High Energy Physics (HEP) Program Status Report to the NAS

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Office of Science, U.S. Department of Energy

HEP PROGRAM – MODEL, GUIDANCE, STRATEGIC PLANNING

High Energy Physics (HEP) Program Model

The DOE Office of Science is a part of a mission agency

- Provide science leadership and support to enable significant advances in specific science areas
- Develop and support a specific portfolio of selected facilities & experiments to obtain the science
- Labs with a variety of resources needed to design, build, operate selected facilities & projects
  - Lab infrastructure, including computing facilities (NERSC, SCiDAC program etc)

The HEP Program

- **Long Term View:**
  - Strategic planning process to determine the portfolio of projects/experiments
  - Long-term support for our responsibilities in designing, building and operating projects
  - Plan stages of experiments for ever-increasing precision
  - Interagency and International partnerships as needed to leverage additional science and expertise
- **Complementary Approaches**
  - e.g. searching for dark matter particle detection using accelerators, direct detection underground experiments and indirect searches from gamma-ray surveys
- **Collaboration/Teamwork:**
  - Encourage and 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
  - Scientists at labs and universities have long term commitments, responsibilities on the projects & experiments, in addition to data analysis, to bring everything needed to accomplish the science
  - Long term support is needed to support long term responsibilities

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", Particle Physics Project Prioritization Panel ("P5")

    ➔Strategic Program Planning
    - HEPAP unanimously approved a new long term strategic planning report from the "P5" subpanel in May 2014

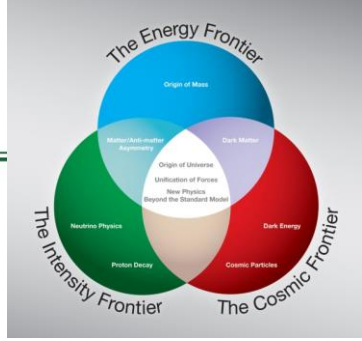
- **Astronomy and Astrophysics Advisory Committee (AAAC)**
  - Reports to NASA, NSF and DOE on areas of overlap

National Academy of Sciences

- NWNH, Mid-decade review; also participation in BPA, CAA meetings

Other: community science studies (e.g. Snowmass, Rocky-IV) reviews, etc.

2008-2009 Guidance



2008 HEPAP Particle Physics Project Prioritization Panel (P5) – Strategic Plan

Progress in achieving the goals of particle physics requires advancements at the

- Energy Frontier - Exploit the capabilities of the Tevatron and LHC at the to make discoveries
- Intensity Frontier - Implement a world-class program; neutrino program at Fermilab as flagship
- Cosmic Frontier - Address compelling high-impact scientific opportunities with an emphasis on dark energy and matter
  - Joint Dark Energy Mission (JDEM) in collaboration with NASA
  - Large Synoptic Survey Telescope (LSST) in collaboration with NSF
  - Direct dark matter search experiments
  - Develop a more detailed plan (PASAG)
- Develop accelerator technologies needed by Nation & for a U.S. leadership role in particle physics

2009 HEPAP Particle Astrophysics Science Advisory Group (PASAG)

- To further define the HEP "particle astrophysics" program
- Recommended an optimized program over the next 10 years in 4 funding scenarios
- Defined Prioritization Criteria for Contributions to Particle Astrophysics Projects
- Dark matter & dark energy remain the highest priorities; but shouldn't zero-out other activities
  - Continue working with NASA on concepts for a Joint Dark Energy Mission
  - Continue development of LSST camera concept; support R&D
  - Recommended the High Altitude Water Cherenkov (HAWC) project with NSF

2010 Guidance

2010 NRC Astro2010 New Worlds New Horizon (NWNH)

-- Recommended a coordinated ground/space-based Dark Energy program

- Highest priorities: WFIRST (space), LSST (ground)

CMB – "Progress in detecting [CMB gravitational waves] is rapid, with advances from ground-based telescopes, suborbital flights, and the recently launched Planck satellite. The committee recommends a technology program to advance detection techniques"

- HEP supports advanced detector and readout technology at national labs and universities.

