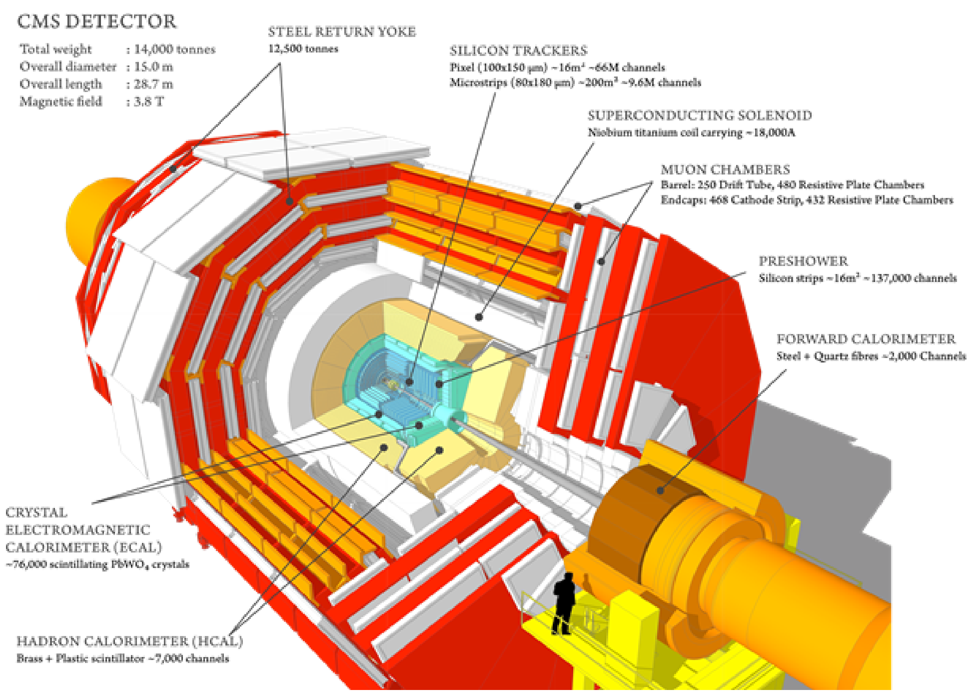
U.S. CMS Compact Muon Solenoid Operations Program
Quarterly Report for the Period Ending June 30, 2016

U.S. CMS Operations Program



Program Manager's Summary

During this quarter, the second quarter of **calendar year 2016** (2016Q2), the LHC winter technical stop ended, and CMS got ready to take physics. After an early commissioning period, the experiment has transitioned to steady physics quality data taking. LHC performance was breaking records in instantaneous luminosity, beam intensity and running efficiency. This allowed CMS to take large amounts of data, and also meant that CMS trigger and data taking chains were strained to deal with the highest luminosities that have ever been achieved. While this has presented some challenges, the quality of the data has been excellent and the experiment has had a data taking efficiency of approximately 92% during this period.

All subcomponents with U.S. maintenance and operations responsibility preformed well, with detailed metric regarding performance and data taking efficiency given in the Detector Operations section. Before and during the first weeks of the new run detector components were calibrated and timed-in, achieving resolutions and performance at the level of previous years or better. A number of detector components were repaired, and others were upgraded, in particular in the Regional Calorimeter Trigger, the Endcap Muon Trigger and some HCAL readout front-ends. These are Phase1 detector upgrade deliverables that were commissioned and integrated. Details are given in later in the report.

Software and computing was well-prepared for the start of the run, and dealt well with the fast onset of high luminosity running. CMS within weeks produced a dataset larger than that of 2015. That meant that from the beginning of the run, U.S. CMS Software and Computing needed to operate at its highest levels of performance, while also preparing for a future of even higher LHC luminosity. The U.S. computing facilities all had high levels of availability and usage, which allowed for the efficient reconstruction of detector data and the simulation of billions of events that would be needed for analyses targeting ICHEP 2016 in August. Meanwhile, there was a concerted effort from both the development and operations teams to bring innovations such as multicore processing, premixed pileup samples for simulations and resizable jobs into production. While some of these innovations are still coming to full fruition, the pieces are now in place for these goals to succeed. Work continues on aspects of data access that will make opportunistic resources more useful to CMS, and tests of production workflows on those resources have given positive results. Software development is already preparing for the 2017 run, in anticipation of new detector components and even higher instantaneous luminosity. Looking even further into the future, efforts continue on long-term projects such as improved software packaging, new data access protocols and track reconstruction on new computing architectures.

The report from the Resource Manager gives detailed account of spending and changes in the spending plan, as tracked through change tracking. One large bill payed was for the U.S. contribution to the CMS Maintenance and Operations cost, which are invoiced in Swiss franc. Resources deployed at CERN, and paid directly in Swiss francs, account for approximately 27% of the 2016 spending plan. The bills in Swiss francs covered during this period came in at exchange rates of 0.97 CHF/USD which led to cost savings over the rate of 0.9 CHF/USD used for planning. This allowed project management to respond to additional needs in particular for detector operations. A list of these changes can be found in the tables in the Resource Manager's report in the next section.

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.

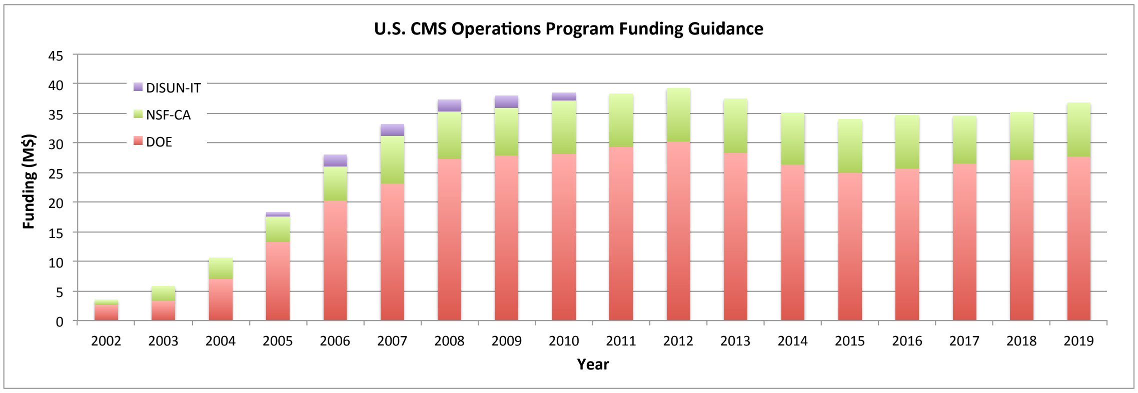


Figure 1: The annual U.S. CMS Operations Program funding provided by DOE and NSF. For 2002 through 2016 the chart shows the actual funding, while for 2017 onward the current funding guidance is shown.

