U.S. DEPARTMENT OF ENERGY | Office of Science

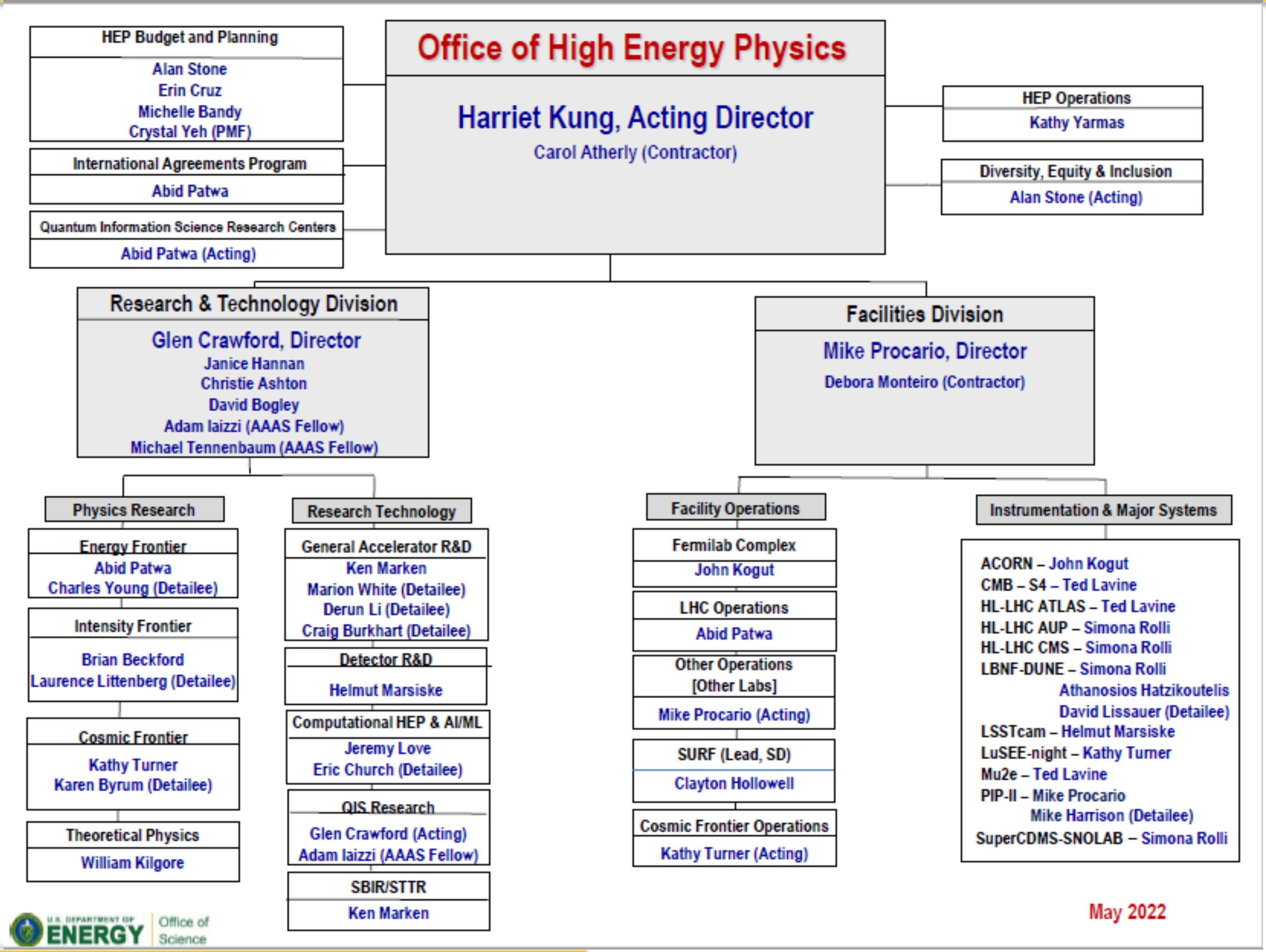
55th Annual Users Meeting

Glen Crawford, Director of Research and Technology R&D

DOE Office of High Energy Physics

June 13th, 2022

HEP Organization Chart



In the past year, HEP said goodbye to:
Associate Director Jim Siegrist
John Boger
Altaf Carim
Lali Chatterjee
L.K. Len

And we welcomed:
Acting Director Harriet Kung
Athanasios Hatzikoutelis
Jeremy Love
Crystal Yeh

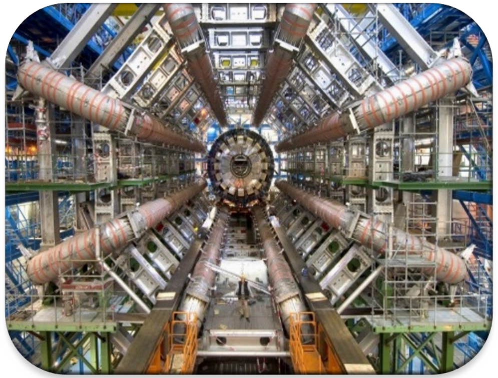
Additional new hires underway in Facilities and Research

Welcome New DOE Office of Science Director

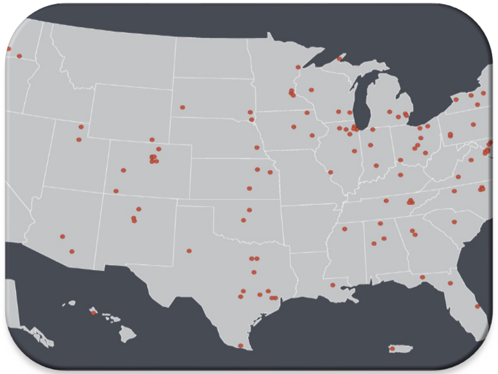
Welcome Dr. Asmeret Berhe, our new DOE Office of Science Director!

