Structure Wakefield Acceleration (SWFA) Development for an Energy Frontier Machine

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Abstract: The goal of the high-energy physics (HEP) Advanced Accelerator Concepts (AAC) program is to develop transformational technologies to enable a low-cost, high-efficiency machine serving the HEP frontier. HEP published the AAC General Accelerator Research and Development (GARD) 2016 roadmap on three technologies: Structure Wakefield Acceleration (SWFA), Plasma Wakefield Acceleration (PWFA), and Laser Plasma Acceleration (LPA) [1]; the SWFA is currently the most mature technology and therefore the most likely to lead to a buildable linear collider in the near term. Since 2016, considerable progress on the roadmap has been made [2]. In addition, new SWFA ideas (not incorporated into the 2016 roadmap) have emerged that have lead to impactful results in recent years. Taking the opportunity of Snowmass 2021, we advocate to update the AAC roadmap, in general, and SWFA roadmap, in particular, to encompass the latest developments in the field, including THz acceleration in picosecond pulse regime; advanced structures (e.g. metamaterial, crystal, nanostructures, etc.); revolutionary fabrication techniques like 3D-printing and brazeless structures; and near-term applications, like compact X-band other applications ray sources, and other applications. Progress will only be made through the continuous support and increased coordination of the AAC groups.

Introduction: Under the SWFA roadmap, which was developed during an era of implementing Snowmass 2013 recommendations, four principal technologies—facility design, drive beam, main beam, and wakefield structures—have been investigated. The two SWFA schemes under development are the collinear wakefield accelerator (CWA), in which the drive and main beam follow the same path through a structure, and the two-beam accelerator (TBA), only used in SWFA, where the drive and main beam pass through different structures. The key task of facility design research and development (R&D) is the integration of the sub-components into a self-consistent parameter set needed for the application: a future linear collider or other non-HEP application (e.g., a compact X-ray source). The drive-beam technology uses the electron beam as the power source of both schemes, although the drive beam format for the two schemes is very different. In the CWA scheme, a single e- drive bunch with a carefully shaped longitudinal profile is used to accelerate a single e- or e+ main bunch, while the TBA scheme requires the generation of a high-current electron drive-bunch train as is done at the AWA Facility [2]. The main-beam technology ranges from the conventional e+e- damping ring technology to new efforts that use a shaped main beam to significantly increase efficiency. The structure technology aims to develop structures capable of high-gradient and high drive-to-main efficiency that accommodates higher order mode damping.

Current Status and New Directions: Due to the nature of SWFA, it has advantages for LC in terms of positron acceleration and emittance preservation. Very recently, ~300-MeV/m acceleration in a short THz dielectric SWFA was achieved using an intense 20-GeV beam at FACET (a GV/m-level gradient was demonstrated during a breakdown test) [3–4]. In addition, 500 MV/m of surface field was also recorded in the RF breakdown test of 200-GHz metallic SWFA using the same beam at FACET [5]. In 2019, ScienceDaily reported a new world record for a terahertz-powered accelerator with a 200-MV/m gradient and significantly improved electron beam quality [6]. The study of accelerator development in the THz regime is a complete paradigm shift from that of conventional microwave accelerators [7--9]. All aspects of the accelerator-related technologies need to be miniaturized: smaller structures, shorter beams, shorter pulse lengths, smaller footprint, and so on. As a result, the level of precision of the structure fabrication and beam control must move beyond the status quo. This may lead to the exploration of completely new territory, and along the way, it will promote basic research and early-stage development of new multidisciplinary research areas.

In the TBA approach, although structures operate in the microwave regime, the acceleration gradient may be significantly enhanced due to the use of short RF pulses (~10 ns) from the wakefield power extractors. In 2020, a 200-MW 5-ns wakefield pulse out of a dielectric structure [10] and 380-MW out of a advanced metamaterial structure [11] were reported. New broadband coupling and high-shunt-impedance structures are needed to demonstrate high-efficiency and high-gradient short-pulse accelerators. New trends of metallic and dielectric accelerators in cryogenic temperatures have been explored in recent years [12-14], as well as new fabrication techniques to lower fabrication costs. These efforts are guided by the goal to design a 3 TeV e+e- LC based on SWFA technology [15]

Near- and Mid-Term Applications: Near-term applications are important demonstrations of accelerator technology that will advance collider R&D. SWFA-driven X-FEL, compact gamma-ray source, medical applications, and other technology are actively being pursued. The efforts need to be strengthened through collaborative work with industry and various funding agencies.

Challenges and Suggestions to AF6: In order to push forward the SWFA roadmap, despite significant progress that has been made in the past, many challenging issues should be resolved in the coming decade. However, two important issues we are facing for the effort of SWFA are: (1) resources have decreased over the past 10 years related to accelerating structure development, in particular the study of fundamental issues of high-gradient accelerating structures, like RF breakdowns, multipactoring, etc; and (2) many efforts among different institutes around the world lack coherence. We would like to take the opportunity of Snowmass to address the critical needs of accelerator frontier over the next decade. The AAC community can plan to update the SWFA roadmap (similar intentions to update the roadmap have been raised in PWFA [16] and LWFA [17] communities too), and promote its visibility so that the HEP community understands that with increased support, the effort from different research groups around the world can be established, coordinated, and carried out efficiently.

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