Heavy-Flavor Results at CMS

Roberto Covarelli for the CMS collaboration
Department of Physics and Astronomy
University of Rochester
I-14327 Rochester, UNITED STATES

The CMS experiment [1] at the LHC is a multi-purpose detector. Due to its versatility, especially of the trigger system, and to the excellent muon transverse-momentum (p_T) resolution, several heavy-flavor physics results have been obtained, using proton-proton data recorded in 2010–11 at a center-of-mass energy of 7 TeV.

1 Quarkonia

From the theoretical point of view, the prompt charmonium cross section is a clean probe of Non Relativistic QCD approaches. Recently, J/ψ and ψ(2S) cross-sections have been computed at Next-to-Leading Order (NLO) in these models, using the long-distance matrix elements as determined in Tevatron data. In the same model, predictions for the ratio of χ_c over J/ψ production rate, and the analogous for χ_{c2} over χ_{c1}, have been obtained. At relatively high p_T, a significant fraction of the J/ψ and ψ(2S) comes from b-hadron decays and, if it is separated experimentally from the prompt component, provides a direct test of the Fixed-Order Next-to-Leading-Log (FONLL) prediction for the $b \to \psi$ production cross section.

The differential cross sections can be expressed as:

$$\frac{d^2\sigma}{dp_T dy}(Q\overline{Q}) \cdot \mathrm{B}(Q\overline{Q} \to \mu^+\mu^+) = \frac{N_{\mathrm{rec}}(Q\overline{Q})}{\int \mathcal{L}dt \cdot \langle A \cdot \varepsilon \rangle \Delta p_T \Delta y} \quad (1)$$

where $N_{\mathrm{rec}}(Q\overline{Q})$ is the $Q\overline{Q}$ yield in a given p_T-y bin, $\int \mathcal{L}dt$ is the integrated luminosity, $\langle A \cdot \varepsilon \rangle$ is the average value in the bin of the geometrical acceptance, determined using Monte Carlo (MC) simulations, times the reconstruction efficiency of the di-muon, and $\Delta p_T \Delta y$ is the size of the bin. Multiplication by $1 - f_B$ (f_B) yields the prompt (non-prompt) component of the total inclusive cross section. Muon trigger and reconstruction efficiencies are determined in CMS from the data using the "tag-and-probe" method [2], which uses independent J/ψ samples to provide a sample of muons unbiased with respect to the selection under investigation.

The measurement of the J/ψ and ψ(2S) differential cross sections [3] uses a data sample corresponding to an integrated luminosity of 37 pb^{-1}. Using a fit to the invariant mass and decay length distributions, production cross sections have been measured separately for prompt and non-prompt charmonium states, as a function of the transverse momentum in several rapidity ranges (Fig. 1, left). The ratio of the differential production cross sections of the two states, where many systematic uncertainties (e.g. from luminosity and muon efficiency) cancel, is also determined. The branching fraction of the inclusive $B \to \psi(2\mathrm{S})X$ decay is extracted from the ratio of the non-prompt cross sections to be $(3.08 \pm 0.12\,(\mathrm{stat.} + \mathrm{syst.}) \pm 0.13\,(\mathrm{theor.}) \pm 0.42\,(\mathcal{B}_{\mathrm{PDG}})) \times 10^{-3}$.

The p_T-differential measurement of the relative prompt production rate of χ_{c2} and χ_{c1} is based on a sample of 4.6 fb^{-1} of data [4]. The two states are reconstructed in their radiative decays $\chi_c \to J/\psi + \gamma$, with the photon converting into an e^+e^- pair in the tracker barrel region. A very good signal purity is obtained with this method, as well as a resolution of about 6 MeV/c^2, that allows a clear separation of the two states. Results for the cross-section ratio are shown in Fig. 1, right.

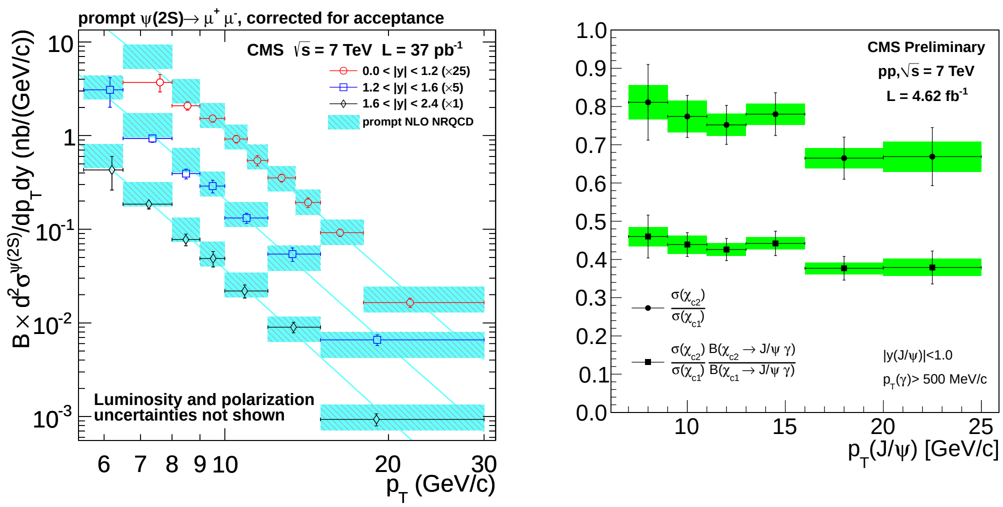

Figure 1: Left: Measured differential cross section for prompt $\psi(2\mathrm{S})$ production as a function of p_T for different rapidity bins. The blue histograms indicate the theoretical predictions from NRQCD calculations. Right: Measured χ_{c2} over χ_{c1} cross section ratio as a function of J/ψ p_T.

