U.S. DEPARTMENT OF ENERGY | Office of Science

Department of Energy
Office of High Energy Physics
Cosmic Frontier Report
3rd Dark Matter Berkeley Workshop

Lawrence Berkeley National Laboratory

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Cosmic Frontier Program Managers:

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Outline

- HEP Mission
- Cosmic Frontier Program Overview
- Status of Current Dark Matter Program
- Near Future Possibilities
- HEP Program Planning and Budgets

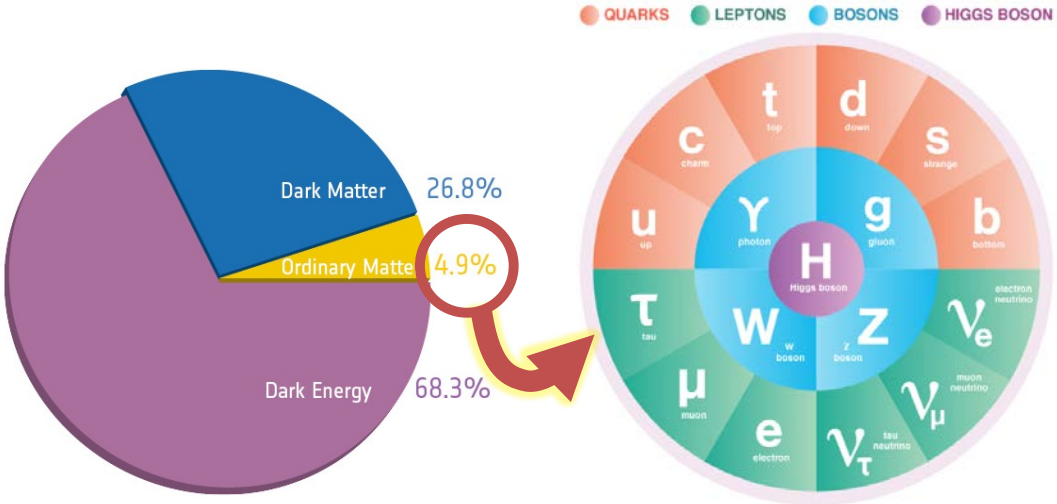
The High Energy Physics Program Mission

…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 Office of High Energy Physics fulfills its mission by:

- Building projects that enable discovery science
- Operating facilities that provide the capability to perform discovery science
- Supporting a research program that produces discovery science



The Science Drivers of Particle Physics

The Particle Physics Project Prioritization Panel (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

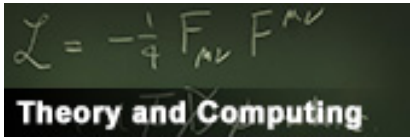
** Since 2011, three of the five science drivers have been lines of inquiry recognized with Nobel Prizes*

HEP Research Subprograms

- **Energy Frontier** researchers accelerate particles to the highest-energies ever made by humanity and collide them to produce and study the fundamental constituents of matter and the architecture of the universe

- **Intensity Frontier** researchers use a combination of intense particle beams and highly sensitive detectors to make extremely precise measurements of particle properties, study rare particle interactions, and search for new physics

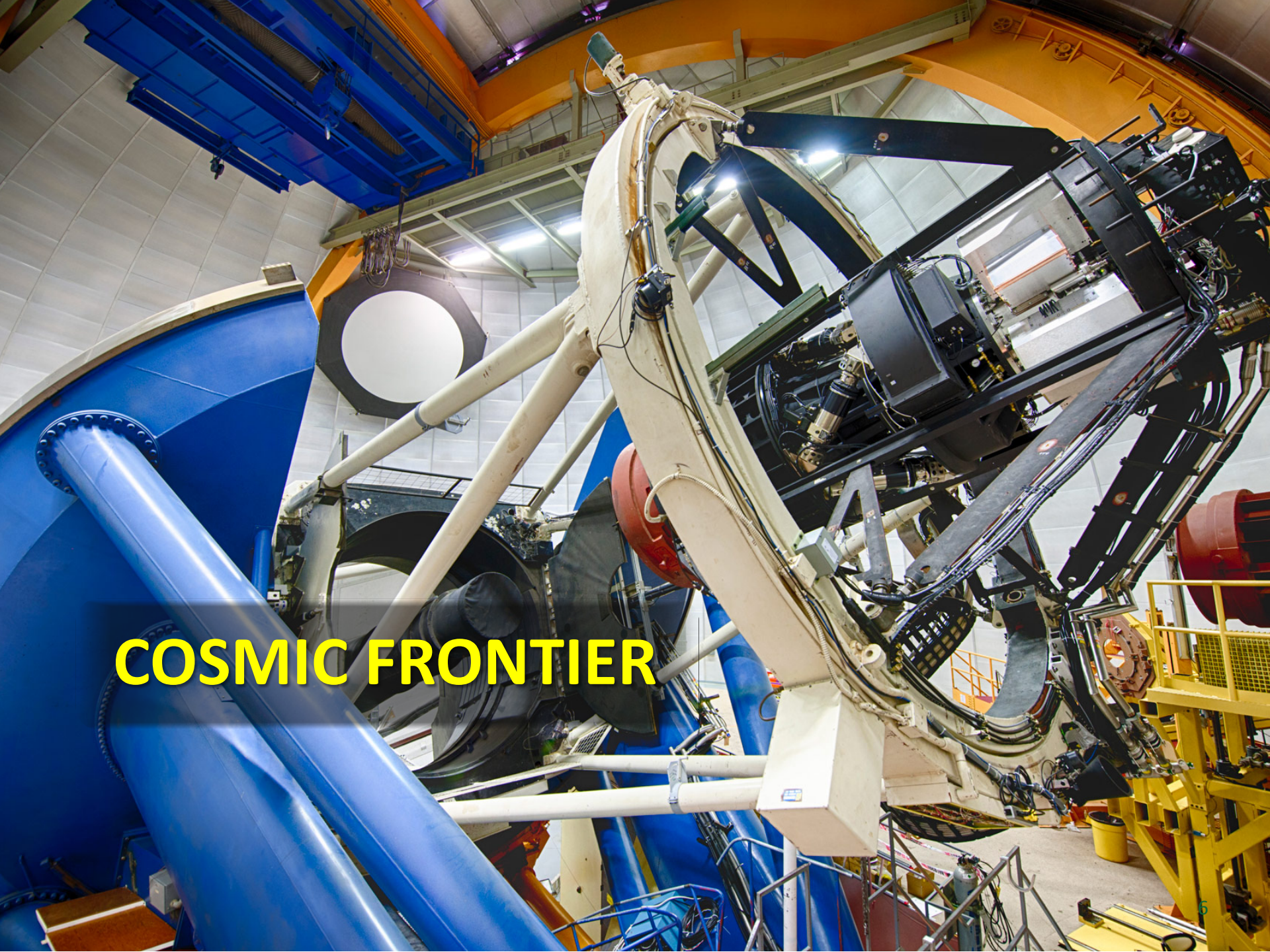
- **Cosmic Frontier** researchers seek to reveal the nature of dark matter and dark energy by using particles from space to explore new phenomena



