U.S. DEPARTMENT OF ENERGY | Office of Science

CMS Detector Upgrade Project

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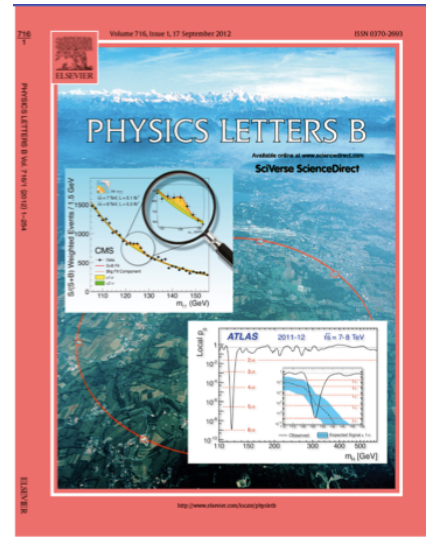
Outline

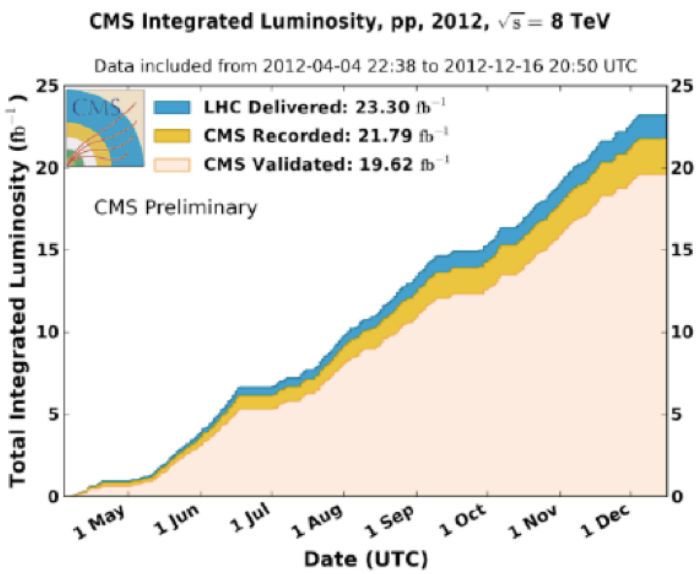
- The Energy Frontier at the LHC
  - Current Program
  - LHC Roadmap
- CMS Detectors Upgrades
- Project approval
  - CERN, DOE, NSF…
- DOE Process and this review

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 $fb^{-1}$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



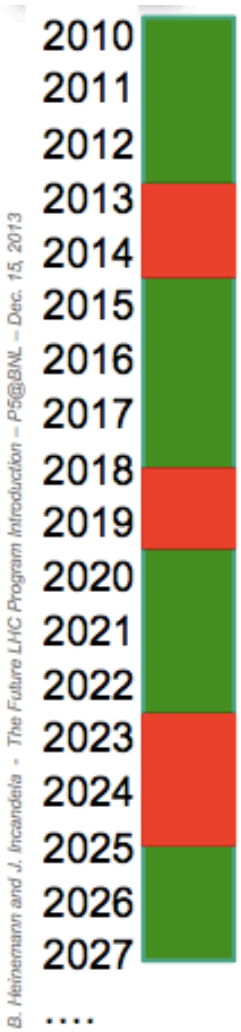


2013-2014: LS1 : repair splices in LHC magnets; detector maintenance and consolidation, upgrades and repairs

2015 -2018: Run II 13~14 TeV

- Ramp up luminosity to nominal ($2x10^{34}$ 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



Run 1: $\sqrt{s}$=7-8 TeV, $\int Ldt$=25 fb^{-1},
L^{peak}=0.7x10^{34} $cm^{-2}s^{-1}$, pileup $\mu \approx 20$

LS1: phase 0 upgrade

Run 2: $\sqrt{s} \approx 13$ TeV, $\int Ldt \approx 120$ fb^{-1},
L^{peak}=1.6x10^{34} $cm^{-2}s^{-1}$, pileup $\mu \approx 43$

LS2: phase 1 upgrade ← LS2 delayed 6 mo., extended 6 mo. relative to original plan at CD-1.

