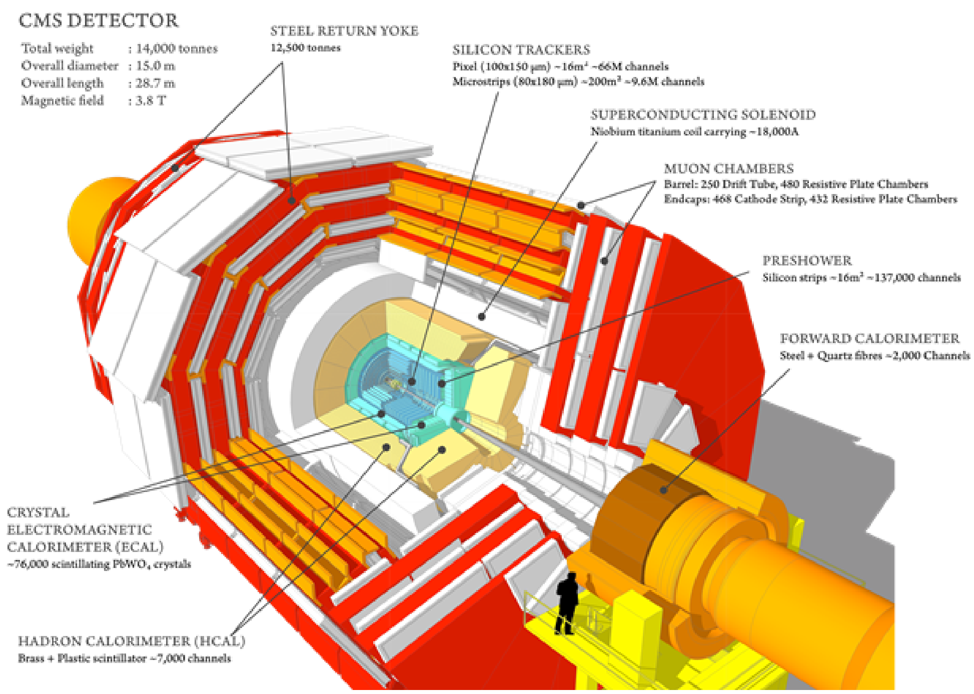
U.S. CMS Compact Muon Solenoid Operations Program Quarterly Report for the Period Ending March 31, 2019

U.S. CMS Operations Program



Program Manager's Assessment

Long shutdown 2 of the LHC (LS2) is now well underway. During this shutdown a number of detector improvements are planned, including new electronics for some muon chambers and the installation and commissioning of the hadronic calorimeter barrel upgrade. An extensive program of routine maintenance tasks is also underway.

Refurbishments of the detector proceed well and largely on schedule. The luminosity system is replacing the Pixel Luminosity Telescope detector planes for Run 3, that were at end-of-life at the end of Run 2. In the Tracker systems, LS2 is an opportunity to improve Single Event Upset performance of the Token Bit Manager, which plagued operations of the Pixel detector during the first half of Run-2. There are several repairs and refurbishments scheduled for the ECAL electronics, including for the large MARATON low-voltage crates. DAQ and Trigger systems also get updated.

The big ticket items for the U.S. groups during LS2 are the Installation and Commissioning of the HCAL Barrel front-end electronics Phase-1 upgrade, and the refurbishment of the inner-ring Endcap Muon Chambers at each station (MEx/1 chambers), outfitting them with new electronics boards to improve latencies and robustness of triggers. Both programs proceed well as described in the Detector Operations section of this report, despite small issues that are being taken care of as we move forward and that to this date do not impact the overall shutdown schedule.

There is no break for Software and Computing data processing during the shutdown, with significant processing campaigns proceeding well. Operational reliability and availability of U.S. computing facilties has been excellent, especially for the Fermilab Tier-1 facility that hit 100% in this metric for this quarter. U.S. analysis computing resources are being used at very high scales, contributing significantly to the physics results shown at various conferences.

CMS continues to produce large Monte Carlo event samples in various detector configurations, including for upgrade studies. Use of High Performance Computing (HPC) resources like the DOE NERSC facility at LBNL and the NSF Pittsburgh Supercomputing Center facility is now becoming routine for the full event simulation chain, and these resources make a significant impact. New allocations for 2019 were granted through the DOE ERCAP and the NSF XSEDE processes, which we intend to efficiently apply to solve CMS physics questions.

The transition to the Rucio data management system made significant progress, and we migrated remaining CMS-supported services to a WLCG-supported solution. The transition of the CMS detector geometry definition package to a community solution was completed. There was good progress in core software development, in particular support of software access to computing accelerators (in particular GPUs and FPGAs) from the CMSSW framework. There is also good progress in modernizing physics software and algorithms, in particular in optimizing tracking software for running on accelerators like GPUs. This prepares CMS software to run efficiently on future HPC machines, that typically are heavily relying on the use of accelerators.

CMS published first physics results based on the full 137/fb Run 2 data sample just mere months after the last collision data was taken, giving testimony to the effective operation and high quality of the data.

Report of the U.S. CMS Resource Manager

The funding provided by DOE and NSF to the U.S. CMS Operations Program for 2002 through 2019, as well as the funding guidance for 2020 through 2021, is shown in Figure 1. The allocations shown for 2019 and beyond do not include any funds designated for HL-LHC OPC in the case of DOE or HL-LHC R&D in the case of NSF.

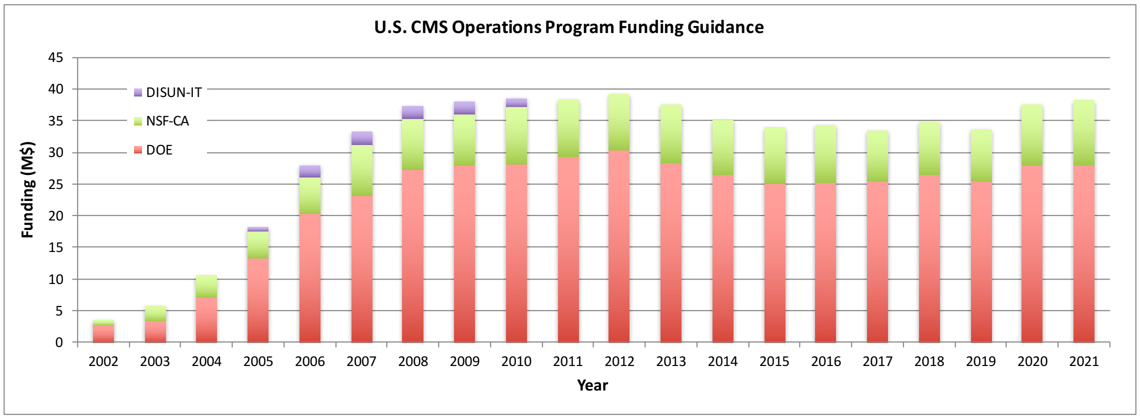


Figure 1: The annual U.S. CMS Operations Program funding provided by DOE and NSF. For 2002 through 2019 the chart shows the actual funding, while for 2020 onward the current funding guidance is shown.

Resources are distributed and tracked across the three areas through which the Operations Program is implemented: Detector Operations (DetOps), Software and Computing (S&C), and Common Operations (ComOps). ComOps is a category for items that would otherwise belong in both, or neither, of the other two categories.

Internal budget reviews for calendar year 2019 took place in August of 2018. As an additional source of input to the planning process, the Resource Allocation Advisory Board provided input in the Fall of 2018. Through these processes, U.S. CMS Management developed a detailed spending plan, while taking into account updated information from the funding agencies.

Primarily during the first quarter of the calendar year, Statement of Work (SOW) agreements were established with each institution that is providing a deliverable in exchange for Operations Program funding. The SOWs specify the tasks to be carried out, as well as any portions of salaries, materials and services (M&S), travel funding, or cost of living adjustments (COLA) to be paid from the Operations Program budget. The SOWs must be approved by U.S. CMS Operations Program management, by the Fermilab Director Designee, and by representatives of the collaborating group and institution. Through March of 2019, a total of 51 SOWs (29 DOE and 22 NSF) were produced and approved. After a SOW is approved, any additional changes are considered and, if approved, enacted through a Change Request procedure.

Figure 2 shows the Spending Plan Change Log which captures revisions that were made prior to SOW approvals, as well as modifications implemented through Change Requests. The information is reported here down to the level-2 subsystem categories within DetOps, S&C, and ComOps. The CY19 spending plan, as of the end of Q1, is shown for DOE and NSF funds in Figure 3.

