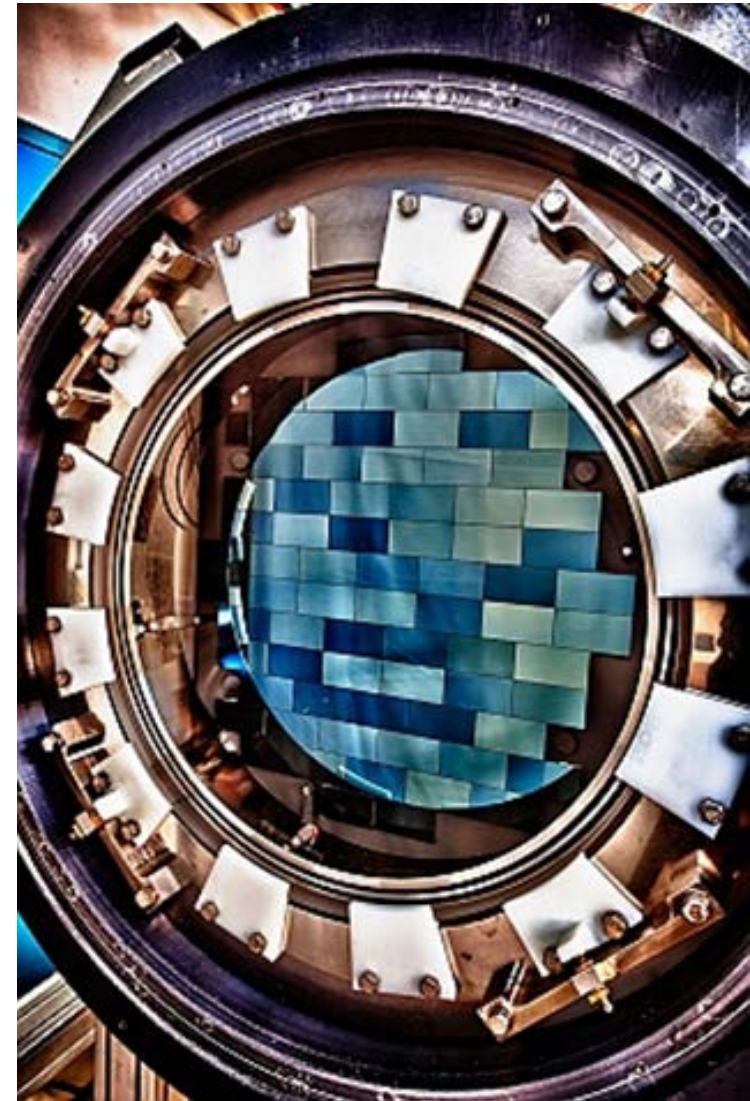




DOE High Energy Physics (HEP) Cosmic Frontier (CF) program status report to the NAS CAA meeting

**March 30, 2016
Kathy Turner**



HEP Cosmic Frontier Program Managers:

Anwar Bhatti (IPA), Eric Linder (IPA), Michael Salamon, Kathy Turner

HEP PROGRAM – MODEL, GUIDANCE, STRATEGIC PLANNING



U.S. DEPARTMENT OF
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HEP Mission & Program Planning

Part of a Mission Agency

- Provides science leadership & support to enable significant advances in specific science areas
- Develops and supports a portfolio of selected facilities & experiments to obtain the science
- Laboratory System
 - Comprehensive resources to design, build, operate selected facilities, projects and instrumentation
 - Infrastructure, including computing facilities (NERSC, SCiDAC program etc)
- Interagency & International partnerships as needed to leverage additional science & expertise

Program Planning, Management & Execution

- Strategic planning process with community input to develop science drivers and a portfolio of facilities & experiments to obtain significant advances in these science areas.
- Program Offices follow the strategic plan to carry out a specific portfolio of selected facilities & experiments to obtain the science.



→ Work proactively with our labs & community to carry out the program



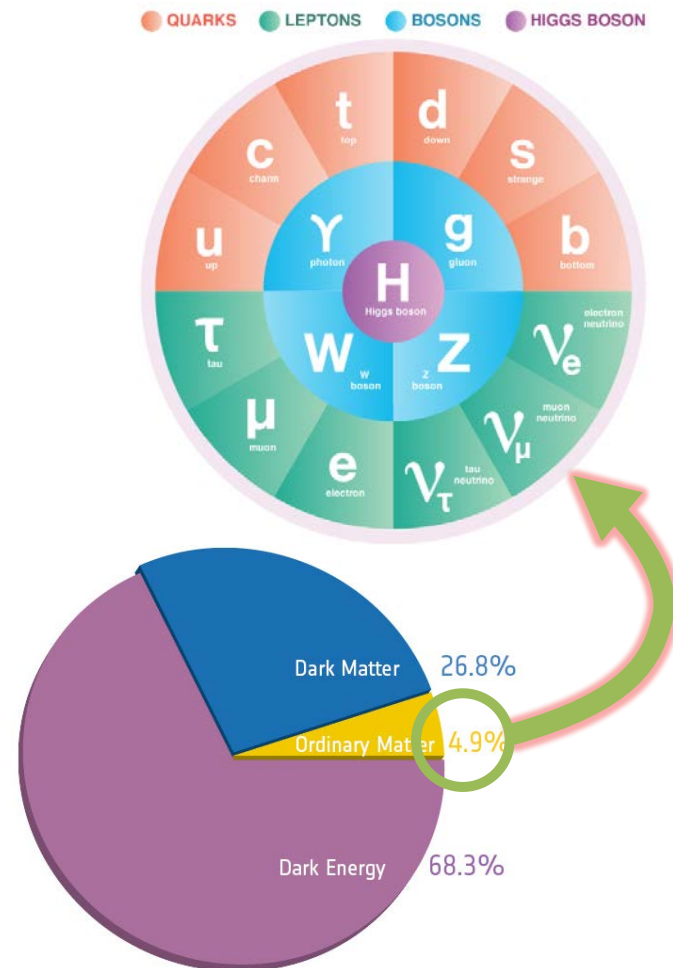
The Office High Energy Physics (HEP) Program Mission

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

- Discover the most elementary constituents of matter and energy
- Probe the interactions between them
- Explore the basic nature of space and time

➔ HEP fulfills its mission by:

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





HEP Program Model

→ The Mission Emphasis translates in to how the HEP Program is managed:

■ **Planning Program**

- Strategic planning process with community input to develop a strategic plan for science drivers and portfolio of facilities and experiments to obtain significant advances in these science areas.

■ **Implementation**

- HEP uses the strategic plan to develop and support a specific portfolio of selected facilities & experiments to obtain the science.
- Plan stages of experiments for ever-increasing precision
- Complementary approaches using different technologies & methods
- Long-term support for our responsibilities in designing, building and operating projects
- Collaboration/Teamwork: Support scientific teams with expertise in required areas to participate in all phases of a project/experiment, in order to produce the best possible science results.

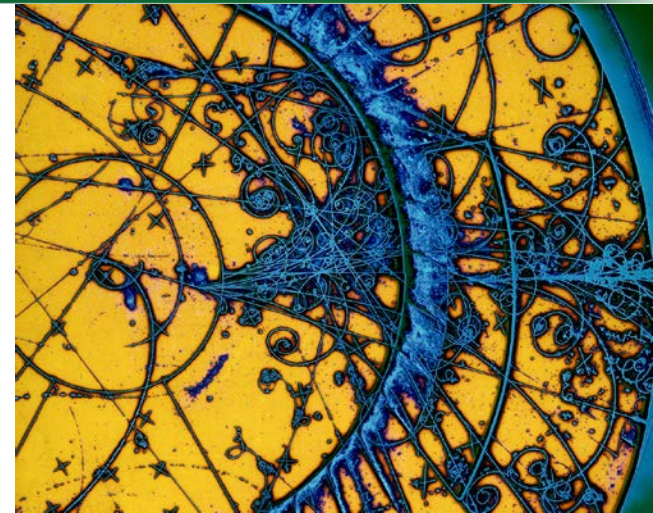


HEP Program Guidance

FACA panels & subpanels provide official advice:

→ High Energy Physics Advisory Panel (HEPAP)

- Reports to DOE and NSF
- Provides the primary advice for the program
 - Subpanels for detailed studies, e.g.
 - Particle Astrophysics Science Assessment Group “PASAG”, DEFT, TFCR, DMSAG
 - **Particle Physics Project Prioritization Panel (“P5”) – Strategic Planning Process**



→ Astronomy and Astrophysics Advisory Committee (AAAC)

- Reports to NASA, NSF and DOE on areas of overlap

National Academy of Sciences

- Reports: New Worlds New Horizons (2010), “Mid-decade review” in astronomy/astrophysics
- Ongoing: Board on Physics & Astronomy (BPA), Committee on Astronomy & Astrophysics (CAA)

Other: community science studies, reviews, DPF input, etc.

Guidance from Astro2010 “New Worlds New Horizons” Report (August 2010)

Specific Recommendations to DOE :

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

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

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

Enabling the Next Discovery → May 2014 P5 Strategic Plan



HEP is implementing the strategy detailed in the P5 report in the context of a global vision for the field

- HEP Addresses the five compelling science drivers with research in three frontiers and related efforts in theory, computing and advanced technology R&D
- Increasing emphasis on international partnerships to achieve critical physics goals

P5 report suggests increasing the project budget fraction to 20%–25%

- “Addressing the [science] Drivers in the coming & subsequent decades requires renewed investment in projects.”

Energy Frontier: Continue LHC program with higher collision energy (13+ TeV)

The U.S. will continue to play a leadership role in LHC discoveries by remaining actively engaged in LHC data analysis and the initial upgrades to the ATLAS and CMS detectors

Intensity Frontier: Develop a world-class U.S.-hosted Long Baseline Neutrino Facility (LBNF)

Continue the design process for an internationalized LBNF and development of a short baseline neutrino program that will support the science and R&D required to ensure LBNF success

Fermilab will continue to send world's highest intensity neutrino beam to NOvA, 500 miles away

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

-- Development of new capabilities in dark matter detection continues with baselining of 2nd-generation experiments & in dark energy exploration with baselining of DESI & continued fabrication of LSST camera.

Advanced Accelerator R&D

Continued R&D in the promising area of beam-driven plasma wakefield acceleration

Accelerator Stewardship

This subprogram focuses on the broader applications of accelerator technologies, including major thrusts in technology to enable ion-beam cancer therapy and R&D for high-power ultrafast laser



May 2014 P5 Report →

Cosmic Frontier Recommendations

P5 strategic plan: 5 science drivers

	Energy Frontier	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●

P5 report recommendations addressed to the Cosmic Frontier →

- **Dark Energy**
 - Build **DESI** as a major step forward in dark energy science
 - Complete **LSST** as planned
- **Dark Matter**
 - Proceed immediately with a **broad second-generation (G2) dark matter direct detection program** with capabilities described in the text
 - Invest in this program at a level significantly above that called for in the 2012 joint agency announcement of opportunity
 - Support one or more third-generation (G3) direct detection experiments
 - Guide G3 by the results of the preceding (G1, G2) searches
 - Seek a globally complementary program and increased international partnership in G3 experiments **(DM-G3 Project is in the P5 plan later in the decade.)**
- **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 later in the decade.)**
- **Cosmic Rays and Gamma Rays**
 - Invest in **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.



HEP PROGRAM – BUDGET



U.S. DEPARTMENT OF
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FY 2014-2017 HEP Program - Budget Status

	FY14	FY14	FY15	FY15	FY16	FY16	FY17
	PRB	Actual	PRB	Enacted	PRB	Enacted	PRB
Energy Frontier	154,687	152,386	153,639	147,584	154,555	150,723	150,998
Intensity Frontier	271,043	250,987	251,245	264,224	247,196	243,121	234,144
Cosmic Frontier	99,080	96,927	101,245	106,870	119,325	130,582	130,069
Theory & Comp. Phys	62,870	64,275	58,850	59,274	60,317	59,083	59,656
Advanced Tech R&D	122,453	150,270	114,242	120,254	115,369	115,494	118,285
Accelerator Stewardship	9,931	9,075	19,184	10,000	14,000	9,000	13,744
SBIR/STTR	21,457	0	20,595	20,794	21,138	20,897	22,580
HEP Subtotal	741,521	723,920	719,000	729,000	731,900	728,900	729,476
Construction, Line Item	35,000	51,000	25,000	37,000	56,100	66,100	88,521
HEP TOTAL	776,521	774,920	744,000	766,000	788,000	795,000	817,997
Office of Science TOT	5,152,752		5,111,155	5,067,738	5,339,794	5,350,200	5,672,069

*FY14 SBIR/STTR was ~ \$21M, so FY2014 actual was ~ \$796M.



