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Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

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Jesus Puerta Pelayo on behalf of the CMS Collaboration

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Jesús Puerta Pelayo
on behalf of the CMS collaboration

CIEMAT, Avenida Complutense 22, Madrid, Spain

Abstract

This note contains a description of the muon system constructed for the Compact Muon Solenoid experiment at LHC. A description of all three different subdetectors composing the spectrometer (Drift Tube Chambers, Cathode Strip Chambers and Resistive Plate Chambers), their construction and commissioning will be reviewed, together with some results obtained in different campaigns of cosmic data taking.

Key words: LHC, CMS, Muon detector, Commissioning, DT, CSC, RPC

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1. CMS muon system description

Processes including muon signals are a fundamental key in the understanding of proton-proton collision physics, since they provide clear signatures and are relatively easy to identify and measure. Moreover, many benchmark physics processes in the LHC energy range are expected to contain muons among their decay products. Therefore the design of CMS was strongly driven by the requirement of a precise, redundant and performing muon system [1]. Indeed, the M in CMS stands for “muon”.

The detection and study of processes such as a Higgs boson decay into the Z-$\mu\mu$ golden channel defined the main requirements to be imposed on the muon system. In order to achieve a good physics performance, a standalone resolution of 9% at 200 GeV and from 15 to 40% at 1 TeV in the measurement of the muon transverse momentum is required. Global resolutions of 1% at low p_t and around 5% at 1 TeV would hence be obtained in combined measurement with the tracker [2].

The muon trigger must have no dead time in order to cope with the 40 MHz collision rate. Muon identification and charge assignment must be granted up to 7 TeV in $|\eta| < 2.4$. A very hermetic and redundant detector is therefore mandatory.

On top of that, the detectors must work in hostile environments, with magnetic field up to 3.5T and muon rate up to 1000 Hz/cm^2 in the endcaps. The constraints are less severe in the barrel, where the magnetic field is much lower and the expected muon rate will not be above 1 Hz/cm^2.

In CMS three different types of detector technologies [3] were chosen to this purpose (See figure 1): for the tracking and triggering of muons, Drift Tube chambers (DT) in the barrel region ($|\eta|$ <1.2) and Cathode Strip Chambers (CSC) in the forward endcaps ($0.9 < |\eta| < 2.4$) form the muon spectrometer. Additionally, both in the barrel and endcap regions, Resistive Plate Chambers (RPC) are installed with the aim of complementing the muon detector with a fast trigger-dedicated detector.

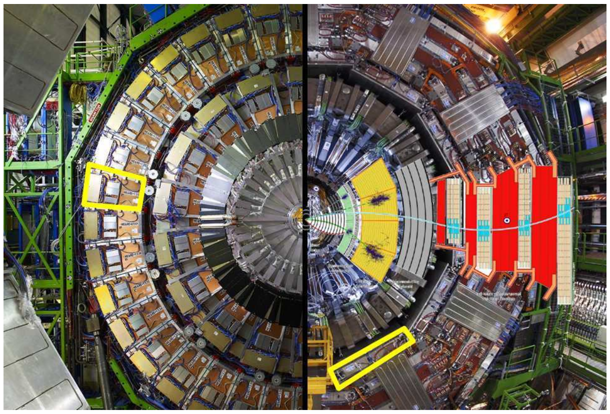

Figure 1: Combined picture of CMS muon detectors. CSCs in the endcap (left) and DTs+RPCs in the barrel part (right). A sketch of the different barrel subdetector layers is superimposed.

1.1. Drift tube chambers

The DT chambers are inserted in the pockets of the 5 slices (“wheels”) that form the magnet return yoke. They are distributed in 4 concentric layers (“stations”) with respect to the beam line, segmented in 12 sectors. It makes a total of 250 chambers. High p_t muons will cross up to four stations in the barrel region.

DTs are composed of rectangular drift cells with a maximum drift time of 380 ns. The cells are distributed in 4 staggered layers, forming independent measurement units called “Super-Layers” (SL). Each DT chamber is composed of three of these SL, two of them with their sense wires oriented in parallel to the beam line, measuring the track projection in the r-ϕ plane (“phi-SL”), and another one with wires placed in the transverse direction, measuring the coordinate in the r-θ plane (“theta-SL”). In the outermost station (MB4) the theta superlayer is suppressed. Superlayers are glued together with a honeycomb panel ensuring planarity and rigidity. A local track is formed by the intersection of the different points measured in each layer. Up to 12 points per muon track in each station provide the necessary redundancy.

