INSTITUTE OF PARTICLE PHYSICS

IPP Submission to the NSERC GSC-19 Long Range Planning Committee

IPP Council*

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1 Introduction

NSERC and the Canadian subatomic physics (SAP) community are currently engaged in a long-range planning exercise intended to develop a strategy for the evolution of the Canadian subatomic research programme. While past plans have typically focused on five-year periods, for the current exercise the LRP committee has been charged with laying out the scientific priorities of the community for the coming decade. NSERC had also asked for guidance on the following issues:

- The role of theory
- The role of TRIUMF
- The balance between operating and capital expenditures
- The relationship between NSERC and other funding agencies

The last point is of particular significance given the increased role played by the Canada Foundation for Innovation (CFI) over the past several years, and the current government proposal for investment in Major Science Initiatives. The IPP welcomes the lengthening of the planning period as it better matches the timescales associated with the large international experimental projects which are now the norm in the field of high-energy physics, having lifetimes of up to twenty years, from the planning stage to the end of data taking. However, the longer timescale also provides the community with an opportunity to produce a plan emphasizing scientific possibilities rather than very detailed financial planning. In that spirit, the planning committee has been asked to address three very different funding scenarios.

- The status quo
- A change of -20%
- A change of +100% phased in over ten years

In particular, the +100% scenario is meant to provoke a vision for what could become of the field, if current funding constraints were considerably relaxed.

In response to the call for submissions to the Long Range Planning Committee, the IPP organized a Townhall meeting coinciding with the IPP Annual General Meeting in June 2005. There were fifteen presentations made, the majority of which represented proposals for new initiatives. Over the following two months, written submissions were solicited from all current and proposed projects. The projects considered in detail in this document are listed in Table 1, broadly categorized into four areas of research. This categorization is motivated below and is used throughout this discussion paper.

For the IPP, this planning cycle begins in a very different environment than that which existed in 2000, when a similar exercise for the five year period now ending took place. At that time, the Canadian community was still heavily engaged in long-term commitments to a number of running experiments (CDF, OPAL, ZEUS, BaBar, HERMES, E787/949), and to a few high-profile projects either just beginning their data taking phase (SNO) or still under construction (ATLAS). The current situation is rather different. While ATLAS is expected to run at least through to the end of this planning cycle, the other large experiments have either ceased operation (OPAL) or will cease operation in the next five years (ZEUS, BaBar, SNO). The ramping down of the associated operating costs will free up resources for new projects, so this is a particularly appropriate time to be thinking hard about our future plans.

The scale of leading-edge projects in particle physics has grown so large that most experiments now involve large international collaborations sited at a few large facilities around the world. While SNOLab is a new example of such a facility here in Canada, Canadian particle physicists still devote a large fraction of their effort and resources

Category	Project	Comments
Energy Frontier	ATLAS	IPP Project at the CERN LHC pp collider
	CDF	IPP Project (finishing) at the Tevatron $p\bar{p}$ collider
	D0	Project (finishing) at the Tevatron
	ILC	International Linear e^+e^- Collider
	ZEUS	IPP Project (finishing) at the HERA ep collider
Underground Physics	SNO	IPP Project (finishing), heavy-water solar neutrino detector
	PICASSO	IPP Project WIMP search super-heated gel detector, SNOLab proposal
	DEAP	WIMP search LAr detector, SNOLab proposal
	EXO	$0\nu\beta\beta$ Xe detector, SNOLab proposal
	Majorana	$0\nu\beta\beta$ Ge detector, SNOLab proposal
	SNO+	Liquid Scintillator solar neutrino detector, SNOLab proposal
Precision Physics	ALPHA	Proposed anti-hydrogen accumulation and study project at CERN
	BaBar	IPP Project finishing at PEP2 B-factory
	GlueX	Exotic hadronic state search proposal at Jefferson National Lab
	MEC	μ conversion project at proposed TRIUMF muon source
	$\pi \to \ell$	Proposed experiment at TRIUMF
	Super-B	Possible very-high-luminosity B-factory
Neutrino and Particle Astrophysics	FLARE	Proposed LAr detector for FNAL neutrino superbeam
	POLARBEAR	Project proposed to probe inflationary physics via CMB polarization
	T2K	IPP Project, Tokai to Kamioka neutrino superbeam facility
	VERITAS	IPP Project, very high energy gamma-ray astronomy

Table 1: Projects and categories discussed in this document.

to what we term “offshore” projects, eg. those based at facilities outside of Canada, such as Fermilab, CERN, DESY and SLAC. The Canadian model for involvement in such collaborative efforts has evolved over the past few decades, from our experiences with early projects at Fermilab and DESY, into the modern IPP model which was the basis for our very successful involvement in offshore projects like OPAL, CDF, ZEUS and BaBar.

The community is heavily invested in the ATLAS experiment with over 40 grant-eligible researchers involved and 22 FTE in 2005. Additionally the IPP has recently approved several new projects (VERITAS, PICASSO, T2K) each of which probes a different type of physics. The strong complementarity between work done at the high-energy frontier and work done at the precision frontier has long been recognized, and the IPP has traditionally supported projects of both types. In the last decade we have also seen a growing complementarity between “traditional” particle physics, and the field of particle astrophysics, one example being dark-matter searches, another being investigations of astronomical phenomena using particle physics techniques.

The SNO experiment is among the Canadian projects that will cease operation in the coming years. As a world-class experiment lead by Canadian researchers and sited in Canada, SNO has played a special role in Canadian particle physics, bringing well-publicized acclaim to the Canadian subatomic physics community. The project has been extraordinarily successful, and there is widespread international recognition of the role played, in this success, by the unique low-radiation background environment provided by the experimental site at the 6800 ft level of Inco’s Creighton Mine. A very low-background environment is a critical aspect of many types of experiment, such as searches for dark matter or neutrinoless double β-decay. Canadian physicists have exploited the success of SNO by proposing the construction of a general-purpose low-radiation background experimental facility (SNOLab). This facility has been funded by the CFI and is now under construction. Many of the proposals for new initiatives are associated with the SNOLab facility. In what follows, we discuss these under the heading of underground physics.

In order to maintain a balanced experimental programme in Canada, the IPP considers it important to maintain a mix of projects in the categories discussed above, as well as a mix of large and smaller-scale projects. In order that limited resources not be stretched too thin, the IPP has a long-standing policy of supporting only a single experimental effort addressing a particular type of research. The aim has been to have a strongly focused experimental programme by encouraging a limited number of strong Canadian teams that can take on substantial responsibilities within the large international collaborations that are now typical of the field. Additionally, for an experiment to be approved as an IPP project it should involve the participation of multiple researchers, preferably at more than one Canadian institution, with at least some of the researchers dedicating the majority of their research time to it.

Overall the IPP approach has been a very successful one. The current programme is the result of these policies. We continue to support several running experiments (CDF, ZEUS, BaBar, SNO) as well as several projects under construction (ATLAS, VERITAS, T2K, PICASSO) each addressing different, but complementary fields of physics. As a number of these projects near completion, and the significant capital expenditures associated with the construction of the Canadian contributions to ATLAS are now complete, now is the right time to address the future experimental programme of the IPP.

Below, we present a general overview of the current status of particle physics with an emphasis on the main questions that are expected to be addressed by the field in the time period covered by this plan. This is followed by a discussion of the status of the Canadian programme and summaries of the current IPP projects, focusing first on those experiments that are nearing completion, then on those which are still preparing for data taking. We then turn to the future, with descriptions of the proposals that have been made for new initiatives. This discussion is framed within the categories outlined in Table 1; the high-energy frontier, underground physics, the precision frontier, and neutrino & particle-astrophysics.

Where it is relevant to do so, issues related to the different funding scenarios will be discussed in sections describing specific projects. A more general overview of the effect of the funding scenarios on the overall IPP programme will be provided separately at the end of the document.

2 Overview of Particle Physics

Particle physics is the most fundamental of all physical sciences. At its heart are two very basic questions: what are the fundamental particles that make up our universe, and how do they interact with one another ? Over the past half-century our ability to address these questions has developed to the point where we now have a well-tested, fully mathematical, and self-consistent theoretical description of the sub-atomic world, referred to as the Standard Model of particle physics. The theory describes our world, at extremely small distance scales, as made up of three generations of fundamental spin-$\frac{1}{2}$ fermions, the quarks and the leptons, having strong, weak and electromagnetic interactions specified by $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge symmetries. Gravity, which is extremely weak at energy scales far below the Planck scale, is not included in the Standard Model, and currently no viable theory of quantum gravity exists, though this remains an active and vibrant field of research.

Since its development, (recently supplemented by neutrino masses) the Standard Model has survived every laboratory test to which it has been subjected. Nevertheless there are many open issues in particle physics, motivated both by decades of experimental work, and by progress in the study of the form extensions to the Standard Model might take. At the high-energy frontier, these issues include the search for the Higgs boson, or for some other mechanism of electroweak symmetry breaking, the search for supersymmetry, and searches for phenomena associated with the existence of large or warped extra dimensions. Away from the energy frontier, recent advances in neutrino physics have opened up a whole new field of experimental investigation that we are only just beginning to exploit. Studies of neutrino mixing may open up a new window on CP-violation, and studies of neutrino masses may provide indirect access to physics at the GUT scale. Over the past decade, there has also been a growing recognition of the overlap between particle physics and cosmology, and a number of the big questions in fundamental science relate to issues of common interest to these two fields, such as the nature of dark matter and dark energy, and the origin of the matter-antimatter asymmetry of the universe. These are all questions that are expected to be addressed by experiments that will be done over the next decade.

Electroweak unification provided theoretical predictions for the masses of the W and Z bosons, which were experimentally confirmed just a few years later. The late 1980s saw the turn-on of the LEP collider, which was designed and constructed to perform precision studies of the electroweak sector, and to search for new physics at the electroweak energy scale. The LEP collider and the four associated experiments, ALEPH, DELPHI, OPAL and L3 took data for over a decade, before being de-commissioned in late 2000, providing us with many stringent tests of the Standard Model. No significant discrepancies were observed.

Over a similar time period, the Tevatron collider at Fermilab has probed the Standard Model in a complementary way, also observing no deviations from its predictions. Although the Tevatron is now producing precision electroweak measurements, such as M_W, that rival those of the LEP experiments, the Tevatron was built as an energy-frontier machine and will continue to be the world's highest energy collider until the turn-on of the Large Hadron Collider. It is currently the only facility that allows direct study of the top quark, which was discovered there in 1995.

In the Standard Model, the masses of the electroweak gauge bosons arise from spontaneous symmetry breaking in the Higgs sector. This leads to the existence of a fundamental scalar particle known as the Higgs boson, which is the only Standard Model particle that has not been observed. The masses of the fundamental fermions are provided via their Yukawa coupling to the Higgs, which must be determined experimentally. The mass of the Higgs boson is not directly predicted by the theory, though its properties are well specified as a function of its mass. Searches for the Higgs were an important part of the LEP experimental programme. No evidence for its existence was found and a lower limit of 114 GeV/c^2 was set on its mass. The Tevatron experiments CDF and D0 continue to search for the Higgs boson in the mass range just above the LEP limit, but will have a rather limited reach with their anticipated data samples.

Precision measurements in the electroweak sector of the Standard Model provide indirect constraints on the mass of the Higgs boson, via its contribution to radiative corrections to electroweak observables. A global fit to all precision electroweak data favours a low mass, just above the direct search limit from LEP, and yields an upper limit of about 1 TeV. This is precisely the energy region that will be probed by the next generation of collider experiments, the LHC, which is nearing construction, and a future linear collider, which is still in the design phase but which is widely acknowledged to be the highest priority for the next international particle physics facility.

Past experiments, including the most recent generation at the energy frontier, have also provided tests of QCD, the theory of the strong interaction. With its self-interacting gluons, QCD has a phenomenology very different from that of weak and electromagnetic interactions; it is simultaneously responsible for asymptotic freedom and for quark confinement into hadrons. At energies where perturbative QCD is valid, the theory accurately describes quark scattering amplitudes. The structure of the theory is tested by measurements of the running of the strong coupling constant, α_s, which has been measured in rather different systems and at different energy scales. This is well illustrated by Figure 9.2 of the *Review of Particle Properties*† which summarizes values of α_s obtained at various energy scales, from measurements of the τ-width, Υ decays, deep-inelastic scattering, and e^+e^- event shapes. The decrease of α_s with the energy scale, predicted by QCD, is clearly displayed.

In principle QCD also describes the low-energy phenomenology. However, in the non-perturbative energy regime the calculations are very much more difficult. The coupling constant α_s becomes large, leading to confinement. As a consequence, only colour-singlet objects can exist in nature. Experimentally, all (well established) observed hadrons are either mesons, consisting of a quark and an antiquark, or baryons, which are made up of three quarks or three antiquarks. However, nothing in the theory forbids other colourless combinations. In fact, the theory predicts the existence of other "exotic" particles which are bound states of quarks and gluons. Perhaps the most spectacular prediction of QCD is the existence of glueballs, which are made up of gluonic degrees of freedom only. There has been a recent resurgence of interest in hadron spectroscopy, with the discovery of new resonances at the

†S. Eidelman *et al.*, Phys. Lett. **B592** (2005).

B-factories, and multiple reports claiming observation of "penta-quark" states. A new experiment,GlueX, proposes to do precision tests of QCD by searching for exotic states.

Though the Standard Model describes all known experimental results, there are rather general reasons for believing that the theory cannot remain valid to arbitrarily high energy. Within the framework of the Standard Model, radiative corrections to the Higgs mass squared go like the mass-squared of the highest energy scale to which the theory remains valid. A possible solution to this problem is provided by the introduction of Supersymmetry. If the mass scale of the superpartners is less than about 1 TeV, supersymmetry still provides an acceptable solution to this problem. This weak-scale supersymmetry also permits gauge-coupling unification at high energies and provides a viable dark matter candidate in the form of the lightest neutralino, providing R-parity is conserved. The LEP, HERA and Tevatron experiments have all performed direct searches for supersymmetric particles, but no evidence has been found. It is expected that weak-scale supersymmetry will be either observed or excluded by LHC experiments such as ATLAS.

Another rather general reason for believing there to be new physics at higher energies than are presently experimentally accessible is that there are many issues that the Standard Model simply does not address. While it is fully self-consistent, it does not explain everything from first principles, and there are questions it does not address at all. These shortcomings are absorbed into 19 free parameters comprising particle masses, interaction strengths, mixing angles and other related quantities. All predictions of the Standard Model are determined as a function of these input parameters which must be determined experimentally. Many of these "shortcomings" are addressed by "Beyond the Standard Model" theories, such as those proposing force unification at high energy.

