U.S. DEPARTMENT OF ENERGY | Office of Science

DOE Office of High Energy Physics Report

2017 U.S. LHC Users Association Meeting
Fermi National Accelerator Laboratory, Batavia, Illinois
November 1-3, 2017

Abid Patwa
Program Manager, Office of High Energy Physics
Office of Science, U.S. Department of Energy

U.S. Department of Energy: Mission

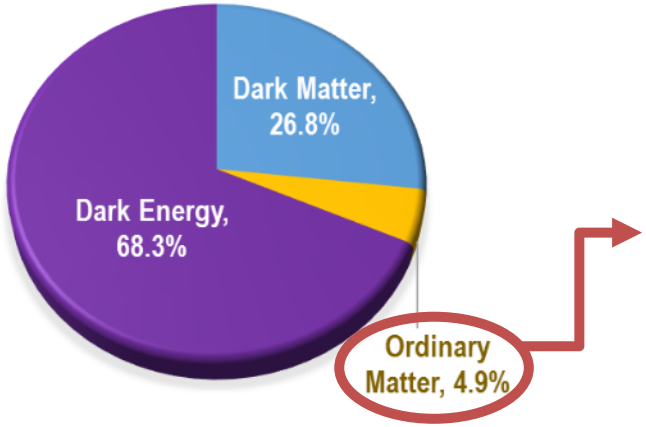
The Mission of the U.S. Department of Energy is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.

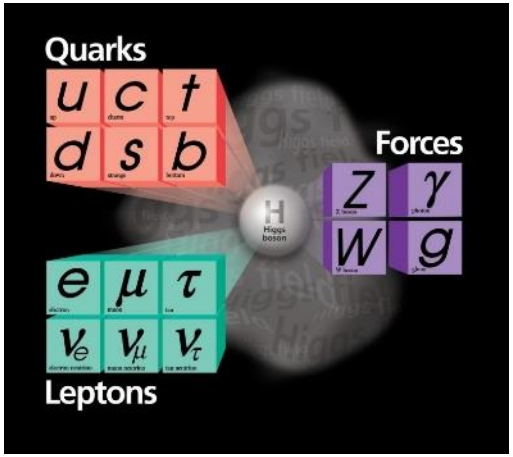
DOE/HEP Mission is to understand how the universe works at its most fundamental level:

- Discover the elementary constituents of matter and energy
- Probe the interactions between them
- Explore the basic nature of space and time

The DOE Office of High Energy Physics fulfills its mission by:

- Building **projects** that enable discovery science
- Operating **facilities** that provide the capability for discoveries
- Supporting a **research** program that produces discovery science





U.S. Department of Energy

Agency Organization

Boards & Councils
- Secretary of Energy Advisory Board
- National Laboratory Policy Council
- Energy Council
- Credit Review Board
- Cyber Council
- Nuclear Security Council
- Jobs Council
- ESAAB

Associate Deputy Secretary

Office of the Secretary
Rick Perry, Secretary
Dan Brouillette, Deputy Secretary
Brian McCormack, Chief of Staff

- Federal Energy Regulatory Commission
- Inspector General
- Ombudsman

Office of the Under Secretary for Nuclear Security and National Nuclear Security Administration
Frank G. Klotz, Under Secretary for Nuclear Security Administrator, NNSA
William White, Acting, Principal Deputy Administrator, NNSA

- Deputy Administrator for Defense Nuclear Nonproliferation
- Deputy Administrator for Naval Reactors
- Associate Administrator for Defense Nuclear Security
- Associate Administrator for External Affairs
- Associate Administrator for Management & Budget
- Office of General Counsel
- Deputy Administrator for Defense Programs
- Deputy Under Secretary for Counter-terrorism & Counter-proliferation
- Associate Administrator for Emergency Operations
- Associate Administrator for Safety, Infrastructure & Operations
- Associate Administrator for Acquisition & Project Management
- Associate Administrator for Information Management & Chief Information Officer

Office of the Under Secretary for Science & Energy
Patricia Hoffman, Acting, Under Secretary for Science and Energy

- Office of Science
- Assistant Secretary for Energy Efficiency and Renewable Energy
- Assistant Secretary for Fossil Energy
- Assistant Secretary for Nuclear Energy
- Assistant Secretary for Electricity Delivery and Energy Reliability
- Indian Energy Policy and Programs
- Office of Technology Transitions[2]

Office of the Under Secretary for Management & Performance
Matthew Moury, Acting, Under Secretary for Management and Performance

- National Laboratory Operations Board
- Associate Under Secretary for Environment, Health, Safety & Security
- Assistant Secretary for Environmental Management
- Economic Impact & Diversity
- Management
- Chief Human Capital Officer
- Chief Information Officer[1]
- Project Management Oversight & Assessments
- Legacy Management
- Hearings & Appeals

- Assistant Secretary for International Affairs
- Assistant Secretary for Congressional & Intergovernmental Affairs
- General Counsel
- Chief Financial Officer
- Intelligence & Counterintelligence
- Enterprise Assessments
- Public Affairs
- Small and Disadvantaged Business Utilization

- U.S. Energy Information Administration
- Advanced Research Projects Agency - Energy
- Energy Policy & Systems Analysis
- Loan Programs Office
- Bonneville Power Administration
- Southwestern Power Administration
- Southeastern Power Administration
- Western Area Power Administration

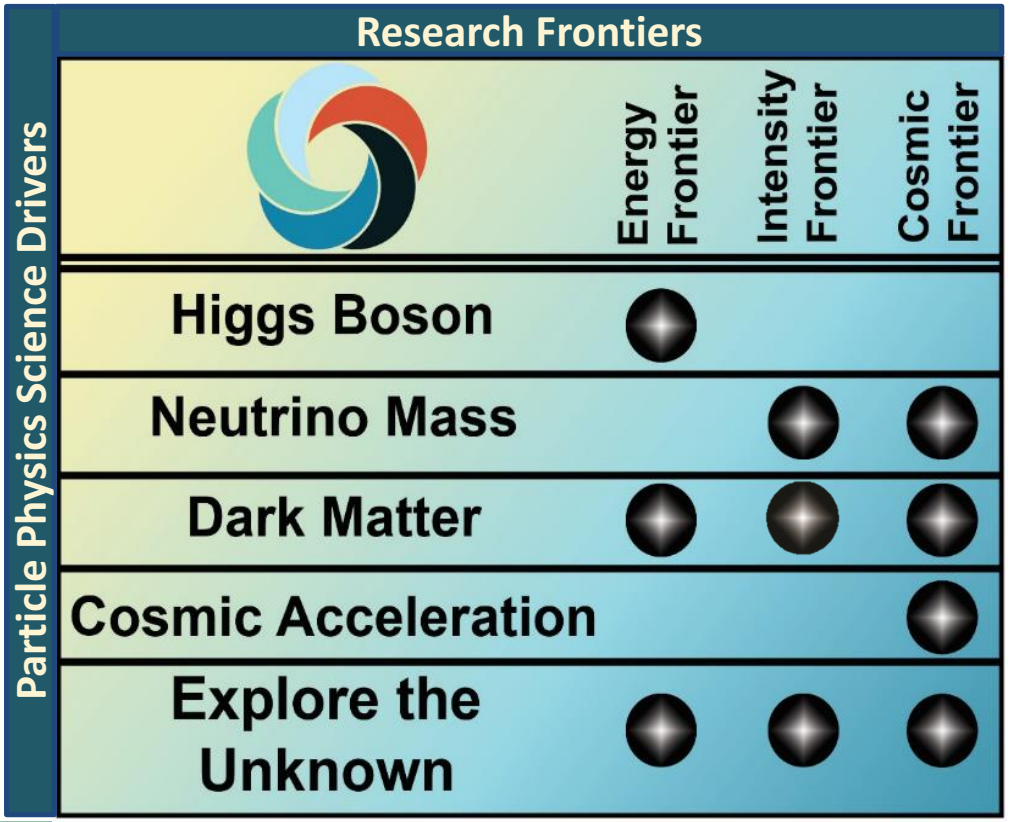
Office of High Energy Physics is within the DOE Office of Science

[1] The CIO reports directly to the Secretary for the purposes of carrying out responsibilities under Subchapter 44 U.S.C.§ 3506(a)(2)(A).
[2] The director of the Office of Technology Transitions also serves as DOE's Technology Transfer Coordinator who reports to the Secretary of Energy

Enabling the Next Discovery

- P5 (U.S. Particle Physics Project Prioritization Panel) identified 5 Science Drivers to address the scientific motivation of particle physics
- Research Frontiers are useful categorization of experimental techniques and serve as the basis of the budget process

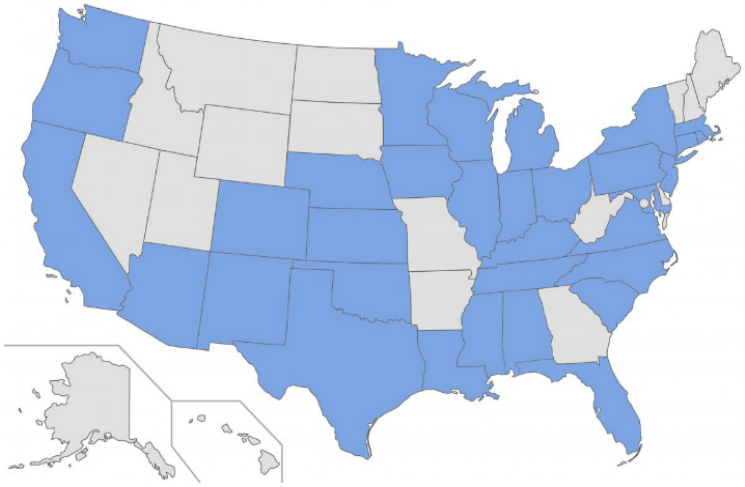
- Research Frontiers are complementary
  - No one Frontier addresses all science drivers
  - Each Frontier provides a different approach to address science driver
  - Enables cross-checking scientific results



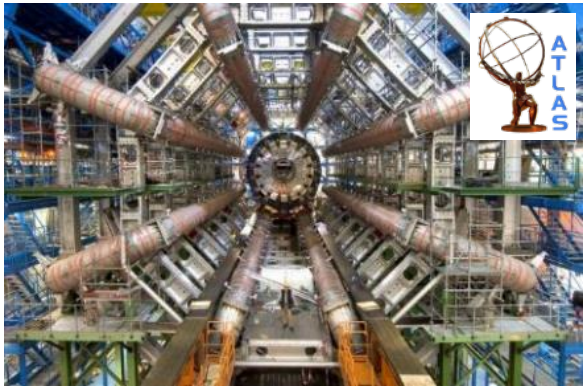
Energy Frontier: LHC, ATLAS, and CMS

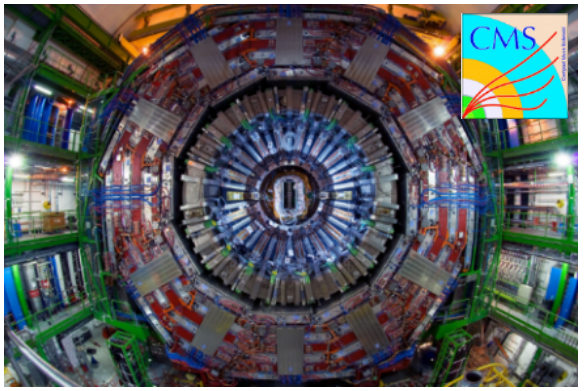
The Large Hadron Collider at CERN is the centerpiece of the U.S. Energy Frontier program and an integral component of the DOE HEP program

- **U.S. ATLAS represents ~20% of the international ATLAS Collaboration**
  - 42 universities, 4 national laboratories (Argonne, Brookhaven, Lawrence Berkeley, SLAC)
  - Brookhaven National Lab is host lab for U.S. ATLAS
- **U.S. CMS represents ~27% of the international CMS Collaboration**
  - 51 universities, 1 national laboratory
  - Fermilab is the host lab for U.S. CMS



