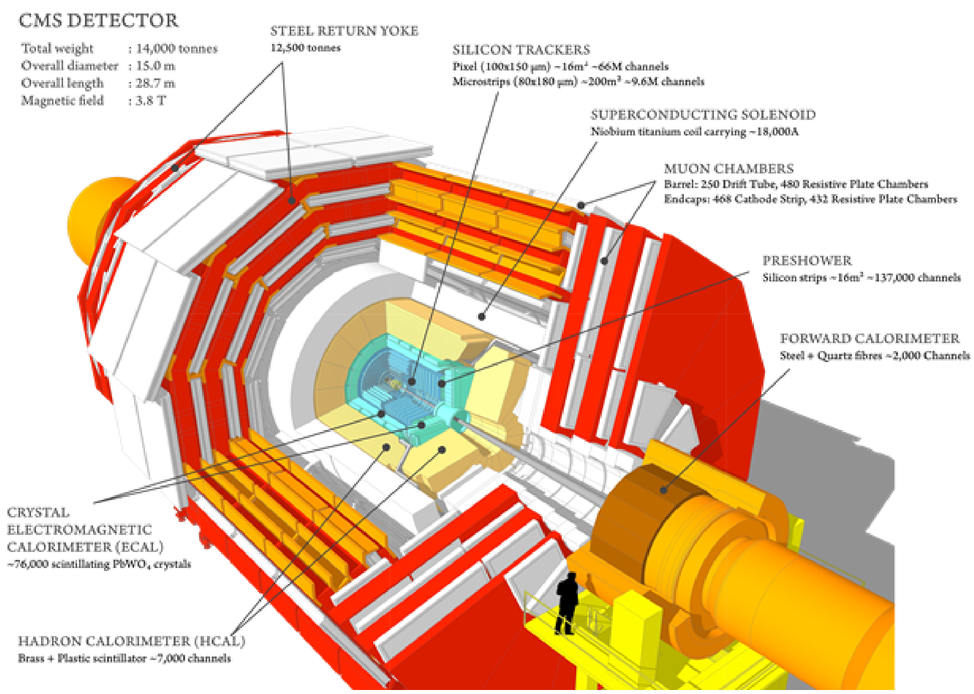
U.S. CMS Compact Muon Solenoid Operations Program
Quarterly Report for the Period Ending December 31, 2017

U.S. CMS Operations Program



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 2017, as well as the funding guidance for 2018 through 2020, is shown in Figure 1. The allocations shown for 2017 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.

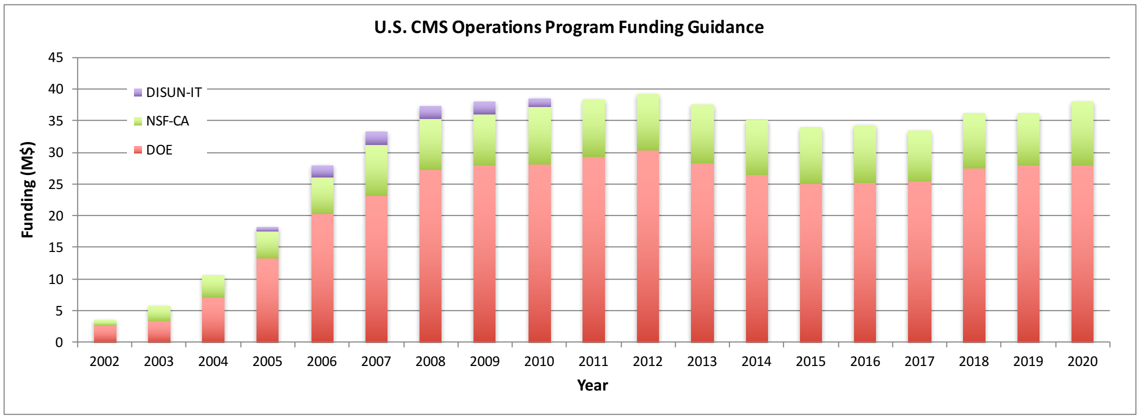


Figure 1: The annual U.S. CMS Operations Program funding provided by DOE and NSF. For 2002 through 2017 the chart shows the actual funding, while for 2018 onward the current funding guidance is shown.

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 2017 took place in July and August of 2016. As an additional source of input to the planning process, the Resource Allocation Advisory Board met five times from September through December of 2016, and issued a report of findings and recommendations. Through these processes, U.S. CMS Management developed a detailed spending plan, while taking into account updated guidance from the funding agencies. This plan was further refined through the January 2017 joint NSF/DOE Operations Program review.

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 December of 2017, a total of 81 SOWs (56 DOE and 25 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

CY17 spending plan, as of the end of Q4, 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 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 through Universities and CERN Team Accounts is budgeted and tracked according to the calendar year. Spending at Fermilab has historically been budgeted according to the fiscal year, however this is the third year that we are 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, $2.5M in subawards went out this quarter, in addition to spending directly at Princeton.

Resources deployed at CERN, and paid directly in Swiss francs, account for approximately 27% of the 2017 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 CY17 Q4 averaged 0.99 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 3,668K 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, according to the workflow described in the following subsection. At the start of the quarter, the Risk Register contained 33 open risks spread across the program. At the end of the quarter, there were 33 risks, with threats summing to $7.6M and opportunities summing to $0.5M. Figure 7 shows the top few risks at the end of the quarter, ranked by *Probability* $\times$ *Cost Impact*, as well as any risks added, realized, and retired 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 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 miti-

WBS	Subsystem	Change Request Number	Description of Change	CY17 Q4 Plan	Change $	CY17 Q4 End
U.S. CMS Detector Operations Change Control Activity						
11	Endcap Muon			$2,188,153	$0	$2,188,153
12	Hardon Calorimeter	CR-042	CERN TA COLA reduced for Maryland and added for Kansas State to work on online and DAQ of HCAL	$1,966,082	($5,060)	$1,961,022
13	Trigger			$1,030,397	$0	$1,030,397
14	Data Acquisition			$886,300	$0	$886,300
15	Electromagnetic Calorimeter			$859,286	$0	$859,286
16/17	Tracker (Fpix & SiTrk)	SOW; CR-009, 010	Engineering labor support at Kansas State for pixel firmware; Labor support for Fermilab and UC Davis for Fpix removal and DCDC refurbishment	$867,781	$77,387	$945,169
18	Detector Support			$92,119	$0	$92,119
19	BRIL	SOW	Engineering labor support at Rutgers for PLT opto-motherboard redesign	$265,930	$6,653	$272,583
11-19	**Detector Operations**			**$8,156,049**	**$78,980**	**$8,235,029**

WBS	Subsystem	Change Request Number	Description of Change	CY17 Q4 Plan	Change $	CY17 Q4 End
U.S. CMS Common Operations Change Control Activity						
21.2	Common Costs (M&OA)			$4,003,924	$0	$4,003,924
21.3	Run Coord. and Monitoring			$440,073	$0	$440,073
21.4	LHC Physics Center			$819,727	$0	$819,727
21.5	Operations Support	CR-108, 109, 110, 111; SOWs	Iowa labor and travel, FNAL engineering and tech labor for fast timing, CERN TA for HCAL Project Manager and fast timing sensors, Rice support for Det Ops L1, Caltech for fast timing test stand equipment	$2,288,925	$477,653	$2,766,578
21.6	Program Office			$1,323,397	$0	$1,323,397
21.7	Education and Outreach			$110,585	$0	$110,585
21	**Common Operations**			**$8,986,630**	**$477,653**	**$9,464,283**

WBS	Subsystem	Change Request Number	Description of Change	CY17 Q4 Plan	Change $	CY17 Q4 End
U.S. CMS Software and Computing Change Control Activity						
22.1	Fermilab Facilities			$6,079,827	$0	$6,079,827
22.2	University Facilities			$3,480,253	$0	$3,480,253
22.3	Computing Operations			$929,522	$0	$929,522
22.4	Computing Infra. and Services			$2,471,440	$0	$2,471,440
22.5	Software and Support			$2,365,184	$0	$2,365,184
22.6	S&C Program Management & CMS Coordination			$205,081	$0	$205,081
22	**Software and Computing**			**$15,531,307**	**$0**	**$15,531,307**
U.S. CMS Operations Program Total				**$32,673,986**	**$556,633**	**$33,230,619**

Figure 2: Spending Plan Change Log for CY17 Q4.