- **Theoretical and Computational Physics** provide the framework to explain experimental observations and gain a deeper understanding of nature

- **Advanced Technology R&D** fosters fundamental research into particle acceleration and detection techniques and instrumentation

- **Accelerator Stewardship** coordinates with accelerator user communities and industry to develop innovative solutions to critical problems, benefitting the broader user communities and the discovery science


COSMIC FRONTIER

2014 P5 Strategic Plan Recommendations for 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 (DM-G2) 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 Project 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 is in the P5 plan, starting about mid-way through their 10 year plan)
- **Cosmic Rays and Gamma Rays**
  - Invest in Cerenkov Telescope Array (CTA) only if the critical NSF Astronomy funding can be obtained

CTA has a broad science reach that transcends fields, with the dark matter detection capabilities of direct importance to particle physics; Using P5 Criteria, a de-scoped US component should be shared by NSF-AST, NSF-PHY and DOE.

Cosmic Frontier Status

Dark Energy: Staged program of complementary suite of imaging and spectroscopic surveys

- *BOSS* final results out soon; *eBOSS*, *DES* continue operations
- *Large Synoptic Survey Telescope (LSST)* received CD-3 in August 2015
- *Dark Energy Spectroscopic Instrument (DESI)* received CD-3 in June 2016
- Have MOA's with NSF-AST for *LSST* partnership & *DESI* cooperation

Dark Matter (direct detection): Staged program of current and next-generation experiments with multiple technologies

- Completed DOE operations funding for current DM-G1 experiments in FY 2016.
- Progress continues on DM-G2 experiments: *ADMX-G2, LZ, SuperCDMS-SNOLAB*
  - ADMX-G2 infrastructure complete at UW; Science data taking operations started in August 2016.
  - *LZ* & *SuperCDMS-SNOLAB* projects received Congressional "MIE starts" approval in FY 2015
  - *LZ* received CD-2/3B in August 2016;
  - *SuperCDMS-SNOLAB* received CD-1 December 2015

Cosmic Microwave Background (CMB)

- *South Pole Telescope polarization (SPTpol)* continues operations.
- *SPT-3G* begins operations in Feb 2017; partnership with NSF.
- Community planning proceeding for CMB-S4 experiment; AAAC subpanel, CMB-S4 Concept, Definition Task force (CDT), being formed.

Cosmic-ray, Gamma-ray

- *Fermi/GLAST*, *AMS*, and *HAWC* continue operations
  - *HAWC* gamma-ray observatory began full science operations in early 2015
- DOE operations funding completed in FY 2016 for *VERITAS* and *Auger*

Axion Dark-Matter eXperiment (ADMX)

Physics: Direct detection search for particle dark-matter made of axions: These are very low mass (μeV to meV) hypothetical particles, predicted to solve a known issue with QCD.

Description: A strong magnetic field resonantly converts dark-matter halo axions into detectable photons. Detector consists of a cryogenically-cooled microwave cavity in a large superconducting 8 tesla magnet. Microwave photons are detected by an ultra-low-noise SQUID/JPA-based microwave amplifier/receiver.

DOE provides support to develop technology for a broadly sensitive search. Intend as definitive-sensitivity QCD dark matter axion search over broad mass range.

Partnership: Primarily DOE support with contributions from the UK; R&D from Heising-Simons Foundation

Collaboration: 25 scientists from 2 countries. LLNL, FNAL, U. of Washington, U. of Florida, UC Berkeley, NRAO, PNNL, LANL, Sheffield University (UK)

HEP funding:

U. Washington (experiment site), U. Florida, LLNL, FNAL.

Status:

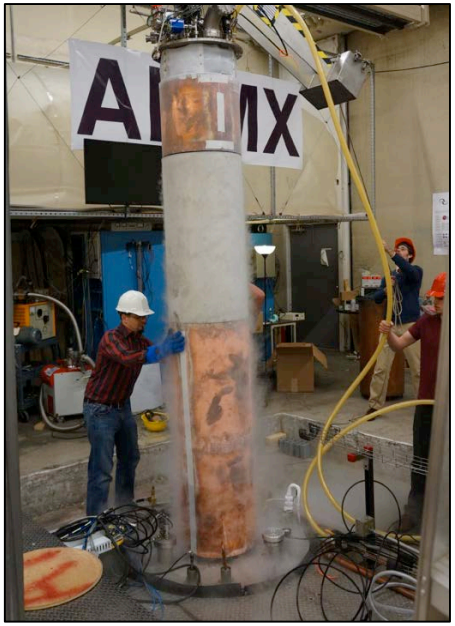
Operates as a phased program with ADMX-2a operations completed in 2015; ADMX-G2 started fabrication at the end of FY14; ADMX-G2 science data taking started in August 2016.

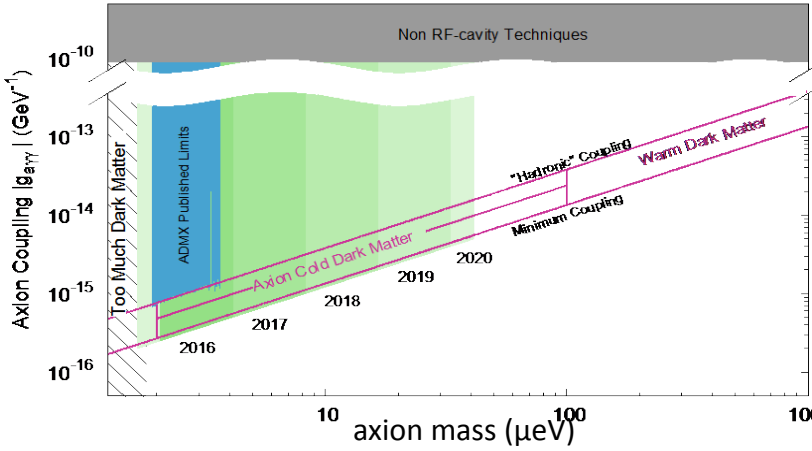
Operations review in Sept. 2016.

