Secondary Emission Calorimetry R&D

Burak Bilki

University of Iowa
Argonne National Laboratory

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 a quasi-uniform total absorption calorimeter itself or placed between absorber materials (usually Fe, Cu, Pb, W, etc.) in calorimeters.

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.

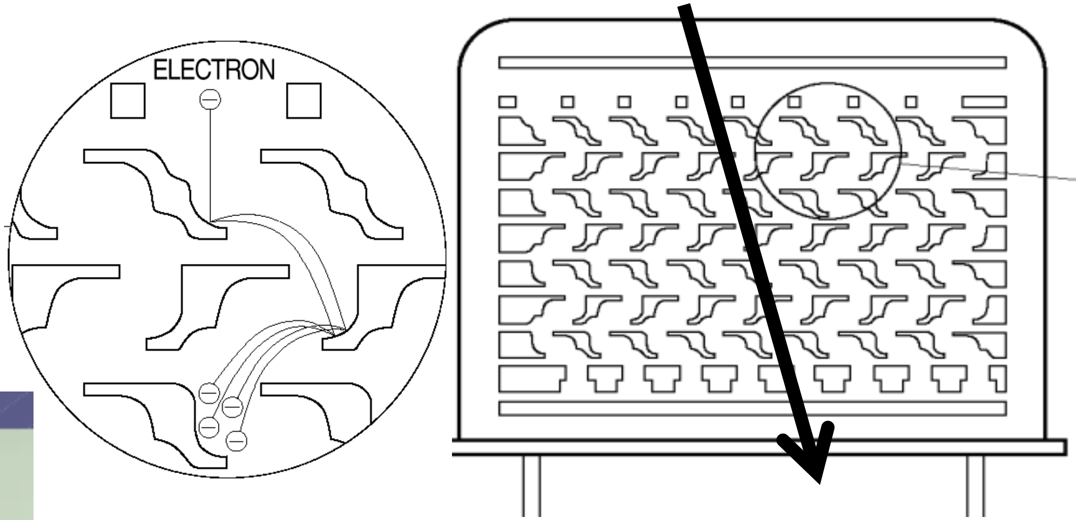
The construction is far easier than a PMT since the entire final assembly can be done in air. There are no critical controlled thin film depositions nor vacuum activation. The module is sealed by welding or brazing or other high temperature joinings with a simple final heated vacuum pump-out and tip-off.

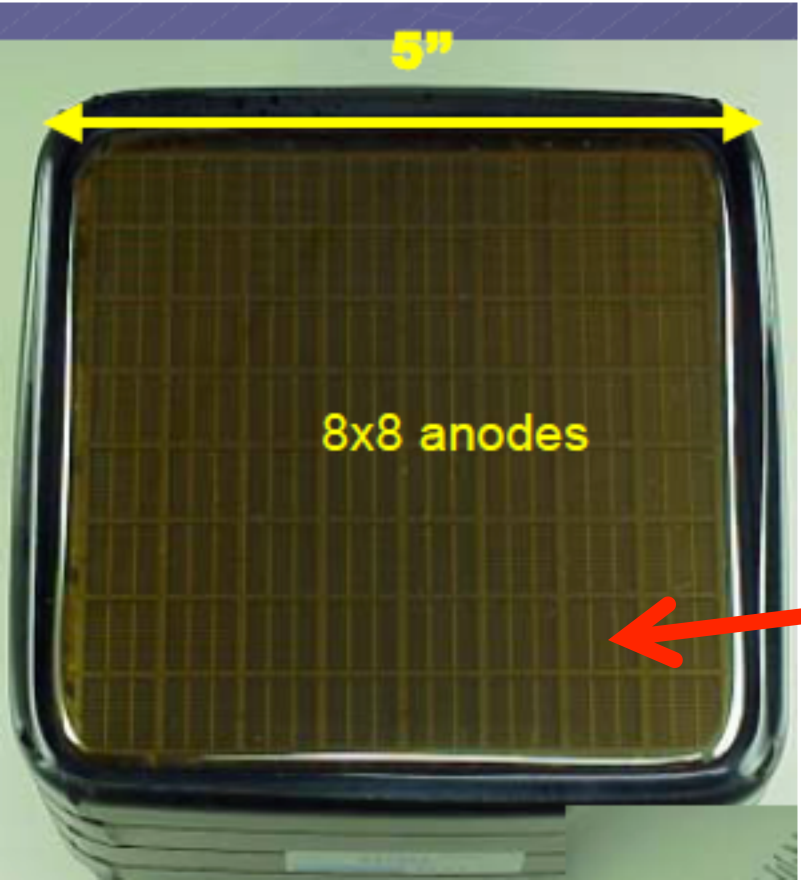
The modules envisioned are compact, high gain, high speed, exceptionally radiation damage resistant, rugged, and cost effective.

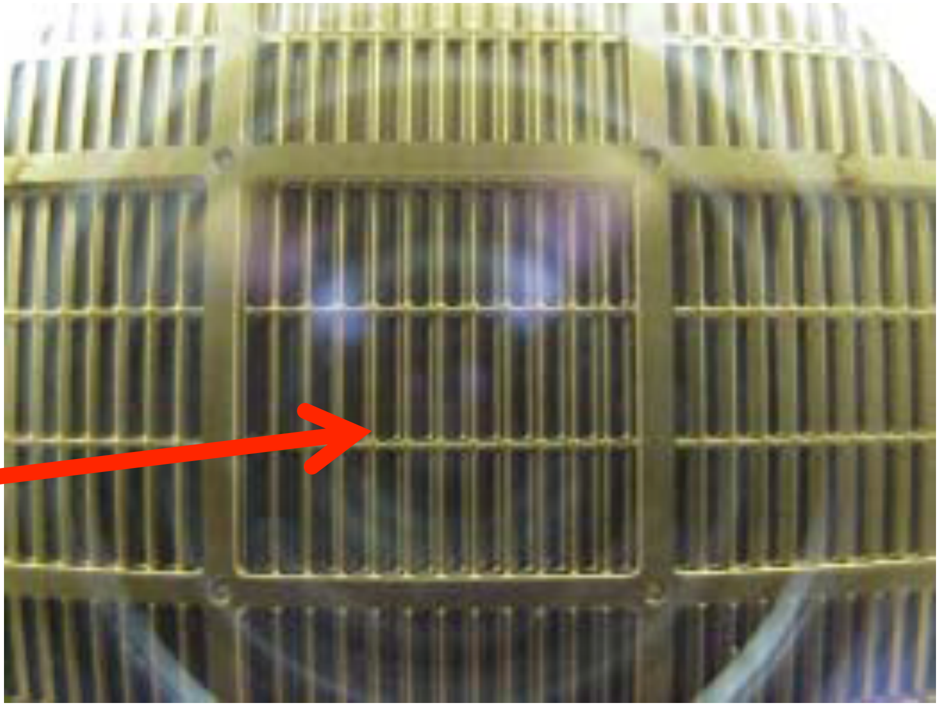
The SE sensor module anodes can be segmented transversely to sizes that are appropriate to reconstruct electromagnetic cores with high precision.