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 June of 2016, a total of 115 SOWs (75 DOE and 40 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 changes to the Phase2 Upgrade R&D spending plan during this quarter are indicated in Table 3. This includes a reduction of $500,000 to the Operations Program spending plan, corresponding to the $500,000 of funding that was redirected by DOE from the Operations Program to HL-LHC OPC. The CY16 spending plan, as of the end of Q2, is shown for DOE and NSF funds in Table 4.

The plan will continue to evolve slightly as Change Requests are executed.

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 5 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 6 shows the total obligations and the spending plan, for NSF funds. Of the $9M in NSF funding, $2.0M 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 Q2 averaged 0.97 CHF/USD. Figure 7 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 7 does not include the 3,756K CHF M&O-A payments, as these are each made through multiple payments to a separate Team Account.

U.S. CMS Detector Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY16Q2 Plan**	**Change $**	**CY16Q3 Plan**
11	Endcap Muon	CR-025	CERN TA UCLA COLA redistribution and reduction	$1,892,167	($2,814)	$1,889,353
12	Hardon Calorimeter	Adjust & CR-032, 033, 034, 035, 036	CERN TA Brown COLA for detector performance, Maryland travel for burn-in and DQM, Iowa materials and labor for radiation damage tests, CERN TA M&S reduction, CERN TA Texas Tech COLA for DQM	$1,759,469	$80,245	$1,839,715
13	Trigger			$825,091	$0	$825,091
14	Data Acquisition			$985,340	$0	$985,340
15	Electromagnetic Calorimeter	CR-013	CERN TA COLA reduction, added travel support	$920,057	($6,753)	$913,303
16/17	Tracker (Fpix & SiTrk)	CR-001, 002, 003	M&O-B adjustment, CERN TA Brown labor for Detector Performance Group, CERN TA UCSD COLA	$853,361	$736	$854,097
18	Detector Support		Adjustment prior to SOW	$114,165	$5,000	$119,165
19	BRIL			$343,754	$0	$343,754
30	Phase 2 Upgrade R&D		See table of Phase 2 Upgrade R&D changes, and notes	$4,037,411	($371,069)	$3,666,341
11-19,30	**Detector Operations**			**$11,730,815**	**($294,655)**	**$11,436,160**

U.S. CMS Common Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY16Q2 Plan**	**Change $**	**CY16Q3 Plan**
21.2	Common Costs (M&OA)			$4,332,942	$0	$4,332,942
21.3	RCMS			$543,397	$0	$543,397
21.4	LHC Physics Center			$860,327	$0	$860,327
21.5	Operations Support	Adjust & CR-093	Adjustments prior to SOW, and support for UC Riverside travel to Fermilab	$1,456,688	$70,302	$1,526,989
21.6	Program Office			$1,205,115	$0	$1,205,115
21.7	E&O			$283,809	$0	$283,809
21.8	Collaboration Support			$0	$0	$0
21	**Common Operations**			**$8,682,278**	**$70,302**	**$8,752,580**

U.S. CMS Software and Computing Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY16Q2 Plan**	**Change $**	**CY16Q3 Plan**
22.1	Fermilab Facilities			$5,923,423	$0	$5,923,423
22.2	University Facilities	SOWs, CR-012	SOWs: additional $125,000 equip at each of 7 Tier-2s; CR-012: Notre Dame travel for univ facilities co-leader	$3,074,858	$878,000	$3,952,858
22.3	Computing Operations		Moved some labor to WBS 22.4 prior to SOW	$929,058	($63,953)	$865,105
22.4	Computing Infra and Services		Data and workflow mngmt labor increases prior to SOW	$2,199,661	$239,823	$2,439,484
22.5	Software and Support			$1,516,139	$0	$1,516,139
22.6	Technologies & Upgrade R&D	CR-011	Shift COLA to labor at Princeton for new arch reco	$865,976	$560	$866,536
22.7	S&C Program Management & CMS Coordination			$605,887	$0	$605,887
22	**Software and Computing**			**$15,115,003**	**$1,054,430**	**$16,169,433**
U.S. CMS Operations Program Total				**$35,528,097**	**$830,077**	**$36,358,173**

Figure 2: Spending Plan Change Log for CY16 Q2.

Phase 2 Upgrade R&D Changes in CY16 Q2		
Description	**Institution**	**Change $**
CR-045: HGCAL M&S and travel for testbeam	Iowa	$10,000
Adjustments prior to SOWs	Various	$118,931
The following portions of Phase2 budget items moved out of the Operations Program when $500,000 was redirected to HL-LHC OPC		
Endcap Calo (module assembly & sensor testing, cassette services)	FNAL	($112,393)
Project Office	FNAL	($166,330)
Trigger (Calo demonstrator boards)	Wisconsin	($70,000)
Trigger overhead	FNAL	($3,038)
Tracker (outer tracker)	FNAL	($148,239)
Total change from Q2 plan to Q3 plan		($371,069)

Figure 3: Phase 2 Upgrade R&D changes for CY16 Q2.

WBS	Subsystem	DOE Funds	NSF Funds	Total
11	Endcap Muon	$1,400,083	$489,270	$1,889,353
12	Hadron Calorimeter	$1,711,288	$128,427	$1,839,715
13	Trigger	$684,011	$141,080	$825,091
14	Data Acquisition	$985,340	$0	$985,340
15	Electromagnetic Calorimeter	$913,303	$0	$913,303
16/17	Tracker (Fpix & SiTrk)	$714,106	$139,991	$854,097
18	Detector Support	$119,165	$0	$119,165
19	BRIL	$172,321	$171,433	$343,754
30	Phase 2 Upgrade R&D	$2,738,940	$927,401	$3,666,341
11-19,30	**Detector Operations**	**$9,438,558**	**$1,997,602**	**$11,436,160**
21.2	Common Costs (M&OA)	$3,487,392	$845,550	$4,332,942
21.3	Run Coordination and Monitoring	$436,697	$106,700	$543,397
21.4	LHC Physics Center	$860,327	$0	$860,327
21.5	Operations Support	$1,209,146	$317,843	$1,526,989
21.6	Program Office	$1,087,565	$117,550	$1,205,115
21.7	Education and Outreach	$173,224	$110,585	$283,809
21.8	Collaboration Support	$0	$0	$0
21	**Common Operations**	**$7,254,352**	**$1,498,228**	**$8,752,580**
22.1	Fermilab Facilities	$5,923,423	$0	$5,923,423
22.2	University Facilities	$114,524	$3,838,334	$3,952,858
22.3	Computing Operations	$397,140	$467,965	$865,105
22.4	Software and Support	$1,981,797	$457,687	$2,439,484
22.5	Computing Infrastucture and Services	$1,254,964	$261,175	$1,516,139
22.6	Technologies & Upgrade R&D	$69,822	$796,714	$866,536
22.7	S&C Program Management and CMS Coordination	$289,670	$316,217	$605,887
22	**Software and Computing**	**$10,031,341**	**$6,138,092**	**$16,169,433**
U.S. CMS Operations Program Total		**$26,724,251**	**$9,633,922**	**$36,358,173**

Figure 4: Spending plan at the end of CY16 Q2, for funds from DOE, NSF, and the total.