Once funds have been committed through purchase orders, in the case of DOE, and sub-awards, in

U.S. CMS Detector Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY19 Q1 Plan**	**Change $**	**CY19 Q2 Plan**
11	Endcap Muon	Pre-SOW	Increase TAMU labor, decrease CERN TA COLA and M&S	$2,043,554	($38,776)	$2,004,778
	Endcap Muon MEX/1	Pre-SOW	Increase Wisconsin M&S, Boston travel, CERN TA M&S	$817,570	$108,998	$926,568
12	Hardon Calorimeter	Pre-SOW	Increase Maryland labor, decrease CERN TA labor and COLA, decrease Virginia and Notre Dame labor, increase Kansas State labor, add FNAL M&S and labor	$2,256,745	($80,392)	$2,176,353
13	Trigger	Pre-SOW	Decrease Northeastern COLA for EMTF	$939,473	($7,263)	$932,209
14	Data Acquisition	Adjust		$1,269,021	($1,991)	$1,267,031
15	Electromagnetic Calorimeter	Pre-SOW	Increase Caltech labor, increase CERN TA COLA	$853,155	$21,779	$874,935
16/17	Tracker (Fpix & SiTrk)	Pre-SOW, CR-020	Increase UC Davis engineering labor; increase M&S for TBM radiation testing,	$837,343	$17,931	$855,273
18	Detector Support			$61,953	$0	$61,953
19	BRIL	Adjust		$366,284	$647	$366,931
11-19	**Detector Operations**			**$9,445,098**	**$20,933**	**$9,466,030**

U.S. CMS Common Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY19 Q1 Plan**	**Change $**	**CY19 Q2 Plan**
21.2	Common Costs (M&OA)			$4,729,245	$0	$4,729,245
21.3	Run Coord. and Monitoring	Adjust		$163,076	$942	$164,018
21.4	LHC Physics Center	Adjust		$888,197	$154	$888,351
21.5	Operations Support	Pre-SOW	CERN TA labor, M&S and travel, SMU labor, M&S, and travel, Virginia labor, MIT labor and travel, FNAL labor, M&S, and travel	$1,471,941	$1,069,508	$2,541,450
21.6	Program Office	Pre-SOW		$1,068,253	$6,499	$1,074,752
21.7	Education and Outreach	Pre-SOW	Restore portion of Notre Dame M&S and travel	$150,000	$50,000	$200,000
21	**Common Operations**			**$8,470,713**	**$1,127,103**	**$9,597,816**

U.S. CMS Software and Computing Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY19 Q1 Plan**	**Change $**	**CY19 Q2 Plan**
22.1	Fermilab Facilities	Pre-SOW	Refined overhead and labor rate estimates	$5,983,502	($28,180)	$5,955,322
22.2	University Facilities	Pre-SOW	Decrease in Tier-2 equipment	$3,489,756	($682,908)	$2,806,848
22.3	Computing Operations	Pre-SOW	Decrease labor and COLA	$1,404,026	($47,988)	$1,356,037
22.4	Computing Infra. and Services	Pre-SOW	Decrease labor	$2,623,703	($164,187)	$2,459,516
22.5	Software and Support	Pre-SOW	Decrease labor	$2,334,925	($131,498)	$2,203,428
22.6	S&C Program Management & CMS Coordination	Adjust		$435,760	($1,176)	$434,584
22	**Software and Computing**			**$16,271,672**	**($1,055,937)**	**$15,215,734**
U.S. CMS Operations Program Total				**$34,187,482**	**$92,099**	**$34,279,581**

Figure 2: Spending Plan Change Log for CY19 Q1.

WBS	Subsystem	DOE Funds	NSF Funds	Total
11	Endcap Muon	$1,598,156	$406,622	$2,004,778
	Endcap Muon MEX/1	$926,568	$0	$926,568
12	Hadron Calorimeter	$1,958,611	$217,742	$2,176,353
13	Trigger	$723,507	$208,703	$932,209
14	Data Acquisition	$1,267,031	$0	$1,267,031
15	Electromagnetic Calorimeter	$874,935	$0	$874,935
16/17	Tracker (Fpix & SiTrk)	$840,718	$14,555	$855,273
18	Detector Support	$61,953	$0	$61,953
19	BRIL	$187,749	$179,182	$366,931
11-19	**Detector Operations**	**$8,439,226**	**$1,026,804**	**$9,466,030**
21.2	Common Costs (M&OA)	$3,741,912	$987,333	$4,729,245
21.3	Run Coordination and Monitoring	$56,082	$107,936	$164,018
21.4	LHC Physics Center	$888,351	$0	$888,351
21.5	Operations Support	$2,285,790	$255,660	$2,541,450
21.6	Program Office	$972,452	$102,300	$1,074,752
21.7	Education and Outreach	$0	$200,000	$200,000
21	**Common Operations**	**$7,944,587**	**$1,653,229**	**$9,597,816**
22.1	Fermilab Facilities	$5,955,322	$0	$5,955,322
22.2	University Facilities	$124,267	$2,682,581	$2,806,848
22.3	Computing Operations	$673,956	$682,081	$1,356,037
22.4	Computing Infrastucture and Services	$1,527,001	$932,515	$2,459,516
22.5	Software and Support	$1,346,344	$857,084	$2,203,428
22.6	S&C Program Management and CMS Coordination	$169,778	$264,806	$434,584
22	**Software and Computing**	**$9,796,667**	**$5,419,067**	**$15,215,734**
U.S. CMS Operations Program Total		**$26,180,480**	**$8,099,101**	**$34,279,581**

Figure 3: Spending plan at the end of CY19 Q1, for funds from DOE, NSF, and the total.

the case of NSF, they are considered obligated. Figure 4 shows the obligations in the areas of DetOps, S&C, and ComOps, as compared to the spending plan, for DOE funds. The spending plan is plotted as if expenditures are carried out in even allocations each month, but this is intentionally not the case due to equipment purchases and the larger of the transfers to CERN-based Team Accounts, the latter of which are targeted for when exchange rates are favorable. Spending at Fermilab has historically been budgeted according to the fiscal year, however spending through Universities and CERN Team Accounts is budgeted and tracked according to the calendar year, so the U.S. CMS Operations Program has been reporting all activities based on calendar year. Figure 5 shows the total obligations and the spending plan, for NSF funds. Of the $8.1M in NSF funding, $4.9M in subawards went out this quarter, in addition to spending directly at Princeton.

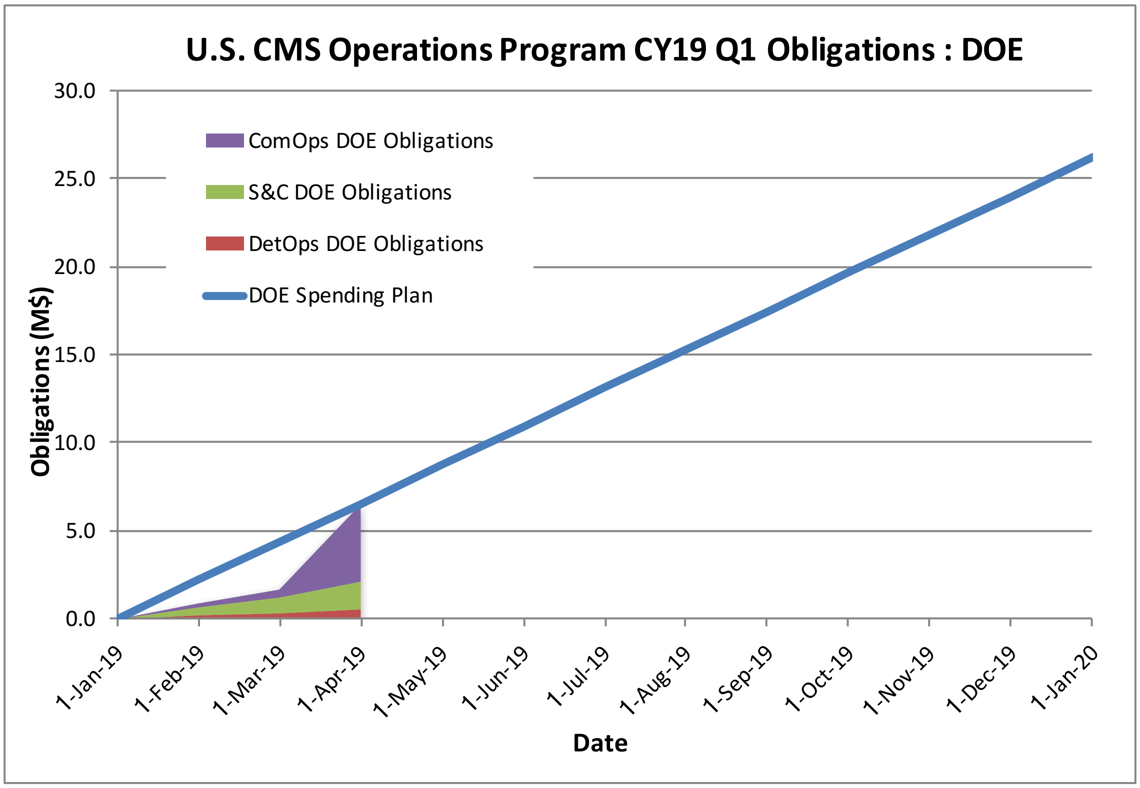


Figure 4: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

Resources deployed at CERN, and paid directly in Swiss francs, account for approximately 22% of the 2019 spending plan. This carries considerable exposure to the exchange rate. A rate of 0.9 CHF/USD has been used for planning, while the actual rate in CY19 Q1 averaged 0.996 CHF/USD. Figure 6 shows the allocated budgets and year-to-date spending through the Team Accounts that are used for expenditures at CERN. Spending for labor and cost of living adjustments occurs at a fairly constant rate. Figure 6 does not include the 3,242K CHF M&O-A payments, as these are made through multiple payments to a separate Team Account.