SEe Dynodes: a) Etched Metal Sheets

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

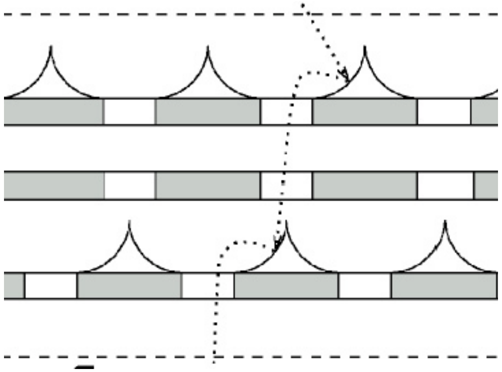


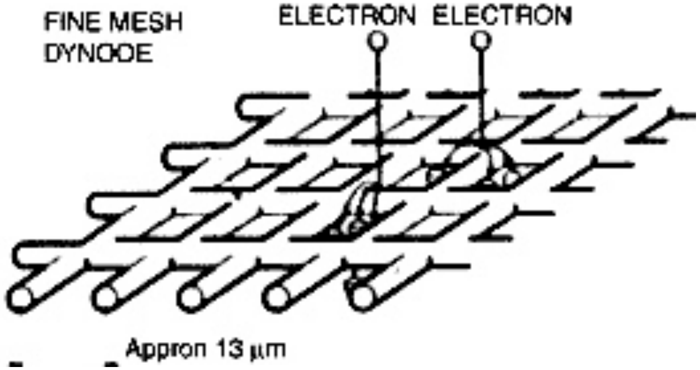


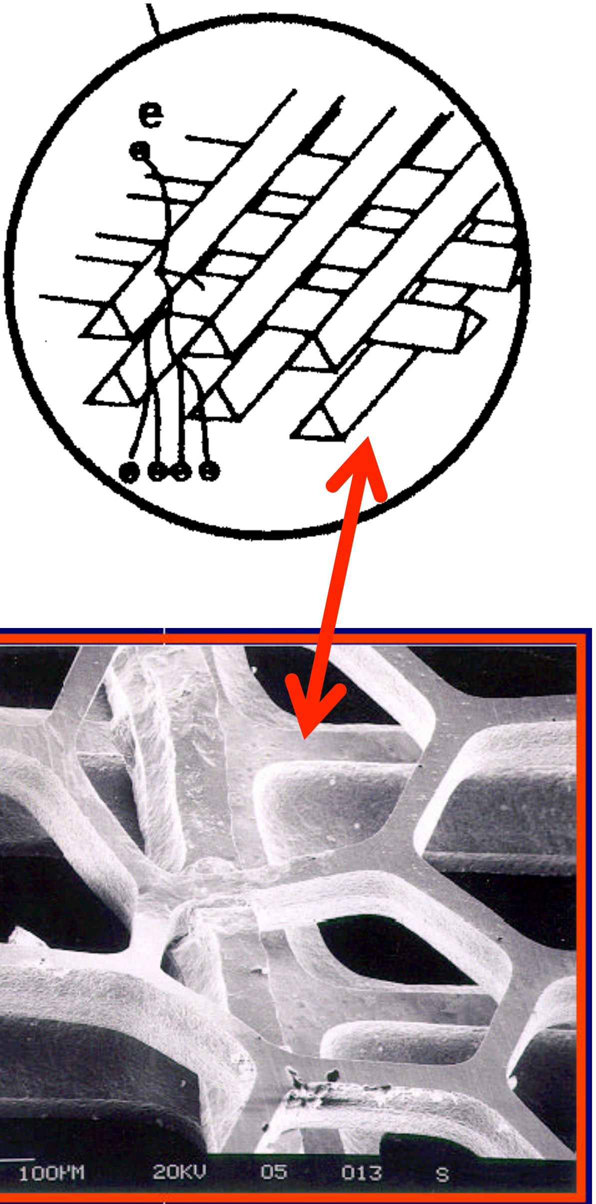


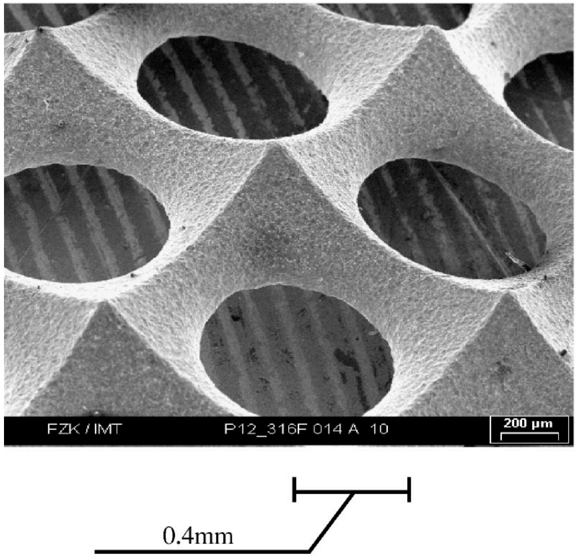
SEe Dynodes: b) Metal Screen Dynodes: 15D - g~10^5

MESH DYNODE VARIANTS







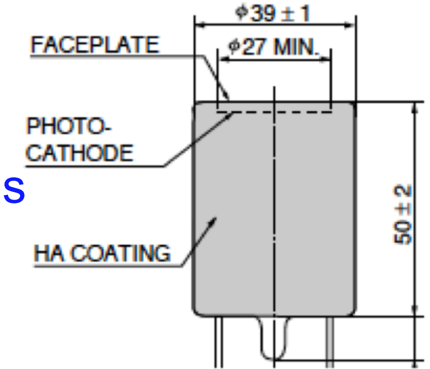


D_n-D_{n+1}: 0.9 mm
C-C mesh: 13 µm
Wire diameter: 5 µm

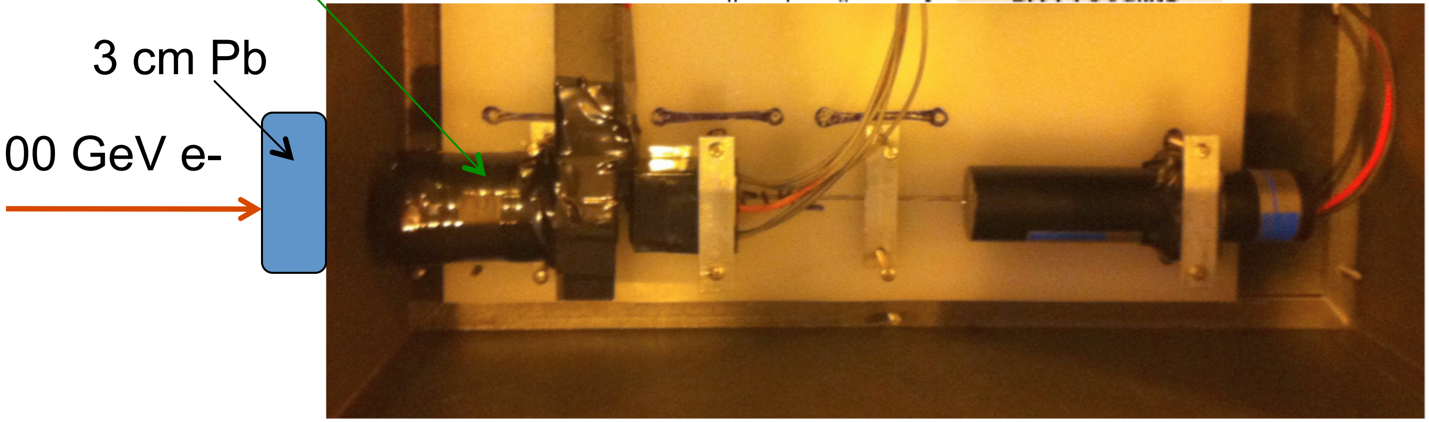
Beam Tests of SE Sensor

CERN SPS, Oct. 2011

Mesh PMT and Base
Facing Downstream
Photocathode Reverse Bias



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.

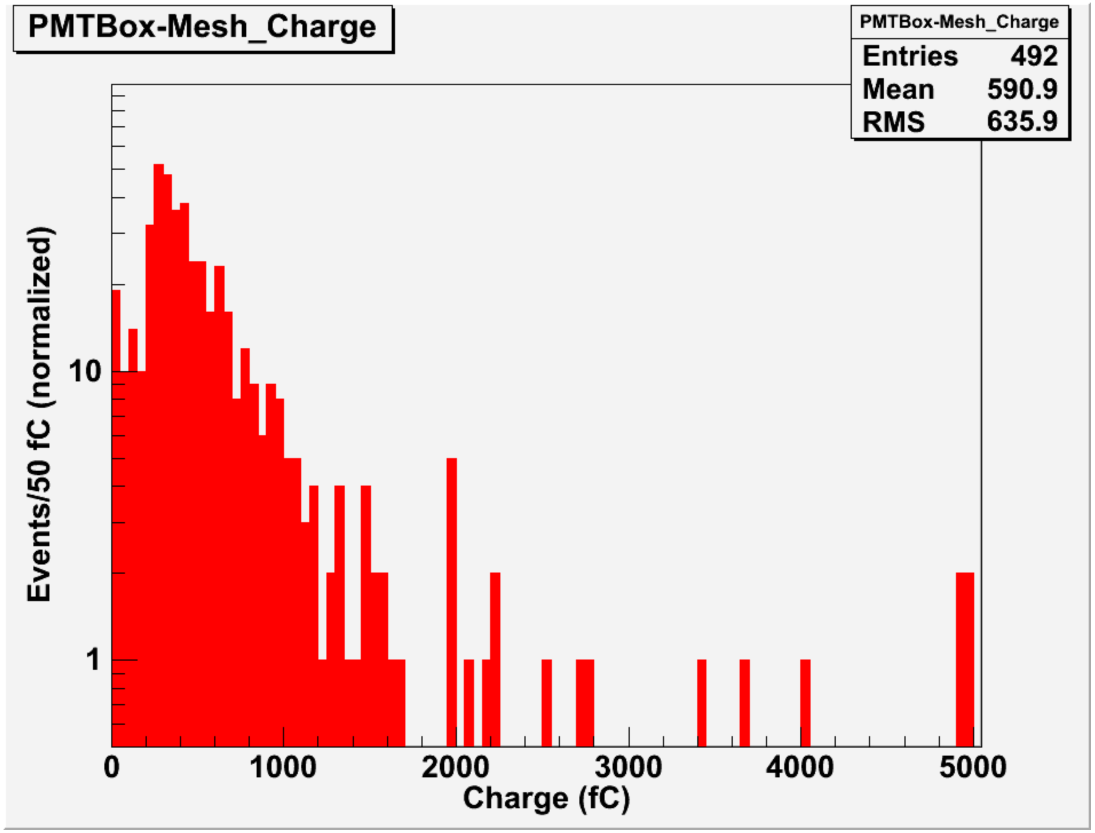
We Expect ~500 Shower electrons to Cross Mesh
→ ~25-50 SEe **assuming all shower e = MIPs**

BEAM TEST: 100 GeV electrons

3 cm Pb ~ 5 X_0 Radiator ~ Shower Max

downstream the mesh PMT w/ photocathode turned off

CERN SPS, Oct. 2011



PRELIMINARY!

Fluctuations High!