HEP Program: FY 2015 → FY 2016 Budget

→ Budgets & Construction/Major Items of Equipment (MIEs) Projects reflects P5 priorities:

FY15:

- The FY15 President's Request for HEP was below P5 funding Scenario A (lowest)
- The enacted FY15 Budget for HEP is **\$766M**, between P5's scenario A&B.

Cosmic Frontier Major Item of Equipment (MIE) Projects – follow P5 recommendation & move forward:

→ **LZ, SuperCDMS-SNOLAB, DESI were all approved as “new starts”**

The actual schedule for starting fabrication depends on each project's schedule, etc.

→ **LSST camera continues fabrication according to it's planned funding profile**

Note: SPT-3G and ADMX-G2 are also starting but are below the MIE project cutoff, so not called out directly in the budget documents.

FY16:

- The FY16 President's Request for HEP was up relative to FY15: +\$22M over FY15 enacted
- The enacted FY16 Budget for HEP of **\$795M** (12/16/15) is above the Request & squarely in P5's scenario B.

Research budgets: Though the approved budget is more than the requested, due to the budget guidance & other constraints, the research budget is still being planned to be a few % reduced wrt FY15.

Cosmic Frontier MIE projects – Fabrication continues:

- **LSST** is being funding according to its planned profile.
- **DESI** is being funded at \$5.0M more than requested in FY16 (budget guidance)
- **LZ** is being funded at \$1.5M more than requested in FY16 (budget guidance)
- **SuperCDMS-SNOLAB** is being funded at \$1M over the requested amount.



HEP Program: FY 2017 Budget Request

The **FY17 President's Request** for HEP of **\$818M** is up relative to FY16 and continues on P5's Scenario B.

- Continue investing in portfolio of high-priority projects for the successful implementation of P5 strategy.
- Request is carefully balanced between support for projects (\$212M), facility operations (\$252M), and scientific research (\$354M) in order to produce scientific results while **“building for discovery”**

Intensity Frontier: The U.S.-hosted international Long Baseline Neutrino Facility and Deep Underground Neutrino Experiment is the highest priority longer-term project. It has made rapid progress & attracted the interest of international partners; engineering design, site preparation & long-lead procurements start.

Energy Frontier: The High Luminosity Large Hadron Collider (HL-LHC) accelerator & detector upgrade projects will significantly extend the discovery reach of the world's highest energy collider. These upgrades are the highest priority near-term large project; an MIE start is planned to match up to the global schedule.

Cosmic Frontier: The complementary suite of MIE projects to address dark matter and dark energy continue their fabrication activities at the planned levels.

Accelerator R&D, Stewardship: The Facility for Advanced Accelerator Experimental Tests II project will enable continued R&D in beam-driven plasma wakefield acceleration & sustain the momentum of excellent achievements & U.S. leadership; MIE start planned in FY17. Accelerator Stewardship R&D will advance U.S. competitiveness; Funding for collaborative R&D in FY17 will put technology to work for better cancer treatment, pollution reduction, national security, and making unique test facilities available to industry.

RESEARCH funds – University Grants: Included in the FY17 budget request is \$100M for University Grants in Office of Science (SC) as Mandatory Funding (as opposed to Discretionary Funding). There is no plan of how this will be split between the 6 SC offices or types of activities to be considered.



HEP PROGRAM – STATUS



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HEP Energy Frontier - Status

Current program

LHC Run II began on June 3, 2015 with collisions at 13 TeV! US continues to play a leadership role

- will increase the reach into search for new physics in high-impact topics:
 - SUSY, dark matter, extra dimensions, probe the nature of the Higgs, etc.

Fabrication Projects

Phase-1 upgrades to the LHC detectors

- Phase-1 U.S. CMS/ATLAS upgrades received CD-2/3 (baseline/construction start) approval on November 12, 2014

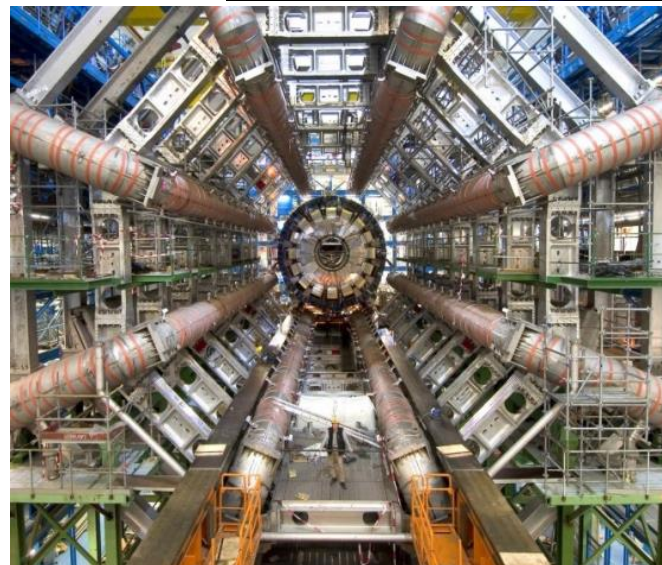
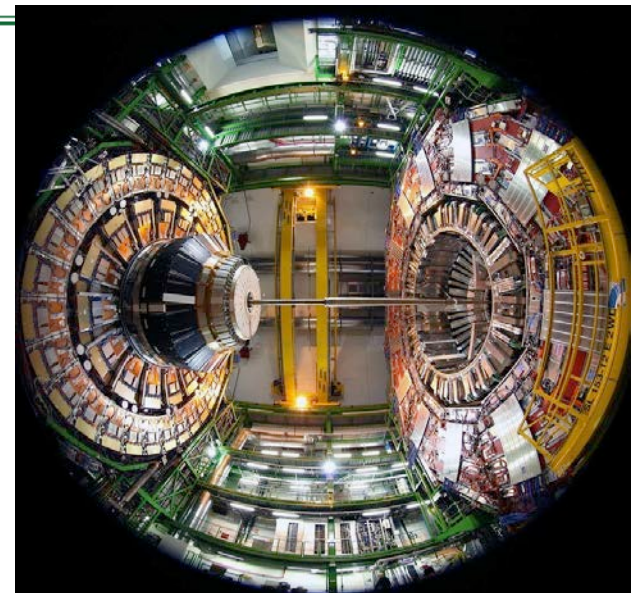
Planned program

Considering high-luminosity LHC upgrade around 2023 to extend discovery reach

- Increase luminosity by 10 times LHC design value to explore new physics at TeV energies
- DOE/HEP actively working with US-CMS/ATLAS to begin mounting HL-LHC Detector Upgrade Project

Modest investments in R&D for future options:

- Lepton colliders
- Very high energy hadron colliders



Intensity Frontier Status

Exploring the unknown through precision measurements – muon-beams,

- P5 recommended development of muon-beam based program at Fermilab:
 - ***Muon g-2***: Successfully tested SC magnet and held CD-2 review in June 2015
 - ***Mu2e***: Reached CD-2/3 on March 4, 2015
- Collaborating with Japan on *K* meson, *c/b* quark, and τ lepton precision studies:
 - ***Belle II***: reached CD-3 in April 2014
 - ***KOTO*** (J-PARC) physics data taking in Spring and Fall 2015

Identify the physics of dark matter

- ***APEX*** and ***Heavy Photon Search (HPS)*** performing particle beam based searches for DM particles



Pursuing the physics associated with neutrino mass

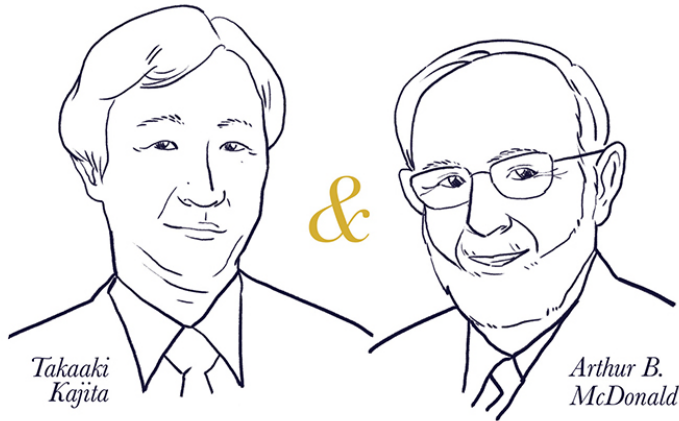
- Mass hierarchy & ν properties studied at Fermilab, Japan, China, and underground:
 - ***Daya Bay, MicroBooNE, MINERvA, MINOS+, NOvA, Super-K, T2K***
- Sterile neutrino search and neutrino CP violation program continues to evolve with P5 recommendations for short-baseline neutrino (SBN) and long baseline neutrino programs
 - A coordinated set of short-baseline neutrino experiments will address the observed anomalies in current neutrino experiments while advancing the R&D necessary for LBNF and DUNE
 - ***DUNE*** established as international experiment for the Long Baseline Neutrino Facility (LBNF)

LBNF/DUNE is a key element of the global vision presented in the P5 report, and a major domestic milestone as the first international science facility hosted in the U.S.



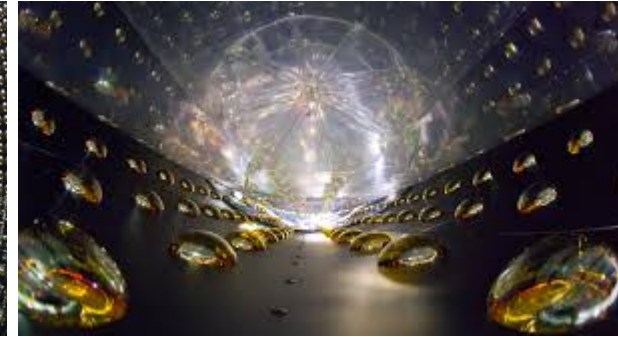
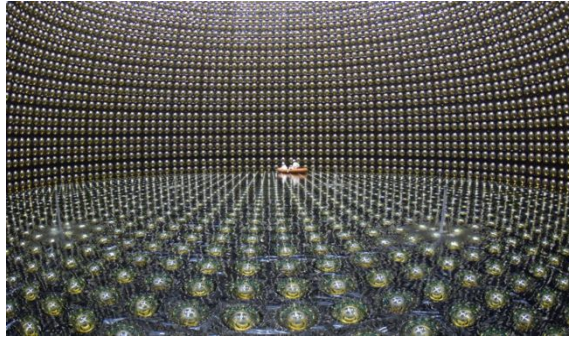
Banner Year For Neutrinos

2015 NOBEL PRIZE
in Physics



NEUTRINO OSCILLATIONS

The discovery of these oscillations shows that neutrinos have mass.



The Breakthrough Prize will be split among 1,370 physicists. Seven leaders of five experiments (SuperK, SNO, Daya Bay, K2K and KamLAND) as well as all of the co-authors of the scientific papers reporting the experiments' groundbreaking results will become Breakthrough laureates. The five teams will share the prize money (\$600,000 to each), with two thirds of those purses going to the leaders and one third to the collaborators.

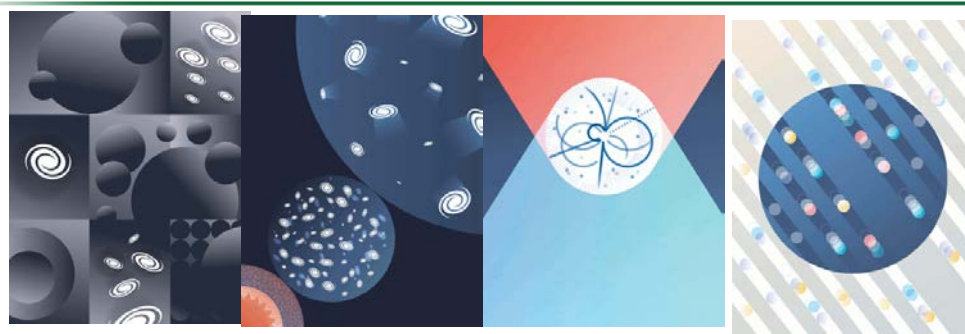
COSMIC FRONTIER PROGRAM – OVERVIEW



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Cosmic Frontier Program



Dark Matter

Cosmic Acceleration

Explore the Unknown

Neutrino Mass

Cosmic Frontier: Through ground-based telescopes, 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 thrusts:

- Study the nature of **Dark Energy**
- Direct Detection searches for **Dark Matter** particles
- **Cosmic-ray & Gamma-ray studies** – particle properties, high energy acceleration mechanisms, indirect searches for dark matter particles
- **CMB** – current minor efforts planned to expand
- **Other:** computational cosmology; + related Theory, Detector development, computational, etc.

