U.S. DEPARTMENT OF ENERGY | Office of Science

DOE Office of HEP Report

DOE / HEP • 2014 U.S. LHC Users Association Annual Meeting
Argonne National Laboratory
November 12 – 14, 2014

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Outline

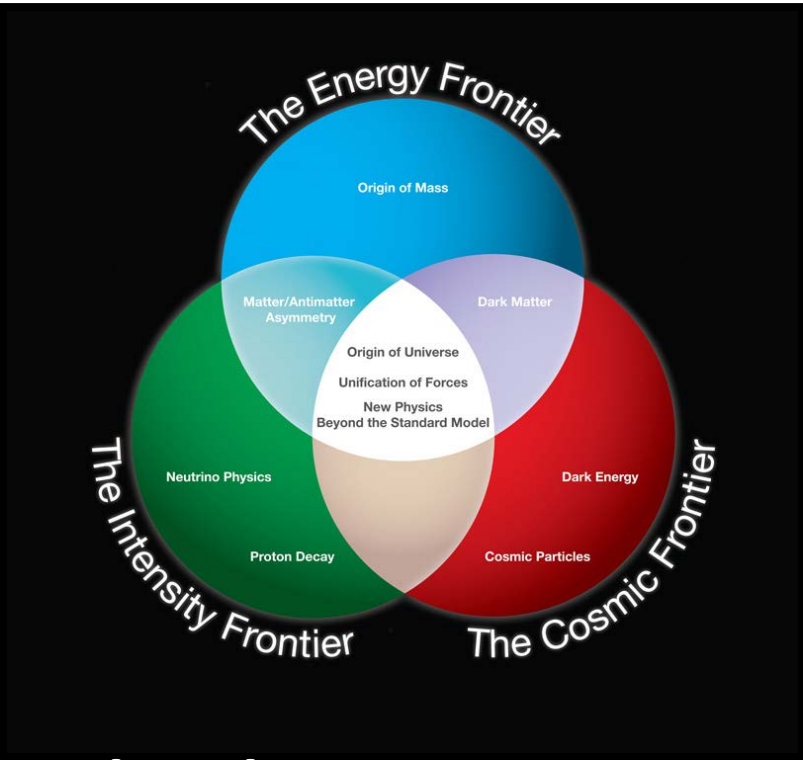
- Overview and P5
- Energy Frontier Program Status and Planning
- HEP Budget, Issues, and P5 Implementation
- HEP Funding Opportunities
- Closing Remarks

This talk will emphasize the Energy Frontier program — which includes research at Tevatron, LHC, and future colliders — within the broader context of the overall HEP program

Science Drivers and Research Frontiers

P5 identified 5 Science Drivers that establishes the scientific motivation of a HEP program while the 3 Research Frontiers provide a useful categorization of experimental techniques

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



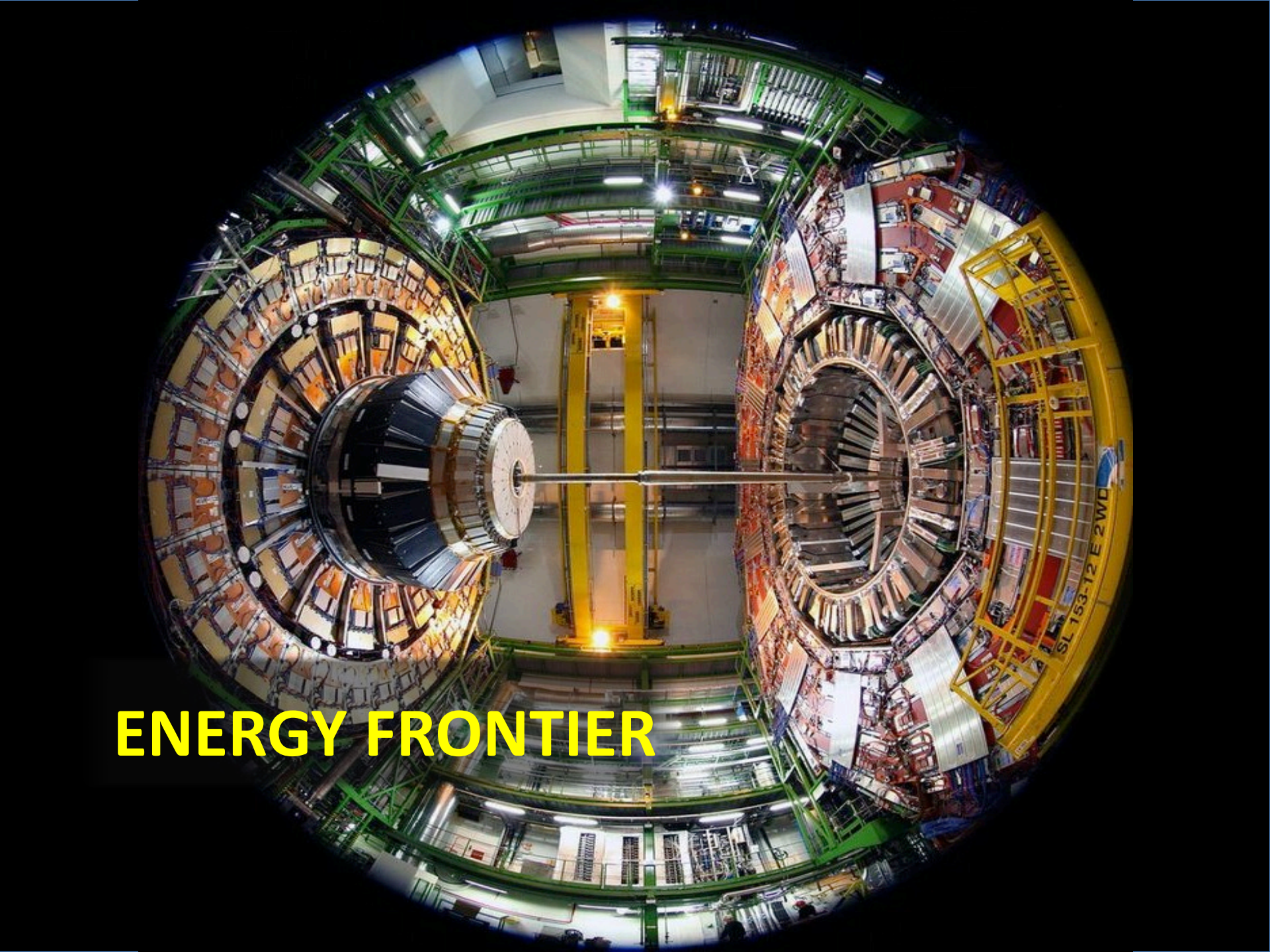
These Science Drivers map into the Physics Frontiers

Adapted from the May 28, 2014 P5 Strategic Plan for U.S. Particle Physics; and the May 29, 2008 Report of the P5 Panel.

Particle Physics Is a Global Field

From Chapter 1 of the P5 Report:

- **The scientific program required to address all of the most compelling questions of the field is beyond the finances and the technical expertise of any one nation or region.**
- **The capability to address these questions in a comprehensive manner is within reach of a cooperative global program.**
- **The field is at a juncture where the major players each plan to host one of the large projects most needed by the worldwide scientific community.**


ENERGY FRONTIER

HEP Energy Frontier Experiments

Experiment	Location	CM Energy; Status	Description of Science	# Institutions; # Countries	#U.S. Institutions	#U.S. Coll.
DØ (DZero)	Fermilab Tevatron Collider [Batavia, Illinois, USA]	1.96 TeV; Operations ended: Sept. 30, 2011	Higgs, Top, Electroweak, SUSY, New Physics, QCD, B-physics	74 Institutions; 18 Countries	31 Univ., 2 National Labs	187
CDF (Collider Detector at Fermilab)	Fermilab Tevatron Collider [Batavia, Illinois, USA]	1.96 TeV; Operations ended: Sept. 30, 2011	Higgs, Top, Electroweak, SUSY, New Physics, QCD, B-physics	54 Institutions; 14 Countries	26 Univ., 1 National Lab	194
ATLAS (A Toroidal LHC ApparatuS)	CERN, Large Hadron Collider [LHC; Geneva, Switzerland / Meyrin, Switzerland]	7-8 TeV; 13-14 TeV Run 1 ended: Dec. 2012 Run 2 start: Spring 2015	Higgs, Top, Electroweak, SUSY, New Physics, QCD, B-physics, and Heavy-Ion	178 Institutions; 38 Countries	42 Univ., 4 National Labs	522
CMS (Compact Muon Solenoid)	CERN, Large Hadron Collider [LHC; Geneva, Switzerland / Cessy, France]	7-8 TeV; 13-14 TeV Run 1 ended: Dec. 2012 Run 2 start: Spring 2015	Higgs, Top, Electroweak, SUSY, New Physics, QCD, B-physics, and Heavy-Ion	190 Institutions; 42 Countries	48 Univ., 1 National Lab	623

