STATUS REPORT

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

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[2] Bonn University, Germany (no funds are requested for Bonn University)

Collaborators Collaborators

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Collaborating personnel will work on the project but are not requesting funding here.

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Project Overview The high energy physics group at Kansas State University participates in the Silicon Detector (SiD) design study [1]. The SiD has excellent prospects for the application of particle flow algorithms, resulting in improved energy and momentum measurements.

One interesting design aspect for the SiD is the reconstruction of long-lived particles [2], such as K_S^0 and Λ^0. Charged tracks from these decays might be hard to reconstruct because standard pattern recognition relies on Vertex detector hits as seeds for tracks. Tracks from the decay of long-lived particles usually lack the vertex detector hits necessary to generate a track seed and these tracks are therefore not reconstructable with the standard tracking.

Our program nicely complements standalone tracking efforts at SLAC which use pattern recognition in the outer tracker but have to assume that the tracks come from the primary vertex and are inefficient for tracks originating from secondary vertices[3]. In summary, tracks from the decay of long-lived particels are not reconstructable with the methods outlined above.

Our Algorithm (Garfield Trackfinder) reconstructs tracks by extrapolating ECAL cluster (MIP-stubs) into the tracker volume. This calorimeter-assisted tracking is crucial for the reconstruction of long-lived particles with the SiD, such as K_S^0 or Lambdas[1], or more exotic, long-lived particles like supersymmetric particles which occur in gauge mediated supersymmetry breaking scenarios A decay of such a particle produced in pair-production at the ILC is shown Fig 2. The algorithm uses ECAL clusters as the start point of pattern recognition.

[1]For example, about 97% of all K_S^0 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.

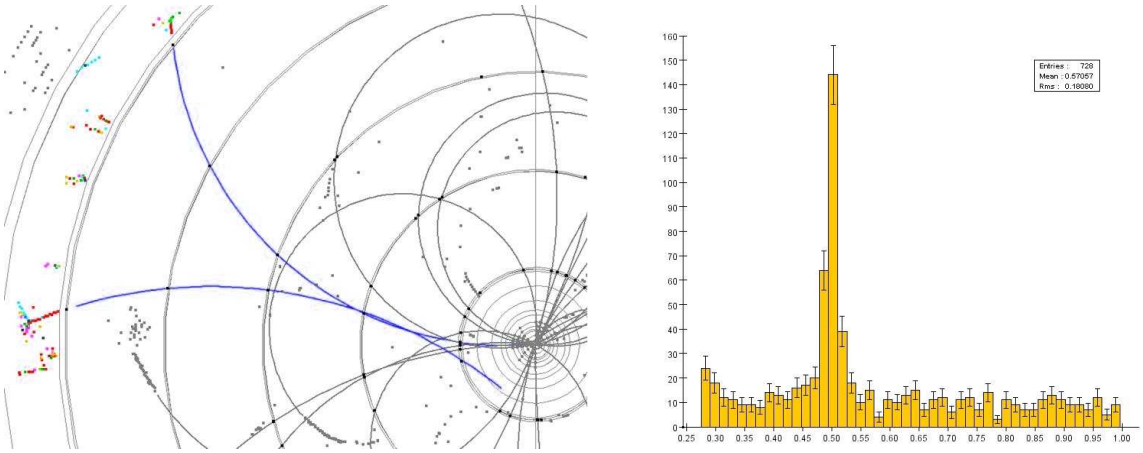

Figure 1: Left: Simulated $K^0_S \to \pi^+ pi^-$ decay in an hadronic event. The K^0_S decay vertex is located in the 9 o'clock position between the first and second outer tracker layer. Right: Reconstructed K0s mass peak in hadronic Z^0 decays. (Both plots are from a Z^0-pole sample)

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. Further information can be found here [4]).

Status Report

Status of the algorithm 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 [5, 6, 7]. A recent update was given at LCWS[8, 9] and at Snowmass[10].

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 [11]. Figure 1 (left) shows a reconstructed event with Garfield tracking and a reconstructed K^0_S decay and the K^0_S mass peak reconstructed with our algorithm.

Recent work went into porting our code to org-lcsim which has now been completed. Figure 3 shows a reconstructed K^0_S decay with the org-lcsim tools. Org-lcsim is the LCIO compliant

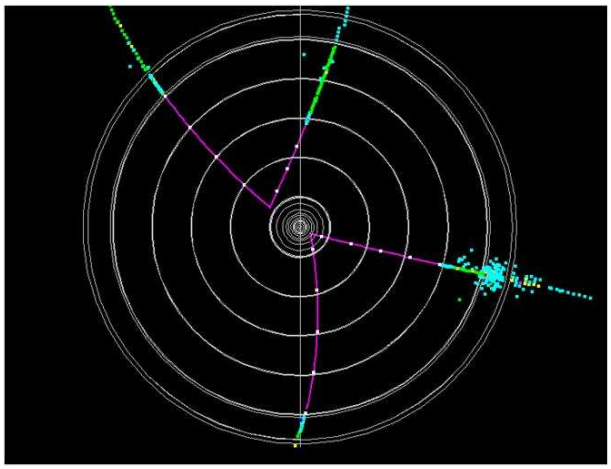

Figure 2: Pair production of $e^+e^- \to \chi_2^0\chi_2^0$, $\chi_2^0 \to \chi_1^0\mu^+\mu^-$ with a long χ_2^0 life time.

version of the java-based ILC software. In our FY05 proposal we listed this milestone under 2006 deliverables which has now been completed earlier.