Office of High Energy Physics at a Glance

FY 2022 Enacted: $1.078B



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

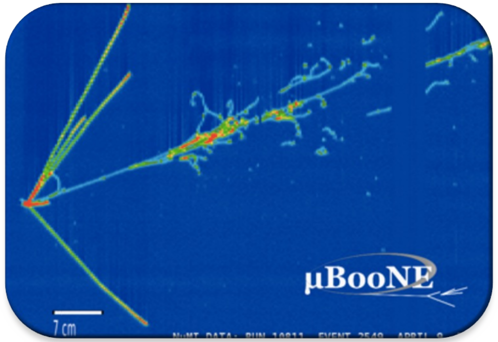


Funding at **>160** Institutions, including **12** DOE Labs

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:

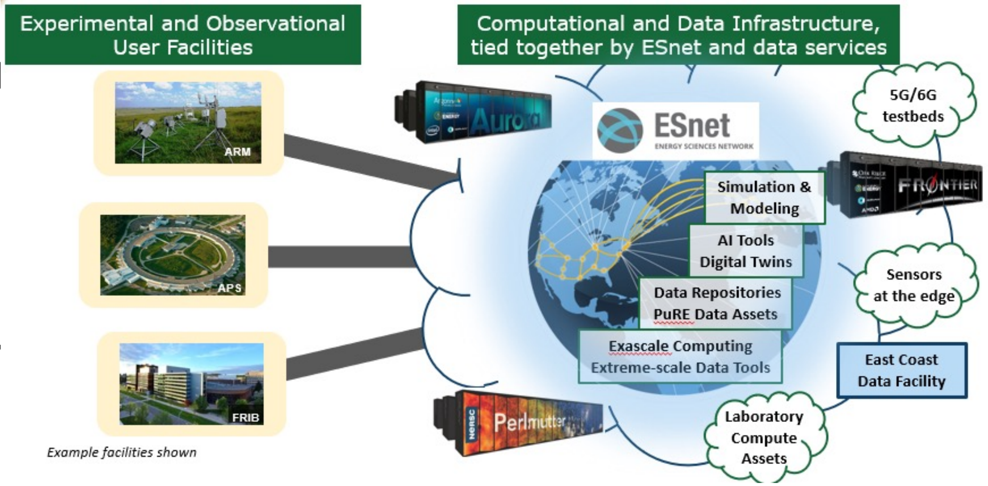
27%, $287M

Projects/Other:

34%, $366M

FY 2022 HEP Budget Highlights

- Supports SC-wide research initiatives:
  - **Reaching a New Energy Sciences Workforce (RENEW)**
  - Continues **QIS, AI/ML, Microelectronics, Integrated Computational and Data Infrastructure,** and **Accelerator Science and Technology initiatives.**
- Funding supports operations at Fermilab Accelerator Complex (88%) and the Facility for Advanced Accelerator Experimental Tests II (90%) of optimal.
- Full support for Infrastructure improvements at SURF.
- Continued support for 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.



Sanford Underground Research Facility (SURF) Refurbishment and Upgrades

FY 2023 Budget Request Highlights

(B/A in thousands)

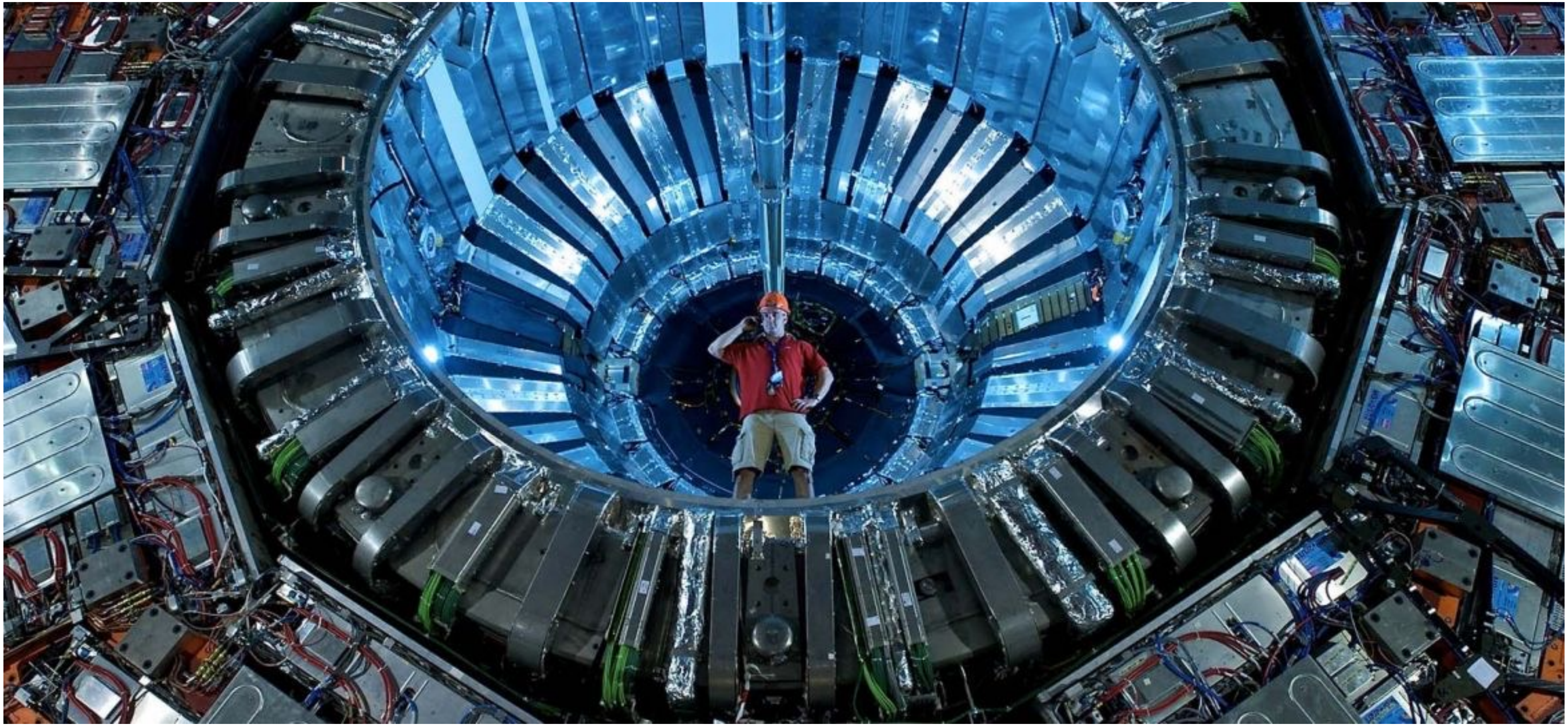
	FY 2021 Enacted	FY 2022 Enacted	FY 2023 Request	FY 2023 Request vs FY 2022 Enacted		FY 2023 Request vs FY 2021 Enacted	
High Energy Physics							
HEP Research	794,000	810,000	**824,020**	14,020	1.73%	30,020	3.78%
Program Subtotal	**794,000**	**810,000**	**824,020**	**14,020**	**1.73%**	**30,020**	**3.78%**
18-SC-42, PIP-II, FNAL	79,000	90,000	**120,000**	30,000	33.33%	41,000	51.90%
11-SC-40, LBNF/DUNE	171,000	176,000	**176,000**	...	...	5,000	2.92%
11-SC-41, Muon to Electron Conversion Experiment	2,000	2,000	**2,000**	...	...	...	...
Construction Subtotal	**252,000**	**268,000**	**298,000**	**30,000**	**11.19%**	**46,000**	**18.25%**
Total High Energy Physics	**1,046,000**	**1,078,000**	**1,122,020**	**44,020**	**4.08%**	**76,020**	**7.27%**

