Context and Environment of Subatomic Physics Research at Canadian Universities

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In June 2014, Samir Boughaba, NSERC's Research Grants Team Leader for Physics, Astronomy and Computer Science, requested that the CINP and IPP jointly prepare a short document on "the context of Canadian subatomic physics research" for distribution to the Subatomic Physics Evaluation Section (SAPES) shortly before the fall policy meeting, with the opportunity for the committee to ask questions on it. This was in response to our request to reinstate the discontinued SAPES fall site visits, given their value to both international and domestic members of the committee in understanding the Canadian research context and environment. We do not believe that this brief can even begin to provide the depth of knowledge that university site visits could provide to SAPES, but it is our hope that this document can at least provide an overview of some of the most important information. In order to understand the overall research environment and the context in which the research is conducted, including the quality of the research space, the age and status of equipment and other infrastructure, technical support personnel, the level of engagement and interactions of the students and postdocs, interactions between researchers within an institution or institutions within geographical proximity, as well as the level of support of the institution's administration, a site-visit is required.

Roles of Canadian research funding agencies in support of subatomic physics

The decisions that you make as SAPES members are of crucial importance to the Canadian subatomic physics research enterprise, as the NSERC Subatomic Physics (SAP) Envelope is the only major means of operating funds support for Canadian subatomic experiment and theory research. The additional operating research funds provided through Canadian universities, or other federal or provincial agencies, are limited in scope and are often not accessible to researchers in non-applied areas. In addition to the SAP Discovery Grants Program (Individual or Project), subatomic physicists also rely on the SAP-RTI program to provide funding for equipment. Historically, the RTI funds were used to build experiments and provide the Canadian hardware contributions to the experiments of large international collaborations, and more recently RTI funds have been used as seed capital funds for projects that apply for larger CFI support. For most subatomic physicists in Canada, the NSERC SAPES awards are their sole source of research operating funding. It should be noted that unlike the USA, universities are not allowed to charge overhead on NSERC grants (an equivalent of overhead is paid separately), and grant holders are not allowed to pay themselves summer stipends from the grants (as Canadian universities pay twelve month salaries).

The NSERC Subatomic Physics Envelope also supports several resource facilities through the Major Resources Support (MRS) program. The resources at these facilities are available to the entire subatomic physics community normally allocated via resource allocation boards. At the University of Alberta, the CPP+ MRS Centre is available to provide help with NSERC-funded projects. The MRS facilities at Carleton, Winnipeg and Victoria are available to support subatomic physics related detector development work. The resources include engineering design, hardware fabrication and installation, and data acquisition/simulation expertise. The Université de Montréal MRS facility provides electronics design and support for subatomic physics projects.

Two NSERC scholarship programs that are commonly used by subatomic physics researchers are the Undergraduate Summer Research Assistantship (USRA) and Postgraduate Scholarship (PGS) competitions. These are awarded directly to the student and in the case of the USRA require an additional funding commitment from the supervisor's NSERC grant. It is important to note that these scholarships are only available to Canadian citizens and permanent residents, so international students studying in Canada are excluded from this means of support. NSERC also runs a series of smaller, more competitive graduate scholarship programs (e.g. Vanier Scholarships) as well as a small PDF fellowship program.

The Canada Foundation for Innovation (CFI) is a major federal source of research infrastructure funding. CFI will fund up to 40% of the costs for a major piece of experimental equipment, with the requirement that 60% of the funds come from elsewhere, including provincial matching funds, industrial or international contributions. In principle the CFI funds, when matched, can be used to make large capital contributions to the experiments of large international collaborations. However, the CFI grant cycle has some uncertainty and the process for decision-making on a grant is independent of NSERC SAPES. CFI also contributes funds to the ongoing operations and maintenance needs of national research facilities on a cost-shared basis through the Major Science Initiatives (MSI) program, including SNOLAB. CFI also provides funding to Compute Canada, which currently operates a variety of national high performance computing centres discussed further below.

The Canada Research Chairs (CRC) program provides direct funding for 2000 research professorships in a wide array of disciplines in Canadian universities. Holders of these chairs often have reduced teaching loads and preferential access to certain types of federal research funding. There are CRC chairs in subatomic physics at the universities of McGill, Carleton, Laurentian, Queen's, SFU, York, Toronto, Guelph, Winnipeg, Alberta, and UBC.

