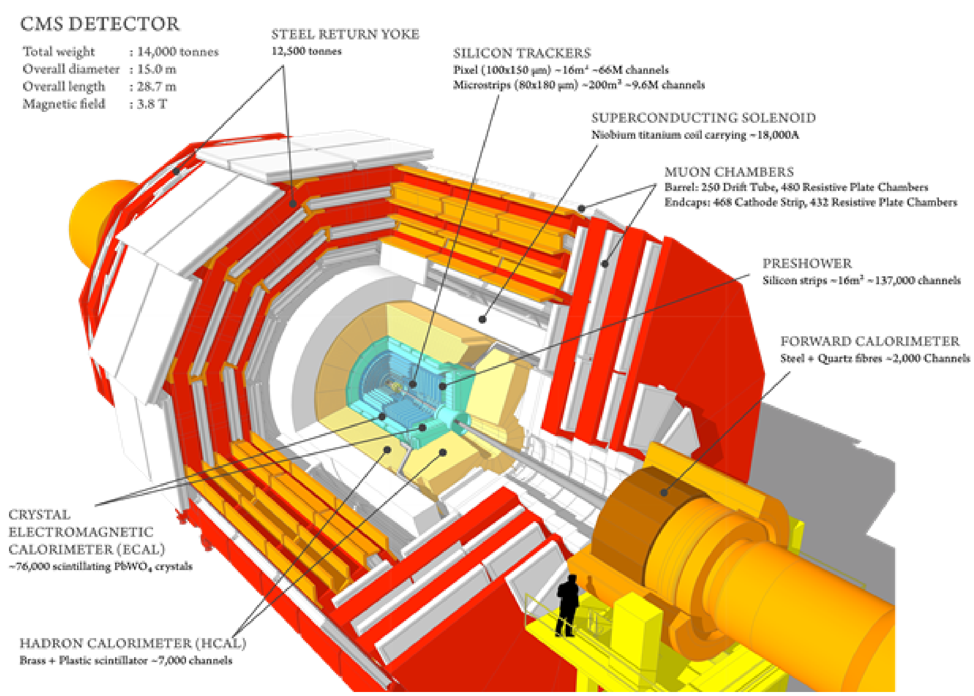
U.S. CMS Compact Muon Solenoid Operations Program
Quarterly Report for the Period Ending September 30, 2015

U.S. CMS Operations Program



Program Manager's Summary

During this third quarter of *calendar year 2015* (2015Q3) CMS was starting physics data taking at increasing LHC luminosities. After a series of commissioning runs, physics data taking began in June, with the improved CMS detector and computing systems ready for efficient high-quality data taking. Between June 3, 2015 and October 12, 2015, the LHC delivered 2.5/pb integrated luminosity of proton-proton collisions at a center-of-mass energy of 13 TeV, of which CMS recorded 2.3/pb.

However, problems with the cryogenic systems for the CMS magnet continued through the quarter. Since March the "Cold Box" (CB) that liquifies Helium for cooling the CMS superconducting solenoid has shown problems, following an incident where compressor oil contaminated the downstream CB circuits. An overall cleanup would take several months and is being planned for the year-end technical stop.

Meanwhile, the CERN cryo group, in collaboration with CMS Technical Coordination, has been trying to find a way to operate the CB with a reasonable duty cycle of at least 70% that would allow operation of the CMS magnet synchronized with the physics operation cycles of the LHC. After a number of corrective actions including replacing filters and thermal recycling of heat exchanges etc, performance of the system has improved and it appears this goal is being met. The impact on useful luminosity for CMS is however significant, and of the 2.3/pb data on tape, approximately 0.40/pb is with the magnetic field off or below nominal value.

As the LHC settled into stable operations the Operations Program also entered an operational mode. Detector performance metrics have been steadily improving and at the end of the quarter were at an excellent level of >92%, with further improvements continuing. Detailed reports on detector components are given below in the Detector Operations section.

Operations of central data processing and management systems has become routine, with adjustments as necessary as experience is being gained. Computing operations clearly benefits from the various development efforts carried out during the shutdown. As always, further developments on computing services continued during the quarter, while support for current operations remains top priority. A focus was to make new classes of computing resources available to CMS processing, such as the Amazon cloud, or clusters at supercomputing centers. CMS software reaps the benefits of the new multi-threaded framework, and development has continued to expand the scope of those gains.

U.S. computing facilities at Fermilab and universities have seen increasing amounts of activity, both in central processing and user data analysis. While utilization has been higher than in recent quarters site performance has remained good — details are given in the Software and Computing section. S&C metrics for 2015 so far are at or above the goal of 98% site readiness for the Tier-1 and 80% site readiness for Tier-2 centers (where the U.S. Tier-2s typically achieve above 95%, for great effectiveness in supporting U.S. physics data analysis).

All computing resources pledged to WLCG for this period of performance are available. This-year's computing hardware upgrade procurements are on track with significant new resources becoming available as they are being commissioned, helping CMS to keep up with the increasing demand as CMS takes more data. The Tier-0 facility was running as expected.

Spending Plan for 2016

The Resource Manager's section below gives details on how the 2015 spending plan develops. The carry-over of DOE funds between fiscal years was analyzed at the end of the quarter. The FY14 $\rightarrow$ FY15 carry-over was $6,320k, including RIPs. This year's spending plan foresees a carry-over "buffer" from FY15 into FY16 of $3,000k to cover the remaining quarter in the calendar year, some of which is already obligated through POs for CERN team accounts. Furthermore the spending plan foresees to make additional $2,590k of carry-over funds available in 2016, to enable next year's upgrade R&D funding to continue and ramp up. At the end of this quarter and fiscal year, Fermilab reports $4,411k carry-over funds into FY16, which is consistent with the spending plan, and consistent with the goal to spend-down about $2M of previous year's carry-over during FY15.

We also assessed the effect of fluctuating exchange rates between Swiss Franc (SFR) and U.S. Dollar (USD). About 28% of all expenses for the Operations Program occur in SFR, and given the exchange rate history the 2016 spending plan assumed an exchange rate of 0.9 SFR per 1 USD. The actual average exchange rate for M&O cost and CERN team account invoicing came out to be about 0.96 SFR per 1 USD. This means we realized significant cost savings over the spending plan. In total, these and other cost under-runs balanced out change orders to allocate additional funds for a number of unforeseen items. Examples are increased costs to support CMS coordination (support for the CMS Muon Project Manager and the CMS Trigger Coordinator), the closeout of R&D cost for the Shashlik calorimeter upgrade proposal R&D in 2015/16, and a number of items to support startup of the HL-LHC project organization to support their Level-2 coordinators and travel cost. Details are given in the resource manager's tables.

Also, cost savings in computing upgrade procurements allowed to buy equipment needed next year, which helps with the planned computing upgrade cost in 2016 and the planned disk procurements for the LPC analysis facility — these were tentatively planned as possible calls on management reserve, and a change request was put through to move forward with these enhancements of storage capacity for physics data analysis.

Resource Allocation Advisory Board

The Operations Program managers together with the HL-LHC upgrade manager have created a Resource Allocation Advisory Board (RAAB) charged with providing advice on questions regarding the allocation of funds between the different activity areas of the program, and on the interplay between the planned HL-LHC upgrade projects, including enabling R&D and pre-construction planning, and the Operations Program. RAAB Membership includes J.Berryhill, P.Bhat and J.Butler (chair) of Fermilab, S.Dasu (USCMS CB chair, observer) from U.Wisconsin , S.Eno from U.Maryland, C.Gerber from UIC, K.Hahn from Northwestern U., and A.Yagil from UC San Diego.

The RAAB was asked to review the longer-term needs and cost estimates, the impact of proposed cuts in U.S. CMS computing upgrades, and the tight management reserve and carry-over allocations in the current spending plan. The board was asked to provide recommendations for the balance of operations versus HL-LHC upgrade allocations, in particular for 2016, in time for the 2016 budget process.

The RAAB undertook a detailed examination of the 2015/16 Operations Program budget. It provided a draft report and preliminary recommendations at the end of this quarter. The RAAB concluded that the budget is indeed very tight and it will require very careful management to provide for both the expansion of computing needed for the analysis of Run 2 data and a level of HL-LHC Upgrade R&D necessary to complete the technical design and secure project approval.

