Feedback From Snowmass

ALEGRO 2023

Mark J. Hogan / Senior Staff Scientist / FACET and Test Facilities Division Director

March 22, 2022

Outline

- Snowmass process, timeline and organization
- Advanced Accelerators Topical Group (AF6) conclusions/recommendations
- Messaging from other frontiers, topical groups and forums:
  - Accelerator Frontier (AF)
  - Energy Frontier (EF)
  - e-e+ Collider Forum
  - Multi-TeV Collider Topical Group (AF4)
  - Implementation Task Force (ITF)
- Other perspectives
- Particle Physics Project Prioritization Panel (P5)
- Summary

U.S. Strategic Planning Process for Particle Physics

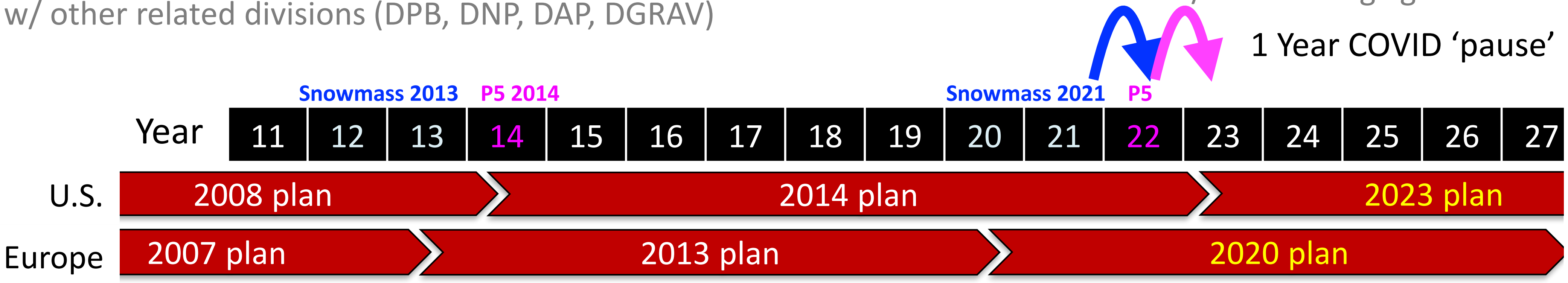
~year-long process
Community-Wide Science Study
(a.k.a. “Snowmass”)

Define the most important questions for the field
Identify promising opportunities to address them

Organized by DPF
w/ other related divisions (DPB, DNP, DAP, DGRAV)

Input to P5

~year-long process
Particle Physics
Project Prioritization Panel (“P5”)
Formulate a 10-year execution plan
(20 year vision) within funding constraints
Subpanel of High Energy Physics Advisory
Panel for DOE/NSF funding agencies



Particle Physics is global:

Snowmass process involves the international community and strategies/plans from other regions

Related to other US domestic programs such as the National Academy of Sciences (NAS) Decadal Survey on Astronomy & Astrophysics (2020) and the NAS Decadal Survey of Elementary Particle Physics (2021)

as well as **international programs**: the 2017 JAHEP/KEK Roadmap (SuperKEKB, J-PARC, Hyper-K, ILC), the 2020 Update of the European Strategy for Particle Physics and the Latin America’s Strategy Forum for Research Infrastructure

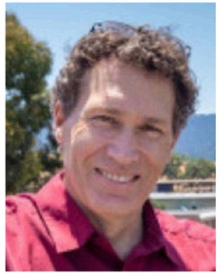
Snowmass'21 Activities Managed by Frontiers and Topical Groups

10 Frontiers	80 Topical Groups
Energy	Higgs Boson properties and couplings, Higgs Boson as a portal to new physics, Heavy flavor and top quark physics, EW Precision Phys. & constraining new phys., Precision QCD, Hadronic structure and forward QCD, Heavy Ions, Model specific explorations, More general explorations, Dark Matter at colliders
Neutrino Physics	Neutrino Oscillations, Sterile Neutrinos, Beyond the SM, Neutrinos from Natural Sources, Neutrino Properties, Neutrino Cross Sections, Nuclear Safeguards and Other Applications, Theory of Neutrino Physics, Artificial Neutrino Sources, Neutrino Detectors
Rare Processes	Weak Decays of b and c, Strange and Light Quarks, Fundamental Physics and Small Experiments. Baryon and Lepton Number Violation, Charged Lepton Flavor Violation, Dark Sector at Low Energies, Hadron spectroscopy
Cosmic	Dark Matter: Particle-like, Dark Matter: Wave-like, Dark Matter: Cosmic Probes, Dark Energy & Cosmic Acceleration: The Modern Universe, Dark Energy & Cosmic Acceleration: Cosmic Dawn & Before, Dark Energy & Cosmic Acceleration: Complementarity of Probes and New Facilities
Theory	String theory, quantum gravity, black holes, Effective field theory techniques, CFT and formal QFT, Scattering amplitudes, Lattice gauge theory, Theory techniques for precision physics, Collider phenomenology, BSM model building, Astro-particle physics and cosmology, Quantum information science, Theory of Neutrino Physics
Accelerator	Beam Physics and Accelerator Education, Accelerators for Neutrinos, Accelerators for Electroweak and Higgs Physics, Multi-TeV Colliders, Accelerators for Physics Beyond Colliders & Rare Processes, Advanced Accelerator Concepts, Accelerator Technology R&D: RF, Magnets, Targets/Sources
Instrumentation	Quantum Sensors, Photon Detectors, Solid State Detectors & Tracking, Trigger and DAQ, Micro Pattern Gas Detectors, Calorimetry, Electronics/ASICS, Noble Elements, Cross Cutting and System Integration, Radio Detection
Computational	Experimental Algorithm Parallelization, Theoretical Calculations and Simulation, Machine Learning, Storage and processing resource access (Facility and Infrastructure R&D), End user analysis
Underground Facilities	Underground Facilities for Neutrinos, Underground Facilities for Cosmic Frontier, Underground Detectors
Community Engagement	Applications & Industry, Career Pipeline & Development, Diversity & Inclusion, Physics Education, Public Education & Outreach, Public Policy & Government Engagement
Snowmass Early Career	Snowmass Early Career to represent early career members and promote

- 30 Frontier conveners
- ~250 Topical Group conveners
- >40 Inter-frontier liaisons
- ~25 Early Career liaisons

Accelerator Frontier


Steve Gourley (LBNL, Retired)


Tor Raubenheimer (SLAC)


Vladimir Shiltsev (FNAL)

In principle only gathering and summarizing information and leave prioritization to P5

AAC Relevant Accelerator Frontier Topical Groups

Link to reports: https://snowmass21.org/accelerator/start

Topical Group		Topical Group co-Conveners			
AF1	Beam Phys & Accel. Education	Z. Huang (Stanford)	M. Bei (GSI)	S. Lund (MSU)	
AF2	Accelerators for Neutrinos	J. Galambos (ORNL)	B. Zwaska (FNAL)	G. Arduini (CERN)	
AF3	Accelerators for EW/Higgs	F. Zimmermann (CERN)	Q. Qin (IHEP, Beijing)	G. Hoffstaetter (Cornell)	Angeles Faus-Golfe (IN2P2)
AF4	Multi-TeV Colliders	M. Palmer (BNL)	A. Valishev (FNAL)	N Pastrone (INFN, Torino)	J.Tang (IHEP, Beijing)
AF5	Accelerators for PBC and Rare Processes	E. Prebys (UC Davis)	M. Lamont (CERN)	R.Milner (MIT)	
AF6	Advanced Accelerator Concepts	C. Geddes (LBNL)	M. Hogan (SLAC)	P. Musumeci (UCLA)	R. Assmann (DESY)
AF7	Accelerator Technology R&D				
	Sub-group RF	E. Nanni (SLAC)	S. Belomestnykh (FNAL)	H. Weise (DESY)	
	Sub-Group Magnets	G. Sabbi (LBNL)	S. Zlobin (FNAL)	S. Izquierdo Bermudez (CERN)	
	Sub-Group Targets & Sources	C. Barbier (ORNL)	Y. Sun (ANL)	F. Pellemoine (FNAL)	

e+e- collider forum:
Maria Chamizo Llatas, Sridhara Dasu, Ulrich Heintz, Emilio A. Nanni, John Power, Stephen Wagner

Implementation Task Force (ITF) (See later slide)

AF6 Co-conveners for Snowmass and Observers for the European LDG activity

AF6: Advanced Accelerator Concepts


Cameron Geddes
Lawrence Berkeley National Lab


Mark Hogan
SLAC National Accelerator Lab


Pietro Musumeci
University of California, Los Angeles


Ralph Assmann
Deutsches Elektronen-Sychrotron

AF4: Multi-TeV Colliders

Mark Palmer


Nadia Pastrone


Jingyu Tang


Marlene Turner


Alexander Valishev


SLAC

AF6: Coordination Meetings and Timeline

- July 2020 Weekly AF6 meetings initiated
- August 2020 Letters of Interest (**LOIs)** submitted
- September 2020 AF6 Snowmass prep LOI Workshop
- Discuss 71 submitted LOIs
- Encourage collaboration to group into focussed set of contributed papers with coherent message
- October 2020 Community planning meeting
- Topical **interest groups** formed focussed around **contributed papers**
- The **long pause**…(**but connected to ES/LDG process**)
- December 2021 AF6 Contributed Paper Planning Meeting
- Scheduled review for each paper in coming weeks
- February 2022 AF6 Review of all Contributed Paper Dafts
- July 2022 Pre-Snowmass review of **AF6 Summary**

In addition:

- Positron polarization
- AAC Agora
- e-e+ Collider Forum
- Cross Frontier Workshops with EF-TF-AF#
- ITF
- …

It was a long and busy couple years!