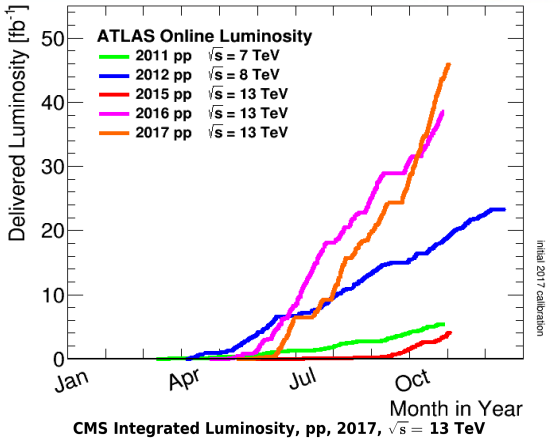
States hosting members of the U.S. LHC experimental program

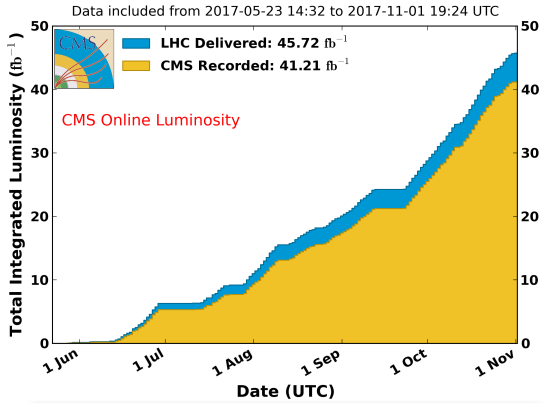




Some Highlights from the LHC

- **Over 665 LHC Run 1+2 papers submitted by *each* of the CMS and ATLAS Collaborations**
  - Excellent showing at the 2017 conferences and workshops
- **LHC continued to set performance records in 2017**
  - Unprecedented peak instantaneous luminosity of ~2.05 x 10^{34} $cm^{-1}s^{-1}$, well above design luminosity!
- **Currently ~46 fb^{-1} of data delivered in 2017 [exceeding goal of 45 fb^{-1} for calendar year 2017]**
  - 100 fb^{-1} of LHC data (since 2010) milestone achieved on October 4, 2017
  - Congratulations to the CERN accelerator team and to the experiments for the excellent work!
- **ATLAS and CMS detector [Phase-I] upgrades for 2019-2020 long-shutdown [LS2] are progressing**
  - An (early) DOE CD-4a in September 2017 for the U.S. CMS upgrade project
  - Installation and commissioning activities for the U.S. ATLAS-built deliverables began in FY 2017 and will continue through LS2



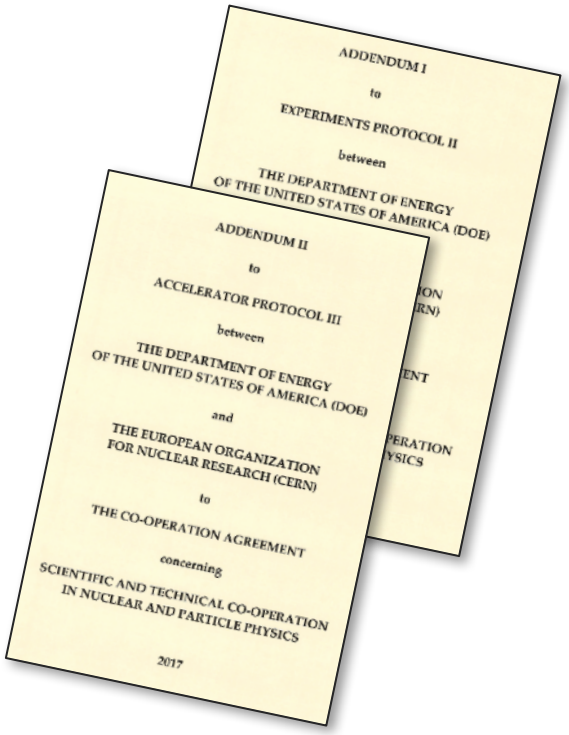


Future of the Energy Frontier

Energy Frontier program continues to build on the *bilateral* U.S.-CERN Agreement and Protocols, signed in 2015

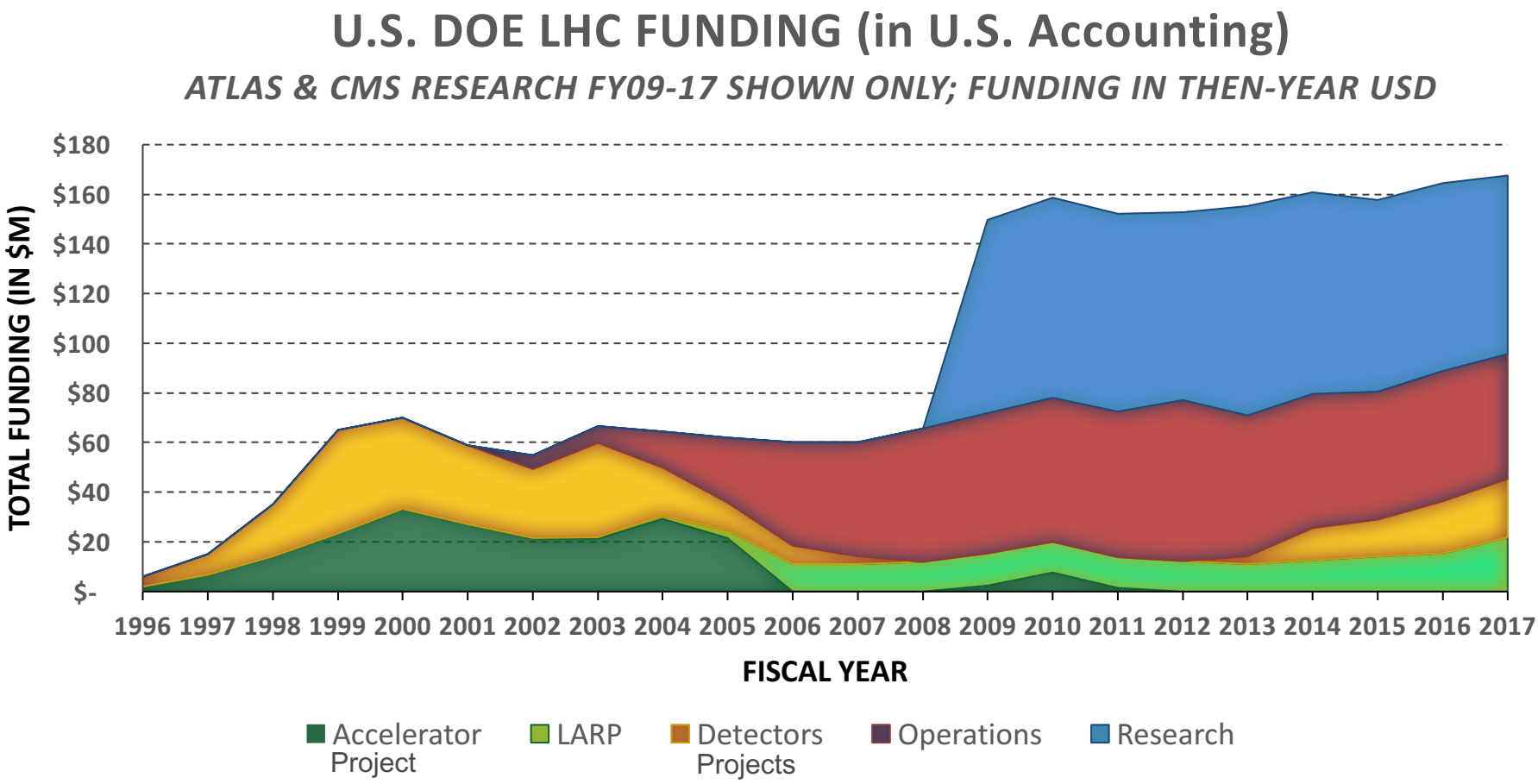
- **Renew cooperation on the CERN-hosted LHC and the U.S.-hosted neutrino programs**
- **Signed May 2017: DOE-CERN addenda to the Protocols**
  - HL-LHC accelerator, experiments; and neutrinos

- **P5 report identified HL-LHC upgrades as highest priority near-term large project**
  - Extends discovery potential by increasing LHC collision rate, enabling detectors to collect a factor of ten more data over another decade
- **U.S. leadership in superconducting magnet technology, and with Nb_3Sn in particular, is essential to the success of the HL-LHC program**
  - HL-LHC Accelerator Upgrade Project uses this expertise to serve HEP community needs
- **U.S. laboratories and institutions will develop and build major subsystems for the HL-LHC ATLAS and CMS detector upgrades**
  - Detector expertise and support provides foundation for continued U.S. leadership in HL-LHC scientific research program



U.S. DOE LHC Funding History

(all amounts follow standard U.S. accounting practices)



- **Difficult to extract LHC-focused Research prior to FY 2009 due to changes in DOE reporting mechanisms between 'proton-based collider' and 'proton-induced neutrino' Research**

U.S. DOE Contributions to the LHC

(all amounts below follow standard U.S. accounting practices)

- **Between Fiscal Years (FY) 1996 and 2007, the U.S. made contributions totaling $531 million (M) to the construction of the LHC and detectors**
  - $450M from the DOE, including $200M to the accelerator and $250M to the ATLAS and CMS detectors
  - $81M from the U.S. National Science Foundation to the ATLAS and CMS detectors
- **U.S. LHC (ATLAS & CMS) Detector Operations Program**
  - Between FY 2002-2017, DOE made contributions totaling $697M for maintenance & operations and software & computing efforts
  - In FY 2017, ~$51M approximately split between the two experiments, including support for data transfer between Tier-0 and U.S. Tier-1s via the ESnet transatlantic network
- **LHC (ATLAS & CMS) Research Program**
  - In FY 2017, ~$72M from DOE supported scientists and students at U.S. National Laboratories and Universities
- **LHC Accelerator R&D Program (LARP)**
  - Between FY 2002 and FY 2017, DOE made contributions totaling $164M
- **LHC Upgrade Projects**
  - **ATLAS and CMS "Phase-1" Detector upgrades**: between FY 2009-2017, DOE made contributions totaling ~$67M approximately split between the two experiments
  - **HL-LHC Accelerator and ATLAS and CMS Detector upgrades**: DOE contributions began in FY 2016 and are planned to continue through project completion (~LS3)

HL-LHC Accelerator Upgrades:
Enabling U.S. Science Participation

2 CIVIL ENGINEERING
2 new 300-metre service tunnels and 2 shafts near to ATLAS and CMS.

"CRAB" CAVITIES
16 superconducting "crab" cavities for each of the ATLAS and CMS experiments to tilt the beams before collisions.

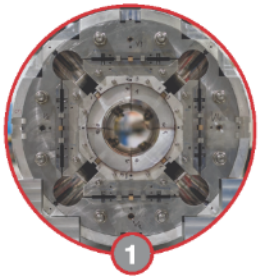
LHC TUNNEL

CMS

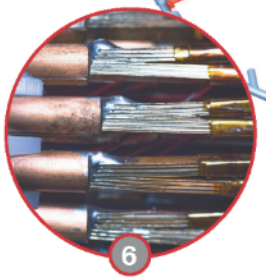
ALICE

ATLAS

LHCb



1 FOCUSING MAGNETS
12 more powerful quadrupole magnets for each of the ATLAS and CMS experiments, designed to increase the concentration of the beams before collisions.



6 SUPERCONDUCTING LINKS
Electrical transmission lines based on a high-temperature superconductor to carry current to the magnets from the new service tunnels near ATLAS and CMS.