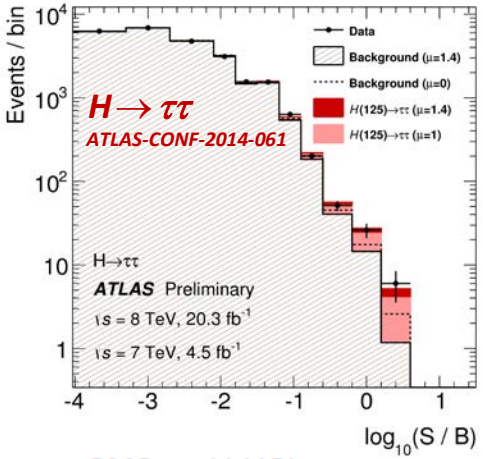
Tevatron data as of October 2014; LHC data as of October 2014.

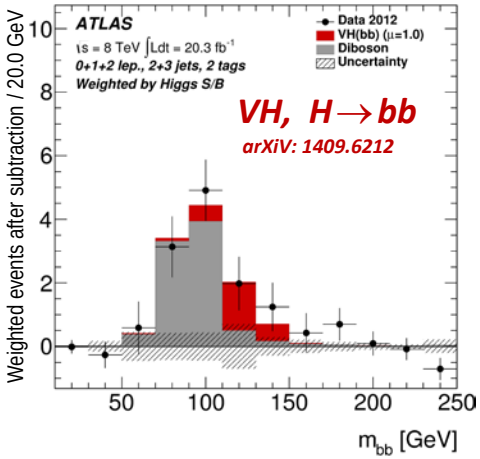
- **Main scientific thrusts**
  - **Completion of Tevatron research at Fermilab [$p\bar{p}$ collider]: DØ Collaboration, CDF Collaboration**
  - **LHC at CERN [pp collider]: CMS Collaboration, ATLAS Collaboration**
- **U.S. is single biggest collaborator in both ATLAS and CMS experiments at LHC**
  - **US-ATLAS: ~21% of the international ATLAS Collaboration**
  - **US-CMS: ~30% of the international CMS Collaboration**
- **Lepton Collider [mainly ILC]: modest support (~4-5 FTE) for detector R&D activities from the Energy Frontier research program**
  - **at universities through DOE financial assistance awards [grants]**
  - **at national laboratories: Fermilab and SLAC**

Energy Frontier Representative Highlights

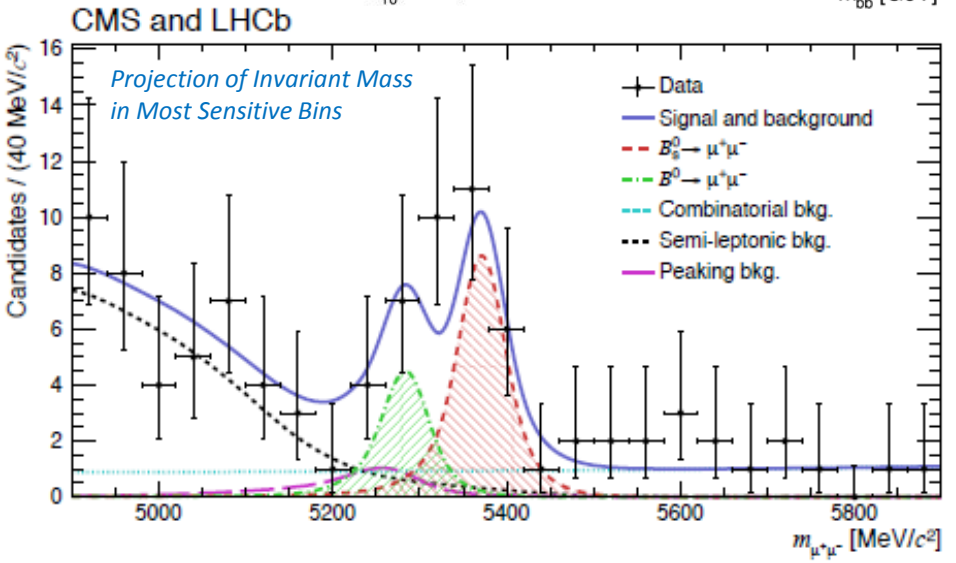
- **Both ATLAS and CMS continue to perform very well with over 360 Run 1 papers submitted by each experiment for publication**
  - **In addition, about 700 conference talks arranged thus far by each experiment during 2014**

- **ATLAS**
  - **New results on the decays of H(125) to fermions**
    - **October 2014 H → ττ result: excess observed with significance of 4.5σ [3.5σ expected for SM H(125)]**
    - **September 2014 VH, H → bb result: excess of 1.4σ observed [2.6σ expected for SM H(125)]**



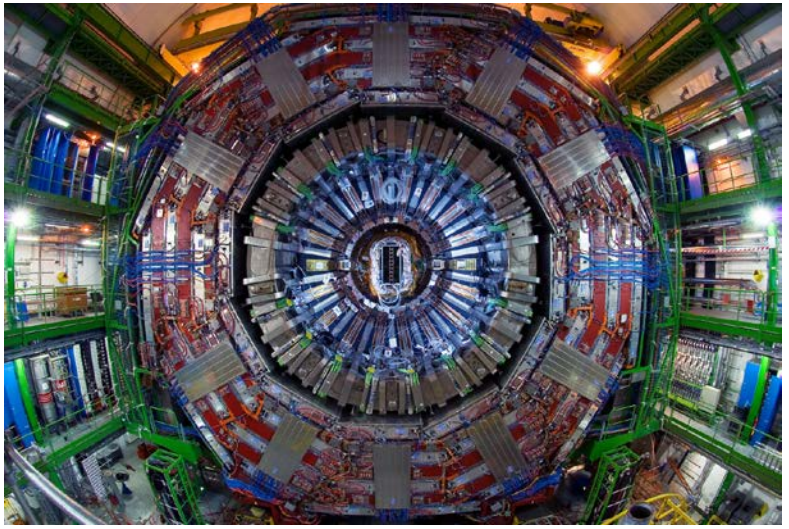


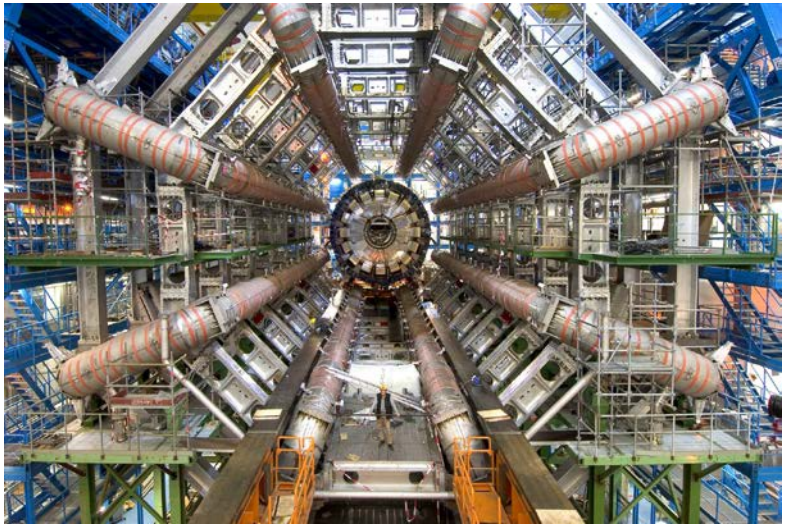
- **CMS**
  - **$B^0_{s,d} \to \mu\mu$ combination with LHCb**
    - **Fit to full Run 1 data sets of both experiments, sharing parameters**
    - **First observation: 6.2σ for the $B^0_s \to \mu\mu$ [expected SM 7.6σ]**
    - **Results presented at the Sept. 2014 CKM Conference in Vienna and paper will be submitted to *Nature***



Energy Frontier Status & Planning (I)

