Snowmass 2021

Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

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

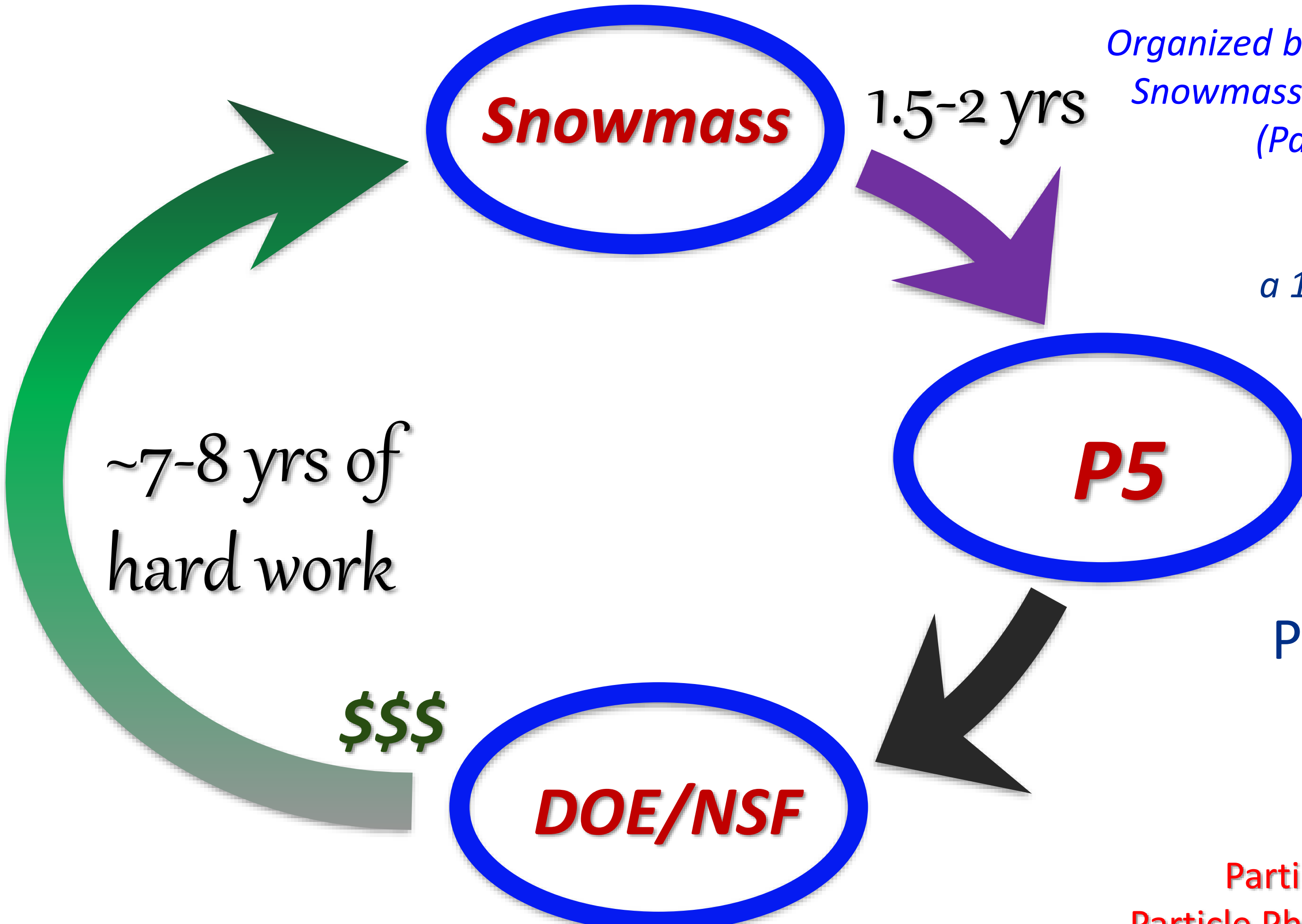
1. Snowmass'21 – Accelerator Frontier

2. National Future Collider R&D program

3. P5 and our challenge

Snowmass'21

"a particle physics community strategic planning study"



