The Collider Detector at Fermilab (CDF) experiment is studying the world's highest energy proton-antiproton ($p\overline{p}$) collisions. The CDF collaboration consists of scientists from eleven different countries, including a group of 20 Canadian particle physicists affiliated with the Institute of Particle Physics (IPP). The IPP group joined CDF in 1991 and is now participating in the Tevatron Run II programme. For Run II, the CDF detector and the Tevatron collider underwent major upgrades and we anticipate a factor of 50-100 increase in the statistics of specific final states by the end of 2008.

Our group has made major contributions to CDF Run-II data analyses by providing massive off-site computing resources and the human resources necessary to coordinate this effort. This involvement along with our long-standing contributions to CDF software has allowed Canadian physicists to make key contributions to the first physics results of Run II.

The Tevatron and the CDF detector are performing very well with data taking efficiencies close to 90% and peak luminosities of 1.5 $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. This has allowed us to collect over 1 $\mathrm{fb}^{-1}$ of data and we anticipate doubling the current dataset between now and the end of next year. The fully realized physics programme of Run II requires the analysis of inverse femtobarns of collision data. This integrated luminosity will allow us to search for new particles and forces, and measure key parameters of the Standard Model of particle physics to unprecedented precision.

This proposal requests funding for the next 3 years in order for the IPP group to fully capitalise on NSERC's significant investment in the CDF II experiment and its physics. This will allow our graduate students, research associates, and faculty to continue their service contributions to CDF and to complete their ongoing physics analyses at the exciting time when the scientific output of the experiment reaches its peak.

| | | | |
|---|---|---|---|
| CDF commissioning run | First operation of Inchworm positioning system | Sep 00 | Dec 00 |
| Tracker Alignment | Analysis of construction survey/first tracks | Oct 00 | Jul 01 |
| CDF-II data-taking | | Mar 01 | Mar 07 |
| CDF-II Physics Analysis | | Jul 01 | Jan 08 |

# A. TITLE

The CDF-II Experiment at the Fermilab Tevatron

# B. INVESTIGATORS

(i) Applicants

| | | | |
|---|---|---|---|
| J. Pinfold | Alberta | Professor | 30% |
| P. Savard | Toronto | Professor | 100% |
| P. K. Sinervo | Toronto | Professor | 70% |
| W. Trischuk | Toronto | Professor | 80% |
| A. Warburton | McGill | Professor | 100% |

(ii) Collaborators

| | | | |
|---|---|---|---|
| B. Burris | Alberta | Computing Professional | 50% |
| P.H. Beauchemin | Toronto | Research Associate | 100% |
| B. Caron | Alberta | Computing Physicist | 20% |
| S. Carron | Toronto | Research Associate | 100% |
| R. Snihur | McGill | Research Associate | 100% |
| A. Buzutu | McGill | Graduate Student | 100% |
| S. Lai | Toronto | Graduate Student | 100% |
| J. Krishna-Prasad | Toronto | Graduate Student | 100% |
| D. MacQueen | Toronto | Graduate Student | 100% |
| S. Pashapour | Toronto | Graduate Student | 100% |
| J.P. Roy | McGill | Graduate Student | 100% |
| S. Sabik | Toronto | Graduate Student | 100% |
| T. Spreitzer | Toronto | Graduate Student | 100% |
| G. Williams | McGill | Graduate Student | 100% |
| I. Vollrath | Toronto | Graduate Student | 100% |

Other Collaborators: physicists from Academica Sinica, Argonne National Laboratory, Istituto Nazionale di Fisica Nucleare, University of Bologna, Brandeis University, University of California at Davis, University of California at Los Angeles, University of California at Santa Barbara, University of Cantabria, Carnegie Mellon University, University of Chicago, JINR-Dubna, Duke University, Fermi National Accelerator Laboratory, University of Florida, Laboratori Nazionali di Frascati, University of Geneva, University of Glasgow, Harvard University, University of Helsinki, Hiroshima University, University of Illinois, Johns Hopkins University, Universität Karlsruhe, KEK, LBL, Liverpool University, University College London, Massachusetts Institute of Technology, University of Michigan, Michigan State University, ITEP Moscow, University of New Mexico, Northwestern University, Ohio State University, Okayama University, Osaka City

University, Oxford University, Universita di Padova, University of Pennsylvania, University and Scuola Normale Superiore of Pisa, University of Pittsburgh, Purdue University, University of Rochester, Rockefeller University, University of Roma, Rutgers University, University of San Diego, Texas A & M University, Texas Tech University, INFN-Trieste, University of Tsukuba, Tufts University, Waseda University, University of Wisconsin, and Yale University.

# A. Executive Summary

The CDF-II experiment is studying 2.0 TeV proton-antiproton ($p\overline{p}$) collisions produced by the Fermilab Tevatron Collider, currently the highest energy collider in the world. The collider data taking period known as Run II started in 2002 and as of September 2005, the accelerator has delivered over 1 $\text{fb}^{-1}$ with an additional 3 $\text{fb}^{-1}$ expected by the end of 2007. The analysis of these integrated luminosities represent an unprecedented scientific opportunity to explore the high energy frontier. The IPP-Canada group requests funding for the next 3 years to take advantage of this outstanding opportunity.

