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Muon reconstruction and identification in CMS Run I and towards Run II

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Abstract

The performance of the muon reconstruction and identification in the CMS experiment at the LHC has been studied on data collected in pp collisions at $\sqrt{s} = 7$ and 8 TeV. Results from the measurements of the muon identification efficiencies, hadron misidentification probabilities as well as the muon momentum scale and resolution are presented.

Keywords: CMS, LHC, muons

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1. Introduction

The Compact Muon Solenoid (CMS) [1] is a multi-purpose detector at the LHC that covers a wide range of physics. The CMS detector identifies and measures muons produced in high energy proton-proton (pp) collisions on a large momentum range with high precision.

2. Muon reconstruction and identification

The standard CMS reconstruction in pp collisions first reconstructs tracks independently in the inner tracker (tracker tracks) and in the muon system (standalone-muon tracks). Then, two different approaches are used to reconstruct muons: the global muon reconstruction, where a tracker-track is found for each standalone-muon track and a combined fit of the tracker and muon-detector hits is performed; and the tracker muon reconstruction, where the tracker-track is extrapolated and matched to segments reconstructed in the muon detector [2].

Four different muon identification algorithms are commonly used in CMS: the loose muon selection, which requires the candidate to be a muon reconstructed by the particle-flow algorithm [3] and a global or a tracker muon; the soft muon selection, which is a tracker muon with tight requirements on the matched muon segment, on the number of hits, the track χ^2, and the impact parameters; the tight muon selection, which requires the particle to be identified as muon by the particle flow event reconstruction and as global as well as tracker muon with requirements on the hits, global track χ^2, and the impact parameters; the high-p_T selection, which requires the candidate to be a global and tracker muon with tight selections optimized to be efficient for muons with high transverse momentum, p_T. The performance of the high-p_T selection will not be shown here.

The efficiency of the muon identification algorithms is studied with the tag-and-probe method [4]: the tag is a very well identified muon which triggered the event, while the probe is a tracker track or a loosely-identified muon matched with the tag to lie either in the J/ψ or Z mass window. The efficiency is obtained by simultaneously fitting the tag-probe invariant mass distributions for the probes passing and failing the selection criteria. The single muon efficiencies are measured with the J/ψ resonance at low p_T ($2 < p_T < 20$ GeV) and with the Z resonance at higher p_T ($20 < p_T < 300$ GeV). Figure 1 shows the single muon efficiencies for the three different algorithms determined with the J/ψ resonance at $\sqrt{s} = 8$ TeV as a function of p_T [5]. The discrepancy

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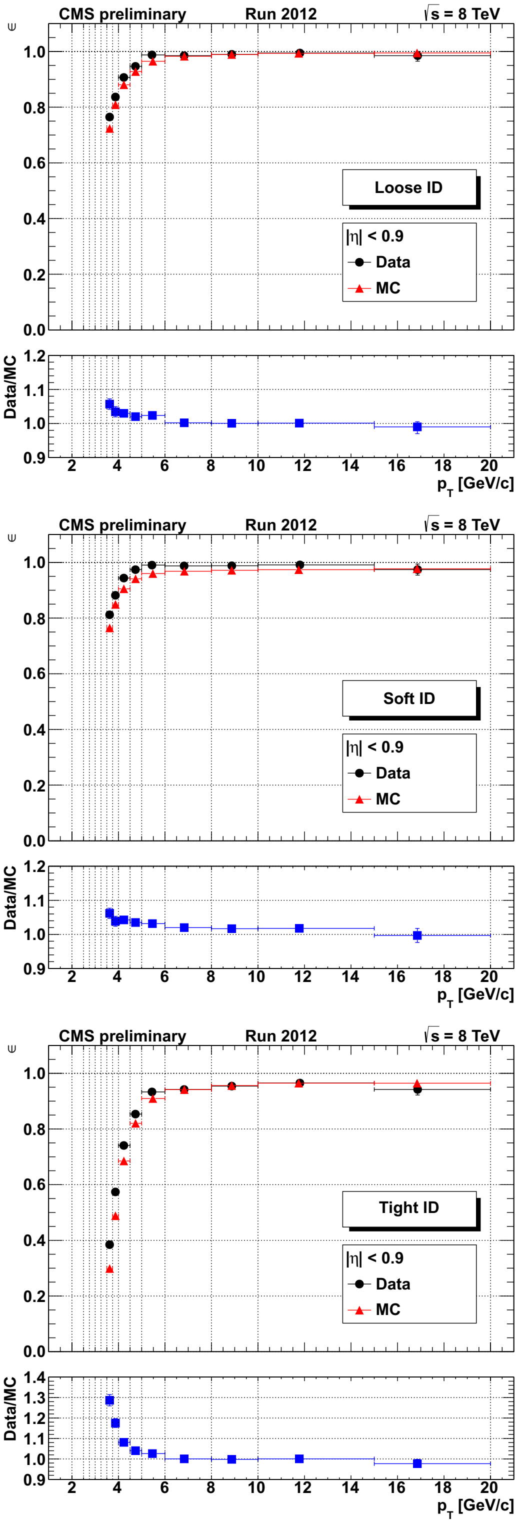

