



# Snowmass'21, P5 and the National Future Collider R&D Program

**Vladimir SHILTSEV (Fermilab)**

with input from S.Gourlay (LBNL), T.Raubenheimer (SLAC), P.Bhat (FNAL), A.Lankford (UCI), and S.Nagaitsev (Jlab)

C3 Workshop, February 6, 2023, Santa Fe

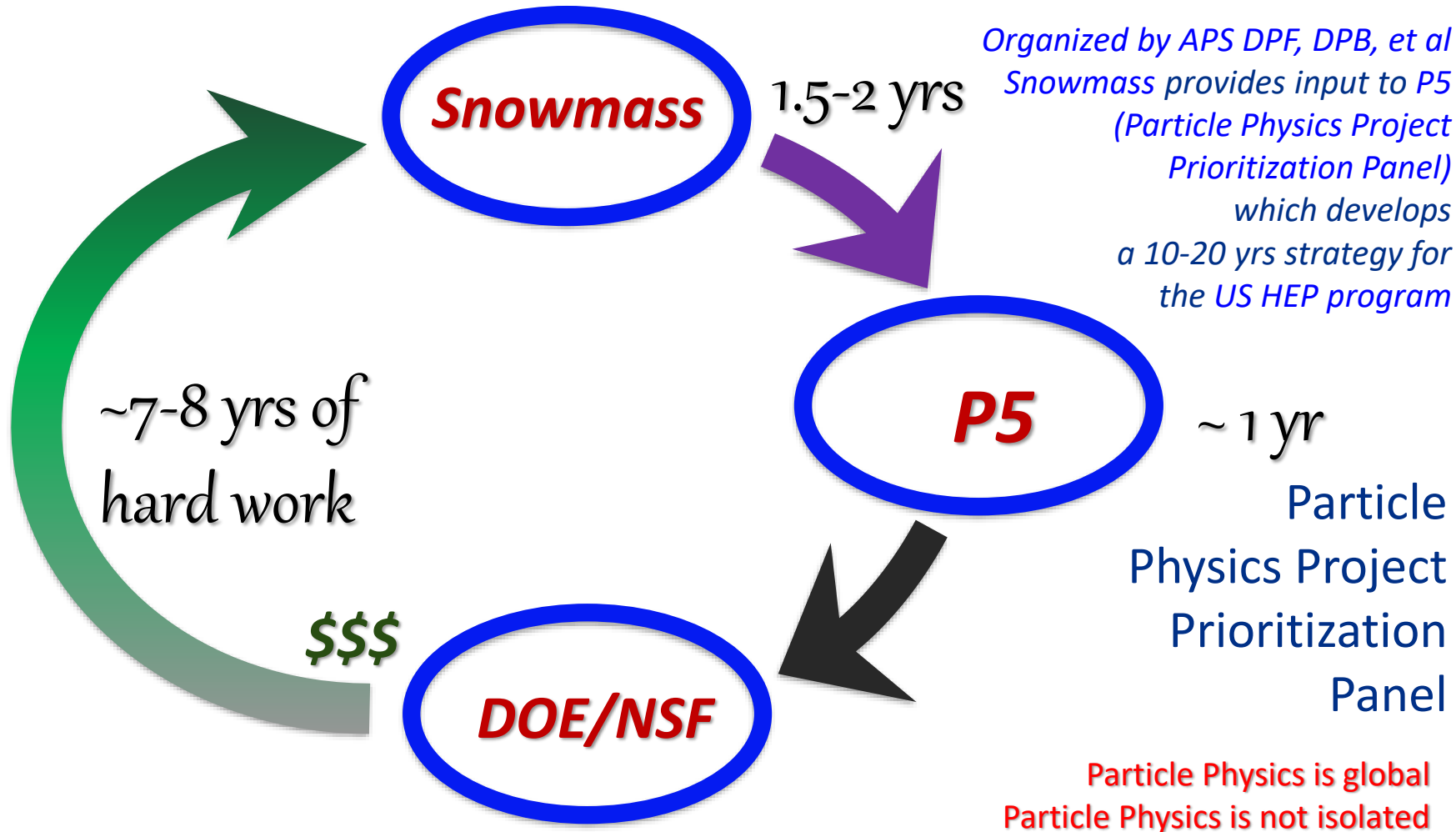
**1. Snowmass'21 – Accelerator Frontier**

**2. National Future Collider R&D  
program**

**3. P5 and our challenge**

# Snowmass'21

*"a particle physics community strategic planning study"*



<https://www.snowmass21.org/>

# Snowmass'21 Accelerator Frontier Conveners



Steve Gourlay  
(LBNL)



Tor Raubenheimer  
(SLAC)



Vladimir Shiltsev  
(FNAL)

(AF – one of 10 frontiers, incl. Neutrino, Rare Processes, Energy, etc)

## Focus:

- Understand the most important questions for the field of *Accelerator Science and Technology*
- Identify promising opportunities and tools to address them
- Consider a mix of large, mid, and small scale accelerators as well as R&D
- **Provide information to P5 to help develop a strategy for the US HEP**

**2020-2022: 257 LOIs, ~60 Workshops, 122 White Papers, Seattle...**



# AF Report: Executive Summary

arxiv:2209.14136

## “Intro”:

- Since last P5, this Snowmass’21 process

## “Future Facilities”:

- TBD by P5 – accelerator/people need to be part of P5; ITF analysis can greatly help
- *Multi-MW FNAL complex upgrade* will be priority for NF in 2030 (AccFrontier is ready)
- Many opportunities for Rare Processes (AF ready), incl. *PAR and utilize what we have*
- Several Higgs/EW factories are feasible: *FCCee, C3 and HELEN* to be explored
- $O(10 \text{ TeV/parton})$  needed for >2040’s, *muon colliders* to be explored/ pre-CDR by 2030
- Need an *Integrated Future Colliders R&D program* in OHEP to provide design reports by next Snowmass/P5’2030 and engage internationally (FCC, ILC, IMCC)

