J/ψ and $\psi(2S)$ measurement in p+p collisions at $\sqrt{s}$ = 200 and 500 GeV in the STAR experiment

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Abstract. In this paper, results on the J/ψ cross section and polarization measured via the dielectron decay channel at mid-rapidity in $p + p$ collisions at $\sqrt{s}$ = 200 and 500 GeV in the STAR experiment are discussed. The first measurement of $\psi(2S)$ to J/ψ ratio at $\sqrt{s}$ = 500 GeV is also reported.

1. Introduction

J/ψ and $\psi(2S)$ are bound states of charm (c) and anti-charm ($\bar{c}$) quarks. Charmonium physical states have to be colorless, however they can be formed via a color-singlet (CS) or color-octet (CO) intermediate $c\bar{c}$ state. One of the first models of the charmonium production, the Color Singlet Model (CSM) [1], assumed that J/ψ is created through the color-singlet state only. This early prediction failed to describe the measured charmonium cross section which has led to the development of new models. For example, Non-Relativistic QCD (NRQCD) [1] calculations were proposed in which a $c\bar{c}$ color-octet intermediate states, in addition to a color-singlet states, can bind to form charmonia.

However, the charmonium production mechanism in elementary particle collisions is not yet exactly known. For many years measurements of the J/ψ cross section have been used to test different J/ψ production models. While many models can describe relatively well the experimental data on the J/ψ cross section in $p + p$ collisions [2–9], they have different predictions for the J/ψ polarization. Therefore, measurements of the J/ψ polarization may allow to discriminate among different models and provide new insight into the J/ψ production mechanism.

2. Charmonium measurements in STAR

In STAR, charmonia have been measured so far via the dielectron decay channel. The STAR detector [10] is a multi-purpose detector that has large acceptance at mid-rapidity, $|\eta| < 1$ with a full azimuthal coverage. Electrons can be identified using the Time Projection Chamber (TPC) [11] through ionization energy loss (dE/dx) measurement. The Time Of Flight (TOF) detector [12] greatly enhances the electron identification capability at low momenta where the dE/dx bands for electrons and hadrons cross each other. At high p_T, electron identification can be improved by the Barrel Electromagnetic Calorimeter (BEMC) [13] which measures electron energy and shower shape. The BEMC is also used to trigger on high-p_T electrons (HT trigger). Minimum Bias (MB) events are triggered by the Vertex Position Detectors (VPD) [14].

3. J/ψ measurements in p+p at $\sqrt{s}$ = 200 GeV

STAR has measured inclusive J/ψ p_T spectra and polarization in $p+p$ collisions at $\sqrt{s} = 200$ GeV via the dielectron decay channel ($B_{ee} = 5.9\%$) at mid-rapidity ($|y| < 1$). These results are compared to different model predictions to understand J/ψ production mechanism in elementary collisions.

Left panel of Fig. 1 shows STAR low and high-p_T measurements of J/ψ p_T spectra [3, 15] compared to model predictions. The Color Evaporation Model (CEM) [16] for prompt J/ψ can describe the p_T spectrum reasonably well, except the region around $p_T \approx 3$ GeV/c where it over-predicts the data. NLO NRQCD calculations with color-singlet and color-octet transitions [17] for prompt J/ψ match the data for $p_T > 4$ GeV/c. NNLO* CS model [18] for direct J/ψ production under-predicts the STAR data, but the prediction does not include contributions from $\psi(2S)$, χ_C and B-meson decays to J/ψ.

