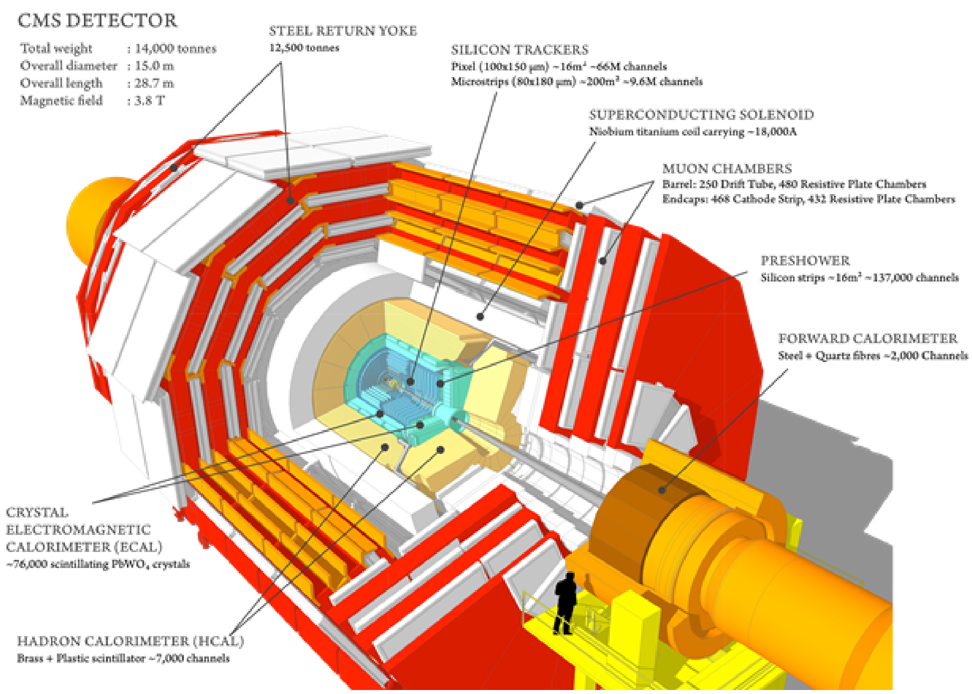
U.S. CMS Compact Muon Solenoid Operations Program
Quarterly Report for the Period Ending December 31, 2017

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.

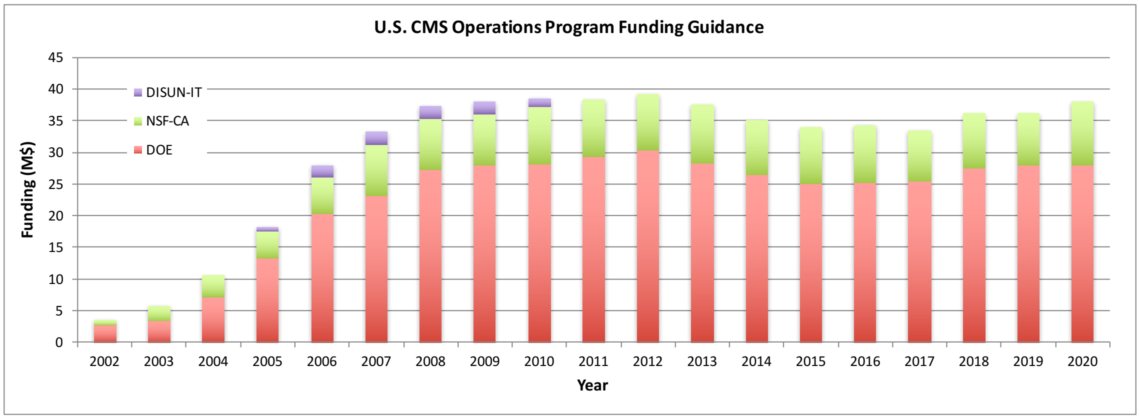


Figure 1: The annual U.S. CMS Operations Program funding provided by DOE and NSF. For 2002 through 2017 the chart shows the actual funding, while for 2018 onward the current funding guidance is shown.

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-

U.S. CMS Detector Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY17 Q4 Plan**	**Change $**	**CY17 Q4 End**
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**

U.S. CMS Common Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY17 Q4 Plan**	**Change $**	**CY17 Q4 End**
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**

U.S. CMS Software and Computing Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY17 Q4 Plan**	**Change $**	**CY17 Q4 End**
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.

