Impressions from Snowmass

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CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

Outline

The Snowmass process

- A bottom-up, community-wide effort:
  - Given all interesting particle physics projects, how do we, the community prioritise?
- Re-iterated every $\sim$ 5 years.
- Distilled down to a summary that is given to the “Particle Physics Project Prioritization Panel” aka P5, a sub-panel to the High Energy Physics Advisory Panel (HEPAP).
- P5 has a broad mandate but tends to focus on large projects and facilities, and presents the priorities given several funding scenaria.
- The P5 report is written under interactions with the Department Of Energy (DoE), and is finally delivered to them by HEPAP.
- The actual decision is made by congress...

The Snowmass process

- The Snowmass Community Planning process itself is organised by:
  - The Division of Particles and Fields (DPF) of the American Physical Society (APS)
- Organised in ten “frontiers” - both project-defining ones (“Why?”), and enablers (“How?”).
- Each frontiers self-organises into several topical groups.
- The topical groups have been meeting over the last two years.
- Now it’s time to wrap up, producing the final reports. That’s what happened at University of Washington in Seattle, July 17 to 26 (with no breaks ...)

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The Snowmass process: The frontiers

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

7/17/22 Snowmass Greeting, July 17, JB 21

The Snowmass process: What DoE offers

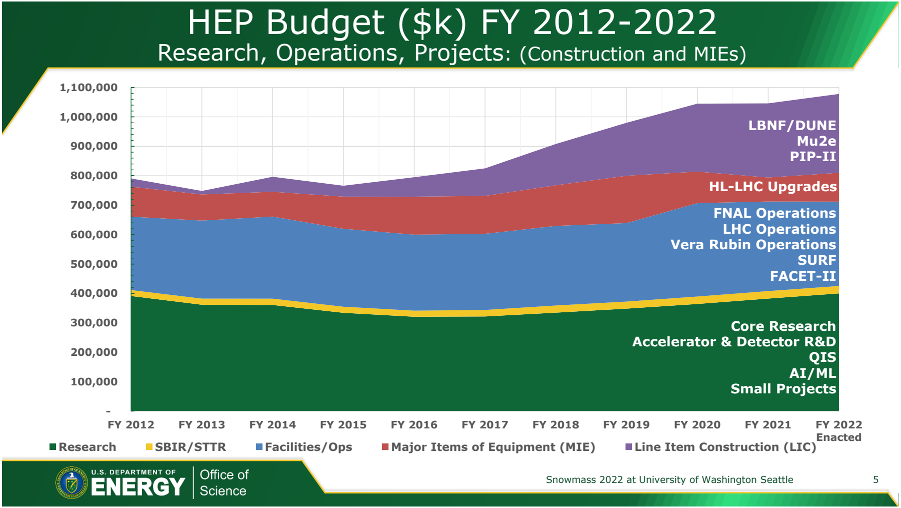
FY 2022/23 HEP Budget Highlights

HEP Budget ($ in K)	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Enacted	FY 2023 Request	FY 2023 House Mark
HEP Research*	814,000	794,000	810,000	824,020	860,000
Line-Item Construction	231,000	252,000	268,000	298,000	298,000
HEP Total	**1,045,000**	**1,046,000**	**1,078,000**	**1,122,020**	**1,158,000**

** HEP Research includes MIEs and Operations*

- High priority areas for **core HEP research** include theoretical and experimental activities in pursuit of discovery science; fostering a diverse, highly skilled workforce; building R&D capacity; driving technology innovation; and conducting world-leading advanced technology R&D
- HEP supports **SC-wide research initiatives**:
  - QIS, AI/ML, Microelectronics, Integrated Computational and Data Infrastructure, Accelerator Science and Technology, Reaching a New Energy Sciences Workforce (RENEW), Accelerate Innovations in Emerging Technologies (Accelerate), and Funding for Accelerated, Inclusive Research (FAIR)
- Facilities support includes operations of **Fermilab Accelerator Complex** and **FACET-II**, infrastructure improvements at SURF
- HEP supports **LBNF/DUNE**, **PIP-II** and **Mu2e** Line-Item Construction projects and **HL-LHC Accelerator**, **ATLAS**, and **CMS** upgrade projects, **ACORN**, and **CMB-S4** Major Item of Equipment (MIE) projects
- HEP supports laboratory-based accelerator and detector test facilities and supports the maintenance and operations of large-scale experiments and facilities that are not based at a DOE National Laboratory, including: **ATLAS** and **CMS** at the LHC; **SURF** and the **LZ** experiment; **Vera C. Rubin Observatory**; **DESI**; experiments in Canada, Japan, and on the International Space Station

