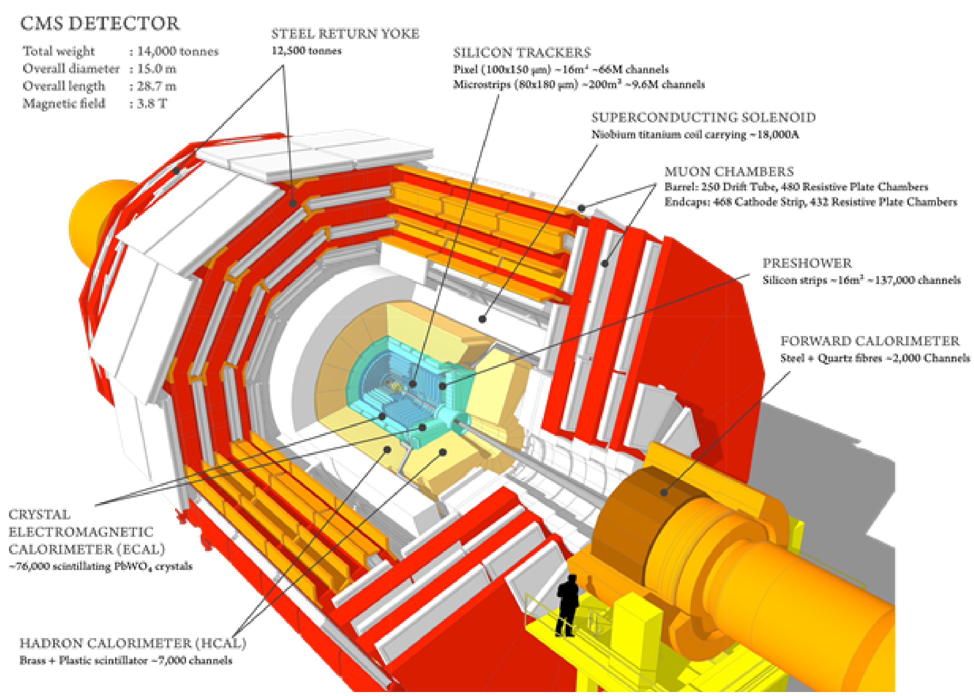
U.S. CMS Compact Muon Solenoid Operations Program Quarterly Report for the Period Ending March 31, 2016

U.S. CMS Operations Program



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Program Manager's Summary

During this quarter, the first quarter of **calendar year 2016** (2016Q1), the LHC and CMS were in an extended "year end technical stop" (YETS). CMS used the machine downtime to make repairs and enhancements to various elements of the detector.

Important and extensive work was done to clean the "cold box" used to refrigerate and liquefy Helium gas to cool the CMS superconductor solenoid magnet. The oil separator unit on the surface was replaced with a new one that has much higher capacity. The helium transfer line was replaced, and the whole cold box system was cleaned with solvents and all filters were replaced. Analysis of the cleaning solvent showed that significant amounts of BREOX oil had accumulated in the system, that have now been successfully removed. The magnet is being cooled down for operations during the startup of the LHC machine in April.

Repairs of CMS systems, in particular leaks in the EMU cooling systems, are described at some detail in the detector operations section. To keep systems running and commissioned, during the technical stop CMS ran a campaign of so-called global runs with cosmic rays that allowed the commissioning of the detector to proceed without beam.

Software and Computing was busy with supporting data analysis, and preparing systems for the expected extensive run. The Tier-1 and Tier-2 facilities met their performance metrics, while also undergoing upgrades and enhancements that will improve their throughput. The Fermilab computing facility did a significant upgrade of the storage systems. The operations teams closed out processing of 2015 data and delivered large numbers of simulated events.

A particular highlight was the successful demonstrator use of the Amazon cloud computing service aws for production running, supported in part by a grant from amazon.com, to deliver large simulation samples in time for use in results presented at winter conferences. The Fermilab Scientific Computing Division started the HEPcloud project, in collaboration with CMS and OSG, with the goal to transform part of the U.S. facilities to a services platform that can include external commercial or opportunistic computing services, including amazon and High Performance Computing Centers funded by DOE and NSF. For CMS a goal is to gain seamless access to on-demand computing resources for fast-turnaround data processing.

Preparing for the run, the deployment of multi-core jobs running multi-threaded applications made good progress. A major version of the experiment software (CMSSW) was released, which is targeted at 2016 data taking and supports multi-threading and many other features. The R&D area continues activities that have made immediate impacts on operations and also prepare the computing systems for the longer term.

The spending plan for 2016 was developed with input from a series of budget reviews in the fall of last year, input from the Resource Allocation Advisory Board RAAB, and discussions with the funding agencies and the Joint Oversight Group JOG. Funding levels for 2016 are low compared to previous years and funding demands for HL-LHC R&D are increasing to prepare for the upgrade project. The U.S. CMS Operations Program is following a tight spending plan, shown in the Resource Manager's report in the next sections, tracking variances and staying within the envelope.

The luminosity expectations for the physics run starting in the coming quarter are for 25/fb, up to 30/fb of data accumulated in the 150 days planned for *pp* luminosity running. This represents a large increase in available luminosity for CMS at 13 TeV, and the outlook for potential discoveries are exciting!

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 {@fig:funding_profile}.

[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.] (figures/CY16_Funding_Profile.pdf){#fig:funding_profile}

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 March of 2016, a total of 95 SOWs (64 DOE and 31 NSF) were produced and approved, with an additional 13 in the pipeline. After a SOW is approved, any additional changes are considered and, if approved, enacted through a Change Request procedure.

Table 1 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 Q1, is shown for DOE and NSF funds in Table 2. 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 3 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 4 shows the total obligations and the spending plan, for NSF funds. Of the $9M in NSF funding, $3.6M 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 Q1 averaged 0.99 CHF/USD. Figure 5 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 5 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**	**CY16Q1 Plan**	**Change $**	**CY16Q2 Plan**
11	Endcap Muon	Adjust & CR-024	TAMU labor adjustment prior to SOW; U. Florida labor and travel, U Wisconsin materials for CSC chamber aging studies	$1,778,337	$113,830	$1,892,167
12	Hardon Calorimeter		Adjustment prior to SOW	$1,816,670	($57,201)	$1,759,469
13	Trigger	Adjust & CR-016	Adjustment prior to SOW; Additional travel and COLA support through Team Account	$744,203	$80,888	$825,091
14	Data Acquisition	CR-006	Rice COLA and M&S for software engineer	$951,577	$33,763	$985,340
15	Electromagnetic Calorimeter		Adjustment prior to SOW	$923,913	($3,856)	$920,057
16/17	Tracker (Fpix&SiTrk)			$853,361	$0	$853,361
18	Detector Support			$114,165	$0	$114,165
19	BRIL	CR-003	U. Tennessee labor support for PLT Operations and Frontend Coordinator	$314,690	$29,064	$343,754
30	Phase 2 Upgrade R&D			$4,037,411	$0	$4,037,411
11-18,30	**Detector Operations**			**$11,534,327**	**$196,488**	**$11,730,815**

