U.S. DEPARTMENT OF ENERGY | Office of Science

Office of High Energy Physics (HEP) Program and Budget Report

Report to the Astronomy & Astrophysics Advisory Committee

June 15, 2020

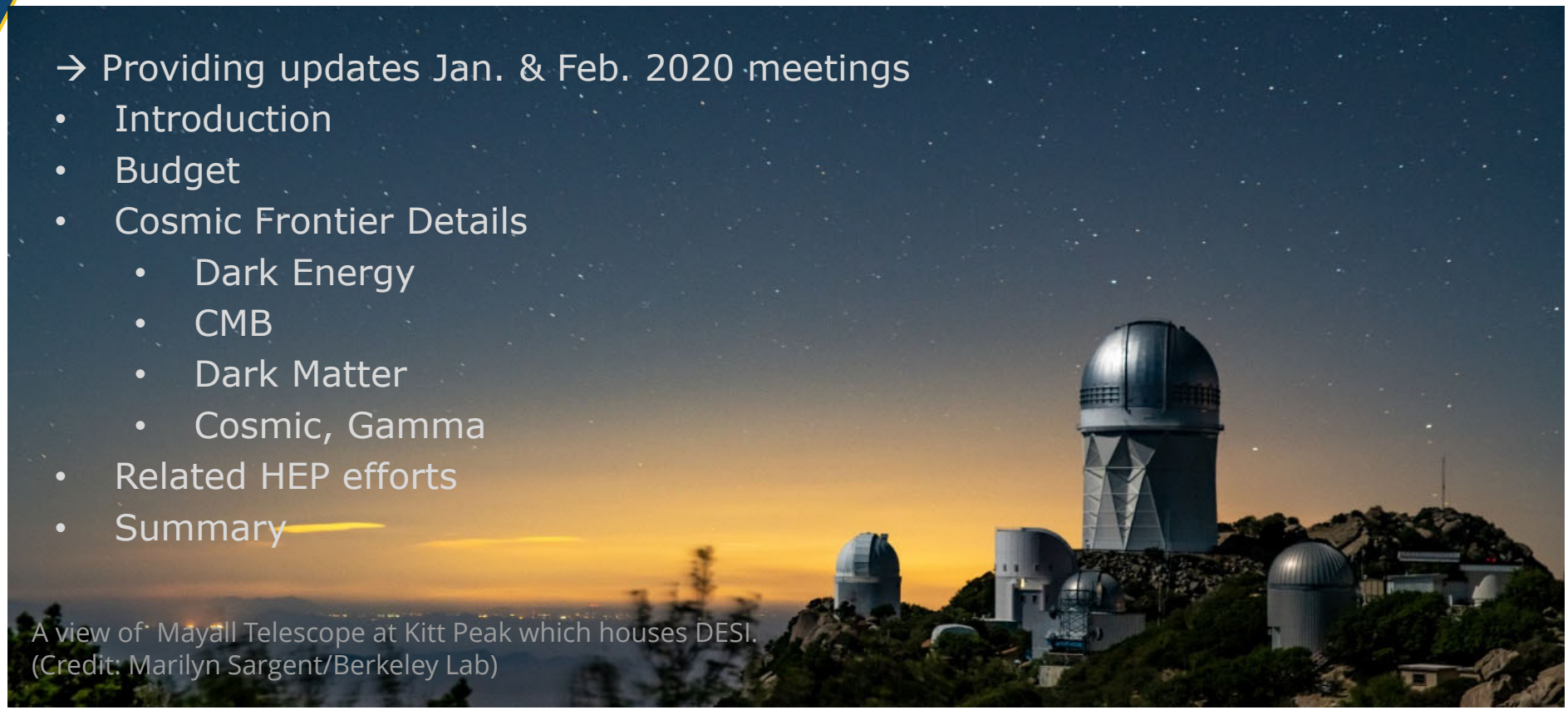
Kathy Turner, Cosmic Frontier Program Manager

+ Karen Byrum (Detailee), Drew Baden (IPA), Eric Linder (IPA)

OUTLINE

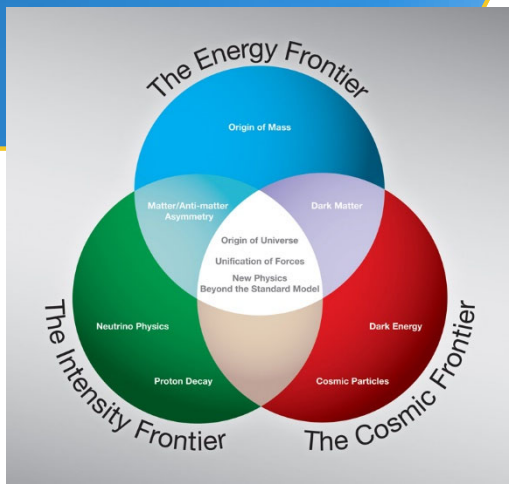
→ Providing updates Jan. & Feb. 2020 meetings

- Introduction
- Budget
- Cosmic Frontier Details
  - Dark Energy
  - CMB
  - Dark Matter
  - Cosmic, Gamma
- Related HEP efforts
- Summary



A view of Mayall Telescope at Kitt Peak which houses DESI.
(Credit: Marilyn Sargent/Berkeley Lab)

HEP Program Layout



HEP is carried out along 3 Frontiers:

Advancements at all 3 frontiers are needed to achieve the long term goals of the field.

→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 Standard Model picture: Cosmic Acceleration (Dark Energy, Inflation), search for Dark Matter particles, New Physics (neutrino properties, relic particles, etc)

- Science Advances: HEP uses a staged suite of projects and experiments with a variety of technologies, methods, etc. to make significant progress in scientific capabilities and results.

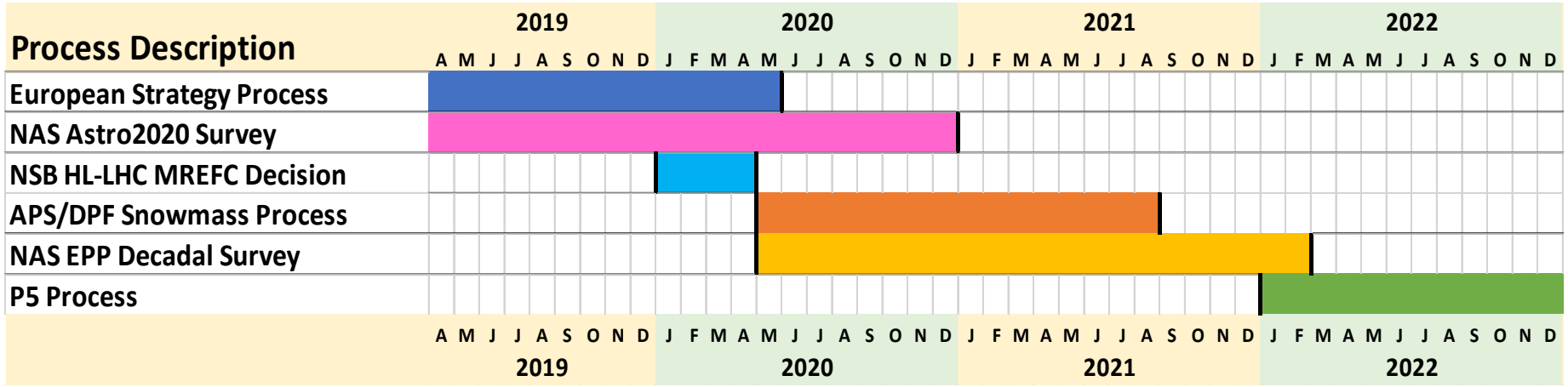
- Partnerships: Many projects and experiments have interagency (NSF, NASA) and/or international partners or contributors; some have private contributions.

HEP Strategic Planning

HEP continues to follow HEPAP's **2014 "P5" strategic plan**.

Preparing for next Strategic Plan:

- To provide timely input to the FY25 budget formulation, the next P5 report will be required by early 2023
- U.S. Community planning a Snowmass process with major meeting occurring in summer 2021
- Potential timeline for the next NAS EPP Decadal Survey could be mid-2020 through early-2022
  - Overlap with Snowmass could enable synergy with Snowmass processes and delivery of report as P5 process begins.



Many Changes since February meeting

Current Events – Global

- COVID pandemic
- Black Lives Matter

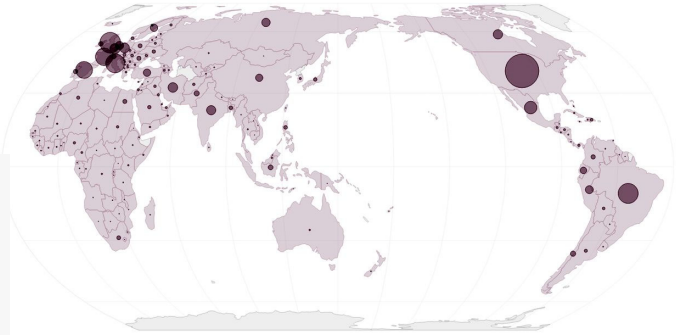
HEP program – Cosmic Frontier:

- DESI completed construction and commissioning and is ready to start data-taking!
- Rubin Observatory planning continues
- Project planning in response to COVID-19

Reflect on Global Events

COVID-19 pandemic – over 100,000 deaths in the US and over 400,000 globally; with ~ 7.5 million confirmed cases globally

→Please continue to follow CDC guidelines to stay safe https://www.cdc.gov/coronavirus/2019-ncov/index.html



Black Lives Matter – Particle Physics and Astronomy/Astrophysics communities spearheaded June 10th as a day to pause:

From **ParticlesForJustice.ORG** → **"**Therefore, as physicists, we believe an academic strike is urgently needed: to hit pause, to give Black academics a break and to give others an opportunity to reflect on their own complicity in anti-Black racism in academia and their local and global communities. This #strike4blacklives is in dialogue with a call from colleagues in astronomy to #shutdownSTEM and #shutdownacademia for at least the day of June 10".

