



U.S. DEPARTMENT OF
ENERGY

Office of
Science

DOE/HEP Program and Budget Update

Committee on Astronomy & Astrophysics (CAA)

March 27, 2019

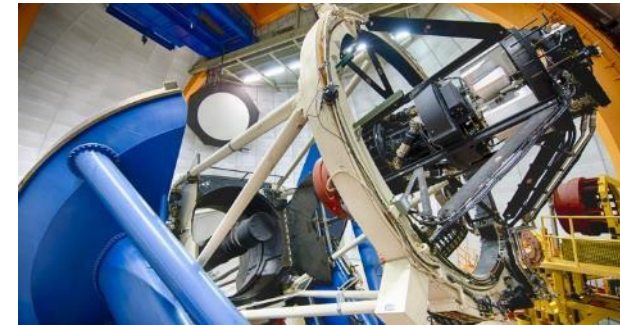
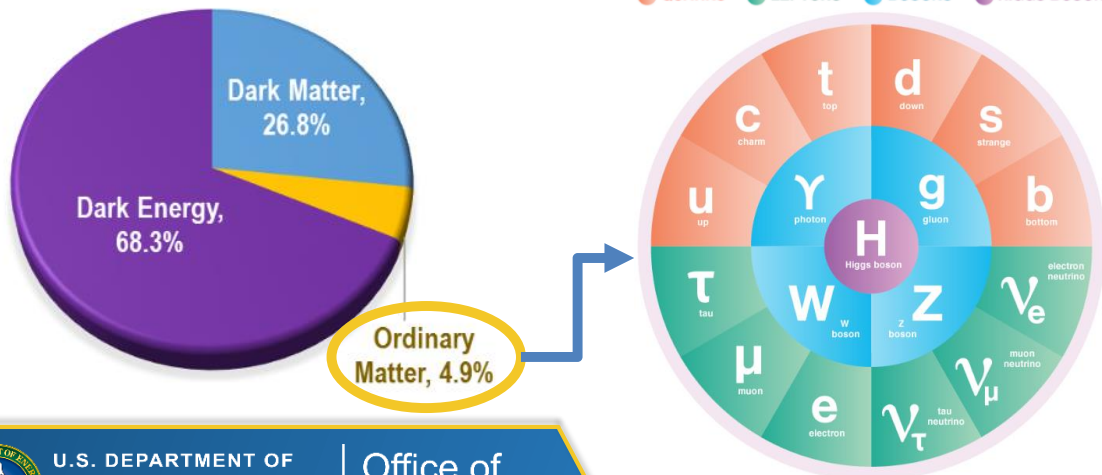
Eric Linder

Office of High Energy Physics

The High Energy Physics Program Mission

... is to understand how the universe works at its most fundamental level:

- ▶ Discover the elementary constituents of matter and energy
- ▶ Probe the interactions between them
- ▶ Explore the basic nature of space and time
- ▶ The DOE Office of High Energy Physics fulfills its mission by:
 - ▶ Building **projects** that enable discovery science
 - ▶ Operating **facilities** that provide the capability for discoveries
 - ▶ Supporting a **research** program that produces discovery science



Cosmic Frontier Experimental Research Program

→ Through ground-based telescopes & arrays, space missions, and deep underground detectors, research at the Cosmic Frontier aims to explore dark energy and dark matter, which together comprise approximately 95% of the universe.

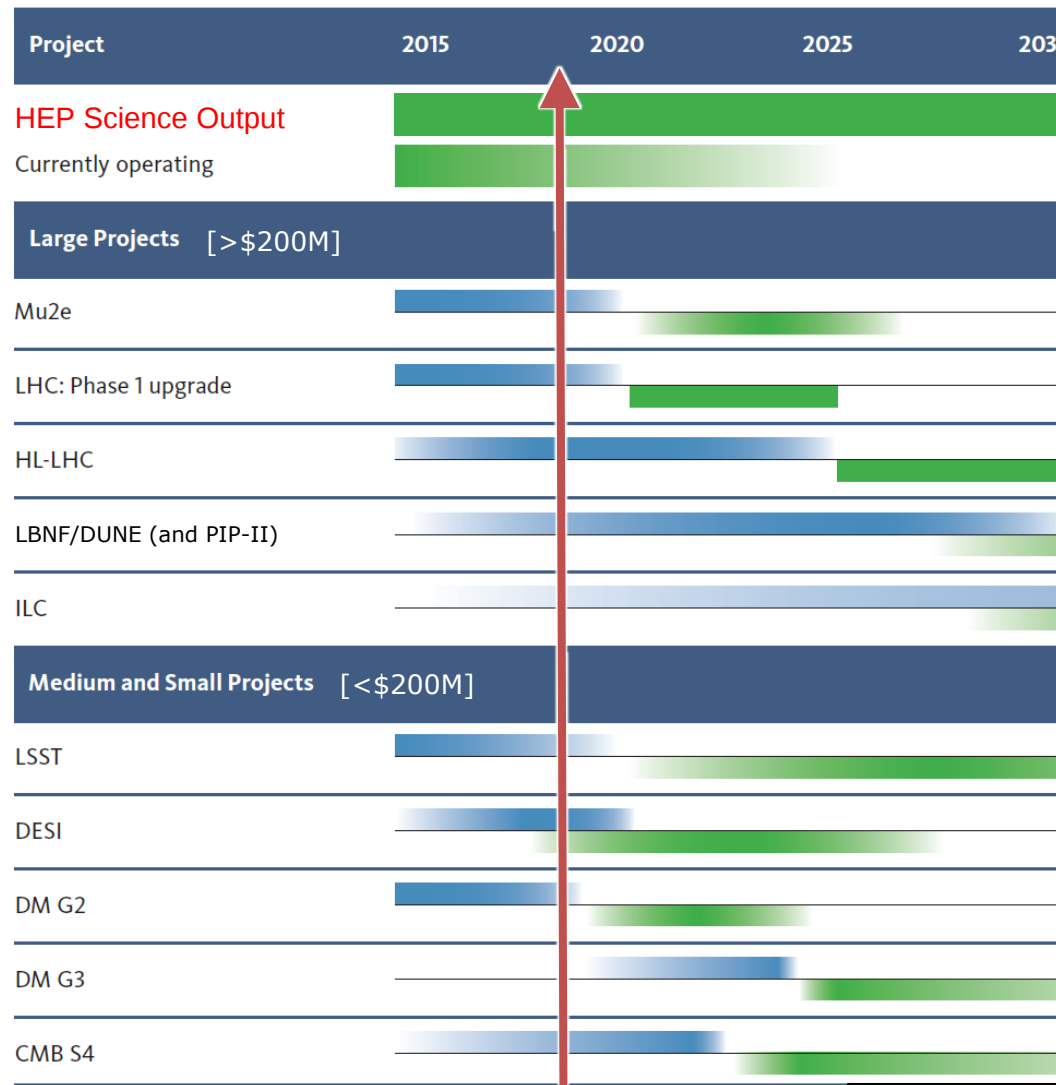
Program Areas:

- Study the nature of Dark Energy
- Direct Detection searches for Dark Matter particles
- CMB – Inflationary Epoch, Dark Energy, Neutrino Properties
- Cosmic-ray & Gamma-ray studies – indirect searches for dark matter particles

Particle Physics Science Drivers	Research Frontiers			
		Energy Frontier	Intensity Frontier	Cosmic Frontier
	Higgs Boson	●		
	Neutrino Mass		●	●
	Dark Matter	●	●	●
	Cosmic Acceleration			●
	Explore the Unknown	●	●	●

→ Strong interaction with Theory, Detector R&D, Computational HEP

P5 Implementation Status – FY 2019



Operating:

- Muon g-2 (1st beam 2017)
- Broad portfolio of small experiments including ADMX-G2, SPT-3G, DES, eBOSS

All projects on budget & schedule

- LHC detector upgrades: on track for 2019/20 installation
- Mu2e : 1st data in 2020
- DESI, DM-G2 (SuperCDMS, LZ) – fabrication completes FY20
- HL-LHC accelerator and detector upgrades started on schedule
- LSST camera fabrication (last funds FY18); I&T, commissioning starting
- LBNF/DUNE & PIP-II schedules advanced due to strong support by Administration & Congress

NOT YET IN CD process:

- **CMB-S4: developing concept with technically-driven schedule & input to Astro2020; HEP plans FY19 CD0**
- DM-G3: R&D limited while fabricating G2
- ILC: cost reduction R&D while waiting for decision from Japan

You are here

Legend: P5 recommendation

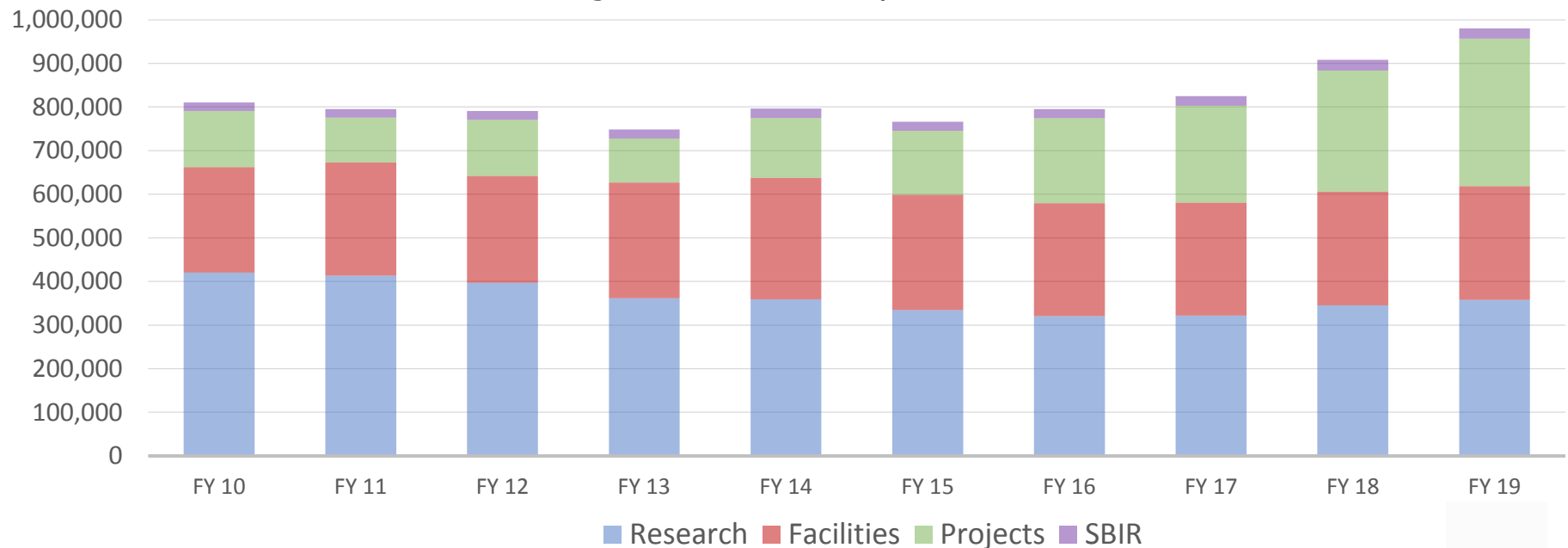
- Approximate Construction
- Expected Physics

