The Collider Detector at Fermilab (CDF) experiment is studying the results of very high energy collisions of protons and antiprotons. The CDF collaboration consists of scientists from five different countries, including a group of 15 Canadian particle physicists affiliated with the Institute of Particle Physics (IPP) in Canada.

The IPP group in CDF is proposing Canadian participation in Run II, the next Fermilab Tevatron Collider programme. The goal of this programme is to acquire approximately 2 $fb^{-1}$ of 2.0 TeV $\overline{p}p$ collisions over a period of 3-4 years starting in September 1999. This corresponds to a factor of 20 increase over the current Run I data set, and a factor of 50 or more increase in the statistics of specific final states when improvements to the CDF detector are taken into account.

This proposal requests funding for the IPP group's hardware contribution to the upgraded CDF detector over the next two years. Funding is requested for an alignment and monitoring system for a new solid-state vertex detector, the SVX II. This system will position the various components of the SVX II around the $\overline{p}p$ interaction point, will allow for movements of the assembled detector around the nominal collision point to compensate for motion in the beamline, and will measure the location of the SVX II *in situ* using a technique known as Frequency-Scanned Interferometry (FSI).

| | | | |
|---|---|---|---|
| SVX II Mount Design | Design static kinematic mounts for SVX II/ISL | Jul 97 | Oct 97 |
| SVX II FSI Design | Design prototype position monitoring system | Jun 97 | Dec 98 |
| Prototype Mounts | Fabricate and evaluate prototype mounts | Sep 97 | Nov 97 |
| Prototype FSI system | Construct and evaluate prototype FSI system | Dec 97 | Oct 98 |
| Design Review of Mounts | Design of mounts reviewed | Dec 97 | Dec 97 |
| Fabricate Mounts | Fabricate static kinematic mounts | Apr 98 | Jun 98 |
| FSI Design Review | Design review of FSI system | Jul 98 | Jul 98 |
| Fabricate FSI System | Complete fabrication of FSI fibres | Aug 98 | Dec 98 |
| Install FSI System | Install FSI system in detector | Jan 99 | May 99 |
| Detector Commissioning | CDF II Detector Commissioning Period | Jun 99 | Nov 99 |
| Run II | Start data-taking for Run II | Nov 99 | Dec 01 |

# A. TITLE

Upgrades for CDF II at the Fermilab Tevatron

# B. INVESTIGATORS

(i) Applicant

| | | | |
|---|---|---|---|
| R.S. Orr | Toronto | | 30% |
| K. J. Ragan | McGill | | 35% |
| P. K. Sinervo | Toronto | | 85% |
| W. Trischuk | Toronto | | 85% |

(ii) Collaborators

| | | | |
|---|---|---|---|
| S. Gadomski | Toronto | Research Associate | 100% |
| tba | Toronto | Research Associate | 100% |
| J. Mayer | Toronto | Research Associate | 30% |
| R. Cropp | Toronto | Graduate Student | 100% |
| B. Hinrichsen | Toronto | Graduate Student | 100% |
| H. Kim | Toronto | Graduate Student | 100% |
| K. Kordas | McGill | Graduate Student | 100% |
| A. Robinson | Toronto | Graduate Student | 100% |
| W. Taylor | Toronto | Graduate Student | 100% |
| A. Warburton | Toronto | Graduate Student | 100% |

Other Collaborators: physicists from Argonne National Laboratory, Istituto Nazionale di Fisica Nucleare, University of Bologna, Brandeis University, University of California at Los Angeles, University of Chicago, Duke University, Fermi National Accelerator Center, Florida State University, Laboratori Nazionali di Frascati, University of Geneva, Harvard University, Hiroshima University, University of Illinois, Johns Hopkins University, Universität Karlsruhe, KEK, LBL, Massachusetts Institute of Technology, University of Michigan, Michigan State University, University of New Mexico, Ohio State University, Osaka City University, Universita di Padova, University of Pennsylvania, University and Scuola Normale Superiore of Pisa, University of Pittsburgh, Purdue University, University of Rochester, Rockefeller University, Rutgers University, Academica Sinica, Texas A & M University, Texas Tech University, University of Tsukuba, Tufts University, University of Wisconsin, and Yale University.

# C. Executive Summary

The CDF collaboration has been studying $p\bar{p}$ collisions at 1.8 TeV using the Fermilab Tevatron Collider. The collaboration has collected 110 pb$^{-1}$ of data between 1992 and 1995 (Run I). CDF is scheduled to take data again starting in 1999. The experiment expects to collect 2 fb$^{-1}$ of collisions in Run II. The order of magnitude increase in integrated luminosity will open new vistas in heavy quark physics including higher statistics, fully reconstructed bottom quark ($b$) hadron samples. These samples provide the potential to observe CP violation in the $B$ sector on a time scale competitive with the dedicated $e^+e^-$ $B$ factories.

The large increase in integrated luminosity results from the commissioning of the Main Injector, a new low-energy ring capable of injecting much larger bunches of protons and antiprotons into the Tevatron Collider. The high luminosity running conditions during Run II will require a major overhaul of the CDF detector components and associated readout electronics, in effect creating a new detector facility known as CDF II.