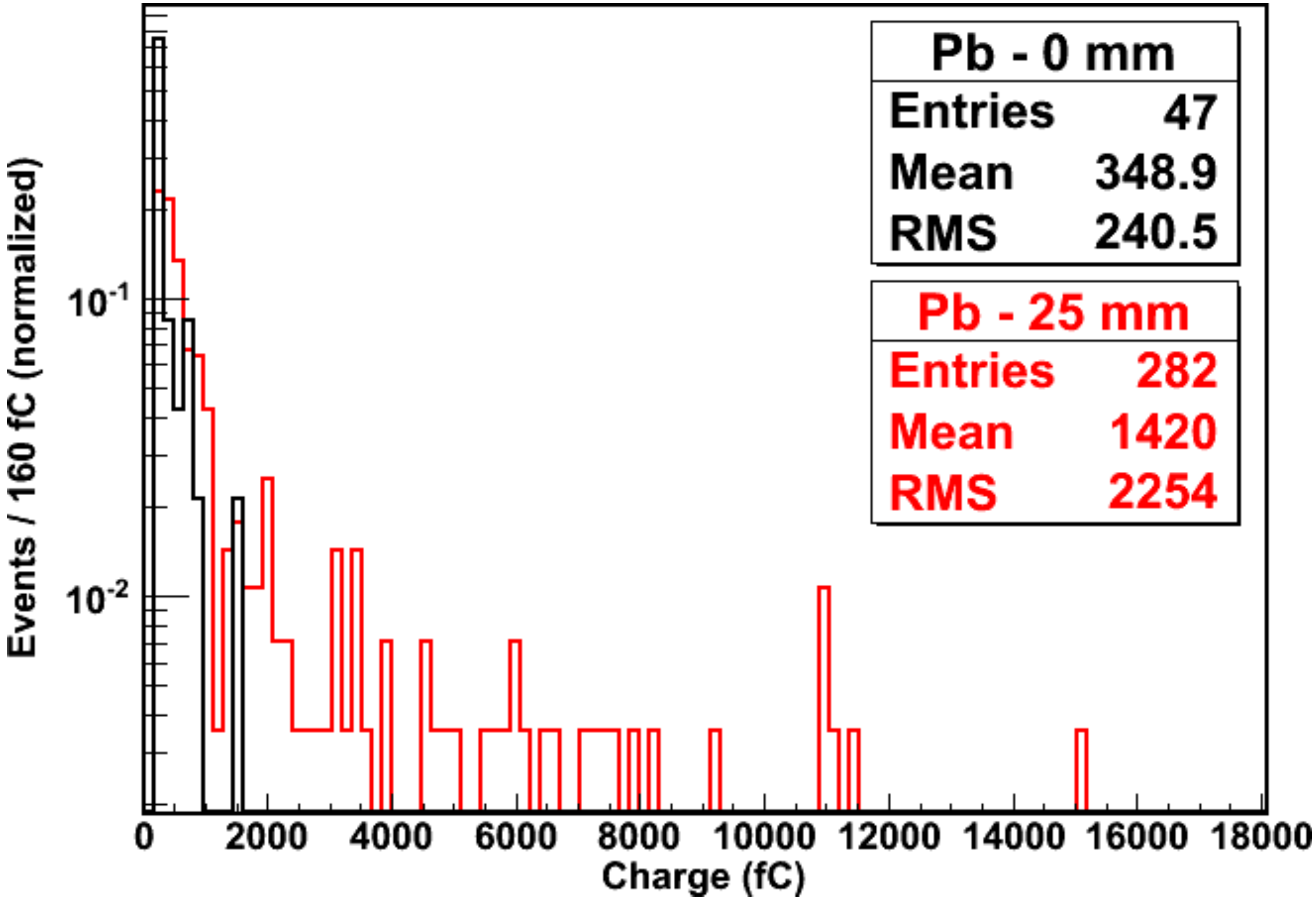
- PMT Dia ~ Shower Dia
- Beam not centered

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

Peak corresponds to ~40 SE electrons (mesh stack gain ~10^5)

100 GeV Electrons – SE Mode

CERN SPS, Oct. 2011



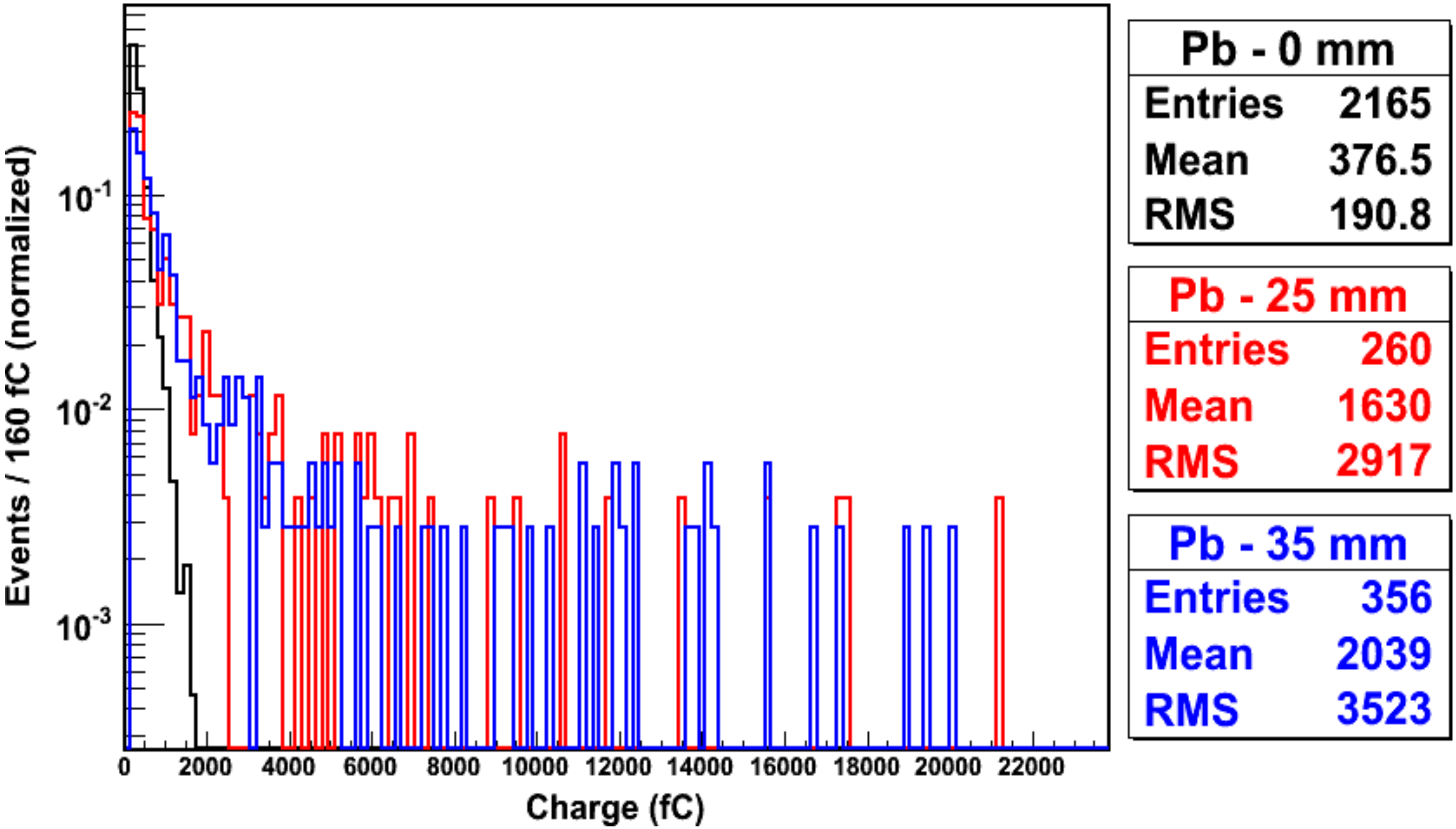
~4 X_0

Charge > 160 fC cut applied. **(1 pe ~ 160 fC)**

Scales with X_0. Note: Shower not laterally contained!

80 GeV Electrons – SE Mode

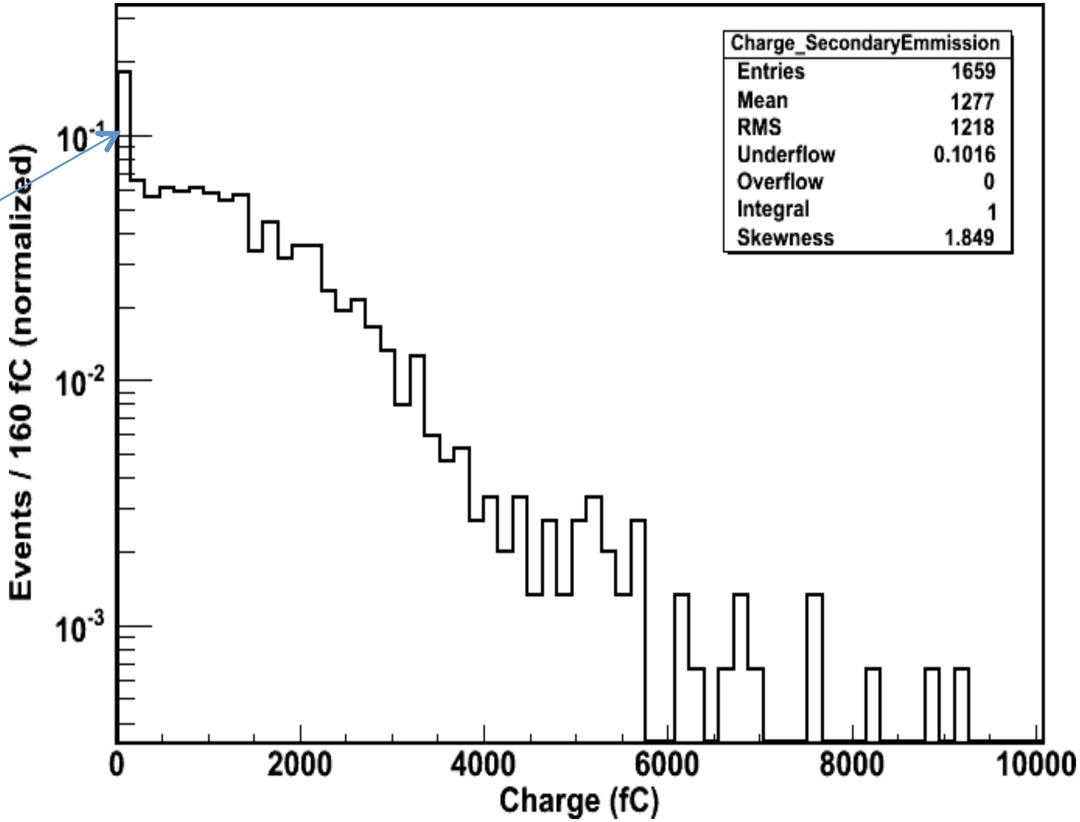
CERN SPS, Oct. 2011



Charge > 160 fC cut applied. **(1 pe ~ 160 fC)**
Scales with X_0 Note: Shower not laterally contained!

