Muon System and Particle Identification

Muon System and Particle Identification Table of Contents

Introduction to Particle Identification R&D

Identification of leptons is critical, and the muon identification is performed by the outermost sub-detector. As is customary, this does not warrant high resolution and uses the return yoke. Two sub-proposals, A and B, are submitted using scintillators with alternate layers of steel and scintillator; both are from the same collaboration, only the funding sources are different.

Once the electromagnetic and the hadronic components are identified, the need for individual hadron identification (K_L are identified by calorimeter and muon detector) remains to be checked. With this in mind, a sub-proposal C, mostly based on simulation, is submitted to study specific physics cases by using information from the rest of the sub-detectors as a starting point.

A.	LCRD	Scintillator-based Muon System	H. Eugene Fisk Paul Kirchin	Fermilab Wayne State
B.	UCLC	Scintillator-based Muon System	Arthur Maciel Mitchell Wayne	NIU Notre Dame
C.	LCRD	Particle Identification and Software Infrastructure for Linear Collider	Robert Wilson	Colorado State

7.2. Scintillator Based Muon System R&D (LCRD)

Muon system and Particle Identification

Contact person: Paul Karchin
email: karchin@physics.wayne.edu
phone: (313) 577-5424

UC Davis
Fermilab
Northern Illinois
Notre Dame
Rice
Wayne State
UT Austin

FY 2003: $57,710

Project Name

Scintillator Based Muon System R&D

Classification (accelerator/detector:subsystem)

Detector:Muon

Institution(s) and personnel

Fermilab, Batavia, Illinois:
Alan Bross, H. Eugene Fisk (Co-contact Person), Kurt Krempetz, Caroline Milstene, Adam Para, Oleg Prokofiev, Ray Stefanski

Northern Illinois University, DeKalb, Illinois:
Gerald Blazey, Dhiman Chakraborty, Alexandre Dychkant, David Hedin, Arthur Maciel

Notre Dame University, South Bend, Indiana:
Mitchell Wayne

Rice University, Houston, Texas:
P. Padley, M. Matveev, J. Roberts

University of California, Davis, California:
Mani Tripathi, Richard Breedon

University of Texas, Austin, Texas:
Karol Lang

Wayne State University, Detroit, Michigan:
Paul Karchin (Co-contact Person)

Contact persons

H. Eugene Fisk
hefisk@fnal.gov
(630) 840-4095

Paul E. Karchin
karchin@physics.wayne.edu
(313) 577-5424

Project Overview:

The linear collider detector design includes a muon system that will identify muons, as distinct from hadrons, primarily by their penetration through the iron flux return. Because the proposed calorimeters are thin in terms of interaction lengths, hadronic showers will leak into the muon steel. The proposed energy-flow algorithms anticipate measuring jet energies by using charged particle momenta, EM shower energies for neutral pions, and hadron calorimetry for neutrons and K_L^o. Fluctuations of the neutral hadron energies leaking from the hadron calorimeter will degrade the energy resolution. An adequately designed and proven muon system could be used to measure the energy escaping detection and improve the energy resolution of the detector. It is in this context that we propose an R&D program for a scintillator-based muon detection and identification system.

The general layout of the barrel muon detectors consists of planes of scintillator strips inserted in gaps between 10 cm thick Fe plates that make up octagonal barrels concentric with the e^+e^- beamline. The scintillator strips, ~5 cm wide and 1 cm thick, would contain one or more ~1 mm diameter wavelength shifting (WLS) fibers. Light produced by a charged particle would be transported via clear fibers to multi-anode photomultipliers located outside the Fe yoke where it will be converted to electronic signals. There would be 14 planes of scintillator with alternating strips oriented at $\pm 45^o$ with respect to a projection of the beam line onto the planes.

Scintillator and Fe calorimeters have been very successfully used in neutrino experiments to measure the energy of jets. For example, with 10 cm of Fe between counters, hadronic resolutions of ~0.8/sqrt(E) are typically achieved. A scintillator strip calorimeter based on MINOS style detectors may provide the required resolution to complement upstream energy-flow measurements.

Given a substantial knowledge base from experiments like MINOS, CDHS and others one might ask if an R&D effort on a scintillator-based muon system is necessary. In fact, it is. There are significant differences in the environments for neutrino experiments and the proposed linear colliders. For the LCD, detectors must be robust and ready to withstand ~20 years of beam time in a radiation environment. The geometry and packaging of the scintillator detectors are very challenging. There is much in the way of mechanical engineering of the iron, fiber and cable routing, etc. that needs to be determined at an early stage to insure that important details for the largest LC detector system are not overlooked.

