Simulation of Secondary Emission Calorimeter for Future Colliders

Calorimetry for the **H**igh **E**nergy **F**rontier, 2-6 October 2017

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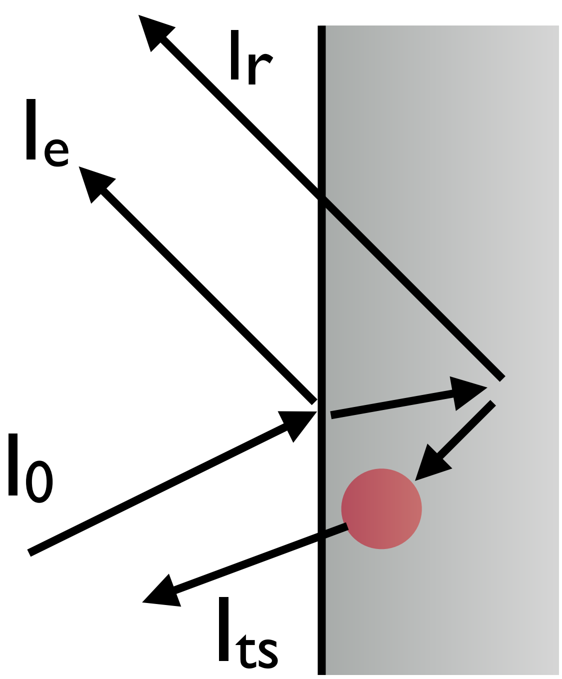
Secondary Electron Emission

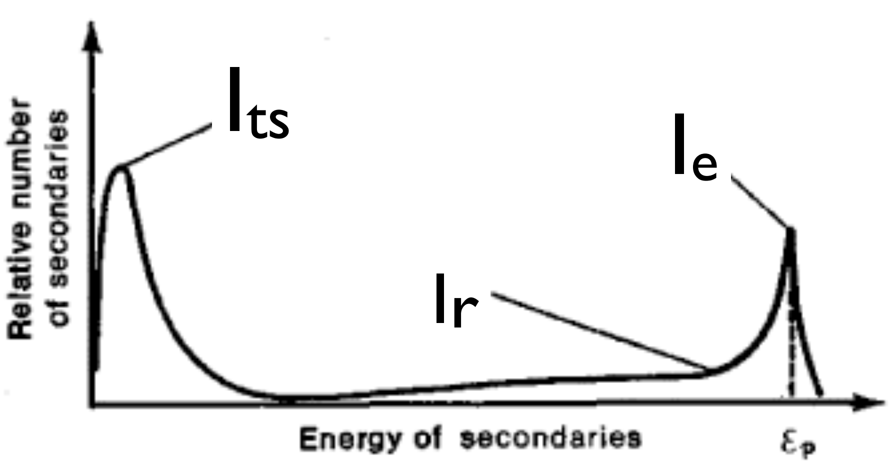
The SEE process was first discovered in 1902 by two German physicists L. Austin and H. Starke [7]

- ☑ electrons are emitted from a solid metal surface when it is bombarded by incident electrons.
- ☑ The incident electrons are called primary and the emitted electrons are called secondary



When electrons hit to a metal surface

- ☑ some portion can be *elastically backscattered* (δ_e)
- ☑ the rest penetrated into the material
  - ☑ some scattered from one or more atoms inside the metal and reflected back out, *rediffused electrons* (δ_r)
  - ☑ the rest interact with a more complicated way and inside the material and yield the *true-secondary electrons* (δ_{ts})



The secondary electron yield

$$\delta = (I_e + I_r + I_{ts})/I_0 = \delta_e + \delta_r + \delta_{ts}$$

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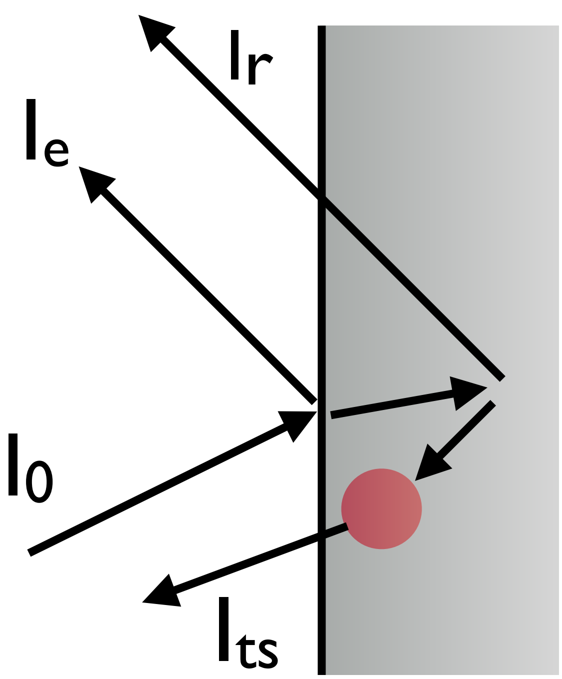
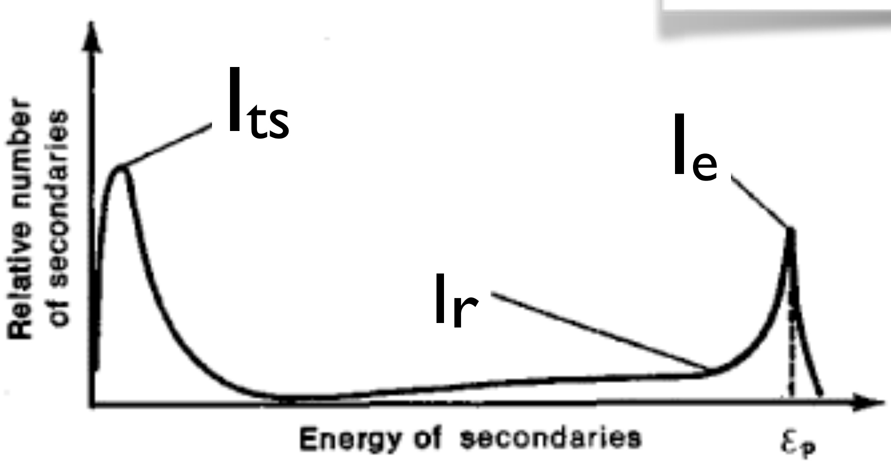


Can we build a calorimeter based on the Secondary Electron Emission process?



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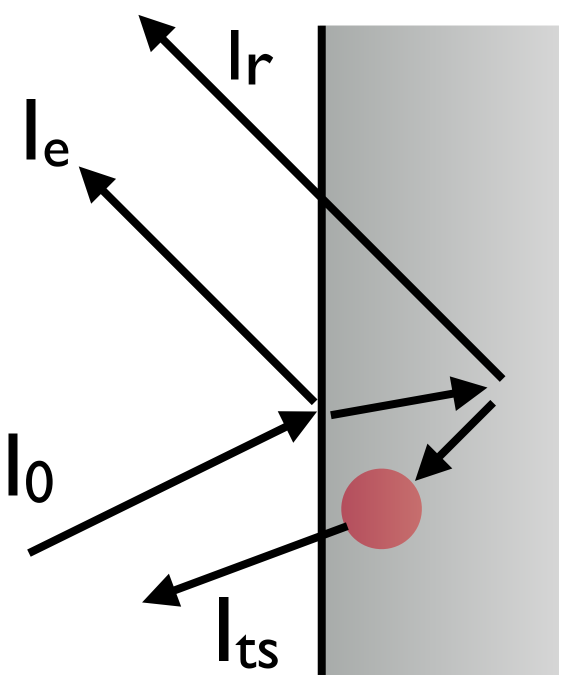
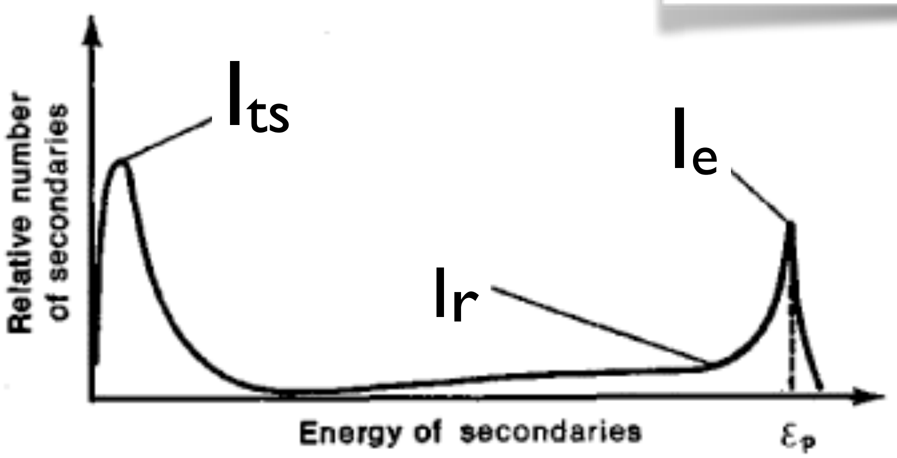


Can we build a calorimeter based on the Secondary Electron Emission process?

TUBITAK 1001 Project - 113F337

Designing a radiation hard, fast and compact calorimeter



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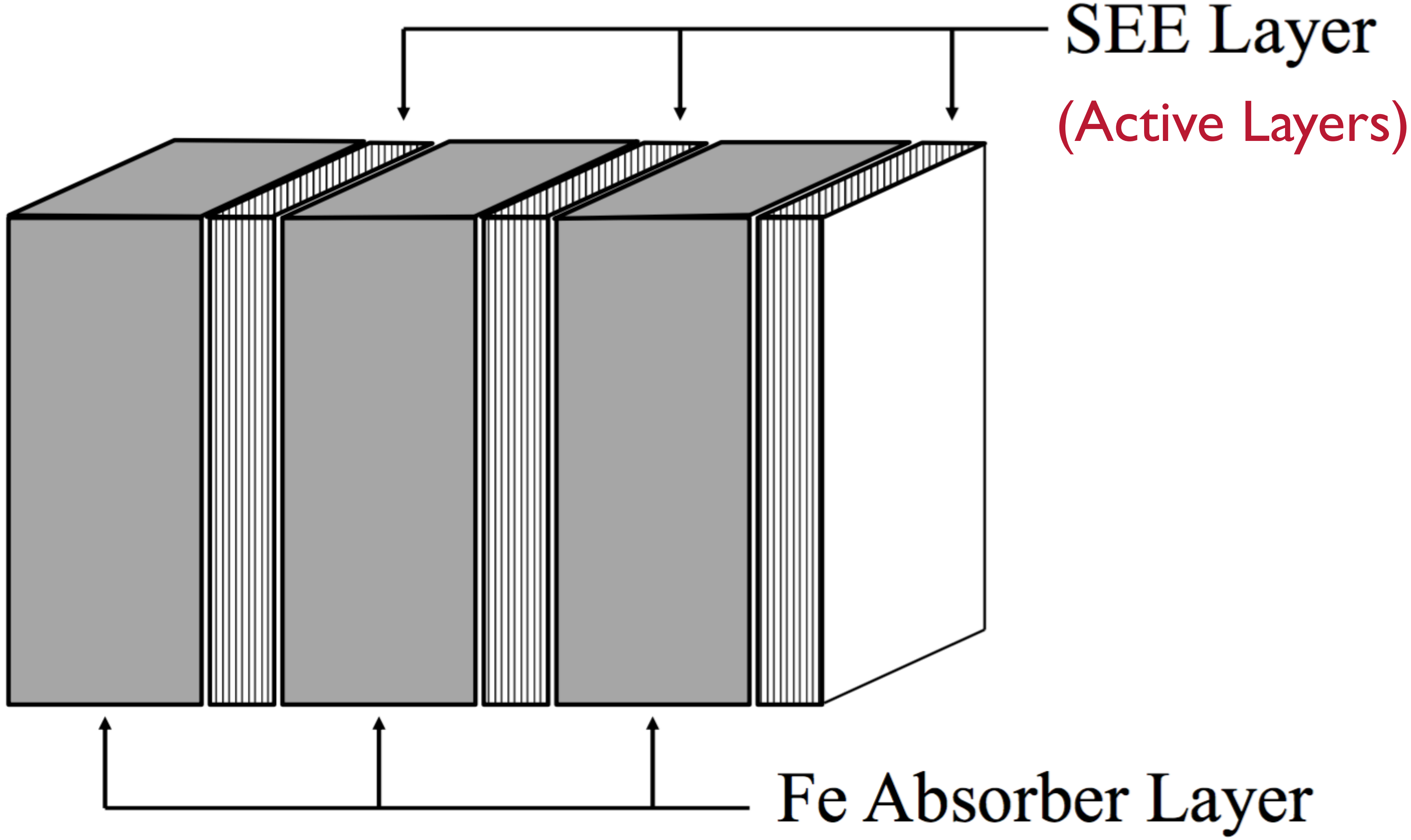
SEE Sampling Calorimeter



Motivation

- The secondary electron emission (SEE) process is used in many applications: e.g. vacuum electronic devices, particle detectors, and scanning electron microscopy.
- In 1990 Derevshchikov et al. [1] proposed to use SEE process in suitably instrumented chambers with radiation hard emitters as active layers in calorimeter.
  - Since then, several other studies were performed to built such a calorimeter [2-6]
- A detailed Geant4 implementation of SEE process will be very helpful for detector R&D and performance comparisons with traditional scintillation sampling calorimeter.

