Linear Collider Detector Development Proposal to Study and Develop Scintillator-Fiber Readout Scintillator Calorimetry with High Spatial Resolution

Toshinori Abe, Anthony Barker, Uriel Nauenberg, Joseph Proulx, Shenjian Chen

Department of Physics, University of Colorado
Boulder, CO 80309-0390

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Chapter 1

The Calorimeter Studies Proposal

1.1 Introduction

We propose to study scintillator based calorimetry with fiber readout using a geometrical configuration where alternate layers are offset relative to one another so that they overlap only a quarter of the previous scintillator plate unit. This is shown in one of the figures below discussing the project. We would like to study the intensity and uniformity of light collection where the fiber is placed straight into the scintillator along the diagonal of a square scintillator piece. In this study we also propose to measure the properties of Avalanche Photo-diodes; in particular their stability, linearity, signal-to-noise ratio, and timing resolution; we propose to use these to provide a signal readout proportional to the light produced in the scintillator. Avalanche Photo-diodes work well in the presence of a magnetic field. A scintillator based calorimeter provides excellent electromagnetic and hadronic shower energy resolution and excellent timing. Both properties are very desirable in the search for new phenomena at the higher energies associated with the Linear Collider.

In the study of supersymmetry we need as good a hadronic jet resolution as possible as well as excellent single particle tracking resolution in order to measure the masses of these states using the energy end-point method. In measuring the masses of the charginos, $\widetilde{\chi}_1^{\pm}, \widetilde{\chi}_2^{\pm}$, and the neutralinos, $\widetilde{\chi}_2^0, \widetilde{\chi}_3^0, \widetilde{\chi}_4^0$, we need to accurately determine the energies of either multi-hadronic final states or Ws and Zs which decay into hadronic final states. An accurate measurement of their energies requires excellent calorimetric energy resolution which can best be achieved using new techniques described partly under the rubric of "Energy Flow" for hadronic states. To obtain good signal to background in determining the presence of a W or Z we need to also obtain good directional resolution. I propose, simultaneously, to use a technique that would improve the spatial resolution of photons, hence, improve the directional resolution of $\pi^0 s$, a major element of hadronic jets. Similarly we can improve the directional resolution of neutral hadrons.

We propose to involve undergraduate students in this program; the students will be supported by University funds under the "Undergraduate Research Opportunities Program" at the University of Colorado. We have involved many such students in the simulation of reactions where Supersymmetric particles are produced in a Linear Collider and we find their contribution to be of very high quality.

1.2 Possible Collaborators

Graham Wilson, from the University of Kansas, is discussing collaborating on several aspects of this proposal. He is interested in developing further the concept of a tungsten absorber based sampling electromagnetic calorimeter with active layers of two types, silicon pads for fine spatial resolution and scintillator plates with fiber readout for improved energy sampling at modest cost and excellent timing resolution. Good timing resolution benefits background rejection from accelerator induced halo muons and cosmic rays, identification of long lived heavy particles and bunch identification.

Critical areas of scintillator based R&D relate to light yield, timing response, plate size, homogeneity, maximizing sampling frequency and retaining a compact design. Further pursuit of understanding the physics requirements on the detector performance will also aid in evaluating the various design choices.

1.3 Supersymmetry Signals

Our group at Colorado has been studying how to measure the masses and other characteristics of Supersymmetric particles. This work has been carried out by undergraduates being supported mainly by University funds. This work is recorded in `http://hep-www.colorado.edu/SUSY`. The analysis is being carried out under the MSSM SUGRA model using the ISAJET [1] software simulation package. We have arrived at the conclusion that, to collect a sufficient number of events in a reasonable period of time, in the determination of the masses of charginos and neutralinos we need to measure the energies of hadronic jets. Hence the need for good calorimetric resolution. The channels we need to observe is the decay into Ws and Zs whose energies we can measure via their decays into hadronic jets. This is needed because a large fraction of their decay branching ratios is into hadronic final states. For example, using the MSSM SPS1 parameters [2] the decay of the $\widetilde{\chi}_1^{\pm}$ occurs 98.3% of the time via $\widetilde{\tau}_1^{\pm}$, ν, and only 1.2% into $W^{\pm}$,$\widetilde{\chi}_1^0$. It is the second channel that we suggest to use to measure the mass of the $\widetilde{\chi}_1^{\pm}$ since the first one is heavily compromised by large backgrounds from the 2γ processes.