R&D Plans:

Hardware development

Develop the mechanical and electronics specifications for a test set-up of 8 (4u & 4v) full width, but short-length strip scintillator planes.
Procure finished strip scintillator, WLS and clear fiber sufficient for the 8 planes. Explore possible cost savings by coordination with MINOS.
Procure approximately 16 multi-anode (64 channel ea.) photomultiplier tubes to instrument most of the 8 prototype planes.
Borrow existing electronics for the tests we need to do, inasmuch as this is possible. This would include tube bases, discriminators, ADCs, trigger counters, trigger logic, etc.
Use the existing cosmic ray test-stand facilities in Lab 3 that were used in the D0 fiber-tracker testing to do our cosmic ray tests.
Obtain cosmic ray data that can be used to further define software algorithms for muon identification.
Define the need for additional Fe in future cosmic ray and beam testing of the prototype modules.
Develop the detailed mechanical and electronics specifications for the LC muon system.

Software development

Muon detector simulation and tracking algorithms: detector geometry optimization, parameter tradeoffs, hit finding ability, tracking in the presence of the central field and through the magnetized Fe flux return. Understand the effects of shower leakage on the energy-flow algorithms.
Establish physics benchmarks for the muon system from several new physics and conventional reactions that yield muons. Generate MC samples covering those physics topics to assure that the muon system is tested for these cases.
Study the impact of background from decays of hadrons to muons in the beam lines and tracking volume. Hadron punch-through rates need to be determined and understood in the forward and central muon detectors, and accounted for in the muon system design.

Goals, Work to be done and deliverables:

Work to be Performed	By	Deliverables
Software Development	Arthur Maciel - NIU Dhiman Chakraborty - NIU David Hedin - NIU Caroline Milstene - Fermilab	muon detector simulation, muon ID and tracking algorithms
Fe Layout, Mechanical Engineering Analysis, Cable & Fiber Routing. Costs.	Kurt Krempetz - Fermilab Ray Stefanski - Fermilab Oleg Prokofiev - Fermilab	Stress/deflection calcs., Engineering drawings. R&D Cost Estimate.
Scintillator strip extrusion Processing using the NIU Machine at Fermilab.	Jerry Blazey & Alexandre Dychkant - NIU Alan Bross - Fermilab	Scintillator spec. document. 1 T prototype scint. devel. 1 T prototype scint. prod'n.
WLS R&D, Insertion in Strips; Testing; Clear fiber Splicing; Waveguide prod'n.	Alan Bross - Fermilab A. Dychkant - NIU Mitch Wayne - Notre Dame	Finished prototype scint. for prototype planes. Test results document.
Engineering &design of Prototype muon detector Planes.	Kurt Krempetz, Adam Para, Gene Fisk - Fermilab Others TBD	Engineering drawings & specification document.
Photomultiplier, electronics, logic, procurement, setup, etc..	P. Karchin - Wayne State Adam Para - Fermilab Mani Tripathi - UC Davis	Logic & test procedures for cosmic ray tests. Develop specs for LC Mu electronics
Cosmic ray test stand for Prototype module testing. (Utilize Lab 3 test stand)	Mitch Wayne - Notre Dame Caroline Milstene - Fermilab Paul Karchin - Wayne State	Mechanical layout of test stand modules. Test data analysis/results document.

Future Plans

The R&D program in the preceding table will take two years to complete. Beyond that, prototype detectors need to be built and tested. This, in turn, requires engineering to produce easily assembled, robust and reliable detectors and electronics. Cosmic ray testing (and a test stand with data acquisition) will be required to provide feedback to muon system developers on questions of signal-to-noise, etc. Further still, the development of a high energy test beam will be essential to assess progress on prototype detectors and their electronics. In addition to measurements of detector efficiency, the energy calibration and resolution obtained for a prototype assembly of Fe plates and detectors in a hadronic beam of known energy, where jets can be observed, will be of significant importance. It is likely that other tracking detectors will need to participate in such tests.