A Semi-Empirical Model with Energy Spectrum

- M. A. Furman and M.T.F. Pivi [8] proposed a detailed MC algorithm for SEE process based on experimental data which regenerate yield and energy spectrum of secondary electrons (to estimate the cloud effect in accelerators).

  - Yield is important to calculate the gain of the detector (e.g. a pmt)

  - Energy spectrum of SEEs is equally important to perform a correct simulation of matter-particle interactions in a sampling calorimeter (e.g. for layer-to-layer energy fluctuations).

- In their model, the secondary electrons are characterised by energy distribution functions (for true, rediffused, and backscattered secondaries), which forms the energy spectrum of secondary electrons. This spectrum, after normalised and integrated over energy, gives the SEE yield.

Our Purpose

In this study, we implemented a detailed MC algorithm in Geant4 as a new physics process (`G4SecondaryElecEmission`) with the following goals

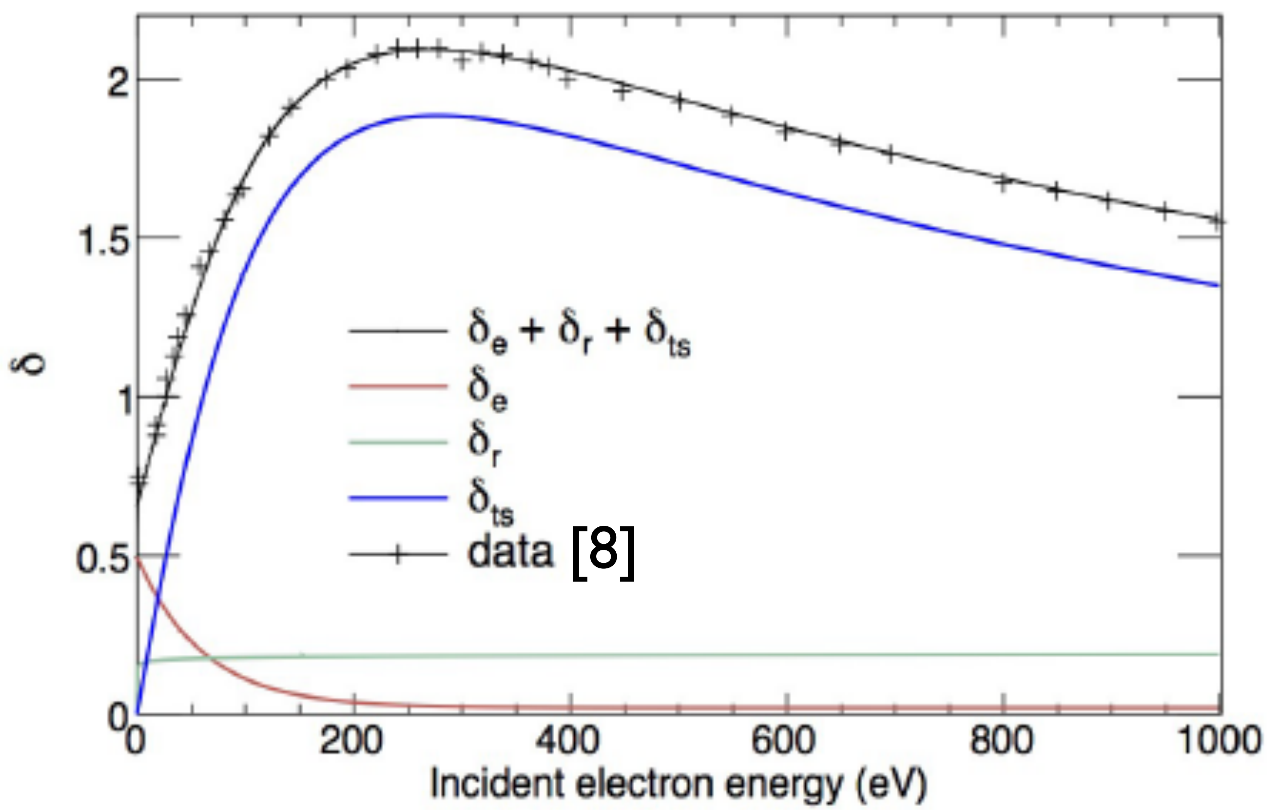
- ☑ to take advantage of a well known and widely used matter and particle interaction simulation toolkit.
- ☑ to incorporate particle shower development into SEE process.
- ☑ to make qualitative comparison with a traditional scintillating calorimeters.

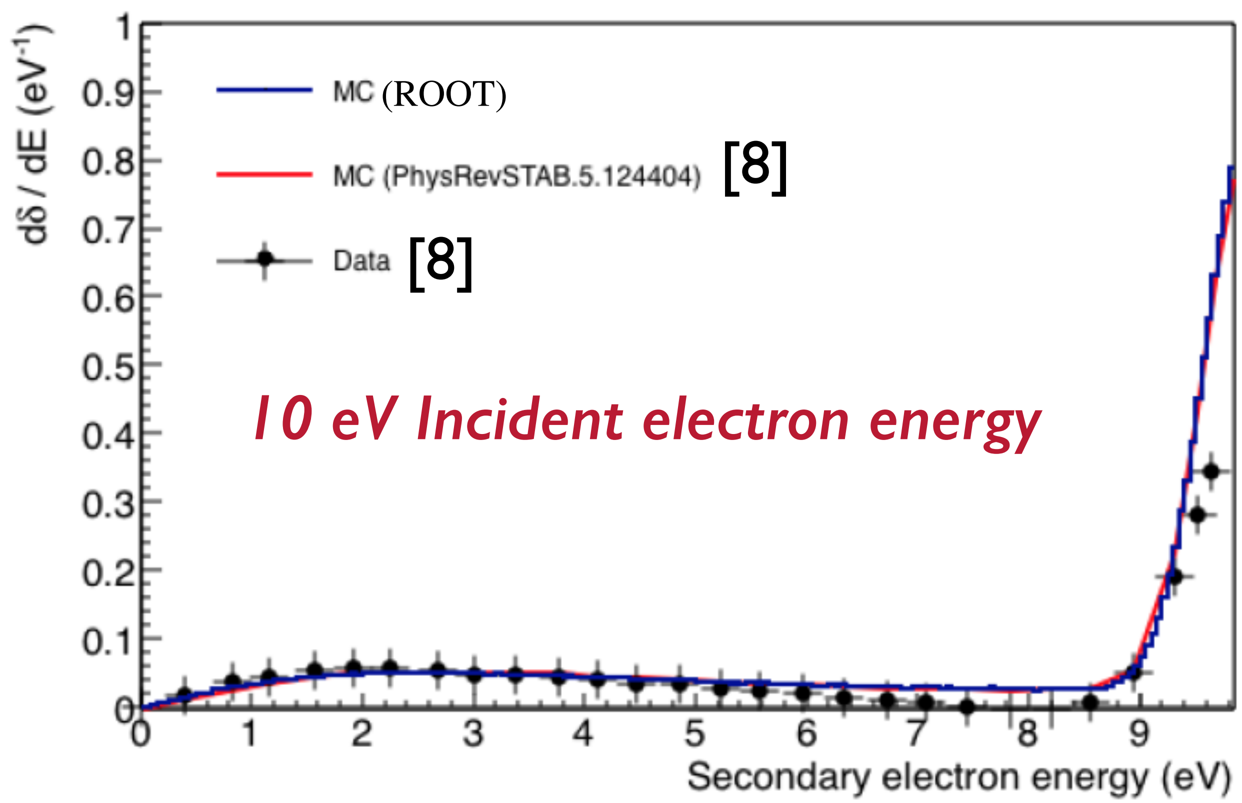
Implementation in ROOT

Our Implementation in ROOT

The model is tested by simulating the secondary electron process on a single thin metal layer. To make direct comparison with published results:

- ☑ The SEY is estimated for different incident electron energies (0-1000 eV)
- ☑ The energy spectrum of the secondary electrons are estimated for the incident electron beams for E= 10, 30, and 295 eV.





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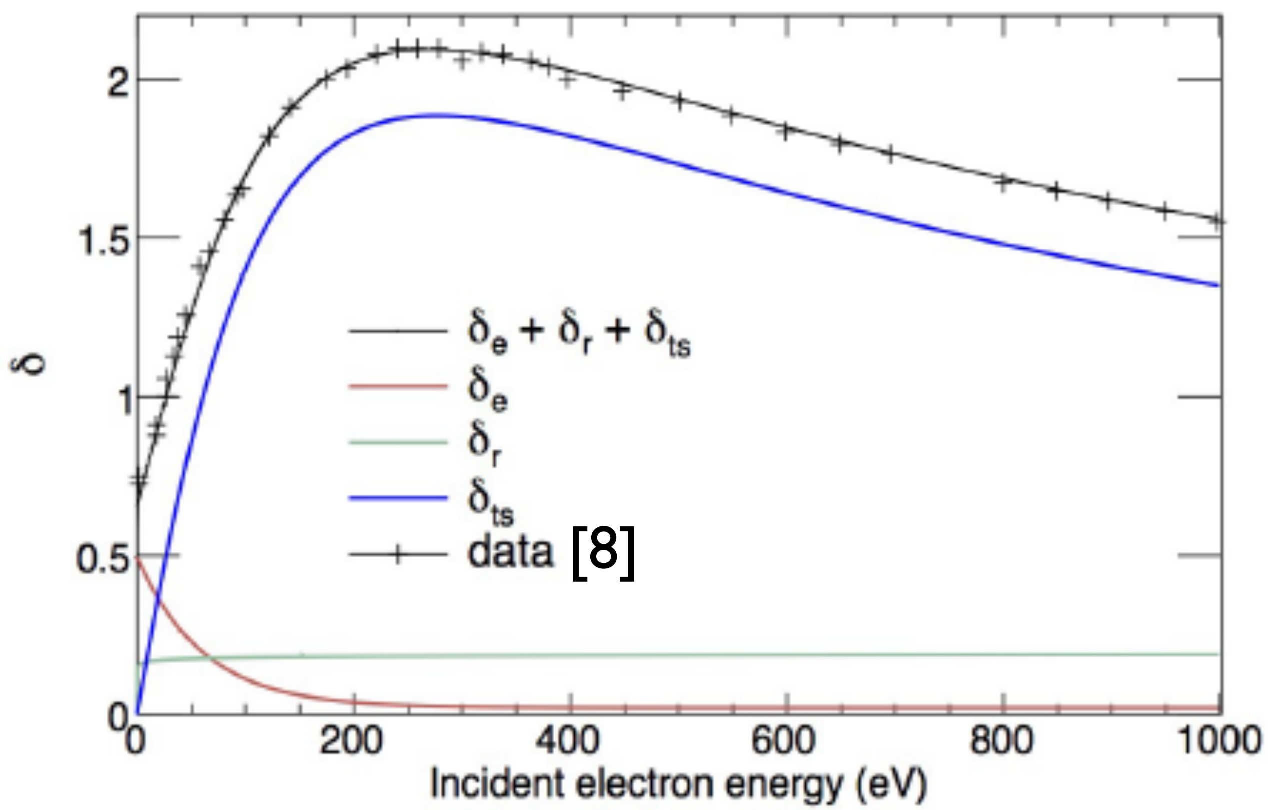

