

**LARGE HADRON COLLIDER**

**\$22,300,000**  
**+\$2,300,000 / 11.5%**

**Large Hadron Collider**

(Dollars in Millions)

FY 2016 Actual	FY 2017 (TBD)	FY 2018 Request <sup>1</sup>	Change over FY 2016 Actual	
			Amount	Percent
\$20.00	-	\$22.30	\$2.30	11.5%

<sup>1</sup> Includes funding for High-Lumosity LHC Upgrade planning.

The Large Hadron Collider (LHC), an international instrument at the CERN (the European Organization for Nuclear Research) laboratory in Geneva, Switzerland, is the most powerful particle accelerator ever constructed. It produces the highest energy particle beams ever created, making it the premier facility in the world for research in elementary particle physics. LHC consists of a superconducting particle accelerator, approximately 16.5 miles in circumference, providing two counter-rotating proton beams with a design energy of 7 TeV (1TeV=10<sup>12</sup> electron volts) per beam. It can also provide colliding beams of heavy ions, such as lead. During 2011 and 2012 (“Run 1”), LHC operated at 4 TeV per beam as a result of a limitation in the electrical connections between the superconducting magnets. After the connections were upgraded during a nearly two-year shutdown, Run 2 began in mid-2015 and will continue through the end of 2018 at 6.5 TeV per beam, exploring a new energy region not accessible during Run 1.

Four large particle detectors collect the data delivered by the LHC. They characterize the reaction products from high-energy proton-proton and heavy ion beam collisions. These are analyzed to investigate the fundamental properties of matter. More than forty international funding agencies provide support for scientists to participate in experiments at the LHC. CERN is responsible for meeting overall LHC project goals and coordinating international participation. The U.S., through a partnership between the Department of Energy (DOE) and NSF, made major contributions to the construction and operation of two of the largest particle detectors, a Toroidal LHC Apparatus (ATLAS) and the Compact Muon Solenoid (CMS), while NSF additionally supports a small number of researchers who participate in the LHC-b detector.

LHC data have resulted in major scientific discoveries. Foremost of these was the July 4, 2012, announcement by the CMS and ATLAS collaborations of the discovery of a particle having properties consistent with the long-sought Higgs boson, a prediction of the Standard Model of particle physics. Its existence was a prediction of the theoretical framework describing the origin of the masses of elementary particles. The experimental confirmation of this theory was recognized by the award of the 2013 Nobel Prize in Physics to Francois Englert and Peter Higgs. Another important discovery was announced on July 14, 2015, when the LHC-b experiment reported the discovery of a class of particles known as pentaquarks, a new way to aggregate quarks (the fundamental building blocks of ordinary matter) in a way never before observed. On June 28, 2016 the same collaboration reported the observation of tetraquark states, another novel aggregation of quarks into four-quark elementary particles.

The resumed program of operation, which began in 2015, is expected to significantly enhance the chances of more groundbreaking discoveries at the LHC. For example, the LHC program includes searches for particles predicted by a powerful theoretical framework known as supersymmetry, which may provide clues as to how the known forces – weak, strong, electromagnetic, and gravitational – evolved from different aspects of the same “unified” force in the early universe.

**Total Obligations for LHC**

(Dollars in Millions)

	FY2016	FY2017	FY 2018	ESTIMATES <sup>1</sup>				
	Actual	(TBD)	Request	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operations & Maintenance <sup>2</sup>	\$20.00	-	\$22.30	\$22.30	\$20.00	\$20.00	\$20.00	\$20.00

<sup>1</sup> Outyear funding estimates are for planning purposes only. The current cooperative agreements end in December 2021 (CMS) and January 2022 (ATLAS).

<sup>2</sup> FY 2018 and FY 2019 include funding for High-Luminosity LHC Upgrade planning.

A worldwide cyber-infrastructure, the LHC grid, is dedicated to LHC data processing, allowing scientists to remotely access and analyze vast data sets. The U.S. LHC collaboration continues to be a leader in the development and exploitation of distributed computing. The LHC grid and the Tier 2 computing centers funded by NSF enable U.S. universities to access LHC data and computing resources and thus train students in both state of the art science and computational techniques. The distributed computing tools and techniques developed for the LHC are expected to have broad application throughout the scientific and engineering communities.

The May 2014 report of the Particle Physics Project Prioritization Panel (P5) recommended to DOE and NSF that the highest priority strategic goal for the U.S. particle physics research program, within a global context, should be continued support for involvement in the LHC program. Within the scope of supported activities, they recommended a further planned upgrade of the accelerator to very high luminosity (nearly ten times the luminosity of initial operation). The high-luminosity upgrade will commence operation in mid-2026, and will facilitate precision measurements that may reveal new physics beyond the Standard Model. This will necessitate significant enhancements to the detectors in order to exploit this scientific opportunity. NSF is now working with the ATLAS and CMS detector collaborations to plan for this possibility. If approved, construction and fabrication activities would begin in FY 2020 in order to be ready for installation activities scheduled for 2024.

