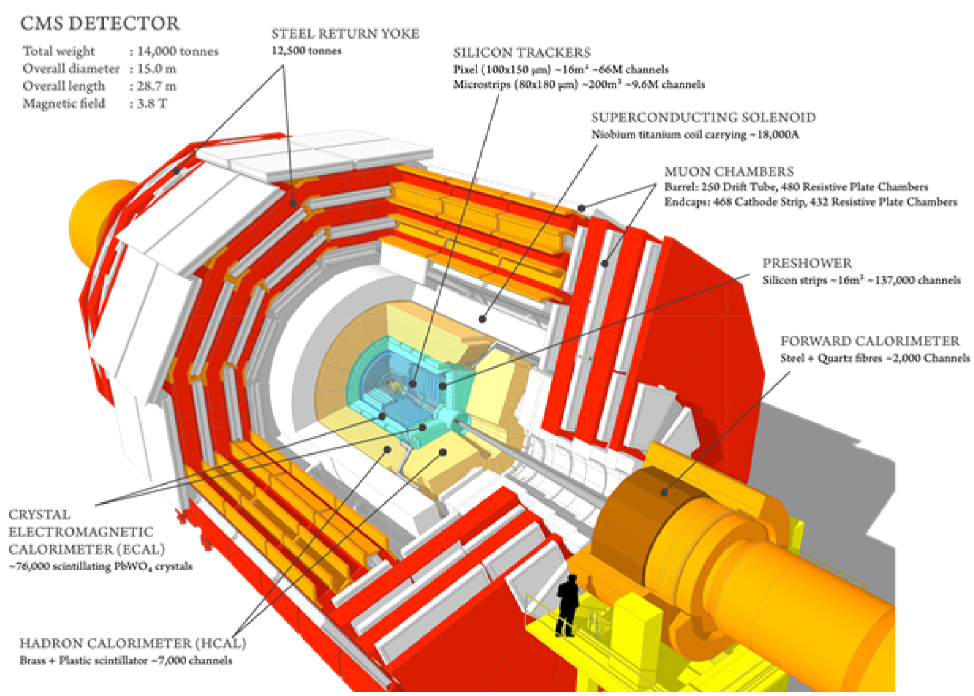
U.S. CMS Compact Muon Solenoid Operations Program
Quarterly Report for the Period Ending December 31, 2016

U.S. CMS Operations Program



Program Manager's Summary

During this quarter, the fourth quarter of **calendar year 2016** (2016Q4),

To Be Completed…

For the agency review, we provide the Resource Manager report in the next section. The remainder of the quarterly report is scheduled for early February.

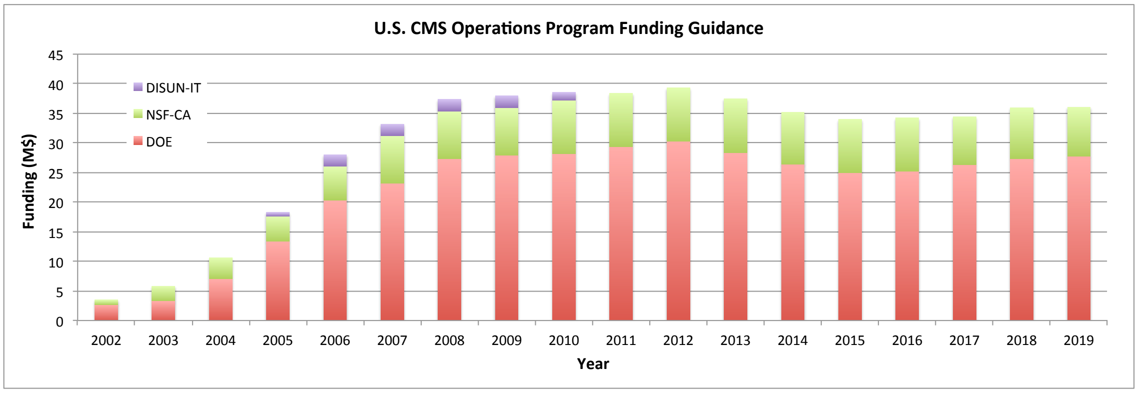


Figure 1: The annual U.S. CMS Operations Program funding provided by DOE and NSF. For 2002 through 2016 the chart shows the actual funding, while for 2017 onward the current funding guidance is shown. This figure does not include the $1M NSF supplement provided in 2016 specifically for Phase2 Upgrade R&D.

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 2016, as well as the funding guidance for 2017 through 2019, is shown in Figure 1.

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 2016 took place in September of 2015. As a new source of input to the planning process, the Resource Allocation Advisory Board met 19 times from June through November, 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.

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 the end of 2016, a total of 135 SOWs (83 DOE and 52 NSF) were produced and approved. After a SOW is approved, any additional changes are considered and, if approved, enacted through a Change Request procedure.

Table 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 CY16 spending plan, as of the end of Q4, is shown for DOE and NSF funds in Table 3.

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

U.S. CMS Detector Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY16Q4 Plan**	**Change $**	**CY16Q4 End**
11	Endcap Muon	CR-028	Northeastern travel funds for postdoc for CSC electronics work during technical stop	$1,973,709	$5,700	$1,979,409
12	Hardon Calorimeter			$1,891,408	$0	$1,891,408
13	Trigger			$826,216	$0	$826,216
14	Data Acquisition			$985,340	$0	$985,340
15	Electromagnetic Calorimeter			$882,913	$0	$882,913
16/17	Tracker (Fpix & SiTrk)		Adjustment	$854,097	($225)	$853,872
18	Detector Support			$119,165	$0	$119,165
19	BRIL			$343,754	$0	$343,754
30	Phase 2 Upgrade R&D	CR-048	UCSB M&S going toward wire bonder for developing practices and procedures for silicon module assembly	$4,665,796	$101,300	$4,767,096
11-19,30	**Detector Operations**			**$12,542,400**	**$106,775**	**$12,649,175**