Overall HEP Budget Trend

- ▶ P5 strategy continues to define investments in future of the field
- ▶ FY 2019 Enacted increases project funding above Request
 - ▶ Profiles for high-priority projects recommended by P5 continue to ramp up
 - ▶ **Research funding could face pressure even if overall HEP budget rises**

HEP BUDGET ALLOCATION BY FISCAL YEAR (\$ IN K)

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



FY19 HEP Budget \$980M: Balancing Research, Operations and Projects

- ✓ **All Cosmic Frontier projects are fully supported.**
- ✓ **FY19 completes the funding for construction of DESI, LZ, SuperCDMS-SNOlab. LSSTCam funding completed FY18.**
- ✓ **Commissioning and Operations Funding is ramping up.**

Project funding of \$338.4M (34.5%) was increased above the Request; many projects are fully controlled by Language

- LBNF/DUNE +35M over FY 2018, and +17M over Request

FY19 Accelerated Project funding:

- **Creates opportunities to launch new initiatives by mid-2020s**
- **Increases pressure to deliver on science earlier**

Research & Operations funding is \$641.6M (65.5%)

- Strong support provided; funding still facing pressure
 - Research budget provides support for scientists in all phases of an experiment
 - Operations provides support for experimental/facility operations & data processing



HEP Project Status - Line Item Construction & Major Item of Equipment (MIE)

Final Year of
Project Funding

Subprogram	TPC (\$M)	CD Status	CD Date
INTENSITY FRONTIER			
Long Baseline Neutrino Facility / Deep Underground Neutrino Experiment (LBNF/DUNE)	1,300 – 1,900	CD-3A	September 1, 2016
Proton Improvement Project (PIP-II)	653 - 928	CD-1	July 23, 2018
Muon g-2 FY 2017	46.4	CD-4	January 16, 2018
Muon-to-Electron Conversion Experiment (Mu2e) FY 2019	273.677	CD-3	July 14, 2016
ENERGY FRONTIER			
LHC ATLAS Detector Upgrade FY 2017	33	CD-3	November 12, 2014
LHC CMS Detector Upgrade FY 2017	33	CD-4A	September 19, 2017
High-Luminosity LHC (HL-LHC) Accelerator Upgrade	208 - 252	CD-1/3A	October 13, 2017
High-Luminosity LHC (HL-LHC) ATLAS Detector Upgrade	149-181	CD-1	September 21, 2018
High-Luminosity LHC (HL-LHC) CMS Detector Upgrade	125-155	CD-0	April 13, 2016
COSMIC FRONTIER			
LUX-ZEPLIN (LZ) FY 2019	55.5	CD-3	February 9, 2017
Super Cryogenic Dark Matter Search - SNOLAB (SuperCDMS-SNOLAB)	18.6	CD-2/3	May 2, 2018
Dark Energy Spectroscopic Instrument (DESI) FY 2019 FY 2019	56.328	CD-3	June 22, 2016
Large Synoptic Survey Telescope Camera (LSSTcam) FY 2018	168	CD-3	August 27, 2015
ADVANCED TECHNOLOGY R&D			
Facility for Advanced Accelerator Experimental Tests II (FACET-II) FY 2019	25.6	CD-2/3	June 8, 2018



FY20 President's Request Budget: HEP Budget \$768M

	(\$K)				
	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted	
				\$	%
Science					
Advanced Scientific Computing Research	810,000	935,500	920,888	-14,612	-1.6%
Basic Energy Sciences	2,090,000	2,166,000	1,858,285	-307,715	-14.2%
Biological and Environmental Research	673,000	705,000	494,434	-210,566	-29.9%
Fusion Energy Sciences Program	532,111	564,000	402,750	-161,250	-28.6%
High Energy Physics	908,000	980,000	768,038	-211,962	-21.6%
Nuclear Physics	684,000	690,000	624,854	-65,146	-9.4%
Workforce Development for Teachers and Scientists	19,500	22,500	19,500	-3,000	-13.3%
Science Laboratories Infrastructure	257,292	232,890	163,600	-69,290	-29.8%
Safeguards and Security	103,000	106,110	110,623	+4,513	+4.3%
Program Direction	183,000	183,000	183,000	0	N/A
Total, Science	6,259,903	6,585,000	5,545,972	-1,039,028	-15.8%

\$768M for High Energy Physics (HEP), \$212M below 2019 Enacted, supports research to understand how the universe works at its most fundamental level by discovering the most elementary constituents of matter and energy, probing the interactions among them, and exploring the basic nature of space and time. The Request supports LBNF/DUNE, the High-Luminosity Large Hadron Collider (HL-LC) Accelerator and Detector Upgrade projects at CERN, and the Muon to Electron Conversion Experiment project. **The request also funds QIS research and Artificial Intelligence.**



