CMS STATUS*

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The status of the construction and installation of CMS detector is reviewed. The 4T magnet is cold since end of February 2006. Its commissioning up to the nominal field started in July 2006 allowing a Cosmic Challenge in which elements of the final detector are involved. All big mechanical pieces equipped with muons chambers have been assembled in the surface hall SX5. Since mid July the detector is closed with commissioned HCAL, two ECAL supermodules and representative elements of the silicon tracker. The trigger system as well as the DAQ are tested. After the achievement of the physics TDR, CMS is now ready for the promising signal hunting.

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1. CMS detector and collaboration

The Compact Muon Solenoid (CMS) is a general-purpose proton–proton detector designed to run at the highest luminosity at the LHC [1]. The detector (Fig. 1) is built around a long (13 m) and large bore ($\phi = 5.9\,\mathrm{m}$) high-field (4T) super-conducting solenoid leading to a compact design for the muon spectrometer. The magnetic flux is returned through 1.5 m of saturated iron yoke (1.8 T) instrumented with muon chambers.

From the beginning CMS was designed to be accessible and maintainable. The barrel yoke is sectioned in five wheels (YB$-$2, YB$-$1, YB0, YB$+$1 and YB$+$2) movable on rails with air pads. The central wheel (YB0, $\sim 2000\,\mathrm{t}$) supports the vacuum tank containing the super-conducting coil, the vacuum tank in turn supports the barrel calorimeters (900 tons), which support the full tracker. The endcap yokes are made of three iron disks each (YE1, YE2 and YE3), which can be opened to access the endcap muon chambers. The first endcap disks (YE$+$1 and YE$-$1) support the 300 tons endcap calorimeters. The CMS Collaboration consists currently of 2030 physicists and engineers from 176 Institutes in 36 countries.

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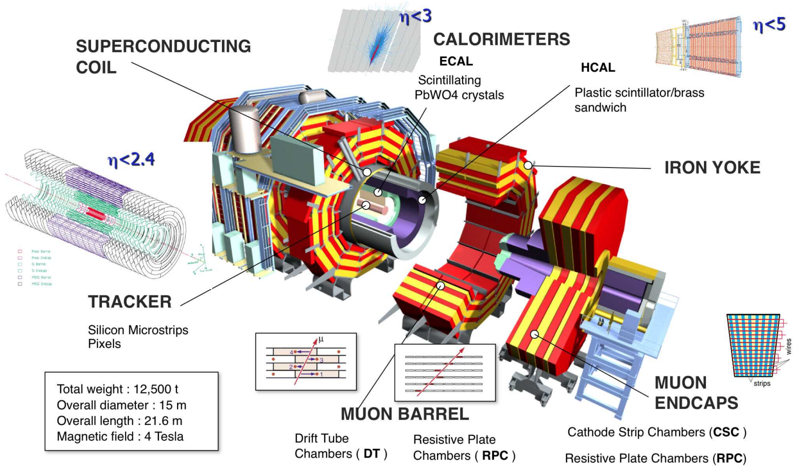


Fig. 1. Overview of the CMS detector.

2. CMS detector assembly overview

The CMS experimental cavern (Fig. 2) is now delivered and ready to receive detector elements as soon as the magnet commissioning is achieved. Heavy lifting operations to transfer CMS underground will start immediately after the magnet test is finished. The system (Fig. 3) has been validated and is ready for operation. The heaviest element (YB0) will be in the cavern by Christmas 2006. All detector elements will be in place by early February 2007. Installation and commissioning of the muon chambers on the magnet yoke is largely made. Fig. 4 presents detectors equipped heavy pieces, during this summer process of detector closing procedure on the surface.

Fig. 2. Main CMS cavern, ready to receive the detector.

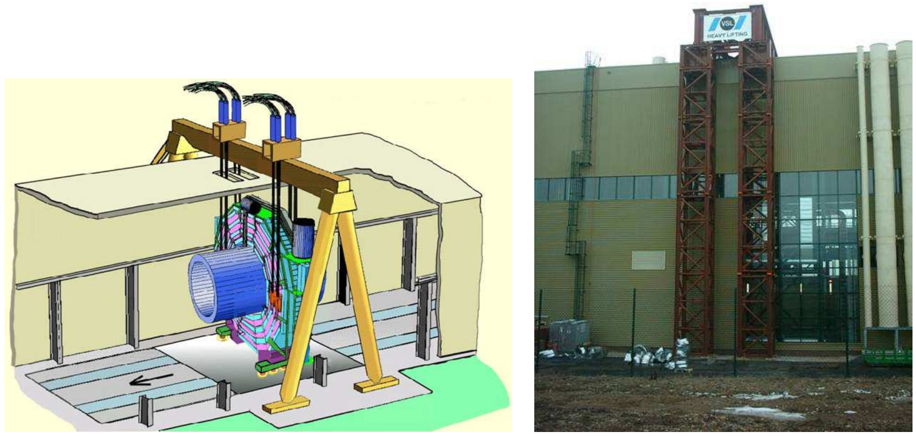


Fig. 3. Heavy lifting principle (left). Elements of the crane (right) at P5.