WBS	Subsystem	DOE Funds	NSF Funds	Total
11	Endcap Muon	$1,628,615	$559,539	$2,188,153
12	Hadron Calorimeter	$1,925,609	$35,413	$1,961,022
13	Trigger	$810,983	$219,415	$1,030,397
14	Data Acquisition	$886,300	$0	$886,300
15	Electromagnetic Calorimeter	$851,286	$8,000	$859,286
16/17	Tracker (Fpix & SiTrk)	$888,544	$56,625	$945,169
18	Detector Support	$92,119	$0	$92,119
19	BRIL	$129,716	$142,867	$272,583
11-19	**Detector Operations**	**$7,213,172**	**$1,021,857**	**$8,235,029**
21.2	Common Costs (M&OA)	$3,188,274	$815,650	$4,003,924
21.3	Run Coordination and Monitoring	$332,137	$107,936	$440,073
21.4	LHC Physics Center	$819,727	$0	$819,727
21.5	Operations Support	$2,510,918	$255,660	$2,766,578
21.6	Program Office	$1,004,097	$319,300	$1,323,397
21.7	Education and Outreach	$0	$110,585	$110,585
21	**Common Operations**	**$7,855,152**	**$1,609,131**	**$9,464,283**
22.1	Fermilab Facilities	$6,079,827	$0	$6,079,827
22.2	University Facilities	$118,306	$3,361,948	$3,480,253
22.3	Computing Operations	$397,791	$531,731	$929,522
22.4	Computing Infrastucture and Services	$1,808,279	$663,161	$2,471,440
22.5	Software and Support	$1,340,171	$1,025,012	$2,365,184
22.6	S&C Program Management and CMS Coordination	$94,683	$110,398	$205,081
22	**Software and Computing**	**$9,839,057**	**$5,692,250**	**$15,531,307**
U.S. CMS Operations Program Total		**$24,907,381**	**$8,323,238**	**$33,230,619**

Figure 3: Spending plan at the end of CY17 Q4, for funds from DOE, NSF, and the total.

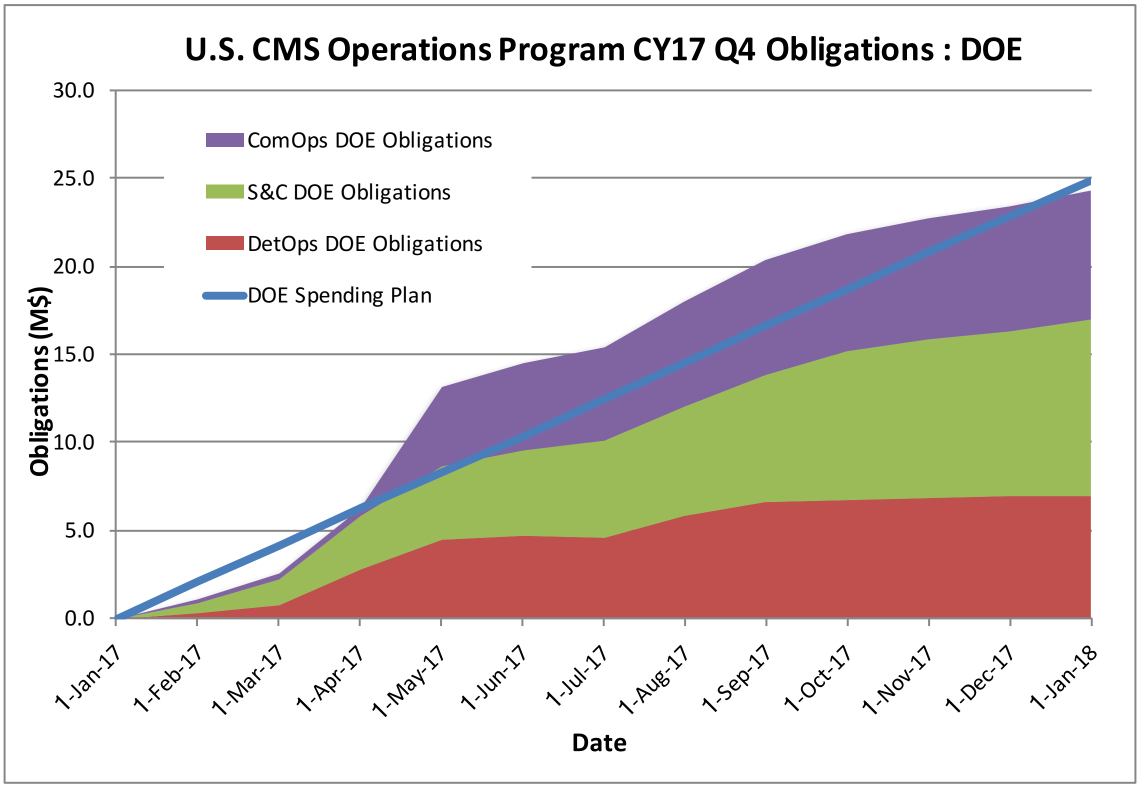


Figure 4: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

gation 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.

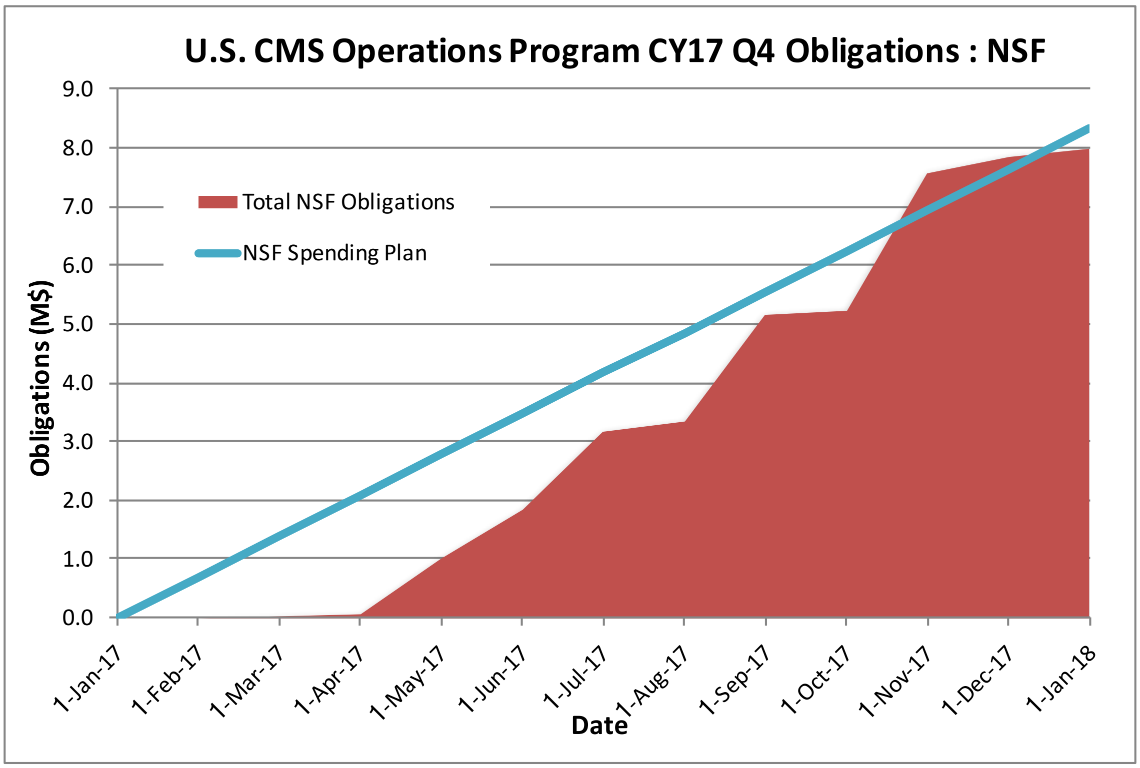


Figure 5: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.