U.S. CMS Common Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY16Q4 Plan**	**Change $**	**CY16Q4 End**
21.2	Common Costs (M&OA)			$4,025,837	$0	$4,025,837
21.3	RCMS			$543,397	$0	$543,397
21.4	LHC Physics Center			$1,072,937	$0	$1,072,937
21.5	Operations Support	SOW	M&S for prototype amplifier ASICs to study photodiodes for precision timing	$2,084,311	$20,868	$2,105,179
21.6	Program Office			$1,205,115	$0	$1,205,115
21.7	E&O			$283,809	$0	$283,809
21	**Common Operations**			**$9,215,407**	**$20,868**	**$9,236,275**

U.S. CMS Software and Computing Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY16Q4 Plan**	**Change $**	**CY16Q4 End**
22.1	Fermilab Facilities			$5,933,423	$0	$5,933,423
22.2	University Facilities			$3,952,858	$0	$3,952,858
22.3	Computing Operations			$865,105	$0	$865,105
22.4	Computing Infra and Services			$2,439,484	$0	$2,439,484
22.5	Software and Support			$1,548,158	$0	$1,548,158
22.6	Technologies & Upgrade R&D			$855,475	$0	$855,475
22.7	S&C Program Management & CMS Coordination			$615,406	$0	$615,406
22	**Software and Computing**			**$16,209,910**	**$0**	**$16,209,910**
U.S. CMS Operations Program Total				**$37,967,717**	**$127,643**	**$38,095,360**

Figure 2: Spending Plan Change Log for CY16 Q4.

WBS	Subsystem	DOE Funds	NSF Funds	Total
11	Endcap Muon	$1,439,439	$539,970	$1,979,409
12	Hadron Calorimeter	$1,762,981	$128,427	$1,891,408
13	Trigger	$685,137	$141,080	$826,216
14	Data Acquisition	$985,340	$0	$985,340
15	Electromagnetic Calorimeter	$882,913	$0	$882,913
16/17	Tracker (Fpix & SiTrk)	$713,881	$139,991	$853,872
18	Detector Support	$119,165	$0	$119,165
19	BRIL	$172,321	$171,433	$343,754
30	Phase 2 Upgrade R&D	$2,898,733	$1,868,363	$4,767,096
11-19,30	**Detector Operations**	**$9,659,911**	**$2,989,264**	**$12,649,175**
21.2	Common Costs (M&OA)	$3,237,813	$788,024	$4,025,837
21.3	Run Coordination and Monitoring	$436,697	$106,700	$543,397
21.4	LHC Physics Center	$1,072,937	$0	$1,072,937
21.5	Operations Support	$1,787,336	$317,843	$2,105,179
21.6	Program Office	$1,087,565	$117,550	$1,205,115
21.7	Education and Outreach	$173,224	$110,585	$283,809
21	**Common Operations**	**$7,795,573**	**$1,440,702**	**$9,236,275**
22.1	Fermilab Facilities	$5,933,423	$0	$5,933,423
22.2	University Facilities	$114,524	$3,838,334	$3,952,858
22.3	Computing Operations	$397,140	$467,965	$865,105
22.4	Computing Infrastucture and Services	$1,981,797	$457,687	$2,439,484
22.5	Software and Support	$1,286,983	$261,175	$1,548,158
22.6	Technologies & Upgrade R&D	$69,822	$785,653	$855,475
22.7	S&C Program Management and CMS Coordination	$289,670	$325,736	$615,406
22	**Software and Computing**	**$10,073,359**	**$6,136,551**	**$16,209,910**
U.S. CMS Operations Program Total		**$27,528,843**	**$10,566,516**	**$38,095,360**

Figure 3: Spending plan at the end of CY16 Q4, for funds from DOE, NSF, and the total.

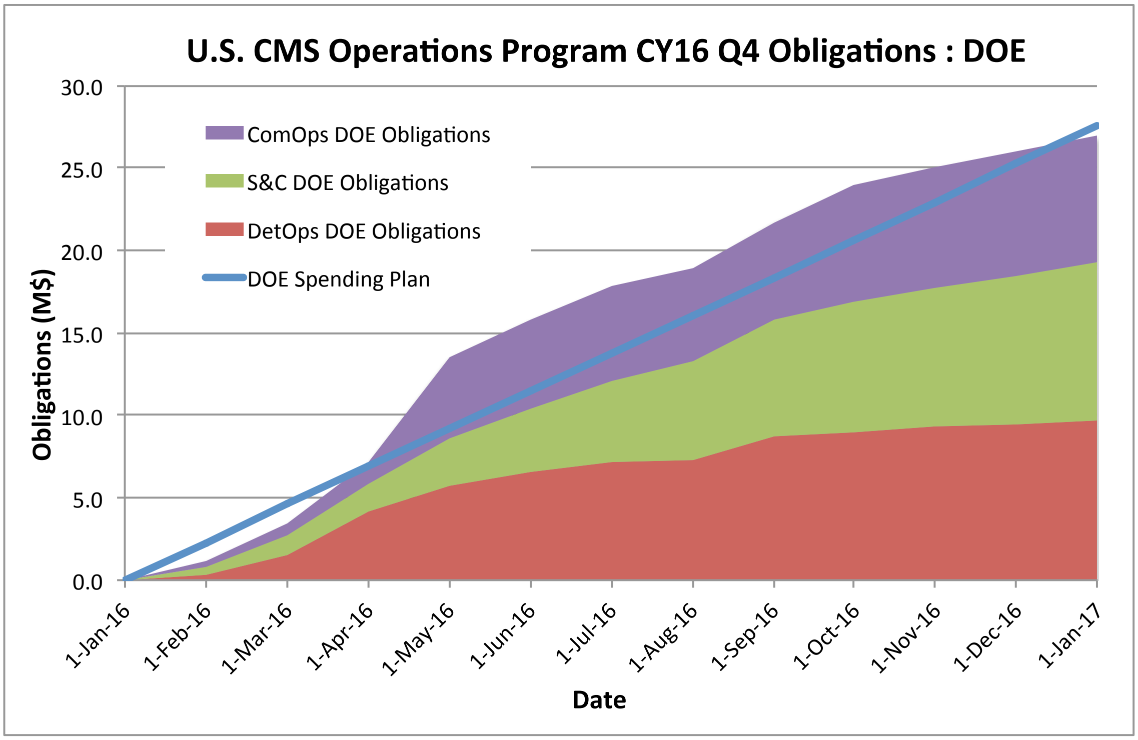


Figure 4: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

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 second 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 $9M in NSF funding (plus $1M Phase2 R&D supplement), $1,337K 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 2016 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 CY16 Q4 averaged 1.00 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 3,756K CHF M&O-A payments, as these are each made through multiple payments to a separate Team Account.