While the Standard Model provides no explanation for the existence of three generations of fundamental fermions, Kobayashi and Maskawa showed that three generations is the minimum required to accommodate a complex phase in the quark mixing matrix, thus providing a mechanism for the description of CP-violation in the Standard Model. CP-violation in the b-quark system is much larger than in the kaon system in which is was first observed. In recent times the B-factory experiments have provided us with the best experimental probe of the SM description of CP-violation. Experiments such as BaBar aim to over-constrain the unitarity triangle, providing a precision test of this sector of the theory. CP-violation is believed to be one of the necessary properties of a fundamental description of our universe that can contribute to the observed matter-antimatter asymmetry. Since the recent discovery that neutrinos have mass and thus also mix, studies of CP-violation in the neutrino sector have also become a field of enormous interest. Another necessary condition believed to be necessary for explanation of the matter-antimatter asymmetry is baryon-number violation, which is predicted by grand-unified theories and results in a finite lifetime for the proton. Searches for proton decay are, in some cases, now performed with the same large-volume detectors used for neutrino studies. The Super-K detector was originally built both for proton decay and for studies of atmospheric neutrinos; the sensitivity to proton decay will be increased with Hyper-K.

Investigations of the neutrino sector have begun to play an increasingly large role in experimental particle physics. The Super-K and SNO experiments have convincingly demonstrated that neutrino oscillations occur and that neutrinos therefore have mass. This result has opened up a whole new field dedicated to the determination of the parameters of the neutrino mixing matrix. The current generation of neutrino experiments provides knowledge of the mass-squared differences Δm^2_{12} and Δm^2_{23}, and the mixing angles θ_{12} and θ_{23}. In contrast to the well-known hierarchy in the quark mixing matrix, in the neutrino mixing matrix the off-diagonal elements are found to be large The next step must be to determine the mixing angle θ_{13} and to search for a possible CP-violating phase. The most promising avenue for these measurements is the study of $\nu_\mu - \nu_e$ oscillations using long-baseline experiments utilizing high-intensity "superbeams", such T2K.

The neutrino masses which most naturally describe the observed neutrino oscillations go beyond the Standard Model, and their small size points to the existence of hitherto-unknown physics at an energy scale $> 10^{10}$ GeV which violates the conservation of electron flavour. An equally high energy range can also be probed by searches for proton decay in the far detector of long-baseline neutrino experiments (e.g. Super-K and Hyper-K), or by detailed measurements of neutrino mixing parameters, including CP-violation. Observation of neutrinoless double β-decay would provide similar evidence for interactions at these energies which violate the conservation of overall lepton number.

Recent developments in cosmology are also beginning to have a large impact on particle physics. In particular, the interplay between large-scale surveys and precision measurements of the cosmic microwave background (CMB) combine to support a "concordance cosmology" dominated by two unknown forms of matter (dark matter and dark energy) which starts from the conditions left by an earlier 'inflationary' epoch of rapid universal expansion at much higher energies. This has enormously stimulated the relatively new field of astro-particle physics since all of these features require new kinds of particle physics beyond the Standard Model. The same is true for whatever physics might be responsible for the observed asymmetry between matter and anti-matter in the universe. Furthermore, the same measurements also constrain the sum of neutrino masses to be < 0.7 eV, which is not so different from the masses indicated by the observed neutrino oscillations. An all-sky satellite map of CMB polarizations could reduce this uncertainty to as low as 0.03 eV.

Collider searches for supersymmetric particles are complemented by non-accelerator based dark-matter searches, such as PICASSO. An indirect but possibly more sensitive approach is to search for dark matter through its annihilation into neutrinos and gamma rays. The latter might be seen by gamma-ray experiments such as VERITAS. Cosmic ray experiments also combine with underground measurements to constrain the existence of rare processes (possibly ranging from the breaking of lepton number to the violation of Lorentz invariance) due to the virtual influence of particles at energies as high as 10^{16} GeV and beyond. Research in these fields will benefit from the new experimental facilities associated with SNOLab. The low-radiation environment that will be provided there is crucial to the success of experiments proposed to search for dark matter, or to probe the nature of the neutrino through searches for neutrinoless double β-decay.

3 Project Summaries

Following the broad categorization of projects outlined in section 1, this section summarizes the current status of existing and proposed Canadian involvement in both onshore and offshore particle physics experiments. In each case we indicate the level of priority assigned to the project by the IPP. This discussion continues in section 10 which deals with the three proposed funding scenarios.

3.1 Projects Terminating before 2009

The past two decades have seen Canada play a significant role in a number of major international particle physics projects. Some of these are now finished (OPAL, for example), while others expect to complete data-taking in the next few years (BaBar, CDF, D0, SNO and ZEUS). Here we highlight some of the achievements of the Canadian involvement in these experiments and summarize their anticipated ramp-down as data-taking ends and data analysis is completed over the course of the first half of this planning period. The IPP supports continued funding for these projects at a level that will allow this work to be completed.

3.1.1 BaBar

BaBar has been an extremely successful project, with a wide range of important results produced with a data set of 230 fb^{-1} recorded through the summer of 2005. The most significant of these has been the observation of CP-violation in B decays and a precision measurement of $\sin 2\beta$. More recently, the broader goal of over-constraining the unitarity triangle is being achieved through increasingly precise measurements of V_{ub} and V_{cb} (which rely in part on parameters determined through $b \to s\gamma$ analyses), and initial measurements of the unitarity angles α and γ. These are only a few of the results reported in the 171 publications so far submitted.

Canada has had an impact on BaBar that far outweighs the size of the group. Specific analyses led by the Canadian group include V_{ub}; several τ results, including searches for final states $\mu\gamma$ and $e\gamma$, which are sensitive to new physics; charmonium physics; and rare B decays such as $B \to K\nu\bar{\nu}$. The group has held numerous leadership positions, including Physics Analysis Coordinator, Run Coordinator (three times), and four Analysis Working Group convenerships (out of a total of 12).

The Canadian group is committed to fully exploiting the factor-of-four increase in integrated luminosity that BaBar will collect through 2008. Resolution of a possible discrepancy in $\sin 2\beta$ measured in gluonic penguin modes will require this complete dataset, as will the measurements of α and γ. The rare decays measurements and searches for new charmonium states undertaken by the group will also clearly benefit from the additional data. We expect there will be a natural ramp-down of activities after data-taking ends with complete phase out occurring by 2010 or shortly thereafter.

3.1.2 CDF

The CDF group in Canada currently consists of six faculty at three institutes (Alberta, McGill and Toronto). CDF currently has in excess of 1 fb^{-1} of data that is being analyzed and anticipates doubling the current data set in 2006. A final dataset in excess of 4 fb^{-1} is anticipated before Tevatron collider operations cease at Fermilab after the LHC at CERN takes over the energy frontier. Canadians made important contributions to the detector upgrade for Run II, and have filled many important roles in the collaboration, including Computing Coordinator (twice), Silicon Project Leader, and Top Physics Group Convener.

Initial results on CDF Run-II physics topics are currently being submitted for publication, with heavy involvement of the Canadian group which has lead authors on roughly 20% of the papers so far produced by CDF-II, including high-profile results like the W-mass and top-quark mass measurements. Completion of the physics measurements in which members of the Canadian group are engaged typically requires 2 fb^{-1} of data and additional time for the understanding and reduction of systematics uncertainties. These topics include:

- Top quark mass: uncertainty less than 2 GeV by 2007
- W boson mass: uncertainty of 30 MeV by 2008
- Observation of electroweak top production (single top) by 2008
- Exotic searches: SUSY searches using trilepton signature.

The CDF-Canada group is well placed to exploit the 4 fb^{-1} data-sample that will be available before the end of the decade; however, with the onset of ATLAS data-taking it is to be expected that the transition will be more abrupt than for BaBar. It is likely that, here too, most activities in the group will have come to an end by 2010, with a steady decrease of effort beginning in 2008.

3.1.3 D0

The Canadian group on D0 consists of five faculty at four institutions (Alberta, McGill, SFU, York). The group is currently analyzing data to search for single top quark production and B_s mixing. They also make significant contributions to triggering, GRID computing and jet energy calibration. This represents expertise that will be valuable to the ATLAS group, as these researchers begin a planned shift from the Tevatron to the LHC. Fermilab is currently planning to run the Tevatron through the summer of 2008, and D0 will continue to take data throughout this period. However,the Canadian group has already begun a transition to ATLAS, and by 2008 only one faculty member in the group intends to spend more than 25% of her research time on this project. All of the current students are expected to graduate by the end of 2009.

3.1.4 OPAL

The OPAL experiment took data from 1989-2000, and data analysis continues even today. Canadians played a large role from the inception of OPAL, including detector construction, data-acquisition development, detector maintenance and calibration, and many physics analyses covering the full range of LEP physics topics: heavy-flavour physics, precision electroweak measurements, tau physics searches, etc. Canadians also played many high-level roles in OPAL management, providing one run coordinator and three physics coordinators, who act effectively as the OPAL Deputy Spokesperson, and numerous Working Group Conveners.

Canadian OPAL analysis efforts are still continuing, with two papers having Canadian principal authors undergoing journal refereeing procedures at the time of writing of this document; one is a precision study of α_S using jet-rates which is the result of Canadian Ph.D. thesis work, and the other is a large gauge-mediated SUSY search summary paper including both new and original analyses and many unique theoretical interpretations.

Since we are entering a period in which many of our efforts on large projects are coming to an end, it is instructive to examine the five years that have passed since LEP ceased operation late in 2000, in order to form an impression of how long the activities of a major experiment can be expected to carry on after the end of data taking. In this five year period OPAL has published approximately eighty papers, at a nearly constant rate of about twenty per year, with only a small indication of a rate reduction in 2005. These papers include detailed precision analyses, combinations of new particle searches with interpretations in different theoretical models, and new analyses motivated by recent theoretical work or performed in reaction to new or controversial results from other experiments. There are also several papers combining the results of all four LEP experiments in both new-particle searches and precision measurements. In this period, 7 Canadian Ph.D. students have published papers based on their thesis work, and almost 25% of the OPAL papers published in 2001-2005 have had Canadian principal authors. This is consistent with the Canadian fraction of OPAL publications over the lifetime of the experiment, representing a significant physics output, beyond our fraction of the overall collaboration.

3.1.5 SNO

The Sudbury Neutrino Observatory (SNO) has had a profound impact on the field of subatomic physics. Its three phases of operation, using pure D_2O, D_2O with NaCl, and then D_2O with Neutral Current Detectors (NCDs), each have different systematic sensitivities, enabling the statistical separation of charged-current, neutral-current, and elastic-scattering neutrino interactions in the SNO detector. Measurements of the fluxes of ^{8}B solar electron neutrinos have provided direct evidence for neutrino flavour oscillations. Data-taking in the present NCD phase is expected to continue through the end of 2006, followed by decommissioning of the NCDs and D_2O removal ending late in 2007.

While SNO's first few publications have been the most highly cited papers of the 21st century, the collaboration is now moving into a phase in which it is publishing additional measurements related to atmospheric neutrinos, day/night effects etc. While operations will cease, and much of the lab staff will move over to work on SNOLab projects at the end of 2007, it is anticipated that analysis of the entire SNO dataset and the production of archival publications will continue through the end of the decade. The scientific importance of the SNO results, as evidenced by their citation rates, equals that of any other recent advances in particle physics. Further, the fact that this project was hosted and largely funded by Canada makes this one of the most important contributions this country has ever made to science.

3.1.6 ZEUS

ZEUS will continue to take data until mid-2007, by which time an estimated integrated luminosity of 750 pb^{-1} will have been accumulated. PETRA, the injector for HERA, will be rebuilt as a third-generation light-source, putting an end to the ZEUS programme.

The Canadian group has been involved in the HERA and ZEUS projects from the outset. The early approval of Canadian funding for the accelerator construction was a strong catalyst for the approval process in Germany. The group was responsible for the construction of significant parts of the ZEUS detector and trigger systems, including upgrades for HERA-II. They have filled numerous roles within the collaboration including Deputy Spokesperson, Physics Coordinator, conveners of the Diffractive, Deep Inelastic Scattering and Soft Photo-production physics groups, Polarization Coordinator and Run Coordinator (four times). The group has worked on most aspects of HERA physics, and initiated a program of forward neutron physics.

Analysis of ZEUS data is expected to continue for at least 3-4 years after mid-2007. Many physics topics of interest (Standard Model tests, Beyond the Standard Model searches, measurement of the *c* and *b* content of the proton, measurement of the light quark SM couplings, improvements in the determination of α_s) will require the full statistical power of the data set from HERA-II, comprising both positron and electron data, each with left and right-handed polarization. Canadian participation is likely to wind down by 2009/10. The final effort will be finishing papers and theses with a small number of PhD students.

3.2 Continuing Projects

3.2.1 ATLAS

The discovery potential and physics breadth of the LHC has engaged the subatomic physics community for the last 15 years. The physics programme includes direct searches for the Standard Model Higgs boson, Supersymmetry, and many exotic theories, including those predicting the existence of extra spatial dimensions, production of mini-blackholes, etc.. Also, the high production rates for Standard Model particles such as top quarks, for example, will permit studies of their properties to unparalleled precision, and Standard Model processes (*eg.* in QCD) will be tested at new energy scales. ATLAS will begin collecting data in 2007, and the production and analysis of those data will occupy a significant fraction of the particle physics community in Canada (and the world) through the following decade. It is not an exaggeration to state that ATLAS has the potential to revolutionize our understanding of fundamental particles and interactions over that period.

The Canadian ATLAS group has successfully completed construction of the hadronic endcap calorimeters, the forward calorimeter and the endcap cryogenic feed-throughs, as well as components for the radiation-hard front-end electronics. In the period 2005-2008, the group's main activities will be aimed at the commissioning and calibration of the calorimeters, and their use in the first physics studies. Members of ATLAS-Canada are already filling high-profile roles in detector commissioning, which is the most important physics activity for ATLAS over the next 3 years. The group is also ramping up their activity on the High Level Trigger system, and is commissioning the beam monitor system. At home, they will also be busy commissioning the Tier-I computing centre at TRIUMF, and Tier-II centres in western and central Canada. These activities are all vital to the tasks of ATLAS data-taking, understanding of the the experimental environment, and for the eventual extraction of world-class physics results.

