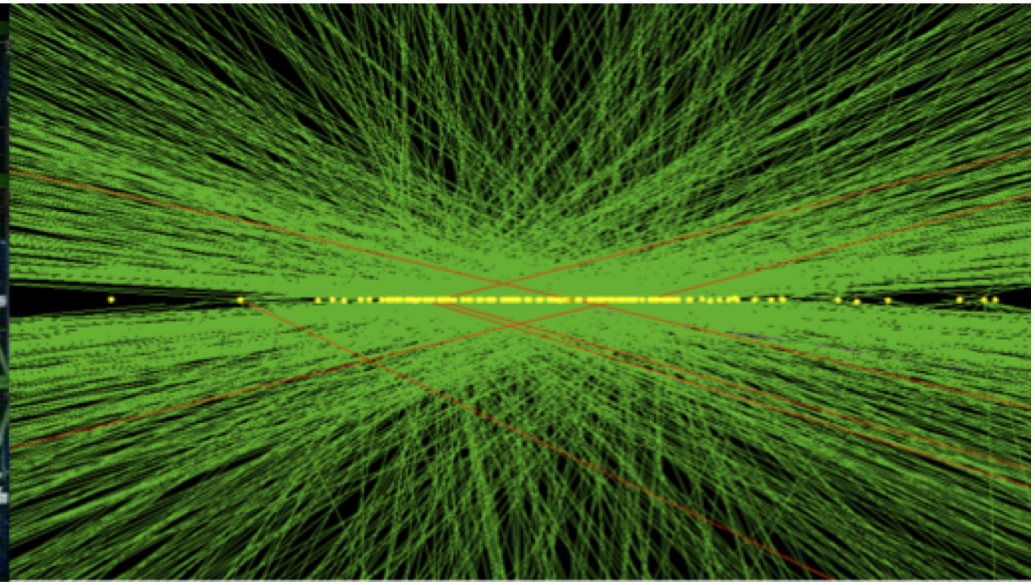
Agenda and Logistics

Vivian O'Dell

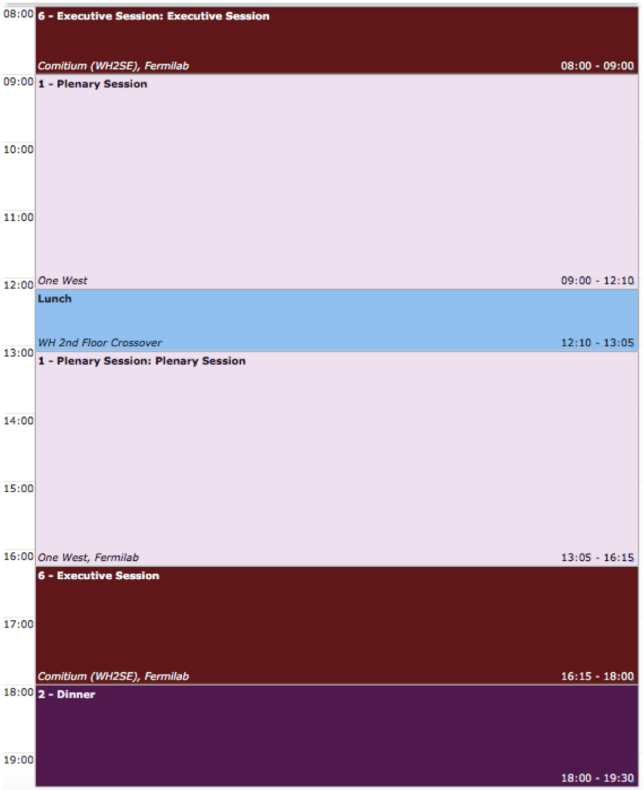
DOE CD-1 Director's Review

March 19, 2019

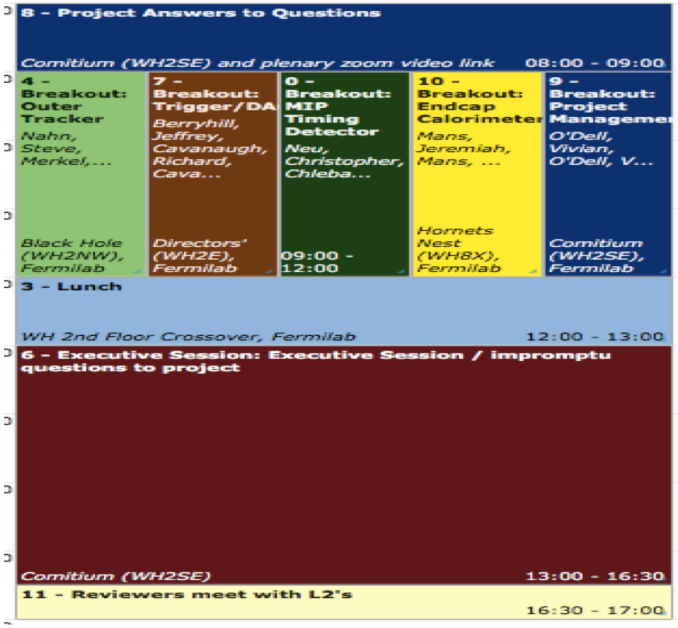


Review Agenda Overview

Tuesday



Wednesday



Thursday

Plenary/Closeout @ 11am in WH1W

All executive sessions are in the Comitium

<u>Breakout Sessions:</u>

Outer Tracker, WH2NW (Black Hole)
Endcap Calo: WH8XO (Hornets Nest)
Trig/DAQ: WH2E (Directors')
MTD: WH2NE (Snakepit)
Management: WH2SE (Comitium)

Lunch (Tues/Wed), Dinner (Wed): 2nd floor crossover

Plenary Session Agenda

09:00 - 12:10 **Plenary Session**

First Day - Plenary overview of L2 areas

Location: One West

09:00 **Lab Intro** *10'*
Speaker: Dr. Joseph Lykken (Fermilab)

09:10 **The CMS HL-LHC Upgrades** *30'*
Speaker: Patricia McBride (Fermilab)

09:40 **Overview of the US CMS HL-LHC Upgrade Project** *45'*
Speaker: Vivian O'Dell (Fermilab)

10:25 **Coffee Break** *15'*

10:40 **L2 Overview: MIP Timing Detector** *50'*
Speakers: Christopher Neu (University of Virginia), David Stuart, Frank Chlebana (Fermilab)

11:30 **Outcome of MTD Technical Review and Recent Progress** *20'*
Speaker: David Stuart

11:50 **MTD Cost, Schedule, Risk and Outcome of OPSS Review** *20'*
Speaker: Frank Chlebana (Fermilab)

12:10 - 13:05 Lunch (WH 2nd Floor Crossover)

13:05 - 16:15 **Plenary Session**

First Day - Plenary overview of L2 areas

Location: One West

13:15 **L2 Overview: Outer Tracker** *45'*
Speaker: Steve Nahn (Fermilab)

14:00 **L2 Overview: Endcap Calorimeter** *45'*
Speakers: Jeremiah Mans, Jeremiah Mans (University of Minnesota)

14:45 **L2 Overview: Trigger/DAQ** *45'*
Speaker: Jeffrey Berryhill (Fermilab)

15:30 **Project Overall Cost/Schedule/Risk Evaluation** *45'*
Speakers: Dr. Lucas Taylor (Fermilab), Lucas Taylor

16:15 - 18:00 **Executive Session**

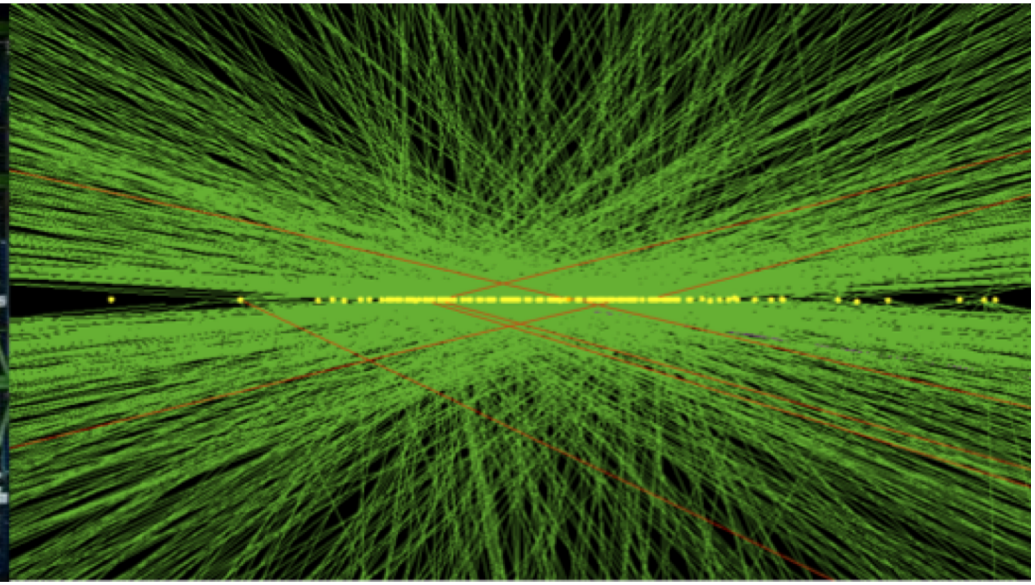
Location: Comitium (WH2SE)

P02 – The U.S. CMS HL-LHC Upgrade

Vivian O'Dell

DOE CD-1 Director's Review

March 19, 2019



Outline

- Preamble: Charge and Background
- Overview
- Project Scope and Organization
- Project Cost and Cost Range
- Project Schedule
- ESH&Q
- Previous Reviews
- Closing Remarks / Summary

CD-1 Charge

Charge #x

- Charge is to assess project readiness for CD-1
- Slides are labelled with charge question # to make it easier to navigate

1. Does the acquisition strategy document a carefully considered analysis of alternatives that support the preferred alternative?
2. Does the conceptual design satisfy the performance requirements?
3. Does the conceptual design report and supporting documentation adequately justify the stated cost range and project duration?
4. Do the project's plans to execute the work make the most efficient use of the financial, human, and technical resources available to them at the participating national labs and universities when they are the most efficient choice?
5. Does the proposed project team have adequate management experience, design skills, and laboratory support to produce a credible technical, cost, and schedule baseline?
6. Are the ES&H aspects of the project being properly addressed and is the ES&H planning currently sufficient for this stage of the project?
7. Is the documentation required by DOE O413.b for CD-1 approval complete and in good order?
8. Has the project satisfactorily responded to the recommendations from previous reviews?

Background

- DOE conducted a June, 2018 IPR
  - The MIP Timing Detector subproject was not at a CD-1 level of maturity
  - Project ESH&Q documentation and process not sufficiently mature
  - This is reflected in the charge you have:
    - "The U.S. CMS HL-LHC upgrade comprises both NSF and DOE projects. The NSF project is reviewed separately. The DOE project was comprehensively reviewed in June 2018, and the Tracker, Endcap Calorimeter and Trigger/DAQ subsystems were deemed to be at a CD-1 level of maturity. However, the MIP Timing Detector was considered not mature enough to proceed to CD-1. The DOE review committee further pointed out some of the project documentation needed to be updated, especially in the ESH and QA areas."
  - All recommendations from the IPR have been addressed