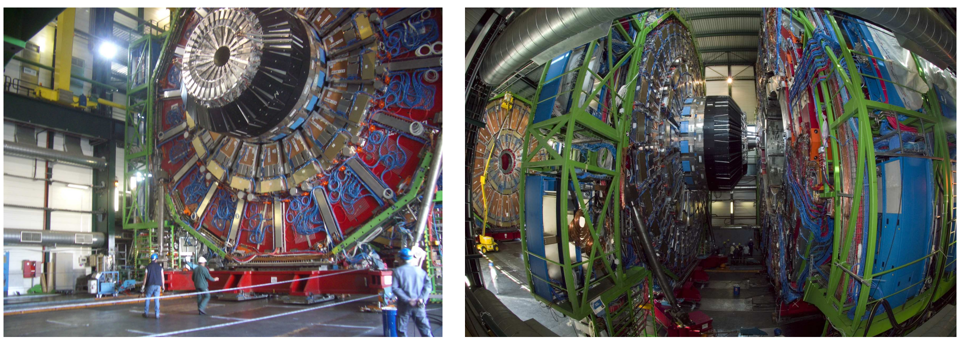


Fig. 4. CMS assembly process: YE1 (left) equipped with the muons chambers and calorimeters sliding on the floor towards YB3 (right).

3. Towards a working detector: the Cosmic Challenge

3.1. CMS solenoid achievement

Fig. 5 shows the insertion of the 4 Tesla coil into the vacuum tank. The coil is made of 5 modules each of length 2.5 m. To reach 4 Tesla four layers of reinforced super-conducting cable are necessary. For the nominal current of 20 kA the radial magnetic pressure reaches 64 atmospheres and the stored energy is 2.7 GJ! The five coil modules have been wound at Ansaldo in Genova, Italy. The 5 modules have been assembled vertically as a single coil in SX5 on a swiveling platform, which was used to turn the coil in the horizontal position and insert it in the outer shell of the vacuum tank supported by YB0. During early spring 2006 the coil was cooled down up to its working temperature without any problem. Fig. 5 (right) gives the coil cool-down curves as recorded during the 4 weeks of the operation. The magnet is now in its commissioning procedure to supply the 20 kA and deliver the nominal 4T field.

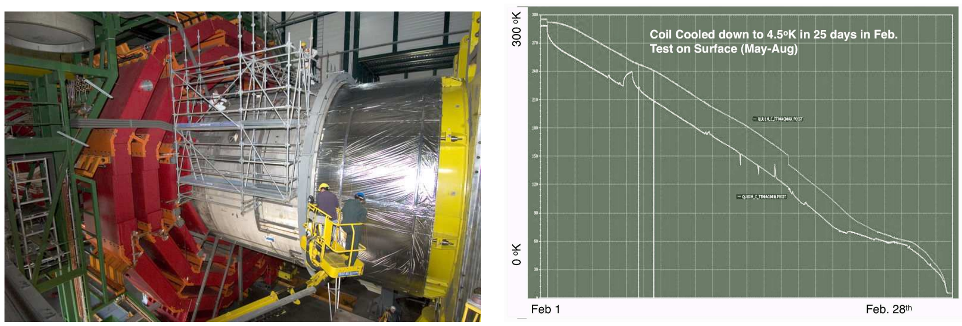


Fig. 5. The coil insert (left) in the vacuum tank supported by YB0 and the coil cool-down curve (right).

3.2. The Cosmic Challenge

The magnet commissioning procedure spread over about 6 weeks will produce for the first time in the surface hall the 4T field. This operation time is used to record cosmic data in the installed detector elements. The muon chambers are used to define the trigger and to start the data acquisition to record the HCAL, ECAL and Tracker data. Fig. 6 shows the installed elements inside the magnet.

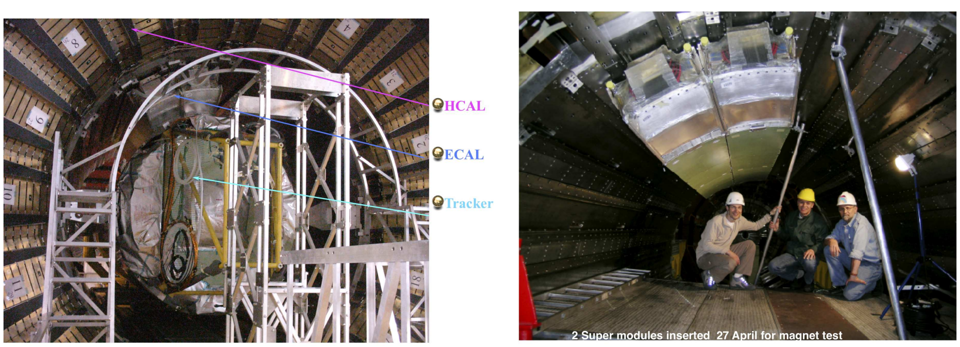


Fig. 6. HCAL, ECAL and Tracker elements installed inside the magnet for the Cosmic Challenge (left). Two ECAL SM inserted into the HCAL (right).