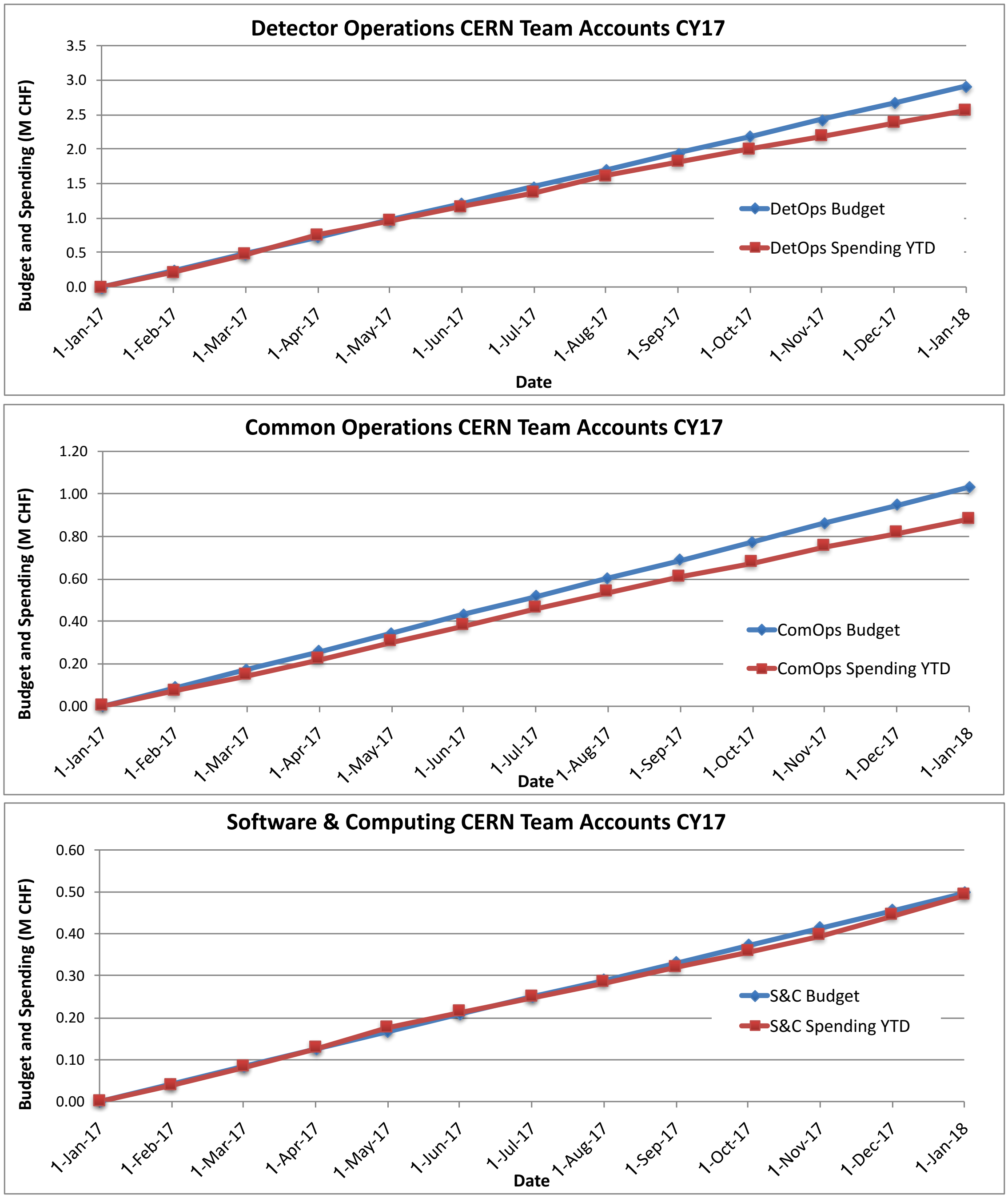


Figure 6: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.

CY17 Q4 Risk Register Summary Table			
	Probability	**Schedule Impact**	**Cost Impact**
Top Risks (ranked by Probability x Cost Impact)			
EMU – EPROM failures on DCFEBs	20%	3 months	$1,000k
S&C - Need to bridge OSG tech evolution staff to new funding	75%	0 months	$200k
ECAL - Laser fails	20%	0 months	$250k

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 added, realized, and retired this quarter.

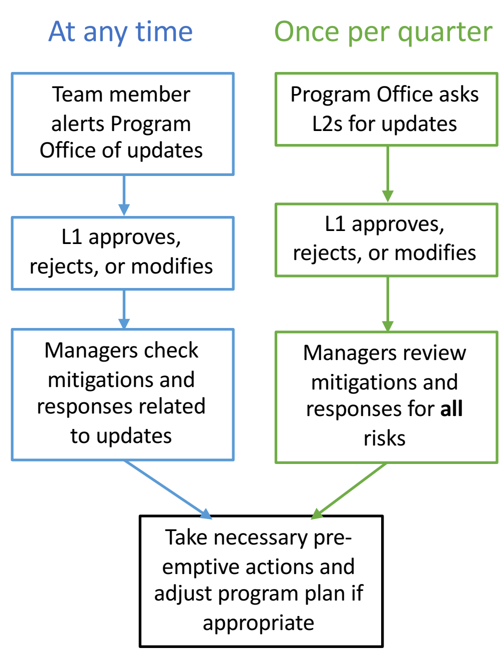
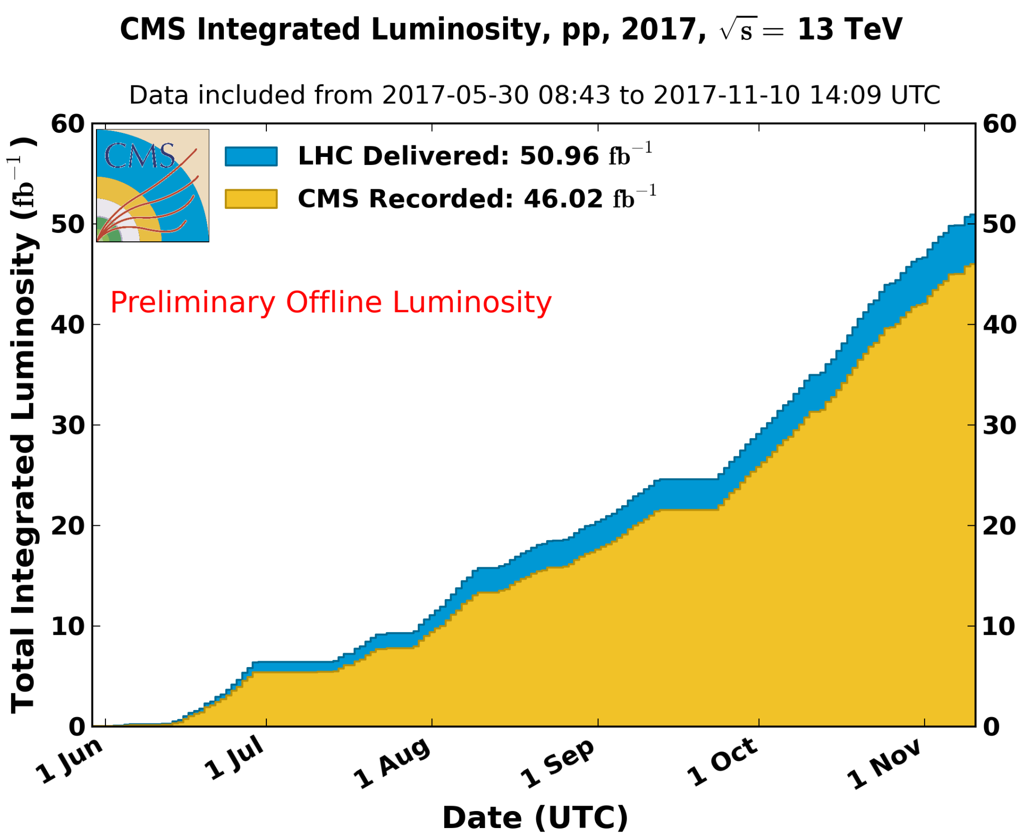


Figure 8: Summary of the two Risk Management Plan workflow paths.

