Simulation Studies for a Silicon Tracker

Classification (subsystem)

Detector: Tracking

Personnel and Institution(s) requesting funding

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Project Overview

A silicon strip outer tracker is an attractive option for the International Linear Collider (ILC). The fine pitch of the strip detectors provide precise measurement of hit position, excellent two-track separation, and low occupancy. With proper design, these features can lead to a tracker with superb momentum resolution and excellent pattern recognition capabilities within a relatively compact volume. A silicon strip tracker is a key feature of the Silicon Detector concept.

To better understand what such a device might look like and how it would perform, a Silicon Detector Tracking group has been formed that meets regularly to share results and exchange ideas. This effort has gained considerable momentum over the past year, and the mailing list has grown to over 50 members of the HEP community.

A number of innovative tracker design concepts have emerged, but the effort is presently handicapped by the absence of detailed simulations that can quantify the relative merit of these different design concepts. Developing the ability to perform realistic simulations of detector performance and track reconstruction, including the effect of backgrounds, is urgently needed to provide a rational basis for the design choices that must be made. In the somewhat longer term, the tracker simulations are an essential component of a larger simulation effort that will be needed to build a credible case that the proposed detector is capable of meeting the physics goals of the ILC.

A number of key design issues have been identified that need to be addressed with simulation studies. These issues include:

- Are stereo layers required in the central (barrel) region, or is it sufficient to have only axial layers used in conjunction with the vertex detector?
- How many tracking layers are required, and how should they be arranged?
- How well can the tracker reconstruct long-lived particles, including K_S, Λ, and possible new long-lived massive particles?
- Is it necessary to fully overlap detectors in a given layer, or are small gaps acceptable?

- What is the impact of tracker material on the performance of energy flow algorithms?
- How accurately can the detector be aligned, and what is the resulting momentum resolution?

Addressing these issues will require a significant and dedicated effort. The best prospect for establishing such an effort is to get a postdoc involved in developing the needed simulation tools and in analyzing the result of these simulations. This project would provide funding for 50% of a postdoc working half time on tracking simulations. The postdoc would be based at Fermilab, where a significant fraction of the tracker design and engineering effort is based. The Brown University DOE grant would provide the remaining 50% of funding, and the postdoc would spend half time working on the DØ experiment. Richard Partridge would continue to contribute to the tracker design effort, and would help guide the simulation effort. He is typically at Fermilab days per week, allowing him to closely monitor the proposed simulation studies.

As part of this project, a variety of simulation tools will be developed to provide realistic and quantitative measurements of tracker performance. A hit digitization package is needed to turn GEANT4 energy depositions into charge measurements on individual strips. A clustering package is needed to identify clusters of strips associated with a hit and to estimate the hit position. A pattern recognition package is needed to find tracks using the hits clusters. Finally, a fitting package is needed to fit the hits and determine track parameters.

Developing the above packages would be a formidable undertaking if one were starting from scratch. Fortunately, the functionality of the above packages already exists in several HEP experiments (including DØ and CDF), and we expect to borrow heavily from these existing packages. Furthermore, many of the relevant experts are at Fermilab where this effort will be based.

Following the development of the required simulation tools, we anticipate using these tools to develop a quantitative understanding of the key design issues listed above. Expected measures of tracker performance include:

- Track finding efficiency as a function of polar angle
- Rate and characteristics of "fake tracks" that don't match a generated track
- Efficiency for reconstructing long-lived particles
- Momentum and impact parameter resolutions and residuals
- Efficiency for matching tracks between the vertex detector, silicon tracker, and calorimeter
- Rate and origin of photon conversions
- Disposition of tracker hits from conversions, albedo, etc.
- Effect of in-flight decays (kinks)

We anticipate that initial simulation studies will be focused on those quantities needed to answer specific design questions. For example, the question of whether additional detector layers with small-angle stereo should be incorporated will depend on comparisons of track-finding efficiency, K_S reconstruction efficiency, and the impact of the increased material on energy flow algorithms.

Looking further to the future, we anticipate that the Silicon Tracker design effort will converge on a "baseline" design for the Silicon Detector Conceptual Design Report. The simulation effort will then focus on a detailed characterization of the performance of the baseline design. Of particular importance is establishing that the baseline design can meet the needs of the full range of ILC physics goals. In addition, it will be important to demonstrate that the design is robust, insensitive to the expected range of backgrounds, and capable of being precisely aligned.

In summary, we propose to initiate a Silicon Detector tracking simulation effort. Support is requested for half of a postdoc, who will be based at Fermilab, for a period of three years. The proposed project includes development of simulation tools for realistically simulating track reconstruction, quantitative comparisons of tracker design options to guide the tracker design, and detailed characterization of tracker performance required for the Silicon Detector conceptual design report.

