J/ψ production in pp collisions with the ALICE experiment

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1 Introduction

After almost fourty years from its discovery, the theoretical description of J/ψ hadropro-duction is still an open topic. Given the high mass of the c quark, charmonia production involves different energy scales: the formation of the quark-antiquark pair is a hard process and can be reliably described through perturbative QCD calculations, but the dynamics of the bound state formation and evolution are intrinsically non-relativistic and they involve soft energy scales.
For this reason, no full-QCD description of quarkonium production can be carried out and many theoretical models have been developed. Among them, the effective field theory NonRelativistic QCD (NRQCD) at LO was found to reproduce the cross-sections measured at the Tevatron [1], which were significantly underestimated by Color Singlet Model (CSM) calculations at LO. Nevertheless, the prediction on the J/ψ degree of polarization was contradicted by the measurement of CDF [2], hence opening an issue which still remains and on which the Large Hadron Collider (LHC) is expected to provide a crucial contribution.

ALICE (A Large Ion Collider Experiment) [3] is the experiment at the LHC dedicated to the study of heavy ion collisions. Nevertheless, the study of pp collisions allows to obtain reference data for heavy-ion physics and to investigate open issues in elementary particle physics.
ALICE is able to detect heavy quarkonia through their leptonic decay: in the central rapidity region ($|y| < 0.9$) this measurement is performed through the detection of e^+e^- pairs in the Inner Tracking System (ITS) and in the Time Projection Chamber (TPC), while at forward rapidity ($2.5<y<4$) the $\mu^+\mu^-$ channel is analyzed by means of the Muon Spectrometer.

In this work, ALICE's results on J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 2.76$ TeV are presented, discussed and compared to theory.

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2 Results

The integrated and differential cross sections for inclusive J/ψ production were measured at forward and central rapidity at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 2.76$ TeV [4]. Both measurements extend down to zero p_T and, when comparing the 7 TeV result with those obtained by the other LHC experiments, a fair agreement is found.
In Figure 1(a) the double differential cross section $(d^2\sigma/dydp_T)$ for inclusive J/ψ production at forward rapidity $(2.5 < y < 4.)$ and at the two center of mass energies is shown. The comparison with NLO NRQCD calculations [5] performed in the region $p_T > 3$ GeV/c shows a good agreement inside the theoretical uncertainty coming from the variation of the factorization, renormalization and NRQCD scales.
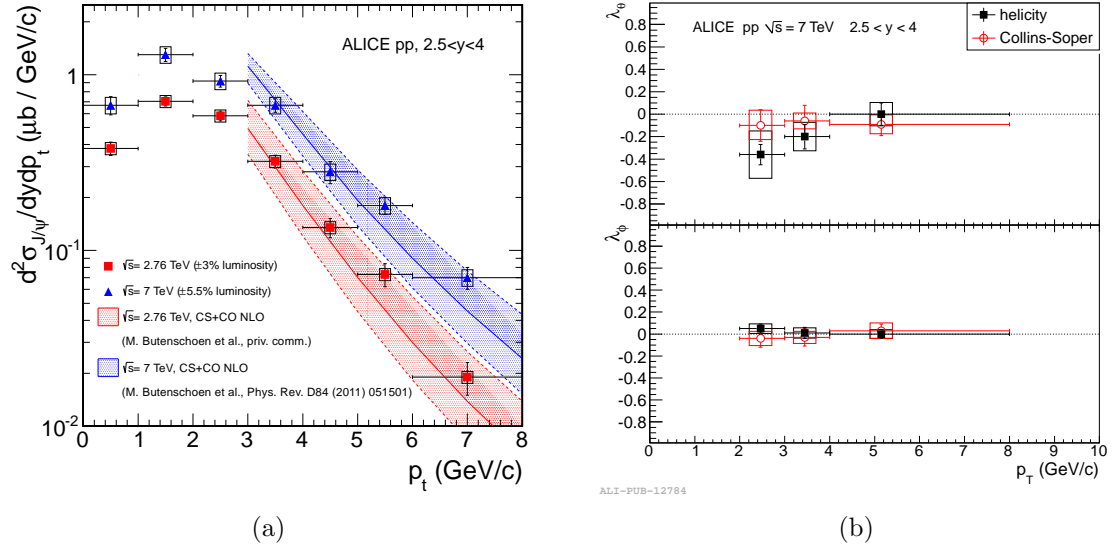

Figure 1: (a) $d^2\sigma/dydp_T$ for inclusive J/ψ production at forward rapidity at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 2.76$ TeV . (b) Polarization parameters λ_θ and λ_ϕ in the helicity and Collins-Soper frames for inclusively produced J/ψ as a function of p_T.