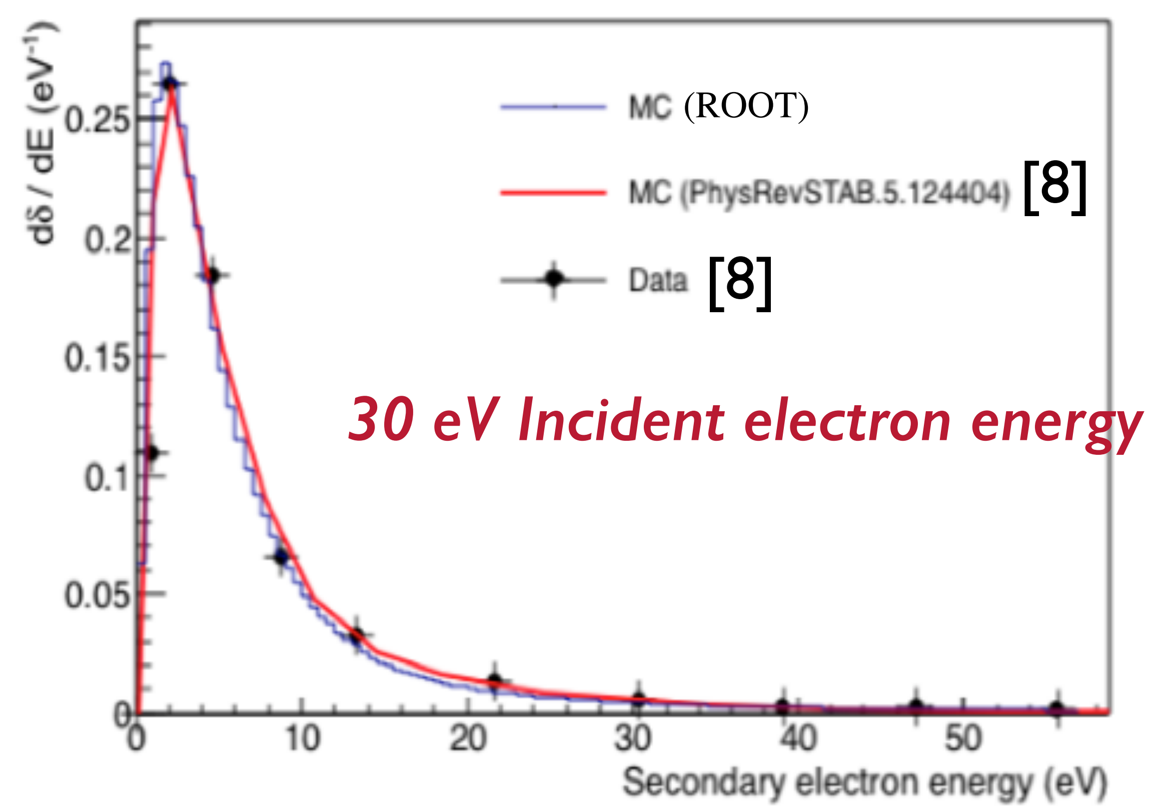

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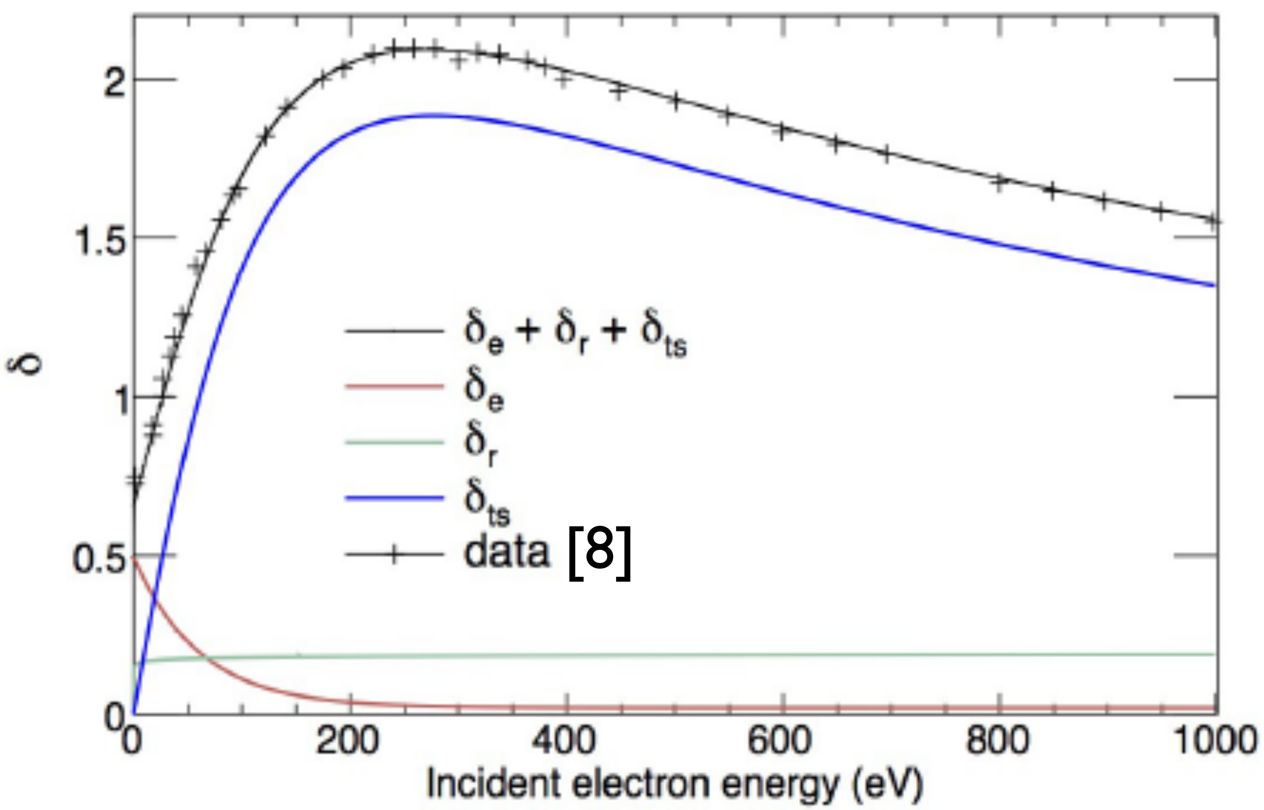
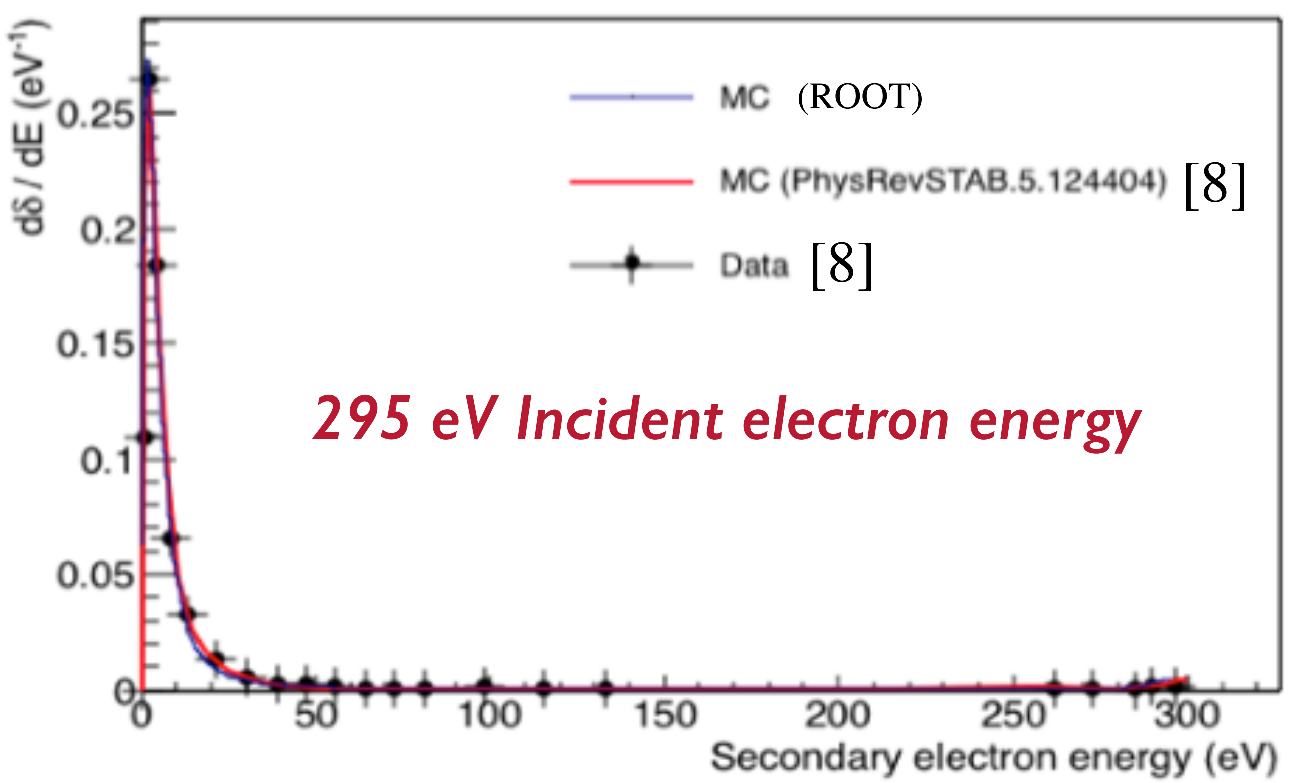