U.S. CMS Common Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY16Q1 Plan**	**Change $**	**CY16Q2 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	CR-092	Princeton materials for fast timing layer testbeam	$1,450,868	$5,820	$1,456,688
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**			**$8,676,458**	**$5,820**	**$8,682,278**

U.S. CMS Software and Computing Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY16Q1 Plan**	**Change $**	**CY16Q2 Plan**
22.1	Fermilab Facilities			$5,923,423	$0	$5,923,423
22.2	University Facilities			$3,074,858	$0	$3,074,858
22.3	Computing Operations			$929,058	$0	$929,058
22.4	Computing Infrastructure and Services			$2,199,661	$0	$2,199,661
22.5	Software and Support			$1,516,139	$0	$1,516,139
22.6	Technologies & Upgrade R&D			$865,976	$0	$865,976
22.7	S&C Program Management & CMS Coordination			$605,887	$0	$605,887
22	**Software and Computing**			**$15,115,003**	**$0**	**$15,115,003**
U.S. CMS Operations Program Total				**$35,325,788**	**$202,308**	**$35,528,097**

Figure 1: Spending Plan Change Log for CY16 Q1.

WBS	Subsystem	DOE Funds	NSF Funds	Total
11	Endcap Muon	$1,402,897	$489,270	$1,892,167
12	Hadron Calorimeter	$1,631,042	$128,427	$1,759,469
13	Trigger	$684,011	$141,080	$825,091
14	Data Acquisition	$985,340	$0	$985,340
15	Electromagnetic Calorimeter	$920,057	$0	$920,057
16/17	Tracker (Fpix-SiTrk)	$837,301	$16,060	$853,361
18	Detector Support	$114,165	$0	$114,165
19	BRIL	$172,321	$171,433	$343,754
30	Phase 2 Upgrade R&D	$3,106,860	$930,551	$4,037,411
11-19,30	**Detector Operations**	**$9,853,994**	**$1,876,821**	**$11,730,815**
21.2	Common Costs (M&OA,LS1,UpgrdLoan)	$3,487,392	$845,550	$4,332,942
21.3	Run Coordination and Monintoring	$436,697	$106,700	$543,397
21.4	LHC Physics Center	$860,327	$0	$860,327
21.5	Operations Support	$1,138,845	$317,843	$1,456,688
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**	**$7,184,050**	**$1,498,228**	**$8,682,278**
22.1	Fermilab Facilities	$5,923,423	$0	$5,923,423
22.2	University Facilities	$114,524	$2,960,334	$3,074,858
22.3	Computing Operations	$461,093	$467,965	$929,058
22.4	Software and Support	$1,741,974	$457,687	$2,199,661
22.5	Computing Infrastucture and Services	$1,254,964	$261,175	$1,516,139
22.6	Technologies & Upgrade R&D	$69,822	$796,154	$865,976
22.7	S&C Program Management and CMS Coordination	$289,670	$316,217	$605,887
22	**Software and Computing**	**$9,855,471**	**$5,259,532**	**$15,115,003**
U.S. CMS Operations Program Total		**$26,893,516**	**$8,634,581**	**$35,528,097**

Figure 2: Spending plan at the end of CY16 Q1, for funds from DOE, NSF, and the total.