In the period 2008-2012, the group's main activity will be participation in the running of the experiment and analysis of the data. The analysis interests of the Canadian group are expected to be diverse, as has been the case in past experiments such as OPAL, ZEUS, CDF and BaBar. Certainly Higgs searches and direct searches for physics beyond the Standard Model (eg. Supersymmetry) will be part of this programme.

ATLAS has already played a significant role in training of highly qualified personnel in Canada. As commissioning work begins, and startup of the LHC draws nearer, the number of students trained at ATLAS is expected to continue to increase. The number of grant-eligible FTE's working on the experiment is expected to rise from approximately 22 to about 30 once data-taking begins.

The IPP strongly supports ATLAS as one of the highest priority projects in Canada. Sufficient operating funds should be allocated to allow the proponents to benefit from the years of construction and commissioning effort by, for example, keeping a complement of people at CERN. This operating model has worked well for Canada in the past. We have traditionally maintained a significant presence at the facilities hosting projects with a large Canadian contribution. This has allowed us to participate fully in data-taking and maintenance of the experiment, as well as to fill important roles in the experiment. In large part, this reliable presence is responsible for Canada's well-earned international reputation in experimental particle physics.

3.2.2 T2K

The T2K (Tokai to Kamioka) experiment, is a neutrino superbeam project currently under construction in Japan and scheduled to begin data-taking in April 2009. A neutrino beam produced by a newly built MW-class machine, J-PARC, will be sent to the Super-K detector, located 2-3 degrees off-axis in order to create a narrow-band beam. The initial goals of T2K are precision measurements of the neutrino mixing parameters θ_{23} and Δm^2_{23} via ν_μ disappearance, and discovery of $\nu_\mu \rightarrow \nu_e$ appearance, which provides a measure of θ_{13}.

Canadians have been involved in T2K since its inception, and have introduced many of the defining aspects of the project. In particular, the use of an off-axis detector to take advantage of a narrow-band beam originated with Canadian researchers. On T2K, Canada has been provisionally assigned responsibility for construction of components of the near detector tracker, namely the ”Fine Grained Detectors” and the Time Projection Chambers, as well as for the beam-profile monitor immediately in front of the target. All of these elements are required in time for beam commissioning in 2009. The construction timescale is rather short. It is therefore essential for the group to receive capital funding in the 2006 competition, in order to meet the schedule for first beam in 2009.

In addition to the NSERC supported activities, TRIUMF accelerator scientists have many important contributions to make, in particular to the target station, remote handling, and the beam damping system of the main accelerator ring. Participation in T2K will allow Canadian scientists to continue to play an important role in uncovering the mysteries of neutrino oscillations in the next ten years, a field that Canadian scientists have been instrumental in establishing.

In the second phase of the project, after a measurement of θ_{13}, T2K will investigate CP-violation in the neutrino sector through a comparison of $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance rates. A factor of 200 improvement in sensitivity is expected using an upgraded 4MW JPARC and a new 1-Mton Hyper-K detector at Kamioka site. The Hyper-K detector will also provide other opportunities in neutrino and particle astrophysics: the large volume will allow an access to the matter induced resonant $\nu_\mu \rightarrow \nu_e$ oscillation in atmospheric ν_μ, predicted at neutrino energies of several GeV, and provides a way to determine the neutrino mass hierarchy. Proton decay can be explored up to lifetimes of 10^{35} years, a level predicted by many grand-unified theories. Super-K provides a stringent indirect limit on WIMP dark matter searches, through WIMP annihilation into two neutrinos in the earth, sun, and the galactic center. Hyper-K will extend this further, and also increase our ability to detect supernova relic neutrinos, extending the sensitivity to the supernova detection beyond our galaxy.

The Canadian T2K group is expected to grow significantly over the next few years, with projections of 9, 10, and 12 grant-eligible FTE's (19 grant applicants) in FY2006, FY2007, and FY2008. This project provides an excellent opportunity for students and post-docs to participate in the design, construction and commissioning of detectors utilizing emerging and popular technologies, and use of these detectors to perform physics analysis. The profile for graduate student involvement in the coming years is currently 5 in FY2005 rising to 8 in FY2006.

The T2K project offers the opportunity for Canadian physicists to lead important aspects of one of the most important neutrino experiments planned for the period covered by the long range plan. The IPP strongly supports the T2K project, in particular recommending sufficient and timely funding for the T2K detector construction.

3.2.3 VERITAS

VERITAS is a very high energy (VHE) gamma-ray astronomy project using the newest generation of imaging Čerenkov telescopes. The project is currently partway through its construction phase; the first of four telescopes is already in operation at Mount Hopkins in Arizona, and the second is under construction. Site clearing and preparation for the proposed Kitt Peak (Arizona) site has begun and operation of the four telescope array at Kitt Peak is expected by late 2006. Complications with the use of Kitt Peak that emerged earlier this year are being dealt with; an environmental assessment will be completed soon, and the NSF and the Tohono O'odham Nation are negotiating the conditions under which access to the site will be granted.

A proposed VERITAS upgrade involves construction of three additional telescopes. This is expected to take place within about a four-year time frame, with operation likely to continue through 2015. The primary goal of the project is to study cosmic-ray acceleration mechanisms, but it will also explore the extra-galactic infra-red background through VHE gamma-ray absorption, search for cold dark matter through WIMP annihilation in galactic centers, and test Lorentz invariance at extremely high energy scales.

VERITAS has been approved as an IPP project and will be the only next generation VHE gamma-ray project supported in Canada. The Canadian VERITAS group is expected to grow to two full-time faculty members, two post-docs, and four to five students, in a collaboration with total size of about 75. Canadian contributions to the project include the laser calibration system, mirror mounts, trigger electronics, and DAQ software. Participation in the proposed VERITAS upgrade would imply additional contributions.

World-wide there are four new VHE gamma-ray projects. VERITAS is unique because of its powerful four-telescope system located in the northern hemisphere, which will complement HESS which is sited in the southern hemisphere. A modest Canadian contribution can have a major impact on this relatively small-scale project. It provides excellent opportunities for students and post-docs. From the group's experience with STACEE, they are expected to have no problem in attracting students. The IPP supports this unique opportunity for the Canadian SAP physics community.

3.2.4 PICASSO

PICASSO (Project in Canada to Search for Supersymmetric Objects), a Canadian conceived and led initiative with international collaboration, is a dark matter search experiment with spin-dependent sensitivity to nuclear recoils from WIMP-nucleus interactions. The detector volume consists of a gel in which are embedded superheated halocarbon liquid droplets, 5 to 100 μm in diameter. Rapid evaporation of a superheated droplet due to heat from WIMP-induced nuclear recoil creates a sound shock wave that is detected by a sensitive piezoelectric microphone. The technique functions at ambient temperatures and pressures, is relatively insensitive to backgrounds from β, γ, and cosmic μ radiation, and can reach energy thresholds as low as $5-10$ keV.

The PICASSO scientific programme is the most mature of those with a proposed siting at SNOLab, with first physics results already published from an initial proof-of-principle phase in which three 1 L detectors (20 g active mass) were located near the D_2O tank in the existing SNO site. A second part to this initial phase is currently underway, with 32 detectors of 4.5 L (2 kg active mass), to conduct R&D targeted at increasing the droplet diameter and refining the detector fabrication process, for scaling to larger masses. This phase is planned to end in summer 2006, to be followed by a second phase, consisting of a detector with 3 kg and then 25 kg of active mass by 2008. The key development at this stage will be the improvement of purification techniques to bring the internal background rates to below 10 events/kg/d. With six months of data-taking, this second phase is expected to have a cross-section reach down to 10^{-3} pb. The third phase is planned to begin in summer 2008 and will consist of 256 detectors of 30 L for a 100 kg active mass; after 12 months of running, a sensitivity near 10^{-4} pb is expected, thereby probing the core of MSSM cross-section predictions.

The Canadian PICASSO effort is based upon 3 grant-eligible FTE, which is projected to increase to 5 FTE by 2009. This includes leadership of the collaboration, physics analysis, detector fabrication, purification, electronics, DAQ, calibration, and simulation. PICASSO has demonstrated first physics results in its proof-of-principle phase. The IPP supports continued funding for PICASSO for the next phase of the project.

3.3 New Initiatives at the Energy Frontier

3.3.1 International Linear Collider (ILC)

The ILC is the next electron-positron collider planned at the high-energy frontier. The ILC physics programme shares many of the broad themes with the LHC, but given the very different capabilities of the two machines and their detectors, rapid progress in the field is likely to require data from both colliders.

International consensus has been reached at many levels that the ILC should be the next large facility for high-energy physics. In 2004 more than 2700 particle physicists signed a document supporting the physics case of the Linear Collider. The regional and international committees for future accelerators have indicated the ILC to be the highest priority new facility. In the US, the DOE has designated the ILC as the first priority mid-term new facility for all of the Office of Science.

Canada has already been involved with the ILC for several years, both in detector and accelerator R&D and in building the physics case for the machine. Currently, the group consists of 10 experimentalists working on detectors (the TPC Tracker and the Calorimeter), several theorists and 2 accelerator experts. This involvement is expected to grow as other projects wind down and ILC construction approaches. We can imagine 20+ grant eligible FTE in Canada working on ILC at some stage during this planning period. At that level, we can certainly envision Canada taking on significant responsibility for detector construction.

The ILC will be a highly visible, world class laboratory, which will attract the brightest minds from around the world. This is an excellent environment for the training of graduate students and postdoctoral researchers. Already, students are involved with the R&D stage of the project. This involvement is expected to increase significantly in coming years.

The IPP recommends that ILC R&D continue to be strongly supported. It is likely that ILC will remain an R&D project until after LHC data-analysis has yielded first results. If those results make a compelling physics case for the ILC, Canada should become a full partner in the project from the outset.

3.3.2 ATLAS Upgrades

CERN is currently considering upgrading the LHC through an increase in luminosity. This upgrade could be planned to coincide with natural replacement timescales for some components of the LHC due to radiation damage, currently expected sometime between 2012-2014. An increase of about one order of magnitude in integrated luminosity would extend the LHC discovery reach by about 20-30% in terms of the mass of new objects, and allow additional and more precise measurements to be performed in statistically limited channels. In order to prepare for a possible upgrade, ATLAS has begun to investigate the changes to the sub-detectors that would be necessary in order to maintain physics performance at higher luminosities.

The potential Canadian role in an ATLAS upgrade is undefined at this stage. Detailed studies are needed to determine the exact nature of the upgrade. Current Canadian expertise in radiation-hard electronics, trigger systems and effects on the performance of the LAr calorimetry (eg. radiation damage, pile-up) may naturally be very useful in these studies. ATLAS-Canada foresees taking part in upgrade studies in the 2008-2012 time period.

The IPP supports the continued R&D for ATLAS upgrades. Should discoveries at the LHC lead to a compelling physics case, an ATLAS upgrade project could become a high priority during the latter years of this planning period.

3.4 New Initiatives in Underground Physics

Building on the success of SNO, a new CFI-funded international facility for underground science, SNOLab, is currently undergoing construction at the SNO site on the 6800 ft level of the INCO Creighton Mine, providing 6 km of water-equivalent overburden shielding. The aims of SNOLab are to probe fundamental areas of physics, including low-energy solar neutrinos, searches for neutrinoless double β-decay, searches for dark matter, and neutrino detection from supernova explosions. Excavation for the new SNOLab facility is currently in progress and expected to continue through to the end of 2006. A surface building has been constructed, and outfitting of the underground areas is expected to be complete and ready for experiments in 2007. To date, SNOLab has received funding from the CFI International Facilities Fund and the Ontario government.

In the following, we give brief descriptions of those SNOLab projects with Canadian leadership and participation. The SNOLab proponents are in the processes of working with international reviewers to optimize the physics programme that can be carried out at this facility. IPP Council felt it was not in a position to second-guess this process in our submission to the LRP. For that reason, we do not make project specific recommendations. However, we strongly support continued R&D to select experiments with compelling physics returns to be sited at this unique facility.

3.4.1 DEAP

The search for cosmological dark matter in the form of weakly interacting massive particles (WIMPs) is currently an area of intense activity worldwide. Guided by supersymmetry models, which independently predict the existence of a new stable WIMP, there are theoretically well-motivated reasons to expect WIMP detection with sensitive target masses on the order of 100 kg to 1000 kg, corresponding to WIMP-nucleon coupling cross sections of 10^{-45} to 10^{-46} cm^2. A WIMP can be detected by its elastic scattering with a target nucleus, by measuring the kinetic energy of the recoiling nucleus. Plans have recently begun for DEAP (Dark Matter Experiment with Argon PSD), a Canadian-led project that uses pulse shape discrimination (PSD) to distinguish between the different arrival times of scintillation light from photons due to background electrons and those due to signal nuclear recoils induced by spin-independent WIMP-nucleon couplings. The use of liquid argon is motivated by cost, scalability to large volumes, light yield, and complementarity to heavier-mass target searches. A 1 kg prototype has been built at LANL, and a small new Canadian group is currently building a CFI-funded 10 kg version, DEAP-1, with a view to seeking early SNOLab space in mounting a sensitive search experiment in late 2006. The group plans to scale up the detector to a 1000 kg mass, at a capital cost of $2M, for data-taking beginning in 2010.

3.4.2 EXO

Complementary to the recent discoveries of neutrino flavour oscillations is the aim of determining whether neutrinos are Majorana particles, *i.e.*, whether they are their own antiparticles. Searches for neutrinoless double β-decay processes, $(A,Z) \rightarrow (A,Z+2) + e^- + e^-$, are the only known techniques to probe the Majorana aspect of neutrinos. Moreover, since the matrix element for the $0\nu\beta\beta$ process depends on m_ν, this is also the most promising method for determination of the absolute neutrino mass scale. The two principal experimental approaches are to identify the $(A,Z+2)$ final state radiochemically after the material (A,Z) has been stored in a mine and to detect ionization or scintillation processes in the decay in real time.

The enriched xenon observatory (EXO) for double β-decay, currently in the design and prototyping stage, combines these two techniques, using xenon which has many properties that make it appropriate to large fiducial masses between 1 and 10 tons. The final state in the process $^{136}Xe \rightarrow ^{136}Ba^{++} + e^- + e^-$ can also be tagged using optical spectroscopy, providing significant rejection of backgrounds. The seven-faculty Canadian component of the EXO collaboration is investigating the option of using a Xe gas-phase counter approach that would permit decay-vertex identification using tracking techniques and would have improved gamma background rejection. The aim is to develop the concept through energy-resolution, tagging, and vessel-design studies by 2006, with a proof of principle demonstration in 2007 using a 30 cm test chamber. Physics results from a 200 kg prototype of the gas option are planned to be available in $\sim$2009 to coincide with the results of parallel liquid xenon tests conducted by other EXO collaborators. EXO, which promises to be the world's largest double β-decay detector, is projected to have Majorana mass sensitivities of better than 400, 70, and 15 meV for detector masses of 200 kg, 1 ton, and 10 ton, respectively.

