Secondary Emission Calorimetry

Burak Bilki

CPAD Instrumentation Frontier Meeting
October 5-7, 2015
University of Texas at Arlington

Outline

- The concept of Secondary Emission Calorimetry
- Secondary Emission modules
- Beam test results of first prototypes
- MCPs as secondary emitters
- Possible implementations

Why Secondary Emission Ionization Calorimeters? - I

- Secondary Emission (SE) signal originates from SE surfaces inside electromagnetic/hadronic showers:
  - SEe^- yield (δ) scales with particle momentum
  - e^-: $3 < \delta < 100$, per $0.05 < E < 100$ keV (material dependent)
  - $\delta \sim 0.05 - 0.1$ SEe^- per MIP
- SE is rad-hard and fast
  - a) Metal-Oxide SE PMT Dynodes survive > 100 GigaRad
  - b) SE Beam Monitors survive 10^{20} MIPs/cm^2

Why Secondary Emission Ionization Calorimeters? - II

Example: ~60-240 SEe^- per 100 GeV pion shower w/ MIPs alone

Normally the secondary electrons are subsequently amplified by a set of dynodes to a suitable level for data acquisition.

➔ The SEe are treated exactly like PEs in a scintillator calorimeter.

In a scintillator calorimeter, many photons are created, but typically 0.1-1% are collected and converted to PEs by a PMT or SiPM. By contrast, in an SE calorimeter, relatively few SEe are created, but almost all are collected and amplified by the dynode stacks.

A set of SE cathodes and dynodes (SE sensors) may serve as active media in a sampling calorimeter.

Secondary Emission Sensor Modules

The SE sensor modules need to have sufficiently large areas of dynode to uniformly sense the charged shower particles. Such large and uniform dynodes include electrochemically etched, micromachined or laser-cut metal mesh dynode sheets.

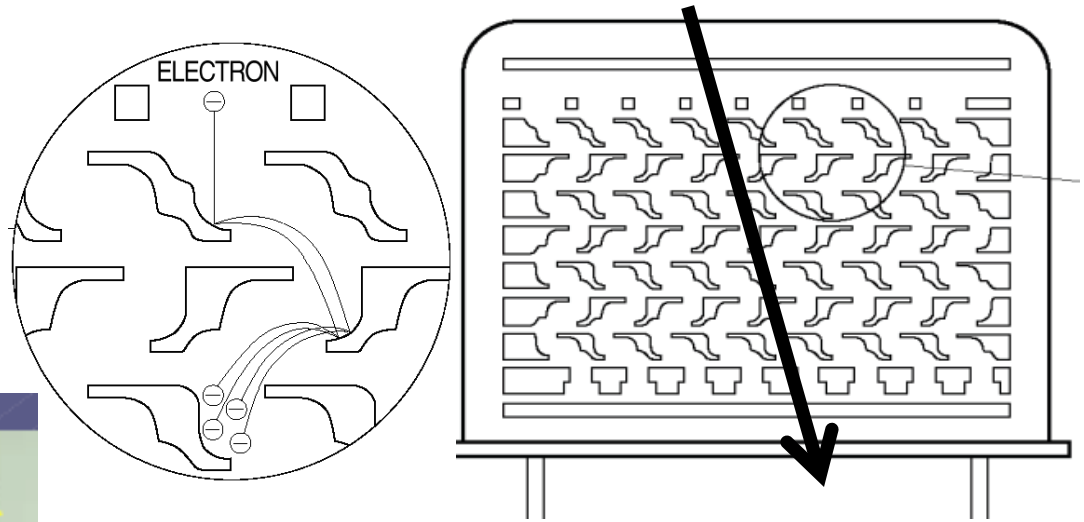
The construction is far easier than a PMT since the entire final assembly can be done in air. There are no critical controlled thin film depositions nor vacuum activation. The module is sealed by welding or brazing or other high temperature joinings with a simple final heated vacuum pump-out and tip-off.

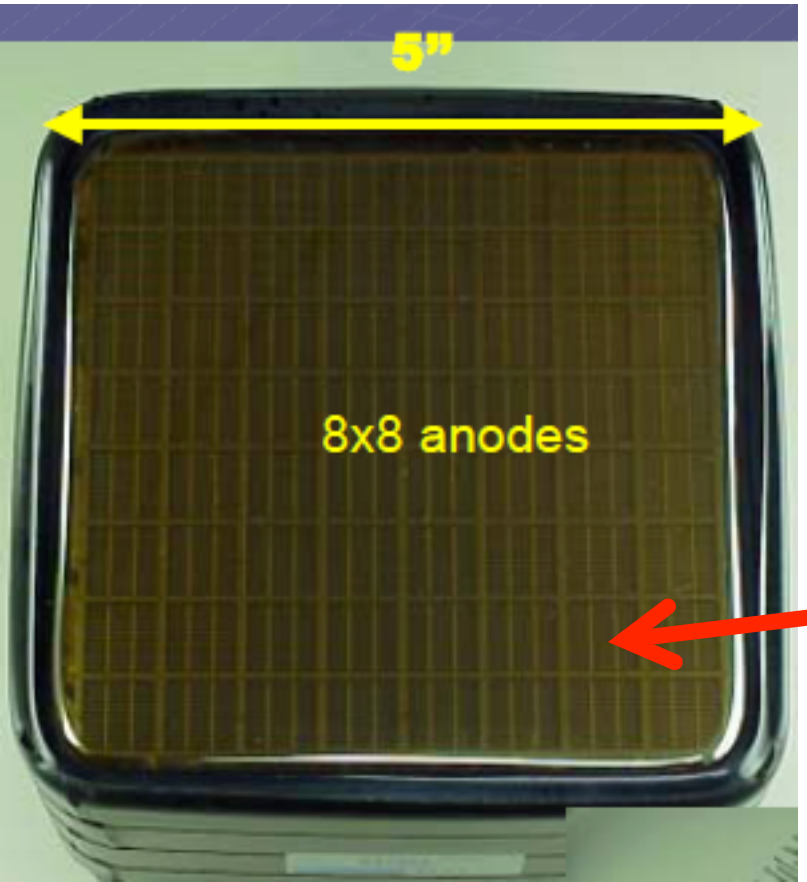
The modules envisioned are compact, high gain, high speed, exceptionally radiation damage resistant and cost effective.

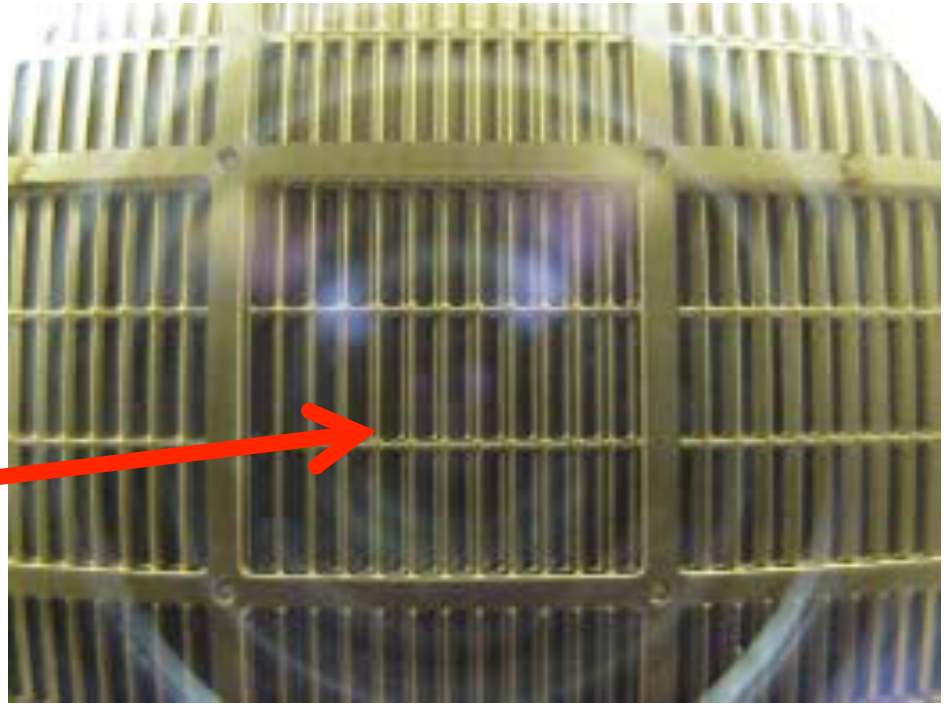
The SE sensor module anodes can be segmented transversely to sizes that are appropriate to reconstruct electromagnetic cores with high precision.