## Accelerator Frontier

S. Gourlay, T. Raubenheimer, V. Shiltsov

G. Arbanis, B. Assmann, C. Barf, M. Bai, S. Beharav, S. Bernasconi, P. Blot, A. Brusa-Geslin, J. Caldeira, C. Gallas, G. Hellenic, M. Hogan, E. Huang, D. Li, S. Li, S. Li, R. Miller, P. Monetti, E. Nanni, M. Palmer, N. Papan, F. Pedersoli, E. Preys, Q. Qin, J. Power, T. Ruan, G. Saldá, D. Sotnikov, V. E. Sun, J. Tang, A. Valishev, B. Wang, F. Zimmermann, A.V. Zolotarev, R. Zou

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, the increasing size, cost and demands required for modern and future accelerator-based HEP projects arguably distinguish them as the most challenging scientific research endeavors. In the meantime, the international accelerator community has demonstrated imagination and creativity in developing a plethora of future accelerator ideas and proposals.

Major developments since the last Snowmass/HEPAP P5 strategic planning exercise in 2013-2014 include start of the PIP-II proton beam construction for the LBNL/DUNE neutrino program in the US; emergence of the FCC/CEPC projects for Higgs/EW physics research at CERN and in China, respectively; a significant evolution of activity related to linear collider projects (ILC in Japan and CLIC at CERN); and, more recently, 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 Roadmap, European Strategy for Particle Physics and the Accelerator R&D Roadmap, EuPRAXIA, etc.

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 300 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 90-TeV (parton  $e^+e^-$ ) discovery collider that would follow the Higgs/EW Factory. This is an important change that will reflect some of the accelerator R&D programs.

The technical maturity of proposed facilities ranges from show-ready to those that are still largely conceptual. Over 100 contributed papers have been submitted to the Accelerator Frontier of the US particle physics broad community planning exercise, Snowmass2021. 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.

**Future facilities:** The accelerator community in the US and globally has a broad array of accelerator technologies and expertise that will be needed to design and construct any of the near-term HEP accelerator projects. P5 will need to prioritize what option(s) should be developed. Planning of accelerator development and research should be aligned with the strategic planning for particle physics and should be part of the P5 prioritization process. Accelerator experts can contribute to the US and international projects under consideration by providing top-down metrics for expected cost-scales and technology/maturity evolution, following the ITF findings.

Among possible actively discussed future facilities options are:

- A multi-MW beam power upgrade of the Fermilab proton accelerator complex that seems to be 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 Dark Matter (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 Accelerator Ring); in general, we should efficiently utilize existing and upcoming facilities to explore dedicated or parallel opportunities for rare process measurements - examples are the SLAC SRF electron beam, MWs of proton beam power potentially available after construction of the PIP-II SRF line, upgrades of the future multi-MW FNAL complex upgrade, and at CERN, a Forward Physics Facility at the LHC, etc.
- 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 FCCs at CERN and proposals of somewhat more advanced linear colliders in the US or elsewhere, such as C<sup>3</sup> and HELEN;
- At the energy frontier, the discovery machines such as O(10 TeV  $e^+e^-$ ) muon colliders have rapidly gained significant momentum. To be in a position for making decisions on collider projects viable for construction in the 2040s and beyond at the time of the next Snowmass/P5, these concepts could be explored technically and documented in pre-CDR level reports by the end of this decade.

The US HEP accelerator R&D portfolio presently contains an collider-specific focus. This creates a gap in our knowledge-base and accelerator/technology capabilities. It also limits our national preparation for a leadership role in particle physics in that the US cannot lead or even contribute to proposals for accelerator-based HEP facilities. To address the gap, the community has proposed that the US 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 create synergistic engagement in projects proposed abroad (e.g. FCC, ILC, IMCC). It would support the development of design reports on collider options by the time of the next Snowmass and P5 (2025-2030), particularly for options that can feasibly be hosted in the US, and to create R&D plans for the decade past 2030. Without such a program there may be few accelerator-based proposals for a future P5 to evaluate.





# (Top Level) Snowmass Summary

arxiv:2301.06581

Science Drivers (6 pages)

(Brief) Frontier Summaries (~40 pages)

(Brief) Cross-Frontier Topics (~10 pages)

High-Level Conclusions (4 pages)



Frontier/Decade	Coming Decade (2025 - 2035)	Next Decade (2035 -2045)
Energy Frontier	U.S. Initiative for the Targeted Development of Future Colliders and their Detectors	
		Higgs Factory Construction
Neutrino Frontier	LBNF/DUNE Phase I & PIP- II	DUNE Phase II (incl. proton injector)
Cosmic Frontier	Cosmic Microwave Background - S4	Next Gen. Grav. Wave Observatory*
	Spectroscopic Survey - S5*	Line Intensity Mapping*
	Multi-Scale Dark Matter Program (incl. Gen-3 WIMP searches)	
Rare Process Frontier		Advanced Muon Facility

Table 1-1. Large-scale projects or programs (total projected costs of \$500M or larger) endorsed by one or more of the Snowmass Frontiers to address the essential scientific goals for the coming and next decades. Projects were not prioritized, nor examined in the context of budgetary scenarios. In the observational Cosmic program, project funding may come from sources other than HEP, as denoted by an asterisk.

