Department of Energy
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H. WEERTS
HIGH ENERGY PHYSICS DIVISION

SEP 30 2010

Dr. Harry Weerts
Director, High Energy Physics Division
Argonne National Laboratory
9800 South Cass Avenue
Argonne, IL 60439

Dear ~~Dr. Weerts~~ Harry:

In FY 2011 the Office of High Energy Physics (HEP) will be conducting a review of Accelerator Science programs supported at national laboratories. Enclosed is a summary Report of the DOE Review of the Laboratory Accelerator Science Program held in December 2008, including HEP responses to the recommendations of the review panel, as well as specific Findings and Comments on the Argonne program. We hope that this will be helpful in your preparations for the upcoming review.

If you have any questions, please free to contact me.

Sincerely,

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

Enclosures

cc: Stephen Streiffer, ANL, w/enclosures
Dennis Kovar, SC-25, w/o enclosures
LK Len, SC-25, w/o enclosures

HEP Review of the Argonne National Laboratory Accelerator Science Program December 2-4, 2008

1. Introduction and Summary

ANL reported on activities in two areas: the generation, management, and characterization of high-current, low-energy electron beams; and the analysis and control of field emission in rf cavities.

The program in advancing accelerator technology for high charge-state, high-current, high-power electron beams is conducted on the Argonne Wakefield Accelerator (AWA), a "dedicated high charge facility constructed to study the beam-structure interactions". The program makes contributions to the development of Novel Concepts and Beam Sources and Instrumentation, and to Accelerator and Beam Physics. The program involves collaborations with a number of universities, industrial firms, and federally funded laboratories. The three students are presently involved with two more expected in the next year and six PhDs have been obtained over the past ten years based on work in this program. Annual funding for the AWA program at the time of the review was ~$2M, with ~$1.3 to 1.5M provided by direct DOE support (including equipment/supplemental funds). Additional support is provided by an industrial partner (Euclid Techlabs) and through ANL LDRD funding and via a Director's post-doctoral position. The proposal requests support for two additional staff (engineer and technician; $450K/yr) and for $100K/yr in additional operational cost support.

The program in the control of field emission in rf cavities contributes to Muon Collider/Neutrino Factory R&D. The program involves numerous university, laboratory, and commercial collaborators, and is intended to provide improved understanding of, and control for, discharges in rf cavities. The effort is at present funded as part of the U.S. Neutrino Factory /Muon Collider Collaboration at $190K/yr, with $144K/yr additional LDRD funding. Additional funding varying from $100K to $250K is requested over the next three years to support modeling of breakdown and use of atomic layer deposition to "breakdown-proof" rf cavities of various types.

2. Accelerator and Beam Physics

2.1. Findings

ANL, with the AWA, is operating a useful facility for fundamental investigations into the physics of intense beams. They have performed space charge studies (in collaboration with

NIU) and have measured the properties of intense beams generated by rf photo-injectors. They have investigations underway on numerous topics, including beam breakup control in dielectric structures, laser pulse shaping, emittance exchange experiments (with NIU and FNAL), beam compression using a dogleg compressor, and generation of high frequency bunch trains. They are in the process of upgrading their accelerator system to higher energy and intensity that will increase the range and flexibility of the available pulse structure.

2.2. Comments

The reviewers found the accelerator physics work to be of high quality and that the program has produced some excellent graduate students, but the work has had less impact than one would have been expect because it does not seem to be well known. One reviewer points out that better advertizing of the results might be beneficial. In the opinion of the reviewers, the future program is sensible, but would be even more so were it tied more tightly to similar efforts (for example – those of the CERN CLIC team, which needs beams of the type under study with the AWA). The reviewers are of the opinion that the group is competent and can be expected to deliver the projected future work. Both reviewers agree that the request for additional funding is not excessive and appears to be cost effective.

3. Novel Acceleration Concepts

3.1. Findings

The Advanced Acceleration R&D/AWA presentation documented a number of novel rf power generation and acceleration concepts. These include: the use of dielectric-loaded structures to achieve high gradients (hundreds of MV/m); use of a high power electron drive beam to generate high accelerating gradients via wake fields; generation of high power rf (as a 7.8-GHz power extractor) using dielectric-loaded structures and a high current bunch train; rf-driven dielectric structures; tailoring the drive bunch train (triangular ramp) to enhance the transformer ration in a wake-field accelerator; a Zeeman-effect based PASER; and a number of other concepts utilizing high charge/current drive beams.