HEP Program Guidance

FACA panels & subpanels provide official advice:

- ▶ High Energy Physics Advisory Panel (HEPAP)
 - ▶ Jointly chartered by DOE and NSF to advise both agencies
 - ▶ **Provides the primary advice for the HEP program**
 - ▶ Subpanels for detailed studies (e.g. Particle Physics Project Prioritization Panel ("P5") in 2008, 2014)
- ▶ Astronomy and Astrophysics Advisory Committee (AAAC)
 - ▶ Advises DOE, NASA, and NSF on selected issues in astronomy & astrophysics of overlap, mutual interest and concern; subpanels, e.g. CMB-S4 Concept Definition Team (CDT), GBS

Formal Advice Also Provided by:

- ▶ National Academy of Sciences (NAS)
 - ▶ Decadal Surveys in Astronomy & Astrophysics, Elementary Particle Physics
 - ▶ **Board on Physics & Astronomy (BPA), Committee on Astronomy & Astrophysics (CAA)**

Other:

- ▶ Community science studies and input (e.g. Snowmass, Dark Energy Task Force, DPF input, Basic Research Needs).
- ▶ Astro-Particle International Forum (APIF) – Agency-level international group
- ▶ Tri-Agency Group (TAG) – DOE, NASA, NSF-AST meetings on LSST, WFIRST, Euclid coordination



Future Computing Update

- ▶ The fields demands for computing and supercomputing are growing
 - ▶ See Jim Siegrist's May HEPAP presentation:
<https://science.energy.gov/hep/hepap/meetings/201805/>
 - ▶ As an example, this 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
 - ▶ Assess the level of effort needed to make HEP code ready for Exascale
 - ▶ Assess the degree the issues and potentially solutions are shared
 - ▶ Across experiments and Frontiers
 - ▶ We have invited the Laboratories to submit Field Work Proposals (FWPs) for this activity
 - ▶ CCE leadership will provide a program plan in near future
 - ▶ NSF launched the Institute for Research and Innovation in Software for High-Energy Physics (IRIS-HEP) to tackle similar issues from the university perspective
- ▶ The first "pre-Exascale" computer, *Summit*, has been delivered to Oak Ridge and is in "Early Science" phase (open to regular use next year); *Perlmutter* 2020
 - ▶ Exascale *Aurora* is planned for 2021
 - ▶ **First codes to run at scale were 3 of the largest cosmology simulations ever**
- ▶ Storage and networking is next on our agenda



Cosmic Frontier Program

Drew Baden (IPA)
Karen Byrum (Detaillee)
Eric Linder (IPA)
Kathy Turner



Cosmic Frontier Experiments

Activity	Location	Science	Current Status	# Collaborators	# Institutions	# Countries
Extended Baryon Oscillation Spectroscopic Survey (BOSS)	APO in New Mexico	dark energy stage III (spectroscopic)	operations started 2015	100 (60 US, 40 HEP)	34 (22 US, 10 HEP)	10
Dark Energy Survey (DES)	CTIO in Chile	dark energy stage III (imaging)	operations started Sep 2013	500	25 (13 US, 9 HEP)	7
Large Synoptic Survey Telescope (LSST) - Dark Energy Science Collaboration (DESC)	Cerro Pachon in Chile	dark energy stage IV (imaging)	science studies, planning	269 (195 US, 47 HEP)	63 (43 US, 22 HEP)	15
Large Synoptic Survey Telescope (LSST) - LSSTcam Project	Cerro Pachon in Chile	dark energy stage IV (imaging)	FY14 fab start; CD3 Aug 2015	142 (111 US, 111 HEP)	17 (11 US, 11 HEP)	2
Dark Energy Spectroscopic Instrument (DESI)	KPNO in AZ	dark energy stage IV (spectroscopic)	FY15 fab start; CD3 June 2016	200 (93 US, 74 HEP)	55 (21 US, 19 HEP)	9
DM-G1: Large Underground Xenon (LUX)	SURF in South Dakota	dark matter - WIMP search	Operations ended in 2016	102 (86 US, 64 HEP)	18 (15 US, 13 HEP)	3
DM-G1: Super Cryogenic Dark Matter Search (SuperCDMS-Soudan)	Soudan in Minnesota	dark matter - WIMP search	Operations ended in 2016	83 (72 US, 44 HEP)	20 (17 US, 7 HEP)	3
DM-G2: ADMX-G2	Univ Washington	dark matter - axion search	Operations started Jan. 2017	23 (21 US, 18HEP)	8 (7 US, 4 HEP)	2
DM-G2: SuperCDMS-SNOLAB	SNOLab in Canada	dark matter - WIMP search	FY15 fab start; CD3 May 2018	109 (86 US, 57 HEP)	22 (16 US, 7 HEP)	5
DM-G2: LZ	SURF in South Dakota	dark matter - WIMP search	FY15 fab start; CD3 Feb. 2017	252 (174 US, 161 HEP)	38 (26 US, 23 HEP)	5
SPT-3G	South Pole	CMB stage 3	Operations started Feb. 2017	59	9 (7 US, 5 HEP)	3
Very Energetic Radiation Imaging Telescope Array System (VERITAS)	FLWO in AZ	gamma-ray survey	HEP ops completed 2016	109 (76 US, 28 HEP)	20 (16 US, 5 HEP)	4
Pierre Auger Observatory	Argentina	cosmic-ray	HEP ops completed 2016	436 (61 US, 18 HEP)	90 (17 US, 6 HEP)	17
Fermi Gamma-ray Space Telescope (FGST) Large Area Telescope (LAT)	space-based	gamma-ray survey	June 2008 launch; operating	252 (104 US, 18 HEP)	109 (37 US, 3 HEP)	22
Alpha Magnetic Spectrometer (AMS-02)	space-based (on ISS)	cosmic-ray	May 2011 launch; operating	250	46 (6 US, 2 HEP)	16
High Altitude Water Cherenkov (HAWC)	Mexico	gamma-ray survey	Operations started Jan. 2015	120 (60 US, 7 HEP)	30 (13 US, 3 HEP)	4

