Quarkonium production in CMS

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1 The CMS detector

The heart of the Compact Muon Solenoid (CMS) detector [1] is a very large silicon tracker, consisting of pixel and microstrip detectors, immersed in a 3.8 T axial magnetic field, and extending over five units in rapidity. The high granularity of the tracker and the strong magnetic field ensure an excellent momentum resolution and good vertexing capabilities. Muons are measured in gas-ionization detectors embedded in the steel return yoke of the solenoid.

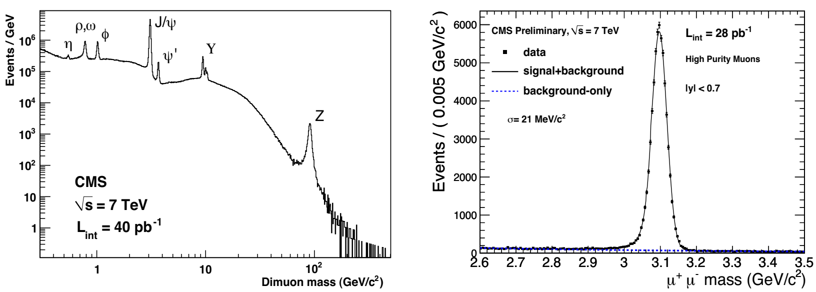

Figure 1: Opposite-sign dimuon mass distribution in pp collisions at $\sqrt{s} = 7$ TeV (left) and mid-rapidity dimuon mass distribution in the J/ψ mass region (right).

Figure 1 (left) shows the opposite-sign dimuon mass distribution reconstructed from the full 2010 data sample of pp collisions at $\sqrt{s} = 7$ TeV, of 40 pb^{-1} integrated luminosity. The J/ψ mass region is shown in the right panel, for muons measured in the barrel detectors, where the dimuon mass resolution is around 20 MeV/c^2 for the J/ψ and around 70 MeV/c^2 for the Υ(nS). The results presented in this paper correspond to a relatively small fraction of the 2010 data, collected during the first months of LHC operation, when the instantaneous luminosity was low enough that CMS could write to permanent storage all the events with two muons, irrespectively of their charge or transverse momentum.

2 J/ψ production

On the basis of a dimuon event sample of 314 nb^{-1} integrated luminosity, CMS measured the J/ψ production cross section in pp collisions at 7 TeV, as a function of transverse momentum and in three rapidity ranges: $|y| < 1.2$, $1.2 < |y| < 1.6$ and $1.6 < |y| < 2.4$ [2]. The *prompt* component of the J/ψ differential cross section is shown in Fig. 2-left, for the most forward rapidity bin. The prompt and displaced J/ψ contributions are discriminated thanks to the measurement of the distance between the dimuon vertex and the interaction point, known with a resolution around 50 μm. The measurement is compared to calculations made with Monte Carlo event generators (PYTHIA and CASCADE), as well as with the Color Evaporation Model, as explained in detail in Ref. [2] and references therein. Unpolarized quarkonium production has been used as the default scenario, by CMS as by the other LHC experiments, for the calculation of the dimuon acceptances for prompt production, given the rather puzzling situation regarding the available measurements at collider energies [3]. The theory calculations include an estimate of the contributions from the feed-down decays of heavier charmonium states ($\psi(2S)$ and χ_c), which should be responsible for more than 30% of the measured prompt yield [4].

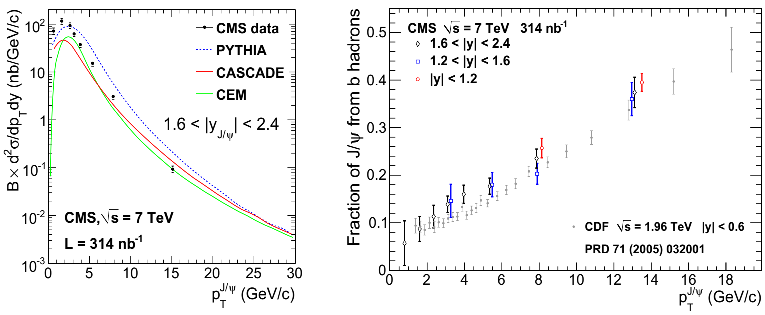

Figure 2: Left: Differential *prompt* J/ψ cross section, in the dimuon channel, as a function of p_{T} for $1.6 < |y| < 2.4$ and in the unpolarized production scenario. The PYTHIA curve was used to calculate the abscissa values where the points are shown, following the procedure explained in Ref. [5]. Right: Fraction of J/ψ production due to b hadron decays, vs. p_{T}, as measured by CMS and CDF.