The Snowmass process: What DoE offers

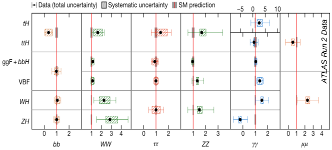


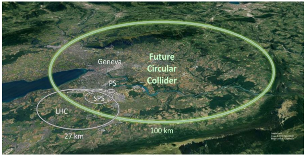
The Snowmass process: What DoE says about FCs

Energy Frontier: LHC/HL-LHC & Future Colliders

- LHC at CERN is the centerpiece of the U.S. Energy Frontier program and an integral component of the DOE-HEP program
- CMS and ATLAS continue to drive physics results in HEP, together achieving today over 2,200 publications since the start of LHC running in 2009
  - Recently at the 10th anniversary of the Higgs discovery, published comprehensive measurements of the Higgs in journal *Nature*
  - More results anticipated during Run 3, started on July 5th with the highest energy particle collisions in the world at 13.6 TeV
- HL-LHC accelerator and detector upgrades progressing well
  - CMS and ATLAS baseline DOE CD-2 reviews planned for this fall
- To advance proposed future colliders, DOE plans to continue coordinating with the U.S. State Department and OSTP
  - Collaborating with CERN and our global partners in the feasibility study for a Future Circular Collider (FCC)
  - Coordinating with the International Linear Collider (ILC) International Development Team on the next phase of a potential ILC in Japan
- Look forward to Snowmass's input for the science reach and ambitions of all proposed future colliders

Observed Rate to Predicted SM Event Rate for Different Higgs Production and Decay Processes





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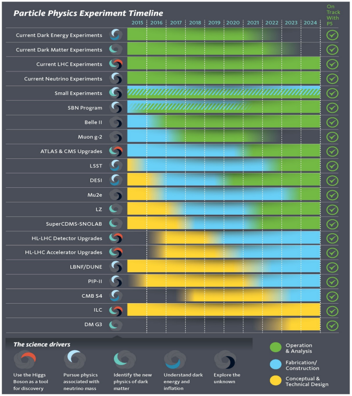
Snowmass 2022 at University of Washington Seattle 9

The Snowmass process: Does it deliver?

P5 Plan in 2022: 8 yrs into the Plan



P5 projects report card

8 Projects have been completed (and transitioned to commissioning & operations)

- Belle-2, Muon g-2, Phase I ATLAS, Phase I CMS
- CD-4 in 2020: DESI and LZ
- CD-4 in 2021: FACET-II and LSSTCamera

4 Projects at CD-2/3 (Baseline/Construction)

- HL-AUP, Mu2e, PIP-II, Super-CDMS

3 Projects at CD-1 (preparing for baseline)

- HL-ATLAS, HL-CMS, LBNF/DUNE

1 Project at CD-0

- CMB-S4

Broad portfolio of small projects from R&D phase to operations

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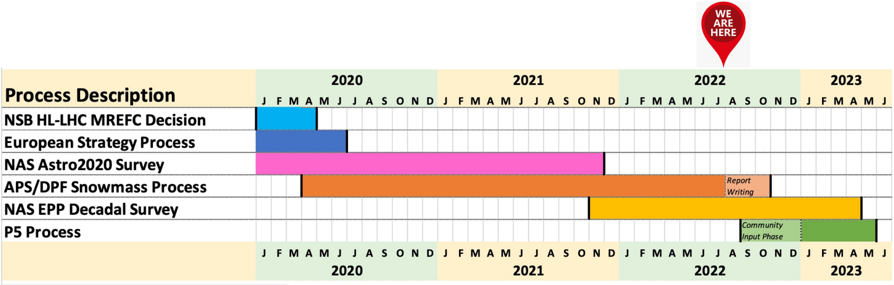
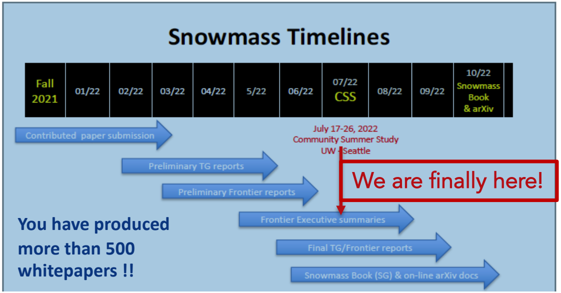
The Snowmass process: Time-line

