Charmonia absorption in p-A collisions at the CERN SPS results and implications for Pb-Pb interactions

P. Cortese[1)] for the NA50 Collaboration:

B. Alessandro[11)], C. Alexa[4)], R. Arnaldi[11)], M. Atayan[13)], C. Baglin[2)], A. Baldit[3)], M. Bedjidian[12)], S. Beolè[11)], V. Boldea[4)], P. Bordalo[7,a)], S.R. Borenstein[10,b)], G. Borges[7)], A. Bussière[2)], L. Capelli[12)], C. Castanier[3)], J. Castor[3)], B. Chaurand[10)], B. Cheynis[12)], E. Chiavassa[11)], C. Cicalò[5)], T. Claudino[7)], M.P. Comets[9)], S. Constantinescu[4)], P. Cortese[1)], J. Cruz[7)], A. de Falco[5)], N. de Marco[11)], G. Dellacasa[1)], A. Devaux[3)], S. Dita[4)], O. Drapier[10)], B. Espagnon[3)], J. Fargeix[3)], P. Force[3)], M. Gallio[11)], Y.K. Gavrilov[8)], C. Gerschel[9)], P. Giubellino[11,c)], M.B. Golubeva[8)], M. Gonin[10)], A.A. Grigorian[13)], S. Grigorian[13)], J.Y. Grossiord[12)], F.F. Guber[8)], A. Guichard[12)], H. Gulkanyan[13)], R. Hakobyan[13)], R. Haroutunian[12)], M. Idzik[11,d)], D. Jouan[9)], T.L. Karavitcheva[8)], L. Kluberg[10)], A.B. Kurepin[8)], Y. Le Bornec[9)], C. Lourenço[6)], P. Macciotta[5)], M. Mac Cormick[9)], A. Marzari-Chiesa[11)], M. Masera[11)], A. Masoni[5)], M. Monteno[11)], A. Musso[11)], P. Petiau[10)], A. Piccotti[11)], J.R. Pizzi[12)], W.L. Prado da Silva[11,e)], F. Prino[11)], G. Puddu[5)], C. Quintans[7)], L. Ramello[1)], S. Ramos[7,a)], P. Rato Mendes[7)], L. Riccati[11)], A. Romana[10)], H. Santos[7)], P. Saturnini[3)], E. Scalas[1)] E. Scomparin[11)], S. Serci[5)], R. Shahoyan[7,f)], F. Sigaudo[11)], M. Sitta[1)], P. Sonderegger[6,a)], X. Tarrago[9)], N.S. Topilskaya[8)], G.L. Usai[5)], E. Vercellin[11)], L. Villatte[9)], N. Willis[9)], T. Wu[9)].

[1)] Univ. del Piemonte Orientale, Alessandria and INFN-Torino, Italy. [2)] LAPP, CNRS-IN2P3, Annecy-le-Vieux, France. [3)] LPC, Univ. Blaise Pascal and CNRS-IN2P3, Aubière, France. [4)] IFA, Bucharest, Romania. [5)] Univ. di Cagliari and INFN, Cagliari, Italy. [6)] CERN, Geneva, Switzerland. [7)] LIP, Lisbon, Portugal. [8)] INR, Moscow, Russia. [9)] IPN, Univ. de Paris-Sud and CNRS-IN2P3, Orsay, France. [10)] Laboratoire Leprince-Ringuet, Ecole Polytechnique and CNRS-IN2P3, Palaiseau, France. [11)] Univ. di Torino and INFN, Torino, Italy. [12)] IPN, Univ. Claude Bernard Lyon-I and CNRS-IN2P3, Villeurbanne, France. [13)] YerPhI, Yerevan, Armenia. [a)] Also at IST, Lisbon, Portugal. [b)] On leave from York College, CUNY, New York, USA. [c)] Also at CERN, Geneva, Switzerland. [d)] Also at FPNT, Cracow, Poland. [e)] Now at UERJ, Rio de Janeiro, Brazil. [f)] On leave from YerPhI, Yerevan, Armenia.