Two Year Budget - University (NSF and DOE) and Fermilab

The budget requested here assumes cost sharing between Fermilab and the collaborating universities. No LCD R&D funds are requested to support the work of Fermilab staff. The costs are to cover FY03 & FY04 although the materials costs require major commitments in FY03. NIU, through a grant from the State of Illinois, will provide $26,000/year in cost sharing of which $15,000 /year will be used for M&S. The remaining $21,000 in M&S costs over the two year period will be provided by Fermilab. The groups from Rice University and the University of Texas request no funds, but will consult on the design of the electronics and detectors, and will develop plans for their future involvement.

Item	Total	UC Davis	NIU	Notre Dame	Wayne St
Agency which funds group's base grant		DOE	NSF	NSF	DOE
M&S Costs					
Software development - use existing facilities					
Scintillator - Shared between the univs & Fermilab					
a. One ton finished scintillator strips ($10/kg)	10,000		5,000		
b. WLS fiber - for eight short modules ($3.5/m)	12,000		3,000	4,000	
c. Clear fiber	15,000			8,000	
d. Light guide manifolds	20,000			6,000	
e. Al for skins, tooling, handling fixtures,	10,000				
e. Raw materials for extrusion facility start-up					
Electronics - for 768 channels = 12 PMs					
a. Multi-anode PMs /alternate, based on M64 PM	24,000	8,000			8,000
b. Modifications to use existing electronics	10,000	4,000			4,000
M&S Cost (sub-totals)	101,000	**12,000**	**8,000**	**18,000**	**12,000**
Personnel Costs - over two years					
Software development					
a. Travel to SLAC/Fermilab		3,000	6,000		2,000
b. Engineering costs		5,000		19,500	5,000
c. Graduate and/or undergraduate students		30,000	15,000	12,000	30,000
Personnel Costs - over two years (sub-totals)	127,500	**38,000**	**21,000**	**31,500**	**37,000**
Indirect costs		8,580	11,600	12,000	7,840
Totals		**58,580**	**40,600**	**61,500**	**56,840**

Univ. Grand Total (2 years) $217,520

First Year Budget - DOE University Groups

Item	UC Davis	Wayne State
M&S Costs		
Electronics - for 768 channels = 12 PMs		
a. Multi-anode PMs /alternate, based on M64 PM	5,000	4,000
b. Modifications to use existing electronics	4,000	4,000
M&S Cost (sub-totals)	**9,000**	**8,000**
Personnel Costs		
a. Travel to SLAC/Fermilab	3,000	1,000
b. Engineering costs	2,500	2,500
c. Graduate student - 6 months salary and benefits	11,370	14,623
Personnel Costs (sub-totals)	**16,870**	**18,123**
Indirect Costs (excluding engineering for permanent equipment): 26% (UCD) 24.5% (WSU)	**3,736**	**3,828**
Totals	**29,606**	**29,951**

Experience of Collaborating Groups

The researchers proposing this work have extensive experience with muon systems and detector technology relevant to a scintillator based muon detector.

Fermilab: D0 muon detector, MINOS

NIU: D0 muon detector, calorimeter R&D, LCD simulation

Notre Dame: D0 fiber tracker

Rice: CMS muon detector

UC Davis: H1 and CMS muon detector, PMT readout and DAQ for Keck Solar2 and STACEE

UT Austin: MINOS

Wayne State: HERA-B muon detector and electronics

7.3. Scintillator Based Muon System R&D (UCLC)

Muon system and Particle Identification

Contact person: Arthur Maciel
email: maciel@fnal.gov
phone: (630) 840-8314

NIU
Notre Dame

FY 2003: $56,089
FY 2004: $59,206
FY 2005: $57,980

Proposal to the University Consortium for a Linear Collider

October 21, 2002

Proposal Name

Scintillator Based Muon System R&D

Classification (accelerator/detector: subsystem)

Detector: Muon

Personnel and Institution(s) requesting funding

Gerald Blazey, Dhiman Chakraborty, Alexandre Dychkant, David Hedin, Arthur Maciel, Northern Illinois University, DeKalb, IL
Mitchell Wayne, University of Notre Dame, Notre Dame, IN

Collaborators

Alan Bross, H. Eugene Fisk, Kurt Krempetz, Caroline Milstene, Adam Para, Oleg Prokofiev, Ray Stefanski, Fermilab
Paul Karchin, Wayne State University, Detroit, MI
Mani Tripathi, University of California, Davis, CA

Contact Persons

Arthur Maciel-NIU
maciel@fnal.gov
(630)-840-8314
Mitchell Wayne-UND
wayne@undhep.hep.nd.edu
(574)631-8475

Changes since preliminary project description

The budget has been revised slightly and now includes the cost of the subcontract to NIU. The NIU budget's indirect costs have been reduced slightly.