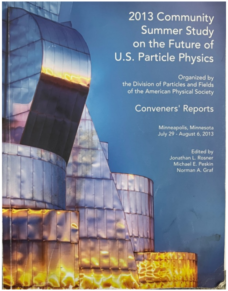
2020's U.S. Strategic Planning Timeline



There are a lot of moving parts and pieces! 9

The Snowmass process: Time-line





- **March 15: Contributed papers (a.k.a. White Papers)**
- May 31: Preliminary Topical Group Reports
- June 30: Preliminary Frontier Reports
- **July 17 – 26: Converge on reports for all the frontiers and produce executive summaries representing the views of their communities and providing the basic input needed for P5**
- September: draft Executive Summary and Report Summary
- October- November: Snowmass Book finalized and ready for submission

- Cover from Snowmass 2013 report, ~ 350 pages
- The new report will be ~500 pages
- All Contributed Papers will remain part of the permanent record of Snowmass

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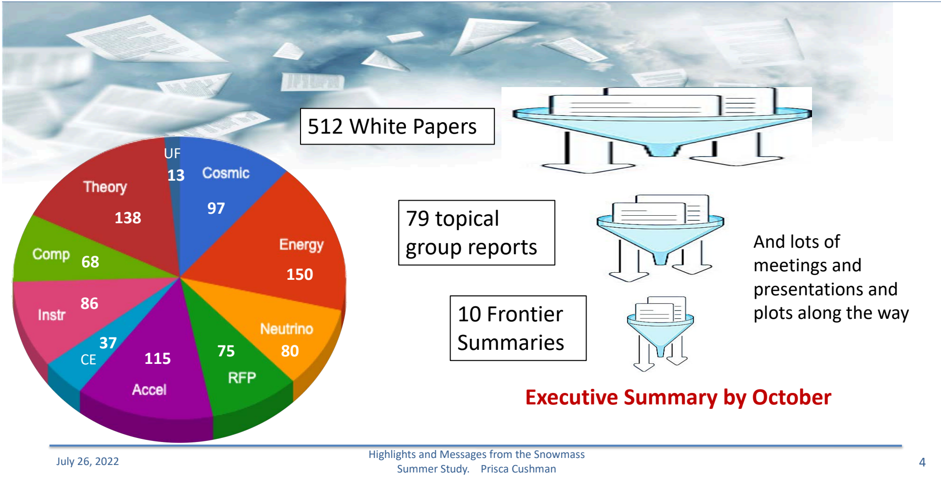
The Snowmass process: Getting there



The Snowmass process: Summarising that ....

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- Will touch on the uptake from the main “Why ?” frontiers:
  - The Neutrino Frontier
  - The Cosmic Frontier
- ... and mainly on “our” Frontier
  - The Energy Frontier
- I won’t talk about the “How?” frontiers (Instrumentation, Accelerator, Computing, ...), sorry. Will be discussed in the talks at FC@DESY on Sept 2.

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The Neutrino Frontier

The science drivers for NF

- What are the neutrino masses?
- Are neutrinos their own antiparticles?

Nuclear Physics funded, small and medium sized

- How are the masses ordered?
- What is the origin of neutrino mass and flavor?
- Do neutrinos and antineutrinos oscillate differently?
- Discovering new particles and interactions
- Neutrinos as messengers

DUNE phase I, large, end of construction by 2030

DUNE phase II, two medium sized detector upgrades a large accelerator upgrade, construction from 2030-2040

Many other projects, most have a small US HEP contribution

The Neutrino Frontier: Main message: LBNF & DUNE

A future program with a healthy breadth and balance of physics topics, experiment sizes, and timescales, supported via a dedicated, deliberate, and ongoing funding process, is highly desirable.

Completion of existing experiments and execution of DUNE in its full scope are critical for addressing the NF science drivers. Both Phase I and Phase II are part of the original DUNE design endorsed by the last P5. DUNE Phase I will be built in the current decade and DUNE Phase II (2 additional FD modules, more capable ND, and use of the 2.4 MW beam power from the FNAL accelerator upgrade) is the priority for the 2030s.

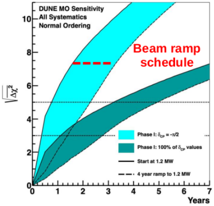
Existing technologies enable the original DUNE physics program for both Phase I and Phase II. However each piece of DUNE Phase II offers broader physics opportunities than originally envisioned. **To exploit these new opportunities directed R&D needs to be supported.**

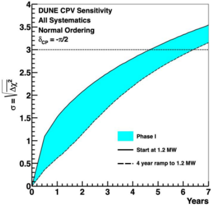
Strong and continued support for neutrino theory is needed.