Operation management moving to Fermilab.

Recent Highlights:

- Featured in Scientific American (Sep 2015)

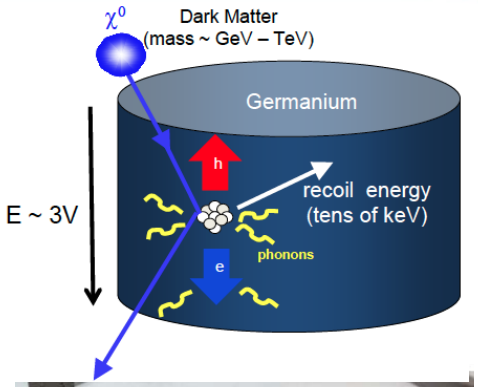


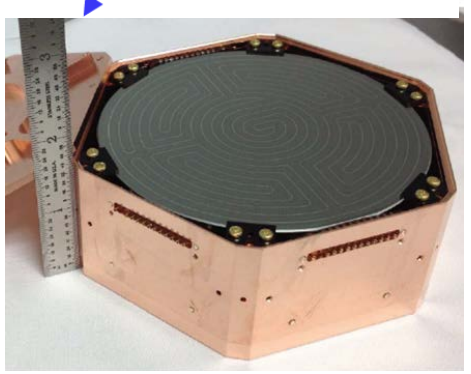


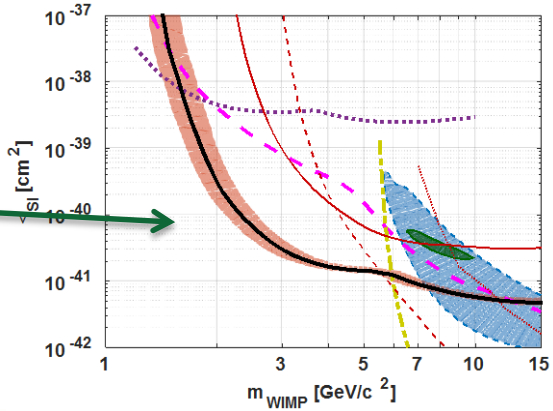
CDMS – Cryogenic Dark Matter Search
SuperCDMS-Soudan → SuperCDMS-SNOLAB

Physics: Direct detection of dark matter particles (WIMPs) using cryogenic solid-state germanium and silicon crystals with sensors that detect ionization and phonon signals. Sensitivity to very small energy depositions allows additional searches for axions and lightly ionizing particles.
Description: SuperCDMS Soudan G1 WIMP experiment 2010-2015; SuperCDMS SNOLAB G2 low-mass WIMP experiment 2016-2025.
Partnership: DOE and NSF, contributions from Canada (CFI, NSERC).
Collaboration: ~90 scientists from 13 US universities & 3 labs, plus institutions from Canada, India, UK and Spain. D. Bauer (FNAL, Spokesperson)
HEP funding: FNAL, SLAC, PNNL, Caltech, Minnesota, South Dakota, Stanford, Texas A&M
Project: FNAL leads SuperCDMS-Soudan operations (D. Bauer);
SLAC leads SuperCDMS-SNOLAB Project (B. Cabrera, Project Director)
Status:
SuperCDMS-Soudan operations completed in FY15; decommissioned in FY16; Analyses progressing.
SuperCDMS-SNOLAB selected as one of three G2 Dark Matter experiments (July 2014); CD-1 approved December 2015. CD-2/3 review planned Nov.2017.
Recent Highlights: (Oct 2016)
New limit on low-mass WIMPS from CDMSlite Run 2 (black line and orange band); > x10 improvement at 3 GeV/c^2 (http://arxiv.org/abs/1509.02448)

Expect new results from CDMSlite Run 3 and additional SuperCDMS Soudan analyses early 2017.



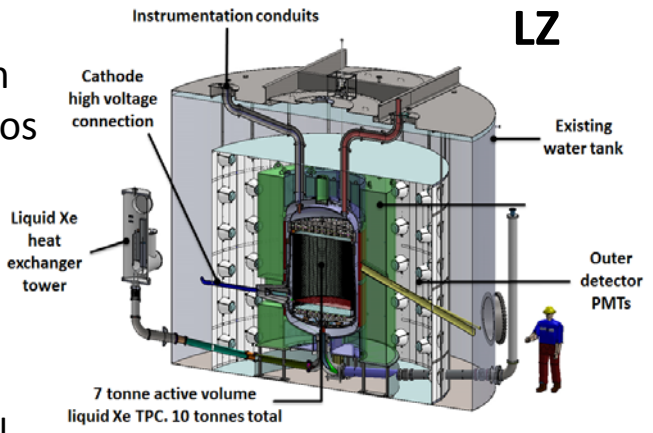




Large Underground Xenon (LUX) + ZEPLIN → LZ

Physics: Direct detection of WIMPS through dual phase liquid Xe.

Description: LUX - 350 kg liquid Xe at Sanford Underground Research Facility (SURF) in Davis cavern 4850' underground. Minimum exclusion of 2.2 x 10^{-46} cm^2 at 50 GeV WIMP (50 GeV). **LZ -** 7 tons of active Xenon and sensitivity near 2 x 10^{-48} cm^2 , close to where astrophysical neutrinos become an irreducible background.



Partnership: LUX: DOE & NSF partnership; contributions from UK, Portugal, Russia. **LZ:** DOE, UK, Korea, Portugal, Russia, SDSTA.

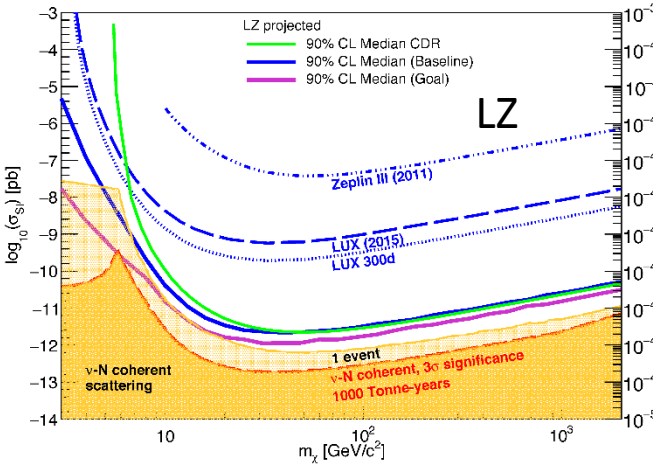
Collaboration: **LUX** - 19 institutions; **LZ** - 31 institutions.