Specific Recommendations to DOE :

- The optimistic funding profile allows investment in:
  - LSST – DOE should partner with NSF
  - WFIRST – DOE should contribute (note that this is not a dedicated dark energy mission)
- At lower funding level: LSST is recommended as the priority because DOE role is critical
- Other identified opportunities:
  - Contributions to NSF mid-scale experiments (2nd priority ground)
  - BigBOSS (now DESI) – mid-scale exemplar, CMB, HAWC etc.
  - NSF & DOE contribute as a minor partner (4th priority ground) to a European-led AGIS/CTA ground-based gamma-ray observatory

2013-2014 Strategic Planning

In recent years, we have new results that point the way forward:

- **Energy Frontier**: Discovery of the Higgs (and so far, nothing else)
- **Intensity Fron**tier: Measurement of the "small" neutrino mixing angle (θ_{13})
- **Cosmic Frontier**: Rapid advances in Dark Matter direct detection; precision Dark Energy studies; possible glimpses of inflation in the early universe
- **Technology R&D**: Recent progress in advanced accelerator concept R&D is spurring ideas for future accelerator test beds that can exploit these successes

→HEP needs a compelling & executable strategic plan, with community behind it

- Community Science Opportunities in 2013 Snowmass report
- The P5 report "Strategic Plan for US Particle Physics in the Global Context" was delivered and approved by HEPAP in the May 22-23, 2014 meeting.

- **P5 plan is a compelling, unified vision for HEP – 5 science drivers**
  - **Use the Higgs boson as a new tool for discovery**
  - **Pursue the physics associated with neutrino mass**
  - **Identify the new physics of dark matter**
  - **Understand cosmic acceleration: dark energy and inflation**
  - **Explore the unknown: new particles, interactions, and physical principles**

2014 P5 Report - Take-Away Messages

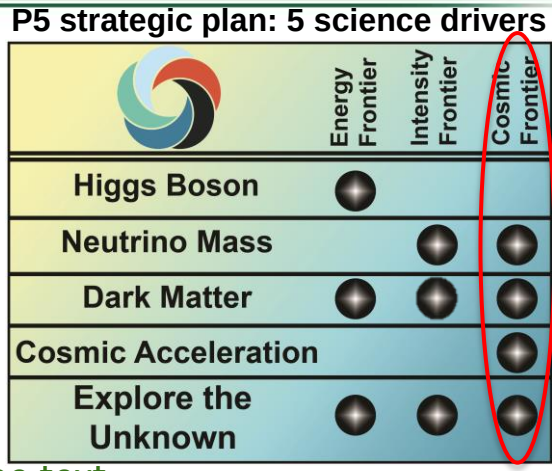
- **A balanced approach is critical**
  - The report recognizes the challenging funding landscape, where choices have to be made & resources stewarded carefully, and confronts these challenges head on.
  - Provided program optimization criteria for considering investments
  - An important reason the P5 plan has widespread HEP community support is its balanced approach:
    - Time-phased, projects of different scales, science goals, on- and off-shore, short-term and longer-term

- **P5 Plan**
  - **Highest priority major projects are Large Hadron Collider (LHC) detector (ATLAS, CMS) upgrades in the near-term and Long Baseline Neutrino Facility (LBNF; aka LBNE) in the mid-term; Near term Cosmic Frontier projects are ready to go**
    - LBNF will be the first truly international experiment hosted by the US

- **HEP share's the community's enthusiastic response to the P5 strategic plan**
  - HEP is developing & aligning the Program along P5 recommendations
  - Implementation strives to maintain the recommended balance; currently moving forward in target areas
  - Full implementation of the plan will take some time, due to budget status and as we work with partners and stakeholders: DOE management, HEP community, DOE Laboratories, Congress, OMB, other US and international Agencies, etc.