SEe Efficiency with Muons

CERN SPS, Oct. 2011



Below Thresh.

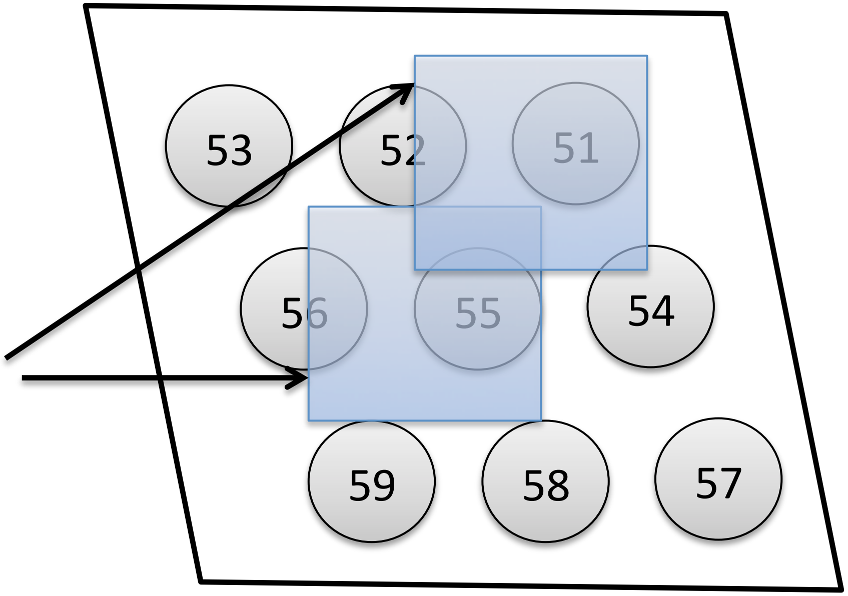
Muon Efficiency ~ 80%
(1 pe ~ 160 fC)

Muons pass through the mesh dynodes (selected by the wire chambers)

SE Module Beam Test

Using mesh dynodes from PMTs

CERN SPS, Nov. 2012

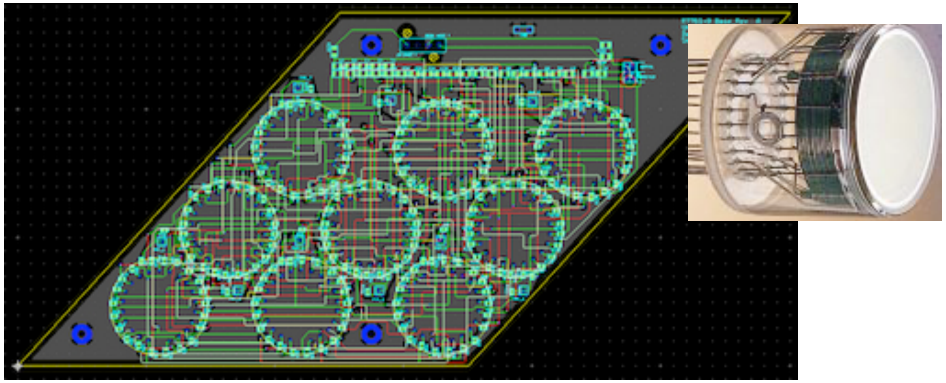


Beam position (into the page)

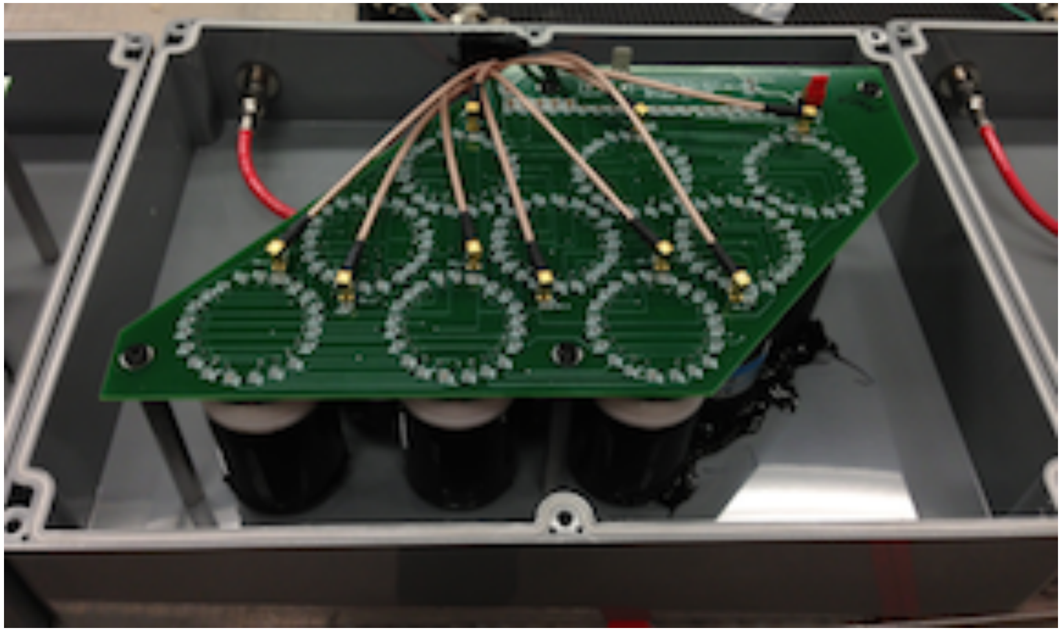
2 datasets

Selected with Wire Chamber

51, … , 59: PMT IDs

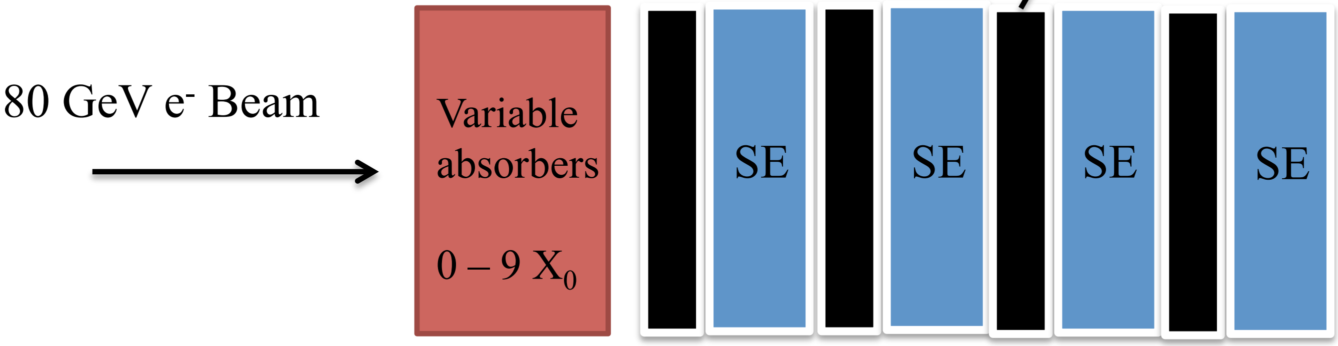


SE Module Beam Test



2-cm iron absorbers:

X_0 = 1.75 cm
Molière Radius: 1.72 cm



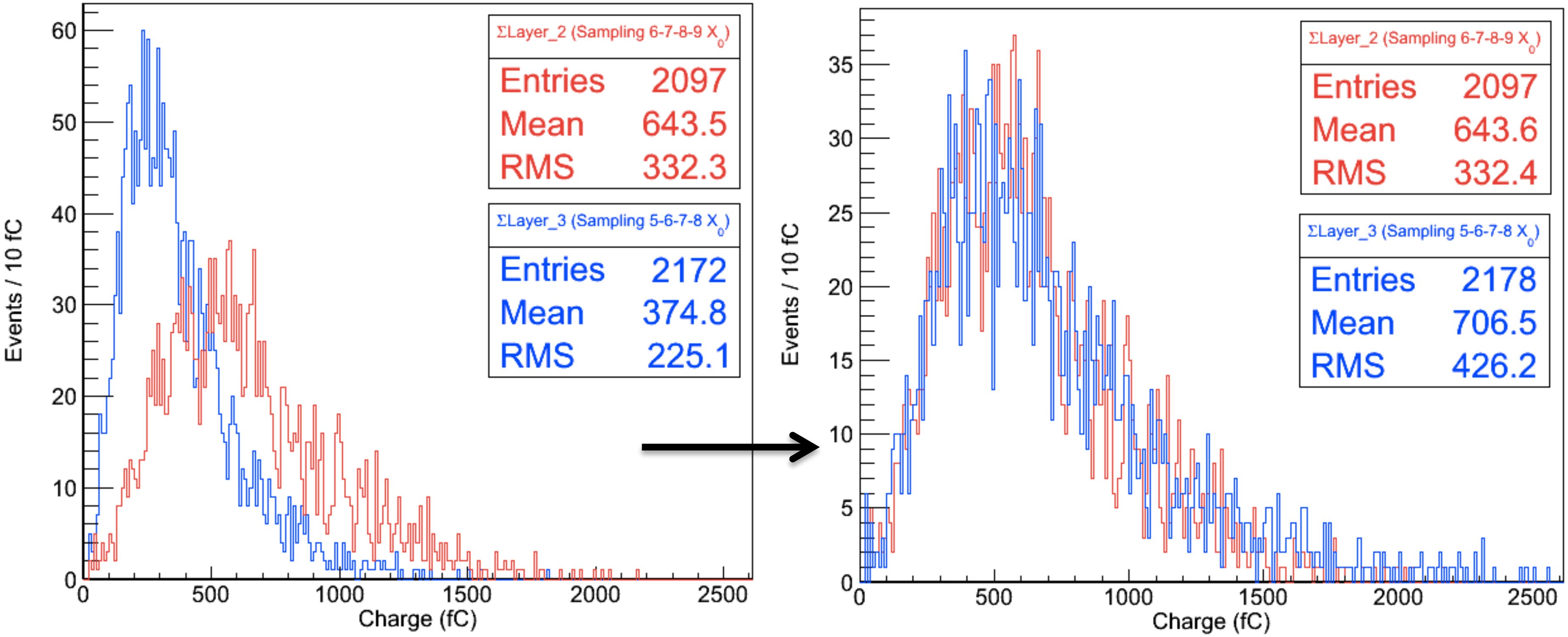
Shower not contained laterally or longitudinally
→ Results require estimates and approximations

SE Module Tests – Preliminary Results

Normalizing responses of different layers

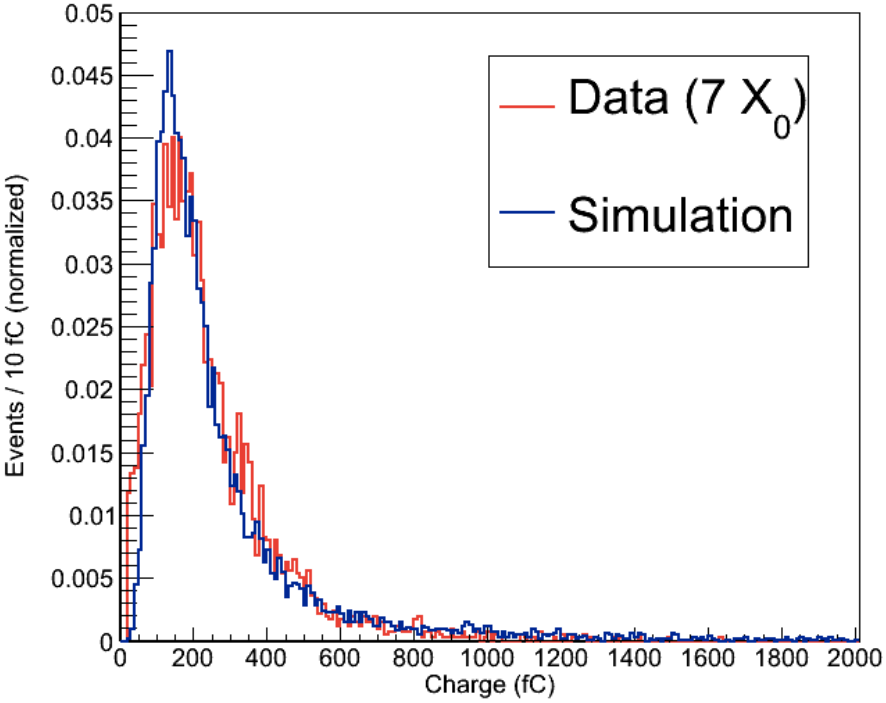
Example: Normalization of Layer 3 response to Layer 2 response using $7X_0$ sampling

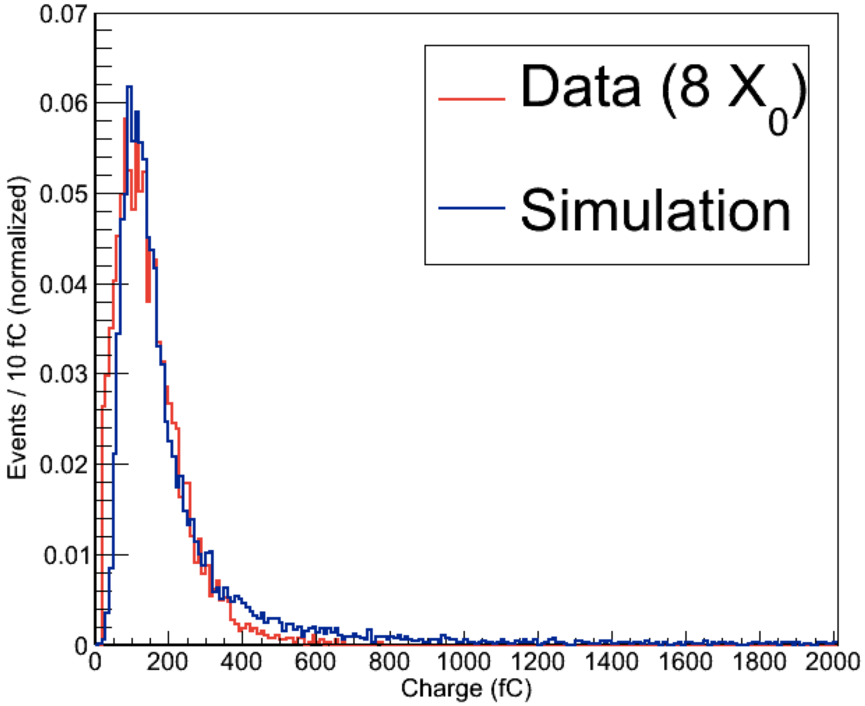
(Also works in the reverse order → next slide)



Charge > 20 fC

SE Module Simulation



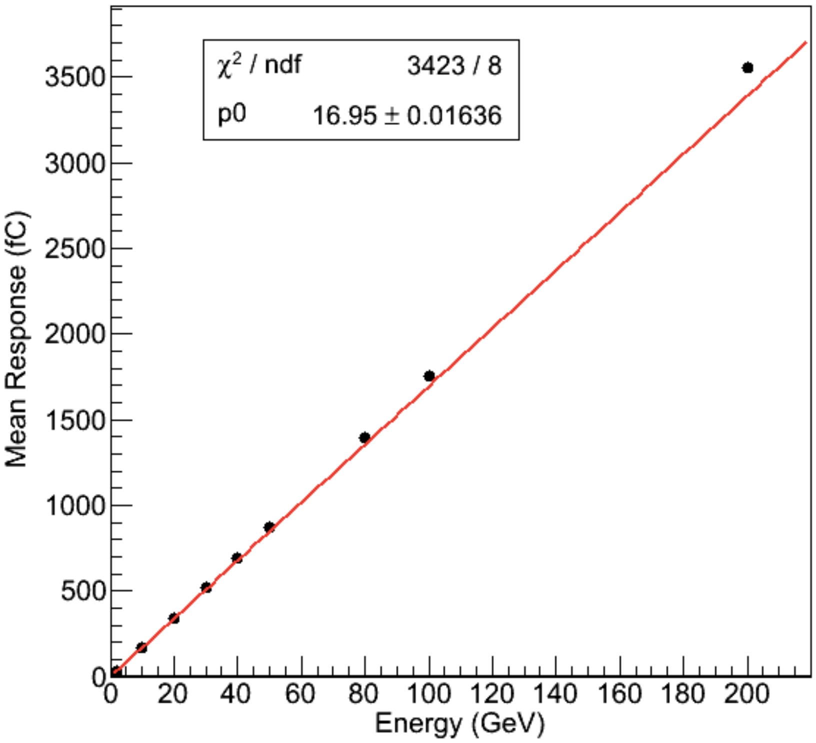


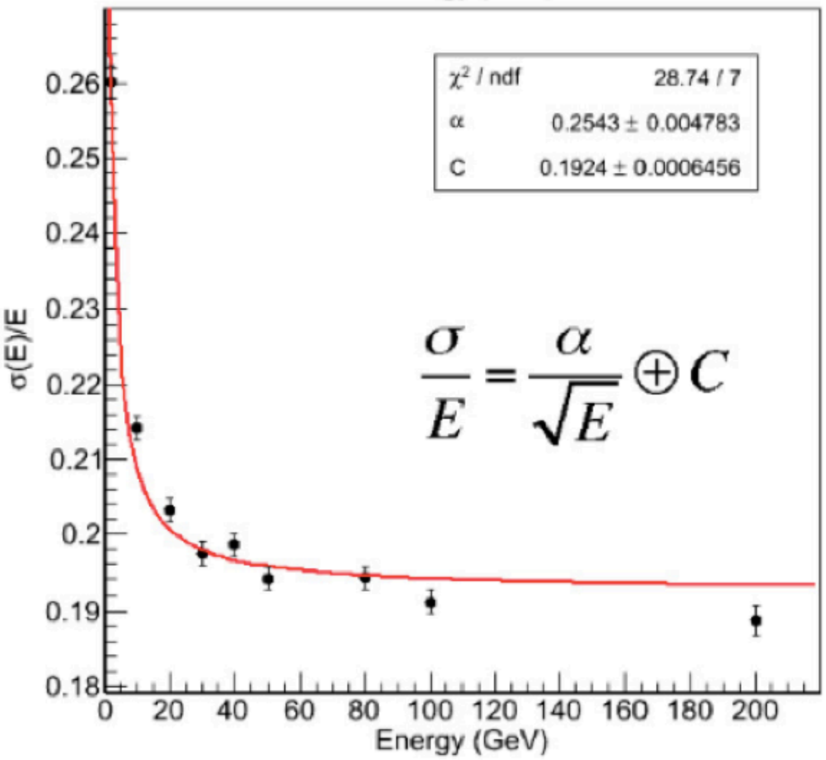
Geant4 simulation of the SE module test beam setup:
80 GeV e^- beam
19 stage mesh dynodes generate SE electrons (dynodes ~ sheets)
Gain is simulated offline (10^6)
Landau fluctuations are implemented offline
Single parameter to tune: Efficiency of SEe production
(mesh dynodes are simulated as solid sheets) → 0 - 0.35% flat random