A Risk Management Plan is being implemented for the U.S. CMS Operations Program, with many aspects drawn from the Fermilab Risk Management Plan. A Risk Register is updated quarterly,

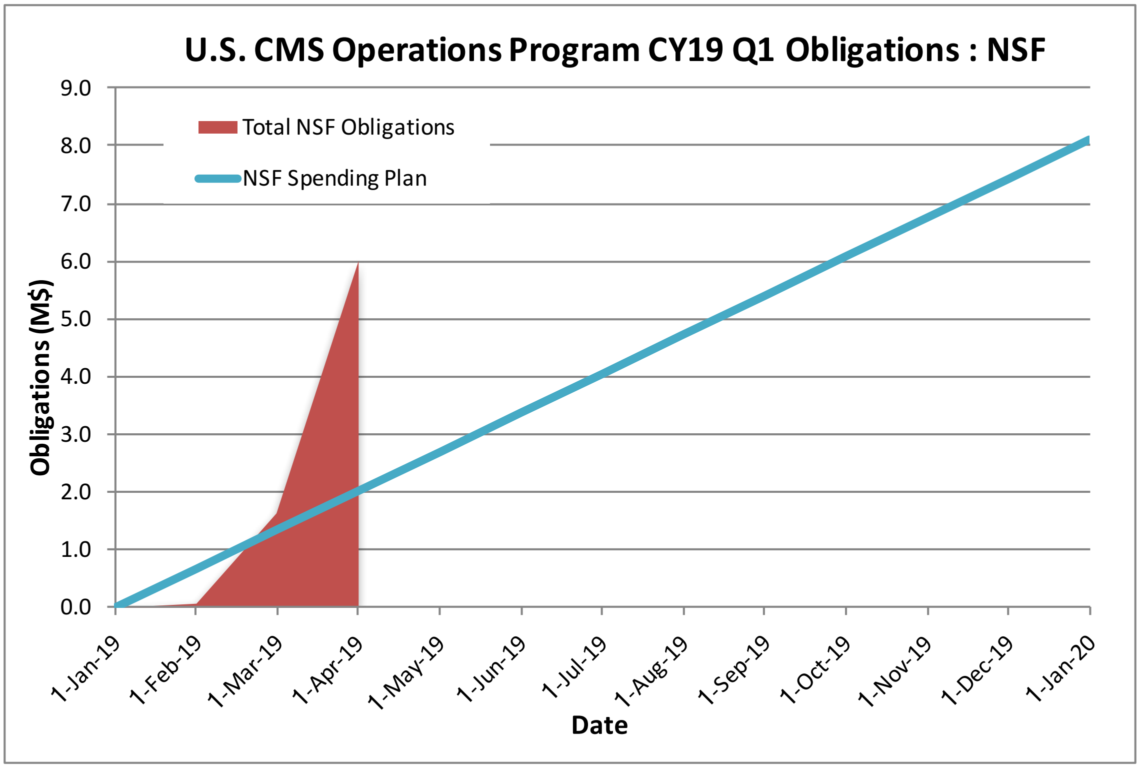


Figure 5: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.

according to the workflow described in the following subsection. At the start of the quarter, the Risk Register contained 32 open risks spread across the program. At the end of the quarter, there were 36 risks, with threats summing to \$5.7M and opportunities summing to \$0.4M. Figure 7 shows the top few risks at the end of the quarter, ranked by *Probability* × *Cost Impact*, as well as any risks realized (even partially), closed, or added this quarter.

Workflow for Risk Management Plan

The following procedures have been put in place to carry out the workflow for the U.S. CMS Operations Program Risk Management Plan. The workflow is divide into two paths: (1) updates that are made at any time, and (2) a review of risks once per quarter. In all of the following, *updates* mean adding new risks, realizing risks, retiring old risks, or modifying existing risks. In all cases, it is the program office team that edits the Risk Register. The following descriptions are also summarized in Figure 8.

(1) At any time:

Any member of the management team (including Program Manager, Deputy Program Manager, L1 Managers, L2 Managers, Resource Manager, and program office lead) shall alert the program office of any updates. The program office informs the corresponding L1 manager, and the L1 manager

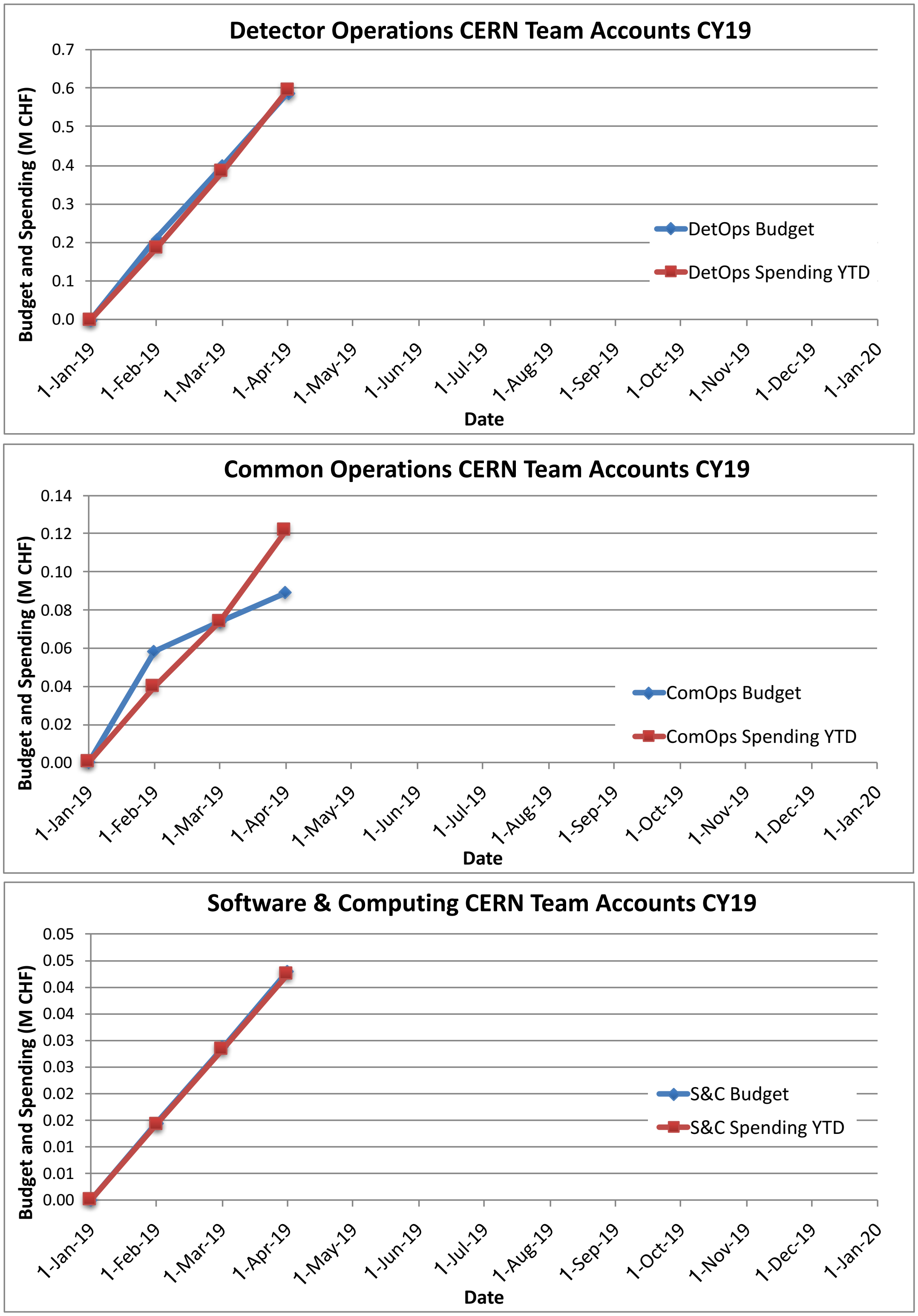


Figure 6: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.