5 COLLIMATORS
15 to 20 new collimators and 60 replacement collimators to reinforce machine protection.

4 BENDING MAGNETS
4 pairs of shorter and more powerful dipole bending magnets to free up space for the new collimators.

DOE contribution:
10 cold mass (Nb_3Sn) assemblies
- **4 each for ATLAS & CMS interaction regions**
- **2 spares**

DOE contribution:
20 Crab Cavities
- **16 + 4 spares**

or:
10 Crab cavities & Hollow e-Lens Components

DOE contribution:
Hollow e-Lens Components (under discussion)

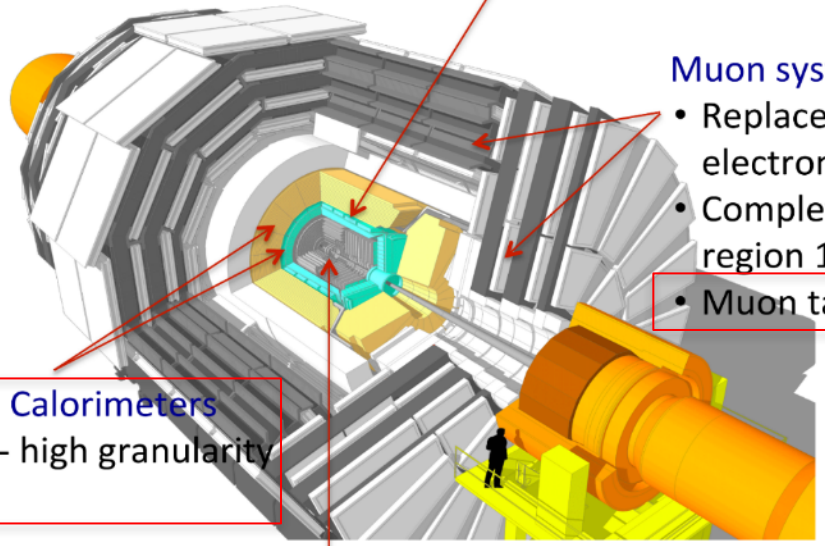
CMS HL-LHC Upgrade

- DOE and U.S. National Science Foundation coordinating U.S. contributions with CERN and international partners on CMS
- Scope of the U.S. deliverables leverages expertise by U.S. scientists

DOE
NSF

Trigger/HLT/DAQ
- Track information at L1-Trigger
- L1-Trigger: 12.5 μs latency - output 750 kHz
- HLT output ≈7.5 kHz

Barrel EM calorimeter NSF
- Replace FE/BE electronics
- Lower operating temperature (8◦)



Muon systems NSF DOE
- Replace DT & CSC FE/BE electronics
- Complete RPC coverage in region 1.5 < η < 2.4
- Muon tagging 2.4 < η < 3

DOE

***Replace Endcap Calorimeters**
- Rad. tolerant - high granularity
- 3D capability

Replace Tracker *
- Rad. tolerant - high granularity - significantly less material
- 40 MHz selective readout (Pt≥2 GeV) in Outer Tracker for L1-Trigger

DOE

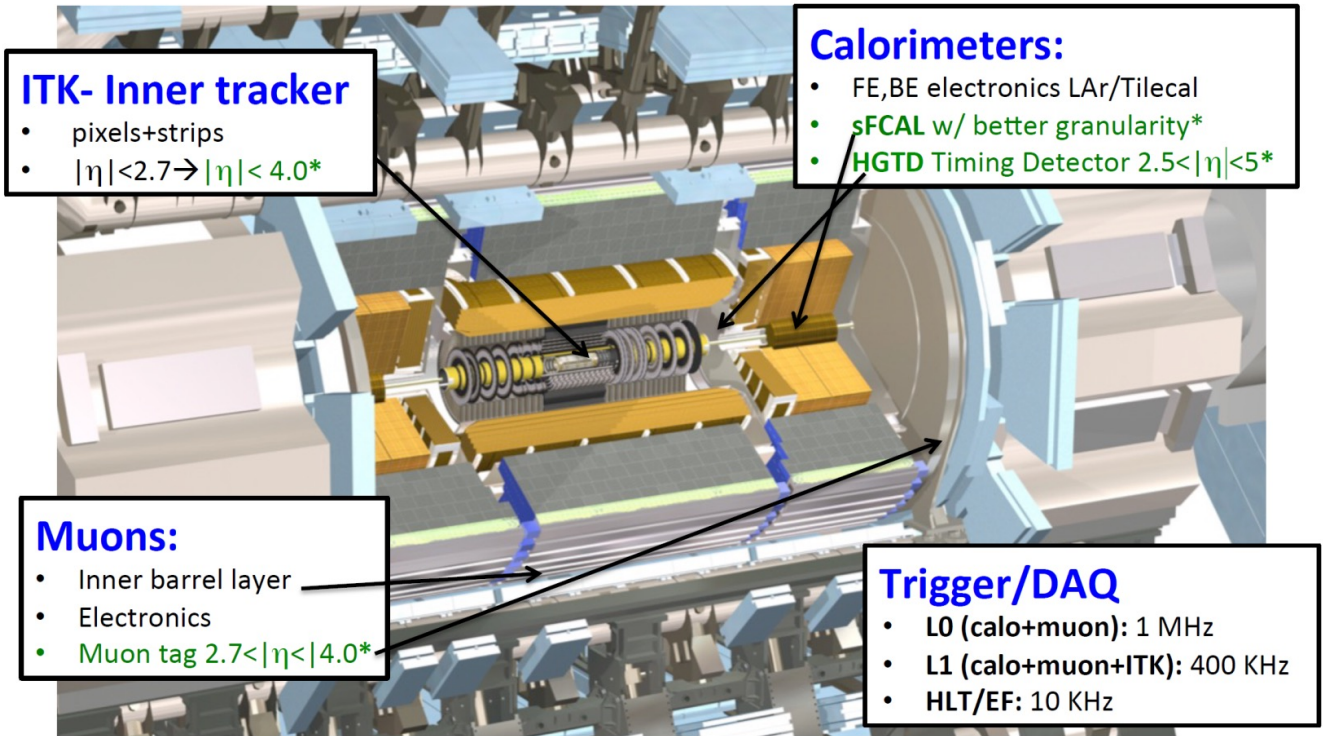
- Extend coverage to η = **3.8** NSF

ATLAS HL-LHC Upgrade

- **Similarly, U.S. ATLAS is defining the scope of its contributions to HL-LHC by leveraging interests and experience of U.S. groups, coordinating with international ATLAS**

- **DOE Scope:**
  - **Barrel Inner Tracker (pixel & strip detector)**
  - **LAr Calorimeter front-end analog chip development**
  - **DAQ hardware (data flow elements)**

- **NSF Scope:**
  - **'Triggering' at high luminosities**
  - **Readout electronics for LAr, Tile, Muons**



** Large forward rapidities, as described in the 2015 ATLAS HL-LHC scoping document (for the reference 275 MCHF CORE total cost scenario)*

NSF & DOE Partnership

- **In addition to the partnership with CERN, the U.S. HL-LHC ATLAS and CMS Detector Upgrade Projects are a partnership between NSF and DOE**
- **Each detector upgrade is managed as a single project**
  - A single resource loaded schedule
  - A single Earned Value Management System with agency specific financial reporting to measure performance and progress
  - Integrated project controls team
- **Partitioning of scope and deliverables to the maximum extent as possible in order to minimize dependencies**
  - Maintaining oversight and coordination through the DOE-NSF U.S. LHC Joint Oversight Group (JOG)
- **Both DOE and NSF have long and successful experience with this single project management model**
  - Agency processes for approval are distinct (DOE Critical Decision, NSF MREFC), but agencies and Administration (OMB, OSTP) are experienced at managing these differences

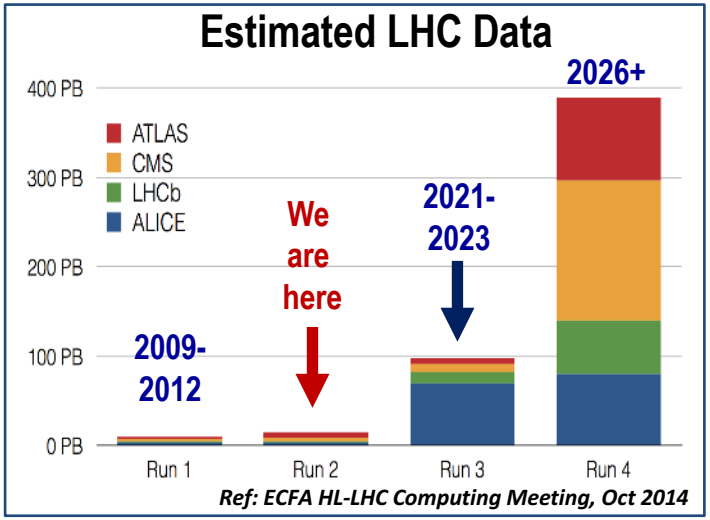
DOE HL-LHC Project Schedules

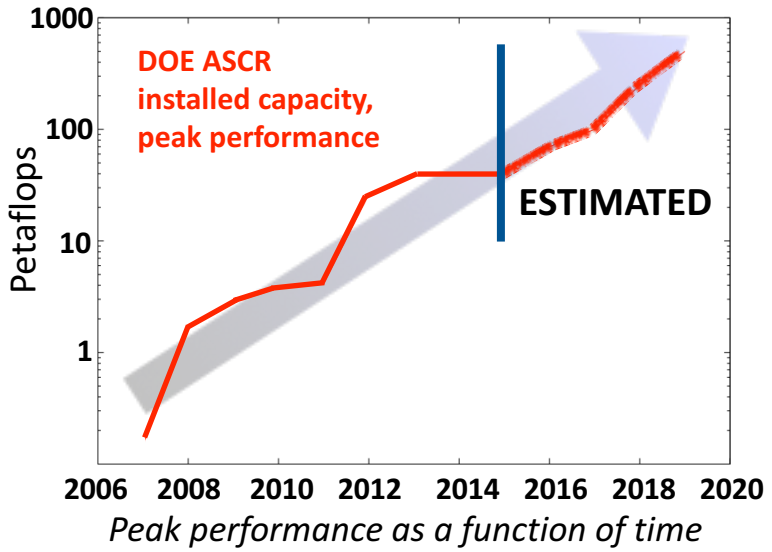
- **HL-LHC Accelerator Upgrade Project**
  - DOE CD-1/CD-3a (Long-lead Procurement) Reviews held in August 2017 went well; DOE CD-1/CD-3a approved in October 2017
  - Project is advanced technically and management team is transitioning well from the LARP R&D mode to DOE project execution with a strong project office at Fermilab
  - Project likely to go for CD-2 (Project Baseline) in the second half of 2018

- **HL-LHC ATLAS and CMS Detector Upgrade Projects**
  - Finalizing resource-loaded schedules, including scope contributions and contingency estimations
  - DOE working with U.S. ATLAS (BNL) and U.S. CMS (Fermilab) project offices to understand funding profiles in preparation for next DOE CD-1 milestone, which is planned for spring 2018

U.S. LHC Computing

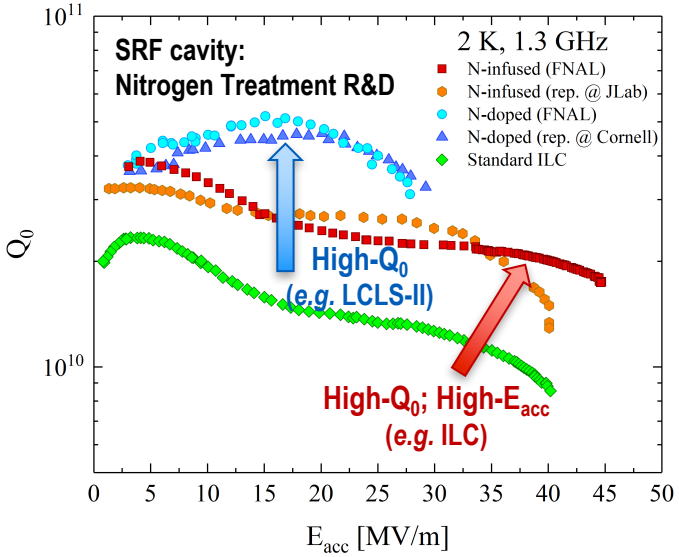
- **We recognize the challenges faced by the experiments in Runs 3 and 4**
- **A central element in our strategy is leveraging DOE High Performance Computing (HPC) resources in the Office of Advanced Scientific Computing Research**
  - ATLAS and CMS leveraging HPCs during Run 2
    - U.S. LHC Operations Program is working with DOE for seeking multi-year HPC allocations, which are useful for planning
  - DOE coordinating with U.S. ATLAS/CMS to utilize HPCs during the HL-LHC running period
  - The Exascale Computing Project plans to increase HPC capacity even faster than the LHC luminosity
  - We are supporting efforts at our labs and universities along this direction
- **Data curation, handling and distribution is equally important**
- **We would like to foster partnerships throughout the global HEP community to prepare for the future computing landscape**