In addition, DT chambers are equipped with dedicated on-chamber electronics for triggering purposes. The wire signals belonging to groups of 9 cells are the input to the so-called "Bunch and Track Identifiers" (BTIs), which thanks to special algorithms based on the meantimer technique, obtain a trigger signal with bunch crossing identification. The individual BTIs look for time coincidences which can correspond to certain track patterns. The different trigger candidates in each chamber are selected and propagated with no dead time to subsequent levels. The final selection of the DT muon trigger propagates the best 4 muon candidates per bunch crossing to the global muon trigger.

1.2. Cathode Strip Chambers

CSCs are installed on the endcap disks of CMS. They are distributed in concentric rings of 18 or 36 chambers, 3 rings in the internal face (ME1), 2 more in the middle disks (ME2, ME3) and one more ring in the far high eta region (ME4), covering from 0.9 to 2.4 in pseudorapidity. Except for the outermost ring in ME1, chambers in the same ring have a certain overlap region, leaving almost no dead zones. There is a total of 468 chambers.

Each CSC is a multiwire proportional chamber with trapezoidal shape, composed of 6 gas gaps, each one equipped with a layer of cathode strips running in radial direction. The strip width varies from 3.2mm to 16mm in the furthermost points. Also for each gas gap there are anode wires of variable length running in perpendicular to the strips (except in the innermost station ME1/1, where they are tilted by 25 degrees in order to compensate for the Lorentz effect). The wire separation can be 2.5 or 3.175 mm, depending on chamber type.

Each crossing muon can provide up to 6 spatial points per chamber. The point is obtained combining the cathode strips and anode wire signals. The cathode strips collect the charge induced in the gas by the crossing muon, and by charge interpolation in three-strip clusters a very precise measurement (between 80 and 450 microns) is obtained. The anode coordinate is provided by the combined readout of wire groups (from 5 to 17 wires). The wire measurement is less precise, but faster. A spatial resolution of about 100 μm per chamber is obtained.

Similarly to DTs, CSC work not only as muon trackers but also as trigger detectors. The trigger signal in a chamber depends on the presence of a "local charged track" trigger, combining ALCT for anode wires and CLCT for cathode strips. The first one looks for a coincidence on at least four wire groups in different layers to assign BX very precisely since the signal is fast. For the cathodes, an interpolation of collected charges in each strip results in a track position estimate of 0.15 strip width precision for the combination of all 6 layers. Both signals are combined and sent to the CSC track finder, which selects muon tracks in a 60 degrees sector. Finally the CSC muon sorter selects 4 muons per BX and transmits them to the Global Muon Trigger.

1.3. Resistive Plate Chambers

The system is completed by Resistive Plate Chambers (RPCs) both in barrel and endcap zones, granting redundancy and fast performance in the trigger system. In the barrel region RPCs and DTs are coupled together, having each DT one or two RPC planes. In the endcaps, similarly to CSCs, RPCs are installed on the faces of the iron disks. A maximum of 6 RPC planes in the barrel and 3 planes in the endcaps are crossed by high momentum muons. In total, 480 chambers in the barrel and 432 in the endcaps constitute the whole system.

An RPC consists of a double thin gaseous gap formed each gap by two bakelite plates separated by insulating spacers. The graphite plates are coated with conductive graphite paint acting as an electrode, insulated from the readout strips. The RPCs work in avalanche mode in order to cope with high background rates, while ensuring excellent time resolution (better than 1.5 ns), and precise bunch crossing assignment. A space resolution of the order of 1 cm is adequate for triggering purposes.

The RPC trigger is based on a pattern comparator algorithm (PACT) searching for spatial and temporal coincidence of hits in consecutive muon stations. The PACT uses tower segments in pseudorapidity to process and assign a predefined transverse momentum value for a given pattern. It sends the best 4 muon candidates from the barrel and the best 4 from the endcap to the Global Muon Trigger.

Figure 2: Lowering of CMS slices, a barrel wheel (left) and one of the endcap disks (right).

2. System performance with cosmic global runs

The muon collaboration of CMS, responsible for the design, construction and maintenance of the muon detectors is composed of an international group of research institutes. The individual muon chambers were assembled in different countries, sent to a common area at CERN for final dressing and certification, and later installed in their final positions.

CMS is divided in different independent slices that were assembled in an construction hall on surface, and then lowered to the experimental cavern along the LHC beamline. The muon detectors in CMS have been progressively installed in their final positions along last years, most of them on the surface assembly hall before the lowering of the different CMS slices to the cavern.

After installation, all chambers went through a thorough certification process. The detector performance, from single chamber behaviour to full reconstruction capabilities and integration issues, has been successfully tested. These tests were carried out in different stages, from single chambers with provisory electronics a to fully equipped detector. In order to proceed with this process, the system has been taking data with cosmic muons since the first detectors were installed. In absence from collision data, cosmic data taking has been an extremely valuable tool for testing and tuning up the system.

