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Performance of muon identification and reconstruction with the CMS detector

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Abstract

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Keywords: CMS, LHC, muons.

1. Introduction

The Compact Muon Solenoid (CMS)[1] 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 performance of muon reconstruction and identification in CMS has been studied on data collected in pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV, at the LHC during Run I data taking period. We present measurements of muon identification efficiencies, hadron misidentification propabilities, and muon momentum scale and resolution.

2. Muon Reconstruction and Identification

In the standard CMS reconstruction for pp collisions, muon tracks are first reconstructed independently in the inner tracker (tracker tracks) and in the muon system (track segments on each muon station combined into a so-called standalone muon trakcs). Based on these objects, two reconstruction approaches are used: Global Muon reconstruction (outside-in) and Tracker Muon reconstruction (inside-out)[2] . In the following we study the performance of different muon identification algorithms with the CMS detector.

The Loose Muon selection, based on the CMS Particle-Flow reconstruction algorithm[3] , combines information from all the CMS subdetectors, including calorimeters, to identify and reconstruct individual particles like electrons, hadrons or muons. The Soft Muon selection requires the candidate to be a Tracker Muon, with a tight matching requirement on at least one muon segment. The Tight Muon selection, for which the candidate must be a Global Muon extending on at least two muon stations and passing cuts on track quality and impact parameters[2] .

3. Kinematic Distributions of Muons

We present here data to simulation comparisons for inclusive muon samples collected with either a minimum bias trigger or a single-muon trigger at $\sqrt{s}$ = 7 TeV. In Fig. 1 we show the distributions of transverse momentum for Soft Muons (left) and for Tight Muons with $p_T > 20$ GeV/c (right), comparing data to Monte Carlo (MC) simulation broken down into its different components. For Tight Muons with $p_T > 30$ GeV/c the leading processes are W and Z production, occasionally associated with hard jets. The data agree with the predictions within 10% throughout all the range $p_T < 200$ GeV/c. This is quite satisfactory, given the known experimental and theoretical uncertainties.

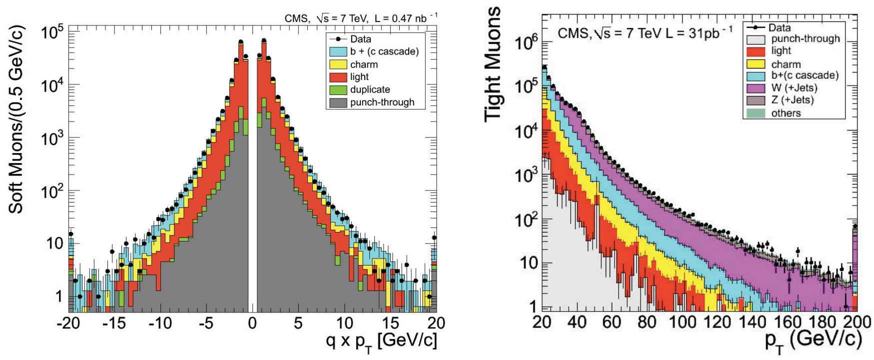

Fig. 1. Distributions of transverse momentum for Soft Muons (left) and for Tight Muons with $p_T > 20$ GeV/c (right), comparing data (points with error bars) to MC.

4. Efficiency and Misidentification

We study exclusive samples of prompt muons, pions, kaons, and protons in data to determine their probabilities to be reconstructed and identified as muons. The efficiency to reconstruct a muon in the inner tracker was measured previously[4] and found to be 99% or higher within the whole tracker acceptance, in good agreement with the expectation from simulations. We evaluate the efficiencies for different selection algorithms for prompt muons[2,5] , by applying a tag-and-probe technique to muons from J/ψ and Z decays. Fig. 2 left shows the identification efficiency at $\sqrt{s}$ = 7 TeV for the Soft Muon selection. The measurement is made using J/ψ events for p_T <20 GeV/c and Z events for p_T >20 GeV/c, in the $|\eta| < 1.2$ range. Fig. 2 right shows the identification efficiency at $\sqrt{s} = 8$ TeV for Tight Muon selection. The measurement is made using Z events for $p_T > 20$ GeV/c muons. The tag-and-probe results in data and in simulation agree within the statistical uncertainties of the measurement at the level of few percent above $p_T > 5$ GeV/c, with some discrepancies at low momentum, arising from a small difference in the widths of the track-to-segment pulls in data and in simulation. The agreement with simulation is at the 1-2% above $p_T > 20$ GeV/c. Identification efficiencies, for muons with p_T larger than a few GeV/c, are above 95% for all selections studied.