Status & Path Forward

- Continue development near term projects recommended by P5.
- Planning activities to support P5 recommendations later in the decade.



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Cosmic Frontier – Program & Funding Considerations

Build Program following the P5 Plan & P5 Criteria:

- Make significant, coherent contributions to facilities/experiments selected for the program at a level commensurate with expected science return on HEP physics goals
- Bring unique, visible, leadership contributions by the HEP community, e.g. large scale instrumentation, “big data” computing facilities & data processing expertise, & use of science collaborations through all stages of the project, leading to science results.
- Support an HEP-style science collaboration in all stages, including coordinated data analysis to get the best possible science results
- Staged implementation & results, with mix of smaller, larger projects, and using multiple methods and technologies as needed
- Form partnerships or use other agency’s facilities when needed (e.g. telescopes)
- For facilities with broader science program (e.g. LSST) than the interests of the HEP program
 - Make project contributions at appropriate level & support research efforts for our science interests
- For Research Support at Labs & Universities (grants), the priority is to support projects & experiments in our program, where we have responsibilities.





Cosmic Frontier Budget History – details

Feb. 2016

Cosmic Frontier (\$K)		FY14 Actual	FY15 PRB	FY15 Actual	FY16 PRB	FY16 Enacted	FY17 PRB
Research+Other	All	52,712	45,435	48,779	50,079	49,910	49,934
Research	All	52,712	45,435	48,779	50,079	46,195	46,991
Research	Grants	13,157	11,422	11,773	12,565	11,595	11,607
Research	Labs	39,555	34,013	37,006	37,514	34,600	35,384
Other Res						3,715	2,943
Exp Operations+Other		10,357	7,238	9,185	7,120	13,837	9,935
Exp Operations		10,357	7,238	9,185	7,120	9,190	8,925
Other Ops						4,647	1,010
Projects	All	30,660	41,000	46,403	58,701	66,835	70,200
Projects	MIE	22,900	41,000	44,178	57,100	64,600	69,500
	LSSTcamera	22,000	35,000	35,000	40,800	40,800	45,000
	DM-G2	900	6,000		11,000		
	LZ			3,050		10,500	10,500
	SuperCDMS-SNOLAB			2,250		2,500	4,000
	DESI			3,878	5,300	10,300	10,000
Projects	Small Proj Fab			1,025	1,601	2,035	0
	All				1,601		0
	ADMX-G2			925		935	
	SPT-3G			100		1,100	
Projects	Future Proj R&D	7,760	0	1,200	0	200	700
	Undesig					200	700
	DESI (BigBOSS)	1,100					
	Dark Matter	5,260		200			
	SPT-3G	1,400		1,000			
TOTAL	All	93,729	93,673	104,367	115,900	122,220	126,116
TOTAL+Other	All	93,729	93,673	104,367	115,900	130,582	130,069



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DOE HEP Cosmic Frontier Status for CAA, March 2016

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TOTAL is the amount CF spends; "Other" includes extra funds for program reviews & direction, etc.

COSMIC FRONTIER: MAJOR RESULTS, ADVANCES



Cosmic Frontier: Prizes in the Last Year

2015 Gruber Cosmology Prize

(John Carlstrom partially funded by Cosmic Frontier on Cosmic Microwave Background research)

Carlstrom, Ostriker, and Page Receive \$500,000 Gruber Cosmology Prize for Theoretical and Experimental Explorations of the Universe



John E. Carlstrom



Jeremiah P. Ostriker



Lyman A. Page Jr

2015 E.O. Lawrence Award

**David Schlegel funded by Cosmic Frontier
on Galaxy Redshift Surveys research; Baryon Oscillation Spectroscopic Survey**

“Exceptional leadership of major projects making the largest two-dimensional and three-dimensional maps of the universe, which have been used to map the expansion rate of the Universe to 10 billion light years and beyond.”



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Cosmic Frontier: Science Advances in the Last Year

Dark Energy

DES –

- Largest weak lensing sky map of dark matter
- Initial weak lensing constraints on dark energy
- Discovery of 17 new Milky Way dwarf galaxy satellite candidates – prime homes for dark matter detection; stringent constraints from joint DES-FGST analysis

BOSS –

- 1-3.5% constraints on distances, Hubble parameter at 3 redshifts
- Constraints on growth at 2 redshifts

eBOSS –

- First two seasons done; first data set (DR13) release Summer 2016

Supernovae –

- 2 Type Ia supernovae at $z > 2.2$ discovered (1 lensed)

CMB

- B-mode polarization tightening constraints on inflation
- Kinematic Sunyaev-Zel'dovich effect measured with increasing S/N (e.g. $>4\sigma$ DES x SPT)

Dark Matter

- LUX: tightest limits on spin-independent cross-section
- SuperCDMS-Soudan: CDMS $> \times 10$ improvement at 3 GeV/ c^2

Cosmic/Gamma Ray – Tighter constraints on DM annihilation in dwarf satellites and dSph by FGST (Pass 8), HAWC, VERITAS

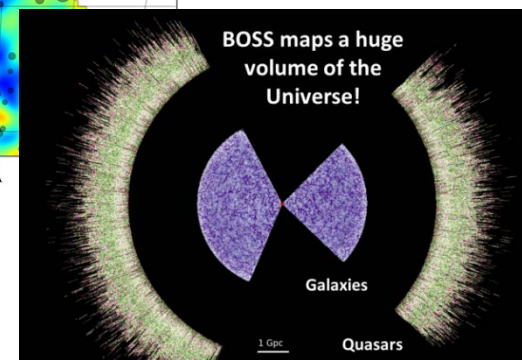
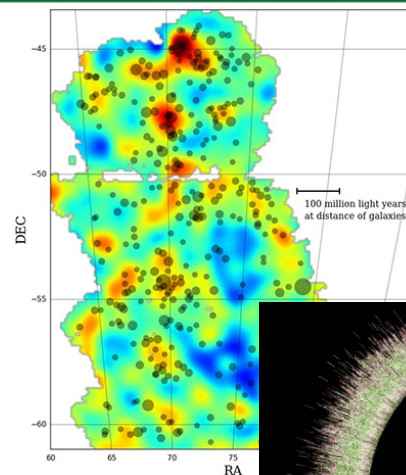
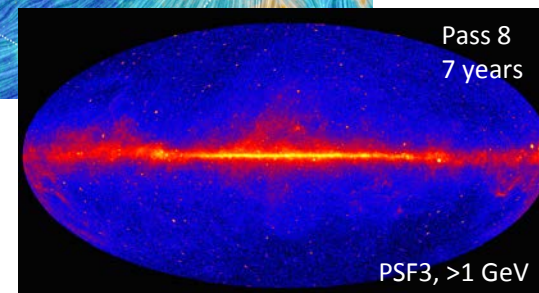
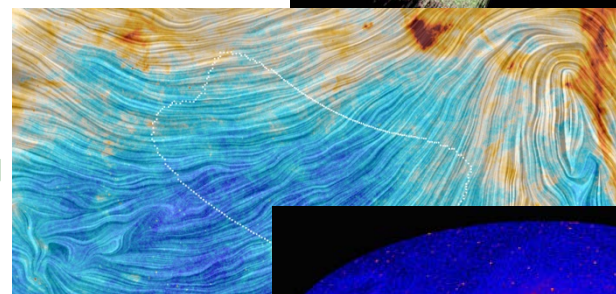


Figure credit: A. Slosar



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DOE HEP Cosmic Frontier Status for CAA, March 2016

Cosmic Frontier: Project Advances in the Last Year

All 4 Cosmic Frontier Major Item of Equipment (MIE) fabrication projects have passed new milestones in the last year:

Dark Energy Spectroscopic Instrument (DESI) - Dark Energy Stage IV spectroscopic

- CD-2 (Baseline of Scope, Cost & Schedule) approved September 2015
- CD-3 (Start of full fabrication activities) review in May 2016

Large Synoptic Survey Telescope (LSST) – Dark Energy Stage IV Imaging

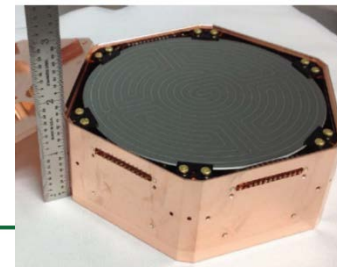
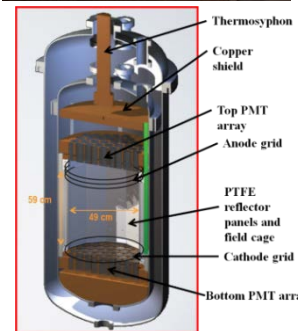
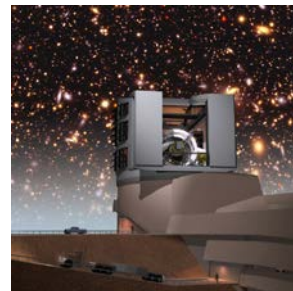
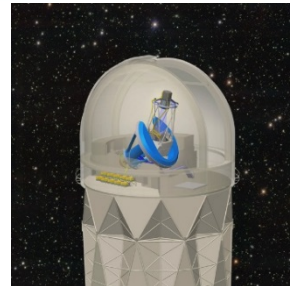
- CD-3 for LSST-camera approved August 2015, LSST status review Feb. 2015

Large Underground Xenon – Zeplin (LZ) - WIMP dark matter search

- CD-1/3a (Approve alternative selection/long lead fabrication) approved April 2015
- CD-2/3b review in April 2016

Super Cryogenic Dark Matter Search at SNOLab (SuperCDMS-SNOLab) - WIMP search

- CD-1 approved December 2015; CD-2/3 review planned in 2017



COSMIC FRONTIER: STATUS & FUTURE PLANNING



Cosmic Frontier – Dark Energy

Precision measurements to differentiate between Cosmological Constant and new fields or modification to General Relativity

- staged, complementary suite of imaging, spectroscopy and supernova survey experiments

Operating/Completed:

- **BOSS (spectroscopic)** ended in FY14; **eBOSS (spectroscopic)** started in FY15
- **DES (imaging)** started 5-year survey in late FY13; partner with NSF-AST

Design, Fabrication:

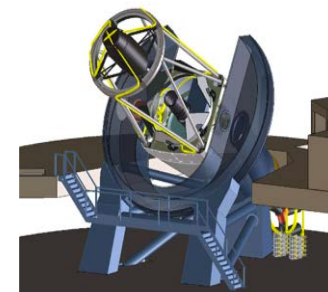
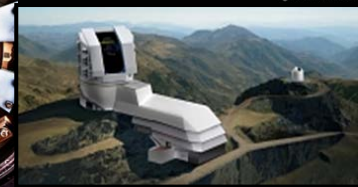
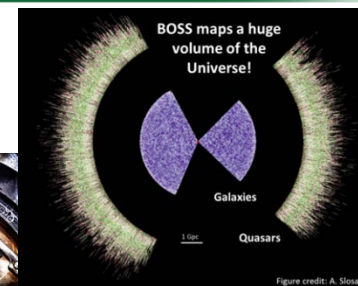
– **Large Synoptic Survey Telescope (LSST, Stage IV imaging)**

- HEP and NSF-AST (lead agency) partnership; LSST Project status review Feb. 2016
- HEP responsible for the LSST camera; started fabrication in FY14, CD-3 (full fabrication) approved Aug. 2015
- LSST Facility Operations phase planning starting (NSF, DOE, etc)
- LSST Dark Energy Science Collaboration (DESC) Operations needs are being developed.

