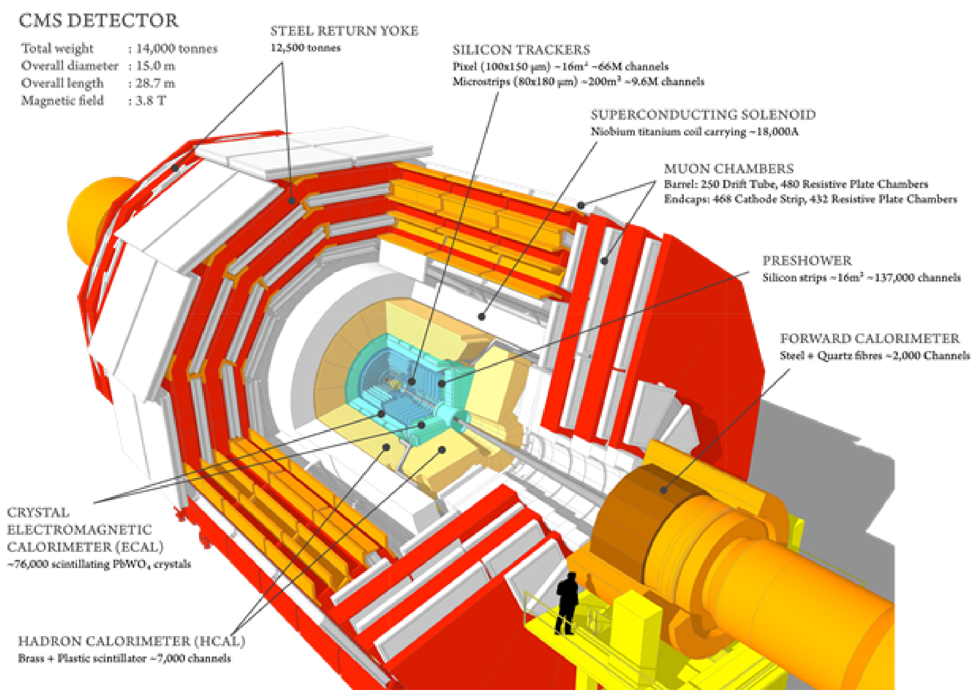
U.S. CMS Compact Muon Solenoid Operations Program
Quarterly Report for the Period Ending September 30, 2018

U.S. CMS Operations Program



Report of the U.S. CMS Resource Manager

The funding provided by DOE and NSF to the U.S. CMS Operations Program for 2002 through 2018, as well as the funding guidance for 2019 through 2021, is shown in Figure 1. The allocations shown for 2018 and beyond do not include any funds designated for HL-LHC OPC in the case of DOE or HL-LHC R&D in the case of NSF.

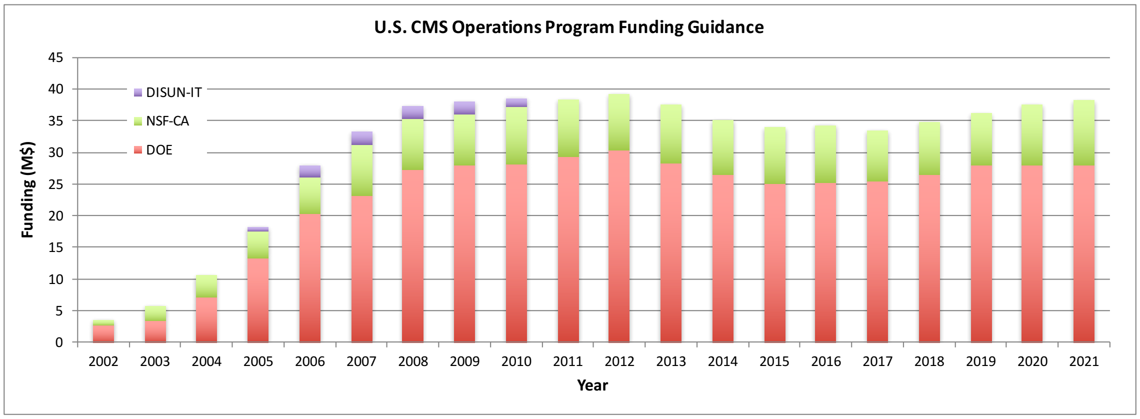


Figure 1: The annual U.S. CMS Operations Program funding provided by DOE and NSF. For 2002 through 2018 the chart shows the actual funding, while for 2019 onward the current funding guidance is shown.

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 2018 took place in September of 2017. As an additional source of input to the planning process, the Resource Allocation Advisory Board met in the Fall of 2017, 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 information 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 September of 2018, a total of 94 SOWs (60 DOE and 34 NSF) were produced and approved. After a SOW is approved, any additional changes are considered and, if approved, enacted through a Change Request procedure.

Figure 2 shows the Spending Plan Change Log which captures revisions that were made prior to SOW approvals, as well as modifications implemented through Change Requests. The information is reported here down to the level-2 subsystem categories within DetOps, S&C, and ComOps. The CY18 spending plan, as of the end of Q3, is shown for DOE and NSF funds in Figure 3.

WBS	Subsystem	Change Request Number	Description of Change	CY18 Q3 Plan	Change $	CY18 Q4 Plan
U.S. CMS Detector Operations Change Control Activity						
11	Endcap Muon	CR-036, 037, 038	Wisconsin grad student COLA, TAMU student travel for slice tests, M&S Northeastern for timing crystals	$1,830,611	$28,320	$1,858,931
	Endcap Muon MEX/1	CR-038, 039	M&S UCLA for ALCT mezzanines moved earlier, M&S Ohio State for xDCFEB production bid	$2,109,887	$396,032	$2,505,919
12	Hardon Calorimeter	SOW, CR-053, 054, 055	Labor and travel for Virginia engineer, COLA for Virginia grad student, Virginia engineer for work on voltage spikes, increased Virginia overheads	$2,145,309	$53,263	$2,198,572
13	Trigger	Adjust	Fermilab overhead adjustment	$902,069	$2,322	$904,392
14	Data Acquisition	CR-011	CERN TA support for computing professinoal	$1,136,920	$8,438	$1,145,358
15	Electromagnetic Calorimeter	CR-023, 024	Reductions in CERN TA COLA	$769,677	($14,273)	$755,405
16/17	Tracker (Fpix & SiTrk)	CR-016; SOW	Labor and travel support for KSU TBM testing; M&S to Vanderbilt for TBM radiation campaign	$985,550	$22,240	$1,007,790
18	Detector Support	Adjust	Fermilab overhead adjustment	$121,058	$418	$121,476
19	BRIL	Adjust	Fermilab overhead adjustment	$358,254	$607	$358,861
11-19	**Detector Operations**			**$10,359,337**	**$497,367**	**$10,856,704**
U.S. CMS Common Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY18 Q3 Plan**	**Change $**	**CY18 Q4 Plan**
21.2	Common Costs (M&OA)	Adjust	Fermilab overhead adjustment	$4,081,142	$10,945	$4,092,087
21.3	Run Coord. and Monitoring	Adjust	Fermilab overhead adjustment	$162,881	$195	$163,076
21.4	LHC Physics Center	Adjust, CR-121	Adjust LPC labor support to UIC; Graduate Scholars	$772,936	$110,438	$883,374
21.5	Operations Support	SOWs, CR 119, 120, 122	SMU timing engineering, Purdue Tracking Co-coord. travel, U of Kansas timing probe station M&S; Reduce COLA and M&S, Purdue engineering student timing layer clock, labor for HCAL and software	$1,844,548	$206,721	$2,051,269
21.6	Program Office	Adjust	Fermilab overhead adjustment	$1,057,448	$5,960	$1,063,408
21.7	Education and Outreach	Adjust	Fermilab overhead adjustment	$110,585	$0	$110,585
21	**Common Operations**			**$8,029,539**	**$334,259**	**$8,363,799**
U.S. CMS Software and Computing Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY18 Q3 Plan**	**Change $**	**CY18 Q4 Plan**
22.1	Fermilab Facilities	Adjust	Fermilab overhead adjustment	$6,141,149	$50,728	$6,191,877
22.2	University Facilities	Adjust	Fermilab overhead adjustment	$3,028,909	$418	$3,029,327
22.3	Computing Operations	Adjust	Fermilab overhead adjustment	$888,587	$4,141	$892,728
22.4	Computing Infra. and Services	Adjust	Fermilab overhead adjustment	$2,758,090	$6,474	$2,764,564
22.5	Software and Support	Adjust	Fermilab overhead adjustment	$2,488,770	$5,131	$2,493,900
22.6	S&C Program Management & CMS Coordination	Adjust	Fermilab overhead adjustment	$420,423	$557	$420,980
22	**Software and Computing**			**$15,725,928**	**$67,448**	**$15,793,375**
U.S. CMS Operations Program Total				**$34,114,804**	**$899,075**	**$35,013,878**

Figure 2: Spending Plan Change Log for CY18 Q3.