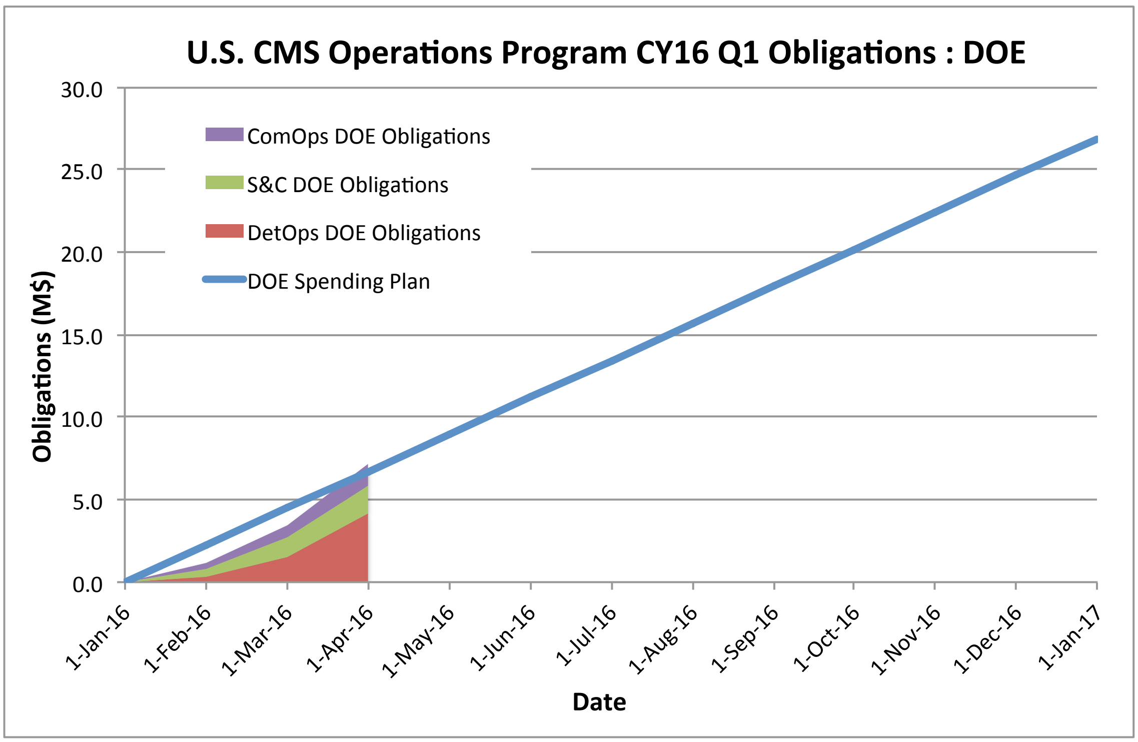


Figure 3: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

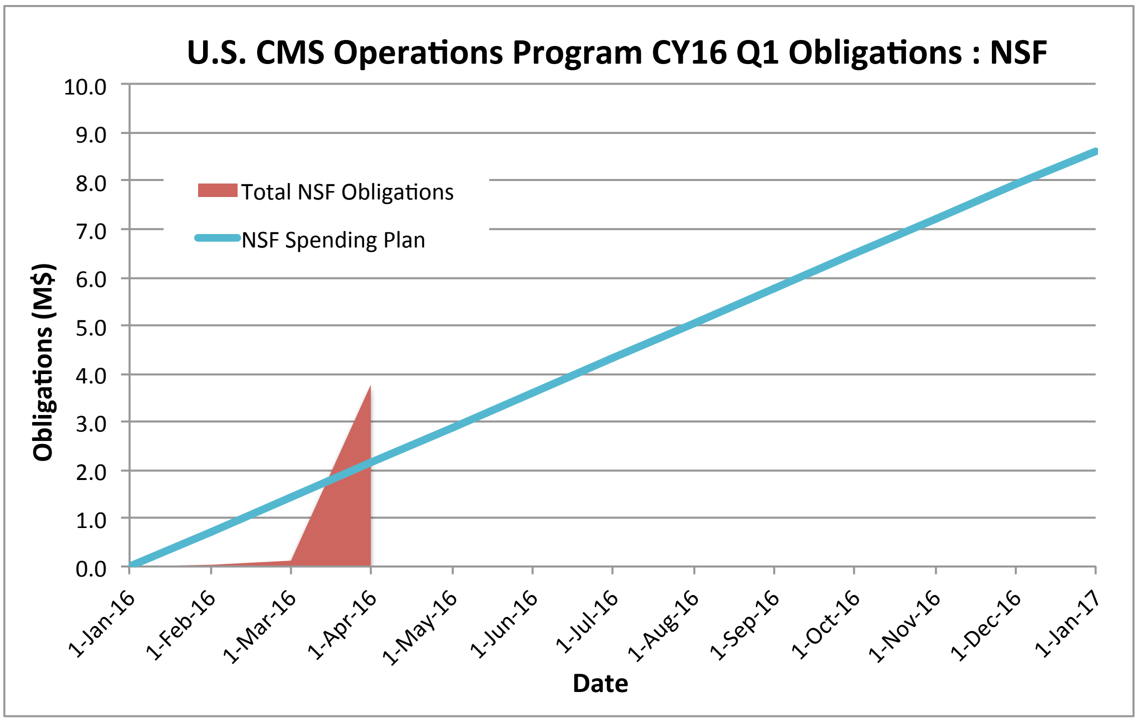


Figure 4: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.

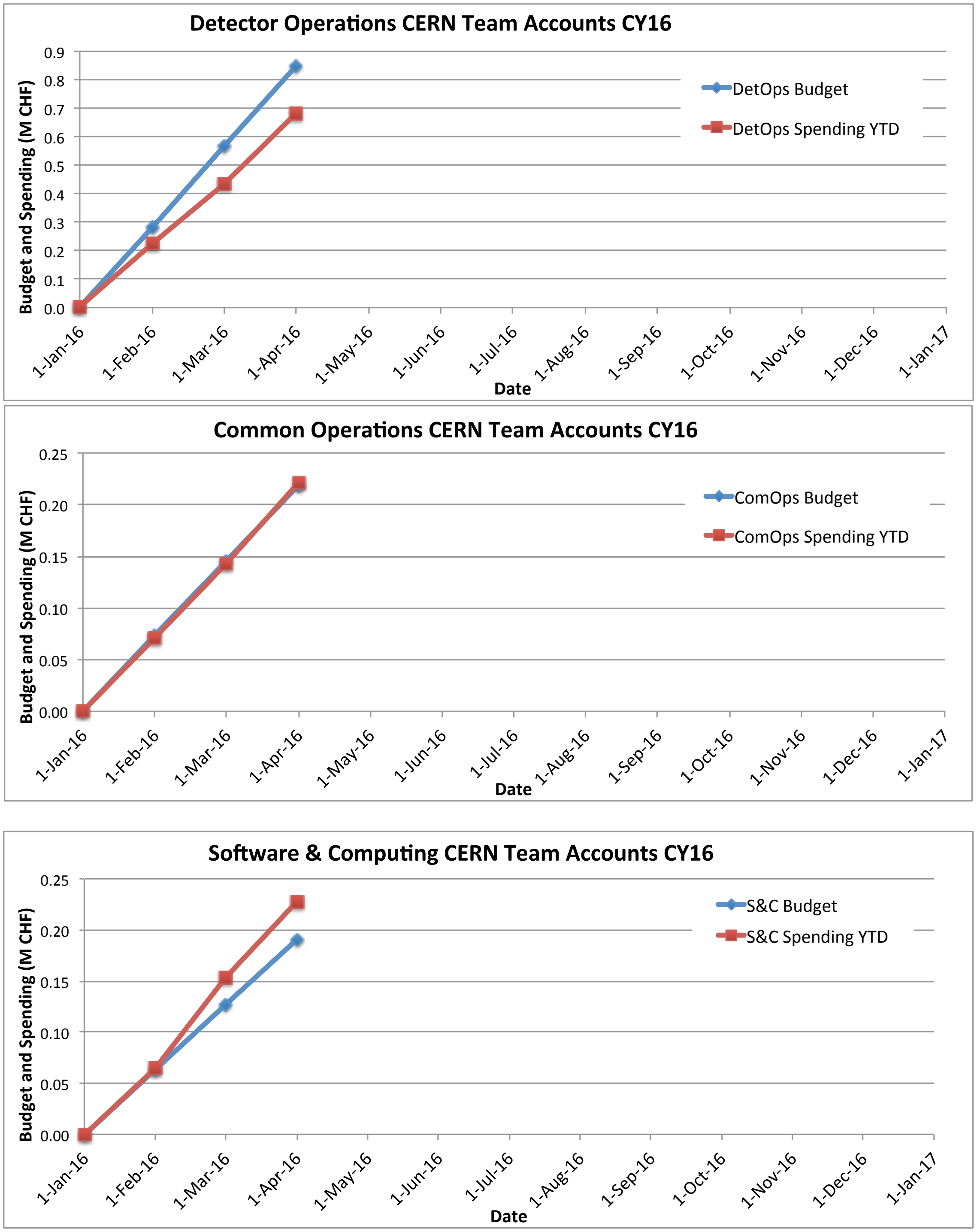


Figure 5: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.