U.S. DEPARTMENT OF
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Office of
Science

Budget

FY 2021 President's Request Budget for DOE Office of Science

SCIENCE

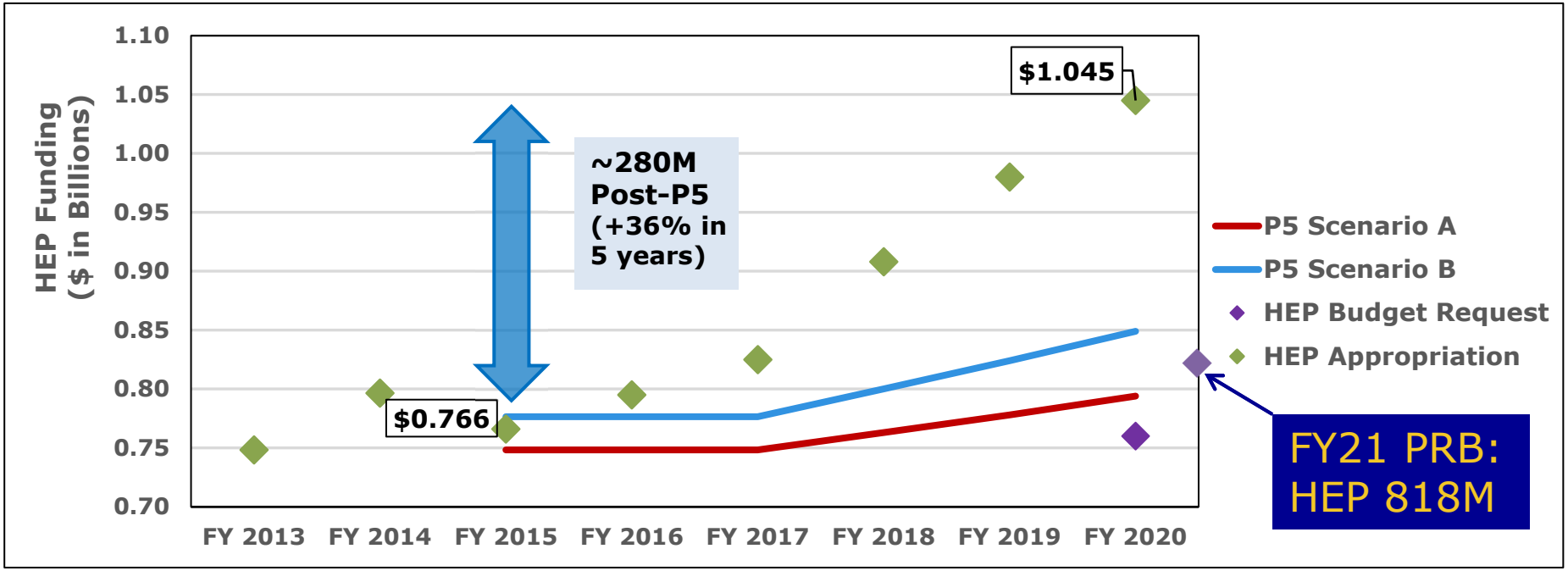
(dollars in thousands)

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 President's Request	FY 2021 Request vs. FY 2020 Enacted	
				$	%
Office of Science					
Advanced Scientific Computing Research	935,500	980,000	988,051	+8,051	+0.8%
Basic Energy Sciences	2,166,000	2,213,000	1,935,673	-277,327	-12.5%
Biological and Environmental Research	705,000	750,000	516,934	-233,066	-31.1%
Fusion Energy Sciences	564,000	671,000	425,151	-245,849	-36.6%
High Energy Physics	980,000	1,045,000	818,131	-226,869	-21.7%
Nuclear Physics	690,000	713,000	653,327	-59,673	-8.4%
Workforce Development for Teachers and Scientists	22,500	28,000	20,500	-7,500	-26.8%
Science Laboratories Infrastructure	232,890	301,000	174,110	-126,890	-42.2%
Safeguards and Security	106,110	112,700	115,623	+2,923	+2.6%
Program Direction	183,000	186,300	190,306	+4,006	+2.2%
Total, Office of Science	**6,585,000**	**7,000,000**	**5,837,806**	**-1,162,194**	**-16.6%**

The SC Request includes ongoing investments to support the Administrations Industries of the Future (IOTF) initiative through research in **quantum information sciences (QIS)** and **artificial intelligence (AI) and machine learning (ML)**. The Request also supports research efforts in next-generation **microelectronics**, genomic sciences to inform biosecurity research, and critical scientific infrastructure needs at DOE laboratories. The Request also initiates several new multidisciplinary research initiatives including: data and computational collaboration with NIH, integrated computational and data infrastructure for scientific discovery, next generation biology, rare earth and separation science, revolutionizing polymer upcycling, and **strategic accelerator technology**. These new initiatives position SC to meet new research demands in an enhanced collaborative effort.

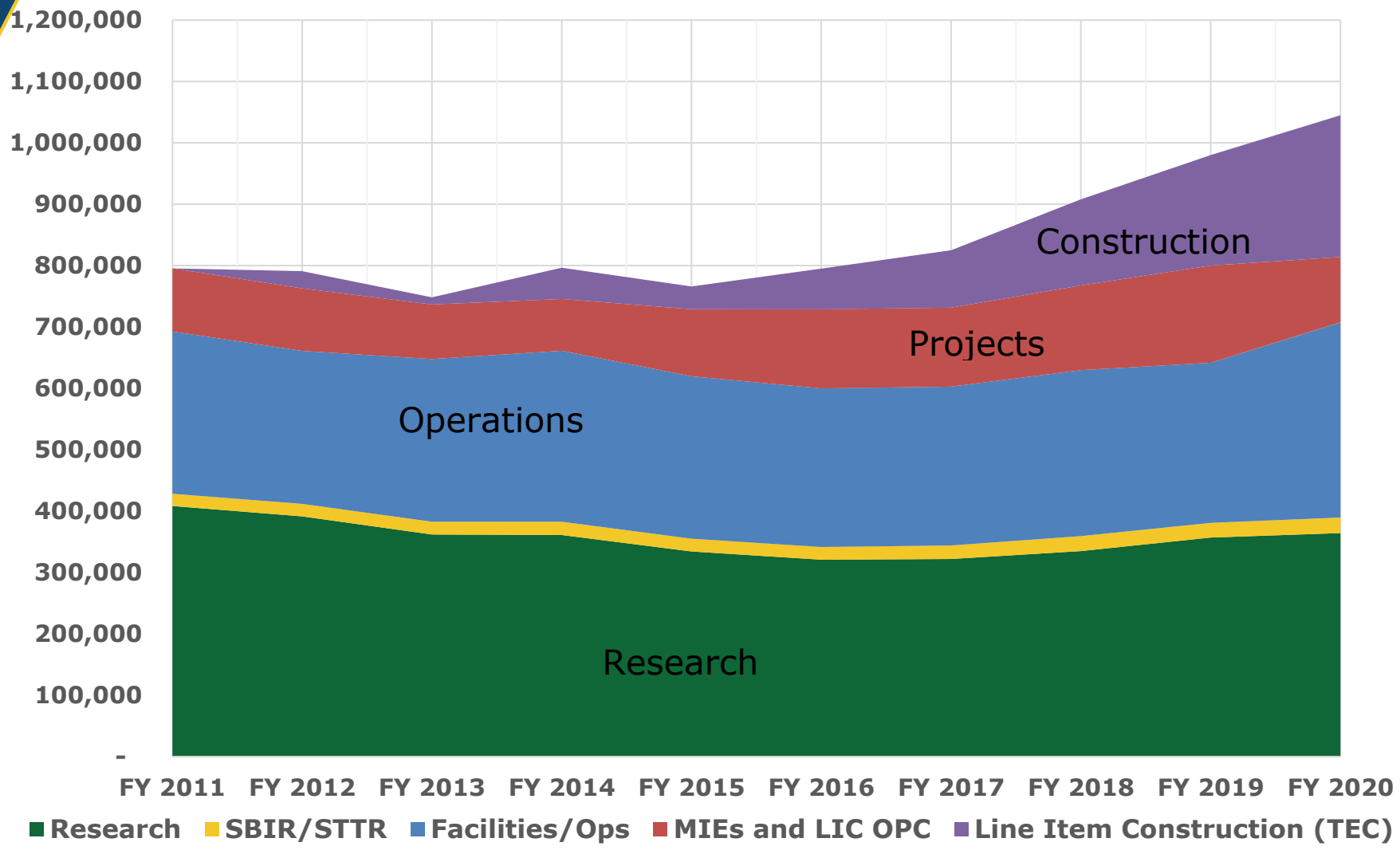
HEP Budget: U.S. Congress Supports P5 Strategy

- U.S. Congress continues to show strong support for executing the P5 strategy, and for accelerating the pace of projects



- When the P5 report was released in May 2014, the FY 2015 budget was already in Congress and the FY 2016 budget was being formulated
- Arguably the first impact (success!) of the P5 report was not seen until FY 2016, and continues today…

HEP Budget ($K) FY 2011-2020



HEP Budgets – Rollups, Initiatives (FY18-21)

HEP ($K)	FY18 ACTUAL	FY19 ACTUAL	FY20 enacted	FY21 request
Research	359,177	372,629	390,077	328,906
Facility Ops	270,488	266,556	316,429	285,725
Projects	278,335	340,815	338,494	203,500
HEP Total	**908,000**	**980,000**	**1,045,000**	**818,131**

FY2020 appropriation

Energy: -5M HL-LHC Projects

Intensity: -14.5M PIP-II OPC; +3M DUNE OPC; Fermilab Accelerator ramps up

Cosmic Project changes: -26.35M DESI, LZ, SuperCDMS-SNOLAB projects; +2M CMB-S4

Cosmic Operations ramps up > $20M for Rubin Observatory, LZ, DESI, SuperCDMS-SNOLAB

Theory, Computational, and Interdisciplinary: +11M QIS; +10M AI/ML; +2.5M LQCD

Advanced Technology: -10M FACET-II SLAC; Operations ramps up

HEP ($K) - Research Initiatives	FY19 actual	FY20 enacted	FY21 request
AI/ML	3,750	15,000	34,500
QIS	27,500	28,500	43,809
Microelectronics			5,000

