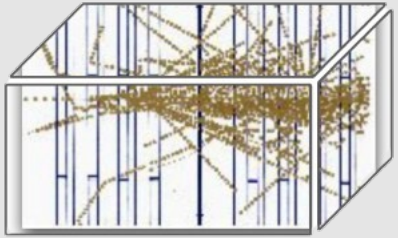

Utilization of Secondary Electron Emission Principle in Calorimeter Active Media

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Secondary Electron Emission Principle

- **Secondary Emission (SE) signal:** Generated with SE surfaces when impacted by energetic particles:
  - SE yield δ: Scales with particle momentum
  - SE e^-: $3 < \delta < 100$, per $0.05 < e^- < 100$ keV (material dependent)
  - $\delta \sim 0.05 - 0.1$ SE e^- per MIP
- **SE Principle in Calorimetry:** Radiation-Hard + Fast
  - a) Metal-Oxide SE PMT Dynodes survive > 100 GRad
  - b) SE Beam Monitors survive 10^{20} MIPs/cm^2

The SE electrons in a calorimeter module will be amplified exactly like photoelectrons in the PMTs.

An Electromagnetic Calorimeter Based on Secondary Electron Emission Principle

16 - 25 X_0 Forward EM Calorimeter

1 X_0 W + SE Sensor Module ; less than 1 cm thick

The SE sensor modules will work like a PMT as an SE e^- is statistically similar to a photoelectron

Target gain ~ $10^5 – 10^6$ e^- per SE e^-

A) Muon MIP:

Expect ~ 0.1 SE e^- per sample module x number of modules* → MIP Signal:

~ 2.5 SE e^- / muon in a 25 X_0 EM module calorimeter
but we measure ~ 8x this in Test Beam!

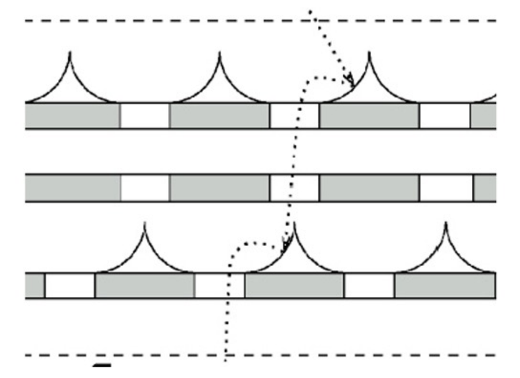
* E. J. Sternglass, "Theory of Secondary Electron Emission by High-Speed Ions", Phys. Rev. 108, 1, 1957

B) EM Showers:

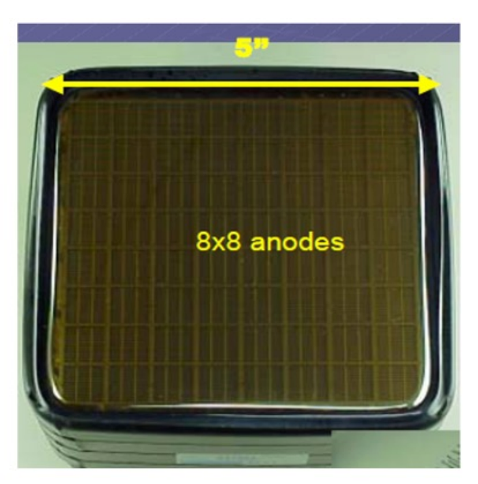
~ 900 shower electrons/GeV yields 45 - 90 SE e^- / GeV
Note that this estimate is based on the MIP response estimate which is a lower limit.

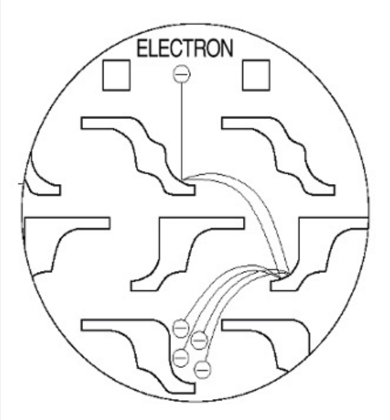
SE Sensor Options

Metal Screen Dynodes which are basically mesh dynode variants. Usually the dynode separation is 0.9 mm and the wire diameter is 5 μm. The gains of these devices are at the order of 10^5. The figure shows a picture of a similar device and the mesh dynode structure.



