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Abstract. The status of the construction and installation of CMS is reviewed. All big mechanical pieces have been assembled in the surface hall SX5 (except the 2^{nd} hadronic endcap calorimeter, HE+1, to be assembled this autumn). Full test of the magnet on the surface will start in March 2005. Waiting for the underground caverns to be ready, installation and commissioning of the hadron calorimeter and of the muon system has started in SX5. The assembly sequence followed by CMS (v33) is based on the completion of the full CMS detector, minus the staged items (ME4/1 and ME4/2, some RPC chambers at low angles, 50% DAQ online farm, 3^{rd} forward pixel disks), in time for physics in mid-2007.

1 CMS detector and collaboration

From the outset the Compact Muon Solenoid (CMS) Detector [1] 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 (Fig. 1).

The central wheel (YB0, 1800 tons) supports the vacuum tank containing the superconducting 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 ton endcap calorimeters.

The CMS Collaboration consists currently of 1890 physicists and engineers from 152 Institutes in 36 countries.

2 Civil engineering and assembly

Excavation of the two underground caverns, UXC55 (for the experiment proper) and USC55 (for the counting rooms and services) was completed in September 2002. Concreting work is well advanced in both caverns (Fig. 2). The caverns will be delivered to CMS in summer 2004, when the installation of infrastructure will start in line with schedule v33. The CMS experimental cavern will thus be ready to receive detector elements around mid 2005.

The big surface hall (SX5) was delivered in January 2000. The hall is big enough (120m long, 20m high) to allow assembly and commissioning of big pieces of the CMS detector on the surface. The Magnet yoke (12000 tons) is complete since mid-2002. Metallic structures for racks on the wheels and disks of the magnet yoke are ready since spring-2003. Gas and cooling pipes for the muon system are being installed. Installation and commissioning of the muon chambers on the magnet yoke will start in June 2003. Heavy lifting operations to transfer CMS underground will start immediately after the magnet test on the surface around mid-2005 (Figs. 2 and 2).

3 Magnet

The assembly of the magnet iron yoke (Fig. 3) comprising 5 barrel rings and 3 endcap disks on each side was completed mid-2002.

Figure 3 shows a longitudinal section of the 4 Tesla coil. The coil is made of 5 modules each of length 2.5m, called CB-2, CB-1, CB0, CB+1 and CB+2. To reach 4 Tesla four layers of reinforced superconducting 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!

For the conductor, 18 out of 21 cables (20 plus 1 spare, each 2650 m long) are complete and the remaining 3 will be finished by September. The five coil modules are wound at Ansaldo in Genova, Italy. Their dimensions (7m diameter x 2.5m high) allow transportation by road to CERN. The first of the 5 coil modules (CB-2) has been wound and is ready for impregnation (Fig. 3); the last coil module (CB+2) should be delivered to CERN in the first half of 2004. The 5 modules will be assembled vertically as a single coil in SX5 on a swivelling platform, which will be used to turn the coil in the horizontal position and insert it in the outer shell of the vacuum tank supported by YB0.

The critical path, previously through coil winding, is now through mandrel production, where problems with the alloy supply had introduced a 4 month delay. It is possible to recover 2 months and the goal is to delay the start of the surface magnet test by a maximum of 2 months with respect to the master schedule v33, i-e to start 1

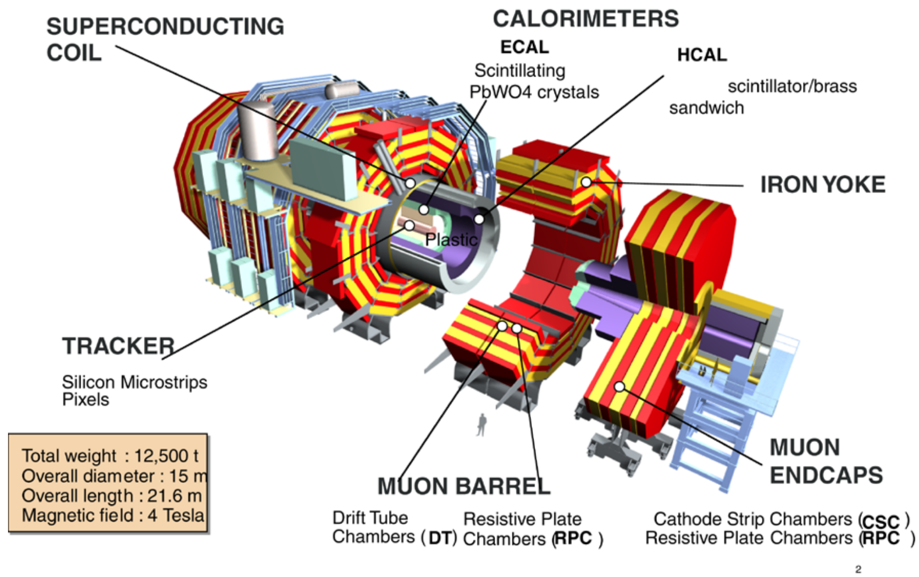

Fig. 1. Overview of the CMS detector

Fig. 2. Concreting work in the two underground caverns: USC55 (*service cavern on the left*) and UXC55 (Concreting work in the two underground caverns: USC55 (*service cavern on the left*) and UXC55 (*experimental cavern on the right*)