CY19 Q1 Risk Register Summary Table			
	Probability	**Schedule Impact**	**Cost Impact**
Top Risks (ranked by Probability x Cost Impact)			
EMU - Optical transmitter failures on DCFEBs	75%	0 months	$75k
S&C - Oracle increases maint. fees for tape libraries & drives	50%	0 months	$100k
ComOps - Fermilab overhead rates increase	50%	0 months	$80k
Risks Open Realized this quarter			
Tracker - Pixels Phase 1 Detector loss of a CO2 cooling loop	5%	0 months	$300k
HCAL - Other problems with Phase 1 Upgrade HB electronics	10%	3 months	$50k
Risks Closed Managed this quarter			
None	5%	2 months	$400k
Risks Closed Retired this quarter			
S&C - Less raw data than expected	5%	0 months	-$400k
S&C - More raw data than expected	5%	0 months	$400k
S&C - Increased LHC live time exposes operational limitations	10%	0 months	$250k
Risks Added this quarter			
Tracker - Detector checkout reveals new repair issue	25%	1 months	$50k
EMU - Cooling system water leaks before LS3	20%	3 months	$50k
EMU - Problems with LS2 CSC electronics installation	10%	2 months	$50k
S&C - Tape migration is slower than anticipated	1%	0 months	$100k
S&C - T2 hardware retirement policy not realistic	1%	0 months	$100k
S&C - T2 disaster	0.3%	0 months	$500k
S&C - T2 hardware pricing uncertainty	5%	0 months	$88k

Figure 7: Summary of the U.S. CMS Operations Program Risk Register. Only the top few risks are shown, as well as any risks that were realized, closed, or added this quarter.

approves, rejects, or modifies the proposed updates. This can also involve iterating with the L2 manager. If updates are accepted, the management team reviews the risk mitigations and risk responses that are associated with the updates. The management team takes into account the risk rank and/or position in the risk rank matrix and takes any necessary pre-emptive actions to incorporate mitigation activities into the plan. If appropriate (again factoring in the probability and impact of the risk), the operations program plan is also adjusted to account for the estimated resources required to execute the risk responses related to the updated risks.

(2) Once per quarter:

Within one month prior to the end of each quarter, the program office lead asks the L2 managers whether they have any updates to the risks in their L2 area. The program office then informs the corresponding L1 manager of any such updates, and the L1 manager approves, rejects, or modifies the proposed updates. As above, this can involve iterating with the L2 manager. As part of the quarterly workflow, the management team reviews *all* of the current risks, and takes any necessary actions and adjusts the program plan if appropriate.

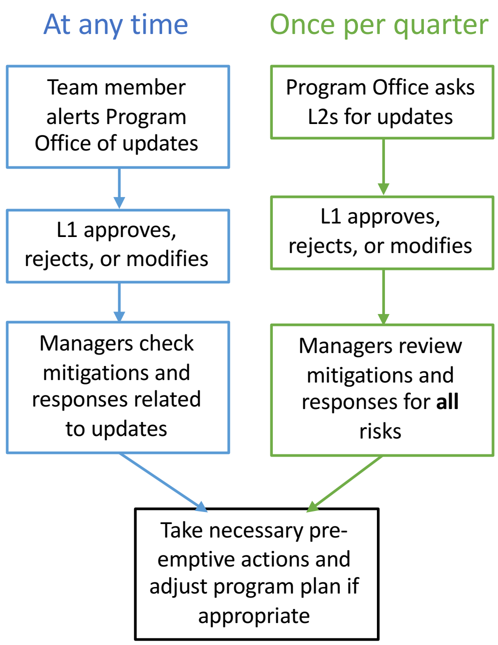


Figure 8: Summary of the two Risk Management Plan workflow paths.

Detector Operations

Long shutdown 2 of the LHC (LS2) is now well underway. During this shutdown a number of detector improvements are planned, including new electronics for some muon chambers and the installation and commissioning of the hadronic calorimeter barrel upgrade. An extensive program of routine maintenance tasks is also underway.

BRIL

During LS2 the plan is to rebuild the Pixel Luminosity Telescope detectors used in the BRIL system. Progress this quarter included the acquisition and testing of readout components. Two labs were established at CERN, at Point 5 and in the Tracker Integration Facility. Detector planes (sensors) for the first replacement PLT have been tested. For a second version more planes will be bump bonded; low quality tested planes have been sent back to PSI. The production of the re-designed opto-motherboards started; the first two boards arrived and are under investigation. Problems with the availability of Digital Optiacl Hybrids (DOHs) are still a concern, but enough DOHs are secured for one full replacement PLT. Furthermore, additional DOHs from the phase 0/1 pixel detector have been secured, and for a subset the connectors have been exchanged. An attenuation test stand is setup to perform quality tests as they are irradiated and their degradation needs to be quantified.

The study of the extracted PLT is ongoing. The failure of the telescope readout in one of the quarters when cooled below 5°C can be reproduced. Cold tests for the replacement PLT are in preparation. One quarter plus full readout will be placed in a freezer box.

The luminosity analysis for the 2018 data taking has been completed and approved.

BRIL 2019 Upgrade Milestones

Subsystem	Description	Scheduled	Achieved
BRIL	Assembly of the replacement PLT - first quarter	Jun 30	
BRIL	Cold cycle tests done - one quarter	Aug 31	
BRIL	Assemble quarters 2,3,4	Sep 30	
BRIL	Certify quarters for full assembly	Nov 31	
BRIL	Mechanical assembly for PLT ready (store in cold boxes)	Dec 31	
BRIL	Full Run 2 Luminosity analysis /software review	Dec 31	

Tracker

The LS2 program began on schedule with the extraction of the pixel detector from CMS.

Pixels

The pixel detector was successfully extracted from CMS on January 10-15 and placed in storage boxes that are being kept near 0°C. So far, the only detector refurbishments that have occurred are the removal of all BPIX DC-DC converters and the removal of BPIX Layer 1. The DC-DC converters are being tested to better understand the failure mode that appeared in October 2017 and the successful operations in 2018. The BPiX Layer 1 is being rebuilt with new modules that have upgraded versions of both the PROC600 readout chip (ROC) and the token bit manager (TBM).

The latest version of the PROC600 ROC has lower crosstalk that should allow for lower operational thresholds, leading to better sensitivity to small deposited charges. The latest version of the TBM corrects a vulnerability to single event upsets (SEUs) discovered in summer 2017. In the new version, SEU recovery can be done with a fast TBM reset that does not require cycling the DC-DC converter. The improved SEU recovery, as well as improvements in the data handling circuitry and a provision to correct a mismatched delay between the PSI46dig ROC and the PROC600 chips that should lead to higher tracking and operational efficiency in the BPiX. SEU recovery with the new TBM was tested in a 60 MeV sulphur ion beam and a 30 MeV oxygen ion beam at Florida State University (FSU). The exposed TBM operated without needing power cycling and the new reset was tested successfully. More SEU testing at FSU and total dose testing with the Sandia Cobalt source will done.

In 2018 it was observed that some layer 1 modules broke after being operated at elevated high voltage (600V). The source of this problem was traced to a short that developed when the sensor bias was too high between the sensor and a nearby metallic test pad kept at low voltage. The sensor-pad gap in the new modules is three times wider than in the old modules, which fixes the problem.

The DAQ team has been working on software improvements for Run 3. The user interface to the PixelSupervisor has been cleaned up, the SEU recovery workloop has been updated, and state transition implementations improved where needed. Similar work will continue throughout LS2.

As a final note, the Phase 0 detector was successfully returned to Fermilab after all potentially usable parts were removed.

Strips

The main goals for operations of the silicon strip detector are to see if it can operate well at a reduced temperature (-25°C) and to regularly exercise the detector to monitor sensor condition, take cosmic data, and exercise the DAQ. In this quarter, the tracker volume humidity seal was restored after the pixel removal, and Strips participated in global DAQ operations with power (and cooling) on at the end of March.

Tracker 2019 Milestones

Subsystem	Description	Scheduled	Achieved
Tracker	Pixel Phase 1 Detector Removed	Jan 31	Jan 15
Tracker	Strips cold and in global run	June 1	Mar 20
Tracker	Strips tested at -25C	Dec 11	
Tracker	Pixel initial checkout complete	Aug 31	

ECAL

The ECAL LS2 work is proceeding according to schedule. The replacement of the MARATON cooling lines has been completed ahead of schedule. The modification of the CANBUS and DCS software update has also been completed ahead of schedule. The laser maintenance is pushed back in order to keep operating the laser in the first quarter of 2019 to study the crystal recovery from radiation damage. The new milestone is Sep 30 for the first laser and Dec 31 for the second laser. The infrastructure update of the laser barracks has begun.

