Muon commissioning and Exclusive B production at CMS with the first LHC data

S. Taroni[a] on the behalf of the CMS Collaboration

[a]INFN Milano Bicocca, Piazza della Scienza 3,
20126 Milan, Italy

The performance of the CMS muon identification and reconstruction are presented, along with the estimated sensitivities of CMS for observing and measuring exclusive final states $B \to J/\psi K^{(*)}$.

1. Introduction

The Compact Muon Solenoid (CMS)[1] is a multi-purpose experiment now in data taking at the Large Hadron Collider (LHC)[2] at CERN. The main goals of the experiment range from the measurement of Standard Model parameters to the potential discovery of physics beyond the Standard Model [3]. To perform this ambitious program, the CMS detector has been designed with a precise muon spectrometer, a superconducting coil that provides a 3.8 T magnetic field for momentum measurements, a sampling hadronic calorimeter, an electromagnetic lead-tungstate calorimeter, and a full silicon tracker.
As final states with muons are a signature for important processes, CMS has a complex and redundant muon system for identifcation, momentum measurement and trigger. Muons are measured in the muon detectors (drift tubes (DT) plus resistive plate chamber (RPC) in the barrel and cathode strip chamber (CSC) plus RPC for the endcap) and in the silicon tracker over a large pseudorapidity range ($|\eta| < 2.4$). The high magnetic field and the match of the information from the muon detectors and from the tracker allow an excellent muon resolution. This muon system has been widely tested with the data acquired in the 2008 in the Cosmic Run At Four Tesla (CRAFT08) exercise [4] and are continuosly monitored with well-known resonances (J/$\psi \to \mu\mu$, Z $\to \mu\mu$) in collisions.

2. Muon performance at CRAFT08

During CRAFT08, CMS collected about 300 millions of cosmic events. These muons were reconstructed using information from the muon detector only (standalone muons), from the tracker only (tracker tracks) or from both the detectors (global muons). This multiple information has allowed a detailed analysis of efficiencies for different algorithms of reconstruction and identification and the determination of the momentum resolution in large p_T range [5].

2.1. Reconstruction and identification efficiency

The efficiencies of the muon reconstruction and identification algorithms were measured by selecting events with global muon reconstructed in one hemisphere of the detector and examining whether there was a corresponding track in the opposite hemisphere, in the region of $|\Delta\phi| < 0.3$ and $|\Delta\eta| < 0.3$ around the direction of the reference global-muon track. To test the performance of the standard reconstruction alghoritm in view of collisions, stringent selections were applied to extract a collision-like sample from the cosmic events. The final datasample was formed by requiring a tight impact parameter cuts to the reference tracks: $r < 4$ cm (the beam-pipe radius) and $|z| < 10$ cm ($\sim 3\sigma$ boundary of the collision region at the start up).
Fig. 1 shows the efficiencies to reconstruct LHC-like global muons and their constituents as a function of the pseudorapidity of the reference

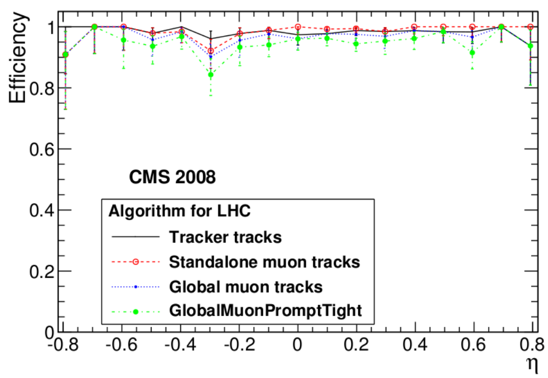


Figure 1. Muon reconstruction efficiencies as a function of η of the reference track.

track. Integrated over the barrel region of the detector ($|\eta| < 0.8$), the efficiency of the standard global muon reconstruction algorithm was measured to be (97.1± 0.6)%; for events in which both the tracker track and the standalone-muon track were found, it was improved to (99.7 ± 0.1)%.

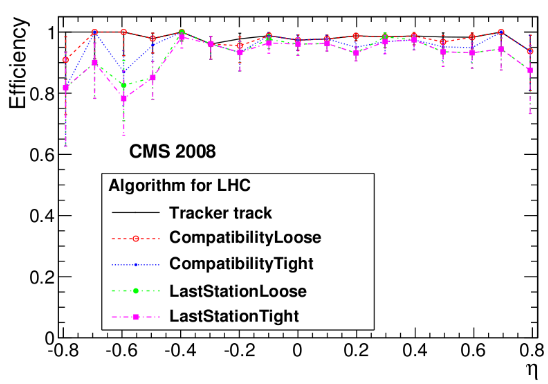


Figure 2. Muon identification efficiencies as a function of η of the reference track for different identification algorithms.

