U.S. DEPARTMENT OF ENERGY | Office of Science

Status of the DOE High Energy Physics Program

High Energy Physics Advisory Panel
May 2018

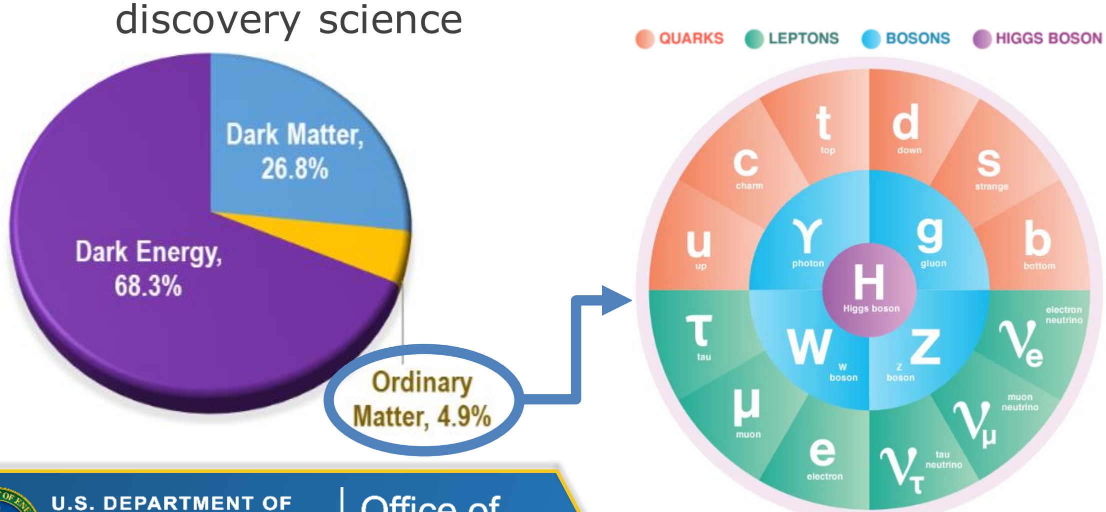
Jim Siegrist
Associate Director for High Energy Physics
Office of Science, U.S. Department of Energy

The High Energy Physics Program 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

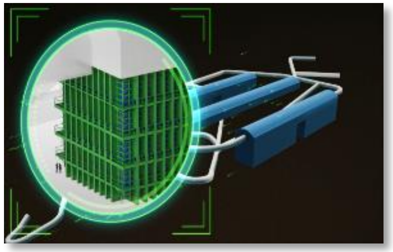
- The DOE Office of High Energy Physics fulfills its mission by:
  - Building **projects** that enable discovery science
  - Operating **facilities** that provide the capability for discoveries
  - Supporting a **research** program that produces discovery science



U.S. Long-Term Particle Physics Strategy

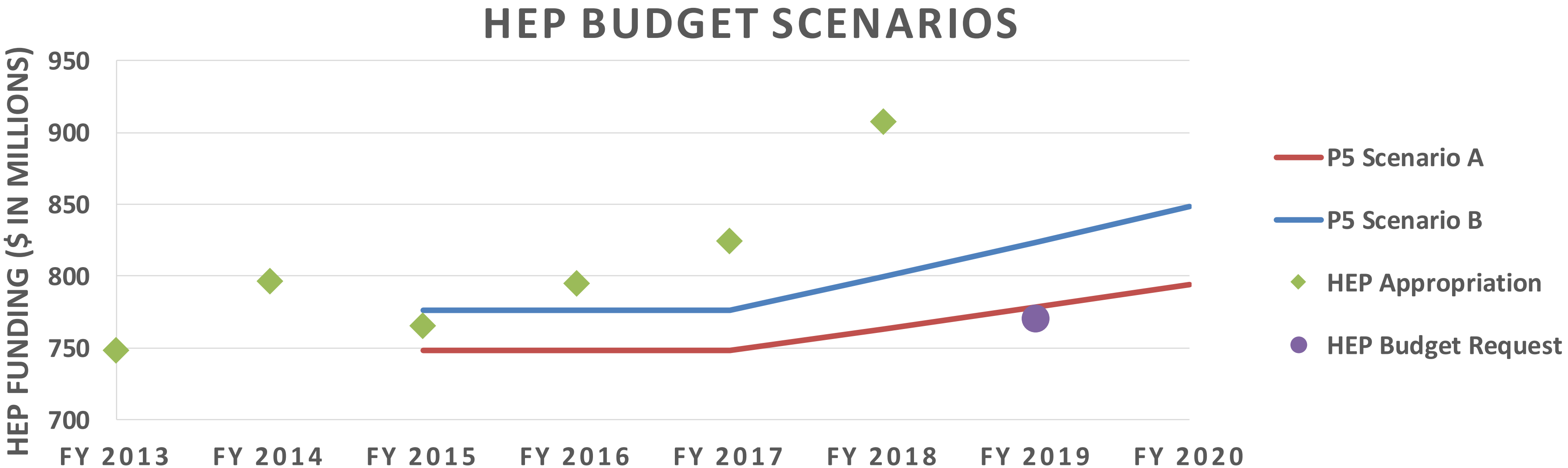
- The global vision presented in the 2014 Particle Physics Project Prioritization Panel (P5) report is the culmination of years of effort by the U.S. particle physics community
  - 2012 – 2013: Scientific community organized year-long planning exercise ("Snowmass")
  - 2013 – 2014: U.S. High Energy Physics Advisory Panel convened P5 to develop a plan to be executed over a ten-year timescale in the context of a 20-year global vision for the field

- P5 report enables discovery science with a balanced program that deeply intertwines U.S. efforts with international partners
  - **U.S. particle physics community** strongly supports strategy
  - **U.S. Administration** has supported implementing the P5 strategy through each President's Budget Request
  - **U.S. Congress** has supported implementing the P5 strategy through the language and funding levels in appropriations bills
  - **International community** recognizes strategy through global partnerships



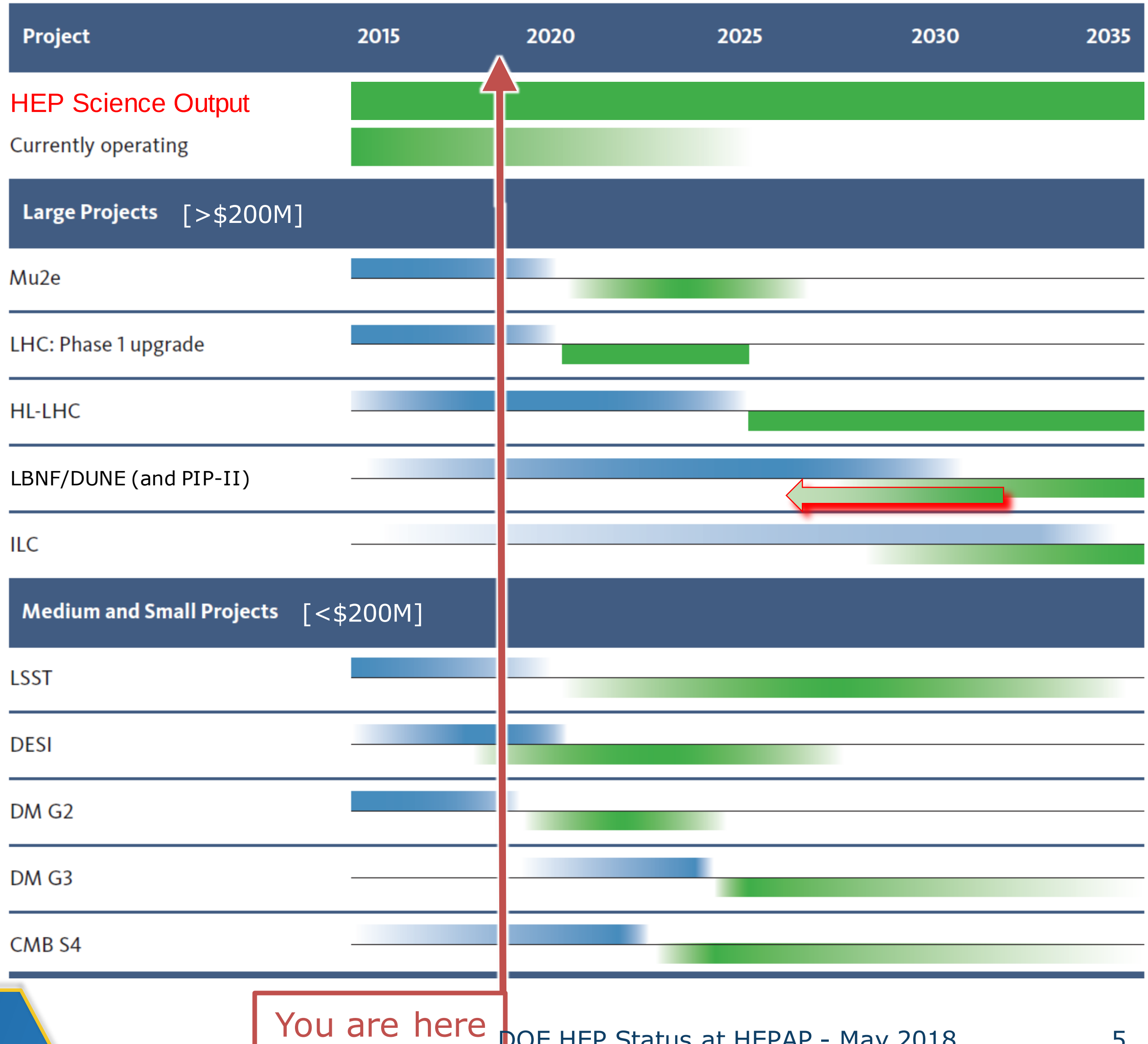
HEP Budget vs. P5 Scenarios

- P5 was charged to consider 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
- FY 2018 Appropriation ($908M) provides funding for all HEP Projects at their recommended profiles. Facilities and Experimental Operations are supported at their optimal levels. Research is funded above 40% of the total HEP budget.
- FY 2019 President's Budget Request ($770M) reflects the P5 vision
  - Preserves flexibility in situ to continue or ramp down efforts contingent on what Congress appropriates



P5 Construction and Physics Timeline

- P5 provided ten-year strategic plan in the context of a twenty-year global vision
- Carefully chosen investments will enable a steady stream of exciting new results for many years to come

