Review of the CMS muon detector system

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The muon detector system of CMS consists of 3 sub detectors, the barrel drift tube chambers (DTs), the end cap cathode strip chambers (CSCs) and the resistive plate chambers (RPCs). During the last years the layouts of the sub detectors have been optimized by testing several prototypes. Now the project is frozen and the mass production of the chambers has started. Several production centers are coordinating their efforts. The muon system will be completed within September 2005. The final detectors, the construction status and planning and some test of the produced chambers will be presented.

1. Physics goals

The goal of the muon detector system is to identify and reconstruct muons in every relevant events where muons or decay into muons are involved. At LCH the first goal is the SM Higgs discovery. A "gold plated" signal of the Higgs boson is the four lepton channel $H \rightarrow ZZ(ZZ^*) \rightarrow 4l^{\pm}$ having relevant significance for the Higgs mass range 130 $GeV \leq m_H \leq 650$ GeV. Other physics searches with muons are the SUSY Higgs decays $h, H, A \rightarrow \mu^+\mu^-$ and the superpartners decays $q, g \rightarrow multilepton + multijet + E_t^{miss}$.

2. Muon detector system

The muon detector system of CMS consists of 3 sub detectors, the barrel drift tube chambers (DTs), the end cap cathode strip chambers (CSCs) and the resistive plate chambers (RPCs). DTs measure 8 ϕ and 4 θ points along 4 muons track segments in the barrel region. The goal is to identify muons, measure charge and momentum and identify the bunch crossing associated to every muon track. The single point resolution must be of the order of 250 μm to get a track segment precision of about 100 μm with the consequence to be under the multiple scattering contribution up to $p_T = 200$ GeV. CSCs measure 6 ϕ and 6 θ points along 4 muons track segments in the endcap region. The goal is the same as DT. The single point resolution must be of the order of $120 - 250$ μm to get a track segment precision of 75 μm (for ME1/1 and ME1/2) and 150 μm(for the others) with the consequence to be under the multiple scattering contribution up to $p_T = 100$ GeV. RPCs measure 6 ϕ points (4 in the endcap) along 1 muons track segment. The goal is to identify muons, estimate their p_T and provide an additional trigger signal for the barrel and endcap regions. The muon detector system is described in detail in the Technical Design Report [1], the latest upgrades are described in the Engineering Design Reports.

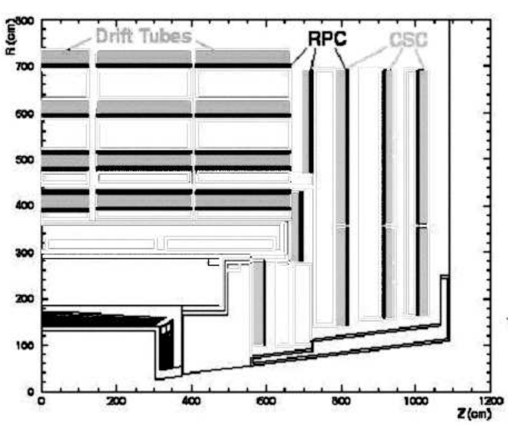

Figure 1. The muon system layout.

The endcap consists of 4 disks along the beam divided in 2 or 3 wheels and 18 or 36 sectors. The barrel consists of 5 wheels along the beam divided in 4 stations (shells) and 12 sectors (S1-S12).

3. Barrel Drift Tubes Chambers

The Barrel DT Muon Detector consists of four station of chambers called MB1-MB4. The chamber dimensions range from $2 \times 2.5\ m^2$ for the innermost station (MB1) to $4 \times 2.5\ m^2$ for the outermost one (MB4). The sharing of the 250 chambers between the 4 different production sites is shown in Fig. 2.

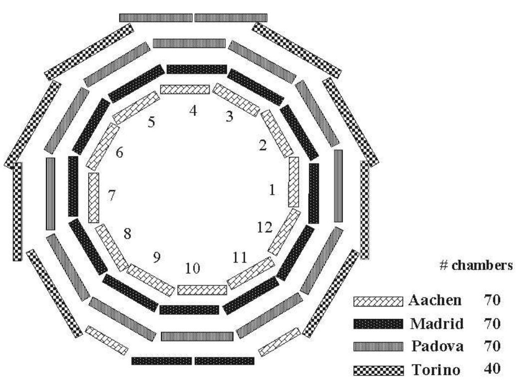

Figure 2. DT chambers production sharing.