HEP funding: LBNL (project office), LLNL, SLAC, Maryland, Rochester, Brown, TAMU, UC-Davis, UC-Santa Barbara, Washington U., Alabama, SUNY Albany, FNAL, Northwestern, South Dakota School of Mines & Technology, Texas A&M, Wisconsin

Status:

LUX: About 400 live days, stopped at end FY16; decommissioning in FY17

LZ: Selected as one of three G2 Dark Matter experiments (July 2014); CD1/3a approved Apr 2015; CD2/3b approved Aug 2016; CD3 review planned Jan 2017.



Recent Highlights:

- **LUX**: tightest limits on spin-independent cross-section
- **LZ**: LZ – cryostat, PMT, outer detector production and infrastructure upgrades at SURF underway. On track for 2020 operations start.

Non-G2 WIMP Search Experiments

PICO-60: Bubble chamber experiment at SNOlab (DOE, NSF, Canada)

Status: Operations funded by Canada in 2017. PICO-60 running with C3F8 target liquid. R&D on next generation bubble chambers with PICO-40L. Collaboration is proposing to Canadian agencies for ton-scale detector.

Highlights: Results in 2016 demonstrate world's best sensitivity to spin-dependent WIMP scattering and continued progress on background reduction.

DarkSide-50: LArTPC 50 kg active mass, Gran Sasso (LGNS), Italy (NSF-lead, major contribution from INFN, DOE)

Status: Running with 153 kg of low-radioactivity underground Ar (UAr).

Highlights: WIMP search results with 2616 kg-day UAr exposure (Oct 2015); Factor of >1000 reduction in 39 Ar measured in the UAr compared to atmospheric Ar.

DarkSide Collaboration planning to propose follow-on experiments:

DarkSide-20k :20-tonnes fiducial mass; 100 ton-year - background-free

Argo: 300-tons depleted argon; start of operations at LNGS 2025

DAMIC: Dark Matter in CCDs (DOE, NSF, +7 countries, operations at SNOLAB (Canada).

Status: Preparing for the deployment of the ~100g detector this year. The science detectors and electronics are currently being testing in a final integration test at FNAL.

Highlights: New results published with SNOLAB data in 2016 produced the best limits for low mass dark matter search using silicon target. The collaboration published a full calibration of the ionization yield of nuclear recoils in Silicon down to energies of 0.7 keV for the nuclear recoil in 2016.

DOE operations funding for these experiments ended in FY16.

Heavy Photon Search (HPS) Experiment at JLAB (Intensity Frontier)

Physics: **Search for a 20-400 MeV Dark Sector photon (A') which may mediate dark matter interactions with regular matter and its annihilations in Dark Matter halos.**

Description: High speed forward magnetic spectrometer using silicon vertex tracking with PbW04 crystal calorimeter for triggering. Measures trident production in JLAB Hall B with 1-6 GeV incident electrons**, searching for A's as a bump in the e+e- invariant mass spectrum and as detached vertices**.

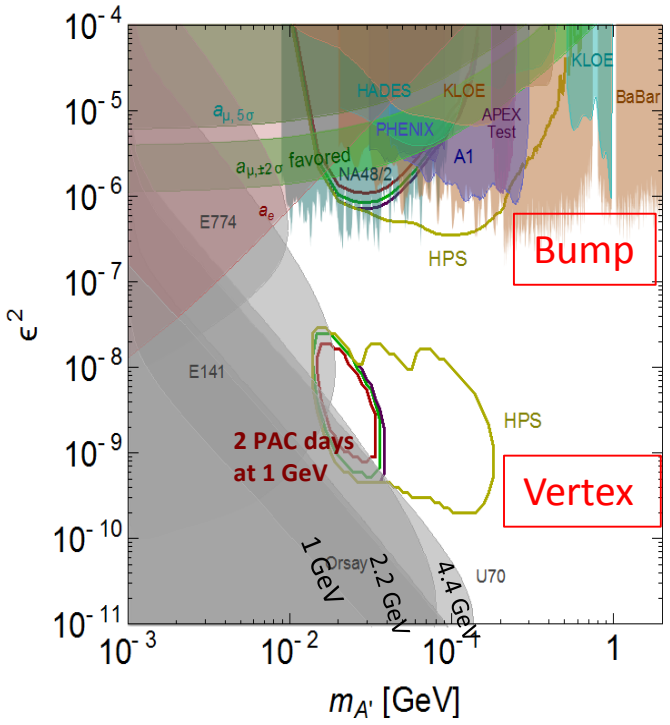
Partnership: DOE HEP, DOE NP, IN2P3, and INFN partnership.

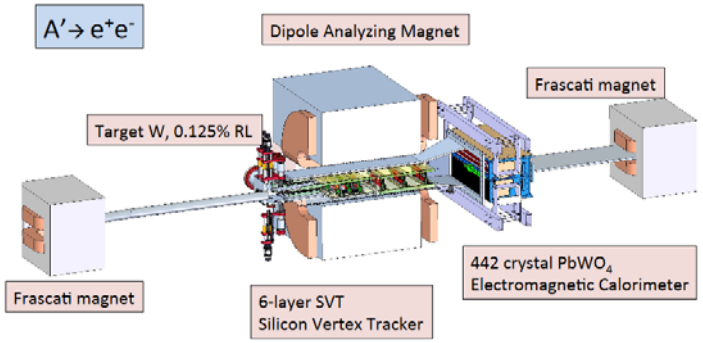
Collaboration: 17 Institutions: SLAC, JLAB, Orsay, Saclay, INFN(6), Glasgow, UNH, ODU, UCSC, W&M, Yerevan, Stony Brook

HEP Funding: SLAC, UCSC, Stony Brook, JLAB

Status and plans: Completed engineering runs at 1.05 (2015) and 2.3 GeV (2016). Preparing first bump hunt results for early 2017, and vertex results later in 2017. Planned SVT Upgrade will boost reach and be installed prior to an extended run, Summer 2018.