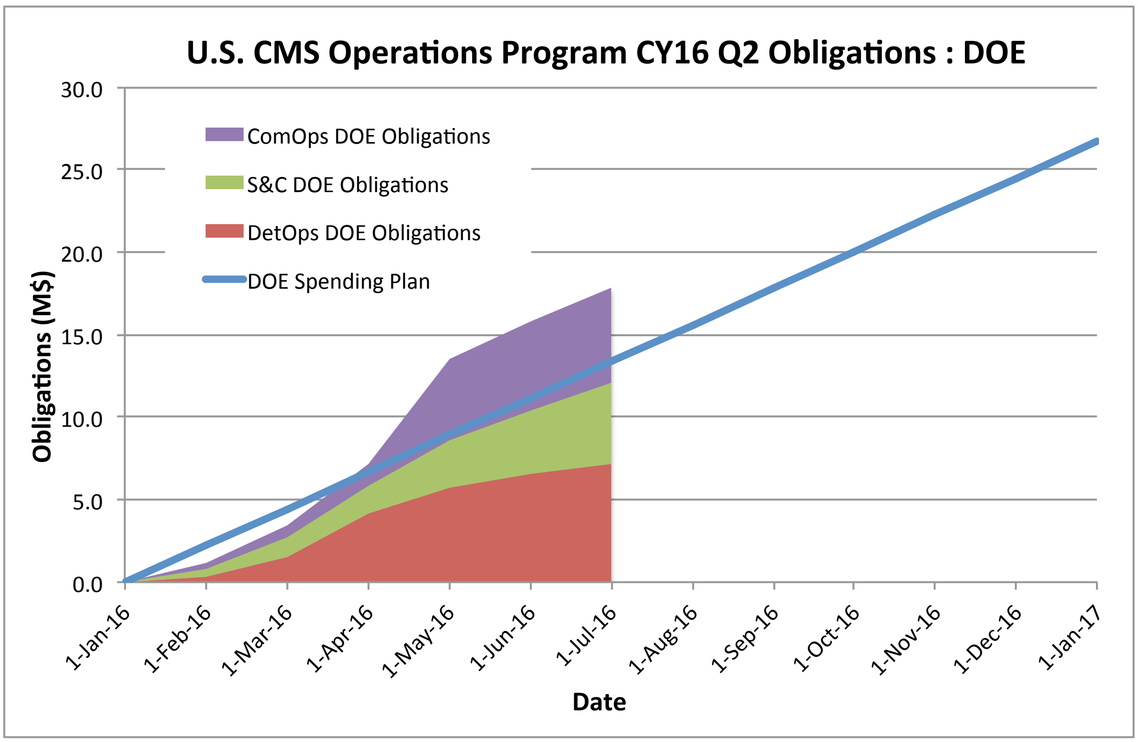


Figure 5: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

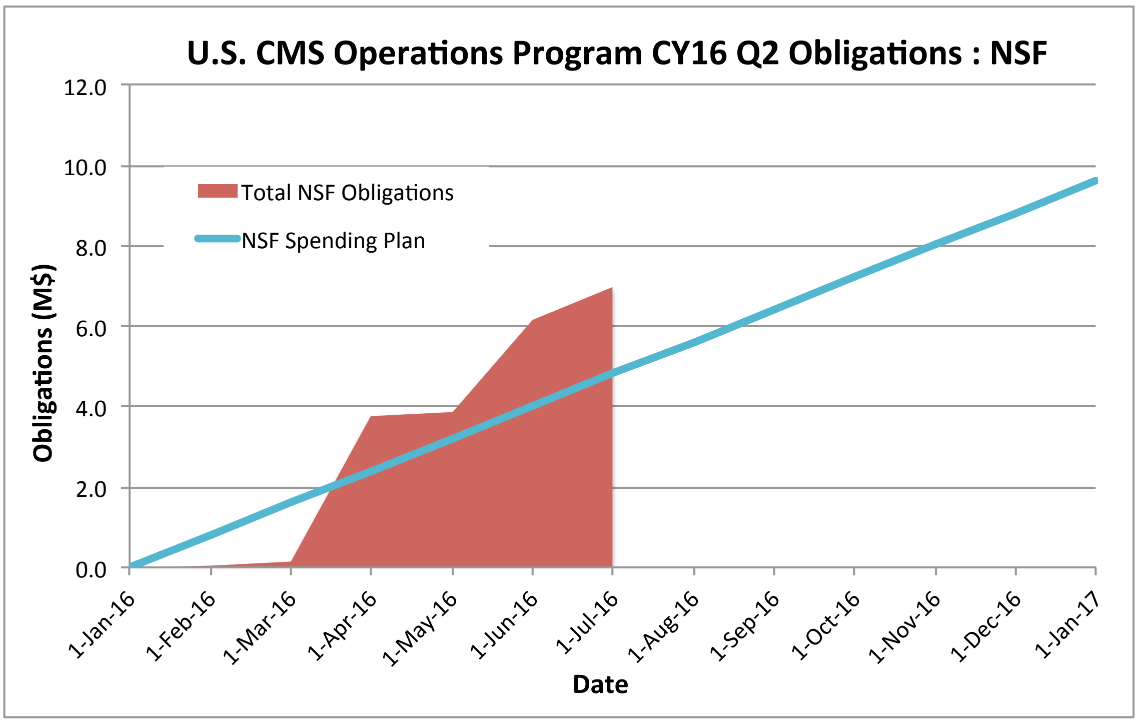


Figure 6: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.