During this year we have been studying the signals that are produced in the MSSM SPS1 simulation. There are cases where we need to measure accurately the energy of Ws and Zs. Because the model indicates that the production cross-sections and decay branching ratios are low we need to include the hadronic decays of these Ws and Zs. In the case of Ws only hadronic decay modes can be used to determine the W energy. To get good signal to background we need to have good energy and directional resolution to have good combined mass resolution.

Typical signals that we have studied are shown in Figure 1.1 and Figure 1.2. These sharp edges have been obtained using leptons and hence, the resolution is due to excellent tracking. We would like to get similar resolutions using hadrons; this is the purpose of the study being proposed here.

1.4 Proposed Detector Development Study

We propose to carry out a simulation and hardware study of scintillator calorimetry with fiber read out in an arrangement that maintains excellent energy and timing resolution while also improving spatial resolution that leads to improvement in the energy and directional resolution of jets that leads to improvement in the energy and mass resolution of the associated Ws and Zs. We propose to start by studying 5 x 5 cm^2 scintillator plates but we can change these depending on cost versus resolution studies. We propose to use a geometrical arrangement as shown in Figure 1.3 and Figure 1.4. This

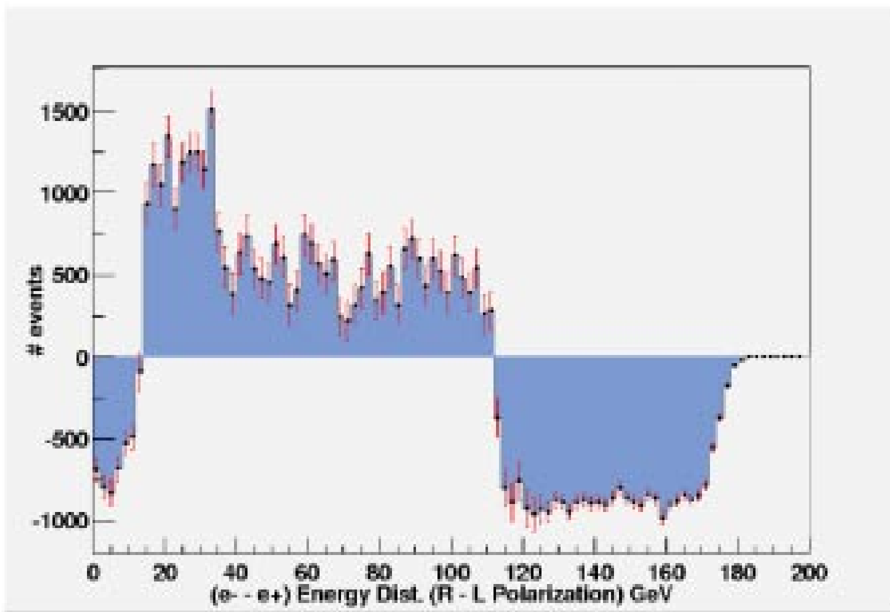

Figure 1.1: The spectral difference between the electrons and positrons for 80% R electron polarization minus the spectra for 80% L electron polarization. This is the only manner we have found to observe clearly the appropriate edges of the signal to determine the masses of the Left and Right Selectron and the Neutralino.

arrangement will localize the position for showers to an apriori resolution of about 1/4 the size of each plate. In this manner we can also correct for light collection dependence as a function of the shower distance from the scintillating fiber which should help improve the energy resolution of the calorimeter. Since the Moliere radius of the shower is comparable with 1/4 of the plate size (2.5 x 2.5 cm^2) we could use light sharing between the various plates to improve on this spatial resolution. The use of scintillator as the detector medium will lead to excellent timing resolution which seems to be essential in the study of signals based on single non-pointing photons.

