EPJ manuscript No.
(will be inserted by the editor)

The J/ψ normal nuclear absorption

G. Borges[6] for the NA50 Collaboration:
B. Alessandro[10], C. Alexa[3], R. Arnaldi[10], M. Atayan[12], S. Beolè[10], V. Boldea[3], P. Bordalo[6,a], C. Castanier[2], J. Castor[2], B. Chaurand[9], B. Cheynis[11], E. Chiavassa[10], C. Cicalò[4], M.P. Comets[8], S. Constantinescu[3], P. Cortese[1], A. De Falco[4], N. De Marco[10], G. Dellacasa[1], A. Devaux[2], S. Dita[3], J. Fargeix[2], P. Force[2], M. Gallio[10], C. Gerschel[8], P. Giubellino[10], M.B. Golubeva[7], A.A. Grigorian[12], S. Grigoryan[12], F.F. Guber[7], A. Guichard[11], H. Gulkanyan[12], M. Idzik[10,b], D. Jouan[8], T.L. Karavicheva[7], L. Kluberg[5,9], A.B. Kurepin[7], Y. Le Bornec[8], C. Lourenço[5], M. Mac Cormick[8], A. Marzari-Chiesa[10], M. Masera[10], A. Masoni[4], M. Monteno[10], A. Musso[10], P. Petiau[9], A. Piccotti[10], , J.R. Pizzi[11], F. Prino[10], G. Puddu[4], C. Quintans[6], L. Ramello[1], S. Ramos[6,a], L. Riccati[10], H. Santos[6], P. Saturnini[2], E. Scomparin[10], S. Serci[4], R. Shahoyan[6,c], F. Sigaudo[10], M. Sitta[1], P. Sonderegger[5,a], X. Tarrago[8], N.S. Topilskaya[7], G.L. Usai[4], E. Vercellin[10], L. Villatte[8], N. Willis[8], T. Wu[8].

[1] Università del Piemonte Orientale, Alessandria and INFN-Torino, Italy
[2] LPC, Univ. Blaise Pascal and CNRS-IN2P3, Aubière, France
[3] IFA, Bucharest, Romania
[4] Università di Cagliari/INFN, Cagliari, Italy
[5] CERN, Geneva, Switzerland
[6] LIP, Lisbon, Portugal
[7] INR, Moscow, Russia
[8] IPN, Univ. de Paris-Sud and CNRS-IN2P3, Orsay, France
[9] Laboratoire Leprince-Ringuet, Ecole Polytechnique and CNRS-IN2P3, Palaiseau, France
[10] Università di Torino/INFN, Torino, Italy
[11] IPN, Univ. Claude Bernard Lyon-I and CNRS-IN2P3, Villeurbanne, France
[12] YerPhI, Yerevan, Armenia
a) also at IST, Universidade Técnica de Lisboa, Lisbon, Portugal
b) also at Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Cracow, Poland
c) on leave of absence of YerPhI, Yerevan, Armenia

Received: date / Revised version: date

Abstract. We present a new determination of the ratio of cross-sections (J/ψ)/DY as expected for nucleus-nucleus reactions if J/ψ would only be normally absorbed by nuclear matter. This anticipated behaviour is based on proton-nucleus data exclusively, and compared, as a function of centrality, with updated S-U results from experiment NA38 and with the most recent Pb-Pb results from experiment NA50.

PACS. 25.75.-q Relativistic heavy ion collisions – 25.75.Nq Quark deconfinement, quark gluon plasma production and phase transitions – 13.20.Gd Decays of J/ψ , Υ and other quarkonia