Detector Operations

The operation of the CMS detector continued relatively smoothly through to the end of the run. The LHC is now off for its annual Year End Technical Stop during which time maintenance will be performed on the accelerator and detectors. Since August the data taking efficiency has consistently been greater than 92.5%, which was the average efficiency last year.

In October a problem appeared in the pixel system that resulted is some loss of channels which is currently being investigated. It is important to note that even with this issue the new pixel detector is now working better than the old one.



Luminosity, at 13 TeV, delivered by the LHC and recorded by CMS, in 2017.{label="fig:Lumi"}

BRIL

The Pixel Luminosity Telescope (PLT) together with the fast beam condition monitor (BCM1F) and HF provided online luminosity measurements continuously. The fast readout for all telescopes works. Two telescopes are degraded, affecting the full pixel information that is used for track-based studies.

In addition to luminosity determination, reconstructed tracks in the PLT are also used for fast measurements of the beam spot and allow tracking of beam conditions. Corrections for efficiency and accidentals are obtained from offline analysis of tracks, and fast turnaround after completion of each fill is being achieved. These corrections change with beam conditions and the expected reduction of efficiency over time. Corrections are also obtained from mini-VdM scans at the start and end of a fill. Luminosity based on full track measurements was broadcast online. Systematic studies led to improved luminosity precision. Preliminary luminosity values have been obtained for the 2018 running (preapproval on 19 Dec).

The PLT will have to be extracted during the year end technical stop. The lab in P5 with two cold boxes was established and spare cards were prepared in case of failures — the $+z$ side was placed in the P5 lab on December 20 and its functionality tested. It is kept at $-10\,^{\circ}\mathrm{C}$. The $-z$ side will be extracted in January.

Table 1: BRIL Metrics

Working Metric	Performance
Fraction of telescopes fully operational	90%
Efficiency of delivery of lumi histograms	$>$ 99%
Uptime of lumi histogram production	$>$ 99%
Lumi lost	0 /pb

Table 2: BRIL Milestones

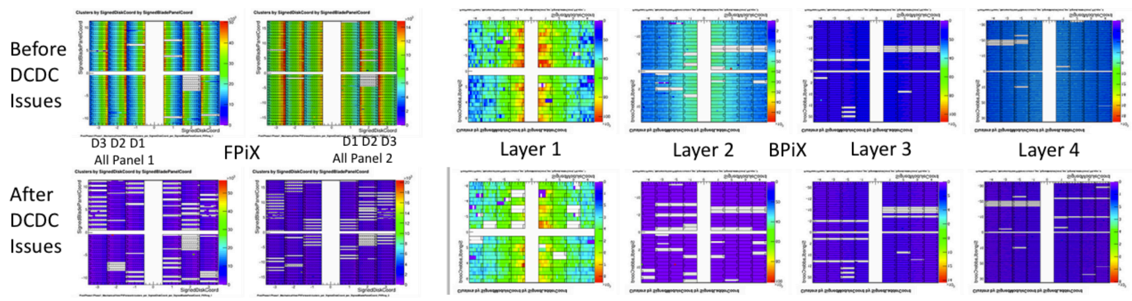
Subsystem	Description	Scheduled	Achieved
BRIL	Update Lumi for 2016	March 1	March 1
BRIL	Ready for Physics	May 1	May 1
BRIL	Improve 2017 Lumi numbers	December	Preapp. Dec 19

Tracker

Operational concerns for the tracker were dominated by the loss of DC-DC converters in the Pixel. Other major operational issues were downtimes for the strip cooling, some online timing and High Voltage scans, and incidents where some strip FEDs getting stuck (sometimes due to power issues). Work was needed in the reconstruction and simulation to keep up with the changing conditions in the pixel detector. Data quality for this quarter was very good as a result of the effort.

Pixels Detector

Starting October 5th, a number of pixel DCDC converters stopped delivering voltage to pixel modules. This occurred both in the Barrel (BPiX) and Forward (FPiX). DCDC converters became non-functional at power or enable/disable cycles. As a consequence, we shut off the automatic recovery for TBM single event upsets and instead did the recovery during inter-fill periods. In general, we lost about 0.5% of the DCDC we cycled during recovery procedures or power cycles. In December, the FPiX detectors on the plus side of CMS were removed and the DCDC converters examined in detail. Preliminary results indicate an issue in one of the voltage regulators on the chip, though the root cause for the trouble is not proven. During the YETS, the rest of the pixel detector will be removed and new (or refurbished) DCDC converters will be installed prior to re-installation.



The Pixel Detector cluster positions before DCDC converter issues appeared and at the end of running showing the loss of active channels due to non-functioning DCDC converters. New white areas indicate a loss of efficiency.

Strip Detector

The main issues in the strips are ongoing maintenance issues, such as power supply swaps, condition sensors etc. The Operations crew tries to minimize downtimes as these issue pop-up. The strips are looking to reduce time spent in SEU recovery and are recognizing the need for better long term solutions for maintaining the strip FEDs. The strips will be run colder in 2018 to allow more poorly cooled modules to have sufficient sensor voltage for physics.

Table 3: Tracker Metrics

	Pixels	Strips
% Working channels	88.6	96.3
Downtime attributed in pb^{-1}	75.5	191.5
Fraction of downtime attributed (%)	8.7	19.8

Table 4: Tracker Milestones

Subsystem	Description	Scheduled	Achieved
Tracker	Pixel Phase 0 Detector Removed	Feb 15	Jan 23
Tracker	Pixel Phase 1 Detector Installed	Mar 30	Mar 12
Tracker	Pixel Phase 1 Detector Ready for Collisions	May 5	Jun 16

ECAL

The ECAL continued to operate smoothly in the final three months of the run. There were no major incidents in any of the systems. Improvements in the DAQ efficiency came from better monitoring tools and consolidation of the single event upset (SEU) recovery procedures between ECAL and the ECAL pre-shower. Increase regularity of updating the laser corrections in the trigger improved the trigger turn on efficiency. The low voltage and laser systems operated without major problems. In December U.S. CMS laser technician David Bailleux received a CMS detector award for "for outstanding contribution to all technical aspects of the ECAL and for his dedication to the ECAL laser system."

Table 5: ECAL Metrics

Metric	Performance
Fraction of channels operational: EB	99.1%
Fraction of channels operational: EE	98.4%
Fraction of channels operational: ES	99.9%
Downtime attributed pb^{-1}	42
Fraction of downtime attributed	6%
Resolution performance	2.5%

Table 6: ECAL Milestones

Subsystem	Description	Scheduled	Achieved
ECAL	Refurbish Maraton to provide redundant thermal interlock	March 1	March1
ECAL	Replace Laser Diode	March 1	March 1
ECAL	Ready for Beam	May 1	May 1
ECAL	Preliminary Calibration	June 15	July 15

HCAL

During the fourth quarter of 2017, the HCAL Operations group focused continuing to take good data, and preparing for the installation of the Phase 1 HE upgrades during the 2017-18 YETS.

The upgraded HF with dual anode readout and TDCs continued to perform well. All the new handles to achieve noise reduction were in place earlier in the year and a substantial reduction in missing Et trigger rates was been achieved. Energy recovery using the "other" anode when one anode has an out-of-time signal was successfully implemented. The HE, with one upgraded HE readout box (out of 36) installed to obtain experience with upgraded system, also continued to perform well.

During the quarter, HCAL downtime was only 1.7 pb^{-1} out of more than 20 fb^{-1} recorded. For calendar 2017, HCAL downtime was 79 pb^{-1} out of 45 fb^{-1} recorded.

Planning to install the complete HE upgrade in 2017-18 YETS is complete. The plan enables installation even with the significant activity required to remove and re-install the pixel detector. The

Installation Readiness Review for the HE Phase-1 upgrade during YETS 17/18 was held November 6, and was successful. The items on the "watch" list from the review have been completed. This includes the external low voltage for for the SiPM bias voltage replacing the DC-DC converters.