Etched Metal Sheets option is identical to the Hamamatsu dynodes that are ~50 cm long in some existing designs. The dynodes are diced from large sheets. The figure shows the picture of a multi-anode PMT of 5” edge size and a sketch of the electron multiplication.

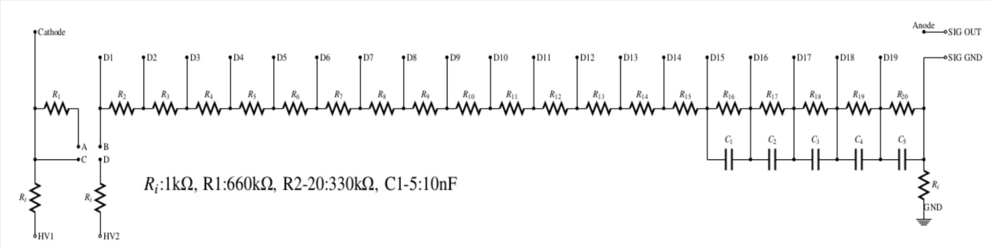


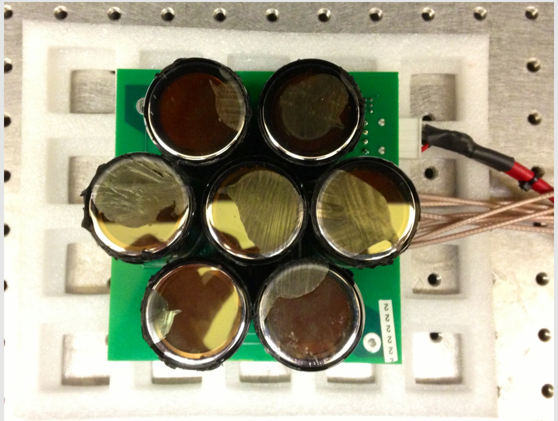


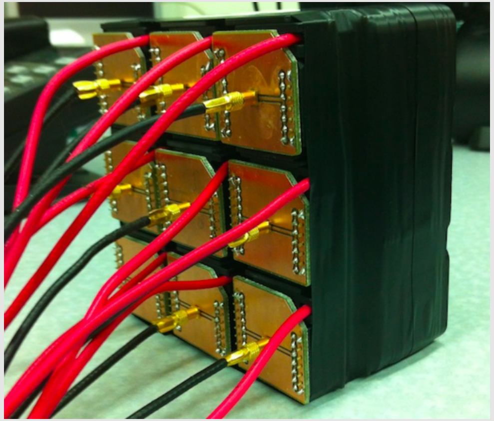
Construction of SE Calorimeter Modules

SE modules with 7 Hamamatsu R7761 19 stage mesh dynode PMTs were constructed. The baseboards were designed to provide three operation modes:

- Normal divider (photomultiplier) mode
- Cathode – first dynode shorted mode
- Floating cathode mode





