CMS Draft Analysis Note

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Updated measurement of the charge ratio of cosmic muons using MTCC data

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Abstract

The cosmic muon charge ratio was measured for the first time in CMS using MTCC data. This note presents the details of the update of this analysis, necessary for its combination with the two new measurements of the charge ratio performed with CRAFT08 data. The updated analysis incorporates corrections due to the magnetic field bias and reconstructs each muon trajectory back to the point of entry in CMS to determine its zenith angle. The new charge ratio results are expressed in terms of $p \cdot \cos\theta_z$, in line with the other analyses.

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1 Introduction

One of the main results obtained from CRAFT08 data was an improved understanding of the magnetic field in the barrel return yoke. The MTCC measurement of the cosmics charge ratio is sensitive to this because it relies solely on stand-alone muon tracks. Even though the main effect is just a change in momentum scale, it is important to update the MTCC result for the new B field scale in order to combine it with the new CRAFT measurements.

In order to facilitate the combination we also adjust the binning at the high end of the momentum range to be consistent with the bins used in the CRAFT analyses, in the momentum range where they overlap.

Finally, we add back-propagation of individual muons to the entry point on top of CMS in order to estimate the incident angle of each cosmic muon allowing us to plot the charge ratio as a function of $p \cdot \cos\theta_{\mathrm{z}}$. As a bonus, the individual propagation using the standard CMS SteppingHelix propagator also gives us an improved estimate of the energy loss for each muon.

2 Updated analysis

The cosmic muon charge ratio was measured by CMS for the first time using MTCC data and it is described in detail elsewhere [1].

For this analysis only the bottom sector of the barrel muon system was used. Special care was taken to accept only muons triggered and reconstructed in a perfectly left-right symmetric fiducial volume, ensuring a charge symmetric acceptance. The setup of the DT chambers is depicted in Fig. 1 (left), together with the left-right symmetric fiducial acceptance.

The signals deposited in the DT detector by cosmic muons of positive and negative charge are displayed in Fig. 1 (right), showing a symmetric illumination of the chambers, a key ingredient of this fully data-driven analysis.

Around 15 million "good" events were recorded with at least DT triggers and at a stable magnetic field above 3.67 T. A sample of about 330 thousand events survive the selection cuts (both fiducial and track quality ones). The measured muon charge ratio and its statistical uncertainty are displayed in Fig. 2, as function of the measured muon momentum, before any correction due to detector effects is applied. At high momentum, above $\sim$ 200 GeV/c, resolution effects make difficult to determine the muon charge (large charge mis-assignment probability), resulting in a lower value of the measured charge ratio. Random charge assignment would yield a charge ratio equal one.

The charge mis-assignment probability is small for low momentum muons, below $\sim$ 100 GeV/c, increasing significantly above that value. In order to improve the quality of the charge ratio measurement, muons with such probability in excess of 25 % are removed from the analysis. The charge confusion correction for those high momentum tracks is large, and the associated systematic uncertainty dominates the measurement above $\sim$ 200 GeV/c. The new CRAFT08 analyses provide precise measurements of the charge ratio in this high momentum region.

3 Magnetic field correction

There are two reasons why we cannot fully re-reconstruct the MTCC data. First of all, modern CMSSW releases are no longer compatible with the old files stored for this analysis. Secondly, the MTCC took place in the surface assembly hall, where the magnetic properties of surround-