ECAL 2019 Milestones

Subsystem	Description	Scheduled	Achieved
ECAL	Complete First Laser Maintenance	Sep 30 (April 30)	
ECAL	Complete Second Laser Maintenance	Dec 31 (July 31)	
ECAL	Complete infrastructure update of laser barracks	Dec 31	
ECAL	Complete replacement of all Maraton input/output Cooling Pipes	June 30	April 1
ECAL	Complete replacement of input HV power connectors	Sept 30	
ECAL	Complete modification of CANBUS and update DCS software	Oct 31	April 1
ECAL	Complete VME PC replacement	Mar 31	March 15
ECAL	Complete network upgrade	May 31	
ECAL	Complete upgrade to XDAQ15	Dec 31	
ECAL	Complete installation of new water pump at surface	Aug 31	
ECAL	Complete insulation of surface to underground area pipes	Dec 31	

HCAL

During the first quarter of 2019, the HCAL Operations group focused on completing the remaining components of the HCAL Barrel (HB) Phase 1 Upgrade electronics and on beginning the HB Phase 1 Upgrade installation.

HB Installation and Commissioning

The HB Phase 1 upgrade, planned for LS2, is progressing well. The necessary parts have arrived at CERN and assembly and testing of the readout modules and other components. is proceeding. More than 170 readout modules have been assembled and tested. (144 are needed in P5 for the detector. The others will be spares and used in test stands.) The installation readiness review (IRR) for HB installation took place as scheduled on February 15, 2019, and the "go ahead" was given to begin installing the upgrade. The removal of the Phase 0 electronics from the HB readout boxes began a few days later. Note that the plan was for the HB Minus half-barrel upgrade to be installed February through June 2019 while the HB Plus half-barrel upgrade will be installed from September through December 2019. Two wedges (HBM10 and HBM11) have had Phase 1 electronics fully installed. The installation time was as expected, adding confidence to schedule projections. Co60 sourcing was done with the legacy electronics so that comparisons between Phase 0 and Phase 1 performance can be made. These two wedges with the new electronics have now been scanned with the Co60 source and the expected performance improvements achieved. In addition, HBM11 was included in global running with cosmic rays in late March and cosmic signals were seen, indicating that the new electronics is performing well.

Two issues came up during the burn-in of the Phase 1 HB electronics. The first is that a number of the SiPM control card mezzanines were of sub-standard quality due to issues with the assembly process. The decision was made to re-make the boards at Fermilab. The production of the new boards is complete and they arrived at CERN March 30. After testing, they will be installed in readout modules. The second is that a number of SiPM mounting boards showed an increase in leakage current when being burned-in. The affected channels were near the edges of the boards. The problem has been identified. An improved design has been reviewed and endorsed. The RFQ for the modified boards is being prepared at Fermilab with delivery expected in late-May.

Even with these two issues, it is expected that the HB Phase 1 Upgrade installation can be completed by the end of 2019.

In Table 1, all HB upgrade electronics related items are abbreviated "HBE".

HCAL Operations

Although the HCAL generally performed well during the 2018 running, there were two significant issues. First, there was an over voltage transient that occurred during the the power-on of CAEN A3100HBP modules on June 30 after a CERN wide power cut that caused irreversible damage of two sectors on the HE minus side, HEM15 and HEM16. Second, HCAL experienced disruptions to the quality of specific primary control links between the front-end controllers (FECs) in the CMS service cavern and the clock, control, and monitoring modules (CCMs) on the detector for HEP10 and HEM9. Redundant (secondary) control links were enabled for these detectors and allowed HCAL to continue taking high quality data. The affected electronics for HEM15 and HEM16 as well as HEP10 and HEM9 have now been removed from the detector. The DC/DC converters on HEM15 and HEM16 were found to be damaged and these modules have now been successfully repaired. Work on the HEP10 and HEM9 CCMs is in progress. The low voltage power supplies will be shipped back to CAEN for modification to prevent future over voltage transients during power-on and a protection circuits for both HE and HB will be designed and installed during 2019. (An ad-hoc protection circuit was quickly added to HE after the June 30 incident to prevent problems from transients.)

Also, the FEC and CCM firmware is being upgraded to be compatible with half-speed control links. This will ease timing and decrease the Single Event Upset probability.

Table 1: HB Upgrade Milestones

Subsystem	Description	Scheduled	Achieved
HCAL	HBE assembly starts at CERN	1-Sep-2018	1-Sep-2018
HCAL	HBE production in “factory mode”	15-Nov-2018	20-Nov-2018
HCAL	HBE IRR passed	15-Feb-2019	15-Feb-2019
HCAL	HBE Minus end upgrade installation begins	19-Feb-2019	18-Feb-2019
HCAL	HBE production complete	28-Feb-2019	see text
HCAL	HBE Minus end Upgrade Complete	30-Jun-2019	
HCAL	HBE Plus end upgrade installation begins	1-Sep-2019	
HCAL	HBE Plus end Upgrade Complete	20-Dec-2019	

2019 HCAL Operations Milestones

Subsystem	Description	Scheduled	Achieved
HCAL	extract HEM09 and HEP10 CCMs	10-Feb-2019	30-Jan-2019
HCAL	extract HEM15 and HEM16 CCMs, RMs, CUs	15-Mar-2019	30-Jan-2019
HCAL	finalize half-speed FEC and CCM firmware	1-Apr-2019	15-Mar-2019
HCAL	reinstall HEM09, HEP10 modules	1-Jun-2019	
HCAL	reinstall HEM15, HEM16 modules	1-Jun-2019	
HCAL	recommission HE with half-speed control links	1-Jun-2019	
HCAL	LV PS back to CAEN for modification starts	1-Jun-2019	
HCAL	new LV protection circuits installed	1-Sep-2019	

EMU

The major CSC activity planned for Long Shutdown 2 is the refurbishment of 180 chambers in the inner rings of the CSC system with updated electronics. Chambers are extracted from CMS and brought to the surface at SX5 where the older electronics boards are stripped off and new ones are being installed. The refurbished chambers are subjected to a battery of tests in an electronics tests stand in SX5, and then monitored under power on a long-term-test stand. After a leak test of the cooling circuits, the chambers are reinstalled in CMS and await recommissioning. The work of chamber refurbishment and testing, infrastructure installation and re-commissioning is distributed among small teams that are composed mostly of graduate students and are led by senior scientists or postdocs.

In January and February, the refurbishment and testing area in SX5 underwent final preparations. This CSC area in SX5 is maintained as a radiation protection (RP) supervised area; the extracted chambers have a low level of radioactivity (less than 0.1 μSv/hr), but they must be stored and worked on in a RP area. One wall of the area was moved outward by one meter to extend the area available for chamber storage. We also completed the storage racks that hold the chambers vertically and a set of wheeled tables that hold the chambers horizontally while they are being refurbished and tested. Two complete independent tests stands were established, complete with low voltage, high voltage, gas, cooling, and VME electronics. An additional long term test stand was completed with a capacity for three chambers and the necessary safety features to operate in unattended mode. The hardware and software for the test stands was refined and debugged and the operation of the stands was validated in mid February.

The first ring of chambers to be refurbished is ME-1/1 (the inner ring of the first station on the negative YE-1 end cap), which comprises 36 chambers. The chambers in this ring require the old digital cathode front end boards (DCFEBs) to be replaced with new DCFEBv2 boards, and the ALCT mezzanines to be replaced with new ALCT LX100 boards. Each DCFEBv2 also requires a copper cooling cover and thermal padding for good thermal contact to the highest power components.

Large-scale assembly of the DCFEBv2 boards began in January. After assembly, the boards are shipped to Ohio State university where they undergo bench tests. They are shipped to CERN in batches of 10 to 40 boards, where they undergo and additional tests of the GBTx communications chip and the parameters of the GBTx are fused. By March 7, enough fully tested boards were available at CERN to be used for chamber electronics refurbishment. As of the end of March, 289 boards have been produced and 280 of these shipped to CERN. For the ME-1/1 ring, 252 boards are needed; the remainder are not needed until November when the ME+1/1 chambers are scheduled to be extracted. The quality of the boards is very high. Only five boards have been set aside for more debugging; all others are working.

The ALCT LX100 boards began large-scale production in February. After assembly, the boards are shipped to UCLA for bench testing, then shipped to CERN. By March 7, enough ALCT LX100 boards were tested and available at CERN to keep up with refurbishment. As of the end of March, all 36 boards needed for ME-1/1 are at CERN. The ME2/1, ME3/1, ME4/1 rings use a different version of the boards (ALCT LX150T) with a more powerful version of the Spartan-6 FPGA. These boards underwent successful pre-series tests in March and should begin production in April.

The first ME-1/1 chamber was extracted on 25 Feb, and extraction continued thereafter at one-to-two chambers per day. As of the end of March, all 36 ME-1/1 chambers have been extracted, 19 of these have had new electronics installed, five have undergone and passed electronics testing, two have had the additional long term test, and one has been reinstalled on the detector. The operation has achieved a steady-state throughput of one-to-two chambers per day, and is on track to complete the full re-installation of ME-1/1 before the scheduled end of access to this ring in early June.

