# Status of CMS

## Progress Summary Report for October 2012 RRB35

Since the last RRB in April, the LHC community achieved a major discovery in particle physics, with profound consequences for our field. CMS was one of the two experiments that observed a new heavy boson with mass of approximately 125 GeV and with spin not equal to 1. The evidence was strongest in the diphoton and four-lepton final states. An excess was observed in the WW mode as well. The fermionic channel analyses (b-quark pair and tau pair decay modes) however, yielded less than the standard model (SM) expectation, albeit with limited statistics at present. In combination, the five channels established the signal with a significance of 5 standard deviations (σ), slightly below the expected significance of 5.8σ. While the properties of the new particle are, within the uncertainties of the present data, consistent with those expected of the Higgs boson, more data are needed to elucidate its precise nature.

CMS is now a remarkable physics production machine, achieving physics results of the highest quality at an impressive rate. This is the consequence of extremely good work performed by many people over many years. Besides the Higgs physics results, many other analysis of either 7 TeV or 8 TeV data produced new physics results in the recent months. CMS had a strong presence at the 36$^{th}$ International Conference of High Energy Physics (ICHEP) in Melbourne where some 25 new analyses on 8 TeV pp collision data, and nearly 60 new analyses on 7 TeV pp collision data were presented. In Heavy-Ion physics, CMS made also a strong impact at the Quark Matter 2012 (QM2012) conference where 8 new analyses on 2.76 TeV PbPb collision data were presented. These preliminary results are being finalized for publication; several have already been sent to various journals, including the paper documenting the new boson discovery that was submitted to Physics Letters B on July 31, 2012. A paper summarizing the Higgs results and aiming a broader scientific audience was submitted recently to Science.

These exceptional physics results would not have been possible without the effort of many collaborators to continuously improve and operate the CMS detector and related infrastructure, as well as the associated areas of trigger, offline software, physics performance validation, and computing. The CMS detectors continued performing at remarkably high levels in the data-taking period of 2012 despite the very high collisions pileup, reaching a peak value of 35 interactions per bunch crossing at instantaneous luminosity of 7.5 $10^{33}$ $cm^{-2}s^{-1}$, well above the design value of 25 interactions/bunch crossing. The intense work developed during the end of the year technical stop allowed the CMS detectors, trigger, and data acquisition to operate with remarkably high data recording efficiency under these extreme conditions. Of particular notice are the CMS wide efforts deployed to implement automatic recovery from faults due to single event upsets (SEU) in the electronics located in UXC provoked by the high radiation in the cavern environment, which allowed to keep the down time at very low levels. The CMS trigger was substantially improved in order to guarantee that the trigger rate didn't exceed the data acquisition and computing capabilities, while assuring high efficiency for the physics we planed to capture. In this respect the upgrade of the DAQ/HLT filter farm, allowing an increase of processing time on 70%, proved to be essential to sustain the high luminosity made possible by the excellent performance of the LHC collider. The extremely high pile-up expected motivated the deployment of a major effort in the offline software and computing areas to reduce the event reconstruction time. Studies with simulation data have shown that the CPU time of tracks reconstruction increases dramatically with the number of pileup events. A dedicated task force initiated at the end of 2011 achieved major improvements of the reconstruction code, both in timing and in memory footprint, which allowed to keep in 2012 the same rate of prompt event reconstruction at Tier0 as in 2011.

The LHC 2012 schedule has been extended until February 2013 with the goal of accumulating in this run enough statistics to establish the quantum numbers of spin and parity of the new particle with a significance of around 3 $\sigma$. An additional effort will be required, as this extension has created a commensurate increase in the needs foreseen for shifters and operational resources.

The discovery of a new Higgs-like boson with a mass of 125-126 GeV opens a new chapter in the history of particle physics. The present CMS Upgrade program, aiming at operation with energy 14 TeV and luminosity up to $2 \times 10^{34}$ $cm s^{-2} s^{-1}$ in the decade up to Long Shutdown 3 (LS3), has now a much more targeted addition to the physics case. A broader picture of physics at the TeV scale should emerge with implications for the future of the energy frontier programme. Amongst the essential inputs will be precision measurements of the properties of the Higgs boson and direct searches for new physics. In this decade, the LHC together with its experiments will be the only facility able to carry out these studies. This programme is very challenging because it requires triggering, and accurate reconstruction and identification of physics objects (leptons including the $\boldsymbol{\tau}$, heavy flavour tagging, photons, jets, missing transverse energy) from relatively low to very high transverse momenta extending to large rapidity (e.g. to characterize events from vector boson fusion). The recent submission of the CMS Technical Design Reports for the Pixel and HCAL detector upgrades is a major step in this programme.

The HCAL and Pixel Upgrade TDRs were reviewed by the LHCC committee. From the preliminary report we highlight the following statement: *"Technical Design Reports (TDR) for the proposed upgrades to the pixel tracker and to the electronics of the Hadronic Calorimeter were presented to the LHCC, providing a complete and comprehensive roadmap for delivering the detectors. Excellent progress was demonstrated in R&D and design. The documentation included detailed work plans, credible schedules and budget estimates and well-motivated physics justifications and notes that front-loading of resources would alleviate potential pressure on the schedule. The LHCC congratulates CMS for this achievement".*

To retain and extend these 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 as ambitious as that of the original LHC programme, in particular ensuring that sufficient resources, both financial and human, are made available in a timely fashion; for R&D in the short term, for prototyping in close relation with industry in the medium term, and further down the line for construction. With these goals in mind, R&D and studies continue for the Phase 2 upgrades of the CMS detectors, in particular the tracker. Additionally, CMS created two working groups to develop the long-term strategy and coordinate R&D for the Trigger and for the Forward Region, where radiation and pileup issues will be particularly severe.