The NA50 experiment has measured charmonia and Drell-Yan production in proton-nucleus collisions at 450 GeV incident energy. We present results on the nuclear absorption cross section σ^{abs}, for J/ψ and ψ', extracted with the Glauber model. The p-A results are then compared with S-U data, and the observed behavior is extrapolated to Pb-Pb collisions, providing a new reference for the study of the anomalous J/ψ suppression [1].

The study of charmonia production in p-A collisions is a unique tool for the study of $c\bar{c}$ interactions in nuclear matter, allowing us to estimate the nuclear absorption cross section. Indeed, in p-A collisions other absorption mechanisms as the interactions with other produced hadrons ("comovers"), are expected to be negligible. The NA50 experiment has recently measured J/ψ, ψ' and Drell-Yan (DY) production in p-A collisions. Preliminary results were reported in Ref. [2]. The data have been collected at the CERN SPS, with a primary proton beam of 450 GeV. Five nuclear targets have been used: Be, Al, Cu, Ag and

W. For the reconstructed events the selections $-0.4 < y_{cm} < 0.6$ and $-0.5 < \cos\theta_{CS} < 0.5$ have been applied (where θ_{CS} is the polar angle of the positive muon in the Collins-Soper reference frame). The acceptances for the measured signals are $A_{J/\psi} = 14.0\,\%$, $A_{\psi'} = 16.4\,\%$ and $A_{DY} = 13.9\,\%$. Details on the analysis procedure, as well as on the study of the x_F dependence of the different signals, can be found in Refs. [3,4].

The DY cross section has been estimated in the mass range $2.9 < m_{\mu\mu} < 4.5$ GeV/c^2. This range was chosen to ease the comparison of the present results with the ones previously obtained by NA38, NA50 and NA51. We have used the MRS (A) low Q^2 $\overline{MS}$ set of parton distribution functions [5] to calculate the DY mass shape. The choice of a particular set of PDFs induces a small bias (a few percent) on the absolute scale of the Drell-Yan cross section, but does not affect the nuclear dependence of DY production. A discussion of this effect can be found in Ref. [6]. DY cross sections are corrected for isospin effects, i.e. they are reported to a hypothetical nucleus made of 'A' protons. The results on DY production are shown in Fig. 1 together with the pp and pd measurements of NA51 [7]. To quantify the deviations of Drell-Yan production from a simple scaling with the number of nucleon-nucleon collisions, we have fitted the DY cross section with a power law, $\sigma_{DY}^{pA} = \sigma_{DY}^{pp} \cdot A^{\alpha}$. We get $\alpha = 0.995 \pm 0.016(\mathrm{stat}) \pm 0.019(\mathrm{syst})$, with $\chi^2/\mathrm{ndf} = 1.0$. This result shows that DY production, at our energies and in our phase space window, is proportional to the number of nucleon-nucleon collisions and can be used as a reference for charmonia suppression studies.

We then studied $B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY}$ and $B'_{\mu\mu}\sigma_{\psi'}/\sigma_{DY}$, where $B_{\mu\mu}$ and $B'_{\mu\mu}$ are the J/ψ and ψ' branching ratios into $\mu^+\mu^-$. These ratios are particularly useful since, contrary to the absolute cross sections, they are free from systematic errors related to the absolute normalizations. In Fig. 2 we plot our results together with the pp and pd points published by NA51 [7]. Using a full Glauber calculation we extract $\sigma^{abs}_{J/\psi} = 4.2 \pm 0.5$ mb and $\sigma^{abs}_{\psi'} = 5.1 \pm 0.8$ mb. It is known that a considerable fraction of the observed J/ψ yield comes from the contribution of χ_c and ψ' decays. Our apparatus is not able to distinguish feed-down J/ψ's from directly produced ones. While the A-dependence of χ_c production