Recent Highlights: First three Ph.D. theses completed (trident MC, bump hunt, vertex search). Demonstration of HPS physics performance led to full JLAB approval for 180 PAC days. **2018 Summer run will be HPS's first dedicated, protracted running**. Detector Instrumentation papers being submitted to NIM.





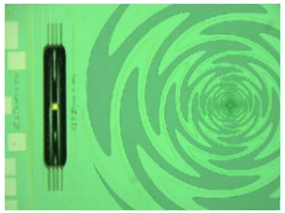
Dark Matter Future R&D (P5 recommendation)

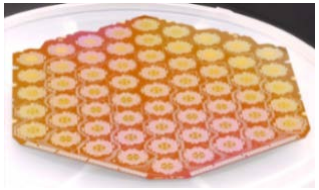
- Limited funds are available for R&D towards
- Near term:
  - R&D efforts that support off-project efforts to help optimize the science of the DM-G2 experiments.
  - R&D efforts that are focused, low cost efforts to support the technology studies for experiments that didn't move to G2 and/or other technologies which have R&D that needs to be to done at this time.
- Longer term:
  - R&D efforts to develop technologies or concepts for possible G2 upgrade projects.
  - R&D efforts to develop technologies or concepts towards G3's.

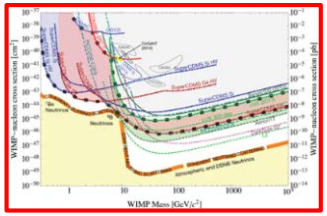
HEP received 8 proposals for FY17-19 funding; Under mail-in review; Decision expected early 2017.

Cosmic Visions (CV) Groups – looking towards the future

- **HEP has started "Cosmic Visions (CV)" groups in several areas: Allows interactions with small HEP community groups as a 2-way line of communication for HEP-funded efforts.**







CV-CMB (Cosmic Microwave Background)

Coordinate HEP technology R&D and other efforts for future CMB-S4 planning.

CV-DE (Dark Energy)

Investigate future directions following the end of construction of DESI and LSST; to complement, build on or extend these experiments in investigating the physics of dark energy.

CV-DM (Dark Matter)

Coordinate and investigate HEP technology R&D to optimize science from DM-G2 experiments and for future DM-G3 planning. Investigate new avenues for unexplored DM phase space.

New Opportunities in DM Searches (1)

- **The search for dark matter (DM) was a high science priority in the 2014 P5 report. P5 also had a recommendation about maintaining a diversity of project scales in the program (i.e. ensuring we have small projects too).**
- **It is important to cover all relevant phase space to the extent feasible. Currently, the majority of the current support and activity for dark matter search is aimed at WIMP and axion searches and is supported in the Cosmic Frontier. Some projects use accelerator beams to search for particle which connects SM particles to dark sector, and are supported in the Intensity Frontier. LHC and other data are also used to search for DM candidates. There are also considerable theoretical studies of dark matter.**
- **To respond to the P5 recommendations above, HEP is interested in identifying new, small project(s) for dark matter searches in areas of parameter space (i.e. mass ranges or types of particles) not currently being explored.**
- **In order to move forward and to understand the possibilities, HEP needs input from the community and is asking the community to organize a workshop in the March/April 2017 timeframe. The workshop should examine the next step(s) for experimentation to explore dark matter, including in unexplored areas of parameter space. It is expected that the workshop will result in a written white-paper report.**

New Opportunities in DM Searches (2)

Whitepaper should be available around June 1, 2017 so that it can be an input for FY19 budget planning. Whitepaper should include:

- Science case for unexplored the DM search phase space
- Concept for small accelerator/non-accelerator projects to accomplish these science goals
  - Technologies and facilities needed
  - Timescale (how long will it take to get ready and reach science goal)

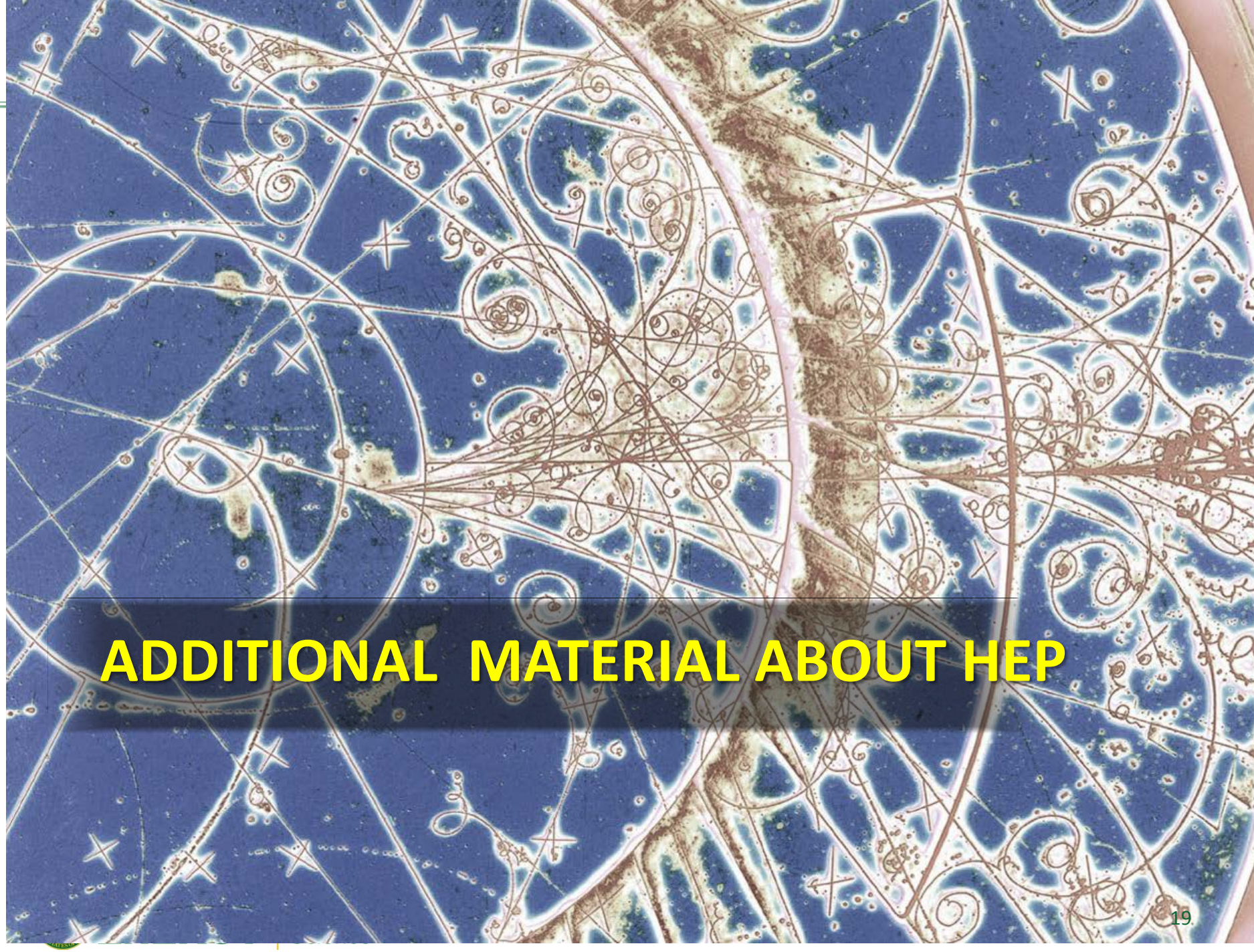
If there is a strong science case for new small project(s):

