The US Snowmass Planning Exercise
The Road(s) Ahead

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Chairperson, Division of Particles and Field
August 26, 2022

Outline

- History of US HEP Community Planning Exercise and Prioritization Panel "P5"
- Previous Snowmass 2013 and P5 2014, including outcomes
- Organization of the current exercise: Snowmass 2021, which just culminated in a 10-day long workshop, the Community Summer Study, CSS, in Seattle Washington
- Impact of COVID on our plans
- Timeline for the report, a.k.a. the "Snowmass Book"
- Discussion of some of the recommendations and takeaway messages from the Snowmass working groups (Frontiers) – my personal opinions
- P5 status and next steps
- **Summary and Outlook**

Thanks to many Snowmass contributors whose excellent material I used to prepare this talk and to my DPF Chair Line colleagues from whom I borrowed slides. Mistakes are mine alone and I try to indicate where I express personal opinions

Resources

- Some Resources for Snowmass 2021:
  - Link to conference homepage for Community Summer Study: http://seattlesnowmass2021.net/
  - Link to CSS agenda
    - List : https://indico.fnal.gov/event/22303/timetable/?view=standard
    - Block: https://indico.fnal.gov/event/22303/timetable/#20220726.detailed
  - CSS SLACK: snowmass2021 – snowmass2021.slack.com
  - Link to Snowmass 2021 portal twiki: https://snowmass21.org/
  - Link to Contributed papers: https://snowmass21.org/submissions/
  - Snowmass Early Career 2021: https://snowmass21.org/start/young
- Historical overview – Snowmass 2013/P5 2014
  - "How to Snowmass (article by C. Quigg)": https://indico.fnal.gov/event/45207/attachments/133652/164937/How_to_Snowmass-final-links.pdf
  - Snowmass 2013 Book: https://tinyurl.com/ypfd679z
  - Link to material and report of P5, 2014: http://usparticlephysics.org/p5/

History: US HEP Community Planning Exercise, a.k.a. Snowmass

- Snowmass, the DPF-hosted Community Planning Exercises, started in 1982
  - The then DPF chair Charles Baltay said: "The 1982 DPF Summer Study was the first attempt in recent years to bring together physicists from the whole country to consider the future of our field from the point of view of the best overall national program. The DPF Executive Committee feels that this summer study was sufficiently useful in this last respect to hold similar summer studies at appropriate times in future years."
    - **The study lasted several months and culminated in a 3-week-long workshop in Snowmass, Colorado**
- Goal: To identify the most important questions in HEP and the tools and infrastructure required to address them
  - To achieve a broader and deeper understanding of the science in our field
  - To engage junior scientists and foster our community development
  - To reach a compelling vision for the field moving forward
  - Provide input to the "Particle Physics Project Prioritization Panel" (P5) process

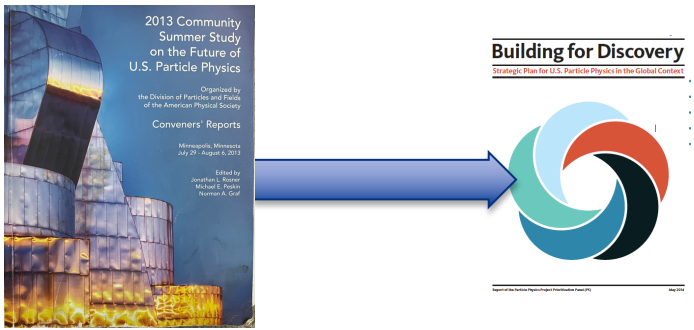
Change of Style in 2013

- In 2013, for reasons external to HEP, the meeting was held outside of Snowmass at the University of Minnesota , "Snowmass on the Mississippi", and was shortened to ~10 days
  - The shorter meeting required more discussion and consensus building to be done in advance at smaller workshops and meetings (in-person)

Snowmass 2013/P5 2014

Snowmass 2021

- In 2013, Snowmass provided input to the High Energy Physics Advisory Panel's (HEPAP) subpanel, the Particle Physics Project Prioritization Panel, a.k.a. P5, charged by DOE and NSF
  - Using Snowmass's scientific input and budget scenarios provided by the funding agency, P5 developed and presented to DOE and NSF, via HEPAP, a 10-year **execution plan, with priorities and recommendations, for the field in the US, with an eye also towards the ten years following that**
- P5 has a broad mandate but tends to focus on large projects and facilities



"P5" Drivers

- **From P5 report:** "Snowmass, the yearlong community-wide study, preceded the formation of our new P5. A vast number of scientific opportunities were investigated, discussed, and summarized in Snowmass reports. **We distilled those essential inputs into five intertwined science Drivers for the field:**
  - Use the **Higgs boson** as a new tool for discovery
  - Pursue the physics associated with **neutrino mass**
  - Identify the new physics of **dark matter**
  - Understand cosmic acceleration: **dark energy and inflation**
  - Explore the unknown: **new particles, interactions, and physical principles**"

Please look at pages 1 and 2 of the 2013 Snowmass Book

Did Snowmass 2013 have an impact on the P5 outcome?

- I would say yes!
- **The main recommendations (LHC, neutrinos) may have been somewhat obvious even at the beginning of the process, but needed justification and incorporation into real budgets with timelines**
- **There were, however, 29 recommendations,** including
  - Maintain a program of projects of all scales, from the largest international projects to mid- and small-scale projects.
  - Increase the budget fraction invested in construction of projects to the 20%–25% range.
  - Provide the flexibility to support new ideas and developments
  - Select and perform in the short term a set of small-scale short-baseline experiments
  - Build DESI and complete LSST,
  - Proceed with G2 Dark Matter programs, support one or more G3 dark Matter Programs
  - Complete Mu2e and muon g-2

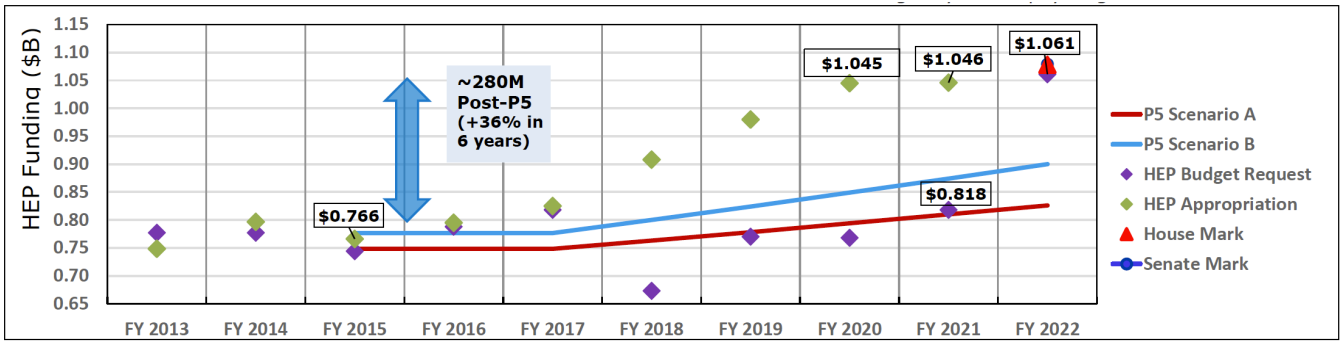
I do not believe that all these would have been included without our strong communities developing excellent proposals

Funding Outcome

Snowmass 2013 Outcomes

- The U.S. particle physics community enthusiastically supported the P5 plan.
  - 2,331 community members signed a letter of support to DOE and NSF (organized by DPF)

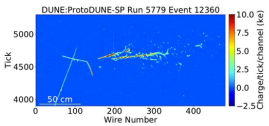
"Four years into executing the P5, the Committee commends the Office of Science and the high energy physics community for achieving significant accomplishments and meeting the milestones and goals set forth in the strategic plan…"



Project Outcome, P5 2014

Snowmass 2021

DUNE/LBNF



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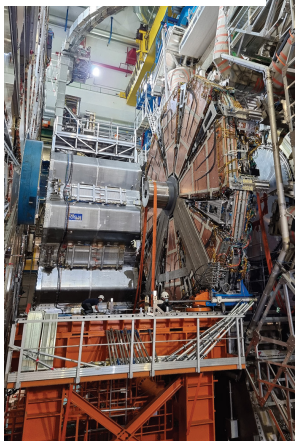
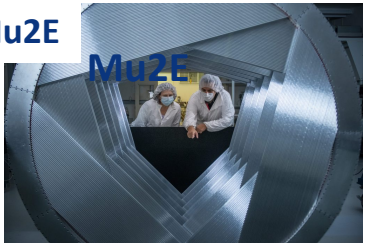
ATLAS Upgrade

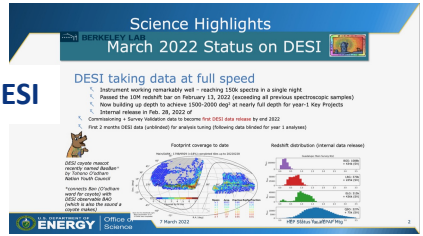


CMS Upgrade

Mu2E



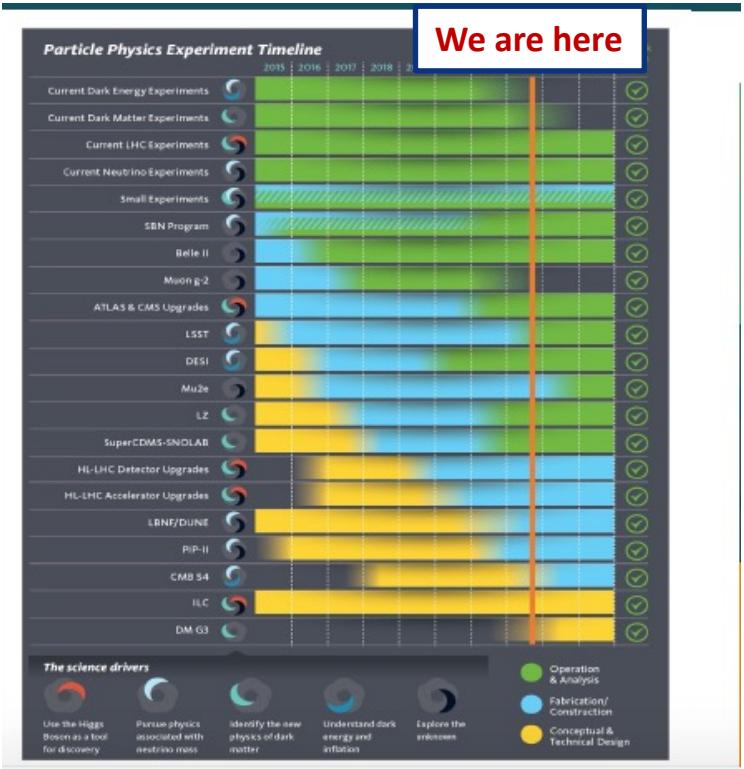
DESI



and many other projects, large and small

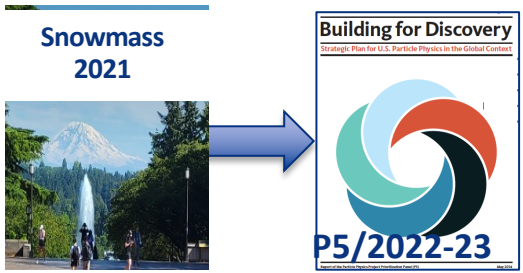
We are ready for a new Strategic Plan!!