The observed damage in HE was confirmed to have a significant component from damage to the HPDs as opposed to just scintillator damage.

A second HE readout box (HEP18) was installed in mid-December after the start of the YETS. The installation went very smoothly. The time from being able to access the HE nose to observing single PE peaks on all 192 channels after installation was less than 25 hours.

The final decision on installing the full upgrade will take place in January and has some dependence on the pixel detector re-work.

Work on the HB Phase 1 upgrades, which will take place in LS2, also continued.

Table 7: HCAL Metrics

Metric	Performance
Fraction of channels operational: HF	100%
Fraction of channels operational: HE	99.85%
Fraction of channels operational: HB	99.77%
Fraction of channels operational: HO	99.72%
Downtime attributed pb^{-1}	78.9
Fraction of CMS downtime due to HCAL	3.1%
Abs Energy Calibration	2%
Inter-calibration Uniformity	2%

Table 8: HCAL Milestones

Subsystem	Description	Scheduled	Achieved
HCAL	HF Phase 1 Installed	April 1	March 15
HCAL	HF Detector Commissioned	June 1	May 1
HCAL	Ready for Physics	June 1	May 15
HCAL	Data Loss $< 1%$	July 15	July 10
HCAL	1% to 2% Calibration	July 15	Nov. 1

EMU

The CSC system completed the 2017 proton-proton run with 98.2% of the channels active. Many of the missing channels come from four chambers that were disabled at the beginning of 2017 data taking: two chambers (ME-1/1/34 and ME-1/1/35) without cooling due to water leaks, and two other chambers (ME-2/1/3 and ME-4/2/21) that are disabled due to low voltage problems. These will be investigated early in 2018 during the Year End Technical Stop (YETS).

The CSC detector shutdown started on Dec 4th. The gas system was stopped and chambers filled with backup gas mixtures (Ar 40%, CO_2 60%). Two spare ME1/1 chambers are ready to be installed in place of ME-1/1/34 and/or ME-1/1/35 in case we would discover that the source of the cooling leak is coming from one of the on-chamber cooling circuit, though we believe this is unlikely. The two spares have been extensively tested in SX5 using our standard DAQ.

During operations, there were several issues with the Maraton low voltage supplies, with a total of six Maraton incidents in 2017. Three of these were random self-switch-off events, and these are the main concern. Other users of these supplies are being consulted to try to learn if there is a systematic issue. The other faults were caused by CANbus communication issues. All will be investigated during YETS.

During collisions, we observed a prominent excess in the local segment (trigger primitives) in the top region of the ME4/2 ring, where the rate was about three times higher than other regions in azimuth. Studies with isolated bunches showed that these segments occurred two and three bunch crossings later than in-time muons. These segments do not contribute to the L1 muon trigger rate because they do not correlate with other stations to form tracks, but they contribute to the DAQ occupancy. It is being investigated if the source of this effect can be mitigated with additional shielding.

Another excess was observed in the ME1/1 chambers during cosmic ray running in the hours following high luminosity runs. These appear to be the result of activation of material near these chambers. The rate from this source (about 250 Hz maximum) is negligible during collider operations.

Both of these features and the results of these studies were reported to the CMS Technical Integration Group in November.

The chamber gains continued to be studied after the HV changes were implemented to improve gain uniformity. The goal is now to find a suitable operating point with lower gain to improve chamber longevity. The plan is now to analyze the full 2017 data to reduce the gain uncertainties. The milestone for implementing the reduced-gain HV settings has been rescheduled for May 2019 in conjunction with the resumption of collider operations.

A productive mini workshop on CSC local reconstruction was held at CERN on Dec 12. Several projects from many groups are ongoing towards developing improved algorithms and searching for new approaches in reconstruction of CSC hits and segments in order to maximize performance in high background and occupancy conditions, typical of high-luminosity running.

A second round of exposure of muon electronics boards at CHARM II was completed in October, with a total dose of 37.2 kRad. As expected, all the optical transmitters on the three DCFEBs in the test eventually failed by the time the exposure reached about 35 kRad. The optical transmitters were then replaced on the irradiated boards, and subsequent tests showed the boards to be working properly otherwise.

At the GIF++ facility, irradiation of the ME1/1 and mini-CSC with a mixture containing 2% of CF_4 (instead of the usual 10%) is in progress. With an accumulated charge comparable to 1/3 HL-LHC we observe no signs of aging so far. Parallel testing of a mini-CSC in B904 using a ^{90}Sr source and 2% CF_4 shows stable operation after the equivalent of one HL-LHC integrated charge. This is of interest for possible future reduction in the use of CF_4, a potent greenhouse gas.

Table 9: CSC Metrics

% Working channels	98.2%
Downtime attributed pb^{-1}	25.2

% Working channels	98.2%
Fraction of downtime attributed	5%
Median spatial resolution	126 μm

Table 10: EMU Milestones

Subsystem	Description	Scheduled	Achieved
EMU		May 1	April 29
EMU		July 1	January 29
EMU	New HV settings for reduced gain	August 1	Reschedule to May 2019

DAQ

The DAQ system continues to work without major issues. During the first few hours of luminosity leveling in each LHC fill, the DAQ handled 1.5 MB events at 90 kHz level-1 trigger rate and the HLT CPUs were up to 90% loaded. The output of the HLT was typical 3 GB/s. The pp-reference run stressed the storage and transfer system (SMTS) with a very high HLT output bandwidth of up to 6 GB/s during a couple of days. Thanks to the close attention of the SMTS and Tier-0 experts, no major problems occurred.

The only downtime caused by the DAQ system was due to circuit breakers tripping on a few racks containing filter-farm and builder-unit nodes. The investigation showed that 4 out of 24 racks had breakers with a too low current rating. A couple of filter-farm PCs were switched off in the affected racks to mitigate the problem. The circuit breakers were replaced after the end of the physics program.

The GEM detector has been integrated into the DAQ system. Provisions for the upgraded DT readout system (μROS) and the new slink-express sender cards with an optical link developed for the ECAL readout have been made. Concerning the HLT, 400 Skylake-based machines have been ordered to replace the old C6220 nodes and the Huawei nodes on loan from CERN IT. The new machines will increase the HLT CPU capacity by 20% compared to 2017. This should provide enough margin to cope with any LHC running condition in 2018 and mitigate any inefficiency from the pixel detector in case that the DCDC problem cannot be fixed during the YETS.

The DAQ monitoring tools were further improved. The most notable additions are the recording of the deadtime values together with the DAQ status information, and the improved diagnostic in the DAQ expert to pin-point the origin of the dead time. The addition of more case-based reasoning modules to the DAQ-expert, who proposed recovery procedures to the DAQ operator, have increased the overall DAQ running efficiency. Andre Holzner of UCSD received a CMS Detector Award "For crucial contributions to many aspects of the CMS data acquisition, in particular the networking and monitoring for run-2."

The development of the online monitoring system (OMS) is progressing. The second review held in December showed that more work is needed before the newly developed meta-data catalog can be deployed in production. The decision has been taken to postpone any further work on the final back-end system and to concentrate on deploying the new user interface as quickly as possible in

2018. The aim is to provide all required services with the new user interface, and to be able to retire the legacy WbM hardware and processes by end of 2018. The work on the back-end will resume once these goals have been achieved.

Table 11: DAQ Metrics

Dead time due to backpressure	0.65%
Downtime attributed pb^{-1}	7.1
Fraction of downtime attributed	0.07%

Table 12: DAQ Milestones

Subsystem	Description	Scheduled	Achieved
DAQ	New sub-systems integrated	Apr 1	Jun 15
DAQ	Event builder expanded, re-optimized for larger events	Jun 1	Apr 1
DAQ	Old HLT Nodes replaced and new nodes commissioned	Jun 1	Jun 21
DAQ	Prototype of OMS (new WBM) ready for field tests	Dec 31	

Trigger

During this quarter the US groups continued their work on the Layer-1 calorimeter (CaloL1) trigger and the endcap muon trigger systems as both continued reliable data-taking. After completion of 2017 data-taking the groups worked on preparations for maintenance to be performed during the year-end shutdown.