3.2. Comments

Both reporting reviewers think it would be appropriate to coordinate the dielectric accelerator work with SLAC so as to make the national program more coherent. This should be straightforward as the SLAC coordinator was an ANL student. It was not entirely clear what the strength of the ties between the groups is, though some contact was apparent. Enhancing this – and publicizing it more actively – would be well worthwhile.

4. Muon Collider/Neutrino Factory

4.1. Findings

The ANL program supports a very specific investigation into causes of and cures for rf breakdown. This issue is relevant to muon-based (and virtually all other conventional rf accelerator-driven) systems in that performance and cost are tightly linked to the available rf gradient. The problem of gradient limitations is further exacerbated in the muon systems by the requirement that the cavities function in environments with high magnetic fields.

The presentation detailed work that started in 2000, citing results developed by a moderately large collaboration examining field-emission dark currents and x-rays emitted from cavities under rf power. It reported that rf breakdown and field emission initiates with high fields at surface defects on a 30-nm length scale. Summary results of modeling the breakdown, surface damage, arcs and maximum achievable gradient were presented. It was conjectured that "breakdown proof" cavities could be obtained through appropriate use of atomic layer deposition (ALD) to smooth out impurities and surface defects. Additional funding support was requested to allow modeling of the effect and to allow ALD tests on cavities in the Fermilab MuCool Test Area.

4.2. Comments

The SRF community has carried out extensive investigations into field emission and rf breakdown without ascertaining the fundamental causes or finding effective cures. The ANL group's perspective is novel, and their findings differ from this larger body of work. The reviewers reporting on ANL believe the group does good work, but feel that a significant influx of new money would be justified only if a different team were involved.

5. Beam Sources & Instrumentation

5.1. Findings

The AARD/AWA group has completed phase space measurements (using pepper-pot methods) on their rf photo-injector system and is in the process of executing a number of other instrumentation development studies, including (but not limited to): OTR-based emittance diagnostics (in collaboration with a University of Maryland group); use of deflecting-cavity-based longitudinal phase space measurements (in collaboration with NIU); electro-optical imaging (in collaboration with NIU); and 4-D transverse phase-space measurements. They have in addition engaged in extensive electron source work, having built a new rf gun, developed expertise in the use of Cs_2Te cathodes, and played a lead role in the modeling of the ILC/CLIC positron source (and have an MOU in development with

CERN for this work). The group's expertise in diagnostics has in addition enabled them to support HEP laboratory astrophysics efforts by participating in detector development (calibration) for Auger (U. Chicago) and Radio-Wave (UCLA/Hawaii).

5.2. Comments

One reviewer finds the group's "crossover" activities to support HEP astrophysics efforts both exciting and encouraging, as they demonstrate a broad outlook and the extent to which accelerator expertise represents a generally applicable technological skill-set. The source and instrumentation efforts at AWA represent valuable assets not only to the high energy physics community, but also to the broader scientific community using accelerator-based methodologies. This includes the fourth-generation light-source community (such as U. Wisconsin/SRC, SLAC/LCLS, and LBNL) and the high-energy laser community (including JLab and organizations involved in the ONR INP FEL program).

Report of the DOE Program Review of
Laboratory Accelerator Science
December 2-4, 2008

1. Introduction

The Office of High Energy (HEP) Accelerator Science program provided $51.9 million in FY 2009 for fundamental accelerator R&D. This program supports long-range, curiosity-driven R&D and includes the following research thrusts: Accelerator and Beam Physics; Novel Concepts; Muon Accelerator R&D, High Gradient Structures; and Beam Sources and Instrumentation. The HEP Review on December 2-4, 2008 focused on the work being performed at Argonne (ANL), Brookhaven (BNL), Fermi (FNAL), Lawrence Berkeley (LBNL) and SLAC (SLAC) national laboratories. The Finding and Recommendations of the review are discussed in the next section and HEP's responses in the third section.

2. Overview

Overall the reviewers found the Laboratory Accelerator Science program to be healthy, with meritorious activities being pursued at all the HEP-funded national laboratories. The research was considered to be of high quality, with little overlap between the research programs in the different laboratories. The program as a whole appeared to be well aligned with the overall HEP mission with the major challenges identified being addressed. The resources going into Accelerator Science were believed to be well justified, although the other areas of accelerator R&D supported by HEP were not within the scope of this review, so the overall balance of the complete portfolio was not addressed..