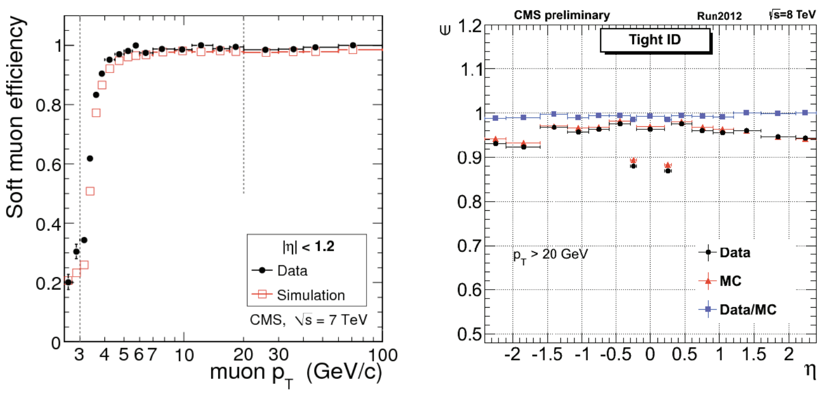

Fig. 2. Tag-and-probe results for the muon identification efficiency for Soft Muon selection at $\sqrt{s} = 7$ TeV (left) in the $\eta < 1.2$ range, and for Tight Muon selection at $\sqrt{s}$ = 8 TeV for $p_T > 20$ GeV/c. Data is compared to simulation.

Misidentification from pions, kaons and protons is also measured from exclusive resonance decays. The probability to misidentify a pion track with $p_T > 4$ GeV/c as Loose (Tight) Muon, averaged over $|\eta| < 2.4$, is $2.16 \pm 0.03 \times 10^{-3}$ ($1.34 \pm 0.02 \times 10^{-3}$) combining $\sqrt{s} = 7$ TeV and $\sqrt{s} =$ 8 TeV data. In case of kaon tracks with $p_T > 4$ GeV/c, the probability of being identified as a Loose (Tight) Muon is $0.51 \pm 0.05\%$ ($0.22 \pm 0.02\%$) using data at $\sqrt{s} = 8$ TeV[6] .

5. Muon Momentum Scale and Resolution

The momentum scale and resolution of muons are studied using different approaches in the range $20 < p_T < 100$ GeV/c, where the momentum measurement is provided by the tracker. One of the methods to study the muon p_T measurement is referred to as MuScleFit (Muon momentum Scale calibration Fit). This calibration method produces an absolute measurement of momentum scale and resolution by using a reference model of the generated Z lineshape convoluted with a Gaussian function[2] . Fig. 3 shows the position of the fitted Z peak in data at $\sqrt{s} = 8$ TeV and simulation reconstructed as a function of muon azimuthal angle ϕ for positively charged muons (left) and negatively charges muons (right), before and after the muon momentum calibration by the the MuscleFit method. The calibrated position of the mass peak is consistent with being flat within the statistical uncertainties, demostrating that the biases are successfully removed. The average bias in the muon momentum scale is measured with a precision of the order of 0.2%, being consistent with zero. The relative p_T resolution is between 1.3% to 2.0% for muons in the barrel and better than 6% in the endcaps in data at $\sqrt{s} = 7$ TeV, in good agreement with simulation. In case of data collected at $\sqrt{s} = 8$ TeV the muon momentum scale and resolution is validated with the J/ψ, Υ and Z decays by comparing the differences in data and simulation.

6. Conclusions

The performance of muon reconstruction, identification, and trigger in CMS has been studied extensively using data collected in pp collisions at $\sqrt{s}$ = 7 TeV and $\sqrt{s} = 8$ TeV at the LHC. These data were used to study several representative muon selections, chosen as benchmarks covering a wide range of physics analysis needs. Apart from the results summarized here, other studies were performed. For example, algorithms to identify cosmic and beam-halo backgrounds among collision events were developed and successfully used in several physics analyses. At high momenta, the

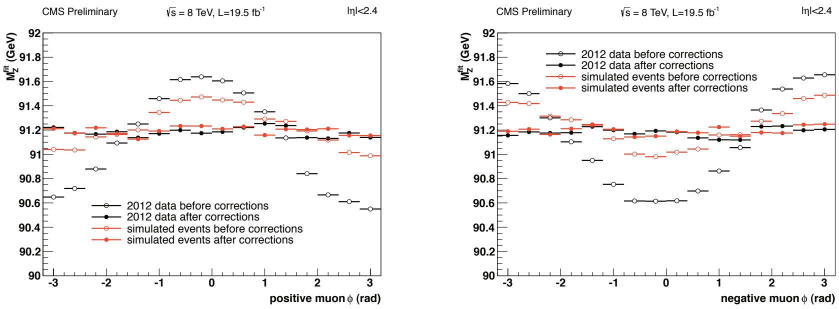

Fig. 3. The position of the fitted Z peak in data (black circles) and simulation (red circles) as function of of muon ϕ for positively charged muons (left) and for negatively charged muons (right) before and after the momentum scale calibration. The uncertainties shown are statistical only.

best measurement of muon p_T is obtained by selective use of information from the muon system in addition to that from the inner tracker, with p_T resolution better than 10% up to 1 TeV/c. Also, the muon trigger efficiency for isolated muons is better than 90% over the full range.

The good performance and detailed understanding of the muon reconstruction, identification and triggering provides the necessary confidence in all elements of the chain from muon detection to muon analysis, which is essential for searches for physics beyond Standard Model as well as accurate Standard Model measurements.

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