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The CMS muon system

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Abstract. An overview of the CMS Muon Detector System design and goals is made. The system includes several types of detectors. In the barrel part Drift Tube Chambers are used, whereas Cathode Strip Chambers have been chosen for the endcaps. The main features, and the performance, of both types of chambers are described. We also report on the current status of the production of these detectors.

1 Introduction

Muons will provide the cleanest signatures for many of the interesting processes which will be studied at the LHC. The CMS Muon Detector [1] should be able to identify these muons, and should allow to trigger on them for well defined p_T thresholds, with the very important additional requirement of being able to identify the bunch crossing associated to their production. Another essential requirement is to measure their momenta with the highest possible resolution for the whole $|\eta|$ range up to 2.4.

A longitudinal view of one quadrant of the CMS detector is shown in Fig. 1. In the barrel part the CMS Muon system consists of four layers of concentric stations interleaved with the iron return yoke of the 4 Tesla superconducting solenoid. This region covers up to $|\eta| < 1.3$. The expected particle rates will be relatively low (< 10 Hz/cm^2) and the magnetic field in the regions where the chambers are located will not be too high (in most of the covered solid angle the field will be lower than 0.4 Tesla, and only in the inner layer of chambers near the endcaps will get close to $0.7-0.8$ Tesla). Given these operating conditions, the decision to use Drift Tube Chambers (DT) with trigger capability was taken.

In the endcaps, covering the range $0.9 < |\eta| < 2.4$, much higher rates are expected and the same applies to the magnetic field which, in addition, can be highly non uniform in some regions. In the most inner chamber of the first layer, particle rates will reach 1 kHz/cm^2 and the axial field value will get close to 3 Tesla. Therefore, a different technology had to be chosen for the endcap region, and the decision was to use Cathode Strip Chambers (CSC) which provide good position resolution and trigger efficiency.

Both in the endcaps and in the barrel of CMS, a third type of muon detector will be installed: Resistive Plate Chambers. They will provide CMS with a redundant and complementary muon trigger system [2]. In the following two sections, the main features of CSC's and DT's will be reviewed.

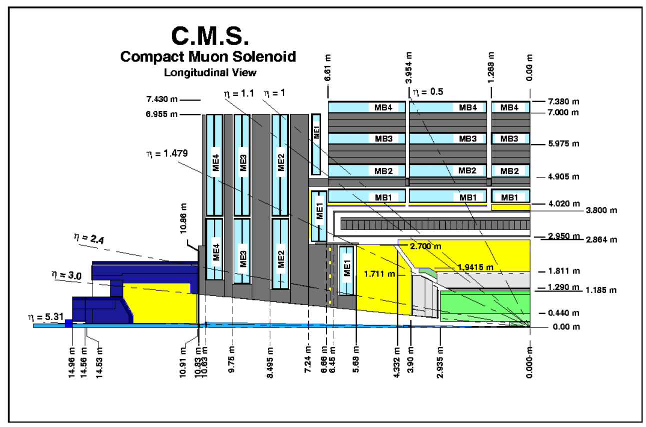

Fig. 1. Longitudinal view of one quadrant of the CMS detector

2 The cathode strip chambers

The basic principle of these chambers is sketched in Fig. 2. They are multiwire proportional chambers with strip cathode readout. As shown in the single gap layer of Fig. 2, one cathode plane is segmented in strips which run in the radial direction to measure the Φ coordinate. This coordinate is obtained by interpolating fractions of charge picked up on several adjacent cathode strips. Wires are perpendicular to the strips and provide a coarse measurement of the radial position (they are readout in groups to reduce the number of electronic channels) and a precise timing for the trigger, thus allowing bunch crossing identification. The chambers consist of 6 of these layers, thus improving the single plane resolution and suppressing very significantly the random hits background. For obvious geometrical reasons these chambers have a trapezoidal shape

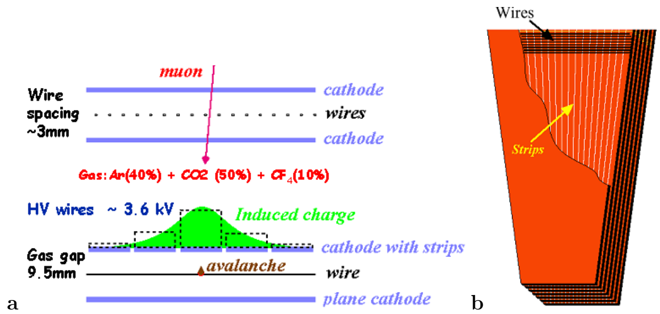

Fig. 2. **a** CSC Working principle. **b** Schematic view of a 6-plane CMS CSC chamber