Figure 1: Identification efficiencies for loose (top), soft (middle) and tight muons (bottom) as function of p_T for $|\eta| < 0.9$ determined in data taken at $\sqrt{s}$ = 8 TeV and MC simulations.

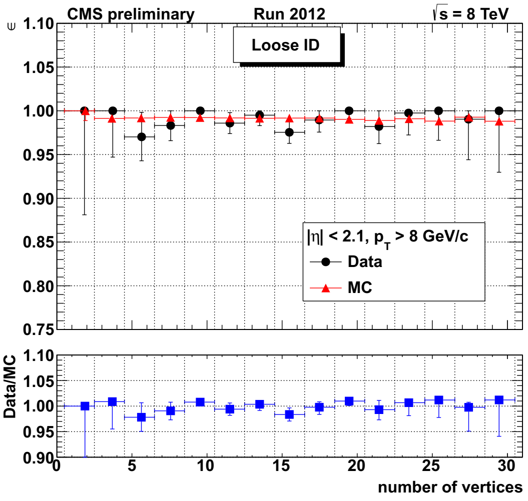

Figure 2: Identification efficiencies for the loose muon selection as function of number of vertices for $|\eta| < 2.1$ and $8 < p_T < 20$ GeV determined in data taken at $\sqrt{s}$ = 8 TeV and MC simulations.

between data and Monte Carlo (MC) simulation in the steep turn-on curve arises from a small difference in the p_T resolution of muons in data and simulation, enhanced by the large variations in efficiency between the individual bins in this region [2]. Data and MC agree within 2-3% in the plateau region which has an efficiency of close to 100% for loose and soft muons and typically 95% for tight muons. The efficiency for all three muon selections continues to be very high for larger values of p_T which are covered by the Z resonance [6].

The single muon efficiencies are also determined as a function of pileup (number of pp interactions) and muon pseudorapidity, η. The efficiency for loose muons as a function of pileup is shown in Fig. 2. There is no visible dependence on the pileup for any of the studied muon selections. Figure 3 displays the η differential efficiency for loose muons coming from Z decays. No dependence on the muon η is found. In contrast to the loose and soft muon selections, the tight muon selection shows a small dependence on η due to the tighter selection criteria.

The probability to identify a pion track with $p_T > 4$ GeV and $|\eta| < 2.4$ as loose (tight) muon is $(2.16 \pm 0.03) \times 10^{-3}$ ($(1.34 \pm 0.02) \times 10^{-3}$) for data collected at $\sqrt{s}$ = 7 TeV and 8 TeV. In case of a proton track with $p_T > 4$ GeV and $|\eta| < 2.4$, the misidentification probability is $(0.58 \pm 0.05) \times 10^{-3}$ for the loose and $(0.16 \pm 0.03) \times 10^{-3}$ for the tight muon selection [7].

