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ON THE A DEPENDENCE IN THE PROCESSES OF DILEPTON PRODUCTION BY HIGH-ENERGY NUCLEONS

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С.Р.ГЕВОРКЯН, В.М.ЖАМКОЧЯН

ОБ А-ЗАВИСИМОСТИ В ПРОЦЕССЕ РОЖДЕНИЯ ЛЕПТОННЫХ ПАР НУКЛОНАМИ ПРИ ВЫСОКИХ ЭНЕРГИЯХ

Рассмотрен процесс образования лептонных пар в нуклон-ядерных столкновениях при высоких энергиях. Показано, что при учете неупругих переходов $N \to \pi \to \mu^+\mu^-$, экспериментально наблюдаемая А-зависимость сечения процесса $NA \to \mu^+\mu^- X$ может быть объяснена в рамках теории многократного рассеяния.

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ON THE A-DEPENDENCE IN THE PROCESSES OF DILEPTON PRODUCTION BY HIGH-ENERGY NUCLEUS

The process of lepton pairs production in nucleon-nucleus collisions at high energies is considered. It is shown, that with due regard for the inelastic transitions $N \to \pi \to \mu^+\mu^-$ the experimentally observed A-dependence of the cross section of the process $NA \to \mu^+\mu^- X$ can be explained in the framework of the multiple scattering theory.

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The discovery of the J/ψ and ψ' resonances stimulated investigations of dilepton production processes in the hadron and photon beams, which led to a great deal of experimental data on these processes at different energies. Because of the smallness of dilepton production cross section for large masses (for example, the J/ψ-meson production cross section by protons of FNAL energies $\sigma(pp \to J/\psi \sim 10^{-34}\ cm^2$), the majority of experiments was performed on nuclear targets. To extract the corresponding cross section on a single nucleon from such data, the cross section on the nucleus is usually divided [1] by the atomic number of the nucleus A or by $A^{2/3}$.

Two experiments [2,3] were recently performed in which the A dependence ($\sigma \sim A^{\alpha}$) of the dimuon production cross section was investigated in detail of neutron [2] and proton [3] beams of FNAL energies within the wide range of dimuon masses. The index of the A dependence was determined to be $\alpha \approx 0{,}6$ for ρ, ω, φ masses while for J/ψ mass region it was $\alpha \approx 0{,}9$, remaining practically constant with the subsequent rise of dimuon masses.

As is shown in the present paper, such A dependence of the cross section of the process $NA \to \mu^+\mu^- X$ can be understood and described

numerically in the framework of multiple scattering theory conveniently generalized for the case of inclusive production of particles on nuclei [4,5].

First, let us consider the behaviour of inclusive dimuon production cross section on middle and heavy nuclei within the J/ψ -meson mass region. It is well known [6,7], that up to FNAL energies, the cross section of the elementary process $NN \to J/\psi X$ is strongly dependent on the energy of colliding nucleons. The cross section of the process, $\sigma(pN \to J/\psi X$, increases with the energy growth, increasing, for example, from the maximum Serpukhov energy (E_p = 70 GeV) up to the FNAL energies (E_p = 400 GeV) roughly by one order. On the other hand, the invariant functions relevant to the elementary processes $NN \to NX$ depend on the energy only through the variable $X = \frac{E}{E_0}$, i.e. $f(E_0, E, P_\perp) = f(X, P_\perp)$ (scaling).

Neglecting for the sake of simplicity the rescatterings of the J/ψ-meson in the nucleus, the account of which is not essential for the given process, since [8] $\sigma^{tot}(\psi N) \approx 1 mb \ll \sigma(NN)$, and using the calculation technique of the inclusive spectra in the multiple scattering theory [4,5], it is easy to find for the cross section of the process $NA \to J/\psi X$ the following expression

$$X \frac{d\sigma}{dx\, d^2P_\perp}(E_0, X, P_\perp) = \frac{1}{(2\pi)^4} \int d^2B\, d^2b\, d\alpha\, d\alpha'\, dz\, \rho(\vec{B}, z)\, \Omega(\alpha, \alpha', \vec{b}) \times$$
$$\times \exp\left\{ i\vec{P}_\perp \vec{b} + i\alpha \ln X - [\sigma - \omega(\alpha, \alpha', \vec{b})] \int_{-\infty}^{z} \rho(\vec{B}, z)\, dz \right\} \qquad (1)$$

Here E_0 is the energy of the incident nucleon, $\vec{P}_\perp$ is the transverse momentum of the J/ψ -meson, $\rho(\vec{B}, z)$ represents the one-particle nuclear density function ($\int \rho(\vec{r})\, d^3r = A$), $\sigma \equiv \sigma^{tot}(NN)$