1 Introduction

Starting with the theoretical prediction that J/ψ suppression is a signature of Quark Gluon Plasma formation [1], J/ψ production has been extensively studied in the past years leading, eventually, to the evidence of an anomalous suppression pattern in Pb-Pb collisions [2]. A robust interpretation of the results obtained in heavy ion collisions require, in any case, comparison with a solid reference in order to precisely establish the features of J/ψ production and absorption in normal nuclear matter. Experimentally, this reference can be deduced from proton or from light-ion induced interactions. A considerable effort has therefore been devoted to collect significant samples of proton-nucleus data leading to high precision p-A results. These results, used as experimental inputs to a Glauber model adjustment, allow us to determine the normal absorption cross-section ($\sigma^{\psi}_{\rm abs}$) of the J/ψ resonance in the surrounding nuclear matter and to evaluate the expected behaviour in Pb-Pb collisions. The previous determination of the normal J/ψ nuclear absorption expected in Pb-Pb collisions, was based on (J/ψ)/DY results obtained by experiment NA38 from the study of 200 GeV S-U reactions, together with the most reliable measurements obtained from NA50 p-A data (either using J/ψ or (J/ψ)/DY results) at 450 and 400 GeV [3]. We determine here $\sigma^{\psi}_{\rm abs}$ and the normalization of the expected Pb-Pb absorption curve using exclusively proton-nucleus results from experiments NA38 (at 450 and 200 GeV), NA51 (at 450 GeV) and NA50 (at 450 and 400 GeV). All these experiments used the same basic spectrometer and, therefore, only small systematic effects are expected when comparing their data. Results from experiment NA3 at 200 GeV, rescaled to the appropriate kinematical domain, are also included in order to increase the number of low energy data points.

2 Proton-nucleus J/ψ absolute cross-sections

2.1 The NA38 results

NA38 was the first experiment to systematically study J/ψ production in ultra relativistic heavy-ion collisions. It used results from several proton-nucleus colliding systems in order to describe the expected J/ψ normal nuclear absorption and check if some additional suppression mechanisms appear in heavier nuclei collisions. NA38 final results are summarized in [4], where J/ψ absolute cross-sections for p-A=C,Al,Cu and W data, collected at 450 GeV, and p-A=Cu,W and U data, obtained at 200 GeV incident beam, are presented. NA51 pp and pd measurements at 450 GeV [5] were also included in the analysis. Results for O-Cu, O-U and S-U at 200 GeV are also reported in the same paper. The authors have used the α power law to describe the data. After seeing a good statistical compatibility between J/ψ results from, on one hand, p-A data at 450 GeV (α=0.919±0.015) and, on the other, p-A and A-B data at 200 GeV (α=0.911±0.034), they conclude that all sets follow the same behaviour described by a power law fit with α=0.918±0.015. Today we understand that the α parametrization does not provide a proper description of the data when very light targets are included. If the same exercise is performed using a Glauber model, with the absorption cross-section as the free parameter to be adjusted to the data, we obtain $\sigma^{\psi}_{\rm abs}$ =7.1±1.6 mb, $\sigma^{\psi}_{\rm abs}$ =7.8±3.5 mb and $\sigma^{\psi}_{\rm abs}$ =7.2±1.4 mb, respectively for the 450 GeV, 200 GeV and global fits.

2.2 The NA50 results

NA50 experiment has developed a much broader proton-nucleus program. A better characterization of the anomalous J/ψ suppression, as observed in Pb-Pb collisions, depends on the determination of a precise and reliable baseline. Three different p-A data sets were collected, using different targets, beam energies and intensities. Results from the first two p-A data samples, referred hereafter as HI96/98 and LI98/00, were collected at 450 GeV using Be, Al, Cu, Ag and W targets, and were recently published [6, 7]. The major difference between both data collections was the incident beam intensity. Results from the third and most recent data set (HI2000), which used a high intensity incident proton beam at 400 GeV, sequentially impinged on Be, Al, Cu, Ag, W and Pb targets, have also been analysed [8]. For a coherent comparison between all available measurements, the published results which were analysed with non-optimized $p_{\rm T}$ and rapidity Monte-Carlo distributions for the charmonia states, and using different PDF sets for Drell-Yan generation, had to be slightly corrected [8]. Independent Glauber fits on the three data sets lead to $\sigma^{\psi}_{\rm abs}$ (HI96/98)=4.4±1.2 mb, $\sigma^{\psi}_{\rm abs}$ (LI98/00)=4.0±1.4 mb and $\sigma^{\psi}_{\rm abs}$ (HI2000)=4.0±0.5 mb, respectively. The fact that these measurements are perfectly compatible allow us to extract a common value for $\sigma^{\psi}_{\rm abs}$ of 4.1±0.5 mb using a simultaneous fit. We also observe that if NA51 results are included and fitted together with NA50 450 GeV data the extracted $\sigma^{\psi}_{\rm abs}$ doesn't change ($\sigma^{\psi}_{\rm abs}$ = 4.1±0.4 mb), showing that the pp and pd results from experiment NA51, follow the extrapolated Glauber behaviour deduced from NA50 p-nucleus data.