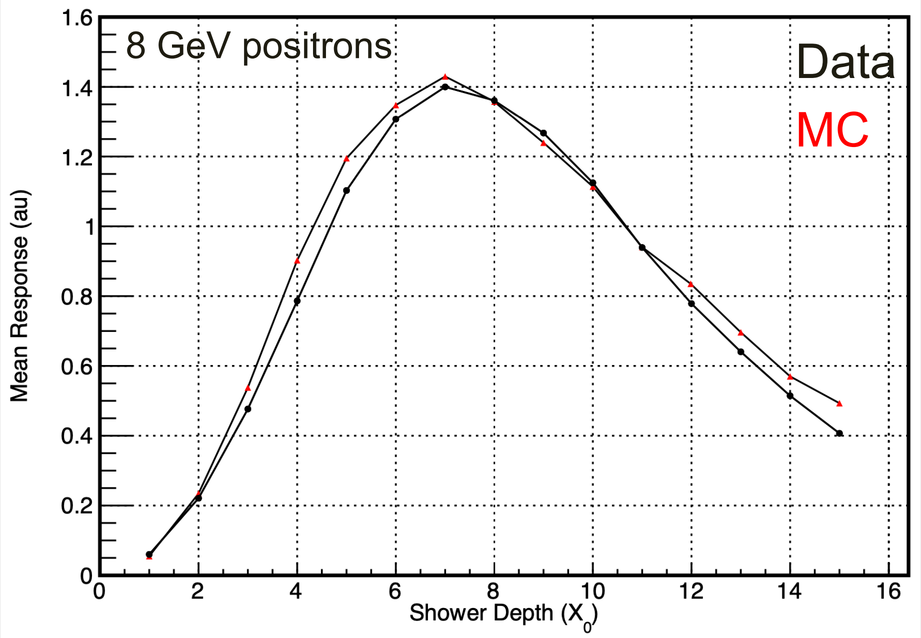


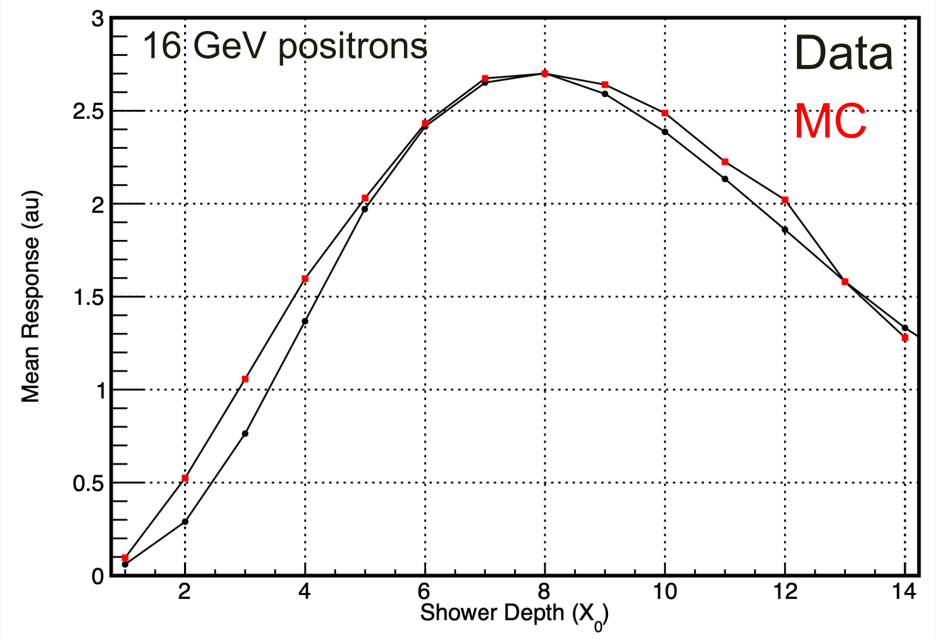
The default operation mode for the SE module was the cathode - first dynode shorted mode (B-C bridge) with an average gain of 6-9$\times$10^5.

E. Tiras, et.al., JINST 11 P10004, 2016

Tests of SE Modules – Metal Screen Dynodes

The SE modules were tested at FTBF with 8 GeV and 16 GeV positrons. The lateral coverage of the modules does not allow an effective measurement of the shower development with steel absorbers. The measurements were taken with the central sensor and up to 16 3 cm × 3 cm × 0.35 cm tungsten absorbers. MC matching is still under development.



