PROJECT DESCRIPTION

TPC signal digitization simulation and reconstruction studies

Personnel and Institution(s) requesting funding

D. P. Peterson, Laboratory for Elementary-Particle Physics, Cornell University

Collaborators

none

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Project Overview

This project involves improvements to the simulations of the response of a TPC and studies of improving charged particle track reconstruction. The project is equally relevant to the LDC and GLD concepts.

Full efficiency for charged particle reconstruction is required for precision particle flow analysis [1]. A TPC for the linear collider must be designed to provide this efficiency over a large solid angle in an environment of high density jets and high noise occupancy. Reconstruction efficiency can be improved with higher readout pad segmentation to the limit of the signal charge width, about 1mm. While it is not even demonstrated that this maximum segmentation would be sufficient to provide full efficiency under all conditions, there are other limitations to such a high pad density: cost, material, heat, and complexity, that may force a larger pad size. Thus, it is necessary to optimize the readout geometry for reconstruction efficiency.

Simple models of the TPC response are not sensitive to the hit distortions resulting from noise. In the simple models, TPC hits are simulated as 3-dimension space points derived from the intersection of the tracks with cylindrical surfaces corresponding to the radial centers of the layers of pads. Charge depositions are treated independently; multiple hits can be created in the same cell regardless of separation. Thus, there is no straight-forward way simulate the effects of overlapping hits.

The goal of this project is to model the charge spreading and signal overlap to provide sensitivity to the effects of overlapping tracks and noise. Charge is spread over neighboring pads and then accumulated in a simulation of the pulse train observed by the readout electronics, usually a flash-analog-to-digital-converter

(FADC). The pulse train is analyzed to find the unambiguous threshold crossings in the same way that real data is analyzed. Thus, signal overlap is fully simulated.

Having full knowledge of the effects of signal overlap is required for critical design questions facing the concepts that include TPC tracking, GLD and LDC. In particular it is necessary to determine the azimuthal and radial segmentation required for full tracking reconstruction efficiency. Tracking reconstruction is affected by beam-related ionizing particles entering the detector. Knowledge of the effects of signal overlap is required for a full analysis of the effects of these particles and, therefore, is critical for the design of the machine-detector interface.

This study currently uses the older (sio) data format. Further developments will require adopting the LCIO [2] data format and access routines which will allow access to larger samples and more complicated events. The next step will be to fully integrate this FADC simulation into existing event generation frameworks. It has not yet been determined which framework we will use first. This will allow the digitized data to be stored directly and will facilitate the addition of noise hit distributions derived from beam background calculations such as those being performed at DESY [3].

Up to this point, all development has been done by D. Peterson. Further development will require support for a graduate student to perform the LCIO and framework tasks as described above.

Broader Impact

This project will result in an increase in the sophistication of the simulation of the TPC response. After the simulation is adapted to use the LCIO data format and, to a greater extent, after the simulation is integrated into an existing framework, it will be disseminated for use by the ILC community. In that way, the project will enhance the infrastructure for research.

Results of Prior Research

GEANT models of track trajectories through matter and magnetic fields are quite sophisticated. They simulate energy loss, scatter and decay. However, the output is parameterized as only space points representing the intersections of the track trajectories with surfaces as shown in figure 1a. In the past two years, a procedure has been developed for converting these space points into simulated pad response.

In the first step of this procedure, "charge centers" are created at locations corresponding to the center of the sections of the trajectory that project onto each pad in the detector. In the second step, "charge" is assigned to the "central cell" (the cell onto which the track segment projects) and to "neighboring cells" according to an input pad-response-function. The charge has attributes of pulse height, drift time, and pulse shape. Note that in this procedure, charge is assigned to a cell not only due to the trajectory section that projects onto the cell, but also from the trajectory sections that project onto neighboring cells. Also, while the original space points do not simulate the response from the tops of curling tracks, this procedure naturally simulates this response because it uses the sections of the track trajectory through the affected cells.

In the third step, the multiple assigned charges in each cell, including charges due to tracks and noise, are accumulated in a simulation of FADC readout. Each charge creates measured pulse height in affected time buckets according to attributes of that charge. Overlapping charges add in the affected time buckets. The effect of overlapping tracks is completely simulated.

In the fourth step, the resultant FADC output is analyzed to detect the unambiguous threshold crossing. This is actually the beginning of reconstruction as the procedure is exactly what would be used for real data. The unambiguous threshold crossings on each pad are "hits", with attributes of pulse height and drift distance. This is the input to track reconstruction. An example is shown in figure 1b for 1cm pads in a 1.9m outer radius TPC.