- LHC is planned to be central component of the U.S. Energy Frontier program for next ~20 year
  - U.S. investments ⇒ leading roles in the [global] LHC physics collaborations
- LHC will resume operations in Spring 2015 at collision energies of 13+ TeV
  - Higher energy will increase the reach into search for new physics in high-impact topics
    - includes SUSY, search for DM, and extra dimensions
- U.S. active in executing initial, Phase-1 upgrades of the ATLAS and CMS detectors
  - CD-2/3 [baseline; start construction] reviews for Phase-1 US-CMS/ATLAS were held in Aug-Sept. 2014
    - CD-2/3 approved for both on Nov. 12, 2014
- Considering high luminosity update to LHC around 2023 to extend discovery potential
  - Increase LHC luminosity by a factor of 10 beyond its design value
  - Explore new physics and new dynamics for *W/Z*, top, and Higgs at TeV energies
  - DOE/HEP actively working with US-CMS/ATLAS to begin mounting the HL-LHC Detector Upgrade Project
    - more on these efforts later in this talk…



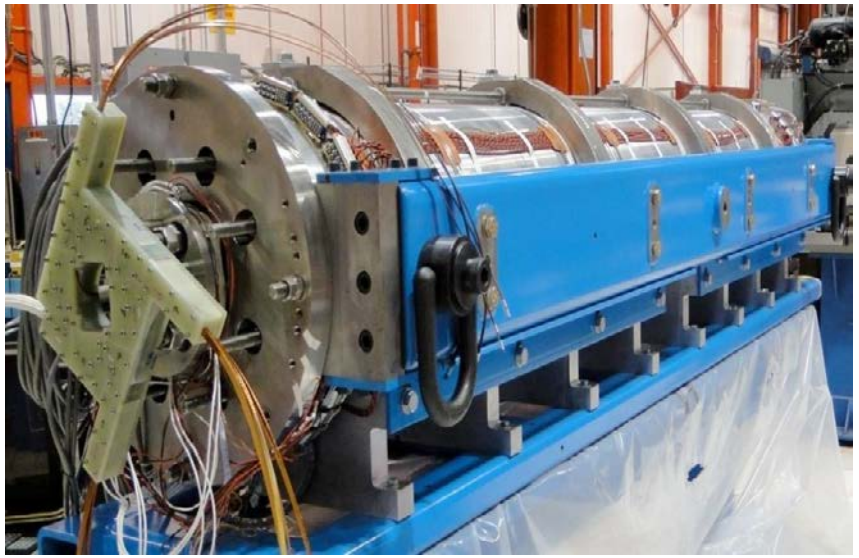


Energy Frontier Status & Planning (II)

- **U.S. leadership in superconducting magnet technology generally, and now Nb_3Sn in particular, is widely recognized and acknowledged**

- **U.S. LHC Accelerator Research Program (LARP) aims to leverage this expertise to serve needs of HEP community**
  - **Consists of four U.S. laboratories: BNL, Fermilab, LBNL, and SLAC (+ industrial firms)**
    - **LARP has been charged to begin prototyping accelerator components for the HL-LHC upgrades in order to reduce risk for the eventual project**

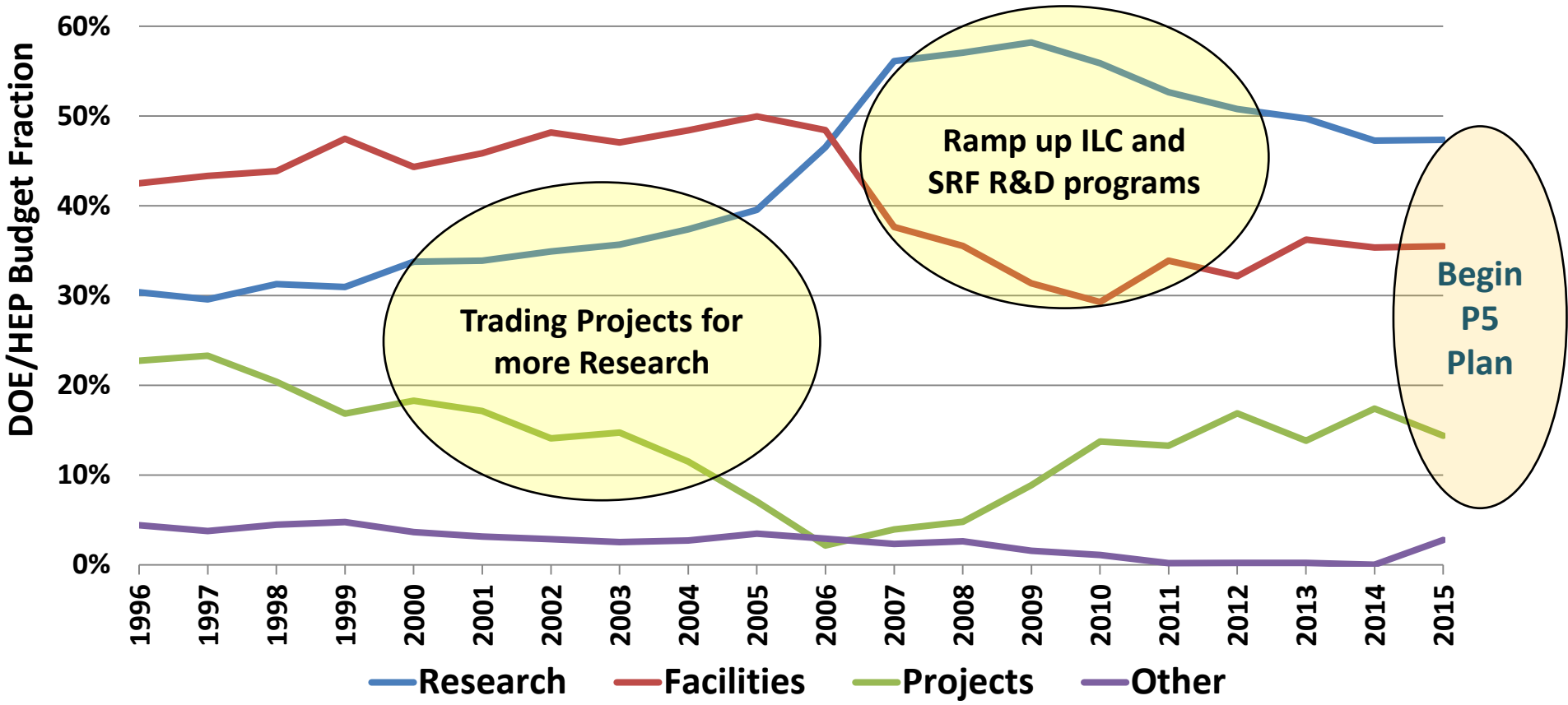
- **U.S. Department of State has given approval to begin negotiating with CERN on the US-CERN LHC Agreement**
  - **Bilateral agreement now being discussed with CERN**
  - **Concurrently, DOE has also initiated the drafting of Annexes (≡ Protocols) for the agreement**
    - **Accelerator Protocol for contribution towards LARP**
    - **Experiment Protocol for contribution towards the HL-LHC detector upgrades**
    - **A protocol outlining contribution towards an international neutrino program**



