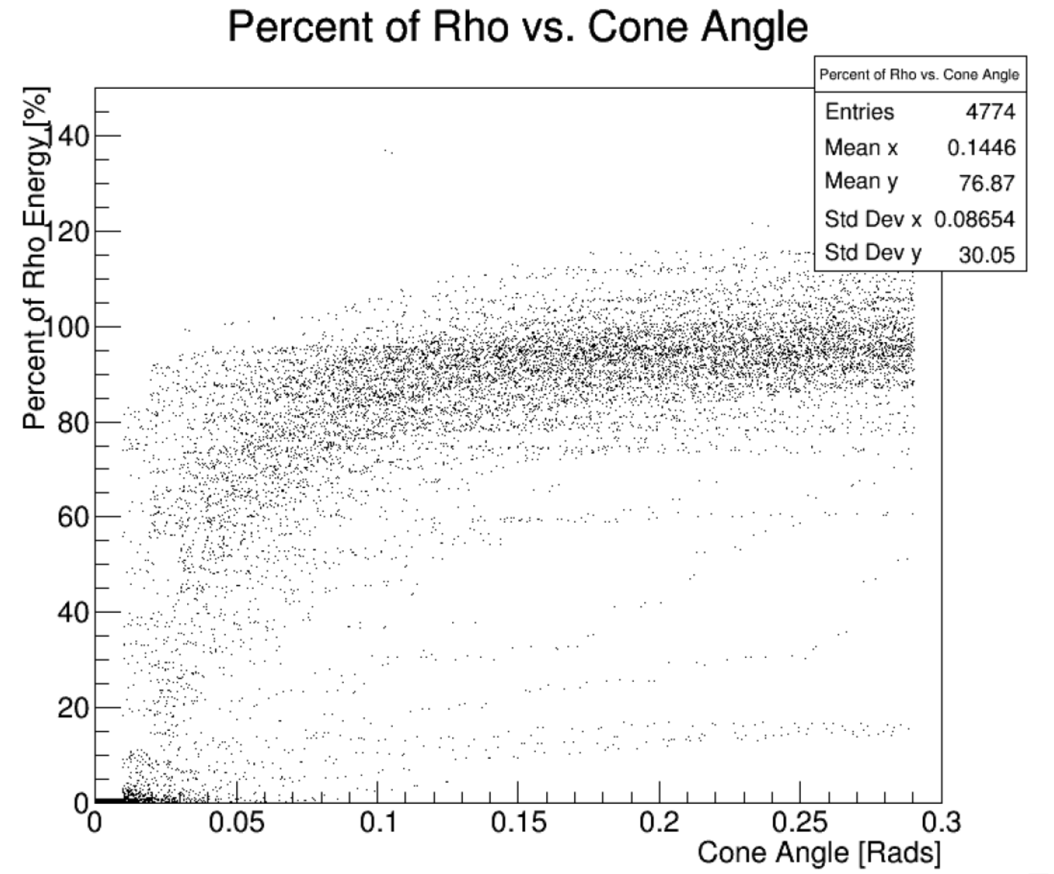
Electron/Positron

Pandora PFOs

INVESTIGATION OF PHOTON-PHOTON OPENING ANGLE

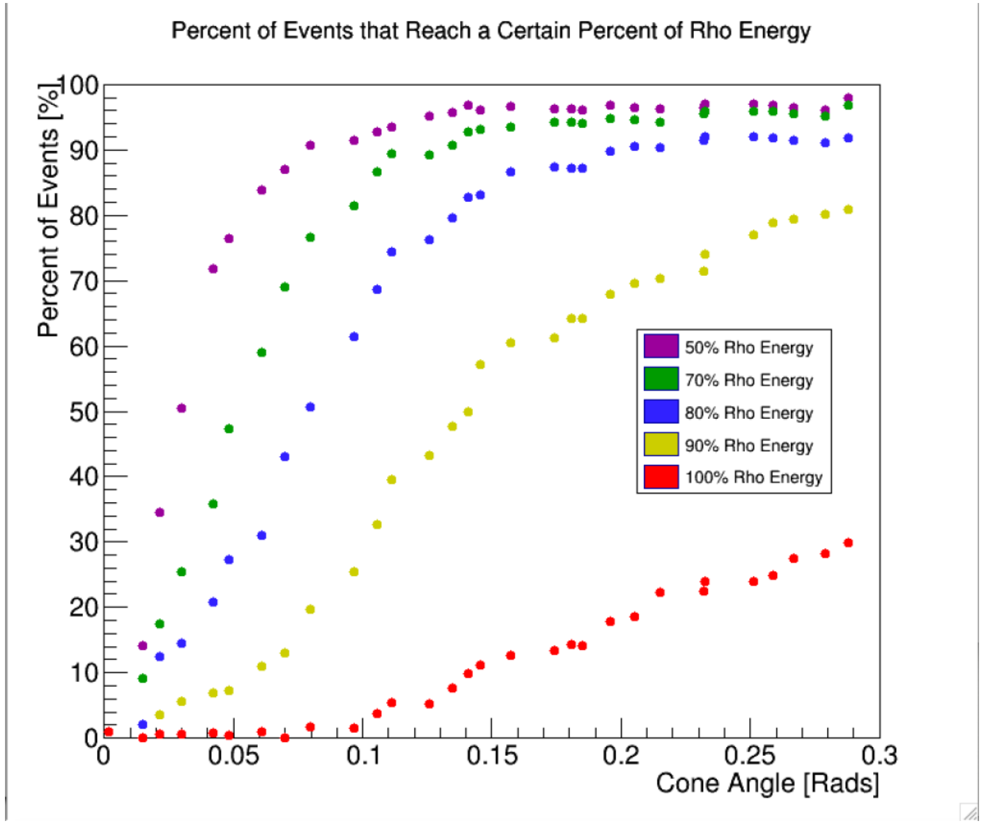


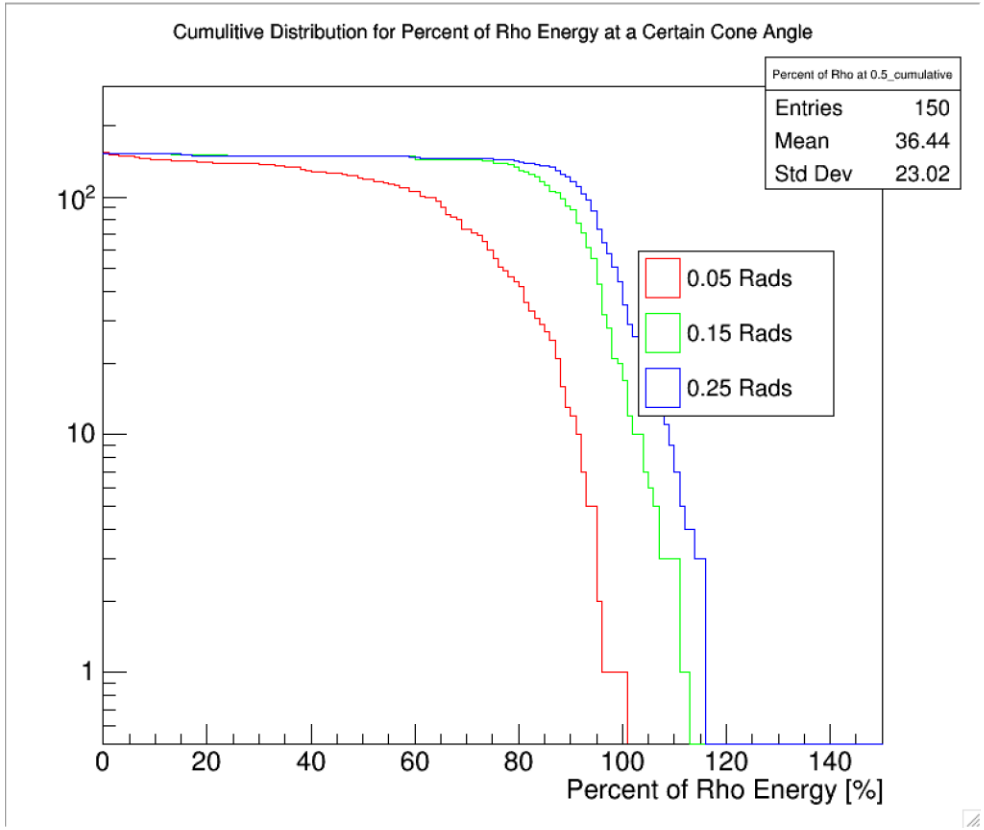




Raw Data
Truth Info
Pandora PFOs

TRUTH ENERGY RESOLUTION AROUND TRUE RHO