They found it difficult to make detailed comment on the division of resources between the research thrusts, except to say that it looks reasonable, in the sense that there is no poor quality work and little duplication – where two or more groups are attacking the same issue, they are usually doing it in different ways. It was believed that for most research topics an incremental investment would probably bring greater dividend. Areas that would greatly benefit from additional funding include new projects (such as FACET) and the operation of the intermediate-scale user facilities (e.g., at ANL and BNL).

It was noted that having a central repository for information on the capabilities of the different electron test beam accelerators (ANL-AWA, BNL-ATF, FNAL-A0 photo injector and SLAC-NLCTA) might facilitate matching user requirements to the appropriate facility (i.e., "this is what I want to do, where is the best place to do it" rather than "what can I do at the facility with which I am familiar").

2.1. Accelerator and Beam Physics

Research in the Accelerator and Beam Physics (ABP) thrust area is pursued at SLAC and FNAL, and to a lesser extent at ANL. Reports at the reviews ranged from fundamental beam physics R&D to support for operating facilities. A recurrent theme at the reviews was how to distinguish between Accelerator Science and Accelerator Development, which are two separate categories in the HEP budget. The reviewers note that different laboratories use different definitions for these categories. SLAC's criterion for Accelerator Science is work that is published, peer-reviewed, and cited. By contrast, FNAL considers R&D which is applicable to accelerators outside FNAL to be Accelerator Science. At both laboratories, other work of a similar nature is funded through other sources, including the HEP Accelerator Development program, and at LBNL similar work is entirely funded as Accelerator Development. Reviewers note that some tasks are tightly enough coupled with operational performance improvements that they might even be funded from Operations rather than Accelerator Science or Accelerator Development. These comments did not question the need or merit of the work, but were directed at the organization of accelerator R&D efforts within the Office of High Energy Physics.

2.1.1. Assessment of the Current Program

The creation of the Accelerator Physics Center at FNAL, the Accelerator Research Division at SLAC and the Argonne Accelerator Institute at ANL is recognition of the importance of Accelerator and Beam Physics (ABP) to the laboratories. The more recent creation of the Center for Accelerator Science and Education at BNL continues this emphasis. (The Center for Beam Physics at LBNL has existed for some time.)

The ABP program at SLAC addresses topics in beam optics and nonlinear dynamics, collective effects, and massively parallel computations. Work carried out recently includes: PEP-II optics modeling and correction; beam-beam luminosity simulations; impedance and wake field calculation methods and modeling; coherent synchrotron radiation (CSR) modeling and analysis; use of state-of-the-art computational tools for the study of beam-cavity interactions in ILC cryo-modules and trapped HOMs in the PEP-II interaction region; and beam breakup calculations for the CEBAF 12-GeV prototype cryo-module. The work is high quality, is published in peer-reviewed journals, and is recognized at international conferences with invited presentations. The staff is well qualified to carry out the proposed research: SLAC staff are recognized as amongst the most capable in the field of e^+e^- colliders and associated beam physics.

The ABP thrust at FNAL encompasses: topics in beam optics and dynamics of direct relevance to improving Run-II luminosity; topics related to beam-beam dynamics in hadron colliders, including simulations; active beam-beam compensation by electron lenses; beam collimation studies including the design and deployment of collimation systems in the Tevatron, Main Injector and Booster; the study of high-energy proton crystal channeling with possible application to future halo-cleaning methods; and ground-motion and electron-cloud studies. The work carried out is of high quality, and has direct relevance to both the FNAL program and future colliders. Staff members are recognized in the field as being well qualified, and are amongst the experts in the beam physics of hadron colliders.

At ANL, forefront research in the physics of intense beams is carried out in support of development of the AWA and its experiments. In the opinion of the reviewers, the accelerator physics work is of high quality and has produced some excellent graduate students, but has had a smaller impact that one would have been expect because it has done a poor job in making its results known.

2.1.2. Future Directions

SLAC lists four deliverables: i) application of optics tuning methods to the ATF2 final focus facility at KEK to achieve the small spot size, ii) continued CSR instability studies to understand limitations for very short bunches, iii) design of damped, high-gradient structures for CLIC and the U.S. High Gradient program and modeling of power flow in the two-beam accelerator, and iv) multi-physics modeling (integrated electromagnetic, thermal and mechanical) for SRF structures.

FNAL lists for its three most important deliverables: i) electron lens development for RHIC and LHC, ii) electron-cloud simulations to better understand limitations and mitigation strategies, iii) ground motion characterization with application to Project X and DUSEL.