Endcap Muon Trigger

The Northeastern, Rice University, and University of Florida groups have maintained the EMTF system 24/7 during operations this quarter. A diagnosis of rare online control PC crashes exposed a clash of system monitoring requests over PCIe. The EMTF firmware has been reworked and successfully tested to improve arbitration. The SWATCH online control software was updated with new reference values for EMTF registers.

A study of an observed higher rate of LCTs (track stubs) originating in ME4/2 at $\phi \approx 90^\circ$ has been performed. Characteristics are consistent with beam or radiation induced backgrounds. No significant impact on tracking performance is observed. A study of the pile-up dependence of the muon trigger also is ongoing, which shows that out-of-time segments do have an effect on higher threshold muon triggers. Options to tighten the timing and spatial matching windows are under investigation.

To debug occasional serial link errors between certain Muon Port Cards (MPCs) and the EMTF, two versions of MPC firmware were loaded and the respective error rates studied. The one with lower error rates (bypassing elastic buffers in the FPGA) will be uploaded in 2018.

Layer-1 Calorimeter Trigger

The Layer-1 Calorimeter Trigger (CaloL1), built by the University of Wisconsin - Madison, is a part of the complete Calorimeter Phase-1 Trigger Upgrade. CaloL1 was in continuous operation during the LHC physics run in the last quarter of 2017. Before cooling was shut down on December 6, the system was powered down for the Year-End Technical Stop (YETS) and currently remains off until cooling is restored and stable.

This was a relatively quiet quarter with a technical stop and two machine development periods. CMS took p-p data at 13 and 5 TeV and participated in a short Xe-Xe reference run. The only change to CaloL1 operations was to update the name to an alias for the uTCA bridge PC. If a PC needs replacement this will make the operation transparent to CaloL1.

During this quarter, another of the ECAL links developed optical power issues. This was resolved by simply moving the fiber on the ECAL side to the RCT position in the dual-transmitter VTTx. In addition, small discrepancies in the trigger primitives were observed in a couple of ECAL towers. This became more pronounced near the end of the run, affecting multiple towers in ieta ± 20 and ± 26. ECAL believed it was due to a timing alignment issue.

Final updates are under way to finish the work on the monitoring of the uTCA via the RCT DCS. During the YETS, the RCT WinCC OA was completely reinstalled to add a DIM framework and uTCA node to the finite state machine. A DIM server that is accessed by the DIM framework is now running as a service on our CaloL1 SWATCH PC and is monitoring the uTCA by querying University of Wisconsin System Manager on our uTCA bridge PC. This was done because it makes the bridge PC as generic as possible, the preference of the CMS Online System Administrators.

Table 13: Trigger Metrics

Frac of MPC Channels	100%
Frac of Upgrade EMUTF Channels	100%
Deadtime attributed to EMTF pb^{-1}	8.4
Fraction of deadtime attributed to EMTF	0.9%
Frac of Calo. Layer-1 Channels	100%
Deadtime attributed to Calo. Layer-1 pb^{-1}	0
Fraction of deadtime attributed to Calo. Layer-1	0%

Table 14: Trigger Milestones

Subsystem	Description	Scheduled	Achieved
TRIG	EMTF commissioned with endcap RPC input	April 1	April 27
TRIG	EMTF ready for Physics	May 1	May 29
TRIG	Calo. Layer-1 commissioned with new ECAL/HCAL/HF Calib	April 1	May 19
TRIG	Calo. Layer-1 Ready for physics	April 1	May 19

Software and Computing

The end of a calendar year is always a busy time for Software and Computing, due to the annual push to wrap up data processing for that year's LHC run and to make preparations for winter conferences. Thanks to efforts throughout the quarter and over the holiday break, CMS finished a legacy re-processing of the 2016 data, nearly completed the end-of-year reprocessing of the 2017 data, and made significant progress on simulations for both current data and HL-LHC events needed for TDR development. This was only possible because of the continued excellent performance of the U.S. Tier-1 and Tier-2 facilities. The Fermilab Tier-1 had a nearly flawless quarter, and the Tier-2 sites had high utilization levels that are consistent with the level of activity of U.S. physicists in the collaboration. In addition to those facilities, the CMS Connect service saw a huge increase in usage over these three months. Long-term development efforts continued in support of the continual improvement of operations. These include the incorporation of new features into the workflow management system and the integration of DOE and NSF HPC centers into regular CMS operations. Explorations of new data storage and management systems are in their early stages, and a wide variety of software modernization efforts will help optimize CMS software and computing far into the future.

Major milestones achieved this quarter

Date	Milestone
4 Dec	Operate until the end of data taking in December the prompt reconstruction according to CMS expectations.
19 Dec	All Tier-2 sites migrated away from the WLCG tools to gfal-2 for file transfers.
31 Dec	Build all CMS software framework external packages with Spack.
31 Dec	Deliver CMS software framework and ROOT builds with C++ Module support.
31 Dec	Integration of suite of data serialization packages in CMSSW for analysis use (eg, to support interoperability with Big Data and Machine Learning tools) and establish machine learning frameworks in the CMS software distribution.
31 Dec	Remove AFS dependency of the CMS software built infrastructure.
31 Dec	Prototype to provide all CMS releases in docker containers.
31 Dec	U.S. University Tier-2 Facilities all met the performance goal for >90% site "availability": 97.66%.
31 Dec	U.S. University Tier-2 Facilities all met the performance goal for >90% site "readiness": 96%.

Fermilab Facilities

Q4 of 2017 was dominated by strong LHC running until the end of the quarter, and large scale data processing in preparation of physics results for upcoming winter conferences. 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 45.4 million wall-clock hours of processing to CMS.

Figure 9 shows the site readiness metrics for the quarter. The yellow band along the bottom of the

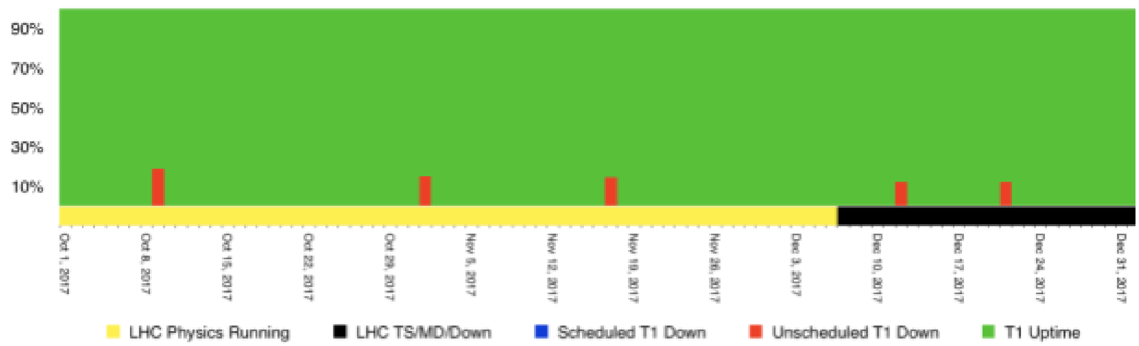


Figure 9: Fermilab readiness metrics for 2017Q4. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. The height of a red bar indicates how much of the day services were affected. Black and yellow across the bottom indicates LHC machine running. This quarter the yellow ended in December with the annual LHC shutdown. Fermilab passed metrics for 99.2% during the quarter.

figure indicates LHC physics operations up until early December, when pp running ended for the year. During this quarter the Tier-1 facility passed CMS site availability metrics 99.2% of the time. There were a handful of short service incidents in the xrootd and FTS services during the quarter all solved within a few hours.

With the end of data-taking at CERN, work began in December to re-factor the Tier-1 CPU resources to using Docker containers, facilitating more dynamic provisioning between the Tier-1 and LPC, and providing SL7 capability in time for the 2018 run.

University Facilities

As seen in Figure 10, CMS production and analysis activities this quarter continued to run at full capacity and even exceeded purchased processing power, taking advantage of the sizable opportunistic processing available at the U.S. CMS Tier-2 sites. During this heavily used period, analysis processing consumption by U.S. physicists continued at the 70-75% level of the total analysis CPU delivered by our sites during the last quarter.

