U.S. DEPARTMENT OF ENERGY | Office of Science

Office of High Energy Physics (HEP) Program

Astronomy & Astrophysics Decadal Survey Meeting

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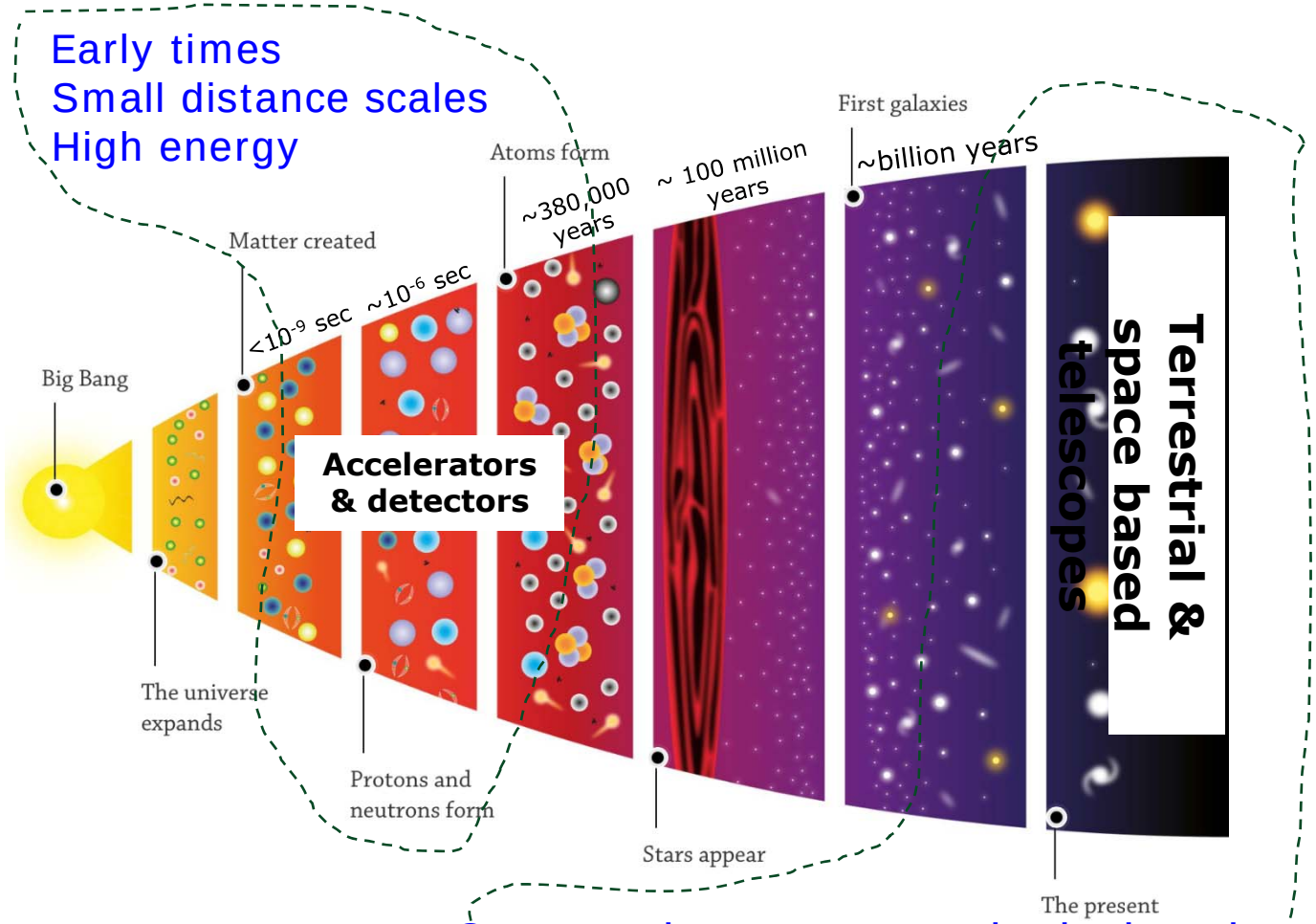
Kathleen Turner

Program Manager for the Cosmic Frontier

Office of High Energy Physics

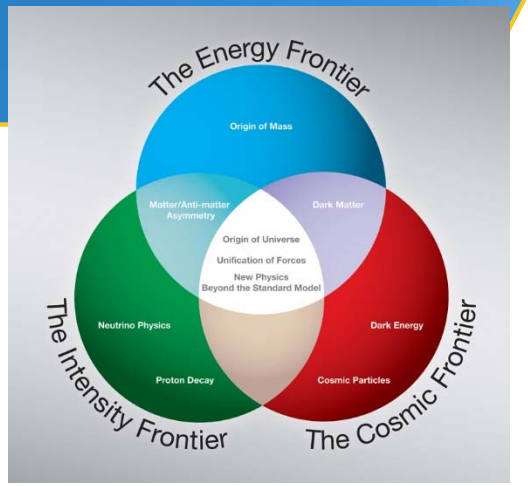
From Quarks to the Cosmos

➔Scientific Areas are intertwined: High Energy/Particle Physics, Cosmology, Astrophysics, and Astronomy.



HEP Intro

HEP's mission: Understand how the universe works at its most fundamental level; Discover and understand the elementary constituents of matter & energy, space & time
→ Explore nature all the way up to the Grand Unification and back to the Big Bang.



<u>HEP is carried out along 3 Frontiers</u>: Advancements at all 3 frontiers are needed to achieve the long term goals of the field.

- **Energy & Intensity Frontiers** are primarily accelerator-based; bulk of the program.
- **Cosmic Frontier** has become an increasingly important area for discovery. Experiments use naturally occurring data to provide complementary input to the Standard Model and beyond: <u>Cosmic Acceleration</u> (Dark Energy, Inflation), search for <u>Dark Matter</u> particles, <u>New Physics</u> (neutrino properties, relic particles, etc)

→looking to Astro2020 for guidance

HEP & Astro2020

NASA, NSF and DOE worked together to deliver a statement of task (SOT) to the National Academy of Sciences for Astro2020

- Identify the most compelling science challenges and frontiers in astronomy and astrophysics, which shall motivate the committee's strategy for the future;
- Develop a comprehensive research strategy to advance the frontiers of astronomy and astrophysics for the period 2022-2032.
  → In addition to projects & experiments, consider need for Research/Scientist support, Experimental Operations, Computing resources, technology development, etc.

→Guidance from Astro2020 will inform HEP on

- Compelling, high impact science directions and research strategies
- Opportunities for HEP to make contributions to:
  - select, high impact experiments with discovery potential
  - that address HEP science goals
  - where DOE HEP researchers and investments can play a significant role in & make unique, significant & necessary contributions (PASAG criteria)
- Partnerships with NASA, NSF & international collaborators as appropriate

HEP Cosmic Frontier & Astro2020 Scope

Cosmic Frontier priority science goals (as per 2014 P5 strategic plan):

- Cosmic Acceleration - Dark Energy, Inflationary Epoch
- Dark Matter - discovering dark matter particles
- Neutrino properties
- New Physics

Astro2020 Scope includes entire breadth of research in the fields;
However HEP is not asking for recommendations on:

- Lab Astrophysics, Solar astronomy, Exo-planets
- Specific projects in gravitational waves or Multi-messenger astronomy/astrophysics… though some of the science topics may overlap with HEP goals

Astro2020 Scope excludes project or activity recommendations in:

- Direct detection or accelerator-based dark matter particle searches that are traditionally considered and carried out by the NSF and DOE particle physics communities (fully covered by HEPAP)
- Construction of projects whose agency-supported implementation is already in progress, specifically JWST, DKIST, LSST, and DESI.

Cosmic Frontier – Efforts & Planning Relevant for Astro2020

- **CMB-S4** is being proposed to Astro 2020 as a partnership of DOE-HEP, NSF-AST/PHY/OPP.
  - **HEP is moving forward on CMB-S4 as recommended in our 2014 P5 strategic plan**

- **Dark Energy –** science ideas for enhancing and going beyond DESI and LSST being proposed to Astro 2020; We are interested in small, medium, large scale project ideas; also consider how to coordinate data across experiments to optimize science.

- **Dark Matter Direct Detection –** excluded in SOT due to purview of HEP/Particle Physics community; fully informed by HEPAP/P5

- **Exploring the Unknown –** always interested in exciting new physics ideas central our mission

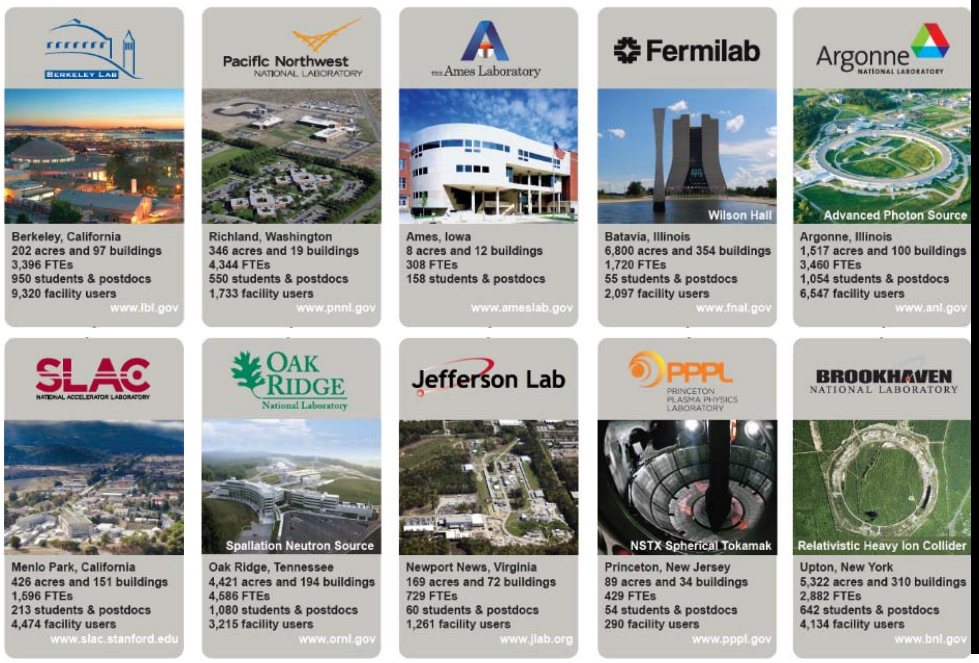
HEP Cosmic Frontier is dynamic – the community & HEP are always looking for high scientific impact opportunities that align with our science goals & make use of HEP community's capabilities.

Mission of the Department of Energy

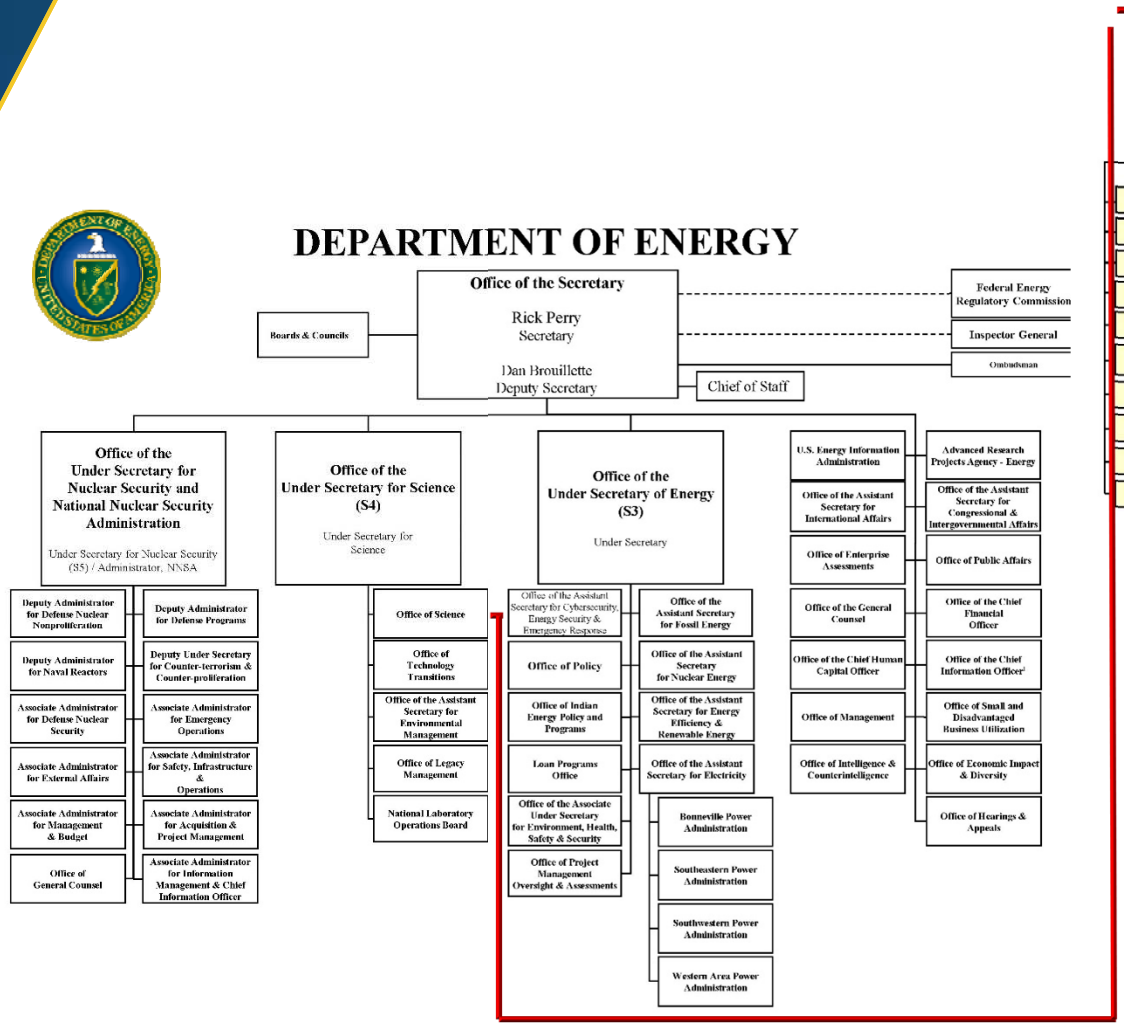
- The mission of the Energy Department is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.
  - Catalyze the timely, material, and efficient transformation of the nation's energy system and secure U.S. leadership in clean energy technologies.
  - **Maintain a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas.**
  - Enhance nuclear security through defense, nonproliferation, and environmental efforts.
  - Establish an operational and adaptable framework that combines the best wisdom of all Department stakeholders to maximize mission success.