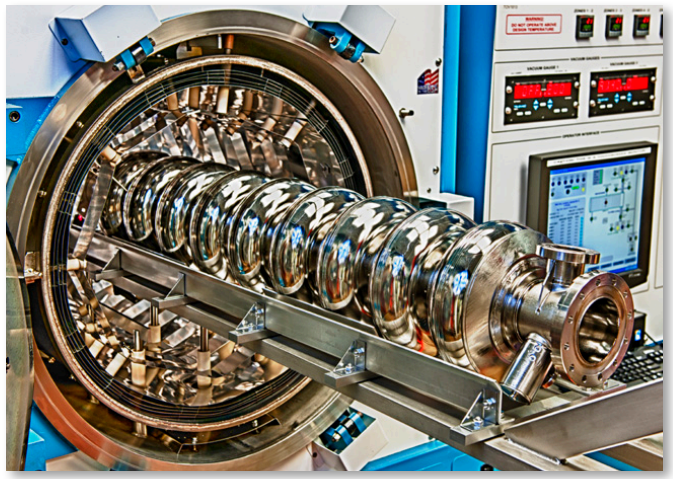




Future Colliders

- **DOE has been coordinating with the international community towards the development of the next collider program**
- **Interest from HEP community to pursue R&D studies for future collider options (*e.g.,* Europe/CERN Future Circular Collider or Japan-proposed ILC)**
  - Current DOE efforts focused on next generation high-field magnet technology to enable higher energy future circular collider
  - For ILC, current DOE efforts focused on cost reduction R&D—for e.g., nitrogen treatment in SRF accelerator cavity technology: potential for up to 10% cost reductions in 3-5 years, up to 15% in 5-10 years
- **Given tight fiscal budgets in the Energy Frontier program, near-term priorities will aim to support the LHC program as well as R&D for the HL-LHC upgrades**
  - Very modest R&D towards these future collider initiatives may continue, as funding allows

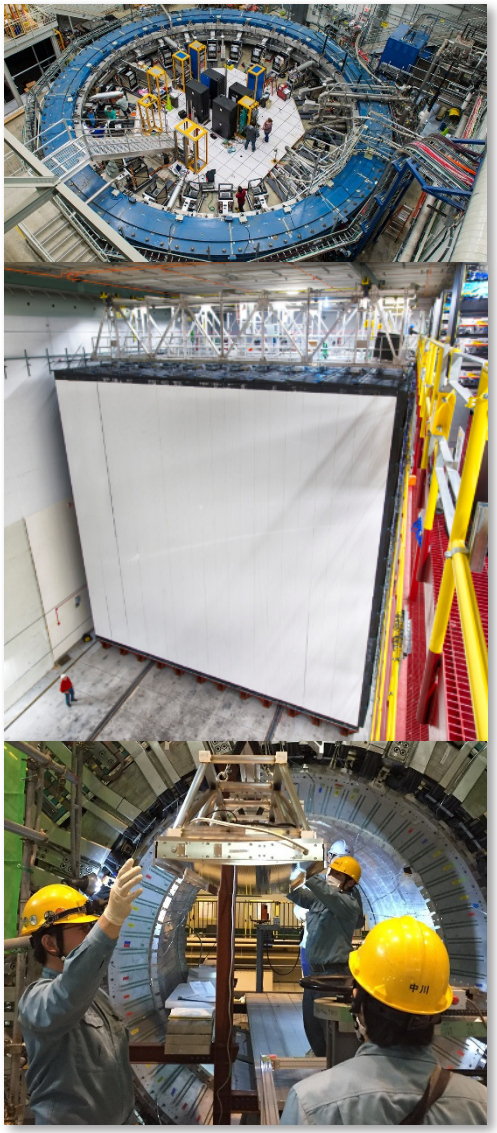




Intensity Frontier Program

Intensity Frontier experiments address the P5 Science Drivers through intense beams and sensitive detectors

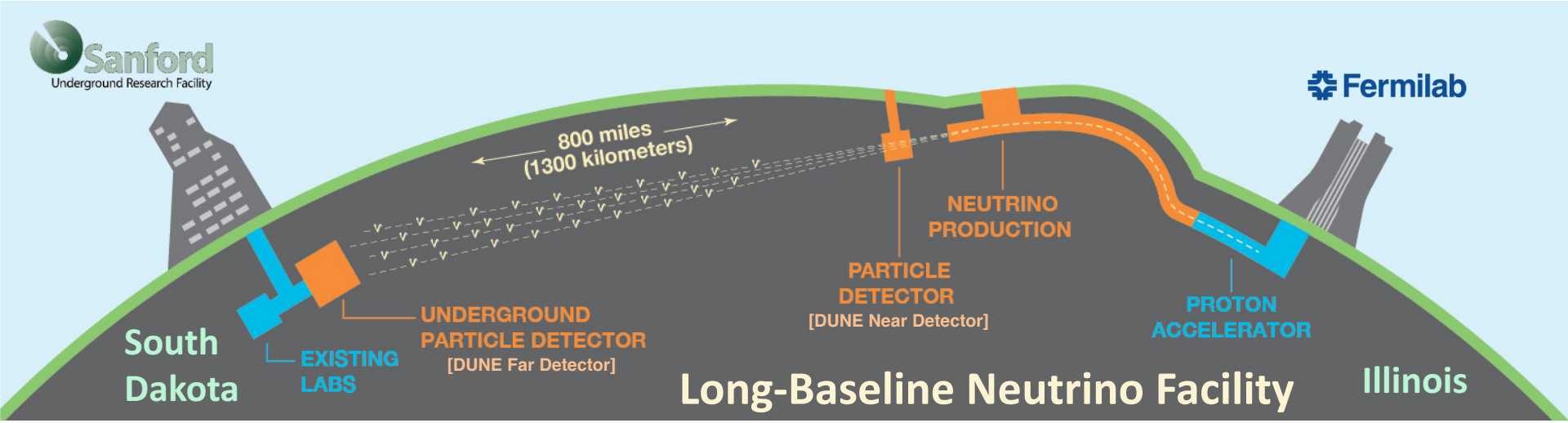
- **Exploring the unknown through precision measurements:**
  - *Muon g-2, Mu2e, Belle II, K0TO*
- **Identify the new physics of dark matter:**
  - *Heavy Photon Search*
- **Pursuing the physics associated with neutrino mass:**
  - *NOvA*, *Daya Bay*, *MINERvA*, *Super-K*, *T2K* ongoing
  - Fermilab Short-Baseline Neutrino (SBN) Program (*MicroBooNE*, *SBND, ICARUS*)
  - Preparing to host world-leading neutrino program with the Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (*LBNF/DUNE*)



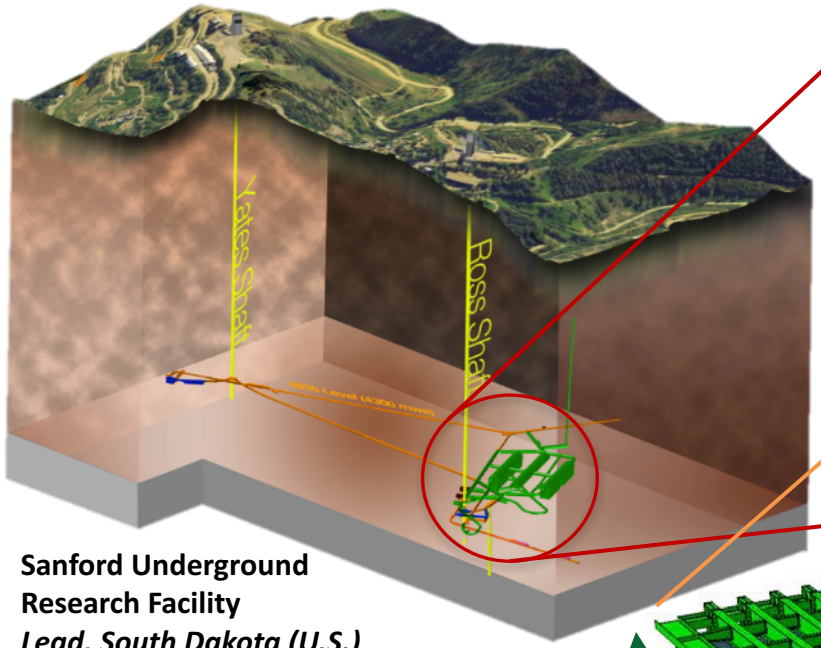
LBNF/DUNE

- **P5 recommended Long-Baseline Neutrino Facility (LBNF) as the centerpiece of a U.S.-hosted world-leading neutrino program**
  - LBNF will produce the world's most intense neutrino beam, send it 1,300 km through the earth to DUNE (Deep Underground Neutrino Exp.)
  - "Mega-science" facility with strong support within the U.S. Government
  - Many potential global partners are interested
- **International DUNE collaboration includes:**
  - **1,032** collaborators, **176** institutions, **31** countries

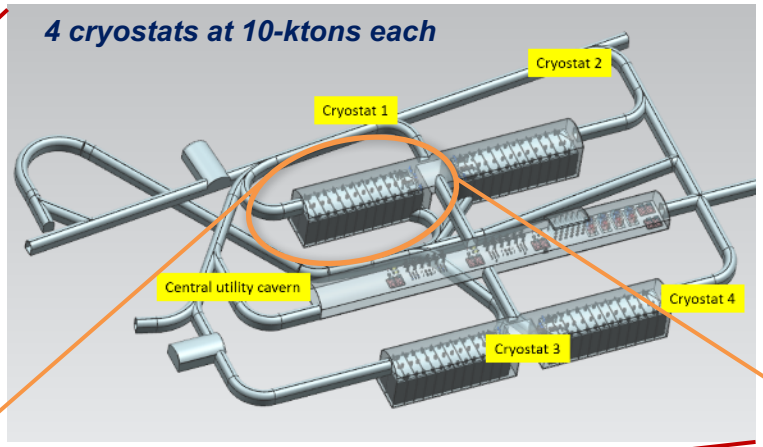
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT



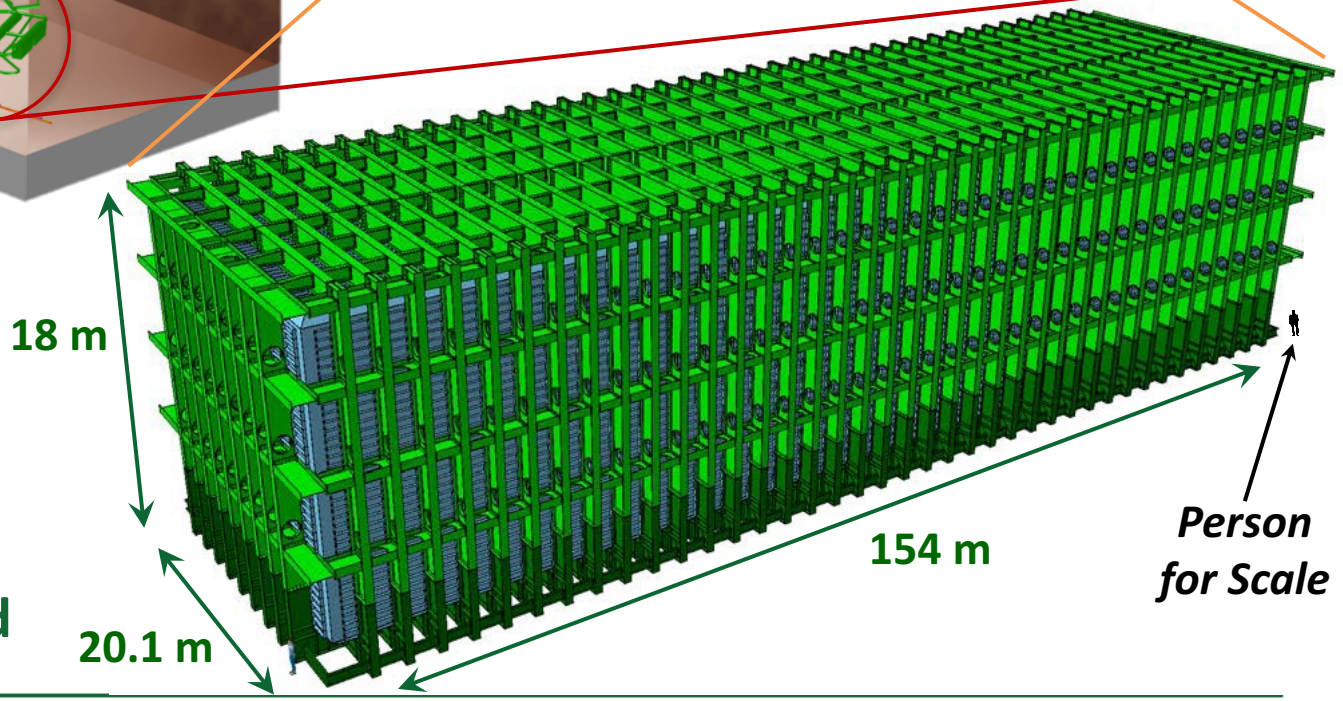
LBNF/DUNE in South Dakota



Sanford Underground Research Facility
Lead, South Dakota (U.S.)



