CMS muon spectrometer, muon reconstruction and identification performance

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The design of the CMS muon identification and reconstruction is presented, as well as its performance on cosmic-rays and collision data. Efficiencies of various trigger, identification, and reconstruction algorithms have been measured for a broad range of muon momenta. Using the cosmic-ray data, CMS has measured the charge asymmetry of cosmic muons, as a function of the muon momentum from 3 GeV/c to 1 TeV/c. For muon momenta below 100 GeV/c the flux ratio is measured to be a constant 1.2766 ± 0.0032 (stat) ± 0.0032 (syst), the most precise measurement to date.

1 Design of the CMS muon spectrometer

The Compact Muon Solenoid [1] (CMS) is a multi-purpose detector designed to exploit the high discovery potential provided by the Large Hadron Collider (LHC). Muons are a distinctive signature for many of the most interesting physical processes at CMS. The purposes of the CMS muon spectrometer are muon identification, momentum measurement and trigger. It is based on three different technologies of gaseous detectors (see Figure 1): the Drift Tubes (DT), the Cathode Strip Chambers (CSC) and the Resistive Plate Chambers (RPC).

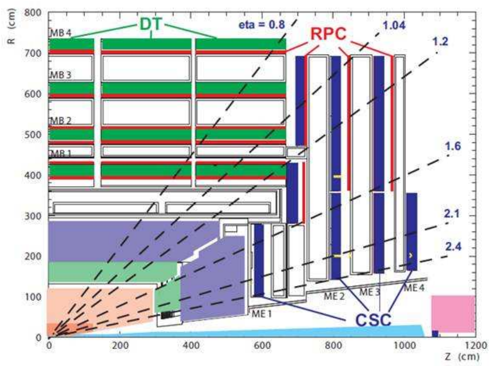

Figure 1: Layout of the CMS muon system.

1.1 Drift tubes

A set of 250 drift tubes chambers cover the barrel region ($|\eta| < 1.2$), where the neutron-induced background is small and the muon rate is low. The chambers are arranged in five wheels, each with four stations forming concentric cylinders along the beam line. They are made of staggered cell layers: two set of four layers measure the bending coordinate $r\phi$ with a precision of about 100 μm. Another set of four layers measure the z (θ) coordinate in the three innermost stations. The DT chambers can trigger on track segments with bunch-crossing identification at level 1.

DT performance has been tested during the commissioning of the detector using cosmic-rays [2, 3]. The efficiency of hit reconstruction has been measured to be greater than 98% over a large part of the drift volume, yielding a segment reconstruction efficiency greater than 99%. The resolution on single hit position is of the order of 260 μm in all chambers. Finally, level 1 trigger reaches a 95% efficiency for muon tracks in the fiducial volume of the chambers.

1.2 Cathode strip chambers

Cathode strip chambers have been chosen to detect muons in the endcap region ($|\eta| < 2.4$), which is characterized by a large and varying magnetic field, and by a higher particle rate. A total of 468 chambers have been arranged in four disks per endcap. Each disk is in turn divided in rings with a varying number of chambers. Each chamber is composed by six gaps with a layer of staggered cathode strips and one of anode wires. The bending coordinate ϕ is measured by the strip centroid with a design resolution of about 150 μm (75 μm for chambers in the innermost ring). The signal from the wires provides a measurement of the radial position, and its fast response is used for bunch-crossing identification at trigger level.

CSC performance has been measured with cosmic-rays [3, 4]: the spatial resolution for local reconstruction has been found to vary between 47 and 243 μm, while the reconstruction efficiency is above 99% both for hits and segments. Finally, for muons with transverse momentum $p_T > 20$ GeV/c the trigger efficiency results greater than 99%.