Dark Energy

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)

Operating Complete!:

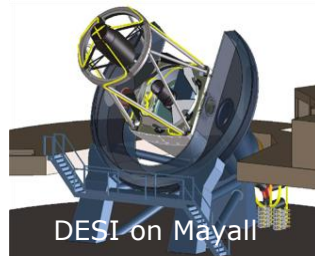
- *eBOSS* (spectroscopic) started in 2015, ended Feb 2019
- *DES* (imaging) started 5-year survey in late FY13, ended Jan 2019

In Fabrication phase:

- *Large Synoptic Survey Telescope* (LSST, Stage 4 imaging)
- *Dark Energy Spectroscopic Instrument* (DESI, Stage 4 spectroscopic)

Planning for the Future

- Cosmic Visions Group
- Three Agency Group (TAG)

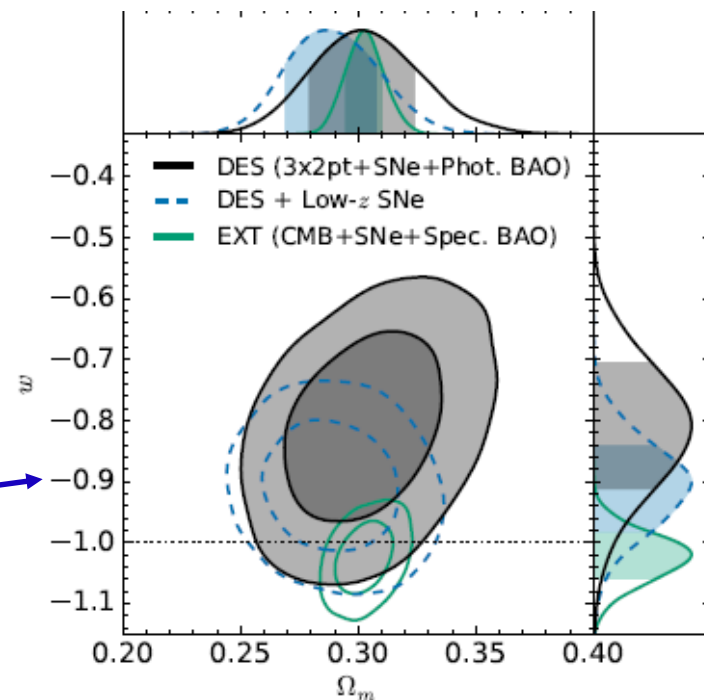
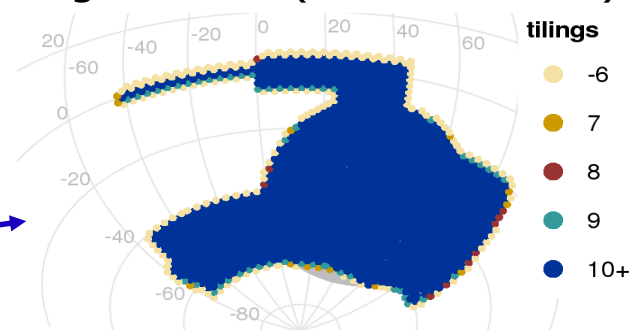


Dark Energy Survey

DOE-HEP partnership with NSF-AST: DOE provided DECam; support DECam operations for DECam & computing (with NSF)

- ▶ Completed Observations Jan 9, 2019
 - ▶ **5085 deg² in 5 filters (grizY), each w/ ten 90s exposures. Successfully met all survey metrics.**
- ▶ 221 scientific publications through Jan. 31, 2019, ~70 in the past 12 months on range of topics spanning astrophysics from solar system to cosmology
- ▶ Public Data Release “DR1” based on 1st 3 years data (Y1-Y3) has > 630 users, 6 Tb data delivered
- ▶ Among the many cosmology highlights in past year:
 - ▶ Constraints on Extended cosmological models from DES Y1 Weak Lensing and Galaxy Clustering (WL)
 - ▶ Cross Correlation of DES WL signal w/ Planck and SPT
 - ▶ Cosmology from 207 DES Y1-Y3 spectro-typed SN1a
 - ▶ Combined DES Y1 WL & Y1 LSS & SN1a cosmology
- ▶ Now concentrating on cosmology through Y3 (later this year) & on producing Y6 data products for analysis, Y6 cosmology to follow

e.g. z-band (850-1002 nm)