## Magnet and Infrastructure

Technical operation of the CMS magnet and the experiment-specific infrastructure and common systems during 2012 has generally been as good, or better, than in 2011, but the timing of some incidents originating in the primary infrastructure of the point 5 site led to significant data-losses during August and September 2012.

On 2 August, the cavern air-treatment plant was inadvertently shutdown during an unannounced intervention. The result was a general cooling shutdown during the last part of a physics fill. On 10 August, a primary cooling failure caused a generalised cooling stop, including the magnet cryo-plant. During recovery, a problem during cold-box reconnection caused the safety system to initiate a fast discharge (the first since CMS became operational), with several days subsequently needed to recover. On 21 August, the Uninterruptible Power Supply (UPS) for the magnet control system was manually switched off (almost certainly a misguided or unintentional manual intervention). This led to a cryogenic shutdown and irreversible slow ramp-down of the magnet current. Various other incidents could have led to additional data-losses in September, particularly the inadvertent shutdown of the ECAL cooling and a power cut due to a bad interlock connection in the 18kV feed to Point 5. A CMS Technical Incident Panel has been set up to investigate all these events, and several have been referred to the CERN-wide Technical Infrastructure Operating Committee. Almost all incidents resulted from misguided (or unguided) human actions, faults in primary infrastructure (HVAC, cooling, power) or a combination of the two. The reaction of CMS systems, including the magnet, was failsafe, as intended, but it was clear that the recovery time of CMS subsystems could be optimised. Immediate process modifications, to address the cold-box reconnection and fast discharge risk, were tested during the September technical stop.

Beam-induced backgrounds have remained well within acceptable limits, even at the highest beam currents, following the beamline repair and bake-out around the -18.5m region in January. The beam radiation monitoring system has functioned well, with only one spurious beam-dump generated, and much progress has been made in exploiting the potential of the monitoring system based on diamond sensors (fast and slow monitors, pixel luminosity telescope (PLT)). The 2$^{nd}$ generation beam halo monitoring system also functioned well, but is now reaching the same sort of fluence limits encountered by its predecessor. Replacement of this system and the front-end electronics of the beam monitors will be done in LS1, after which the PLT will also be brought into operation.

Planning for LS1 progressed significantly following a CMS technical coordination workshop in May and a similar LHC workshop in June. A continuing planning priority is to prolong the access windows for tasks related to ensuring that the Tracker can operate at a much colder temperature after LS1. Meanwhile, the dry gas (air/nitrogen) plant needed to underwrite the humidity control, which is an essential part of this task, is in the final stages of procurement. Similarly the dryers and compressor needed to reduce magnet cryo-system vulnerability to major failures and frequent field cycles are specified and nearing procurement. The sectors and support beams of the shielding wall (YE4) at each end of the experiment, associated with the installation of the 4$^{th}$ endcap muon layer, have been delivered from Pakistan and await filling with shielding concrete. Materials for the reduced diameter (45 mm outside diameter) central beampipe, compatible with the proposed pixel upgrade, are now being delivered to the manufacturer. Various improvements in the heavy logistic systems for movement of, and access to, the detector elements and also for radioprotection shielding of personnel, are in final design, procurement or manufacture. Also progressing are the final designs or preparatory work (during technical stops) of cooling, electrical and safety system consolidation projects to accommodate new (Phase 1) detectors and reduce vulnerability to failures. The preparation of the operational support centre in the Point 5 surface building is on-track for completion just before LS1; however, the provision of adequate lab and storage space (replacing the ISR tunnel) at other CERN locations is bogged down due to administrative issues and may yet cause interference with LS1 activities.

In their report the LHCC states that *"The LHCC endorses the CMS program of work for Long Shutdown 1 (LS1)".*

## Run Coordination

The LHC started delivering first collisions at 8 TeV on March 30$^{th}$ followed by several days of beam commissioning. On April 5th the first stable beams with two bunches colliding in CMS were available, giving pile up of ~27 interactions per crossing at the beginning of the fill. We used the first fills with low luminosity to re-commissioning the detector, and by Monday April 9th CMS was ready to take data in nominal conditions. Since then the machine has increased the number of colliding bunches to reach 1368 bunches with 1.6E11 protons/bunch, for a peak instantaneous luminosity above 7.5E33Hz/cm$^2$. The average peak pileup reached ~35 interactions per crossing. The machine performance has been excellent so far, delivering up to 265/pb per day and 1.3/fb in a single week.

One of the conclusions of the Run Coordination workshop held in November 2011, was that the increase in the number of soft errors (a.k.a. Single Event Upsets, or SEU) would become an issue at higher luminosity, and that a software mechanism to recover from soft errors was needed to complement the (already existing) hardware mechanism. This mechanism was put in place and allowed to significantly reduce the downtime.