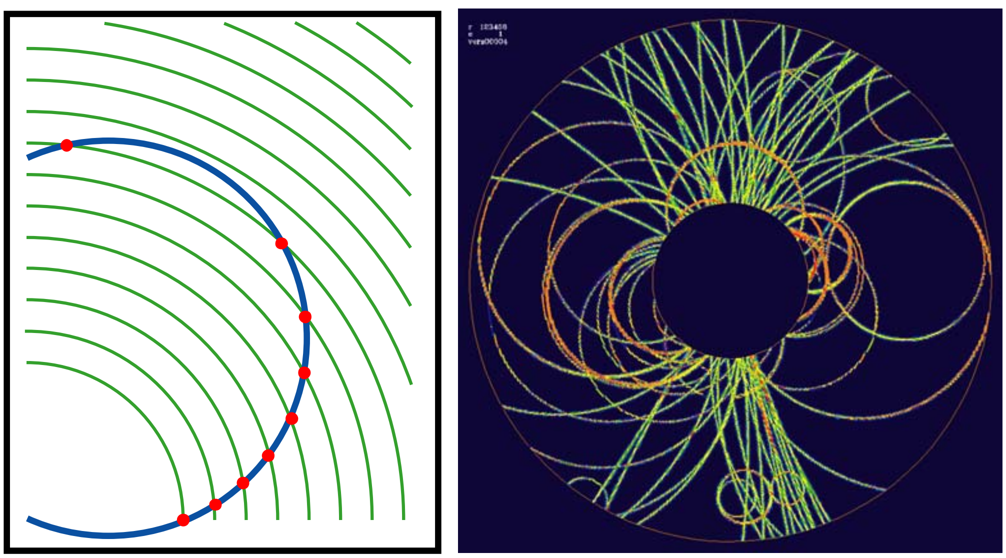

Figure 1: The intersection of a track trajectory with cylindrical surfaces (a) are transformed into multiple "hits" on each pad (b) with attributes of pulse height and drift distance.

The simulated event in figure 1 is used to illustrate the procedure. All tracks are projected onto one endplate. There is no noise and the pad size (10mm) is larger than what would be used at the ILC so that individual pads are (almost) visible.

Events become more complicated with the addition of noise and smaller pads. Figure 2a shows a section of the same event using 3mm pads and with the addition of 3.6% (by volume) random single-pad noise. The confusion resulting from several overlapping tracks, as well as noise, can be seen in figure 2b.

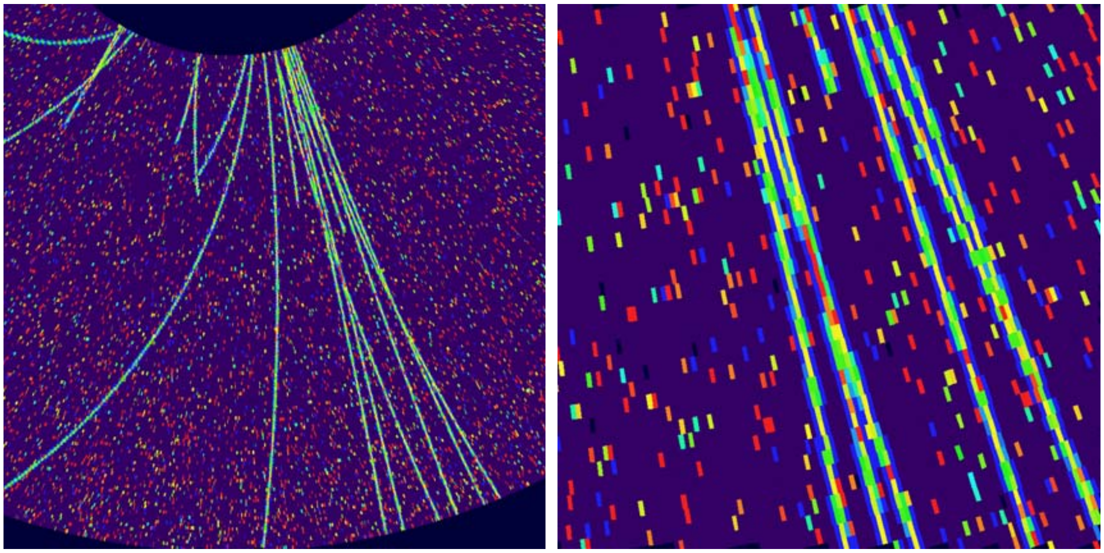

Figure 2: (a) A section of the TPC readout with 3mm pads for an event with 3.6% (volume) noise. There are multiple hits on most pads. As part of the track pattern recognition procedure, only hits within a narrow interaction-point-projecting section of the chamber are selected. (b) A section from the readout is expanded. Color coding indicates pulse height, with red being the highest and blue the lowest.

