U.S. DEPARTMENT OF ENERGY | Office of Science

HEP Program Status and Strategic Planning

Snowmass Community Summer 2022 Study

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Particle Physics Is a Global Field

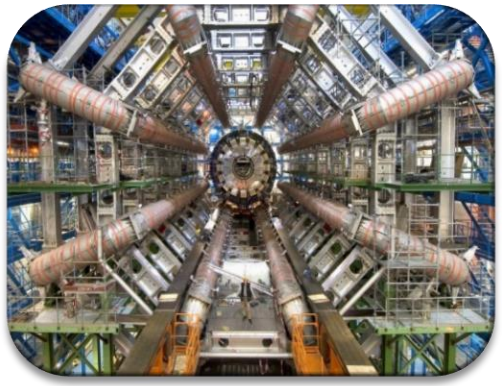
From Chapter 1 of the 2014 P5 Report:

- "The scientific program required to address all of the most compelling questions of the field is beyond the finances and the technical expertise of any one nation or region."

- "The capability to address these questions in a comprehensive manner is within reach of a cooperative global program."
- "The field is at a juncture where the major players each plan to host one of the large projects most needed by the worldwide scientific community."

Office of High Energy Physics at a Glance

FY 2022 Enacted Budget: $1.078B



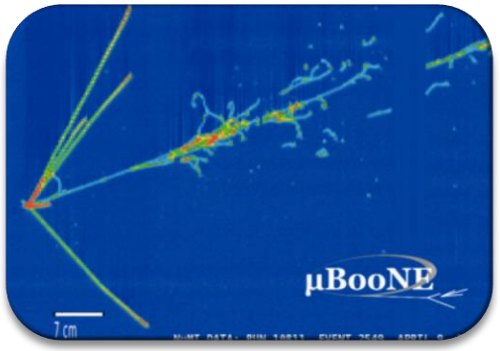
Largest Supporter (**~85%**) of Particle Physics in the U.S.

Funding at **>160** Institutions, including **12** DOE Labs

Over **1,100** Ph.D. Scientists and **500** Grad Students Supported

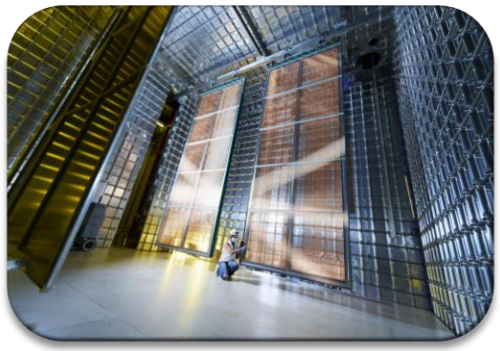
Over **2,400** Users at **2** SC Scientific Facilities

