U.S. DEPARTMENT OF ENERGY | Office of Science

Status of the DOE High Energy Physics Program

NAS Board on Physics and Astronomy
April 2019

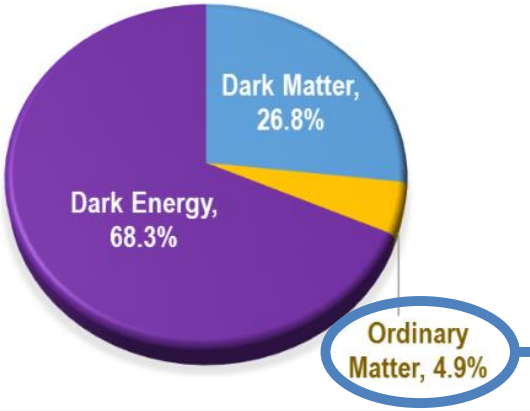
Jim Siegrist
Associate Director for High Energy Physics
Office of Science, U.S. Department of Energy

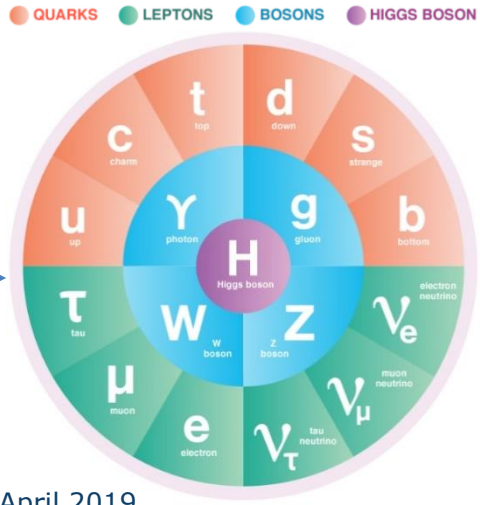
The High Energy Physics Program Mission

… 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





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:

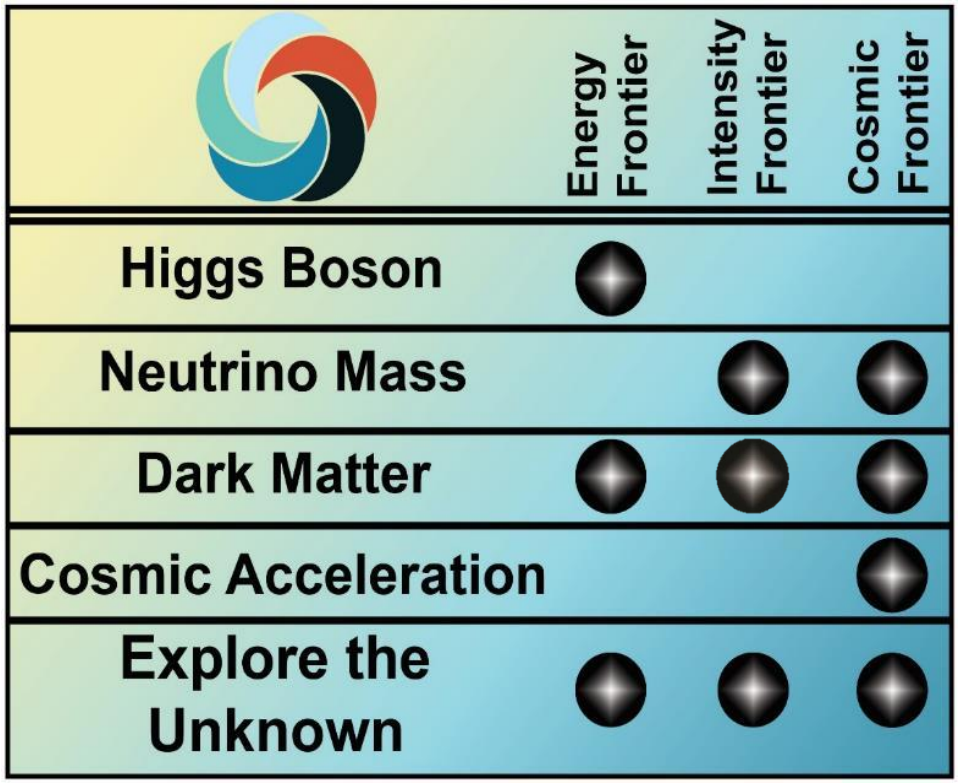
- Use the **Higgs boson** as a new tool for discovery *2013
- Pursue the physics associated with **neutrino mass** *2015
- Identify the new physics of **dark matter**
- Understand **cosmic acceleration**: dark energy and inflation *2011
- **Explore the unknown**: new particles, interactions, and physical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



FY 2018 Early Career Awards: Univ.

- Thomas Faulkner, University of Illinois
  - New perspectives on QFT and gravity from quantum entanglement
- Alexie Leauthaud-Harnett, University of California, Santa Cruz
  - Exploiting Synergies Between Lensing and BAO Surveys for Improved Cosmological Constraints
- Themis Mastoridis, California Polytechnic State University
  - Optimal Design of Radio Frequency Algorithms and Models for Next Generation Accelerators
- Benjamin Safdi, University of Michigan
  - Particle Dark Matter Across Scales
- Hee-Jong Seo, Ohio University
  - Optimal and robust reconstruction of BAO, redshift-space distortions and the Alcock-Paczynski effect
- David Simmons-Duffin, Caltech
  - Precision Computations in Strongly Coupled Conformal Field Theories
- Rachel P. Yohay, Florida State University
  - Probing New Physics with Tau Leptons using the CMS Detector

FY 2018 Early Career Awards: Labs

- Artur Apresyan, FNAL
  - Exploring the Lifetime Frontier with New Detectors and New Searches
- Daniel Bowring, FNAL
  - Microwave Single-Photon Sensors for Dark Matter Searches and Precision Neutrino Measurements
- Daniel A. Dwyer, LBNL
  - Improving Neutrino Detection in DUNE with Pixel Sensors
- Michael Kagan, SLAC
  - Exploring the Higgs Sector at the Energy Frontier with Bottom Quarks, Machine Learning, and the Upgraded ATLAS Pixel Detector
- Aritoki Suzuki, LBNL
  - Development of high throughput techniques for SC microfabrication, assembly and deployment for future high energy physics experiments
- Kazuhiro Terao, SLAC
  - GPU/FPGA Accelerated Deep Learning Technique Development for Discovering Physics in Liquid Argon Time Projection Chambers
- Javier Tiffenberg, FNAL
  - Towards table-top neutrino detectors: A 10 kg Skipper-CCD experiment

DOE Office of Science Statements on Diversity, Equity, and Inclusion

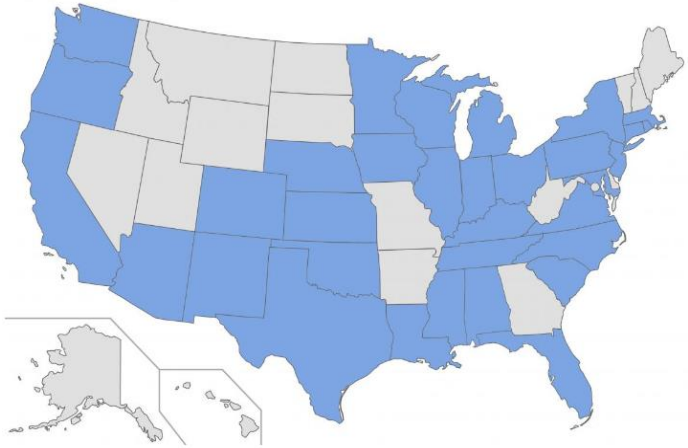
- The DOE Office of Science (SC) is fully committed to fostering safe, diverse, equitable, and inclusive work, research, and funding environments that value mutual respect and personal integrity.
  - Effective stewardship and promotion of diverse and inclusive workplaces that value and celebrate a diversity of people, ideas, cultures, and educational backgrounds is foundational to delivering on the SC mission. The scientific community engaged in SC-sponsored activities is expected to be respectful, ethical, and professional.
  - https://science.energy.gov/sc-2/research-and-conduct-policies/diversity-equity-and-inclusion/
- Office of Science Statement of Commitment
  - The DOE Office of Science (SC) is fully and unconditionally committed to fostering safe, diverse, equitable, and inclusive work, research, and funding environments that value mutual respect and personal integrity.
  - https://science.energy.gov/sc-2/research-and-conduct-policies/diversity-equity-and-inclusion/sc-statement-of-commitment/
- Office of Science Statement on Harassment
  - Harassment of any kind, including sexual and non-sexual harassment, bullying, intimidation, violence, threats of violence, retaliation, or other disruptive behavior is not tolerated in the federal workplace, including Department of Energy (DOE) site offices, or at DOE national laboratories, scientific user facilities, academic institutions, other institutions receiving Office of Science funding, or at locations where activities are funded by the DOE Office of Science.
  - https://science.energy.gov/sc-2/research-and-conduct-policies/diversity-equity-and-inclusion/harassment/

Energy Frontier: LHC, ATLAS, and CMS

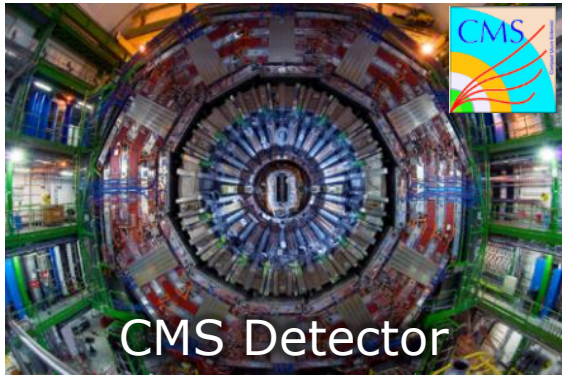
The Large Hadron Collider at CERN is the centerpiece of the U.S. Energy Frontier program

- Only means to produce and study the Higgs boson
- Searches for direct production of dark matter particles
- Explores for signs of new physics through direct production of new particles and precision measurements of known particles

- U.S. ATLAS represents ~19% of the international ATLAS Collaboration
  - 41 universities, 4 national labs (ANL, BNL, LBNL, 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