- R&D funding for likely project(s) could start in FY18, if available.
  - Determine the feasibility of the project
- Proposals for the project(s)
  - Review and possible funding, if available.

These project(s) and associated facility development (if needed) may cost up to ~10M$.

Concluding remarks

- **Dark matter G2 program is progressing. HEP is committed to supporting current G2 projects. This remains a priority.**
- **There is opportunity for funding for new small project(s) which expands the DM phase space over the phase space currently being investigated within or outside HEP programs. New projects may be accelerator based.**
- **HEP would like to get community input on science case and strawman concept for new small project(s) in form of a whitepaper by about June 1, 2017.**


ADDITIONAL MATERIAL ABOUT HEP

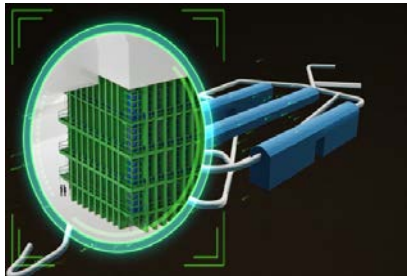
Community Materials

- Steve Ritz is leading community efforts to produce materials to help maintain the visibility of the P5 report
  - Initial materials are available at: http://www.usparticlephysics.org/
  - Steve plans to continue working with the U.S. particle physics community to update the material as needed
- Users' Groups report that Steve's material was helpful during their March 2016 visit to Washington, DC
- U.S. particle physics community should consider using Steve's messages as part of their communications strategy

HEP FY 2017 Budget Overview

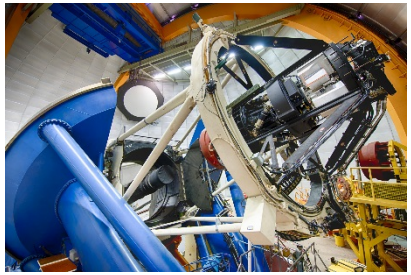
Energy Frontier: Continue to support leadership roles in the highly successful LHC program

- Initial LHC detector upgrade project funding ends in FY 2017
- DOE Mission Need (CD-0) approved in April 2016 for the HL-LHC upgrades, P5's highest priority near-term project
  - R&D and developing TDRs for HL-LHC ATLAS and CMS now in-process
  - Scope, roles and responsibilities continue to be firmed up
- U.S. will continue to play a leadership role in LHC discoveries by remaining actively engaged in LHC data analysis



Intensity Frontier: Solidify international partnerships for U.S.-hosted LBNF/DUNE

- Rapid progress on LBNF/DUNE has attracted attention from interested international partners and FY 2017 investments in site preparation and cavern excavation aim to solidify international partnerships
- Fermilab will continue improvements to accelerator complex while serving high-intensity neutrino beams to short-and long-baseline experiments, enabling full utilization of the FNAL facilities



Cosmic Frontier: Advance our understanding of dark matter and dark energy

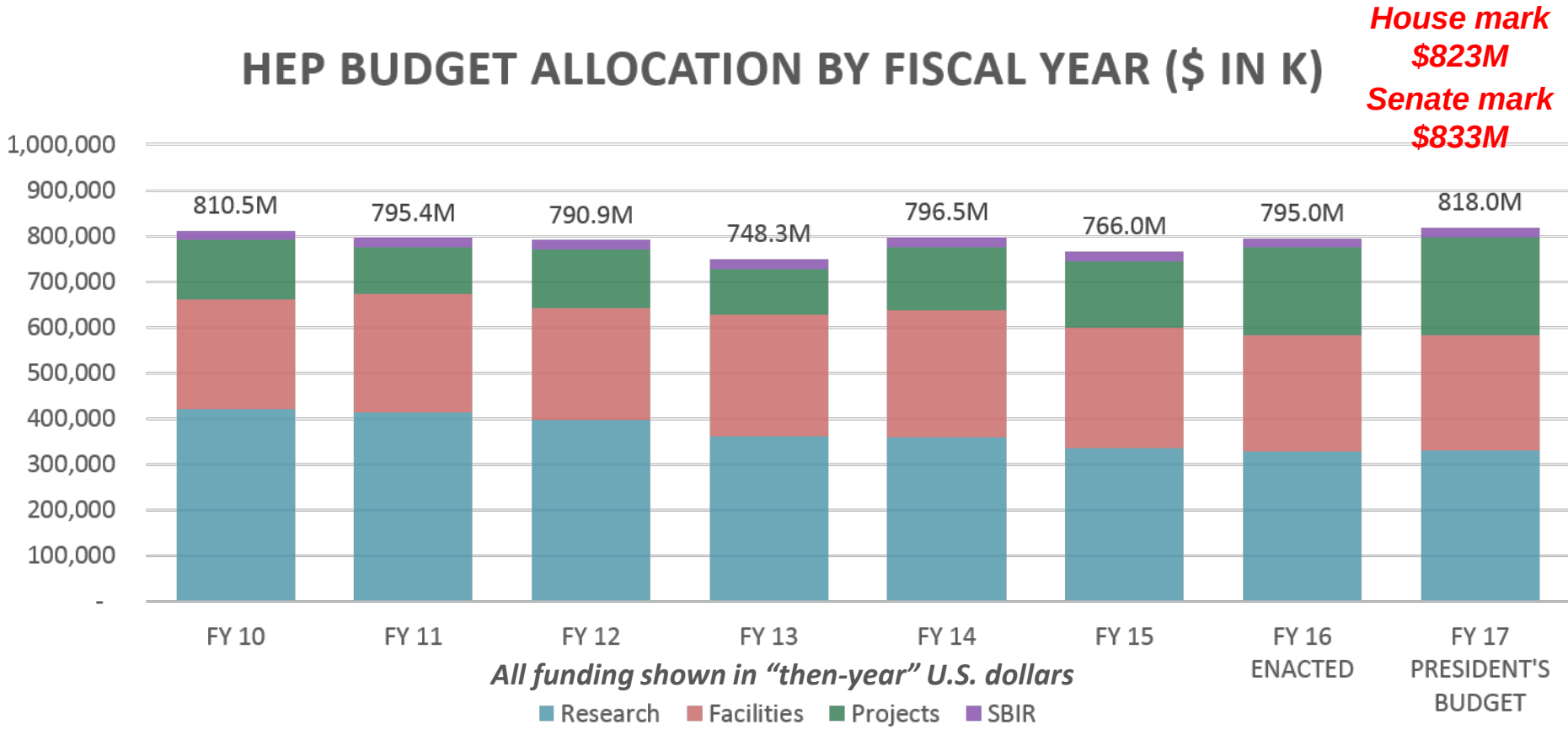
- Fabrication funding ramp up in FY17 supports key P5 recommended Cosmic Frontier projects to study dark matter and dark energy
  - LSSTcam, DESI, SuperCDMS-SNOLab, LZ