~31% of Research to Universities



Research:
39%, $425M

Facility Operations:
27%, $287M



Projects/Other:
34%, $366M

FY 2022/23 HEP Budget Highlights

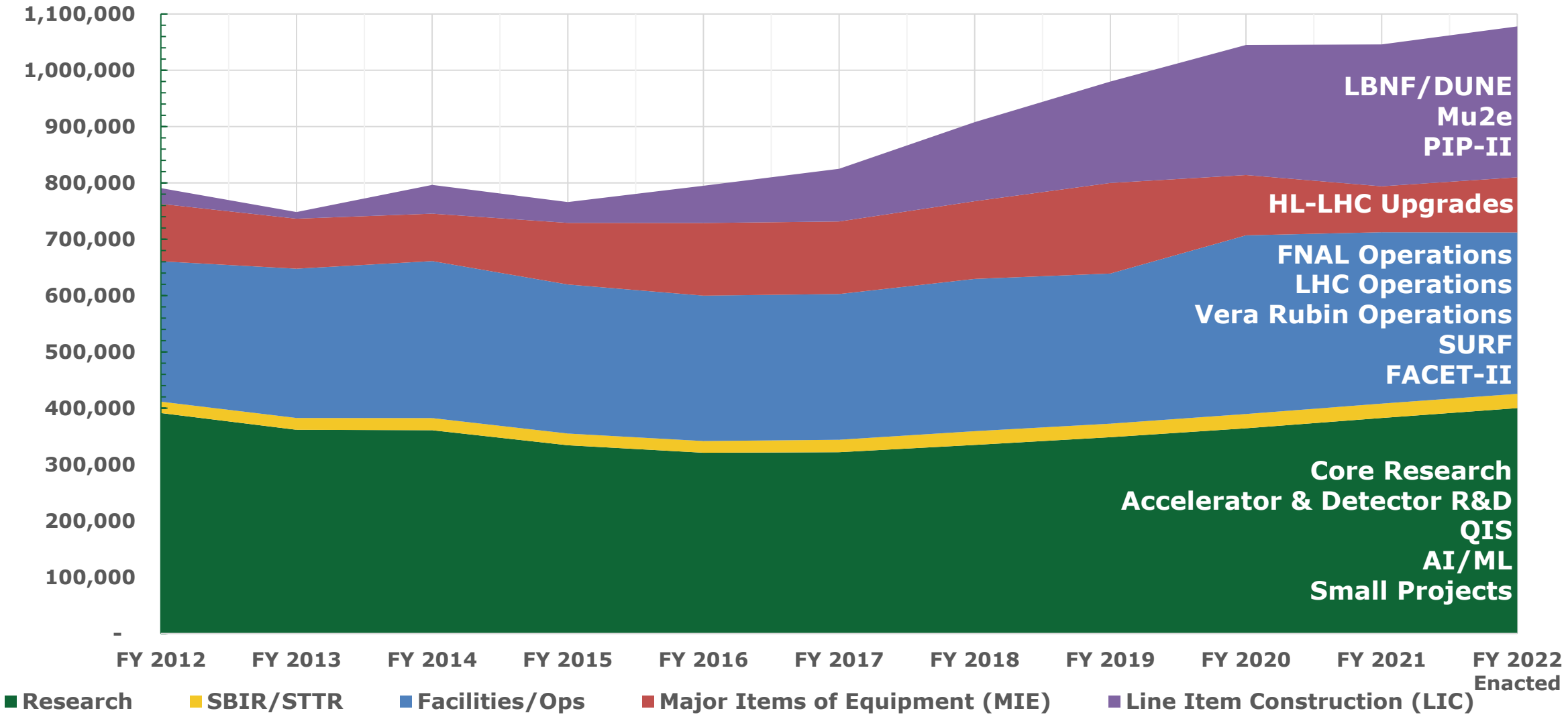
HEP Budget ($ in K)	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Enacted	FY 2023 Request	FY 2023 House Mark
HEP Research*	814,000	794,000	810,000	824,020	860,000
Line-Item Construction	231,000	252,000	268,000	298,000	298,000
HEP Total	**1,045,000**	**1,046,000**	**1,078,000**	**1,122,020**	**1,158,000**

