



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

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# CMS Detector Upgrade Project

Simona Rolli

Program Manager

DOE Office of Science

Office of High Energy Physics

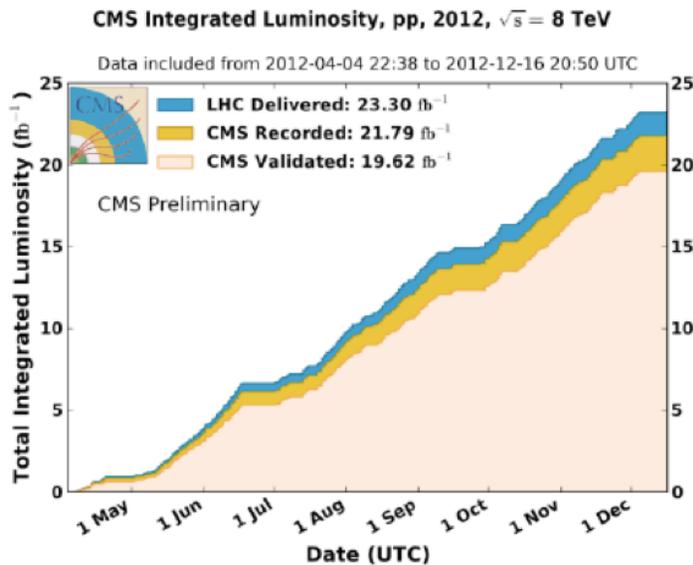
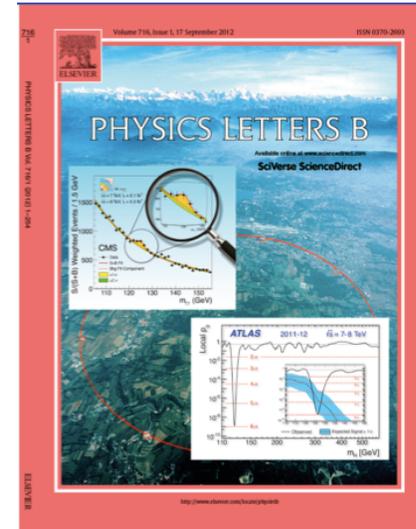
# Outline

- The Energy Frontier at the LHC
  - Current Program
  - LHC Roadmap
- CMS Detectors Upgrades
- Project approval
  - CERN, DOE, NSF...
- DOE Process and this review

# The Energy Frontier Program at the LHC

## 2009-2012 Run I (7-8 TeV)

- > 250 publications/experiment
- Expect > 100 more on Run I data
- 25 fb<sup>-1</sup> of 7+8 TeV pp data
- Higgs boson found!
  - Looks like SM at first glance
- Stringent limits set on physics beyond the SM
- Many precise measurements of SM processes