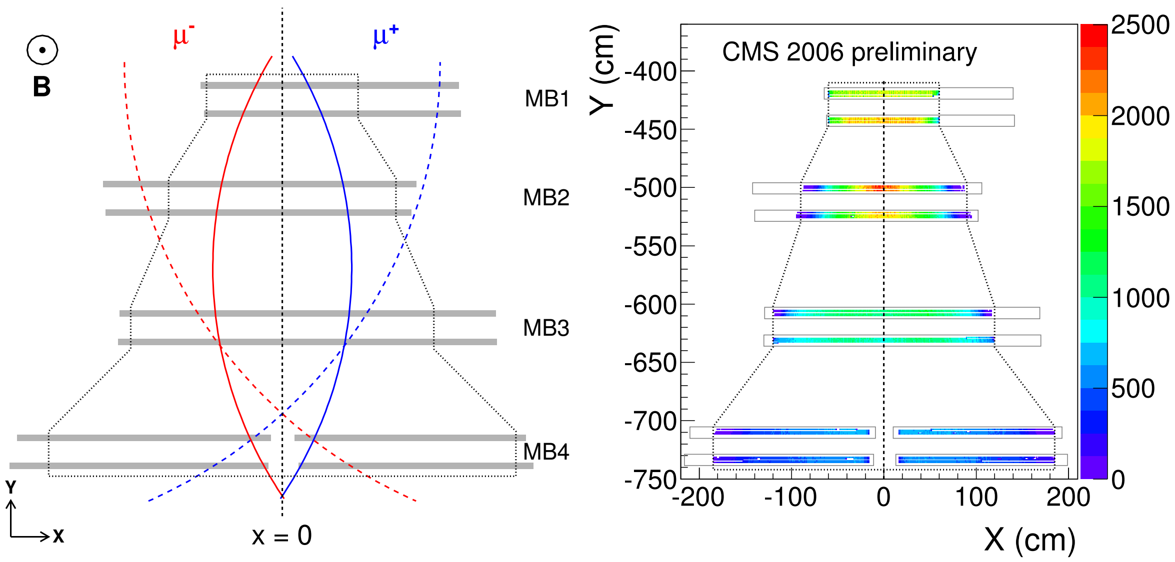

Figure 1: (Right) Definition of the left-right symmetric fiducial geometry (black dotted polygonal line) in the muon system. The dashed lines depict two muon tracks with the same momentum crossing sector 10, the negative one satisfying the MB2+MB3 trigger condition and the positive one failing it. The solid curves represent two muons with the same p in the fiducial geometry, both of them passing the golden muon selection criteria. (Left) Distribution of hits in global XY coordinates, for muons of the MTCC run 4406 in wheel YB+1, after selection cuts are applied.

ing material were not the same as down in the carven (forward shielding and iron in the cavern walls). The updated B field map is therefore not necessarily applicable to the MTCC data. An educated guess is that about 2/3 of the effect observed in CRAFT was present at the surface.

Therefore, the change in magnetic field is applied as an a posteriori correction of the momentum scale. As was shown during CRAFT, the main effect is a momentum scale difference of 20%, constant over a sizeable momentum range (from 10 to 50 GeV/c). Since the effect on surface is expected to be smaller, we scale all measured muon momenta down by $(15 \pm 5)\%$, where $\pm 5\%$ is quoted as a systematic uncertainty due to the magnetic field modeling.

4 Energy loss correction

In order to compare the CMS result with the measurements from other experiments, the charge ratio is expressed in terms of the muon momentum *before entering CMS*, corrected for energy loss in the upper half of the CMS detector and for charge mis-assignment, known as the *true* muon momentum. The measurement of the charge ratio using MTCC data as a function of the true muon momentum, along with the statistical and systematic uncertainties, is depicted in Fig. 3.

5 Systematic uncertainties

Systematic uncertainties arise mainly from finite precision of the detector alignment parameters, from the correction of the charge mis-assignment probability (given by detector resolution) and from the indetermination of the magnetic field scale.

As explained in section 3, there is no possibility to re-reconstruct the MTCC data and, as a

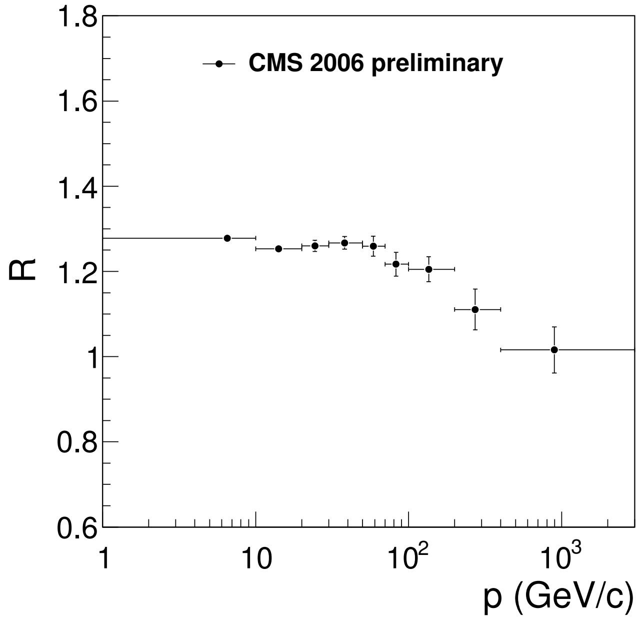

Figure 2: Cosmic muon charge ratio measured with MTCC data, as function of the measured muon momentum, before any correction due to detector effects is applied, together with the statistical uncertainty.

consequence, it is not possible to redo from scratch the detailed studies necessary to determine the systematic uncertainties due to detector alignment and charge mis-asingment.