Choosing a certain percent of the rho energy and looking at the percent of events that contain that amount of the rho energy vs. the cone angle.

0.05rad → ~6cm
~<2 pixels width

Choosing a certain cone angle and looking at the cumulative distribution for how many events get to a certain percent of the rho energy shown on the x-axis.

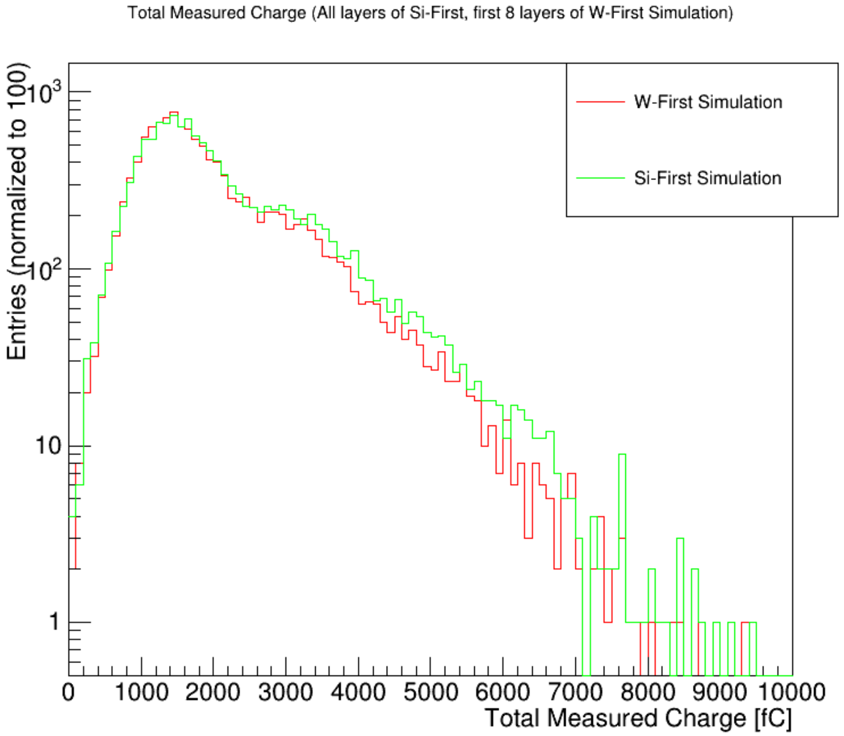
SUMMARY

- Better understanding current results more every day
  - Resolution differences from initial design resolution to current design geometry
  - Comparison between versions of geometry can be tricky
- Initial $\pi^0 \rightarrow \gamma\gamma$ resolution studies underway