SE Dynodes: a) Etched Metal Sheets

Hamamatsu Dynodes
15 cm now → ~50 cm
Already diced from large sheets

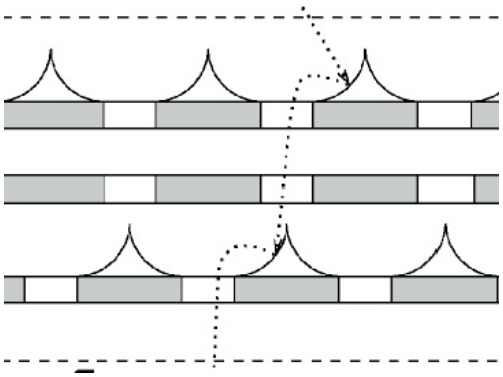


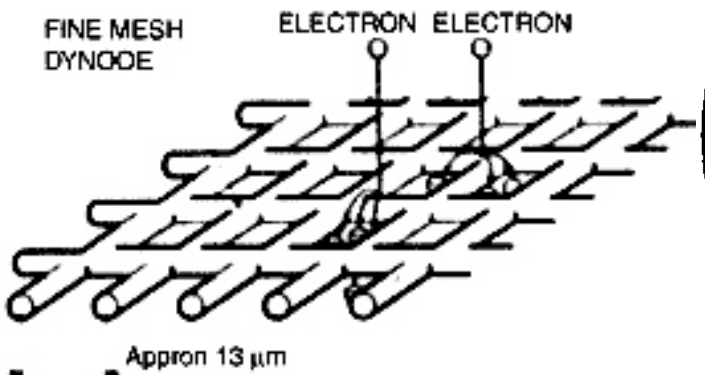


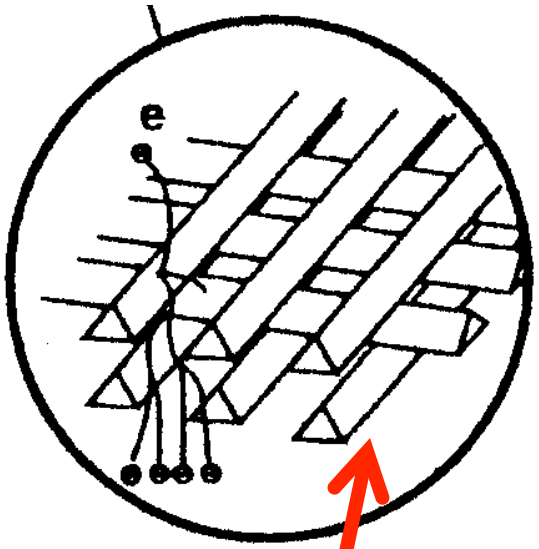


SE Dynodes: b) Metal Screen Dynodes: 15D - g~10^5

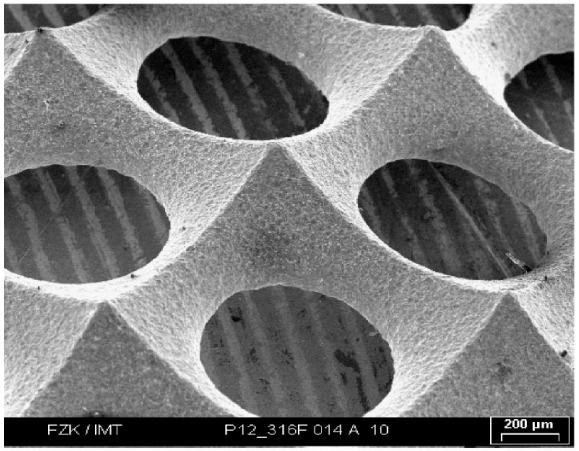
MESH DYNODE VARIANTS



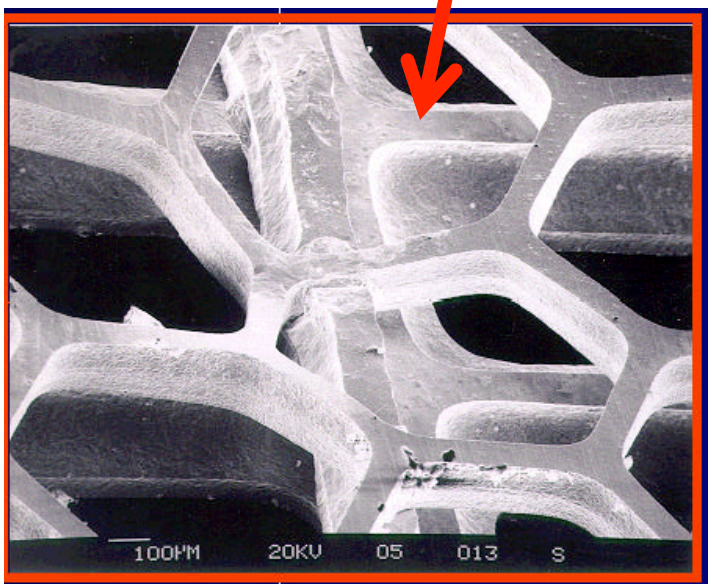




D_n-D_{n+1}: 0.9 mm
C-C mesh: 13 µm
Wire diameter: 5 µm



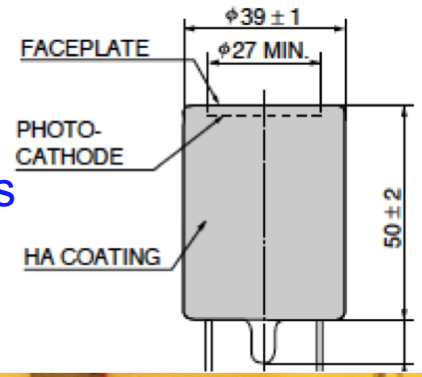
0.4mm



Beam Tests of SE Sensor

CERN SPS, Oct. 2011

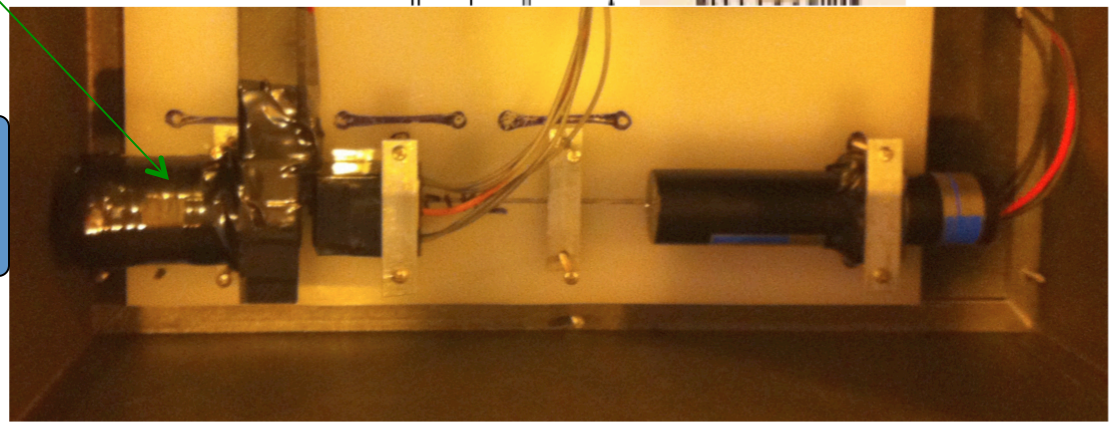
Mesh PMT and Base
Facing Downstream
Photocathode Reverse Bias
or turned off



19 Stage Mesh

3 cm Pb

100 GeV e-



The Hamamatsu 19 stage mesh PMT used in the test beam at CERN – on left in the phototube test box in the beam line. Muons and 100 GeV electrons hitting 3 cm of Pb radiator were sent in on the left. The photocathode was completely disabled by using a +HV base, operating the anode at ~ +2KV, D1 at ground, and the photocathode at small positive voltages or connected to ground through 400kOhms.

We Expect ~500 Shower electrons to Cross Mesh

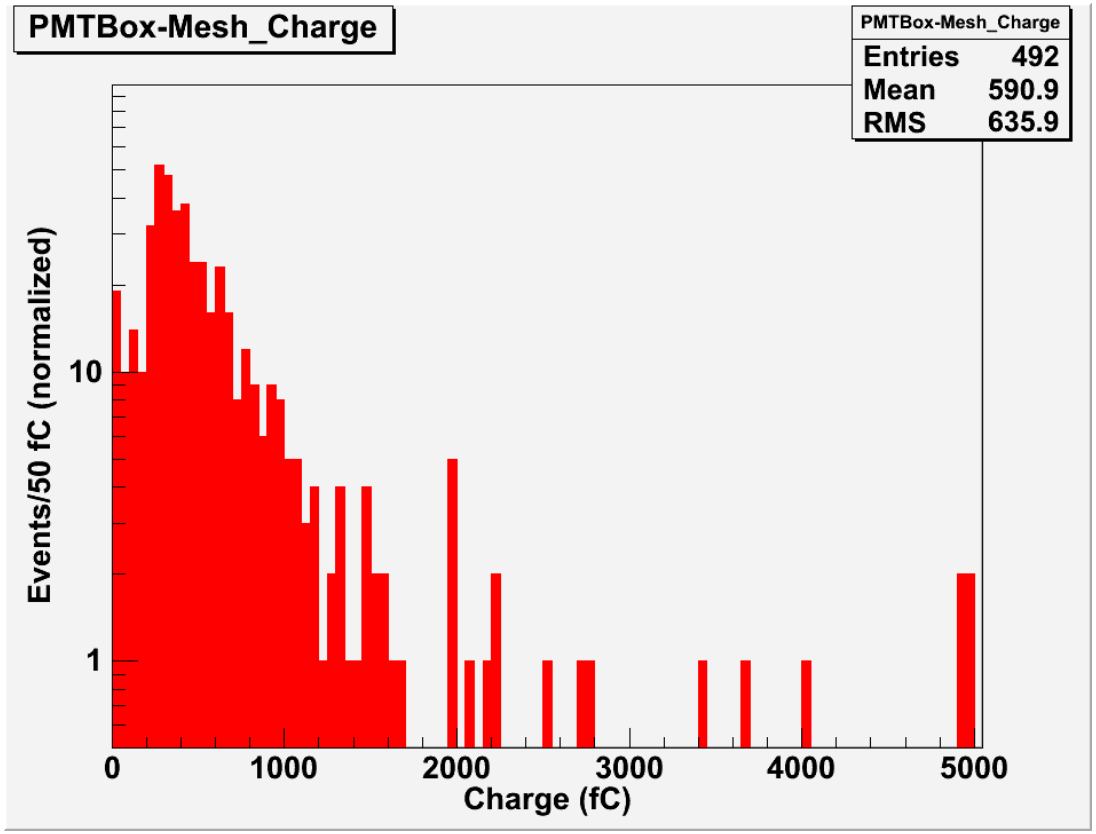
→ ~25-50 SEe **assuming all shower e = MIPs**

BEAM TEST: 100 GeV electrons

3 cm Pb ~ 5 X_0 Radiator ~ Shower Max

Mesh PMT w/ photocathode turned off and downstream

CERN SPS, Oct. 2011



PRELIMINARY!