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 95.76% "available" and 92% "ready". Note that in previous quarterly reports we had mistakenly used a slightly more restrictive definition of the official WLCG metric. The CMS requirement for each of these metrics is 80%, but the U.S. CMS performance goal is 90%, which we have met for the calendar year 2017 (97.66% and 96%, respectively).

The U.S. CMS Tier-2 centers delivered 50.2% of all computing time by Tier-2 sites in CMS last quarter. This is a further decrease of 1.3% from the previous quarter and 2.6% from two quarters ago, indicating that our pressure on CMS to diversify the geographical spread of production work may be having a positive effect. However, given that over 70% of our U.S. processing resources for analysis is used by local U.S. physicists, as seen in Figure 2, and that we also take our fair share (about 30%) of non-U.S. Tier-2 analysis usage, U.S.-based researchers are doing approximately 50%

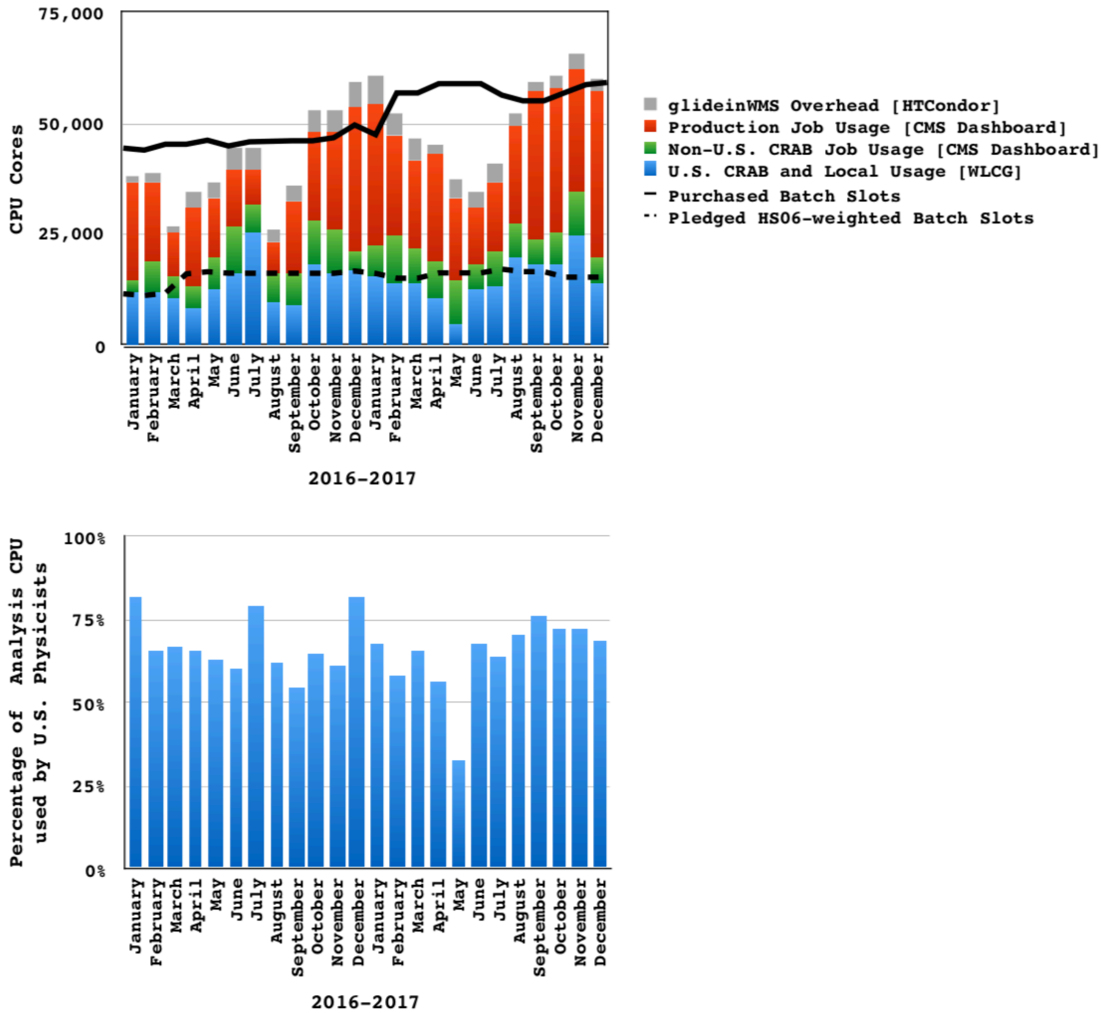


Figure 10: How processing resources were used at the U.S. CMS Tier-2 sites, by month.

of the global analysis work in CMS, commensurate with our ~50% resource contribution overall.

As for progress on Tier-2 milestones and upgrades, since the end of the previous quarter, all sites have migrated away from the WLCG tools to gfal-2 for file transfers. One site (Caltech) has migrated to cvmfs 2.4. Migrating the rest will be a carry-over milestone for 2018. Other partial carry-overs for 2018: one site still needs to implement load-balanced gridFTP, one site still needs to upgrade to XrootD 4.6.x, two sites still need to upgrade at least one CE to SL7, three sites still need to upgrade to HTCondor 8.6.x and HTTPS XrootD, and five sites still need to upgrade to version 3.4 of the OSG software stack. We will be including a complete list of 2018 milestones before the time of the next quarterly report.

This was an eventful quarter for the Tier-3 effort. CMS Connect saw a steep increase in users as the CMS gridpack production campaign that is making use of it went into full production, as shown in Figure 11. Over all of 2017, CMS Connect delivered 2.7 million wall hours of computing, of which 78% came during Q4. The Tier-3 team also restructured the central T3 PhEDEx installation so that it could be maintained by multiple team members instead of a dedicated Fermilab intern. Finally, we did not meet our milestone of deploying and operating one Tier-3-in-a-box system this year. We deployed a system at Colorado, but have not been able to bring it into operation due to unanticipated complications. To keep progress moving, as commissioning on the first Tier-3-in-a-box system at Colorado continued, a second system was deployed at Maryland, and a third one is being prepared for deployment to Puerto Rico early next quarter. (As a side benefit, the Puerto Rico deployment will help the island's recovery efforts from Hurricane Maria.) In addition to those specific developments, the Tier-3 support team continued to provide routine support to individual sites. This quarter, six sites sought assistance on topics ranging from OSG and PhEDEx software to site-planning advice.