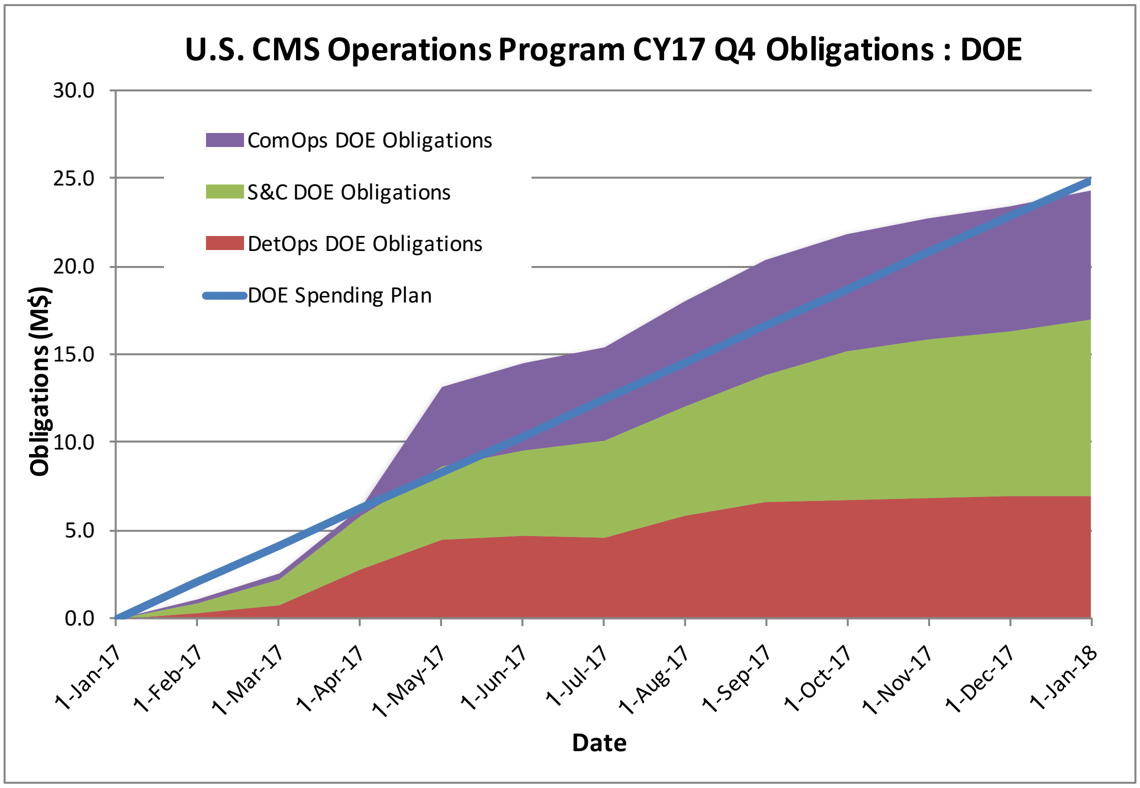


Figure 4: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

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.

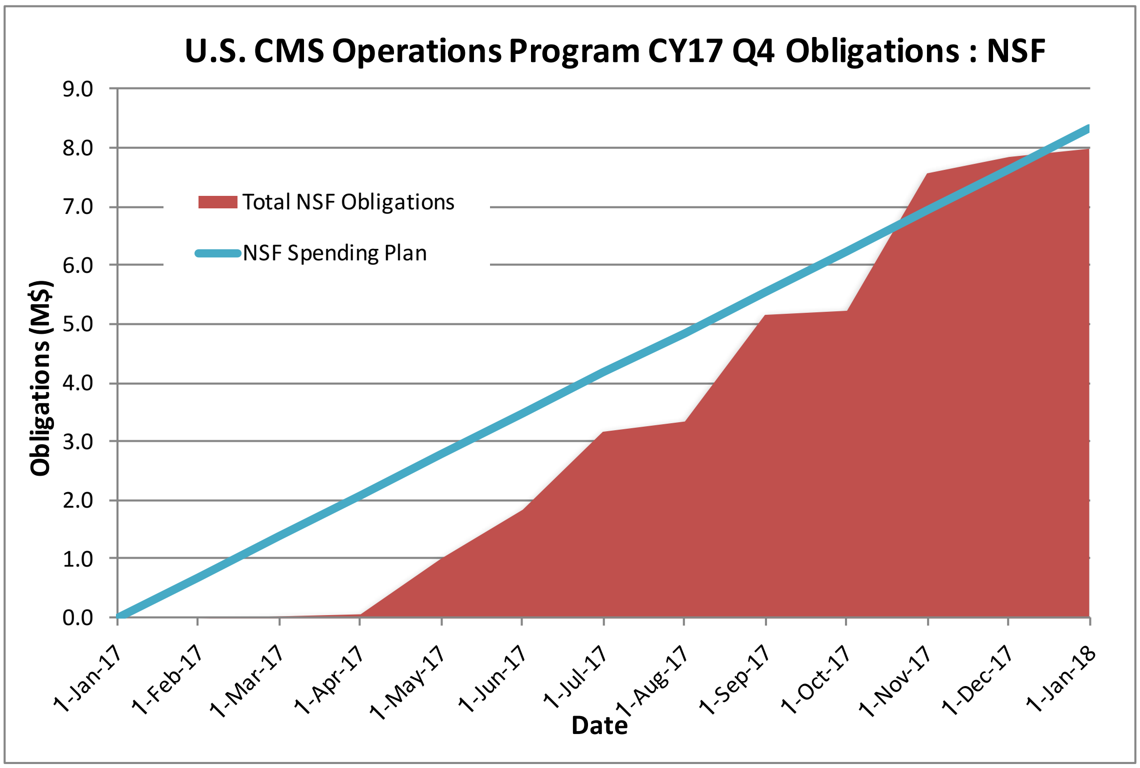


Figure 5: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.