The IPP contribution to the Run I experimental programme has been focussed and effective. Our most important contributions have been in the physics analyses that we have spearheaded. The group has been one of the lead instututions in the reconstruction of exclusive B meson decay modes.

We are proposing a Canadian involvement in the Run II physics programme. We believe the arguments for this scientific investment by Canada to be very strong: The Tevatron Collider will be the most exciting high-energy colliding facility for the next decade while we prepare for its natural follow-on, the LHC programme, in which Canada has made a significant investment. Canada already has a strong group involved in hadron collider physics, and a continued investment in CDF will ensure that Canadians are well positioned to compete in the physics studies of LHC data. Finally, the proposed programme represents the scientific interests of a young group that has already made an impact on the design and development of the Run II experiment. The group has received substantial external support for the Run II programme, and an NSERC investment would be well-leveraged.

The specific hardware requests in this proposal were established as part of the CDF II baseline at a DOE review in February 1997. We are requesting funding for the hardware contributions to the CDF II detector that represent Canada's contribution to the detector upgrades.

# D. The Run II Physics Programme at Fermilab

The high instantaneous luminosity and centre-of-mass energy that will be achieved during Run II will allow the CDF collaboration to pursue a broad physics programme that is described in our NSERC operating grant request. Here we limit our discussion to those physics channels that will most benefit from the installation of the hardware we propose.

The Run II Collider programme will, in our opinion, revolutionise our understanding of the heaviest known pair of quarks, the top and bottom isospin partners. Currently, our knowledge of the top quark is limited by the statistics of the Run I sample. Emphasis has been placed on the design of the Run II upgrades to enhance the top quark yield by both extending and improving the lepton identification systems, and by significantly improving the bottom quark tagging capability. Significant effort is being placed on improving our triggering and acceptance for bottom quark decays in order to record sufficient statistics to measure CP violation and to make substantial improvements in the precision of our measurements of bottom hadron lifetimes, masses and branching fractions.

CDF has made measurements of bottom hadron lifetimes, mixing and branching fractions that are among the most precise world values. For example, the IPP group recently completed a detailed study of bottom meson branching fractions into exclusive final states containing a $J/\psi$ meson, and the resulting ratios of branching fractions are of equivalent precision to the current world average values [2]. We expect to collect bottom hadron samples that are a factor of 100 larger than those currently available. This will allow us to improve the precision of our existing measurements of $B^0$ and $B_s^0$ mixing, $b$ hadron lifetimes and branching fractions, and $b$ quark production cross sections by almost an order of magnitude. However, the primary goal of the Run II bottom physics programme is to achieve the necessary sensitivity to observe CP violation.

Analyses of Run I data have resulted in clean samples of $B^0 \to J/\psi K_s^0$ decays, a CP eigenstate that would evidence CP violation provided one efficiently flavour-tags the other $b$ hadron produced in the final state. The Run I studies [1] indicate that we can achieve flavour-tagging efficiencies $\epsilon$ and "dilution factors" $D$ such that the tagging quality factor $\epsilon D^2$ would be approximately 0.10 for this decay mode in Run II. We conservatively estimate that the uncertainty in our measurement of the Standard Model parameter $\sin 2\beta$ will be $\sim 0.14$.

The measurement of the asymmetry in the CP eigenstate $B^0 \to \pi^+\pi^-$ is another important goal, as it is related to the parameter $\sin 2\alpha$, the second of the three parameters responsible for CP violation in the Standard Model. In order to have reasonable acceptance for this mode, CDF must be able to trigger on the presence of two relatively low-momentum charged particles. The large backgrounds arising from low-energy light quark and gluon jets will be rejected in real time with a combination of a new Level 1 tracking trigger, the XFT II, and a Level 2 secondary vertex trigger, the SVT, that identifies secondary vertices using SVX II data. With this SVT trigger, it will be possible to identify and fully reconstruct $\sim 5$ $B^\circ \to \pi^+\pi^-$ decays per pb$^{-1}$. This will allow a measurement of $\sin 2\alpha$ with an uncertainty of $\sim 0.10$ with 2 fb$^{-1}$of data.

These two channels illustrate the $B$ physics capabilities of the proposed experiment. CDF in Run II will be competitive with the dedicated $e^+e^-$ $B$ factory experiments. It has the potential for making unique contributions to our understanding of $b$ hadron lifetimes, decays and spectroscopy, as well as the mechanism for CP violation.

# (i) CDF Detector Upgrades for Run II

## (a) Introduction

Conditions at the Tevatron in the Main Injector era will be substantially different from the conditions during Run I, CDF's most recent data-taking run. Peak luminosities are projected to be $\sim 2\times10^{32}$ cm$^{-2}$s$^{-1}$, 10 times greater than the highest luminosities achieved during Run I. The collision energy will rise from 1.8 to 2.0 TeV, thereby increasing the cross sections for high-$P_T$ final states by as much as 30%. In addition, bunch spacings as short as 132 ns are foreseen, compared to the Run I bunch spacing of 3.5 $\mu$s, in order to reduce the average number of interactions per crossing.

