Office of High Energy Physics

Report of the DOE Program Review of HEP Laboratory General Accelerator R&D

July 30–August 4, 2018

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1 Introduction

The Office of High Energy Physics (HEP) General Accelerator R&D (GARD) program supports a broad research program that includes the following research thrusts: Accelerator and Beam Physics (including theory, simulation, beam instrumentation and controls); Particle Sources and Targetry; Advanced Accelerator Concepts; RF Acceleration Technology (including R&D for Superconducting RF Systems and Materials, Normal Conducting High Gradient Accelerator Structures, and RF Sources); and Superconducting Magnets and Materials. The GARD Review on July 30–August 4 focused on the work in these areas being performed at Argonne (ANL), Fermilab (FNAL), Lawrence Berkeley (LBNL) and SLAC (SLAC) national laboratories; in FY2018, the GARD program provided $79 million for these areas of accelerator research and technology development, of which $69 million is in support of research efforts at the national laboratories, including test facility operations. There are no GARD-funded activities at BNL, nevertheless, for completeness, the review also included a stop at BNL since the Accelerator Test Facility there does support user experiments funded by GARD and because a comparative review of all HEP-funded electron accelerator test facilities was sought.

The review was co-chaired by L.K. Len and Eric Colby with the review committee consisting of Félicie Albert, John Galambos, David Kehne, David Larbalestier, Peter McIntyre, Steve Milton, Patric Muggli, Robert Rimmer, Steve Russell, Tsuyoshi Tajima, Antonio Ting, and Yoshishinge Yamazaki, along with DOE observer Glen Crawford. To ensure full coverage of the program, each reviewer was assigned certain specific topics to review. In addition, each reviewer was encouraged to comment on *all* aspects of the review, not simply those topics specifically assigned. Overall, the review committee was charged to make a comparative assessment of the respective labs' GARD research programs, as well as relevant accelerator test facilities, and those assessments form the core of this report.

In what follows, the findings, comments, and recommendations of the review are discussed for each test facility and by thrust area in Section 2. HEP's responses are given in Section 3 and a brief summary of the review is contained in Section 4. Following the main report, the appendices include the charge letter for the review, list of recommendations, committee members and agendas of the review sessions at each institution.

2 Overall Program Evaluation

Overall, the reviewers found the HEP Laboratory GARD program to be healthy and vibrant, with broad, meritorious activities being pursued at all the HEP-funded national laboratories. In general, strong progress is being made against a majority of the goals identified in the three GARD Roadmap Workshops that followed the HEPAP P5 and Accelerator R&D Subpanel reports[1]. The performance and accomplishments of all the laboratories have improved considerably compared to five years ago. The user facilities and test facilities are producing an impressive amount of science and there is notable investment in young people and future capabilities. The research at the different laboratories was considered to be of high quality, with strong HEP mission alignment, and executed in a lean and efficient manner.

The P5 and subsequent subpanel and GARD research roadmap reports seem to have energized the HEP accelerator community. It is evident that the roadmap process has had a very positive effect. Every laboratory reported progress against these roadmaps and it is clear they are using them to plan and prioritize activities and facility use. As a result, the program as a whole was found to be well aligned with the overall HEP mission.

Coordination within the GARD community of code developers has improved through the Consortium for Advanced Modeling of Particle Accelerators (CAMPA) program. ***It was recommended that the coordination and integration should be continued to avoid duplication, as well as provide steady support for code maintenance.*** In the advanced accelerator concepts area, the laboratories (LBNL, ANL, and SLAC) have moved rapidly toward development of practical high-gradient wakefield accelerators, and are now addressing important issues such as emittance preservation and positron acceleration. GARD support at FNAL for superconducting radio frequency (SRF) R&D has produced dramatic breakthroughs in cavity gradients and understanding the underlying science. In response to the RF technology roadmap, the normal conducting (NCRF) group is focusing efforts to increase efficiency and reducing overall cost of accelerators by creating innovative and practical designs and manufacturing techniques. In the superconducting magnet and conductor development area, FNAL and LBNL are pursuing new innovative designs and techniques to improve ultimate magnet performance. Considering the currently available budget for research, the resources going into GARD were believed to be well justified.[2]

The one exception to this overall positive assessment is that some reviewers commented that only modest improvements have been made over the past five years with regards to proton beam and targetry investments when compared with those for electron beams. Both of these areas are

[1] The three completed research roadmap reports for the GARD thrusts—Advanced Accelerator Concepts, Radio Frequency Acceleration Technology, and Superconducting Magnets and Materials—can be found on the HEP webpage: https://science.energy.gov/hep/community-resources/reports/. HEPAP reports are available online at https://science.energy.gov/hep/hepap/reports/.

[2] Because accelerator-related activities in other areas such as Accelerator Stewardship, directed accelerator R&D, US Particle Accelerator School, and US-Japan Research Collaboration supported by HEP were not within the scope of this review, the overall balance of the entire HEP accelerator portfolio was not addressed.

identified in the 2015 Accelerator R&D subpanel report. To some reviewers, making the necessary funding adjustments in favor of protons and targetry seemed slow.

2.1 Test Facilities

In this section, we discuss the findings, comments, and recommendations of the review committee for each of the beam test facilities at each of the laboratories visited, namely, the Argonne Wakefield Accelerator (AWA) at ANL, the Accelerator Test Facility (ATF) at BNL, the Fermilab Accelerator Science and Technology / Integrable Optics Test Accelerator (FAST/IOTA) at FNAL, the Berkeley Laboratory Laser Accelerator (BELLA) at LBNL, and the Facility for Advanced Accelerator Experimental Tests (FACET) / FACET-II at SLAC. When compared to the 2013 GARD laboratory review, the improvement in facility condition at ANL and BNL is dramatic: major changes are in place at the IOTA beamline at FNAL, BELLA still has the look and feel of a new facility, and FACET is in the midst of a major upgrade. ATF and FACET/FACET-II are National User Facilities, while AWA and BELLA prefer to operate as test facilities with collaborators. FAST/IOTA expressed desire to become a user facility. Discussions of other test facilities without beam will be included in the relevant GARD research thrusts in Section 2.2 below.

2.1.1 Argonne Wakefield Accelerator (AWA)

ANL operates the AWA as a small test facility with a staff of eight FTEs, down from ten FTEs previously. Since the last review (2013), the facility has undergone an extensive renovation. No major maintenance issues are expected over the next several years. AWA consists of two independent linacs that can be used for structure testing, two-beam accelerator (TBA) experiments, collinear dielectric wakefield acceleration (CWA) and plasma wakefield acceleration (PWFA). In addition, the emittance exchange (EEX) beam line provides a unique and exciting capability that is just starting to be explored. An electron beam with an energy of 75 MeV, and a second, 15 MeV, witness beam are available for these advanced acceleration tests. The AWA offers bunch charges ranging from 1 pC to 100 nC (highest available among the reviewed laboratories). The EEX beamline allows beam profile manipulation in 6-D phase space. AWA's unique niche is the ability to generate high-charge pulses and the expertise to shape the beam profile to tailor it for experimental needs.

In the past five years, the AWA team has produced 40 publications, ~100 conference proceedings, and 15 graduate students (11 of whom have graduated). The AWA provides 1000 hours of beam time a year, and has produced a number of significant results. These include results from the successful TBA experiment where 300 MW of RF power at a frequency of 11.7 GHz was extracted from the 75 MeV beam line to accelerate the witness beam in the dielectric wakefield structures at a gradient of 150 MV/m; the successful demonstration of a two-stage TBA; the use of the EEX technique to achieve a transformer ratio of 5 in a CWA; and the use of micro-lens arrays to improve the homogeneity of AWA's laser beam profile. The group has fostered a strong engagement with outside collaborators in industry, academic institutions, and other laboratories both domestically and internationally. In particular, they continue to maintain a strong partnership with Euclid Techlabs, with visiting scientists stationed at AWA contributing to all aspect of facility operations. Internally, there is also nascent engagement with the Advanced Photon Source. These collaborations enabled them to bolster their program and increase scientific output. AWA appears to enjoy very strongly support from the ANL upper management.

The review committee was very impressed by the capability, performance and accomplishments of the AWA program. It is a unique facility, ideally suited to study wakefield excitation in dielectrics. Dielectric accelerators can operate at low frequencies (10's to 100's of GHz), essentially in the linear regime, and can thus greatly benefit from the high-charge, long, shaped bunches to efficiently generate and extract energy from the wakefields. This is enabled by the emittance exchange capability of the AWA, as previously mentioned. Furthermore, dielectric or hybrid metallic-dielectric structures could be incorporated in CLIC-like collider designs, taking advantage of all the work done for CLIC and yet operate at higher gradient than CLIC. This possibility has attracted the interest of CERN, as demonstrated in one of the support letters included in the documentation provided. This could be a very important Advanced Accelerator Concepts (AAC) contribution to an actual collider in the short to mid-term, should CLIC be built.

In spite of its modest budget, the small AWA group operates like an efficient, well-oiled machine, allowing them to punch way above their weight. The highly dedicated staff is very motivated, competent and multi-purposed, and as a consequence, very productive. It provides good value for GARD. The committee was unanimous that even a modest injection of funds would have a huge return. The AWA program effectively employs both post-docs and graduate students, acting as a fertile training ground for future accelerator physicists. Despite the recent loss of its long-time group leader, the committee commended the present dual leadership of Manoel Conde and John Power for doing an excellent job in maintaining an excellent scientific program, engaging/growing outside collaborators, and maintaining a strong engagement of students. The addition of Sasha Zholents has added vision to the program. The research has begun to shift its focus to PWFA and CWA, which is appropriate and should be continued.

The review committee recommended that the AWA program: (1) assess the effects on uptime of hiring one or more additional technicians; and (2) assign or hire a group leader.

2.1.2 Accelerator Test Facility (ATF)

The BNL ATF is a National User Facility that hosts proposal-driven, peer-reviewed experiments. It has both a flexible electron beam system and a terawatt-power (TW) CO_2 laser that can support experiments separately or together in Building 820. It also operates an ultrafast electron diffraction (UED) facility in Building 912.

The ATF electron beam is delivered to two experimental beamlines with energies that can range from 20-80 MeV with tunable charge, energy, energy spread, and beam size. The TW CO_2 long-wavelength mid-IR laser can be brought into interaction with the electron beam or other targets. The combination of electron beam plus CO_2 laser has significant value for studying laser wakefield acceleration compared to shorter-wavelength laser facilities because of the larger bubbles in the blowout regime at 10 μm wavelength. It is also very interesting for ion acceleration studies because of the low corresponding critical plasma density that allows for the use of gas jet (instead of solid target) and of optical diagnostics of the plasma. Multiple near IR lasers are also available and can be transported to any experiment for use as probes, or even brought into interaction with the electron beam. Diagnostics are located at six interaction points. An X-band deflecting cavity for longitudinal diagnostics was commissioned in FY 2017.

The ATF has a staff of ~11 FTEs, supporting a research program that includes plasma and dielectric wakefield acceleration, dielectric laser acceleration, high-brightness radiation sources**,** beam manipulation and beam instrumentation. The ATF has sophisticated longitudinal and transverse beam manipulation capabilities. Research at the ATF produced 26 journal publications and 41 conference papers since 2013, a low number compared with other test beam facilities, and the panel found this overall level of productivity to be disappointing. There are currently 22 active experiments, with 11 of these having university affiliations. Approximately 20% of the FY 2018 experiments are funded by GARD.

The scientific output, as well as the number of running hours, have somewhat suffered from the ATF-II upgrade. All ATF personnel have multiple duties in order to maximize efficient use of operating hours, however, overall staffing was found to be thin. With different facilities within the ATF (accelerator, laser, UED) sharing the lean staff of operators, a loss of a single person would have a large impact. This is being addressed by cross-training BNL Collider-Accelerator Department (C-AD) personnel to fill in as necessary.

Due to cost constraints, the planned move of the electron beam accelerator and associated infrastructure from B820 to B912 has been cancelled. This necessitated expenditure on deferred maintenance over the past few years, including the replacement of a failed klystron in FY 2017. Operation of the B820 accelerator is extended for five years. The major items of deferred maintenance are expected to be completed in the first quarter of FY 2019.

The ATF is well suited to be a National User Facility with beamlines conducive to quick, efficient change-out of experiments. The management and technical support is talented, dedicated, and responsive to user needs. The transition to Accelerator Stewardship appears to have been made without harm to the ATF program. The operation as a user facility has improved since the last review, thanks in part to the appointment of a new facility manager two years ago. The CO_2 laser has finally improved its performance to a truly single pulse TW laser (100% of 2 Joules in 2 ps) by using isotope filling in the CO_2 amplifiers. The group appears to be more focused on facility operation in support of user experiments rather than internal research. The primary focus of the

ATF staff is on the development of the high-power CO_2 laser. Their science goals are not clear. Nevertheless, the research being conducted by the ATF users has scientific merit and appears to be well accommodated by BNL staff in a manner that increases likelihood of success.

Only a few experiments are dedicated to advanced accelerator concepts in spite of having the appropriate infrastructure for such research, and, unfortunately, the new 10 TW laser system under development will not be able to be used in tandem with the accelerator. Since there are other facilities that can do similar work, the relocation of the accelerator does not seem cost effective.