In December 2014, the Government of Canada launched the first two competitions of the Canada First Research Excellence Fund (CFREF), a new mechanism to support research in Canada. All CFREF awards are for up to seven years and there is no prescribed size for CFREF awards. Following the 2nd competition, in September 2016 CFREF announced it would support the creation of the Canadian Particle Astrophysics Research Centre (CPARC), with $63.7 million in funding over seven years. CPARC was renamed the Arthur B. McDonald Canadian Astroparticle Physics Research Institute (McDonald Institute) in May 2018. The McDonald Institute is headquartered at Queen’s University, with members located at seven affiliated Canadian universities – Alberta, British Columbia, Carleton, Laurentian, McGill, Montréal and Toronto. The new centre also partners with the Canadian Institute for Advanced Research (CIFAR), the Institute of Particle Physics (IPP), the Perimeter Institute, SNOLAB and TRIUMF. The McDonald Institute is primarily involved in and supporting projects based at SNOLAB, or potentially based there: direct detection of dark matter projects, including PICO, NEWS-G, SuperCDMS, DEAP-3600 and the future liquid argon program; and neutrino physics projects such as SNO+, nEXO, LEGEND, and the supernova watch experiment HALO. In addition, a central thrust of the McDonald Institute is to strengthen astroparticle theory across Canada. The McDonald Institute also supports related programs in high-energy neutrinos and new R&D initiatives. The McDonald Institute used the funds to create 15 faculty positions spread across Canada (Queen’s 7, Alberta 2, Carleton 2, Laurentian 1, Montreal 1, Toronto 1), 52 positions for researchers, engineers, designers, and technicians, as well as provide opportunities for 22 postdoctoral fellows and 43 graduate students on an annual basis. An additional research scientist position equivalent to faculty rank was also established at TRIUMF. Additional research positions have been created at various institutions across Canada made possible from pooled funds administered by the McDonald Institute and provided by CFREF. These HQP positions average fifty on an annual basis, providing funding for postdoctoral fellowships, graduate students, and undergraduates. Queen's University has fulfilled its commitment to add seven new faculty members,

including three in cross-disciplinary fields (materials engineering, isotope geo-chemistry and chemistry), in support of the McDonald Institute. The 15 new faculty hires (whose salaries were bridged by CFREF funds) were initially ineligible to apply for NSERC grants during the bridging period; hence their research was supported by the McDonald Institute and university funds during this period. Starting gradually at the end of the 3rd year of the award, a number of Queen's faculty were moved off McDonald Institute funds and onto Queen's University funds to allow them to apply for NSERC funding. Starting in 2021, all CFREF-supported faculty members are eligible to apply to NSERC as co-PI (though not as PI until the end of the bridging period). The next CFREF competition is expected to be launched in 2022. The Canadian astroparticle physics community is considering another application for funds in this new CFREF competition, with a new scope.

Also noteworthy is that within the Canadian research environment there are various resources, such as subsidized technical shops, that can be accessed through the leveraging of institutional and grantee resources. Moreover, the cost sharing of resources from grantees on different research projects within an institution, or even from different institutions, is common and the use of the MRS centres facilitate and encourage these efficiencies.

Canadian subatomic physics research institutes

TRIUMF, Canada's particle accelerator centre, is funded via a separate mechanism. TRIUMF was incorporated in 2021 and at the time of writing of this document is owned by 14 Canadian universities. The main source of TRIUMF's ongoing operations funding is $267.3M in core operating funds plus $25M for infrastructure projects over five years (2020-25) from the Government of Canada administered through the National Research Council of Canada (NRC). Additional funds come indirectly from CFI (through Canadian universities), and capital funds come from the province of British Columbia including for the construction of buildings. In addition to its extensive on-site research programs, TRIUMF is a vital national support centre for all types of subatomic physics research, including detector construction and testing facilities. The individual CFI awards are now being used to build unique research infrastructure that TRIUMF is unable to support through its NRC funding. A number of TRIUMF research scientists have academic appointments at partnering universities, some of which are jointly funded, and supervise graduate students from the universities with which they are affiliated. Note that in the table in the Appendix, students listed under TRIUMF may also be listed by the universities where they are registered.

SNOLAB, Canada's underground physics laboratory, is located two kilometres below the earth's surface in the Vale Creighton nickel mine near Sudbury Ontario. SNOLAB operations are currently funded through CFI and the Province of Ontario with in-kind support from Vale. Inc. The construction of the surface facilities and underground laboratories of SNOLAB were funded by the International Joint Venture program of the CFI, the Ontario Innovation Trust, the Northern Ontario Heritage Fund Corporation and FedNor. SNOLAB research scientists can have academic appointments at partnering universities and supervise graduate students from across the country. SNOLAB research scientists receive NSERC grants that support the training of our vibrant research community and next generation of innovators.

Perimeter Institute (PI) is an independent, resident-based research institute devoted to foundational issues in theoretical physics located in facilities in Waterloo, Ontario. PI receives public funding from both the Ontario Government and Government of Canada, as well as from CFI. Private funds come from a variety of individuals, corporations, and foundations – including BMO Financial Group, Templeton Foundation, SunLife Financial and others. Researchers are also supported by grants and awards from NSERC and Templeton. In addition to its full-time faculty members, PI has Associate Faculty members who are

regular faculty members at partnering Canadian universities and are also employed part-time at PI. PI offers a course-based Master's program through which students receive an M.Sc. from the University of Waterloo. PI faculty supervise Ph.D. students who receive their degree from the partnering university where their supervisor has an affiliation. Note that in the table in the appendix, students listed under Perimeter Institute may also be listed by the universities where they are registered.