2.1.3. Expected deliverables in next 5-10 years

The most compelling scientific opportunities seem to cluster in two areas: (1) *Fundamental understanding of collective effects and their limitations* (e.g.; Can electron clouds and their associated instabilities be mitigated in future hadron colliders, high-intensity hadron accelerators, damping rings for linear colliders, and conventional e^+e^- colliders?; What are the limitations imposed by CSR, and can they be mitigated?; Can impedances and wake fields be calculated with the necessary accuracy?; Can emittances be controlled to the level required for the next generation of high-brightness photon sources and colliders?) and (2) *Advanced Computation* (i.e.; development and deployment of massively parallel computational tools to better understand increasingly complex systems as beam intensities increase, and as higher performance is required.)

The reviewers believe that the program proposed by SLAC is better aligned with these goals and has a broader range of applicability. The proposed FNAL program, while important and worth pursuing, does not seem to fit well within the scope of the Accelerator Science program. The proposed FNAL work seems to offer a payoff in the 5-10 year time frame, and therefore would more accurately be labeled "Development."

2.1.4. Benefits of additional investments

The benefit of additional investments would seem to be more rapid progress in understanding of collective effects and their mitigation in increasingly complex accelerators of the future. This thrust area serves a stewardship role for accelerator scientists at SLAC and FNAL by funding mostly salaries of accelerator physicists. Therefore, reduction in funding in this area would weaken one of the core competencies at each of the labs.

2.1.5. Recommendation

DOE HEP should better define the scope of Accelerator Science, Accelerator Development and the individual programs for ILC, SRF and SC Magnets in order to ensure that Accelerator Science funding truly serves the long-term interests of the field.

2.2. Novel Acceleration Concepts

Research in the Novel Accelerator Concepts (NAC) thrust area is pursued at SLAC, LBNL, and ANL. The thrust area also includes the Accelerator Test Facility (ATF), which BNL operates as a user facility for advanced accelerator R&D. The NAC thrust is probably the highest profile activity within the Accelerator Science Program, delivering very high quality results. Both the SLAC and LBNL programs are world-leading, of the highest quality, and are carried out by world experts in this field.

2.2.1. Assessment of the Current Program

The SLAC program pursues direct laser acceleration (DLA) and plasma wake-field acceleration (PWFA) concepts. The DLA program was funded at $1.4M in FY08, with $1.9M requested for FY09. The PWFA effort in FY08 was $0.45M, and the FY09 request is $0.75M. . The demonstration of 50-GeV/m electron acceleration by PWFA in E167 is one of the "crown jewel" accomplishments of HEP Accelerator Science. Long-term efforts in PWFA at SLAC are represented in the FACET proposal. Progress in this field requires a high energy electron beam of sufficient intensity and brightness – only available at present from the SLAC linac. Further, there exists right now a window of opportunity for carrying out these experiments while the intellectual knowledge base is still in place, and while there are not yet demands for use of the first 2/3 of the linac for LCLS. This window of opportunity would appear to close within 8-10 years or so. Therefore, the time seems right to pursue FACET.

LBNL, through the LOASIS program, pursues laser-driven plasma wake-field acceleration, also known as laser wake-field acceleration or LWFA. The demonstration in 2004 of the first high quality electron beam from LWFA is also one of the "crown jewel" accomplishments of HEP Accelerator Science, garnering front-cover attention in ***Nature***. The subsequent demonstration of GeV beams from plasma channels continues the high quality work.

The ANL effort is focused on developing the Dielectric Wake-field Accelerator (DWA) concept as a possible path toward a TeV-scale linear collider. This impressive program has made steady progress, demonstrating 100 MV/m in a dielectric structure, and demonstrating high RF power (~50 MW) generation in short pulses.

The BNL ATF is a good example of the fulfillment of the accelerator science stewardship role of HEP. The ATF enables a broad range of fundamental accelerator science research in a very productive, cost-effective, user-based mode of operation. In addition, the facility has served as a training ground for a substantial number of accelerator science PhDs. The outstanding quality of the research performed at ATF is evinced by the number of publications in high-impact journals. The ATF is a unique facility, bringing together high-quality electron beams with powerful lasers and diagnostics systems, supported by a knowledgeable staff. The health and vitality of the facility benefit from the strong emphasis on user-mode operations. The rigor of peer-reviewed, proposal-driven research guided by a program advisory committee upholds the quality of the research performed.