Committee recommendations for the ATF include: (1) expedite cross-training of C-AD personnel to reduce risk of reduced uptime due to loss of personnel; (2) continue detailed tracking of deferred maintenance to improve and maintain uptime; and (3) develop clear, long-term plans in terms of running of the two facilities (in B820 and B912) and the scientific program/vision for activities in the next five years and beyond.

2.1.3 Fermilab Accelerator Science and Technology / Integrable Optics Test Accelerator (FAST/IOTA)

The Fermilab Accelerator Science and Technology (FAST) facility is based on the superconducting radiofrequency infrastructure, originally motivated by the International Linear Collider (ILC), developed over the last decade with initial funding from the American Recovery and Reinvestment Act of 2009. It comprises an electron gun, two capture cavities, an ILC cryomodule and a 140-meter beamline. The FAST linac is used to inject electrons into the Integrable Optics Test Accelerator (IOTA), a small storage ring dedicated to studying the effects of high space charge beam dynamics in a ring geometry. While the initial studies use an electron beam, the main program at the IOTA is geared toward proton physics in support of future Intensity Frontier research. The former High-Intensity Neutrino Source front-end is being refurbished as the proton injector for the IOTA.

The electron beam has been commissioned and tested in stages from 50 MeV to 300 MeV. During this commissioning, a record high beam acceleration gradient of 31.5 MV/m in an ILC cryomodule was achieved, with an energy gain of 255 MeV. Overall, the recently completed FAST linac (with upgraded subsystems) and the new IOTA ring are in good condition. On the other hand, the cryoplant is decades old and may require near term replacement.

The running cost the SRF linac is relatively high and a complementary AAC program could be considered with the bunch train produced by the linac. However, beam parameters as well as the lack of a witness bunch could limit the science reach and the type of AAC experiments that could be performed. As such, some reviewers thought that proposals to use it for AAC R&D seemed out of place.

Of all the laboratories reviewed, FNAL seemed to have benefited the most from HEP efforts (P5 and Accelerator R&D Subpanels, and GARD research roadmap workshops) to define a prioritized path forward for accelerator R&D. These subpanel reports have provided the basis for a more focused and coherent program at FNAL. The result is a rejuvenated program compared to 2013 and well aligned with HEP priorities. Overall, the facilities and people found at Fermilab are extremely impressive and capable. This is the only laboratory with research directed towards high power proton beam specific issues. IOTA is also the only GARD facility capable of performing experimental ring studies among the labs reviewed. Results from the IOTA are eagerly anticipated.

Annual collaboration meetings are held with participation from 29 collaborating institutions. FAST/IOTA envisions becoming a user facility, as part of the Fermilab Accelerator Complex, operating six months per year with two shifts per day.

There has been substantial progress in constructing FAST/IOTA, and the assembled researchers and technicians have a high level of competence. The future promise for the group is high. The transitioning plan from the commissioning phase to the operations/research phase presented is based on well-established paradigms and is sound. Since operational time is expected to increase to 6 months per year (up from 2-4 months during installation/commissioning), increasing 2.2 additional FTEs for operations seems reasonable. As FAST/IOTA group already has a large number of existing collaborations with other national laboratories, universities, and small companies in experiments, simulations, and theory, it might be more reasonable to consider operating it in a collaboration mode rather than a national user facility.

The committee recommends that FAST/IOTA: (1) increase operations staff as planned; (2) cycle young research scientists through operations for experience in and exposure to a wide variety of accelerator issues; (3) upgrade the cryo-plant; and (4) defer the decision to convert to a user facility to allow joint cost and workload sharing with collaborators during early operational years.

2.1.4 Berkeley Lab Laser Accelerator (BELLA)

The BELLA facility is devoted to exploring laser plasma acceleration (LPA). The program is addressing single and multiple-stage laser plasma acceleration with future goals of achieving beam matching, emittance preservation, and developing a positron source from developed electron beam LPAs. The facility is powered by a 1-Hz, 1.3-PW laser (producing 40 J, 30 fs pulses), which has been operational since 2013. Construction of a second beamline is under way, which will allow BELLA to deliver two 0.5 PW laser beams to the experimental hall. Specific programmatic goals of the facility are guided by and well-aligned with the AAC Roadmap: achieve a 10 GeV electron beam from a single-stage capillary discharge plasma by 2019, continue with staging two 5 GeV LPA modules together after the completion of the second beamline in 2020, and work towards beam emittance preservation. The BELLA team expressed the desire to remain a collaboration-based facility.

The BELLA group has 76 publications and 5,500 citations from 2014 to 2018. Much experimental progress has been achieved over the last five years. Highlights of accomplishments include: acceleration of a 30-pC beam to 4.3 GeV in a single-stage LPA in 9 cm of capillary discharge using just 0.3 PW of laser power; successful demonstration of the staging of multiple LPA modules at 100 MeV/40 TW; successfully guiding LPA drive laser in a 20-cm low plasma density capillary with laser heater; precise control of spatio-temporal properties of focused PW laser to enable efficient acceleration; ~6-GeV beams from heater-assisted plasma channels powered by PW-laser pulses; and the development of high-quality beam injection methods, active plasma lens to provide strong focusing, and diagnostics to measure target and beam quality.

The overall operation of the BELLA facility is very smooth, efficient and superbly managed. The BELLA program has a well-defined vision of its future research and is well-suited to conduct LPA research towards a possible electron collider. It is the leading LPA program in both the U.S. and the world. The research closely follows the goals of the P5 report and the AAC Roadmap—in fact, LBNL is the first lab in this review to show a clear roadmap toward a real linear collider application. BELLA's world leadership is made possible by a large, well-led, very competent staff, substantial funding, as well as a well-conceived research plan that focuses on achieving the milestones toward a future collider or light source. The program addresses very systematically all issues, small and large, related to LPA applications.

In general, the probability of achieving an electron beam of 10 GeV with a bunch charge of 100 pC is high. However, achieving beam matching and preserving emittance (to be investigated in 2019) are more challenging. The group has been investigating this issue and appears to have a solid understanding of the issues. Staging two or more LPA modules is widely recognized as a difficult problem. Nonetheless, LBNL has demonstrated two-stage acceleration with 100 MeV acceleration per stage, albeit with only 15% efficiency. It is expected that the staging efficiency will improve at 5+5 GeV. There is also still no clear path forward for injection and acceleration of positrons in an LPA.

The BELLA program makes excellent use of knowledge and capabilities available at LBNL (for example, control systems for combining laser beams) and other labs. The group also runs other LPA experiments with strong synergies with the main program, which increase the return on the investment in equipment and knowledge. This helps attract additional funding that benefits the whole program. The facility is in good overall condition but being now 5 years old it is beginning to show age, with components needing maintenance and replacement. Operating BELLA in the collaborative model is working well and should remain that way.

The committee noted that BELLA has the potential to knock the ball out of the park for laser plasma acceleration, and as such is a wise investment for GARD. It is recommended that: (1) BELLA be supported well; and (2) future maintenance and replacement of aging components on BELLA be monitored and budgeted for.

2.1.5 Facility for Advanced Accelerator Experimental Tests (FACET/FACET-II)

SLAC operates two test facilities under the GARD program: the Next Linear Collider Test Accelerator (NLCTA) and the Facility for Advanced Accelerator Experimental Tests (FACET/FACET-II). The Accelerator Structure Test Area (ASTA) and the End Station Test Beam (ESTB) are no longer supported under HEP.

The NLCTA has the capability to, and was supporting, beam tests for dielectric laser acceleration, echo seeding, high-gradient research and development, X-band gun development, and ILC klystron and modulator development work. However, following the recommendation of the HEPAP Accelerator Subpanel, its scope was limited to the testing of high-gradient RF accelerating structures from the GARD-supported R&D within the Technology Innovation Directorate.

FACET was the main beam test facility at SLAC until April 2016. It made use of the first two-thirds of the SLAC linac to deliver 20 GeV electron and positron beams, primarily for studies of ultra-high gradient acceleration. To make way for the BES LCLS II project, FACET had to cease operation and reconfigure to use only the middle third of the SLAC linac. It is currently undergoing an upgrade to FACET-II, and will get a new, improved electron injector at Sector 10. Installation of the FACET-II injector is complete and commissioning is starting. The FACET-II experimental area remains unchanged at Sector 20. One downside of this new configuration is that the LCLS II beam now runs through the FACET-II area, which might cause access problems. This issue was addressed in the FACET-II project review, but it is likely that the throughput of user experiments will be lower than the previous level. FACET/FACET-II has strong user involvement and there is a high demand for beam time to be available again. This facility is unique in the AAC program in having the capability for positrons, and a proposal to add a small positron damping ring is planned for the next phase. FACET-II will continue to operate as a National User Facility, providing high-quality electron and positron beams for plasma wakefield acceleration (PWFA) and staging experiments, as well as other user experiments.

The FACET facility at SLAC has been an important component of the AAC program. It hosted more than 200 users and 25 experiments with balanced priorities between focused PWFA research and diverse user programs with ultra-high field. Four postdocs from the FACET team were appointed faculty positions at various universities, and they have returned with their graduate students to continue to participate in FACET user experiments. The user experiments at FACET have seen a lot of success, with many high impact publications. More than half a dozen of these are *Nature* articles. The beam-driven PWFA alone had produced one high-profile result a year, including mono-energetic electron beam acceleration; high efficiency electron beam acceleration; first high-gradient positron acceleration; and the demonstration of low emittance, narrow energy spread acceleration.

The total number of annual FACET experiments is limited, but the quality is high. The results obtained during the FACET runs are quite impressive, and so far it is the only facility that has produced real results on positron acceleration. There is no reason to doubt that the scientific program of FACET-II will be as good as or better than FACET's. The experimental program is guided by user input, and there appears to be active engagement with the outside community through workshops, proposals, etc. The only possible issue is that the users seem to be largely the same groups from year to year.

Since FACET-II and LCLS II both use a common section of the accelerator tunnel, installation, commissioning, operations, and maintenance of each will be in conflict. While some of these conflicts can be dealt with via scheduling, inevitable schedule slips and unexpected maintenance make well-defined prioritization essential. The staff, and users should have this information at their disposal so that on-the-spot decisions can be made. Operations may have to rely more heavily on automation and reliability of the experimental apparatus. By necessity, the positron ring is very compact and fits tightly into the accelerator tunnel. Installation and maintenance plans should be developed long in advance of required work.

The FACET-II program is one of the leading PWFA programs in the world, certainly the best in the U.S. It is perfectly in line with the GARD program. Use of two laser pulses on the new RF-gun to generate two electron bunches should allow for studies of beam loading, acceleration efficiency, emittance preservation and other major demonstration experiments. However, in order to carry out other important *AAC Roadmap* milestones such as PWFA staging and positron acceleration on electron wake, a second RF-gun and a sailboat chicane will be necessary.

Operation of the facility will be optimized by using machine learning approaches to minimize tuning time and reach target parameters. New diagnostics for the very intense bunches need to be developed. The facility will greatly benefit from procedures, diagnostics and knowledge acquired and used at LCLS. The current facility can address many of the collider-relevant issues. At the same time the beam parameters will allow for more science-driven experiments with very high fields, a nice complementary program.

It was noted that (1) FACET-II's presentations did not show the same detailed level of thinking, preparation, and dedicated participation that were seen at BELLA, AWA and ATF; and (2) FACET-II appears to have a flavor of being a distinctly second priority behind the needs and plans of LCLS II, which may affect access to technical resources.

The committee recommends that FACET-II create well-defined schedules and priorities that are specifically designed to avoid accelerator tunnel access conflicts between FACET-II and LCLS II. These priorities should be disseminated to operations crews, research staff, and users. FACET-II should also continue the consolidation of RF testing in the NLCTA facility.

2.1.6 Comparison of Facilities

The committee was asked to compare the R&D programs and facilities at the laboratories reviewed, and to place them into 4 "tiers" using the 8 merit criteria in the charge letter (see Section 5.1). The reviewers were also asked to rank how well each test facility aligns its current and future program to the goals in the GARD roadmaps or recommendations of the reports of the HEPAP P5 and Accelerator R&D Subpanels. The outcomes with respect to facilities from this exercise are based on the evaluations of the previous sections and rankings provided by the committee members, and are discussed below; while those in connection with GARD research thrusts are presented in Section 2.2 below and summarized in Section 2.2.6.

2.1.6.1 Tier Ranking of Facilities

The scientific impact and quality of facility operations were compared by categorizing the accelerator facilities into tiers, with facilities providing high scientific impact in a given GARD thrust area[3] and outstanding operations placed in Tier 1, and facilities with marginal scientific impact and/or operations issues placed in Tier 4.

Table 1: Tier Ranking of Test Facilities Reviewed. There are no dedicated GARD-funded facilities for particle sources and targetry at this time.

	Accelerator & Beam Physics	Adv. Accelerator Concepts	Particle Sources & Targetry	RF Acceleration Technology	Superconducting Magnet/Material
Tier 1	FAST/IOTA	BELLA		SRF@FNAL	FNAL
Tier 2		ATF, AWA, FACET		NLCTA	BNL, LBNL
Tier 3					
Tier 4					

2.1.6.2 Alignment of Facilities' Present and Future Program to HEP Goals

The committee also scored each facility with respect to the facilities' alignment to the stated recommendations in the GARD Subpanel Report and the three GARD Roadmaps. Two scores were given, one assessing the current program as it stands, the second assessing the *potential* of the facility to support a well-aligned program in the future. The reviewers were given the following selections to pick from: *"Best in World"*, *"Best in US"*, *"Excellent"*, *"Good"*, *"Fair"*, *"Poor"*, *and "Not Applicable"*. The entries from all the individual reviewers were collected and analyzed to produce the average scores as shown in Table 2.