BACKUP

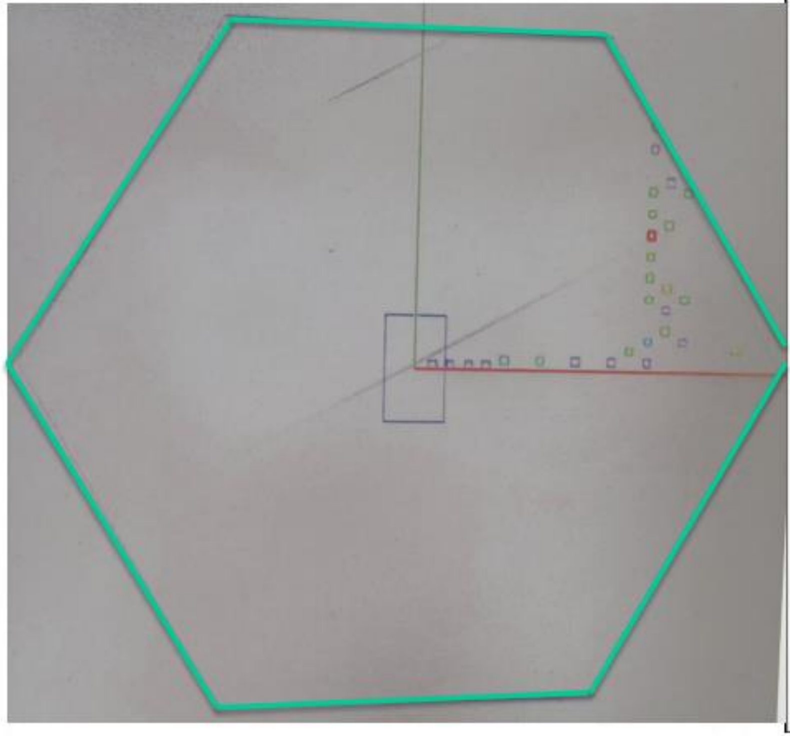
W-FIRST VS SI-FIRST SIMULATION

- Distribution of energies in simulation depending on which way the test beam was facing into the detector, small differences

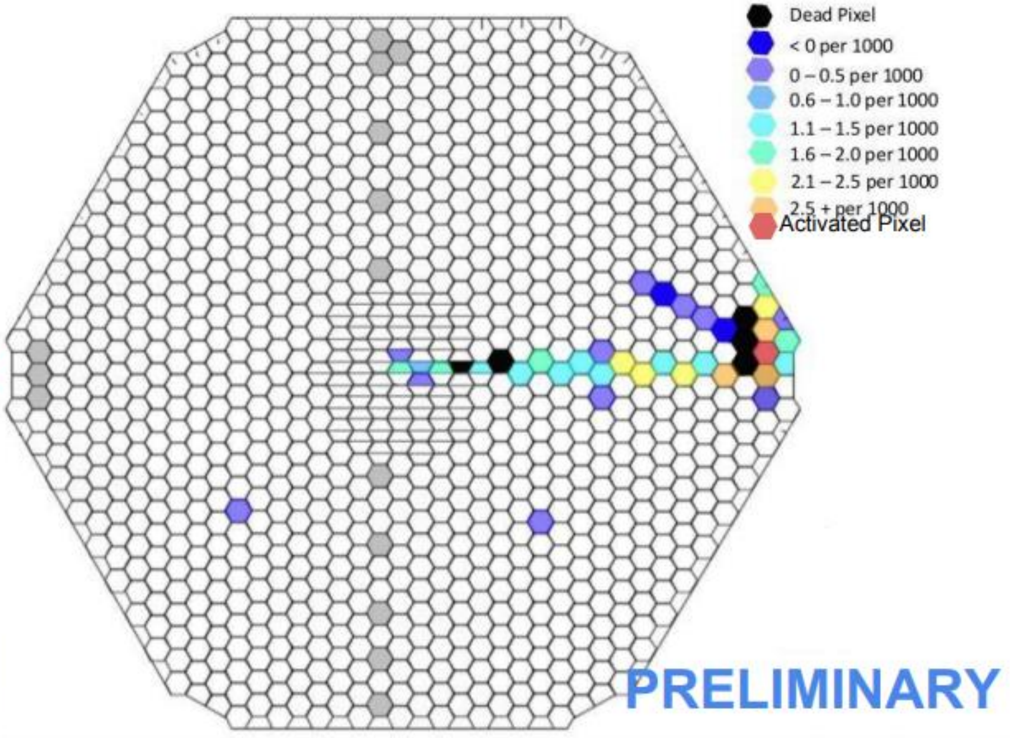


Cross-Talk on Test Beam Sensor

SLAC Test Beam



Probe-Tested Sensor



- Additional signal detected in pixels along trace of activated pixel (cross talk)
- Should be reduced with new shielded KPiX model