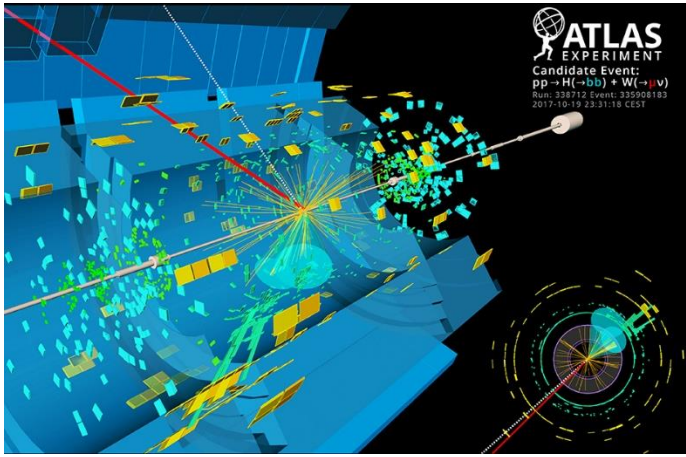


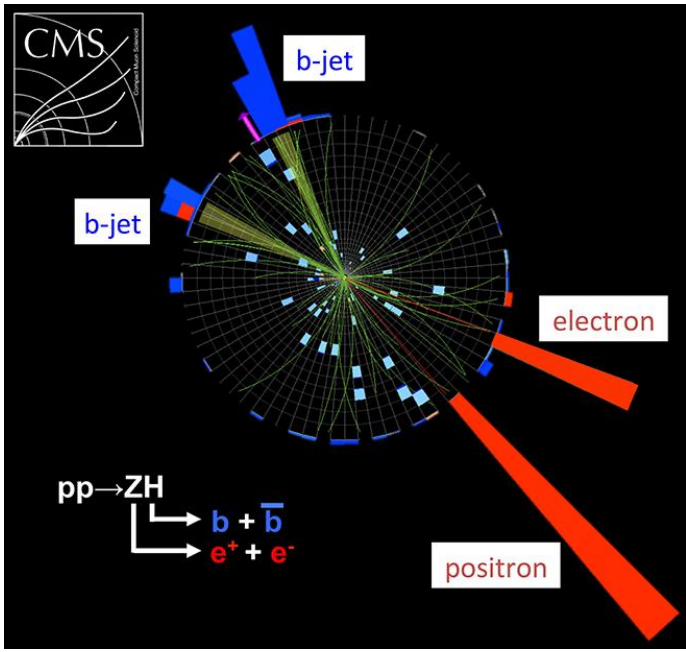
States hosting members of the U.S. LHC experimental program



Higgs to bb Observation

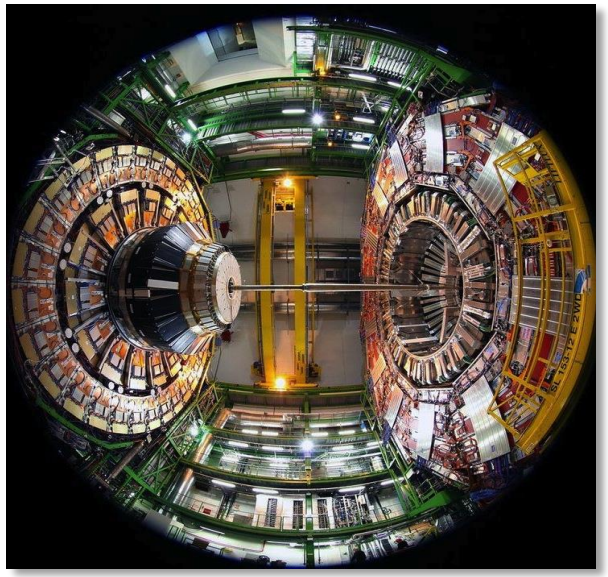
- August 2018: ATLAS and CMS experiments at the LHC independently observed the Higgs boson decaying to bottom quarks
  - ATLAS combination yields observed (expected) significance of 5.4σ (5.5σ)
  - CMS combination yields observed (expected) significance of 5.6σ (5.5σ)
    - arXiv: ATLAS 1808.08238, CMS 1808.08242
- Observed Higgs boson channels now include:
  - Production with top quarks
  - Decays to photons, pairs of Z or W bosons, and tau leptons
- Results so far consistent with Standard Model predictions, within uncertainties
  - Precision measurements of Higgs properties will continue to explore for new physics



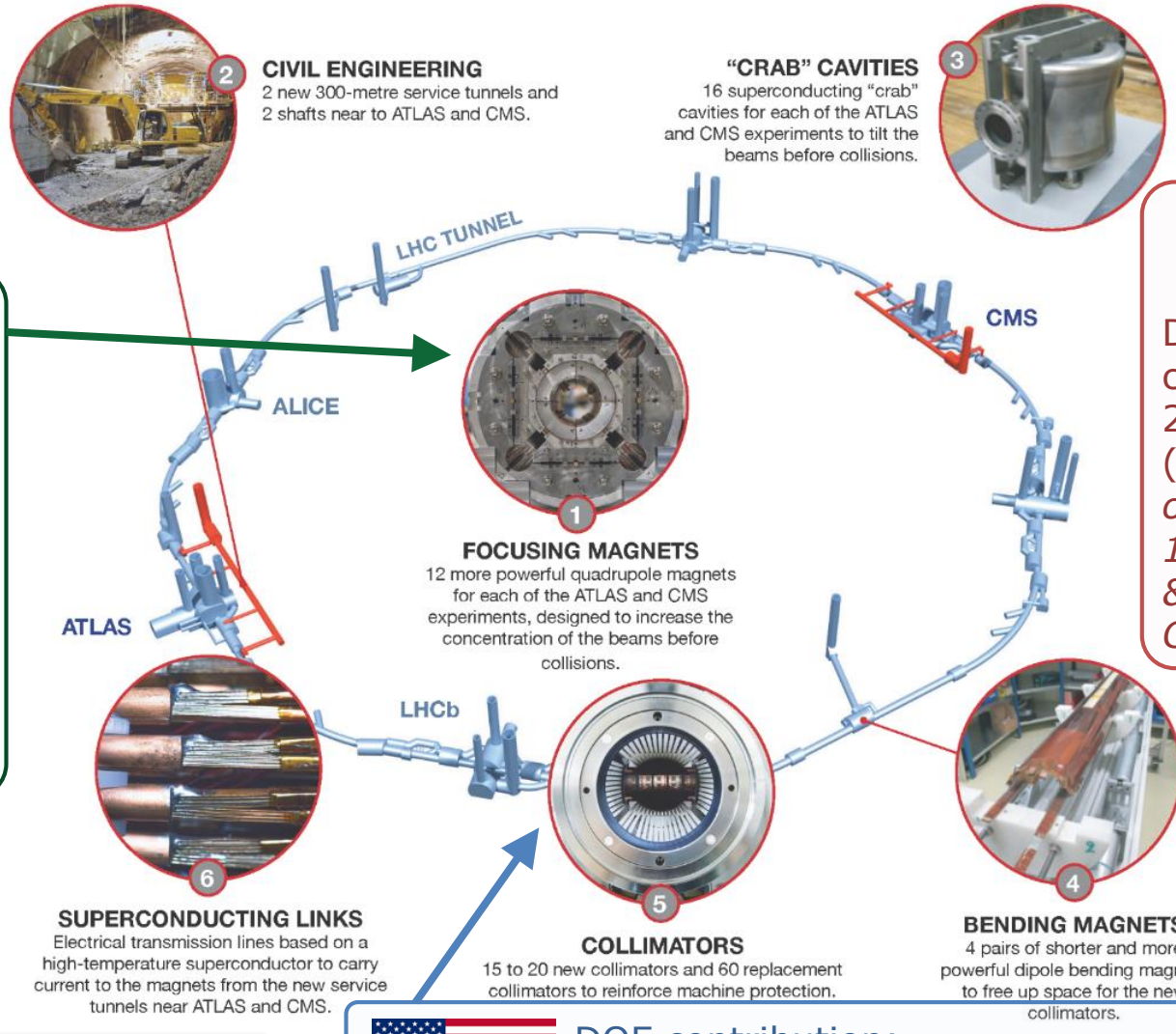


Future of the Energy Frontier

- Future program building on historic bilateral U.S.-CERN Agreement, signed in 2015
- High-luminosity LHC (HL-LHC) upgrades in 2024-2026 will extend discovery reach
  - Will increase particle collision rate by 10 times LHC design value to explore new physics at highest particle collider energies
  - **Together recognized by P5 as the highest-priority large project in the near term**
- DOE HEP actively working with CERN, U.S.-CMS and U.S.-ATLAS to develop and execute the projects:
  - HL-LHC Accelerator Upgrade
  - HL-LHC ATLAS Detector Upgrade
  - HL-LHC CMS Detector Upgrade



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

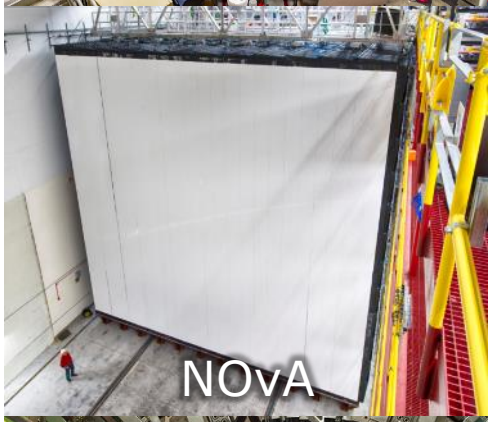
DOE contribution:
20 Crab Cavities (16 + 4 spares)
or:
10 Crab cavities & Hollow e-Lens Components

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

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:
  - COHERENT, Daya Bay, MicroBooNE, MINERvA, NOvA, PROSPECT, Super-K, T2K ongoing
  - Ramping up Fermilab Short-Baseline Neutrino Program with Far Detector [ICARUS] and Near Detector [SBND]
  - Preparing to host world-leading neutrino program with the Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE)

