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Towards an Advanced Linear International Collider

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Advanced and Novel Accelerators (ANAs) can provide acceleration gradients orders of magnitude greater than conventional accelerator technologies, and hence they have the potential to enable a new generation of more compact, high-energy machines. Four technologies are of particular interest, all of which rely on the generation of a wakefield that sustains intense electric fields suitable for particle acceleration. In the laser wakefield accelerator (LWFA) and plasma wakefield accelerator (PWFA) the wakefield is driven in a plasma by an intense laser or particle beam, respectively; in the structure wakefield accelerator (SWFA), the wake is excited by a particle bunch propagating through a slow-wave solid structure; and in the dielectric laser accelerator (DLA), a laser pulse directly drives an accelerating mode in a dielectric structure.

In view of the great promise of ANAs, and of the substantial worldwide effort to develop them, the Advanced LinEar collider study GROup, ALEGRO, was formed at the initiative of the ICFA ANA panel. ALEGRO aims to foster studies on accelerators based on ANAs and focused on high-energy-physics applications, with the ambition of proposing a machine that would address some of the future goals of particle physics.

We propose as a long-term goal the design of an e^+/e^-/gamma collider with center-of-mass energy in the multi-TeV range setting the baseline for a technology path supporting up to 30 TeV- **the Advanced Linear International Collider (ALIC)**. On the path to this collider, a number of milestones have to be established. These will lead to spin-offs at lower energy that will benefit ultra-fast X-ray science, medicine, and industrial applications. **The major goal for our community over the next five to ten years is the construction and operation of dedicated ANA facilities that can reliably deliver high-quality, multi-GeV electron beams from a small number of staged accelerating modules.** The successful demonstration and robust operation of these stages would provide a platform for ANAs with a large number of stages eventually generating high-quality beams in the TeV energy range.

Other challenges that must be met for the complete ALIC concept include the design of appropriate particle sources and potential phase-space cooling methods, the development of high-power lasers needed for LWFAs and DLAs, the achievement of required tolerances (synchronization alignment, and pointing stability), and the availability of additional tools such as the development of novel diagnostics, intelligent process control and feedback systems for the ultra-fast bunches generated by ANAs, as well as fast and accurate numerical simulation methods. The development of the full-physics and efficient simulation tools that are needed for the design of an advanced multi-TeV collider requires robust and sustained team efforts. The sharing of modules/codes, inter-operability through the development of libraries of algorithms and physics modules, as well as the definition of standards for simulation input/output and for data structures, must be encouraged.

The R&D during the upcoming years will focus on producing quality accelerated bunches (emittance and energy spread) with increasing energies (multi GeVs). **The results of this R&D depend on the availability of suitable laser and particle beams.** Such R&D often requires large facilities with well equipped infrastructure and operational support, and that can deliver laser pulses of hundreds of terawatt to petawatt power, or multi-GeV high-charge electron bunches to drive wakefield in plasmas (LWFA and PWFA) or advanced structures (SWFA). The results also strongly depend on the level of control of the experimental parameters. **The exquisite control needed to reach collider parameters comes at the cost of a large investment in intelligent feedback and control systems for accelerators and ultra-fast lasers.** All these elements explain why much of the progress towards collider development is expected to occur at facilities hosted by national laboratories, in synergy with contributions from university groups playing a key role through the generation of new ideas and concepts and training future accelerator and plasma physicists.

A number of key research items related to what could be the first stage of ALIC, consisting of an injector and an accelerator module, and producing beams in the 5-25 GeV range, are planned to be

addressed by the international community at running or upcoming facilities, as listed below:

- **External injection** of a high-quality electron bunch in an accelerator section.
- For collider applications, it is essential that ANAs reach levels of **bunch quality, efficiency, stability and reproducibility** equivalent to those produced by conventional accelerators.
- **Plasma sources** with sufficient control and reproducibility of the density, as well as tapering of the entrance and exit density ramps to assist in beam manipulation between stages must be developed.
- **Operation at high repetition rate** is an important step towards ALIC. Operation at a kilohertz repetition rate requires development of lasers that must therefore produce kilo- to mega-watts of average power.
- **Producing** high-quality electron (e^-) and **positron (e^+) bunches** in the 5 to 25 GeV energy range.
- The availability of **independently shaped drive- and main-beams at** PWFA and SWFA facilities would provide the ability to control the bunch parameters with sufficient accuracy and tune experiments to reach collider-level beam parameters, in particular in terms of beam loading, energy spread and efficiency.
- Advanced structures for SWFA capable of high-efficiency and high-gradient need continued development and extensive **breakdown** tests to determine the operational accelerating gradient under collider conditions, i.e. with breakdown rates in the 10^{-7} range.
- Providing beams for **first high-energy physics applications** such as dark matter search experiments as well as collider components tests.

All these topics will be addressed with various emphases at the facilities in the Table below.

Facility	Readiness	ANA	Specific Goals
BELLA	Operating	LWFA	e^-, 10 GeV, multi-GeV staging
kBELLA	Design study	LWFA	e^-, 1 GeV, kHz rep rate, 1 kW avg. power
KALDERA	Start 2025	LWFA	e^-, 1 GeV, kHz rep rate, 1 kW avg. power
EuPRAXIA	Design study	LWFA, PWFA	e^-, 5 GeV, reliability
AWAKE	Operating	PWFA p-driven	e^-, beam quality, multi-GeV, HEP fixed target exp.
FACET II	Start 2020	PWFA	e^-, 10 GeV boost, beam quality, e^+ acceleration
FLASHForward	Operating	PWFA	e^-, 1.5 GeV, beam quality, high rep rate, 10 kW avg. power
AWA	Operating	SWFA	e^-, sub-GeV, high charge, beam shaping, TBA and CWA

The Table highlights operating or upcoming facilities capable of delivering beams in the GeV range or above, that are essential tools to address crucial questions relevant to ALIC development in the next 5 to 10 years. During this period, the facilities already operating or in their building phase will be mainly dedicated to the development of a single stage of ALIC. However, **multi-stage challenges with high-energy beams** also need to be addressed. It is thus clear that **in the longer term, a facility to test staging with collider-like quality beams is necessary.**

These ambitious projects require strong scientific and financial support to make suitable progress towards ALIC.

Bibliography

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