Run 3: $\sqrt{s} \approx 14$ TeV, $\int Ldt \approx 350$ fb^{-1},
L^{peak}=2-3x10^{34} $cm^{-2}s^{-1}$, pileup μ=50-80

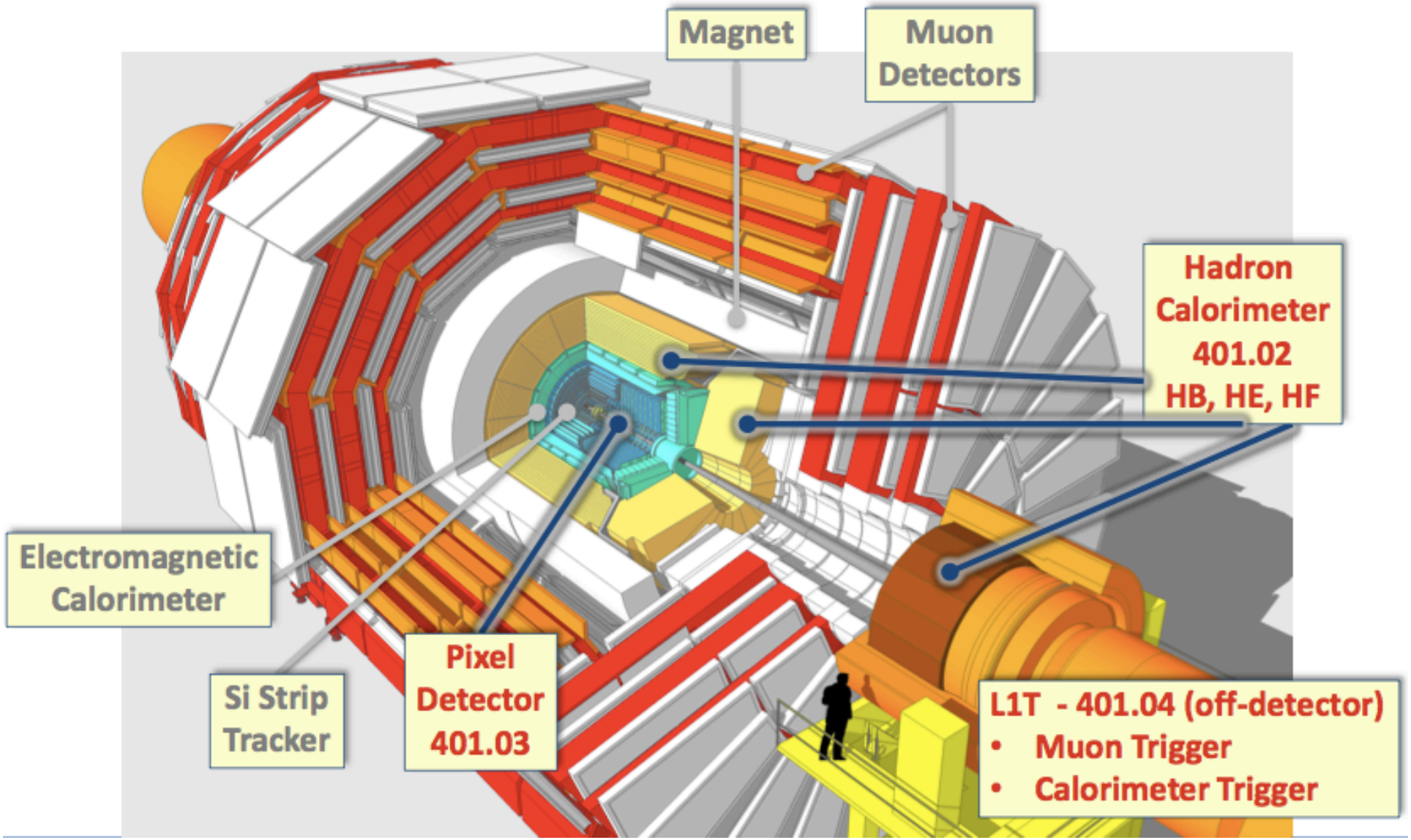
LS3: phase 2 upgrade

HL-LHC: $\sqrt{s} \approx 14$ TeV, $\int Ldt \approx 3000$ fb^{-1},
L^{peak}=20x10^{34} $cm^{-2}s^{-1}$ leveled to L^{peak}=(5-7.5)x10^{34} $cm^{-2}s^{-1}$
pileup $\mu \approx 140$-200

Detectors Upgrades

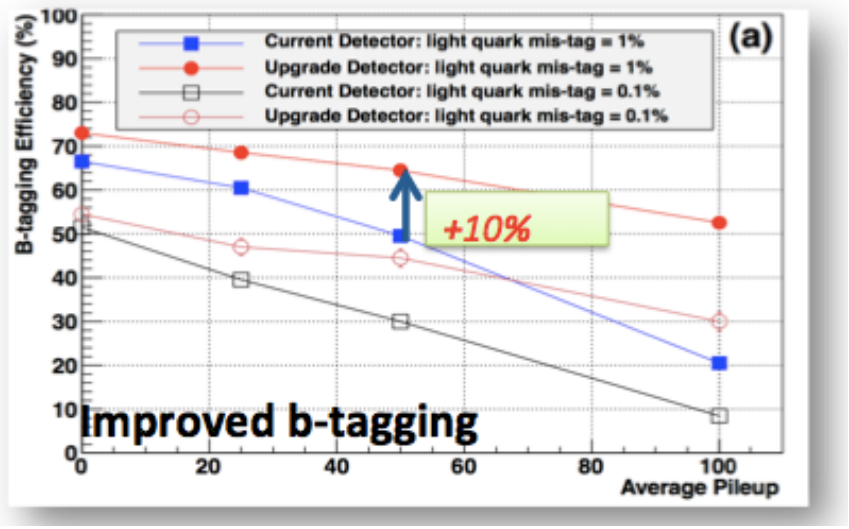
- Detectors will need to be upgraded to be able to cope with higher luminosity, e.g.
  - Improve trigger capabilities
    - better discriminate the desired signal events from background as early as possible in trigger decision
- Upgrade and/or replace detectors as they e.g.
  - Cannot handle higher rate due to bandwidth limitations
