SWFA demonstrators with integrated technologies for future large-scale machines

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Abstract: In the AAC GARD roadmap for Structure Wakefield Acceleration (SWFA), several small-scale demonstrations are planned to show the feasibility of technology integrations and paths toward large-scale machines. Since the last Snowmass and P5 report, remarkable progress has been made in critical components of SWFA, such as high charge generation, simplified staging, beam shaping, and high-frequency structure fabrication [1]. These advances provide solid ground to build two high-fidelity SWFA demonstrators: one for short-pulse two-beam acceleration (TBA) used in the conceptual 3 TeV Argonne Flexible Linear Collider (AFLC) and the other for high-efficiency collinear wakefield acceleration (CWA) used in a proposed 5 GeV multi-beamline XFEL. Taking the opportunity of Snowmass 2021, we present the detailed design of the two demonstrators and future modules toward large-scale machines.

Introduction: The AAC field conducts long-term research aimed at a future large-scale collider that will operate at substantially higher energy and lower cost than is possible with current accelerator technology [2]. In SWFA, a high-charge drive beam traveling through a structure excites wakefields, which are then used to accelerate a low-charge main beam, in either the same structure (collinear wakefield acceleration, CWA) or a parallel structure (two-beam acceleration, TBA). Based on the TBA approach, a 3 TeV AFLC has been designed to reach high gradient (~300 MV/m) by using short pulse (20 ns) and dielectric-loaded structures [3]. Based the CWA approach, a 5 GeV multi-beam XFEL has been proposed with the goal of accelerating the main beam in 10 separated beamlines at high repetition (50 kHz) and high transformer ratio (5) [4]. The Argonne Wakefield Accelerator (AWA) facility is the testbed for in-house and collaborative SWFA research, where high charge generation [5], simplified staging [6], and beam shaping [7], together with other critical technologies, have been recently demonstrated. Based on this solid progress, two demonstrators with integrated technologies—namely the 500 MeV short-pulse TBA demonstrator [8] and the CWA energy doubler—have been proposed as the first milestone towards the SWFA-based large-scale machines.

500 MeV short-pulse TBA demonstrator for long-term TeV-scale colliders: This demonstrator is designed based on the recent advances of the SWFA research, which include: (1) simplified staging acceleration of a main beam, up to 5 MeV in two structures [6]; (2) high power generation, up to 380 MW, [9] and high gradient acceleration, up to 320 MeV/m [10]; (3) development of novel structures such as dielectric-loaded [11], dielectric-disk [12], and metamaterial ones [9]; (4) high-charge drive-beam generation up to 1 uC for bunch train [5]; and (5) development of a fast kicker and septum to distribute drive trains [13].

The proposed machine aims to accelerate the 15 MeV main beam to 500 MeV in the current AWA experimental area (14.5 m × 1.5 m). Two 70 MeV drive bunch trains, each of which contains eight bunches with 40 nC/bunch, will be separated by the kicker/septum into two stages. In each stage, the drive beam will be decelerated to 20 MeV by two 26 GHz decelerators, which generate 1.3 GW, 3 ns radiofrequency (rf) pulses. The low-charge single main beam will be successively accelerated in four corresponding structures at a gradient of 260 MeV/m. The baseline design uses dielectric-disk structures, and other candidates are under consideration.

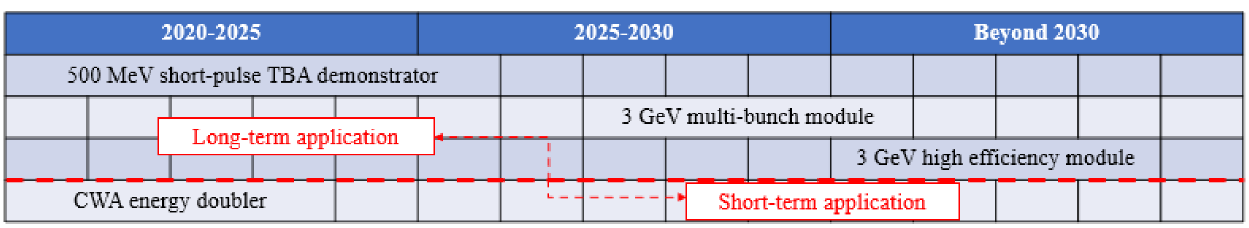
Laser shaping will also be applied to shape the main beam in order to increase beam loading while maintaining low energy spread.

CWA energy doubler for near-term XFELs: This demonstrator is particularly designed based on the recent progress of mm-wave to THz acceleration in SWFA, which includes: (1) advanced fabrication of high-frequency structures [4]; (2) beam breakup (BBU) control using a FODO channel around the structure [14]; and (3) precise drive-beam shaping [7].

The proposed machine aims to accelerate the 50 MeV main beam to 100 MeV with a transformer ratio of 10 in two successive 0.5 m long, 180 GHz corrugated waveguide structures. The 10 nC drive bunch will be shaped to a modified doorstep shape to achieve a high transformer ratio while preserving the bunch energy chirp to mitigate the BBU instability. A FODO channel with tapered gradient or length will be made of permanent magnets and placed around the structures for BBU control.

Future modules: Based on the success of the 500 MeV short-pulse TBA demonstrator, a larger-scale machine, namely the 3 GeV TBA module, is proposed as the next step for AFLC. This module will be placed in an upgraded AWA bunker that could hold more stages and more structures per stage. The main beam will contain 13 GHz bunches generated by an X-band photoinjector. Drive-beam charge modulation will be applied to control the rf pulse shape to fully compensate for the beam loading effect in the accelerator to achieve high rf-to-main-beam efficiency.

A high-efficiency 3 GeV TBA module is foreseen as the final short-pulse TBA demonstrator for AFLC. It will use the high-efficiency L-band klystrons under development by CERN-SLAC and keep all other components of the previous module. Once successful, it will be a fully functional and scaled brick for AFLC.



Timeline of the demonstrations.

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