Large-scale cryogenic vessel will house state-of-the-art neutrino detector 1.6 km (1 mile) underground



LBNF/DUNE Project Groundbreaking

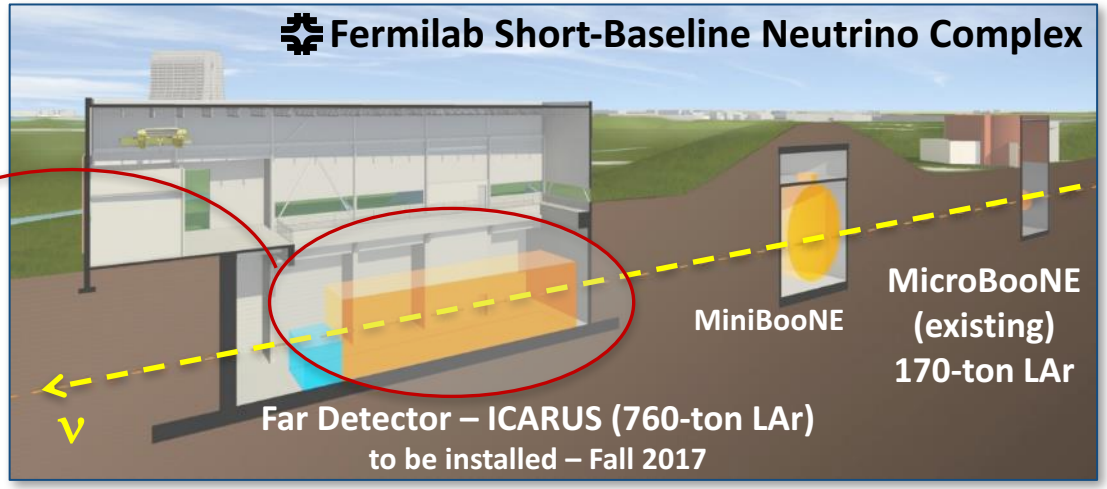
21 July 2017 – Lead, South Dakota (United States)

From Left: Fermilab Director N. Lockyer; Exec. Director of Programs G. Blair, STFC U.K.; Prof. S. Bertolucci, INFN Italy; Director for International Relations C. Warakaulle, CERN; Rep. R. Hultgren, Illinois; Rep. K. Noem, South Dakota; Senator M. Rounds, South Dakota; Senator J. Thune, South Dakota; Assoc. Director for HEP J. Siegrist, U.S. DOE; Deputy Assistant to the President and Deputy U.S. Chief Technology Officer M. Kratsios; South Dakota Governor D. Daugaard; Project Manager S. Lundgren, Kiewit/Alberici; Exec. Director M. Headley, SURF; and Chair of the Board C. Peterson, South Dakota Science and Technology Authority. *Photo Courtesy: Reidar Hahn, Fermilab.*

"Today's groundbreaking … serves as a model for what the future of mega-science research looks like: an intensely collaborative effort between state, local and federal governments, international partners, and enterprising corporate and philanthropic pioneers whose combined efforts will significantly increase our understanding of the universe." **— Deputy Assistant to the President and Deputy U.S. Chief Technology Officer Michael Kratsios, White House Office of Science and Technology Policy**

Advancing Technology Towards LBNF/DUNE

- **Fermilab Short-Baseline Neutrino Program**
  - Resolve experimental anomalies in measured ν-spectrum, including search for sterile neutrino
  - Demonstrate the detector technology for DUNE
- **The largest liquid argon neutrino detector in the world, ICARUS, was transported this summer from Europe (CERN) to the U.S. (Fermilab in Illinois)**
  - First major item of equipment to ship for the international neutrino program



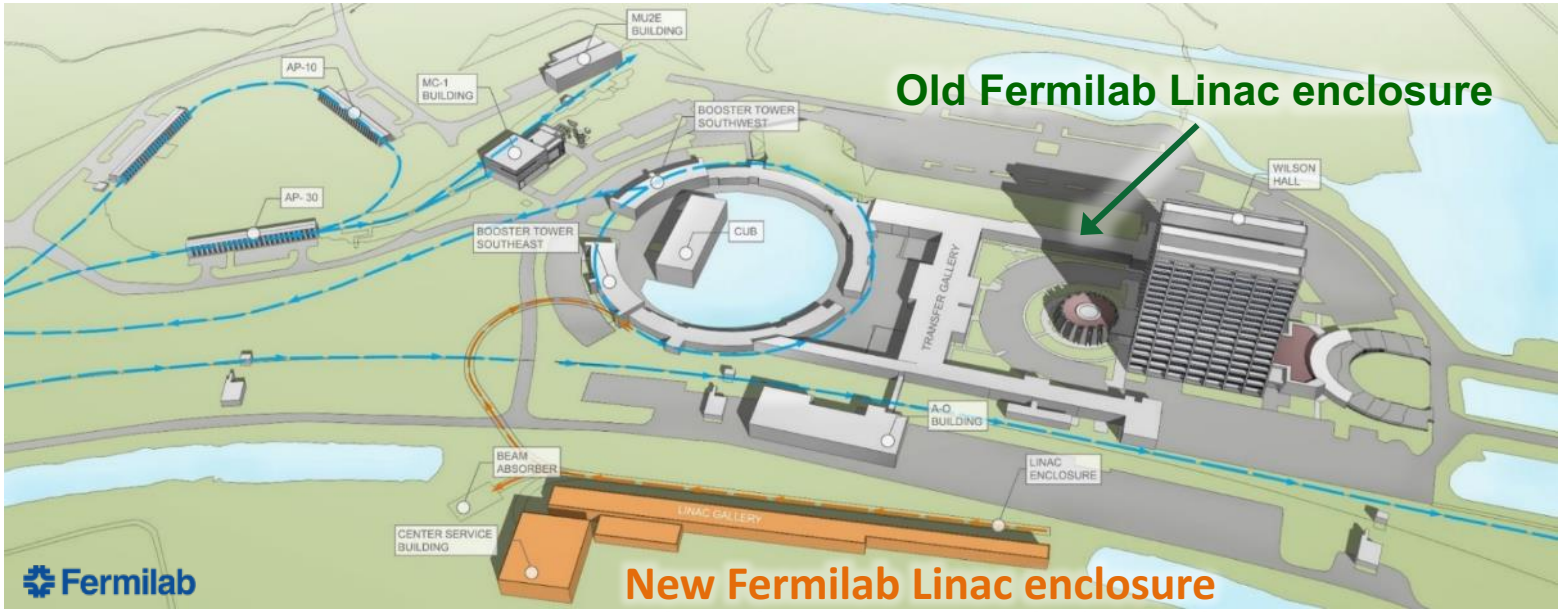
#IcarusTrip


Fermilab's new home for refurbished ICARUS
ICARUS arrives at Fermilab
July 26, 2017
17 June 2017
On Barge near Mainz, Germany
Transatlantic Voyage
via Big Rig from Indiana to Fermilab
24-26 July 2017
Great Lakes Cargo Vessel
6 July 2017
12 June 2017
Leaving CERN in Geneva, Switzerland
United States
Ireland
Germany
France
Belgium
Paris
London
Spain
Portugal
Madrid
Barcelona
Ottawa
Montreal
Toronto
Chicago

Proton Improvement Plan II (PIP-II)

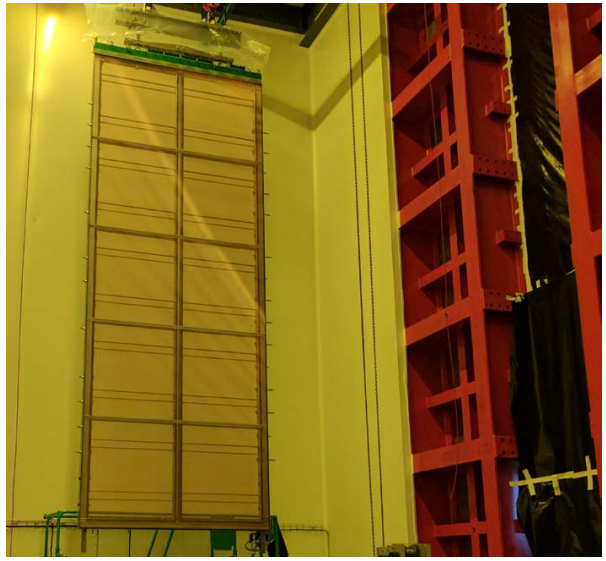
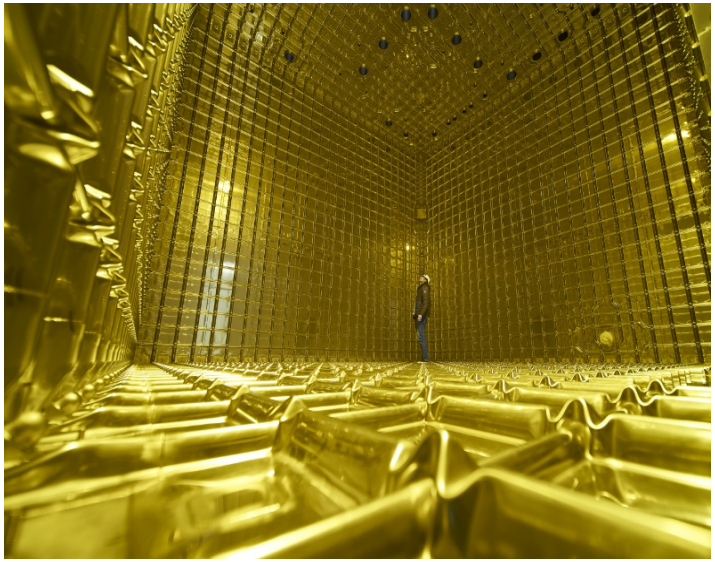
The P5 report recommended that PIP-II proceed immediately in order to provide increased proton beam intensity (of > 1 megawatt) for LBNF

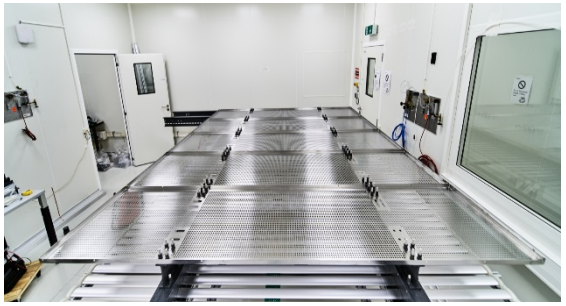
- **Replace the existing 50 year old linear accelerator with a higher power, modern one powered by superconducting radiofrequency cavities**
- **Supports longer-term physics research goals by providing increased beam power and high reliability for future experiments at Fermilab, including LBNF/DUNE**