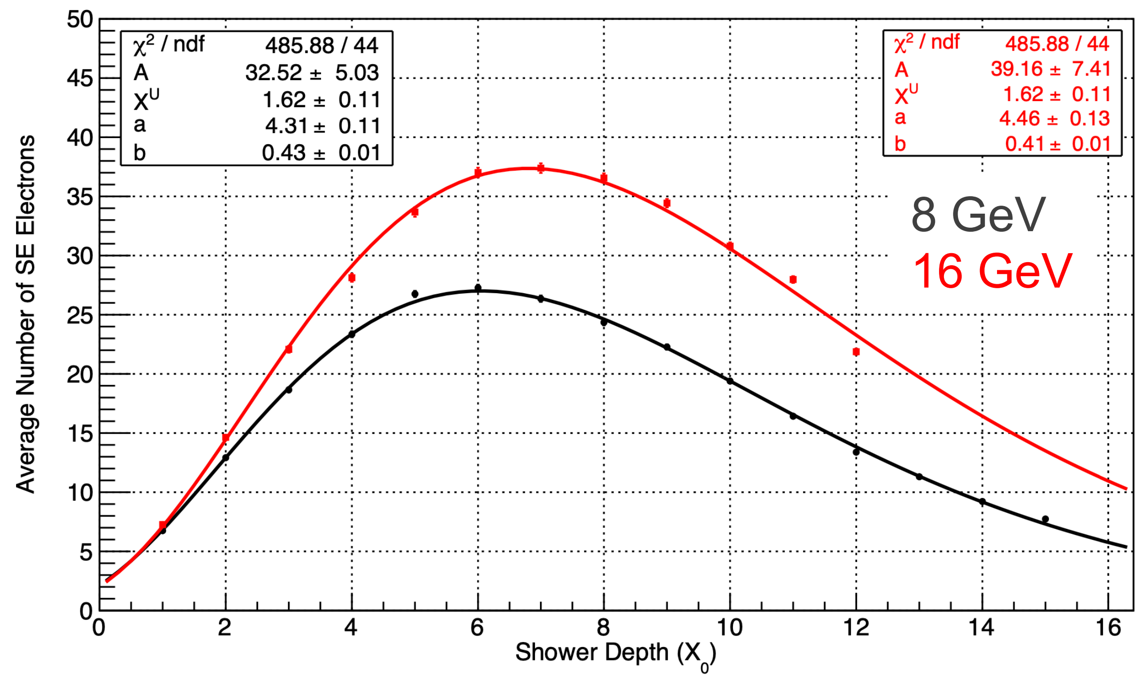


The results validate the principle of SE calorimetry.

Tests of SE Modules – Etched Metal Sheet Dynodes

16 mm x 16 mm active area, cathode – first dynode shorted mode, calibration was obtained using the laboratory gain measurements in the same mode.

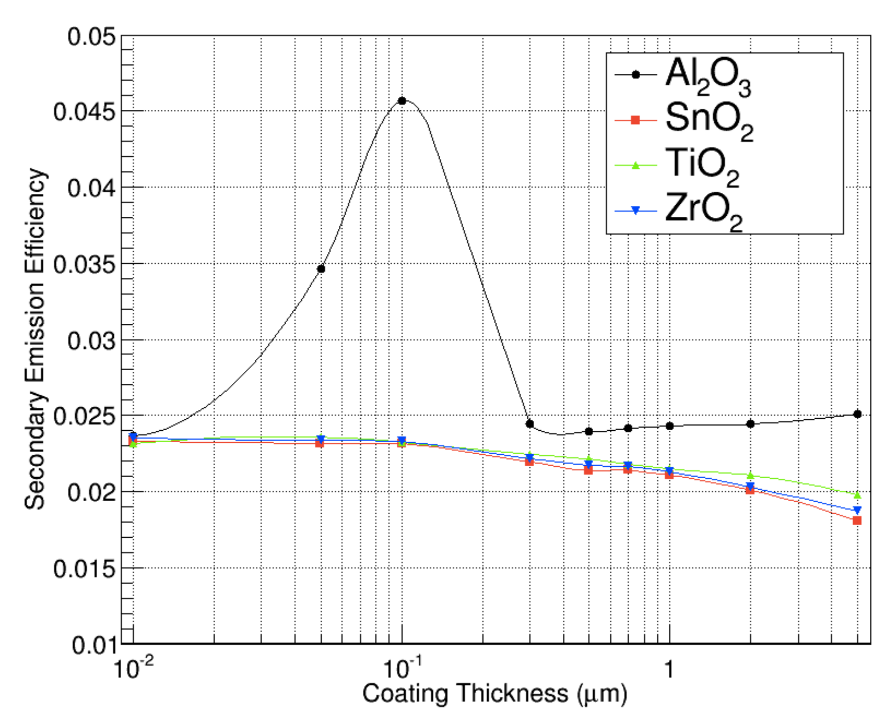
~280 SE e⁻ for 8 GeV and ~400 SE e⁻ for 16 GeV; 25-35 SE e- / GeV → limited lateral coverage