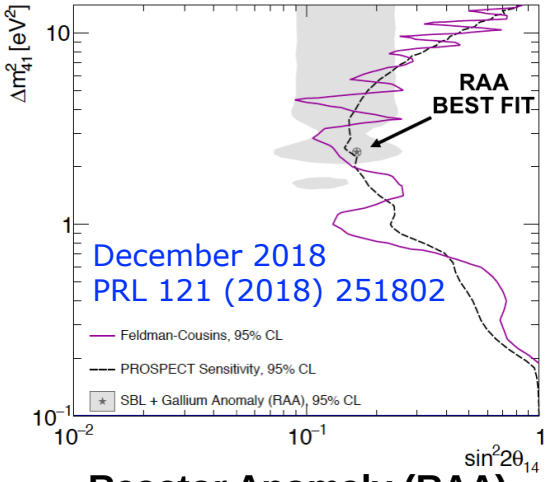


PROSPECT

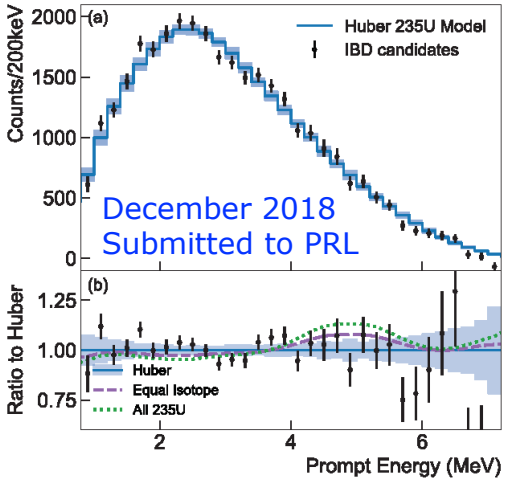
- Precision Oscillation and Spectrum Experiment
  - Segmented Detector
  - ^{6}Li-doped liquid scintillator
  - ~4 ton, 14x11 segments
  - ~4.5%/√E resolution
- Physics Objectives
  - Search for short-baseline oscillation at <10m
  - Precision measurement of ^{235}U reactor $\bar{\nu}_e$ spectrum
- Started data taking in March 2018
  - Best signal/background for antineutrino detection ever on-surface
  - > 5σ reactor neutrino detection in <2 hrs on Earth's surface

PROSPECT $\bar{\nu}$
prospect.yale.edu

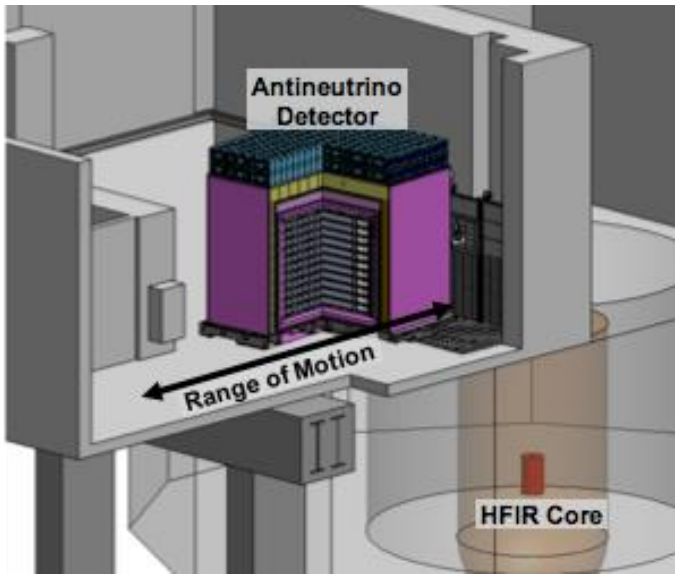
HEISING-SIMONS FOUNDATION



Reactor Anomaly (RAA) best-fit point disfavored at > 95% CL



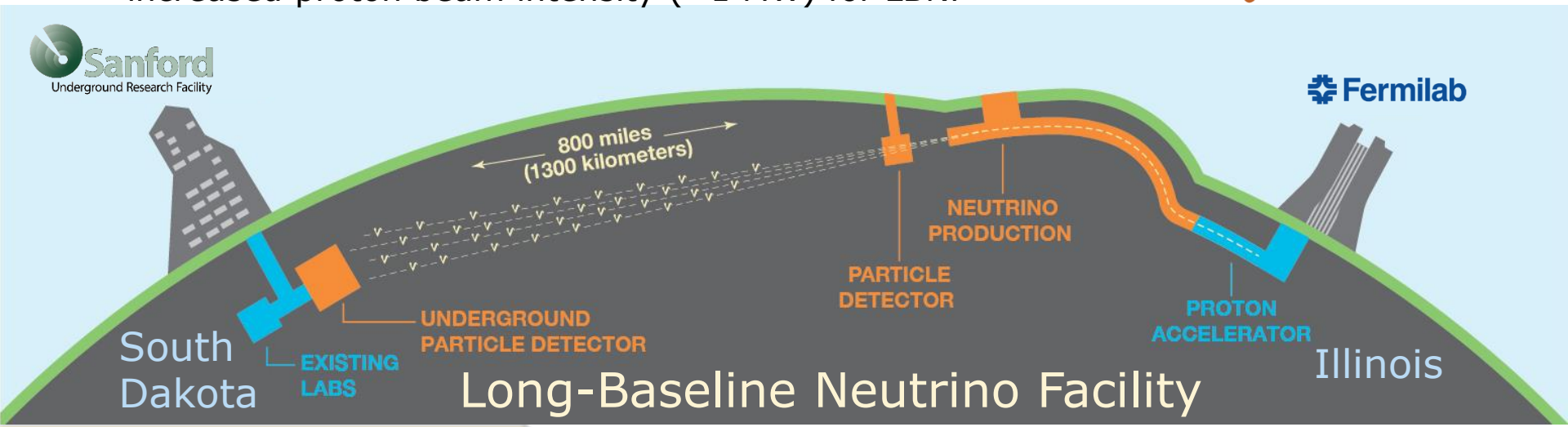
High-statistics ^{235}U spectrum measurement



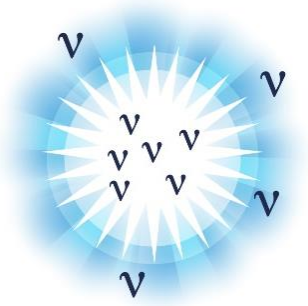
Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment

- 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 1,180 collaborators from 184 institutions, 32 countries
- Proton Improvement Plan II (PIP-II) will provide increased proton beam intensity (>1 MW) for LBNF

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT



DUNE Science Goals

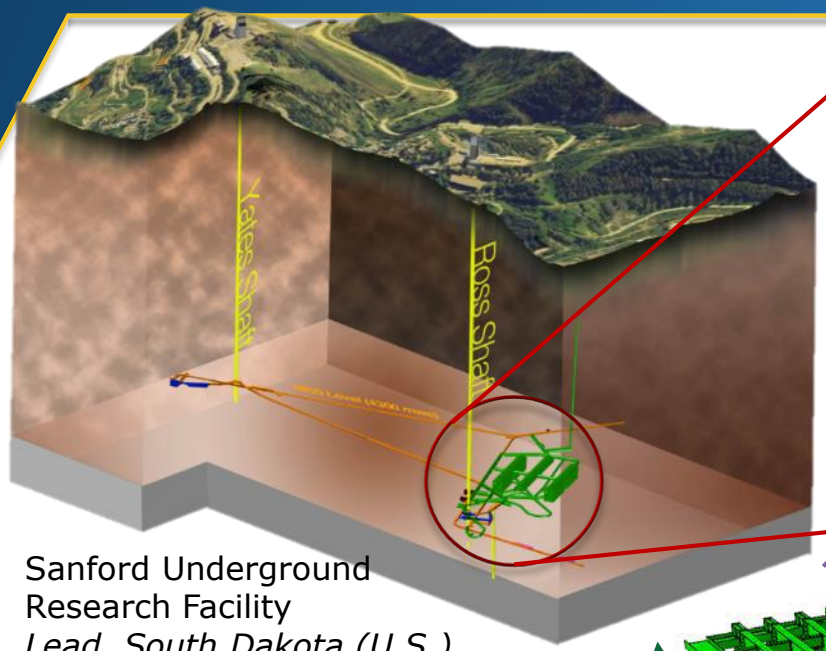


- **Origin of matter**
  Discover what happened after the big bang: Are neutrinos the reason the universe is made of matter?

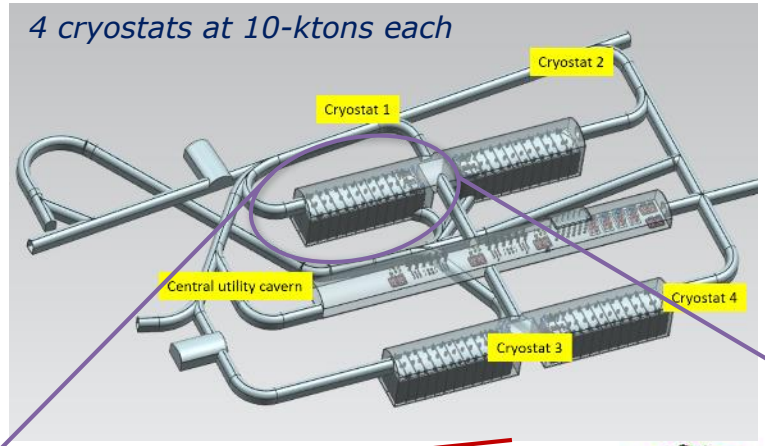
- **Neutron star & black hole formation**
  Use neutrinos to look into the cosmos and watch the formation of neutron stars and black holes in real time

- **Unification of forces**
  Move closer to realizing Einstein's dream of a unified theory of matter and energy