J/ψ polarization was studied, at forward rapidity, through the analysis of the angular distribution of the decay products [6], which follows the general formula:

$$\mathrm{W}(\cos\theta, \phi) \propto \frac{1}{3 + \lambda_\theta} \cdot \left(1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi\right), \quad (1)$$

where θ and ϕ are the polar and azimuthal angles of one of the two muons with respect to a given reference frame [7] (helicity and Collins-Soper were considered for this analysis) and λ_θ, λ_ϕ and $\lambda_{\theta\phi}$ are the polarization parameters. Due to statistics restrictions and acceptance issues, the analysis was limited to the first two parameters,

assuming the third one to be zero (an a-posteriori check confirmed this assumption). Moreover, an integration of the two-dimensional Eq.1 over ϕ and $\cos\theta$ was performed in order to extract the λ_θ and λ_ϕ respectively in a one-dimensional approach. Possible biases in the acceptance correction were avoided by means of an iterative procedure. The result, shown in Figure 1(b), is that no significant polarization is observed in both the considered frames; in the helicity frame a 1.6σ hint for a negative λ_θ value can be found at low p_T. The comparison with NLO calculations of CSM and NRQCD, reported in [8], shows a better qualitative agreement with the second one, but a firm conclusion will be possible when higher p_T will be reached by the experiments.
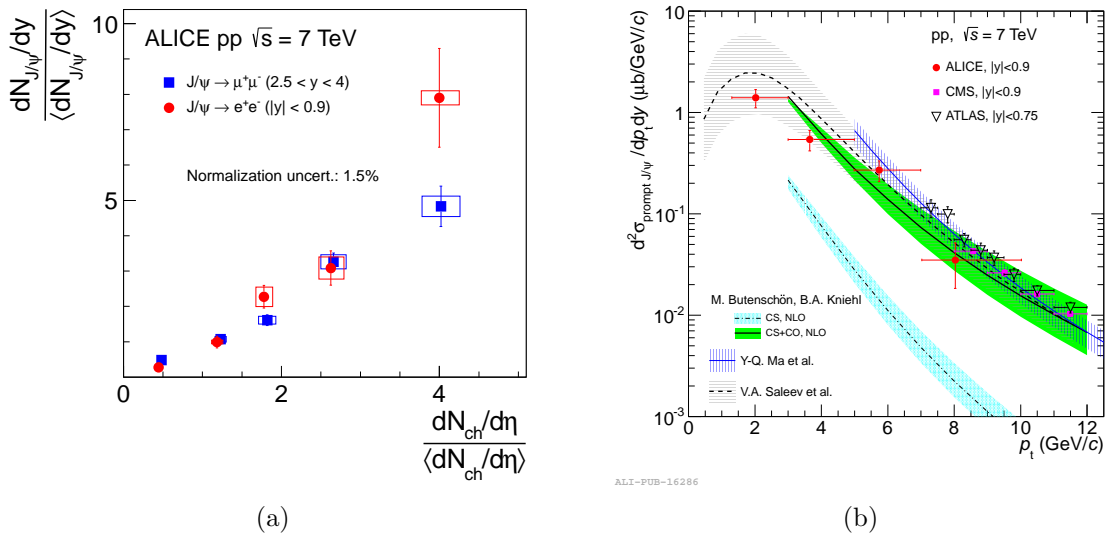

(a)

(b)

Figure 2: (a) Relative J/ψ yield as a function of the relative charged particle multiplicity density at mid-rapidity. (b) $d^2\sigma/dp_T dy$ for prompt J/ψ production at mid-rapidity as a function of p_T.

The measurement of the J/ψ production yield as a function of the charged particle multiplicity [9] was carried out by ALICE both at forward and mid-rapidity. The results (see Figure 2(a)) show a linear increase of the J/ψ yield with the multiplicity in both the rapidity ranges. For a complete understanding of this result, in clear disagreement with the decreasing trend expected from MC simulations (PYTHIA 6.4 Perugia-0 tuning), more experimental and theoretical work are needed.

ALICE has also been able to study prompt J/ψ production for $|y| < 0.9$ and down to $p_T = 1.3$ GeV/c [10], thus complementing the higher-p_T measurements of ATLAS and CMS [11]. The subtraction of the non-prompt component was carried out

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by means of an unbinned 2-dimensional likelihood fit to the invariant mass and the pseudo-proper decay length distributions. The result, shown in Figure 2(b), significantly extends the p_T range reached by the other LHC experiments and the agreement with NLO NRQCD calculations [5], already found in the inclusive case at forward rapidity, is again verified.

3   Conclusions

ALICE has been studying J/ψ hadroproduction in the two rapidity regions $2.5 < y < 4$ and $|y| < 0.9$, down to $p_T = 0$. The inclusive production cross-sections at 7 TeV and at 2.76 TeV are in fair agreement with NRQCD calculations at NLO.
The produced J/ψ are basically unpolarized at forward rapidity in the region $2 < p_T < 8$ GeV/c in both the helicity and Collins-Soper frames and the inclusive J/ψ yield, at both mid and forward rapidities, shows a linear increase as a function of the charged particle multiplicity. The prompt J/ψ cross section was measured for $|y| < 0.9$ and down to $p_T = 1.3$ GeV/c, finding good agreement with NLO NRQCD calculations.

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