Work done at the University of Oregon:
C. Gallagher

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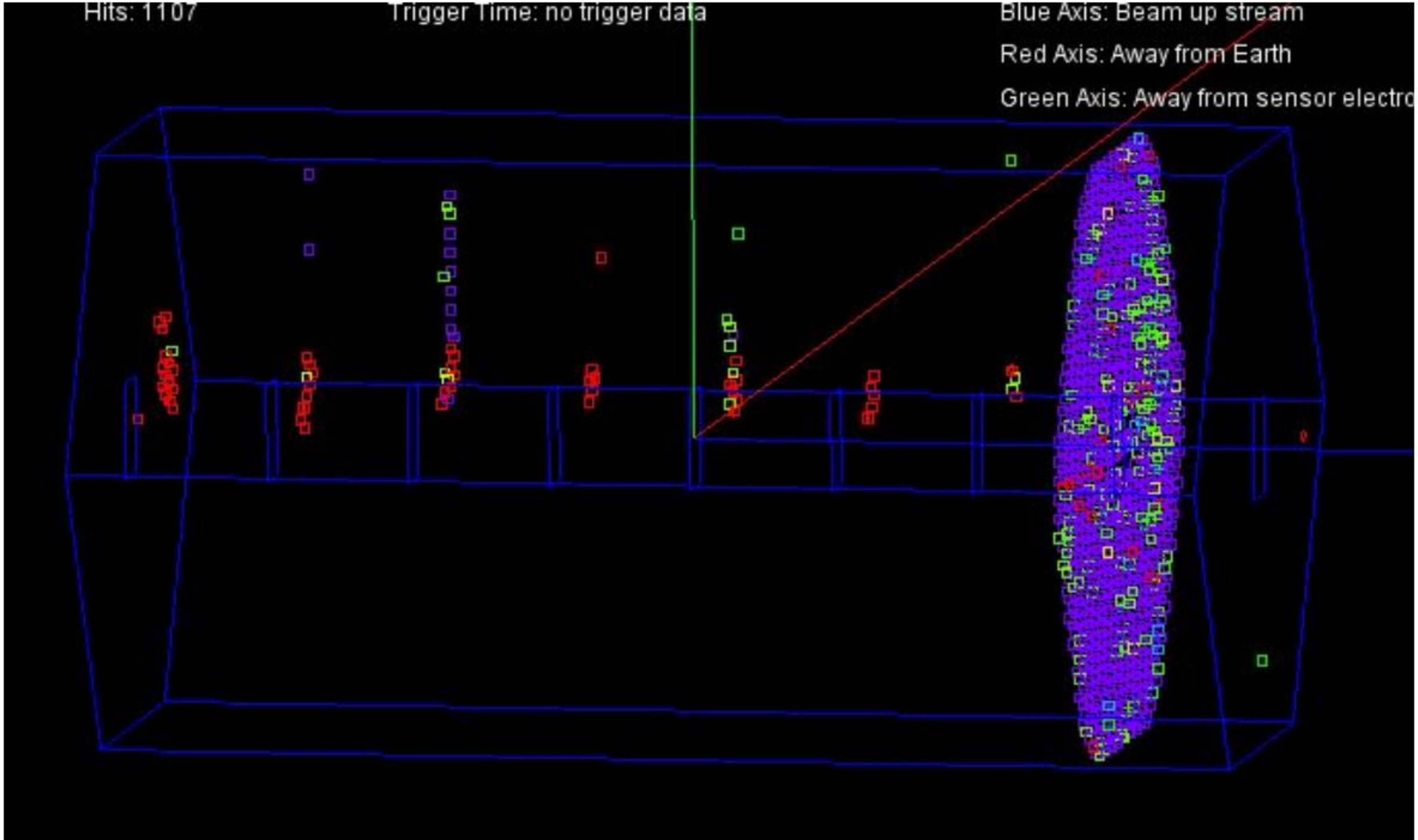
"monster events" with many negative amplitude and out of time hits



BACKSCATTER