5.5. Studies of the Use of Scintillating Fibers for an Intermediate Tracker which Provides Precise Timing and Bunch Identification: Progress Report and Request For Funds
(LCRD)

Tracking

Contact person: Rick VanKooten
email: rvankoot@indiana.edu
phone: (812) 855-2650

Fermilab
Indiana
Notre Dame

Year 1: $45,400
Year 2: $46,000
Year 3: $21,500

This copy of the FY04 proposal is a placeholder until a progress report is available.

Project Name

Studies of the Use of Scintillating Fibers for an Intermediate
Tracker which Provides Precise Timing and Bunch Identification :
Progress Report and Request for Funds

Classification (accelerator/detector:subsystem)

Detector: Tracking

Institution(s) and personnel

Indiana University (Bloomington), Department of Physics:
Richard J. Van Kooten (professor), Keith Turpin (undergraduate student),
50% LC postdoc (starting March 2004).

University of Notre Dame, Department of Physics:
Barry Baumbaugh (engineer), Michael Hildreth (assistant professor),
Randy Ruchti (professor), Mitchell Wayne (professor),
Jadzia Warchol (research professor)

Fermi National Accelerator Laboratory
Alan Bross (Physicist)

Contact person

Rick Van Kooten
rickv@fnal.gov
(812) 855-2650 Fax: (812) 855-0440

Project Overview

The performance and capabilities of the charged particle tracking in either a TPC-based large LC detector or silicon-based detector can be enhanced by the presence of an intermediate tracker at radii just below the inside radius of the TPC, or in a silicon strip device, particularly with long strips, either inside or outside the central tracker. In the case of a TPC-based detector, such a device would link tracks between the vertex and central tracking detectors, improve pattern recognition, and provide reliable and stable measurement points close to the TPC for use in the calibration of the TPC and monitoring variations of its characteristics with time. An intermediate tracker built from scintillating fibers has the advantages of very compact radial extent, simplicity of operation, and good single-hit resolution (80–100 μm). Possibly most importantly, in both tracking scenarios a scintillating fiber tracker can offer high-precision timing of tracks in events.

The current NLC/JLC machine design provides beams composed of trains of many (>100) bunches with bunch spacings of 1.4 ns. Large rates (10's of nb) of two-photon interactions are expected both from interactions of virtual photons from each beam and virtual photons with real photons from beamstrahlung. During the crossing of each bunch train one expects many of these two-photon interactions that result in “mini-jets” of particles spraying into the detector. The overlap in the tracking devices of the much more prevalent “mini-jets” with the e^+e^- interaction events of interest can be a problem if bunches are not identified in time which would allow the removal of extraneous particles from the analysis. Simulation studies already performed before the initial proposal submission show significant impact on Higgs events with missing energy when two-photon events from prior or subsequent bunches are overlaid on top of the event of interest[1]. A good knowledge of this background and how tracks and soft jets are distributed inside of detected events is needed. The planned resolution of a TPC tracking subdetector would result in integration of these two-photon events over 4–5 bunches, whereas a system with sub-nsec timing could identify from which individual bunch the tracks have originated. Depending on the technology used (silicon strip or silicon drift), a silicon based detector would integrate over even more bunches.

Using a scintillating fiber intermediate tracker coupled by clear fiber to light detection elements (visible light photon counters (VLPC's), Si:As devices manufactured by Boeing[2] or hybrid avalanche photodiodes run in Geiger mode) read out by the SVXIIe (or more recent versions such as the SVXIV) chip, it may be possible to achieve time resolutions less than 1 ns to associate tracks with individual bunches as well as complement time measurements in the TPC or silicon tracker. Dominant effects determining time resolution should be light intensity and the fluorescence decay time of the scintillator light, i.e., time dispersion of photons within the fiber is not as important.

Using the resources and expertise developed within our groups and the DØ collaboration from working on the successful Scintillating Fiber Tracker[3] in the DØ detector at Fermilab, we propose to demonstrate the feasibility of sub-ns timing in a scintillating tracker device. This project would answer important questions regarding the impact of NLC/JLC beam structure and thus accelerator technology choice on detector design.

---

[1] R. Van Kooten, *Studies of Event Overlap in Higgs Events: Need for Bunch ID*, presented at Chicago Linear Collider Workshop, Gleacher Center, Chicago, IL, 8 Jan. 2002 and available at `http://hep.physics.indiana.edu/~rickv/nlc/overlap_chicago.pdf`.

[2] Boeing Electronic Systems, 3370 Miraloma Ave., Anaheim, CA 92803; M.D. Petroff *et al*., Appl. Phys. Lett. **51** (1987) 406.