Organized by APS DPF, DPB, et al
Snowmass provides input to P5 (Particle Physics Project Prioritization Panel) which develops a 10-20 yrs strategy for the US HEP program

~ 1 yr

Particle Physics Project Prioritization Panel

Particle Physics is global
Particle Physics is not isolated

https://www.snowmass21.org/

Snowmass'21 Accelerator Frontier Conveners

Snowmass 2021

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…

Snowmass 2021

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 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. Shiltsev

(Top Level) Snowmass Summary

Snowmass 2021

arxiv:2301.06581

Science Drivers (6 pages)

(Brief) Frontier Summaries (~40 pages)

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

High-Level Conclusions (4 pages)

SLAC-PUB-17717
January 2023

Report of the 2021 U.S. Community Study
on the Future of Particle Physics
(Snowmass 2021)

Summary Chapter

2021 – 2022 Snowmass Steering Group

Snowmass 2021 Frontier Conveners:

Editor: Michael E. Peskin

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

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

Frontier Conveners: S. Gourlay[1], T. Raubenheimer[2], V. Shiltsev[3]

Topical Group Conveners: G. Arduini[4], R. Assmann[5], C. Barbier[6], M. Bai[2], S. Belomestnykh[3], S. Bermudez[4], A. Faus-Golfe[7], J. Galambos[6], C. Geddes[1], G. Hoffstaetter[8], M. Hogan[2], Z. Huang[2], M. Lamont[4], D. Li[1], S. Lund[9], R. Milner[10], P. Musumeci[11], E. Nanni[2], M. Palmer[12], N. Pastrone[13], F. Pellemoine[3], E. Prebys[14], Q. Qin[15], G. Sabbi[1], Y.-E. Sun[16], J. Tang[17], A. Valishev[3], H. Weise[5], F. Zimmermann[4], A.V. Zlobin[3], R. Zwaska[3]

Contributors: P. Bhat[3], J. Power[16], T. Roser[12], D. Stratakis[3]

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https://arxiv.org/abs/2209.14136

Snowmass 2021

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

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

July 14, 2022

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

P.C. Bhat[1,†], S. Belomestnykh[1,5], A. Bross[1], S. Dasu[6], D. Denisov[4], S. Gourlay[7], S. Jindariani[1], A.J. Lankford[8,†], S. Nagaitsev[1,2,†], E.A. Nanni[3], M.A. Palmer[4], T. Raubenheimer[3], V. Shiltsev[1], A. Valishev[1], C. Vernieri[3], F. Zimmermann[9]

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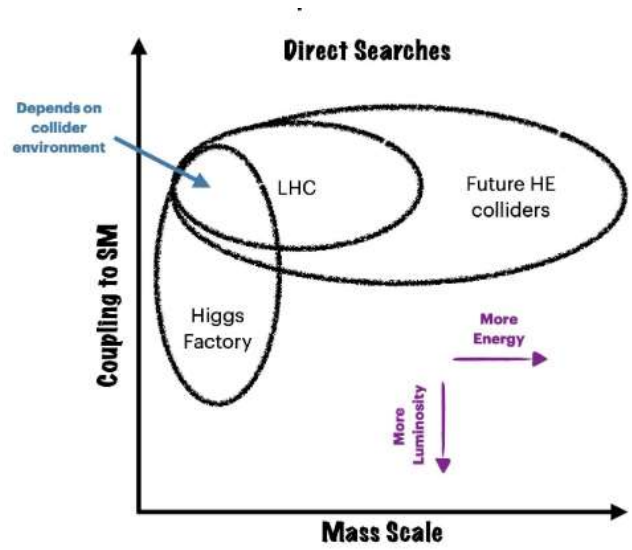
https://arxiv.org/abs/2207.06213

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 **~10 TeV scale**.
  - FCC-hh, SppC, ~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 (8
  - Lepton and hh colliders 10
  - eh colliders (3 opti
- ITF addres   s):
  - Phys   arameters
  - Size, c   , environment
  - Technic   adiness, 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)


nheimer (SLAC)


Katsunobu Oide (KEK)


Jim Strait (FNAL)