2.3 NA50 vs NA38 results

The absorption cross-sections reported in Sect 2.1 and 2.2, for p-A data at 450 GeV, are not in agreement. If NA38 p-A 450 GeV data are fitted without including the pp and pd results from NA51, we get $\sigma^{\psi}_{\rm abs}$ =4.8±2.6 mb, fully compatible with NA50 $\sigma^{\psi}_{\rm abs}$ values. However, the significantly lower NA38 normalization, as shown in Table 1, points out systematic discrepancies with respect to NA50 (and NA51) measurements. Indeed, looking back at the NA38 data, we found an inefficiency reconstruction problem due to the high occupancy of the muon chambers. This problem was due to the fact that the main absorber was made of 480 cm of Carbon while the standard NA50 configuration replaces the last 80 cm by Iron. Taking into account such inefficiency, an overall (and approximate) 11% correction has to be applied which brings the NA38 measurements to statistical compatibility with the NA50 p-A 450 GeV results. Although the NA38 data cannot bring any additional information beyond the one already given by the higher statistics NA50 data, the fact that both experiments are now in agreement is important since it proves that systematic errors between the two setups are small and that NA50 p-A 450 GeV results can be safely compared with NA38 p-A 200 GeV numbers.

Table 1. Normalizations and absorption cross-sections obtained using a Glauber model fitted to different sets of p-A high energy data.

Data	N_0^{450} (nb/A)	N_0^{400} (nb/A)	$\sigma^{\psi}_{\rm abs}$ (mb)
NA38,51	5.5±0.6		7.1±1.6
NA38	5.0±0.5		4.8±2.6
NA51,50	5.6±0.1	5.1±0.1	4.1±0.4
NA50	5.6±0.1	5.1±0.1	4.1±0.5

At an incident momentum of 200 GeV, the NA38 p-A data are not sufficient, by themselves, to give a reliable Glauber fit. In order to be able to obtain a meaningful absorption cross-section measured at this energy, we