Snowmass 2021



When most projects have gone into operation (green) or are solidly into construction/fabrication (blue) and there are too few in the design stage, (orange) it is time to develop the next plan!!

Time for a new Snowmass/P5



Snowmass 2021

- **Why "Snowmass"?**
  - The name Snowmass is retained since it implies **an outlook or state-of-mind** as to how we pursue our science in US HEP:
    - **Community driven and inclusive – all people and ideas are welcome**
    - **Global** - Open to all, including physicists from all over the world, and takes into account the plans in all other regions
    - **Interdisciplinary** – reaches out to related fields
  - **Why 2021?**
    - **It started in 2020, but because of the pandemic, it took two years so 2021 is the "average" of the years??**

Evolution of the Frontier Structure

- In 2013, we had
  - THREE "cutting edge scientific working groups", a.k.a. Frontiers: Energy, Intensity, and Cosmic; and
  - FIVE cutting edge supporting and infrastructure working groups, a.k.a. Capability Groups.
- In 2021, we have TEN Frontiers
  - The Intensity Frontier split into two
    - Neutrinos
    - Rare Decays and Precision Measurements
  - Theory became a full activity
  - The FIVE Capability groups were transitioned to Frontiers, since they all have major R&D and scientific components
  - The "Communication, Education, and Outreach" group was renamed the "Community Engagement Frontier"

Organization in Ten "Frontiers" -I

Snowmass 2021

Accelerator


Steve Gourlay
(LBNL)


Tor Raubenheimer
(SLAC)


Vladimir Shiltsev
(FNAL)

Cosmic


Aaron Chou
(Fermilab)


Marcelle Soares-Santos
(U.Michigan)


Tim Tait
(UC Irvine)

Community Engagement


Kétévi Assamagan
(BNL)


Breese Quinn
(Mississippi)

Computing


Steven Gottlieb
(Indiana U.)


Ben Nachman
(LBNL)


Daniel Elvira
(FNAL)

Energy


Meenakshi Narain
(Brown U)


Laura Reina
(FSU)


Alessandro Tricoli
(BNL)

Instrumentation


Phil Barbeau
(Duke)


Petra Merkel
(FNAL)


Jinlong Zhang
(ANL)

Organization in Ten "Frontiers" - II

Snowmass 2021

Neutrino


Patrick Huber
Virginia Tech


Kate Scholberg
Duke University


Elizabeth Worcester
BNL

Rare Processes & Precision Measurements


Marina Artuso
(Syracuse U.)


Alexey Petrov
(Wayne State U.)


Bob Bernstein
(FNAL)

Theory


Nathaniel Craig
(UCSB)


Csaba Csaki
(Cornell)


Aida El-Khadra
(UIUC)

Underground Facilities and Infrastructure


Laura Baudis (U. Zurich)


Jeter Hall (SNOLAB)


Kevin Lesko (LBNL)


John Orrell (PNNL)

All frontiers have topical subgroups (details on Twiki)

Accelerator:	7	Instrumentation:	10
Cosmic:	7	Neutrino:	10
Community Engagement:	7	Rare Processes:	7
Computing:	7	Theory:	11
Energy:	10	Underground:	6

More than 1500 people have signed up to participate in Snowmass!

Snowmass 2021 organization

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

From the US and many other nations. From HEP and many related disciplines.

Snowmass Early Career (SEC) - I

- Early Career physicists have been formally represented at Snowmass since at least 2001 and gained even more formal recognition in 2013 and now in 2021/22
- This Snowmass they were treated as a full frontier
  - Many problems have been exposed and HEP will have to develop the means to make progress faster
  - The EC physicists are contributing to the Snowmass book
- The issues addressed by the Community Engagement frontier and the SEC are now at the forefront of our agenda and those of the DOE and NSF

Snowmass Early Career (SEC) - II

- Early Career physicists have been formally represented at Snowmass since at least 2001 and gained even more formal recognition in 2013 and now in 2021/22
- Key Initiatives:
  - **Snowmass Coordination:** Coordinate with the Snowmass frontiers and help get EC members involved in the process
  - **In-reach:** Professional development and building cohesion within the early career community
  - **Diversity, Equity, and Inclusion (DEI):** Initiatives to make HEP more representative, welcoming, inclusive, and equitable.
  - **Survey:** Collect data on the early career membership
  - **Long-Term Organization:** There is interest in defining an early career organization to continue after Snowmass

DPF Oversight and Coordination

- Snowmass includes all aspects of high energy physics and takes an interdisciplinary and international approach
  - **Snowmass Steering Group [met weekly]**
    - DPF Chair line + representatives of four closely associated APS Divisions: **Astrophysics, Nuclear Physics, Gravitational Physics, Physics of Beams**
  - **Snowmass Advisory Group [met monthly]**
    - DPF Executive Committee + **representatives of major regional and international organizations**
  - **Snowmass All-Conveners Group [met monthly]**
    - DPF chair line, 30 frontier conveners, the UW chair and deputy chairs of the CSS
  - **Community Summer Study (CSS) Program Committee [met weekly]**
    - One convener chosen by each frontier, Steering Committee, Early Career scientist representatives, UW chairs of CSS
  - **CSS Local Organizing Committee [endless meetings]**

Letters of Intent

- **Letters of Interest** (April 1 – August 31, 2020) – https://snowmass21.org/loi
  - Two pages
- Not done in 2013 (or previously)
- >1500 submitted

There was a Snowmass 2021 kickoff (virtual) **Community Planning Meeting (CPM),** Oct 5-8, 2020, to initiate the work based on the LOIs received. A major step was to turn the LOIs into a smaller number of contributed papers, or white papers.

Impact of COVID

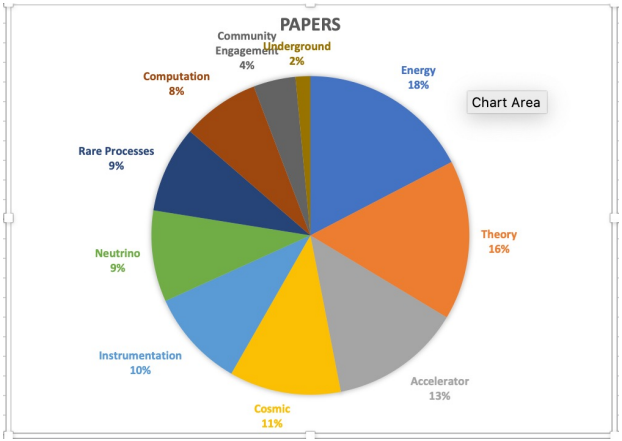
- This edition of Snowmass was planned to run from the summer of 2020 to a final get-together in July of 2021 at the University of Washington
- By early 2021, it became clear that COVID would have a major impact on our ability to carry out the necessary work because of
  - Lack of face-to-face meetings reduced efficiency
  - Heavy burdens fell on our young physicists, who do many of the studies
    - **Especially young physicists with children, who now had care for them all day and school them at home**
- In consultation with **DOE, which agreed to delay P5 by one year, to 2022/23**, we decided to take a ~7month pause/slowdown with the expectation that conditions would improve because of vaccines and mitigation measures
  - **The meeting at University of Washington was delayed until July of 2022**
- The pause/slowdown began in January of 2021
- The startup dates varied among the frontiers, but by September everything was restarted and there was a **"Snowmass Day" on September 24, 2021**, to review the plans for completing the work in for the July 2022 meeting
- We hoped that vaccination and mitigation would enable us to have a large face-to-face component to our planned hybrid meeting in UW

Contributed Papers, a.k.a. White Papers

Snowmass 2021

These were due March 5, 2022

- **Links to Submitted Papers, by Frontier**
- Energy Frontier (EF) (150)
- Neutrino Physics Frontier (NF) (80)
- Rare Processes and Precision Measurements (RF) (76)
- Cosmic Frontier (CF) (98)
- Theory Frontier (TF) (140)
- Accelerator Science and Technology Frontier (AF) (115)
- Instrumentation Frontier (IF) (86)
- Computational Frontier (CompF) (68)
- Underground Facilities and Infrastructure (UF) (13)
- Community Engagement Frontier (CommF) (37)



total submissions: 515

Contributed paper submission database compiled by SEC

Community Summer Study (CSS) and Workshop

Snowmass 2021

- Community Planning Meeting on Oct 5-8, 2020: Goals, Presentations, and Recordings.
- Snowmass Day: September 24, 2021 August 2021
- **Snowmass Community Summer Study starts (July 17, 2022) Home Page for Seattle, July 17-26, 2022**

Participation in this CSS Hybrid Meeting

- **Participants**
  - Number of in-person participants: 743
  - Number of virtual participants: 654
  - Local Organizing Committee/Volunteer/Press: 58
- Total number of participants: 1397

- This is close to the largest in-person attendance ever but is certainly the largest if remote participation is included.
- Its execution is a story by itself, which I hope will be written
- Special precautions were taken by the community to limit the spread of COVID. Our Community did amazing job of complying with voluntary measures to keep us all safe!