**2013-2014: LS1** : repair splices in LHC magnets; detector maintenance and consolidation, upgrades and repairs

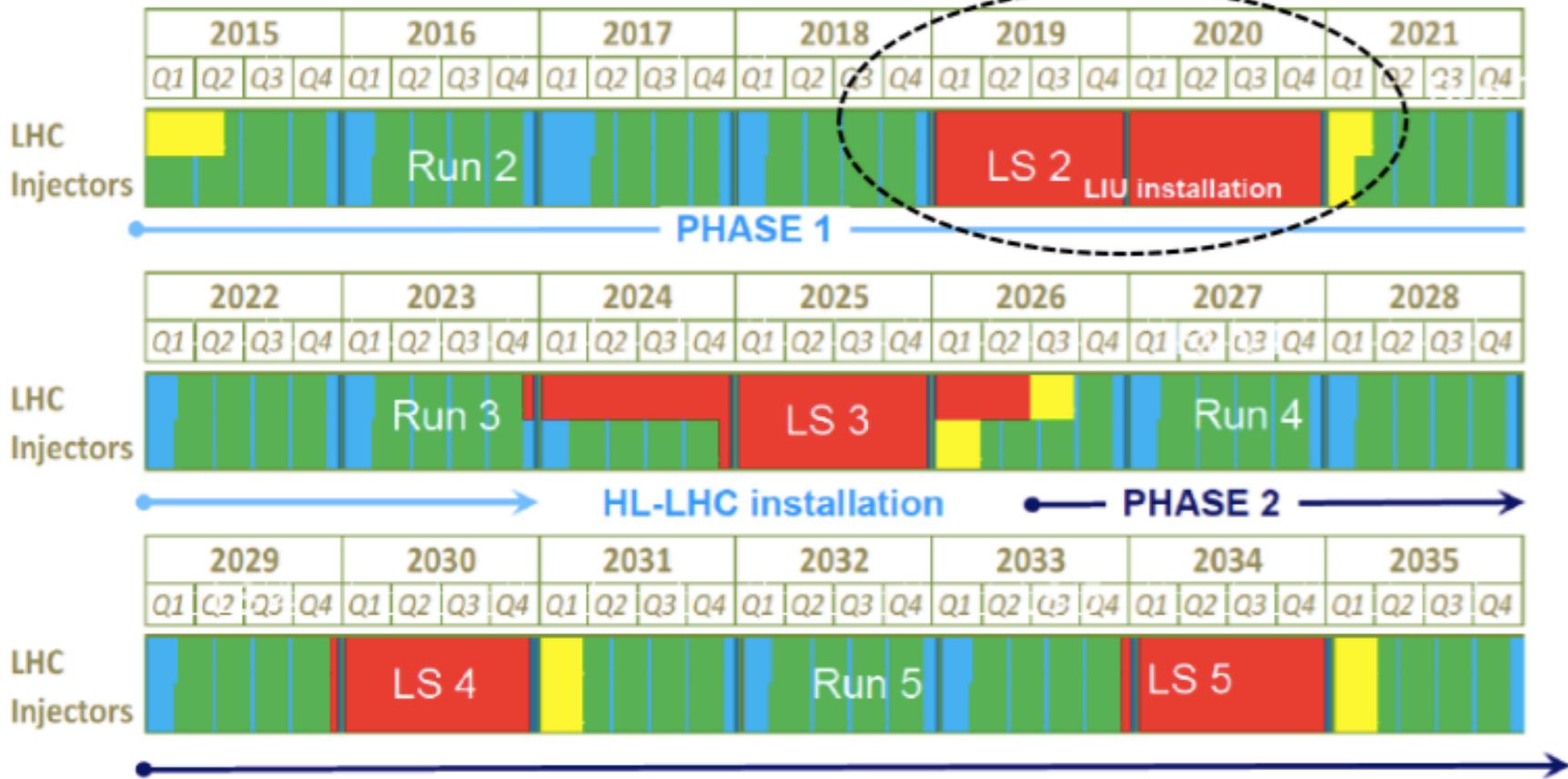
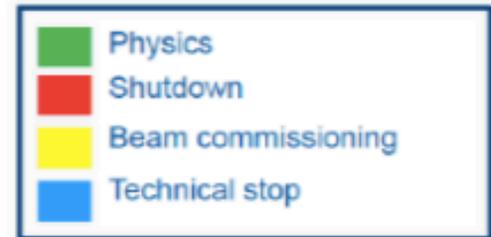
**2015 -2018: Run II** 13~14 TeV

- Ramp up luminosity to nominal ( $2 \times 10^{34}$  by LS2, higher after LS2)
- Higgs Precision Measurements;