Broader Impact

The Brown High Energy Physics group takes an active role in ensuring that the results of our research have a broad impact on society. We accomplish this goal through a variety of means, including integrating research and teaching experiences, propagation of new results through publication and public lectures, and mentoring the next generation of scientific leaders. For example, last summer we recruited Allison Chang, a Brown undergraduate student, to participate in a research project at SLAC that studied vibration stabilization issues for a Linear Collider. We believe that a close involvement between faculty and students is one of the best ways to introduce students, especially members of under-represented groups such as Allison, to the excitement and rewards of science. Last summer's research was a tremendously rewarding experience for Allison - not only did she learn a great deal about physics and data analysis, but she also came away with a much deeper understanding of the nature of scientific inquiry.

Results of Prior Research

Richard Partridge has been working in the area of silicon tracker design for the Silicon Detector for more than a year, and has presented studies of tracker design concepts and performance measures at the past two ALCPWG meetings. Other research activities include participation in the DØ experiment at the Tevatron Collider, and he has recently joined the CMS experiment. Prior experience on silicon tracker design includes simulation studies and a significant leadership role in the proposed Run IIb upgrade for the DØ experiment, where he was a co-coordinator of the upgrade during the initial design phase and later served as deputy project manager.

The above research is supported in part by Task C of the Department of Energy grant DE-FG02-91ER40688. This grant largely supports research by the Brown High Energy Physics group in the study of hadron collider physics as members of the DØ and CMS collaborations.

Facilities, Equipment and Other Resources

The proposed research will be based at Fermilab, allowing close interaction with the tracker design and engineering efforts taking place at the laboratory.

No specialized equipment is required for this project. Computing requirements are expected to be modest, and existing computing resources available to the Brown group will be utilized for this project.

FY2005 Project Activities and Deliverables Project activities in the first year are focused on developing the tools needed to perform realistic tracking simulations. Where possible, we anticipate adapting existing algorithms to the Silicon Tracker rather than developing new algorithms.

- Incorporate a realistic hit digitization model into the Silicon Detector Monte Carlo
- Develop a clustering package for reconstructing clusters from the digitized hits
- Implement a track reconstruction package that performs track finding from the reconstructed clusters
- Begin to compare the performance for different tracker design options, with a focus on the most critical design issues

FY2006 Project Activities and Deliverables Project activities in the second year are focused on performing the tracker simulation studies needed to support the tracker design effort.

- Compare tracker performance for axial-only designs with axial+stereo designs
- Optimize the number of tracker layers and the placement of the layers
- Develop a V-finding algorithm and study the efficiency for reconstructing long-lived particles, including K_S and Λ decays
- Participate in studies of the impact of tracker design on energy flow algorithms
- Perform additional tracking studies as needed to optimize the tracker design

FY2007 Project Activities and Deliverables

Project activities in the third year are focused on further studies needed to finalize the conceptual design for the tracker and to perform simulation studies in support of documenting the detector performance at the conceptual design stage.

- Complete simulation studies of any remaining design issues
- Perform simulation studies needed to document the performance of the tracker design
- Asses the alignment precision that can be achieved using experimental data
- Participate in simulation studies of the Silicon Detector conceptual design to document the ability of the detector to meet ILC physics goals

Budget justification: Brown University

The proposed budget will support 50% of a postdoctoral research associate, with the remaining 50% provided by the existing Brown University DOE grant. It is expected that the postdoc will spend 50% of his or her time working on ILC tracker simulation, with the remaining 50% spent on the DØ experiment at Fermilab. A starting full-time salary of $44,000/year with 4% annual salary increases is assumed. Brown's benefit rate is currently 35.2%.

Support is also requested for travel expenses associated with the tracking simulation project. Estimated travel expenses include one trip per year to an ALCPWG meeting ($1000) and two trips/year to SLAC to meet with tracking and simulation experts there ($ 500/trip).

Indirect costs are calculated using the off-campus rate of 26% that is applied for personnel based at Fermilab.

Three-year budget, in then-year $

Institution: Brown University

Item	FY2005	FY2006	FY2007	Total
Postdoctoral Research Associates	22,000	22,880	23,795	68,675
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	22,0000	22,880	23,795	68,675
Fringe Benefits	7,744	8,054	8,376	24,174
Total Salaries, Wages and Fringe Benefits	29,744	30,934	32,171	92,849
Equipment	0	0	0	0
Travel	2,000	2,000	2,000	6,000
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	31,744	32,934	34,171	96,849
Indirect costs	8,253	8,563	8,884	25,700
Total direct and indirect costs	39,997	41,497	43,055	124,459