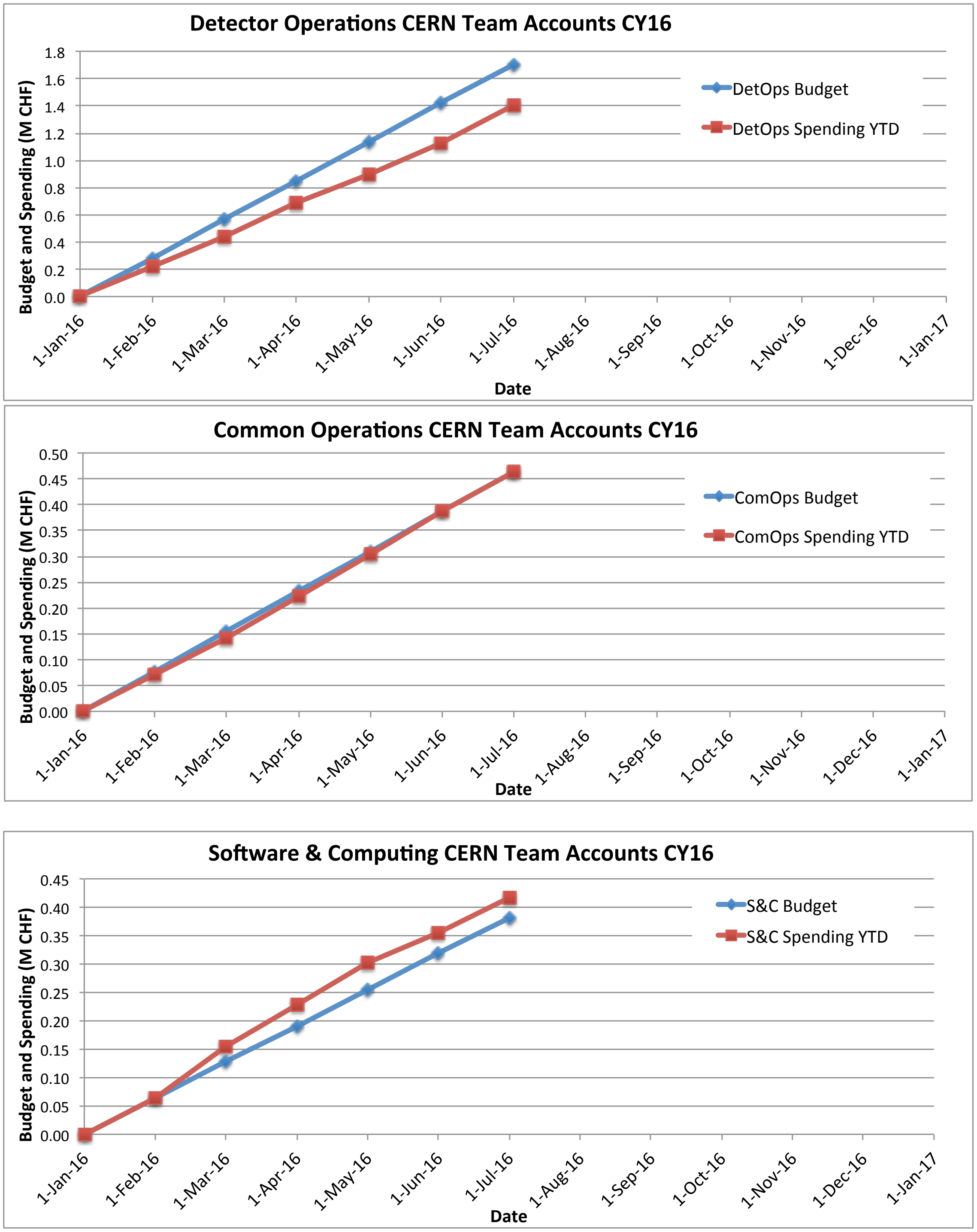


Figure 7: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.

Detector Operations

During this quarter, CMS came out of the winter technical stop ready to take physics. After an early commissioning period, the experiment has transitioned to steady physics quality data taking. The performance of the LHC has been record breaking and the experiment has had to deal with the highest luminosities that have ever been achieved. While this has presented some challenges, the quality of the data has been excellent and the experiment has had a data taking efficiency of approximately 92% during this period. Below we review the status of various US contributions to the detector.

BRIL

The luminosity calibration for physics analyses shown at the ICHEP 2016 conference during the summer was obtained from a successful VdM scan and by combining measurements from different systems. The U.S.-built Pixel Luminosity Telescope (PLT) provides full hit-information for track reconstruction, now at significantly higher rate. The track analysis has improved and provides corrections for the luminosity measurement due to non-luminosity contributions, and monitors beam conditions. The track measurement is prepared to provide an independent online luminosity value.

Online monitoring and DQM were improved to include the experiences gained during the 2015 run. As the data taking commenced warning and alarm tools were commissioned that reduce the pressure on shift personnel. Although some elements of the system were not working, the luminosity measurement was not affected by this. Replacements to be installed during EYETS 2016/17 are being assembled and tested in a simulated environment in the laboratory at CERN.

Table 1: BRIL Metrics.

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

Table 2: BRIL Milestones.

Subsystem	Description	Scheduled	Achieved
BRIL	Recommission Hardware	March	March
BRIL	Ready to deliver Lumi	May	May
BRIL	Improved Lumi Numbers for 2016	December	
BRIL	Recover telescopes	EYETS 2016/17	

Tracker

The tracker system has maintained good availability and has met its milestone.

Pixels

The Forward Pixel detector had an early issue with a poor threshold setting leading to a loss of resolution. The mistake, affecting about 6% of the 2016 data taken before June 30, was fixed shortly after being detected from results of the timing scan. We are also nearing the point in luminosity where we may need to refine compensation mechanisms for pixel.

Strips

With the increase in luminosity, there has been dynamic efficiency loss in the fist layer of the Strip detector. There are ongoing investigations into mitigating the effects and updating the simulation due to Heavily Ionizing Particles (HIPs) and pileup from to the 25ns beam structure. There are no clear winners yet for the mitigation.

Table 3: Tracker Metrics.

Metric	Pixels	Strips
% Working channels	98.7	96.5
Fraction of deadtime attributed	13%	12%

Table 4: Tracker Milestones.

Subsystem	Description	Scheduled	Achieved
Tracker	Ready for Physics&May	May	
Tracker	Pixel Phase 1 ready to insta	ll Nov.	

ECAL

In this quarter the ECAL rapidly achieved all its performance milestones and metrics. The system operated with high efficiency and very little downtime. The trigger, selective readout and spike killing thresholds were all retuned and deployed on time. The stage 2 of the ECAL phase 1 trigger upgrade was successfully deployed, leading to sharper turn-on curves and better position resolution. The calibrations rapidly achieved the same resolution performance as 2015. The refurbishment of the LV crates was completed on schedule in April. There were no major problems with hardware, DAQ and trigger, or software during the second quarter.

