Recent Charmonium Results form HERA-B

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HERA-B is a fixed-target multi-particle spectrometer experiment at the 920 GeV HERA proton beam at DESY. Approximately 150 million events were recorded with a dilepton trigger during the 2002/2003 HERA run. About 300,000 leptonic $J/\psi \rightarrow l^+l^-$ decays (170,000 in the $\mu^+\mu^-$ channel and 130,000 in the e^+e^- channel) have been reconstructed in this data sample. In addition, a huge sample of 220 million minimum biased triggered events were recorded, allowing an independent measurement of the J/ψ production cross section.

The dilepton triggered samples allow for the first time the study of charmonium production in the negative Feynman-x (x_F) region, and will provide an important input for testing the charmonium production mechanism. Results will be presented on the nuclear dependence of charmonium production, on J/ψ, χ_c and ψ' production and on their differential distributions. Furthermore, the first measurement of the nuclear suppression of charmonium production in the negative x_F region will be presented.

1 Introduction

In the data taking period of 2002/2003 HERA-B was routinely running and collected $164 \cdot 10^6$ events applying a dilepton J/ψ–trigger. HERA-B is able to reconstruct the decays of J/ψ, ψ', χ_c or Υ either in the $\mu^+\mu^-$ or in the e^+e^- decay channel. In Fig. 1 the J/ψ and ψ' peaks in the invariant mass spectra of the whole data sample are shown, corresponding to a total statistics of $N(J/\psi) \approx 300'000$ and $N(\psi') \approx 5'000$ for both decay channels. The availability of both channels is, besides the increase of statistics, crucial to cross check the results.

The target wires, close to the 920 GeV proton beam of HERA, are made of different materials (Carbon, Tungsten or Titanium) which can be used simultaneously to perform measurements of the dependence on the atomic mass number A and to control systematic effects. This enables a measurement of the nuclear dependence of the J/ψ-production by using two wires of different materials in parallel.

In order to minimize the sensitivity to systematic effects from luminosity and Monte Carlo (MC) efficiency determination, all cross section measurements are performed relative to the J/ψ production cross section. In the ratio of cross sections, the luminosity dependence and common systematic effects in the efficiency cancel out. To determine the reference value of $\sigma_{pN}(J/\psi)$ at the HERA-B energy, a global analysis has been performed on all available published J/ψ cross section measurements including the measurement of HERA-B using a sample of $2.3 \cdot 10^8$ minimum bias triggered events, which are independent from the J/ψ triggered data [2] (Fig. 1, right). The best value, obtained from a fit on $\sigma_{J/\psi}(\sqrt{s})$ with the help of a non relativistic QCD inspired model including color octet (NRQCD) [3], is for the energy of HERA–B of $\sqrt{s} = 41.6$ GeV

$$\sigma_{J/\psi} = (502 \pm 44)\,\text{nb/nucl.} \quad \text{and} \quad \sigma_{\psi'} = (65 \pm 11)\,\text{nb/nucl.} \tag{1}$$

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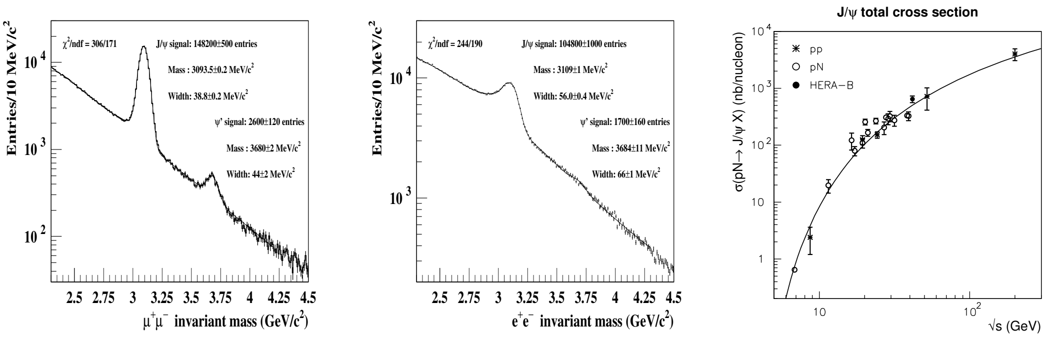

Figure 1: J/ψ production signal in the invariant mass spectra for both decay channels of triggered data and the determination of the J/ψ reference cross section using minimum biased data from HERA-B and result from other experiments.

leading to a ratio of $R_\psi = (0.130 \pm 0.019)$. The $\sigma_{J/\psi}$ value, which is in pretty good agreement to the other experiments, will be used for all further analysis as reference cross section.

