Status of CMS

Progress Summary Report for April 2013 RRB36

Since the last RRB in October 2012, the LHC program of pp collisions at $\sqrt{s}$ = 8 TeV was concluded and the first LHC p-Pb collision run at $\sqrt{s}$ = 5 TeV/nucleon was successfully accomplished. The CMS detector performed extremely well under increased pp luminosity, which reached a peak at $7.7 \times 10^{33} cm^{-2}s^{-1}$ corresponding to 39 interactions per crossing. The data taking efficiency in 2012 was 93.5%, which is 3% higher than in 2011.

Using the full pp dataset (~25 fb^{-1}) CMS updated and extended the results on the new boson. In the H → ZZ(4l) channel, a signal significance of 6.7σ is now observed, which is consistent with 7.2σ expected for the Standard Model Higgs at a mass of 125 GeV. In the other high-resolution mode, H → γγ, updated results were obtained on the signal strength, $\mu = \sigma/\sigma_{SM}$, which is now measured to be ~0.8 ± 0.3. The two high-resolution modes allowed independent determinations of the Higgs mass that are quite compatible: 125.8±0.6 GeV, in H → ZZ(4l); and 125.4±0.8 GeV, in H → γγ. The four-lepton channel permitted tests of the spin-parity of the new boson. From these studies, the pure pseudoscalar hypothesis is excluded at 99.8% C.L. and, for the first time, simple spin 2 models are excluded with greater than 98.5% C.L. Significantly, a strong indication of signal is seen in a fermionic decay mode of the Higgs for the first time, namely in the H → ττ channel, which is reported with a significance of nearly 3σ.

The new measurements of the spin-parity (J^P) assignments for this particle, coupled with the measured strength of the interaction of this particle with other particles, strongly indicates that the new particle is a Higgs boson, responsible for Electroweak Symmetry Breaking. While all of these measurements are consistent with values predicted for a SM Higgs boson, they still fall far short of the requisite precision to rule out all Beyond Standard Model (BSM) scenarios. Additional data from Run 2 of the LHC and HL-LHC will allow CMS and ATLAS to make decisive progress on most, if not all, aspects of this question.

Meanwhile, the direct search for physics beyond the Standard Model has been pursued. Particularly relevant are the searches for the Supersymmetric partners of the top and bottom quarks (stops and sbottoms), which are expected to be relatively light given their special role in natural Supersymmetry[1]. For stops (sbottoms) produced via gluino cascades, these searches have excluded gluino masses of up to ~1.3 TeV (~1.15 TeV), for LSP masses of less than 500 GeV. Searches for direct production of these particles without a gluino intermediary are underway. The Exotica analysis group has also updated many of their searches using the full 8 TeV dataset. No evidence for new physics was found thus far, but additional results are expected as the year progresses.

Precise measurements of Standard Model processes provide a complementary avenue to a possible discovery of new physics. The very large number of top quarks produced in the full 2012 dataset has been exploited to perform a test of CPT invariance by producing the most precise measurement to date of the top-antitop mass difference, $\Delta m_t = -272 \pm 196$ (stat.) ± 122 (syst.) MeV. CMS has also now made the most precise measurement of the ratio (R) of the branching fraction to bottom quarks (t→bW) to the branching fraction

[1] Natural Supersymmetry corresponds to those versions of Supersymmetry that provide a means for stabilizing the Higgs mass without excessive fine-tuning of the parameters of the model.

to all three types of quarks (t→qW; where q = d, b or s). The measured value of R is $1.023^{+0.036}_{-0.034}$, in very good agreement with the SM expectation.

In the heavy ions run, CMS collected about 31 nb^{-1} of integrated luminosity in proton-lead collisions. In addition we took a short run of pp collisions of about 5 pb^{-1} at 2.76 TeV that will be used as a reference for the interpretation of the PbPb data collected in 2011. The availability of the samples of PbPb, pPb and pp taken with the same detector with the same conditions will allow very detailed studies of strongly interacting matter at the highest densities. The data analysis has already started. The first results from the pPb pilot run resulted in the observation of the long range correlation between charged particles as a function of charged particle multiplicity. CMS has already observed similar effects in pp and PbPb data, and it was extremely interesting to see that the same effect is present in the matter produced in pPb collisions.

Long Shutdown 1 has started with an intense sequence of activities to open the detector for the first time in 3 years. The moving system for the disks and wheels of the magnet yoke is being improved in order to facilitate and speed up this operation in the future. Due to activation of materials, equipment removed from the underground areas is transferred to the Operational Support Centre in SX5, which includes an access controlled Radiation Protection zone. The large number of interventions aiming at services maintenance and modifications is now being started. The successful completion of the programme will require the foreseen common fund resources to be available.

After three years of operation, many sub-detector components, inaccessible while CMS is closed, require access and substantial maintenance effort to recover faulty parts and to improve robustness. A careful planning of these activities was established in 2012 and is now being monitored closely. New CSC and RPC muon chambers and electronics systems are being built to be installed during LS1. The upgrade of the photo-sensors and electronics of the Forward Hadron Calorimeter and the installation of new SiPM in the Hadron Outer Calorimeter is also foreseen in LS1. A fully integrated schedule developed by Technical Coordination includes installation milestones and a detailed work-plan.

The preparations for Run 2 in 2015 and beyond, at increased energy and luminosity, involve all CMS areas. In the trigger area the focus is to preserve sensitivity for electroweak scale physics and for TeV scale searches similar to what was achieved before LS1, while keeping the trigger rate within acceptable bounds. The first stage of the L1 trigger upgrade will be implemented during LS1 and the full upgrade is expected to be concluded one year later. Improved HLT trigger algorithms will also be developed in order to cope with the expected increase of trigger rate (relative to the 8 TeV run, at 13 TeV and luminosity $2.10^{34} cm^{-2} s^{-1}$ a factor ~5 higher rate is expected). In parallel, a new DAQ system will replace the present system that has reached the end of its lifetime.