Fluctuations High!

- PMT Dia ~ Shower Dia
- Beam not centered

NOTE μ MIP:
Detection Eff ~10%
Response ~1-2 "SEe"

Peak corresponds to ~40 SE electrons

SE Module Beam Test

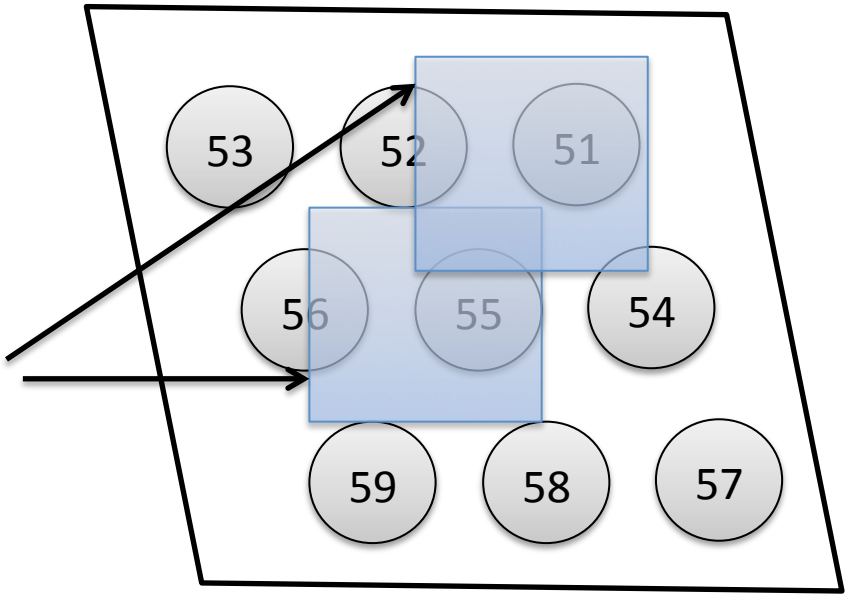
Using mesh dynodes from PMTs

CERN SPS, Nov. 2012

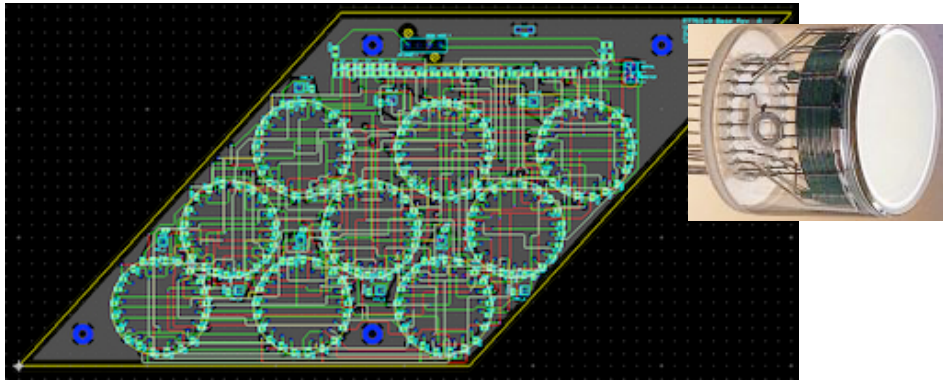
Beam position
(into the page)

2 datasets

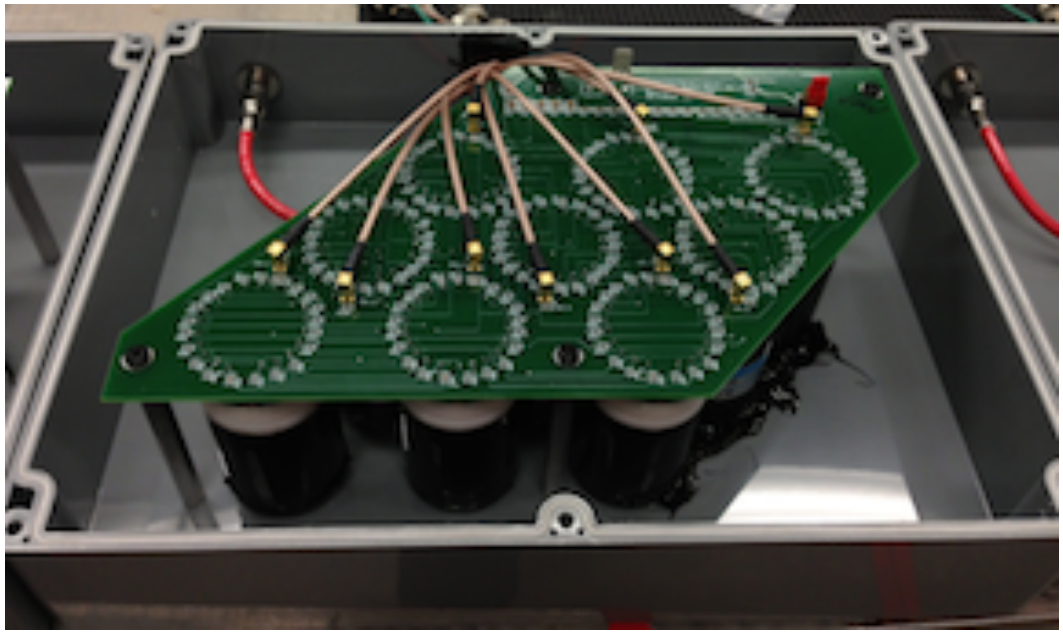
Selected with
Wire Chamber



51, … , 59: PMT IDs

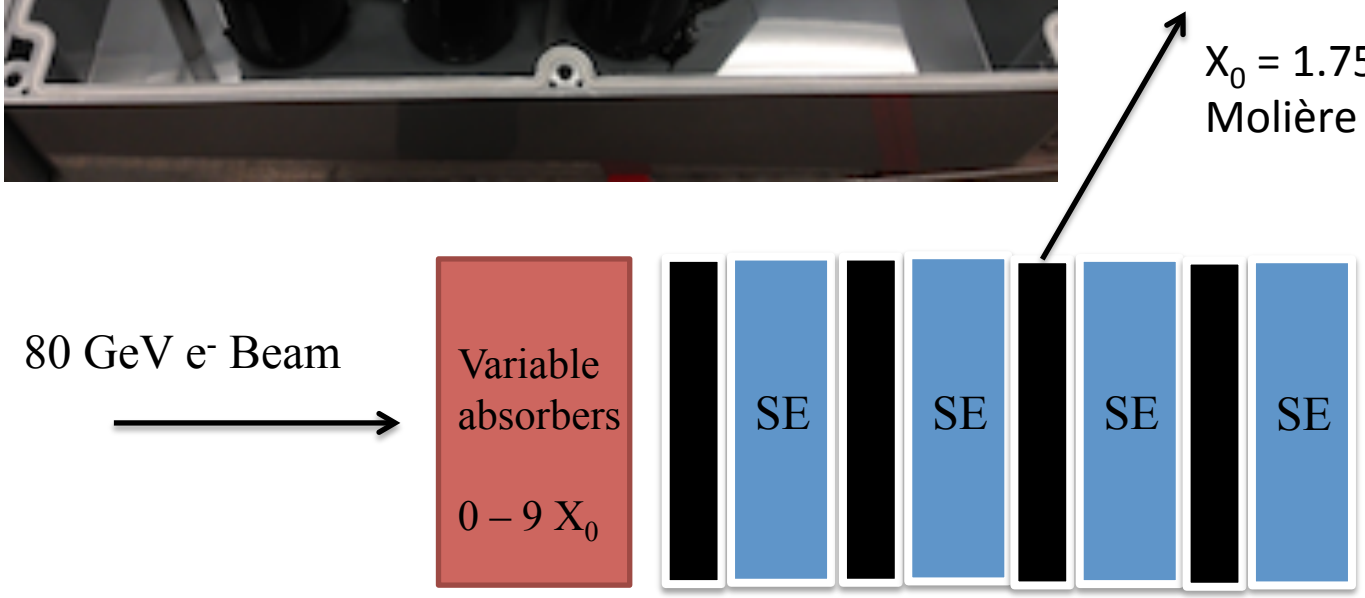


SE Module Beam Test



2-cm iron absorbers:

X_0 = 1.75 cm
Molière Radius: 1.72 cm



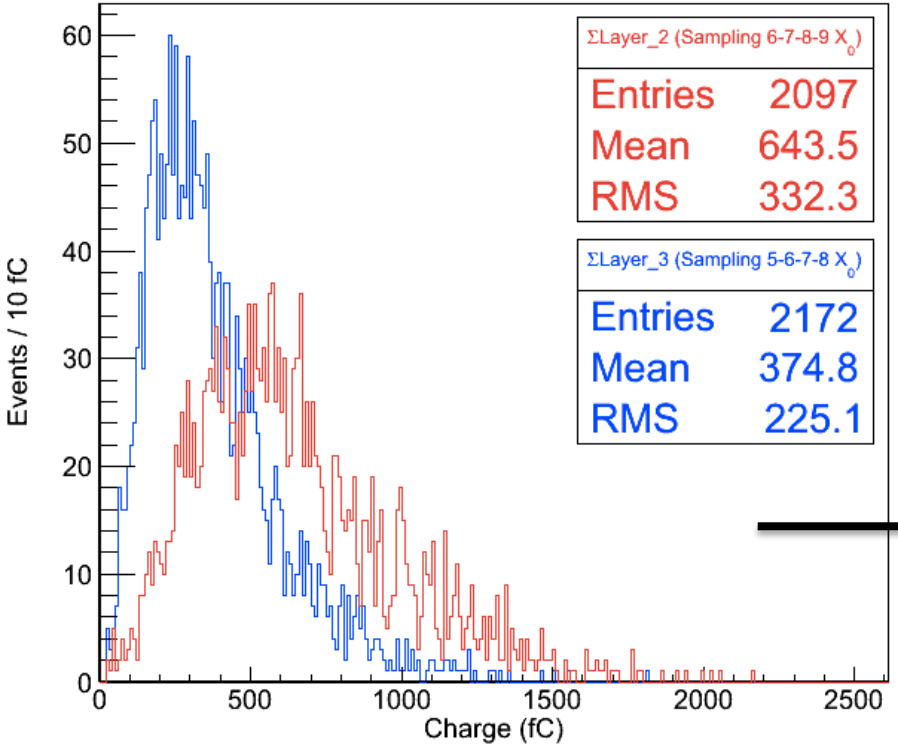
Shower not contained laterally or longitudinally
→ Results require estimates and approximations

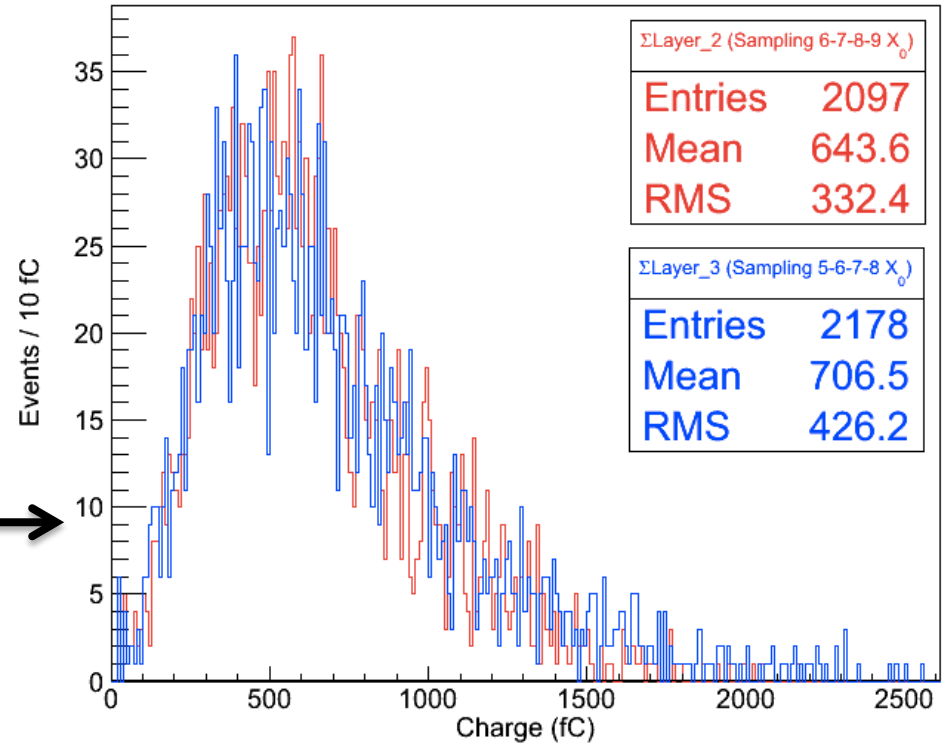
SE Module Tests – Preliminary Results

Normalizing responses of different layers

Example: Normalization of Layer 3 response to Layer 2 response using $7X_0$ sampling

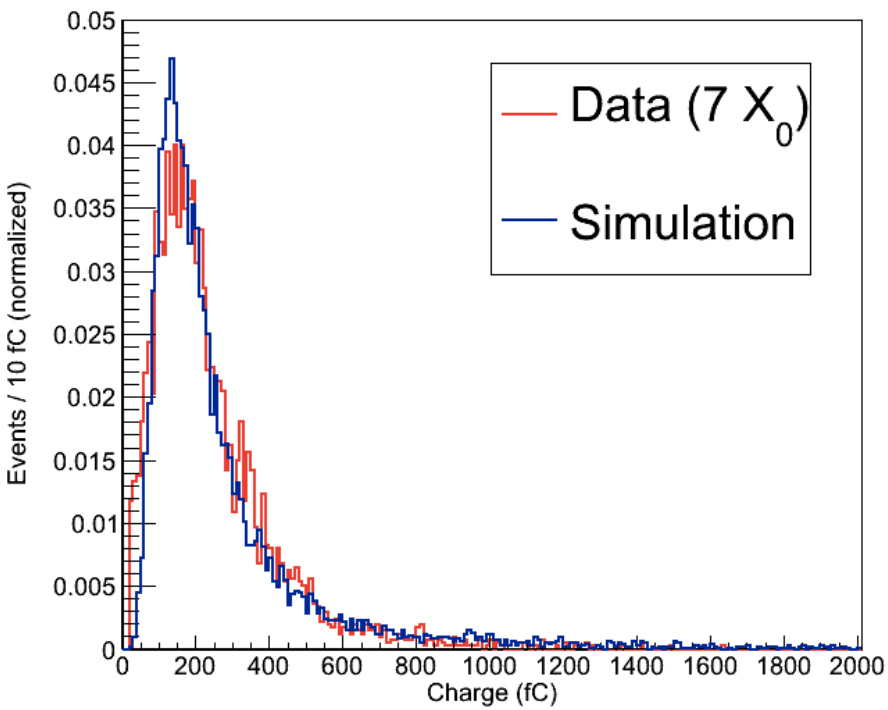
(Also works in the reverse order → next slide)

