Snowmass 2021

Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

National Future Collider R&D Program: Scope and Drivers

Vladimir SHILTSEV (Fermilab)

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

NAS EPP-24 Meeting #4, December 13, 2022

This presentation is mostly based on the Snowmass *Accelerator Frontier Report* and the *Future Collider R&D Initiative* White Paper

Accelerator Frontier

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]

[1] *Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[2] *SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*
[3] *Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*
[4] *CERN, 1211 Meyrin, Switzerland*
[5] *Deutsches Elektronen-Synchrotron, 22607 Hamburg, Germany*
[6] *Oak Ridge National Laboratory, Oak Ridge, TN 37830, USA*
[7] *Université Paris-Saclay, CNRS/IN2P3, 91406 Orsay, France*
[8] *Cornell University, Ithaca, NY 14850, USA*
[9] *Michigan State University, East Lansing, MI 48824, USA*
[10] *MIT, Cambridge, MA 02139, USA*
[11] *UCLA, Los Angeles, CA 90095, USA*
[12] *Brookhaven National Laboratory, Upton, NY 11973, USA*
[13] *INFN Torino, 10127 Torino TO, Italy*
[14] *University of California, Davis, Davis, CA, 90095, USA*
[15] *ESRF, 38000 Grenoble, France*
[16] *Argonne National Laboratory, Lemont, IL 60439, USA*
[17] *IHEP, Bejing, 100039 China*

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)

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]

[1] Fermi National Accelerator Laboratory
[2] University of Chicago
[3] SLAC National Accelerator Laboratory
[4] Brookhaven National Laboratory
[5] Stony Brook University
[6] University of Wisconsin, Madison
[7] Lawrence Berkeley National Laboratory, Retired
[8] University of California, Irvine
[9] CERN

[†] Lead Contacts; Email: pushpa@fnal.gov, andrew.lankford@uci.edu, nsergei@fnal.gov

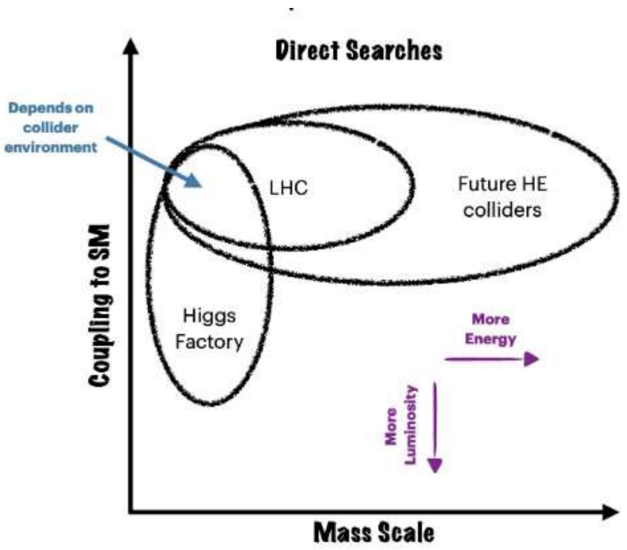
https://arxiv.org/abs/2207.06213

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**

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)


Phi


Steve Gourlay (LBNL)


nheimer (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)

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
CLIC-3	3	5.9	3-5	19-24	18-30	~550
ILC-3	3	6.1	5-10	19-24	18-30	~400
MC-3	3	2.3	>10	19-24	7-12	~230
MC-10-IMCC	10-14	20	>10	>25	12-18	*O*(300)
***pp* at FNAL**	24	3.5	>10	>25	18-30	~400
FCChh-100	100	30	>10	>25	30-50	~560