- Renewed focus on new physics
  - What will 13~14 TeV running tell about BSM physics?

# LHC Roadmap

## LHC roadmap: according to MTP 2016-2020

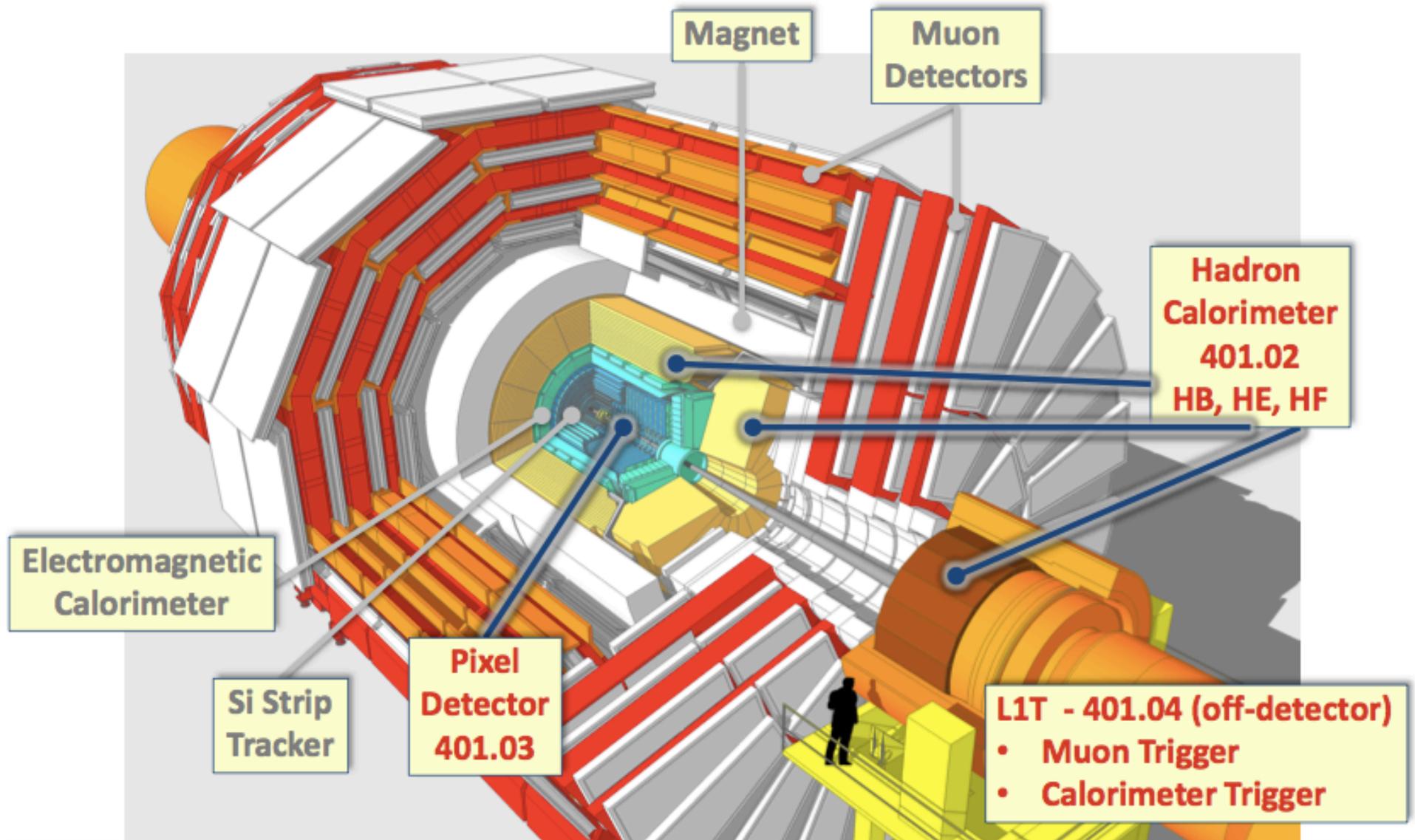
LS2 starting in 2019 => 24 months + 3 months BC  
 LS3 LHC: starting in 2024 => 30 months + 3 months BC  
 Injectors: in 2025 => 13 months + 3 months BC