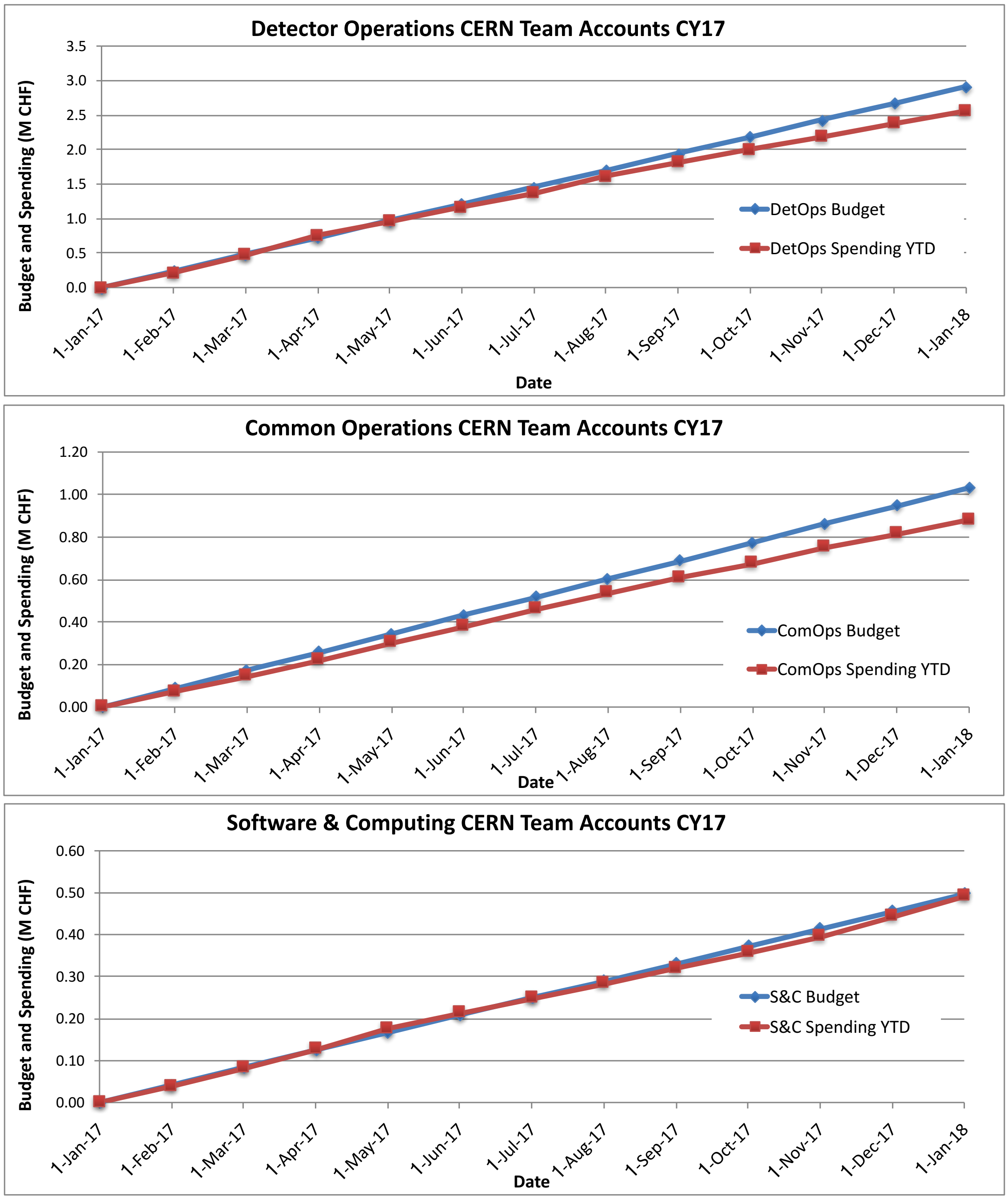


Figure 6: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.

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.