The expected increased rate puts the computing systems in the period post-LS1 under tremendous pressure. Preliminary estimates indicate that for the highest foreseen LHC luminosity, and with the present offline reconstruction software, the required computer power would be a factor 12 higher than available today. An enormous challenge is being faced by different CMS areas, (namely trigger, offline reconstruction software, physics validation, and computing), to reduce this factor as much as possible by improving our tools. Nevertheless, preliminary estimations of the achievable improvements indicate that an increase of the GRID computing resources by a factor of the order two may be required to keep the present physics acceptance.

To retain and extend the CMS capabilities to higher luminosities in the 2020s in the framework of the HL-LHC, the existing systems need to be upgraded or replaced. This will require a vision nearly as ambitious as that of the original LHC programme. R&D and studies for the Phase 2 upgrades of the CMS detectors are being pursed actively. By the end of 2014 we foresee to finalize a Technical Proposal describing the whole upgrade program, including physics performance studies, a technical description of the new detectors, and initial cost estimate and timelines. This will be followed in 2016 by detailed TDRs for each big sub-detector or sub-system upgrade, with more complete information.

Magnet and Infrastructure

For the period since the last report, the CMS common systems and infrastructure worked well, without failures causing significant data losses. Two further disconnections of the magnet cold box occurred in the shadow of interruptions in data-taking, once again caused by a poorly managed operations (outside CMS control), the second one by a series of technical faults. Further measures have been taken to better avoid such unintentional disconnections. However, the recognition during 2012 that re-connection can only safely be done at around 2T, implies a minimum magnet recovery time of 12 hours and raises serious concerns about the number of ramping cycles of the magnet these incidents cause. This has triggered studies of how to make the cryo-system of the magnet more robust against failures.

The proton-proton run ended just before the end-of-year CERN closure, during which CASTOR was installed on the negative end of CMS and both ZDC calorimeters were installed in the LHC tunnel, in preparation for the Heavy Ion Run. The installation of CASTOR was an excellent "engineering test" of procedures for working in an activated environment. Despite some technical problems prolonging the installation, both the individual and the collective dosages could be kept within very reasonable limits.

Long Shutdown 1 has started with an intense sequence of activities to open the detector for the first time in 3 years. The CASTOR and HF Calorimeters and TOTEM T1 have been dismounted, taking the opportunity to install permanently mounted winches with fixed diverter pulleys to reduce risk in the process of moving the HF calorimeters to their garages.

During the opening of the magnet yoke, the moving system for the disks and wheels of the magnet yoke system is also being fitted with a much more sophisticated guiding system. This major upgrade was designed to reduce both the risk and timescale needed to open the detector, an important element of the strategy to enable the installation of the Phase 1 pixel tracker upgrade in an end-of-year technical stop. Facilities in the detector Operational Support Centre in SX5, including the access controlled RP zone, are being completed just in time to accept equipment being dismounted from the underground areas. The ventilation and air conditioning system for the pixel lab was somewhat delayed but is currently under commissioning. Facilities for replacement and testing of electronics in the muon and HCAL systems will also be ready when needed.

Both YE4 compound shielding disks have been filled with a special hematite and boron loaded concrete developed with the help of CERN GS dept. As soon as CMS is open the team responsible for heavy movements will start a vertical test assembly of the three elements of YE4 to verify this complicated procedure before underground assembly of the disks.

A complete initial set of elements of the 45mm inner diameter central beampipe (required for the Phase 1 pixel upgrade) have now been machined at the manufacturer's premises. Electron beam welding will start soon and delivery of the pipe to CERN is expected in August, slightly ahead of schedule.

The largest investment of resources is in services maintenance and modifications. The complete revision of the P5 cooling plants will take until early June, with temporary chillers providing cooling for the pixel tracker cold room and the computing resources of the High Level Trigger "farm". New or revised cooling and dry air plants and distribution pipework are being installed to support the lower temperature operation of the silicon strip tracker, essential after LS1, and the requirements of the new detector layers of the muon system upgrade. Re-cabling is about to start for a major revision and extension of the UPS system to improve electronics robustness against power disturbances. At present, the LS1 activities are on schedule, but successful completion of the programme will require the foreseen common fund resources to be available.

Run Coordination

The LHC delivered 23.2 fb^{-1} during the 2012 pp run and CMS recorded 21.8 fb^{-1} corresponding to 93.5% efficiency. The data taking efficiency has increased by 3% with respect to 2011 due to the automation of recovery procedures from known problems, the improvement of the alarms and monitoring tools, the implementation of dead time mitigating measures, and more experienced shift crews. The dead-time in CMS was reduced by 50% compared to 2011 and the down-time decreased by 20%. The data validated for physics analysis corresponds to 90% of the recorded data, similar to past years. The percentage of validated data would have been higher were it not for some run time losses due to misguided operations discussed in the previous section.

During the last period of the year the LHC was providing instantaneous luminosities close or above $7.5 \times 10^{33} cm^{-2} s^{-1}$, being the record luminosity $7.7 \times 10^{33} cm^{-2} s^{-1}$ which is 77% of the nominal LHC luminosity. The peak average pile up was 34.5 interactions per crossing.

During the whole year the CMS online luminosity was closely monitored comparing the HF luminosity with the pixels and the BCM1F luminosities to understand possible drifts on the HF gains. A second VdM scan took place in November with better beam conditions with the ultimate aim to reach a precision in the luminosity measurement of 2%.

At the end of 2012 the LHC did machine development studies to understand the performance of the machine with 25ns beams. The machine delivered collisions with 396 bunches spaced by 25ns at √=8TeV with very low emittances (1.8μm to 2.3μm which corresponds to half of the nominal emittance for 25ns beams). These fills were very useful for CMS to understand the detector behavior with bunch spacing of 25 ns as foreseen after Long Shutdown 1.

