1. Project Name: Study of the Mechanical Behavior of Thin silicon and the Development of hybrid silicon pixels for the LC

Classification (accelerator/detector subsystem)
Detector: tracking and vertex

Institution(s) and personnel
Purdue University: Daniela Bortoletto, Ian Shipsey

Collaborators
FERMILAB: Simon Kwan, Jim Fast, Cristian Gingu, William Wester

Contact Person
Daniela Bortoletto
daniela@physics.purdue.edu
(765) 494 5197

2. Project overview

The scope of this project is twofold. The first goal is to increase our understanding of the mechanical stability of thin silicon. Second we would like to understand the physics reach of a thin hybrid pixel system at a linear collider. The mechanical studies will have an impact not only for hybrid pixels but also for CCD, silicon microstrip detectors and other attractive thin substrate technologies such as MAPS (Monolithic Active Pixels Sensors).

Physics studies have shown the jet flavor identification with high efficiency and purity is a critical element in the full exploitation of the physics potential of the Linear Collider (LC). Jet flavor identification can be achieved in the highly collimated jets expected at the LC with precise vertex detection based on pixel detector technology achieving an impact parameter resolution of $5\mu m \oplus 15\mu m/p_t(GeV/c)$ or better. In this expression the first term depends on the detector intrinsic single point resolution and geometry while the second term accounts for multiple scattering. The impact resolution requirements translate into a single point resolution of 7μm and a material budget of 0.5% X_0 for each layer in an n layer device.

The Charged Coupled Devices (CCD) operating at the SLD have demonstrated a resolution and a thickness close to the requirements. Improvements are needed to achieve the readout speed required for operation at future machines such as TESLA where the single bunch crossing will occur every 330 ns. Another areas of concern is the radiation tolerance of a CCD and studies are taking place to evaluate the radiation damage of the SLD CCDs.

Several studies have taken place in Europe that investigate an alternative approach to jet flavor identification based on solid-state hybrid detectors. Hybrid pixel detectors will be used as vertex detectors for the CMS and Atlas experiments. They have the advantage of fast time stamping, sparse data read out, and excellent radiation tolerance. Research and

Development are required for possible application of this technology to the LC in the following areas: (1) improvement in the point resolution, which is currently limited by the pixel dimensions of 50 μm × 300 μm (2) reduction in material. The standard thickness in silicon processing is 270μm.

Better resolution can be achieved by adopting an interleaved pixel read out as shown in [1]. This approach is similar to charge sharing through capacitive coupling in silicon strip using intermediate strips [2] and it has already produced interesting results. Moreover since this R&D was started in Europe, several advances have taken place such as the development of 0.25 μm technology that should allow the hybrid technology to achieve a smaller cell dimension.

A reduction in material can be achieved directly by fabricating thin silicon sensors and read-out, or by thinning the substrates after processing. The Atlas and the BTeV collaborations have already performed extensive R&D on thinning techniques for hadron colliders applications. Since the voltage required to fully deplete a silicon sensor is proportional to the detector thickness squared, a reduction by a factor of 2 in the thickness implies a factor of 4 in the required operating voltage at any given integrated fluence with clear beneficial implications for the lifetime of the detector itself.

The project is a collaboration between Fermilab and Purdue University. The group at Purdue University has already received funding through the DOE ADR program to study thin silicon sensor production. The proposed effort builds upon our experience in design and testing of silicon micro-strip and silicon pixels for CDF and CMS. We have access to CADENCE design tools and DESSIS simulation tools. The mechanical aspects of the project building upon our experience in the mechanical design, fabrication, and assembly of the silicon detector for CLEO III, and the mechanical design and prototyping of parts of the CMS forward pixel detector.

The detector facility at Purdue University contains two fully equipped clean rooms for the design, testing and assembly of detectors for High Energy Physics. These clean rooms are part of a complex dedicated to microstructure detector development and fabrication including silicon strip and pixel devices and micro pattern gas detectors. The total clean room space is 3000 sq ft in three laboratories containing a CMM, wirebonder, electrical testing equipment, probe stations, optical tables, microscopes and high precision measuring devices. The labs are fully equipped with computer facilities for control, data acquisition and analysis. The labs have both temperature and humidity control and HEPA filtering of the airflow. Included in the clean rooms is additional space of class 1000. In a separate location there is a detector irradiation facility with an X-ray source and an ultra clean gas delivery system used for the development and testing of micro pattern gas detectors.

Other technical resources are also available, such as machine and electronic shops within the physics department, a central machine shop and state of the art facilities on campus, such as SEM, TEM (Transmission Electron Microscopy) and EDS (Energy Dispersive Spectroscopy). In addition to the technical staff, an engineer and technician, there is the

normal complement of graduate students and research associates working on specific projects. There is also an exceptional pool of talented undergraduates who work on R&D and detector construction projects

References:
[1] M. Battaglia et al., IEEE Nuclear Science Symposium and Medical Imaging Conference, October 15-20, 2000, Lyon, France, IEEE Trans.Nucl.Sci. 48 (2001) 992-996; M. Battaglia et al., Proceedings of the 9th Int. Workshop on Vertex Detectors, Lake Michigan MI (USA), September 2000, Nucl.Instrum.Meth. A473 (2001) 79-82.
[2] A Piesert, in Instrumentation in High Energy Physics, New York, Wrold Scientific, 1, 1992