- The Request continues support for three Line-Item Construction Projects:
  - Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (**LBNF/DUNE**)
  - Proton Improvement Plan II (**PIP-II**), and
  - Muon to Electron Conversion Experiment (**Mu2e**)
- The Request will also continue five Major Item of Equipment (MIE) projects:
  - High-Luminosity Large Hadron Collider (HL-LHC) **Accelerator, ATLAS,** and **CMS Detector** Upgrade Projects;
  - Accelerator Controls Operations Research Network (**ACORN**); and
  - Cosmic Microwave Background Stage 4 (**CMB-S4**)

FY 2023 Budget Request Highlights

- High priority areas for **core 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
- In partnership with SC programs, HEP will continue support for: **QIS, AI/ML, Microelectronics, Advanced Computing, Accelerator Science and Technology,** and **RENEW; Accelerate Innovations in Emerging Technologies (Accelerate);** and **Funding for Accelerated, Inclusive Research (FAIR)**
- Funding support to operate **Fermilab Accelerator Complex** (87% of optimum) and **FACET-II** (91% of optimum).
- 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 detectors at the Large Hadron Collider (LHC) at CERN in Geneva, Switzerland;
  - Sanford Underground Research Facility (SURF) in Lead, South Dakota, and the LZ dark matter experiment at SURF;
  - Vera C. Rubin Observatory in Chile;
  - Dark Energy Spectroscopic Instrument (DESI) at the Mayall telescope in Arizona; and,
  - Experiments hosted in Canada, Japan, and on the International Space Station.

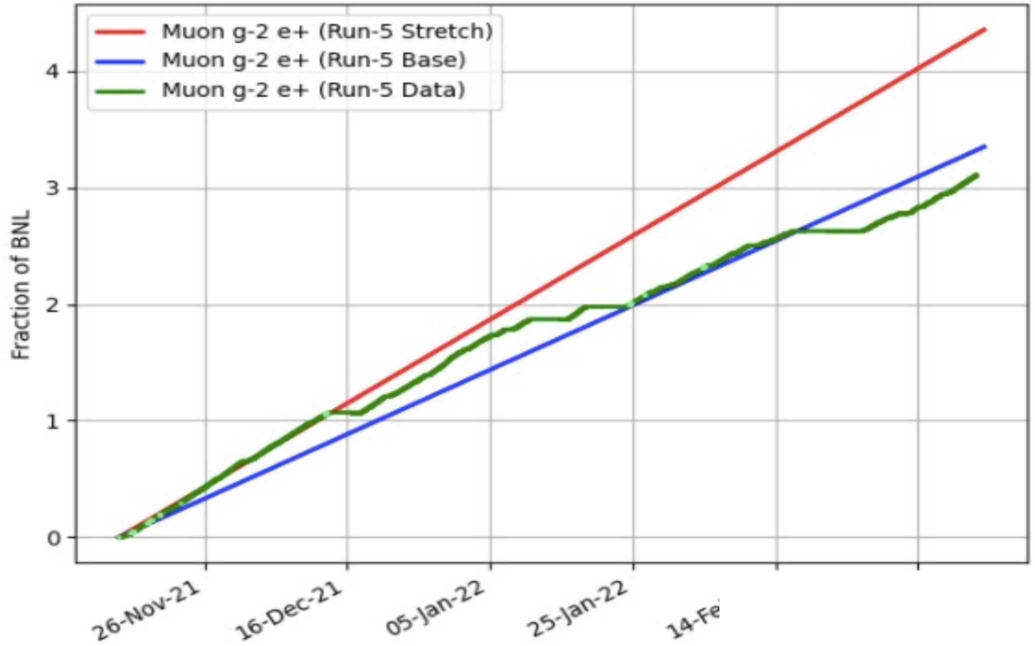
Science Highlights



Muon G-2 Operations

Number of positrons hitting calorimeters (our proxy for stored muons) CTAGs

Fraction wrt number of electrons/positrons in BNLs final result



3.1 BNLs so far Run 5, 16.0 total all runs

Still accumulating at a good rate when accumulating.

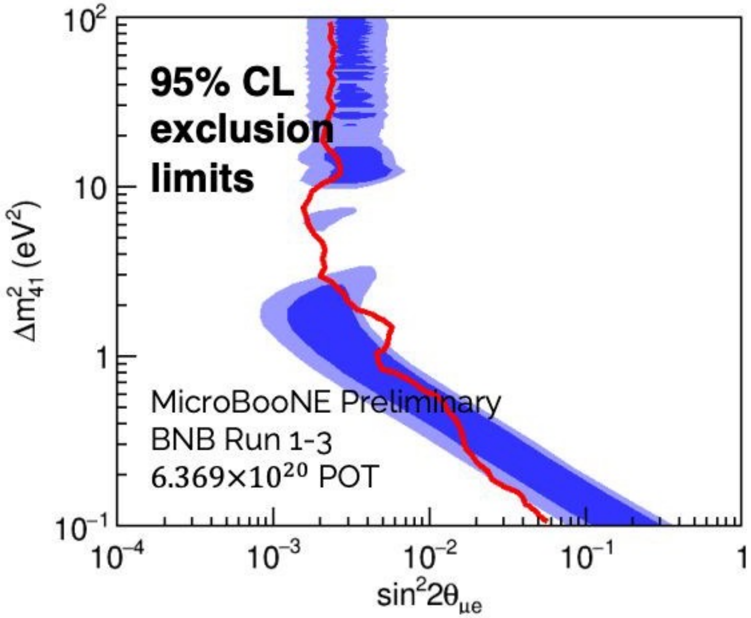
Blue line (base) derived from average running from previous year