** HEP Research includes MIEs and Operations*

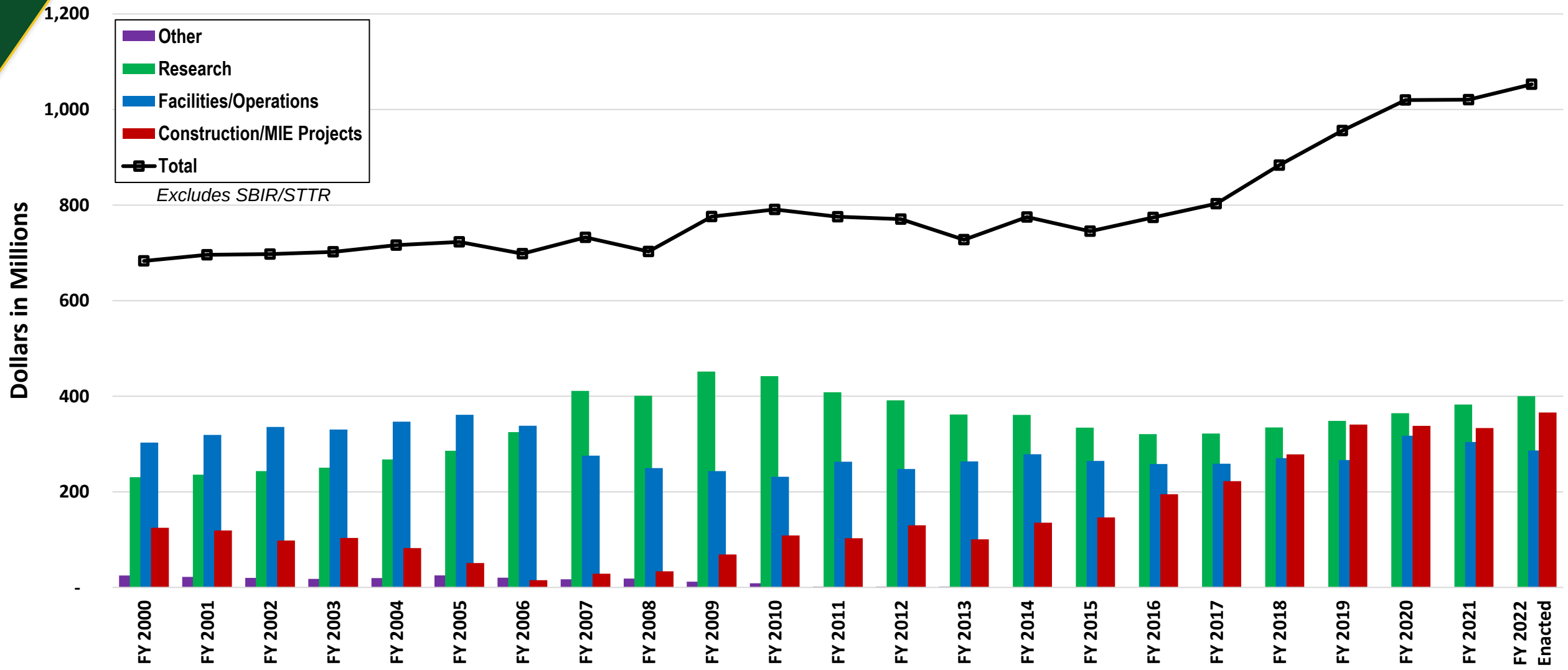
- High priority areas for **core HEP research** include theoretical and experimental activities in pursuit of discovery science; fostering a diverse, highly skilled workforce; building R&D capacity; driving technology innovation; and conducting world-leading advanced technology R&D
- HEP supports **SC-wide 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

HEP Budget ($k) FY 2012-2022

Research, Operations, Projects: (Construction and MIEs)

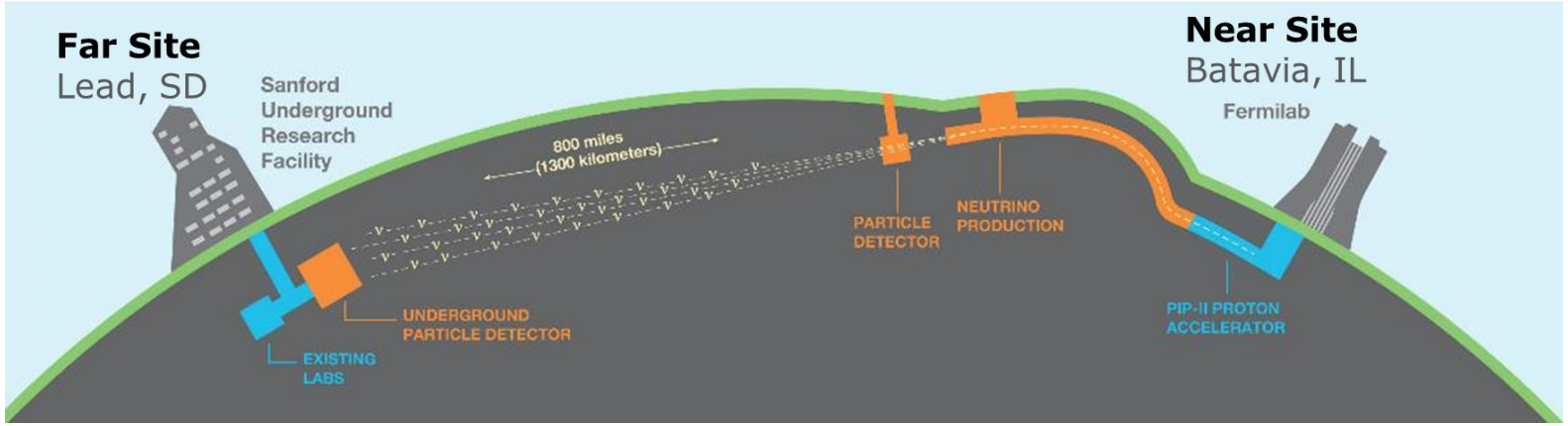


HEP Budget by Component FY 2000-2022



Global Support and Status of LBNF/DUNE & PIP-II

- Success of LBNF/DUNE and PIP-II relies on the expertise, facilities, and capabilities from international partners
  - Major partners include CERN, France, India, Italy, and UK