# CMS Detector Upgrade

- The purpose of this project is to upgrade 3 CMS subsystems to maintain current performance with increasing LHC luminosity
  - In partnership with NSF
  - The upgraded systems are to be nominally installed during operational shutdown in 2019-2020
    - installation is not part of any threshold KPP, to decouple the US project from external schedule)
    - Trigger (and FPIX) will complete and install much earlier than LS2
- Enable CMS to exploit the physics opportunities afforded by these machine upgrades
- Provide at least 3 to 4 years of operation at much higher luminosity than original CMS design

# The CMS Detector



# CMS Upgrade Roadmap

## Phase-0

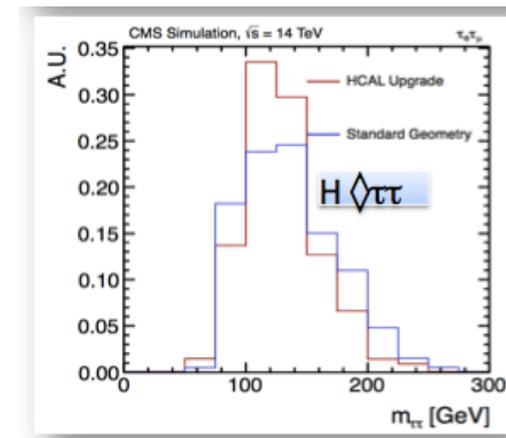
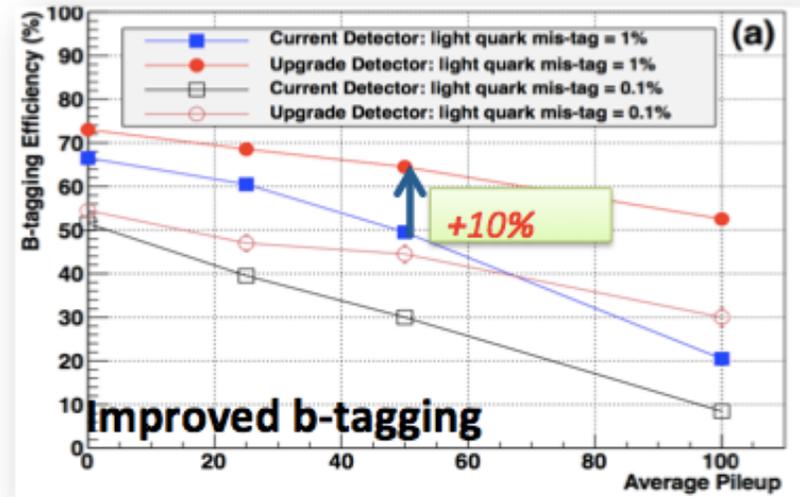
- Complete muon coverage
- Colder tracker
- Photodetectors in HCAL
- New beampipe and infrastructure updates

## Phase-I

- New Si pixel tracker
- L1 trigger upgrade
- HCAL electronics

## Phase-II

- New pixel and strip tracker
- Calorimeter
- Muon system
- Trigger system
- Computing
- ...