Snowmass in Seattle

Snowmass 2021

AF6 Summary Report

Report of Snowmass 21 Accelerator Frontier Topical Group 6 on Advanced Accelerators

https://arxiv.org/abs/2208.13279#

Contents

Next few slides: highlights with representative report text

SLAC

AF6: Priority Research Directions

With the goals of addressing these long standing questions and realizing the promise of advanced accelerators, in addition to a strengthened R&D program to solve outstanding critical issues, two new research directions can be identified. An integrated design study is needed to unite all the various elements in AAC and offer a clear and actionable R&D path towards a future collider. At the same time, in order to increase the technology readiness level of advanced accelerators and provide a viable path to an AAC collider, the need is also clear to pursue nearer-term applications

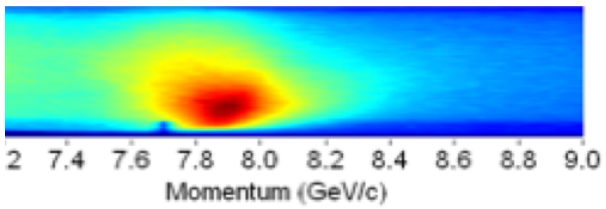
At the same time, synergies with existing or near future colliders should be explored in the near term. The extremely high fields of advanced accelerator concepts could be used for transverse focusing of the beam, advanced phase space manipulations or particle sources.

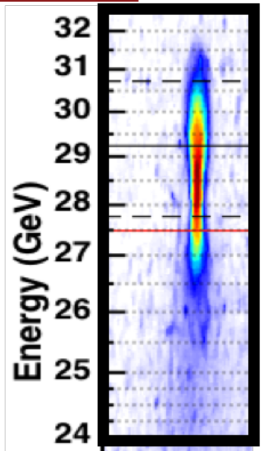
Rapid Experimental Progress Since Last Snowmass

LWFA: 8 GeV **energy gain** in 20 cm stage using BELLA PW laser

PWFA: 9 GeV in 1.3 m using SLAC at FACET

New: 12 GeV from LWFA at U Texas (submitted)

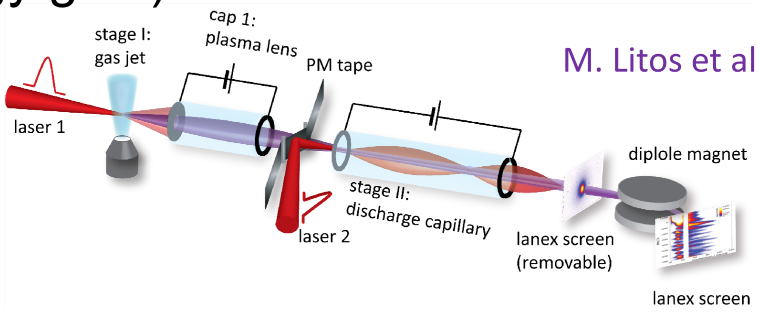




A. J. Gonsalves et al. PRL (2019)

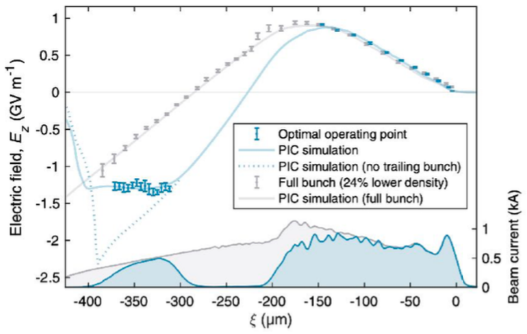
M. Litos et al. PPCF (2015)

Proof-of-principle **staging** of LWFAs (~100 MeV energy gain) using high gradient plasma-lenses



S. Steinke et al. Nature (2016)

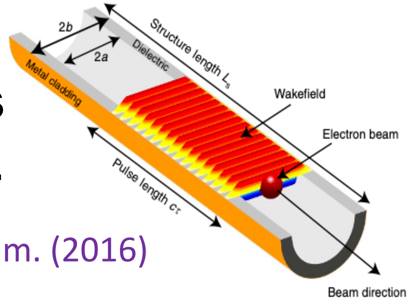
Optimized beam loading in PWFA enables uniform, **high-efficiency** acceleration.



42% transfer efficiency
with 0.2% energy spread

C. A. Lindstrom et al. PRL (2021)

Demonstration >1**GeV/m gradients** SWFA dielectric structures.



B. O'Shea et al. Nature Comm. (2016)

Plasma recovery at high rep-rate

R. D'Arcy et al., Nature (2022)

Demonstration 0.5 **GW power** SWFA structures.

Driver Technology:

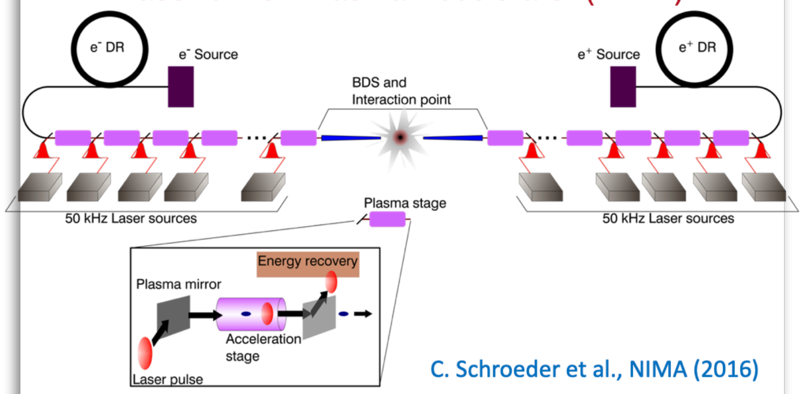
Superconducting XFELs, New laser technology (fibers, Thulium) promise high average power at high efficiency

Also: positron PWFA, hollow channels for low emittance growth, 0.1 micron emittance

Wakefield-based Colliders:
Staged High-gradient Accelerators with Geometric Gradients 0.2 - 2 GeV/m

- Collider designs have been developed to guide research priorities (efficiency, staging…)
- Allows better engagement with traditional collider community

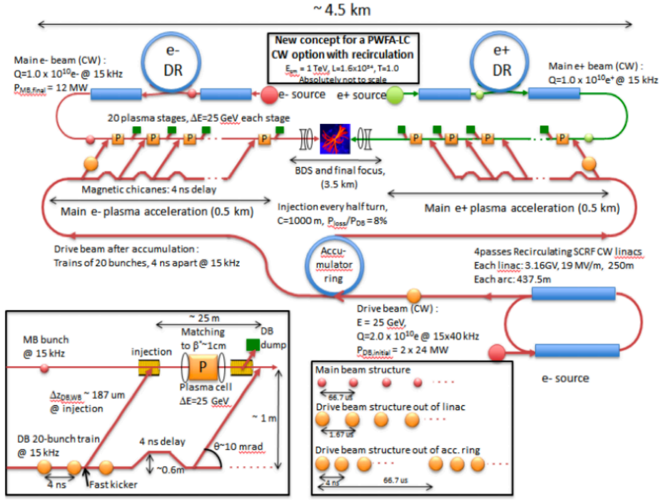
Laser-driven Plasma Accelerator (LWFA)



C. Schroeder et al., NIMA (2016)

5 GeV/stage; Geometric gradient: 2.3 GV/m

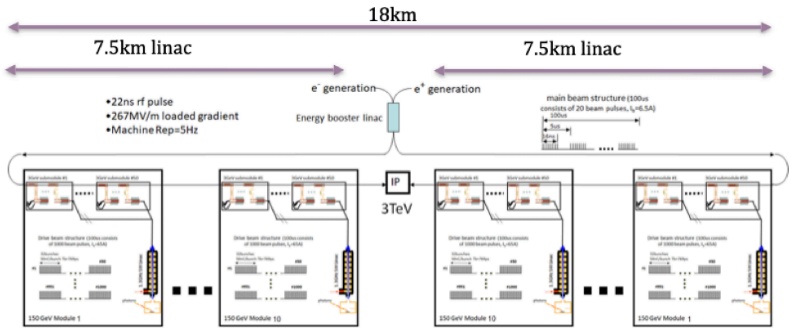
Beam-driven Plasma Accelerators (PWFA)