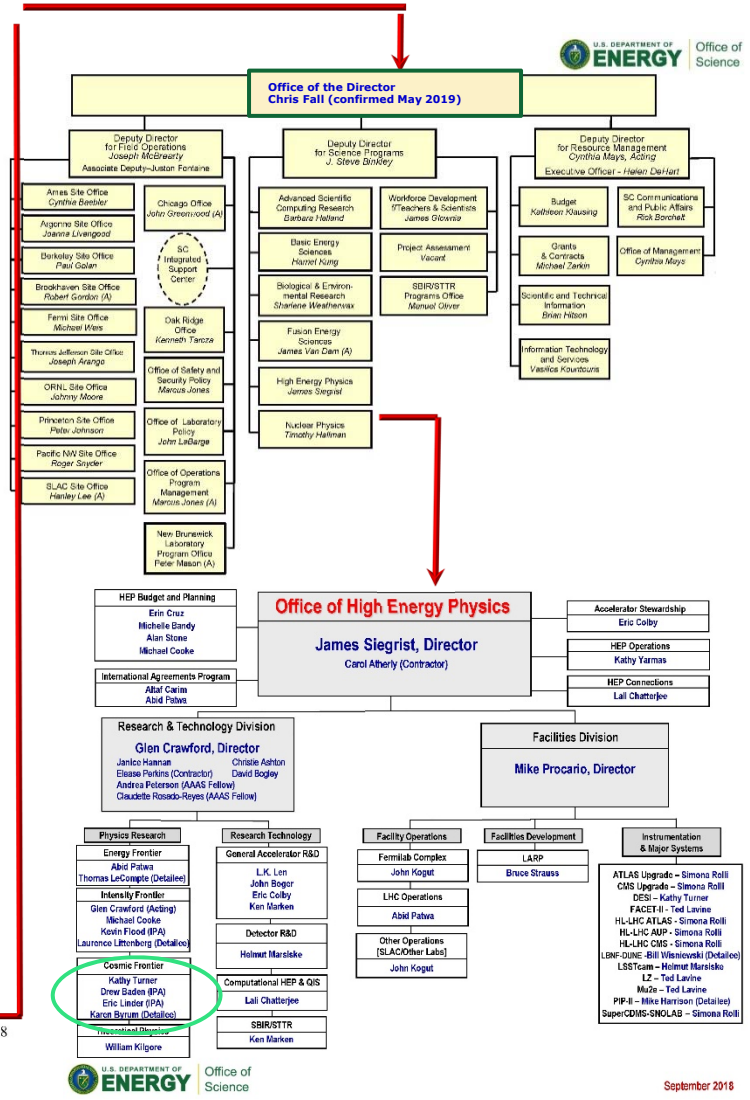
Mission of the DOE Office of Science

- The Office of Science Mission is to deliver the scientific discoveries and major scientific tools that transform our understanding of nature and advance the energy, economic, and national security of the United States



DOE Organization Chart





DOE Office of High Energy Physics (HEP) Program Mission

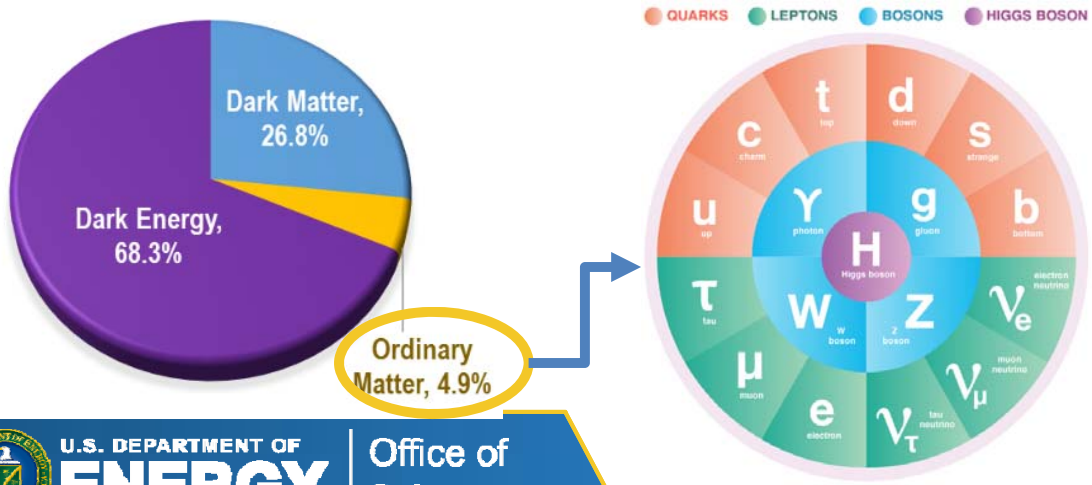
DOE is a mission-oriented agency, and includes **maintaining a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas.**

HEP's mission: 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

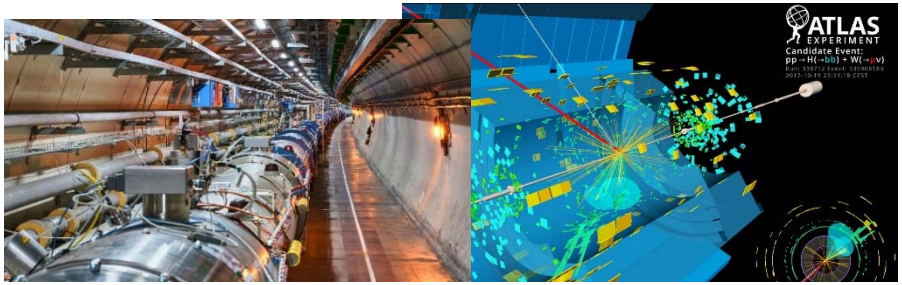
HEP fulfills its mission by

- Building **projects** that enable discovery science
- Operating **facilities and experiments** that provide the capability for discoveries
- Supporting a research program to produce discovery science



HEP Program – Exploring the **Standard Model**

The **Standard Model (SM) of particle physics** describes 3 of 4 known fundamental forces (em, weak, & strong interactions; not gravity) in the universe, as well as classifying all known elementary **particles**.



→HEP is primarily a Particle Accelerator based program:
Energy & Intensity Frontiers

→**Cosmic Frontier is an increasingly important area for discovery.** Experiments use naturally occurring data to provide additional input to the SM picture: Cosmic Acceleration (Dark Energy, Inflation), search for Dark Matter particles, New Physics (neutrino properties, relic particles, etc)

Areas of study to fully carry out the program:

- Theoretical research
- High Performance Computing → Exascale; Machine-learning
- State-of-the-Art Detector and Accelerator technology development
- Quantum Information Science (QIS) is a quickly-growing area.

HEP Program Advice, Guidance, Partnerships and Coordination

Official Advice: Federal Advisory Committee Act (FACA)

High Energy Physics Advisory Panel (HEPAP)

- Advises **DOE & NSF**: Provides the primary advice for the HEP program; Subpanels:
  - 2009 Particle Astrophysics Science Advisory Group (PASAG) – Strategic Plan
  - 2014 Particle Physics Project Prioritization Panel ("P5"): 10-year Strategic Plan

Astronomy and Astrophysics Advisory Committee (AAAC)

- Advises **DOE, NASA, & NSF** on issues of overlap, mutual interest and concern
- Subpanels: CMB-S4 Concept Definition Taskforce (2017)

Advice Also Provided by: National Academies of Sciences (NAS)

- Decadal Surveys: **Astronomy & Astrophysics**, Elementary Particle Physics
- Board on Physics & Astronomy (BPA), Committee on Astronomy & Astrophysics (CAA)

Other Input

- Community studies & input, e.g. Snowmass, APS/DPF
  - Basic Research Needs (BRN) studies – process to develop new HEP initiatives

Partnerships, Coordination

Significant Interagency and International Partnerships & Coordination – this is a global field!

History of Reports – feeding into DOE HEP Cosmic Frontier planning

NOTE: List of reports (most likely!) not complete, esp. before 2010

2004 HEPAP - Scientific Assessment Group for Experimental Non-Accelerator Physics (SAGENAP)
2006 AAAC - Task Force for CMB Research (TFCR)
2006 AAAC - Dark Energy Task Force (DETF)
2006 NAS - Elementary Particle Physics 2010 (EPP2010)
2007 NAS - Beyond Einstein: An Architecture for Implementation
2007 AAAC - Dark Matter Science Assessment Group (DMSAG)
2008 HEPAP - Particle Physics Project Prioritization Panel (P5)
2009 HEPAP - Particle Astrophysics Science Assessment Group (PASAG)
2010 NAS - Astro2010 NWNH (New Worlds New Horizons)
2012 AAAC - Dark Energy Task Force (Rocky III)
2013 APS/DPF Snowmass report, Planning the Future of Particle Physics
2014 HEPAP - Particle Physics Project Prioritization Panel (P5)
2017 AAAC - CMB-S4 Concept Definition Taskforce
2018 HEPAP HEP Portfolio Review of Operating Experiments
2018 AAAC – Gemini-Blanco-SOAR subpanel

HEPAP/PASAG Report – Oct. 2009

Guidance:

- **Dark energy** funding (recommended for largest budget portion) should not significantly compromise US leadership in dark matter, where a discovery could be imminent
- **Dark energy and dark matter** together should not completely zero out other important activities (except in the lowest funding scenario - **even then a limited CMB participation is recommended**)

HEP Objectives in Planning following PASAG:

The report helped define the HEP Cosmic Frontier and set priorities and scientific deliverables for the future. **Dark Matter (DM) and Dark Energy (DE) remain the highest priorities in this area.**

- Follow **PASAG Criteria** & make contributions to:
  - select, high impact experiments with discovery potential
  - that address particle-astrophysics and cosmology goals
  - where DOE HEP researchers and investments can play a unique, significant role in and make significant contributions

- Achieve earliest, best, and most cost-effective U.S. DE & DM science results

- Partnerships with NASA and NSF and international collaborators as appropriate

2009 PASAG Report: Prioritization Criteria for participation by the HEP Program →

The science addressed by the project is necessary

- Addresses fundamental physics (matter, energy, space, time).
- Anticipated results: either at least one compelling result or a preponderance of solid, important results. Check that anticipated results would not be marginal, either in statistics or in systematic uncertainties, relative to the needed precision for clear science results.
- Discovery space: large leap in key capabilities, significant new discovery space, and possibility of important surprises.

HEP/Particle physicist participation is necessary

- Transformative techniques and know-how to have a major, visible impact; project would not otherwise happen.
- Leadership efforts are higher priority than participation
- The particle physics community participation brings needed expertise in terms of science, technology, or computing, etc.

Scale matters, particularly for projects at the boundary between particle physics, cosmology and astrophysics.

- Relatively small projects with high science per dollar help ensure scientific breadth while maintaining program focus on the highest priorities.

Programmatic issues: International context: cooperation vs. duplication, competition.

Astro2010 "New Worlds New Horizons" Report (August 2010) → DOE/HEP Guidance, Response

NWNH recommended a coordinated Dark Energy program

- Highest priority large project in space: WFIRST (DOE, NASA)
- Highest priority large project on ground: LSST (DOE, NSF)

Specific Recommendations to DOE:

- The optimistic (doubling) funding profile allows investment in:
  - **LSST** – DOE should partner with NSF
  - **WFIRST** – DOE should contribute to the NASA mission
- At lower funding (constant with inflation) level:
  - **LSST** is recommended as the priority because DOE role is critical

"In lower scenarios, DOE should participate in LSST ahead of WFIRST since DOE is making a larger relative $ contribution and its technical role is thought to be relatively more critical".