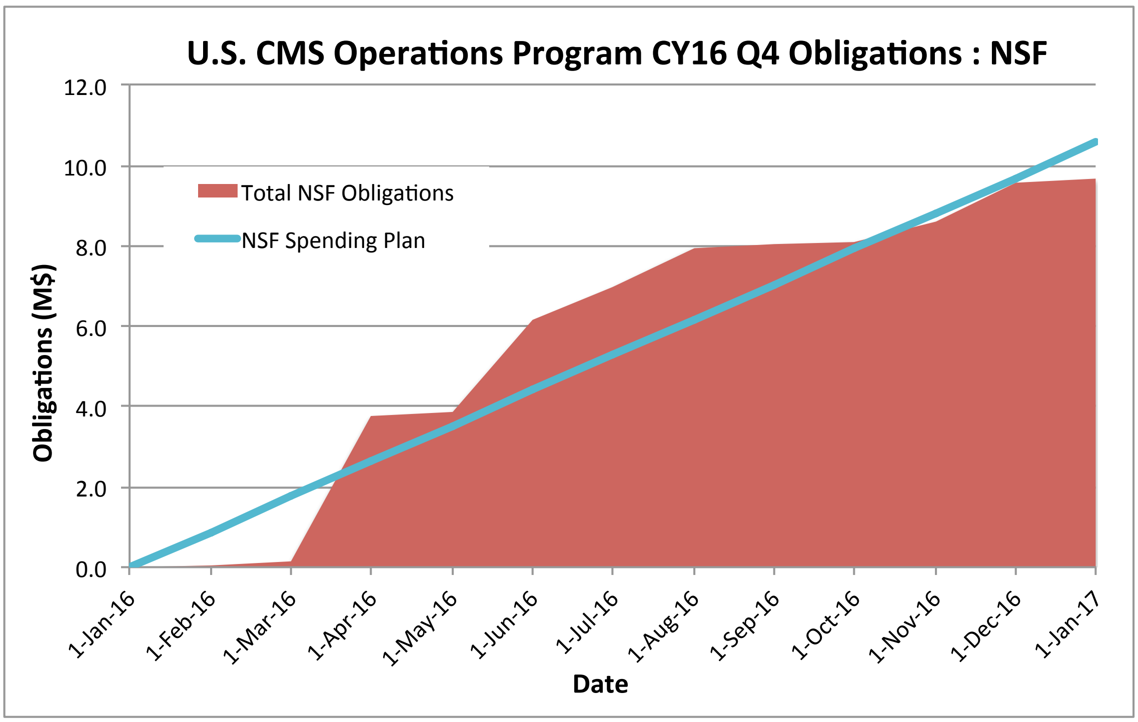


Figure 5: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide. Since NSF funding is transitioning from the end of one five-year Cooperative Agreement to another, Princeton and 15 institutions that receive sub-awards have been granted six month no cost extensions. This will allow institutions to complete their invoicing, and will enable proper allocation of the Phase2 supplement which arrived relatively late in 2016. These are the primary reasons the obligations at the end of the year are lower than the corresponding spending plan.