# Significance of the CMS Upgrade Project

## Scope: without upgrades CMS would suffer performance problems

- The **pixel detector** would become inefficient at tracking, track seeding, primary vertex reconstruction, secondary vertex reconstruction and b-tagging!!!!
  - The pixel detector's key role in track seeding for the High Level Trigger would be seriously compromised
- The **calorimeter** would suffer from radiation damage and isolation would be compromised.
  - The lack of timing would result in poor ability to assign energy contributions to the correct beam crossing. Lack of timing would also make it difficult to veto accidental coincidences between beam background or cosmics and collision data that can mimic rare physics events
- The **trigger** would lack the ability to use isolation,
  - This would especially affect the  $\tau$  triggers and the muon trigger
    - the PT threshold will be so high that physics will be lost.

## Schedule: motivated by LHC/CMS Operating Plans

- Target installations motivated by technical stops
- Part of a larger upgrade coordinated by International CMS

# US Role

- US has made critical contributions to LHC machine
  - E.g. Inner Triplet magnets
- US is single biggest collaborator in CMS
  - CMS: 678 US authors (31%)
    - 247 US graduate students
- US Contributions
  - Major contributions to design, construction and operation of most sub-detectors
  - Major impact on physics analyses
  - Leadership in all areas
- US is actively participating in the upgrades
  - US CMS plans are based on 3 TDRs in which US groups played a leading role
  - Joint DOE and NSF Effort

# CMS Proposal/Project Approval

**CERN:** LHCC : “The LHCC endorses the HCAL and Pixel Upgrade without reservations”  
( The US has a very strong participation in the TDRs, guaranteeing alignment with international CMS)

## US DOE:

- CD0 “Approve Mission Need” approved Sept 2012
- CD1 “Approve Alternative Selection and Cost Range” approved October 2013
- Plan/goal for moving forward
- CD-2, Approve Performance Baseline approved November 2014
- CD-3, Approve Start of Construction approved November 2014
- **Annual Independent Project Review** ← We are here!
- CD-4, Approve Project Completion FY20

## US NSF

- Proposal for new “mid-range” Cooperative Agreement submitted in May 2013, approved in March 2014, funded in July 2014

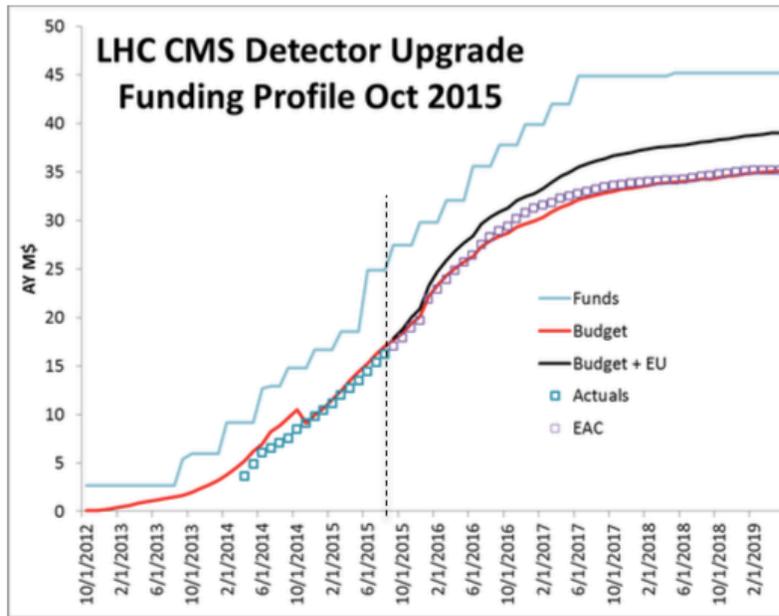
- Technical Proposal for the Upgrade of the CMS detector through 2020 (CERN-LHCC-2011-006)
- HCAL Phase 1 TDR (CERN-LHCC-2012-015 ; CMS-TDR-10. – 2012)
- Pixel Phase 1 Upgrade TDR (CERN-LHCC-2012-016 ; CMS-TDR-11, 9/2012)
- TRIGGER Phase 1 TDR in preparation for submission to the March LHCC meeting