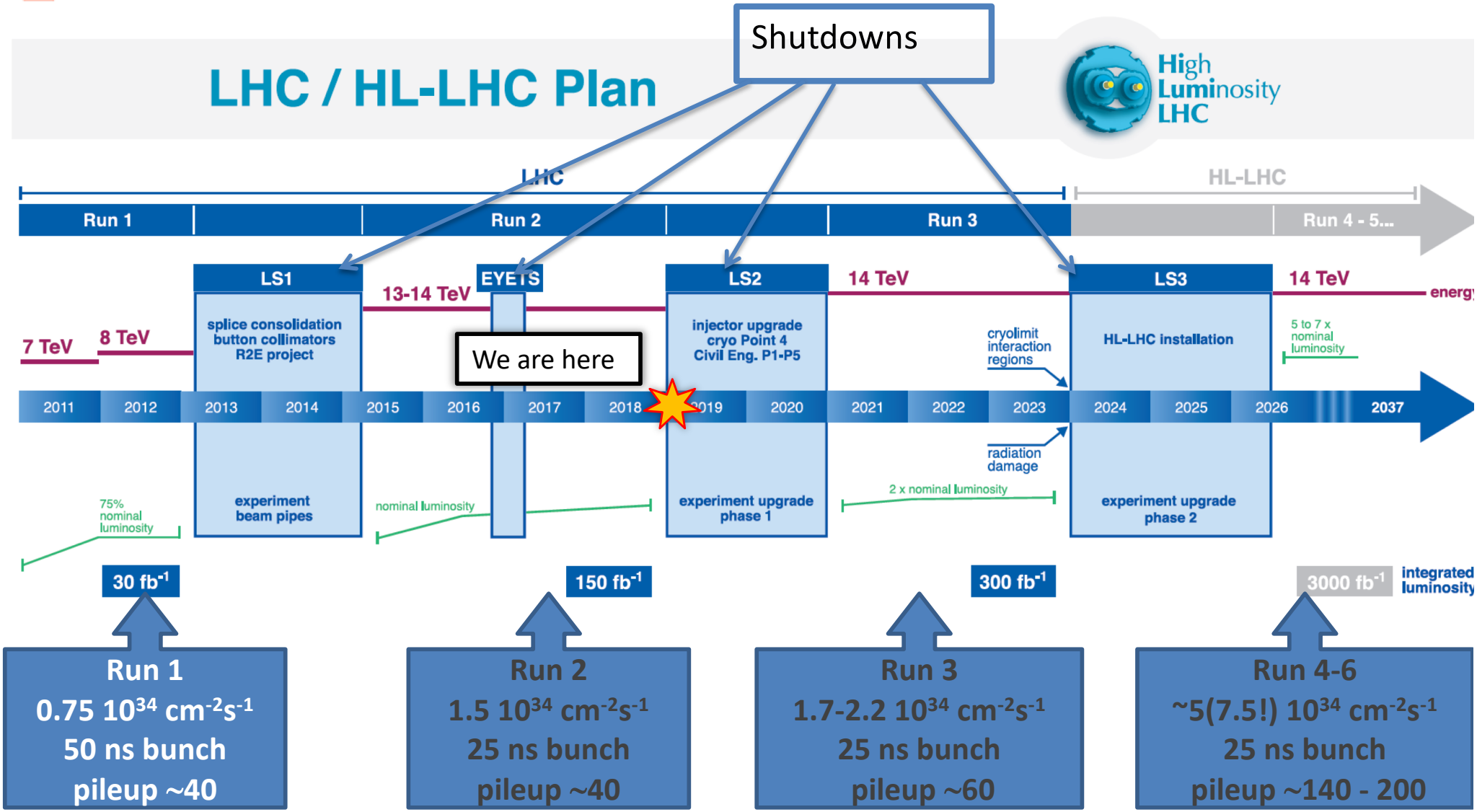
Biographical Sketches

Charge #5

- **Vivian O'Dell, Project Manager**
  - U. S. CMS HL-LHC Upgrade Project Manager since January 1, 2015
  - Fermilab senior scientist
  - Management experience
    - Project Manager for D0 Run IIb upgrades (O413.3b project)
    - U. S. CMS Level 2 Project Manager for Data Acquisition from 2002 – completion of construction project. Continued as the leader of the U. S. CMS DAQ effort in the Operations Program.
    - U. S. CMS Deputy Detector Operations Manager (2011-2013) and Detector Operations Manager (2014)
- **Vaia Papadimitriou, Deputy Project Manager**
  - U. S. CMS HL-LHC Deputy Project manager since July, 2018
  - Fermilab senior scientist
  - Management experience
    - LBNE/LBNF Beamline Project Manager (~$200M) (2009-2018) (O413.3b project)
    - Associate Division Head of Accelerator Division – LBNE/LBNF (2009-2018)
    - Assistant Division Head of Accelerator Division - Accelerator Performance (2006-2009)
- **Anders Ryd, Deputy Project Manager and NSF PI**
  - HL-LHC U.S. CMS deputy upgrade project manager (2014-present)
  - Professor, Cornell 2003 – present

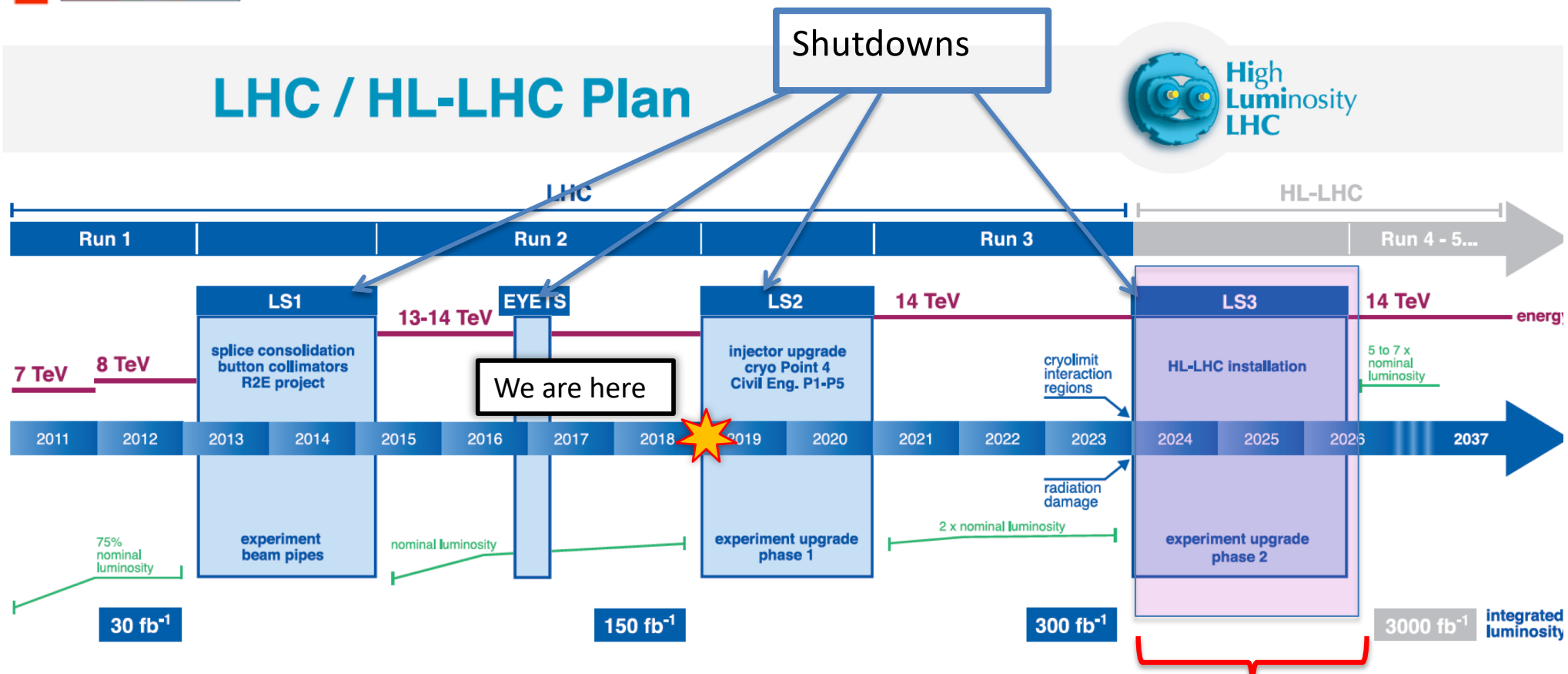
Project Overview

Project Schedule and Context



Upgrades installed in long shutdowns between science runs

Project Schedule and Context

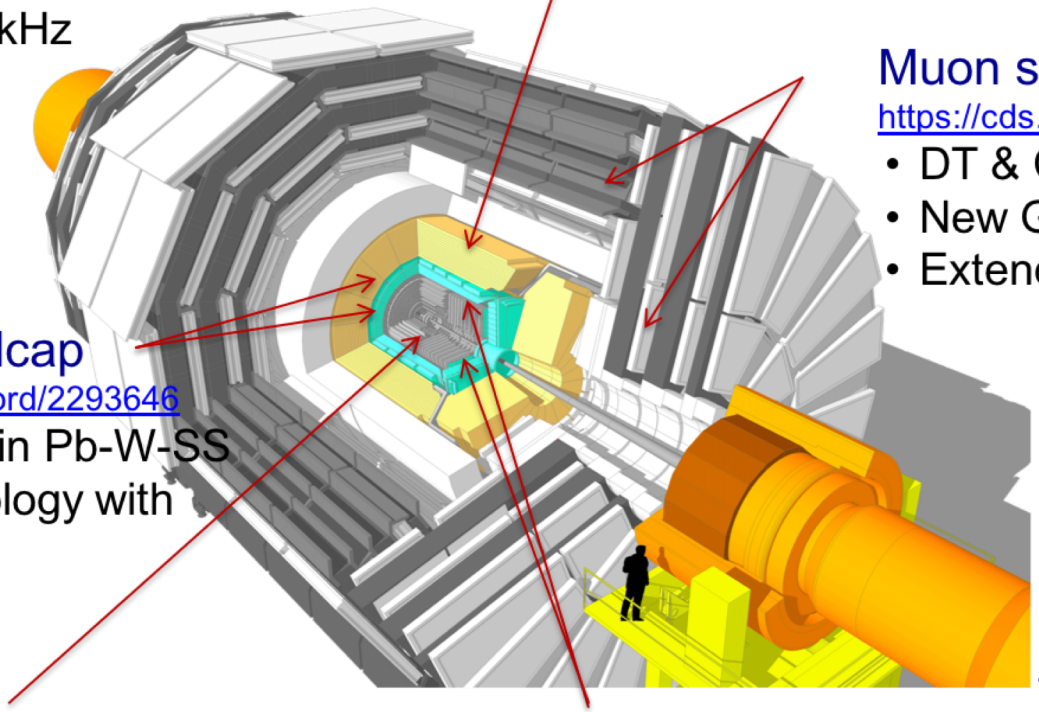


HL-LHC Upgrades: Installed during LS3
(CY 2024 – mid 2026)
HL-LHC operations continues through 2037

CMS HL-LHC Upgrades with links to TDRs

L1-Trigger/HLT/DAQ
https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193
- Tracks in L1-Trigger at 40 MHz for 750 kHz PFlow-like selection rate
- HLT output 7.5 kHz

Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

Calorimeter Endcap
https://cds.cern.ch/record/2293646
- Si, Scint+SiPM in Pb-W-SS
- 3D shower topology with precise timing

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure
https://cds.cern.ch/record/2020886

Tracker https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

MIP Timing Detector
https://cds.cern.ch/record/2296612
- $\simeq$ 30 ps resolution
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Project Scope and Organization

Scope of Selected Alternative

Charge #1,7

- The project received CD-0 in March, 2015.Three options were enumerated in the “Mission Need” document
  - Option 1: DOE and NSF work together to support the HL-LHC ATLAS + CMS Upgrade projects
  - Option 2: DOE and NSF both act independently in their support of the upgrades
  - Option 3: DOE chooses not to support the HL-LHC upgrades (i.e. do nothing)
- Option 1 (US scope is a partnership between DOE and NSF) is selected as the preferred alternative. This DOE proposal reflects the preferred choice.
  - The Project Office (402.1/402.0) is shared between DOE and NSF. All other scope is independent between DOE and NSF
- More details, including alternate design choices, can be found in the “Alternatives Analysis and Lifecycle Costs” CMS-doc-13472 and as an appendix in the DOE “Acquisition Strategy” CMS-doc-13517
  - This document has been reviewed by DOE. The alternative chosen is agreed to by NSF.

CMS HL-LHC Upgrades: DOE contributions

L1-Trigger/HLT/DAQ

402.6

https://cds.cern.ch/record/2283192
https://cds.cern.ch/record/2283193

- Tracks in L1-Trigger at 40 MHz for 750 kHz PFlow-like selection rate
- HLT output 7.5 kHz

Barrel Calorimeters

WBS #'s

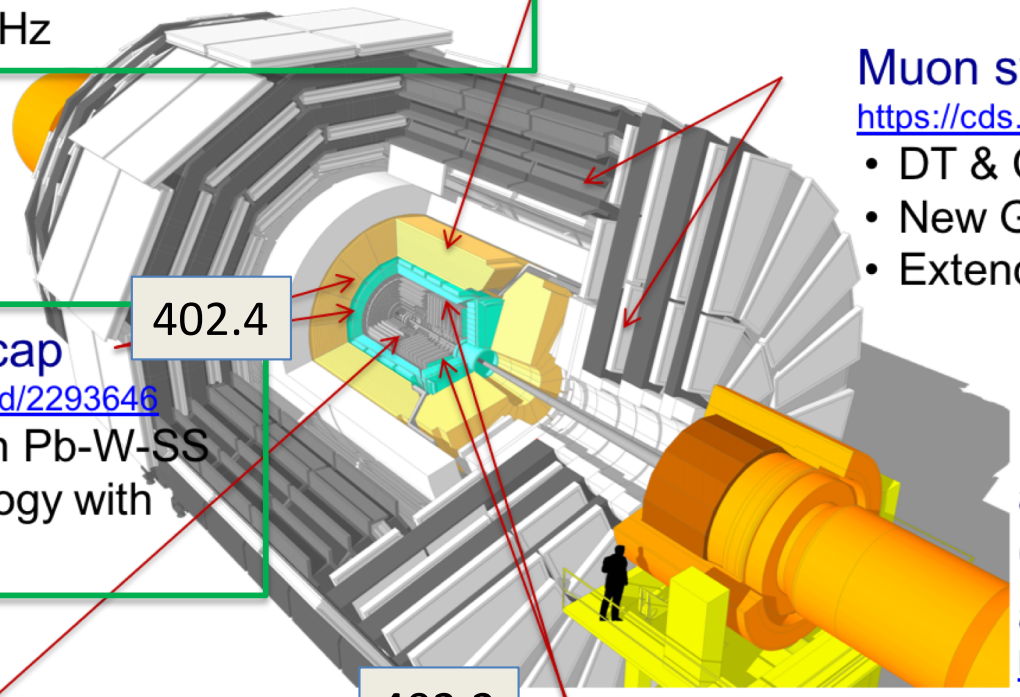
https://cds.cern.ch/record/2283187

- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

Muon systems

https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$



402.4

Calorimeter Endcap

https://cds.cern.ch/record/2293646

- Si, Scint+SiPM in Pb-W-SS
- 3D shower topology with precise timing

Beam Radiation Instr. and Luminosity, and Common Systems and Infrastructure

https://cds.cern.ch/record/2020886

402.2

Tracker

https://cds.cern.ch/record/2272264

- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

MIP Timing Detector

402.8

https://cds.cern.ch/record/2296612

- $\simeq$ 30 ps resolution
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Scope Overview

Charge #2,3

- DOE deliverables are described in the Conceptual Design Report (CMS-doc-13151)
- Captured in the preliminary KPPs (CMS-doc-13237)
- Basic scope (L2 area):
  - 402.2 Outer Tracker -- modules, inner barrel detector
  - 402.4 Endcap Calorimeter – Active material for Hadronic Section (silicon / scintillator modules / cassettes), concentrator ASIC
  - 402.6 Trigger/DAQ – calorimeter and correlator trigger systems
  - 402.8 MIP Timing Detector – Barrel Modules, Trays/ Endcap Modules, Endcap Readout ASIC
- The conceptual design was reviewed in a series of technical reviews prior to last year's CD-1 for all except MIP Timing Detector
- The MIP Timing Detector conceptual design was revised and reviewed in November, 2018

Key Performance Parameters

Charge #7

- Each WBS L2 area has developed a set of ***preliminary*** Key Performance Parameters, both Threshold and Objective (see next slide)
  - 8 KPPs: 2 Outer Tracker, 1 Calorimeter Endcap, 3 Trigger/DAQ, 3 MIP Timing Detector
  - These KPPs finish at tested deliverables received by CERN
- Objective KPPs adds Installation and Commissioning costs
  - Includes integrating the deliverables into the full sub detector above ground
- Threshold KPPs are ***not*** tied to the LHC schedule
- Objective KPPs ***may be*** tied to the LHC schedule
  - Installation/Commissioning includes integration above ground
- Cost and schedule is based on the Objective KPPs

Key Performance Parameters

Charge #7

[CMS-doc-13237]

The KPPs are broken out by subproject.
Each subproject will describe their KPPs and the design/construction plan to achieve them.

