PROJECT DESCRIPTION

Design of a Monolithic Pixel Detector Module

Personnel and Institution(s) requesting funding

Marco Battaglia

Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA
and Dept. of Physics, University of California, Berkeley CA 94720, USA

Collaborators

David N. Brown, Devis Contarato, Leo Greiner, Benjamin Hooberman

Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA

Project Leader

Marco Battaglia
MBattaglia@lbl.gov
(510) 486-7029

Project Overview

We propose a R&D project addressing the conceptual and engineered design of a ladder for the Vertex Tracker with the required mechanical stability and system integration, while minimising the amount of material. The Vertex Tracker performance is critical for accomplishing the objectives of the ILC in understanding key issues of particle physics from the origin of mass to its relation to the Cosmo. Preliminary simulation studies have shown that a single point resolution better than 5 μm and a material budget not significantly in excess to 0.1 $\%X_0$ per layer are needed to fulfill this goal.

While a very significant effort is being deployed in developing Silicon pixel sensors which are much more precise, thinner and faster than those ever installed in a particle physics experiment, only a limited attention has been devoted to the design of a detector module stiff enough to guarantee the sensor accuracy in the detector reference frame and light and integrated enough to offer minimal disturbance to the passage of particles and provide electrical and thermal services. The ILC Si sensor R&D has now successfully progressed to the stage when the design of a realistic detector module is needed to guide further R&D towards the choice of an optimal pixel sensor for the Vertex Tracker. There are three main open issues to which the proposed program could answer. The first concerns the optimisation of the sensor thickness. Early experience on sensor backthinning, to which our group contributes, shows that the thinning of pixel chips down to 50 μm and below is feasible. CMOS pixel chips have been backthinned to 50 μm and to the epi-layer ($\simeq 20\mu$m), DEPFET test diodes to 50 μm and CCDs to 20 μm. These first tests have been successfull and a more systematic characterisation of yields and performances is currently in progress. Below about 100 μm of thickness, the problems offered by mechanical stability and, possibly also charge collection, are becoming quite increasingly important and it is essential to leverage the advantage of a reduced material budget from thinner sensors with the increased requirements on the chip support structure. The goal of $0.1\%X_0$/layer is ambitious. The VXD3 detector at SLD, the most precise vertex detector installed at a collider experiment, achieved $0.41\%X_0$/layer. Several concepts based on thin sensors mounted on various supports (carbon-fiber composites, Si carbide foam, diamond-coated composite materials are among those considered), which would amount to about $0.1\%X_0$, have been proposed and some studies are being carried out at RAL in the UK. The proposed project will develop the design of a low-mass detector module, with a support structure possibly based on carbon composites and vitreous carbon foam, produce prototypes, mount thinned Si chips and perform a full characterisation of mechanical behaviour and stability, including temperature and humidity cycling. In a second phase working detectors will be installed and the ladder tested under operational conditions, including power cycling. Sensor technology specifics will be considered and both CMOS and DEPFET pixel sensors will be tested.

The second issue concerns chip cooling requirements, which has significant implications both in terms of sensor technology and material budget. We propose to study airflow cooling both in terms of heat extraction, under realistic conditions such as power cycling, and in terms of ladder stability. This study will assess the power dissipation threshold beyond which active cooling of the modules is needed and the module stability under temperature change and airflow-induced vibrations.

Finally, the design of a detector module will address the issue of the routing of signal lines and services, which also contribute to the overall material budget of a detector layer.

The project will also investigate offline software alignment procedures. This will be carried out, based on the experience gained by the LBNL group with the alignment of the Babar vertex detector at PEP-II. In the second year, a test setup will be built to study the ladder alignment using particle tracks. The test setup will use a highly collimated laser beam to simulate the passage of a charged particle and will correlate the displacement of the recorded pixel clusters with real-time survey data.

