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NUCLEAR SCREENING IN J/ψ AND LEPTON PAIR PRODUCTION

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It is widely accepted that hard processes on nuclei are not screened since their cross sections are small. It is assumed that inelastic rescatterings inside a nucleus do not influence the hard parton component of the hadron. However, this statement is not true near the kinematic boundary.

The leading hadron produced in an inelastic collision carries, on the average, about half of incident momentum. Thus, it cannot produce particles with $x_F \approx 1$ in subsequent collisions, i.e., the interior nucleons of the nucleus are screened. But the momentum spectrum of hadrons produced in an inelastic collision is known experimentally only at asymptotical distances. To find the momenta at a finite distance from the interacting point, let us employ the colour string model. After an inelastic collision, i.e., a colour exchange, the hadron is retarded by the colour string with tension κ. It is clear that hadronization of the string does not influence the retarding force acting on the fast end of the string. Its energy E decreases by $\Delta E = \kappa \Delta z$ over a distance Δz from the colour exchange point. Thus the J/Ψ (or $\ell \bar{\ell}$) production cross section is

$$\sigma_{hA}^{\Psi}(E, x_F) = \int d^2 b \int_{-\infty}^{\infty} dz\, \rho(b, z) \exp[-\sigma_{hN}^{in} T(b, -\infty, z)] \times$$

$$\times \{\sigma_{hp}^{\Psi}(E, x_F)[1 - \delta(b, z)]/2 + \sigma_{hn}^{\Psi}(E, x_F)[1 + \delta(b, z)]/2\} \exp[-\sigma_{\Psi N}^{in} T(b, z, \infty)] +$$

$$+ \int d^2 b \int_{-\infty}^{\infty} dz_1\, \rho(b, z_1) \sigma_{hN}^{in} \exp[-\sigma_{hN}^{in} T(b, -\infty, z_1)] \int_{z_1}^{\infty} dz_2\, \rho(b, z_2) \times$$

$$\times \{\sigma_{hp}^{\Psi}(\tilde{E}, \tilde{x}_F)[1 - \delta(b, z_2)]/2 + \sigma_{hn}^{\Psi}(\tilde{E}, \tilde{x}_F)[1 + \delta(b, z_2)]/2\} \times \qquad (1)$$

$$\times \exp[-\sigma_{\Psi N}^{in} T(b, z, \infty)].$$

The shifts in energy $\tilde{E} = E - \kappa \Delta z$ and Feynman variable $\tilde{x}_F = x_F (1 - \kappa \Delta z / E)^{-1}$ are taken into account here; $\Delta z = z_2 - z_1$; $\rho(b, z)$ is the nucleon density, depending on the impact parameter b and the longitudinal coordinate z; $\delta(b, z) = (\rho_n - \rho_p)/\rho$ is the relative difference of the neutron and proton densities;

$T(b, z_1, z_2) = \int_{z_1}^{z_2} dz\, \rho(b, z)$; the hadron-nucleon inelastic cross section is σ_{hN}^{in}; The cross section $\sigma_{\Psi N}^{in} \simeq 2$ mb is dominated by the contribution of the reaction $\Psi N \to DDX$. The $\Psi N \to \Psi X$ cross section is small, about 0.08 mb.

The first term in expression (1) corresponds to the case when the incident hadron produces J/Ψ on one of the nucleons without undergoing an inelastic scattering before the hard process. It is clear that such events take place on the nuclear surface and their contribution to the cross section increases with A as $A^{2/3}$.

If the incident hadron undergoes inelastic scatterings before producing the J/Ψ, the corresponding contribution described by the second term in expression (1) has approximately a linear A dependence at $x_F \simeq 0$ and $\propto A^{2/3}$ as $x_F \to 1$.

