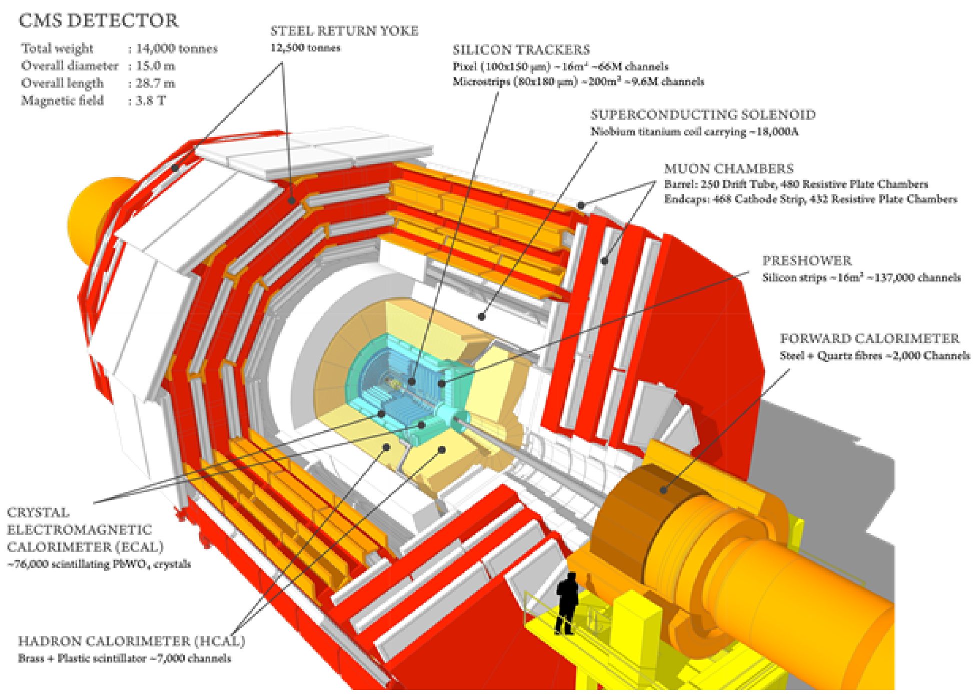
U.S. CMS Compact Muon Solenoid Operations Program
Quarterly Report for the Period Ending December 31, 2018

U.S. CMS Operations Program



Program Manager's Assessment

When in December the LHC Run 2 officially ended after a Heavy Ion running period all LHC goals for luminosity delivered and excellent beam quality were fulfilled. In total during Run 2 LHC delivered an integrated luminosity of 162.85/fb of proton-proton collisions at 13 TeV center-of-mass energy, of which CMS was able to record 150.26/fb. The CMS program thus has achieved the Run 2 luminosity goals.

During this year in 2018 CMS accumulated 63.87/fb of pp collision data and 1.707/nb of lead-lead collisions at 5.02 TeV/nucleon HI data. Data recording efficiency achieved the highest value yet and averaged to 94% over the year. The mean number of interactions per bunch crossing for the 2018 pp run was measured to be an average pile-up of 32.

With the end of Run 2 LHC started the Long Shutdown 2 and CMS will take advantage of this period to do a large number of detector repairs and refurbishments. In particular CMS will complete the Phase 1 upgrade by installing the upgraded HCAL barrel electronics. There will also be significant improvements to the endcap muons system by refurbishing the on-chamber readout and trigger electronics of the innermost set of cathode-strip chambers, and a variety of improvements, consolidations and maintenance across all of the detector.

Operations of the computing systems was generally very successful, with significant progress in preparing data and software releases making available the latest calibration and data quality improvements to data processing for the upcoming winter conferences. Challenges were mostly associated with the high data rates of HI collisions, and they were met thanks to previous experience and careful preparation for this run. Difficulties with the Monte Carlo production system at the end of the previous quarter were resolved, allowing all facilities to return to a level of full utilization.

CMS made good use of the NERSC HPC systems, running full simulation workflows and this way giving some relief to the U.S. CMS production systems and enhancing CMS physics opportunities. The U.S. Tier-1 and Tier-2 facilities were as robust as ever, with high levels of availability to the experiment. All sites made continued progress with a variety of technology upgrades. The most significant of these was the commissioning of a new tape library system at Fermilab, which has proceeded ahead of schedule. The experiment's computing infrastructure continues to be upgraded, with an increasing use of community- and industry-standard tools. In particular, CMS is making rapid progress with migration to the Rucio data management system, which was developed for the ATLAS experiment but is now becoming a community project with CMS as one of the major users. A variety of software developments have targeted the improved use of heterogeneous processing architectures, important for the exploitation of HPC and opportunistic computing.

The 2018 spending plan ended this quarter, with a total obligated spending of $35,097,859. Through the year a total of 95 SOWs (61 DOE and 34 NSF) were produced and approved to allocate funding at U.S. CMS universities, Fermilab, and CERN Team Accounts. The quarter had a number of change orders that amounted to just a small overall cost variance, covered by management reserve, of +$84K. The Risk Register was updated as reported in this document. The top risk of EMU - EPROM failures on DCFEBs boards that are exposed to large amounts of radiation will soon be retired with the planned installation of refurbished on-chamber electronics during the coming LS2.

Physics output reached new records in the number of papers published. At the end of the year the number of Run 2 physics publications submitted to journals reached 280, for a total of some 850 CMS physics papers on collider data.

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.

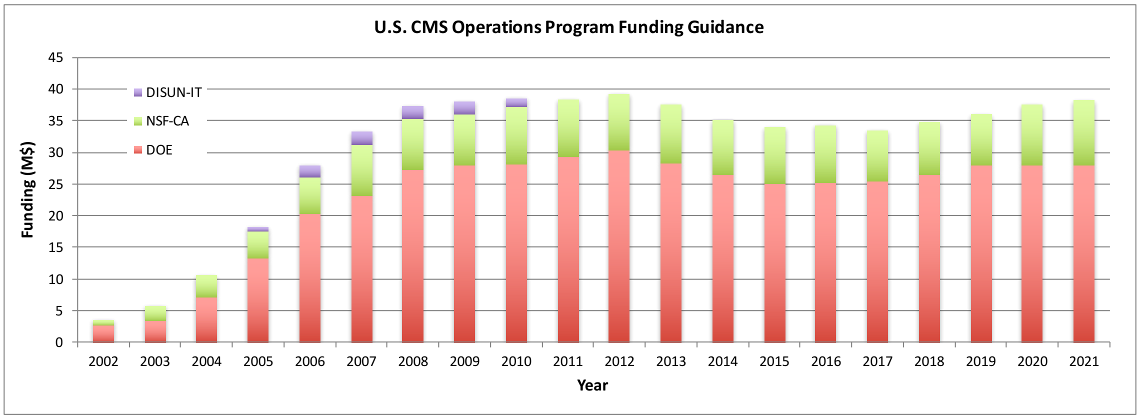


Figure 1: The annual U.S. CMS Operations Program funding provided by DOE and NSF. For 2002 through 2018 the chart shows the actual funding, while for 2019 onward the current funding guidance is shown.

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 December of 2018, a total of 95 SOWs (61 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 Q4, is shown for DOE and NSF funds in Figure 3.

U.S. CMS Detector Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY18 Q4 Plan**	**Change $**	**CY18 Q4 End**
11	Endcap Muon	CR-042	Reduce CERN TA M&S for supplies/consumables	$1,858,931	($7,112)	$1,851,819
	Endcap Muon MEX/1	CR-041	Increase M&S Ohio State for DCFEB ADCs lead time, reduce CERN TA M&S for optical fibers	$2,505,919	$7,112	$2,513,031
12	Hardon Calorimeter	SOW, CR-056, 057, 058	Alabama Labor support; CERN TA COLA for Alabama, CERN TA COLA for burn in work, FSU M&S for HB laser	$2,198,572	$115,802	$2,314,374
13	Trigger			$904,392	$0	$904,392
14	Data Acquisition	CR-012	Reduce CERN TA COLA for Rice	$1,145,358	($39,421)	$1,105,937
15	Electromagnetic Calorimeter	CR-025	Increase CERN TA COLA for FSU	$755,405	$3,387	$758,791
16/17	Tracker (Fpix & SiTrk)	CR-019	Move funds from labor and travel to M&S, incurring different overhead	$1,007,790	$3,480	$1,011,270
18	Detector Support			$121,476	$0	$121,476
19	BRIL			$358,861	$0	$358,861
11-19	**Detector Operations**			**$10,856,704**	**$83,247**	**$10,939,952**

U.S. CMS Common Operations Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY18 Q4 Plan**	**Change $**	**CY18 Q4 End**
21.2	Common Costs (M&OA)			$4,092,087	$0	$4,092,087
21.3	Run Coord. and Monitoring			$163,076	$0	$163,076
21.4	LHC Physics Center			$883,374	$0	$883,374
21.5	Operations Support	Adjust	University of Kansas travel for Fast Timing test beam	$2,051,269	$733	$2,052,002
21.6	Program Office			$1,063,408	$0	$1,063,408
21.7	Education and Outreach			$110,585	$0	$110,585
21	**Common Operations**			**$8,363,799**	**$733**	**$8,364,532**

U.S. CMS Software and Computing Change Control Activity						
WBS	**Subsystem**	**Change Request Number**	**Description of Change**	**CY18 Q4 Plan**	**Change $**	**CY18 Q4 End**
22.1	Fermilab Facilities			$6,191,877	$0	$6,191,877
22.2	University Facilities			$3,029,327	$0	$3,029,327
22.3	Computing Operations			$892,728	$0	$892,728
22.4	Computing Infra. and Services			$2,764,564	$0	$2,764,564
22.5	Software and Support			$2,493,900	$0	$2,493,900
22.6	S&C Program Management & CMS Coordination			$420,980	$0	$420,980
22	**Software and Computing**			**$15,793,375**	**$0**	**$15,793,375**
U.S. CMS Operations Program Total				**$35,013,878**	**$83,981**	**$35,097,859**

Figure 2: Spending Plan Change Log for CY18 Q4.

WBS	Subsystem	DOE Funds	NSF Funds	Total
11	Endcap Muon	$1,500,930	$350,889	$1,851,819
	Endcap Muon MEX/1	$2,513,031	$0	$2,513,031
12	Hadron Calorimeter	$2,266,574	$47,800	$2,314,374
13	Trigger	$672,153	$232,238	$904,392
14	Data Acquisition	$1,105,937	$0	$1,105,937
15	Electromagnetic Calorimeter	$758,791	$0	$758,791
16/17	Tracker (Fpix & SiTrk)	$835,527	$175,743	$1,011,270
18	Detector Support	$121,476	$0	$121,476
19	BRIL	$176,126	$182,735	$358,861
11-19	**Detector Operations**	**$9,950,546**	**$989,405**	**$10,939,952**
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	$1,796,342	$255,660	$2,052,002
21.6	Program Office	$961,108	$102,300	$1,063,408
21.7	Education and Outreach	$0	$110,585	$110,585
21	**Common Operations**	**$6,888,210**	**$1,476,322**	**$8,364,532**
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		**$27,012,845**	**$8,085,014**	**$35,097,859**

Figure 3: Spending plan at the end of CY18 Q4, 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, $49k in subawards went out this quarter, in addition to spending directly at Princeton.

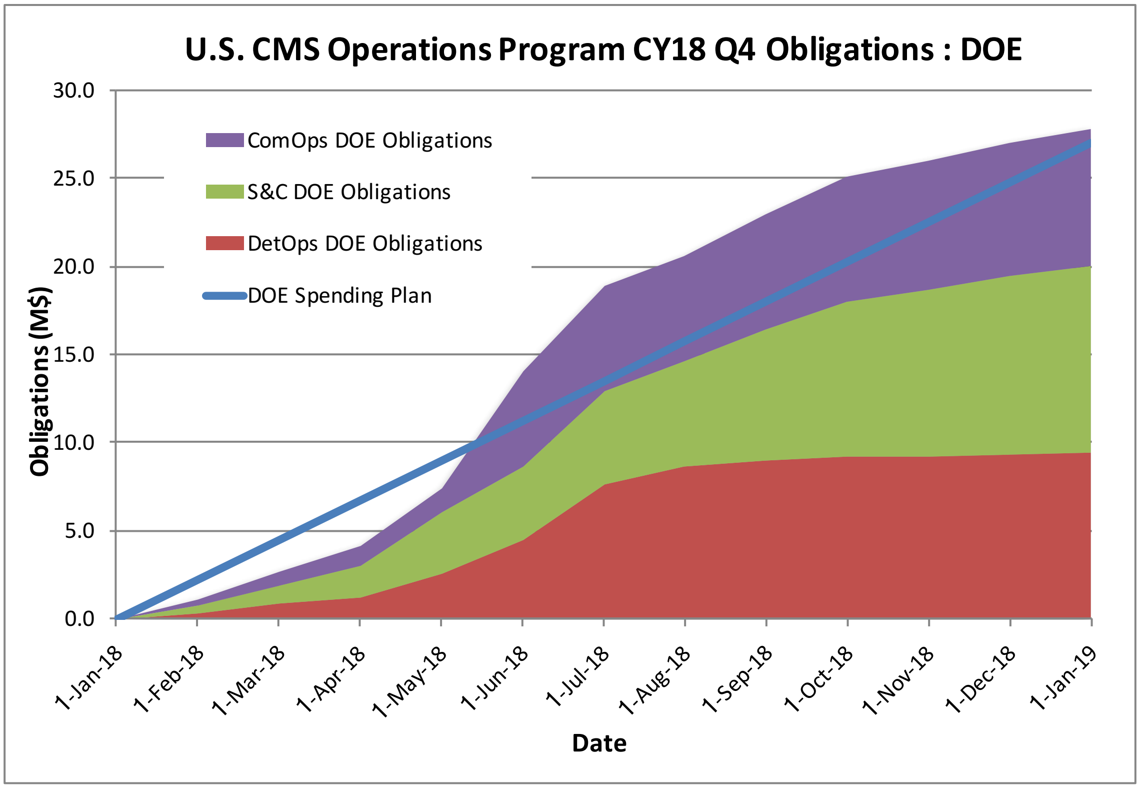


Figure 4: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

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 Q4 averaged 1.00 CHF/USD. Figure 6 shows the allocated budgets and year-to-date spending through the Team Accounts that are used for expenditures at CERN. Spending for labor and cost of living adjustments occurs at a fairly constant rate. Figure 6 does not include the 3,859K 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

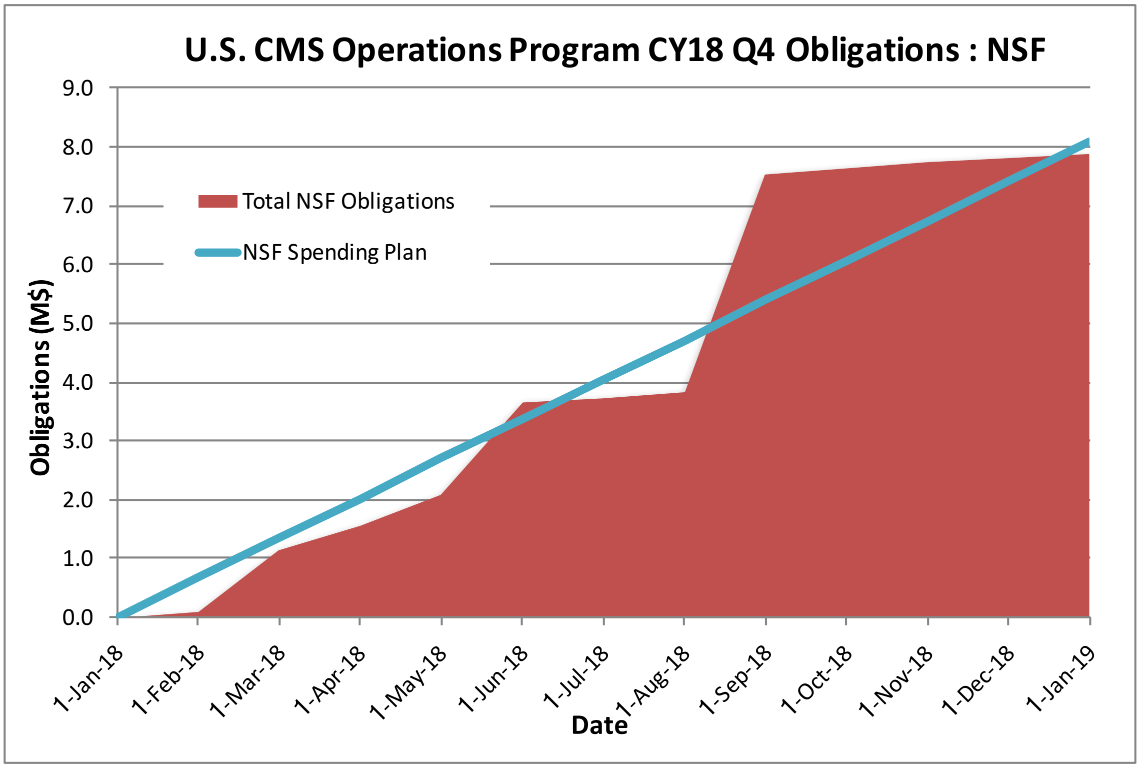


Figure 5: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.

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 32 risks, with threats summing to \$5.3M 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

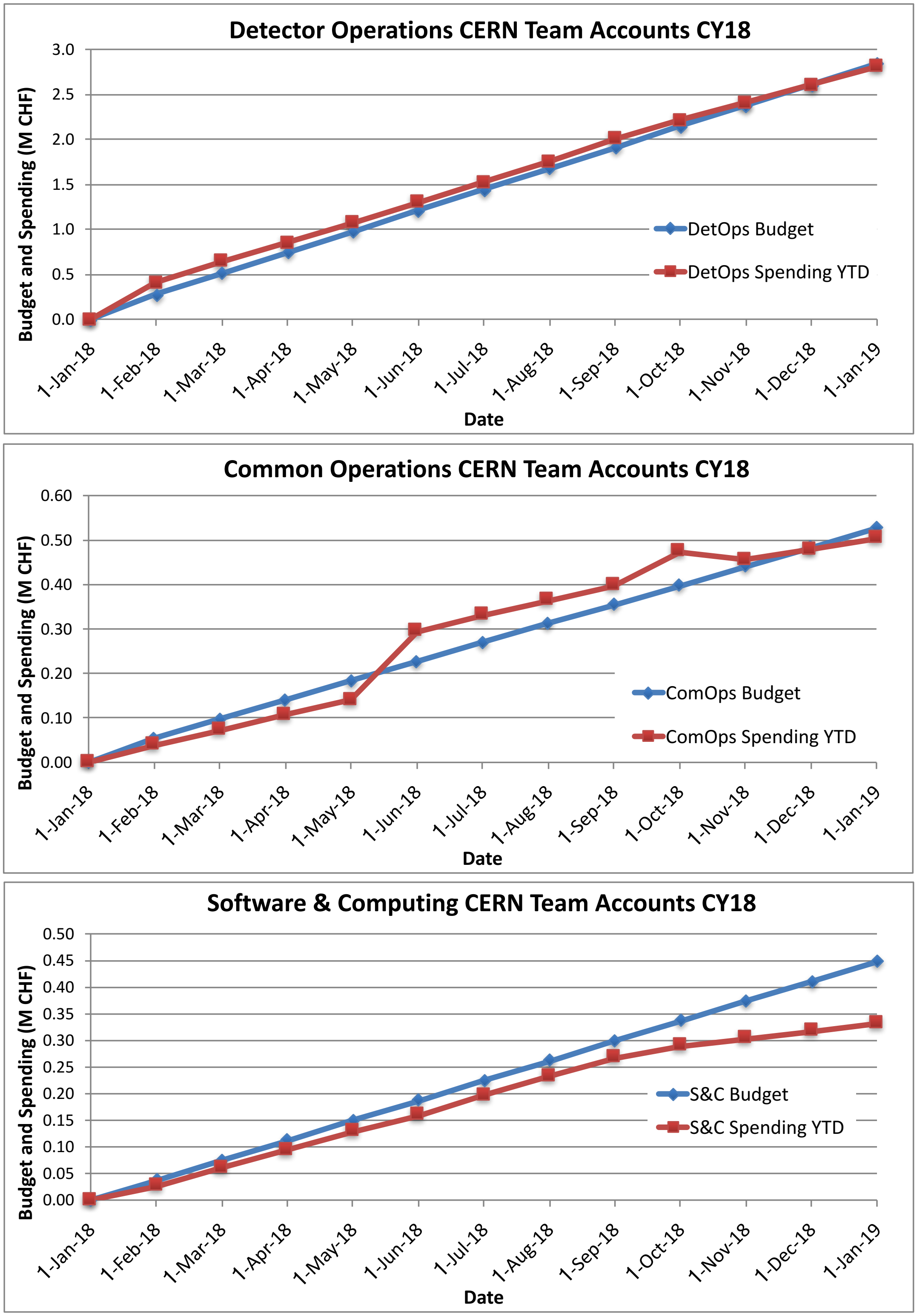


Figure 6: Budget plan and year-to-date spending, in Swiss francs, through DetOps (top), ComOps (middle), and S&C (bottom) Team Accounts.

CY18 Q4 Risk Register Summary Table			
	Probability	**Schedule Impact**	**Cost Impact**
Top Risks (ranked by Probability x Cost Impact)			
ECAL - Laser fails	20%	0 months	$250k
S&C - Oracle increases maintenance fees for tape libraries an	50%	0 months	$100k
ECAL - Need for additional COLA for Post-docs	50%	0 months	$60k
Risks Open Realized this quarter			
None			
Risks Closed Managed this quarter			
EMU - cooling system water leaks	5%	2 months	$400k
EMU - EPROM failures on DCFEBs	20%	3 months	$1000k
Risks Closed Retired this quarter			
S&C - OSG services no longer provided externally	2%	0 months	$1663k
S&C - Bridge OSG technology evolution staff to new funding	75%	0 months	$200k
S&C - New library not in operation for heavy ion run	25%	0 months	$100k
Risks Added this quarter			
S&C - Hardware retirement policy not realistic	10%	0 months	$200k

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.

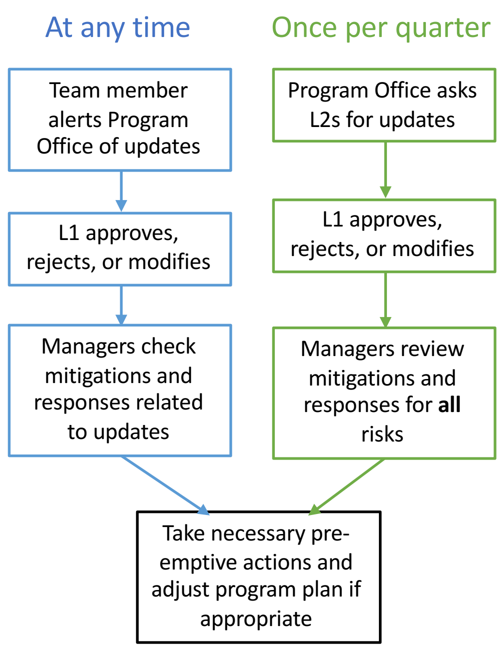


Figure 8: Summary of the two Risk Management Plan workflow paths.

Detector Operations

Calendar year 2018 proved to be a most successful year for LHC and CMS operation. The LHC delivered record luminosity, and the CMS experiment had the highest recording efficiency to date. After a Heavy Ion (HI) run at the end of the period, the LHC entered into Long Shutdown 2 (LS2). The CMS experiment will take advantage of this period to complete the Phase 1 upgrade by installing the upgraded HCAL barrel electronics. There will also be significant improvements to the endcap muons system and a variety of improvements, consolidations and maintenance across all of the detector.

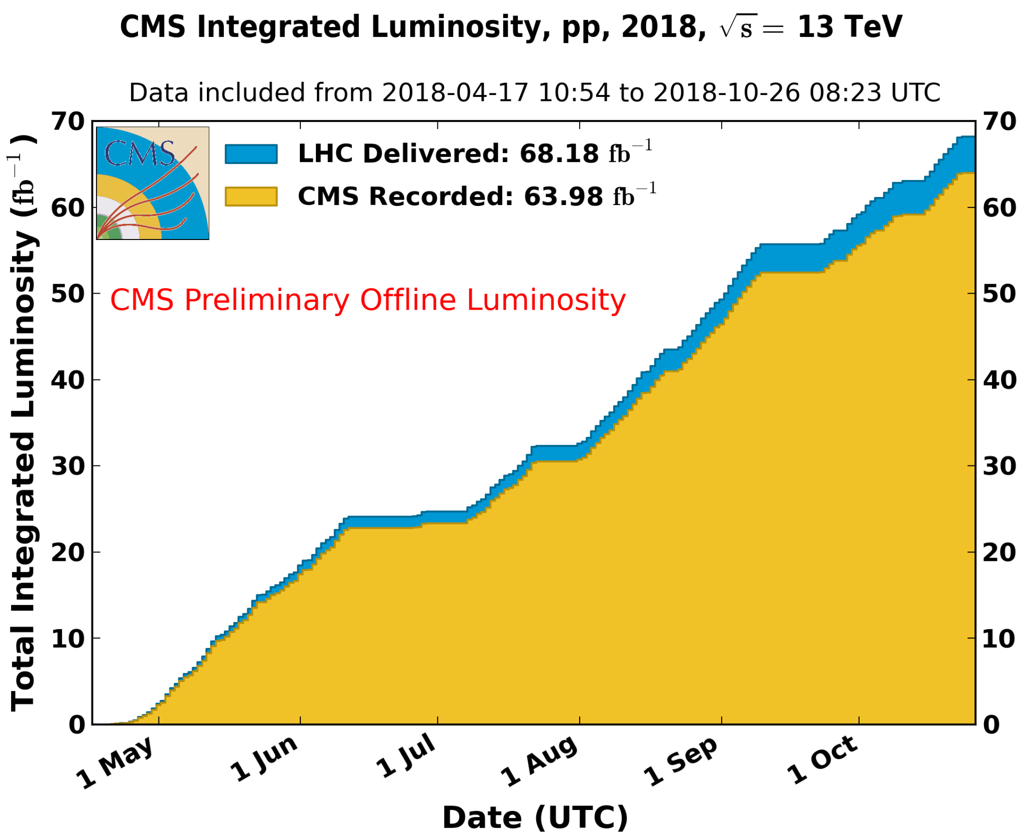


Figure 9: Proton-Proton luminosity, delivered by the LHC and recorded by CMS, during the 2018 run.

BRIL

The Pixel Luminosity Telescope (PLT) successfully ran to the end of Run 2. While the PLT temporarily lost a quarter of the detector at the end of the proton run, the detector could be recovered in time for the HI running. The cause is not yet fully established (it most likely was due to severe Single Event Upsets, SEU). The PLT was unstable during a series of tests in December and experienced drop outs of the same quarter after power cycles. The PLT is at its expected end of lifetime and will be refurbished during LS2. The lab space at CERN is prepared, including the cold boxes, to receive the PLT and to perform detailed post-run studies. The replacement SRA to be installed for Run 3 are being tested and electronic readout cards are being produced at Rutgers and at CERN.

Starting with a comprehensive re-analysis for all BRIL instruments, we conducted a luminosity offline analysis for the full 2018 run.

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 2018 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	December

Table 3: BRIL 2019 Milestones

Subsystem	Description	Scheduled	Achieved
BRIL	Assembly of the replacement PLT (2)	Jun 15	
BRIL	Test replacement PLT	Dec 31	
BRIL	Full Run 2 Luminosity analysis	Dec 31	

Tracker

The final stretch of the proton running was smooth for the tracker. HI running was much easier on the detector than in previous runs. Both strip and pixel detectors operated successfully with new firmware to cope with high rate HI running. Consequently, he number of power cycles needed to recover stuck modules was very small.

Pixel Detector

It was discovered that some channels are incorrectly masked due to noise during the short period of high voltage ramping at the start of stable beams. Enabling the error recovery mechanisms and pixel readout only after the instability has passed allowed more channels to be maintained good during collisions. Some calibrations were further optimized for speed. Gains in calibrations times between 30 and 90 percent of the original were realized.

Strip Detector

Once tuned, primarily during the early HI running, the HI hybrid firmware worked well. The new firmware is more sensitive to the thresholds used to determine a hit due to the potential to incur large dead times if too many false hits register.

Table 4: Tracker Metrics

	Pixels	Strips
% Working channels	94.4	96.0
pp Downtime attributed in pb^{-1}	13.9	96.9
pp Fraction of downtime attributed (%)	6.2	42.8
HI Downtime attributed in μb^{-1}	0.07	7.6
HI Fraction of downtime attributed (%)	0.2	21.1

Table 5: Tracker 2018 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

Table 6: Tracker 2019 Milestones

Subsystem	Description	Scheduled	Achieved
Tracker	Pixel Phase 1 Detector Removed	Jan 31	
Tracker	Pixel initial checkout complete	Aug 31	

ECAL

The run concluded with no major problems for ECAL. The detector performed excellently for both the final part of the proton run, and the HI run in November with no significant data losses.

A review of the planned LS2 activities was conducted in November. During LS2 the main hardware activities will be the replacement of flexible cooling pipes for the Maraton Low Voltage crates, rearrangement of the LV CAN buses, calibration of the High Voltage system, laser tests with longer fibers to assess if it is possible to move the laser barrack, off-detector electronics maintenance, investigations on some known problematic towers to possibly recover some bad channels, oSLB maintenance, DCC firmware tests to investigate very rare CRC errors, improvements of the DCS for finer granularity in the automatic actions, changes in the ECAL Safety system for better redundancy and maintainability, trigger and DAQ developments in view of Run3, and upgrade of the cooling pipes from surface to the underground service cavern in preparation for HL-LHC.

Table 7: 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}	0.5
Fraction of downtime attributed	2 %
Resolution performance	2%

Table 8: ECAL 2018 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	July 1

Table 9: ECAL 2019 Milestones

Subsystem	Description	Scheduled	Achieved
ECAL	Complete First Laser Maintenance	April 30	
ECAL	Complete Second Laser Maintenance	July 31	
ECAL	Complete infrastructure update of laser barracks	Dec 31	
ECAL	Complete replacement of all Maraton input/output Cooling Pipes	June 30	
ECAL	Complete replacement of input HV power connectors	Sept 30	

Subsystem	Description	Scheduled	Achieved
ECAL	Complete modification of CANBUS and update DCS software	Oct 31	
ECAL	Complete VME PC replacement	Mar 31	
ECAL	Complete network upgrade	May 31	
ECAL	Complete upgrade to XDAQ15	Dec 31	
ECAL	Complete installation of new water pump on surface	Aug 31	
ECAL	Complete insulation of surface to underground area pipes	Dec 31	

HCAL

Operations

During this quarter the HCAL group focused on continuing to take data efficiently, and on preparing for HB Phase 1 Upgrade installation during 2019.

The HE Phase-1 upgrade installed during the 2018 shutdown continued to operate well. However, there are two previously reported issues. First, an over-voltage transient that occurred during the the power-on of the HCAL Endcap CAEN A3100HBP LV power supply modules on June 30, after a CERN wide power cut, caused irreversible damage of two sectors on the HE minus side, HEM15 and HEM16. As previously reported, 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 is not too severe (about 10% on some triggers) and also the impact on the HLT is limited and well understood. Object reconstruction quality is the same at the few percent level, so 2018 data will not be severely impacted.

Second, 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 for HEP10 and HEM9. Redundant (secondary) control links were enabled for these detectors and allowed HCAL to continue taking high quality data. The investigation to establish the origin of these instabilities continues, and the ngCCMs in HEP10 and HEM9 will be removed as soon as they can be accessed during LS2.

HCAL was ready for the start of data taking in spring 2018, and has been running smoothly including during the HI run, except for the issues noted above. Data losses during offline certification due to HCAL problems were 745 pb^{-1} out of 62.1 fb^{-1} (1.2%). 387 pb—1 of these losses were due to the HE front end problems which were resolved during the run. The data losses due to HCAL were less than 1% on June 30, but the issues discussed above caused this increase to 1.2% averaged over the entire run.

Work on HCAL calibration continues and and calibration accuracy is at the three percent level.

Table 10: HCAL Milestones Performance

Milestone	Comment
Feb 28	HE Phase 1 Installed and Co-60 Calibration completed. This milestone was achieved Feb. 24.
Apr 1	HE Detector Commissioned. This milestone was achieved March 15.
Jun 1	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 1.2% averaged over the entire run.

Table 11: 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	173 pb^{-1}
Fraction of CMS downtime due to HCAL	10.9%
Abs Energy Calibration	3%
Inter-calibration Uniformity	2%

Table 12: HCAL 2018 Milestones

Subsystem	Description	Scheduled	Achieved
HCAL	HE Phase 1 Installed and 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	1.2%
HCAL	1% to 2% Calibration	July 1	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 went into “factory mode” in late November with production expected to complete by mid February 2019. Assembly and burn-in of spare modules will continue into March 2019. As of December 20, 2018, 52 readout modules had been assembled and successfully tested. During the testing, a number of modules had issues that were successfully resolved. The “internal readiness review (IRR)” for HB installation is scheduled for February 15, 2019. Note that the HB Minus end upgrade will be installed February through June 2019, while the HB Plus end upgrade will be installed from September through December 2019. In the following table HB upgrade electronics is abbreviated “HBE”.

Table 13: 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	Nov 20
HCAL	HB Upgrade Minus end upgrade installation begins	Feb 19	
HCAL	HB Upgrade HBE production complete	Feb 28	
HCAL	HB Upgrade Minus end Upgrade Complete	June 30	
HCAL	HB Upgrade Plus end upgrade installation begins	Sept 1	
HCAL	HB Upgrade Plus end Upgrade Complete	Dec 20	

Table 14: HB 2019 Operations Milestones

Subsystem	Description	Scheduled	Achieved
HCAL	extract HEM09 and HEM10 CCMs and requalify	Feb. 10	
HCAL	extract HEM15 and HEM16 CCMs, RMs, CUs	Mar 15	
HCAL	install spare modules into HEM15/HEM16	June 1	
HCAL	send LV PS units to CAEN for modification to reduce risk of future over-voltage incidents	May 1	
HCAL	design and prototype an LV protection circuit compatible with both HE and HB LV PS units	May 1	

Subsystem	Description	Scheduled	Achieved
HCAL	produce LV protection modules	July 1	
HCAL	install LV protection modules in HE	Sep 1	
HCAL	finalize and qualify half-speed FEC and CCM firmware	April 1	
HCAL	reprogram HE CCMs and FECs	May 1	
HCAL	recommission HE with half-speed control links	June 1	

EMU

Operations at CERN

At the end of Run 2 data taking in December, 98.6% of the channels in the CSC system were working and being read out. The average fraction of channels working in 2018 was higher than in 2016 and 2017.

New high voltage settings were implemented in October to prolong the lifetime of the chambers. The HV was lowered in all rings except ME2/1, ME3/1, ME4/1. By design, there was no appreciable change in efficiency. The resolution was worse by 10-15% in some chambers as a result of the lower gain but this change does not raise concerns about the muon tracking performance.

Additional tests of algorithms for the OTMB boards were carried out late in the year. These included larger regions of shared strips between adjacent boards, changes in the ALCT-CLCT matching windows, and changes in the layer requirements. The results can be studied carefully during LS2 to determine optimal settings for Run 3.

During Technical Stop 2 in Sep-Oct, small improvements were made to the Rotating Shielding between the quadrupoles and the detector. A marginal reduction in background was observed for the top chambers in ME+4/2.

Between the end of data taking and the power-down of the detector for the end of the year, a systematic test was carried out where all EPROMs in the DCFEBs were erased, reprogrammed and tested. EPROMs on all 504 boards programmed successfully.

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 in 2018. In November, CMS technical coordination approved a program to replace the Finisar transceiver on the old DCFEBs with rad-hard VTTx. This replacement requires a small adapter board for which prototypes were built by colleagues from Tomsk State University.

A radiation test on CSC electronics was carried out in October at the CHARM facility with a total dose of 38.7 kRad. The boards exposed were a mixture of old electronics and new prototypes. All new prototype boards performed well after exposure, while some of the old boards showed some radiation sensitivity starting at 18-29 kRad. Of note was a fuse failure on the ALCT base boards after a dose 18 kRad, which led to consideration of modifying the boards to bypass this fuse during

LS2.

CSC 30x30 cm^2 mini-chambers were used to study a gas mixture with 0% CF4. With a radiation dose equivalent to 3 times HL-LHC exposure, no sign of gain reduction was observed. The chambers were opened after exposure, and some visual changes were evident on the wires and the pads. These are under study.

Table 15: CSC Metrics

% Working channels	98.4%
Downtime attributed pb^{-1}	0
Fraction of downtime attributed	0%
Median spatial resolution	134 μm

MEX/1 Detector Improvement

Ten pre-series DCFEBv2 boards were delivered to OSU on 24 October, as scheduled. The general quality of the assembly was good, and all ten boards were made to work and passed all the automated tests at OSU. Two boards were sent to CERN and underwent successful tests of programming the FPGAs via GBTx. Work was also carried out at Boston University to set up systematic tests of the GBTx communication that can be done routinely as part of production testing. With the success of the GBTx at CERN, the testing of the pre-series boards was completed and the full production of the pcb's was released on 09-Nov.

Three pre-series ALCT mezzanine LX100 boards were delivered to UCLA at the end of October, where they completed their bench tests successfully. The production order is being placed. One prototype board was sent to CERN for integration studies.

The machining of all of the parts for the low voltage junction boxes was completed at University of Wisconsin. The parts were shipped to CERN where they were assembled.

The testing was completed for a sample of the longest type of 48-fiber optical fiber assembly tested at on the ME1/1 test stand at CERN. The milestone for fibers ready to install was adjusted to Jun-15 2019. This is in response to the more mature LS2 installation schedule, which indicates that the fibers will not be installed before July 2019T. Technical coordination and procurement requested a combined proposal for all of the fibers needed for LS2 by CSC, GEM, and RPC, so this was prepared and submitted in December.

In December, a third 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 test stand for an ME1/1 chamber was fully reconstituted at SX5. In addition, and ME3/1 chamber was delivered to SX5 and was set up with a separate test stand.

Prototype modifications were made to the DCFEB covers both for the DCFEBv2 boards (for ME1/1), and the DCFEBs with VTTx adapters (for ME2/1, 3/1, 4/1). After appropriate modifications to the copper covers, all chips were able to maintain a good temperature below 40°C.

The low voltage distribution boards (LVDB), which are a Russian responsibility, progressed according to schedule. All boards were tested and at CERN ready for installation by the end of November.

This is not an US project, but an important partner deliverable. Production and testing was completed in Minsk. All 120 boards have been delivered to CERN.

In summary, the new CSC electronics production is on schedule for installation in LS2, starting in March 2019.

Table 16: EMU 2018 Milestones

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

MEX/1 Detector Improvement

Table 17: EMU 2018 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	Nov 9
EMU-MEX/1	CSC on-chamber optical fibers ready for installation	Nov 1	now Jun 15 (2019)
EMU-MEX/1	CSC LV junction boxes ready for installation	Jan 15 (2019)	

Table 18: EMU 2019 Milestones

Subsystem	Description	Scheduled	Achieved
EMU-OPS/1	LV power in place for plus end cap	Aug 8	
EMU-OPS/1	Ready to join MWGR with ME-1/1	Sep 1	
EMU-OPS/1	Ready to join MWGR with ME+234/1	Nov 1	
EMU-MEX/1	First ME-1/1 chamber extracted to SX5	Feb 25	
EMU-MEX/1	CSC DCFEBv2 boards ready for installation ME-1/1	Mar 11	

Subsystem	Description	Scheduled	Achieved
EMU-MEX/1	ALCT-LX100 ready for installation in ME-1/1	Mar 11	
EMU-MEX/1	Full production of ALCT-LX150T released	Apr 15	
EMU-MEX/1	ME-1/1 installed and commissioned	Jun 2	
EMU-MEX/1	ALCT-LX150T ready for installation in ME+234/1	Jun 10	
EMU-MEX/1	First ME+234/1 chamber extracted to SX5	Jun 17	
EMU-MEX/1	New LV power in place for ME+234	Jun 30	
EMU-MEX/1	ALCT-LX100 ready for installation on ME2/2,3/2	Jun 30	
EMU-MEX/1	First ME+1/1 chamber extracted to SX5	Oct 28	
EMU-MEX/1	OTMB production complete	Nov 15	

DAQ

The operation conditions during the reporting period were diverse. The last weeks of the proton physics data taking were rather smooth. Occasional backpressure to Pixel FED 1227 was traced to a bad FEROL40 board. The rare problem where the event-builder software gets stuck has not occurred anymore. A bug in EOS caused all transfers from Point 5 to the Tier-0 to fail on a Sunday evening. The subsequent fill was taken without B-physics streams to avoid filling the Lustre file system at Point 5. The problem was caused by an automatic failover to the secondary headnode at CERN IT, which had a buggy version of EOS installed.

The latest Squid version 4.3 was deployed during the technical stop. This version provides major improvements in handling failed parent peers. The squid hierarchy was simplified, and thus avoids HLT failures when several peers are down.

The HI run was challenging for the filter farm and the storage and transfer systems. Long processing times on the HLT required a lot of manual interventions during the first days. Adjustments to the HLT menu were implemented to avoid most of the long-running algorithms. The HLT output was 6-7 GB/s during fills, which is about twice the rate during proton physics.

The main problem sustaining this rate came from the 4 spinning-disk RAID array used to temporarily store selected events on the builder unit. The I/O capacity was too low and caused large delays in merging the output. The problem was mitigated by moving the output buffer to the RAMdisk used for the input data. The transfer to Tier-0 was at best 4 GB/s during the fill and 6 GB/s during the interfill. However, there were several periods where the throughput to EOS was very low. The Lustre occupancy became never critical due to problems on LHC side leading to long interfills, which allowed to drain the system.

A failure of the NetApp filer, which hosts the home directories and project space, blocked any runs for 4 hours. We lost about 20 min of HI collisions. The root cause has not been identified and is being followed up with the manufacturer.

A major power cut at CERN occurred the day after the heavy-ion program finished. The recovery of the power and cooling took two days. There were a few hardware failures in the DAQ system. The most critical was a failure on one of the storage elements (OST) of Lustre. The recovery was difficult and required help from NetApp support. Luckily, no data was lost.

The DAQ integration facility in building 904 has been brought up to date and is being used for the burn-in tests for the new HCAL backend electronics, which will be installed during LS2.

Most of the DAQ system has been switched off mid December to limit the power consumption during the yearly cooling maintenance. The majority of HLT nodes (24k cores) have been allocated to the online cloud to process offline workflows.

A new OMS release was deployed in December. It adds runtime, downtime and deadtime analysis pages, as well as summary pages. The last outstanding pages, which contain HLT and run-control information, should become available in January 2019.

Table 19: DAQ Metrics

Dead time due to backpressure	0.6%
Downtime attributed pb^{-1}	2.9
Fraction of downtime attributed	1.6%

Table 20: DAQ 2018 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	Event-builder & SMTS ready for heavy-ion run	Oct 31	Oct 31
DAQ	All relevant WbM pages migrated to new OMS GUI	Dec 31	

Table 21: DAQ 2019 Milestones

Subsystem	Description	Scheduled	Achieved
DAQ	Migrated all DAQ s/w to gitlab	Feb 1	
DAQ	SRCMS and XDAQ releases from gitlab deployed	Mar 15	
DAQ	Core XDAQ packages built with C++11/14	Jun 1	
DAQ	Evaluated storage-manager h/w for Run 3	Aug 1	

Subsystem	Description	Scheduled	Achieved
DAQ	OMS DB tables fully replace legacy tables from WbM/SCAL	Oct 1	
DAQ	Central DAQ hardware choices finalized	Nov 1	

Trigger

During this quarter the US groups continued their work on the Layer-1 calorimeter (CaloL1) trigger, endcap muon trigger (EMTF), and global 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

Data-taking operations went smoothly with no downtime attributed to the EMTF system during the last quarter for either proton or ion running, including a high pile-up fill. Work was done to improve the configurability and diagnostics of the automatic CSC link recovery procedures to improve system robustness. Also some register settings stored in text files were moved to database tables.

A comprehensive study of the EMTF trigger rates during 2017 and 2018 was done, which indicates how algorithmic improvements have reduced the pile-up dependence of trigger rates. Projections matched actual results from the high pile-up run conducted this quarter. Studies on future algorithm changes such as using an improved CSC bend angle, and vetoing halo muons for a displaced muon trigger, are underway and could lead to improvements for Run 3.

Layer-1 Calorimeter Trigger

During the fourth quarter of 2018 CaloL1 provided smooth data taking in heavy-ion collisions. A few problems with ECAL links were discovered using CaloL1 DQM and were fixed. The trigger rates for some centrality triggers were unstable, but this effect was not caused by the trigger system itself. With the start of the heavy-ion collisions it was observed that the jet rates increased, and to get it under control special masks were provided for high pseudorapidity ECAL and HCAL towers. Some ECAL towers were hot for short periods of time and were fixed by the ECAL group. The CaloL1 was turned off at the beginning of December together with the CMS detector.

Global Trigger

Throughout 2018, we developed and maintained the emulator software for the Global Trigger (μGT), which involved improving the fidelity of the emulator itself and updating the unpacker software to include a variety of new trigger algorithms. We also added increased flexibility to the emulator framework and continued to maintain the μGT Data Quality Monitoring software. During the past year, we provided a series of L1 Trigger Menus to serve both the startup needs and the physics goals of the experiment during operations. In support of that, we routinely performed

L1 rate estimations, produced prescale columns, and developed a software package to facilitate a more rapid estimation of L1 rates due to any variations in running conditions.

Field Operations Group of the Trigger Studies Group

The Field Operations Group (FOG) activities for this past quarter focused on the ending of proton running and heavy ion (HI) running. Near the end of the proton run, trigger rate references were evaluated to see which ones needed to be updated for the last weeks of running. Following that support was given in preparing the HI trigger menu and for monitoring the HI run. At the conclusion of the 2018 run, FOG activities have largely ramped down, but are expected to start ramping back up in the 2nd half of 2019 in preparation for Run 3.

Table 22: Trigger Metrics

Frac of MPC Channels	100%
Frac of Upgrade EMUTF Channels	100%
Deadtime attributed to EMTF pb^{-1}	0
Fraction of deadtime attributed to EMTF	0%
Frac of Calo. Layer-1 Channels	100%
Deadtime attributed to Calo. Layer-1 pb^{-1}	0
Fraction of deadtime attributed to Calo. Layer-1	0%

Table 23: Trigger 2018 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

Table 24: Trigger 2019 Milestones

Subsystem	Description	Scheduled	Achieved
TRIG	Architecture for bringing GE1/1 signals to EMTF specified	Aug 30	
TRIG	EMTF online software framework extended to include GE1/1	Aug 30	
TRIG	Neural network PT assignment implementation into EMTF firmware	Dec 31	
TRIG	Initial algorithm to include GE1/1 into EMTF	Dec 31	

Subsystem	Description	Scheduled	Achieved
TRIG	Remove legacy BMTF firmware and keep only Kalman filter	Dec 31	
TRIG	Modify the Kalman filter algorithm to use the upgraded trigger primitives	Dec 31	
TRIG	Deinstall old RCT hardware	Sept 30	
TRIG	Exchange microSDs in all CTP7 cards	Sept 30	
TRIG	Calo Trig: Fix the cable trays in P5	Sept 30	
TRIG	Calo Trig: Initial demonstration of pileup mitigation algorithms involving machine learning	Jul 1	
TRIG	Calo Trig: Performance results of pileup mitigation algorithms involving machine learning	Dec 31	
TRIG	Assess needs for any rate monitoring software developments	Dec 31	
TRIG	Update rate monitoring software to adapt to evolution in DAQ infrastructure	Dec 31	

Software and Computing

The final quarter of 2018 marked the end of the Run 2 proton collisions, a heavy-ion run, and the end of LHC operations until 2021. Computing operations were generally successful, with significant progress in preparing data and software releases for the upcoming winter conferences. Challenges were mostly associated with the high data rates of HI collisions, and they were met thanks to previous experience and careful preparation for this run. Difficulties with the Monte Carlo production system at the end of the previous quarter were resolved, allowing all facilities to return to a level of full utilization. CMS made good use of the NERSC HPC systems.

The U.S. Tier-1 and Tier-2 facilities were as robust as ever, with high levels of availability to the experiment. All sites made continued progress with a variety of technology upgrades. The most significant of these was the commissioning of a new tape library system at Fermilab, which has proceeded months ahead of the expected schedule. The experiment's computing infrastructure continues to be upgraded, with an increasing use of community- and industry-standard tools to avoid a reliance on in-house products. In particular, CMS is making rapid progress with migration to the Rucio data management system, which was developed for the ATLAS experiment but is now becoming a community project. A variety of software developments have targeted the improved use of heterogeneous processing architectures.

Major milestones achieved this quarter

Table 25: Software & Computing milestones.

Date	Milestone
15 Oct 2018	Functional installation of Rucio on CERN hardware, no high avaiability.
6 Nov 2018	IBM TS4500 tape library system fully in production at FNAL.
15 Nov 2018	Release of a new DAS version that is capable of integrating Rucio data.
3 Dec 2018	Successful transition of LPC user metadata handling to the new FERRY service.
10 Dec 2018	Setup multiple Oracle DBs at CERN for Rucio.
10 Dec 2018	Migration of the Detector Database Core application to the new CERN IT-supported DD4HEP.
11 Dec 2018	CMSWeb migrated from SiteDB to CRIC.
31 Dec 2018	All milestones and upgrades at 5 of the 7 Tier-2 sites completed. Remaining sites either have a plan to complete in January 2019 or are held up by campus networking providers.
31 Dec 2018	Analysis prototype demonstration of using functional programming, based on optimized community library `awkward-array`.
31 Dec 2018	Integration of vectorized Kalman filter tracking `mkFit` into CMSSW.
31 Dec 2018	Upgrade to Frontier Squid-4 and developed and deployed outage monitoring for the Web Proxy Auto Discover.

Fermilab Facilities.

Throughout this quarter the Fermilab computing facilities continued to provide reliable custodial storage, processing and analysis resources to U.S. CMS collaborators. The site was well utilized, with the facility providing 43.1M wall-clock hours of processing to CMS.

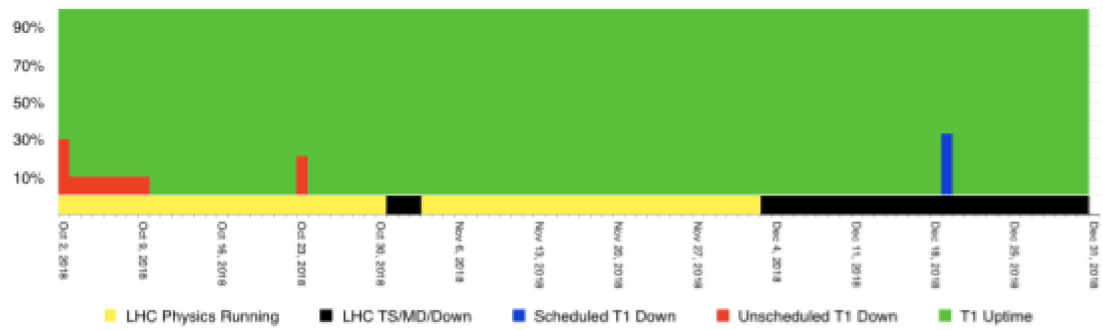


Figure 10: Fermilab readiness metrics for 2018Q4. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. The height of a red/blue bar indicates how much of that day services were affected. Black and yellow across the bottom indicates LHC machine running. This quarter LHC continued proton-proton physics running. Fermilab passed the metrics 98.5% of the time during the quarter.

Figure 10 shows the site readiness metrics for the quarter. During this quarter the Tier-1 facility passed CMS site availability metrics 98.5% of the time. The blue in the figure indicates a scheduled downtime in December to apply security updates to the tape and disk storage nodes. There were two periods of failing metrics during the quarter. Early in the quarter a bad fiber on the incoming 100Gb network link led to reduced incoming transfer throughput. In October a failing storage node caused failing transfers, which affected site availability.

The quarter marked a major milestone for the Tier-1 with the successful commissioning of the IBM TS4500 tape robot library. First replicated datasets began to be written to it in late October for commissioning, and the system was fully in production by the beginning of November. By the end of the quarter over 5 PB of data, including nearly all of the raw data from the 2018 HI run, was successfully written to tapes in the new library, months ahead of schedule.

There was much work on the LPC CAF during this quarter, including successful transition from the Vulcan user metadata service to the new FERRY service. Preparations for upgrading the LPC EOS storage system also were nearly completed, with the upgrade scheduled in January. The refactoring of the LPC HTCondor batch resources also made significant progress with a test pool being deployed for users to aid transition. This refactoring aligns the LPC HTCondor resources with the Docker container migration done earlier in the year for the Tier-1 batch farm. The move of these LPC resources to production was also scheduled during the EOS upgrade downtime in January.

University Facilities

As seen in Figure 11, CMS production and analysis activities this quarter recovered to run at high levels relative to full capacity. Problems with central CMS production world-wide in the late 3rd and early 4th quarters of 2018 prevented full utilization of the sites. Total analysis usage has remained steady, although analysis activity by U.S. researchers has dropped from an average of 70% of total usage of our sites to about 60% in the past quarter. We will track the evolution of this metric in future quarters.

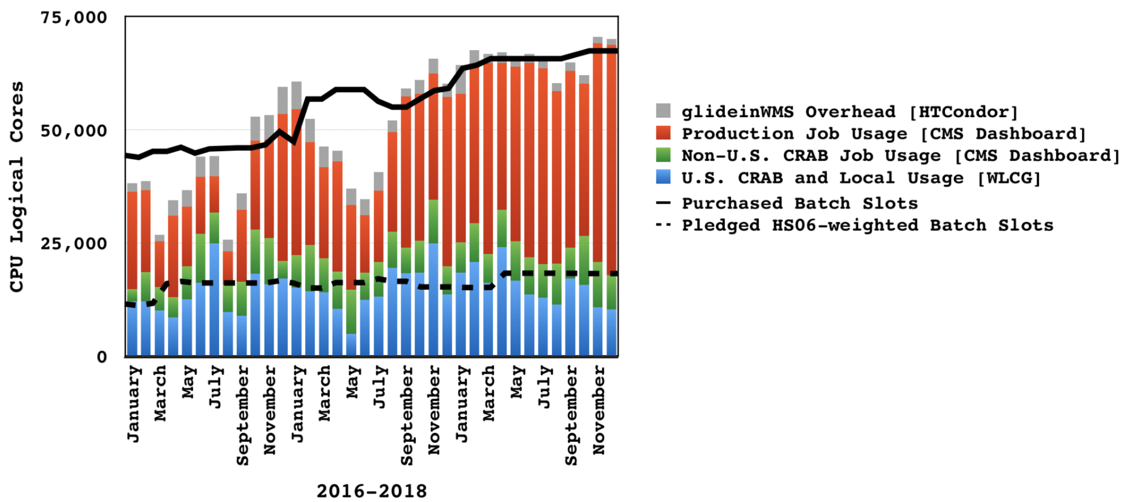


Figure 11: Processing usage at the U.S. CMS Tier-2 sites by month, broken down by type of usage (production, analysis by U.S. researchers, and non-U.S. researchers, e.g.) compared to purchased processing.

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 97% (+1% over the previous quarter) "available" and 88% (+0%) "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. Nonetheless our commitments to CMS were met with success. The U.S. CMS Tier-2 centers delivered 50.8% of all computing time by Tier-2 sites in CMS last quarter, up about 2.6% from the previous quarter.

Site personnel made strong efforts to wrap up any remaining milestones and upgrades before the end of the calendar year. Generally these fall into a few broad categories of upgrading to SL7, implementing IPv6, and simplifying the architecture of the sites. Two planned upgrades for 2018, upgrading to HTCondor 8.8 and HDFS 3, were cancelled due to lack up upstream software releases. Upgrading all processing nodes to SL7 is difficult for sites that co-locate storage and processing, so such sites will be allowed to meet this milestone in 2019 as long as progress has been shown, e.g. installing newly purchased processing nodes with SL7.

The IPv6 milestones (storage access, stageout, XRootD, transfers) have been achieved at every site except MIT where IPv6 is still not available from their facility and at Caltech where everything is in place except reverse-DNS at their campus. Neither of these cases is the fault of the Tier-2 sites since they depend on their host institutions for networking. The only other milestones that were not achieved in 2018 were upgrading the remaining one-third of worker nodes and CE's at Wisconsin as well as stageout by https, and a few upgrades at MIT that they promised to complete by the end of January 2019.

The U.S. CMS Tier-3 support team provided help to ten sites on a number of issues mainly related to OSG software upgrades, Singularity, PhEDEx transfers, XRootD, basic systems administration, in particular upgrading to EL7. Routine CMS Connect support continued and techniques were established and documented to use CMS Connect to access GPU resources interactively as well as to launch a Spark cluster (leveraging the VC3 software). Finally, the team provided support for three U.S. CMS Tier-3 sites that started running production jobs (Baylor, Colorado, and Rutgers).

Computing Operations

The proton-proton data taking period was completed at the end of October. It was followed by a month-long HI run in which CMS recorded 5.3 PB of raw data. Switching the Tier-0 configuration for HI operations was smooth. All pp data are now archived, and were passed through prompt reconstruction (with the exception of the parked B physics data). Distribution and archival of the HI data will be completed in early January 2019.

