Charmonium Production in pp Collisions with ALICE

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The ALICE Collaboration studies the production of J/ψ meson in pp collisions at the center-of-mass energies of 2.76 and 7 TeV at mid- and forward-rapidity. Inclusive production cross-sections are presented as a function of the collision energy, rapidity and transverse-momentum. The J/ψ polarization measurements in the helicity and Collins-Soper frames is discussed. A novel result on the correlation between the collision charged particle multiplicity and J/ψ yield is also shown.

1 Introduction

Due to their large mass, the heavy quark pairs are considered to be produced in hard scatterings of partons which can be described perturbatively. However, the bound states of heavy quark pairs are formed via soft non-perturbative processes. Because of this interplay between the perturbative and non-perturbative aspects, quarkonium production is a unique and a very important testing case for QCD. Various theoretical approaches, recently reviewed in [1, 2] were proposed to describe the data. However the consistent description of both the differential production cross-sections and the polarization proved to be difficult to achieve.

2 Data analysis

	2.76 TeV	7 TeV
$\|y\| < 0.9$	1.1 nb^{-1}	5.6 nb^{-1}
$2.5 < y < 4$	19.9 nb^{-1}	15.6 nb^{-1}

Table 1: Integrated luminosity, L_{int}, used in the data analysis at mid- and forward-rapidity.

ALICE [3] studied the production of J/ψ mesons down to zero transverse-momentum, p_t, using their decays into e^+e^- at mid-rapidity ($|y| < 0.9$) and into $\mu^+\mu^-$ at forward-rapidity ($2.5 < y < 4$). In this report we present results on the J/ψ production in pp collisions at $\sqrt{s}$ =2.76 TeV and 7 TeV. The integrated luminosities of the analyzed data samples at the two different rapidity intervals are given in Table 1. A detailed description of the analysis and the detectors used for reconstructing the electron and muon candidates can be found in [4, 5]. The electrons and muons passing the analysis cuts are combined in opposite-sign (OS) pairs to construct an invariant mass distribution. In the di-electron channel (at mid-rapidity) the signal is obtained by subtracting the background which is estimated using the like-sign (LS) pairs [4] or track rotations [6]. In the di-muon channel (at forward-rapidity)

the signal shape is described by a Crystal Ball function while the background is parameterized using the sum of two exponentials [4].

In order to extract cross-sections, the raw signal counts extracted from the invariant mass distribution need to be corrected for triggering efficiencies, kinematical acceptance and reconstruction efficiencies. This is performed using a Monte-Carlo procedure based on generating a large sample of J/ψ mesons embedded in simulated pp events. All the particles are then transported through the realistic ALICE detector setup constructed in GEANT [7].

3 Results

Figure 1 presents the inclusive differential cross-section $d^2\sigma_{J/\psi}/dp_t dy$ in pp collisions at $\sqrt{s}$ =7 TeV [4] and 2.76 TeV [5]. At 7 TeV the p_t dependent cross-sections at mid-rapidity and forward-rapidity are shown together with the results from CMS [8] and ATLAS [9] at mid-rapidity and LHCb [10] at forward-rapidity. At mid-rapidity, the p_t coverage of the ALICE results is

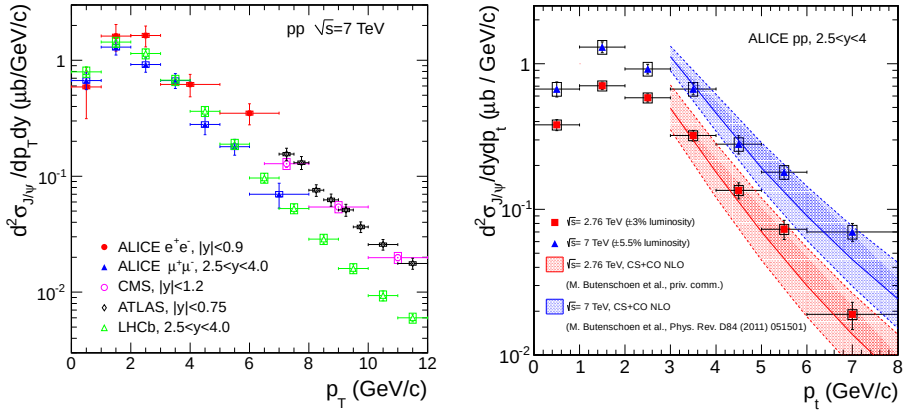

Figure 1: Differential cross-section $d^2\sigma_{J/\psi}/dp_t dy$ in pp collisions at 7 TeV [4] and 2.76 TeV [4]. The model calculations are from [11].

complementary to that from CMS and ATLAS. At forward-rapidity the ALICE results are in agreement with those from LHCb.

The inclusive cross-section at forward-rapidity in pp collisions at $\sqrt{s}$ =2.76 TeV and 7 TeV is shown in the right panel of Figure 1. The results at both energies are compared with the predictions of a NRQCD calculation [11] which includes both color singlet and color octet terms at NLO.