Vladimir Shiltsev (FNAL)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REPORT


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Marlene Turner (LBNL)


Spencer Gessner (SLAC)

See also T.Roser talk in Panel 2

ITF's Evaluations: Higgs Factories & Multi-TeV

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

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

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^3	HELEN	CLIC	ILC‡	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†	0†	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} cm^{-2}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 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

240 GeV cme e+e- ring

6-10 TeV cme muon collider

24 TeV pp collider

7 km Linear

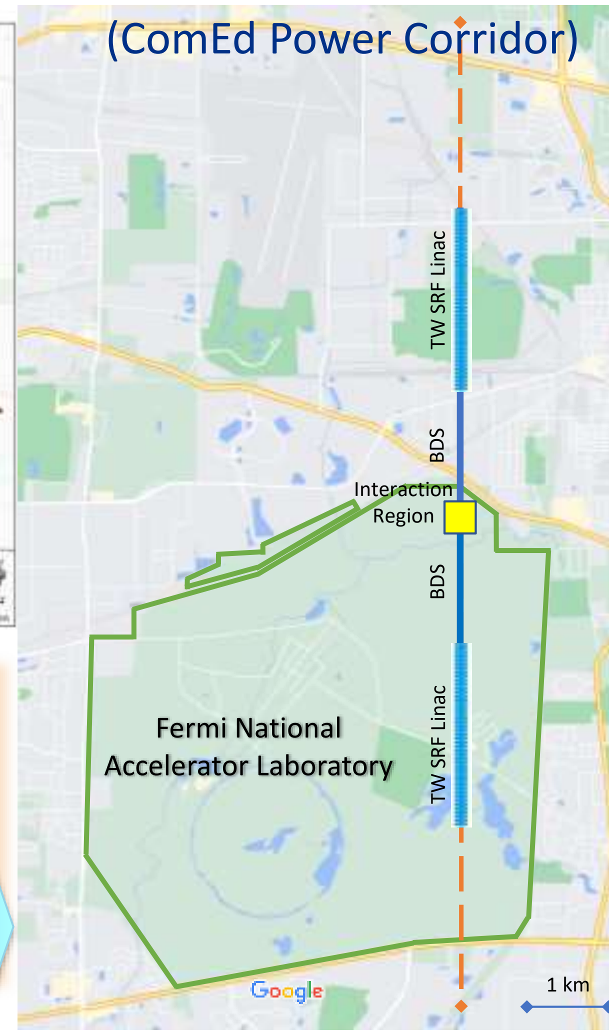
250 GeV cme e+e- linear

C^3 and HELEN colliders

upto ~550 GeV if outside

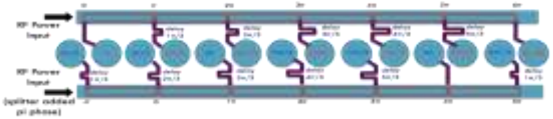
12 km Linear

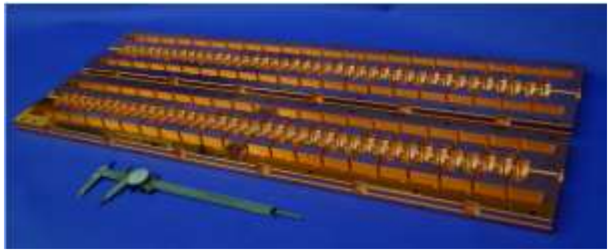
(ComEd Power Corridor)

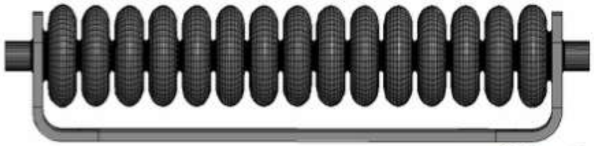


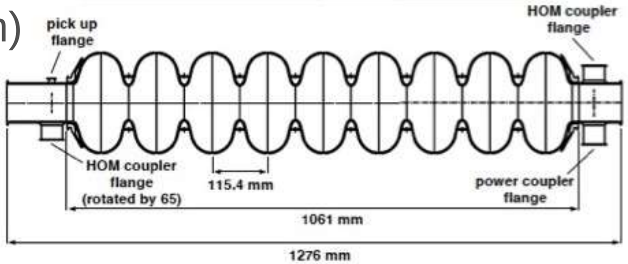
Collider Options, Technologies and Challenges