The board noted the possibility that expensive repairs will be needed for the endcap hadron calorimeter, which has to be considered as an additional cost risk. The RAAB believes that the current HL-LHC R&D plan, calling for funding of ~$6.4M of which $1M would come from outside the Operations Program, is approximately correct but that some more scrubbing or deferral of costs until 2017 may be possible. The report provides specific principles for use in prioritization of upgrade activities to guide the process.

The RAAB also finds that it is essential to maintain the budget for computing hardware at the level presented at the recent budget review in September. This cost number takes into account the lower costs that have recently been obtained for disk procurement and several cost reduction measures implemented by operations program management, but does not foresee reduction in the computing resource upgrades.

The RAAB recommends that some of the funding allocations for computing upgrades and HL-LHC R&D investments should be held back as management reserve. This would allow changes based on developments during the year, allowing reallocation of funds between ops and upgrades and between different upgrade projects, based on changing needs.

Even with these very stringent measures, the RAAB found it likely that management reserves will have to be used up in 2016, putting future years at risk. While the RAAB has only looked briefly at 2017, it anticipates the need for a budget for computing hardware that is similar to 2016 and increased HL-LHC upgrade R&D needs. While some help, about $1.25M, is expected for upgrade R&D from “OPC” funding, it will be hard to maintain even the same level of funding as in 2016.

Summary

So far, 2015 turned out to be a successful but tough year for CMS. Run 2 data taking started successfully with improved detector, software and computing systems, despite very significant challenges between physics, operations, and upgrades. The improvements in detectors, DAQ, Software, Computing that were installed during LS1 work well and were successful. The data taking goes well, and CMS is achieving high data quality and run efficiencies. However, this quarter also saw slower than expected LHC ramp-up of intensity and persistent problems with the cryogenic system needed to supply the CMS magnet with liquid helium. Still, CMS is on track to take excellent data efficiently and the collaboration is excited about the physics opportunities of LHC Run2.

The U.S. CMS Operations Program is following the spending plan, tracking variances and staying within the budget envelope. The funding level in 2015 is relatively low compared to previous run startup years and the additional needs for HL-LHC R&D are very challenging. This requires prioritizing, cut backs and resourcefulness, and prioritization decisions by the program managers are being aided by the new Resource Allocation Advisory Board.

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 2015, as well as the funding guidance for 2016 through 2019, is shown in Figure 1.

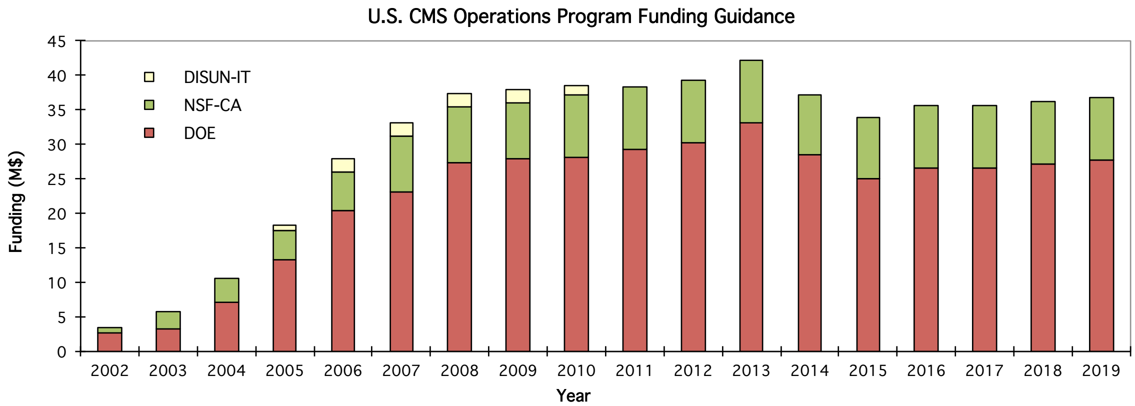


Figure 1: The annual U.S.CMS Operations Program funding provided by DOE and NSF. For 2002 through 2015 the chart shows the actual funding, while for 2016 onward the current funding guidance is shown.

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 2015 took place in August and September of 2014. Through this process, U.S.CMS Management developed a detailed spending plan. This plan was further refined through the March 2015 joint NSF/DOE Operations Program review.

Primarily during the first quarter of the calendar year, Statement of Work (SOW) agreements were established with each institution that is providing a deliverable in exchange for Operations Program funding. The SOWs specify the tasks to be carried out, as well as any portions of salaries, materials and services (M&S), travel funding, or cost of living adjustments (COLA) to be paid from the Operations Program budget. The SOWs must be approved by U.S.CMS Operations Program management, by the Fermilab Director Designee, and by representatives of the collaborating group and institution. Through September of 2015, a total of 109 SOWs (71 DOE and 38 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. There was a relatively large number of Change Requests relating to Phase 2 (HL-LHC) Upgrade R&D this quarter. These are summarized separately in Table 3. The CY15 spending plan, as of the end of Q3, 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

WBS	Subsystem	Change Request Number	Description of Change	CY15Q3 Plan	Change $	CY15Q4 Plan
U.S. CMS Detector Operations Change Control Activity						
11	Endcap Muon		Insurance rate change	$1,836,040	$456	$1,836,496
12	Hardon Calorimeter	CR-030, CR-031	Contractor time reduction; CR-030: Engineering labor at Iowa; CR-031: COLA decrease and Maryland SWF increase	$1,598,163	$5,495	$1,603,658
13	Trigger	CR-015	U Florida TA COLA Adjustment	$919,475	$6,666	$926,141
14	Data Acquisition			$780,208	$0	$780,208
15	Electromagnetic Calorimeter			$841,815	$0	$841,815
16/17	Tracker (Fpix&SiTrk)			$732,798	$0	$732,798
18	Detector Support			$258,262	$0	$258,262
19	BRIL	CR-002	TA M&S and COLA reduction; Princeton SWF increase	$388,180	$0	$388,180
30	Phase 2 Upgrade R&D	CR-031 to CR-044	See table of Phase 2 Upgrade R&D Change Requests	$3,237,253	$777,702	$4,014,955
11-18,30	**Detector Operations**			**$10,592,194**	**$790,319**	**$11,382,513**
U.S. CMS Common Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY15Q3 Plan**	**Change $**	**CY15Q4 Plan**
21.2	Common Costs (M&OA, LS1, Loan)	CR-085, CR-086, CR-087, CR-088, CR-089	CR-085: NSF M&O-A and LS1 actual exchange rate, CR-086: DOE LS1 actual exch. rate and early payment, CR-087: DOE M&O-A payment 1 actual excahnge rate, CR-088: DOE M&O-A payment 2 actual excahnge rate, CR-089: DOE M&O-A payment 3 actual excahnge rate	$5,415,822	($513,049)	$4,902,773
21.3	RCMS			$554,413	$0	$554,413
21.4	LHC Physics Center	CR-082	Brown SWF support	$635,637	$38,542	$674,179
21.5	Operations Support	CR-078, CR-079, CR-081, CR-084, CR-090	CR-078: Fairfield EndCap Calorimeter activities; CR 079 UCLA CSC Project Manager; CR-081: Cornell HL-LHC deputy project manager; CR-084: Boston SWF support; SOWs for Wisconsin and Nebraska SWF; CR-090: Caltech SWF support	$1,455,591	$329,080	$1,784,671
21.6	Program Office		Pre-SOW adjustment	$1,029,394	$20,000	$1,049,394
21.7	E&O	CR-083	Notre Dame outreach professional	$286,480	$59,000	$345,480
21.8	Collaboration Support			$10,000	($7,500)	$2,500
21	**Common Operations**			**$9,387,337**	**($73,927)**	**$9,313,410**
U.S. CMS Software and Computing Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY15Q3 Plan**	**Change $**	**CY15Q4 Plan**
22.1	Fermilab Facilities		None this quarter	$6,556,269	$0	$6,556,269
22.2	University Facilities			$4,142,508	$0	$4,142,508
22.3	Computing Operations			$1,129,031	$0	$1,129,031
22.4	Computing Infrastructure and Services			$2,106,931	$0	$2,106,931
22.5	Software and Support			$1,951,086	$0	$1,951,086
22.6	Technologies & Upgrade R&D			$899,330	$0	$899,330
22.7	S&C Program Management & CMS Coordination			$694,276	$0	$694,276
22	**Software and Computing**			**$17,479,431**	**$0**	**$17,479,431**
U.S. CMS Operations Program Total				**$37,458,962**	**$716,392**	**$38,175,354**

Figure 2: Spending Plan Change Log for CY15 Q3.