Table 2: Alignment Ranking of Test Facilities with present and future HEP goals.

Current-Future Alignment	Facilities
Excellent-Excellent	AWA, BELLA, NLCTA, FACET-II, IOTA, LBNL-SCM, FNAL-SRF
Good-Excellent	FNAL-SCM, FAST (for SRF purposes)
Good-Good	ATF
Poor-Fair	FAST (for AAC purposes)

[3] The GARD topic areas are Accelerator & Beam Physics (ABP), Advanced Accelerator Concepts (AAC), Particle Sources and Targetry (PST), RF Acceleration Technology (RF), and Superconducting Magnets and Materials (SMM).

2.2 General Accelerator R&D Thrust Areas

The GARD program currently supports research at four of the five laboratories visited by the review committee, namely, Argonne National Laboratory, Fermi National Accelerator Laboratory, Lawrence Berkeley National Laboratory and SLAC National Accelerator Laboratory. GARD does not currently support any research efforts at Brookhaven National Laboratory.

ANL GARD research is carried out at its High Energy Physics Division's AWA program. As mentioned earlier, the AWA group relatively small with a small budget, but it has managed to develop its own, unique accelerator research program and executes it effectively. The group has been productive in their main areas of research, namely accelerator and beam physics as well as AAC.

FNAL has the most extensive and diverse portfolio of GARD-funded effort, the only laboratory to participate in all GARD research thrust areas. The work is carried out in the Accelerator Division and the Technical Division. The overall program is impressive, and members of its staff appear to be leaders in most of the activities presented, with an abundance of "superstar" young scientists in various leadership roles. The list of awards won by researchers in the GARD program is long.

At LBNL, GARD research is spread over different groups within the Accelerator Technology and Applied Physics Division (ATAP). Wim Leemans, the current ATAP director, provides excellent leadership. As a result, all four thrusts of the LBNL GARD program are well defined, well organized, and exhibit strong synergy between them. The overall program is one that has a clear vision with 5-10 year plans to guide the scientists to deliver on objectives that are aligned with HEP priorities.

SLAC's GARD efforts is distributed across two directorates: the Accelerator Directorate (AD) and the Technology Innovation Directorate (TID). The research activities span all GARD thrusts, with the exception of superconducting magnets, and are carried out by a quality staff with a healthy balance of experience and youth. Overall, there appears to be good collaboration and synergy among these groups.

In the sections that follow, we discuss the findings, comments, and recommendations by the review committee organized by the programmatic thrust areas. As noted earlier, various reviewers were specifically assigned to focus on particular thrust areas, but all reviewers were encouraged to indicate their views on all topical areas.

2.2.1 Accelerator and Beam Physics

All of the laboratories reviewed have activities in this thrust area. Those institutions currently operating test accelerators (ANL, BNL, FNAL and SLAC) emphasize work that makes use of these facilities, though in most cases their program is even broader than that supported by the test facility.

ANL

ANL effort in this thrust area includes research that can be broadly categorized under beam control, diagnostics and modeling/simulation. These activities are pursued in support of its programmatic objectives in advanced acceleration concepts (dielectric wakefield acceleration) and beam manipulation (emittance exchange) using the AWA facility. The emittance exchange (EEX) beamline offers an outstanding tool to study the effects of phase space manipulation on the advanced accelerating schemes. This capability is unique among the test facilities reviewed and is clearly their niche. It opens a lot of possibilities for applications and exquisite beam control, such as bunch shaping for improving the transformer ratio of wakefield accelerators, bunch compression, and flat beam generation. The EEX beam manipulation technique has also been used to develop new beam diagnostics for single-shot wakefield and transverse phase space measurements. All these activities are guided and optimized with a modeling/simulation effort. A clear, ten-year roadmap with milestones and goals was presented. The committee noted that the AWA group is excellently qualified to carry out the research, and should get high support.

BNL

There are no GARD-funded R&D at BNL at the time of this review. However, the ATF does have a vigorous and diverse schedule of user experiments, which includes accelerator and beam physics studies, many led by university researchers.

FNAL

FNAL has the biggest effort among the labs in the Accelerator and Beam Physics thrust. Efforts are directed towards solving near term issues such as reducing beam loss in existing and next generation high intensity machines, as well as longer term applications including optical stochastic cooling, electron lenses, and integrable optics. Fermilab accelerator and beam physics R&D comprises the following components: beam instabilities, space-charge effects and mitigation in multi-MW facilities; beam cooling in future colliders; and the development of modeling tools and beam theory to support these activities. These studies are grounded in theory and have planned experimental verification. Some FAST experiments, e.g., flat beams, have already been done. However, the more impactful experiments will happen in IOTA.

The IOTA ring at FNAL is the most meaningful proton accelerator work within the GARD portfolio, and it is well aligned with the Proton Improvement Plan (PIP). Among the reviewed facilities, IOTA is the only one capable of performing experimental ring studies. Experimental work on the IOTA ring will be given priority over all other work involving the FAST/IOTA facility, and is well supported by a healthy Synergia collaboration. The list of first campaign experiments to be done at IOTA—integrable optics, electron beam cooling, and optical stochastic cooling—were well thought out and unique. Each of these areas has high probability of achieving stable beam acceleration while preserving high brightness, and each is worthy of support.

The committee heard presentations on high-current beams R&D at FNAL directed toward FAST and IOTA to explore the possibility of using integrable optics for a replacement of the Booster. The reviewers noted that while the work on FAST needs better justifications, the IOTA program, on the other hand, is an interesting and potentially promising approach to mitigate space charge effects and beam loss, and should be supported by the GARD program.

The committee recommends that FNAL beam expertise be used to guide and perform experiments at existing top-notch AAC facilities (such as FACET-II and others). This would be a cost-effective and most community-serving way to contribute to AAC research. FNAL could also contribute to the AWA beam manipulation techniques (flat beams). In view of the fact that FAST ranked poorly as a potential AAC facility (see Section 2.1.6.2), a comprehensive and convincing AAC plan would need to be developed if the FAST facility is to be considered as part of this research portfolio.

LBNL

At LBNL, the GARD accelerator and beam physics research thrust encompasses the studies of laser-plasma acceleration at the BELLA center, and accelerator design and modeling in the Center for Beam Physics, which has recently been reorganized into the Accelerator Modeling Program (AMP) and Berkeley Accelerator Controls and Instrumentation (BACI). The BELLA program will be covered in the next section; in this section we discuss accelerator and beam physics activities in the AMP and BACI groups.

The Accelerator Modeling Program at ATAP is a world-leading program with an excellent publication record. The progress made by the AMP program in novel numerical algorithm development is very impressive. The main focus of the modeling program is on GARD priorities—in LPA simulation and high intensity proton accelerators. Besides supporting the BELLA and other accelerator/FEL programs, it is also geared toward producing a suite of open source codes. The program has laid out a clear roadmap for exploiting coming exa-scale computing capabilities to enable accurate modeling that could simulate an entire plasma-based collider (LPA or PWFA) by the year 2023. This is a very ambitious goal. However, this is also a very important contribution to the AAC community that will greatly increase confidence in numerical simulation results. It was noted that many projects nation-wide have benefited from the linac beam simulation code IMPACT developed by the AMP group. For instance, IMPACT is the main code for FRIB beam modeling and simulation. The AMP team, with its unique expertise, is also contributing to strengthen the IOTA modeling effort.

The AMP group continues to make a concerted effort to support their code-user base by making their codes more useful and usable and by paying attention to code integration via the Berkeley Laboratory Accelerator Simulation Toolkit (BLAST). Jean-Luc Vay leads the Consortium for Advanced Modeling of Particle Accelerators (CAMPA) program that coordinates and integrates the development of common data format across different simulation codes in use at FNAL, LBNL, SLAC and UCLA. CAMPA helps to facilitate data sharing and to avoid duplication of efforts.

The BACI group has become the leading experts in precision timing/control and fiber laser technology. They are developing the technology of laser coherent combining and stacking to support k-BELLA. The team is investing in young people as much as funding allows but they survive mainly on project funds and have little “base” R&D funds to fall back on. They are also keen to explore further innovations in RFQ’s such as using genetic optimization algorithms for performance optimization, and to develop a next generation CWRF gun as well as continuing to develop high performing and cost effective low-level radio frequency (LLRF) and timing systems. There is strong synergy between RF control and laser technologies.

The committee recommends that (1) the accelerator modeling program develops a plan to release the IMPACT code suite as open source, and (2) the BLAST initiative be very strongly supported, in particular by providing resources for users support and further code developments.

SLAC

The GARD program at SLAC includes experimental and simulation work on plasma wakefield acceleration (at FACET/FACET-II) and laser-driven dielectric structures (formerly at NLCTA, now at UCLA), along with collider studies and more general beam physics work. PWFA and DLA activities will be discussed in the next section. Here we discuss the beam physics activities.

SLAC’s core competencies in beam physics include lattice design and single-particle dynamics in storage rings, wakefields and impedances, collective effects in highly charged beams (such as electron cloud and beam-beam effects), simulations and parallel computing. This research is being carried out by a competent staff, with some renowned accelerator physicists who have received prestigious awards. There are currently 13 graduate students in accelerator physics and engineering. Over the years, SLAC had produced more than 60 Ph.D.s in accelerator physics and won 13 of 28 APS thesis awards in beam physics. The Accelerator Division beam physics group published 28 journal articles since the last GARD review, with accomplishments in single-particle dynamics in circular particle accelerators, collider studies, collider lattice and positron damping designs, novel FEL techniques, improved understanding of coherent synchrotron radiation and implementing CSR model to FACET-II. The group’s research plan includes analytical studies of dynamic aperture in nonlinear, periodic systems; extending CSR theory and code development to 3D; participating in collider studies for SuperKEKB, FCC-ee, CepC and HE-LHC; exploring machine learning on FACET-II and LCLS II; and collaboration with FNAL on nonlinear beam dynamics, optical cooling and single-electron quantum experiment at IOTA. A group dedicated to machine learning for accelerator applications has been established.

Accelerator and beam physics activities in TID is centered on the Advanced Computational Electromagnetics 3D Parallel (ACE3P) code group. ACE3P is a suite of C++-based finite-element electromagnetic codes running at NERSC that is used to model a wide spectrum of phenomena of interest to HEP and other SC programs. Their state-of-the-art advanced accelerator modeling program uses: high performance computing (HPC) for virtual prototyping complex accelerator components; advanced numerical algorithms to integrate multi-physics modeling capabilities; and code integration to combine electromagnetic codes with beam dynamics and particle-matter interaction codes to study machine performance and reliability. The group is part of the CAMPA initiative that works on the coordination and integration of accelerator codes on HPC platforms, the development of common data format and modeling interface, and code dissemination. The group's plan is laid out on a research roadmap timeline.

The review committee observed that SLAC is continuing to make progress furthering the development of conventional, linear optics based ring lattices, a good hedge and complement to the integrable optics path being pursued at FNAL. The reviewers also noted that the SLAC modeling group has some of the best tools in the community in the ACE3P suite, which is continuously being developed, and more importantly, is being disseminated more broadly. They added that this small group is still very resource limited and has lost some important people in recent years. However, they have a strong core capability and try very hard to support users of the codes, notably by hosting very effective workshops to train new users and promote new capabilities. This is one of the areas the committee consider to be a good place to invest if extra funds are available.

2.2.2 Advanced Accelerator Concepts (AAC)

As discovery science in high energy physics and related fields requires ever-higher beam energies, intensities, and performance, it is becoming uneconomical to build such machines using conventional RF technology. The AAC thrust therefore focuses on developing new, potentially transformational ways to achieve very high accelerating gradients that could lead to more compact, and hopefully more affordable, accelerators. As laid out in the AAC research roadmap[4], there are only a few approaches being pursued, primarily plasma-based or structure-based wakefield accelerators. These approaches can produce very high accelerating gradients (~GV/m). In the plasma case, the accelerating structure can be created either with an electron drive beam (as in plasma wakefield acceleration, PWFA) or with a powerful laser beam (laser plasma acceleration, LPA). In the GARD program, the former avenue is currently being pursued at ANL and SLAC, and the latter avenue is being pursued at LBNL (also by users at ATF, and at UCLA, CU-Boulder, UMD and UT-Austin, but only the national laboratory programs are being reviewed at this time).

Another approach, being pursued at ANL, is to use the wakefield of the drive beam directly, in a dielectric structure, to accelerate a witness bunch. This can be done either in a collinear arrangement (collinear wakefield accelerator, CWA), where one beam follows the other in the same vacuum pipe, or in a two-beam accelerator (TBA) configuration, where the wakefield of the

[4] The report from the Advanced Accelerator Concepts Research Roadmap Workshop can be found here: https://science.energy.gov/~/media/hep/pdf/accelerator-rd-stewardship/Advanced_Accelerator_Development_Strategy_Report.pdf

drive beam is coupled out of one beam line into a second one where the witness beam is accelerated. The collinear version is also being studied at FACET/FACET-II. While GV/m gradients are possible in the collinear geometry, the TBA gradients are expected to be of order 100s MV/m.

