Calorimeter-based Tracking for Particle Flow and Reconstruction of Long-lived Particles with the SiD Detector

Tracking

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Calorimeter-based tracking for particle flow and reconstruction of long-lived particles with the SiD detector

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1 Project Overview

The high energy physics group at Kansas State University is interested in the SiD detector concept [1] because of its excellent prospects for the application of particle flow algortihms, resulting in improved energy and momentum measurements. One of the main concerns with respect to the SiD concept has been the reconstruction of long-lived particles (K^0_S, Λ) [2]. We address this issue with our proposal.

The reconstructing of long-lived particles in the SiD with standard tracking can be considered a problem because tracking with the SiD relies on Vertex detector hits as seeds for tracks, assuming that the Tracker with only five layers is not capable of providing pattern recognition. Tracks from the decay of long-lived particles usually lack enough vertex detector hits to provide a track seed and these tracks are lost. For example, about 97% of all K^0_S in hadronic events decay more than 3 cm away from the beam pipe and have thus less than the necessary number of three vertex detector hits to form a track seed.

This problem is addressed by the Garfield tracking algorithm, an algorithm developed for the SiD by von Toerne and Onoprienko. The algorithm was specifically intended for the reconstruction of tracks without vertex detector hits. The algorithm uses ECAL clusters as the start point of pattern recognition. The cluster provides the track's endpoint and the track direction at that point. The algorithm extrapolates the track into the tracking volume and assigns tracker hits to the track. The algorithm constitutes a full outside-to-inside tracking algorithm that complements the standard (inside-to-outside) tracking algorithm.

We propose to further develop our tracking algorithm and to perform dedicated studies of

the impact of our algorithm on particle flow methods. Particle flow is a natural topic in this regard because our tracking relies on calorimetry and our project can be viewed as being at the interface of tracking and calorimetry. Although we count ourselves as part of the SiD tracking effort we collaborate with ECAL groups and groups interested in particle flow in general. We are also interested to develop algorithms that will improve particle flow. Other groups working on particle flow concentrate on the calorimeter (ECAL at U. Iowa and HCAL at Northern Illinois U.). We will concentrate on tracking-related particle flow software, thus optimizing the division of labor.

2 Broader Impact

We see the linear collider effort as excellent opportunity to increase our outreach efforts. We will implement linear collider segments into our existing outreach efforts.

Quarknet We are a Quarknet center [3], serving the western, rural part of Kansas. During our first Quarknet summer institute in 2003, we trained four lead teachers and attracted about 30 teachers in the following year. We will include a linear collider segment into the next institutes.

Undergraduate Research Our research has already attracted one undergraduate student from a Kansas College. We have found that the proposed research topic, reconstuction and tracking is very attractive for students for several reasons. Simulated events can be easily visualized with the advanced event display that is part of the java-based reconstruction software. The code also runs standalone on standard PCs equipped with LINUX or windows operating systems. Since the JAS package is publicly available, we installed it on the student's private Notebook as well. We see this as an additional step of empowering the student and encouraging him to experiment with the self-contained code.

Colloquia Von Toerne has introduced students at a four-year college (Benedictine College in Atchison, KS) to his work by giving a colloquium about his research. We will continue to give colloquia about linear collider to a broader audience.

We also intend to disseminate the results of our research by publication in international journals.

3 Results of Prior Research

Prior research has focussed on the implementation of the Garfield tracking algorithm, a basic reconstruction algorithm for long-lived particles with the SiD. A proof-of-principle version was completed in the summer of 2004 and was presented at the ALCPG meeting in Victoria and at several other occasions [4, 5, 6, 7].

The algorithm is comprised of about 5,000 lines of code and has been implemented as part of the standard java-based reconstruction software (hep-lcd). Our code is available through

CVS and through the package's homepage [8]. Figure 1 shows a reconstructed event with Garfield tracking and a reconstructed K^0_S decay.

