Project name

Cherenkov compensated calorimetry

Classification (accelerator/detector:subsystem)

Detector:subsystem

Institution(s) and personnel

University of Iowa, Department of Physics and Astronomy:
Yasar Onel (professor) Co-PI, E. Norbeck (professor), J.P.Merlo, A.Mestvirisvili (post-doc), U.Akgun, A.S. Ayan, F. Duru (grad.students), I.Schmidt (Mechanical Engineer), M.Miller (electronics engineer), Jon Olson (undergrad. scholar)

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Aldo Penzo (professor)

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Project Overview

Introduction:

We propose to study a novel idea to employ a dual readout calorimeter, simultaneously measuring the Cerenkov light with ionization on hadron-initiated showers on an event-by-event basis to compensate calorimeters, and to achieve precision energy resolution.

Briefly, the idea is that as a shower fluctuates more into charged pions rather than neutral pions, that a Cerenkov signal generated in a transparent absorber/active medium, which arises mainly from the e-m component of the shower, is reduced in a correlated fashion with the ionization signal, thereby enabling a correction of the energy given by an ionization signal.

Preliminary infinite media GEANT simulations have indicated that the correction can in principle enable an energy resolution substantially better than existing calorimeters [1], which rely instead on suppressing the e-m signal relative to the hadronic signal.

Technical Proposal:

If a hadron shower were to fluctuate entirely into neutral pions (i.e. an extreme charge exchange for example), ionization and Cerenkov signals both can achieve excellent resolutions if sufficiently well sampled (NaI and Pb-glass calorimeters can have excellent resolutions on electrons, for example). However, as the hadron shower fluctuates into charged pions and neutrons (etc.), both signals or measures of the energy, the ionization and Cerenkov signals, become degraded. In general, with a single calorimeter signal, it is not possible to know how much the signal is degraded or reduced compared with the initial hadron energy. However, in preliminary studies, the Cerenkov signal appears to degrade at a much larger rate as a function of Fpi, the fraction of charged pions, compared to ionization signals (both scintillation light from LScint, BaF2, and NaI, and a drifted ionization signal collected from LArgon were studied). If the Cerenkov and the ionization signals are highly correlated, then measuring both will determine how large the fluctuation is on any event, which can be then used to correct the energy.

These preliminary homogeneous calorimeter GEANT studies done some years ago indicate that an achievable energy resolution may allow a stochastic term less than 20%/√E, perhaps as low as 15%/√E, with a constant term tuned less than 1% on a hadron calorimeter. We propose to make an extensive MC study of designs which could be more easily be used in practice.

Historically, the E1A neutrino calorimeter, a pure liquid scintillator ionization hadron calorimeter, achieved a stochastic term of 11%/√E(GeV), showing the remarkable effect of large (i.e. 1/√N) signals, but with a constant term of 9% [8]. On the other hand, the SPACAL lead-fiber calorimeter achieved a hadron energy resolution of ~35%/√E, with a constant term of about 1%, as limited by the packing fraction of 20%. A compensated Cu-SciFi calorimeter constructed for SSC and the scintillator tile-Cu absorber calorimeters for ATLAS achieve resolution terms of about 60%-50%/√E, largely due to the low compensated packing fraction of about 2-3%. If the packing fractions in these practical devices were to be increased to about 25%-30%, the stochastic term could be reduced by ~x3, provided that the sampling fraction F and the sampling thickness d are such that the sampling fluctuations are less than the sampled energy statistics [5] [i.e. s/E = $(d/F)^{0.5}$ x $(E)^{-0.5}$, where d is the sampling thickness and F is the sampling fraction.] However, the constant term would increase to about 7%-8%. Thus it is worth considering if a "2nd" measurement could be used to adjust the constant term downwards, while allowing a large signal for a small stochastic term. Using typical SPACAL data for Fpi

[6], [7] the pion fluctuation fraction, and estimating the contribution from nuclear breakup by Wigmans [7], measuring the energy of the e-m component to about +/- 30%/√E should allow the adjustment of the constant term to ~1%.

