J/ψ production in p-A collisions at 158 and 400 GeV: recent results from the NA60 experiment

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Abstract

The NA60 experiment has studied muon pair production in p-A and In-In collisions at the CERN SPS. We present new results on nuclear effects on J/ψ production in p-A at 158 GeV, the same energy used for collecting A-A data at the SPS. We then compare nuclear effects with previous results from fixed target experiments, and with the results obtained from a p-A data sample taken by NA60 at 400 GeV. Based on the 158 GeV results, we calculate the expected J/ψ suppression in In-In and Pb-Pb collisions due to cold nuclear matter effects, and we extract a new estimate for the anomalous suppression at SPS energies. Finally, we show preliminary results on J/ψ polarization in p-A collisions.

1. Introduction and p-A data analysis

The suppression of charmonium states in nuclear collisions is considered as one of the most powerful signatures of the production of a deconfined state. However, it was soon realized that cold nuclear matter effects, and in particular the interaction of the projectile and target nucleons with the c̅c̅ pair, may sizably contribute to the observed suppression. Such effects are usually studied in p-A collisions, then extrapolated to A-A and compared with the observed yield in nuclear collisions, as a function of centrality.

At the SPS, the NA50 experiment has performed an accurate measurement of J/ψ production in p-A collisions at 400/450 GeV, i.e. with an incident proton energy higher than the energy per nucleon of Pb-Pb and In-In collisions, studied by the NA50 and NA60 experiments, respectively. Cold nuclear matter effects have been parameterized by fitting the A-dependence of the J/ψ production cross section per N-N collision with the usual $A^\alpha$ power-law, or calculating, in the frame of the Glauber model, the J/ψ absorption cross section $\sigma_{abs}^{J/ψ}$. An extrapolation to A-A, based on the assumption of a constant $\sigma_{abs}^{J/ψ}$ as a function of incident energy and c.m. rapidity has revealed, by comparison with J/ψ production yields in A-A, the presence of a suppression which exceeds cold nuclear matter effects (anomalous suppression).

In order to provide reference p-A data collected at the same energy and kinematic domain of the A-A data, NA60 has studied for the first time J/ψ production in p-A collisions at 158 GeV. The incident beam, with an intensity of $\sim 5 \cdot 10^8$ protons/s, was sent towards a target system made of several subtargets, with mass numbers ranging from 9 (Be) to 238 (U), which were simultaneously exposed to the beam. For details on the NA60 experiment, based on a muon spectrometer coupled to a Si pixel vertex telescope, see e.g. [4].

The analysis of the J/ψ production data at 158 GeV has been performed in the rapidity domain $0.28 < y_{cm} < 0.78$, covered with reasonable acceptance by all the sub-targets. The preliminary
results shown in this paper refer to cross-section ratios $\sigma_{pA}/\sigma_{pBe}$ between the target with mass number $A$ and the lightest one (Be). In this way, the beam luminosity factors cancel out, apart from a small beam attenuation factor. On the other hand, the track reconstruction efficiencies in the vertex spectrometer do not cancel out completely, since each target sees the vertex spectrometer under a slightly different angle. Therefore, the efficiency of the vertex spectrometer has been computed with the highest possible granularity (down to the single-pixel level, when track statistics is large enough) and on a run-per-run basis. As a check, we have verified, injecting in our Monte-Carlo these efficiencies, that we were able to reproduce the muon pair matching rate (of the order of $\sim 60\%$), and its time evolution, observed for $J/\psi$ events in real data.

2. Results on p-A collisions

In Fig. 1(left) we present the $J/\psi$ cross-section ratios, relative to Be, for the 7 nuclear targets (Be, Al, Cu, In, W, Pb and U) exposed to the beam. The results are shown as a function of $L$, the mean thickness of nuclear matter crossed by the $c\bar{c}$ pair in its way through the nucleus.

![Graph showing J/\psi cross-section ratios for p-A collisions at 158 GeV (circles) and 400 GeV (squares), as a function of L.](image)

Figure 1: Left: $J/\psi$ cross-section ratios for p-A collisions at 158 GeV (circles) and 400 GeV (squares), as a function of $L$. Right: compilation of $\alpha$ vs $x_F$.

The systematic errors shown in Fig. 1(left) include contributions from uncertainties on target thicknesses, on the $y$ distribution used in the acceptance calculation, and on the reconstruction efficiency. We only quote the fraction of the total systematic error which is not common to all the points (i.e. the one which affects the evaluation of nuclear effects). By fitting the A-dependence of the cross-section ratios in the frame of the Glauber model, we get $\sigma_{J/\psi}(158 \text{ GeV}) = 7.6 \pm 0.7\text{(stat.)} \pm 0.6\text{(syst.)}$ mb. Alternatively, a fit using the $A^\alpha$ power-law gives $\alpha(158 \text{ GeV}) = 0.882 \pm 0.009 \pm 0.008$. In Fig. 1(left) we also show the results of the same analysis, carried out on a data sample taken by NA60 at 400 GeV, with the same configuration of the experimental set-up, in order to minimize the relative systematic errors. These results refer to the rapidity range $-0.17 < y_{cm} < 0.33$, corresponding to the same rapidity in the lab of the 158 GeV data. We clearly note that the A-dependence of this data sample is less steep than the one measured at 158 GeV. We get $\sigma_{J/\psi}(400 \text{ GeV}) = 4.3 \pm 0.8\text{(stat.)} \pm 0.6\text{(syst.)}$ mb, and $\alpha(400$
GeV) = 0.927 ± 0.013 ± 0.009. Nuclear effects on J/ψ production at 400 GeV had already been studied by NA50, in the range −0.425 < y_{cm} < 0.575, close to the one of the NA60 data. Their result [3], \( \sigma_{abs}^{J/\psi}(400 \text{ GeV}) = 4.6 ± 0.6 \text{ mb} \), is in excellent agreement with our findings.