WBS	Threshold KPP	Objective KPP
402.2 Outer Tracker	T-KPP-OT-1: OUTER TRACKER FLAT BARREL CONSTRUCTION COMPLETE The Outer Tracker "Flat" Inner Barrel consists of three layers of silicon modules, with sufficient granularity and noise performance to ensure a projected occupancy of < 5%, and capable of [illegible] information to the L1 The project shall cor Barrel detector and c Integration Facility o shall be demonstrate to CERN.	O-KPP-OT-1: OUTER TRACKER FLAT BARREL INSTALLATION AND COMMISSIONING COMPLETE The Outer Tracker "Flat" Inner Barrel consists of three layers of silicon modules, with sufficient granularity and noise performance to ensure a projected occupancy of <
402.2 Outer Tracker	T-KPP-OT-2: OUTE CONSTRUCTION C The Project shall est centers for the Outer shall build about 1/3 the Outer Tracker. T graded before sendi	
402.4 Endcap Calorimeter	T-KPP-CE-1: CALO CONSTRUCTION C The project shall cor hadron section of th shall also construct t the silicon and scinti hadron section of th for a testbeam syste shall assemble the o electromagnetic calo electromagnetic calo The project shall des data/trigger concentr calorimeter. The pro low voltage power s calorimeter. Calorimeter silicon a sufficient granularity, to enable cell-by-cell calibration at the 5% level the end of operation. The cassettes shall be demonstrated to operate standalone and delivered to CERN.	

WBS	Threshold KPP	Objective KPP
402.6 Trigger and DAQ	T-KPP-TD-1: BARREL CALORIMETER TRIGGER CONSTRUCTION COMPLETE The project shall design, produce, and test the electronics required for receiving data from the barrel calorimeter, processing them for L1 trigger reconstruction, and transmitting output to the Correlator Trigger and DAQ. The project also includes development of software and firmware needed to operate the electronics and implement L1 trigger reconstruction. The barrel calo test data patter detector readou ΔR = 0.01 and photons in the	O-KPP-TD-1: BARREL CALORIMETER TRIGGER INSTALLATION AND COMMISSIONING COMPLETE The project shall design, produce, and test the electronics required for receiving data from the barrel calorimeter, processing them for L1 trigger reconstruction, and transmitting output to the Correlator Trigger and DAQ. The project also includes development of software and firmware needed to operate the electronics and implement L1 trigger reconstruction.
402.6 Trigger and DAQ	T-KPP-TD-2: CONSTRUCTI The project sha required for rec and track trigge reconstruction, trigger compon development o the electronics The Correlator simulated test readout data, t calorimeter clu efficiently. For efficiency of the primitive tracks	

WBS	Threshold KPP	Objective KPP
402.6 Trigger and DAQ	T-KPP-TD-3: DAQ CONSTRUCTION COMPLETE The project shall specify, procure, and test the equipment needed for the startup online Storage Manager and Transfer System. Deliverables are the storage-system hardware and the software used for collecting, aggregating and distributing events accepted by the high-level trigger. The Storage Manager startup hardware shall be sized to support data buffering of at least 1 day of data from the HLT at a minimum of 31 GB/s, concurrently transferring data to CERN central computing and transferring monitoring data to the online monitoring system.	O-KPP-TD-3: DAQ INSTALLATIO COMMISSIONING COMPLETE The project shall specify, procure, a needed for the startup online Stora Transfer System. Deliverables are t hardware and the software used fo aggregating and distributing events level trigger. The Storage Manager be sized to support data buffering o from the HLT at a minimum of 31 G transferring data to CERN central computing and transferring monitoring data to the online monitoring system. The project shall install and commission the new storage manager hardware and software.
402.8 Timing Layer	T-KPP-TL-1: BARREL TIMING LAYER CONSTRUCTION COMPLETE The project will construct and qualify concentrator cards (CCs) and trays of modules+readout units (RUs) for the BTL. CC and module+RU performance will match the specification of production prototypes, whose sensor components and associated front-end readout electronics have been demonstrated in cosmic ray, source, and/or test beam exposures to be capable of measuring the arrival time of minimum-ionizing particles with a resolution of < 40ps at the start of the HL-LHC run. The specification further states that the time resolution will be < 60ps even after withstanding the radiation damage from fluences corresponding to an integrated 4000/fb of HL-LHC luminosity, as borne out in prototype testing of irradiated components. The project shall deliver to CERN 100% of the CCs (476 which includes 10% spares) and approximately 60% of the total trays needed for the BTL.	O-KPP-TL-1: BARREL TIMING LAYER INSTALLATION AND COMMISSIONING COMPLETE The project will construct and qualify conc (CCs) and trays of modules+readout units BTL. CC and module+RU performance will mat specification of production prototypes, wh components and associated front-end rea have been demonstrated in cosmic ray, so test beam exposures to be capable of me arrival time of minimum-ionizing particles of < 40ps at the start of the HL-LHC run. T further states that the time resolution will after withstanding the radiation damage fr corresponding to an integrated 4000/fb of luminosity, as borne out in prototype testi components. The project shall deliver to CERN 100% o which includes 10% spares) and approxim the total trays needed for the BTL. The project shall participate in the integrat trays into the MTD detector at CERN. The additionally participate in the installation, t calibration of the detector.

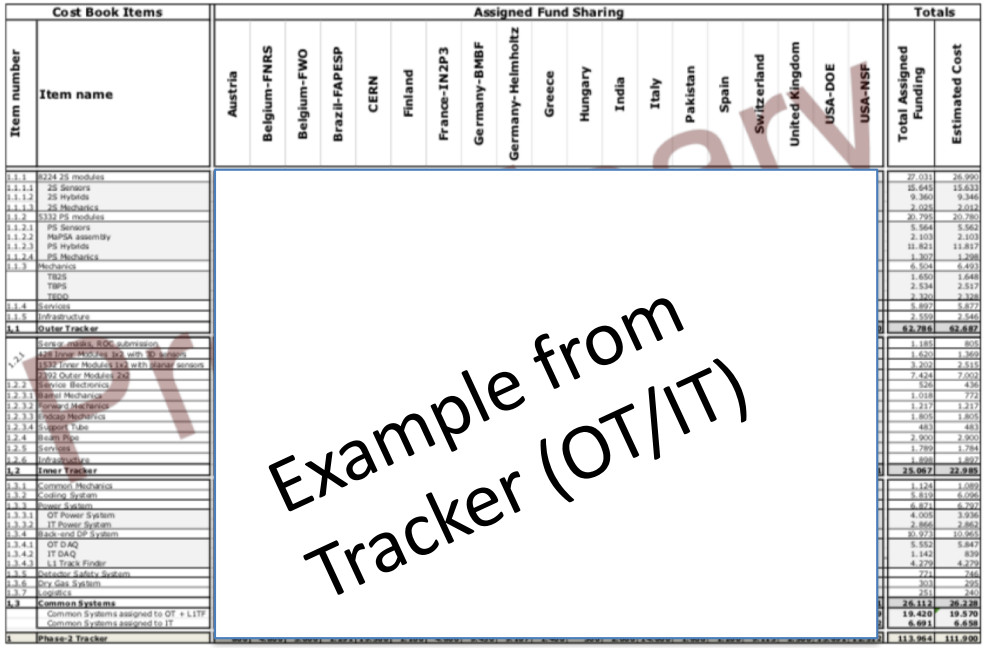
WBS	Threshold KPP	Objective KPP
402.8 Timing Layer	T-KPP-TL-2: ENDCAP TIMING LAYER CONSTRUCTION COMPLETE The project shall provide and qualify the front-end ASIC design for the ETL. The project shall construct and qualify modules for the ETL. The project shall deliver to CERN at least 50% of the ETL modules. ASIC and module performance will match the specification of production prototypes, whose sensor components and associated front-end readout electronics have been demonstrated in cosmic ray, source, and/or test beam exposures to be capable of measuring the arrival time of minimum-ionizing particles with a resolution of 30-40ps per track, for most tracks, at the start of the HL-LHC run. The specification further states that the time resolution will remain between 40-60ps even after withstanding the radiation damage from fluences corresponding to an integrated 4000/fb of HL-LHC luminosity, as borne out in prototype testing of irradiated components.	O-KPP-TL-2: ENDCAP TIMING LAYER INSTALLATION AND COMMISSIONING COMPLETE The project shall provide and qualify the front-end ASIC design for the ETL. The project shall construct and qualify modules for the ETL. The project shall deliver to CERN at least 50% of the ETL modules. ASIC and module performance will match the specification of production prototypes, whose sensor components and associated front-end readout electronics have been demonstrated in cosmic ray, source, and/or test beam exposures to be capable of measuring the arrival time of minimum-ionizing particles with a resolution of 30-40ps per track, for most tracks, at the start of the HL-LHC run. The specification further states that the time resolution will remain between 40-60ps even after withstanding the radiation damage from fluences corresponding to an integrated 4000/fb of HL-LHC luminosity, as borne out in prototype testing of irradiated components. The project shall participate in the integration of the ETL modules into the MTD detector at CERN. The project shall additionally participate in the installation, testing and calibration of the detector.

Deliverables to CMS

- CMS deliverables are agreed upon in subsystem Upgrade Management Boards and Upgrade Resource Boards (in which U.S. personnel are also members)
- These are documented in MOUs between CMS and CMS member Funding Agencies and are agreed upon at the CERN RRB
  - These MOUs are now in preparation to be sent to the April RRB
  - They will be available for CD-2

Deliverables and Assigned Funding for the individual Items by Funding Agency

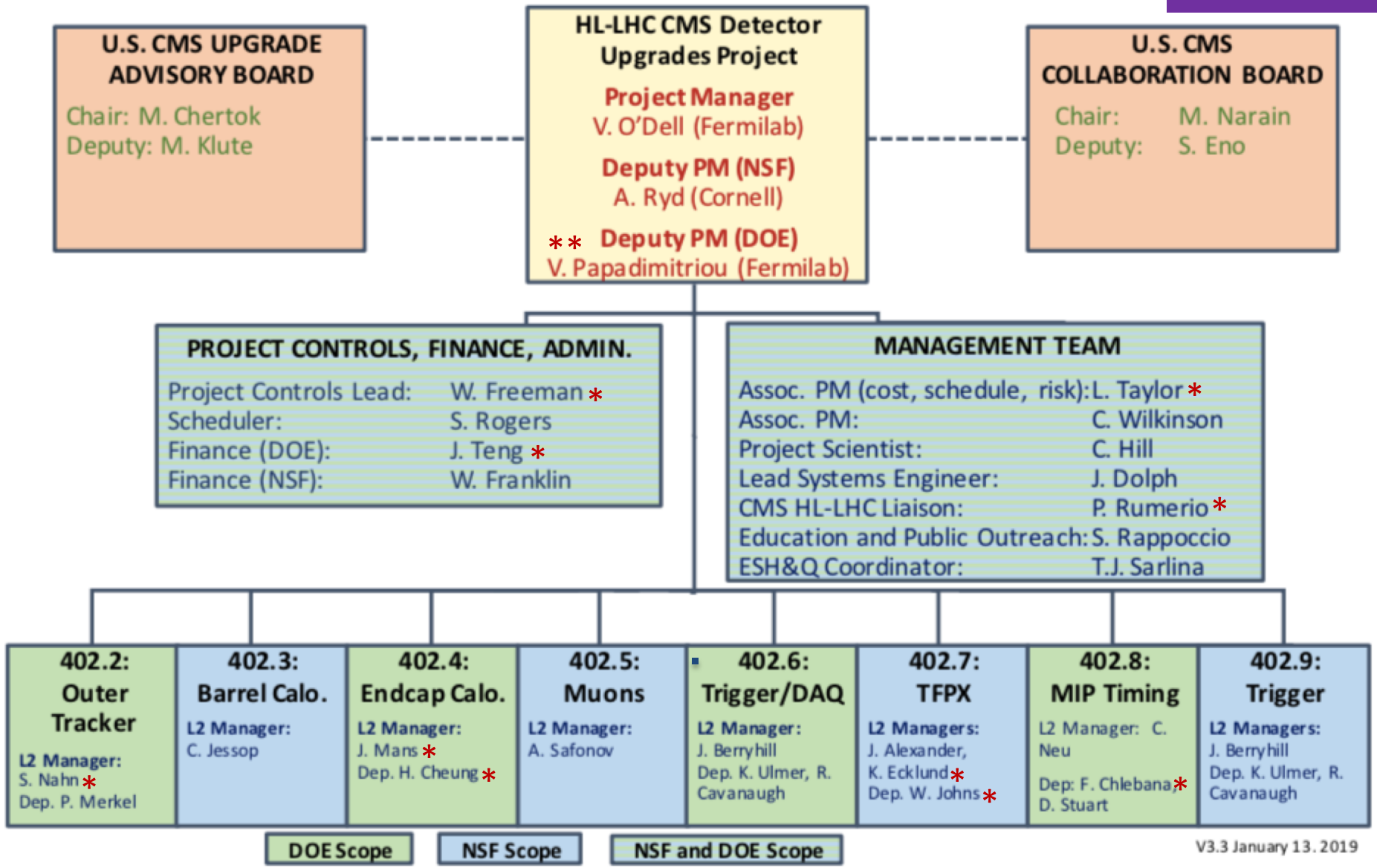
(including Estimated Costs)