WBS	Subsystem	DOE Funds	NSF Funds	Total
11	Endcap Muon	$1,508,042	$350,889	$1,858,931
	Endcap Muon MEX/1	$2,505,919	$0	$2,505,919
12	Hadron Calorimeter	$2,150,772	$47,800	$2,198,572
13	Trigger	$672,153	$232,238	$904,392
14	Data Acquisition	$1,145,358	$0	$1,145,358
15	Electromagnetic Calorimeter	$755,405	$0	$755,405
16/17	Tracker (Fpix & SiTrk)	$832,047	$175,743	$1,007,790
18	Detector Support	$121,476	$0	$121,476
19	BRIL	$176,126	$182,735	$358,861
11-19	**Detector Operations**	**$9,867,299**	**$989,405**	**$10,856,704**
21.2	Common Costs (M&OA)	$3,192,246	$899,841	$4,092,087
21.3	Run Coordination and Monitoring	$55,140	$107,936	$163,076
21.4	LHC Physics Center	$883,374	$0	$883,374
21.5	Operations Support	$1,795,609	$255,660	$2,051,269
21.6	Program Office	$961,108	$102,300	$1,063,408
21.7	Education and Outreach	$0	$110,585	$110,585
21	**Common Operations**	**$6,887,477**	**$1,476,322**	**$8,363,799**
22.1	Fermilab Facilities	$6,191,877	$0	$6,191,877
22.2	University Facilities	$121,322	$2,908,005	$3,029,327
22.3	Computing Operations	$421,470	$471,258	$892,728
22.4	Computing Infrastucture and Services	$1,826,031	$938,532	$2,764,564
22.5	Software and Support	$1,455,980	$1,037,920	$2,493,900
22.6	S&C Program Management and CMS Coordination	$157,409	$263,571	$420,980
22	**Software and Computing**	**$10,174,089**	**$5,619,286**	**$15,793,375**
U.S. CMS Operations Program Total		**$26,928,865**	**$8,085,014**	**$35,013,878**

Figure 3: Spending plan at the end of CY18 Q3, for funds from DOE, NSF, and the total.

Once funds have been committed through purchase orders, in the case of DOE, and sub-awards, in the case of NSF, they are considered obligated. Figure 4 shows the obligations in the areas of DetOps, S&C, and ComOps, as compared to the spending plan, for DOE funds. The spending plan is plotted as if expenditures are carried out in even allocations each month, but this is intentionally not the case due to equipment purchases and the larger of the transfers to CERN-based Team Accounts, the latter of which are targeted for when exchange rates are favorable. Spending through Universities and CERN Team Accounts is budgeted and tracked according to the calendar year. Spending at Fermilab has historically been budgeted according to the fiscal year, however this is the fourth year that we are reporting all activities based on calendar year. Figure 5 shows the total obligations and the spending plan, for NSF funds. Of the $8.4M in NSF funding, $2.8M in subawards went out this quarter, in addition to spending directly at Princeton.

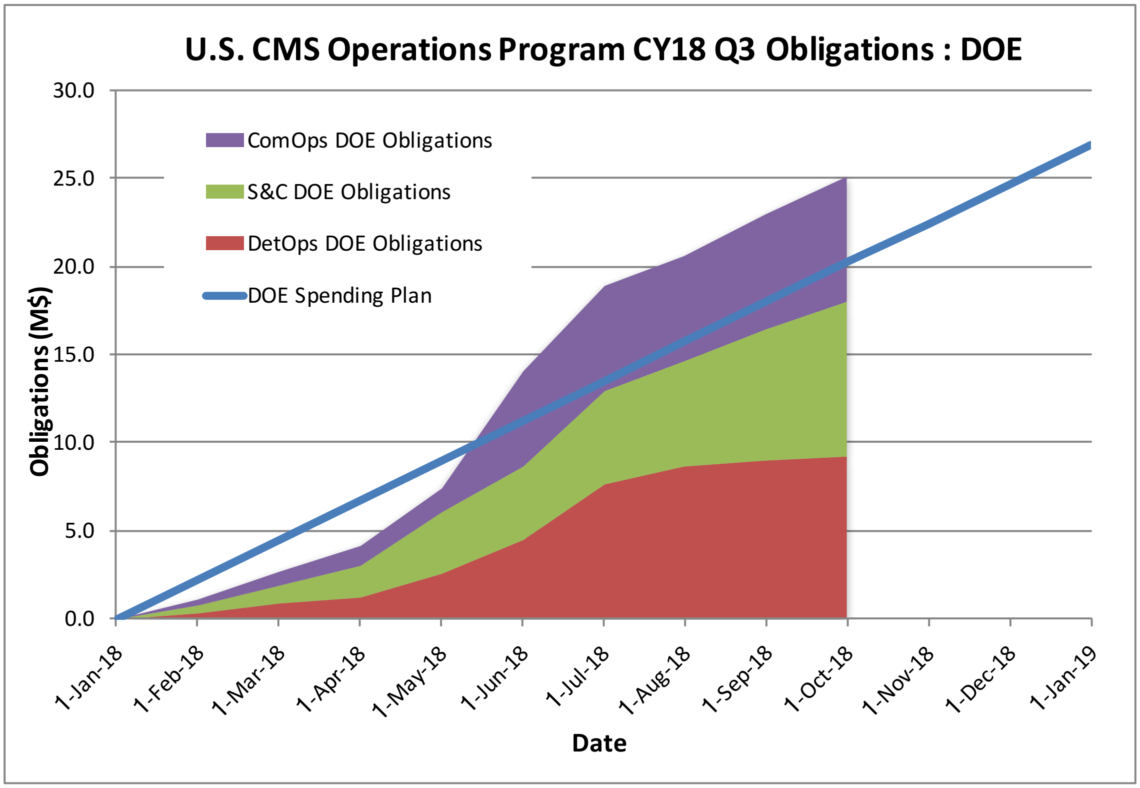


Figure 4: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

Resources deployed at CERN, and paid directly in Swiss francs, account for approximately 26% of the 2018 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 CY18 Q3 averaged 0.98 CHF/USD. Figure 6 shows the allocated budgets and year-to-date spending through the Team Accounts that are used for expenditures at CERN. Spending for labor and cost of living adjustments occurs at a fairly constant rate. Figure 6 does not include the 3,859K CHF M&O-A payments, as these are made through multiple payments to a separate Team Account.

A Risk Management Plan is being implemented for the U.S. CMS Operations Program, with many

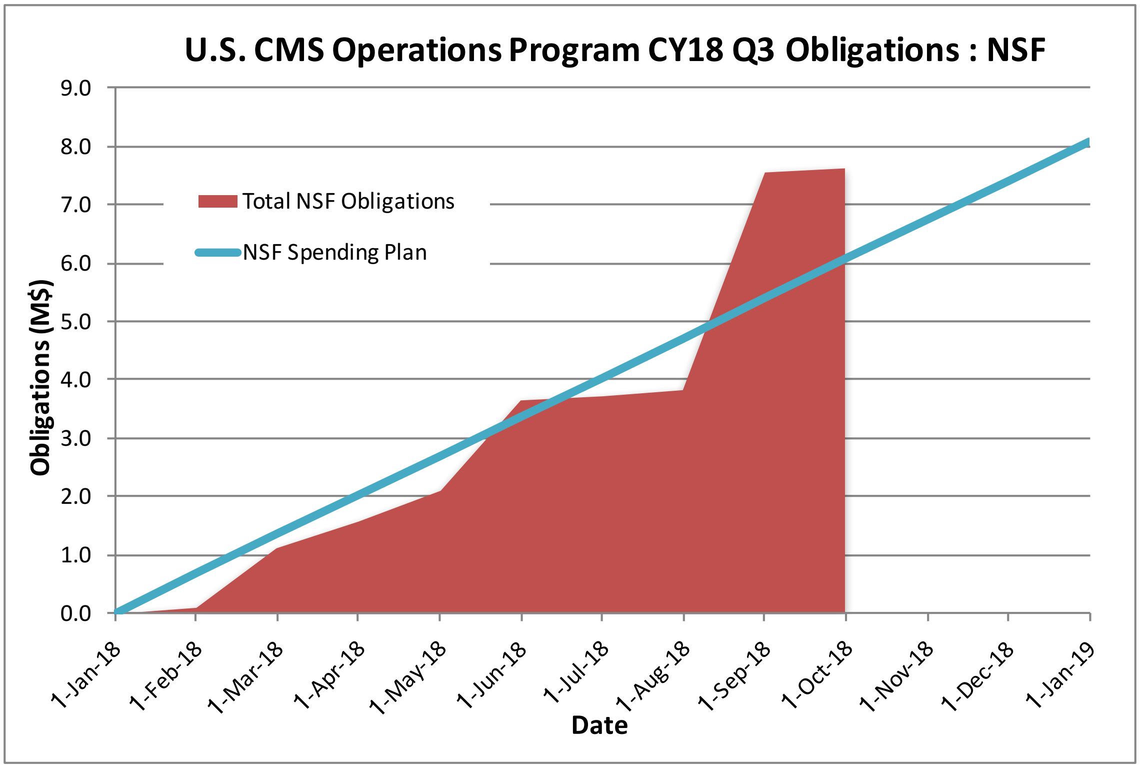


Figure 5: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.

aspects drawn from the Fermilab Risk Management Plan. A Risk Register is updated quarterly, according to the workflow described in the following subsection. At the start of the quarter, the Risk Register contained 36 open risks spread across the program. At the end of the quarter, there were still 36 risks, with threats summing to \$8.4M and opportunities summing to \$0.5M. Figure 7 shows the top few risks at the end of the quarter, ranked by *Probability* $\times$ *Cost Impact*, as well as any risks realized (even partially), closed, or added this quarter.