There are unique opportunities for NF to contribute to leadership of a cohesive, HEP-wide strategic approach to DEI and community engagement, which is urgently needed.

The Neutrino Frontier: Main message: LBNF & DUNE

DUNE staging





Phase I: Construction ends around ~2030

✔ Unambiguous MO

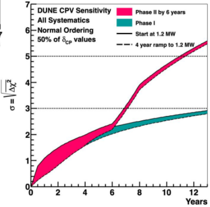
✔ 3σ CPV at maximal δ_{CP}

Phase II:

✔ P5 goal of 5σ CPV for 50% of δ_{CP}

✔ Precision δ_{CP}, Δm^2_{32}, θ_{23}, θ_{13}

Requires 2.4 MW, 40 kt and full ND

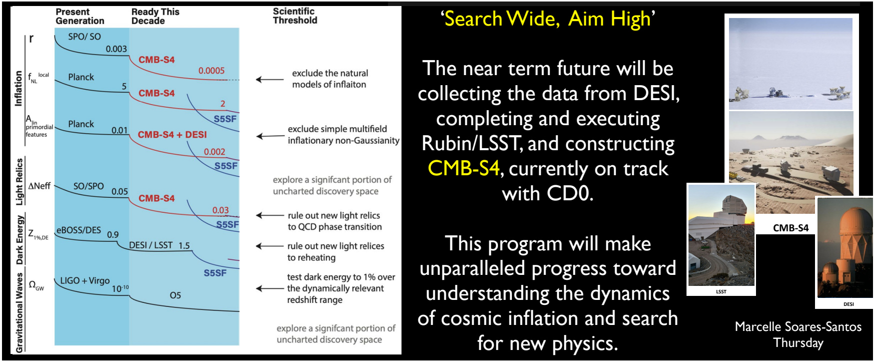


Construction should start around ~2030:

FD mass
ND upgrade
Beam upgrade

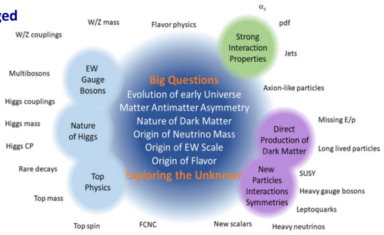
Figures from SNOWMASS neutrino colloquium by C. Wilkinson

The Cosmic Frontier



The Energy Frontier

- **Compared to Snowmass 2013 the physics landscape has significantly changed**
  - The program of measuring the Higgs boson properties is well underway at the LHC with growing precision
  - A broad range of searches have explored multiple BSM scenarios without convincing evidence of new physics
  - The HL-LHC is an approved project
- **Without a robust support for the HL-LHC and a clearly defined path towards a Higgs factory we leave critically important physics unchecked and crucial questions unanswered**
- **The EF community should be prepared to explore a broad range of BSM phenomena at the 10 TeV mass scale**



The Energy Frontier community voices a strong support for

1. **HL-LHC operations and 3 ab^{-1} physics program, including auxiliary experiments**
2. **The fastest path towards an e^+e^- Higgs factory (linear or circular) in a global partnership**
3. **A vigorous R&D program for a multi-TeV collider (hadron or muon collider)**

The Energy Frontier: Studied projects

Higgs-boson factories (up to 1 TeV c.o.m. energy)

Collider	Type	$\sqrt{s}$	$\mathcal{P}[\%]$ e^-/e^+	$\mathcal{L}_{\rm int}$ ab^{-1}/IP	Start Date Const.	Start Date Physics
HL-LHC	pp	14 TeV		3		2027
ILC & C^3	ee	250 GeV	$\pm80/\pm30$	2	2028	2038
		350 GeV	$\pm80/\pm30$	0.2		
		500 GeV	$\pm80/\pm30$	4		
		1 TeV	$\pm80/\pm20$	8		
CLIC	ee	380 GeV	$\pm80/0$	1	2041	2048
CEPC	ee	M_Z		50	2026	2035
		$2M_W$		3		
		240 GeV		10		
		360 GeV		0.5		
FCC-ee	ee	M_Z		75	2033	2048
		$2M_W$		5		
		240 GeV		2.5		
		$2\ M_{top}$		0.8		
μ-collider	$\mu\mu$	125 GeV		0.02		

Multi-TeV colliders (> 1 TeV c.o.m. energy)