SE Calorimeter Simulation

Using SE module MC tune

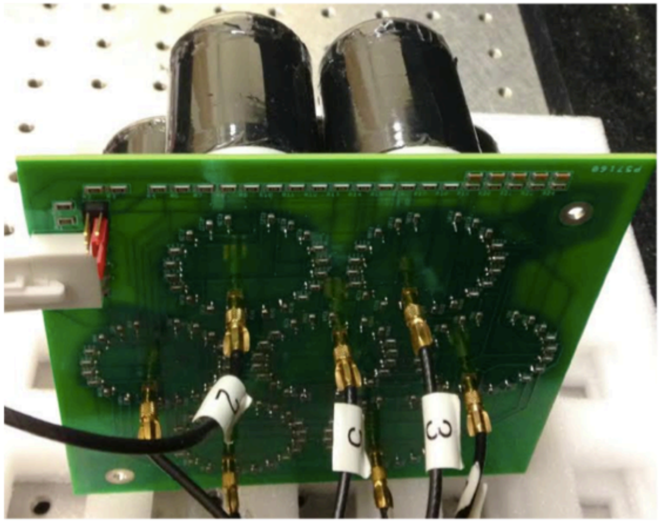
25 X_0 sampling calorimeter
1.75 cm Fe absorbers
19-stage SE sensor ~ 2 cm
Lateral size 1 m x 1 m

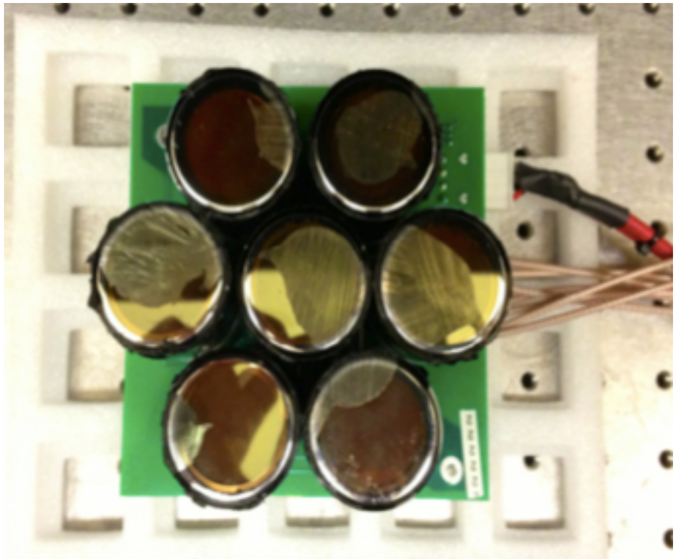




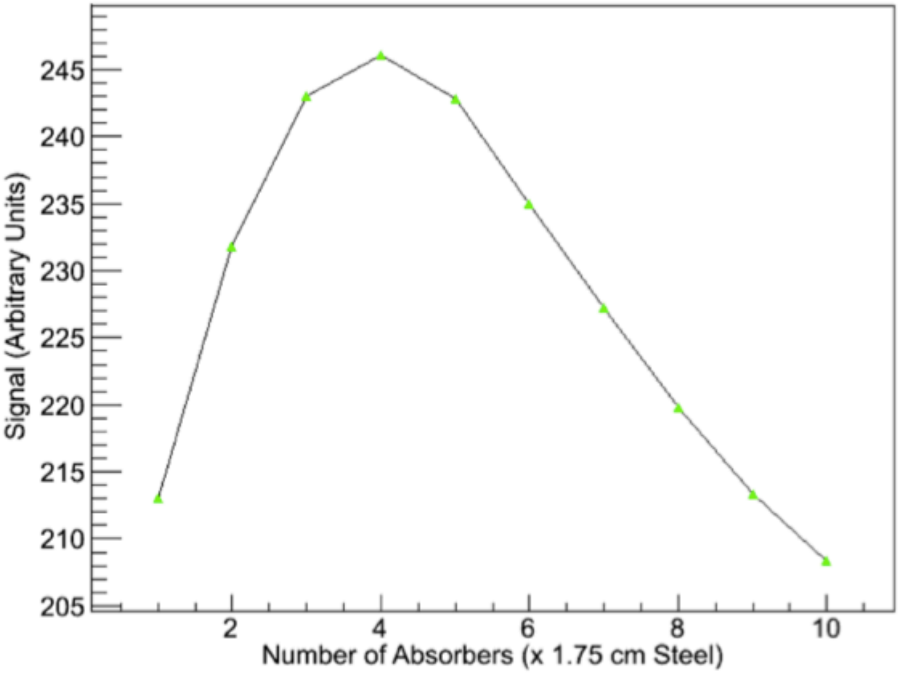
Second Generation SE Module - I

7 closest-packed PMTs with photocathodes turned off





4 GeV shower profile



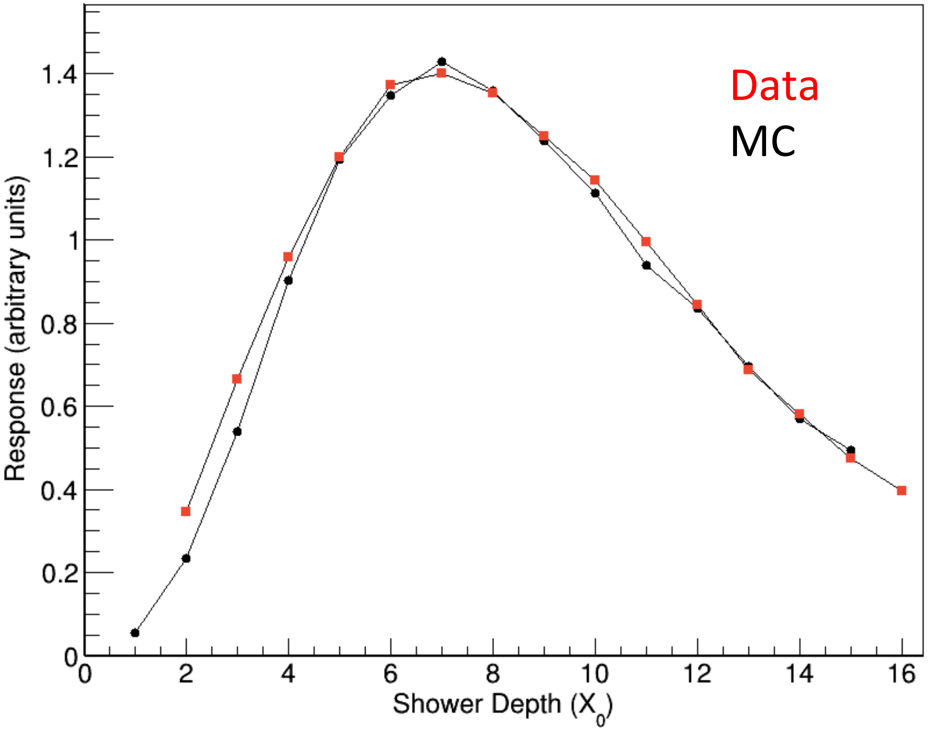
20 cm x 20 cm x 1.75 cm
steel absorbers

Second Generation SE Module - II

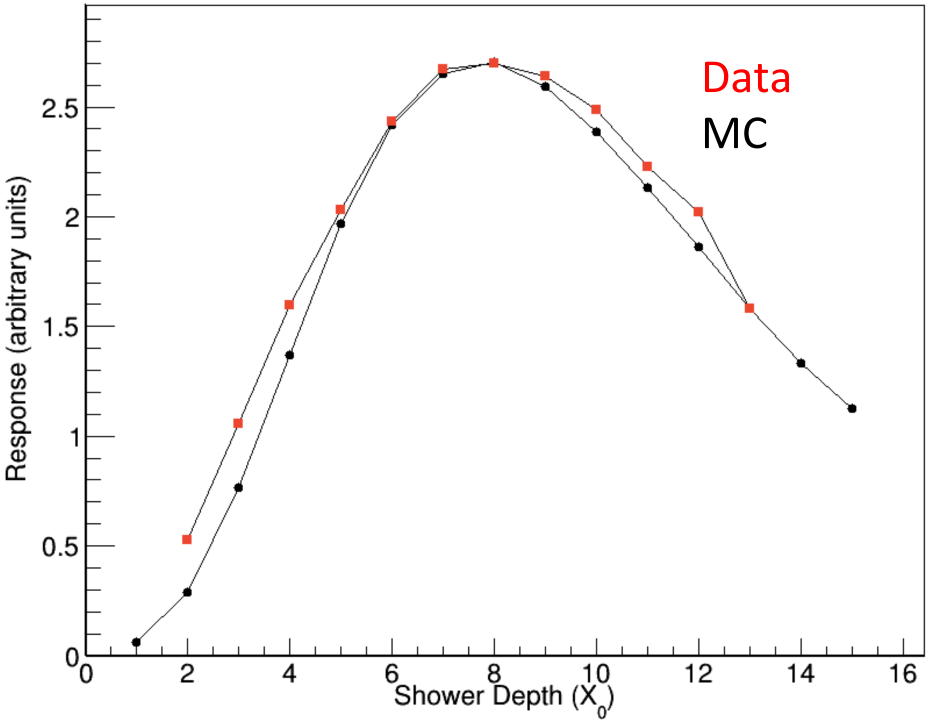
Tests with single SE sensor and up to 15 3 cm x 3 cm x 0.35 cm W plates