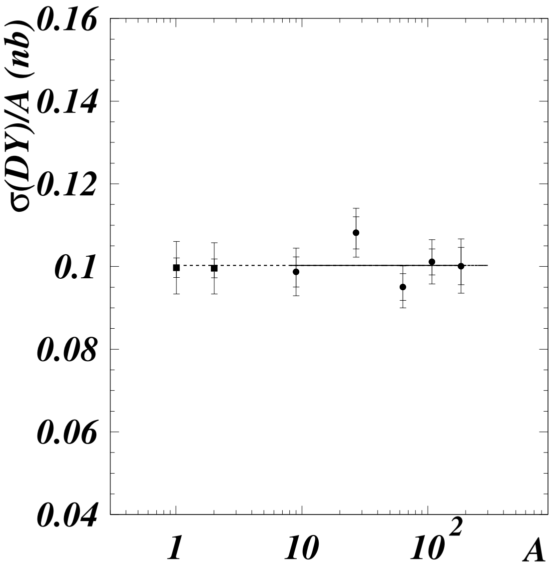

Figure 1. Drell-Yan cross sections for pp, pd and p-A collisions at 450 GeV.

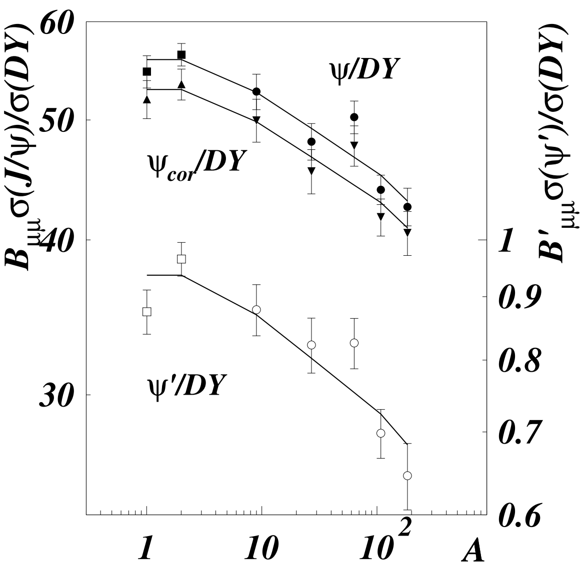

Figure 2. ψ/DY, ψ'/DY and ψ_{cor}/DY ratios in pp, pd and p-A collisions.

is not known, we can correct for the ψ' decays using the measured $B'_{\mu\mu}\psi'/DY$ and taking into account the branching ratios $J/\psi \rightarrow \mu^+\mu^-$, $\psi' \rightarrow \mu^+\mu^-$ and $\psi' \rightarrow J/\psi + X$ [8]. After correcting for this effect we obtain $\sigma^{abs}_{J/\psi,\mathrm{cor}} = 4.1 \pm 0.6$ mb, with $\chi^2/\mathrm{ndf} = 1.0$, for the nuclear absorption of directly produced J/ψ mesons.

We then compare the absorption cross section extracted from p-A collisions with the same quantity obtained in S-U collisions, $\sigma^{abs,SU}_{J/\psi}$, using the results published by NA38 [9] (see Fig. 3). Those data were collected at 200 GeV/nucleon, in the rapidity interval $0 < y_{cm} < 1$ and in 5 centrality classes. The ratios $(J/\psi)/\mathrm{DY}$ and ψ'/DY can also be used in S-U collisions, since Drell-Yan continues to scale with the number of binary nucleon-nucleon collisions [1,10]. We do not expect the slightly different x_F coverage between our p-A and S-U data to influence the value of $\sigma^{abs}_{J/\psi}$ [11]. We get $\sigma^{abs,SU}_{J/\psi} = 7.1 \pm 3.0$ mb, with $\chi^2/\mathrm{ndf} \approx 0.02$, using the same Glauber approach as used for the p-A analysis. Although the J/ψ absorption cross section is higher in S-U collisions, the two results are compatible within errors. When the ψ' feed-down is removed, using the $B_{\mu\mu}\sigma_{\psi'}/\sigma_{DY}$ values published in Ref. [9], we obtain $\sigma^{abs,SU}_{J/\psi,\mathrm{cor}} = 6.3 \pm 2.9$ mb, with $\chi^2/\mathrm{ndf} \approx 0.02$, showing a better compatibility between the two results. Therefore, we performed a simultaneous fit of the p-A and S-U points with a common $\sigma^{abs}_{J/\psi}$. Since we cannot correct for the contamination of χ_c radiative decays, we make the assumption that $\sigma^{abs}_{\chi_c} = \sigma^{abs}_{J/\psi}$.