Collider	Type	$\sqrt{s}$	$\mathcal{P}[\%]$. e^-/e^+	$\mathcal{L}_{\rm int}$ ab^{-1}/IP	Start Date Const.	Start Date Physics
HE-LHC	pp	27 TeV		15		
FCC-hh	pp	100 TeV		30	2063	2074
SppC	pp	75-125 TeV		10-20		2055
LHeC	ep	1.3 TeV		1		
FCC-eh		3.5 TeV		2		
CLIC	ee	1.5 TeV	$\pm80/0$	2.5	2052	2058
		3.0 TeV	$\pm80/0$	5		
μ-collider	$\mu\mu$	3 TeV		1	2038	2045
		10 TeV		10		

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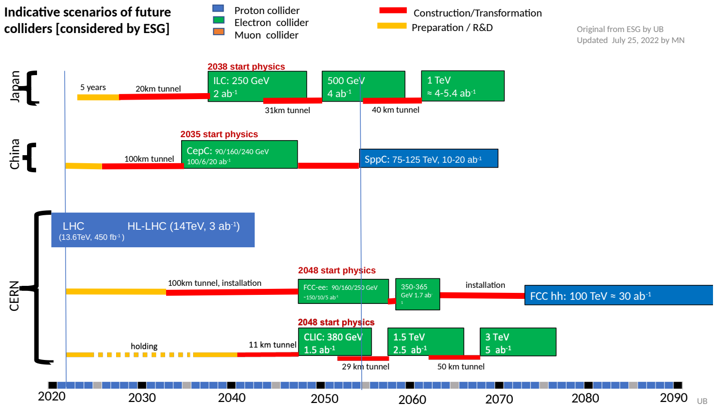
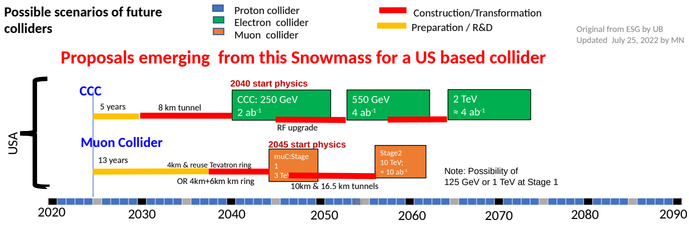
The Energy Frontier: Timelines



The Energy Frontier: Timelines



- **Timelines technologically limited**
- Uncertainties to be sorted out
  - Find a contact lab(s)
  - Successful R&D and feasibility demonstration for CCC and Muon Collider
  - Evaluate CCC progress in the international context, and consider proposing an ILC/CCC [ie CCC used as an upgrade of ILC] or a CCC only option in the US.
  - International Cost Sharing

- Consider proposing hosting ILC in the US.

The Energy Frontier: Higgs factory comparison

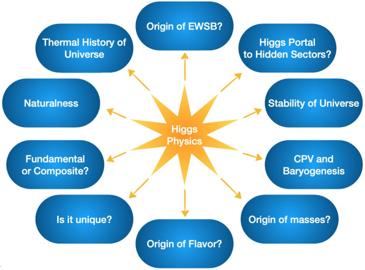
Pushing the Higgs-boson precision program is crucial

The Higgs discovery has given us a unique handle on BSM physics and any future plan needs to make the most out of it.

Energy Frontier Higgs Factory First Stages

EF benchmarks	y_u	y_d	y_s	y_c	y_b	y_t	y_e	y_μ	y_τ	Gauge Couplings: Tree	Gauge Couplings: Loop induced	Higgs Width	λ_3	λ_4
LHC/HL-LHC	$>\mathcal{O}(1)$	$>\mathcal{O}(1)$	$>\mathcal{O}(1)$	$\mathcal{O}(1)$	$\mathcal{O}(.1)$	$\mathcal{O}(.1)$	$>\mathcal{O}(1)$	$\mathcal{O}(.1)$	$\mathcal{O}(.1)$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(.1)$	$\mathcal{O}(1)$	$>\mathcal{O}(1)$
Higgs Factory + HL-LHC: ILC/C^3 250	$>\mathcal{O}(1)$	$>\mathcal{O}(1)$	$>\mathcal{O}(1)$ *	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$>\mathcal{O}(1)$	$\mathcal{O}(.1)$	$\mathcal{O}(.01)$	$\lesssim\mathcal{O}(10^{-3})$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(1)$	$>\mathcal{O}(1)$
Higgs Factory + HL-LHC: CLIC 380	$>\mathcal{O}(1)$	$>\mathcal{O}(1)$	?	$\mathcal{O}(.1)$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$>\mathcal{O}(1)$	$\mathcal{O}(.1)$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(1)$	$>\mathcal{O}(1)$
Higgs Factory + HL-LHC: FCC-ee 240	$>\mathcal{O}(1)$	$>\mathcal{O}(1)$	?	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$>\mathcal{O}(1)$	$\mathcal{O}(.1)$	$\mathcal{O}(.01)$	$\lesssim\mathcal{O}(10^{-3})$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(1)$	$>\mathcal{O}(1)$
Higgs Factory + HL-LHC: CEPC 240	$>\mathcal{O}(1)$	$>\mathcal{O}(1)$	?	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$>\mathcal{O}(1)$	$\mathcal{O}(.1)$	$\mathcal{O}(.01)$	$\lesssim\mathcal{O}(10^{-3})$	$\mathcal{O}(.01)$	$\mathcal{O}(.01)$	$\mathcal{O}(1)$	$>\mathcal{O}(1)$

