Strategic Plan – Accelerator R&D Division, Collider-Accelerator Department

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Motivation and Goals

The Accelerator R&D Division (ARDD) was established within BNL's Collider-Accelerator Department (C-AD) in December, 2009 (see organization chart in Fig. 1), primarily in recognition of the growing importance of a variety of advanced accelerator research projects in planning the long-term future of the RHIC facility. The Department is pursuing a significant number of R&D efforts, with implications for short-term RHIC performance improvements (e.g., beam cooling and superconducting rf cavities), long-term planning for an Electron-Ion Collider EIC (e.g., development of Energy Recovery Linacs – ERL – design of eRHIC, research on high-intensity polarized electron sources), applications in areas of national need (e.g., Rapid-Cycling Medical Synchrotrons – RCMS – ERL and ion source developments), and considerations of other long-term accelerator projects (e.g., X-ray FELs). It was felt that the focus on the R&D projects had to be strengthened, and separated from the dominant day-to-day demands of ongoing RHIC operations, to ensure more timely R&D results.

Another goal of establishing ARDD was to increase the visibility of BNL's accelerator R&D program within DOE, and to increase the national visibility of such R&D being carried out with funding from DOE's Office of Nuclear Physics (ONP), which supports most of the above projects. Other funding, as indicated later in this document, comes from the High Energy Physics Office (OHEP), from BNL Laboratory Director's R&D (LDRD) program, from the Office of Naval Research (ONR), and from CRADA's with commercial companies (e.g., BEST Medical, supporting the RCMS development). The ARDD furthermore strengthens the potential synergy with other BNL accelerator R&D units (e.g., the OHEP-funded Accelerator Test Facility, ATF, and muon collider research, the BES-funded Source Development Laboratory, and the BNL overhead-funded laser and photocathode research carried out within the Instrumentation Division) and with the recently established Center for Accelerator Science and Education (CASE) operated jointly by BNL and Stony Brook University. The CASE-ARDD connection is strong, and has already led to attracting students and post-docs to work with ARDD staff on cutting-edge accelerator science, as well as to increased funding (from sources other than ONP) supporting RHIC R&D objectives.

The groups that comprise the new division existed previously under the Accelerator Division, but lacked a central R&D coordination, which is now provided under ARDD. The Accelerator Division remains strong, and has ongoing RHIC operations and performance improvements as its primary focus. It also oversees R&D when the focus is short-term and the tasks well matched to the expertise of its members, as in the case of stochastic cooling developments for short-term improvements to RHIC's heavy-ion collision luminosity. Staff members of the Accelerator Division and of ARDD often collaborate on projects, so that the entire range of expertise of the scientific, professional and technical staff is available to be allocated according to priorities established to optimize RHIC's overall scientific impact, in both the short and long terms.

There are potential future advantages to consolidating the currently fragmented accelerator R&D units in different departments and divisions at BNL into a larger force with greater capabilities and a broader basis of experience, facilities and scientific staff. As examples, both the laser-photocathode work conducted within BNL's Instrumentation Division and the electron accelerator expertise in the ATF within the Physics Department are quite relevant to eRHIC R&D and design, while ARDD research on ERLs is of great interest for future X-ray sources contemplated by BNL's Photon Sciences Directorate. Such consolidations are presently under consideration at BNL. If they occur, staff time would be strictly charged according to the account numbers and funding sources for the different groups. This is, for example, presently the case for work done by ARDD staff under OHEP funding via the LARP (LHC Accelerator Research Program), which has been going on for some time. Several LARP goals – e.g., development of strong superconducting quadrupole magnets and of crab cavities – are also of great interest for eRHIC.

The objective of this Strategic Plan for the ARDD is to provide scientific and strategic vision, together with manpower planning and prioritization for the various R&D projects. The projects chosen address the goals of the ARDD program, as derived from C-AD's mission statement, to:

- Optimize and improve current accelerators in the RHIC complex
- Innovate new accelerator concepts
- Pursue cutting-edge research in
  - high-luminosity colliders
  - high-current, high-brightness acceleration techniques
  - electron and ion sources and accelerating structures
  - beam cooling techniques
- Address accelerator implications of fundamental interest to national issues such as energy, the environment, health care and national security.

The ARDD's exciting research program addresses world-class accelerator R&D problems such as: the design of a high-luminosity electron-ion (and polarized-electron polarized-proton) collider; generation of polarized electron currents one to two orders of magnitude greater than available today; and development of a high-current (one to two orders of magnitude greater than current performance) high-brightness ERL. The work in these areas has the potential for applications in a broad range of sciences. Discovery science applications beyond EIC may be achieved by using the developed technology to increase the luminosity of large hadron colliders and the flux of hard X-ray coherent sources.