Astro2010 "New Worlds New Horizons" Report (August 2010) → DOE/HEP Guidance, Response, cont.

Other identified opportunities:

- **Contributions to NSF mid-scale experiments (2nd priority in ground-based)** e.g. BigBOSS, CMB, HAWC experiments, etc.
- **NSF & DOE contribute as a minor partner (4th priority in ground-based)** to a European-led AGIS/CTA ground-based gamma-ray observatory
- **CMB:** technology program to advance detection techniques"
- Joint Agency competed **Research Networks in Theoretical and Computational Astrophysics program** ($2M/year DOE)

"DOE may have opportunities to contribute to mid-scale ground-based projects with NSF (ground priority #2), and should contribute to ACTA with NSF and to the Theory & Computation Network (TCN). These smaller programs and ACTA have lower priority than LSST & WFIRST."

➔Following the report, NSF and DOE moved forward on a LSST partnership. DOE later began development of the DESI project (previously "BigBOSS").

Astro2010 NWNH (2010) & PASAG (2009) →DOE HEP Comments & Path Forward following the reports

HEP Comments

Budgetary scenarios: Funding projections following NWNH tended towards the lower funding amounts & didn't have the same profile assumed by NWNH

HEP Objectives:

- Follow **PASAG Criteria** and make contributions to select, high impact experiments with discovery potential
  - that address HEP goals & where DOE HEP researchers & investments can play a significant role in and make significant contributions
- Achieve earliest, best, and most cost-effective U.S. dark energy and dark matter science results
- Partnerships with NASA and NSF and international collaborators as appropriate

HEP Priorities

- Dark matter – direct detection experiments are a priority (not part of Astro2010 study)
- Maintain a leading U.S. role in dark energy research (Astro2010 recommendation)
- Other opportunities for contribution as funding permits

HEP Path Forward – Follow:

PASAG guidance on Dark Matter – direct-detection dark matter experiments with NSF Physics

PASAG/NWNH guidance on Dark Energy

- **Work w/NSF-AST to move forward on LSST**; match up project planning, funding & schedules as needed
- HEP will consider other proposals and partnerships as appropriate (HEP moved forward on DESI)

PASAG/NWNH guidance in other areas: Cosmic-ray, Gamma-ray, CMB

- NWNH CMB technology recommendation - **HEP supports advanced detector and readout technology at national labs and universities. HEP also supports research efforts on many experiments. DOE/NERSC computing efforts making major contributions to many ground-based experiments & Planck.**
- NWNH Theory & Computation Research Network recommendation: **HEP currently supports** a competed Theory Program that covers all HEP-related studies, including computational cosmology, and cosmological modelling, simulations and theory studies; Do not plan a separate program in this area.

HEPAP P5 Strategic Plan

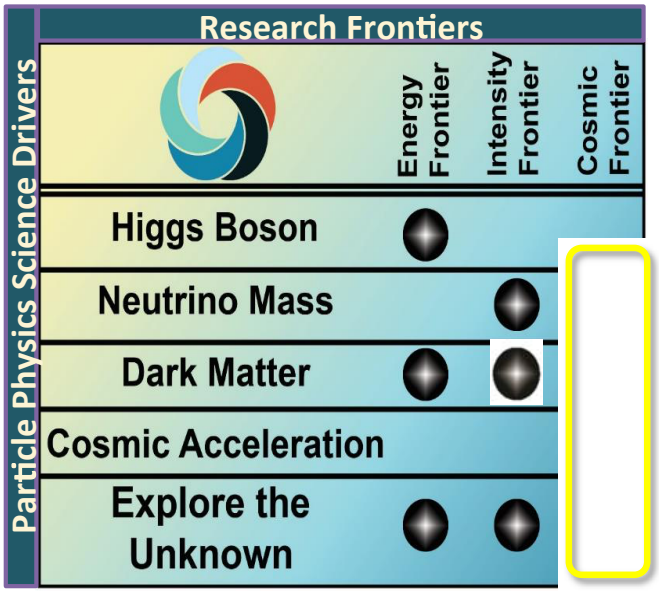
As a mission agency, HEP uses a community-driven strategic planning process to identify the projects that provide significant leaps in science & capabilities

- 2013: APS-DPF led community scientific input ("Snowmass")
- 2014: HEPAP P5 Subpanel developed a 10-year plan in several funding scenarios.

The P5 report enables discovery science with a balanced program that deeply intertwines U.S. efforts with international partners

- **Compelling, unified vision for HEP; Widespread community buy-in**
- **Five intertwined science drivers define the big issues**
- **Balanced approach across Frontiers, project size, short- & long-term**
- **Global program w/international partners**

2014 P5 Report: Strategic Plan & 5 HEP Science Drivers



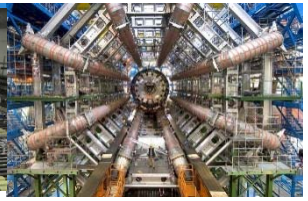
Pursuing the Next Discovery: The Science Drivers of Particle Physics

The 2014 P5 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*

2014 P5 Strategic Plan



Energy Frontier

Continue strong collaboration in the Large Hadron Collider (LHC) including the High-Luminosity LHC accelerator and detector upgrades - highest priority near-term large project:

- Complete "Phase-1" (2018) upgrades of ATLAS and CMS experiments
- Continue collaborations with the "Phase-2" (High-Luminosity LHC, 2023-25) upgrades of the accelerator and the ATLAS and CMS experiments

Intensity Frontier

P5 recommended substantial investments in the U.S. neutrino program

- Develop a world-leading neutrino program with U.S-hosted (Fermilab) Long-Baseline Neutrino Facility (LBNF) Deep Underground Neutrino Experiment (DUNE) as the centerpiece. The Proton Improvement Plan II (PIP-II) program of updates to the accelerator complex, will provide proton beams with power >1 MW by the time of first operation of the new LBNF.
- Develop, with international partners, a coherent short- & long-baseline neutrino program at Fermilab.

Cosmic Frontier

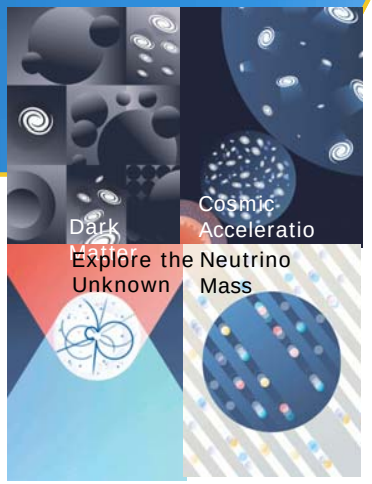
P5 recommended significant investments in:

- **Dark Energy: build LSST & DESI**
- **Dark Matter: direct detection search suite of "generation 2" experiments**
- **CMB: support as part of the core program within multi-agency context; carry out multi-agency CMB-S4 project**

Advanced Technology R&D Strategy

- Leadership role in superconducting magnet technology to increase performance and decrease costs
- Accelerator R&D with a focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term accelerators
- Focus resources toward directed detector instrumentation R&D in the near-term for high-priority projects
- Reassess the Muon Accelerator Program, in consultation with international partners

2014 P5 Report – Cosmic Frontier



Dark Energy

- Complete **LSST** as planned
- Build **DESI** as a major step forward in dark energy science

Dark Matter

- Proceed immediately with a broad second-generation (G2) **dark matter direct detection program** with capabilities described in the text
- Invest in this program at a level significantly above that called for in the 2012 joint agency announcement of opportunity
- Support one or more third-generation (G3) direct detection experiments
- Guide G3 by the results of the preceding (G1, G2) searches
- Seek a globally complementary program and increased international partnership in G3 experiments (DM-G3 is in the P5 plan in later part of their 10 year plan.)

Cosmic Microwave Background (CMB)

- Support CMB experiments as part of the core particle physics program
- The multidisciplinary nature of the science warrants continued multi-agency support

(CMB-S4 Project starts ~midway through the P5 10-year plan.)

New Physics: Explore the Unknown, including through cosmic rays & gamma rays

P5: Program & Project Criteria

HEP uses P5's Criteria in developing our program →

Program optimization criteria

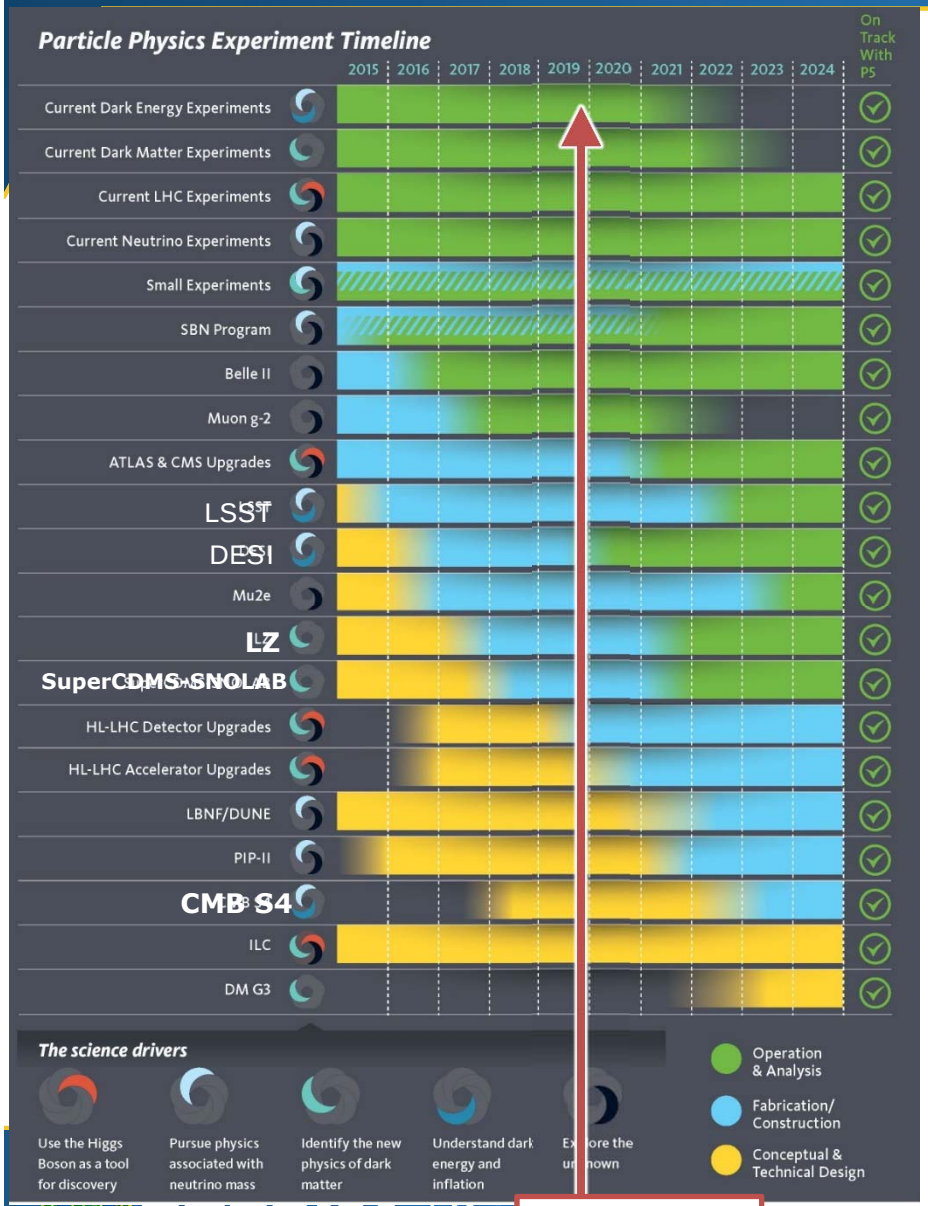
– Science: based on the Drivers, assess where we want to go and how to get there, with a portfolio of the most promising approaches.
– International context: pursue the most important opportunities wherever they are, and host world-leading facilities that attract the worldwide scientific community; duplication should only occur when significant value is added or when competition helps propel the field in important directions.
– Sustained productivity: maintain a stream of science results while investing in future capabilities, which implies a balance of project sizes; maintain and develop critical technical and scientific expertise and infrastructure to enable future discoveries.

Individual project criteria (can also be applied to research efforts/proposals)

– Science: how the project addresses key questions in particle physics, the size and relevance of the discovery reach, how the experiment might change the direction of the field, and the value of null results.
– Timing: when the project is needed, and how it fits into the larger picture.
– Uniqueness: what the experiment adds that is unique and/or definitive, and where it might lead. Consider the alternatives.
– Cost vs. value: the scope should be well defined and match the physics case. For multidisciplinary/agency projects, distribution of support should match the distribution of science.
– History and dependencies: previous prioritization, existing commitments, and the impacts of changes in direction.
– Feasibility: consider the main technical, cost, and schedule risks of the proposed project.
– Roles: U.S. particle physics leadership

For Cosmic Frontier, the 2009 PASAG Criteria also continues to be used!