The chambers are made of three different suplerlayers (SL) glued together and to a thick honeycomb plate providing stiffness and support for the chamber (Fig. 3). The wires in the two outer superlayers (SL1,SL3) are parallel to the beam line in the CMS reference. In the inner quadruplet (SL2), the wires are orthogonal to the beam line. In each SL there are four layers of parallel drift tubes. The cells are staggered by half of the pitch to improve the efficiency of the chamber and to reduce the left-right ambiguity. The sketch of the final cell is shown in Fig. 4. Some modification in the cell design was introduced in 1999 to increase the mechanical strength of superlayers and to optimize the electronic segmentation. More details can be found in [2].

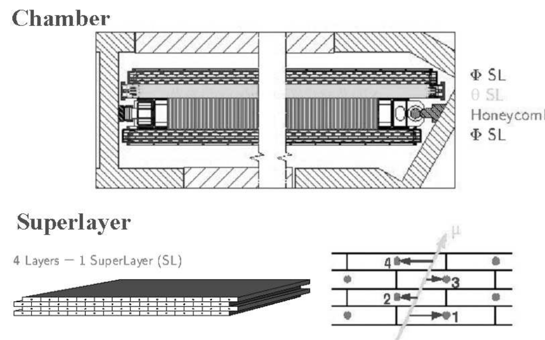

Figure 3. DT chamber and superlayer.

The strips placed at the center of the cell above and below the wire are field shaping electrodes, they improve the linearity of the space-time relationship. The working conditions are $Ar - CO_2$ $(85 - 15\%)$ for the gas, $V_{wire} = 3600\ V$, $V_{strip} = 1800\ V$, $V_{cathode} = -1200\ V$ at 970 $mbar$ for the electrodes, $Q_{th} = 5\ fC$ for the charge threshold.

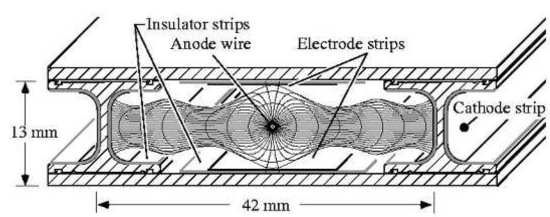

Figure 4. Sketch of the DT cell showing drift lines and isochrones.

Chambers and SLs are tested in every site following a test procedure described in the Quality Check (QC) document. Several parameters are measured, they must be inside a specific range. When a parameter is out of range the recovering procedure starts. Required measurement are i.e. wire tension and position, currents, gas tightness, noise efficiency and resolution for every cell. The number of disconnected cells is about 0.3%, the number of noisy cells ($noise > 500\ Hz$) is about 0.5% with a global limit of 1%. The pressure drop time constant (defined as the time needed for the overpressure to be reduced by a factor $1/e$) is larger than 1000 min with a QC limit of 135 min. The chamber performance has been studied with a test beam using the last chamber prototype [2] and the first produced chamber. A new test beam is foreseen in May 2003 with the 25 $nsec$ bunched beam. In the best conditions (straight tracks and zero magnetic field) the single cell resolution is 170 μm (3 $nsec$) and the efficiency is 99.8%. Every chamber is tested with cosmic rays to check that every cell works with the expected efficiency, time spectrum and resolution. The plot in Fig. 5 describes the DT chamber production planning and achievement. The production started in April 2001 and will be completed by September 2005 with a rate of 18 $DT/site/year$.

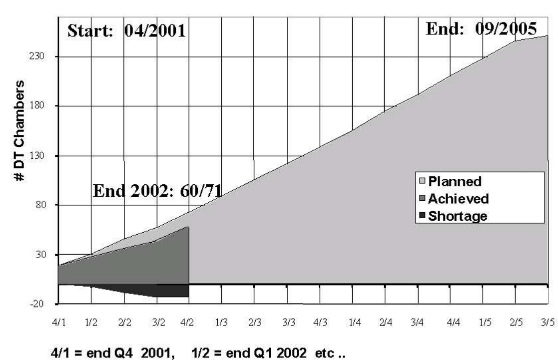

Figure 5. DT chambers production planning (all the sites).

At end 2002 the number of built chambers is 60 (24% of the full production) and 19 where sent to CERN. Two installation tests were successfully performed the first in August 2002 with one MB2 chamber the second in December 2002 with two chambers (MB1,MB3).

4. Endcap Cathode Strip Chambers

The CSC Endcap Detector consists of four disks of chambers called ME1-ME4. In the different rings they are called (i.e. for disk 1) ME1/1-ME1/3. The sharing of the 540 chambers (432 without the staged ME4) between the different production sites is shown in Fig. 6.