2.2.2. Future Directions

For the Direct Laser Acceleration program, SLAC lists as the three most important future accomplishments: i) demonstration of acceleration and focusing of a bunched beam in a structure of length 100-1000 optical wavelengths, ii) design and demonstration of a large scale integrated structure, and iii) simulation of a DLA accelerator showing emittance preservation. For the PWFA effort, SLAC lists: i) acceleration of a discrete witness bunch with narrow energy spread and preserved emittance, ii) identification of optimal technique for positron acceleration, iii) study of a high-demagnification plasma lens.

For the LOASIS program, LBNL lists as the three most important future accomplishments: i) controlled injection with a capillary at 1 GeV, ii) demonstration of staging of two accelerator modules, iii) demonstration of reproducible, low-emittance, low-energy-spread, ~100-pC, 1-GeV beams.

ANL lists as the three most important future accomplishments relative to DWA: i) further enhancement of the drive beam source to provide bunch trains at high charge, corresponding to drive beam power in the GW range, ii) experimental testing of structures up to 500 MV/m, iii) development of GW-level, pulsed rf power sources based on the AWA drive beam.

BNL lists as future goals: i) provide picosecond, 10-TW, CO_2 laser beams for ATF experiments, ii) establish a high power, x-band rf power station at ATF to serve user experiments, iii) investigate Compton back-scattering of a laser from a high-brightness electron beam as a viable source of high-repetition gamma rays suitable for production of polarized positron beams.

2.2.3. Expected deliverables in next 5-10 years

Within Novel Acceleration Concepts, the most compelling scientific opportunities cluster around demonstration of the three main branches of this thrust area:

- Demonstration of acceleration of witness electron and positron bunches in a beam-driven plasma with narrow energy spread, preserved emittance and efficient energy transfer
- Demonstration of optical acceleration of bunched beams over macroscopic distances with adequate focusing and emittance preservation
- Demonstration of low energy-spread, low-emittance, high-charge beam acceleration to multi-GeV energies by laser-driven plasma acceleration

Two of the three approaches have already completed the first round of demonstration experiments. Demonstration at the level which gives confidence that a linear accelerator could actually be built and deliver the required beam quality, with these very new technologies, should be the focus of the next decade of research. The BELLA and FACET proposals represent significant steps in this direction.

The ANL dielectric wake field approach has perhaps a nearer timeline. Aspects of the program would seem to merge well with two-beam schemes based on normal conducting structures (CLIC), while other aspects share some commonalities with the high-gradient program. In that sense, this research effort has a nearer term horizon than the others within this thrust.

The reviewers believe all branches of the NAC thrust are strong programs with high potential for payoff in the long term and should be continued. Their views are mixed on prioritizing the available options.

2.2.4. Recommendations

This thrust area seems ripe with potential payoff from increased investments. The next major advance in acceleration concepts is just around the corner. We may be glimpsing these future approaches right now. Increased funding could place one or more of these concepts on firm ground within the next 10 years, to the point that one could imagine constructing an accelerator based on these new technologies. In particular approval of FACET or BELLA would address this opportunity. Support at cost of living effort for the other is recommended.

2.3. Muon Collider/Neutrino Factory

Work is ongoing at ANL, BNL, FNAL, and LBNL on Muon Collider and Neutrino Factory designs. Part of the work ($4M in FY09) is performed coherently as part of the Neutrino Factory/Muon Collider Collaboration (NFMCC), and some Muon Collider activities ($5M) are coordinated by the Fermilab-based Muon Collider Task Force (MCTF).

2.3.1. Assessment of the Current Program

The program at present is aimed at the most challenging and significant technological aspects of NF and MC designs. There are four main experimental programs that target the most fundamental issues: (1) The MICE experiment, which is intended to demonstrate muon cooling on an individual particle basis; (2) The MERIT experiment, which successfully demonstrated the feasibility of the Hg jet target concept for multi-MW proton beams; (3) The EMMA proof-of-principle experiment for non-scaling, fixed-focus, alternating gradient cyclotrons; and (4) a collection of individual, challenging technical component demonstrations, including rf cavities in high magnetic fields, absorber technology, low-frequency SCRF cavities, and high-field magnets. In parallel with the experimental effort is a significant simulation effort aimed at developing 6-D cooling, and tracking the muon emittance from beginning to end.

The format of the Laboratory Accelerator Science review, with separate presentations of the thrust areas by each laboratory, was less than ideal for getting a complete picture of the MC/NF effort distributed across several laboratories. Nonetheless, the reviewers were impressed with the results and progress reported by the muon collaborations, and with the high return on research per dollar. They also noted the effectiveness of the NFMCC approach to coordinating and managing the R&D.