Community Summer Study Hybrid Workshop

Snowmass 2021

Organization of the meeting -

Snowmass 2021

	Sunday, July 17	Monday, July 18	Tuesday, July 19	Wednsday, July 20	Thursday, July 21	Friday, July 22	Saturday, July 23	Sunday, July 24	Monday, July 25	Tuesday, July 26	Wednesday, July 27
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	
07:30 - 08:00 AM											
08:00 - 08:30 AM	Registration										
08:30 - 09:00 AM											
09:00 - 09:30 AM											
09:30 - 10:00 AM	Introductory Plenary	Parallel	Parallel	Parallel	Parallel	Parallel	Parallel		Snowmass Frontier Summaries	NAS EPP Decadal Stud	
10:00 - 10:30 AM								Parallel		Snowmass Frontier Summaries	
10:30 - 11:00 AM											
11:00 - 11:30 AM										Snowmass Workshop Summary	
11:30 - 12:00 PM										Closing remarks	
12:00- 12:30 PM	Lunch	Lunch, Poster & Exhibit	Lunch, Poster & Exhibit, and FOA/DOE General Meeting	Lunch, Poster & Exhibit and NSF General Meeting	Lunch,1) DOE Prgrm Managers ,Astrophysics,2) NSF Special PI meeting	Lunch,DOE Prgrm Managers 1) Energy 2) Theory	Lunch and Communicating HEP to the public and the govt	Lunch and COV Roundtable; lessons (to be learned			in the scheduel and afor the mttend
12:30 - 01:00 PM											
01:00 - 01:30 PM											
01:30 - 02:00 PM											
02:00 - 02:30 PM	Introductory Plenary	Parallel 1: AI/ML Parallel 2 : Underground Science	Panel: Careers and Training the Next Generations	Parallel 1: Neutrino; Parallel 2: Rare processes	Colloquium on Rare Processes and Precision Measurements	Colloquium on Underground Physics	Colloquium on Energy Frontier	Presentation: Snowmass Early Career	Panel: Interconnections with other fields		
02:30 - 03:00 PM											
03:00 - 03:30 PM		Parallel 1: The next accelerators; Parallel 2: LQCD	Parallel 1: Lepton Colliders Parallel 2: Cosmic	Colloquium on Instrumentation	Colloquium on new Accelerators and R&D	Colloquium on Theory	Colloquium on Computing	Parallel 1: Underrepresented Minorities; Parallel 2: Instrumentation projec	Coffee		
03:30 - 04:00 PM	Coffee										
04:00 - 04:30 PM		Coffee	Coffee		Coffee	Coffee	Coffee	Coffee	Talks: national, International Leaders		
04:30 - 05:00 PM											
05:00 - 05:30 PM	If	DEI: Talks and Panel	Colloquium on Community Engagement		Colloquium on Cosmic Frontier	Colloquium on Neutrino Physics	Quantum Information Science in HEP	talks: DOE, NSF, FNAL Director, other US labs	Panel International Status and Plans		
05:30 - 06:00 PM											
06:00 - 06:30 PM											
06:30 - 07:00 PM											
07:00 - 07:30 PM											
07:30 - 08:00 PM		Reception and Poster and Industry	Industry Networking	Adam Riess Public Lecture	Physics Slam	Conference Dinner	ColliderScope				
08:00 - 08:30 PM											
08:30 - 09:00 PM											
09:00 - 09:30 PM											
09:30 - 10:00 PM											
10:00 - 10:30 PM											

Parallel Sessions

Parallel Sessions

Organization of the CSS

- Day 1: charge to the Frontiers and to Snowmass, perspectives from funding agencies
- Day 2-8:
  - Morning – Many frontier parallel sessions
  - Afternoon – Plenary sessions of three hours duration, mostly important presentations by frontiers explaining their key conclusions to the other frontiers. **Get out of your lane and learn what others are doing!**
    - In some cases, a three-hour slot has two sessions running simultaneously
  - Afternoon Sessions of General interest
    - Sessions on selected cross-cutting topics of general interest to several frontiers or he whole community
  - Meetings during lunch period (no food consumed at meeting – COVID safety) with funding agencies and additional general topics
- Day 9-10:
  - Perspectives of important national and international leaders and organizations
  - Conference summaries via several panels and a summary talk, all aimed at producing clear, concise input to P5 and the basis for a consensus after P5 concludes
  - Conference synthesis – Prisca Cushman

Key Frontier Summaries

https://indico.fnal.gov/event/22303/timetable/?view=standard_inline_minutes

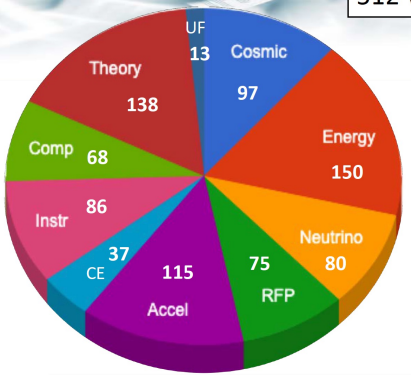
- July 19: 5:30 PM → 7:00 PM HEP Community Engagement: Is the HEP Community going to take responsibility for Engagement (or not)?
- July 20: 3:40 PM → 5:13 PM Detector Technologies for the Next Decades
- July 21: 2:00 PM → 3:30 PM Rare Prcesses and Precision Measurements
- July 21: 3:30 PM → 5:00 PM Beams, Accelerator R&D and Future Facilities: Accelerator Frontier Vision
- July 21: 5:30 PM → 7:00 PM Cosmic Probes of Fundamental Physics
- July 22: 2:00 PM → 3:30 PM Advancing Research at Underground Facilities (UF)
- July 22: 3:30 PM → 5:00 PM Theory Frontier: A Vision for the Future
- July 22: 5:30 PM → 7:00 PM Big Picture Neutrino Science
- July 23: 2:00 PM → 3:30 PM Physics on the Energy Frontier
- July 23: 3:30 PM → 5:00 PM The Future of Computing for HEP
- July 23: 3:30 PM → 5:00 PM The Future of Computing for HEP
- July 24: 2:00 PM → 3:30 PM Snowmass Early Career

Special Summary Sessions

https://indico.fnal.gov/event/22303/timetable/?view=standard_inline_minutes

- Highlights from the frontiers
  - July 25: 8:00 AM → 9:45 AM Physics Highlights from the Frontiers
  - July 25: 10:15 AM → 12:00 PM Enabling the Physics Goals: Enabling Science
- Projects under development/consideration
  - 9:00 AM Large Experiments/Facilities and the proposed timelines
  - 10:30 AM Mid- and Small-scale Experiments/Facilities and the proposed timelines

512 White Papers



79 topical group reports

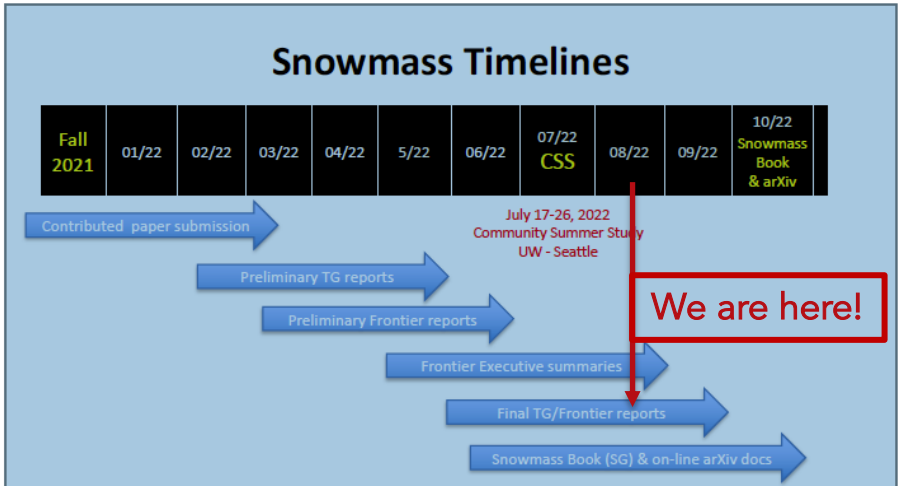
10 Frontier Summaries

And lots of meetings and presentations and plots along the way

Executive Summary by October

Prisca Cushman

Timeline for Snowmass Book

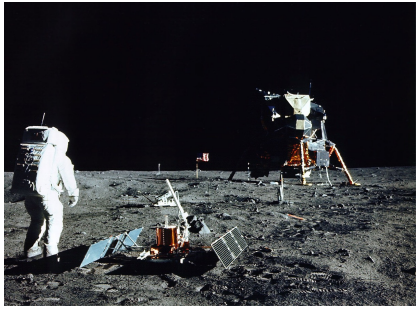


- **March 15: Contributed papers (a.k.a. White Papers)**
- May 31: Preliminary Topical Group Reports
- June 30: Preliminary Frontier Reports
- **July 17 – 26: Converge on reports for all the frontiers and produce executive summaries representing the views of their communities and providing the basic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

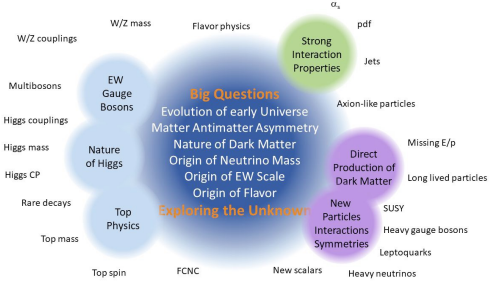
Personal and Preliminary View of Outcomes

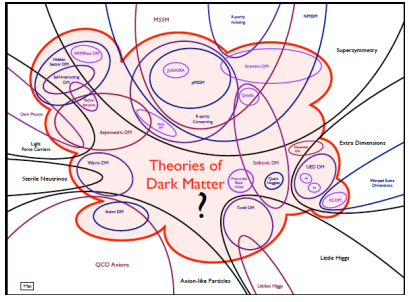
Campaigns vs Explorations

Snowmass 2021



1. Have a goal that you know is achievable
2. Have the means to carry it out
3. Have the determination and support to do it





In 2013/2014 with the Higgs newly discovered and the first 13 TeV run coming up, it was possible to imagine we would find specific targets and mass scale to shoot at that was accessible .