- "Meat" of the MOUs is cost-sharing, in CORE CHF, at WBS L3/L4
- The U.S. Project works with CMS to define the deliverables, and checks that these tables are consistent with KPPs

U. S. CMS HL-LHC Upgrade Organization

Charge #5

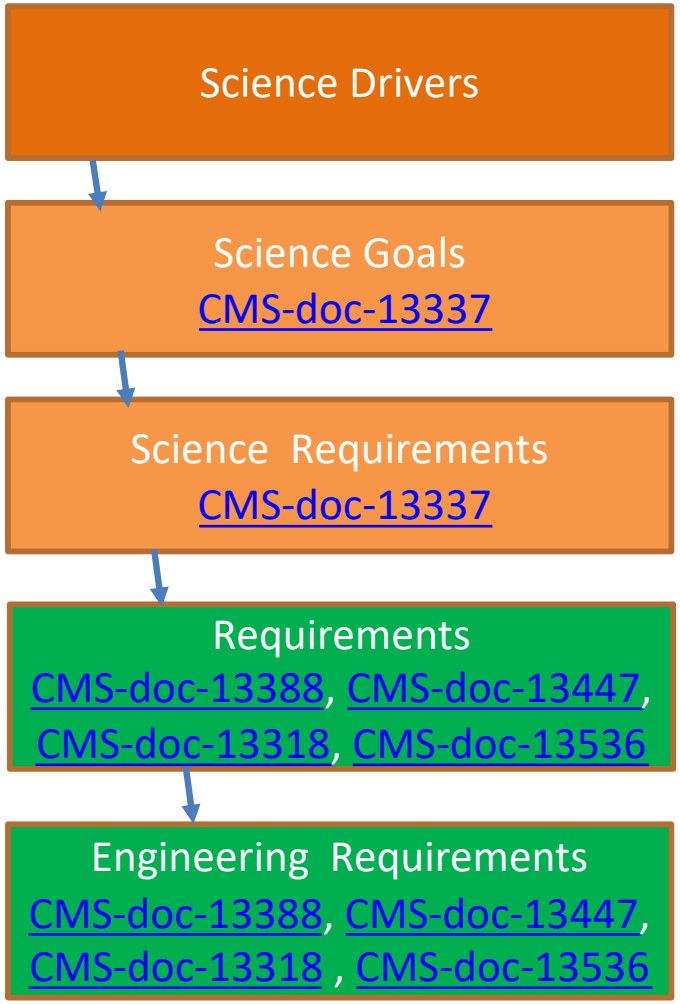


* **Phase I project management experience** ** **LBNF project management experience**

Science Flowdown

Charge #2

- Formalized science flowdown to technical requirements
- Highest to lowest levels:
  - **Science Drivers** - come from the P5 report and are broad scientific questions that multiple HEP experiments are trying to address in different ways
  - **Science Goals** - more specific scientific questions that we are addressing with CMS
  - **Science Requirements** - CMS wide (i.e. multiple sub-systems) performance requirements that CMS needs to meet in order to achieve the science goals
  - **Science-Engineering Requirements** - USCMS sub-detector specific performance requirements that a given L2 project needs to meet in order for the whole of CMS to meet the science requirements
  - **Engineering Requirements** - technical requirements that a particular US CMS subsystem L2 project needs to meet with its designs in order for the science-engineering requirements to be met



More in B/O 5: Management

Project Cost and Cost Range

Cost Summary

Charge #3

- Three components to the Total Project Cost (TPC)
  1. Budget at Completion (BAC) - the estimated cost of the activity
     - BOE estimates made in direct cost or labor hours, which are then fully loaded with site-specific rates and overheads, and escalated
  2. Estimate Uncertainty (EU) - contingency based on confidence in estimate, scales with BAC
  3. Risk - contingency based on probability of divergence from expected cost range, because of an unlikely event which has cost and schedule impacts
     - Cost and schedule impact determined from Monte Carlo simulation
- TPC = BAC + EU + Risk
  - **Bottom line: Total Project Cost (range) is $142.6M-$183.1M**
  - **Overall contingency is ~ 37% (CTG)**
  - **Point estimate is $161.5M**

Estimate Uncertainty Rules

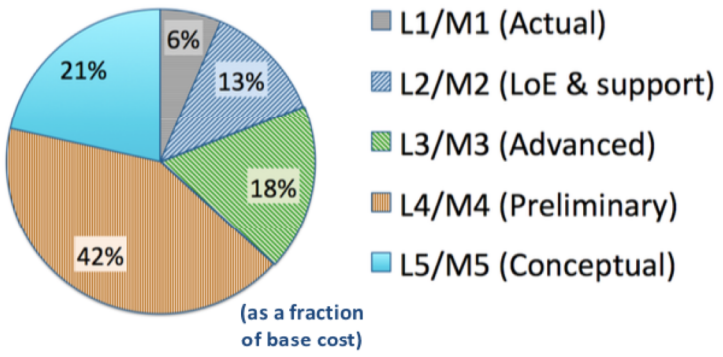
TPC = BAC + EU + Risk

Charge #3

- Cost estimates are intrinsically uncertain
  - Design not final, labor needs or vendor costs can vary
- Estimate uncertainty (as % of base cost) is assigned by CAMs to each activity, depending on maturity of estimate
  - Follow standard Fermilab OPSS guidance (past experience)

CMS-doc-12919

Estimate Type	Estimate Maturity Code	Mean estimate uncertainty Fermilab OPSS guidance (% of base cost)
Actual cost / Existing PO	L1/M1	0
Level of effort / Support / Oversight	L2/M2	0 – 20
Advanced	L3	10 – 25
	M3	10 – 20
Preliminary	L4	25 – 40
	M4	20 – 40
Conceptual	L5/M5	40 – 60
Pre-conceptual – Common work	L6/M6	60 – 80
Pre-conceptual – Uncommon work / Rough estimate	L7/M7	80 – 100
Beyond state of the art	L8/M8	>100



Cost Weighted Estimate Maturity

Cost by L2 and EU

TPC = BAC + EU + Risk

Charge #3

CMS-doc-13215

CMS-doc-13237

WBS	Labor (hours)	Labor (FTE-years)	Direct M&S $	Direct + Indirect + Escalation ($)	Estimate Uncertainty ($)	Total Cost ($)
Total	999831	565.53	58,695,490	120,339,112	30,557,909	150,897,021
Threshold KPP (DOE)	890457	503.67	54,833,503	112,319,820	28,577,389	140,897,209
402.1 PM - Project Management (DOE)	51017	28.86	6,421,731	16,380,447	1,906,017	18,286,464
402.2 OT - Outer Tracker	355984	201.36	18,966,920	39,622,678	11,091,768	50,714,446
402.4 CE - Calorimeter Endcap	264314	149.50	19,575,921	37,579,018	10,409,971	47,988,989
402.6 TD - Trigger and DAQ (DOE)	101208	57.25	3,600,274	8,099,087	2,334,150	10,433,237
402.8 TL - Timing Layer	117934	66.70	6,268,657	10,638,591	2,835,483	13,474,074
Objective KPP (DOE)	109374	61.86	3,861,987	8,019,292	1,980,519	9,999,811
402.1 PM - Project Management (DOE)	6636	3.75	127,200	1,745,283	254,052	1,999,335
402.2 OT - Outer Tracker	4862	2.75	2,016,504	2,410,079	703,622	3,113,701
402.4 CE - Calorimeter Endcap	45288	25.62	1,367,411	2,319,154	600,701	2,919,855
402.6 TD - Trigger and DAQ (DOE)	8758	4.95	58,072	818,603	230,921	1,049,525
402.8 TL - Timing Layer	43830	24.79	292,800	726,172	191,223	917,395

Threshold KPPs BAC+EU

Objective KPPs BAC+EU

BAC + EU by L2 area and KPP type. Does not include Risk Contingency

Risk Management

TPC = BAC + EU + Risk

Charge #3

- Use lab-wide standard risk management procedures (PPP-doc-65)
- HL-LHC CMS tailoring described in Risk Management Plan (CMS-doc-13749)
  - Risk register (CMS-doc-13480), risk analysis (CMS-doc-13481)
  - Risk board formed, meets at least quarterly
- Amount of technical risk was called out at June 2018 IPR as too low as a fraction of overall risk costs
  - Held series of risk workshops last fall with outside reviewers to go through all risks
  - Bottom line – technical risks went up, escalation / exchange rate risks went down as we updated bases to FY19, overall risk cost went up slightly.

More details on risks in talk by Lucas (P09)
Subdetector specific risks covered in L2 talks

Total Project Cost

Charge #3,#8

CMS-doc-13215

CMS-doc-13481

- M&S and Labor (costed and contributed)

HL-LHC CMS Upgrades Project costs including direct costs, indirect costs, escalation and cost contingency	M&S				Labor					Risk	Total (M$)
	Direct Cost (M$)	Base Cost (M$)	EU (M$)	M&S (M$)	Contrib (FTE-years)	Costed (FTE-years)	Base Cost (M$)	EU (M$)	Labor (M$)	Risk Contin-gency (M$)	
402.1 PROJECT MANAGEMENT	6.55	7.00	0.65	**7.66**	1.79	30.82	11.12	1.51	**12.63**	**5.65**	**25.93**
402.2 OUTER TRACKER	20.98	24.55	7.10	**31.65**	99.21	104.90	17.48	4.69	**22.18**	**1.06**	**54.89**
402.4 ENDCAP CALORIMETER	20.94	23.77	6.58	**30.35**	79.62	95.50	16.13	4.43	**20.56**	**1.93**	**52.83**
402.6 TRIGGER AND DAQ	3.66	4.36	1.34	**5.70**	31.69	30.51	4.56	1.22	**5.78**	**0.74**	**12.22**
402.8 TIMING LAYER	6.56	7.61	1.52	**9.12**	63.02	28.47	3.76	1.51	**5.27**	**1.27**	**15.66**
Total Cost	**58.70**	**67.28**	**17.20**	**84.48**	**275.33**	**290.20**	**53.05**	**13.36**	**66.42**	**10.64**	**161.54**
Funding Guidance											**161.55**

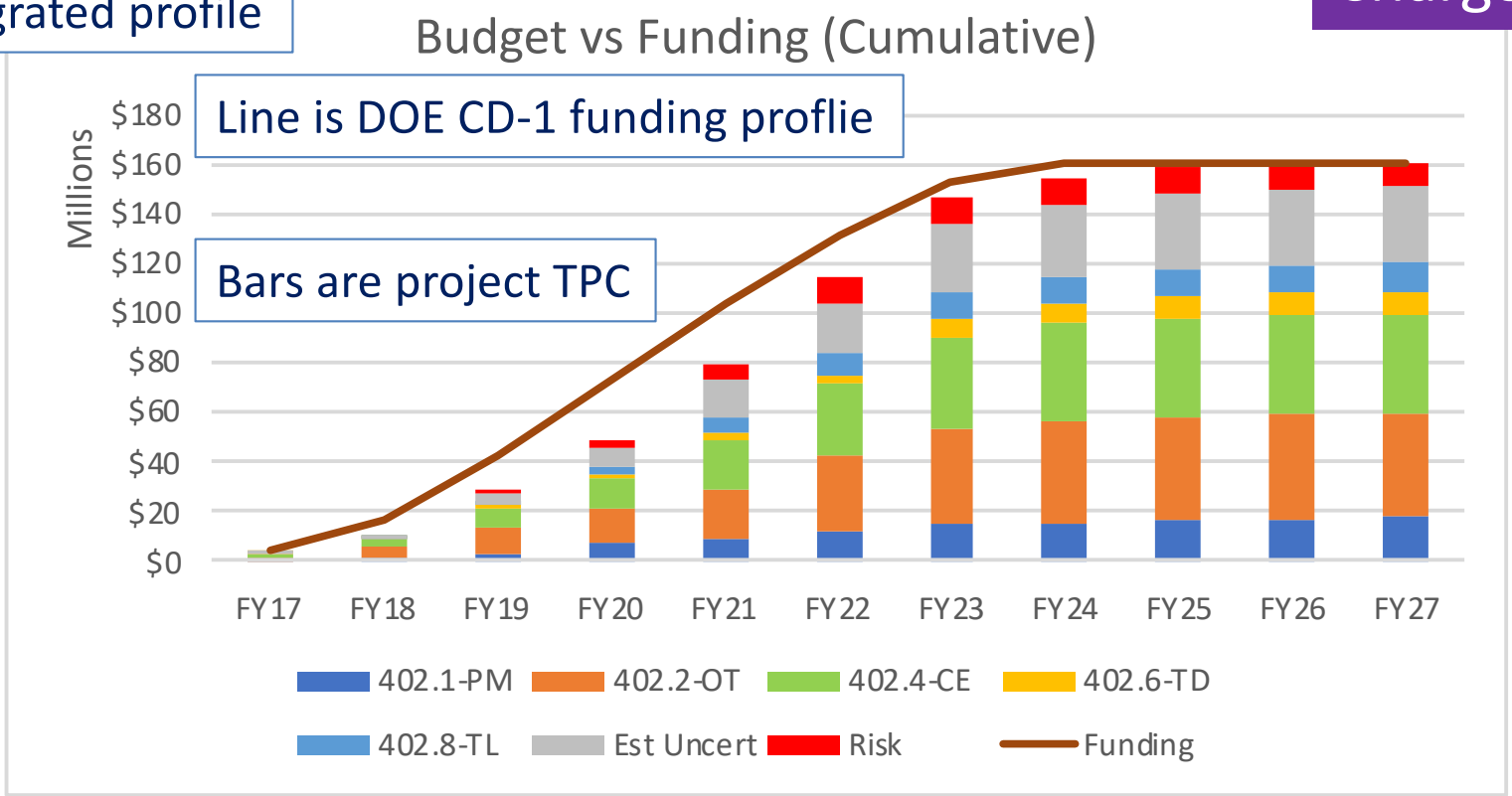
2019-03-04---cost-rollup---CD1-v2-DR.xlsx
Last updated: Lucas Taylor 2019-03-09