The wide kinematic coverage of ALICE, which is unique among the LHC experiments, allows the extraction of the p_t integrated J/ψ cross-section. In the left panel of Figure 2 we present the $d\sigma_{J/\psi}/dy$ at $\sqrt{s}$ =2.76 and 7 TeV. The results refer to the inclusive J/ψ production which is a sum of the direct component and of J/ψ resulting from decays of higher-mass charmonium states (mainly the χ_{c1}, χ_{c2} and $\Psi(2S)$ states) and from b-hadron decays. The contribution from higher-mass charmonium states measured at lower energies [12, 13] amounts to ≈33% while the contribution from b-hadron decays is 10-15% in the p_t range covered by ALICE [10, 14].

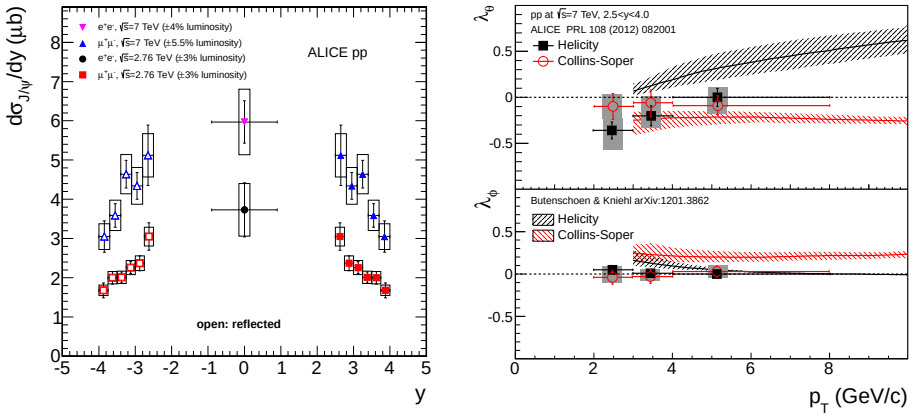

Figure 2: Left: $d\sigma_{J/\psi}/dy$ in pp collisions [5]. Right: Polarization parameters λ_θ and λ_ϕ as a function of p_t for inclusive J/ψ measured in the helicity and Collins-Soper frames [17].

The J/ψ is a spin-1 boson allowing for three degenerated states corresponding to projections of the angular momentum $J_z = \pm 1$ (transversal polarization) and $J_z = 0$ (longitudinal polarization).

The observed polarization is a superposition of the polarization from all the production mechanisms thus making this measurement a very important constraint for theoretical calculations. Existing models have difficulties in describing at the same time both the J/ψ production cross-section and the polarization. In particular NRQCD at leading order predicts for high-p_t J/ψ a large transverse polarization at CDF energies [15].

ALICE measured the J/ψ polarization at forward-rapidity in the helicity ($z-$axis is the J/ψ own momentum direction in the center-of-mass frame of the pp collision) and Collins-Soper ($z-$axis is the bisector of the angle between the direction of one beam and the opposite of the direction of the other one, in the rest frame of the J/ψ) frames. The measured angular distribution of the decay leptons is parameterized using the general form [16]

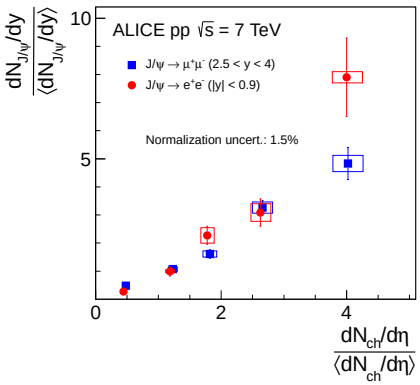

Figure 3: J/ψ yield as a function of the charged particle density at mid-rapidity [6].

$$W(\theta,\phi) \approx \frac{1}{3+\lambda_\theta}(1+\lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi),$$

where θ (ϕ) are the polar (azimuthal) angles. The λ_θ, λ_ϕ and $\lambda_{\theta\phi}$ are parameters extracted from data which quantify the degree of polarization. The right panel of Figure 2 shows the ALICE results on λ_θ and λ_ϕ for inclusive J/ψ at forward-rapidity [17]. In both reference frames all the parameters are compatible with zero. Recent NLO calculations within the NRQCD factorization [18] have shown good agreement with the ALICE results.

To investigate further the J/ψ production mechanisms, the yield was measured as a function of the charged particle pseudo-rapidity density $dN_{ch}/d\eta$. Figure 3 presents the relative J/ψ yield at mid- and forward-rapidity as a function of the relative charged particle density at mid-rapidity [6]. The results indicate that the J/ψ production at both mid- and forward-rapidity tends to be accompanied by the production of many other charged hadrons. A possible reason for the observed results could be multiple partonic interactions [19, 20].

4 Conclusions

We presented results obtained by the ALICE Collaboration on J/ψ production in pp collisions at $\sqrt{s}$ =2.76 and 7 TeV. The inclusive cross-sections as a function of p_t and rapidity were shown. The NLO NRQCD calculations show a good agreement with the ALICE results at forward-rapidity. The measured polarization parameters λ_θ and λ_ϕ are compatible with zero. We have also shown that the relative J/ψ yields at mid- and forward-rapidity increase linearly with the charged particle density at mid-rapidity.

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