High Luminosity LHC
CMS Detector Upgrade
Project

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Outline

• The Energy Frontier at the LHC
  – HEP Mission
  – LHC Roadmap
  – Mission Need & Capability Gap
• The CMS Detector Upgrade & DOE Role
  – Alternatives for participation
• Project Scope & Approval process
  – International Partnership
• Funding
  – Preliminary Schedule & Cost Estimate
• This review
HEP Mission

Understand how the universe works at its most fundamental level:
• Discover the most elementary constituents of matter and energy
• Probe the interactions between them
• Explore the basic nature of space and time

We carry out this mission through experiments on the Energy, Intensity and Cosmic Frontier by:
• building projects that enable discovery science
• operating facilities that provide the capability to perform discovery science
• supporting a balanced research program that produces discovery science
Priority Within HEP

The The Particle Physics Project Prioritization Panel (P5) report (2014) identifies the following 5 major science drivers in particle physics:

• ✔ **1. Use the Higgs boson as a new tool for discovery**  
  – Exclusive realm of LHC

• **2. Pursue the physics associated with neutrino mass**  
  – Addressed by the U.S. LBNF program, LSST, IceCube (both NSF MREFC projects)

• ✔ **3. Identify the new physics of dark matter**  
  – Many complementary experiments including the LHC

• **4. Understand cosmic acceleration: dark energy and inflation**  
  – Addressed by e.g. LSST

• ✔ **5. Explore the unknown: new particles, interactions and physics principles**  
  – LHC is at the “Energy Frontier” and is in the best position to explore the unknown!  
    • Complementary to e.g. LIGO (an NSF MREFC project)
LHC: the plan toward High Luminosity

Long Shutdown 3 (LS3) – a 2.5-year shutdown and installation period *beginning in Jan 2024* – is the overall milestone that drives the upgrade construction completion schedule. Overall LS3 schedule will be revisited in November with results from Hi-Lumi C&S Review and Experiments “baseline” review and LHCC Upgrade Scrutiny Group.
Mission Need & Capability Gap

• Support of the ATLAS & CMS detector upgrades at the HL-LHC would enable the U.S. community to remain at the forefront of science and the continued pursuit of the prime mission of HEP at the world’s premier collider accelerator.
  
  – If the U.S. fails to contribute to the HL-LHC upgrades, their ability to participate in future physics would be impaired.

• After the planned shutdown in 2024-2025, to increase the LHC luminosity, each detector is expected to integrate 3,000 fb\(^{-1}\) of data per run, compared to 300 fb\(^{-1}\) of data during the run immediately prior to the HL-LHC upgrades.
  
  – The pile-up conditions are expected to be factors of 5–8 times higher than those presently seen at the LHC.

• In order to operate for an additional decade within this challenging physical environment the ATLAS & CMS detectors requires upgrades to:
  
  – Tracker detectors,
  – Calorimeter detector systems
  – Trigger and data acquisition systems

• Additionally novel timing detectors are added to both CMS & ATLAS

• The proposed upgrades are designed to address these needs.
Potential Approach to detector upgrades

• **Option 1:** The DOE & NSF work together on the Upgrade
  – The initial US-CMS construction projects and the Phase I Upgrade Projects
    • Were done in a partnership with NSF
      – The cost sharing was approximately 75% HEP and 25% NSF
    • Supplied several key elements of the detector
      – The US supplied ~25% of the total detector
  – DOE/NSF JOG still active

• **Option 2:** HEP engage in a partial and independent support of the Upgrade
  – The scope of the upgrade would be reduced and/or the schedule would be impacted
  – This would impact the future participation of US scientists in CMS

• **Option 3:** Do Nothing
  – This would GREATLY impact the future participation of US scientists in CMS
CMS Detector Upgrade

- **L1 Trigger/HLT/DAQ**
  - NSF and DOE
  - L1 40 MHz in/750 kHz out with tracking for PF-like selection
  - HLT 7.5 kHz out

- **Barrel Calorimeters**
  - NSF
  - ECAL single crystal granularity in L1 Trigger with precise timing for $e/\gamma$ at 30 GeV
  - ECAL and HCAL new back-end electronics

- **Muon Systems**
  - NSF
  - DT & CSC new FE/BE readout
  - New GEM/RPC $1.6 < |\eta| < 2.4$
  - Expanded coverage to $|\eta| < 3.0$

- **Calorimeter Endcap**
  - DOE
  - Si, Scint + SiPM in Pb-W-SS
  - 3D shower imaging with precise timing
  - Also known as HGCal