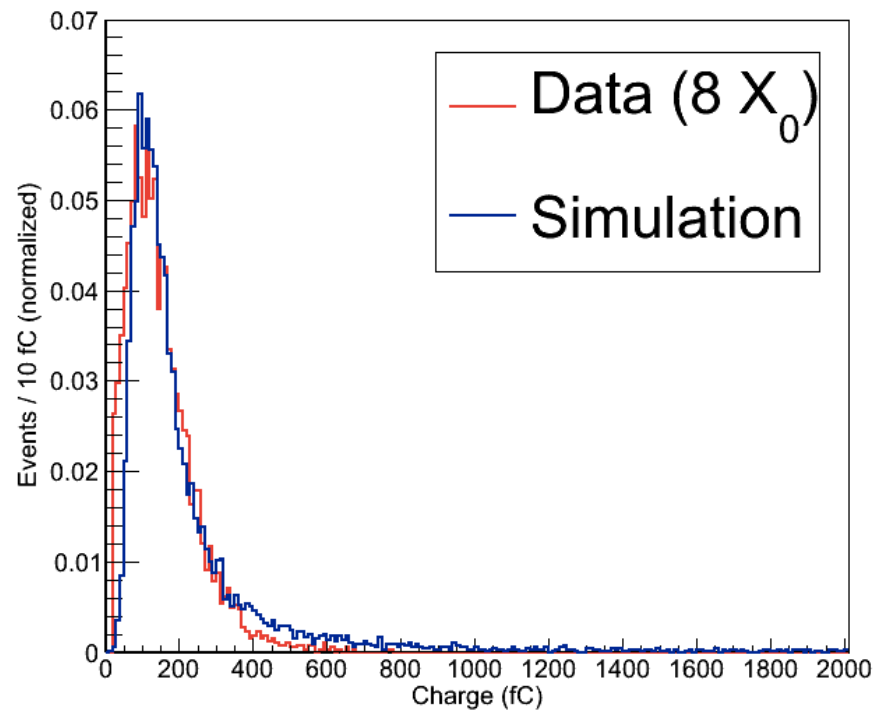




Charge > 20 fC

SE Module Simulation

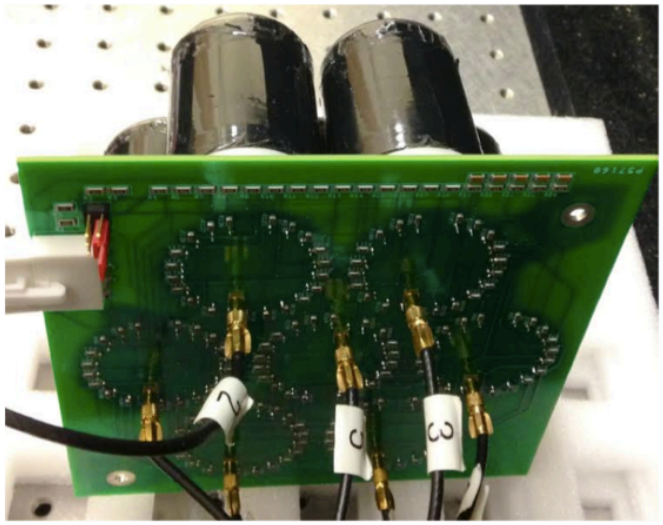


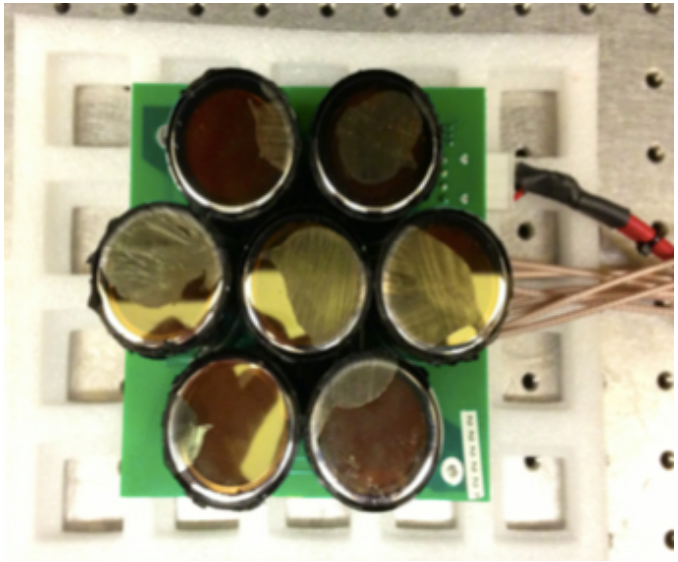


Geant4 simulation of the SE module test beam setup:
80 GeV e^- beam
19 stage mesh dynodes generate SE electrons (dynodes ~ sheets)
Gain is simulated offline (10^6)
Landau fluctuations are implemented offline

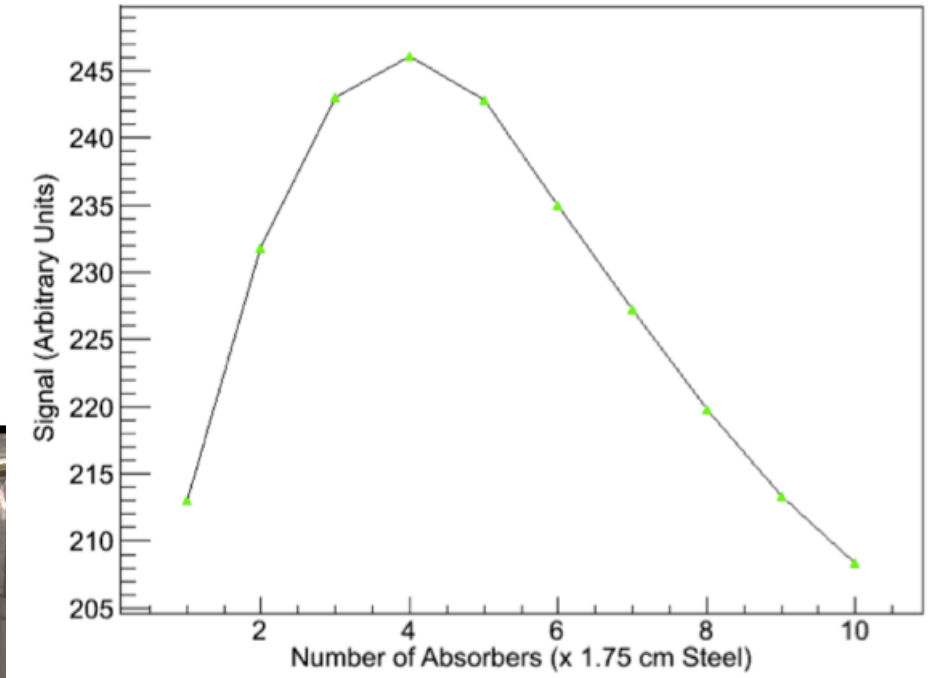
Second Generation SE Module - I

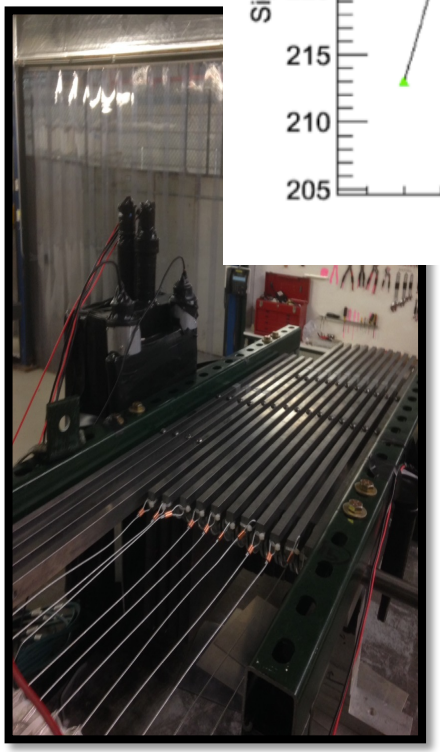
7 closest-packed PMTs with photocathodes turned off





4 GeV shower profile





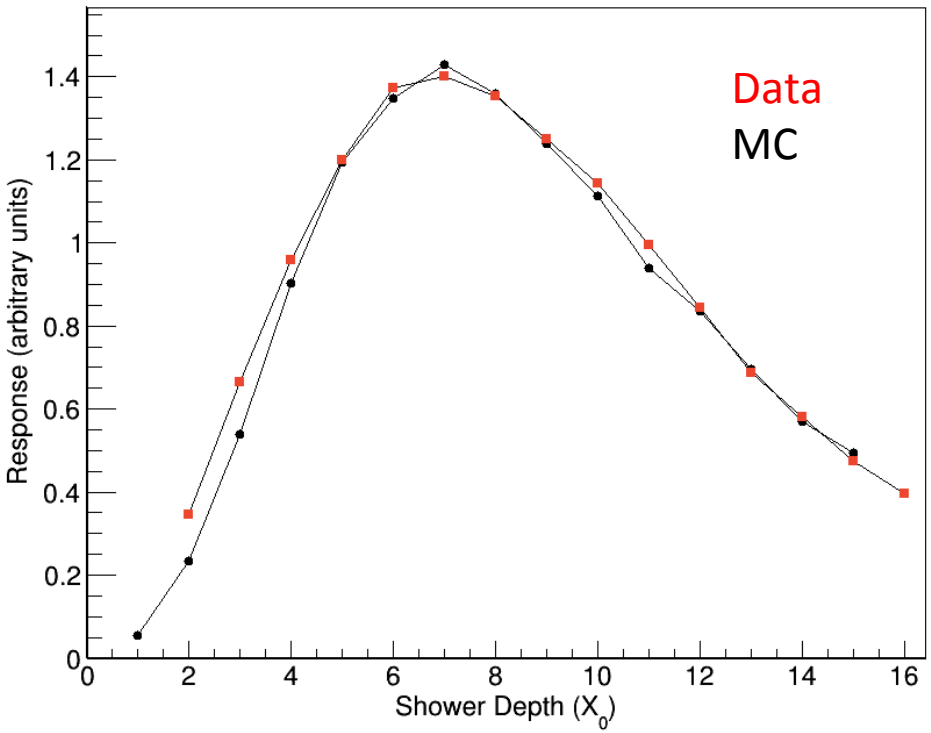
20 cm x 20 cm x 1.75 cm steel absorbers

Second Generation SE Module - II

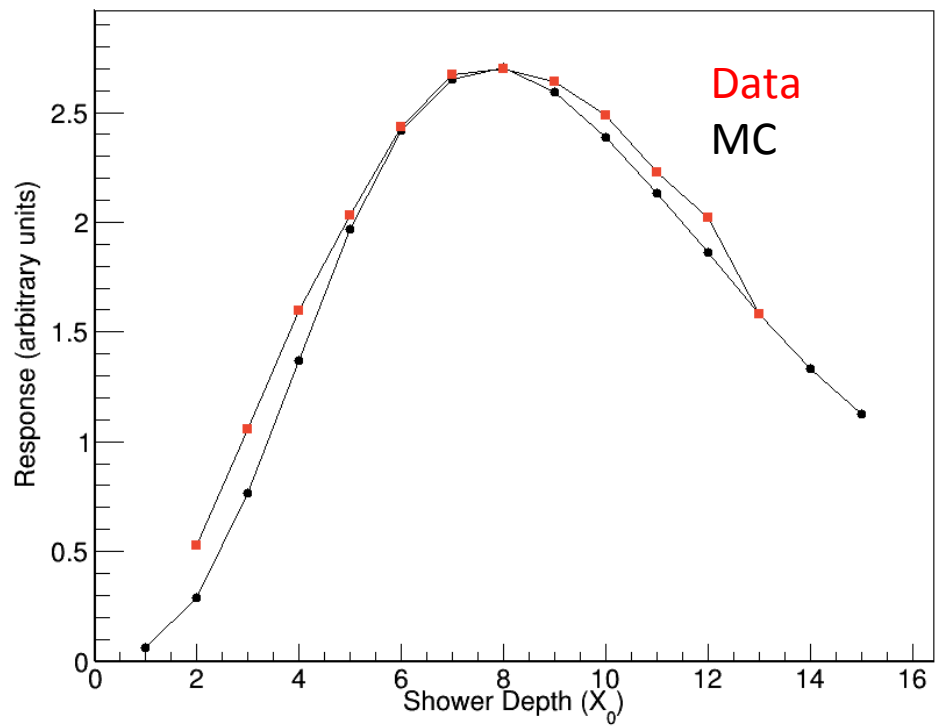
Tests with single SE sensor and up to 15 3 cm x 3 cm x 0.35 cm W plates