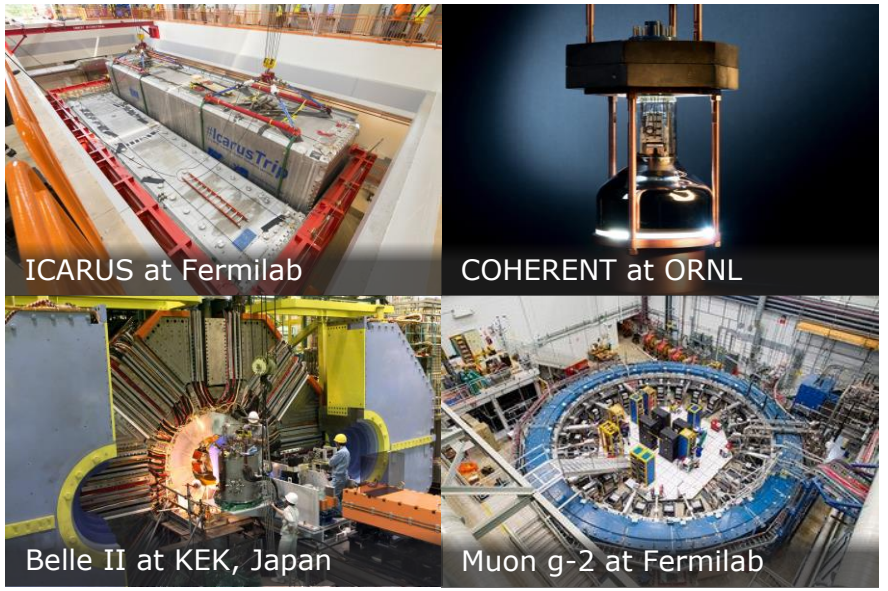


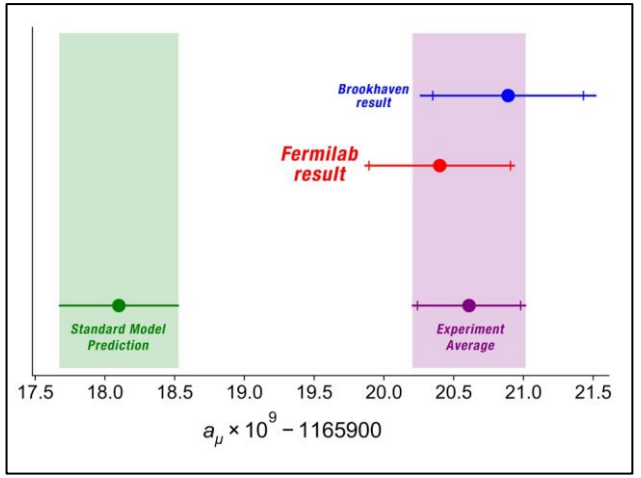
- U.S. investments in LBNF/DUNE and PIP-II matched by international contributions of ~$966M
- Project management has made significant progress and improvements
  - Reorganization into subprojects along with improvements in project management and oversight have been implemented and show clear benefits
  - New funding guidance from SC significantly improves the project schedule, reduces risks and is responsive to partners and HEP community concerns
  - LBNF and PIP-II will enable DUNE to be a first in class experiment. Further capabilities will be considered by next P5.
- DOE's LBNF/DUNE CD-1RR Review held on July 11-15, 2022
  - Recommended approval to proceed with the CD-1RR, pending re-evaluation of the total project cost and the cost range.

Intensity Frontier

Intensity Frontier advances 3 of the 5 science drivers: **Neutrinos**, **Dark Matter**, and **Exploring the Unknown**

- **Pursuing physics associated with the Neutrino mass**
  - Neutrino beam experiments: NOvA, MINERvA, Fermilab Short-baseline Neutrino program, SUPER-K, and T2K
  - Neutrino new initiatives: COHERENT and PROSPECT (ORNL)
  - Preparing to host world-leading LBNF/DUNE neutrino program
- **Identifying the new physics of Dark Matter**
  - Support for provisional future experiments: LDMX, HPS, LANL beam dump expt., and other accelerator-based light dark matter
- **Exploring the Unknown through precision experiments**
  - Rare decay programs: Belle-II and K0TO
  - Muon programs: Muon g-2 and Muon-to-Electron Conversion (Mu2e)