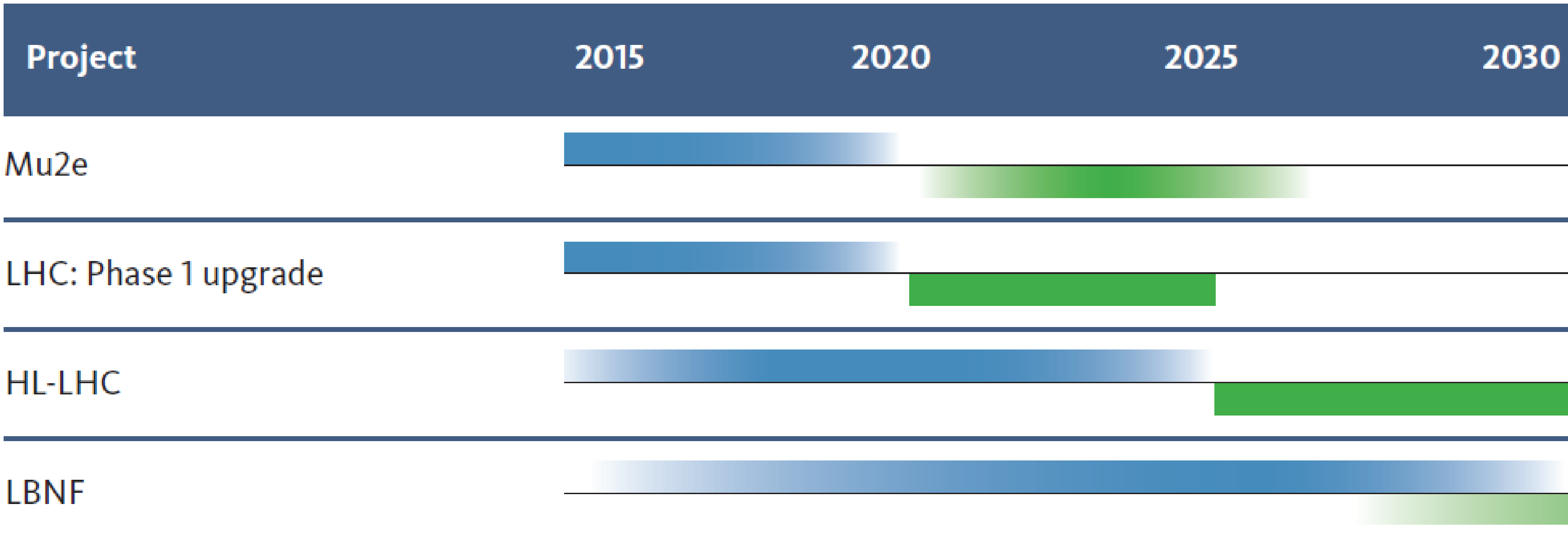


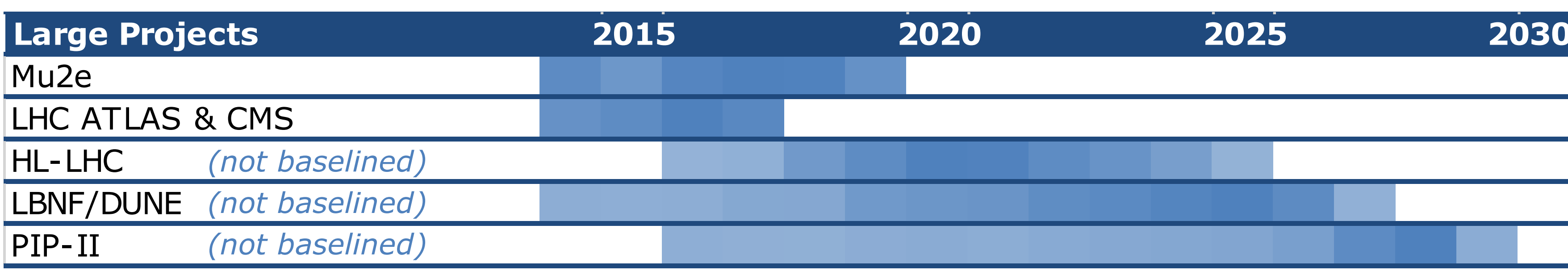
Legend:

- ***Approximate Construction***
- ***Expected Physics***
- ***LBNF/DUNE Early Science***

P5 Large Projects

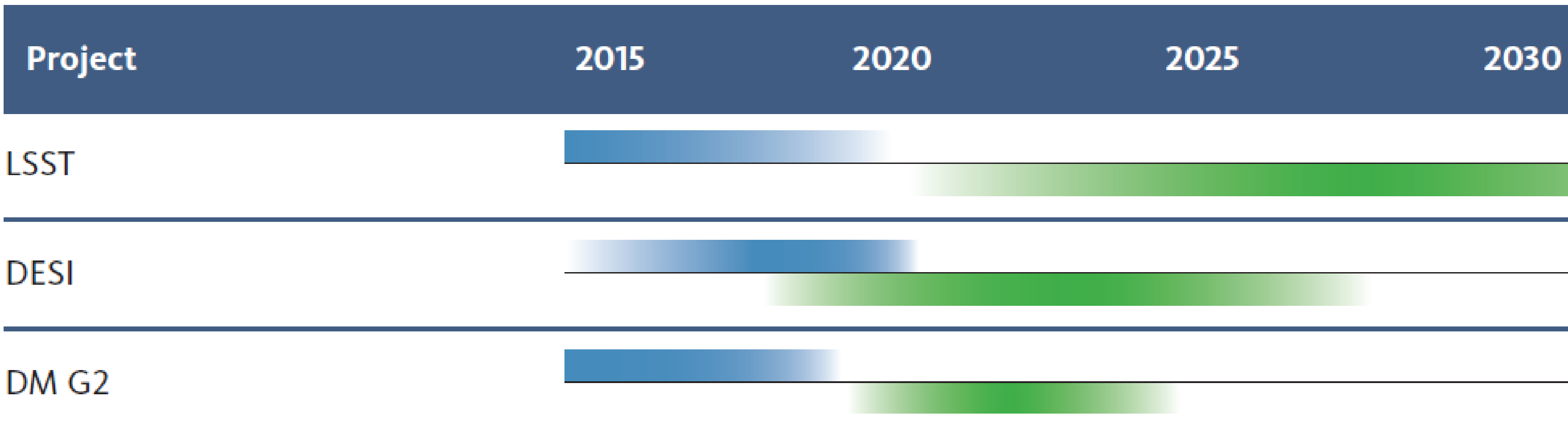
- P5 timeline vs. FY19 Budget Request project funding profiles
  - Appropriation language and DOE CD process will impact final profiles





P5 Medium and Small Projects

- P5 timeline vs. FY19 Budget Request project funding profiles
  - Appropriation language and DOE CD process will impact final profiles



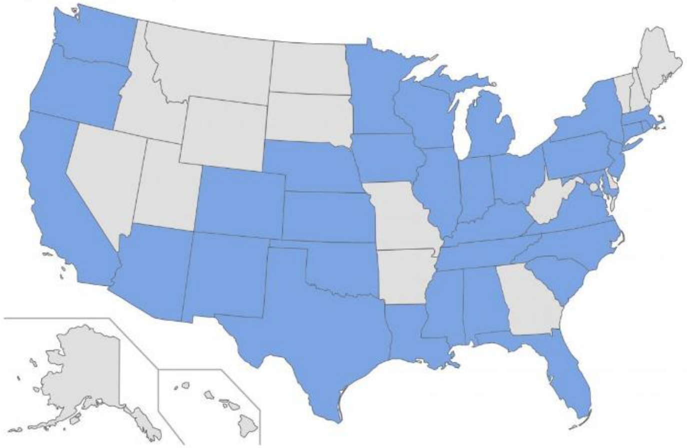
Small Projects Portfolio

- HEP has funded a number of “small projects” and will continue to pursue timely physics opportunities with new experimental technique
  - Long list includes COHERENT, ADMX-G2, HPS, …
- Intermediate Neutrino Research Program workshop and FOA enabled PROSPECT, ANNIE
- Future Basic Research Needs workshops may help define and prioritize additional opportunities for small project investments
  - Potential topic areas include: accelerator applications (compact accelerators), light dark matter, detector R&D

Energy Frontier: LHC, ATLAS, and CMS

The Large Hadron Collider at CERN is the centerpiece of the U.S. Energy Frontier program

- U.S. ATLAS represents ~19% of the international ATLAS Collaboration
  - 41 universities, 4 national labs (Argonne, Brookhaven, Lawrence Berkeley, SLAC)
  - Brookhaven is host lab for U.S. ATLAS
- U.S. CMS represents ~29% of the international CMS Collaboration
  - 53 universities, 1 national lab
  - Fermilab is host lab for U.S. CMS