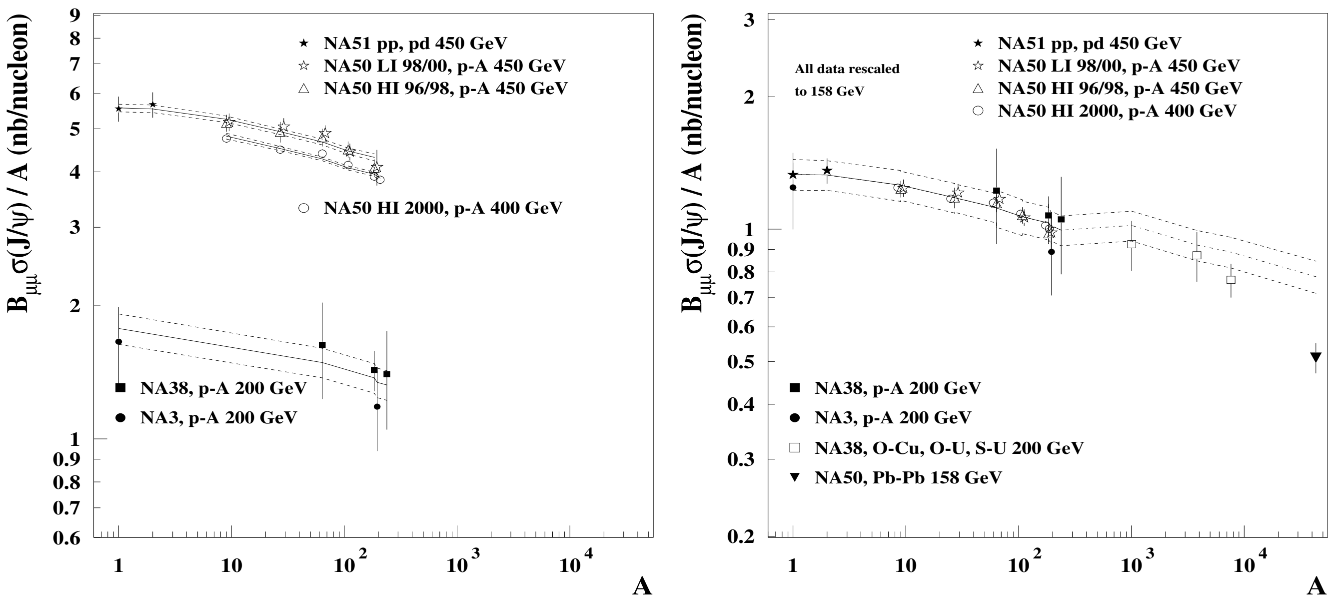

Fig. 1. Simultaneous Glauber fit with a common J/ψ absorption cross-section and 3 independent normalizations (left). Ion J/ψ absolute cross-section results are compared with the extrapolated behaviour from p-A data, rescaled to 158 GeV (right).

have included the available p-A results from experiment NA3, obtained with H_2 and Pt targets [9] and reported in the positive x_F hemisphere and full $\cos(\theta_{CS})$ domain. In order to convert these results to the NA38 kinematical domain, they have to be divided out by 0.907±0.084 for x_F (using the distribution parametrized as in Ref. [10]) and by a factor 2 for $\cos(\theta_{CS})$ (assuming an uniform distribution). The Glauber model adjusted to the complete set of data at 200 GeV (both NA38 and NA3 results) leads to $\sigma^{\psi}_{\rm abs}$ =3.3±3.0 mb. Although this result is obtained with poor accuracy, the 200 GeV data are very important since they establish the expected normalization for J/ψ production at an energy similar to the one used in Pb-Pb collisions. The very large $\sigma^{\psi}_{\rm abs}$ error bar obtained at 200 GeV does not exclude a $\sigma^{\psi}_{\rm abs}$ energy dependence behaviour but also allows to assume that $\sigma^{\psi}_{\rm abs}$ may be the same at the 3 different energies (450, 400 and 200 GeV). Under this assumption, NA50 p-A data at 450 and 400 GeV are simultaneously fitted together with the NA38/NA3 results at 200 GeV, using three independent normalizations and a common absorption cross-section. Our final result obtained from J/ψ absolute cross-sections is $\sigma^{\psi}_{\rm abs}$ =4.1±0.4 mb. The full Glauber fit is presented in the left plot of figure 1 and its numerical results are reported in Table 2. From the normalizations obtained at the different energies, we compute the factors which scale down the J/ψ production cross-section from the 450 GeV (0.319±0.025) and 400 GeV (0.348±0.027) kinematical domains to the 200 GeV kinematical domain. The right plot of figure 1 presents all data rescaled to 158 GeV after applying the previous experimental rescalings plus an additional factor scaling down J/ψ absolute cross-sections from 200 GeV to 158 GeV and taking into account the small x_F change. The $\sqrt{s}$ factor (0.737±0.006) was deduced using a phenomenological description of the $\sqrt{s}$ dependence of the cross-section, $\sigma_\psi = \sigma_0(1 - \mathrm{M}_\psi/\sqrt{\mathrm{s}})^{\mathrm{n}}$ [10], with n=12.8±0.3 obtained from a new fit to the available measurements. The x_F correction (1.020±0.013) is computed based on the x_F distribution parametrized as a function of $\sqrt{s}$, also presented in [10]. In the same plot, we have included the J/ψ absolute cross-section results reported by the NA38 experiment for O-Cu, O-U and S-U [4] as well as the corresponding value measured by NA50 for Pb-Pb [11]. We conclude that while the light ion results from NA38 are in agreement with the extrapolated behaviour deduced from p-A collisions, the integrated Pb-Pb result is considerably lower.