The muon identification algorithms were also tested. The efficiencies of the algorithms with different selections were compared with the efficiency of tracker tracks (fig. 2) as function of η of the reference track. The efficiencies agree within 1-2% in most cases.

The dependence of the efficiency of the different muon reconstruction and identification algorithms on the p_T of the reference muons at the point of closest approach (PCA) is shown in fig. 3. As expected, none of the studied algorithms show a strong p_T dependence in the range above 10 GeV/c.

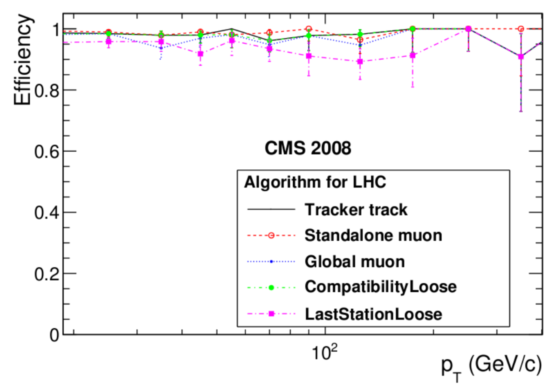


Figure 3. Muon reconstruction and identification efficiencies in the barrel region of the detector ($|\eta| < 0.8$) as a function of p_T of the reference track for different algorithms.

2.2. Momentum resolution

The muon momentum resolution was measured by the width of the distribution of the relative residuals, R(q/p_T):

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

where $(q/p_T)^{upper}$ and $(q/p_T)^{lower}$ are the ratios of the charge sign to the transverse momentum for muon in the upper and lower detector halves, respectively. Fig. 4 shows the resolution as a function of the p_T: below 200 GeV/c the contribution of the muon detector hits is low, the multiple scattering in the tracker is dominant in this region; for high p_T the resolution for the global muons is not as good as that of tracker tracks, but it can be improved including, if necessary, the first muon station information with a track by track choice.

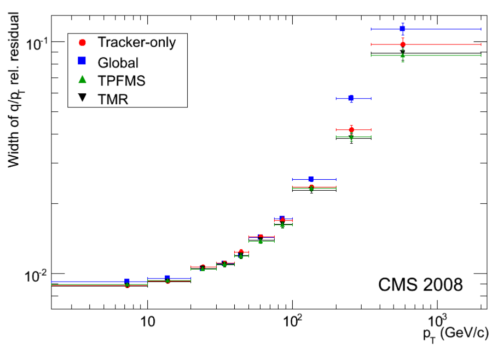


Figure 4. Widths of Gaussian fits to the distributions of the normalized residuals, for different muon reconstruction algorithms, as a function of p_T of the reference track

3. Exclusive B production with the first LHC data

This excellent performance of the muon system can be exploited in the study of the heavy flavour sector. Thanks to the strong signature of the $J/\psi \to \mu\mu$, CMS can carry out a rich program of charm and beauty analyses already with the data foreseen for the first year ($O(100\text{pb}^{-1})$). One of these studies is the measurement of the differential cross section and the lifetime ratio using the exclusive decays $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^{0*}$, with $J/\psi \to \mu\mu$ and $K^{0*} \to K^+\pi^-$. The choice of the exclusive channel assures a reduced systematics w.r.t. the inclusive $B \to J/\psi X$ and allows the rejection of background process (inclusive b and prompt J/ψ) using the invariant mass and the proper decay length of the reconstructed B candidate. In addition, it can be a test of the CMS detector performance because both decay modes are well known, deeply studied at the B-factories, and the BR for each mode known with a precision better than 5%.

A Monte Carlo study at 10 TeV showed the feasibility: $\sim$ 1750 B^+ and $\sim$ 900 B^0 events are expected in 10 pb^{-1} of integrated luminosity [6]. In this study, the J/ψ candidates are reconstructed by vertexing oppositely charged muons with p_T>3 GeV/c and candidate K^{0*} mesons by pairs of oppositely charged tracks having p_T>0.5 GeV/c. B^+ mesons are obtained by combining a J/ψ candidate with a track having p_T>0.8 GeV/c, and B^0 mesons by combining J/ψ with K^{0*} candidates. For each event, the B^+ (B^0) candidate with the best vertex probability is chosen, requiring p_T(B)>9 GeV/c.