FY 2017 HEP Funding by Activity

HEP Funding Category ($ in K)	FY 2015 Current	FY 2016 Enacted	FY 2017 Request	Explanation of Changes (FY17 vs. FY16)
Research	334,225	327,389	331,123	Sustain support for research program
Facilities	264,634	254,979	252,037	Overall operations support reductions due to scheduled completion of projects
Projects	99,373	107,620	108,516	**Other Project Costs (OPC) includes CDR, project-specific R&D, prototyping and testing, installation and commissioning/pre-operations before CD-4*
Energy Frontier Projects	*15,000*	*19,000*	*18,967*	*Initial ATLAS/CMS upgrades complete in FY17; OPC* begins for HL-LHC detector upgrades*
Intensity Frontier Projects	*48,170*	*17,685*	*9,349*	*Reduction from ramp down of g-2 & end of LBNF/DUNE OPC*; SBN Program increases*
Cosmic Frontier Projects	*45,203*	*66,835*	*70,200*	*Planned ramp up supports fabrication of LSSTcam, DESI, SuperCDMS-SNOLab, LZ*
Other Projects	*1,000*	*4,100*	*10,000*	*Increase to support the FACET-II project*
Construction (Line Item)	37,000	84,115	103,741	Request engineering design, site preparation and long-lead procurement for the LBNF/DUNE; planned profile for Mu2e
SBIR/STTR	20,768*	20,897	22,580	
Total	**766,000***	**795,000**	**817,997**	***House mark $823M; Senate mark $833M***

**** SBIR/STTR added to FY 2015 for comparison to FY 2016/2017***

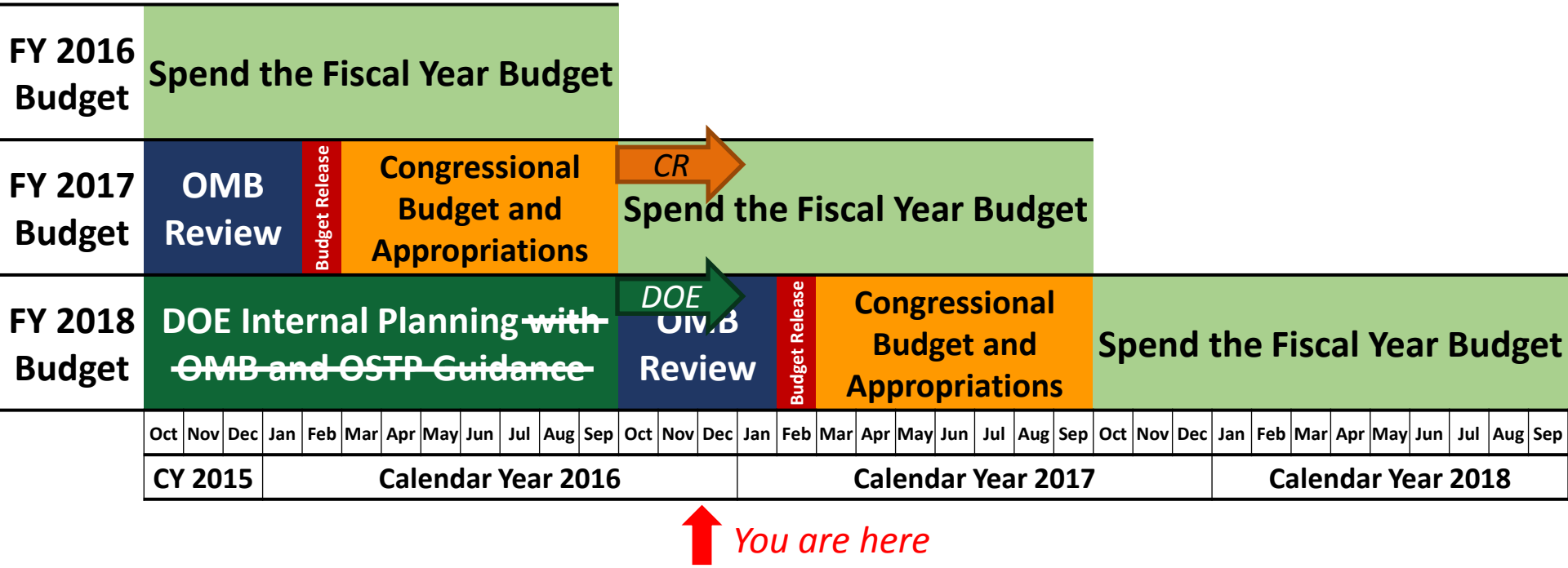
Overall HEP Budget Trend



- Significant dip in FY 2013 from Congressional sequestration
- FY 2015 request developed prior to P5 report release
- FY 2017 House/Senate markups increase project funding
- FY 2017 CR through Dec. 9, 2016, at $791M equivalent annual level of funding