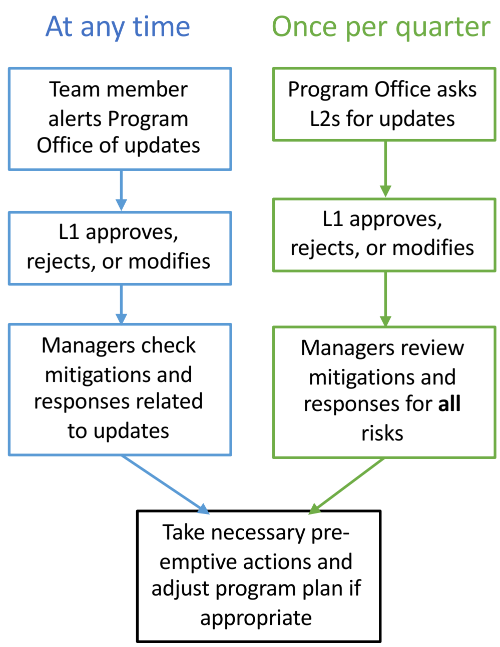
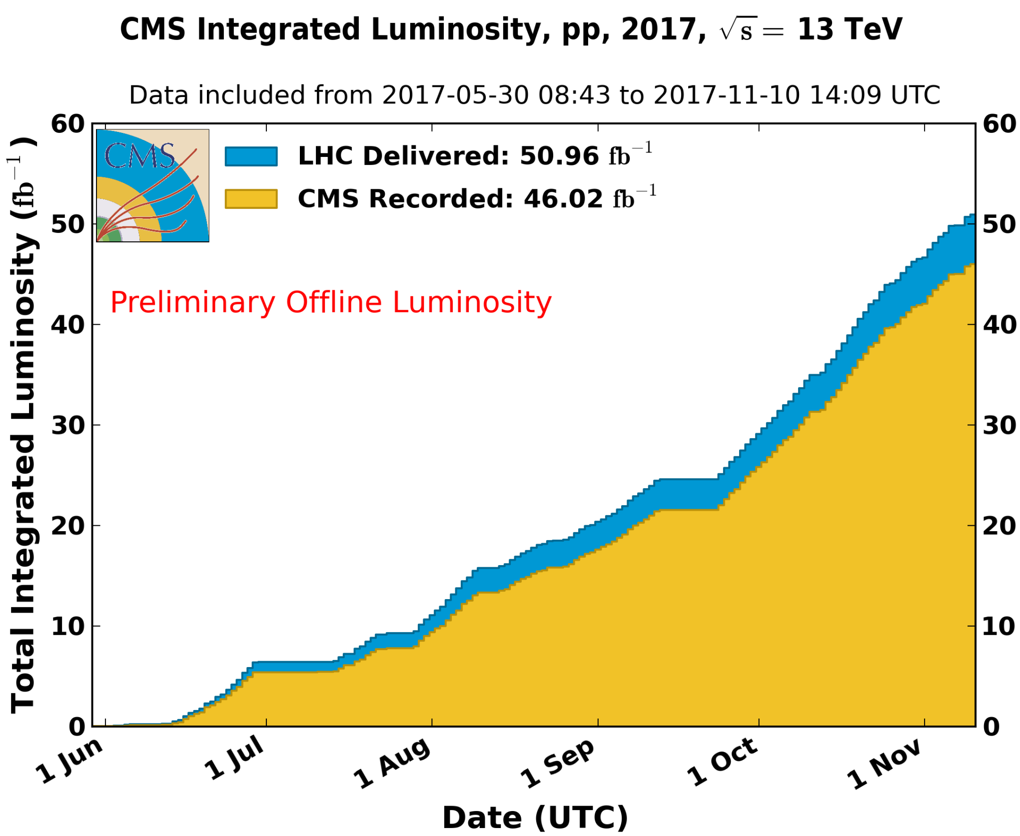


Figure 8: Summary of the two Risk Management Plan workflow paths.

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

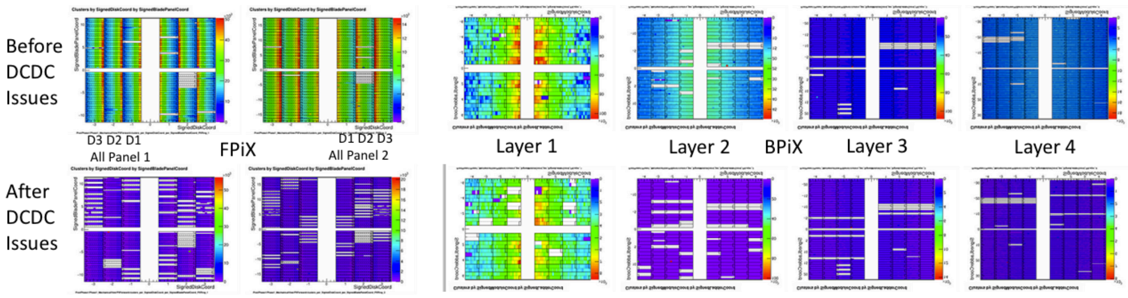
Subsystem	Description	Scheduled	Achieved
BRIL	Update Lumi for 2016	March 1	March 1
BRIL	Ready for Physics	May 1	May 1
BRIL	Improve 2017 Lumi numbers	December	Preapp. Dec 19

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 the LHC, with the end of operations for the year and a big push to prepare results from the year's dataset for upcoming conferences and subsequent paper submission. This was clearly reflected in U.S. CMS Software and Computing Operations for the final quarter of 2017. The computing facilities at both Fermilab and the universities saw high rates of utilization thanks to both high demand and excellent availability. Computing Operations was extremely busy as it provided a consistent processing of the 2016 data and started generating simulation samples needed for analysis of that data. Operations made use of innovations such as the multi-threaded event framework, multi-core pilot jobs, and pre-mixed pileup samples to make all of this processing more efficient. These technologies were the result of long-term developments in the Computing Infrastructure and Services and Software and Support areas, which have continued to push in these directions and additional ones such as improvements in the workflow systems, advances in processing at resources such as NERSC and continued development of the software for new computing architectures. Many of these developments were presented at the CHEP conference in October 2016. Preparations for the coming LHC year, such as software to reflect detectors being installed during the EYETS, are well underway.