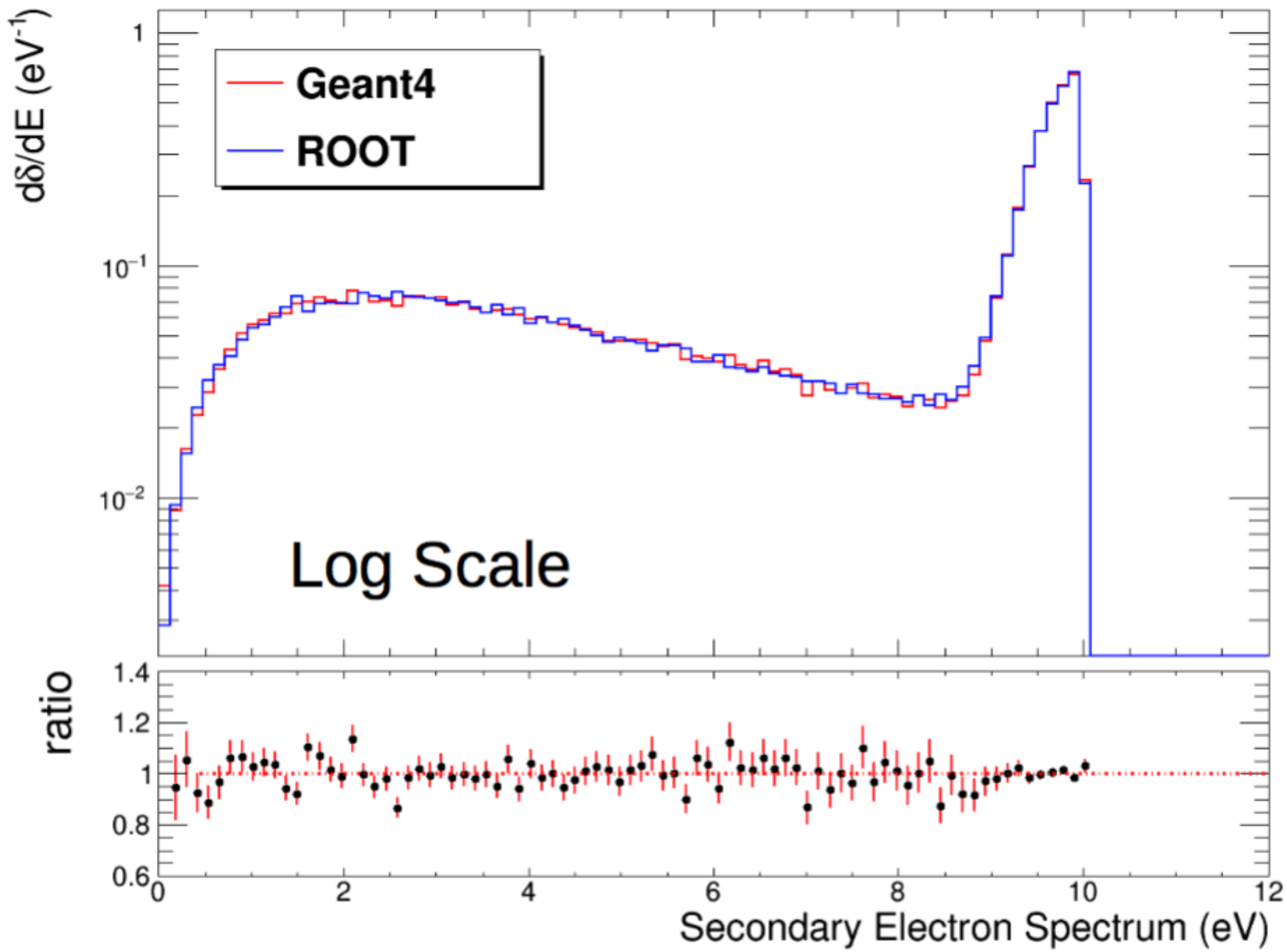
Implementation in Geant4

Implementation into the Geant4

- ☑ We implemented Furman's algorithm as a new physics process (`G4SecondaryElecEmission`) class and with a new particle (`G4SEElectron`) class.
  - G4SEElectron was treated like an electron but it was only allowed to have process defined in `G4SecondaryElecEmission`
- ☑ A user physics list was constructed based on `G4SecondaryElecEmission` and then was registered to Geant4 hadronic physics list (e.g. QGSP).
- ☑ Geant4 implementation was tested against the ROOT implementation by performing a thin foil simulation.

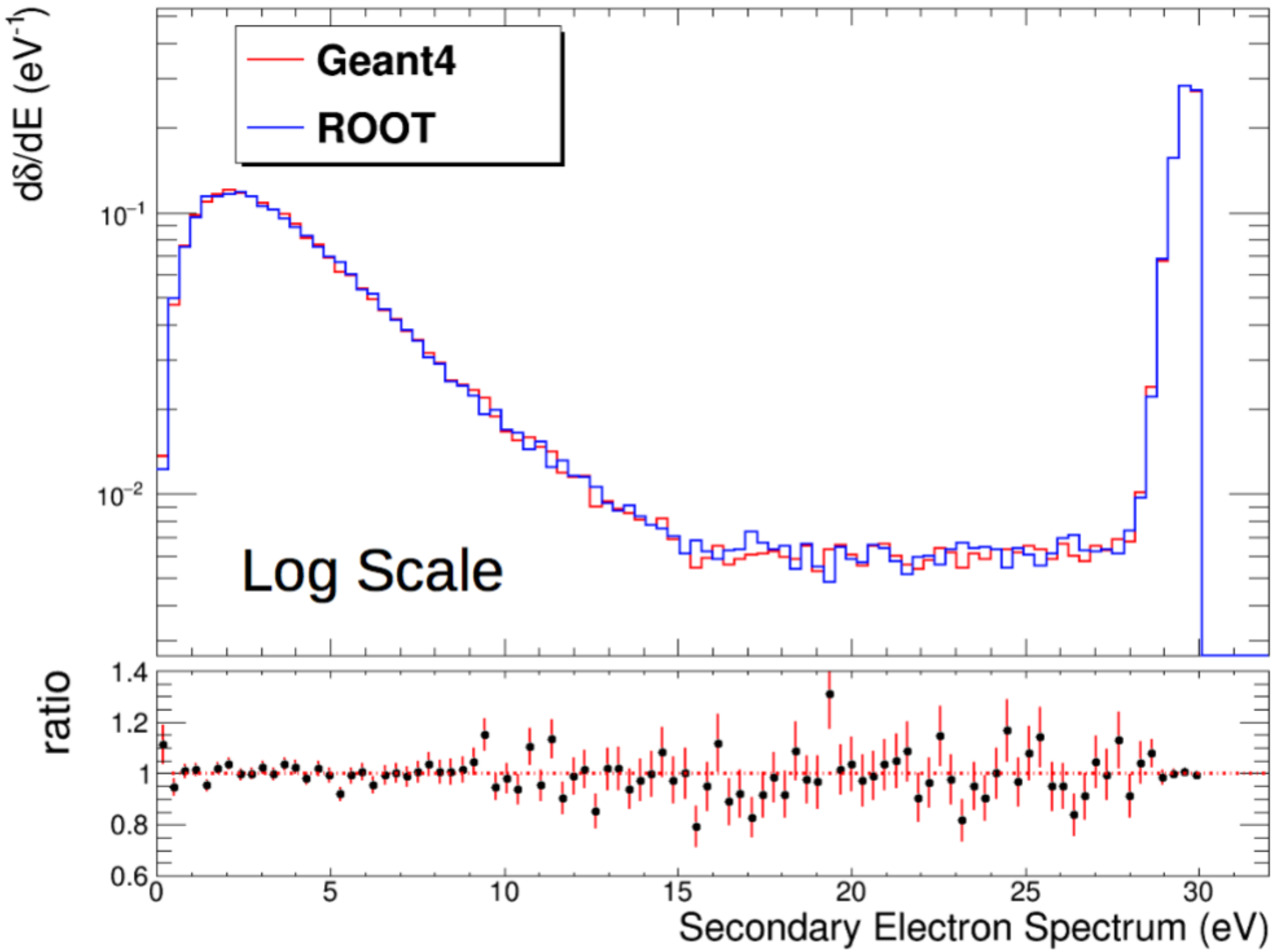
Geant4 - SEE Process for a Thin Foil

10 eV Incident electron energy



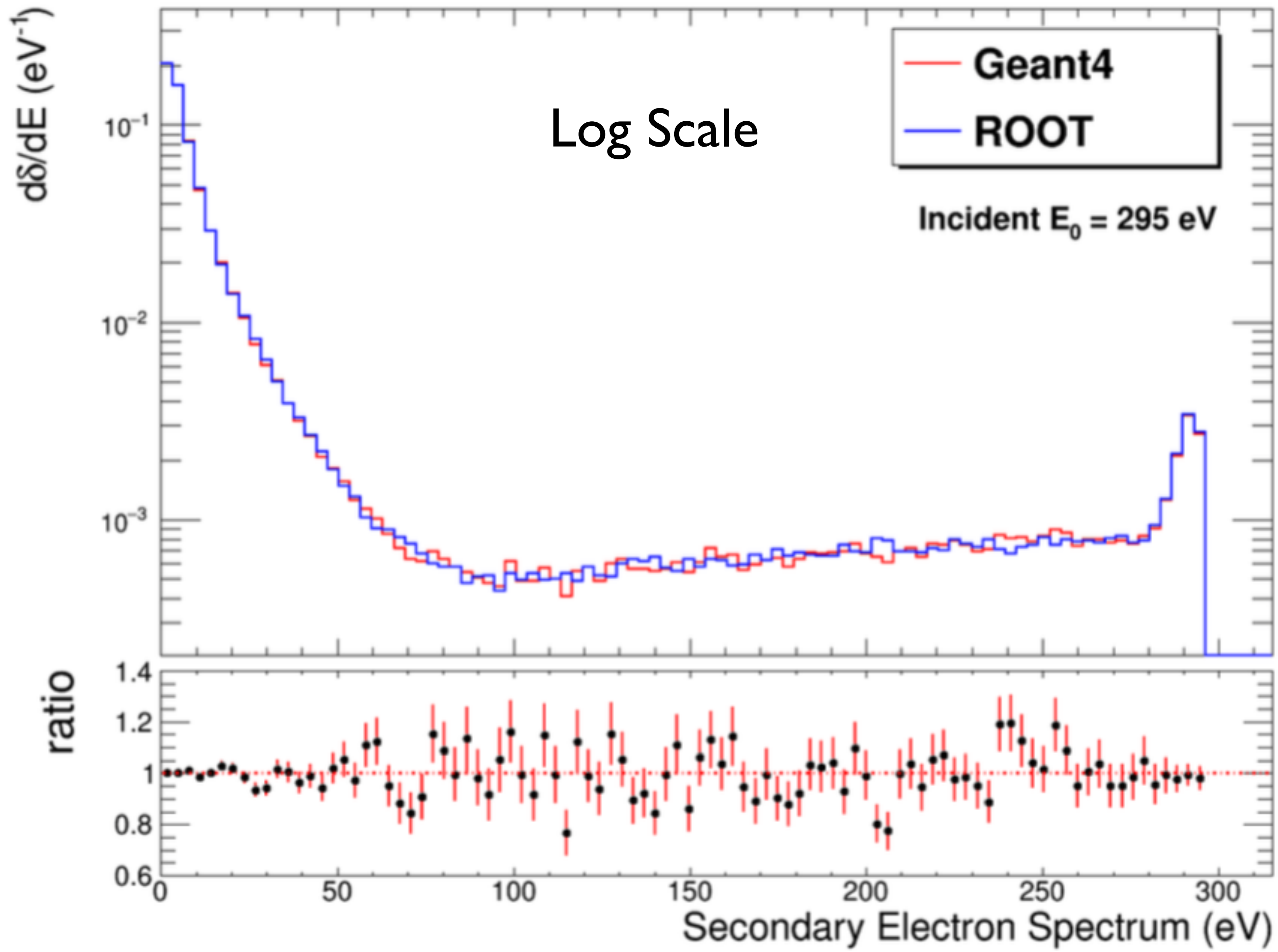
Geant4 - SEE Process for a Thin Foil

30 eV Incident electron energy



Geant4 - SEE Process for a Thin Foil

295 eV Incident electron energy



Geant4 - Thin Foil Results

- Both MC and Geant4 simulations are consistent with the observed secondary emission electron data.
  - In our Geant4 simulation we were able to estimate both the yield and energy spectrum of the secondary electrons depending on the incident electron energy