Workflow for Risk Management Plan

The following procedures have been put in place to carry out the workflow for the U.S. CMS Operations Program Risk Management Plan. The workflow is divide into two paths: (1) updates that are made at any time, and (2) a review of risks once per quarter. In all of the following, *updates* mean adding new risks, realizing risks, retiring old risks, or modifying existing risks. In all cases, it is the program office team that edits the Risk Register. The following descriptions are also summarized in Figure 8.

(1) At any time:

Any member of the management team (including Program Manager, Deputy Program Manager, L1 Managers, L2 Managers, Resource Manager, and program office lead) shall alert the program office

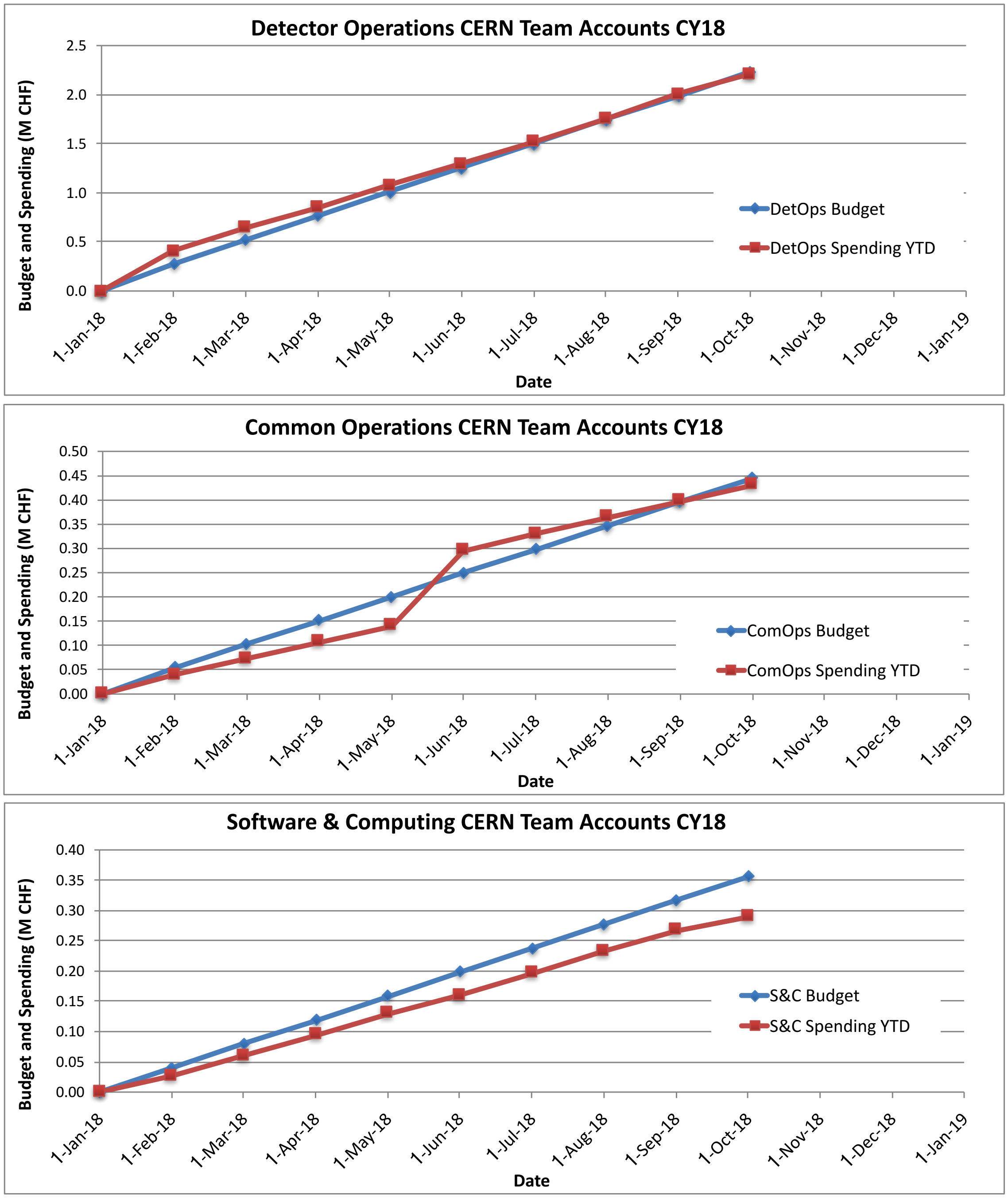


Figure 6: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.

CY18 Q3 Risk Register Summary Table			
	Probability	**Schedule Impact**	**Cost Impact**
Top Risks (ranked by Probability x Cost Impact)			
EMU – EPROM failures on DCFEBs	20%	3 months	$1,000k
S&C - Bridge OSG technology evolution staff to new funding	75%	0 months	$200k
EMU - Optical transmitter failures on DCFEBs	75%	0 months	$75k
Risks Open Realized this quarter			
EMU - Optical transmitter failures on DCFEBs	75%	0 months	$75k
Risks Closed Managed this quarter			
None			
Risks Closed Retired this quarter			
None			
Risks Added this quarter			
None			

Figure 7: Summary of the U.S. CMS Operations Program Risk Register. Only the top few risks are shown, as well as any risks that were realized, closed, or added this quarter.

of any updates. The program office informs the corresponding L1 manager, and the L1 manager approves, rejects, or modifies the proposed updates. This can also involve iterating with the L2 manager. If updates are accepted, the management team reviews the risk mitigations and risk responses that are associated with the updates. The management team takes into account the risk rank and/or position in the risk rank matrix and takes any necessary pre-emptive actions to incorporate mitigation activities into the plan. If appropriate (again factoring in the probability and impact of the risk), the operations program plan is also adjusted to account for the estimated resources required to execute the risk responses related to the updated risks.

(2) Once per quarter:

Within one month prior to the end of each quarter, the program office lead asks the L2 managers whether they have any updates to the risks in their L2 area. The program office then informs the corresponding L1 manager of any such updates, and the L1 manager approves, rejects, or modifies the proposed updates. As above, this can involve iterating with the L2 manager. As part of the quarterly workflow, the management team reviews *all* of the current risks, and takes any necessary actions and adjusts the program plan if appropriate.

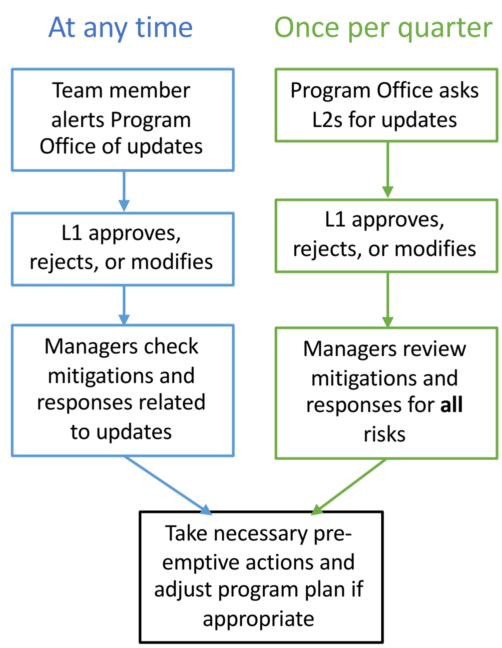


Figure 8: Summary of the two Risk Management Plan workflow paths.

Detector Operations

During this quarter, the LHC reached its goal of delivering at least 150 pb^{-1} of proton collisions during Run 2, see Figure 9. Additional luminosity will be acquired before the switch-over to heavy ion (HI) running in November. During this year's run CMS has maintained a data recording efficiency of about 94%, even with the instantaneous luminosity reaching 2×10^{34} $\mathrm{Hz/cm}^2$. An issue did develop with two sectors of the endcap HCAL (HE) but studies show the impact on physics to be small.