Fit to $A \frac{\left(X+X_0^U\right)^{a-1} e^{-c\left(X+X_0^U\right)}}{\Gamma(a)}$

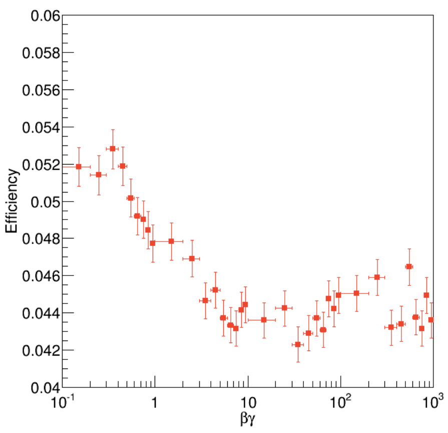
Enhancement of Secondary Electron Emission

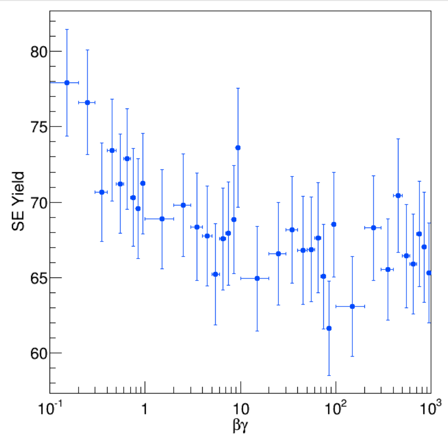
The cathode and the dynodes of the SE sensors can be made by coating the mesh copper foils with secondary emitters like Al_2O_3, SnO_2, TiO_2 or ZrO_2. The coating can be done with magnetron sputtering with the simplest options being Al_2O_3 and TiO_2.



Average secondary electron emission efficiency was calculated for various thicknesses of Al_2O_3, SnO_2, TiO_2 and ZrO_2 with 4 GeV muons (MIP).

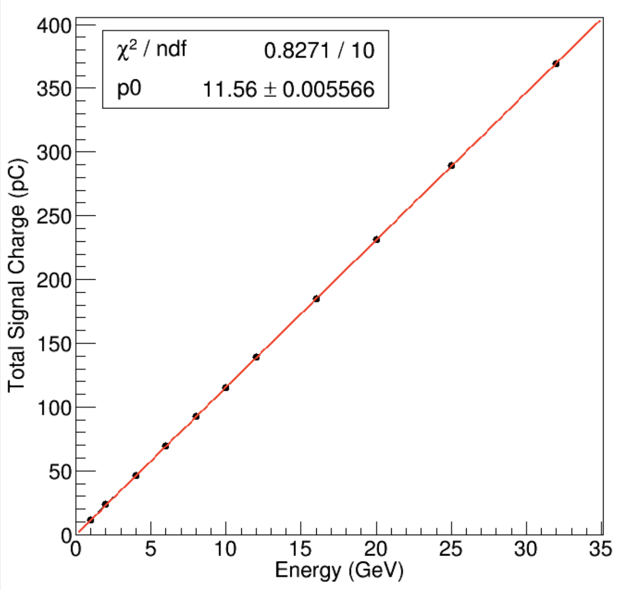
The best performance was predicted to be with 100 nm thick Al_2O_3.