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

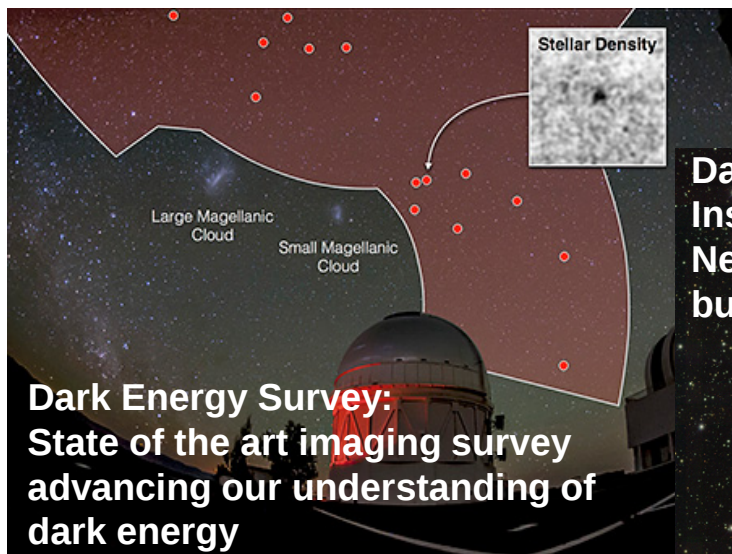
- “HEP experiment” with LBNL managing:
 - build DESI instrumentation & data management system for use on Mayall telescope
- HEP coordinating with NSF-AST to use (“lease”) the Mayall telescope
 - MOA signed for transition phase (FY16-18); both agencies support Mayall
 - MOA in development for operations phase (FY19+); HEP fully supporting Mayall for dark energy science operations
- Status: CD-3 review (ready for full fabrication phase) in May 2016
- Plan: Mayall shutdown, ready for DESI 1QFY18; DESI+Mayall commissioning complete & data-taking starts 1QFY20

Research: In addition to above, HEP has research-only activities on **Euclid**, **WFIRST**, & **supernova surveys**

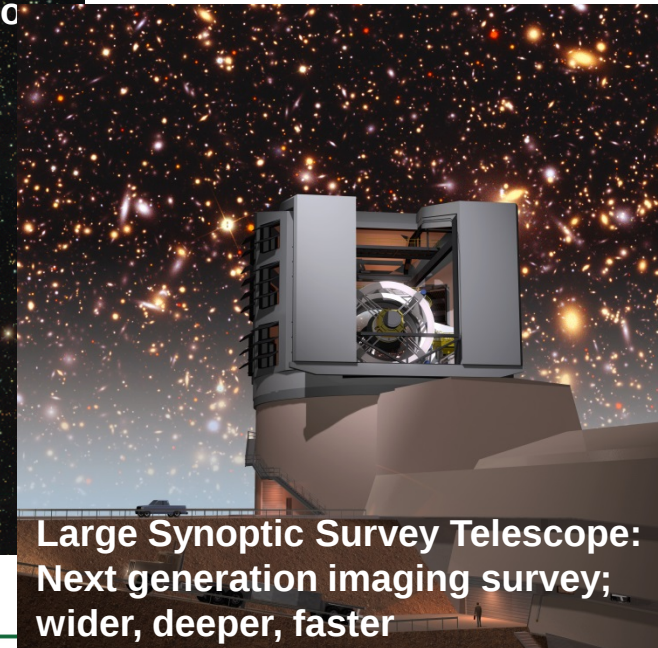
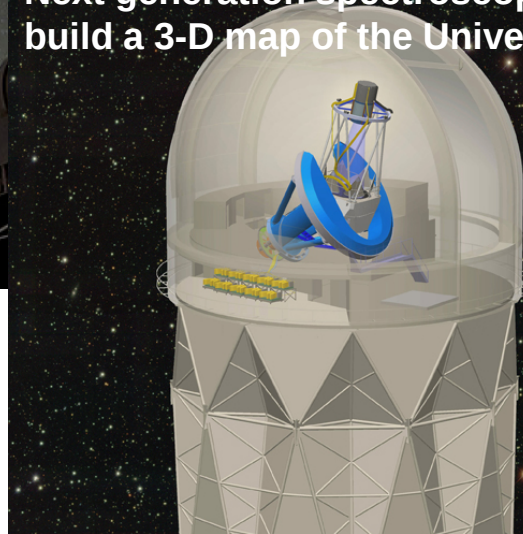


Understanding Dark Energy

A suite of imaging and spectroscopic surveys aim to address the question of what drives cosmic acceleration



Dark Energy Spectroscopic Instrument:
Next generation spectroscopy to
build a 3-D map of the Universe



Cosmic Frontier: Direct Detection Dark Matter (DDDM)

→ Learn the identity and nature of Dark Matter with staged program of experiments with multiple technologies & methods

Operating:

DM-Generation 1 (DM-G1): **ADMX-II, LUX, CDMS-Soudan, DarkSide-50, COUPP/PICO, DAMIC**
– completing operations efforts by FY 2016

Design, Fabrication:

-- Progress continues on DM-G2 program selected by HEP & NSF-PHY in July 2014

o **ADMX-G2** axion search at Univ of Washington (HEP)

- small project (below MIE); fabrication FY14 – FY16; Operations starting 2017 (review Sept. 2016)

o **LZ** at Homestake Mine in SD

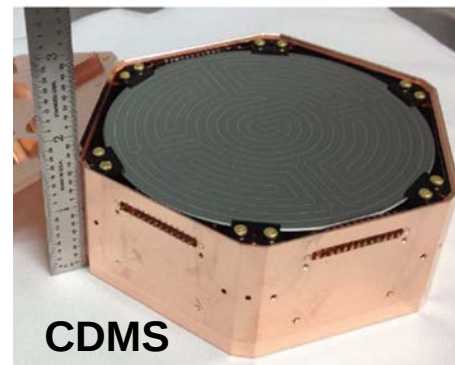
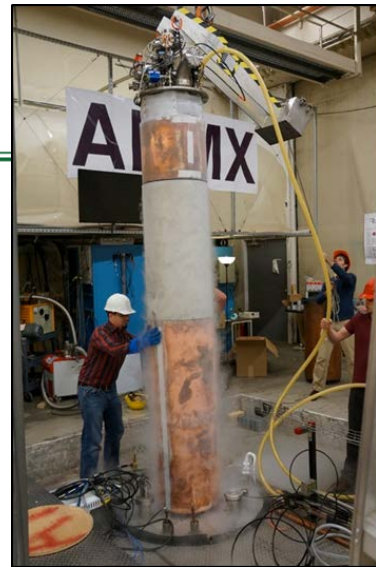
- WIMP dark matter search through dual phase liquid Xe – higher mass range
- HEP leads, LBNL Project Office
 - Fabrication start (CD-1/3a) in April 2015; CD-2/3b review in April 2016.

o **SuperCDMS-SNOLab** at Sudbury Neutrino Observatory in Canada

- WIMP search using cryogenic solid-state crystals – lower mass range
- HEP+NSF-PHY partnership, SLAC Project Office
 - CD-1 approval in Dec. 2015; CD-2 planned for FY17

HEP plans for future (P5)

- HEP concentrating on getting the DM-G2 experiment(s) successfully started
- Limited R&D support planned in FY16+ for near term priority R&D off-project efforts to support the DM-G2's & possible future; DM-G3 concept R&D later on...



Cosmic Microwave Background

Gain insight into the inflationary epoch at beginning of universe

- Probe dark energy, **neutrino** properties from CMB lensing (by cosmic structure)
- B mode polarization power spectrum starting to be mapped
- Probe high energies $\sim 10^{12}$ x LHC, Planckian fields

Stage 2 (2009-15) – Planck satellite (74 detectors), ground-based (~ 1000 det.);

Stage 3 (2016-20) – SPT-3G, POLARBEAR/Simons Array, AdvACT (~ 20000 det.);

Stage 4 ground based – unified into CMB-S4 ($\sim 500,000$ detectors)

→ CMB-S4 (community led) collaboration is planning an array of telescopes in Chile & the South Pole with participation by DOE labs and universities; bringing together the major S3 collaborations

→ Technology mature: needs scale-up of detector fab/test, readout.

HEP has been involved at a low level in CMB for decades (1977 LBNL measures CMB dipole; 1992 COBE → 2006 Nobel Prize), esp. in technology and computing.

- Now funding SPT-3G camera, several research-only efforts.

- HEP Cosmic Visions CMB group coordinating HEP efforts;
- **CMB-S4 Community draft Science Book (149 pages)**
 - recent workshop at LBNL w/180 attendees
- As recommended by P5, HEP is planning to participate in CMB-S4.
 - A small R&D funding wedge starting in FY18 would put us in line with the P5 recommended project timeline
- DOE and NSF starting agency coordination group meetings

In Atacama: CLASS, ACT, PolarBear/Simons



Cosmic Frontier – Cosmic-ray, Gamma-ray

Use ground-based arrays, space telescopes, and an experiment on the International Space Station to perform indirect searches for dark matter, fundamental physics

Operating/Analysis:

- **Fermi/GLAST** (w/NASA)
 - HEP participation planning in coordination with NASA; supporting the Large Area Telescope Instrument Science Ops Center (LAT-ISOC) at SLAC
 - HEP plans to continue supporting LAT-ISOC operations through the 10 year survey (done in FY18) and LAT-ISOC operations that require SLAC participation is envisioned after that [all based on continued operations by NASA!]
- **VERITAS** (w/NSF)
 - HEP participation ramping down; Last year of operating funds provided in FY15 (budget period through April 2016); research efforts also winding down; their current funds will carry them until ~ FY17
- **Auger** (w/NSF-PHY)
 - HEP participation in operations & research ramping down in FY16; no participation planned on upgrade
- **AMS** (w/NASA)
 - operations continuing
- **HAWC** (w/NSF)
 - 5 year operations started early 2015



VERITAS in Arizona



HAWC full operating array, Mexico



Cosmic Visions – looking towards the future

Following P5, HEP Labs & Community are redirecting programs to align with P5 priorities

- Considerable LDRD effort directed at CMB, dark energy, dark matter future technologies

HEP has started “Cosmic Visions (CV)” groups in several areas

- Allows interactions with small HEP community groups (~ monthly) as a 2-way line of communication
- CV groups can collect, coordinate HEP community status and HEP funded efforts for R&D, planning, studies & options for future datasets, experiments, projects
- HEP can use this information to help us develop, coordinate and focus our planning and efforts as well as providing input to the HEP community.

NOTE: Of course, any HEP-funded R&D/technology plans need to be in the context of the larger non-HEP and global community (so as not to duplicate efforts or go off in directions that don't make sense)

CV Groups:

CV-CMB

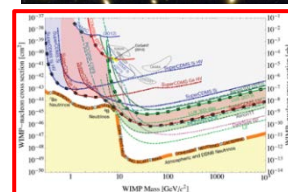
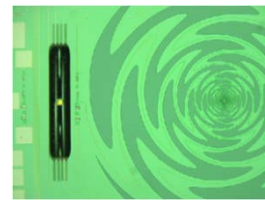
Coordinate HEP technology R&D and other efforts as input for future CMB-S4 planning

CV-DE

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

CV-DM (Dark Matter Direct Detection)

Coordinate HEP technology R&D and other efforts as input for planning current and possible future technology needs and studies and as input to future DM-G3 planning



Cosmic Frontier

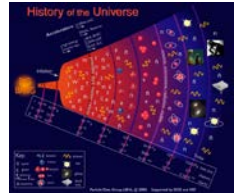
Interagency & International Activities & Considerations

Interagency Coordination:

- Agencies coordinate efforts: NSF, NASA, DOE talk regularly about program planning, overlaps, issues
- Depending on science, project, contribution, and agency considerations, sometimes we partner on fabrication, provide facilities or use other agency's facilities

Project Coordination & Oversight:

- Interagency Joint Oversight Group (JOG) : VERITAS, HAWC, LSST, DES, SuperCDMS-SNOLab
- Interagency Coordination Group (ICG): DESI, SPT-3G
- Finance Board meetings: Auger, FGST



Tri-Agency Group (TAG) – DOE, NASA, NSF-AST

Meeting monthly with US-leads on LSST, WFIRST, Euclid to discuss commonalities, coordination

International Efforts

- DOE making country-level agreements to allow science partnerships to move forward.
- HEP participating on the Global Science Forum's Astro-particle Physics International Forum (APIF) and its follow-on

Cosmic Frontier – HEP & SC Related Efforts

Theory program

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

Advanced Detector Development program

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

Comp HEP program

- Coordinates DOE Supercomputer allocations via various ASCR and DOE Competitions
 - Cosmic Simulations, Emulators, Data Analysis
 - Computational HEP, SCIDAC – focused computational challenges
 - HEP Forum for Computational Excellence
- High Performance Computing – Comp HEP & ASCR coordination & partnerships on some efforts, including Cosmic Simulation and Data analytics
- Manages allocations on NERSC facility for HEP Cosmic Frontier Simulations and Experiments
NERSC used for analysis of many CMB experiments: in 2014 ~10 experiments with ~100 users, with ~10M CPU-hours
HEP has an MOU with NASA for Planck analysis at NERSC – in 2014, 100M CPU-hours.
NERSC Allocations 2015:
 - Total HEP Target Plus OT: 340 M Hours (expected to triple by 2018); Cosmic Frontier related is ~ 40% of this.