3.4.3 Majorana

A complementary approach to the search for neutrinoless double β-decay is the proposed Majorana experiment, the apparatus for which consists of an array of Ge detectors enriched to 86% in ^{76}Ge and contained in a Cu vacuum cryostat. The use of high-purity and enriched Ge as both a source and detector is well proven to provide good energy resolution and low backgrounds, using demonstrated technologies, for separation of the the $2\nu\beta\beta$ and $0\nu\beta\beta$ processes. The intrinsic granularity of the source/detector design permits the veto of Compton-scatter background events for which energy is deposited in multiple fiducial volumes; double β-decay events, in contrast, have their energy deposited at single sites in the detector. This granularity also lends itself well to scaling of the project to higher masses through several phases, beginning with a 180 kg detector built from three staged 60 kg modules.

The Majorana project is currently in an R&D phase through 2007. Construction, Ge enrichment, and staged commissioning of the three 60 kg modules is planned to occur between 2008 and 2012 (with first data in 2010), followed by a 180 kg operating phase up to 2015. The 180 kg phase is projected to have sensitivity down to Majorana masses of 120 meV (degenerate hierarchy); subsequent phases with 500 kg and 1000+ kg, which would require different technologies, are also being planned. A 500 kg detector running for $\sim$10 years is expected to detect Majorana masses as low as 50 meV, with sensitivity to an inverted-hierarchy scenario.

Canadian participation in Majorana currently consists of two faculty members and one SNOLab scientist, and is expected to increase with SNOLab hosting the experiment. The Canadian contribution will provide the on-site infrastructure, including the critical underground electroforming facility and the ancillary analytical requirements for verification of radio-purity. Canadians will also contribute in the calibration, the understanding and reduction of backgrounds, data extraction and physics analysis.

3.4.4 SNO+

The concept of SNO+ is to reuse the SNO acrylic vessel with liquid organic scintillator in lieu of a D_2O-based detector volume, potentially providing new avenues into several different areas of neutrino physics. In particular, the use of liquid scintillator can render the detector sensitive to low-energy ($\sim$1 MeV) neutrinos, which will help to complete understanding of neutrinos from Earth's sun and probe the neutrino-matter interaction, a regime that is sensitive to new physics effects such as non-standard couplings, varying-mass neutrinos, sterile neutrino admixtures, and CPT violation. Improved determination of neutrino oscillation parameters, in particular θ_{12}, are also envisaged, as is a demonstration of the MSW effect (matter-enhanced neutrino oscillations).

SNO+ might also be used as a transducer, to measure the flux of antineutrinos produced by Earth's natural radioactivity, thereby helping to inform geophysical models by determining the radiogenic component of Earth's total heat flow. The large ($\sim$1 kton) quantity of scintillator would also be capable of detecting supernova neutrinos, and the addition of $\beta\beta$ isotopes to the liquid scintillator (SNO++) is envisaged to enable competitive searches for neutrinoless double β-decay. Although liquid scintillator has poorer energy resolution than dedicated $0\nu\beta\beta$ experiments, in SNO+ this would be somewhat compensated by high statistics and low backgrounds; a sensitivity to Majorana masses below 100 meV is estimated.

The Canadian-led SNO+ project currently has the involvement of six Canadian faculty and is recruiting collaborators in the U.S. and Europe. Proof-of-principle efforts have focused on preliminary engineering considerations in the mechanical support of the SNO acrylic vessel and liquid organic scintillator design. Purification R&D will continue through the end of 2006, when proposals will be submitted for capital funding to begin during 2007, when the heavy water from SNO will be removed.

3.5 New Initiatives at the Precision Frontier

Some of the most important breakthroughs in particle physics have been made by experiments pushing the "sensitivity envelope" rather than probing the high-energy frontier. These include low and medium-energy experiments searching for processes which are extremely rare in, or forbidden by, current theories, but which could have relatively large contributions from new physics. Past examples include the discovery of neutral currents 30 years ago, which was the first experimental verification of the Z^0 boson predicted by the then-infant Standard Model. Other experiments probe symmetries in nature looking for deviations that might be due to new physics. The breakthrough measurement of CP-violation in the neutral kaon system 40 years ago was the first experimental hint of the third generation of particles, and completely changed our view of matter and anti-matter. A more recent example is provided by the indirect constraints on the mass of the top quark, provided by precision electroweak measurements at LEP. These early results, from the first few years of LEP running, pointed the way to the eventual discovery of the top quark at the Tevatron.

3.5.1 GlueX: the Search for Exotic gluon and quark states

A number of QCD-based model calculations, as well as numerical QCD calculations, agree on the range of masses of exotic bound states with purely gluon content, or with valence gluons and quarks. The GlueX experiment is optimized for their detection. GlueX will use a clean photon beam impinging on a liquid hydrogen target. Because the $p\gamma$ initial state is simple and well understood, the experimental results can be cleanly interpreted and the existence of exotic states verified. GLUEX will use a combination of large detectors and a strong magnetic field to detect all of the particles produced, contain their total energy, and reconstruct their properties. The results will be compared with theoretical models of confinement, and test predictions of QCD.

The experiment will take place at the upgraded Thomas Jefferson National Accelerator Facility in Newport News, Virginia. There are 29 institutions in GlueX and approximately 100 physicists from the U.S.A., Canada, Mexico and Europe, including the universities of Regina and Alberta. Presently, the multi-year and extensive detector R&D effort is being completed. Early construction is expected to start in 2007 with the experiment to begin operation by 2011.

The GlueX experiment has not yet been approved by the U.S. department of energy, but has received favourable reviews. If approved in 2007, it will receive the bulk of its funding from U.S. sources. The physics is interesting, and a critical mass of people exists in Canada to take a leading role in the experiment. We support the continued involvement of the Canadian group in GlueX as we monitor the approval process in the U.S.

3.5.2 Charged-current universality in $\pi^+ \to \ell^+ \nu_\ell$

The best test of charged current universality comes from the charged pion decay ratio

$$R_{e/\mu} = \frac{\Gamma(\pi \to e\nu + \pi \to e\nu\gamma)}{\Gamma(\pi \to \mu\nu + \pi \to \mu\nu\gamma)}$$

which has been measured to a precision of 0.3%, while the Standard Model calculation is an order of magnitude more precise. Deviations from the Standard Model could indicate the presence of non-universal gauge interactions or additional scalar or pseudo-scalar interactions.

Past measurements of $R_{e/\mu}$ at TRIUMF and PSI were limited by both statistical and systematic uncertainties. Members of the TRIUMF experiment (E248) are proposing a new experiment to improve the sensitivity. A new experiment at TRIUMF is proposed to improve the precision of $R_{e/\mu}$ by a factor of five, providing access to new physics at mass scales in the 1000 TeV range. The experiment would use an existing TRIUMF beam-line, and many detector elements and readout electronics which already exist. The principal detector elements are scintillating crystals for measurement of the positron spectrum. The TRIUMF 46 cm diameter $\times$ 51 cm long sodium iodide (NaI(Tl)) crystal “TINA” will be used, along with NaI(Tl) crystals currently used in the “crystal box” detector at the Brookhaven National Laboratory (BNL). Alternatively, pure CsI crystals from BNL are also available. All detectors will be read out by high-speed wave-form-digitizers built for the rare-kaon-decay experimental program.

A new group has formed to perform the $R_{e/\mu}$ measurement at TRIUMF, with participation from UBC, TRIUMF, Carleton University, Arizona State University, BNL and Osaka University. Since the major equipment for this project already exists, the capital outlay would be minimal. With the relatively small cost and interesting physics, the IPP supports this project.

3.5.3 Anti-hydrogen with the ALPHA experiment

The ALPHA experiment at the CERN anti-proton decelerator, AD, seeks to produce, trap and measure the properties of anti-hydrogen atoms. These measurements, principally of the atomic spectra of anti-hydrogen, could eventually provide direct charge-parity-time (CPT) reversal tests which are complementary to those performed in other systems. Anti-hydrogen atoms were experimentally produced at CERN in 1996 and Fermilab in 1998; however, those relativistic anti-hydrogen atoms annihilated almost immediately and were not suitable for precision studies. Cold anti-hydrogen atoms have recently been produced by the ATHENA and ATRAP collaborations at CERN. However, these experiments did not actually trap the cold anti-hydrogen, a necessary step in performing precision symmetry tests. The cold anti-hydrogen atoms in ATHENA and ATRAP were produced by mixing anti-protons and positrons in a nested Penning trap. The first ALPHA milestone will be to reproduce these results, but with an entirely new ALPHA apparatus; 5 MeV anti-protons from the AD are slowed in a degrader to a few keV, and trapped in the catching trap, where, via collisions with cold electrons, anti-protons are cooled and then trapped.

ALPHA is an interdisciplinary collaboration with members from subatomic physics, atomic physics, and other disciplines. The Canadian ALPHA group consists of researchers from TRIUMF, Calgary, Manitoba, Université de Montréal, Simon Fraser, York and UBC, about 15 physicists in all, totaling about 4 FTE, and including members of both the ATHENA and ATRAP collaborations. The group is particularly strong in detector and readout system development, and in software, allowing them to play a dominant role in many important aspects of the experiment.

ALPHA is a interesting R&D project and as with other such projects IPP is supportive as long as the cost is commensurate with the potential particle physics benefits. However, it is not clear that the physics case for ALPHA currently meets this standard.

3.5.4 High Luminosity "Super B-factory"

The physics motivation for a Super B-factory is to extend the new physics sensitivity of the heavy flavour sector to the point at which many key CP and rare decay measurements become limited only by "irreducible" theoretical uncertainties rather than by experimental statistical uncertainties. When the nominal BaBar and Belle experimental programmes finish near the end of 2008, the world $B\overline{B}$ sample will total approximately 2×10^9 events, or 2 ab^{-1}. Individual Super-B proposals aim to ultimately acquire a data sample corresponding to 40 - 100 ab^{-1}, an increase of about two orders of magnitude. Proposals from SLAC and KEK both assume a cessation of current operations around 2008, for Super-B construction and installation, with targeted startup dates between 2011-2012. Studies have indicated that a single Super B-factory operating on this timeline would be both competitive with and complementary to LHCb, and could potentially serve to elucidate any new physics discoveries made at the LHC. In particular, while LHC experiments may provide first evidence of SUSY via observation of non-SM particles, the pattern of deviations from SM predictions in the heavy-flavour sector may be required in order to understand the SUSY-breaking mechanism.

At the present moment, both the SLAC management and the DOE disfavour a SLAC-based Super B-factory, so it seems likely that Super B will be sited at KEK if it is built at all. To date, associated R&D activities have mainly occurred within the context of the existing BaBar and Belle collaborations, so there is not yet a clearly defined "Super-B Collaboration". There has not yet been a strong expression of interest from Canadian physicists to join this effort. However given the fact that BaBar and Belle are currently in the prime of their experimental programmes and that LHC startup is only a few years away, it is currently too early to assess the likely level of Canadian interest in a Super B-factory.

The prospects of Super-B, and any possible Canadian involvement, are sufficiently unclear at this time that it is impossible to make any firm recommendations. Should the project be approved and a Canadian group form, the IPP could imagine support for Canadian involvements in a Super B-factory sometime late in the current planning period.

3.5.5 MUSIC: Muon Science Innovation Collaboration

Precise measurements of the properties of muons provide many constraints on new physics models, and muons have also been used as important probes for the study of material and nuclear properties. Such measurements depend on controlled, high-intensity muon production sources. The proposed MUSIC muon source at TRIUMF would provide the world's highest intensity beam of muons.

The initial particle physics experiment to make use of the MUSIC muon source is proposed to be MEC, a search for Muon-Electron Conversion via the process $\mu + \text{Nucleus} \rightarrow \text{e} + \text{Nucleus}$. MEC would have a sensitivity 10^4 times greater than any previous experiment. Muon-electron conversion at MEC would provide direct evidence for lepton-flavour violation which is not associated with neutrino mixing. Experimental upper limits on muon-electron conversion and the related process $\mu \rightarrow \text{e}\gamma$ already provide some of the most stringent constraints on physics beyond the Standard Model, such as supersymmetric models, and the new MEC project would increase the reach to the many thousands of TeV scale.

The potential impact of MEC is comparable to that of other leading, planned exploratory high precision experiments. If the muon source were to be made available from other resources, and a Canadian community were to develop, IPP could imagine support for the MEC project towards the end of the planning period.

3.6 New Initiatives in Neutrino and Particle Astrophysics

3.6.1 FLARE

FLARE is a long-baseline superbeam proposal to build a 15-50 kton liquid argon detector in Canada, for a neutrino beam from Fermilab (NuMI). The physics goals are similar to those of T2K, namely the measurement of θ_{13} through $\nu_\mu \rightarrow \nu_e$ appearance, and eventual study of CP violation. The higher energy NuMI neutrino beam requires a longer baseline in order to be at the probability maximum. This results in a larger matter effect (20% instead of 10% for T2K), making the two experiments complementary as this could allow the degeneracy in neutrino oscillation parameters to be resolved. A combined result from FLARE and T2K would also aid in the separation of θ_{13} and CP-violating phase effects.

Like T2K, FLARE uses a detector sited off-axis, to make use of a narrow band beam. One proposed far detector site, providing the required baseline, is in Northern Ontario. The liquid argon TPC technology in FLARE is an extension of the proven ICARUS 300 ton detector technology to a 15-50 kton industrial cryogenic storage tank. Very detailed tracking information allows effective suppression of neutral current π^0 background, which is one of the two main backgrounds in ν_e appearance searches.

There are two proposed NuMI off-axis beam projects; NOνA, which uses liquid scintillator, and FLARE. NOνA received stage-I approval from the Fermilab PAC earlier this year. FLARE is considered as a potential extension of NOνA. Since the Canadian site is being considered, there is a potential for a large Canadian impact. Currently, there is one committed faculty member in Canada with some interest expressed by others. Grant requests to the NSERC Special Research Opportunity Programme and to CFI are being considered. The total cost of the project is estimated to be around US$100M.