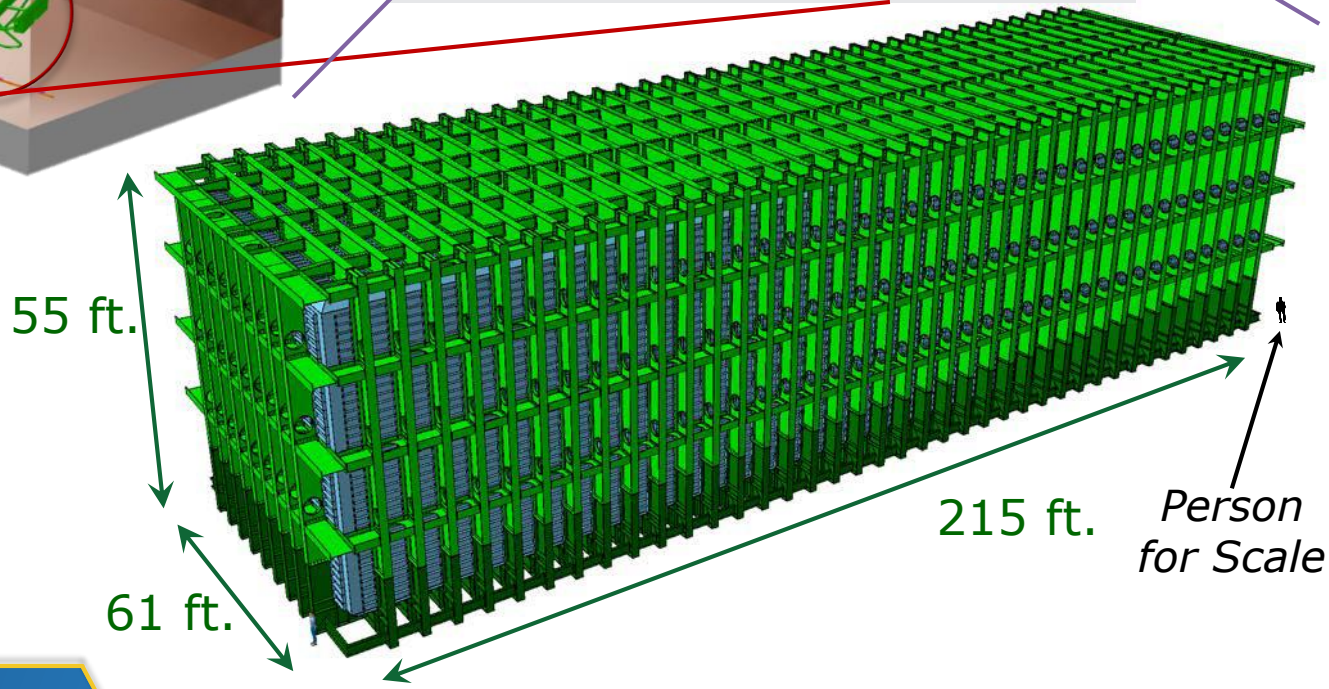
LBNF/DUNE in South Dakota



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



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



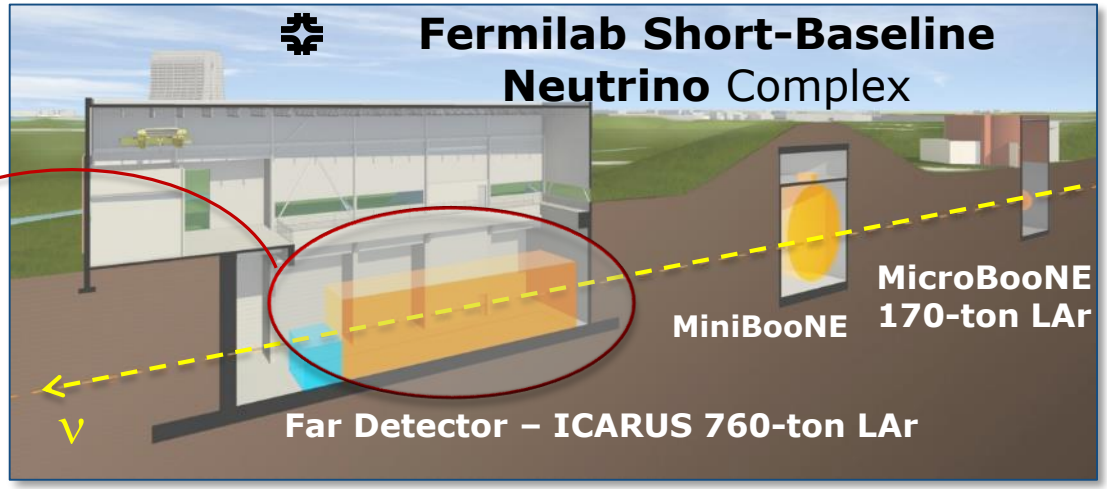
Proton Improvement Plan II (PIP-II)

- 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

From left: Senator Tammy Duckworth (IL), Senator Dick Durbin (IL), Rep. Sean Casten (IL-6), Rep. Robin Kelly (IL-2), Rep. Bill Foster (IL-11), Fermilab Director Nigel Lockyer, Rep. Lauren Underwood (IL-14), Illinois Governor JB Pritzker, DOE Under Secretary for Science Paul Dabbar, Fermilab PIP-II Project Director Lia Merminga, DOE Associate Director for High Energy Physics Jim Siegrist, University of Chicago President Robert Zimmer, Consul General of India Neeta Bhushan, British Consul General John Saville, Consul General of Italy Giuseppe Finocchiaro, Consul General of France Guillaume Lacroix, DOE Fermi Site Office Manager Mike Weis, DOE PIP-II Federal Project Director Adam Bihary and Consul General of Poland Piotr Janicki. Photo: Reidar Hahn

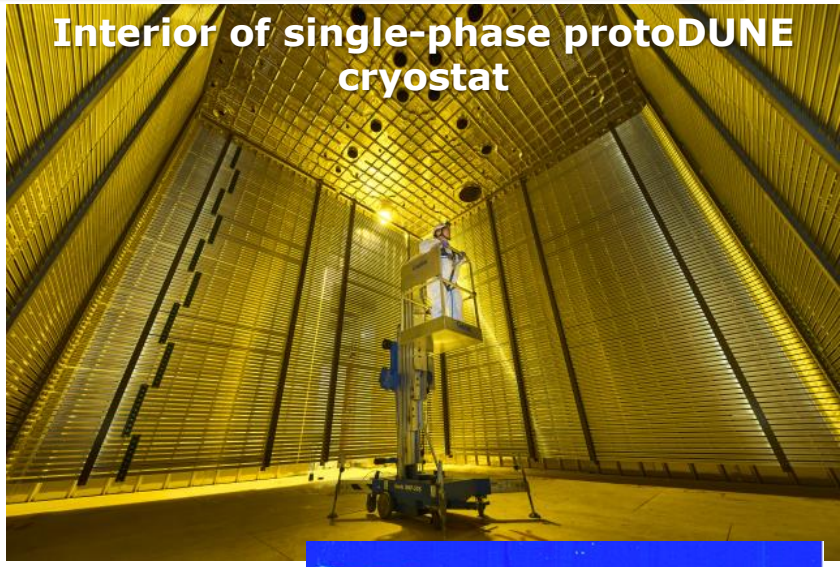
Advancing Technology Towards LBNF/DUNE

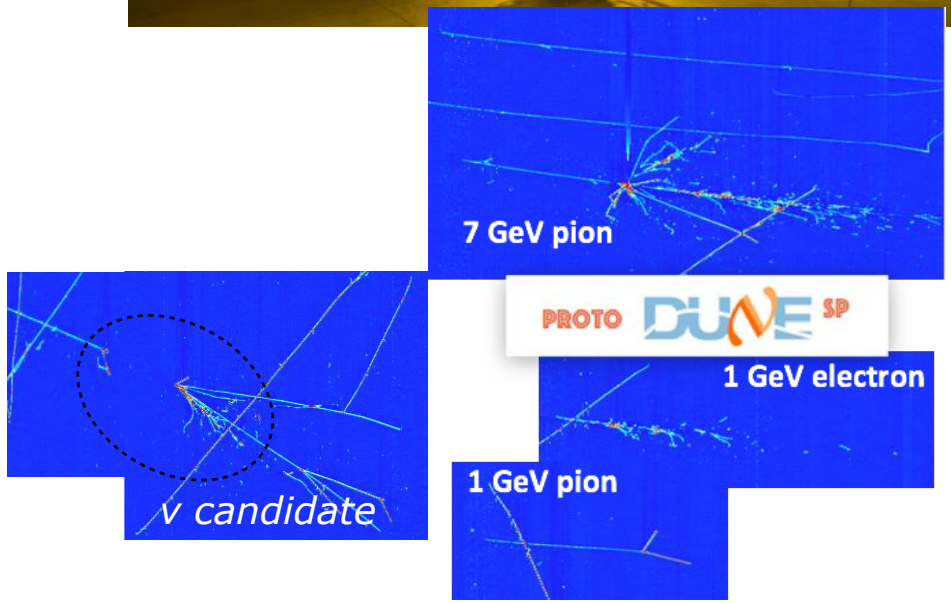
- Fermilab Short-Baseline Neutrino Program
  - Resolve experimental anomalies in measured ν-spectrum, including search for sterile neutrino
  - Demonstrate the detector technology for DUNE
- The largest liquid argon neutrino detector in the world, ICARUS was transported last summer from Europe to Fermilab
  - Liquid argon fill and transition to commissioning in spring-summer 2019



ProtoDUNE

- ProtoDUNE is not a formal part of the DOE LBNF/DUNE project, but is a critical, internationally-supported precursor
- Testing full size components in a neutrino beam at CERN
  - ProtoDUNE will use 6 full-sized drift cells
  - A DUNE detector module has 150 cells
- Two designs:
  - Single phase liquid argon has been successfully built before
    - Will be used for first full size detector
    - ProtoDUNE-SP completed July 2018, now taking data
  - Dual phase liquid argon could be lower cost
    - Electronics are outside the liquid
    - After successful prototype, ProtoDUNE-DP now in fabrication





Growing LBNF/DUNE International Partnerships

- CERN is an important partner with DOE through cooperative agreements signed in 2015 and 2017
- UK-U.S. Science and Technology Agreement signed Sep. 20, 2017
  - Major project under this agreement is UK investment in LBNF/DUNE/PIP-II program
- DOE and DAE-India Project Annex II on Neutrino Research signed April 16, 2018
  - Expands accelerator science collaboration with India to include the science for neutrinos
- DOE and Italian Ministry of Education, Universities and Research agreements on neutrinos and accelerators
  - Agreement under an umbrella agreement on neutrino science collaboration signed June 28, 2018
  - Annex agreement for PIP-II accelerator signed Dec. 4, 2018
- Statements of Interest each from CEA and CNRS (France), expressing interest in U.S.-hosted Neutrino Program, signed December 2018
- Close coordination by DOE with U.S. Government agencies, including the State Department, on establishing cooperative agreements
  - Actively pursuing engagements with other potential global partners to advance particle physics program

CERN

UK

India

Italy

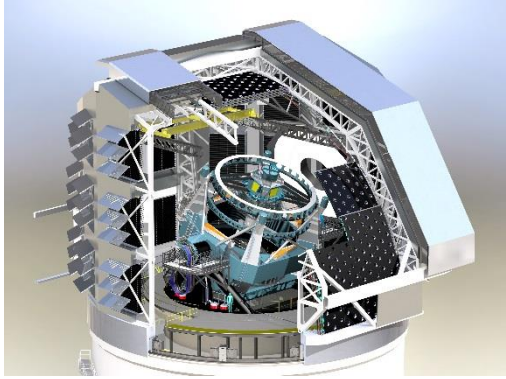
Cosmic Frontier Program I

Cosmic Frontier experiments address the P5 science drivers using naturally occurring cosmic phenomena