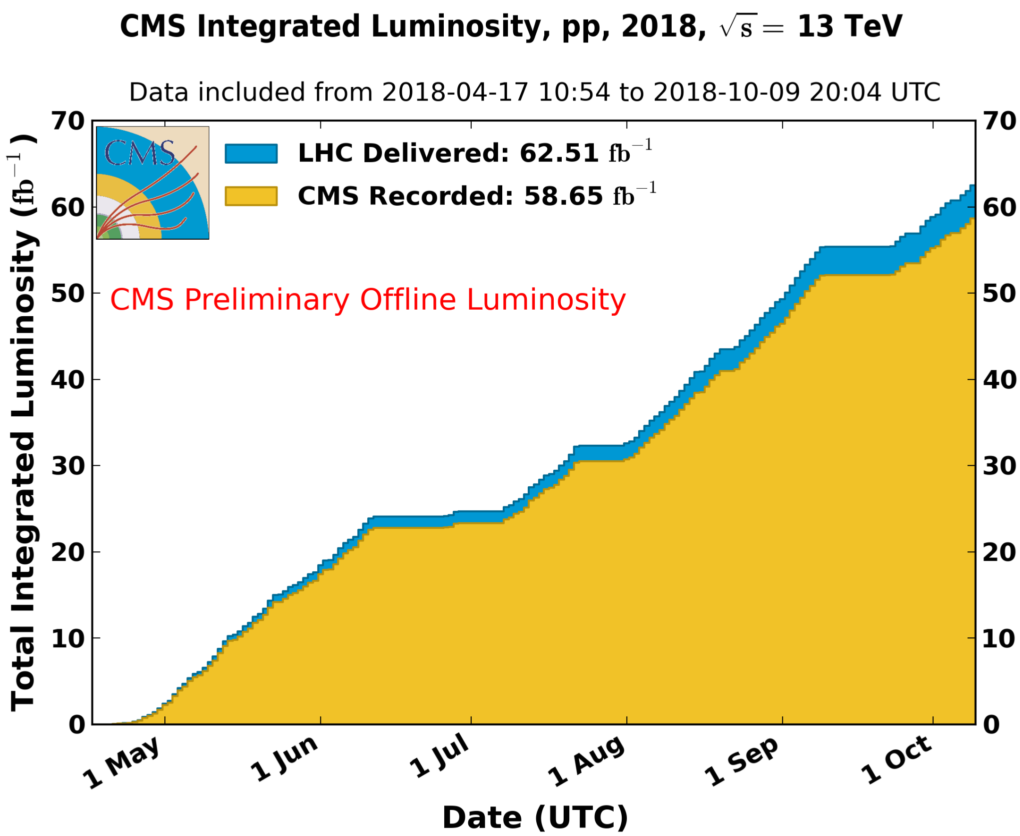


Figure 9: Luminosity, delivered by the LHC and recorded by CMS, through October 9.

BRIL

The Pixel Luminosity Telescope (PLT) together with the fast beam condition monitor (BCM1F) and the forward hadron calorimeter (HF) provide online luminosity measurements continuously. The PLT was the primary luminometer during the majority of physics data taking. First luminosity estimates have been provided for early analyses.

Two out of 16 PLT telescopes exhibit degraded pixel information and therefore are disabled for luminosity evaluation. The silicon pixels reach the end of their expected lifetime due radiation damage. The first remedy to compensate reduced charge collection efficiency was to raise the field voltage. Power supply modules with increased range were installed. The efficiency reduction (a few percent) is measured with the visible cross section obtained with the VdM scan versus obtained from mini-scans at the beginning and end of a fill.

A full recalibration of the detector planes (thresholds) resulted in a major recovery of the efficiency value and reduced the slope of decline with respect to integrated luminosity. HV scans are used to study the working point of the detectors. Recovery procedures for SEU are in place. The first iteration is a reset of the readout loop, and severe SEUr require a full power cycle. Increasingly manual interventions are necessary.

To prepare tor the refurbishment of the PLT the first 40 planes have been certified. Another batch of 20 will arrive from PSI shortly and will be subjected to a qualification program at the CERN test stand. For one full PLT 48 planes are required. Readout cards are assembled at Rutgers to be shipped to CERN. An extensive test program is planned including cold-warm cycling as this turned out problematic in the past for readout components.

Table 1: BRIL Metrics

Working Metric	Performance
Fraction of telescopes fully operational	90%
Efficiency of delivery of lumi histograms	99%
Uptime of lumi histogram production	$>$ 99%
Lumi lost	0 /pb

Table 2: BRIL Milestones

Subsystem	Description	Scheduled	Achieved
BRIL	Pixel Luminosity Telescope reinstalled	March	March
BRIL	Update Lumi for 2017	March	March
BRIL	Ready for Beams	April	March
BRIL	Preliminary Luminosity for Conferences	July	July
BRIL	Improve 2018 Lumi numbers	December	

Tracker

Both strip and pixel trackers have developed and tested new firmware to cope with the high rate expected for the HI running. With the new firmware the rate of transmission errors is higher in the pixel detector, but these errors occur only a few times per FED per fill and do not stop the run, so they are considered no significant problem.

Pixels

We are starting to notice recently that some of the Layer 1 modules in the BPiX do not work well at the beginning of the fill. These modules recover later, but we do not know the root cause of the issue. We have developed special recovery procedures and are developing tools to allow us to monitor readout chip internal values during data taking. Voltages for the BPiX layer 1 and the inner

FPiX ring were raised by 50V to increase charge collection. Layer 1 voltages were not raised higher due to a shorting issue with the L1 cables (to be addressed in LS2).

Strips

The recent issues in the tracker cooling seems to be linked to icing, but this needs more investigation. An added benefit from the new HI firmware in the strips will be a better ability to cope with events that change the baseline response in the front end chips. Nevertheless it was decided not to deploy the HI firmware as it would have required a change of code, e.g. in the High Level Trigger, downstream of the DAQ.

Table 3: Tracker Metrics

	Pixels	Strips
% Working channels	94.4	96.0
Downtime attributed in pb^{-1}	16.2	175.0
Fraction of downtime attributed (%)	2	19

Table 4: Tracker Milestones

Subsystem	Description	Scheduled	Achieved
Tracker	Pixel Phase 1 Detector Removed	Jan 20	Jan 20
Tracker	New pixel DC-DC converters installed	Jan 30	Jan 30
Tracker	Pixel Phase 1 Detector Re-installed	Feb 21	Feb 21
Tracker	Strips and Pixel Phase 1 Detector Ready for Collisions	May 11	Apr 19

ECAL

The ECAL ran successfully in this quarter with no major issues. Minor firmware issues with the Data Concentrator Board (DCC) that caused intermittent problems were resolved. The water pipes to two MARATON LV supplies were replaced. This is maintenance scheduled for all 136 MARATONs in LS2 but conducted now on these two crates as they will be inaccessible when the detector is open. Refurbishment of the laser barracks has begun. Again this is preparatory for the major changes scheduled in LS2. The re-reco calibrations for the 2018 dataset were finalized and reconstruction has begun.

Table 5: ECAL Metrics

Metric	Performance
Fraction of channels operational: EB	99 %
Fraction of channels operational: EE	98.3 %
Fraction of channels operational: ES	99.9 %
Downtime attributed pb^{-1}	23
Fraction of downtime attributed	1.34 %
Resolution performance	2%

Metric	Performance

Table 6: ECAL Milestones

Subsystem	Description	Scheduled	Achieved
ECAL	ECAL fully powered on with HV/LV fully functional	March 1	March 1
ECAL	Complete sLINK upgrade and tests	March 21	April 1
ECAL	Initial thresholds and calibrations set	April 1	April 1
ECAL	Ready for Beam	April 15	April 1
ECAL	Preliminary Calibration	June 15	

HCAL

Operations

The newly installed HE Phase-1 upgrade operated very stably; however, certain events have affected data-taking since July. Following a CMS-wide power interlock on June 30, the power-on cycle of the CAEN A3100HBP power supply modules that provide low-voltage to the on-detector HE front-end electronics led to irreversible damage of two sectors on the HE minus side, HEM15 and HEM16. An investigation of this incident led to a full understanding of the problem. A specific power supply unit sent a 22V, 10ms transient pulse to the HEM15 and 16 readout boxes, significantly exceeding the operating voltage of 10V and damaging components with a 12V rating. This event is associated with an extremely rare and intermittent vulnerability associated with a calibration EPROM in the A3100HBP modules.

Following the investigation, HCAL has installed a secondary safety system to mitigate the risk of damage from potential future transients, and we have been working closely with CAEN to pinpoint the exact cause of the transient and provide a suitable long-term solution.

The physics impact of this incident is small but measurable. From studies, the impact on the L1 Trigger (about 10% on some triggers) and on the HLT is not too severe. Object reconstruction quality is the same at the few percent level so 2018 data will not be severely impacted. For the end-of-the year re-reconstruction of data, the Particle Flow algorithm will be modified for the affected HE region (40° in phi on the minus endcap) to reduce the impact.

More recently, HCAL has also experienced disruptions to the quality of specific primary control links between the front-end controllers (FECs) in the CMS service cavern and the clock, control, and monitoring modules (CCMs) on the detector. Redundant (secondary) control links were enabled and have allowed HCAL to continue taking high quality data. In parallel, we are conducting an investigation to establish the origin of these instabilities.

February 28 Milestone
HE Phase 1 Installed and Co-60 Calibration completed. This milestone was achieved Feb. 24.

April 1 Milestone
HE Detector Commissioned. This milestone was achieved March 15.

June 1 milestone
Data losses due to HCAL less than 1%. This milestone was achieved at the end of June. However,

the HE front end issues due to the malfunctioning LV power supplies have caused this to increase to 1.3% currently.