Further details of the CDF II Detector Upgrade are included in the CDF operating grant request that accompanies this request and a more complete description can be found in the CDF II technical design report [1]. Here we will focus on the upgrades to the silicon vertex detector (SVX II) and its associated silicon vertex trigger (SVT). These are the systems to which we propose to make specific hardware contributions.

## (b) The Silicon Vertex Detector Upgrades

The charged particle tracking system, inside the 1.4 Tesla axial magnetic field of the CDF spectrometer, is the very heart of the detector. The innermost element of this system is the SVX II that will provide additional coverage, two coordinate measurements, improved radiation resistance and faster readout. CDF has had silicon vertex capability since 1992. It has been crucial in a number of key physics analyses including the discovery of the top quark and the measurements of $b$ hadron lifetimes and $B$ mixing. The SVX II will have the following improvements:

- The detector will be extended from 65 cm to 96 cm long. This provides almost complete coverage of the Tevatron luminous region, which has a Gaussian profile with a length of $\sim 30$ cm.
- The silicon sensors will be double-sided to permit 3-D readout and vertex reconstruction.
- The SVX II will have five silicon layers (as compared to four for the SVX$'$).
- The readout electronics for the new device (the "SVX-3" chip) will support simultaneous data acquisition, digitization and readout to minimize deadtime.
- The digitization and readout following a Level 1 trigger will be faster (approximately 6 $\mu$s), to allow silicon data to be used in the Level 2 SVT trigger.

The SVX II is composed of three barrels, each 32 cm long. A barrel consists of 12 wedges in $\phi$, each with five layers of silicon. Three of the layers have 90° stereo while the remaining two have small stereo angles. The resolution per measurement for the axial layers is approximately 12 $\mu$m. The innermost and outermost silicon layers are located at radii of 2.54 cm and 10.65 cm, respectively. Overall, the vertex tagging capability of the experiment will improve by over 50% compared to Run I performance. The impact parameter resolution of high momentum charged tracks will be $\sim 30$ $\mu$m and $\sim 60$ $\mu$m in the $r-\phi$ and $r-z$ planes, respectively.

The silicon sensors are mounted on ladders that are held in place between a pair of beryllium bulkheads, which have cooling water channels to carry away the heat generated by the readout electronics. The readout electronics are mounted on top of each silicon ladder to minimise the gaps between the three barrels. The SVX II readout will have $\sim$ 405 000 channels, and will record both strip location and integrated charge. The silicon ladders, consisting of three sensors microbonded together, will have a maximum bowing of $\sim 100$ $\mu$m, and will be assembled into a barrel using a coordinate measurement machine (CMM) to determine their positions to $\sim 5$ $\mu$m.

### (c) The Silicon Vertex Trigger (SVT)

The $B$ physics reported by CDF to date has relied on the presence of one or more leptons in the final state of the $B$ decay, as the requirement of a lepton candidate was the only way to trigger on such decays. For Run II, CDF is adding a trigger based on the impact parameter of high momentum ($P_T > 2$ GeV/c) tracks, that will provide access to nonleptonic $B$ meson final states. In particular, we plan to isolate a sample of $B^0 \to \pi^+\pi^-$ decays to measure $\sin 2\alpha$.

There are many challenging aspects to the implementation of this trigger. It must be able to accept input from the Level 1 at rates of up to 50 kHz and it must find clusters from information provided by the SVX-3 readout chips for the approximately 6000 hit strips in each event. The cluster information is compared to a series of pre-defined roads (over half a million are foreseen) in order to group the hits into candidate tracks. The tracks are then fit to determine their impact parameter with precision better than 35 $\mu$m.

Studies of the Run I data show that an impact parameter cut of 100 $\mu$m will have sufficient selectivity to reduce the Level 2 trigger rate below 18 Hz at full design luminosity and still maintain an efficiency for $B$ decays in excess of 50%.

Since this trigger functions only in the plane transverse to the beam, any misalignment of the silicon detector axis and the beamline will result in an apparent beam spot projection (on the $r-\phi$ plane) that may exceed the desired 100 $\mu$m impact parameter cut (a result of the extended luminous region at the Tevatron). Tilts in excess of 100 $\mu$rad will result in a drastic falloff of trigger selectivity. The accelerator has the capability to correct for misalignments of up to 200 $\mu$rad, but deviations of several mrad were observed during Run I. The IPP group proposes to construct a system capable of remotely positioning the SVX II with a precision better than 100 $\mu$rad.

# E. Proposed Hardware Contributions to CDF II

We propose to design, fabricate and install i) the static kinematic mounts required to support the SVX II barrels, ii) the dynamic kinematic mounts required to position the silicon tracking system parallel to the beamline, and iii) the position monitoring system required to determine the internal alignment of the subdetectors constituting the SVX II and the relative position of the silicon tracking system and the wire tracking chamber. The IPP group has taken sole responsibility for each of these items. They were approved as part of the CDF II baseline detector at a DOE review in February 1997. The technical aspects of this proposal are described in this section.