3.3. Detector response to muons

Fig. 7 and Fig. 8 (left) show muons data as recorded by the HCAL, the Forward Tracker (TEC) during their validation phases and the muon DT which will be used as trigger for the Cosmic Challenge. All ECAL supermodules are also tested with cosmic muons providing the first crystal inter-calibration constants. For the first time end of July 2006, CMS has seen in the drift tubes tracks curved by the magnetic field. Fig. 8 (right) shows an event taken in August with a field of 3.80 Tesla during the Cosmic Challenge and showing active muon, HCAL, ECAL and Tracker detectors.

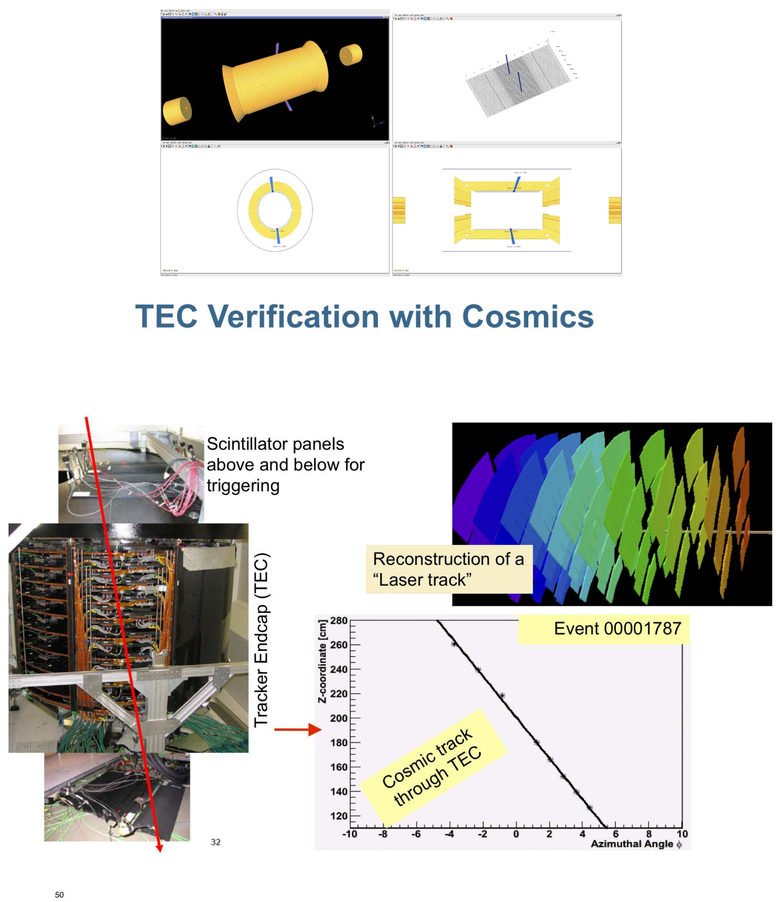


Fig. 7. Muon event in the HCAL (top) and in the TEC tracker (bottom).

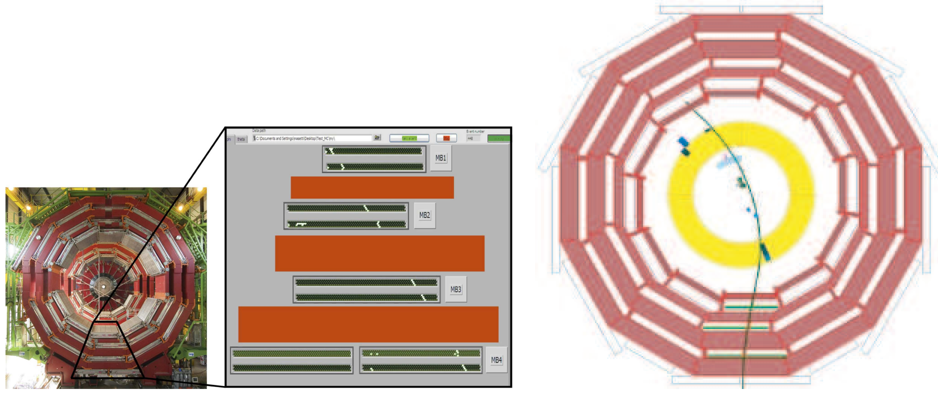


Fig. 8. Muon data recorded in CMS DT chambers without magnetic field (left). On the right, an event display taken end of August with a field of 3.80 Tesla during the Cosmic Challenge and showing active muon, HCAL, ECAL and Tracker detectors.