The two-dimensional proper decay length $c\tau$ is defined as

$$c\tau = M_B \cdot L_{xy}/p_T^B \qquad (2)$$

where M_B and p_T^B are the mass and transverse momentum of the B candidate, and the transverse flight length L_{xy} is the projection of the vector pointing from the primary to the secondary vertex onto the transverse momentum.

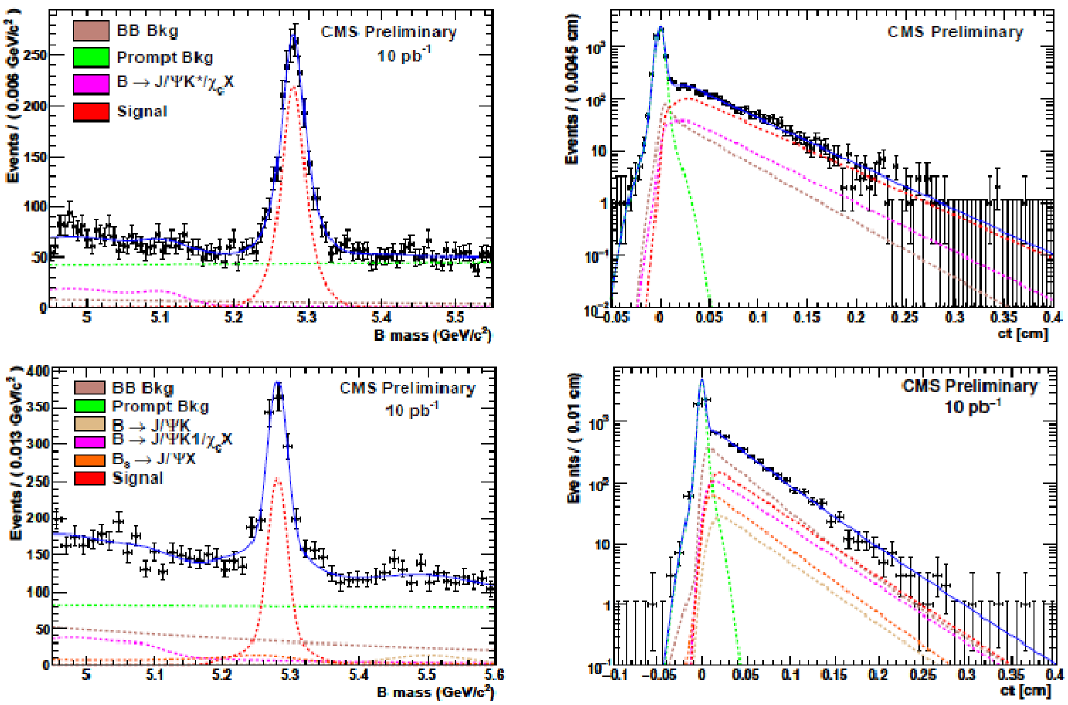
Signal yields and lifetimes are extracted using an unbinned extended maximum-likelihood fit to the invariant mass and proper decay length $c\tau$ of the reconstructed candidates, that are shown in fig. 5, for all $p_T^B > 9$ GeV/c.

The lifetime ratio that can be obtained is

$$R_0 = \frac{\tau(B)}{\tau(B^0)} = 1.10 \pm 0.05(stat.) \pm 0.01(syst.) \qquad (3)$$

that means a statistical uncertainty less then 5% and of the same order of the systematics, already with the low statistics of 10 pb^{-1}. In order to measure the cross section, the B^+ and B^0 lifetimes are then fixed to the obtained values and the signal and background yields are fitted for different p_T^B bin. The differential cross sections, thus determinated, can be carried out with a statistical precision of less than 10%; the systematics is dominated by the luminosity uncertainty and it is of the order of 13-14% per p_T^B bin.

Figure 5. Simulated distributions of M_B and $c\tau$ for the B^+ (top) and B^0(bottom), showing the fit together with the signal and background components. Points with error bars represent a sample of simulated events corresponding to 10 pb^{-1}.



4. Summary

In conclusion, CMS can contribute to study the heavy flavour sector. A MC study has shown the feasibility of measuring the differential cross section and the lifetime ratio using the exclusive decays $B^+ \rightarrow J/\psi K^+$ and $B^0 \rightarrow J/\psi K^{0*}$ already with $10pb^{-1}$.

These studies can be performed thanks to the high performance of muon detection and tracking in CMS, which were widely tested during the cosmic data taking and were continously monitored in collisions using well-known resonances.

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