25 GeV/stage; Geometric gradient: 1 GV/m

E. Adli et al., arXiv:1308.1145 (2013); Chen et al., arXiv2009:13672

Structure Wakefield Accelerator (SWFA)

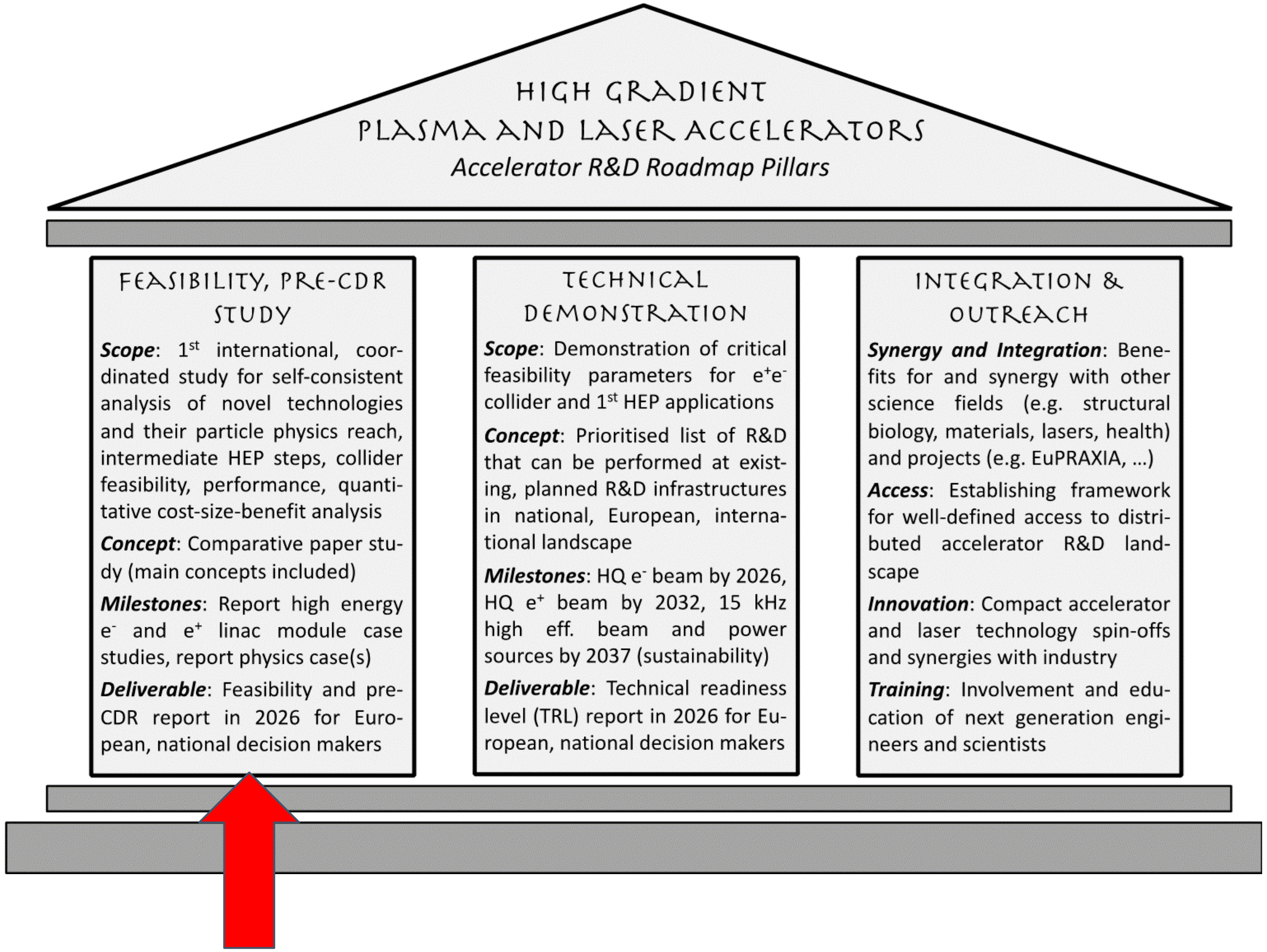


0.267 GeV/stage; Geometric gradient: 0.2 GV/m

https://accelconf.web.cern.ch/ipac2013/papers/tupea088.pdf

Next step – integrated design studies

Integrated Design Study and Near Term Applications



European Strategy for Particle Physics Roadmap for Accelerator R&D highlights the need for pre-CDR study

Strong overlap of AAC with compact light sources

AF6 Recommendations (1/3)

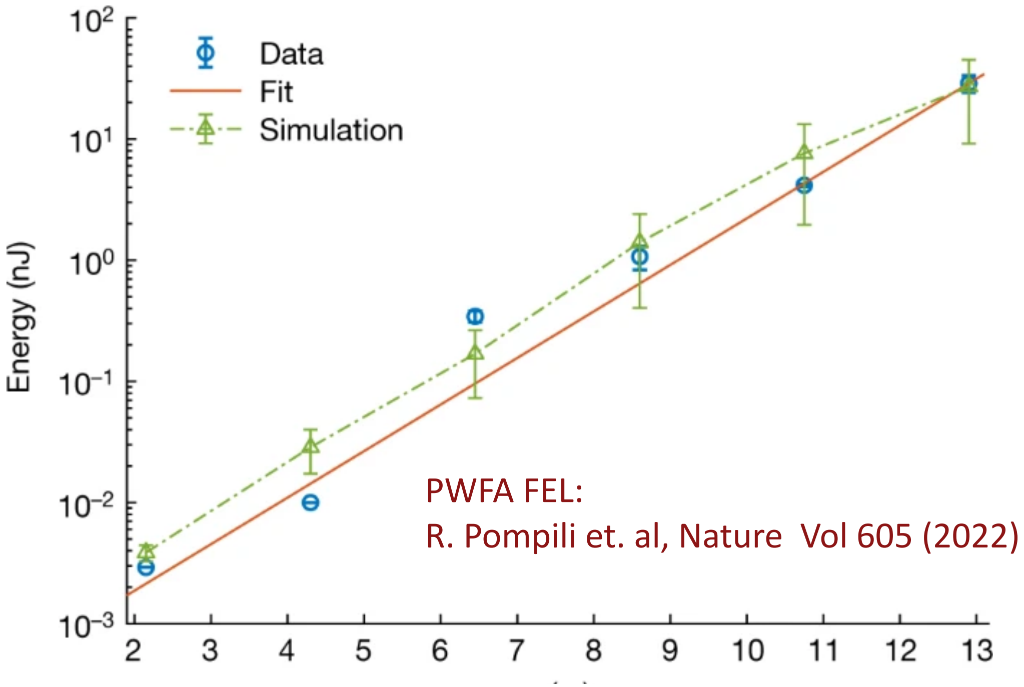
Priority research should continue to address and update the Advanced Accelerator Development Strategy:

- Vigorous research on advanced accelerators including experimental, theoretical, and computational components, should be conducted as part of the General Accelerator R&D program to make rapid progress along the advanced accelerator R&D roadmaps towards an eventual high energy collider, develop intermediate applications, and ensure international competitiveness. Priority directions include staging of multiple modules at multi-GeV, high efficiency stages, preservation of emittance for electrons and positrons, high fidelity phase space control, active feedback precision control, and shaped beams and deployment of advanced accelerator in real-world applications.

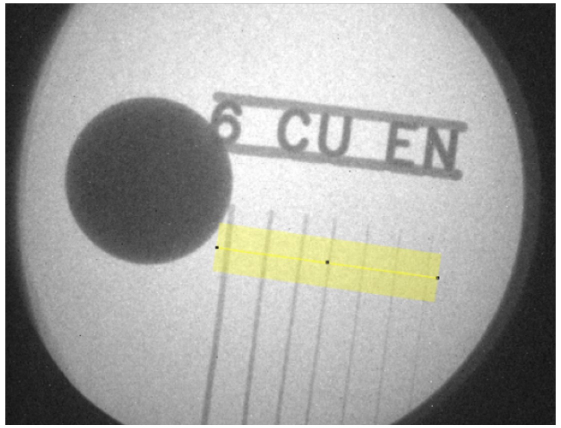
- A targeted R&D program for a integrated design study of a high energy (1–15 TeV) advanced accelerator-based collider should be performed in coordination with international efforts detailing all the components of the system, such the injector, drivers, plasma source, beam cooling, and beam delivery system. This would set the stage for a future conceptual design report, after the next Snowmass.