4. CMS detector construction status

4.1. Muon chambers

The full CMS muon system is now installed and commissioned. Fig. 9 (left) shows endcap disk fully equipped with CCS and RPCs. Fig. 9 (right) shows the foreseen precision performance of the CMS muon system.

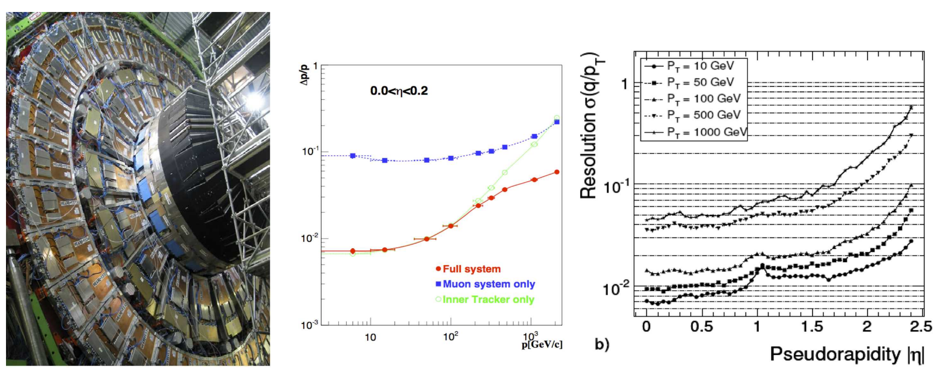


Fig. 9. Endcap disk equipped with muon chambers (left). Performance of the CMS muon system (right).

The CMS muon system involves 3 types of chambers: Drift Tubes (DT) in the barrel, Cathode Strip Chambers (CCS) in the endcaps and RPCs both in the barrel and in the endcaps used for the trigger. Centrally produced muons are measured three times, in the inner tracker and in the return flux. They are then identified and measured in four Muon Barrel stations (MB) inserted in the five barrel yoke wheels. Special care has been taken to avoid pointing cracks and to maximize the geometric acceptance. Each muon station contains two superlayers (SL) of four planes of aluminum drift tubes oriented along the z-axis designed to give a muon vector in r–ϕ space, with 100 μm precision in position and better than 1 mrad in direction. The first 3 stations also contain one superlayer of four planes of orthogonal drift tubes measuring the θ coordinate. The 250 MB chambers have been built in four production sites: CIEMAT, Aachen, Legnaro and Torino. Dubna and IHEP, Protvino have produced the plates and I-beam electrodes. The endcap muon system also consists of four Muon Endcap stations (ME). Each station consists of six planes of Cathode Strip Chambers (CSCs). The chambers are arranged that all muon tracks traverse four stations at all rapidities, including the transition region between the barrel and the endcaps. The complete endcap muon system consists of 540 ME chambers. The 108 ME4 chambers of the fourth station have been staged. In total, the 432 ME chambers have been delivered by FNAL, US, PNPI-St Petersburg, Russia, IHEP-Beijing, China and Dubna, Russia. The four muon stations include RPC triggering planes that also identify the bunch crossing and enable a cut on the muon transverse momentum at the first trigger level. A new conceptual design of the RPC trigger algorithm confirmed that a noise below 10 Hz/cm^2 is needed for safe triggering in the barrel region. All chambers have been produced by General Tecnica, Italy. The production of endcap RPCs has been done in Korea.

4.2. Hadron calorimeter: HCAL

The coil radius is large enough to install essentially all the calorimetry inside and hence avoid the coil-calorimeter interference. The Hadron Calorimeter (HCAL) in the central region ($|\eta| < 3$) is a copper(brass)/scintillator sampling calorimeter. It consists of a barrel part (HB) supported on rails by the vacuum tank and of two endcaps (HE) supported by the endcap magnet yoke. The transition region barrel/endcap has been optimized to avoid dead regions and pointing cracks. Scintillators placed around the coil detect late fluctuations of hadronic showers in the barrel region and form the hadronic outer (HO) system. The light is channeled by clear fibres fused to wavelength shifting fibres embedded in scintillator plates. The light is detected by photo-detectors that can provide gain and operate in high axial magnetic fields (proximity focused hybrid photodiodes, HPDs). Coverage up to rapidities of 5.0 is provided by a steel/quartz fibre calorimeter (HF). The Cerenkov light emitted in the quartz fibres is detected by photomultipliers. Each half-barrel of HB is made of 18 wedges. All the wedges made of brass material have been fabricated by Felguerra Industry in Spain. Fig. 10 (top) shows the 18 assembled wedges making a half-barrel at it insert into the coil. Fig. 10 (bottom) gives the foreseen jet E_{t} and jet–jet Mass resolutions.