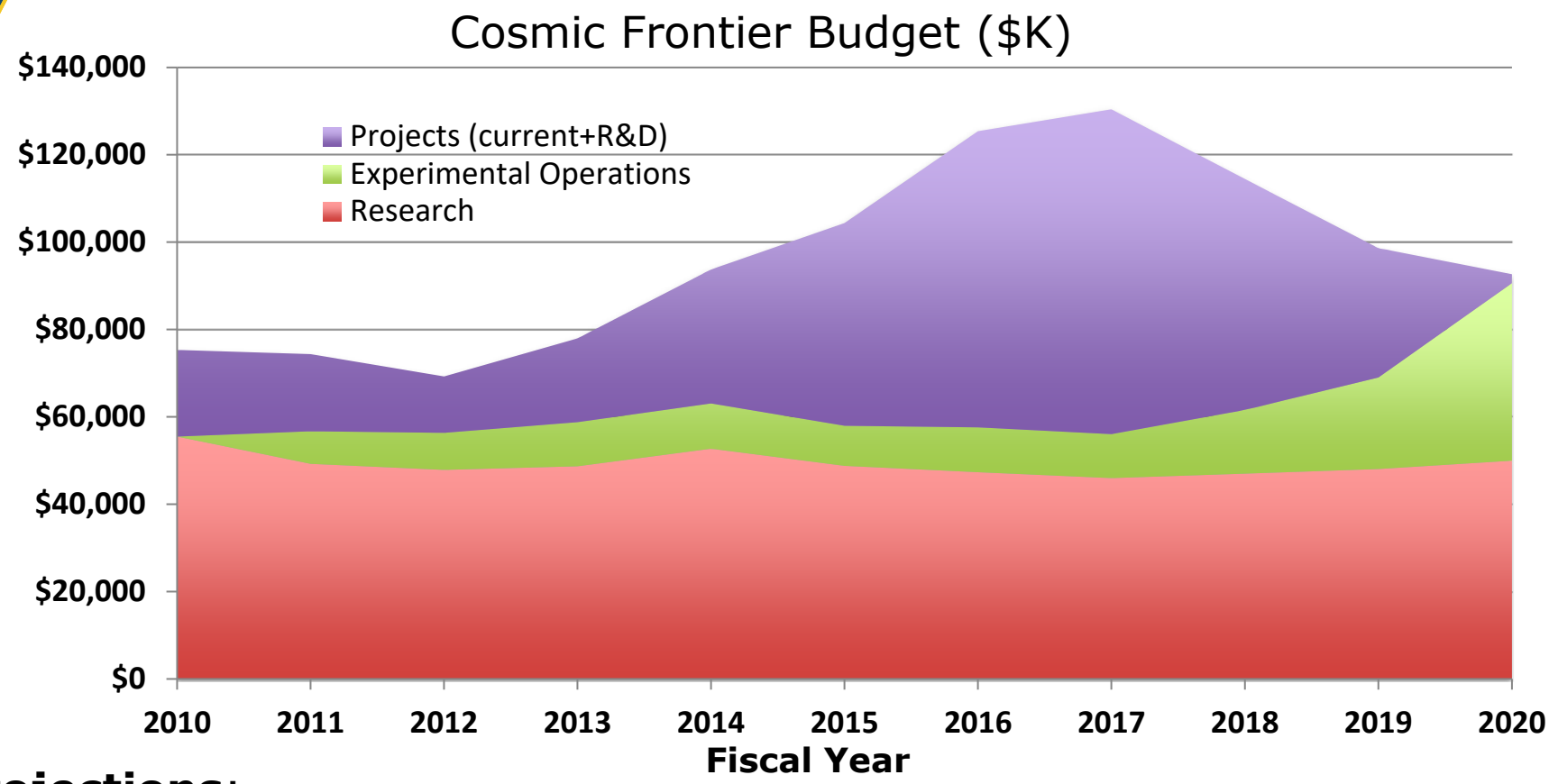
HEP Cosmic Frontier Budget: FY 18-21

HEP Cosmic Frontier ($K)	FY18 Actual	FY19 Actual	FY20 Enacted	FY20 June	FY21 Request
Research	47,008	48,053	48,072	49,970	29,220
Facility Ops	14,570	20,957	41,358	40,660	37,400
Projects	52,835	29,615	2,000	2,000	1,000
SBIR	2,487	2,869	3,471	3,471	2,300
TOTAL	**116,900**	**101,494**	**94,901**	**96,101**	**69,920**

FY20 appropriation:
Cosmic Project changes: -26.35M DESI, LZ, SuperCDMS-SNOLAB projects; +2M CMB-S4
Cosmic Operations ramps up > $20M for Rubin Observatory, LZ, DESI, SuperCDMS-SNOLAB

HEP Cosmic Frontier MIE Projects ($K)	FY18 Actual	FY19 Actual	FY20 enacted	FY21 request
LSST Camera	9,800			
DESI	20,000	9,350		
LZ	14,100	14,450		
SuperCDMS SNOLAB	7,400	2,550		
CMB-S4			2,000	1,000

Cosmic Frontier Budget History (FY10-20)



Projections:

- **Experimental Operations**: As the current Projects complete, estimated needs 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. Guidance from Astro2020, next P5.

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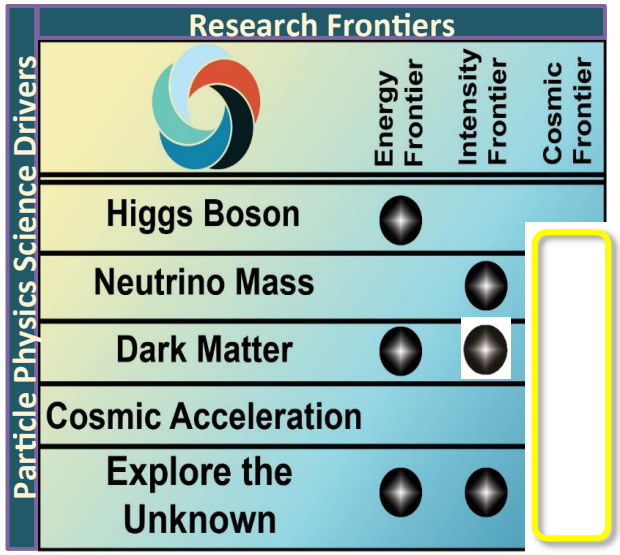
Cosmic Frontier

Cosmic Frontier Experimental Research Program

Address 2014 "P5" strategic plan science drivers using naturally occurring cosmic phenomena via ground-based telescopes & arrays, space missions, and deep underground detectors

→ Use Staged Suite of Experiments



Cosmic Acceleration:

- Imaging & Spectroscopic surveys to determine the nature of **Dark Energy** (with NSF/AST)
- Study the Inflationary era using its imprint on the cosmic microwave background (**CMB**) at energies near the Planck scale (with NSF)

Dark Matter: Search for particle dark matter (high- and low-mass WIMPs; axions) through direct detection experiments deep underground (with NSF/PHY)

- Cosmic-ray & Gamma-ray studies provide indirect searches for dark matter particles & searches for New Physics
- Future planning: Dark Matter New Initiatives (DMNI) – concept development small projects

Neutrino Mass: Unique constraints from Dark Energy and CMB experiments

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

Dark Energy Spectroscopic Instrument (DESI)

DOE's DESI is ready to take data!

- premier multi-object spectrograph and the first **Stage IV dark energy** project to start operations
- designed and built through the efforts of a large international collaboration ~ 500 researchers at 75 institutions in 13 nations.
  - Partners: STFC, Heising-Simons, Gordon and Betty Moore, France, Mexico, Spain, NSF

DOE/LBNL-led Major Item of Equipment Project to fabricate instrumentation & data management system, upgrades of NSF's Mayall telescope; Total Project Cost $56.328M

- HEP has MOU w/NSF-AST to "lease" the Mayall telescope
- Full support for Mayall dark energy operations has started

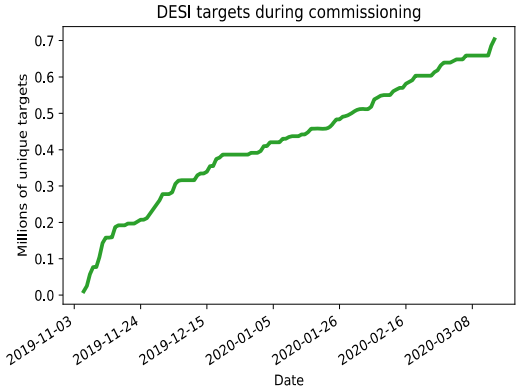
LBNL continues to lead the Operations Phase & Scientific Collaboration

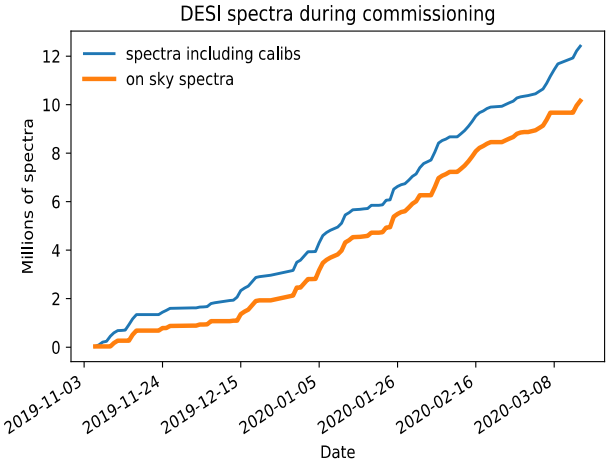
See https://vimeo.com/422889846

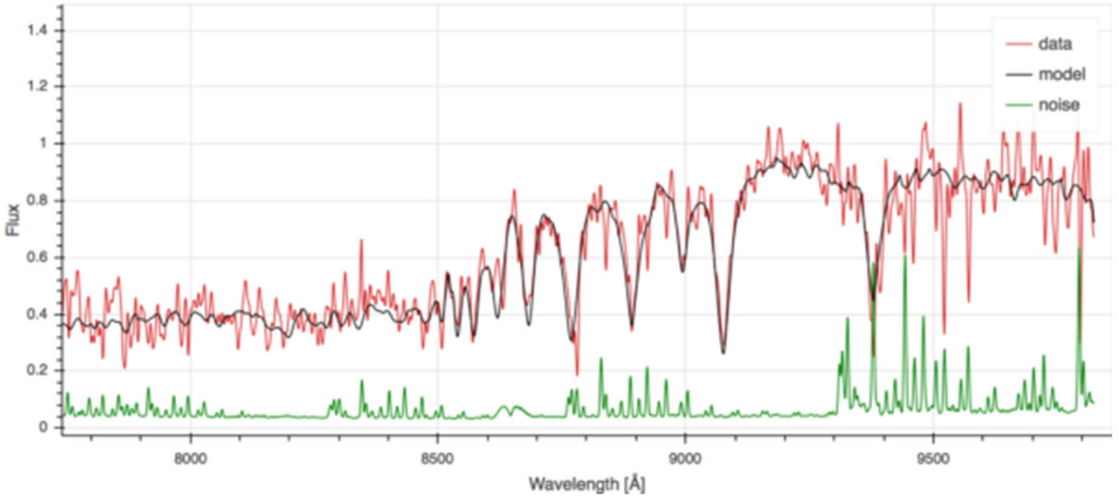
DESI Commissioning Successful – Completed mid-March 2020

5-month Commissioning Run went as planned

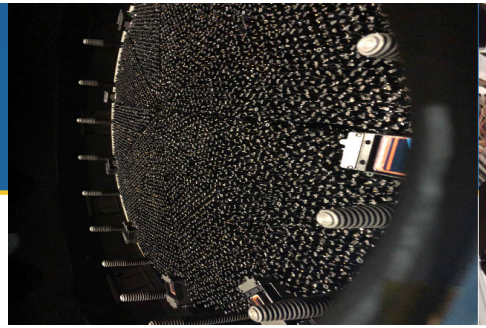
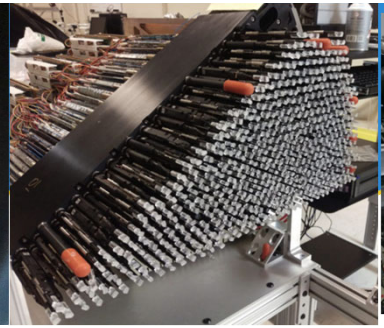
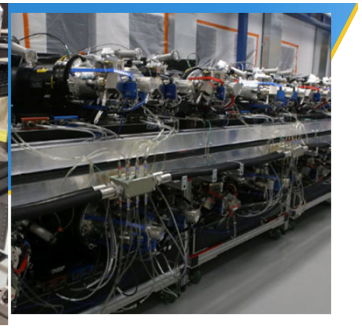
- Key Performance Parameters all met and exceeded performance
  - 8 sq deg Corrector Mechanical Systems & Optics – installed, commissioned
  - Focal plane system – installed, commissioned
    - high-precision (10 micron) positioning of the fibers under active feedback
  - Spectrograph system – installed, commissioned
  - Instrument control system – installed, commissioned
  - Offline system infrastructure – installed, commissioned
  - Commissioning and demonstration of End-to-end function
- 12 Million On-sky Spectra taken, 700K unique objects



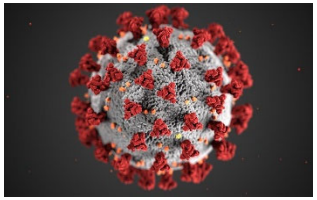




DESI Timeline

Sept. 2012 CD-0 Mission Need
2019: All imaging surveys for target selection completed (16,000 sq deg)
Oct. 2019 First light; Commissioning started
March 2020: Mini-SV survey obtained 100K's science quality spectra
March 16, 2020: All Project Deliverables complete, including Commissioning
April 2, 2020: CD-4 review – passed
May 11, 2020: CD-4 approved, fabrication complete, ready to operate



COVID-19 impacts – Survey Operations are on hold
March 16 - 22, 2020: DESI was closed up and put into safe mode
April 17, 2020: Inauguration event postponed
Kitt Peak developing a restart plan for the site
DESI will require a short recommissioning and restart to operations after a 4-month survey validation run

- Work continuing during shutdown: Targeting survey public data will be out in a few months; analysis ongoing, remote system testing, planning

Early Operations - needed items identified: Spares, Safety systems upgrade, Dry air system - - contamination monitor found that even though there was new air compressors, it turns out the pipes were old & will need to be replaced

Vera C. Rubin Observatory

New state of the art observatory on Cerro Pachon in Chile

- For the first ten years of operations, the observatory will perform the wide-field, optical and near-infrared imaging **Legacy Survey of Space and Time (LSST)**, using the **LSST Camera** and the **Simonyi Survey Telescope**.

