Development and Evaluation of Forward Tracking in the Linear Collider

Classification (subsystem)

Detector: Tracking

Personnel and Institution(s) requesting funding

University of Oklahoma, Department of Physics: Michael G. Strauss (Associate Professor)

Collaborators

Post-doctoral Researcher (to be named)

Project Leader

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Project Overview

Traditional e^+e^- tracking detectors have provided excellent track finding capability and track resolution in the central region, but diminished performance in the forward direction, closer to the beam pipe. However, forward tracking will be a critical component of the Linear Collider (LC) physics program and the LC detector will require outstanding forward tracking to attain the maximum physics potential.

There are important physics processes with enhanced cross sections in the forward region that can only be effectively measured by having exceptional forward tracking. For instance, certain production and decay modes of supersymmetric particles are peaked in the forward direction. Some important Standard Model processes, like Higgs production via WW t-channel fusion are also predominantly along the beamline. Quality forward tracking will be required to maximize the ability to do certain physics. Because the colliding beams disrupt each other and induce radiation, an accurate measurement of the differential luminosity requires an angular measurement of Bhabhas with an uncertainty, $\Delta\theta$, of 100 μrad over polar angles of 100-500 mrad. The best algorithms for determining jet energies are particle flow algorithms which require measurement of energy in the calorimeter as well as the momentum of charged tracks in the same jet. Multijet events often produce jets in the forward direction. Consequently, to measure jet energies in the forward region with good efficiency, quality tracking must extend to small polar angles. Other physics considerations include the ability to efficiently measure the charge of all tracks, not just those in the central region, and minimizing the material in the forward region so that conversions do not cascade and disrupt tracking pattern recognition. These physics goals can be accomplish by developing forward tracking that uses minimal material in order to preserve momentum resolution of the order $\sigma(1/p_t) = 10^{-4}$ GeV^{-1}, with polar angle coverage down to about 110 mrad. Many issues regarding forward tracking need to be studied in detail now so that relevant questions can be answered and reasonable technology choices can be made, particularly for the Silicon detector tracking option.

The tracking system must be able to maintain its superior resolution and pattern recognition capabilities well into the forward region, for which backgrounds increase steadily while the mean p_t, and the lever-arm available to reconstruct tracks and measure p_t, shrink steadily. In addition, good angular resolution must be maintained for the differential luminosity measurement. These issues present great challenges to the design of a forward tracking system, and it is essential that a realistic simulation and reconstruction package that can easily investigate alternate technologies and geometries be developed and utilized so that these questions can be addressed.

At present, only a few studies have been done to choose tracking hardware options or develop software algorithms to assure quality track finding and resolution in the forward direction. The TESLA collaboration has done some simulation of tracking in the forward direction. The default TESLA design uses seven layers of intermediate silicon disks and a forward chamber, possibly made of straw tubes, behind the TPC. Studies show that TESLA gets a resolution of $\Delta\theta \approx 30\mu$rad at a polar angle of about 120 mrad. Some other layouts of the TESLA tracker have been investigated to determine if pattern recognition can be improved by eliminating "ghost" hits. The TESLA studies show that reasonable tracking can be done in the forward region with the level of realism modeled in their simulation. There have not been TESLA studies that investigate alternate tracking geometries, technologies, and algorithms that might improve forward tracking. Tracking options that might provide better resolution need to be investigated. The U.S. LC tracking group has expressed their opinion that forward tracking is at the core of the tracking program, and that simulation and software development is of paramount importance to the LC tracking effort.

We propose a systematic software effort to understand tracking capabilities and develop tracking algorithms in the forward direction, to about 110 mrad from the beamline. These studies will use the detailed Monte Carlo and simulation being developed by Norman Graf and collaborators at SLAC. A realistic simulation must include beam related backgrounds, accurate simulations of charge deposition, full energy deposition from tracks and backgrounds, realistic detector response, digitization, cluster finding, merging and hit recognition algorithms, detailed coordinate determination, and accurate track finding algorithms. Some of these parameters are not yet in the LC Monte Carlo simulation. We would make the Monte Carlo more realistic and use the enhanced Monte Carlo to investigate the forward tracking potential. Such an effort will allow an informed choice for forward tracking technologies and design parameters. We will help determine the essential hardware components needed to assure quality tracking and physics capabilities in the forward direction, and to eventually develop quality pattern recognition and tracking algorithms in the forward direction. The software tools we develop will be used to facilitate future physics studies.