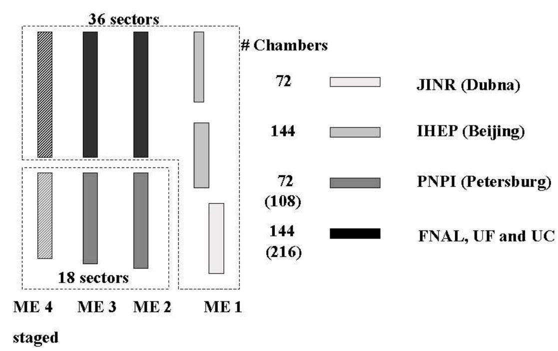

Figure 6. CSC chambers production sharing.

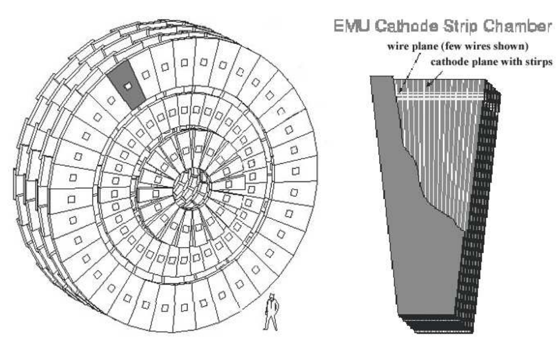

Figure 7. CSC endcap and single chamber.

Chambers are trapezoidal shaped, they cover

10^0 or 20^0 sectors. The length of chambers is between 1.7 m (ME1/1) to 3.4 m (ME234/2). A full endcap with a single CSC chamber is shown in Fig. 7. Every chamber consists of 6 planes. Every plane is a multiwire proportional chamber in which one cathode plane is segmented into strips perpendicular to the wires. Strips run radially with a width ranging from 3 to 8 mm in the bottom side and from 8 to 16 mm in the top side for different chambers. Wires are spaced by 3.2 mm ganged in groups of 5-16. A single CSC gas gap plane is shown in Fig. 8 in two different cross sections. The working conditions are $Ar/CO_2/CF_4$ (40/50/10%) for the gas, $V_{wire} = 3600\ V$ at 970 $mbar$ for the anode voltage. In the best conditions the single layer resolution is 50 μm.

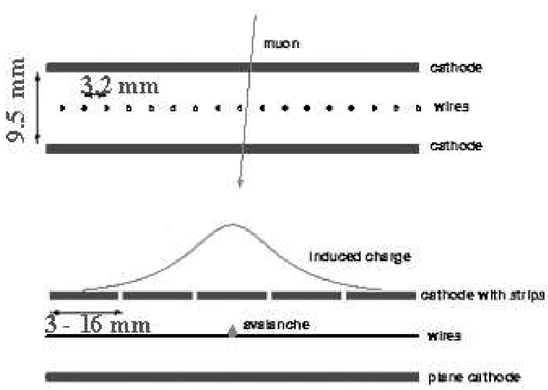

Figure 8. CSC single plane in two different cross sections.

At the end of 2002 considering every production sites 280 chambers were built (65% of the full production) and 45 were sent to the CERN. The plot in Fig. 9 describes the CSC chamber production planning and achievement (up to September 2002) in the USA production sites. The full production of the CSC chambers will be completed at the end of 2003.

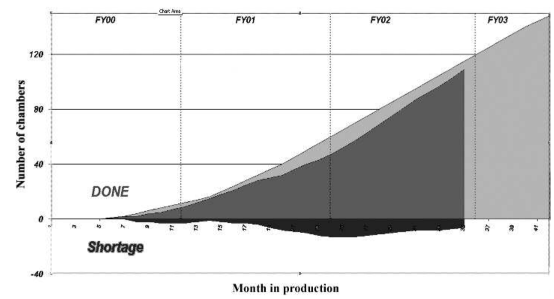

Figure 9. CSC chambers production planning in the USA sites.