The copper covers and thermal pads experienced serious procurement delays; the main order of copper arrived only in late March and the thermal pad order is not anticipated until June. In each case, we were able to procure small quantities or borrow material from other subsystems in order to avoid an impact on the refurbishment schedule.

The assembly of the new low-voltage junction boxes was completed in January. Of the 36 new boxes 18 have now been installed on the detector. The final set of 12 additional Maraton low voltage supplies arrived at CERN in March.

The new optical fibers for ME2/1, ME3/1, ME4/1 were shipped to CERN at the end of March.

The old DCFEB boards extracted from ME1/1 will later be installed in ME2/1, ME3/1, ME4/1. Before this, however, they are to have their old Finisar optical transceivers removed and retrofitted with VTTx optical transmitters. This operation is being carried out by our colleagues from Tomsk State University (RU). The extracted DCFEB boards are transported to a radioprotection lab on the

CERN Prevessin site where the work is carried out with appropriate radiation controls. Approximately 30 DCFEBs have been retrofitted as of the end of March.

In summary, the main CSC activity of LS2, refurbishment of the inner ring chambers, has reached a steady state and is on schedule.

EMU 2019 Milestones

Subsystem	Description	Scheduled	Achieved
EMU-MEX/1	CSC LV junction boxes ready for installation	Jan 15	Feb 1
EMU-MEX/1	First ME-1/1 chamber extracted to SX5	Feb 25	Feb 25
EMU-MEX/1	CSC DCFEBv2 boards ready for installation on ME-1/1	Mar 11	Mar 7
EMU-MEX/1	ALCT-LX100 ready for installation in ME-1/1	Mar 11	Mar 7
EMU-MEX/1	Full production of ALCT-LX150T released	Apr 15	
EMU-MEX/1	CSC on-chamber optical fibers ready for installation	Apr 15	
EMU-MEX/1	ME-1/1 installed and commissioned	Jun 2	
EMU-MEX/1	ALCT-LX150T ready for installation in ME+234/1	Jun 10	
EMU-MEX/1	First ME+234/1 chamber extracted to SX5	Jun 17	
EMU-MEX/1	New LV power in place for ME+234	Jun 30	
EMU-MEX/1	ALCT-LX100 ready for installation on ME2/2,3/2	Jun 30	
EMU-OPS/1	LV power in place for plus end cap	Aug 8	
EMU-OPS/1	Ready to join MWGR with ME-1/1	Sep 1	
EMU-MEX/1	First ME+1/1 chamber extracted to SX5	Oct 28	
EMU-OPS/1	Ready to join MWGR with ME+234/1	Nov 1	
EMU-MEX/1	OTMB production complete	Nov 15	

DAQ

The central DAQ system was mostly switched off until March 11 due to the cooling maintenance at Point 5. Only basic IT services, TCDS, selected miniDAQs, and DAQ testbeds were on whenever possible. CERN IT replaced the core network routers in the underground area. This resulted in 2 days without the private CMS network and several short interruptions thereafter. In addition, we operated as many HLT machines as possible in cloud mode to process CMS offline workflows. Since

March 26, all current and most of the retired HLT machines are on. They provide 32k physical cores (766 kHS), and process more jobs than all Tier-1s combined. The changing conditions required a lot of attention from the sys-admin team.

The DAQ software was migrated from SVN to git(lab). This transition was imposed by CERN IT as the SVN service was stopped in February. The development teams of the XDAQ and RCMS frameworks took the opportunity to restructure the software repositories, change the build system for RCMS, and embark on the use of continuous integration (CI) to ease release procedures. The F3 monitoring was ported to elasticsearch version 6. All central DAQ machines except for the HLT nodes have been updated to the latest CentOS 7.6 operating system, OFED version and Lustre kernel modules. This transition was completed successfully and the new releases were used for the first MWGR on March 20-22.

The preparation for Run 3 has started with reshuffling of the older generation of HLT nodes which will be operated exclusively in cloud mode from now on. They need to be relocated to make room in the racks that are powered by UPS for the future core services. The daq3val testbed, which provides 100 Gbps Ethernet and Infiniband connections between 16 Skylake event-builder nodes, is used to measure and optimize the event-building performance from the backend interface (FEROL40) to the HLT processing on the filter units. The measurements have confirmed the feasibility of a folded event-builder setup, where the readout and builder executables run on the same machine. This would require half the number of event-builder machines and switch ports. We started to evaluate new hardware for the storage and transfer system. In collaboration with a company, initial measurements have been performed using a benchmark application which emulates the merging and transfer workload.

The OMS project finished the migration of the core pages from the old WBM system that is being replaced. The remaining pages which include HLT information and the run-info table were released in January. The focus has shifted to the support of the subsystem pages. The OMS team worked hard to simplify and document the steps required to create API endpoints and corresponding OMS pages. The development process has been presented at several meetings and a couple of subsystems have started with the transition or the development of new pages. The redesign of the database schema inherited from WBM is in full swing, and stakeholders which need to provide data inputs have been contacted. In addition, we work on a proposal on how the deadtime and downtime shall be accounted for in Run 3. A new scheme needs to be worked out, as the current downtime definition relies on SCAL hardware which will no longer be available.

DAQ 2019 Milestones

Subsystem	Description	Scheduled	Achieved
DAQ	Migrated all DAQ s/w to gitlab	Feb 1	Feb 1
DAQ	RCMS and XDAQ releases from gitlab deployed	Mar 15	Mar 15
DAQ	Core XDAQ packages built with C++11/14	Jun 1	
DAQ	Evaluated storage-manager h/w for Run 3	Aug 1	
DAQ	OMS DB tables fully replace legacy tables from WbM/SCAL	Oct 1	

Subsystem	Description	Scheduled	Achieved
DAQ	Central DAQ hardware choices finalized	Nov 1	

Trigger

During this quarter the U.S. groups continued their maintenance, operations, and development work on the Layer-1 calorimeter (CaloL1) trigger, endcap muon trigger (EMTF), and global Level-1 trigger systems, as well as on the field operations of the Trigger Studies Group. These preparations will provide improvements and reliable running during Run 3 data taking operations.

Endcap Muon Trigger

The EMTF groups provided support for the first Midweek Global Run of 2019, although ultimately no endcap muon detector systems were included into the run. In preparation, the online software was updated to the latest version of SWATCH and the latest feature requests from 2018, and the repository was moved to a new centralized project GitLab area.

An EMTF micro-TCA slow control monitoring project is well underway, making use of communication via the IPMI interface. This is a project involving a student working with the University of Florida and another from the University of California, Davis, under the supervision of the University of Florida engineer. The goal is to be able to monitor at a glance through a web page the status of the EMTF links, power, temperatures, etc. Currently a prototype web page is working with dummy data, and next will be the development and test of web socket communication to the system.

A tool to monitor the Level-1 trigger cross sections as a function of pileup has been been developed. One can apply various quality criteria and study the pileup dependence of trigger cross sections (computed from rates and luminosities recorded in the online database). We will see if it can be integrated in a more centralized way for the Trigger project.

Optical cables for the connection between newly installed GE1/1 electronics and the EMTF have been ordered.

Layer-1 Calorimeter Trigger

During the last quarter of 2018, CaloL1 provided smooth data taking in heavy-ion collisions. The CaloL1 was turned off at the beginning of December 2018 together with the CMS detector. The major activities during the first quarter of 2018 were the preparation for the removal of the old RCT hardware from P5 and utilizations of its parts, and the preparation for the first Midweek Global Run (MWGR), March 20-22. The racks with the old RCT cards were inspected, and the cabling, crates, cards, and power supplies are to be removed from the racks. Part of hardware will be stored in B904 to be used for different projects. The plan for this work is now under discussion. The preparation for the first MWGR 2019 included an update of the SWATCH software and checking different parts of the hardware. The Calo L1 was successfully turned on, optical power on all fibers was checked and some small problems were fixed (fibers with low optical power were cleaned). The system provided smooth operation during MWGR. Some additional work together with central DAQ may be needed for a full update to the most recent SWATCH software implementation, and should be completed/checked by/during the next MWGR.

Field Operations Group of the Trigger Studies Group

This quarter, the Field Operations Group (FOG) has begun to turn its attention to preparations for Run 3. Notre Dame graduate student Kelci Mohrman has agreed to serve as L3 manager within FOG for the trigger rate monitoring (RateMon) software used both to monitor trigger rates in real time during data taking as well as in data certification for the trigger. We made improvements RateMon focusing on streamlining operational activities, saving more data about the trigger rate fits that are used to determine if the rates are in the acceptable range for a given amount of pileup, and improving the automatic fitting applied to the rate curves so that it now picks the best fit function rather than applying a standard default. These modifications are targeted at improving operational efficiency for Run 3. Mohrman presented RateMon plans at the CMS Level-1 Trigger Workshop and also the High-Level Trigger Workshop, and is now working to identify priorities that need to be addressed in RateMon development in advance of Run 3. A clear priority that has already emerged is the transition from Web-Based Monitoring (WBM) to the new Online Monitoring System (OMS).