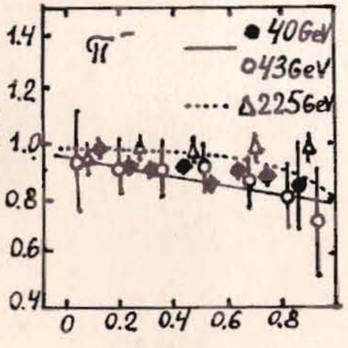
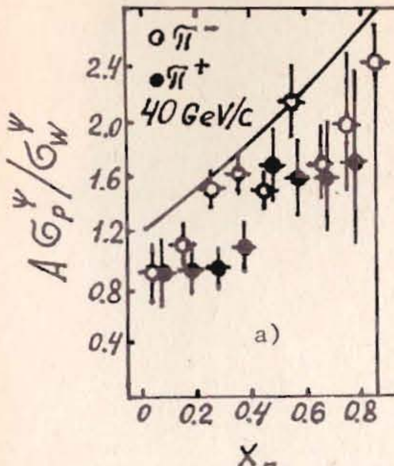


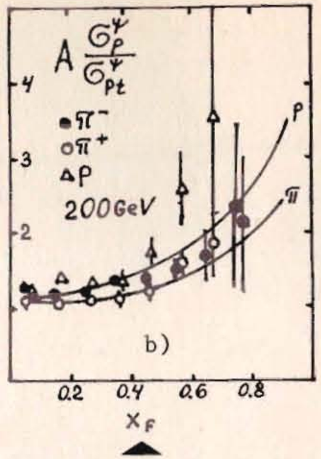
Fig.1

Such behaviour of the exponent $\alpha(x_F)$ is confirmed by the data [4-6] shown in fig.1. The x_F-dependence of the ratio $A\sigma_{hp}^{\Psi}(x_F)/\sigma_{hA}^{\Psi}(x_F)$ is shown in fig.2. The theoretical curves are obtained by using expression (1). The nuclear density $\rho(b, z)$ is taken in the Woods-Saxon form. We neglect the small (about 7%) difference between the values of $\sigma_{\pi^+ p}^{\Psi}$ and $\sigma_{\pi^- p}^{\Psi}$. The energy dependence of $\sigma_{\pi N}^{\Psi}$ is taken in the form [6] $\sigma_{\pi N}^{\Psi}(E) \propto \propto \exp(-a/E)$, where $a \approx 20$ GeV. The x_F-dependence is approximated by $\sigma_{\pi N}^{\Psi}(x_F) \propto (1 - x_F)^2$; $\sigma_{NN}^{\Psi}(x_F) \propto (1 - x_F)^5$. The string tension κ for the colour octet string can be considerably larger than the value $\kappa \simeq 1$ GeV/fm, obtained [2] for the static triplet string. The data [8] for the high hadron pair production off nuclei are well described [9] with $\kappa \simeq 3$ GeV/fm. We have used this value here.

Influence of the Fermi-motion compensates partially the effect of retardation. Nevertheless, the estimates made for 40 GeV incident energy have shown [6] that the corresponding correction is small and decreases rapidly with increasing energy.

It is worth noting that the comparison of the data in fig.2b for the proton and pion beams confirms the retardation effect. Indeed, the x_F-dependence of $\sigma_{pp}^{\Psi}(x_F)$ is steeper than that of $\sigma_{\pi N}^{\Psi}(x_\Phi)$. The comparison of the data in figs.2a and 2b also shows that the effect of retardation is shifted to larger x_F values when the energy increases.