5. Resistive Plate Chambers

The RPC detector (Fig. 10) covers both the forward and the barrel regions. Every DT or CSC chamber has 1 or 2 RPC chambers close to it in the front or backward surface (both surfaces in MB1 and MB2). In the barrel region the chambers are called RB1-RB4. The 480 chambers, 120 in every station, are under construction in two sites (Bari and General Tecnica) and two other sites (Sofia and Naples) will start in 2003. In the forward region the chambers are called RE1-RE4. The total number of RE chambers is 756 but 50% of them has been staged (RE1/2, RE1/3, RE2/2, RE3/2, RE4/2), the construction will start in 2003 in three production sites. An RPC consists of two resistive electrodes divided by a small gap. The electrodes are parallel plates made of phenolic resin (bakelite)with a bulk resistivity of $1-2\ 10^{10}\Omega/cm$. The outer surface of the bakelite is coated with conductive graphite to form the HV and the ground electrodes. Aluminum strips are laid down to one surface, separated from the graphite coating by a PET film. The avalanche is created inside the gap and the charge is induced on the strips. The detector can operate in streamer or avalanche modes, for the higher rate capability the avalanche mode is used. Resistive electrodes are necessary to prevents surface sparking damages.

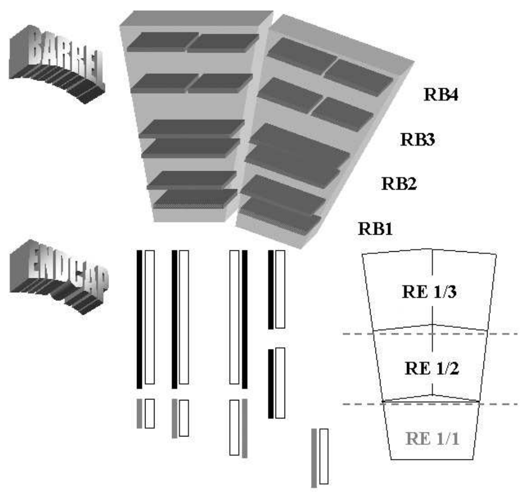

Figure 10. RPC detector, two sectors for the barrel and one 20^0 sector for the forward regions.

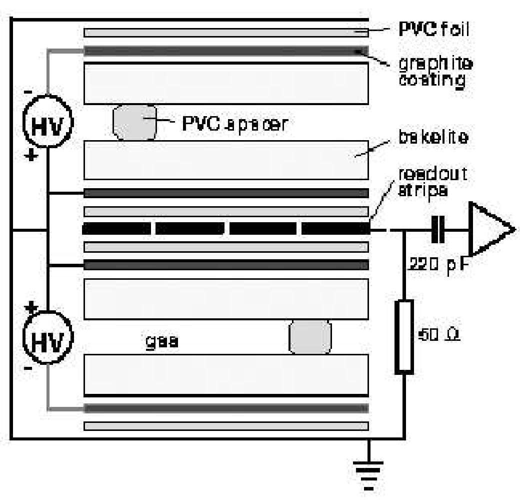

Figure 11. Section of the RPC double gap.

The resistivity must be optimized considering it contributes to the drop of voltage produced by the current through the plates ($V_d \propto rate\ \rho$). The time performance is related to the gap width. The section of the RPC chamber is shown in Fig. 11. The double gap is used to improve efficiency and resolution. The gap width is 2 mm, the strip width is 35 mm, the operating H.V. is about 9.0 kV and the gas is $C_2H_2F_4$ – iC_4H_{10} (95% – 5%). The time resolution is less than 3 $nsec$. The production and test rate for the RB chambers is 10 chamber/month/site. The production planning for the first 200 chambers is described in Tab. 1. The production rate for the endcap (RE) will be 12 chamber/month/site.

Table 1
RB chambers production planning.

25 RB3	end September 2002
25 RB1	end January 2003
25 RB2	end March 2003
25 RB4	end April 2003
2 Wheels	January 2004

6. Installation

The installation planning of DT and barrel RPC (they are attached together) is the following:

Table 2
DT-RB installation planning.

YB0 YB+2 S8-S12	Sep-Dec 2003
YB-1 S8-S9	Sep-Dec 2003
YB0 S2-S6 YB-2 S8-S9	Jan-March 2004
YB+1 S8-S12	Jan-March 2004
YB+1 YB+2 S2-S6	Sept-Nov 2004
YB-1 S10-S12	Sept-Nov 2004
YB-1 S2-S6, YB-2	April-June 2005
S1 S7	after Aug 2005

The installation of CSC will be done during 2003 and 2004. Forward RPC will be available very late with respect to CSC but they have the advantage to be decoupled from them.

7. Conclusions

The CMS muon system has been designed to achieve the LHC physics goals. The required performances were obtained with detector prototypes and were confirmed with the produced chambers. The production status at end of 2002 is DT 24%, CSC 65%, RPC_B 8%. The small shortage with respect to the planning is compatible with the installation planning.

Acknowledgments

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2. M. Aguilar-Benitez et al., Nucl. Instr. and Meth. A 480 (2002) 658.