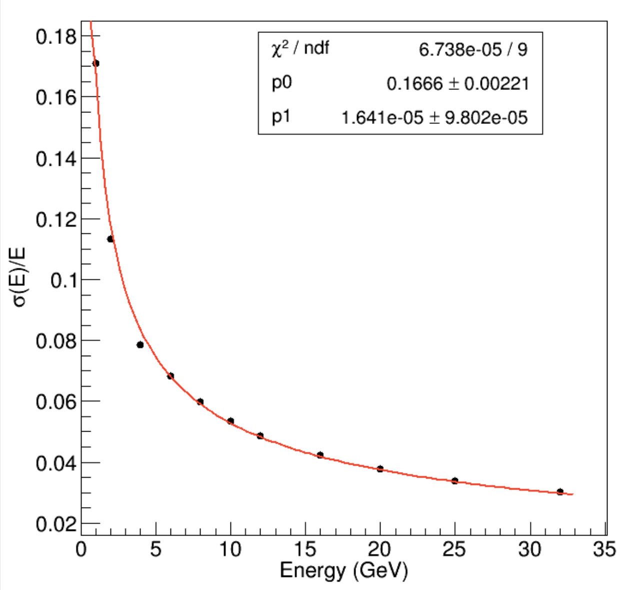




Projection to a Full-Scale SE Sensor

- The mesh structure made by holes of size between 10 and 100 microns and hole spacing of 50 – 100 microns.
- 150 microns distance between the dynode layers.
- Vacuum housing (no dramatic vacuum requirements).
- Start with a 9-stage multiplication and 16 active layers interleaved with 1 X_0 tungsten absorbers





The detector response is linear in the energy range of 1-32 GeV and the electromagnetic energy resolution is obtained as $^{16.7\%}/_{\sqrt{E}}$ with a negligible constant term.

Construction of Dedicated SE Sensors

The construction requirements for an SE Sensor Module are much easier than a PMT, since:

1. The entire final assembly can be done in air. Dynodes used as particle detectors in Mass Spectrometers or in beam monitors cycle to air repeatedly.
2. The thin film deposition procedure and the handling of the coated SE layer are not as delicate procedures as for the photocathodes.
3. The SE module is sealed by normal vacuum techniques.
4. The vacuum necessary is 100 times higher than that needed for a PMT photocathode.

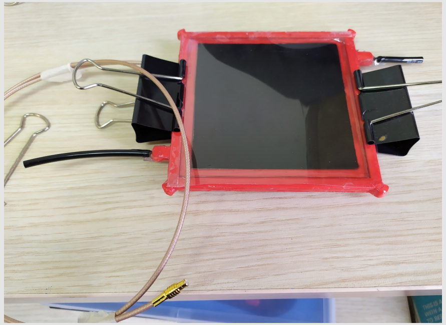
The modules envisioned are compact, high gain, high speed, exceptionally radiation damage resistant, rugged, and cost effective, and can be fabricated in arbitrary tileable shapes. The SE sensor module anodes can be segmented transversely to sizes appropriate to reconstruct electromagnetic cores with high precision.

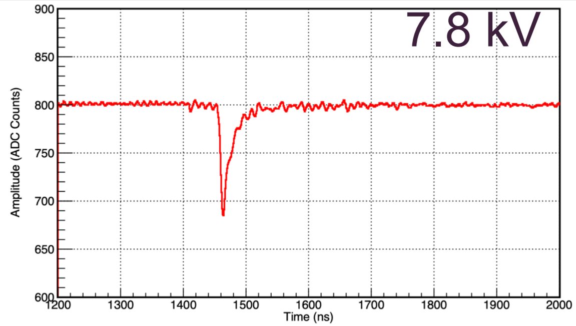
Development of Hybrid Resistive Plate Chambers
A Recent Implementation of SE Principle

A novel implementation probing a hybrid readout where part of the electron multiplication is transferred to a thin film of high secondary emission yield material coated on the readout pad with the purpose of reducing/removing gas flow and enabling the utilization of alternative gases.

Built several 10 cm x 10 cm x 1.3 mm chambers with single pad readout and Al_2O_3 and TiO_2 coating.

Coating of Al_2O_3 made with magnetron sputtering at Gazi University Photonics Application and Research Center (https://fotonik.gazi.edu.tr/). Coating of TiO_2 made with airbrushing after dissolving TiO_2 in ethanol.