The heavy ion run took place in January-February 2013. The LHC delivered 32.0 nb^{-1} that CMS collected with 98.1% data taking efficiency. The run was extended until 14^{th} February to allow ATLAS and CMS to collect a reference pp sample at √=2.38TeV. The LHC delivered to CMS 5.51μb^{-1} (5.41μb^{-1} recorded) during the low energy pp run. During this period two VdM scans were performed for both pPb and Pbp configurations.

At the end of the run CMS took cosmics data to have a reference sample for the muon trigger components to compare to during LS1.

Tracker

The silicon pixels and strips systems have both maintained very high levels of performance and reliability throughout the 2012 pp and the 2013 p-Pb run. Accumulated failures in the pixel system will be recovered in 2013 when the pixel detector is extracted. As an investment for 2015, considerable effort has been devoted in the backend firmware and automatic recovery procedures of pixel and strip systems reducing downtime and dead-time close to zero during the p-Pb run.

The Tracker Detector Performance Group has updated the results of the detector condition calibrations for reprocessing of the collision data collected. A more robust algorithm has been used to detect and mask noisy and inefficient channels in the Strip Tracker, reducing the fraction of masked single strips by more than a factor of 3. The alignment and reconstruction parameters of the Tracker detector have been recomputed, including Lorentz angle evolution with radiation.

The Tracker offline teams are also working for the preparation of the 2015-and-beyond run by reviewing the existing reconstruction, monitoring and calibration tools and working on an improved detector simulation to take into account the increasing radiation dose and the larger occupancy. Simulation studies for Phase I and Phase II Upgrade are on-going.

During LS1 improvements to cooling and humidity controls are necessary to allow lowering the operating temperature of the tracker. Refurbishment of the C6F14 cooling plant is on-going according to schedule, to allow future low temperatures at higher radiation-induced power. The Tracker interfaces sealing against humid gas infiltration are insufficient. We developed and prepared a simple engineered approach to the problem, backed-up by thorough testing on mock-ups. The whole interface area inside the cryostat will be covered by industrial vacuum barrier foils, and flow of dry gas will increase tenfold provided by a new dry gas membrane plant installed on the surface. Humidity will be monitored with new radiation-tolerant sensors and a dedicated sniffer system pumping gas for analysis in an accessible area.

Electromagnetic Calorimeter

The CMS ECAL, comprising barrel, endcaps and preshower detectors, operated reliably throughout the 2012 (proton-proton) and early 2013 (proton-lead) running periods. The data quality was excellent, with more than 98% of the delivered luminosity declared good for physics in 2012, and close to 100% in 2013.

The number of active channels – ~99% in the barrel/endcaps and ~97% in the preshower – was stable during 2012-13.

The ECAL performance, as measured by the electron energy scale and resolution and Z→ee mass resolution in both barrel and endcaps, is excellent and very stable in time following a dedicated calibration using the full 2012 CMS dataset.

The new solid-state laser used to monitor the crystal response proved to be reliable and stable throughout 2012. A second has been ordered, to provide full redundancy for future running.

The electronics noise in the barrel has increased slightly (at the expected rate) due to an increase of the APD (Avalanche PhotoDiode) dark current. Although the electronics noise in the endcaps has remained constant the effective energy-equivalent noise in both barrel and endcaps has increased due to the reduction in light output of the crystals, caused by LHC irradiation. These effects have been implemented in the CMS simulation for future studies.

A limited set of ECAL hardware interventions is planned during LS1 with the possibility to recover a large fraction of the currently inactive channels. In addition, the opportunity will be taken to consolidate many parts of the online (trigger and DAQ) and offline software in order to prepare for 13 TeV running, and provide a more robust system in the long term.

Looking further ahead, studies of the ECAL longevity should reach a conclusion in the coming months and decisions will be made on the optimum path to take for operation in Phase II of the LHC (up to 3000 fb^{-1}).

Hadron Calorimeter

After the successful operation of HCAL detector during proton-proton run in 2012 and Heavy Ion run at the beginning of 2013, the group is now focusing on the following four LS1 tasks:

1. Replacement of present, thick window, single anode photomultipliers on HF with new, thin window, multi-anode PMTs. The replacement of photomultipliers will reduce rate of punch-through window hits. All needed PMTs and base-boards have been delivered to CERN. Quality Control station has been set up in B904.

2. Replacement of boards responsible for clock distribution in all HBHE and HO Clock and Control Modules (CCMs). CCM resides in each Readout Box and is only accessible when CMS detector is open. The installation of new CCM modules will allow us to eliminate data loss caused by Single Event Upsets (SEUs) experienced during 2011-2012 running period. The production of all boards has been completed on the schedule, and all the boards were received at CERN in early January. QC tests at 904/H2 started (by now close to 50% of all boards have been tested/OK). Installation Readiness Review has been successfully passed on March 6, 2013.

3. Replacement of all HO HPDs with SiPMs. This replacement will significantly improve Signal/Noise ratio of HO readout and allow HO to more efficiently identify muons. All SiPM components have been received at CERN, and testing of the assembled packages has been completed. Results indicate high quality of components with only handful of parts requiring repair.

4. Replacement of VME based HF BackEnd crates with crates based on uTCA industrial standard. This replacement is the first step of Phase1 upgrade of HF electronics, which will improve noise rejection and granularity of HF readout and trigger. Very promising results of tests of the new data acquisition board (uHTR) have been obtained during Heavy Ion run, including comparison of data obtained with present system (VME). We have obtained positive feedback from Procurement Readiness Review on Feb 6, 2013. HF uHTR parts have been purchased in March 2013 and production of prototype modules is taking place in India.