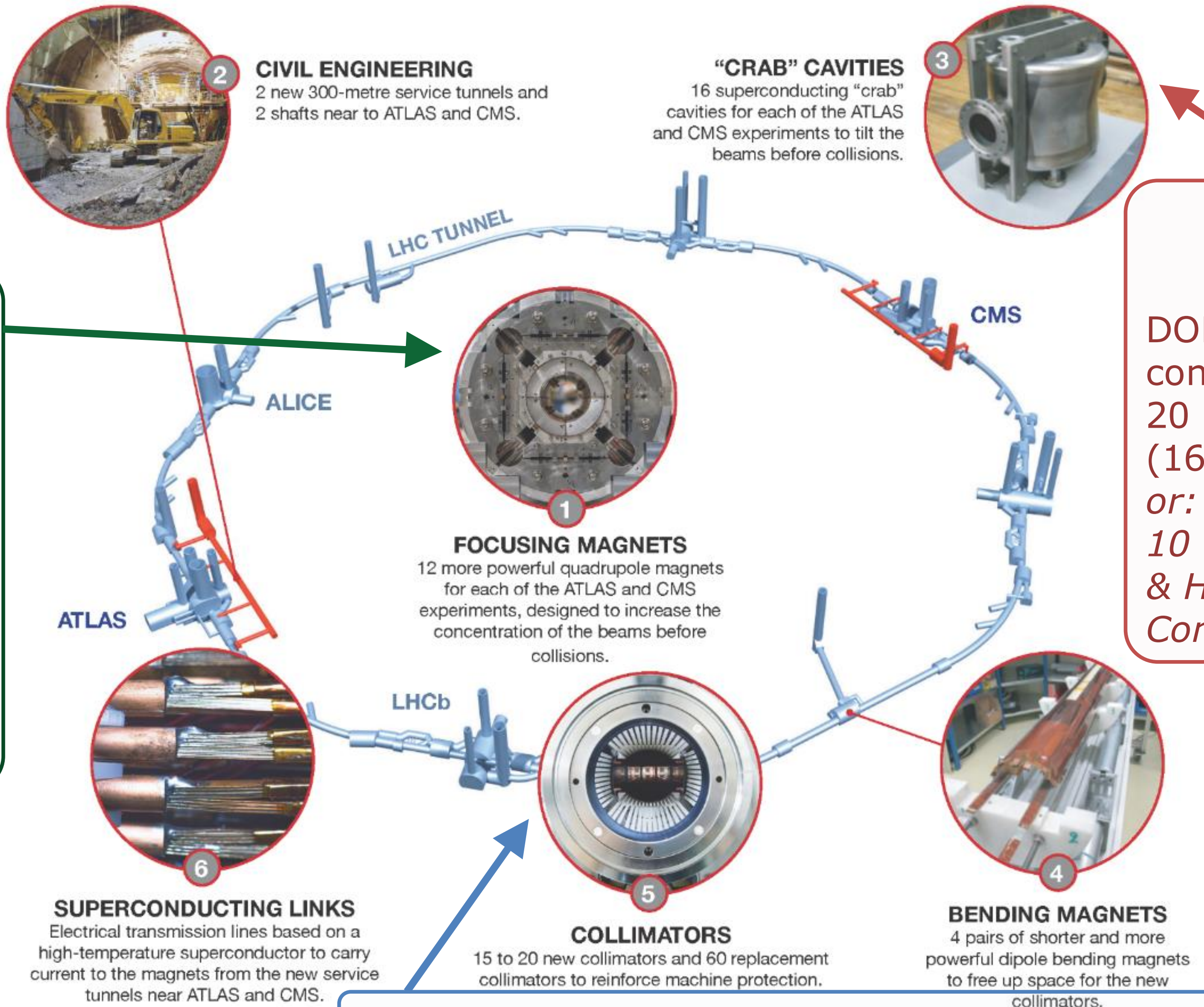
States hosting members of the U.S. LHC experimental program

Large Hadron Collider Tunnel

ATLAS Detector

CMS Detector

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



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)

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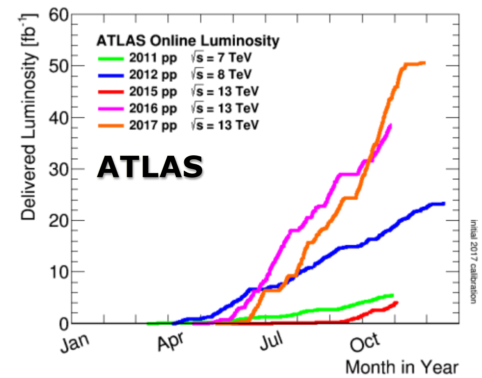
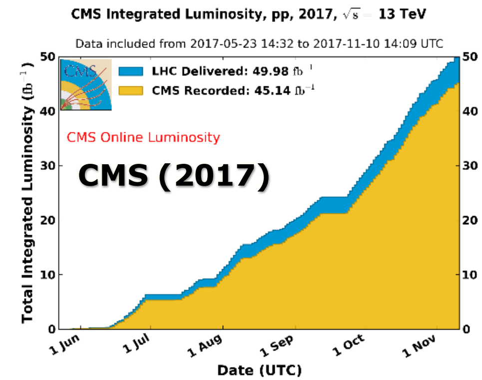
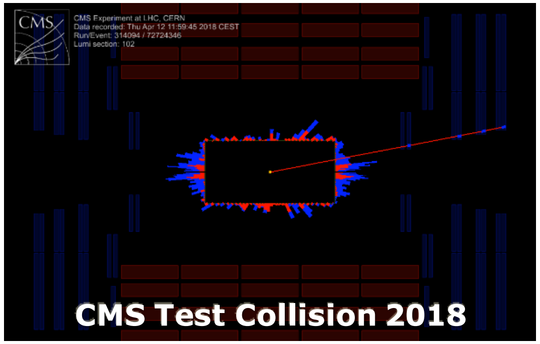
EF Highlight: LHC Collisions Resume

- Over 730 LHC Run 1+2 papers submitted by each of the CMS and ATLAS Collaborations
- LHC resumed collisions on April 12, 2018!
  - LHC delivered ~50 fb^{-1} in 2017, exceeding 45 fb^{-1} goal
  - Aiming to deliver 60 fb^{-1} to experiments in 2018
- ATLAS and CMS Phase-I upgrades progressing
  - Early DOE CD-4a in Sep. 2017 for the U.S. CMS upgrade
  - Installation & commissioning for the U.S. ATLAS-built deliverables began in FY 2017, continue through LS2
    - DOE closely monitoring the international ATLAS New Small Wheel installation plans
- HL-LHC Projects working towards next DOE CD milestones
  - HL-LHC Accelerator Upgrade Project aiming for DOE CD-2 (Project Baseline) in Fall 2018
  - HL-LHC ATLAS and CMS Detector Upgrade Projects working to understand funding profiles in preparation for DOE CD-1 in Summer 2018

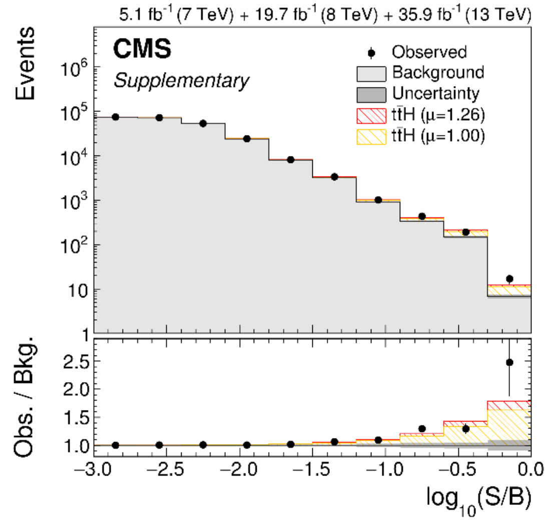


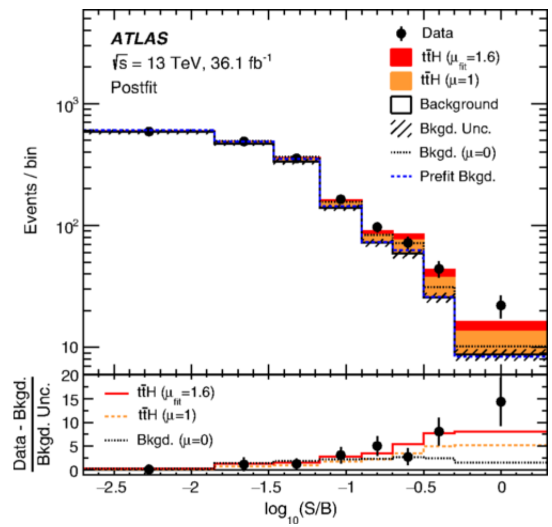


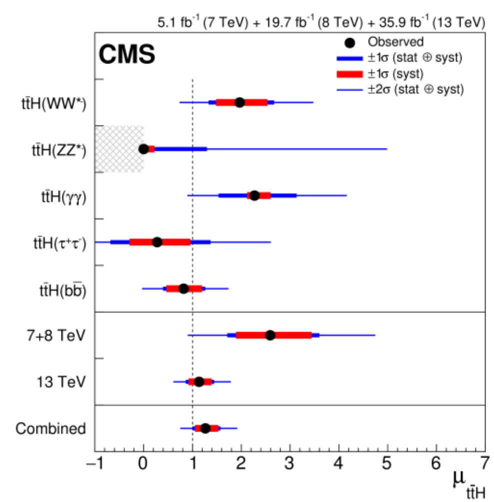


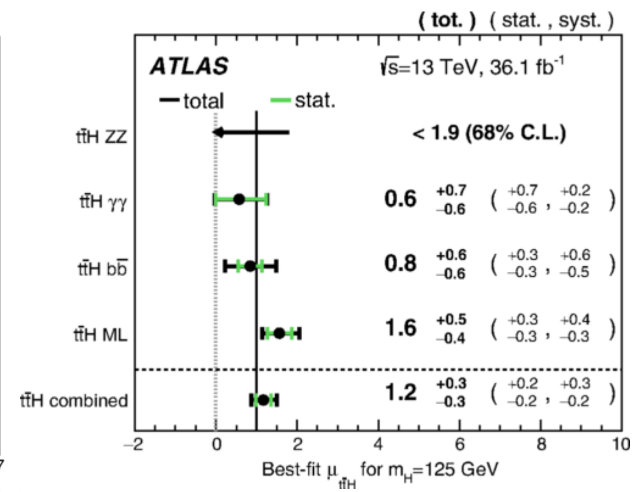
EF Highlight: ttH Production

- April 2018 results from ATLAS and CMS on Higgs production in association with a top quark pair
  - **ATLAS** combined result observes 4.2σ significance (3.8σ expected)
    - *Phys. Rev. D* **97**, 072003
  - **CMS** combined result observes 5.2σ significance (4.2σ expected)
    - Accepted for *Phys. Rev. Lett.* [arXiv:1804.02610]



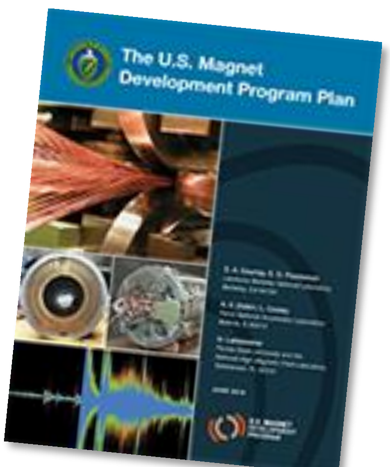


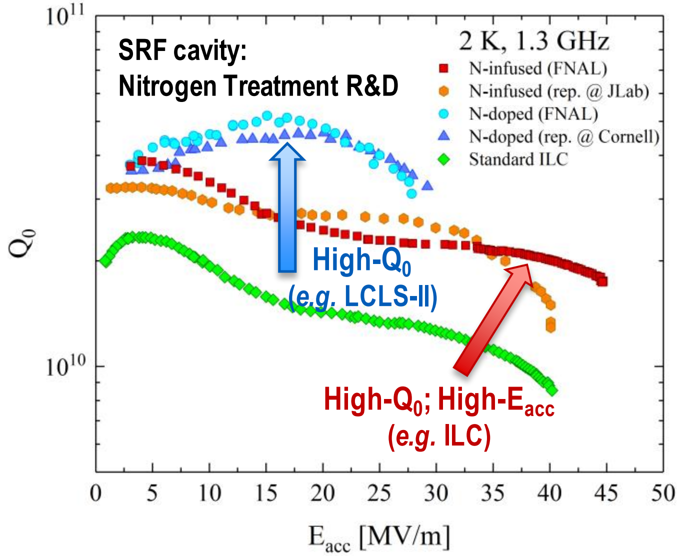




Future Colliders

- DOE coordinating with international community towards development of the next collider program
  - U.S. looks forward to a decision this year by Japan to host the ILC as an international project
  - Global strategy for circular collider awaits 2020 European Strategy Update for Particle Physics
- Interest from HEP community to pursue R&D studies for future collider options
  - Circular collider: DOE efforts focused on high-field magnet technology to enable higher energy
  - ILC: DOE efforts focused on cost reduction R&D, *e.g.*, nitrogen treatment in SRF cavities has potential for up to 10% cost reductions in 3-5 years, up to 15% in 5-10 years
- Under any fiscal constraints 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