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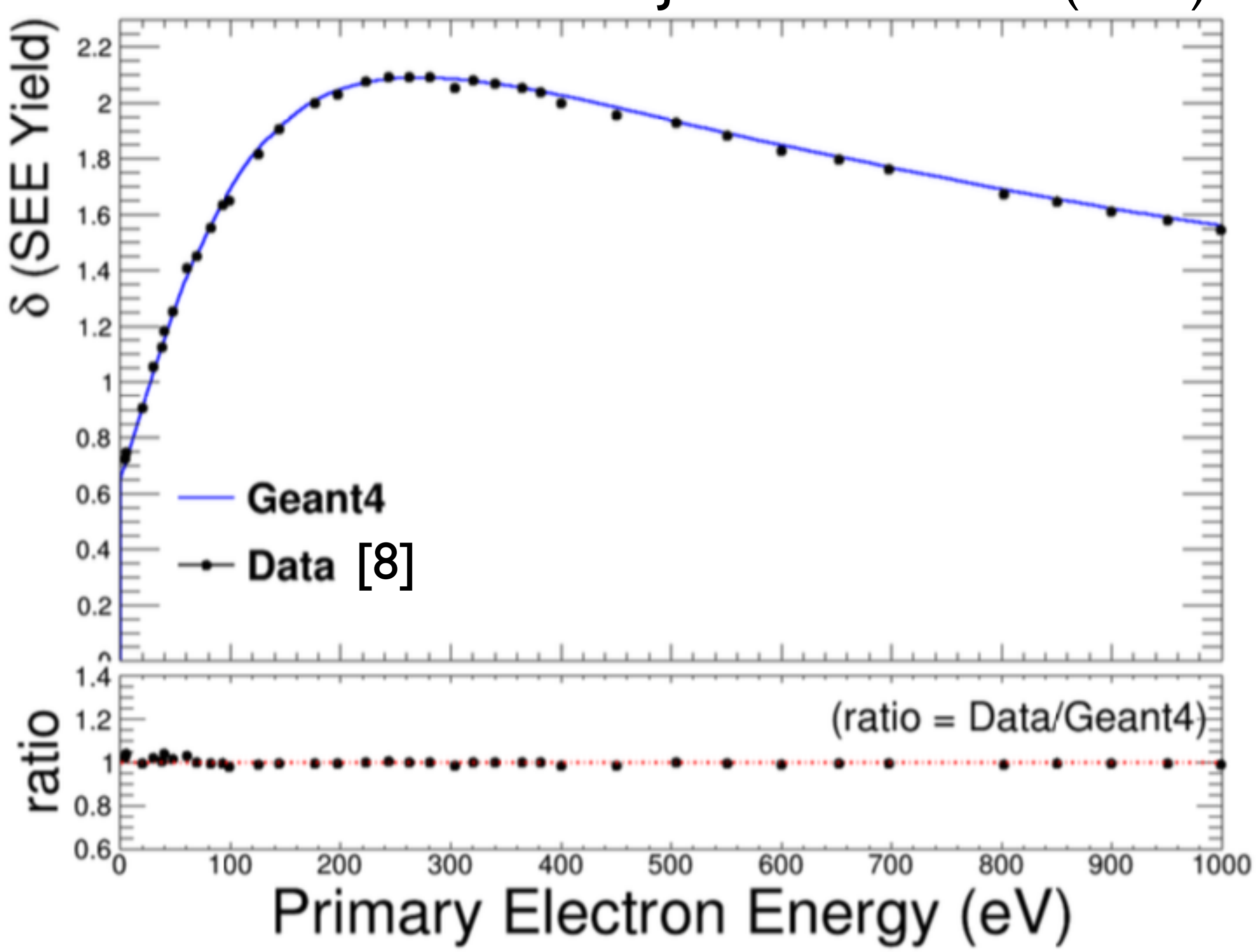

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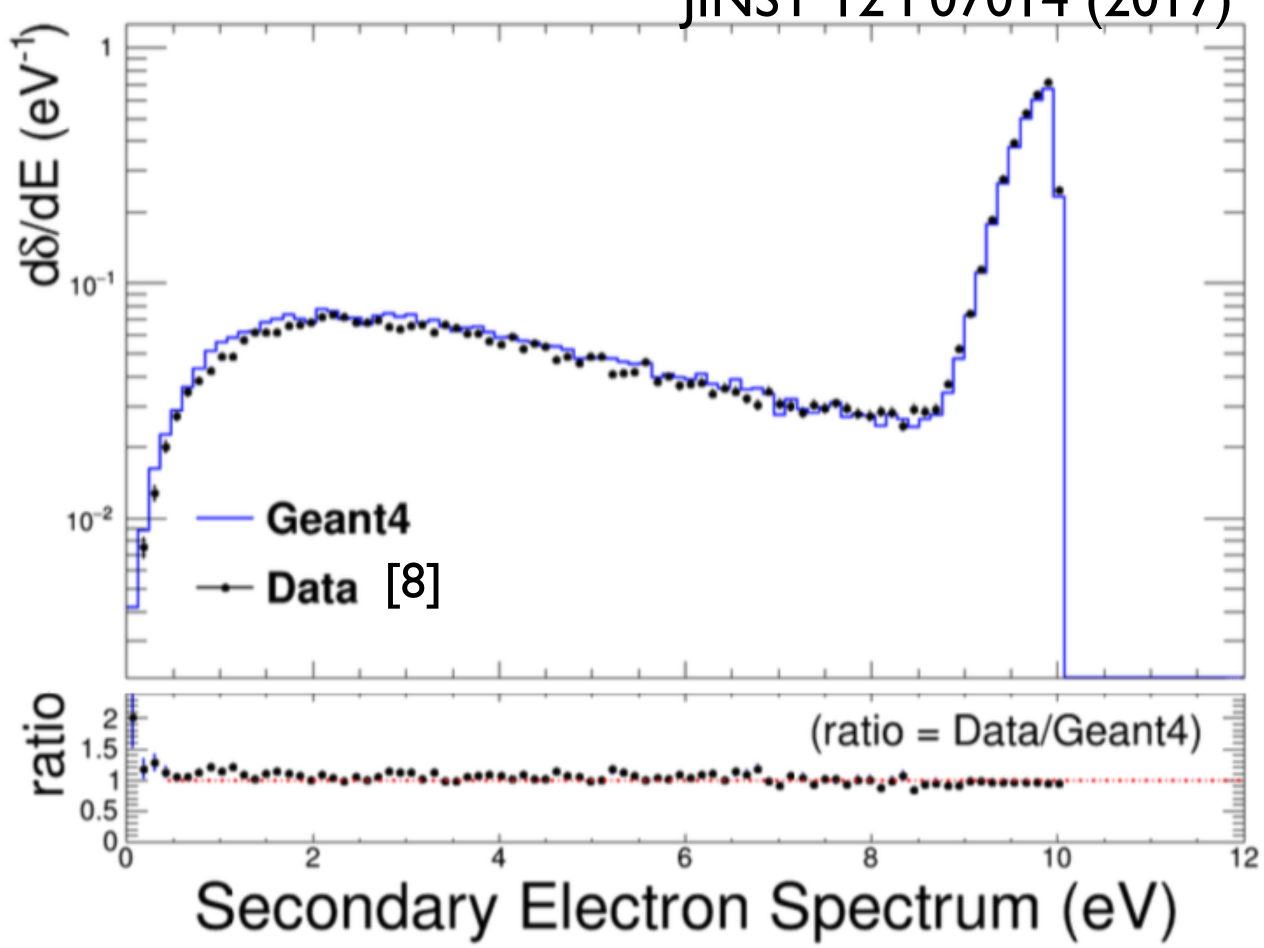
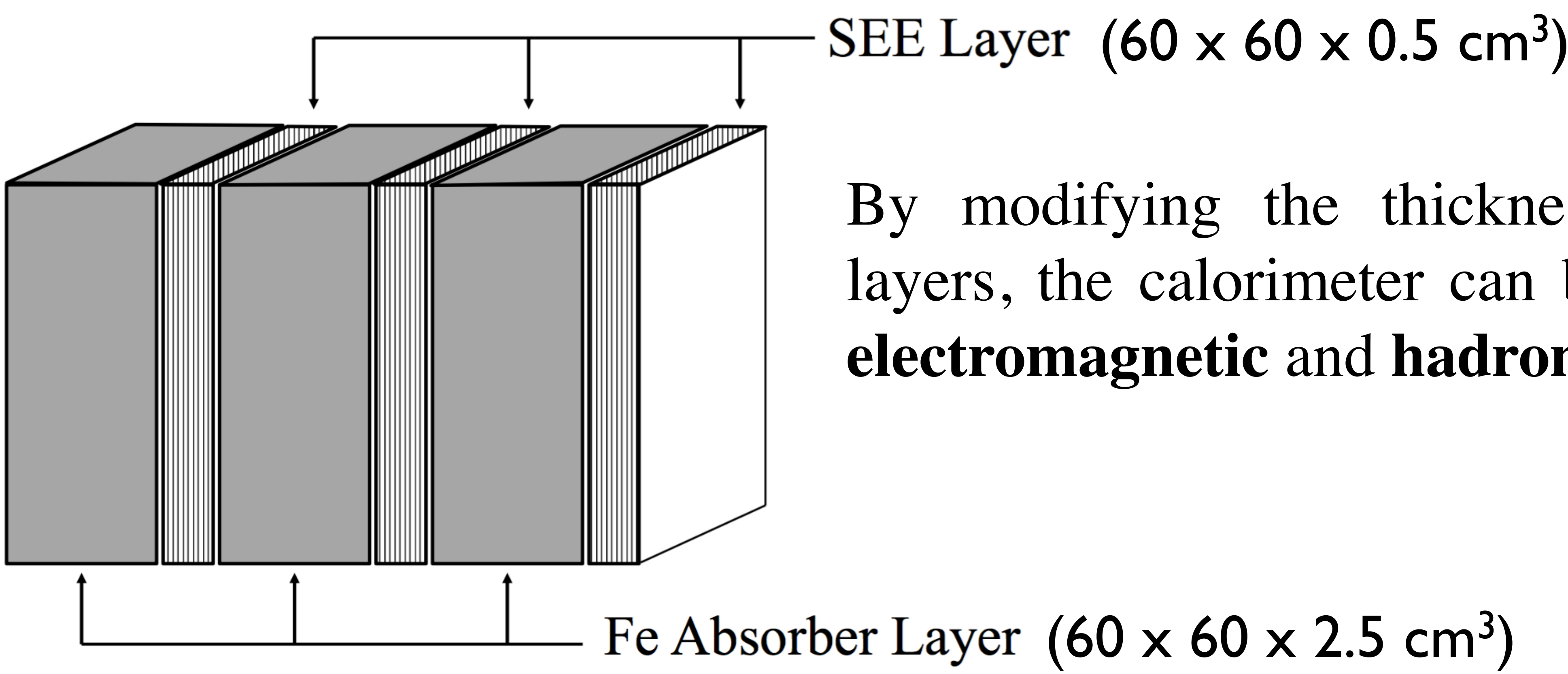


Sampling Calorimeter Simulation

Detector Geometry & Readout



By modifying the thickness of the absorber layers, the calorimeter can be designed both as **electromagnetic** and **hadronic** calorimeter

1 calorimeter module: 5 calorimeter layers (1 readout module)
1 calorimeter layer: 1 absorber layer + 1 SEE layer
1 SEE layer: 8 copper dynodes with 0.6 mm separation
Dynode thickness: 10 micron

Modularity and dimensions are chosen similar to a scintillation sampling calorimeter as in [9].

Geant4 - Results for EM Showers

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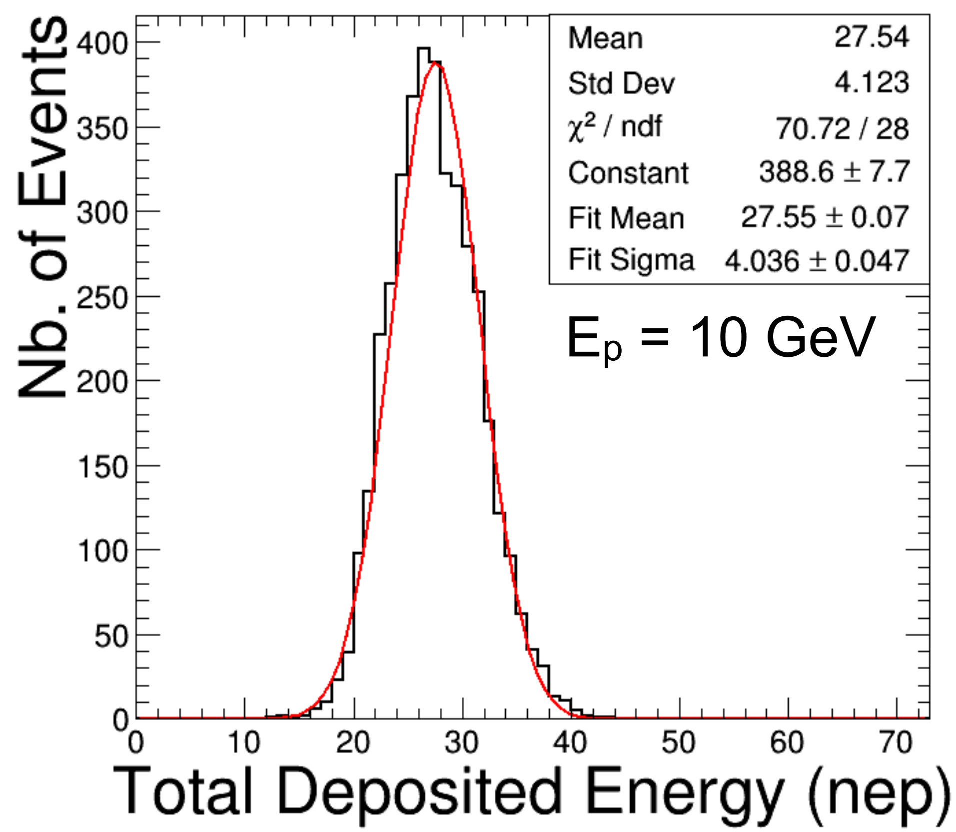