P5: Cosmic Frontier Strategy

P5 report recommendations addressed several thrust areas of the Cosmic Frontier

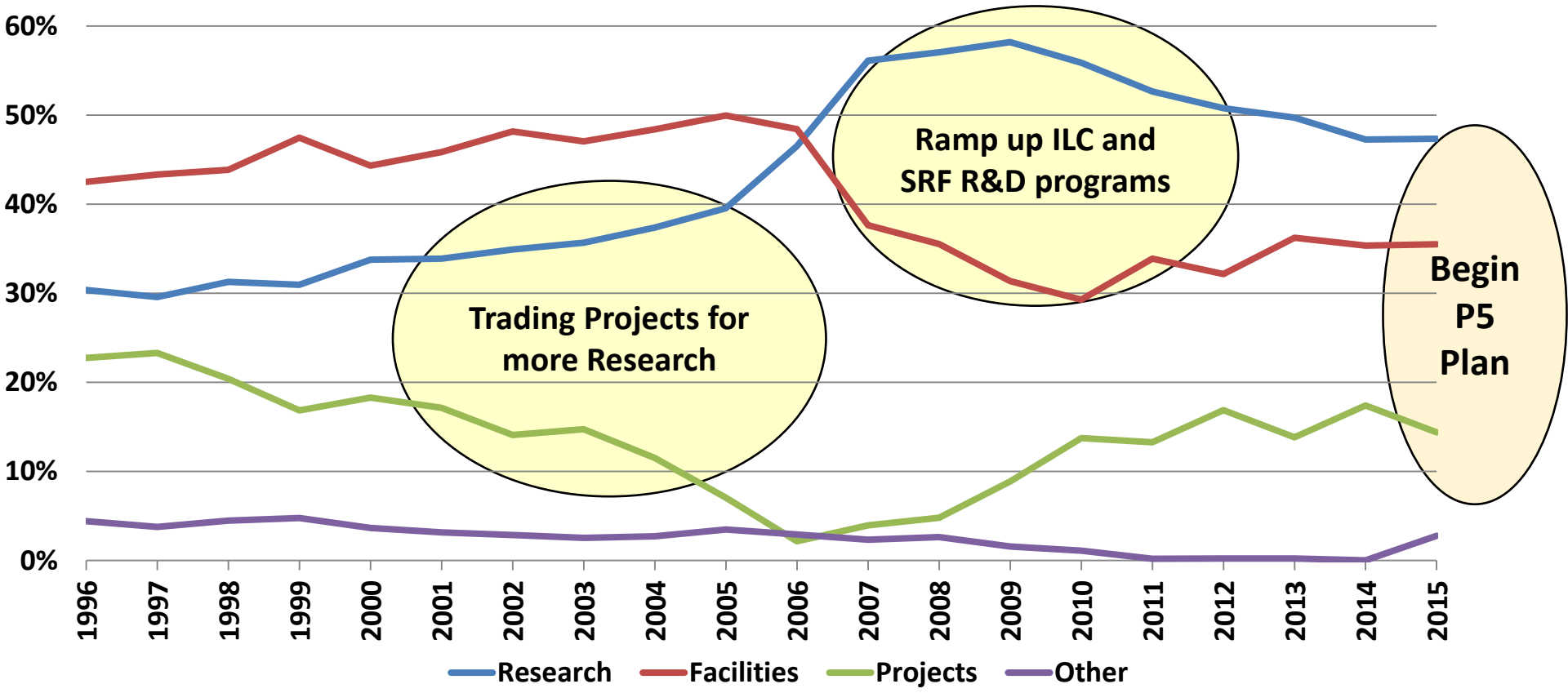


- **Dark Energy**
  - Build DESI as a major step forward in dark energy science
  - Complete LSST as planned
- **Dark Matter**
  - Proceed immediately with a broad second-generation (G2) dark matter direct detection program with capabilities described in the text
    - Invest in this program at a level 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
- **Cosmic Microwave Background (CMB)**
  - Support CMB experiments as part of the core particle physics program
  - The multidisciplinary nature of the science warrants continued multiagency support
- **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

Funding Trends by Fiscal Year

(FY2015 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 is guiding the FY 2015 budget; clear impacts should begin to become evident in FY 2016 President's Request budget**