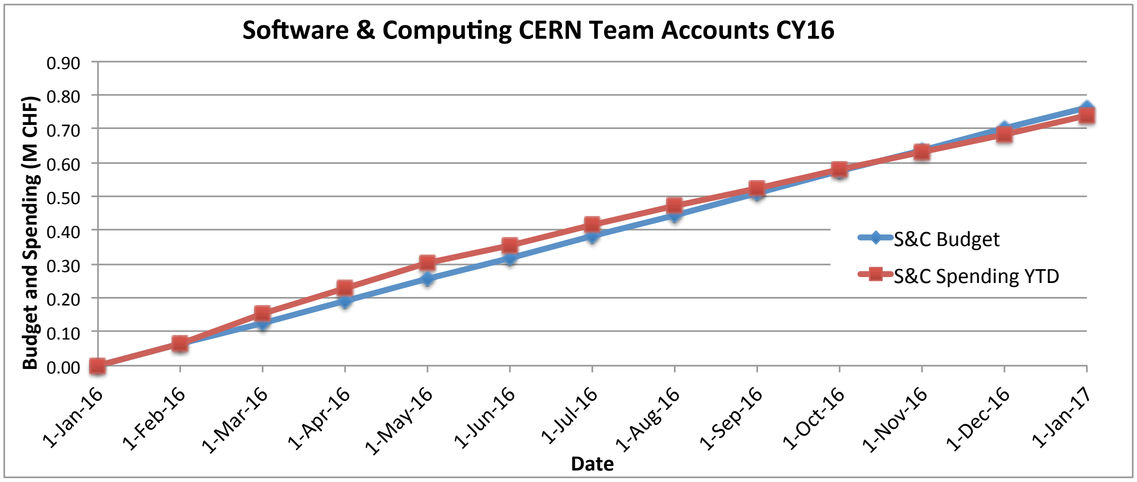
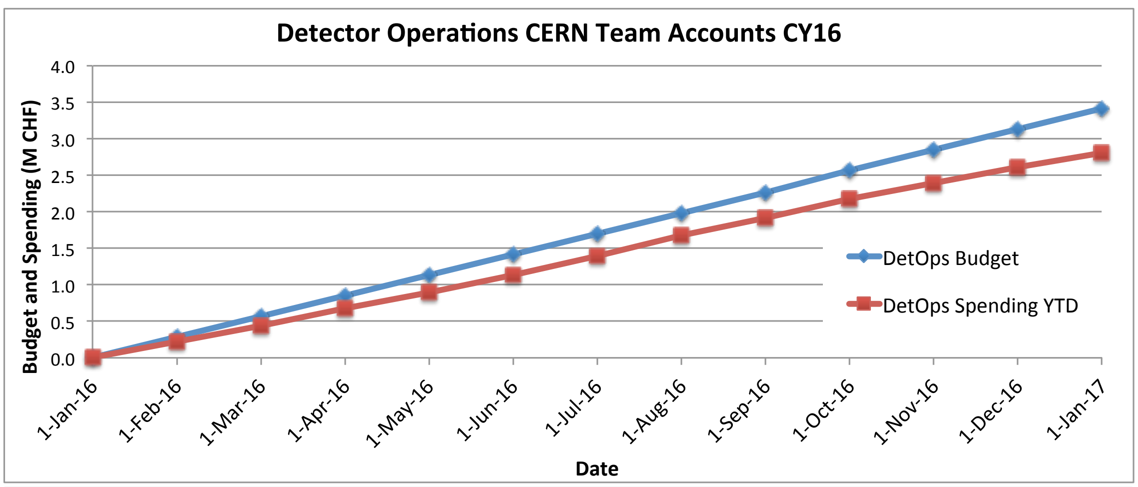
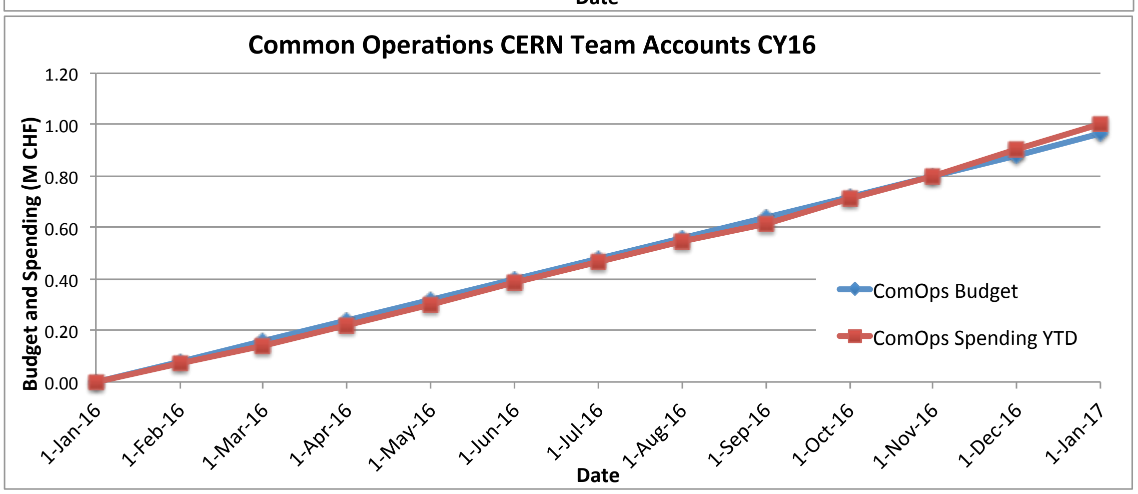


Figure 6: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.





Detector Operations

After an outstanding proton-proton run, the LHC switched to heavy ion collisions in November. CMS recorded a total of $38 fb^{-1}$ of proton proton data in 2016 taken at 13 TeV. The heavy ion running was colliding protons on lead at two energies, 5.02 TeV and 18.6 TeV. Below we provide additional details on the performance of the various subdetectors. In December the accelerator and detector were shut down for an extended year end technical stop (EYETS). This will be used to perform a number of upgrades, most importantly the installation of a new pixel detector for CMS.

BRIL

The Pixel Luminosity Telescope (PLT) participated successfully in the proton-proton collision and the heavy ion physics runs. The monitoring and alarm tools were working and allowed fast turnaround in critical situations. The PLT measured sources of background that correlate well with similar measurements performed by the beam conditions monitoring systems. The PLT can measure it in two ways, the occupancy of the PLT in non-colliding but filled bunches, and the occupancy of the PLT preceding a bunch train. The PLT published online background measurements.

The luminosity measurement quality was continuously checked and values are made accessible for data analyses from a database. Successful calibration was obtained with VdM scans in pp-collisions and for the heavy ion running. The luminosity values for 2016 pp-runs have been improved by offline analysis of measurements from the pixel, HF, BCM1F, and PLT detectors. Comparison between CMS and ATLAS measurements is ongoing. The likely cause for an approximately 5% difference between the two experiments is the different beam profile at the two collision points.

During the EYETS two dead telescopes in one quadrant are scheduled for repair. Spare parts have been assembled and placed in the laboratory at CERN for further testing. The port card which is responsible for the communication with the detectors is the potential source of the failure. The laboratory at P5 is installed.

Table 1: BRIL Metrics

Working Metric	Performance
Fraction of telescopes fully operational	82%
Efficiency of delivery of lumi histograms	99%
Uptime of lumi histogram production	99%

[BRILMetrics]

Table 2: BRIL Milestones

Subsystem	Description	Scheduled	Achieved
BRIL	Recommission Hardware	March	March
BRIL	Ready to deliver Lumi	May	May
BRIL	Provide online beam background measurement	October	October
BRIL	Improved Lumi Numbers for 2016	December	December
BRIL	Recover telescopes	EYETS 2016/17	

[BRILMIlestones]

Tracker

The tracker system performed to expectations.

Pixels

The Forward Pixel detector had a small (order 2%) issue in late proton / early heavy ion running with a loss of efficiency in the inner barrel layer. The loss was traced to a needed increase in the regulated digital voltage sent to the Read Out Chip (ROC). The needed increase was a consequense of the acumulated radiation damage and indicated that the Barrel Pixel inner layer was entering a new regime where non-traditional settings needed to be adjusted in order to operate the ROCs. Otherwise, pixel operations were routine. The Phase 1 project is using the time before installation to replace damaged cables. Hence the Phase 1 detector will not be ready to be installed until Q1 2017.