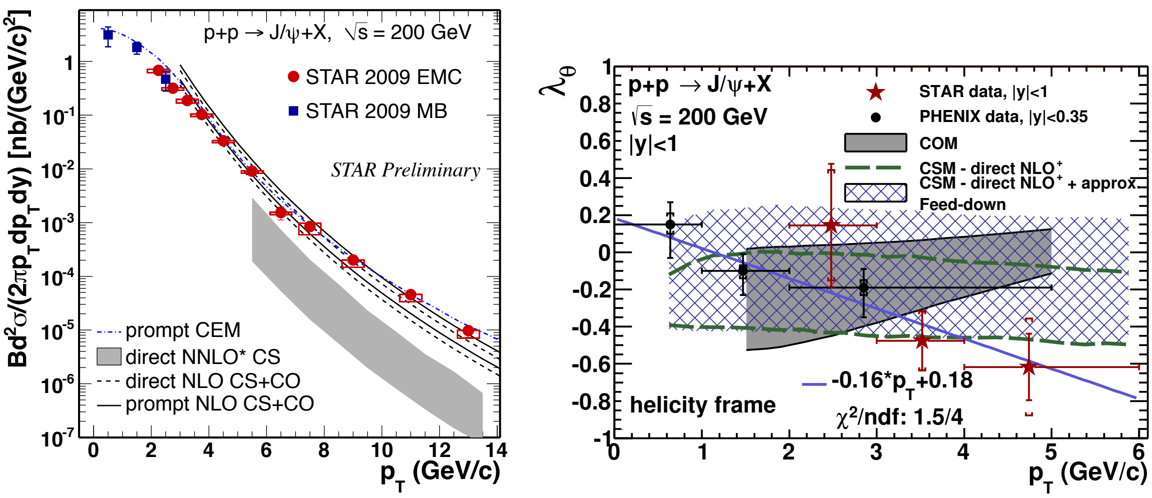

Figure 1. Left: J/ψ invariant cross section vs p_T in p+p collisions at $\sqrt{s}$ = 200 GeV at mid-rapidity at low [15] and high p_T [3] shown as blue squares and red circles, respectively, compared to different model predictions [16–18]. Right: Polarization parameter λ_θ vs J/ψ p_T for $|y| < 1$ [19] compared to the PHENIX measurement [20] and two model predictions [21, 22].

In p+p collisions at $\sqrt{s} = 200$ GeV STAR has also measured J/ψ polarization parameter λ_θ in the helicity frame at mid-rapidity and $2 < p_T < 6$ GeV/c [19]. *J/ψ* polarization is analyzed via the angular distribution of the decay electrons that is described by: $\frac{d^2N}{d(\cos\theta)d\phi} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi$, where θ and ϕ are polar and azimuthal angles, respectively; λ_θ, λ_ϕ and $\lambda_{\theta\phi}$ are the angular decay coefficients. The p_T dependence of λ_θ is shown on the right panel of Fig. 1 with low-p_T PHENIX results [20] and compared to NRQCD calculations [21] and the NLO$^+$ CSM prediction [22]. A trend observed in the RHIC data is towards longitudinal polarization as p_T increases and, within experimental and theoretical uncertainties, the result is consistent with the NLO$^+$ CSM model.

The inclusive J/ψ production is a combination of prompt and non-prompt J/ψ. The prompt J/ψ production consists of the direct one ($\sim$60%) and feed-down from excited states $\psi(2S)$($\sim$10%) and χ_C($\sim$30%), while non-prompt J/ψ originate from B-hadron decays. STAR has estimated the contribution from B-meson decays using a measurement of azimuthal angular correlation between high-p_T J/ψ and charged hadrons [2, 3]. The relative contribution of B-hadron decays to inclusive J/ψ yield is strongly p_T dependent and it is 10-25% for $4 < p_T < 12$ GeV/c, as it is shown on the left panel of Fig. 2. The measurement is consistent with the FONLL+CEM prediction [23, 24].

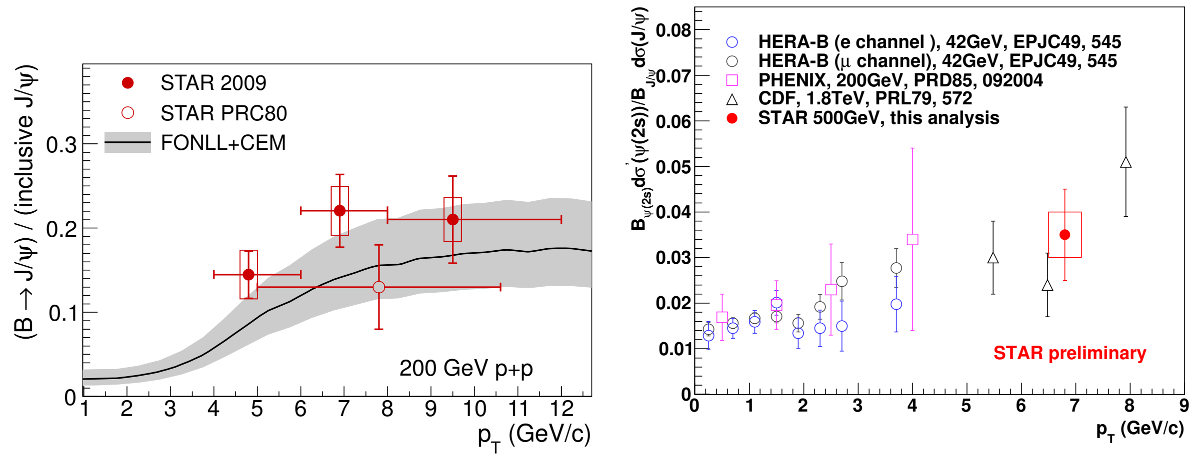

Figure 2. Left: relative contribution from B-meson decays to inclusive J/ψ production in p+p at $\sqrt{s} = 200$ GeV [3] compared to FONLL+CEM calculations [23, 24]. Right: ratio of $\psi(2S)$ to J/ψ in $p+p$ collisions at $\sqrt{s} = 500$ GeV from STAR (red circle) compared to results from other experiments at different energies.