The liquid argon TPC may turn out to be a critical technology for second generation long baseline neutrino oscillation experiments, depending on the size of θ_{13} and the background processes. Based on the results of T2K and NOνA, a compelling case could emerge for FLARE's liquid argon technology sometime towards the end of the planning period. However, given the Canadian involvement in T2K, it is not clear that the IPP could support Canadian participation in FLARE unless the Canadian neutrino community were to identify this as the highest priority next-generation neutrino project.

3.6.2 POLARBEAR

POLARBEAR is a next generation ground based Cosmic Microwave Background experiment to search for the signature of inflationary gravity waves imprinted on the CMB as a curl-component polarization. The detector is being constructed at White Mountain in California. In addition to probing inflation, POLARBEAR will address other particle physics issues; for instance, a polarization map of 10% of the sky with POLARBEAR-II would yield an uncertainty of 0.2 eV on the sum of the neutrino masses. An eventual all-sky satellite measurement could reduce this to as low as 0.03 eV.

International particle physics and cosmology communities have been unanimous in their prioritization of CMB polarization as a probe for accessing inflation-scale physics. Sensitive ground based and balloon experiments with different technologies are the next step in an experimental programme that will eventually lead to satellite experiments. POLARBEAR is one of the leading next generation experiments exploring deep into the parameter space for inflationary gravity waves. It uses new “radiometer on chip” technology, and a multiplexed readout system. SAGENAP recommended POLARBEAR as “a novel and highly promising technique” and “a project that merits funding” in its report in December 2004.

POLARBEAR is a collaboration of Canadian (McGill), US, and UK institutions, comprising about 10 grant eligible faculty members or 5 FTE in total. One Canadian faculty member has committed the majority of his research time to the construction of the first stage. With a postdoc and student(s), there is sufficient critical mass to have an impact on the first stage. CFI is supporting the construction of a cosmology instrumentation laboratory at McGill University, where the readout electronics will be designed, tested, and integrated. For the first stage of POLARBEAR (2006/7), the proposed Canadian contribution is the $210K multiplexed readout electronics. A multiplexed system is essential as the cryo-coolers cannot sustain the heat load from the large number of wires which would have to traverse the heat gap between warm readout electronics and sub-Kelvin sensors. The second stage of the experiment (2008/9) will deploy a factor of 3 more sensors (an additional $450K).

CMB polarization is one of the highest priority projects in observational cosmology. POLARBEAR is a well recognized ground based project, already under construction. As is the case for gamma-ray astronomy, technology and methods developed in particle physics have a great impact on this field. There is significant interest among the Canadian community, and we hope that the project will attract more members and establish itself in the IPP community. Under such circumstances, we could imagine support for this new initiative.

4 The Role of Theory

Theoretical high energy physics has a long and distinguished tradition in Canada, and like experiment work, has a history that goes back to the founding of the field itself. A vibrant theory community is a prerequisite for any healthy research programme in particle physics. Canada’s theorists have an excellent track record both for producing cutting-edge research and for training students, many of whom have gone on to prominent positions around the world. Theorists make up just under half of the particle physicists in Canada, and the majority of these are IPP members, despite most of IPP’s spending being on experimental projects. Through this membership theorists endorse IPP’s claim to represent the broad interests of the entire particle physics community.

4.1 Overview of Current Activity

An overall summary of theoretical activity is difficult to give in the same way as has been done for experiments because theory is not organized in terms of projects in the same way as is the experimental effort. Activity in theoretical high-energy physics at present broadly breaks up into four areas of focus: String theory; Phenomenology; what for lack of a better name might be called “Beyond the Standard Model” (BSM) physics; and “Field Theory” or “None of the Above”. The first three of these areas have as their goal the discovery of the theory which will replace the Standard Model at the energies above which the Standard Model is expected to fail.

Phenomenology takes a 'bottom up' approach which is addressed to the direct interpretation and modeling of what is seen or can be expected to be seen in existing experiments, or in those which are to commence in the reasonably near future. The defining character of this research is that its scope is largely driven by what is possible for these experiments to find.

String theory lies at the opposite extreme, taking a 'top down' approach which is based on the discovery in the mid-1980's that quantum mechanics and gravity can only be reconciled on the highest energy scales within a very restrictive theoretical framework (for which our best candidate is string theory). Unfortunately the restrictions are strongest at very high energies, which are likely to be (but need not be) much beyond the reach of experiments for the foreseeable future. The hope is that the high-energy restrictiveness can partially compensate for the difficulty of finding decisive experimental tests at the energies to which we have access.

"Beyond the Standard Model" physics provides a bridge between the previous two categories. On one hand, like phenomenologists, the goal of theorists here is to address the known theoretical problems with the Standard Model. On the other hand, important information as to how this is done may come from string theory (or any other proposals for physics at very high energies). Since most of the details of physics at very high energies are irrelevant to experiments, the BSM theorist's focus is on identifying the new low-energy features of putative theories at high energies (like string theory) to see which ones can help with low-energy Standard Model problems.

The fourth category is a catch-all to describe areas of research that are often driven by intrinsically theoretical or mathematical ideas. These explore the properties of classical and quantum field theories for their own sake, and their value to the subatomic physics research programme lies in the ubiquitous use to which such theories find applications in describing nature.

4.2 Demographics:

The Canadian high energy theory community is thriving, and continues to bring new members to IPP. At present there are 73 professors in particle theory working across Canada, and all but a handful of these are members of IPP. This makes up about 46% of the IPP membership. Of these 73 professors, almost a third are newcomers to the Canadian particle physics community since 2000, demonstrating that Canadian universities continue to actively invest in this area.

One of the great strengths of the theoretical programme is its success in attracting students into the field. Although this is more difficult to document than for experimental collaborations, it can be quantified for those universities which list their students and postdocs according to their fields of research. For example, the 4 theorists presently at McGill presently supervise 4 pdfs and 13 graduate students.

4.3 Funding Requirements:

Theoretical research is not organized in terms of projects in the same way as is the experimental effort, and the present funding system reflects this fact. The main research expenses incurred by theorists are salaries, computers, and costs related to travel and the organization of meetings, workshops and schools. In Canada, individual theorists are largely funded by Discovery Grants which they can spend exclusively on their own research or which they can choose to pool with other researchers for common expenses. The flexibility of this system fits very well with the nature of theoretical research.

Salaries are usually the largest expense, affecting a researcher's ability to employ both postdocs and graduate students. Theory grants are typically small enough that they can be consumed by the salary of a single postdoc or of a few graduate students (even though theory students draw a relatively large proportion of outside fellowships). This has recently been a problem because competition with American universities for postdocs (and to some extent students) has driven competitive salaries beyond the reach of many. To combat this loss of competitive edge GSC-19 has raised the level of theory grants from 12% to 14% of the envelope over the last few years, raising the median theory grant to around $40K.

The IPP has recently launched an initiative designed to provide direct support for theoretical postdoctoral researchers in Canada, in the form of fellowships providing $20k of matching funds to complement researchers resources, to allow them to offer more competitive salaries for postdoctoral researchers. With the the help of the Perimeter Institute, a pilot programme funding two such positions was recently launched. It is hoped that the current subatomic physics envelope could eventually support six of these fellowships, and one could imagine expanding further if the NSERC budget were to grow, and with it the resources available to the IPP.

Travel expenses cover the costs incurred by researchers, postdocs and students to attend workshops and conferences, and are also largely covered by Discovery Grant funds. Unfortunately, finding funds for the organizational costs of meetings, schools and workshops became more difficult when NSERC stopped supporting these activities. The slack has been taken up partly by IPP, which uses a small part of its grant to support international meetings held in Canada, and partly by the various kinds of Institutes which have sprung up around the country — e.g. Perimeter Institute, Pacific Institute for Theoretical Physics (PITP), Canadian Institute for Theoretical Astrophysics (CITA) etc. — partly to fill this need.

The importance of computer expenses depends on the nature of work being done. Besides the initial cost of purchasing the machines, there are usually additional expenses in the form of contributions to the salary of the person hired to maintain the system. Depending on the department this cost can also represent a sizable fraction of a typical theory grant, comparable to the cost of a graduate student. Unfortunately, GSC-19 usually does not fund these costs and neither do universities. Since theorists do not have large project grants on which to draw, these costs also come from the limited funds in their Discovery Grants.

5 Computing Resources for Subatomic Physics

The use of computers for data analysis, simulation of experiments, and sophisticated theory calculations is essential to particle physics. Most projects in the field would not be possible without the significant computing resources required to transport and archive the raw data, to perform first-pass reconstruction, and to store the resulting samples. Our discipline has evolved to the point at which these issues are considered as integrated extensions of the experimental apparatus. Although the profitable use of shared resources is sought whenever practical, in some cases the required computing is on a scale that makes it impractical to use shared facilities, requiring dedicated computing centres to be built.

One such example is the ATLAS experiment, which has a computing model that includes dedicated Canadian resources. Raw data are archived at CERN, where a preliminary analysis is done using the best knowledge currently available for calibration. The raw data and the results of the first-pass analysis are also sent to dedicated remote centres worldwide for backup and further analysis. The size of the raw data set for ATLAS is a few Petabytes (10^{15} bytes) per year, a scale significantly larger than any Canadian scientific effort has previously had to handle. The secondary data sets will also be on the Petabyte scale.

Raw data are typically reprocessed when better calibration constants and improved analysis algorithms become available. The size of the samples requires that this must be done at the remote centres because the main laboratory site is fully occupied with handling the data streaming continuously off the detector. The remote centres must therefore also have significant processing power.

Dedicated resources are needed to deal with the continuous arrival of raw data from overseas. Shared facilities, particularly for storage, are clearly not viable in this case. Subsequent data analyses in which specific physics groups and individual physicists access the data, however, occur in a far less continuous way. At this stage, it is more efficient that resources be shared with other particle physics experiments or other fields.

We are fortunate in Canada to be the beneficiaries of significant recent investment in high-performance computing (HPC). These investments, made mostly by the CFI, have established so-called HPC consortia across the country. The particle physics community has made good use of these resources. The ATLAS-Canada computing model engages the HPC consortia in the generation of large samples of simulated data and, after data-taking begins, in the latter steps of data analysis during which physics results are extracted.

Large-scale Monte Carlo calculations of physics processes followed by sophisticated detector simulations and physics-object reconstruction are essential to every experiment in our field. This important aspect of particle physics computing also lends itself well to the use of distributed and shared facilities. In Canada, the particle physics community possesses considerable longstanding experience in the production of Monte Carlo data samples that are significant, both in numbers of samples and numbers of events per sample, and in the breadth of particle physics analysis that they enable. Canadians, at geographically disparate computing facilities across the country, have already made high-impact and leadership contributions to Monte Carlo sample generation in many of the current multipurpose collider detector efforts, including BaBar, CDF, D0, and ZEUS.

It must be emphasized that both dedicated centres and shared facilities are generally crucial to our future experimental programme. This division of tasks makes the most efficient use of the overall computing resources.

The theory community also employs both approaches to its computing requirements. Whereas most of the needs of this community can be met by the HPC consortia, there are also theory projects that use dedicated computing facilities. A good example of this is the lattice QCD community. Several collaborations have built dedicated compute farms in the US, Europe, and Japan to do calculations that require extensive CPU time. In Canada, the University of Regina runs a 260-processor farm dedicated to lattice QCD calculations.

To set the scale for dedicated facilities, the cumulative requirements to 2009 for a dedicated ATLAS Tier-1 facility at TRIUMF are 2,856 kSI2k of CPU[‡], 1,385 TB of disk, and 1,112 TB of tape. Two Tier-2 distributed centres are envisaged to require 1,375 kSI2k of CPU and 730 TB of disk. The estimated cost of the proposed TRIUMF computing centre is $21.6M (using educational pricing), including personnel. The real costs, after vendor discounts, are $13.6M. The estimated cost of the Tier-2 centres after vendor discount is $5.3M. However, this does not include the infrastructure upgrades that would be necessary in the universities to house the hardware, and includes only a minimal complement of personnel, with little in the way of user support.

The scale of the computing requirements for many experiments dictates the use of geographically distributed computing and storage resources. Even if the requirements are such that a project fits into the HPC consortia, these resources will be "gridded" in the near future; this is already true for facilities such as WestGrid. It is likely that most large-scale serial type computing will be done on the Grid in the near future. Further Grid development and deployment are anticipated over the next five years and beyond.

The TRIUMF Tier-1 computing centre is a vital complement to the HPC consortia used in Canadian particle physics. The IPP recommends that it be funded at the requested level. Proper exploitation of this facility relies on excellent networking, which is already a crucial aspect of HPC in the IPP scientific programme. It is critical, therefore, that the networking infrastructure provided in Canada by CANARIE, which is up for funding renewal in 2007, be maintained. HEPnet/Canada coordinates networking issues in Canada and abroad for the Canadian SAP community, in particular negotiating access to transatlantic links to CERN and DESY (for example, the recent dedicated link to CERN for ATLAS through CANARIE). This service is, and will remain, invaluable.

Finally, it is critical that funding for computing support personnel also be made available. Many groups fund such people from their NSERC MFA grants. The particle physics community also benefits from personnel funded through the MFA grant to C3.ca, the analogue of the IPP for the high-performance computing community. This category of funding should at least be maintained and is a good candidate to be increased in the increased funding scenario.

6 IPP and TRIUMF

TRIUMF is Canada's only national subatomic physics laboratory and as such is vital to the health of particle physics in our country. TRIUMF supports on-site as well as off-site scientists and engineers who are directly involved in research related to the IPP experimental programme. On-site physicists take major responsibilities in IPP projects;

[‡]The unit kSI2k corresponds to the kiloSpecINT2000 benchmark; one 3 GHz CPU corresponds to about 1.1 kSI2k.

detector physicists as well as mechanical and electrical engineers provide essential expertise for the detector design and construction. TRIUMF funds faculty and engineer positions at its member universities. It also provides infrastructure for detector construction, such as the clean rooms, machine shops, and design offices as well as test-beam facilities. Major detector construction projects such as the E787/949 drift chambers, the BaBar central drift chamber, the HERMES TRD, and the ATLAS hadronic endcap liquid argon calorimeter took place at TRIUMF with support from the detector facility group, engineers and technicians. From 2006, the focus of TRIUMF construction for off-site projects is currently focused on preparations for the T2K near detector. TRIUMF additionally supports two scientists on Large Advanced Detector Development (LADD) facility, which is funded by the CFI.