Phase 2 Upgrade R&D Change Requests in CY15 Q3			
Change Request Number	**Institution**	**Description**	**Change $**
CR-031	CERN	Purchase of HGC prototype sensors	$60,000
CR-032	UCSB	Engineering design of front-end ASIC, HGC module	$190,000
CR-033	Minnesota	Technical labor & M&S for cassette for test beam	$40,000
CR-034	Maryland	Qualification and testing of rad tolerant scintillator	$35,000
CR-035	FNAL	HGCAL R&D labor	$30,000
CR-036	Minnesota	M&S funds for HGCAL test cassettes	$10,000
	UCSB	M&S funds for HGCAL test cassettes	($10,000)
CR-037	Cornell	Engineer for fwd pixel mechanical modeling	$29,343
CR-038	CERN	HGCAL R&D labor	$10,000
	FNAL	HGCAL R&D labor & adjustment	$10,000
	Minnesota	HGCAL labor, M&S, and travel	$30,000
CR-039	Ohio State	HL-LHC tracker upgrade L2 manager support	$46,123
CR-040	Iowa	Shashlik R&D completion	$50,000
CR-041	Caltech	Shashlik R&D completion	$60,000
CR-042	Virginia	Shashlik R&D completion	$85,000
CR-043	Notre Dame	Shashlik R&D completion	$85,000
CR-044	Brown	Outer tracker test beam labor & travel	$10,584

Figure 3: Phase 2 (HL-LHC) Upgrade R&D Change Requests in CY15 Q3.

the case of NSF, they are considered obligated. Figure {@fig:DOE_obligations} 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, while spending at Fermilab has historically been budgeted according to the fiscal year. Of special note is that this year we have transitioned to reporting based on calendar year rather than based on fiscal year. There are two features of Figure 5 related to this transition. First, obligations for DOE spending at Fermilab in the last three months of calendar year 2014 have been included in the plotted obligations for 2015. Second, to accommodate the three month offset between fiscal year and calendar year, a buffer of $3M has been allocated this year, drawing from carry over from previous years. This is indicated by the difference between the solid and dashed blue lines. Figure 6 shows the total obligations and the spending plan, for NSF funds. Of the $9M in NSF funding, $2.5M in subawards went out this quarter, in addition to spending directly at Princeton.

Resources deployed at CERN, and paid directly in Swiss francs, account for approximately 28% of the 2015 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 CY15 Q3 averaged 0.96 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 last 823K CHF of the Upgrade Common Fund

WBS	Subsystem	DOE Funds	NSF Funds	Total
11	Endcap Muon	$1,501,776	$334,720	$1,836,496
12	Hadron Calorimeter	$1,530,247	$73,411	$1,603,658
13	Trigger	$778,331	$147,810	$926,141
14	Data Acquisition	$780,208	$0	$780,208
15	Electromagnetic Calorimeter	$841,815	$0	$841,815
16/17	Tracker (Fpix-SiTrk)	$703,520	$29,278	$732,798
18	Detector Support	$258,262	$0	$258,262
19	BRIL	$115,300	$272,880	$388,180
30	Phase 2 Upgrade R&D	$3,263,171	$751,785	$4,014,955
11-19,30	**Detector Operations**	**$9,772,630**	**$1,609,884**	**$11,382,513**
21.2	Common Costs (M&OA,LS1,UpgrdLoan)	$3,894,968	$1,007,805	$4,902,773
21.3	Run Coordination and Monintoring	$554,413	$0	$554,413
21.4	LHC Physics Center	$674,179	$0	$674,179
21.5	Operations Support	$1,595,945	$188,726	$1,784,671
21.6	Program Office	$931,844	$117,550	$1,049,394
21.7	Education and Outreach	$229,000	$116,480	$345,480
21.8	Collaboration Support	$2,500	$0	$2,500
21	**Common Operations**	**$7,882,849**	**$1,430,561**	**$9,313,410**
22.1	Fermilab Facilities	$6,556,269	$0	$6,556,269
22.2	University Facilities	$111,217	$4,031,291	$4,142,508
22.3	Computing Operations	$713,568	$415,463	$1,129,031
22.4	Software and Support	$1,677,995	$428,936	$2,106,931
22.5	Computing Infrastucture and Services	$1,694,841	$256,245	$1,951,086
22.6	Technologies & Upgrade R&D	$206,191	$693,139	$899,330
22.7	S&C Program Management and CMS Coordination	$464,016	$230,260	$694,276
22	**Software and Computing**	**$11,424,097**	**$6,055,334**	**$17,479,431**
U.S. CMS Operations Program Total		**$29,079,575**	**$9,095,779**	**$38,175,354**

Figure 4: Spending plan at the end of CY15 Q3, for funds from DOE, NSF, and the total.

payments and the 3,827K CHF M&O-A payments, as these are each made through multiple payments to a separate Team Account.

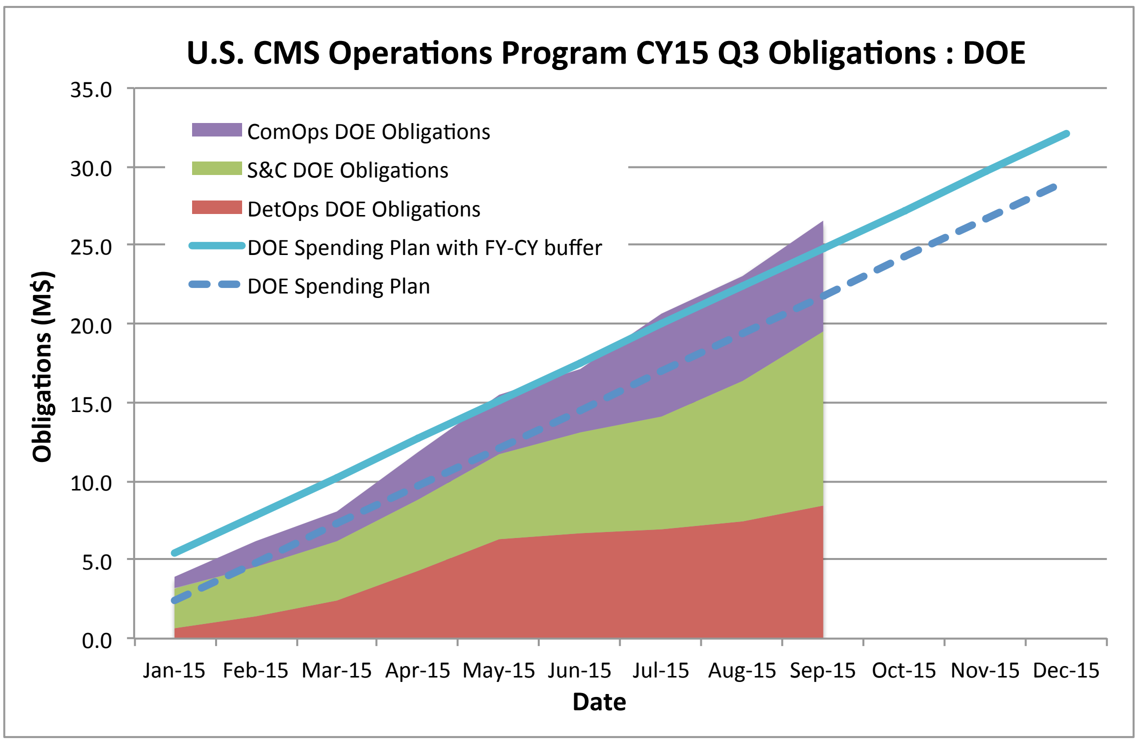


Figure 5: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide. The lines show the spending plan with (solid) and without (dashed) a required buffer to bridge the difference between fiscal year and calendar year for funds spent at Fermilab, as described in the text.