March 2005. This 2-month slip can be integrated in the overall v33 schedule by suppressing the full magnetic test underground and performing only the cryogenic tests.

4 Tracker

The volume available for tracking is a cylinder of 6m long and 1.2m in radius. The whole volume is filled with 210 m^2 of silicon strip sensors, comprising 10M channels, and $\sim$40M silicon pixels close to the interaction region. The whole tracker volume will be maintained at -10^oC in dry atmosphere to minimise the effects of radiation damage of the silicon detectors.

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). The SST has silicon detectors of two different thicknesses: 320 μm in the inner region (r¡ 600mm) and 500 μm in the outer region. All mechanical components have been designed in detail. TOB rods, TOB wheels and TIB shells are already in procurement. Contracts for the support tube, the thermal screen and the TID disks are close to be awarded.

A highly automated procedure is needed to assemble the sensors plus hybrids into modules and most centres

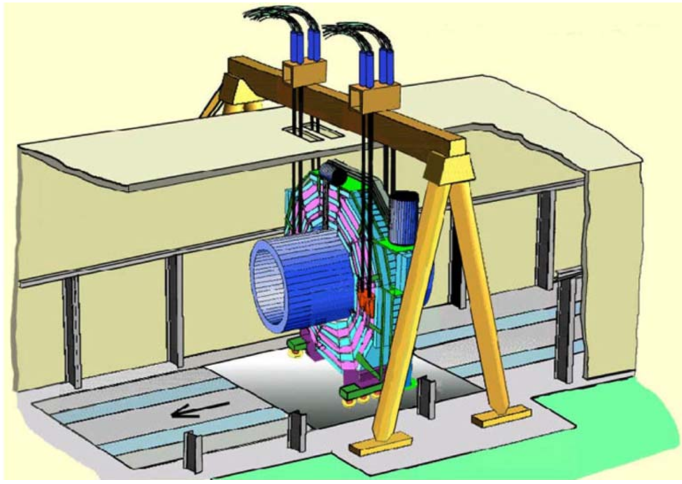

Fig. 3. Transfer of the central wheel YB0 (2000t) fully instrumented with muon chambers and supporting the 13m long superconducting coil

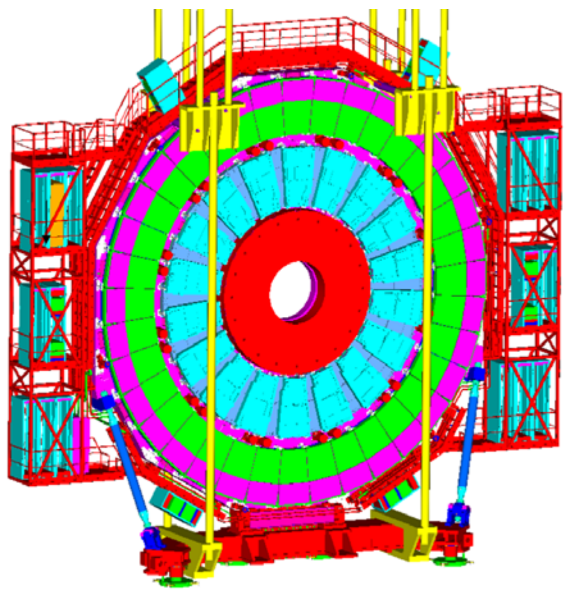

Fig. 4. Transfer of one of the YE2 end cap disk (800t), fully instrumented with muon chambers and racks of electronics

have been certified. A total of 16,000 silicon modules are needed. All elements needed to start module production are in hand. The procurement of front-end hybrids was delayed due to problems with the mechanical properties of the first prototypes. An order for 4700 (25%) hybrids has been placed before the main contract becomes operational in October. The schedule of module production consistent with the CMS master v33 schedule is shown on Fig. 4.

Module production is currently showing 5 month delay with respect to the schedule in Fig. 4, mainly because of the delay with the hybrid procurement. The aim is to recover much of this delay by using over-capacity, though if there are no further delays, the 5 months could be covered by a 3-month tracker float plus 2 months of master contingency.