HEP BUDGET AND ISSUES

Funding Trends by Fiscal Year

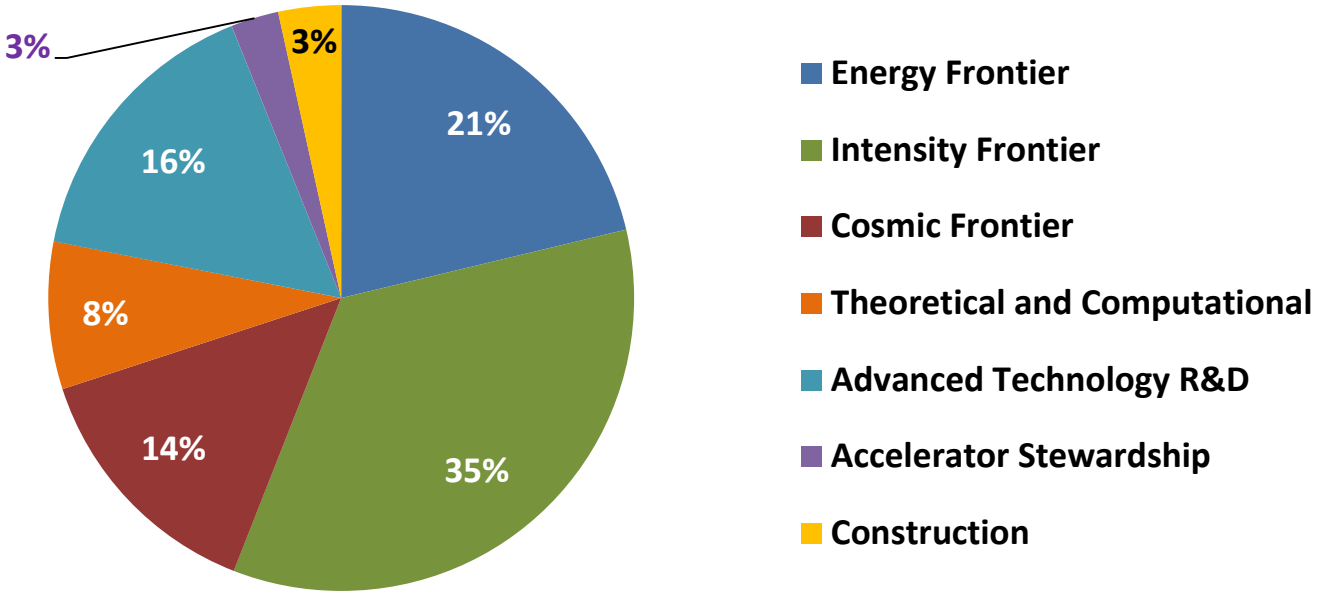
— FY2015 shows President's Request —



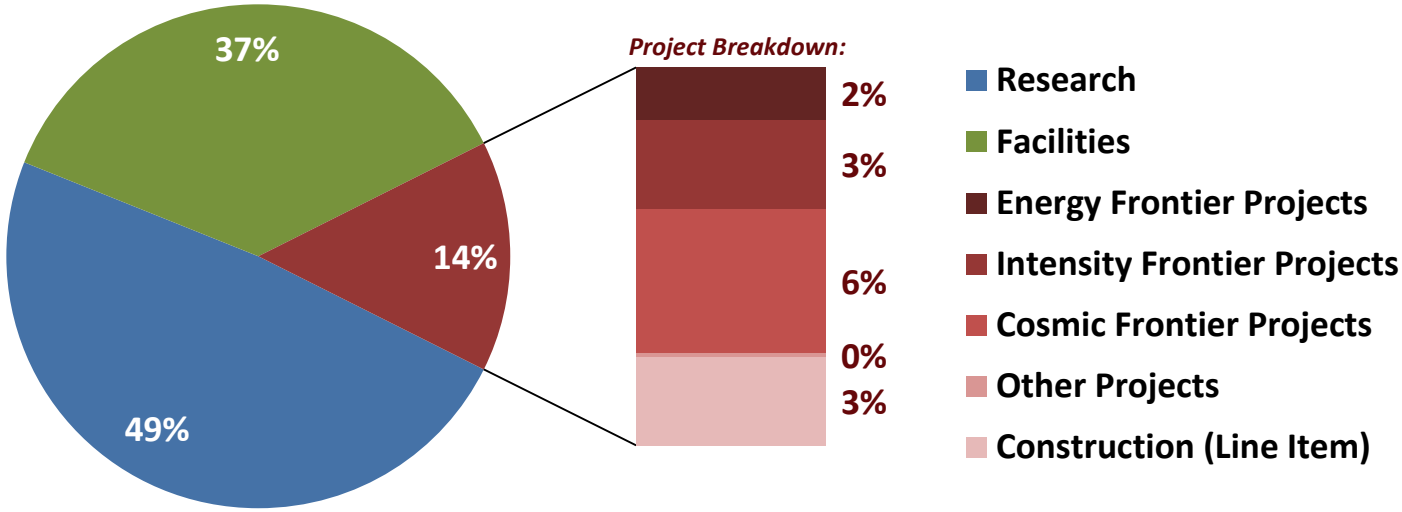
- P5 report recommendation suggests increasing the project budget fraction to 20%–25%
  - *"Addressing the [Science] Drivers in the coming and subsequent decades requires renewed investment in projects."*
- Impacts of P5 report strategy should begin to become evident in FY2016 DOE budget

FY 2015 HEP Budget Request Overview

HEP FY15 Request Funding by Subprogram



HEP FY15 Request Funding by Activity



FY 2015 High Energy Physics Budget

HEP Funding Category *($ in K)*	FY 2013 Actual	FY 2014 Sept AFP	FY 2015 Pres. Req.	Explanation of Changes (FY15 *vs.* FY14)
Energy Frontier	149,446	152,386	153,639	Reduction for Tevatron completion; research offset by LHC Phase-1 upgrade activities
Intensity Frontier	274,412	250,987	251,245	Reductions for NOvA project completion, Belle-II offset by increase for beam line ops & refurbishment at FNAL
Cosmic Frontier	80,063	96,927	101,245	Ramp-up of LSSTcam
Theoretical and Computational HEP	66,398	64,275	58,850	Reduced to offset investments in future facilities
Advanced Technology R&D	142,291	150,270	114,242	Reduced to offset project increase; Shift towards Directed R&D
Accelerator Stewardship	3,132	9,075	19,184	Support new R&D efforts, open accelerator test facilities to industry
Construction (Line-Item)	11,781	51,000	25,000	Mu2e on-profile; LBNE reduced in FY15 Request; [request made during P5 report development]
SBIR/STTR	20,791	21,601	20,595	HEP Total reduced after an appropriation
TOTAL (DOE HEP):	**748,314***	**796,521**	**744,000**	(*) FY 2013 Actual reflects sequestration
DOE Office of Science (SC):	**4,681,195**	**5,066,372**	**5,111,155**	

- **FY 2015 is currently in a 72-day Continuing Resolution (CR) until Dec. 11, 2014**
  - **Total HEP funding level based on FY 2015 President's Request [$744M]**