Strips

The previously reported fix to the inner layer has held up well. Issues have just been routine maintenance.

Table 3: Tracker Metrics

	Pixels	Strips
% Working channels	98.72	96.23
Fraction of deadtime attributed (Protons)	1.3%	20.3%
Fraction of deadtime attributed (Proton-Ion)	0%	10.3%

[TrackerMetrics]

Table 4: Tracker Milestones

Subsystem	Description	Scheduled	Achieved
Tracker	Ready for Physics	May	May
Tracker	Pixel Phase 1 ready to install	Nov.	(delayed to Q1 2017)

[TrackerMilestones]

ECAL

The operation of the ECAL achieved its performance milestones in the first quarter of 2016. The second and third and fourth quarters have thus been devoted to maintaining the excellent performance. A particular focus in the fourth quarter was to prepare the calibrations for a re-reconstruction of the data as a legacy dataset in 2017. The calibration used during 2016 provided comparable precision to previous runs in 2012 and 2015 (an average of 1.5% in the barrel, 2.5% in the endcap) but extensive work has been done to understand better the time dependence of the crystal transparency, photo-detector gains and pedestals that should result in an improved performance. In addition the higher statistics data samples of Z's and W's will provide a better intercalibration.

Table 5: ECAL Metrics

Metric	Performance
Fraction of channels operational: EB	99.07 %
Fraction of channels operational: EE	98.71 %
Fraction of channels operational: ES	99.75 %
Fraction of deadtime attributed	26%
Resolution performance	1.54%

[ECALMetrics]

Table 6: ECAL Milestones

Subsystem	Description	Scheduled	Achieved
ECAL	Complete LV Connector Repairs	March	March
ECAL	Reestablish same level of working channels as fall	April	May
ECAL	Reestablish L1 Performance	May	May
ECAL	Confirm resolution performance	June	June

[ECALMilestones]

HCAL

During the fourth quarter of 2016, the HCAL Operations group focused on acquiring good data and on preparing for the 2016-2017 EYETS.

The HCAL performed extremely well in 2016 and only 26 pb^{-1} of data was lost due to HCAL problems of the 41 fb^{-1} delivered (less than 0.1%). The quality of the HCAL data was also excellent with only 126 pb^{-1} of the 37 fb^{-1} certified as good for physics lost due to HCAL problems. This represents a reduction of a factor of four from 2015 and meant that HCAL was responsible for only about 10% of the data lost in offline certification. The key to this improved performance was a much improved HCAL alarm tool and improved data quality monitoring.

HCAL performance during the heavy ion run was also excellent with similar high efficiency as in the proton-proton running.

During the fourth quarter, signal loss due to radiation damage in the HE continued roughly as expected as a function of integrated luminosity based on previous years' data.

Work continued on those Phase I electronics upgrades which are planned to be installed in the 2016-17 EYETS. These include upgrades to both the HF and HE frontends.

All the components for the HF upgrades are at CERN including those needed for both converting to dual anode readout of PMTs and installing new QIE10 boards. The installation of the HF upgrade began in December after the end of the heavy ion run with the removal of the first 21 PMT boxes from HF-, and progress so far has been ahead of schedule.

For HE, the problems with the ngCCMs have been overcome by producing a second batch of HE ngCCMs which have now been received at CERN. All needed parts are on hand at CERN. However, there are remaining concerns about the firmware which is still under development and has increased latency with respect to the current system. Since the HE electronics boards will not be accessible after they are installed, there is heightened concern that an incident during firmware reprogramming, such as an inopportune power cut, might render the HE electronics hardware inoperable, with no chance to replace it. Accordingly, there will be a review on January 13, 2017 where the decision will be made whether to proceed with the HE upgrades in the 2016-17 EYETS.

Milestones for this Quarter
June 1 Milestone
Operate HCAL detector efficiently with goal of loss of data due to HCAL less than 1% and maintain calibration at 1-2% level with efficient noise rejection and improved reconstruction.
Achieved by end of May except calibration at 3% to 4% level. Calibration and energy reconstruction improvements continue.

December Milestone
Complete 2016 Radiation damage studies including Castor table studies.
The necessary data was taken and preliminary results available by the end of December. Data analysis continues.

Metrics: Fraction of channels working:
HF: 2 channels out of 1728 dead (99.9% working channels)
HB: 3 channels out of 2592 dead (99.9% working channels)
HE: 1 channel out of 2592 dead (99.96% working channels)
increased latency with respect to the legacy system, HO: 9 channels out of 2160 dead (99.6% working channels)
Total: 15 channels out of 9072 dead (99.83% working channels)
Fraction of downtime and data lost at certification due to HCAL
Goal: less than 1% for both. Achieved for third 2016: 0.06% downtime loss and 0.3% additional loss at certification.
Precision of absolute HCAL absolute energy calibration
Goal: 2% . Achieved 2% .
Inter-calibration uniformity between individual HCAL towers (HBHE, HO, HF)
Goal 1-2 % . Achieved 1-3% systematic differences between different phi symmetry methods.

Table 7: HCAL Milestones

Subsystem	Description	Scheduled	Achieved
HCAL	Ready for Physics	May	May
HCAL	Provide resource loaded schedule for EYETS work	July	July
HCAL	Prepared for HE/HF front end electronics installation	Dec.	HF Dec.
HCAL	Complete Rad Dam studies	Dec.	Dec.

Subsystem	Description	Scheduled	Achieved

[HCALMilestones]

EMU

The CSCs finished the 2016 proton run with very little downtime to CMS. They operated smoothly in the heavy ion run as well, aside from one period when a low-voltage power supply failed and a 60-degree sector was disabled.

The chambers being tested at the GIF++ facility finished the year with a radiation dose equivalent to ten years of HL-LHC running, at 5×10^{34} $cm^{-2}s^{-1}$ luminosity, with no signs of aging so far. The testing will continue next year to establish a safety factor.

