Proton-driven, plasma wakefield acceleration for HEP applications

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Applications of plasma-based accelerators often depend on opportunities. AWAKE [1] addresses an opportunity afforded by high energy (hundreds of GeV to TeV, and tens to hundreds of kJ) proton bunches available today. These can in principle drive large amplitude accelerating fields (~1GV/m) or wakefields in a single plasma hundreds of meters to kilometers-long and lead to energy gain by externally injected electrons that can reach the TeV scale [2].

High-energy physics applications for electron beams produced by AWAKE [3] are described in another LoI entitled "high energy physics applications of the AWAKE acceleration scheme" and include: search for dark photons, strong field quantum electrodynamics, high-energy electron-proton collisions, a compact electron injector using the RHIC-EIC proton beam. Some of these topics could be addressed before an e^+e^- or ep plasma-based collider could be designed or built. **AWAKE could thus lead to the first application of a plasma-based accelerator to particle or high-energy physics.**

Rapid progress has been made by the AWAKE experiment at CERN in using a long, SPS proton bunch to drive wakefields in a 10m-long plasma. In these proof-of-principle experiments AWAKE has demonstrated that these proton bunches, too long to drive large amplitude wakefields, self-modulate in a high-density plasma and then drive large amplitude fields [4]. Electrons externally injected with 20MeV energy were accelerated to ~2GeV [5]. We demonstrated that the self-modulation process is controllable and reproducible. We showed that the wakefields can be manipulated with plasma density gradients to increase the energy gain and possibly optimize the self-modulation process [6].

A program exists (known as AWAKE Run 2) to extend this scheme to produce sufficient quality electron bunches [7], first with energy around 10GeV, later with around 100GeV and possibly at the TeV scale in the more distant future. Since the drive proton bunch carries so much energy, this is in principle done "simply" by extending the plasma length from ~10m to ~100m and then to the kilometer scale. This is supported by a strong plasma source development program in collaboration with plasma physics institutes. The expected acceleration gradient is ~1GeV/m, which allows for the relatively small size of the accelerator.

AWAKE has a clear roadmap towards early application for HEP. It is as follows:
Within the next 5 years (2021-2025):

- Demonstration of seeding of the self-modulation process with an electron bunch and optimization of the modulation process using a plasma density step with multi-GeV acceleration of electrons.
- Development of metal vapor, laser-ionized vapor source: 10m for self-modulation of the proton bunch, 10m for acceleration of the electron bunch.

Within the next 10 years (2021-2030):

- Demonstration of acceleration of an electron witness bunch to 2-10GeV with preservation of incoming emittance and percent energy spread.

- Development of scalable plasma sources (1 to 10m), helicon [8] and discharges to replace the second plasma source. These can in principle be made as long as necessary since they are based on a modular scheme that that can be tailored for reaching the desired energy.
- Development of accelerator plasma source 50-100m long.
- Demonstration of acceleration in a scalable plasma source (helicon or discharge), acceleration to 10 to 50GeV.

Starting in 2029:

- Application to beam dump experiments, 50-100GeV electron bunch.

Preliminary studies show that particles energy, flux and beam quality necessary for early HEP application can be produced by the acceleration scheme.

It is important to note that the planned experiments address many of the challenges all plasma-based accelerators face: external injection, beam quality generation, large energy gain, reproducibility, plasma source quality, etc. It therefore naturally complements other existing programs geared towards high-energy physics applications.

The research and development program is active at CERN where suitable proton bunches and infrastructure are available. AWAKE is already an international collaboration that includes experts in all required fields (experiment, simulation, theory, accelerators). In addition, high-energy physics programs that could use high-energy electron beam produced by an AWAKE scheme have been clearly identified and early ones are already active at CERN (dark photon searches). **Besides the expertise in plasma-based acceleration and beam physics, one the strengths of AWAKE is that it is embedded in the high-energy physics laboratory that can both support its development and benefit from its applications.**

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