Snowmass2021 - Letter of Interest

[Tile Multiple-Readout Compensated 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

Contact Information:

Name (Institution) [email]: David R Winn (Fairfield University)[winn@fairfield.edu]

Authors: Yasar Onel[1], Burak Bilki[1], James Wetzel[1], Lucien Crimaldi[2], Donald Summers[2], David Winn[3]

1. University of Iowa 2. University of Mississippi 3. Fairfield University

Abstract: We propose to explore novel techniques and materials to develop unprecedented optimization in the long-term performance of calorimeters as required by the challenging environment of future colliders and high intensity experiments, by extending Dual Readout from fibers to tiles to be able to use Cerenkov tiles with lower index of refraction than available rad-hard fibers – higher em/hadron contrast, and by employing multiple sensor signals (3 or more types of sensors, beyond plastic scintillator or quartz Cerenkov fibers) with different responses from different sensors sampling the same jet, e-m, or hadronic showers. Examples include transition radiators, secondary emission, and hydrogen or isotope enhanced tiles.

Tile Multiple-Readout Compensated Calorimetry

Yasar Onel[1], Burak Bilki[1], James Wetzel[1], Lucien Crimaldi[2], Donald Summers[2], David Winn[3*]

Iowa Mississippi Fairfield

Abstract: We propose to explore novel techniques and materials to develop unprecedented optimization in the long-term performance of calorimeters as required by the challenging environment of future colliders and high intensity experiments, by extending Dual Readout from fibers to tiles to be able to use Cerenkov tiles with lower index of refraction than available rad-hard fibers – higher em/hadron contrast, and by employing multiple sensor signals (3 or more types of sensors, beyond plastic scintillator or quartz Cerenkov fibers) with different responses from different sensors sampling the same jet, e-m, or hadronic showers. Examples include transition radiators, secondary emission, and hydrogen or isotope enhanced tiles.

As an example of needed calorimeter resolution in the Energy Frontier, future experiments would benefit from reconstructing/identifying W and Z bosons by jet-jet decays, 5-6 times more abundant than leptonic decays, and especially the ability to separate W-›jet-jet from Z-›jet-jet decays. Reasonable separation requires a relative jet energy resolution of ~3% at 100 GeV, with typical jet single particle energies ~10-15 GeV. A ~3% jet energy resolution from 50-500 GeV yields a 2.6-2.3σ W/Z separation (Fig 1)[1].

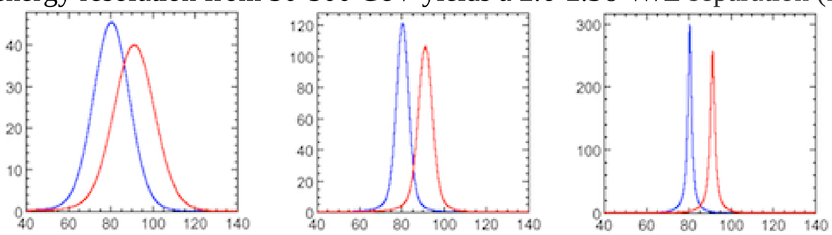

Fig. 1a,b,c: W(blue)/Z(red)**-›**jet-jet mass separation: *Left* - typical hadron calorimeter $\sigma_E/E=60\%/\sqrt{E}$; *Middle* σ_E/E = 3% at 50 GeV with a 2.6σ separation; and *Right* -perfect resolution with ~4.5σ separation.

Intensity Frontier:

- Requirement of excellent calorimeter energy and position/angle resolution in future LHCb, e^+e^- b-factories, beam-dump dark photon/DM, and high energy neutrino scattering at future μ/ν factories.

- *b, τ via jet-jet decays in b-factories,* b-physics pp (LHCb) or ep collider experiments.
- *τ detection via jet-jet decays- Long Baseline* (LB) high energy ν Detectors (muon factory ν_μ beams).
- *LB ν/Atmospheric ν:* Combined Cerenkov light + ionization (drifted LAr) in large detectors
- *Dark Photon/DM experiments* Ex: 1-10 GeV tagged electron beams to detect small missing $\mathbf{p}_T$.
- *Tagged ν_e Beams from K-decay* –requires high rate (>100 MHz) and rad-resistant calorimetry[2,3]

Cosmic Frontier:

- *Future balloon or AMS-like space-based* (as proposed for the China Space Station[4]) experiments: more compact calorimeters yet with similar resolution, when combined with particle-flow.