P5 Implementation Status – FY 2019



All HEP Projects on budget & schedule

Cosmic Frontier:

Operating small experiments including **ADMX-G2, SPT-3G;** recently completed **DES, eBOSS**

Projects fully funded as of FY19:

- **LSST: full science operations 2023**
- **DM-G2 (SuperCDMS & LZ): fabrication completes FY20; full science starts FY21**
- **DESI: 1st light on lenses April 2019, science operations in FY20**

Projects in planning:

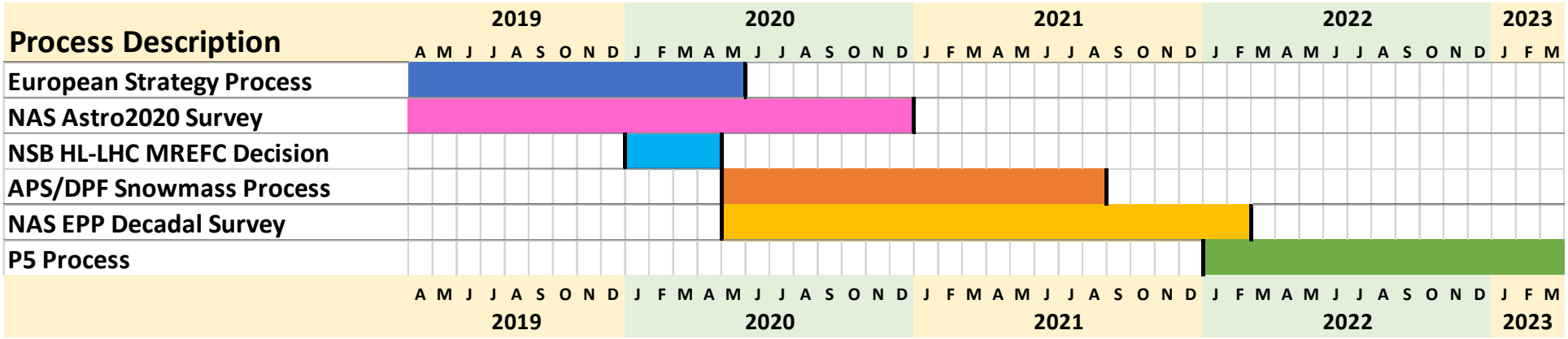
- **CMB S4**: developing technically-driven schedule to inform agencies, Astro2020; **HEP working to obtain Critical Decision 0 (CD0)**
- **DM-G3**: R&D limited while fabricating G2

Timeline for Updating the U.S. Strategy in HEP

- **The May 2014 P5 report was successful because it was well informed & supported 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: NAS Astronomy and Astrophysics Decadal Survey for 2020
  - 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

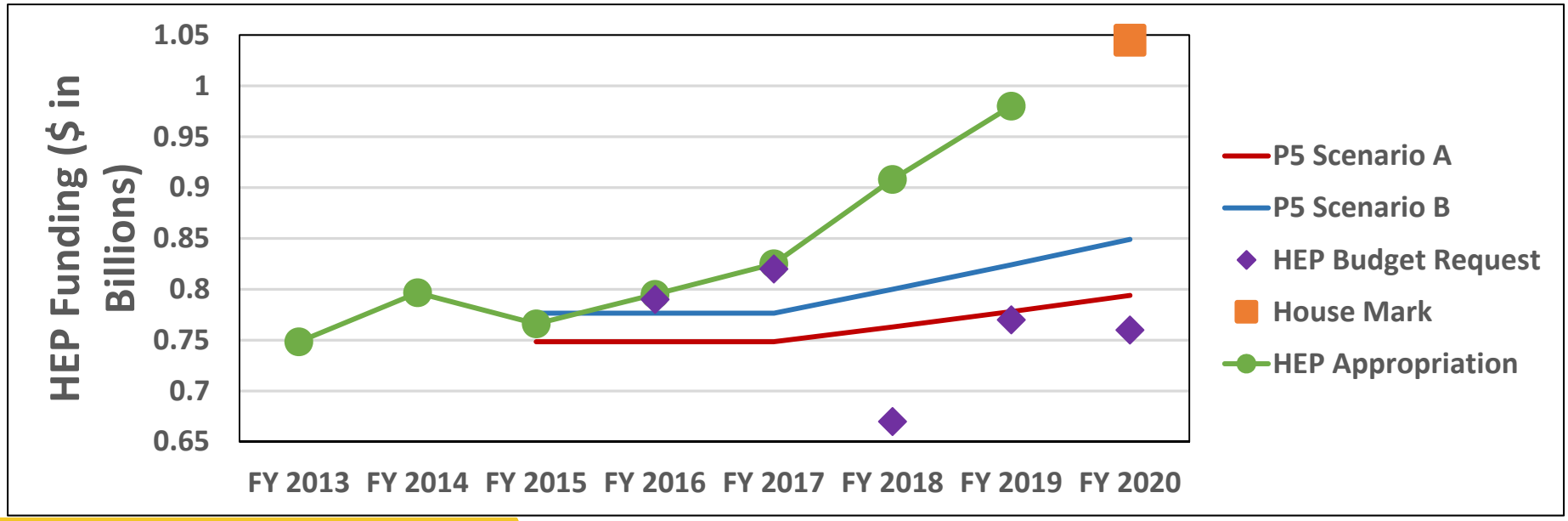
Possible Strategic Planning Timeline

- **From a DOE perspective, the earliest that new APS/DPF Snowmass, NAS Elementary Particle Physics Decadal Survey, and P5 strategic plan 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**



U.S. Congress Supports P5 Strategy

- Congressional appropriations reflect strong support for P5
- Recent appropriations reports include language recognizing community's efforts:
  - FY19 Senate EWD: "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…"



HEP Budget: FY18-20

HEP Funding Category ($ in K)	FY 2018 Actual	FY 2019 Enacted	FY 2020 Request	FY 2020 vs. FY 2019
Research	359,177	380,847	301,357	-79,490
Facilities/Operations	270,488	260,803	239,746	-21,057
Projects	278,335	338,350	226,935	-111,415
Total	**908,000**	**980,000**	**768,038**	**-211,962**

FY 2019 Budget continues support for P5-guided investments in mid- & long-term

FY 2020 Request: balanced program of world-leading research, facilities and projects

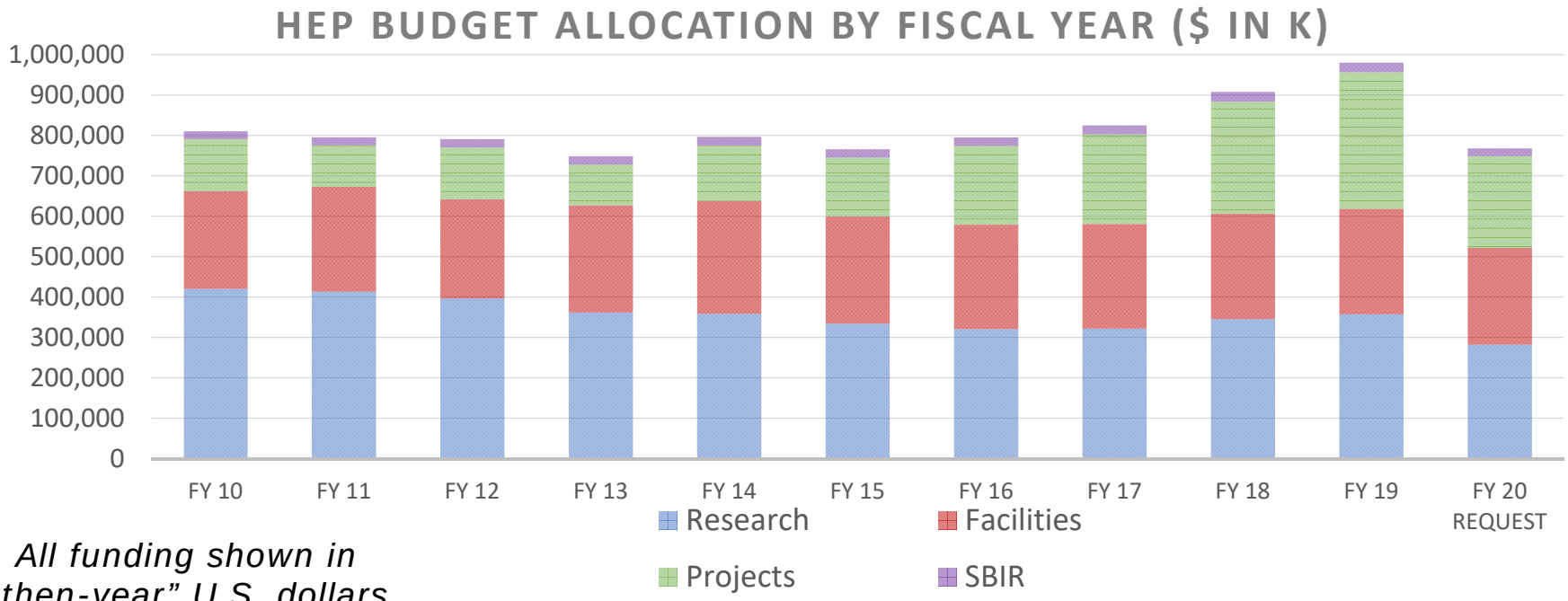
- Quantum Information Science: SC-wide initiative to accelerate discovery
- Artificial Intelligence (AI)-Machine Learning (ML) research to tackle challenges across HEP
- Cosmic Microwave Background Stage 4 (CMB-S4) R&D to develop large-scale project

FY 2020 House Marks

- DOE Office of Science: **$6.87B,** $285M above FY19 enacted and $1.32B above FY20 request
- High Energy Physics: **$1.045B**
  - [*HEP Core Program*]—Within available funds, the recommendation provides $25,000,000 for the Sanford Underground Research Facility, not less than $50,000,000 for Accelerator R&D, and $97,975,000 for the HL–LHC Upgrade Projects.
  - The Committee strongly urges DOE to **maintain a balanced portfolio** of small, medium, and large scale experiments, and to **ensure adequate funding for research** performed at universities and the national laboratories. The Committee encourages DOE to fund facility operations at levels for **optimal operations**.

Budget: Overall HEP Trend

- P5 strategy continues to define investments for the future

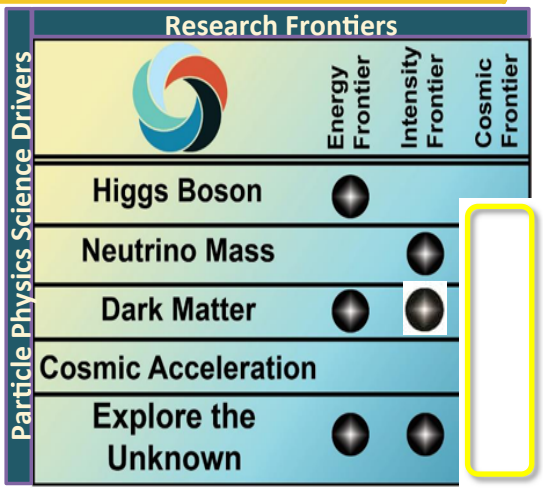


All funding shown in "then-year" U.S. dollars

- **Research**: primarily supports scientists participating in all aspects of an experiment (design, fabrication, operations, data planning & analysis)
- **Experimental/Facility Operations** and **Projects**: primarily supports technical personnel, materials, supplies, procurements, consumables

Cosmic Frontier Experimental Research Program

Address P5 science drivers using naturally occurring cosmic phenomena via deep underground detectors, ground-based telescopes & arrays, space missions.