This has not happened yet

We are no longer doing campaigns but explorations or investigations
No “no lose” theorems for any sector or approach. **This will be FUN!**

Current Status and Outlook

- No mass/energy scale for BSM physics
- Many new ideas have expanded the search space, e.g. for Dark Matter, but also in other topics as well
  - Huge mass range: **arguably 90 orders of magnitude**
  - Possibility of complex physics in hidden sectors
- **Some hints exist that may point us in a particular direction, e.g. flavor anomalies**
  - **Or they may be illusory**
- Calls for a new strategy
  - More diverse, with large, medium, and small experiments
  - More interconnected – use all available information from all Frontiers, scales of experiments, theory, …

Every frontier is seeking BSM physics:

From Cosmic: Delve deep, search wide! Search wide, aim high!

Talk to each other, use all connections to gain insight!

Snowmass Takeaways
Neutrino Frontier

Science drivers for the Neutrino Frontier

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

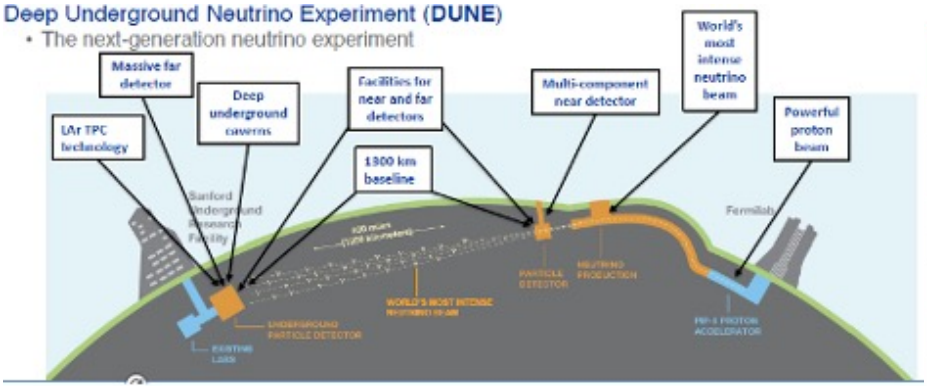
Neutrino Frontier Message

- 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 NF science drivers
- 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.

NF has a program of Precision Measurements and BSM searches

Large Projects: Neutrino Frontier

Snowmass 2021



LBNF/DUNE-US Project + DUNE Int'l Project

Capability Description	Phase I	Phase II
Beamline		
1.2MW (includes 2.4MW infrastructure)	X	
2.4MW		X[1]
Far Detectors		
FD1 – 17 kton	X	
FD2 – 17 kton	X	
FD3		X[2]
FD4		X[2]
Near Detectors		
ND LAr	X	
TMS	X	
SAND	X	
MCND (ND GAr)		X

Note 1: requires upgrades to LBNF neutrino target and upgrades to Fermilab accelerator complex. The LBNF facility is built to support 2.4MW in Phase I.
Note 2: Caverns and cryo-infrastructure built in Phase 1

- Neutrinos are beginning to establish themselves as searching for BSM physics and as making many measurements to counter a criticism
- DUNE Phase 2 is the Neutrino community's highest priority project for this upcoming P5 period. It has three components, and a high cost.
- The FNAL booster upgrade must provide 2.4 Mw to DUNE but can be designed to provide more beam for other programs
  - This is a major decision point

Snowmass Takeaways
Energy Frontier

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.**
- 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.
  - A US-sited linear e+e- collider (ILC/CCC) **(Cold Copper Collider)**
  - Hosting a 10-TeV range Muon Collider
  - Exploring other e+e- collider options to fully utilize the Fermilab site
  - I sense that elements of the community at Snowmass are frustrated by a timeline which now appears to produce the next new collider about 25 years from now

Energy Frontier Benchmark Scenarios

Snowmass 2021

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

Collider	Type	$\sqrt{s}$	$\mathcal{P}[\%]$ e^-/e^+	$\mathcal{L}_{\text{int}}$ ab^{-1}/IP	Start Date Const.	Start Date Physics
HL-LHC	pp	14 TeV		3		2027
ILC & C^3	ee	250 GeV	$\pm 80/\pm 30$	2	2028	2038
		350 GeV	$\pm 80/\pm 30$	0.2		
		500 GeV	$\pm 80/\pm 30$	4		
		1 TeV	$\pm 80/\pm 20$	8		
CLIC	ee	380 GeV	$\pm 80/0$	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)

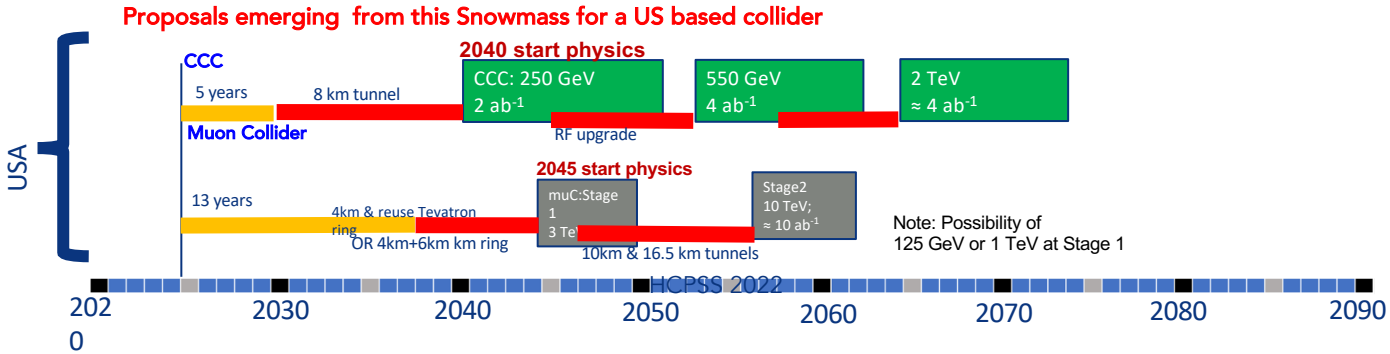
Collider	Type	$\sqrt{s}$	$\mathcal{P}[\%]$. e^-/e^+	$\mathcal{L}_{\text{int}}$ ab^{-1}/IP	Start Date Const.	Start Date Physics
HE-LHC	pp	27 TeV		15		
FCC-hh	pp	100 TeV		30	2063	2074
SppC	pp	75-125 TeV		10-20		2055
LHeC	ep	1.3 TeV		1		
FCC-eh		3.5 TeV		2		
CLIC	ee	1.5 TeV	$\pm 80/0$	2.5	2052	2058
		3.0 TeV	$\pm 80/0$	5		
μ-collider	$\mu\mu$	3 TeV		1	2038	2045
		10 TeV		10		

Possible scenarios of future colliders

Proton collider
Electron collider
Muon collider

Construction/Transformation
Preparation / R&D

Snowmass 2021
Original Snowmass ESG1 talk
Updated July 25, 2022 by MN

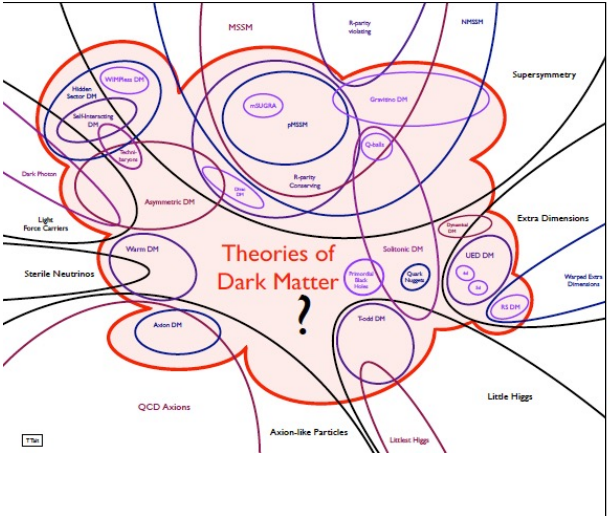


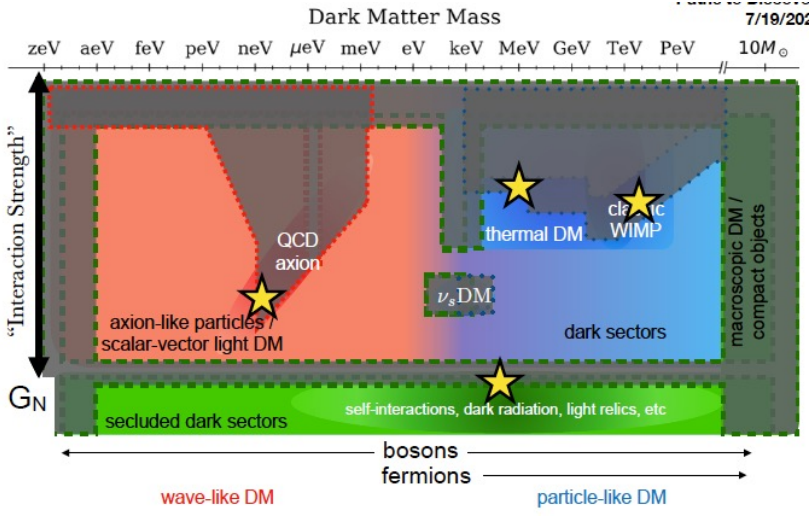
- Timelines technologically limited so take with a "grain of salt"
- Uncertainties to be sorted out
  - Find a contact lab(s)
  - Successful R&D and feasibility demonstration for CCC and Muon Collider
  - Evaluate CCC progress in the international context, and consider proposing an ILC/CCC [ie CCC used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

Snowmass Takeaways
Cosmic Frontier/Dark Matter

Snowmass 2021

- The space of dark matter models encompasses a dizzying array of possibilities, representing many orders of mass and couplings.
- But there is a plan: '**Delve Deep, Search Wide**' employs a range of direct searches for WIMPs interacting with targets on Earth, indirect searches for annihilation products, and cosmic probes based on structure, to scrutinize priority targets such as WIMPs and QCD axions, while broadly scanning parameter space, leaving no stone unturned.