The program at the University of Oklahoma will continue to work in conjunction with the LC community. We have been using the current simulation package developed by Norm Graf and will continue to work closely with the existing LC tracking simulation groups. Some pattern recognition tools have already been incorporated into the LC simulation. Using these tools is a good place to start when studying forward tracking issues, but is insufficient to develop the best algorithms for meeting the forward tracking physics issues. For instance, the strategy for the current tracking algorithm in the Silicon detector is to first find tracks in the CCD vertex detector then to extrapolate these tracks into the central and forward detectors. However, there are very important questions that have not been investigated: (1) How well do five layers of CCDs do at pattern recognition given realistic backgrounds and detector performance? (2) What is the track finding efficiency and purity using this pattern recognition technique? (3) Will the proposed thickness of the detectors cause so much showering that pattern recognition is impossible? (4) Are there other algorithms that give better performance in the forward region?

We would like to concentrate on answering questions regarding forward tracking with the Silicon Detector (SiD) tracking option that have not been investigated. Many of these questions are outlined in the document “Critical Questions for SiD” by M. Breidenbach, H. Weerts, J. Brau, and J. Jaros. We would like to develop simple pattern recognition code that could easily compare different designs in order to answer questions that have been raised by this report. (1) What detector layout will will offer robust pattern recognition? (2) Should the forward tracking depend on VXD pixel endplates? (3) How feasible is pattern recognition in the VXD with pixel endplates? (4) How thick can the system be before it degrades the calorimetry? (5) Does forward tracking need stand alone track finding capability, without help from VXD endplates calorimetry pixels?

We will continue to work closely with groups developing hardware that might be used as key components in the forward tracking of the LC. We have developed a working relationship with the group at Louisiana Tech that is working on GEM technology that could be used in the forward tracking region.

At the end of this project, we will know

1. The detector design that maximizes the forward tracking potential.
2. The detector technology that offers the best prospect for meeting the physics goals outlined above.
3. Whether three-dimensional technologies are necessary for tracking in the forward direction.
4. Whether reasonable resolution and pattern recognition can be performed to 110 mrad.
5. How beam-related backgrounds interfere with tracking capabilities in the forward region.

Broader Impact

This entire proposal focuses on developing a broader impact by teaching and training a postdoctoral researcher in the area of tracking software. The requested funds will be used for the salary of one researcher who will be learning from the principle investigator of this project who has years of experience in developing tracking software. In essence, the entire request for funds is for the purpose of education.

Results of Prior Research

We have not received any previous funding for LC projects. However, we have been involved with the LC project by attending conferences and working informally with people involved in the software effort at Stanford, and the hardware effort at Louisiana Tech University. We have installed and run the standard Monte Carlo tools available for LC simulations.

Our current research at OU focuses on many areas that are directly related to this proposal. We are funded from the Department of Energy, DE-FG02-04ER41305, “Experimental Physics Investigations Using Colliding Beam Detectors at Fermilab and the Large Hadron Collider” from May 1, 2004 until April 30, 2005, for $480,000. Part of this project funds work at the DØ detector where the principle investigator is currently the convener of the tracking group. The tracking group has developed a combined tracking algorithm that uses both a road finding method and a histogramming method to find tracks in the DØ detector. The road finding method, is particularly good at finding tracks in the forward region of the detector. Lessons learned from that algorithm may be applied to forward tracking at the LC.

Facilities, Equipment and Other Resources

This project requires only computing facilities and internet access. We have plenty of equipment available to complete the program. In fact, OU has both a supercomputing center and a cluster of Linux computers available for High Energy physics applications.