Trigger 2019 Milestones

Subsystem	Description	Scheduled	Achieved
TRIG	Architecture for bringing GE1/1 signals to EMTF specified	Aug 30	
TRIG	EMTF online software framework extended to include GE1/1	Aug 30	
TRIG	Neural network PT assignment implementation into EMTF firmware	Dec 31	
TRIG	Initial algorithm to include GE1/1 into EMTF	Dec 31	
TRIG	Remove legacy BMTF firmware and keep only Kalman filter	Dec 31	
TRIG	Modify the Kalman filter algorithm to use the upgraded trigger primitives	Dec 31	
TRIG	Deinstall old RCT hardware	Sept 30	
TRIG	Exchange microSDs in all CTP7 cards	Sept 30	
TRIG	Calo Trig: Fix the cable trays in P5	Sept 30	
TRIG	Calo Trig: Initial demonstration of pileup mitigation algorithms involving machine learning using High-Level Synthesis	Jul 1	
TRIG	Calo Trig: Performance results of pileup mitigation algorithms involving machine learning	Dec 31	
TRIG	Assess needs for any rate monitoring software developments	Dec 31	
TRIG	Update rate monitoring software to adapt to evolution in DAQ infrastructure	Dec 31	

Software and Computing

While LHC accelerator and CMS detector are in Long Shutdown 2 there is no break for Software and Computing. Data processing continues to operate as during LHC running periods, minus the prompt processing and archiving of newly recorded data. The U.S. CMS facilities deployed sufficient computing resources to fulfill the 2019 pledges to CMS, and operational reliability and availability has been excellent, especially for the Fermilab Tier-1 facility. This has enabled use of U.S. analysis computing resources at very high scales, contributing significantly to the physics results shown at various conferences. It also enabled CMS to produce significant numbers of Monte Carlo events in various configurations for running period and detector. This success was also enabled by using High Performance Computing (HPC) resources like the DOE NERSC facility at LBNL and the NSF Pittsburgh Supercomputing Center facility. New allocations for 2019 were granted through the DOE ERCAP and the NSF XSEDE processes, which we intend to efficiently apply to solve CMS physics questions.

On the side of infrastructure software, the transition to the `Rucio` data management system made significant progress and we upgraded the transition plan. We also migrated the remaining CMS-supported services relying on CMS topology and other metadata from the CMS-specific database (`SiteDB`) to a WLCG-supported solution (`CRIC`). Software development continued with progress in the software framework support for computing accelerators like GPUs and the transition to a community solution for the detector geometry description (`DD4HEP`). The development of tracking on accelerators like GPUs made a lot of progress towards preparing CMS to run efficiently on the future HPC machines of DOE and NSF that typically are dominated by the use of accelerators.

Major milestones achieved this quarter

Date	Milestone
Jan 22	Fermilab LPC EOS upgraded to latest version and HTCondor pool re-factored to container based architecture
Jan 25	Release of software for MTD TDR studies
Feb 5	`SciTokens` issuer released to production CMSWeb instance
Mar 9	Release of first version of software for low-level reconstruction and calibration for ultra-legacy processing of Run 2 data
Mar 26	CMS onboarded to HEPCloud
Mar 31	Fermilab Tier-1 site has deployed sufficient processing, storage and archival resources to meet the 2019 CMS resource pledge.
Mar 31	All Tier-2 sites have deployed sufficient processing and storage resources to meet CMS resource pledges.
Mar 31	Updated `Rucio` transition plans presented at CMS Offline & Computing Week

Fermilab Facilities

Throughout this quarter the Fermilab Facilities continued to provide reliable custodial storage, processing and analysis resources to U.S. CMS collaborators. The site was well utilized, with the facility providing 43.8 million wall-clock hours of processing to CMS.

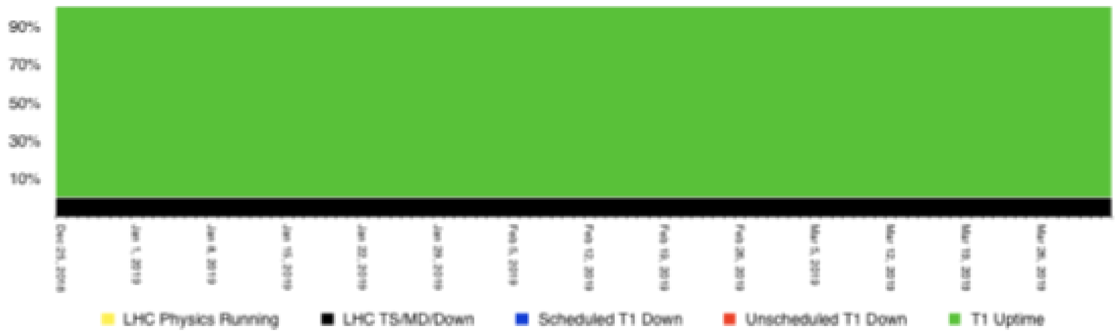


Figure 9: Fermilab readiness metrics for Q1 of calendar year 2019. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. The height of a red bar indicates how much of each day Fermilab services were affected. Black and yellow across the bottom indicates LHC machine running. During this quarter the LHC was shutdown for the first year of the long shutdown. Fermilab passed metrics 100% during the quarter.

Figure 9 shows the site readiness metrics, and during this quarter the Tier-1 facility passed CMS site availability metrics 100% of the time. Two incidents in this period were caught quickly enough to not impact delivery of computing resources to CMS: In preparation for turning on IPv4/IPv6 on our storage resources the Tier-1 disk dCache had an IPv6 address earlier than needed, causing transfer failures to some sites in March. Also during March the LPC EOS instance was flooded by user requests, causing it to be unavailable for several hours.

In January the Fermilab LPC took a day downtime to successfully upgrade EOS to the latest version, also used by CERN. The HTCondor batch resources used by the LPC users were also migrated from a static node to a more dynamic docker container based architecture, in time for users' preparations for winter physics conference approvals.

University Facilities

As seen in Figure 10, CMS production and analysis activities this quarter continued to run at high levels relative to full capacity. Total analysis usage has remained high and the faction of analysis activity by U.S. researchers at our sites has returned to the historical average of ~70% after a lull in activity over the winter.

All of the U.S. CMS Tier-2 sites operated successfully last quarter. On our two official performance metrics based on CMS test jobs, all sites were at least 95% "available" and 83% "ready", which is above the CMS requirement for each of these metrics of 80%. The U.S. CMS performance goal is 90%, which all sites met except for Caltech and Purdue. Nonetheless our commitments to CMS were met with success.

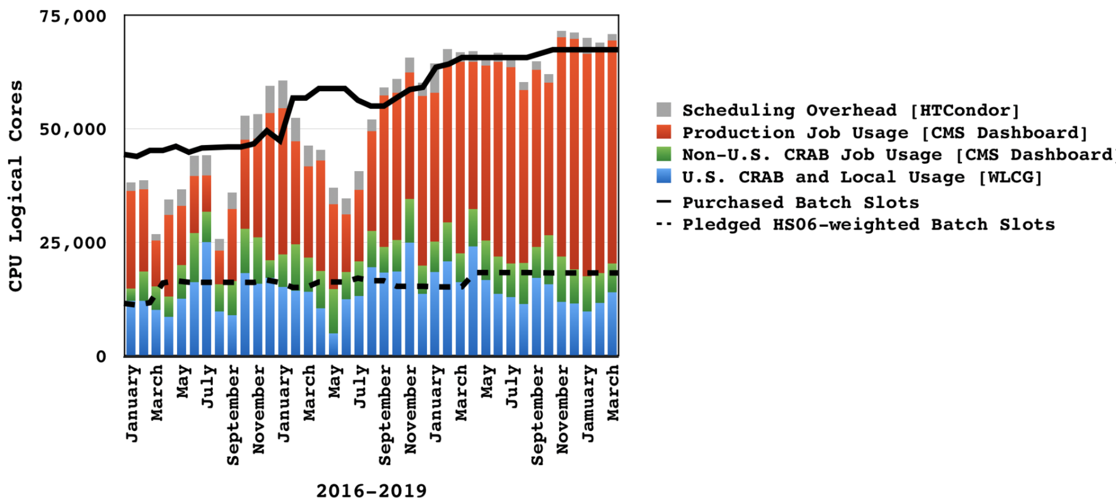


Figure 10: Processing usage at the U.S. CMS Tier-2 sites by month, broken down by type of usage (like production, analysis by U.S. researchers, and non-U.S. researchers) compared to purchased processing capacity.

