NUCLEAR EFFECTS IN J/ψ HADROPRODUCTION

L.N. EPELE, C.A. GARCIA CANAL

Laboratorio de Fisica Teorica, Departamento de Fisica, Universidad Nacional de La Plata, C.C. 67, 1900 La Plata, Argentina

and

M.B. GAY DUCATI

Instituto de Fisica, Universidade Federal do Rio Grande do Sul, 90000 Porto Alegre, Brazil

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A phenomenological picture of the parton recombination model for shadowing at small values of x is applied to hadron–nucleus J/ψ production. Agreement with experimental data is obtained provided that a further suppression of J/ψ production inside the nucleus is taken into account.

It is well established that the cross section per nucleon for interactions between real photons and nuclei decreases with increasing nuclear mass number A. This effect is called shadowing and is not more than the similar observed effect in hadron–nuclei scattering. It is by now clear that the fact that nucleons inside a nucleus are shadowed by nucleons on the nuclear surface is also present when the incident photon is a virtual one as in deep inelastic scattering. In summary, shadowing implies

$$\sigma_{\gamma A} < A\sigma_{\gamma N}, \quad \sigma_{hA} < A\sigma_{hN}, \quad \sigma_{\gamma^* A} < A\sigma_{\gamma^* N} .$$

It is worth mentioning that these facts are by no means obvious in the framework of the parton model, where, due to the intrinsic incoherence of partons, one should expect a cross section linearly growing with A.

Shadowing effects have been clearly observed in muon–nucleus deep inelastic scattering [1] which have also been analysed from a theoretical or phenomenological point of view [2,3].

Very recently, the E537 Fermilab experiment has reported [4] on the J/ψ resonance production in 125 GeV/c $\bar{p}$ and π^- interactions with Be, Cu and W targets. These data clearly show nuclear target effects in the sense that the J/ψ production is suppressed in W interactions relative to the rates corresponding to the lighter targets. The E537 experiment claims that the observed effects, especially pronounced for the Feynman x variable $x_F > 0.5$, are opposite to any EMC-type effects previously reported. However, it has been pointed out [5] that the kinematical region explored by the experiment is certainly coincident with the region characteristic of shadowing of deep inelastic scattering, and does not correspond to the region where the standard EMC effect occurs.

In order to complete this scenario, it is necessary to recall that the J/ψ-hadroproduction cross section is generally suppressed with respect to the Drell–Yan continuum one due to absorption effects on the resonance when the reaction is in a nuclear target [6–8].

In this note we present a phenomenological analysis of nuclear effects in J/ψ hadroproduction. In this analysis we found it necessary to include an effective J/ψ absorption in nuclei after its production where shadowing-like suppression is considered.

As a first approximation and in the standard quark–parton language, shadowing could be understood as due to a kind of fusion of partons, more probably gluons, coming from neighbouring nucleons in the nucleus. This effect should be clearly present at very small values of the scaling variable x where the sea contribution is dominant. This means that at very small x, quarks and gluons from different nucleons are no more independent in the sense that they are not directly assigned, as in the naive parton model, to a given nucleon. As deep inelastic scattering is connected to the infinite momentum frame, the phenomenon of shadowing is related with the longitudinal size of nuclei, nucleons and partons [2]. The spatial parton distributions overlap, at a given impact parameter, if the longitudinal size Δz, of a gluon or a sea quark, is larger than the longitudinal Lorentz contracted size of the nucleus, Δz_A. Notice that the effect will be present even if $\Delta z > \Delta z_N$, where Δz_N is the longitudinal nucleon size. The longitudinal dimension of a parton of momentum px, with p being the nucleon momentum, of the order [9] $\Delta z \sim 1/px$ and for that reason partons of very small x can correlate. It is clear that gluons dominate the nucleon momentum sharing, then they are the principal protagonists of the mentioned overlapping. It has been already shown [10] that the recombination of gluons at very small x contributes negatively to the gluon evolution equation giving rise to an effective shadowing correction. As a consequence, a detectable reduction of the nucleon structure function in this kinematical region of small values of x occurs. In the present case of J/ψ production, dominated by the gluon-fusion mechanism, it is necessary to extrapolate the above argument because now the probe is the gluon instead of a photon (real or virtual). From a simple phenomenological viewpoint we have decided to extend the approximation to gluon initiated hard scattering.