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

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

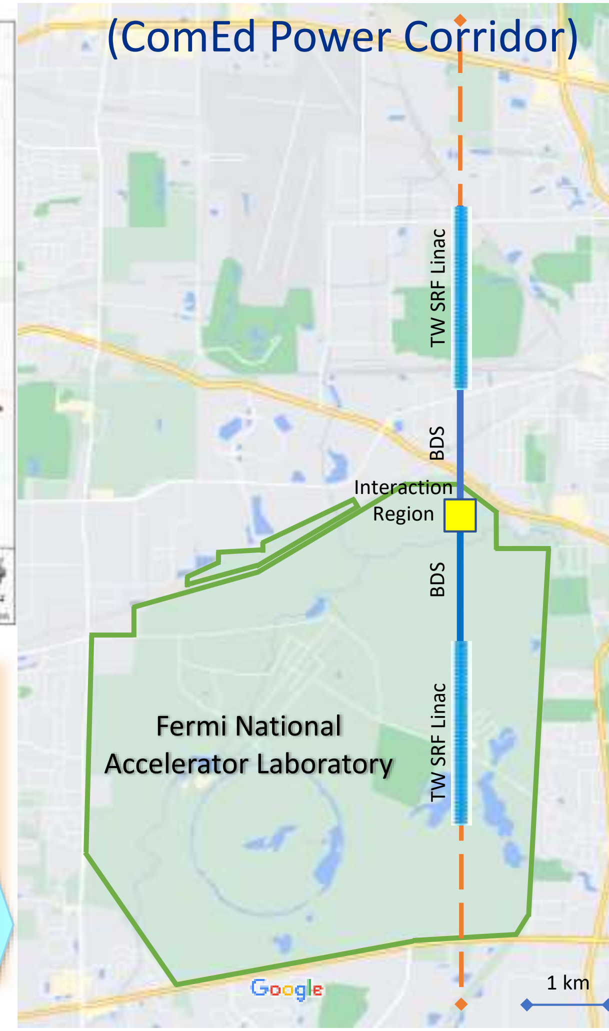
7 km Linear

250 GeV cme e+e- linear

C^3 and HELEN colliders

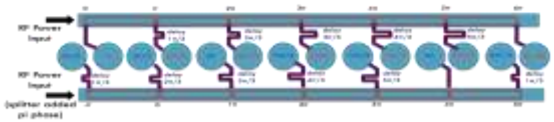
upto ~550 GeV if outside

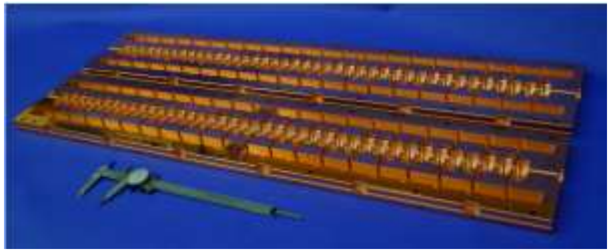
12 km Linear



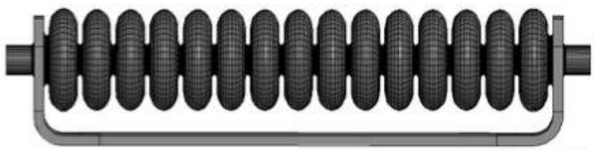
Collider Options, Technologies and Challenges

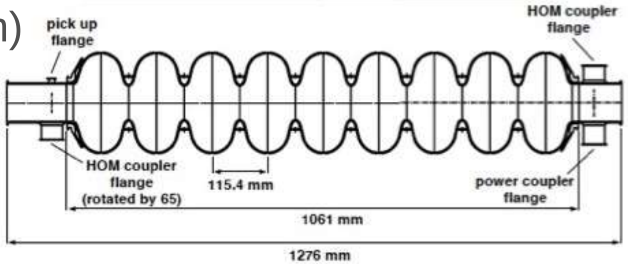
- C^3: Cool Copper Collider
  - 72-150 MV/m, 5.7 GHz, 77K copper structures
    - Advance beyond NLC (65MV/m) and CLIC (100MV/m)
    - Needs R&D and viability demonstration
    - Needs complete and self-consistent design