- C^3: 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 (Nb3Sn?)
    - 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)

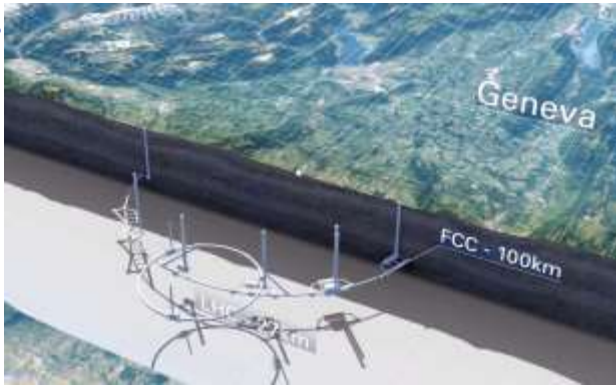




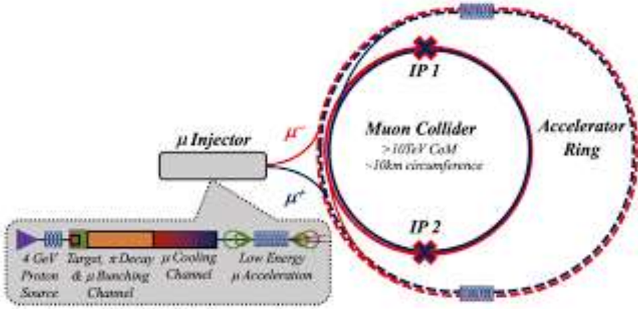


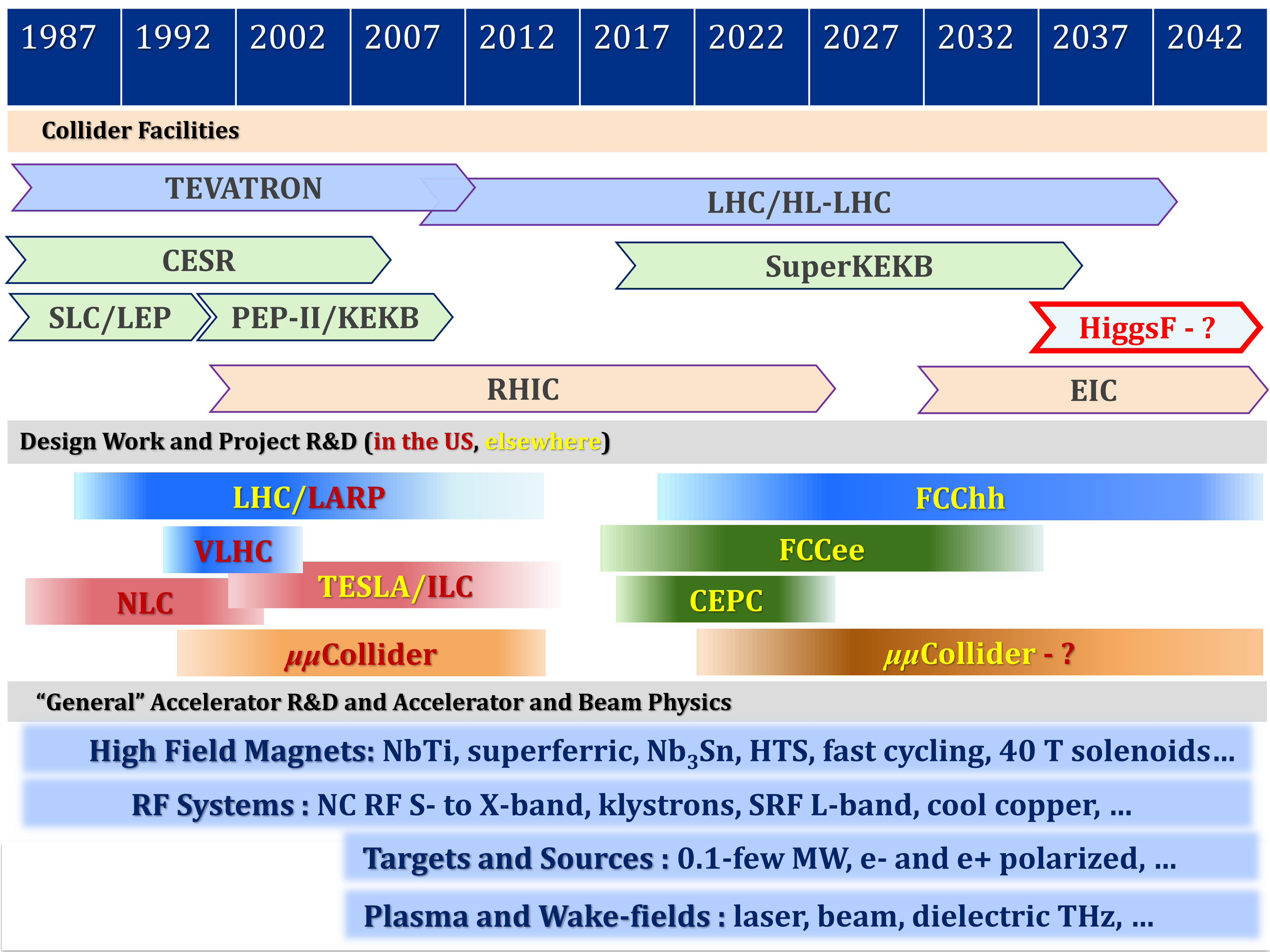


U.S. Engagement in Global Projects

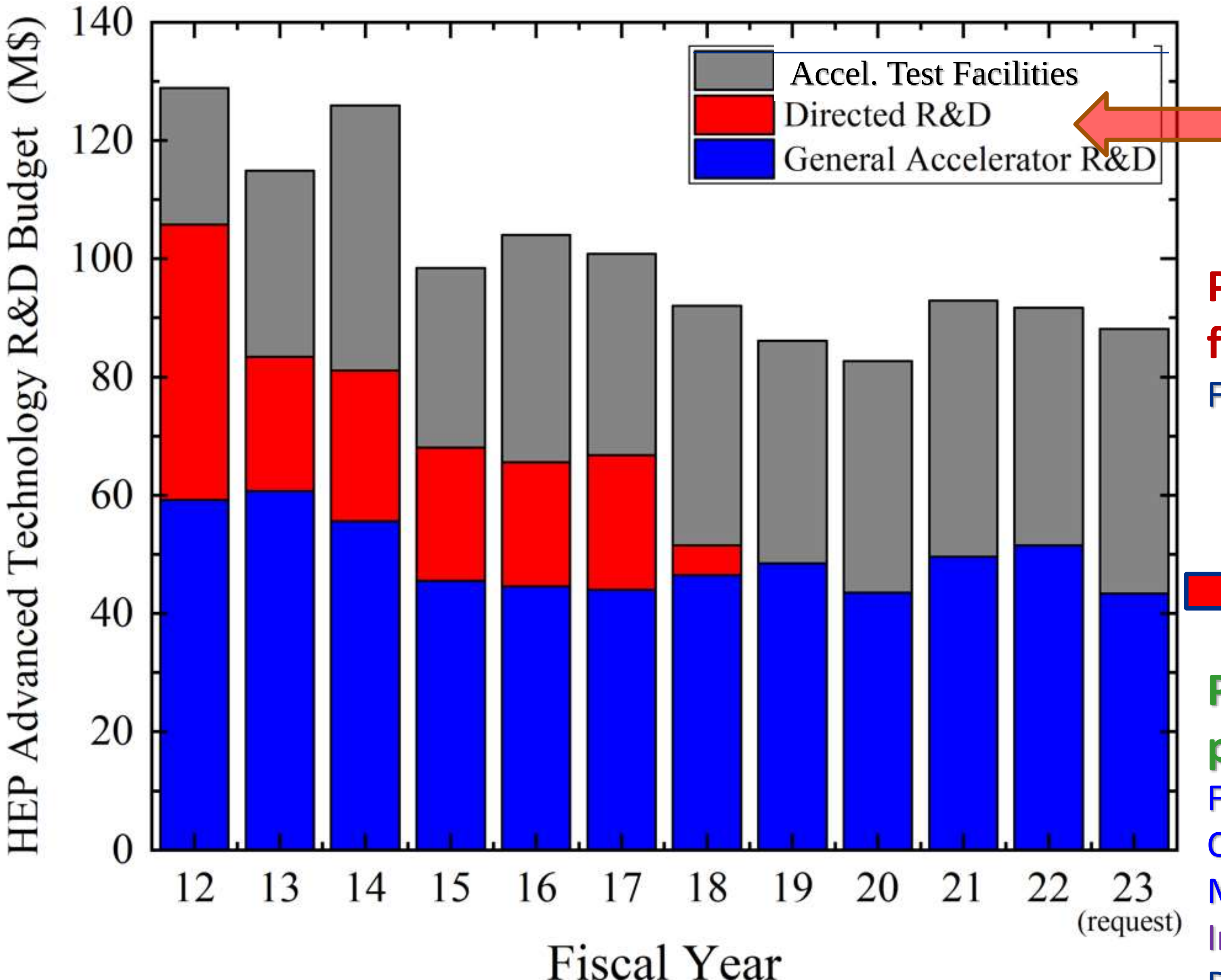


- International Linear Collider (ILC)
  - U.S. scientists engaged in efforts of the GDE, TDR, and ILC-IDT (ILC International Development Team)
    - SRF R&D for ILC main linacs, other areas
    - Polarized positron source and damping ring, …
- Future Circular Colliders (FCC)