Technical Progress Towards DUNE: protoDUNE





International Partnerships for U.S.-hosted Neutrino Program

- **International partnerships for LBNF/DUNE and PIP-II continue to grow**
  - CERN is an important partner and is meeting commitments according to the signed DOE-CERN Protocol and Addendum; planning to begin cryostat procurement
  - DOE looks forward to completing U.S.-India Project Annex II
  - Discussions continue with Italy, Brazil, and other Latin American nations
- **Institutions from several countries have signed international Cooperative R&D Agreements with Fermilab to work on LBNF/DUNE development**
  - Including Australia, France, Germany, Mexico, and Brazil

- **Recently, UK-U.S. Science and Technology Agreement signed 20 September 2017**
  - By UK Science Minister Jo Johnson and U.S. Acting Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs Judith Garber
  - The first major project under this agreement is UK investment of £65 million ($88 million) in LBNF/DUNE

Cosmic Frontier Program

Dark energy program through suite of complementary surveys, in partnership with NSF

- **Fast sky scanning surveys catch dynamic events, like supernovae:** *Dark Energy Survey (DES)* operating, *Large Synoptic Survey Telescope (LSST)* camera in fabrication
- **Deep, high accuracy surveys study dim, more distant objects:** *BOSS* completed; *eBOSS* operating, *Dark Energy Spectroscopic Instrument (DESI)* in fabrication

Dark matter searches through direct detection experiments with multiple technologies, in partnership with NSF

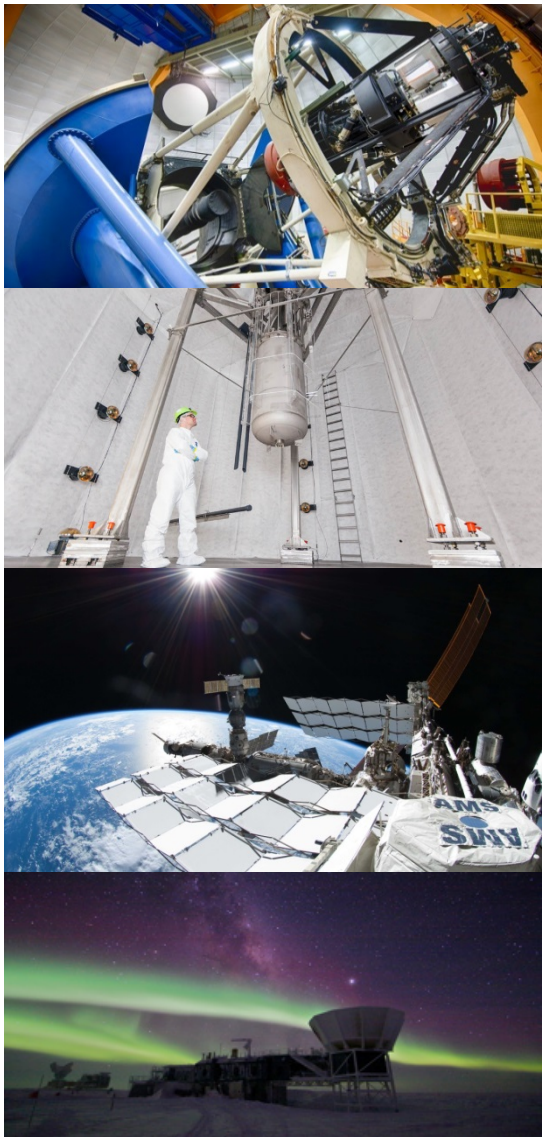
- **First-gen. experiments produced world's most sensitive searches**
- **Progressing toward next generation experiments:** *ADMX-G2 operating, LZ in fabrication, SuperCDMS-SNOLAB*

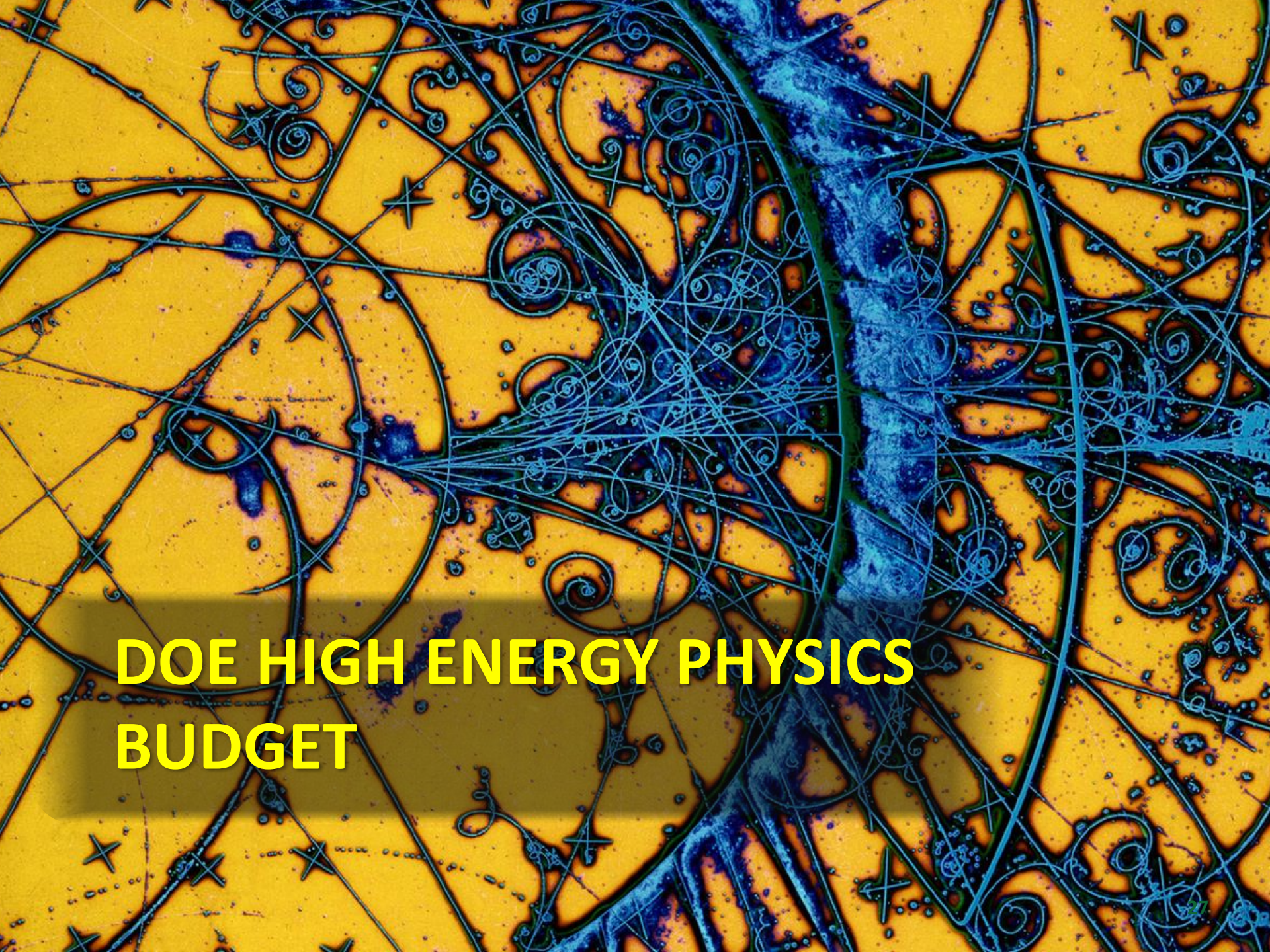
Study high-energy particles produced from cosmos, in partnership with NSF, NASA

- **Cosmic- and gamma-ray detectors on Earth and in space:** *Fermi/GLAST*, *AMS*, and *HAWC*

Study cosmic acceleration imprint on cosmic microwave background (CMB), in partnership with NSF, NASA

- **New generation now operating:** *SPT-3G*




DOE HIGH ENERGY PHYSICS
BUDGET

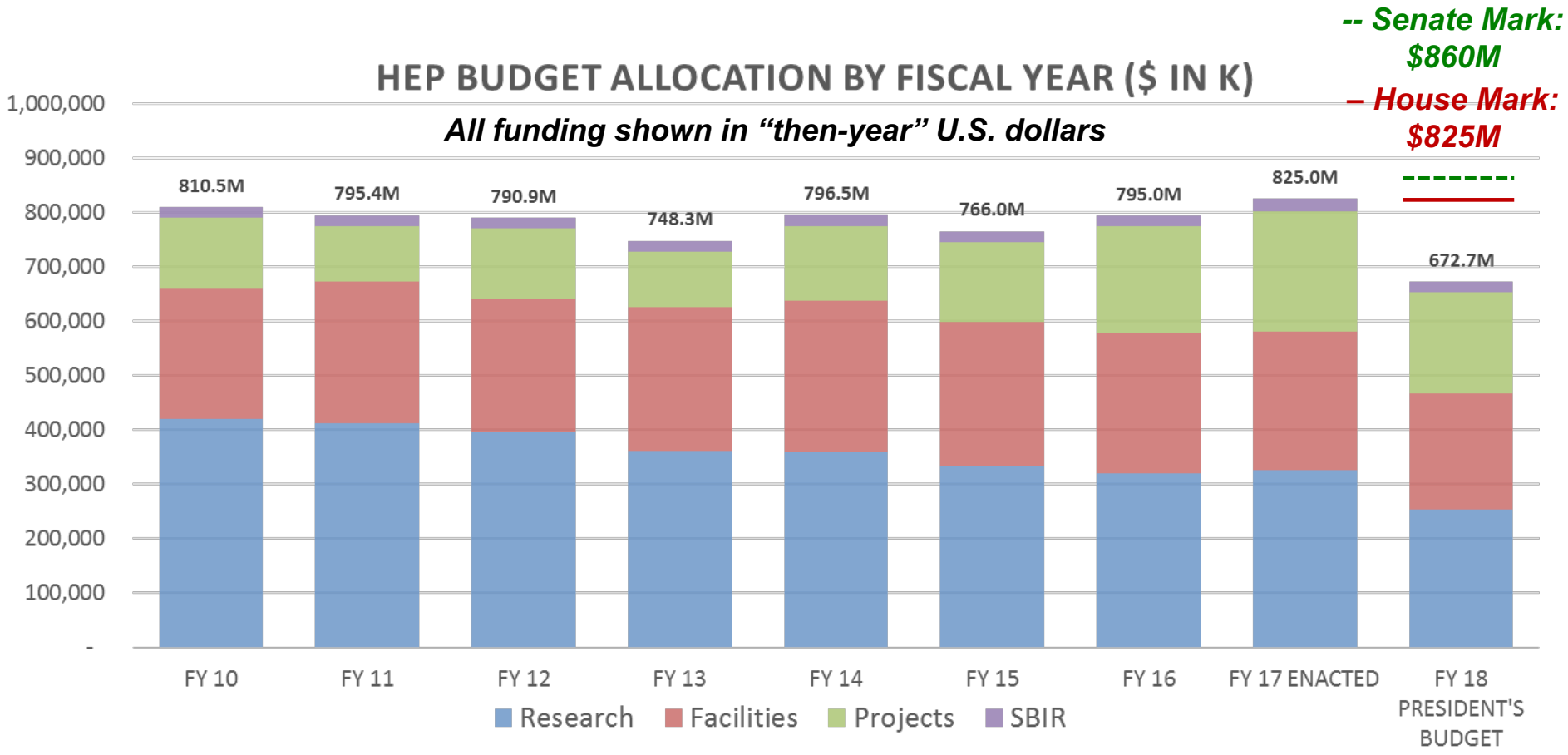
HEP FY 2018 President's Budget Request

HEP Funding *($ in thousands)*	FY 2016 Enacted	FY 2017 Annualized CR	FY 2017 Enacted	FY 2018 Request	FY 2018 vs. FY 2016		FY 2018 vs. FY 2017 Enacted	
Research	341,663	352,344	347,852	272,887	-68,776	-20%	-74,965	-21%
Facility/Operations	258,236	252,084	255,162	213,813	-44,423	-17%	-41,349	-16%
Projects & Constr.	195,101	189,061	221,986	186,000	-9,101	-4%	-35,986	-16%
Total	**795,000**	**793,489**	**825,000**	**672,700**	**-122,300**	**-15%**	**-152,300**	**-18%**