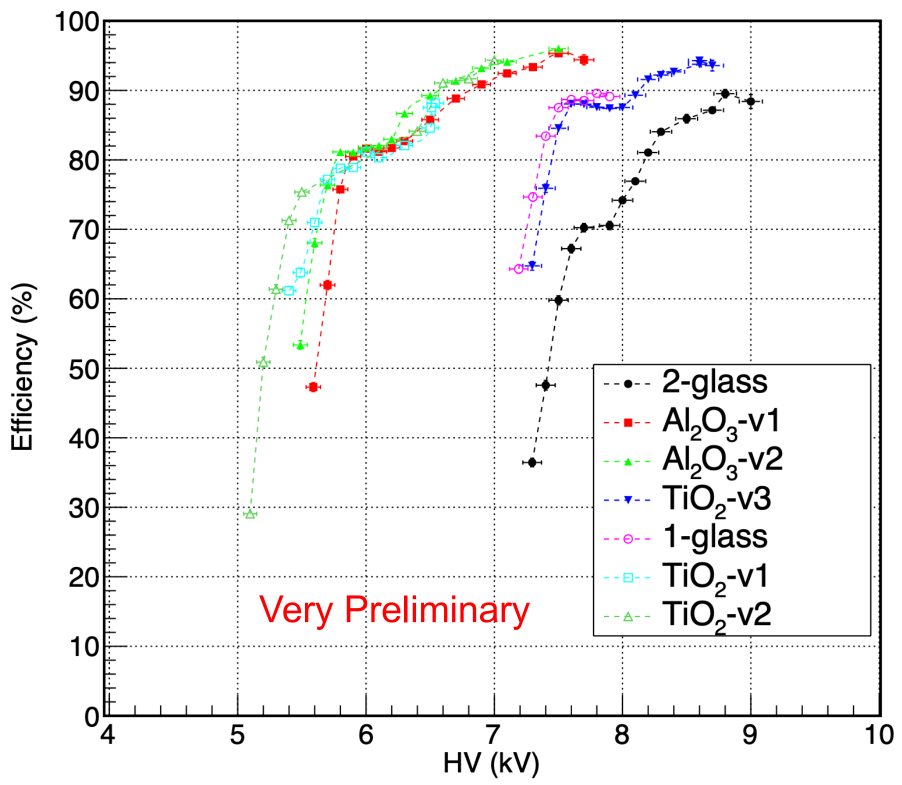


First-Generation Hybrid RPCs

We tested the first-generation hybrid RPCs as well as the standard 1-glass and 2-glass RPCs at Fermilab test beam. The lateral size of the chambers was 10 cm x 10 cm, the gas gap was 1.3 mm and the gas mixture was the DHCAL RPC gas mixture R134A : Isobutane : SF_6 ; 94.5 : 5.0 : 0.5 at 2-3 cc/min flow rate (lower than the nominal 5 cc/min).

The chambers tested:

1. 2-glass RPC
2. 1-glass RPC
3. 500 nm Al_2O_3 (v1)
4. 350 nm Al_2O_3 (v2)
5. 1 mg/cm^2 TiO_2 (v1)
6. 0.5 mg/cm^2 TiO_2 (v2)
7. 0.15 mg/cm^2 TiO_2 (v3)



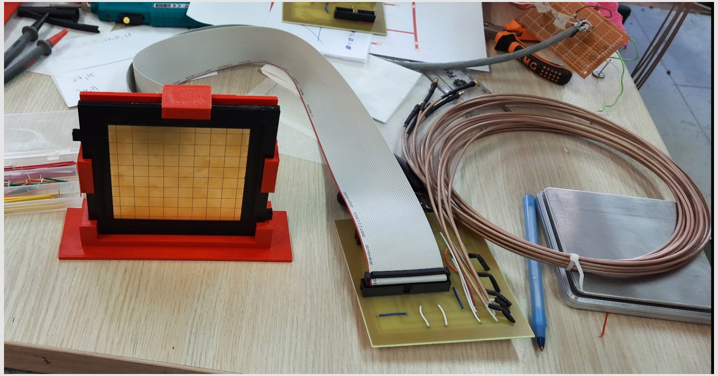
The charge multiplication in the secondary emission layer is qualitatively validated.