Red line (stretch) derived from best achieved rate from previous year

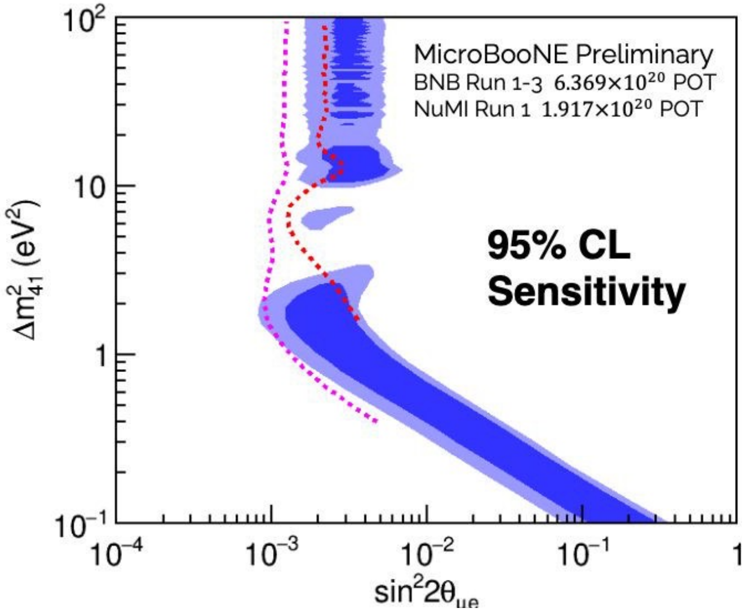
Storing ~10-20% less beam.
Past, typically 450-500 high energy positrons recorded per fill. Now need regular tuning to stay above 400

New results at Neutrino 2022 Conference

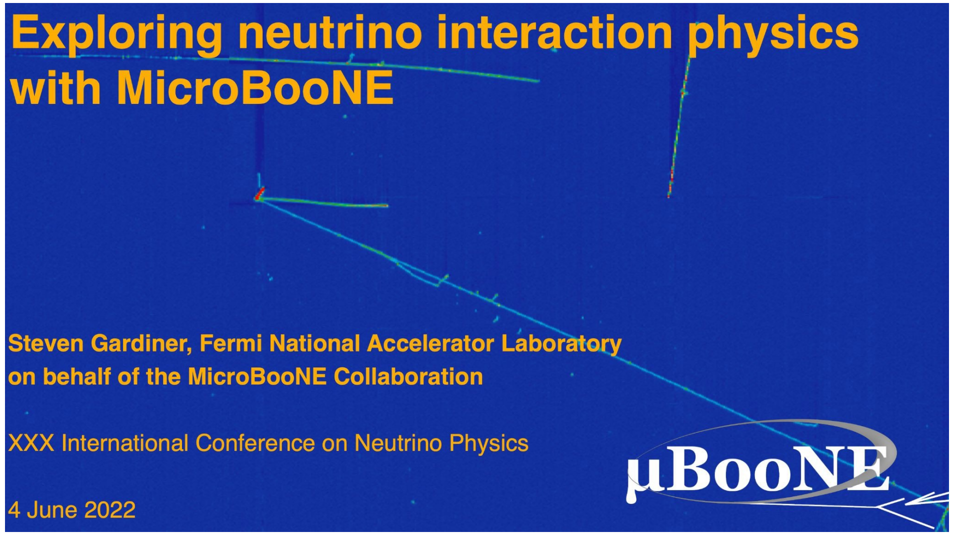
Oscillation fits



Projected Sensitivity



Multiple cross-section measurements

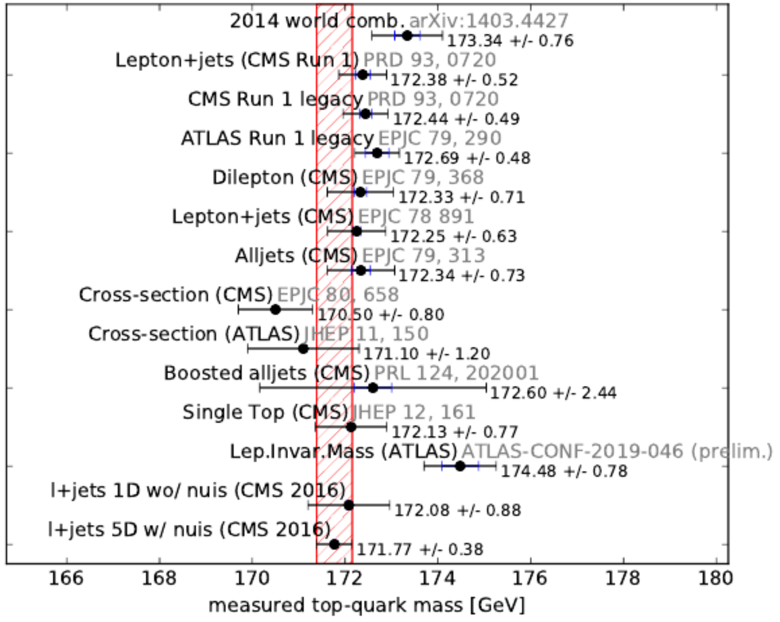


Developing new measurement techniques, calibrations, and tools with data that will benefit SBN, DUNE

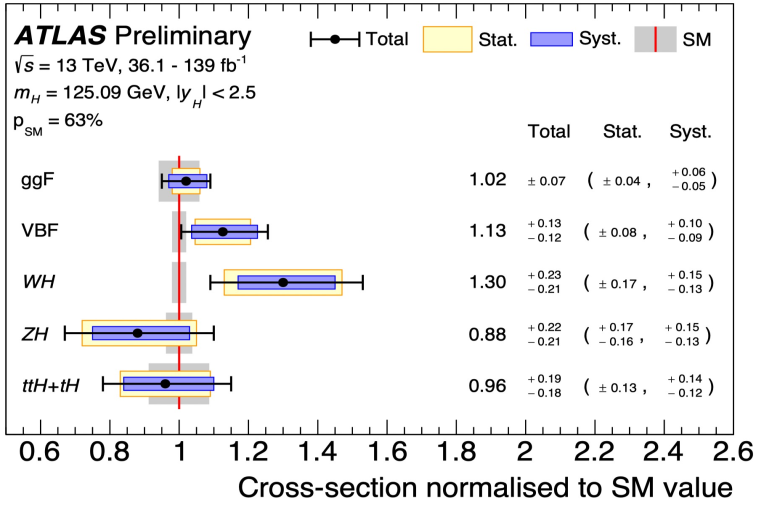
Wire-Cell inclusive analysis shown above;
also oscillation results from deep-learning based analysis