- **The 2018 President's Budget Request for HEP is a combination of U.S. Administration, DOE Office of Science, and P5 priorities**
- **FY18 Budget Request reduces near-term science for P5-guided investments in mid- and long-term programs**
  - **All projects continue, some with delays**
  - **Research maintained at 40% of the program budget, but Request will reduce activities at the National Labs and Universities, with higher priority given to the Lab programs that are critical to execute P5 recommendations**
  - **Operations support for ongoing experiments reduced to make this possible**
- **Both the U.S. Administration and U.S. Congress support the overall P5 strategic plan**

Overall HEP Budget Trend

- P5 strategy continues to define investments in future of the field
- Current draft of the U.S. House of Representatives FY 2018 appropriations bill is flat with respect to FY 2017, while the U.S. Senate draft bill is slightly up

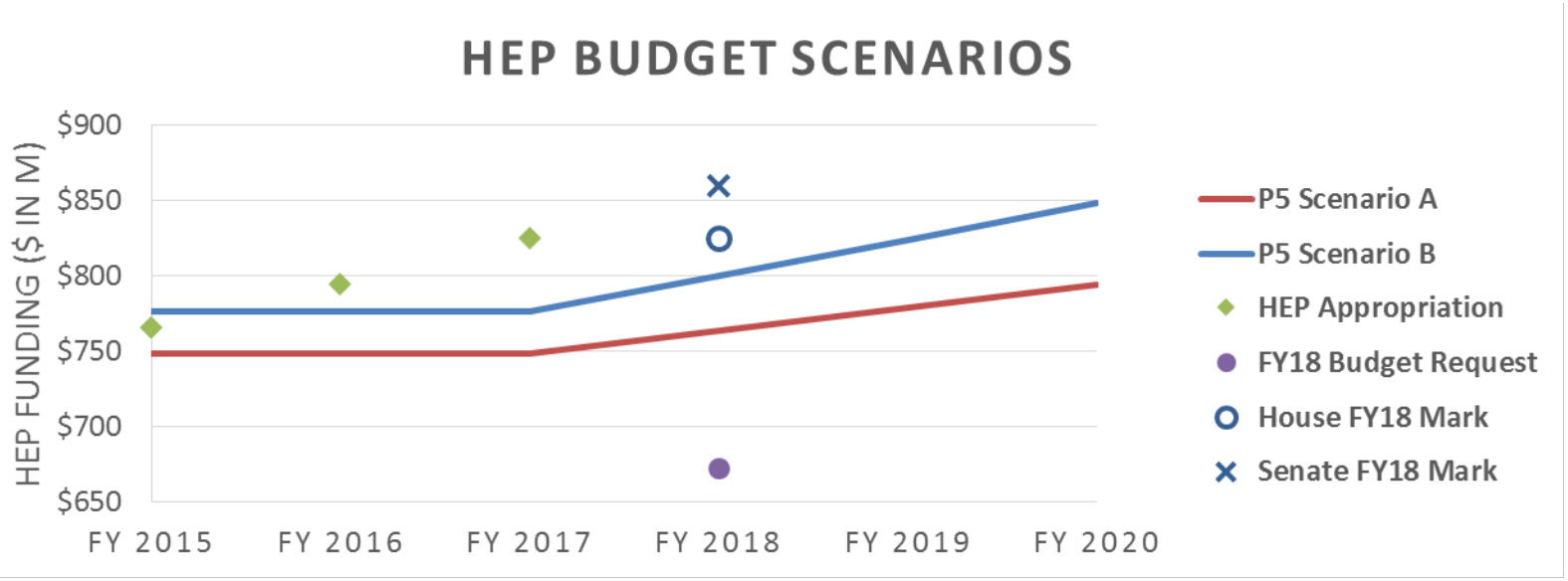


Status of FY 2018 Appropriations

- **U.S. House of Representatives released draft language for the FY 2018 budget in June 2017; U.S. Senate in mid-July 2017**
  - Language in both chambers of U.S. Congress supportive of HL-LHC Accelerator Project, HL-LHC ATLAS and CMS Detector Upgrade projects, LBNF/DUNE, and Cosmic Frontier projects
  - U.S. ATLAS and U.S. CMS Operations held roughly flat with respect to FY 2017 funding
  - Research funding will by necessity continue to be constrained, but efforts critical to executing the P5 recommendations remain a priority
- **DOE is also working with Fermilab and SBN managements to develop FY 2018 operations schedule for the SBN complex, including ICARUS**
- **Funding level is set once the Congressional appropriation bill has passed**
- **Fiscal Year 2018 began on October 1, 2017, with a Continuing Resolution (CR) currently through December 8, 2017**
  - CR was passed by U.S. Congress and signed by the President in September

HEP Budget *vs.* P5 Funding Scenarios

- P5 was charged to consider three 10-year budget scenarios for HEP within the context of a 20-year vision for the global field
  - Scenario A was the lowest constrained budget scenario
  - Scenario B was a slightly higher constrained budget scenario
  - Scenario C was "unconstrained," but not considered unlimited
- FY 2018 appropriations process is progressing
  - President's Budget Request released May 23; House/Senate Marks in June/July
  - Congressional Appropriations Committees draft legislation
  - Final language of appropriations bill (and report) impact how funding is directed



Closing Summary

- **CERN-DOE partnership strong and growing**
- **LHC program at CERN across three fronts: upgrades, operations, research**
  - HL-LHC Accelerator Upgrade and HL-LHC ATLAS and CMS Detector Upgrade projects are ramping up
  - Will continue to support LHC detector operations: future computing models are under study
  - Research funding will continue to be constrained in current fiscal environment
- **U.S.-hosted neutrino program is progressing with LBNF/DUNE and PIP-II**
  - Far-site civil construction has begun; International interest is ramping up
  - DUNE is on-track for technical component construction beginning in 2019
- **HL-LHC and LBNF/DUNE are the two large projects called out in the P5 strategy – we are well on our way!**

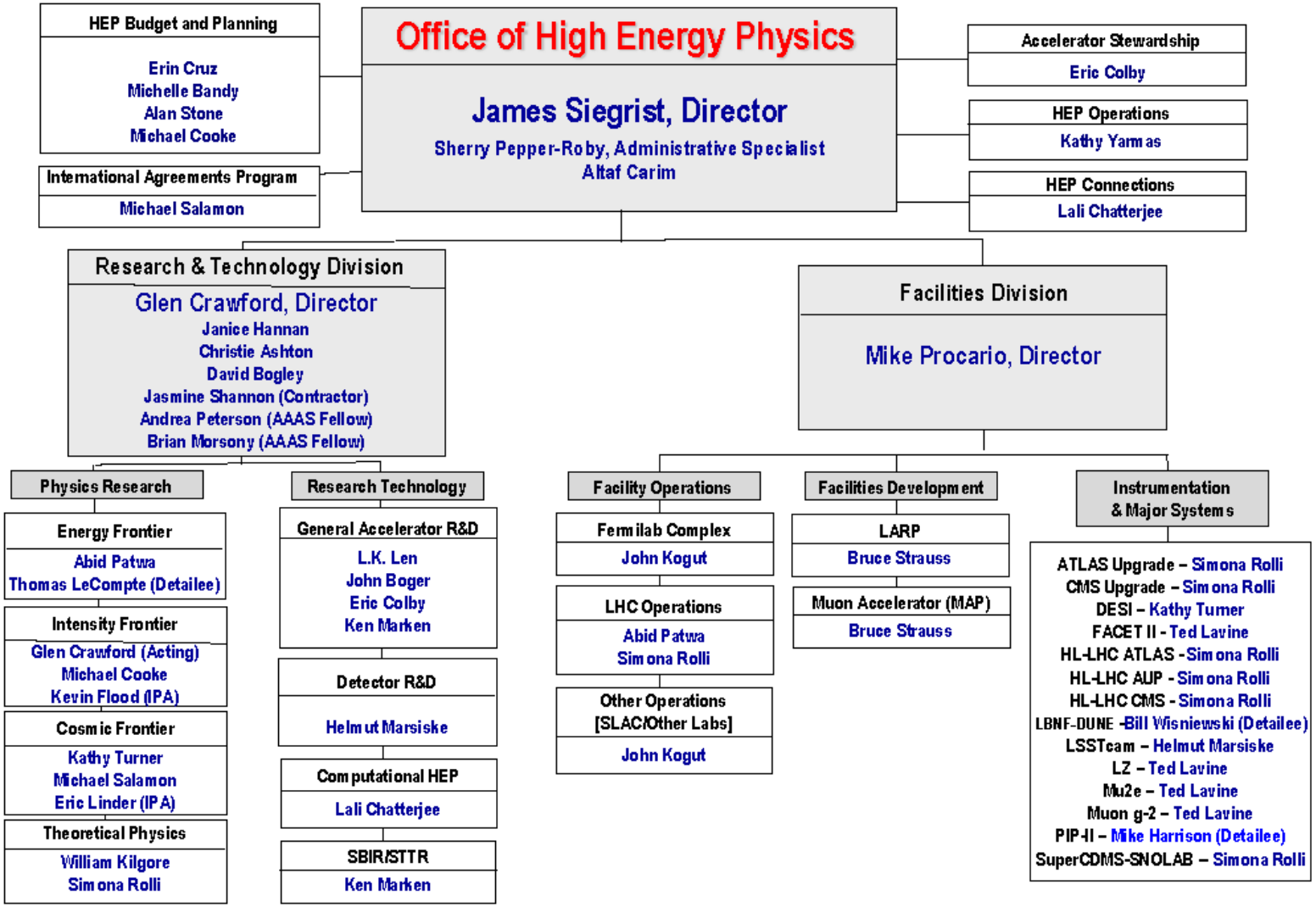
U.S. DEPARTMENT OF
ENERGY

Office of
Science

HEP MIE Project Status

Subprogram	TPC ($M)	CD Status	CD Date
INTENSITY FRONTIER			
Long Baseline Neutrino Facility / Deep Underground Neutrino Experiment (LBNF/DUNE)	1,300 – 1,900	CD-3A	September 1, 2016
Proton Improvement Project (PIP-II)	465-650	CD-0	November 12, 2015
Muon g-2	46.4	CD-3	August 20, 2015
Muon-to-Electron Conversion Experiment (Mu2e)	273.677	CD-3	July 14, 2016
ENERGY FRONTIER			
LHC ATLAS Detector Upgrade	33	CD-3	November 12, 2014
LHC CMS Detector Upgrade	33	CD-3	November 12, 2014
High-Luminosity LHC (HL-LHC) Accelerator Upgrade	180-250	CD-0	April 13, 2016
High-Luminosity LHC (HL-LHC) ATLAS Detector Upgrade	125-155	CD-0	April 13, 2016
High-Luminosity LHC (HL-LHC) CMS Detector Upgrade	125-155	CD-0	April 13, 2016
COSMIC FRONTIER			
LUX-ZEPLIN (LZ)	55.5	CD-3	February 9, 2017
Super Cryogenic Dark Matter Search - SNOLAB (SuperCDMS-SNOLAB)	16-21	CD-1	December 21, 2015
Dark Energy Spectroscopic Instrument (DESI)	56.328	CD-3	June 22, 2016
Large Synoptic Survey Telescope Camera (LSSTcam)	168	CD-3	August 27, 2015
ADVANCED TECHNOLOGY R&D			
Facility for Advanced Accelerator Experimental Tests II (FACET-II)	46-60	CD-1	December 21, 2015