2 Charmonium Production

2.1 Kinematical J/ψ Distributions

A good understanding of the kinematical distributions of J/ψ and ψ' production as a function of x_F and p_T^2 is the basis for further measurements and interpretations of all effects causing nuclear suppression or enhancement of charmonium production in nuclear interactions. With respect to the earlier experiments in that field, HERA-B is the first fixed target experiment covering the region of negative Feynmann-x ($x_F = \frac{p_L^{\mathrm{cms}}}{(p_L^{\mathrm{cms}})_{\max}}$) in the range of $x_F \in [-0.35, 0.15]$. The negative x_F region corresponds to small forward momenta of the produced $c\bar{c}$ pair leading to a formation of the J/ψ inside the nucleus. Since the p_T coverage of the older experiments is mostly overlapping with HERA-B, a good opportunity for cross checks is given.

Usually, the kinematical distributions are parameterized by the following interpolating shape functions provided by the Experiment E705 [4]:

$$\frac{dN}{dx_F} \propto \frac{\Big((1-x_1)\cdot(1-x_2)\Big)^C}{x_1+x_2} \quad \text{and} \quad \frac{dN}{dp_T^2} \propto A\left(1+\Big(\frac{35\,\pi}{256}\cdot\frac{p_T}{\langle p_T\rangle}\Big)^2\right)^{-6}$$

where $x_{1,2} = \frac{1}{2}\cdot(\sqrt{x_F^2 + \frac{4\,M^2}{s}} \pm x_F)$. The x_F parameterization is inspired by the anticipated structure function factorization of the parton fusion process for J/ψ hadro-production. The parameters C and $\langle p_T \rangle$, obtained from a fit on the corresponding kinematical distribution, give a good tool to compare the consistency of different data samples from various experiments.

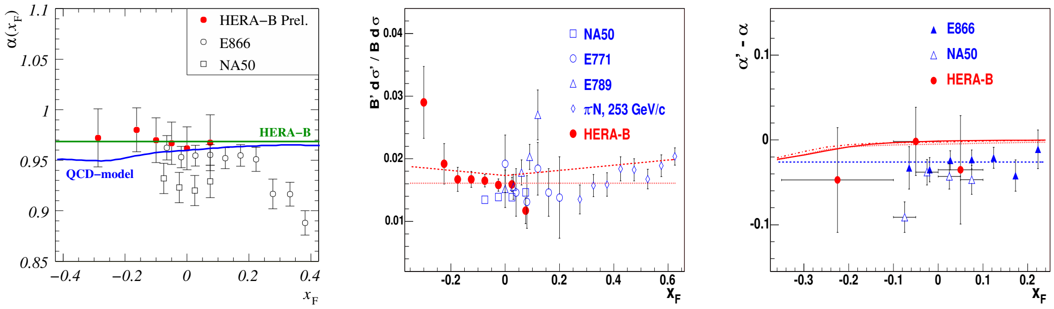

Figure 2: The Hera-B measurement of the x_F dependence of α of J/ψ production, the ψ' production ratio $R_{\psi'}$ and the difference of α for J/ψ and ψ' production $\Delta\alpha$ in comparison to E866 and NA50. The uncertainties are statistical only.

2.2 Nuclear Dependence

The nuclear dependence of the J/ψ production can be measured with low systematic uncertainty by using two different targets with different materials (carbon and tungsten) simultaneously:

$$\sigma(pA \to J/\psi X) = A^{\alpha} \cdot \sigma(pN \to J/\psi X) \Rightarrow \alpha = \frac{1}{\ln(A_{\mathrm{W}}/A_{\mathrm{C}})} \cdot \ln\left(\frac{N_{\mathrm{W}}^{J/\psi}}{N_{\mathrm{C}}^{J/\psi}} \cdot \frac{\mathcal{L}_{\mathrm{C}}}{\mathcal{L}_{\mathrm{W}}} \cdot \frac{\epsilon_{\mathrm{C}}}{\epsilon_{\mathrm{W}}}\right) \quad (2)$$

A possible suppression of the J/ψ production by nuclear effect leads to $\alpha < 1$. The measurement making use of the muon data of HERA-B is compatible with a small suppression with $\alpha = 0.969 \pm 0.003_{\mathrm{stat}} \pm 0.021_{\mathrm{sys}}$ (Fig. 2). This is in good agreement with the theoretical predictions [5] and the earlier measurements in the positive x_F region of the E866 [6] and NA50 [7] experiments. In the commonly covered $x_F$region, a good agreement is found and confirmed by the $\alpha(p_T)$ distribution.