The many efforts to reduce both dead time and down time started to pay off in summer. We see a significant reduction of the dead time from 1.8% in April-June to 1% in July-August, and a reduction of the down time from 5.9% to 3.8% in these same periods. On many occasions, data taking efficiency was close to 99%. This comes mainly from the automation of recovery procedures for known problems, the improvement of the alarms and monitoring tools, and the implementation of dead time mitigating measures by subdetectors. The total luminosity delivered to CMS so far in 2012 is 14.7fb$^{-1}$ and CMS recorded 13.6fb$^{-1}$ for 93% efficiency (to be compared to 91% in 2011). These numbers include the commissioning period and runs taken with the magnet off. The data certified as golden for data analysis corresponds to approximately 90% of the recorded luminosity (nearly 92% in July-August).

Several special runs or fills have been accomplished. Two sets of Van der Meer scan, one low PU fill for W/Z precision measurements, one 90m $\beta^*$ run with join data-taking with TOTEM, and one high-pile up fill with up to 66.5 pile up events in average, were done. Finally, a first p-A pilot run took place on September 13th and was very successful. One fill with 1km $\beta^*$ and few fills with 25ns bunch trains are still scheduled before the end of the year.

## Tracker

The silicon pixels and strips systems have both maintained very high levels of performance and reliability throughout the 2012 run. The working fraction of the Tracker remains steady at 98% for the strips and 96% for the pixels. A small number of pixel modules are unable to operate in high pile-up conditions and these were disabled at the start of the 2012 run. The accumulated failures in the pixel system will be recovered in 2013 when the pixel detector is extracted.

Down-time and dead-time in the Tracker system have been kept at a low level throughout the 2012 run. A large improvement came through the mechanical repair on the beam-line at Point 5 during the winter stop, reducing the beam-background in the pixel barrel, curing the largest potential problem at its source. Further improvement has come from the automation and subsequent optimization of the recovery of the readout system after single-event-upsets inside the detector.

Radiation damage is monitored closely. The pixel system is being recalibrated periodically to track and compensate radiation damage effects in the electronics. No such intervention is needed yet in the strip system. A detailed radiation damage model has been developed which is very useful to appreciate the impact of different operating scenarios on the long-term evolution of the radiation damage in the silicon sensors.

Preparations for LS1 consolidation activities on the Tracker systems continue to make good progress. The main objective is to improve the Tracker cooling, sealing, and humidity control to allow the silicon strip and pixel detectors to operate in future with coolant temperature as low as -25 °C. R&D and prototyping activities are advancing well for the Tracker upgrades, with further details in the Upgrade section of this report. A Technical Design Report has been completed for the upgrade of the pixel detector, detailing the Physics gains and the main features of the new system. The upgrade addresses the limitations of the present pixel detector, greatly improving the robustness and precision of tracking and vertexing in high pile-up conditions.

## Electromagnetic Calorimeter

Throughout the 2012 running period the ECAL, comprising barrel, endcaps and preshower, has operated reliably, with the number of active channels – ~99% in the barrel/endcaps and ~97% in the preshower – stable in time.

The ECAL data acquisition firmware and software have undergone some significant improvements in the first half of 2012 in order to detect and mitigate rare problems in localized parts of the detector that could be due to radiation-induced single event upsets (SEUs). Automated procedures restore synchronization without stopping ongoing runs, thereby minimizing downtime.

As the instantaneous luminosity has increased, the number of pileup events has also increased beyond the original design specifications. The ECAL has coped with these increases. An important improvement is the inclusion of periodic recalibration of the ECAL response into the L1 trigger using laser-monitoring data. As a result, the e/γ trigger rate is stable in time and with luminosity.

The monitoring system has evolved in 2012 with the inclusion of a new solid-state laser that has proven to be more reliable than the old lamp-pumped lasers. The new laser was commissioned in parallel to the old laser in the first half of 2012 and has been used to generate the transparency corrections in the prompt reconstruction since July. A long-term slow drift of the amplitude of the new laser has been observed, mainly due to aging of some of the auxiliary optical components. Further investigations are ongoing to exclude any malfunctioning of the laser itself, in view of purchasing an identical spare during LS1.

The energy resolution in the prompt reconstruction is good and stable in time, following an initial 1-2 month period required to recalibrate the ECAL after the winter shutdown. Although optimum resolution will only be achieved with refined calibration, the quality of the prompt reconstruction data has put CMS in an excellent position to be able to observe the new SM Higgs-like boson this summer.

## Hadron Calorimeter

During first 6 months of LHC operations in 2012, the hadron calorimeters (HCAL) continued to operate reliably with over 99% of active channels.

This year we have observed first signs of radiation damage in the high-eta regions of HE (Hadron Endcap) and HF (Hadron Forward) calorimeters. The observed signal losses for approximately 15 $fb^{-1}$ delivered to CMS in 2012 are the following: in the central part of HF (eta= 3.5-4.2) signal loss is at the level of 3%, reaching 5% at the highest eta range (eta=5). In HE, signal loss is in the range of 4-8% in the eta=2 region and 7-14% in the eta=2.3

region. Within the accuracy of the present measurements, the observed radiation damage effects are consistent with the expectations.

The HCAL calibration chain has been modified in order to account for the observed radiation damage. The HF correction is based on the laser measurements and collision data. The correction for HE mega-tiles is currently under study.

HCAL has made significant progress in the preparation of activities foreseen during LS1: replacement of photo-detectors on HO (HPDs -> SiPMs) and installation of new, multi-anode PMTs on HF. In the central region, the Clock and Control Modules (CCM) will be modified in order to eliminate a source of dead-time induced by Single Event Upsets (SEUs).