LHC Highlights

- Most precise top mass measurement by CMS
  - m_{top} = 171.77 ± 0.38 GeV
- Top mass measured by fitting 5 uncorrelated observables and includes multiple statistical checks to ensure no double counting
- Strong constraint of jet-related uncertainties from the reconstructed W-mass (one of the observables)



- ATLAS: Higgs boson couplings based on the full Run 2 data
- Global fits yield signal strength measurement:
  - μ = 1.06 ± 0.06
- Precision of Higgs coupling measurements continually improve at the LHC

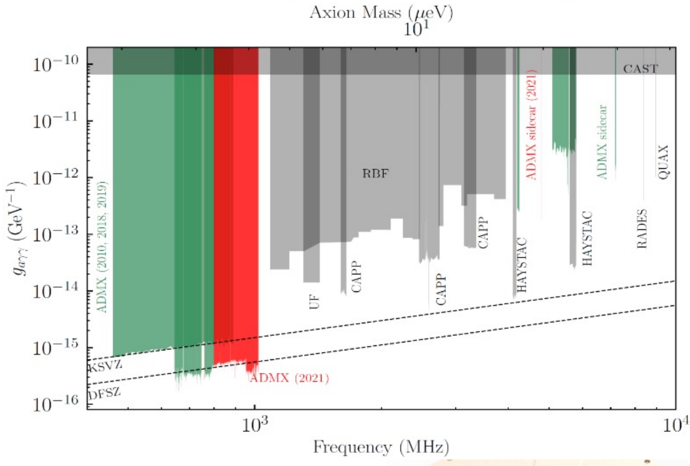


- **DOE looks forward to more LHC results from the rich physics program in Run 3 beginning this year!**

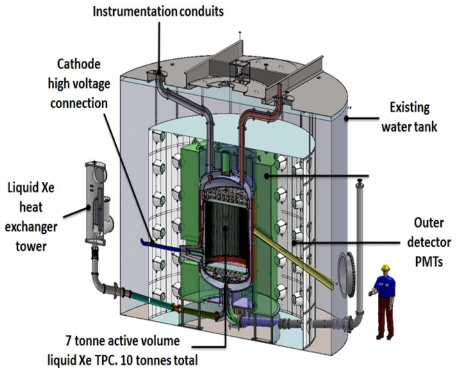
DOE/HEP Cosmic Frontier: Dark Matter

Suite of 3 “gen-2” direct detection search experiments following the 2014 P5 recommendation; variety of particle types over a wide mass range.

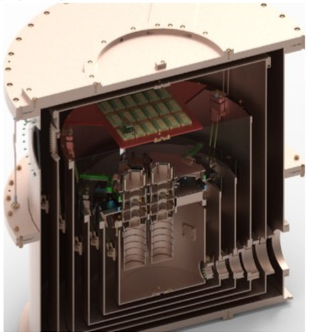
ADMX-G2 2021 results are 5-orders of magnitude better than previous limits, ruling out axion DM hypothesis in this mass-coupling range; continues operations & planned upgrades to search next range



LZ operates a mile underground in S. Dakota to search for WIMPs using liquid Xenon detector; Commissioning complete late 2021

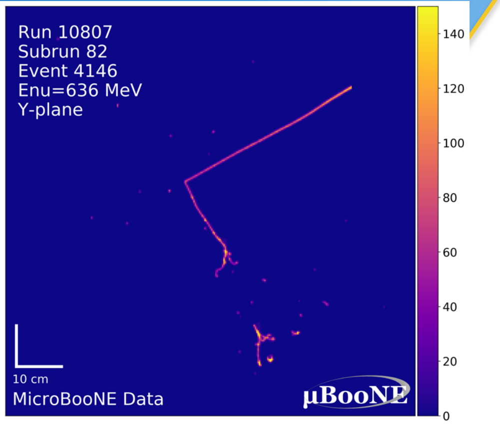


SuperCDMS SNOLAB Solid-state WIMP search detector Creighton nickel mine in Canada (HEP+NSF). Fabrication and partial operations in 2023; full operations in 2024.