[3] A. Bross et al., *The D0 scintillating fiber tracker*, published in Proceedings of Notre Dame 1997: Scintillating Fiber Detectors, World Scientific; B. Baumbaugh, IEEE Trans. Nucl. Sci.**43** (1996) 1146.

Progress Report of Partial First Year

After a positive review by the review committee of the U.S. Linear Collider Steering group, funds were requested from the Department of Energy through a supplemental proposal as requested by our DoE contact. Funds were available for the first year starting June 2003. The report covers work starting in Summer 2003. Progress was also reported at the meeting of the American Linear Collider Workshop at Cornell University, 13–16 July 2003 and at the IEEE Nuclear Science Symposium at Portland, Oregon, 20–24 Oct. 2003 (paper N36-14, to be published in the proceedings).

Plans for modification of an existing cosmic ray test stand[4] at Lab 3 at FNAL were started. This is a large structure that will remain at FNAL and will make it possible to mount layers of prototype scintillating fiber ribbons from DØ on carbon fiber scintillators approximating the inner radius carbon fiber structure of a TPC. External precision position measurements will be provided by existing layers of proportional drift tubes. As an initial effort, a modification of a more modest system was also investigated, consisting of moving a radioactive source to known positions along a scintillating fiber and reading out the fiber from both ends as shown in Fig. 1. This system is compact enough to be operated at Indiana or Notre Dame University, and can study single prototype fibers containing new dyes with larger light-yields and faster decay times from Notre Dame University's SBIR and STTR projects[5], in collaboration with the Ludlum Corporation.

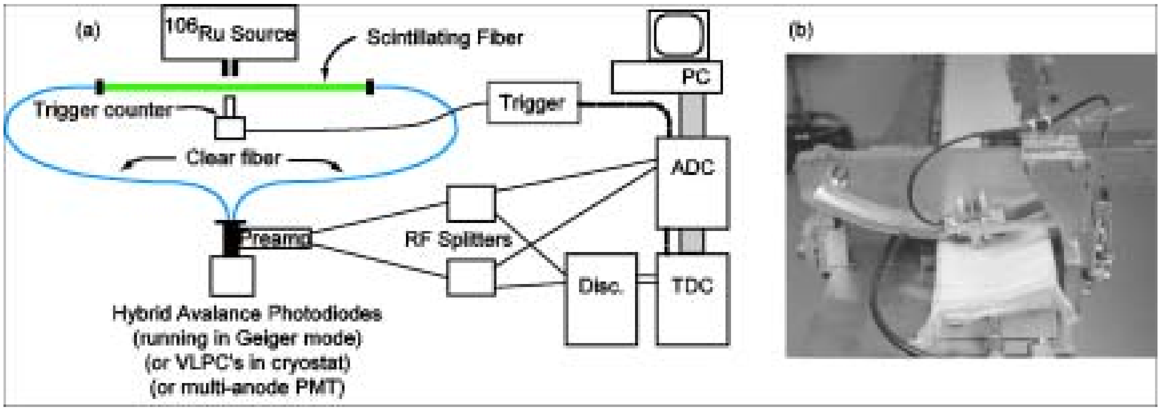

Figure 1: (a) Schematic of X-ray source scintillating fiber test setup being assembled; (b) existing X-ray test setup scanning a scintillating fiber ribbon at Fermilab.

With this system, the timing resolution can be determined from the width of the distribution of time difference measurements from the ends. Different light detection technologies and their response to the scintillating light and typical number of photons can be tested. Since pulse amplitude (i.e., resolving the number of photons) is not

---

[4] Described in P. Baringer *et al*., *Cosmic Ray Tests of the DØ Preshower Detector,* Nuc. Inst. and Meth. **A469** (2001) 295.

[5] R. Ruchti, et al., *Waveshifters and Scintillators for the Detection of Ionizing Radiation*, N36-2, to appear in the proceedings of IEEE Nuclear Science Symposium, 20-24 Oct. 2003, Portland, Oregon.

important in this application, hybrid avalanche photodiodes running in Geiger mode[6] should be a less expensive alternative to VLPC's and don't require as complex a cooling system. Engineering plans are complete to speed up an existing preamplifier card to be able to resolve sub-nsec timing. Fast TDC's and discriminators have been purchased as well as a 500 MHz oscilloscope with a PC interface. System-wide timing resolutions will be explored using the cosmic ray test stand at FNAL.