# Future Colliders in the Snowmass Accelerator Frontier Report and the Future Collider R&D Initiative White Paper

7

## Accelerator Frontier



Submitted to the Proceedings of the US Community Study  
on the Future of Particle Physics (Snowmass 2021)

July 14, 2022

### U.S. National Accelerator R&D Program on Future Colliders

P. C. BHAT<sup>1,†</sup>, S. BELOMESTNYKH<sup>1,5</sup>, A. BROSS<sup>1</sup>, S. DASU<sup>6</sup>, D. DENISOV<sup>4</sup>, S. GOURLAY<sup>7</sup>,  
S. JINDARIANI<sup>1</sup>, A. J. LANKFORD<sup>8,†</sup>, S. NAGAITSEV<sup>1,2,†</sup>, E. A. NANNI<sup>3</sup>, M. A. PALMER<sup>4</sup>,  
T. RAUBENHEIMER<sup>3</sup>, V. SHILTSEV<sup>1</sup>, A. VALISHEV<sup>1</sup>, C. VERNIERI<sup>7</sup>, F. ZIMMERMANN<sup>9</sup>

<sup>1</sup>Fermi National Accelerator Laboratory

<sup>2</sup>University of Chicago

<sup>3</sup>SLAC National Accelerator Laboratory

<sup>4</sup>Brookhaven National Laboratory

<sup>5</sup>Stony Brook University

<sup>6</sup>University of Wisconsin, Madison

<sup>7</sup>Lawrence Berkeley National Laboratory, Retired

<sup>8</sup>University of California, Irvine

<sup>9</sup>CERN

<sup>†</sup> Lead Contacts; Email: pushpa@fnal.gov, andrew.lankford@uci.edu, nsergei@fnal.gov

Frontier Conveners: S. Gourlay<sup>1</sup>, T. Raubenheimer<sup>2</sup>, V. Shiltsev<sup>3</sup>

Topical Group Conveners: G. Arduini<sup>1</sup>, R. Assmann<sup>2</sup>, C. Barbier<sup>3</sup>, M. Bai<sup>2</sup>, S. Belomestnykh<sup>3</sup>, S. Bermudez<sup>4</sup>,  
A. Faus-Golfe<sup>7</sup>, J. Galambos<sup>6</sup>, C. Geddes<sup>1</sup>, G. Hoffstaetter<sup>4</sup>, M. Hogan<sup>2</sup>, Z. Huang<sup>2</sup>, M. Lamont<sup>4</sup>, D. Li<sup>1</sup>,  
S. Lund<sup>9</sup>, R. Milner<sup>10</sup>, P. Musumeci<sup>11</sup>, E. Nanni<sup>2</sup>, M. Palmer<sup>12</sup>, N. Pastrone<sup>13</sup>, F. Pellegrino<sup>3</sup>, E. Prebys<sup>14</sup>,  
Q. Qin<sup>15</sup>, G. Sabbi<sup>1</sup>, Y.-E. Sun<sup>16</sup>, J. Tang<sup>17</sup>, A. Valishev<sup>3</sup>, H. Weiss<sup>5</sup>, F. Zimmermann<sup>4</sup>, A. V. Zlobin<sup>3</sup>,  
R. Zwaska<sup>3</sup>

Contributors: P. Bhat<sup>3</sup>, J. Power<sup>16</sup>, T. Roser<sup>12</sup>, D. Stratakis<sup>3</sup>