The systematic uncertainties, S, were originally calculated as function of the muon momentum inside CMS, p_{in}. The back-propagation of individual muons to the entry point on top of CMS provides an estimate of the true muon momentum, p_{true}, introducing a small correction to p_{in} (already corrected for the magnetic field scale), in particular for medium and high momentum muons, for which the systematic uncertainties are significantly larger. Exploiting this smooth $p_{\text{true}}(p_{\text{in}})$ dependence, the systematic uncertainties are recalculated, in a muon-by-muon basis, as function of p_{true}, by integration:

$$S(p_{\text{true}}) = \frac{\int S(p_{\text{in}}) p_{\text{true}}(p_{\text{in}})\, dp_{\text{in}}}{\int p_{\text{true}}(p_{\text{in}})\, dp_{\text{in}}},$$

where the integral runs over all the muons. A similar procedure is used for $S(p_{\text{true}} \cdot \cos\theta_z)$.

The systematic uncertainty due to the indetermination of the magnetic field scale is estimated by varying this scale by $\pm 5\%$, equivalent to $1/3$ of the scale correction itself. The observed differences in the charge ratio measurement are quoted as a systematic uncertainty.

The relative contribution of the various sources of systematic uncertainty are depicted in Fig. 4, together with the total systematic uncertainty, as function of the muon momentum and its vertical component. The relative systematic uncertainties are summarized in Table 1, both for p and $p \cdot \cos\theta_z$.

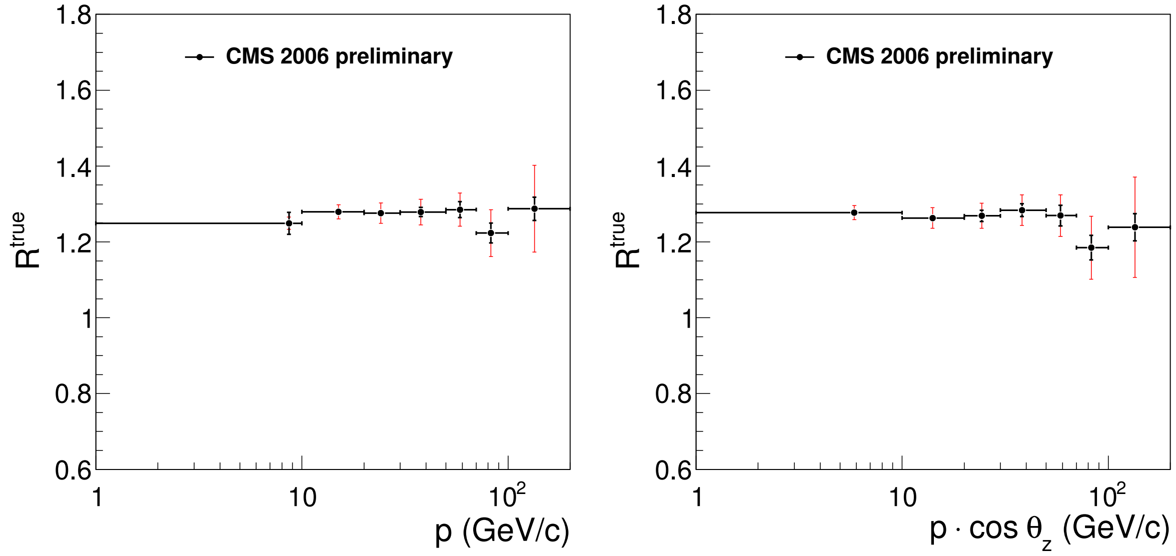

Figure 3: Charge ratio, as a function of the (left) muon momentum and (right) its vertical component, corrected for energy loss in the detector and for charge mis-assignment, after propagating the muon track to the entry point in CMS. The inner black error bars denote the statistical uncertainty and the outer red ones the systematic.