In addition, there is ongoing effort to understand performance of HCAL for High-Luminosity LHC operations in post-LS3 era. We have launched studies to determine effects of radiation damage of HF quartz fibers and HE scintillators on physics performance of HCAL. In particular, an investigation of light yield loss and light transmission loss in scintillator tiles used in HE (after its exposure to neutron flux $(1.5 \pm 0.3)\ x10^{15}$ n/cm^2) is underway. The irradiation was carried out at the IBR-2M reactor at JINR (Dubna). Preliminary results are expected by CMS Upgrade week in Hamburg (June 2013).

Muon Detectors

Endcap Cathode Strip Chambers (CSC):

The CSC muon system ran smoothly through the late-2012 and early-2013 data runs, and attention is now focused largely on the LS1 upgrades, i.e. the creation of the new ME4/2 muon station, and overhaul of the electronics used in the high-rate inner ME1/1 muon station. The CSC group has been reorganized to create additional task forces that concentrate on particular aspects of these upgrades.

The chamber factory at Prevessin B904 set up to build 72 new ME4/2 chambers continues to run smoothly, building about one chamber each week. Enough chambers have been built to install one endcap, and the production of chambers for the second endcap proceeds on schedule.

The ME1/1 electronics improvement project is in high gear. The new cathode readout (DCFEB) boards passed all of their tests with flying colors and are now in full production, as are low voltage distribution boards (LVDB7) for these chambers. However, a review at the end of February found that several developments need to succeed in the next few months before a final decision is to be made on the replacement by the middle of June; these are described as follows:

- Last Fall it was decided to abandon development of a semi-custom chip that would have allowed distribution of clock and control signals to the DCFEB boards via optical fibers, and to make use of some of the existing SCSI cables for this purpose. This has required development of a new patch panel interface board (PPIB). Prototypes of those boards have just become available and are being tested.
- Prototypes of new readout boards (ODMB) are almost ready, and will be tested during the next 2-3 weeks in full chain tests at CERN and elsewhere.
- Examination of the YE1 nose and in particular the "choke point" needs to show that routing of optical fibers within the existing infrastructure (cable trays, etc.) can be accomplished.

Barrel Drift Tubes (DT):

The DT collaboration is preparing for a substantial work of maintenance and upgrade during the Long Shutdown 1 (LS1) in 2013/14. The original robustness of the system has deteriorated and many small local interventions are needed to restore it, even though, thanks to the constant care provided by the on-site operation team, the fraction of good channels of 98.8% has still been very high during the 2012 data taking, and the downtime caused to CMS as a consequence of DT failures was less than 1%.

The upgrade activities planned for the LS1 evolve in good accordance to the schedule, both for the theta Trigger Board (TTRB) replacement and for the Sector Collector (SC) relocation from UXC to USC. The TTRB work aims at reconstituting the stock of spare boards for the long-term operation of the chamber Minicrates. With the SC work, data and trigger primitives from each of the 250 DT chambers will be available in USC on optical fibers. This work is the corner stone for any long-term upgrade plan of the DT system. The project was reviewed in an ECR by a panel of experts from the CMS Electronics and Technical Coordination teams in June. Since then, measurements on the signal transmission from the chambers up to the USC electronics have been performed with the prototypes of the new electronics, in order to optimize the design parameters of the optical transmission links. The project was reviewed in an ESR in February, with very positive outcome.

Resistive Plate Chambers (RB and RE):

The RPC system was operating very smoothly in the 2012 run, showing an excellent stability and very high data tacking efficiency. During 2012 the percentage of operating channel was about 98.2% (98.4 % in 2011). Most of the hardware problems will be fixed during LS1.

A new HV calibration scan was done at the beginning of the 2012 data taking to define the high voltage working point of every chamber. The results were very encouraging, showing that most of the chambers have a very stable plateau curve with a stable efficiency and cluster size at the nominal working point.

During the 2012 the stability of the endcap chambers was improved. In particular we implemented a faster HV working point correction with atmospheric pressure, in order to follow fast pressure oscillations.

The upgrade project accumulated a delay of about 6 months due to a problem in the cleaning procedure of the bakelite foils produced by an external company. The problem was found by our experts and solved in few months. The CMS Korean group is in charge for the gap production and the first batch of 80 gaps was delivered in October 2012 at the three test sites (Ghent, Mumbai/Chandigarh and CERN). Prototype tests for the on-detector and off-detector electronics have been completed and the full production has started.

Muon Alignment:

When CMS opens, major components of the Link and Barrel Alignment systems will be removed. This operation, besides allowing for maintenance of the detector underneath, is needed for making interventions that will reinforce the alignment measurements and make the operation of the alignment system more reliable. For that purpose and also for their general maintenance and recalibration, the alignment components will be transferred to the Alignment Lab situated in the ISR area.

For the track-based alignment, the attention is focused on the determination of systematic uncertainties, which have become dominant, since now there is a large statistics of muon tracks. This will allow for an improved Monte Carlo misalignment scenario and updated alignment position errors, crucial for high momentum muon analysis such as Z′ searches.

Trigger and Data Acquisition

L1 Trigger:

The L1 Trigger group successfully deployed a new menu for the heavy ion run in 2013, which included inputs from the Castor and ZDC calorimeters as well as the beam shower and beam halo counters. A special L1 Accept signal was created for the TOTEM experiment for their reduced readout rate. The Technical Design Report for the L1 Trigger upgrade is well advanced. It has been reviewed internally by CMS, and a presentation to the LHCC was made in March. The focus of the upgrade is to preserve sensitivity for electroweak scale physics and for TeV scale searches similar to what was achieved before LS1. It will address this by improving the isolation of electrons, photons, and muons; improving the identification of hadronic tau decays; improving the muon p_T resolution; improving jet-finding with pile-up subtraction; and offering a global trigger menu with a greater number of triggers and with more sophisticated relations between the input objects (e.g. invariant mass). The electronics design will be based on the Micro-TCA (**μTCA**) telecommunications architecture with state-of-the-art Xilinx Virtex-7 FPGAs and optical links operating at up to 10 Gbps, offering much improved flexibility compared to the current trigger system.