1.3 Resistive plate chambers

The CMS muon spectrometer is completed by a system of resistive plate chambers designed to improve the muon trigger efficiency: 480 chambers arranged in six stations in the barrel, and 432 chambers ordered in three stations in the endcap (up to $|\eta| < 1.6$), provide a fast response (~ 2 ns) for unambiguous bunch-crossing identification at level 1.

The level 1 trigger efficiency has been measured to be between 80 and 90% for muons in the the fiducial volume of the chambers during the commissioning of the detector [3, 5].

2 Muon reconstruction performance in cosmic-ray events

The reconstruction performance of the CMS muon spectrometer has been studied in a large sample of cosmic-ray events collected during the 2008 [6]. The efficiency of various reconstruction and identification algorithms has been measured through cosmic-ray muons crossing all the detector: good quality muons reconstructed in one hemisphere are selected and the corresponding track in the opposite hemisphere is searched within $|\Delta\phi| < 0.3$ and $|\Delta\eta| < 0.3$ around the reference track. A minimum transverse momentum $p_T > 10$ GeV/c is required to ensure the muon cross all the detector. To test algorithms developed for collision data, cuts are applied on the distance of the point of closest approach of track to the nominal interaction point: $r < 4$ cm and $|\Delta z| < 10$ cm. Figure 2 shows the measured efficiencies for muon tracks reconstructed using information from the tracker system only (*tracker tracks*), from the muon system only (*standalone muons*), and from all the sub-detectors (*global muons*). Also shown are the efficiencies for two main algorithms of muon identification: in the *compatibility* approach, after that a tracker track has been extrapolated to the muon system and matched to local segments, cuts are applied on related variables computed on the base of calorimeter and

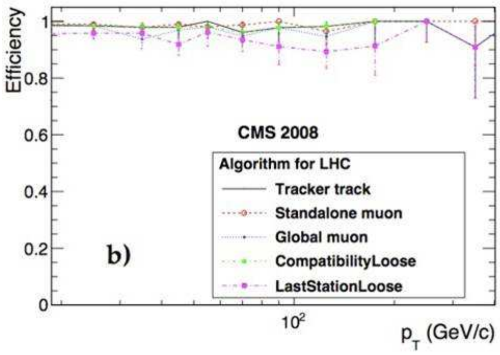

Figure 2: Muon reconstruction and identification efficiencies as a function of the muon transverse momentum p_T.

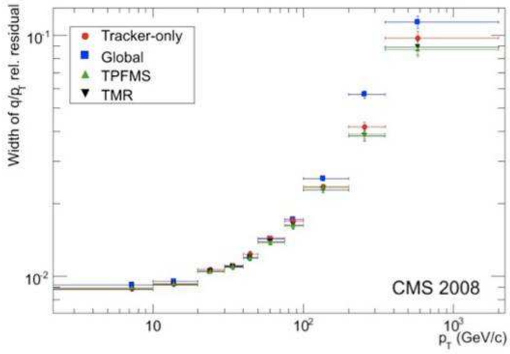

Figure 3: Width of the relative residual distributions for different muon reconstruction algorithms.

muon system information. In the *last station* algorithm, a well matched segment is required in the outermost station.

The resolution on the muon momentum measurement is estimated by the width of the distribution of the relative residuals, $R(q/p_T)$:

$$R(q/p_T) \quad = \quad \frac{(q/p_T)^{upper} - (q/p_T)^{lower}}{\sqrt{2}(q/p_T)^{lower}}, \tag{1}$$

where $(q/p_T)^{upper}$ and $(q/p_T)^{lower}$ are the ratio of the track charge to the transverse momentum for muons reconstructed in the upper and lower detector hemisphere, respectively. Figure 3 shows the momentum resolution for tracker tracks, global muons, and for other two reconstruction algorithms which combine tracker information to hits found in the innermost muon station only.