The observation of a dependence of nuclear effects on the incident proton energy can be further investigated by comparing our results with previous studies done at fixed target energies. To do that, in Fig. 1(right) we show a compilation of \( \alpha \) values as a function of \( x_F \), including results from HERA-B at 920 GeV [7], from E866 at 800 GeV [8] and from NA50 at 450 GeV [9]. Our analysis at 400 and 158 GeV has been plotted in Fig. 1(right) for various \( x_F \) bins. We notice that nuclear effects become stronger (smaller \( \alpha \)) at higher \( x_F \), and that, for a certain \( x_F \), they are also stronger for a lower incident proton energy. It is worthwhile to note that a theoretical description of the kinematic dependence of cold nuclear matter effects on J/ψ production is still missing. An interplay of final state dissociation of the \( c \bar{c} \) pair, parton shadowing and possibly initial state energy loss has been shown to reproduce some of the observed features (see e.g. [10]), but clearly more work is needed in order to arrive at a quantitative description.

3. Anomalous J/ψ suppression in In-In and Pb-Pb collisions

The p-A results at 158 GeV shown in the previous section have been collected at the same energy and in the same \( x_F \) range of the SPS A-A data. It is therefore natural to use these results to calculate the expected size of cold nuclear matter effects on J/ψ production in nuclear collisions. In order to do that, we have determined, as a function of the forward energy \( E_{ZDC} \) and using the Glauber model, the expected shape \( dN_{J/\psi}^{exp} / dE_{ZDC} \), assuming that J/ψ production scales with the number of N-N collisions and that the produced J/ψ are absorbed in nuclear matter according to the value \( \sigma_{abs}^{J/\psi}(158 \text{ GeV}) \) given in the previous section. The measured \( dN_{J/\psi} / dE_{ZDC} \) has then been normalized to \( dN_{J/\psi}^{exp} / dE_{ZDC} \) using the procedure detailed in Ref. [5]. This procedure, which was used up to now, does not take explicitly into account, when extrapolating from p-A to A-A, the presence of shadowing effects. It can be shown [11] that in the kinematic region where A-A data are measured (0 < y_{cm} < 1), this method leads to an overestimation of the anomalous suppression, of the order of \( \sim 5\% \). We have therefore corrected our result for this small bias, using the EKS98 [12] parameterization of shadowing effects. In Fig. 2(left) we present, as a function of the number of participants, our result for the anomalous J/ψ suppression in In-In and Pb-Pb collisions. We can see that up to \( N_{part} \sim 200 \) the J/ψ yield is, within errors, compatible with our extrapolation of cold nuclear matter effects. For \( N_{part} > 200 \) an anomalous suppression is present, which reaches \( \sim 20\% - 30\% \) for central Pb-Pb collisions. With this new evaluation of the anomalous suppression, the effect becomes smaller with respect to the past. This is essentially due to the larger \( \sigma_{abs}^{J/\psi} \) value now used in the determination of the nuclear reference.

4. J/ψ polarization in p-A collisions

A study of the J/ψ polarization in p-A collisions can be performed by studying the angular distribution of the decay muons. This study has been shown to be relevant, at collider energies, for investigating the quarkonium production models, since various theoretical approaches [13] predict different values, as a function of \( p_T \), for the polarization parameters \( \lambda, \mu, \nu \), obtained through a fit of the muon angular distribution \( d^2 \sigma / d \cos \theta d\phi \propto 1 + \lambda \cos^2 \theta + \mu \sin \theta \cos \phi + (\nu/2) \sin^2 \theta \cos 2\phi \). In Fig. 2(right) we present our preliminary results for \( \lambda \) and \( \nu \) (\( \mu \) is compatible with zero everywhere), obtained in the helicity reference frame, compared with recent HERA-B
Figure 2: Left: anomalous $J/\psi$ suppression in In-In (circles) and Pb-Pb collisions (triangles), as a function of $N_{\text{part}}$. The boxes around the In-In points represent correlated systematic errors. The filled box corresponds to the uncertainty in the absolute normalization of the In-In points. A 12% global error, due to the uncertainty on $\sigma_{J/\psi}^{\text{abs}}$ (158 GeV), is not shown. Right: the $J/\psi$ polarization parameters $\lambda$ and $\nu$, in the helicity reference frame, as a function of $p_T$, for NA60 data, compared with recent results from HERA-B. The boxes represent the total errors.

The data seem to indicate slightly negative $\lambda$ values at low $p_T$, which level around zero at larger transverse momentum. $\nu$ values are close to zero in the $p_T$ range explored by NA60.

5. Conclusions

We have shown new results on $J/\psi$ production in p-A collisions at 158 and 400 GeV. We see that nuclear effects become more important when moving towards lower energy, an observation that remains valid when extending the comparisons to other sets of results. Using the new 158 GeV results for determining the expected cold nuclear matter effects in A-A results in a smaller anomalous suppression with respect to previous estimates. The effect is anyway still sizeable ($\sim 25\%$) for central Pb-Pb collisions.

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