Project Overview The linear collider detector design includes a muon system that will identify muons, as distinct from hadrons, primarily by their penetration through the iron flux return. Because the proposed calorimeters are thin in terms of interaction lengths, hadronic showers will leak into the muon steel. The proposed energy-flow algorithms anticipate measuring jet energies by using charged particle momenta, EM shower energies for neutral pions, and hadron calorimetry for neutrons and K_L's. Fluctuations of the neutral hadron energies leaking from the hadron calorimeter will degrade the energy resolution. An adequately designed and proven muon system could be used to measure the energy escaping detection and improve the energy resolution of the detector. It is in this context that we propose an R&D program for a scintillator-based muon detection and identification system.

The general layout of the barrel muon detectors consists of planes of scintillator strips inserted in gaps between 10 cm thick Fe plates that make up octagonal barrels concentric with the e+e- beamline. The scintillator strips, with nominal width of 5 cm and 1 cm thickness, will contain one or more 1 mm diameter wavelength shifting (WLS) fibers. The investigation of optimal strip properties and sizes is a part of this project.

Light produced by a charged particle will be transported via clear fibers to multi-anode photomultipliers located outside the Fe yoke where it will be converted to electronic signals. Nominally there are 14 planes of scintillator with alternating strips oriented at 45° with respect to a projection of the beam line onto the planes.

Given a substantial knowledge base from experiments like MINOS, CDHS and others one might ask if an R&D effort on a scintillator-based muon system is necessary. In fact, it is. There are significant differences in the environments for neutrino experiments and the proposed linear colliders. For the LCD, detectors must be robust and ready to withstand 20 years of beam time in a radiation environment. The geometry and packaging of the scintillator detectors are very challenging. There is much in the way of mechanical engineering of the iron, fiber and cable routing, etc. that needs to be determined at an early stage to ensure that important details for the largest LC detector system are not overlooked.

FY2003 Project Activities and Deliverables

NIU Software Development: a C++/GEANT4 stand-alone representation of a preliminary muon detector sub-subsystem. Package framework, and implementation of (i) modularity towards an easy plug-in of different sub-detectors (trackers, calorimeter) (ii) detector geometry and parameter input as decoupled as possible (e.g. external data bases) from simulation code, for easy changes in detector characteristics. This project is to be coordinated with other LCD sub-detector developers, towards a sub-systems compatible and flexible full detector simulation package. In parallel, development of muon tracking algorithm for continuous assessment of detector model development.

The first year deliverable will be an initial package for the GEANT4 based physics event simulation; a general framework capable of hosting all subdetectors, a preliminary description of the muon sub-system, and a muon stand-alone tracking algorithm.

NIU Hardware Development: joint work with Fermilab for the commissioning of a scintillator extrusion facility. Design of a Test Stand for the Quality Control of extruded scintillator plates. Initial studies of techniques to embed fibers into the muon strips.

Deliverables will include the production of extruded scintillator strips and inital measurements of their properties compared to standard methods of producing counters. This will require the manufacture of a die.

UND Hardware Development: Devise a fiber routing scheme. Create a technique for the splicing/joining of WLS and Clear fibers. Decide on the specifications, and order the WLS fibers.

FY2004 Project Activities and Deliverables

NIU Software Development: Continued development of the simulation package described in the previous item. Completion of the muon system representation according to the then current detector design. Coupling to the other subdetectors. Simulation based studies of detector parameter trade-offs and optimization.

The second year deliverable will be a simulation package providing fast and reliable access to different detector design characteristics and parameter choices. With it, we expect to achieve a solid understanding of the muon system tracking ability, fake rates, and sub-systems integration, such as the inter-dependence of parameter choices and the mutual assistance with calorimetry and cenral tracking for particle ID, energy flow and energy/momentum resolution.

NIU Hardware Development: Measurements of the performance (such as light yield and resultant efficiencies and time resolutions) as a function of paramters such as position along the strip, fiber placement and number of fibers, and counter length. Comparisons will be made between extruded and non-extruded strips. At least one additional size die will be made and prototype strips manufactured.