<sup>1</sup>Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

<sup>2</sup>SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

<sup>3</sup>Fermi National Accelerator Laboratory, Batavia, IL 60510, USA

<sup>4</sup>CERN, 1211 Meyrin, Switzerland

<sup>5</sup>Deutsches Elektronen-Synchrotron, 22607 Hamburg, Germany

<sup>6</sup>Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA

<sup>7</sup>Université Paris-Saclay, CNRS/IN2P3, 91406 Orsay, France

<sup>8</sup>Cornell University, Ithaca, NY 14850, USA

<sup>9</sup>Michigan State University, East Lansing, MI 48824, USA

<sup>10</sup>MIT, Cambridge, MA 02139, USA

<sup>11</sup>UCLA, Los Angeles, CA 90095, USA

<sup>12</sup>Brookhaven National Laboratory, Upton, NY 11973, USA

<sup>13</sup>INFN Torino, 10127 Torino TO, Italy

<sup>14</sup>University of California, Davis, Davis, CA, 90095, USA

<sup>15</sup>ESRF, 38000 Grenoble, France

<sup>16</sup>Argonne National Laboratory, Lemont, IL 60439, USA

<sup>17</sup>IHEP, Beijing, 100039 China

<https://arxiv.org/abs/2209.14136>

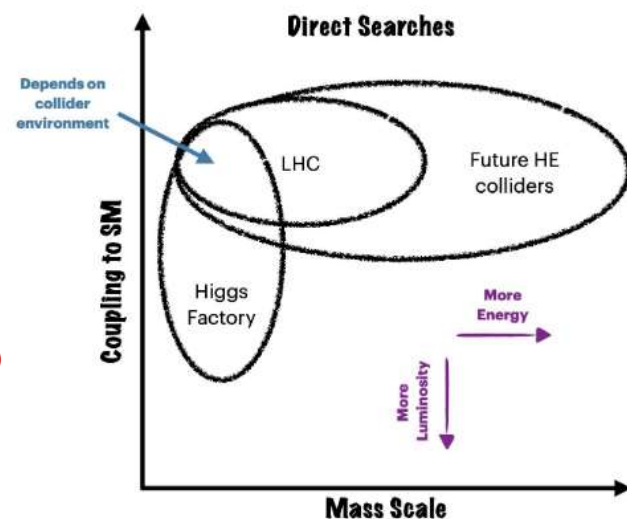
<https://arxiv.org/abs/2207.06213>

arXiv:2209.14136v2 [physics.acc-ph] 17 Nov 2022

arXiv:2207.06213v1 [physics.acc-ph] 13 Jul 2022

# The Global Energy Frontier Landscape

- Strong consensus in the global community that an  **$e^+e^-$  Higgs Factory** should be the next global collider, and that it should be realized as soon as possible.
  - Strong candidates: ILC, CLIC, FCC-ee, CEPC
  - Promising, novel concepts: C3, HELEN, FNAL-SF (site-filler)
- Beyond a Higgs Factory, progress at the Energy Frontier would need a high energy collider to access physics at  **$\sim 10$  TeV scale**.
  - FCC-hh, SppC,  $\sim 10$  TeV Muon Collider, etc
- see Snowmass EF Summary: <https://arxiv.org/abs/2211.11084>





# Snowmass: >30 Colliders

<https://arxiv.org/abs/2208.06030>

- The Accelerator Frontier **Implementation Task Force (ITF)** is charged with developing metrics and processes to facilitate a comparison between collider projects:

- Higgs/EW factories (12 options)
- Lepton colliders with 3 TeV cme (9 options)
- Lepton and hh colliders 10 options
- eh colliders (3 options)

- ITF address the following issues:
  - Physics and technical parameters
  - Size, cost, and environment
  - Technical readiness, and R&D required
  - Cost and schedule

Combined experience in construction and commissioning of >20 accelerator projects



Thomas Roser  
(BNL, Chair)



Phil



Steve Gourlay  
(LBNL)



meimer  
(SLAC)



Katsunobu Oide  
(KEK)



Jim Strait  
(FNAL)



Vladimir Shiltsev  
(FNAL)



Reinhard Brinkmann  
(DESY)



John Seeman  
(SLAC)

**REPORT**



Dmitry Denisov



Meenakshi Narain  
(Brown U.)



Liantao Wang  
(U.Chicago)



Sarah Cousineau  
(ORNL)

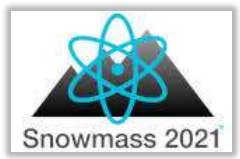


Marlene Turner  
(LBNL)



Spencer Gessner  
(SLAC)

<sup>9</sup>See also T.Roser talk in Panel 2



# ITF's Evaluations: Higgs Factories & Multi-TeV

ITF Report – T. Roser, et al, arXiv:2208.06030

	<b>CME (TeV)</b>	<b>Lumi per IP (10<sup>34</sup>)</b>	<b>Years, pre- project R&amp;D</b>	<b>Years to 1<sup>st</sup> Physics</b>	<b>Cost Range (2021 B\$)</b>	<b>Electric Power (MW)</b>
<b>FCCee-0.24</b>	0.24	8.5	0-2	13-18	12-18	290
<b>ILC-0.25</b>	0.25	2.7	0-2	<12	7-12	140
<b>CLIC-0.38</b>	0.38	2.3	0-2	13-18	7-12	110
<b>HELEN-0.25</b>	0.25	1.4	5-10	13-18	7-12	110
<b>CCC-0.25</b>	0.25	1.3	3-5	13-18	7-12	150
<b>CERC(ERL)</b>	0.24	78	5-10	19-24	12-30	90



# Power and Luminosity Discussion Continues

- e.g., in Frascati, at the e+e-FACT'22 Workshop (Sep. 12-15, 2022)
- see below summary table (Proc. eeFACT'22, F.Zimmermann et al)

Proposal	CEPC		FCC-ee		CERC		C <sup>3</sup>	HELEN	CLIC	ILC <sup>±</sup>	RELIC		EIC
Beam energy [GeV]	120	180	120	182.5	120	182.5	125	125	190	125	120	182.5	10 or 18
Average beam current [mA]	16.7	5.5	26.7	5	2.47	0.9	0.016	0.021	0.015	0.04	38	39	0.23–2.5
Total SR power [MW]	60	100	100	100	30	30	0	3.6	2.87	7.1	0	0	9
Collider cryo [MW]	12.74	20.5	17	50	18.8	28.8	60	14.43	–	18.7	28	43	12
Collider RF [MW]	103.8	173.0	146	146	57.8	61.8	20	24.80	26.2	42.8	57.8	61.8	13
Collider magnets [MW]	52.58	119.1	39	89	13.9	32	20	10.40	19.5	9.5	2	3	25
Cooling & ventil. [MW]	39.13	60.3	36	40	NE	NE	15	10.50	18.5	15.7	NE	NE	5
General services [MW]	19.84	19.8	36	36	NE	NE	20	6.00	5.3	8.6	NE	NE	4
Injector cryo [MW]	0.64	0.6	1	1	NE	NE	6	1.96	0	2.8	NE	NE	0
Injector RF [MW]	1.44	1.4	2	2	NE	NE	5	0*	14.5	17.1	192	196	5
Injector magnets [MW]	7.45	16.8	2	4	NE	NE	4	13.07*	6.2	10.1	0 <sup>†</sup>	0 <sup>†</sup>	5
Pre-injector [MW]	17.685	17.7	10	10	NE	NE	–	13.37	–	–	NE	NE	10
Detector [MW]	4	4.0	8	8	NE	NE	NE	15.97*	2	5.7	NE	NE	NI
Data center [MW]	NI	NI	4	4	NE	NE	NE	NI	NI	2.7	NE	NE	NI
Total power [MW]	259.3	433.3	301	390	89	122	150	110.5	107	138	315	341	79
Lum./IP [ $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ ]	5.0	0.8	7.7	1.3	78	28	1.3	1.35	2.3	2.7	200	200	1
Number of IPs	2	2	4 (2)	4 (2)	1	1	1	1	1	1	2	2	1 (2)
Tot. integr. lum./yr [1/fb/yr]	1300	217.1	4000 (2300)	670 (340)	10000	3600	210	390.7	276	430	79600	79000	145
Eff. physics time / yr [ $10^7 \text{ s}$ ]	1.3	1.3	1.24	1.24	1.3	1.3	1.6	2.89	1.2	1.6	2	2	1.45
Energy cons./yr [TWh]	0.9	1.6	1.51	1.95	0.34	0.47	0.67	0.89	0.6	0.82	2	2.2	0.32