- **Tracker**
  - DOE
  - Si Strip Outer Tracker designed for L1 Track Trigger
  - Pixelated Inner Tracker extends coverage to $|\eta| < 3.8$ NSF

- **MIP Timing Detector**
  - DOE
  - < 60 ps resolution
  - Barrel: Crystals + SiPMs
  - Endcap: LGADs
  - Also known as “Timing Layer” (TL)
US Involvement in HL-LHC

• The principal laboratory for the LHC program is CERN, which assumes the ultimate responsibility for mounting and guiding the LHC program

• The DOE contribution to HL-LHC consists of upgrades to the accelerator and to both ATLAS and CMS totaling ~ $550M
  – HL-LHC AUP $200-250M
  – HL-LH ATLAS Upgrade $125-155M (not including I&C)
  – HL-LHC CMS Upgrade $125-155M (not including I&C)

• NSF guidance = $150M MREFC (plus development funds in 2017-20) to ATLAS & CMS ($75M each)
  – MREFC funding is targeted to begin April 2020, pending National Science Board and Congressional approvals.
The approval process for the HL-LHC CMS Detector Upgrade has four steps:

- **Step 1**: overall scope and cost for the entire upgrade program is defined, with the possibility to maintain different options, which may depend on technical issues and/or on funding availability. **April 2015**
- **Step 2**: the detailed Technical Design Reports (TDR) for the various subsystems are reviewed individually, with the requirement that each fits in the overall approved plan for scope and cost (Project Baseline). **October 2018**

- **Step 3**: the final design and construction readiness of the major detector components is reviewed. Some at different times, with the requirement that they are compatible with the overall construction and installation plan (Start of Construction).
- **Step 4**: as sub-systems are coming together in the experiment, an operations readiness review should be held to evaluate the capability of the completed detectors to provide the expected performance and mark the end of the upgrades construction project.
DOE Project Approval

• CD-0: Mission Need (April 2016)
  – Total Project Cost Range: $180-$250 Millions
• CD-1: Approve Alternative Selection and Cost Range (Fall 2019)
• CD3a: Approve long-lead procurement (Spring 2020)
• CD-2/3, Approve Performance Baseline & Start of Construction
  – Q1/Q2 FY20 – under discussion depending on int'l schedule, DOE budget etc
• CD-4, Approve Project Completion
  – Q4FY27

DOE Project Approval is interleaving with the NSF MREFC project approval:
  CDR April 2017
  PDR September 2018
  FDR September 2019
  NSF Start of Construction April 2020 (modulo 2020 budget appropriation)
• At CD-0 the cost range was $125-155M, with a profile strongly front-loaded
• In September 2017 a different profile, less front-loaded was given to the project, with the envelope somehow capped at $152M – revised in Feb 2018 to reflect the FY19 PBR
• Early in 2018 I&C costs were added to the TPC in out-years (OPC funds, not fungible)
• Following the 2019 appropriation a strongly front-loaded profile was given – superseded by the FY20 PBR, bringing us back to something similar to Sept 2017 (however $10M more were advanced in FY19)
• The current preliminary profile is continuously under development in OHEP and will be until CD-2
• Preliminary FY20 House & Senate points to funding similar to PBR.

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Simona Rolli, HL-LHC CMS Upgrade CD-1 IPR
Preliminary TPC and Cost Range

Cost range is $144M to $183M
Preliminary Schedule
This Review

1. Does the acquisition strategy document a carefully considered analysis of alternatives that supports the preferred alternative?
   – Customized AoA for this type of upgrade project – similar to HL-LHC AUP and HL-LHC ATLAS

2. Does the conceptual design satisfy the performance requirements?
   – Verification of the science requirements flowdown to performance parameters

3. Does the conceptual design report and supporting documentation adequately justify the stated cost range and project duration?
   – Construction costs, I&C costs, schedule in the context of intl project/CERN
   – Float to CERN due dates (including intl CMS I&C schedule)

4. Do the project’s plans to execute the work make the most efficient use of the financial, human, and technical the resources available to them to meet the mission need? Does the project use the 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?
Backup
Project Organization
DOE Critical Decisions

**CD-0: Mission Need (April 2016)**
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): $125-$155 Millions*

**CD-1: Approve Alternative Selection and Cost Range (August 2018)**
Conceptual Design Maturity and Alternative Analysis
Scope & WBS
Cost, Schedule and Risk Estimate
Project Management Organization and E&SH

**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

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