A major effort was made to prepare the HCAL Upgrade Technical Design Report. The report presents the physics motivation for the HCAL upgrade, describes the new Front-end and Back-end electronics, and discusses technical and physics performance of the upgraded detector. More details are given in the Upgrade session of this document.

## Muon Detectors

**Endcap Cathode Strip Chambers (CSC):**
The CSC muon system has run smoothly in the 2012 data run, coping well with the ever-increasing luminosity. Problems that appear due to single event upsets (SEU's) motivated an improvement of our system diagnostics. Periodic broadcast of reset commands have greatly decreased the frequency of SEU-related problems. A significant readout data loss at high level 1 trigger rates observed in 2011 was eliminated in 2012. Removal of CASTOR has nearly equalized the background rate between the two endcap muon systems.

From 2011 to 2012 the number of chambers that were inoperable due to loss of low voltage (LV) power has grown from 9 to about 11, mostly in ME1/1. Long-term study has now shown LV instability on an additional 21 ME1/1 chambers. Detailed plans for LV improvements in LS1 are being made.

The CSC data volume has been found to grow with luminosity and at times exceed the nominal 2 kBytes per FED. Firmware to allow zero-suppression of anode data reduces the CSC data volume by 15%. Various fixes will greatly alleviate the readout bottleneck after LS1.

The chamber factory at Prevessin B904 set up to build 72 new ME4/2 chambers has reached full operation and is on schedule. Problems seen in 2011 with breakage of wires during chamber winding were corrected by the vendor in short order.

The new cathode readout board of the ME1/1 chambers has successfully gone through the pre-production phase, and 7 of these boards have been installed on an ME1/1 chamber at B904 for integration tests. So far the tests have been successful.

**Barrel Drift Tubes (DT):**
Although the year 2012 is the third year without access to the chambers and the Front-End electronics, the fraction of good channels is still very high, 98.8%. The downtime caused by DT failures is less than 1%.

The LV power supplies have operated stably since the intervention during the 2011/2012 Year-End Technical Stop. The measurements of the noise from single hit rate as a function of the LHC luminosity show that the noise rate is amazingly consistent with expectations from the simulations in the Muon TDR.

The upgrade activities planned for the 2013-2014 Long Shutdown evolve according to schedule, both for the theta Trigger Board (TTRB) replacement and for the Sector Collector (SC) relocation from UXC to USC. This work is the cornerstone for any long-term upgrade plan of the DT system. For that reason the prototypes of the new electronics that will replace the SC in UXC have also been submitted to irradiation tests which qualified it for use in the future HL-LHC. The project has been reviewed in an ECR by a panel of experts from the CMS Electronics and Technical Coordination teams on June 6.

**Resistive Plate Chambers (RB and RE):**
The RPC system is running very smoothly in the 2012, showing an excellent stability and very high data tacking efficiency. During 2012 the percentage of operating channel was about 98.2% (98.4 % in the 2011). Most of the hardware problems will be fixed during the 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. The current and background measurements, taken during the no-beam period, have shown results very similar to the 2011, with an average current less than 1μA per chamber and a noise less than 0.1 Hz/cm$^2$.

During the 2012 the stability of the endcap chambers was improved, which is crucial because the 3-out-3 trigger logic used in that region. 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 will be 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 in July. The full production will be delivered at CERN in the first part of the 2013 and will be commissioned at the integration center B904.

**Muon Alignment:**
The new alignment for the DT chambers has been successfully used in physics analysis.

The remaining main areas of development over the next few months will be preparing a new track-based CSC alignment and producing realistic APEs (alignment position errors) and MC misalignment scenarios to match the latest muon alignment constants. Work on these items has been delayed from the intended timeline, mostly due to a large involvement of the muon alignment manpower in physics analysis over the first half of this year.

## Trigger and Data Acquisition

**L1 Trigger:**
The L1 Trigger group deployed several major improvements this year. The single muon trigger rate has been reduced by a factor two since 2011 and the coverage in pseudorapidity has been restored from 2.1 to 2.4 by further tuning of the algorithms, with minimal inefficiency. Moreover, raising the energy seed threshold for jets in the Global Calorimeter Trigger significantly reduced the strong pile-up dependence of the multi-jet and HT triggers, allowing them to run to the highest luminosity delivered by the LHC to date: $7.6\times10^{33}$ Hz/cm$^2$. The developed L1 trigger menu and prescale settings will allow CMS to

continue to take efficient physics data at even higher luminosities of up to at least 8.5x$10^{33}$ Hz/$cm^2$, with the detector readout able to handle the maximum 100 kHz L1 rate. The performance of the L1 trigger system was reported at the ICHEP conference in July this year. The calibration for ECAL transparency changes, for example, has significantly sharpened the efficiency turn-on curve in $E_T$.

**Trigger Coordination:**

The careful menu preparation and the many developments introduced in the HLT (e.g. particle flow, improved muon reconstruction and electron isolation) have allowed CMS to run successfully up to the highest delivered luminosities. Thanks to the introduction of the Pile-Up (PU) subtraction algorithms, the HLT cross section is now constant with the luminosity, with small sensitivity to the PU.