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	33%
Resolution performance	Excellent

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 performancet	June	June

HCAL

During the second quarter of 2016, the HCAL Operations group focused on completing the commissioning of the new hardware installed during the 2016 YETS and on acquiring good data. The upgraded hardware includes: switching to μTCA (Phase I) back-ends as the primary read-out for HB/HE, switching to the Stage-2 L1 trigger based on HB/HE trigger primitives from the μTCAs as well as increased segmentation in the HF trigger towers, and the installation of a split readout from one PMT box for HF where the signals from 22 PMTs go both to the current QIE8 frontends and a prototype Phase 1 Upgrade HF QIE10 frontend.

The HCAL group is also commissioning a small system on the Castor table located close to the beamline to study radiation damage to new scintillators that might be used in a possible replacement of some of the HE scintillator during Long Shutdown 2 or as scintillator for the HL-LHC Upgrades. This system uses prototype Phase 1 HE electronics and will enable the HCAL group to gain valuable operational experience with this new electronics as well. The system will be installed during the July Technical Stop.

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

Milestones for this Quarter June 1 Milestone: Operate HCAL detector efficiently with goal to minimize of data due to HCAL to 1% or less, maintain calibration at 1-2% level with efficient noise rejection and improved 25ns energy reconstruction.

Achieved by end of May except calibration at 3% to 4% level. Calibration and energy reconstruction improvements continue.

Metrics Fraction of channels working

- HF: 3 channels out of 1728 dead (99.8% working channels)
- HB: 3 channels out of 2592 dead (99.9% working channels)
- HE: 1 channel out of 2592 dead (99.96% working channels)
- HO: 9 channels out of 2160 dead (99.6% working channels)
- Total: 16 channels out of 9072 dead (99.8% working channels)

Fraction of downtime and data lost at certification due to HCAL

- Goal: less than 1% for both. Achieved second quarter: 0.8%.

Precision of absolute HCAL absolute energy calibration

- Goal: 2% . Currently 3% to 4%.

Inter-calibration uniformity between individual HCAL towers (HBHE, HO, HF)

- Goal 1-2%. Currently 3% to 4% 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	
HCAL	Prepared for HE/HF front end electronics installation	Dec.	
HCAL	Complete Rad Dam studies	Dec.	

EMU

The CSCs have been operating well, although a very small number (about 0.5%) of the electronics boards showed operational problem when the CMS solenoid was energized. Some of these were recovered in work in accesses. The timing settings were verified with the first colliding beam data, and required very little adjustment in the settings.

As higher values of instantaneous luminosity were achieved in the later part of the quarter, these were incidents observed where particular DCFEBs stop taking data. This is believe to be related to Single Event Upsets (SEUs) in the optical transceivers. These boards are currently restored by remote power cycling, and studies are ongoing to develop ways to recover from these SEUs automatically.

New firmware was installed on all of the Trigger Motherboards (TMBs) and Optical Trigger Motherboards (OTMBs) that now provides monitoring of many individual rates and correlated rates of the various signals used in triggering chambers. The study of this monitoring data is essential to predict the behavior of the system at higher luminosity values. The software was also finalized to allow monitoring of single event upsets (SEUs) in the Digital Front End Boards.

Work continued on investigation, repair, mitigation of water leaks. Techniques for repairing and preventing future leaks to the ME1/1 cooling system were investigated. A solution now favored involves epoxy sheaths around the joints in the cooling pipes. Further tests are required to verify that this provides robust joints. Meanwhile, no additional leaks have developed since the original one occurred in November 2015.

The performance of the CSC system was assessed with the new data. The efficiencies for hits and segments were measured in the 2016 data and results were comparable to the 2015 values. The hit resolution was also studied and was found to be slightly better than in 2015.

Table 8: CSC Metrics.

Metric	Performance
% Working channels	98.7%
Fraction of deadtime attributed	3%
Median spatial resolution	121 μm

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		
coun	ters in (O)TMB	July	June
EMU	Implement improved CSC segment		
patt	ern recognition	August in	progress

DAQ

Table 10: DAQ Metrics.

Metric	Performance
Dead time due to trigger throttling	~ 0
Downtime due to DAQ	15 min

Table 11: DAQ Milestones.

Subsystem	Description	Scheduled	Achieved
DAQ	New HLT Nodes		
	installed and commissioned	May	May
DAQ	uTCA test system added to DAQ2VAL	Aug	
DAQ	DAQ2 ready for 2 MB event size		
and	50 event pileup	Dec	

During Year-End Technical Stop 2015-2016 DAQ was optimized to build events with up to 1.2 MB event sizes at L1 accept rate of 100 kHz, and an HLT output bandwidth of $\sim$ 2 GB/s. The DAQ is performing with very little down time ($\sim$ 15 min) and negligible dead time. There was only 15 minutes down time, which was due to disk failure in the storage manager system. Figure 8 shows the event size vs. number of reconstructed primary vertices as measured in a recent run. Work is underway to use these measurements to optimize the event builder for larger event sizes using the actual distribution of fragment sizes.

Recent measurements show, that without hypethreading, the present L1/HLT menus and 100,kHz L1 rate, result in HLT CPUs that are $\sim$ 85% loaded at the start of the fills. Trigger coordination