TRIUMF has been Canada's point of contact in a series of international particle physics projects (E787/AGS, BaBar/SLAC and ATLAS/LHC). We must find a way to build on these successes through a continued involvement of TRIUMF in off-shore particle physics projects. Between 2000 and 2005 TRIUMF contributed $16.7M to the LHC preparations at CERN. In the current 5-year plan of (2005-2010) $6.8M of contributions to off-shore particle physics projects are foreseen. This includes $5M for the ATLAS Tier 1 computer center. The remainder ($1.8M) is allocated to external accelerator projects, the commissioning of the LHC, neutrino beamline work at J-PARC (T2K), and accelerator R&D for the ILC. Unfortunately this is considerably less than what was hoped for in the original 5-year plan. Expertise in accelerator/beamline and detector development/construction that are accumulated at TRIUMF is an invaluable asset for the Canadian particle physics community. If it is not utilized it will be lost.

Since the resources TRIUMF has available to support both onshore and offshore projects are limited, a protocol for the support of particle physics projects was established at the time of the 1998-1999 GSC-19 competition. This protocol sees TRIUMF supporting IPP projects that have received favourable peer-review and financial support from GSC-19. The IPP has direct representation at Agency committee meetings (ACOT) and on the long range planning committee at TRIUMF. It is vital for the IPP that TRIUMF carefully set the right balance in the allocation of resources for the future of subatomic physics in Canada. The IPP strongly recommends a clarification of TRIUMF's role in the support of off-shore projects in particle physics, which should be commensurate with its intended role as Canada's National Laboratory for particle physics.

6.1 TRIUMF and Particle Theory

The dynamic demographics of high-energy theory in Canada is not currently reflected at TRIUMF, where the last staff theoretician was hired several decades ago. At present there is only one particle theorist, who is very close to retirement age, reflecting the strong nuclear-physics focus of the theory effort at TRIUMF.

While there is certainly a need for TRIUMF to continue to help provide theoretical support for its in-house programme, its mandate as a national facility for subatomic physics argues for the strengthening of TRIUMF support for particle theory. Indeed the development of a world-class in-house particle theory group – including staff scientists, postdoctoral fellows, and support for conferences and schools – would provide a relatively inexpensive way for TRIUMF to contribute to the high-energy physics community with moneys spent entirely within Canada.

7 Major Science Investment Panel and the IPP

The Prime Minister's National Science Adviser launched a review of Canada's funding of large science projects in 2004, shortly after he was appointed. Members of the IPP have consulted on the drafting of a document that proposes to rationalize the funding of large science projects through the formation of a Major Science Investment Panel (MSIP). A first draft was circulated for community comment in late 2004, to which Council – with input from the membership – provided its perspective[§]. In early October 2005 the Science Adviser hosted a townhall meeting

[§]The IPP response to the call for comment on the first MSIP draft can be found on our web-page at: `http://www.ipp.ca/MSIP.pdf`.

in Ottawa, where big science stakeholders were invited to comment on the penultimate draft of the MSIP proposal. This proposal is now being forwarded to government for implementation.

The MSIP process is intended to address the growing diversity of funding sources and mechanisms that have sprouted in attempts to cope with the funding of large-scale scientific endeavours. Most recently, the advent of the CFI has resulted in a most welcome boom of construction of scientific infrastructure (including SNOLab, the Canadian Light Source, as well as computer installations that are central to several IPP projects' ability to analyze their data). However, the mismatch created by the appearance of these facilities without corresponding increases in operating support, has put additional stress on a system that was already struggling to cope with the appearance of a large number of new faculty provided by the CRC programme.

While the support for science in general, and IPP science in particular, is most welcome, it has led to several direct appeals to the government for ad-hoc solutions to the funding mismatches. Further, even the established funding mechanisms – such as TRIUMF's five year planning/funding cycles – have been strained in this new landscape. The MSIP proposal addresses the situation by establishing both a secretariat, that would steer proposals to fund major science installations through the funding maze in Ottawa, and a panel that brings together the heads of the major funding bodies (NSERC, CIHR, CSA and NRC, along with Industry Canada) to discuss and prioritize Canada's investment in big science. In its current form, the proposal does not envisage re-grouping the funding available for such projects under one umbrella that could be managed by the MSIP. Instead it proposes to shepherd proposals from the various existing peer-review processes, helping them secure funding within the context of the current system and only as a last resort proposing exceptionally large projects to cabinet for direct funding. In its response to the MSIP discussion document in the spring of 2005, the IPP expressed its skepticism that an MSIP without direct access to funds could be effective.

Many IPP projects are, by their very nature, based at off-shore facilities. Even the largest economic regions (US, EU, Japan) can no longer afford to build particle physics facilities "on their own". Following the ITER design and siting process, the world is struggling to come to terms with the international (and inter-regional) collaboration that will be necessary to make the next particle accelerators (and telescopes) a reality. While Canada has a long history of being a good international partner – in many instances on the basis of particle physics projects we have undertaken (ZEUS/HERA, OPAL/LEP, ATLAS/LHC) we must find a way to ensure that we can continue to lead in this area – as the US, Europe and Japan are coming to terms with the end of their ability to undertake particle physics projects as purely regional initiatives. We hope that the MSIP process will provide Canada with a single voice that can engage these international science initiatives in the future and as a result ensure that Canada remains a significant partner as particle physics research moves into the 21^{st} century.

The IPP supports the MSIP process. We see it as a way of clarifying the funding mechanisms available to large projects (such as the experiments at SNOLab, ATLAS, the ILC and others) that the community will be working on in the coming decade. We see a crucial ingredient of this process being a well-formulated and public peer-review process that prioritizes the projects it considers and supports. One of the hallmarks of the NSERC/GSC process is the peer review that is the corner-stone of the funding allocations. The GSC-19 model, that puts resources to support operating costs, capital costs as well as infrastructure support (MFAs) into a single envelope, is even better, as it allows the community to prioritize the ebb and flow between these three areas as a function of the scientific needs in any given year. This process is the envy of many of our international collaborators. We can only hope that the MSIP will have the flexibility and expertise to make equally informed decisions, albeit on a larger scale.

As an example, we believe that such a process could be used to put the TRIUMF five-year plan funding on a less ad-hoc footing. In our view, this would include a better understanding of the prioritization of TRIUMF's commitments to its on-site programme and its support for Canadian and off-shore particle physics projects.

In the same vein, we encourage NSERC and the MSIP to identify the resources necessary to properly operate SNOLab as a Canadian facility that is available to the international community, without assuming that the required operations funds could be made available at the expense of projects currently funded out of the GSC-19 envelope.

FY	Operating funds (M$)	Equipment funds (M$)	Infrastructure funds (M$)	Total (M$)	Envelope Fraction
1999	9.2	3.3	1.5	14.0	0.70
2000	9.2	3.4	1.5	14.2	0.73
2001	9.0	2.1	1.5	12.6	0.69
2002	9.9	2.0	1.5	13.4	0.63
2003	9.5	2.2	1.8	13.5	0.61
2004	10.3	1.0	1.8	13.2	0.59
2005	9.8	1.6	1.8	13.3	0.60

Table 2: Funding for IPP associated projects for fiscal years 1999–2005. IPP projects received an average of 0.65 of the GSC-19 envelope over this period.

8 Operating and Capital Expenditure Balance

A healthy and sustainable particle physics programme requires a balance among technology R&D, detector construction, experiment operations and physics analysis. This balance is a delicate one, which has, in the past, resulted in periods during which existing and successful Canadian projects have had their operating support reduced to bare survival levels, and in which new and deserving initiatives found it difficult to proceed due to a lack of detector construction funds. This dynamic has become increasingly complicated with the welcome infusion of capital funds from CFI and other sources into the field without accompanying operating support, and with the reduction of resources from TRIUMF available for particle physics.

Individual particle physics experiments have financial requirements that differ during the construction and operational phases. They typically have large capital expenditures during the construction (or upgrade) phase, requiring significant budgets for materials, engineering infrastructure, and technical support. During operational phases, projects need funding supporting research associates, graduate students, computing facilities for data analysis and for travel or relocation to host laboratories for detector operations and analysis work.

This situation is recognized in the funding envelope model of GSC-19, which includes both operating and equipment funds. This differs from most other GSCs which do not allocate equipment funds. The GSC-19 model allows, for example, funds to be shifted from equipment to operating as an experiment moves towards data-taking, or technical infrastructure to move from one project to another at a different project phase. Common infrastructure from NSERC-funded MFA grants at universities plays a particularly important role in the sharing of infrastructure costs across projects. The IPP supports the continuation of this model.

The situation is illustrated in Table 2 which shows the evolution of IPP-related operating and equipment funding since 1999. Two things are immediately evident. The first is that the amount of money allocated by GSC-19 to equipment in FY2005 is less than half of what it was in FY1999, reflecting the end of major construction on the ATLAS project. The second is that the fraction of the envelope available to IPP projects has been falling in recent years. It has been shifting into capital expenditures on non-IPP projects, thus weakening the internationally recognized IPP programme. We note this with concern, given the significant needs for T2K and SNOLab related construction funds and for sufficient operating funds to allow us to reap the scientific benefit of the large Canadian capital investment in ATLAS and the LHC accelerator.

In the flat funding model, it is essential for the IPP part of the GSC-19 envelope to be restored to its historical fraction, which we estimate to be about 65%. Without this, it will not be possible to fund detector construction for T2K, where Canadian groups have taken a leading role, or detector R&D and construction for SNOLab where Canadians clearly have a unique opportunity in underground physics, or to increase the ATLAS operating budget to a level which will not compromise the physics output of the Canadian groups.

In the +100% funding scenario, IPP would request both a significant increase to Canadian IPP infrastructure and new funds for the operation of experiments. The infrastructure would naturally be at least partially in the form of significant increases in engineering, technical, and computing professional support at Canadian universities. With such increases, the roles that Canadians could take in proposing, developing and constructing the next generation of particle physics experiments would be enormously improved, making our impact on T2K, the ILC, SNOLab and other new projects substantially larger. An increase in experiment operations support would be in the form of additional research associates, students, and travel to host laboratories. From our experience with projects such as OPAL, ZEUS, BaBar, CDF etc., we know that it is critical that there be sufficient operating funds to allow Canadian groups to fully participate in the physics programme enabled by the years of work on detector design and construction and by significant Canadian capital investments.

8.1 Detector R&D

Experiments at the energy and precision frontiers typically rely on very sophisticated devices, which makes pushing the envelope of detector and electronics R&D an essential aspect of experimental particle physics. Such R&D programmes are is often undertaken for a specific experiment, but in some cases, are performed more generically, often in collaboration with other particle physics projects, medical imaging, and other fields. Important R&D has also been performed in close and fruitful collaboration with industry.

Many particle physics projects have important detector R&D components which are supported by GSC-19. Current examples include research into silicon-based photo-multipliers (SiPM) for efficient scintillation light collection in strong magnetic fields, being performed at Regina for GlueX, but with applications in a future ILC detector also in mind. In contrast, T2K will also be using SiPM for their fine-grained calorimeter, but the development of these is being jointly performed by Hamamatsu and a Russian company (CPTA) in close collaboration with T2K members. There are also strong Canadian developments in the use of gas-electron-multiplier (GEM) detectors for use in T2K and the ILC, and many other examples of detector R&D across Canada. IPP supports detector R&D where the costs are commensurate with the potential particle-physics benefit of the associated project or projects.

The Laboratory for Advanced Detector Development, LADD, is a CFI-funded facility located at UBC/TRIUMF and at the Université de Montréal. It was funded as a general-purpose detector R&D facility, primarily for particle physics and medical imaging applications. Currently, these facilities are extensively used by two IPP projects, T2K and PICASSO. LADD is in the process of applying to CFI for their next phase, LADD2. They are already developing Liquid Xenon (LXe) detectors for medical applications, and propose to develop LXe detectors for next-generation particle physics applications, including cold-dark-matter searches and high-rate calorimeters for a possible ATLAS upgrade. IPP encourages the support of LADD, and the continued close collaboration between LADD and particle physics projects.

9 Training of Highly Qualified Personnel

In addition to the science produced by all of the IPP projects, there is another important aspect of the IPP programme which in many ways is equally important: the training of what NSERC calls ”Highly Qualified Personnel” (HQP).

Although this is often narrowly interpreted as meaning the training of the next generation of particle physicists, it also includes the training of students and post-docs who either change fields within physics or who do not remain in academia. Although the statistics for this latter group is harder to find, the comparatively small number of academic posts which become available each year guarantees that *most* of the students being trained in particle physics do not remain within the field. These people instead move to other areas of research, or bring their practical and problem-solving skills to elsewhere in the economy.

It should be emphasized that this spin-off into the work force of people skilled in mathematics, computing and state-of-the-art technology represents an extremely important economic contribution of particle physics to Canadian society. The attractiveness of the the ideas in field act to draw people into the physical sciences, where they ac-

University	**Name**	**Year of Hire**	**Theory/Experiment**
Alberta	Roger Moore	2003	Experimentalist
Carleton	Alain Bellerive	2001	CRC Experimentalist
	Manuella Vincter	2004	CRC Experimentalist
	Bruce Campbell	2004	Theorist
	David Asner	2005	Experimentalist
	Heather Logan	2005	Theorist
McGill	Guy Moore	2002	Theorist
	Andreas Warburton	2003	Experimentalist
	Steve Robertson	2003	IPP-Experiment
	Brigitte Vachon	2004	CRC Experimentalist
	Robert Brandenburger	2004	Theorist
	Keshav Dasgupta	2005	Theorist
	Matt Dobbs	2006	CRC Experimentalist
Laurentian	Jacques Farine	2002	Experimentalist
McMaster	Cliff Burgess	2005	Theorist
Perimeter	Rob Myers	2002	Theorist
	Lee Smolin	2002	Theorist
	Fontini Markopoulou	2003	Theorist
	Jaume Gomis	2005	Theorist
	Freddie Cachazo	2005	Theorist
	Justin Khoury	2005	Theorist
Queen's	Mark Chen	2000	Experimentalist
	Tony Noble	2002	CRC Experimentalist
	Mark Boulay	2005	CRC Experimentalist
Regina	Bhaskar Dutta	2002	Theorist
	Mauricio Barbi	2004	Experimentalist
Simon Fraser	Mike Vetterli	2001	Experimentalist
	Dugan O'Neil	2002	Experimentalist
Toronto	Amanda Peet	2000	Theorist
	Erich Poppitz	2001	Theorist
	Pierre Savard	2002	Experimentalist
	Kentaro Hori	2002	Theorist
	Peter Krieger	2004	Experimentalist
	Richard Teuscher	2005	IPP-Experiment
TRIUMF	Makoto Fujiwara	2004	Experimentalist
	Reda Tafirout	2004	Experimentalist
	Fabrice Retiere	2004	Experimentalist
	Leonid Kurchaninov	2005	Experimentalist
	Isabel Trigger	2005	Experimentalist
UBC	Moshe Rozali	2001	Theorist
	Mark van Raamsdonk	2002	Theorist
	Scott Oser	2003	CRC Experimentalist
Victoria	Dean Karlen	2002	Experimentalist
	Maxim Pospelov	2002	Theorist
	Adam Ritz	2005	Theorist
Western	Vladimir Miransky	2000	Theorist
	Alex Buchel	2003	Theorist
York	Wendy Taylor	2004	CRC Experimentalist

Table 3: Grant-eligible hires since 2000, in experimental and theoretical particle physics at Canadian institutions.