Monte Carlo simulations were pursued to verify the expected behavior of the scintillating fibers. Photons were generated from a Poissonian distribution along a specified length of scintillating fiber, with an exponential time distribution according to the scintillator and wavelength shifter decay times. Photons were ray-traced down the scintillating fiber and then clear fiber, including helical modes, photons captured in the cladding, and known attenuation lengths. The quantum efficiency of light detection elements at the ends of the clear fibers was included. The existing DØ scintillating fiber was simulated, with PTP and 3HF dyes for the initial fluorescence and wavelength-shifting, respectively, with a known decay time of $t_{decay} = 8.2 \pm 0.2$ nsec. The time difference between the first detected photon at each end was taken, and in the case of using VLPC's for readout (~80% quantum efficiency) for 1 m of scintillating fiber followed by 4 m of clear fiber on each end, a time resolution of s ~ 2.5 nsec was found as shown in Fig. 2.

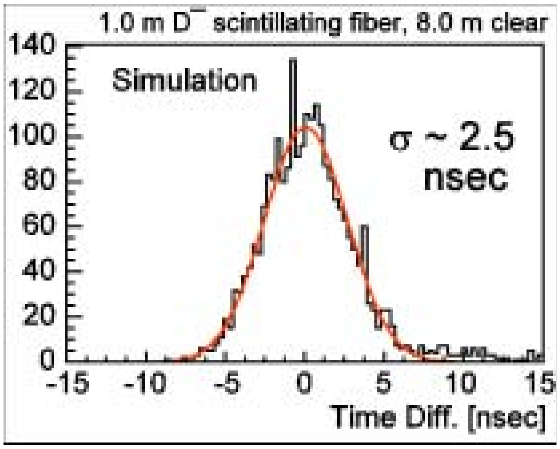

Figure 2: Monte Carlo simulation of the timing difference between the first photon detected at each end of DØ scintillating fiber 1-m long with 4-m of clear fiber on each end.

Using the same simulation, the effects of having more photons make it to the light detection element, i.e., using scintillators with greater light yield or shorter clear fiber runs, were explored. As shown in Fig. 3(a), having brighter fibers or more efficient transport of photons after emission would both improve the timing resolution. The plot shows the goal of better than 1 nsec timing resolution, albeit on a single channel. Fig. 3(b) shows how the timing resolution improves for different scintillator/wavelength shifting decay times, in this case found using 10 photons at the end of the fibers.

---

[6] J.C. Jackson, et al.,, *A Novel Silicon Geiger-Mode Avalanche Photodiode*, IEEE-International Electron Devices Meeting (IEDM), vol. 32.2, December, 2002; J.C. Jackson, et al., *Characterization of Geiger Mode Avalanche Photodiodes for Fluorescence Decay Measurements*, SPIE, the International Society for Optical Engineering, Photodetector Materials and Devices VII, San Jose, CA, vol. 4650, January, 2002.

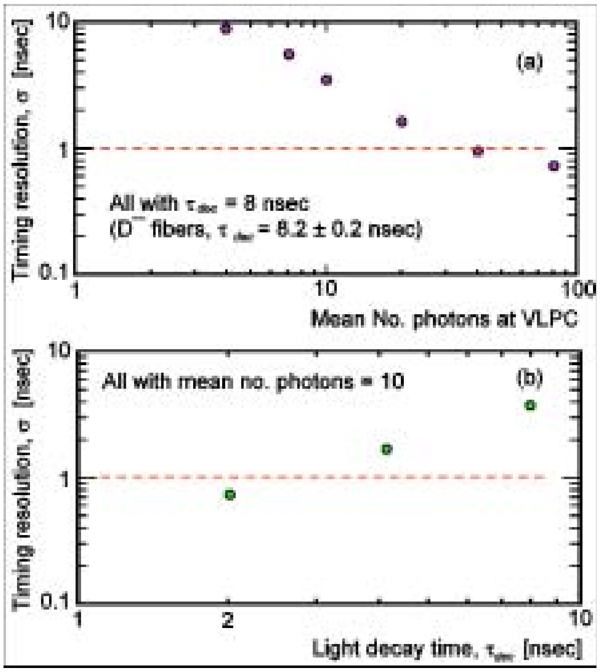

Figure 2: Monte Carlo simulation of the timing difference between the first photon detected at each end of DØ scintillating fiber 1-m long with 4-m of clear fiber on each end.

In the investigation of the integration of an intermediate layer of scintillating fiber at the inner radius of a TPC, we have joined a consortium of American and Japanese research groups working on TPC detector R&D (M. Ronan, LBL, contact person). Work will continue on the impact of intermediate tracking on track pattern recognition and track parameter resolution in both such a TPC-based detector and for one incorporating a silicon tracking system.

Planned Activities

For the remainder of this year and Year 1 of this proposal, we plan to complete the modifications to the radioactive source setup and the cosmic ray test stand. We would then complete the testing of a variety of different scintillating fiber formulations with different lengths of clear fiber in both setups. We plan to evaluate a number of different light detection technologies in regards to sensitivity, timing resolution, and cost: visible light photon counters, hybrid avalanche photodiodes operating in Geiger mode, and multi-anode photomultiplier arrays. We will compare these measurements with results of Monte Carlo simulations already started of the different fiber formulations, configuration, and light detection devices.