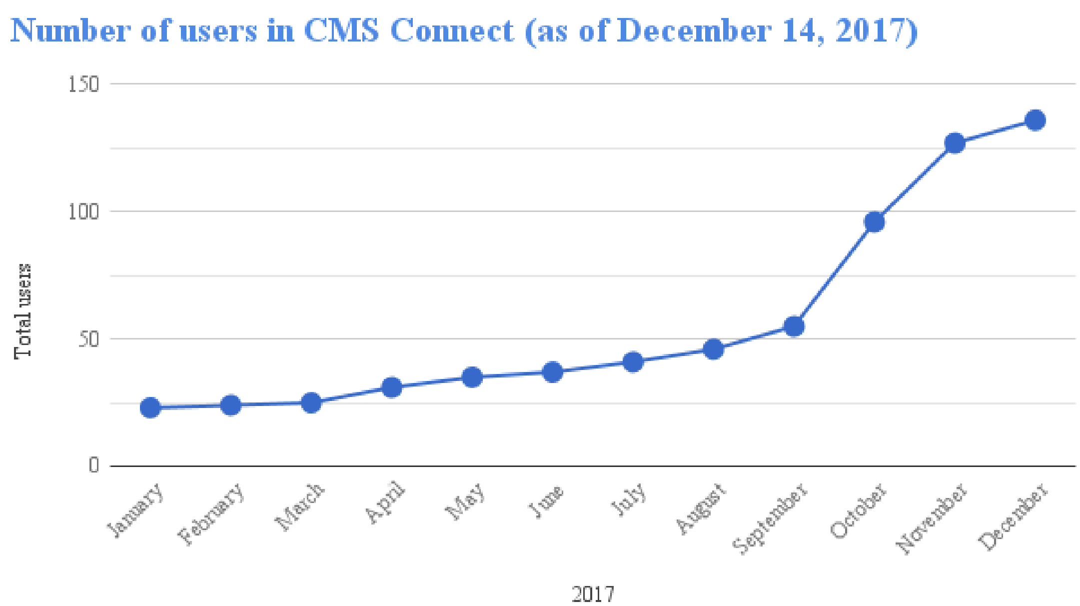


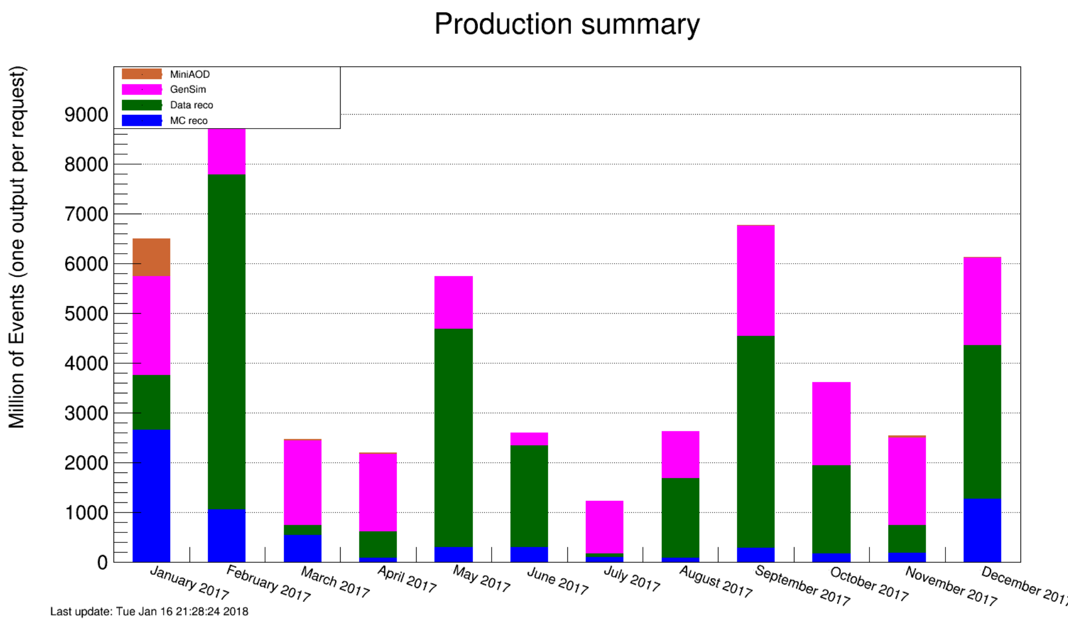
Figure 11: Total number of registered users for CMS Connect throughout 2017.

Computing Operations

Legacy re-reconstruction of the 2016 data was ongoing at the start of the fourth quarter. The campaign started in August and the remaining half a billion events, 10% of the sample, were processed by middle of October. The legacy re-reconstruction of the 2016 data was followed by a re-reconstruction of early 2017 data. The campaign included 1.3 billion events and was completed by late October. Additional re-reconstruction requests of 2017 data came end of November. About 90% of those requests were completed by the end of the year. Requests that came in late December are not yet complete.

Monte Carlo events needed for the 2017 data analysis were generated throughout the quarter. Over 5B events were generated and processed all the way to the small MINIAOD data tier used for analysis. About 250M Monte Carlo events for the HL-LHC upgrade were also generated during the quarter. Although the number of events was (relatively) small, the large pile-up and need to rely on standard event mixing (as opposed to the pre-mixing that has been implemented for current simulations) made this campaign a significant consumer of resources and attention.

Overall, CMS data and Monte Carlo processing used all the CPU resources available to the activities. Over the Christmas/New Year holidays 175,000 cores were utilized. During this time a large number of HL-LHC upgrade workflows and workflows with significant validation steps executed allowed us to reach for a few days the maximum number of jobs production could handle. Additional production manager machines are being configured to increase the ceiling.



Computing Infrastructure and Services

Several improvements were made to the workflow management systems during this quarter. WMAgent was modified to adjust the number of submitted jobs based on the load of the underlying HTCondor schedd. Porting of the workflow operations layer developed by the operations team into the workflow system continued, beginning with the component that replicates data before assigning workflows. Finally, a mechanism to stop Tier-0 prompt reconstruction processing was implemented and put in the hands of shifters to allow for after-hours pausing of the system until problems are resolved.

Opportunistic use of NERSC reached nearly-final status where the operations teams are submitting production workflows to NERSC resources using a dedicated WMAgent and GlideinWMS pool. The remaining work is to remove the need for the dedicated agent and pool. Also useful for opportunistic use of resources, during this quarter we deployed Frontier caching using CloudFlare, a free, commercial CDN into production.

On the NSF HPC side, U.S. CMS successfully applied for XSEDE allocations on Bridges and Stampede2. Stampede2 is a KNL based system, just like Cori2 at NERSC, while Bridges is an Intel-based HPC system. Both will be accessed via standard OSG APIs starting in Q1 2018, i.e. will be treated no differently than any Tier-2 or Tier-1 site in global CMS. The required integration is being done by OSG, and has started in Q4.

The WMArchive team focused on visualization this quarter and on supplementing ElasticSearch with FluxDB as a storage backend to be able to visualize data over longer time periods.

On the data management side, a fourth queue for small, high-priority transfers was added to PhEDEx and further tuning of PhEDEx to address operational issues was performed. The PhEDEx team also began exploring delegating tape staging to FTS. In November, CMS held a data management review workshop and agreed to have a comparative review of possible future data management systems in Summer 2018. Members of the U.S. CMS operations program have begun a review of the Rucio data management system as an input to that CMS review, and are participating in an OSG meeting on Rucio in Q1 2018, together with representatives from LIGO and IceCube.

A 200TB XRootd cache at UCSD to cache the 700 TB namespace of all 2016 MINIAOD(SIM) data was in stable operations throughout Q4. We observed peak cache miss rates of up to 30% when the cache is under heavy use, serving up to ~20 Gbps of data to compute nodes at UCSD. We consider this as an indication that the "working set" among the 2016 MINIAOD(SIM) data is larger than 200TB, and are preparing to increase the size of the deployed cache accordingly.

In addition, we started to engage a Computer Science group at U.C. Santa Cruz (Carlos Maltzahn and one of his graduate students) with a focus on storage systems (CEPH) and IO patterns. The student is working towards an analysis of CMS data access patterns with an ultimate goal for R&D on "intelligent" storage systems. This connection is an early pay-off from the NSF S2I2 conceptualization activities that introduced Maltzahn to U.S. CMS.

Software and Support

The last quarter of calendar year 2017 saw the end of the 2017 proton-proton running period as well as reference runs for 2018. Releases were built to support data taking as well as to support the end-of-year processing campaigns for data and MC. We also supported releases for HL-LHC upgrade sample production as well as planned the switch to CentOS7-based releases for the 2018 data taking period. We implemented two prototype solutions to provide Docker containers of CMS software releases, either building individual containers per release or using a container with mounted CVMFS file system.

The core software development work concentrated on further improving the multi-threading performance for increasing core counts, with particular progress in alleviating the ROOT I/O bottleneck, which was tackled both on the CMS and ROOT side. We completed the C++ modules introduction to the CMS software framework and ROOT. We observe around 20% memory decrease in ROOT's startup phase. We also provided generalized access methods to accelerator hardware like GPUs and FPGAs and made progress in integrating the advanced tracking projects into the CMS software framework. These projects made progress on several fronts, especially in optimizing execution on KNL nodes and GPUs.

We continued the work on a client-server implementation of the CMS visualization solution in preparation for the HL-LHC era. The support for Big Data analysis tools and Machine Learning frameworks was continuously improved, the latter with work on uproot to convert ROOT data structures seamlessly into numpy arrays to allow for data exchange between the different frameworks.

To enable larger opportunistic resource usage on OSG, we enabled the infrastructure to use the commercial Content Delivery Network provider Cloudflare and its free Frontier caching service when local squids are not available.