The Canadian nuclear and particle physics communities are self-organized into two institutes, the CINP and IPP, which are federally-incorporated non-profit corporations. Both institutes are supported by a combination of NSERC MRS funds and internal funds provided by their institutional members. The IPP and CINP provide representation of their respective research communities to various bodies, such as the Canadian Subatomic Physics Long Range Planning Committee, ICFA and NuPECC, and enhance university-based theoretical and experimental subatomic physics research in Canada. The IPP has the additional role of coordinating the participation of Canadians in international particle physics collaborations, and employs Research Scientists who hold academic appointments at IPP Institutional Member universities and who can be located at an IPP university or at a laboratory, in Canada or abroad. IPP Research Scientists hold NSERC grants and supervise both M.Sc. and Ph.D. students who receive their degrees through their affiliated university. IPP also operates a Summer Fellowship program for undergraduate students, which has them work with a Canadian research team in May and June before placing them at CERN for July and August as part of CERN’s Summer Student Programme.The Early Career Theory Fellowship was launched by IPP in 2019 to connect Canadian postdocs with foreign research groups. The CINP does not presently employ any Research Scientists, as NSERC has indicated that any personnel so-hired would not be eligible to apply for grants.

Compute Canada is an organization formed by the research community across Canada with operations funded by CFI (and the corresponding provincial funding organizations) via the MSI program.
The subatomic physics community uses computing resources for the storage, analysis and reconstruction of data, production of simulated data samples, and theoretical calculations. The great majority of computing resources and support are requested and obtained from Compute Canada via a competitive resources allocation process based on scientific merit. These resources are shared and located at four national computing centres at the universities of Victoria, Simon Fraser, Waterloo and Toronto. Compute Canada is an organization formed by the research community across Canada and has been primarily funded by CFI, and initially also by NSERC, as well as provincial and institutional partners for matching funds. Today, Compute Canada is in the process of being replaced by a newly formed organization, The Digital Research Alliance of Canada. The Digital Research Alliance of Canada is directly funded by the Ministry of Innovation, Science and Economic Development Canada (ISED) and will formally commence its operations for Fiscal year 2022. ISED also funds CANARIE which provides the overall Canadian research community with high-speed network connectivity between research institutions and the Compute Canada computing centres. In addition to Compute Canada Tier-2 resources, the ATLAS experiment also requires a dedicated Tier-1 facility, located at Simon Fraser University, which is operated 24/7 by dedicated TRIUMF personnel and SFU, independently of Compute Canada. The Tier-1 centre has been funded by CFI with matching funds from the province of British Columbia. CANARIE provides the ATLAS Tier-1 centre with a dedicated link to CERN to receive ATLAS raw data in quasi-real time.

Apart from desk-top computers, which are purchased with NSERC Subatomic Physics Project or Individual Discovery grants, small local clusters at several institutions and the ATLAS Tier 1 as mentioned above, essentially all computing in Canada is now provided via Compute Canada.

Canadian M.Sc. and Ph.D. programs

One of the unique aspects of the training of physics graduate students in Canada is the structure of the Master of Science (M.Sc.) degree program. In Canada, the completion of the M.Sc. degree in physics in most institutions requires the production of a substantial (~100 pages) thesis on original research, as well as the completion of a required number of graduate level physics courses. In many institutions, an oral defense of the M.Sc. thesis is required. It normally takes 2-3 years to complete a M.Sc. degree, with this time divided about 1/3 on coursework and 2/3 on research under the close supervision of the supervisor. Subatomic physics M.Sc. students are exposed to a large number of research techniques, but not to the depth or level of research independence expected of a Ph.D. student. Some M.Sc. students have a desire to enter industry in the early stages of their career, and may have little interest in an academic career, and therefore begin their M.Sc. with no intention of continuing towards a Ph.D.

The successful completion of the Ph.D. degree requires a significantly greater level of research depth and independence. Ph.D. students are required to take additional graduate courses, complete a comprehensive exam, and orally defend a 100-200 page thesis. Students performing particularly well in their M.Sc. studies may have the opportunity to transfer directly to the Ph.D. program after their first year of Master's studies. Other students may elect to complete the M.Sc. first and then apply to the Ph.D. program. In some universities, it is possible for an exceptionally strong student to directly enter the Ph.D. program without having an M.Sc. In most Canadian universities, if a student enters a Ph.D. program without an M.Sc., either via direct entry or transfer, it is not possible for the student to later receive an M.Sc. degree should problems arise in the course of their Ph.D. studies. The typical graduate student spends 3-5 years in the Ph.D. program, in addition to the time spent in the M.Sc. program.