## (i) Static Kinematic Mounts for SVX II

It is crucial that the silicon detectors be assembled such that all the internal components are in proper relative alignment. The SVX II is comprised of three barrels that are mounted in a cylindrical spacetube made of two layers of carbon fibre separated by a filler material. During assembly, this cylinder will be cut in half and mounted in a fixture to maintain its shape. Each barrel will then be mounted on the inner surface of this cylinder, supported by a set of static kinematic mounts. Once the barrels are in rough position, the two halves of the spacetube will be glued together and the load transferred to the rigid full tube. The barrel positions can then be fine-tuned with respect to one another to an accuracy of 5 $\mu$m by adjusting the kinematic mounts and studying their positions with a coordinate measurement machine. This fine-tuning will be performed using a differential screw that remains in each of the support legs after installation. An assembly drawing of one pair of these static kinematic mounts is illustrated in Fig. 1.

The kinematic mounts must be designed to allow the detector to expand or contract due to either thermal effects or "sagging" of the material. However, the mounting scheme must ensure that the overall motion of the detector remain constrained and predictable. These mount points must also be adjustable during installation so that the detector components can be aligned with respect to each other. We have studied the detailed geometry of the detectors and have selected the optimal number and arrangement of mounts.

A total of 15 mount points is needed for the SVX II assembly (we have requested 20 to allow for spares). The machining will be performed either in the McGill University machine shop, the University of Toronto Physics Department shops or at a local vendor. The subdetectors will be assembled at Fermilab with the aid of an IPP technician, a physicist and collaborators on the SVX II project.

## (ii) Dynamic Kinematic Mounts

In order to ensure that the SVT will function independent of beamline motion, we have designed and prototyped and now propose to fabricate a system capable of remotely

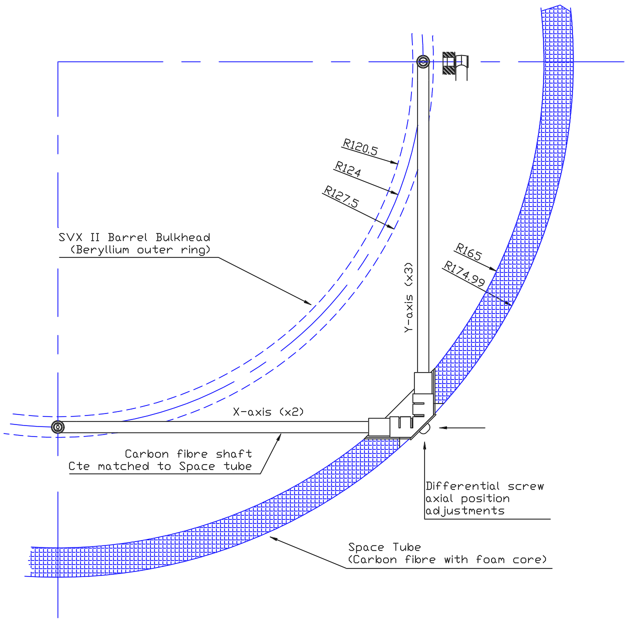



Figure 1: An overview of two kinematic mount support legs on one end of an SVX II barrel. Each leg includes a differential screw that allows the detector barrel to be precisely re-positioned after final installation.

re-orienting the silicon trackers with respect to the beam. In order to satisfy the SVT trigger requirements the alignment between the detector axes and beamline must be retained within 100 $\mu$rad. During Run I, total drifts of the beam with respect to CDF in excess of 2 mrad were observed. Small drifts, up to 200 $\mu$rad, can be compensated for by adding small bumps to the beam orbit around the CDF experiment. Beyond this it will be necessary to physically move either the machine or the detector.

We propose to add the ability to reposition the silicon support structure, joined by kinematic mounts to the rest of the tracking system. In order to compensate for all possible axis shifts, our proposed system has the ability to move each of five points up to a distance of 5 mm. Although we anticipate only infrequent adjustments (less than once per month) this system will be capable of operating in the presence of a magnetic field so that adjustments can be made without ramping down the solenoid. In one direction the devices must be able to lift a significant fraction of the combined weight of the silicon trackers and their support structures. The mass of these objects is estimated to be 15 kg. To this one must add some fraction of the cable plant that will be dressed along the walls of the support structure. We anticipate that the total load will not exceed 30 kg. Since small misalignments will be compensated for by orbit corrections to the Tevatron this positioning system need have step sizes no smaller than 10-20 $\mu$m– about one tenth of the accelerator's full compensation range. Finally the system must be compact in order to fit into the overall structure of the CDF tracker and not introduce excess material in the acceptance of the endcap calorimeters.

With these requirements in mind, we have designed a set of inchworm stepping devices

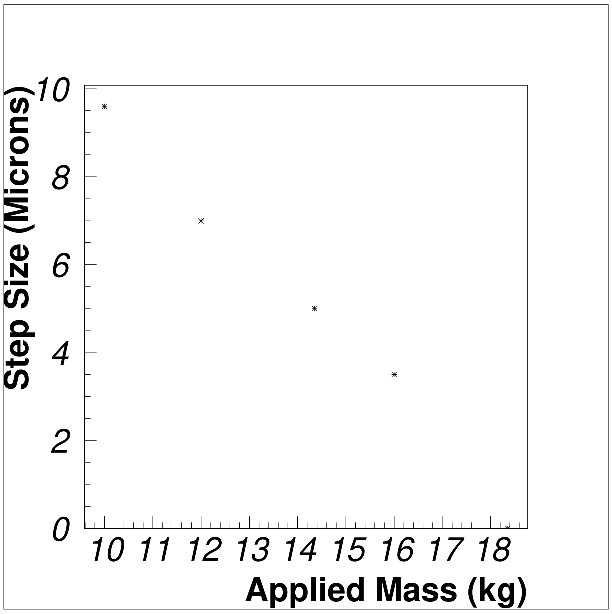



Figure 2: Step-size versus load from prototype inchworm.