In Year 1 and 2, in addition to these Monte Carlo simulations, we will also continue simulations of the impact of overlapping events on the physics signal of Higgs boson events in a linear collider detector as well as integrated simulations of an intermediate layer of tracking in such a detector (for both cases of a TPC and silicon-based central tracker) in regards to track timing, track resolutions, and pattern recognition.

Although this effort has not yet begun, in Year 1 we still plan to exploit an existing effort at FNAL aimed at using fast timing information in the DØ fiber tracker for a *z* position measurement. Currently, a replacement[7] for the CFT readout electronics is being designed to allow the readout to proceed at the 132 ns Tevatron bunch crossing interval which will occur in the latter stages of Run II. For as long as the collider runs instead at the 396 ns crossing rate, the two extra data pipelines on the custom ASIC can be used to provide timing information through a time-to-amplitude converter. Simulations of photon propagation convoluted with the measured response of the discriminators on these boards suggest that a timing resolution of 2 ns can be achieved using only one end of each fiber (the CFT readout is at only one end of the detector; the other end of each fiber is polished to provide reflected photons). Once these boards are available, we can perform tests using the existing DAQ system without major modifications, using both ends of the fibers to provide better resolution. Further modifications to the design may be possible depending on our results.

From the results of Year 1 driving a decision for the optimal combination of fiber formulation and light detection technology, a 1024-channel prototype system using the chosen combination will be setup in Year 2. At the end of Year 1, four 256-fiber ribbons will be constructed from the best fiber formulation available, trying whenever possible to use existing D0 optical connectors, etc. Using the cosmic ray test stand, the system-wide timing and position resolutions will be measured over this larger number of channels. Through the collaboration with the consortium of American/Japanese TPC researchers, the possibility of operating the fiber tracker prototype with a TPC prototype of another group will be explored.

In Year 3, we will begin the additional research direction of the embedding of such scintillating fibers and/or fast wavelength-shifting fibers into calorimeter systems allowing or supplementing the precise timing of neutral clusters in a linear collider detector. To begin, the chosen formulation fast fibers will be embedded in grooves of small tile squares of scintillator plastic. Infrastructure established in the previous years will be used to measure the timing resolution of the combination, both in the cosmic ray test stand and in a test beam. Collaborations will be formed with existing calorimeter groups to determine possible inclusion of fibers or fiber/tile combinations and tests with existing calorimeter module prototypes.

Funding Request

A funding award of the previous year covered most of the equipment needed for setting up and modifying the cosmic ray test stand and radioactive source system.

The funding request is shown below and is for equipment and materials only. The 50% salary for the fraction of a postdoctoral research associate has been committed by Indiana University, as are travel costs.

---

[7] J. Estrada, C. Garcia, B. Hoeneisen, and P. Rubinov, *MCMII and the Trip Chip*, DØ note 4009, August 2002.

The request for Year 1 reflects the addition of the evaluation of different light detection technologies. The ribbon purchase of Year 1 and the Year 2 request covers equipment and material for the additional channels of a prototype tracker, and Year 3 for explorations of this technology in calorimeters.

Budget

Item	**Cost**
Year 1	
PC system for radioactive source setup and DAQ interface cards	$3,500
Geiger-mode hybrid avalanche photodiodes	$4,000
64-channel fast timing multianode photomultipliers: Hamamatsu H-8500 and Burle 85011 MCP-PMT	$5,800
Ru-106 radioactive source	$2,100
4 prototype fiber ribbons (256 fibers each, 60 cm long); re-use of clear fibers, optical connectors; test components (gas for PDT system; LNHe, LN for VLPC cryogenics)	$30,000
Indirect costs (N/A, equipment only)	$0
Total Year 1	**$45,400**
Year 2	
Additional channels electronics and DAQ	$16,000
Light detection devices (multi-anode PMT's or Geiger-mode hybrid avalanche photodiodes, or VLPC's)	$24,000
Mechanical modifications, cosmic ray test stand	$3,000
Computing upgrades	$3,000
Indirect costs (N/A, equipment only)	$0
Total Year 2	**$46,000**
Year 3	
Plastic scintillator tiles, wrapping, optical connectors	$5,000
Mechanical for integration into calorimeter module	$5,000
Clear and scintillating or wavelength-shifting fiber	$4,000
Consumables, setup in test beam	$4,000
Separate PC system and DAQ interface cards	$3,500
Indirect costs (N/A, equipment only)	$0
Total Year 3	**$21,500**