  - Suffer from radiation damage making them less efficient

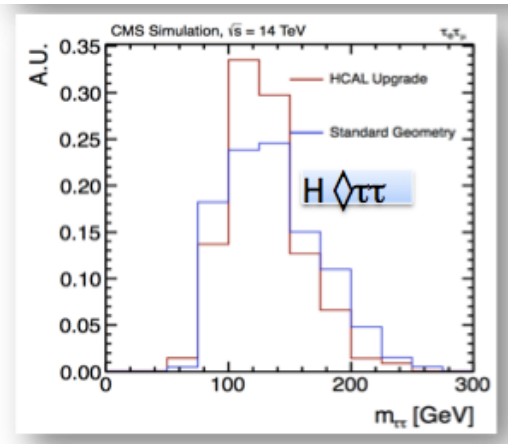
The CMS Detector



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 τ 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

- Technical Proposal for the Upgrade of the CMS detector through 2020 (CERN-LHCC-2011-006) — 2011
- HCAL Phase 1 TDR (CERN-LHCC-2012-015 ; CMS-TDR-10. – 2012) — 2012
- Pixel Phase 1 Upgrade TDR (CERN-LHCC-2012-016 ; CMS-TDR-11, 9/2012) — 2012
- TRIGGER Phase 1 TDR in preparation for submission to the March LHCC meeting — 2013

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	FY14
• CD-3, Approve Start of Construction	FY14

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

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-1 Funding Guidance:

	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	Total
FY 2014 PRB Integrated funding	1,500	7,500	15,250	24,750	33,250	
FY 2014 PRB TPC	1,500	6,000	7,750	9,500	8,500	33,250
OPC	1,500	6,000				7,500
TEC			7,750	9,500	8,500	25,750

Current Status (cont'd)

CD-2: Approve Performance Baseline
Establish preliminary baseline
Review Project Risk and Contingency
Complete design package
Identify long-lead procurements

CD-3: Approve Start of Construction
Prepare ES&H documentation
Complete design package
Request DOE authorization for construction

WBS ID	WBS Name	Design % complete
401	LHC CMS Detector Upgrades Project	87
401.02	HCAL	81
401.02.03	HF Front-End	90
401.02.04	HB/HE Front-End	77
401.02.05	HCAL Back-End	96
401.03	FPIX	91
401.03.03	FPIX Components	90
401.03.04	FPIX Assembly & Testing	94
401.03.05	FPIX Pilot System	98
401.04	Trigger	96
401.04.03	Muon Trigger	95
401.04.04	Calorimeter Trigger	97

Current Funding Guidance

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
Total DOE	**1.5**	**6.25**	**7.5**	**9.5**	**8.5**	**0**	**0**	**33.25**
NSF(May-April)	0.45	2.50	3.00	2.5	2.20	1.30	0	11.95
Total	**1.95**	**8.75**	**10.5**	**12.0**	**10.70**	**1.30**	**0**	**45.20**

This Review

Will need to assess whether:

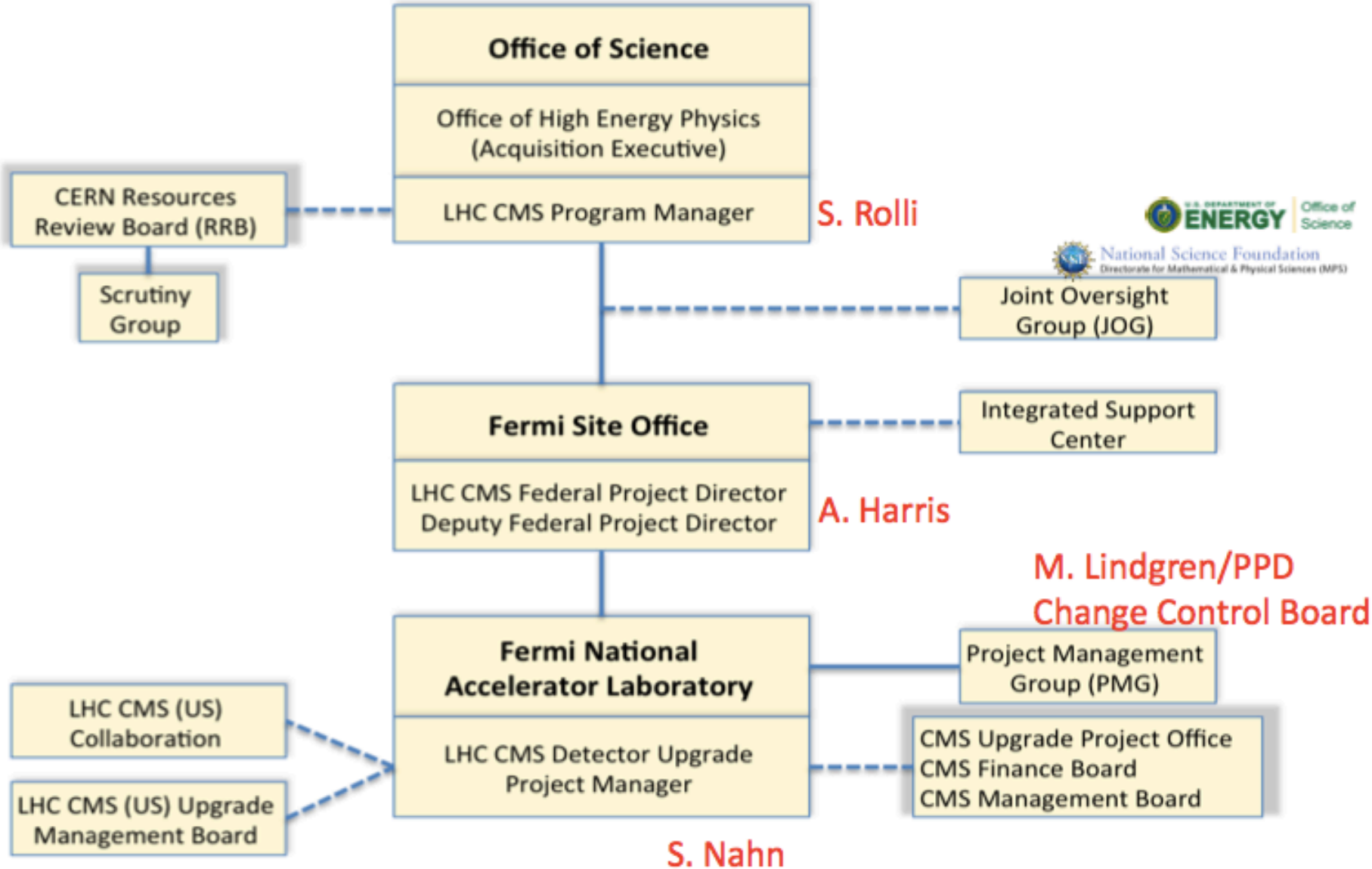
- The proposed Technical Design and associated implementation approach satisfies the performance requirements and the CD-4 goals are well defined
- The Performance Baseline of cost estimate and schedule is consistent with the plan to deliver the technical scope with the stated performance
- The Maturity of Design is sufficient for the project to continue with procurement and fabrication, with cost and schedule projection consistent with the approved baseline
- Contingency is adequate for the risk
- The management structure and resources are adequate to deliver the proposed final design within the baseline as identified in the PEP
- CD-2/3 prerequisite documentation has been provided and is complete
- All ES&H aspects are being properly addressed given the project current status of development