Data Management

- Each Project/Experiment has provided a Data Management Summary to HEP
- Used for referencing in research proposals; also to check against *AAAC Principles for Access in Astrophysics and SC Statement on Digital Data Management*



RESEARCH SUPPORT



HEP Cosmic Frontier Program

Research Funding – Opportunities, Review

FY16 Comparative Review process – for University Grants

- Had a dedicated Cosmic Frontier review panel in Nov. 2015
- Recommendations for funding for successful proposals has gone out
- The next opportunity to propose is for FY17 (proposals due ~ early September 2016)
- HEP will have meeting with prospective PIs at ICHEP in Chicago in August 2016

FY16 Early Career (all HEP proposals considered together) – open to University faculty and Lab scientists

- Had review panel in Feb. 2016; results out April/May 2016

FY16 Comparative Review of Lab Cosmic Frontier Research Programs

- Will be held in July 2016 (held ~ every 3 years)

Cosmic Frontier

Statistics on Comparative Review Research (University) Grants

				FY12	FY13	FY14	FY15
Cosmic CR – \$M request (Y1)				\$3.3	\$7.7	\$7.5	\$6.8
Cosmic CR – \$M funded (Y1)				\$1.6	\$3.4	\$4.4 w/FFF	\$3.3 w/FFF
Cosmic CR - proposal counts							
		#proposals	received	11	33	29	27
		#proposals	reviewed	10	28	28	27
		#proposals	funded	6	18	19	14
		#proposals	success rate	60%	64%	68%	52%
Cosmic CR - PI counts							
		#PI's	received	21	61	40	43
		#PI's	reviewed	20	54	38	43
		#PI's	funded	13	27	25	21
		#PI's	success rate	65%	50%	66%	48%

Funding:

- Typically the total of all requests is for ~ twice the funds we have available.
- We typically fund the grants at less than their request.
- FY15 Cosmic requests \$21.9M (for full grant period) and \$6.8M for Year1.
- Funds shown above are for the Year 1 of the grants approved this year. Funds for Years 2 and 3 of grants awarded in previous years are also provided out of the research budget.



Cosmic Frontier – Statistics on Early Career Awards (Labs & Universities)

FY10 FY11 FY12 FY13 FY14 FY15

Awards (5-year):

FY10

Newman (Pitt)
Mahapatra (TAMU)

FY11

Chou (FNAL)
Slosar (BNL)
Hall (Maryland)

FY12

Mandelbaum (CMU)
Padmanabhan
(Yale)
Carosi (LLNL)

FY13

Bolton (Utah)
Chang (ANL)

FY14

Dahl (Northwestern)

FY15: none



Summary

- An exciting time for HEP and the Cosmic Frontier!
- Close coordination with the other agencies.
- P5 developed compelling, realistic strategic plan with a consensus vision for US HEP
→HEP is moving forward to implement it.



BACKUP

COSMIC FRONTIER: GENERAL



HEP Cosmic Frontier Program

Research Funding - priorities

We are a science mission oriented agency. The projects in the program that are picked for the (P5) strategic plan are ones that will provide significant leaps in science. HEP supports the community to carry out these projects & experiments.

- **HEP funding priority is to support projects/experiments in our program, where we have responsibilities.**

Research Support – for scientists at labs and universities

- In practice, HEP traditionally supports teams/collaborations of scientists with the necessary expertise and responsibilities to take experiments through all phases, from R&D, Fabrication, Operations, & Data Analysis
 - Science planning is expected throughout all phases to end up with coordinated data analysis by a collaboration (One precision result rather than 100 independent results)
 - It is understood that people have different strengths and are involved in different aspects of project.
- The priority for research funding will be to sufficiently support the science collaborations to carryout the project design, fabrication and operations and to plan and carry out the data analyses to deliver the science.
 - - Ensure some room in the research program for development of ideas for new projects that are aligned with the science drivers.
- Distribution of efforts across science topics and projects will necessarily change to support changing priorities and status of the experiment
- Funding for theory/simulations/phenomenology/computational efforts in direct support of our Cosmic Frontier experiments (otherwise should be proposed to the Theory program).



Cosmic Frontier – Program Planning & Execution

Build Program following the P5 Plan & P5 Criteria with

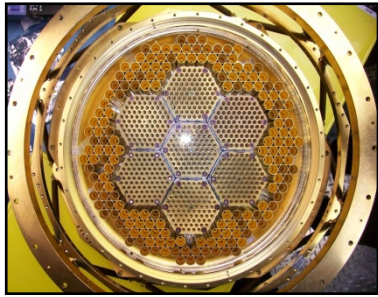
- Make significant, coherent contributions to facilities/experiments selected for the program at a level commensurate with expected science return on HEP physics goals
- Support an HEP-style science collaboration in all stages, including coordinated data analysis to get the best possible science results
- Form partnerships or use other agency's facilities when needed (e.g. telescopes)
- For facilities with broader science program (e.g. LSST) than the interests of the HEP program
 - project contributions at appropriate level & support research efforts for our science interests

For projects being considered:

- Balance & Stages: Staged implementation, results; varying project size; varying methods/technologies; balance between science areas and speculative/guaranteed results
- Science goals and how it will address DOE-HEP goals?
- Make unique, significant, coherent contributions to facilities/experiments selected for the program at a level commensurate with expected science return on HEP physics goals
 - Roles & responsibilities in line with our contributions/expertise
 - **What does HEP community bring to the table?**
Need to bring unique, visible, leadership contributions, especially if it's an area usually supported by another agency. Typically this is expertise in developing & delivering state-of-the art instrumentation, lab infrastructure & project management, "big data" computing facilities and expertise, and having a cohesive science collaboration to carry out all phases of the project/experiment and deliver precision results.

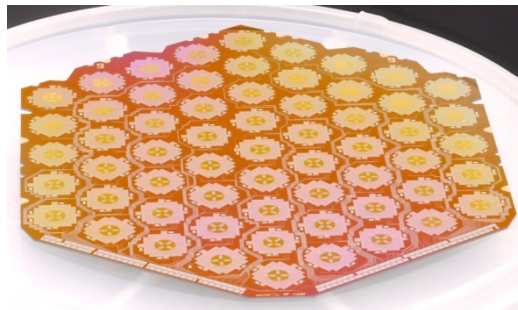
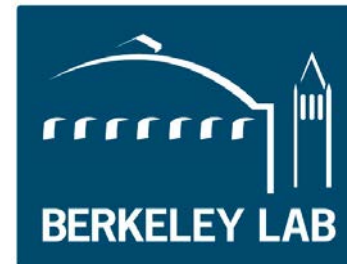


HEP CMB Technology – from Stage 1 to Stage 4



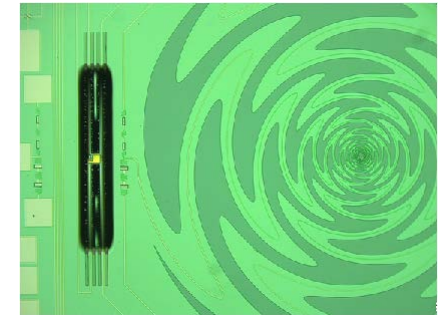
Detectors – bolometers, sinuous pixels, multichroic, massive arrays

Electronics – high density interconnectivity



Optics – cold optics, lenslets, anti-reflection coatings

Readout – multiplexing, superconducting LC resonators, superconducting NbTi striplines



P5 Report – Program & Project Criteria



HEP will use P5 criteria to develop the program and determine which projects, and at what level, to invest in.

- Program optimization criteria

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

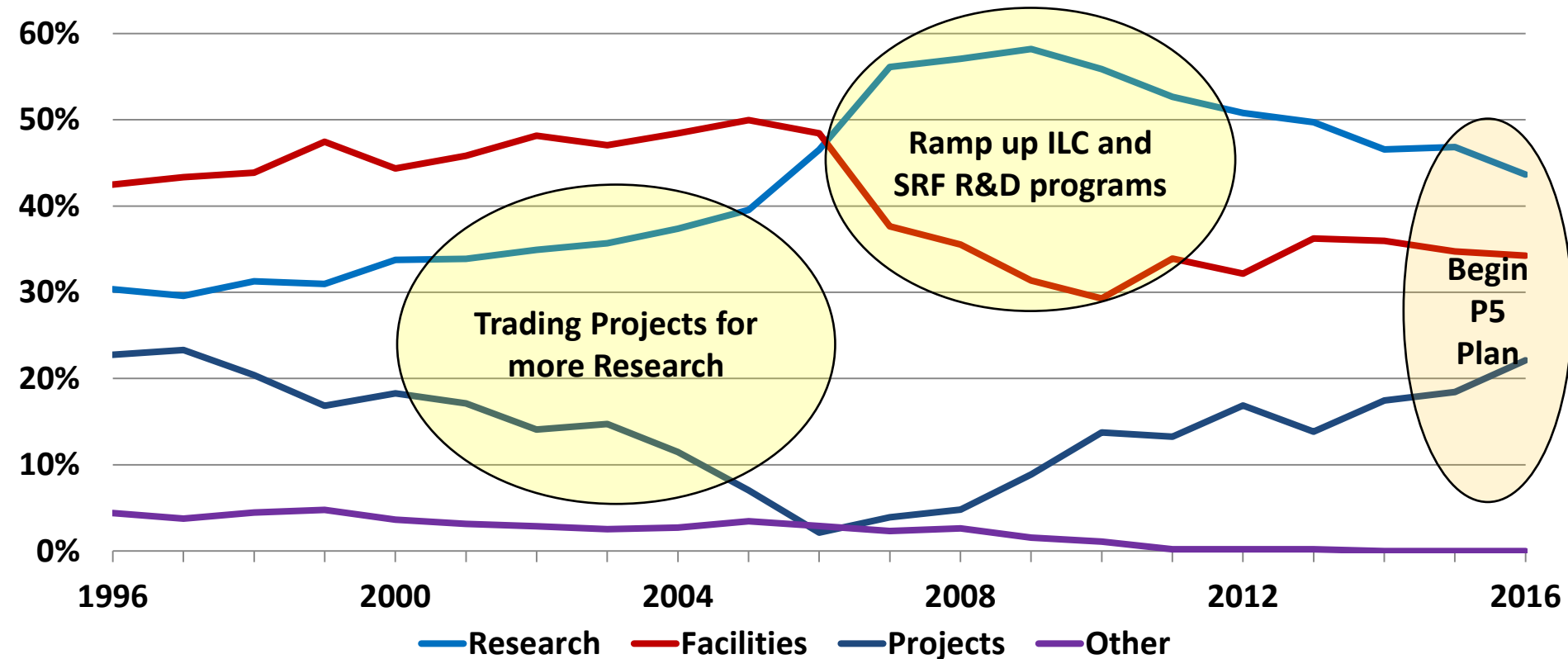
- Individual project criteria

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



HEP - Funding Trends by Fiscal Year

(FY 2016 shows President's Request)



- P5 report recommendation suggests increasing the project budget fraction to 20%–25%
 - “Addressing the [science] Drivers in the coming and subsequent decades requires renewed investment in projects.”
- P5 report strategy has informed the HEP request in the FY 2016 DOE budget



Guidance from Astro2010 “New Worlds New Horizons” Report (August 2010)

Recommendation – International Collaborations (World-wide Open-skies policy):

U.S. investors in astronomy and astrophysics, both public and private, should consider a wide range of approaches to realize participation in international projects and to provide access for the U.S. astronomy and astrophysics community to a larger suite of facilities than can be supported within the United States. The long-term goal should be to maximize the scientific output from major astronomical facilities throughout the world, a goal that is best achieved through opening access to all astronomers. These could include not only shared construction and operation costs but also strategic timesharing and data-sharing agreements.

Recommendation - International Coordination/cooperation:

Approximately every 5 years the international science community should come together in a forum to share scientific directions and strategic plans, and to look for opportunities for further collaboration and cooperation, especially on large projects.

Recommendation - Stewardship :

NASA, NSF, and DOE should on a regular basis request advice from an independent standing committee constituted to monitor progress toward reaching the goals recommended in the decadal survey of astronomy and astrophysics, and to provide strategic advice to the agencies over the decade of implementation.

