Research and Educational Opportunities at the Argonne Wakefield Accelerator (AWA) Facility

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Abstract: The Argonne Wakefield Accelerator (AWA) facility [1] (Figure 1) develops future acceleration methods and technologies. The primary method under development is Structure Wakefield Acceleration (SWFA), an electron beam-driven wakefield acceleration method to enable an affordable future multi-TeV e+e- collider [2,3] and/or a 300-GeV Higgs factory for exploring high-energy physics (HEP). In addition, the AWA educates the next generation of accelerator scientists and engineers. Over the last decade, the AWA has supported graduate-student research with a yearly average of graduating three Ph.D.'s per year and regularly hosts summer interns. The AWA also provides university partners, other national laboratories, and industry a user-friendly testbed for developing novel accelerator concepts.

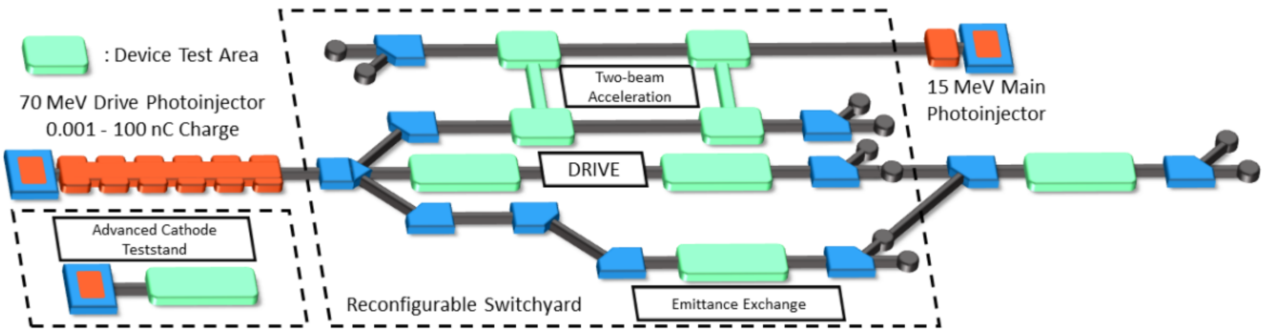

FIG. 1. AWA test facility [1].

Facility Impact: In 2016, the Advanced Accelerator Concepts (AAC) Roadmap [4] identified SWFA as one of the three AAC methods capable of enabling energy frontier accelerators. In 2020, the European Strategy Report [5,6] reinforced this view by urging the world HEP community to support advanced accelerator test facilities to mature SWFA for applications to the energy frontier. The primary AWA facility mission is to advance the SWFA Roadmap, but AWA research and development (R&D) also helps to advance the plasma wakefield acceleration (PWFA) Roadmap as well as supporting missions relevant to basic energy sciences (BES), nuclear physics (NP) and National Nuclear Security Administration (NNSA).

- RESEARCH. Cost is the major impediment to the Energy Frontier and the AWA test facility is dedicated to developing an affordable AAC using SWFA [2,3]. R&D at the AWA includes critical topics needed to realize a SWFA, such as the development of novel high-gradient accelerating structures, high-brightness and high-charge particle sources, fundamental research in beam physics associated with beam-driven wakefield acceleration (PWFA and SWFA) concepts (beam shaping, instability control), beam diagnostics, and near-term Roadmap spinoffs like a Multi-User XFEL [7] for BES and electron cooling needed for NP.
- COLLABORATORS. Dedicated test facilities accessible to collabo/rators are essential testbeds for the emergence and experimental tests of new ideas. At the AWA, collaborator-initiated research is carried out collaboratively with AWA members. Research topics are broad and involve collaboration with domestic and international partners from universities, national laboratories, and industry. These types of activities benefit HEP and other accelerator-based applications important to BES and NP.
- EDUCATION: The AWA test facility has a strong track record of educating future scientists and engineers, including with both undergraduate and graduate students. Graduate students can be hosted onsite at the AWA over multiple years, or they can perform short-term experiments for Ph.D. research in as little as a few weeks. Students who stay at the AWA over multiple years eventually gain many

kinds of accelerator-related experience, including physics and engineering design, installation, operation, and experiments.