2.3 ψ' Measurement

Beside the J/ψ, a clear peak of the ψ' state is detected at $M \approx 3.7\,\mathrm{GeV}/c^2$ (Fig. 1). The study of the ψ' to J/ψ production ratio in proton nucleus interactions is a good framework to compare the existing models of charmonium production and of charmonium absorption in nuclear matter. The ratio has been measured as [8]

$$R_{\psi'} = \frac{BR(\psi' \to l^+l^-) \cdot \sigma(\psi')}{BR(J/\psi \to l^+l^-) \cdot \sigma_{J/\psi}} = \frac{N_{\psi'}}{N_{J/\psi}} \cdot \frac{\epsilon_{J/\psi}}{\epsilon_{\psi'}} = (1.83 \pm 0.03)\,\% \quad (3)$$

Furthermore, the nuclear dependence of $R_{\psi'} \propto A^{\alpha(\psi') - \alpha J/\psi}$ has been measured according to Eq. 2. The HERA-B measurements are in well agreement with the results of the earlier experiments E866 [6] and NA50 [7] and both, $R_{\psi'}$ and $\Delta\alpha$ are compatible with no x_F dependence. The results averaged over all target materials are compared to theoretical calculations using the Color Evaporation model (CEM, [9]) for Color Singlet nuclear absorption and Non Relativistic QCD (NRQCD [10]). At the current state, the data are compatible with both models. In addition, the parallel measurement of ψ' in the electron and muon decay channels can be used to constrain the double ratio $R_{\psi'}(\mu)/R_{\psi'}(e) = (1.00 \pm 0.08 \pm 0.04)$ as a sensitive test of lepton universality.

2.4 χ_c Measurement

A measurement of the production ratio of χ_c to the J/ψ production is an other important tool to discriminate between different models for quarkonium production. HERA-B has access to these states via the radiative decay channel $\chi_c \rightarrow J/\psi\gamma \rightarrow l^+l^-\gamma$ by selecting the χ_c based on the mass difference $\Delta M = M(l^+l^-\gamma) - M(l^+l^-)$. The background is determined by event mixing and subtracted from the spectrum. Using a signal description consisting of two Gaussians and making use of the full statistics' the two states χ_{c_1} and χ_{c_2} can be separated in the μ-decay channel applying a rather strong cut on the transverse photon energy of $E_T(\gamma) > 0.4$ GeV. The production ratio (Eq. 4) has been found to be $R_{\chi_c} = 0.21 \pm 0.05_{\text{stat}}$ using data from the μ-channel only. This ratio can be used to test various QCD models for charmonium formation. As can been seen in Fig. 3 the CSM (with color singlet) is disfavored with respect to the NRQCD model.

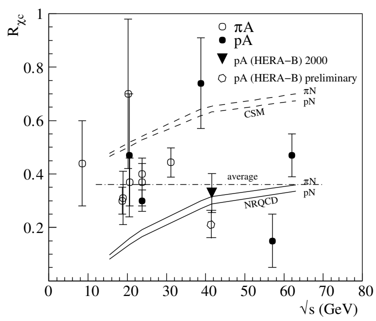

Figure 3: First measurement of R_{χ_C} and the comparison of the production ratio to various models.

$$R_{\chi_c} = \frac{\sum_{i=1}^{2} \sigma(pA \rightarrow \chi_{c,i}) \cdot BR(\chi_{c,i} \rightarrow J/\psi\gamma)}{\sigma(pA \rightarrow J/\psi)} = \frac{N_{\chi_c}}{N_{J/\psi}} \cdot \frac{\epsilon_{J/\psi}}{\epsilon_{\chi_c}} \cdot \frac{1}{\epsilon_\gamma} \tag{4}$$

3 Conclusion

HERA-B stopped data taking in March 2003. Nevertheless, a rich physics program in the field of quarkonia production in nuclear matter could be realized which extends the existing measurements into the unexplored kinematical region of negative x_F.

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