Deliverables will include a better understanding of the performance of strips of various lengths, widths, and fiber placement. Combined with the simulation effort, this can be used as a guide for an initial choice of counter dimension and mechanical properties.

UND Hardware Development: Quality assurance on WLS and Clear fibers. Design and use a system to measure optical transmission. Engineering design of prototype light guide manifolds.

FY2005 Project Activities and Deliverables

NIU Software Development: Completion of the muon simulation, track reconstruction and analysis software. Completion of all simulation based studies of detector design characteristics and parameter optimization.

The third year deliverable will be a mature package for the GEANT4 based physics event simulation, reconstruction and analysis; documented, external user friendly, able to host the then available non muon sub-detectors, and with a version-controlled description of the muon sub-system, holding the necessary detail for physics reach studies.

NIU Hardware Development: Produce a significant number of pre-production prototypes to understand production details, costs, and uniformity. Depending on the needs of other R&D efforts, these counters could then be installed and used in test beams (e.g. calorimeter tests).

Deliverables will include the produced counters. Also a third year deliverable (both hardware and software) should be a significant contribution to the muon system TDR.

UND Hardware Development: Production of prototype manifolds for eight planes. Test manifolds, install the manifolds with light guides for the eight planes.

Budget justification

All NIU salaries for professional support staff (including electronics, computing, and machine shop personnel) will be provided by the Department, the State, or other grants. The NIU budget requests support for an undergraduate student through the REU program and for the summer support for a masters graduate student. It is our experience that students at this level are well-matched to the R&D tasks in this proposal. Three NIU undergraduates worked on LC muon related tasks (both simulation and detector R&D) during the Summer of 2002, and this request will aid in continuing student involvement.

The NIU budget requests K$4 in materials and supplies which will be used to purchase needed material for constructing prototype counters (such as scintillator, fiber, or PMTs). Travel funds of K$3 are requested to support international and domestic travel.

NIU grant matching funds for the support on LC muon R&D are primarily from the State of Illinois' HECA program. This provides the salary for Dychkant, and partial support for Maciel and Hedin. In addition, HECA funds will provide K$9 for student support, K$15 for equipment and M&S, and K$2 for domestic travel.

UND requests support for the mechanical engineering associated with fibers: routing and layout, optical coupling of clear and WLS fibers. Manifold engineering, such as mold development using carbon fiber, epoxy techniques. The UND budget must also cover materials such as fibers, manifold parts etc.

Three-year budget, in then-year K$

Institution: Northern Illinois University.

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	0	0	0
Graduate Students	4.5	4.5	4.5	13.5
Undergraduate Students(REU)	3.0	3.0	3.0	9.0
Total Salaries and Wages	7.5	7.5	7.5	22.5
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	7.5	7.5	7.5	22.5
Equipment	0	0	0	0
Travel	3.0	3.0	3.0	9.0
Materials and Supplies	4.0	4.0	4.0	12.0
Other direct costs	0	0	0	0
Total direct costs	14.5	14.5	14.5	43.5
Indirect costs (*)	5.8	5.8	5.8	17.4
Total direct and indirect costs	20.3	20.3	20.3	60.9

(*) 25% on REU (=K$0.8) and 44% on remainder (=K$5.1)

Institution: University of Notre Dame

Item	FY2003	FY2004	FY2005	Total
Other Professionals(1)	7.0	8.0	10.0	25.0
Graduate Students	3.0	7.0	8.0	18.0
Undergraduate Students	0	2.0	2.0	4.0
Total Salaries and Wages	10.0	17.0	20.0	47.0
Fringe Benefits(2)	1.4	1.6	2.0	5.0
Total Salaries, Wages and Fringe Benefits	11.4	18.6	22.0	52.0
Equipment	9.0	9.0	5.0	23.0
Travel	0	0	0	0
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Subcontract	20.31	20.31	20.31	60.93
Total direct costs	40.71	47.91	47.31	135.93
Indirect costs(3)	15.379	11.296	10.67	37.345
Total direct and indirect costs	56.089	59.206	57.980	173.275

(1) Engineering work
(2) 20% of "Other Professionals".
(3) 48.5% of "MTDC" and "1st $25,000 of Subcontract".