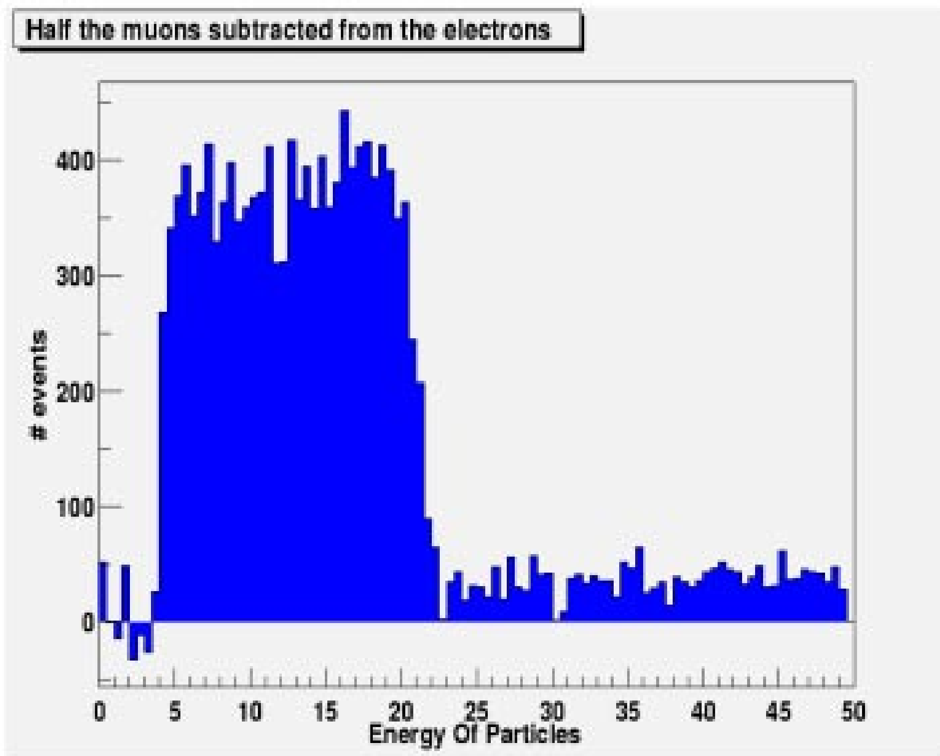

Figure 1.2: The spectral distribution of electrons or positrons in the case where we observe only an $e^-\mu^+$ or $e^+\mu^-$ after subtracting the $\mu^\pm$ spectrum in the same events since that would represent the background from channels that would occur through $\tau^\pm$ decays. We determined that this channel was the most effective to observe clearly the appropriate edges of the signal to determine masses of the electron sneutrino and the Neutralino.

A preliminary study of the directional resolution improvement is shown in Figure 1.5 where we show the difference in ϕ between the reconstructed position and the actual position of a photon striking a plate where there is no offset as compared to when there is. Our preliminary expectation of a factor of 2 improvement is clearly seen. Hence we can expect at least a factor of 4 improvement in the $\delta\phi\delta\theta$ directional resolution of the photon and, hence, of the associated π^0.

We propose to use a scintillating fiber insertion into the scintillator plate that is a straight line along the diagonal of the scintillating plate. We believe

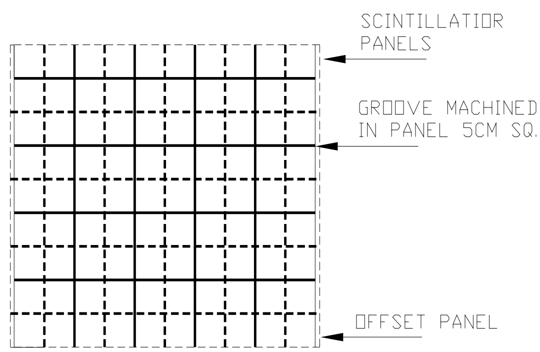

Figure 1.3: Geometrical arrangement of 5x5 cm^2 scintillator plates where alternate layers are offset. This is the xy-view of the barrel plates.

that placing a fiber in a circle is more demanding and manpower consuming than placing it in a straight line as shown in Figure 1.6. Our experience in building the KTeV anti-counters was that fibers broke often when being inserted into a circular path.

We propose to study the performance of large active areas avalanche photo-diodes (2 cm^2) as produced by Advanced Photonics, Inc. and Radiation Monitoring Devices, Inc [3].