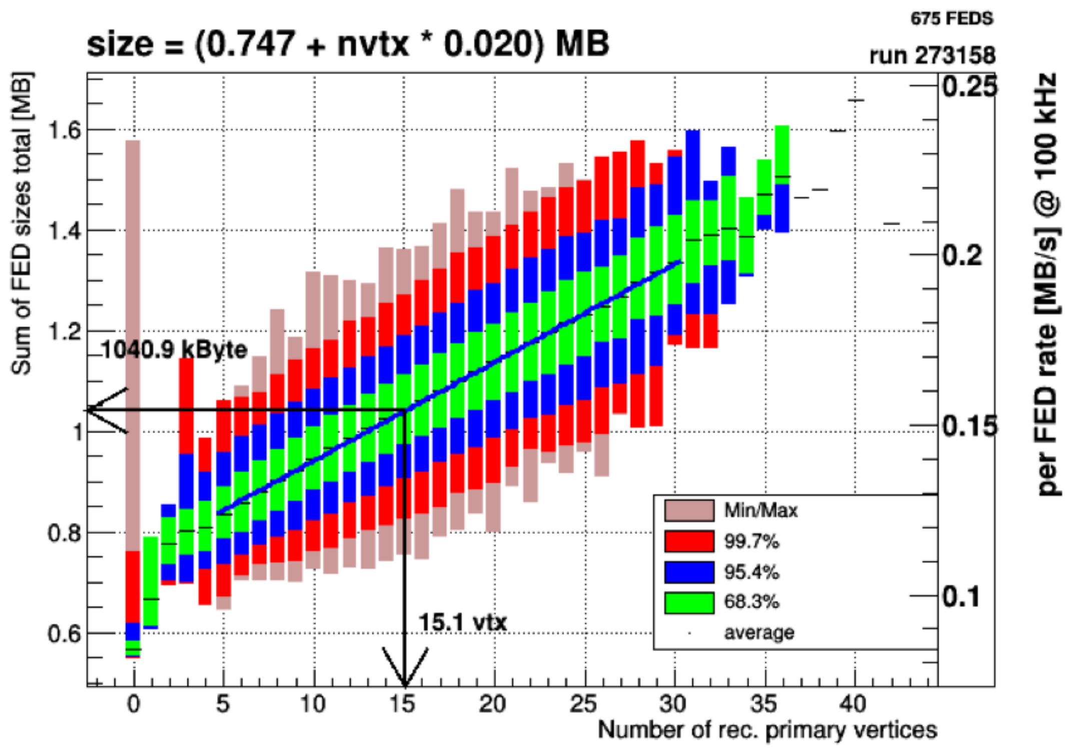


Figure 8: Event size distribution vs. number of reconstructed primary vertices. At the start of a typical LHC fill, average number of reconstructed primary vertices is ∼ 22 corresponding to average event size of 1.2 MB. Work has started to optimize the system for even larger event sizes expected when pileup will increase another 30%.

estimates that hyper-threading will provide 15-20% additional CPU power. Other handles for reducing the time per event are being worked on. The high accept rate of the HLT is also putting lots of pressure on transfer system. Occasional delays in the transfer to tier 0 were mitigated by adding more transfer nodes that are handling files from different luminosity sections.

Trigger

During this quarter U.S. groups continued their work on the Stage-2 Layer-1 Calorimeter (CaloL1) Trigger Upgrade, and the endcap muon trigger upgrade as both moved into steady state operations and data-taking.

Regional Calorimeter Trigger and Stage-2 Layer-1 Calorimeter Trigger

The Layer-1 Calorimeter Trigger (CaloL1) built by the University of Wisconsin group, as a part of the complete Calorimeter Phase-1 Trigger Upgrade, has been in continuous operations since p-p data taking started in late April 2016 CaloL1 has been in continuous operation.

Through this time, the tools for operation and monitoring have matured. The CaloL1 online software (SWATCH) has been in operation since the beginning of March, and includes link and error monitoring, Look-Up Table verification, and checks during state changes to ensure reliable operation. Hot tower monitoring is in development. The online Data Quality Monitoring (DQM) described in the previous report has been updated to include emulation of the data sent by CaloL1 to L2 using the Calorimeter Trigger Primitives received.

Endcap Muon Trigger

The Rice University, Northeastern, and University of Florida groups have successfully commissioned the Phase-1 upgrade for the endcap muon trigger for 2016 physics operations.

The commissioning of the endcap muon trigger has included resolving discrepancies in the software emulator vs. firmware results on data, now at the level of 2% but under continued study. The online DQM package for the new system was developed by the groups and deployed in time for the first collisions, and has been used to spot some detector and optical link issues that have been resolved. Experts from the university groups have maintained on-call coverage of the system during the physics runs that took place during this quarter.

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	

Table 13: Trigger Metrics.

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

Software and Computing

As the LHC started into operations for 2016 and quickly produced a dataset larger than that of 2015, U.S. CMS Software and Computing needed to operate at its highest levels while also preparing for a future of even stronger machine performance. The U.S. computing facilities all had high levels of availability and usage, which allowed for the efficient reconstruction of detector data and the simulation of billions of events that would be needed for analyses targeting ICHEP 2016 in August. Meanwhile, there was a concerted effort from both the development and operations teams to bring innovations such as multicore processing, premixed pileup samples for simulations and resizeable jobs into production. While some of these innovations are still coming to full fruition, the pieces are now in place for success. Work continues on aspects of data access that will make opportunistic resources more useful to CMS, and tests of production workflows on those resources have given positive results. Software development is already looking forward to 2017, in anticipation of new detector components and even higher instantaneous luminosity. Looking even further into the future, efforts continue on long-term projects such as improved software packaging, new data access protocols and track reconstruction on new computing architectures.

Table 14: Major S&C milestones achieved this quarter.

Date	Milestone
April 20	Fermilab dCache upgraded to v2.13, operation transferred to Data Management Services group
June 1	WMAgent ready for multicore versions of all available multithreaded workflows Fermilab Facilities

Fermilab Facilities

This quarter for the Fermilab Facilities marked the beginning of significant data taking at CERN for the year and transfer of much of that data to Fermilab storage facilities. About 4 PB of custodial data was written to Fermilab tape this quarter. Early on in the quarter, before the LHC run began in earnest, Fermilab completed the upgrade of its disk-only dCache instance to the latest supported version. This was essentially a re-build of the disk storage at Fermilab, and utilized the FY15 8 PB disk purchase. The new disk pools were deployed empty with the new dCache version, and data transferred into it at record rates in time for deployment in April. In addition to the physical change, the new dCache instance changed operational supervision within Fermilab. The same group within SCD, Data Management Services, now manages both the public dCache instance for Fermilab as a whole, and the CMS dCache instances, a large step towards the service-based facility management model.

Figure 9 shows the site readiness metrics for the Tier 1 during the quarter. The downtime taken on April 18 for the dCache upgrade is seen in blue; following are a few red marks due to transfer inefficiencies immediately following. Those were understood and resolved by the end of that week, and metrics stayed mostly green since. Site utilization remained high this quarter, completing the simulation and reprocessing work needed for summer conference physics results. During this period the Tier-1 facility provided 32.5 million wall hours to CMS.

Figure 9: Fermilab readiness metric for 2016Q2. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. Fermilab passed metric 95% during this quarter.

University Facilities

The third quarter was a very busy time for the U.S. CMS Tier-2 facilities during a period of intensive data analysis and central production activities for simulated data in the run-up to the summer physics 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 have operated successfully this quarter. On our two official performance metrics based on CMS test jobs, all sites were at least 94% "available" (a 4% improvement on the previous quarter) and 80% "ready". The availability metric comes from the WLCG and the readiness metric a fine-grained measure of more CMS-specific services. The CMS goal for each of these metrics is 80%. The U.S. CMS Tier-2 centers delivered 47.1% of all computing time by Tier-2 sites in CMS (our commitment to global CMS is > 25%), an increase of 4% over the previous quarter. As shown in Figure 10, our Tier-2 facilities continue to be seven of the eight most-used Tier-2 sites in all of global CMS.