Detector Operations

During this quarter LHC and CMS were in a year end technical stop (YETS). This provided an opportunity to make repairs and enhancements to the various elements of the detector as described below. Importantly extensive work was undertaken on the CMS magnet's liquid helium system, which include repairs, enhancements and most importantly cleaning. The cleaning procedure confirmed that the system had been contaminated with BREOX oil which has now been successfully removed. By the end of quarter the work was completed and process to cool down the magnet and turn on the field was underway. It is anticipated that the magnet will be at full field by late April.

During the technical stop there was a campaign of global running with cosmic rays that allowed the commissioning of the detector to proceed without beam. As there was no colliding beams, we are not reporting metrics this quarter.

BRIL

The main emphasis of the US-CMS hardware effort as part of the BRIL sub-detector group is the pixel luminosity telescope (PLT). It is part of a set of detectors to measure the beam conditions and provide luminosity-equivalent particle rate measurements.Last year the PLT detector was installed inside the CMS detector and successfully participated in Run 2 as primary online luminosity detector. The PLT provides fast triple-coincidences in 3-layer telescopes, but also, at a lower rate, full hit-information readout. Based on the latter detailed studies were performed that resulted in the luminosity publication for the new 13 TeV data set.

The detector has been successfully recommissioned and already participated in first collisions of the 2016 run. A trigger has been added that significantly increases the acquisition rate of full hit-information at high beam currents. The online monitoring and DQM have been improved to include the experiences during the 2015 running. As the data taking commences warning and alarm tools are commissioned that are expected to reduce the pressure on shift personnel.

Table 1: BRIL Milestones.

Subsystem	Description	Scheduled	Achieved
BRIL	Recommission Hardware	March	March
BRIL	Ready to deliver Lumi	May	
BRIL	Improved Lumi Numbers for 201	6 December	

Tracker

Pixels Pixel completed the calibrations and software upgrades needed before beam and is ready for collisions. The frequency to send data to the central DAQ was increased via a hardware intervention. This was deemed necessary in order to handle the data rates expected in 2016. Timing and bias scans will be performed with early collisions.

Strips The Strip detector completed the calibrations needed before beam and is ready for collisions. The strips provided a beamspot for the LHC in some early collisions testing, verifying the beam is still fairly well centered. There is an increase in the leak rate of coolant in one part of the strip tracker and we are keeping an eye on it. Timing and bias scans will be performed with early collisions.

Table 2: Tracker Milestones

Subsystem	Description	Scheduled	Achieved
Tracker	Ready for Physics	May	

Subsystem	Description	Scheduled	Achieved
Tracker	Pixel Phase 1 ready to install	Nov.	

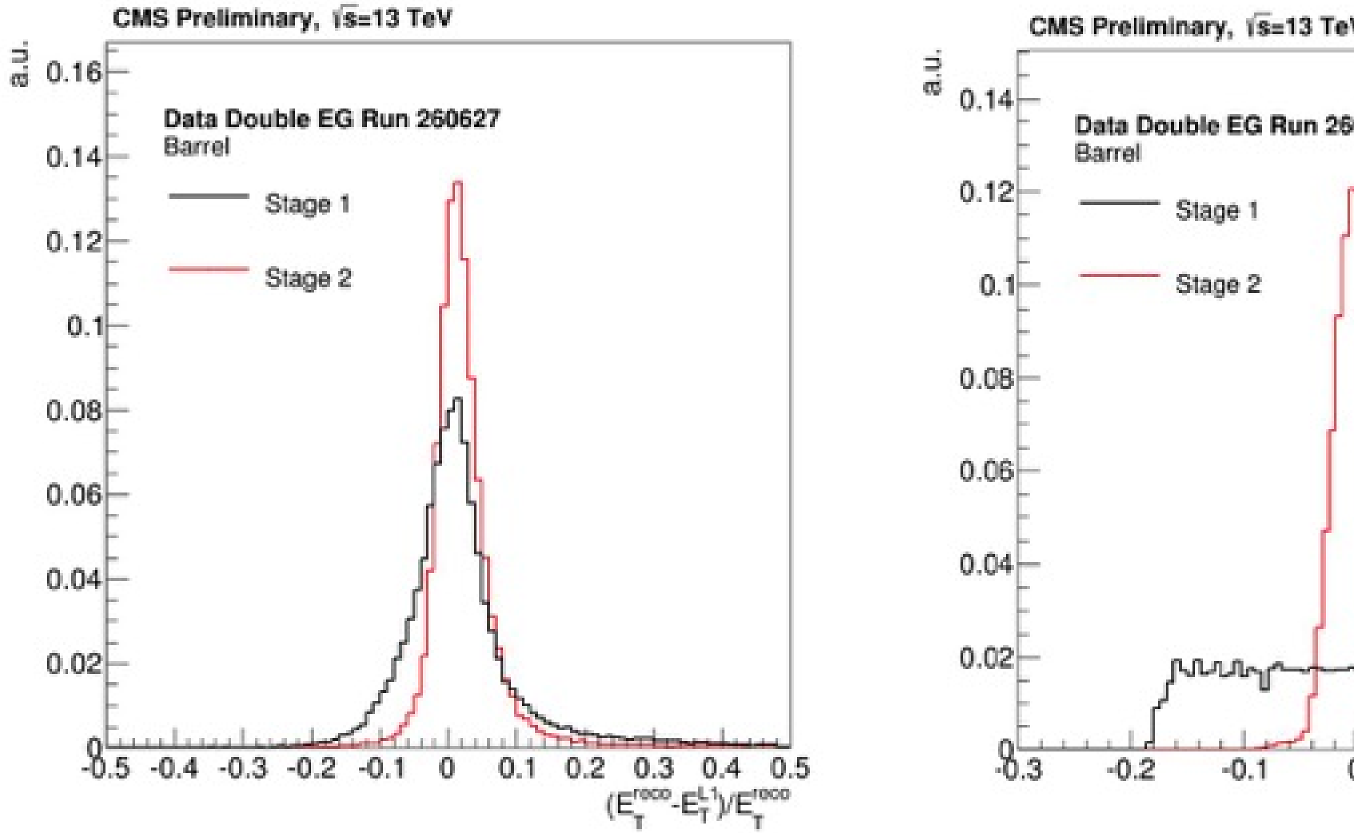
ECAL

The first quarter of 2016 was a technical stop in which a number of important issues were addressed. A planned refurbishment of the MARATON (MAgnetic and RAdiation TOleraNt) low voltage crates took place. All 136 crates were retrofitted with stainless steel water connectors shown in Figure x.1 to replace the brass connectors that are susceptible to corrosion. This was a considerable undertaking as the crates are mounted on the detector so they must be carefully removed and transported to the Meyrin site for repair and testing before re-installation. The work was completed successfully in late February.