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

8 GeV shower profile



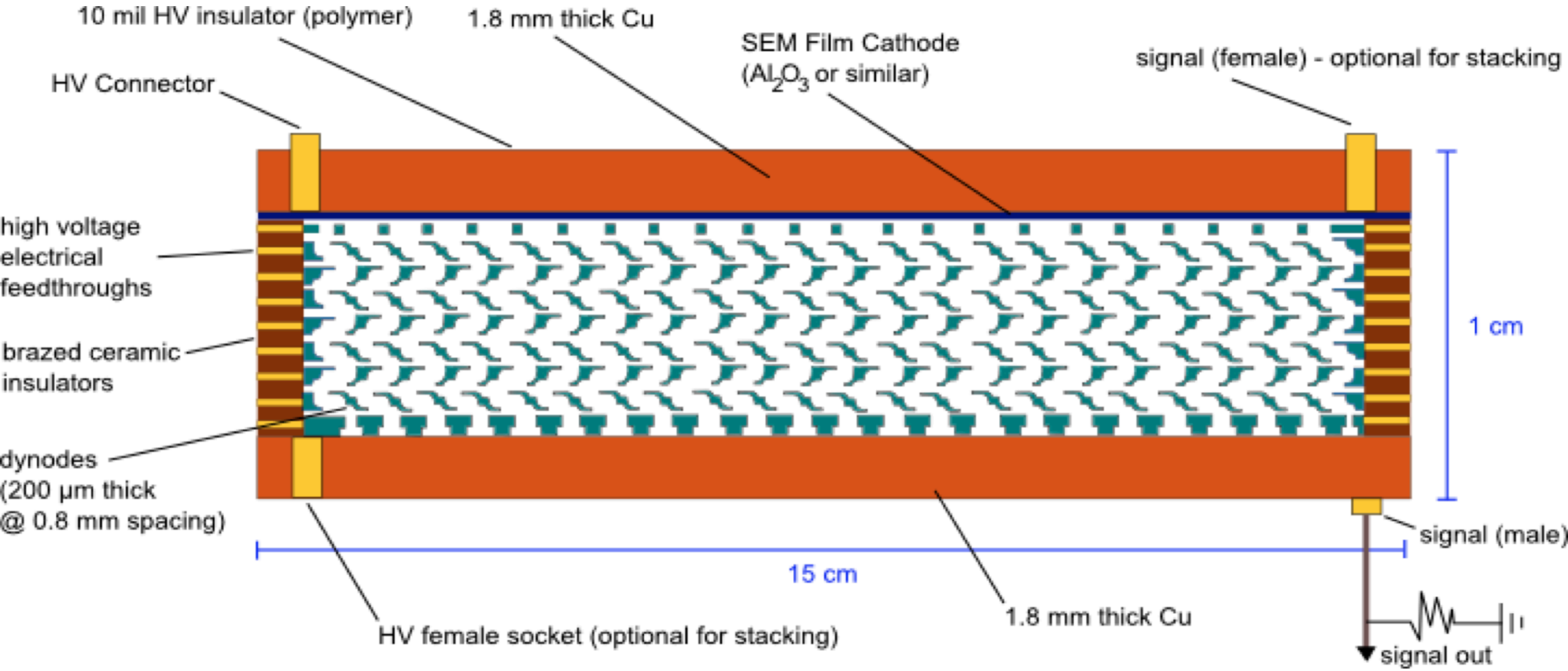
16 GeV shower profile



Sub-Conclusions

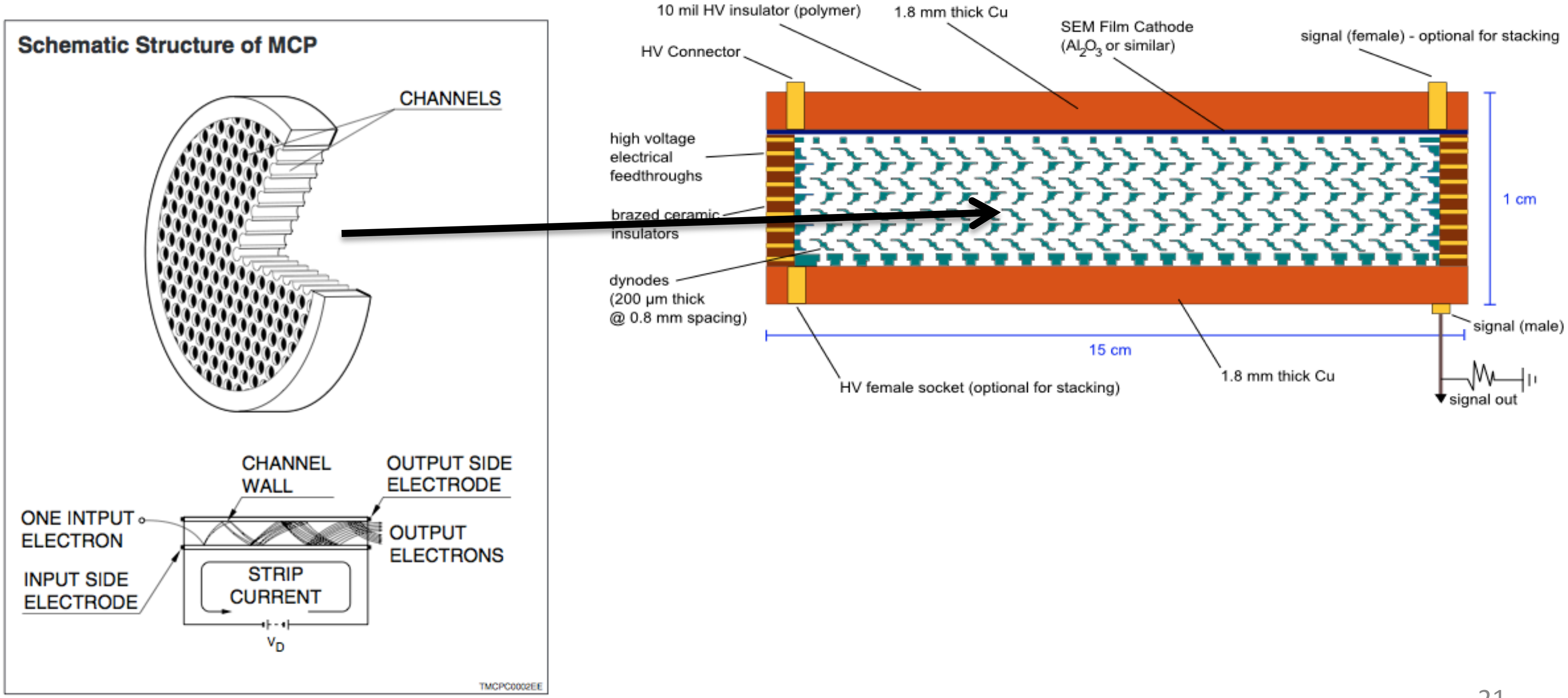
Progressive beam test results are encouraging for better prototypes.

More beam test needed now with a dedicated Secondary Emission module.



MCPs As Secondary Emitters - I

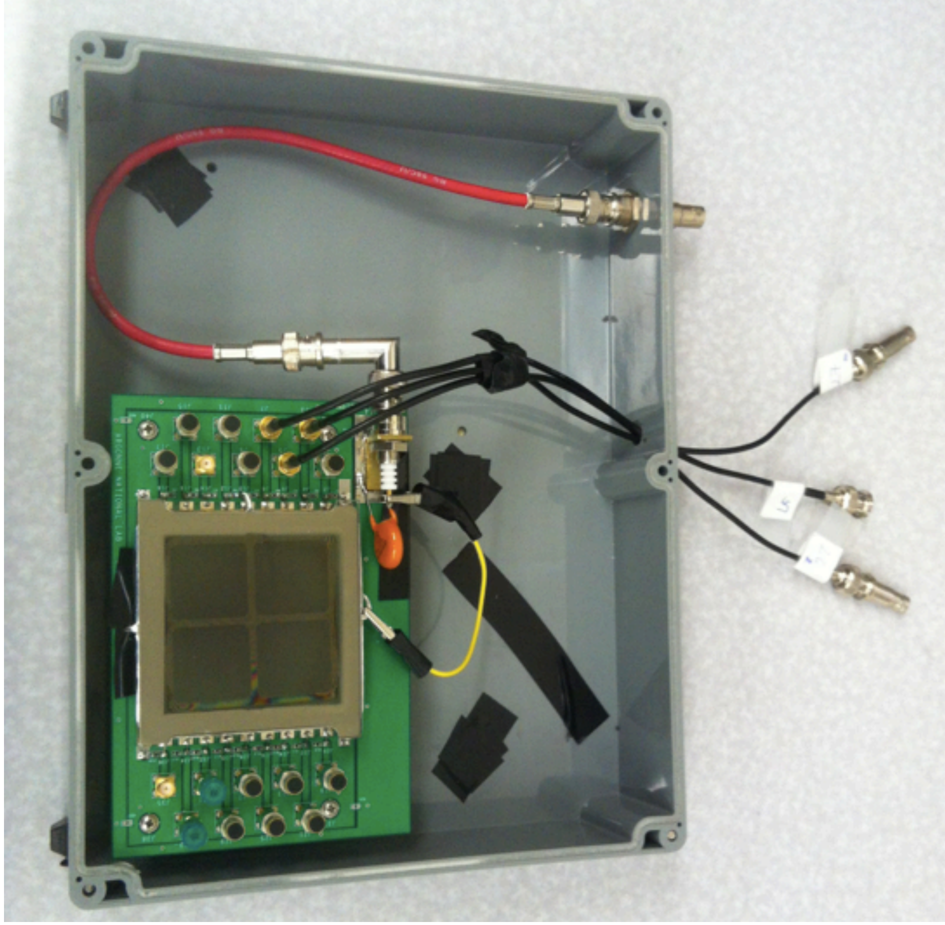
- Should work effectively
- Have simpler design than a regular MCP
- Should be very fast