As for progress on milestones and upgrades, the connection of the Tier-2 sites to the LHCONE VPN by ESNet is still proceeding with only one site remaining. Connection of Tier-3 sites on request is also proceeding, with one completed. Four sites have upgraded to HTCondor 8.4.x and three have deployed IPv6 compliant xrootd. Upgrading to version 3.3 of the OSG software stack, which is essential to do before the end of support at the end of August, has been completed at most sites. One site has also upgraded its worker nodes to RHEL 7, using Docker containers to provide an SL6 environment for CMS, and was actively working on retiring their SRM server. Improvement of HS06 benchmarking and APEL normalization constants has been maintained, with the consistency of the reports to the WLCG being cross-checked monthly.

Nine Tier-3 sites required assistance from the Tier-3 support team this past quarter on issues related to OSG software upgrades, PhEDEx, networking and basic Linux systems adminstration. The central PhEDEx service was transitioned to support by the same team that runs PhEDEx for the Tier-1. Beta testers continue to exercise CMS Connect and a tutorial for new users was held in June.

Computing Operations

April, May and June was the time when Operations prepared and started the massive production campaign for ICHEP, to be held Aug 3-10. In this quarter we completed 7.6B DIGI-RECO events (90% of which was targeted towards ICHEP), 2.0B GEN-SIM events and 5.3B MINIAOD events. The LHC started to run and after the initial ramp-up performed beyond expectations. We reconstructed 2.9B events at the Tier-0 and re-reconstructed another 0.2B data events. The Computing

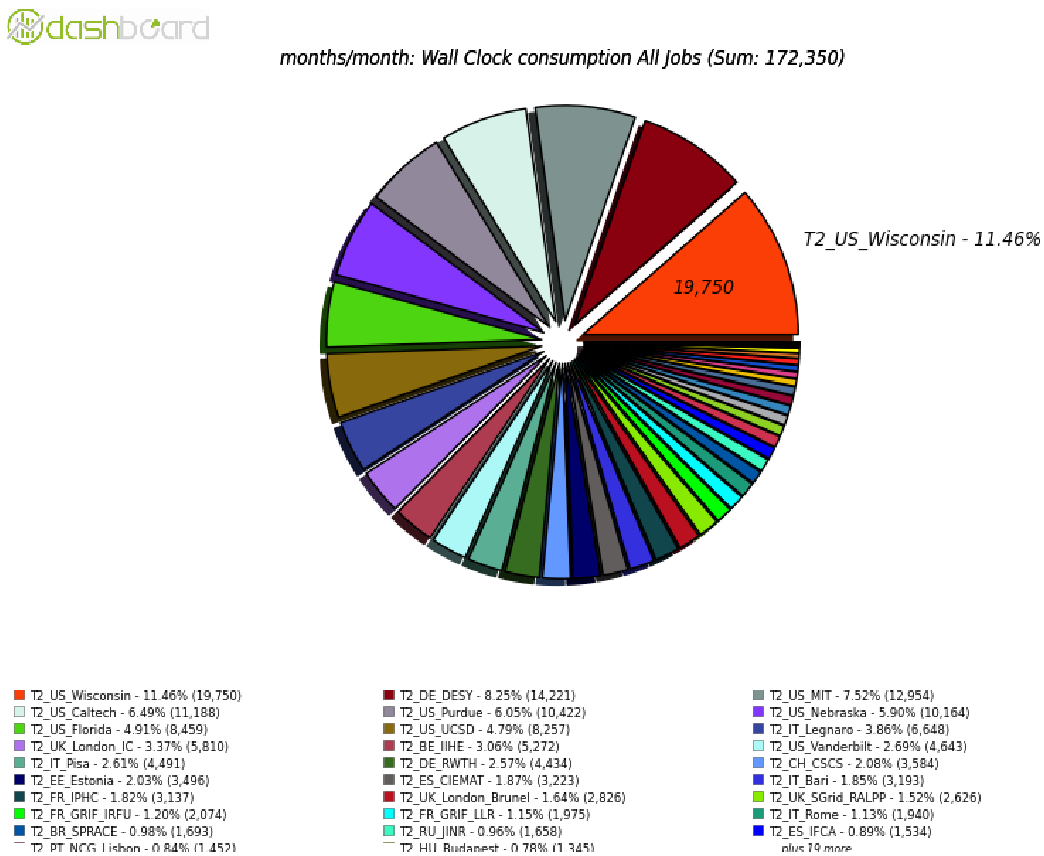


Figure 10: Percentage of total computing time delivered to CMS by Tier-2 sites world-wide, by site.

Operations project continues to perform as promised. The production summary for MC events is shown in Figure 11.

The Computing Operations group has worked on integrating multicore processing, the new Request Manager v2 and the premixing production workflow, all of which are crucial for continued efficient event production. Due to time pressure, none of the three options were implemented for the initial part of the ICHEP processing, but multicore usage was enabled gradually and worked fine. A plan has been developed for the pileup simulation using pre-mixed samples of minimum bias events. It was implemented at a lower priority and steady progress has been made. We are confident pre-mixing can be used for the upcoming large productions, where it will be paramount due to the higher than expected pileup.

To address inefficiencies in operations and to design more effective tools for the operators work we are organizing a Computing Operations internal workshop in the month of August after ICHEP.

Computing Infrastructure and Services

The CIAS area moved forward on several fronts during this quarter. Final modifications were made to WMAgent workflow management system to enable the submission and modification of workflows to run in multithreaded mode. CMS Computing Operations has performed testing of these