MARATON low voltage crate cooling block showing the fittings that were replaced.

In the preshower detector a number if low voltage connectors had proved unreliable leading to dead regions during the fall 2016 run. These were replaced in February and all sections of the pre-shower are now functional and ready to take data. The high voltage system which provides power to the crystal photo detectors was re-calibrated during the shutdown leading to improvements in the performance of the system. Routine maintenance of the laser monitoring system was conducted. The laser system has performed excellently during the fall run showing excellent stability.

In addition the Level-1 calorimeter trigger upgrade has been commissioned leading to significant improvements in the ECAL Level-1 trigger performance. The trigger is now better able to see the granularity of the 5x5 trigger primitive via the use of dynamic clustering within the 5x5. Figure **??** shows the improvement in the energy and position resolution that results. This leads to higher efficiency in the trigger.


CMS Preliminary, $\sqrt{s}$=13 TeV
a.u.
Data Double EG Run 260627
Barrel
Stage 1
Stage 2
$(E_T^{reco}-E_T^{L1})/E_T^{reco}$
CMS Preliminary, $\sqrt{s}$=13 Te
Data Double EG Run 26
Barrel
Stage 1
Stage 2

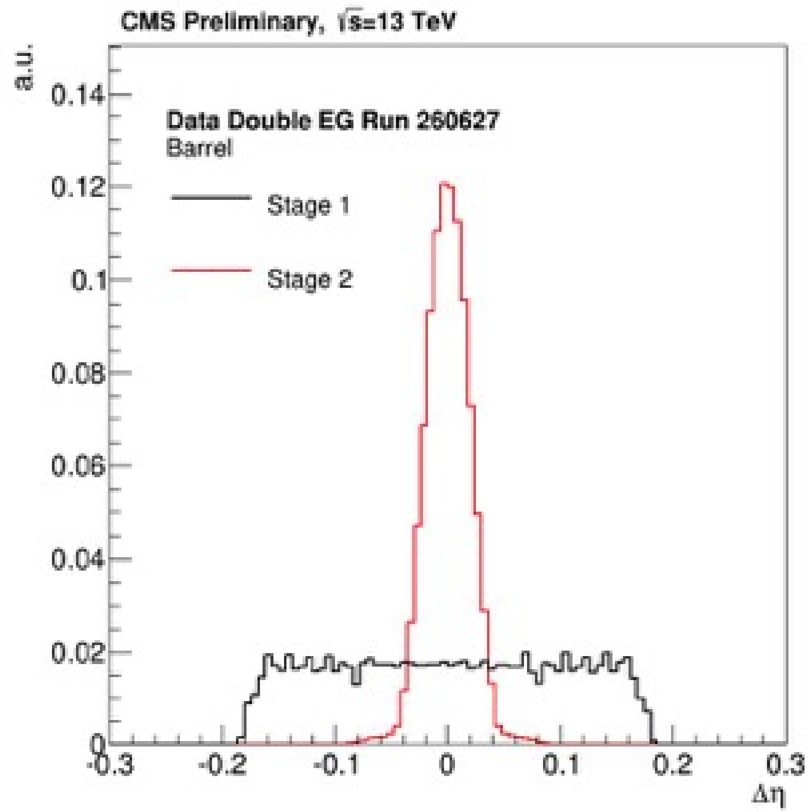


Table 3: ECAL Milestones.

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

HCAL

During the year-end technical stop (YETS) in the first three months of 2016, the HCAL focused on preparing for the 2016 Run. In addition to routine hardware repairs and maintenance, many upgrades were deployed during the YETS. These included: switching to μTCA (Phase 1) back-ends as the primary read-out for HB/HE, switching to the Stage-2 Level-1 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 front-ends and a prototype Phase 1 Upgrade HF QIE10 front-end.

This will enable the HCAL group to gain valuable operational experience with the Phase 1 Upgrade front-ends prior to their installation in the 2016-17 EYETS. The HCAL group also is also commissioning a small system on the Castor table located close to the beam line 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 the scintillator for the Phase 2 Upgrades. This system uses prototype Phase 1 HE electronics and will enable HCAL group to gain valuable operational experience with this new electronics as well. The software necessary to control and monitor the all new hardware was deployed and commissioned.

During late March 2016, the HCAL successfully participated in data taking for the first beam splash events from the LHC.

Table 4: HCAL Milestones.

Subsystem	Description	Scheduled	Achieved
HCAL	Ready for Physics	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 water leak in YE+1, discovered in December 2015, was investigated and repaired during the access period of the year end technical stop. The leak was located in the electronics cooling circuit of the chamber ME+1/1/13. This chamber was removed and taken to the surface for investigation. The leak occurred at one joint of the copper cooling pipes, and x-ray investigation showed that the joint had insufficient solder in the weld. After investigation, the cooling circuit was replaced and the electronics reinstalled. Two additional chambers at the bottom of the station were also removed and repaired due to water collateral damage. All three chambers were replaced after refurbishment and testing and are working properly.

Additional actions were taken to prevent future leaks. All circuits were tested at 12 bar pressure. Accessible shut-off valves were installed to permit rapid isolation of any leaking chamber. Humidity sensors and water leak detection cables were installed inside the YE1 nose to give early detection of any leak. Water collectors were installed around the YE1 nose and inside YB0. A possible preemptive replacement of the ME1/1 cooling circuits is under study and is being followed up by a CMS Technical Incident panel.

Several individual electronics problems were fixed during the technical stop, including a low voltage issue that had disabled an entire chamber and the replacement of one VME crate. By the end of the access period, 99.4% of the CSC electronics channels are enabled and functioning properly.

The CSC system was powered up on 22 January and participated in all midweek global runs. The new EMTF trigger came on line in MWGR#2, and the CSC electronics were timed in for the new trigger with cosmic rays. At the end of March, the timing was examined further with beam splash events. The CSC is on track for stable operations in the 2016 physics run.

Table 5: EMU Milestones.

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

DAQ

Extensive measurements of the DAQ system were carried out during YETS 2015-16 to understand and mitigate performance bottlenecks in the system. We are confident that the system can handle the expected load with some margin. Further improvements on the transport layer could yield an additional performance boost.

In preparation for the 2016 run, the computing infrastructure, DAQ, TCDS, DCS were consolidated and improvements based on the 2015 operational experience were implemented. The consolidated system successfully used during Midweek Global Runs and ready for collisions. Integration of new sub-detector back-end electronics of the Level-1 trigger upgrade, were also completed during Year-End Technical Stop 2015-2016 (YETS 2015-16).