Order of Magnitude for Fractional Uncertainty: ★ $\lesssim\mathcal{O}(10^{-3})$ ◆ $\mathcal{O}(.01)$ ◆ $\mathcal{O}(.1)$ ◆ $\mathcal{O}(1)$ □ $>\mathcal{O}(1)$? No study Beyond HL-LHC



Higgs Factories

- Higgs couplings at sub-percent level
- Search for exotic Higgs decays
- Explore Higgs portal to hidden sector
- Stress-test consistency of the SM
- Direct access to low-mass/weak-coupling BSM

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The Energy Frontier: FCs pros & cons

Higgs Factories

Support a fast-start for construction of an e+e- Higgs Factory

Viability of Facilities and Challenges (from AF)

- ILC:
  - Ready to go, polarization
  - Long, e+ source,
  - consider CCC technology for upgrades
- FCCee & CEPC :
  - Ongoing feasibility study
  - Longest, $$, power consumption
- CLIC:
  - Lowest power needs, shortest
  - 2-beams (or klystrons?), tolerances
- Cool Copper Collider or HELEN:
  - **new proposals from Snowmass**
  - lower cost option to ILC/CLIC
  - large gradients at least 70MV/m (HELEN)
    CCC capability up to 120-155 MV/m

Multi-TeV Machines

Support for R&D for EF multi-TeV colliders

Viability of Facilities and Challenges (from AF)

- CLIC-3 TeV :
  - Established CDR, demo facilities
  - Long, $$$, huge power consumption
- FCChh-100 TeV:
  - Re-use FCCee tunnel, high-L, LHC exp.
  - 20(?) yrs for 16 T magnets, $$$, power
- SPPC-125 TeV:
  - Re-use CepC tunnel, ep 0.12+62.5 TeV
  - (N) yrs for 20 T magnets, $$$, power
- Muon Collider-10(14) TeV:
  - Potentially lowest cost, best Lumi/TWh
  - 6D cooling R , D on many subsystems

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The Energy Frontier: Detector R&D

Detector R&D Needs

Preparation of a Technical Design for a Detector needs an R&D program

- Highly segmented detectors with good resolution were simulated to make the case for physics studies for Higgs Factories & Multi-TeV Colliders.
- **We do need complex/cutting-edge detectors to meet the ambitious physics goals!** The needs extend beyond generic R&D.
  - Address the specific detector challenges for e^+e^- colliders.
- **Such a program needs to start now**
  - to explore the technology to build a full-scale e^+e^- collider detector
  - It takes about 10 years from CD0 to end of construction of a collider detector.
  - **Thus investment in targeted detector R&D for a Higgs Factory has to start soon!**

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The Energy Frontier: Detector R&D

Detector R&D Needs for Higgs Factory

Main features identified together with Instrumentation Frontier:

- Pixel tracker with lowest possible mass and possible radius
- Low-mass outer tracker for excellent momentum resolution to high energies
- A highly segmented calorimeter for particle flow
- A large superconducting solenoid enclosing calorimeter and tracker
- Muon chambers
- Triggerless readout
- Timing detectors
- Particle ID K/π/p separation
- sophisticated electronics to handle large data volume

- Understanding the Machine Detector Interface
- Need engineering to go from prototypes to detector

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The Energy Frontier: R&D $:s

Medium Project Scale R&D requests

Project	R&D Start date (yr)	R&D End Date (yr)	R&D cost M$
Higgs Factory detector R&D	now	2035	~100-150
CCC higgs factory	2024	2028	~100
CCC High Energy	2045	2050	~200
Muon Collider (1-3 TeV)	now	2040	~300
Muon Collider (10 TeV)	2040	2047	~200

Estimated US Contributions
In the spirit of Snowmass numbers are very preliminary. They give an approximate scale.