FY2005 Project Activities and Deliverables

During the first year, we would hire a post-doctoral researcher who will increase the realism of the Monte Carlo in the forward direction, develop and adapt tools for LC forward track finding, and investigate the tracking efficiency and purity for various detector geometries.

There are a number of tools that have been developed within the high-energy community, or are being developed within the Linear Collider community that can be adapted for the purpose of understanding tracking in the forward region. For instance, very good forward tracking has been attained by the DØ collaboration using the "AA" tracking algorithm. Tools and algorithms developed for DØ tracking may be useful to compare with current forward tracking algorithms in the LC environment. By integrating tools that have been developed within the high energy community and current Linear Collider software tools, and by developing new algorithms and tools, a comprehensive and precise understanding of forward tracking will emerge.

Initially, we will characterize the efficiency and practicality of the currently proposed forward tracking technology and geometry, such as the silicon detector default geometry using endcap disks with radially aligned silicon microstrips. We will also characterize other designs being considered like the use of Gas Electron Multipliers (GEMs) as charge amplifiers and/or collectors in the forward region as proposed by groups at Louisiana Tech and Hampton University. All our studies will be done in collaboration with other groups working on tracking hardware and software. We will coordinate our efforts with the SLAC and LBNL simulation and reconstruction groups, and will cooperate with universities that are developing hardware that may be used for LC forward tracking.

After one year we expect to have (1) developed a realistic Monte Carlo including backgrounds in the forward region, full energy deposition, and accurate detector response, (2) implemented existing reconstruction tools into a unified package, and (3) determined tracking efficiency and purity for the default detector technologies and geometries in the forward region. Further work will need to be done to develop and optimize future algorithms, to develop mature tracking algorithms, and to add more realism to the simulation.

FY2006 Project Activities and Deliverables

We will focus specifically on some of the issues dealing with the SiD tracker. The primary questions about the SiD tracker involve pattern recognition. Finding actual tracks from particles in a densely populated hit environment can be an extremely challenging problem, even for conventional tracking systems that have many more layers than the SiD. The current SiD baseline proposal has 5 layers of pixellated vertex detector followed by 5 layers of Si strip detectors in the central region, but does not have a well developed baseline detector for the forward region. One milestone that should be completed by the second year is to develop a baseline detector that can accomplish the physics goals. Questions that have still not been answered about the central region will need to be addressed in the forward region, like whether K^0 mesons and Λ^0 baryons can be found with only 5 vertex layers and 5 silicon layers. Answering questions about the track pattern recognition and track resolution with the SiD detector will be the major focus both in the first and second year once the necessary tools have been developed.

FY2007 Project Activities and Deliverables

The direction during the last year of this proposal will depend heavily on the findings during the first two years. The final paragraph of the Project Description above lists the goals of the three year project. At the end of the third year, we expect to have those questions answered so that the LC detector collaboration will have the tools and information to answer the important questions about forward tracking technologies and physics parameters.

Budget justification:

The budget is for supporting a post-doctoral researcher half time. The other half of the time the post-doc will be involved in doing physics with DØ or investigating other aspects of physics at the LC. The proposed tracking studies need manpower to use the available tools and develop new tools to answer the relevant questions. Consequently, the most important use of funds for answering these questions is to support people who can develop and run the needed sophisticated simulations.

Three-year budget, in then-year K$

Institution: The University of Oklahoma

Item	FY2005	FY2006	FY2007	Total
One-half FTE Post-doctoral Researcher	$20,000	21,000	$22,050	$63,050
Total Salaries and Wages	$20,000	21,000	$22,050	$63,050
Fringe Benefits	$7400	$7770	$8159	$23,329
Total Salaries, Wages and Fringe Benefits	$27,400	$28,770	$30,209	$86,379
Total direct costs	$27,400	$28,770	$30,209	$86,379
Indirect costs	$13,152	$13,810	$14,500	$41,462
Total direct and indirect costs	$40,552	$42,580	$44,709	$127,841