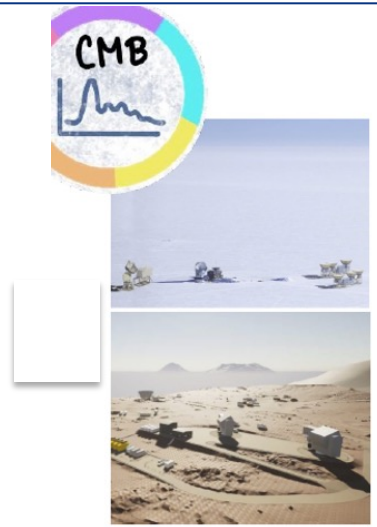




CF: Big Project

Snowmass 2021

- The next big project is CMB-S4
  - Endorsed as a "start" by P5 in 2014
  - **Has CD-0 from DOE**
- 2022-2036: Build and operate CMB-S4 (current large project)
- 2024: Target date for CD-0 for Spec-S5 (next large project)
- 2029: Begin CD process for LIM, GWO (future large project)



CMB-S4

Top immediate CF priority
Uniquely addresses cosmic inflation, will impact the science of HEP frontiers

Snowmass Takeaway
Rare Processes and Precision Measurements

Snowmass 2021

	Physics Driver
1	New physics in flavor/flavor problem
2	Probes of spacetime symmetries and gravity
3	Electric Dipole Moments
4	Baryon-lepton number violation
5	Charged Lepton Flavor Violation
6	Dark Sector Probe
7	QCD at work in hadron spectroscopy

Experiment	Status	Time Scale	Driver	
LHCb, LHCb Upgrade 2 [ATLAS, CMS for some modes]	LHCb U2 now in CERN baseline program	Now-midterm	1,2,6,7	medium see B. Bernstein's talk
Belle II and its upgrades		Now-midterm	1,2,6,7	medium see B. Bernstein's talk
BESIII/STCF		Now-midterm	1,2,6,7	
FCCee/CEPC	Proposed	Post HL-LHC	1,2,6,7	
Rare K decay experiments	Now/proposed	Now-midterm	2	medium
η,η' factories	Now/proposed	2030's	1	small/medium
N-Nbar, MAGE, table-top experiments on quantum-gravity interface	Proposed	late 2020's-2030's	2,4	small
Storage ring EDMs	Proposed	2030-2040	1,2,3,6	medium
Rare muon decay experiments/ Mu2e-II+advanced muon facility at FNAL	Now/proposed	2030-2040	4,5,6	AMF: large
Dark Matter New Initiative	Proposed	late 2020's	6	small/medium

- Many different types of projects, spanning small, medium, and large
- Some require accelerator or beam line upgrades
  - Implications for Proton source (a.k.a. booster) upgrade at FNAL
- Some involve completely new associations, e.g. with AMO

Would like the PHYSICS of FLAVOR to be a SIXTH "DRIVER"

RPF: Muon Science

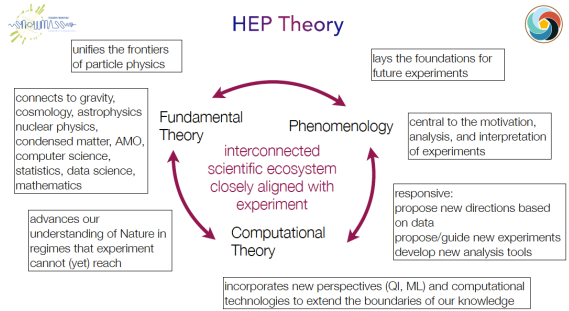
Snowmass 2021

- **Advanced Muon Facility (AMF) at FNAL**
- The Advanced Muon Facility would employ PIP-II to enable
  - A world-leading facility to study CLFV in all three muon modes: $\mu^- N \rightarrow e^- N$; $\mu \rightarrow e\gamma$; and $\mu \rightarrow 3e$
    - Two new small rings for $\mu^- N \rightarrow e^- N$ and $\mu^- N \rightarrow e^+ N'$ and at high-Z and additional x100 in rate
    - x100-1000 more beam for $\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$ than are possible at PSI
    - a possible DM experiment
  - possible muonium-antimuonium oscillation experiment
  - possible atomic physics studies with muonia
  - possible muon EDM experiment

Snowmass Takeaways
Theory Frontier

Snowmass 2021

- A unified view of theory based on three pillars



138 white papers!
Plus
Excellent support of other frontiers' needs

- An extraordinary quantity of work in support of this vision

Topical Group		Topical Group Conveners			
TF01	String theory, quantum gravity, black holes	Daniel Harlow	Shamit Kachru	Juan Maldacena	
TF02	Effective field theory techniques	Patrick Draper	Ira Rothstein		
TF03	CFT and formal QFT	David Poland	Leonardo Rastelli		
TF04	Scattering amplitudes	Zvi Bern	Jaroslav Trnka		
TF05	Lattice gauge theory	Zohreh Davoudi	Taku Izubuchi	Ethan Neil	
TF06	Theory techniques for precision physics	Radja Boughezal	Zoltan Ligeti		
TF07	Collider phenomenology	Fabio Maltoni	Shufang Su	Jesse Thaler	
TF08	BSM model building	Patrick Fox	Graham Kribs	Hitoshi Murayama	
TF09	Astro-particle physics and cosmology	Dan Green	Joshua Ruderman	Ben Safdi	Jessie Shelton
TF10	Quantum information science	Simon Catterall	Roni Harnik	Veronika Hubeny	
TF11	Theory of Neutrino Physics	André de Gouvêa	Irina Mocioiu	Saori Pastore	Louis Strigari

TF: Critical Needs

- Support the essential role of theory similar to (and at least as strong as) recommended by the European Strategy Update, both in relation to projects and in its own right.
- **Support for a balanced program of Projects and Research, as both are essential to the health of the field.**
- **Support for people, especially early career, who are the key "infrastructure" of Research.**
- **Support for targeted funding advancing the physics goals.** (E.g. LQCD Project, LHC Theory Initiative, Neutrino Theory Network, QIS, AI/ML, Exascale Computing Project, SciDAC…)

Snowmass Takeaways
Accelerator Frontier

- To enable the near-to medium-term future
  1. A National Future Collider R&D Program
- To enable medium- and long-term future
  1. General Accelerator R&D (GARD)
  2. Accelerator and Test facilities

AF: Large Facilities

- Work is needed to understand the optimal path for the accelerator upgrades to LBNF / DUNE
- Multiple global options exist for Higgs factories that could be constructed: (ILC, FCC-ee, CEPC, CLIC)
  - Technology development is providing potential improvements, e.g. C^3, HELEN, High Q_0 SRF, High η RF, … but need to understand the full accelerator designs
- Options are being considered for 10+ TeV colliders but R&D is needed to develop technology and understand costs and timescales
- Technology and physics R&D is progressing and will provide options for accelerators in future decades
- Accelerator development should be part of P5

AF: Fermilab Proton Source Upgrade

Snowmass 2021

- PIPII SRF linac for 1.2 MW for DUNE in Main Injector
  - 800 MeV protons
  - Beam ops in 2028-29
  - 162.5 MHz bunches
  - Up to 2mA → 1.6 MW possible
  - ~17 kW for LBNF/DUNE **ν**'s
- PIP-II enables the accelerator complex to reach design proton power on LBNF (MI) target of 2.4 MW, but still leaves 98.8% of the beam for other users!
  - The "Booster upgrade/replacement" can be designed to provide the necessary factor of two in beam power for DUNE (2.4 MW out of Main Injector) **and a variety of beam conditions to enable small and mid-size experiments described in the Rare Processes Frontier with e.g. the addition of an accumulator ring**

Does the potential of the physics program described in the RPF support the extra cost of a versatile proton source?

AF: From the ITF Report Draft: Tables 1-3, 5

	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	280
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-FNAL	6-10	20	>10	19-24	12-18	O(300)
MC-IMCC	10-14	20	>10	>25	12-18	O(300)
FCChh-100	100	30	>10	>25	30-50	~560

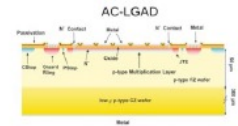
Snowmass Takeaways Instrumentation Frontier

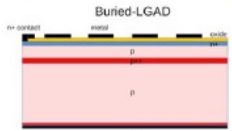
- Double the US Detector R&D budget over the next five years and modify existing funding models to enable R&D Consortia along critical key technologies for the planned long term science projects, sustaining the support for such collaborations for the needed duration and scale
  - CERN RD Collaborations for targeted and coordinated detector R&D wildly successful. We recommend the establishment of a similar model of R&D Consortia in the US,
- Advance performance limits of existing technologies and push new techniques and materials, nurture enabling technologies for new physics, and scale new sensors and readout electronics to large, integrated systems using codesign methods.
- Develop and maintain the critical and diverse technical workforce, and enable careers for technicians, engineers and scientists across disciplines working in HEP instrumentation, at laboratories and universities
  - We cannot build these amazing HEP detectors without our technical workforce and without giving equal value to colleagues working in instrumentation.
- Expand and sustain support for blue-sky, table-top RD, and seed funding. Establish a separate review process for such pathfinder R&D.
- Develop and maintain critical facilities, centers and capabilities for the sharing of common knowledge and tools, as well as develop and maintain close connections with international technology roadmaps, other disciplines and industry.

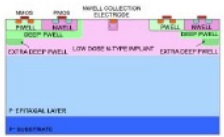
IF: Instrumentation Enables All Frontiers

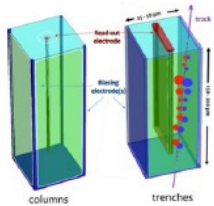
Snowmass 2021

Despite all the challenges, great things are happening









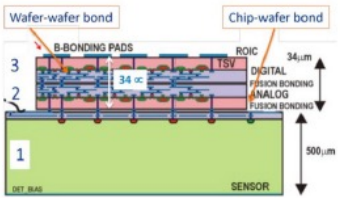
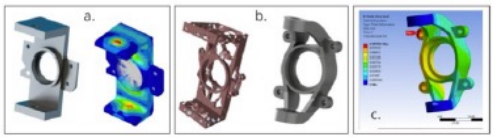
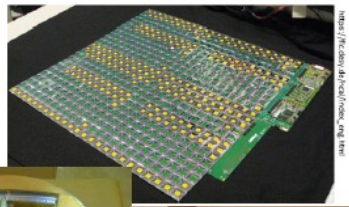
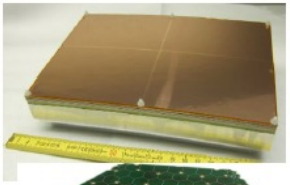
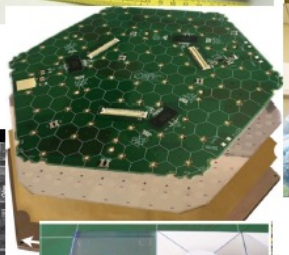


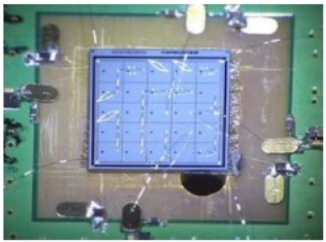
Figure 1: Example of 3D integration of sensor and readout chip.