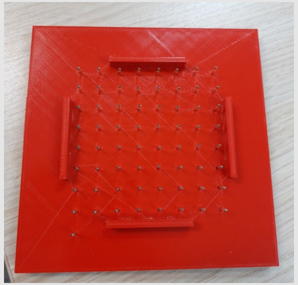
Efficient if charge > 300 fC

Second-Generation Hybrid RPCs

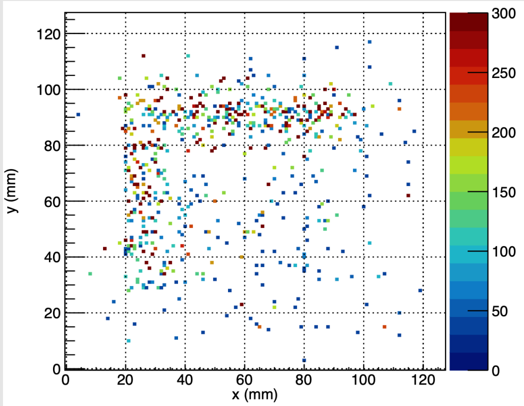
The hybrid RPCs with segmented readout of their anodes were constructed and tested at FTBF. The purpose was to study the spatial and timing properties of the various SE coatings in detail. The tests were negatively impacted by the accelerator problems.

The figure shows the average avalanche charge as a function of the wire chamber coordinates for the outermost L-shaped readout area. The boundary of the readout area is visible (very low statistics).





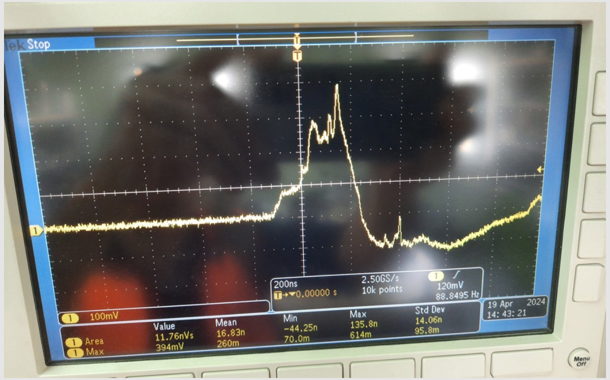
	1	2	3	4	5	6	7	8	
	9	10	11	12	13	14	15	16	
	17	18	19	20	21	22	23	24	
	25	26	27	28	29	30	31	32	
	33	34	35	36	37	38	39	40	
	1	2	3	4	5	6	7	8	
	9	10	11	12	13	14	15	16	
17/18	19	20	21	22	23	24	25	26	



Development of Hybrid Drift Tubes

A recent development to be used as the beam loss monitoring system at the Turkish Accelerator and Radiation Laboratory.

127 μm diameter nichrome wire coated with TiO_2/Al_2O_3 is used as the central electrode at the center of a 10 mm inner-diameter stainless steel tube. TiO_2 coating is done by dipping the wire in the TiO_2-ethanol solution and letting ethanol evaporate; >90% coating coverage with relatively good uniformity (observed with optical microscope). Al_2O_3 coating is done with magnetron sputtering, ~40% coating coverage with the current wire rotation system.



1 conventional and 5 hybrid drift tubes are under laboratory tests. $Ar:CO_2$-90:10

This work is supported by Tübitak grant no 123F335.

Conclusions

- Secondary electron emission principle provides opportunities to develop new generation particle detectors as well as to enable the evolution of the existing detectors.

- High secondary electron emission materials can be easily applied on various surfaces in the laboratory and facilities that can apply them in much larger areas exist.

- Secondary emission calorimetry is a feasible option particularly for electromagnetic calorimetry in high radiation environments, as well as other implementations such as beam loss monitors and Compton polarimeters.

- The construction of the dedicated secondary emission sensor modules is simple. The envisaged modules are compact, robust and cost effective.

- The preliminary tests validate the idea of using secondary electron emission materials for various detector types.

- Highly segmented readout for imaging calorimetry is possible.