The CPU time per event increases with PU because of the increased event complexity, but it does so linearly up to the highest pile-up, without indication of any run-away effects. The added CPU power available after the extension of the HLT farm has proven essential with the high luminosities that the LHC is routinely providing, and will allow CMS to run without dead time, with the present menu, up to 8.5x$10^{33}$ Hz/$cm^2$ with 100kHz of L1 input rate.

The average rate of events sent to the prompt reconstruction is around 300-350Hz ("core"data), in full agreement with the expectation. Starting from mid-May, an additional "parking" data stream was enabled, with an added average of 300Hz of events that are stored but will be reconstructed only during the long shutdown. Such parked data include vector boson fusion triggers for Higgs studies, B-physics and quarkonia triggers, multijet and other hadronic triggers for extended searches for SUSY.

A "data scouting" stream was also introduced, with high rate (>$10^3$Hz) but reduced data content (i.e. only calorimeter jets reconstructed during HLT online processing, and no raw data) so that the bandwidth used is limited. It allows a high statistics first look at data in hadronic final states at low $p_T$, searching for specific new features in data.

**DAQ:**

As the final step of the DAQ/HLT construction towards nominal LHC conditions, a 2nd extension of the HLT farm has been installed and put into operation in May 2012. This extension comprised 256 PC system boards, each with two 8-core CPUs of the new SandyBridge generation. This brought the total HLT capacity to ~14'000 cores and ~30 TByte of memory. In order to take advantage of the multi-core and hyper threading CPUs, about 20'000 instances of the HLT are running in parallel. It provides a capacity for HLT of about 170 ms/event (on a 2.7 GHz E5430 processor core) at 100 kHz L1 rate in pp collisions.

The DAQ system has been deployed for pp physics data taking in 2012. It was operating with a L1 trigger rate up to ~90 kHz and, typically, a raw event size of ~700 kByte , and up to 1 kHz recording of events with a size of ~500 kByte after compression. This stream includes all physics triggers both from the "core" program and the "parked" data sets introduced in 2012. The DAQ performed with high efficiency (downtime was below 1%). Run control added fast recovery in the case of sub-detector read-out faults, including those induced by SEU and other soft errors.

Good 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.

# Offline Software

At the time of the last RRB report, the data taking release was CMSSW_5_2_X, which was the successful result of the high pileup task force. Work for this release concentrated on improving the technical performance of the code. An effort to improve physics performance, including reducing the high level reconstruction's sensitivity to pileup, was undertaken since then. A snapshot of the current development release 6_0_X was made in the beginning of May to fulfill this need, and became the 5_3_X release series. This release was validated and transitioned into operations after the June technical stop.

The 6_0_X release series continued to integrate improvements in other areas of the project, and provided a good testing ground for updates to ROOT and Geant4. In addition a major redesign of the digitization software was done in order to improve its memory scaling behavior as a function of number of simultaneous interactions simulated. In production releases before 6_0_0 it was impossible to create 100 PU event samples within available grid resources. The new design has been successfully tested up to 200 simultaneous PU events.

Another activity of the offline group has been to support the work needed to produce the Pixel and HCAL TDRs. In the beginning of the year the upgrade software for both the HCAL and Pixels was based on the 4_2_X release series, which implied to back port tracking improvements from the 5_2_X series into the upgrade releases used to generate samples for the TDRs. In addition, it took intense effort to rewrite, integrate, and test the new jet reconstruction code using the new HCAL segmentation and other new upgrade features in time to create the necessary upgrade samples for physics study. Work is ongoing in the 6_X_Y series to migrate the upgrade code into the main stream. We will use geometry databases and configuration to support the current, and all future detector variations in the same release.

# Computing

Since the last RRB, the CMS Computing Project has been in operations for the 2012 run. All systems are performing the tasks expected and resource utilization levels are high.

The Tier-0 has been processing events of increasingly higher average pile-up and instantaneous luminosity. The code improvements introduced in the beginning of the year have allowed the reconstruction time to remain within the planning estimates. In 2012 CMS began collecting additional data above the amount that could be reconstructed continuously at the Tier-0. This additional data stream was named "Parked Data" and is intended for additional studies during long shutdown 1. CMS has averaged about 300Hz of parked data for much of 2012, and will increase for the final few months of the year.

The Tier-1 resources have been completely used with organized processing. We are currently averaging 101% of pledge utilization at the Tier-1s with a combination of data skimming, data reprocessing, and simulation. CMS transitioned software versions in July to commission the best available software. This involved reprocessing the data taken up to that point and reprocessing 8TeV simulation samples. CMS currently has 1.7B events of 8TeV simulation at the latest release and will finish the year with 3B events.

The Tier-2 centers continue to be well balanced between simulation and analysis processing. 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 (PPD)

Before the start of the 2012 data-taking, the PPD and Physics groups worked on the optimization of the reconstruction algorithms in view of the higher LHC luminosity. This work has been integrated in the 52X CMSSW release. The PPD team coordinated the validation of this release, successfully proving the high physics performance standards.

In preparation of the ICHEP conference a new campaign of MC production has been organized to ensure the production of the 8TeV samples needed by the High Priority Analyses (HPA). The Dataset Definition Team has worked at the definition and optimization of the Primary Datasets, defined the content of the "data parking" stream, and coordinated the deployment of high-rate streams for the scouting of particular physics signatures.