7.4. Particle Identification and Software Infrastructure for Linear Collider Physics and Detector Studies (LCRD)

Muon system and Particle Identification

Contact person: Robert Wilson
email: wilson@lamar.colostate.edu
phone: (970) 491-5033

Colorado State
SLAC

FY 2003: $35,100

PARTICLE IDENTIFICATION AND SOFTWARE INFRASTRUCTURE FOR LINEAR COLLIDER PHYSICS AND DETECTOR STUDIES

Robert J. Wilson
Abner Soffer
Colorado State University

OVERVIEW

A primary goal of the next linear collider is to provide detailed investigations of fundamental physics in the 500-1000 GeV energy regime that are not possible with a hadron collider. Particle Identification (PID) in the broad sense will surely play a central role. While at this stage there is no compelling argument to include a specialized *hadron* ID system, the extent to which hadron ID capability is required is an open question that must still be studied. The issue has particular relevance for detectors without gas-based tracking systems, which lack even rudimentary hadron ID.

The primary purpose of this proposal is to support a core of activity in the American Linear Collider Physics Group (ALCPG) Particle ID working group. We propose to build on the previous work of our group in three areas: Completion and expansion of a fast Particle ID package and its integration into the Java Analysis Studio-based Linear Collider Detector (LCD) simulation package; investigation of the need for particle identification in linear collider physics analyses, with particular emphasis on hadron identification; coordination of the ALCPG Particle ID working group, with an emphasis on cross-detector subsystem issues.

The software infrastructure tasks will be done in close collaboration with Stanford Linear Accelerator Center staff Anthony Johnson, Gary Bower and Norman Graf.

BACKGROUND

In its broadest sense, particle identification is one of the primary goals of a Linear Collider detector. The subset of particles that can be identified at the sub-detector level is restricted to a few long-lived charged and neutral types, but the real interest lies with the more complex reconstructed particles such as D, B, W, Z^0 *etc*. and, of course, exotics such as Higgs and SUSY particles. Therefore, a central mission of the ALCPG Particle ID working group (WG), as outlined by Wilson at the recent LC Retreat [1], is not only to investigate single particle identification capabilities of subsystems, but also to coordinate the cross subsystem aspects. As a practical matter, many of the associated issues have low priority in the individual detector working groups, but taken together they represent an important part of the overall detector design optimization.

The most pressing PID issue is the longstanding question of the need for hadron identification for high energy Linear Collider physics; this question is particularly acute for an LCD design with silicon as the primary tracking device, which would lack even the basic hadron ID capabilities provided by gas-based trackers [2]. There have been a few modest efforts to address this issue. Mercadante and Yamamoto [3] have shown that the production of long-lived tau slepton pairs in a certain mass range may be detected with dE/dx in a gaseous tracking chamber. Wilson [4] has investigated the effect of hadron ID on neutral B meson tagging, and Soffer has considered the use of hadron ID for charm vertex tagging and R-parity and baryon number violating SUSY decays [5]. Most such studies have been done with crude event generator-level ID, partly due to the lack of tools in the U.S. group's standard simulation and reconstruction package. So far, no compelling justification for hadron ID has been found. However, the investigation is clearly incomplete, in large part due to the lack of a sustained effort.

SIMULATION & RECONSTRUCTION SOFTWARE

At this stage, we believe that it is premature to embark on hardware R&D related to the primary particle ID issues. Rather, we propose to assist with the construction of the necessary software infrastructure that will allow these questions to be addressed more effectively. One of us (Wilson) has been making contributions to the JAS-based package developed at SLAC towards this end. We wish to expand on that effort in parallel with addressing the specific goals of the Particle ID working group.

Though the JAS-based LCD simulation, reconstruction, and analysis package is complete in many respects, the original design did not include a particle identification component, or even the appropriate infrastructure. Building on a prototype framework from Gary Bower (SLAC), Wilson has developed the infrastructure and code for particle ID and, in the process, contributed to other aspects of the JAS and LCD software infrastructure. A prototype was included on the resource CD-ROM distribution at Snowmass 2001; a much-improved version, including usage instructions and analysis code examples, is available at the PID WG web site[1]. The following is a brief description of the current package.

PROTOTYPE FAST PID PACKAGE

The prototype package provides the essential infrastructure, utility classes and examples to enable the standard LCD reconstruction to include PID. It can take as input either LCD detector simulation files (.lcd), in which case it invokes track reconstruction, or event generator data (StdHep format), in which case it performs the standard fast simulation (MCFast). The fast PID package functions identically in both cases.