Major milestones achieved this quarter

Date	Milestone
Nov	Request Manager v1 to v2 transition complete
Dec	WMArchive put into production
Dec	Completion of the roll-out of connections the Tier-2 sites to LHCONE VPN by ESNet.
Dec	For at least 3 sites, implement load-balanced GridFTP servers via DNS or IP as a prelude to decommissioning bestman2.
Dec	Tier-1 PhEDEx and FTS upgrade complete

Fermilab Facilities

This quarter brought to a close the second year of LHC Run 2. Throughout the quarter the Fermilab Facilities continued to provide reliable custodial storage, processing and analysis resources to USCMS collaborators. Site utilization was high, with the facility providing a record 44 million wall clock hours of CPU to CMS.

Figure 9 shows the site readiness metrics for the Tier 1 during the quarter. After the heavy ion run completed in December, Fermilab upgraded the PhEDEx and FTS (data transfer) services. A missed step in the upgrade led to missed metrics on the 17th and 18th. Procedures have been improved for future upgrades. Overall the site performed very well, passing metrics 97.5% of the time for the quarter. During LHC running periods the site passed metrics 99.5% of the time this quarter.

The Fermilab LPC computing resources continued to be well utilized. By the end of this quarter preparations were complete to move LPC users off aging BlueArc based storage to new NFS servers, with the transition scheduled first of the year.

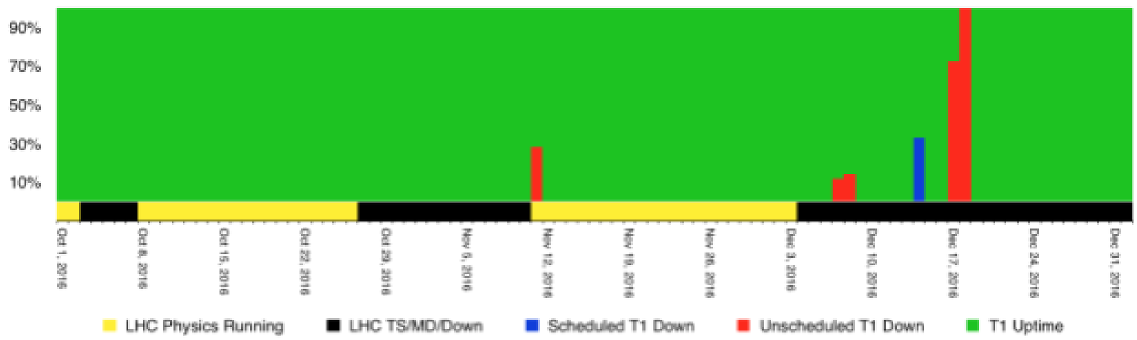


Figure 9: Fermilab readiness metrics for 2017Q4. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. The height of a red bar indicates how much of the day services were affected. Black and yellow across the bottom indicates LHC machine running. This quarter LHC continued proton-proton physics running. Fermilab passed metrics 97.5% during the quarter overall, and 99.5% during LHC running.

University Facilities

This quarter was an extremely busy time for the U.S. CMS Tier-2 facilities during a period of intensive data analysis and greatly increased central production activities for simulated data for the upcoming winter conferences. High performance is expected from the sites at all times, but especially during the critical periods before major conferences. All of the U.S. CMS Tier-2 sites operated successfully this quarter. On our two official performance metrics based on CMS test jobs, all sites were at least 92% "available" and 90% "ready". The CMS goal for each of these metrics is 80%. The U.S. CMS Tier-2 centers delivered 47.2% of all computing time by Tier-2 sites in CMS (our commitment to global CMS is > 25%), as shown in Figure 10. This is an increase of 3.4% over the previous quarter.

As for progress on milestones and upgrades, the connection of the Tier-2 sites to the LHCONE VPN by ESNet was completed during this quarter. We also completed the major milestone that at least three sites implement load-balanced GridFTP servers via DNS or IP, which is a prelude to decommissioning bestman2. Sites are making progress in decommissioning BDII, a legacy component. We have a goal to complete this well before the end of March 2017, when OSG support for BDII is ending. Sites are also making progress converting at least one CE to RHEL7, with three out of seven sites completing this milestone before the end of the quarter. The few other minor incomplete milestones will be carried over to the next quarter.

Eight Tier-3 sites required assistance from the Tier-3 support team this past quarter on issues related to patching the COW Linux kernel vulnerability, PhEDEx upgrades, networking and basic Linux systems adminstration. The team is putting significant effort towards preparing documentation for upcoming OSG software changes connected to gridftp and HDFS filesystems. CMS Connect effort has shifted to user education and helping to port user applications to the platform, starting with gridpack generation, which is a broad need for CMS MC generation. Kenyi Hurtado presented a poster on CMS Connect at CHEP.