Dual Readout (DR) is the precursor to multiple readout. DR is a technique to correct calorimeter response functions by measuring separately the electromagnetic component and the hadronic component of a hadron or jet calorimeter shower, event-by-event. A second method for improved calorimetry is particle flow/high granularity readout. One method, Cerenkov Compensation, that approximates this is by measuring Cerenkov light and ionization simultaneously & independently in calorimeter events. This was first invented and studied in detail using GEANT MC in 1988 by our group ["Compensating Hadron Calorimeters with Cerenkov Light", D. R. Winn and W. Worstell, IEEE Trans. Nuclear Science Vol. NS-36 , No. 1, 334 (1989)]. This technique has been reduced to practice by R.Wigmans et al. from Texas Tech (TTU), based in part on our group's development of parallel Cerenkov fiber calorimetry first for SSC and forms the forward calorimeter in CMS. However, the TTU group used parallel fiber geometry, with parallel, longitudinal quartz Cerenkov fibers and plastic scintillating fibers in a Cu matrix – incompatible with high granularity reqadout. Despite showing the benefits of significantly better hadron energy resolution of dual readout using parallel fibers not reaching better than σ_E/E ~30%/√E. We consider instead quartz and other Cerenkov tiles and scintillating tiles to fix a number of defects using tiles in a manner similar to the construction of the Barrel and Endcap calorimeters in CMS, and extended by adding tiles with more contrast between hadronic and e-m signals. In particular, compared with fibers, tile construction *1. Reduces Constant Term* – unavoidable issue – scintillator light attenuation ~2+ m of fiber;. *2. Enables Pointing/Projective Geometry; 3. Lower Scintillator & Photodetector Raddam*; *4. Reduces Fiber Bundle & Photodetector Punchthrough* and streaming in grooves; *5. E-M and Hadronic Components of Incident Jets:* Parallel fibers low ability to detect + separate incident direct e-m component inside of a jet -no longitudinal segmentation*; 6. High Resolution EM* Front End possible; 7. Calibration*:* Parallel fiber geometry difficult to calibrate, as radiation damage & attenuation varies w/ length; *8. Timing & Pileup* easier with tiles; *9. Longitudinal Segmentation; 10. Cerenkov (Fiber)Index of Refraction:* High Radiation Resistant Cerenkov fibers limited to quartz, with n=1.46 – h/e_C ~0.25-0.20 – limiting resolution. Low index n tiles possible -> lower h/e_C ratio (aerogels, Teflon AF, Siloxanes, Fluoride glasses,….) *11. Particle Flow/Energy Flow High Granularity* Calorimetry incompatible with fibers; *12. Other Sensors for Dual, Triple Readout:* Parallel fibers cannot use other hadronic or n-enhanced sensors, and other e-m energy sensors. Examples: ionization detectors (solid – Si, Diamond, GaAs; liquid- LArgon; gasses – micromegas..); β->1 sensitive detectors such TRD, or ultra-low-index materials(aerogels, MgF2, water, perfluoros, silicones,..); secondary emission sensors with higher response to slow particles β ->0 and minimal response to minimum ionizing energy (new large MCP); inorganic non-hydrogenous scintillators (LYSO, PbWO4 et al.), and $_6$Li, 1_0B or $_3$He containing materials; 12. Cost: the cost of tiles is significantly less per mass or volume of sensitive material than that of fibers, and the cost of a fabricated tile absorber matrix is considerably less than the parallel fiber Swiss cheese.

Multiple Readout: Adding *more kinds* of sensor tiles with characteristics different than those of quartz and plastic scintillator improves resolution – tiles relatively insensitive to MIPs, OR more sensitive to γβ->0 increases the contrast between e-m and hadronic energy (enhancing the low energy hadronic signal) *ie Multiple Readout.*– one such sensor is Secondary Emission; its signal scales as dE/dx, with a MIP SE signal ~100x less than that of the energy of the peak signal (peak signal for protons occurs at ~200KeV - n+p -> p+n knock-on protons), contrasted with TRD which can limit β->1.

Theoretical Multiple Readout Resolutions: ~15%-18%/√E on jets: scintillator sensors with h_i/e_i ~ 0.6-0.8 (likely hydrogenous & n-sensitive), and Cerenkov sensors with $h_c/e_C \leq 0.2$ are needed. To achieve $h_c/e_C <$ 0.2, lower index of refraction Cerenkov radiators are required(i.e. βthresh ->1), but require enough thickness for photons to achieve an e-m resolution < 70%/√E(GeV) or Npe > 2 pe/GeV. These are available; we propose using such tiles in a calorimeter prototype.

[NOTE: Homogeneous non-hydrogenous dense inorganic scintillators (LYSO, PbWO4,CeF3): - h_i/e_i ~ 0.4 and h_c/e_C ~ 0.25, or [h_i/e_i]/[h_c/e_C] ~1.6. Homogeneous calorimeters *cannot* achieve dual readout compensation better than ~50-60%/√E on hadrons, even with perfect separation between ionization & Cerenkov light in the homogeneous detector, such as might be possible, for example, in noble liquids read out with drifted ions and with Cerenkov light .]

We suggest construction of a hanging-file calorimeter prototype able to test tiles of quartz, various plastic and nanocrystal doped scintillators (including quartz tiles with nanocrystls, secondary emission, aerogel , LYSO (e-m front section only), Teflon-AF, new clear Kapton, TRD, and tiles doped with neutron sensitive materials as a search for the highest resolution jet calorimetry. Where possible we will borrow tile planes to adapt to the hanging file from the HEP community.

[1] Mark Terwort, Status of the CALICE analog calorimeter technological prototypes, arXiv:1209.2594
[2] Longhin, L. Ludovici, F. Terranova A novel technique for the measurement of the electron neutrino cross section, arXiv:1412.5987
[3] A. Meregaglia, ENUBET: Enhanced NeUtrino BEams from kaon Tagging, Journal of Instrumentation, Volume 11, Dec. 2016 , 14th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD16)
[4] S. N. Zhang et al. (HERD), Proc. SPIE Int. Soc. Opt. Eng. 9144, 91440X (2014), 1407.4866.