The first year tests is to use a radiation source and a triggered cosmic rays using a simple scintillator hodoscope to study the light collection efficiency of a 5 x 5 cm^2 scintillating plate of various thicknesses covered by tyvek and with various side refecting materials to observe light collection variations. We also propose to study the efficiency, voltage linearity, light intensity linearity, signal-to-noise ratio, and stability of the avalanche photo-diodes under various temperature environments and various wavelengths.

In later years we propose to actually build a multiplate array to use with an electron beam to study the energy and geometrical resolution of such a calorimeter. The preliminary arrangement for the electromagnetic

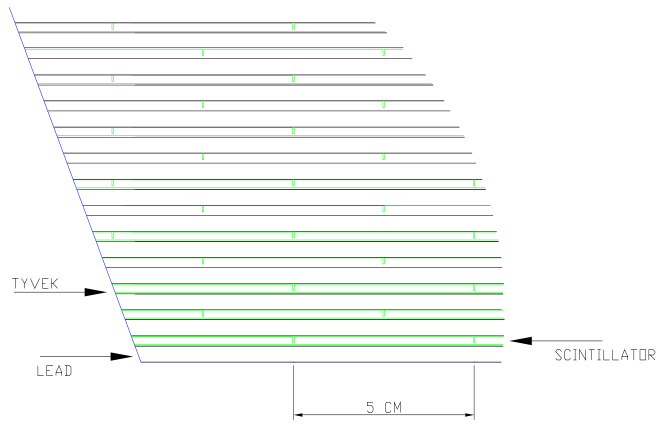

Figure 1.4: Geometrical arrangement of 5x5 cm2 scintillator plates where alternate layers are offset. Instead of lead, indicated in the figure, we are considering initially tungsten. This is the z-view of the barrel plates.

calorimeter portion would be 2 mm tungsten plates alternating with 2 mm thick, 5 x 5 cm^2 scintillator plates. We believe 1 mm scintillator plates are too thin to be used with $\approx$ 1 mm diameter fibers. Then we would plan to use a similar arrangement for a hadronic calorimeter to be used with the "Energy Flow" concept to determine how much we can improve the hadronic jet energy and direction.

In the same period we propose to carry out software simulation studies to determine the expected improvement in π^0 and hadron energy and direction resolution and therefore associated jet energy and directional resolution. We would like to study the use of "neural nets" in the determination of jet energies. In particular we would like to investigate the usefulness of a disk file of actual hadronic showers versus incident hadron energy. We would like to compare the observed shower pattern with the patterns on disk using neural nets and determine whether this technique would further improve the directional and energy resolution of jets.