  - CERN conducting FCCee 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)



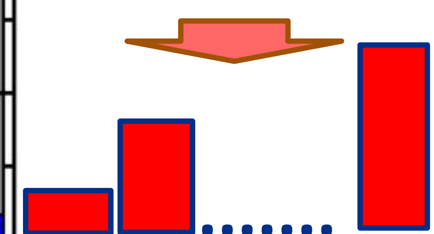

1987
1992
2002
2007
2012
2017
2022
2027
2032
2037
2042
Collider Facilities
TEVATRON
LHC/HL-LHC
CESR
SuperKEKB
SLC/LEP
PEP-II/KEKB
HiggsF - ?
RHIC
EIC
Design Work and Project R&D (in the US, elsewhere)
LHC/LARP
FCChh
VLHC
FCCee
TESLA/ILC
NLC
CEPC
μμCollider
μμCollider - ?
"General" Accelerator R&D and Accelerator and Beam Physics
High Field Magnets: NbTi, superferric, Nb3Sn, 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



Completed:
US ILC
US LARP (LHC)
US MAP (Muon)

Proposed for FY24-30:
Future Colliders



Proposed program :
FCCee, ILC,
C^3, HELEN,
Muon Collider, etc
In US and abroad
Design and R&D

https://arxiv.org/abs/ 2209.14136

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

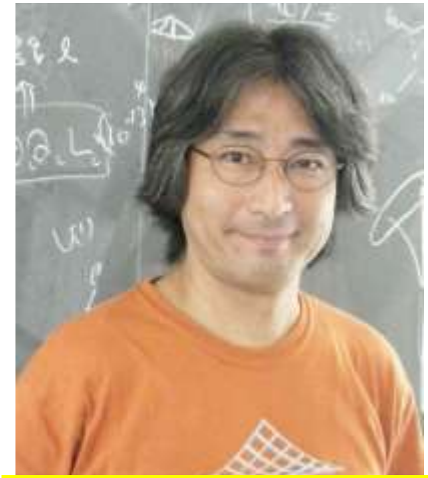
- Organization:
  - Coherent national program
  - Collaborative effort of U.S. national labs and universities
- Coordination:
  - Centrally coordinated and funded
  - Coordinated with global design studies and R&D
  - Periodic assessment
- Support:
  - An impactful program might require an average annual 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^3 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, μμ)
- 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