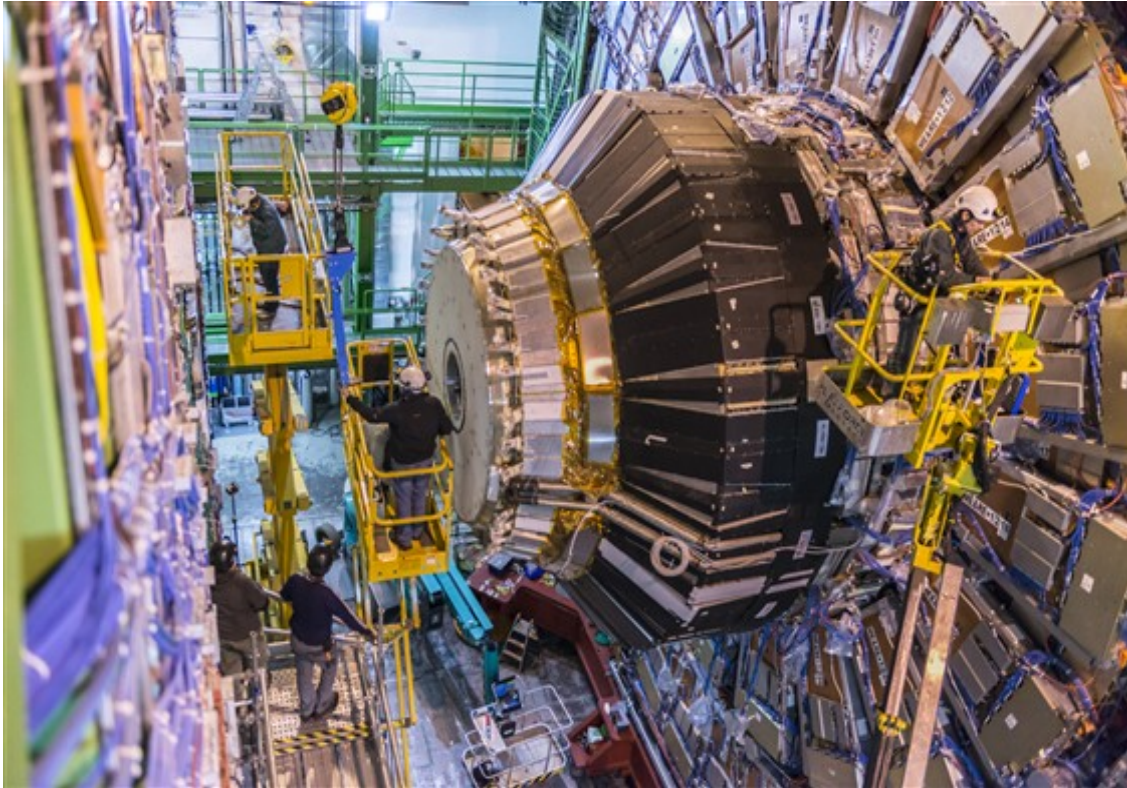
Through the participation of young investigators, graduate students, undergraduates, and minority-serving institutions in this international project, LHC serves the goal of helping to produce a diverse, globally-oriented workforce of scientists and engineers. Innovative education and outreach activities allow high school teachers and students to participate in this project.

**Management and Oversight**

- **NSF Structure:** A program director in the Directorate for Mathematical and Physical Sciences, Division of Physics is responsible for day-to-day project oversight. The Division of Acquisition and Cooperative Support provides financial and administrative support. An Integrated Project Team, consisting of representatives from the Mathematical and Physical Science Directorate, other experienced program officers, the Large Facilities Office, and other areas of the Office of Budget, Finance, and Award Management, contribute to the planning activities that may lead to a major construction upgrade.
- **External Structure:** U.S. program management occurs through a Joint Oversight Group (JOG), created by NSF and DOE. The JOG has the responsibility to see that the U.S. LHC program is effectively managed and executed to meet commitments made under the LHC international agreement and its protocols. NSF operations support is provided through cooperative agreements with Princeton University for US-CMS and with Stony Brook University for US-ATLAS.
- **Reviews:** There is one major management/technical review each year with a panel of external, international experts, a follow-up review six months later, as well as bi-weekly telephone reviews by NSF/DOE program directors to monitor progress. NSF and DOE conduct separate and joint external reviews of the detector upgrade activities so that each agency is fully cognizant of the activities of the other partner. The most recent major joint management/technical review was held in January 2017. Two JOG review meetings per year monitor overall program management. The most recent JOG was held in April 2017.

**Renewal/Recompetition/Termination**

Because of the planned incremental program of enhancements to the accelerator, along with parallel upgrades to the detectors, the LHC project is expected to be scientifically productive for at least 15 to 20 more years. Through an internal competition process among the research community, the ATLAS collaboration selected Stony Brook University to lead NSF-funded operations, while Princeton University was re-selected to continue to lead CMS operation. The U.S. ATLAS and CMS collaborations submitted renewal proposals that were successfully reviewed and approved. The new awards took effect in early 2017. The cooperative agreements end in December 2021 (CMS) and January 2022 (ATLAS).



The CMS Detector undergoing maintenance in December 2013. *Credit: CERN.*