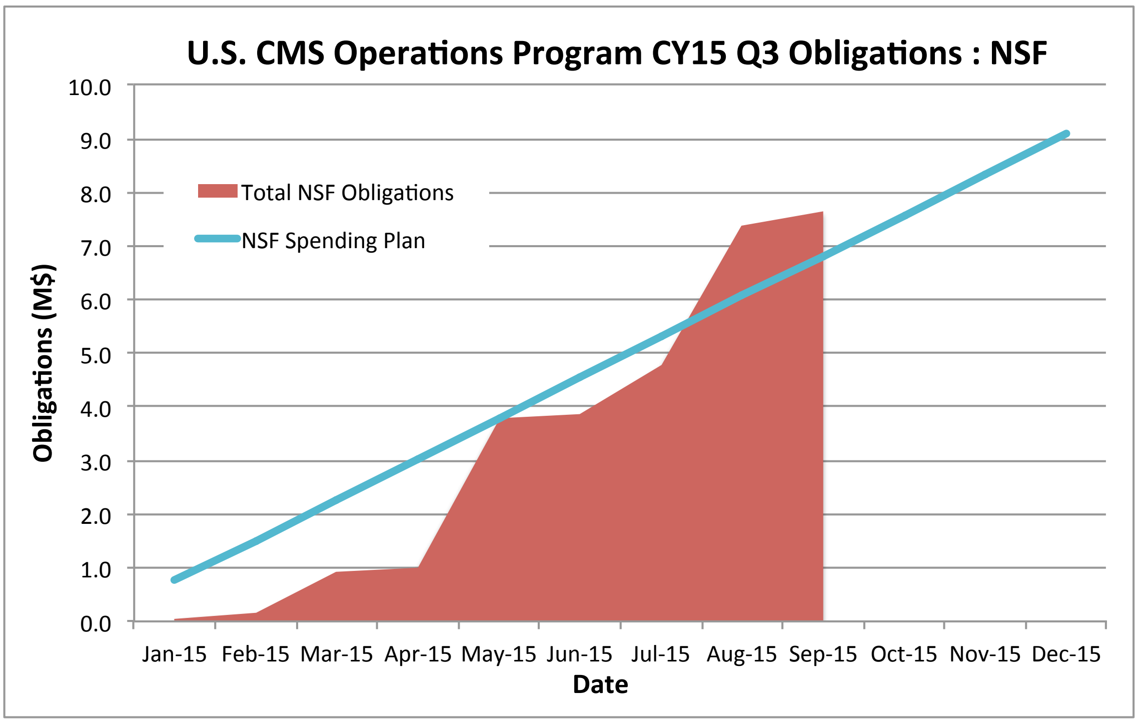


Figure 6: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.

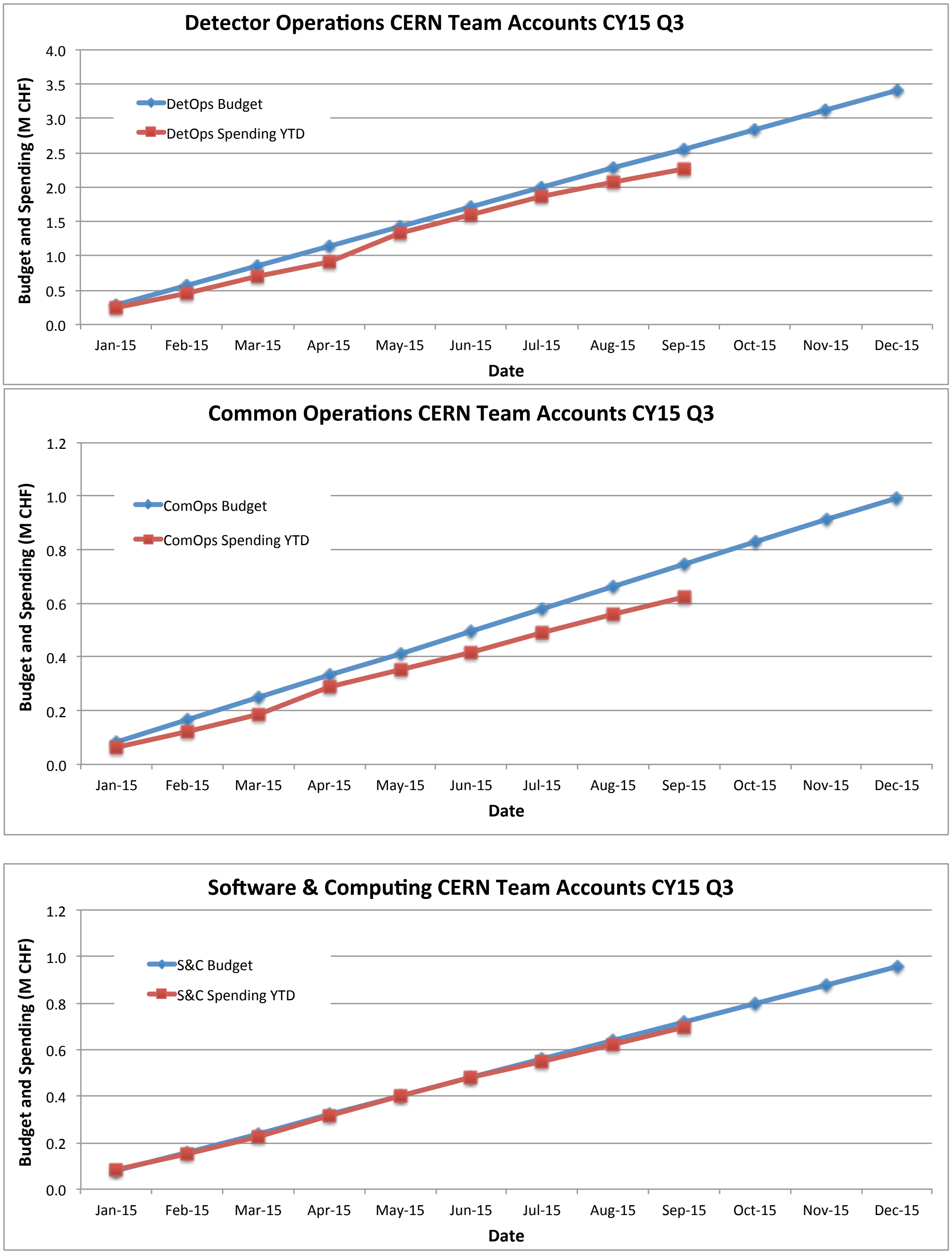


Figure 7: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.

Detector Operations

Problems with the CMS magnet continued through the quarter. Since March the "Cold Box" (CB) that produces Liquid He for the operation of the CMS magnet has shown problems, after an incident where compressor (Breox) oil contaminated the CB circuit. For definitive recovery the system requires an overall cleanup, which will take several months. Meanwhile, the CERN cryo group, in collaboration with CMS Technical Coordination, has been looking for a way to operate the CB with a reasonable duty cycle of at least 70% that would allow operation of the magnet synchronized with physics operation of the LHC until the Year End Technical Stop (YETS). After a number of corrective actions, performance of the magnet has improved and it appears this goal is being met.

Figure 8 shows the total luminosity delivered and recorded by CMS during 2015. Of this data, approximately 0.40/fb is with the magnetic field off or below nominal value.