Plasma Acceleration Based Light Sources

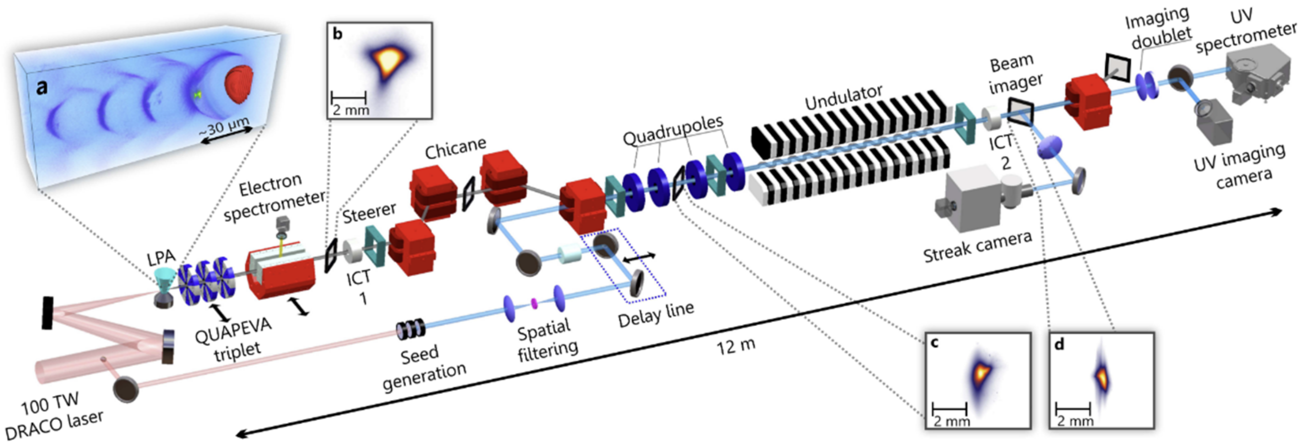
LWFA FEL: W. Wang et. al, Nature Vol 595 (2021)



PWFA FEL:
R. Pompili et. al, Nature Vol 605 (2022)



LWFA Thomson precision imaging



Seeded FEL: M. Labat et al.: DOI:10.21203/rs.3.rs-1692828/v1

Strong Role in Workforce Development

- Over 1000 research papers published annually in advanced and novel accelerators
- Spawning numerous new ideas, concepts, techniques that will help bring a future advanced accelerator based collider to fruition
- Attracts students and new researchers to the field
- Provides opportunities that are important for involving more diverse communities
- Support the goals expressed in the CEF papers for diversity, equity and inclusion

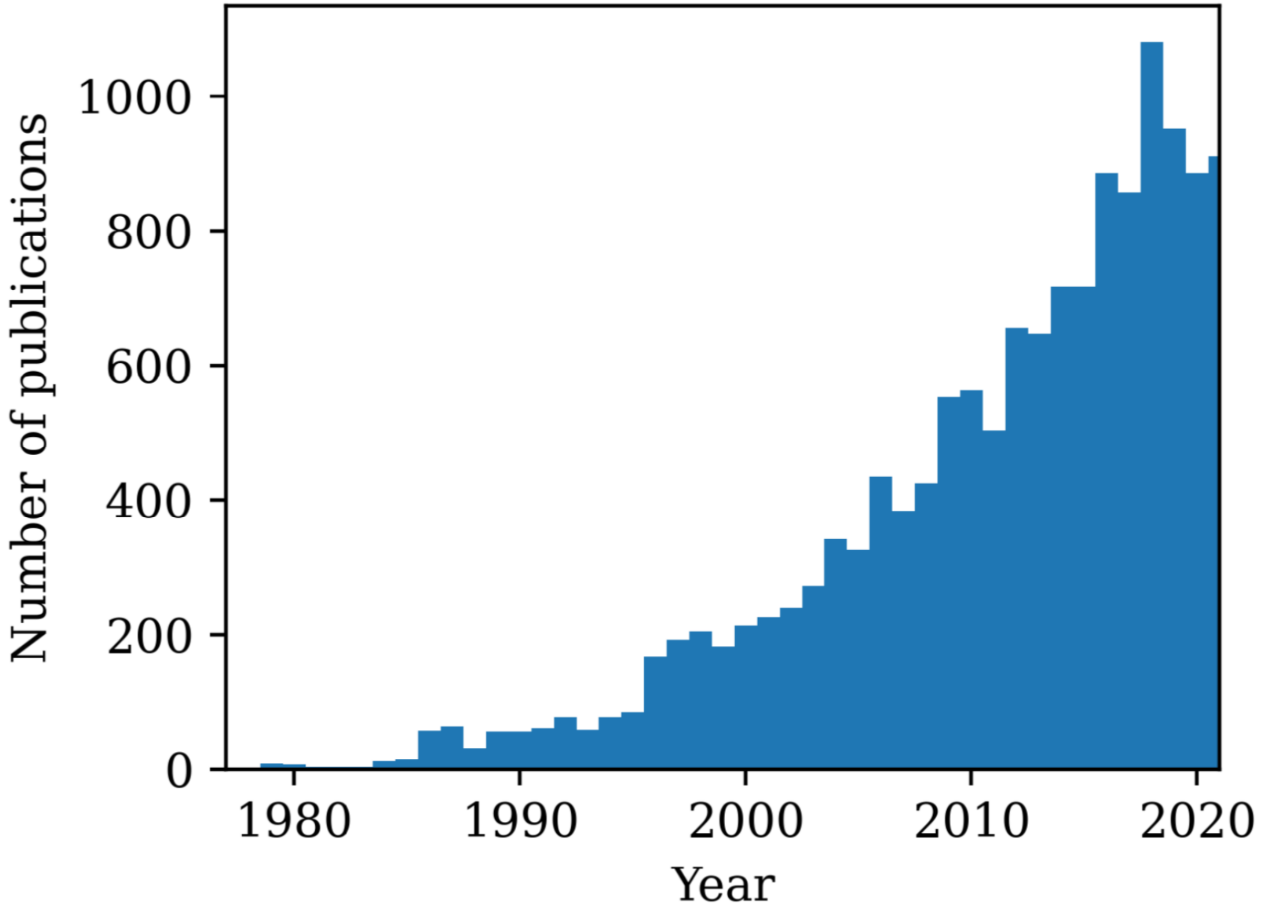


Figure 1: Example strong research, showing the number of publications per year as obtained from a Google Scholar search on articles containing all of the following keywords: "laser+plasma+wakefield+accel*".

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AF6 Recommendations (2/3)

- Research in near-term application should be recognized as essential to progress towards HEP goals. Mechanisms should be identified for HEP to pay close attention to and participate in research activities aimed at real-world deployment of advanced accelerators. The interplay and mutual interests in accelerators between HEP, BES, FES, ARDAP and other offices within DOE as well as cross-agency should be strengthened.

- Advanced accelerators should continue to play a key-role in workforce development and diversity in accelerator physics. University programs and graduate students greatly benefit from the scientific visibility of the advanced accelerator field. Access to user facilities for graduate students and early career researchers as well as formal and hands on training opportunities in advanced beam and accelerator physics should be continued and enhanced.

- Enhanced driver R&D is needed to develop the efficient, high repetition rate, high average power laser and charged particle beam technology that will power advanced accelerators colliders and societal applications.