that use piezoelectric cells to move along a precise reference bar. Each inchworm consists of a carrier, made of two machined frames, connected by a piezoelectric cell. The cell in each frame expands causing the frame to release its grip on the reference bar. In this way the quiescent state of the carrier is locked onto the rail – in case of a power failure the device will not move. The piezoelectric cells operate cyclically in order to move the inchworm along the rail, alternately gripping the rail with one of the two carriers, and then expanding or contracting the central piezoelectric cell. The cells we are currently studying are capable of lifting in excess of 300 kg. An application-specific driver circuit excites the 3 cells of a single inchworm at frequencies of about 1 Hz. Thus, with 10 $\mu$m steps, the full range of motion could be covered in minutes.

In late 1996, we designed and machined a prototype inchworm device. It was assembled in early 1997 and we have been studying and fine tuning it during the first half of this year. We have made several incremental improvements to the design during these tests. The device can now lift in excess of 15 kg while taking finite sized steps. We believe this is very close to sufficent for our application. We have learned a tremendous amount from the assembly and testing of this prototype and expect the next version to meet the load goal and thus be the first production device. We will continue to test the prototype for long-term stability, radiation sensitivity and operation in a magnetic field.

The prototype inchworm occupies a volume of $25 \times 25 \times 80$ mm$^3$. We will equip five support points between the silicon detector space frame and the wire-chamber endplates with such devices, three of which are shown schematically in Fig. 3. We are therefore requesting funds for seven inchworms (this includes two spares).

## (iii) Position Monitoring System

The silicon detector systems in use in high energy physics experiments today are all smaller devices than those proposed for CDF II. All previous detectors have relied on the overall rigidity of the mechanical ructure and precise construction tolerances to achieve an initial alignment suitable for further refinement using particle tracks. Several experiments [3, 4] have implemented independent position monitoring of their detectors. These systems measure the relative positions of the detector elements during data-taking – typically the position of the silicon support structure with respect to the inner-wall of the adjacent gaseous tracking detector. This has the drawback that an observed shift could be due to the movement of either detector.

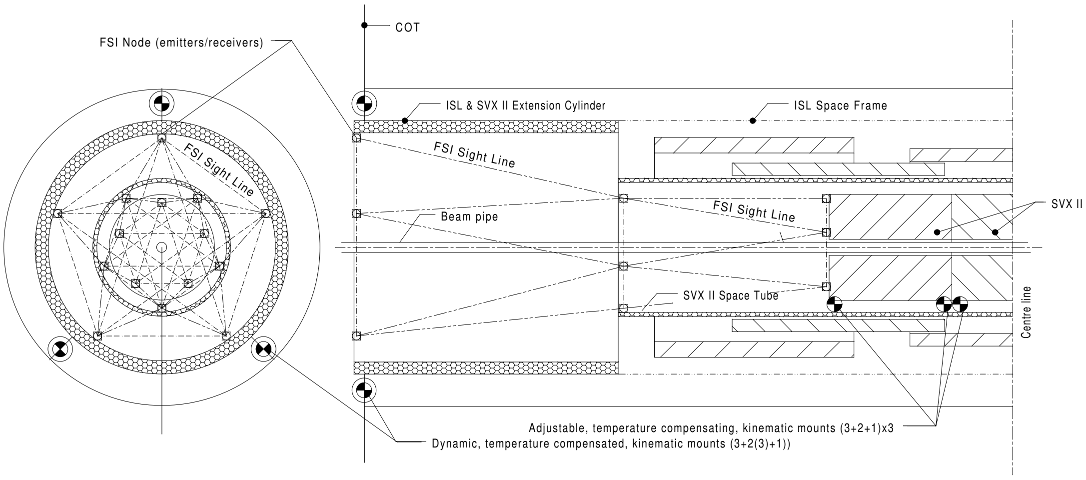
In order to overcome this problem, we propose a system that has the ability to make **absolute** distance measurements on an over-constrained geodetic grid. A set of scanned laser interferometric distance measurements will allow us to pinpoint changes in the locations of individual grid nodes that are fixed to the vertex detector support structure. This is supplemented with a series of LED light sources rigidly attached to silicon ladders that illuminate neighbouring silicon sensors, thereby relating their relative position with respect to the silicon support structure. This will provide a measurement of the silicon sensor positions themselves relative to the rest of the tracker and not just the support structure. The former is what we are interested in while the latter can move independently of the silicon.

### (a) Frequency Scanned Interferometry

An overview of the Frequency Scanned Interferometric (FSI) scheme proposed as the mainstay our position monitoring solution can be found in the ATLAS operating grant request submitted to NSERC in the fall of 1997. We propose that the work on these two systems proceed in parallel. In this document we will focus on the CDF-specific aspects of our proposal and refer the interested reader to the ATLAS document for further details.