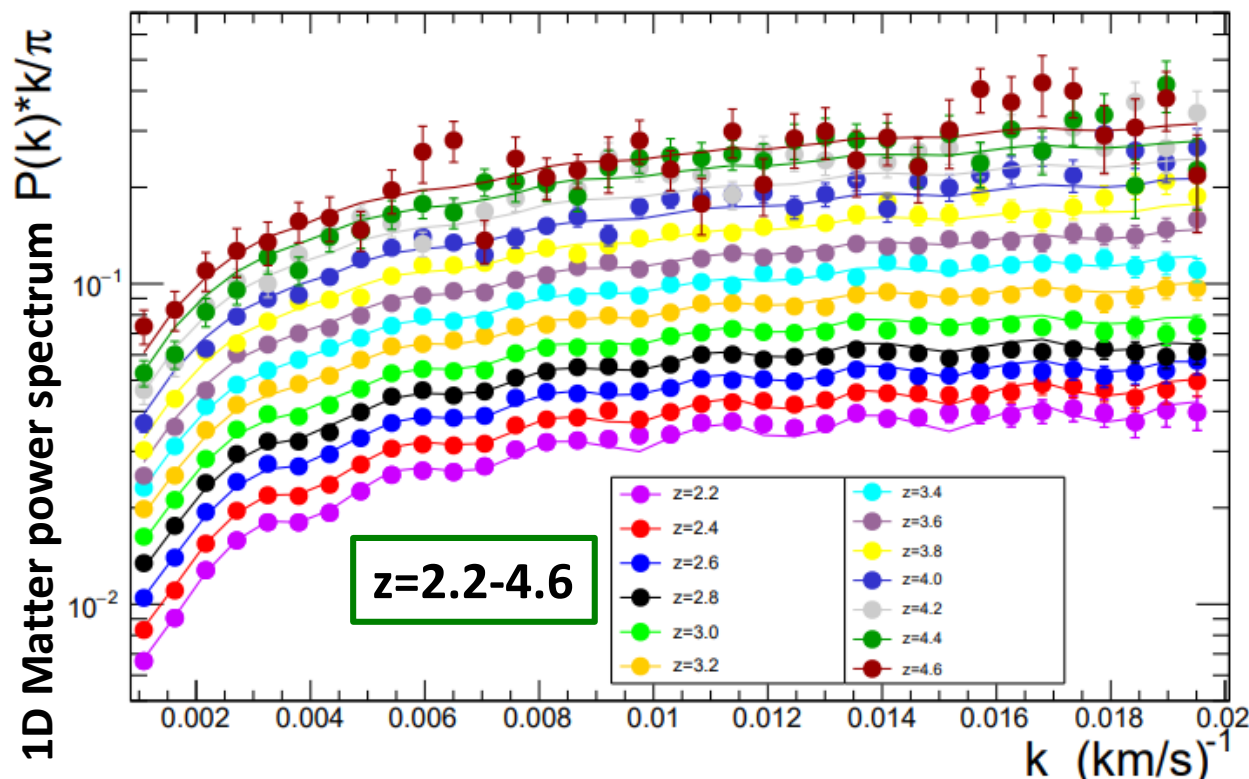
Science Highlight – Extended Baryon Oscillation Spectroscopic Survey (eBOSS)

Major Milestone: 1D power spectrum from Lyman-alpha forest (Chabanier+ 1812.03554)

- Three-fold improvement over results from BOSS (2013)
- Find matter power spectrum described by $\sigma_8=0.820\pm0.021$ and $n_s=0.955\pm0.005$

Implications for Cosmology: Test of neutrino physics and models of dark matter at $2 < z < 5$

Also: 1901.01950 – first BAO measurement using MgII ($z=0.3-1.6$; 4.7%); important systematic crosscheck



Large Synoptic Survey Telescope (LSST) - Status

DOE-HEP & NSF-AST partnership:

- NSF & DOE Review of Facility Operations Dec 2017
- NSF/DOE Project Status & Commissioning review Aug 2018

HEP MIE LSST Camera project funding completed in FY18;
Integration & Commissioning within overall LSST project.
FY18 Commissioning support started; funded on Ops budget
(see FY19 appropriations); FY19 Facility Ops support started

- Seven test rafts were installed successfully starting I&T efforts
- 16 science rafts now assembled, tested and accepted (2.3 Gpix)
- Only 7 sensors remain to be delivered

Dark Energy Science Collaboration (DESC):

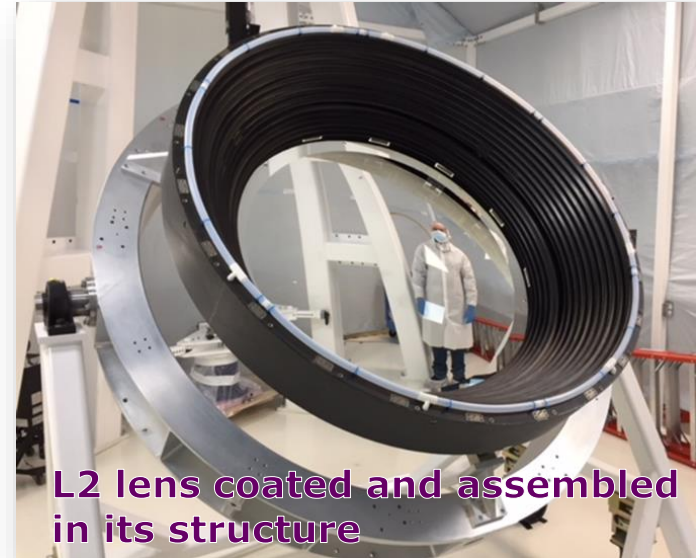
- Set up to carry out planning and eventual data analysis for DOE HEP science goals
- Operations Plan review held May 2018
- Data Challenge 2 Run 2.0 production underway on Theta at ANL, Cori at NERSC, and CC-IN2P3
- CosmoDC2 input catalog available for catalog studies