- 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

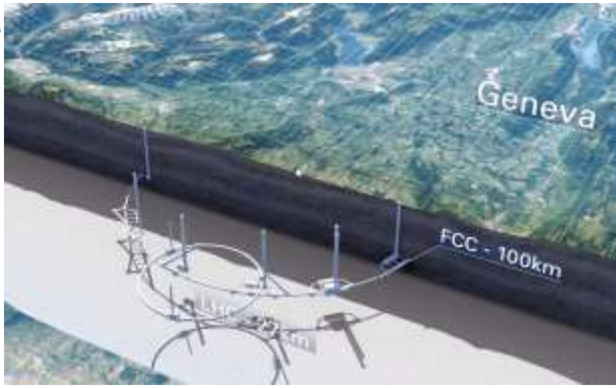


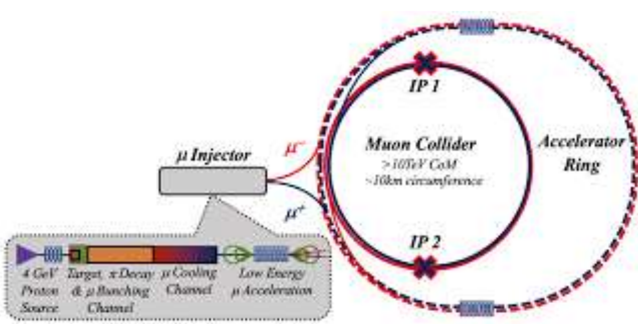


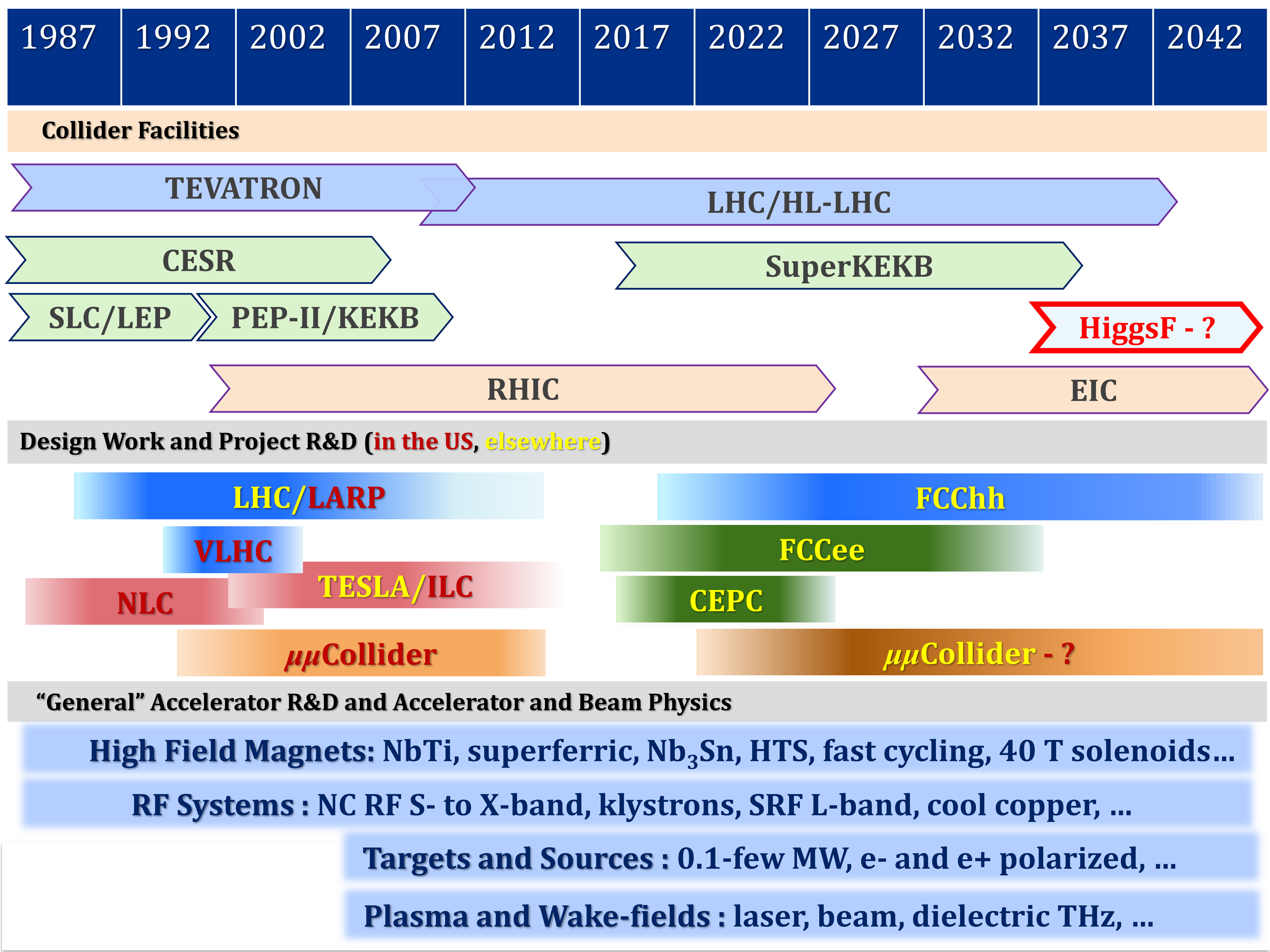
- Muon Collider (*see more in Panel 2*)
  - 3…6…10…14 TeV cme, discovery and precision
    - Based on existing technologies (RF, magnets, targets) and beam physics, but pushes the envelope
    - Needs R&D and viability demonstration
    - Needs complete and self-consistent design
    - Longer term R&D in stages ("first decade", next one)