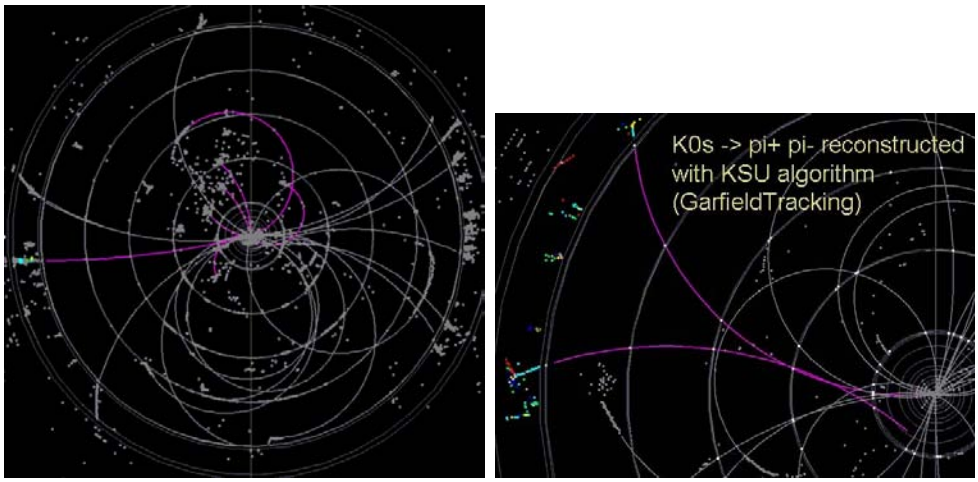

Figure 1: Left: Event display for a linear collider event (simulated Z0-pole data). Tracks reconstructed with the K-State Garfield algorithm are highlighted. Right: Reconstructed decay of a long-lived particle using Garfield.

We have also studied design options for the SiD. We investigated the impact of the length of ladders in the tracker barrel. We found that long ladders spanning halfs the size of the barrel still allow the reconstruction of the K0s. A shorter ladder length improves pattern recognition slightly [6].

The Kansas State High Energy Physics group is mainly funded by our DOE base-grant and an DOE-EPSCoR grant. Prior L.C. research was funded by the EPSCoR grant. Quarknet outreach acvtivities are supported by a DOE+NSF grant.

4 Collaboration with other LC groups

We collaborate with the following groups on several aspects of our research.

University of Iowa We collaborate on particle flow. Iowa investigates questions related to the calorimeter while we are interested in track-cluster matching and the question of impact of strange partcile decay of particle flow.

Northern Illinois University We use NIU's GEANT4 simulation interface "LCDG4" and have generated multihadronic and single particle Monte Carlo samples with it. We provide feedback and bug-reports about LCDG4 to the developers at NIU.

SLAC We cooperate by testing code released by Norman Graf's simulation group.

FNAL D. Onoprienko is now stationed at Fermilab, participates in SiD meetings their and is in contact with other linear collider experts stationed at Fermilab.

5 Facilities, Equipment and Other Resources

The Kansas State University High Energy Physics group has at its disposal approximately 2000 ft^2 of space in the physics department "high bay lab", including a 550 ft^2 class 10000 clean room containing probe stations, a manual wire bonder, and an optical microscope with video and computer interfaces.

Our K-State HEP group has access to a proton beam of up to 14 MeV from the tandem van de Graff accelerator in the Kansas State James R. Macdonald Laboratory (JRML, a DOE national user facility). DOE EPSCoR funds were used to instrument a JRML beam line for radiation tests of silicon sensors, and we have sole use of this line and a guarantee of beam time for the next three years. The HEP group also has access to the K-State physics department mechanical shop and the Kansas State Electronics Design Laboratory (KSU-EDL), which is staffed by two engineers, a technician, and several student interns. The KSU-EDL supports our work on readout electronics for detectors. KSU-HEP computing consists of a 12 node LINUX cluster containing mostly Pentium 3 and older processors. The group maintains good connectivity via Internet2 connections and an IP/ISBN video-conferencing system. Linux PC-cluster is sufficient computing resources for code development and the generation of modest Monte Carlo samples. No additional computing resources are requested from this grant. For the generation of larger Monte Carlo samples we intent to utilize a Linux cluster at Fermilab in collaboration with Northern Illinois University.

6 Description of project activities

We seek resources from the Department of Energy to continue our linear collider research effort and to further explore the physics reach of the SiD detector design and its particle flow capabilities.

FY2005 activities and deliverables In fiscal year 2005 we plan to further improve our Garfield tracking algorithm and explore its physics capabilities. One issue that we need to address is to better understand track reconstruction in busy events. While our base-line reconstruction studies Z-pole hadronic decays, these are far less busy than the important multihadronic events at higher energies. We will continue our study of SiD design options and will investigate particle flow questions along two avenues. The first is the general impact of long-lived particle decays (K^0_S and Λ^0) on particle flow calorimetry and to understand the extend to which long-lived particles affect the reconstruction of multi-hadronic events.

