Proposal to the
University Consortium for a Linear Collider

July 25, 2003

Proposal Name

Investigation and Design Optimization of a Compact Sampling Electro-magnetic Calorimeter with High Spatial, Timing and Energy Resolution

Classification (accelerator/detector: subsystem)

Detector: electromagnetic calorimetry (barrel, endcap, low-angle).

Personnel and Institution(s) requesting funding

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Collaborators

There are a number of people working on related topics with whom we would expect to be able to collaborate well - but at the moment no formal collaboration exists.

The University of Colorado group (U. Nauenberg - contact person) are engaged in related activities for scintillator calorimetry and are discussing collaborating.

We have benefited and anticipate continuing to benefit from on-going simulation infrastructure efforts presently supported or contributed to by SLAC, ANL and NIU and collaborating with individuals at those institutions.

We are discussing with colleagues working on related activities in both Italy and Japan - in contact with P. Checchia (Padova) and K. Kawagoe (Kobe).

E. von Toerne and T. Bolton from Kansas State plan to collaborate on linear collider work but the form of their participation requires more discussion.

We acknowledge assistance with optics simulation from S. Bentvelsen (NIKHEF).

Contact Person

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Project Overview

Motivation: Existing linear collider (LC) detector designs emphasise precision tracking of charged particles ($\sigma(\frac{1}{p_t}) \approx 5 \times 10^{-5}\mathrm{GeV}^{-1}$) leading to fractional energy resolutions of better than 2.5% for the highest energy charged particles at a 1 TeV LC. Many of the golden physics channels have multiple heavy bosons in the final state and possibly missing energy : WW, ZH, ZH, $t\bar{t}$, ZHH, $\nu\bar{\nu}$VV, chargino-pairs, etc. This leads to multi-jet final states with high multiplicities containing several W's and/or Z's with resulting particle energies similar to W and Z decay, and so with relatively low energy. The requirements on detecting missing energy also dictate a hermetic design, so coverage is required as close to the beam-axis as possible.

Given the precision tracker and a modest energy "dynamic range", much attention has been focussed on applying the principles of energy-flow (EF) to the measurement of jet energies and angles. The concept is : use the tracker to measure charged track energies, use the electro-magnetic calorimeter (ECAL) to separate non-photons from photons and measure photons, and use the hadron calorimeter (HCAL) to separate non neutral hadrons from neutral hadrons and measure neutral hadrons. Since most of the non-charged energy is in photons and the charged particles and many of the neutral hadrons interact in the ECAL, the ECAL performance is crucial to successfully applying the EF concept.

A particularly promising approach applies the principles used in the limited solid-angle Silicon-Tungsten (Si-W) ECALs used for luminosity measurements at SLC and LEP to a 4π detector for the LC [1]. These are sampling calorimeters with layers of Tungsten absorber interspersed with layers of Silicon pads. Despite their technical merits, these approaches appear rather expensive for a large radius ECAL; they also down-weight energy resolution and downplay timing resolution in favor of excellent position resolution and shower imaging power. Better stochastic energy resolution (i.e. higher sampling frequency) would improve the measurement of the predominantly low-energy photons. Excellent timing resolution for bunch identification (ID) is essential for X-band where the bunch crossing time is 1.4 ns, and highly desirable for background rejection (halo-muons, cosmic-rays, back-scatters) and identification of long-lived particles. Note that one expects about one overlaid $\gamma\gamma \rightarrow$ hadrons event with about 100 GeV of calorimetric energy per 100 ns for NLC [2], so bunch ID would be very helpful.

The requirements for calorimetry in the forward region are less well developed and quite different and deserve particular study. Suffice it to say that electron and photon detection are priorities in this harsh environment, and pile-up minimization will be critical.

Plans: We would like to investigate by means of EM shower simulations and physics studies various concepts for the ECAL design and the optimization of these designs, paying attention to all four aspects of the intrinsic ECAL performance : energy, time and position resolution and shower imaging power and also global detector performance characteristics, namely hermeticity, feasibility and cost. Existing concepts such as Si-W with many longitudinal readout layers (eg. 40 as in [3]) and Lead-Scintillator sandwiches such as the Shaslik approach or crystal calorimeters (no longitudinal subdivision) are good examples of very different performance characteristics and cost. Objective evaluation of various approaches to the ECAL requires further understanding of the physics benefits and physics requirements taking into account relevant constraints [1]

The approach which we plan to investigate in detail, particularly regarding feasibility, is a hybrid approach for a compact sampling ECAL. The approach would use Silicon-pad readout planes for excellent position resolution and shower imaging power with a reduced number of longitudinal layers instrumented (eg. 10 instead of 40) and augment this with many fine sampling layers with scintillator. Using scintillator rather than Silicon to do the primary sampling should allow many more layers to be sampled at a lower cost, thus leading to better stochastic energy resolution. The likely choice of absorber is Tungsten - but high cost and difficulties in obtaining thin Tungsten layers imply that Lead should also be evaluated. The design should be compact in order to minimize the Molière radius and thus keep good angular resolution. A high sampling frequency is necessary to ensure good energy resolution and the use of fast scintillators enables excellent timing resolution which can be on the 100 ps level near the shower maximum. Regardless of the eventual utility of the hybrid Si/Scintillator scheme we propose investigating, it is likely that a shower maximum detector designed for good time resolution would benefit any design based on slow readout, and the studies we plan to pursue will be useful for such a detector. Marrying Silicon with scintillator would also give a powerful tool for controlling and localising any non-uniformities in the scintillator response. The design has to make sure that the scintillator sections are integrated properly with the silicon sections in a sensible overall ECAL design.