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 baseline pixel system consists of 3 barrel layers and 2 forward disks. Good progress has been made on pixel electronics and sensors. Figure 4 shows a picture of the first pixel module (Module 00) equipped with 2x8 pixel readout chips (ROC) in DMILL technology successfully operated at 40 MHz.

The final ROC will be in DSM technology (0.25 μm) with better performance expected (smaller pixel size, more buffers, less data losses) for operation at very high luminosity. Translation of the ROC into 0.25 μm is almost finished with submission expected in June.

Pixel module production is scheduled to start in the beginning of 2005.

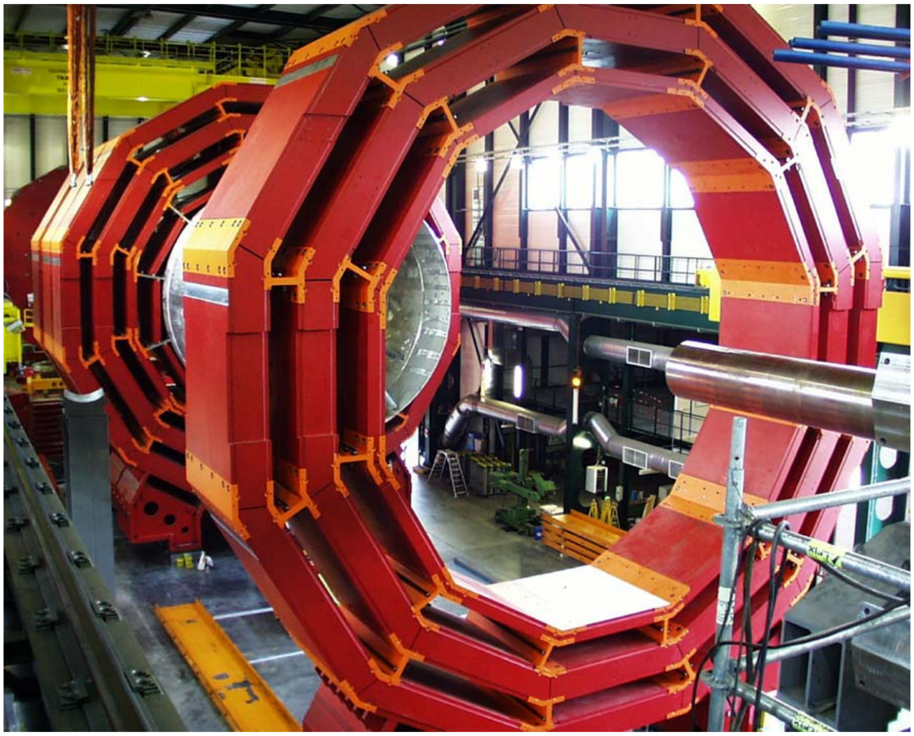

Fig. 5. View of the Magnet iron yoke complete in SX5

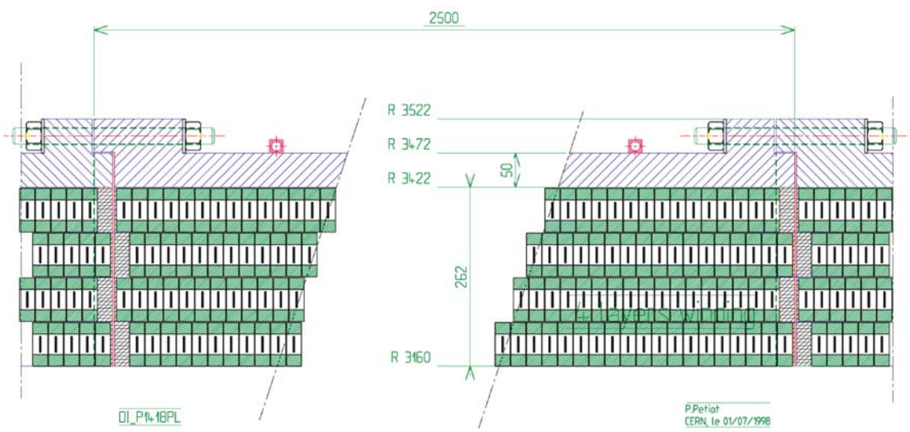

Fig. 6. The coil is made of 5 coil modules of length 2.5m and external diameter $\sim$ 7m. Each coil module is made of four layers of reinforced superconducting cables. Each coil module needs four uninterrupted cables of length 2.65 km

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.