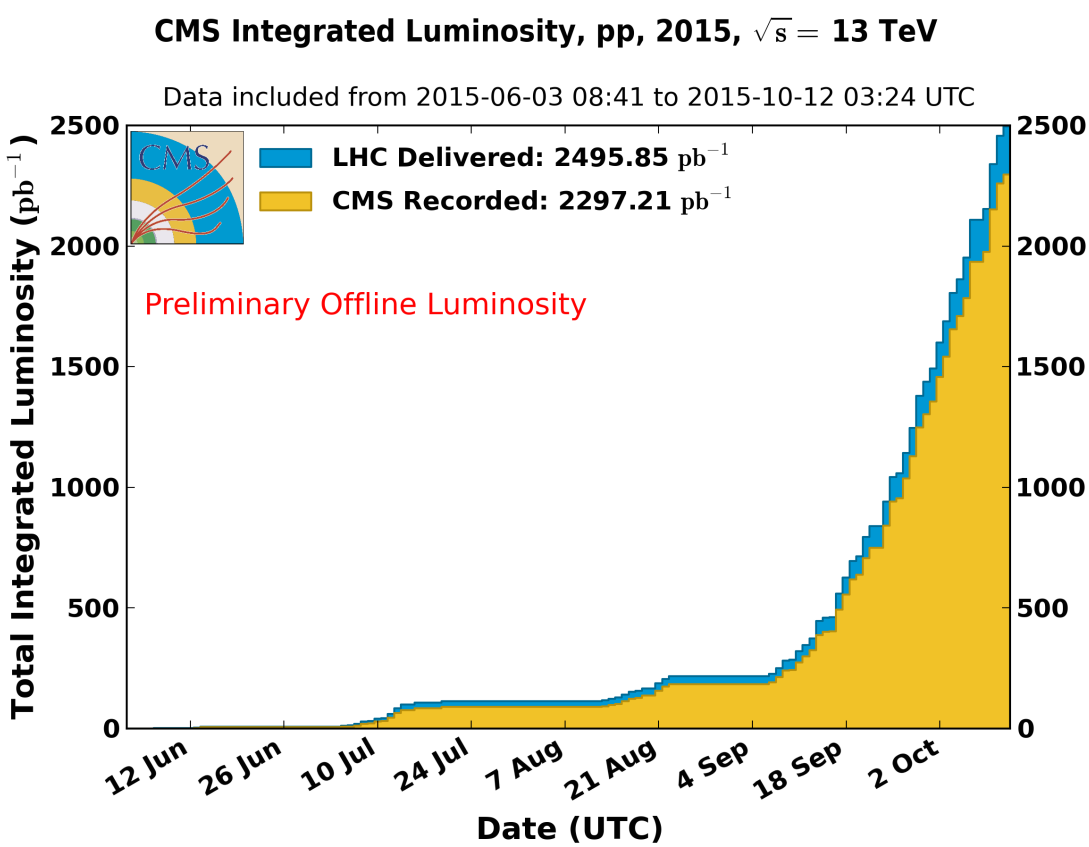


Figure 8: Cumulative offline luminosity versus day delivered to (blue), and recorded by CMS (orange) during stable beams and for p-p collisions at 13 TeV centre-of-mass energy in up to October 2015. The delivered luminosity accounts for the luminosity delivered from the start of stable beams until the LHC requests CMS to turn off the sensitive detectors to allow a beam dump or beam studies. Given is the luminosity as determined from counting rates measured by the luminosity detectors after offline validation. This preliminary calibration is based on short van-der-Meer scans performed routinely by LHC in every fill.

As part of our activity-based reporting, with the start of the physic run in this quarter we begin to again give performance metrics for each detector component. These are presented in each sub-detector section below.

BRIL

Highlight of this quarter was the successful calibration of the Pixel Luminosity Telescope (PLT) detector and other luminosity detectors using a full van der Meer (VDM) scan. With detector and software ready and working the PLT provided the fastest turnaround of all LHC detectors in reporting luminosity to the LHC. Furthermore, the calibration agrees within 1% with preliminary calibrations from previous beam scans. CMS is now in a position to publish the luminosity online with 99% uptime.

In addition to a trigger based on triple coincidences, the PLT has implemented a second trigger to randomly select the bunch crossings for saving full particle track information. This trigger mode is in its commissioning phase. It will allow comparative systematic studies and potentially will improve the luminosity uncertainty.

Table 1: BRIL Milestones.

Subsystem	Description	Scheduled	Achieved
BRIL	Hardware installed	Jan	Jan
BRIL	Ready to deliver Lum	March	March
BRIL	Ready to deliver bkg nums	May	May

Table 2: BRIL Metrics.

Metric	Performance
Fraction of telescopes operational	14/16
Efficiency of delivery of lumi histograms	100 %
Uptime of lumi histogram production	100 %

Tracker

The tracker system performed well and met its milestones. There had been an ongoing problem with condensation in the pneumatic control lines for the cooling system which has been traced to short sections of plastic tubing in the system. The plan is to replace these short sections with aluminum jacketed pipe in the year end technical stop and to mitigate the problem with bleed valves in the meantime.

Tracker - Strips

Strips have accounted for 4% of the lost lumi since the start of the high intensity running. We continue to try and recover problematic FEDs (less than 1% of the Strips), but the emphasis is now on smooth data taking rather than detailed channel recovery.

Tracker - Pixels

Major downtime from the pixels has come from the testing of Heavy Ion firmware for the pixel fed. As the request for firmware that could run at a much higher rate for heavy ion collisions was made in May 2015, the opportunity to develop with beam in 2012-2013 was lost, and we did not fully develop an alternative testing method during Long Shutdown 1 (LS1). The firmware passes all tests outside of collisions, and we are left with using collisions to fully map out the areas of problems with the heavy ion firmware. The pixels accounted for 21% of the lost lumi since the start of the high intensity running. 98.6% of the pixel tracker channels are working. 99.8% of the FPiX channels are working.

Table 3: Tracker Milestones.

Subsystem	Description	Scheduled	Achieved
Tracker	Installation and checkout		Achieved
Tracker	Tracker operate -15C		Achieved
Tracker	Pixel operate -10C		Achieved
Tracker	Ready for proton beams	March	March

Table 4: Tracker Metrics.

Metric	Pixels	Strips
% Working channels	98.6%	97.5%
Fraction of deadtime attributed	21%	4%

ECAL

All parts of ECAL (EB/EE/ES) are taking data normally. Substantial effort has been devoted to improving the data-taking efficiency of ECAL by simulating higher than normal data acquisition rates and solving the rare errors that occurred. The ECAL optical links to the legacy and upgraded calorimeter triggers have been successfully validated and the detector has been synchronized with the rest of CMS using beam splash events and proton-proton collisions data.

In addition, the laser used for calibrating the crystals has been operating well. At the end of Run 1 there was a laser power stability issue that was traced to a flawed humidity sensor, which has since been replaced. With that replacement the operation has been stable with no power loss in the system.

A successful test beam campaign was conducted in Sep 2015 using electrons provided by the H4 beamline at the CERN-SPS. Measurements of highly irradiated PbWO4 crystals were recorded, with special two-sided readout, to study the changes in light collection efficiency as a function of the radiation-induced crystal transparency change.

Table 5: ECAL Milestones.

Subsystem	Description	Scheduled	Achieved
ECAL	Finish HV Install	Feb	May
ECAL	Baseline levels zero suppression	March	March
ECAL	Complete install HV calib system	April	May
ECAL	Selective readout	June	First pass completed
ECAL	Trigger thresholds	June	First pass completed
ECAL	Zero suppression thresholds	June	First pass completed

Table 6: ECAL Metrics.

Metric	Performance
Fraction of channels operational: EB	99.1%
Fraction of channels operational: EE	98.9%
Fraction of channels operational: ES	98.4%
Fraction of deadtime attributed	14%
Resolution performance	TBD

HCAL

The HCAL project focused on two tasks, operating the HCAL detector for LHC collisions at 13 TeV in Run 2, and developing and installing the Phase 1 upgrades.

With Run 2 underway, a major emphasis has been the collection of high quality data from all HCAL subsystems (HBHE, HF, and HO). To accommodate collisions with 25 ns bunch spacing, new local reconstruction code was developed and commissioned; the improved algorithm substantially improves the mitigation of out-of-time pileup. Using data taken early in Run 2, the calibration of the HBHE and HF sub-detectors has been adjusted, and corresponding corrections to the Level-1 trigger look-up tables have been implemented.

The long-term stability of the response of HCAL photo-detectors in Run 2 is being monitored using the LED calibration system. The average gain of the legacy HBHE hybrid photodiodes (HPDs) has been nearly stable over the last six months at the level of 1%, although a slow drift, either up or down, of the individual HPD gains with time is observed, comparable to effects seen in Run 1. The gains of the new PMTs for the HF are stable within 1%, with no evidence of gain loss as a function of integrated luminosity. Similarly, the gain of the HO Silicon PhotoMultipliers (SiPMs) is very stable, with no sign of dependence on the magnetic field.

Table 7: HCAL Milestones.

Subsystem	Description	Scheduled	Achieved
HCAL	Fully functional HCAL in CRAFT runs	March	March
HCAL	prepared to do HF Phase scan and ϕ symmetry calibration analysis	May	May
HCAL	New HBHE backend operating in parallel with legacy system	July	July

The status of the HCAL metrics is as follows:

- Fraction of channels working
  in HF, 1 dead channel out of 1728
  in HBHE, 7 dead channels out of 5184
  in HO all 2150 channels work.
  In total $>$ 99.9% working channels
- Fraction of downtime attributable to HCAL since LS1, 0.5%
  2.7/pb lost of 562/pb
- Intercalibration uniformity between individual HCAL towers
  HB: depth 1: 3-4%
  HE: depth 1: $\approx$ 1-2%, depth 2,3: 3-4%
  HF: depth 1: 1-1.5%, depth 2: ~3% (still some outliers)

Unfortunately, there have been issues that led to a significant loss of data that were identified during data certification. These were triggered by loss of synchronization between the HF back end and front end electronic. This caused 75/pb of data to be declared as bad. In addition an issue with a low voltage power supply for HF caused 10/pb bad data. These issues are now resolved. There is also an issue with μHTR registers being occasionally corrupted when a detector re-configuration is issued. This problem is still under study, but a temporary work-around was implemented.