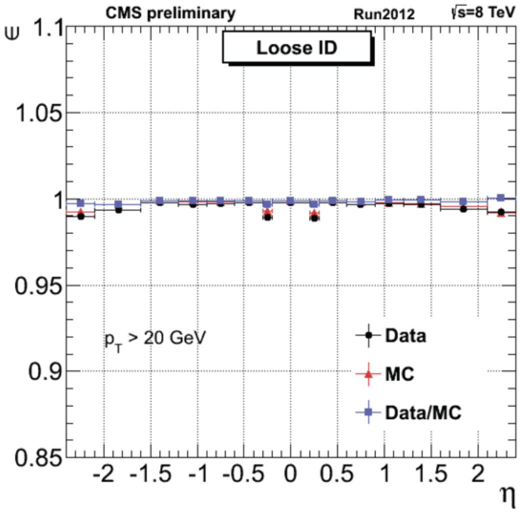

Figure 3: Identification efficiencies for the loose muon selection as function of $|\eta|$ for $20 < p_T < 300$ GeV determined in data taken at $\sqrt{s} = 8$ TeV and MC simulations.

3. Momentum scale and resolution

The measurement of the muon momentum depends on the detector alignment and the description of the material and the magnetic field. To account for small imperfections in these conditions at low and intermediate p_T, mass constraints on the dimuon decays from the J/ψ and Z resonances are used to calibrate the muon momentum scale and measure the momentum resolution [2]. Figure 4 displays the position of the Z peak fitted in the region 75 - 105 GeV before and after the momentum scale calibration for data taken at $\sqrt{s} = 8$ TeV and MC simulations [8]. The calibrated position of the mass peak is consistent with being flat showing that the bias has been removed. The corrections are small, typically below 1%.

4. Summary

Muons play an important role in the physics program of the CMS detector at the LHC. The performance of muon reconstruction, momentum scale and resolution and the misidentification of hadrons have been extensively studied in pp collisions at $\sqrt{s} = 7$ TeV and 8 TeV. Many results have not been discussed in this context and can be found in [1, 9]. The good performance and understanding of muon reconstruction, identification and triggering is needed to provide the necessary confidence in the physics analyses that use muons.

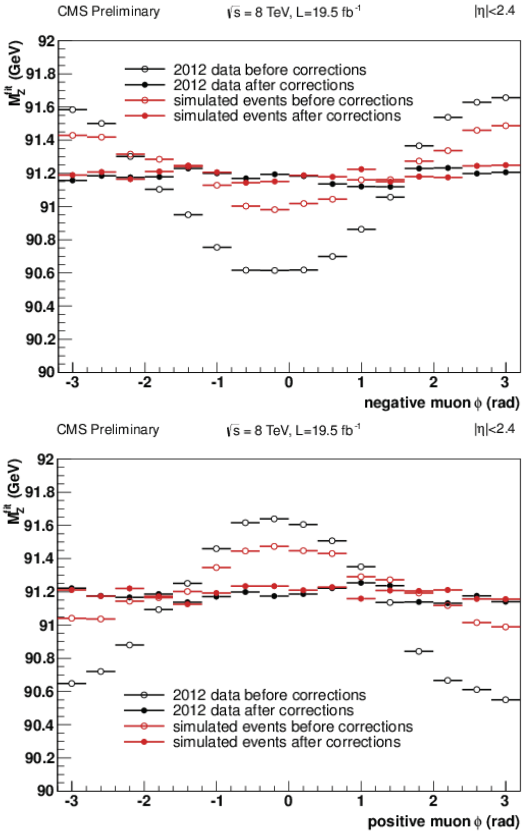

Figure 4: The position of the fitted Z peak in data and MC simulations as function of muon ϕ for negatively charged muon (top) and positively charged muons (right) before an after momentum scale calibration. Only statistical errors are shown which are smaller than the size of the points.

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