The Global Event Description Task Force, leaded by Physics and PPD coordination, has worked to complete the integration of the particle flow approach in the release 53X for the benefit of all CMS analyses. New features and improvements came from all POGs (tracking, electron, muons, etc.). The work is not yet fully concluded. Two workshops (one at CERN in June and one at FNAL in August) have been organized with the aim of planning and discussing the future of the GED activity.

In summer, after the ICHEP effort, and following a careful cycle of validation, the 53X release has been deployed in production both at Tier0 and for MC simulation. The data acquired up to that moment have been re-reconstructed with the new software, providing a consistent and homogeneous dataset for analysis.

The DQM and Data Certification team has deployed a continuous effort to promptly certify the quality of the acquired data. In parallel, a campaign of certification of the data re-reconstructed using the new release has been organized. The next step will be to review the data certification definition used by the different Detector Performance Groups (DPGs) and Physics Object Selection Groups (POGs) in order to maximize the data certification efficiency.

The Alignment and Calibration Database group has devoted its activities to ensure high quality of the detector conditions with particular emphasis on the calorimeter calibrations, which are crucial for the Higgs in diphoton analysis.

Physics Data MC Validation team is now starting to concentrate their activity on the releases for data processing during Long Shutdown 1 and for the upgrade.

# Physics

The period since the last RRB has been historic for CMS Physics. The observation of a new boson with a mass of 125.3 ± 0.6 GeV – a strong candidate for a Higgs boson – has captured worldwide interest and had a profound impact on the field of particle physics.

These recent months have also been very productive for CMS Physics groups besides the Higgs physics analysis group (HIG PAG). CMS made a strong showing at the 36$^{th}$ International Conference of High Energy Physics (ICHEP) in Melbourne where some 25 new analyses on 8 TeV pp collision data, and nearly 60 new analyses on 7 TeV pp collision data were presented. In Heavy-Ion physics, CMS made a gala appearance at the Quark Matter 2012 (QM2012) conference where 8 new analyses on 2.76 TeV PbPb collision data were presented; one of which won the best talk award. As the summer conference season draws to a close, these preliminary results are being finalized for publication; several have already been sent to various journals, including the paper documenting the new boson discovery that was submitted on July 31, 2012.

For the discovery announcement on July 4, 2012, the HIG PAG prepared analyses on the 5 $fb^{-1}$ 8 TeV dataset wherein they searched for evidence of a Higgs boson in 5 different final states. Prominent signals were observed in the high-resolution $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ(4l)$ modes. Corroborating excess was observed in the $H \rightarrow W^+W^-$ mode as well. The fermionic channel analyses ($H \rightarrow bb$, $H \rightarrow \tau\tau$) however, yielded less than the standard model (SM) expectation, albeit with limited statistics at present. Collectively, the 5 channels established the signal with a significance of 5 standard deviations ($\sigma$), slightly below the median expected significance of $5.8\sigma$. The properties of the new boson were shown to be consistent with those of the SM Higgs boson within limited precision of the discovery sample. More data is needed to elucidate the nature of the new particle.

With the discovery of a strong candidate for a fundamental scalar, the question of what (if anything) is stabilizing the Higgs boson mass at ~125 GeV has become a principle goal of the CMS experiment. Though constrained by previous null results from the LHC, supersymmetry remains a strong possibility for such a "natural" solution to this hierarchy problem. Third-generation squarks play a special role in natural SUSY, so searches for stops and sbottoms have received an increased attention of the SUSY group (SUS PAG). For stops/sbottoms produced via gluino cascades, searches have excluded gluino masses of ~1 TeV for almost any stop/sbottom mass. For direct production of stops/sbottoms, 95% confidence level (CL) limits range from ~300-500 GeV. The SUS PAG also has a suite of analyses targeting EW production of chargino/neutralinos where masses from ~200-500 GeV are now excluded.

The Exotica physics analysis group (EXO PAG) continued its broad search program for physics beyond the SM. They also continue to be the most prolific PAG in CMS, with about 40 new results since the last RRB. Highlights of these analyses include the 5 high priority analyses (HPA) performed on 8 TeV for ICHEP: the search for hadronic resonances in dijet events, the search for new dilepton resonances (e.g. Z′), a search for new gauge bosons in events with lepton and MET (e.g. W′), a search for heavy neutrinos, and the search for mini black hole production.

Because of the special role the third generation plays in many extensions to the SM, a new PAG has been established called "Beyond Two Generations" (B2G). Its initial composition is the analyses that previously resided in the EXO sub-group that was called "Top-like BSM". The B2G PAG is off to a good start with the approval of its first results and the first paper in the final approval stages before the imminent journal submission.

The top physics group (TOP PAG) has entered a new phase of precision measurements. The top pair and single top (t-channel) production cross sections have been measured at both 7 and 8 TeV, and the top quark mass has been measured with ~1 GeV precision to be $173.4 \pm 0.4 \pm 0.9$ GeV, reaching the highest precision ever achieved by a single experiment. The group is also studying more complicated properties of the top quark such as spin correlations, top polarization and charge asymmetry, differential cross sections, and searches for rare processes. They have also recently made the first determination of $\alpha_s$ at the top pair production energy scale.