As alluded to above, subatomic physics graduate students at Canadian universities usually take graduate classes and do research work in a concurrent manner from an early stage of their graduate studies. Typically, both M.Sc. and Ph.D. students also have Teaching Assistantship (TA) duties for four or eight months of the year. This differs from some other countries, where the physics graduate student spends several years exclusively working on graduate classes and passes a qualifying exam before transitioning 100% to research. During the full duration of the M.Sc. and Ph.D. degrees, subatomic physics students are normally supported by a combination of TA funds, Research Assistantship funds from their supervisor's NSERC grants, and scholarships. Note, however, that in some institutions TA funds are not available to all international students and the difference is made up from the supervisor's NSERC research grant. Subatomic physics students performing research at offshore labs typically try to complete their courses in a manner that enables them to move to the labs for extended periods of time. When they move to the labs, they no longer receive TA funds and the funding difference is made up from the supervisor's NSERC research grant. When students are posted at a lab such as CERN, there can be a significant difference in the cost-of-living as compared to their home city, and a Cost Of Living Adjustment (COLA) must be provided from the grant. More information on these support levels are given in the table in the Appendix to this document.

Regional differences in the training of Highly Qualified Personnel (HQP)

Canada is a sparsely populated country of vast geographic extent. As a result of this geography, and the fact that education is a provincial jurisdiction, it is not surprising that a number of regional variations in physics HQP training have developed. The university system is primarily publicly funded through the provinces, with tuition fees varying considerably from province to province. Some provincial governments, e.g. Ontario and Quebec, operate graduate scholarship programs, but others do not. Tuition fees and other academic costs cannot be paid directly from the NSERC grant of the supervisor, but rather is paid by the students from the support they receive from research grants, teaching and any scholarships that they might hold. The universities in Quebec, Ontario, Saskatchewan, Alberta and B.C. follow a fairly

traditional model, with most of the research performed at the larger, research-intensive Ph.D. granting universities. Quebec is distinguished with a significantly lower tuition rate for Quebec students than the rest of the country. Tuition fees in the other provinces are more similar, with Alberta being the lowest and Ontario the highest. In all provinces, the cost of supporting a student from the supervisor's grant is two to three times less expensive than the cost of hiring a postdoc.

HQP training in subatomic physics also involves undergraduates extensively, especially at primarily undergraduate institutions. Universities in Atlantic Canada are a prime example of the role of undergraduates in NSERC-funded research. Relative to its population, the Atlantic region has a very large number of small, primarily undergraduate universities and a much smaller number of Ph.D. granting institutions. These primarily undergraduate universities attract students from across Canada, many of them being very good students. As part of their B.Sc. Honours project requirements, they take part in the research of physics faculty members. In addition to their contributions to NSERC-funded research, the students graduating from these undergraduate research programs often go on to become subatomic graduate students across the country and therefore have a broad impact on HQP training in Canada.

To further illustrate the regional differences in HQP-training, we also profile the universities in the province of Manitoba. The University of Manitoba (UofM) is the only Ph.D.-granting institution, and the other universities in that province are all primarily undergraduate. Active researchers at the universities of Winnipeg and Brandon hold adjunct faculty status at the UofM and as such can directly supervise M.Sc. and Ph.D. students. Their graduate students register and take their classes through the UofM, but spend significant time at the campuses of their supervisors.

A sense of the institutional and regional differences and similarities can be obtained from the table in the Appendix. Although the table and other information provided in this document provide information about the various institutions engaged in subatomic physics in Canada, in order to fully understand the overall research environment and the context in which the research is conducted, a site-visit to the various institutions is required.

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Appendix:
Table of information provided by various
Canadian universities in geographic order of east to west

Institution	**No. funded SAP Faculty**	**Local facilities**	**SAP Research Programs**	**Typical Grad Student Support from Supervisor/yr** **assuming students are at the university (when at the labs, the supervisor pays the TA rate plus COLA)**
Memorial – Grenfell campus (Corner Brook, NL)	2 Theory	Atlantic Computational Excellence Network (ACEnet)	Low energy QCD, precision PV tests of Standard Model, Searches of physics beyond SM. Collaborative projects with JLab, Mainz, Dubna. (1 PhD, 1 MSc)	Ph.D. program available through St. John's campus of Memorial. Supervisor contributes $8k-19k (NSERC) grant
St. Francis Xavier (Antigonish, NS)	1 Exp	One room lab space (newly developed) & Atlantic Computational Excellence Network (ACEnet)	Belle II, BaBar	Undergraduate institution
Saint Mary's (Halifax, NS)	3 Exp	Subatomic physics has been listed in SMU's strategic research plan. 2 rooms lab space, Linux servers, Atlantic Computational Excellence Network (ACEnet)	Leads CFI-funded IRIS and CANREB facilities at TRIUMF. Offshore research at GSI, Mainz (Germany); JLab, MSU (USA), RIKEN (Japan) (3 PDF, 3 PhD, 1 MSc)	$28-32k
Acadia (Wolfville, NS)	1 Theory	Designated room for undergraduate students working in subatomic theory	Non-perturbative QCD effects in rare B decays, light-front holographic QCD, hadron structure	Undergraduate institution
Mount Allison (Sackville, NB)	1 Exp, 1 Theory, 1 adjunct Theory (Acadia)	1 detector lab, computers	Experimental research at Mainz (Germany). Theory: non-perturbative computation of rare B decay observables for LHCb	Undergraduate institution
McGill Montréal, QC)	Particle: 7 Exp, (includes 2 IPP RS), 6 Theory Nuclear: 2 Exp, 3 Theory	ATLAS sTGC lab for characterization of thin gap chambers, Photon detector laboratory with test equipment nEXO lab for photon detector development, Machine shop	Particle and Nuclear Theory, ATLAS, Belle II, CALICE, TRIUMF collinear laser spect, CPT, VERITAS, HELIX, TITAN, EXO. Total SAP: (11.5 RA/PDF, 37 PhD, 24 MSc)	$18.2k from NSERC grant, $4.8k TA. Departmental merit based scholarships available. Students working at national labs receive cost-of-living top-ups.
Concordia (Montréal, QC)	1 Theory	Unix server	Theory: part-time RA, 3PhD, 1 MSc	$8-10K from NSERC grant; $7.5k TA; $5k scholarship, International Fee Remission, additional performance-based scholarships ($3K-$10.8K); Total = $22.5k