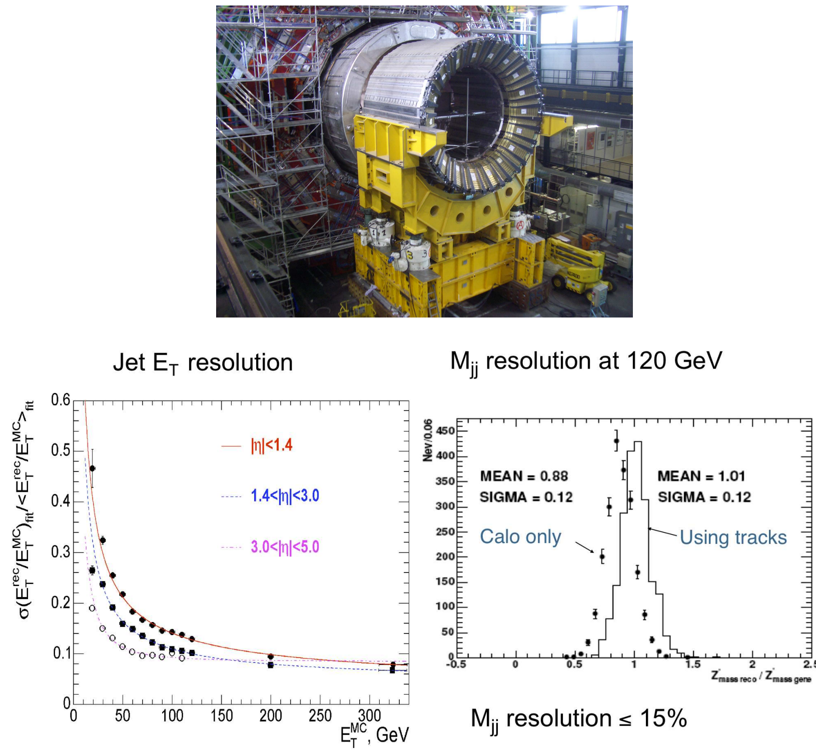


Fig. 10. Half barrel HCAL insertion into the magnet coil (top). Jet E_{t} and mass jet–jet resolutions (bottom).

4.3. Electromagnetic calorimeter: ECAL

The high precision electromagnetic calorimeter (ECAL) of CMS is made of dense lead tungstate (PbWO4) crystals (61200 for the barrel and 7324 for each endcap). It fits well the compact design of CMS. The scintillation light is detected by silicon avalanche photodiodes (APDs) in the barrel region (EB, $|\eta| < 1.48$) and vacuum photo-triodes (VPTs) in the endcap region (EE, $1.48 > |\eta| < 3.0$). ECAL surrounds the tracker volume and the photo-detectors have to work in the 4T magnetic field. Photon–pizero separation in the forward region requires a pre-shower detector (ES) in front of the crystals. The pre-shower system (ES) is installed in front of the endcap calorimeter ($1.6 < |\eta| < 2.6$). At present 22 SM are fully integrated and validated in the electronics integration center. Until now 16 have been intercalibrated with cosmics. A total of 30 SM will be installed into the HCAL before these detectors goes down to the cavern to be inserted into the coil. Fig. 11 gives the achieved design performance of the ECAL.

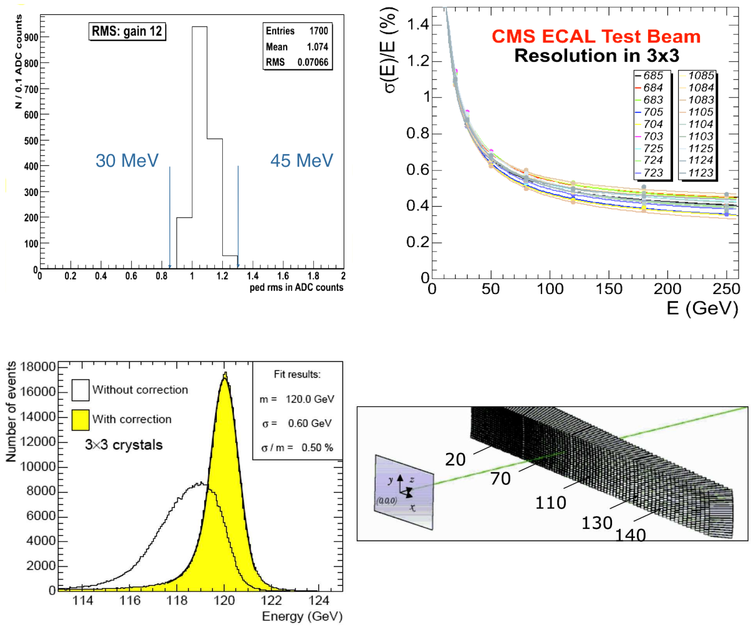


Fig. 11. Performance of the ECAL. The achieved electronics noise (40 MeV per channel) and the resolution for a 3×3 crystal matrix (top). The corrected energy measurement for a widely illuminated SM area (bottom). The achieved resolution for 120 GeV electrons was measured to be 0.5%.