Several data taking campaigns known as Global Runs with at that time available detectors took place in the last years. First one of such campaigns was the so-called Magnet Test and Cosmic Challenge (MTCC). At least 10% of each available subdetector was equipped for data taking, and the magnet was turned on and tested for the first time. Several latter global runs followed in the cavern, named MWGRs (Middle Week Global Runs), CRUZETs (Cosmic Runs at ZEro Tesla) and finally a weeks-long global run with magnet on and 95% of the CMS detectors in, CRAFT (Cosmic Run at Four Tesla). In total, several hundred million trigger events have been registered since the beginning of CMS commissioning. Thanks to all these global runs and several other private data taking stages, the individual subdetectors have reached a good level of knowledge while getting ready for collisions.

2.1. Subdetector performance

A few examples of results on detector performance obtained with cosmics will be shown here [4].

In the barrel, the reconstruction efficiencies and resolutions have been measured for DT chambers, being the average single cell efficiency above 98.5%, and obtaining single layer resolutions from 200 to 260 μm. Combining these values, an approximate spatial resolution for track reconstrucion of about 100 microns is obtained. The comparison of measured apparent drift velocity with and without magnetic field is shown in figure 3 for selected wheels and stations. This value is magnetic field dependent, and it affects the trigger performance. A good knowledge of this parameter is fundamental, not only for precise track reconstruction, but also as input parameter for a correct trigger configuration.

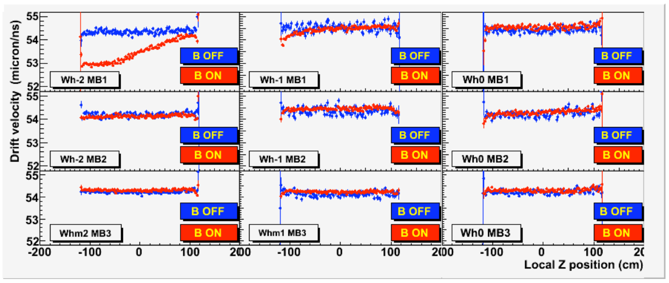

Figure 3: Drift velocity measured for the first three stations of DTs. The decrease in the apparent drift velocity for MB1s is clearly observed.

Several studies have been also performed on CSC resolution and efficiencies, confirming previous results obtained in muon beam tests. In all chambers the measured efficiency to obtain a track segment in a chamber was well above 99%. The local trigger efficiencies have shown an excellent behaviour, close to 100%. Some precision studies on CSC resolution show interesting results. As an example, in figure 4 the resolution per layer for the innermost ring as a funcion of distance to the beam line is shown. This resolution clearly improves as we move towards the beam, since the strip witdth is much thinner there due to the CSC trapezoidal geometry.

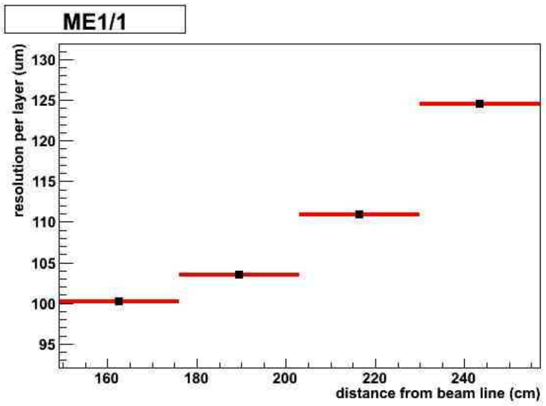

Figure 4: Resolution per layer for the inner ring of CSCs (ME1/1) versus distance from beam line.

Good synchronization between subdetectors is crucial for the muon trigger system. Altough cosmics have a random time structure and the detectors are optimised for bunched beams, a huge progress has been made in advance. Special trigger algorithms for cosmics have been developed and the integration of different pieces is a fact. The alignment system has also confirmed using reconstructed tracks the measurements provided by the optical system.

2.2. First physics results

In order to achieve a better knowledge of the CMS system as a whole the cosmic rays were studied in detail, being the first physics results extracted from CMS.

The angular distribution of the muons registered in the CMS cavern clearly shows the structure of the shaft used to lower the biggest CMS pieces. Also in the regions correspondig to the other two smaller pits an excess of muons can be observed. It shows the accuracy of the CMS muon reconstruction capability. (See figure 5).

The momenta spectrum of muons both in cavern and on surface has been measured, helping in the tuning of the MC simulations. Moreover, during MTCC the positive to negative ratio of atmospheric muons was measured [5], obtaining a compatible value with previous measurements. It was a crucial test that allowed a very good understanding of the muon reconstruction under magnetic field, the alignment system, etc.