EMU

The transition to 25 ns LHC beam bunch spacing went smoothly for the CSC system. Figure 9 shows the track segment times in the CSC readout window displaying the 25 ns beam structure clearly.

The spatial resolution for reconstructed hits on CSC chambers was measured from collision data. The resolution varies by chamber type, with a median value of 128 μm. The resolutions are very close to the values from Run 1, aside from the ME1/1 chambers, where the resolution on the inner region (ME1/1a) has gone from 64 μm to 51 μm. This improvement is largely due to the removal of the 3-to-1 cathode strip ganging in this region performed during the LS1.

A sample of $Z \rightarrow \mu\mu$ events from Run 2 collision data were used to make the first measurement of the efficiencies for CSC segments and trigger primitives (LCT). The average for all 540 chambers is greater than 96% with a few outliers from known outstanding chamber issues and low statistical

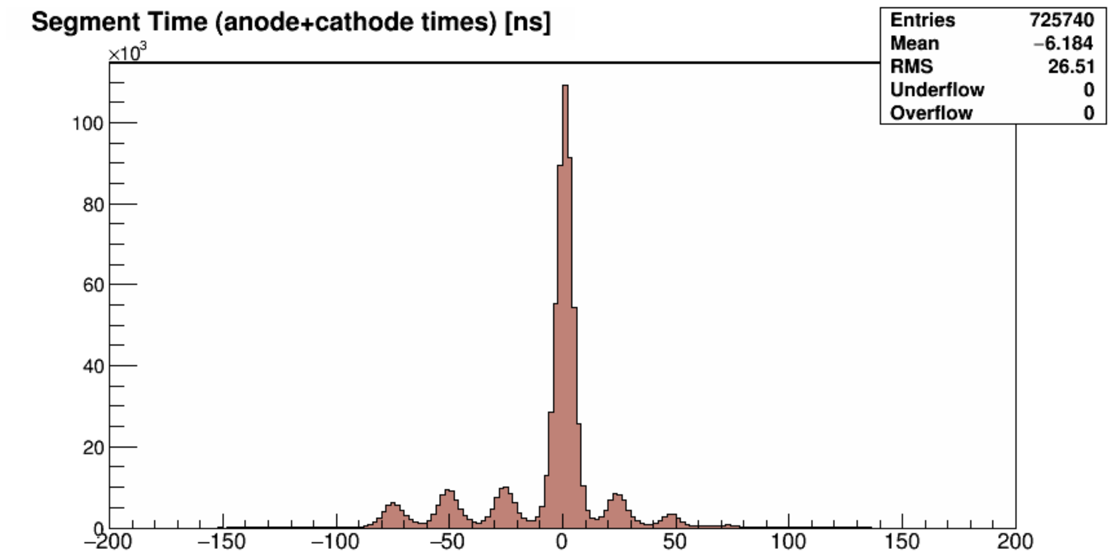


Figure 9: The timing of CSC Segments relative to the triggered beam crossing in 25 ns collision data.

accuracy. The efficiencies are more uniform than in Run 1 due to the high fraction of operational system channels.

Table 8: EMU Milestones.

Subsystem	Description	Scheduled	Achieved
EMU	CSC ready for collisions	May	April
EMU	Calibration for HLT and Offline included in DB	July	delayed
EMU	Fine timing adjustments with collision data completed	July	July

The milestone “Calibration for HLT and Offline included in DB” has been delayed. It is now expected that it will be completed in December. There are technical problems with taking calibration data at Point 5. These have been worked on since July, but they can only be done when CMS is not taking data. Operational issues that affect physics running are given higher priority. We are using a set of calibration constants from Run 1, except for ME1/1 and ME4/2 chambers where these constants are not available. For these, we use typical values for each chamber. The impact of this delay is low, the reconstruction is quite insensitive to the calibration. The main motivations for the calibration are to represent the cross talk correctly in the simulation and to allow more precise tracking of gas gain.

Table 9: CSC Metrics.

Metric	Performance
% Working channels	99.3%
Fraction of deadtime attributed	8%
Median spatial resolution	128 μm

DAQ

DAQ met all its milestones and performing with negligible down time during physics data taking. The LHC has not yet completed its luminosity ramp up. Presently CMS is taking data with 80 kHz Level-1 trigger rate and average event size of 650 kB, which is below the design throughput of the DAQ2.

Event Builder throughput performance was demonstrated in emulation runs, and it was shown that event building can be sustained at 100 kHz Level-1 accept rate, with a margin of 1.5 times the Run 1 event size of 750kB. (N.B. the design performance of the old DAQ1 was 100 kHz Level-1 accept rate for 1 MB size events). These tests were done with the full DAQ chain, involving event building, High Level Trigger (HLT) processing emulated as sleep, and collecting events selected by the HLT into single files per stream, ready to be send to the Tier-0. Actual demonstration of DAQ2 performance however requires real detector data with the full HLT menu, but for that test the LHC luminosity still needs to increase.

Table 10: DAQ Milestones.

Subsystem	Description	Scheduled	Achieved
DAQ	Hardware Installation of DAQ2 with new HLT nodes complete	April	April
DAQ	Complete DAQ2 is operational for collisions	July	May
DAQ	μTCA DAQ link commissioned for new trigger and HCAL FEDs	July	June
DAQ	DAQ2 with Run I design performance	Sept.	Sept.

Table 11: DAQ Metrics.

Metric	Performance
Dead time due to trigger throttling	0.007%
Downtime due to DAQ	negligible

Trigger

During this quarter the U.S. groups continued their work on the regional calorimeter (RCT) and the endcap muon triggers.

Regional Calorimeter Trigger

During the last three months, the CMS RCT participated in data taking at 25 ns bunch crossing. CMS switched from calorimeter triggers with the RCT and GCT to triggers with the RCT and the new Stage-1 MP7. Accordingly, configuration and hardware monitoring were added to the Trigger Supervisor, and the histograms in online Data Quality Monitoring (DQM) were updated to use the readout from the MP7. The RCT output can be readout via CDAQ using the CTP7. Using this data path, a second set of emulator and occupancy histograms were added to the RCT online DQM.

The new HF μHTR links to the RCT were commissioned. There were still some issues with links going into error state, and with the HF link synchronization. This caused effects in the jet rates, similar to the ECAL issues, that were mitigated using the same firmware as for the ECAL oRMS. These issues will need further dedicated studies outside of physics running.

Endcap Muon Trigger

The groups at Rice University, Northeastern, and University of Florida maintained on-call coverage of the CSC Track-Finder during the reporting period, with only a few instances needing intervention. We eventually had to replace a QPLL module on one sector processor that had occasionally lost synchronization during operations.

The CSC Track-Finder group also participates in the CMS TimeX group, which is part of Run Operations. In that context, the CSC Track-Finder delay buffer depths are being monitored to flag any shifts in the TCDS clock timing, which has been observed by several CMS subsystems. We participated in system tests of the new reset procedure in order to avoid these TCDS timing shifts.

Table 12: Trigger Milestones.

Subsystem	Description	Scheduled	Achieved
TRIG	Legacy RCT ready for physics	June	June
TRIG	MPC ready for physics	June	June
TRIG	CSCTF Ready for physics	June	June
TRIG	Stage-1 Layer-1 calorimeter trigger ready for physics	Sept.	Sept.

Table 13: Trigger Metrics.

Metric	Performance
Frac legacy RCT channels	100%
Frac of deadtime attributed legacy RCT	0.18%
Frac of MPC Channels	100%
Frac of EMUTF Channels	100%
Frac of deadtime attributed to legacy EMUTF	0.13%
Frac of Stage-1 Layer-1 Channels	100%
Frac of deadtime attributed to Stage 1 Layer 1	0%

Software and Computing

As the LHC has settled into stable operations this quarter, the Software and Computing also entered a operational mode. Various aspects of operations, like central processing and data management, have become routine, with adjustments as experience is gained. Stable and robust operations is facilitated by advances in computing and software that resulted from the various development efforts carried out during LS1. While development continues on many products and services, the top priority is now to support computing operations, with an eye towards the use of new resources such as amazon.com cloud computing or clusters at supercomputing centers. CMS software performance benefits from the multi-threaded framework, and development continues to expand the scope of those gains. As a result, facilities at Fermilab and the universities have been increasingly utilized, and resources have been much more full than in previous quarters, while site performance has remained good. End-of-year hardware purchases will help to keep up with the increasing demands.