Cosmic Acceleration:

- Imaging & Spectroscopic surveys to determine the nature of **Dark Energy**
- Study the Inflationary epoch using its imprint on the cosmic microwave background (**CMB**)

Dark Matter:

- Direct searches for **Dark Matter** particles with deep underground detectors
- Cosmic-ray & gamma-ray studies provide indirect searches for dark matter particles & searches for New Physics

Neutrino Mass: **Dark Energy** and **CMB** experiments place unique constraints neutrino masses

Explore the unknown: search for New Physics, e.g. relic particles from the early universe

Cosmic Frontier Program

Study cosmic acceleration (dark energy) through staged program of complementary surveys (in partnership with NSF-AST)

- Imaging surveys map cosmic structure over vast volumes of space: *Dark Energy Survey (DES)* completed operations, *Large Synoptic Survey Telescope (LSST)* camera in fabrication
- Spectroscopic surveys build deep, 3D maps of cosmic structure and growth: *eBOSS* completed, *Dark Energy Spectroscopic Instrument (DESI)* in fab

Study cosmic acceleration (inflation) at energies near the Planck scale and neutrino properties through the cosmic microwave background (CMB) (in partnership with NSF)

- New generation South Pole experiment: *SPT-3G* in operation
- Next generation array 10x more sensitive: *CMB-S4* in planning

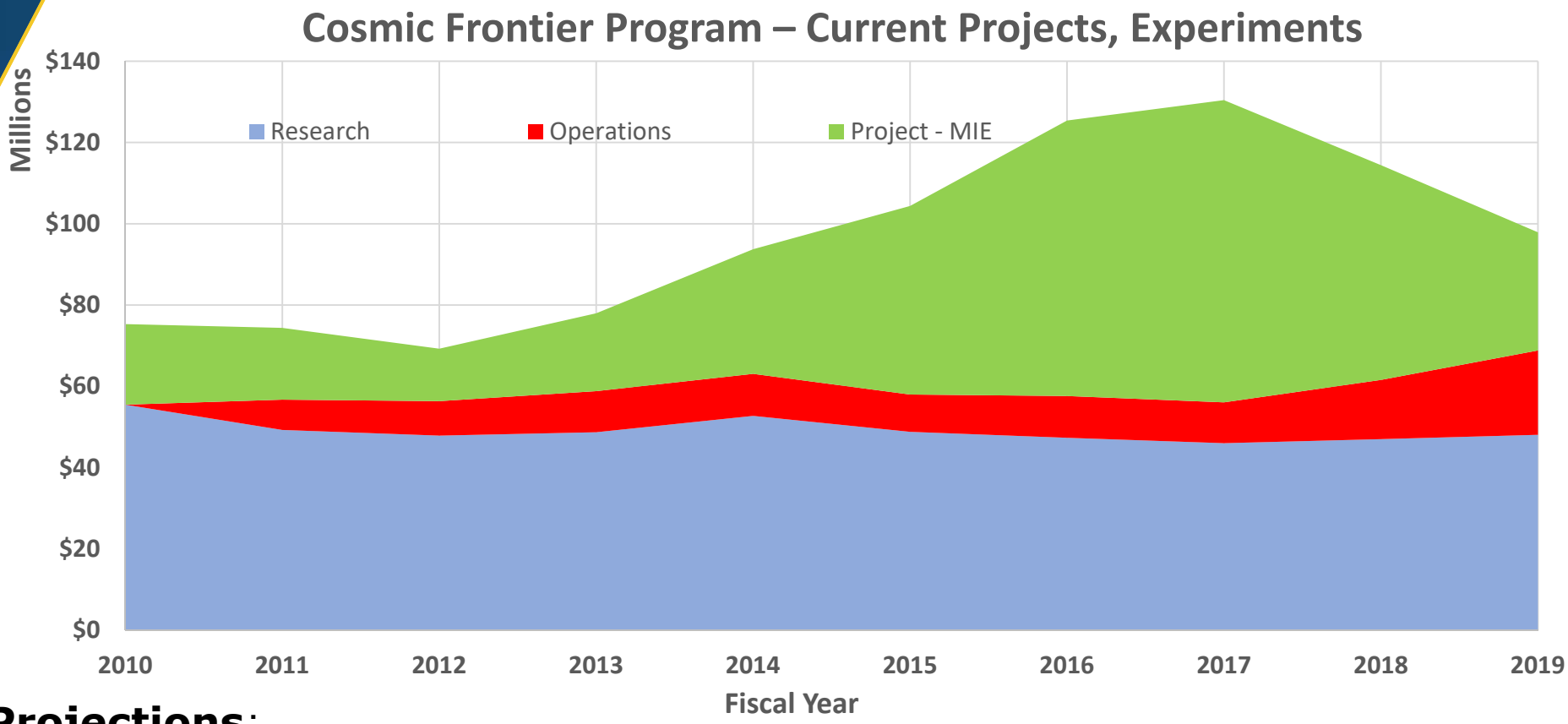
Search for dark matter through direct detection experiments over a wide mass range (in partnership with NSF-PHY)

- High- and low-mass WIMP sensitivity: *LZ* and *SuperCDMS-SNOLAB*, in fab
- Axion (ultralow mass) experiment: *ADMX-G2* in operation

Explore the unknown, e.g. through high energy particles from dark matter annihilations in cores of galaxies (in partnership with NSF, NASA)

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

Cosmic Frontier Budget History (FY10-19)



Projections:

- As the current Projects complete, estimated costs for Experimental Operations ramps up to ~ $55M to $60M by FY2024; levels to ~ $40M by FY2030.
- Future opportunities: Compelling Cosmic Frontier Projects will be considered and supported within available overall HEP Project funds.

Cosmic Frontier – Partnerships, Coordination, Planning

NSF and NASA partnerships on most experiments and projects

DOE-HEP, NSF-AST, -PHY, -OPP

- Full HEP Office has meetings about 2 times/year w/NSF
- Regular Joint Oversight Group (JOG) or Joint Coordination Group (JCG) meetings and close coordination of planning/issues for particular projects or experiments.
- Invited to each other's reviews, program planning, meetings.

DOE-HEP & NASA - Meetings and coordination as needed.

Three Agency Group (TAG) – DOE, NSF, NASA coordination on LSST, Euclid, WFIRST, +

International partners or contributions on most experiments and projects; some have private contributions

-- International Resource Committees support coordination of needs & resources (FGST, LSST-DESC)

International coordination group

- Astro-Particle International Forum (APIF) – Agency-level

Cosmic Frontier – Future Planning

Dark Energy

Cosmic Visions Dark Energy group -- Future directions to investigate optimizing science in DESI/LSST era and/or follow-on projects

- Community workshops held in 2016 at UChicago; in 2017 at LBNL
- White paper on small "enhance" efforts in Jan 2018 arXiv:1802.07216;
- Proposals to Astro2020

CMB (see CMB-S4 planning slides)

AAAC subpanel → Collaboration and pre-Project Design Group, Interim Integrated Project Office; Proposal to Astro2020

Dark Matter direct detection New Initiatives

Process to respond to recent theoretical and technology developments, and to P5 recommendations for a broad dark matter search program and need to include small projects

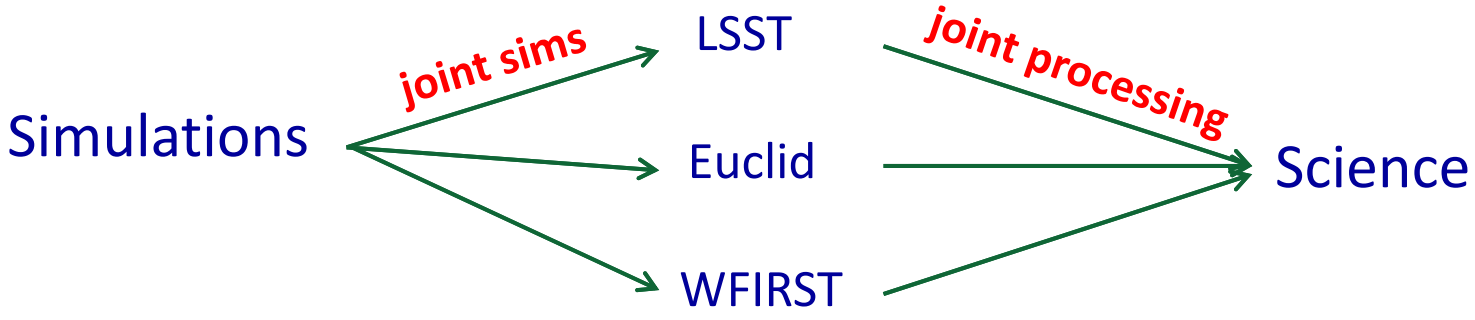
Tri-Agency Group

DOE/NASA/NSF-AST meetings on **Euclid, LSST, WFIRST** coordination

- Agency program managers, +Project Leads, +coordinated project task forces

Task forces:

- Joint Data Processing task force annual report March 2019
- Joint Cosmological Simulations task force report December 2018
  - Submitting Astro2020 APC white paper
- Investigating funding mechanisms to support these important efforts - since they're not part of the project scope.



Astro2020 Dark Energy Projects

Dark Energy projects with HEP community interest for Astro2020

- Massively multiobject spectroscopy – 3D mapping the cosmos
  - Great synergy in LSST followup (southern sky)
  - Pushing to high redshift, large volumes
  - Implementations: 6.5m **MegaMapper**, 11.4m **SpecTel**, extending existing projects (DESI+, DESI-South, LSST spectroscopy)
  - Includes technology R&D: Germanium CCD (1.4um), Dense fiber positioners
- Exascale Cosmological Simulations
  - Joint (interagency) projects input, joint science output
  - Expanding the nonlinear structure frontier, pushing to smaller scales
- 21 cm Cosmology
  - BMX testbed, Packed Ultra-wideband Mapping Array (**PUMA**); Planning unique DOE role & bringing Lab capability
- **CMB-S4** – of great interest to dark energy community
  - Many cross-cutting science topics

Cosmic Microwave Background in HEP

Gain insight into **inflationary epoch** at the beginning of the universe, **dark energy, neutrino properties and new physics** by studying oldest visible light. Data is also of interest to wider astronomical community.


South Pole Telescope (SPT) and BICEP/Keck Array

Current Experiments:

- *SPT-3G* – HEP provided support for major upgrade of the camera to greatly increase sensitivity; operations started Feb 2017 (NSF-led)
- HEP supports advanced detector and readout technology at national labs and universities and research efforts on many experiments. DOE/NERSC computing efforts making major contributions to many ground-based experiments & Planck.

CMB-S4: Community-based Collaboration brought together ground based community to plan future

- Notional array of several telescopes in Chile & South Pole with ~ 0.5 M detectors
- Needs scale-up of detector fabrication, testing, and readout

***CMB-S4 Collaboration* Science, Technology Books:**

https://arxiv.org/abs/1610.02743 ; https://arxiv.org/abs/1706.02464

CMB-S4 – P5 Recommendation

2014:

- P5 recommended HEP participation with NSF in CMB-S4, starting in middle of P5 decade.
- CMB science is a priority in all funding scenarios; Very significant HEP community interest

Project/Activity	Scenario A	Scenario B	Scenario C	Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	Technique (Frontier)
Medium Projects									
LSST	Y	Y	Y		✓		✓		C
DM G2	Y	Y	Y			✓			C
Small Projects Portfolio	Y	Y	Y		✓	✓	✓	✓	All
Accelerator R&D and Test Facilities	Y, reduced	Y, some reductions with redirection to PIP-II development	Y, enhanced	✓	✓	✓		✓	E,I
CMB-S4	Y	Y	Y		✓		✓		C
DM G3	Y, reduced	Y	Y			✓			C
PINGU	Further development of concept encouraged				✓	✓			C
ORKA	N	N	N					✓	I
MAP	N	N	N	✓	✓	✓		✓	E,I
CHIPS	N	N	N		✓				I
LAr1	N	N	N		✓				I

- CMB-S4 is the last remaining project recommended by P5 for HEP to now implement
- Planned as the HEP flagship Cosmic Frontier fabrication project in 2020s

CMB-S4 Progress to date

Following P5:

- HEP labs and community ramped up efforts on technology development and concept planning to align with P5.
- HEP moved forward in planning for CMB-S4
- HEP coordinating planning with NSF-AST/OPP/PHY

2016:

- Science collaboration established, spokespersons elected
- DOE & NSF charged AAAC subpanel: CMB-S4 Concept Definition Taskforce (CDT)

2017:

- CDT report provided science goals, initial strawperson concept design, cost, and schedule (Oct)

2018:

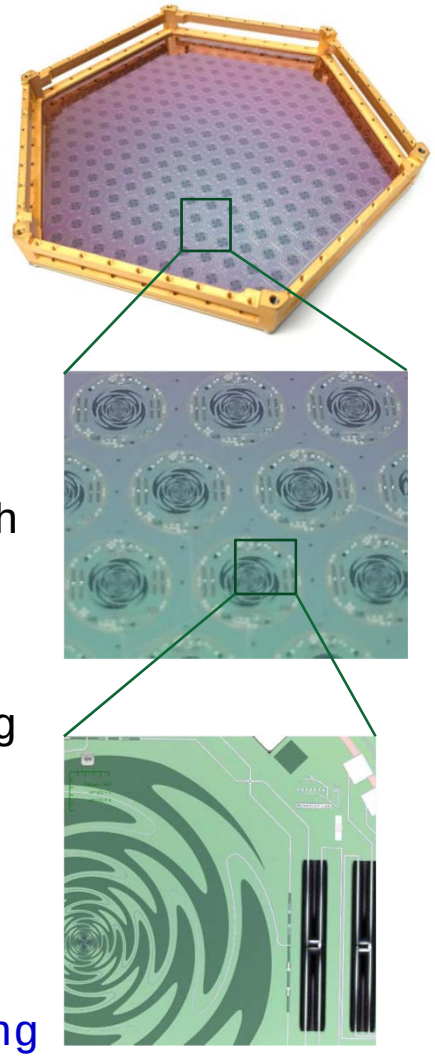
- Following CDT, pre Project Design Group (pPDG) established by DOE labs
  - Focus on project development and coordination, and getting to CD1
- CMB-S4 collaboration & pPDG working together to develop concept for Decadal Survey and to make progress on technology & concept design.

CMB-S4 Project and Collaboration Planning Status - 2019

- CMB-S4 project continuing preparation

Formed Integrated Project Office (IPO) – under Jim Yeck

  - Refine cost, plan for detectors, concept & layout of scope
  - Detector fabrication & readout issues at the forefront of R&D/planning - No new technology, but scale-up needed.



- CMB-S4 collaboration progress
  - Focusing on July submission(s) to NAS Astro2020 decadal survey

- IPO and Collaboration are working together to plan concept with technically driven schedule and for submission of plans to Astro2020, agencies, etc.