The second is improve particle flow techniques using the Garfield tracking algorithm. This is done in several ways:

- By identifying clusters that come from charged tracks.

- By complementing the standard tracking algorithm and we increase the tracking efficiency (two track finder find more tracks than one).
- By identifying calorimeter backscatter. The are charged tracks that originate from particles interactions in the calorimeter and that traverse the tracking volume. Our algorithm is capable of reconstructing these and we intend to provide a dedicated package for the identification of calorimeter backscatter. This will improve particle flow because cluster created by the backscatter can be removed.

Deliverables are improved version of our tracking and reconstruction package which will be released to the linear collider community via CVS. We will also provide a detailed study on the impact of long-lived particles on particle flow and a suite of reconstruction routines that will be used in particle flow analyses.

FY2006 activities and deliverables In FY2006 we intend to continue our particle flow studies and to perfrom in addition a detailed study of the physics reach for long-lived (10^{-8} s lifetime) particles with the SiD detector concept. We would also like to develop a new version of the Garfield prgram that is compliant with the new world-wide Input/Output format (LCIO). A LCIO-compliant version of the java-based linear collider software is being developed at SLAC. We intend to port our code to the new LCIO framework as soon as the LCIO based reconstruction package is released.

FY2007 activities and deliverables FY2007 We will investigate tracking in the forward region. Due to its excellent angular coverage of the ECAL our algorithm can also be applied for tracks in the far forward region. Our algorithm only requires an ECAL cluster and a couple of hits to form a tracks seed. Our algorithm already performs well in the forward region. We will study in detail how to optimize our algorithm to the forward region.

In FY07 we will also implementing our algorithm for other detector concepts as well. We are interested to collaborate with Mike Ronan (Berkeley) for use of our algorithm for the large detector option.

Deliverables for 2007 will be that our algorithm be compliant with several detector options.

7 Budget

Budget justification This section provides an explanation and breakdown of our requested budget for fiscal years FY05, FY06 and FY07. A context for the requests has been provided in Section 6.

Personnel
We request partial funding (20%) for research associate Dima Onoprienko. We also ask for funds to pay hourly students for participation in research projects.

Equipment/Materials
No funds for equipment or materials are requested from this grant.

Travel
we request support for domestic travel for the post-doc and for von Toerne to collaborate with other groups, attend simulation workshops and present results at L.C. conferences. The travel for FY2005 is slighlty higher due to the planned participation of Onoprienko at the 2005 Snowmass workshop.

Facilities and Administrative costs (F& A) at K-State
The standard Kansas State University rate for indirect costs (Facilities and Administration) is 46%. KSU makes a contribution to F& A costs which brings the effective rate down to 33% for the High Energy Physics group.

Three-year budget, in then-year K$

Item	FY2005	FY2006	FY2007	Total
Other Professionals	9.4	9.7	10.1	29.2
Graduate Students	0	0	0	0
Undergraduate Students	3.0	3.0	3.0	9.0
Total Salaries and Wages	12.4	12.7	13.1	38.2
Fringe Benefits	3.1	3.2	3.3	9.6
Total Salaries, Wages and Fringe Benefits	15.4	15.9	16.5	47.9
Equipment	0	0	0	0
Travel	4.5	2.0	2.0	8.5
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	19.9	17.9	18.5	56.3
Indirect costs	6.6	5.9	6.1	18.6
Total direct and indirect costs	26.5	23.9	24.5	74.9

Columns might not add up due to rounding

References

[1] Silicon Detector Design study (SiD), `http://www-sid.slac.stanford.edu`

[2] See for example, John Jaros, plenary talk, ALCPG meeting 2004 in Victoria.

[3] K-State Quarknet center, `http://www.phys.ksu.edu/~evt/Quarknet/quarknet.html`

[4] Kansas State 2004 DOE review, Presentation by D. Onoprienko, `http://www.phys.ksu.edu/hep/DoE-Review/`

[5] Presentation by von Toerne at Victoria Linear Collider Workshop, July 2004, accessible through http://www.phys.ksu.edu/hep/lc/longlived/k0s_lcd.htm

[6] Presentation by von Toerne in the SiD tracking meeting, October 22nd 2004, accessible through http://www.phys.ksu.edu/hep/lc/longlived/k0s_lcd.htm

[7] Seminar at University of Oregon, January 10th 2005.

[8] http://www.phys.ksu.edu/hep/lc/longlived/k0s_lcd.htm