Contingency on Cost to Go: 37.2%

Funding vs. TPC (TPC=BAC+EU+Risk)

Charge #3,#8

Integrated profile



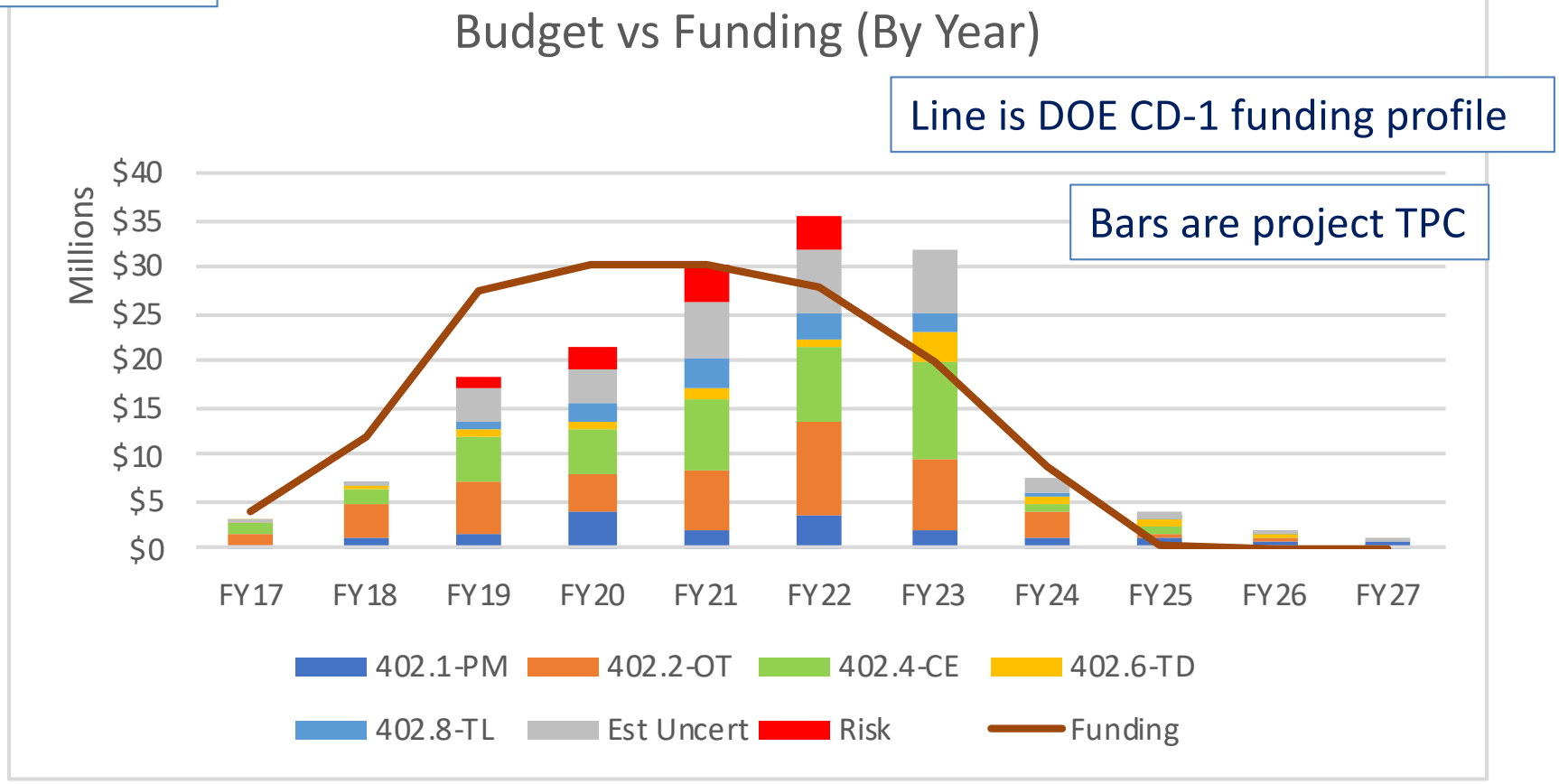
	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27
Funding Cumulative	$ 4,000	$ 16,000	$ 43,500	$ 73,950	$ 104,400	$ 132,400	$ 152,400	$ 161,050	$ 161,550	$ 161,550	$ 161,550
TPC Cumulative	$ 2,861	$ 10,124	$ 28,309	$ 49,602	$ 79,973	$ 115,365	$ 147,342	$ 154,715	$ 158,828	$ 160,715	$ 161,497

- Project profile fits current DOE guidance. DOE warns that guidance will change before June CD-1. The project is studying various scenarios with IPT in order to adjust as needed.

Funding vs. TPC (TPC=BAC+EU+Risk)

FY profile

Charge #3,#8



	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27
Funding Profile	$ 4,000	$ 12,000	$ 27,500	$ 30,450	$ 30,450	$ 28,000	$ 20,000	$ 8,650	$ 500	$ -	$ -
TPC Profile	$ 2,861	$ 7,263	$ 18,185	$ 21,292	$ 30,372	$ 35,391	$ 31,977	$ 7,374	$ 4,112	$ 1,887	$ 782

Total Project Cost: CD-1 Range

Charge #3

- Use AACEI / DOE estimate classes
  - Mapped to Fermilab maturity categories

    CMS-doc-13723

- Cost range based on maturity is $142.6M-183.1M

	Primary Characteristic	Secondary Characteristic		
ESTIMATE CLASS	**DEGREE OF PROJECT DEFINITION** Expressed as % of complete definition	**END USAGE** Typical purpose of estimate	**METHODOLOGY** Typical estimating method	**EXPECTED ACCURACY RANGE** Typical variation in low and high ranges [a]
Class 5	0% to 2%	Concept screening	Capacity factored, parametric models, judgment, or analogy	L: -20% to -50% H: +30% to +100%
Class 4	1% to 15%	Study or feasibility	Equipment factored or parametric models	L: -15% to -30% H: +20% to +50%
Class 3	10% to 40%	Budget authorization or control	Semi-detailed unit costs with assembly level line items	L: -10% to -20% H: +10% to +30%
Class 2	30% to 70%	Control or bid/tender	Detailed unit cost with forced detailed take-off	L: -5% to -15% H: +5% to +20%
Class 1	70% to 100%	Check estimate or bid/tender	Detailed unit cost with detailed take-off	L: -3% to -10% H: +3% to +15%

Notes: [a] The state of process technology and availability of applicable reference cost data affect the range markedly. The +/- value represents typical percentage variation of actual costs from the cost estimate after application of contingency (typically at a 50% level of confidence) for given scope.

Component of cost estimate	AACEI / DOE Estimate Class*	Fermilab Estimate Class	Point estimate (M$)	Low range of cost estimate: Methodology*	Low range of cost estimate: (M$)	Upper range of cost estimate: Methodology*	Upper range of cost estimate: (M$)
Base cost + Estimate Uncertainty	Class 1	L1/M1 (Actual) L2/M2 (LoE)	**28.79**	**-6.5%** (AACEI: -3% to -10%)	**26.9**	**9%** (AACEI: +3% to +15%)	**31.4**
	Class 2	L3/M3 (Advanced) L4/M4 (Preliminary)	**89.67**	**-10%** (AACEI: -5% to -15%)	**80.7**	**12.5%** (AACEI: +5% to +20%)	**100.9**
	Class 3	L5/M5 (Conceptual)	**32.44**	**-15%** (AACEI: -10% to -20%)	**27.6**	**20%** (AACEI: +10% to +30%)	**38.9**
Risk-based contingency	90% C.L. from PRA risk MC		**10.64**	70% C.L. from PRA risk MC	**7.4**	95% C.L. from PRA risk MC	**12.0**
CD-1 point estimate of TPC			**161.54**	**CD-1 lower cost range**	**142.6**	**CD-1 upper cost range**	**183.1**

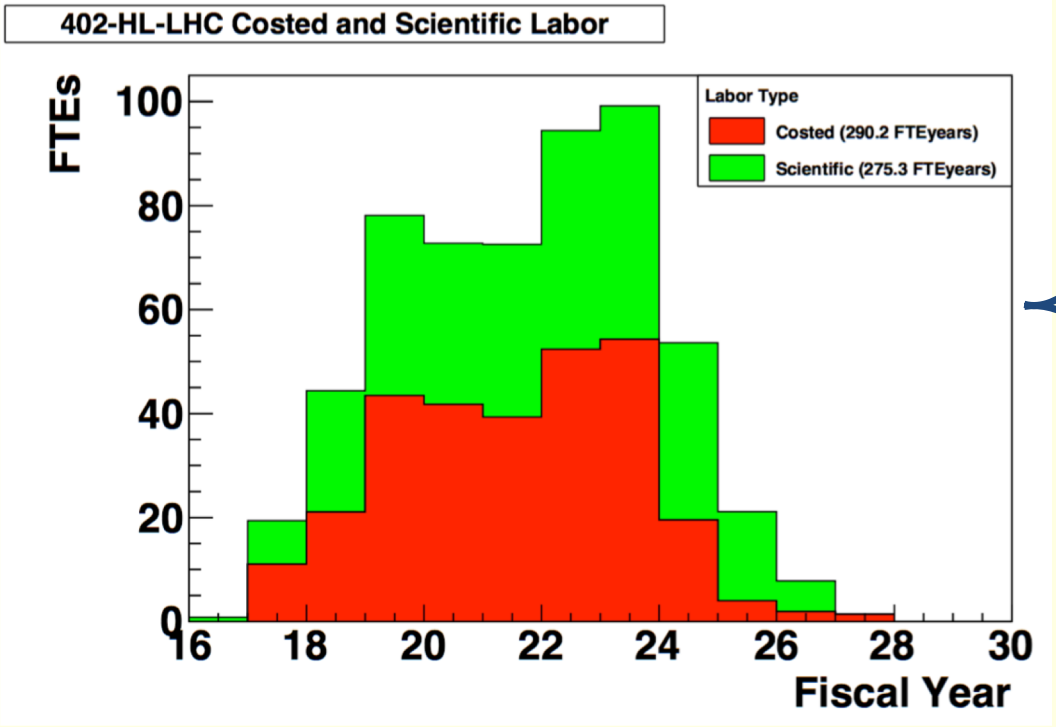
* AACEI: Association for the Advancement of Cost Engineering International. See: DOE G 413.3-21, Cost Estimating Guide, Section 4 and Appendix H.