4 main science themes: probing dark energy and dark matter, inventory of the solar system, exploring the transient optical sky, & mapping the Milky Way.

- **DOE is participating for the Stage IV Dark Energy capabilities**

- Both NSF and DOE support community science.
- DOE efforts organized by DESC.

Vera C. Rubin Observatory Project

NSF (lead agency) and DOE partnership
- **NSF roles led by AURA; DOE roles led by SLAC.**

Agency Oversight and Reviews:
- Weekly NSF/DOE Joint Oversight Group (JOG) meetings
- Joint reviews of Project and Facility Operations plans

Construction to build and commission the observatory; have 2012 MOA

- **NSF MREFC Project ($473M) 8.4m** Telescope and Site, Peta-scale Data Management, Education & Public Outreach; **Simonyi & Gates** contributions to long-lead items. **Chile** partnership.

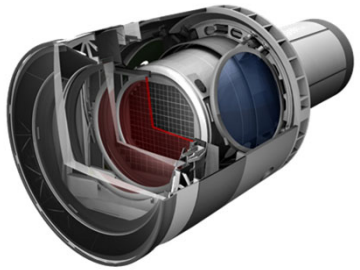
- **DOE Camera MIE Project ($168M);** completes when the 3.2 G-pixel Camera is integrated and tested at SLAC; Commissioning in Chile is lined up to complete with MREFC. **France/IN2P3** contributions.

Facility Operations supported by both agencies; plan addendum to the 2012 MOA

Rubin Observatory – Project Status (as of mid-March 2020)

Project is going well & significant progress has been made

- Continues to meet technical requirements in support of the Science Requirements Document. Significant progress on dome and telescope mount



The 3.2 Gigapixel LSST Camera will be the largest electronic camera ever built for ground-based facilities.

DOE responsibilities →

LSST Camera Project: 96.6% complete

All MIE funding provided by FY18, TPC $168M; MIE completes when Camera is integrated and tested at SLAC; Planned to complete May 2021 [Critical Decision 4 in March 2022]

- February 2020 data: Project had $1.6M of contingency on $4.9M remaining work, a healthy 33%, and on track for a successful completion

Rubin Observatory Commissioning is supported on HEP program funds; lined up to complete with NSF's MREFC at the end of FY2022. HEP support for commissioning started FY18: camera I&T, commissioning observatory systems

DOE LSST Camera scope status

WBS	Baseline ($K)	% complete
3.06.05 Utility Trunk	$1,385	97%

WBS	Baseline ($K)	% complete
3.04.02 Corner Raft Tower	$7,064	100%

WBS	Baseline ($K)	% complete
3.04.01 Science Raft Tower	$17,507	100%

WBS	Baseline ($K)	% complete
3.03 Sensors	$34,011	100%

WBS	Baseline ($K)	% compl
3.07.02 Aux Electronics	$2,298	100%

WBS	Baseline ($K)	% complete
3.06.01 Camera Body	$2,395	100%

WBS	Baseline ($K)	% complete
3.06.04 Cryostat	$16,394	99%

WBS	Baseline ($K)	% complete
3.06.02 Shutter	$3,030	100%

WBS	Baseline ($K)
3.06.03 Filter Exchange System	Contributed

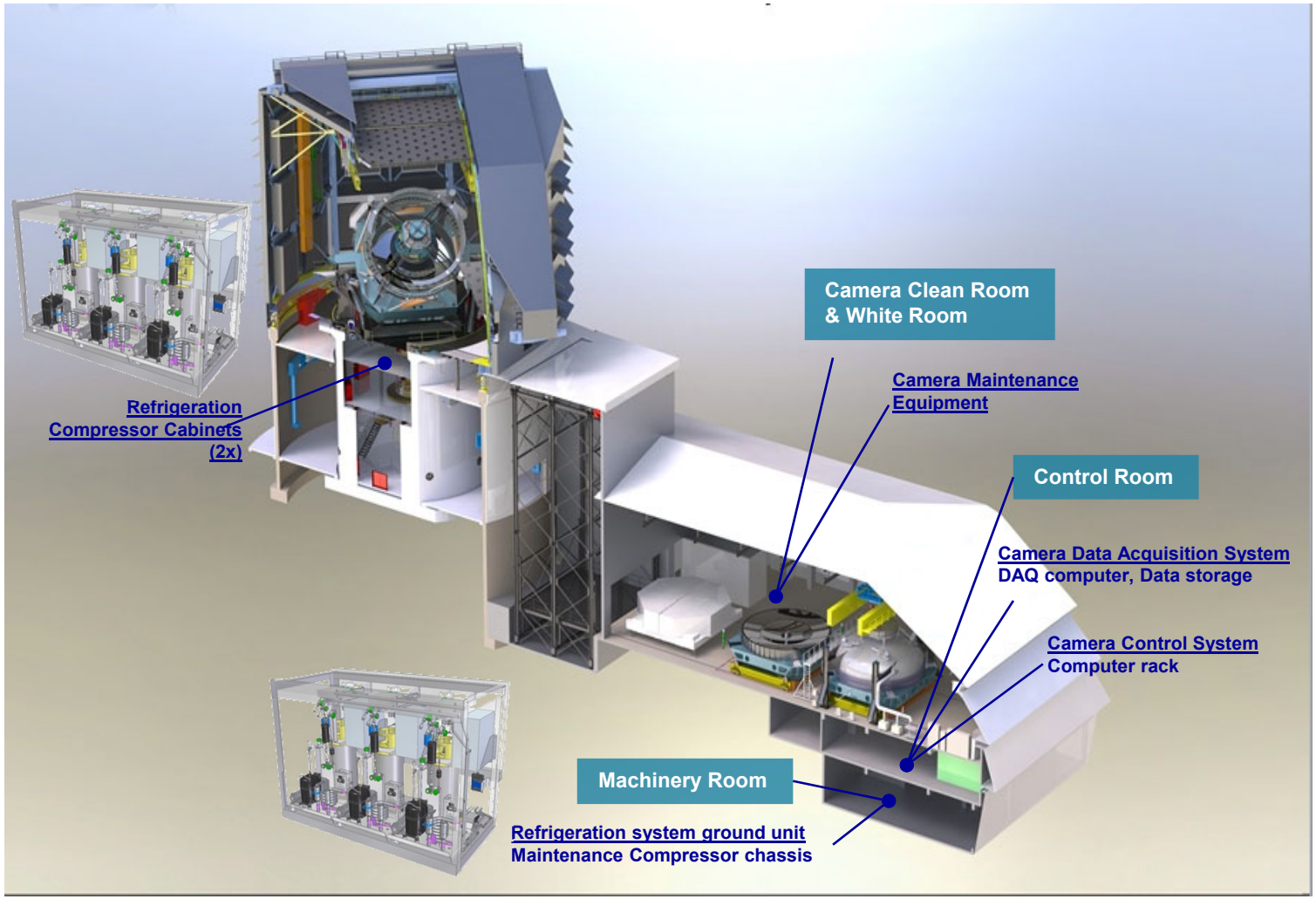
3.05.04 L3 Lens Assembly

3.05.02 Filters (6)

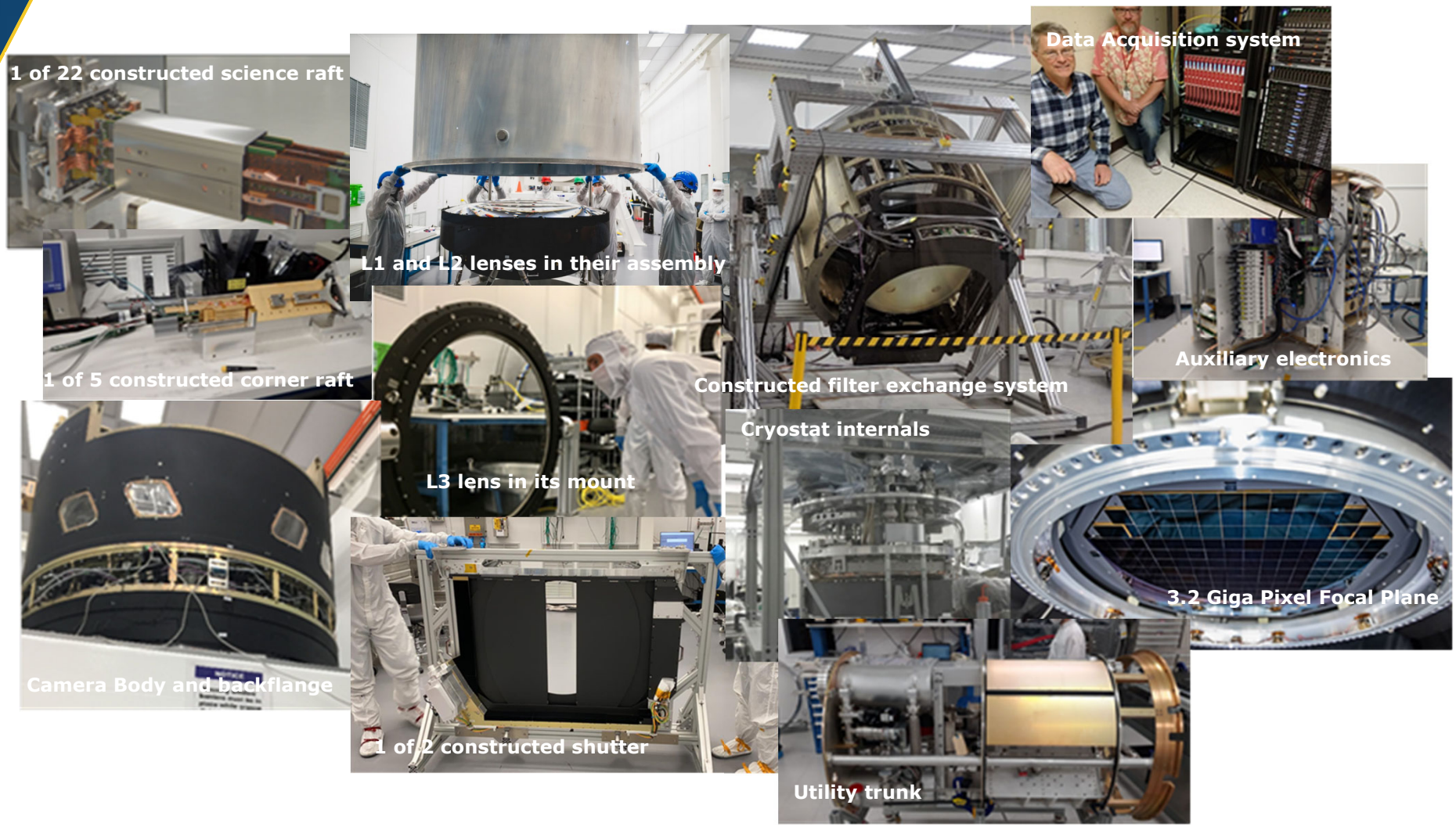
3.05.03 L1-L2 Lens Assembly

WBS	Baseline ($K)	% complete
3.01 Management	$15,488	96%
3.02 Systems Integration	$9, 376	96%
3.05 Optics	$28,151	94%
3.07.01 Control System	$5,183	92%
3.07.02 Data Acq Sys	$5,424	100%
3.08 Integration and Test	$13,407	87%
TOTAL	**$161,112**	**96.9%**