2011

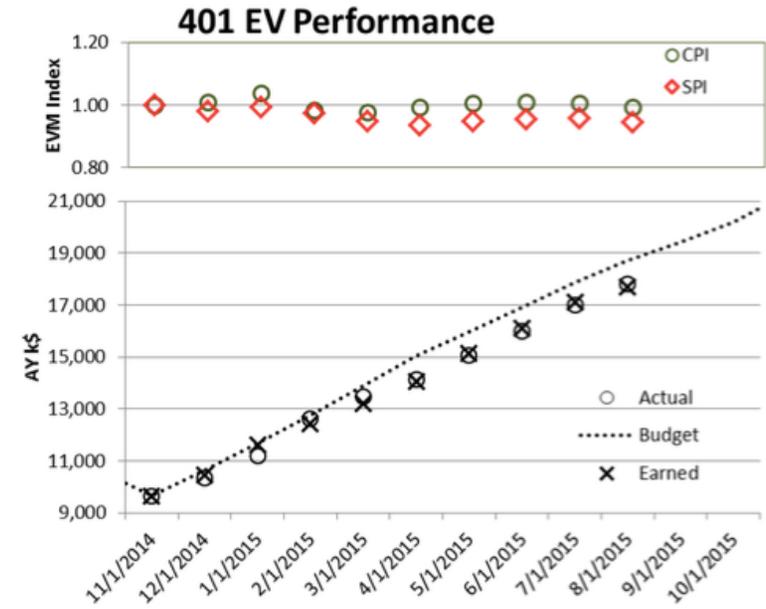
2012

2013

# Current Status (cont'd)



Funding Profile



Fiscal Year	2013	2014	2015	2016	2017	2018	2019	Total
OPC-Design	1.5	6.25						7.5
TEC-MIE			7.5	9.5	8.5			25.75
<b>Total DOE</b>	<b>1.5</b>	<b>6.75</b>	<b>7.5</b>	<b>9.5</b>	<b>8.0</b>	<b>0</b>	<b>0</b>	<b>33.25</b>
NSF(May-April)	0.45	2.50	3.00	2.5	2.20	1.30	0	11.95
<b>Total</b>	<b>1.95</b>	<b>8.75</b>	<b>10.5</b>	<b>12.0</b>	<b>10.70</b>	<b>1.30</b>	<b>0</b>	<b>45.20</b>

# This Review

Will have to evaluate the following:

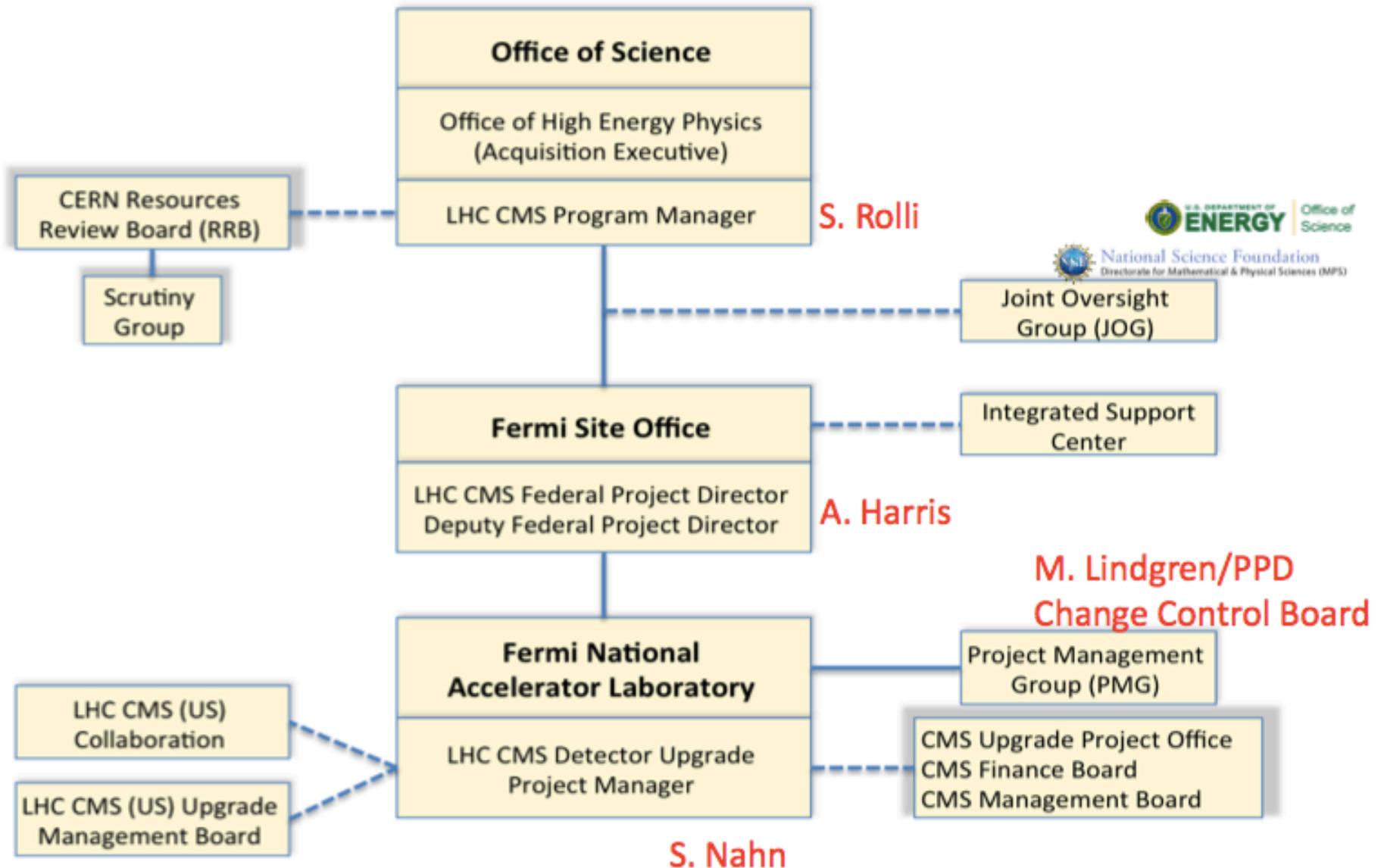
1. Management: is the management structure and resources adequate to deliver the proposed technical scope within stated performance by CD-4, both overall and from the point of view of individual DOE and NSF awardees?
2. Estimate to Complete: is the Estimate to Complete updated and credible? Review annual goals and performance metrics from the prior year and advise DOE and NSF of any concerns relating to variances between goals and outcomes of the prior year. Review the proposed annual goals and performance metrics for the current year and advise DOE and/or NSF on their suitability as effective indicators of performance in the coming year.
3. Cost & Schedule: Are the current project cost and schedule projections consistent with the approved baseline cost and schedule? Are the technical and financial status of the project accurately represented in the most recent monthly reports, reflecting project milestone status, EVM, risk and contingency management, configuration management and change control board actions, EH&S, and discussion of any other issues relevant to project performance from the point of view of awardees and sub-awardees?
4. Risk: Has the risk analysis been updated to accurately reflect the risks that remain in completing the project? Is the contingency still adequate for the risks? Are there any significant risks that jeopardize CD-4 completion and require high level management attention?