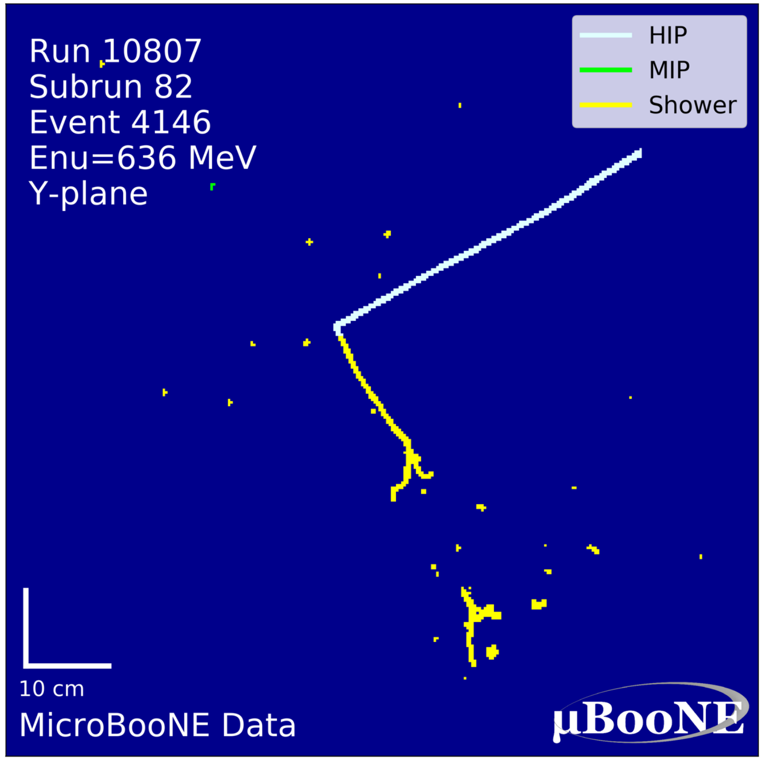


AI/ML Initiative

- **The President has placed a high priority on ensuring continued U.S. leadership in AI research and development**
  - Lead the world in the development of trustworthy AI and prepare the future U.S. workforce for the integration of AI systems across all sectors of economy and society.
  - Launched the AI for Science Initiative to support these goals in FY20
- Broad interest in AI is being driven by the accumulation of large datasets and growing computational capacity for processing
  - Machine Learning (ML) is included when appropriate as tool to derive insights from these large datasets
- HEP has a long track record of successful AI/ML research and development across many experiments and decades
  - **One recent example is the Deep Learning low energy excess analysis developed by MicroBooNE >>**
    - Using semantic segmentation to identify the detector hits caused by protons, muons, or electrons based on the unique signatures left in the detector.
- **Also supported through dedicated AI for HEP FOA** (DE-FOA-0002705)
  - More information on HEP's involvement in the AI initiative here



Raw Detector Hits



Deep Learning Prediction

QIS: Superconducting Quantum Materials and Systems

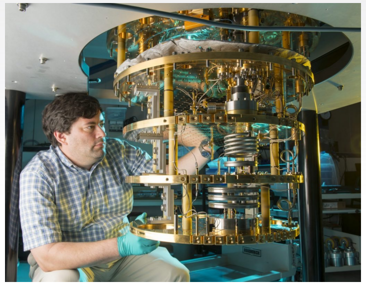
- Significant progress being made in advancing QIS technologies at Fermilab's SQMS Center

Vision/Goals

- **Establish Fermilab as a National Center** for Quantum Information Science
- Advance quantum technologies as new and **unique tools** for particle physics discovery
- Build upon Fermilab **technological strengths** to advance quantum technology
- Develop and deliver **new quantum platforms and testbeds** to enable a new decade of experiments in quantum computing and sensing for Fermilab and the broader physics community
- Make an impact in **technology transfer** and commercialization

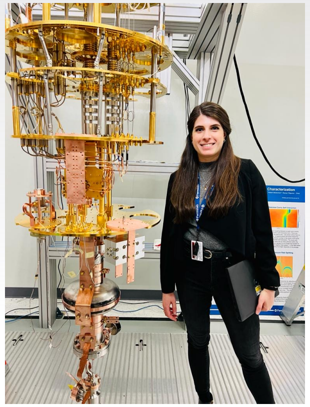
Key Initiatives

- **Develop and deploy Fermilab's first quantum computer:** enabled by our own expertise in superconducting RF technology and cryogenics, to solve pressing and currently unapproachable HEP physics problems
- **Develop and deploy quantum sensors for fundamental physics: realize pilot experiments,** searches for dark matter, precision experiments, gravitational waves, quantum physics
- **Demonstrate qubits of record performance with immediate tech transfer**



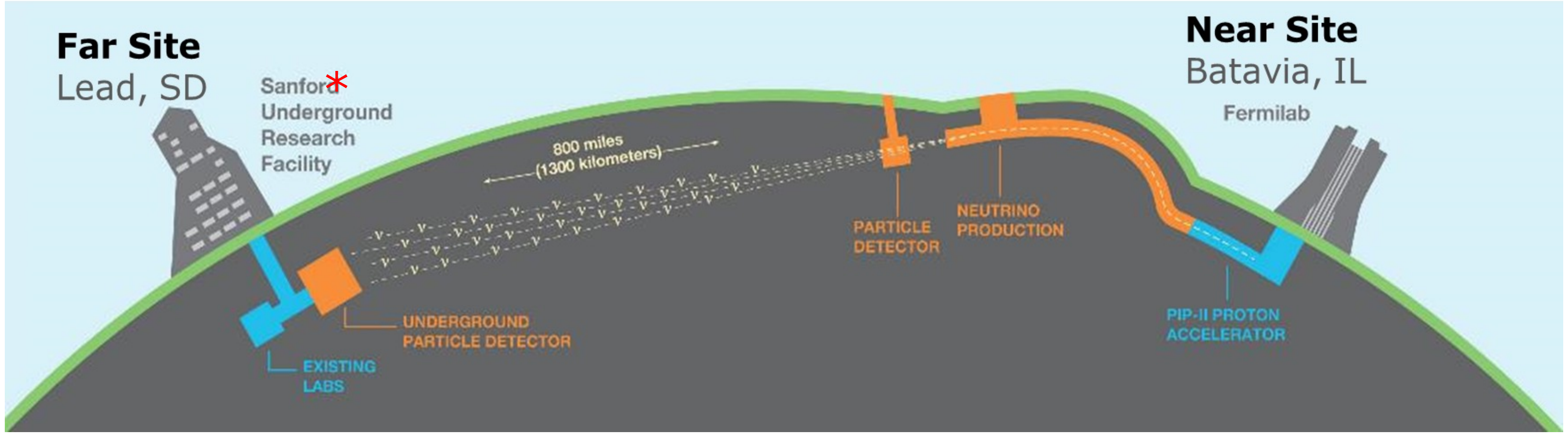
Recent Achievements

- **Record coherence** cavity-qubit integrated quantum system, quantum memory
- **World's best exclusion limit for** dark photon/dark matter at ~1.3 GHz frequency
- Launched unique **multi-institutional study** for materials characterization, nanofabrication and measurements of quantum devices
- > 40 publications, >100 students and postdocs supported, > 100 projects supported, > 350 researchers



Global Support for LBNF/DUNE

- The $978M US investment in PIP-II is supported by $310M from partners
- The ~$3B US investment in LBNF/DUNE is supported by $262M in facilities contributions and $394M in international support of DUNE