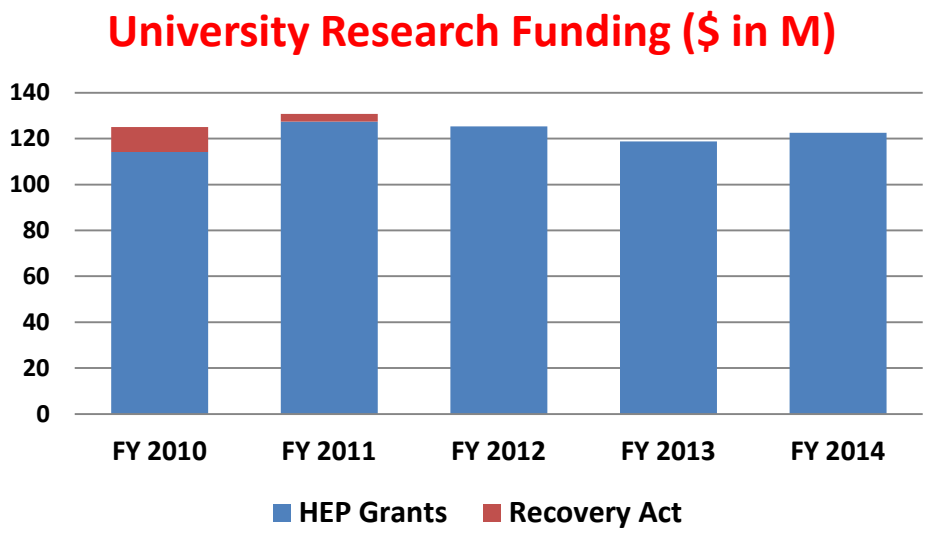
FY 2015 HEP Budget by Activity

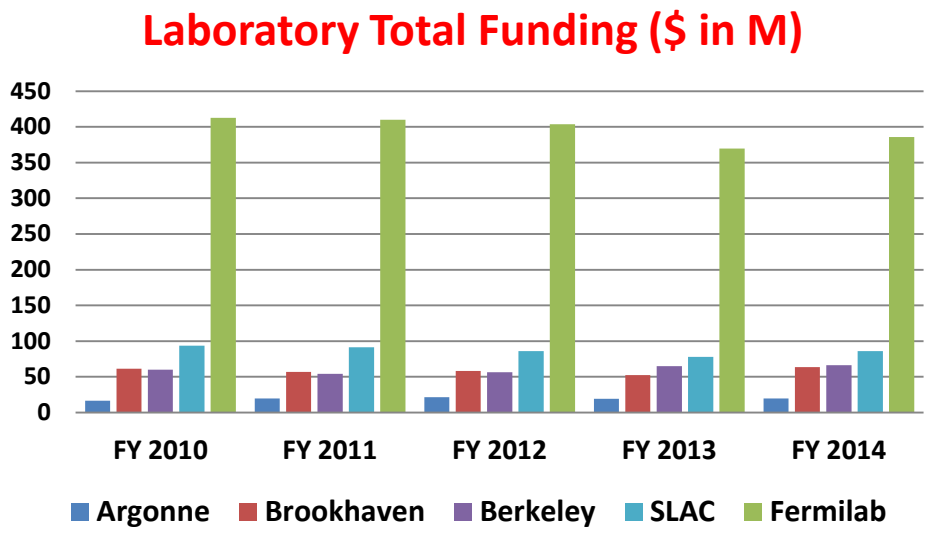
HEP Funding Category *($ in K)*	FY 2013 Actual	FY 2014 Sept AFP	FY 2015 Pres. Req.	Explanation of Changes (FY15 *vs.* FY14)
Research	**364,766[a]**	**373,932[a]**	**352,227**	Research reductions support project investments
Facilities Ops. and Exp. Support	**265,123**	**278,683**	**264,208**	Small decrease in Cosmic Frontier operations as certain experiments ramp-down
Projects	**85,853**	**71,305**	**81,970**	
Energy Frontier Projects	*0*	*0*	*15,000*	*LHC Phase-1 Upgrade MIEs requests; (non-add)*
Intensity Frontier Projects	*63,494*	*37,400*	*24,970*	*Belle-II ramp down, FNAL acc. upgrade R&D reduction; (non-add)*
Cosmic Frontier Projects	*19,159*	*30,705*	*41,000*	*LSSTcam fabrication support and R&D related project costs; (non-add)*
Other Projects	*3,200*	*3,200*	*1,000*	*Lattice QCD hardware project; (non-add)*
Construction (Line-Item)	**11,781**	**51,000**	**25,000**	Mu2e on-profile; LBNE reduced in FY15 Request [request made during P5 report development]
SBIR/STTR	**20,791**	**21,601**	**20,595**	HEP Total reduced after an appropriation
TOTAL (DOE HEP):	**748,314**	**796,521**	**744,000**	

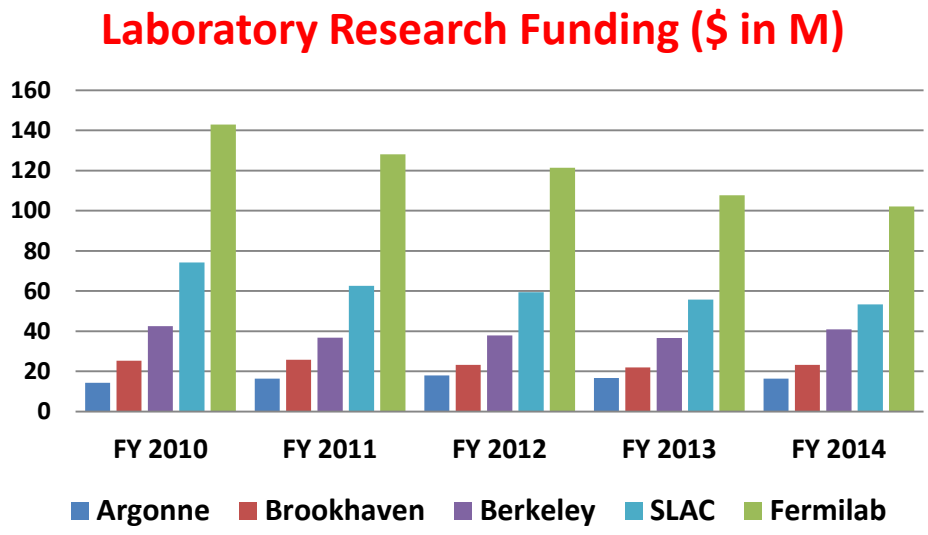
[a] FY13 and FY14 Research supported R&D for projects (*e.g.,* LHC Phase-1 upgrades) seeking starts in FY 2015;
MIE = Major Items of Equipment

HEP Funding Trends

- University funding level has been constrained in recent years
  - Full funding requirements affect resource allocations
  - Additional budget pressures in FY15 due to the current CR
- Investments in Laboratory projects are being supported by reductions in Laboratory research







HEP Funding Trends (cont.)

- University funding level has been constrained in recent years
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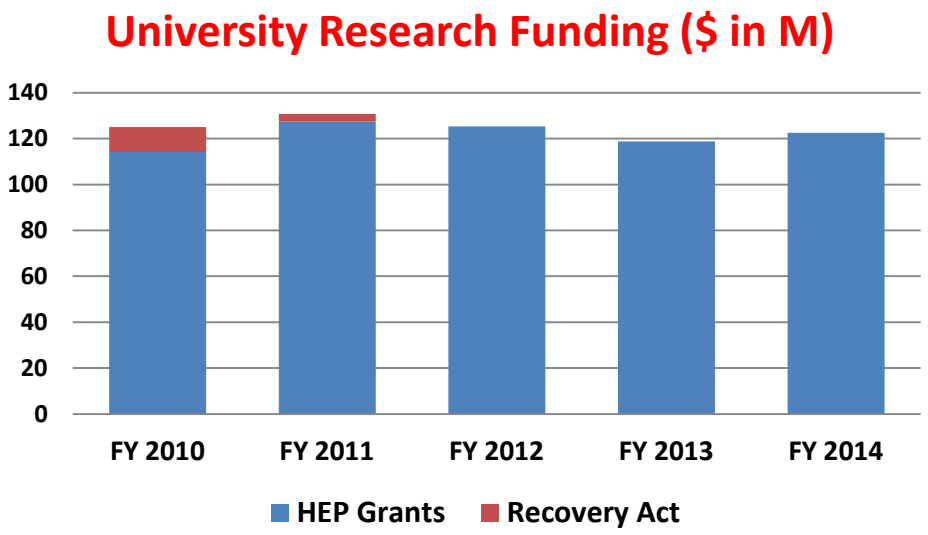
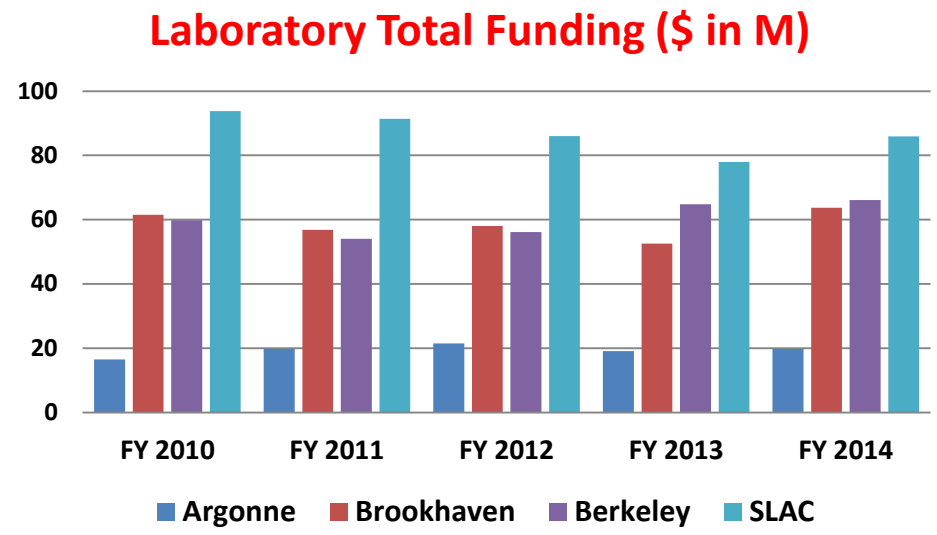
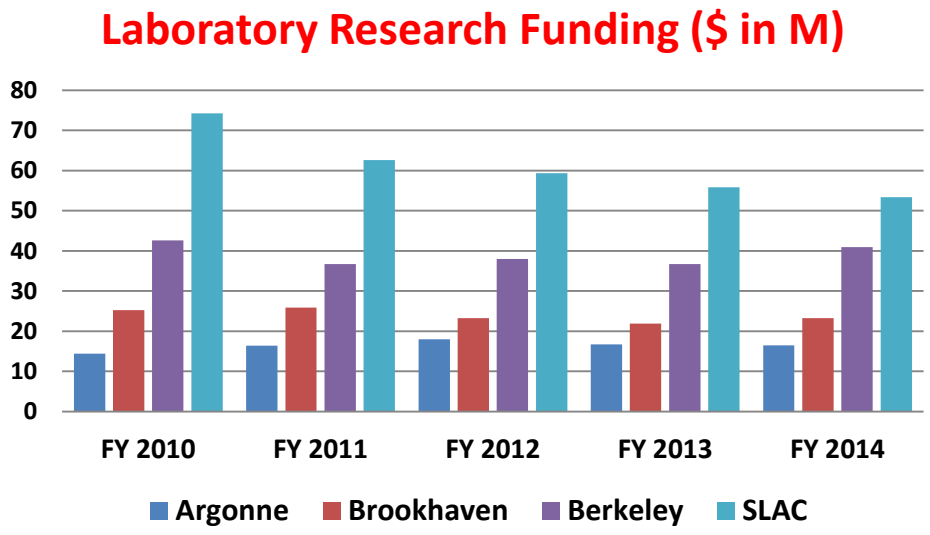