Processing during the fourth quarter was dominated by four activities: generating a new version of miniAODs (19 billion events), re-reconstructing early 2018 data (2.6 billion events), and Monte Carlo generation for the 2017 (1 billion events) and the 2018 (6 billion events) detector configurations.

The MiniAOD v3 production made the staging and transfer of the large AOD datasets necessary which caused congestion in the workflow management system and thus CPU resources of CMS were not being fully utilized for a brief period end of October.

Issues with EOS/Unified at CERN required manual intervention for a large number of processing requests. The setup is in the process of being changed and the Unified system that orchestrates production workflows will be modified to use a shared filesystem other than EOS.

With the end of the data taking the high level trigger farm is now being utilized for offline data and Monte Carlo processing. Over the December holiday period data processing ran steadily with about 200k cores in use, while analysis used about 50k cores, see Figure 12.

The last quarter of 2018 was also the last quarter of the NERSC allocation year. For 2018, CMS, the Fermilab FIFE experiments, and SciDAC were allocated a combined 93M hours on the NERSC supercomputer. The total allocation was 97% utilized, with CMS using 42M hours of NERSC CPU. CMS has received an allocation of 82M hours at NERSC for 2019. In addition, CMS used a total of 4.5M hours on the Bridges supercomputer at the Pittsburgh Supercomputing Center during 2018. A new XSEDE request was being prepared for submission in January 2019.

Computing Infrastructure and Services

Work on Rucio has progressed considerably during this quarter as the team builds up and transitions from PhEDEx to Rucio. The effort on Rucio or Rucio-related issues is split roughly evenly between U.S. CMS members and CMS members outside the U.S., with overall leadership provided by U.S. CMS members. A fully working Rucio testbed has been installed on CERN hardware using Kubernetes and Docker, tools widely used in industry. This testbed is easily replicated and that replica will become the production system. The CMS DAS (Data Aggregation Service) has been integrated with Rucio and is able to give users a coherent view of data from DBS, Rucio, and other services. CMS Rucio has been moved onto production Oracle hardware at CERN.

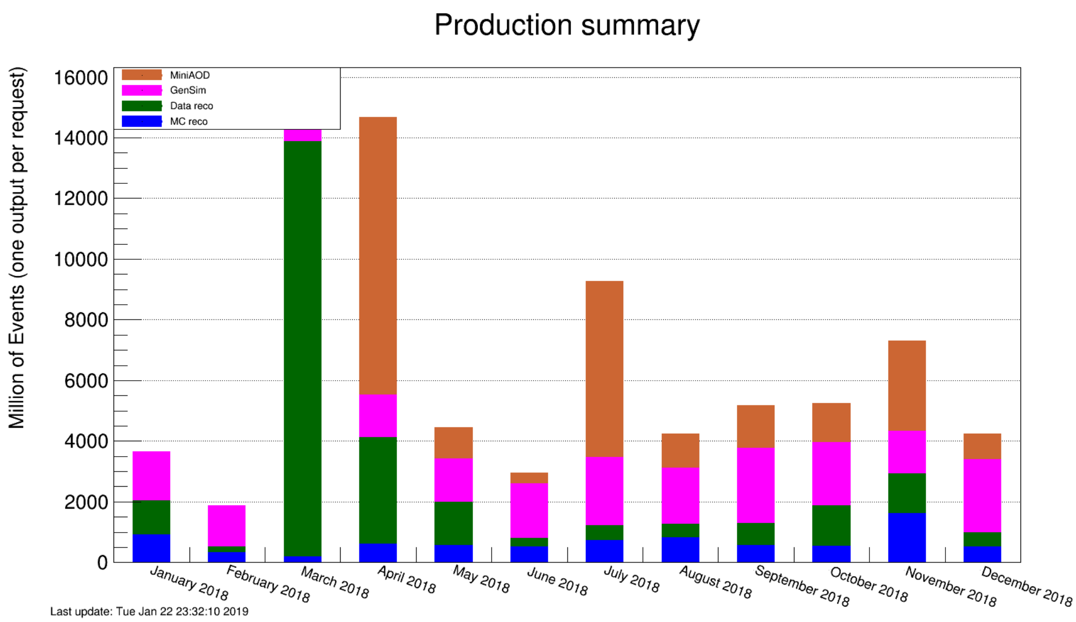


Figure 12: Numbers of events produced from different categories of workflows during 2018.

In this quarter, we helped migrate additional computing services from the CMS-specific SiteDB information service to the CERN-supported CRIC. By utilizing a service developed and supported by CERN as opposed to an internal one, we hope to reduce the overall maintenance burden.

U.S. CMS continues to support the CERN-led effort to modernize the CMSWeb stack. This development project will provide CMS with more agility for updating services and replaces the decade-old custom infrastructure U.S. CMS developed for web service deployments with an industry standard one based on Kubernetes. As with the SiteDB to CRIC transition, we believe utilizing software supported by an external community will help reduce CMS's maintenance burden. Additionally, this overhaul has allowed us to start modernizing the authentication and authorization mechanisms used by CMS. A first part of this, the ability for CMSWeb to issue "SciTokens" (www.scitokens.org) to access CMS's distributed storage was put into the CMSWeb testbed during Q4.

In the XRootd/XCache project, per-directory access/usage statistics collection were implemented, which will also be the basis of implementation of per-directory quotas. The team assisted in debugging and understanding problems reported by StashCache and ATLAS and attended the newly created XCache DevOps meetings.

Software and Support

Reconstruction software release integration was very active during this quarter. The main task was to support the heavy ion data taking, requiring optimization of the RAW data formats and their compression. In addition to supporting the releases for 2018 proton-proton data and MC processing and the MTD detector TDR production, a 20% speed-up of the MINIAOD production workflow was achieved without any changes in physics output.

The framework activities concentrated on enabling new advanced code developments in GPU, vectorized tracking and machine learning based on TensorFlow, where contributions have been submitted to the TensorFlow community. Further improvements of the multi-threading performance have been achieved, especially for non-event data that is not bound to any event or luminosity-section boundaries. Studies continued to compare TBB-based multi-threading with a similar implementation based on OpenMP, where several fruitful discussions with the OpenMP development team led to improvements on both sides. We were also requested to report at an ATLAS workshop on how CMS stores metadata in its production ROOT file

The Frontier infrastructure was migrated to frontier-squid-4 and CentOS 7, and we deployed a new outage monitor for the Web Proxy Auto Discovery.

The migration to the DD4HEP framework to describe and use the CMS detector geometry from various places in CMSSW progresses well, achieving the milestone of migration of the DDCore application.

The CMS visualization solution Fireworks was released on macOS Mojave, and EvE7, the evolution of the community solution for ROOT-based detector and event visualization, was integrated into the main ROOT repository.

The evolution of analysis tools using functional programming and industry technologies saw a large boost in this quarter with a dedicated analysis porting effort using the underlying community libraries like awkward-array to efficiently analyze columnar data.

The R&D on vectorized tracking on advanced hardware included a first version into CMSSW and is testing and optimizing its performance, especially on Intel Skylake Gold nodes important for HPCs.

Other activities

The security team aims to revise the security processes and documents to guarantee secure operation of U.S. CMS sites. The team completed an initial version of the CMS computing workflow description covering both production and analysis use cases. A main document describes these in detailed separate diagrams, along with an additional diagram describing the workflow from the site perspective. Using the feedback given by the U.S. CMS management team, the security team is modifying these diagrams and adjusting them accordingly.

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 four U.S. CMS blueprint meetings this quarter. These included discussions on strategies for how caching data can improve data availability metrics (or reduce cost) at sites; developments by the CMSSW framework group to support the use of accelerators by CMSSW algorithms; understanding the drivers that define disk needs for HL-LHC; and developments in the WLCG tape working group and their impact on HL-LHC strategies for data management. Planned blueprint meetings for next quarter include detailed modeling of network and tape-recall needs for HL-LHC, additional discussions of caching strategies, and the ongoing scitoken project.

We also initiated a new effort towards an analytics driven model of the needs of data resident on disk and its evolution. We presented an initial study of how much, and what sorts, of data are used each month (or each week) by CMS analysts at the WLCG DOMA working group in December. This work will further support the CMS ECOM2X working group as it evolves towards a HL-LHC software and computing strategy for CMS.