Data taken with wire chamber i.e. the leakage is a bit more under control (but still there)

8 GeV shower profile



16 GeV shower profile



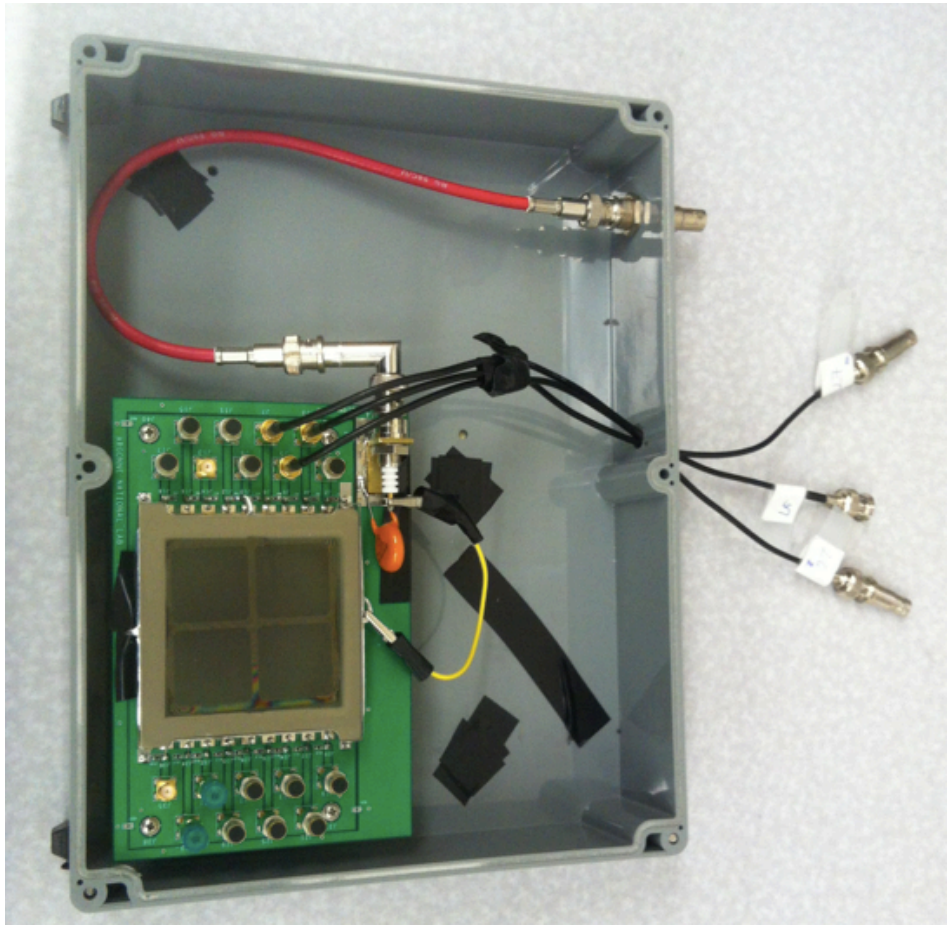
MCPs As Secondary Emitters

- Should work effectively
- Have simpler design
- Should be very fast

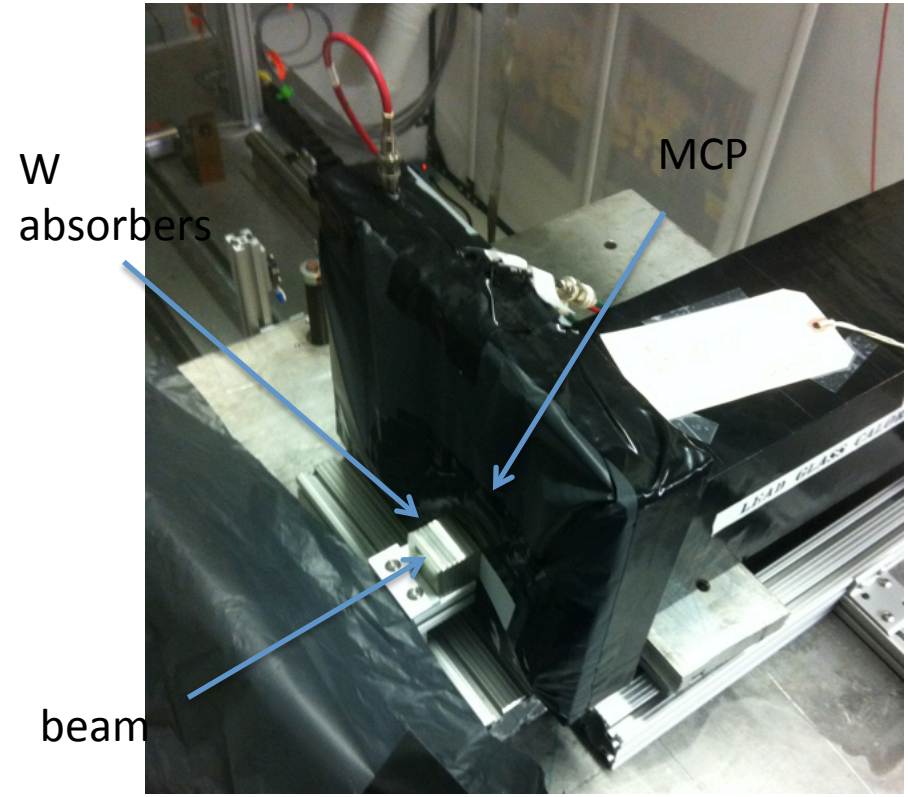
Previously studied by A. Rhonzin et.al. and currently by Fermilab and Caltech (next talk).

No dedicated SE test module yet. But…

We had the Argonne LAPPD (Large Area Picosecond PhotoDetector) MCP to study some (very) preliminaries.

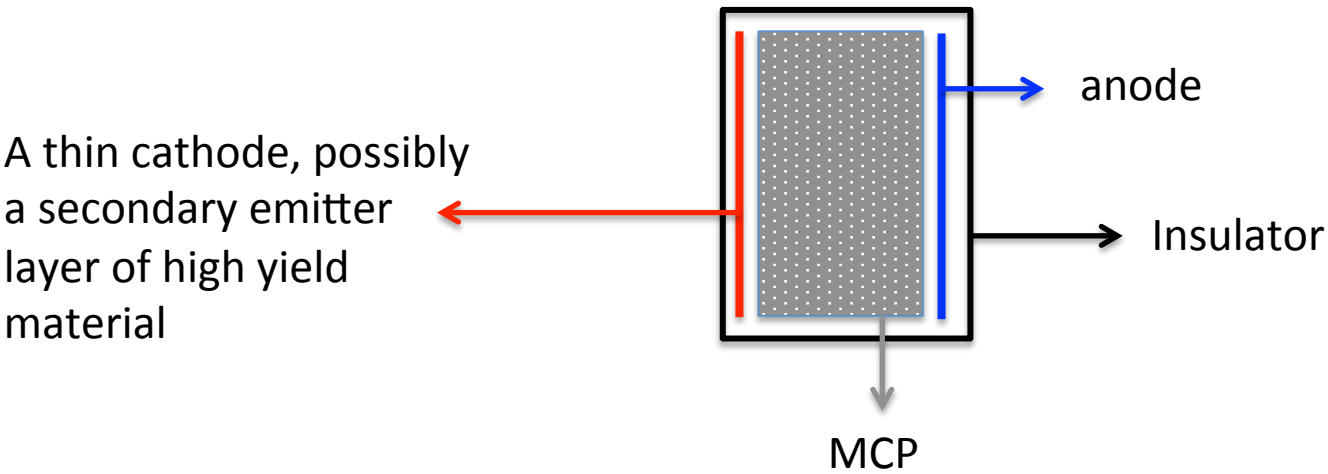


Fermilab test beam Nov 12-18 2014



Secondary Emission (SE) Calorimetry with MCPs

Ideal SE module utilizing MCPs



Argonne MCP comes as a complete photodetector box with a relatively thick glass window. Newer production allows the turning off of the photocathode.

➔ Nevertheless, it is worth trying it as a secondary emission module
→ a reasonable shower profile is an indicator of potential performance.

