Accelerator Frontier Executive Summary

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For over half a century, high-energy accelerators have been a major enabling technology for particle and nuclear physics research as well as sources of X-rays for photon science research in material science, chemistry, and biology. Particle accelerators for energy and intensity frontier research in high energy physics (HEP) continuously drive the accelerator community to invent ways to increase the energy and improve the performance of accelerators, reduce their cost, and make them more power efficient. Despite these past efforts, increasing size, cost and timescale required for modern and future accelerator-based HEP projects arguably distinguish them as the most challenging scientific research endeavors. Major developments since the last Snowmass/HEPAP P5 strategic planning exercise in 2013 include start of the PIP-II proton linac construction for the LBNF/DUNE neutrino program in the US, emergence of the FCCee/CEPC projects for Higgs/EW physics research at CERN and in China, respectively, a significant eduction of activity related to linear collider projects (ILC in Japan and CLIC at CERN); and paradoxically,

the end of the Muon Accelerator Program in the US and creation of the International Muon Collider Collaboration (IMCC) in Europe. The last decade saw several notable planning advancements, including the US DOE GARD roadmaps, European Strategy for Particle Physics Accelerator R&D Roadmap, EuPRAXIA, etc.

In the meantime, the international accelerator community has demonstrated imagination and creativity in developing a plethora of future accelerator ideas and proposals. The technical maturity of the proposed facilities ranges from shovel-ready to those that are still largely conceptual. Over 100 contributed papers have been submitted to the Accelerator Frontier of the US particle physics decadal community planning exercise, Snowmass’2021. These papers cover a broad spectrum of topics: beam physics and accelerator education, accelerators for neutrinos, colliders for Electroweak/Higgs studies and multi-TeV energies, accelerators for Physics Beyond Colliders and rare processes, advanced accelerator concepts, and accelerator technology for Radio Frequency cavities (RF), magnets, targets, and sources. In 2020-2022, extensive discussions and deliberations have taken place in corresponding topical working groups of the Snowmass Accelerator Frontier (AF) and in numerous joint meetings with other Frontiers,

Snowmass-wide meetings, a series of Colloquium-style Agoras, cross-Frontier fora on muon and e+e− colliders and the collider Implementation Task Force (ITF). The outcomes of these activities are summarized below.

• A multi-MW beam power upgrade of the Fermilab proton accelerator complex is the highest priority

for the neutrino program in the 2030s; corresponding accelerator technology and beam physics studies are needed to identify the most cost- and power-efficient solutions that could be timely implemented leading to breakthrough results of the DUNE neutrino program;

• several beam facilities for axion and DM searches are shown to have great potential for construction in the 2030s in terms of scientific output, cost and timeline, including PAR (a 1 GeV, 100 kW PIP-II Accumulator Ring);

• in the area of future colliders - several approaches are identified as both promising and potentially feasible, and call for further exploration and support: in the Higgs/EW sector - there is growing support for the FCCee at CERN and proposals of somewhat more advanced linear colliders in the US, such as C3 and HELEN;

• in the energy frontier, the discovery machines such as O(10 TeV c.m.e.) muon colliders have rapidly gained significant momentum; to be in a position for making choices and decisions on collider projects viable for construction in the 2040s and beyond at the time of the next Snowmass/P5, these concepts should be explored technically and documented in pre-CDR level reports by the end of this decade. Given that the U.S. HEP accelerator R&D portfolio presently contains no collider-specific scope – creating a gap in our knowledgebase and accelerator/technology capabilities and limiting national aspirations for a leadership role in particle physics - it was proposed that the U.S. establish a **national integrated R&D program on future colliders** in the DOE Office of High Energy Physics (OHEP) to carry-out technology R&D and accelerator design for future collider concepts. This program would aim to enable synergistic

engagement in projects proposed abroad (e.g. FCC, ILC, IMCC), develop design reports on collider options by the time of the next Snowmass and P5 (2029–2030), particularly for options that can feasibly be hosted in the US, and to develop R&D plans for the decade past 2030.

**Planning of accelerator R&D should be aligned with the strategic planning for the HEP field and be considered as part of the P5 prioritization process.**

In addition to the above focused activities, more general accelerator technology developments are found to be critical and need additional attention and support to achieve aspirational community goals by the end of

this decade:

• Novel high-power targets should be developed to be able to accept multi-MW beams;

• energy-efficient SC and cold-NC RF cavities and structures need to demonstrate 70 MV/m to 120 MV/m gradients needed for cost efficient compact Higgs linear colliders;

• conceptual breakthroughs in 16 T high-field dipole magnets, O(30 T) solenoids and O(1000 T/s) fast ramped magnets should demonstrate convincing feasibility proof for several energy frontier collider schemes;

• advanced wakefield accelerator concepts should strive toward feasibility studies and integrated design reports for an O(10 TeV c.m.e.) collider and experimentally demonstrate collider-quality emittances, efficiencies and energy spreads, staging, final focusing schemes and positron acceleration.

• Next generation accelerators and colliders for discovery science push accelerator science towards ultimate performance with unprecedented beam energy, intensity, and brightness. Reduction of power consumption is one of the main challenges of future colliders. Long-term fundamental accelerator and beam physics research and development in Accelerator and Beam Physics is essential to meet these needs.

The above items call for a substantial increase in corresponding R&D support, augmented with other measures to make the US competitive in education and attraction of accelerator talent, such as

• creating an undergraduate level recruiting program structured to draw in women and underrepresented minorities (URM) that could be coordinated with the USPAS.

• re-establish a program of beam physics research on general collider related topics towards future e+e− colliders and muon colliders

• strengthen and expand capabilities of the US accelerator beam test facilities to maintain their competitiveness with respect to worldwide capabilities