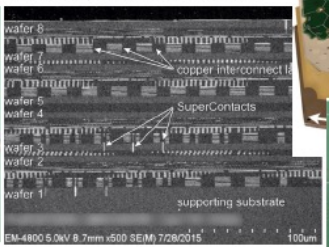


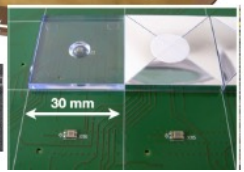












and for collider physics

Snowmass Takeaways Computing Frontier

- Long-term development, maintenance, and user support of essential software packages cutting across project or discipline boundaries is largely unsupported.
  - the US HEP community should take a leading role in long-term development, maintenance, and user support of essential software packages with targeted investment.
- Research and development (R&D) for software and computing cutting across project or discipline boundaries receive insufficient support.
  - through existing and reshaped funding programs, cross-cutting R&D efforts should be supported from proof of concept to prototyping and (if successful) to production ready deliverables
- Scarcity of personnel and expertise jeopardizes the ability for full and optimal use of heterogeneous and high performance computing (HPC) resources
  - support computing professionals/researchers, and physicists for code re-engineering and adaptation to use heterogeneous resources effectively. To serve the needs of inherently serial algorithms, traditional CPU-based hardware should coexist with heterogeneous resources
- Scarcity of personnel and expertise jeopardizes the ability for full and optimal use of heterogeneous and high performance computing (HPC) resources
  - documentation and training efforts at multiple levels should be encouraged and extended. To enhance their career opportunities, bridge positions and awards should be created for HEP scientists and engineers working on software and computing

CompF: Main Computing Recommendation

- We recommend the creation of a standing Coordinating Panel for Software and Computing (CPSC) under the auspices of **DPF** mirroring the panel for advanced detectors (CPAD) established in 2012

.

- *Promote, coordinate, and assist the HEP community on Software and Computing, working with scientific collaborations, grassroots organizations, institutes and centers, community leaders, and funding agencies on the evolving HEP Software and Computing needs of experimental, observational, and theoretical aspects of the HEP programs. The scope should include research, development, maintenance, and user support.*

Snowmass Takeaway
Community Engagement Frontier

1. Our goal and hope is that by the end of Snowmass 2021, all of us will be convinced of and committed to the following propositions:
   - It is critical that we all agree on the importance of everyone working together in CEF to organize and develop our ongoing CE efforts in a coherent manner focused on improving our HEP community and achieving the vision we are defining for our field.
   - A structure must be established within HEP for taking ownership and responsibility for implementing CEF recommendations and monitoring their progress across the entire field.
2. CEF is a Frontier that cuts across all other Frontiers, and everyone in HEP works within and is a part of CEF. Furthermore, there is no activity within our field that lies outside CEF. For these reasons, every activity in every Frontier is dependent on progress in the work of CEF.

By far the most surprising thing the conveners encountered was the extremely low participation in CEF by members of our field,

Community Engagement Frontier

Nevertheless, significant work was done over a very wide range of topics:

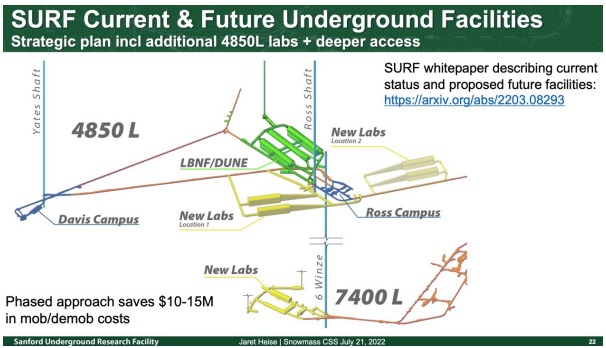
- Applications and Industry
- Career Pipeline and development
- Diversity, Equity, and Inclusion
- Physics Education
- Public Education and Outreach
- Public Policy and Government Engagement
- Environmental and Societal Impacts (sustainability)

Some High-Level Proposals:

1. A panel or program to shepherd CEF recommendations
2. Review CEF integration is Snowmass (separate workshop)

Snowmass Takeaways Underground Frontier

- Neutrinos, rare processes, and cosmic frontier experiments and enabling R&D require more spac than available
- Leverage the LBNF excavation enterprise to increase underground space at SURF in a timely and cost-effective way to allow the US to compete for siting nextgen WIMP dark matter experiments
- Make SURF an SDSTA-managed DOE User Facility to foster cross-cutting underground science in the US
- Invest in the diversity of people and expertise required for the design, installation, integration, and operations of this increasingly complex program



A Partial List of Key Issues

- How to promote and advance DEI?
- How to provide better support the members of our HEP Community, especially EC scientists
  - How can we support for the requested Early Career organization?
- How can we stay a vibrant field with the long timelines and few big projects?
- Fermilab Booster Upgrade and RPF experiments
  - What opportunities will there be for small and mid-size projects?
- The formation of an underground USER facility with an expanded SURF capability at 4850'.
- How to improve support for IF and AF to ensure continued development and transfer of expertise?
- How to provide sustained support for Computing?
- Quantum Science and Technology appeared for the first time
  - Where does it fit into HEP – will it be the11th Frontier for Snowmass 203X?

We have about two months to complete the Snowmass book

Personal View: Snowmass 2021 Achieved its Goals

Snowmass is critical piece of U.S. strategic planning

Unique, key elements of Snowmass

- Community driven
- Science driven
- Everyone can contribute
- Full coverage of the field
- Vision of what could be
- Brings science communities together
- Brings different generations of researchers together
- Defines key scientific questions and approaches

Snowmass results guide the direction of the field and are the scientific input to the next P5

On to P5

Snowmass was WONDERFUL!!!

Snowmass results will be critical input to P5

- The hard work was impressive and is an important documentation of visions for our field

Turning towards P5

- Every idea presented at Snowmass will receive due consideration
- Report is not written
- Decisions are not made
- P5 will take a fresh look at our project program
- P5 is a process and the process will be followed

Next P5 chair:

JoAnne Hewett

Preliminary P5 Timeline

- Form Panel by early fall
  - Call for nominations for P5 in early Aug 22
    - Deadline is 8/31
  - Panel members should wear a "community hat"
- Hold hybrid in-person/virtual town halls in fall of 2022
  - To gather additional community input and further information n potential future projects
  - To provide an opportunity for each Panel member to start on equal footing covering all frontiers
- Deliberations Winter/Spring 2023
  - With ample opportunity for additional community input
- Goal is for report in late spring/early summer 2023 for HEPAP to approve and submit to DOE/NSF

Considerations for Next P5 – H. Kung

(*Deputy Director for Science Programs Office of Science*)

- Grand, long-term, and global vision for the U.S. particle physics
- Realistic budget scenarios
- Balanced portfolio of small/mid-scale/large projects
- Must consider a holistic view of program
  - Project costs
  - Operations costs
  - Research program to deliver the science
  - Technology R&D for the future
- Community engagement, including this week's Snowmass study process, remains critical to success.

For a great "Community Summer Study and Workshop synthesis"

Snowmass 2021

- See outstanding talk by Prisca Cushman!

Summary and Outlook

- Despite all the challenges, an amazing amount of outstanding work has been done by this large US, international, and interdisciplinary community and we emerged from the July meeting, with the needed input to the Snowmass Book and P5.
- We will give P5 a thorough scientific of the most important physics opportunities, and the capabilities needed to achieve them
- We hope and expect that we will emerge from this 2021-22/2023 Snowmass/P5 with a program that will have the same or a higher level of community support than we achieved in 2013/2014!

Thanks to everyone in HEP and associated disciplines, in the US and other nations, who helped us to produce a great result!

Thank you for your attention!
Questions?

Backup Slides

FCC Feasibility Study 2021-2025

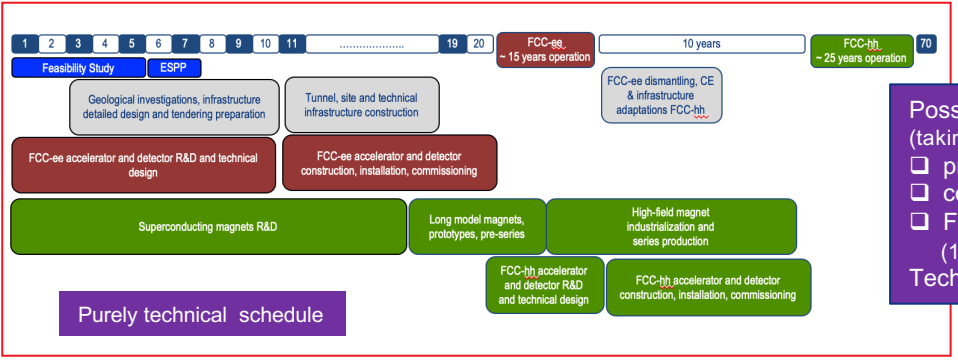
Numbers are for 100 km ring

	√s	L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	230 x10^{34} 28 8.5 1.5	75 5 2.5 0.8	2-4 experiments Total ~ 15 years of operation
pp FCC-hh	100 TeV	5 x 10^{34} 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	$\sqrt{s_{NN}}$ = 39TeV	3 x 10^{29}	100 nb^{-1}/run	1 run = 1 month operation
ep Fcc-eh	3.5 TeV	1.5 10^{34}	2 ab^{-1}	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb Fcc-eh	$\sqrt{s_{eN}}$ = 2.2 TeV	0.5 10^{34}	1 fb^{-1}	60 GeV e- from ERL Concurrent operation with PbPb

Potentially a multi-stage facility with immense physics potential (energy and intensity).