- UNIQUE CAPABILITIES. Its unique capabilities in electron bunch generation and control enable the AWA to advance the HEP General Accelerator R&D (GARD) Roadmaps: AAC Roadmap released in 2016 [4] as well as the Accelerator and Beam Physics Roadmap currently under development.
  - BEAM CAPABILITIES [11]. *The AWA is uniquely equipped to generate the high-charge, shaped electron bunches needed to simultaneously achieve high-gradient and high-transformer ratio in beam-driven wakefield accelerators (S/PWFA) including*: electron bunches with record charge of 100 nC in single bunch with peak currents up to 25 kA; adjustable bunch length, 1 μC bunch trains from ~1 GHz to 1 THz. Control over the 6D distribution of the bunch using emittance exchange (EEX), a round to flat beam transformer (RFBT), and laser pulse shaping. *The facility includes three independent photoinjector beamlines*: a 70-MeV drive beamline, a 15-MeV witness beamline, and a standalone 2-MeV test-stand for fundamental studies of cathodes in RF guns.
  - EXPERIMENTAL SWITCHYARD. *The AWA maintains a highly reconfigurable experimental switchyard including five experimental test zones.* Four of the zones are often reconfigured by AWA staff to support a wide range of collaborator experiments. The zone after the linac contains the RFBT and a set of four quads for matching the beam into either the EEX beamline or straight ahead. The zones downstream of the EEX beamline give access to arbitrarily shaped bunches [8,9]. Finally, the facility has an extensive suite of diagnostics including, but not limited to, transverse phase space measurements (most zones), longitudinal phase space measurement, and the development of single-shot diagnostics [10].
- SYNERGIES. The AWA's unique beam physics capabilities [11] and flexible beamlines support the wider accelerator community, including HEP (e.g., PWFA and laser wakefield acceleration), BES (multi-user XFEL), NP (e.g., EIC electron cooling), industry (e.g., SBIR) as well as a testbed for developing artificial intelligence/machine learning methods developed that can eventually be deployed at DOE Office of Science user facilities.

AWA Upgrade and AWA-HE. Over the next decade, the AWA facility will further advance the GARD Roadmaps (primarily AAC and SWFA) and synergistic concepts both within and outside of HEP, support collaborators, and educate students to become experienced accelerator researchers. To continue making progress on the Roadmaps, the following AWA improvements are required:

- AWA UPGRADES. In the near term, the AWA will focus on upgrading beam stability and beam quality while adding new capabilities necessary to advance the GARD Roadmaps. *Beam stability.* AWA plans to collaborate with the LBNL BACI group [12] to implement a new synchronization system that will dramatically improve the beam stability. In parallel, the AWA control system will be migrated to EPICS. *Beam quality.* Plans are underway to upgrade our radiofrequency (RF) photocathode gun and first two accelerating sections to RF symmetric cavities to minimize emittance dilution. *Beam capabilities.* Given the current size of the facility, the largest SWFA module that can be tested at the AWA is the 500-MeV demonstrator [13]. Note, this demonstration requires additional hardware and significant beamline installation. Taken together, these upgrades allow AWA to continue its near term progress on the SWFA Roadmap by: (i) increasing the number of experiments that can be performed each year at the AWA and (ii) enabling a new class of experiments that need brighter and more stable beams (e.g., the tests of THz structures with sub-100 um apertures) and achieving a major SWFA milestone.
- AWA-HE (HIGH ENERGY) PROPOSAL. In several years, after completing the 500-MeV demonstrator [13], the AWA will become limited in its ability to continue advancing the SWFA Roadmap. Our vision is to continue to advance the Roadmaps by enacting a phased upgrade of the AWA facility so that by the end of the decade the SWFA method will be ready to present an SWFA CDR for a 3-TeV e+e- linear collider. *Bunker expansion.* Step 1 is to expand the AWA bunker length so that it occupies all available space in its current building. *Energy upgrade.* Step 2 is to add more RF stations and accelerating structures to increase the energy from 65 to 150 MeV. This will enable GV/m class acceleration gradients and a 3-GeV demonstrator.

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