Summary of FY15 Request *vs.* Senate & House

HEP Funding Category ($ in K)	FY 2014 Sept AFP	FY 2015 Pres. Request	FY 2015 House Mark	FY 2015 Senate Mark
Energy Frontier	152,386	153,639	157,888	156,069
Intensity Frontier	250,987	251,245	266,691	244,939
Cosmic Frontier	96,927	101,245	103,056	106,641
Theoretical and Computational	64,275	58,850	60,670	60,416
Advanced Technology R&D	150,270	114,242	125,605	119,638
Accelerator Stewardship	9,075	***19,184***	***3,000***	***19,184***
Construction	51,000	25,000	37,000	47,000
SBIR/STTR	21,601[(a)]	20,595	21,090	20,595
TOTAL (DOE HEP):	**796,521**	**744,000**	**775,000**	**774,482**

[(a)] HEP Total reduced for SBIR/STTR after an appropriation.

- **House and Senate marks are very similar in the total; above President's Request**
  - **House language includes MIEs for US-ATLAS/CMS Phase-1 upgrades, to initiate fabrication, and for DM-G2**
- **Accelerator Stewardship very different between House and Senate marks**

FY15 Budget: Energy Frontier

Energy Frontier ($K)	FY 2013 Actual	FY 2014 Sept AFP	FY 2015 Pres. Req.	Comments
Research	**86,172**	**81,987**	**78,841**	Redirect research to LHC detector upgrades
Facility Ops. and Exp. Support	**60,274**	**57,399**	**59,798**	US-CMS and US-ATLAS Ops. Program
LHC Detector Operations	*56,912*	*54,103*	*55,522*	*ATLAS/CMS M&O; Computing (non-add)*
Other	*3,362*	*3,296*	*4,276*	*IPAs, Detailees, Reviews; (non-add)*
Projects	**3,000 [a]**	**13,000 [a]**	**15,000**	US-CMS/ATLAS Phase-1 Upgrades
LHC CMS Detector Upgrades	*1,500*	*6,750*	*7,500*	*First TEC Req. in FY 15; (non-add)*
LHC ATLAS Detector Upgrades	*1,500*	*6,250*	*7,500*	*First TEC Req. in FY 15; (non-add)*
TOTAL (Energy Frontier):	**149,446**	**152,386**	**153,639**	

[a] In FY13 and FY14 Appropriations: support for US-LHC Phase-1 [R&D] was contained under Energy Frontier Research;
TEC = Total Estimated Cost (typically refers to Capital Equipment expenses)

- **Reductions in research funding during FY 2015 primarily due to:**
  - **Ramp-down of the Fermilab Tevatron research program**
  - **Redirections to support current and future experimental capabilities (*e.g.*, Phase-1 upgrades)**
- **Congressional marks restore some support for research as well as to other HEP projects delayed through funding levels under a Continuing Resolution**

HEP Budget Scenario

- **"Are we in Scenario A or B of the P5 report?"**
  - Based on the House and Senate markups of the appropriation bills, we anticipate that we will be able to implement Scenario B
  - However, the current 72-day CR is at a level below Scenario A
- **This complicates planning for HEP, but we will respect the P5 priorities:**
  - Projects that are baselined or nearly baselined will be fully funded
    - this includes the LHC Phase-1 upgrades, Mu2e, and LSST
  - High-priority near-term efforts (*e.g.,* DM-G2 experiments) will get sufficient funding to keep them going thru the CR; we will try to enhance their funding after an appropriation
  - Decisions on how to fund longer-term investments (*e.g.,* Future Circular Collider studies or ILC R&D) will be delayed until the budget situation is better known
- **To the greatest degree possible the laboratories should defer costs**
  - Consider delaying new hires or making major commitments until after the budget situation has clarified
  - Some laboratories may have funding shortfalls that are great enough to require layoffs
    - these should be considered in light of our hopes to carry the P5-Scenario B vision
- **University research will also be impacted**
  - At the CR funding level, 3-5% reductions in university grant support expected
  - Will try to restore this to "flat cash" in event of HEP budgets near Congressional marks

Projects Not Recommended by P5 Report

- **A number of projects were not recommended in any P5 scenario**
  - **Additional efforts beyond this list have been or will be curtailed based on agency priorities (*e.g.*, CTA)**
  - **Working with the Labs on redirection of resources from these projects/activities**

	Scenarios			Science Drivers					
	FY 2013 Appropriated Budget baseline: flat for 3 yrs, then +2% per yr.	FY 2014 President's Request baseline: flat for 3 yrs, then +3% per yr.	Unconstrained Budget						
Project/Activity	Scenario A	Scenario B	Scenario C	Higgs	Neutrinos	Dark Matter	Cosm. Accel.	The Unknown	Technique (Frontier)
Large Projects (> $200M)									
NuSTORM	N	N	N		✓				I
RADAR	N	N	N		✓				I
Medium Projects ($50M – $200M)									
ORKA	N	N	N					✓	I
MAP	N	N	N	✓	✓	✓		✓	E,I
CHIPS	N	N	N		✓				I
LAr1	N	N	N		✓				I

P5 Implementation and LHC

- Recommendation #10 of P5 strategic plan noted that the U.S. continue the strong collaboration in the LHC with the Phase-2 (HL-LHC) upgrades of the accelerator and both general-purpose experiments (ATLAS and CMS)
  - The LHC upgrades constituted P5's *highest-priority near-term* large project
- Thus far, agencies' efforts for HL-LHC detector upgrades have progressed on three fronts:
  - DOE and NSF cooperating as part of the DOE-NSF interagency partnership, necessary for success
  - U.S. at early discussion stage with CERN and the international funding agencies to understand costs of overall upgrades and scope
  - Discussing with US-ATLAS/CMS management to define overall plan for project, including understanding prioritized scope/costs, institutional responsibilities, and timeline
    - DOE/NSF jointly held two productive meetings [Aug. 15, Sept. 24] on current progress, agency requirements, and near-term plans
    - Several regular phone discussions on status, defining U.S. roles, and next steps…
- Opportunities for initial R&D activities on Phase-2 are possible through:
  - U.S. DOE LHC Ops program: in near term, ~$2–3.5 M per experiment per year for R&D activities
  - An application for a financial assistance award, submitted by a U.S. institution to the DOE Energy Frontier research program, that contains a "balanced" LHC research & upgrade scope
  - In either case, US-CMS and US-ATLAS requested by DOE to develop a prioritized list of plans
- If there is funding at Congressional marks, efforts will be considered to strengthen needed infrastructure towards the HL-LHC upgrades from within research program

P5 Implementation and ILC

- P5 Recommendation #11 noted that the U.S. should engage in modest and appropriate levels of ILC accelerator and detector design in areas where the U.S. can contribute critical expertise and consider higher levels of collaboration if ILC proceeds
- DOE in continued discussions with the Americas Linear Collider Committee (ALCC) to develop program for future R&D efforts – for both Accelerator R&D and Detector R&D
- Thus far, modest ground-level R&D efforts continue as funding allows
  - *for e.g.,* through Energy Frontier research program
    - physics and detector modeling and optimization studies, electron and hadron calorimetry development, studies for pixellated vertex detectors, particle flow algorithms
  - *and* through Accelerator R&D program
    - SRF R&D, including high-Q work; cryogenic cooling, engineering, and beam dynamic studies
- Site-specific accelerator R&D and design will be near-term priority of R&D efforts towards ILC
  - Implement initially through discussions between DOE and labs on redirection of efforts
- Once current budget situation is clarified, aim to integrate ILC Detector R&D activities
  - However given tight fiscal constraints, near-term priorities for R&D will emphasize:
    - HL-LHC Detector Upgrades
    - Dark Matter (*e.g.,* DM-G2 and G1 Ops)
    - LAr for Short-Baseline Neutrino / Long-Baseline Neutrino Facility (SBN / LBNF)