The standard model physics group (SMP PAG) continued its physics program of testing perturbative QCD and electroweak interactions. In addition to the completion of sophisticated analyses on 7 TeV data, the SMP group has begun to analyze 8 TeV data and completed inclusive measurements of the W and Z boson production cross sections at this new energy. Working closely with the HIG PAG, the group has also measured the WW and ZZ production cross sections at 8 TeV. Likewise, they have also recently completed the analysis detailing the first observation of the Dalitz decays of Z bosons to 4 leptons at a hadron collider.

The B-physics group (BPH PAG) has provided results in the study of B and quarkonium physics that are competitive and complementary to dedicated experiments. With the observation of a new B baryon, $\chi^{0^*}{}_{b}$, the BPH PAG oversaw the discovery of the first new particle with the CMS detector. The group has also performed precision measurements of the $\Upsilon$ polarization. Finally the search for the rare $B_{s/d} \rightarrow \mu\mu$ decays is ongoing. If the branching ration is equal to the SM expectation of ~3.5 x $10^{-9}$, CMS should be able to establish it with >4σ significance by the end of the 2012 pp run.

The forward and small-x QCD group (FSQ PAG) studies QCD and electroweak scattering processes characterized by particle production at high pseudorapidity. A number of interesting measurements have been performed recently including the measurement of the total inelastic pp cross section at 7 TeV, a search for exclusive γγ production and a study of strangeness in the underlying event.

Physics Object Groups (POGs) continued to study and recommend the best reconstruction and selection criteria for each of the physics objects used in analysis. Given its central importance to nearly all measurements, a new luminosity POG (LUM) was established to oversee the determination of the LHC luminosity. Activity has progressed on the "global event description" (GED), an extension of the particle flow algorithm.

The HIG & SUS PAGs have carried out physics studies for the upgraded CMS detector in support of the pixel and HCAL TDRs recently submitted to the LHCC.

## Heavy Ions Physics

Since last RRB, the Heavy Ion group analyzed the data from the PbPb runs in 2011 and initiated preparations for the upcoming p-Pb run, expected in January of 2013. With almost 160 $mb^{-1}$ available for physics analyses the heavy ion group submitted until now 18 papers for publication. Recent results were presented at the Quark Matter 2012 conference in Washington DC. There were total of 21 oral presentations given by CMS members, and 6 posters, two of which were awarded plenary flash talks.

The results obtained with the 2011 data cover a wide spectrum of physics observables. In jet physics we made an updated measurement of dijet asymmetry where we quantified its $p_T$ dependence and improved the overall precision of the measurement. We studied in detail jet fragmentation and performed the first measurement of the jet shape in heavy ion collisions. We collected a sizeable sample of γ-jet events and evaluated the amount of energy lost by the jet by comparing the energy of the jet to the energy of the photon. We found that the jets suffer a significant energy loss and quantified the energy-loss dependence on the centrality of the collisions.

In the 2011 PbPb run CMS has used a dedicated trigger that selected events containing at least one track with $p_T$ above 12 GeV/c. This high-$p_T$ trigger allowed the measurement of the azimuthal asymmetry of charged particles with $p_T$ up to 60 GeV/c. We observed a non-zero elliptic anisotropy ($v_2$) of charged particles for momenta up to about 40 GeV/c, related to the path-length dependence of the parton energy loss mechanism. For the first time, we were able to identify jets containing b-quarks and measure their suppression to be the same or very similar to the light quark jets.

The excellent resolution of CMS muon detector allowed the measurement of the suppression of 2S and 3S states of the Upsilon, as compared to 1S and to the pp reference. The suppression was measured as a function of the centrality of the collision. Together with the measurement of the suppression of J/ψ and ψ′, we see a clear pattern where the degree of suppression is related to the binding energy of the quarkonium state. We hope to use the suppression pattern to directly measure the temperature of the medium.

We are advancing our measurements of W and Z boson production. The increased statistics of the 2011 run together with the improved reconstruction software will allow for a detailed study of the centrality and $p_T$ dependence of W and Z production.

In early 2013 we expect to collect data with proton-nucleus and proton-proton collisions at the matching center-of-mass energies. The pPb run will provide important physics reference for the interpretation of PbPb data as well as better insight into the parton structure of the nucleus. The preparation for the pPb run will require a new trigger configuration. The requested proton-proton data is essential to establish a reference for both the pPb and PbPb results, by increasing the available statistics by a factor of ~30 to match the effective nucleon-nucleon luminosity sampled already in the 2011 PbPb run. On September 13, 2012 we successfully collected over 2 million pPb events at a nucleon-nucleon center-of-mass energy of 5 TeV. We used prototype trigger and readout configurations. The data from this short test run is being analyzed and it will be very valuable for the preparation of the month-long pPb run in January of 2013.

In parallel to the data analysis and the preparation for the pPb run we are planning a Level-1 trigger upgrade that needs to be ready before the next PbPb run. The upgrade to the calorimeter trigger will significantly increase the selectivity of the jet trigger, which will allow handling of the much higher event rates expected in future LHC PbPb runs.

## Upgrades

The detector projects targeting LS1 (2013-2014) are all in pre-production or production. A fully integrated schedule developed by Technical Coordination includes installation milestones and a detailed work-plan. The start of RPC chamber production was delayed due to a contamination problem in the production of the Bakelite sheets. With this now solved, production of sub-assemblies of sheets is starting and full chamber production will ramp up by the end of this year to a rate of 20 chambers per month, allowing completion in time for the installation milestone. Twelve CSC chambers have been fabricated for the ME4/2 CSC stations, and production proceeds at a rate of 3 per month. The new ME1/1 electronics has passed pre-production tests and integration tests are ongoing, and new Theta Trigger Boards for the DT readout have passed pre-production testing. 100% of the Photomultipliers for the Forward Hadron Calorimeter have been received from Hamamatsu and tested, and production of base-boards and adapter boards for retro-fitting the readout boxes is ongoing. The SiPMs (Silicon Photomultipliers) and the associated electronics cards for the Outer Hadron Calorimeter (HO) are being tested with a system test and burn-in facility in B904.