Our algorithm also been improved to run stable in busy events up to multi-jet final states at 500 GeV such as $e^+e^- \to t\bar{t} \to 6\,jets$. However the yield of reconstructed $K_S^0 \to \pi^+\pi^-$ is not yet satisfactory in busy events while it is good in our benchmark events (hadronic Z decays at the Z-pole).

Our efficiency studies (that were performed by scanning a few dozen events) showed that the algorithm failed in step one: reconstructing the Mipstub within the ECAL cluster. Since at the current stage we are using a typical ECAL clusterer (which in org-lcsim is NearestNeighborCluster) it became obvious to us that we need a better MipStub finder. Dima Onoprienko is currently implementing an idea for such a finder that would suit our needs (high efficiency, good direction resolution, good to mediocre purity). We will also implement existing MipStub finder from other PFA groups.

Implications for Particle Flow Only little energy really is transported by k0s and Lambda. We estimate 2% of the total energy in hadronic events comes from the decay $K_S^0, \Lambda^0 \to$ charged tracks. This not necessarily means that K_S^0 and Lambdas are unimportant. The following rough calculation hall illustrate this point. We assume for a moment that we do not reconstruct track from the decay of long-lived particles. If the ECAL clusters from the decay products always remain in the mother jet the energy measurement is not affected at all. This however is unlikely since the particles will be deflected by SiD's large magnetic field and the cluster created by the tracks might be far off and end up in another jet.

Assuming a 50% accuracy on the measurement of the K_S^0+Lambda fraction this would contribute 1% to the total energy uncertainty on the jet energy. With 30% over sqrt E and a typical jet energy value of E=100 GeV, we obtain roughly a jet energy uncertainty of 3%

based on Calorimeter performance. The effect from K^0_S+Lambda decays would then increase the energy uncertainty to 3.3, which is a relative increase by 10%. It is in roughly that order of magnitude (probably lower) in which K^0_S and Lambda decays could affect particle flow. This possible effect can be mitigated by algorithms that can reconstruct the tracks or that improve the track - cluster matching. Further studies are necessary to quantify this.

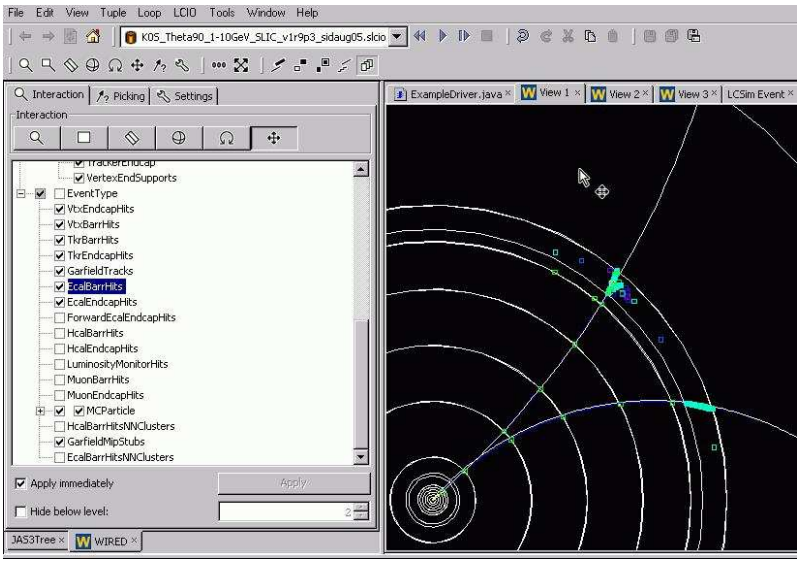

Figure 3: Event display for a linear collider event based on the org.lcsim framework. Shown is a $K^0_S \to \pi^+\pi^-$ decay reconstructed with our algorithm.

FY2006 Project Activities and Deliverables In fiscal year 2006 we will further investigate 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 also want to 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, we increase the tracking efficiency (two track finder find more tracks than one).

Deliverable will be the release of our particle flow tools. We will also start a detailed study of the physics reach for long-lived ($\approx 10^{-8}$ s lifetime) particles with the SiD detector concept. This study will continue into FY2007.

FY2007 Project Activities and Deliverables

In FY2007 we will continue to study the physics reach for long-lived particles. We will also 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.

Permitting time and resources, we will also implement 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 the completion of our physics reach studies.

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

Personnel
We request partial funding (15%) for post-doctoral research associate Dima Onoprienko. We also ask for funds to pay hourly students for participation in research projects in FY2006 and FY2007.

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. Onoprienko will attend the simulation workshop in Boulder (Jan. 06).

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.

Two-year budget, in then-year K$

Institution: Kansas State University

Item	FY2006	FY2007	Total
Other Professionals	7.3	7.6	14.9
Graduate Students	0	0	0
Undergraduate Students	1.8	1.5	3.3
Total Salaries and Wages	9.1	9.1	18.2
Fringe Benefits	2.4	2.5	4.9
Total Salaries, Wages and Fringe Benefits	11.5	11.6	23.1
Equipment	0	0	0
Travel	2.0	1.9	3.9
Materials and Supplies	0	0	0
Other direct costs	0	0	0
Total direct costs	13.5	13.5	27.0
Indirect costs	4.5	4.5	9.0
Total direct and indirect costs	18.0	18.0	36.0

Numbers 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] Tim Nelson, Presentation at SiD Workshop, Fermilab, Dec. 2005.

[4] https://wiki.lepp.cornell.edu/wws/bin/view/Projects/TrkKansasCalAssist

[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] D. Onoprienko, LCWS05 (Reconstruction parallel session), March 05

[9] E. von Toerne, LCWS05 (Calorimetry parallel session), March 05.

[10] D. Onoprienko, presentations at Snowmass 05, August 05.

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