- Interagency (NSF-DOE) Joint Coordination Group (JCG) meeting bi-weekly to share information, monitor, and review.
  - HEP, NSF-AST, NSF-OPP, NSF-PHY

- **At DOE:**
  - CD0 awaiting decision by DOE/SC Leadership
  - HEP working w/IPO & funding near term R&D, concept planning

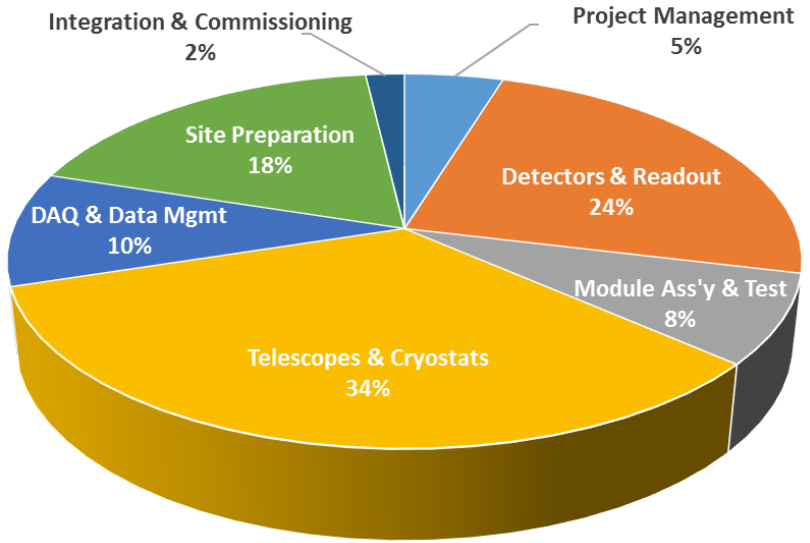
CMB-S4 Planning - Current state of the project

- Integrated Project Office (IPO) started with 2017 CDT design
  - Focused on using existing technologies w/scale-up
- Continued development in last few years
  - People with experience at South Pole, Chile, Detector development, Project Management, etc.
- Concept reviewed and scrubbed – continually
- Agencies & IPO working to synchronize & align processes.

Current cost estimate

- $560M w/35% contingency
- Scope distribution TBD; will depend on capabilities in each agency's community etc.

HEP is excited about moving forward on CMB-S4!

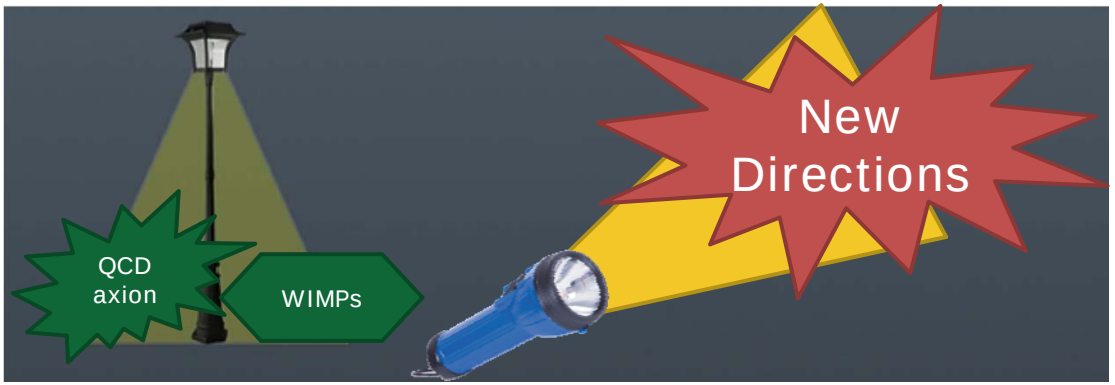


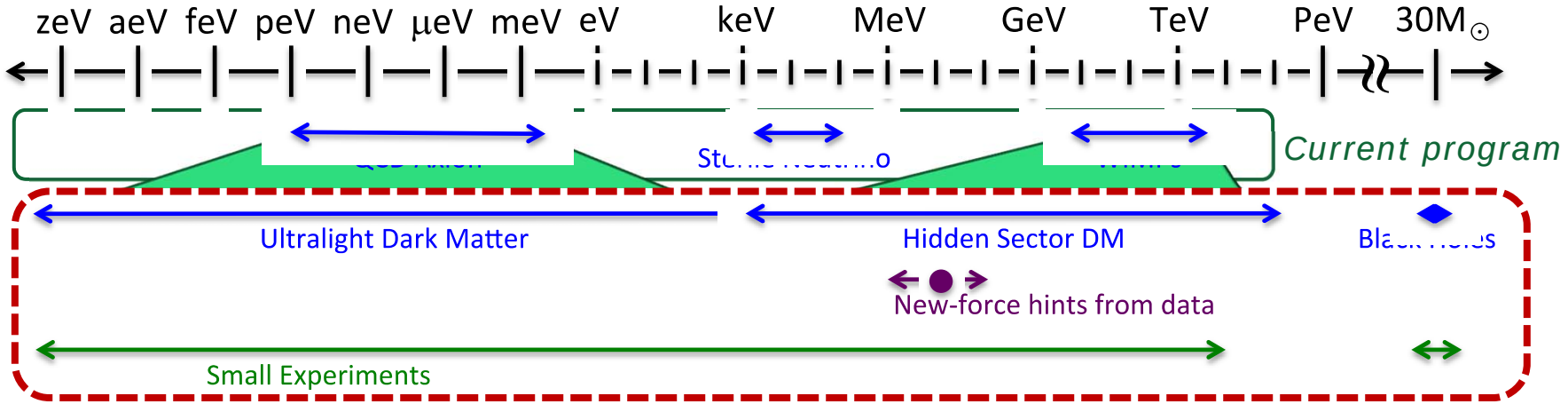
New Opportunities in Dark Matter Science

Recent **theoretical studies** highlight well-motivated frameworks with sharp, predictive targets from cosmology, fundamental physics, and anomalies in data

- WIMPs, QCD axions central ideas that will be studied with current & planned experiments
- Generalized theories have led to new paradigms that small experiments could address

Technological advances allow new experimental methods





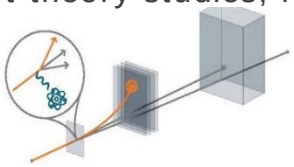
New Directions in Dark Matter

New Initiatives in Dark Matter

P5 recommended the search for dark matter particles as a high priority & program should include small projects. The initiative follows recent theoretical advances plus recent development of new technologies

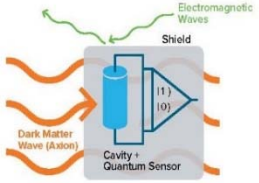
- March 2017: Community-led workshop collected new ideas, *https://arxiv.org/abs/1707.04591*
- January 2019: Basic Research Needs study (workshop Oct.2018): https://science.osti.gov/hep/Community-Resources/Reports
  - Assessed the science landscape for dark matter particle searches and identify which high impact science areas would be suitable to be pursued with small projects in the HEP program, using DOE lab infrastructure & capabilities → Identified 3 priority Physics Research Directions (PRD)
  - Develop the case(s) for additional HEP funding to support such new initiatives in the future.
- 2019: Review & fund proposals to develop small project designs and near term technology development.
- 2020+: Select concept(s) for fabrication (possibly in stages)
- Continue to support theory studies, research efforts, tech. R&D as necessary and appropriate

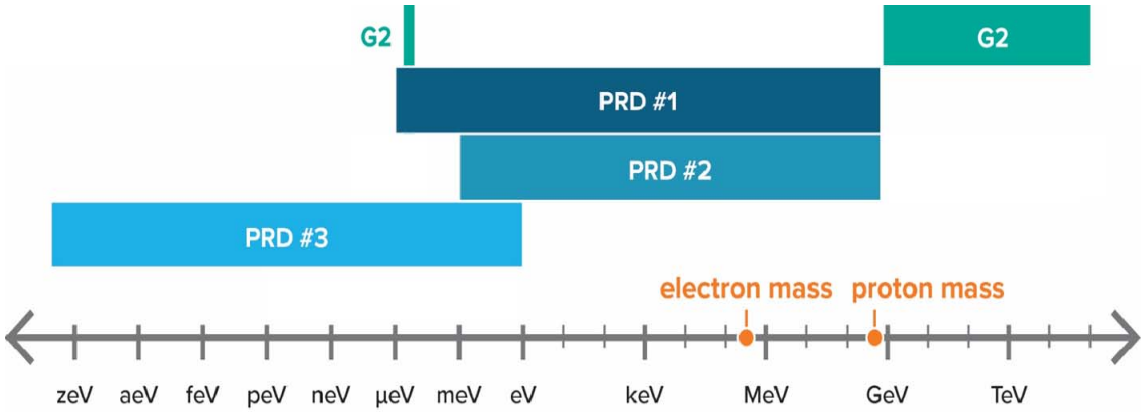
PRD 1
Create and Detect DM at Accelerators.



PRD 2
Detect Galactic DM Underground.

PRD 3
Detect Wave DM in the Laboratory





HEP Computing Challenges

- P5 recommended a program of challenging scientific experiments that have equally challenging computing needs
  - As an example, in FY2019 year NERSC requests were up 50% over 2018
  - ASCR's Exascale Computing project will play an important role in satisfying this demand, but much of HEP code is not ready for Exascale
- We have charged the Center for Computational Excellence (CCE) to be a matchmaker between HEP and ASCR experts to look at several example codes

- The HEP Computing Infrastructure Working Group was formed in 2017 to develop a strategy for meeting the computing needs
  - **See talk at HEPAP, 5/31/19**
- Successfully addressing computing challenges will require continued effort from the community and coordination with ASCR and NSF's Institute for Research and Innovation in Software for High-Energy Physics (IRIS-HEP) which is tackling similar issues from the university perspective

Other HEP Efforts related to Cosmic Frontier

Theory program

- Vibrant Theory Program supporting all areas including Cosmic Frontier; QIS actively growing area; Support for Theory centers and groups at several universities and labs.

Advanced Detector Development program

- Active R&D developing next generation detectors, including CCDs, TES superconducting bolometers, MKIDs, readout electronics, optics. Key elements for DES, LSST, CMB-S4. Important impact on X-ray detector, medical detectors.

Computational HEP program

- Coordinates DOE Supercomputer allocations via various ASCR and DOE Competitions
  - Cosmic Simulations, Emulators, Data Analysis
  - Computational HEP, SCIDAC – focused computational challenges
  - HEP Center for Computational Excellence
- High Performance Computing – Comp HEP & ASCR coordination & partnerships on some efforts, including Cosmic Simulation and Data analytics
- Manages allocations on NERSC facility for HEP Cosmic Frontier Simulations and Experiments

Quantum Information Science (QIS)

- Powerful new windows to accomplish HEP mission & advance QIS Foundational theory, computing, sensors (enable dark matter searches), technology, experiments; with DOD, NIST
- FY2020 Budget Request includes funds in HEP, BES (Basic Energy Sciences), and ASCR (Advanced Scientific Computing Research) for at least one jointly-supported and multidisciplinary QIS Center, as per the National Quantum Initiative Act (Dec. 2018)

Closing Remarks

- Excellent science results continue to be produced from our operating experiments!
- Community continues to be unified in support of P5 strategy
- 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 community continues to perform well on delivering projects, a foundation of the long-term strategy
- **Significant planning for the future – looking forward to Astro2020 for exciting opportunities & directions!**

U.S. DEPARTMENT OF
ENERGY

Office of
Science

History of DOE and NSF Coordination

Joint FACA panels

HEPAP – jointly advises DOE, NSF

AAAC – congressionally mandated FACA panel advising DOE, NSF, NASA

Projects with NSF/PHY

NSF funded community participation:

- Long history with FNAL on Tevatron and neutrino experiments
- Long history with SLAC on B-physics

NSF/DOE partner on LHC projects (MREFC for CMS and Atlas, still in progress)

- MREFC process

NSF/DOE partner on fabrication, ops, and research efforts in Cosmic Frontier:

- Pierre Auger (Cosmic ray), VERITAS, HAWC (Gamma rays), SuperCDMS (dark matter)

Projects with NST/AST:

NSF/DOE partner on fabrication, ops, and research efforts in Cosmic Frontier:

- DES, eBOSS, DESI, LSST; Dark Energy is DOE's science interest; surveys are of interest by wider astronomy community
- HEP research contributions to BICEP, PolarBear

Projects with OPP (polar):

CMB experiments SPTpol, SPT-3G

Across divisions

- NERSC computing for CMB experiments

All projects above have DOE/NSF Joint Oversight Groups (JOG) or Joint Coordination Groups (JCG). Many also have MOU's.

Astro2010 "New Worlds New Horizons" Report (August 2010) → Guidance to HEP

- Highest priority large space based project to start development: WFIRST
- Highest priority large ground based project to start development: LSST

Specific Recommendations to DOE :

A program fitted under the DOE budget doubling scenario means that roughly $40 million per year would be available by the end of the decade, after due allowance for an underground dark matter detection program as recommended by HEPAP-PASAG. This amount will be sufficient to allow participation in LSST, WFIRST, and ACTA as well as some of the smaller astrophysical initiatives recommended by HEPAP-PASAG under Scenario C. In addition, a $2 million per year Theory and Computation Networks program is recommended.