Sketch of possible approaches to such a hybrid ECAL: Many ways to integrate scintillator

[1] eg. Note that ZHH has been used to justify the Si-W ECAL design, yet without taking into account beam constraints or mass constraints.

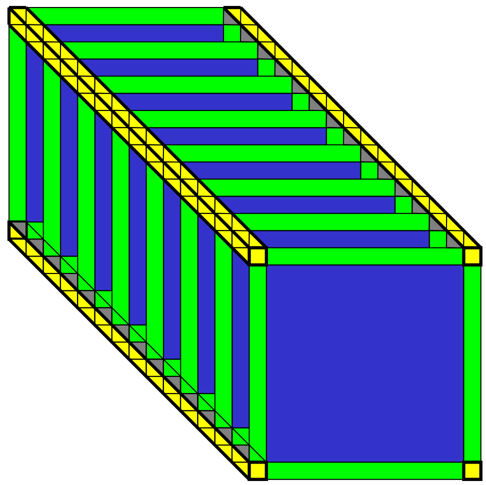

Figure 1: *Illustration of the scintillator part of a possible design: scintillating tiles (blue), primary WLS fibers (green), secondary WLS fibers (yellow).*

readout exist. A conventional approach could use absorber layers and thin scintillating tiles coupled to wavelength shifting (WLS) fibers and clear fibers such as employed for MIP-detection in [4]. Light-yields for very thin tiles are an issue if it is required that each scintillator layer is capable of detecting MIPs, and the insertion of fibres in thin tiles makes homogeneity of response more problematic. However, for the purposes of calorimetric energy resolution and timing resolution, it is not necessary for every single layer to be instrumented individually (layers can be optically summed), and the presence of many Silicon layers assures MIP detection in many layers. One possible method (Figure 1) of extracting the light with minimum dead space would be 5 cm $\times$ 5 cm $\times$ 1 mm scintillating tiles with primary square cross-section (1 mm $\times$ 1 mm) WLS fibers coupled to some or all of the 4 tile edges. Up to four additional secondary (1 mm $\times$ 1 mm) WLS fibers shifting the WLS light to even longer wavelength could integrate the light from many longitudinal samplings running longitudinally at the tile corners. The basic principles have already been applied in eg. [5]. The above dimensions result in only 0.2% of the transverse area being used for longitudinal light propagation if one integrates over the whole shower. Only a few small holes would be needed in the Silicon pad readout planes. Another potential approach which may allow a very fine sampling of the shower is to use absorber layers embedded with scintillator with the scintillator read out transversely. This has the advantage of much reduced sampling fluctuations for a fixed sampling fraction with obvious benefits in compactness. Several mechanical solutions come to mind : solid absorber with holes for scintillating fibers (like SPACAL), grooved sheets of absorber to construct an absorber/scintillator matrix, stacked hollow absorber rods etc. This would be followed by transverse readout with WLS bars coupled to secondary WLS fibers as before. Exactly which route to consider with priority depends also on photon detector considerations. Possible choices such as multi-anode photo-multipliers, APDs and Silicon-PMs have very different features in terms of area, noise, quantum efficiency and B-field tolerance.

ECAL Design Study:

We have started looking at the predicted performance of various configurations. As an example we show in Figure 2 the predicted energy resolution for 1 GeV photons for a Tungsten-Scintillator ECAL with 75 sampling layers. The Tungsten thickness is 1.4mm. The dependence on both the scintillator thickness and light-yield is shown.

We have also started looking at the consequences of a hybrid design on the energy resolution. We are encouraged to find that there is a slight anti-correlation (typically -20%) between the energy measurements in scintillator and silicon leading to small improvements in resolution.

Personnel

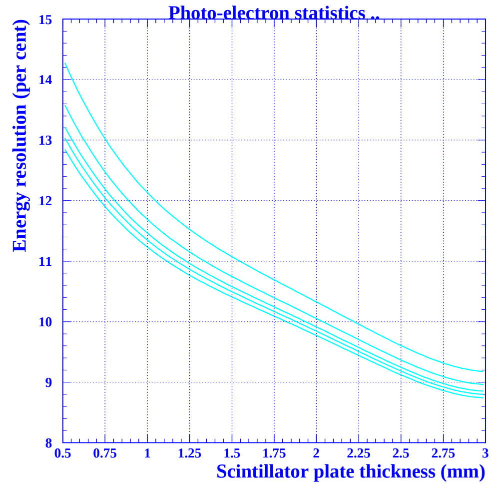

Figure 2: *Energy resolution vs scintillator sampling thickness. The lowest curve shows the contribution from only sampling fluctuations. The four upper curves include the effect of photo-electron statistics with assumptions of 2.5 photo-electrons/mip/mm (upper curve), 5.0 pe/mip/mm, 10.0 pe/mip/mm and 20.0 pe/mip/mm. Note the suppressed zero.*

Gallagher is a graduate student who has been working on evaluating jet reconstruction performance dependence on detector resolutions in a linear collider detector environment.