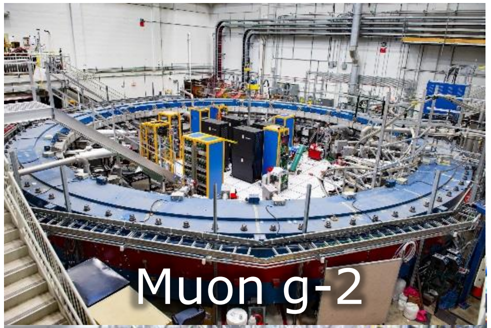




Intensity Frontier Program

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

- Exploring the unknown through precision measurements:
  - Muon g-2, Muon-to-Electron Conversion Experiment (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
  - Ramping up Fermilab Short-Baseline Neutrino Program (MicroBooNE, SBND, ICARUS)
  - Preparing to host world-leading neutrino program with the Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE)



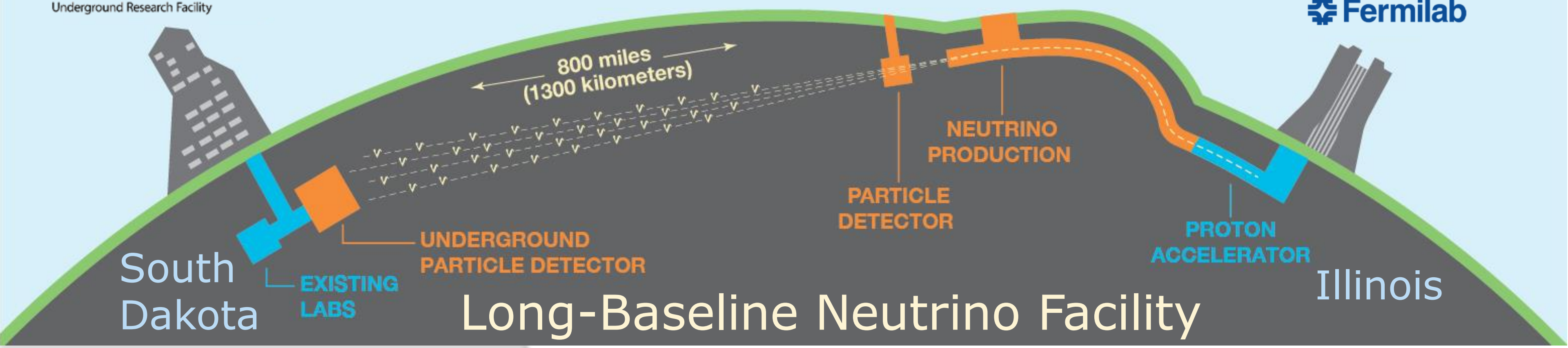
Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment

- 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 800 miles through the earth to DUNE
  - Strong support within the U.S. Government and many interested potential global partners
- International DUNE collaboration includes:
  - Over 1,100 collaborators from 176 institutions, 31 countries
- Proton Improvement Plan II (PIP-II) will provide increased proton beam intensity (>1 MW) for LBNF

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

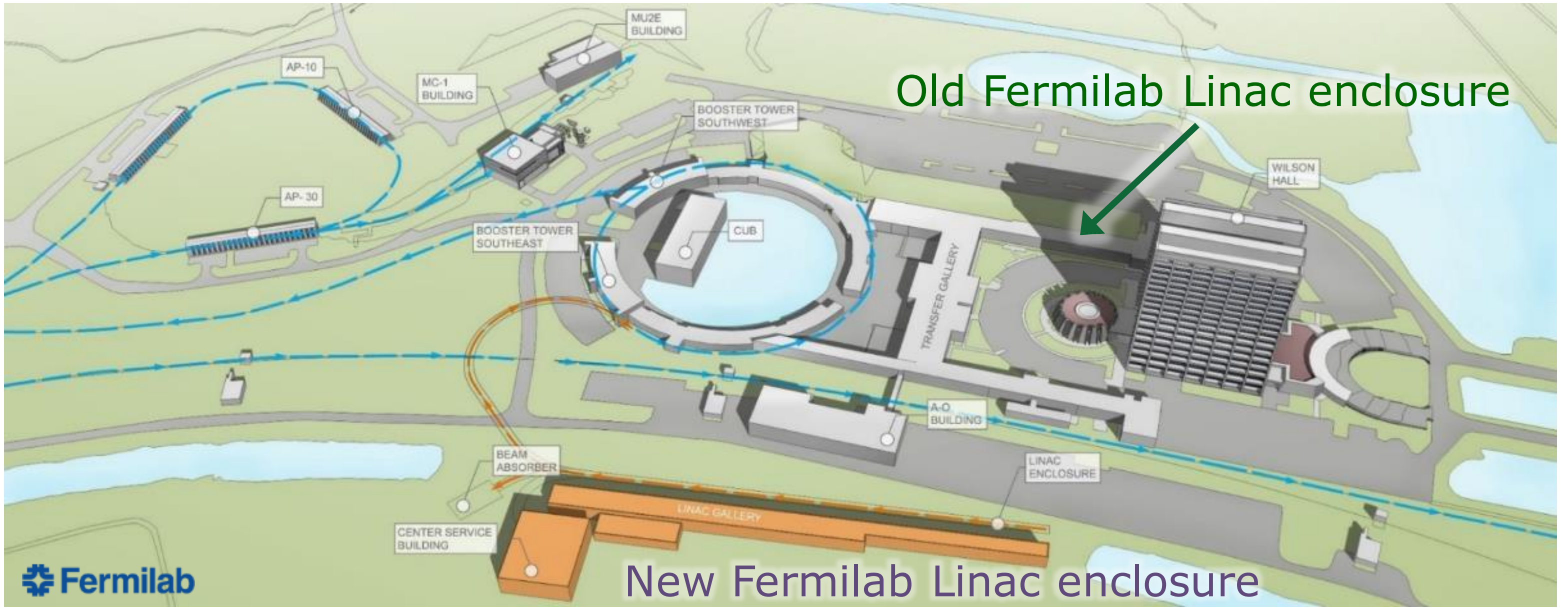
Sanford Underground Research Facility

Fermilab



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; 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



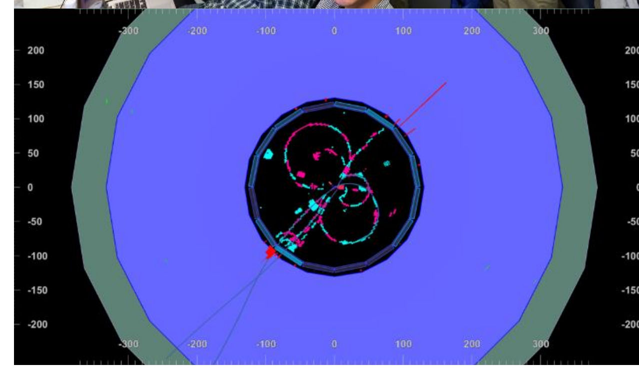
International Partnerships

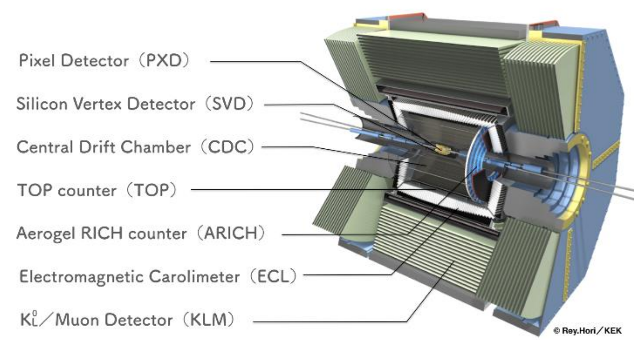
- DOE-DAE (India) Project Annex II on Neutrino Research signed April 16, 2018 in New Delhi
  - By U.S. Secretary of Energy Rick Perry and India’s Atomic Energy Secretary Sekhar Basu
  - Expands accelerator science collaboration to include the science for neutrinos

- Paul M. Dabbar, DOE Under Secretary for Science, has sent letters to Canada and France inviting their participation in LBNF/DUNE and PIP-II
- Fabiola Gianotti, Director-General of CERN, has extended an invitation to Under Secretary Dabbar to visit CERN
- A loan agreement between DOE, CERN, and Italy (MIUR) is now in the process of being signed for the ICARUS detector while the detector operates at Fermilab
- Working within DOE to develop MOUs to enable partnership activities on the U.S.-hosted neutrino program

IF Highlight: First Collisions at Belle II

- Belle II collaboration includes over 750 researchers from 25 countries and regions
  - Includes a dozen U.S. Universities and Laboratories
- U.S. Belle II project delivered key components of imaging Time-Of-Propagation (iTOP) and Klong-Muon (KLM) detector upgrade
  - Received DOE Project Management Achievement Award for delivering components ahead of schedule and under budget
- Belle II aims to collect 50x the data of Belle over 10 years, using the 40x luminosity improvement of SuperKEKB
- April 26: First collisions at SuperKEKB, after successfully storing electron and then positron beams in March 2018





Cosmic Frontier Program

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

- Fast, wide area sky scanning surveys cover large volume and 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: 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
- Advancing the second generation DM experiments: ADMX-G2 operating; LZ in fabrication; SuperCDMS-SNOLAB progressing