Table 7: HCAL Metrics

Metric	Performance
Fraction of channels operational: HF	100%
Fraction of channels operational: HE	94.4%
Fraction of channels operational: HB	99.9%
Fraction of channels operational: HO	99.7%
Downtime attributed to HCAL pb^{-1}	173
Fraction of CMS downtime due to HCAL	10.9%
Abs Energy Calibration	2-3%
Inter-calibration Uniformity	2%

Table 8: HCAL Milestones

Subsystem	Description	Scheduled	Achieved
HCAL	HE Phase 1 Installed & Co-60 calibration completed	Feb 28	Feb 24
HCAL	HE Detector Commissioned	Apr 1	March 15
HCAL	Ready for Physics	Apr 15	April 1
HCAL	Data Loss $< 1\%$	June 1	June 30
HCAL	1% to 2% Calibration	July 1	now 2% to 3%

HB Installation and Commissioning

The HCAL Barrel (HB) Phase 1 upgrade, planned for LS2, is progressing well. The HB silicon photomultipliers, selected to be the same type as those used for the HE upgrade, were delivered on schedule and have performed very well in quality control tests. The production of 900 HB QIE cards is complete, and a quality control testing and calibration campaign was completed at Fermilab in September. Other components of the HB front end are being produced and tested at sites in the U.S. and India. All of these components are being shipped to CERN. The production schedule for the SiPM mounting cards has recently slipped. However, they are expected to arrive at CERN in time for the schedule to be maintained, although some contingency has been lost. Assembly in Building 904 at CERN is expected to go into "factory mode" in mid-November with production complete by mid-January 2019. Assembly and burn-in of spare modules will continue into February 2019. In the table below, all items related to HB upgrade electronics are abbreviated "HBE".

Table 9: HB Upgrade Milestones

Subsystem	Description	Scheduled	Achieved
HCAL	HB Upgrade HBE assembly starts at CERN	Sept. 1	Sept 1
HCAL	HB Upgrade HBE production in "factory mode"	Nov 15	
HCAL	HB Upgrade HBE production complete	Jan 24	
HCAL	HB Upgrade Minus end upgrade installation begins	March 15	
HCAL	HB Upgrade Minus end Upgrade Complete	July 14	

Subsystem	Description	Scheduled	Achieved
HCAL	HB Upgrade Plus end upgrade installation begins	Sept 1	
HCAL	HB Upgrade Plus end Upgrade Complete	Dec 20	

EMU

Operations at CERN

The CSC system operated very smoothly in this quarter. At the end of September, 98.5% of the channels in the CSC system were working and being read out. This is down slightly from 98.7% at the beginning of the quarter. There are two chambers off due to low voltage issues, inherited from 2017, and these will not be accessible for repair until Long Shutdown 2. In August, there was one incident of a Maraton LV power supply shutting off spontaneously.

Levels of background hits in the CSC chambers were measured and found to be comparably to those in 2017. In particular, no effect can be observed from the additional shielding that was installed on the rotating shielding.

New algorithms and settings were tested for the OTMB boards that form the trigger primitives from the CSCs. The new firmware allows for changes of timing matching that can be more robust against loss of trigger data in high pile-up environments. The firmware was tested at B904 and at GIF++ and the was installed first on one CSC chamber in CMS. The initial analysis shown no harm from the new firmware, and additional data are being accumulated to make a more precise assessment of the efficiency.

The failure of Finisar optical transceivers in the ME1/1 DCFEBs continues to be a concern. A total of twelve failed in 2017, and six so far in 2018. A possible remedy has been developed in the form of an adapter board with a rad-hard VTTx optical transmitter that could replace the Finisar on the old DCFEBs. Eight prototypes adapter boards were built by colleagues from Tomsk State University and tested at CERN and Rice in September.

In the GIF++ facility, an ME1/1 chamber and a 30 cm x 30 cm mini-chamber is being irradiated with a reduced fraction of CF4 (2% instead of 10%). The goal is to accumulate three times the expected HL-LHC exposure. So far, it has accumulated about 1.5 times HL-LHC exposure, and shows no indication of a reduction in gain. Mini-chambers were also tested at B904 with 5%, 2% and 0% CF4, and also at PNPI with 5% and 1.6%. None of these mixtures tested showed any reduction in gain. The 0% test has accumulated about 1.6 times HL-LHC exposure and will continue up to 3 time HL-LHC.

Table 10: CSC Metrics

% Working channels	98.5%
Downtime attributed pb^{-1}	16.5
Fraction of downtime attributed	1%
Median spatial resolution	127 μm

Table 11: EMU Milestones

Subsystem	Description	Scheduled	Achieved
EMU		April 4	March 29
EMU	New HV settings for reduced gain	July 31	now Oct 8

MEX/1 Detector Improvement

The CMS Electronics System Review (ESR) held by CMS technical coordination for the LS2 CSC on-chamber electronics improvement program was on 2 July. Its main focus was the ALCT mezzanine boards and the DCFEBv2 boards, but it also covered the LVDB5, HV and LV infrastructure, and optical fiber additions. The U.S. CMS Production Readiness Review for the DCFEBv2 board was held in conjunction with the ESR. Both reviews were successful, and all of the recommendations from the reviews have been addressed.

Following the completion of the ESR, the orders were set up for the production of the DCFEBv2 boards and the ALCT mezzanines. In the first week of September, the orders were placed for production and assembly of DCFEBv2 boards. The first 10 pre-series boards are expected on 24 Oct, and after these are tested, the full production can be released. For the ALCTs, we have placed orders for the longest lead-time parts, and will begin fabrication later in the Fall. Two changes were made to the budgets through change requests. The funding for ALCT boards that was originally requested for 2019 was moved to 2018 instead, to allow both types of mezzanine cards (LX100 and LX150T) to begin production in time for installation in LS2. Also, the budget for the DCFEBv2 was increased by 5% to meet the bid of a vendor that could meet the required production schedule.

The low voltage distribution boards (LVDB), which are a Russian responsibility, progressed according to schedule with the full production and assembly completed in September.

In September, a second workshop was held on CSC planning for LS2. More detailed plans were discussed for the movement and refurbishment of chambers with new electronics. The area in SX5 where the refurbishment and testing will take place was cleared and remodeled in preparation for LS2. A tentative assignment was made for teams to work on eight groups of tasks, including chamber extraction and re-installation, chamber refurbishment, chamber test stands, installation of new services, and re-commissioning.

Table 12: EMU Milestones - MEX/1 Detector Improvement

Subsystem	Description	Scheduled	Achieved
EMU-MEX/1	ALCT mezzanine prototype received	Apr 30	Apr 6
EMU-MEX/1	Second xDCFEB prototype received	May 1	Jun 1
EMU-MEX/1	CSC On-chamber Electronics System Review completed	Jun 15	Jul 2
EMU-MEX/1	Order placed for Maraton LV supplies	Aug 31	Jun 25
EMU-MEX/1	Production of xDCFEB PCBs released	Sep 2	now Nov 15

Subsystem	Description	Scheduled	Achieved
EMU-MEX/1	CSC on-chamber optical fibers ready for installation	Nov 1	
EMU-MEX/1	CSC LV junction boxes ready for installation	Jan 15 (2019)	

DAQ

Operation of the CMS DAQ system during the reporting period was affected by a number of issues. We lost 100 pb^{-1} due to central DAQ problems. Two-thirds of the downtime was due to different kinds of hardware failures. The longest downtimes were caused by a failure of one of the two CPUs in a readout unit PC, by a FEROL40 μTCA crate acting up and crashing the controller PC, and by dying optics in a Mellanox network cable. In addition, we experienced many more hardware failures in the HLT farm than in the past. These failures did not lead to any data loss, but required manual interventions to restore the system and resurrect events left behind.

An unresponsive DAQ function-manager tomcat was the main source of downtime caused by software. The recovery time was prolonged due to a slow reaction time of the DAQ shifter. Additional downtime was created due to a bug in the FEROL40 firmware and due to a not-understood problem in the event-builder software. We observed a couple of problems with the EOS file system at the Tier 0. It caused no data loss, but delayed data transfers by up to a few hours. The SMTS team needed to do several manual interventions on the storage manager and transfer system to recover files corrupted or lost on EOS.

The failure of multiple FUs in one rack revealed a missing feature in squid-3 used since early 2018, which prevents HLT processes to access frontier directly in case that the squid hierarchy is broken. The frontier/squid setup for the HLT farm needs to be revisited during LS2. This will be also done in view of a possible use for loading conditions at luminosity-section boundaries instead of run starts only. This would eliminate the need to inject changing conditions into the event stream.

We deployed the new HLT file-broker at end of July. This tool is used to distribute files to the HLT processes. It replaces the NFS file-locking mechanism which caused problems since the beginning of 2018 (c.f. last quarter's report.) The file broker worked flawlessly. The performance measurements show a slight improvement over the old scheme that was based on locks.