	Completed			In Progress		
Project	Master’s	PhDs	RAs	Masters	PhD	RAs
ATLAS	20	7	15	11	13	13
BaBar	16	3	11	6	11	6
CDF	3	11	6	3	8	3
D0	1	0	0	3	3	1
E787/949	8	4	11	0	1	2
HERMES	6	3	10	0	0	0
OPAL	8	54	48	0	0	0
PICASSO	5	1	0	4	4	3
SNO	45	15	28	9	13	13
T2K	0	0	0	5	0	3
VERITAS	0	0	0	1	1	1
ZEUS	7	19	24	1	5	3
Totals	119	117	153	43	59	48

Table 4: Graduate students and Research Associates trained on a selection of past and present particle physics projects with Canadian involvement.

quire vital skills which are in high demand in areas ranging from banking to computing. Of those HQP trained in IPP-related programmes, some specific examples of occupations held include the following: financial analyst for the National Bank of Canada; founder of a Canadian internet company with over 50 employees; CEGEP college instructor; medical-physics research scientist; owner of a water purification business; AECL scientist; cancer-therapy radiation physicist; Nortel scientist; scientist with Motorola Toronto; data processing manager; and employee of CSIS.

Those trainees who remain in particle physics eventually do end up in academic appointments, and this is possible because of the willingness of the university community to continue investing in the field by hiring new faculty. Indeed, the willingness to do so is an important measure of the vibrancy of a field. Over the last five years particle physics has seen an unprecedented renewal in faculty appointments. Table 3 lists forty-eight new faculty that have been hired over the last five years. While eight of these were transfers of faculty-level researchers who had previously held positions at other Canadian institutions, these numbers indicate a strong willingness on the part of universities to continue their strong support of research in particle physics.

While the IPP community is already benefiting from the arrival of these forty new members of the community who have received significant additional financial resources from NSERC, the CFI and elsewhere, few of them have fully ramped up their research efforts. They are still in the process of growing the sizes of their research groups from a single graduate student and perhaps a research associate to a more representative three or four graduate students and at least one RA. This additional growth, expected in the first few years of the current planning period, will put further pressure on the GSC-19 funding envelope.

In addition to the permanent faculty level particle physics researchers who have been hired into university positions, IPP projects have trained a huge number of postdoctoral research associates and graduate students over the last five to ten years. Table 4 summarizes the numbers of students and research associates who have been trained on various particle physics experiments.

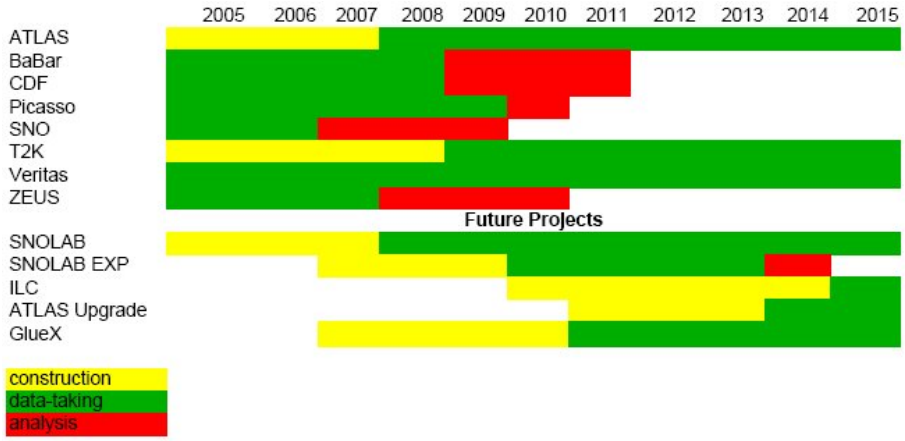

Table 5: Timelines for current and proposed particle physics experiments in Canada

10 Funding Recommendations

Based on our understanding of the project, theory and infrastructure needs outlined in the previous sections, the IPP council spent a full day considering the different funding scenarios outlined in the charge from NSERC to the Long Range Planning committee. We attempted to do more than just “work through the numbers”. We asked ourselves where disproportionate measures might be necessary (or possible) in the various funding cases. Rather than attempting a 10-year, project-by-project breakdown – which would quickly become obsolete – we considered projects in each of the four categories and made some attempt to balance the IPP effort in these areas in each of the funding scenarios. In what follows, we provide tables that show how we recommend funding could be allocated, along with a summary of the thinking that went into that process, and suggestions for the possible projects these funds could support.

While many of our projects have received substantial support from funding sources outside NSERC (TRIUMF, CFI, DOE, etc.) the purpose of this section of our document is to understand and recommend what could best be done with the NSERC GSC-19 resources in the three proposed funding scenarios: a 20% cut in funding, status-quo funding and a doubling of the GSC-19 budget over the planning period.

We take as our “baseline” a funding level of $14.3M, which represents the 65% of the current GSC-19 envelope that has historically been available for IPP projects. The evolution of this fraction over the last eight years is summarized in section 8, and it is clear that it has been somewhat less than this over the last couple of years. This lower level (60%) is a consequence of the completion of ATLAS construction, the onset of major ISAC construction and the recent cancellation of the K0Pi0 project. We anticipate that the next wave of major construction projects (T2K and SNOLab) will restore the balance between sub-disciplines in GSC-19 to this traditional 65% level and believe that the investigator demographics applying to GSC-19 will more than warrant such a return. Still, the first column of each of the tables in this section shows the breakdown of GSC-19 funding in the four physics categories for 2005-06 – which total less than the $14.3M level. This column is included for comparison with how we see the possible evolution of the funding available to each area.

In considering the -20% and status-quo scenarios Council took the attitude that we would not attempt to fold in inflation. We sincerely hope that it will be possible to find the resources to make up for inflation, otherwise the status quo scenario results in more than a 30% reduction in effort over ten years, while in the -20% scenario it would result a 50% reduction over the same time frame. Thus the numbers in all of these tables (yes, even the +100% scenario) should be treated at 2005 dollars.

To aid in this discussion, Table 5 shows the anticipated timelines for terminating and continuing IPP projects as

Annual Funding ($M)	Current Level	2006-2009	2010-2015
Energy Frontier	4.7	4.3	4.2
Underground Physics	4.5	4.1	3.6
Precision Physics	1.5	1.2	0.8
Neutrino Physics	0.7	2.0	1.1
Infrastructure	1.8	1.7	1.4
Totals	"14.3"	13.2	11.1

Table 6: Recommendations for funding in -20% scenario. The "Total" under current level, reflects the seven year average of the IPP fraction of the envelope multiplied by the current $22M GSC-19 funding level; the individual components are the actual split from 2005-06.

well as projections for the timing of possible contributions to future initiatives.

10.1 Falling Funding Scenario:

Here we considering the effect of a fall in funding available to GSC-19 by 20%. As a worst case scenario we consider what would have to be done if the 20% reduction had to be implemented over the first five years of the planning period, which would result in an $11.1M funding level from 2010 onward.

10.1.1 Energy Frontier

In this scenario we would be forced to reduce support for the IPP projects that are terminating in the early years of the planning period. This would jeopardize completion of the physics programmes of these experiments, in which the Canadian community has invested heavily over last decade or more, both in effort and in resources. At the energy frontier, we would still try to include a small increase in the support for ATLAS operating over the early part of the planning period (middle column) as the current energy frontier projects (CDF, D0 and ZEUS) draw to a close. More alarmingly, this funding scenario clearly sets up a major clash in the early part of the next decade where one would have to make a choice between continued involvement in ATLAS or shifting Canada's HEP resources to the ILC.

10.1.2 Underground Physics

The biggest immediate victim of this scenario would likely be the underground physics programme. This is not a statement about the quality of physics that we expect to emerge from SNOLab, but simply a reflection of the fact that once the R&D necessary to finalize the design of one or more of the SNOLab experiments is finished in the next few years, these experiments would be ready for capital construction support just at the time the full effect of the 20% funding cut has hit the envelope.

While we support the proper completion of the SNO experiment, one would have to seriously consider diverting some or all of the SNO operating resources to support SNOLab experiments sooner than the end of 2007. In this scenario it is clear that the GSC-19 envelope could not even support the operating costs of SNOLab, let alone provide for any meaningful participation in the construction of Canadian contributions to experiments sited at the lab. We would clearly only be able to support participation in relatively modest experiments, like PICASSO. But even the scaling up of PICASSO would have to be carefully considered if some of the R&D underway on other projects showed another technique to be more promising.

10.1.3 Precision Physics

The world-wide particle physics programme is currently moving away from high statistics, precision physics measurements that have been the hallmark of e^+e^- colliders like CESR, LEP, PEP, and the KEK B-factory. Even smaller efforts like the RSVP project (including K0Pi0 and MECO) and BTeV have been canceled as the emphasis of particle physics has turned to the energy frontier and to neutrino measurements. This trend is mirrored in the Canadian community where only a small number of researchers are proposing projects in this area. In the -20% scenario it was not clear to us that the envelope could support even one project like this in the early part of the planning period. However we did not rule out the possibility of playing a small part in a project such as GlueX or $\pi \rightarrow \ell$ early in the next decade.

10.1.4 Neutrino and Particle Astrophysics

The excitement that has followed the definitive observation of neutrino flavour oscillations by the SNO experiment and others has spawned a world-wide stampede into accelerator and reactor based neutrino experiments. Canada has a significant community moving in this direction – including several former members of the SNO collaboration. They have coalesced around the T2K experiment which we strongly support. However the -20% funding scenario leaves little room to make even the currently proposed contribution to the T2K near detector and would not likely permit involvement in a second generation experiment. Of course the determination of θ_{13} in the first generation will go a long way to determining the viability (and cost) of second generation efforts. While we chose to focus the bulk of the funding on neutrino experiments, we also include some funding for particle astrophysics, which could continue at a low, and reducing level, in this funding scenario.

10.1.5 Infrastructure

After considering the priorities and need for resources of the individual IPP projects (and potential new IPP projects) we think it is worthwhile to consider the impact the proposed funding scenarios would have on the operations of the IPP itself. We currently devote 93% of our financial resources to the eight IPP Research Scientists. A further 3% is spent in the support of international conferences and workshops held in Canada. The remainder provides for the operation of Council meetings and the attendance of the Director at various national and international meetings of interest to Canadian particle physicists. While we maintain that the IPP Scientists have all the characteristics and qualifications of particle physics faculty at Canadian universities, the fact remains that we have not been able to follow the run up in salaries that have been experienced in universities over the last 10 years. The IPP RS remain at least 5% (and in individual cases more than 10 %) behind their faculty peers at our member institutions. In a funding scenario where the budget fell by 20% or remained constant in $, we would likely have to reduce the number of Research Scientists, by one (flat funding) or two (-20%), in order to support the remaining seven (or six) at salaries comparable to those paid to university faculty.

Beyond the IPP funding itself, this scenario would have a major impact on the support of MFA personnel. We imagine that the current support for 13 FTE staff, would have to be reduced to 10 FTE. This would clearly impact our ability to take on technical roles in future experiments and to support the HEP computer infrastructure that is currently in place.

10.1.6 Theory

If this scenario, the main priority would be to keep as much of the remaining funding in operating grants as possible, since this preserves the flexibility of the current system as much as possible. Since individual theorists are the best judge of how to make use of their limited resources, this strategy maximizes their choice.

Annual Funding ($M)	Current Level	2006-2009	2010-2015
Energy Frontier	4.7	4.6	5.6
Underground Physics	4.5	4.5	5.5
Precision Physics	1.5	1.3	0.8
Neutrino Physics	0.7	2.0	1.6
Infrastructure	1.8	1.8	1.8
Totals	"14.3"	14.3	14.3

Table 7: Recommendations for funding in the status quo scenario. The "Total" under current level, reflects the seven year average of the IPP fraction of the envelope multiplied by the current $22M GSC-19 funding level; the individual components are the actual split from 2005-06.

10.1.7 Summary: Falling Funding Scenario

In this scenario we would fail to meet the needs of the community in a number of ways. At the energy frontier we would risk providing insufficient funding to exploit our investment in ATLAS and would likely lose any chance to be a partner in the ILC. In underground physics, we would not be able to fund the operations of SNOLAB, let alone take a major role in any of the proposed experiments. In neutrino and particle astrophysics we risk our proposed contribution to T2K. We might also lose two IPP RS positions, severely compromising our ability to assume leading roles in running experiments and weakening university programs. An additional loss of 3 FTE of MFA-funded personnel would mean that our ability to lead major construction or computing projects would be compromised.

10.2 Status Quo Scenario:

In its discussions, Council spent the bulk of its time on this scenario. It should be clear that the strain on the GSC-19 envelope is enormous. The pressures that have been added to it through the construction of various CFI facilities, the introduction of new researchers through the CRC programme, and general faculty renewal, have only exacerbated this situation. Even in a status quo scenario, Canada could miss out on a significant amount of particle physics that it has already demonstrated the expertise and leadership to accomplish and in which is has already made significant capital investment.

10.2.1 Energy Frontier

In this funding scenario we felt we would be able to "properly" support the terminating energy frontier projects over the next few years, while ramping up ATLAS operating funding during the critical commissioning phase between now and the end of the decade. Despite the apparent ramp-up in support in this area in the latter part of the planning period, there would still be difficult decisions to make early in the next decade if it looked like the ILC were about to become a reality. It would be difficult to support the continued operation of ATLAS and make a meaningful contribution to a linear collider detector with the funding that would be available in this scenario.

