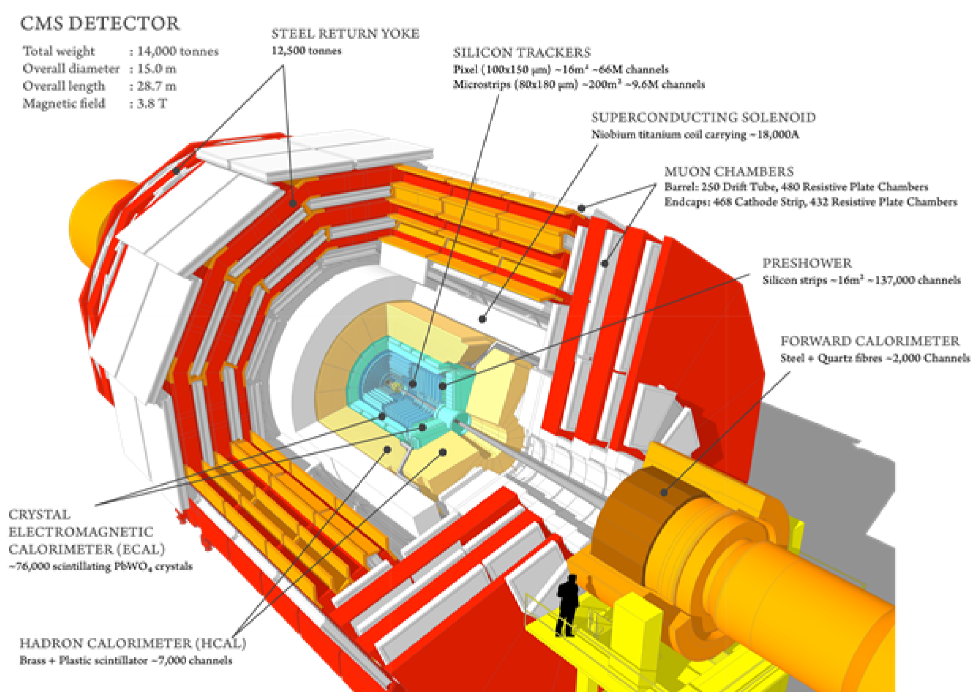
# U.S. CMS Compact Muon Solenoid Operations Program
# Quarterly Report for the Period Ending September 30, 2016

U.S. CMS Operations Program



## Program Manager's Summary

During this quarter, the third quarter of **calendar year 2016** (2016Q3), CMS went through a period of very intense and productive data taking. With outstanding LHC performance and excellent data taking efficiency at 92.5%, CMS already has exceeded its luminosity goal for 2016 which was set at 25 $\mathrm{fb}^{-1}$.

The LHC delivered almost 34 $\mathrm{fb}^{-1}$ of integrated proton-proton luminosity at 13 TeV, of which CMS collected 31 $\mathrm{fb}^{-1}$, as shown in Figure 1. There were unprecedentedly long periods of uninterrupted running, many weeks with no programmed technical stops. The machine duty factor and availability was much higher than predicted or planned for, overall better than 60 %, to be compared with about 35 % during Run-1 and in 2015. This came both from good system availability and long luminosity lifetimes.

Also, the LHC has now exceeded its design luminosity, regularly reaching instantaneous luminosities of $1.2 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$ and above, and approaching the peak luminosity soft limit of $\sim 1.7 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$ imposed by the inner triplet magnets.

To address the unanticipatedly high instantaneous luminosities and to understand the impact on the experiment, CMS has initiated a Luminosity Study Group to look at all aspects of the performance of the detector, trigger, DAQ, and computing (hardware and software)

While we very much welcome the increase in LHC availability and luminosity, the improvements in instantaneous luminosity lead to an increase in the average pile-up and the overall dataset sizes, producing additional stress on computing.

There is clearly a large impact on computing resources for data storage, reconstruction and analysis. CMS computing resource requests for 2016 were endorsed by the CERN Resources Review Board in May of 2015, based on the then-best prediction of luminosity for 2016. The higher availability and new LHC performance projections for 2016, 2017, and 2018 predict more data and a large increase in demand for resources. Shortfalls were analyzed and are typically 20-30% in each Tier level and category (CPU, disk, tape) relative to the original 2016 request.

CMS and U.S. CMS have worked to mitigate some of the resource impact in this new situation. Some of the approaches taken so far are to

- reduce the number of AOD and MiniAOD copies and versions, which lowers the need for disk storage, but impacts the availability of datasets for analysis
- decrease RECO and RAW data on disk to only 2-3 months and 50% of the datasets to limit the disk space use during data taking, but makes detector commissioning and debugging based on RAW data harder, and will eventually no longer allow for fast or emergency data reprocessing in case of unexpected behavior in the data.
- reduce availability of Run-1 data and MC to save disk and tape space, impacting ongoing data analysis and publication processes
- start a massive tape deletion campaign making space on existing tape media and library slots.

These immediate measures mitigate the additional computing needs down to a level of increase by +20% instead of the expected +40%. Other measures are being considered and their impact is being studied, in particular to further limit the HLT output rate and to reduce number of Monte Carlo events relative to data. While this is a good start, much work still needs to be done in the

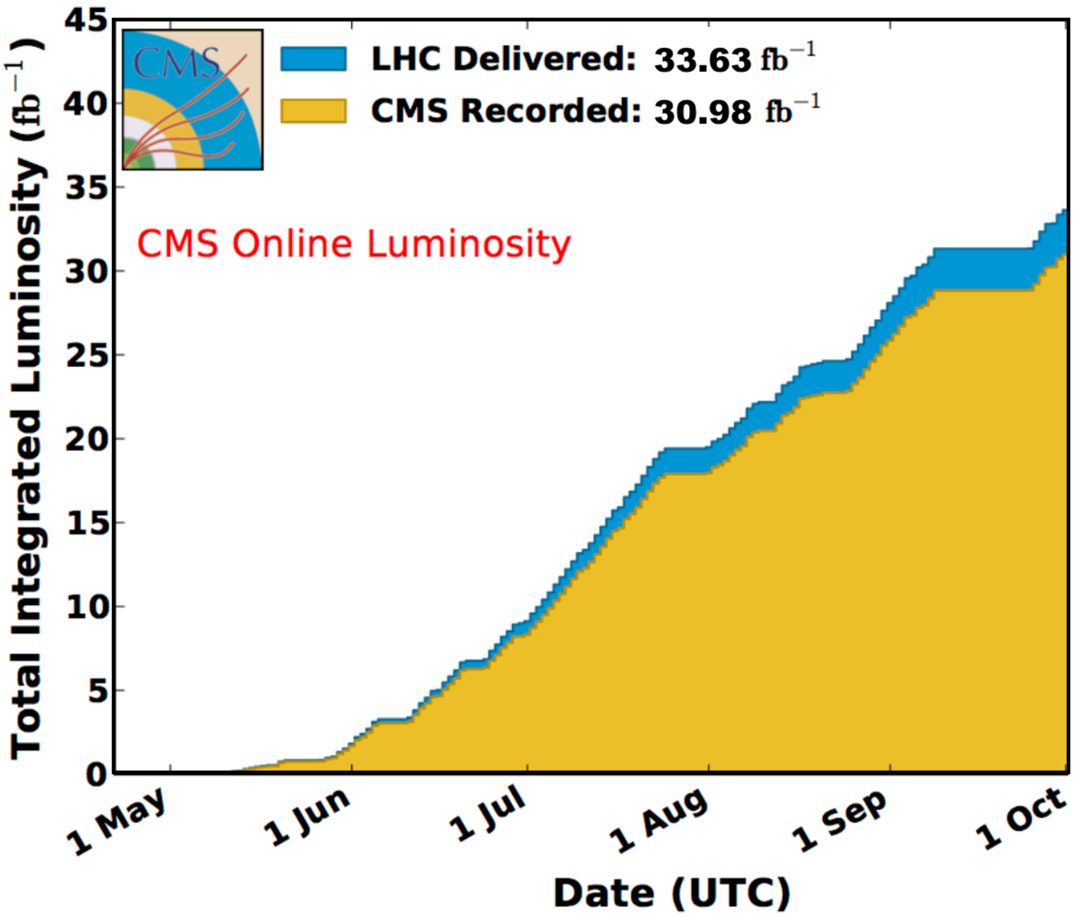



Figure 1: Integrated luminosity accumulated during this quarter.

experiment to understand more drastic mitigation scenarios and their possible impact on trigger, physics and detector operations, to as much as possible mitigate as the additional resource needs to accommodate improved LHC availability in 2016 and beyond.

On the detector side, operation of CMS has been excellent. All detectors had high up-time and performance despite the extraordinarily high luminosity and pileup. High fraction of channels are working, typically better than 98%. However, there are some problems, expected and unexpected, at high instantaneous luminosity. More detail is given in the Detector Operations section of this report.

The Pixel detector is performing well even at highest luminosities. However, the strip detectors, as the luminosity increased during the early summer, developed an efficiency problem with the APV amplifier chip, referred to as Highly Ionizing Particle (HIP) problem. Studies during this quarter showed that the design of the APV indeed allowed a change in setting of chip parameters to address these effects at high luminosity conditions. In August, settings for the chip were changed such to eliminate the problem.