Table 14: Major milestones achieved this quarter

Date	Milestone
July 2015	Production release CMSSW_7_5_0 made available
August 2015	Implement continuous integration for WMAgent
September 2015	Tier-1 purchases completed for 2015

Fermilab Facilities

Run 2 data taking continued through the quarter. The Fermilab facility received over a petabyte of LHC collision data so far. Utilization of the Tier-1 has increased and the Fermilab facility was normally full to capacity. Site readiness improved over the previous quarter, and Fermilab passed CMS site tests 98% of the time, as shown in Figure 10.

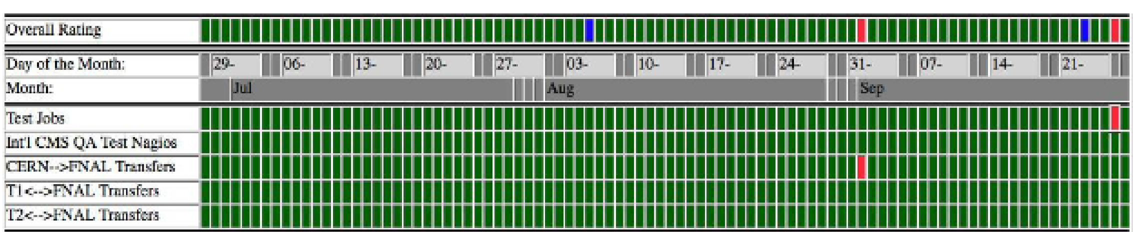


Figure 10: Fermilab readiness metrics for 2015Q3. Green indicates a passing metric, red a failed metric. Blue indicates a scheduled downtime. Fermilab was 98% available during the quarter.

The 2015 Tier-1 equipment purchase cycle was completed. New hardware began to arrive and be installed late September. We were able to take advantage of very good market pricing this year both for disk and CPU, and used this as an opportunity to buy-ahead equipment for the next years, when significant additional budget pressure is expected. Fermilab purchased 168 nodes of 48-core Intel CPU batch nodes, and approximately 8 PB of disk storage toward the 2016, and to some extent 2017, CMS pledges. The increased size of the batch farm required upgrades in network connectivity to the storage pools, and management reserve funds were used to facilitate these procurements. About 6 PB of tape media was purchased and installed to hold incoming Run 2 data.

University Facilities

This quarter saw a continuing increase in the use of the U.S. CMS Tier-2 facilities, as shown in Figure 11. The increase was largely due to running part of the CMS data reconstruction at U.S. Tier-2 sites. This workflow has been possible at Tier-2 sites since May, enabled partly by development work undertaken during LS1. These workflows place a heavy strain on the site's internal networking capabilities, but all U.S. sites are able to handle the increased load. Physics analysis with CRAB3 is also increasing.

The seven U.S. Tier-2 sites are planning or are in the process of finalizing their hardware purchases for 2015. The connection of the Tier-2 sites to the LHCOne VPN provided by ESNet is proceeding as planned and is completing this quarter. All sites have deployed the HTCondor-CE computing element, and have either retired or are planning to retire their GRAM CEs very soon.

All U.S. CMS Tier-2 sites are operating successfully, in terms of the performance metrics based on CMS test jobs. All sites were at least 92.4% available (corresponding to a 4.4% improvement over the third quarter 2015) and 95% ready, which is 1% point better than last quarter. The goal for both of these metrics is 80%. The 7 U.S. sites delivered 44% of all CMS Tier-2 computing time (the goal is to be >25%) and are among the 8 top most-used Tier-2 sites in CMS.

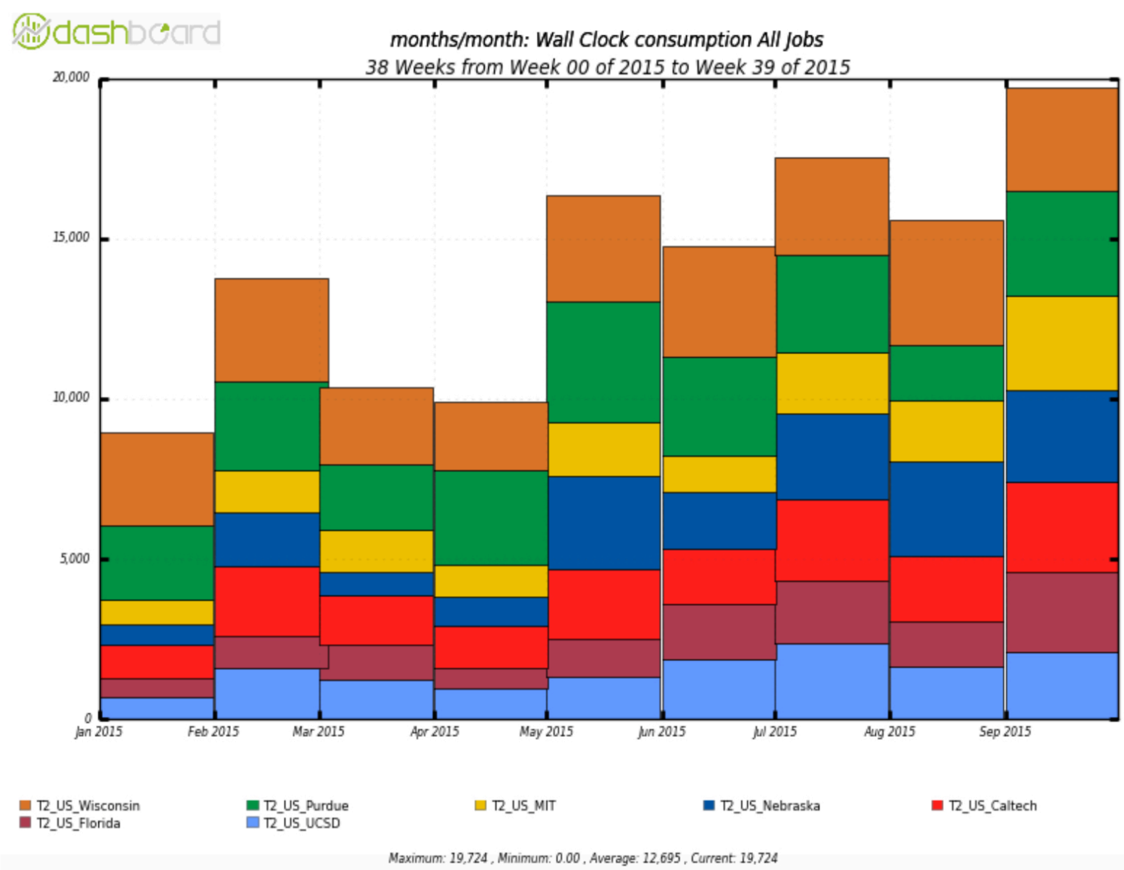


Figure 11: Wall clock time consumption of CMS workflows at the U.S.CMS Tier-2 sites by month.

Fourteen Tier-3 sites required assistance from the U.S. CMS Tier-3 support team this quarter. Support activities include helping sites complete the transition from OSG 3.1 to 3.2, which had a critical security patch for GUMS that could only be applied to upgraded sites. In addition, the site support team continues to assist several sites in rebuilding their site in preparation for Run 2. In particular, there is an ongoing effort to implement a modern cluster configuration and provisioning system at the University of Maryland, as well as new efforts to rebuild clusters at Rice and FSU. Efforts continue to refresh documentation for site configuration and administration.

Progress on CMS Connect focused on integrating the infrastructure with CMS monitoring, which required significant software development. Documentation is nearly complete and beta testing should begin during the next quarter.

Operations

The Tier-0 operated in data-taking mode, and prompt processing of all freshly recorded data was successful and proceeded without significant problems. Smaller issues and software changes were quickly taken care of. The core Tier-0 software developer and co-leader (D.Hufnagel) is moving on helping with other development projects as the Tier-0 enters an operations-dominated period.