Given the complexity of the upgraded silicon tracker we are proposing a system capable of making absolute distance measurements between various spaceframes supporting the silicon sensors. By making an over-constrained set of measurements we intend to monitor the shape of the grid with a precision of better than 10 $\mu$m using FSI [5].

We propose to make a series of 100 measurements over a grid consisting of 30 nodes, half of which are shown schematically in Fig. 3. We request funds to construct 120 interferometers to allow for spares and the possibility of adding further redundancy to the geodetic grid. One of the advantages of the system we propose is that it will be possible to make a large number of simultaneous measurements with a single laser. The longest distance we propose to measure is about 80 cm. Other distances are as short as 20 cm, requiring a factor of 16 less input power (per measurement) or about 1 mW. If we were to use only one laser and make all 100 measurements simultaneously the total power required of the laser would be about 1 W. Tunable Ti-sapphire lasers exist in this power range, but they are unreasonably expensive for this application.




SVX II Schematic Views Showing Mounting Points and FSI Nets

Figure 3: The proposed geodetic grid to over-constrain the geometry of the CDF silicon detector support structure.

We are studying ways to increase the optical efficiency of each interferometer arm, and are prototyping the optical elements of the light-delivery system to evaluate our current design. We anticipate that a solid state pumping tunable laser, with a power output of only 30 mW will suffice. If we are unsuccessful at increasing the optical efficiency of the interferometer arms then we will optically multiplex the output of a low power solid state laser distributing it, in turn, to subsets of measurements.

It should be noted that we are requesting a similar 30 mW laser and optical table setup in this grant as in the ATLAS grant. The optical system requested here can be deferred until April 1999 on the grounds that only then would it be required for installation at CDF. All tests could be performed with the ATLAS test setup. Should the ATLAS setup not be available a system for testing the CDF interferometers would be required sooner.

### (b) Relative Position Measurements: LED Light Spots

The first DELPHI vertex detector implemented a series of LED light spots to monitor the position of the silicon sensors during data-taking [4]. We propose to include such a system to monitor the positions of one layer of SVX II ladders. The proposed light spots would be focussed on the silicon sensor surfaces using a small prism. The main problem with any such system is to find a suitably stable reference surface on which to mount the light sources. We propose here to use the support rails of an adjacent layer of silicon ladders as supports since these are designed to be sufficiently rigid to resist most anticipated mechanical distortions. Light will be delivered to the prisms through a series of 25 $\mu$m diameter optical glass fibres with 200 $\mu$m cladding. The LED light sources will be located in the counting room 40 metres away. The use of the silicon strips as the precision position detector will result in a "test-pattern" being overlaid on the raw SVX II data. Any observed motion can be correlated with the absolute FSI measurements of

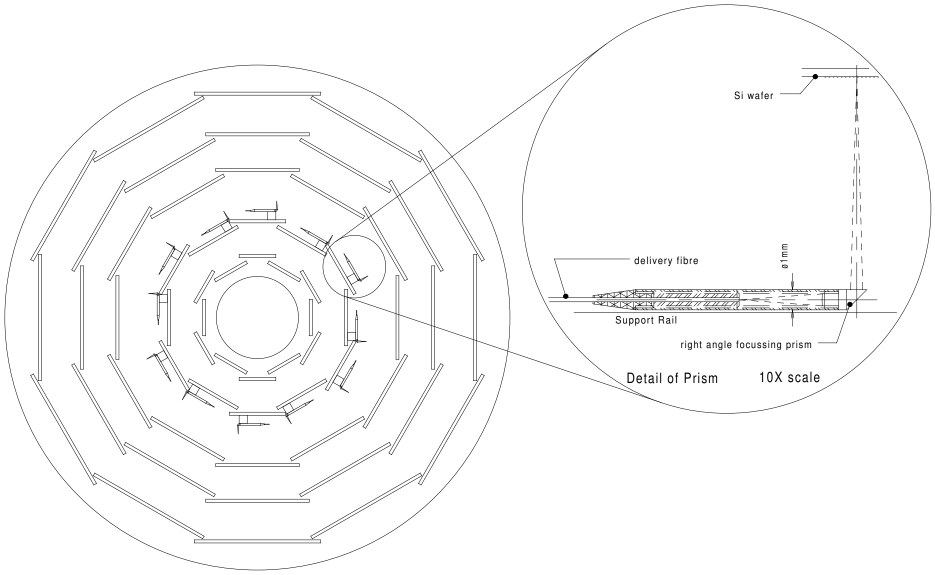



Figure 4: The proposed layout of LED light spot delivery fibres around the SVX-II barrels. A blowup of a single delivery fibre is illustrated.

the positions of the spaceframes in order to determine the absolute location of the silicon sensors.

Light spots 50 $\mu$m in diameter can be focussed on the surface of the silicon from a distance of a few centimetres. Averaging several hundred measurements of these spot positions will allow a statistical precision on the location of the sensors of a few $\mu$m. While this accuracy is good, the information obtained is insufficient to determine absolute changes in position of the silicon sensors. It is for this reason that we propose this as a partial solution coupled to the more robust FSI absolute length measurements.