5 Electromagnetic calorimeter, ECAL

The high precision electromagnetic calorimeter (ECAL) of CMS is made of about 76,000 dense lead tungstate (PbWO4) crystals. The scintillation light is detected by silicon avalanche photodiodes (APDs) in the barrel region (EB, $|\eta|$¡1.48) and vacuum phototriodes (VPTs) in the endcap region (EE, 1.48¡$|\eta|$¡3.0). ECAL surrounds the tracker volume and the photodetectors have to work in the 4T magnetic field. A preshower system (ES) is installed in front of the endcap calorimeter ($1.6 \leq |\eta| \leq 2.6$).

The crystal production plan foresees a large increase in crystal production by growing larger ingots from which two crystals can be cut. However, difficulties have been encountered with the new wire-based machine for cutting these larger boules. Progress is being made in resolving these difficulties and in preparing for cutting on an industrial scale. As a consequence, 3500 crystals instead of 5500 will be delivered in the first quarter of 2003 (Fig. 5).

Fig. 7. CB-2 ready for impregnation at Ansaldo (Genova, Italy)

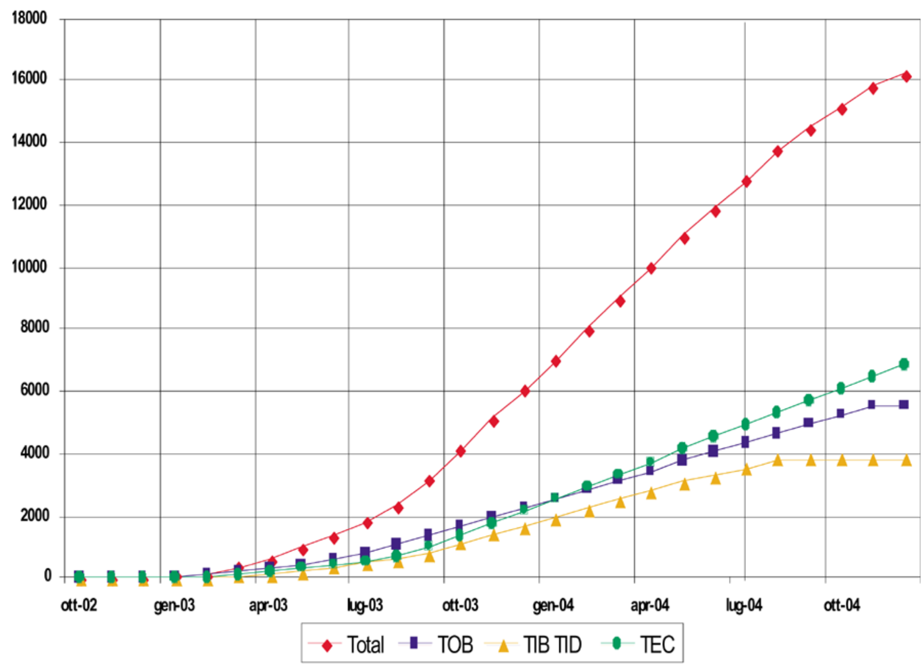

Fig. 8. Schedule of silicon module production consistent with v33 schedule. 16,000 modules should be finished by Dec 2004

This slippage does not yet put crystal production on the critical path. About 15000 out of 62000 of the barrel crystals have been delivered and are being used to construct modules (400 or 500 crystals) in CERN and Rome. Twenty-one modules from a total of 144 have been produced. Two bare supermodules (SM) (1700 crystals) have been assembled (out of 36 needed in total for the barrel). Figure 5 shows the first production supermodule (SM1) equipped with the front plate and the monitoring fibres.

The rate of 6000 APDs/month has been reached and more than 85,000 out of the 130,000 APDs have been delivered. About 4100 VPTs have been delivered to the Rutherford Appleton Laboratory (UK) and tested to 1.8T.

The ECAL electronics underwent a major revision in 2002 primarily to contain costs. A new chip, called FENIX, was introduced in the front-end electronics sitting on the detector. Its function is to generate trigger sums for the L1 decision and to store for each channels the digitised information until an L1 trigger accept. Figure 5 shows the layout of the various boards sitting behind one trigger tower of 25 crystals.

The very front-end (VFE) boards serve 5 crystals each and contain for each crystal a multigain preamplifier and