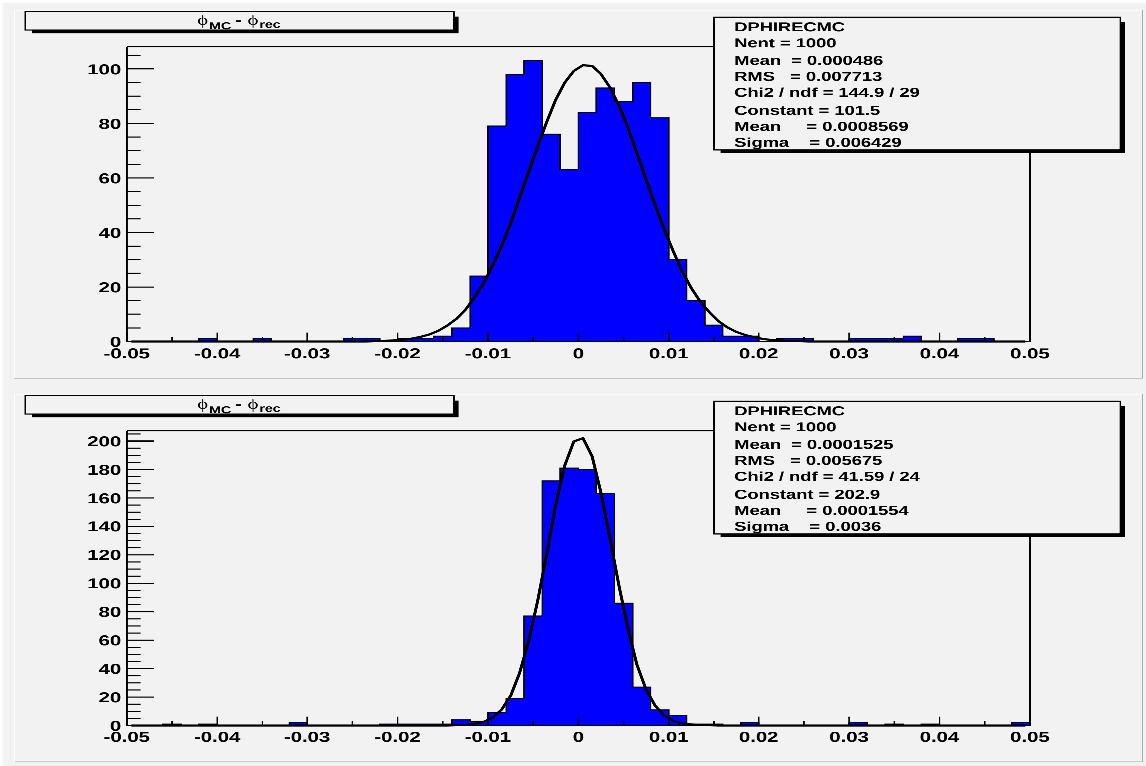

Figure 1.5: Difference in ϕ between the actual position of a photon shower and assuming it is at the geometrical center of the tile array for a calorimeter with no offset plates and that where the plates are offset. The photon is striking the barrel calorimeter normal to the surface.

1.5 Budget

The budget request by the University of Colorado is for the partial support of a Research Associate, request for equipment funding to be shared with the University, request for supplies and materials and travel to meetings of the American LCD group.

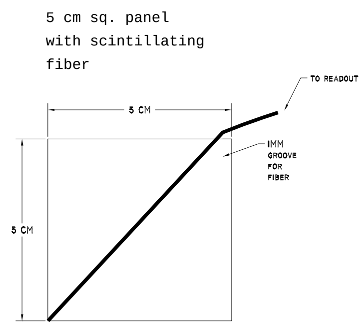

Figure 1.6: This figure shows the placement of the fiber in the scintillator plate.

Budget Request

ITEM	**2003**
A. SALARIES AND WAGES	
Research Associate:	
To be named; 50% time 12 mos.	20,000
Research Assistant:	
Joseph Proulx; 100% time 12 mos.	23,000
University Contribution	-23,000
Technical Staff	
Engr. Phys. Sci. Tech. III Eric Erdos	
28% 12 mos.	16,876
University Contribution	-16,707
Students	
2 undergraduates	7,200
University Contribution	-7,200
Total Salaries and Wages	20,169

ITEM		2003
B. FRINGE BENEFITS		
Res. Assoc.:20.3%		4,060
Engr. Phys. Sci. Tech. III: 18.8	*University Contribution*	-3,141
Total Fringe Benefits		4,092
C. EQUIPMENT		
Calorimeter Scintillator Testing Unit		20,000
University Contribution		-10,000
Total Equipment		10,000
D. SUPPLIES AND MATERIALS		
Scintillator Plates, Cables,		
Scintillating Fibers, Black Box,		
Resistors, Capacitors		3,000
Other		1,000
Total Supplies and Materials		4,000
E. TRAVEL		
Travel to American LC meetings		2,000
Total Travel		2,000
F. TOTAL DIRECT COSTS		40,261
G. INDIRECT COSTS (On-Campus)		
On-Campus 47% of M.T.D.C.		14,223
H. TOTAL COSTS (On-Campus)		54,484

Bibliography

[1] F. Paige, S. Protopopescu, in Supercollider Physics, page 41, edited by D. Soper (World Scientific, 1986); H. Baer, F. Paige, S. Protopopescu, X. Tata in Proceedings of the Workshop on Physics at current accelerators and Supercolliders, edited by J. Hewett, A. White, and D. Zeppenfeld, (Argonne National Laboratory, 1993).

[2] look at the cross-sections and branching ratios in `http://hep-www.colorado.edu/SUSY`. Click on "information relevant".

[3] We would like to thank Vladimir Issakov from the Brookhaven National Laboratories for a discussion on large area Avalanche Photo-diodes.