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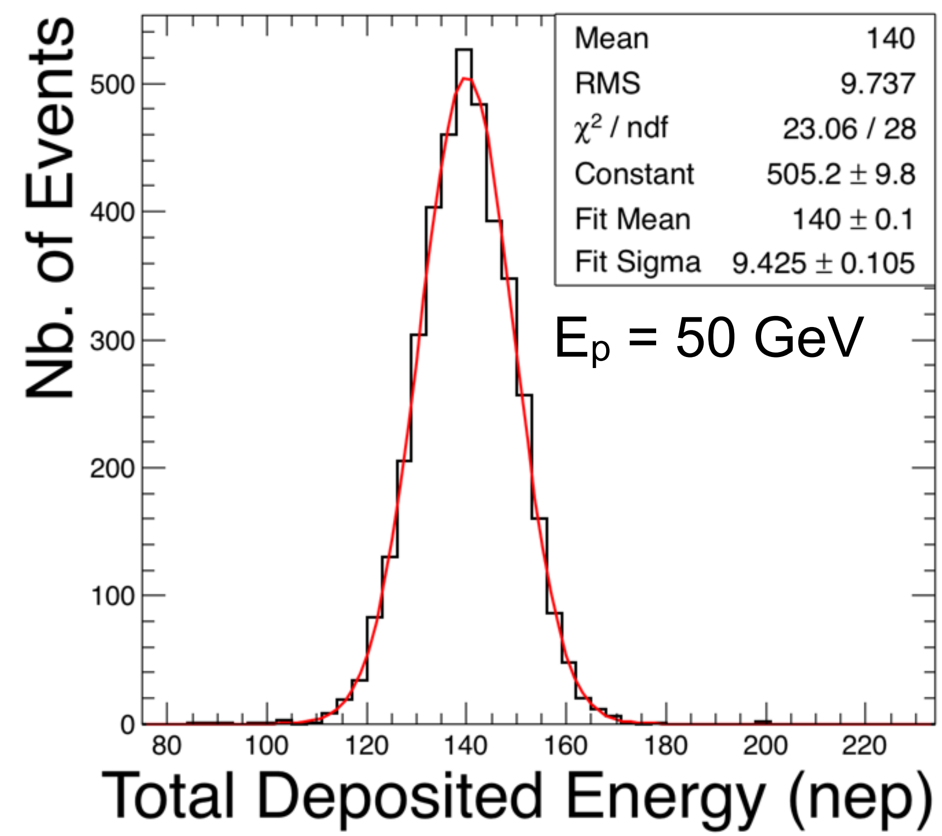
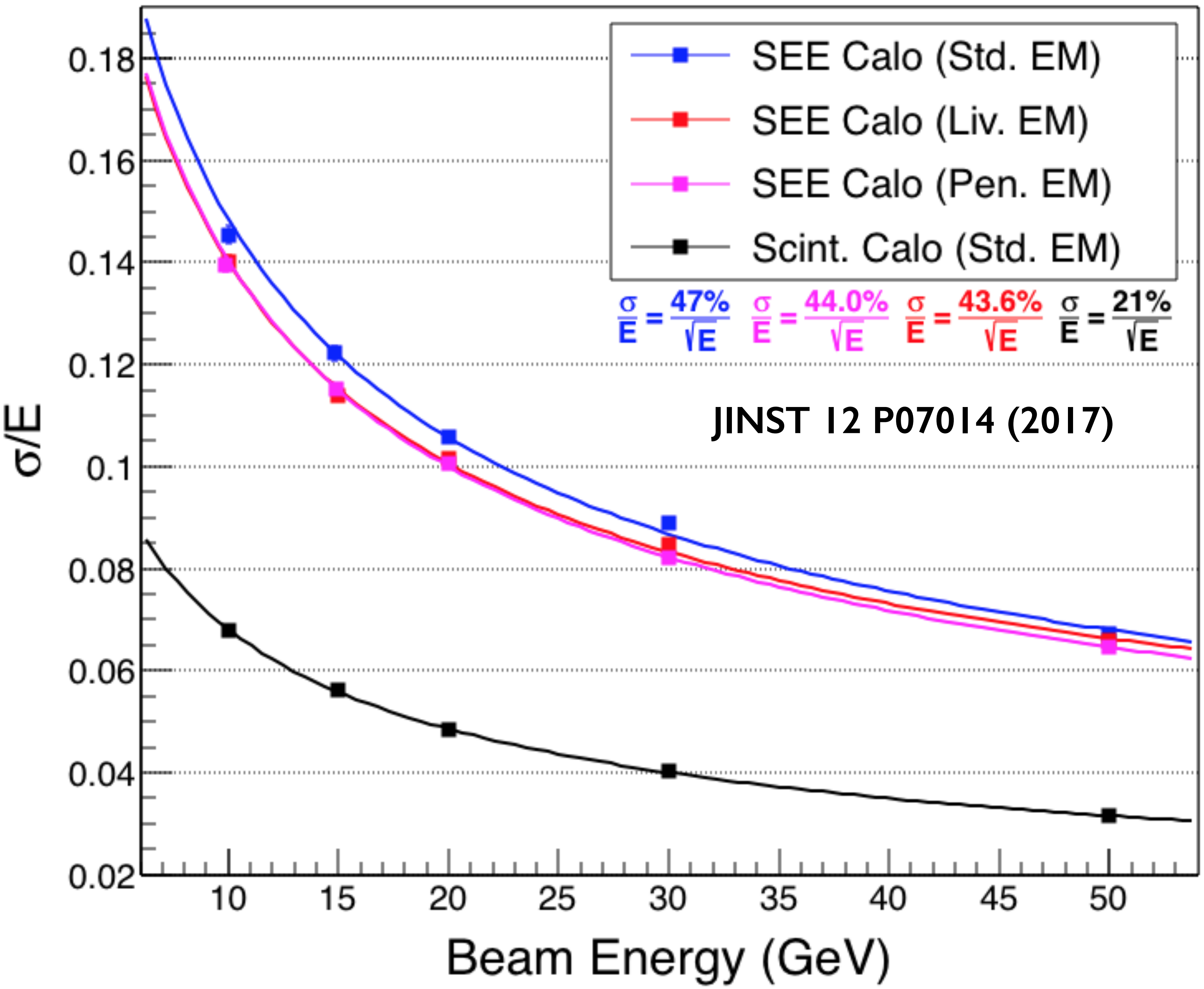


nep: number of equivalent particles (10 GeV muon)

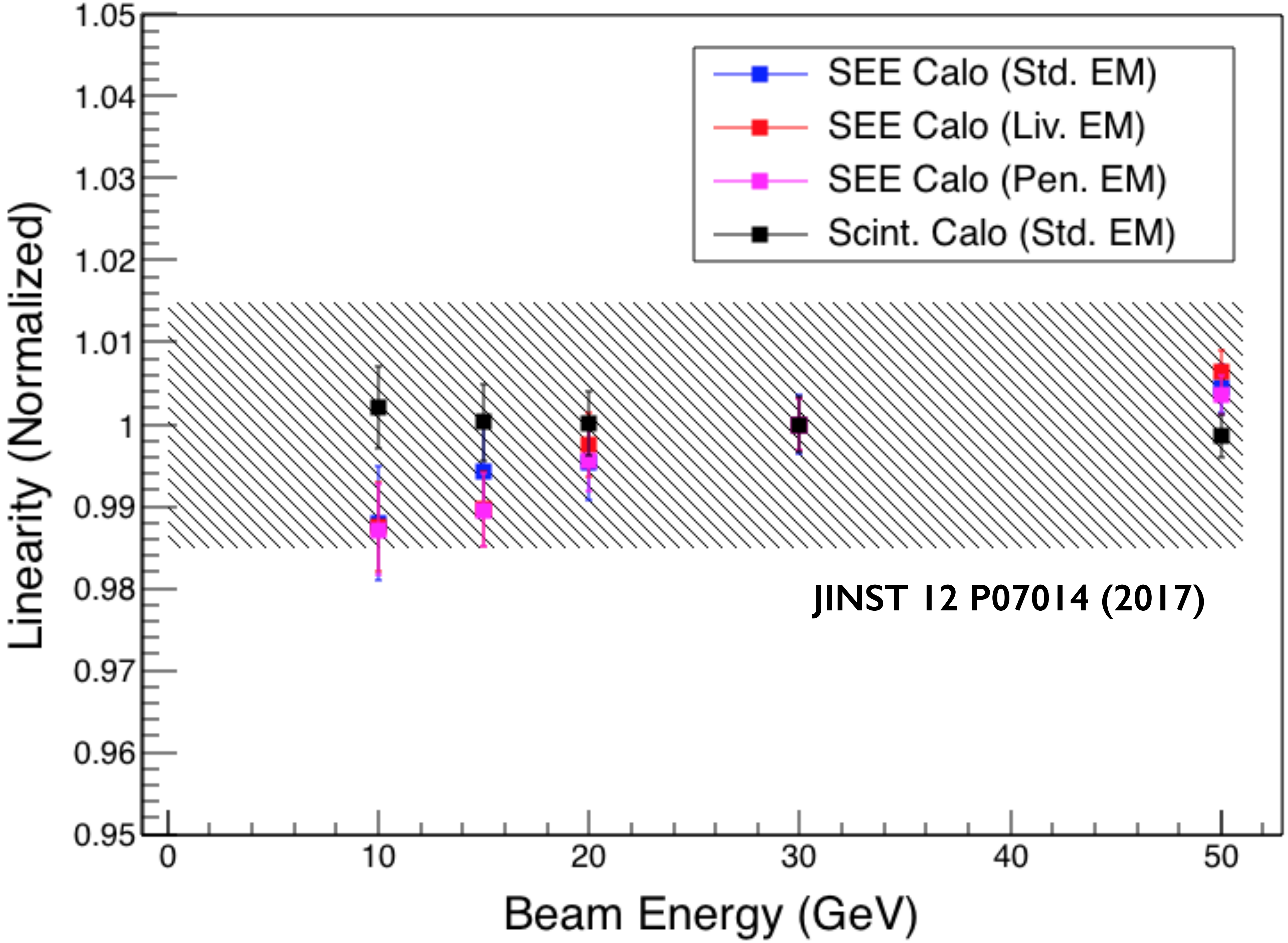
E (GeV)	SEE Calo.			Scintillator Calo.		
	mean	σ	σ/mean	mean (*)	σ (*)	σ/mean (*)
10	27.55±0.07	4.04±0.05	0.146	57.07±0.05 (55.8±0.3)	3.86±0.04 (4.5±0.3)	0.067 (0.080)
15	41.59±0.08	5.05±0.06	0.121	85.45±0.07 (83.9±0.1)	4.80±0.05 (5.3±0.1)	0.056 (0.063)
20	55.51±0.09	5.87±0.07	0.106	113.91±0.08 (114.1±0.2)	5.51±0.06 (6.3±0.2)	0.048 (0.055)
30	83.66±0.11	7.43±0.08	0.089	170.85±0.10 (169±0.5)	6.87±0.07 (7.4±0.4)	0.040 (0.44)
50	140.04±0.15	9.42±0.10	0.067	284.32±0.13 (281±1.0)	8.95±0.09 (7.9±0.9)	0.031 (0.028)

(*) Results from [9]