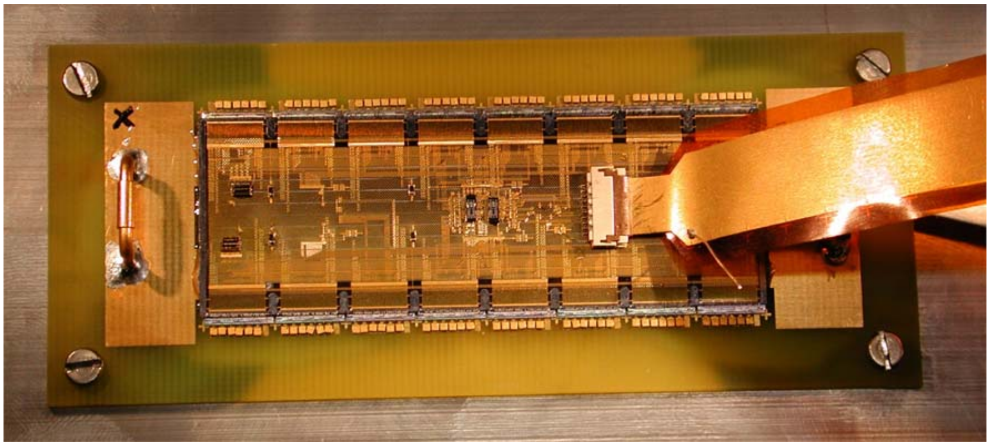

Fig. 9. Module 00 equipped with 2x8 DMILL readout chips, successfully tested at 40 MHz

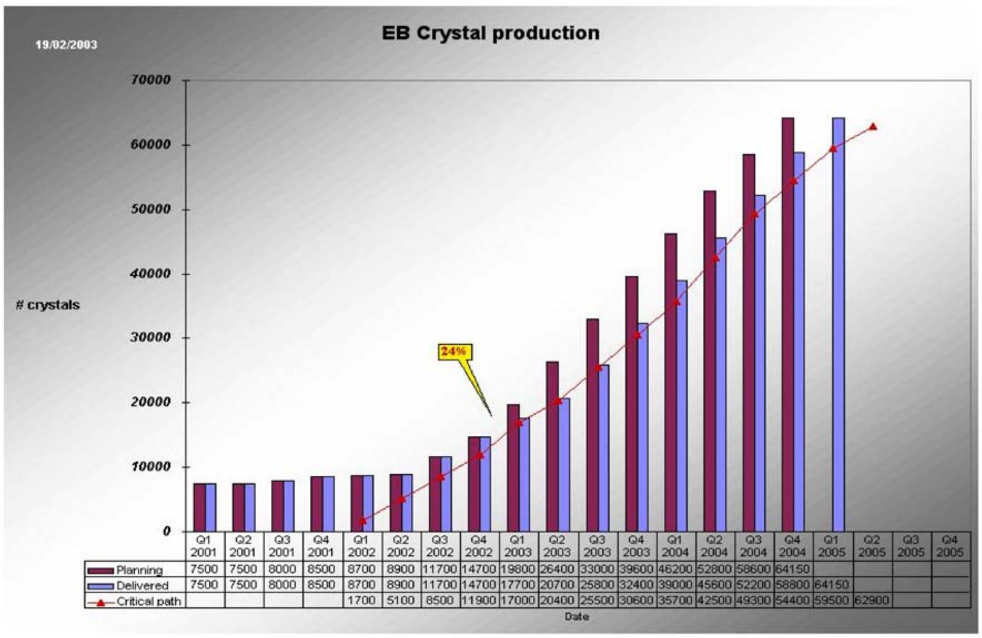

Fig. 10. Barrel Crystal delivery schedule

a 40 MHz ADC. Five VFE boards are necessary to equip a trigger tower of 5x5 crystals (vertical boards in Fig. 5). A sixth board contains the low voltage regulators. The front end (FE) board (top board in horizontal position Fig. 5) contains the new FENIX chips and a chip to control the readout and trigger. Only two optical links are needed per trigger tower (one for the trigger and one for the readout), instead of 25 in the previous design.

The very front-end chips (pre-amplifier and ADC) have been redesigned in Deep Sub-Micron technology (DSM). The new chain is expected to have better performance and to be cheaper. All new DSM chips have been recently submitted and will be ready for tests in June. CMS expects to launch the pre-production of the final front-end electronics in autumn 2003 after systems tests during the summer. Orders for the optical links (based on tracker links) will be placed soon. The clock and control system developed for the CMS tracker has been adopted.

A new ECAL schedule has been produced, taking into account the new electronics project. The ECAL should be completed and commissioned by April 2007. The plan foresees the calibration of at least 9 SMs in beams in 2004 and 1 Dee in 2006.

Photon-pizero separation in the forward region requires a preshower detector (ES) in front of the crystals. Mass production of the silicon sensors has started in Russia and India (about 22% of sensors have been produced and tested) and should start soon in Taiwan. Even though excellent results were obtained with the DMILL version of the ES front-end electronics (PACE) the decision was taken to transfer to 0.25μm technology and make use of the new DSM ADC being developed for the ECAL.