Finally, there is the dielectric laser acceleration (DLA), being pursued at SLAC (as well as by users at ATF). In this case, a laser is used to produce the accelerating fields directly in a dielectric structure.

While there are no AAC experiments at FNAL, scientists there are collaborating in and contributing to the PWFA experiment at FACET/FACET-II, in the areas of beam stability and emittance preservation.

It was noted by the reviewers that the laboratories (ANL, LBNL, SLAC) have moved rapidly toward development of practical high-gradient wakefield accelerators, to a point where this method appears quite feasible. The most pressing research identified in the *AAC Research Roadmap* is emittance preservation and positron acceleration, which are being studied at LBNL and SLAC. They also noted that emittance preservation should be a priority for all programs.

ANL

At ANL, advanced accelerator concepts are tested at the AWA. The focus of the AWA group is dielectric wakefield acceleration. While in the past it had focused on the TBA approach, it has begun to shift focus to the CWA approach as well as expanding into PWFA with their UCLA collaborators to better contribute to the overall AAC thrust. The structure-based dielectric wakefield acceleration approach, being closest to a conventional accelerator, has some advantages. It will be able to accelerate positrons as easily as electrons, and perhaps will have fewer unknown issues compared to LPA and PWFA. Since the GARD review, they have successfully accelerated the witness beam in a two-beam approach at a gradient of 150 MV/m. They have also demonstrated two-stage TBA by accelerating a witness bunch through two acceleration stages. To improve acceleration efficiency, they have applied the EEX technique to the drive beam and demonstrated a transformer ratio of ~5 in CWA. By incorporating a new accelerating structure—the dielectric disk accelerator—and by beam shaping and using a more efficient klystron, the site power requirement for their 3 TeV TBA linear collider conceptual design dropped from 397 MW to 184 MW. Other AAC activities undertaken by the AWA group include testing various accelerating structures, some in collaboration with their collaborators, cylindrical dielectric, iris loaded metallic, planar dielectric (with Euclid), photonic band gap (LANL), coaxial dielectric (Omega-P), and metamaterial/left-handed (MIT) structures. They have a list of 22 experiments to be conducted with their collaborators.

The R&D goals of the AAC program over the next few years are to achieve a transformer ratio of 10, emittance reduction, accelerating gradient > 300 MV/m, and extracting higher RF power (> 1

GW) to conduct more realistic staging experiments. The group is also working toward a 500 MeV TBA, a CWA energy doubler and a TBA efficiency doubler.

The committee unanimously agreed that the AWA program is running smoothly and productively on a rather small budget because it has a very motivated and competent team. The team can be even more productive if additional technical support is available. This is because the run time appears to be limited by the overhead time in switching from experiment to experiment. The emphasis on structure-based wakerfield accelerator approach at AWA is somewhat unique. The work presented by Alexander Zholents that examined the theoretical limits of gradient and stability limits was notable. The reviewers noted that the group provides a good training ground for developing accelerator expertise and, for this reason, encouraged continued support. ***They recommended that the AWA group set and work towards more ambitious goals in terms of larger accelerating gradients, and give priority to emittance preservation studies and developing collider parameters in order to maintain relevance to a future AAC collider.***

BNL

There is no GARD-funded R&D at BNL at the time of this review. However, as noted above, the ATF does have a vigorous and diverse schedule of user experiments, many led by university researchers, which includes some in the advanced accelerator concepts thrust.

FNAL

Currently, there are no AAC-related experimental activities at FNAL. Fermi scientists, however, have published a number of AAC-related papers. These papers stem from their expertise in accelerator physics and their applications to AAC. These contributions are important and most welcomed. FNAL is beginning to get into the AAC field with a small effort collaborating on FACET-II experiments aimed emittance preservation and beam dynamics issues. This should be encouraged. They have also expressed an interest in opening FAST/IOTA to outside AAC users.

LBNL

LBNL uses its BELLA facility to study laser plasma acceleration. The program at BELLA Center is strongly aligned to the GARD *AAC Research Roadmap.* Their near-term goal is to demonstrate 10 GeV electron beam acceleration in a single capillary discharge plasma module and in a 5 GeV + 5 GeV staging experiment. Future plans include emittance preservation, positron acceleration and kHz LPA operation with a new facility known as k-BELLA that will possess a 1 kHz laser.

Research accomplishments for the period of 2013-2018 include: 4.3 GeV acceleration in a single 9-cm plasma channel; staging demonstration of (100+100)-MeV LPA; full-power guiding of a BELLA laser pulse over a distance of 20-cm in a laser-heated capillary discharge plasma; precise control of spatio-temporal properties of focused PW laser to enable efficient acceleration; new 6-9 GeV acceleration in a heater-assisted plasma channel; high-quality beam injection; strong focusing active plasma lens; and diagnostics for measuring target and beam quality.

The review committee ranked BELLA as the leading experiment for laser plasma acceleration in the world. It was noted that the program had built into its planning 5 years ago flexible provisions for extreme-power drive laser, plasma channel, powerful diagnostics for the accelerated bunch, and staging for a second-pass acceleration. Those provisions have paid off and enabled them to achieve impressive results for their first channel. They have designed a second channel and provisions to experiment with several approaches to staging. The reviewers found that the BELLA program is still very entrepreneurial; they have, since the last review in 2013, established a better balance in its research portfolio and is able to be more selective in taking on additional work that better complements the GARD program. The BELLA group has grown to be a powerhouse in the AAC community because Wim Leemans has done an outstanding job with the program. He clearly runs a tight ship but there is also great strength and depth in the team and a strong investment in young people for the future.

As noted earlier, the program has and is addressing very systematically all LPA issues, including a five or ten GeV first stage, a second laser beam line to drive the second stage of a (5+5)-GeV staging experiment, the development of a plasma-based injector, the development of kW-class lasers capable in the long term to reach collider beam rates, and the acceleration of positrons. It is however not clear at this point how positron bunches suitable for LWFA acceleration could be produced without damping ring.

The BELLA program is getting excellent support from its sister programs—the Accelerator Modeling Program and the Berkeley Accelerator Controls and Instrumentation. Modeling and numerical support have seen much strengthening in the last five years, resulting in high quality and quantity of publications. BACI is supporting BELLA well with its world-leading FPGA expertise. The development of fiber based high power laser through coherent combination is unique among the reviewed laboratories and should remain well supported.

The team is well on track according to the roadmap and the facility is very impressive. The reviewers also thought that the effort to develop applications of LPAs is a wise one, since even if it is not successful, it is likely that these efforts will uncover shortcomings in the technology that can then be addressed in the LPA R&D program. Besides linear colliders for high energy physics, there is tremendous opportunity for other potential applications of LPA.

The committee recommends that the BELLA experimental program be strongly supported, in particular through operations support; that it continues to make emittance preservation a high research priority; and continues to develop fiber based high power laser as a LPA driver.

SLAC

SLAC has two programs that contribute to this thrust area, the plasma wakefield acceleration and the dielectric laser acceleration programs. The PWFA program used the 20 GeV electron beam of FACET to carry out experimental studies until April of 2016, when LCLS II took over the first kilometer of the SLAC linac. The FACET-II project, now under construction, will use the middle kilometer of the SLAC linac, with a new and improved photo RF injector gun at Sector 10. Even though the FACET-II drive beam is only 10 GeV, the overall system is an improvement over FACET because of its higher quality beam from the new injector. The injector is complete and was being commissioned at the time of this review. While the science and applications of the DLA is interesting, the HEPAP GARD Subpanel found that it is not as compelling for linear collider application. The subpanel recommended that GARD curtail funding for that program in favor of other approaches. The DLA program used to carry out its testing at the NLCTA, but relocated the experiment to UCLA as of fiscal year 2016 when GARD ceased funding beam testing at the NLCTA.

The PWFA program at FACET-II directly targets advisory panel roadmap goals: e.g. high quality beams at high energy (> 9 GeV), positron acceleration, and staging. It is the only wakefield accelerator program that has a potentially feasible approach to positron acceleration. As currently envisioned, the first part of the program will be with two electron bunches, generated by applying two laser pulses on the RF gun. The low emittance bunches should allow for studies of beam loading, acceleration efficiency and emittance preservation at the mm-mrad level, and all major demonstration experiments. The second part of the program will include a positron bunch. To be truly relevant the system will need the sailboat chicane for the drive e- bunch and witness e+ bunch experiments. The third part of the program will include an independent e-bunch from a second RF-gun, added to conduct true external injection studies. This is a very important part of the program. With all these attributes, the facility is ideally suited for PWFA research.

Narrow energy spread acceleration with high-efficiency has been demonstrated in the SLAC PWFA program. The research has produced admirable results with regard to energy, energy spread, and positron acceleration. Energy gain of 9 GeV for electron and 4 GeV for positron in 1.3 meters have been achieved. In the positron case, the energy spread was 1.8% with low beam divergence and no halo. The AAC experiments at FACET have been very successful, with many high impact publications, with more than half a dozen of them being *Nature* articles. The PWFA program alone had produced one high-profile result a year, including mono-energetic e-beam acceleration; high efficiency e-beam acceleration; first high-gradient positron; and demonstration of low emittance, narrow energy spread acceleration.

SLAC has a reasonable chance to achieve the 10-year goals—emittance preservation with high-efficiency high-gradient electron PWFA, development of high-brightness beams from PWFA injectors, identification of optimum method for positron PWFA. Any reduction in funding will proportionally reduce the likelihood of success. The SLAC technical infrastructure (personnel, services, etc) is capable of providing the support to achieve these goals. This research is in direct alignment with the P5 and GARD subpanel reports, and with the AAC research roadmaps.

The review committee recommended that numerical support for the PWFA program, which is deemed crucial to the experiments and collaborations, be strengthened.

The DLA program leverages advances in two major industries, namely, the solid state laser industry for its 2 μm laser and the semiconductor industry to fabricate its miniature accelerating structure. The program also benefited from the Moore Foundation funding for the Accelerator on a Chip (ACHIP) program. Accomplishments since the 2013 GARD review include the demonstration of 1.8 GV/m axial fields with 0.85 GeV/m average gradient; completed a comprehensive design study; miniaturized diamond-cathode electron gun prototype now in operation; incorporated ponderomotive focusing into fabricated structures; and initial demonstration of DLA acceleration.

One disappointment expressed by some reviewers was that the DLA investigator was not able to specify what kind of beam could be expected from this technology (e.g. charge, emittance, energy spread), not even from simulations. This was particularly disappointing since a similar question had been asked, but unanswered, during the 2013 review.

2.2.3 Particle Sources and Targetry

In comparison to other GARD thrusts, the level of activities in Particle Sources and Targetry at the national laboratories is relatively small and the efforts are more development than research. It is well known that while multi-MW beam power accelerators appear to be feasible, the production targets on the other hand still need significant development for neutrino, neutron and rare isotope production. For these applications, targetry is what limits facility performance, not the accelerator.

ANL

The AWA team is studying issues related to high-power, high-brightness electron beam generation. At present, they produce the world's highest charge per bunch (100 nC). AWA also has a photoinjector, the Argonne Cathode Test-stand (ACT), devoted to photocathode R&D and material characterization. This is one of very few resources across the laboratories dedicated to particle source research. In general, the existing high-intensity electron source already produces electron bunches that are adequate for AWA needs. However, the availability of this dedicated apparatus allows the team to incorporate new technologies and tailor the beam to further improving wakefield generation. R&D activities include high-charge Cs_2Te cathode development; high-charge bunch train generation, laser relay imaging system, micro lens array (MLA) laser homogenizer; thermal emittance studies; and transverse emittance reduction. Until recently, AWA was also leading the development of positron source for the ILC. This effort involves target modeling studies as well as hardware development. At the conclusion of that effort, AWA had built and tested a prototype positron rotating target with its associated cooling system.

The review committee considers the Particle Sources and Targetry efforts at AWA to be very strong. It had successfully developed an in-house cathode coating capability and demonstrated high-charge bunch production. The MLA not only allows them to improve the homogeneity of the laser profile, but can also be used to generate special patterns of interest to the AWA program.

BNL

There are no GARD-supported activities at BNL, but the ATF does make use of its tried and true photocathode source technology; major improvements were not reported nor needed. BNL also operates the Brookhaven Linac Isotope Producer (BLIP), which is routinely used as “work for others” or “collaborator” facility to irradiate high-power target materials.

FNAL

FNAL has the only ongoing GARD-supported effort in targetry, and it is relatively small. In spite of that, they have been able to leverage their funding effectively through the establishment of the international RaDIATE collaboration. The importance of high-power target development for PIP II was emphasized in the lab director’s presentation, but no design work has yet started. Since the last GARD review, the RaDIATE collaboration has grown from 5 institutions to 14 institutions on the MOU with 70 participants. The high-power targetry R&D at FNAL has completed: its proton irradiation studies on graphite; proton and ion beam studies on beryllium; in-beam thermal shock test on beryllium at CERN’s HiRadMat facility; the RaDIATE organized proton irradiation at BNL’s BLIP facility; and preparations for in-beam thermal shock test on previously irradiated material at CERN’s HiRadMat.