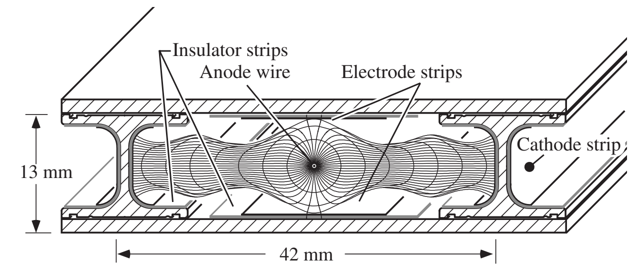

Fig. 3. Sketch of a DT cell showing drift lines and isochrones

and there are large chambers covering 10 degree sectors and smaller chambers covering 20 degree sectors.

CSC chambers are equipped with trigger electronics to find muon track segments. A Local Charged Track (LCT) is formed when at least 4 out of the 6 layers give signals, either the strips (CLCT) or the wires (ALCT), which line up in a pattern consistent with a particle going through. In the case of the cathodes, muon tracks can be localized within half a strip in each layer by finding the strip with maximum signal amplitude and comparing the values on the left and the right neighbouring strips. By combining the information from the 6 layers the Φ coordinate of the muon track can be established with an accuracy of 0.15 strips (of the order of 1-2 mm). The anode trigger looks for coincidences of hits in several layers every 25 ns. In order to remove wrong timing from random hits, at least 2 layers in coincidence are required when establishing the bunch crossing.

Segments found by anode and cathode electronics are time correlated and combined into 3D tracks before being sent to the Track Finder. There, the segments from different stations are connected to get full tracks with p_T, Φ and η values assigned. The obtained tracks are ranked according to their quality and at the end of the process the four best muons in the endcaps are sent to the Global Muon Trigger [2].

The performance of these chambers had been established with prototypes already at the time of the CMS Muon TDR [1], and all tests with final CSC's have so far confirmed the expectations. In particular, the chamber resolution is always found to be below 100 microns. Most recent tests of the chamber equipped with final electronics have also confirmed that trigger efficiencies are not lower than 98% and are not affected by rates even higher than the ones expected at LHC.

CMS endcaps consist of a total of 432 of these chambers (not including the 4th layer ME4, which was descoped). All planes cover a sensitive area of 6000 m^2, and there are 2 million wires, and 220000 cathode electronic channels.

Chamber assembly is either finished or near completion in the production sites (Fermilab, Dubna, PNPI in St. Petersburg, and IHEP in Beijing). Equipping with electronics and final testing is also progressing well in the so called FAST sites (Florida and UCLA in the US take care of chambers assembled in Fermilab). The chambers are tested with cosmic rays and certified are shipped to CERN where they pass additional preinstallations tests. More than 70 chambers have been already installed, by october 2003, on the CMS endcap disks in building SX5 at CERN.

As a short summary, the project is well on schedule and installation is proceeding without any problems. Off chamber electronics will be produced and installed in 2004 - 2005. The CSC construction project will be finished in 2005.

3 The drift tube chambers

The basic unit of these chambers is the drift tube shown in Fig. 3. Dimensions are 42×13 mm. Grounded aluminium plates 1.5 mm thick, top and bottom, and grounded aluminium extruded I beams, at both sides, close the cell and are the main components in the mechanical assembly. A 50 microns diameter stainless steel anode wire is located in the center of the cell. Aluminium strips 0.1 mm thick, mylar insulated, are glued to the I beams to form the cathodes. Two additional aluminium electrode strips, also mylar insulated, and glued to the top and bottom plates, improve the electric field configuration in the cell. The nominal operating voltages are 3600 V for the wires, -1200 V for the cathodes and 1800 V for the field shaping strips. Drift tubes are filled with a gas mixture of Ar/CO_2 (85%/15%) slightly above atmospheric pressure.

Four layers of these cells make what we call a Superlayer (SL) which is a full working unit, with high voltage and front end electronics inside the gas volume. SL's are made gast tight, set under high voltage and tested with cosmics before getting assembled to make a DT chamber. Each of these chambers consist of 3 SL's, the outer ones having wires parallel to the beam direction, to measure the Φ coordinate, and a third SL with wires perpendicular to the beam direction to measure θ. Typical chamber dimensions range from 2.5×2 m^2 for the inner ones (MB1) to 2.5×4 m^2 for the outer ones (MB4). The SL's are glued to a honeycomb panel which provides the chamber with enough mechanical stiffness. Minicrates containing the readout and trigger electronics sit on the front side of this panel. MB4 chambers include only the two Φ SL's.