U.S. Engagement in Global Projects

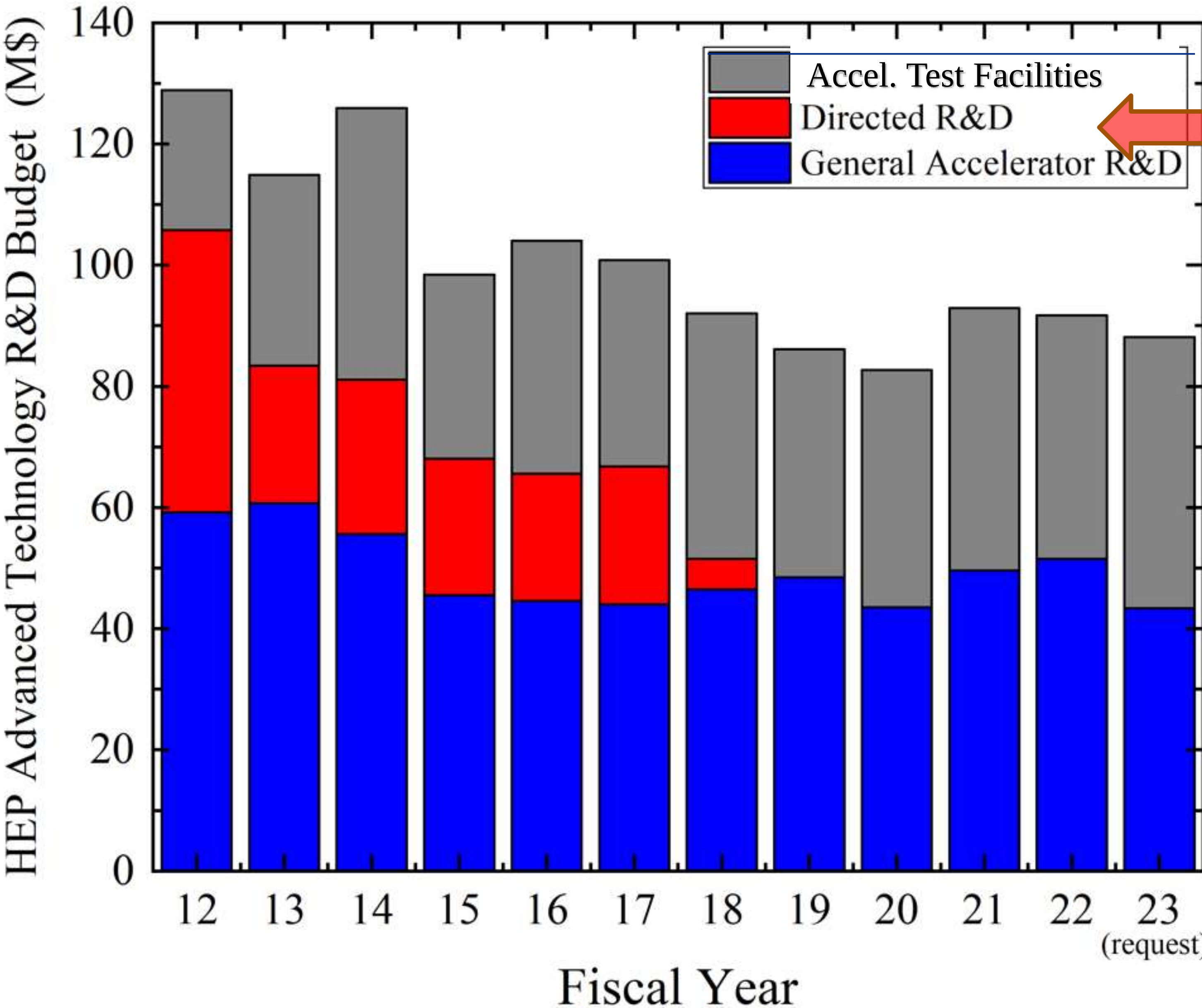
- International Linear Collider (ILC)
  - U.S. scientists engaged in efforts of the GDE, TDR, and ILC-IDT (ILC International Development Team)
    - SRF R&D for ILC main linacs, other areas
    - Polarized positron source and damping ring, …
- Future Circular Colliders (FCC)
  - CERN conducting FCCee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





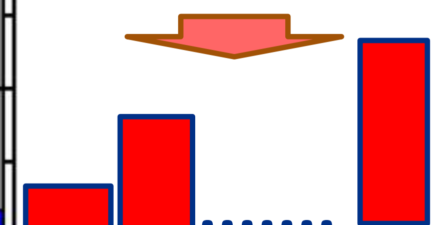

1987
1992
2002
2007
2012
2017
2022
2027
2032
2037
2042
Collider Facilities
TEVATRON
LHC/HL-LHC
CESR
SuperKEKB
SLC/LEP
PEP-II/KEKB
HiggsF - ?
RHIC
EIC
Design Work and Project R&D (in the US, elsewhere)
LHC/LARP
FCChh
VLHC
FCCee
TESLA/ILC
NLC
CEPC
μμCollider
μμCollider - ?
"General" Accelerator R&D and Accelerator and Beam Physics
High Field Magnets: NbTi, superferric, Nb_3Sn, 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…

Back up slides

Useful Resources (References):

1. Snowmass Accel. Frontier report – S.Gourlay et al, arxiv:2209.14136
2. Future Collider R&D WP – P.Bhat et al , arxiv:2207.06213
3. ITF Report – T.Roser, et al, arXiv:2208.06030
4. RMP “Colliders” – V.Shiltsev, F.Zimmermann, Rev.Mod.Phys. **93**, 015006 (2021)
5. Landscape of accelerators – V.Shiltsev, Physics Today **73**, 4, 32 (2020).
6. Ultimate colliders – V.Shiltsev, Proc. IPAC’21, WEPAB017 (2021).