In the next 5 years, the Targetry R&D program plans to complete post-irradiation examinations (PIE) on all currently irradiated materials to confirm material choices, operating parameters, and lifetimes for 1-2 MW operation (which benefits LBNF at PIP-II) by 2020. It also plans to complete the in-beam thermal shock experiment on previously irradiated materials to inform designs for 2-4 MW operation of graphite, beryllium and titanium beam intercepting components by 2021. The program will perform low energy ion irradiations on graphite, beryllium, and titanium, as well as high and low energy irradiations on promising materials to benefit next-generation high-power targetry facilities. They also have developed contingency scope for increased funding.

The committee learned that the main goal of the FNAL Targetry R&D is to gain understanding of material lifetimes to enable optimized higher power neutrino targets. It viewed the R&D efforts to be sound and vibrant, but underfunded. In order to meet future HEP needs, ***it was recommended that more resources be devoted to the design and development activity for the PIP II targetry.***

Neither LBNL nor SLAC maintains an HEP-funded R&D program on either particle sources or targetry development. It should be noted that the LBNL BACI group recently delivered the state-of-the-art RFQ for PIP-II at FNAL and the APEX gun for LCLS II at SLAC. As mentioned above, the FACET group at SLAC had recently completed it Accelerator Improvement Project of the electron injector at Sector 10, which is expected to produced very high quality electron bunches for the user experiments.

2.2.4 Radio Frequency Acceleration Technology

The GARD RF Acceleration Technology thrust encompasses R&D activities in superconducting RF, normal conducting RF, and RF sources. This is a broad thrust and all reviewed laboratories have some level or activity in this area, but the major efforts are at FNAL and SLAC.

ANL

At ANL, the RF structure work involves mainly the AWA facility. As part of their energy upgrade, they designed and fabricated six normal conducting L-band structures, along with klystrons providing an additional 80 MW of pulsed power. They have also developed X- and K-band power extraction and transfer structures for two-beam acceleration that generated 300 MW and 55 MW, respectively. The group also participates, with their collaborators, in various metallic and dielectric RF structure testing, as well as RF breakdown, field emission, multipacting and mitigation studies.

The committee commented that except for the presentation on the development of "brazeless" accelerator at AWA by a collaborator from the industry, no other presentation by industry was done during this review. It is not clear why the "brazeless" structure is more cost effective than the common "brazed" structure, nevertheless, it is deemed vital for future accelerator prospects to support accelerator industries both financially and technically. Further ANL efforts to support industries are encouraged.

FNAL

FNAL has the largest GARD-funded program in the GARD RF Acceleration Technology thrust. Fermilab has targeted superconducting radiofrequency (SRF) technology as a key capability for future projects and has rapidly become a major player and world-leading in several areas. The initial development of their SRF infrastructure was motivated by the International Linear Collider (ILC). The program has invested heavily in facilities and equipment and has attracted a number of high performing young researchers. The lab has also invested heavily in specialized and dedicated analytical tools to promote fundamental scientific understanding of SRF processes and phenomena. This is paying off with great progress in many areas and in an impressive publication rate. The serendipitous discovery of nitrogen doping has changed the direction of the field and has been adopted quite boldly by LCLS II. The field is now catching up with this discovery and attempting to explain why nitrogen doping works and extrapolate the high Q benefits to higher gradients.

Within the Fermilab Complex for Accelerator science and technology R&D (Fermi-CARD) SRF operations, the program maintains and operates a wide collection of test facilities, including cavity and cryomodule processing facilities (mechanical polishing, electropolishing, buffered chemical processing, high pressure water rinsing), assembly and testing facilities (string/full cryomodule assembly, vertical test stands, horizontal test stands), the Materials Science Lab and the Ultra-low Temperature Facility located across the Fermilab campus (ICB, IB1, IB4, MP9, MDB, CMTF) and at ANL. These facilities are used for GARD and other HEP-funded accelerator R&D activities. Other non-GARD/HEP funded users can also pay to use these facilities under the usual HEP “user facility model” arrangement. These customers would also pay for new capabilities that are specific to their experiments.

The FNAL SRF program has made several important innovations in recent years: nitrogen processing to enhance gradient and cure Q disease, fast cool-down to expel magnetic trapped flux, and the 75 °C baking─all of which have the potential to reduce cost and increase the gradient. They have built up an impressive base of instruments to study the surface microphysics and how it is affected by process parameters, and used those tools to good effect to link physics understanding to process development. The new Materials Science Lab helps shorten the time for sample analyses, leading to fast test cycles. The present bottleneck of the throughput for testing cavities is high-pressure water rinsing system. Additionally, some of the liquid helium supply systems are in need of modernization and redundancy. Development of methods to grow a Nb_3Sn layer on the inner surface of a Nb cavity is also impressive. The group has built up a very nice capability to make and test specimen coupons and cavities, and used it to reach encouraging performance. These SRF R&D components fit perfectly toward GARD objectives.

The SRF program supports 20 FTEs (5 on GARD research and 15 on Fermi-CARD facility operations), and is complemented by support from Early Career Awards, LDRDs, directed R&D funds from LCLS II HE and ILC cost reduction R&D. The research goals are aligned with the GARD RF Research Roadmap[5], i.e., pushing the boundaries of the technology towards unprecedented accelerating gradients and cavity Q factor, which will enable next generation of HEP, BES and NP accelerators. With its new large dilution refrigerator, FNAL is also capable of conducting 3D SRF qubits study at ultra-low temperatures, relevant to applications in quantum computing and dark sector searches. The group publishes ~10 articles per year in high-impact journals and many papers in the proceedings of international conferences. They are working with major collaborators worldwide, and have built strong links to local universities to further expand its capabilities, particularly in areas of material science and SRF theory.

The committee members were unanimously impressed by the accomplishments of the FNAL SRF group. They noted that the program, led by a young and dynamic team, is sound and vibrant, and is performing beyond expectation. The reviewers also commented that the lab and HEP have invested heavily in SRF at FNAL, far in excess of GARD funding, which is primarily directed at R&D. This, coupled with an energetic and enthusiastic team, has made FNAL the best lab in the world for SRF science and technology in a relatively short time. Together with their world-wide collaborators, they have effectively deepened the understanding of the physics in SRF loss mechanisms and gradient limitations. However, there was no mention of understanding and mitigating the fundamental limitation of field emission, though there is an activity to implement

[5] GARD RF Acceleration Technology Thrust (including NCRF, SRF and RF sources) Research Roadmap: https://science.energy.gov/~/media/hep/pdf/Reports/DOE_HEP_GARD_RF_Research_Roadmap_Report.pdf

the plasma cleaning method developed at SNS for use on LCLS II modules. The reviewers thought achieving the goals of >60 MV/m might be a challenge.

Recommendations from the committee include: continue supporting SRF R&D at the same or higher level, devoting more efforts to further understanding of the field limitations in SRF cavities both experimentally and theoretically; increasing high-pressure water rinsing capacity to increase the throughput of cavity testing; modernizing and increasing redundancy of cryogenic plants in order to fully support cavity testing and operation of SRF modules reliably; and supporting the field emission studies as the cavity gradient and surface electric field increase.

LBNL

At LBNL, the conventional RF group at LBNL, now labeled BACI, is often overshadowed by the much larger programs within ATAP but is producing impressive results and continues to innovate. This group recently delivered the state-of-the-art RFQ to FNAL for PIP-II, the APEX gun to SLAC for LCLS II, and advanced fiber optic timing systems for LCLS I. The group had also developed and delivered the novel 200 MHz RF cavities for the muon ionization cooling experiment (MICE). The BACI group has a staff of 5 postdocs and 7 students, but it also gets technical support from the Engineering Division. There are strong collaborations with other labs and projects. The group is exploring new opportunities in superconducting quantum bits (QUBITS) control. Some LLRF instruments are decades old.

The committee members noted that the LBNL BACI team is a world leader in high beam power RFQ. The successes in RFQ accelerator and FPGA-based fiber-optic laser timing and distribution systems are impressive. These have become world standards. BACI's advanced technology on precision RF controls has been and will continue to contribute to the future HEP accelerators.

It was recommended that BACI (1) maintains the technologies for high beam power RFQs with reasonable funding, (2) fully documents its RFQ systems with detailed drawings and techniques used for the high beam power RFQs, and (3) modernizes its decades-old measurement tools.

SLAC

SLAC has a long and illustrious history in research and development in RF Acceleration Technology. It is a world-recognized intellectual center for development and testing of normal conducting accelerating structures, high power RF devices and sources, high gradient studies, and sophisticated accelerator modeling. Experiments are conducted on the NLCTA, ASTA, TS4 Lead Mini Bunker and FACET facilities. Simulation, modeling and virtual prototyping support is provided by the ACE3P team, with its suite of 3D parallel codes running on the NERSC high performance computer. SLAC is a major contributor to the GARD-RF research roadmap, as such, its program is highly aligned with the HEP priorities. Leadership has produced a goal-oriented program that supports the P5 report and roadmap plans. Major research topics include: advanced

RF sources for transcending cost-capability limits; engineered materials for high performance-active/passive components; virtual prototyping—multi-physics and advanced algorithms; new paradigm of THz accelerators & sources; and integrating materials research + novel structure topologies. SLAC is also researching into additive manufacturing of copper cavities and other components.

Since 2015, the SLAC RF group has become part of the newly created Technology Innovation Directorate (TID), and the team has grown from 2 members to 9, including five young new members. There are also strong support from the 4-member Advanced Computational Group, as well as 2 postdoctoral fellows and 4 graduate students. There have been 4 Ph.Ds. awarded based for this work, one DOE Early Career Award in THz accelerators, and multiple patents. SLAC has demonstrated accelerating gradients of 250 MeV/m, and new accelerator topologies have been invented and tested. SLAC has also helped the SRF community by testing superconducting materials with an innovative mushroom cavity and high power short RF pulses at 11.4 GHz. Virtual prototyping using ACE3P codes on high performance computers has provided cost-effective component design and critical engineering analysis for RF accelerator technologies, and is now widely used across DOE accelerator complex and beyond to academia and industry. ACE3P has become even more useful with the addition of mechanical and thermal simulations as well as beam transport simulations.

Sixty different high gradient RF experiments have been performed, with each lasting 2-8 weeks to collect enough statistics. These experiments were primarily carried out at TS4, ASTA and NLCTA. Detailed materials characterization and analyses have led to improvements in breakdown field. The GARD-support program also used 3000 hours at NLCTA during FY18, and is expected to use 6000 hours in FY19. The NLCTA test facility has well-leveraged infrastructure, but lab area is crowded and suffers from space sharing. This has been partly due to superconducting gun tests which were performed in the same area. These SRF gun tests at NLCTA have now concluded and the experimental section of the tunnel will be isolated via shielded walls. ASTA will no longer be used for GARD research in the out years. Since the last GARD review, the group has published ~50 refereed journal articles, hundreds of conference papers, and more than 15 invited talks at international conferences.

The review committee noted that the SLAC RF group is well-led and more dynamic than before. At one time there was concern that this team's survival was in jeopardy, but its prospects are now quite the opposite. The amount of ideas and work that come out of this group is quite impressive. The committee regarded Sami Tantawi as a national asset and was pleased to see that he is now finally being supported to develop new talent and collaborations. There was a great deal of youth and energy on display at SLAC, especially within the RF Accelerator Technology Team. The main challenge for this group is prioritizing the prolific number of ideas to be tested. The former NLCTA and the klystron test lab are unique assets in the DOE complex that could never be replicated in the modern era. It is imperative that these be preserved and modernized if DOE is going to stay in the NCRF game. The SLAC RF group is re-thinking the fundamental philosophy for RF source design in an effort to dramatically reduce costs per generated Watt of RF power. The team has identified modulator costs, RF source costs, and efficiency as major concerns for the NCRF community and is making strong progress in addressing them. The development of cryogenically cooled NCRF structures is a significant breakthrough in the technology and an important clue to the previous breakdown limit in copper structures. It deserves to be properly tested and may lead to a scalable mid-temperature technology or may point the way to a different paradigm for room temperature structures using harder but still highly conducting alloys. The distributed coupling structure is another interesting development that may have useful applications provided it can be fabricated cost-effectively. The team is keen to collaborate on possible SRF applications of these structures. The committee also regarded the research on additive manufacturing of RF cavities and other components to be excellent and should be encouraged. This is both the current and future wave of manufacturing and cuts across many areas of HEP.

Recommendations from the committee include: (1) increase funding to the creative non-superconducting RF group; (2) increase funding/emphasis on research on additive manufacturing of RF and other components; and (3) NLCTA should be maintained to test new structures and their applications.

2.2.5 Superconducting Magnets and Materials

Superconducting magnet R&D is recognized by the P5 and the GARD Subpanel as a technology R&D area that is critical for future very high-energy proton-proton colliders. The GARD Subpanel Report calls for vigorously pursuing major cost reductions by investing in magnet development and in the most promising superconducting materials, targeting potential breakthroughs in cost-performance. A GARD workshop was held to chart out a program strategy with research roadmap and milestones. The resulting superconducting magnet strategy is published in the US Magnet Development Program (MDP) report[6].