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 HAL designs are supported by performance and physics simulation studies, and the collaboration has approved the Technical Design Reports. The prototyping is well advanced and the cost estimates have been updated with the engineering designs and prototype experience. The new pixel detector uses a new readout chip and DAQ to allow significantly higher data rates, and has four barrel layers and three disks per end to provide significantly more robust tracking performance at high pileup. New cooling, cabling and powering systems achieve a significant reduction in mass. In the HCAL upgrade the present HPD photodetectors in HB and HE are replaced with SiPMs, and a new front-end chip provides much improved timing information for HF, HB and HE. The new front-end electronics has significantly better signal/noise and allows depth segmentation in HB and HE. The result is improved noise rejection, isolation and particle-flow performance at high pileup.

The physics motivations of the Pixel and HCAL Upgrade have been extensively studied and are reported in the TDR's. Regarding the Pixel Upgrade the LHCC report notes that *"For H → ZZ* with $Z^{(*)}$ → $\mu^+\mu^-$, $e^+e^-$, the upgrade detector provides the equivalent of a similar physics reach as the current detector with 40-50% more luminosity. For the associated Higgs production ZH → ll, bb , the improvement in signal efficiency is 65%. The sensitivity of the SUSY search in a γγ+MET final state depends on the rate of electrons misidentified as photons. In the upgraded detector, that rate is estimated to be 1.25% compared to 7.0% for the existing detector. These physics studies for the upgraded pixel detector strongly motivate the upgrade.* In what concerns the HCAL Upgrade the LHCC committee considers that *"The physics studies demonstrate a strong motivation for the upgrade. The study of H→ZZ→4l shows that improved HCAL noise levels allow tightening of electron H/E cut by a factor of 3 and the isolation cuts can be significantly tightened for both electrons and muons with no distortion of critical observables. For the SUSY signature μ+j+MET, fake MET was significantly reduced without affecting true MET in signal events. In addition, the tt+jets $H_T$ distribution is closer to the generator-level $H_T$.* The report concludes that *"The LHCC endorses the HCAL and pixel upgrades without reservations"*.

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 be possible only with the upgrade. Prototype micro-TCA 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 micro-TCA, 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. The Technical Design Report for the L1-Trigger upgrade will be completed in early 2013.

R&D and studies continue for the Phase 2 upgrade beyond 2020. Two working groups have been formed to develop the long term strategy; one for the Trigger and the other for the Forward Region, where radiation and pileup issues will be particularly severe. The work will include developing the conceptual strategy, simulation studies, and an associated R&D program. Work continues on the design of a new tracker for Phase 2, with the capability of providing track information to the hardware trigger.

# 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, Oct 13, 2012, CMS has published 188 physics papers in PRL, PRC, PRD, EPJC, PLB, and JHEP. Members of the CMS collaboration, who gave talks at international conferences worldwide, wrote their contributions to the conferences' proceedings; so far, 845 conference reports were published (since Jan 1, 2010). The corresponding increments in these categories since the last RRB in April 2012 are: Papers – 53; CRs – 89.

The eight most cited CMS physics papers to-date, each with at least 100 citations are:

1. Combined results of searches for the standard model Higgs boson in pp collisions at sqrt(s) = 7 TeV - Phys.Lett.B710 (2012) 26-48; 366 citations.

2. Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC - Phys.Lett.B716 (2012) 30-61; 192 citations.

3. Search for Supersymmetry at the LHC in Events with Jets and Missing Transverse Energy - Phys.Rev.Lett. 107 (2011) 221804; 184 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; 183 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; 168 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; 149 citations.

7. Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions at the LHC - JHEP 1009:091, 2010; 138 citations.

8. Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 7 TeV - Phys.Rev.Lett.105:022002, 2010; 152 citations.

# Conclusion

The CMS experiment is traversing an historic period in particle physics, which culminated recently with the observation of a Higgs-like boson. The investigation of the nature of this new particle will be intensively pursued with the data accumulated until December 2012. CMS expects that the total integrated luminosity at 8 TeV will exceed 25/fb, allowing to reach a significance of 3 sigma in the measurement of the spin and parity of new particle.

The CMS detector is performing extremely well meeting the high pileup challenge. The CMS collaboration made an enormous effort to prepare detectors, trigger, software, computing, and physics tools, to be ready to profit from instantaneous peak luminosity up to $8.5x10^{33}cm^{-2}s^{-1}$ corresponding to an average of 40 pile-up events. These efforts were already rewarded with an extraordinary physics output.

The physics goals of the CMS Upgrade program have been considerably strengthened with the observation of the new heavy boson. On the other hand, the studies presented in the Upgrade TDR demonstrate the soundness of the proposed detector upgrades, designed to face the challenges of triggering and reconstruction of physics objects at 14 TeV and at luminosity up to $2.10^{34}$ $cms^{-2}s^{-1}$.