As a follow-up to EPROM issues encountered in the DCFEB boards and MPC cards, a radiation test was carried out at the CHARM facility at CERN. The boards irradiated were MPC mezzanine prototypes carrying two EPROM samples as well as four anode front end boards. They were exposed to about 34 krads in a 1-week time period. Full analysis of the irradiated boards is still under way.

A USCMS EMU electronics workshop was held a Texas A&M on 6-9 December. The main focus was new electronics boards design for phase 2 upgrade, but many useful engineering discussions took place concerning the operation of the present CSC system.

The CSC system power and gas were shut down on 16-December, and the year end technical stop began. Plans were made to make preventive cooling repairs on four ME1/1 chambers and to extract five faulty DCFEB boards for analysis and replacement. This is expected to take place in early January. If other (non-muon) activities are curtailed, cooling repairs could be made on additional ME1/1 chambers.

Table 8: CSC Metrics

% Working channels	98.4%
Fraction of deadtime attributed	1%
Median spatial resolution	170 μm

[CSCMetrics]

Table 9: EMU Milestones

Subsystem	Description	Scheduled	Achieved
EMU	CSC ready for collisions	May	April
EMU	Extract SEU rates for DCFEBs	June	June
EMU	Implement additional coincidence counters in (O)TMB	July	June
EMU	Implement improved CSC segment pattern recognition	August	July

[EMUMilestones]

DAQ

The DAQ system is pushed in all fronts to its limit due to CMS's desire to collect a maximum number of events especially during proton-lead runs at the end of the year. Obtimization and additional Storage Manager hardware installed during last Quarter payed off and DAQ was able to record 6 GB/s during p-lead operations with ver negligiable dead time. The downtime contribution of the DAQ system is ~ 1 minutes during the reporting period.

WEB Based Minitoring Upgrade project kickoff workshop took plance in Vilnius. Architectire and PI between the Aggregation Layer and presentation layer was base lined. Simple prototype as a proof of pronciple of the proposed achitecture and API is due end of April.

DAQ Test Stand (DAQVAL) is partitined to provide a second minidaq for commissioning of the Pixel Phase I detector before installation in cavern. A second partion is used for the development and testing of the control softare of the new readout module (FEROL40) that will be deployed to readout the new Pixel detector.

A new minidaq system is commissioned in Building 904 that is be used by HCAL. System could be expanded to have 8 DAQ coulmns to accomudate other sub-systems.

Table 10: DAQ Metrics

Dead time due to trigger throttling	~ 0
Downtime due to DAQ	1min

[DAQMetrics]

Table 11: DAQ Milestones

Subsystem	Description	Scheduled	Achieved
DAQ	New Sub-systems integrated and commissioned	Apr	
DAQ	Event builder expanded, re-optimized for larger events	Jun	
DAQ	Old HLT Nodes replaced and commissioned	Jun	
DAQ	Prototype new WMB ready for field tests	Dec	

[DAQMilestones]

Trigger

Regional Calorimeter Trigger and Stage-2 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. It operated during the last quarter in p-p and p-Pb physics runs. CaloL1 was shut down and remained off for about 40 hours around the 2nd of November. The CMS detector went dormant to avoid issues during a replacement of a 400 kV transformer in the French power lines supplying CERN. The operation of CaloL1 was restored on the 3rd of November without issue and it was in continuous operation until the beginning of the Extended Year End Technical Stop (EYETS) on 5 December, when rack cooling went off. Also in this period, the CaloL1 online software (SWATCH) was updated to 0.11.1, which fixed general SWATCH issues sending alerts to the L1 Page, the main trigger shifter interface. The plans for the next quarter are to improve the CaloL1 error handling in SWATCH (e.g. SMS messages to experts), update the calibrations and scale factors for CaloL1, work with ECAL trigger experts regarding two issues with ECAL links, and move 72 HCAL fibers at CaloL1 due to a HCAL μHTR firmware mapping change.

Endcap Muon Trigger

The Rice University, Northeastern, and University of Florida groups have successfully supported and made incremental improvements to the phase-1 upgrade for the endcap muon trigger for the remainder of 2016 physics operations. Experts from these groups maintained on-call coverage of the system during the physics runs that took place during this quarter. For the running period overall, only 1.3% of the run downtime was attributed to the EMTF system. Four MPC cards that had been replaced were sent to Rice University for diagnosis and repair, which required in once instance a new optical pigtail and in others reprogramming an EPROM. The DAQ firmware for the EMTF was reworked to use an 80 MHz clock (from 40) to improve its high rate performance, which now no longer is a limitation for CMS high-rate running. The online SWATCH software that controls EMTF is essentially complete in its baseline functionality. Development during this quarter included adding the ability to load and verify the large PT LUT (previously performed by an expert tool). The algorithm firmware was updated in the EMTF to switch to symmetric patterns, which has reduced the logic space usage in the FPGA somewhat. The EMTF emulator in the CMSSW offline software was completely rewritten for ease of long-term maintenance and extension, and shows better better agreement with the results from the firmware. A detailed comparison of the LCTs received by the EMTF with those by the legacy CSCTF show agreement to 99.8%, with the remainder of discrepancy isolated to hard resets issued during running.

Table 12: Trigger Milestones

Subsystem	Description	Scheduled	Achieved
TRIG	Restore RCT for Physics	March	done
TRIG	Stage 2 Layer 1 ready for Med. Lumi. Physics	April	done
TRIG	Commision Stage 2 Layer 1 for High Lumi. Physics	Dec	
TRIG	CSCTF Ready for physics	April	done
TRIG	Ship one uTCA Muon Sorter to CERN	April	done
TRIG	Commission initial uTCA Muon Sorter Firmware	July	
TRIG	Commission final uTCA Muon Sorter Firmware (Ghostbusting)	Dec	

[TriggerMilestones]

Table 13: Trigger Metrics

Frac of MPC Channels	100%
Frac of Upgrade EMUTF Channels	100%
Frac of deadtime attributed to Upgrade EMUTF	1.3%
Frac of Stage-2 Layer-1 Channels	100%
Frac of deadtime attributed to Stage 2 Layer 1	0%

[TriggerMetrics]

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.