FY 2015, 2016 High Energy Physics Budget

HEP Funding Category ($ in K)	FY 2013 Actual	FY 2014 Request	FY2014 Actual	FY2015 Request	FY2015 Enacted	FY2016 Request	Explanation of Changes (FY16 vs. FY15)
Energy Frontier	149,446	154,687	152,386	153,639	147,584	154,555	*LHC detector upgrade fabrication; R&D for high-luminosity LHC upgrades*
Intensity Frontier	274,412	271,043	250,987	251,245	264,224	247,196	*Operations and upgrade of NuMI for NOvA and MicroBooNE; R&D for LBNF and SBN*
Cosmic Frontier	80,063	**99,080**	**96,927**	**101,245**	**106,870**	**119,325**	*Planned ramp-up of LSSTcam; progress on DESI, LZ, SuperCDMS-SNOLAB, ADMX-G2*
Theoretical and Comp.	66,398	62,870	64,275	58,850	59,274	60,317	*Increase for Lattice QCD project; slight reduction in theory research*
Advanced Technology R&D	142,291	122,453	150,270	114,242	120,254	115,369	*Reduction to shift to P5 priorities; MAP reduction in response to P5*
Accelerator Stewardship	3,132	9,931	9,075	19,184	10,000	14,000	*Increase for new research areas; expand open test facility efforts*
Construction (Line Item)	11,781	35,000	51,000	25,000	37,000	56,100	*Planned profile for Mu2e; engineering and design for LBNF*
SBIR/STTR*	0	21,457	0*	20,595	20,794	21,138	
HEP Total	**727,523**	**776,521**	**774,920**	**744,000**	**766,000**	**788,000**	
SC Total	4,681,195	5,152,752	5,066,372	5,111,155	5,067,738	5,339,794	

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

HEP Program: FY 2015 → FY 2016 Budget

FY15:

- The FY15 President's Request for HEP was below P5 funding Scenario A (lowest)
- Based on the FY15 House and Senate markups of the appropriation bills, we anticipated that we will be able to implement Scenario B

The **enacted FY15 Budget** for HEP is $766M, between P5's scenario A&B.

Cosmic Frontier Major Item of Equipment (MIE) Projects

➔ **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 profil**e**

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 is up relative to FY15:
+$44M over FY15 Request & + $22M over FY15 Enacted

It is ~ $11.5M above the **FY14 Request** ($776M). If the FY16 Request is passed, this would be slightly above the P5 scenario B, which was flat-flat for 3 years starting with the FY14 Request and then increasing 3% per year.

HEP Program: FY 2015 →2016 Priorities

- **HEP is implementing the strategy detailed in the May 2014 report of the Particle Physics Project Prioritization Panel (P5), formulated in the context of a global vision for the field**

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

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

- **Cosmic Frontier: Advance our understanding of dark matter and dark energy**
  - Development of new capabilities in dark matter detection and dark energy exploration continues
  - Lay the ground work for future projects

- **Accelerator Stewardship**
  - broader applications of accelerator technologies

- **Construction/Major Items of Equipment (MIEs) support reflects P5 priorities:**
  - **The Long Baseline Neutrino Facility (LBNF)** continues its design phase as the project baseline cost and technical scope are revised while incorporating international in-kind contributions
  - The **LHC ATLAS and CMS Detector Upgrade** projects continue fabrication
  - **Muon g-2** continues accelerator modifications and fabrication of the beamline and detectors
  - **LSSTcam** fabrication support increases according to planned profile (fabrication started FY14)
  - Fabrication proceeds on the **Dark Energy Spectroscopic Instrument (DESI)**
  - Fabrication proceeds on the dark matter experiment MIEs: **SuperCDMS-SNOLab** and **LZ**
  - Construction continues for the **Muon to Electron Conversion Experiment (Mu2e)**