6 Conclusions

With the corrections described in this note, the MTCC result is ready to be combined with the new CRAFT results. The improved description of the magnetic field and individual propagation of muons to the top of the CMS detector gives a more accurate result. Since the changes only affect the "horizontal axis" (ie the momentum, not the charge), the effects on the final charge ratio result are minimal.

References

[1] M. Aldaya and P. Garcia-Abia, "Measurement of the charge ratio of cosmic muons using CMS data", *CMS Note* **2008/016** (2008).

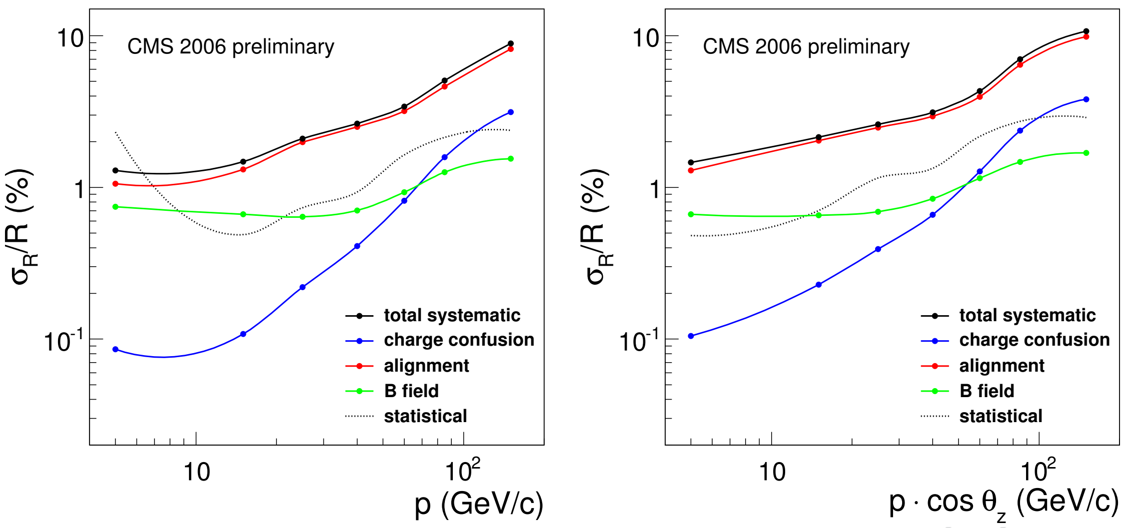

Figure 4: Relative systematic uncertainty, together with the contribution of the various sources, as function of (left) the muon momentum and (right) the vertical component of the muon momentum. The statistical uncertainty is also displayed.

Table 1: Relative systematic uncertainties as a function of p and $p \cdot \cos\theta_z$.

		σ/R (%)				
p range (GeV/c)	R	stat.	syst.	ch. mis.	alignment	B field
5 - 10	1.2490	2.31	1.30	0.09	1.06	-0.75
10 - 20	1.2793	0.49	1.48	0.11	1.32	0.66
20 - 30	1.2756	0.74	2.10	0.22	1.99	-0.64
30 - 50	1.2787	0.93	2.63	0.41	-2.50	0.70
50 - 70	1.2849	1.64	3.42	0.82	-3.19	-0.91
70 - 100	1.2232	2.14	5.06	1.58	-4.63	-1.29
100 - 200	1.2874	2.38	8.89	3.14	-8.18	-1.54
		σ/R (%)				
$p \cdot \cos\theta_z$ range (GeV/c)	R	stat.	syst.	ch. mis.	alignment	B field
2 - 10	1.2771	0.48	1.46	0.10	1.29	-0.66
10 - 20	1.2629	0.70	2.15	0.23	2.03	0.65
20 - 30	1.2686	1.15	2.61	0.39	2.48	-0.70
30 - 50	1.2837	1.33	3.13	0.66	-2.94	0.82
50 - 70	1.2693	2.17	4.31	1.27	-3.95	-1.15
70 - 100	1.1848	2.72	7.01	2.37	-6.42	-1.49
100 - 200	1.2384	2.89	10.69	3.81	-9.85	-1.69