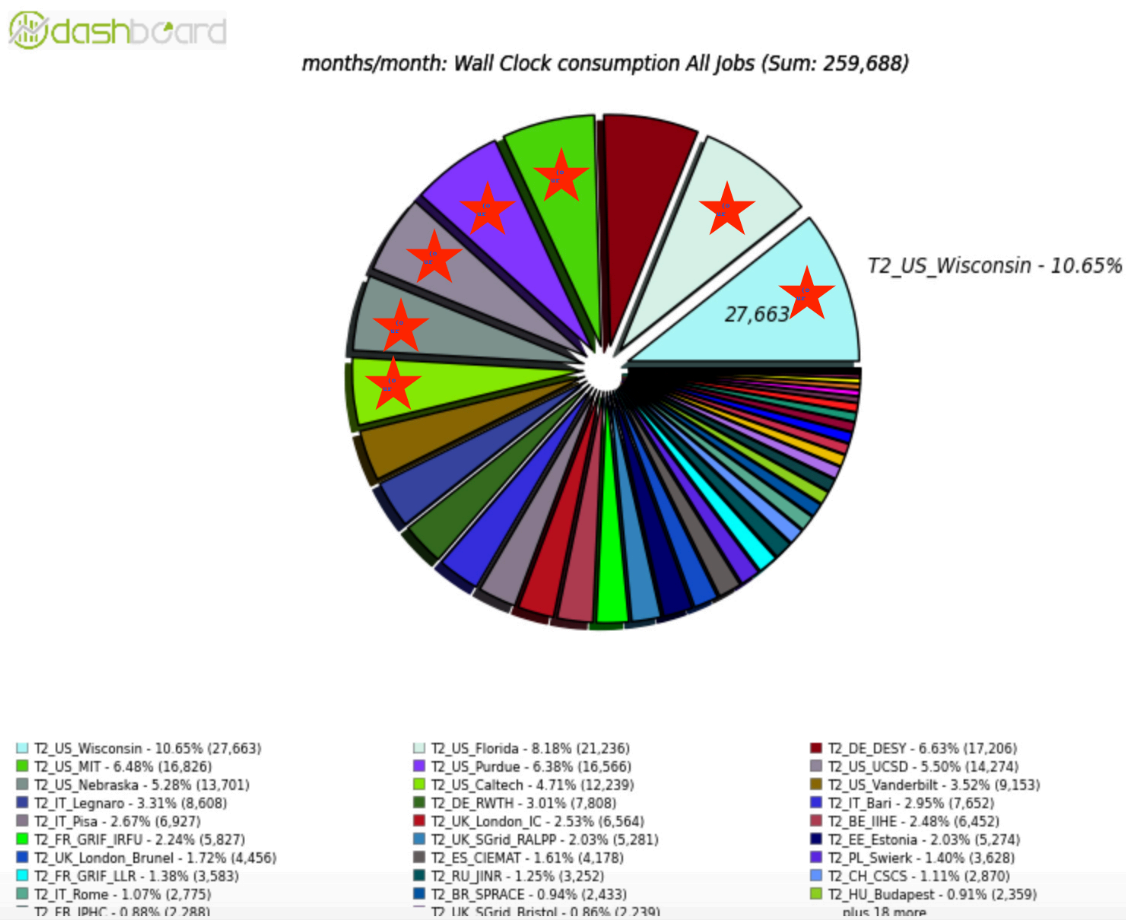


Figure 10: Percentage of total computing time delivered to CMS by Tier-2 sites world-wide, by site.

Computing Operations

The re-reconstruction campaign to provide a uniform 2016 dataset started end of September 2016. About 50k processing cores were used during steady-state running and all original processing requests were completed during October. The reconstruction program was set up to use four threads, taking advantage of our long-term efforts towards a multi-threaded software framework. This matched well to the eight-core pilots of the CMS glide-in system, reaping the fruits of other development work. But operating multi-core systems at this scale led to the emergence of new behaviors. Additional lower-priority single-threaded generation and simulation campaigns being carried out at the same time were able to regularly push out the jobs of the re-reconstruction campaign. Investigation of the resulting priority inversion led to a tuning of the submission infrastructure in favor of multi-threaded jobs. While this mitigated the issue, unwanted fragmentation of pilots requires further investigation.

Additional re-reconstruction requests, for both the special LHC runs with a few bunches with extremely high pileup and the Van der Meer scans, were received in October. Processing of the special LHC runs led to significant challenges. The data were recorded with too many events per processing unit and excessive use of CPU and memory were encountered due to the very high pile-up. After several attempts the data are now processed at dedicated machines at the University of Nebraska. This experience will be useful for future processing of high-intensity events.