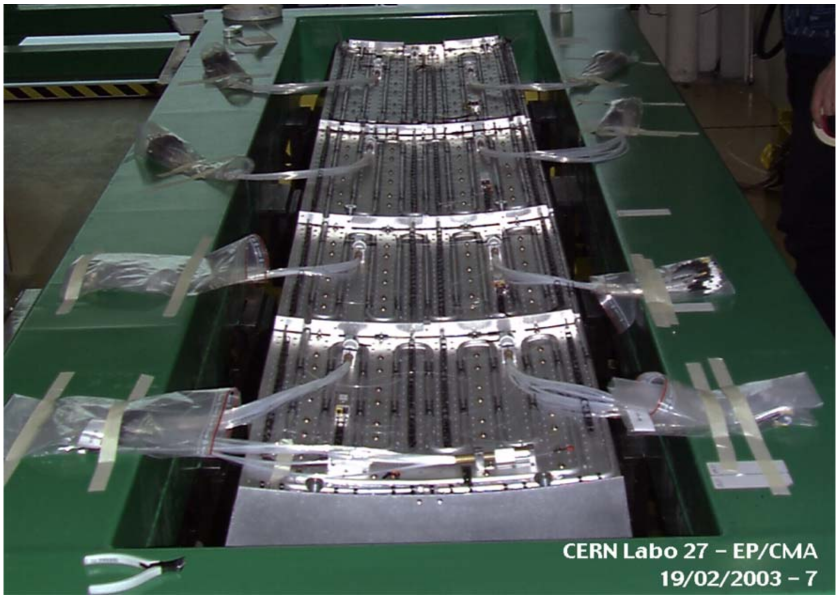

Fig. 11. Production of the first bare supermodule (SM1) complete with 1700 crystals. Laser monitoring fibres entering the front face of the crystals are visible

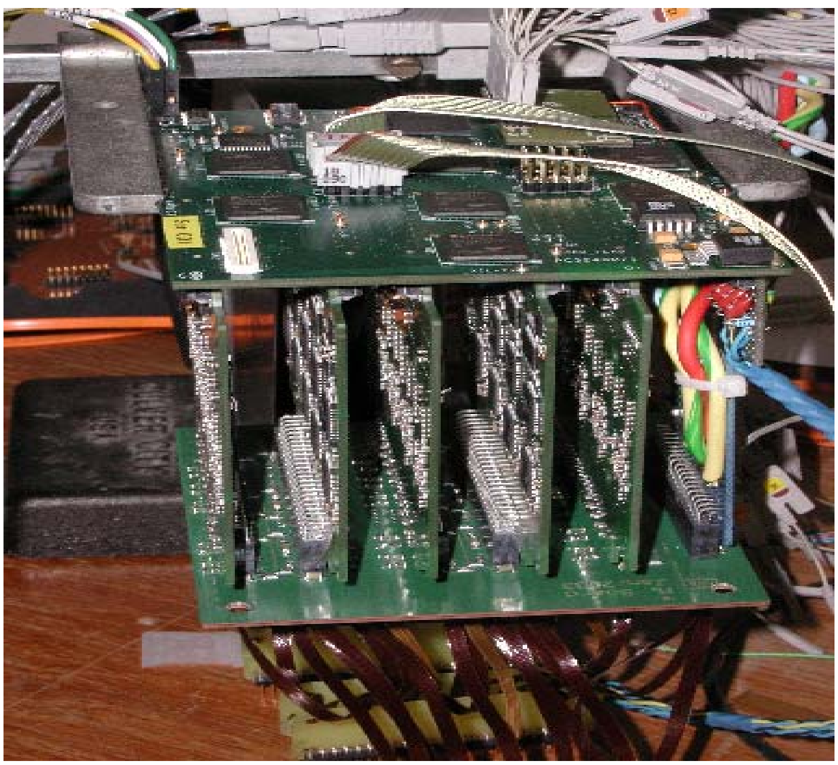

Fig. 12. Font-end electronics layout for one trigger tower (5x5 crystals)

6 Hadron calorimeter, HCAL

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 barrel is made of two half-barrels, HB+1 and HB-1, which have been assembled in SX5. Figure 6 shows HB+1, complete with all its megatiles (plastic scintillator embedded with wavelength-shifting fibres) inserted. Visible on the picture are bundles of clear fibres waiting to be connected to the readout boxes.

The first hadronic endcap (HE-1) calorimeter mounted on the first disk of the endcap yoke (YE-1) has been ready since Feb 2003 (Fig. 6). All the megatiles for HE have also been produced and have been already inserted in HE-1.

Fig. 13. View of the first half-barrel hadron calorimeter (HB+1) assembled in SX5 and sitting in its cradle. The cradle is used for the assembly and for the insertion into the coil

Fig. 14. HE-1 mounted on the first disk of the endcap yoke YE-1

The second hadronic endcap (HE+1) will be mounted on YE+1 on the other side of the hall in the summer of 2003.

