J/ψ and ψ' nuclear absorption in p-A and S-U collisions at the CERN/SPS

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Abstract. We present preliminary NA50 results on J/ψ and ψ' production by 400 GeV/c incident protons on various targets. Production cross-sections are determined for each p-target system. Their dependence on the target mass number A is studied using a Glauber model. The data obtained by experiment NA38 from S-U interactions at 200 GeV/nucleon incident momentum are also reanalyzed which, together with our most recent 400 GeV and previous 450 GeV proton-nucleus results, lead to the J/ψ absorption cross-section in nuclear matter. We finally determine the expected "normal" J/ψ production in 158 GeV/nucleon Pb-Pb collisions as a function of centrality.

1. Introduction

The production of charmonium states in proton-nucleus interactions has been a subject of extreme interest along the past few years, mostly motivated by the observation of the anomalous J/ψ suppression in Pb-Pb collisions [1]. Indeed, an accurate understanding of normal nuclear absorption mechanisms is of first importance in order to correctly interpret the charmonia results obtained in heavy ion collisions. NA50 is a high luminosity fixed target experiment at the CERN/SPS dedicated to the study of dimuon production in Pb-Pb and p-A interactions. We report here preliminary results from a new p-A data sample obtained at 400 GeV/c incident energy and devoted to the accurate study of charmonia production as a function of the target mass number. Together with previous NA50 p-A results and a reanalysis of S-U data from experiment NA38, a common absorption cross-section is deduced using a Glauber model to fit our measurements. Finally, we present the comparison of updated Pb-Pb results with the most recent nuclear absorption curve as deduced from our studies on lighter systems.

2. Experimental setup and data analysis

The main detector of the NA50 experiment [2] is a muon spectrometer consisting of an air-core toroidal magnet located between two sets of four multiwire proportional chambers. It detects charmonia states in the kinematical domain $2.92 < y_{Lab} < 3.92$ and $|\cos\theta_{CS}| < 0.5$ via their decay into muon pairs, using a dimuon trigger provided by two sets of scintillator hodoscopes located before and after the magnet. Six different targets (Be, Al, Cu, Ag, W and Pb) with interaction lengths between 26% and 39%, were sequentially exposed to a high intensity primary 400 GeV/c proton beam (3∼4×10^9 protons during the 3.2 s burst) on a short run by run basis. Such a procedure, never used before in any NA50 p-A data collection, minimizes time dependent effects between different targets and allows a precise determination of the charmonia normal nuclear aborption. The opposite-sign dimuon mass spectrum obtained for masses above 1.5 GeV/c^2 is the result of a sum of four physical contributions (J/ψ and ψ' resonances, the DY process and simultaneous semi-leptonic decays of open charm mesons) plus a combinatorial background originating from uncorrelated π and K decays accepted in the spectrometer. This background is estimated from the like-sign muon pair sample according to $\frac{dN^{bkg}}{dM} = 2\sqrt{\frac{dN^{++}}{dM}\frac{dN^{--}}{dM}}$, after applying a cut which forces equal acceptances for positive and negative muons. The different physical components are obtained fitting the opposite-sign dimuon mass spectrum in the $1.5 \leq M_{\mu\mu} < 8.0$ GeV/c^2 mass region, where the shape of each contribution is determined via Monte-Carlo and spectrometer simulation, using the same selection criteria and reconstruction programs as for real data. Typical acceptances are $\mathcal{A}_{J/\psi}$ =13.8%, $\mathcal{A}_{\psi\prime}$ =16.3% and $\mathcal{A}_{\mathrm{DY}_{2.9-4.5}}$ =14.5%.

3. Results

The DY cross-sections are measured in the $1.5 \leq M_{\mu\mu} < 8.0$ GeV/c^2 mass region. The MRS(A) low Q^2 $\overline{MS}$ set of parton distribution functions [3] is used to calculate the DY mass shape. Fig 1 shows the Drell-Yan absolute cross-sections for $2.9 \leq M_{\mu\mu} < 4.5$ GeV/c^2 as a function of the target mass number, after an isospin correction equivalent to assume that all targets are made only of protons. The fit to our data using the well known parametrization, $\sigma^{\mathrm{DY}}_{\mathrm{p-A}} = \sigma^{\mathrm{DY}}_0 \times A^\alpha$, leads to α^{DY}=0.986 ± 0.020, in agreement with the expectation that DY production is proportional to the number of nucleon-nucleon collisions. Applying the same power law to fit our charmonia absolute cross-sections, we obtain α^ψ=0.931 ± 0.007 and $\alpha^{\psi\prime}$=0.858 ± 0.019. As such a power law is a poor approximation for very light targets, the Glauber formalism [4] is used to fit

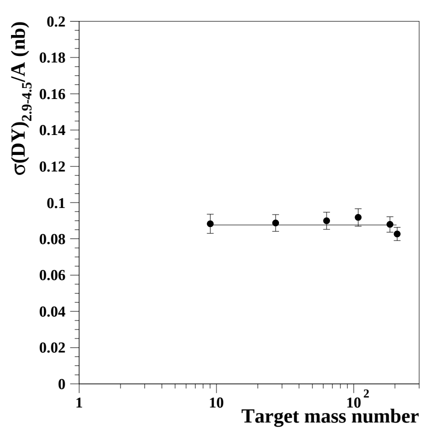

Figure 1. Drell-Yan cross-sections for p-A at 400 GeV. The line represents a power law fit with α^{DY}=1.