- To be continued under ICFA (Sustainability Panel, Beam Dynamics Panel, Advanced and Novel Accelerators Panel)



# Future Colliders: Options for Fermilab Site

Snowmass Whitepaper, P.Bhat, et al, <https://arxiv.org/abs/2203.08088>

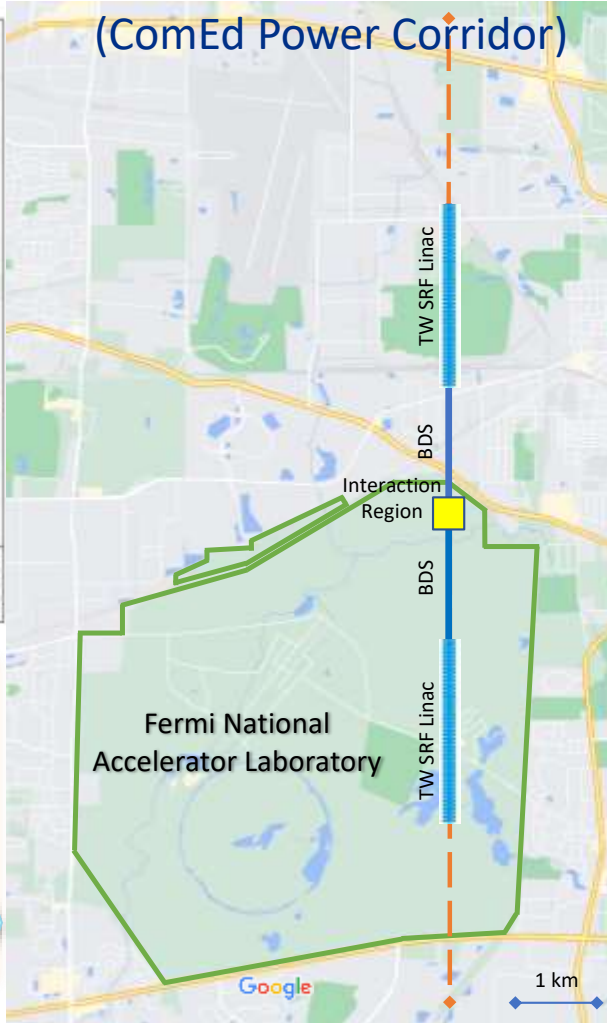
16 km Ring



7 km Linear



12 km Linear  
(ComEd Power Corridor)



**240 GeV cme e+e- ring**  
**6-10 TeV cme muon collider**  
**24 TeV pp collider**

**250 GeV cme e+e- linear**  
**C<sup>3</sup> and HELEN colliders**  
**upto ~550 GeV if outside**

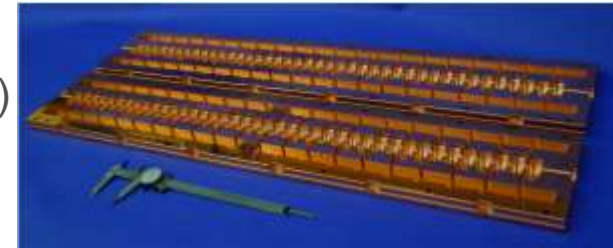
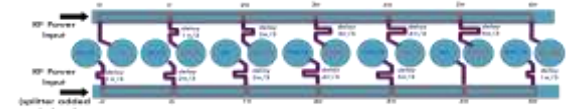




# Collider Options, Technologies and Challenges

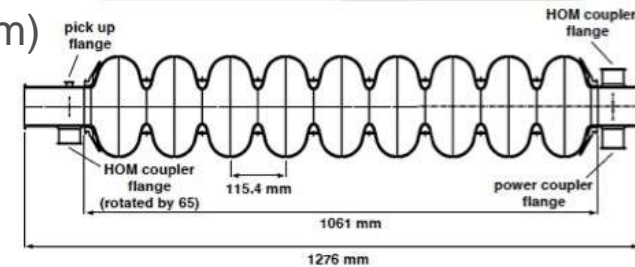
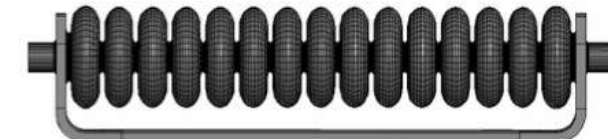
- **C<sup>3</sup>: Cool Copper Collider**

- 72-150 MV/m, 5.7 GHz, 77K copper structures
  - Advance beyond NLC (65MV/m) and CLIC (100MV/m)
  - Needs R&D and viability demonstration
  - Needs complete and self-consistent design