Trigger Coordination:

The HLT ran successfully in the last months of pp data taking of 2012, with initial luminosities exceeding 7×10^{33} Hz/cm^2, corresponding to a Pile-Up of around 35. The latest menu developments, in particular the PU subtraction in the Particle Flow jet algorithms, allowed to control the non linear behavior of multi-jet and HT algorithms up to the highest luminosities. The average "core" (promptly reconstructed) data rate was around 350-400Hz, while the "parking" data rate was increased to almost 600Hz, improving in particular the acceptance of the VBF channel for Higgs studies. Parking data is being reconstructed profiting from the long shutdown in 2013-14.

The CPU time per event increased linearly with PU up to the highest luminosity, and the extended CPU farm allowed to always run without dead-time, and without moving to menus with reduced physics acceptance, that had been prepared for emergency.

The p-Pb run at the beginning of 2013 was extremely successful too. HLT menus were ready to cope with the different run conditions provided by LHC, with a low CPU load on the filter farm and with a typical output rate of 1.2 kHz, in full agreement with expectations.

The preparations for the operations at higher energy and luminosity in 2015 have begun. A thorough review of the physics objects used in the HLT, and of their use in the menus is under way. The aim is to have the online reconstruction as similar as possible to the offline one, to be able to put HLT thresholds closer to what is used in the final selection, reducing rates without affecting the acceptance. At the same time, the design phase for the updated HLT software infrastructure and for its service tools (monitoring, configuration) has started.

DAQ:

The online system, including computing infrastructure, Detector Control System (DCS), and DAQ has been deployed for pp physics data taking in 2012, as well as Heavy Ion physics in early 2013, with high efficiency (above 99%). Further automation in the run control of the DAQ has been implemented.

In order to use the online HLT farm as an opportunistic resource for offline data processing a cloud infrastructure has been installed on the HLT cluster. Initial tests with offline workflows on this HLT cloud have been done by the CMS computing group. Full-scale exploitation will require a re-configuration of the cluster network.

Progress was made in the definition and implementation studies of the DAQ2 system, which is foreseen to replace the existing central DAQ system during LS1. By the time the LHC restarts after LS1, the current computer nodes, networking, and storage infrastructure will have reached the end of their lifetimes (with the exception of the HLT nodes installed in 2011 and 2012). The new DAQ2 system will need to accommodate the readout of both existing and new μTCA based off-detector electronics and have the possibility to provide an increased throughput capacity. Design, implementation and tests have been done with a small-scale demonstrator system addressing the readout of the off-detector electronics, the event builder and HLT farm. The DAQ link connecting the μTCA based off-detector electronics (currently 6 Gpbs) has been implemented and tested. Evaluation of advanced networking technologies such as 10 and 40 Gbps Ethernet and 56 Gbbs FDR Infiniband and multi-core NUMA CPU architectures for the readout aggregation and event building and distribution are in progress.

Offline Software

The CMSSW_5_3_X cycle, in production at the time of last RRB report, has successfully accomplished its main mission to support data taking up to the end of the first LHC run, coping with the highest luminosities provided by the machine. It will be the legacy analysis release for 2012 data during 2013. While the physics performance of this release is frozen, we expect to be maintaining it, for the foreseeable future, for minor feature enhancements like the addition of new generator capabilities when requested.

The main development cycle has become the 6_X_Y series. CMSSW_6_1_0 was built on schedule before the Christmas break, providing an important benchmark point for the program of improvements to be carried out in 2013. Its key purpose is twofold: it is being used as a test ground for Geant4 optimizations which can be forward ported into the latest development release and it constitutes a stable code base on which the simulation for upgrade studies, a major milestone for 2013, is being built. A structured program of releases incorporating various scenarios, from a high pile-up phase 1 to a phase 2 straw man model, has been setup and is currently relying on 6_1_X as a basis.

In parallel, further developments are being integrated into the 6_2_X cycle, which also serves as a first entry point for upgrade developments. This release is expected to contain the latest version of Geant4, and all the most recent technical and algorithmic developments in the reconstruction code, targeting the completion of the adoption of the Global Event Description paradigm into CMSSW and the capability to handle the harsh pile-up environment expected for 2015.

Computing

Since the last RRB, all computing systems have performed smoothly and resource utilization levels have been high. The Computing Project is currently engaged in two separate, but equally important, tasks: finishing the preparations of 2012 data samples and preparing for 2015.

Starting even before the end of the heavy ion run, CMS has been performing the final pass processing of the 2012 data. Parked samples that did not require the final calibration were processed first followed by early and mid 2012 samples with final calibrations. The late 2012 samples with final calibrations have been submitted and CMS is in good shape to have all data completed in time for analysis users and summer conference results. To facilitate this CMS has been reconfiguring the Tier-0 resources to be more similar to a Tier-1 and a Tier-2. Users have been encouraged to submit analysis jobs to the Tier-2 endpoint, and the data management system has been enabled to allow direct transfers from CERN to Tier-2s to replicate processed samples.

The other concentration is on preparation for 2015. CMS has a long list of improvements intended to maximize the efficiency of the resource usage to allow the most physics with the smallest requested increase in capacity. There are techniques in both data and workflow management currently in integration testing that will hopefully improve the access to the data for the entire collaboration by making better use of the network and storage resources through the use of data federation techniques and dynamic data placement.

CMS is currently executing on average 200k grid submissions per day, and 50k Tier-2 cores are used continuously. CMS is performing integration testing on the next generation of analysis tools, which should deliver more functionality to the user community.

Physics Performance and Datasets

The data-taking and the related operations in the last quarter of 2012 and in 2013 have been extremely smooth. The 53X release, validated and deployed at Tier0 before summer, proved to be reliable and robust, while the Alignment and Calibration group ensured high quality of the detector conditions. The resulting promptly-reconstructed datasets delivered very high-quality physics performance that allowed the collaboration to present results at the Winter Conferences without the need for major reprocessing of the data.