3 Measurement of the charge asymmetry of atmospheric muons

The CMS collaboration has recently measured the flux ratio of positive to negative muons in cosmic-rays as a function of the muon momentum [7]. The measurement combines data samples collected during the 2006 magnet test and the extended data taking period of 2008, and information both from global and standalone muons. The raw charge ratio measured in CMS has to be corrected for several effects such as energy loss crossing the earth surface to the detector cavern, momentum resolution and mis-assignment of the charge. Final results are shown in Figure 4 for a broad range of muon momentum (3 GeV/c to 1 TeV/c). For momenta below 100 GeV/c, the flux ratio is measured to be a constant 1.2766 ± 0.0032 (stat) ± 0.0032 (syst). For higher momenta, an increase of the charge asymmetry is observed, in agreement with theoretical model of muon production in cosmic-ray showers, and with previous measurements.

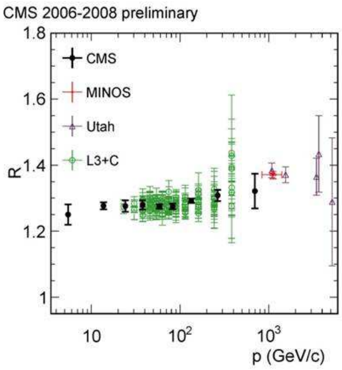

Figure 4: Flux ratio of positive to negative muons in cosmic-rays.

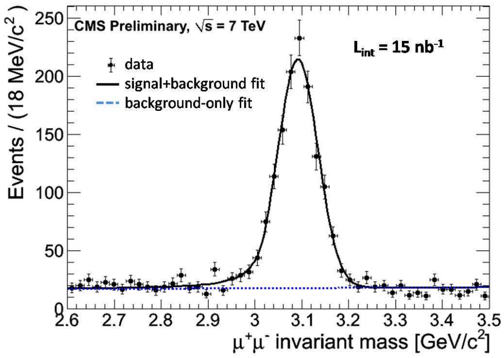

Figure 5: $J/\psi \to \mu^+\mu^-$ reconstructed invariant mass spectrum.

4 First results with collision data

The CMS muon spectrometer is starting to show its potential for detecting and reconstructing particle decays into muons. With 15 nb^{-1} of collision data at a center-of-mass energy of 7 TeV, a narrow J/ψ resonance has been measured in the $\mu^+\mu^-$ invariant mass spectrum (see Figure 5). First candidate $W \to \mu\nu$ and $Z \to \mu^+\mu^-$ decays have also been reconstructed.

5 Conclusions

The design of the CMS muon spectrometer and its performance on cosmic-rays has been presented. Efficiency of trigger, identification and reconstruction algorithms have been measured. The CMS muon system proved to improve the momentum resolution of reconstructed tracks at high transverse momentum. The CMS collaboration has measured the charge asymmetry of cosmic muons in the momentum range between 3 GeV/c to 1 TeV/c. For muon momenta below 100 GeV/c, the flux ratio is measured to be a constant 1.2766 ± 0.0032 (stat) $\pm\ 0.0032$ (syst), which is the most precise measurement to date. First muons have been detected in proton-proton collisions at a center-of-mass energy of 7 TeV. In particular, a clear $J/\psi \to \mu^+\mu^-$ resonance has been measured, and first vector boson candidates have been reconstructed.

References

[1] CMS Collaboration, JINST **3** (2008) S08004.

[2] CMS Collaboration, JINST **5** (2010) T03015 [arXiv:physics.ins-det/09114855].

[3] CMS Collaboration, JINST **5** (2010) T03002 [arXiv:physics.ins-det/09115422].

[4] CMS Collaboration, JINST **5** (2010) T03018 [arXiv:physics.ins-det/09114992].

[5] CMS Collaboration, JINST **5** (2010) T03017 [arXiv:physics.ins-det/09114045].

[6] CMS Collaboration, JINST **5** (2010) T03022 [arXiv:physics.ins-det/09114994].

[7] CMS Collaboration, CMS PAS MUO-10-001 [arXiv:hep-ex/10055332].