4. J/ψ and $\psi(2S)$ measurements in p+p at $\sqrt{s} = 500$ GeV

In order to further test the charmonium production mechanism and constrain the feed-down contribution from the excited states to the inclusive J/ψ production, the J/ψ and $\psi(2S)$ signals were extracted in $p+p$ collisions at $\sqrt{s} = 500$ GeV at mid-rapidity. The J/ψ p_T spectrum is shown on the left panel of Fig. 3. The STAR results at $\sqrt{s} = 500$ GeV (full circles) are compared to those at $\sqrt{s} = 200$ GeV (open circles) and with measurements of other experiments in p+$\bar{p}$ collisions at different energies. The STAR measurements cover p_T range of 4 - 20 GeV/c with a good precision. It was also observed that J/ψ cross section follows the x_T scaling: $\frac{d^2\sigma}{2\pi p_T dp_T dy} = g(x_T)/(\sqrt{s})^n$, where $x_T = 2p_T/\sqrt{s}$, with $n = 5.6 \pm 0.2$ at mid-rapidity and $p_T >$ 5 GeV/c for a wide range of colliding energies [2]. At $\sqrt{s} = 500$ GeV the same x_T scaling of high-p_T J/ψ production is seen, as shown on the right panel of Fig. 3.

Right panel of Fig. 2 shows $\psi(2S)/J/\psi$ ratio from STAR (red full circle) compared to measurements of other experiments at different colliding energies, in $p+p$ and p+A collisions. The STAR data point is consistent with the observed trend, and no collision energy dependence of the $\psi(2S)$ to J/ψ ratio is seen with the current precision.

The statistics available at $\sqrt{s} = 500$ GeV will allow us to extract the frame invariant polarization parameter, also in different reference frames, providing model independent information about the J/ψ polarization [25]. It will be possible to measure the azimuthal polarization parameter, λ_ϕ, and improve precision of the λ_θ measurement. Analysis of J/ψ polarization at $\sqrt{s} = 500$ GeV is ongoing.

5. Summary

In summary, STAR has measured the inclusive J/ψ cross section and polarization in p+p collisions at $\sqrt{s} = 200$ GeV as a function of p_T. The measurements are compared to different model predictions of the J/ψ production. The p_T spectrum is described well by the NRQCD calculations while the measured polarization parameter λ_θ is consistent with the NLO$^+$ CSM prediction. STAR new result for J/ψ at $\sqrt{s} = 500$ GeV extends p_T reach up to 20 GeV/c. The first measurement of $\psi(2S)/J/\psi$ ratio in p+p collisions at $\sqrt{s} = 500$ GeV is reported and compared with results from other experiments. No collision energy dependence is observed.

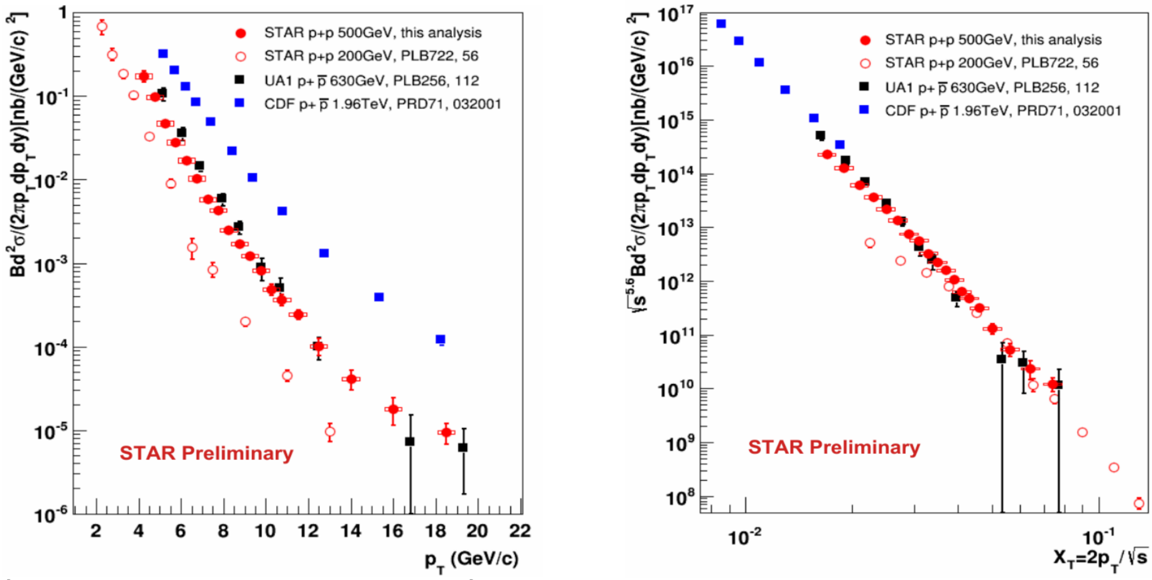

Figure 3. J/ψ invariant cross section vs p_T, left panel, and invariant cross section multiplied by $\sqrt{s}^{5.6}$ vs x_T, right panel, in p+p collisions at $\sqrt{s}$ = 500 GeV at mid-rapidity shown as full circles compared to measurements at different energies.

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