# Backup

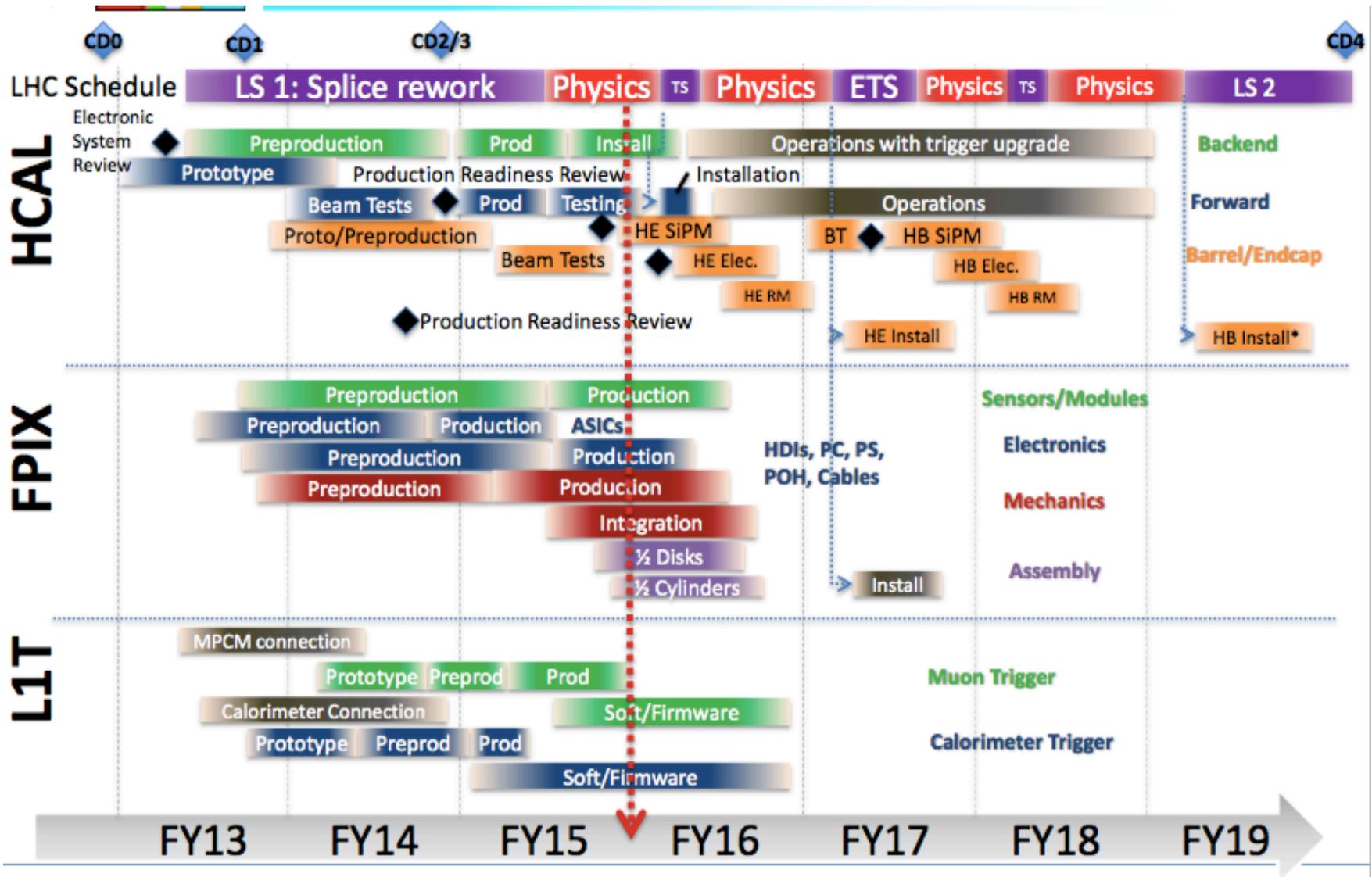
# Key Performance Parameters

	Threshold KPP	Objective KPP
HCAL	Complete <b>production</b> of the <b>HCAL Front End and Back End</b> electronics. <b>Installation</b> of the HCAL <b>Back End</b> electronics and <b>connection</b> to the Calorimeter <b>trigger</b> . <b>Test stand integration</b> of the HCAL <b>electronics</b> and <b>demonstration</b> of the full design <b>functionality</b> . Demonstration that the HCAL <b>Front End</b> Electronics is <b>ready to install</b> .	Complete production of the HCAL Front End and Back End electronics. <b>Complete installation and checkout of the HCAL Front End electronics in the CMS detector</b> . Installation of the HCAL Back End electronics, connection to the calorimeter trigger, <b>and integration with- the CMS data acquisition system</b> . <b>Demonstration of the full design functionality</b> .
FPIX	<b>Complete four half cylinders</b> , each with three half disks. System is <b>demonstrated</b> by read out in <b>test stand</b> at CERN and <b>turned over</b> to CMS Technical Coordination <b>to install</b> .	Complete four half cylinders, each with three half disks <b>and components for a spare half disk</b> . System is demonstrated by read out in test stand at CERN and turned over to CMS Technical Coordination to install.
L1T	<b>Delivery, installation and validation</b> , based on test data patterns, of Layer 1 of the upgrade calorimeter trigger and the upgrade endcap muon <b>trigger</b> . <b>Demonstration of 98% agreement</b> between the installed upgrade <b>trigger</b> electronics at CERN <b>and trigger emulation</b> of this electronics using test data patterns, followed by a <b>factor of two reduction</b> of calorimeter and endcap muon trigger <b>rates</b> for electrons, photons, muons and taus <b>with respect to the present system</b> with <b>less than 15% efficiency loss, demonstrated</b> using trigger <b>emulation</b> on data taken after LS1. Incorporation of additional CSC chamber data into the endcap muon trigger logic.	Delivery, installation and validation, based on test data patterns, of Layer 1 of the upgrade calorimeter trigger and the upgrade endcap muon trigger. Demonstration of <b>99.5%</b> agreement between the installed upgrade trigger electronics at CERN and trigger emulation of this electronics using test data patterns, followed by a factor of two reduction of calorimeter and endcap muon trigger rates for electrons, photons, muons and taus with respect to the present system with less than <b>10%</b> efficiency loss, demonstrated using trigger emulation on data taken after LS1. Incorporation of additional CSC chamber data into the endcap muon trigger logic.

# Project Organization - DOE



# Baseline Schedule



# Scorecard (Sept 2015)

Current CD:	CD-2/3	Date of Current CD approval:	11/12/2014	
Next CD:	CD-4	Forecast:	3/1/2019	Baseline:12/30/2019
	DOE		NSF	TOTAL
% Complete	55.6%		35.2%	50.7%
TPC	33.22		11.5	44.72
ETC	12.0		5.2	17.2
Contingency	5.77		2.10	7.88
Cumulative CPI	0.99		1.04	0.99
Cumulative SPI	0.94		0.96	0.95
Float to CD-4 (days)	195 (working)			

# Cost & Schedule Summary

	WBS	BAC	CTG	EAC	Contingency
<b>DOE</b>	<b>401</b>	<b>26,820</b>	<b>11,985</b>	<b>27,054</b>	<b>5.773</b>
	401.01 PM	5,655	2,996	5,513	
	401.02 HCAL	9,116	4,881	9,471	
	401.03 FPIX	7,158	2,477	7,242	
	401.04 L1T	4,891	1,631	4,828	
<b>NSF</b>	<b>401</b>	<b>8,100</b>	<b>5,250</b>	<b>8,003</b>	<b>2,103</b>
	401.01 PM	330	237	365	
	401.02 HCAL	3,949	2,753	3,840	
	401.03 FPIX	3,552	2,105	3,579	
	401.04 L1T	270	156	218	

# Level 1 Milestones

Level 1 Milestone	Schedule
<b>CD-0 Approve Mission Need</b>	<b>9/18/2012 (actual)</b>
<b>CD-1 Approve Alternative Selection and Cost Range</b>	<b>17/10/2013 (actual)</b>
<b>CD-2 Approve Performance Baseline</b>	<b>4<sup>th</sup> Qtr FY14</b>
<b>CD-3 Approve Start of Construction</b>	<b>4<sup>th</sup> Qtr FY14</b>
<b>CD-4 Approve Project Completion (defined as delivery of components)</b>	<b>1<sup>st</sup> Qtr FY20</b>