Muon systems were operating smoothly, but a couple of things were to take note of. Five out of 504 DCFEB boards in the ME1/1 system have shown a problem writing Xilinx EPROMs. This problem is not currently understood and is being studied further.

Scintillator radiation damage in the HCAL end cap is being tracked carefully. At the start of Run-2 there were worries about the very steep decline of light output. However, the so-called dose rate effect predicts that signal loss per accumulated luminosity would decrease with larger instantaneous luminosity, and that is what has now been observed. The extrapolations now give less reason to worry about light loss, until the Phase2 upgrade will replace this detector, but studies continue.

The updated DAQ system continues to perform well with negligible down time. There is good progress in performance optimization of the event builder system. Following extensive testing of the HLT Cloud for operations between LHC fill, the HLT farm is now integrated into and available for the offline data production system.

The cold box unit for cooling the CMS superconducting solenoid performed beautifully, and the repair and refurbishment plan during the shutdown clearly succeeded.

Computing facility performance was excellent during the quarter, where the Fermilab Tier-1 facility achieved a site readiness metric of 100% in the past six months, where the CMS target is 90%. All resources pledged to WLCG for 2016 are available. The U.S. Tier-1 is highly used and over the quarter provided 47% of the total Tier-1 CPU time used by CMS. Also the U.S. Tier-2 facilities performed very well, with site readiness above 88% where the CMS target is 80%. Also for the Tier-2s all resources pledged to WLCG for 2016 are available.

The Full LHC dataset was processed in time and used by dozens of analyses presented at the ICHEP conference. The bulk of production resources can now run with multicore pilots, to fully take advantage of multithreading. Ever-greater use of the AAA data federation allows to provide the data inputs to the production chain run remotely, giving better flexibility in the workflow location. Pileup samples used for simulation are now pre-mixed, leading to improved I/O and processing time, and enabling the use of a broader set of computing resources. Workflows that in Run-1 used to be confined to the Tier-1 only can now be run at Tier-2 centers, increasing the flexibility and resource availability of the system.

There is continued progress with the integration of resources at the NERSC High Performance Computing center. U.S. CMS is running re-reconstruction workflows for production, and work is continuing, with help from the NERSC experts, to increase both scale and efficiency.

The software group is developing software for the 2017 installation of Phase-1 detector upgrades, to take advantage of the all-new 4-layer pixel detector that gives new track-seeding capabilities. This is important as pileup increases. Also, the to-be-upgraded electronics in the HCAL end cap gives TDC capability and effective depth segmentation improving robustness and performance of HCAL reconstruction.

The highlight of this quarter clearly was the very successful and sustained *pp* data taking. We achieved excellent performance of detectors, operations, software and computing systems, and problems get solved with good efficiency. The LHC continues to perform beautifully, providing both physics opportunities and challenges for data handling and processing, computing resources, software improvements. A wealth of results were shown at ICHEP in Chicago, with major U.S. contributions and leadership, enabled by U.S. CMS Operations.

# Report of the U.S. CMS Resource Manager

The funding provided by DOE and NSF to the U.S. CMS Operations Program for 2002 through 2016, as well as the funding guidance for 2017 through 2019, is shown in Figure 2.

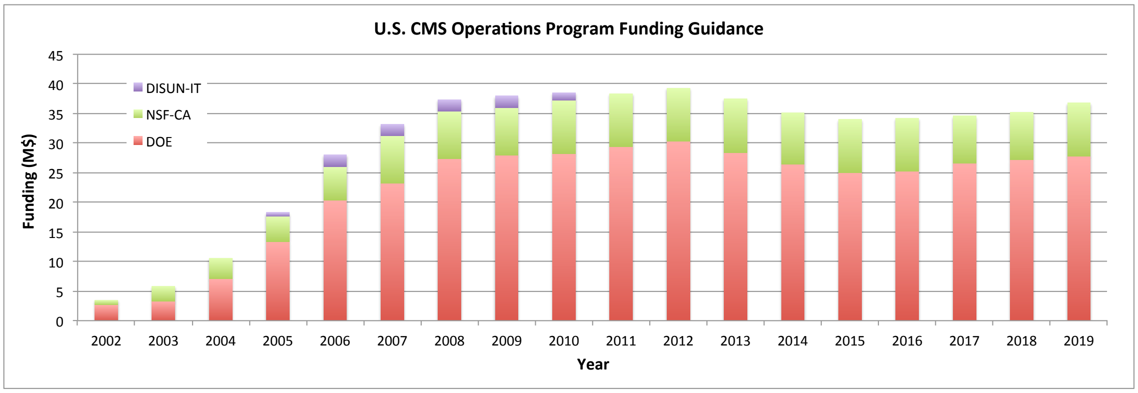



Figure 2: The annual U.S. CMS Operations Program funding provided by DOE and NSF. For 2002 through 2016 the chart shows the actual funding, while for 2017 onward the current funding guidance is shown. This figure does not include the $1M NSF supplement provided in 2016 specifically for Phase2 Upgrade R&D.

Resources are distributed and tracked across the three areas through which the Operations Program is implemented: Detector Operations (DetOps), Software and Computing (S&C), and Common Operations (ComOps). ComOps is a category for items that would otherwise belong in both, or neither, of the other two categories.

Internal budget reviews for calendar year 2016 took place in September of 2015. As a new source of input to the planning process, the Resource Allocation Advisory Board met 19 times from June through November, and issued a report of findings and recommendations. Through these processes, U.S. CMS Management developed a detailed spending plan, while taking into account updated guidance from the funding agencies.

Primarily during the first quarter of the calendar year, Statement of Work (SOW) agreements were established with each institution that is providing a deliverable in exchange for Operations Program funding. The SOWs specify the tasks to be carried out, as well as any portions of salaries, materials and services (M&S), travel funding, or cost of living adjustments (COLA) to be paid from the Operations Program budget. The SOWs must be approved by U.S. CMS Operations Program management, by the Fermilab Director Designee, and by representatives of the collaborating group and institution. Through September of 2016, a total of 131 SOWs (82 DOE and 49 NSF) were produced and approved. After a SOW is approved, any additional changes are considered and, if approved, enacted through a Change Request procedure.

Table 3 shows the Spending Plan Change Log which captures revisions that were made prior to SOW approvals, as well as modifications implemented through Change Requests. The information is reported here down to the level-2 subsystem categories within DetOps, S&C, and ComOps. The changes to the Phase2 Upgrade R&D spending plan during this quarter include the allocation of the $1M supplement that has been provided through NSF specifically for Phase2 Upgrade R&D.

The CY16 spending plan, as of the end of Q3, is shown for DOE and NSF funds in Table 4. The plan will continue to evolve slightly as Change Requests are executed.

Once funds have been committed through purchase orders, in the case of DOE, and sub-awards, in the case of NSF, they are considered obligated. Figure 5 shows the obligations in the areas of DetOps, S&C, and ComOps, as compared to the spending plan, for DOE funds. The spending plan is plotted as if expenditures are carried out in even allocations each month, but this is intentionally not the case due to equipment purchases and the larger of the transfers to CERN-based Team Accounts, the latter of which are targeted for when exchange rates are favorable. Spending through Universities and CERN Team Accounts is budgeted and tracked according to the calendar year. Spending at Fermilab has historically been budgeted according to the fiscal year, however this is the second year that we are reporting all activities based on calendar year. Figure 6 shows the total obligations and the spending plan, for NSF funds. Of the $9M in NSF funding (plus $1M Phase2 R&D supplement), $875k in subawards went out this quarter, in addition to spending directly at Princeton.

Resources deployed at CERN and paid directly in Swiss francs account for approximately 27% of the 2016 spending plan. This carries considerable exposure to the exchange rate. A rate of 0.9 CHF/USD has been used for planning, while the actual rate in CY16 Q3 averaged 0.98 CHF/USD. Figure {@fig:Team_Accounts} 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 {@fig:Team_Accounts} does not include the 3,756K CHF M&O-A payments, as these are each made through multiple payments to a separate Team Account.

| U.S. CMS Detector Operations Change Control Activity | | | | | | |
|---|---|---|---|---|---|---|
| **WBS** | **Subsystem** | **Change Request Number** | **Description of Change** | **CY16Q3 Plan** | **Change $** | **CY16Q4 Plan** |
| 11 | Endcap Muon | CR-026, CR-027 | UCLA M&S for comparator ASIC encapsulation, Texas A&M M&S for CTP7 boards for GE1/1 backend | $1,889,353 | $84,355 | $1,973,709 |
| 12 | Hardon Calorimeter | SOW, CR-037, CR-038 | Brown SOW: labor for HE/HF burn-in, testing, and ops; Various: re-align COLA & travel with highest priorities; Maryland: extend support for electronics labor | $1,839,715 | $51,694 | $1,891,408 |
| 13 | Trigger | | Adjustment | $825,091 | $1,126 | $826,216 |
| 14 | Data Acquisition | | | $985,340 | $0 | $985,340 |
| 15 | Electromagnetic Calorimeter | CR-014, CR-015 | CERN TA COLA reductions due to updated plans for grad students at Princeton, Florida State, and Virginia | $913,303 | ($30,390) | $882,913 |
| 16/17 | Tracker (Fpix & SiTrk) | | | $854,097 | $0 | $854,097 |
| 18 | Detector Support | | | $119,165 | $0 | $119,165 |
| 19 | BRIL | | | $343,754 | $0 | $343,754 |
| 30 | Phase 2 Upgrade R&D | SOWs, CR-047 | NSF Suppliment SOWs; CR-047: Iowa rad hard scint. | $3,666,341 | $999,455 | $4,665,796 |
| **11-19,30** | **Detector Operations** | | | **$11,436,160** | **$1,106,240** | **$12,542,400** |

| U.S. CMS Common Operations Change Control Activity | | | | | | |
|---|---|---|---|---|---|---|
| **WBS** | **Subsystem** | **Change Request Number** | **Description of Change** | **CY16Q3 Plan** | **Change $** | **CY16Q4 Plan** |
| 21.2 | Common Costs (M&OA) | 94,95,97 | M&O-A adjustments for actual exchange rate | $4,332,942 | ($307,105) | $4,025,837 |
| 21.3 | RCMS | | | $543,397 | $0 | $543,397 |
| 21.4 | LHC Physics Center | SOW | UIC: leadership and technical support labor | $860,327 | $212,610 | $1,072,937 |
| 21.5 | Operations Support | 96,98,99 | Rice: support for US CMS L1 Det Ops manager; MIT cost adjust; CERN TA COLA for key computing ops | $1,526,989 | $557,322 | $2,084,311 |
| 21.6 | Program Office | | | $1,205,115 | $0 | $1,205,115 |
| 21.7 | E&O | | | $283,809 | $0 | $283,809 |
| **21** | **Common Operations** | | | **$8,752,580** | **$462,828** | **$9,215,407** |

| U.S. CMS Software and Computing Change Control Activity | | | | | | |
|---|---|---|---|---|---|---|
| **WBS** | **Subsystem** | **Change Request Number** | **Description of Change** | **CY16Q3 Plan** | **Change $** | **CY16Q4 Plan** |
| 22.1 | Fermilab Facilities | | Adjustments prior to SOW | $5,923,423 | $10,000 | $5,933,423 |
| 22.2 | University Facilities | | | $3,952,858 | $0 | $3,952,858 |
| 22.3 | Computing Operations | | | $865,105 | $0 | $865,105 |
| 22.4 | Computing Infra and Services | | | $2,439,484 | $0 | $2,439,484 |
| 22.5 | Software and Support | CR-014 | CERN TA labor support for new processor architectures | $1,516,139 | $32,018 | $1,548,158 |
| 22.6 | Technologies & Upgrade R&D | CR-013, CR-014 | Increased UCSD event formats labor support; Processor SDT&Env R&D moved from Princeton to Nebraska | $866,536 | ($11,061) | $855,475 |
| 22.7 | S&C Program Management & CMS Coordination | CR-013 | Increased UCSD offline reconstruction coordination labor support | $605,887 | $9,519 | $615,406 |
| **22** | **Software and Computing** | | | **$16,169,433** | **$40,476** | **$16,209,910** |

| | | | |
|---|---|---|---|
| **U.S. CMS Operations Program Total** | **$36,358,173** | **$1,609,544** | **$37,967,717** |

Figure 3: Spending Plan Change Log for CY16 Q3.

| WBS | Subsystem | DOE Funds | NSF Funds | Total |
|---|---|---|---|---|
| 11 | Endcap Muon | $1,439,439 | $534,270 | $1,973,709 |
| 12 | Hadron Calorimeter | $1,762,981 | $128,427 | $1,891,408 |
| 13 | Trigger | $685,137 | $141,080 | $826,216 |
| 14 | Data Acquisition | $985,340 | $0 | $985,340 |
| 15 | Electromagnetic Calorimeter | $882,913 | $0 | $882,913 |
| 16/17 | Tracker (Fpix & SiTrk) | $714,106 | $139,991 | $854,097 |
| 18 | Detector Support | $119,165 | $0 | $119,165 |
| 19 | BRIL | $172,321 | $171,433 | $343,754 |
| 30 | Phase 2 Upgrade R&D | $2,797,433 | $1,868,363 | $4,665,796 |
| **11-19,30** | **Detector Operations** | **$9,558,836** | **$2,983,564** | **$12,542,400** |
| 21.2 | Common Costs (M&OA) | $3,237,813 | $788,024 | $4,025,837 |
| 21.3 | Run Coordination and Monitoring | $436,697 | $106,700 | $543,397 |
| 21.4 | LHC Physics Center | $1,072,937 | $0 | $1,072,937 |
| 21.5 | Operations Support | $1,766,468 | $317,843 | $2,084,311 |
| 21.6 | Program Office | $1,087,565 | $117,550 | $1,205,115 |
| 21.7 | Education and Outreach | $173,224 | $110,585 | $283,809 |
| 21.8 | Collaboration Support | $0 | $0 | $0 |
| **21** | **Common Operations** | **$7,774,705** | **$1,440,702** | **$9,215,407** |
| 22.1 | Fermilab Facilities | $5,933,423 | $0 | $5,933,423 |
| 22.2 | University Facilities | $114,524 | $3,838,334 | $3,952,858 |
| 22.3 | Computing Operations | $397,140 | $467,965 | $865,105 |
| 22.4 | Software and Support | $1,981,797 | $457,687 | $2,439,484 |
| 22.5 | Computing Infrastucture and Services | $1,286,983 | $261,175 | $1,548,158 |
| 22.6 | Technologies & Upgrade R&D | $69,822 | $785,653 | $855,475 |
| 22.7 | S&C Program Management and CMS Coordination | $289,670 | $325,736 | $615,406 |
| **22** | **Software and Computing** | **$10,073,359** | **$6,136,551** | **$16,209,910** |
| **U.S. CMS Operations Program Total** | | **$27,406,900** | **$10,560,816** | **$37,967,717** |

Figure 4: Spending plan at the end of CY16 Q3, for funds from DOE, NSF, and the total.

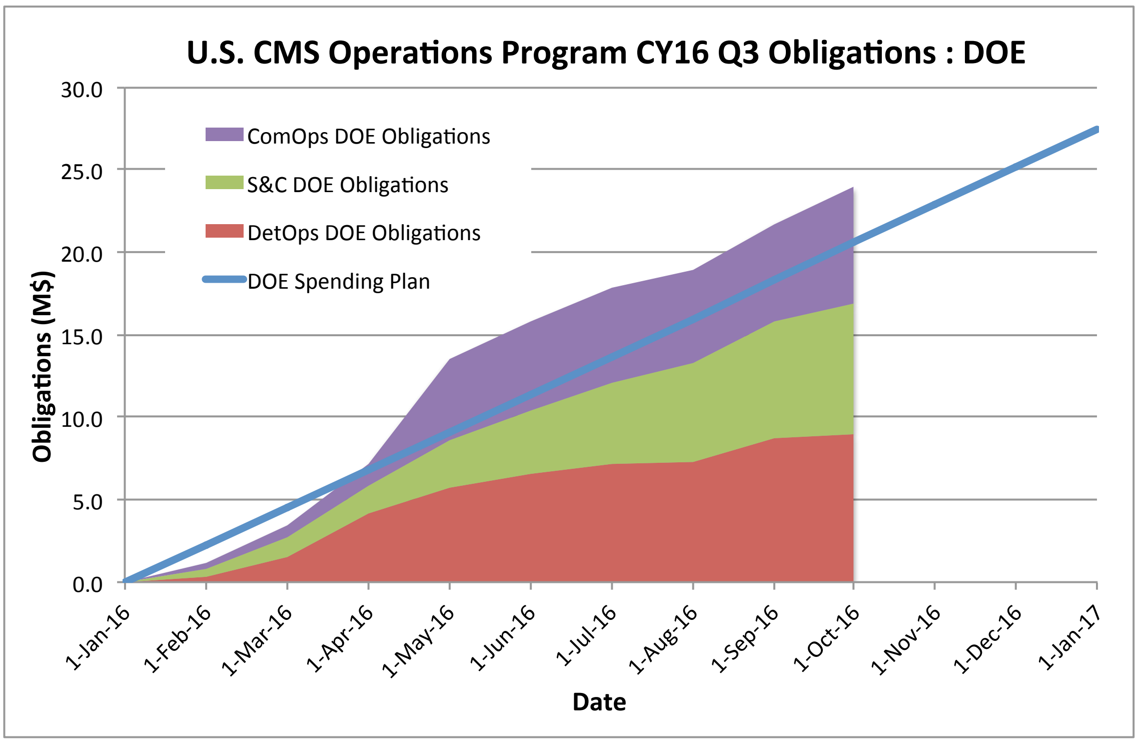



Figure 5: Obligations and spending plan for DOE funds. The spending plan is indicated with the assumption of equal monthly increments just as a rough guide.

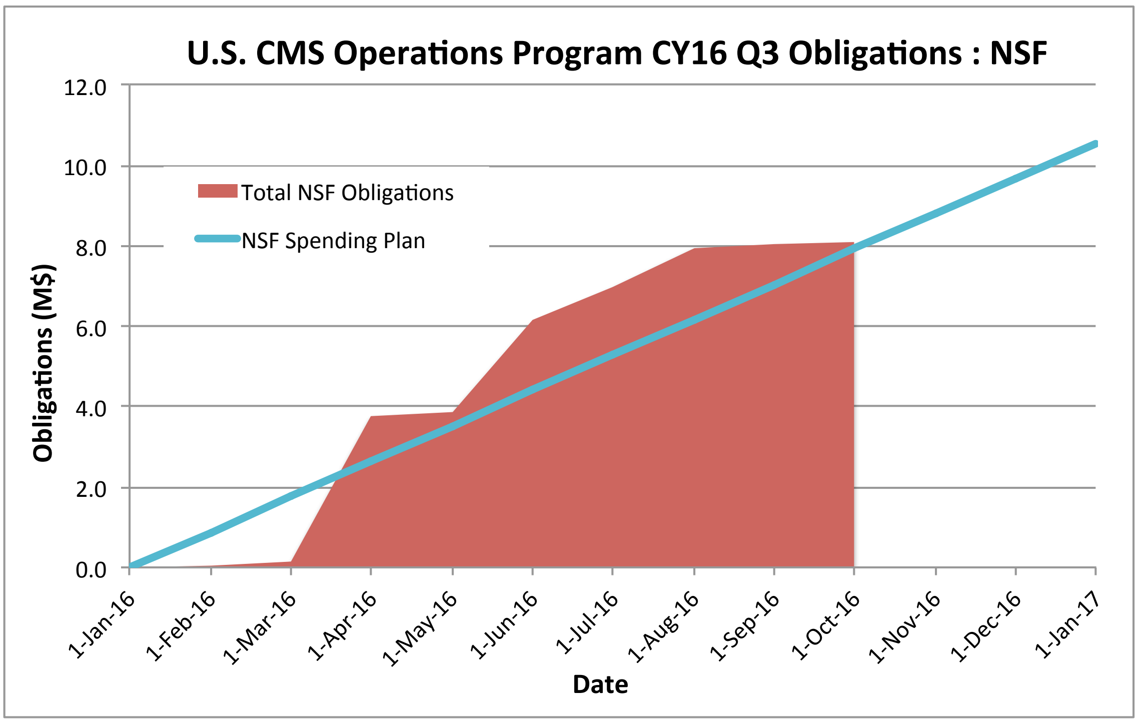
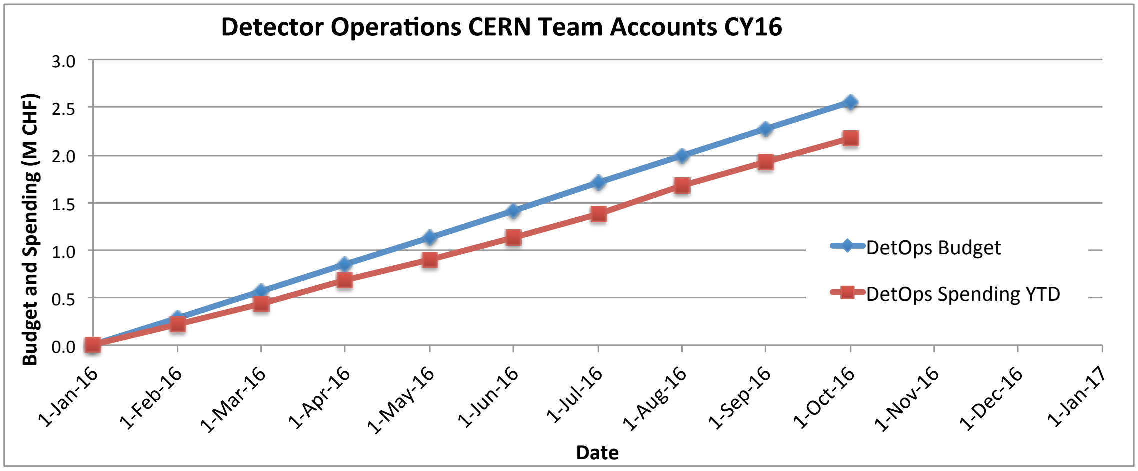
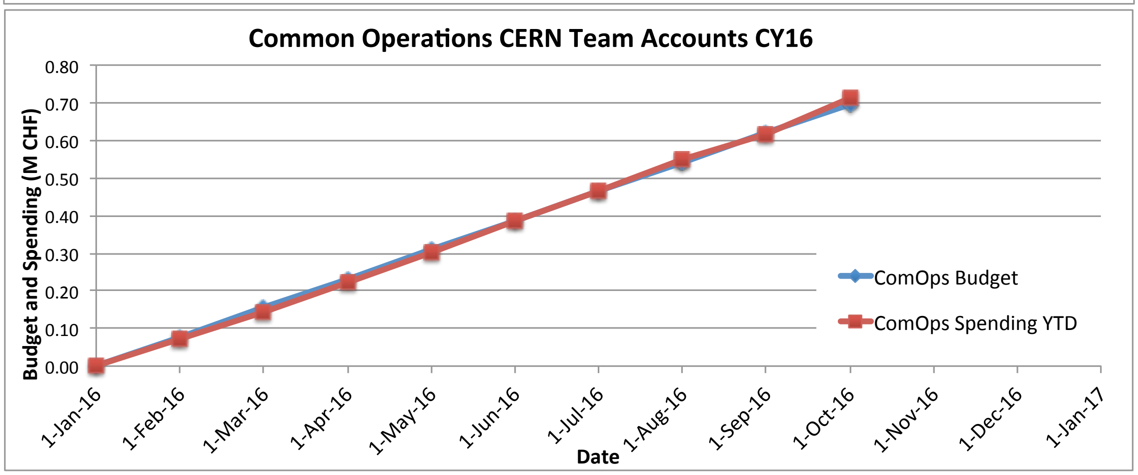


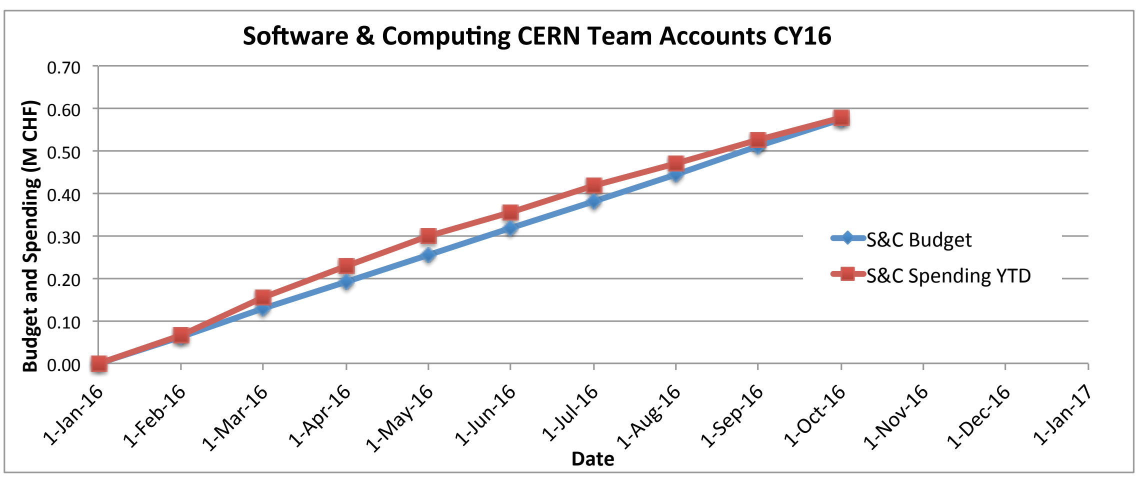

Figure 6: Obligations and spending plan for NSF funds. The spending plan is indicated with the assumption of equal monthly increments as a rough guide.



Detector Operations CERN Team Accounts CY16
Budget and Spending (M CHF)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1-Jan-16
1-Feb-16
1-Mar-16
1-Apr-16
1-May-16
1-Jun-16
1-Jul-16
1-Aug-16
1-Sep-16
1-Oct-16
1-Nov-16
1-Dec-16
1-Jan-17
Date
DetOps Budget
DetOps Spending YTD

Common Operations CERN Team Accounts CY16
Budget and Spending (M CHF)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1-Jan-16
1-Feb-16
1-Mar-16
1-Apr-16
1-May-16
1-Jun-16
1-Jul-16
1-Aug-16
1-Sep-16
1-Oct-16
1-Nov-16
1-Dec-16
1-Jan-17
Date
ComOps Budget
ComOps Spending YTD

Software & Computing CERN Team Accounts CY16
Budget and Spending (M CHF)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1-Jan-16
1-Feb-16
1-Mar-16
1-Apr-16
1-May-16
1-Jun-16
1-Jul-16
1-Aug-16
1-Sep-16
1-Oct-16
1-Nov-16
1-Dec-16
1-Jan-17
Date
S&C Budget
S&C Spending YTD

## Detector Operations

During the third quarter of the 2016 spending year, the LHC and the CMS experiment have performed admirably, exceeding expectations in both the luminosity delivered and recorded. Below we review the status of various US contributions to the detector.

### BRIL

The operations of the Pixel Luminosity Telescope (PLT) went smoothly during the last three months. The monitoring and alarm tools are working and allowing fast turnaround in critical situations. The PLT now provides full hit-information for track reconstruction at the significantly higher rate needed to quantify non-luminosity contributions and to obtain a cross check luminosity value.

The PLT is now able to measure sources of background that correlate well with similar measurements performed by the beam conditions monitoring systems. This has been confirmed by study of a fill which included beam gas manipulation. The PLT can measure it in two ways, the occupancy of the PLT in non-colliding but filled bunches, and the occupancy of the PLT preceding a bunch train. The PLT has been prepared to publish online background measurements in parallel to the BCM1F that experiences efficiency degradation due to radiation damage.

Two telescopes in one quadrant are dead and a spare quadrant has been assembled and placed in the laboratory at CERN for further testing. The port card which is responsible for the communication with the detectors is a potential source of failure and three replacement cards are in production. The luminosity measurement quality is continuously checked and values are made accessible for data analyses from a database. The 5% differences in the luminosity calibration between 2015 and 2016 is still under investigation and multiple sources such as changes in beam orbit and profile, details of the VdM scan and changes in efficiency of the luminosity detectors were considered. The change in the beam profile is a likely cause still under investigation as it may also be the source of the CMS/ATLAS difference in 2016.

Table 1: BRIL Metrics

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

Table 2: BRIL Milestones

| Subsystem | Description | Scheduled | Achieved |
|---|---|---:|---:|
| BRIL | Recommission Hardware | March | March |
| BRIL | Ready to deliver Lumi | May | May |
| BRIL | Provide online beam background measurement | October | |
| BRIL | Improved Lumi Numbers for 2016 | December | |
| BRIL | Recover telescopes | EYETS 2016/17 | |

## Tracker

### Pixels

For the pixel detector, only small repairs and maintenance have been needed this quarter. The Phase 1 upgrade pilot detector has been included in global running, and we are learning how to operate the new DAQ components. Notably, the use of the mini-DAQ by the tracker group has been pioneered due to the work on the pilot detector. We are also training new people in the commissioning and operations of the Phase 1 detector with test stands and for the expected arrival of the first two Phase 1 forward pixel half cylinders.

### Strips

The hardware issue of dynamic efficiency loss in the first layer of the Strip detector has been solved. A specific setting in the readout chip configuration was needed to address the problems. The chip designers are studying the setting in more detail, and we are tuning the tracking simulation for the fix. We are studying noise that persists after collisions. The noise creates non-track clusters during cosmic running and therefore is a nuisance. The strips also have the usual maintenance issues with power supply replacements, etc.

Table 3: Tracker Metrics

| Metric | Pixels | Strips |
|---|---|---|
| % Working channels | 98.7 | 96.5 |
| Fraction of dead time attributed | 18% | 15% |

Table 4: Tracker Milestones

| Subsystem | Description | Scheduled | Achieved |
|---|---|---|---|
| Tracker | Ready for Physics | May | May |
| Tracker | Pixel Phase 1 ready to install | Nov | |

## ECAL

The operation of the ECAL achieved its performance milestones in the first quarter of 2016. The second and third quarters have thus been devoted to maintaining the excellent performance. Overall this has been done but there was a significant incident in July that caused concern. The cooling of the MARATON low voltage supply for EB SM 17 failed and the MARATON interlock did not set, causing a dramatic increase in temperature. On-call U.S. staff came in within 20 mins to fix the problem. A dual interlock system with redundancy to mitigate a such a failure has now been implemented. Live channel performance and resolution performance metrics have been maintained. A re-reconstruction of the data is planned in the fall which will improve the ECAL calibration to better than 2015 levels and to the best that it has ever been due to the larger statistics that is now available.

Table 5: ECAL Metrics

| Metric | Performance |
|---|---|
| Fraction of channels operational: EB | 99.07% |
| Fraction of channels operational: EE | 98.71% |
| Fraction of channels operational: ES | 99.75% |
| Fraction of dead time attributed | 26% |
| Resolution performance | Excellent |

Table 6: ECAL Milestones

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

## HCAL

During the third quarter of 2016, the HCAL Operations group focused on completing the commissioning of the new hardware installed during the 2016 year-end technical stop (YETS), and on acquiring good data. The HCAL performed extremely well through September 2016 and only 26 $pb^{-1}$ of data was lost due to HCAL problems, of the 32 $fb^{-1}$ delivered (less than 0.1% ).

During the 2016 YETS the HCAl group installed a split readout from one PMT box for HF where the signals from 22 PMTs go both to the current QIE8 front ends and a prototype Phase 1 upgrade HF QIE10 front end. This has enabled HCAL to obtain operational experience with the HF Phase 1 upgrade electronics before it is installed in the 2017 extended year-end technical stop (EYETS). During the September technical stop, the HCAL group installed and commissioned a small system on the Castor table located close to the beam line to study radiation damage to new scintillators that might be used in a possible replacement of some of the HE scintillator during Long Shutdown 2 or as scintillator for the Phase 2 Upgrades. This system uses prototype Phase 1 HE electronics and will enable HCAL group to gain valuable operational experience with this new electronics as well.

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

**Milestones for this Quarter**

Work out a resource loaded schedule for EYETS work by July.
Achieved in July. The resource loaded schedule is being updated as appropriate.

June Milestone: Operate HCAL detector efficiently with goal to minimize of data due to HCAL to 1% or less, maintain calibration at 1-2% level with efficient noise rejection and improved 25ns energy reconstruction.
Calibration achieved by end of May, however only at a 3% to 4% level. Calibration and energy

reconstruction improvements continue.

Metrics: Fraction of channels working:
HF: 2 channels out of 1728 dead (99.9% working channels)
HB: 3 channels out of 2592 dead (99.9% working channels)
HE: 1 channel out of 2592 dead (99.96% working channels)
HO: 9 channels out of 2160 dead (99.6% working channels)
Total: 15 channels out of 9072 dead (99.8% working channels)
Fraction of downtime and data lost at certification due to HCAL
Goal: less than 1% for both. Achieved for third quarter: 0.08% downtime loss and 0.4% additional loss at certification.
Precision of absolute HCAL absolute energy calibration
Goal: 2% . Currently 3% to 4% .
Inter-calibration uniformity between individual HCAL towers (HBHE, HO, HF)
Goal 1-2 % . Currently 3% to 4% systematic differences between different phi symmetry methods. The plan is to reach goal values for 2016 data re-reconstruction campaign.

Table 7: HCAL Milestones

| Subsystem | Description | Scheduled | Achieved |
|---|---|---|---|
| HCAL | Ready for Physics | May | May |
| HCAL | Provide resource loaded schedule for EYETS work | July | July |
| HCAL | Prepared for HE/HF front end electronics installation | Dec | |
| HCAL | Complete Rad Dam studies | Dec | |

## EMU

The CSCs have been operating well, causing very little downtime to CMS during the last quarter. The peak instantaneous luminosities encountered were considerable higher than anticipated, but the CSC system experienced no particular problems related to the high luminosity. Considerable work was done during the LHC technical stop in September to repair minor problems and maintain a high fraction of working channels.

New firmware was developed to help the recover automatically when the optical outputs are affected by SEUs. The deployment of this firmware was limited due to some problems encountered writing to some of the EPROMs in the DCFEBs. These problems were investigated in the technical stop, but there is not yet a clear understanding. A bit less than 1% of the DCFEBs are currently disabled due to EPROM issues.

After an extensive analysis, the HV settings on wire groups in all chambers were adjusted to make the gas gains much more uniform. The gains were measured after the corrections and showed that the adjustments were very successful with very few outliers, which have been corrected further. This is a prelude to potentially reducing the gas gain in all chambers in order to improve longevity still preserving efficiency.

A new segment-finding algorithm for CSCs was released in the official CMS software in late July. The new, conceptually simpler, algorithm uses roads to locate the hits to assign to a segment, and specifically provides improved pattern recognition in conditions of high occupancy (from e.g. showering muons, or high pileup.) Benchmarking against the default algorithm on recent high-luminosity data is now underway, with the objective of replacing the default algorithm in standard reconstruction before LHC running in 2017.

A plan is still on track for preventing cooling leaks in ME1/1 with epoxy sheaths around the joints in the cooling pipes. The technical method was endorsed by CMS technical coordination. The sheaths still need to undergo radiation testing and a full plan is being developed for treating one end cap during the approaching year end technical stop. Still, no new leaks have been observed since the original leak in November 2015.

Table 8: CSC Metrics

| Metric | Performance |
|---|---|
| % Working channels | 98.5% |
| Fraction of dead time attributed | 1% |
| Median spatial resolution | 127 $\mu$m |

Table 9: EMU Milestones

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

## DAQ

The DAQ system is pushed on all fronts to its limit due to CMS's desire to collect a maximum number of events and the unanticipated instantaneous luminosity of the LHC, with increased pileup and related increase in event size. Nevertheless, the DAQ system performed with negligible dead time. The downtime contribution of the DAQ system is $\sim$ 69 minutes during the reporting period. The reason for this larger than usual downtime were two independent human mistakes by the DAQ on-call and a PSX service which stopped responding. The documentation has been improved to avoid human mistakes in the future and a watch-dog service was deployed to monitor the responsiveness of PSX services.

Continued progress in our performance optimization of the event builder system allowed it to track the steep increase of the instantaneous LHC luminosity throughout the year. Figure 7 demonstrates that the system could build events with a L1 rate of 100kHz for events larger than 2MB (milestone 3). Note that event sizes of more than 1.5MB will only be reached next year after the upgraded pixel detector and HCAL readout electronics has been commissioned.

The Storage and Transfer System (STS) disk writing and reading performance has increased by 50% following recent firmware updates from the vendor. Nevertheless, a third unit was added to provide

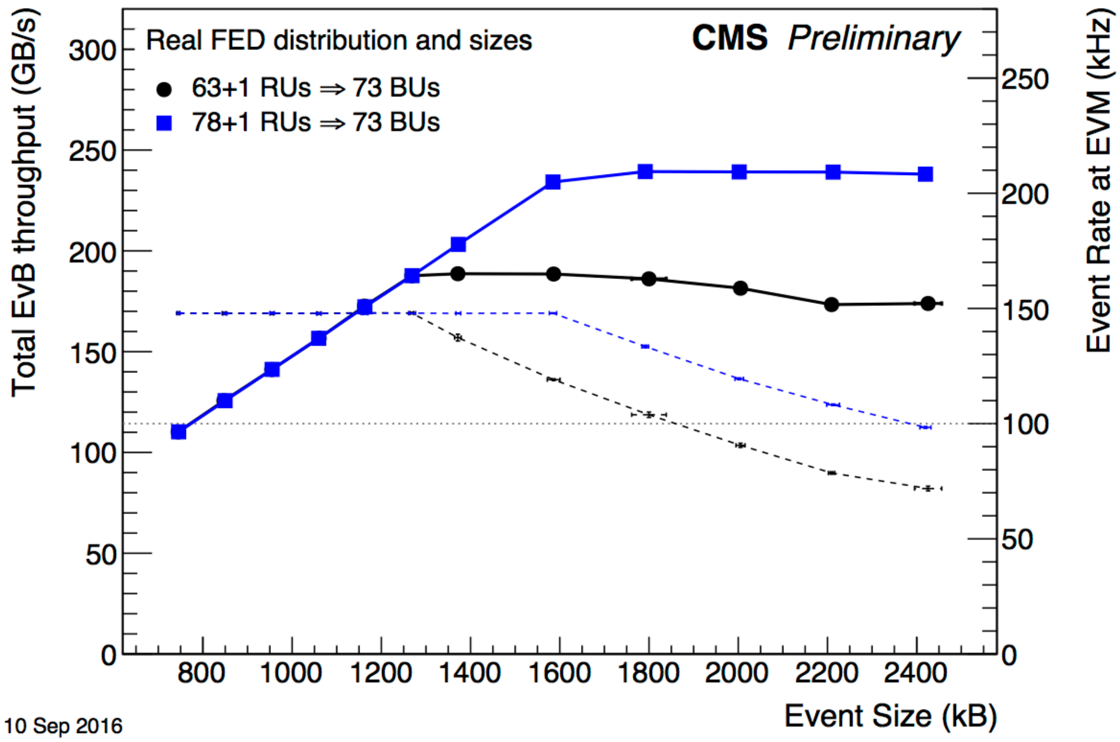



Figure 7: Total EvB throughput vs. event sizes for the current production FED builder (black) and if one splits the tracker and pixel FB which exceed the RU throughput of 4GB/s (blue).

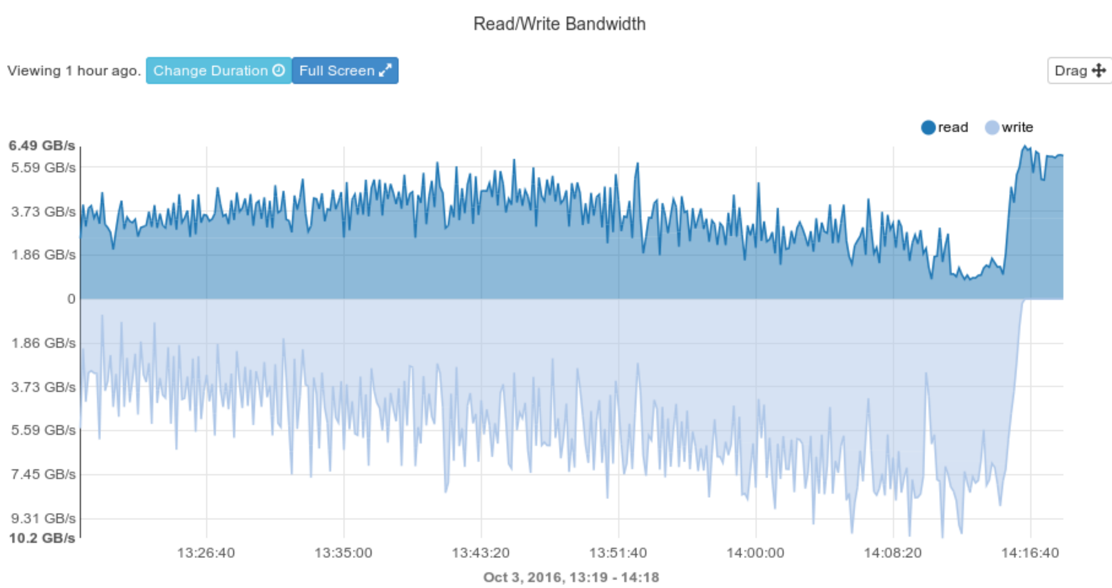



Figure 8: Read and write bandwidths from a test run. Reads and writes are balanced up to 4.5GB/s. At higher recording speeds the Lustre system gives priority to write. Read bandwidth increases to about 6GB/s when writing is stopped.

50% more disk space and another 50% boost in performance. Combined improvements provide plenty of headroom for special runs and the heavy-ion period where events sizes are larger than the nominal event sizes in $pp$ collisions or HLT recording rate will be greater than the standard physics rates. The expanded system can handle simultaneous writes (recording of HLT output) and reads (mostly transfers to Tier-0) of $\sim 4.5$ GB/s. At higher recording rates, the Lustre file system gives priority to writing while limiting the read speeds. Initial tests showed that recording rates could be increased to $\sim 6$ GB/s without significant delays on time-critical transfers.

The DAQ validation test stand was expanded to have $\mu$TCA based data sources and a small replica of the Trigger Control and Distribution System (TCDS) (milestone 2) that will be used to provide triggers to $\mu$TCA units. These new units extend the testing capability to include SLinkExpress links of the FEROL unit and allows testing of the new FEROL40 unit developed by the CERN DAQ team. Installation of a minidaq-like DAQ system in the detector assembly area (Bat 904) is complete and instrumental for commissioning Phase1 upgrade deliverables. The initial system will be used by HCAL and ECAL and later will be expanded to 8 units.

Table 10: DAQ Metrics

| Metric | Performance |
|---|---|
| Dead time due to trigger throttling | $\sim 0$ |
| Downtime due to DAQ | 69min (6% of total lost lumi) |

Table 11: DAQ Milestones

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

## Trigger

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

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

The Layer-1 Calorimeter Trigger (CaloL1), built by the University of Wisconsin group as a part of the complete Calorimeter Phase-1 Trigger Upgrade, has been in continuous operation since p-p data taking started in late April 2016, and has had no downtimes associated with it during the last quarter. Throughout this period, the CaloL1 online software (SWATCH) has been updated to version 0.11.0, and includes updates to the monitoring and thresholds for errors and warnings. The online Data Quality Monitoring (DQM) described in the previous report has been in use by the CaloL1 On-Call, Online Trigger Shifter, and L1 DOCs. Recently, the calibrations in the calorimeter chain were updated to improve trigger performance, this included CaloL1, CaloL2, a new ECAL spike killer, and new HCAL corrections for radiation damage.

**Endcap Muon Trigger**

The Rice University, Northeastern, and University of Florida groups have successfully supported and made incremental improvements to the Phase-1 upgrade for the end cap muon trigger for 2016 physics operations. A new data format was deployed in the muon port card and track-finder processor firmware to incorporate more robust transmission of CSC data over the optical links, leading to less acceptance loss when a particular CSC becomes non-functional. A new version of firmware for the Muon port card to support these data format modifications to the EMTF was generated in early July and was gradually deployed at P5 in August-September on all 60 MPC boards. Six MPC boards were replaced due to various problems with downloading and optical links. They are being investigated at Rice. Two spare MPC boards were shipped from Rice to CERN. The online software monitoring the optical links also now has warning and error level thresholds to alert the shift crew in case of problems. The firmware for the track-finding algorithm was revised to improve the efficiency for high $p_T$ muons and for di-muons, and also the BX assignment. Experts from the university groups have maintained on-call coverage of the system during the physics runs that took place during this quarter.

Table 12: Trigger Milestones

| Subsystem | Description | Scheduled | Achieved |
|---|---|---|---|
| TRIG | Restore RCT for Physics | March | done |
| TRIG | Stage 2 Layer 1 ready for Med. Lumi. Physics | April | done |
| TRIG | Commission Stage 2 Layer 1 for High Lumi. Physics | Dec | |
| TRIG | CSCTF Ready for physics | April | done |
| TRIG | Ship one uTCA Muon Sorter to CERN | April | done |
| TRIG | Commission initial uTCA Muon Sorter Firmware | July | |
| TRIG | Commission final uTCA Muon Sorter Firmware (Ghostbusting) | Dec | |

Table 13: Trigger Metrics

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

# Software and Computing

The eyes of the physics world were on ICHEP 2016, where the first significant analyses of LHC data from this year were presented in early August. With about a factor of five greater integrated luminosity than was available from the 2015 LHC run, there was significant pressure on the CMS Software and Computing systems to provide the necessary samples for physics analysis in time for the conference. This effort was a complete success, allowing CMS to present tens of new results. The operations teams are credited with the successful operations, processing many billions of events during this period. As usual, the U.S. CMS computing facilities played a key role in this effort, as they hosted the data and ran the jobs for event simulation and reconstruction and user analysis. But improvements never cease: at the same time, the facilities also made significant evolutions in their configurations and support, and CMS operations quickly turned its focus towards the production of samples for 2017 conferences. These efforts are taking advantages of earlier successful projects to deploy systems such as multi-core pilots, which can run multi-threaded applications, now including the simulation code. Longer-term developments continued, showing progress in new data management and workflow management products that will allow for more efficient and flexible use of facilities. Software releases are being prepared for the heavy-ion run and for the 2017 detector configuration, with some Phase-1 upgrades in place. A variety of exploratory research projects continue to show interesting results.

Table 14: Major milestones achieved this quarter

| Date | Milestone |
|---|---|
| August 2016 | Decommission GRAM CEs at Tier-2 sites |
| August 2016 | Upgrade HTCondor CEs at Tier-2 sites to version 8.4.x |
| August 2016 | Upgrade all Tier-2 sites to OSG 3.3+ |
| September 2016 | LPC-CAF job submission at Fermilab using CRAB3 |
| September 2016 | Completion of Tier-1 Storage transition to FNAL Data Management Services |

## Fermilab Facilities

The Fermilab computing facilities continued to provide reliable custodial storage, processing and analysis resources to U.S. CMS collaborators. An additional 4 PB of custodial data was written to Fermilab tape this quarter. Site utilization was high, with the Tier-1 facility providing over 31 million hours of CPU to CMS. In September, CRAB3 submission to the LPC analysis resources was commissioned, allowing U.S. CMS LPC users to use CMS's official analysis job management system on the LPC CAF. Prior to this users submitted work to the LPC compute resources via direct HTCondor submission and custom-made scripts. Now, users can use the same job automated submission tools for both LPC resources and grid resources, which is a great simplification.

Figure 9 shows the site readiness metrics for the Tier-1 during the quarter. Though this metric predominantly shows green for passing, there were several occasions of failed metrics during this period, mostly related to an upgrade and transition of responsibility of the Tier-1 tape dCache storage systems. Red marks during July and August were primarily due to failures in components of the old tape dCache version.

In September the tape dCache installation was upgraded to the same version (2.13) as was already

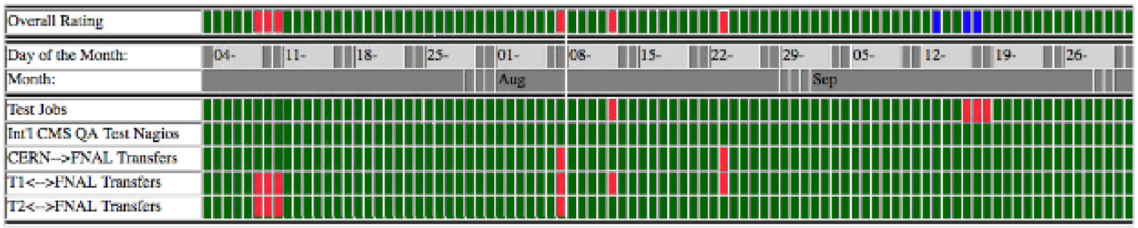



Figure 9: Fermilab readiness metric for the third quarter of 2016. Green indicates a passing metric, red a failing metric, and blue a scheduled downtime. The Fermilab Tier-1 computing center passed the metric during 93% of this quarter.

done in the last quarter for the disk instance. This allowed to move responsibility for all Tier-1 storage systems to the Data Management Services department in the Fermilab Scientific Computing Division, which already operates the CMS disk-only dCache and general purpose dCache for all other Fermilab experiments.

In August it was discovered that two of the high-availability transformer systems powering the Feynman Computing Center (FCC) were no longer able to auto-switch to generator backup. A two day downtime was necessary to preemptively repair the auto-switch functionality. All CMS servers and storage are housed in FCC, as are most of the lab's networking and computing services. Power had not been down in FCC since 2012. The downtime was well coordinated within the lab and with CMS during weeks prior, and impact reduced to only those two days. All critical Tier-1 services and analysis capabilities in the LPC returned to service as planned.

### University Facilities

The fourth quarter was a very busy time for the U.S. CMS Tier-2 facilities during a period of intensive data analysis and greatly increased central production activities for simulated data. High performance is expected from the sites at all times, but especially during the critical periods before major conferences. All of the U.S. CMS Tier-2 sites have operated successfully this quarter. On our two official performance metrics based on CMS test jobs, all sites were at least 90% “available” and 90% “ready”. The CMS goal for each of these metrics is 80%. The U.S. CMS Tier-2 centers delivered 43.8% of all computing time by Tier-2 sites in CMS (the U.S. commitment to CMS is > 25%), as shown in Figure 10. Most significantly, multi-threaded workflows have been run on U.S. sites at large scale for the first time last quarter, taking advantage of this long-term development effort in CMS.

As for progress on milestones and upgrades, the connection of the Tier-2 sites to the LHCONE VPN by ESNet is nearly complete, with one final site that is connected but still in a debugging phase. Connection of Tier-3 sites on request is also proceeding, with two sites in progress. After completing these sites, the roll-out of LHCONE to the U.S. CMS University Facilities will be complete, unless there are further requests.

Three major milestones were completed last quarter. All sites have decommissioned GRAM CEs, which were replaced earlier by HTCondor CEs and upgraded to HTCondor 8.4.x and version 3.3 of the OSG software stack. Four sites (one more than the previous quarter) have deployed IPv6-compliant xrootd, and all but one site have upgraded worker nodes to cvmfs 2.2.2 or later, which allows us to export AAA data federations.

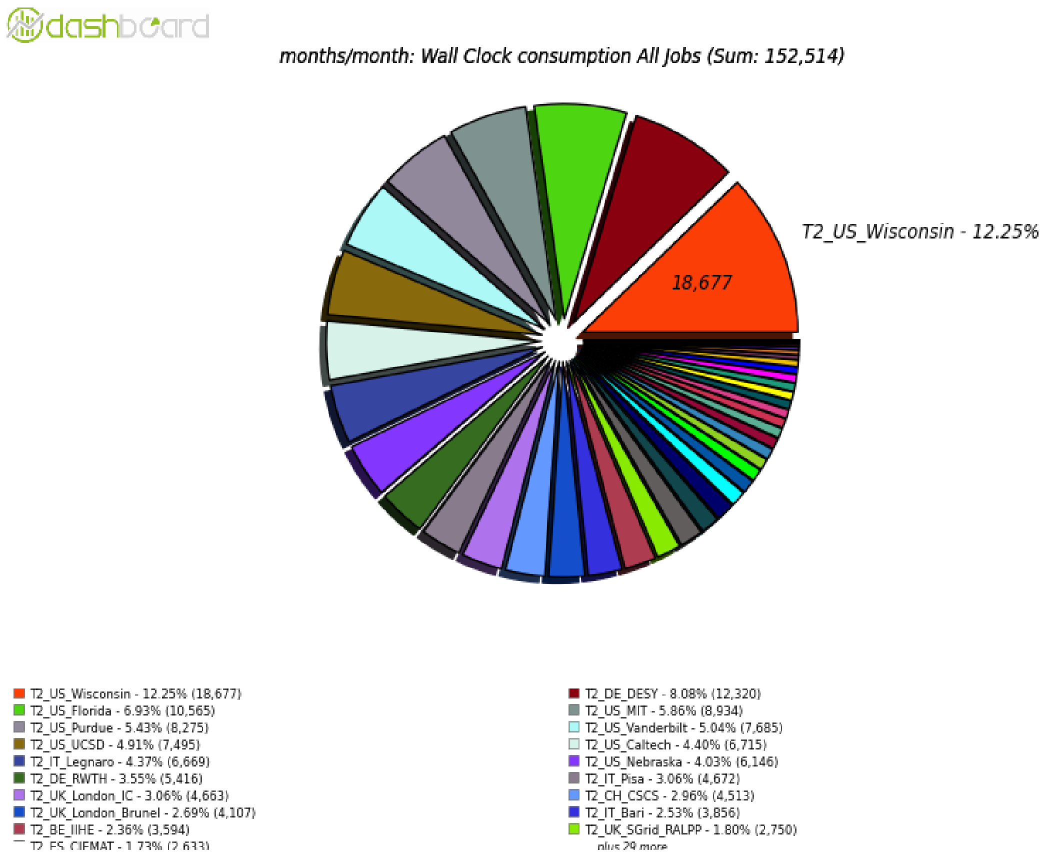



Figure 10: Percentage of total computing time delivered to CMS by Tier-2 sites world-wide, by site.