Backup

Key Performance Parameters

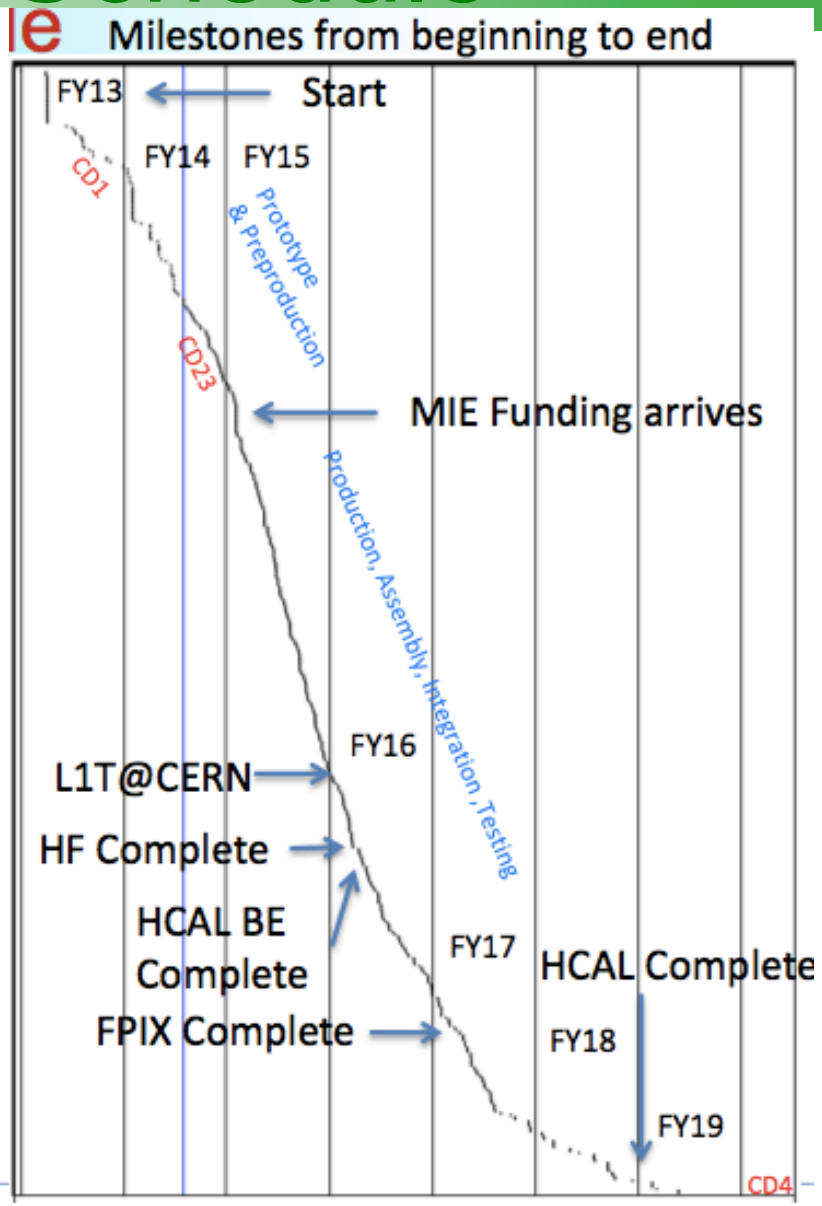
	Threshold KPP	Objective KPP
HCAL	Complete **production** of the **HCAL Front End and Back End** electronics. **Installation** of the HCAL **Back End** electronics and **connection** to the Calorimeter **trigger**. **Test stand integration** of the HCAL **electronics** and **demonstration** of the full design **functionality**. Demonstration that the HCAL **Front End** Electronics is **ready to install**.	Complete production of the HCAL Front End and Back End electronics. Complete installation and checkout of the HCAL Front End electronics in the CMS detector. Installation of the HCAL Back End electronics, connection to the calorimeter trigger, and integration with- the CMS data acquisition system. Demonstration of the full design functionality.
FPIX	**Complete four half cylinders**, each with three half disks. System is **demonstrated** by read out in **test stand** at CERN and **turned over** to CMS Technical Coordination **to install**.	Complete four half cylinders, each with three half disks and components for a spare half disk. System is demonstrated by read out in test stand at CERN and turned over to CMS Technical Coordination to install.
L1T	**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 98% 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 15% efficiency loss, demonstrated** using trigger **emulation** 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 99.5% 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 10% 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

- Starts FY13, Ends FY20Q1
  - Activities start Jan 1, 2013 or beginning of FY14
- Continuous stream of milestones to project end
  - ~13 months between last Technical Objective KPP and CD-4
- Tiered Milestone Hierarchy reflects successively higher levels of oversight
  - Grace periods before notifying next up the chain
- Schedule risk implemented via Risk tool



Baseline Cost

L2	DOE			NSF			Grand Total
	Cost (AY k$)	EU	Total	Cost (AY k$)	EU	Total	
PM	5,538	453	5,991	501	68	569	6,560
HCAL	8,842	2,302	11,144	3,704	1,134	4,838	15,982
FPIX	6,686	1,335	8,021	3,289	753	4,042	12,063
L1T	5,153	1,435	6,588	336		336	6,924
Grand Total	**26,219**	**5,525**	**31,745**	**7,829**	**1,955**	**9,784**	**41,529**

Reminder: EU ≡ Estimate Uncertainty, contingency proportional to Cost

- Risk analysis at 90% C.L. = 1,836 k$
  - 1,401 k$ tied to 50 Specific threats in Risk Register
  - 435 k$ provision for Top Down Risk based Generic Scenario model
- NSF + DOE TPC = 43.36 k$
  - DOE with all Risk = 33.58 M$ (CD-1 range 29.2-35.9, TPC 33.22 M)
  - Contingency on Work to Go: 33%