We propose to deliver 72 LED light spots, two on each ladder of one layer of the three SVX II barrels. A schematic layout around the SVX II barrel can be seen in Fig. 4. These light spots will require a fibre delivery system similar to that of the FSI system, although the fibres and fibre assemblies will be simpler. The LED source is signficantly less complicated than the laser system. A relatively simple LED driver circuit is proposed with discretely adjustable light intensities.

## (iv) Related Upgrade Responsibilities

The IPP group is involved in a number of activities associated with the Run II experiment that complement and reinforce the proposed hardware responsibilities. In order to better understand how we are going to deliver the LED fibres to the silicon ladders one of our students will be participating in the SVX II ladder assembly. While working on the LED system he will also become a key member of the SVX II contruction team. To further understand what lines of sight will be available for the FSI system, one of us has become

| System | Total Cost |
|---|---:|
| Static Kinematic Mounts | 22,100 |
| Dynamic Kinematic Mounts | 54,975 |
| Position Measurement System | 149,821 |
| Travel | 27,186 |
| Total | 254,081 |

Table 1: A summary of the equipment cost of the proposed upgrades.

a member of the tracker integration team, studying construction tolerances for the entire silicon tracker system. This will have to be pursued much further over the next two years if the FSI system is to be a success. We are taking joint responsibility for the alignment of the silicon tracker system, using the information provided by the position monitoring system, the survey data and the *in situ* charged particle data. We have also taken responsibility for the beam position monitoring and alarms systems.

We plan on making an initial alignment of the silicon and wire chamber using the survey data acquired during construction and installation of these devices. Initial refinement of the alignment will come from cosmic ray data taken during detector commissioning in 1999, and from the position monitoring system discussed in this proposal. Final alignment of the detectors will be performed using high-momentum charged particles produced in collisions. We anticipate that these activities will involve 2.0 FTE physicists and students in the group, and will extend well into the data collection phase of the experiment.

## (v) Budget

The costs of the proposed hardware contributions are summarised in Table 1, based on estimates developed from the conceptual designs and prototypes we have described above. The costs have been estimated using a “bottoms-up” methodology. We have identified the subcomponents and activities required to design and fabricate the mounts and positioning systems. This detailed breakdown is provided in Section F.

The cost of the mounts (both static and dynamic) is dominated by the machining of components and we have based these costs of prototype parts that we have built for CDF during the past year. For the FSI system the cost is roughly evenly divided between optical components (including fibres) for the interferometer arms and conventional optical equipment for the light source. The latter is well known and has been roughly constant since we started working on this project 18 months ago. The interferometer arms are in the process of being prototyped. We expect to place an order for two prototype quills before the end of September 1997. We are confident that the final construction costs, which represent very little scaling down from the prototype costs, can be met.

The budget also includes support for travel by the design engineer, G. Stairs, to Fermilab to attend integration and engineering meetings with the Fermilab-based engineering staff, and video-conference costs to participate in biweekly SVX II project meetings. Installation of the mounts and FSI system are both estimated to require two person-months at Fermilab by G. Stairs and K. Vincent, and the associated travel costs are also included in the budget.

We have also provided the proposed annual costs of the project in Section F. Fabrication and installation of the mounts must take place in the first year of the project, while some parts of the light source system are only required in the second year, provided that adequate funding is available for the ATLAS test-bed.

## (vi) Schedule

The SVX II assembly schedule requires that the final kinematic mounts be available for installation starting in July 1998. Pre-prototype static mounts and a prototype inchworm have been funded through a special IPP grant and University of Toronto internal funds (November 1996). The position monitoring system components mounted directly on the detector must also be available starting in September 1998. The off-detector components of the FSI system, such as the full-power laser and readout system are required in the middle of 1999. An important milestone is the FSI Design Review a detailed review of the requirements for this device will be performed based on studies using the prototype solid-state laser system.

## (vii) Personnel

We have estimated that these three hardware projects will require supervision by 1.0 FTE physicist over the two years of this proposal. The static and dynamic kinematic mounts are being designed by G. Stairs, and the components will be assembled by K. Vincent. Both personnel are supported by NSERC Major Facilities Access grants and their salaries are not part of this proposal. Machining of the necessary components will be supervised by G. Stairs. The FSI position measurement system consists in large part of optical components whose assembly will be supervised by one R.A. and one physicist. The funding for these personnel and their associated travel has been included in the CDF project grant request submitted this year.

Installation of the components in CDF will be performed by Fermilab technicians under the supervision of G. Stairs and IPP physicists. IPP physicists and students will participate in the design and prototyping at their home institutions, and will be responsible for commissioning and operating the positioning and monitoring systems at Fermilab during data taking. We anticipate commissioning will require 1.0 FTE physicist for a period of 6 months.

# References

[1] *The CDF Detector for the Tevatron Run II: Technical Design Report,* F. Abe *et al.*, CDF/DOC/PUBLIC/3777 (September 1996).