Recommendation - Research Networks in Theoretical and Computational Astrophysics

A new program of Research Networks in Theoretical and Computational Astrophysics should be funded by DOE, NASA, and NSF. The program would support research in six to eight focus areas that cover major theoretical questions raised by the survey Science Frontier Panels.

NASA/DOE: To enable the large-scale theoretical investigations identified as science priorities by this survey, the committee proposes a new competed program to support coordinated theoretical and computational research—particularly that of fundamental relevance to upcoming space observatories. For NASA an annual budget of \$5 million is recommended. For DOE an annual funding level of \$1 million is recommended for activities related to space-based research.

NSF/DOE: This is a new competed program coordinated between NSF and DOE to support coordinated theoretical and computational attacks on selected key projects that are judged ripe for such attention. An NSF annual funding level of \$2.5 million is recommended. For DOE an annual funding level of \$1 million is recommended. A similar program is proposed for NASA and DOE above in the space-based program recommendations.

Recommendation - Data Handling

Proposals for new major ground-based facilities and instruments with significant federal funding should be required as a matter of agency policy to include a plan and if necessary a budget for ensuring appropriate data acquisition, processing, archiving, and public access after a suitable proprietary period.

Recommendation - Stewardship - Data Curation

NSF, NASA, and DOE should plan for effective long-term curation of, and access to, large astronomical data sets after completion of the missions or projects that produced these data, given the likely future scientific benefit of the data. NASA currently supports widely used curated data archives, and similar data curation models could be adopted by NSF and DOE.

FY2017 – President's Request Budget - Research

Included in the FY17 budget request is \$100M for University Grants in Office of Science as Mandatory Funding (as opposed to the rest of the SC budget, which is Discretionary Funding). Discussion is on p20 here:

http://energy.gov/sites/prod/files/2016/02/f29/FY2017BudgetinBrief_0.pdf

“In addition to the FY 2017 Request, an authorization proposal for the Office of Science for \$100 million of mandatory funding for University Grants will be transmitted to Congress, for a total FY 2017 Budget of \$5.672 billion. Funding will be made available through a competitive merit-based review of proposals solicited from and provided by the university community. The solicitations will be designed to open new paths as well as accelerate ongoing activities of interest to the SC basic research endeavors in the mission areas of Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, **High Energy Physics** and Nuclear Physics.”

Cherry Murray's presentation

http://science.energy.gov/~media/sc1/pdf/2012/Murray_2017_Budget_Presentation.pdf):

“HEP: Topics described in the 2014 HEPAP Long Range Plan and also topics that span multiple SC programs, including quantum information sciences/the entanglement frontier and quantum field theory across disciplines.”

BACKUP

COSMIC FRONTIER:

PROJECT & EXPERIMENT SUMMARIES



Baryon Oscillation Spectroscopic Survey (BOSS)

Science: Stage 3 Dark Energy experiment - spectroscopic experiment
Galaxy clustering redshift survey including **Baryon Acoustic Oscillation (BAO)** distance and **Redshift Space Distortion (RSD)** growth methods. Mapped 3-D positions of 1.5 million galaxies & line-of-sight to 160,000 quasars using Lyman-alpha forest.

Description:

BOSS was the flagship survey on the Sloan Digital Sky Survey (SDSS) Phase III at Apache Point Observatory in New Mexico; **DOE funded the SDSS spectrograph upgrade needed for BOSS and also BOSS operations.**

Partnership: DOE, NSF, the Sloan Foundation, and private and foreign institutional contributions

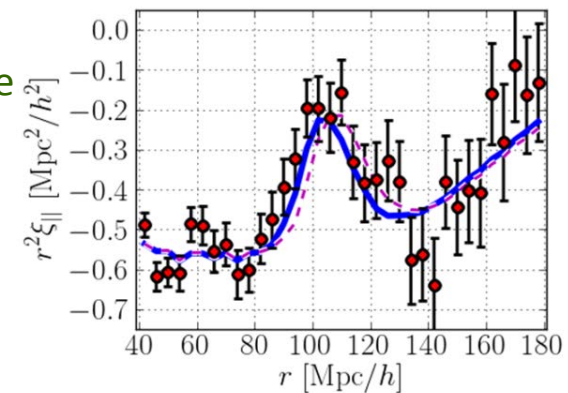
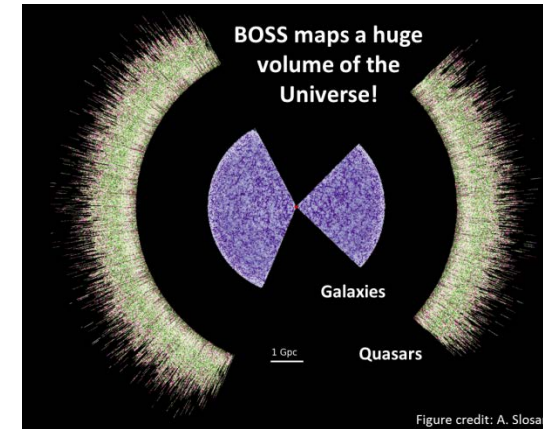
Collaboration: ~160 scientists from ~15 US institutions and

UK, Brazil, Germany, France, Japan

HEP funding: LBNL (project office), BNL, Utah, Yale, OSU, Michigan, Irvine

Recent Highlights: (Apr 2016)

- Final data set (DR12) publicly released Jan 2015 <http://www.sdss.org>
- E.O. Lawrence Award to PI David Schlegel, May 2015
- Final results from 5-year galaxy survey published April 2016, D_A and $H(z)$ at $z=0.3$ and $z=0.57$ arxiv.org/abs/1509.06371
- Current cosmology defined by Planck 2015 + BOSS galaxies + BOSS Lyman-alpha forest + supernovae



Extended Baryon Oscillation Spectroscopic Survey (eBOSS)

Science: Stage 3 Dark Energy experiment – wide-field optical spectroscopy

Galaxy clustering redshift survey including **Baryon Acoustic Oscillation (BAO) distance** and **Redshift Space Distortion (RSD) growth methods**. Mapping 3-D positions of 500,000 galaxies, 500,000 quasars & lines-of-sight to 120,000 quasars using Lyman-alpha forest.

Description: Cosmological survey on the 4th generation of the Sloan Digital Sky Survey (SDSS-IV) at Apache Point Observatory; DOE funded a spectrograph upgrade for SDSS-III. HEP grant to support **eBOSS** operations FY15-17.

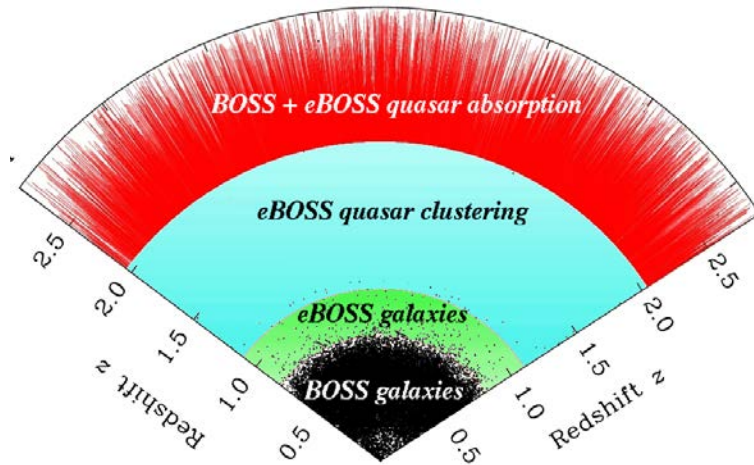
Partnership: DOE, the Sloan Foundation, more than 50 private and foreign institutions

Collaboration: ~220 scientists from ~20 US institutions and UK, Brazil, Chile, Mexico, Germany, France, Japan, Spain, China

HEP funding: LBNL, BNL, Utah, Yale, Harvard-CfA, Ohio State, Ohio, UC-Irvine, Pittsburgh

Recent Highlights: (March 2016)

- 6-year survey began July 2014
- First use of WISE IR data for target selection in spectroscopic cosmology survey
- DECam data for Fall 2016 spectroscopy – first use of DECam in spectroscopic cosmology survey
- First data set (DR13) to be released in Summer 2016, <http://www.sdss.org>
- 10 papers published or submitted using 1st year data



Dark Energy Survey (DES)

Physics: Stage-III dark energy experiment - imaging survey

4 techniques: galaxy angular clustering (300 million galaxies), weak lensing tomography, galaxy cluster counts (10000s), supernova distances (3500).

Description:

- HEP supported fabrication of Dark Energy camera (DECam), managed by Fermilab, installed on Blanco telescope at CTIO (Chile), and is now supporting survey operations, camera maintenance, and some of the data processing.
- NSF supported telescope upgrade and development of the data management system; supporting facility and data processing during operations phase.
- 525 night survey over 2013-2018

Status: Completed 3rd full year of operations in February 2016

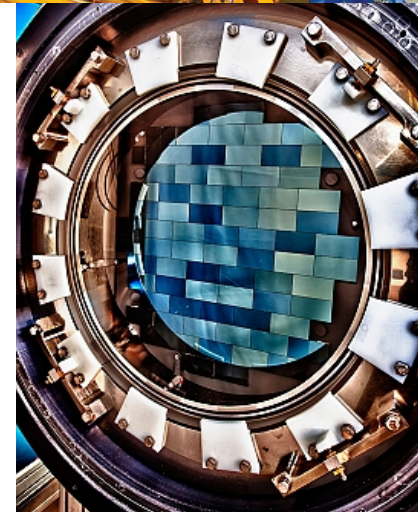
Partnership: DOE/NSF partnership + private & foreign contributions; JOG meets monthly.

Collaboration: 4 DOE labs (FNAL lead, ANL, SLAC, LBNL), NOAO/CTIO, NCSA, 20 universities and consortia from US, Spain, UK, Brazil, Germany, Switzerland, Australia.

HEP funding: FNAL, ANL, SLAC, LBNL, BNL, Illinois, Chicago, Michigan, Penn, OSU, UCSC

Recent Highlights:

- 17 new dwarf galaxy satellite candidates; limits on DM joint with FGST (Mar, Aug 2015, Mar 2016)
- Weak lensing cosmic shear, galaxy-galaxy lensing, galaxy clustering, and cross-correlations with CMB, first cosmology constraints (July 2015-Mar 2016)
- 62 papers posted, mostly from Science Verification data (May 2014-Mar 2016)



Dark Energy Spectroscopic Instrument (DESI)

Physics: Stage 4 Dark Energy experiment – spectroscopic survey

Galaxy clustering redshift survey including [Baryon Acoustic Oscillation \(BAO\) distance and Redshift Space Distortion \(RSD\) growth methods](#). Mapping 3-D positions of ~25 million galaxies & line-of-sight to 1.5M quasars using Lyman-alpha forest.

DESI will [complement the DES → LSST imaging surveys](#).

Description:

- Project will fabricate 10 new spectrographs & robotic fiber positioner system to be installed and operated on the existing Mayall 4-m telescope on Kitt Peak.
- HEP leading the DESI fabrication (LBNL management) and will provide support for operations of the telescope facility during the operations phase

Partnership: DOE, NSF/AST, STFC (UK), France + additional foreign and private contributions, including the Heising-Simons Foundation

→ DOE+NSF MOA for HEP to start supporting NOAO operations costs in FY16, ramping up to full support by HEP for dark energy survey operations in FY2019.

- Bi-weekly DOE/NSF Joint Oversight Group (JOG) meetings

Collaboration: 39 US and international institutions.

HEP funding: LBNL (Project Office) + FNAL, SLAC, ANL, BNL, Ohio State, Michigan, Yale, Pittsburgh, CMU, SMU, Utah, Irvine, Cornell, Penn, Harvard

Status:

Approved as an MIE project in FY15

CD-1 granted (Mar 2015); CD-2 “baseline” approved (Sep 2015)

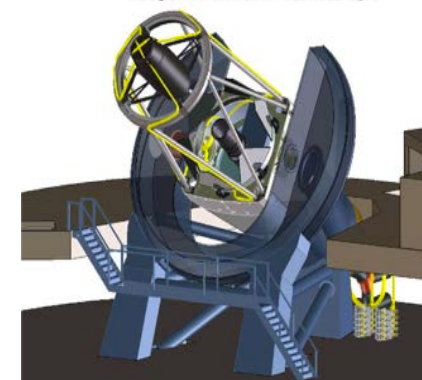
Recent Highlights:

Targeting surveys proceeding

All 4 corrector lenses manufactured (Dec 2014)



Mayall 4-Meter Telescope



Large Synoptic Survey Telescope (LSST)

Physics: Stage 4 Dark Energy experiment – Imaging survey

- DOE’s interest is in Stage-IV precisions measurements of the nature of Dark Energy. Stage-IV imaging using multiple cosmological probes including weak lensing.
- Optical/NIR imaging survey with repeated scans of the sky – “time domain”.
- The data will also be used by the wider community for a variety of astronomical measurements.

