AF6 report

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ABSTRACT: This file is the draft of the summary and priority directions for initial feedback

2 Executive Summary

Efficiently harnessing the interaction of charged particles with extremely high electromagnetic fields at very high frequencies is the key to reaching ultra high gradients (GeV/m and beyond) and hence to reducing the dimensions, $C0_2$ footprint, and costs of future high energy physics machines, with the potential to reduce power consumption and offer e+e- and $\gamma - \gamma$ machines at and beyond 15 TeV. In addition to proven high gradient and ultra-bright beam generation, these systems have the potential for fast cooling, for short beams to increase luminosity per unit beam power, and for practical energy recovery to extend the reach of high energy physics. Techniques range from laser and beam driven plasma and advanced structure accelerators to advanced phase space manipulations and generation of beams with extreme parameters [1]. Recognizing this promise the last Snowmass and P5/HEPAP recommended, and DOE developed with the community, an organized Advanced Accelerator Development Strategy, and work has been aligned to this strategy [2].

In the last decade advanced accelerator research has seen tremendous progress including the demonstration of multi-GeV acceleration in a single stage [3, 4], positron acceleration [5], efficient loading of the structure [6], the first staging of plasma accelerators [7], demonstration of beam shaping to improve efficiency in plasmas [**?**] and structures [**?**], high gradient structures [8] and greatly improved beam quality which recently culminated in the spectacular first demonstrations of laser-driven and beam-driven plasma based FELs [9, 10]. At the same time, potential issues for colliders have been addressed demonstrating that in principle the required nm-class beam quality can be preserved (addressing potential limits due to scattering, hosing, and radiation), and that shaped bunches can be used to efficiently accelerate beams without energy spread growth. Driver technologies (SRF linacs, high average power lasers) are developing consistent with the needs of future colliders.

While recent results indicate that the main building blocks of future advanced accelerators are workable and promising, significant development is still required. This should in particular further detail methods for high wall-plug efficiency and high repetition rates to fulfill future collider luminosity requirements, for small energy spreads and beam emittance preservation over many acceleration stages and for plasma-based schemes, show that high quality positron beams can be accelerated.

With the goals of addressing these long standing questions and realizing the promise of advanced accelerators, in addition to a strengthened R&D program to solve outstanding critical issues two new research directions can be identified. An integrated design is needed to unite these techniques for future colliders. At the same time the need is also clear to pursue nearer-term applications both inside and outside high-energy physics.

In order to move forward, a vigorous R&D program is required. The US is in a good position in this respect with several state of the art of beam test facilities mainly dedicated to research in the advanced accelerator field, including FACET-II, BELLA, ATF, AWA and FAST-IOTA as well as numerous universities. Strong R&D using these facilities and programs is needed to push forward the key next steps in the Development Strategy including staging of multiple modules at multi-GeV, high efficiency stages, preservation of emittance for electrons and positrons, and shaped beams, as well as the development of efficient, low-cost and high repetition rate drivers. The facilities are organized in a beam test facility council which serves to foster collaboration and minimize duplication of efforts. Proposed upgrades of the test facilities (including a kBELLA high repetition rate driver and accelerator demonstrator, positrons at FACET-II, and a GeV-class scalable module at AWA) and new R&D are needed to maintain US position in developing this next generation of capabilities in an international environment with $B-class investment overseas.

The development of an integrated design study for compact high-gradient colliders is deemed critical to guide the efforts and provide a clear and actionable R&D path. This builds on recent work that has developed collider concepts and parameter sets. The study would provide detailed examples of how the main challenges can be addressed and clarify where experimental demonstrations, or detailed simulations of the relevant sub-systems, are needed. The design study should include enough detail to make cost estimates and should include strategies for demonstration colliders at moderate energies c.a. 100 GeV. In particular, bottom-up estimates will be needed for the new technology and components that have unusually tight tolerances. Developing this will require funding which has not been available to date. Notably, the European roadmap for accelerators includes a full chapter on advanced accelerators and is well aligned with our call for an organized integrated design study. The minimum requested funding for this task is 147 FTE-years and 3.15 MCh. It is critical that in order to avoid losing leadership in this field, a process slowly occurring in many scientific areas as recently highlighted in a high-profile BESAC report [11], the US should at least match in investment.

Successful deployment of advanced concepts in real-world accelerator applications such as coherent and/or incoherent radiation sources will be essential to provide the necessary intermediate steps before compact accelerators can be applied to the most demanding high-energy physics applications. The international community has long recognized the role of such near-term applications as stepping stones for high energy physics machines and has strongly invested in them (see for example the EUPRAXIA project). Even though the advanced accelerator field was born and is still squarely centered in the US, it is telling that the most recent high profile plasma-based FEL demonstrations occurred in Europe and Asia. This kind of research in the US is unfortunately not seen as directly impacting HEP, putting in jeopardy the US leadership in the field.

At the same time, synergies with existing or near future colliders should be explored in the near term. The extremely high fields of advanced accelerator concepts could be used for transverse focusing of the beam, advanced phase space manipulations or particle sources. Possible upgrade paths of existing and near-term machines that could benefit from advanced accelerator concepts should be identified. Efforts on high brightness electron sources, polarized positron generation, high average power laser drivers, and beam delivery systems are particularly important in this regard.

While advanced accelerators in plasmas and structures continue to advance towards collider and near term applications, innovative concepts such as nanoplasmonics and laser-driven structures continue to emerge offering the potential for greater reach, new accelerator components, and near term applications in the future. In this context, advanced accelerator R&D and facilities serve all novel accelerator research. Furthermore, they play a critical role in accelerator and beam workforce development and diversity since they allow hands-on training with strong publication (over 1000 papers/year) for the next generation of accelerator scientists from more diverse communities who are often attracted to the field by the scientific novelty and rich physics of advanced accelerators.

Priority research should continue to address and update the Advanced Accelerator Development Strategy:

- Vigorous research on advanced accelerators including experimental, theoretical, and computational components, should be conducted as part of the General Accelerator R&D program to make rapid progress along the advanced accelerator R&D roadmaps towards an eventual high energy collider, develop intermediate applications, and ensure international competitiveness. Priority directions include staging of multiple modules at multi-GeV, high efficiency stages, preservation of emittance for electrons and positrons, and shaped beams and deployment of advanced accelerator in real-world applications.

- A targeted R&D program for a integrated design study of a high energy (1–15 TeV) advanced accelerator-based collider should be performed that details all the components of the system, such the injector, drive laser, plasma source, beam cooling, and beam delivery system. This would set the stage for a future conceptual design report, after the next Snowmass.

- Enhanced driver R&D is needed to develop the efficient, high repetition rate, high average power laser and accelerator technology that will power laser-driven advanced accelerators colliders and societal applications.

- Support of upgrades for Beam Test Facilities are needed to maintain progress on advanced accelerator Roadmaps. These include development of a high repetition rate facility, proposed as kBELLA, to support precision active feedback and high rate; independently controllable positrons to explore high quality acceleration, proposed at FACET-II; and implementation of a integrated SWFA demonstrator, proposed at AWA.

- A study for a collider demonstration facility at an intermediate energy (20–80 GeV), and near term applications, should establish a plan that would demonstrate essential technology and provide a facility for physics experiments at intermediate energy.

- A DOE-HEP workshop in the near term should update and formalize the U.S. advanced accelerator strategy and roadmaps including updates to the 2016 AARDS Roadmaps

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