Proposal to the
University Consortium for a Linear Collider

October 7, 2002

Proposal Name

Tracker simulation studies and alignment system R&D

Classification (accelerator/detector: subsystem)

Detector: tracker

Personnel and Institution(s) requesting funding

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Project Overview

Introduction

The University of Michigan group has a long-term interest in helping design and construct the central tracking system for a linear collider detector. This interest is driven not by a particular favorite technology, but by the critical importance of charged-particle tracking to the physics processes we wish to investigate, which include Higgs production and decay, along with certain supersymmetric channels.

Results of Prior Research

We have contributed extensively to linear collider simulation studies, both in technical tracking reconstruction issues and in evaluating physics analysis demands upon tracker performance. Riles has served as a co-convener of the linear collider central tracking working group since 1998, sharing leadership responsibilities in different years with Dean Karlen, John Jaros and Bruce Schumm. Riles has shared responsibility for organizing working group meetings, evaluating baseline tracker designs, coordinating tracking simulations, creating & maintaining the group web site, and assembling annual joint R&D proposals.

As part of the baseline tracker design optimization, Riles wrote a stand-alone Monte Carlo hit generator and 3-d helical track fitter to study the effects of multiple scattering on particle momentum resolution *vs* momentum and *vs* polar angle for various tracker configurations. This work served as an independent cross check of the resolution studies carried out by Bruce Schumm using an analytic Billoir approach.

Yang began linear collider studies in fall 2000. He has been carrying out two related studies in parallel: 1) Studies of Higgs physics capability and 2) influence of central tracking performance on Higgs physics. As a member of the Higgs working group, he has evaluated the precision with which the Higgs mass and cross section can be evaluated at 350 GeV and 500 GeV center of mass energies. This study has used both the JAS fast Monte Carlo and the full simulation packages. Yang has independently confirmed and improved upon preliminary findings by European groups with the use of a more sophisticated and powerful fitting technique, based on Monte Carlo event interpolation. In parallel, Yang has examined the influence of central tracker parameters on the Higgs mass precision. In addition, he has assisted the SLAC simulations group in comparing the tracker's performance in full Monte Carlo simulations *vs* performance in parametrized fast Monte Carlo simulations. He has given numerous presentations on Higgs physics and tracking at various linear collider workshops and at Snowmass 2001[1, 2]. Yang's studies of the Higgsstrahlung process are nearly complete and find that current baseline tracker designs in the U.S. are close to where improved resolution does not yield comparable improvement in Higgs mass resolution, because of expected intrinsic beam energy spread in present accelerator designs.

Research Plan

Simulation Studies

In the coming years we wish to extend the above Higgs studies to supersymmetry final states to understand quantitatively whether they impose more or less stringent requirements than Higgsstrahlung on tracking resolution. In particular, we will begin by exploring the slepton production channel, where one can determine slepton and neutralino masses from the end-points of the final-state lepton spectra. The sharpness of the end-points will be governed in part by track resolution. We wish to quantify the influence of tracking resolution on sparticle mass resolution. We expect there to be two distinct regions of importance: 1) high-momentum end-points where the same effects seen in our Higgs analysis are expected to be important; and 2) low-momentum end-points where multiple scattering may prove important.

One of the outstanding issues in comparing a gaseous central tracker to a silicon system is the importance of the greater material burden in the silicon design to low-momentum track resolution. It has been suggested by members of the linear collider supersymmetry working group that for significant regions of supersymmetry parameter space, momentum resolution in the 1-10 GeV range will limit the precision with which supersymmetry particle masses can be determined. If true, then the desire for precise sparticle mass determination may well govern the choice of barrel tracker technology. We wish to explore this possibility quantitatively, taking into account other known sources of sparticle mass resolution degradation. The University of Colorado group led by U. Nauenberg has carried out a series of studies of slepton final states for the linear collider supersymmetry group, including studies of sparticle mass determinations. We expect to work closely with the Colorado group in extending their existing analyses to address tracking performance requirements quantitatively. In addition, we will continue contributing to the tracking infrastructure development, where we have taken responsibility for more sophisticated hit merging and for evaluation of track reconstruction performance.

Alignment System

We also wish to carry out R&D on precise alignment of the linear collider tracking subsystems. The unprecedented excellent track momentum resolutions contemplated for a linear collider detector will demand minimizing systematic uncertainties in subdetector relative alignments. At the same time, for reasons discussed above, there is a strong desire for a very low material tracking system. In the case of a silicon main tracker and in the case of silicon forward disks (envisioned in all linear collider detector designs now on the table), the low material budget may lead to a structure that is far from rigid. The short time scales on which alignment can change (e.g., from beam-driven temperature fluctuations) probably preclude reliance on traditional alignment schemes based on detected tracks, where it is assumed the alignment drifts slowly, if at all, during the time required to accumulate sufficient statistics. A system that can monitor alignment drifts "in real time" would be highly desirable in any precise tracker and probably essential to an aggressive, low-material silicon tracker. The tradeoff one would make in the future between low material budget and rigidity will depend critically upon what a feasible alignment system permits.