Resolution vs Energy

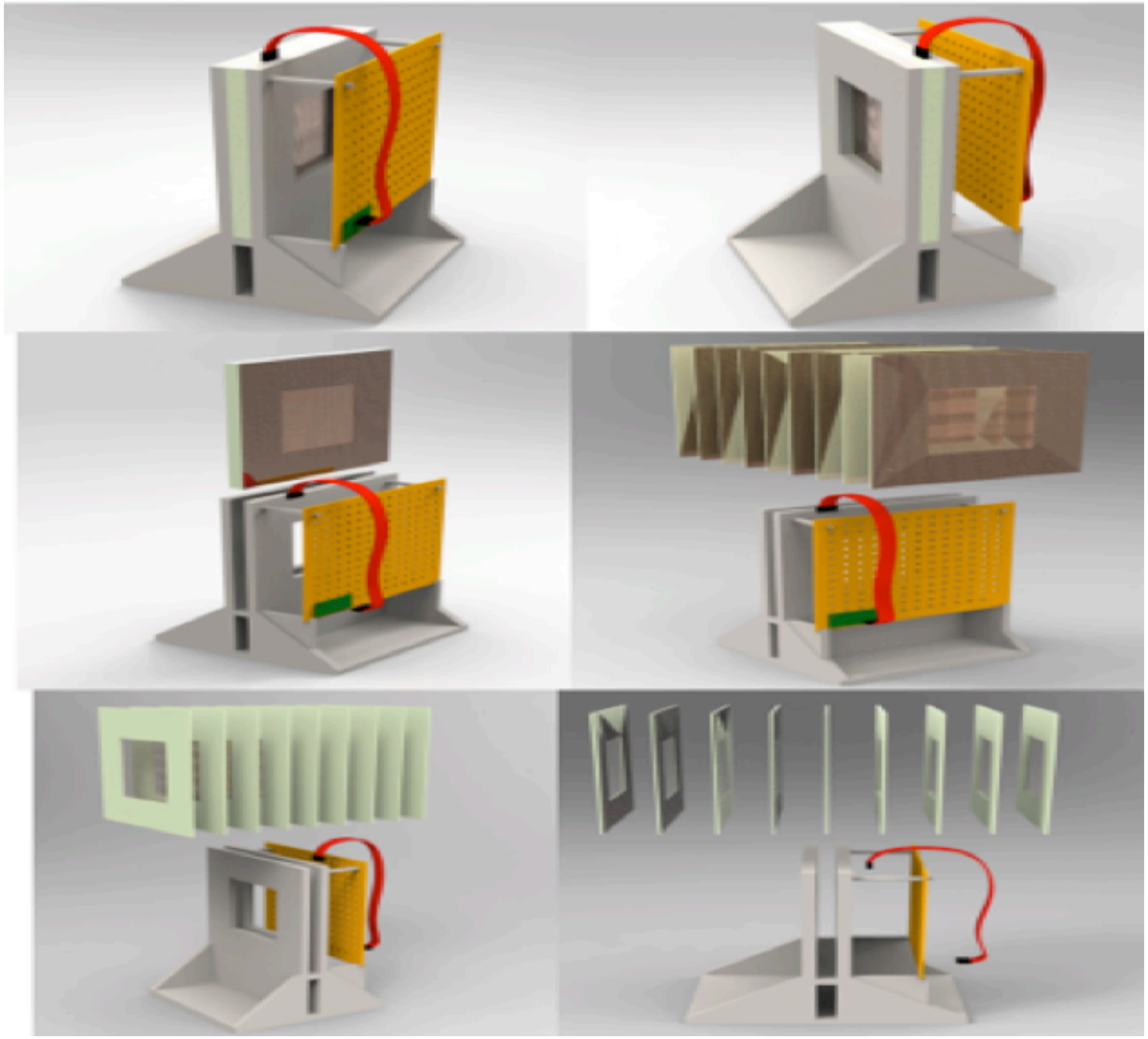


Electron Response Linearity



Building the Calorimetry

SEE Calorimeter: Prototype Design



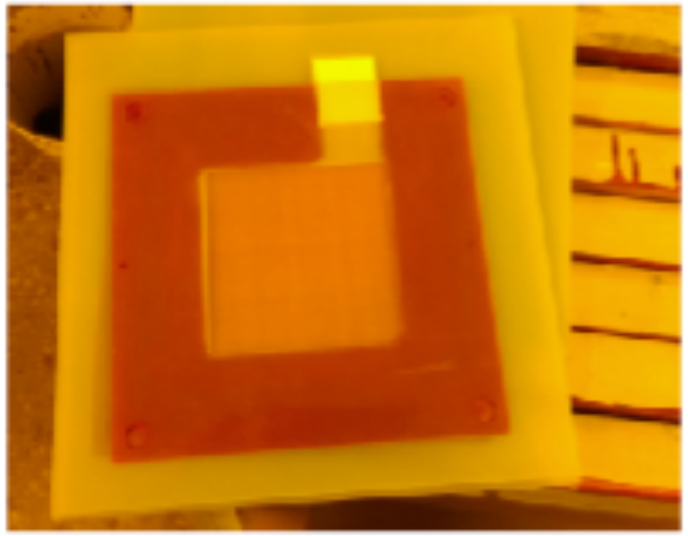
SEE Calorimeter:Building the Prototype

Preparing the mash dynodes

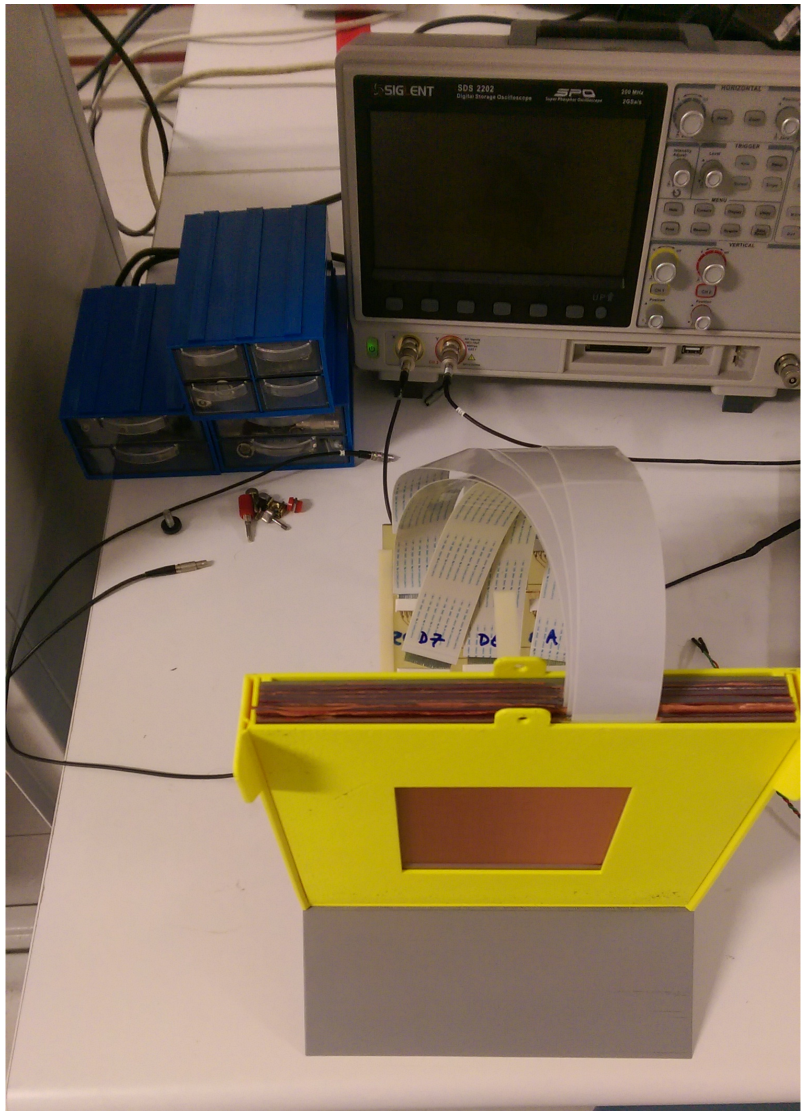
SEE Calorimeter:Building the Prototype

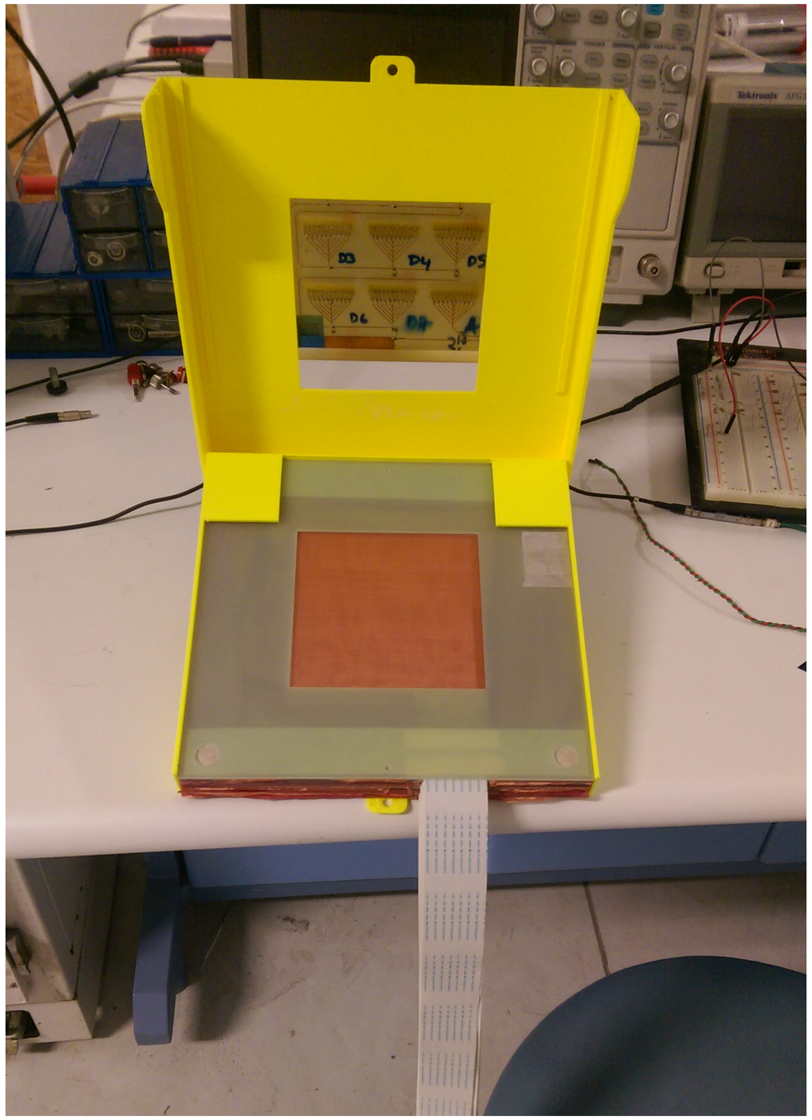
Finalizing the dynodes

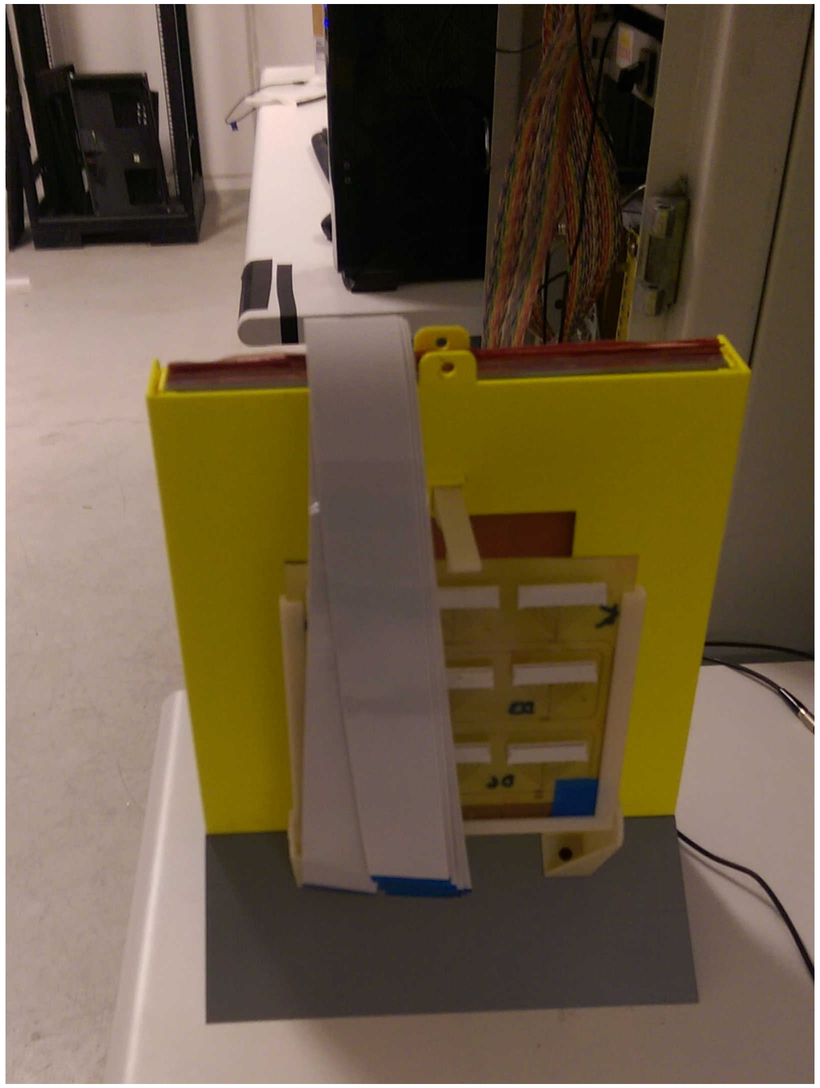


The SEE Calorimeter Module

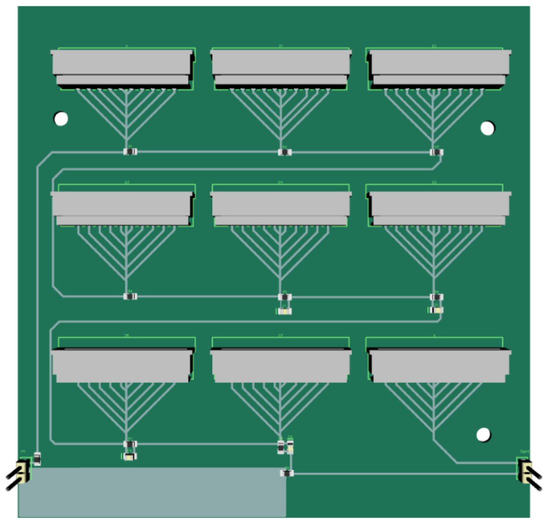


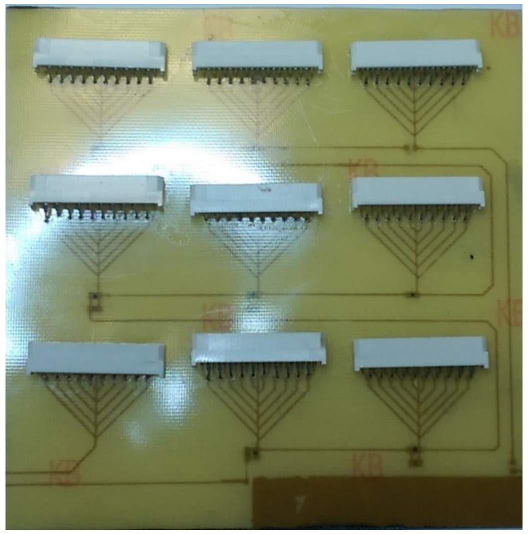




Designed SEE Readout Electronics

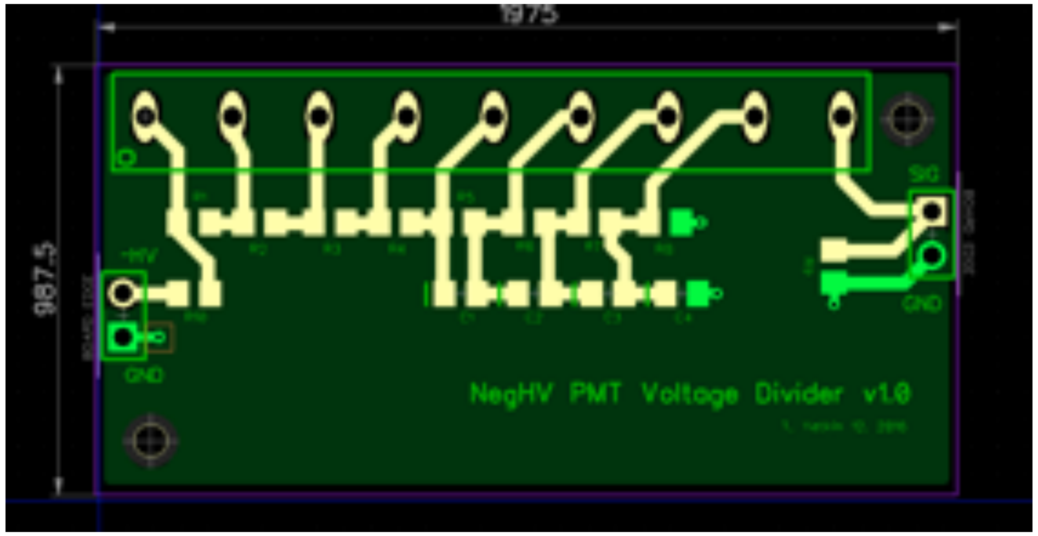
Voltage Divider used in the prototype





cables connecting
SEE layers to HV divider

Voltage Divider: a smaller version



Summary & Outlook

- ☑ We implemented a new physics process into Geant4 for SEE.
  - By using this physics process we simulated a thin foil and obtained yield and energy spectrum for secondary electrons consistent with experimental data.
- ☑ After that we simulated a sampling calorimeter based on this physics process and made comparisons with scintillation based sampling calorimeter.
  - Linearity: < 1.5% for SEE calorimeter, < 0.5% for scintillator calorimeter
  - Resolution (stochastic): 47% for SEE calorimeter, 21% for scintillator calorimeter
  - Resolution of SEE calorimeter is worse than the resolution of the scintillator calorimeter up to factor of ~2. We attribute this difference to reduced sampling fraction in the active material volume.
- ☑ We are in the process of simulating hadronic showers to evaluate SEE process for hadronic calorimeters.