Candidate PC servers for the next generation HLT nodes have been evaluated. An order for the replacement of the HLT nodes acquired in 2011 has been issued and host are delivered to CERN. They will be installed in mid-April and will be commissioned in the following weeks. During YETS 2015-16, the HLT farm was used partly as a cloud infrastructure for offline data processing. In particular, during February, it provided ~40% of the combined T0/T1 capacity, including workflows with demanding I/O requirements.

Table 6: DAQ Milestones.

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

Trigger

The Regional Calorimeter Trigger (RCT) and Stage-2 Layer-1 Calorimeter Trigger are U.S. deliverables. The RCT operation operated during the first CMS Global Run (GR) at the beginning of February 2016. It operated without any issues. For the second GR two weeks later, it was used to verify calorimeter trigger timing and before making the switch to operating with the CaloL1. The switch to triggering with new trigger systems was made during the 2nd Global Run. CaloL1 was fully integrated into CMS Run Control by the 3rd global run at the beginning of March. The new control software, called SWATCH, configures, operates, and monitors the new hardware. Additionally, in the 4th CMS global run, the configuration using the database was enabled, allowing configuration keys to be used, so that tasks such as masking inputs for special runs are simplified. Immediately after the 4th global run, at the end of March, this mechanism was used to mask off most of the calorimeter for the LHC beam splash data taking. A two-trigger-tower wide region of ECAL was left in to simulate collision timing as much as possible with splash. In addition, during the 4th global run CaloL1 Data Quality Monitoring became available on-line, and was used during splash operations. In the next month, before first collisions, CaloL1 will continue to work on remaining issues to be ready for physics data taking.

Endcap Muon Trigger

The Rice University, Northeastern, and University of Florida groups have successfully deployed the phase-1 upgrade for the endcap muon trigger over the winter shutdown and are preparing for operations with the Endcap Muon Track-Finder, which replaces the CSC Track-Finder used last year and in Run 1. The Endcap Muon Track-Finder has been used for cosmic muon data runs since February this year. A single track segment trigger was recently added to aid in detector commissioning with cosmic muons. The DAQ readout is working, and a complete online DQM package has been developed and is in operation to monitor the input trigger primitives and output tracks as was done with the CSC Track-Finder. Hardware for a muon sorter has been installed in order to provide local triggering for CSC operations, and will be commissioned soon. The online control and monitoring software is undergoing rapid development to keep pace with central software developments and has achieved core functionality and monitoring. One Muon Sorter was shipped to CERN in February. Experts from the university groups have maintained on-call coverage of the system during the global commissioning runs that took place during this quarter.

Table 7: Trigger Milestones.

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

Software and Computing

In general, Software and Computing was focused on preparations for 2016 data-taking and the high-profile ICHEP conference where results from the 2016 data will be presented. The Tier-1 and Tier-2 facilities all met their performance metrics, while also undergoing upgrades and enhancements that will improve their throughput. The Tier-1 facility in particular was engaged in a significant upgrade of the storage systems. The operations teams wrapped the processing of 2015 data events and then proceeded to deliver simulated events at huge rates, resulting in high utilization of the U.S CMS facilities. A particular highlight was the use of the Amazon cloud computing service to deliver large simulation samples in time for use in results presented at winter conferences. The infrastructure and services area made steady improvements to many systems to be prepared for this year's event rates and complexity. Quite a few developments across all areas of the program were related to the deployment of multi-core jobs running multi-threaded applications. A major version of experiment software (CMSSW) was released, which is targeted at 2016 data taking and supports multi-threading and many other features. The R&D area continues activities that have made immediate impacts on operations and also prepare us for the longer term.

Table 8: Major S&C milestones achieved this quarter

Date	Milestone
February	Deliver enhancements necessary to run the digitization step in multi-threaded mode efficiently.
February	Deliver CMSSW_8_0_0 for 2016 data taking. A required feature for this release is software to support the L1 trigger up
February	Migrate the production architecture to CC7 and GCC 5.3.
March	Deployment of the 2016 WLCG resource pledge at Tier-1 and Tier-2 sites.
March	Commission multi-core submission at all Tier-2 sites.
March	Completed migration from SE names to abstract names across all tools.
March	Conduct review of data management tools.

Fermilab Facilities

Fermilab Facilities work was dominated by preparing for the 2016 LHC running and delivery of the 2016 pledged resources to CMS. The CPU portion of the pledge was deployed and made available to CMS earlier in the year, and the disk storage portion made ready for CMS during this quarter. The 8 PB of disk storage purchased in FY15 enabled a rebuild of the disk storage endpoint for the Tier-1 facility, with an upgrade to the latest dCache "Golden Release", 2.13, to be completed in April. During March data was transferred from the production dCache instance into this new dCache at impressive rates, setting a PhEDEx transfer record of nearly 10 GB/sec, and copying nearly 10 PB of data in that month.

Figure 6 shows the site readiness metrics for the Tier 1 during the quarter. Late in Februrary, along with the rest of the WLCG Tier 1 and 2's, FNAL took a downtime to address a critical glibc vulnerability. The site-wide reboots enabled a java change which prevented transfer attempts from many sites to authenticate properly, leading to the failed metrics during that period.

Site utilization was also high during this quarter with high priority simulation and reprocessing needed for the winter conference results in March. These workflows consumed data at a very high rate, often reaching sustained network read rates of 30 GB/s between dCache storage and the CPU farm. During this time the Tier 1 provided 32 million wall hours to CMS. Utilization also ramped up with analysis use of the LPC farm, often peaking at nearly 5k cores in use at a time.

In January and February the FNAL HEPCloud tests generated over half a billion Monte Carlo events for CMS in time for winter conferences. In these tests FNAL facilitated the use of AWS cloud resources by CMS's production infrastructure. During this exercise close to 60,000 AWS cores were utilized continuously for almost 2 weeks, providing over 15 million wall hours. These tests demonstrated commercial cloud resources like those at AWS can be acquired at large scales for costs that are larger than, but comparable to, the cost of

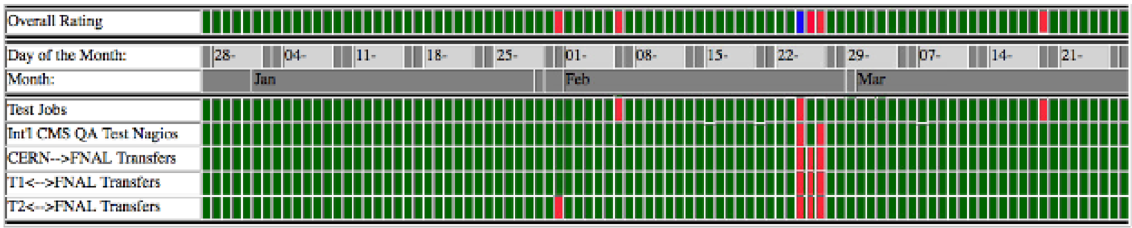


Figure 6: Fermilab computing facilities readiness metrics for 2016Q1. Green indicates periods of passing the set metric, red denotes time where the facility fails the metric, and blue indicates scheduled downtime. The Fermilab Tier-1 facility passed the metric 94% of this quarter.

similar on-site resources.