We propose to investigate the capability of existing precise alignment schemes and to develop a system customized to the needs of a linear collider detector. Two natural candidate schemes to explore include the Rasnik alignment system implemented for the CDF detector and the Frequency Scanned Interferometer (FSI) system being developed for the ATLAS detector. Both are designed to achieve 1-D or 2-D point resolutions of order 1 micron, which should be adequate for a linear collider tracking system. The Rasnik system is based on many CCD cameras trained on 2-D images whose positions are sensitive to relative misalignments. The FSI system is based on multiple interferometers fed by optical fibers from the same laser source, where the laser frequency is scanned and fringes counted to obtain a set of absolute lengths. Given the desire for low material burden in a silicon tracker, it's not clear that either system in its present design will be appropriate for a linear collider detector, although the FSI method seems more promising in that respect and is the one we will at least initially focus upon. As an active member of the LIGO Experiment since 1997 and leader of the LIGO Scientific Collaboration's Detector Characterization Working Group, Riles has acquired expertise in precise interferometry, including beam modulation techniques that may usefully enhance the FSI method. As part of our R&D effort, we would explore these and perhaps other alternative methods of optical metrology.

It should be noted that the methods developed for central and forward tracker alignment may also prove useful for a vertex detector, where again, there is a strong desire for thin detector material that may be subject to short-term position fluctuations. Similarly, the methods developed here may prove useful for alignment monitoring of accelerator components far upstream of the detector (e.g., in the main linacs). Given the natural wide distribution of accelerator components *vs* a relatively compact tracker system, however, it's not clear that a tracker solution will be cost effective for the accelerator. In any case, we will stay cognizant of vertex detector and accelerator needs and explore these possibilities, as the tracking alignment system design evolves.

FY2003 Project Activities and Deliverables

During the first year we will carry out simulation studies of the tracking performance requirements imposed by measurements of slepton production, specifically imposed by desired precision on sparticle masses. We will write a detailed technical report on our findings in which the gaseous and silicon tracker designs are compared quantitatively.

We will also initiate a program of alignment R&D. Specifically, we will acquire the components for and build a demonstration-level frequency-scanned interferometer on an optical bench. We will purchase a relatively inexpensive commercial laser for the initial studies, one without the performance tolerances (tuning range, frequency stability) needed for a final production alignment system. In parallel, we will come up with a conceptual design of an alignment scheme for the American baseline silicon barrel tracker and the silicon forward disk trackers and write a general simulation program that allows the performance evaluation of various schemes. It is envisioned that hundreds of absolute length measurements between pairs of reference points would be used in a global fit to determine the local and global alignment parameters of the tracking subsystems. A progress report on this effort will be delivered no later than the winter 2004 American linear collider physics group meeting.

FY2004 Project Activities and Deliverables

Simulation studies in the second year will depend on findings from the first year on slepton production. We expect, however, to investigate other supersymmetry channels involving isolated leptons whose precise measurement imposes stringent performance requirements on the tracker. Chargino production is a natural channel to investigate. We will deliver a technical report on our findings.

Using the FSI infrastructure put together in the first year, we will carry out measurements on the bench of performance and explore modifications to improve absolute precision, robustness, and measurement speed. A technical report will be written on our findings.

FY2005 Project Activities and Deliverables

We anticipate that our supersymmetry/tracking simulation studies will have been completed to satisfaction by the start of the third year, but depending on what has been learned, we may wish to pursue certain specific topics in further detail. If so, another technical report will be written on our findings.

We hope by the start of the third year to have a concrete design in hand for a full alignment system and to have evaluated singly the primary issues affecting that design. At that point we would wish to build a partial prototype of the system to test system integration issues, including miniaturization of the components tested previously on the optical bench. We expect to continue deferring the purchase of a commercial laser with the frequency tuning range and stability envisioned for the final system. If such a laser is indeed needed to satisfactorily address outstanding R&D issues, however, we would expect to request a grant supplement when the time comes. We do not request funding for its purchase here.

Budget justification

In the first year, we request funding here for a half-time graduate student, for employment of undergraduates, for the purchase of the components needed to build a bench-level frequency scanned interferometer, and for travel to biannual linear collider meetings.

In the second year, we request funding for a half-time postdoctoral fellow, for two half-time graduate students, for employment of undergraduates, for additional optical equipment to enhance the frequency scanned interferometer, and for travel.

In the third year, we request funding for a quarter-time technician, a half-time postdoctoral fellow, for two half-time graduate students, for employment of undergraduates, for components of a partial alignment system prototype, and for travel.

Three-year budget, in then-year K$

Institution: University of Michigan

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	0	15	15
Postdoctoral Fellow	0	21	22	43
Graduate Students	7	14	15	36
Undergraduate Students	3	3	4	10
Total Salaries and Wages	10	38	55	103
Fringe Benefits (@28%)	3	11	15	29
Total Salaries, Wages and Fringe Benefits	13	49	70	132
Equipment	20	10	25	55
Travel	3	3	3	9
Materials and Supplies	0	0	0	0
Other direct costs (tuition)	5	12	12	29
Total direct costs	41	74	110	225
Indirect costs (@26%,excl. tuition/equipment)	4	14	19	37
Total direct and indirect costs	45	88	129	262

References

[1] H. Yang and K. Riles, "Measurement of Higgs Mass and Cross Section at a Linear Collider", to appear in the Snowmass 2001 Proceedings.

[2] H. Yang and K. Riles, "Impact of Tracker Design on Higgs Mass and Cross Section Resolutions", to appear in the Snowmass 2001 Proceedings.