LSST Camera
- Location of Off-Telescope Components



LSST Camera Status in Pictures – All hardware has been fabricated at the sub-system level and most has been assembled



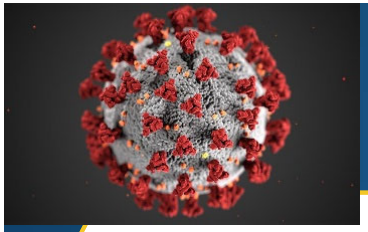
Commissioning Status – in pictures

Installation of the MIE delivered refrigeration cabinets on the summit (Jan 2020)

Commissioning camera in Chile delivered by MIE and MREFC and being reverified prior to installation on the summit (Apr 2020)

Refrigeration pathfinder unit built at SLAC and delivered to the summit (Feb 2020)

Installation and flushing of the refrigeration lines (Oct 2019)



Rubin Observatory – Current Status

Both the Rubin Observatory and LSST Camera MREFC and the MIE efforts have been seriously impacted by the COVID-19 crisis. Delays of 6-12 months?

COVID -- In mid-March:

- Observatory reduced construction activities in Chile to essential work. Site was secured as safely as possible; Small crews doing intermittent inspections.
- Chile closed its borders; Offices in La Serena telework only.
- Due to the California shelter-in-place order and the resulting SLAC shutdown, **Camera fabrication activities were halted**. The camera was left in a safe mode and is being monitored remotely. Only essential security/safety personnel could go to SLAC. Software, computing, and other work that can be done remotely/by telework is continuing.

Current Camera Status

- Camera restrictions continue with gradual and phased re-start of activities at SLAC starting mid-May
- Phased restart with strict personnel safety measures and reduced work efficiency has increased duration and cost of remaining work significantly; at the same time risks have increased dramatically due to the continuing COVID pandemic

LSST Camera Project – Path Forward

- The Camera KPPs constrain the requirement trade-off within the overall Project to ensure the integrated design will meet the science requirements.
- All 7 MIE KPPs can be verified at the component (as opposed to system) level
- Further work on the MIE will not change the KPP performance; all remaining work consists of assembly and will not enhance components

- 6 of 7 Threshold KPPs met or exceeded; Filter 'sensitivity range' on track and expected to be met; Filters will be delivered by Nov.2020.

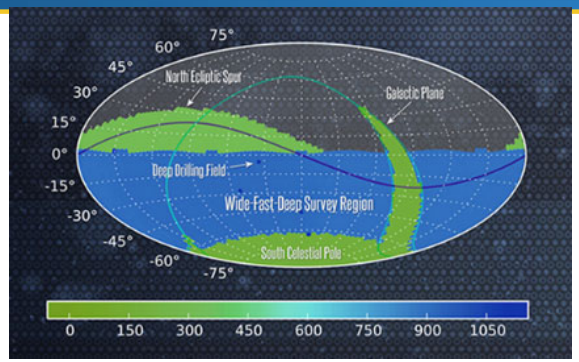
- 5 of 7 Objective KPPs met; 1 is not fully met for the combination of readout time, Readout noise and number of pixels. 'Sensitivity range' is expected to be met.

Key Performance Parameters (KPP)

Description of Scope	Threshold KPP	Objective KPP	Performance
Field of view coverage (square degrees)	> 9.3	> 9.6	9.73
Pixel size	0.2 arcsec	0.2 arcsec	0.2 arcsec
Number of pixels	> 2.6 Gigapixels	> 3.2 Gigapixels	3.2 Gigapixels (2 sec/No Defect) 3.1 Gigapixels (2 sec/13e-) 2.9 Gigapixels (2 sec/9e-)
Array readout time	< 3 seconds	< 2 seconds	1.996 seconds
Sensitivity range	320-1050 nm	320-1050 nm	300-1100 nm
Shutter minimum exposure time	< 2 seconds	< 1 second	0.901 second *
Readout electronic noise, single exposure	< 13 electrons	< 9 electrons	< 9 electrons

DOE will be considering options – Complete Camera Project on threshold KPPs and then complete the assembly as part of the Camera commissioning; Otherwise will likely need to rebaseline since cost/schedule will be exceeded

Rubin Observatory: Facility Operations Planning



The Rubin Observatory will conduct a 10-year deep, wide, fast, optical imaging Legacy Survey of Space and Time (LSST) using DOE's LSST camera and the Simonyi Survey Telescope

→18,000 sq deg, 6 filter bands, ~ 1000 visits per sky patch

- Catalog of more than 20 billion galaxies & 17 billion stars

FY19: NSF and DOE funding started ramp-up.

May 2019: DOE & NSF agree to provide ~ equal support for operations.

- DOE & NSF, with input from the Operations planning team, has been investigating options for laying out DOE & NSF scope and budgets
  - DOE will support the US Data Facility; selection process in development

Rubin Observatory: Facility Operations Planning

DOE and NSF will consider **international in-kind contributions** in exchange for data rights/access during the 2 year proprietary period (same rights as US and Chilean scientists).

→ In-kind priority is to offset operations costs; 2nd priority is to enhance US science, esp. LSST science. Agencies will make final decisions on in-kind contributions and agreements.

→ In-kind process is proceeding but delayed due to COVID19. Feedback to proposers on intended contributions by end of July. Proposals due to Rubin Observatory by end of Sept. 2020. Goal is agreements by end of CY2020.

Survey Cadence status report on simulations progress based on community input in 2019 will be shown at the virtual Project Community Workshop in August. It is expected the project will use the COVID19 delay to gather further community input in a series of workshops as the project converges on the final strategy in 2022.

Joint NSF/DOE Operations Planning status review – held April 2020 by ZOOM

Related Efforts:

Satellite Mega-Constellations impacts on astronomical observations is being studied in the community → Many groups involved.

- JASON study being held in late June 2020
- Satellite Constellations 1 (SATCON1) workshop from 29 June to 2 July 2020.

Dark Energy Stage III
- Extended Baryon Oscillation Spectroscopic Survey

Precision measurements to differentiate between cosmological constant and/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)

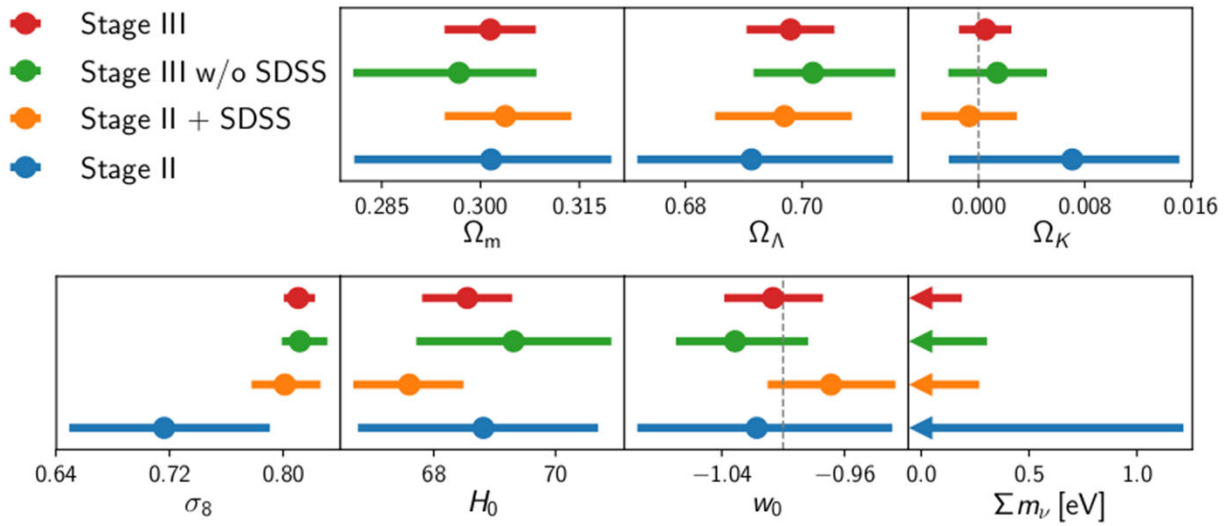
eBOSS -- Stage 3 Spectroscopic Survey for Dark Energy.

- Started in 2014, ended March 1, 2019; successor to BOSS (2009-2014)
- Part of Sloan Digital Sky Survey (SDSS-IV), Apache Point Observatory, NM
- DOE/HEP partnership w/Sloan Foundation, US universities, international
  - **DOE/HEP: provided new spectrograph for BOSS & eBOSS**
  - **DOE/HEP: major sponsor of observatory operations for BOSS & eBOSS**

Major Milestone: Final results and papers in Collaboration review; submitting in July

→BAO/RSD from LRG, ELG, & quasars over 0<z<2; BAO from Lyman-alpha forest & quasars at z=2.35

→ Tighter cosmological constraints than SNe Ia; 1% precision estimates of H0; 50X improvement relative to Stage-II in 5-parameter likelihood spanned by w, Wk, neutrino mass, sigma_8, and H0; Stage-III (Planck, SDSS, Pantheon SNe Ia, DES yr1) is 1000X decrease in likelihood volume



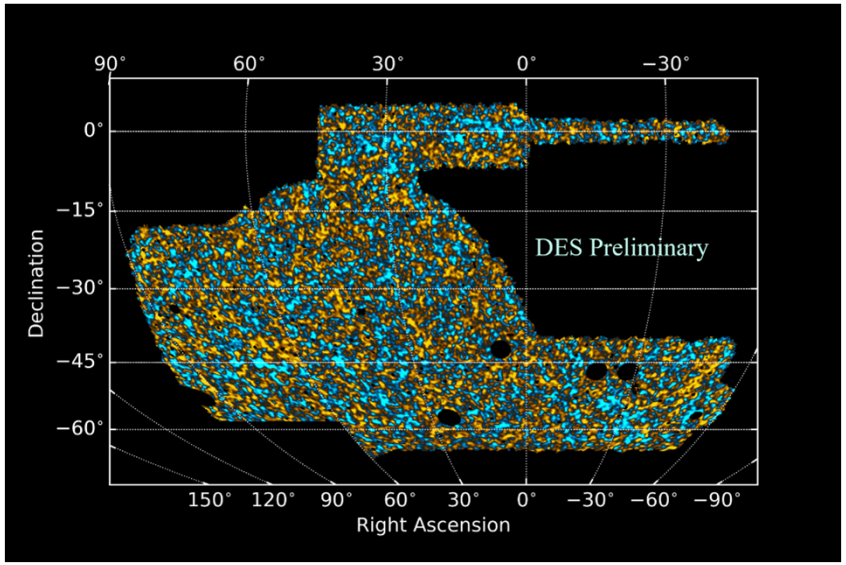
Dark Energy Stage III: Dark Energy Survey (DES)