HEP FUNDING OPPORTUNITIES

Funding Opportunity Announcement Status

- **The FY2015 HEP Funding Opportunity Announcement (FOA) for the annual university comparative review in research is now closed and the process is now in-progress**
  - **Opened on July 22, closed on September 23, 2014**
  - **Panel deliberations for HEP subprograms to be held on Nov. 17-21 and Dec. 3-5, 2014**

- **The Accelerator Stewardship FOA is now closed**
  - **Opened June 13, closed on September 4, 2014**
  - **Focused on two distinct activities:**
    - **Applied R&D focused on developing a prototype in response to a specific technical challenge**
      - **Particle Therapy Beam Delivery Improvements**
      - **Ultrafast Laser Technology Program**
      - **Energy Efficiency Improvements for SC Accelerators**
    - **Basic research that broadly impacts many accelerator applications**

- **FY 2015 Early Career Research Program FOA is open [DE-FOA-0001170; LAB-14-1170]**
  - **Pre-proposals have been submitted; encourage/discourage responses sent in Oct.**
  - **Final proposals due November 20, 2014 at 5 PM Eastern Time**

Office of Science (SC) Digital Data Management

- **Data management involves all stages of the digital data life cycle including capture, analysis, sharing, and preservation. The focus of the SC Digital Data Management is the sharing and preservation of digital research data**
  - **See Dr. Laura Biven's presentation on SC Digital Data Management at the September 2014 HEPAP meeting: *http://science.energy.gov/hep/hepap/meetings/201409/***
  - **FOAs issued after October 1, 2014, will require a Data Management Plan (DMP) and compliance with the SC Statement**
  - **Requirements for DMPs and guidelines are available at: *http://science.energy.gov/funding-opportunities/digital-data-management/***

- **Additional HEP-specific guidance on DMPs is available**
  - ***http://science.energy.gov/hep/funding-opportunities/digital-data-management/***
  - **HEP will be working with the DOE National Laboratories to make available accessory information about individual experiments and projects led by respective labs**
  - **For more information please contact Dr. Lali Chatterjee and/or your DOE PM**

- **ATLAS and CMS have developed DMPs for their collaborations**
  - **When applying for financial assistance [universities] or submitting FWPs [labs] for research, PIs can cite the DMPs for their experiments with the appropriate links**

Closing Remarks

- **P5 strategic plan is a compelling, unified vision for HEP**
  - Five intertwined Science Drivers define big issues
  - HEP *is* global: both the P5 plan and DOE's implementation of the plan recognizes this fact
- **A balanced approach to planning that P5 stresses is critical**
  - Time-phased, projects of different scales, balanced across Frontiers, on- and off-shore
  - DOE implementation strives to maintain that balance
- **Energy Frontier LHC activities on ATLAS & CMS are now across 5 different fronts:**
  - Complete Run 1 data analyses with 450+ Run 1 publications expected from each experiment
  - Preparations for experimental operations during Run 2, which resumes this Spring 2015
  - Execute LHC Phase-1 [2018] detector upgrades
  - Initiate R&D for HL-LHC Phase-2 [2023] upgrades
  - Initial stages of developing the U.S. HL-LHC Upgrade Project
- **We share the community's enthusiastic response to the P5 strategic plan**
  - We are moving forward with implementation in targeted areas
  - But given the current fiscal environment, ***full*** implementation of the plan will take some time
  - For projects planned within the Energy Frontier portfolio, it is important that U.S. collaborators are *aligned* to U.S. collaboration's plans to proceed during the coming years
    - DOE will work closely with U.S. collaboration's management (*e.g.*, US-ATLAS/CMS *or* ALCC for ILC) as well as international partners to define U.S. roles and responsibilities

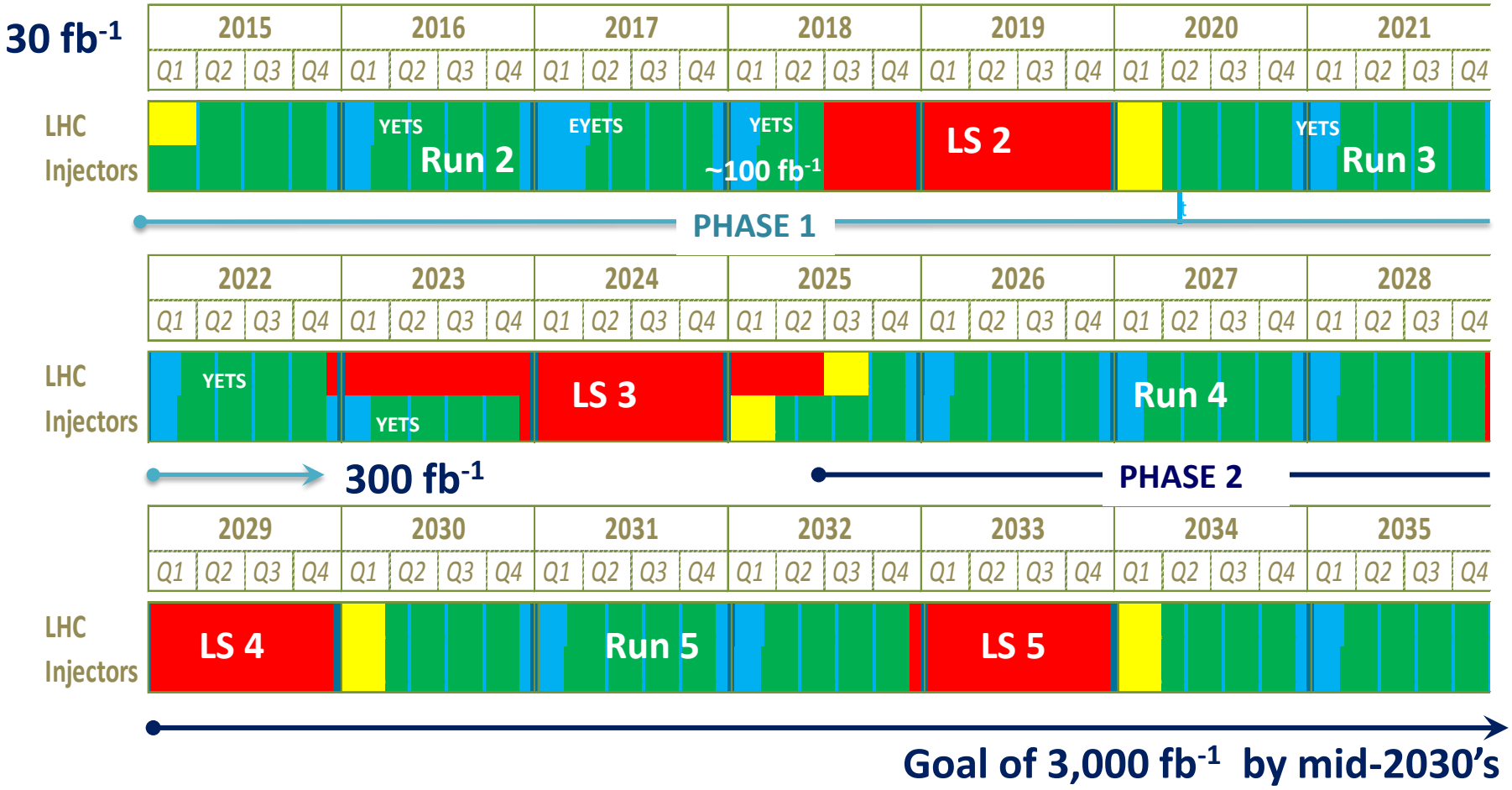
REFERENCE SLIDES

Detailed LHC schedule — Beyond Long Shutdown 1 (LS1)

LS2 starting in 2018 (July) ⇒ 18 months + 3 months BC
LS3 LHC: starting in 2023 ⇒ 30 months + 3 months BC
Injectors: in 2024 ⇒ 13 months + 3 months BC