ANL is conducting a very specific investigation into the causes and cures for rf breakdown in cavities for accelerating muons, and in cavities for other particles. They reported that rf breakdown and field emission initiate with high fields at surface defects on a 30-nm length scale, and conjectured that "breakdown proof" cavities could be obtained through appropriate use of atomic layer deposition (ALD) to smooth out impurities and surface defects. These results are somewhat controversial, and the reviewers suggest supporting the investigation at the current level with monitoring.

2.3.2. Future Directions

The collaboration's high level goals are to develop options for the U.S. in the 2012/2013 time frame. The focus is on the production and delivery of two products: (1) **Neutrino Factory Reference Design Report** by the International Design Study. The collaboration would like significant US involvement in this. Timescale aimed at beginning a construction start in the late 2010s, and (2) **Muon collider feasibility study** to be completed by 2013, in time for community consideration of linear collider and muon collider approaches. Construction could start in the early to mid 2020s.

These goals are aligned with the goals and recommendations of the HEPAP Particle Physics Project Prioritization Panel. The collaborations have submitted to HEP a 5-year plan to achieve these goals. The plan has the effort level increasing to 80 FTEs, and the annual budget increasing from the present $9M to more than $20M.

The NFMC program is potentially very important for the future of particle physics in the U.S., and specifically the long-term future of FNAL. A neutrino factory is a credible continuation of the neutrino program at FNAL, which would build upon the investment in the Project X proton driver. A muon collider might be a realistic, cost effective alternative to a CLIC-type of multi-TeV lepton collider in the second half of the 2020s. (This assumes that a first generation linear collider operating up to 1 TeV is built first.) The feasibility of a muon collider has advanced considerably in the last decade, and more progress can be anticipated over the next few years as various research projects (MICE, EMMA, etc.) address other key technologies.

The reviewers agree that it should be a goal of the U.S. HEP program to contribute to the international effort on neutrino factories, and to lead the MC design, and they find that the proposed 5-year plan has high significance and merit. Two reviewers explicitly support an increase in expenditure on this area, with the clear aim of demonstrating the basic technologies and completing a first attempt at an end-to-end design and preliminary cost estimate, on the timescale of 2013.

However, the funds would need to come from additional resources allocated for this purpose and with some very clear goals laid down. Given the size and scale of the proposed program, it should compete with all the other Accelerator R&D resources in the HEP, namely the ILC, SRF and Accelerator Development programs. The effort to produce a cost estimate for a muon collider is large. Balancing this effort against the other research thrusts within Accelerator Science seems inappropriate; the size and scope of the activity required to produce a feasibility study with costs implies that it should be considered in the context of the other accelerator development efforts within HEP, in particular, the ILC program.

2.3.3. Expected deliverables in next 5-10 years

Deliverables in the next five years are to: (1) develop the NF Reference Design Report; (2) complete a Muon Collider feasibility study; (3) obtain results from the MICE experiment demonstrating single-particle emittance reduction; (4) complete the EMMA proof-of-principle experiment and (5) select the 6-D cooling technology to be demonstrated

It should be possible in the following five years to: (1) Perform a complete beginning-to-end simulation of a NF and MC; (2) perform an engineering design of the main MC and NF components, and prototype key components and technologies and (3) design, build and test with beam a demonstration 6-D cooling channel.

2.3.4. Benefits of additional investments

Additional investments could put the MC "on the table" for consideration by the community in the mid 2010s. It would lead to a demonstration of 6-D cooling within the next decade. Again, the requested increase is beyond what one would consider for Accelerator Science; it is more at the level required for an engineering design, and therefore needs to be balanced against the other HEP initiatives.

2.3.5. Current level of investment

The near-term milestones are unachievable at the current funding level. Flat funding during the next 5 years would preclude a 6-D cooling demonstration in the coming decade, and further postpone the determination of muon collider feasibility.

2.3.6. Recommendations

The U.S. HEP program should adopt the goal of contributing to the international effort on neutrino factories and leading the MC design. The DOE should seriously consider the proposed 5-year plan, which the reviewers find has high significance and merit. Given the size and scale of the proposed program, it should compete with all the other Accelerator R&D resources in the HEP, namely the ILC, SRF and Accelerator Development programs.

2.4. High Gradient Accelerating Structures

SLAC serves as the host for the U.S. High Gradient Collaboration, whose members include ANL, NRL, and several universities and small businesses. SLAC's effort is focused on normal-conducting (NC), metallic accelerating structures, while ANL focuses on dielectric wake-field acceleration (DWA). For FY 2009, SLAC is pursuing the High Gradient thrust with a budget of $3.5M.