This program will significantly profit of synergies with activities of other groups at LBNL in the Physics, Nuclear Science and Engineering Divisions, channeling the know-how accumulated in major projects, from CDF and Babar and the concurrent ATLAS and STAR projects, to the ILC application, minimising the cost-to-benefit ratio, if this activity can be started soon. This is evident from the budget request, where the requested funding is targeted to secure engineering support and to a limited number of ad-hoc purchases.

At the same time, we are actively engaged in reaching out to partner groups, engaged in R&D for the ILC Vertex Tracker, to share the resources made available through this project to a wider community. We have established contacts with SLAC, University of Oregon, Purdue University, Max Planck Institute, Munich (Germany), Rutherford Appleton Laboratory, Didcot (UK) and IReS, Strasbourg (France). Max Planck Institute and IReS will share pixel structures and readout systems for the ladder construction and characterization. We shall keep close links with the ILC group at SLAC and the other US institutions involved in Vertex Tracker R&D, which will have access to the facilities and expertise being established at LBNL.

Broader Impact

The development and deployment of increasingly complex high granularity trackers in particle physics experiments has come at the expense of increased material in the tracking volume. At next generation detectors for the ILC, but also for the LHC upgrade, tracking granularity and channel counts will increase even further. Lower mass is crucial at the LHC due to the tenfold increase in track multiplicity as well as at the ILC to provide the required precision track reconstruction and minimize the deterioration of calorimetric measurements.

This project aims at developing highly integrated electrical-mechanical-thermal structures with particular emphasis on material reduction. Experience earned in this project will benefit other applications in HEP and beyond relying on low-mass, high-resolution detectors.

As the activity described in the present proposal will be carried out as a collaboration between Universities and a National Lab, the project will see the participation of students. One UC Berkeley GSR, already supported through the LDRD grant, will work at the characterisation of prototypes, which will integrate well with his current activity in sensor backthinning. We plan to involve an additional GSR, working part-time on the software alignment and funded independently from this proposal. The project will be open to undergraduate students, within the framework of the Undergraduate Research and Apprentice Program (URAP) at UC Berkeley, which is already offering research opportunities in the ILC program and enables under-represented minorities and disabled students to connect to research. The educational impact from student contribution to cutting edge research and technology development reaches far beyond the academic world because a large fraction of the students find employment in industry. We shall encourage women and students from minority-serving institutions to join this program.

The program will be open to collaboration from national and international partners, active in ILC R&D. Contacts have already been establised with several institutes mentioned above. Its success also relies on the ability to disseminate the results within the ILC community and beyond.

Results of Prior Research

LBNL is engaged since the beginning of FY05 in an R&D program on advanced Si pixel sensors for the ILC. A part of this project is aimed to study the backthinning of CMOS pixel sensors. After identifying a commercial partner company in the Bay Area a first batch of CMOS pixel structures have been backthinned to 50 μm and characterised. Results have been presented at the LCWS05 conference in March 2005 and are summarised in the Proceedings currently in press. We are presently engaged in a second phase, where the sensor response is being characterised with a ^{55}Fe radioactive source, collimated laser light of different wavelengths and a high energy electron beam. After characterisation, detectors are backthinned to different thicknesses and tested through the same protocol. Comparing the data allows to study variations in charge collection due both to bulk contribution and to interface effects from the thinning process. This activity, funded as part of an LDRD project on Advanced Si Pixel sensors for the ILC, which will continue through FY07, offers an important synergy with the proposed project. The STAR group at LBNL, which will collaborate to this project, is developing a very ambitious Vertex detector, based on CMOS pixel sensors similar to those being considered for the ILC and respecting almost equally tight constraints in terms of material budget. Their partnership ensures that this project will start from the experience of cutting-edge solutions for low mass mechanics for detector applications and tailor it towards the ILC specs.

