The Need for Research into

Early Conceptual Integration and Optimization,

and

Maturity Evaluation

of

Future Accelerators

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We call for a systematic and organized effort of the accelerator community in research into the early conceptual integration, optimization, and maturity evaluation of future and advanced accelerator concepts. The Office of Science OHEP and its GARD ABP program is the most appropriate and capable in the United States of providing the systematic support of this effort.

At the recent GARD ABP Roadmap Workshop [1] we reviewed the research needs and opportunities which would help improve existing complex accelerators, develop new concepts of future accelerator facilities, and possible significant upgrades of existing ones. The emphasis was on how all the accelerator physics constraints, engineering technical challenges, and environmental impacts are integrated and optimized to arrive at the desired overall conceptual design. We identified two general areas:

Area 1: Accelerator physics topics for the near term (<10 years), for example, those related to well established facility projects with CDRs/TDRs. They do not strongly rely on GARD for the present design choices or performance projections but could greatly benefit from R&D that may result in future upgrades, performance enhancements, cost risk mitigation, or shorter commissioning period. The possibilities are:

1.1 High Power Proton Sources (1 MW – multi-MW):

a) Beam physics issues related to beam loss control (space-charge, instabilities, collimation, e-lens compensation, integrable optics) will benefit from innovative approaches, theoretical and experimental studies (at e.g. IOTA, and operational accelerators in the US and abroad) and validated computer models and codes. A key challenge would be to reduce particle losses (dN/N) at a faster rate than increases in achieved beam intensity (power) (N).
b) Expanded small topical national and international collaborations could prove quite successful and useful, as well as collaborative work synergistic with the goals of EIC, MC, NUSTORM and ADS.

1.2 Circular e+e- colliders (FCCee, CepC):

a) Several new developments call for expansion of general studies of: optimized beam and beam-beam parameters for circular Z-W-Higgs-Top factories including 3D beam size flip-flop from the beam-beam effect, polarization, IR collision optimization, and ep interactions in a collider.
b) An Interaction Region (IR) design with gamma-gamma laser-beam conversion should be performed, in parallel with possible design considerations of the high-power laser system.
c) Pico-meter vertical emittance preservation techniques in high-charge e+e- circular colliders with strong focusing IRs, detector solenoids, and beam-beam effects (in synergy with SuperKEKB).

1.3 Linear e+e- Colliders (ILC, CLIC, Cryo-NCLC):

a) To reduce the expected commissioning time of linear colliders, end-to-end emittance preservation simulations (including parallel processing) as well as tuning tools (e.g., ML/AI) for linear colliders should be developed. Experimental tests of the beam-based alignment techniques in presence of realistic external noise sources are needed and possible at high-energy low-emittance linac-based facilities such as XFEL, LCLS-II, and FACET-II.
b) Novel new techniques for linear collider, such as a plasma-based final focus or a cryogenic normal conducting RF linac design, need to be evaluated and advanced through comprehensive beam physics studies performed in tandem with facility design and cost analysis.

1.4 Hadron Colliders (FCChh, SppC, HE-LHC, EIC):

a) Accelerator physics issues for vacuum system designs with electron cloud interactions in TeV hadron colliders with bunch spacing of less than 25 nano-seconds.
b) Over the next decade, many valuable accelerator physics explorations can be done at CERN, RHIC, IOTA, and other accelerators on topics of importance ranging from more efficient collimation techniques, to electron lenses, to dynamic aperture optimization methods.
c) Magnet design studies aimed at higher fields, cost reduction, and better field quality, especially for lower injection energy or with possible new integrable optics solutions.
d) Studies aiming towards obtaining lower emittances from new particle sources for injecting beams in high-bunch-charge colliders, generation of high intensity ion species, and high energy emittance cooling.
e) Exploration of lower cost hadron main colliding rings by using top-up injection.

Area 2: Accelerator physics problems for long term accelerator facility plans (>10 years), those with intermediate readiness and others close to "strawman" machine designs, with advanced concepts, ERL-based, or low wall plug power, that are crucial to make those accelerators scientifically, technically, and fiscally possible. The low environmental impact of future accelerators is now one of the driving accelerator design criteria. The optimization studies can help focus on the new techniques or capabilities that have the highest future potential.

2.1 Superbeams 3-10 MW (PIP-III) and Neutrino Factories:

a) Beam physics and design optimization studies towards conceptual design of 3-10 MW super-beam facility design (focusing on power efficiency and cost-per-physics-result outcome).
b) Optics/DA methods needed (integral, VFFAG) to increase the beam lifetime in racetracks of NuFact.
c) Very-fast-ramping and high-field radiation-hard magnets (expanding on the US MDP), very high power tunable RF (expanding on the GARD RF roadmap), and laser stripping injection schemes.

2.2 Muon Collider and Neutrino Sources (Higgs-3-14 TeV MC):

a) Design optimization studies toward scientifically, technically, and fiscally possible muon collider, ideally, via joining the world muon effort, aimed at a CDR in 5-7 years (a TDR in 10-15 years).
b) Studies of new and improved muon emittance cooling mechanisms – from six dimensional cooling to positron ring-based muon sources. Final stage muon cooling studies are needed.
c) Explore challenges and opportunities of orders of magnitude higher muon production rates.
d) Accelerator protection from decaying muons and neutrino radiation hazard mitigation.
e) Very-fast-ramping and high-field radiation-hard magnets (expanding on the US MDP).

2.3 Advanced Concept Colliders AAC (Beam-Plasma, Laser- Plasma, DWA, Microstructures):

a) New collider concepts with overall comprehensive design optimization and systematic accounting of all beam physics and technology related issues. For example, these are needed to progress the AAC collider optimization beyond current "strawman design" status. These studies should be coordinated with concurrent conceptual development of detectors.
b) Optimized AAC electron acceleration technology for a collider; optimized positron acceleration; plasma multi-cell layout optimization, and the physics of drive beam instabilities and optimization.
c) Optimized beam power to wall-plug power efficiency.
d) Overall cost reduction and component damage and lifetime studies for the AAC colliders.

[1] GARD ABP Roadmap Workshop #2 (Fermilab, April-May 2020):

https://indico.fnal.gov/event/22709/