The photodetectors (HPDs) delivery now has reached the planned rate of 40 units per month. Final readout electronics was validated in the test beam, including that to be installed in the readout boxes. Starting in autumn 2003 electronics will be installed in the surface hall. After a burn-in period, commissioning operations, including cosmics and source calibrations, will begin and continue until the magnet test mid-2005.

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. All 36 steel absorber wedges for the HF have been produced and delivered to CERN. Quartz fibres (the active medium) have been inserted into 15 wedges (Fig. 6).

Fig. 15. HF wedges complete with quartz fibres inserted

Fig. 16. Installation of a MB1 chamber with final tooling

A beam-test of a few HF endcap wedges is foreseen in 2003.

7 Muon system

7.1 Barrel muon chambers (MB)

There are 250 MB drift tube chambers to be built (50 MBs/wheel x 5 wheels) in four production sites: CIEMAT, Aachen, Legnaro and Torino. The three sites at CIEMAT, Aachen and Legnaro are now producing chambers at the required rate of 18 chambers/year/site. The fourth site, Torino, will start production in end-2003. Around seventy chambers have been assembled and around fifty chambers have been delivered to CERN. All the honeycomb plates should be delivered by April 2003. The plate electrode and I-beam electrode manufacture at Dubna and IHEP, Protvino in Russia are going well and buffers for over 6 months have been built-up. There has been a delay in the construction of minicrates that house the trigger and readout electronics. A chamber with the first minicrate will be tested in beam in May 2003. The mass assembly of minicrates will start only in September 2003. As a consequence the first chambers will be installed in the lower sectors without minicrates starting in Q4 2003. Figure 6 shows trial insertion of a MB1 chamber without minicrate using the final tooling for insertion.

7.2 Endcap muon cathode strip chambers (ME)

The complete endcap muon system consists of 540 ME cathode strip chambers. The 108 ME4 chambers of the fourth station have been staged. In total there are 432 ME chambers to build. There are four production sites: FNAL, US (ME2/2, ME3/2, 144 chambers), PNPI-St Petersburg, Russia (ME2/1, ME3/1, 72 Chambers), IHEP-Beijing, China (ME1/2, ME1/3, 144 chambers) and Dubna, Russia (ME1/1, 72 chambers). 139 out of 144 chambers have been manufactured at Fermilab; 40 out of 72 chambers

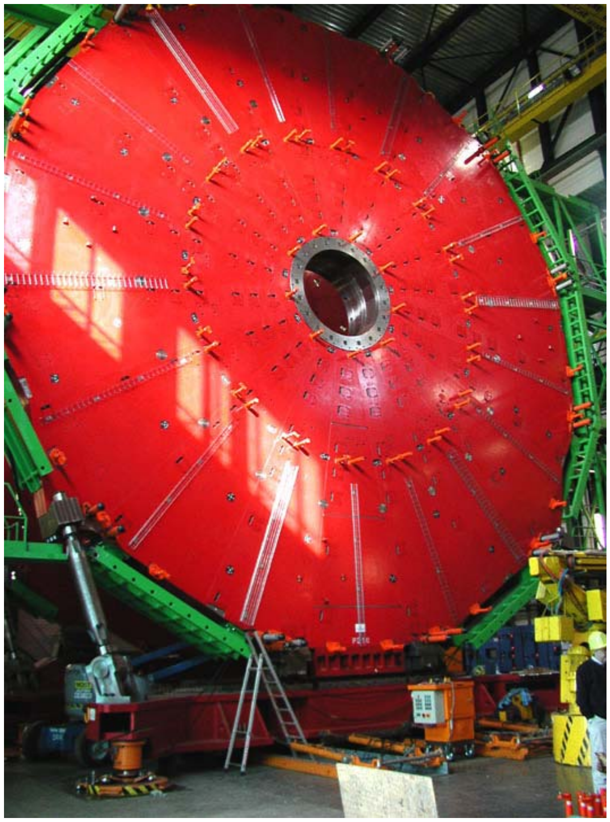

Fig. 17. The support posts have been installed on YE+2, ready for endcap muon chambers to be mounted as soon as the gas and cooling pipes have been laid down

have been manufactured at PNPI; 86 out of 144 chambers have been manufactured at IHEP and 50 out of 72 chambers have been assembled in Dubna.

The production of anode and cathode front-end electronics boards is proceeding as planned. The FAST (Final Assembly and System Testing) sites at the Universities of Florida and UCLA are continuing assembly of chambers with front-end electronics. The US FAST sites have shipped 45 ME chambers to CERN for installation. The start of ME installation has been delayed to mid-June primarily due to problems encountered by the company contracted to install services on the yoke (Fig. 7.1).