AF6 Recommendations (3/3)

- Support of upgrades for Beam Test Facilities are needed to maintain progress on advanced accelerator Roadmaps. These include development of a high repetition rate facility, proposed as kBELLA, to support precision active feedback and high rate; independently controllable positrons to explore high quality acceleration, proposed at FACET-II; and implementation of a integrated SWFA demonstrator, proposed at AWA.
- A study for a collider demonstration facility and physics experiments at an intermediate energy (c.a. 20–80 GeV) should establish a plan that would demonstrate essential technology and provide a facility for physics experiments at intermediate energy.
- A DOE-HEP sponsored workshop in the near term should update and formalize the U.S. advanced accelerator strategy and roadmaps including updates to the 2016 AARDS Roadmaps

AF6 Takeaway Messages

- Advanced accelerators in beam and laser driven structures/plasmas offer **potential** for compact, energy efficient future e-e+/gg colliders to 15 TeV range with few TeV/km geometric gradients
- Strong **progress** since last Snowmass assessing limits and with experimental demonstrations
  - Experimental results: 10 GeV class beams, beam loading & efficiency, plasma recovery, staging, high transformer ratio, positrons, and FEL-lasing demonstrating high beam quality
  - Concepts addressing: ion motion, synchrotron radiation, scattering, hosing and positron acceleration
- The next steps are a **collider Integrated Design Study** to advance overall technical maturity combined with strengthened R&D including test facilities and **near term applications**.
  - Includes: alignment and jitter tolerances, matching/coupling between many's of stages, optimized BDS and Final focus
  - Stepping stones leading to a collider demonstrator and future colliders

Selected Highlights from the AF Summary Report Exec. Summary

- In addition, since the last Snowmass meeting that took place in 2013 was shortly after the confirmation of the Higgs, the goals for the Energy Frontier have changed as a result of the LHC measurements. While a **Higgs/EW factory** at 250 to 360 GeV **is still the highest priority** for the next large accelerator project, the **motivation for** a TeV or **few TeV e+e collider has diminished. Instead**, the community is focused on a **10+ TeV (parton c.m.e) discovery collider** that would follow the Higgs/EW Factory. This is an important change that will refocus some of the accelerator R&D programs.
- Advanced wakefield accelerator concepts should **strive toward demonstration of collider quality beams**, efficient drivers and staging, and development of self-consistent parameter sets for potential colliders based on wakefield acceleration in plasma and structures (in close coordination with international programs such as the European Roadmap, EuPRAXIA, etc.);
- Finally, in accelerator and beam physics - the focus should be on experimental, computational and theoretical studies on acceleration and control of high intensity/high brightness beams, high performance computer modeling and AI/ML approaches, and design integration and optimization. The program should also include the **overall energy efficiency** of future facilities and 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.

Full Report: https://arxiv.org/abs/arXiv:2209.14136

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Wikipedia

https://en.wikipedia.org › wiki › Damning_with_faint...

Damning with faint praise - Wikipedia

Damning with faint praise is an English idiom, **expressing oxymoronically that half-hearted or insincere praise may act as oblique criticism or condemnation.**

performance computer modeling and AI/ML approaches, and design integration and optimization. The program should also include the overall energy efficiency of future facilities and 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.

Full Report: https://arxiv.org/abs/arXiv:2209.14136

From the Energy Frontier Executive Summary

The EF currently has a top-notch program with the LHC and the High Luminosity LHC (HL-LHC) at CERN, which sets the basis for the EF vision. **The EF supports continued strong US participation in the success of the LHC, and the HL-LHC construction, operations, computing and software, and most importantly in the physics research programs, including auxiliary experiments.**

The discussions on projects that extend the reach of the HL-LHC underlined that preparations for the next collider experiments have to start now to maintain and strengthen the vitality and motivation of the community. Colliders are the ultimate tool to carry out such a program thanks to the broad and complementary set of measurements and searches they enable. Several projects have been proposed such as ILC, CLIC, FCC-ee, CEPC, Cool Copper Collider (C^3) or HELEN for e^+e^- Higgs Factories, and CLIC at 3 TeV centre-of-mass energy, FCC-hh, SPPC and Muon Collider for multi-TeV colliders. For a detailed discussion of timeline, cost, challenges of those accelerator projects we refer to the Accelerator Frontier Integration Task-Force (ITF) report [1] and the appendix 6.A.3. Dedicated fora were established across frontiers to bring together diverse expertise in the study of future e^+e^- and $\mu^+\mu^-$ colliders. Results from their studies are available in their reports [2, 3] and have informed the studies presented in this report.

Full Report: https://arxiv.org/abs/2211.11084

Majority of the EF community does not recognize AAC technologies as realistic technological options for either Higgs Factories and multi-TeV collider

From the Energy Frontier Executive Summary

The EF community proposes several parallel investigations over a time period of ten years or more for pursuing its most prominent scientific goals, namely

1. **supporting the full (3 - 4.5 ab1) HL-LHC physics program**
2. **proceeding with a Higgs factory**
3. **planning for multi-TeV colliders at the energy frontier**

The proposed plans in five year periods starting 2025 are given below.

For the five year period starting in 2025:

1. Prioritize the HL-LHC physics program, including auxiliary experiments
2. Establish a targeted e+e Higgs factory detector R&D program
3. Develop an initial design for a first stage TeV-scale Muon Collider in the US
4. Support critical detector R&D towards EF multi-TeV colliders

For the five year period starting in 2030:

1. Continue strong support for the HL-LHC physics program
2. Support construction of an e+e Higgs factory
3. Demonstrate principal risk mitigation for a first stage TeV-scale Muon Collider

Plan after 2035:

1. Continuing support of the HL-LHC physics program to the conclusion of archival measurements
2. Support completing construction and establishing the physics program of the Higgs factory
3. Demonstrate readiness to construct a first-stage TeV-scale Muon Collider
4. Ramp up funding support for detector R&D for energy frontier multi-TeV colliders.

From the Executive Summary Report of the Snowmass 2021 e^+e^- Collider Forum

Full Report: https://arxiv.org/abs/2209.03472

Circular colliders will be implemented in stages running at the Z, WW threshold, ZH, tt pair production. The ultimate upgrade path is a follow-on hadron collider, which is outside the scope of this report. Near term linear colliders provide most of the statistics at the ZH, and will also run at Z, WW and tt threshold, providing polarized electrons and positrons to enhance the signal. Linear colliders provide an upgrade path for energies above 0.5 TeV. Long-term linear collider proposals aim to lower cost by increasing acceleration gradient and lowering power consumption. The new C^3 [5] concept has made progress on both fronts. Very-long term options will require significantly more accelerator R&D but will dramatically increase gradient (>1 GeV/m) and efficiency with Wakefield Accelerators (WFAs) with strawman designs starting at 1-TeV and the potential to reach the $O(10)$-TeV scale, or Energy Recovery Linacs (ERL) to reduce power consumption while providing very high luminosities and center of mass energy, such as CERC [6], ReLiC [7] and ERLC.

A circular Higgs Factory will provide the best precision for most Higgs couplings, but direct probing of Higgs self-coupling and ttH couplings is deferred to a future higher energy proton collider. Whereas a linear Higgs Factory will provide access to the Higgs self-coupling and ttH coupling.

The primary consideration for the delivery of physics results is the start time of the physics program. Given the maturity of the technology, the ILC holds the advantage for an early start of the program. The FCC-ee and CEPC are able to complete the required runs at various luminosities faster but their larger civil engineering work requires significantly more time and cost. An early start of the civil engineering construction of a circular machine is therefore key to timely realization of physics. The ILC and C^3 have cost, higher energy-reach, and polarization advantages but with lower luminosity, needing significantly longer running time to achieve the same level of precision for measurements compared to circular machines. Among the newer proposals only C^3 proposes a timescale which is suitable for early physics, although it does require an early demonstrator. From a potential siting point of view all but the C^3 machine require green-field sites. Development of WFA-based $O(10)$-TeV scale machine, with sufficient luminosity capability for O(10) ab^{-1}, and energy-recovery technologies for improved power-to-luminosity costs, requires continued R&D investment.

Recognition of the potential of WFAs and the need for continued R&D
Gradient and Efficiency (Luminosity per unit power) are important

SLAC

AF4 (multi-TeV Colliders) Evaluated Maturity of Collider Concepts

Review of hadron and lepton colliders options, with focus on evaluating the maturity of the various concepts and the type of support that will be required to provide the high energy physics (HEP) community with the design inputs required for a machine decision.

Collider Concepts	Collider-in-Sea MuIC	WFA MuC ReLIC (≤3 TeV) SppC Multi-TeV ILC (Nb_3Sn) CCC (TeV)	FCC-hh FCC-eh CLIC TeV ILC (Nb)
Technical Maturity	• Low maturity conceptual development. • Proof-of-principle R&D required. • Concepts not ready for facility consideration.	• Emerging accelerator concepts requiring significant basic R&D and design effort to bring to maturity.	• Designs have achieved a level of maturity to have reliable performance evaluations based on prior R&D and design efforts. • Critical project risks have been identified and sub-system focused R&D is underway where necessary.
Funding Approach	• Funding for basic R&D required. • Availability of "generic" accelerator test facility access often necessary.	• Efforts would benefit from directed R&D funding to mature collider concepts. • Availability of test facilities to demonstrate a broad range of technology concepts required. • Some large-ticket demonstrators are generally necessary before a detailed "reference" design can be completed.	• Funding approach typically transitions to "project-style" efforts with significant dedicated investment required.

Figure 1 The AF4 evaluation of the maturity level of various concepts. Further details for the evaluation of the various concepts can be found in the "Concept Assessments" Section. The color code is that the concepts shown in blue offer a path to constituent center-of-mass energies >10 TeV, while those shown in orange are electron-hadron machines, and those shown in black are lepton collider concepts which will reach only into the 1-few TeV range.