Need to be vetted further.

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The Energy Frontier: Bottom line

The intermediate future is an e^+e^- Higgs factory

The intermediate future is an e^+e^- Higgs factory, either based on a linear (ILC, C^3, CLIC) or circular collider (FCC-ee, CepC).

- **The various proposed facilities have a strong core of common physics goals**: it is important to **realize at least one somewhere in the world.**
- **A fast start towards construction is important**. There is **strong US support** for initiatives that could be realized on a time scale relevant for early career physicists.
- **For the next decade and beyond**
  - **2025-2030**: Establish a targeted e^+e^- Higgs Factory detector R&D for US participation in a global collider
  - **2030-2035**: Support and advance construction of an e^+e^- Higgs Factory
  - **After 2035**: Begin and support the physics program of an e^+e^- Higgs Factory

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The Energy Frontier: Bottom line

The long-term future is a multi-TeV collider

- A 10-TeV **muon collider** (MuC) and 100-TeV **proton-proton collider** (FCC-hh, SppC) directly probe the order 10 TeV energy scale with different strengths that are unparalleled in terms of mass reach, precision, and sensitivity.
- The main limitation is technology readiness. **A vigorous R&D program** into accelerator and detector technologies **will be crucial.**
- **For the next decade and beyond**
  - **2025-2030**:
    - Develop an initial design for a first stage TeV-scale Muon Collider in the US (pre-CDR)
    - Support critical detector R&D towards EF multi-TeV colliders
  - **2030-2035**: Demonstrate principal risk mitigation and deliver CDR for a first-stage TeV-scale Muon Collider
  - **After 2035**:
    - Demonstrate readiness to construct and deliver TDR for a first-stage TeV-scale Muon Collider
    - Ramp up funding support for detector R&D for EF multi-TeV colliders

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The Energy Frontier: US wants to get back on the field

EF Colliders: Opportunities for the US

- Our vision for EF can only be realized as a **worldwide program** and we need to envision that **future colliders will have to be sited all over the world** to support and empower an international vibrant, inclusive, and diverse scientific community.
- The US community has to continue to work with the international community on detector designs and develop extensive R&D programs.
  - To realize this, the funding agencies (DOE and NSF) should fund a **R&D program** focused on participation of the US community in future collider efforts as partners (as currently US is severely lagging behind).
- **The US EF community has expressed renewed interest and ambition to bring back energy-frontier collider physics to the US soil** while maintaining its international collaborative partnerships and obligations, for example with CERN.
  - The international community also realizes that a vibrant and concurrent program in the US in energy frontier collider physics is **beneficial for the whole field, as it was when Tevatron was operated simultaneously as LEP.**

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The Energy Frontier: ILC in the US !!???

EF Colliders: Opportunities for the US

- **Planning to proceed in multiple parallel prongs may allow us to better adapt to international contingencies** and eventually build the next collider sooner. Such a strategy will also help develop a robust long term plan for the global HEP community, with U.S. leadership in EF colliders.
- **Attractive opportunities** to be considered are:
  - **A US-sited linear e^+e^- collider (ILC/C^3)**
  - **Hosting a 10-TeV range Muon Collider**
  - **Exploring other e^+e^- collider options to fully utilize the Fermilab site**
- Bold "new" projects offer the next generation some challenges to rise to and inspire more young people from the US to join HEP and in the long term help with strengthening the vibrancy of the field.

↳ **New C^3 proposal gained momentum during Snowmass 21**

↳ **More than 40 contribute papers on Muon Collider studies during Snowmass 21**

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The Energy Frontier: The vision

The Energy Frontier vision in a nutshell

It is essential to

- **Complete the HL-LHC program,**
- **Start now a targeted program for detector R&D for Higgs Factories**
- **Support a fast start of the construction of a Higgs factory**
- **Ensure the long-term viability of the field by developing a multi-TeV energy frontier facility such as a *muon collider* or a *hadron collider*.**

Support to AF, CEF, CompF, IF, and TF is crucial to the realization of the EF vision

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The Energy Frontier: in 5-10-15 years

EF Resources and Timelines

➢ Five year period starting in 2025

- Prioritize *HL-LHC physics program,* including auxiliary experiments
- Establish a targeted *e+e- Higgs Factory detector R&D* for US participation in a global collider
- Develop an *initial design for a first stage TeV-scale Muon Coll.* in the US (pre-CDR)
- Support critical *detector R&D towards EF multi-TeV colliders*