Table 2. Results from the simultaneous Glauber fit using J/ψ absolute cross-sections from NA51/NA50 data at 450 and 400 GeV and NA38/NA3 data at 200 GeV. Individual Glauber fit results are also reported.

Data	N_0^{450} (nb/A)	N_0^{400} (nb/A)	N_0^{200} (nb/A)	$\sigma^{\psi}_{\rm abs}$ (mb)
NA51,50	5.6±0.1	5.1±0.1		4.1±0.4
NA38, 3			1.7±0.3	3.3±3.0
NA51,50,38,3	5.6±0.1	5.1±0.1	1.8±0.1	4.1±0.4

3 Proton-nucleus (J/ψ)/DY results

3.1 NA50 results

Since J/ψ absolute cross-sections may be affected by normalization uncertainties, (J/ψ)/DY ratios can be used as a good alternative to determine $\sigma^{\psi}_{\rm abs}$. Moreover, the Drell-Yan (DY) cross-section scales linearly with the number of nucleon-nucleon collisions (in NA38/NA50 phase space) providing a good reference to study the J/ψ nuclear absorption. The drawback of this method is the low DY statistics. For this reason, only the high statistics NA50 data samples are able to provide (J/ψ)/DY ratios. A simultaneous Glauber fit to both NA50 p-A 450 and 400 GeV (J/ψ)/DY measurements (also including NA51 results at 450 GeV), with all data isospin corrected to a pp system, leads to $\sigma^{\psi}_{\rm abs}$ =4.2±0.4 mb. This result, in very good agreement with the corresponding value obtained from J/ψ absolute cross-sections, is adopted as our best estimate of $\sigma^{\psi}_{\rm abs}$ reported in Table 3.

Table 3. Results from the simultaneous Glauber fit using (J/ψ)/DY results from NA51/NA50 data at 450 and 400 GeV.

Data	N_0^{450}	N_0^{400}	$\sigma^{\psi}_{\rm abs}$ (mb)
NA51,50	57.5±0.8	59.3±1.5	4.2±0.4

3.2 Comparison with results from ion collisions

The parameters extracted from the simultaneous fit presented in Sect. 3.1 (N_0^{450} and $\sigma^{\psi}_{\rm abs}$) allow us to deduce the J/ψ absorption behaviour expected for Pb-Pb collisions. Based on recent Pb nuclei "neutron-halo" measurements [12], we introduce 2 parameter Fermi distributions for neutrons, with the same half density radius as for protons (6.624 fm) but with a larger diffuseness parameter (0.667 fm) and compute the expected Pb-Pb absorption curve using a Glauber model. For comparison purposes with (J/ψ)/DY heavy ion results at lower energies, the absorption curve has to be rescaled to the 158 GeV kinematical domain. J/ψ rescaling is performed according to the methods already explained in Sect. 2.3. The DY pp rescale is computed at LO using the GRV 94 LO PDF sets. The simultaneous change in energy and kinematical domain from 450 GeV to 200 GeV amounts to 0.504±0.012 while the much smaller drop in $\sqrt{s}$ and $x_{\rm F}$ from 200 GeV to 158 GeV leads to 0.7085×1.091=0.773. An additional factor of 0.969 is applied for the isospin correction from pp to Pb-Pb. The statistical uncertainty of the absorption curve obtained at 158 GeV amounts to $\sim\pm8\%$ at low centrality and $\sim\pm9\%$ at high centrality. Figure 2 shows the Pb-Pb absorption curve, rescaled to 158 GeV, as a function of L (the average path length traveled by the $c\bar{c}$ pair through nuclear matter), with the reanalyzed results of the NA38 200 GeV S-U (J/ψ)/DY measurements and the most recent Pb-Pb 2000 (J/ψ)/DY results.