The very first absorption calorimeters used homogeneous media Cerenkov light, in order to measure electromagnetic shower energy. Modern Pb-glass and especially water (Super-K) calorimeters achieve excellent resolutions on electrons (<2%/√E 9,000 p.e./GeV). However, on hadrons, both Pb-glass walls [2] and swimming pool calorimeters [3] have achieved a hadronic energy resolution of ~35%/√E, but with a constant term of ~10%.

Recent results by the CMS Forward Calorimeter Group (in which the proposers are participants) have shown that sampling Cerenkov calorimeters consisting of quartz fibers embedded in Cu serve as an adequate forward calorimeter[4]; the results indicate that the signal response is approximately given by: $(1\ \text{p.e./F})(NA/0.2)^{1.5}$, where F is the fiber packing fraction in percent, and NA is the fiber numerical aperture. At F~1%, at NA=0.2 and 0.4 mm diameter fibers, the Cu-fiber calorimeter achieves an energy resolution of about 100%/√E(GeV) on electrons, with a constant term <0.1%. With a F~25% packing fraction of NA~0.6 200 micron core clear fibers (n~1.6), one would therefore expect an electromagnetic energy resolution of better than ~10%/√E. This would be sufficient to measure Fpi, the fluctuations in the shower, to about +/- 30%/√E, which would in principle allow a constant term of 1-2%. Using similar scaling for a packing/sampling fraction of the ionization medium embedded in Cu, at say, F~25% for the ionization medium and d~0.5 mm thick sampling, one might obtain s/E ~15%-18% (as scaled from either the ATLAS (calorimeter), with a constant term near 1%.

If successful in R&D, the main uses in LC calorimeters would be to:

(1) High Resolution E-M Calorimeter Compensation for Jet Energy Resolution

To correct for jet energy from hadrons interacting in high resolution e-m calorimeters, at present, the use of an extremely non-compensated but very high resolution e-m calorimeter in front of a compensated hadron calorimeter results in relatively poor jet energy resolution, as in the CMS calorimeter system, where a PbWO3 front end with superb em resolution results in a jet resolution degraded to ~100%-120%/√E, mainly from jet energy deposited in an uncompensated, e/h~2, ~1-2Lint em calorimeter. For example, in a lead tungstate or cerium fluoride calorimeter in the front of LC experiments, 2 photo-readouts would be provided, with optical filters which accept either the scintillation light or the Cerenkov light generated in the crystal. Or with a Si or LArgon e-m calorimeter, additional Cerenkov sampling via fibers or plates would be provided.

(2) Intrinsic Hadron Calorimeter Energy Resolution

Increase hadronic and jet energy calorimeter energy resolution sufficiently so that Z_o identification and other precision dM/M and missing transverse energy measurements by jets becomes more feasible i.e., so that at least the intrinsic particle energy resolution is such that the calorimeter contribution to the jet-jet mass width is below the intrinsic Z or narrow Higgs widths this may require s/E ~ 25%/√E (together of course with requirements on increased transverse segmentation and adaptive global jet-cone algorithms which are not part of this study).

(3) Background Rejection

The Cerenkov signal in CMS prototype copper-quartz-fiber forward calorimeter for 375 GeV single pions has been shown to rise in <1 ns and to fully develop in less than 5 ns (0% →95% of the signal on the end of a cable). The superb timing available has been shown in MC to allow beam-gas and beam-halo muon rejection, and to associate signals with the beam crossing and with other calorimeter cells to a high enough precision to play a useful role in determining interesting events from the multiple events in an LHC crossing (very different from LC of course). However, the rate capability (small PMT have been run near 1 GHz for LHC tests) and timing of a well-designed Cerenkov fiber or plate component may play a crucial role in the environment of the LC interaction region where a calorimeter may still receive a considerable load of uninteresting signals & potential pile-up from beam-associated backgrounds and high instantaneous rates (albeit for short times, say ~10s of ns per crossing). Multiple measurements of the same hadron/calorimeter shower allow consistency checks for event-associated upsets (for example a splash through a PMT or a FET). Therefore a simultaneous Cerenkov-signal readout of an ionization calorimeter may be interesting on these grounds alone.