However, if the budget is lower, the HEPAP-PASAG recommended investment in dark matter detection will be reduced and the available funds will decrease to $15 million under Scenario A. DOE is a minor partner in the two largest projects that the survey committee has recommended—LSST and WFIRST—and it is likely that the phasing will involve choices by NSF and NASA, respectively. Other considerations being equal, the recommended priority order is to collaborate first on LSST because DOE will have a larger fractional participation in that project, and its technical contribution is thought to be relatively more critical. ACTA, Theory and Computation Networks, and the smaller initiatives have lower priority.

Summary: **In lower scenarios, DOE should participate in LSST ahead of WFIRST since DOE is making a larger relative $ contribution and its technical role is thought to be relatively more critical.** DOE may have opportunities to contribute to mid-scale ground-based projects with NSF (ground priority #2), and should contribute to ACTA with NSF and to the Theory & Computation Network (TCN). These smaller programs and ACTA have lower priority than LSST & WFIRST.

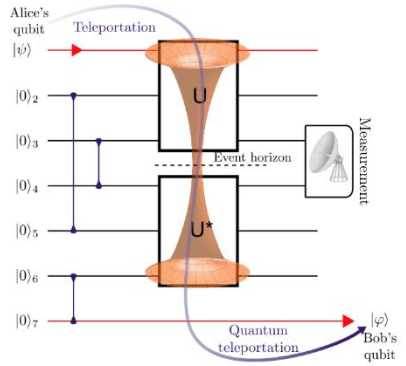
Quantum Information Science Enabled Discovery (QuantISED) for High Energy Physics

Powerful new windows to accomplish HEP mission & advance QIST Foundational theory, computing, sensors, technology, experiments -- Partnerships with DOD, NIST

Examples:

- 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… See https://www.nature.com/articles/s41586-019-0952-6
- Accelerator cavities adopted for quantum regime: Record high photon lifetimes achieved at Fermilab in 2017-2018 → seconds of coherence after targeted treatment
- Sensor studies – many will enable dark matter searches over a wide mass range.

→FY2020 Budget Request includes funds in HEP, BES (Basic Energy Sciences), and ASCR (Advanced Scientific Computing Research) for at least one jointly-supported and multidisciplinary QIS Center, as per the National Quantum Initiative Act signed into law in December 2018



Cosmic Frontier Budget History (FY10-19)

Funding in $K	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
Research	55,487	49,252	47,843	48,681	52,712	48,779	47,327	45,990	47,008	48,057
Experimental Operations	0	7,460	8,505	10,111	10,357	9,185	10,274	10,055	14,570	20,748
Projects	19,828	17,652	12,891	19,159	30,660	46,403	67,780	74,375	52,835	29,090
TOTAL	**75,315**	**74,364**	**69,239**	**77,951**	**93,729**	**104,367**	**125,381**	**130,420**	**114,413**	**97,895**

Funding types:

- Research: primarily supports scientists participating in all aspects of an experiment (design, fabrication, operations, data planning & analysis)
- Experimental/Facility Operations and Projects: primarily supports technical personnel, materials, supplies, procurements, consumables

Cosmic Frontier Budget History (FY10-19) – Major Item of Equipment (MIE) Projects

Cosmic Frontier MIE Projects ($K)		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dark Matter	SuperCDMS-Soudan	1,500	0	0	0	0	0	0	0	0	0
	SuperCDMS-SNOLAB	0	0	0	0	0	2,250	3,000	3,400	7,400	2,550
	LZ	0	0	0	0	900	3,050	10,500	12,500	14,100	14,450
Dark Energy	DES	8,610	4,000	0	0	0	0	0	0	0	0
	DESI	0	0	0	0	0	3,878	10,300	12,800	20,000	9,350
	LSST	0	1,900	5,500	8,000	22,000	35,000	40,800	45,000	9,800	0
Gamma-ray	HAWC	0	0	1,500	1,500	0	0	0	0	0	0
	TOTAL	10,110	5,900	7,000	9,500	22,900	44,178	64,600	73,700	51,300	26,350

Dark Energy – Current Program

Precision measurements to differentiate between cosmological constant or new fields, or modification to General Relativity

Staged, complementary suite of imaging and spectroscopic surveys to determine its nature (in partnership with NSF-AST)

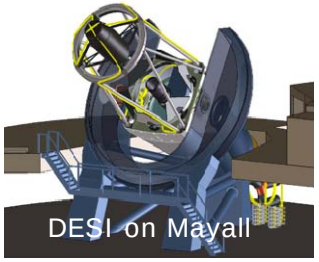
Completed Data-Taking:

– *eBOSS* (spectroscopic) started in 2015, ended Feb 2019
– *DES* (imaging) started 5-year survey in late FY13, ended Jan 2019

Projects in Fabrication phase:

– *Large Synoptic Survey Telescope* (LSST, Stage 4 imaging)

– *Dark Energy Spectroscopic Instrument* (DESI, Stage 4 spectroscopic)

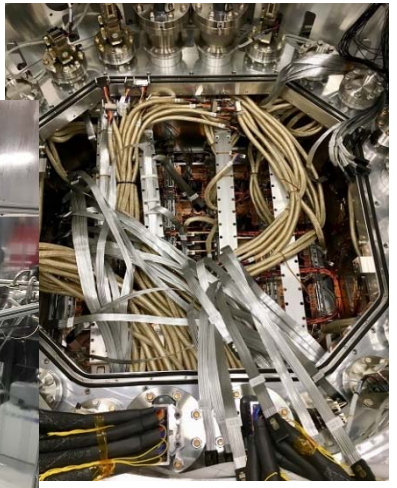


Large Synoptic Survey Telescope (LSST) - Status

DOE-HEP & NSF-AST partnership:

- NSF/DOE Facility Operations review Dec 2017
- NSF/DOE Project Status & Commissioning review Aug.2019

View of top of cryostat during installation of optical translation modules



Funding: HEP MIE LSST Camera project funding completed in FY18; Integration & Commissioning as part of overall LSST project will be funded with non-MIE funds.

Status:

- FY18 Commissioning support started; funded on Ops budget); FY19 Facility Ops support started
- LSSTcam Project in fabrication (92% complete); Deliverables complete 2/21; CD-4 3/22
- **Sensors:** ITL and e2v have completed and delivered all sensors per their contracts.
- **Science Rafts:** 5 ready for installation; starts in June
- **Commissioning Camera:** final testing underway; shipping June 2019

Raft module in construction at BNL

Dark Energy Science Collaboration (DESC):

- Set up to carry out planning and eventual data analysis for DOE HEP science goals
- Operations Plan review held May 2018; planning continues
- Data Challenge 2 Run 2.0 production underway on Theta at ANL, Cori at NERSC, and CC-IN2P3
- CosmoDC2 input catalog available for catalog studies

Dark Energy Spectroscopic Instrument (DESI) - Status

DOE-led experiment, mounted and operated on the NSF's Mayall telescope at Kitt Peak.

- Spectroscopic Survey – for Baryon Acoustic Oscillation and other studies
- HEP has MOU w/NSF-AST to "lease" the Mayall telescope
- HEP MIE project funding completes in FY19
- Full support for Mayall dark energy ops starting FY19

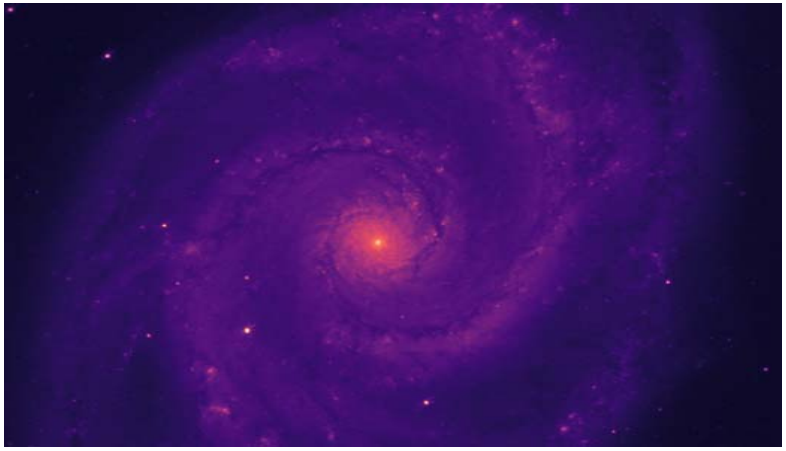
Status:

- Project in fabrication (88% complete); Deliverables complete 2/20; CD-4 9/21
  - Project status & Operations plan review, Fall 2018
  - Installation & Commissioning phase has started!
  - Full dark energy survey operations starting FY20
  - Recent: 6th spectrograph completed & tested; 10th spectrograph assembly completed

Targeting: Legacy Surveys – completed March 2019
http://legacysurvey.org/ covering 15000 deg^2 in g,r,z + 4 IR bands

- Mayall z Band Legacy Survey (MzLS), Beijing-Arizona Sky Survey (BASS) on Bok, DECam Legacy Survey (DECaLS) on Blanco
- **Data Release 8 April 2019**

Mock Focal plane installation at Mayall



First light on corrector lenses (on 4/1/19; Whirlpool galaxy as seen by commissioning instrument

Dark Matter – Current Program

➔Direct Detection (primary method)

Staged suite of complementary direct detection experiments with multiple technologies to search for dark matter particles

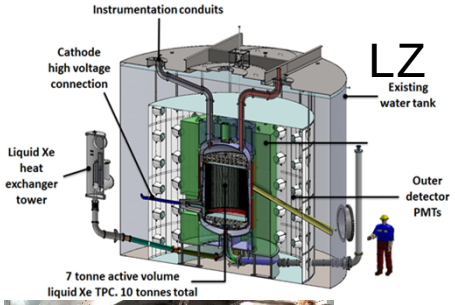
- High- and low-mass WIMPs; Axion (very low mass) search

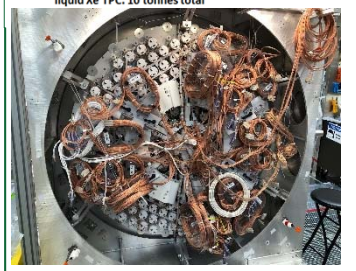
Operating: ADMX-G2 axion search at UWash (HEP)

Projects in Fabrication phase: Dark Matter Generation 2

LZ at Homestake Mine in South Dakota (HEP)

- WIMP search through dual phase liquid Xe; ~10-1000 GeV mass range
- Project in fabrication (86% complete); Deliverables complete 7/20; CD-4 3/22
- Operations planning and funding started
- Operations Plan Review March 2019

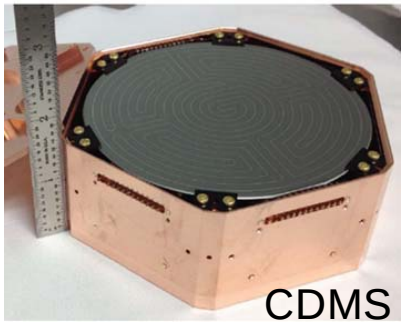




LZ PMT array May.2019

SuperCDMS-SNOLab in Canada (HEP+NSF-PHY partnership)

- WIMP search using cryogenic solid-state crystals; ~1-10 GeV mass
- Project in fabrication (76% complete); Deliverables complete 2020; CD-4 2021
- Operations planning and funding started; Pre-operations 2019
- Operations Plan Review June 2019



➔Indirect Detection searches

Gamma-ray & Cosmic ray experiments operating: Fermi, HAWC, AMS

Cosmic Microwave Background

Gain insight into **inflationary epoch**, **dark energy, neutrino properties, searches for relic particles, and new physics** by studying the oldest visible light.


South Pole Telescope (SPT) and BICEP/Keck Array

Operating Experiments:

SPT-3G *(NSF-led, with HEP participation)* – HEP provided support for major upgrade of the camera to greatly increase sensitivity; operations started Feb 2017 (NSF-led)

HEP Efforts:

- Research efforts on many experiments – ground, Planck
- DOE/NERSC computing making major contributions to many ground-based experiments & Planck.
- Following the 2014 P5 recommendation, advanced detector and readout technology R&D and concept planning ramped up in preparation for CMB-S4.