The DQM and Data Certification team has deployed a continuous effort to promptly certify the quality of the data. The luminosity-weighted certification efficiency (requiring all sub-detectors to be certified as usable for analysis), w.r.t the recorded luminosity is 90% for 2012 pp data-taking and 97.5% for the 2013 pPb data.

In parallel to the data taking, the MC production has been running at full steam, reconstructing more than 4 Billions of events with the new release. A careful definition of priorities was necessary to ensure that the samples needed for HCP, Moriond and future conferences were produced accordingly to the needs of the Physics groups.

Given the size of the MC and data samples a lot of attention to the medium term planning of the utilization of the computing resources was required. This lead to the decision to reprocess the full dataset, including a selection of Parked Primary Datasets, for Summer 2013 conferences with the 53X release and the latest alignment and calibration constants.

Already at the end of 2012, but even more with the beginning of the Long Shutdown 1, the PPD project is increasing its attention to the validation and production needs for the upgrade studies, starting with the preparation of the Phase 1 TDRs.

In parallel, all PPD areas have begun working on the consolidation of the tools for DQM, Validation and Alignment & Calibration, profiting from this period without beam to improve and streamline all workflows in view of higher energy running.

The Global Event Description (GED) effort is capitalizing on the experience of the 2012 run and targets a new release in the summer. Meanwhile, the effort is also focusing on physics motivated studies for the optimization of the detector design of the future upgrades based on the needs of a Particle Flow based reconstruction.

Physics

The period since the last RRB has seen the end of pp collisions at $\sqrt{s}$ = 8 TeV and the LHC's first p-Pb collision run at $\sqrt{s}$ = 5 TeV/nucleon. With these final Run 1 datasets in hand, CMS Physics groups have been busy analyzing these data in preparation for the winter conferences. Moreover, despite the fact that the pp run only concluded in mid-December (and there was consequently less time to complete data analyses), CMS again made a strong showing at the Rencontres de Moriond in La Thuile (EW and QCD) where nearly 40 new results were presented. The highlight of these preliminary results was the eagerly anticipated updated studies of the properties of the Higgs-like boson discovered in July of last year. Meanwhile, preparations for Run 2 and physics performance studies for Phase 1 and Phase 2 upgrade scenarios are ongoing.

The Higgs analysis group produced updated analyses on the full Run 1 dataset (~25 fb^{-1}) for 4 of the 5 different final states that were used to claim the discovery. In the $H \rightarrow ZZ(4l)$ channel, a signal significance of 6.7σ is now observed. This high-resolution mode allows for an increasingly precise determination of the mass (125.8 GeV ± 0.5) as well as tests of the spin-parity of the new boson. From these studies, the pure pseudoscalar hypothesis is excluded at 99.8% C.L. and, for the first time, simple spin 2 models are excluded with greater than 98.5% C.L. In the other high-resolution mode, $H \rightarrow \gamma\gamma$, updated results were presented on the signal strength, $\mu = \sigma/\sigma_{SM}$, which is now measured to be ~0.8 ± 0.3. Significantly, strong indication of fermionic decays of the Higgs is seen for the first time; $H \rightarrow \tau\tau$ is reported with a significance of nearly 3σ. Finally, a corroborating excess of data over background expectation continues to be seen in the $H \rightarrow W^+W^-$. While all of these measurements are consistent with values predicted for a SM Higgs boson, they still fall far short of the requisite precision to rule out all BSM scenarios. Data from Run 2 of the LHC and HL-LHC will be needed to better address this issue.

Meanwhile, the direct search for BSM physics has also continued. The SUSY analysis group has performed searches with the full 8 TeV dataset (~20 fb^{-1}) for stops and sbottoms, which are expected to be relatively light given their special role in natural supersymmetry. In all cases, the observed data are consistent with the SM expectation and 95% C.L. limits are set. For stop (sbottoms) produced via gluino cascades, these searches have excluded gluino masses of up to ~1.3 TeV (~1.15 TeV) , for LSP masses of less than 500 GeV. The Exotica analysis group has also updated their searches using the full 8 TeV dataset. A highlight of these results is the world's most stringent limits on heavy stable charged particles (HSCP's) that are predicted in a number of BSM scenarios. For the first time, these limits cover fractionally, as well as multiply, charged states in addition to q=1. Other flagship results were updated upper limits on the mass of resonances in dileptons and dijets where masses from ~3-5 TeV have been excluded. Exotica also updated their monojet + MET search in which the most stringent direct constraints on the spin-dependent cross-section for a dark matter candidate were obtained. Finally, the "Beyond Two Generations" (B2G) group updated two searches using the entire 8 TeV dataset. Both these analyses look for top quarks in the final state that might have arisen from a BSM decay; in one case coming from a 5/3 charged top "partner" which CMS now excludes up to 770 GeV and in the other case coming from extra gauge boson where the 95% C.L. on the mass of such a W′ is now ~2 TeV. Many additional searches are under-way and will be reported over the course of the next year or so.

The top physics group has now completed its transition to precision measurements, including differential cross-sections and searches for rare phenomena. The very large number of top quarks produced in the full 2012 dataset has been exploited for a test of CPT invariance by producing the most precise measurement to date of the top-antitop mass difference, $\Delta m_t = -272 \pm 196$ (stat.) $\pm$ 122 (syst.) MeV. With ~17 fb^{-1} of 8 TeV data collected in 2012, the top group has also now made the most precise measurement of the ratio (R) of the branching fraction to bottom quarks ($t \rightarrow bW$) to the branching fraction to all three types of quarks ($t \rightarrow qW$; where q = d, b or s). The measured value of R is $1.023^{+0.036}_{-0.034}$, in very good agreement with the SM expectation.