Benavidez is an undergraduate student who has been working on GEANT4 simulations of sampling calorimeter energy resolution and the optical simulation of a tile-fiber setup.

Hensel is a post-doctoral researcher who joined us in February 2003 and has experience with physics analysis, detector simulations and scintillator-based detectors. Hensel will spend up to 50% of his time on linear collider work once he has established his research work with D0.

Baringer, Bean, Besson and Wilson are faculty. Wilson has been involved in linear collider work since 1995 while working on the OPAL detector at LEP. He has worked on studies of the linear collider detector concept: notably hermeticity and forward tracking requirements. He has also contributed to several physics studies: measuring the average centre-of-mass energy, measuring extra-dimensions and measuring the W mass at threshold. He brings to the project a strong appreciation of the physics needs and a background of experience in calorimetric detectors. He has been supervising the work of Gallagher and Benavidez. Baringer, Bean and Besson all have experience from e^+e^- colliders including SLC, PEP and CESR. Baringer has experience with scintillator-based detector elements. Bean and Besson are also involved in the RICE experiment at the South Pole doing calorimetry with radio-waves, and Besson has experience with shower simulations.

FY2004 Project Activities and Deliverables

Investigate the transverse and longitudinal segmentation dependence of the performance of the Si-W ECAL concept and the hybrid Silicon and Scintillator readout concept for a range of potentially achievable detector characteristics. Performance issues that will be investigated are single particle energy, angular and directional resolution vs energy, photon-pion separation vs energy and time resolution. We have started these studies with a full MC shower simulation package with a detailed geometry. For the electro-magnetic showers, GEANT4 is being used. We plan to cross-check the results with EGS or GEANT3. Checking results with a different code will increase confidence in the results[2].

Evaluate the utility of timing resolution with respect to pile-up (does adding 4 or 5 bunch crossings matter to the physics).

[2] although it is no substitute for test-beam

Complete and document the study of the physics impact of various detector resolution assumptions.

Build a collaboration with existing and new interested parties in the U.S. and internationally.

Develop further the concept of the hybrid Silicon and Scintillator readout, if the performance prospects studies are encouraging. Identify promising directions and plan specific lab. work aimed at demonstrating the key features of the particular design: eg. mechanical construction, light yield, uniformity, attenuation length.

FY2005 Project Activities and Deliverables

Continue performance studies of various designs including emphasis on the overall physics performance.

Begin lab. work aimed at validating the design in preparation for proto-type development.

Mechanical studies related to constructing such a calorimeter: tolerances, robustness.

Tests of light yield, uniformity and attenuation length using a β-source and a cosmic-ray test-stand.

Tests of photo-detectors matched to project requirements.

Based on test results iterate prototype design and propose building such a prototype to the consortium. Together with favorable review and more collaborators plan prototype construction and testing.

FY2006 Project Activities and Deliverables

Build prototype ECAL module/modules to demonstrate the required performance of the Scintillator + Absorber part of the design in terms of energy resolution and time resolution. It would be preferable to integrate Silicon readout at this stage - in order to test the overall energy and angular performance. This would require early convergence on such a concept from advocates of both approaches.

Beam tests with electrons, muons and pions.

Budget justification

FY2003. Computers, domestic and international travel, graduate student, 1 undergrad.

FY2004. 0.2 FTE Technician, graduate student, 2 undergrads, domestic and international travel, 0.25 FTE post-doc, equipment (source, cosmic-ray test stand, scintillators, optical readout, photo-detectors, absorber), machine shop labor.

FY2005. 0.3 FTE Technician, graduate student, 0.5 FTE post-doc, equipment (KU share in prototype module), machine shop labor, 2 undergrads, domestic and international travel.

Three-year budget, in then-year K$

Institution: University of Kansas

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	18	34	53
Graduate Students	16	17	18	50
Undergraduate Students	4	9	10	23
Total Salaries and Wages	20	44	62	126
Fringe Benefits	1	6	11	18
Total Salaries, Wages and Fringe Benefits	21	50	73	144
Equipment	0	35	45	80
Travel	5	6	12	23
Materials and Supplies	6	10	14	30
Other direct costs	0	0	0	0
Total direct costs	32	101	144	277
Indirect costs	14	29	43	87
Total direct and indirect costs	46	131	187	364

References

[1] J. Brau, A. Arodzero, and D. Strom, Snowmass 1996 proceedings, pp 437-441.

[2] LC Physics Resource Book for Snowmass, May 2001.

[3] TESLA Technical Design Report, March 2001.

[4] G. Aguillion et al., NIM A417 (1998) 266.

[5] J. Fent et al., NIM 211 (1983) 315.