Exploring the Unknown

Use ground-based arrays, space telescopes, and an experiment on the International Space Station to explore the unknown, e.g. indirect searches for dark matter

Many significant inter-agency & international partnerships

Operations continuing:

Fermi/GLAST (w/NASA)

- HEP is supporting the Instrument Science Ops Center at SLAC;
- In coordination with NASA, HEP is planning to continue support of critical efforts at SLAC if operations > 10 years

AMS (w/NASA)

- Operations continuing on ISS

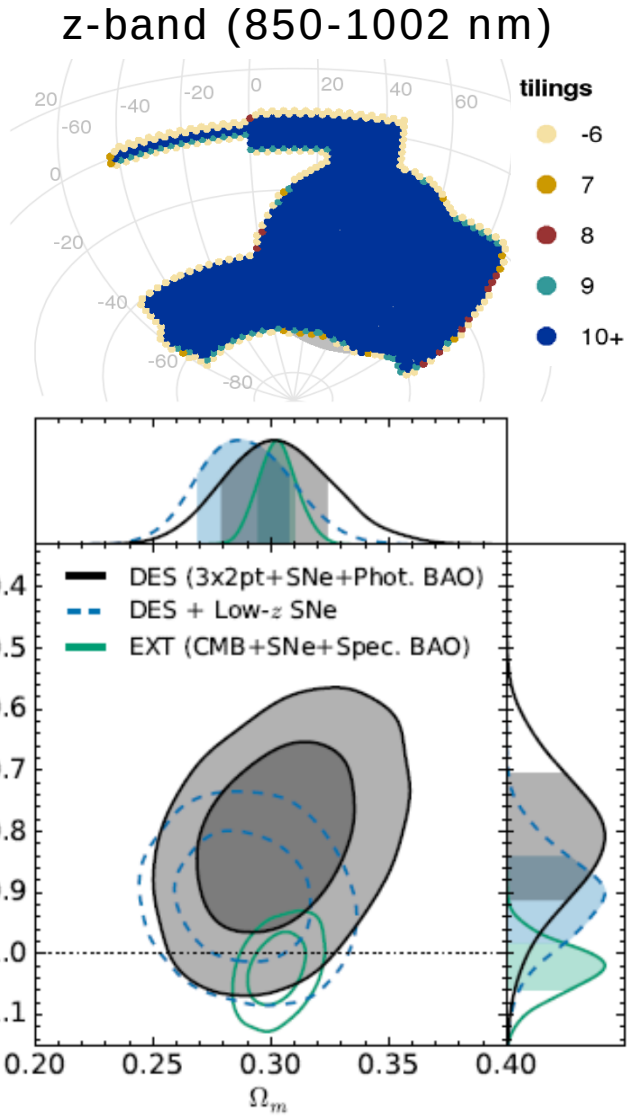
HAWC (w/NSF)

- 5 year operations started early 2015

Lower program priority for new experiments

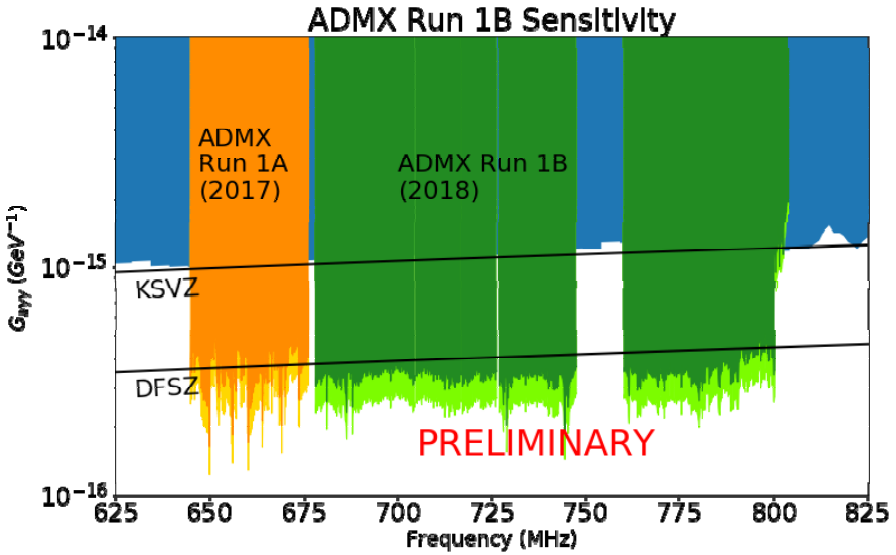
Dark Energy Survey

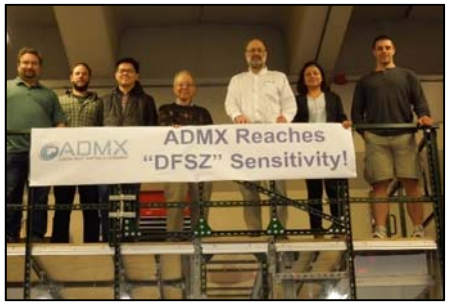
- **DOE-HEP partnership with NSF-AST**
- Completed Observations Jan 9, 2019
  - Year Six included observations and processing of “Deep Fields” to 10x DES wide-field depth
  - Will reduce weak lensing systematics through improved calibration of photometric redshift and characterization of blending of neighboring galaxies in DES wide-field data
- Many cosmology results, including:
  - Combined analysis of DES-Y3 supernovae (SNe), DES-Y1 photometric baryonic acoustic oscillation (BAO), and DES-Y1 weak lensing + galaxy clustering (3x2pt) **detects Dark Energy at 4σ from DES alone**
    - T. Abbott et al. 2019 (PRL)
- Now concentrating on cosmology through Y3 and on producing Y6 data products for analysis; Y6 cosmology to follow

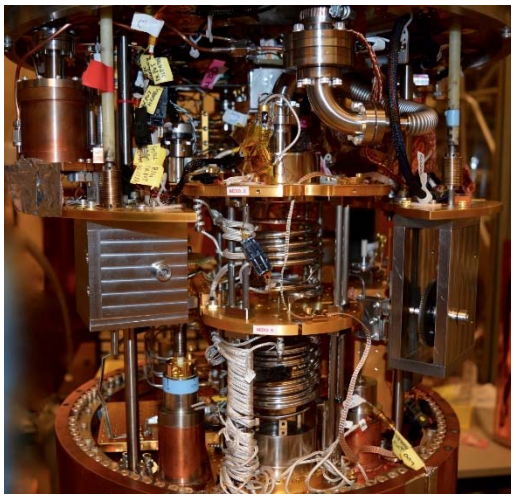


ADMX-G2

- 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





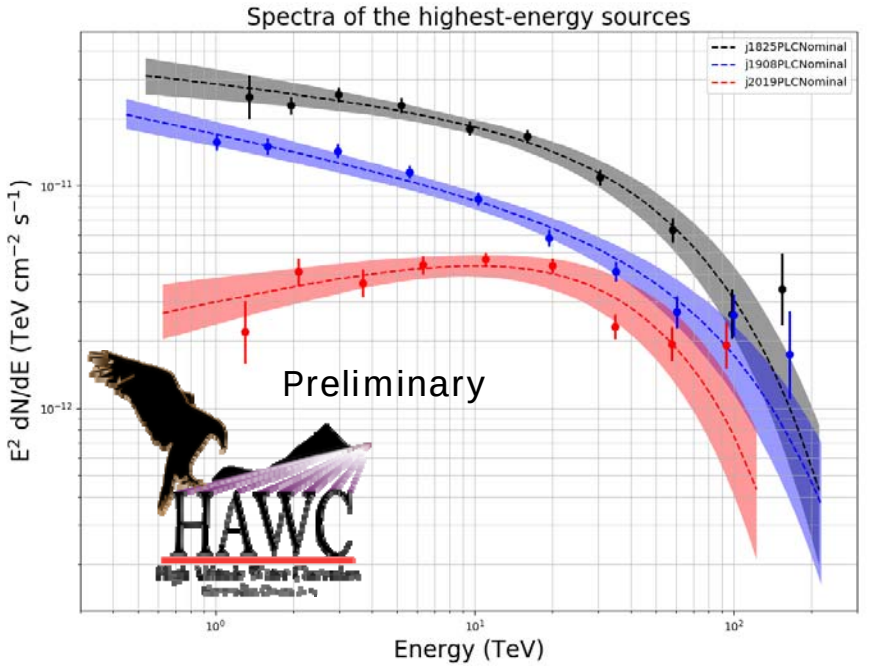


[Right] ADMX experiment insert showing the RF cavity (bottom), dilution refrigerator (above cavity), and frequency-tuning mechanism (left).

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

High Altitude Water Cherenkov (HAWC) Experiment

- HAWC gamma/cosmic-ray observatory located on the Sierra Negra mountain in Mexico
  - 5 year ops. started early 2015
  - Partnership with NSF-PHY, Mexico
- New result: Testing Lorenz Invariance with Highest Energy gamma rays
  - If Lorenz Invariance is violated, then gamma-rays can decay into e^+e^- pairs
  - HAWC's proof of the existence of gamma-rays >100 TeV provides more than an order of magnitude better constraints on superluminal Lorentz Invariance



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/

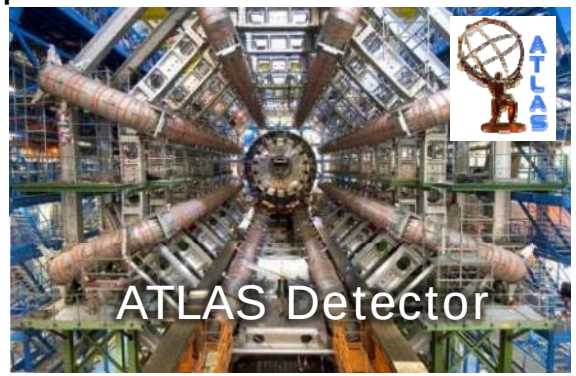
Community Communications Efforts

- Community groups and Steve Ritz working to update content on usparticlephysics.org
  - Coordinated effort of DPF Executive Committee, Fermilab UEC, SLUO, and USLUA
    - With help from AAAS S&T Policy Fellow Andrea Peterson
  - New brochure will describe collaborative nature of particle physics
    - Universities, national laboratories, private industry, international partners
- Community members also working on additional material for individual science drivers
  - Cosmic Acceleration
  - Dark Matter
  - Neutrinos

Energy Frontier: LHC, ATLAS, and CMS

Centerpiece: CERN Large Hadron Collider w/ATLAS, CMS detectors

- Only means to produce and study the Higgs boson – discovered 2012
- Searches for direct production of dark matter particles – set constraints on supersymmetric dark matter candidates, explores Higgs boson as "messenger" between the standard model particles and dark matter
- Search for new physics via direct production of new particles & precision measurements of known particles



P5 recommended: HEP highest-priority large project in the near term

- High-luminosity LHC (HL-LHC) upgrades in 2024-2026 will extend discovery reach; 10x collision rate to explore new physics
- HL-LHC Accelerator, ATLAS Detector, CMS Detector Upgrades
- U.S.-CERN bilateral Agreement, signed in 2015

Intensity Frontier Program

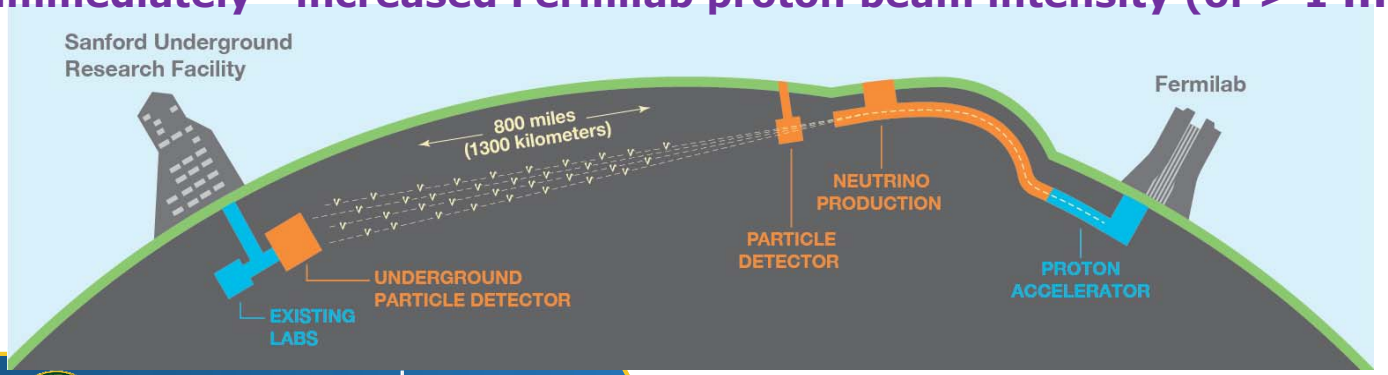
Intensity Frontier experiments address the P5 Science Drivers through intense beams and sensitive detectors

- Exploring the unknown through precision measurements:
  - Muon g-2, Mu2e, Belle II, K0TO
- Search for Heavy Photons - dark matter candidates
- Pursuing the physics associated with neutrino mass:
  - Suite of operating experiments and projects in fabrication at Fermilab (e.g. MicroBooNE, MINERvA, NOvA, ICARUS, short-baseline program)and international (e.g. SuperK, T2K)

P5 recommended HEP highest-priority large project in the longer term

- Long-Baseline Neutrino Facility (LBNF) as the centerpiece of a U.S.-hosted world-leading neutrino program - will produce the world's most intense neutrino beam, send it 800 miles through the earth to the Deep Underground Neutrino Experiment (DUNE), a mile underground at Homestake Mine, S. Dakota. LBNF/DUNE has strong US government & International support.

P5 report recommended the Proton Improvement Plan II (PIP-II) to proceed immediately - increased Fermilab proton beam intensity (of > 1 megawatt) for LBNF



Belle II