Eleven Tier-3 sites required assistance from the Tier-3 support team this quarter on issues related to OSG software upgrades, PhEDEx, networking and basic Linux systems adminstration. CMS Connect is up to 18 registered users, who have so far submitted a total of 11K jobs. The Tier-3 support team is also working on R&D for connecting campus clusters to the CMS global pool and preparing for the transition when Bestman support from the OSG ends.

## Computing Operations

The activities in computing operations during the month of July were still dominated by the processing of the incoming data and Monte Carlo production requests that were both used for ICHEP 2016 at the beginning of August. The month of August was dedicated to a cleanup of a number of non-urgent tasks that had accumulated and the first internal Computing Operations workshop was held in this context during the middle of August. The workshop resulted in a list of action items that identifies the short and middle term goals for operations. A number of shortcomings like the long production tails, difficult to manage workflow agent failures and needed monitoring improvements were identified and collected and are now more carefully tracked in the Computing Operations organization. The workshops had excellent attendance and the feedback was very stimulating, and there are plans on a follow-up meeting in the near future. During September activities slowly ramped up and finally towards the end of September the large re-reconstruction campaign of the 2016 data started, to provide a uniform processing of all 2016 data for 2017 winter conferences. The system reacted very well and the campaign got off to a good start.

The re-reconstruction campaign makes use of multicore pilots and runs re-reconstruction jobs as multicore applications. GEN-SIM generations still rely on single-core applications. Some multicore/single-core competition that sometimes leads to priority inversion is still under investigation.

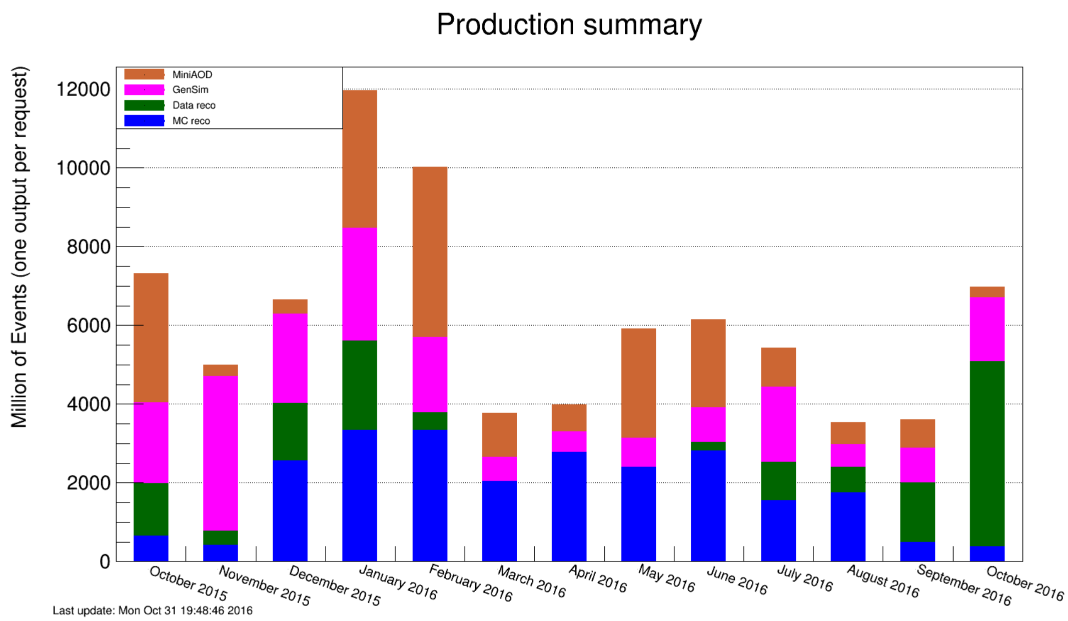



Figure 11: Number of events produced per month for the various types of production requests.

In Figure 11 the number of produced events for the various types of production requests are shown. During this quarter we reconstructed 3.8B MC events, 3.1B data events, and generated 3.3B MC GEN-SIM events and 2.2B MINIAOD events.

On the data management front, the big disk and tape deletion campaigns (freeing of order 30 PB of tape) have been successfully performed using Dynamo, the new dynamic data management framework. New and somewhat more aggressive policies for data cleanup have been implemented and have allowed for more flexibility in the data management, without noticeable impact on users and production.

## Computing Infrastructure and Services

Development work has continued on caching proxies as a means of advancing our previous work in distributed data federations. We continue to stress test the XRootd caching proxy at the single host level. This is done in collaboration with U.S. ATLAS (SLAC and UChicago) and OSG. It is a necessary step both for the Tier-3-in-a-box program and for a possible future deployment at Tier-2 scale. Presentations on these projects were planned for the October CHEP.

Several small improvements were made to the caching software to improve stability as a result of these tests. Investigations of memory management are ongoing, indicating problems in glibc in

RHEL 6. Planning for a larger scale distributed multi-host XRootd cache at a scale appropriate for a U.S. CMS Tier-2 have started. The scale envisioned right now is ten hosts with a total of up to 150 disks. The tests will be performed with hardware that is part of the Tier-2 program. In addition, an evaluation of the HTTP protocol as possible future replacement for the XRoot protocol has been undertaken.

GlideinWMS 3.3 was released with improved support for cloud computing resources. This release adds support for EC2 spot pricing and support for submission via GCE (Google Compute Engine). This release also adds support for a new feature which will allow CMS to submit jobs that, at run time, claim a range of core counts. This will allow us to increase the occupancy over time of our GlideinWMS pilots. Finally, GlideinWMS now supports front-end policies specified in external python files through a plugin type architecture. This makes it easier to express complex provisioning policies more easily.

Two improvements increasing magnitude and flexibility of our resources were put in place during the quarter. The ability to direct analysis workflows to the Fermilab LPC CAF (which is not grid accessible) has been put into production, as mentioned in the Fermilab Facilities report. At NERSC, we have commissioned the site for data re-reconstruction and Monte Carlo DIGI-RECO workflows. NERSC has been used in production for re-reconstruction with about 1,000 cores. With increased scale, NERSC could become a significant resource for U.S. CMS computing needs.

## Software and Support

During this quarter the software organization has produced 18 production releases in the CMSSW_8_0_X series. These introduced support for new CMS systems such as CTPPS and fixes for operational issues encountered in the 2016 data taking. Mitigation for the large baseline shifts due to highly ionizing particles in the tracker was developed for both the reconstruction and simulation at the end of July, but fortunately the problem was fixed on the detector so the code did not need to be deployed for prompt reconstruction. Instead, the simulation samples to be made in the fall will include a suitably luminosity-weighted component for the time period when the effect was taking place, along with the appropriate reconstruction code. In addition, the pileup scenario of the simulation will be changed in order to match the distribution for all of the 2016 data taking period.

The heavy-ion program is sufficiently prepared to use the same software release for its data run as the proton-proton program uses. Some of their specific needs, such as support for the ZDC detector and L1 trigger changes, went into the latest release of the 8_0_X series.

There have been six development releases in the CMSSW_8_1_X series, during this period. A longer than expected timeline to describe the Phase 1 upgraded detectors to be installed over the extended year end technical stop has delayed the final release. However, it is now understood that simulations of the 2017 detector will unlikely be needed for earlier than summer conferences, especially given the late start of data taking in May.

The testing of Geant4 v10.2 has been successful, as has testing in multi-threaded mode. We will use this latest Geant4 release in multi-threaded processes for 2017 simulations. Also of note in this development cycle is the near completion of Phase 2 of the multi-threaded framework, which is needed for many core systems like the newly available KNL HPC machines.

### Technologies and Upgrade R&D

The U.S. CMS Big Data in HEP project has prepared a first comparison of industry big data technologies, led by personnel from Fermilab and Princeton and the NSF-funded DIANA project. A current CMS dark matter search was used to compare the performance of the traditional ROOT-based analysis workflow with a parallel implementation of the same analysis use case using Apache Spark. The first results look encouraging, but more studies are needed to make statements about applicability of industry technologies for HEP analysis.

The project on Kalman filter tracking on parallel architectures showed continued progress on optimizing tracking for Xeon and Xeon Phi KNC platforms, in collaboration with the separate NSF-funded effort on this topic. Progress was also made on porting the parallel tracking algorithm to CUDA/GPUs and first tests with Xeon Phi KNL

There is also continued progress on the long-term effort to investigate future computing platforms for high energy physics. These include new benchmarking measurements on the latest Intel/ARM/PowerPC platforms, and engagements with industry on both hardware platforms and support software (e.g. compilers).

A project exploiting analytics techniques on Apache Spark and ElasticSearch has shown results from analyzing the monitoring data from the CMS data transfer system. The project provides a platform for CMS to aggregate data transfer system monitoring information and facilities to analyze the data.

Public presentations on all of this work were being prepared for the CHEP 2016 conference in October.