Table 14: Major milestones achieved this quarter

Date	Milestone
November 2016	Request Manager v1 to v2 transition complete
December 2016	WMArchive put into production
December 2016	Completion of the roll-out of connections the Tier-2 sites to LHCONE VPN by ESNet.
December 2016	For at least 3 sites, implement load-balanced GridFTP servers via DNS or IP as a prelude to decommissioning bestman2.
December 2016	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 FNAL 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 hours

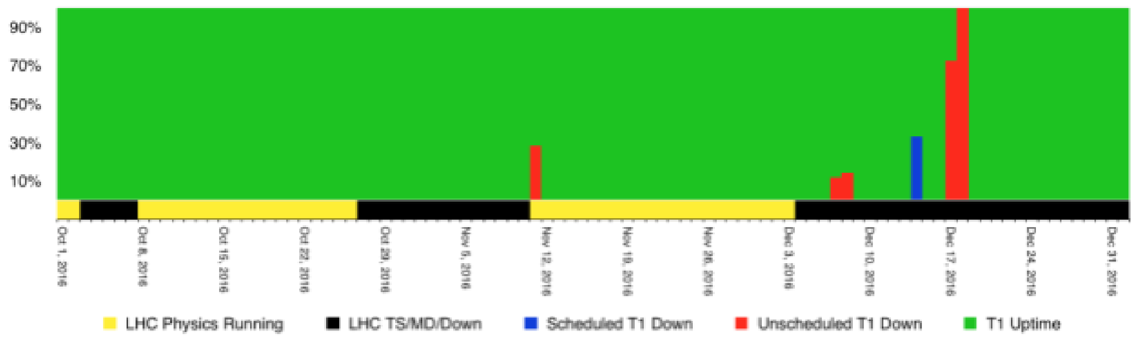


Figure 1: Fermilab readiness metrics for Q1 of FY17. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. The height of the red bar indicates how much of the day services were affected. Black and yellow across the bottom indicates LHC machine running. FNAL passed metrics 97.5% during the quarter overall, and 99.5% during LHC running.

Figure 7: Fermilab readiness metric for the fourth quarter of 2016. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. The Fermilab Tier-1 computing center passed the metric during xx% of this quarter.

of CPU to CMS.

Figure 7 shows the site readiness metrics for the Tier 1 during the quarter. After the heavy ion run completed in December, FNAL 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 FNAL 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.

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 8. 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 3 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 3 out of 7 sites completing this milestone before the end of the quarter. The few other minor incomplete

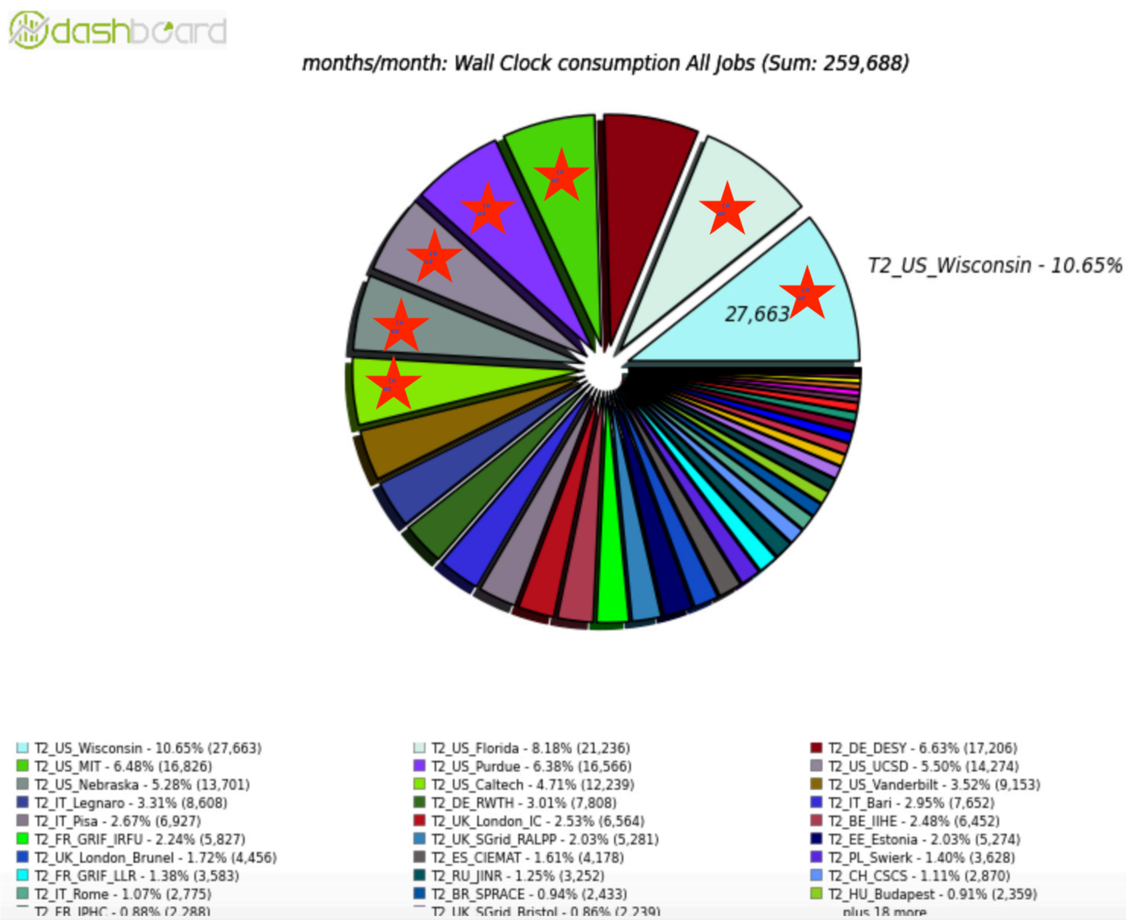


Figure 8: Percentage of total computing time delivered to CMS by Tier-2 sites world-wide, by site.