Université de Montréal (Montréal, QC)	5 Exp, 2 Theory	500m^2; class 10 000 clean room with class 1000 section;300m^2 detector construction space; local computing. In house Tandem Van de Graaff facility, proton and heavy ion test beams for detector calibrations; irradiation facility to study radiation hardness of materials and detector components; low energy (keV) mono-energetic neutron facility for detector calibrations; machine shops with 3 NC lathe/milling machines, 2 technicians; MRS Supported Groupe Technologique for particle physics instrumentation R&D, prototyping and development of detector read-out modules, support of SAP projects	Experimental Particle Physics Program: ATLAS, PICO, SuperCDMS (4 PDF, 7 PhD, 7 MSc); Theory (1 PDF, 1 PhD, 4 MSc)	$16.8k (MSc) and $19.2k (PhD) from NSERC grant; $2k TA; $1.5k scholarship; Total=$20.3k (MSc) and$22.7k (PhD). Performance-based scholarship also available (10k$)
Carleton University (Ottawa, ON)	10 Exp, 5 Theory (Note:1 Exp supported via CPARC CFREF)	Half of large research wing devoted to SAP Research; Large high bay assembly area for detector assembly and testing; ATLAS CFI funded lab for muon chambers assembly (Phase1 NSW upgrade); SNOLAB CFI cryogenic facility for development of noble liquid detectors and optical readout; ATLAS CFI award for chip and sensor testing (Phase2 ITk upgrade); Computer farm with ~400 cores + > 400 TB storage for HEP with dedicated computer room with stand alone HVAC system; Access to precision machine shop at the Science Technology Centre; NSERC MRS personnel (design, electronics, machining) and detector facilities available to community; CFREF and CPARC technical team	Particle Physics Experimental Program: ATLAS, EXO, DEAP, ILC (10 PDF, 10 PhD, 10 MSc); Theory (3 PDF, 7 PhD, 1 MSc)	$16k from NSERC grant for PhD ($12k for MSc), $10.5k TA, ~$5k scholarship; total = $31.5k ($27.5k for MSc)

Queen's University (Kingston, ON)	10 Exp, 2 Theory Includes 1 IPP RS	Two clean rooms, Four general laboratories; optical cryostat, CDMS test cryostat, bubble chamber, optical spectrometers for scintillation studies, dark rooms for PMT testing, low background counting facilities (radon emanation); local computing - HPVCL on campus; three admin assistants, an engineer, and 4 technical staff members supporting the SNOLAB effort. Through CPARC: 5 additional administrative staff and are starting to hire technical staff. (one so far) Through the MRS: 3 technical staff. 3 non-CPARC admin. supporting the group	Current Particle Physics Program: DEAP-3600, SNO+, PICO/PICASSO, NEWS-G, SuperCDMS and CUTE (test facility), SBC, KDK (at Oak Ridge), IceCube (6 PDF, 9 PhD, 13 MSc)	$12k from NSERC grant, $8k TA, $6k scholarship; Total=$26k
Laurentian (Sudbury, ON)	6 Exp Five are supported by SNOLAB/MI, of which three are Emeritus and Adjunct and 2 are Adjunct at LU. One is an Emeritus Professor.	SNOLAB Lab on campus shared among the experiments, 4 rooms for computer, electronics and test work, 1 room for detector testing and storage, 2 chemistry labs, 2 half rooms for storage; also uses SNOLAB cleanroom space; (1 technician MI support for the group)	EXO, HALO, PICO, SNO+ 2RA/Postdoc, 3 PhD, 7 MSc students	Average $16k from NSERC grant for MSc, $19k for PhD, plus $9k TA for MSc, $13k TA for PhD, $1k university stipend (one-time); for Graduate students supported by LU faculty at institutions where they have Adjunct status (Carleton, McGill), the GTA/level of support matches that reported by these institutions
SNOLAB (Sudbury, ON)	15 Exp research scientists (adjunct professors at Laurentian and other Universities)	4,900 m^2 underground clean room research laboratory with associated services and infrastructure including lay down areas, personnel facilities and material handling. 3,300 m^2 surface facility including clean room laboratories, meeting rooms, control rooms, office space, warehouse, laydown areas and material handling. Low background counting facilities. Scientific, technical and logistics support for experiments	SNO+, DEAP-3600, DarkSide, Argo, PICO, HALO, Scintillating Bubble Chamber, DAMIC, SENSEI, EXO/nEXO, SNO+, SuperCDMS, CUTE	