2.4.1. Assessment of the Current Program

Remarkable progress has been achieved in the last several years in high-gradient (HG) rf accelerating structures, with gradients of 100 MV/m or more achieved in both NC and dielectric-loaded structures. The gradient continues to improve over time. The gradients achieved for NC structures are presently about one-half of the theoretical limits.

The work is carried out by a talented group of scientists and engineers. It utilizes one of the core competencies of SLAC: expertise in normal-conducting rf structure and component design and manufacture. SLAC's capabilities in this area are a valuable national resource.

2.4.2. Future Directions

The motivation for work in this field is twofold: i) to increase accelerating gradients in NC and dielectric-loaded structures, ii) to further explore NC technology and DWA as options for a future linear collider, so they are available for consideration when LHC physics results are obtained.

SLAC lists as the future goals: i) demonstration of efficient accelerator structures with loaded gradients above 100 MV/m and efficiencies of at least 30%, ii) demonstration of structures with wake-field damping features, and iii) demonstration of a 1-m long, collider-ready accelerator structure with a loaded gradient above 100 MV/m.

The ANL goals are: i) developing high-charge electron beams to drive very high gradients in dielectric-loaded and other accelerating structures, ii) using these beams to pursue gradients of 200-500 MV/m in dielectric, metallic, and other advanced structures,

and iii) developing GW-scale rf power sources for possible use in a dielectric-based, two-beam acceleration scheme.

2.4.3. Expected deliverables in next 5-10 years

One reviewer endorses the above SLAC goals and suggests focusing on item (iii) above, that is, the production and demonstration of an accelerating structure that incorporates the necessary wake-field damping, and achieves high loaded gradient with good efficiency in order to prove the basic building block for a future linear collider. There is some urgency, in the sense that this demonstration should be completed within the next 4 years or so in order to be "on the table" for the community's discussion of linear collider options. This reviewer also suggests designating the production engineering of the structure as a deliverable within the 10-year window to reduce the cost.

2.4.4. Benefits of additional investments

Additional investments would speed progress in the field, namely development of the high-power rf sources required to support high gradient operation, and the development of wake-field damping features. A reduction in investment would slow progress to the point where the demonstration of a collider-ready structure by 2012 would be jeopardized.

2.4.5. Current level of investment

The reviewers believe the current level of investment is sufficient to achieve the near-term goals.

2.5. Beam Sources and Instrumentation

The main effort in this thrust area is the FNAL A0 photo-injector program, with a budget of \$2.8M in FY 2009 and a requested increase to \$4.9M in FY 2011. ANL also has a modest program in Beam Sources and Instrumentation (BSI).

2.5.1. Assessment of the Current Program

The A0 photo-injector supports a program addressing fundamental questions in emittance exchange, plasma wake fields and diagnostics for short bunches. The first demonstration of a flat electron beam with 100:1 emittance ratio is an excellent and impressive result. Further studies in emittance exchange and manipulation are well founded. The production of 9 Ph.D. students shows the value of the program as an educational resource.

One reviewer compares the A0 program with the BNL ATF. While these two programs are operated in different ways, their budgets are not too different, and they both serve as platforms for advanced accelerator R&D. In his opinion, the BNL ATF is more effective and productive.

At ANL, the AWA group develops diagnostics for their intense electron beams, including OTR-based emittance diagnostics, deflecting-cavity-based longitudinal phase space measurements, and electro-optical imaging. Their expertise in diagnostics has enabled them to support HEP laboratory astrophysics efforts by participating in detector calibrations for the Auger and Radio-Wave experiments. In electron source development, they have built a high-charge rf gun, developed expertise in alkali metal cathodes, and played a lead role in the modeling of the ILC/CLIC positron source.

One reviewer finds the AWA group's "crossover" activities to support HEP astrophysics exciting, and believes that the group is valuable asset not only to the high energy physics community, but also to the broader scientific community using accelerator-based methodologies. This includes fourth-generation light sources and high-energy lasers.

The reviewers do not find that the A0 facility supports a vigorous program in BSI development that addresses the most important future needs. Much will be required of the electron, positron, proton and H^- sources of the future. Likewise on instrumentation, there are needs associated with the collision of beams of nanometer spot sizes that warrant research in new instrumentation. But these aspects are not a focus of the A0 program.

2.5.2. Future Directions

FNAL lists as future goals: i) performing emittance-exchange experiments using flat beam and transverse to longitudinal exchange, ii) ellipsoidal beam generation, iii) demonstrate feasibility of a coherent x-ray source based on a flat beam and image-charge undulator.