- Earliest timescale for making a construction decision for a 10+ TeV machine will be sometime in the next decade
- Interest remains in the possibility of alternative paths exploring the TeV-scale including lepton-ion and g-g colliders.
- **Significant R&D required to mature concepts in the yellow shaded area. Green maturity level required for decision making and informed comparison**. 10+ TeV options highlighted in blue

Continued progress in R&D, technology demonstrations with first applications and proceeding with an Integrated Design Study can move WFA concepts in the 'right' direction

From the Snowmass Summary Report Executive Summary

Accelerator Frontier: The Accelerator Frontier aims to prepare for the next generations of major accelerator-based particle physics projects to pursue the EF, NF, and RPF physics goals.

A multi-MW beam-power upgrade of the Fermilab proton accelerator complex is required for DUNE Phase II. Studies are required to understand what other requirements the beam complex needs to meet if the same upgrade is to be used for RPF-related experiments.

In EF, a global consensus for an e^+e^- Higgs Factory as the next collider has been reaffirmed. While some options (e.g. the ILC) have mature designs, other options require further R&D to understand if they are viable. In order to further explore the energy frontier, very high-energy circular hadron colliders and/or multi-TeV muon colliders will be needed, both of which require substantial study to see if construction is feasible in the decade starting in 2040 or beyond. A team of experts formed an "Implementation Task Force" that developed metrics and a process to facilitate a comparison among the many proposed accelerator concepts. Their findings are summarized in part in the Accelerator Frontier Report and are presented in detail in a white paper. It is proposed that the U.S. establish a national integrated R&D program on future colliders to carry out technology R&D and accelerator design studies for future collider concepts.

Will a National Collider Initiative include AAC concepts? "You're not ready for that" - T. Raubenheimer

The Implementation Task Force (ITF)

- Key question for Snowmass'22 Accelerator Frontier to address: "...What are the time and cost scales of the R&D and associated test facilities as well as the time and cost scale of the facility?"
- The ITF was charged with developing metrics and processes to facilitate the evaluation of facility proposals and allow a fair comparison between between them, including the expected costs, using the same accounting rules, schedule, and R&D status


Steve Gourlay (LBNL)


Philippe Lebrun (CERN)


Thomas Roser (BNL, Chair)


Tor Raubenheimer (SLAC)


Katsunobu Oide (KEK)

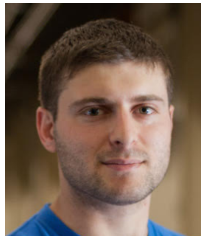

Jim Strait (FNAL)

Developed a parameter spreadsheet and solicited community input:

- Higgs factory colliders with a typical CM energy of 250 GeV
- High energy lepton colliders with up to 3 TeV CM energy
- Lepton and hadron colliders with 10 TeV or higher parton CM energy Lepton-hadron colliders


Sarah Cousineau (ORNL)


Marlene Turner (LBNL)


Spencer Gessner (SLAC)


Vladimir Shiltsev (FNAL)


Reinhard Brinkmann (DESY)


John Seeman (SLAC)

Marlene's talk from Elba: https://agenda.infn.it/event/28376/contributions/179407/

AF6 (+AAC Community) Prepared 1-15 TeV Collider Parameter Sets

AAC Community responded by providing parameter sets for cme up to 15 TeV as Input to the ITF and the AF (see details in white papers and ITF report)

Proposal Name	CM energy nom. (range) [TeV]	Lum./IP @ nom. CME [10^{34} cm^{-2}s^{-1}]	Years of pre-project R&D	Years to first physics	Construction cost range [2021 B$]	Est. operating electric power [MW]
Muon Collider	10 (1.5-14)	20 (40)	>10	>25	12-18	~300
LWFA - LC (Laser-driven)	15 (1-15)	50	>10	>25	18-80	~1030
PWFA - LC (Beam-driven)	15 (1-15)	50	>10	>25	18-50	~620
Structure WFA (Beam-driven)	15 (1-15)	50	>10	>25	18-50	~450
FCC-hh	100	30 (60)	>10	>25	30-50	~560
SPPS	125 (75-125)	13 (26)	>10	>25	30-80	~400

Table 3: Main parameters of the colliders with 10 TeV or higher parton CM energy. Total peak luminosity for multiple IPs is given in parenthesis. The cost range is for the single listed energy. Collisions with longitudinally polarized lepton beams have substantially higher effective cross sections for certain processes. The relevant energies for the hadron colliders are the parton CM energy, which can be substantially less than hadron CM energy quoted in the table.

AF6 report:
"…to **reducing the dimensions, CO2 footprint and costs of future high energy physics machines**, with the potential to **reduce power consumption** and offer e+e- and $\gamma - \gamma$ machines to and beyond 15 TeV energies."

Selling points for AAC Concepts:

1. Compact
2. Lower power consumption
3. Lower cost

ITF Report Compares 1-15 TeV Lepton Collider Luminosity and TRL

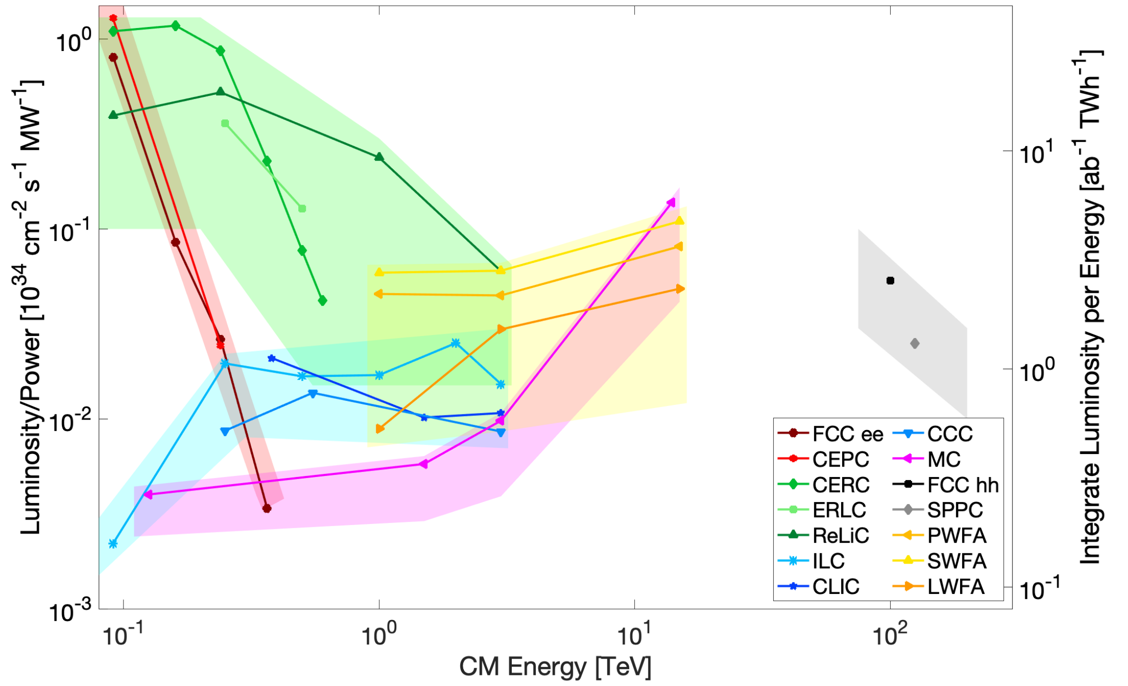


Figure 4: Figure-of-merit Peak Luminosity (per IP) per Input Power and Integrated Luminosity per TWh. Integrated luminosity assumes 10^7 seconds per year. The luminosity is per IP. Data points are provided to the ITF by proponents of the respective machines. The bands around the data points reflect approximate power consumption uncertainty for the different collider concepts.