Feasibility Study:

- ❑ Focus is on FCC-ee and magnet R&D
- ❑ ~ 40 MCHF/year from CERN budget (half for magnet R&D)
  Additional funding from EU and collaborating institutes (e.g. CHART)
- ❑ Results will be summarised in Feasibility Study Report end 2025



Possible schedule
(taking into account resources constraints):

- ❑ project's approval by end of decade
- ❑ construction's start early 2030s
- ❑ FCC-ee operation: 2048-2063
  (10 years Z, W, H and 5 years tt)

Technical schedule: operation starts early 2040s

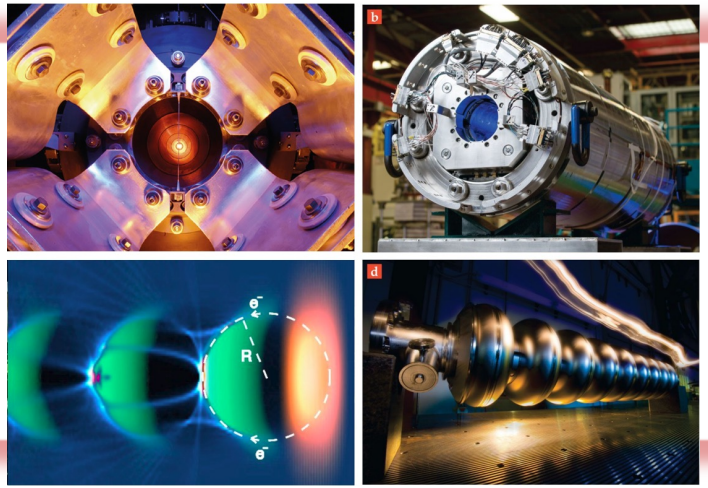
Accelerator R&D: Next Decade

Sources and Multi-MW targets:

- intense e^+ sources

- 2.4 MW for PIP-III

- 4-8 MW for a **muon collider**



Magnets for Colliders and RCSs:

- 16T dipoles
- 40T solenoids
- 1000 T/s fast cycling ones

…coordinated with US MDP

Wakefields:

- collider quality beams
- efficient drivers and staging
- close coordination with Int'l (Euro Roadmap, EUPRAXIA,..)

SC/NC RF:

- 70-120 MV/m C^3
- 70 MV/m TW SRF
- new materials
- high Q_0
- efficient RF sources

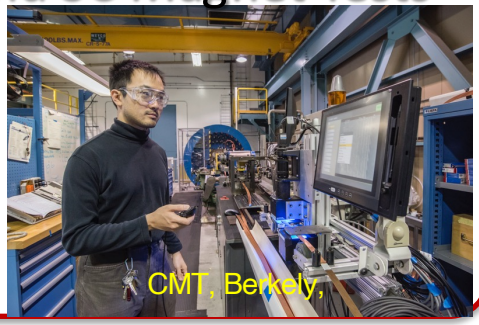
Accelerator and Test Facilities

Enable technology progress and beam research

Snowmass 2021

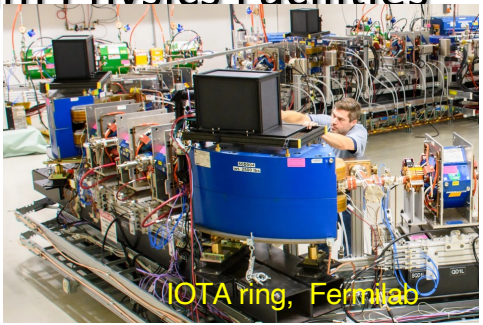
SRF and SC Magnet Tests

BNL
FNAL
LBNL
SLAC
Cornell



Beam Physics Facilities

FNAL
BNL
ANL



MISSING PIECE!

Facility for multi-MW beam targetry R&D and testing

Wakefield/Plasma Studies

SLAC
LBNL
UT-Austin
ANL
UCLA

P5 Recommendations for Energy Frontier

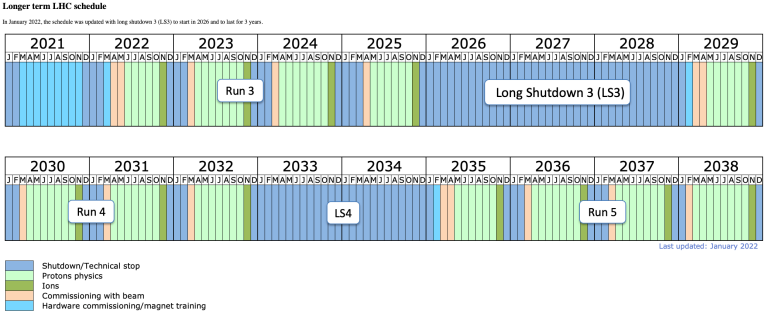
Snowmass 2013 Outcomes

- **Recommendation 10: The LHC upgrades constitute our highest-priority near-term large project.**
- **Recommendation 11**:Engage in **modest** and appropriate levels of **ILC** accelerator and detector **design** … Consider higher levels of collaboration if ILC proceeds.
- **Recommendation 24:** Participate in global conceptual **design studi**es and critical path R&D for future very **high-energy proton-proton colliders**. Continue to play a leadership role in superconducting magnet technology
- **Recommendation 26:** Pursue accelerator R&D. Focus on outcomes and capabilities that will dramatically **improve cost effectiveness** for mid-term and far-term **accelerators.**

Ahead and towards the High Luminosity LHC (HL-LHC) ~2027

Snowmass 2021

Snowmass 2013 Outcomes



New possible schedule

- LS3 start 25→ 26
  - (+1 year)
- LS3 length 2.5→ 3 years
  - (+0.5 years)
- Run-4 start 27→29
  - (1.5 years)
- **Run-5 start 32 → 35**
  - **(+3 years total)**

HL-LHC

- CMS and ATLAS continue to produce 2 papers/each/month
- They are very enthusiastic about Run 3 – many new ideas
- They are working energetically on the HL-LHC Upgrade
- Contributed many new studies and proposed initiative for Snowmass and for the European Strategy Upgrade

P5 Recommendations for Neutrino Frontier

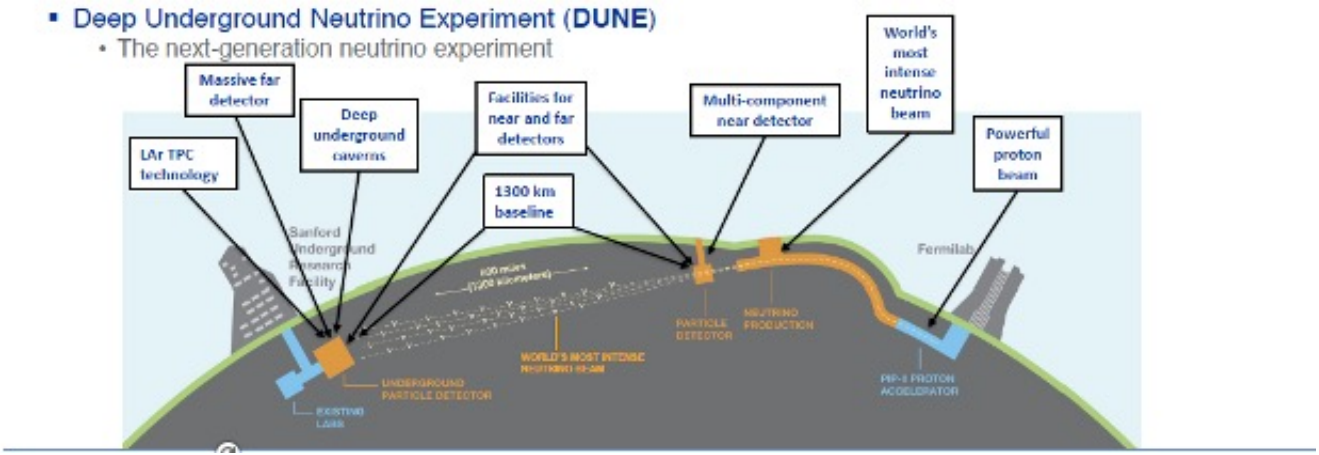
Snowmass 2013 Outcomes

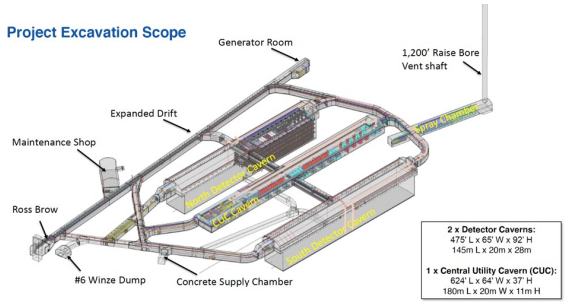
- **Recommendation 12:** In collaboration with international partners, develop a **coherent short- and long-baseline neutrino program hosted at Fermilab.**
- **Recommendation 13:** Form a new international collaboration to design and execute a highly **capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S.** To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. **LBNF is the highest priority large project in its timeframe.**
- **Recommendation 14**: **Upgrade the Fermilab proton accelerator com**plex to produce higher intensity beams. R&D for the Proton Improvement Plan II **(PIP-II)** should proceed immediately, followed by construction, to provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility.
- **Recommendation 15:** Select and perform in the **short term a set of small-scale short-baseline experiments** that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.