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.

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.

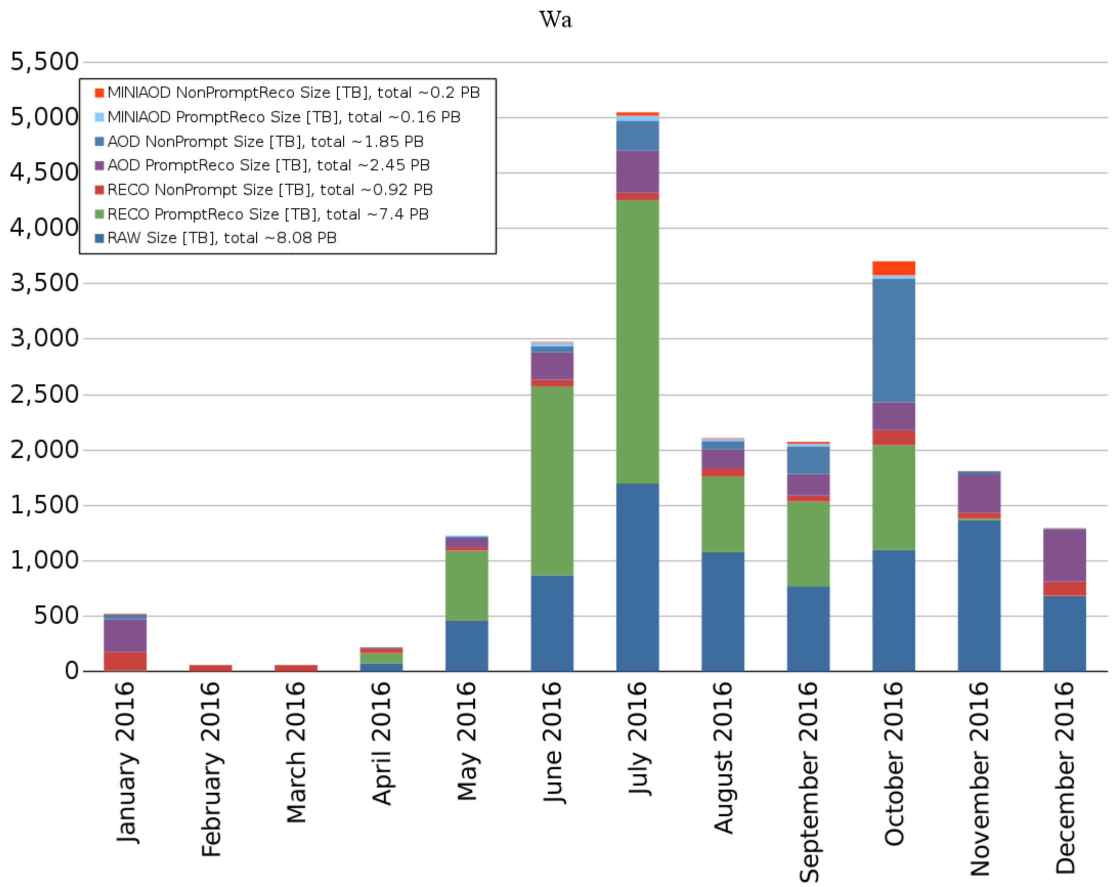


Figure 9: Volume of data output in the re-reconstruction campaign.

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.

Monte Carlo generation for the analyses targeting conferences in Spring 2017 started in the middle of November. After 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

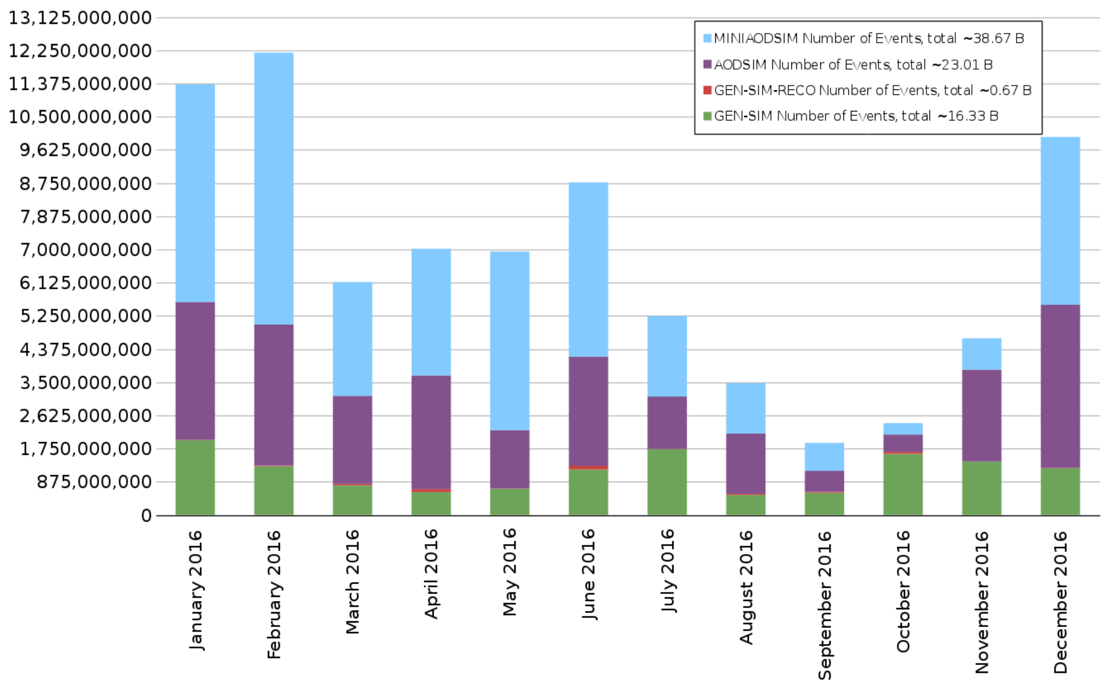


Figure 10: Monte Carlo generation in 2016 by number of events.

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.

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 FNAL 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.