Proposal Name (c.m.e. in TeV)	Collider Design Status	Lowest TRL Category	Technical Validation Requirement	Cost Reduction Scope	Performance Achievability	Overall Risk Tier
FCCee-0.24	II					1
CEPC-0.24	II					1
ILC-0.25	I					1
CCC-0.25	III					2
CLIC-0.38	II					1
CERC-0.24	III					2
ReLiC-0.24	V					2
ERLC-0.24	V					2
XCC-0.125	IV					2
MC-0.13	III					3
ILC-3	IV					2
CCC-3	IV					2
CLIC-3	II					1
ReLiC-3	IV					3
MC-3	III					3
LWFA-LC 1-3	IV					4
PWFA-LC 1-3	IV					4
SWFA-LC 1-3	IV					4
MC 10-14	IV					3
LWFA-LC-15	V					4
PWFA-LC-15	V					4
SWFA-LC-15	V					4
FCChh-100	II					3
SPPC-125	III					3
Coll.Sea-500	V					4

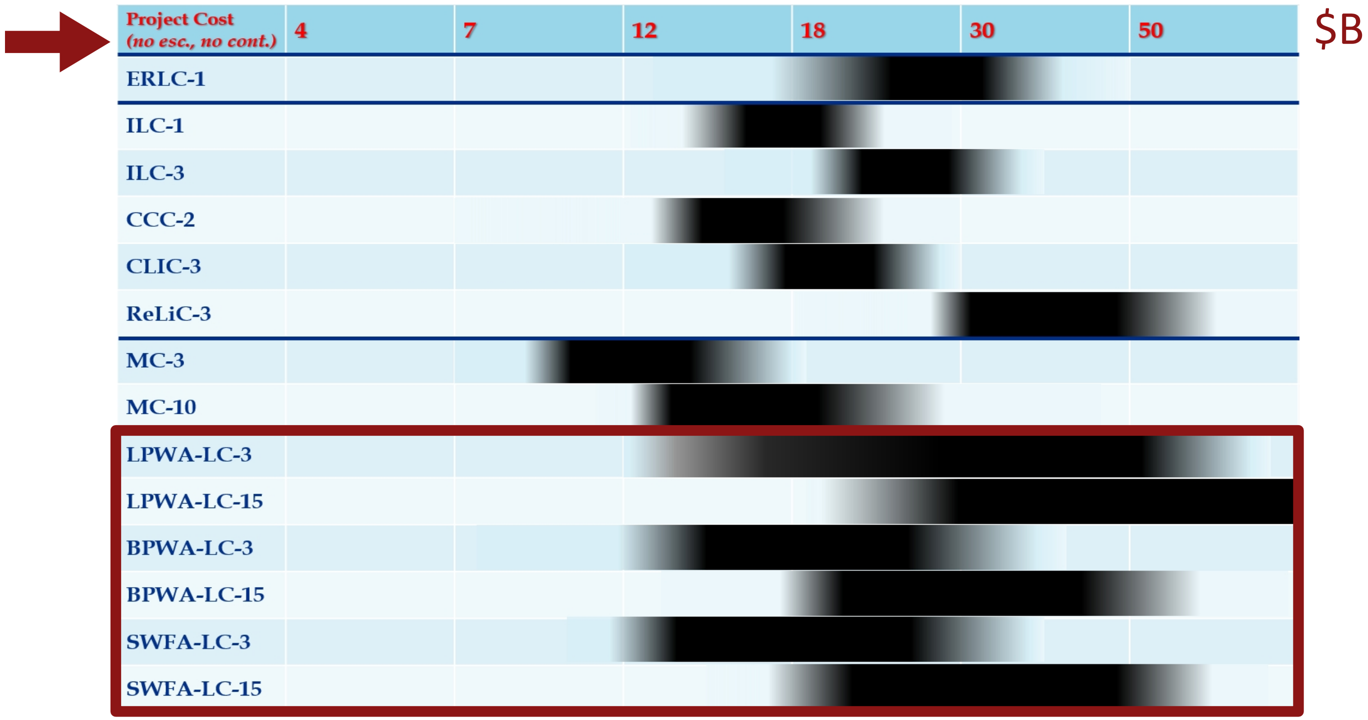
For all collider concepts the ITF took proponents inputs(energy, luminosity…) 'as is' with no pushback

ITF Evaluated and Compared Collider Properties

Proposal Name	Power Consumption	Size	Complexity	Radiation Mitigation
FCC-ee (0.24 TeV)	290	91 km	I	I
CEPC (0.24 TeV)	340	100 km	I	I
ILC (0.25 TeV)	140	20.5 km	I	I
CLIC (0.38 TeV)	110	11.4 km	II	I
CCC (0.25 TeV)	150	3.7 km	I	I
CERC (0.24 TeV)	90	91 km	II	I
ReLiC (0.24 TeV)	315	20 km	II	I
ERLC (0.24 TeV)	250	30 km	II	I
XCC (0.125 TeV)	90	1.4 km	II	I
MC (0.13 TeV)	200	0.3 km	I	II
ILC (3 TeV)	~400	59 km	II	II
CLIC (3 TeV)	~550	50.2 km	III	II
CCC (3 TeV)	~700	26.8 km	II	II
ReLiC (3 TeV)	~780	360 km	III	I
MC (3 TeV)	~230	10-20 km	II	III
LWFA (3 TeV)	~340	1.3 km (linac)	II	I
PWFA (3 TeV)	~230	14 km	II	II
SWFA (3 TeV)	~170	18 km	II	II
MC (14 TeV)	~300	27 km	III	III
LWFA (15 TeV)	~1030	6.6 km	III	I
PWFA (15 TeV)	~620	14 km	III	II
SWFA (15 TeV)	~450	90 km	III	II
FCC-hh (100 TeV)	~560	91 km	II	III
SPPC (125 TeV)	~400	100 km	II	III

Collider Cost Estimate

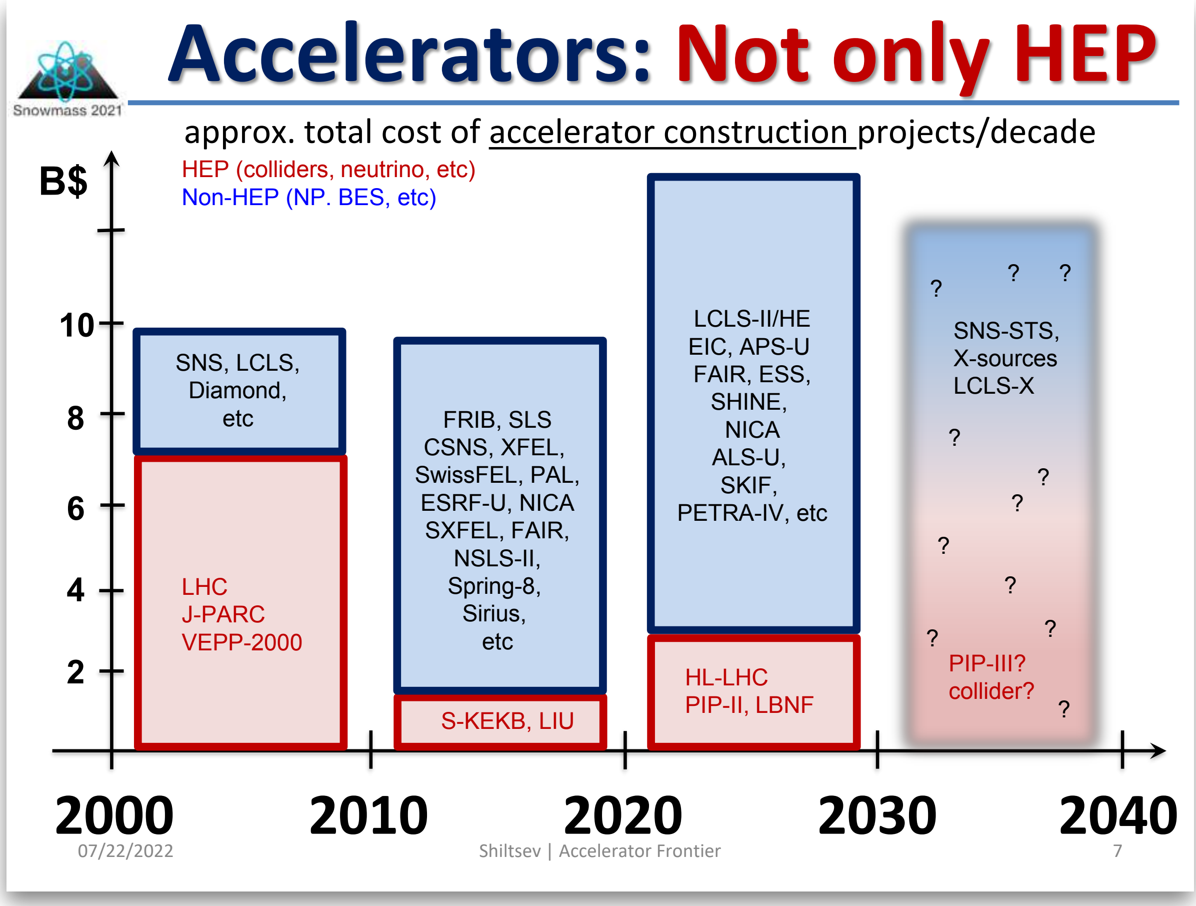
- Based on 30 parameter model developed by the ITF
- Upper bound (if build right now)
- Lower bound (estimated after technology R&D), however it is noted in the report that additional cost reduction R&D may further reduce costs