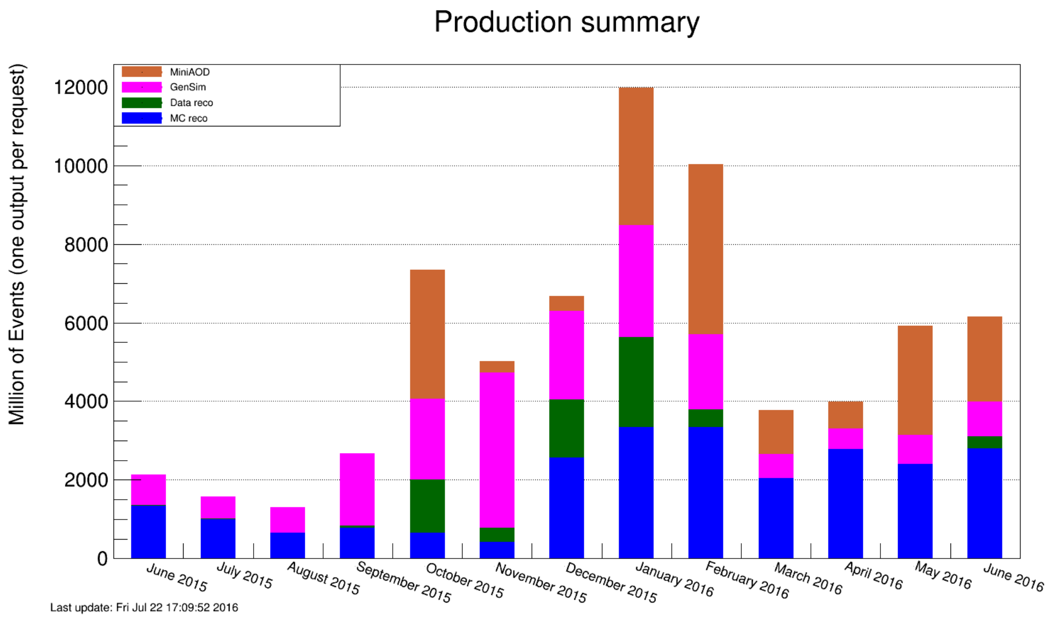


Figure 11: Production summary for the last 13 months. A steady, very high production rate was accomplished during this quarter.

workflows and will make the switch at a convenient time.

WMArchive has reached approximately 50% of the final scale (saving 50% of the job report documents) for the last 1.5 months of the reporting period. The service is currently running on pre-production hardware and should move to 100% scale and production hardware during the next quarter.

The Request Manager v2 migration is also proceeding; our CMSSW release validation has switched over entirely to v2. Computing Operations and the CMS PPD organization are pushing forward on validation and will switch submission to using v2 at a convenient transition point, but are already using v2 for monitoring.

For GlideinWMS, version 3.2.14 was released; it improves the draining of glideins from sites. Support was added for the RHEL7-supplied python version. Most relevant to CMS, changes were made to the ClassAd parsing to enable dynamically resized jobs; this will allow CMS to fit its jobs into a slots with a range of core counts and increase the CPU efficiency of our resources.

Opportunistic work advanced on three different sets of resources: NERSC's Cori and Edison machines, SDSC's Comet, and OSG opportunistic resources. In all three cases, production-like workflows were commissioned and successfully executed. We expect to integrate these resources into the GlideinWMS global pool and use them for production work early in Q4. We have an allocation on TACC Stampede and began testing CMS workflow submission there.

The new asynchronous POSIX implementation of XRootd caching proxy was tested under increasing load and realistic access patterns. Caching proxy logging functionality was converted to use standard XRootd trace and logging functions; previously the proxy used XRootd client logging functions).

The XRootd caching proxy was installed at a CMS Tier-3 facility at University of Notre Dame, configured as a caching cluster with a redirector and two high-performance disk servers (10 Gbps network, 12 4TB disks) with intention of adding more disk servers later on. Notre Dame has about 10,000 opportunistic CPUs that can become available to the Department of Physics and all those jobs are directed to go through the caching proxy. As the caching cluster is currently under-sized for such load, we were able to identify several issues in the caching proxy and XRootd POSIX layer that would be otherwise hard to trace. Two relatively minor issues are still present and as they are relatively rare we are still trying to understand their origin (but most likely they are caused by inconsistent mutex use in XRootd POSIX layer).

Software and Support

The software support effort intensified during Q3 in order to cope with the LHC ramp to full 2016 luminosity production. The data-taking release series, CMSSW 8_0, had 14 updates for operational issues. The software development release this quarter is making good progress on achieving 2016 milestones. Code for the Phase-1 upgrades in HCAL and pixels has been integrated so that the current development release, CMSSW 8_1, can be used to generate simulation samples for 2017. Work continues on the Fireworks display; an ECAL crystal detailed view has been developed during this quarter. U.S. CMS has contracted with squid developers to add a feature required by Frontier, our distributed database solution. This feature, called collapsed validation forwarding, was broken in the latest releases. The latest releases are also the only ones that support IPv6 addressing. Fixing the feature in the latest releases was beyond the capabilities of our local support person, hence the expert contractor. The contractor finished this work, and the Fermilab personnel are now working to integrate it into a release so that we are now in the good position of having a release that supports both collapsed validation forwarding and IPv6.

In the area of core software, we have removed our dependence on apt, a piece of open source legacy software that is no longer supported. This effort grew out of discussions in the packaging working group of the HEP Software Foundation (HSF); we hope to gain further improvements in sustainability in this area through similar efforts. For instance, an outcome of the recent HSF workshop in Paris was that many of the experiments agreed that Spack, a tool developed for the HPC community from LLNL and proposed for HEP use by Fermilab, shows great promise. Building and packaging large HEP software stacks on new systems and architectures is a task that is being duplicated by many HEP experiments unnecessarily. It will take some work to adapt the legacy systems to a common one for the field but it will better position us for the future where computing will be more heterogeneous than it is today.

In the near future, CMS Software and Computing management will have to re-plan the work to be done this fall for two reasons. Highly Ionizing Particles (HIP) produced near the beam at high luminosity are having a serious effect on our tracking and b-tagging efficiency. Code to both simulate this HIP effect and mitigate its effect in the reconstruction has been developed this quarter but it needs to be validated and deployed in the next. In addition, given the unexpected performance of the LHC, the pileup distributions we simulated for 2016 are no longer suitable for Monte Carlo (MC) samples, and need to be redone to enhance statistics at high instantaneous luminosity. Small variations in the pileup distributions between data and MC can be handled with re-weighting techniques, but only with sufficient statistics at relevant pileup levels. To address both of these problems we will have to make effective use of computing facilities this fall to be ready for 2017 winter conferences.

Technologies and Upgrade R&D

During this quarter, we finished the initial version of "resizable jobs". This is a modification to the HTCondor-based global pool allowing for the number of cores in a given job to be dynamically adjusted based on the runtime environment found on the worker node. This mechanism is waiting on an updated version of glideinWMS that supports this new mode.

The work with HTTP for data access advanced to a functional testbed at Caltech; a corresponding module for accessing HTTP via DAVIX was submitted to CMSSW. It is currently under review. The new module should allow performant access to ROOT files via HTTP (and supports all of CMSSW's enhancements on top of bare ROOT). Performance tests are ongoing.

Beyond the WLCG facilities, we have maintained the capability to run at DOE supercomputing facilities (namely NERSC). This quarter, we worked toward maintaining a stable environment at Cori and Edison, as well as working with the NERSC staff to understand and correct performance deficiencies. We expect to be able to resume production workflows next quarter.

For the tracker prototype, this quarter continued our focus on improving vectorized track building; further, the prototype is working toward improved integration with realistic CMSSW-based data. This work is performed in collaboration with personnel supported by NSF awards PHY-1520969, PHY-1521042 and PHY-1520942.