Project Description:

- LSST Project - new 8.4 m telescope facility & associated instrumentation on Cerro Pachon, Chile
- LSSTcam Project (HEP responsibility) – SLAC management; major effort by BNL, LLNL, contributions from LBNL, FNAL, universities.

Status:

- LSSTcam - Approved as MIE (Major Item of Equipment) project in FY14;
- CD-2 “baseline” approved Jan 2015; CD-3 full fab approved August 2015

Partnership:

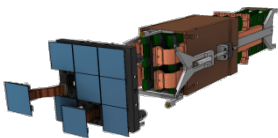
- NSF is the lead-agency, responsible for telescope facility & data management system
- DOE is responsible for the 3-billion pixel imaging camera (LSSTcam), managed by SLAC.
- DOE and NSF-AST MOA describes the roles & responsibilities
- NSF/DOE Joint Oversight Group (JOG) meets weekly, briefs OSTP regularly.

Collaboration: Dark Energy Science Collaboration (DESC) formed, led by SLAC, to provide science results needed to satisfy DOE; planning & studies for precision analyses.

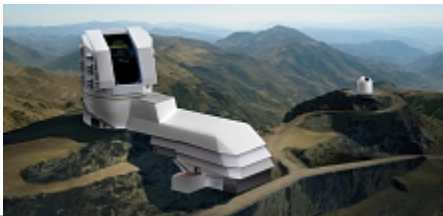
HEP funding: SLAC, FNAL, ANL, LBNL, BNL, 16 HEP universities

Recent Highlights:

- “First Stone” ceremony on Cerro Pachon site (Apr 2015)
- Completion of M1M3 mirror (Feb 2015)



LSST - Science Raft Tower,
Part of DOE deliverables



Large Underground Xenon (LUX) + ZEPLIN → LZ

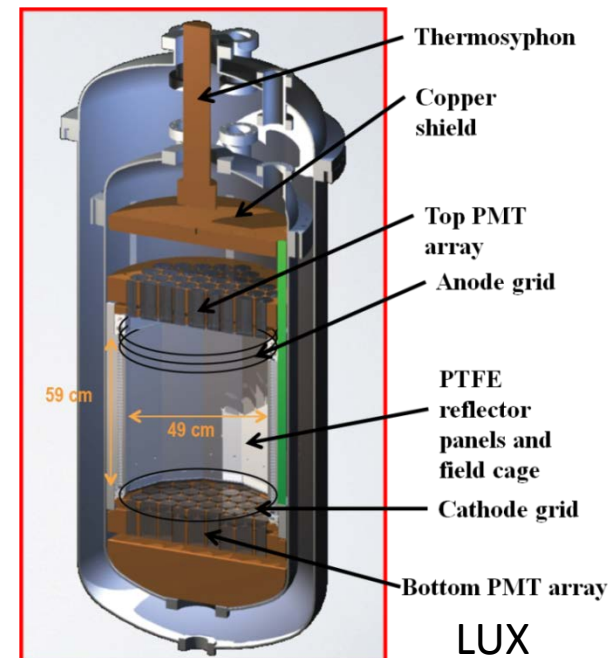
Physics: Direct detection of WIMPS through dual phase liquid Xe.

Description: **LUX** - 350 kg liquid Xe at Sanford Underground Research Facility (SURF) in Davis cavern 4850' underground. Will reach sensitivity to WIMP (50 GeV) of $\sim 2 \times 10^{-46} \text{ cm}^2$. **LZ** - 7 tons of active Xenon and sensitivity near $2 \times 10^{-48} \text{ cm}^2$, 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:

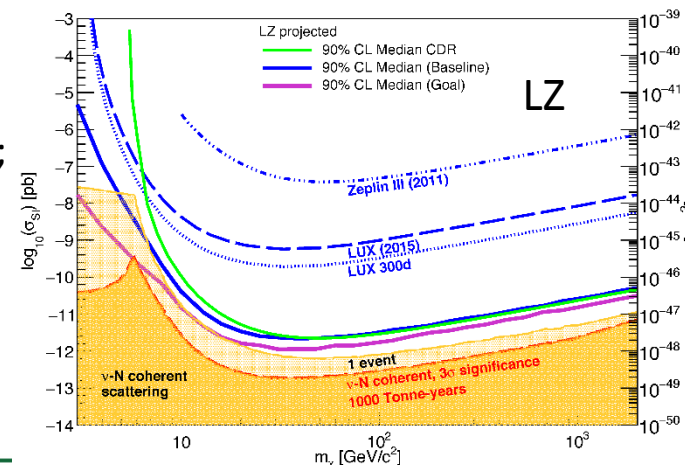
LUX About 400 live days, stops end FY16; decommissioning in FY17

LZ selected as one of three G2 Dark Matter experiments (July 2014);

CD1/3a approved Apr 2015; CD2/3b review April 2016

Recent Highlights: (Mar 2016)

- **LUX** - tightest limits on spin-independent cross-section
- **LZ** – fabrication started and major procurements underway



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:

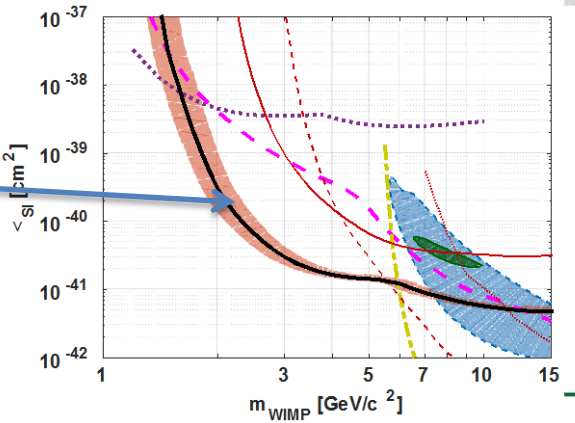
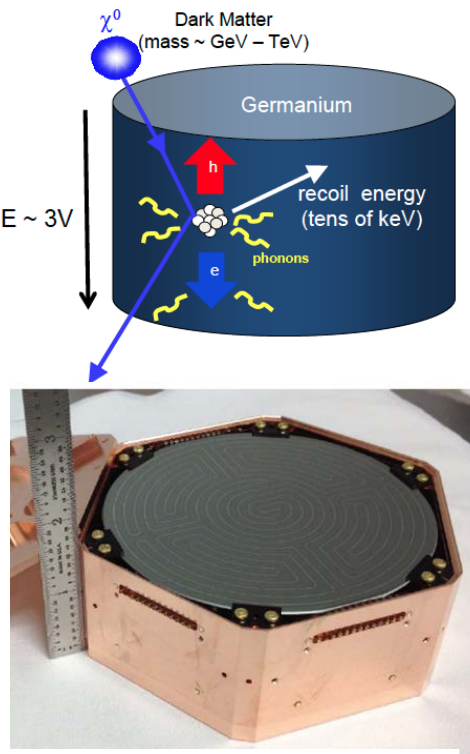
SuperCDMS-Soudan operations complete in FY15; analysis and decommissioning in FY16

SuperCDMS-SNOLAB selected as one of three G2 Dark Matter experiments (July 2014); CD-1 approved December 2015. CD-2/3 expected in 2017.

Recent Highlights: (March 2016)

New limit on low-mass WIMPS from CDMSlite Run 2 (black line and orange band); > x10 improvement at 3 GeV/c² (<http://arxiv.org/abs/1509.02448>)

Expect new results from CDMSlite Run 3 and additional SuperCDMS Soudan analyses in summer/fall 2016.



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

Operates as a phased program with ADMX-2a operations completed in 2015, ADMX-G2 started fabrication at the end of FY14, and regular ADMX-G2 operations in 2016.

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

Collaboration: 23 scientists from 2 countries. LLNL, FNAL, U. of Washington, U. of Florida, UC Berkeley, NRAO, PNNL, LANL, Sheffield University (UK)

HEP funding:

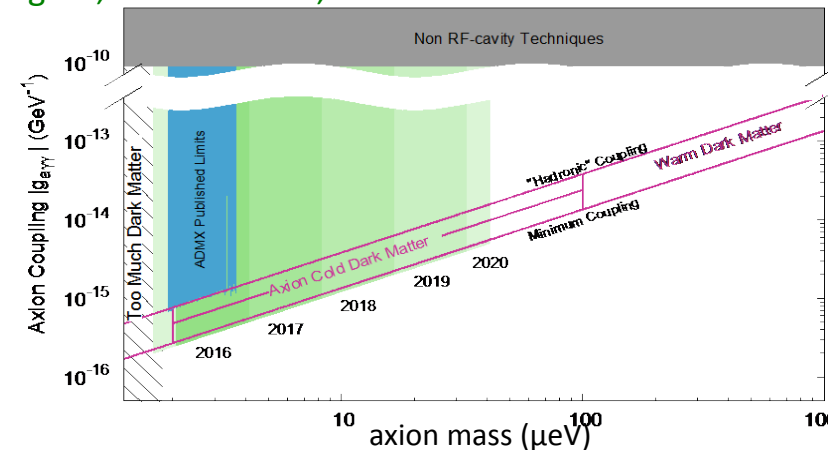
U. Washington (experiment site), U. Florida, LLNL, FNAL, PNNL.

Status

ADMX-G2 selected as one of three G2 Dark Matter experiments, HEP funding for FY14-FY16. Nearing end of commissioning.

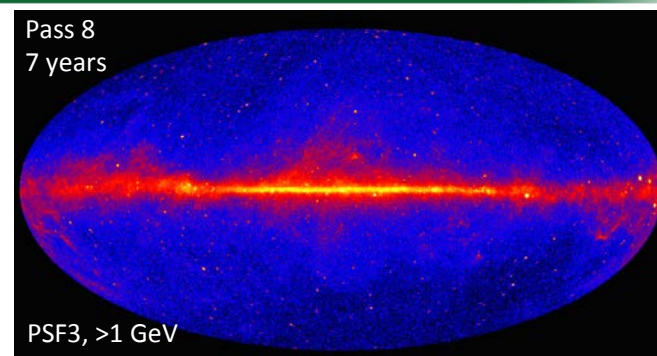
Recent Highlights:

- Featured in Scientific American (Sep 2015)

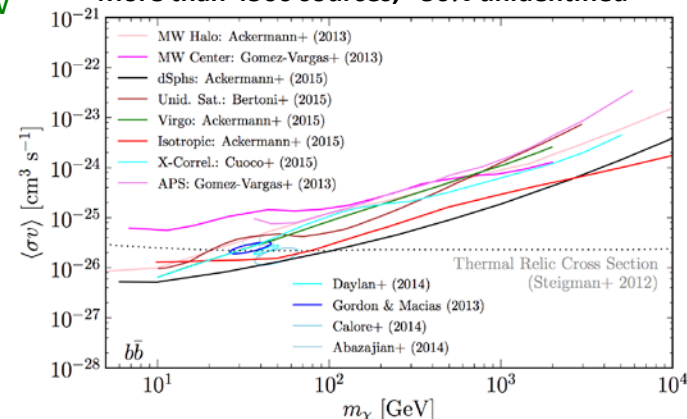


Fermi Gamma-ray Space Telescope (FGST)