University Facilities

The second quarter was a very busy time for the U.S. CMS Tier-2 facilities, where multi-CPU scheduling was deployed at every site. In order to complete the upcoming Monte Carlo DIGI-RECO campaign in a timely manner with available resources before the ICHEP conference this summer, CMS must use a multi-threaded application. All seven of the U.S. Tier-2 sites completed multi-core deployment before the DIGI-RECO campaign began on April 1 and are ready to support production fully.

The seven U.S. sites are actively purchasing hardware for 2016 and met their WLCG deployment goals before April 1. The connection of the Tier-2 sites to the LHCONE VPN by ESNet is still proceeding with two sites remaining. All sites have deployed the HTCondor-CE computing element, and all but two of the sites have retired all of their GRAM CEs. The motivation for this transition is better stability and scalability as well as easier support.

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 90% "available" and 93% "ready". The CMS goal for each of these metrics is 80%. The U.S. CMS Tier-2 centers delivered 42.9% of all computing time by Tier-2 sites in CMS (our commitment to global CMS is > 25%), making them seven of the eight most-used Tier-2 sites in all of global CMS, see Figure 7.

Nine Tier-3 sites required assistance from the Tier-3 support team this past quarter on issues related to OSG software upgrades, PhEDEx, XrootD, and gfal2. The T3 documentation was completely rewritten, achieving a 2016 milestone. Progress on CMS Connect continues with the first beta testers starting to use the system.

Operations

Operations started the quarter with the highest event production rate observed in the past year during January and February, which tapered off afterwards. Activity started with the re-MINIAOD campaign and the heavy-ion data production, which was leftover from the very high-throughput runs. At the same time we continued activities on the GEN-SIM and MC RECO campaigns. The very end of the quarter was dedicated to the preparation of the CMSSW_8_0_x campaigns that will follow, in particular the first slice of about 3 billion events that the physics groups have requested to prepare for the ICHEP conference (Aug 3-10).

In this quarter we have completed 8.8B DIGI-RECO events (including 5.5B 76x re-reco), 4.8 B GEN-SIM events and redone 9.2B MINIAOD and 2.0B data events re-reconstructed. This is a substantial increase with respect to the production activity earlier in the year as shown in Figure 8.

The Computing Operations group has worked on integrating the new multicore processing, the new RequestMgr2 and the premixing production workflow. All those efforts are will play an important role to continue to use all resources efficiently in view of the increase in pileup and the more complex logistics of

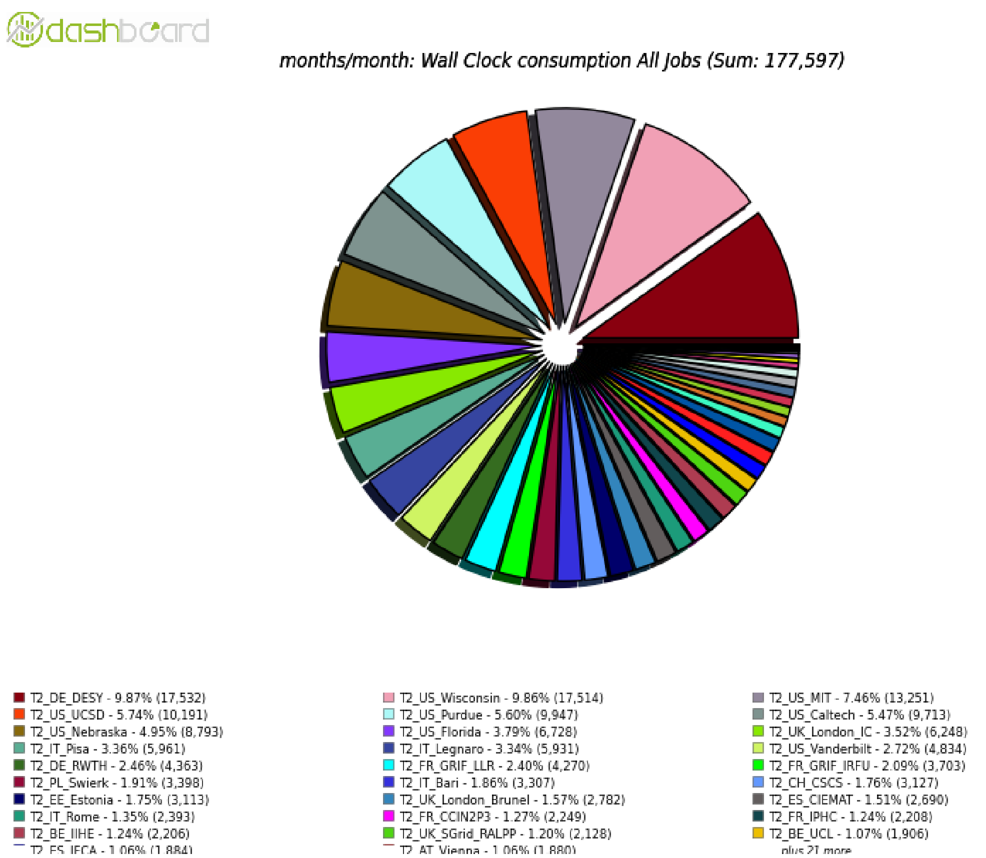


Figure 7: Percentage of total computing time delivered to CMS by Tier-2 sites world-wide, by site.

the processing requests. A good fraction of March was used for the integration of those new features, which is continuing.

Computing Infrastructure and Services

This quarter was a period without data taking, but the Tier-0 was busy catching up from the enormous data taking rates of the heavy-ion run at the end of Q1. Weaknesses in the Tier-0 in coping with these rates were identified and improvements made to make this easier next time.

WMAgent and WMArchive progressed with an initial version of WMArchive being provided and 10%-scale data being sent from WMAgent to WMArchive for both short-term and long-term storage and analytics. WMAgent was also improved to cope with several various premixing scenarios that may be required, leaving the decision on the exact scenario for later. Significant work also went into streamlining how workflows are constructed and finished to reduce the time from workflow start to data being announced as ready for physicists.

