(Excerpt from the)
Mission Need Statement
for the
LHC CMS Detector Upgrade

1. STATEMENT OF MISSION NEED

The mission of the Office of Science (SC) is to foster, formulate, and support forefront basic and applied research programs which advance the science and technology foundations necessary to accomplish Department of Energy (DOE) missions: efficiency in energy use, diverse and reliable energy sources, improved health and environmental quality, and fundamental understanding of matter and energy.

The Office of High Energy Physics (HEP) mission is to understand how the universe works at its most fundamental level, which is done by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time.

The experimental HEP program is focused on three frontiers of scientific discovery: the Energy, Intensity, and Cosmic frontiers. At the Energy Frontier, powerful accelerators investigate the constituents of matter and the architecture of the universe. The only Energy Frontier facility is now at the European Center for Particle Physics (CERN) which operates the Large Hadron Collider (LHC). CERN is the largest particle physics laboratory in the world. It has twenty Member States and is located near Geneva, on the border of Switzerland and France. In 1997 CERN and the U.S. signed a cooperation agreement that established a framework for U.S. involvement in the LHC project.

The DOE HEP and NSF Experimental Elementary Particle Physics (E-EPP) programs supported the contribution of detector subsystems for two of the detectors at the LHC: Compact Muon Solenoid (CMS) and A Toroidal LHC Apparatus (ATLAS). The LHC began operations in 2009 and has delivered over 5 fb^{-1} of data to CMS with luminosities peaking at 3×10^{33} cm^{-2} s^{-1} at center of mass energy of 7 TeV. This corresponds to 1/3 of its design luminosity and half of its design energy. By 2019 peak luminosities are expected to reach 2-3 x 10^{34} cm^{-2} s^{-1}, 10 times current luminosities and corresponding to 50 to 80 interactions per crossing (pile-up) with 25 ns bunch spacing operation. The CMS detector requires upgrades to the Pixelated Inner Tracking (Pixel) Detector, the Hadron Calorimeter (HCAL) Detector and the Trigger. This Mission Need documents the need to upgrade U,S. supplied components in order to carry out a detector wide upgrade to handle the expected data rates.

2. CAPABILITY GAP/MISSION NEED

The high energy and luminosity available at the LHC offers the best opportunities for exploration of new physics beyond the Standard Model (SM) and for making precision measurements of properties of known phenomena.

Experiments at the LHC have recently announced results on the search for the Higgs Boson and are poised to make further exciting discoveries that will change our fundamental understanding of nature. Significant US participation in the full exploitation of the LHC has the highest priority in the US high-energy physics program. The US participation in the CERN experiments has been crucial. Approximately 1,200 physicists from U.S. institutions conduct research as collaborators in CMS and ATLAS , supported as part of the DOE High Energy Physics research programs and the contribution of US scientists is substantial for example in several key analysis aimed at the Higgs discovery or search for new phenomena. Given the broad experience gained during the earlier LHC runs, US physicists are in a unique position to contribute to further LHC analyses in the best possible way while maintaining the leadership role the US has had over the past two decades.

Capability Gap

To date in 2012, the LHC has doubled the total luminosity delivered and is expected to continue its operation at center of mass energy of 8 TeV and is expected to deliver from 10 to 20 fb^{-1} to each experiment. A long shutdown is being planned for 2018 after which peak luminosities are expected to reach 2-3 x 10^{34} cm^{-2} s^{-1} corresponding to 50 to 80 interactions per crossing (pile-up) with 25 ns bunch spacing operation. Upgrades are needed to the Pixelated Inner Tracking (Pixel) Detector, the Hadron Calorimeter (HCAL) Detector and the Trigger.

Pixel: The pixel detector plays a key role in the identification of primary vertices, secondary vertices, and secondary tracks. These elements are essential for the efficient identification of long-lived particles, such as *b* quarks, and for the search for new physics at the LHC. The upgrade of the Pixel Detector is driven by radiation damage, caused by particles produced at the collision point. The upgraded Pixel Detector would replace the degraded present detector while being itself more radiation tolerant to future damage. In addition the upgrade is driven by the data loss at peak luminosity due to the increased number of tracks per crossing at the expected higher luminosities. The new detector and associated electronics will enable expanded tracking information to enhance track reconstruction. The implementation of the upgraded Pixel Detector would improve all aspects of CMS tracking:

HCAL: The HCAL upgrade will implement depth segmentation to cope with the higher luminosities; use a new photo-detector, that provides the high gain needed for

segmentation; and new electronics, required to read out the increased data stream and to provide enhanced information to the upgraded Regional Calorimeter Trigger (RCT).

Trigger: The present CMS trigger will need significant modifications to operate at the higher LHC luminosity. Due to the increased occupancy of each crossing the current Level-1 trigger system will experience degraded performance. Rebuilding of the Regional Calorimeter Trigger (RCT) using new technologies addresses peak instantaneous luminosity, high pileup, and overall efficiency.

There is a planned shutdown in 2018 for upgrades of the LHC, and this is the best opportunity to install detector upgrades that are designed to enable CMS to fully exploit the physics opportunities afforded by these machine upgrades. The excellent performance of the LHC in 2011 and 2012 has demonstrated its ability to deliver luminosity that exceeds expectations and it is therefore prudent to plan for higher than anticipated luminosity and pile-up conditions.

The ongoing data taking operation at lower luminosities has helped CMS gain experience to plan for upgrades at the higher luminosity that will be needed to study new physics with high efficiency. The overall CMS physics program can only succeed if the necessary upgrades are implemented; thereby ensuring that high efficiency for expected physics is maintained as energy and luminosity increase beyond current design.

The CMS detector including the U.S. supplied components are not capable of handling the higher data rates of the LHC expected in 2018 and beyond without the planned upgrades.

Other Potential Capabilities

HEP is supporting the US ATLAS collaboration in the international ATLAS collaboration at the CERN Collider. The ATLAS experiment is in a similar circumstance and will need upgrades also, which will be the subject of another mission need. There are no other capabilities worldwide capable of addressing this physics.

Impact if Gap is Not Resolved

The DOE's High Energy Physics program has invested in the building of the CMS detector and is a major participant and contributor in the physics the detector enables. If the US fails to contribute to the upgrade their ability to participate in future physics would be impaired.

The priority of fulfilling the mission need relative to other programs

In 2008, the HEP Advisory Panel (HEPAP)/P5 Report identified continued U.S. participation in the LHC physics program as the highest priority for the U.S. HEP program. Highlights of the LHC physics program include searching for the Higgs Boson, investigating the possibilities of

additional symmetries of nature or additional dimensions of space-time, and the nature of the dark matter.

Benefits from Closing the Gap

Support of the upgrade of the CMS Detector at the LHC would enable the US community to remain at the forefront of High Energy physics and the continued pursuit of the prime mission of HEP.

Internal/External Drivers

The upgrade schedule for the LHC severely constrains the schedule for the upgrade of the CMS Detector.

DOE HEP has a Joint Oversight Group (JOG) in place with the NSF to coordinate the two agency partnership for the support of common LHC based experiments. Through the JOG the understanding has been reached that HEP could be the lead agency in a joint project with the NSF for the upgrade of the CMS Detector. Under this understanding HEP would provide about 75% of the project cost and NSF the remaining 25%.

3. POTENTIAL APPROACH

The potential approach is that the agencies work together, with HEP as lead agency, and support the CMS Detector Upgrade. This option best addresses the goals and priorities for HEP at the Energy Frontier.