Labor Profile (Costed and Contributed)

Charge #3

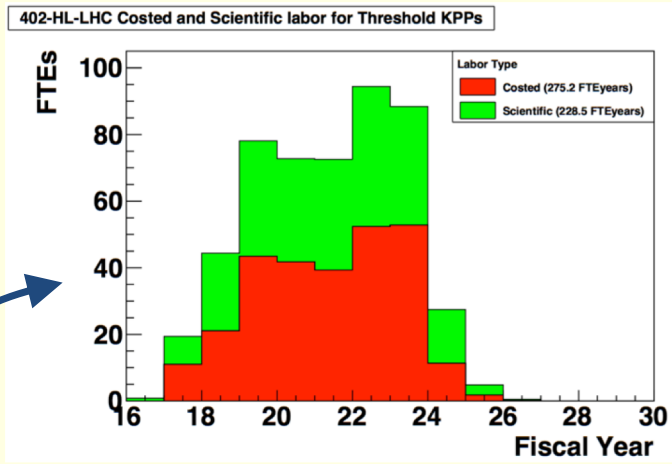
Total DOE labor: 566 FTE-years

- **Costed labor: 290 FTE-years**
- **Contributed: 275 FTE-years**



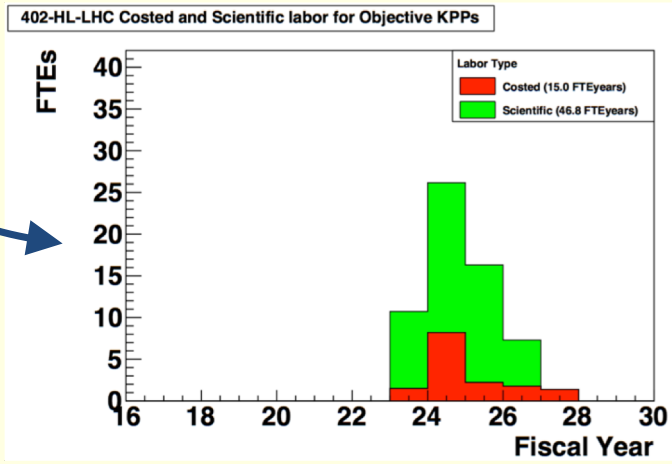
Threshold KPPs

(construction)



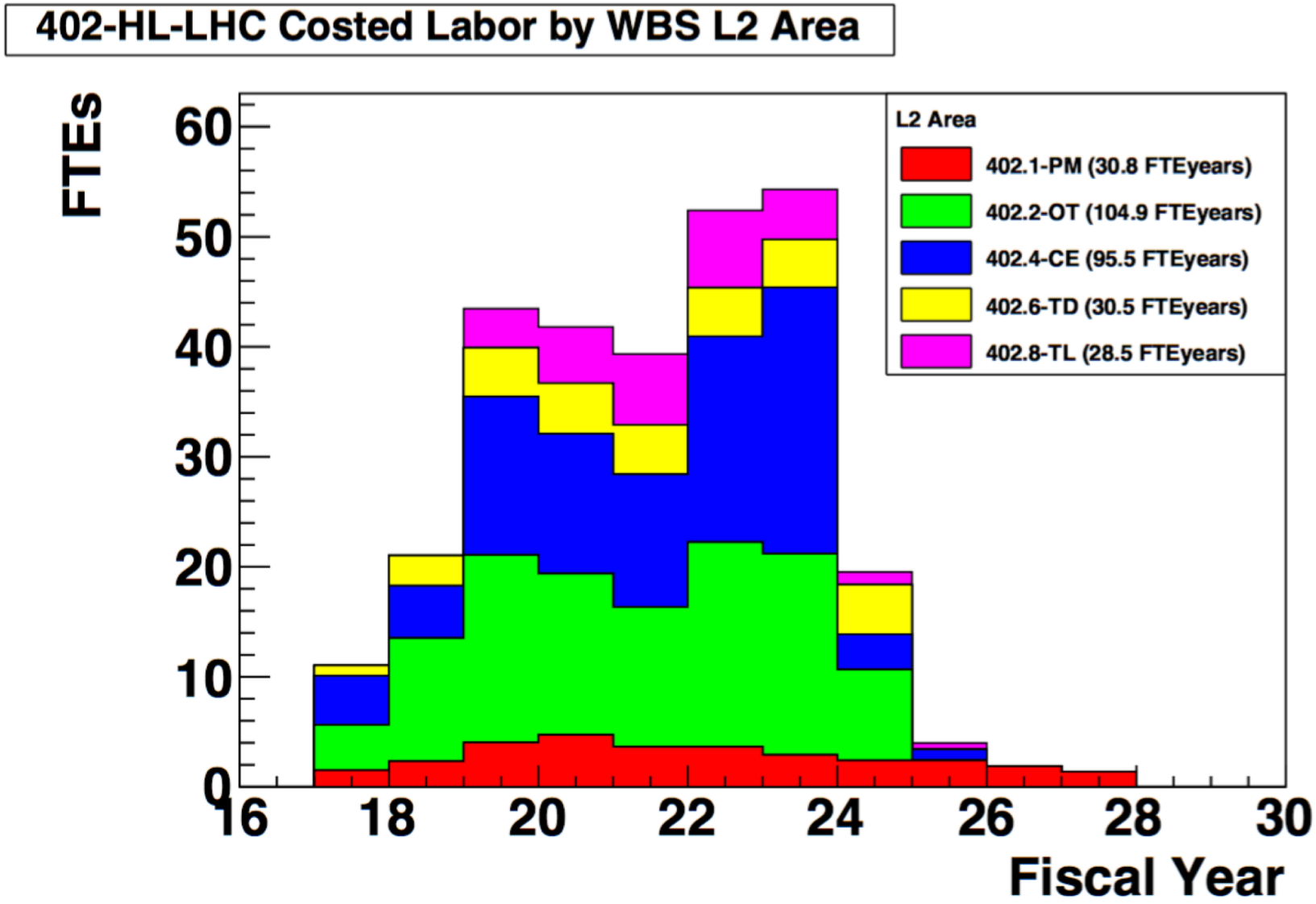
Objective KPPs

(integration and commissioning)



Labor Profile by L2 area (Costed)

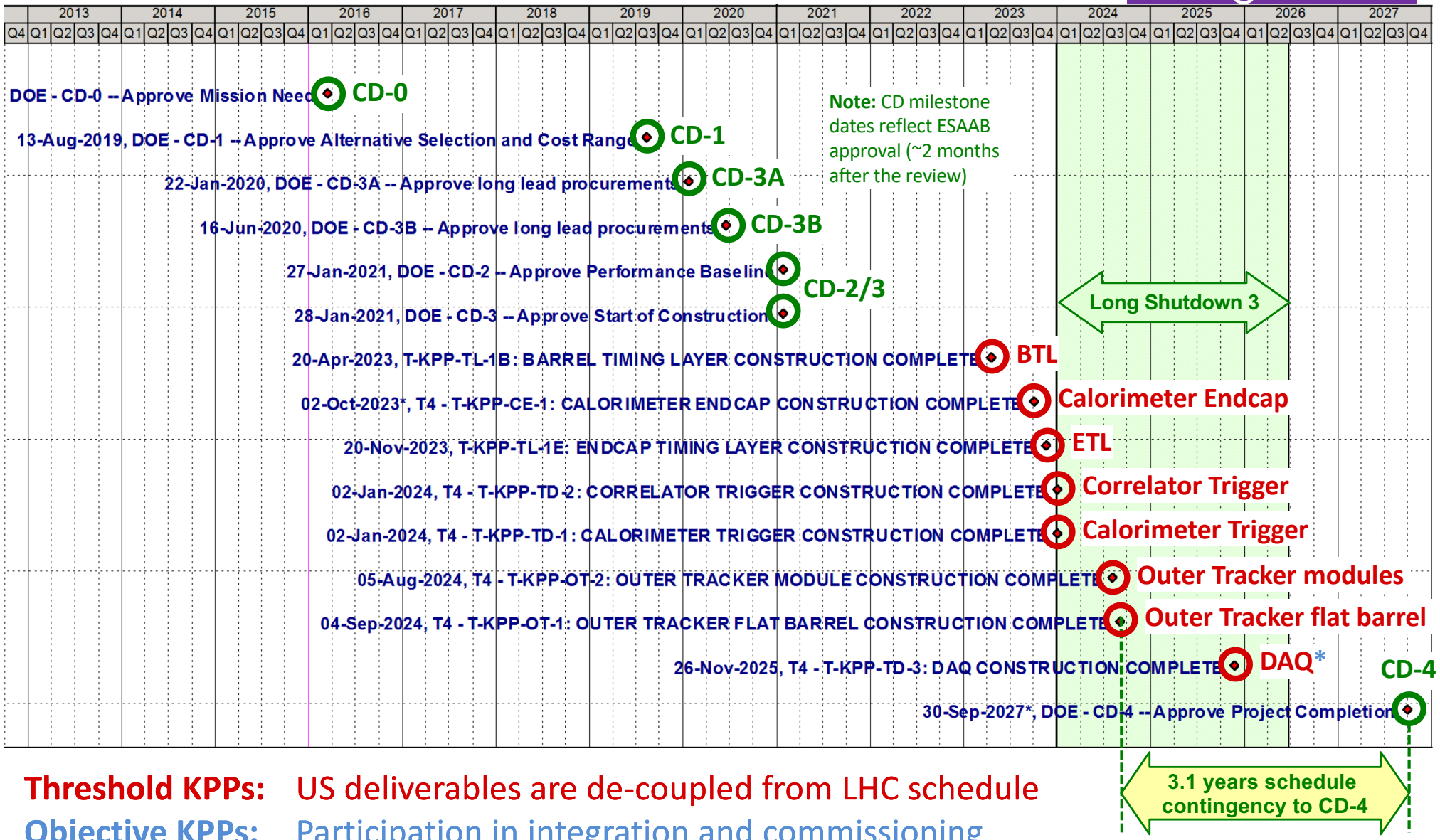
Charge #3



Project Schedule

CD and Threshold KPPs Milestones

Charge #3



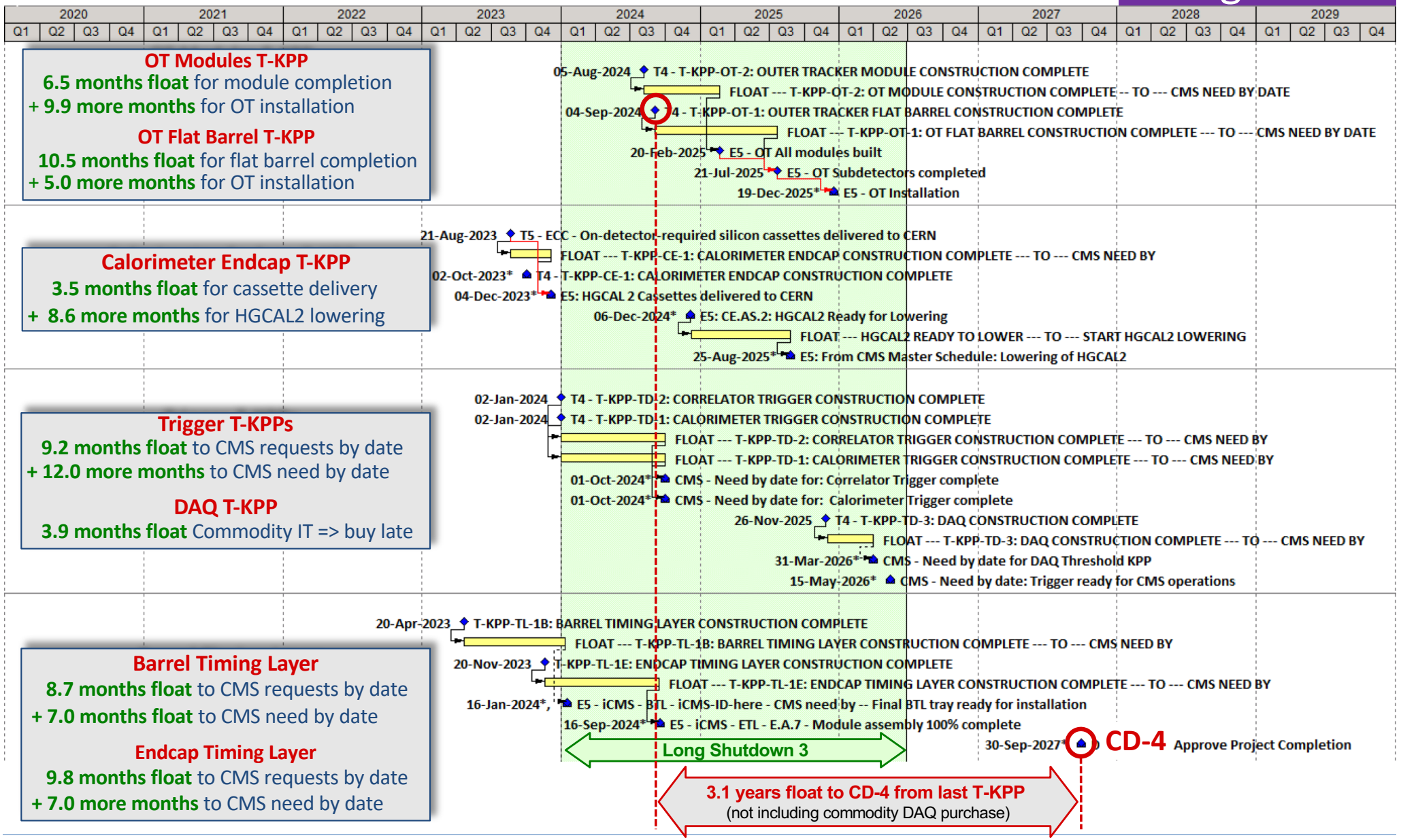
Threshold KPPs: US deliverables are de-coupled from LHC schedule

Objective KPPs: Participation in integration and commissioning

* DAQ is a low risk commodity IT purchase

Schedule Contingency (Yellow bars are float)

Charge #3



CD schedule for HL-LHC CMS

- We plan for the following CD review dates:
  - CD-1 June, 2019
  - CD-3a November, 2019 ($17.2M)
    - Early procurements for Outer Tracker, Endcap Calorimeter silicon sensor
      - Custom procurement sole sourced to CERN. Directorate, procurement, and legal engaged.
      - Ready for execution with ESAAB approval of CD-3a
  - CD-3b April, 2020 ($2.6M)
    - Early procurements for MIP Timing Detector: Barrel Crystals, Silicon Photomultipliers
      - Standard procurement

See Procurements Management B/O B03

  - CD-2/3 November 2020
    - Needed for start of construction in FY21

CD schedule for HL-LHC CMS

Project schedule driven CD-3 dates

CD-3a needed for Calorimeter and Tracker Silicon order

CD-3b needed for Timing Layer LYSO/SiPMs orders

- CD-3a November, 2019 ($17.2M)
  - Early procurements for Outer Tracker, Endcap Calorimeter silicon sensor
    - Custom procurement sole sourced to CERN. Directorate, procurement, and legal engaged.
    - Ready for execution at the time of ESAAB approval of CD-3a
- CD-3b April, 2020 ($2.4M)
  - Early procurements for MIP Timing Detector: Barrel Crystals, Silicon Photomultipliers
    - Standard procurement

Investigating combining these steps to minimize reviews.