➢ Five year period starting in 2030

- Continue strong support for *HL-LHC program*
- Support and advance *construction of an e+e- Higgs Factory*
- Demonstrate principal risk mitigation and deliver *CDR for a first-stage TeV-scale Muon Coll.*

➢ After 2035

- Support continuing *HL-LHC physics program* to the conclusion of archival measurements
- Begin and support the *physics program of the Higgs Factories*
- Demonstrate readiness to construct and deliver *TDR for a first-stage TeV-scale Muon Coll.*
- Ramp up funding support for *detector R&D for EF multi-TeV colliders*

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Impressions

- Very intense 10 days - with no day off.
- Great organisation:
  - Mornings with Frontier/topical group parallels (Meaning that I was almost only following EF-BSM parallels)
  - Afternoons with plenaries - each frontier got its, non-shared, plenary.
  - Also specific cross-frontier parallels eg. Energy/Accelerator
- 735 on-site participants (+654 remote). All having a 2 hour lunch on University Street, just off-campus ⇒ lots of opportunities for off-the-record cross-frontier discussions.
- About 35 Europeans, 10 Japanese on-site.
- Lab directors (US of course, but also CERN, KEK, IHEP, Triumf) , APS, ICFA, STFC and IDT chairs present ....

Impressions

- The Americans didn't "make the Wave" about FCC - more noted with interest the activities in Europe.
- Fabiola's sobering presentation on the FCC time-line probably contributed to that.
- Surprises :
  - US wants to get back with a domestic Energy Frontier facility.
  - ILC in US on the table !
  - Great revival of the interest in the muon collider.
  - Little mention of Plasma Wakefields, at least outside the AF ...
  - And: The closest to a mention of the war in Ukraine in any talk was a mention of current "supply-chain difficulties" in the DoE talk - quite a stark contrast to ICHEP !

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Conclusions: P5 chair

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Hitoshi Murayama

Put Captions Here

symmetry
dimensions of particle physics
topics
follow +
A joint Fermilab/SLAC publication

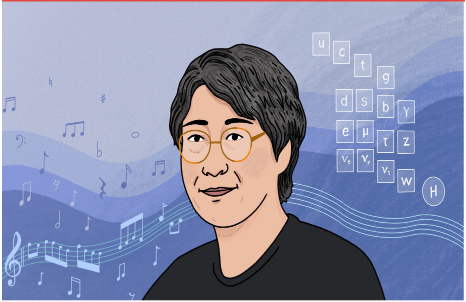

Illustration by Sandbox Studio, Chicago with Corinne Mucha

Hitoshi Murayama brings people together

04/19/22 | By Kimberly Hickok

Building international research communities is a cornerstone of Murayama's physics career.

- MacAdams Professor of Physics at the University of California, Berkeley
- Faculty Senior Staff at Lawrence Berkeley National Lab
- University Professor, Kavli Institute for the Physics and Mathematics of the Universe, University of Tokyo
  - Member, American Academy of Arts and Sciences
  - Fellow, American Association for the Advancement of Science
  - Fellow, American Physical Society
  - Humboldt Research Prize
  - Breakthrough Prize (KamLAND)
  - Yukawa Commemoration Prize
  - Sloan Research Fellowship
  - Served on SLAC Policy Committee, HEPAP & subpanels, Fermilab Physics Advisory Committee, CERN Scientific Policy Committee, CEPC/SppC International Advisory Committee

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Conclusions: the last section of the EF report

snowmass2021_efreport_v2.3:

2.8.8 Vision Summary

The Energy Frontier aims to facilitate a comprehensive international program for US participation in the exploration of the "known unknown" physics beyond current reach, requiring future colliders.

The most viable path forward for the energy frontier that has been identified during the Snowmass process is proceeding forward with the construction of a Higgs factory as soon as possible, to complement the experiments of the HL-LHC, enabling operation during or just after the operation of the HL-LHC. This step should be followed by a multi-TeV energy frontier collider, going beyond the reach of the HL-LHC.

The proposals and R&D efforts to address the innovative detector developments for Higgs factories are well underway globally and many challenges are resolved. Bold "new" projects such as a linear e^+e^- Cool Copper Collider, and a muon collider will offer the next generation some challenges to rise to. It will inspire more young people from the US to join HEP and in the long term help with strengthening the vibrancy of the field.

Realizing our ultimate goal will require significant funding and government support. The community feels that there is potential to raise funds and obtain government buy-in for a future collider project located in the US. However, funding is not all that is needed. We also need a future program that continues to inspire the next generation of high energy physicists, and one that entices the next generation of graduate students to choose high energy physics as their field.