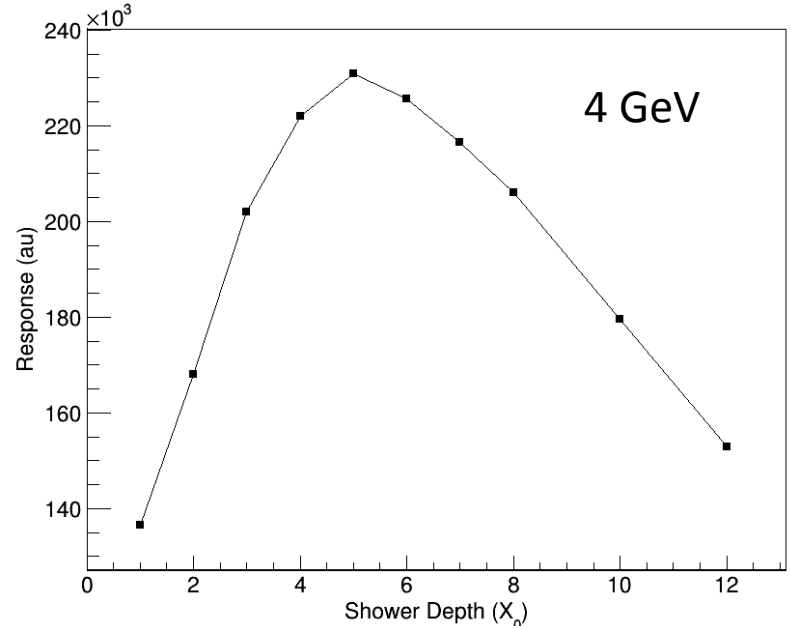
Secondary Emission (SE) Calorimetry with MCPs

Tested the LAPPD with up to 12 3 cm x 3 cm x 0.35 cm W plates

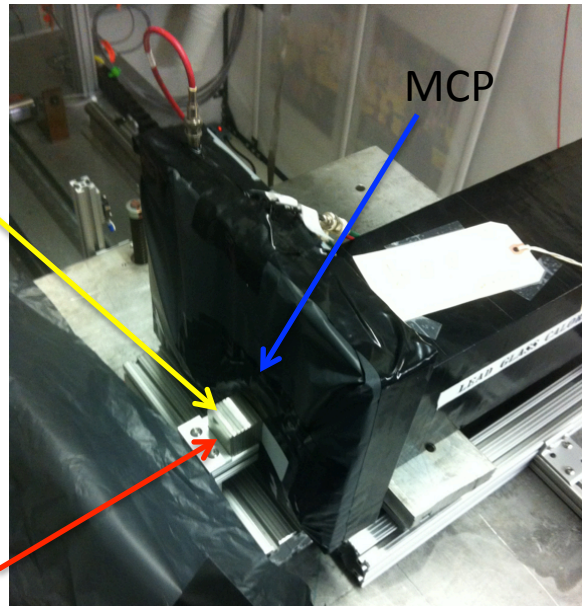
4 GeV and 8 GeV secondary beams were used triggering with positrons (i.e. with the Čerenkov counter signal in the trigger decision)

Two strips were read out at one end (smaller than the shower size)

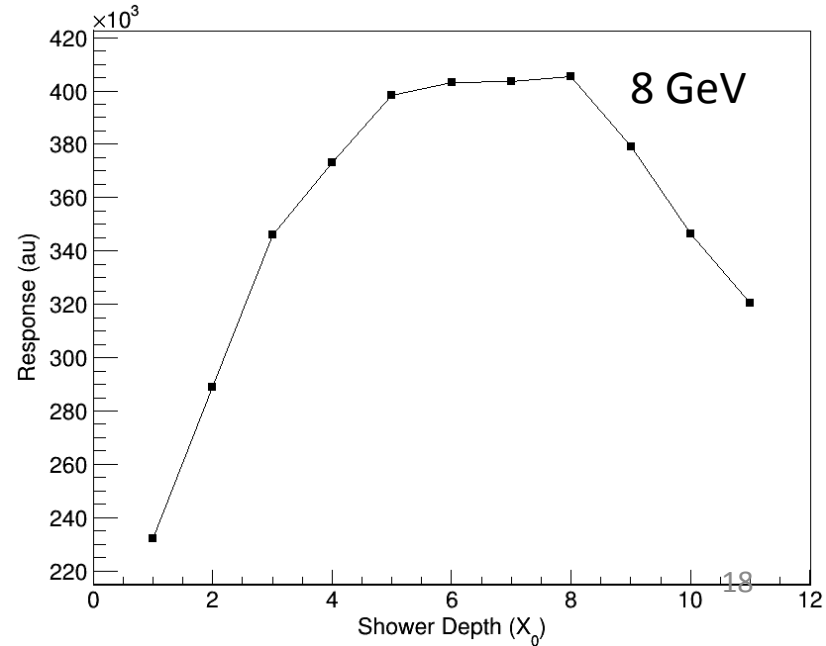
Results quite encouraging!