Activity in this research area takes place at three of the institutions covered in this review—BNL, FNAL, and LBNL, but GARD only supports efforts in the latter two labs. A significant amount of magnet-related R&D at these three laboratories is funded by HEP's LARP directed R&D program and the Accelerator Stewardship program, but those efforts are not part of the current review and will not be discussed here[7].

In the conductor development activities within the GARD Superconducting Magnet and Material thrust, the most innovative parts at FNAL are the high C_p and Artificial Pinning Center (APC) efforts. The APC idea came from the university program, but was not acknowledged. By contrast, LBNL clearly embraces collaborations with the university GARD program, especially in Bi-2212

[6] The research roadmap for the GARD Superconducting Magnets and Materials Thrust: "*The U.S. Magnet Development Program Plan*" https://science.energy.gov/~/media/hep/pdf/Reports/MagnetDevelopmentProgramPlan.pdf

[7] We note, however, that many of the staff members at FNAL and LBNL have roles in GARD, LARP and Stewardship, so the separation of effort is somewhat imprecise.

and REBCO (CORC cables). These collaborations have been rewarding to both sides, leading also to several job offers at the labs and in the industry making these advanced conductors.

Both FNAL and LBNL talk about the possibility of using subwindings of their model dipoles to create a background field dipole that could support future subscale studies. FNAL suggests using the outer subwinding; LBNL suggests using 2 or 3 layers of Canted Cosine Theta (CCT) as a background field dipole. Both approaches are of course possible, but the reviewers also considered BNL's 11 T racetrack-geometry common-coil dipole, which offers an 11 T background field with very friendly geometry to assemble a racetrack winding in the clear mid-plane aperture, and to provide side and end support and instrumentation. It was noted that BNL has offered the use of this dipole for testing to any R&D group, yet neither FNAL nor LBNL have availed themselves of the opportunity.

BNL

The superconducting magnet R&D program at BNL does not receive any support from the GARD program and is currently not part of the Magnet Development Program (MDP) Collaboration. As mentioned above, the only superconducting dipole in US that can serve as a background field dipole for cost-effective studies of subscale windings of high-field cables (Nb_3Sn, Bi-2212, REBCO) is Gupta's 11 T common-core dipole. The reviewers commented that GARD management should consider using this background field dipole for subscale studies in parallel with their much more expensive plans to build a succession of model dipoles.

FNAL

FNAL has the most extensive infrastructure for supporting the Superconducting Magnet and Material R&D activities. Fermi-CARD operates and maintains all the test facilities in this GARD thrust that are related to magnet R&D, construction and testing activities. As with the SRF case, the magnet test facilities are also scattered over many buildings (IB1, IB2, IB3 and IB3A) on the FNAL campus. These consist of the superconducting (SC) magnet fabrication and testing facilities, SC strand and cable lab, and magnet measurement stands. They support users from the high-field superconducting magnets and materials thrust area in GARD, as well as the LDRD and Early Career research programs. Magnet testing by users from construction projects (HL-LHC, LCLS II, PIP-II, Mu2e, Muon g-2, IOTA, for example) are also accommodated under the usual HEP "user facility model" arrangement.

The FNAL SC magnet R&D program develops baseline technologies for present and future accelerators. These include R&D on materials, strand and cable, magnet training, as well as modeling and structural design. However, FNAL's main focus is on the development of accelerator-quality magnets that have appropriate aperture and field for beam, alignment properties, control of high-order multipoles during injection and energy ramp, appropriate length, and heat load and quench management. They have successfully completed technology transfer of the 11 T dipole magnet, developed under this program, to CERN. Currently, as part of MDP, FNAL is developing a 15 T dipole magnet. Their next desired focus is on the development of high-field accelerator dipoles, based on Nb_3Sn conductor, that are capable of operating at over 16 T fields. In the longer term, the program aims at developing hybrid accelerator dipole magnets—LTS plus HTS insert—at fields over 20 T. The SC magnet R&D program supports ~7 FTEs, with another 60 staff members, supported by other means, who have long term experience in magnet design, fabrication and testing. The program generated 45 journal papers since the last GARD review.

The reviewers agreed that the R&D work on heat capacity enhancement could provide a margin of stability against micro-quenches, but, to determine the effectiveness of the technique, it would be important to know what the heat spectrum of micro-quenches look like as these typically propagate to cause a quench. The R&D to enhance J_c using artificial pinning centers could also be an important topic for GARD. It was pointed out that its potential significance for dipoles involves another parameter not yet considered─the copper fraction in the superconducting strands. If J_c were doubled in the non-copper part of the strand and the overall cross-section of the wire/cable is reduced, then in a quench event, twice the current would need to flow in a given cross-section of copper within each strand. As a rule of thumb, J_{Cu} approximately equal to 1 kA/mm^2 during quench is workable for quench protection. Unless that limit can be doubled it, would not be feasible to realize the benefit from enhancements to J_{sc}. Research to explore that question would be valuable, and could perhaps be accomplished in a subscale winding program, but no such study has been proposed by either of the two labs that comprise the MDP.

The reviewers noticed that the presentations by FNAL's senior management emphasized the strongest parts of the superconducting program (i.e., the SRF program) and did not give the same weight to the magnet program. There was concern that this may be reflected in a lack of mentoring to the younger magnet staff. While not publically recognized, FNAL has lost some of its recent magnet program Ph.D. staff. It might be good for management to study this loss so as to better understand how to rebuild the effort to attain similar standing as LBNL, some important parts of which came from FNAL.

Overall, the reviewers thought the FNAL SC magnet program was disappointing. FNAL chose a 4-layer cosine theta magnet with high costs and long time-constant and so far have seen no results. The whole program awaits the test later this year. A major challenge in their 4-layer, 15 T demonstrator dipole design is the wobbly interface between the inner and outer 2-layer subwindings. The stress concentrations that can jeopardize winding integrity are not adequately addressed. It seems the presenter is unaware of recent results on degradation of B_{c2} of the Nb_3Sn cores at 140Mpa, significantly lower than the 15 T demonstrator, and that will prevent the winding to reach the stated design value even if there are no other problems.

The recent Magnet Task Force exercise initiated by the Fermilab Director to rethink and redesign the FNAL SC magnet R&D is in principle a good effort. The report, in the opinion of the GARD review committee, badly needs an editor as it is way too long. Even though much of it is reasonable and laudable, it is not yet well situated in the context of the MDP. The lack of a FNAL commitment to a signed MDP MOA until the week prior to the review has made full MDP planning very difficult. Now that it is signed, more effective integration should be possible, since much of the task force report covers ideas and thrusts being done at LBNL anyway.

By end of 2018, there should be test results from Fermilab's 15 T demonstrator and from LBNL's Canted Cosine Theta magnet, CCT5. It is recommended that GARD and/or MDP initiate an international workshop to bring together magnet developers from US, Europe, and Asia to examine the results of those tests, and from tests of magnets being developed within CERN's FCC initiative, and try to learn as much as possible to best motivate the next stage of development of high-field dipoles. No further model dipole development should be undertaken until such examination can be made.

LBNL

LBNL continues to maintain a strong core GARD program in this thrust area. The LBNL Superconducting Magnet Group ("Supercon") prides itself on having a clear program strategy, both internally (with the formation of Berkeley Center for Magnet Technologies, BCMT) and nationally (being a key contributor in the development of the research strategy and roadmap for US high-field magnet development program, MDP). LBNL is the lead-lab for the MDP, and is contributing heavily to it in program leadership and technical elements. The Supercon team is comprised of a dynamic and energetic team with significant breadth and depth in advanced SC magnet technology, covering materials, modeling and analysis, diagnostics, and testing.

LBNL is making significant progress in the underlying technology ranging from diagnostics to magnet design modeling, and is collaborating with National High Magnetic Field Laboratory (NHMFL) on the development of high temperature superconductors (Bi2212 and REBCO). Since the 2013 review, the program has made technical advances in developing and testing LTS and HTS magnets, including Nb_3Sn magnets (HD3, CCT1/2/3/4), Bi2212 racetrack coil, and REBCO (3 and 40-turn CCTs). There have also been good progress in the development of novel diagnostics: passive and active acoustic systems, advanced quench antennae, and multi-source diagnostics for improving the understanding of magnet training. Magnet modeling has also seen major advances with the incorporation of multi-physics in a rigorous and systematic approach.

Supercon operates a magnet test facility at LBNL with a 24 kA DC power supply, fast data acquisition (500 kHz, 16-bit) and advanced quench detection and protection. Its short-sample test facility operates a 15 T magnet, test temperature of 4.2–50 K, with a 5 kA power supply.

The Supercon program is motivated by the MDP goals and aligned well with the GARD research roadmap and its milestones. The group is developing the multi-shell CCT assemblies as a path toward high-field dipoles for future hadron colliders. Reaching a goal of 16 T would require ~6 shells. The current phase of the program is focused upon building a 2-shell CCT to explore construction issues with the goal of making a ~10 T dipole that could serve as a background field dipole for subscale studies for the high-field insert shells which will be required for higher field. The goal was to complete that dipole by end of 2018. The program got off to a disappointing start with its first shell. They made a rookie mistake of not allowing for the transverse growth of the Nb_3Sn cable when it undergoes phase change during heat treatment, so that the cables protruded beyond the outer surface of the shell structure.

The second CCT doublet was completed and tested, and took 85 quenches to reach 86% short sample. It was found that (1) initial quenches (with fast increase of current from quench to quench) originated from epoxy cracking; most of the quenches thereafter originated from stick-slip friction; and (2) quenches occurred pretty much everywhere on the windings, and on both inner and outer shells. This is in contrast to training on either cosine theta or block coil windings. In these cases, quenches typically concentrate on poles, mid-planes and transitions, where stress concentrates. The group plans to use Mix 61, a new epoxy formulation developed at NHMFL, in future CCT windings in an effort to eliminate epoxy cracking. There is good likelihood that may work. It was noted that the prospect for improving the quenches from stick-slip friction is more problematic. CCT is a clever winding strategy, with very nice flexibility for magnets that do not entail large Lorentz forces, but in this geometry, the Lorentz force points in a turning pattern that is at steep-to-middle angles with respect to the interface over much of the winding, and by design there is little provision for preload. Thus it is very problematic to control stick-slip.

The group has matured its acoustic sensor methods for monitoring coil motion, and used it to spectacular effect in analyzing the locations of each quench and distinguishing quenches by their acoustic signature between those originating from epoxy cracking and those originating from stick-slip motion. This is an extremely important piece of work and will benefit *all* groups developing high-field magnets. Refining the acoustic measurements to estimate the actual heat energy that is released in the originating disturbance for each quench could inform the studies for how to take best use of the above method for enhancing wire heat capacity.

The group is also conducting a nice development of Bi-2212 winding technology using subscale racetrack windings. He has developed a reproducible method to make the windings and operate them. These windings should be tested in a background field. It raises the question, why not testing them in the BNL 11 T dipole?

Overall, the committee found that the LBNL program has a confident, well-articulated and broad approach to achieving high-field dipole magnets The LBNL program is making investments in new approaches, a younger generation with young-generation tools (multi-physics modeling, new types of sensors for complete quench analysis, HTS, not just LTS materials), and a novel CCT test bed for much more rapid and comparative testing of new ideas. They are also focusing on trying to understand magnet behavior at the fundamental level, especially training behavior in Nb_3Sn magnets, and mentoring very effectively a younger generation who is now a central part of the GARD program. There is strong interaction with FNAL, the NHMFL, the broader US university community and CERN. Their strong scientific approach has already propelled LBNL to a leading position, not just in the U.S. but worldwide. In as much as LBNL is leading the U.S. MDP program, LBNL leadership can propel MDP to become the clearly accepted world-leading superconducting accelerator magnet R&D effort, but with two caveats:

- Significant additional resources are needed to enable MDP to achieve this potential
- FNAL management must embrace an MDP vision, rather than subordinating MDP to a Fermilab-centric vision. The split vision at FNAL has made MDP collaborations slower, more complex and more top-down than bottoms-up. LBNL is clearly setting the scientific vision at the present time but there are good opportunities for FNAL to partner in doing this if their management can clearly signal, especially to the younger staff, that they are fully behind MDP.

Since the committee recommendation for the magnet program is relevant to both FNAL and LBNL, it is reiterated here. As noted above, ***by end of 2018, there should be test results from Fermilab's 15T Cosine Theta demonstrator and from LBNL's CCT5. The committee recommends that GARD and/or MDP initiate an international workshop to bring together magnet developers from U.S., Europe, and Asia to examine the results of those tests, and from tests of magnets being developed within CERN's FCC initiative, and try to learn as much as possible to best motivate the next stage of development of high-field dipoles. No further model dipole development should be undertaken until such examination can be made.***

2.2.6 Comparison of R&D Programs

As noted in Section 2.1.6, the committee was asked to compare the R&D programs at the laboratories reviewed, and to place them into different "tiers" using the 8 merit criteria listed in the charge letter.

The scientific impact and quality of the R&D activities at each laboratory were compared by categorizing the research programs into "tiers" under each GARD thrust area. Programs that provided the highest scientific impact were placed in Tier 1, while those programs with marginal impact were placed in Tier 4. The discussions and rankings of each R&D thrust were led by the designated subcommittee. While the entire committee participated in all the discussions, no attempt was made to cross-normalize the rankings between the different thrusts. Because some subcommittees preferred to distribute their rankings over all tiers (as in the AAC thrust), and others chose to rank on a more "absolute" scale, it would not be meaningful to compare the rankings of one subcommittee with those of another.