- In addition to NSF and NASA partnerships, most experiments and projects have international partners or contributions and some also have private contributions

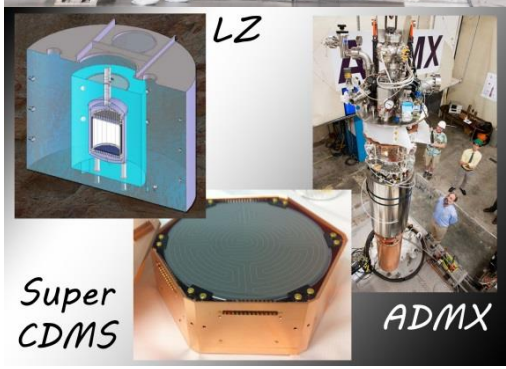
- Study dark energy's role in the accelerating expansion of the universe through staged suite of complementary surveys
  - Enables precision measurements that differentiate between cosmological constant, modification to gravity, or new fields
  - Fast, wide area imaging surveys scan large volumes and catch dynamic events like supernovae: Dark Energy Survey (DES) operating, Large Synoptic Survey Telescope (LSST) 3-billion pixel camera in fabrication
  - Deep, high accuracy spectroscopic surveys study dim, more distant objects: eBOSS operating, Dark Energy Spectroscopic Instrument (DESI) in fabrication

- Study inflation in the early universe using its imprint on the cosmic microwave background (CMB)
  - South Pole Telescope 3G is operating, planning for P5-recommended next-generation CMB Stage 4 experiment underway
    - AAAC Conceptual Design Team (CDT) developed strawman design (2017), Lab tech. development and pre-Project Design Group (pPDG) studies ongoing



Cosmic Frontier Program II

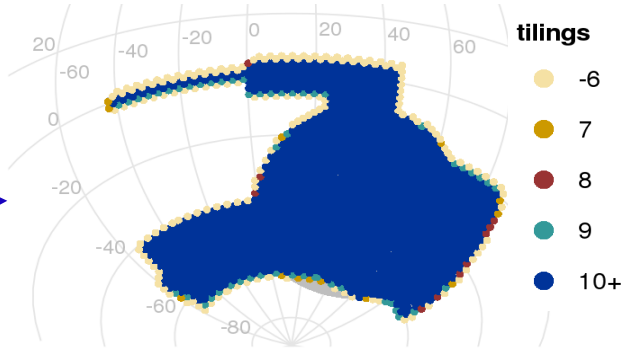
- Staged suite of dark matter direct detection experiments use multiple technologies to search for WIMP, Axion particles
  - First-generation experiments produced world's most sensitive searches
  - P5-recommended 2nd generation experiments are advancing
    - ADMX-G2 axion search is operating; LZ and SuperCDMS-SNOLAB WIMP search projects in fabrication
  - Planning for small project(s) to address new priority science areas to search for dark matter
- Pursue the physics associated with neutrino mass
  - Dark Energy and CMB experiments also place unique constraints on the sum of neutrino masses
- Explore the unknown through cosmic- and gamma-ray experiments
  - Perform indirect searches for dark matter and antimatter
  - Study fundamental physics properties such as breakdown of Lorentz invariance & high energy acceleration mechanisms
  - Space-based Fermi/GLAST & AMS and ground-based HAWC are currently operating

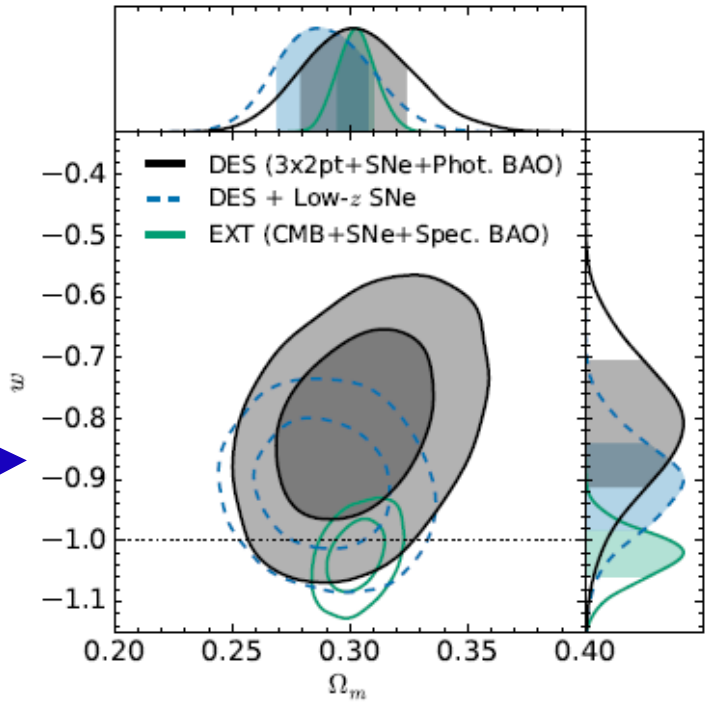


Dark Energy Survey

- **DOE-HEP partnership with NSF-AST: DOE provided DECam; now supporting DECam operations & computing (with NSF)**
- Completed Observations Jan 9, 2019
  - ~5100 sq. deg. in 5 filters (grizY), each w/ ten 90s exposures. Successfully met all survey metrics.
- 221 scientific publications through Jan 31, 2019, ~70 in the past 12 months on topics spanning astrophysics from solar system to cosmology
- Public Data Release using Y1-Y3 data (Jan 2018)
- Cosmology highlights in the past year:
  - Constraints on Extended cosmological models from DES Y1 Weak Lensing and Galaxy Clustering (WL)
  - Cross Correlation of DES WL signal w/ Planck & SPT
  - Cosmology from 207 DES Y1-Y3 spect.-typed SN1a
  - Combined DES Y1 WL & Y1 LSS & SN1a cosmology
- Now concentrating on cosmology through Y3 (expected Fall 2019) & on producing Y6 data products for analysis, Y6 cosmology to follow

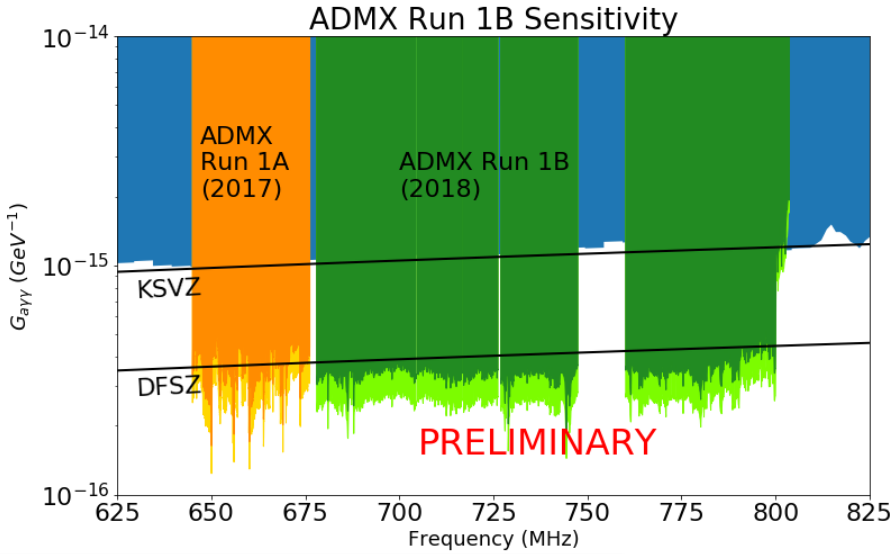
z-band (850-1002 nm)

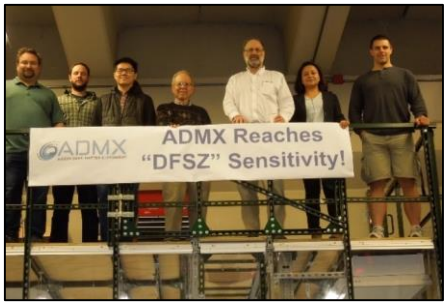


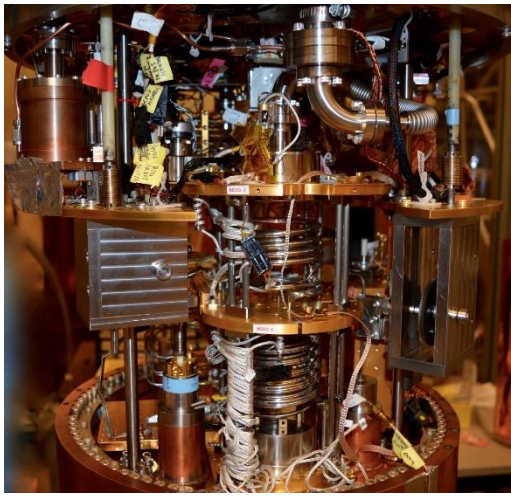


ADMX-G2

- Axion Dark-Matter eXperiment Generation 2
  - Located at University of Washington, managed by Fermilab
  - Primarily DOE supported with contributions from the UK, Germany and Australia; R&D support from the Heising-Simons Foundation
- Uses a strong magnetic field and resonant cavity to convert dark matter axions into detectable microwave photons
  - Operations approved to cover range 0.5 to 2 GHz (~ 2 to 8 micro-eV mass) – started Aug. 2016; planned to complete ~ Jan. 2022
  - **Run 1A** (2017) & **Run 1B** (2018) – both reached "invisible" axion (DFSZ model) sensitivity!
  - Run 1C starting soon





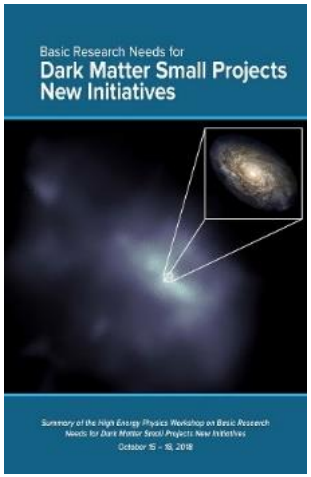


[Right] ADMX experiment insert showing the RF cavity (bottom), dilution refrigerator (above cavity), and frequency-tuning mechanism (left).

