Snowmass2021 - Letter of Interest
*[*Secondary Emission Calorimetry*]*

Instrumentation Frontier Topical Groups: (check all that apply □/■)

□ (IF1) Quantum Sensors
□ (IF2) Photon Detectors
□ (IF3) Solid State Detectors and Tracking
□ (IF4) Trigger and DAQ
□ (IF5) Micro Pattern Gas Detectors (MPGDs)
■ (IF6) Calorimetry
□ (IF7) Electronics/ASICs
□ (IF8) Noble Elements
□ (IF9) Cross Cutting and Systems Integration

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Abstract: This LOI is for further development of novel calorimeter sensors for electron, photon and hadron energy measurement based on Secondary Emission(SE) to measure ionization. The SE Calorimeter(SEcal) uses sheet-type or transmission dynodes directly as the active detection medium; the shower particles in an SECal cause direct secondary emission from dynode arrays comprising the sampling or absorbing medium. The resulting secondary emitted electrons are amplified by the downstream dynodes. The SE sensor modules can be made radiation hard at GigaRad levels, are easily transversely segmentable at the ~mm scale, and in a calorimeter has energy signal rise-times and integration better than plastic scintillation/PMT calorimeters. Applications are mainly in the Energy and Intensity Frontiers, and have broad applications in radiation detection. In the Cosmic Frontier, the high vacuum in space enables secondary emission sensors without vacuum seals.

Secondary Emission Calorimetry

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Introduction: Secondary Emission[1] (SE) is extraordinarily radiation resistant, and a fast process occurring in less than 1 ns in metal oxides. The SE beam monitors used at accelerators have no change in operation up to 10^{21} protons/cm2 and use a simple native metal oxide film a few nm thick (alumina or titania)[2] and cycle to air. In PMT dynodes, the submicron thick metal-oxide coatings on the dynodes survive 10's GRad of heavily ionizing electron bombardment with tolerable degradation[3]. Essentially an SE calorimeter is composed of a monotonous array of PMT dynodes without a photocathode, which can self-operate at the Gain-BW of PMT, (~10^6 x 100 MHz). Dynode arrays can cycle to air without degradation, such as those used in mass-spectrometry detectors[4], and do not require thin film control as in photocathodes, making construction far easier and cheaper than PMT. Detectors in the forward regions at present and future colliders would greatly benefit from this device. Precision calorimetry at very high rates for lepton number violation would also benefit.

In a Secondary Emission (SE) calorimeter ionization detector module, Secondary Emission electrons (SEe) are generated from an SE surface/cathode/"dynodes", when charged hadronic or electromagnetic particles (shower particles) penetrate an SE sampling module either placed between absorber materials (Fe, Cu , Pb, W etc) in calorimeters, or as a homogeneous calorimeter consisting entirely of dynode sheets as the absorbers. An SE cathode – as on PMT dynodes - is a thin (10-50 nm thick) film. These films are typically simple metal-oxides Al_2O_3, MgO, CuO/BeO, or other higher yield materials. The simple as-found native oxide on Al produces 6 SEe/per incident at the peak of the SE yield parametrization as shown in Figs below. On the inner surface of a metal plate in vacuum, which serves as the entrance "window" to a compact vacuum vessel (metal or metal-ceramic), an SE film cathode is analogous to a photocathode, and the shower particles are similar to photons incident. The SEe produced from the top SE surface by the passage of shower particles, as well as the SEe produced from the passage of the shower particles through the dynodes, are similar to p.e. The SEe are then amplified by sheets of dynodes – metal-meshes or other planar dynodes. The SEe yield δ is a strong function of momentum, following dE/dx as in the Sternglass[5] formulae. The yield follows a universal curve when normalized to the peak yield, as shown in Fig.1. As shown in Fig. 2 from CERN data, yields from a MIP on robust materials like alumina or titania films are only 1.10-1.2, requiring many dynodes for a MIP signal. On the other hand, as the shower is fully absorbed, those yields rise to about 6-7 at low energies. This variation with particle energy gives rise to quasi-compensation effects as the low energy nuclear fragments of hadron showers have high yields; for example 1 MeV alpha particle produces ~20 SEe. *We emphasize the comparison between SEe and p.e. – both are the result of dynode amplification; in a scintillation calorimeter, many photons are made per GeV, but typically only ~1-0.1% are collected and converted to p.e.; in an SE calorimeter, relatively few SE electrons from the shower particles are generated as the showers pass through the dynodes, but essentially all those SEe are amplified by the downstream dynodes. The statistics of p.e. and SEe are similar.*

SE sensor modules can make use of electrochemically etched/machined or laser-cut metal mesh dynode sheets, as large as ~30 cm square or more, to amplify the Secondary Emission Electrons (SEe), much like those that compact metal mesh or mesh dynode PMT's use to amplify p.e.'s. The secondary

emission yield follows dE/dx vs E or p. MIPs typically saturate at 0.15 SEe/mip, and rise by a factor of 20 at the low energy peak, typically 4-7 SE/incident particle, although thin film synthetic diamond can emit up to 120 SEe at 3 KV incident. We have studied this using GEANT4[6] to MC.

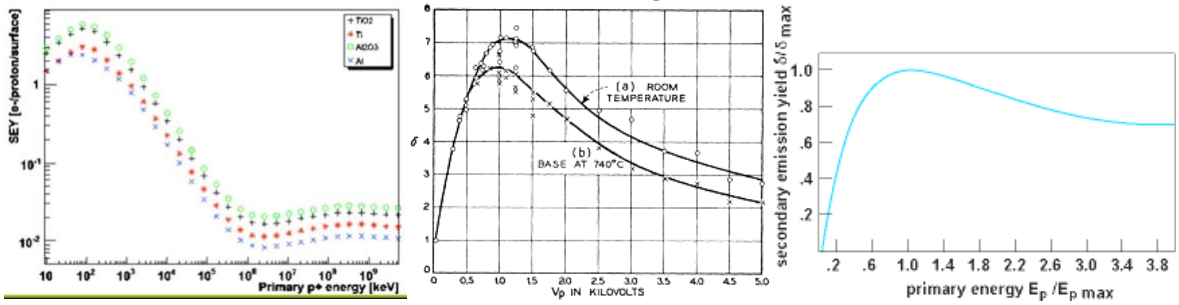

Fig 1a,b,c: Yield vs proton energy for titania and alumina and for the bare metals; Yield for MgO vs electron energy. Universal curve of SE scaled by maximum yield and by maximum energy

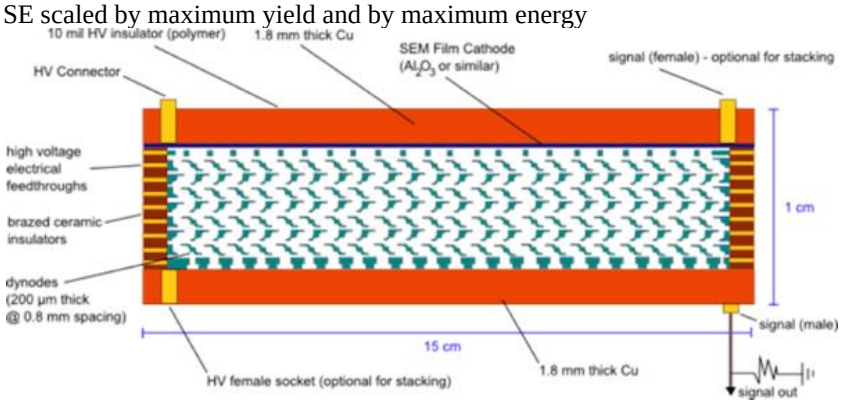

Figure 2: A cartoon of a proposed Secondary Emission Calorimeter Module, using etched metal sheet dynodes similar to those used by Hamamatsu. Commercial Cu-Be meshes are also possible and low cost ($20/m^2)

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; Mass Spectrometer dynodes cycle to air repeatedly.
2. there are no critical controlled thin film vacuum depositions for a photocathode, cesiation or other oxygen-excluded processes or other required vacuum activation is not necessary (although possibly desired for enhanced performance).
3. bake-out can be a refractory temperatures, unlike a photocathode which degrades at T>300°C;
4. the SE module is sealed by normal vacuum techniques (welding, brazing, diffusion-bonding or other high temperature joinings), with a simple final heated vacuum pump-out and tip-off.
5. The vacuum necessary is *100 times higher* than that needed for a PMT cathode

Modules envisioned are compact, high gain, high speed, exceptionally radiation damage resistant, rugged, and cost effective, and can be fabricated in arbitrary tileable shapes. Mesh dynodes will work at 10% gain in 1.2 T at 45° to the B-field[7]. The SE sensor module anodes can be segmented transversely to sizes appropriate to reconstruct electromagnetic shower cores with high precision. The GEANT4 sampling calorimeter response performance is between 35-50 Secondary Emission electrons (SEe) per GeV of e-m deposition, in a calorimeter with 1cm Cu absorbers interspersed with 15 planes of Cu mesh dynodes, with a gain per SEe of ~10^5 per SEe, and an e/pi<1.2. The calorimeter pulse width 10%-10% is estimated to be <11 ns based on shower length, secondary electron transit time estimate, and mesh PMT TTS. A MC of a *homogeneous* (i.e. no absorber except dynode sheets) calorimeter using 10µm W mesh sheets at 10 µm spacing (40% density of W) generates > 40,000 SEe per GeV, and a stochastic term inferred of less than 1%/√E(GeV), assuming each SEe is amplified by the downstream mesh to a conveniently detectable level (g>4 x 10^4 per SEe). An SEe is treated exactly like a p.e. in a scintillator calorimeter, where many photons are created, but 0.1-1% are converted to p.e. by a PMT of SiPM; by contrast, in an SE calorimeter, relatively few SE electrons are created, but almost all are collected and amplified by the dynode stacks as SEe.

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