Trigger capability is one of the most relevant features of these chambers. Because of the fact that even layers in a SL are half a cell shifted with respect to the odd layers,

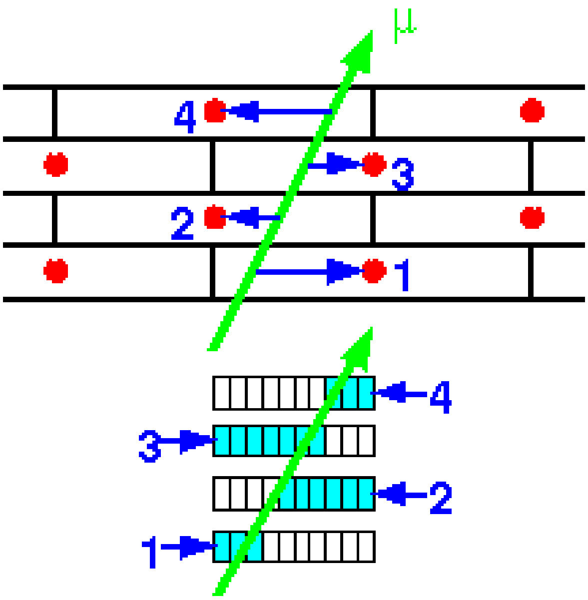

Fig. 4. The working principle of the Bunch and Track Identifier (BTI)

a meantimer technique can be used to identify a crossing muon track as illustrated in Fig. 4. The first component of the trigger electronics is called Bunch and Track Identifier (BTI) [3]. The BTI collects the signals from the cells and injects them in shift registers where they propagate at a speed corresponding to the drift velocity. It looks for coincidences ($\geq$ 3 hits aligned along a valid track pattern) every clock count. Alignment should occur after a fixed time, equal to the maximum drift time in the cell, and this allows to identify the bunch crossing. Triggers generated by the alignment of 4 hits have top quality. In addition to the time information, the BTI gives a measurement of the position (with a resolution of 1 mm) and the track angle (with a resolution of 60 mrad).

The BTI information from the two Φ SL's is combined by the so called Track Correlator (TRACO) at the chamber level. This reduces the noise and improves the angular resolution to 10 mrad. A Trigger Server (TS) then selects the best two muon candidate tracks in each chamber removing possible ghost tracks. Additional infomation from the θ SL is also used to define an η track segment which can be used to check if it is pointing to the vertex.

Following a similar philosophy to the endcap Track Finder the next step is to try to match track segments from different stations to find full tracks and then assign p_T, Φ and η values. Up to 4 best muon candidates, according to quality and highest p_T values, are selected and sent to the Global Muon Trigger [2].

The performance of these chambers has been studied extensively with several prototypes [4] and final chambers [5] in several test beams, as well as with cosmics, under different conditions including the presence of magnetic field and, also, with high background noise rates. In all cases, CMS requirements were found to be fulfiled. Single wire resolutions are below 300 microns and efficiencies are higher than 99%. A chamber equipped with final trigger and readout electronics was tested in may 2003 with an LHC-like muon beam with 25ns bunch-to-brunch crossing. The preliminary results obtained so far confirm a trigger efficiency higher than 98%, and agree well with the trigger emulator predictions and with the chamber TDC information.

The CMS barrel consists of 5 wheels with 50 DT chambers each, amounting to a total of 172000 wires. Chambers are produced at 4 sites: Aachen (70), CIEMAT (70), Legnaro (70) and Torino (40). The first 3 sites are operational since 2001 and they are, in october 2003, at the 50% level of production. Present production rate in the 3 sites is 20 chambers per year. Torino will produce the first MB4 chamber by the end of 2003, and will reach the same production rate than the other sites during 2004. In all cases, the present plan is to complete chamber production before the end of 2005. There are now more than 80 DT chambers at CERN getting ready for installation in the yoke wheels. A test of the installation procedures and the required tooling was made in august 2002 with satisfactory results. The starting of the installation phase has been scheduled for november 2003.

As a short summary, the production of the DT chambers is on schedule. The good results obtained in the test beam with the trigger electronics have given green light to the mass production. There will not be minicrates ready to install in the chambers before april 2004 but this will not prevent the start of chamber installation in november 2003 as scheduled.

4 Conclusions

The goal of the CMS Muon Detector is to provide muon identification, muon trigger with well defined p_T thresholds from 4 GeV/c in the barrel and 2-3.5 GeV/c in the endcaps of 100 GeV, with unambiguous identification of the bunch crossing, and muon track reconstruction with a momentum resolution $\delta p_T/p_T$ in the range of 8-15 % and 20-40 % at 10 GeV/c and 1 TeV/c, respectively. The achieved performance of the DT and CSC Chambers, as reported in this paper, will allow to meet these requirements.

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