See recent article in National Geographic: https://www.nationalgeographic.com/science/2018/10/news-admx-dark-matter-detector-physics/

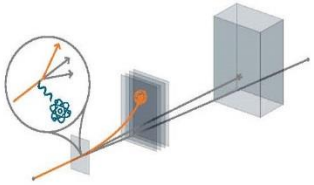
New Initiatives in Dark Matter

- P5 recommended the search for dark matter particles as a high priority & also that the program should include small projects
  - March 2017: Community-led workshop collected new ideas
  - 2018-19: Basic Research Needs workshop held
    - Chaired by Rocky Kolb & Harry Weerts
    - Charged to assess the science landscape for dark matter particle searches and identify which high impact science areas would be suitable to be pursued with small projects in the HEP program, using DOE lab infrastructure & capabilities
    - Final report identified 3 priority Physics Research Directions (PRD)
  - Funding Opportunity Announcement to develop experimental designs



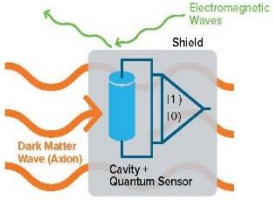
https://science.energy.gov/hep/community-resources/reports/

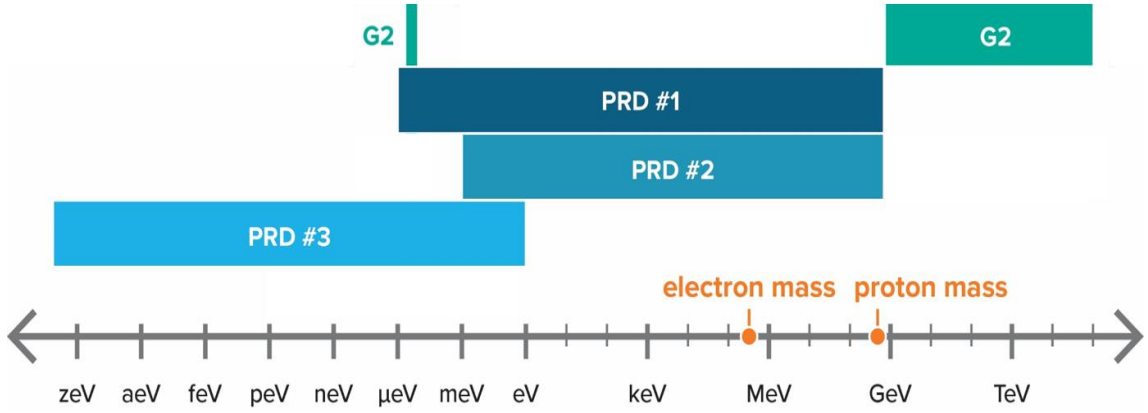
PRD 1
Create and Detect DM at Accelerators.



PRD 2
Detect Galactic DM Underground.

PRD 3
Detect Wave DM in the Laboratory





CMB-S4 Timeline and Coordination

- CMB-S4 was recommended by P5
  - DOE and NSF communities and expertise formed a CMB-S4 collaboration
- AAAC approved the CMB-S4 Concept Definition Taskforce subpanel report in Oct. 2017
  - Plan has array of telescopes located at South Pole and Chile working in tandem
  - Strawperson technical design, cost, schedule
- Pre-Project Design Group (pPDG) set up and working with Collaboration to progress forward
- Further developing concept with a technically limited schedule
  - Planning submission to the National Academies Astronomy and Astrophysics Decadal Survey committee 2019
- DOE and NSF (AST, PHY, and OPP) are having coordination meetings
  - DOE is supportive of CMB-S4's plan, including aiming for CD-0 in FY19

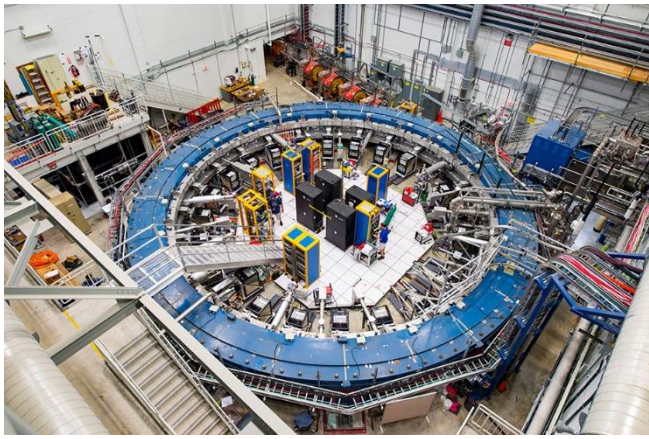
Enabling Discovery

- **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

Muon g-2 Prediction

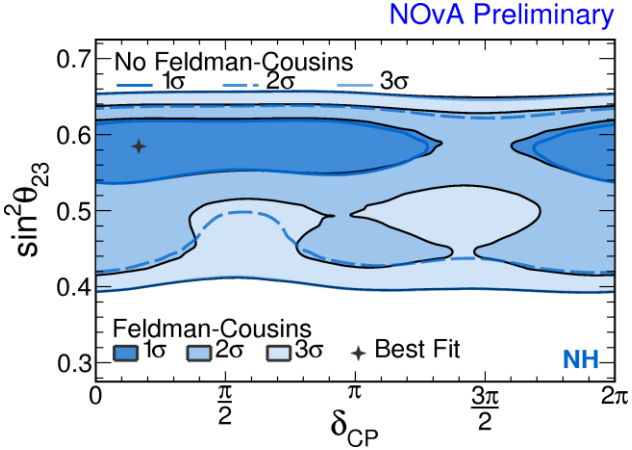
- Theorists make most precise prediction of how muons wobble as they travel in a powerful magnetic field
- Precise comparison between the prediction and the measurement of the muon's magnetic moment provides a stringent test of the Standard Model
- A team of physicists improved this prediction using Lattice QCD, modeling all the possible particle interactions on supercomputers at the Leadership Computing Facility at Argonne National Laboratory and Brookhaven's Computational Sciences Initiative
  - Team led by BNL with contributions from the RBC Collaboration (RIKEN BNL Research Center, Brookhaven Lab, and Columbia University) and the UKQCD collaboration
  - Combined the simulations with related experimental measurements to produce the highest overall precision prediction to date
  - Produced first-principles lattice QCD+QED calculation at physical pion mass of the leading-order hadronic vacuum polarization contribution to muon g-2
- DOI: 10.1103/PhysRevLett.121.022003



SciDAC: HEP Data Analytics on HPC

PI: J. Kowalkowski (FNAL)

- NOvA Neutrino + Antineutrino Analysis
  - Large-scale analysis campaigns carried out at NERSC for the first time, in support of the first set of electron antineutrino appearance results shown at the Neutrino 2018 conference
  - Impact: Most precise measurement of antineutrino oscillations to date, with 8x higher resolution than any prior NOvA result
  - 50x faster than any previous result: reviewed by collaboration in <24h
- LHC Generator Tuning
  - Addressing need for tuning and parameter space exploration with high precision simulations
  - Providing HPC-capable data parallel application of Pythia incorporating matrix element calculations



Corrected contours reveal large islands in parameter space where sensitivity is greatly improved.

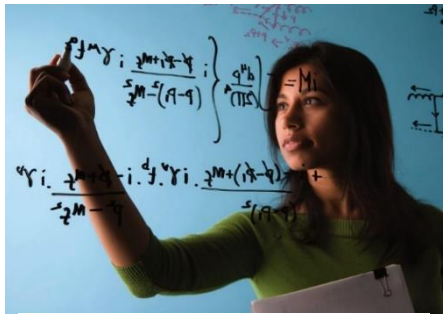
http://news.fnal.gov/2018/07/fermilab-computing-experts-bolster-nova-evidence-1-million-cores-consumed/

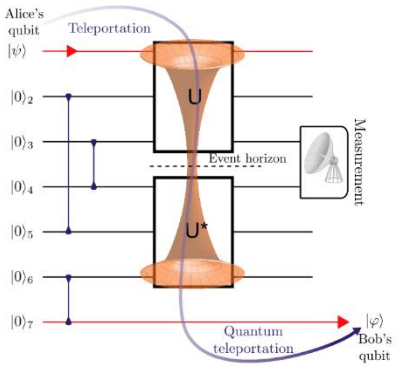
- Project Experiment Collaborators
  - NOvA - A. Sousa (University of Cincinnati)
  - DUNE - A. Norman (FNAL)
  - ATLAS – P. Calafiura (LBNL)
  - CMS – S. Mrenna (FNAL)
- ASCR Partners
  - MATH: Rational approximation of multi-dimensional functions, Optimization with surrogate models for generator tuning
  - CS: Data parallel tools and object stores

Fermilab Argonne NATIONAL LABORATORY Lawrence Berkeley National Laboratory University of CINCINNATI Colorado State University

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

Powerful new windows to accomplish HEP mission & advance QIST
Foundational theory, computing, sensors, technology, experiments





Example: Cosmos and Qubits

Foundational concepts and mathematical formulations that explore black hole physics and how black holes scramble information lead to new ways to study how qubits stabilize in the laboratory & fault tolerance. Simulating worm holes/study of teleportation protocols…

Quantum Simulation Experiments

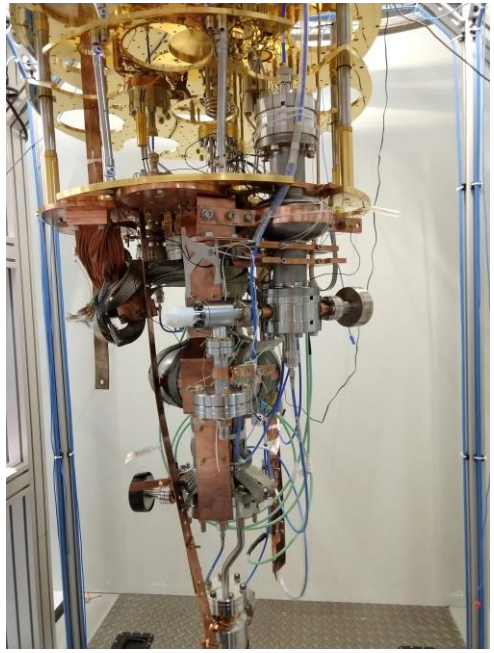
https://www.nature.com/articles/s41586-019-0952-6