[2] *A Study of B Meson Decays Involving a $J/\psi$ Meson,* G. Sganos, University of Toronto Ph.D. thesis, June 1996 (unpublished);
*Ratios of bottom meson branching fractions involving $J/\psi$ mesons and determination of b quark fragmentation fractions,* F. Abe *et al.*, Phys. Rev. D **54**, 6596 (1996).

[3] *The Mark II Silicon Strip Vertex Detector,* C. Adolphsen *et al.*, Nucl. Instrum. Methods **A313**, 67 (1992).

[4] *The DELPHI Microvertex Detector,* N. Bingefors *et al.*, Nucl. Instrum. Methods **A328**, 447 (1993).

[5] *Frequency Scanned Interferometry (FSI): The basis of a survey system for the ATLAS ID using fast automated remote interferometry,* ATLAS-INDET-112 (August 1996);
*Development of a Novel Alignment System for the ATLAS Inner Detector and an Investigation of the Effect of Alignment Inaccuracies on Tracker Performance,* A. Fox-Murphy, Oxford University Ph.D. thesis (unpublished), August 1996.

# F. BUDGET

| **SVX Kinematic Mounts** | | Total |
|---|---|---|
| Legs ($20 \times 500$) | | 10,000 |
| Differential Screw | 150 | |
| Carbon fibre straw | 100 | |
| Attaching hardware | 250 | |
| Mounting Plates ($12 \times 300$) | | 3,600 |
| Prototyping | | 5,000 |
| Tooling | | 3,000 |
| Shipping and taxes (2.3% GST) | | 500 |
| **Total Cost of SVX Mounts** | | **22,100** |

| **Inchworm Mounts** | | Total |
|---|---|---|
| Mounts ($7 \times 4,625$) | | 32,375 |
| Piezoelectric cells (3) | 2,025 | |
| Mount point on COT | 700 | |
| Two clamps ($2 \times 500$) | 1,000 | |
| Inchworm body | 700 | |
| Rail assembly | 200 | |
| Control logic and power supply | | 5,000 |
| Interface to Slow Controls | | 8,000 |
| VME crate and power supply | 6,000 | |
| VME CPU | 2,000 | |
| Final Prototype | | 7,000 |
| Shipping and taxes (2.3% GST + 2.7% Shipping) | | 2,600 |
| **Total Cost of Inchworm Mounts** | | **54,975** |

# BUDGET (continued)

| **Position Monitoring System** | | Total |
|---|---|---|
| Prototype Retroreflectors | | 3,000 |
| Retroreflectors ($120 \times 60$) | | 7,200 |
| Reflectors | 30 | |
| Support Ball/Assembly | 30 | |
| Prototype Fibre Assemblies | | 7,000 |
| Fibre Assemblies ($120 \times 380$) | | 45,600 |
| Monomode fibres ($2 \times 40$ m) | 80 | |
| Injection & termination optics | 70 | |
| Connectors ($4 \times 15$) | 60 | |
| Quill Assembly | 170 | |
| Optical Components | | 65,861 |
| Reference cavity | 5,000 | |
| Optical table legs & isolators | 8,650 | |
| Optical table accessories | 5,000 | |
| Solid-state laser (30 mW) | 22,925 | |
| Photodiodes & frames | 1,985 | |
| Beam splitters & frames | 1,722 | |
| Mirrors & frames | 558 | |
| Light multiplexor | 6,000 | |
| Amplifiers (5) | 1,250 | |
| ADC's | 1,000 | |
| Phototube | 3,271 | |
| HV power supply | 500 | |
| VME crate & power supply | 6,000 | |
| VME CPU | 2,000 | |
| LED Position Monitoring System | | 14,060 |
| LEDs (10) and power supply | 1,100 | |
| Fibres (144) | 5,760 | |
| Prisms (144) | 7,200 | |
| Shipping and taxes (2.3% GST + 2.7% Shipping) | | 7,100 |
| **Total Cost of Position Monitoring System** | | **149,821** |

# BUDGET (continued)

| **Travel** | | Total |
|---|---|---|
| Design Meetings | | 6,350 |
| Airfare to FNAL (5) | 3,000 | |
| Per diem (10 days) | 400 | |
| Housing (10 days) | 600 | |
| Car rental (10 days) | 350 | |
| Videoconferences (10) | 2,000 | |
| Kinematic Mount Installation | | 11,160 |
| Airfare to FNAL (6) | 3,600 | |
| Per diem (56 days) | 2,240 | |
| Housing (56 days) | 3,360 | |
| Car rental (56 days) | 1,960 | |
| Position Monitoring System Installation | | 9,675 |
| Airfare to FNAL (6) | 3,600 | |
| Per diem (45 days) | 1,800 | |
| Housing (45 days) | 2,700 | |
| Car rental (45 days) | 1,575 | |
| **Total Travel Cost** | | **27,185** |

# Funding Profile Summary

| **Task** | **1998-1999** | **1999-2000** |
|---|---|---|
| SVX Kinematic Mount Production | 22,100 | |
| Inchworm Mount Production | 54,975 | |
| FSI Prototypes & Optics | 83,966 | |
| LASER and final optical table | | 65,861 |
| Travel | 16,768 | 10,417 |
| **Total Annual Cost** | **177,803** | **76,278** |
| **Total Cost** | **254,081** | |