Several software tools saw improvements, too. The event builder now reports per-FED fragment sizes (average and RMS) to the monitoring system. This feature had been requested by ECAL to ease their monitoring of the detector. The HLTd and merger code has been improved to better handle files appearing at the end of run. Additional features and diagnostic power were implemented in the DAQExpert tool which is used to assist the DAQ shifter. The Level-0 FM and Level-0 Automator was improved to deal with race conditions and operator errors.

The work on the online monitoring system (OMS) continues. A new version was released in August with new pages displaying prescale sets and prescale changes, the DCS states per luminosity section, and a new run keys portlet became available. User settings are now reflected in the URL, which allows to share page-settings between users. New endpoints were added in the API. New methods have been added to retrieve a HTML page containing all available endpoints and to retrieve the metadata for a resource. The work focuses now on the reporting of down- and dead time, as well as on weekly, monthly and yearly summaries of the data taking.

CASTOR is being recommissioned after 3 years for the upcoming heavy-ion run and was reintegrated into the DAQ system without any problems.

In order to prepare for the HI run, a data-challenge was proposed by CMS DAQ and organized by CERN IT. The aim was to find any bottle neck in the IT infrastructure caused by the much large throughput expected from all four LHC experiments during the HI run than during standard proton physics. The test allowed us to further tune the storage manager and transfer system to balance recording vs. transfer bandwidth. No evidence for interference between the experiments was observed. We are reasonably confident that we can record 7 GB/s to the storage manager during the run with 4.6 GB/s simultaneous transfer to Tier 0, and transfer up to 7 GB/s while not writing to the storage manager during inter-fill periods.

The testbed for the Run3 DAQ system has been commissioned. All hardware has been installed and the data networks have been configured. Tests of individual components are being done, while the configuration for the end-to-end system is being worked on.

Table 13: DAQ Metrics

Dead time due to backpressure	0.6%
Downtime attributed pb^{-1}	100
Fraction of downtime attributed	9%

Table 14: DAQ Milestones

Subsystem	Description	Scheduled	Achieved
DAQ	First version of OMS GUI with limited functionality deployed	Mar 1	Mar 6
DAQ	Specification and design outline for DTH prototype P1	Apr 1	Mar 13
DAQ	New HLT nodes commissioned	May 1	Apr 5
DAQ	Testbed for DAQ 3 installed	Jun 1	Jul 15
DAQ	First DTH prototype P1 board	Oct 1	
DAQ	Event-builder & SMTS ready for heavy-ion run	Oct 31	
DAQ	All relevant WbM pages migrated to new OMS GUI	Dec 31	

Trigger

During this quarter the U.S. groups continued their work on the Layer-1 calorimeter (CaloL1) trigger and the endcap muon trigger (EMTF) Level-1 trigger systems, and on the field operations of the Trigger Studies Group, providing improvements and reliable running during 2018 data taking operations.

Endcap Muon Trigger

For data-taking operations, we had a successful deployment of an automated CSC link recovery procedure to minimize the impact on data-taking quality and efficiency when links occasionally lose synchronization. However, there were two occurrences of losing trigger primitives at EMTF in one endcap (38 pb^{-1} downtime), that were resolved with the reconfiguration of FPGAs. It was suspected this fault had to do with PCIe reads from the processors, and a fix has been developed.

During the technical stop in September, several updates to the infrastructure, firmware, and software were made to improve the robustness of the muon trigger. The firmware for the Vadatech MCHs in the EMTF crates was updated to the latest version. An EMTF firmware fix for the suspected PCIe read errors was deployed, as was an update to reset the receivers of MPC links after hard reset to further improve robustness. Further diagnostics were added as well. The online SWATCH software for EMTF was upgraded to enable the automatic CSC link recovery procedure (re-sync requests), where an upper limit to the number of re-sync requests when repairing CSC optical links was set to avoid unnecessary downtime when links cannot be recovered. The online software also was updated to implement the configuration of registers from text files to avoid the necessity of recompiling and deploying new online software releases during operations for every change of a register.

A study of the DQM monitoring plots indicated that the LCT efficiency is low for several ME1/3 chambers. CSC experts were informed, and the inefficiency was traced to some problems in CFEB connections and timing that have now been fixed. Additionally, a study of track segment residuals in EMTF tracks indicates a measurable shift between the YE1-YE2 disks in one endcap. Using the latest CSC alignment constants rather than ideal geometry is found to mitigate the position bias, leading to a small improvement in the turn-on trigger efficiency. Deployment of constants online was performed after the Technical Stop.

Layer-1 Calorimeter Trigger

During the previous quarter the CaloL1 was calibrated for a new HCAL trigger primitives compression scheme, and a new calibration was also used for CaloL2. The MicroSD cards that failed on two CTP7's and were replaced last quarter. They were overused by writing diagnostic data to them. Routine writing of diagnostic data to the MicroSD cards is now stopped, and the problem does not appear in any other cards. New MicroSDs are ordered and should be swapped on all the cards during LS2. All spare CTP7s not in operation at P5 have had their MicroSD cards replaced.

During this quarter there were few problems with ECAL links that were all promptly reported using CaloL1 DQM, most of the problems were intermittent, required masking of single ECAL channel, all were unmasked after the links were fixed by the ECAL group. Once during the run one CTP7 card went unresponsive, and the card was promptly rebooted. This caused a loss of ≈ 50 pb^{-1} of data. The cause is now known and the card has been replaced. Apart of this the operation was smooth.

The CaloL1 participated in preparation for the HI run. The firmware was already prepared before and did not require any additional work, the DQM was updated to display new trigger information.

Field Operations Group of the Trigger Studies Group

The U.S. Trigger Project contributes to all aspects of the Field Operations Group (FOG) to ensure successful operation of the High Level Trigger. During last year two graduate students and a postdoc have participated in on-call shifts. Until his term recently ended, the postdoc was also co-convener of the FOG group. The U.S. takes primary responsibility for the maintenance and continued development of the trigger rate monitoring software, including the tools for creating and updating the reference fits.

During 2018 the U.S. led the following activities: Performing on call shifts and training other new experts in on call shift procedures, making updates to the rate monitoring software to streamline the process of creating new reference fits for monitoring trigger rates, performing a thorough re-evaluation of all trigger rate references to make sure they were all sufficiently accurate reflections of the expected rate for current triggers, and adding functionality to the rate monitoring tools so that users can re-run the monitoring over historical runs, rather than just the data currently being taken, to test updates to shift monitoring tools. One new graduate student is being trained in current on-call procedures and rate monitoring software development so that an experienced student will be available after LS2 to help with the startup.

Table 15: Trigger Metrics

Frac of MPC Channels	100%
Frac of Upgrade EMUTF Channels	100%
Deadtime attributed to EMTF pb^{-1}	38
Fraction of deadtime attributed to EMTF	4%
Frac of Calo. Layer-1 Channels	100%
Deadtime attributed to Calo. Layer-1 pb^{-1}	50
Fraction of deadtime attributed to Calo. Layer-1	5%

Table 16: Trigger Milestones

Subsystem	Description	Scheduled	Achieved
TRIG	EMTF commissioned with endcap RPC input	April 1	April 27
TRIG	EMTF ready for Physics	May 1	May 29
TRIG	Calo. Layer-1 commissioned with new ECAL/HCAL/HF Calib	April 1	May 19
TRIG	Calo. Layer-1 Ready for physics	April 1	May 19

Software and Computing

During this quarter, as the LHC moved towards the end of proton collisions for Run 2, the Software & Computing group made progress on supporting analysis of Run 2 data while also making preparations for Run 3 and beyond. Utilization of facilities remained high (modulo a late-summer vacation dip), as the facilities themselves continued their excellent performance. Of particular note for the facilities is that the Fermilab Tier-1 center has received its new tape library, thus beginning the transition to a new tape technology. Computing operations continued to deliver samples needed for physics analysis, while also working through some operational problems that arose, as detailed below. A number of development efforts are taking shape as CMS moves away from home-grown solutions and towards community projects, both in the short term (with the deployment of the CRIC site information system and the overhaul of the CMSWeb platform) and longer term (with the choice of Rucio as the data management system for Run 3 and beyond, and first steps towards its deployment). A variety of activities are enabling the use of non-traditional architectures and non-traditional facilities, such as those at HPC centers.

Major Milestones Achieved this Quarter

Date	Milestone
1 Jul	Complete Rucio functional review in advance of CMS DM review
5 Jul	New Fermilab tape buffer disk nodes deployed in production
1 Jul	C++ Modules integration in CMSSW
1 Jul	Functioning CPU version of Machine Learning benchmark
1 Aug	Create CMSSW interface producer for tracking on advanced architectures
1 Aug	Allow concurrent Run transitions in multi-threaded CMSSW
1 Aug	"Pixel tracking @GPU" integrated/prototyped in CMSSW
1 Aug	"Parallel kalman filter" integrated/prototyped in CMSSW
15 Aug	TS4500 tape robot delivery and assembly at FNAL
1 Sep	Migration and cleanup of CMS HEP environment script to EOS/CVMFS
17 Sep	2018 FNAL CPU purchase awarded
30 Sep	Use CMS portion of initial allocation at NERSC
1 Oct	Working GPU version of Machine Learning benchmark
1 Oct	uproot-writing, awkward-arrays in uproot published as uproot

Fermilab Facilities

During this quarter the LHC proton-proton run continued and the Fermilab Facilities provided reliable custodial storage, processing, and analysis resources to U.S. CMS collaborators. The site was well utilized, with the facility providing 43.0 million wall-clock hours of processing to CMS.