2 b-baryons

Precise measurements of the Λ_b and $\overline{\Lambda}_b$ cross-sections, as well as searches for new b-baryon states have been performed at CMS, using data samples of 1.9-5.3 fb^{-1}.

Λ_b baryons are reconstructed through their decays to $J/\psi\Lambda \to \mu^+\mu^- p\pi^-$ [5]. A good resolution is obtained with a mass-constrained vertex fit to the 4-particle candidates, while the request of a large significance of J/ψ and Λ vertex displacement rejects background from prompt tracks. Efficiencies are determined from "tag-and-probe" and MC simulation. A slight excess of the total measured cross section with respect to MC@NLO predictions is found, consistent with CMS measurements of other b-hadron species. However, unlike other b-hadrons, the p_T spectrum falls more rapidly than NLO QCD predictions, and this is attributed to a difference in the hadronization mechanism. The particle over anti-particle cross-section ratio is found to be compatible with 1 at all p_T values.

Among the neutral "cascade" b-baryons (Ξ_b^0), only the $J^P = \frac{1}{2}^+$ state had been previously observed; however color hyperfine splitting predicts the mass of the $J^P = \frac{3}{2}^+$ state to be large enough for a $\Xi_b^{0*} \to \Xi_b^- \pi^+$ decay. Therefore the state is searched in this channel [6], profiting of the presence of three weakly decaying particles in the chain (Ξ_b^-, Ξ^-, Λ^0) which allows reconstruction of three detached vertices to reject background from prompt tracks. The result is an observation with a significance corresponding to 6.9 standard deviations. The measured mass of the new resonance is $5945.0 \pm 0.7\,(\text{stat.}) \pm 0.3\,(\text{syst.}) \pm 2.7\,(\text{PDG})$ MeV/c^2, in agreement with theoretical predictions (Fig. 2).

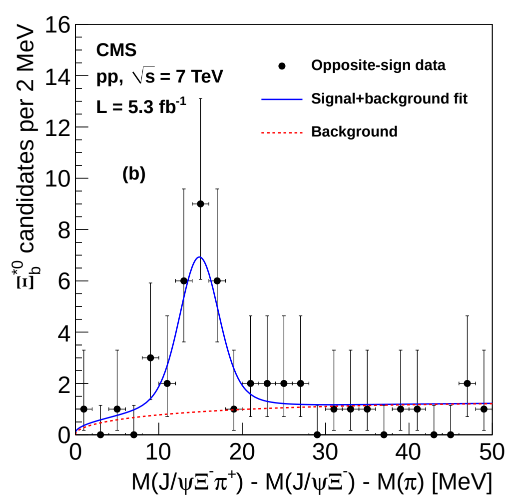

Figure 2: $Q = M(J/\psi\Xi^-\pi^+) - M(J/\psi\Xi^-) - M(\pi^+)$ distribution in the $0 < Q < 50$ MeV/c^2 range, along with the result of the signal-plus-background fit (blue solid curve); the background term is also shown (red dashed curve).

3 Rare decays

In CMS searches for B_s^0, B^0 and $D^0 \to \mu^+\mu^-$ decays have been performed. These decays are predicted to be rare in the Standard Model (SM) and, especially in the B

sector, a significant enhancement over the SM branching ratios ($\mathcal{B}_{\rm SM} \sim 10^{-10} - 10^{-9}$) is predicted in most supersymmetric theories. An observation of a non-SM value of the branching fraction would therefore represent an indirect evidence for new physics.

For the B_s^0 and B^0 analysis [7], the dataset corresponds to an integrated luminosity of 5.0 fb^{-1}. The analysis is performed separately in two channels, at low and high muon pseudo-rapidity, and then combined for the final result. A "normalization" sample of events with $B^+ \to J/\psi K^+$ decays is used to remove uncertainties related to the $b\bar{b}$ production cross section and the integrated luminosity and reduce uncertainties on efficiencies, which are determined from MC. Selection is based on several types of variables, including high p_T, vertex displacement and dimuon isolation, and has been optimized to mitigate the effects of high pileup. A "blind" analysis approach is applied.

An event-counting experiment is performed in dimuon mass regions around the B_s^0 and B^0 masses. MC simulations are used to estimate backgrounds due to other rare B decays and combinatorial backgrounds are evaluated from the data in dimuon invariant mass sidebands. The observed number of events is consistent with background plus SM signals. The resulting upper limits on the branching fractions are $\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 7.7 \times 10^{-9}$ and $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.8 \times 10^{-9}$ at 95% CL.

Similar techniques are exploited in the search for $D^0 \to \mu^+\mu^-$ [8], but the data sample used corresponds to 90 pb^{-1} only, due to the trigger limitations in selecting the normalization sample $D^0 \to K^-\mu^+\nu_\mu$. The resulting upper limit is $\mathcal{B}(D^0 \to \mu^+\mu^-) < 5.4 \times 10^{-7}$ at 95% CL.

References

[1] The CMS Collaboration, S. Chatrchyan *et al.*, JINST **3**, S08004 (2008).

[2] The CMS Collaboration, CMS-PAS MUO-10-004 (2011).

[3] The CMS Collaboration, S. Chatrchyan *et al.*, JHEP **1202**, 011 (2012).

[4] The CMS Collaboration, CMS-PAS BPH-11-010 (2012).

[5] The CMS Collaboration, S. Chatrchyan *et al.*, Phys. Lett. **B714**, 136 (2012).

[6] The CMS Collaboration, S. Chatrchyan *et al.*, Phys. Rev. Lett. 108, 252002 (2012).

[7] The CMS Collaboration, S. Chatrchyan *et al.*, JHEP **1204**, 033 (2012).

[8] The CMS Collaboration, CMS-PAS BPH-11-017 (2012).