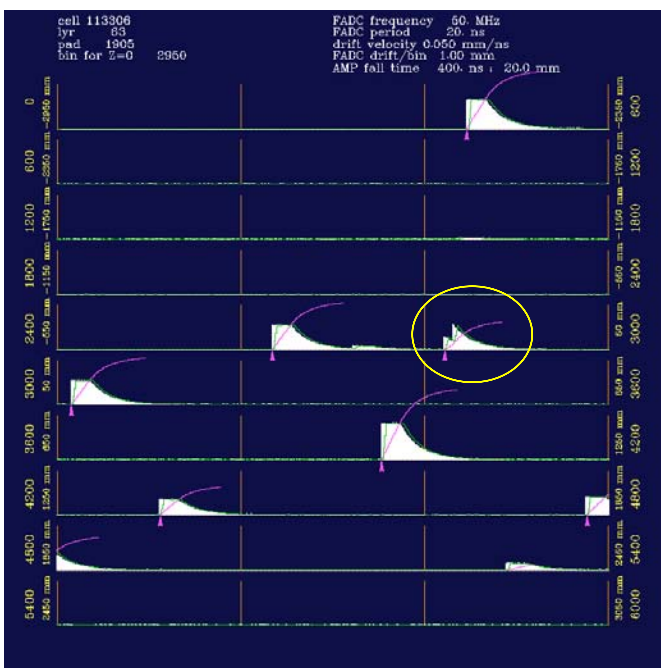

Figure 3: The FADC pulse height spectrum from one pad in the TPC readout. The spectrum is separated into 8 lines for display. This is taken from a region of overlapping tracks. The resulting overlapping signals are visible (indicated by the circle) and only slightly separated in time. Recognized threshold crossings are indicated by the pink arrows. Signals from the two tracks are not resolved. (Other markings in the figure are diagnostics for the FADC pattern recognition.)

Reconstruction of tracks from the resulting charge/time signals is far more complicated than the reconstruction using the track-surface intersections (figure 1a) as input. As described above, reconstruction first requires pattern recognition of the threshold crossing in the FADC, as shown in figure 3. The hits on individual pads (figure 2b) must be clustered to determine the precision hit position information.

Preliminary results for this project were shown at LCWS04, Paris, April-2004 [4]. Results indicating the pad segmentation sufficient for full pattern recognition were shown at ALCPG, Victoria, July-2004 [5]. Most recently, at ECFA, Vienna, November-2005 [6], results were shown for the noise tolerance for the specific case of random noise hits and a particular pad size.

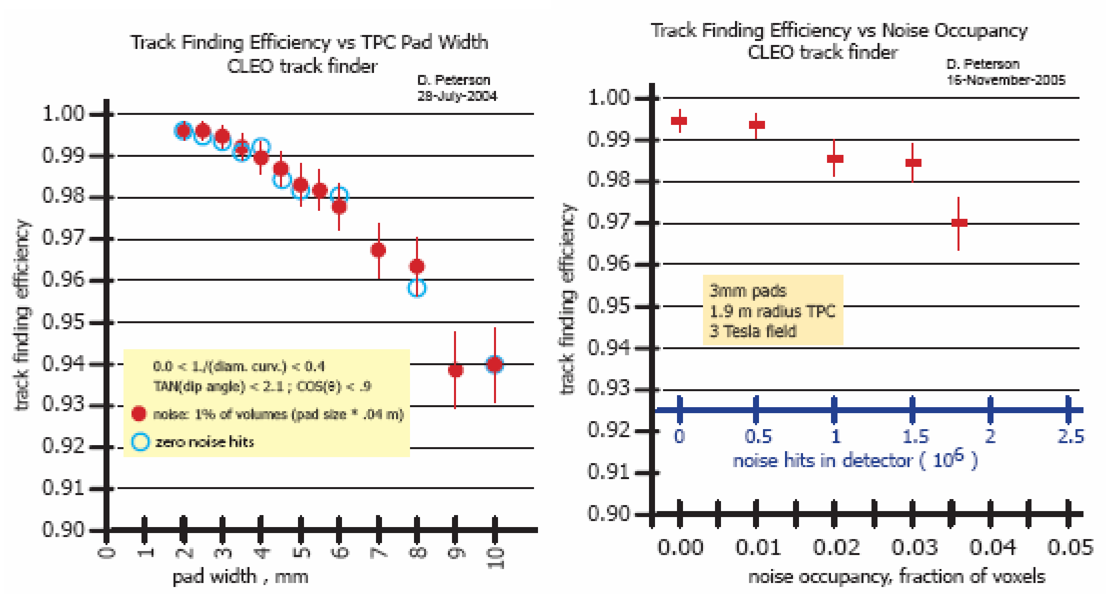

Figure 4: (a) Reconstruction efficiency as a function of pad size. (b) Reconstruction efficiency as a function of noise density. In both cases the TPC has outer radius 1.9m and the magnetic field is 3Tesla.