Figure 10 shows the site readiness metrics for the quarter. The Tier 1 facility passed CMS site availability metrics 98.1% of the time. The blue entries in the figure indicate a scheduled downtime in July for work needed on the power infrastructure in the Feynman Computing Center. There were two periods of failing metrics during the quarter: In August a bug in dCache triggered by a security-mandated move to TLS 1.2 encryption resulted in failed data transfers to several sites.

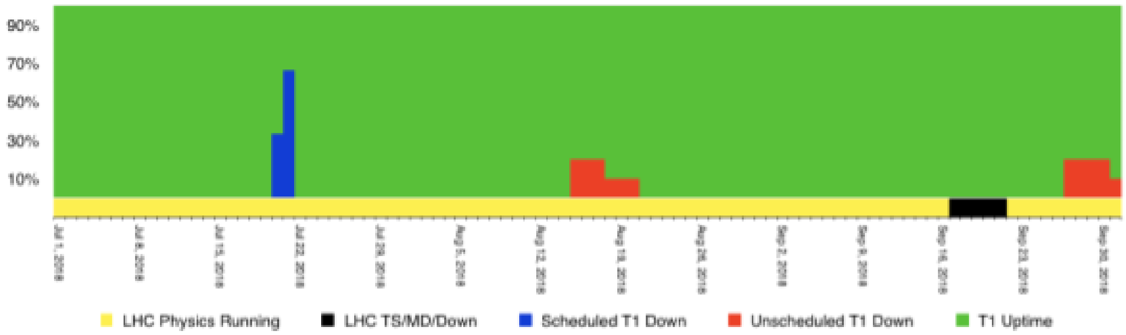


Figure 10: Fermilab readiness metrics for 2018Q3. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. The height of a red bar indicates how much of the day services were affected. Black and yellow across the bottom indicates LHC machine running. This quarter LHC continued proton-proton physics running. Fermilab passed metrics 98.1% during the quarter.

In September a bad fiber on the incoming 100Gb network link led to reduced incoming transfer throughput.

At the beginning of the quarter FNAL received new storage nodes to replace equipment being retired out of the tape dCache pool. The dCache pool serves as the disk buffer in front of the tape system, and these nodes were successfully introduced into production without downtime. In September the PO for the batch worker nodes replacing retiring workers was awarded, with delivery expected late October/early November.

Towards the end of the quarter Fermilab received delivery of new TS4500 tape library and began commissioning. Legal conflicts between suppliers of LTO8 media resulted in worldwide unavailability of the LTO8 tape media. A decision was made to initially move to the lower capacity M8 (reformatted LTO7) cartridges to be able to commission the robot before the end of the LHC run. That media arrived on October 2, allowing commissioning of the new system to proceed in earnest during the coming quarter.

University Facilities

As seen in Figure 11, CMS production and analysis activities this quarter continued to run at high levels approaching full capacity. August is typically a slower month for CMS computing due to conferences and holidays. There were also issues with central production during September which affected usage.

All of the U.S. CMS Tier-2 sites operated successfully last quarter. On our two official performance metrics based on CMS test jobs, all sites were at least 96% “available” and 88% “ready”. The CMS requirement for each of these metrics is 80%, but the U.S. CMS performance goal is 90%, which all sites met except for Caltech, which had a series of downtimes due to unrelated technical problems during September. Nonetheless our commitments to CMS were met with success. The U.S. CMS Tier-2 centers delivered 48.2% of all computing time by Tier-2 sites in CMS last quarter, approximately unchanged from the previous quarter.

Steady progress to complete milestones and upgrades at the Tier-2 sites is being made. Generally these fall into a few broad categories of upgrading to SL7, IPv6, and simplifying the architecture of the sites. Https-based transfers are now possible between several sites.

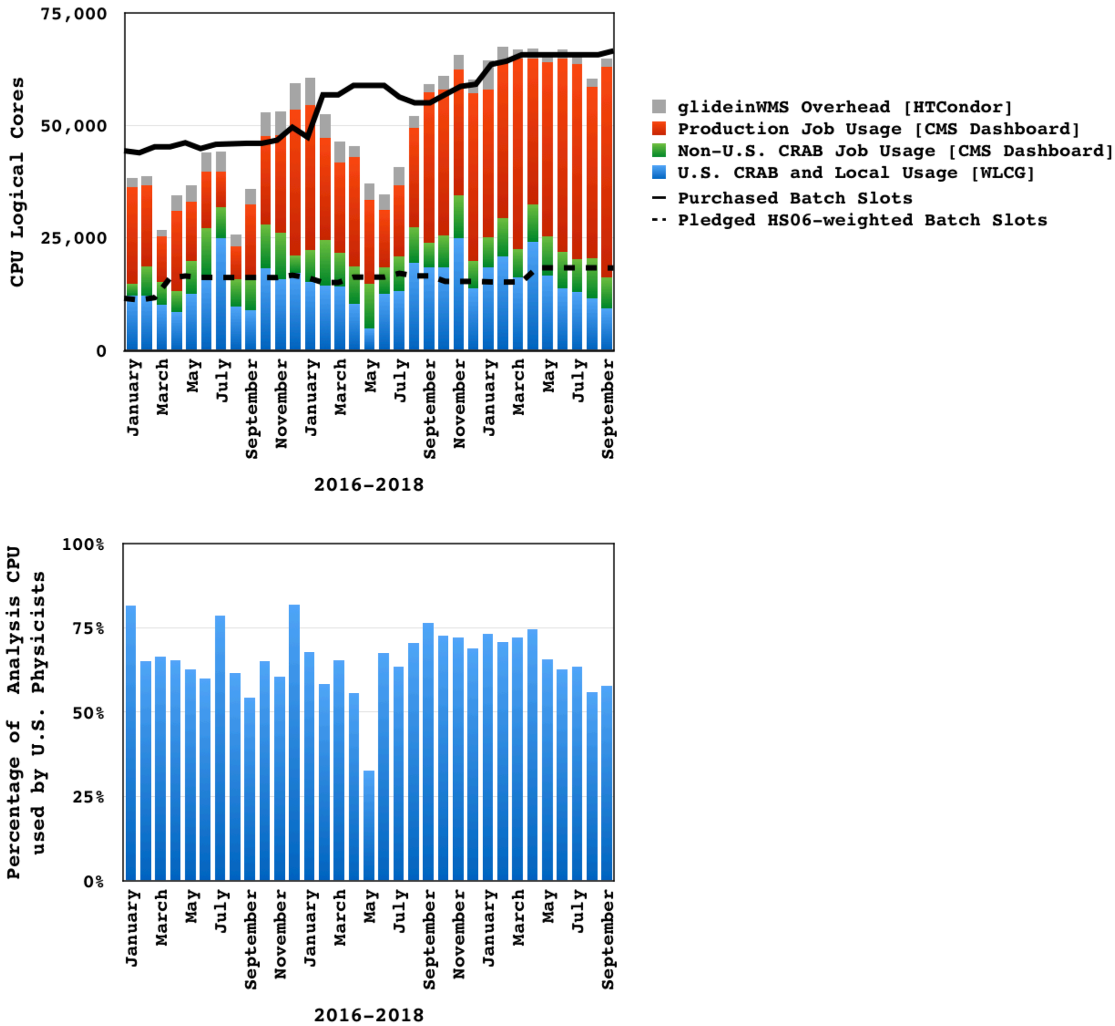


Figure 11: How processing resources were used at the U.S. CMS Tier-2 sites, by month.

The U.S. CMS Tier-3 support team provided help to thirteen sites on a number of issues mainly related to OSG software upgrades, PhEDEx transfers, XRootD, and basic systems administration. CMS Connect also required some work to address dashboard issues and to create a new EL7 login node to prepare for the eventual retirement of the EL6 one. Work also began on allowing interactive GPU access via CMS Connect. The team tracked issues with GGUS instead of OSG tickets. There were two Tier-3 related presentations made by team members at CHEP.

Computing Operations

Digitizing and simulating Monte Carlo events for the 2017 data analyses was again the largest processing activity in the quarter. About 5 billion events were processed, the remaining third of the requested Monte Carlo events.

In July small numbers of Monte Carlo events for the 2018 data analyses were produced with updated software versions. In September generation of the premixing library with the final software for the 2018 detector configuration started. This was completed later that month and Monte Carlo event production using the premix library started. So far 200 million events have been processed. About three quarters of the current requests will use the resource-efficient, pre-mixing pile-up method, which takes advantage of computing technologies developed in the US.