Toronto (ON)	10 Exp, 4 Theory (includes 2 IPP RS)	1 prototyping lab (50m2); 1 Construction Lab (100m2); 1 clean room (100m2); 1 storage room (40m2); 1 general laboratory space (140 m^2 in 4 rooms) Access to computing via SciNet and NDRIO/Alliance with local workstations; Access to machine shop, electronics design/fabricaion and graphics services; 2 technicians (supported on CFI) Departmental Physics Computing Services is an excellent resource for support, software and hardware advice	Particle Physics Experimental Program: ATLAS, SuperCDMS, Mathusala, DUNE, T2K, SRF (8 PDF; 30 PhD+ MSc); Theory (1 PDF, 10 PhD+MSc)	$21k from NSERC grant, $7k TA, $7-12k scholarship; Total=$35-40k Note: HEP students at the University of Toronto are admitted to both direct-entry PhD and MSc (usually followed by PhD). First year grad students usually do 1-year M.Sc. with required courses and a research report.
York (Toronto, ON)	3 Exp, 4 Theory	Two labs for small construction projects; 320 compute ores, machine shop	ATLAS, T2K, ALPHA, DUNE. Experiment (2 PDF, 4 PhD, 3 MSc) Theory (2 PDF, 2 MSc)	$9k-$15k from NSERC grant, $11k TA, $4k scholarship; Total=$24-$30k
McMaster (Hamilton, ON)	1 Exp, 1 Theory	CFI-funded detector lab, local computing and lab space available	Radioactive beam experiments at TRIUMF and Argonne (2 PhD); Theory (1 PDF, 4 PhD, 2 MSc)	Supervisor contributes $11.5k, univ TA and scholarship brings total to $25.5k
Guelph (ON)	3 Exp 2 Theory	Laboratory for detector development projects Extensive Machine Shop Contributed 700-core CFI-funded cluster to SHARCNET	Led the NSERC funded TIGRESS gamma-ray spectrometer, the CFI-funded DESCANT neutron detector array and GRIFFIN gamma-ray spectrometer. Offshore experiments at Argonne (USA), RIKEN (Japan), Munich(Germany). Theoretical studies of nuclear forces, ab-initio nuclear structure calculations, nuclear astrophysics. Experiment: (5 PDF, 9 Ph.D, 7 M.Sc.) Theory: (1 PDF, 6 M.Sc.)	$17k from NSERC grant, $13k TA, Total=$30k
Perimeter Institute (Waterloo, ON)	10 PI faculty (all theory)	Office and seminar space; local computing resources	Particle theory, quantum fields and strings, quantum gravity; 36 graduate students at or associated with PI. See discussion on p.3 re grad student supervision.	Resident PI students have most support from NSERC grant, (no TA as there is no undergraduate program at PI), plus a scholarship