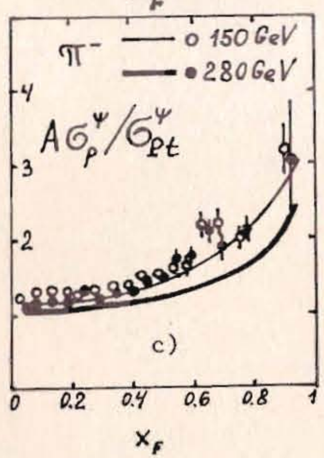


Fig.2

2. The data [6] in fig.2b show that there is a difference between $\sigma_{\pi^+ A}^{\Psi}$ and $\sigma_{\pi^- A}^{\Psi}$. This is due to the fact that $\sigma_{\pi^+ p}^{\Psi} \neq \neq \sigma_{\pi^- p}^{\Psi}$. The theoretical curves in fig.2 should be compared with the ratio

$$A(\sigma_{\pi^+ p}^{\Psi} + \sigma_{\pi^- p}^{\Psi})/(\sigma_{\pi^+ A}^{\Psi} + \sigma_{\pi^- A}^{\Psi})$$

where the contribution of $\delta(b, z)$ is cancelled.

On the other hand, the reaction of J/Ψ production on nuclei can be used to measure the value of δ characterizing the relative difference of the neutron and proton densities in that region of the nucleus which gives the main contribution to the cross section.

$$\bar{\delta} = \frac{(\sigma_{\pi^+ A}^{\Psi} - \sigma_{\pi^- A}^{\Psi})(\sigma_{\pi^- p}^{\Psi} + \sigma_{\pi^+ p}^{\Psi})}{(\sigma_{\pi^+ A}^{\Psi} + \sigma_{\pi^- A}^{\Psi})(\sigma_{\pi^- p}^{\Psi} - \sigma_{\pi^+ p}^{\Psi})} . \qquad (2)$$

If $x_F \approx 0$, there is no nuclear screening and $\bar{\delta} \simeq (A - 2Z)/A$. But when $x_F \to 1$ the screening becomes large and one measures the value of δ on the nuclear surface. This statement is model-independent. The smallness of $\sigma_{\Psi N}^{in}$ permits one to avoid the problem to consider secondary interactions. Thus the method proposed seems to be promising (cf.ref. [10]).

The effective thickness of the corresponding nuclear matter can be estimated in this model: $\Delta z \simeq (1 - x_F)E/\kappa$. To increase the sensitivity to the value of δ, one has to choose intermediate energies, where the difference $\sigma^{\Psi}_{\pi^- p} - \sigma^{\Psi}_{\pi^+ p}$ is larger, or to investigate the $\mu^+\mu^-$ pair production outside the J/Ψ peak.

3. In addition to the effect considered above the shadowing of the wee-partons of the nucleus also takes place, due to the overlap of parton clouds in the system of reference where the nucleus is fast [11]. This shows up at $x_F > \frac{M_\Psi^2 R}{s R_N} A$, and becomes significant at large energies, which may explain the discrepancy between the data and calculation in fig.2a and 2c.

4. The approximation used here neglects the gluon bremsstrahlung which should be present, since the quarks change their colour every time they interact with a nucleon inside the nucleus. We assume that the bremsstrahlung is confined inside the colour flux tube. In the framework of the simplified approach presented above this should show up as an effective increase in the value of κ with respect to the static one.

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Копелиович Б.З., Нидермайер Ф. E2-84-834
Ядерное экранирование образования J/Ψ мезонов и лептонных пар

Торможение адронов цветными силами при прохождении через ядро приводит к значительному экранированию вблизи кинематической границы $X \to 1$. Показано, что, изучая импульсный спектр образования J/Ψ или $\ell\bar{\ell}$ на ядрах, можно эффективно измерить различие плотностей нейтронов и протонов в разных слоях ядерного вещества до поверхности.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Kopeliovich B.Z., Niedermayer F. E2-84-834
Nuclear Screening in J/Ψ and Lepton Pair Production

The incident hadron turns into a coloured state in an inelastic collision inside a nucleus and is slowed down by colour forces. This leads to a considerable nuclear screening near the kinematical boundary $x_F = 1$. The momentum dependence of J/Ψ or $\ell\bar{\ell}$ production off nuclei provides a model-independent information about the difference of neutron and proton densities inside the nucleus up to the nuclear surface.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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