Table 3: Tier Ranking of R&D Programs for each GARD Thrust. Note that ranking was not normalized across different GARD Thrusts, also the scoring resolution between tier levels in each thrust may vary.

	Accelerator & Beam Physics	Adv. Accelerator Concepts	Particle Sources & Targetry	RF Acceleration Technology	Superconducting Magnet/Material
Tier 1	ANL, FNAL, LBNL	LBNL	FNAL	FNAL, LBNL, SLAC	LBNL
Tier 2	BNL, SLAC	ANL, SLAC			
Tier 3		BNL			FNAL
Tier 4		FNAL			

3 HEP Responses

While concerns raised by the reviewers are covered above, there are, however, a few that deserve mentioning in this separate HEP response section. The full set of reviewer recommendations to the labs are compiled in Appendix 5.2.

The research supported by the GARD program was considered by the review committee to be well-aligned with HEP mission and needs. The overall quality of research in the five laboratories reviewed was high. In general, there were no poor performers and the individual programs did not have significant duplication. Also, there are no bad program elements or wasteful activities in the GARD program. However, the balance between electron and proton R&D, though somewhat improved, is still not commensurate with the current U.S. HEP aspiration of becoming world leader in the Intensity Frontier. The GARD program is, through a series of workshops, engaging its accelerator community to chart out appropriate research roadmaps and milestones for each thrust to help guide and balance its emphasis on the future needs of Energy Frontier and Intensity Frontier.

The GARD community has been motivated and energized by the HEPAP Accelerator R&D Subpanel Report to come together to develop a strategic plan for each of the research thrusts. At the time of this review, strategic plans with research roadmaps and milestones have been completed for three of the five GARD thrusts, namely, Advanced Accelerator Concepts, Radio Frequency Acceleration Technology, and Superconducting Magnet and Material. These roadmaps have been very effectively used by all the laboratories to plan, guide and deliver on their research objectives. The remaining thrusts—Accelerator and Beam Physics; and Particle Sources and Targetry—will be done in the coming year.

The effective and timely response of the GARD community in developing and executing the research roadmaps was highlighted in this review. However this review also surfaced several important activities where science impact is high, but continued progress is constrained by existing infrastructure, personnel, and/or available funding. HEP will work with the labs to identify priority areas for additional investments in the GARD portfolio, which may necessitate re-balancing of other efforts.

For example, there is a concern that GARD and/or FNAL is underinvesting in the high power targetry R&D effort. This is because it is well-known that ultimately it is the target that limits facility performance, not the accelerator. HEP is aware of this concern, and plans to take appropriate actions to correct the situation have been developed for this GARD thrust. Meanwhile, with strong proposals submitted by FNAL, complementary efforts have been supported with funding from HEP's US-Japan Science and Technology Cooperation Program.

4 Summary

An on-site review of the HEP GARD program was conducted at ANL, BNL, FNAL, LBNL and SLAC. Although the ATF at BNL is not supported by GARD, much of the proposal-driven research conducted there is supported by GARD, hence the ATF was included in this review. Based on its findings, the review committee had provided tier rankings of the GARD programs at the laboratories and tier ranking of the test/user facilities reviewed. In addition, it has also provided specific recommendations for each laboratory and DOE as listed in Appendix 5.2. In general, the committee found the HEP Laboratory GARD program to be healthy and the research to be of high quality. There were no poor performing or wasteful research elements at the different laboratories. The committee also found the program to be well aligned with the overall HEP mission, especially in thrust areas where GARD research roadmaps have been developed.

There are, however, two exceptions:

1. The proton and electron R&D activities are not considered well-balanced as proton R&D should be enhanced; and
2. There was some concern about insufficient investment in high-power target development, which could limit the energy reach of future Intensity Frontier experiments.

Even though the reviewers considered the research to be of high caliber at each of the laboratories, they were especially impressed by the productivity and cost-effectiveness of the AWA and ATF; the thoroughness and world-leading research efforts at BELLA and FNAL-SRF; and the renewed exuberance and innovation in the NCRF program at SLAC.

5 Appendices

5.1 Charge Letter

Department of Energy
Washington, DC 20585

May 21, 2018

MEMORANDUM FOR LK LEN

FROM: GLEN CRAWFORD, DIRECTOR
RESEARCH AND TECHNOLOGY DIVISION
OFFICE OF HIGH ENERGY PHYSICS

SUBJECT: Charge for HEP General Accelerator R&D Lab Review

The mission of the Department of Energy High Energy Physics (HEP) program is to seek an understanding of how our universe works at its most fundamental level. The General Accelerator R&D (GARD) subprogram supports that mission by fostering fundamental research and development in the science and technology of particle accelerators. This subprogram nurtures the technologies needed to design and build the future accelerator facilities that will be used to carry out the HEP research program thereby advancing our strategic goals for science.

This letter is to request that you conduct an onsite review of HEP-supported laboratory research efforts in the area of the GARD subprogram on July 30-August 4, 2018. The purpose of this review is to assess the quality and impact of the recent scientific achievements by these research groups; the feasibility, relevance and impact of the proposed research on achieving the scientific goals and milestones of the HEP mission; and the national deployment and balance of accelerator test facilities Your panel will also review the operation of user/test facilities at each laboratory, including reliability, facility up-keep and improvement, cost containment, and how well the users are being served.

For each laboratory's GARD research group, we request a specific evaluation of:

1) The quality and impact of the research by the group since the last review in 2013;
2) The scientific significance, merit, and feasibility of the proposed research;
3) The competence and future promise of the group for carrying out the proposed research;
4) The adequacy of resources for carrying out the proposed research, and cost-effectiveness of the research investment;
5) The quality of the support and infrastructure provided by the laboratory;
6) Where an experimental facility exists,
   - The reliability and cost containment of operation;
   - What is the condition of the facility? What is the deferred maintenance backlog and its associated risk and cost?
   - How impactful is each experiment to achieving the goals of the P5 and GARD subpanel reports, the relevant GARD research roadmaps, and on accelerator science in general?
   - How well the users are being served?

   - Is the facility well suited to conduct these experiments?
   - Could this work be done at other test facilities?
7) How the group benefits the laboratory's experimental program (as applicable), and how well the group's activities relate to the overall HEP mission; and
8) The overall soundness of the GARD program, potential areas where consolidation or redirection will be beneficial and feasible.

The research efforts should be presented in terms of the laboratory group's contributions (as applicable) along the following programmatic thrust lines:

- Accelerator and Beam Physics (including modeling, simulation as well as beam instrumentation and controls)
- Particle Sources and Targetry
- Advanced Accelerator Concepts
- RF Acceleration Technology (including SRF, NCRF and RF Sources)
- Superconducting Magnets and Materials
- Test Facility Operations

The laboratories should provide information in this format on both their accomplished and proposed research in advance of the review, including the level of effort for each thrust line (FTEs and funding), using the provided Excel template worksheet.

The final report should outline the laboratory-based accelerator R&D program in each of these thrusts and discuss the unique and important elements that the laboratory programs bring to bear in addressing these research topics. **In this context, we request a comparative assessment of each lab's overall performance in these areas relative to its peers, as well as an assessment versus comparable university groups.** The overall evaluation of the lab's research will be an important input to the process of optimizing resource allocations within the various research thrusts.

The HEP GARD program supports a wide range of research thrust areas that are important to HEP needs, both in the mid and long term time scales. As part of this review, we are also requesting the reviewers to provide additional general findings and comments about the current status and future promise of the programmatic thrust areas listed above, for example:

- What are the expected deliverables of this research thrust in the next 5-10 years?
- Are adequate resources in place to plausibly achieve these goals?
- Do the labs have sufficient technical and management infrastructure to reliably deliver the goals for this programmatic area and respond to new developments?
- What is the benefit of additional investments in this particular thrust? What are the likely impacts of reduced investments?

I encourage you to interact with the laboratory groups at the review and provide them with whatever immediate feedback you find appropriate. Upon the completion of the review, reviewers should send a letter summarizing their findings and evaluations, which includes their overall findings on the GARD thrusts, an assessment of lab contributions to these thrusts, and the individual lab evaluations. The letters will be confidential within OHEP.

Individual lab evaluations, along with the findings on the each research thrust, and assessment of laboratory contributions therein, will be incorporated into a summary report. I would like to receive the draft individual laboratory evaluations and the summary report no later than October 1, 2018. Thank you for taking on this important task.

Glen Crawford
Director, Research and Technology R&D Division
Office of High Energy Physics

Cc: J. Siegrist
M. Procario
E. Colby
M. Demarteau, ANL
D. Lissauer, BNL
W. Leemans, LBNL
J. Lykken, FNAL
N. Holtkamp, SLAC

5.2 List of Recommendations

ANL

1. AWA: Assess the effects on uptime of hiring one or more additional technicians.
2. AWA: Assign or hire a group leader.
3. AAC: Set and work toward more ambitious goals in terms of accelerating gradient, place priority on emittance preservation studies, and develop collider parameters to maintain possible relevance to a future AAC collider.

BNL

1. ATF: Expedite cross-training of C-AD personnel to reduce risk of reduced uptime due to loss of personnel.
2. ATF: Continue detailed tracking of deferred maintenance to improve and maintain uptime.
3. ATF: Develop clear long term plans in terms of running of the two facilities (in B820 and B912) and the scientific program/vision for activities in the next five years and beyond.

FNAL

1. FAST/IOTA: Increase operations staff as planned.
2. FAST/IOTA: Cycle young research scientists through operations for experience in and exposure to a wide variety of accelerator issues.
3. FAST/IOTA: Upgrade the cryo-plant.
4. FAST/IOTA: Defer the decision to convert to a user facility to allow joint cost and workload sharing with collaborators during early operational years.
5. ABP/AAC: Use FNAL beam expertise to guide and perform experiments at existing top-notch AAC facilities (such as FACET II and others), and also consider contributing to the AWA beam manipulation techniques.
6. ABP/AAC: Do not start AAC program at FAST facility unless and until a comprehensive and convincing plan could be developed.
7. PST: Devote more resources to the design and development activity for targetry.
8. RFA: Continue to support SRF R&D at the same or higher level, devoting more efforts to further understanding of the field limitation in SRF cavities both experimentally and theoretically.
9. RFA: Increase high-pressure water rinsing capacity to increase the throughput of cavity testing.
10. RFA: modernize and increase redundancy of cryogenic plants in order to fully support cavity testing and operation of SRF modules reliably.
11. RFA: Support the field emission studies as the cavity gradient and surface electric field increase.
12. SMM: After the test results are known for the FNAL 15 T cosine theta dipole demonstrator and the LBNL CCT5 magnet, initiate an international workshop to bring together magnet developers from US, Europe, and Asia to examine the results of those tests, and from tests of magnets being developed within CERN's FCC initiative, to learn as much as possible to best motivate the next stage of development of high-field dipoles. No further model dipole development should be undertaken until such examination can be made.

LBNL

1. BELLA: Support it well.
2. BELLA: Monitor and budget for future maintenance and replacement of aging components.

3. ABP: Develop a plan for the Accelerator Modeling Program to release the IMPACT code suite as open source.
4. ABP: Support the BLAST initiative very strongly, in particular by providing resources for users support and further developments.
5. AAC: Support the BELLA experimental program strongly, in particular through operations support.
6. AAC: Continue to make emittance preservation a high research priority.
7. AAC/ABP: Continues to develop fiber based high power laser as an LPA driver.
8. RFA: Maintain the technologies for high beam power RFQs with reasonable funding
9. RFA: Document fully with detailed drawings and techniques used for the high beam power RFQs.
10. RFA: Modernize BACI's decades-old measurement tools such as network analyzers.
11. SMM: After the test results are known for the FNAL 15 T cosine theta dipole demonstrator and the LBNL CCT5 magnet, initiate an international workshop to bring together magnet developers from US, Europe, and Asia to examine the results of those tests, and from tests of magnets being developed within CERN's FCC initiative, to learn as much as possible to best motivate the next stage of development of high-field dipoles. No further model dipole development should be undertaken until such examination can be made.

SLAC

1. FACET-II: Create well-defined schedules and priorities that are specifically designed to avoid accelerator tunnel access conflicts between FACET-II and LCLS II, and disseminate this information to operations crews, research staff, and users.
2. NLCTA: Continue the consolidation of RF testing in the NLCTA facility.
3. AAC: Strengthen numerical support for the PWFA program.
4. RFA: Increase funding to the creative non-superconducting RF group.
5. RFA: Increase funding/emphasis on research on additive manufacturing of RF and other components.
6. RFA: Continue to maintain NLCTA for testing new structures and their applications.

DOE

1. Continue to support the CAMPA effort for the coordination and integration of code development to avoid duplication, as well as for continued code maintenance.
2. After the test results are known for the FNAL 15 T cosine theta dipole demonstrator and the LBNL CCT5 magnet, initiate an international workshop to bring together magnet developers from US, Europe, and Asia to examine the results of those tests, and from tests of magnets being developed within CERN's FCC initiative, to learn as much as possible to best motivate the next stage of development of high-field dipoles. No further model dipole development should be undertaken until such examination can be made.