CMS S&C initiated a review of its data management tools and procedures. Short-term development goals were defined for PhEDEx as well as a medium-term goal of identifying the exact needs for Run 3 and Run 4 and evaluating possible solutions. PhEDEx was deemed suitable for Run 2 and possibly Run 3. Also in the data management arena, discussions were begun with WLCG and CERN IT to turn the CMS SpaceMon project into a common WLCG project to monitor the use of disk space with the aim of reducing "dark" disk space.

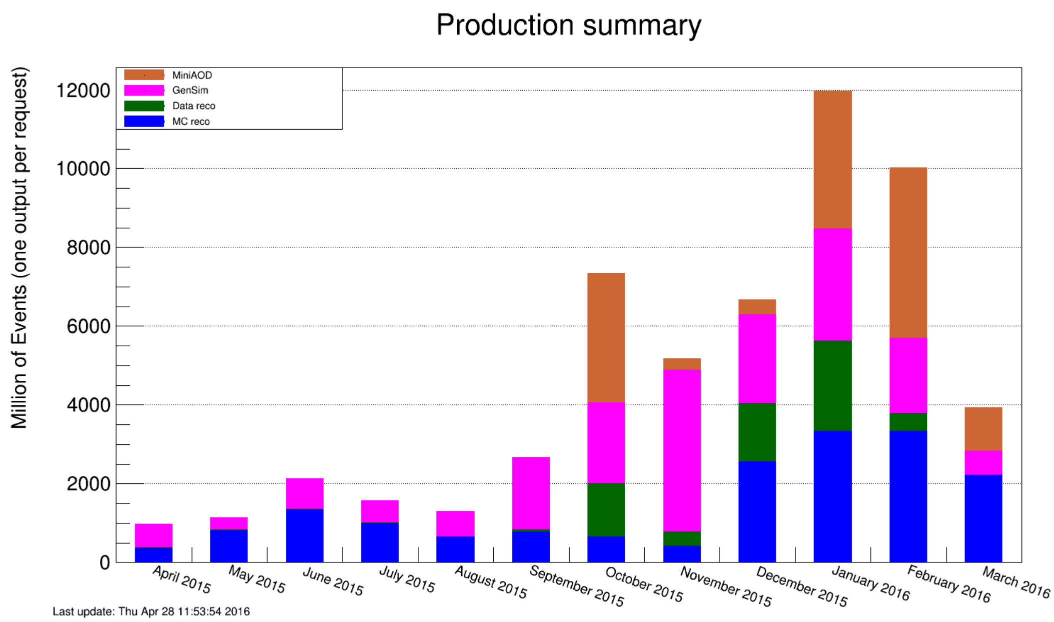


Figure 8: Production summary for the last 13 months. A steep increase of the production rate in the first and second quarter of FY16 are due to re-making the MINIAOD, the data re-reconstruction, and the MC re-processing with version 76x.

In XRootd, a number of changes were made to the core software in order to improve the caching performance of the proxy layer. The caching proxy is a core component of our "T3 cluster in a box" strategy proposed as part of the next five-year NSF Cooperative Agreement proposal, and piloted as part of the NSF-ACI funded "Pacific Research Platform" project. The caching proxy software was originally developed by the NSF funded "Any Data, Anytime Anywhere" (AAA) project, and is now being refined as limitations are discovered and understood. All of these improvements are going directly into the repository of the core XRootd project, and thus benefit all customers of XRootd rather than just CMS.

Software and Support

During this quarter, S&S completed three of its major milestones for the year. CMSSW_8_0_0, intended to be used for 2016 data taking, was released in February, to give plenty of time to the physics organization to validate it. It contains the necessary changes to the reconstruction and the L1 trigger for the upgrades installed over the end-of-year shutdown. A long series of minor releases followed throughout March for patches in L1 trigger monitoring and emulation code as the L1 trigger software itself evolved.

The CMSSW_8_0_0 release uses CC7 and GCC 5.3 as its default architecture, thereby completing another milestone. Staying current with the compiler improves technical performance, and moving to CC7 allows us to take advantage of the latest OS developments. In particular the improved support of lightweight containers gives us greater flexibility in the area of workload management. Also as of the CMSSW_8_0_0 release, it is possible to run all CMS workflows efficiently in multi-threaded applications. Since the reconstruction was used this way to reprocess the 2015 data, and the multi-threaded Geant4 application was validated last year, the only remaining piece was the digitization code which includes the pileup handling. This is a major achievement for CMSSW, but it means that heightened vigilance is needed to keep it thread safe. In order to help the FNAL framework team with this maintenance task, we have engaged our university colleagues at Florida who will help monitor and fix problems as they arise.

Technologies and Upgrade R&D

During this quarter, we did initial prototyping 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 will improve overall utilization of resources. Within the "global pool," we continue to utilize AAA-based mechanisms to overflow workflows between sites; the system put in place last quarter for production was in expanded use this quarter (to about 10% of all production work). We are investigating using the same mechanism to tune memory and runtime limits. To better understand how the AAA infrastructure could fit better into the larger HTTP ecosystem, beyond the Xrootd protocol, we have allocated hardware at Caltech to do comparative performance studies.

To further improve accessibility of data, we have focused on integrating machine learning techniques to predict dataset popularity for initial placement. The original results were presented on ACAT'16 conference[1] and subsequently published[2]. Further work was continued in collaboration with a student from Lithuania.

Beyond the WLCG facilities, we have maintained the capability to run at DOE supercomputing facilities (namely, NERSC). This quarter, we continue work on automating the end-to-end job submission process. The current focus areas include performance issues with Cori worker node network and our inability to generate images that include CVMFS (this can currently only be done by NERSC administrators, leading to long turn-around times).

For next-gen architectural and platform work, we have been able improve CMSSW support on GCC 6, Clang 3.8.0, AArch64, and PPC. This includes the full chain: from integration tests to deployment on CVMFS. We have been involved in CERN Openlab to provide HEP-centric feedback to vendors (such as Huawei and Intel) on their respective future architectures.

For the tracker prototype, this quarter focused on the next step on improving vectorized track building; further, the prototype is working toward improved integration with realistic CMSSW-based data. This is in collaboration with NSF PHY-1520969, PHY-1521042 and PHY-1520942.

[1] ACAT'16, Predicting dataset popularity for the CMS experiment. V. Kuznetsov, T. Li, L. Giommi, D. Bonacorsi, T. Wildish. https://indico.cern.ch/event/397113/session/12/contribution/164

[2] Predicting dataset popularity for the CMS experiment. V. Kuznetsov, T. Li, L. Giommi, D. Bonacorsi, T. Wildish arXiv:1602.07226 [physics.data-an]