Cosmos and Qubits

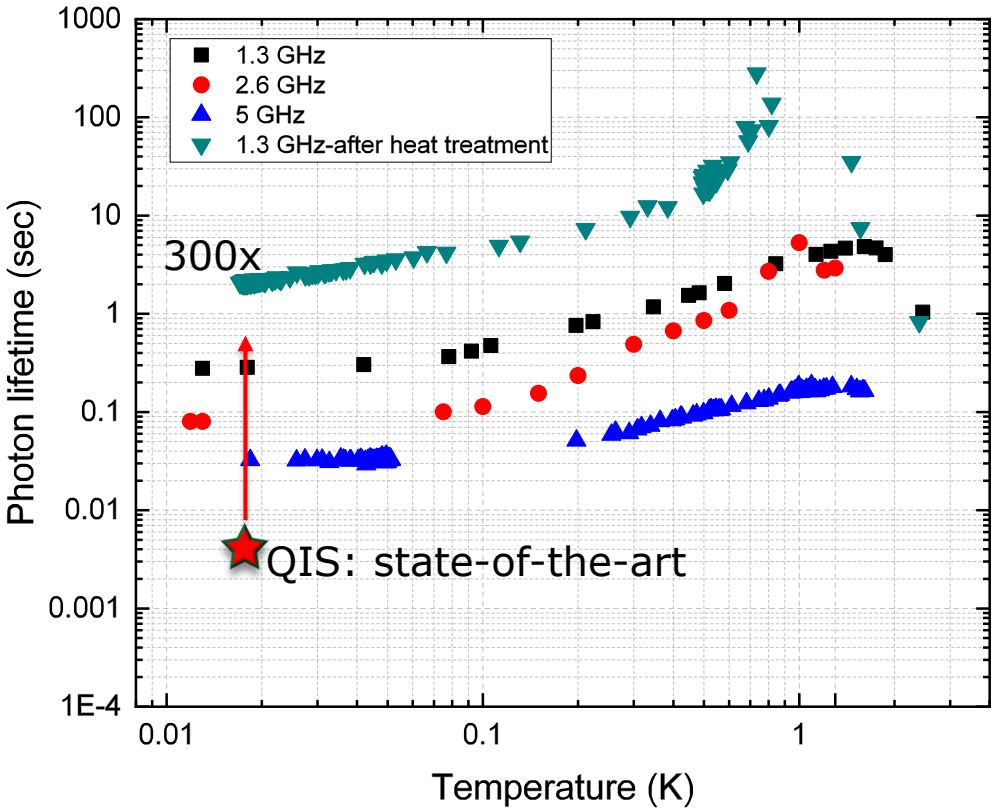
Partnerships with DOD on above and with NIST on sensors

QuantISED Highlight: Accelerator cavities adopted for quantum regime

- Record high photon lifetimes achieved at Fermilab
  - **Seconds** of coherence after targeted treatment

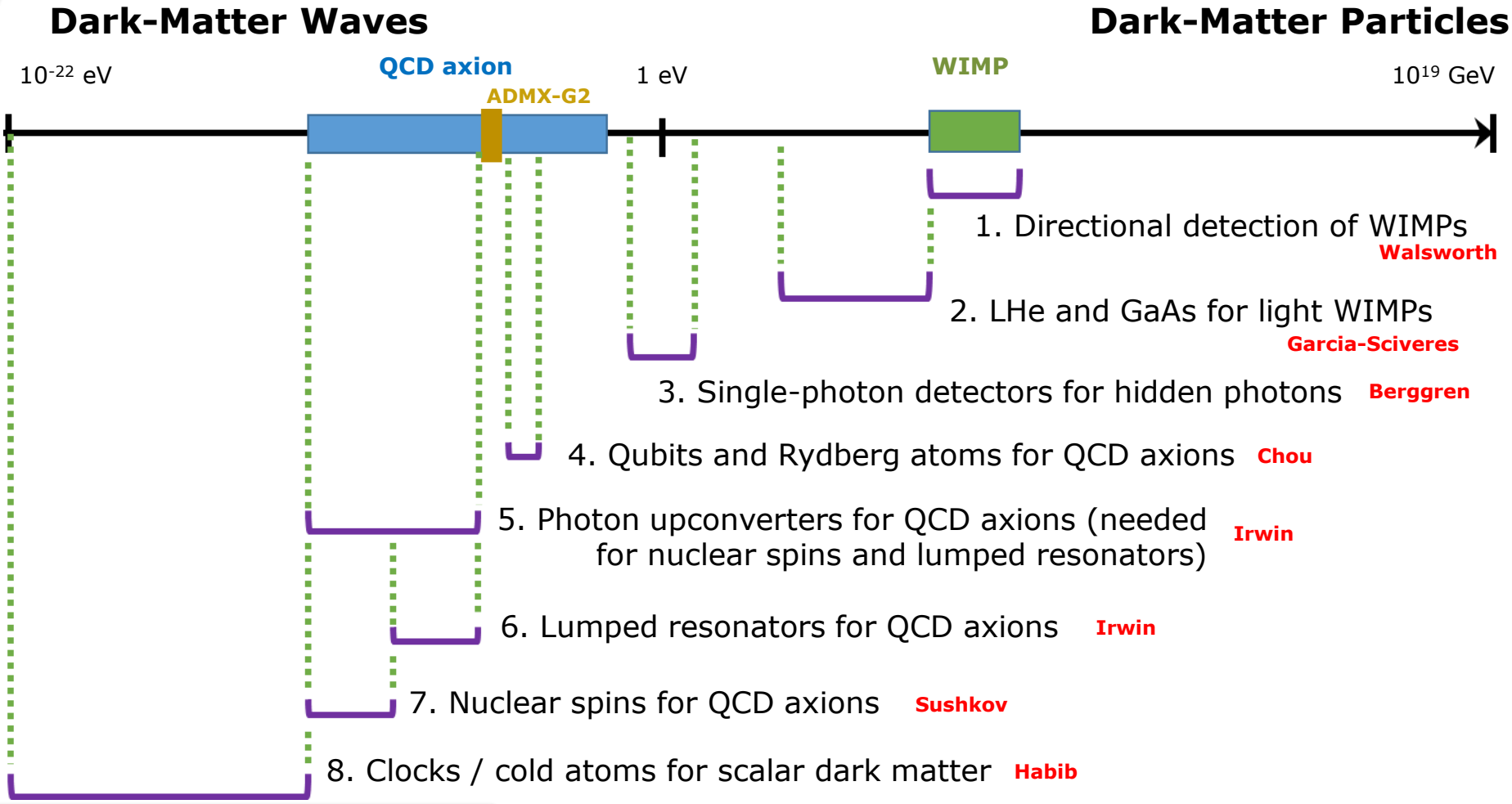


A. Romanenko, R. Pilipenko, S. Zorzetti, D. Frolov, M. Awida, S. Posen, A. Grassellino, arXiv:1810.03703
A. Romanenko and D. I. Schuster, Phys. Rev. Lett. 119, 264801 (2017)



HEP-QIS QuantISED Sensor Portfolio

For Dark Sector, New Interactions, and QIST

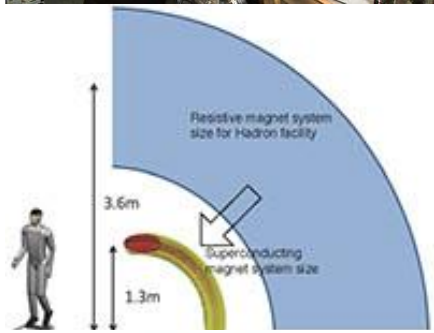


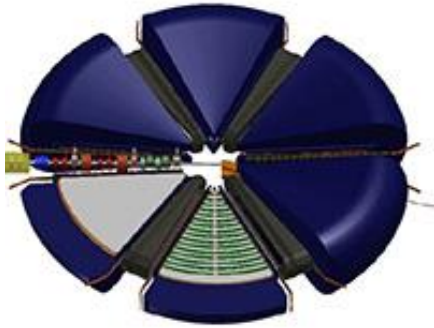
+9. Quantum simulation and optimization of dark matter experiments **Balantekin**

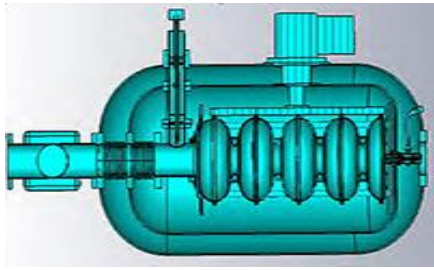
Accelerator Stewardship

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.

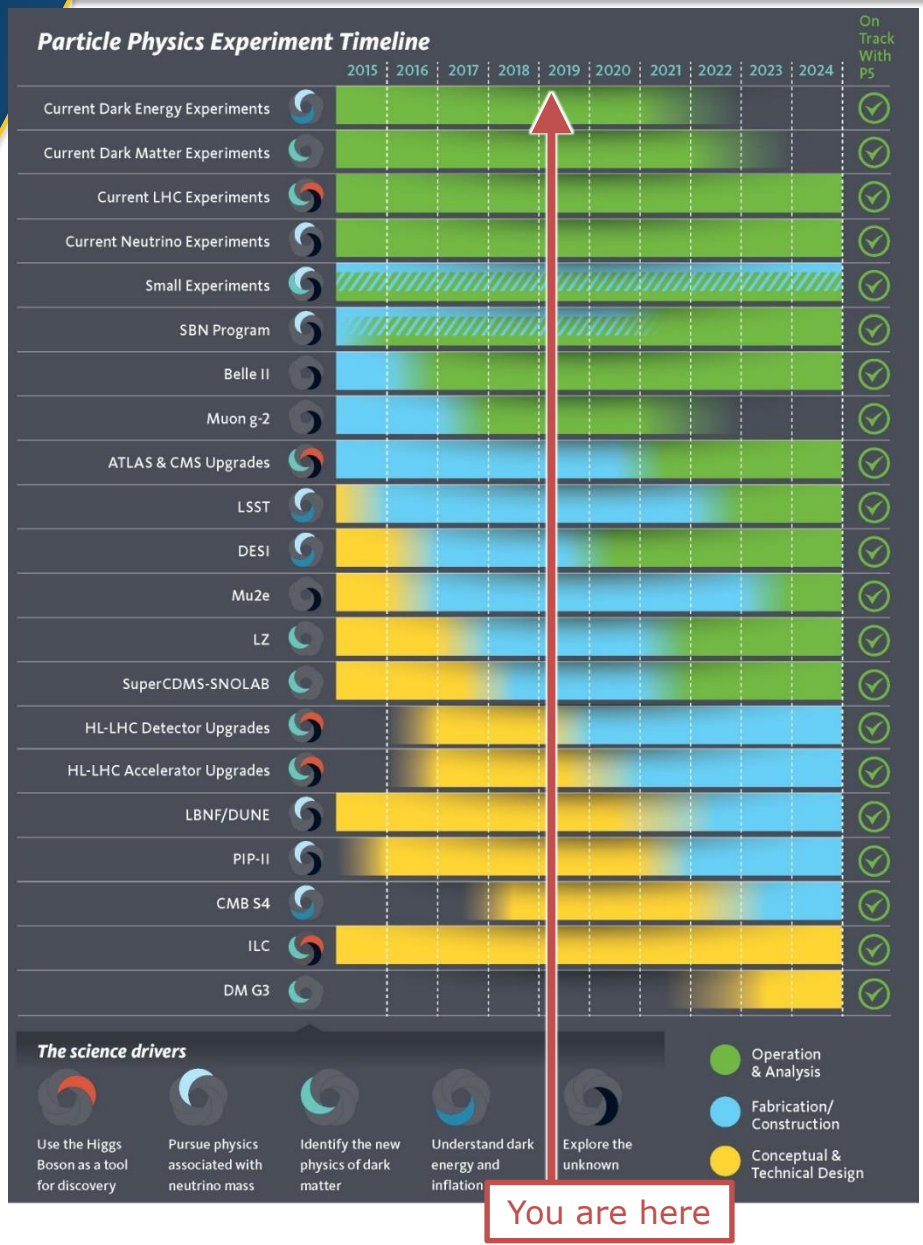
- Improve access to national lab accelerator facilities
  - Make resources and facilities, such as Brookhaven National Laboratory's Accelerator Test Facility II (ATF-II), available for industrial and for other U.S. government agency users and developers of accelerators and related technology
- Develop 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