Further sudies on absolute muon rate, charge spectrum, effect of the moon shadow etc. are currently ongoing.

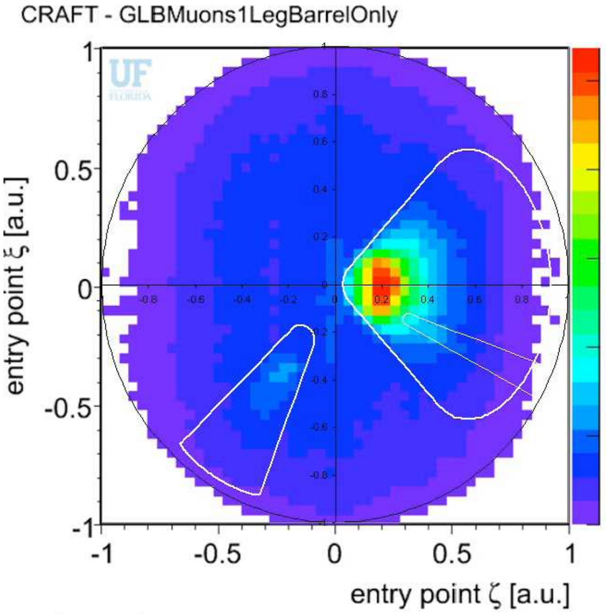

Figure 5: Distribution of muons registered in the experimental cavern extrapolated to the surface.

2.3. *First LHC beams in CMS*

From September 10th 2008 the proton beams from LHC commissioning crossed the CMS detector during several days.

Several runs were taken during beam circulating periods, allowing CMS to register muon halo events, with muons crossing the detector in parallel to the beam pipe. Also when the beam was dumped on the collimators, a “splash” of muon events could be seen in the calorimeters and the muon chambers. These data taking periods were extremely useful for CMS, in particular for the endcap detectors, whose orientation is unfavored by the cosmic distribution. An accurate alignment of CSC chambers was achieved using a short run containing halo muons. An accuracy of 270 μm in the r-ϕ plane and of 0.35 mrad in the phi$_z$ coordinate could be obtained with a few minutes of crossing beams. As shown in figure 7, the measurements agree with optical alignment results.

3. Conclusions

The CMS muon system is nowadays a complete, precise, very accurate and well understood muon detector. In the last years, thanks to the efforts of the muon collaboration the subdetectors have been thoroughly commissioned and they have served the rest of CMS as trigger provider and reference. The system is ready and looking forward to exploring the physics of LHC data.

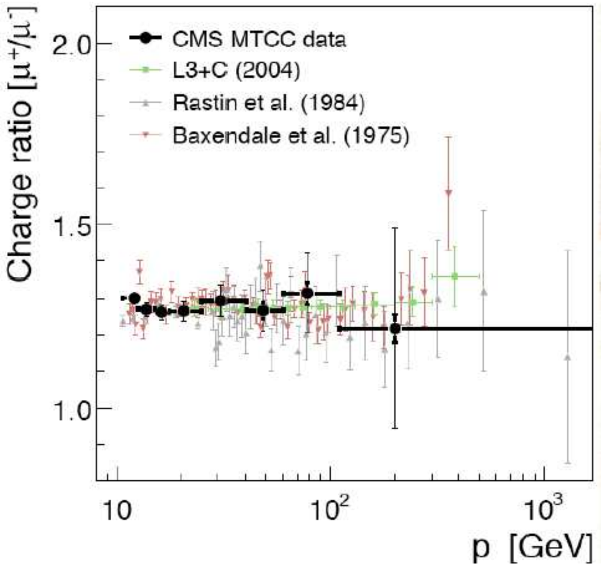

Figure 6: Muon positive to negative charge ratio versus momentum as measured during MTCC. Comparisons with other experiments are present in the plot.

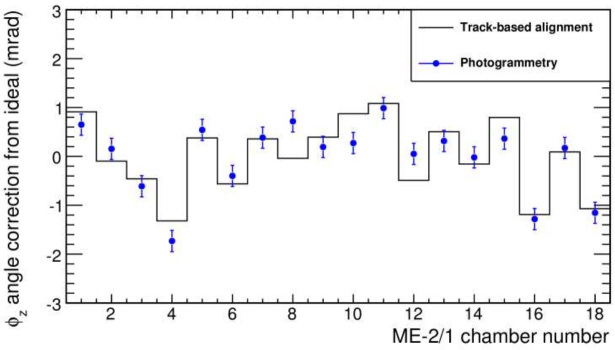

Figure 7: Corrections from nominal positions of CSC chambers measured by the alignment system, compared to the corrections using offline analysis of muon tracks.

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