4.4. Tracker

The volume available for tracking is a cylinder of 6 m long and 1.2 m in radius. The whole volume is filled with 210 m^2 of silicon strip sensors, comprising 10 M channels, and $\sim$ 40 M silicon pixels close to the interaction region. The whole tracker volume will be maintained at 10° C in dry atmosphere to minimize the effects of radiation damage of the silicon detectors. Stereo information is provided by back-to-back microstrip detectors with strips at a small angle. The Silicon Strip Tracker (SST) is made of 3 independent mechanical structures: the Tracker Outer Barrel (TOB), the Tracker Inner Barrel (TIB) and Inner Disks (TID) and the Tracker End-Caps (TEC), Fig. 12 (left). The SST has silicon detectors of two different thicknesses: 320 μm in the inner region ($r < 600$ mm) and 500μm in the outer region. A highly automated procedure was needed to assemble the sensors plus hybrids into modules. A total of 16 000 silicon modules have been assembled. System tests of small parts of the tracker (TEC petal, TOB rod, and TIB shell) have been carried out and have shown that the signals are clean (low spurious noise). The rapidity coverage of the tracker is $-2.5 < |\eta| < 2.5$. All high p_t charged particles, produced in the central rapidity region, are reconstructed with a momentum precision of $\Delta p_t/p_t = 0.005 + 0.15\,p_t$ (p_t in TeV). High track finding efficiencies are achieved for high p_t tracks even inside jets. The baseline pixel system consists of 3 barrel layers and 2 forward disks. Fig. 12 (right) shows a picture of the design principle of the pixel detector. The mechanics of the pixel system have been designed to allow independent insertion with the beam pipe in place. The insertion procedure has been tested on a full-scale mechanical mockup. Fig. 13 shows some of the silicon tracker achieved elements.

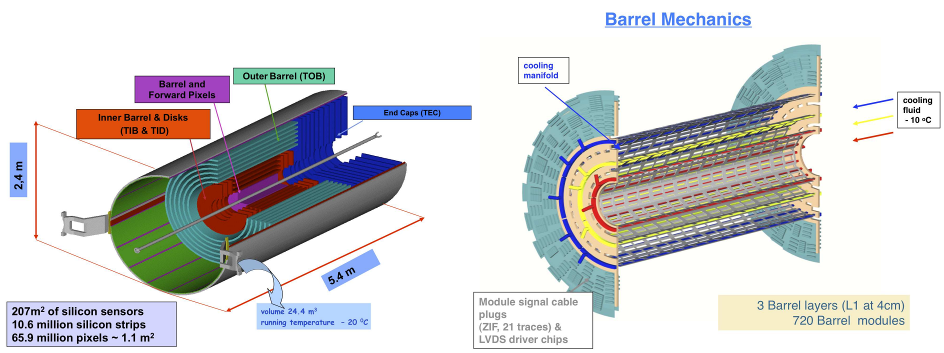


Fig. 12. Silicon tracker design (left). The barrel mechanics for the pixel detector (right).

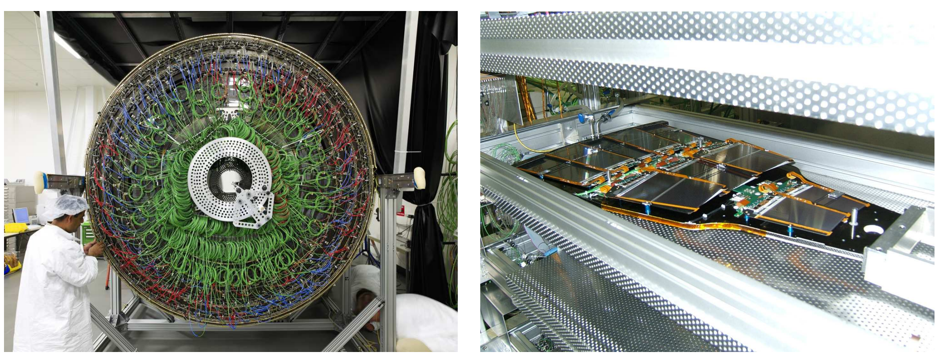


Fig. 13. The completed Tracker Inner Barrel (left), a TEC petal (right).

4.5. CMS trigger and DAQ schemes

The trigger and data acquisition consists of four parts: the front–end detector electronics, the calorimeter and muon first level trigger processors, the readout network and an on-line event filter system. The first two parts are synchronous and pipelined with a pipeline depth corresponding to $3\,\mu$s.

The latter two are asynchronous and based on industry standard data communication components and commercial PCs. The resources that would have been required for a hardware second level trigger processors are invested in a high bandwidth (500 Gbit/s) readout network and in the event filter processing power (10^6–10^7 MIPs), both of which are more suitable for upgrading as commercially available technology develops. The CMS Level-1 trigger decision is based upon the presence of physics objects such as muons, photons, electrons, and jets, as well as global sums of E_{t} and missing E_{t} (to find neutrinos). The Level-1 Trigger as described in Technical Design Report [2] is outlined in Fig. 14 (top).