P5 Implementation Status – FY 2019



All projects on budget & schedule

- Projects fully funded as of FY19
  - Muon g-2: 1st beam 2017
  - LHC detector upgrades: on track for 2019/20 installation
  - Mu2e : 1st data in 2020
  - LSST: full science operations 2023
  - DM-G2 (superCDMS & LZ): 1st data 2020
  - DESI: 1st light on April 1, 2019
- HL-LHC accelerator and detector upgrades started on schedule
- LBNF/DUNE & PIP-II schedules advanced due to strong support by Administration & Congress
- CMB S4: developing technically-driven schedule to inform agencies, NAS Astro 2020 Decadal Survey
- DM-G3: R&D limited while fabricating G2
- ILC: cost reduction R&D while waiting for decision from Japan
- Broad portfolio of small projects running

FY 2019 HEP Enacted Budget

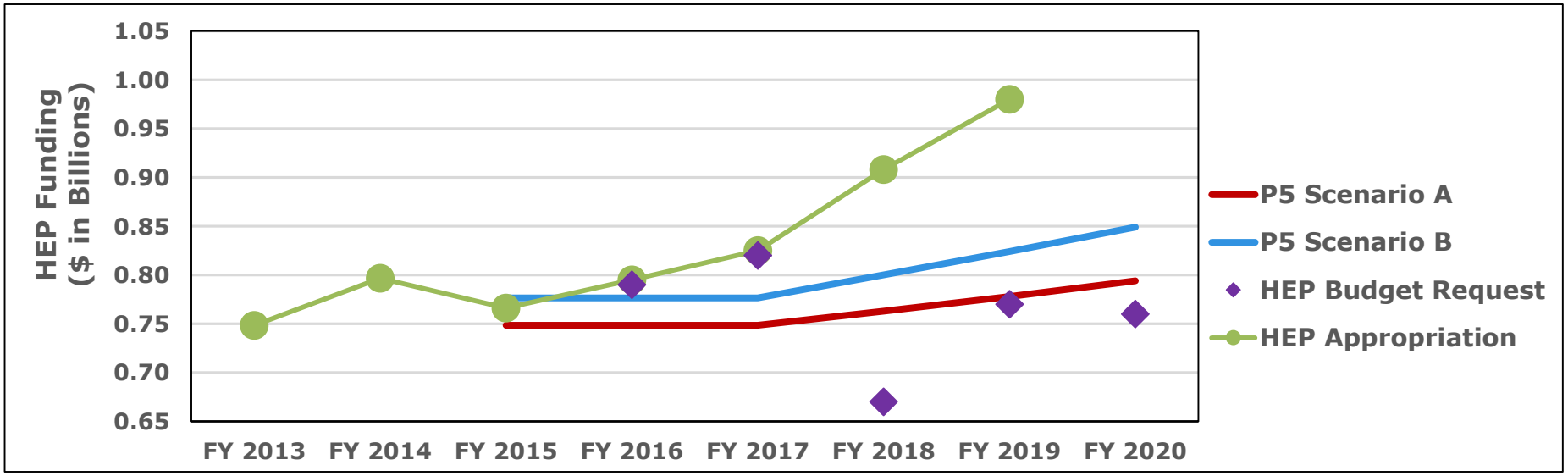
HEP Funding Category ($ in K)	FY 2017 Actual	FY 2018 Actual	FY 2019 Enacted	FY 2019 vs. FY 2018
Research	344,043	359,177	380,847	+21,670
Facilities/Operations	258,696	270,488	260,803	-9,685
Projects	222,261	278,335	338,350	+60,015
Total	**825,000**	**908,000**	**980,000**	**+72,000**

- FY 2019 Appropriations supports the SC and P5 priorities
  - SC: interagency partnerships, national laboratories, accelerator R&D, QIS
  - P5: preserve vision, fine-tune execution
- FY 2019 HEP Budget continues support for P5-guided investments in mid- and long-term program
  - "Building for Discovery" by supporting highest priority P5 projects to enable future program
  - Research support advances P5 science drivers and world-leading, long-term R&D in Advanced Technology, Accelerator Stewardship, and Quantum Information Science
  - Operations support enables world-class research at HEP User Facilities

U.S. Congress Supports P5 Strategy

- FY 2019 Senate Energy and Water Development Appropriations Report:
  - "The Committee recommends $1,010,000,000 for High Energy Physics. **The Committee strongly supports the Department's efforts to advance the recommendations of the Particle Physics Project Prioritization Panel Report [P5],** which established clear priorities for the domestic particle physics program…"

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



Timeline for Updating the U.S. Strategy

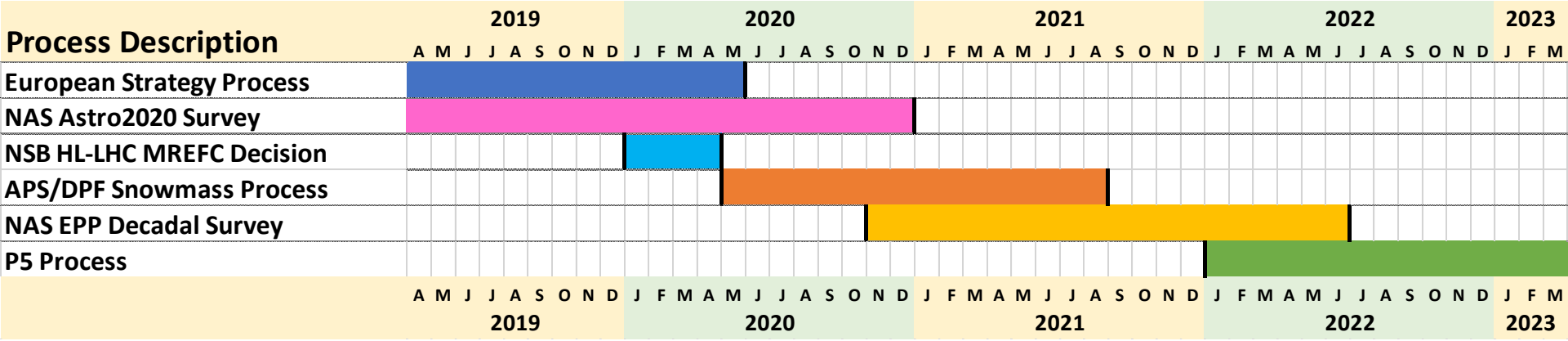
- **The May 2014 P5 report was successful because it was well informed by the science community**, including information from:
  - 2010 New Worlds, New Horizons in Astronomy and Astrophysics
  - 2012 Report of the Subcommittee on Future Projects of High Energy Physics (Japan)
  - 2013 European Strategy for Particle Physics Report
  - 2013 U.S. Particle Physics Community-driven "Snowmass" process
- The timeline of processes that impact the next strategic plan:
  - 2018-20: New NAS Astronomy and Astrophysics Decadal Survey
  - 2019: Start of European Strategy for Particle Physics process
  - 2019/20: Anticipated Japanese decision on ILC
  - 2020: Release of updated European Strategy for Particle Physics
  - 2020: Earliest opportunity for National Science Board to approve obligating HL-LHC MREFC
- **From a DOE perspective, the earliest that new APS/DPF Snowmass, NAS Elementary Particle Physics Decadal Survey, and P5 processes could begin is 2020**
  - **Relative timing of Snowmass, P5, and NAS EPP Decadal Survey to be determined**
  - **Enables receiving next P5 recommendations by March 2023, in time to inform FY 2025 budget formulation**

Possible NAS EPP2020 Charge Elements

- The aim of a new NAS Elementary Particle Physics Decadal Survey would be to complement and enhance the current highly successful model of strategic planning for U.S. particle physics
  - Current community-driven process successfully engages the U.S. particle physics community in exploration of opportunities and prioritization of future projects
  - NAS process would provide a broader perspective on impact of field and engagement across disciplines
- Four major themes may form the basis of a charge for a new EPP decadal survey:
  1. Survey of progress and promising scientific areas
  2. International landscape and connections
  3. Cross-disciplinary aspects of particle physics
  4. Societal benefits of particle physics

Possible Strategic Planning Timeline

- To provide timely input to the FY25 budget formulation, the next P5 report will be required by March 2023
- Given constraints for each part of the strategic planning process, a potential timeline for the next NAS EPP Decadal Survey could be late 2020 through mid-2022
  - Partial overlap with Snowmass and P5 processes may suggest that staggered/bifurcated delivery of the report could be optimal



Closing Remarks

- Excellent science results continue to be produced from our operating experiments!
- Broad support is enabling us to implement the P5 strategic plan and achieve its vision
  - Thanks to DOE Management, Administration, and Congress for support
- The particle physics community continues to perform well on delivering projects, a foundation of the long-term strategy
- Community continues to be unified in support of P5 strategy

U.S. DEPARTMENT OF
ENERGY

Office of
Science