DARK ENERGY SURVEY

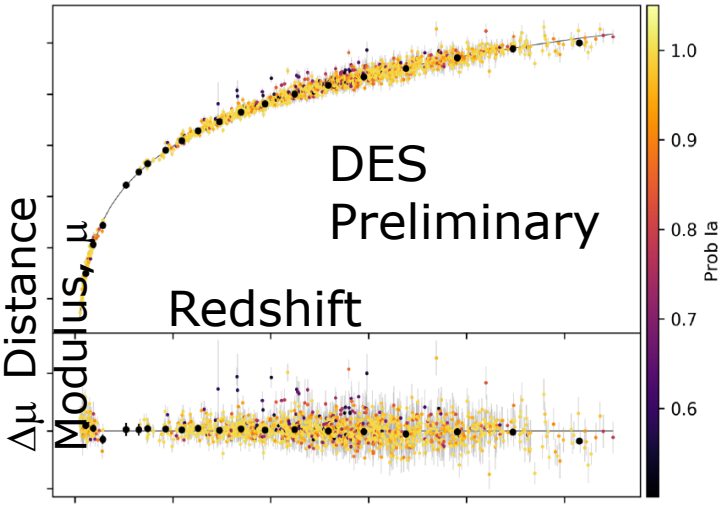
***Stage 3 Dark Energy Imaging survey:* on NSF's Blanco Telescope at CTIO**

- **DOE-HEP partnership with NSF-AST:** HEP provided Camera (DECam); NSF provided data system; both participate in operations, science
- Completed Observations Jan.2019; Met all survey metrics
- Public "DR1" based on 1st 3 years data (Y1-Y3) in 2018
- Public "DR2" based on 1st 6 years data (Y1-Y6) in early 2021
- 276 science publications on range of topics (May.2020)

Collaboration is now concentrating on Y3 "3x2pt" weak lensing, Y5 SN1a, and Y3 cluster cosmology analyses; Y6 cosmological results to follow



3x2pt" Weak Lensing Analysis Y1-Y3 data



Photometric-Typed Y1-Y5 SN1a

Determining the Nature of Dark Energy – Next Generation

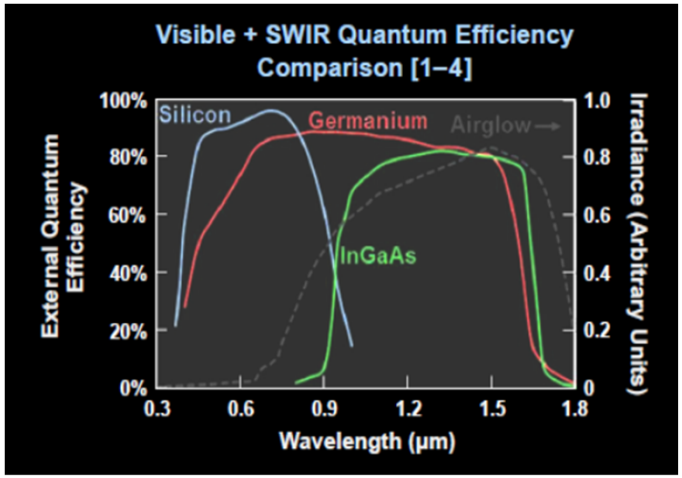
Power of a cosmic survey for precision measurements of cosmological parameters is limited by Redshift accuracy, Redshift range, Statistics

➔To fully exploit current program of ground- and space-based experiment will require advances in theory, simulations, joint data analysis and computing

- Cross-cutting theory and simulations efforts
- Joint modeling and analysis of imaging, spectroscopic, CMB and other data
- Exascale Cosmological Simulations - Expanding the nonlinear structure frontier, pushing to smaller scales
- need advances in technologies for Stage 5, methods to increase redshift range, accuracy and statistics.

Community efforts:

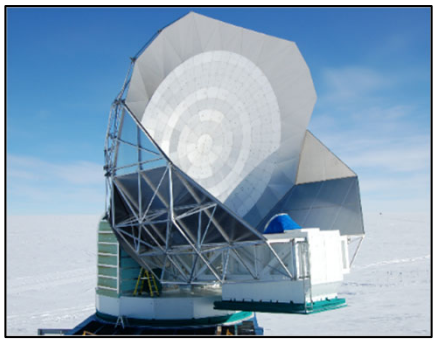
- Cosmic Visions Dark Energy group investigating ways to optimize science in DESI/LSST era
  - White paper on small "enhance" efforts in Jan 2018 arXiv:1802.07216
- Technology development for Stage-V surveys, e.g.
  - Germanium CCD R&D
  - "Skipper" CCDs ultra-low readout noise; precision counting of single photons in the optical & NIR
  - Fiber positioner designs to increase density
- HEP community is leading or participating in some concepts – White Papers submitted to Astro2020

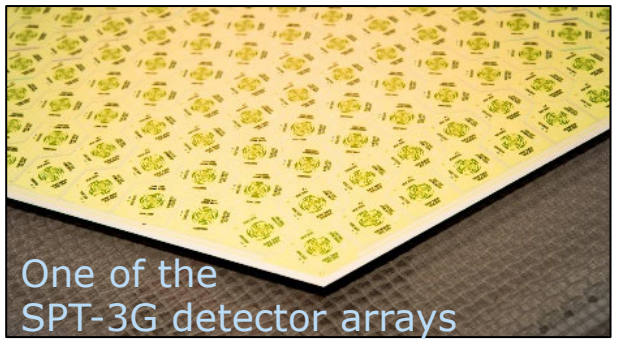


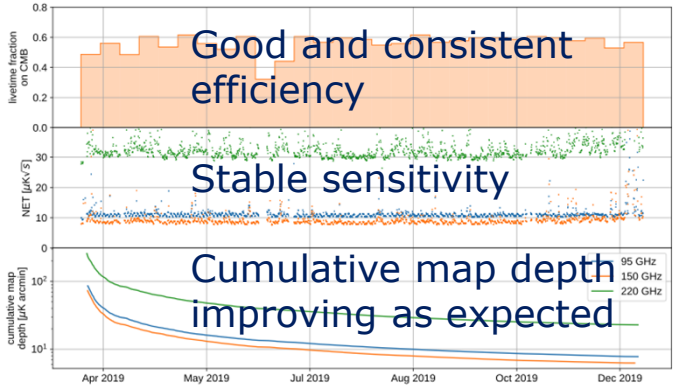
Cosmic Microwave Background

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

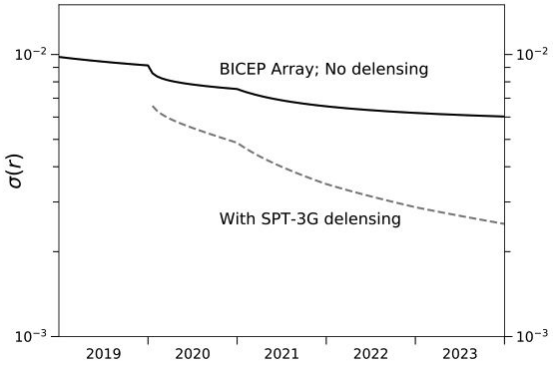
- HEP (via NERSC computing) participates in science collaborations (e.g. **BICEP, PolarBear**) and had a significant role in **Planck.**
- ***SPT-3G:*** DOE-HEP partnership with NSF (-OPP,-PHY,-AST)
  - DOE HEP fabricated the 16,000-detector SPT-3G focal plane greatly increasing instrument sensitivity.







SPT-3G is running at full power and high observing efficiency
- no COVID impacts as of June



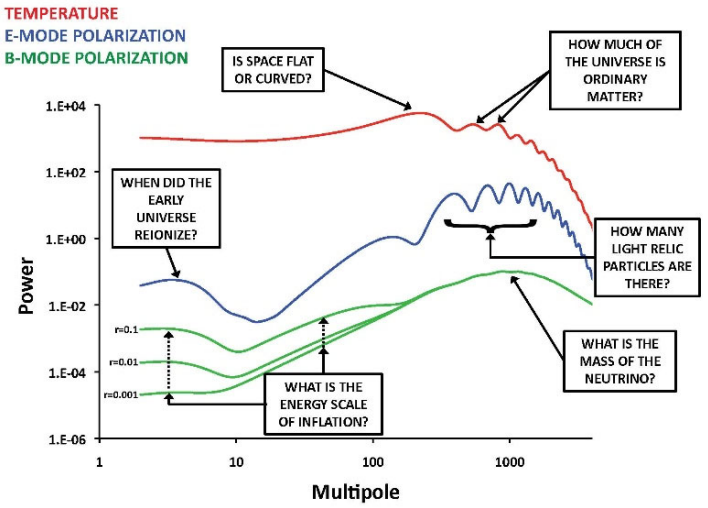
SPT science

- Site + large aperture + high sensitivity camera gives SPT world-leading sensitivity from degree to arcmin angular scales.
- High redshift cluster survey explores Dark Energy
- Neutrino properties and searches for new particles via precision measurements of E-mode and lensing signal
- *BICEP Array + SPT-3G delensing will achieve the best constraints on "r," which is related to the inflation energy scale, prior to CMB-S4.*
  - Also, supports EHT ~ 10 days/year (was part of 2019 first black hole image)

Cosmic Microwave Background Stage 4 (CMB-S4) Project → Discovery Science!

CMB-S4 recommended by P5 in all scenarios

Goal: cross critical science thresholds



2 sites, Atacama in Chile, South Pole

- Deep & wide N_{eff} & Legacy Survey with 2 x 6m telescopes targeting ~60% of sky w/240,000 detectors over 6 bands.
- Ultra-deep "r" survey with 18 x 0.55m small refractor telescopes targeting ≥ 3% of sky w/150,000 detectors over 8 bands and a dedicated de-lensing 6m telescope with 120,000 detectors.