The results for the two data sets are shown in Fig. 4. We have also included the NA38 p-W and p-U results measured at 200 GeV [12], although their error bars are quite large. Due to the different energies and rapidity coverages, we expect a significant difference between the absolute normalizations of the data sets taken at the two energies. The normalizations $(B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY})^{pp}_{450\,\mathrm{GeV}}$ and $(B_{\mu\mu}\sigma_{J/\psi}/\sigma_{DY})^{pp}_{200\,\mathrm{GeV}}$ are left as free parameters in the fit. The fit gives a common $\sigma^{abs,pA,SU}_{J/\psi} = 4.4 \pm 0.5$ mb, with 0.75 ± 0.04 as the ratio between the normalizations of the two data sets. When the ψ' feed-down is subtracted, the quality of the fit improves and we get $\sigma^{abs,pA,SU}_{J/\psi,\mathrm{cor}} = 4.3 \pm 0.6$ mb, with $\chi^2/\mathrm{ndf} = 0.6$.

Finally, using the value $\sigma^{abs}_{J/\psi} = 4.4 \pm 0.5$ mb, and using the Glauber model, we have calculated the expected J/ψ suppression in Pb-Pb interactions due to normal nuclear absorption. The normalization of the curve has been obtained by rescaling to 158 GeV the

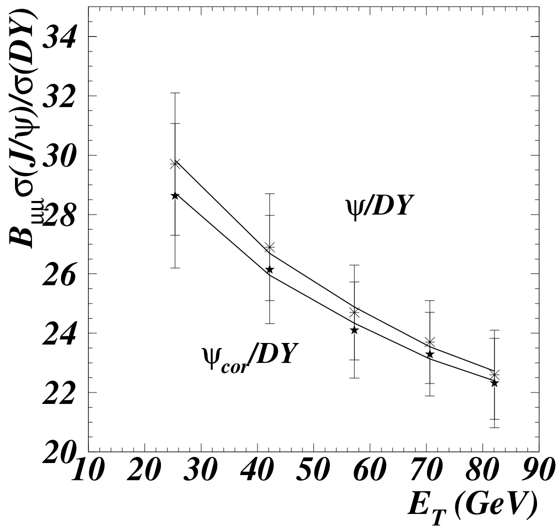

Figure 3. Glauber fit to the ψ/DY and ψ_{cor}/DY ratios, in S-U collisions.

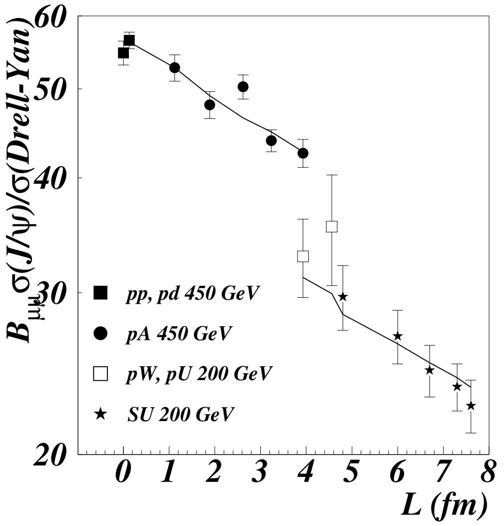

Figure 4. Simultaneous fit to the p-A and S-U ψ/DY ratios.