ESH&Q

Charge #6

- Since the June, 2018 IPR, Project has:
- Strengthened ESH&Q team
  - Added ESH&Q professional, engaged associate PM, lab management
- Updated all documents and invoked approval chain through doc-db
  - Integrated Safety Management Plan (CMS-doc-13395)
  - Preliminary Hazard Awareness Report (pHAR) (CMS-doc-13394)
  - Quality Assurance Plan (CMS-doc-13093)
  - Security Vulnerability Assessment (CMS-doc-13755)
  - NEPA exclusion (CMS-doc-13483)
- Held dedicated ESH&Q review

Project Management B02, B04,B05, B06

Previous Reviews

Previous IPR Review

Charge #5,8

- An Independent Project Review was held in June, 2018
  - Final report here: CMS-doc-13603
- The Outer Tracker, Endcap Calorimeter, and Trigger/DAQ were recommended to proceed to CD-1
- The MIP Timing Detector was not at a CD-1 level of maturity
  - No reviewed Conceptual Design and RLS at a planning package level
  - These two deficits have since been addressed.
- Additional important recommendations to the project office were made, mainly in cost vs. funding profile, documentation, ESH&Q
- In response to the IPR, project management was strengthened:
  - Added a deputy PM with recent project management experience
  - Added a professional ESH&Q coordinator
  - Fully staffed MTD management

Previous Reviews

Charge #8

- IPR, June 2018
- 24 recommendations
  - 15 for CD-1; 6 for CD-2 (not including 3 “proceed to CD-1”)
  - For CD-1 (1: CE, 2 TD, 4 MTD, 8 PM)
- ESH&Q review
  - 5 recommendations (all for CD-1)

Covered in detail in Management B/O

- MTD conceptual design review
  - 8 recommendations (all for CD-1)

Covered in P04

- Review pages/reports are linked in our project main page

June 2018 IPR Recommendations for PO

Charge #8

- Summary of main recommendations
  - ✓Project TPC must fit within the DOE funding guidance
    - **Done.**
  - ✓MIP Timing Detector needs a reviewed Conceptual Design, and all cost and schedule elements developed to CD-1 quality.
    - **Done.**
  - ✓Revise the Integrated Safety Management Plan and Quality Assurance Plan to accurately document Project process for safety and quality. Document process for identifying relevant codes and standards.
    - **Done.**
  - ✓Implement document revision control and review
    - **Done.**

All recommendations for PO in backup

Closing Words

- The DOE scope is well defined
- The selected alternative optimizes the upgrade for cost and schedule
- Conceptual design passed review; 'sound and executable
- All June 2018 IPR recommendations addressed
- Cost, schedule, and risks are understood
- ESH&Q programs brought to appropriate maturity
- The project team has been strengthened; it is motivated, qualified, and ready to deliver
- All required documentation for CD-1 is in place

Summary

- The CMS collaboration is embarking on a major upgrade campaign to deliver a detector that can efficiently collect data from 2026-2037
- The U. S. is contributing to the upgrades commensurate with its size in the collaboration and is managed by a joint DOE/NSF project office
- We are ready to proceed to CD-1 and look forward to your feedback

Backup slides

Total Project Cost

Charge #3,#8

CMS-doc-13215

CMS-doc-13481

- M&S and Labor (costed and contributed)
  - Showing the cost evolution since CD-1 v1 (June 2018)
    - Note the reduced funding guidance

HL-LHC CMS Upgrades

Project costs including direct costs, indirect costs, escalation and cost contingency

	M&S				Labor					Risk	Total (M$)	Total CD1 IPR June 2018 = Base + EU + Risk (M$)
	Direct Cost (M$)	Base Cost (M$)	EU (M$)	M&S (M$)	Contrib (FTE-years)	Costed (FTE-years)	Base Cost (M$)	EU (M$)	Labor (M$)	Risk Contin-gency (M$)		
402.1 PROJECT MANAGEMENT	6.55	7.00	0.65	**7.66**	1.79	30.82	11.12	1.51	**12.63**	**5.65**	**25.93**	27.83
402.2 OUTER TRACKER	20.98	24.55	7.10	**31.65**	99.21	104.90	17.48	4.69	**22.18**	**1.06**	**54.89**	56.25
402.4 ENDCAP CALORIMETER	20.94	23.77	6.58	**30.35**	79.62	95.50	16.13	4.43	**20.56**	**1.93**	**52.83**	53.78
402.6 TRIGGER AND DAQ	3.66	4.36	1.34	**5.70**	31.69	30.51	4.56	1.22	**5.78**	**0.74**	**12.22**	12.44
402.8 TIMING LAYER	6.56	7.61	1.52	**9.12**	63.02	28.47	3.76	1.51	**5.27**	**1.27**	**15.66**	14.69
Total Cost	**58.70**	**67.28**	**17.20**	**84.48**	**275.33**	**290.20**	**53.05**	**13.36**	**66.42**	**10.64**	**161.54**	164.98
Funding Guidance											**161.55**	**165.00**

2019-03-04---cost-rollup---CD1-v2-DR.xlsx
Last updated: Lucas Taylor 2019-03-09

Note: Base Cost = Direct + Indirect + Escalation

Contingency on Cost to Go: 37.2%

IPR Recommendations (1)

Charge #8

- Cost and Schedule: 3 recommendations

#17: Prior to seeking CD-1, work with DOE to define project funding profile guidance that supports the entire project scope, cost and schedule estimate, including Objective KPPs. Update the Acquisition Strategy, Preliminary Project Execution Plan, and other relevant CD-1 documents to reflect this agreement.

- We have done this

See Plenary P02,P09,Management B07

#18: Prior to seeking CD-1, synchronize all documents to have consistency between project data points such as schedule dates, budget amounts, and WBS numbering.

- We have reviewed all documentation, removed overlaps wherever possible. We have instigated formal sign-offs using doc-db electronic signatures

See Management B07

#19: Prior to seeking CD-1, the schedule, WBS Dictionary, risk register, cost estimates, and other relevant CD-1 documents for 402.8 Timing Detector need to be developed to achieve CD-1 quality.

- We have have done this.

See Plenary P03, P05

IPR Recommendations (II)

Charge #8

- Management

#20: Project management should work closely with US CMS on a strategy to successfully complete MTD scope with minimal impact to the project. Successful completion of an external review of the MTD conceptual design is required prior to CD-1 approval.

- We have done this. In terms of cost, the MTD scope is within the cost envelope we had set aside for it at at previous CD-1. In terms of human resources, we have minimal overlaps with the other subdetectors. We have had an external review of the MTD conceptual design.

See Plenary P03, P04

#21: Project management should proactively engage in identifying qualified candidates to fill key project positions, in advance of impending changes

- We have added deputies in all L2 areas, and we have developed short lists for qualified individuals to step into project positions

#22: Revise the ISM and Quality Assurance Plans to accurately document the process for receipt, review, concurrence, coordination and oversight of project specific deliverables.

- We have added an ESH&Q professional to the project team, updated both the ISM and the QAP and held a dedicated review of our ESH&Q plans (CMS-doc-13709)

See Management B/O B02, B05

IPR Recommendations (III)

Charge #8

- Management

#23: Develop a clear plan for identification and documentation of codes, standards, requirements and timing for inclusion

See Management B/O B02

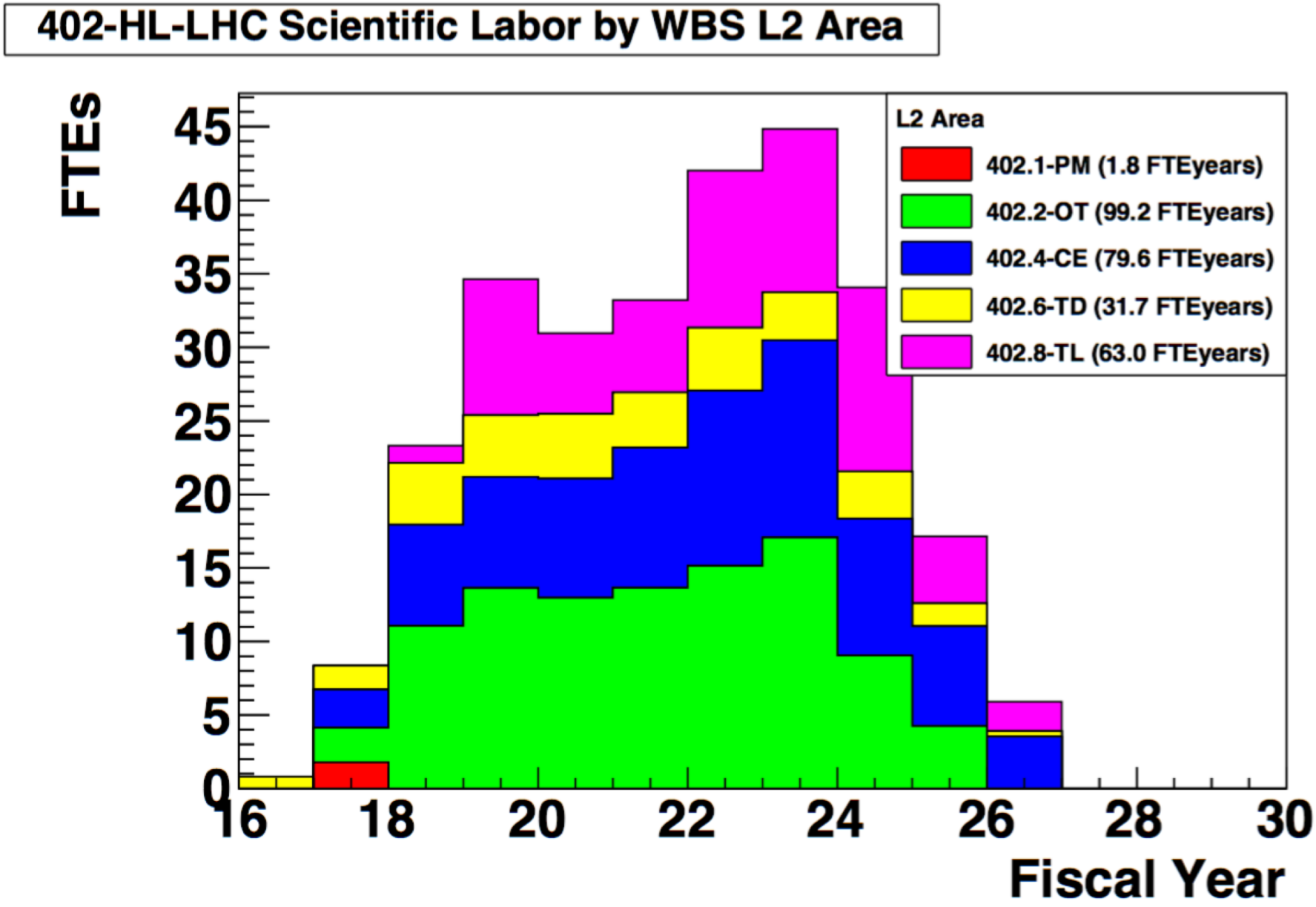
- We have identified required codes and standards and documented them here (CMS-doc-13717)

#24: Review and revise required documentation to comply with the CD-1 minimum requirements ensuring that document control practices and revision control are properly applied throughout with approval or approval process defined and consistency in the project cost and schedule data.

See Management B/O B07

- We have reviewed all documentation, removed overlaps wherever possible. We have instigated formal sign-offs using doc-db electronic signatures. Cost and schedule data is broken out in a separate document (in addition to the pPEP) here: CMS-doc-13723

Labor Profile by L2 area (Contributed)



Some representative measurements at HL-LHC

- HL-LHC will enable unprecedented precision in measurements of standard model (SM) properties, and expand the discovery reach

P5 Science Driver 1

- 2-5% on Higgs Couplings (except for Zγ)
- First evidence of di-Higgs production (Higgs self-couplings) needs full HL-LHC stats (3ab^{-1})

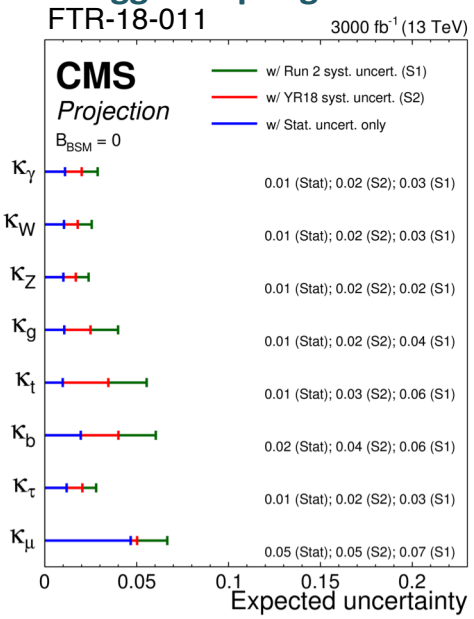
P5 Science Driver 3

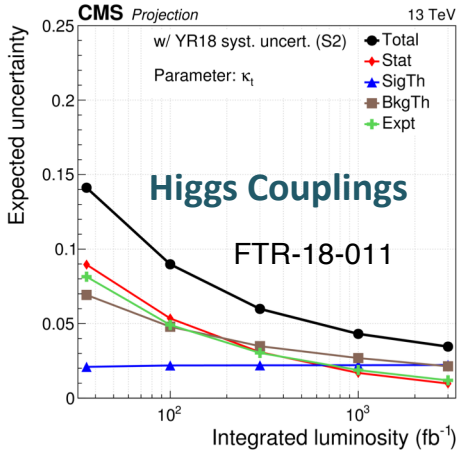
- Access to small cross section SUSY processes
  - e.g. Stau discovery with 5σ (not possible with 300 fb^{-1})