	<u>Milestone</u>	<u>Typical Float</u>
CD-4		16 months
Level 2 milestones—Federal Project Director		6 months
Level 3 milestones—Project Manager		3 months

# Near Term Milestones

T2 Milestone - DOE Federal Project Director		Status	Baseline	Projected
401.04 Trigger				
L2 - Deliver Muon Sorter Electronics to CERN	Completed	3-May-16	31-Aug-15	
L2 - Deliver Stage 1 Calorimeter Layer 1 & Muon Track Finder electronics to CERN	Completed	3-May-16	31-Aug-15	
T3 Milestone - Fermilab Directorate		Status	Baseline	Projected
401.02 Hadron Calorimeter				
L3 - US Production of uHTRs Complete	Completed	10/29/2015	6/15/2015	
401.03 Forward Pixels Detector				
L3 - Delivery of first batch production Bump Bonded pixel Detectors		10/22/2015	12/14/2015	
T4 Milestone - Project Manager		Status	Baseline	Projected
401.02 Hadron Calorimeter				
L4 - Delivery of production HB/HE uHTRs	Completed	8/5/2015	6/11/2015	
L4 - Calibration Module Prototype Complete	Completed	9/24/2015	7/6/2015	
L4 - Production HB/HE Crates Ready for Installation	Completed	10/13/2015	7/6/2015	
L4 - HE prototype RMs complete	Completed	8/24/2015	7/31/2015	
L4 - Ready for 2015 Test Beam	Completed	8/11/2015	8/3/2015	
L4 - Delivery of ngCCM modules from US	Completed	9/1/2015	8/6/2015	
L4 - PO Issued for HE Production SIPM	Completed	7/25/2016	8/28/2015	
L4 - Installation of HCAL/Trigger optical plant complete	Completed	4/9/2015	8/31/2015	
L4 - Installation of Optical Splitters Complete	Completed	6/12/2015	8/31/2015	
L4 - Delivery of Calibration Modules from Brazil		9/11/2015	9/22/2015	
L4 - Delivery of QIE Cards from Brazil to CERN		8/13/2015	9/30/2015	
L4 - Delivery of QIE Cards from Turkey to CERN		9/22/2015	9/30/2015	
L4 - Ready for HE Production ESR		10/27/2015	10/21/2015	
L4 - Release designs for pre-production in India		7/27/2015	11/19/2015	
L4 - HB/HE ngCCM ready for 2015 testbeam		7/27/2015	11/30/2015	
L4 - QIE11 ready for production ESR		8/21/2015	11/30/2015	
L4 - Ready for ESR Production Readiness Review		10/19/2015	11/30/2015	
401.03 Forward Pixels Detector				
L4 - Test System Software and Database Complete		1/30/2015	9/3/2015	
L4 - Delivery To CERN Complete		10/6/2015	10/1/2015	
L4 - Milestone: complete procurement of TBM and ancillary chips		7/1/2015	10/5/2015	
L4 - Delivery of first batch production Bump Bonded pixel Detectors		7/29/2015	10/29/2015	
L4 - Detector Control System (DCS) Complete		8/18/2015	12/22/2015	
L4 - Milestone: HDI completed		10/19/2015	2/9/2016	
L4 - Milestone: Production port card completed and available for half cylinder assembly		9/14/2015	3/3/2016	
L4 - Milestone: FPIX POH delivery and testing completed		10/12/2015	3/7/2016	
401.04 Trigger				
L4 - CTP Infrastructure Complete	Completed	10/2/2015	5/27/2015	
L4 - MSM Software and Firmware Complete	Completed	5/18/2015	8/31/2015	
L4 - MSM Production Complete	Completed	8/27/2015	8/31/2015	
L4 - MSM Commissioning Complete	Completed	1/26/2016	8/31/2015	
L4 - Commissioning of MS for Final Operations complete	Completed	1/26/2016	8/31/2015	
L4 - EMUTF Infrastructure On-site Commissioning Complete	Completed	3/31/2016	8/31/2015	
L4 - EMUTF Production Complete		6/1/2015	9/21/2015	
L4 - CIOx Software and Firmware Complete		8/25/2015	4/12/2016	

# DOE Critical Decisions

## **CD-0: Mission Need (Sept 2012)**

the CMS Detector needs upgrades to handle the expected increased data rates  
This initiative will allow the High Energy Physics (HEP) program to continue the forefront exploration of the Energy Frontier at the world's premier collider accelerator.

*Total Project Cost Range (DOE): \$22-\$34 Millions*

## **CD-1: Approve Alternative Selection and Cost Range (October 2013)**

Conceptual Design Maturity and Alternative Analysis

Scope & WBS

Cost, Schedule and Risk Estimate

Project Management Organization and E&SH

## **CD-2: Approve Performance Baseline (November 2014)**

Establish preliminary baseline; Review Project Risk and Contingency; Complete design package; Identify long-lead procurements

## **CD-3: Approve Start of Construction (November 2014)**

Prepare ES&H documentation; Complete design package; Request DOE authorization for construction