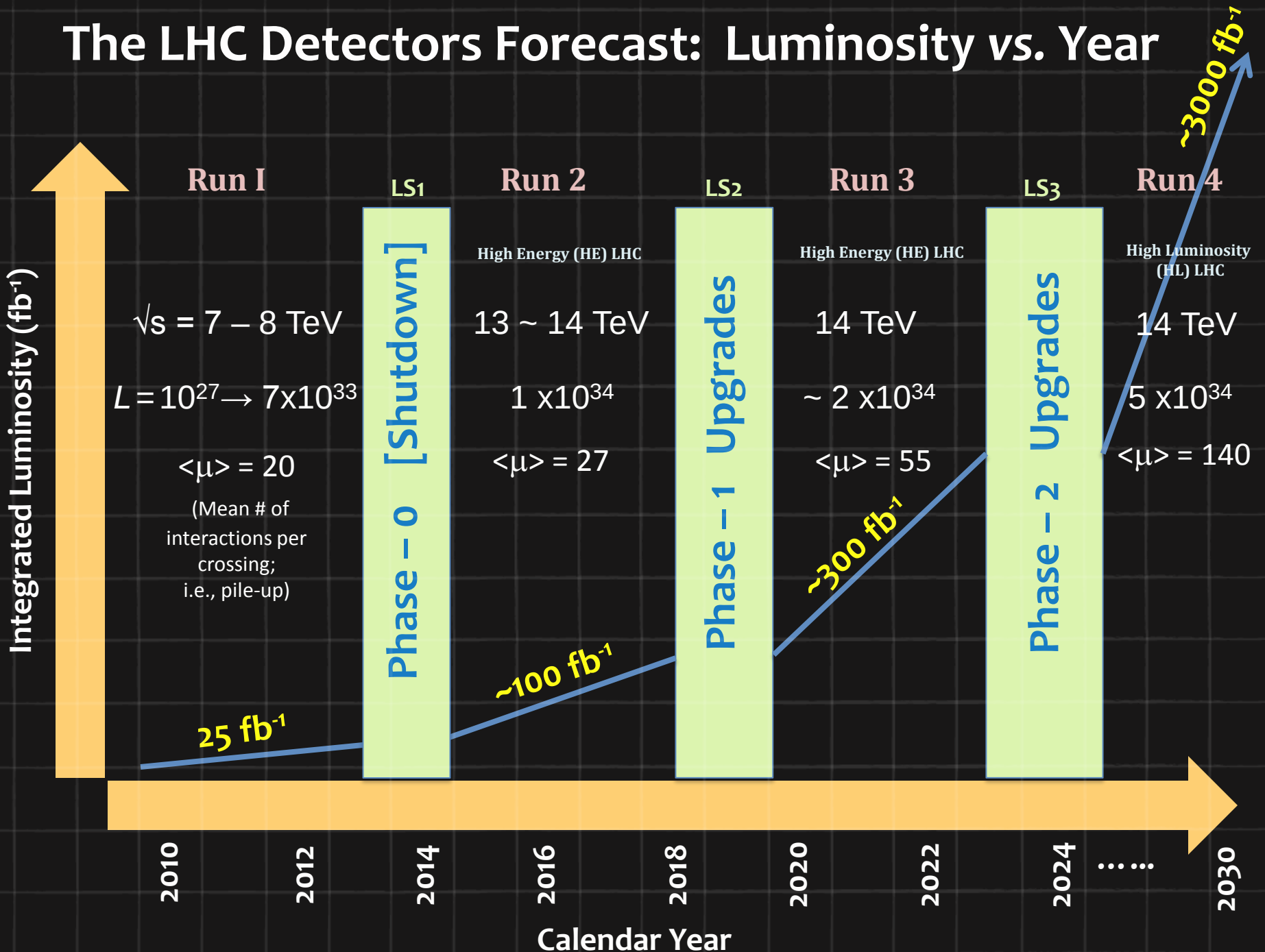
(Extended) Year End Technical Stop: (E)YETS

Physics
Shutdown
Beam Commissioning
Technical Stop



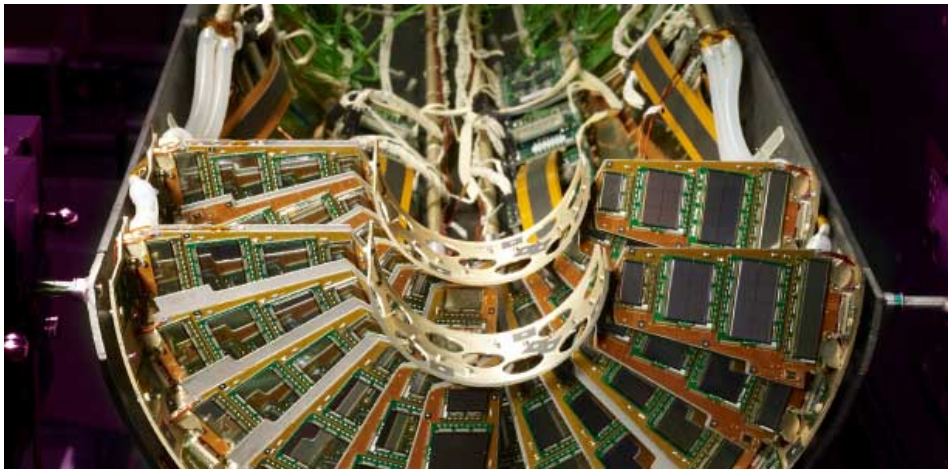
LHC schedule approved by CERN management and LHC experiment's spokespersons and technical coordinators: Monday, 2nd December 2013.

The LHC Detectors Forecast: Luminosity *vs.* Year



LHC Phase-1 Detector Upgrades

- CD-0 was approved for upgrades to the ATLAS and CMS detectors on 9/18/2012
- CD-1 was approved for upgrades to the ATLAS and CMS detectors on 10/17/2013
  - Cost: $32.2—34.5M for ATLAS, $29.2—35.9M for CMS
- The upgrades are a joint effort with NSF, which expects to contribute another $10—12 million per project
- The scope in both cases is primarily related to improving the trigger and data acquisition systems to handle larger data rates
  - U.S. CMS is also building replacements for the Endcap Pixel detector



Existing CMS Endcap Pixel Detector

- The U.S. projects are integrated into an international effort to upgrade the detectors.
- There will be a long shutdown of the LHC in 2018 to install the upgrades
- Requesting equipment funds in FY15
  - CD-2/3 reviews for each detector held in August-September 2014

Accelerator Project to Upgrade LHC (APUL)

- **Scope:** Two superconducting magnets for CERN's LHC
- **Background:** CERN requested the magnets to increase the reliability of spares
- BNL participated in this type of magnet production for the US-LHC Project

Total Project Cost: $11,440k

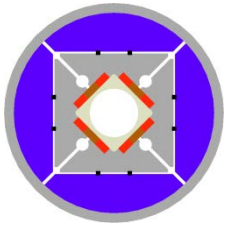
Schedule: CD4 – April 2014

Status

Completed on-time,
On-budget

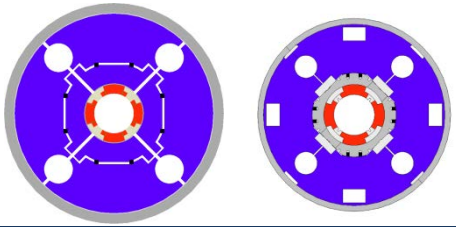
Superconducting Magnets

Subscale Quadrupole
SQ
0.3 m long
110 mm bore

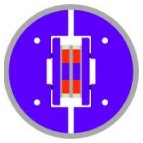


LBNL Subscale Magnet SM
0.3 m long
No bore

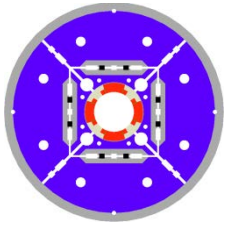
Technology Quadrupole
TQS - TQC
1 m long
90 mm bore



Long Racetrack LRS
3.6 m long
No bore

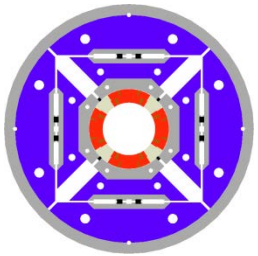


Long Quadrupole LQS
3.7 m long
90 mm bore



Significant progress made towards building magnets for future LHC upgrades

High Field Quadrupole
1 m long
120 mm bore



Continue to innovate in magnet design: