[Photomultiplier and Dynode Techniques for in-situ Calorimeter Sensors to Survive in the Forward Region of Future Colliders, High Intensity and Low Earth orbit Cosmic Frontiers]

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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Photomultiplier and Dynode Techniques for in-situ Calorimeter Sensors to Survive in the Forward Region of Future Colliders, High Intensity and Low Earth orbit Cosmic Frontiers

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Present and Future Hadron and E-M calorimeters, pre-radiators, and calorimeter stub-pre-trackers:

- Calorimeters in the Forward Region (η≥3)at near and far future pp, ep, e+e- and muon colliders will need to measure high-energy jets at irradiation levels ~1 GigaGy and $>10^{17}$ neutrons/cm^2 . This exposure is planned for HL-LHC/SLC in the forward region in the next 10-15 years.
- At 10m from the interaction, the η≥3 forward region at HLHC/SLHC, the occupancy of a 1cm^2 patch of calorimeter is 100%, with pileup of 100-1000 events/crossing.
- In future colliders, calorimeter channels operate at 40MHz-!00MHz, with hysteresis pulse-pulse <5%.
- For pileup mitigation, a time precision for jets must be ~30ps or better, with energy flow capability.
- In order to calibrate, the energy scale is from ~0.1 GeV to >10 TeV, a dynamic range of 10^6-10^7.

Studies of vector-boson scattering and fusion require very forward jet tags and precision measurement of the subsequent vector boson decays. The η reach necessary will grow with increasing energy. Future experiments would benefit from reconstructing/identifying Z's & W's by jet-jet decays (rate 5-6x of lepton decays) *and especially to separate jet-jet W decays from Z decays*. Reasonable separation requires a relative jet energy resolution of ~3% at 100 GeV, with typical jet single particle energies ~10-15 GeV. A jet energy resolution of 3%-4% over 50-500 GeV yields a 2.6-2.3σ W/Z separation (Fig 1). To separate/identify Z and W from their jet-jet decays requires a hadronic energy resolution scaling like ~20%/√E. To measure H->gg, and the tiny rates for decays to $\pi^0\pi^0$, ee requires e-m energy resolution to scale like 2%/√E with a ~1% constant term.

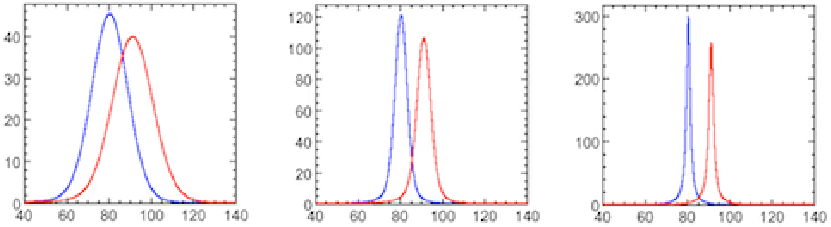

Fig. 1a,b,c: W/Z to jet-jet mass separation: *left* - typical hadron calorimeter σ_E/E=60%/√E; *middle* σ_E/E = 3% at 50 GeV: 2.6σ separation; and *right* -perfect resolution: ~4.5σ separation.

At the present time, almost none of the presently used calorimetry basic sensors (collected ions/electrons, optical signals) can either survive the raddam or operate without hysteresis at rate or both. We propose to study the capability of photomultiplier and dynode technologies as a potential energy-flow calorimeter with multiple signal compensation.

Metal-oxides on the surfaces of metal or ceramic dynodes at present survive many GRad exposures of electron bombardment at the last dynodes. Photomultipliers with quartz or synthetic sapphire windows survived unshielded for decades in space conditions. The first airport x-ray scanners used PMT which survived for 20 years. Comparative tests on gamma-irradiation of industrial photo-multipliers and various PMT window materials confirmed that degradation of PMT sensitivity depends only on PMT window transmission loss.

Photomultipliers in calorimeters produce huge background signals from muons crossing the PMT from Cerenkov in the PMT glass and direct dynode secondary emission. We propose to turn that *bug* into a *feature*: Compact PMT with metal envelopes and quartz or sapphire windows are available, and could be manufactured in quantity. An example is a 5x5 cm area Hamamatsu PMT with etched metal dynodes and2x2 or 4x4 anodes, only 1.5 cm thick. Similarly mesh-type dynodes can be compact with even better magnetic field resistance. Depending on the application, PMT could be manufactured with a metal "window" – no photocathode – for dynode secondary emission as the shower particles sampling detector. Such a detector would be much cheaper than a PMT and could have vacuum 100 times higher than the PMT which needs UHV to protect the photocathode.

A PMT with a quartz or sapphire window and coupled to a quartz, sapphire, MgF_2 or silica aerogel tile may prove to be quasi-compensating, by in effect dual sampling. The Cerenkov light is more sensitive to e-m showers, while the dynode secondary emission is proportional to dE/dx for shower particles traversing the PMT. The SEe yield is a strong function of momentum, following dE/dx as in the Sternglass formula and peaking for low-β particles as in a hadron shower. We propose to carefully test the proposition of quasi-dual compensation by MC and beam tests, also examining the waveform which may indicate differences in the Cerenkov signal and the direct dynode signal in the shower.

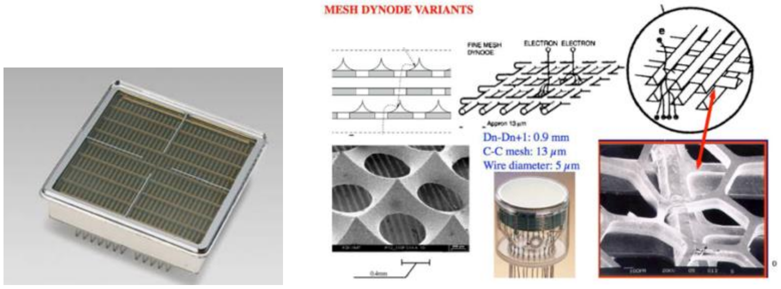

Fig 1: Examples of magnetic field operable and potentially compact PMT using mesh and channelized etched dynode. At left is a 5x5cm x 1.5 cm thick PMT using channelized dynodes with a 0.4ns risetime. Using the 10% risetime time resolution, a 40ps resolution or better is possible.

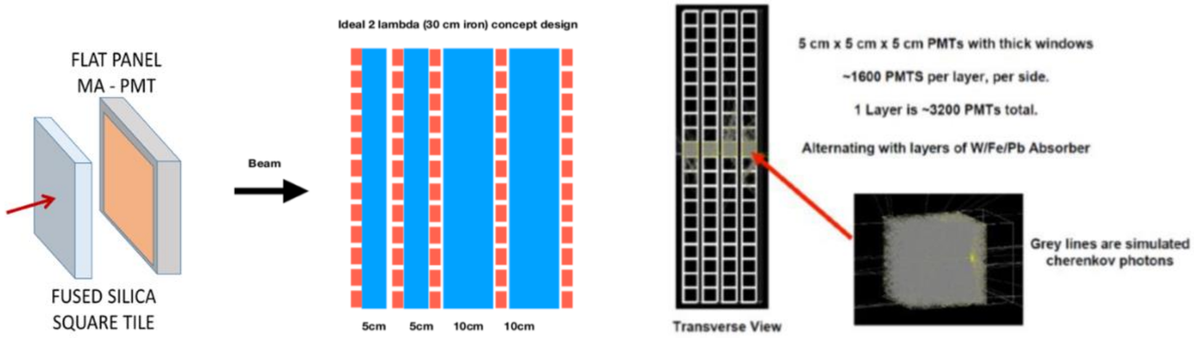

*Fig.*2: Cartoon of a ~1.5-2 λ stub quartz+PMT calorimeter. *Left* is the basic calorimeter component, a rad-hard Cerenkov tile sensitive to high β/mips coupled to the PMT, with the dynode stack sensitive to dE/dx of the showering particles, and peaking at lower momentum, most sensitive to low energy hadrons and ion fragments. Middle is an example of a stub calorimeter. The Orange rectangles represent Quartz tiles ~1.25x1.25 cm, coupled to 5x5cm 4x4 multianode compact as in the figure at right.. The blue is Fe absorber tiles. Right is a preliminary MC of a simple calorimeter.

Tests we propose include: measuring the PMT neutron response; radiation damage of *operating* quartz window metal envelope PMT to γ and n; PMT+Cerenkov tile response to mips and at hadron and e-m shower maxes, with 4 types of Cerenkov tiles; PMT powered so that the photoelectrons do not reach the dynodes, and PMT powered so that the middle dynode is in effect the anode at virtual ground and the 1st dynode and last dynode or anode at -HV while the remaining dynodes are stepped down by ~150V per stage.