Proposal

We therefore propose:

FY 03 and 04:

Cerenkov Compensation MC Studies:

Study Cerenkov Compensation schemes using GEANT and LC simulation tools:

(a) MC "Calibration": Tune existing codes and reproduce the reported resolutions and response of existing calorimeters: the ATLAS scintillator plate-WLS fiber calorimeter, the CMS Forward Cerenkov Fiber calorimeter, and of at least one tested/published drifted-ion sampling calorimeter (Si or LArgon), and of at least on homogeneous crystal calorimeter. These will include full propagation of individual signal photons or electrons (for example, as captured on the WLS fibers, and realistic photodetectors, including both APDs and PMTs).

(b) WLS Fiber-Scintillator + Clear Fiber Geometry: MC Study an ATLAS-style/Gildmeister [6] Scintillating Tile/fiber Cu absorber Calorimeter geometry with high scintillator packing fractions, up to 40% of scintillator, and up to 40% of clear Cerenkov radiator fibers. (A very brief study will also be made using WLS fibers on clear C-radiators, but this is anticipated to fail.)

(c) Plate Geometry: MC Study of a classic plate absorber geometry: Cu absorber plate + [scintillator, LArgon, or Silicon] plate + Cerenkov plate. The Cerenkov plate would be read-out using an APD array

(d) All Fiber Geometry: MC study of Cu-absorber + Scintillating Fiber + Clear Fiber Calorimeter.

(e) Homogeneous Calorimeter Geometry: MC study of the simultaneous Cerenkov readout of e-m crystal calorimeter (lead tungstate), using filters and 2 photodetectors, and of collecting drifted ions and Cerenkov light in LXe. The authors have shown in detail that Cerenkov light and ionization light can be measured independently and simultaneously in LScintillator using filters (somewhat counterintuitively, the Cerenkov light is measured by using a low-pass filter i.e., the long-wavelength Cerenkov light despite the lower yield because of the shifting properties of the fluorine in the scintillator).

Budget-FY03-04

Institution	Item	Cost
Iowa	Partial support of two grad. student	$6,000
Iowa	½ post-doc	$25,000
Fairfield	Partial support for undergrad. students	$6,000
IowaState	Partial support for undergrad. students	$4,000
Iowa	Travel	$6,000
Fairfield	Travel	$4,000
IowaState	Travel	$2,000
Fairfield	Photon counting PMTs	$12,000
Fairfield	Tech. Support	$5,000
Iowa	Tech. Support	$5,000
Iowa	CERN test beam operations and shipping	$6,000
Fairfield	CERN test beam operations and shipping	$4,000
Iowa	MC studies	$4,000
Iowa	Iowa total	$52,000
IowaState	IowaState total	$6,000
Fairfiled	Fairfield total	$31,000
	Grand total	$89,000

REFERENCES:

[1] **D.R.Winn** and W.A. Worstell, "Compensating Hadron Calorimeters with Cerenkov Light", IEEE Trans. Nuclear Science Vol. NS-36 , No. 1, 334 (1989).
[2] Bitsadze et al., NIM (1988)

[3] B.C.Brown et al., Fermilab Report 1987 (also published in IEEE Trans.Nuc.Sci. 1989-90)
[4] N. Akchurin, **Y. Onel, D. R. Winn** et al., NIM A399, 202 (1997)
[5] O.Ganel et al., Proc.7th Conf. on Calor. in HEP, 141 (1997) Tucson
D.Acosta et al., NIM A316, 184 (1992)
[6] O.Gildmeister et al., Proc.2nd Conf. on Calor. in HEP (1991) Capri
ATLAS Tile Calorimeter TDR CERN/LHCC/96-42
[7] R.Wigmans, Proc.7th Conf. on Calor. in HEP 182 (1997) Tucson
[8] A.Benvenuti et al., NIM 125 447 (1975)

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