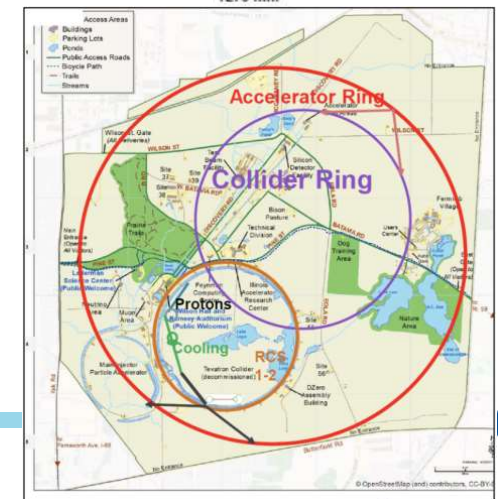
- **HELEN: High Energy LEptoN collider**

- 70 MV/m, 1.3 GHz, 2 K Nb structures (Nb<sub>3</sub>Sn?)
  - Advance beyond XFEL (28 MV/m) and ILC (31.5MV/m)
  - Needs R&D and viability demonstration
  - Needs complete and self-consistent design



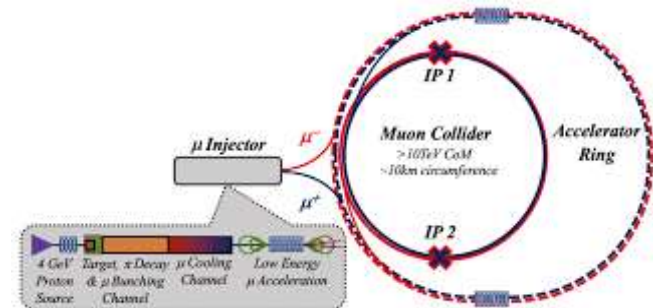
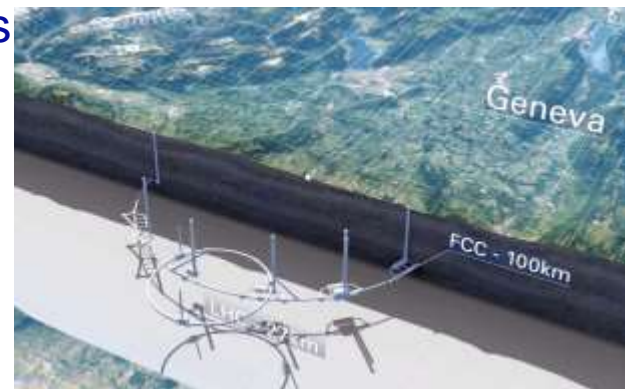
- **Muon Collider** (see more in Panel 2)

- 3...6...10...14 TeV cme, discovery and precision
  - Based on existing technologies (RF, magnets, targets) and beam physics, but pushes the envelope
  - Needs R&D and viability demonstration
  - Needs complete and self-consistent design
  - Longer term R&D in stages (“first decade”, next one)



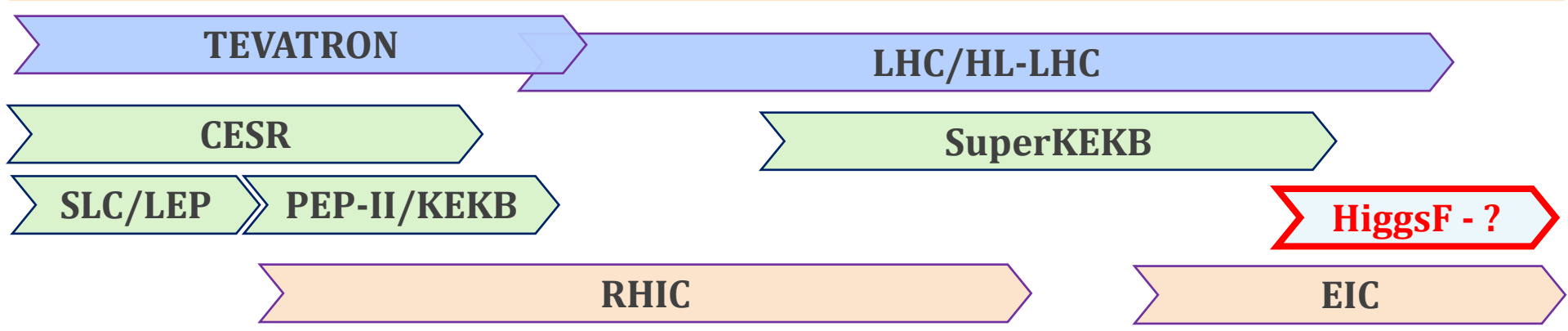
# U.S. Engagement in Global Projects

- International Linear Collider (ILC)
  - U.S. scientists engaged in efforts of the GDE, TDR, and ILC-IDT (ILC International Development Team)
    - SRF R&D for ILC main linacs, other areas
    - Polarized positron source and damping ring, ...
- Future Circular Colliders (FCC)
  - CERN conducting FCCee and magnets studies plus financial feasibility; Feasibility Study Report in 2025
  - CERN/DOE agreement signed in Dec. 2020
    - Opportunities for engineering design studies, beam physics studies, High  $Q_0$  SRF R&D, magnet R&D,..
- Muon Collider Collaboration (IMCC)
  - Intense work in progress in the International Muon Collider Collaboration; US community engaged
    - Machine scenarios, beam induced background, neutrino radiation, demonstrator facility, detector/physics studies
    - US community ready to engage - exploring formal U.S. engagement (3 Universities are in, talks w. DOE)



