Argonne Flexible Linear Collider (AFLC) – Beyond Concept: A 3-TeV Linear Collider Using Short rf Pulse (~20 ns) Two--Beam Accelerator

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Abstract: Generally, high gradient is desirable for a TeV-class linear collider design because it can reduce the length of total linacs, and thus construction costs. More importantly, the efficiency and cost to sustain such a gradient remain a high priority, as does the optimization process of an overall design. In 2009, the concept of an Argonne Flexible Linear Collider (AFLC) was first proposed at Argonne National Laboratory [1]. The distinguishing features of this conceptual design are its modular configuration and short-radiofrequency (rf) pulse (~20 ns), high-gradient (~300 MeV/m) operation, which make it scalable in high-fidelity from a GeV-scale stepping-stone facility to a TeV class machine. It also allows for flexible configuration to meet different needs. A preliminary study showed that ~15% efficiency may be achievable, which provides an opportunity to lower the site power below 200 MW for a 3TeV collider. Since its inception, main challenges involved with AFLC have been progressively addressed at the Argonne Wakefield Accelerator (AWA) facility, which include efforts to develop a wakefield-based 1-GW pulsed power source; low-cost, high-gradient accelerators; and staging. In the new era of Snowmass 2021, strong technological and resources are requested to support research in all facets of AFLC, moving this conceptual design to a true feasibility study.

Identification and Significance: Currently, multiple Higgs factory designs are under investigation, including circular (FCC-ee and CEPC) and linear (CLIC-380-GeV and ILC-250-GeV) machines. On the energy frontier, CLIC-3-TeV has been the only well-established candidate for a TeV-scale electron-positron linear collider for a decade. The CLIC-3-TeV is based on the room-temperature two-beam accelerator (TBA) scheme with an rf pulse length of 240 ns and a loaded gradient of ~100 MV/m. Its latest CDR version was published in 2018 [2]; however, ~600 MW of the estimated site power and ~5% wall plug efficiency seem to be an obstacle for the physics community to accept it as it is. Meanwhile, schemes using plasma or laser-based wakefield acceleration are emerging, where the accelerating gradient at the GV/m level has been demonstrated in various experiments. However, issues with efficient acceleration, scalable staging, and accelerations with beam preservation have yet to be demonstrated. Therefore, an alternative design of a high-energy machine beyond the Large Hadron Collider era remains attractive and meaningful. We propose a new scheme that uses a high gradient, a short pulse, and a modular design capable of achieving 3 TeV with a beam power of 31.2 MW at IP and a wall plug efficiency of 15% [3].

Brief Description of AFLC: AFLC, which was conceptually formed in 2009, is a 3-TeV machine based on a short-rf-pulse (~20 ns), high-gradient (~300 MeV/m of the loaded gradient), high-frequency (26 GHz), dielectric TBA (Figure 1). This is a modular design and its unique locally repetitive drive beam structure allows a flexible modular configuration to meet different needs. Preliminary study shows an efficient (~15% wall plug efficiency) short-pulse collider may be achievable. Major components include:

1. High-current drive beam accelerator, including klystrons (already commercially available) and conventional standing wave linac.
2. High-gradient accelerating structures to sustain 300 MV/m at 20 ns pulse length.
3. High power extraction devices capable of >1 GW at 20 ns pulse length.
4. Positron production and damping rings.
5. Final beam delivery system.

CTE (critical technology element) to be addressed: At present, a total of seven CTEs have been identified for the AFLC design:

- CTE1: polarized e+ source at the full LC (linear collider) operational parameters including damping ring;
- CTE2: polarized e- source at the full LC operational parameters including damping ring;
- CTE3: main beam acceleration;
- CTE4: drive beam power source;
- CTE5: staging of multiple acceleration structures to high energy;
- CTE6: beam delivery system; and
- CTE7: appropriate main-beam parameters at the IP.

Four of the CTEs (1, 2, 6, and 7) are already at TRL4, since they were taken from the CLIC or ILC designs due to their similarities with our scheme. The other three CTEs (3, 4, and 5) will be brought to TRL4 in the next 5 to 10 years if resources are available.

Research and Development Plan (2021~2030): The AWA facility at Argonne has developed a high-current accelerator that can provide high-quality, high-charge, short-bunch-length beams using a 1.3-GHz photoinjector rf gun. The facility can generate a 70-MeV bunch train with up to 1µC total charge, as well as an independent 15-MeV high -brightness witness beam. It will provide a unique platform to test GW-level power extraction, >250 MV/m accelerating gradient, and scalable acceleration staging. The main deliverables related to AFLC development are:

1. *500-MeV AFLC demonstrator inside the AWA existing bunker [4].*
2. *Efficiency improvement with a shaped bunch or modulated bunch train, which is also preparation for a 3-GeV stepping-stone facility.*

Synergies with the HEP GARD Community: The 2016 AAC Roadmap includes R&D plans for laser-driven plasma-accelerator R&D [5] , beam-driven plasma accelerator R&D [6], and beam-driven SWFA R&D, as there are many commonalities between these three advanced accelerator approaches. Strong collaborations with researchers and institutes across the field are critical and beneficial. In the process of AFLC R&D, joint efforts in high-shunt impedance structures, high-efficiency, high-power rf components, and high-current beam transportation and control are needed [7–10].

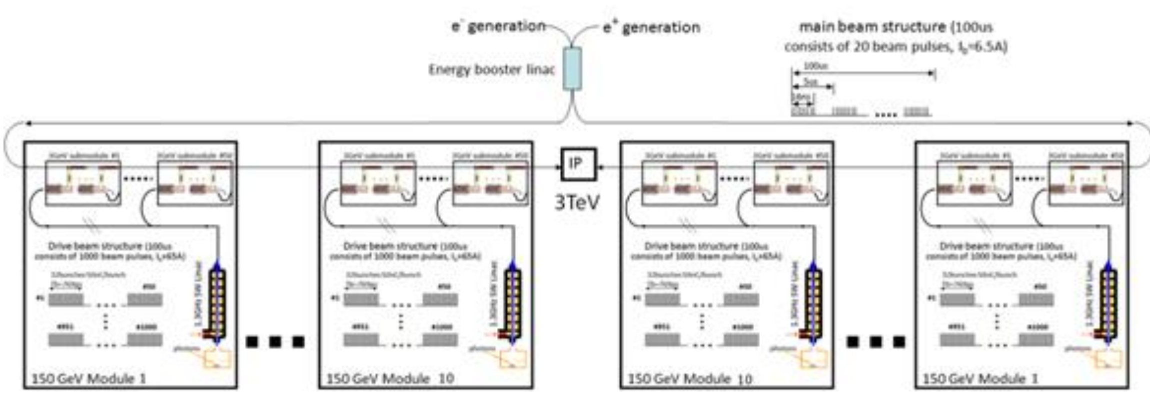

FIG. 1. Conceptual layout of AFLC; there are ten 150-GeV stages in one side of the machine.

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