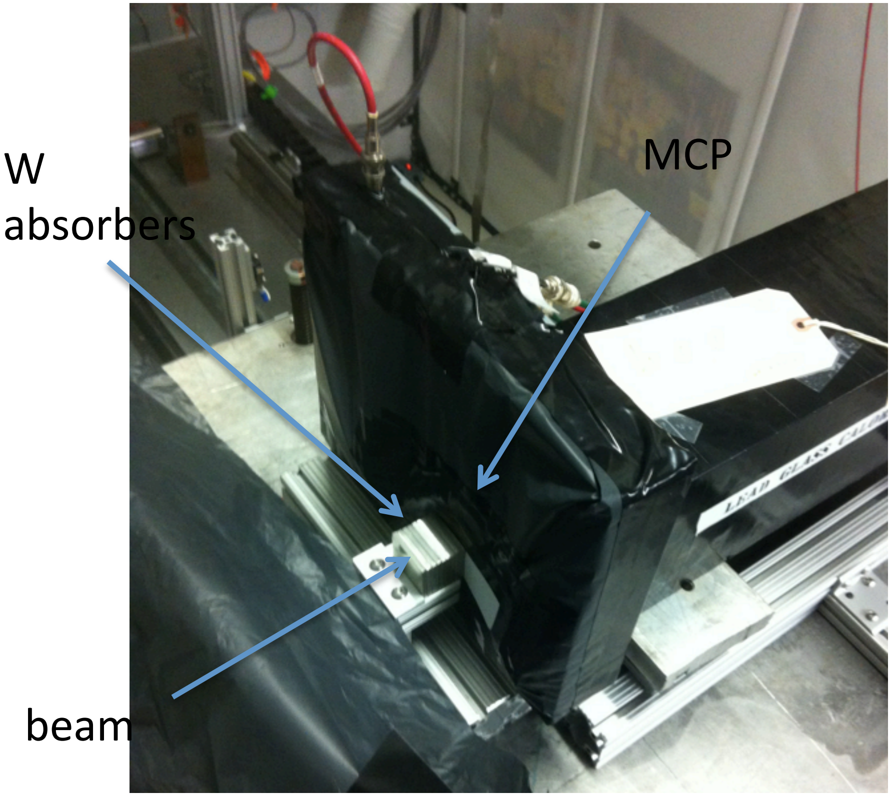
MCPs As Secondary Emitters - II

No dedicated SE test module yet. But…

We had the Argonne MCP to study some (very) preliminaries.



Fermilab test beam Nov 12-18 2014

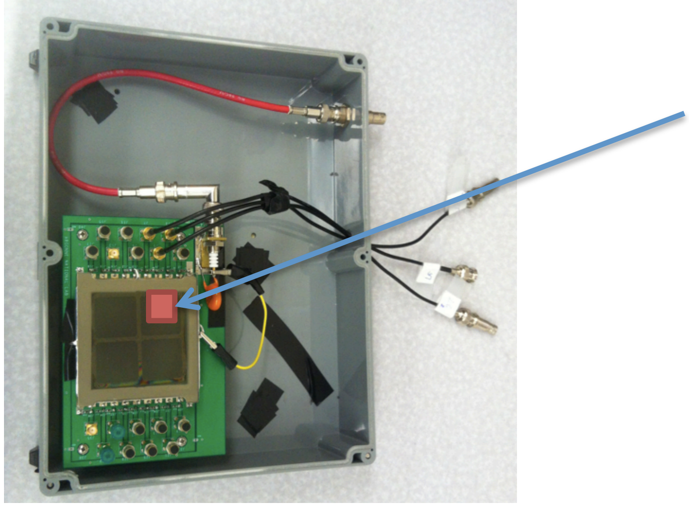


W absorbers

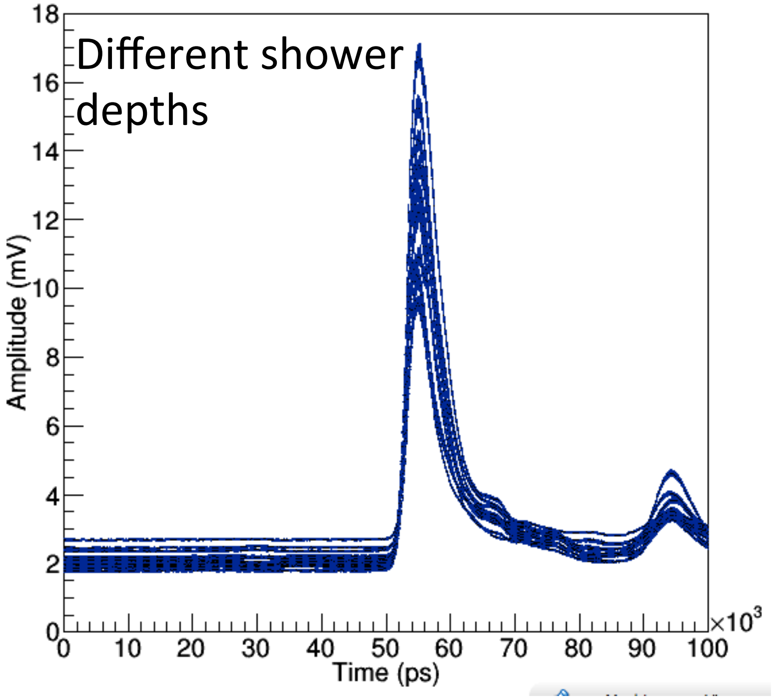
MCP

beam

MCPs As Secondary Emitters - III



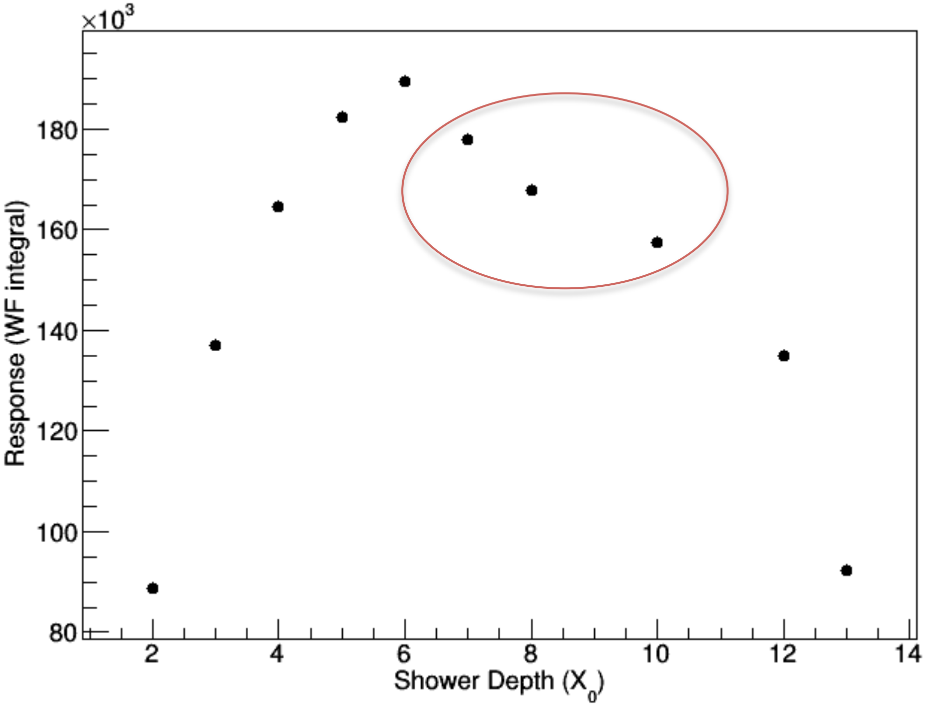
Trigger: 1 cm x 1 cm
Read out 3 strips with scope



Different shower depths

Integrate from 48 to 66 ns

8 GeV shower profile



Conclusions

- Secondary Emission calorimeter is radiation-hard and fast.
- Progressive beam test results are encouraging.
- A dedicated Secondary Emission module is needed for complete validation.
- SE calorimetry is feasible for large-scale applications.
- SE calorimetry is suitable for fine readout segmentation hence imaging calorimetry.
- Large implementation options exist once the proof of concept is established (forward calorimetry for hadron/lepton/ion colliders, beam monitors, Compton polarimetry for lepton colliders, etc.).