It should be noticed that this kind of "shadowing" is not the only nuclear effect present in our problem because the A-behaviour at small values of $x_{(2)}$ is different for the standard Drell–Yan processes and for the J/ψ-production cross sections, as has already been pointed out [8]. In other words, J/ψ production presents clear peculiarities that are probably related to strong screening effects. In particular there seems to exists an unbalance between elastic and inelastic rescattering originated screening [11]. There exist also other causes for an A-dependence of the production rates as the possible interactions of partonic constituents of J/ψ with the nucleus or the interaction of J/ψ itself with nucleus or even the interaction of the J/ψ constituents with other quarks or gluons co-moving with the hadron [12]. In any case, each of these effects is related to different kinematical regions of x_1 and $p_\perp$. In what follows we discuss this combined effect in an entirely phenomenological manner through the introduction of an effective factor fixed from previous experiments.

Before presenting our approach and just to make our proposal self-contained, let us fix the relevant notations and definitions and discuss the kinematical aspects of the problem.

A typical hadron (h)–nuclei(A) reaction like the one under consideration is described in terms of the momentum fraction of h and A carried by the corresponding partons that we call x_1 and x_2, respectively. The invariant mass of the hard process is $M^2 = sx_1x_2$, where s is the center-of-mass energy of h+A. Finally, $x_F = x_1 - x_2$ measures the longitudinal fraction of momentum in the center of mass of the hard process, while the other relevant variable is $\tau = x_1x_2 = M^2/s$. In the E537 experiment, this variable is fixed to 0.04. This implies that the range of measured values of x_2, lies between $0.05 < x_2 < 0.18$ as shown in fig. 1.

Once we have characterized the kinematical range experimentally explored in $\pi A \to$ J/ψ, that is clearly coincident with the shadowing region in deep inelastic scattering, we study the A-dependent behaviour of the rate of cross sections.

$$R_A = \sigma^{\pi A}/A\sigma^{\pi D} . \quad (1)$$

We consider first the factorisation for this ratio proposed in ref. [2] under the assumption of its validity for the case of a gluon probe

$$R_A(x, Q_0^2, A) = R_s(x, Q_0^2, A) R_a(x, Q_0^2, A) , \quad (2)$$

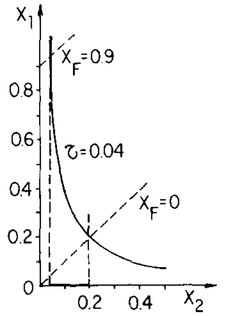

Fig. 1. Kinematically allowed region for the x_1, x_2 variables in the E537 experiment. The x_2 variable runs in the shadowing characteristic region, because of the scanned x_F range, $0 < x_F < 0.9$.

where R_s is the shadowing factor, which works at very low x, Q_0^2 is a fixed momentum transfer and R_a is the ratio of structure functions including the standard EMC effects, as those due to nuclear binding physics. The function $R_A(x, Q_0^2, A)$ is supposed to describe the rate behaviour of all values of x, where three essential regions can be distinguished; shadowing dominated, standard EMC, and Fermi motion dominated, respectively.

The experimental data coming from the EMC Collaboration [1] show that shadowing increases as A increases. On the other hand, the hadron–nucleus data show that the rate $R=A'F_2^A(x, Q^2)/AF_2^{A'}(x, Q^2)$ decreases as $x\to 0$, more sharply for $A'_1<A'_2(A_{Be}<A_{Cu})$.

In order to check this picture of the low-x effect, we have employed the low density parton recombination model of refs. [10,11,2], which describes shadowing by the ratio

$$R_s(x, Q_0^2, A)$$
$$=1, \qquad x_c<x<1,$$
$$=1-K_s(A^{1/3}-1)\frac{\Delta z-\Delta z_c}{\Delta z_A-\Delta z_c}, \quad x_A<x<x_c,$$
$$=1-K_s(A^{1/3}-1), \qquad 0<x<x_A, \qquad (3)$$

where K_s, the recombination parameter, is of the order of 0.2, $\Delta z_c=1/x_c p\sim 2r_0 m/p$, r_0 being the nucleon radius and x_c is a critical value characterizing the region where shadowing begins. Finally, $\Delta z_A=1/x_A p\sim 2Rm/p$, R being the nuclear radius and x_A corresponds to the x region where shadowing saturation occurs.

The additional nuclear effect, namely the J/ψ suppression in nuclei, could be taken into account by adding a new phenomenological factor to the cross section ratio (2).