7.3 RPCs

The muon stations in the barrel and in the endcaps include RPC triggering planes that identify the bunch crossing time and enable a cut on the muon transverse momentum at the first trigger level. The barrel RPCs (RB) are installed with DTs as a single body. Two final RB1 chambers have been operating in the gamma irradiation facility (GIF) for the last three months and so far have integrated a charge corresponding to the first 3 years of LHC operation. No signs of degradation have been observed. The gap production for the barrel is continuing; 650 gaps and 45 chambers have been manufactured.

Underfunding in the endcap RPC (RE) system has led to staging of chambers at $|\eta| > 1.6$ (RE1,2,3/1) and all of RE4. An RPC gap factory has been installed in Korea and gap production should start in mid-2003. Chamber assembly in China and Pakistan should commence soon afterwards.

8 Trigger and data acquisition, TriDAS

The Data Acquisition and High-Level Trigger Technical Design Report was submitted to LHCC in December 2002 [2]. The review of the TDR is going on and project approval is expected in May. The DAQ system 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 (Fig. 7.1).

The TDR describes in detail a scenario for a starting luminosity of $2\text{x}10^{33}$ cm^{-2}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. The

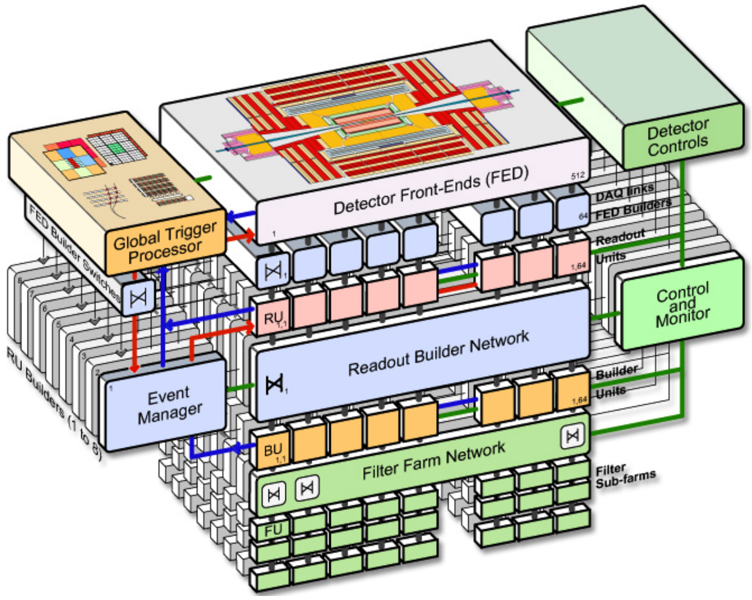

Fig. 18. The DAQ system is made of 8 independent systems (*slices*). Each slice consists of 64 RUs, a 64x64 EVB and 64 BUs and associated filter units. A slice can read up to 12.5 kHz. This design allows natural commissioning phases (*Staging*)

single farm design provides 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.

9 Cost and schedule

The cost of CMS at LHC start up is 513 MCHF. The funding shortfall is 13 MCHF. This shortfall will be mainly covered by starting with a reduced RPC system in the endcaps and a reduced DAQ system with only 4 slices (50 kHz L1 rate).

The initial CMS detector will therefore be the complete detector as described in the TDRs except for the ME4 muon station, the 3^{rd} forward pixel disks, 4 DAQ slices missing (needed at high luminosity to run at 100 kHz L1 rate) and a reduced Endcap RPC system.

The master assembly sequence currently being followed (v33) is based on completion of the initial CMS detector in time for first beams in April 2007. The sub-detector ready-for-installation targets include 3 months of float.

The schedule for coil winding and delivery is now understood. A delay of 2 month for the surface magnet test can be anticipated. This delay can be compensated by reducing the magnet test underground.

The remaining schedule uncertainties are the tracker module production, the ECAL crystal and electronics delivery.

The underground critical path passes through first access to the USC cavern, its equipment with racks and crates, copper and optical cabling from detector to USC, and finally TRIDAS integration.

10 Conclusions

CMS is following an assembly sequence, v33, that allows an initial detector to be ready for the first physics run starting in 2007. The proposed initial detector will be able to exploit the physics potential of the first physics run at medium luminosity ($\sim 2.10^{33}$ cm^{-1}s^{-1}) for which an integrated luminosity of order 10 fb^{-1} could be accumulated in about 7 months (30% efficiency). Most of the mass interval in which the Higgs can be detected will be explored. SUSY squarks and gluino with masses up to about 2 TeV can be discovered in the jet plus missing E_t channel.

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