The goals for ANL's BSI program may be found in the section on HG accelerating structures.

At the beginning of FY 2011, FNAL plans to move the A0 photo-injector to the New Muon Laboratory to provide beams for tests of cryo-modules for Project X and the ILC. While there are important beam dynamics questions to answer, the danger is that much more will actually be required to perform realistic system tests with beams. For instance, beam instrumentation will be required to measure beam parameters to assess beam quality following acceleration. Since a program of beam tests and their goals was not presented, it is difficult at this point to assess the usefulness of this aspect of the longer-term A0 activity. There is also the issue of proliferating test beams, each of which must be supported by an ongoing operations budget. The reviewers believe more justification is appropriate before going forward with this program, and would look to the Project X and ILC programs to support A0 operations in FY 2011 if one of the primary purposes is to provide a test beam.

The A0 photo-injector seems to be an under-utilized resource. The reviewers encourage the A0 group to actively develop collaborations to bring needed ideas, students and energy to this program.

2.5.3. Expected deliverables in next 5-10 years

The most important scientific opportunities are not systematically targeted in this thrust. These would include the development of the next generation of beam sources (electrons, positrons, protons and H^- ions) that will be required in the next generation of colliders and high power proton accelerators.

2.5.4. Benefits of additional investments

Other, presently missing, elements of the thrust could be pursued, as mentioned above.

2.5.5. Current level of investment

The reviewers believe that near-term milestones that reflect the long-term needs of the community for beam sources and instrumentation need to be developed. They believe that the present funding level for the A0 program is adequate, and do not think that the case was made for increased funding beyond cost of living.

3. HEP Response to Recommendations

The major recommendations and HEP responses are discussed below

3.1. Accelerator and Beam Physics:

DOE HEP should better define the scope of Accelerator Science, Accelerator Development and the individual programs for ILC, SRF and SC Magnets in order to ensure that Accelerator Science funding truly serves the long-term interests of the field.

HEP has worked over the last year to better define the scope of the different activities supported and some progress has been made, however, this is still a work in progress. The Accelerators for Americas Future Symposium and Accelerator Workshop were organized to obtain information and guidance that will help of structure the accelerator science and development activities in HEP in a manner that will both better define the scope of activities and enable it to better serve the program and the Office of Science.

This reorganization is broader than accelerator and beam physics but clearly this area will be affected.

3.2. Novel Concepts: This thrust area seems ripe with potential payoff from increased investment. The next major advance in acceleration concepts is just around the corner. We may be glimpsing these future approaches right now. Increased funding could place one or more of these concepts on firm ground within the next 10 years, to the point that one could imagine constructing an accelerator based on these new technologies. In particular approval of FACET or BELLA would address this opportunity. Support at cost of living effort for the other is recommended.

FACET and BELLA have been funded and funding in the out-years is allocated for supporting their operations. Additional funding has been provided for enhanced research capabilities and operations at ATF and AWA.

3.3. **Muon Accelerator R&D:** The U.S. HEP program should adopt the goal of contributing to the international effort on neutrino factories and leading the MC design. The DOE should seriously consider the proposed 5-year plan, which the reviewers find has high significance and merit. Given the size and scale of the proposed program, it should compete with all the other Accelerator R&D resources in the HEP, namely the ILC, SRF and Accelerator Development programs.

HEP directed Fermilab to take the lead in setting up a national organizational structure for managing a 5-year muon accelerator R&D campaign and submit a proposal for review. The proposal has been independently reviewed and HEP plans to support this effort.

3.4. **High Gradient Structures:** The reviewers believe the current level of investment is sufficient to achieve the near-term goals.

The long-term direction and scientific priority of this area has still not been well established. Programmatic decisions have been further complicated by its close coupling to directed international R&D efforts (e.g. ILC, CLIC) and local (SLAC) programs which are in a period of transition. Funding for this activity has in general been flat.

3.5. Beam Sources and Instrumentation: Near-term milestones that reflect the long-term needs of the community for beam sources and instrumentation need to be developed The reviewers believe more justification is appropriate before going forward with the A0 program, and would look to the Project X and ILC programs to support A0 operations in FY 2011 if one of the primary purposes is to provide a test beam.

This area, as Acceleration and Beam Physics, has seen some progress, but will be further addressed when HEP restructures its Accelerator R&D activities in response to the Accelerator Workshop Report. The A0 activities will be moved out of Accelerator Science.