Strategic Plan

General Principles

The Strategic Plan follows a number of fundamental principles.

1. Successful operation and improvement of existing machines and development of new accelerators requires a continuous program of accelerator science research.

2. Accelerators are the key to fundamental issues that face our nation, such as energy, the environment, health care and national security, and accelerator R&D is the tool to make progress in these important areas.

3. A successful team of accelerator scientists and engineers must have a critical mass and diverse range of talents to cover the complex aspects of modern particle accelerators.

4. Successful accelerator R&D requires involvement of R&D staff in an operating facility and, just as important, involvement of operations staff in R&D.

5. Education in accelerator science (undergraduate, graduate and post-doctoral) is both a national priority and a benefit to R&D efforts.

6. The central focus of the C-AD ARDD is Nuclear Physics R&D and operations, clearly targeted at RHIC and its potential upgrades, such as luminosity increases and eRHIC.

7. The funding level of ARDD efforts is in line with that at comparable facilities, namely, at a level of about 5% of the RHIC operations budget.

8. It is in the national interest to provide synergy between various funding sources for R&D. It is essential, however, that funding is kept clearly separated and accounts are charged accurately according to project and source of funding.

Mission Statement

The mission of the Accelerator R&D Division at the Collider-Accelerator Department is to develop and improve the suite of particle / heavy ion accelerators used to carry out the program of accelerator-based experiments at BNL; and to design and construct new accelerator facilities in support of the BNL and national missions. The Division participates in operations and provides a venue for Accelerator Division staff to participate in R&D. The division performs all these functions in an environmentally responsible and safe manner under a rigorous conduct of operations approach.

Accelerator R&D Division Organization

The C-AD Associate Chair for Accelerator R&D heads the ARDD and reports to the C-AD Chair (see Fig. 1). At the time of establishment of the ARDD (December 2009), the division comprised the following groups: eRHIC, R&D Accelerator Physics and SRF. An LHC Accelerator Research Program (LARP) unit funded by the Office of High Energy Physics (OHEP) is included in the R&D Accelerator Physics group. The detailed group structure of ARDD is shown in Fig. 2.

The R&D Accelerator Physics group provides a major linkage of personnel to the C-AD Accelerator Division (AD). ARDD research activities and the initiative of AD staff to take part in ARDD activities are encouraged. At the same time, participation of ARDD staff in RHIC operations is also strongly encouraged. Following the fundamental principles stated above, AD staff working on ARDD items are charged to the ARDD operations account and ARDD staff engaged in RHIC operations charge time to AD operations account.

Naturally, accelerator short-term R&D is carried out also in the Accelerator Division, e.g. RHIC beam studies, as well as construction / improvement projects. Long-term R&D is to be done mostly at the ARDD. Decisions on the divisional site of research depend on various factors, including relevant expertise. The ultimate decision in borderline cases is in the hands of the C-AD Chair. Clearly long-term R&D can sometimes lead to shorter-term benefits. For example, the Coherent Electron Cooling R&D aimed at eRHIC may lead to an increase of luminosity for RHIC polarized proton collisions.

Education in accelerator science at all levels is provided by a direct connection of the ARDD to the Center for Accelerator Science and Education (CASE), a Stony Brook University and BNL joint institute. CASE also provides another avenue for resources (over and above Office of Nuclear Physics funding) to complement ARDD programs.

Future possible directions for further growth of ARDD have been identified as consolidation of other accelerator R&D units at BNL. The units most clearly ready for such a move are the OHEP funded Accelerator Test Facility (ATF) and the Advanced Accelerator Group (AAG, which works on muon collider R&D), both located presently in the BNL Physics Department. The advantages of such a move, beyond enhanced intellectual cross-fertilization, are consolidation of accelerator teams that bring new capabilities to C-AD (such as laser scientists, beam dynamics scientists and capabilities in high-brightness electron acceleration) and reciprocally an increased matrixed support to the two groups. Two examples can be used to demonstrate these synergies. An experiment to study the effect of the shielding of coherent synchrotron radiation – an important question for eRHIC – is being done at the ATF in collaboration with ARDD scientists. Wakefield excitation in Stochastic Cooling kickers and pickups is being studied to take advantage of the very short bunches of the ATF. Complementing the advantages to ONP, there are important safety and management benefits for the ATF and AAG, as well as the expanded accelerator science intellectual environment.