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

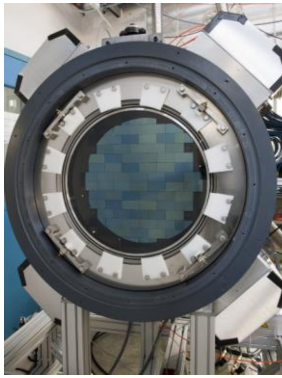
Study cosmic acceleration imprint on cosmic microwave background (CMB), in partnership with NSF

- Currently observing with SPT-3G; CMB-S4 planning underway

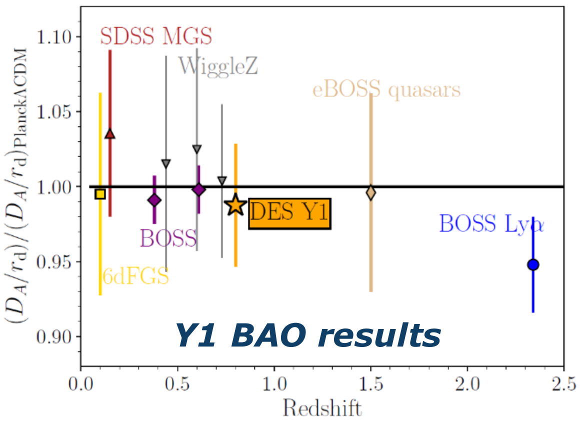



CF Highlight: DES Y1 Results

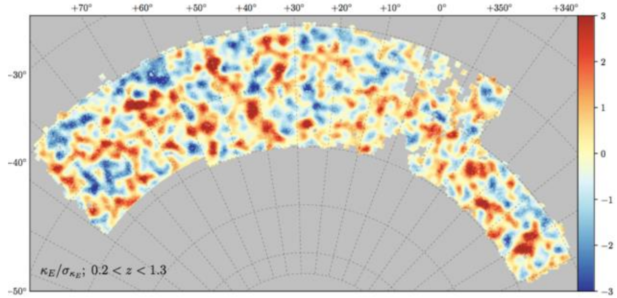
- DES studies Dark Energy via survey of 300 million galaxies, 3,000 supernovae with 570-megapixel Dark Energy Camera on Blanco telescope in Chile
  - Planned 5 year ops. began Aug. 2013; extended through Dec. '18



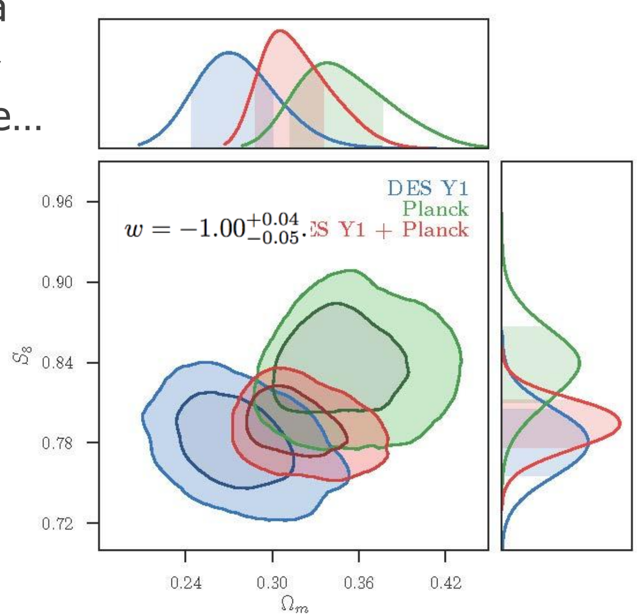
- Cosmology results from DES Year 1 data
  - Aug. 2017: Galaxy clustering & weak lensing; competitive with Planck
  - Dec. 2017: Baryon Acoustic Oscillation (BAO) to z=1
  - Jan. 2018: Data Release 1; first 3 yrs. of survey data
  - Over 150 papers: most distant supernova, new Milky Way dwarf satellites to constrain dark matter, & more…



Y1 BAO results



DES Y1 produced largest map of dark matter in the Universe



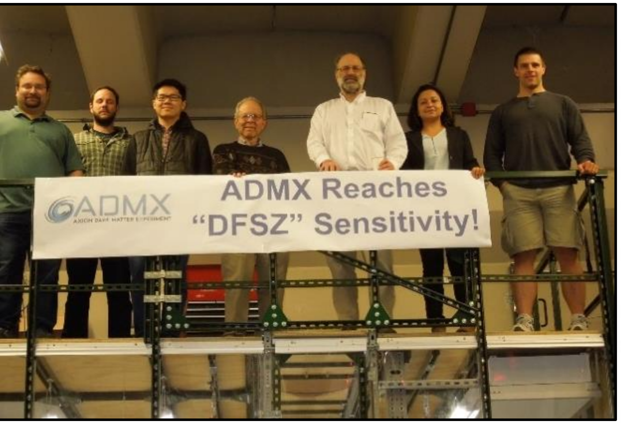
Y1 galaxy clustering & weak lensing

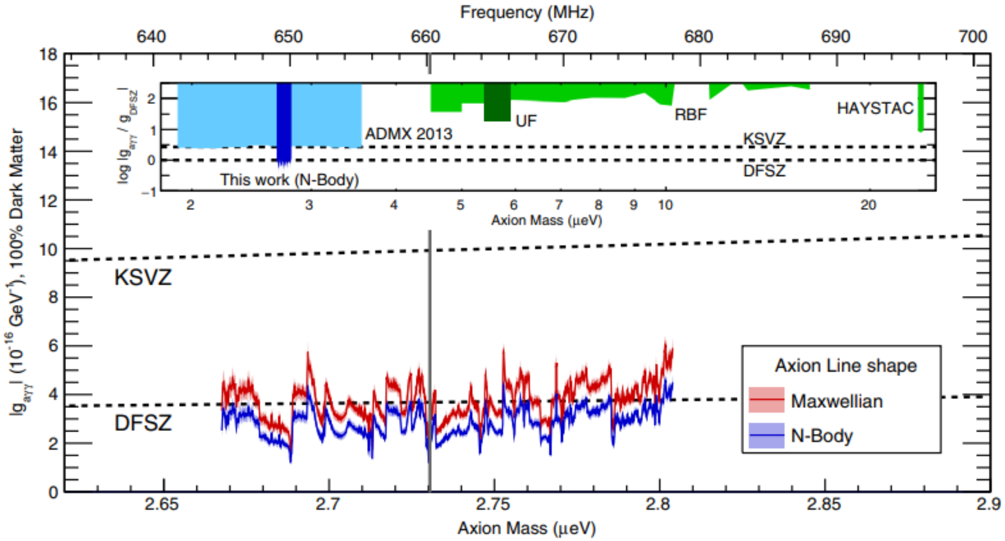
CF Highlight: ADMX-G2

- Axion Dark-Matter eXperiment Generation 2 at U. Washington
  - Uses a strong magnetic field and resonant cavity to convert dark matter axions into detectable microwave photons
  - Selected as one of three G2 dark matter experiments following P5
    - Currently stepping through range 0.5 to 2 GHz (~ 2 to 8 micro-eV)
    - Dec. 2017 review of operations status (now led by Fermilab)

Scientific American January 2018

- Results:
  - May 2017: ADMX first experiment to reach Dine-Fischler-Srednicki-Zhitnitsky (DFSZ) sensitivity limit for any axion mass range!





Quantum Information Science in DOE-SC

ASCR	BES	HEP	NP
Quantum algorithms; uncertainty quantification and verification & validation methods; software stack; quantum networks	Synthesis, characterization, theory, modeling, and instrumentation to advance quantum materials & chemical phenomena	Black hole physics; quantum gravity and quantum error correction; fundamental aspects of entanglement	Isotopes and trapped ions for quantum devices; lattice quantum chromodynamics

Quantum Field Theory and Topology

Control of Quantum Phenomena

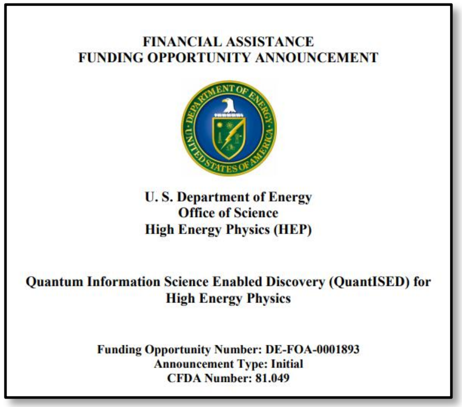
- SC Unique Strengths
  - Intellectual capital accumulated for more than a half-century
  - Successful track record of forming interdisciplinary yet focused science teams for large-scale and long-term investments
  - Demonstrated leadership in launching internationally-recognized SC-wide collaborative programs

HEP Motivations and Thrust Areas in QIS

- **Fundamental High Energy Physics and QIS**
  - Foundational Concepts and related experiments, including:
    - Convergent development of Black Hole physics, Quantum Error Correction, holographic duality
  - Field Theory/Analogue Simulations using QI and entanglement, including:
    - Perturbative QCD models exploiting QI, de Sitter space, & gauge duality
    - Tensor Networks/ Gauge symmetries
    - Field theories, including lattice gauge theories
  - Entanglement/QIS based Experiments for P5 science drivers
    - Exploiting superposition, entanglement, and squeezing
- **Quantum Computing for HEP**
  - Data analysis techniques, algorithms for HEP computations and modelling
- **Quantum Controls & Sensor Technology**
  - Controls, qubits, and other technology to advance dark universe & space time sensors
  - Advancing QIS technology using HEP expertise and capabilities

FY 2018 QIS FOA & Lab Announcement

- **Quantum Information Science Enabled Discovery (QuantISED) for High Energy Physics**
- **Closed April 16, 2018**
  - **HEP received an enthusiastic response!**
- **Objective:** Forge new routes to scientific discovery along HEP mission and P5 science drivers, invoking interdisciplinary advances in the convergent field of QIS, and intersection with expertise, techniques, technology developed in HEP community
- **Topics:**
  - **A:** High Energy Physics and QIS Research
  - **B:** Quantum Computing for HEP on current or future quantum computing systems
- **Track 1:** Pioneering Pilots *(open to Topics A or B)*
  - **Work scope:** Novel concepts, test problems, design studies (TRL 1)
  - **Award:** $100k - $500k over 1-2 years
- **Track 2:** HEP-QIS Consortia *(Open to Topic A only)*
  - **Work scope:** Address P5, small experiments, early research on tools (TRL 1-2)
  - **Award:** FOA 500k – $2M (FOA) or $1M - $4M (LAB) over 2-3 years


FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

U. S. Department of Energy
Office of Science
High Energy Physics (HEP)

Quantum Information Science Enabled Discovery (QuantISED) for High Energy Physics

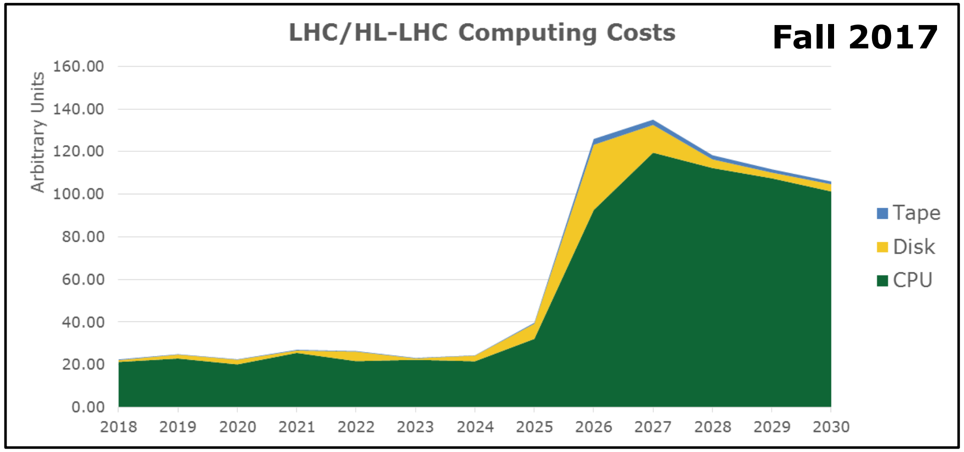
Funding Opportunity Number: DE-FOA-0001893
Announcement Type: Initial
CFDA Number: 81.049

Adv. Tech. R&D: Research Roadmaps

- Following the release of the HEPAP Accelerator R&D Subpanel Report in April 2015, the General Accelerator R&D (GARD) Program has engaged its research community to address the Subpanel recommendations to develop research roadmaps for these thrust areas:
  - Superconducting High Field Magnets
    - Produced the U.S. Magnet Development Program Plan
  - Advanced Accelerator Concepts
    - Laser-driven plasma wakefield acceleration (LWFA)
    - Particle-beam-driven plasma wakefield acceleration (PWFA)
    - Dielectric wakefield acceleration (DWFA)
  - Radiofreqency Acceleration Technology
    - Superconducting RF
    - Normal Conducting RF
    - RF Sources
- Community-developed roadmaps include:
  - Pressing challenges to be addressed to move the field forward
  - Prioritized milestones aligned to the most compelling research
- *More details in Glen Crawford's presentation tomorrow at HEPAP*

HEP Computing Strategy

- Successful implementation of the broad science program envisioned by P5 will require an equally broad and foresighted approach to the computing challenges
  - **Meeting these challenges will require us to work together to more effectively share resources (hardware, software, and expertise) and appropriately integrate commercial computing and HPC advances**
- Last year OHEP stood up an **internal working group** charged with:
  - Developing and maintaining an HEP Computing Resource Management Strategy, and
  - Recommending actions to implement the strategy
- Working group began by conducting an initial survey of the computing needs from each of the three physics Frontiers, and assembled this into a preliminary model
  - Energy Frontier portion alone was a large factor beyond the current computing budget
  - Large data volumes with the HL-LHC require correspondingly large amounts of computing to analyze it
    - Grid-only solution: **$850M ± 200M**
    - Using the experiments' estimates of future HPC use reduces this to **$650M ± 150M**



Computing Strategy Development

- OHEP initiated a **consultative process** with the HEP community to:
  - More accurately capture the largest expected computing needs
  - Look for opportunities where economies of scale and optimal use of resources can close the gap

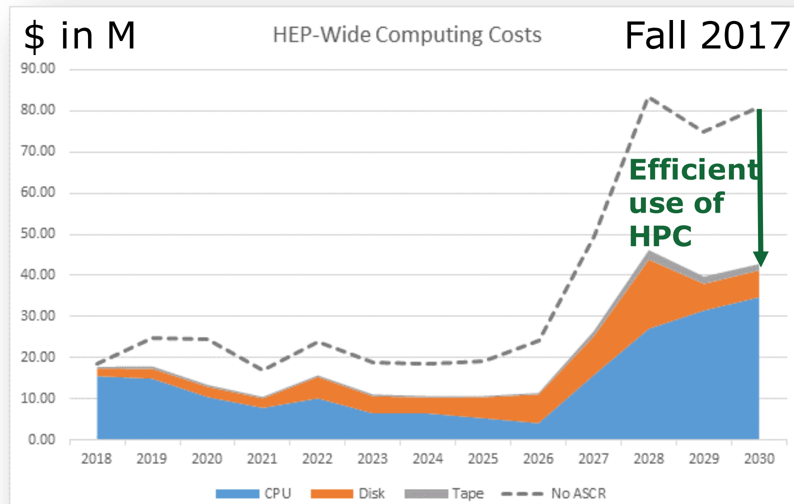
- **Inventory of HEP Computing Needs Roundtable Meeting** – *just completed!*
  - Focused on hardware, software, and personnel needs for the next decade
  - Identification of next steps
- **Commonalities Roundtable Meeting** – *later this year*
  - Focused on identifying common elements in software and workflows, HPC applicability, and integration with Exascale, HSF, S2I2, and other computing initiatives

What We've Learned So Far

- HPC architectures will continue to evolve, but moving to vectorized, multithreaded codes tailored to I/O-bound systems will result in higher efficiency codes
  - Engaging HPC experts to analyze code has helped identify algorithm alternatives and data flow bottlenecks, in some cases resulting in spectacular speedups (e.g. 600x). Continued engagement is therefore essential!
  - Need to identify which codes could benefit the most
- Using Exascale machines badly (e.g. by ignoring the GPU/accelerator) will result in a factor-of-40 penalty in performance that will not be tolerated. HEP will lose its allocations if it does this.
  - Engaging Exascale Computing Project (ECP) experts early and often will result in faster adoption of best practices for exascale machines, and influence ECP design choices to HEP's benefit. HEP needs a coordinated interface to both ECP & the Leadership Computing Facilities.
  - Need to identify which codes could benefit the most
- LQCD regularly rewrites its code, has reaped significant speedup benefits every time
- Reinforced that multiyear NERSC allocations & better metrics for pledges are needed
- End-to-end network data flow models are needed to support tradeoff analysis of storage vs. CPU vs. network bandwidth on a system-wide and program-wide basis
  - Greater sharing of the underlying data management software layer may also be beneficial

Updated HEP Computing Model

- In preparation for the Inventory Roundtable, the largest HEP experiments from all three frontiers were asked to provide a **more detailed estimate** of their expected computing needs
  - CPU, storage, network, personnel, and HPC portability
- Cost estimates for all experimental frontiers:
  - "Business as usual" (minimal additional HPC use): **$600M ± 150M**
  - With effective use of HPC resources this reduces to: **$275M ± 70M**
- By 2030 cost share by frontier is estimated to be:
  - ½ Energy Frontier
  - ¼ Intensity Frontier
  - ¼ Cosmic Frontier
- **A strategy encompassing all HEP computing needs is required!**



Next Steps

- OHEP exploring a process to enable multiyear allocations at NERSC
- Studies of selected HEP codes
  - In-depth analysis of 1-2 critical codes to identifying resource bottlenecks and opportunities for speedup (both general and GPU-accelerated), drawing on expertise at NERSC, the LCFs, and the ECP
  - Discussions with the broader community to assess the potential for vectorization and efficient CPU/GPU utilization of the most resource-intensive codes in use; "dissect-a-thons" to triage codes
  - Identification of recurrent kernels and themes in HEP software
- Identification of common areas where efficiencies of scale can be jointly explored
  - Data processing and storage models optimized for current and anticipated CPU/storage/network costs
  - Shared best programming practices

Community input is important — please work with your experiment's computing leads to provide input

Closing Remarks

- Broad support is enabling us to implement the P5 strategic plan and achieve its vision
  - Many thanks to the DOE Management, the Administration, and Congress for their support
  - The particle physics community continues to perform well on delivering projects, a foundation of the long-term strategy
  - Excellent science results continue to be produced from our operating experiments
- Meeting the computing needs of the future HEP portfolio is a concern
  - Failure to meet this challenge could undermine the successful implementation of the P5 strategy

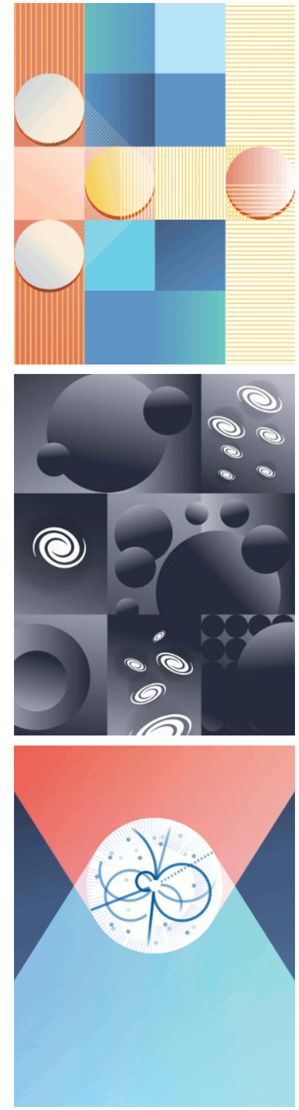
U.S. DEPARTMENT OF
ENERGY
Office of
Science

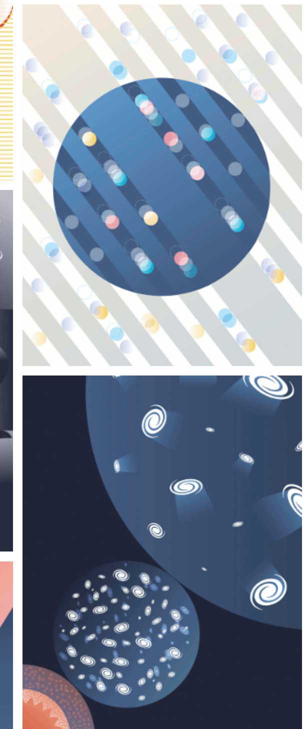
The Science Drivers of Particle Physics

The U.S. long-term strategy report identified five **intertwined science drivers**, compelling lines of inquiry that show great promise for discovery:

- Use the **Higgs boson** as a new tool for discovery **2013*
- Pursue the physics associated with **neutrino mass** **2015*
- Identify the new physics of **dark matter**
- Understand **cosmic acceleration**: dark energy and inflation **2011*
- **Explore the unknown**: new particles, interactions, and physical principles

** Since 2011, three of the five science drivers have been lines of inquiry recognized with Nobel Prizes*





Enabling the Next Discovery

- P5 identified **5 Science Drivers** to address the scientific motivation in 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	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●

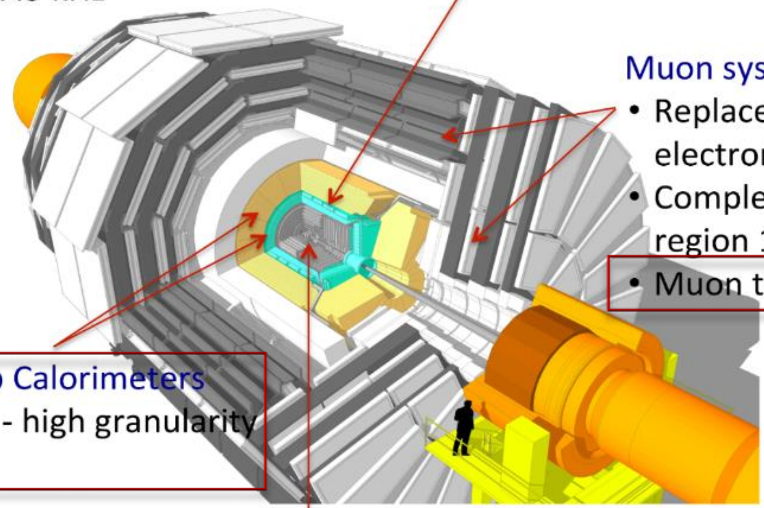
CMS HL-LHC Upgrade

- DOE and NSF 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 $1.5 < \eta < 2.4$
- Muon tagging $2.4 < \eta < 3$

DOE

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

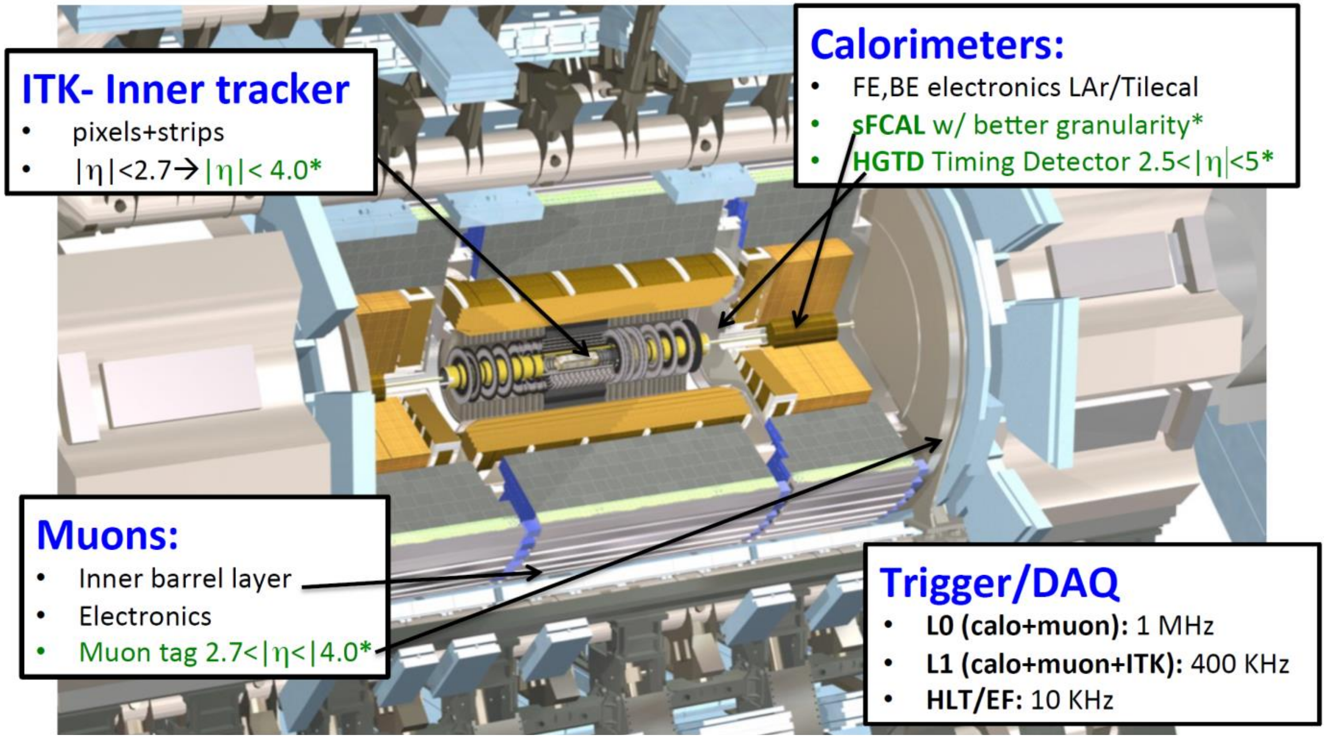
☐ = Significant U.S. contributions

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 $\eta = 3.8$ **NSF**

ATLAS HL-LHC Upgrade

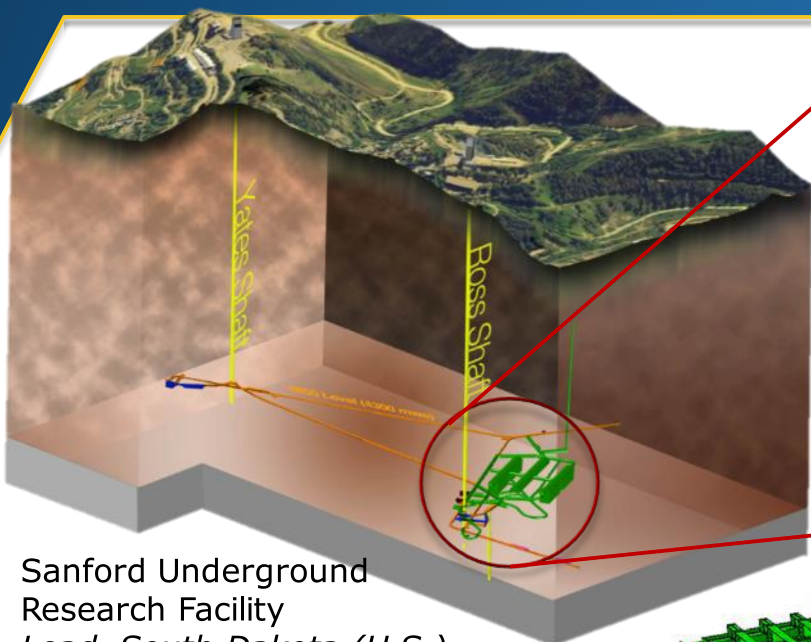
- Similarly, U.S. ATLAS is defining the scope of its contributions to HL-LHC by leveraging interests and experience of U.S. groups, coordinating with international ATLAS

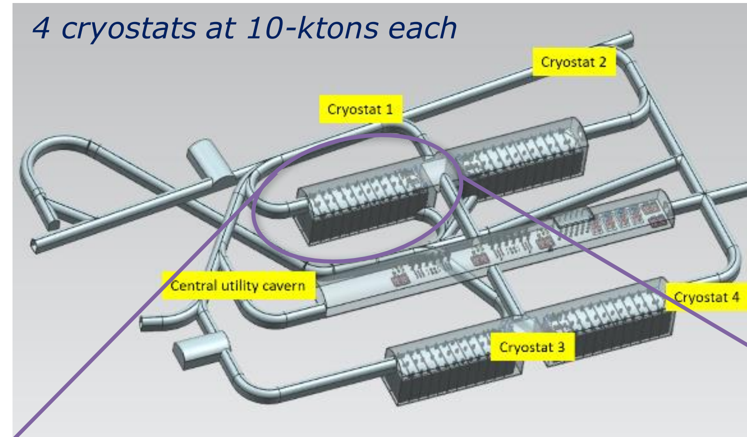
- DOE Scope:
  - Barrel Inner Tracker (pixel & strip detector)
  - LAr Calorimeter front-end analog chip development
  - DAQ hardware (data flow elements)
- NSF Scope:
  - 'Triggering' at high luminosities
  - Readout electronics for LAr, Tile, Muons



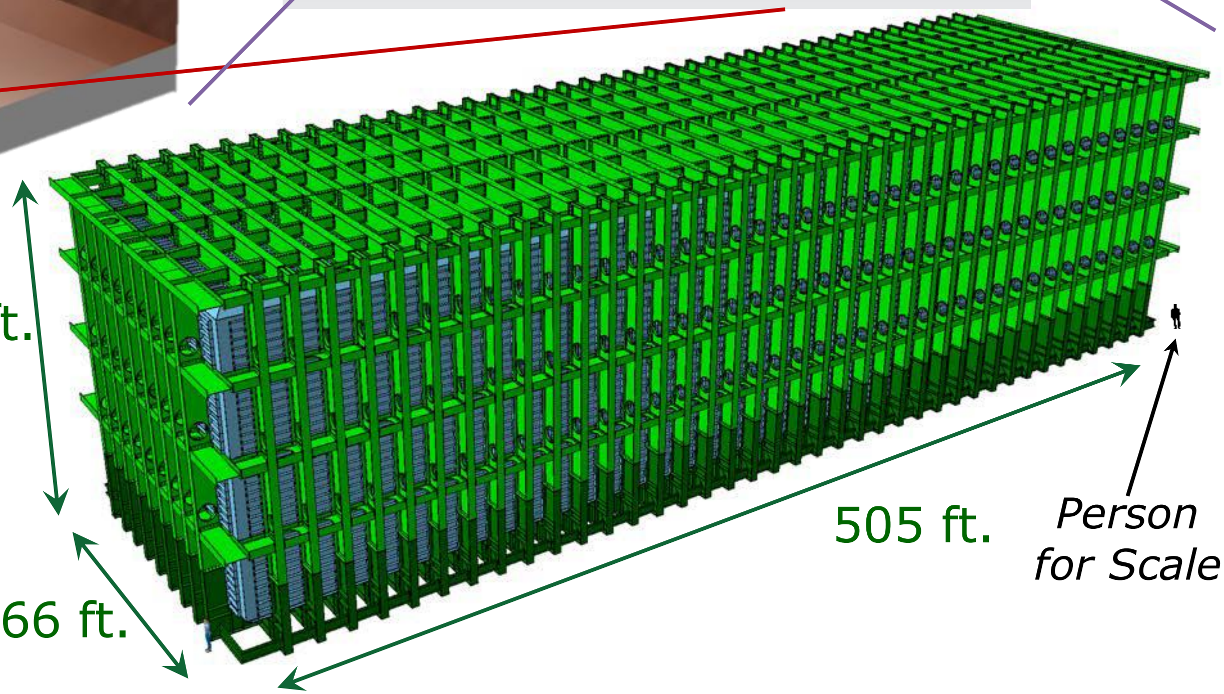
** Large forward rapidities, as described in the 2015 ATLAS HL-LHC scoping document (for the reference 275 MCHF CORE total cost scenario)*