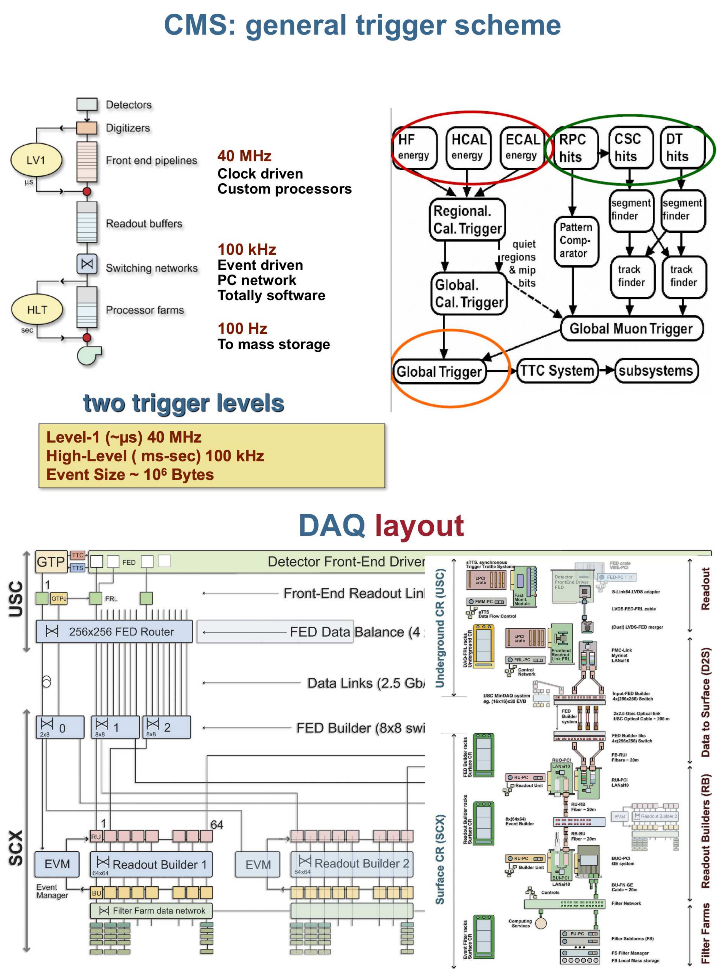
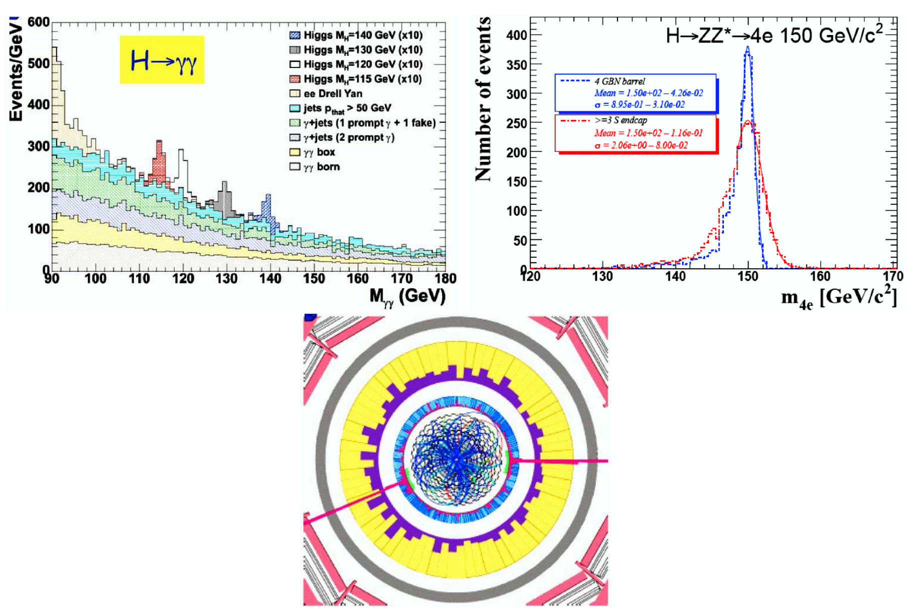


Fig. 14. The general CMS Trigger scheme (top). The DAQ system (bottom) is made of 8 independent systems (slices). Each slice consists of 64 RUs, a 64×64 EVB and 64 BUs and associated filter units. A slice can read up to 12.5 kHz.