In another precision measurement, the standard model physics group has studied the rate of production of a W boson associated with a charm quark that is the first direct probe of the strangeness component of the proton at the LHC. This measurement was made on the 5 fb^{-1} of 7 TeV data collected in 2011, looking for events containing a jet from the charm quark (c-jet) as well as decays of the W into a lepton and a neutrino. A related measurement is of the production of a W boson along with a bottom-antibottom pair. With 5 fb^{-1} of 7 TeV data, the measured production rates were found to agree with the theoretical predictions. In other heavy quark physics, at the Hadron Collider Physics Symposium in Kyoto, the B-physics group presented a measurement of the Λ_b lifetime of 1.503 ± 0.052(stat.)± 0.031(syst.) ps.

In preparation for the start of Run 2 in 2015, activity continues adapting the "global event description" (GED), an extension of the particle flow algorithm, to the expected high pile-up conditions. Finally, the "Future Physics" groups (which now has contributions from Higgs, SUSY and Exotica) have carried out physics studies to demonstrate the performance of the Phase 1 upgraded CMS detector in support of the L1 trigger TDR currently being finalized within the collaboration. Preparations for similar studies to be done for the Phase 2 upgraded CMS detector as preparation for a planned ECFA workshop in October are at an advanced stage.

Heavy Ions Physics

Last January and February LHC delivered collisions of protons and lead nuclei at 5.02 TeV. CMS collected about 31 nb^{-1} of integrated luminosity with 98% data taking efficiency. This represents a large increase over the data taken during September 2012 pilot run. In addition, we took a short run of pp collisions of ~5 pb^{-1} at 2.76 TeV that will be used as a reference for the interpretation of the PbPb data collected in 2011. The availability of the samples of PbPb, pPb and pp taken with the same detector with the same conditions will allow very detailed studies of strongly interacting matter at the highest densities.

The pPb and pp runs required preparations of the trigger and detector configurations that were very successful. The detector worked flawlessly during the whole data taking period. The focus of the data collection was to write all high p_T probes: jets, photons and muons to tape together with a significant fraction of minimum bias and zero bias events.

The data analysis has already started. The first results from the pPb pilot run resulted in the observation of the long range correlation between charged particles as a function of charged particle multiplicity. CMS has already observed similar effects in pp and PbPb data. In heavy ion collisions such correlations can be explained by relativistic hydrodynamics of a strongly interacting fluid or flow. It was extremely interesting to see that a similar effect is present in the matter produced in pPb collisions, somewhat contrary to expectations.

The analysis of the pp, pPb and PbPb data is expected to continue during LS1. The plan is to have a steady output of measurements related to jet and photon physics, especially in relation to the strong jet quenching observed early in the LHC heavy ion program. Quarkonium and weak boson physics will profit from large statistics of events containing muons or electrons.

In LS1 we started an intense effort to upgrade the Level-1 calorimeter trigger to be ready to accept significant increase in luminosity expected during the next PbPb run in the fall of 2015. The upgrade to the calorimeter trigger will significantly increase the selectivity of the jet trigger, enabling us to sustain the much higher event rates expected in future LHC PbPb runs.

Upgrades

The detector projects targeting LS1 (2013-2014) are all in production. A fully integrated schedule developed by Technical Coordination includes installation milestones and a detailed work-plan. The first RPC chambers were produced and are being qualified and the production will ramp up to a rate of 20 chambers per month. 32 CSC chambers have been fabricated for the ME4/2 CSC stations. Production proceeds at a rate of 4 per month. The new ME1/1 Front End Board is in production and the off-detector electronics integration tests are ongoing. Production of the new Theta Trigger Boards for the DT readout has started and the relocation of the Sector Collector boards with new Optical Links has been successfully tested. All the components for the upgrade of the Forward Hadron Calorimeter electronics (MAPMTs and readout boards) have been received at CERN and assemblies are being qualified. The situation is similar for the Hadron Outer Calorimeter's new SiPMs and readout modules.

Three projects are planned for the period after LS1: the Pixel detector replacement, the HCAL electronics upgrade, and the L1-Trigger upgrade. The Pixel and HCAL projects have prepared Technical Design Reports that have been endorsed by the LHCC at its September 2012 session. The projects are now finalizing the prototyping and will enter construction by the end of 2013. Engineering design reviews will take place during the summer. A final prototype of the Read Out Chip for the Pixel detector is being produced and parts have been ordered to allow enough module assemblies for qualification of the production centers. Design and testing of the support structures especially cooling performance is progressing as expected. The Pixel Pilot System to be installed during LS1 is being tested. For the HCAL upgrade, a full prototype slice of the new HF back-end electronics has been successfully operated during the p-Pb run at the beginning of this year.

For the L1-Trigger upgrade, studies of the trigger performance at high pileup are ongoing for the present trigger system and for new algorithms that will only be possible with the upgrade. Prototype μTCA boards are under test for the calorimeter trigger, and new track finder electronics is under development for the muon triggers to allow integration across the different chamber types. The design for the global trigger, again in μTCA, is under study. A plan has been developed to allow a new trigger to be developed in parallel to the present operating trigger by optically splitting input signals, and prototype boards for splitting the signal for the EM calorimeter are under test. The Technical Design Report for the L1-Trigger upgrade will be submitted to the LHCC in April 2013.

Planning for Phase 2

In preparing documentation for Phase 2, we will follow a similar approach as we followed for Phase 1, with a Technical Proposal covering the whole upgrade program, including physics performance studies, a technical description of the upgrades, and initial cost estimate and timelines. This will be followed by detailed TDRs for each major sub-detector or sub-system upgrade, containing more complete technical designs and updated cost and schedule information.

The present work towards Phase 2 is focused on:

(a) Radiation damage studies and simulations to map the degradation in performance of the sub-detectors at LS3, and at a total integrated luminosity of 3000 fb^{-1}

(b) Simulation of detector and physics-object performance, and studies of benchmark physics channels for the degraded detector, and demonstration of improvements that can be obtained with specific upgrade options.