LSST DESC Science Requirement Document (SRD)

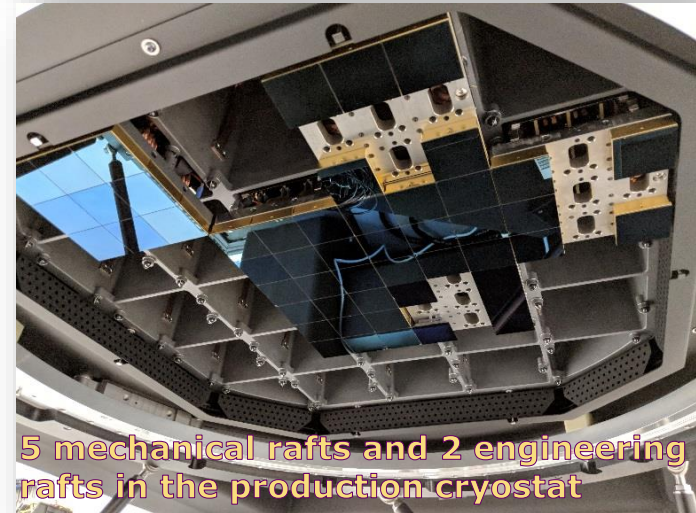
<https://arxiv.org/abs/1809.01669>

Some associated code and data products on public site

<https://zenodo.org/record/1409816>



L2 lens coated and assembled in its structure



5 mechanical rafts and 2 engineering rafts in the production cryostat

Dark Energy Spectroscopic Instrument (DESI) - Status

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

- ▶ 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 status & Operations plan review, Fall 2018
- Installation & Commissioning phase has started!
- Full dark energy survey operations starting FY20

Targeting – Legacy Surveys

<http://legacysurvey.org/>

covering ~~14000~~ 15000! deg^2 in g,r,z + 4 IR bands

- ▶ Mayall z Band Legacy Survey (MzLS) – 100% complete!
- ▶ Beijing-Arizona Sky Survey (BASS) on Bok – 100%!
- ▶ DECam Legacy Survey (DECaLS) on Blanco – 100%!

Legacy Surveys finished in March 2019

Data Release 7 in July 2018; DR8 coming April 2019



CAA - March 2019



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Cosmic Microwave Background

Gain insight into **inflationary epoch** at the beginning of the universe, **dark energy & neutrino properties** by studying oldest visible light.

Current Experiments:

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



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

- Notional array of several telescopes in Chile & South Pole with on the order of 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>

Ongoing Planning:

As recommended by P5, HEP is planning to participate in CMB Stage 4

- HEP labs already heavily involved in R&D to align with P5

CMB-S4 is the last remaining P5 project to start

HEP coordinating planning with NSF AST/OPP/PHY

HEP labs spearheaded formation of **pre-Project Design Group** (chair Jim Yeck)

Working together on planning concept with technically limited schedule.

Meeting regularly with agencies.



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CMB-S4 – Status

► Collaboration

- ANL meeting March 2018, collaboration officially formed
 - Org chart, bylaws, organization, etc
 - Spokespeople: John Carlstrom (U Chicago), Julian Borrill (LBNL)

► Fermilab March 13-15, 2019

- Focused on R&D and science issues needed to get to CD1, wider astro community engagement
- Serious progress and coherence in collaboration in a short time

► pre-Project Design Group (pPDG) established following CDT report

- Will be POC on DOE R&D and concept planning towards CMB-S4 CD-1
 - DOE provided \$1.5M FY18 R&D funding, went through pPDG to design/engineering (+LDRD+Research)
- DOE+NSF agree on Jim Yeck as pPDG lead (project manager experience from LHC, IceCube, LBNF, ESS)
- Collaboration and pPDG planning to a technically limited schedule, based on CDT study, preparing input to Astro 2020 and to move through DOE and NSF processes
- DOE is planning to work towards supporting pPDG and Collaboration's schedule

► DOE and NSF moving forward in sync:

- Collaboration to focus on a single design for both funding sources
- Enable DOE and NSF timescales to be in sync (DOE CD and NSF MREFC process)
- NSF/DOE Joint Coordination Group
 - Meet biweekly-monthly
 - Agencies, pPDG, spokespeople in close communication