Current ARDD Activities

The R&D strategy of the ARDD naturally revolves about RHIC and eRHIC. The common theme is superconducting RF. To date, the achievements of the program have been in establishing a niobium chemistry facility (offsite at Advanced Energy Systems), operations with a SRF electron gun at 1.3 GHz, and the development of a unique high-current ERL cavity.

Brief descriptions of the current portfolio of accelerator R&D and AIP activities at the ARDD follow. The timelines and milestones indicated for some of these projects are consistent with an overview plan for manpower for the ARDD efforts presented later in this document.

Core projects:

- 56 MHz SRF cavity for RHIC. This is an ONP AIP project, aimed at a luminosity enhancement of about 50% beyond the bunched beam stochastic cooling enhancement for full-energy heav-ion collisions. The objective of this project is to install the cavity in RHIC in summer 2013, in time for use in Run 14. Beyond the allocated AIP funding, this project relies heavily on support from C-AD mechanical engineering, vacuum group, cryogenics group, RF group, controls group, etc. for design, installation and operations.

The components are mostly fabricated by industry. A list of high-level milestones follow:

- Program start January 2008
- 1st External review committee January 2009
- Cavity design complete September 2010
- 2nd External review committee March 2011
- Dampers, probes design complete June 2011
- Cryostat design complete July 2011
- Cavity fabrication complete September 2011
- Vertical Test Facility (see next activity) ready September 2011
- Cryostat fabrication complete December 2011
- Cavity processing complete January 2012
- Dampers, probes fabricated February 2012
- Cavity string assembly complete April 2012
- Cryomodule assembly complete August 2012
- Cold testing complete June 2013
- In-tunnel installation complete September 2013

- Completion of the construction of the large Vertical Test Facility (VTF). This is part of C-AD operations to provide infrastructure for future SRF cavity tests, such as the 56 MHz cavity and eRHIC prototype cavities. It includes 3 vertical test dewars that can accommodate SRF cavities up to 38 inches in diameter and 96 inches in length. The dewars are being connected to a liquid helium refrigeration system that will allow for testing down to 1.8 K. A soft wall class 10,000 clean space is also being installed that will house a furnace designed for heat treatment of SRF cavities to 800°C, as well as a soft wall class 100 clean room for cavity assembly. The plan is for these installation activities to be completed by summer 2011. However, as of the final editing of this document, serious uncertainties regarding the FY2011 budget, following a long Continuing Resolution, have led to a (hopefully temporary) postponement of expenditures not directly related to the ongoing RHIC run, and this may cause some delay in completing the above clean room areas on schedule. Planning is also underway for the procurement of a fixed wall clean room that will allow for assembly of complete eRHIC cryomodules, and several locations in the vicinity of the VTF have been identified as possible locations for its installation.

- A SRF Cavity Chemical Processing Facility has been installed off-site, in collaboration with Advanced Energy Systems, a local small business, using $1.8M of BSA patent revenue funding. This facility is designed for chemical etching, high pressure rinsing and assembly of SRF cavities in a class 10 clean room prior to transport to BNL for testing in the VTF. This facility is presently being enhanced through Fermilab funding by the installation of an electro-polishing system, an alternate method to prepare the SRF cavity RF surfaces that is showing great promise in providing superior RF performance.

- R&D ERL. The demonstration of a high-current ERL is an Electron Ion Collider (EIC) priority item as established by the EIC Advisory Committee. This effort is funded in part by DOD (mostly ONR), and in part by ONP R&D funds, C-AD technical support (also

ONP), BNL Director's Office funding and various SBIRs. The objective of this program is to begin commissioning the gun and accelerating cavity in 2011, commission the ERL in early 2012 and then study the machine to increase the current and characterize the beam properties in the 2012-2013 period. Over a longer term (2014-2017), we would seek to add a second return loop to the ERL, in order to test the multi-pass high-current ERL operation needed eventually for eRHIC. While led by ARDD staff, the construction of this complex device requires significant support from the various engineering groups at C-AD, matrixed from the other divisions whenever operations priorities permit. High-level milestones for the single-pass ERL development follow:

  - 5-cell cryomodule to Bldg. 912 October 2008
  - Start cold-emission tests March 2009
  - Gun cavity start processing January 2010
  - 1st External Review Committee February 2010
  - HTSS delivered for assembly July 2010
  - Gun cavity string delivered April 2011
  - Gun cryomodule delivered August 2011
  - Sub-systems connections to gun September 2011
  - Beam tests G5 metal photocathode October 2011
  - Beam tests G5 multi-alkaline December 2011
  - ERL injection components installation February 2012
  - System integration & checkout May 2012
  - ERL all Systems testing start May 2012