A common set of methods for all *FastRecon* classes has been defined for geometry and performance parameter input at the initialization stage. Convenience methods have been provided to allow performance parameters to be changed after the class has been instantiated. The class *DEdxFastRecon* is an example of a subsystem fast simulation module. Currently, it uses a truncated Bethe-Bloch formula to simulate the track energy loss (motivated by the works of Yamamoto and Hauschild [6]). A similar class, *DircFastRecon*, has been developed for DIRC (Detector of Internally Reflected Cerenkov light) studies. The results of the PID reconstruction are accessed through the *ReconstructedParticle* class, which is being developed in collaboration with the SLAC group.

An example analysis code, provided with the package, demonstrates how to produce histograms and generate purity and efficiency matrices. With this system, one can easily run through an event sample, generate the PID information for one configuration, rename the histograms folder (a JAS feature), change the detector configuration with a single line

[1] http://hep45.hep.colostate.edu/~wilson/flc/jas/pid/

of code, and rerun the analysis very rapidly. For example, on a 650 MHz computer this whole process takes less than 3 minutes (including re-compilation) for fast simulation and reconstruction of 1000 t-tbar events in two detector configurations (the US "Large-2" with TPC dE/dx only and the same detector with a DIRC).

PHYSICS REQUIREMENTS FOR PARTICLE ID

To ensure the success of the Linear Collider program, the detector capabilities that will be needed to address different physics scenarios must be determined before significant resources are spent on detector R&D. For example, one should not assume there is no need for hadron ID without a thorough study of the physics that may be lost due to this assumption. Though our preliminary studies found no obvious need for hadron ID, it is clear that more time and thought should be invested to understand these questions. In some cases, improvements to our previous studies are obvious. For example, Soffer's study of the use of proton ID to detect R_p and baryon number violating neutralino decays should be extended to the lower-background center-of-mass energies below the t-tbar threshold, and repeated with different SUSY parameters. Wilson's b-tagging and single particle ID studies should be extended to higher energies. Similarly, the significance of other PID requirements, such as low-momentum lepton ID, must be determined in coordination with detector subsystem and physics working groups.

Complementary to the identification of physics processes that might benefit from hadron ID, one of the tasks of the PID WG is to evaluate the hadron ID potential of gas and silicon-based tracking systems, as well as specialized detectors, such as scintillator time-of-flight or quartz-based Cerenkov ring-imaging devices. The negative effects these systems may have on others, e.g., photon resolution degradation in the calorimeter due to additional material [7], must also be quantified. A set of benchmark physics processes is needed to allow a quantitative comparison of the loss or gain associated with different technology choices. The effort on this task will be modest unless a clear need for hadron ID emerges.

A broader PID working group mission is to facilitate an appropriate degree of standardization in the identification of heavy particles (D, B mesons, W, Z bosons). A well-designed infrastructure and standardized user interface to the identification of both heavy and light particles will prevent the inefficient use of time and resources that can easily occur, especially in nascent large collaborations. The role of the PID WG will be to interface the techniques used for heavy particle identification to the standard PID software infrastructure, and to ensure that the infrastructure is flexible and user-friendly enough to satisfy the full variety of particle identification needs. This involves issues of coordination between detector subsystems as well as higher-level analysis techniques, such as jet and vertex reconstruction. We expect this role of the PID WG to develop over time and be a subject of discussion among the different working groups.

DELIVERABLES

I. SIMULATION

We will: complete the integration of the fast PID simulation and reconstruction with existing core code-base (and continue to adapt it as the implementation of the *ReconstructedParticle* class is refined); extend the hadron identification fast simulation package and simplify its use by non-experts, including a simpler method to implement new models, particularly energy loss in different gas mixtures and pressures; add new basic fast simulations of other PID systems, such as Time-of-Flight, as needed; continue development of a schema for integration of subsystem-level ID information and reconstructed particle-level software component integration (*e.g.*, lepton, photon and hadron ID) into a uniform particle ID package, including techniques for heavy particle reconstruction.

II. USE OF HADRON ID FOR LC PHYSICS

We will: perform a broader study of the physics justification for hadron identification – this will include extensions to our previous studies (which concentrated on 500 GeV center of mass energy) to higher and lower energies, and a broader range of physics channels; help to generate a list of benchmark physics processes for the physics WGs to use for quantitative comparisons of the capabilities and negative effects of particle ID technologies.