(c) R&D on detector technologies, and conceptual design for systems expected to be in need of improvement or replacement

The goal of this work is to develop conceptual designs for the Phase 2 detector, and to simulate the physics performance in preparation for decisions on scope and preparation of the Technical Proposal. We anticipate this process to complete by summer 2014. In addition to physics performance, consideration will be given to cost, infrastructure requirements (including radiation shielding and services), and to the scope of work during shutdown periods. By LS3, parts of the detector will have received significant radiation dose; minimization of radiological risks to personnel will be a key concern in developing the upgrade plan.

We anticipate completion of the Technical Proposal by late 2014, with TDRs for the major sub-detectors and systems to follow by 2016. As for Phase 1, following an internal review process, the documents will be submitted to the LHCC, and cost and funding information will be presented to the RRB.

Targeted R&D is essential to develop the options and solutions under consideration, and to converge on the scope of work for the Technical Proposal and later for the TDRs. In this program we will capitalize as far as possible on common R&D with other experiments and CERN.

Given that the tracking system and endcap calorimeters will need major upgrades, and that both of these will require significant R&D, we anticipate 3-4 years for the R&D followed by 5-6 years for construction. The timescale for the TP and TDRs is well matched to the HL-LHC schedule, however the simulation studies and R&D which are already ongoing, must proceed rapidly.

Publications

Since the start of LHC collisions, CMS has published physics results in a variety of forms, most notably papers in refereed journals and conference reports (CRs). The list and details of these publications are being updated regularly and are publicly available from the CERN Document Server (CDS) at http://cdsweb.cern.ch/collection/CMS?ln=en.

As of today, Mar 29, 2012, CMS has published 233 physics papers in PRL, PRC, PRD, EPJC, PLB, and JHEP. (There are also 28 instrumentation/detector papers published in JINST). Members of the CMS collaboration, who gave talks at international conferences worldwide, wrote their contributions to the conferences' proceedings; so far, 1050 conference reports were published (since Jan 1, 2010). The corresponding increments in these two categories since the last RRB in October 2012 are: Papers – 45; CRs – 205.

The 17 most cited CMS physics papers, based on pp collisions at the LHC, to-date, each with at least 100 citations are:

1. Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC - Phys.Lett.B716 (2012) 30-61; 844 citations.

2. Combined results of searches for the standard model Higgs boson in pp collisions at sqrt(s) = 7 TeV - Phys.Lett.B710 (2012) 26-48; 467 citations.

3. Search for Supersymmetry at the LHC in Events with Jets and Missing Transverse Energy - Phys.Rev.Lett. 107 (2011) 221804; 221 citations.

4. Search for Supersymmetry in pp Collisions at 7 TeV in Events with Jets and Missing Transverse Energy - Phys.Lett.B698:196-218, 2011; 204 citations.

5. Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt(s)$ = 0.9 and 2.36 TeV - JHEP 1002:041, 2010; 201 citations.

6. Observation and studies of jet quenching in PbPb collisions at nucleon-nucleon center-of-mass energy = 2.76 TeV, Phys.Rev. C84 (2011) 0249062; 195 citations.

7. Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 7 TeV - Phys.Rev.Lett.105:022002, 2010; 184 citations.

8. Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions at the LHC - JHEP 1009:091, 2010; 165 citations.

9. Search for the standard model Higgs boson decaying into two photons in pp collisions at s√=7 TeV - Phys.Lett. B710 (2012) 403-425; 144 citations.

10. Measurements of Inclusive W and Z Cross Sections in pp Collisions at s√=7 TeV - JHEP 1101 (2011) 080; 134 citations.

11. First Measurement of the Cross Section for Top-Quark Pair Production in Proton-Proton Collisions at s√=7 TeV - Phys.Lett. B695 (2011) 424-443; 109 citations.

12. Prompt and non-prompt J/ψ production in pp collisions at s√=7 TeV - Eur.Phys.J. C71 (2011) 1575; 108 citations.

13. Search for Resonances in the Dijet Mass Spectrum from 7 TeV pp Collisions at CMS - Phys.Lett. B704 (2011) 123-142; 102 citations.

14. Measurement of W+\W− Production and Search for the Higgs Boson in pp Collisions at √s = 7 TeV - Phys.Lett. B699 (2011) 25-47; 102 citations.

15. CMS Tracking Performance Results from early LHC Operation - Eur.Phys.J. C70 (2010) 1165-1192; 102 citations.

16. Search for Dijet Resonances in 7 TeV pp Collisions at CMS - Phys.Rev.Lett. 105 (2010) 21180; 101 citations.

17. Search for neutral Higgs bosons decaying to τ pairs in pp collisions at s√=7 TeV - Phys.Lett. B713 (2012) 68-90; 100 citations.

Conclusion

The CMS experiment is traversing an historic period in particle physics following the discovery of a Higgs boson in 2012. The investigation of the nature of this new particle is being intensively pursued. Improved measurements of the strength of the interaction of this particle with other particles together with comparisons of data with expectations of a variety of spin-parity models strongly indicates that indeed we have observed a Higgs boson that is responsible for Electroweak Symmetry Breaking.

The CMS collaboration is confidently moving into a new phase with a challenging two-year long period of very intense activity. Very careful planning and appropriate definition of priorities will be required if we are to succeed on so many different fronts: full exploitation of the physics with the available dataset including the “parked” data; preparation of the detectors, infrastructure, and offline systems for Run2 at higher energy and higher luminosity; construction of the Phase 1 upgrade detectors and systems to be installed after LS1; conceptual design, R&D and simulation of the Phase 2 CMS detector.

The CMS collaboration is confident that it has the strength to achieve all of these goals in the most efficient and cost-effective manner and we gratefully acknowledge the continued support of all our Funding Agencies.