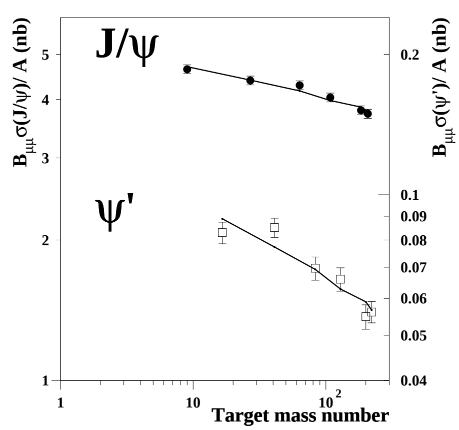

Figure 2. Glauber fit to J/ψ and ψ' absolute cross-sections for p-A at 400 GeV leading to $\sigma^{\psi}_{\mathrm{abs}}$ =4.2±0.5 mb and $\sigma^{\psi\prime}_{\mathrm{abs}}$ =9.6±1.6 mb.

the data. The results are shown in Fig 2 for J/ψ (left scale) and ψ' (right scale). From the measured cross-sections we are led to $\sigma^{\psi}_{\text{abs}}$ =4.2±0.5 mb and $\sigma^{\psi\prime}_{\text{abs}}$ =9.6±1.6 mb.
NA50 has developed through the years a wide p-A program. From the different data collections performed between years 1996 and 2000 [5, 6], using a 450 GeV/c proton beam at several intensities, we obtain individual J/ψ absorption cross-sections which are in agreement, within errors, with our most recent measurement allowing to perform a simultaneous Glauber fit including all NA50 p-A data. The best estimates of each sample ($B_{\mu\mu}\sigma(J/\psi)$ or $\frac{B_{\mu\mu}\sigma(J/\psi)}{\sigma(DY_{2.9-4.5})}$) are used and the NA51 p-p, p-d results on $\frac{\psi}{DY}$ at 450 GeV/c [7] are also included in this global fit of a common $\sigma^{\psi}_{\text{abs}}$, leaving three normalizations as free parameters which also account for the different energies and kinematical conditions. For the 400 GeV results, luminosity systematic errors are not included since they affect all targets in the same way. The result of the fit is $\sigma^{\psi}_{\text{abs}}$ =4.3±0.3 mb.
In order to compare $\sigma^{\psi}_{\text{abs}}$ obtained in p-A collisions with the one measured in A-B collisions, we use the NA38 S-U data at 200 GeV/nucleon incident energy, measured in the kinematical domain $3 < y_{Lab} < 4$ and $|\cos\theta_{CS}| < 0.5$ [8]. Since these data were analysed with criteria different from the ones used nowadays, a complete reanalysis is performed using the most recent techniques. The same parton distribution functions as in p-A analysis are used (MRS(A) low Q^2 $\overline{MS}$) to generate the DY contribution and results are presented in six different centrality regions. Using the full Glauber model generalized to take into account the centrality of the collision, we extract $\sigma^{\psi}_{\text{abs}}$ =7.3±3.3 mb from the fit to the S-U $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{2.9-4.5})}$ results. Although higher, this value is compatible with the one measured from p-A systems, thus allowing a global fit. Fig 3 presents the best J/ψ production estimate of each data sample plotted as a function of L (the average path crossed by the $c\bar{c}$ pair through nuclear matter). The common fit gives $\sigma^{\psi}_{\text{abs}}$ =4.3±0.3 mb. $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{2.9-4.5})}$ results are shown on the right scale and J/ψ absolute cross-sections results are shown on the left scale of Fig 3. The measured ratios of normalizations for $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{2.9-4.5})}$ results between 450 GeV and 200 GeV and for $\frac{B_{\mu\mu}\sigma(\psi)}{A}$

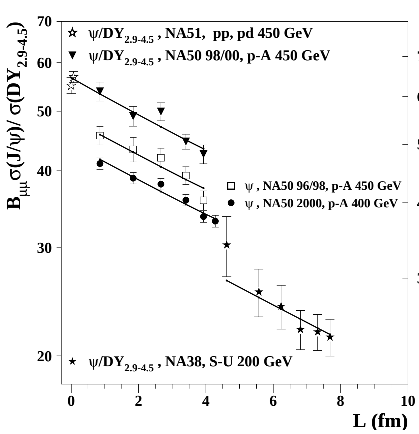

Figure 3. $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{2.9-4.5})}$ (left) and $\frac{B_{\mu\mu}\sigma(\psi)}{A}$ (right) results for NA50 p-A and NA38 S-U data fitted with a common $\sigma^{\psi}_{\text{abs}}$ =4.3±0.3 mb.