Figure 2-right shows the evolution of the fraction of J/ψ mesons resulting from b hadron decays with the J/ψ p_{T}. The strong increase with p_{T} is seen in all the three rapidity ranges probed by CMS. The pattern is similar to the one previously observed by the CDF experiment, at lower energies [6], while the values at the LHC energies are slightly higher.

3 Upsilon production

The CMS experiment has also measured the total and differential production cross sections of the Υ(1S), Υ(2S) and Υ(3S) resonances, as a function of p_T, in pp collisions at 7 TeV, on the basis of a dimuon event sample of 3.1 pb^{-1} integrated luminosity [7]. The Υ(nS) yields are extracted via an extended unbinned maximum likelihood fit. Each Υ state is parameterized by a "Crystal Ball" function, with the final state radiation tails fixed from Monte Carlo simulation studies and a single resolution parameter fitted from the data, constrained to scale with the Υ(nS) masses. The mass of the Υ(1S) is left free in the fit and the masses of the heavier states are fixed by their world average differences. A second-order polynomial is chosen to describe the background in the 8–14 GeV/c^2 mass range.

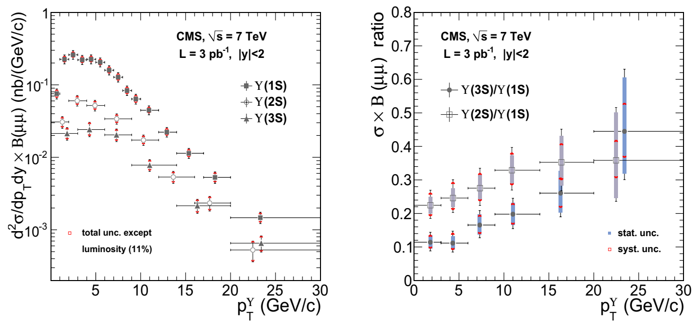

Figure 3: Υ(nS) differential cross section (left) and cross section ratios (right), as a function of p_T, in the rapidity range $|y^\Upsilon| < 2$.

The p_T-differential Υ(nS) cross sections, for the rapidity interval $|y^\Upsilon| < 2$, are shown in Fig. 3-left. The error bars represent the sum in quadrature of statistical and systematic uncertainties, excluding the global uncertainty on the luminosity (11%). The corresponding cross section ratios are shown in the right panel of the same figure. The luminosity uncertainty does not affect these ratios. The measurements clearly indicate that the relative cross sections of the 2S and 3S states, with respect to the 1S state, increase very fast with p_T, reaching a fourfold increase for the 3S state from $p_T \sim 2.5$ to $p_T \sim 25$ GeV/c. This increase can be attributed to several causes and only future measurements will allow for a clear understanding of the observation. For instance, part of this effect could be due to a steeper p_T dependence of the χ_b production cross section, leading to a more important feed-down contribution to the 1S state at low p_T than at high p_T, convoluted with the very reasonable assumption that the 1S state is much more affected by χ_b decays than the heavier Υ states.

4 Summary and outlook

The CMS experiment is operating very well and producing high-quality physics results, as illustrated by the selection presented in this paper. We will soon complement the measurements of (relative) production cross sections of several quarkonium states with the measurements of their polarizations, as a function of p_{T} and rapidity, on the basis of the data CMS collected throughout 2011, corresponding to almost 5 fb^{-1}. Studies of χ_c production are also ongoing, as illustrated in Fig. 4, where we can see the effect of the very good mass resolution provided by the measurement of the decay photon through conversion to e^+e^- pairs.

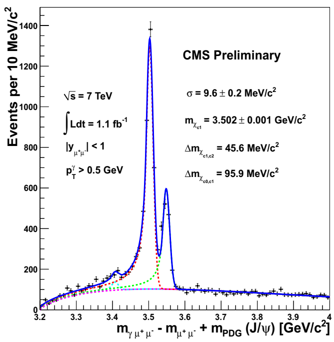

Figure 4: Mass distribution of the $\chi_c \to \mathrm{J}/\psi + \gamma$ candidates.

In summary, CMS will surely contribute to a significant improvement in our understanding of quarkonium production.

References

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