W absorbers

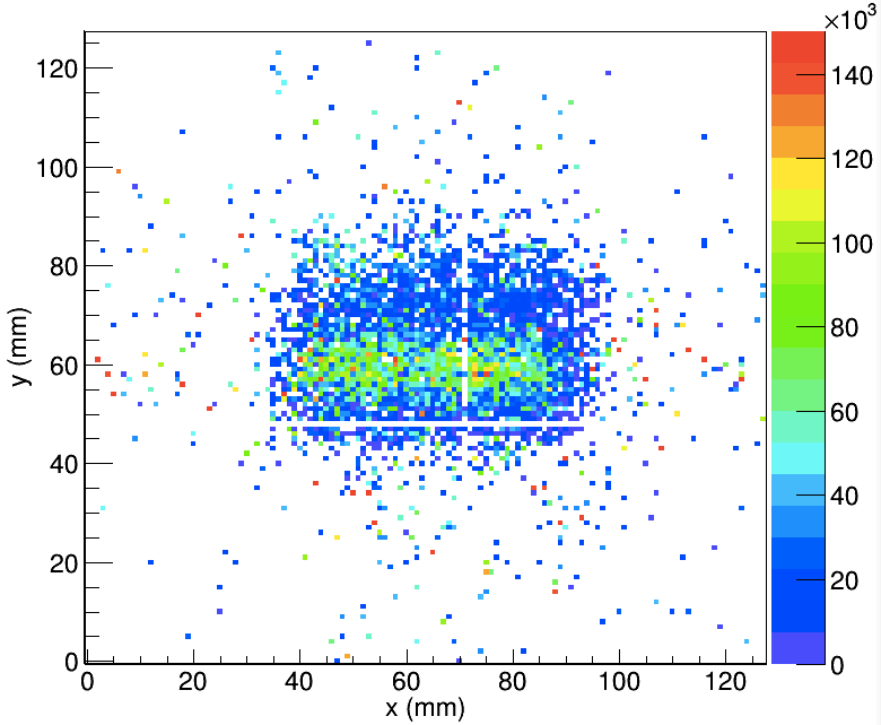


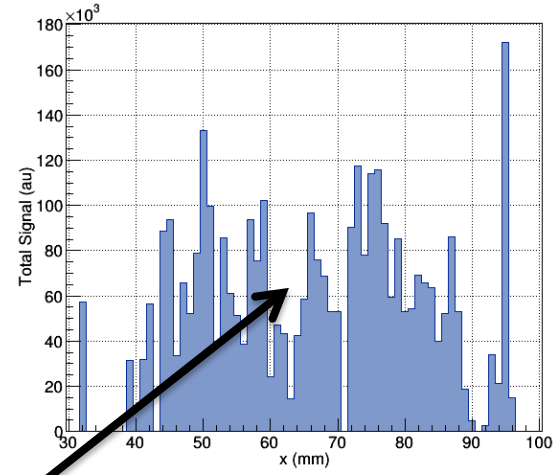
beam



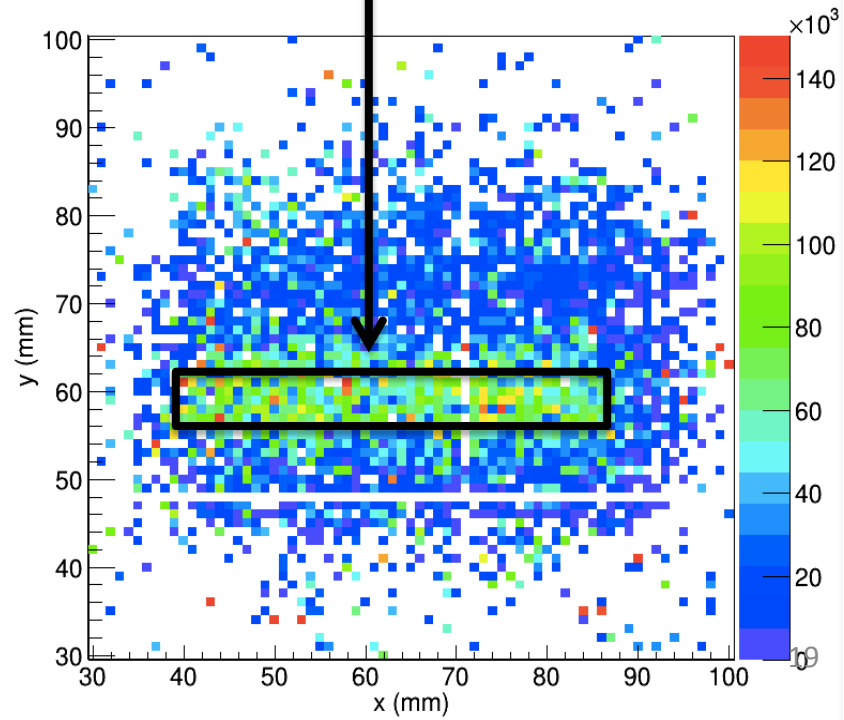
Position Reconstruction with LAPPD

Total signal (R+L) profile





~ window boundary



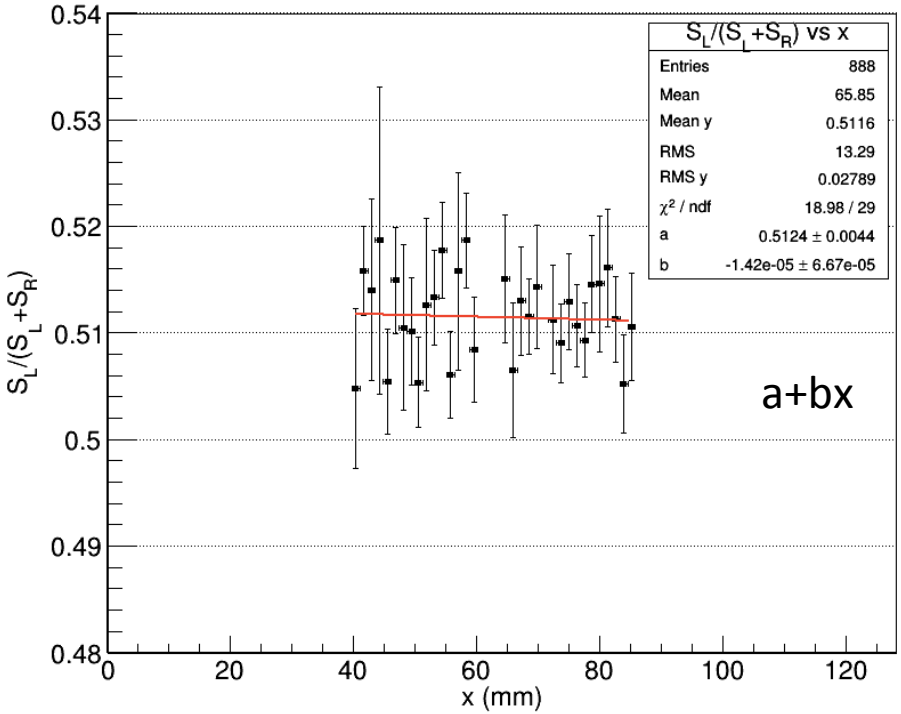
Trigger area ~ 5 cm x 3 cm
One strip read out at both ends

Select the events with particles traversing the strip:

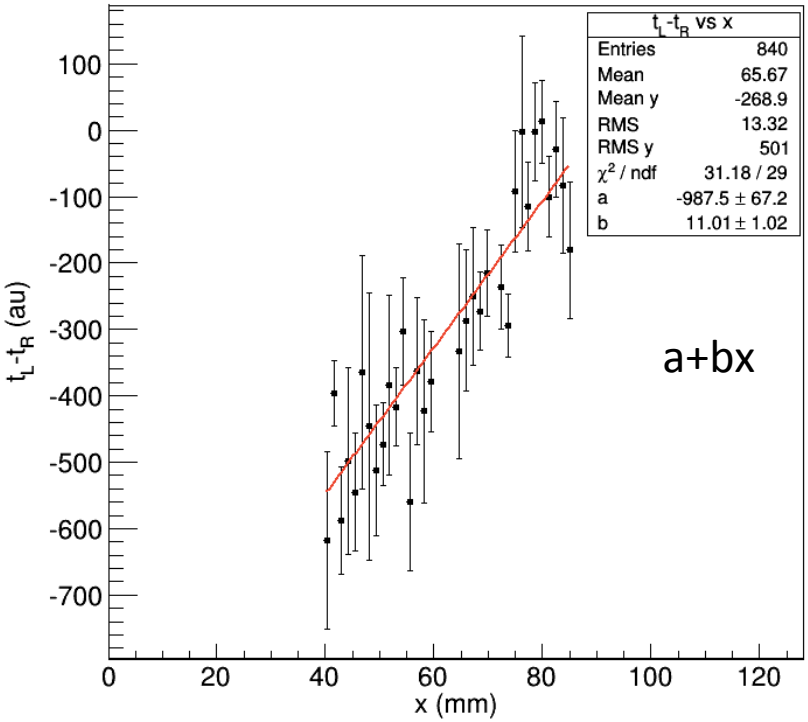
X: 40 – 85 mm
Y: 56 – 62 mm

Position Reconstruction with LAPPD

Fraction of the L signal as a function of x along the strip



Time difference between L and R signals



Very small correlation, not quite significant.

Strong correlation!

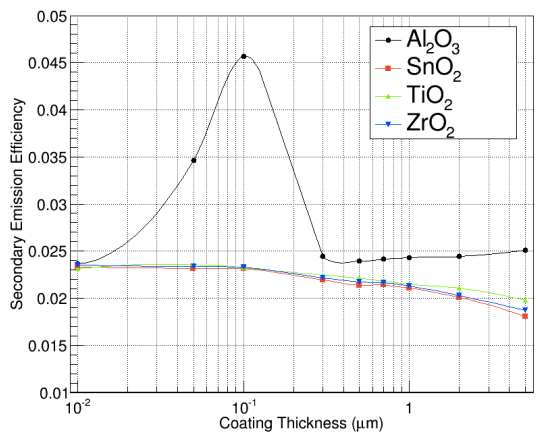
Event position can be reconstructed with timing techniques.
→ More on this in the next talk.

Conclusions

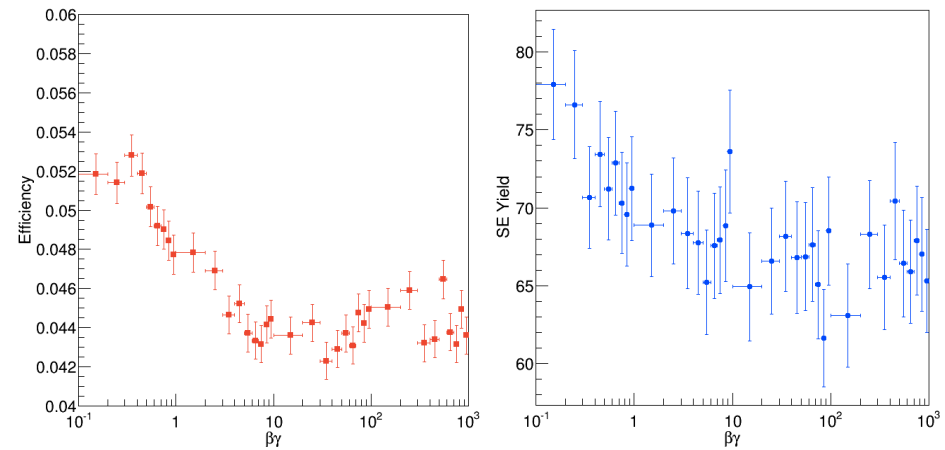
- Secondary Emission calorimeter is radiation-hard and fast.
- Progressive beam test results are encouraging.
- SE calorimetry is feasible for large-scale applications.
- SE calorimetry is suitable for fine readout segmentation hence imaging calorimetry.
- <u>There are many implementation areas for SE calorimetry:</u>
    - Forward calorimetry for hadron/lepton/ion colliders
    - Beam monitors
    - Compton polarimetry for lepton colliders

Outlook

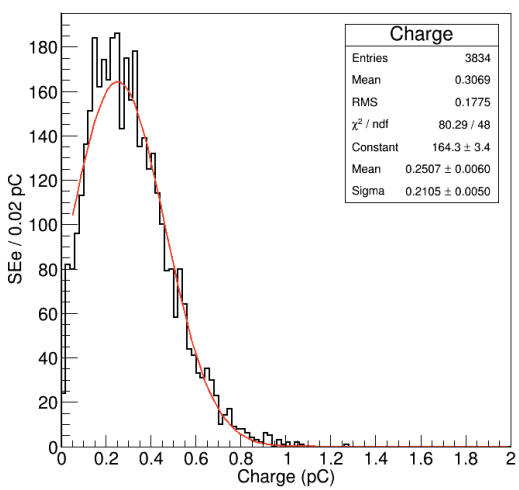
A dedicated Secondary Emission module is needed for complete validation: Identify a secondary emitter as the cathode. Then use either dynodes of the same type or MCPs as multipliers.



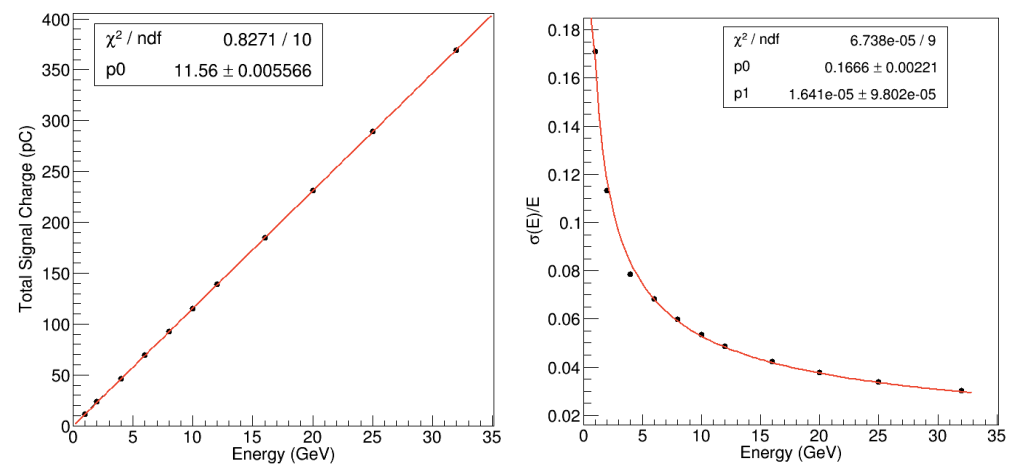
Average secondary electron emission efficiency of different secondary emitters (shown in different colors) as a function of their thicknesses.



Secondary electron emission efficiency of the 100-nm Al_2O_3 coated copper cathode. All errors are statistical.



The generated charge in a 9-stage secondary emission device as a result of an efficient secondary emission at the cathode.



The linearity of the SE detector response (left) and the energy resolution (right). The results are for a 16-layer prototype with 1 X0 sampling with tungsten absorbers. The active medium is modeled as a 9-stage dynode SE module.