We propose to write

$$R_A=R_{ss}R_sR_a\,. \qquad (4)$$

Here R_{ss} is the new corrective factor. It is possible to have some general indications of its magnitude using general arguments, in particular, one expects that R_{ss} should depend on x_2.

The A-dependence of J/ψ production processes, experimentally obtained [6,7], depends on the x_F-range observed, as is explicitly shown in fig. 3 of ref. [6]. It has been found that for $x_2\to 1$ this dependence is reproduced by a factor A^α with $\alpha\approx 0.97$, while for $x_2\to 0$ α decreases down to a value of the order of 0.7. Consequently, the number of J/ψ events decreases with respect to the number of dimuons as $A^{\alpha-1}$. This is precisely the factor R_{ss} that we have introduced above.

After this general presentation we would like to show the results we have obtained by using the low density parton recombination model [13] together with the strong screening effect in nuclei just discussed in the case of J/ψ, p̄ and π^- productions.

We consider the rate of fig. 2a of ref. [4], or fig. 2 of ref. [5], concerning R_A(W/Be). Since $A_W\ll A_{Be}$, as a first approach we can neglect shadowing in Be. Hadron nucleus J/ψ data for W covers the range $0.05<x<0.18$ while Drell–Yan data for W covers the range $0.15<x<0.45$. We have obtained the shadowing prediction for R_W^{DY} and the model [2] agrees in the region where experimental data is available. We obtain the results of fig. 2 with $K_s=0.22$, practically

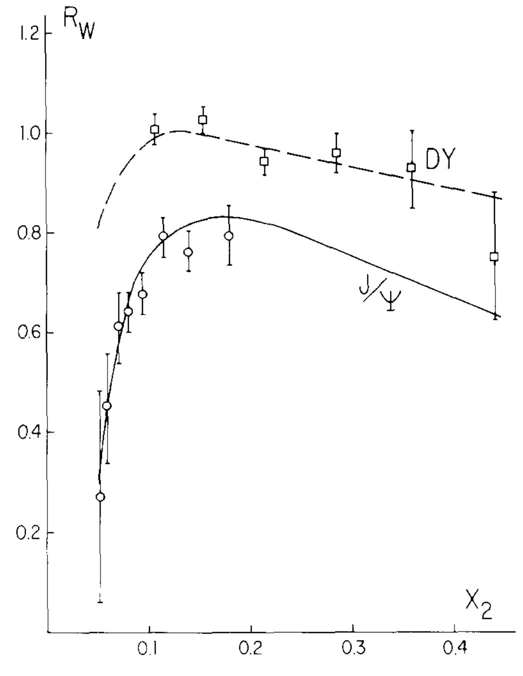

Fig. 2. Prediction of the shadowing model of ref. [2] for the ratio R_W^{DY} (dashed curve), and our prediction including absorption effects for the ratio $R_W^{J/\psi}$ (solid curve). Data are from ref. [4] for J/ψ (⌽) and from ref. [14] for DY(⌸).

the same value for the recombination parameter which reproduces quite well the results for deep inelastic in Fe(Cu) (see ref. [2]), and even the very recent ones for Sn. Since we have considered Be as D in what concerns the shadowing ratio, the same curve is the prediction for hadron–nucleus scattering for the case $A=\mathrm{W}$. On the other hand, the hadron–nucleus data shown an evident shadowing-like effect but much stronger than the obtained with the simple model of ref. [2]. However, as was mentioned above, there exists an important difference between the two processes because of the extra nuclear effect present in the J/ψ resonance production. We have found that this effect can be parametrized in terms of an $x_F(x_2)$-dependent α parameter, which is in accordance with the analysis of ref. [11]. We have analyzed this dependence and we can get a good description of the behaviour with the quadratic form

$$\alpha=0.97-0.27x_F^2\,. \tag{5}$$

Expression (5) allowed us to obtain the prediction of fig. 2 by using the proposal given in (4). This kind of α-dependence on x_F is in agreement with the data of ref. [6] and fulfills the requirement of being an even function of x_F. Our excellent result indicates that both gluon detected shadowing and a further nuclear absorption, of any kind, are present in low x_2 J/ψ hadroproduction. It means that the A-dependent suppression of J/ψ is due to two distinct and additive nuclear effects.

We conclude by observing that a complete analysis and comparison of shadowing and nuclear suppression dependence with x_2 is waiting for an extension of the range of the experimental data now available to lower values of this variable for Drell–Yan processes and to still higher ones for J/ψ hadroproduction.

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