III. PID COORDINATION ACROSS SUBSYSTEMS

We will: coordinate a review of the pan-detector particle ID requirements for benchmark physics topics (*e.g.*, strategies for particle ID across the entire range of momentum called for by physics); work with the other WGs to develop a definition of the software interface and infrastructure issues related to heavy particle identification.

PERSONNEL

Professor Robert J. Wilson will be the lead physicist for the program. A substantial fraction of his research time will be devoted to linear collider detector activities. He has extensive experience in particle ID detectors and e^+e^- physics, and has been associated with future linear collider development for numerous years.

Dr. Abi Soffer is a research scientist with Prof. Wilson's group. A substantial fraction of his time will be devoted to linear collider detector activities; previously he was essentially full-time on BaBar. He has extensive experience with physics, data analysis and OO code design. He is based at SLAC, which will facilitate an efficient collaboration with that group. He was a recipient of an APS fellowship for Snowmass 2001.

A new graduate student will be recruited to the project. This student will work on the Linear Collider as part of his or her particle physics and computing training before moving on to thesis analysis on a running experiment. This approach has been used successfully with Prof. Wilson's past two graduated Ph.D. students.

FIRST YEAR BUDGET

Most of the resources for this project will come from a partial redirection of effort for Prof. Wilson and Dr. Soffer. Salary support is requested to support a new student for one year. After this year, the student will move to a thesis analysis on one of the group's current running experiments and will be supported from other sources. The travel request is an essential part of this proposal. The domestic travel for Wilson will be covered by redirection of travel funds in the current DoE grant. However, there are no funds for LC-related international travel (e.g., none were available to attend the International LC meeting held recently in Korea) nor are there funds for any travel for Soffer – since he is based at SLAC and has previously worked ~100% on BaBar, there are no BaBar travel funds in the grant that can be redirected. Finally, we would like to allow the student to attend at least one LCD domestic meeting and to give a presentation on his or her LC work at the annual regional meeting of the APS.

	Budget (k$)
Student Salary (1 year)	18.4
Domestic Travel – Res. Sci. + student	3.6
4 LCD workshops+1 APS	
International Travel - faculty	2.2
1 LCD workshop/conference	
Indirect cost @ 45%	10.9
Total:	**35.1**

REFERENCES & RELATED PAPERS AND TALKS BY THE PROPOSERS

[1] Wilson, R.J., "Report from the Particle ID/Muon", Santa Cruz Workshop 2002.

[2] Wilson, R.J., "Hadron ID in the S2 Detector", "PID – Santa Cruz Workshop 2002.

[3] Mercadante, P.G. and Yamamoto, H., "Analyses of Long Lived Slepton NLSP in GMSB Model at Linear Collider," in 1999 Sitges meeting proceedings: *Physics and Experiments with Future Linear Colliders*, edited by E. Fernandez and A. Pacheco, Universitat Autonoma de Barcleona/IFAE Publications, 2000.

[4] Wilson, R.J., "Some Thoughts on Hadron Identification with Linear Collider Detectors," in 1999 Sitges meeting proceedings, see ref. [3]; Wilson, R.J., "B^0 Tagging with Kaons," in the FNAL meeting proceedings: *Physics and Experiments with Future Linear Colliders*, edited by A. Para.

[5] Soffer, A., SNOWMASS-2001-E3039, APS/DPF/DPB Summer Study on the Future of Particle Physics (Snowmass 2001), Snowmass, Colorado, 2001; Soffer, A., "A Look at R_p and Baryon Number Violation Using Hadron ID" – Santa Cruz Workshop 2002.

[6] Yamamoto, H., "dE/dx Particle Identification for Collider Detectors," in 1999 Sitges meeting proceedings, see ref. [3]; Hauschild, M., "Particle Identification using a TPC," in the FNAL meeting proceedings: *Physics and Experiments with Future Linear Colliders*, edited by A. Para.

[7] Bower, G., "The Effect of a DIRC on EMCal Resolution", presented by Wilson at the Santa Cruz Workshop 2002.

[8] American Linear Collider Working Group, "Linear Collider Physics: Resource Book for Snowmass 2001", SLAC-R-570. – Section 3.6 on particle ID provided by R.J.Wilson.