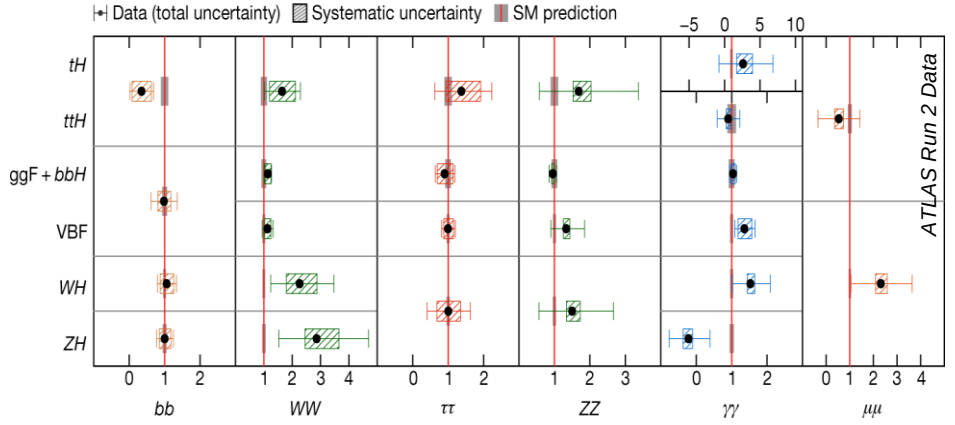


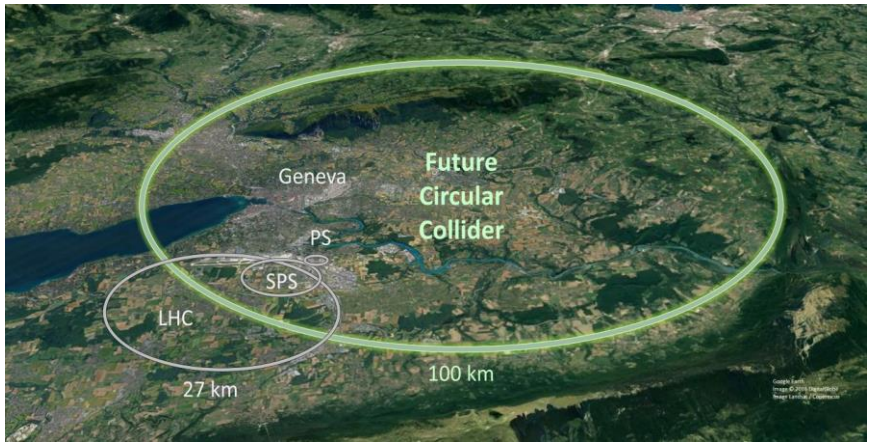
The first Muon g-2 results from Fermilab, when combined with the Brookhaven results, show a deviation from theory at a significance of 4.2 sigma (or standard deviations). Analysis of additional data is underway.

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





Cosmic Frontier – Progress & Future

Cosmic Frontier has grown into a critical part of the HEP program

Cosmic phenomenon are used to study the fundamental nature of matter, energy, space and time in areas complementary to accelerator experiments, aligned with the P5 Science Drivers

→Cosmic Acceleration to study the phases of the cosmos:

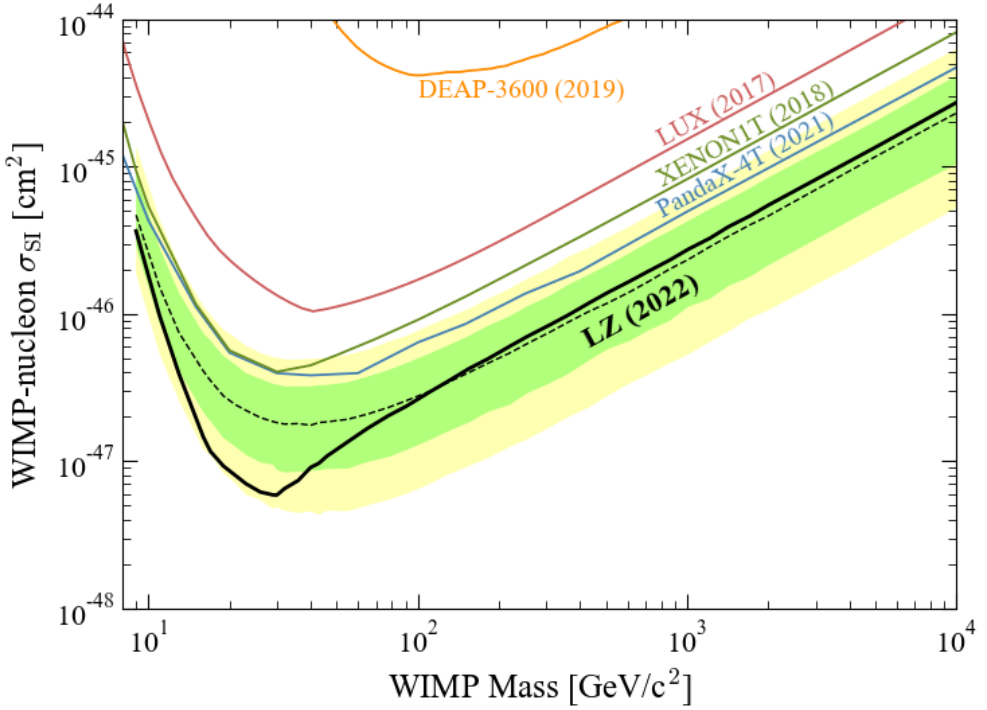
- Nature of Dark Energy: DESI and Rubin Observatory/LSST Camera
- Peer into the era of Inflation with SPT-3G and CMB-S4
- Search for the Dark Ages signal using LuSEE-Night pathfinder

→Dark Matter:

- Direct Detection Dark Matter searches: ADMX-G2, LZ, SuperCDMS-SNOLAB, Dark Matter New Initiatives concepts

→Neutrinos:

- Constrain neutrino properties using dark energy survey & CMB data

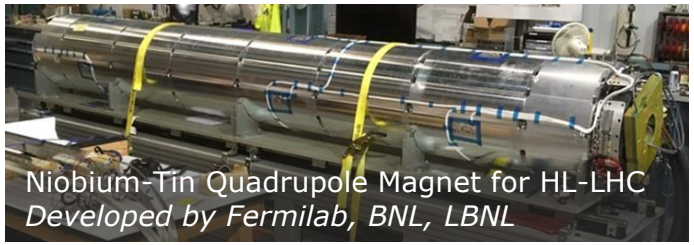


LZ's First Results released on July 7, 2022

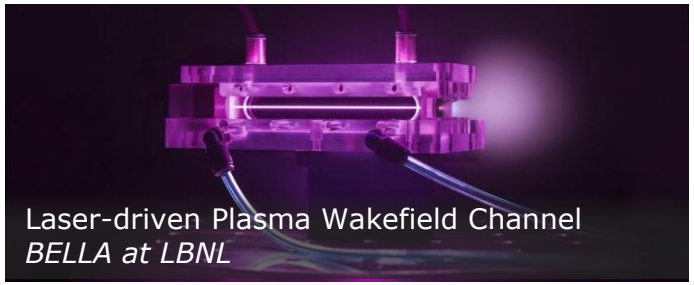
LZ, the world's largest direct-detection dark matter detector, has already set the world's most sensitive limits over a large mass range for WIMPs (weakly interacting massive particles), with only 60 days of data-taking. The experiment will continue its search.

Advanced Detector and Accelerator Technology and R&D

- Advanced detector technology
  - Basic Research Needs on High Energy Physics Detector R&D identifies strategic technology areas for future long-term R&D investments by DOE in pursuit of the HEP science drivers
- High-field magnets to enable future colliders
  - Accelerator R&D guided by the 2020 updated roadmaps for the U.S. Magnet Development Program
- Superconducting radiofrequency (SRF) accelerators
  - Expertise and continued R&D enable reliable next-generation accelerators, including PIP-II, Higgs Factories, LCLS-II, and FRIB
- Advanced accelerator concepts
  - Advanced Accelerator Development Strategy Report provides roadmaps for wakefield accelerator technology that could enable a future multi-TeV collider
  - FACET-II upgrades will provide unique capabilities for plasma-driven wakefield acceleration