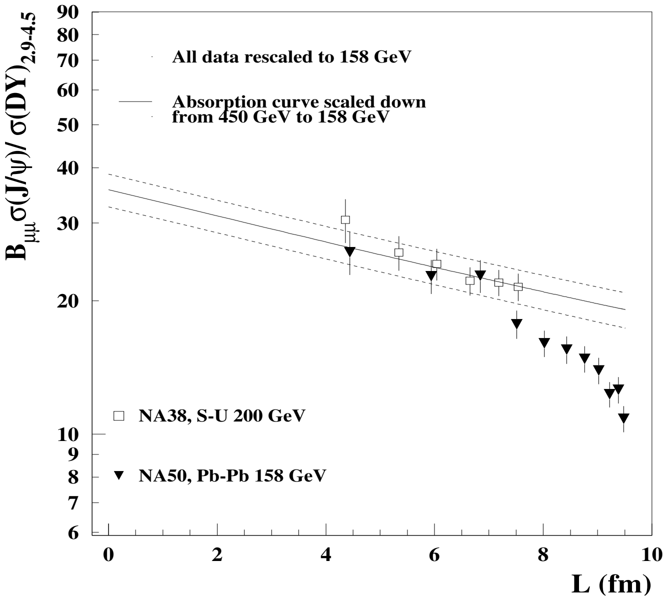

Fig. 2. Comparison of NA38 S-U and NA50 2000 Pb-Pb (J/ψ)/DY results with the absorption curve deduced exclusively from p-A measurements.

4 Conclusion

We have determined an absorption curve deduced exclusively from NA50 (J/ψ)/DY p-A results. The available J/ψ absolute cross-section measurements from different experiments, collected over a wide energy range, allow to assume that $\sigma^{\psi}_{\rm abs}$ is the same between 450 GeV and 200 GeV. From a simultaneous fit performed on these measurements, we have obtained the experimental rescaling factors which scale down J/ψ production cross-section, in energy and rapidity, from 450 GeV to 200 GeV. An additional phenomenological factor rescales data from the 200 GeV to the 158 GeV kinematical domain. The corresponding DY rescaling factors are computed using LO calculations. We observe that the reanalyzed NA38 S-U (J/ψ)/DY results lie on top of the absorption curve, showing that there is small room for other additional suppression mechanisms. J/ψ production measured in peripheral Pb-Pb reactions is in agreement with the expected behaviour deduced from p-A data. Central Pb-Pb measurements do not follow the behaviour extrapolated from lighter systems so that an amount of extra suppression is needed in order to account for Pb-Pb results.

This work is partially supported by the Fundação para a Ciência e Tecnologia, Portugal.

References

1. T. Matsui and H. Satz, Phys. Lett. **B178** (1986) 416.
2. M.C. Abreu *et al.*, Phys. Lett. **B410** (1997) 327.
3. G. Borges *et al.*, J. Phys. **G30** (2004) S1351.
4. M.C. Abreu *et al.*, Phys. Lett. **B466** (1999) 408.
5. M.C. Abreu *et al.*, Phys. Lett. **B438** (1998) 35.
6. M.C. Abreu *et al.*, Phys. Lett. **B553** (2003) 167.
7. B. Alessandro *et al.*, Eur. Phys. J. **C33** (2004) 31.
8. B. Alessandro *et al.*, Charmonium production and nuclear absorption in p-A interactions at 400 GeV, in preparation
9. J. Badier *et al.*, Z. Phys. **C20** (1983) 101.
10. G.A. Schuler, Habilitationschrift, Univ. Hamburg, Germany, 1994, CERN-TH-7170-94 (hep-ph/9403387).
11. M.C. Abreu *et al.*, Phys. Lett. **B410** (1997) 337.
12. A. Trzcinska *et al.*, Phys. Rev. Lett. **87** (2001) 082501.