IPP scientists have been supported by NSERC to participate in the CDF project since 1991, when the experiment was in preparation for a data-taking period known as Run I. In anticipation of the large increase in luminosity we completed a major overhaul of the CDF sub-detectors and associated readout electronics, creating the new detector facility known as CDF-II. The Canadian hardware contribution to the CDF-II detector, funded through an NSERC equipment grant, focused one the silicon vertex detector support mechanics. We have also made significant contributions to the Offline Project by developing most of the calorimetry reconstruction and simulation software. More recently, we committed the resources necessary to make our CFI-funded Beowulf cluster (450 2.4 GHz Xeon processors with approximately 30 TB of disk) the main Monte Carlo production facility for the CDF collaboration.

These NSERC and CFI-sponsored efforts have allowed us to play a very important role in the experiment as is evidenced by the scientific productivity of our group and the leadership roles of our faculty and research associates. We have published and submitted more papers than other groups of our size, including the first high-pt physics paper of Run II, the best single measurement of the top mass to date, and the first measurement of the W boson mass in Run II. The leadership roles assumed by members of the group include Calorimetry group leader, Simulation Group leader, Head of Offline Operations, Silicon Detector Project leader, Offline Analysis leader, and Top and Electroweak Physics Group convener. Another important contribution of our group involves the training of graduate students and research associates in hadron collider physics. The Tevatron remains the ideal training ground for the next generation of physicists that will work at the Large Hadron Collider.

We intend to continue our effort on CDF in order to capitalise scientifically on the Canadian contributions to CDF-II. The scientific programme for the next three years showcases outstanding opportunities that include measurement of Bs mixing, a first single top cross section measurement, precision electroweak measurements (W mass, top mass, etc.), precision measurements of top quark properties, and searches for new phenomena. Many of these measurements (e.g. Bs, single top, new phenomena like SUSY trileptons) will probably require integrated luminosities beyond 2 $\text{fb}^{-1}$ with additional time required to thoroughly understand the data.

This proposal requests funding for the next 3 years in order for the IPP group to fully capitalise on NSERC's significant investment in the CDF II experiment and its physics. This will allow our graduate students, research associates, and faculty to continue their service contributions to CDF and to complete their ongoing physics analyses at the exciting time when the scientific output of the experiment reaches its peak.

# B. The Canadian CDF-II Physics Program

The multi-purpose CDF detector makes possible the pursuit of a very broad physics program that is progressing on several principal fronts: high-precision inquiry into electroweak physics observables of top quarks and intermediate vector bosons; exploration of both perturbative and nonperturbative QCD, including measurements of heavy-quark hadroproduction; and energy-frontier searches for physics beyond the Standard Model, a description of Nature that is generally reasoned to be incomplete.

Canada's CDF group is engaging in physics analyses that span this breadth. Below, we summarise the significant Canadian efforts underway using the early Run-II data; we follow this with a discussion of the Tevatron luminosity program and its projected physics reach.

## (i) Top Quark Physics Studies

Since the discovery of the top quark during Run I of the Fermilab Tevatron, emphasis has turned to the precise characterization of its properties. Given the relatively small samples collected in Run I, much remains to be discovered about this unusually massive and highly short-lived fermion. The current Run II dataset represents an order of magnitude increase in statistics over the world's previous top quark sample and, together with new analysis approaches and improved detector functionality, is enabling precision measurements of this exotic particle. The CDF Run II upgrades have enhanced the top quark yield per unit of time-integrated luminosity by both extending and improving the lepton identification systems, and by significantly improving the bottom quark tagging capability. Combined with the additional time-integrated luminosity and the higher cross section afforded by the increase in centre-of-mass energy from 1.8 to 2.0 TeV, we are now able to study samples of top-quark candidates of order $10^3$ in number.

### (a) Top Mass

The top quark's great mass is arguably its most striking feature, one that figures prominently in radiative corrections to Standard Model descriptions of electroweak observables. A precise understanding of the top mass is therefore crucial to providing constraints on the Higgs boson mass and consistency checks of the Standard Model, both with much sensitivity to new physics.

The Canadian top-mass effort (Arguin, Sabik, Savard, and Sinervo) is focussing on the lepton + jets and dilepton channels of $t\bar{t}$ production and decay, whereby both top quarks decay into *b*-quark jets and W bosons. In the dilepton channel, both W bosons decay leptonically whereas in the lepton + jets channel, on W boson decays leptonically and the other hadronically. The resultant topologies consists of one or two charged leptons, missing transverse energy due to the neutrino, and two to four jets. A major challenge to measuring the top mass is the complicated reconstruction of the final state required. In the case of the dilepton channel, the two neutrinos are not measured which requires solving a kinematically underconstrained problem. For the l +jets case, CDF's b-jet-tagging capabilities are employed, with efficiencies of approximately 40%, to reduce these combinatorics significantly. A second major challenge is overcoming the largest systematic uncertainty, namely that due to the jet energy scale. Uncertainties in the jet energy scale arise from model dependence in our descriptions of fragmentation and the particle