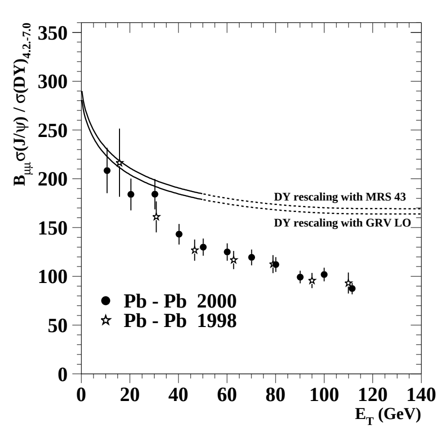

Figure 4. $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{4.2-7.0})}$ Pb-Pb results compared with 2 different curves representing the $DY_{4.2-7.0}$ normalization uncertainty.

results between 450 GeV and 400 GeV are 0.65±0.03 and 0.910±0.027, respectively. With the measured $\sigma_{\rm abs}^{\psi}$ we can calculate the expected nuclear absorption for Pb-Pb collisions as a function of centrality, using the Glauber formalism. The result is compared with the latest $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{4.2-7.0})}$ results from our 2000 and 1998 Pb-Pb data samples in Fig 4. The curve normalization is estimated from the S-U data rescaled to the Pb-Pb kinematical conditions using a $\sqrt{s}$ dependence of the J/ψ cross-section as in ref. [9] and a LO calculation for DY. $\frac{B_{\mu\mu}\sigma(\psi)}{\sigma(DY_{4.2-7.0})}$ measurements do not depend on the precise set of parton distribution functions (PDFs) used to generate DY, whereas the $DY_{4.2-7.0}$ rescaling from 200 GeV to 158 GeV does. The two curves presented in Fig 4 refer to this uncertainty where the DY rescaling is calculated using two different PDF sets (MRS 43 and GRV LO).

4. Conclusions

Results from a new NA50 proton-nucleus data sample collected at 400 GeV incident energy are presented. This specific data collection used rotating targets on a short time run by run basis. Such a procedure, never used before in NA50 p-A data takings, allows to ignore time dependent systematic effects between different targets and, therefore, to precisely measure the J/ψ production behaviour in proton-nucleus data. From these data we obtain α^{ψ}= 0.931±0.007 and $\alpha^{\psi\prime}$=0.858±0.019. Using a Glauber model to fit our results we measure $\sigma_{\rm abs}^{\psi}$ = 4.2±0.5 mb and $\sigma_{\rm abs}^{\psi\prime}$ =9.6±1.6 mb. A systematic study including our most recent 400 GeV p-A results, previous 450 GeV NA50 p-A results and the reanalysis of the 200 GeV/nucleon S-U data, gives $\sigma_{\rm abs}^{\psi}$ =4.3±0.3 mb. Based on the behaviour observed in lighter systems, we compute the expected J/ψ production for 158 GeV/nucleon Pb-Pb collisions as a function of centrality. We observe that the experimental J/ψ production measured in Pb-Pb reactions does not follow the extrapolated behaviour from lighter systems so that an amount of extra suppression is needed in order to account for the Pb-Pb measurements.

Acknowledgments

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References

[1] M.C. Abreu et al (NA50 Collaboration), *Phys. Lett.* **B 477** (2000) 87.
[2] M.C. Abreu et al (NA50 Collaboration), *Phys. Lett.* **B 410** (1997) 327.
[3] A.D. Martin et al, *Phys. Rev.* **D 51** (1995) 4756.
[4] R.J.Glauber, Lectures in Theoretical Physics, NY, 1959, Vol. 1, 315.
[5] B.Alessandro et al (NA50 Collaboration), *Euro. Phys. J.* **C**, in print.
[6] B.Alessandro et al (NA50 Collaboration), *Phys. Lett.* **B 553** (2003) 167.
[7] M.C. Abreu et al (NA51 Collaboration), *Phys. Lett.* **B 438** (1998) 35.
[8] M.C. Abreu et al (NA38 Collaboration), *Phys. Lett.* **B 449** (1999) 128.
[9] G.A. Schuler, Habilitationschrift, Univ. Hamburg, 1994 (CERN-TH-7170-94)