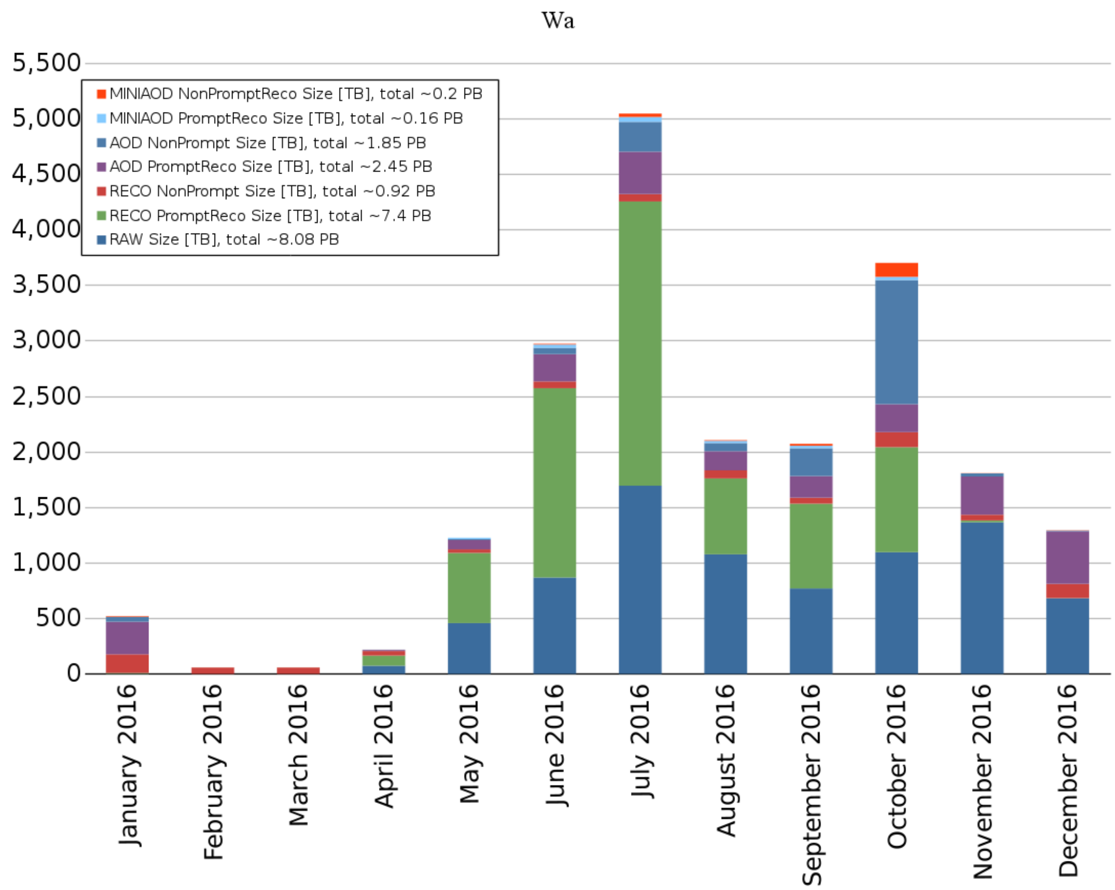


Figure 11: Volume of data output in the re-reconstruction campaign.

Monte Carlo generation for the analyses targeting conferences in Spring 2017 started in the middle of November. fter a thorough development effort, the campaign is an pre-mixed pileup samples, where individual minimum bias events are generated and combined into a pileup sample before the start of the campaign. Instead of reading N minimum bias events during the digitization step to simulate the pile-up condition, one pre-mixed event is read instead. The pre-mixing approach results in much lower input data rates and also lower CPU consumption. The challenge lies in assembling a sample of sufficient size and placing it at well-networked sites in advance of the campaign. By the end of 2016 Monte Carlo samples totaling 6 billion events were generated for this campaign. The campaign is ongoing and new sample requests still being received.

In addition to these activities, the LHC completed its 2016 run with heavy-ion collisions. Last year the processing of these high-occupancy events caused great stress on the Tier-0 system, leading to much just-in-time development work. This year, the Tier-0 performed well with no new development needed.