Science	Stage 2	Stage 3	Stage 4	Top Level goal for CMB-S4
Inflation "r"	≤0.1	≤0.01	≤0.001	Detect or rule out compelling classes of inflationary models
σ(Neff)	0.14	0.06	0.03	Detector/rule out light relic particles w/ spin
σ(Mν)	0.15eV	0.06eV	0.02eV	3σ detection
# detectors	~1000	~10,000	~500,000	Deployed on multiple telescopes
Sensitivity (μK^{-2})	10^5	10^8	10^8	2° to 1' angular scales

CMB-S4 planning, status

CMB-S4 Project Office is planning unified ~$600M TPC multiagency project

- As recommended by P5 (2014) and AAAC/CDT (2017)
- Planned Partnership DOE/HEP & NSF (AST, PHY, Polar), scope ~ 60/40 DOE/NSF (±5%)

Integrated Project Office (IPO) - technical studies, concept design, planning

- Proposed timeline is for DOE CD-1/3a and NSF-PDR in 2021
- Technology Assessments complete:
  - Detector fab fall 2019, Optical coupling May 2020, Readout June 2020

NAS Astro2020 Decadal Survey underway, expect recommendations in early 2021

- July 2019 submission of White Paper; Fall 2019 RFI, February 2020 Q&A
- Full TRACE completed March 2020

DOE & NSF: Weekly Joint Oversight Group (JOG) meetings

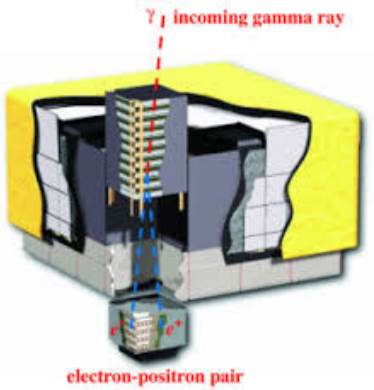
DOE Status as of (June2020):

Approved Critical Decision 0 (CD-0) "Mission Need" in July 2019

- providing R&D support for Project planning, technology R&D; also Lab R&D
- working to support the IPO timeline of FY2021 CD-1/3a
- **completing a process to select a lab to lead our efforts**
- **status review, Aug 18-20**, zoom only

NSF MSRI-R1 to U. Chicago (Sept 2019) to begin work on Preliminary Design

Fermi Gamma-ray Space Telescope: Large Area Telescope (LAT)

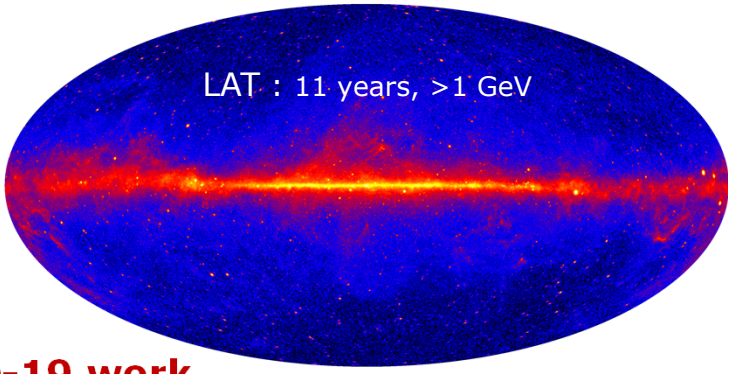


DOE HEP partnered with NASA on fabrication of the LAT at SLAC, together with international contributors: France, Italy, Japan, Sweden.

Science: Study ~20 MeV->300 GeV ɣ rays with particle physics detector technology in space. Indirect Dark Matter (DM) detection, etc.

Current Status:

- Launched June 2008, 5-year mission with 10-year goal
- LAT Operations: HEP, in coordination with NASA, continues support of critical efforts at SLAC
- 2019 July: NASA extended *Fermi* through FY22 based on the 2019 Senior Review, invited *Fermi* to propose for the next Senior Review in 2022

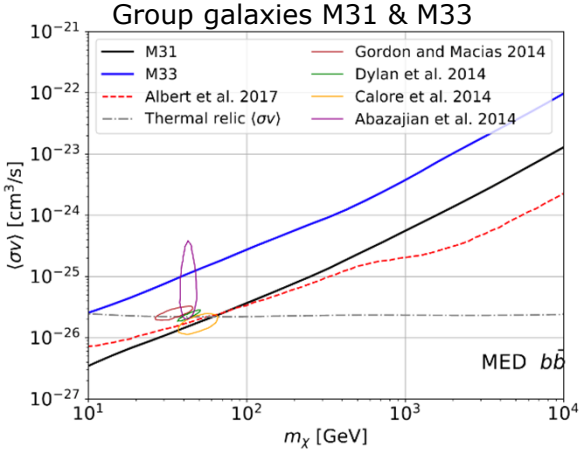


COVID-19: FGST continues full operations during COVID-19 work lockdown (all remote at-home operations support by SLAC)

LAT Collaboration Science Results (as of June 2020)

- 636 papers published
- New limits on photon-axion coupling from non-detection of prompt ɣ-ray emission from extragalactic SN; prospects for deeper limits from LAT operation during the LSST survey; Meyer & Petrushevska 2020, PRL, in press
- Competitive limits on DM annihilation based on LAT detection of Andromeda (M31), which has large ɣ-ray contribution from pulsars & interstellar diffuse, and non-detection of Triangulum (M33); Di Mauro et al. 2019, PRD, 99, 123027

Dark matter limits from Local Group galaxies M31 & M33



Alpha Magnetic Spectrometer (AMS-02)

Physics: Search for antimatter, dark matter annihilations & new particle phenomena on International Space Station (ISS).

→ Multi-purpose particle-physics spectrometer detects cosmic-rays up to multi-TeV; uses permanent magnet

→ 95% of construction costs from Europe and Asia

International Collaboration, with DOE/HEP leading US roles

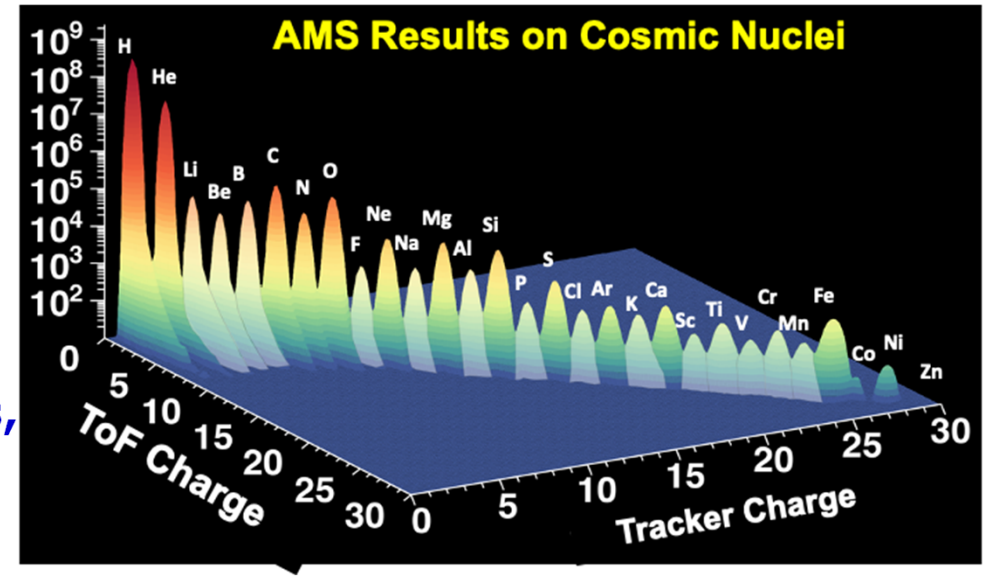
~ 250 scientists from 46 institutions in 16 countries

- **Under the agreement with NASA, DOE-HEP is responsible for management of the science program**
- DOE-HEP supports MIT group and their roles in Leadership, Science and Project Fabrication and Experimental Operations, led by Prof. Sam Ting
- NASA provides the use of the ISS power, data, and mission management
- CERN hosts the Operations Control Center

Recent Highlights

~150 billion cosmic rays collected.

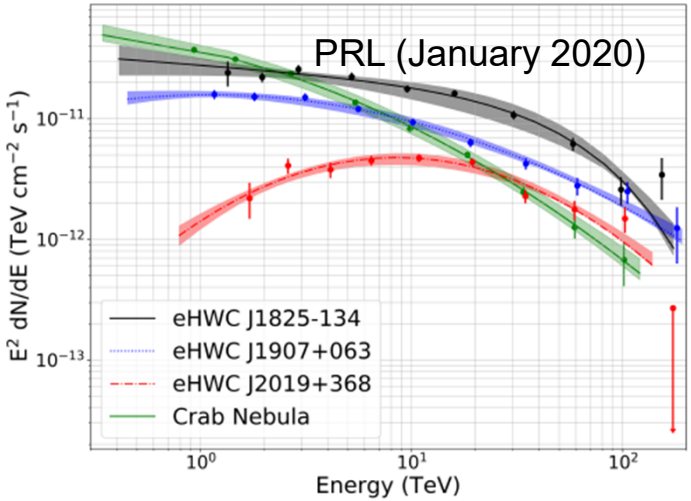
- **Recent EVAs by NASA enable AMS to operate beyond 2028.**
- **High precision results on cosmic-ray elementary particle and nuclei fluxes, search for heavy antimatter and the origin of dark matter.**



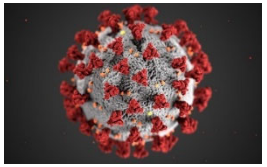
High Altitude Water Cherenkov (HAWC)

Gamma/cosmic-ray observatory located on the Sierra Negra in Mexico: Water Cherenkov Air Shower Detector, now with Outrigger array

- Partnership with NSF-PHY, Mexico
- 5 year ops. started early 2015
- HEP support for operations complete at end of 2020
- All sky γ-ray survey 100 GeV to > 100 TeV; Wide FOV and high energy sensitivity



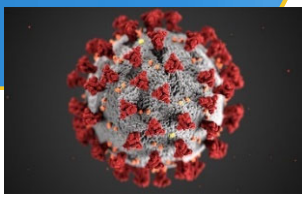
<u>Recent Results:</u> Provides ~ 2 orders of magnitude better constraints on superluminal Lorentz Invariance violation; If Lorentz Invariance is violated, then g-rays above an energy threshold rapidly decay into e^+e^- pairs and can't propagate to earth
HAWC detected multiple g-ray sources whose spectra extend beyond 100 TeV



COVID: HAWC continues its current remote monitor and control of operations.

- HAWC produces 2TB of data/day which is stored on portable arrays in the local town with ~90 days capacity
- Data was just transferred to Mexico City (via Uber) and is being copied and transferred to UMD

Axion Dark-Matter eXperiment Generation 2 (ADMX-G2)



Stage 2 Direct Detection Dark Matter Axion Search

DOE-HEP experiment located at Univ of Washington; Managed by Fermilab; contributions from UK, Germany, Australia and private.