1987	1992	2002	2007	2012	2017	2022	2027	2032	2037	2042
------	------	------	------	------	------	------	------	------	------	------

**Collider Facilities**



**Design Work and Project R&D (in the US, elsewhere)**

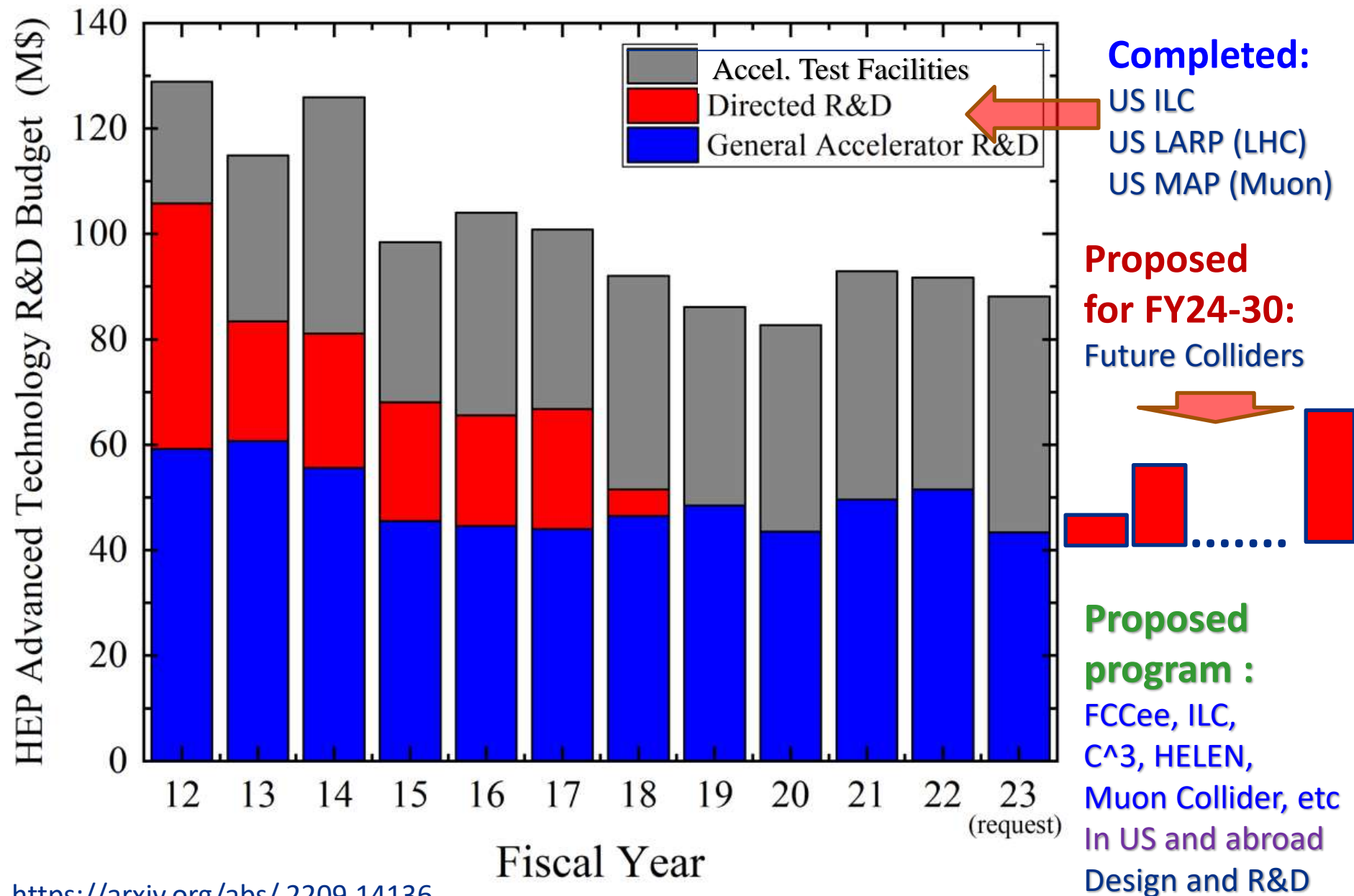


**“General” Accelerator R&D and Accelerator and Beam Physics**

- High Field Magnets:** NbTi, superferric, Nb<sub>3</sub>Sn, HTS, fast cycling, 40 T solenoids...
- RF Systems :** NC RF S- to X-band, klystrons, SRF L-band, cool copper, ...
- Targets and Sources :** 0.1-few MW, e- and e+ polarized, ...
- Plasma and Wake-fields :** laser, beam, dielectric THz, ...



# Gap in R&D Towards Future Colliders





# A National Future Collider R&D Program

Supported by the *Snowmass'21* AF

P.Bhat, et al, <https://arxiv.org/abs/2207.06213>  
S.Gourlay, et al, <https://arxiv.org/abs/2209.14136>

- The U.S. HEP **accelerator R&D program currently has no support** for development of collider concepts for strategic planning.
  - **Compromises U.S. leadership**
- An **integrated national R&D program on future colliders** is proposed to address this shortcoming in the U.S. accelerator R&D.
- The overarching objective: address in an **integrated fashion** the technical challenges of promising future collider concepts, particularly those aspects of accelerator design, technology, and beam physics that are not covered by the existing General Accelerator R&D (GARD) program.
- The goal is to inform decisions in down-selecting among the Higgs/EW factories and 10+ TeV scale collider concepts by the next European strategy update and the **next US community planning cycle**. The program will:
  - develop collider concepts and proposals for **options feasible to be hosted in the U.S. (e.g., CCC, HELEN, Muon Collider, etc)**
  - enable synergistic U.S. engagement in **ongoing global efforts (e.g., FCC, ILC, IMCC)**