DOE Office of High Energy Physics

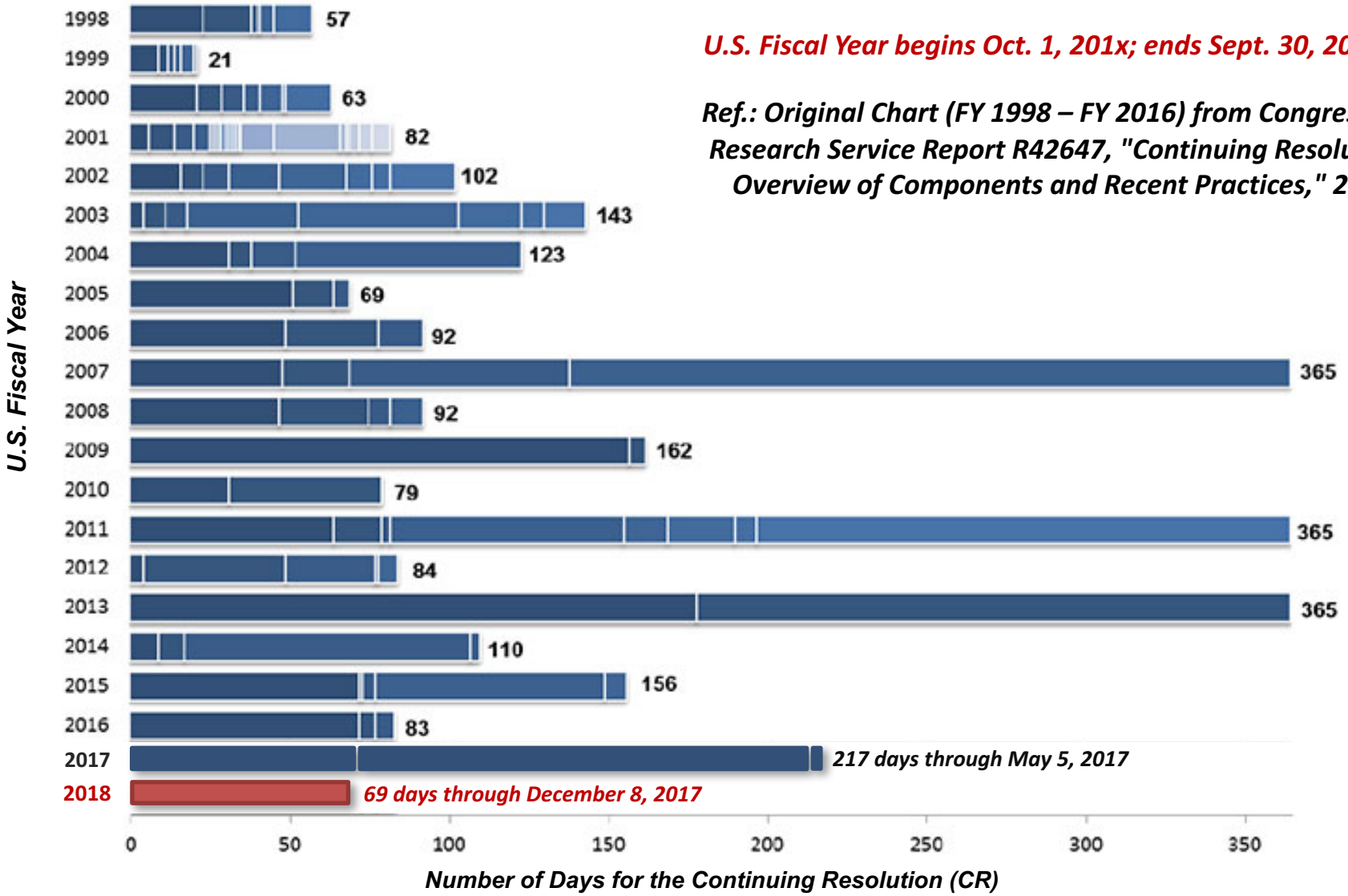


HEP underpins and advances the DOE missions and objectives through a balance portfolio of scientific research, facilities' operations and projects, and by the development of key technologies and trained person-power needed to work at the cutting edge of science.

Department of Energy Research and Innovation Act

- **Passed by the United States House of Representatives under unanimous consent (voice vote) on January 24, 2017**
  - now being considered by the United States Senate
- **SEC. 305. HIGH-ENERGY PHYSICS.**
  - (a) Sense Of Congress.—It is the sense of Congress that—
    - (1) the Director should incorporate the findings and recommendations of the report of the Particle Physics Project Prioritization Panel entitled "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context" into the planning process of the Department; and
    - (2) the nations that lead in particle physics by hosting international teams dedicated to a common scientific goal attract the world's best talent and inspire future generations of physicists and technologists.
  - (b) International Collaboration.—The Director, as practicable and in coordination with other appropriate Federal agencies as necessary, shall ensure the access of United States researchers to the most advanced accelerator facilities and research capabilities in the world, including the Large Hadron Collider.
  - (c) Neutrino Research.—The Director shall carry out research activities on rare decay processes and the nature of the neutrino, which may include collaborations with the National Science Foundation or international collaborations.
  - (d) Dark Energy And Dark Matter Research.—The Director shall carry out research activities on the nature of dark energy and dark matter, which may include collaborations with the National Aeronautics and Space Administration or the National Science Foundation; or international collaborations.

Duration of CRs: FY 1998 – FY 2018



U.S. Fiscal Year begins Oct. 1, 201x; ends Sept. 30, 201(x+1)

Ref.: Original Chart (FY 1998 – FY 2016) from Congressional Research Service Report R42647, "Continuing Resolutions, Overview of Components and Recent Practices," 2016.

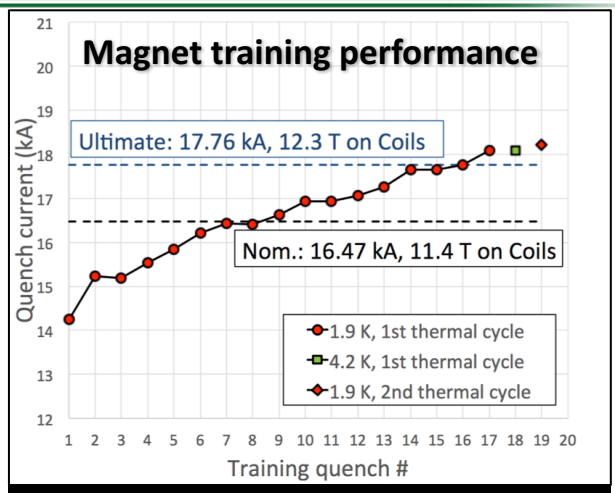
CMS LHC Physics Center (LPC) and ATLAS Center (ATC)

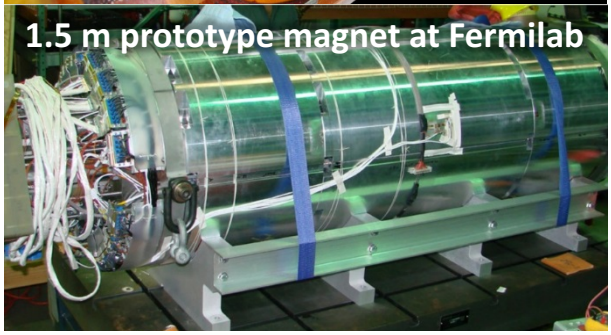
- **LPC at Fermilab and ATC at BNL, ANL, LBNL, and SLAC serve as user-based regional centers for the collaborations**
  - Nexus for physics analysis, Tier-1 computing support at BNL (ATLAS) and Fermilab (CMS), and mentorship & training within the collaborations
  - "Centers of Excellence" for U.S.-CMS/ATLAS championed by the collaborations
  - Offer variety of programs: topical workshops, seminars, data analysis schools

- **Critical link for physicists to participate directly in CMS/ATLAS in the U.S.**
  - LPC hosts over 350 users annually, with 100 resident at Fermilab, including all 49 U.S. institutions on CMS and visiting colleagues from Asia, Europe, and Latin America
  - U.S. CMS and U.S. ATLAS scholars' programs hosts distinguished researchers to foster physics collaboration and enhance U.S. contributions
- **Model very successful and adopted by others in HEP**
  - Fermilab Neutrino Physics Center and the U.S. Theory community

Successful Test of New HL-LHC Magnet

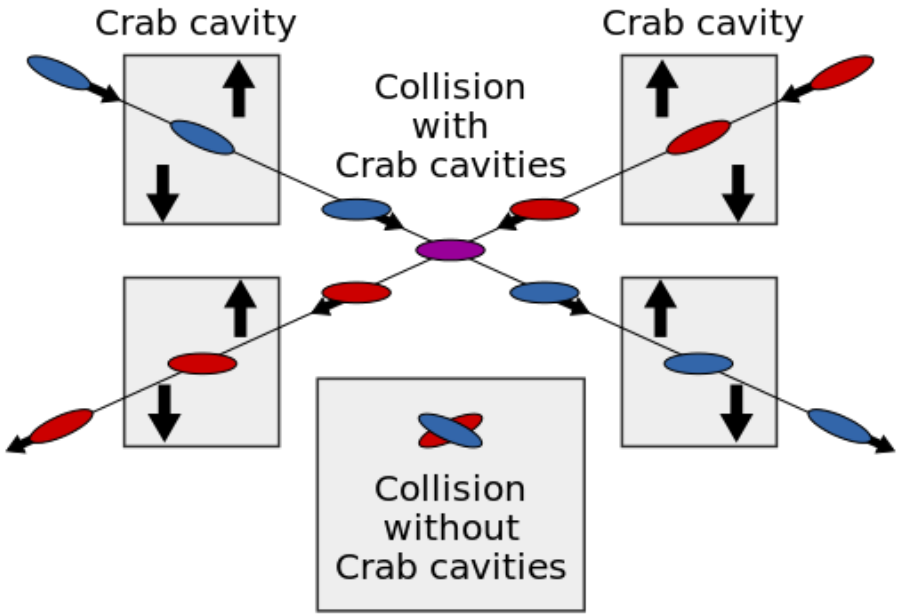
- **U.S. and CERN successfully co-created prototype superconducting accelerator magnet much more powerful than those now in the LHC**
- **New quadrupole magnet will replace ~5% of the LHC's focusing and steering magnets when the accelerator is converted into the High-Luminosity LHC**
  - Current LHC magnets made from NbTi, which can remain superconductive in a magnetic field up to 10 T
  - New magnet made from Nb_3Sn, capable of carrying current through a magnetic field of up to 20 T
- **Culmination of 10 year effort designing and perfecting a new and reproducible process to wind, form, bake and stabilize the coils**
  - Nb_3Sn must be baked at 650° C to become a superconductor
  - Heat-treatment changes the material's atomic structure and it becomes almost as brittle as ceramic

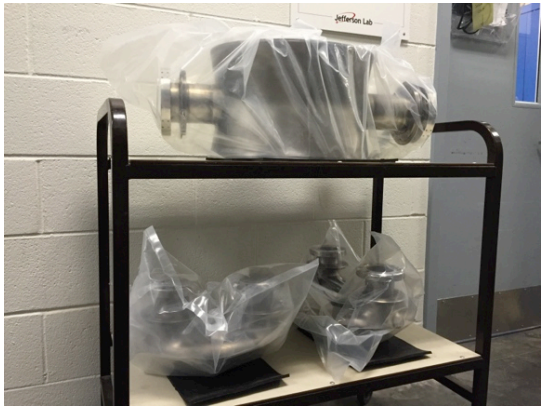




Status of LARP Crab Cavities Effort for HL-LHC

- **R&D is moving forward on the Crab Cavities that are part of the current plan for the High Luminosity LHC (HL-LHC) accelerator upgrade**
  - Require compact SRF cavities
  - Twist proton bunches at interaction point to collide head-on
  - Level the luminosity and tune the collision pile-up density distribution
- **LHC Accelerator Research Program (LARP) spearheaded the design and initial development of the concept for the HL-LHC**
- **February 2017 three (naked) Crab Cavities were tested: all went well beyond the operating voltage of 3.4 MV**
  - One US-LARP DQW went up to 5.4 MV
  - One US-LARP RFD reached 4.03 MV
  - One CERN DQW went up to 5.04 MV
- **Good results for the Crab Cavity testing in the CERN SPS in 2018**





Double Quarter Wave (DQW) ready for final assembly at JLAB

RF Dipole (RFD) chemical processing