- ☑ We are also developing an open source program based on ROOT for different SEE algorithms and materials published in the literature so far.
- ☑ **The prototype is ready to be tested.**

This project was supported by TUBITAK
Project Number: 113F337

References

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[6] Brianza, I., et al, NIM A, 797, (2015), 216-221

[7] L. Austin, H. Stark, Annalen der Physik 314.10, (1902), 271-292

[8] DOI:10.1103/PhysRevSTAB.5.1 24404

[9] Abramowicz. H. , et al, Nucl. Inst. Meth., 180 (1981) pg. 429

Backup

Backup: Semi-Empirical Models

- Since the discovery of secondary emission of electrons from metal surfaces, there has been many approaches to quantify this process by using semi-empirical models, including Monte Carlo studies. Some of them are

  - A. A Schultz and M. A. Pomerantz (Phys. Rev. Sec. Ser., 130, 6, (1963), 2135-2141)

$$\delta = \epsilon^{-1}\left(\frac{dE}{dx}\right)\Delta x \sec\theta$$

  - J. J. Scholtz et.all (Phillips J. Res., 50, (1996), 375- 389)

$$\delta = B\frac{E_p}{\Omega R}(1 - e^{-\alpha R})/\alpha$$

  - A. Shih et.all (Applied Surface Science 111 (1997) 251-258)

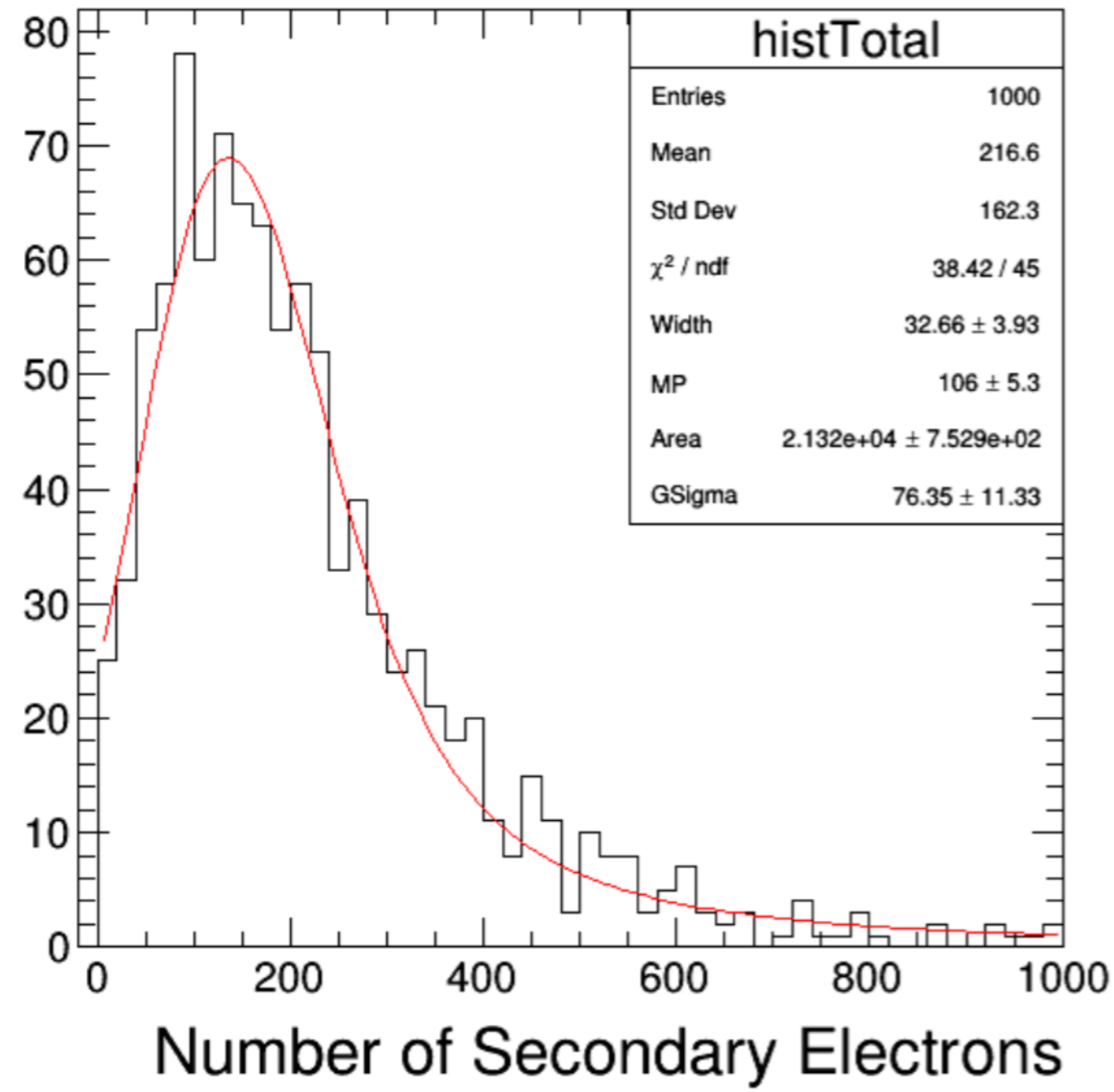
$$\delta(x) = \left(\frac{A}{2}\right)^{\frac{1}{n+1}}\frac{1}{B(R-x)^{\frac{n}{n+1}}}$$

  - D. Kramer et.all. (Nuclear Physics B (Proc. Suppl.) 172 (2007) 246–249)

$$\delta = 0.01 C_F L_S \left(\frac{dE}{dx}\right)_{el}$$

Energy Calibration

- The experimental study in [9] uses 10 GeV muons to obtain absolute calibration, where energy is quoted in number of muon equivalent energy-npe.
- Our results are given with the same calibration method.



example muon signal in SEE calorimeter