# Future Colliders R&D Program

P.Bhat, et al, <https://arxiv.org/abs/2207.06213>

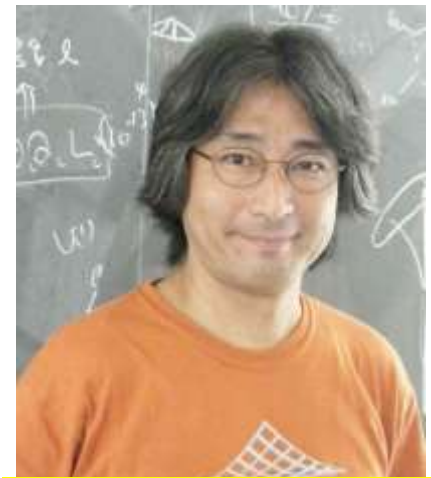
- **Organization:**
  - Coherent national program
  - Collaborative effort of U.S. national labs and universities
- **Coordination:**
  - Centrally coordinated and funded
  - Coordinated with global design studies and R&D
  - Periodic assessment
- **Support:**
  - An impactful program might require an average annual investment of \$25M (minimum) or more between now and the next Snowmass/P5 cycle.
- **Important:** this program will also ensure the critical recruitment, development, and retention of a skilled workforce in accelerator science and technology

# Future Colliders R&D Program: Synergies

- Present GARD thrusts (and **synergies**):
  - Accelerator and Beam Physics
    - Integrated machine design, codes, instrumentation and controls, beam facilities
  - Superconducting magnets and materials (MDP)
    - High-field SC magnets, advanced SC materials, test facilities, ...
  - RF Acceleration Technology
    - High performance NC and RF cavities, RF sources, test facilities, ...
  - Particle Sources and Targets
    - Multi-MW targets, positron sources, test facilities ...
  - Advanced Acceleration Methods
    - Wakefield modeling & simulation tools
- Non-HEP synergies (see **Sarah C. talk**):
  - Technologies and expertise from BES, NP, ARDAP, NSF...
- International partners (see **Lenny R. talk**):
  - Coordination with future collider activities abroad is a must !
  - Tons of expertise and support for FCCee, ILC, MuColl, technologies...

# ...and Now It's All to P5

- Chaired by Hitoshi Murayama
- Web site: <http://hitoshi.berkeley.edu/P5/>
- Charge
- Composition: 29 total, 4 from accelerators



Hitoshi Murayama



Cameron Geddes



Mark Palmer



Tor Raubenheimer



Bob Zwaska

- **Four “Town Halls”, including:**
  - April 12-14, 2023 : NBL, *Energy Frontier, Instrumentation*
  - May 3-5, 2023 : SLAC, *Accelerators*
  - Early Career (virtual) townhalls: weeks of May 15, June 5 and June 26



# P5 boundary conditions:

- **P5 Charge calls for** “...an updated strategic plan for U.S. high-energy physics that can be executed over a 10-year timeframe in the context of a 20-year, globally aware strategy for the field.”

- **HEP budget (FY23 request 1,122M\$) guidance for P5:**

“...FY 2024–FY 2033 budget scenarios:

1) increases of 2.0 percent per year during fiscal years 2024 to 2033 with the FY 2024 level calculated from the FY 2023 President’s Budget Request for HEP.

2) budget levels for HEP for FY 2023 to 2027 specified in the Creating Helpful Incentives to Produce Semiconductors and Science Act of 2022, followed by increases of 3.0 percent per year from FY 2028 to FY 2033.”

- **Submit P5 preliminary comments by August 2023 and a final report by October 2023.**

# What can we do (to help P5):

- Support the *Future Colliders R&D Program* proposal:
  - aka “US Initiative for the Targeted Development of Future Colliders and their Detectors”
- Develop high level R&D plans (goals, deliverables, timeline, resources), possibly under two scenarios (like Europeans)
  - Aspirational
  - Minimal
  - Taking into account the US and International landscapes
- Many opportunities:
  - **This C<sup>3</sup> Workshop**
  - **Muon Collider School/Meeting Feb.27-Mar 10 at KITP/SLAC**
  - **FCC in the US Workshop at April 24-26, BNL**
  - **LCWS (International Linear Collider Workshop) May 15-19 at SLAC**
- Coordinate all the plans/inputs, “speak one voice”:
  - Anticipate the P5 “Accelerator Quartet” to be instrumental, others can help

# Summary:

- The U.S. has a rich history in particle accelerators and colliders, which enabled major discoveries in particle physics and establishing of the Standard Model.
  - Lost energy frontier leadership to Europe in 2009 (LHC)
- Future colliders are an essential component of strategic vision for particle physics. Currently, EF focus on:
  - (shorter term) Higgs/EW factories ( $e^+e^-$ )
  - (longer term) 10+ TeV scale TeV ( $pp$ ,  $\mu\mu$ )
- To ensure continued progress, U.S. leadership is critical
  - Develop compact, cost-effective options for hosting future colliders at home
  - Needs to be a key partner in developing next generation colliders abroad
- “Snowmass’21”:
  - Pointed out a lack of collider expertise in the US and a gap in our R&D portfolio
  - Proposed to set up an **integrated US Future Collider R&D Program**

# Back up slides