LBNF/DUNE in South Dakota





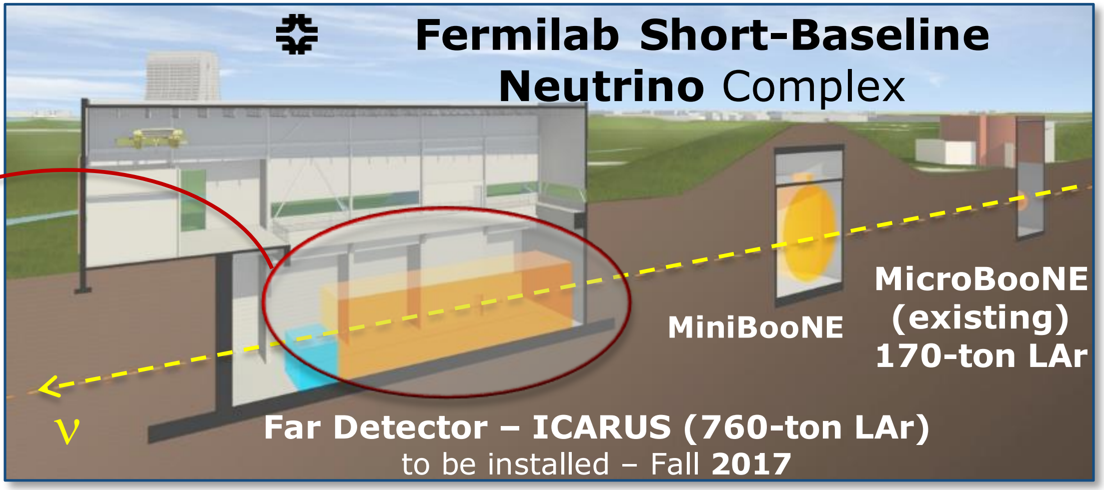
Sanford Underground Research Facility
Lead, South Dakota (U.S.)



Large-scale cryogenic vessel will house state-of-the-art neutrino detector one mile underground

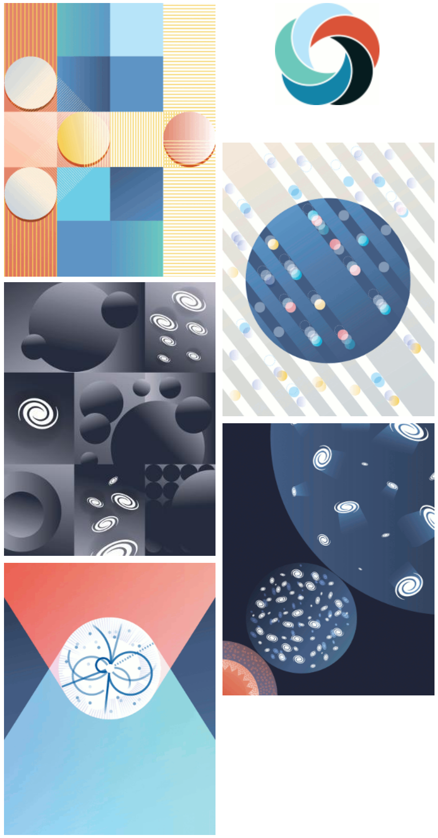
Advancing Technology Towards LBNF/DUNE

- 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 from Europe to Fermilab
  - First major item of equipment to ship for the international neutrino program



Enabling Discovery

- **Advanced Technology R&D** supports and advances research at all three experimental Frontiers
  - Fosters cutting-edge research in the physics of particle beams, accelerator R&D, and particle detection
  - Three broad categories: **Near- to mid-term** directed R&D; **Mid-term** R&D to demonstrate feasibility; **Long-term** research to enable breakthroughs in technology

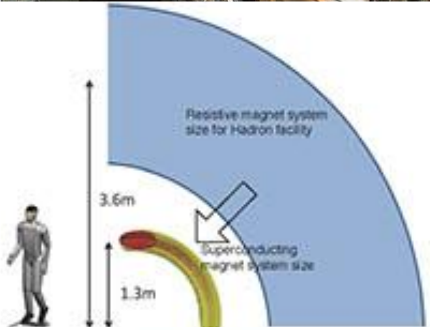


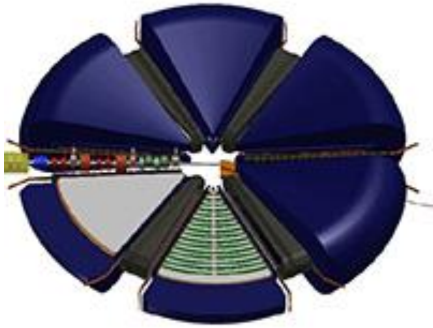
- **Theoretical and Computational HEP** provides the mathematical, phenomenological, and computational framework to understand and extend our knowledge of particles, forces, and the nature of space and time
  - **Theoretical research** essential for proper interpretation and understanding of the experimental research activities
  - **Advanced computing** tools necessary for designing, operating, and interpreting experiments and simulations
- Implementing the P5 strategy requires advancing computing infrastructure to handle the exponentially increasing needs
  - Partnerships with Advanced Scientific Computing Research (ASCR) are an important part of addressing HEP computing needs

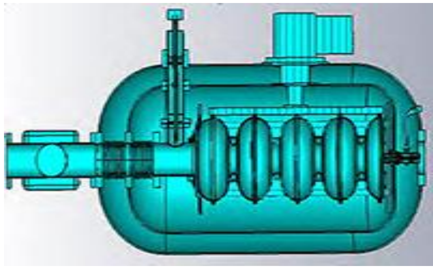
Accelerator Stewardship

Mission: Support fundamental accelerator science and technology development of relevance to many fields and to disseminate accelerator knowledge and training to the broad community of accelerator users and providers.

- Improve access to national lab accelerator facilities
  - Make resources and facilities, such as Brookhaven National Laboratory's Accelerator Test Facility II (ATF-II), available for industrial and for other U.S. government agency users and developers of accelerators and related technology
- Develop innovative solutions to critical problems outside of the DOE Office of Science
  - More performant, lower cost accelerators for medicine
  - 1000x speedup of laser-based science tools
  - Accelerator tech. for Energy & Environmental applications
- Broaden and strengthen the community
  - Bringing accelerator scientists, application scientists, and industrialists together to address high-impact challenges







Closed Funding Opportunity Announcements

- FY18 HEP Comparative Review [DE-FOA-0001781]
  - FOA closed September 12, 2017
  - Review panels held in November 2017
  - Selection for an award by DOE expected by spring 2018
- U.S.-Japan Science and Technology Cooperation Program in High Energy Physics [LAB 18-1802]
  - LAB call closed December 15, 2017
  - Joint U.S.-Japan panel met April 5-6, 2018
  - Funding decisions will be approved by U.S.-Japan Joint Committee on High Energy Physics, April 19-20, 2018

EPSCOR FOA & Lab Announcement

- **Building EPSCOR-State/National Laboratory Partnerships**
- **Post Date:** March 28, 2018
  - **Letter of Intent Due:** 4/25/18, 5 PM Eastern **(required)**
  - **Close Date:** May 16, 2018, at 5 PM Eastern
  - **Awards:** Up to $15M total of awards
    - Ceiling $250,000 per year, floor $150,000 per year per award
- **Objective:** DOE's Established Program to Stimulate Competitive Research (EPSCoR) program announces its interest in receiving applications for building EPSCoR-State/DOE-National Laboratory Partnerships
  - These partnerships are to advance fundamental, early-stage energy research collaborations with the DOE national laboratories
  - Participation by graduate students and/or postdoctoral fellows is required. Junior faculty from EPSCoR jurisdictions are encouraged to apply. Utilization of DOE user facilities are encouraged.
  - **Applicant institutions (entities) may not submit more than one Letter of Intent (LOI) as the lead organization**
  - DOE EPSCoR eligible jurisdictions:
    - Alabama, Alaska, Arkansas, Delaware, Guam, Hawaii, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, Montana, Nebraska, Nevada, New Hampshire, North Dakota, Oklahoma, Puerto Rico, Rhode Island, South Carolina, South Dakota, Vermont, Virgin Islands, West Virginia, and Wyoming

DEPARTMENT OF ENERGY
OFFICE OF SCIENCE
BASIC ENERGY SCIENCES

BUILDING EPSCOR-STATE/NATIONAL LABORATORY PARTNERSHIPS
FUNDING OPPORTUNITY ANNOUCEMENT (FOA)
NUMBER: DE-FOA-0001897
ANNOUNCEMENT TYPE: INITIAL
CFDA NUMBER: 81.049

QIS Scope and Relevance to HEP

- What's different now? Current and future QIS applications differ from earlier applications of quantum mechanics, such as the laser, by exploiting uniquely quantum properties:
  - **Superposition** – quantum particles or systems exist across all their possible states at the same time, with corresponding probabilities, until measured
  - **Entanglement** – a superposition of states of multiple particles in which the properties of each particle are correlated with the others, regardless of distance
  - **Squeezing** – a method of manipulating noise in systems that obey the Heisenberg uncertainty principle, by permitting large uncertainty in one variable to improve precision in the other related one
- Quantum information concepts and approaches are proving increasingly important across various high energy physics topics
  - Black hole information paradox
  - Testing of fundamental symmetries
  - Search for dark matter
  - Emergence of spacetime

Overall HEP Goals for QIS Activities

- Focused efforts in order to:
  - Advance the science drivers identified by P5 using QIS
  - Advance QIS itself through capabilities, expertise, and fundamental knowledge of the HEP community – in foundations, analogue simulation, controls, qubit technology, and more
  - Develop the appropriate and necessary interdisciplinary collaborations to advance high energy physics in particular and science more broadly
- As QIS is an SC cross-cutting initiative, partnerships with other SC programs, other agencies, and/or industry are expected where relevant