P5 Science Driver 5

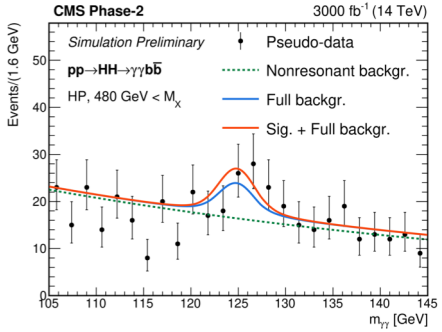
- Study of rare SM processes and discovery of new heavy particles with small cross sections
  - (Dark Matter, Vector-like-quark, Long-Lived particles…)
- MTD extends the reach for new particle searches

Higgs Couplings

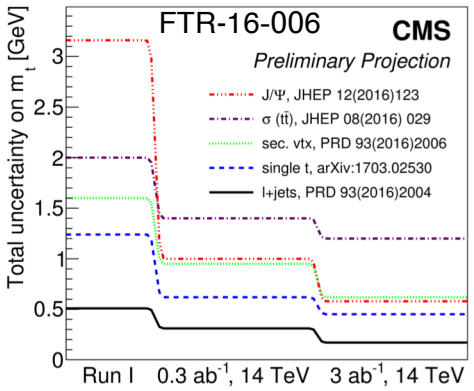




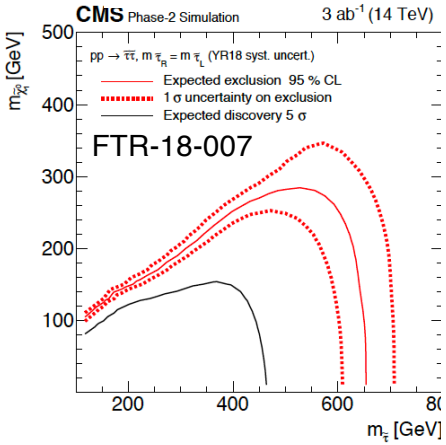
Di-Higgs production



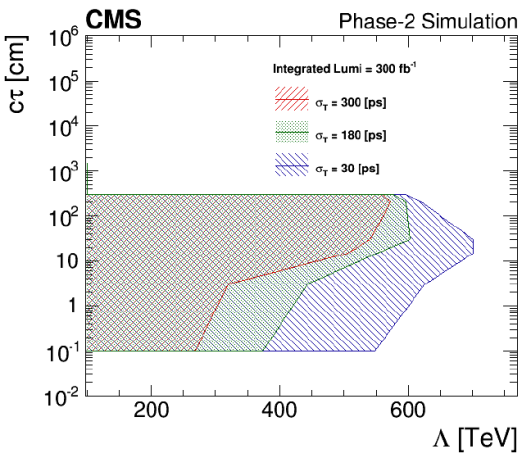
Top Quark mass uncertainty



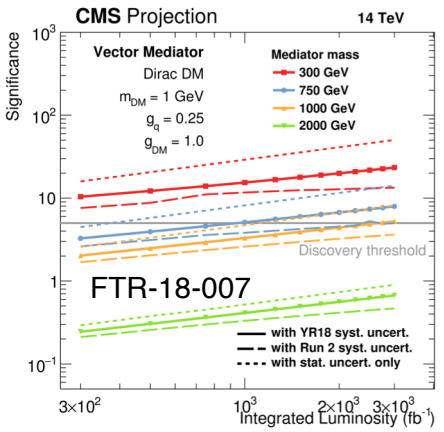
$\tilde{\tau}$ pair production



GMSB $\tilde{\chi}_1^0 \to \tilde{G} + \gamma$

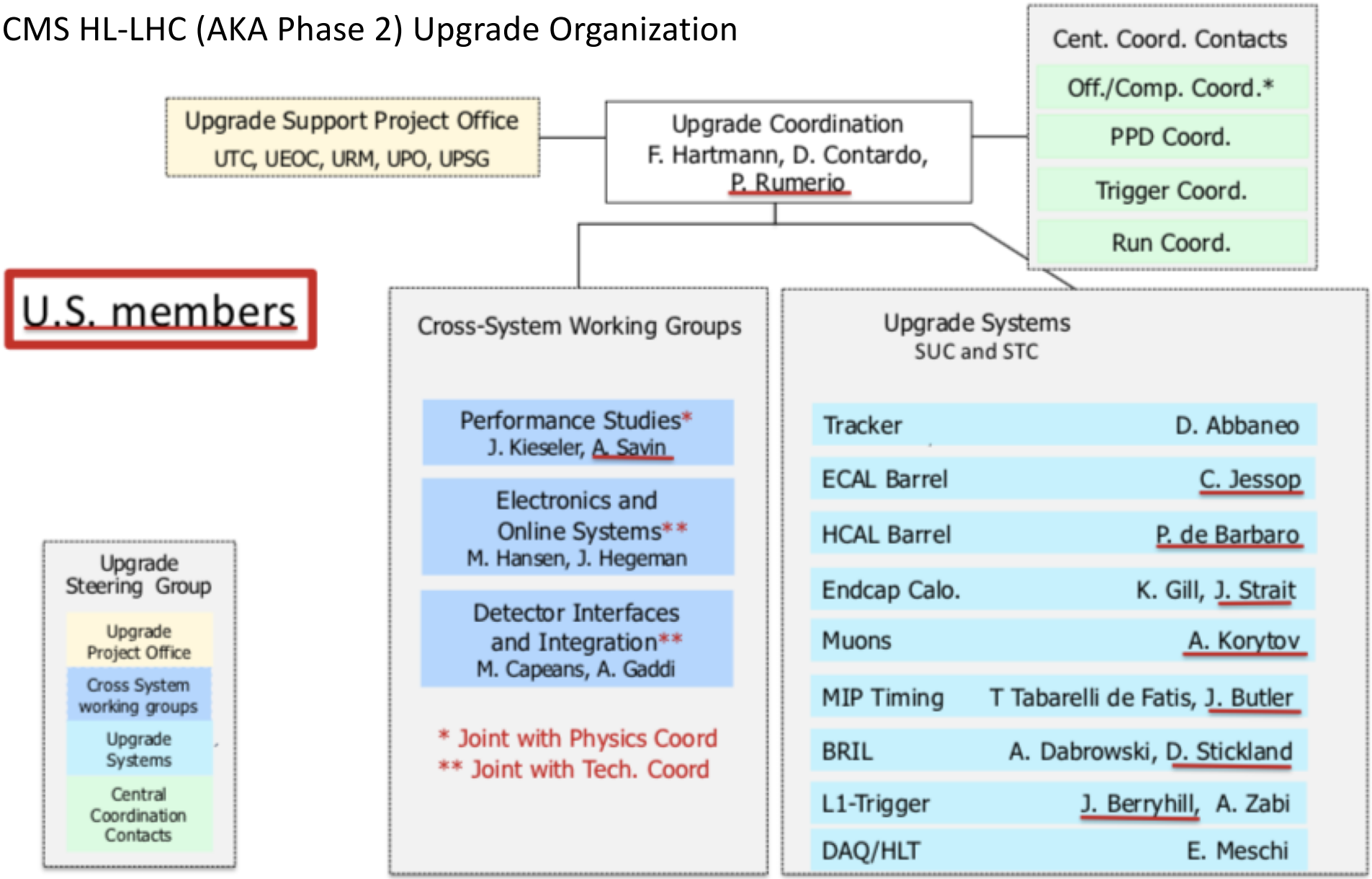


Dark Matter (mono-Z)



CMS HL-LHC Upgrade Organization

CMS HL-LHC (AKA Phase 2) Upgrade Organization



Strong U.S. CMS Roles in CMS

- The U.S. is embedded in all facets of leadership in international CMS
  - Deputy Spokesperson, Physics Coordinator, Offline Coordinator, HL-LHC Upgrade Deputy Coordinator, Spokesperson Advisory Group, Collaboration Board Deputy, Trigger Coordinator, Publications Committee Chair
- This leadership reflects U.S. technical and managerial skills
  - U.S. engaged in all decision making, oversight, and technical interfaces
- Scientists leading the U.S. CMS HL-LHC upgrades are also leaders in the international CMS organization
  - Ensures smooth communication between the U.S. project and the overall project

CMS Project Reviews (per subproject)

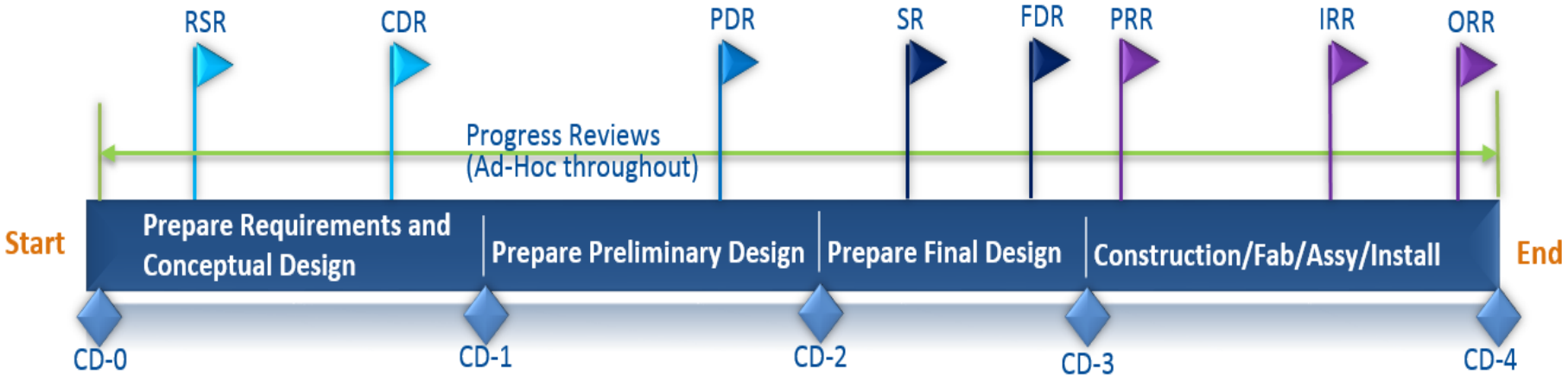
- Standard yearly reviews
  - All subsystems have a CMS internal Annual Review yearly
  - Phase 2 Upgrade Group twice a year
    - Reports to LHCC / DRC / RRB
- Before construction
  - Electronics Systems Review (ESR) – Review the soundness and documentation of the electronics design, including interfaces of electronics to other systems including AC power and safety grounding prior to the start of construction
  - Engineering Design Review (EDR) - review and document final design prior to the start of construction
  - Engineering Change Review (ECR) – review and document any design changes needed after the EDR
- Before committing funds
  - Procurement Readiness Review (PRR) – determine/approve readiness prior to committing funds to major purchases (a PRR may precede the EDR in certain circumstances – i.e. for the Silicon procurements for OT / CE)

CMS Project Reviews (per subproject)

- During construction
  - Manufacturing Progress Review (MPR) – evaluate/monitor fabrication and delivery from a vendor or institution during construction
- After construction
  - Installation Readiness Review (IRR) – determine readiness prior to approving installation of the new detector or system
  - Operations Readiness Review (ORR) – determine readiness prior to transferring the new detector to operations
- The U.S. scope is reviewed in all of these CMS reviews
- Additionally, the U.S. project calls reviews as needed
  - Examples:
    - Technical Reviews supporting Conceptual / Preliminary / Final designs
    - Reviews of areas of particular concern, e.g. ASICs
    - Facility reviews (site visits, ESH&Q reviews)
- And of course the U.S. project is reviewed yearly in Director's Reviews, DOE IPRs

OPSS Recommended Reviews

- OPSS recommends the following reviews: (see OPSS documentation here)
  - Requirements and Specifications Review (RSR)
  - Conceptual Design Review (CDR)
  - Preliminary Design Review (PDR)
  - Safety Review (SR)
  - Final Design Review (FDR)
  - Production Readiness Review (PRR)
  - Installation Readiness Review (IRR)
  - Operations Readiness Review (ORR)
  - Progress Reviews



NOTE: Timeline will likely require tailoring for each project

Reviews

OPSS Recommended Reviews	CMS / U.S. CMS Reviews
Requirements and Specifications Review	CMS Technical Proposal/LHCC review
Conceptual Design Review (CDR)	U.S. CMS Project Reviews (Tech. reviews)
Preliminary Design Review (PDR)	U.S. CMS Project Reviews
Safety Review (SR)	U.S. CMS and CMS ESH(Q) Reviews
Final Design Review (FDR)	CMS EDRs / ESRs
Production Readiness Review (PRR)	U.S. CMS PRRs/CMS PRRs
Installation Readiness Review (IRR)	CMS IRR
Operations Readiness Review (ORR)	CMS ORR
Progress Reviews	U.S. CMS Status Reviews / CMS Annual Reviews/ Phase 2 Upgrade Group Reviews (external)

Project Overview

- In order to achieve the physics of the HL-LHC, CMS must upgrade the detector
  - Higher granularity, more radiation hard, better and more complex trigger/DAQ, reduce impact of “pile-up” – the other 200 collisions in the same bunch crossing as the interesting event
- Upgrade is done in an international collaboration with >50 funding agencies from 46 countries
- U.S. makes up 27% of the physicists on CMS