LBNF Dune

Snowmass 2021

Snowmass 2013 Outcomes





PIP-II/LBNF/DUNE

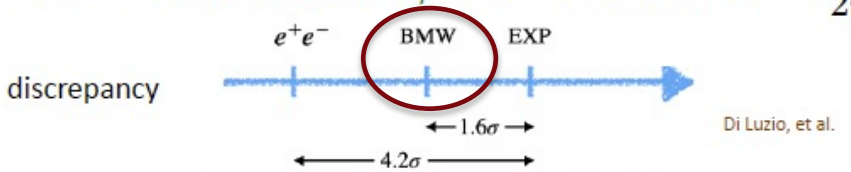
- Powerful Proton Beam (PIP-II, at FNAL))
- Deep underground caverns (So. Dakota)
- Dune detector ➔ 4 x 17 kT liquid Argon Detectors (So. Dakota)

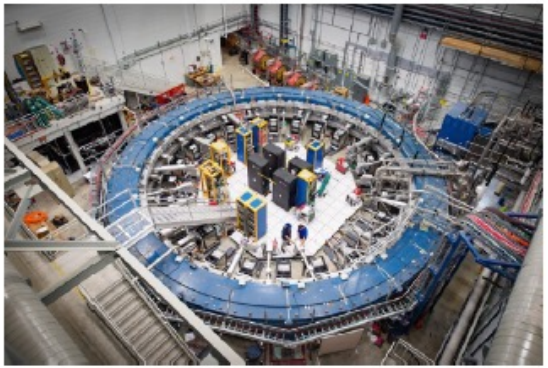
Muon g-2

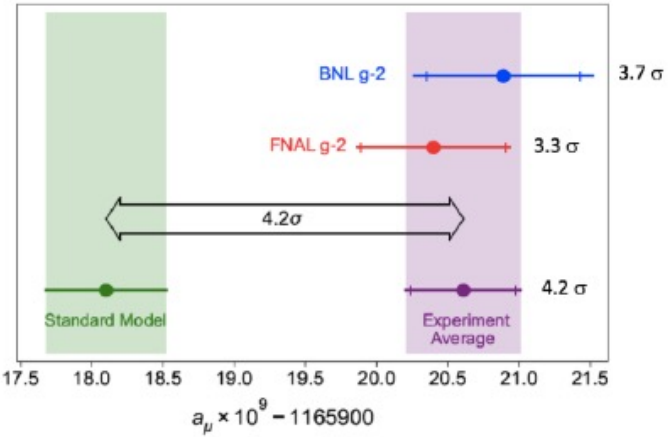
Snowmass 2021

Snowmass 2013 Outcomes

★ Muon's magnetic properties (g-2): $a_\mu = (g-2)/2$ with $\vec{\mu} = g\frac{e}{2m}\vec{s}$







FNAL (g-2): $a_\mu(\mathrm{Exp}) = 116592061(41) \times 10^{-11}$

$a_\mu(\mathrm{Theory}) = 116591810(43) \times 10^{-11}$

$a_\mu(\mathrm{BMW}) = 116591954(55) \times 10^{-11}$

Goal of Snowmass 2021

- This Snowmass Community Planning exercise is again organized by the Division of Particles and Fields (DPF) of the American Physical Society as
  - **A ~ year-long "Science" study** in which the entire HEP community comes together to identify opportunities and, to the extent possible, document a vision for the future of particle physics in the U.S. and its international partners.
  - Its narrative will communicate the opportunities for discovery in particle physics to the broader scientific community and to the government.
  - **It will provide a validated set of inputs to the next P5**, which is expected to begin its work in the late fall of 2022 and produce a report in the spring of 2023.
- Young-Kee Kim, DPF Chair, 2020: "DPF aims for everyone's voice to be heard. Your contributions and participation are critical for the success of Snowmass and they will naturally occur as part of one or more working groups directed by the conveners of the now 10 Frontiers"

For Snowmass 2021, the final meeting of Community Planning Exercise just took place at the **University of Washington in Seattle from July 17 to 26 in 2022**

P5 Report, May 2014

Snowmass 2021

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context

Report of the Particle Physics Project Prioritization Panel (P5) May 2014

Distilled from the Snowmass 2013 inputs, five Science Drivers for the field:

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles.

- 29 recommendations
- Projects prioritized according to funding scenarios

As a result, highly impactful on the

- Directions/achievements in HEP
- Federal funding profile

for the current and near-future projects in the decade.

Timing of this Snowmass

- The 2014 P5 recommendations are now “launched”, based on significant budget increases in FY2018-2021
- It is time to start defining the next strategic plan, which could start to get its first, early funding in 2024/25
- Other US Domestic Programs are moving forward with their programs, e.g. NAS Decadal survey on Astronomy and Astrophysics
- Global programs are also moving forward, for example,
  - 2017 JAHEP/KEK Roadmap
  - 2020 Update of the European Strategy for Particle Physics
  - Latin America: Strategy Forum for Research Infrastructure
  - ….

Aspirations over Time

- At Snowmass **2001**, goals were to discover the **Higgs**; detect **SUSY whose lightest members would be accessible at a 500 or 800 GeV linear collider**, explore the SUSY spectrum up to ~20TeV, where the heaviest members were expected to provide insight into the SUSY-breaking interactions.
- When the LHC was starting in 2010, **SUSY was considered the low-hanging fruit, observable in a few hundred pb^{-1}**
- By Snowmass 2013, the **Higgs was found** (7, 8 TeV), **SUSY not**!
- By **2015 -2018:** The LHC showed it **could study the Higgs at an unexpected level of precision,**
  - **still no SUSY and no new mass scale**

Current aspirations for many are to study the Higgs much better than we can at the HL-LHC and search for new particles, interactions at >~ 10 TeV

EF Recommendations on Muon Collider Program

- **Recommendation 25: Reassess the Muon Accelerator Program (MAP).** Incorporate into the GARD program the MAP activities that are of general importance to accelerator R&D… and consult with international partners on the early termination of MICE.

It would be wise to focus on **how circumstances have changed in physics, technology, and studies** that have made a reexamination of the status of directed muon collider R&D appropriate in 2024+

DESI

Snowmass 2021

Science Highlights

BERKELEY LAB

March 2022 Status on DESI

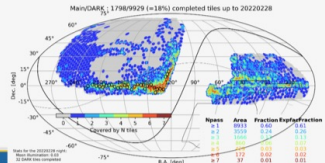
DESI taking data at full speed

- Instrument working remarkably well – reaching 150k spectra in a single night
- Passed the 10M redshift bar on February 13, 2022 (exceeding all previous spectroscopic samples)
- Now building up depth to achieve 1500-2000 deg² at nearly full depth for year-1 Key Projects
- Internal release in Feb. 28, 2022 of
- Commissioning + Survey Validation data to become first DESI data release by end 2022
- First 2 months DESI data (unblinded) for analysis tuning (following data blinded for year 1 analyses)

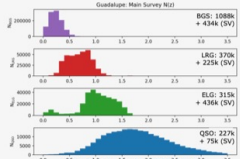
DESI coyote mascot recently named BaoBan by Tohono O'odham Nation Youth Council*

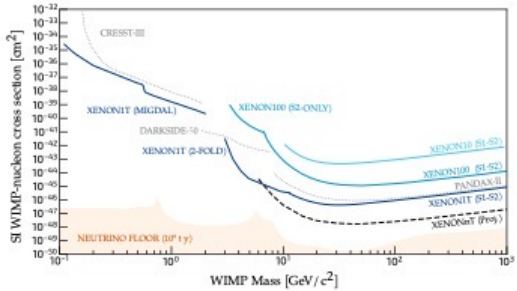
**connects Ban (O'odham word for coyote) with DESI observable BAO (which is also the sound a coyote makes)*

Footprint coverage to date



Redshift distribution (internal data release)

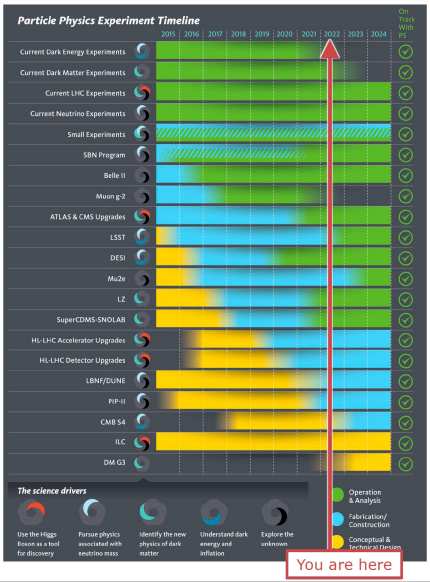




A Project Ready to "Approve"

- Is there a collider construction project ready to be presented for approval?
  - Physics Case
  - Demonstrated Technical Design
  - Host organization
  - Cost Estimate
  - Plausible demonstration of funding
  - Understanding of how risk will be "shared"
- Until something like this exists, it is not likely a project can move forward in the US

We have done a superb job of developing projects through the first two steps , as seen in this Agora series, but have not done so well at the remaining four tasks.



Successful implementation of the 2014 P5 strategy continues

Continuous physics analyses and output throughout the "P5 envisioned" 10-year plan

Even with extraordinary challenges due to COVID-19, there was great progress!

- **Projects fully funded or ongoing as of FY 2022:**
  - **Initial Phase-1 LHC detector upgrades: ATLAS and CMS**
  - **Mu2e**
  - **SuperCDMS at SNOLAB (DM-G2)**
- HL-LHC accelerator and detector upgrade projects underway
- LBNF/DUNE & PIP-II schedules advanced due to strong support by the U.S. Administration & Congress; Muon g-2 is operating
- DESI, LZ and LSSTCam (for Rubin Observatory) projects completed; CMB-S4 in concept planning
- Broad portfolio of small projects running

Harriet Kung

The previous "Snowmass" occurred in 2013

A year-long community-wide effort,
culminating with
"Snowmass on the Mississippi"
July 29 – August 6, 2013

(~700 participants)

The need for Snowmass 2021

Snowmass 2021

Snowmass Goals: **Snowmass is a scientific study**

To define the most important questions for the field of particle physics

To identify promising opportunities to address them

- **Timing:** 2014 P5 recommendations are being favorably carried out: Significant increase in FY2018-21; Continued support in FY2022.
  It is time to embark the next strategic plan: aiming at FY2024-25.
  - **Related US domestic programs:**
    - NAS Decadal survey on Astronomy & Astrophysics (2020)
    - NAS survey on Elementary Particle Physics (EPP2024)
  - **Global programs:**
    - 2017 JAHEP/KEK Roadmap: SuperKEKB; J-PARC; Hyper-K; ILC …
    - 2020 Update of European Strategy for Particle Physics
    - Latin America: Strategy Forum for Research Infrastructure