10.2.2 Underground Physics

In this scenario it would be possible to finish the SNO measurements and recoup the heavy water in the manner proposed by the collaboration; however if the SNOLab support came from the GSC-19 envelope, there would be no resources left over to actually make Canadian contributions to the experiments. Should additional resources be made available to fund the SNOLab operating costs, one would then have the resources to make a significant contribution to a medium-sized SNOLab experiment (something on the scale of a 180kg Majorana, the next phase of EXO or SNO+) in addition to being the primary source of funds for a smaller experiment like PICASSO.

10.2.3 Precision Physics

Here again we do not foresee significant resources being made available for a major experiment in the area of precision physics. While we are concerned by the shift of focus of the world-wide particle physics community from this line of investigation for at least the next decade, it is not the status-quo funding envelope of Canadian subatomic physics that is going to change this.

10.2.4 Neutrino and Particle Astrophysics

In this scenario we were able to find resources to “properly” support the current T2K near detector plans and still leave resources available in the latter part of the planning period for a second generation neutrino experiment – be that a follow-on to T2K or an experiment based on a liquid argon TPC. Resources to better support a particle astrophysics programme (a successor to VERITAS or cosmic microwave background measurements such as POLARBEAR) would also be possible in this scenario.

10.2.5 Infrastructure

As discussed above, even in the status-quo funding scenario it is not obvious that one would be able to continue to fund the eight IPP Research Scientist positions “properly”, although we would make every effort to continue to do so. As discussed in the theory recommendation above, the sharing of financial resources via the RS programme is a mechanism that provides researchers across the country with colleagues who are able to spend significant time at the laboratories where the large scale HEP experiments are underway, as well as strengthening the HEP groups at universities across the country.

NSERC phased out its direct support of conferences and workshops during the funding down-turn in the 1990s. The IPP’s limited resources in this area now remains one of the few alternatives open to Canadian particle physics conference organizers. Our funds are perennially over-subscribed (this fall we are considering requests for $25K, more than twice our budget, and we expect additional requests to come at other times during the year). Even in the status-quo scenario we would suggest consideration being given to re-instituting financial support for the organization of conferences, workshops and summer schools. In the more optimistic scenario (see below) we imagine that $50K might be devoted to this annually. The IPP Council would be happy to act as the peer-review body to consider these proposals for particle physics, if a central competition were deemed too unwieldy to setup.

10.2.6 Theory

If funding stays at the present level, salaries remain the biggest problem. salaries. Even with the recent increases, it is still not possible to allocation sufficient funds to bring most theorists to the level at which they can afford to pay graduate students (who typically cost $10K per student) as well as competitive postdoctoral salaries (which cost $40K and more). So, in this scenario, it is crucial that the theory fraction of the envelope be maintained.

In this case a relatively modest outlay by IPP can help to address the shortfall at a more modest cost than a further across-the-board increase of theory grants. It can do so by providing a post-doctoral fellowship programme wherein IPP would annually provide matching funds for part of a postdoctoral salary to be awarded on a nation-wide competitive basis to particularly strong candidates. As described in section 4 a pilot project along these lines is being jointly funded this year by the IPP and Perimeter Institute, with an IPP proposal for more permanent funding being submitted to GSC-19.

10.3 Envelope Doubling Scenario:

Even in this, the most optimistic scenario, the excellent quality of the projects under consideration means that it can still be difficult to strike the proper balance. We interpreted this scenario to mean that the GSC-19 budget would

Annual Funding ($M)	Current Level	2006-2009	2010-2015
Energy Frontier	4.7	6.7	9.9
Underground Physics	4.5	6.9	7.4
Precision Physics	1.5	1.7	1.2
Neutrino Physics	0.7	2.1	3.5
Infrastructure	1.8	2.1	2.7
Totals	"14.3"	19.5	24.7

Table 8: Recommendations for funding in +100% scenario. The "Total" under current level, reflects the seven year average of the IPP fraction of the envelope multiplied by the current $22M GSC-19 funding level; the individual components are the actual split from 2005-06. In our model the budget in 2014-15 reaches $28M. The last column represents the annual average budget over the last five years which continues to grow during that period.

grow by about 10% (of the current level) per year throughout the planning period and identified projects that could be undertaken at the appropriate stage of the planning period to follow such a growing envelope in as realistic a way as possible.

10.3.1 Energy Frontier

The IPP projects currently underway could be brought to a natural conclusion. As many investigators involved in the current generation of collider experiments make the transition to ATLAS we would find it possible to properly support their entry into the experiment, including modest additional capital contributions to devices that currently have been de-scoped, such as the High-Level Trigger, to ensure the completion of a fully functional ATLAS experiment in 2007.

Approval of the ILC may be linked to discoveries from the LHC, so the timing of such approval is rather uncertain. However, given that the time frame for continued Canadian participation in ATLAS is likely to extend past the next decade, this funding scenario is the only one that is likely to simultaneously permit a significant Canadian involvement with the ILC, which would require Canadian contributions to the the collider and the detectors on a scale at least as large as for the LHC and ATLAS.

10.3.2 Underground Physics

In this scenario we found it possible for GSC-19 to support a significant fraction of the SNOLab operating costs and still participate in the construction of up to three SNOLab projects. Indeed, we see one of the prime arguments for a significant increase in the GSC-19 budget to be the ability to fund both SNOLab operations and Canadian involvement in the experiments. In this scenario We would have the resources to satisfy the aspirations of the PICASSO project through its next few phases in the early part of the planning period and to either be a significant partner in one of the proposed double β-decay experiments or the dominant contributor to a more modest experiment (eg. SNO+). Further, there would be the resources to mount one additional effort with a capital requirement of $12-15M early in the next decade.

10.3.3 Precision Physics

This funding scenario also allowed us to be a little more generous in our support of smaller "precision" physics projects, such as perhaps a high statistics muon symmetry experiment, over the course of the planning period. It was only in this funding scenario where we could contemplate a meaningful participation in the second phases of ATLAS and the linear collider. However several times in our discussions it was clear that one of the hall-marks of

Annual Funding ($M)	Current Level	2006-2009	2010-2015
Energy Frontier	4.5	6.6	7.4
Underground Physics	4.5	6.9	7.4
Precision Physics	1.7	1.8	3.8
Neutrino Physics	0.7	2.1	3.5
Infrastructure	1.8	2.1	2.7
Totals	"14.3"	19.5	24.7

Table 9: Recommendations for funding in +100% scenario, with linear collider included in "Precision Physics" sub-category. In our model the budget in 2014-15 reaches $28M. The last column represents the annual average budget over the last five years which continues to grow during that period.

the linear collider was to provide a next generation of "precision physics", much as OPAL was a follow-on to the original discovery of the W and Z bosons in hadron colliders. For this reason, we considered re-classifying the linear collider from the energy frontier to the precision physics category here. The result is shown in table 9. Without any attempt at fine-tuning we found the "balance" that was restored by looking at things in this way, in the latter part of the planning period, striking.

10.3.4 Neutrino and Particle Astrophysics

In this funding scenario we were not only able to find resources to fully support the currently proposed, initial phase, of the T2K near detector, but could also imagine supporting modest upgrades that would be ready to take data early in the next decade. Further, we were able to earmark resources towards the end of the decade that could be directed towards a second generation neutrino detector such as FLARE, should a physics case for this arise. As with the other scenarios we included particle astrophysics in this category. Clearly the optimistic scenario would leave considerably more resources available to pursue these projects as well.

10.3.5 Infrastructure

In this, the most optimistic funding scenario, one can be more creative in considering what the IPP could do. One might naturally consider doubling the number of IPP Research Scientists. Perhaps more realistically one might want to increase from eight to twelve and ensure that the IPP-RS salaries were fully competitive with their faculty peers. If one, instead, takes a bottom-up approach and asks what qualitative difference to the Canadian particle physics community would be provided by additional RS positions one is led to conclude that three or four additional scientists would be very beneficial. The IPP has a policy of allowing no more than two RS to be hosted at any of its fourteen member institutions. This traditional compromise ensures that the eight RS are available to support the experimental particle physics activities of the largest number of member institutions while not putting undue limitations on the host institution possibilities for the RS. In practice, this policy has resulted in two IPP RS being sited at two or three Canadian institutions (at various times these have included Carleton, McGill, Toronto, UBC and Victoria). Adding four RS positions would ensure that at least one RS would end up in some of the other IPP institutions (Alberta, Queens, Montreal, Regina, Simon Fraser and York).

In this funding scenario we also anticipate significant increases to the MFA-supported infrastructure that could be made available to research groups at universities across the country, increasing from the 13 FTE currently supported to about 20 FTE over the course of the planning period.

10.3.6 Theory

If funding were to double, then there are a number of ways in which IPP could assist theorists. The main priority would be to keep as much theory funding as possible in operating grants (since individual theorists remain the best judges of how to allocate funds), with the goal of raising them to a level sufficient to cover postdoctoral and graduate salaries. This might obviate the necessity for IPP providing the funds for postdoctoral fellowships in theory.

However, additional funds could also allow IPP to support theory in a number of other ways. In particular, increased funding could allow a more systematic support for the organization of schools and conferences than is at present possible. These funds have dried up from NSERC sources, and are difficult to secure when organizing such conferences in Canada. IPP could provide this funding, as well (perhaps) as providing a distributed administrative infrastructure for their organization, similar to the way that a number of existing Theoretical Physics Institutes (like PITP or Perimeter) do for some sub-disciplines in some parts of the country.

10.4 Summary: Envelope Doubling Scenario

In this scenario the Canadian particle physics community could truly fulfill the potential it has established through the hiring of over 40 young and energetic investigators over the last five years. In addition to a rejuvenation of the complement of researchers, this hiring wave represents a 20 % increase in the absolute size of the community. We are about to embark on a new era of particle physics. With the ATLAS experiment beginning to take data early in the planning period, the SNOLab and T2K experiments beginning to produce results in the middle of the planning period and the prospect of being full partners in the ILC towards the end of the planning period, Canada has put itself in an excellent position to enhance its standing in the worldwide enterprise of particle physics.

While Canadians have established themselves as full partners in the ATLAS experiment, the arrival of half a dozen new faculty members with aspirations to extend Canada's reach in the ATLAS experiment can only further enhance the physics we will do there. To capitalize on this opportunity will require significant additional funding, for additional hardware contributions (for example to the High Level Trigger), and for support of the additional students and postdocs that would be trained as a part of making these additional projects a success. The SNOLab experiments are just being defined. We have hired new faculty and researchers who, given the proper resources, will ensure that Canadians play a leading role in one, or several, of these experiments. Canada is already a leading partner in the preparation of the near detector for the T2K experiment. Given the additional resources in this scenario we could enhance our contributions to the current plans and ensure our continued participation in the follow-on to the T2K project, that may be warranted towards the end of the planning period.

Finally, Canada has been a successful partner in major international high energy experiments since the early 1980s. The successes of Canadian efforts on experiments like OPAL, BaBar, ZEUS, among others, make us a partner of choice in current projects like ATLAS and T2K. This funding scenario and the emergence of a new cohort of junior faculty members, put Canada in an ideal position to play a leading role in the ILC project, potentially making contributions to both the detector and the accelerator complex. While there are already a dozen faculty and several FTE of research effort going into ILC R&D, this effort is tempered by the uncertainty surrounding the timescale for the eventual construction of a linear collider. When the ILC schedule is put on a firmer footing, it is likely that a community of Canadian researchers, to rival the size of the current Canadian contingent on ATLAS, will emerge. Relative to other countries with active high energy physics programmes, the recent surge of hiring gives Canada clear advantages in taking on a construction project in the second half of the planning period and then exploiting the physics from that programme through the following decade. However, to make this a success will require sufficient funding.

11 Summary of Recommendations

Here we summarize the recommendations made throughout the document. Within the four broad "levels" of support these recommendations simply follow the order in which they appear in our document and do not imply any additional relative priority.

We strongly support:

- The Canadian costs for the completion, commissioning and operation of the ATLAS experiment along with the associated physics analysis;
- The Canadian contributions to the T2K near detector and operating resources sufficient to allow the group to play a major role in the physics analysis;
- The R&D necessary to lay the ground-work for a Canadian contribution to a linear collider experiment towards the middle of the next decade;
- The R&D necessary to make an informed decision on which are the most promising double-beta decay, dark matter and solar neutrino experiments that could be performed at SNOLab;
- Clarification of TRIUMF's commitment and ability to support off-shore particle physics, in particular our contributions to accelerator projects, on a less ad-hoc basis;
- The continued strong GSC support for the Canadian theoretical particle physics programme.

We support:

- The orderly completion of the on-going Canadian projects, particularly the IPP projects: BaBar, CDF, SNO and ZEUS;
- Continued participation in the VERITAS project and physics;
- The scale up of the PICASSO experiment with a view to reaching a full scale experiment in SNOLab early in the next decade;
- The R&D necessary to contemplate participation in high luminosity upgrades for the ATLAS experiment towards the middle of the next decade;
- Continued R&D and eventual construction funds for the GlueX experiment should this be approved for construction at JLab;
- The $\pi \to \ell$ experiment at TRIUMF, assuming it is approved by the TRIUMF EEC;
- TRIUMF's efforts to assemble a Tier-1 data hub for the LHC computing GRID;
- The HEPnet efforts to secure access to the networking infrastructure critical to 21^{st} century high energy physics;
- The establishment of a framework that harmonizes and rationalizes the funding mechanisms available to big science projects in Canada, such as the proposed MSIP;
- The use of an NSERC peer-review mechanism to determine operating support for SNOLab;

- A balance of support for capital construction projects (thereby assuring the future of our field) and operating support (ensuring that we are able to capitalize on past investments by maximizing the physics return on those projects);
- The funding necessary to support students and research associates not only to maximize the physics we extract from our research but also to train the next generation of high-tech quantitative researchers who end up in fields outside academia.

If a sufficient Canadian community were to develop, we could imagine support for:

- The R&D for an eventual participation in a Super *B*-factory experiment, if the physics case is made;
- A $\mu \rightarrow e$ conversion experiment based on an intense muon source that might become available by the end of the planning period, if the physics case is made;
- The participation of Canadian researchers in the next phase of CMB polarization measurements.

It is not clear that we could support:

- A significant Canadian effort on the ALPHA anti-hydrogen project as it is unclear whether the CPT tests it will make are likely to compete with those made in other subatomic physics measurements;
- Canadian participation in the FLARE experiment that might proceed if θ_{13} appears large enough to allow an assault on CP-violation in the lepton mixing matrix.

We hope the Long Range Planning committee will find this summary of the Canadian particle physics programme and projections for how it might evolve in the coming decade useful. This document can be found at:

`http://www.ipp.ca/ipp_lrp2005.pdf.`