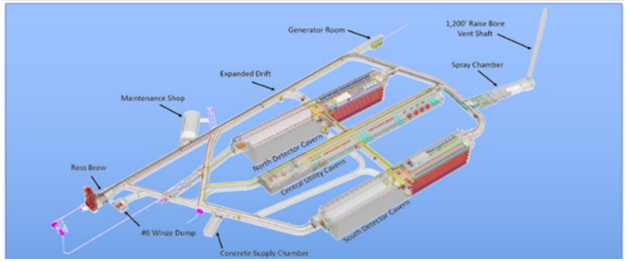


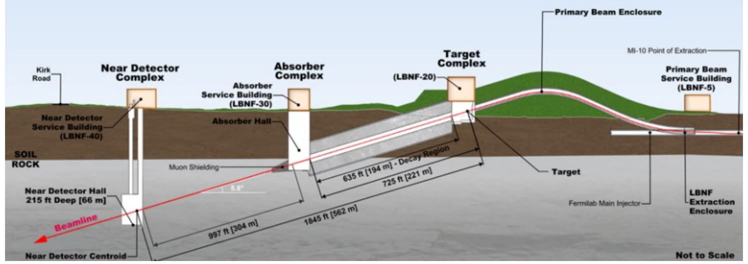
** The Far Site also benefits from significant contributions by the State of South Dakota and private donations for SURF (~$160M)*

- Success of LBNF/DUNE and PIP-II relies on the expertise, facilities, and capabilities from Partners
  - **Expertise-** Liquid Argon Time Projection Chamber technology first deployed at scale in **Italy**
  - **Facilities-** Neutrino Platform at **CERN** for detector prototyping and PIP-II cryoplant from **India**
  - **Capabilities-** SRF cryomodule production in **France** and **UK**

LBNF/DUNE Status

- Team and execution strategy has reorganized as subprojects to allow each element of the project to be baselined and executed when they are ready





- Far Site
  - **Far Site Conventional Facilities- Excavation (FSCF-EXC):** Completes excavation of underground spaces at Far Site
  - **Far Site Conventional Facilities- Building, Site & Infrastructure (FSCF-BSI):** Outfits surface and underground spaces with conventional systems (power, HVAC, etc.)
  - **Far Site Detectors and Cryogenics (FDC):** Fabricates, installs and commissions two far detector modules and support cryogenic systems

- Near Site
  - **Near Site Conventional Facilities & Beamline (NSCF+B):** Accelerator systems to produce the neutrino beam and all near site facilities to support the beamline and near detector
  - **Near Detector (ND):** Fabricates, installs and commissions hardware and systems for the near detector including cryogenic systems

LBNF/DUNE Cost Growth

- Current cost estimate of LBNF/DUNE exceeds the cost range of $1.26-$1.86 billion approved at the CD-1 Refresh in 2015. The project will submit a revised cost estimate and range to be approved in a CD-1 Reaffirmation (CD1-RR) in Summer 2022.
- Major drivers for cost increases:
  - **The cost of the excavation was underestimated**
    - Much of the underestimation was due to the condition of the mine being worse than expected.
  - **The cost of installation was assumed to be off project**
    - When the installation cost estimate was better understood it was too high to handle off project.
  - **Full understanding of needed project scope**
    - Primarily with the Near Detector since the needed capabilities and facilities were not sufficiently understood early on.
  - **As recommended by DOE's independent reviews, a more appropriate degree of contingency has been applied for higher confidence**
    - The amount increased due to both cost growth and as a fraction of the cost estimate.
  - **Stretching the funding out raised costs due to inflation and standing army**

The Path to the Full Physics Reach

- The P5 Report in 2014 called for:
  - Space for at least 40kt far detector fiducial volume
  - Initial 1.2 MW beam power later upgraded to multi-megawatt power
  - A suitable near detector
  - Specific expectations for early phase of data collection

- **DOE has always planned to meet the capabilities needed to reach the full P5 science reach in a phased manner:**
  - PIP-II will provide 1.2MW beam, and DOE will consider future upgrades for multi-megawatt beam operations.
  - LBNF/DUNE will provide two far-detector modules (23-24 kt LAr fiducial volume) and DOE will consider proposals for future far detectors modules
  - The initial Near Detector design has evolved greatly to support a broader physics program, which encompasses three of the five P5 drivers, including exploring new particles, interactions and physical principles. LBNF/DUNE will provide a Near Detector that supports the collaboration’s initial physics goals and DOE will consider proposals for further near detector capabilities to reach the final P5 goals.

Proton Improvement Plan II (PIP-II)

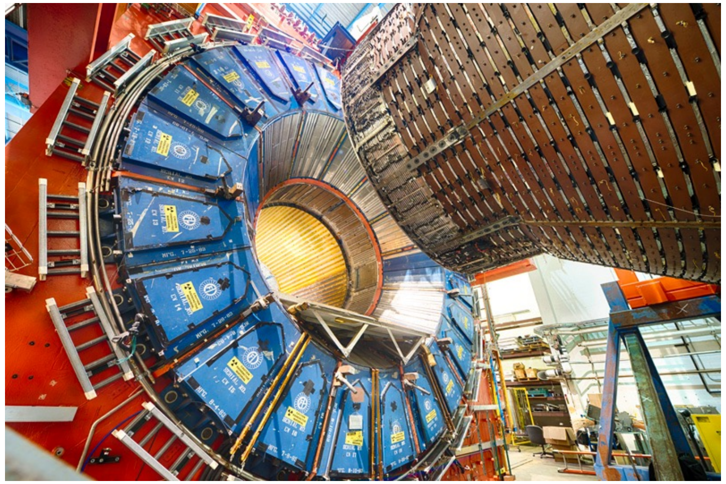
The U.S. Department of Energy has formally approved the start of full construction (CD3) for the PIP-II project, an essential upgrade to the accelerator complex at Fermi National Accelerator Laboratory. The heart of the project is a powerful new superconducting linear accelerator that will enable the world's most intense high-energy neutrino beam.