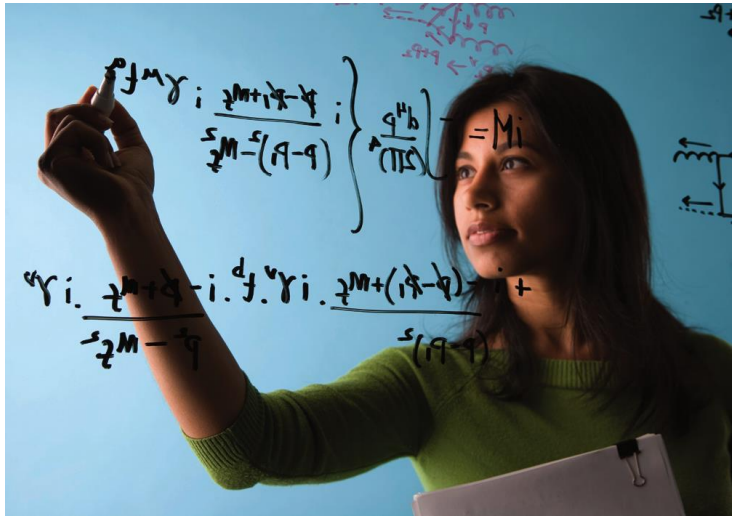

Niobium-Tin Quadrupole Magnet for HL-LHC
Developed by Fermilab, BNL, LBNL


LCLS-II SRF Cavity Processing
Photo credit: Fermilab


Laser-driven Plasma Wakefield Channel
BELLA at LBNL

HEP Theory Program

- A thriving HEP Theory program is necessary to provide the vision and the mathematical framework for understanding and extending our knowledge of particles, forces, space-time, and the universe



- Exciting areas seeing rapid development are:
  - Dark matter phenomenology, particularly light dark matter
  - The structure of black holes and the nature of quantum gravity
  - Cosmology and the nature of dark energy
  - Experimental puzzles like Muon *g*-2, the *W*-boson mass
  - Planning for the future with strong involvement at Snowmass

- HEP Theory supports HEP Experiments by devoting resources to programmatic priorities
  - Computational resources to support lattice calculations advancing the experimental program
  - The Neutrino Theory Network provides theoretical support for our neutrino experiments

HEP Core Research & SC Research Initiatives

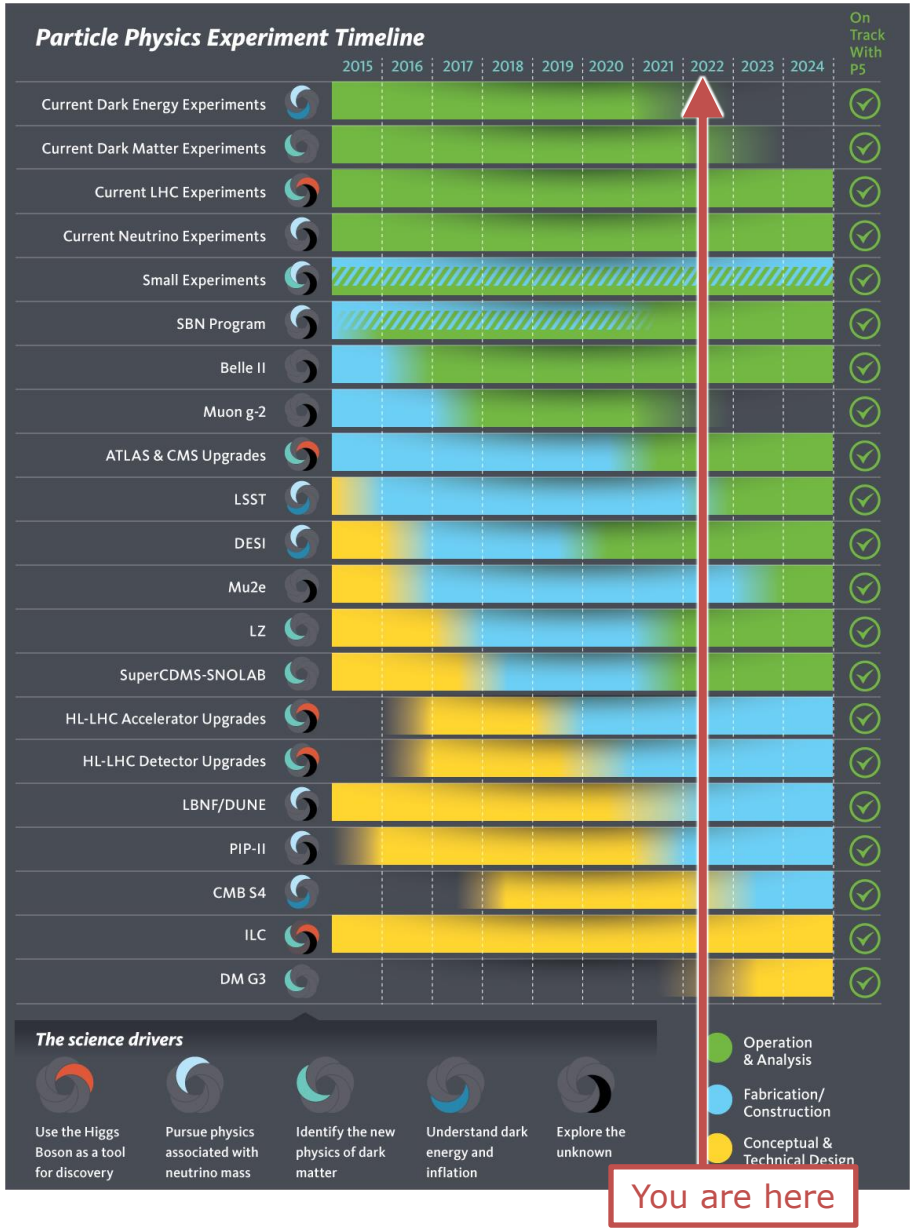
- Our mission is to deliver the science
- HEP core research as well as operations support are necessary to realize the science opportunities offered by building Projects
  - HEP-style projects also require coordinated research and operations support for design, R&D, testing, integration, installation, and commissioning
  - Balancing research and operations with the needs of current and future Projects requires careful prioritization
- SC Research Initiatives offer opportunities for HEP to contribute to high-priority, cross-cutting efforts
  - HEP brings unique capabilities and expertise in AI/ML, QIS, Microelectronics
  - Provides the opportunity for HEP to benefit from advances, potentially growing the core research program