- Polarized electron gun for eRHIC. This is a BNL LDRD project, and another EIC priority item. An accompanying, funded LDRD project is for the development of a laser for the polarized gun. The gun R&D aims at demonstrating the principle of a multiple cathode gun with a funneling mechanism to produce potentially up to 50 mA of highly polarized electron beam, nearly two orders of magnitude above current state-of-the-art. The objective of this project is to operate two of the 20 cathodes in the design by the end of 2014. The personnel effort will be mostly from the ARDD division.

- eRHIC 704 MHz cavity R&D. The development of high-current ERL cavities for the eRHIC ERL is yet another EIC R&D item. Based on the lessons learned from the development of the 5-cell cavity of the R&D ERL, a new generation 5-cell cavity is being designed and will be fabricated and tested by the end of 2013. The funding for this work is provided by a grant from DOE OHEP to Stony Brook University to develop a high-current 704 MHz cavity for the CERN Superconducting Proton Linac. This is a good demonstration of the benefits of the close ties between CASE and BNL's ARDD.

- Coherent Electron Cooling (CeC) R&D. This is yet another EIC priority item. The objective of this research is to develop the details of CeC theory and simulations and carry out a demonstration experiment to prove the principles of this powerful method for cooling high-energy hadron beams. The CeC research was launched by ARDD staff initially with SBIR support for simulation work by Tech-X Corporation, and with some BNL LDRD support for the development of the Coherent Electron Cooler FEL wiggler amplifier. Beginning in FY11, ONP has provided competitive accelerator R&D funding

to work toward the proof-of-principle CeC experiment in RHIC, in collaboration with TJNAF and Tech-X. The initial allocation from ONP for this work is just under $1.5M, with follow-up proposals and reviews planned to secure similar annual funding over the next several years. If granted, the proposed funding profile would permit a demonstration of CeC by about 2016. BNL has been asked to contribute $2.0M to an upgrade of the cryosystem for RHIC IP2, needed for the CeC demonstration experiment.

- eRHIC R&D. This is a comprehensive design and study effort to develop all aspects of the machine layout, lattice, beam-dynamics, and detector-integrated interaction region for a high luminosity polarized electron-ion collider. The aim is to develop, by 2012, a pre-conceptual machine design, based on a staged approach with respect to the energy of the electron beam and collider luminosity, in sufficient detail to permit thorough external reviews of the design and cost estimates. The development of compact size recirculation magnets for the electron ERL, which presents a critical item for minimizing the cost of eRHIC, has been funded by BNL LDRD. Present (scientific + professional + technical) manpower for the effort is 6 FTE.

Other projects:

The following projects have involved some past effort from ARDD staff, or are under consideration for the future, or are funded entirely by non-ONP sources:

- Polarized electron SRF gun. This was an LDRD project aimed at investigating the possibility of a low emittance polarized SRF gun for the ILC. A University of Peking graduate student carries out most of the current work. The project will be phased out by April 2011.

- Diamond amplified photocathode. This innovative high-quantum-efficiency photocathode method was developed to provide high-charge bunches for the high-energy electron-cooling project. This project will be moved to BNL's Instrumentation Division, where most of the effort is presently occurring.

- Low energy electron cooling of RHIC (future AIP). Electron cooling was proposed to increase the luminosity of the RHIC collider for heavy ion beam energies below 10 GeV/nucleon. Providing collisions at such energies, termed RHIC "low-energy" operation, will help to answer one of the key questions in the field of QCD, about the existence and location of a critical endpoint on the QCD phase diagram. The required electron beam can be produced by using either an electrostatic or RF beam accelerator. Different approaches require different levels of R&D. Besides such challenges as operation in a wide range of energies, the use of the same electron beam to cool ions in two collider rings, and suppression of recombination, this would be the first electron cooler to cool beams directly while they are undergoing collisions. The objective of this program is to provide a luminosity improvement for the low energy RHIC program by 2016-17, if the physics results extracted from early beam energy scans in 2010-12 justify obtaining much larger statistical samples at beam energies below RHIC injection energy. This project would require significant AIP funding and strong support from C-AD engineering, vacuum, instrumentation and controls groups. There is currently insufficient manpower available to launch the program before ~2014, in light of the above priorities.