Data processing was impacted by three issues during the quarter:

1. Storage space at CERN filled up due to temporary files from incomplete workflows. Small intermediate files from the processing step are merged into large multi-GB files for analysis and archiving. The available CPU at CERN from the HLT farm and Tier-0 occupancy had been overestimated by more than a factor of two. Consequently, too many workflows were assigned, requiring more space, progressing more slowly, and keeping the temporary space occupied. In addition the large number of workflows in the system and the non-negligible failure rate prevented workflows from finishing. No new workflows were assigned to CERN for the next month and a half to work down the processing backlog and clear the space used for unmerged files.

2. Misconfigured workflows caused a huge number of very short jobs (only minutes long instead of several hours) that brought the global HTCondor pool to its limits. For about two weeks we were not able to utilize all the compute resources available to CMS.

3. Instabilities of the CERN EOS storage system caused processing interrupts and operator interventions. Various issues were in play: fuse-mount instabilities due to IP-based authorization and enabling IPv6, files getting "lost" during namespace compacting, permission issues, and self-inflicted namespace overload. For now EOS is behaving stably again but it is not entirely clear whether all issues have been addressed.

The Tier-0 reformatted and reconstructed detector data as they were recorded. Two LHC machine development periods fell into this quarter. During the September machine development period, transfer tests between the experiment at P5 and the CERN EOS storage system were done in preparation for the heavy-ion data recording in the following quarter. The performance goal was achieved on the second day of testing.

500 million events of the parked data for B physics (out of 9.8 billion recorded so far) were passed through the prompt reconstruction process end of August.

Computing Infrastructure and Services

WMAgent has implemented changes related to the dataset parentage which have been fixed at several levels. This was the last obstacle to widespread usage of StepChain workflow types, which are well suited to HPC running. In addition, the WMAgent development team has also implemented

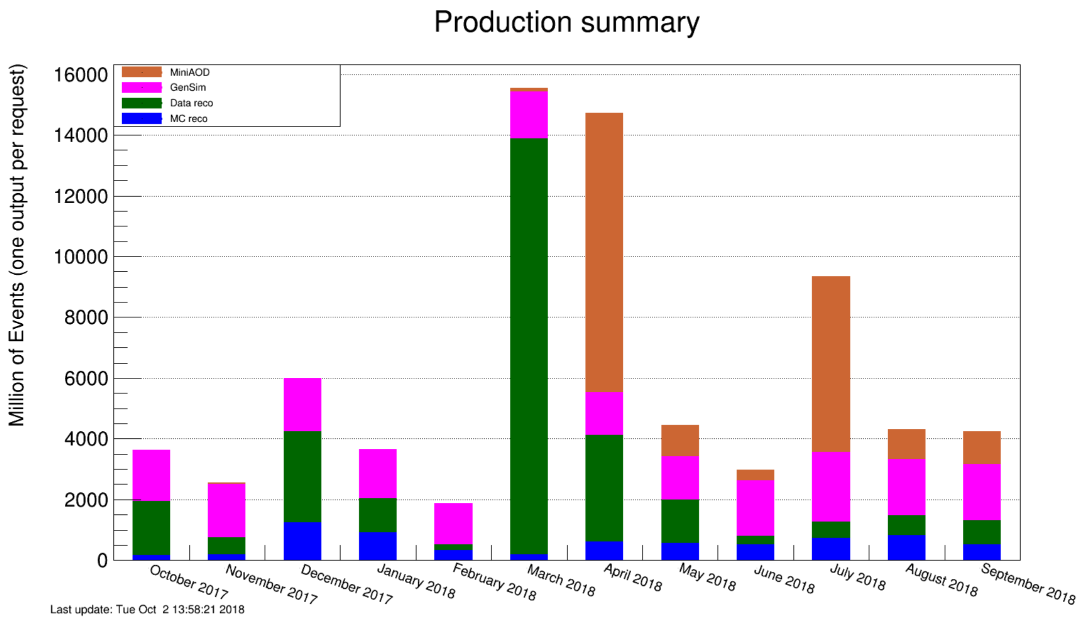


Figure 12: Numbers of events produced from different categories of workflows during 2018.

the CRIC client APIs in WMCore; these are already being used by an agent in production and some analysis services. CRIC is a WLCG supported replacement for the CMS-only project SiteDB. SiteDB is scheduled to be fully retired in the first quarter of 2019.

We continue to contribute to the overhaul of CMSWeb led by CERN. In this quarter, we demonstrated CMSWeb could be converted to a Kubernetes-based infrastructure with no CMS-specific frontend to maintain and each backend component converted to Docker. Work remains to be done to integrate CMS's authentication scheme; we plan to continue to improve this prototype with a goal of replacing the current CMSWeb platform in the first quarer of 2019.

After a comprehensive review, CMS has chosen Rucio as the next generation CMS data management product. The transition to Rucio has begun with the setup of a CMS instance of Rucio on CERN hardware using the Kubernetes stack. The transition (development, integration, and corresponding cross-coordination) has begun to be planned out in detail. The current goal for full transition from the existing Dynamo/PhEDEx system at the start of 2020.

A variety of technical improvements have been made to the Xrootd infrastructure used by CMS. For example, we have improved the cache purge algorithm to also take into account file-usage. This is needed to be able to operate several cache instances on the same node and for serverless caching (e.g., on laptops, desktops). We have also implemented new features prerequisite to integrating the Xrootd-based cache with Rucio. Finally, improvements have been made to HTTPS-based third party copy in Xrootd, allowing us to perform copies between sites without GridFTP. This helps U.S. CMS (along with OSG) mitigate the risk from the Globus Toolkit's end-of-support.

We commissioned the Bridges HPC at PSC for CMS and made it directly usable for CMS production workflows. Using Rucio, we transferred the new Fall 18 version of the pileup library to make it locally available at NERSC. This allowed scaling up to about 25k cores in use at NERSC for CMS production workflows. By the end of reporting period, we had used nearly all the CMS share of the original 50 Mhour allocation at NERSC as well as the CMS allocation at Bridges.

Software and Support

We finalized the integration of the production releases for MC and data re-miniAOD of 2016 data, main 2018 data and MC processing and 2018 heavy-ions data taking. Progress was made on making CMSSW C++17 standard compliant and building the visualization on macOS using system compilers.

Work continued on allowing concurrent event processing in multi-threading mode of CMSSW. We concentrated on run and luminosity block transitions and IOVs (intervals of validity). We also investigated the usage of OpenMP 4.5 task APIs in our CMSSW toy framework and started comparisons to our current TBB implementation, discussed with HPC experts at the CCE Scalable I/O workshop. We made a lot of progress establishing a ML suite for benchmarking purposes, by having now the first GPU based benchmark application available.

In addition to maintenance of the current and near-term geometries of the detector, we made progress in transitioning to the community geometry description solution DD4HEP. The community foundation of our visualization package FireWorks, EvE, was evolved into the ROOT7 era and is ready to be included into the December ROOT release. We also made progress on the client-server implementation of our visualization.

Kalman filter tracking on advanced architectures achieved additional speed-ups on Skylake Gold architectures while retaining the efficiency and purity of the non-parallel Kalman filter implementation. The GPU pixel tracking R&D integration in CMSSW made progress by prototyping the use of CUDA from the framework.

Together with DIANA-HEP, we enabled uproot file writing support for numpy arrays and other types for interoperability of the HEP analysis environment with industry tools. Ten CHEP contributions featured topics whose maintenance, integration into production and scaling to higher scales were supported by the operations program.

Other activities

Blueprint

The Blueprint activity continues to focus on computing model evolutions and discussions as a means to identify research and development for HL-LHC. We organized five U.S. CMS blueprint meetings this quarter. These included: initial results from a HL-LHC CMS cost model; results from the Big Data Express project at Fermilab, Oak Ridge, and KISTI; concepts for future analysis facilities; design and results from a caching system at UCSD; and initial results from the U.S. CMS machine learning benchmark design project.

The Blueprint team is an active participant in the CMS ECOM2X working group. Our modeling efforts will be used as a basis for discussion on how to evolve the CMS computing and analysis model towards HL-LHC. We have organized initial presentations on our work during the quarter. Blueprint modeling work and results were also presented in a talk at the CHEP conference. We are also actively engaged in the WLCG DOMA working groups to advance the WLCG HL-LHC strategy discussions. In particular, U.S. CMS co-leads two of the three WLCG DOMA working groups, one on transfer protocols and one on data access patterns and caching.

Security task force

The security team documented U.S. CMS site security responsibilities and shared the document amongst the site administrators. This document provides a set of responsibilities that every site in the U.S. CMS collaboration must comply with. A list of security policies and procedures from WLCG, OSG and EGI is included in its appendix.

The team also verified and updated the U.S. CMS Incident Response procedure to be aligned with the Global CMS Incident Response procedure, and developed an internal procedure for incident response for the U.S. CMS security task force. Training remains a priority for the security team. It prepared training material for incident response and job traceability, and conducted three training sessions with 17 participants from 10 Tier-2 sites (including the seven U.S. HEP sites, the nuclear physics site at Vanderbilt, and two sites in Brazil). A separate session shared the training and the site security responsibilities with Fermilab site administrators.