P5: Considerations When Looking Ahead

Key Elements of a Successful P5

- Well informed by the science community
- Set a grand long-range vision for U.S. particle physics
- Faced budget constraints realistically
  - "Community made tough choices."
- Balanced portfolio
  - Domestic and international
  - Small, mid-scale, and large projects
- Community engagement critical to success
  - "Bickering scientists get nothing."

P5 Implementation Status



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

Community Engagement in 2014 P5 Process

- The May 2014 U.S. P5 report was successful because it was **well informed by the science community**, including information from:
  - 2010 New Worlds, New Horizons in Astronomy and Astrophysics
  - 2012 Report of the Subcommittee on Future Projects of High Energy Physics (Japan)
  - 2013 Update of the European Strategy for Particle Physics Report
  - 2013 U.S. Particle Physics Community-driven "Snowmass" process
- Community **engagement continued during** the P5 process:
  - Public website for providing news, receiving input
  - Public meetings, including in-person and virtual "Town Halls"
  - Engagement with experiments/projects to understand scope and estimated cost
  - Outreach and engagement with full community, including early career stages
  - Regular P5 presentations at HEPAP, including preliminary comments
- P5 report **rollout included targeted engagement** with HEP community, science interested public, and decision makers
  - Annual efforts to update community communications materials aided in continued engagement
- Initial and continuing **community support for P5 strategy** has been critical to successful implementation

U.S. Particle Physics Strategic Planning Process

- Each of these processes provides important input to the next P5 strategic process
  - Updated 2020 European Strategy for Particle Physics
  - NAS Astronomy and Astrophysics Decadal Survey (2021)
  - 2021-2022 Community Snowmass Process
  - New NAS Decadal Survey in Elementary Particle Physics
  - Upcoming HEPAP Report on International Benchmarking
- The next P5 process is planned to begin in Fall 2022
  - A P5 report by Spring 2023 would inform FY 2024 Congressional actions and the FY 2025 U.S. budget formulation process

Snowmass, NAS, HEPAP Studies Inform P5

- Snowmass provides the community's scientific vision
- NAS Decadal Survey is the external, independent vetting of the science, plus broader and/or new perspectives
- HEPAP International Benchmarking informs the global nature of the program

HEPAP

Considerations for Next P5

- Grand, long-term, and global vision for 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

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