Facilities, Equipment and Other Resources

LBNL is well equipped for the production of support structures using composite material and their mechanical characterisation. Further, there is a very significant know-how on lightweight structures for high precision detectors in collider experiments. Work for the CDF Run2b upgrade has demonstrated the viability of a highly integrated Si detector module, including cooling, support and embedded electronic bus-work. Experience with the ATLAS Pixel detector, whose mechanical structure has been designed and built at LBNL and is presently being installed at the LHC, and the STAR vertex detector, being designed at LBNL for the STAR upgrade at RHIC, offers an important opportunity to start the ILC specific R&D on the foundation of state-of-the-art design concepts.

The ILC Advanced Detectors R&D Lab of our group has an environmental chamber which will be used to characterise temperature cycling and humidity effects on prototype ladders. We can also perform power cycling of CMOS pixel sensors to study power dissipation and survey the temperature gradient of prototype ladders using a high resolution IR camera. We have access to a fully equipped characterisation facility to perform studies of cooling and mechanical stability with nitrogen and air flow. This is equipped with a laser holography system which will be used to measure in real time distortions in prototype structures with sub-micron resolution. This system is very useful for looking at thermal distortions and small scale bending over a large area. A capacitive probe system measures the position of refernce points with sub-micron resolution and a bandpass of 1 KHz. This is above the resonant frequencies of any of the structures that we intend to construct alowing to study for displacements and vibration induced by the air cooling or any other driving forces.

Alignment studies and data analysis will be performed at NERSC using the computing and data storage resources awarded to the ILC project.

FY2006 Project Activities and Deliverables

During FY2006 the project would be carried out alongside the ongoing STAR upgrade effort. We will gather experience by performing common tests of the structures developed for the STAR vertex detector. During the first year of the project a first prototype will be built and equipped with thin dummy detector chips and characterised. The technology-dependance of the design will studied and a second prototype based on the use of back-thinned DEPFET sensors will also be considered.

FY2007 Project Activities and Deliverables

In the second year, two fully operational ladders will be produced, equipped with working detector chips and characterised with collimated lasers and a high energy electron beam. They will be based on CMOS and DEPFET pixel sensors. CMOS sensors will be acquired through a common submission with the STAR group and IReS, Strasbourg, carried out as part of the EuDET program, while DEPFET sensors will be made available at no costs by MPI, Munich as part of an ongoing collaborative effort, including also radiation hardness characterisation to be performed at LBNL.

Budget justification: Lawrence Berkeley National Laboratory

The budget request covers the cost of engineering support, production of prototypes and the limited additional equipment needed to extend the capability of the ILC detector lab in the characterisation of ladder prototypes.

We request support for 0.25 FTE from the Engineering Division at LBNL, if this will be awarded, matching funding should be made available by the Physics and Engineering divisions to make 0.5 FTE available to this program. The engineer will work in close contact with the group working at the design of the STAR vertex detector upgrade and adapt that design to the ILC specifications based on experience at STAR and ATLAS. In addition, we request

1.5 months of a mechanical engineer machinist and mechanical shop recharges for prototype production. Finally, funding is requested for a vibration isolated workstation, an upgrade of the capacitive probe system for high accuracy real-time position survey and a DAQ computer and interface. In the second year, costs also include the procurement of CMOS chips, through a shared submission and their backthinning.

Two-year budget, in then-year K$

Institution: Lawrence Berkeley National Laboratory, Berkeley CA.

Item	FY2006	FY2007	Total
Other Professionals	31235	33782	65017
Graduate Students	0	0	0
Undergraduate Students	0	0	0
Total Salaries and Wages	0	0	0
Fringe Benefits	21542	23299	44841
Total Salaries, Wages and Fringe Benefits	52777	57081	109858
Equipment	5000	2000	7000
Travel	500	500	1000
Materials and Supplies	2000	7000	9000
Other direct costs	2384	3578	5962
Total direct costs	62661	70159	132820
Indirect costs(1)	0	0	0
Total direct and indirect costs	62661	70159	132820

(1) Includes xx% of first $xx subcontract costs