Cosmic Frontier Budget History

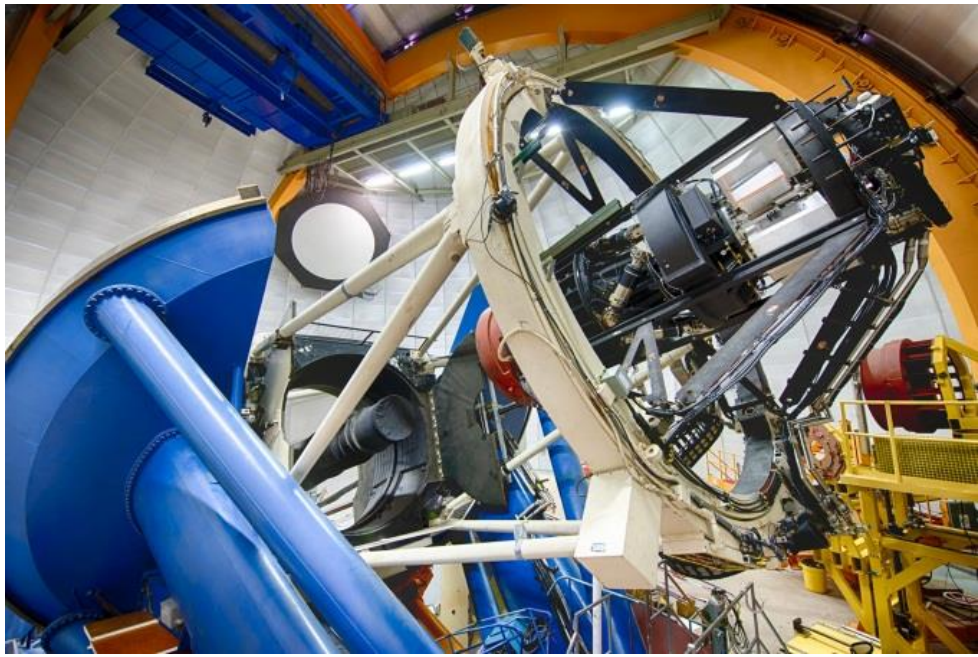
Budget in $K	FY 2013 Actual	FY 2014 Actual	FY 2015 Request	FY 2015 Enacted	FY 2015 Current (March 2015 "snapshot")	FY 2016 Request
Research	48,652	52,712	45,435	49,060	48,185	50,079
Grants	*12,233*	*13,157*	*11,422*	*11,659*	*11,609*	*12,565*
National Laboratories	*36,419*	*39,555*	*34,013*	*37,401*	*36,576*	*37,514*
Facility Operations and Experimental Support	10,111	10,357	7,238	8,790	8,890	7,120
Projects	19,159	30,705	41,000	44,203	45,653	58,701
MIE	*9,500*	*22,900*	*41,000*	*41,878*	*43,428*	*57,100*
HAWC (FY13 MIE completed)	*1,500*	*…*	*…*			
LSST camera (FY14 fab start)	*8,000*	*22,000*	*35,000*	*35,000*	*35,000*	*40,800*
DM-G2: LZ, SuperCDMS-SNOLab (FY15 approved)	*…*	*900*	*6,000*	*4,800*	*4,800*	*11,000*
DESI (FY15 MIE approved)				*2,078*	*3,628*	*5,300*
***Small Project Fabrication**, FY15: SPT-3G, ADMX-G2*				*2,225*	*1,025*	*1,601*
***Future Project R&D**, FY15: SPT-3G, ADMX-G2*	*9,659*	*7,760*		*100*	*1,200*	
TOTAL	**77,951**	**93,729**	**93,673**	**102,053**	**102,728**	**115,900**
Other Costs	2,112	3,198	7,572	4,817	5,832	3,425
Total – Cosmic	80,063	96,927	101,245	106,870	108,560	119,325

HEP COSMIC FRONTIER PROGRAM – STATUS

Cosmic Frontier

Program thrusts:

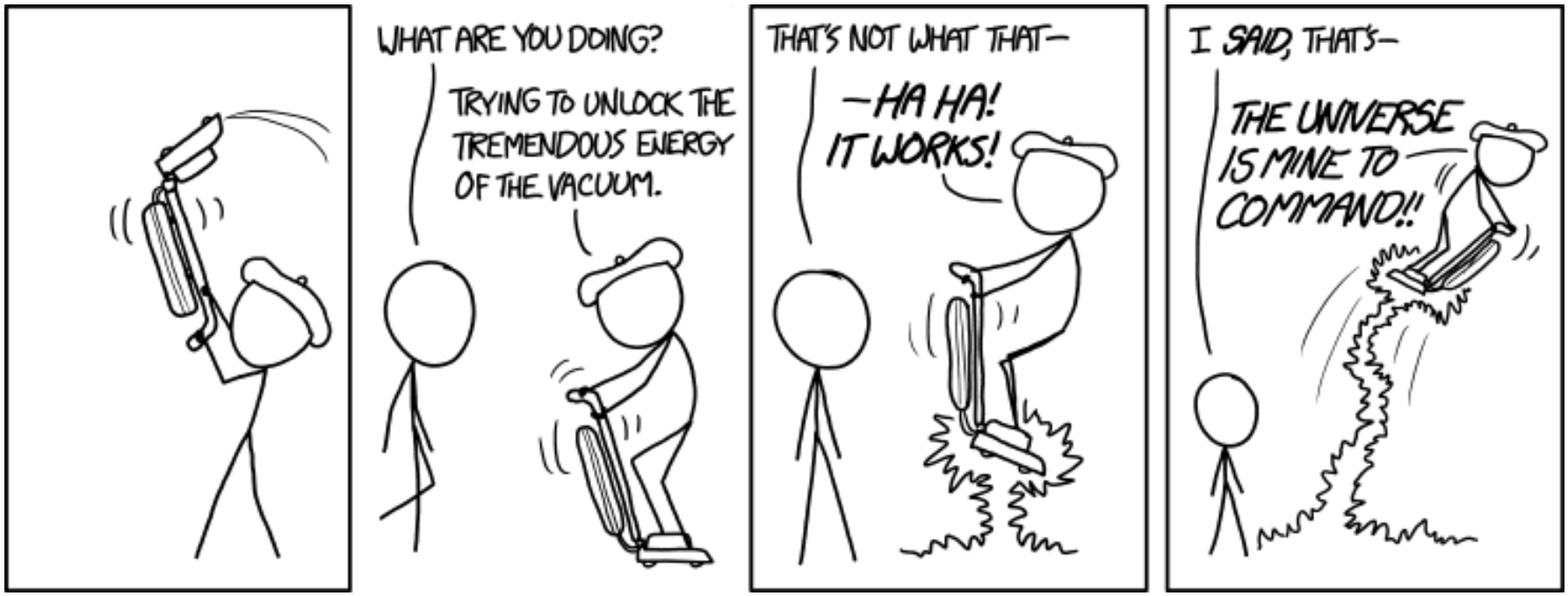
- Studies of the nature of **Dark Energy** using imaging and spectroscopic surveys
- Direct detection searches for **Dark Matter** particles
- Study of the high energy universe and indirect dark matter searches using **Cosmic-ray, Gamma-ray** experiments
- **CMB** experiments to study the nature of inflation, neutrino properties, and dark energy
- **Other** efforts, including
  - Computational cosmology efforts
  - Other experiments



Future program:

- **Continue moving forward to get P5-recommended projects going and to align the program with P5 priorities.**

Science Highlights (April 1)

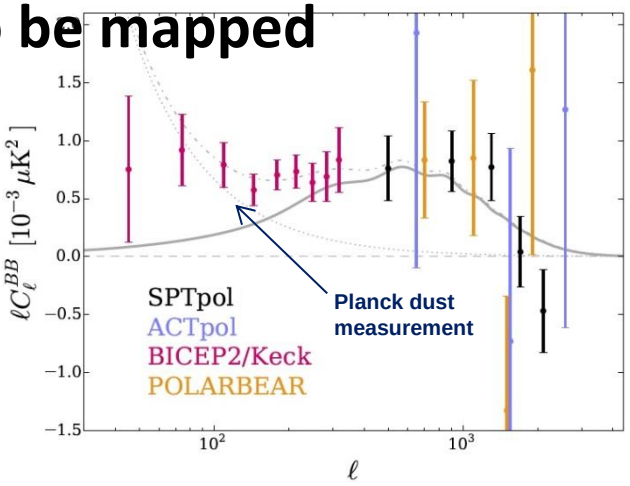


xkcd.com/1486

HEP Cosmic Frontier Highlights

CMB – B mode power spectrum starting to be mapped

DOE partnering on SPTpol, SPT-3G; research & computing efforts and LDRD efforts on Planck, BICEP/Keck, POLARBEAR

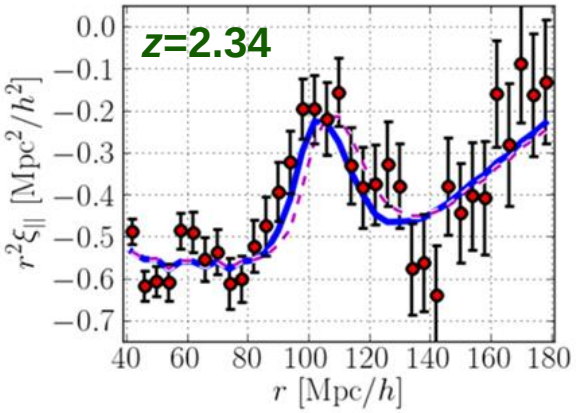


Gamma Ray studies – HAWC in full operation w/300 tanks

NSF, DOE, Mexico partnership

March 2015 Inauguration Ceremony

Dark Energy – BOSS public release of final data DR12 - Detection of BAO in decelerating epoch

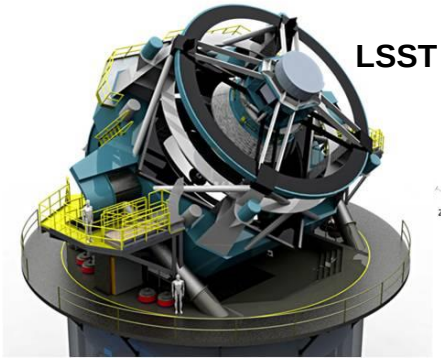


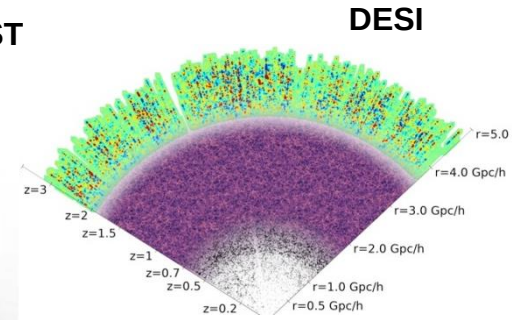
Dark Matter – DES data led to discovery of new dwarf galaxy satellites (expected to be dark matter dominated); Fermi Gamma Ray Space Telescope uses them to put tight limit on dark matter annihilation cross-section. ➔March 2015: 4 papers released from collaboration & independent groups!

Cosmic Frontier Status – Dark Energy

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

– Operating & planning complementary suite of imaging, spectroscopy and supernova survey experiments





- **Operating:**
  - *BOSS* (spectroscopic) ended in FY14
  - *DES* (imaging) started FY13
  - SN surveys continue

Design, Fabrication:

- ***Large Synoptic Survey Telescope*** **(LSST, Stage IV imaging)**
  - Approved as an MIE project in FY14
  - Partnership with NSF (DOE+NSF MOU), with foreign, private contributions
  - LSST-camera CD-3a approved June 2014, CD-2 "baseline" approved Jan 2015
  - CD-3 review scheduled for August 2015
- ***Dark Energy Spectroscopic Instrument*** **(DESI, Stage IV spectroscopic)**
  - Approved as an MIE project in FY15
  - CD-1 approved March 2015; CD-2 "baseline" review scheduled for July 2015
  - Finalizing MOA with NSF to start supporting NOAO operations costs in FY16, ramping up to full support for dark energy survey operations in FY2019

Cosmic Frontier Status – Dark Matter (direct detection)

Learn the identity and nature of Dark Matter:
Staged program of experiments w/multiple technologies

- **Operating:**
  - 1st generation (DM-G1) experiments:
    - ADMX, LUX, CDMS-Soudan, DarkSide, COUPP/PICO

- **Design, Fabrication:**
  - DOE and NSF announced in July 2014 selection of Dark Matter Generation 2 (DM-G2) experiments to move forward to fabrication phase: *ADMX-G2, LZ, SuperCDMS-SNOLab*
    - ADMX-G2 is a small project (below MIE) and started at the end of FY14.
    - LZ & SuperCDMS-SNOLab are approved as MIE projects in FY15
    - LZ had successful CD-1 review in March 2015
    - SuperCDMS-SNOLab CD-1 review planned for summer 2015

- The overall DOE & NSF coordinated DDDM program will need to include DM-G2 project(s), operations of current experiments, background and material studies, and future R&D efforts
- HEP will concentrate on getting the DM-G2 experiment(s) successfully started. Actions for a specific R&D or DM-G3 program will take place later on, and assumes adequate funding.

Cosmic Frontier Status – Cosmic-ray, Gamma-ray

Explore particle acceleration mechanisms and perform indirect searches for dark matter candidates

- Using ground-based arrays, space telescopes, and AMS on the International Space Station

- **Operating:**
  - *Fermi/GLAST, VERITAS, Auger, AMS, HAWC*

- **Future Planning: Cherenkov Telescope Array (CTA)**
  - US Community planning participation in a European-led next generation gamma ray observatory
  - HEP response to P5 recommendation, funding availability & programmatic priorities:
    ➔HEP not continuing support of research, planning, R&D efforts on CTA.

AMS on the International Space Station

HAWC full operating array (Jan 2015)

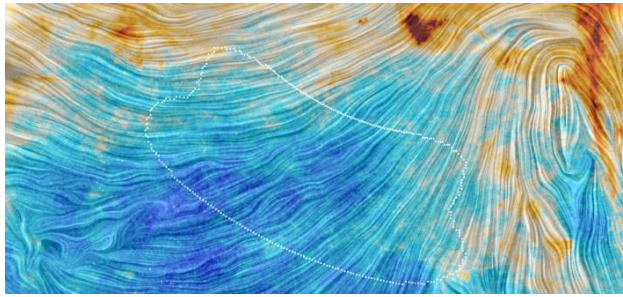
Cosmic Frontier Status – CMB

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

- **Operating:**
  - *South Pole Telescope polarization* (SPTpol) where HEP provided support for outer-ring detectors
  - Also participation in Planck (through NERSC); research activities on BICEP2, POLARBEAR
- **Fabrication:**

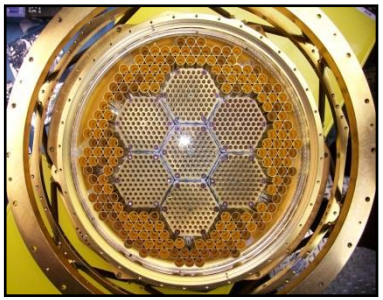
  SPT-3G
  - major upgrade of the camera to greatly increase sensitivity; HEP funding R&D and fabrication phase (FY14-16)
- **Planning:**
  - Community planning for a CMB Stage IV experiment
    - HEP will oversee coordination of efforts within the HEP program
    - HEP discussing roles with NSF, NASA
- **High Performance Computing**
  - NERSC used for analysis of many CMB experiments: in 2014 ~ 10 experiments with ~ 100 users at a time, with ~ 10M CPU-hours
  - HEP MOU with NASA for Planck analysis – in 2014, 100M CPU-hours, NERSC Achievement Award for High-Impact Science

South Pole Telescope (SPT)



Planck view of BICEP2 field

HEP CMB Technology – from S1 to S4



Detectors – bolometers, sinuous pixels, multichroic, massive arrays

Electronics – high density interconnectivity

Argonne NATIONAL LABORATORY

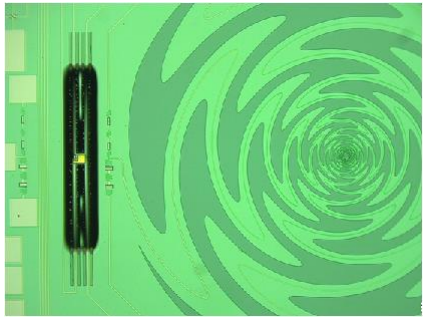
Fermilab

SLAC NATIONAL ACCELERATOR LABORATORY

BERKELEY LAB

Lenslets, anti-reflection coatings

Readout – superconducting LC resonators, superconducting NbTi striplines



HEP PROGRAM - SUMMARY

An exciting time for HEP and the Cosmic Frontier!

P5 developed compelling, realistic strategic plan with a consensus vision for US HEP
→HEP is moving forward to implement it.

Looking forward to participation in mid-decade review to get input on Cosmic Frontier opportunities