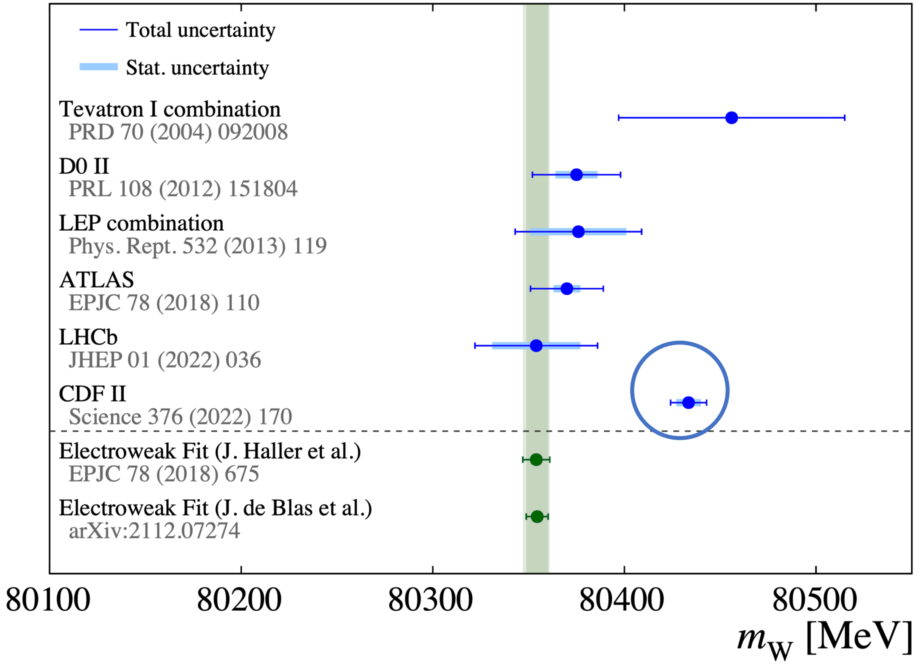
W-mass by CDF at the Tevatron

- To-date, most precise W-mass measurement by CDF
- Twice as precise compared to the earlier measurement after Fermilab's Tevatron operations ended in FY 2011
- 4-fold increase in statistics using the full Tevatron dataset of 8.8 fb^{-1}
- Better understanding of systematic uncertainties, including the proton & antiproton parton distribution functions (PDFs) by adding LHC data to the PDF fits

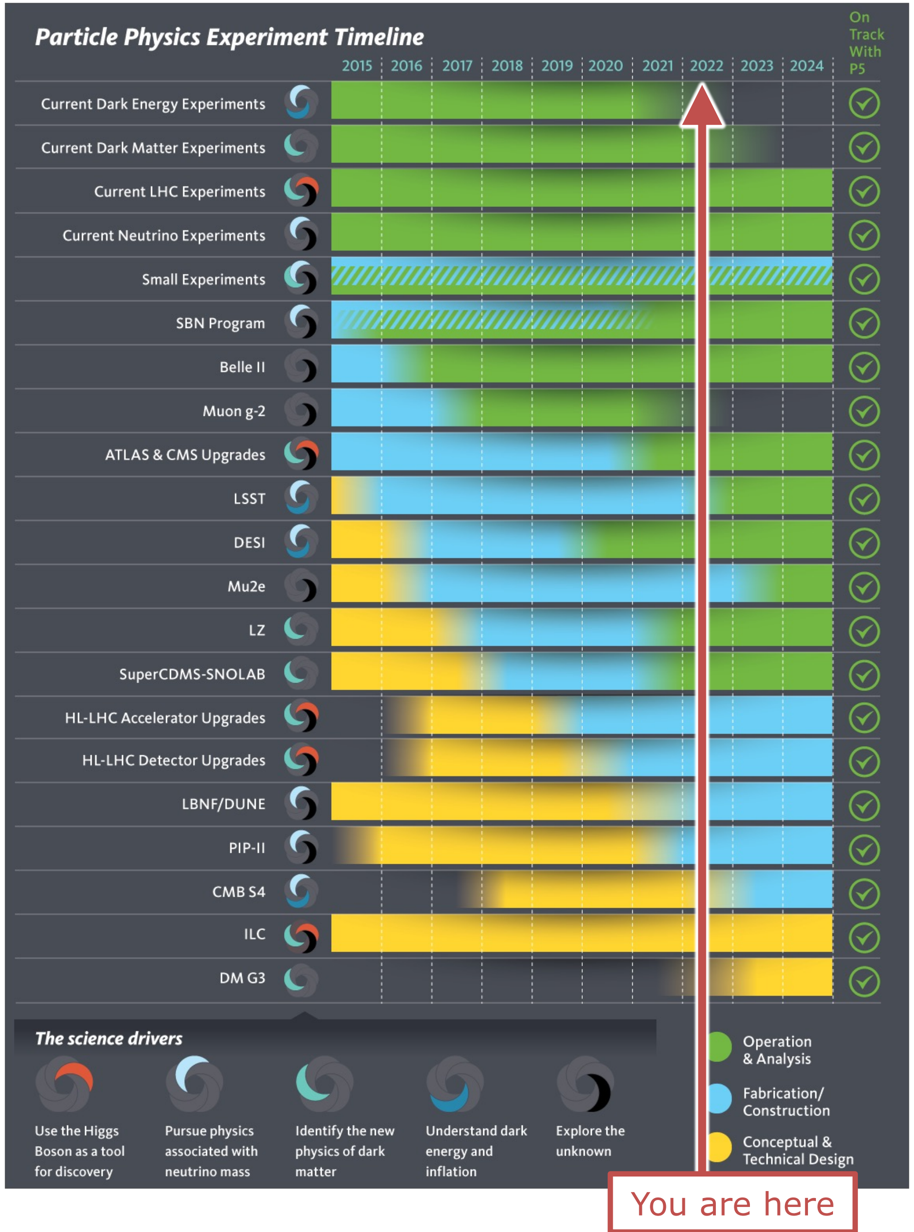
- CDF's new result – released April 2022:
  - m_W = 80,433.5 ± 6.4 (stat) ± 6.9 (syst) MeV

- W-mass measurement above the value in the Standard Model and most previous measurements. Already generating top-cited phenomenology papers.
- Look forward to measurements by other independent experiments (e.g., at the LHC) for further confirmation





P5 Implementation Status



Successful implementation of the 2014 P5 strategy continues.

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

- **Projects fully funded as of FY21:**
  - **Muon g-2**
  - **LHC detector upgrades: ATLAS and CMS Phase-1**
  - **Mu2e**
  - **LSSTcam (for Vera C. Rubin Observatory)**
  - **DM-G2 (superCDMS & LZ)**
  - **DESI**
- HL-LHC accelerator and detector upgrade projects underway
- LBNF/DUNE & PIP-II schedules advanced due to strong support by Administration & Congress
- Broad portfolio of small projects running

Next P5 process to start in Fall 2022 after Snowmass

Thank you!