5.3 Committee Members

Felicie Albert
Lawrence Livermore National Laboratory

Eric Colby, Co-Chair
Office of High Energy Physics, DOE

Glen Crawford
Office of High Energy Physics, DOE

John Galambos
SNS, Oak Ridge National Laboratory

David Kehne
Naval Research Laboratory

David Larbalestier
Florida State University

L.K. Len, Co-Chair
Office of High Energy Physics, DOE

Peter McIntyre
Texas A&M University

Steve Milton
Los Alamos National Laboratory

Patric Muggli
Max-Planck-Institut für Physik

Robert Rimmer
Thomas Jefferson National Accelerator Facility

Steve Russell
Los Alamos National Laboratory

Tsuyoshi Tajima
Los Alamos National Laboratory

Antonio Ting
University of Maryland

Yoshishinge Yamazaki
Michigan State University

5.4 GARD Review Transmittal Letter

Department of Energy
Office of Science
Washington, DC 20585

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Deputy Director
SLAC National Accelerator Laboratory
2575 Sand Hill Road, MS 103
Menlo Park, CA 94025

Dear Dr. Hafidi, Dr. Mueller, Dr. Lykken, Dr. Symons, and Dr. Holtkamp:

I have enclosed the report from the Department of Energy Program Review of High Energy Physics (HEP) Laboratory General Accelerator R&D (GARD) held on July 30–August 4, 2018. It conveys our evaluation of the performance, effectiveness and the quality of the GARD program at each of the laboratories, based on the findings of the review committee, presentations from the review, laboratory visit, and our office's assessments. It also provides guidance for your future program planning.

I would like to thank you and your staff for the hospitality shown the review team and for the quality of the review. Despite the tight schedule and logistics challenges, the review at each laboratory proceeded smoothly as the review committee traveled from one laboratory to the next. All the presentations by the staff of each laboratory were polished, well organized, and informative.

Overall, the review committee was very favorably impressed by the review and its associated materials. They did, however, point out some areas for your consideration and they made some suggestions and recommendations which may improve the quality of your program. The details of their findings, comments, and recommendations can be found in the enclosed report. You will find the complete list of recommendations in the appendix. Since the recommendations are specifically directed at the operation of the GARD-supported facilities and research programs at the laboratories, please work with L.K. Len of our office to address the review committee's suggestions and recommendations in the coming weeks.

We hope that the review report is helpful to you in planning the next several years of HEP GARD activities at the laboratory.

Sincerely,

Glen Crawford
Director, Research and Technology Division
for High Energy Physics

Enclosure

5.5 Meeting Agendas

5.5.1 Argonne National Laboratory

GARD Review

Location: Bldg 360, Rm. A-224, Argonne National Laboratory
Wednesday, 1 August 2018 from 08:00 to 17:00 (US/Central)

Agenda

8:00	Coffee and Light Breakfast	
8:30	Executive Session	
9:00	Welcome to Argonne	M. Norman
9:05	HEP long term roadmap	M. Demarteau
9:20	AWA Overview: 2013-2018	M. Conde
9:40	AWA Roadmap: 2018 and beyond	J. Power
10:00	Two Beam Acceleration for the Linear Collider	C. Jing
10:15	Collinear Wakefield acceleration for the XFEL	A. Zholents
10:30	Break (10 minutes)	
10:40	AWA Tour (50 minutes)	
11:30	High Gradient and High Efficiency Acceleration	J. Shao
11:45	Electron beam phase space manipulation.	G. Ha
12:00	Electron source development	E. Wisniewski
	Working Lunch (12-1pm)	
12:15	AWA Control System	W. Liu
12:25	AWA Collaborator Program	S. Doran
12:35	Wrap-up	M. Conde
12:40	Exec Session (30 minutes)	
13:10	Management and AOB session	
14:00	Dismissed	

5.5.2 Brookhaven National Laboratory

Start Time	Duration	Title	Speaker
8:00	0:50	Executive Session	LK Len
8:50	0:10	Welcome	D. Gibbs
9:00	0:25	BNL AS&T Overview & ATF Introduction	M. Palmer
9:25	0:25	ATF Operations and Electron Beam Capabilities	C. Swinson
9:50	0:25	CO2 Laser Capabilities and Upgrade Plans	M. Babzien (C. Cullen)
10:15	0:25	Facility R&D Thrusts: ATF Laser R&D and Simulation	M. Polyanskiy (I. Pogorelsky)
10:40	0:15	Coffee Break	
10:55	0:20	Approach to Evolving Experiment and Facility Requirements	K. Kusche/E. Lessard
11:15	0:25	Looking Ahead and Response to Recommendations	M. Palmer
11:40	0:20	Q&A	All
12:00	0:45	Working Lunch for Committee	
12:45	0:05	Board Shuttle	
12:50	0:30	B820 Tour	M. Babzien/I. Pogorelsky
13:20	0:05	Board Shuttle	
13:25	0:30	B912 Tour	M. Fedurin/C. Folz
13:55	0:05	Return to Berkner	
14:00		Depart	

5.5.3 Fermi National Accelerator Laboratory

July 31, 2018, HEP General Accelerator R&D Lab Review
Ver. 11, 07/16/18, SN, SAB, VS

Plenary Session

08:00 **Executive Session** *30'*

08:30 **Welcome** *5'*
Speaker: Nigel Lockyer (Fermilab)

08:35 **Fermilab GARD Program Overview / Accelerator & Beam Physics** *30'*
Speaker: Sergei Nagaitsev (Fermilab)

09:05 **Fermilab GARD program in SRF and Magnets** *30'*
Speaker: Anna Grassellino (Fermilab)

09:35 **Test Facilities Overview: Fermi-CARD** *30'*
Speaker: Sergey Belomestnykh (Fermilab)

10:05 – 10:20 **Coffee Break** *15'*

Breakout 1: Superconducting RF Session

10:20 **SRF Acceleration Technology and Test Facilities** *45'*
Speaker: Alexander Romanenko (Fermilab)

11:05 **Transformational R&D: towards Higher Q/Higher Gradients Nb cavities** *30'*
Speaker: Anna Grassellino (Fermilab)

11:35 **Towards New Materials for SRF cavities: Nb_3Sn and films** *25'*
Speaker: Sam Posen (Fermilab)

12:00 – 13:00 **Lunch** *60'*

13:00 **Graduate student report (SRF)** *15'*
Speaker: Bianca Giaccone (University of Milan, Italy)

13:15 **Connecting Cavity Performance to Physics of the Surface** *20'*
Speaker: Martina Martinello (Fermilab)

13:35 **Cryogenic operations** *30'*
Speaker: Jay Theilacker (Fermilab)

Breakout 2: Superconducting Magnets Session

10:20 **Superconducting Magnets and Materials, Magnet Test Facilities** *45′*
Speaker: George Velev (Fermilab)

11:05 **Magnet Task Force: Program and Plans** *30′*
Speaker: Giorgio Ambrosio (Fermilab)

11:35 **Status of 15T dipole and Nb_3Sn quench studies** *25′*
Speaker: Stoyan Stoynev (Fermilab)

12:00 – 13:00 **Lunch** *60′*

13:00 **Nb_3Sn conductor R&D** *30′*
Speaker: Xingchen Xu (Fermilab)

13:30 – 13:35 **Break, join Breakout 2**

13:35 **Cryogenic operations** *30′*
Speaker: Jay Theilacker (Fermilab)

Breakout 3: Beam Physics Session

10:20 **Accelerator and Beam Physics (our vision in high intensity and high brightness beams)** *40′*
Speaker: Vladimir Shiltsev (Fermilab)

11:00 **Transformational R&D in nonlinear beam dynamics** *20′*
Speaker: Alexander Valishev (Fermilab)

11:20 **Beam stability and loss control through electron lenses** *20′*
Speaker: Giulio Stancari (Fermilab)

11:40 **Toward high brightness: optical stochastic cooling** *20′*
Speaker: Jonathan Jarvis (Fermilab)

12:00 – 13:00 **Lunch** *60′*

13:00 **Grad. student report (IOTA)** *15′*
Speaker: Nikita Kuklev (UChicago)

13:15 **SYNERGIA development and Numerical Studies of Landau Damping** *30′*
Speaker: Alex Macridin (Fermilab)

13:45 **FAST Beam facility operations** *30′*
Speaker: Jerry Leibfritz (Fermilab)

Breakout 4: Targets, Sources and AAC

10:20 **High-power Targetry** *30'*

Speaker: Patrick Hurh (Fermilab)

10:50 **CERN HiRadMat (BeGrid2) experiment** *20'*

Speaker: Kavin Ammigan (Fermilab)

11:10 **Electron-beam control and beam-wave interaction** *30'*

Speaker: Philippe Piot (NIU/Fermilab)

11:40 **Round-to-flat beam transformation experiment at FAST (grad. student report)** *20'*

Speaker: Aliaksei Halavanau (NIU)

12:00 – 13:00 **Lunch** *60'*

13:00 **Plasma Wakefield Acceleration: Physics, Experiments, Plans** *30'*

Speaker: Sergei Nagaitsev (Fermilab)

13:35 **Join Beam Physics Breakout Session**

13:45 **FAST Beam facility operations** *30'*

Speaker: Jerry Leibfritz (Fermilab)

14:15 – 14:30 **Coffee Break** *15'*

Tours (may still adjust the times...)

- 14:35 **Tour of SRF and Magnet Facilities (ICB, IB1-IB4)** *1h00'*
- 15:35 **Tour of MP9** *20'*
- 15:55 **Tour of CMTF and FAST/IOTA** *40'*

16:35 **Arrive at Wilson Hall** *10'*

Closing Remarks, Executive Session, Reception

16:45 **Fermilab GARD: Summary** *15'*

Speaker: Joe Lykken (Fermilab)

16:45 **Executive Session** *60'*

18:00 **Reception** *60'*

5.5.4 Lawrence Berkeley National Laboratory

GARD Review

August 2nd, 2018	**Speaker**	**Talk**	**Questions**	**Duration**
8:00 Executive session		1:00		
9:00 Overview of LBNL GARD activities	W. Leemans	0:20	0:10	0:30
9:30 Magnet Development Program	S. Prestemon	0:20	0:05	0:25
9:55 CCT progress	D. Arbelaez	0:15	0:05	0:20
10:15 Conductor development	I. Pong	0:10	0:05	0:15
10:30 Break		0:15		0:15
10:45 Diagnostics	M. Martchevskii	0:10	0:05	0:15
11:00 Stewardship: advanced concepts for medical, colliders,...	L. Brouwer	0:10	0:05	0:15
11:15 HTS magnet technology	T. Shen	0:10	0:05	0:15
11:30 BELLA Center -- US Roadmap	W. Leemans	0:20	0:05	0:25
11:55 Towards 10 GeV	T. Gonsalves	0:15	0:05	0:20
12:15 Staging experiments and second beamline	S. Steinke	0:15	0:05	0:20
12:35 Lunch break		0:45		0:45
13:20 Tour -- BELLA Center/BACI lasers/MDP	Tour BELLA laser, HTT and HTU lasers, medical laser setup, BACI systems, magnet systems	1:30		1:30
14:50 Collider modeling	C. Schroeder	0:15	0:05	0:20
15:10 Modeling of experiments	C. Benedetti	0:15	0:05	0:20
15:30 Break		0:15		0:15
15:45				
15:45 BACI overview	D. Li	0:15	0:05	0:20
16:05 Laser technology	R. Wilcox	0:10	0:05	0:15
16:20 QIS	G. Huang	0:10	0:05	0:15
16:35 AMP overview	J.L. Vay	0:15	0:05	0:20
16:55 ECRP	C. Mitchell	0:10	0:05	0:15
17:10 Hosing, BBU etc...	R. Lehe	0:10	0:05	0:15
17:25 Break		0:10		0:10
17:35 Poster session (with food and drinks)	students/postdocs/staff	1:00		1:00
18:35 Adjourn				

5.5.5 SLAC National Accelerator Laboratory

	Day 1		
8:00	**Executive session**	LK Len	60m
9:00	Welcome	CC Kao	10m
9:10	Accelerator research in AD	B. Dunham	20m
9:30	Beam Physics and Colliders	Z. Huang	20m
9:50	PWFA overview	M. Hogan	30m
10:20	**Coffee break**		30m
10:50	Experimental area upgrade	D. Storey	20m
11:10	Machine Learning at FACET-II	B. O'Shea	20m
11:30	FACET-II: Project Status	S. Green	20m
11:50	FACET-II: Operations Planning	G. Yocky	20m
12:10	FACET-II: New Science Opportunities	V. Yakimenko	20m
12:30	**Lunch (15 min student talks; Nasr, Gold)**		1h
13:30	RF Accelerator – Introduction, Vision and Impact	S. Tantawi	15m
13:45	Advanced Computation for RF Accelerator R&D	C. Ng	25m
14:10	The Role of Structures and Materials in the Advancement of RF Accelerators	E. Nanni	35m
14:45	Transcending RF Source Limitations	M. Kemp	35m
15:20	RF Accelerator Conclusion/Outlook	E. Nanni	10m
15:30	**Coffee break**		30m
16:00	Direct Laser Acceleration	England	20m
16:20	Tour		60m
17:20	**Executive session**		60m
18:20	**Reception**		1h 10m