From the results shown in figure 4, a 3mm pad size is sufficient for full reconstruction efficiency. This is for a particular event topology ($e^+e^- \rightarrow$ HZ) and a particular chamber (1.9m outer radius, 3T field). These studies should be repeated for the current concepts and for various events types. The results indicate that the reconstruction is degraded above 1% noise occupancy. This is for random single-pad noise. Reconstruction may be more difficult with correlated noise due to overlapping events or multiple small curling tracks coming from scattered beam.

Studies of TPC performance have been done using a modified version of the current generation of the CLEO track reconstruction algorithm. This generation of the CLEO track reconstruction algorithm was substantially written by DPP and has been used in every CLEO publication in the last 5 years [7].

Work described in this section has been supported at Cornell by NSF cooperative agreement PHY-0202078, 4/1/2003 – 3/31/2008, entitled "Support of the Cornell Electron Storage Ring (CESR) Facility.

Facilities, Equipment, and Other Resources

The Cornell University Laboratory for Elementary-Particle Physics (LEPP) has extensive computing resources and support staff used largely for CLEO data-collection, calibration, and analysis code development as well as CESR accelerator machine operations and simulation. In addition, these resources support the particle physics theory group, the development of the Energy Recovery Linac, and the ongoing Cornell/Purdue ILC TPC development program (project 5.7). Proposed studies will use the existing computing facilities at Cornell University.

FY2006 Year Project Activities and Deliverables

During the first project year, we will create a simple framework to access LCIO data through the provided FORTRAN access functions. On completing the access to LCIO, we will immediately be able to analyze larger data sets to determine the track reconstruction efficiency with respect to several variables: momentum, longitudinal angle, decay length, and jet density.

We will begin the integration of the simulation into an existing analysis framework.

The deliverable for FY2006 will be openly available code allowing the user to input LCIO formatted space points corresponding to the intersection of tracks with surfaces and output LCIO formatted digitized FADC response. A second deliverable will be an expanded study of the track reconstruction efficiency.

FY2007 Project Activities and Deliverables

Completion of the integration of the simulation into an existing framework will be a deliverable for FY2007.

During the second year we will further optimize the reconstruction algorithm.

Budget Justification: Cornell University

The budget for each of FY2006 and FY2007 provides 1 full year support for a Cornell graduate student as well as funds for that student to travel to one domestic workshop.

Current costs for a graduate student, for the year beginning September 2005, are academic year stipend: $18237, summer stipend: $7623, 50% of tuition: $15650, health insurance: $1346. The tuition payment and health insurance are treated as "other direct costs", not fringe benefits.

Cost for FY2006 and FY2007 shown in the table are for, respectively, 1 and 2 years beyond the September 2005 academic year. Tuition is inflated by 4.5% per year. Stipends and health insurance are inflated by 9% per year.

The $2000 travel cost is for the student to attend one domestic workshop.

The stipends and travel costs are subject to overhead.

Overhead is 58% for FY2006 and increases to 59% for FY2007.

Two-year budget, in then-year K$

Institution: Cornell University

	FY2006	FY2007	Total
Other Professionals	0	0	0
Graduate Students	28.187	30.724	58.911
Undergraduate Students	0	0	0
Total Salaries and Wages	28.187	30.724	58.911
Fringe Benefits	0		0
Total Salaries Wages and Fringe Benefits	28.187	30.724	58.911
Equipment	0	0	0
Travel	2.000	2.000	4.000
Materials and Supplies	0	0	0
Other Direct Costs	17.821	18.689	36.510
Total Direct Costs	48.008	51.413	99.421
Indirect Costs	17.508	19.307	36.815
Total direct and Indirect Costs	65.516	70.720	136.236

[1] Energy flow analysis is further described in the "TESLA TDR", http://tesla.desy.de/new_pages/TDR_CD/start.html, Part IV, page 2.
[2] LCIO webpage: http://lcio.desy.de/
[3] "Background Studies for the LDC TPC", A. Vogel, ECFA 2005, Vienna, 15-November-2005, https://ilcsupport.desy.de/cdsagenda/fullAgenda.php?ida=a0575
[4] “TPC Detector Response Simulation and Track Reconstruction”, D. Peterson, LCWS 2004, Paris, 19-April-2004, http://indico.cern.ch/conferenceDisplay.py?confId=a04172
[5] “TPC Detector Response Simulation and Track Reconstruction”, D. Peterson, ALCPG workshop, Victoria, 28-July-2004, http://www.linearcollider.ca:8080/lc/vic04/abstracts/detector/sumul/
[6] "TPC digitization and track reconstruction: efficiency dependence on noise", D. Peterson, ECFA 2005, Vienna, 15-November-2005 https://ilcsupport.desy.de/cdsagenda/fullAgenda.php?ida=a0575
[7] CLEO has published 120 articles (total) in the years 2001:2005, not listed separately.