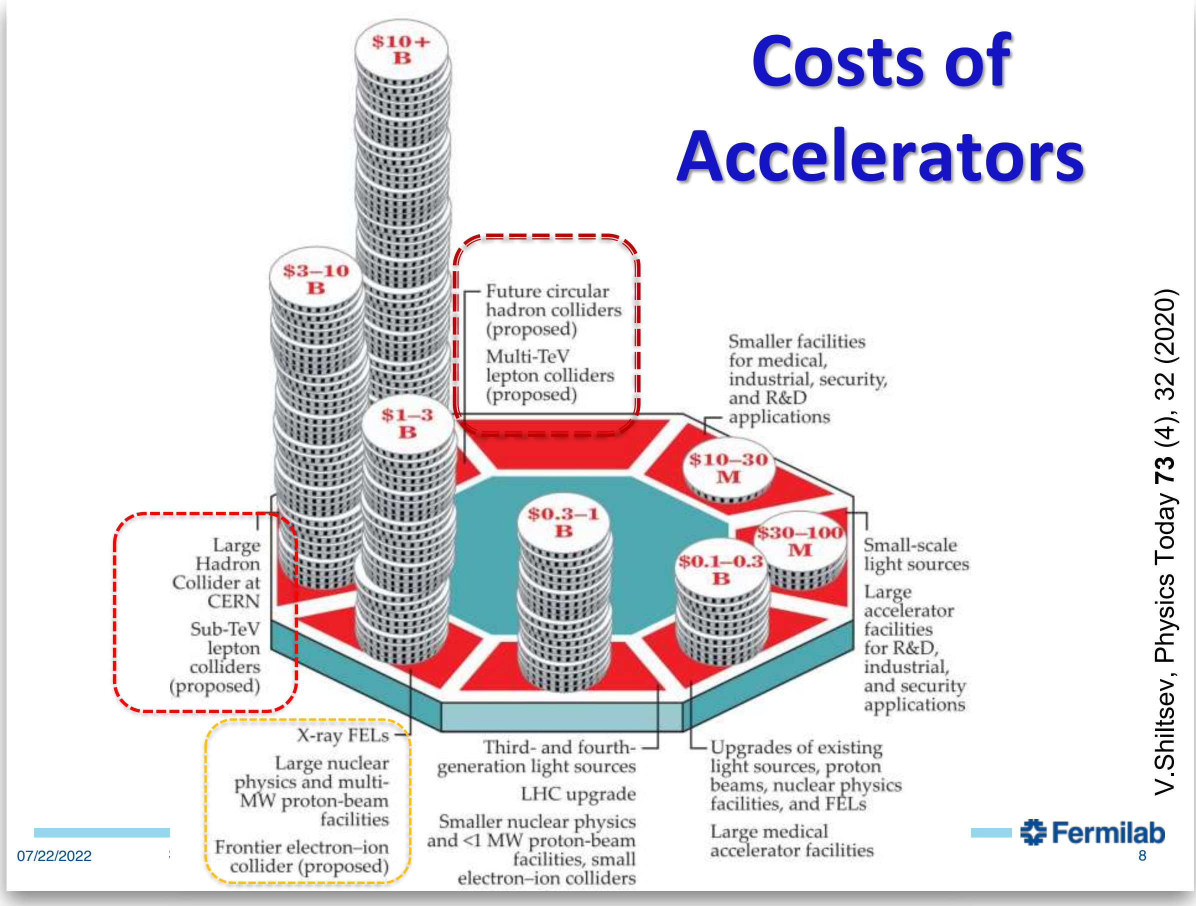


ITF Full Report: https://arxiv.org/abs/2208.06030

SLAC

We will Need a Dramatic Increase in Political/Financial Support to Realize Many of the Collider Concepts Discussed at Snowmass and in the ITF





From V. Shiltsev Snowmass presentation 'Beams, Accelerator R&D and Future Facilities: Accelerator Frontier Vision'
https://indico.fnal.gov/event/22303/contributions/245315/attachments/157756/207133/AF_Colloquium_CSS_072222_v5.pdf

https://en.wikipedia.org/wiki/Snowmass_Process

- No unexpected particles were observed in the first 15 years of data-taking at the Large Hadron Collider (LHC) – this lack of discovery leaves no clear focus for the next decade of high energy searches
- Physicists argued for precision measurements at a Higgs factory…Muon colliders were discussed at the 2013 Snowmass, but shelved due to insufficiently advanced technology. However, at the 2022 final Snowmass meeting there was an "enthusiastic revival" of the concept
- The possibility of establishing any major new project in the US in the 2023-2033 decade, including a Higgs Factory, is limited due to the rising costs and multi-year delays of existing projects.
- In particular, at Snowmass, physicists expressed deep concern about the Deep Underground Neutrino Experiment (DUNE) project, which has risen from a base cost of $1.3B in 2015 to $3.1B for a de-scoped instrument. Cost over-runs and delays of DUNE are problematic due to stiff competition from a similar experiment in Japan, leaving physicists to question the value of DUNE results when they are obtained. Worries were expressed by physicists that issues with DUNE were "smoothed over, not smoothed out." Some physicists at Snowmass suggested that the DUNE project might be cancelled, comparing the ominous cost-growth to the Superconducting Super Collider (SSC) that was cancelled when the cost tripled.

P5 Process is Underway

http://hitoshi.berkeley.edu/P5/

Chaired by Hitoshi Murayama (Berkeley)

Town Halls (in person) have been scheduled, additional virtual Town Halls TBD

- Lawrence Berkeley National Laboratory: Cosmic Frontier (except for High-Energy Astrophysics and Gravitational Wave), February 22-24
- Fermilab/Argonne: Neutrino, Rare Processes and Precision Frontier, High-Energy Astrophysics, Mar 21, 22, 24 (Fermilab), 23 (Argonne)
- Brookhaven: Energy, Instrumentation, Computational Frontiers, Gravitational Wave, Apr 12-14
- SLAC: Underground, **Accelerator**, Theory Frontiers, Community Engagement, **May 3-5**

Panel Members

- Shoji Asai (University of Tokyo)
- Amalia Ballarino (CERN)
- Tulika Bose (Wisconsin)
- Kyle Cranmer (Wisconsin)
- Francis-Yan Cyr-Racine (New Mexico)
- Sarah Demers (Yale)
- Cameron Geddes (LBNL)
- Yuri Gershtein (Rutgers)
- Karsten Heeger (Yale), Deputy Chair
- Beate Heinemann (DESY)
- JoAnne Hewett (SLAC) HEPAP chair, ex officio
- Patrick Huber (Virginia Tech)
- Kendall Mahn (Michigan State)
- Rachel Mandelbaum (Carnegie Mellon)
- Jelena Maricic (Hawaii)
- Petra Merkel (Fermilab)
- Christopher Monahan (William & Mary)
- Hitoshi Murayama (Berkeley), Chair
- Peter Onyisi (Texas Austin)
- Mark Palmer (Brookhaven)
- Tor Raubenheimer (SLAC)
- Mayly Sanchez (Florida State)
- Richard Schnee (South Dakota School of Mines and Technology)
- Seon-Hee (Sunny) Seo (IBS Center for Underground Physics)
- Jesse Thaler (MIT)
- Christos Touramanis (Liverpool)
- Abigail Vieregg (Chicago)
- Amanda Weinstein (Iowa State)
- Lindley Winslow (MIT)
- Tien-Tien Yu (Oregon)
- Bob Zwaska (Fermilab)

Most are not accelerator people

Looking to P5 and Beyond – What Should Our Community Do?

- Reframing of LC Higgs Factory as first step toward multi-TeV linear colliders (HEP-Ex and HEP-Th want 10+ TeV because LHC excluded a lot)
  - Emphasis on e-e+ or gamma-gamma WFA for multi-TeV upgrade
- Broaden our participation in non-AAC meetings/workshops, e.g.
  - Muon collider workshop – March, UCSB
  - 2023 International Workshop on Future Linear Colliders (LCWS2023) – May
    - https://indico.slac.stanford.edu/event/7467/overview
- WFA has made significant progress since last Snowmass – conveying that progress and status is important as it is not well known
- Engage the particle and detector physicists – we have unique and interesting issues with WFA detectors e.g. short bunches. Relaying concept parameters so they can have to something to calculate with is very important.
- WFA wants to move from a Strawman to self-consistent sets of parameters with support for an Integrated Design Study, but we need engagement from the linear collider community and the particle physicists working on detectors to make that a reality

Summary & Outlook

- Snowmass is a science focused planning exercise that occurs every 8 years to create a vision for particle physics in the next decade(s)
- Recently, Snowmass2021 process culminated in meeting in July 2022
- Information in the Snowmass proceedings (reports) now goes to P5 to set funding priorities for the U.S Government
- Exploiting LHC is immediate priority but longer term aspirations have shifted from a few TeV to precision Higgs Factory then discovery machine at 15TeV (c.m.e./parton)
- Accelerator Frontier and other reports encourage continued R&D and emphasize the need for designs with documented self-consistent parameter sets and identified technology gaps
- Energy Frontier is not convinced AAC technologies are viable options – we need to share our progress and engage broader communities in our planning to change this mindset