The U.S. Federal Budget Cycle

- Typically, three budgets are being worked on at any given time
  - Executing current Fiscal Year (FY; October 1 – September 30)
  - White House Office of Management and Budget (OMB) review and Congressional Appropriation for coming FY
  - Agency internal planning for the second FY from now
- This year's cycle is not "typical"
  - Congress has not yet passed a budget for FY 2017 (*see next slide…*)
  - DOE planning for FY 2018 has proceeded so far without guidance from the White House



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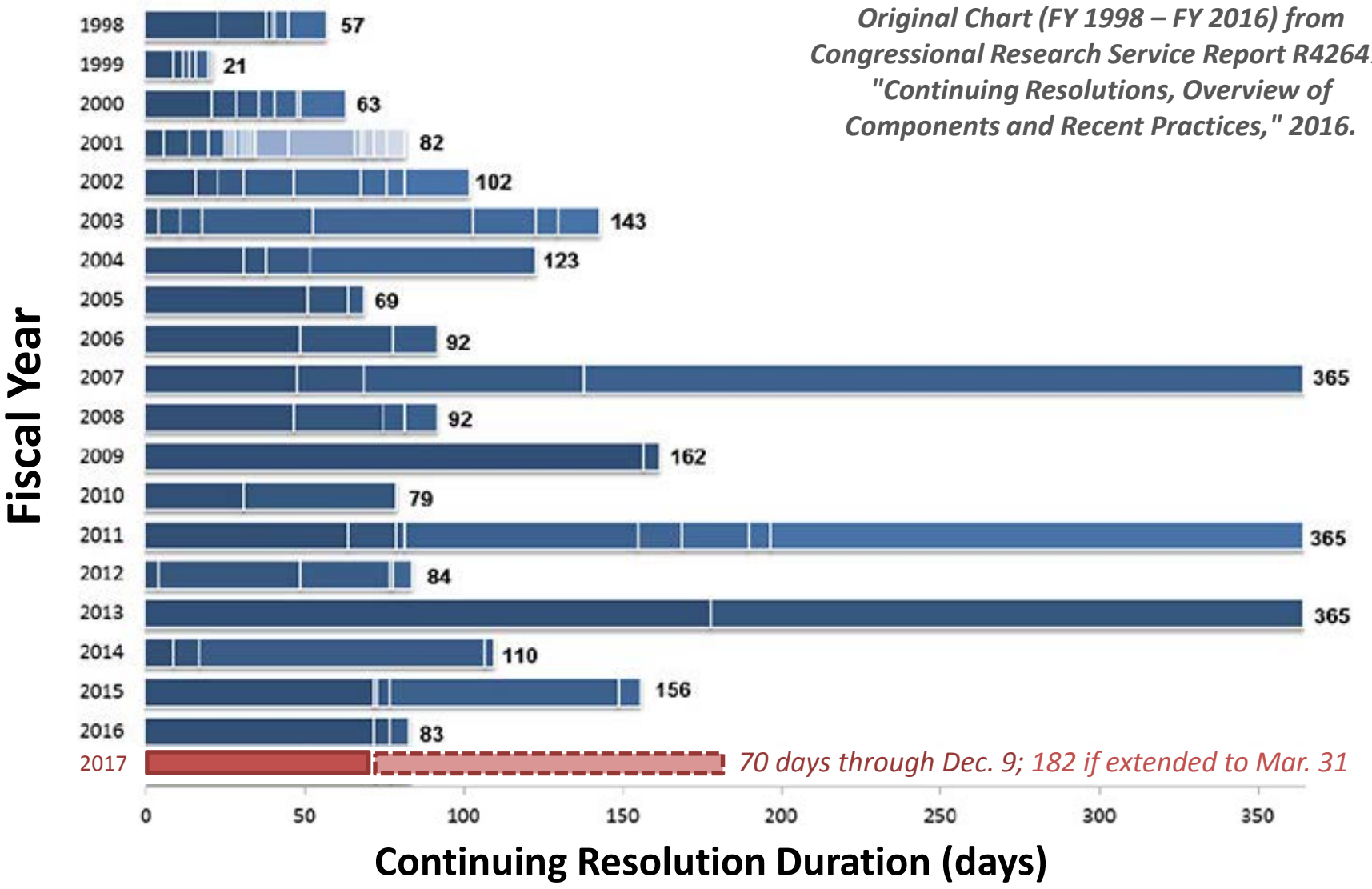
Duration of CRs: FY 1998 – FY 2017



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

Breaking the Cycle: Continuing Resolution

- If the U.S. Congress and the President have not passed all appropriations bills by September 30, a Continuing Resolution (CR) may be passed to avoid a U.S. Government shutdown
  - Must pass some level of appropriations to have legal authority to spend money!
  - CRs typically extend level of funding from the previous year for a set amount of time
- A CR may impede the start of new projects
  - Projects with total cost >$10M must be line-items approved by Congress in an appropriations bill before its "new start," or its Total Estimated Cost (TEC) funding, can begin
  - It is possible, though not typical, for CRs to include "anomalies" that would allow new starts
- A CR may impact the ramp-up of new projects
  - DOE is committed to the successful execution of projects that have reached CD-2 and aims to provide the baseline funding profile
  - Projects that have not reached CD-2 are most likely to be impacted under a CR
- A CR may also impact future-year planning through such effects…

- Currently, an FY 2017 Continuing Resolution (CR) in effect through December 9, 2016
  - Funding through Dec. 9 equivalent to $791M level of funding, if extrapolated to full FY
  - Latest news suggests FY 2017 CR may be extended through March 31, 2017
- DOE has limited flexibility for adjustments under a CR, but will work closely with laboratory and project management to minimize any impacts
  - More about CR impact on FOAs will be presented in Glen Crawford's HEPAP talk tomorrow

DOE Project Management

- **Construction projects and fabrication of large pieces of experimental equipment costing over $5M are managed through a series of "Critical Decision" milestones**
- **The CD process ensures successful project execution and scientific return on agency investments, but funding must still be appropriated**
  - **Projects reaching CD-3 may have technical readiness, but they must be supported in the President's Budget Request and receive funding from Congress before they can begin**
- **U.S. projects require use of U.S. accounting (contingency, labor, etc.) *vs.* CORE (M&S only)**