- LARP R&D. The LHC Accelerator Research Project (LARP) R&D is performed under HEP funding. Several BNL physicists partially or fully supported by LARP and Toohig fellows are strongly involved in the commissioning of the LHC and upgrade activities. Their contributions include work with the AC dipoles, luminosity monitor, measurement and correction of LHC optics, long-range beam-beam compensation, instability measurements and other areas of beam physics common to RHIC activities. A significant contribution to possible future LHC luminosity upgrades was made via a long-term visitor studying the feasibility and implementation of crab crossing. These cavities are now considered as a vital component of the LHC upgrade by CERN, and are also of great interest to attain user-demanded luminosities at eRHIC. There is thus a clear benefit from these projects to C-AD, in intellectual enrichment as well as improvement of RHIC luminosity and R&D on enabling technologies for eRHIC. The current eRHIC high-luminosity Intersection Region design also makes use of high field gradient Nb_3Sn superconducting quadrupole magnets developed and demonstrated for LARP.

- Proton Electric Dipole Moment (pEDM). This R&D subject is associated with a proposed novel experiment to measure (or place limits at significant sensitivity levels on) the electric dipole moment of the proton using a circulating longitudinally polarized beam in a dedicated storage ring. This project is presently in its initial R&D phase, and involves ring and lattice design, beam dynamics studies, spin coherence simulations, ultra-high precision beam position monitoring and very high DC electric fields, carried out mostly by non-C-AD personnel. C-AD is providing R&D support at the level of about 1 FTE towards a smooth transition into a possible construction project within a few years.

Manpower estimates and timelines:

In preparation for the February 2011 annual budget briefing with ONP, C-AD and the ALD for Nuclear and Particle Physics have considered the overall manpower levels that could sustainably be used to support the core R&D projects described above. In FY2011, 15 FTE of non-scientific C-AD manpower is being used to support the critical eRHIC-relevant R&D projects. In order to progress at a pace consistent with aiming for a CD-2 decision on eRHIC by FY2017, this combined effort will have to grow to 20 FTE by FY2013, and remain at that level through FY2017. In addition to the non-scientific support, we anticipate a steady devotion of 10 scientific FTE to the R&D program throughout the FY2011-2017 period. Support for this manpower comes from RHIC operations funding, although this can be supplemented by eRHIC project R&D funding in the later years of the period. Needed purchases for the various projects are supported from the funding sources indicated above in each case. Explicit M&S funding for accelerator R&D projects from RHIC operations is anticipated to remain steady at about $1.5M/year during this period, and should be supplemented by further ONP funds for the Coherent electron Cooling project, under a competitive program.

Within these manpower constraints, the breakdown of manpower among the various projects and sub-tasks, and the consequent bottoms-up timelines possible for the four main eRHIC-related R&D programs, are shown in Table 1 below, and summarized in Fig. 3. This table and figure represent the heart of the ARDD strategic plan for the coming 7 years.

Conclusions

Accelerator Science and Technology (AST) is strategically important to BNL objectives. AST is driving current BNL user facilities such as NSLS, RHIC and others. Furthermore, AST is a major driver of possible future user facilities at BNL, such as eRHIC and X-Ray FELs.

BNL has world-class research programs in accelerator science, such as high-current and high-brightness electron beams, photocathode R&D, advanced synchrotron light source development, free-electron lasers (4 FEL prize winners are from BNL, more than any institute world-wide), beam cooling, laser and plasma acceleration, and much more. BNL has unique experimental facilities such as the ATF (an OHEP-funded user facility for advanced accelerator concepts), the BES-funded Source Development Laboratory for FEL studies, and the ONP- and ONR-funded high-current superconducting ERL that is under construction. BNL has also developed a state-of-the-art SRF niobium treatment facility and vertical Superconducting RF cavity testing facility. Its photocathode R&D effort continues to be at the cutting edge internationally.

The Accelerator R&D Division of C-AD has been established to enhance accelerator R&D in the department and to promote accelerator science higher education. The division has a rich portfolio of projects and highly recognized accelerator scientists.

The focus of ARDD is on nuclear physics accelerator R&D related to RHIC and eRHIC. Efforts such as HEP-funded LARP and future HEP, BES or other funded Work for Others is strictly charged to the appropriate account. Yet clearly the synergy of related accelerator science operations makes the sum greater than a simple addition of the individual components.

The Accelerator R&D Division is a powerful and essential tool for accelerator R&D and accelerator science higher education, and as such enhances the current and future accelerator projects at C-AD and more broadly at BNL. We hope it will be recognized as a national resource as well.