3. Project Activities and Deliverables

3.1 FY2003

Several activities to study the mechanical stability of thin silicon and determine if the hybrid technology is a viable solution are planned for the first year:

1) Verification that the requirement 5μm ⊕ 15μm /p_t(GeV/c) is correct in collaboration with the LC tracking and vertexing simulation group. Simulation of the optimal interleaved pixel layout to achieve the needed single point resolution of 7 μm. Establish target thickness for layers of hybrid pixel devices at different distances from the interaction point. The optimization process will be carried out by studying the effect of the layer thickness on the flavor tagging efficiency and purity. This is a crucial element to determine the Higgs branching fractions.
2) Studies with vendors of the minimum thickness that can be achieved in single sided pixel manufacturing. This will use ADR funding.
3) The Fermilab group will lead in studies of thinning the ROC and silicon sensors by continuing and expanding the R&D that is already taking place within BTeV. Blank silicon samples will also be used.
4) Produce prototypes with interleaved sensors and ROC already available, monitor their behavior, and build a measurement fixture for mechanical studies. These studies will be conducted with the readout chip designed for the BTEV detector which is designed for n on n sensors since in high intensity proton machines space charge inversion will be reached after a few months of running.
5) Studies of alignment and fabrication of low mass support frames. Metrology will be performed during cooling cycles. These will need to be conducted at cryogenic temperatures for CCD application. Finite Element Analysis (FEA) will be also performed to understand the mechanical stability of the thin silicon.

The first year deliverable will be an initial determination of the potential of hybrid technology for the LC. We will also study systematically the stability issues associated with thin silicon.

3.2 FY2004

In the second year we will continue the mechanical studies of the initial prototypes. Systematic studies will also be performed to determine the resolution and charge collection efficiency with cosmic rays, diodes, and possibly beam tests. Comparison of MC simulations with the performance of interleaved n on n pixels readout with the BTEV chip.

This will allow a first evaluation of the potential gain in resolution that can be achieved with thin and interleaved hybrid sensors.

3.3 FY2005

Based on the results of FY2003 and FY2004, we plan to start the production of thinner sensors with the optimal interleaved LC layout. This will require masks and fabrication funding. We will also need a readout chip to match the p on n sensor for the LC. The chip designers could use the latest chip technology that will be available at that point to minimize pixel size.

The third year deliverables will be thin interleaved sensors designed to achieve the intrinsic point resolution needed at the LC and an optimal chip for the LC. This will allow a realistic assessment of the viability of the hybrid technology for the LC.

4. Budget Justification

4.1 First Year Budget

The first year equipment budget will allow Fermilab to build a system to study the mechanical issues connected with the thinning of sensors and readout chips. The study will include precision measurement of the stability of the support schemes including temperature cycles. Some of these studies will be conducted with blank silicon and some with BTeV prototypes. Fermilab will provide personnel to perform finite element analysis (FEA) studies. The personnel will be supported with Fermilab funding.

The graduate student at Purdue will start device simulation and MC studies to understand the optimal interleaved sensors layout for the LC. Thin sensors provided by the ADR funding will allow a determination of the yield and the minimum thickness that is achievable by the vendors.

Equipment breakdown:
1) Precision alignment tooling: $1.5K
Vacuum holders for sensor/ROC assemblies and holder for support frame that precisely aligns the modules to the support frames. Cost is based on recent experience with similar tooling for Run IIb R&D efforts.
2) Adhesives: 0.4K
Adhesives for attachment of modules to supports. Cost is based on recent purchases of adhesives in minimum quantities for Run IIb R&D.

3) Engineering analysis (FEA): (1.5 K at no cost - supported by Fermilab)
This allows for 30 hours of engineering analysis by the FNAL analysis group.
4) Fabrication and assembly of a low-mass support frame: $2.7K
Support frame will be either beryllium or carbon composite and will need to be of reasonably high precision.
5) Thinned silicon, 2 batches @ $1K per batch: $2K
Cost estimate is based on previous purchases.
6) Metrology, assuming we draw on available infrastructure from BTeV: $2.0K
This involves modifications to allow us to mount our samples in a dry chamber at low temperature in order to be optically inspected through a window. BTeV has already built the chamber itself for their pixel studies. We will need to provide mounting and cooling connections to our samples. In particular we will need to go to much lower temperatures than BTeV. Modifications to allow for operation at cryogenic temperature dominate this cost.

The travel request includes 2K for Purdue to visit companies and attend LC meetings

4.2 Second Year Budget

The second year requires support for a cosmic ray setup and beam tests with interleaved pixel prototype matching the BTEV chip. The travel request includes 2K for Purdue to visit companies and attend LC meetings.

4.3 Third Year Budget

The third year budget is for the production of hybrid-pixel specific for LC development. This requires funding for prototype sensors and readout chip. This is necessary since most of the development for ATLAS, CMS and BTEV is based on n on n sensors while at the LC single sided p on n sensors could be more cost effective since the radiation level at the LC is less challenging. The travel request includes 2K for Purdue to visit companies and attend LC meetings.

4.4 Three-Year Budget in then-year K$

Institution: Purdue University

Item	FY2003	FY2004	FY2005	Total
Graduate student	23	24	25	72
Equipment	8.6	8	120	136.6
Travel	2	2	2	6
Total direct costs	33.6	34	147	214.6
Indirect Costs	5.75	6	6.25	18
Total	39.35	40	153.25	232.6