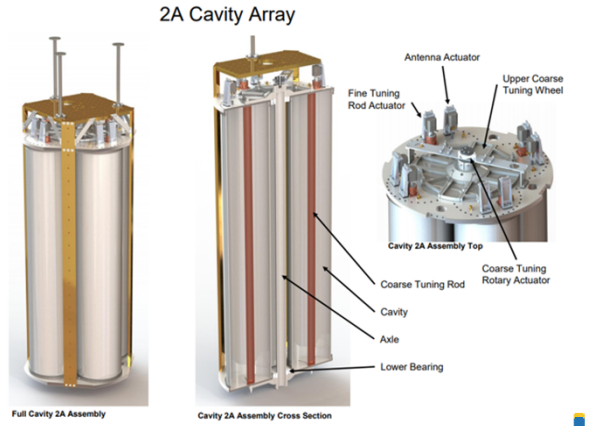
- Uses a strong magnetic field and resonant cavity to convert dark matter axions into detectable microwave photons

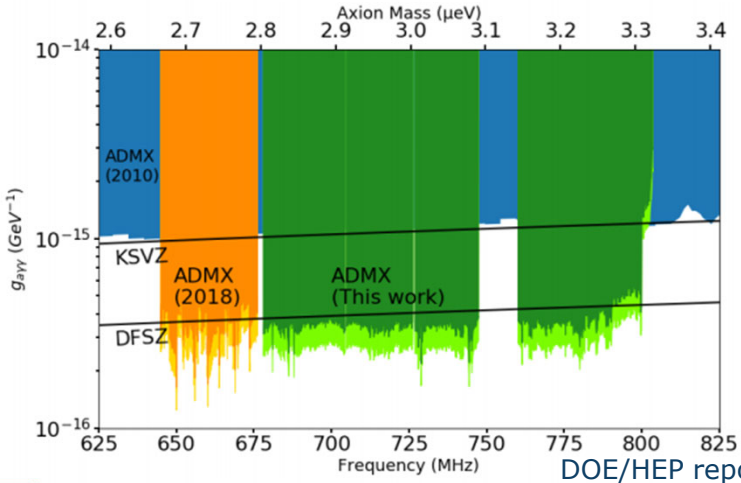
COVID-19: ADMX-G2 has continued data-taking operations; primarily remote w/onsite maintenance

In Operations: Runs 1A-2B (6 runs) covering 0.5 - 2 GHz (~ 2 to 8 micro-eV mass)
Started Aug. 2016; completion ~ 2023. **Only experiment sensitive to DFSZ axion.**

Published Data: Run 1A (645-800 MHz): PhysRevLett.120.151301 (Apr 9, 2019)
Run 1B (680-800 MHz): PhysRevLett.124.101303 (Mar 11, 2020)
Now Operating: Run 1C (800-1020 MHz) now operating smoothly (covered ~ 35 MHz so far)
Under development: Run 1D (1020 – 1390 MHz) – plan to start early 2021
Run 2A 4-cavity array and cold electronics

ADMX 2-4 GHz - Planning New Initiative, 14 superconducting cavity array



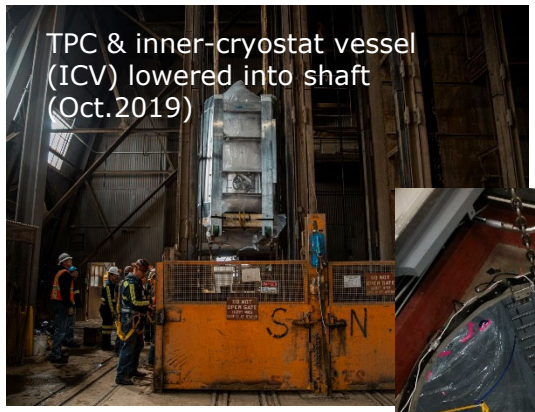


LUX - ZEPLIN (LZ) Experiment

Stage 2 Direct Detection Dark Matter WIMP Search.

- **HEP experiment (led by LBNL); Collaboration of 4 countries, 36 institutions**
- Uses a dual phase liquid Xe 10-ton TPC; sensitivity ≤ 2 x 10^{-48} cm^2 , close to where astrophysical neutrinos become irreducible background.
- Located nearly 1 mile underground in the Sanford Underground Research Facility (SURF) in Lead, SD.

Xenon: Kr Removal Plant at SLAC



TPC & inner-cryostat vessel (ICV) lowered into shaft (Oct.2019)

Project Status, Schedule (HEP TPC $55.5M)

- MIE Project – near completion
- Installation, commissioning in progress.
- **Threshold Key Performance Parameters complete;**
  - **Early CD-4 expected in September 2020**
- Final installation and commissioning underway
- Operations planning & pre-ops activities ongoing

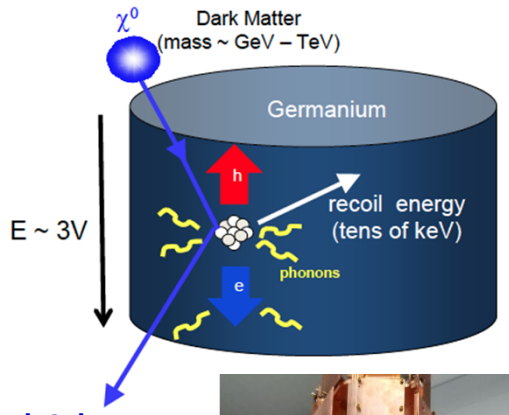
TPC/ICV inside OCV in water tank (Dec. 2019)

COVID-19 impacts (6/9/2020) Some efforts on hold due to restricted access and shelter-in-place at labs, industry, universities; Remote efforts in design, planning continue. Work at SURF restarted May.

Super Cryogenic Dark Matter Search at SNOLAB (SuperCDMS SNOLAB)

Stage 2 Direct Detection Dark Matter WIMP Search.
HEP & NSF/PHY project, w/Canada (CFI, NSERC).

- Cryogenic solid-state germanium and silicon crystals with sensors that detect ionization & phonon signals; ~1-10 GeV/c^2 mass
- Will be located 2km underground at SNOLAB, Sudbury, Canada.

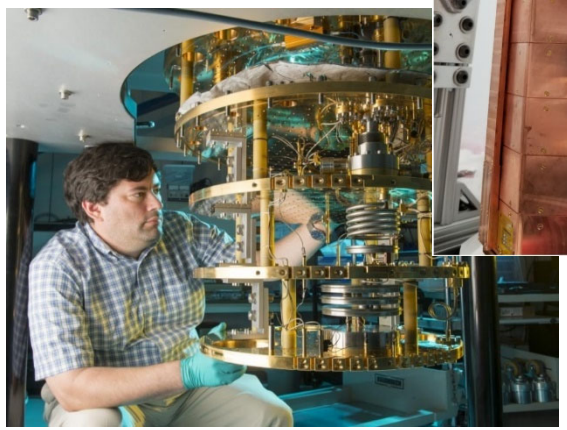


Project Fabrication Status (HEP TPC $18.6M)

- Led by SLAC, significant effort by FNAL, SNOLAB, universities
- Detector and tower fabrication ongoing; cryostat procurement bid came in high; redesign for 7 towers (was 31) in progress; expect first procurements shortly for new design.
- As of March 2020, plan to complete March 2021 w/CD-4 Sept. 2021

Operations planning ongoing

- Pre-operations effort underway (but paused for COVID) to calibrate, characterize, and test early detectors: CUTE at SNOLAB; NEXUS at FNAL



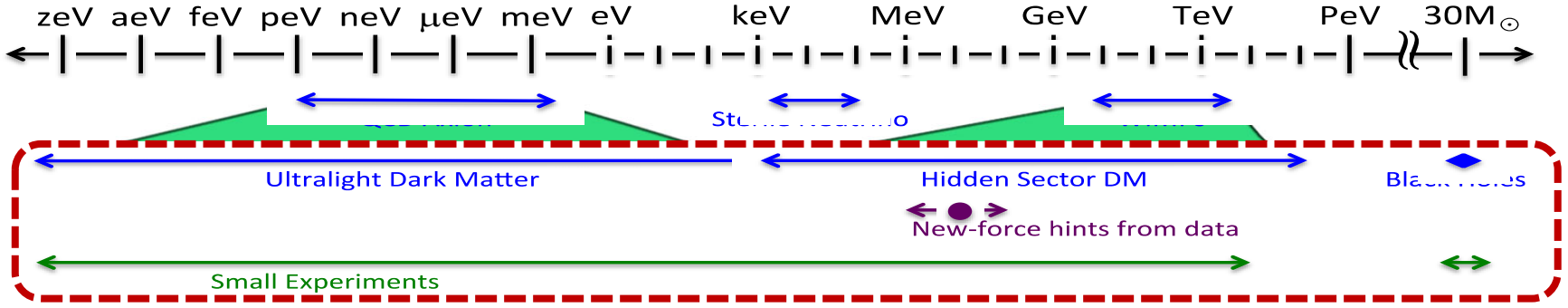
COVID-19: Many efforts on hold due to restricted access; remote efforts in design, planning continue. Initial cost & schedule impacts provided to agencies.

- Expect 6-12 month delay wrt March plan

Dark Matter New Initiatives (DMNI) – Timeline & Funded Proposals for Concept Development

P5 recommended the search for Dark Matter particles as a high priority & also that the program should include small projects

➔Recent theoretical advances and development of new technologies opened new avenues to explore dark matter



➢2017 Community Workshop -> https://arxiv.org/abs/1707.04591
➢2018: Basic Research Needs (BRN) study; https://science.energy.gov/hep/community-resources/reports/
➢**2019: Funding Opportunity Announcement (FOA); Six selected to develop concept and execution plans for potential small projects, funding started in FY19 or FY20**

Cosmic Frontier:
- ADMX Extended (2-4GHz) – A. Sonnenschein (FNAL)
- OSCURA (Skipper CCD detector) – J. Estrada (FNAL)
- DM-Radio axion search – K. Irwin (SLAC)
- TESSERACT (Multiple detectors, w/TES readout) – D. McKinsey (LBNL)

Intensity Frontier (accelerator based)
- Beam Dump exp at FNAL – R. van der Water (LANL)
- Light Dark Matter Experiment (LDMX) – T. Nelson (SLAC)

Following completion of Concept & Execution plans, small projects will be reviewed before advancing to fabrication phase.

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Other Efforts & SUMMARY

HEP Efforts related to the Cosmic Frontier

Theory program

- Vibrant Theory Program supporting all areas including Cosmic Frontier

Advanced Detector Development & Accelerator R&D programs:

- Active R&D developing next generation detectors, including CCDs, TES superconducting bolometers, MKIDs, readout electronics, optics, fiber positioners.

High Performance Computing, Computational HEP program

- **DOE Supercomputer allocation** coordination via various ASCR and DOE Competitions
  - Computational HEP, SCIDAC – focused computational challenges
  - NERSC facility allocations for Cosmic Frontier Simulations, Data Processing, Analysis
- **High Performance Computing** → Exascale; Comp HEP & ASCR coordination & partnerships on some efforts, including Cosmic Simulation and Data analytics
- **Artificial Intelligence/Machine-learning** becoming an agency area of particular interest
- **HEP Center for Computational Excellence (CCE**) investigates ways to optimize code
- **HEP Computing Infrastructure Working Group** formed in 2017 to develop a strategy for meeting the computing needs, since projected needs are larger than availability

New Initiatives – quickly growing areas

- **Quantum Information Science (QIS)**
  - Powerful new windows to accomplish HEP mission & advance QIS Foundational theory, computing, sensors (enable dark matter searches, CMB), technology, experiments; DOD, NIST
- **Artificial Intelligence, Machine Learning – rapidly growing area**
- **Microelectronics Initiative (in FY2021 request)**

SC offices (ASCR, BES, FES, HEP) partnering to support multi-disciplinary microelectronics research that will promote basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.

Summary

Excellent science results continue to be produced from our operating experiments!

P5 strategic plan is supported by Community and broad support is enabling it to be fully implemented.

HEP budget increased 7% in FY20; Cosmic operations ramp up, research flat.
FY21 President's request has been released.

HEP Cosmic Frontier projects from Astro2010 and P5 are about to commence observations and deliver Stage 4 dark energy science – and much more!

- **DESI completed commissioning, ready to operate!**
- LSST camera project is 96% complete!
- CMB-S4 has DOE CD-0 and NSF MSRI-1. Ready to continue progress

- HEP looks forward to Astro2020 assessment of the most compelling science challenges, a comprehensive research strategy, and articulated decision rules with an eye to where DOE HEP researchers and investments can play a significant role in & make unique, significant & necessary contributions.
- Snowmass is starting, leading to next P5

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