Western Ontario (London, ON)	2 Theory (1 cross-appointed with PI)	Computing resources: SHARCNET	Theory (1 PDF, 3 PhD)	$18k from NSERC grant (note: 1 international student comes at that level of funding, additional students come progressively more expensive), $5k TA, $4k scholarship; Total=$27k
Manitoba (Winnipeg, MB)	4 Exp with 1 search underway, 1 Theory, 2 additional research-active Emeriti (3 exp, 1 theory) and 8 Adjuncts	Computer cluster, Clean room, 3 CFI-funded detector labs, 3D printers (plastic and metal), Various subtractive machines (CNC, etc.), Low energy proton source detector test facility, Access to nano-fabrication lab, Robotic microchip bonder (soon)	Canadian Penning Trap at Argonne; cold neutrons at SNS and NIST ultra-cold neutrons at TRIUMF; MOLLER at JLab; P2 at MESA/Mainz; Atomic Parity Violation and TITAN at TRIUMF/ISAC, Electron-Ion Collider, Chiral Belle at SuperKEKB. 30 students enrolled in SAP GS, at the UM, in total. Exp: 15 PhD, 10 MSc; Theory: 2 PhD, 3 MSc. (Of these graduate students, 13 are funded via UWinnipeg or Brandon and 4 via TRIUMF) 7 PDF/RA.	PhD students $21k, MSc students $20k from grant, plus COLA and TA-buyout for offsite students
Winnipeg (MB)	4 Exp + 1 adjunct from TRIUMF; 1 Theory	Four labs, including clean room, gas systems, detectors, DAQ electronics, lasers, NMR equipment, SQUIDS, Xe polarizer, magnetometers, magnetic shielding	Neutron EDM search with Ultra-cold neutrons at TRIUMF, neutrinos, electron scattering, particle theory, string theory; (8 PhD and 5 MSc at Manitoba; 3 are co-supervised with Brandon)	Supervisor typically contributes $19k; total funding as at UManitoba
Brandon (MB)	1 Theory		Numerical and analytic studies in non-equilibrium field theory, non-perturbative field theory and transport theory (2 PhD, 1MSc at Manitoba; co-supervised with Winnipeg)	Supervisor typically contributes $19k; total funding as at UManitoba
Regina (SK)	Nuclear Physics: 3 Exp +1 emeritus + 3 adjunct from JLab; ParticlePhysics: 2 Exp + 1 adjunct from TRIUMF; 1 Theory with 1 search underway	Three labs including detector construction and testing space, two CPU clusters; 3D printer, access to electronic and machine shops at subsidized rate. Non-SAP faculty in related areas: 1 nuclear imaging, 1 neutron imaging search underway	GlueX and Meson form factors at JLab; Electron-Ion Collider; Nuclear structure and nuclear astrophysics at ISAC, NSCL/FRIB (USA) & GANIL (France); T2K. Nuclear Physics Expt: JLab (2 PDF, 6 PhD, 1 MSc supported via a mix of NSERC and local funds), EIC (1 PhD, 1 MSc). Particle Physics Expt: T2K(1 PDF, 1 PhD, 1 MSc); Halo-1kT (no HQP yet)	Nuclear Physics: Supervisor contributes $14-26k, to this add: TA=$5k and scholarships from Fac.Grad.Studies. Total=$23-34k. Particle Physics: Supervisor contributes $17-20k. To these add: TAs = $5k-$10K and/or scholarships from Fac.Grad.Studies. Total=$25k (amount committed to the student)

Saskatchewan (Saskatoon, SK)	1 Exp, 2 Theory	Faculty are members of the Subatomic Physics Institute (SPIN). 2 detector testing rooms. Collaboration with Canadian Light Source on campus has been helpful on many occasions. non-SAP faculty in related areas; 1 theory cosmology, 1 accelerator physics, 1 applied nuclear	Experiments at Triangle Universities Nuclear Lab (USA). Particle physics theory and phenomenology. (Exp: 2 MSc. Theory: 1PDF, 3 PhD, MSc). Theory research program includes: QCD sum rules and hadronic physics; Dark matter and particle astrophysics; Nuclear Compton scattering and photonuclear reactions	Supervisor contributes $10.5k, TA+ scholarship: $10.5k. Total: $21k
Alberta (Edmonton, AB)	7 Exp, 2 Theory	8 labs (Radon free shop, Low background counting, IceCube Lab, Radioactive work lab, X-Ray lab, Assembly Lab, Detector lab, Clean Assembly Lab); Electronics shop, Machine shop, CPP+ personnel available to the community (engineer, detector technician, electronics technician);WestGrid (part of Compute Canada),Thor cluster (ATLAS),Theory cluster	Particle Physics Experimental Program: ATLAS, DEAP, IceCube, PICO/PICASSO, P-ONE, SBC, SNO+, MoEDEL, ALTA	MSc students: ~$28km from all sources. PhD students: ~29k from all sources
Calgary (AB)	2 Exp, 1 Theory	2 research labs; Clean Room for trace metal sample preparation; 3 magnetic sector mass spectrometers (two thermal ionization sources, one inductively coupled plasma source); Machine shop	Experimental Program: high precision mass measurements, double beta decay, and investigation of nuclear isomers using TITAN; ALPHA antihydrogen at CERN. Theory: R-process nucleosynthesis (1 RA, 1 PhD, 1 MSc.); Hadronic-to-quark-matter phase transition (1 RA, 1 PhD)	$11.8k from NSERC grant, $13.2k from TA, Total: $25k
Simon Fraser (Burnaby, BC)	Particle Physics: 4 Exp Nuclear Physics & Chemistry: 2 Exp	Local machine shop and a major nano fabrication and characterization facility (4D labs) available. Particle: Use of TRIUMF and SFU clean rooms & CFI infrastructure for ATLAS ITk upgrade. ITk sensor probing, module production and petal assembly. Computation: ATLAS Tier-1 project moved from TRIUMF to Compute	ATLAS (4 PDF, 7 graduate students) ATLAS ITk (2 PDF, several, engineers and technicians) P-ONE (1 PDF, 2 graduate students) Nuclear: In-trap decay spectroscopy using TITAN; gamma-ray and decay spectroscopy @ ISAC-1,2; integrated plunger program using neutron activation &	Particle: $21k for PhD students from NSERC grant, + TA and scholarships; Total=$27.8k Nuclear: $13-15k from NSERC, $6k TA, $0-2k scholarship. Total=$21-23k. Note: Assuming 1 term of TA-ship per year, and good grades a PhD student must receive about $17k from the