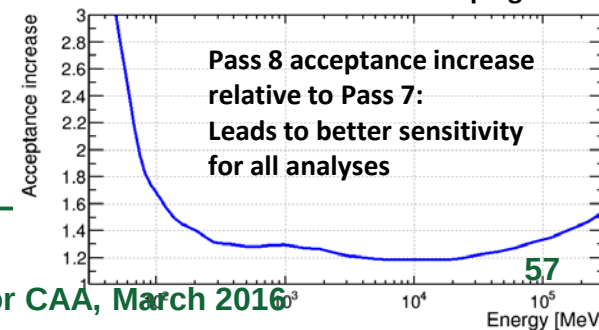
- **Physics:**
- Study high-energy (~ 20 MeV- >300 GeV) γ rays using particle physics detector technology in space
- Indirect Dark Matter (DM) detection; high-energy acceleration mechanisms
- **Partnership:**
- DOE, NASA and 4 international agencies partnered on construction of the Large Area Telescope (LAT), managed by SLAC; NASA leads the mission
- DOE supports LAT Instrument Science Operations Center (LAT_ISOC) at SLAC
- **Status:**
- Launched June 2008 for 5-year mission with 10-year goal; NASA Senior Review Panel (SRP) 2014 recommended continuation of the Fermi extended mission at a modestly reduced funding level, re-review by SRP in early 2016
- Event reconstruction and analysis upgraded ("Pass 8") to production in 2015
- Next with P8: $E < 0.1$ GeV; $E > 50$ GeV; diff. emission model; 4th γ -ray source cat.
- *HEP expects to support operations for up to a 10 year survey (done in FY18); planning in coordination with NASA*
- HEP to support the operations of FGST LAT-ISOC through at least FY16 to coordinate with the current NASA approval. Depending on NASA approval, HEP expects to continue supporting LAT-ISOC operations through 10 year survey (done in FY18).
- **Recent highlights: (March 2016)**
- Fermi-LAT counterpart limits on Gravitational Wave event (arXiv:1602.04488)
- Limits to DM annihilation cross-section from a combined analysis of MAGIC and Fermi-LAT observations of dwarf satellite galaxies (arXiv:1601.06590)
- Search for γ -rays from DM in the SMC with Fermi LAT (arXiv:1603.00965)
- Fermi-LAT observations of recently discovered dSph galaxy candidates



Gamma-ray sky Preliminary 7-year Pass 8 findings:
More than 4500 sources, >50% unidentified



Many independent approaches to DM search in LAT data. Dark matter interpretation of Galactic Center excess is in tension with limits from dSph galaxies



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High Altitude Water Cherenkov (HAWC) Gamma Ray Observatory

Physics: Sky survey 100 GeV to > 100 TeV γ -rays

- Indirect dark matter search from γ -ray annihilation & decay
- Quantum gravity effects on propagation of γ -rays
- Particle acceleration in extreme magnetic and gravitational fields: gamma-ray bursts, supermassive black holes, neutron stars, supernova remnants

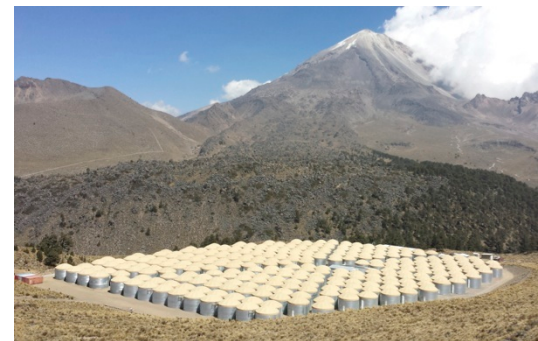
Description: Air Shower Detector with 300 Water Cherenkov Detector tanks covering 20,000 m² at 4100 m on Sierra Negra Volcano, Mexico. Field of view is 2 sr with exposure to 2/3 of the sky each day. Operations managed by LANL.

Status: Construction completed March 2015; HEP plans 5 years of operations

Partnership: DOE, NSF (lead), Mexico (CONACyT), Germany (Max Planck Inst. Heidelberg)

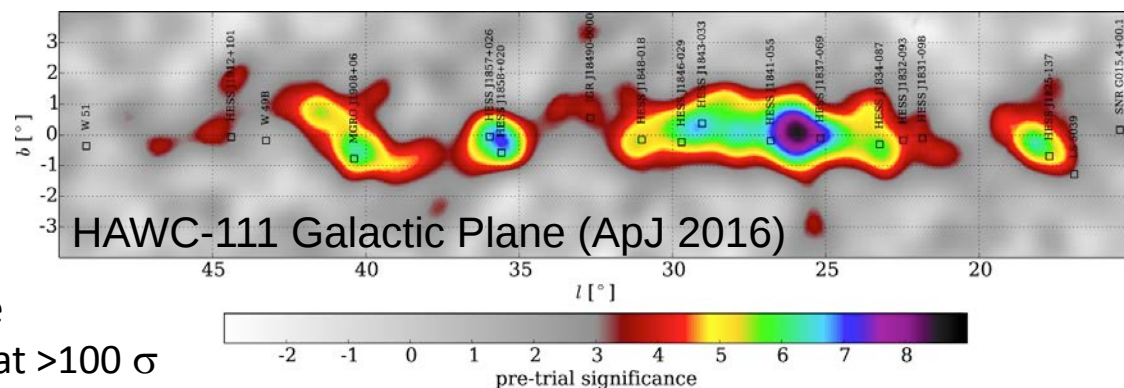
Collaboration: ~ 100 scientists from US (LANL + 15 universities), Mexico, and Germany

HEP funding: LANL (HEP lead), Univ. New Mexico, Rochester



Recent Highlights: (March 2016)

- Publication of new TeV sources with data from 1/3 of HAWC for < 1 yr (Astrophysical Journal, 2016)
- Current Preliminary map from the full detector is > 5 times more sensitive than that in publication, with the Crab at $> 100 \sigma$
- Limits on dark matter annihilation in 14 nearby dwarf spheroidals were presented at 34th International Cosmic Ray Conference (Aug 2015)



VERITAS

(Very Energetic Radiation Imaging Telescope Array System)

Physics: Studies very high energy (85 – 30,000 GeV) gamma-rays.

Description: Array of four 12-meter Cherenkov telescopes, at the Whipple observatory in Arizona.

Status: Operations continuing; HEP participation ramping down

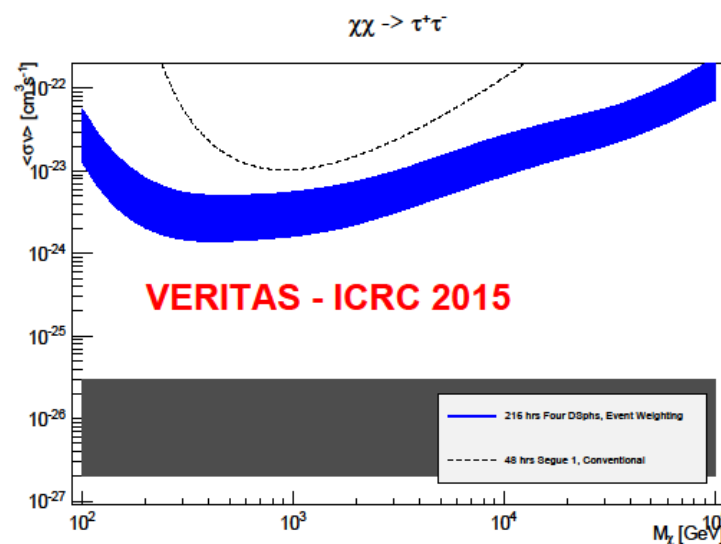
Partnership: NSF, DOE, Smithsonian (managing agency)

Collaboration: ~100 scientists from US (DOE, NSF, SAO), Canada, Ireland, and Germany.

HEP Funding: ANL, Washington Univ. (St. Louis), Purdue, Iowa State, Smithsonian Astrophysical Observatory (SAO). NSF & DOE site-operations grants funded through mid-2016.

Recent Highlights:

- 10x improved DM limits: 2007-12 data for 5 dwarf galaxies
 - Dwarf gal. = Cleanest case for astrophysical DM detection
- Cosmology: Detected quasar ~7.6 billion light years away ($z \sim 1$)
 - Strong constraints on extragalactic background light



Multiple DM-decay channels calculated

Another 10x better by 2019
(More data = 5x; Better analysis = 2x)

Alpha Magnetic Spectrometer (AMS)

Physics: Search for antimatter, dark matter annihilations & new particle phenomena in space.

Description: Multi-purpose spectrometer detects cosmic-rays up to 1 TeV, sited on the International Space Station (ISS).

Status: Launch in May 2011; operations continuing; 77 billion cosmic ray events have been collected.

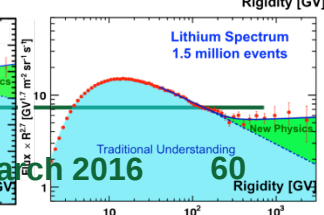
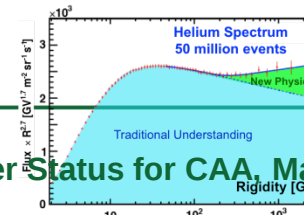
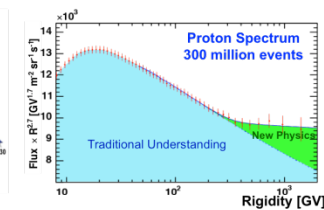
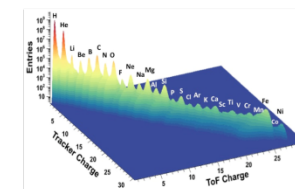
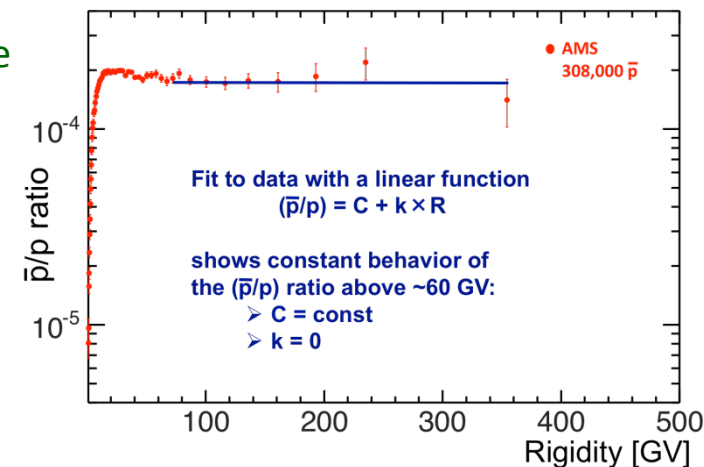
Partnership: DOE-led in US; NASA provided a dedicated Space Shuttle flight, the use of the ISS resources (power, data, etc) and mission management; CERN hosts AMS Payload Operations Control Center.

Collaboration: International collaboration (led by Sam Ting, MIT) of 16 countries, 60 institutes and 600 physicists. 95% of the ~\$2B construction costs came from Europe and Asia.

HEP funding: MIT (research and fabrication/operations)

Recent Highlights:

- 1) Antiproton flux and antiproton/proton ratio is based on 308,000 antiproton events. The rigidity independent behavior of the ratio above ~60 GV is not explained by current cosmic ray models.
- 2) Unexpected change of the behavior of light cosmic ray nuclei – protons, He and Li – at rigidity ~300 GV.



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Cosmic Frontier – Major Item of Equipment (MIE) Projects

→There are 4 MIE Projects – LSST, DESI, LZ, SuperCDMS-SNOLAB

Large Synoptic Survey Telescope (LSST) – Dark Energy Stage IV Imaging

NSF project, HEP providing the LSSTcam (SLAC managing)

- LSSTcam & overall LSST Project going well; In CD-3 (full fabrication phase); Status review early Feb. 2016

Dark Energy Spectroscopic Instrument (DESI) - Dark Energy Stage IV spectroscopic

“HEP experiment” with LBNL managing: build DESI instrumentation & data management system, install & operate it on the Mayall telescope

- DESI project recently re-furbished the Mosaic camera on the Mayall, with LBNL providing the CCD’s and Yale the mechanical parts and software. With NOAO, they installed “Mosaic-3” to use for z-band “MzLS” 2-year targeting survey for DESI; Also available for astronomers for other research; data being made public

HEP coordinating with NSF-AST to use (“lease”) the Mayall telescope

- MOA for FY16-18 signed – HEP ramps up, NSF ramps down funds for Mayall operations for transition phase
- MOA for FY19+ being worked on – HEP providing full costs for Mayall for dark energy science operations

Current schedule:

- CD-3 review (ready for full fabrication phase) in May 2016
- Mayall shutdown, ready for DESI 1QFY18; DESI+Mayall commissioning complete & data-taking starts 1QFY20



Cosmic Frontier – Major Item of Equipment (MIE) Projects

→There are 4 MIE Projects – LSST, DESI, LZ, SuperCDMS-SNOLAB

LZ at Homestake Mine

- WIMP dark matter search through dual phase liquid Xe – higher mass range
 - HEP leads, LBNL Project Office
- CD-1/3a approved April 2015; CD-2 “baseline” review being held in April 2016

SuperCDMS-SNOLAB

- WIMP search using cryogenic solid-state crystals – lower mass range
 - HEP+NSF-PHY partnership, SLAC Project Office
- CD-1 approval in Dec. 2015; CD-2 planned for FY17