Activities in Monte Carlo production and reprocessing have been relatively low, so the production systems kept up with incoming requests. Streamlining of production and processing activities continued. The operations team was well prepared to deal with production campaigns which started in the beginning of October. In particular, the integration of the new dynamic disk space management tool for production data samples will be very valuable to help staying within quotas. In this quarter we completed 2.44B DIGI-RECO events, 3.38B GEN-SIM events and re-done 50M MINIAOD. The last number is expected to increase dramatically in the next quarter as we are have just started the re-reconstruction campaign. Running production requests on HLT resources will be a topic for the next quarter as use of HLT for data taking was priority this quarter.

There was substantial progress on data transfers and data management. Integration of AAA operations continued, and while there are still issues reported regularly the operations team is getting more experienced in solving problems. The Dynamic Data Management (DDM) system was deployed and started automatic deletions of data sets in the production data space. The system protects data from deletion by a simple locking mechanism, and any data in use by production at any site has to be explicitly locked. Thus any production activity that requires data has to set and release locks, either automatically or by hand. Integration of DDM into all production activities will continue for some time before it can be considered complete. In the next quarter we expect to review the DDM policies and continue development towards further optimizing space usage. Tape pledges at the Tier-1 centers have been reviewed and we are continuing our deletion campaigns to free up space on existing tapes. We plan to use the new DDM tools to help reduce the effort required for the deletion campaigns.

Computing Infrastructure and Services

Work centered around supporting Run 2 data taking and continuing to lay the groundwork for future improvements. All projects made progress on modernizing code.

Work on WMAgent concentrated on continued small improvements and the addition of new workflow types and features to support running on Amazon Web Services (AWS), including a new chained workflow type. The WMAgent team completed a campaign to modernize its Python code and automated testing of changes in continuous integration. The transition to version 2 of Request Manager continues and is expected to be complete by the first quarter in 2016.

With development effectively finished the Tier-0 entered a period of operation during data taking. Updates included production of the MINIAOD data tier and supporting the automatic data management.

Development responsibilities for CRAB3, initially done by U.S.CMS, have almost completely shifted to international CMS. CRAB3 usage continued to grow With users migrating from CRAB2.

The CMS metadata services DAS and DBS served ever larger numbers of requests with the beginning of the run began, requiring some changes to enable the larger load. For DAS we implemented horizontal scaling to additional servers. DBS struggled with memory consumption issues that are being solved with Python generators, and the new code will be moved into production in the next quarter.

There was a major GlideinWMS release during the quarter and two patch releases. The former provides the important ability to schedule an additional high-IO job in a multicore pilot. This is crucial for the Tier-0 to avoid scheduling too many high-IO jobs on a single physical machine or leaving resources unallocated. This will be put into production in the next quarter. In the future, GlideinWMS will improve the monitoring related to completed multicore glideins. Coupled with the AWS pilot project, the GlideinWMS team will add native configuration support for EC2 spot pricing and availability zones in the glidein factory.

Efforts continue to increase the operational robustness of the remote data access (AAA) infrastructure. A number of issues in the stability of the regional redirectors were identified and fixed; along the way many sites were upgraded to newer versions of Xrootd, that provided a number of improvements. Further improvements to monitoring and testing are being considered, and the transitional federation for less-performant sites will be fully populated in the coming quarter.

We continue to make progress on cloud and opportunistic resource usage. We completed our computing allocation at SDSC, using 1.8M core hours on the Gordon machine, roughly equivalent to 4M core hours at CMS Tier-2 centers. This allocation was used for GEN-SIM as well as DIGI-RECO jobs. For the latter, the pileup samples were read via XRootd from the UCSD Tier-2, and the GEN-SIM inputs for the DIGI-RECO step were read via Xrootd from Fermilab. Output data was staged out directly to the Fermilab storage systems and file merging was run at Fermilab. This was an improvement to the previous use of Gordon in 2013 requiring no significant local disk space at Gordon and thus simplifying operations significantly.

There are two projects that aim at establishing a new capability to elastically grow computing resources on demand. For use of cloud computing resources we collaborate as part of the Fermilab HEPCloud in the amazon.com Web services (AWS) project. For future use of High-Peformance Computing (HPC) centers like NERSC and Comet, we collaborate with OSG working through the remaining issues in using these resources.

Software and Support

The Software and Support group continues to contribute to improving software. For data taken in 2015 the CMSSW_7_4_X release series is being maintained as the main production release. Introduction of multi-threaded reconstruction resulted in large memory savings and reduced processing latency, enabling to handle the high Run 2 trigger rates. During software commissioning on the

Tier-0 system it was found that its use of a very large number of output modules and just-in-time compilation within ROOT causes larger concurrency inefficiencies than expected in testing. These problems were fixed in a new development release series CMSSW_7_6_X, which will be used for the end-of-year reprocessing.

Maintenance work was also done on the 7_4 release to allow it to be used in the HLT, which is currently running in single threaded mode. Due to a lack of sufficient memory per core it cannot sustain the highest trigger rate that occurred during the last two weeks of data taking without moving to multi-threaded processing. In Figure 12, the point circled in black marks the current limit of the single-threaded HLT application, and the green circle marks the rate that the new multi-threaded application allows. This new capability comes just in time to maximize physics data taking efficiency for CMS.

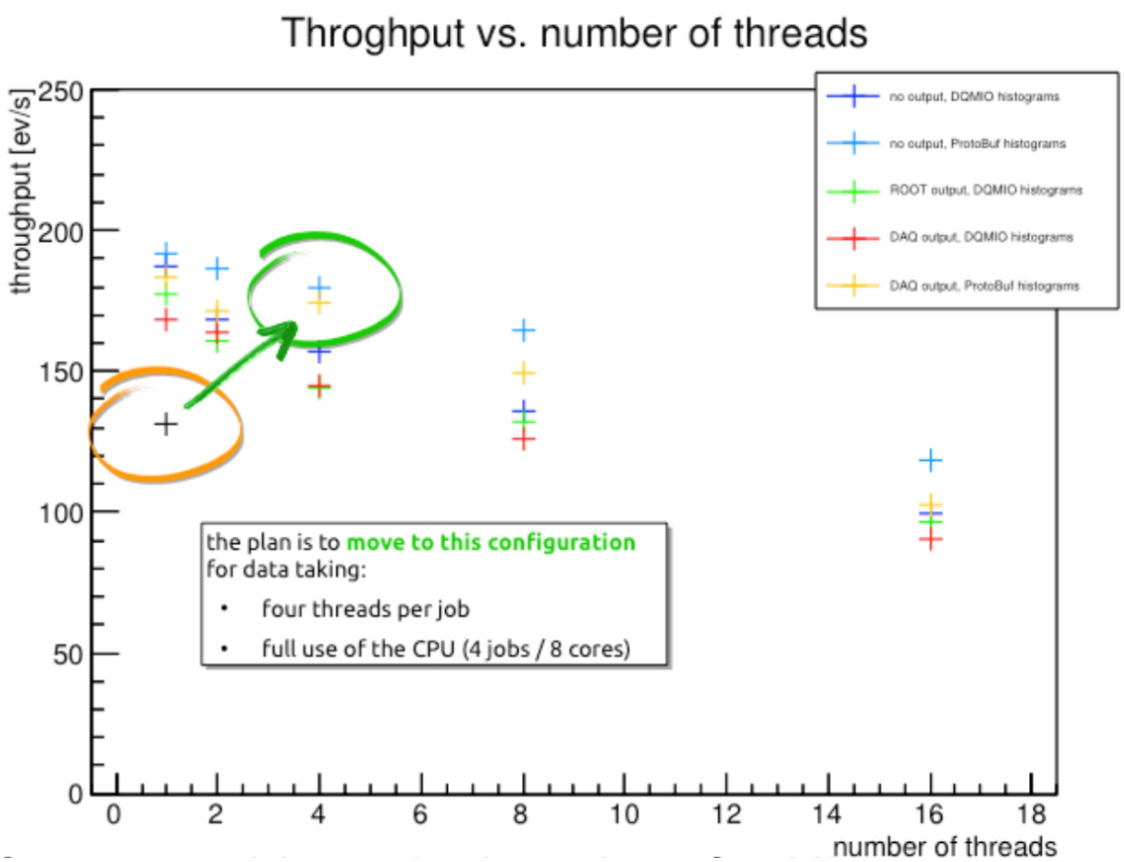


Figure 12: Event throughput rates as a function of the number of threads for single- and multi-threaded applications.

Meanwhile the CMSSW 7_5_X release series is being prepared to operate during the upcoming heavy-ion run. For this release the GEN-SIM application was validated to run effectively in multi-threaded mode.