The DAQ system, Fig. 14 (bottom), has to assemble the data from the triggered event, contained in about 500 front–end buffers (readout units, RUs), into a single processor in a farm for executing physics algorithms (so-called High Level Trigger or HLT algorithms) so that the input rate of 100 kHz is reduced to the 100 Hz of sustainable physics at high luminosity. The size of a raw data event in CMS is 1 Mbyte. The DAQ system consists of 8 independent slices able to handle 12.5 kHz of L1 rate each. This modularity allows to start with a reduced system at low luminosity and to progressively add more slices as the luminosity increases. The corresponding TDR [2] describes in detail a scenario for a starting luminosity of $2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. For the first physics run starting in 2007 the initial DAQ will consist of only 4 slices, which limits the L1 trigger rate at 50 kHz. This design allows natural commissioning phases (Staging). Single farm design provides also a maximum flexibility for the physics selection. It was shown with realistic algorithms that the plan of a farm consisting of 1000 dual CPUs to reduce the rate from 50 kHz to 100 Hz of good physics data is working. Results have confirmed the feasibility of the proposed DAQ design. The setup is presently under test in the Cosmic Challenge to evaluate all the software and hardware components

5. Towards physics

CMS just achieved its Physics Design Reports (TDR) [3]. In the proceedings of the conference many results issued from that work have been presented in detail. Fig. 15 shows some of the most striking results related with the Higgs boson production at LHC [4–6].



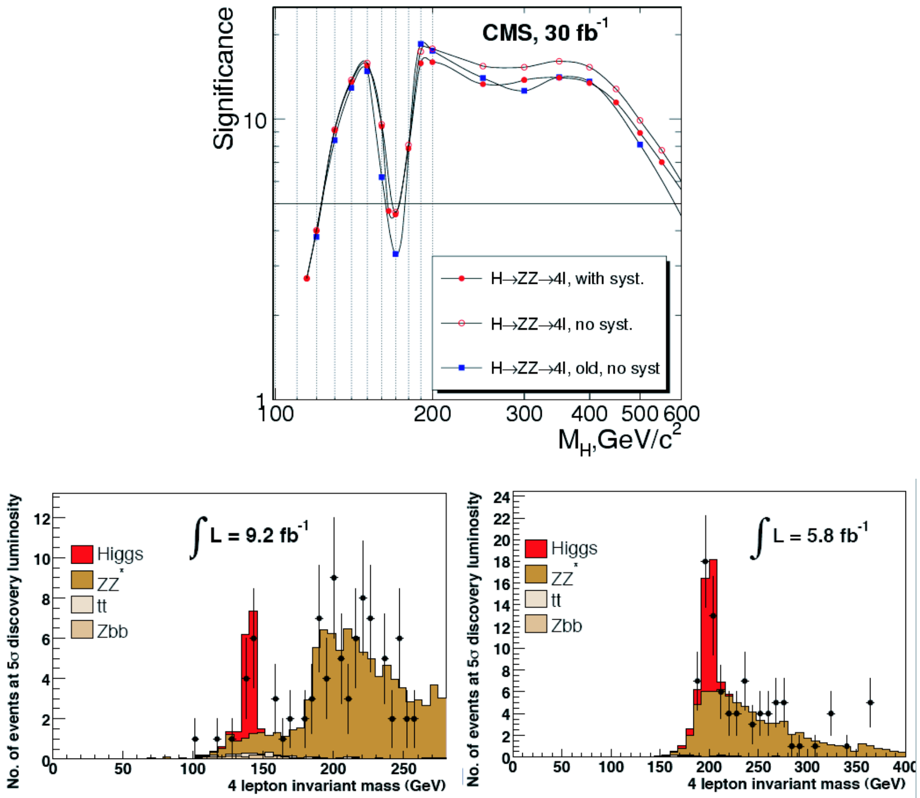


Fig. 15. Higgs discovery potential with the CMS detectors.

6. Conclusion

CMS is following an assembly sequence that allows a complete detector (except for ME4/2 and 3rd forward pixel layer) to be ready for the first physics run. The muon system as well as the HCAL are delivered and used in the present Cosmic Challenge combined with the magnet reception tests. First curved tracks have been observed in the involved detector elements (Muons, HCAL, ECAL and Tracker) placed in the magnetic field, Fig. 8 (right). The ECAL barrel will be in place before the first LHC collisions as well as the Tracker which after its commissioning phase starting this autumn, will be inserted inside the calorimeters in April 2007. The pixel detector will be installed during the 2008 shut down as well as the EndCap ECAL and the pre-shower. The proposed detector will be able to exploit the physics potential of the first physics run at medium luminosity (2×10^{33} cm^{-2} s^{-1}) for which an integrated luminosity of the order of

$10\,\mathrm{fb}^{-1}$ could be accumulated during the first year of operation (30% efficiency). With $10\,\mathrm{fb}^{-1}$ most of the standard model Higgs can be probed. SUSY squarks and gluino with masses up to about 2 TeV can be discovered in the jet plus missing E_t channel. For these discoveries full acceptance must be maintained. The installation of a complete barrel and endcap ECAL for the first physics run is vital to discovering a Higgs below a mass of 140 GeV.

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