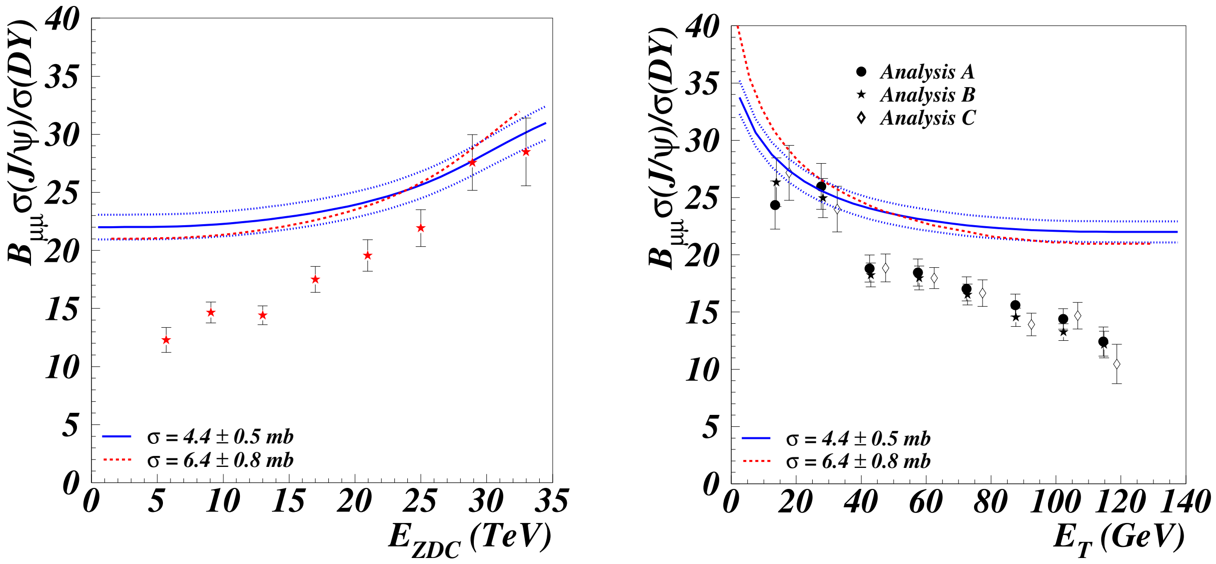

Figure 5. The ψ/DY in Pb-Pb collisions vs. $E_{\rm ZDC}$ (left) and $E_{\rm T}$ (right).

value of $(B_{\mu\mu}\sigma_{{\rm J}/\psi}/\sigma_{DY})^{pp}_{200\,{\rm GeV}}$ obtained in the previous fit. The scaling factor is computed using a leading order calculation for DY and using a well known parametrization of the $\sqrt{s}$ dependence for the J/ψ cross section [13]. We get $(\sigma_{{\rm J}/\psi}/\sigma_{DY})^{pp}_{158\,{\rm GeV}}/(\sigma_{{\rm J}/\psi}/\sigma_{DY})^{pp}_{200\,{\rm GeV}} = 1.051 \pm 0.026$. The uncertainty on the parameters of the simultaneous fit of Fig. 4 has been taken into account in the calculation of the absorption curve at 158 GeV, also taking into account the correlations between the fit parameters. The resulting uncertainty on the calculation of the absorption reference for Pb-Pb is $\sim 4\,\%$ with a slight dependence on centrality. In Fig. 5 the estimate of the Pb-Pb nuclear absorption curve is presented as a function of $E_{\rm ZDC}$ and $E_{\rm T}$. The uncertainty on the calculation is represented by the dotted curves. We also plot our previous estimate (dashed curve) corresponding to $\sigma^{abs}_{{\rm J}/\psi} = 6.4$ mb [1]. The curves are superimposed to the preliminary NA50 results presented in Ref. [6]. In spite of the different value of the absorption cross section with respect to our previous estimate, the nuclear absorption curves do not differ very much in the region corresponding to semi-peripheral collisions. This is essentially due to the normalization constraints imposed by the S-U points.

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