CMB-S4 Science and Planning

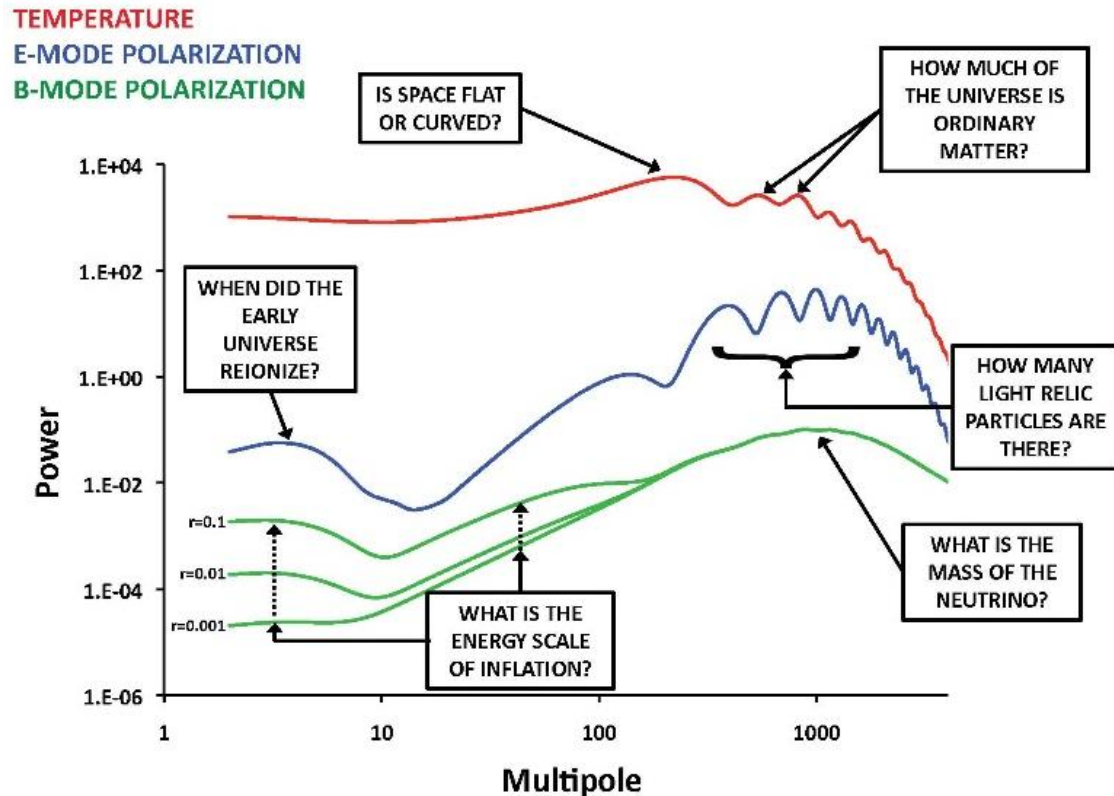
AAAC approved CMB-S4 Concept Definition Task Force (CDT) report Fall 2017

Sites at South Pole and Chile

- 3 large aperture telescopes of 6m diameter,
- 14 small aperture cameras of 0.5m diameter
- 9 frequency bands from 20–220 GHz

20 Decadal Survey science white papers submitted

194 members and growing; 144 US + Australia, Canada, France, Germany, Italy, Japan, Sweden, Taiwan, UK



Collaboration, preProject Development Group (pPDG) developing technically driven project plan

- includes full TRACEable schedule, management plan, bottoms up costing, and with proposed NSF and DOE roles and responsibilities defined.
- **basis for documentation for Decadal Survey and to advance thru DOE CD, NSF phases.**
- held review of the DSR Dec 11–13, 2018, co-chairs Mark Reichanadter, Steve Ritz.



CMB-S4 – Agency Planning & Coordination

DOE Planning

- Supportive of the Team's plan & working towards supporting pPDG and Collaboration's schedule
- DOE provided \$1.5M FY18 R&D funding, went through pPDG to design/engineering (+LDRD+Research); FY19 amount still in discussion

DOE HEP planning CD0, start of project process, in spring 2019

DOE and NSF coordination:

NSF/DOE Joint Coordination Group meets biweekly/monthly

- Agencies, pPDG, spokespeople in close communication
- Will work to enable synchronization of DOE and NSF timescales & processes



Astro2020 Decadal Survey - HEP

DOE, NASA, NSF worked together to deliver a statement of task to the National Academy of Sciences for Astro 2020 Decadal Survey.

→DOE-HEP continues to support detector development & experiment concept development for the future.

→Community has been actively planning:

CMB – CMB-S4 will be proposed to Astro 2020 for partnership of DOE-HEP, NSF-AST/PHY/OPP

Dark Energy – science ideas for enhancing and going beyond DESI and LSST will be proposed to Astro2020; small, medium, large scale project ideas

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

Other timelines: From a DOE perspective, the earliest that new “Snowmass,” NAS Elementary Particle Physics Decadal Survey, and P5 processes could begin is 2020

- **European Strategy for Particle Physics report 2020**
- **Relative timing of Snowmass, P5, and NAS EPP Decadal survey tbd**
- **Enables receiving next P5 recommendations in time to inform FY 2024/25 budget**



Closing Remarks

- ▶ **Excellent science results continue to be produced from our operating experiments!**
- ▶ **Broad support is enabling us to implement the P5 strategic plan and achieve its vision**
 - ▶ Thanks to DOE Management, Administration, & Congress for support
 - ▶ SC programs in QIS, computing, and SLI provide additional support to enable P5
 - ▶ **Community continues to be unified in support of P5 strategy**
- ▶ **The FY 2019 appropriation will enable continued P5 progress**
 - ▶ Maintaining a healthy research budget is an ongoing challenge
- ▶ **The particle physics community continues to perform well on delivering projects, a foundation of the long-term strategy**

Congratulations DES and eBOSS!