		Canada facility at SFU in 2018. Also hosting ATLAS Tier-2 and small Tier-3. Nuclear: D/T neutron generator, 8pi HpGe/BGO spectrometer, segmented HpGe counting station, radiochemistry lab, alpha spectrometer, XRFIN system	spectroscopy	NSERC grant. If their grades dip below a certain level it is $20k. If they do not TA, it is $26.5k.
Northern British Columbia (Prince George, BC)	2 Exp (including one emeritus)	One lab room for training: radioactive sources, solid-state and scintillation detectors, and data acquisition system	Ultra-cold neutrons at TRIUMF; Qweak/Moller at Jlab; Dragon at TRIUMF-ISAC	Mostly undergraduate; some MSc students at $5k/yr from NSERC
British Columbia (Vancouver, BC)	SAP: 8 Exp, 6 Theory (Includes 1 IPP RS) (does not include those reported by TRIUMF)	Use of TRIUMF facilities; Electronics shop (phas.ubc.ca/elab) Machine shop: (phas.ubc.ca/machine-shop) Student Machine shop: the above are staffed by 18 engineers/engineering technicians	ATLAS, Belle II, BaBar, TREK at JPARC, CAST at CERN, NA62 at CERN, SuperCDMS, and Theory group.	~ $10.5k from TA, ~$15k from supervisor-for non-scholarship students Students may have supervisors buy out 1or 2 of their 4 TA units per year for 1or 2 of their years, so for PhD students in their final 1-2 yrs, typically $5k from TA, $20k from supervisor. Top-ups for Scholarship students: for NSERC scholarship holders: $8700 for CGSM, $6000 for PGSD, $0 for CGSD for UBC internal 4 year grad scholarship holders: $8000 ALL PhD students get a $5198 full tuition award for 1st 4 years of PhD. MSc students do not get a tuition award. Scholarship students do not receive RAs until their scholarship runs out. Grad funding to the student total package ranges from $26,133 for non-scholarship MSc students, to $40,119 for CGSD awardees as seen in: https://phas.ubc.ca/graduate-program-financial-support

TRIUMF-Accelerator Physics (Vancouver, BC)	13 staff	TRIUMF accelerator facilities, SRF testing facilities, Ion source test stands, target laboratories, beta-NMR and MuSR facilities	Research Program: SRF and cyclotron development, target and ion-source development, wakefield acceleration (5 PDF, 13 PhD, 2MSc, 4 Engineers in Training (EIT)). See discussion on p.3 re grad student supervision.	For resident graduates students spending more than 4 months at TRIUMF the following minimum annual funding requirements apply: MSc: $20,000 + applicable benefits coverage (up to $1335) + tuition and student fees - external tuition awards PhD: $24,000 + applicable benefits coverage (up to $1335) + tuition and student fees - external tuition awards
TRIUMF – Nuclear Physics (Vancouver, BC)	11 Exp, 3 Theory	TRIUMF facilities: DRAGON, TUDA, SONIK, TIGRESS, GRIFFIN, GPS, DESCANT, TRINAT, TITAN, FRANCIUM, OSAKA, IRIS, EMA	Nuclear Physics Program: ISAC/ ARIEL RIB Exp (19 PDF, 11 PhD, 4 MSc) Theory (3 PDF, 3 PhD, 1MSc). See discussion on p.3 re grad student supervision.	See above.
TRIUMF – Particle Physics (Vancouver, BC)	14 Exp, 2 Theory	TRIUMF facilities: TUCAN (UCN) facility, detector facilities, ATLAS upgrade facilities; ATLAS Tier-1 and T2K Tier-1 (hosted at SFU), M11 test beam (e, μ,π), PMT test facility, Photon Sensing Facility. Proton Irradiation Facility (PIF) and Neutron Irradiation Facility (NIF)	Particle Physics Experimental Program: ATLAS, T2K/Hyper-K, TUCAN, ALPHA, nEXO, DEAP, HALO, Muon g-2, NA62, PIENU (20 PDF, 12 PhD, 11 MSc); Theory (3 PDF, 1 PhD, 4 MSc). See discussion on p.3 re grad student supervision.	See above.
Victoria (BC)	10 Exp, 3 Theory Includes 2 IPP RS	Large shared lab space; clean room; machine shop; electronics shop; local computing cluster plus access to Compute Canada grid; MRS detector development expert available to the community	Particle Physics Experimental Program: ATLAS, T2K, Belle II, BaBar, ALTAIR Accelerator/ARIEL/ILC (7 PDF, 16 PhD, 15 MSc); Theory (2 PDF, 6 PhD, 2 MSc)	Department policy Minimum: Domestic PhD: $19.3k from NSERC grant, $2.8k TA, Grad award $3.5k; Total $25.7k Domestic MSc: $17.9k from NSERC grant, $2.8k TA, Grad award $3k; Total $23.8k International: + 1.5k tuition top-up.