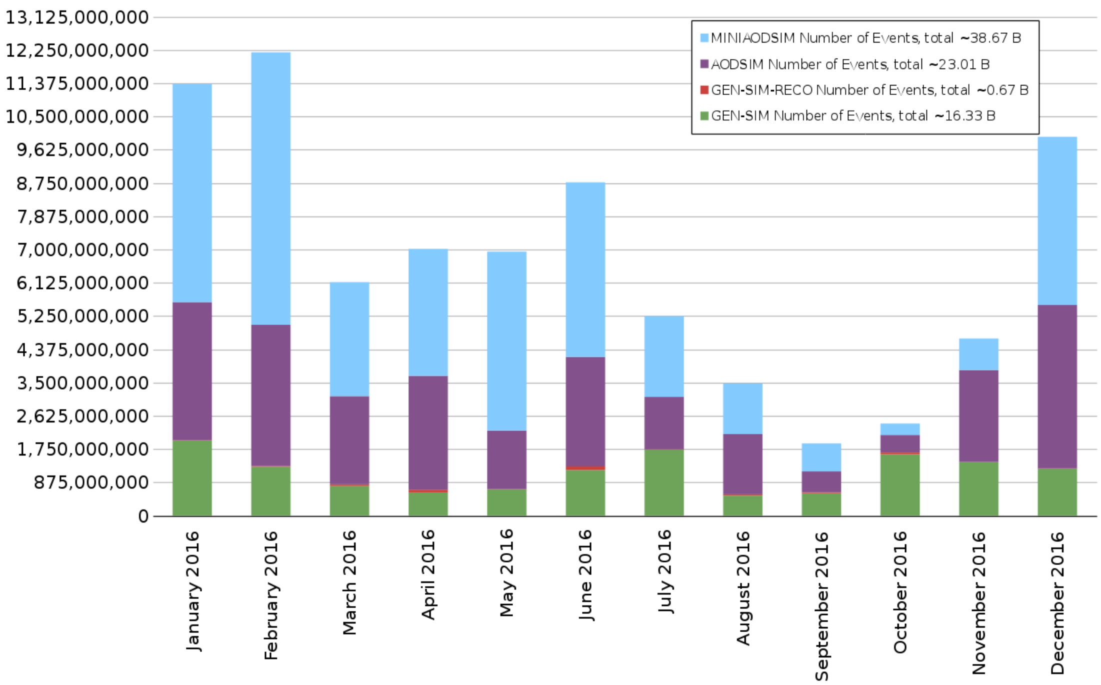


Figure 12: Monte Carlo generation in 2016 by number of events.

Computing Infrastructure and Services

During this quarter to workflow team completed the transition of our Request Manager (ReqMgr) system from version 1 to 2. The new ReqMgr is much more maintainable and gives us a platform to streamline the operations process and add more intelligence into the core of the workflow system. The workflow management system also commissioned the ability to run jobs whose core count is chosen by the GlideinWMS system within a range, an improvement which promises to increase the overall resource utilization and efficiency. NERSC resources were used to run production workflows for DIGI-RECO and GEN-SIM-DIGI-RECO at scales of up to 3000 cores submitted through the normal submission infrastructure as well through a virtual extension (HEPCloud) of the Fermilab Tier-1 facility.

Our central web-based infrastructure encountered some scaling issues this quarter which were addressed by horizontally scaling the DBS service and beginning to investigate connection throttling to ensure that we preserve enough capacity for our production systems and only provide the excess capacity for end-user requests. Associated with this, a rewrite of the DAS service with Python3 was begun. WMArchive, the service to store job-related information in a permanent archive, was put into production during the reporting period.

Two types of benchmarking exercises were performed. We benchmarked the data caching component of our Tier-3 in a box prototypes, and found the systems supported close to 10 Gbps read and a little less than half that write performance. The write-performance limit is understood to be the fundamental limit of the SATA disk subsystem. We consider this sufficiently adequate for deployment.

As second benchmarking test, we defined a Tier-2 scale XRootd data caching pilot to be deployed and operated in Southern California. Initial benchmarking was performed during Supercomputing 17. A distributed cache of 9 systems with 12 SATA disks each was exercised with up to 9k clients reading simultaneously. Maximum I/O performance of 57.8 Gbps reads with simultaneous 45Gbps "writes" were achieved. However, at this scale of use, the distributed cache is so busy that it writes only roughly half the I/O fetched via the WAN to disk in order to maximize read I/O, rather than having writes slow down reads. This is the desired functionality of the cache.

More detailed benchmarking is expected to continue next quarter. Both of these benchmarking efforts were conducted in collaboration with OSG and PRP, and are described in more details in the PRP monthly reports to NSF-ACI.

Software and Support

In this quarter, the framework software team finished Phase 2 of the multi-threaded framework implementation and is now concentrating on improving the performance of writing output. This was identified as the bottleneck in using higher core counts during execution, which was reported at CHEP from measurements on NERSC Cori, Vesta at ACLF, and KNL systems. We started the ROOT I/O developer forum to increase cohesiveness of the I/O optimization effort.

We released the software and reconstruction configuration for the 2016 end-of-year reprocessing pass and the first major release intended for the 2017 Monte Carlo production. The 2017 geometry that includes the new detectors being installed during the EYETS was finalized and included in this release, as well as updates to the visualization solution. We implemented the possibility to include python packages in CMSSW directly from the current community package manager (PIP).

The vectorized tracking R&D project made progress in refining the track fitting and starting on vectorizing the track building stage. Progress was made in the investigation of optimized HL-LHC tracker detector layouts that would reduce the amount of computing resources and were reported at ICHEP 2016.

The optimization of ROOT's performance using the C++ modules implementation of CMSSW was presented at CHEP and the ISOC++ standardization committee meeting to make it part of the standard and reduce maintenance effort in the long term.

We presented a study on using Apache Spark for CMS analysis at CHEP. The study was based on converting ROOT files into a Spark-friendly format. This was superseded shortly afterwards by developing the capability to read ROOT files directly from Spark.

The web proxy auto configuration for the distributed access of alignment and calibration constants was put into operation to support opportunistic resources and was reported on at CHEP as well.

In total, the U.S. CMS Software and Computing program's software area submitted 6 contributions to CHEP 2016.