The U.S. CMS Tier-2 centers delivered 49.4% of all computing time by Tier-2 sites in CMS last quarter, down about 1.4% from the previous quarter but consistent with historical averages. While we deliver ~50% of the Tier-2 computing power world-wide, the ~70% analysis usage by U.S. researchers shows that the extra capacity delivered above our headcount n particular goes to supporting data analysis by U.S. researchers, as is its purpose. The storage and processing deployment milestones to meet the April 1, 2019 pledge amounts to CMS were successfullly made.

The U.S. CMS Tier-3 support team provided help to fifteen sites on a number of issues mainly related to OSG software upgrades, Singularity, PhEDEx transfers, XRootD, and HDFS. We are also preparing for the transition from OSG CA host certificates to InCommon IGTF or alternative CA options. InCommon certificates have been tested and the Let's Encrypt CA is being explored. CMS Connect support continued and several interventions were required to handle issues with problematic users causing service degradation. Access to GPU resources at Vanderbilt were enabled and a workaround to allow interactive access to GPU resources was documented. Finally, the support team initiated a significant effort to verify the functional status of all U.S. Tier-3 sites and to remove from databases any sites that are no longer maintained.

Computing Operations

During the long shutdown CMS computing operations continues the processing of Run 2 data and is starting preparations for Run 3.

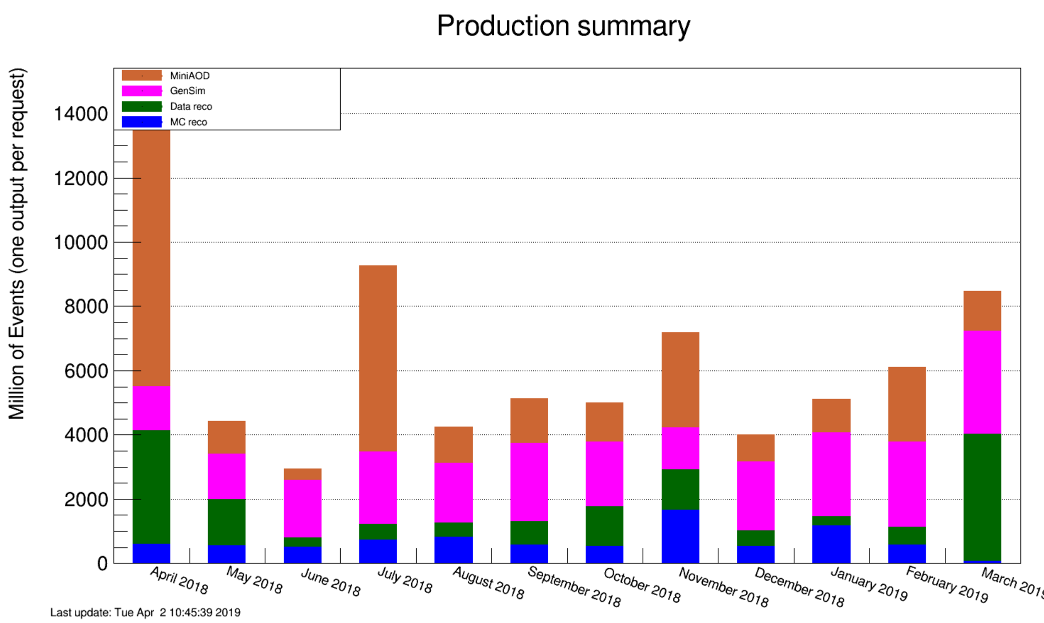
Distribution, archival, and reconstruction of the heavy ion data was completed in the first half of January. About 200 million additional Monte Carlo events with classical pile-up event handling were simulated with the 2018 detector configuration. Over 4.2 billion additional Monte Carlo events with the 2018 detector configuration and 2 billion events with the 2017 detector configuration using the resource-efficient, pre-mixing pile-up method were also simulated and made available to the analysis teams.

Large parts of the "parked" physics data from 2018 were staged back from tape for processing. However, delays in finalizing the small miniAOD data format delayed start of processing until end of March. For the MIP Timing Detector TDR a simulation campaign was completed within a few weeks. An issue in the processing of the forward electromagnetic calorimeter in the heavy ion (HI) data was identified and requires a re-processing of 2018 HI data.

CMS reviewed the data on tape and identified datasets that are superseded. The tape deletion campaign is expected to free about 30 PBytes of space and is currently reviewed by the CMS physics groups.

Two issues impacted production activities: the EOS/`Unified` issue continued to require manual intervention at the beginning of the quarter and a new EOS/`Unified` issue developed and caused a slow down toward the end of the quarter. New metadata queries were added to `Unified` and overloaded the metadata database service, DBS, in the second half of March. Identifying the culprit took time and the queries were corrected end of March.

Overall data processing used all available production resources up to 200k cores. During the quarter, up to 30k cores from NERSC and up to 10k cores from underutilized ATLAS sites were used.



Computing Infrastructure and Services

The Rucio transition project progressed during this quarter on a number of fronts. The Kubernetes setup was further refined with regular synchronization of data between PhEDEx and Rucio. Work began on the code necessary to interface WMAgent with Rucio, and code was added to DAS to present Rucio rules. The plans for the transition were revised and expanded with a planned transition of the NanoAOD data tier first followed by other data; the updated CMS-wide milestones were presented at CMS Offline and Computing Week in March 2019.

In this reporting period, the remaining CMS-supported services relying on CMS topology and other metadata were migrated from the CMS-specific solution (SiteDB) to a WLCG-supported one

(CRIC). We are now planning the shutdown of SiteDB in order to free up effort for further consolidation around CRIC; this shutdown has been delayed to Q2 2019 due to unavailability (maternity leave) of the CERN-based manager of the CMSWeb service.

U.S. CMS continues to support the CERN-led effort to modernize the CMSWeb stack. During this quarter, the Kubernetes-based prototype has matured and has one outstanding issue which requires resolution by CERN IT. Once resolved, we can start the final planning for rollout of this infrastructure (if no additional issues are discovered, Q3 2019 is possible). Finally, the ability for CMSWeb to issue "`SciTokens`" (www.scitokens.org) to access CMS's distributed storage was moved into production. This allows continued testing of new authorization mechanisms across the WLCG infrastructure.

This quarter additional effort has started at the University of Notre Dame for workflow management; this partially alleviates the shortage caused by the loss of a developer (Ryu) at FNAL during the previous quarter. The new developer, Kenyi Hurtado, has been working with Alan Malta to understand our production software stack. Hurtada is beginning to do minor bug fixes and cleanups to better understand the code. Next quarter, he will begin on a project to refactor how WMAgent interacts with HTCondor, improving the scalability of the agent by allowing bulk submission of jobs.

The original XSEDE allocation ended and U.S. CMS got renewed allocations at PSC and TACC. We also received hours at SDSC and Jetstream (XSEDE Cloud). CVMFS commissiong continues at TACC, SDSC and Jetstream. NERSC is being used at good pace and worked to onboard CMS into the HEPCloud production system.

Software and Support

A broad variety of activities have continued in support of both current CMS operations and long-term preparations for the HL-LHC. The CMS event processing framework is being adapted to handle accelerator processors such as GPUs, allowing for the exploration of pixel tracking on GPUs and for easier switching between legacy CPU and new GPU algorithms. Concurrency is being improved, most recently by modifying the EventSetup system to allow multiple such modules to run concurrently during the same interval of validity update. Efforts continue on developing the pre-mixing of pileup events in the simulation, a key technology for improving the resource needs of that process. New developments include the integration of the MTD for HL-LHC studies and options to allow for the easier production of run-dependent pileup profiles.

The transition to the community-supported DD4HEP package for the description of detector geometry is also continuing, with changes to the package structure that will support the transition, and the integration and validation of the description of the muon drift tubes. Geometry navigation performance has been improved by 75%. The event visualization tools are being moved towards a web-based system, with the first implementation of cross view selection on the client side.

There has been significant progress on the development of columnar-based analysis tools. The addition of certain accelerated functions have sped up one step of the boosted H to bb analysis by a factor of 125. New functionality has been added to easily swap among different histogramming packages. More users are starting to contribute code to the effort, expanding the developer base.

A turnkey system for machine learning benchmarking has been developed. Two benchmarks are now available, one focused on data analysis and one on event reconstruction. Each can run on both GPU and CPU systems.

Many R&D efforts continue, including exploration of different technologies for analytics/monitoring efforts; a study of the use of raw detector information for event classification; and development of parallel Kalman filter tracking and a segment-linking tracking algorithm.

Other activities

Multiple versions of the reconstruction software were released, targeted towards the reconstruction of heavy ion data, the reconstruction of parked data for b physics, simulation and reconstruction of the MTD for HL-LHC TDR studies, and low-level reconstruction and calibration for the ultra-legacy reprocessing of Run 2 data.