The values Ω and ω are expressed through the cross sections of the elementary processes $NN \to J/\psi X$ and $NN \to NX$ as follows

$$\Omega(\alpha,\alpha',\vec{b})=\int\frac{d\sigma_{N\to\psi}(E',x,P_\perp)}{d^2P_\perp}\frac{}{x}\,e^{-i\vec{P}_\perp\vec{b}-i\alpha\ln x+i\alpha'\ln\frac{E'}{E_0}}\cdot d^2P_\perp dx\frac{dE'}{E'} \quad (2)$$

$$\omega(\alpha,\alpha',\vec{b})=\int\frac{d\sigma_{N\to N}}{d^2P_\perp dx}\,e^{-i(\alpha+\alpha')\ln x-i\vec{P}_\perp\vec{b}}\,dx\,d^2P_\perp \quad (3)$$

Eq. (1) describes the process in which the incident nucleon undergoes a number of elastic and inelastic rescatterings within the nucleus, producing then the J/ψ-meson on one of the nucleons having the longitudinal coordinate z. The J/ψ-meson is assumed to go out from the nucleus without interacting with the nucleons.

Below we shall consider the cross sections of the inclusive production integrated over the transverse momentum of the muon pair. Integrating Eq.(1) over $\vec{P}_\perp$ we get

$$x\frac{d\sigma}{dx}(E_0,x)=\frac{1}{(2\pi)^2}\int d\alpha\,d\alpha'\,\Omega(\alpha,\alpha',E_0)\,e^{i\alpha\ln x}\,N(0,\sigma-\omega(\alpha,\alpha')) \quad (4)$$

where

$$\Omega(\alpha,\alpha',E_0)=\int\frac{d\sigma_{N\to\psi}}{dx}(x',E_0,x)\,e^{-i\alpha\ln x+i\alpha'\ln x'}\,dx\,d\ln x' \quad (5)$$

$$\omega(\alpha,\alpha')=\int\frac{d\sigma_{N\to N}}{dx}\,e^{-i(\alpha+\alpha')\ln x} \quad (6)$$

and $N(\sigma_1,\sigma_2)=\int\frac{e^{-\sigma_1 T(\vec{b})}-e^{-\sigma_2 T(\vec{b})}}{\sigma_2-\sigma_1}$ are effective nucleon numbers $T(\vec{b})=\int_{-\infty}^{\infty}\rho(\vec{b},z)\,dz$

Before passing to numerical calculations, let us see how the energy dependence of the cross section of the elementary process $NN\to J/\psi X$ affects the A dependence of the corresponding cross section on nucleus. It is most evident on the example of the total cross section of the pro-

cess $NA \to J/\psi X$. Integrating Eq.(4) over the variable X and assuming the cross section of the process $NN \to J/\psi X$ to have the threshold dependence on the energy, $\frac{d\sigma_{N\to J/\psi}}{dx}(E,x) \sim E^{\ell}$, one may easily find

$$\sigma(NA \to J/\psi X) = \sigma(NN \to J/\psi X) N(0,\sigma - \omega(0,i\ell)) \qquad (7)$$

Hence, it is clear, that if the energy dependence of the cross section of the process $NN \to J/\psi X$ is negligible ($\ell = 0, \omega(0,0) = \sigma, N(0,0) = A$), the ratio of the cross section of the J/ψ production on nucleus to that on a single nucleon, should be equal simply to the atomic number A . On the other hand, at sufficiently large $\ell (\ell \gg 1)$ $\omega(0,i\ell)$ becomes much smaller than σ , and therefore, this ratio varies as $A^{2/3}$ ($N(0,\sigma) \sim A^{2/3}$ at $\sigma \gg 1$). Physically this result is caused by the fact, that if the energy dependence of the cross section of the elementary production process is sufficiently strong , the nucleons which produce J/ψ-mesons are arranged on the front surface of the nucleus, the area of which is proportional to the square of the nucleus radius, i.e. to $A^{2/3}$.

Another effect which could appreciably influence the A dependence of the cross section of the process $NA \to J/\psi X$ consists in the possibility of the π -mesons production by nucleons with the subsequent production of J/ψ -resonance. It is known [9], that the cross section of the J/ψ production on the isotopsymmetrical target (for example, on the C^{12} nucleus) by π -mesons is roughly two times greater than that by protons, $\frac{\sigma_p(x>0)}{\sigma_\pi(x>0)} = 0{,}46 \pm 0{,}063$ [2,3].

The experiments we are interested in, the dependence of the muon pairs production was investigated within the incident nucleon fragmentation region ($X > 0{,}25$ in the neutron [2] and $X > 0{,}2$ in the proton [3] experiments) and the X dependence of the spectra in the case

of dimuon production by nucleons is considerably sharper than in the pion beams [9,10]. This leads to the J/ψ production cross section by pion beams by more than two times greater than that of nucleons.

The inclusive cross section describing J/ψ-meson production as two-step transition $N \to \pi \to J/\psi$ could be represented in the following form

$$x\frac{d\sigma}{dx}(N\to\pi\to J/\psi)=\frac{1}{(2\pi)^2}\int d\alpha d\alpha' \Omega_{N\to\pi}(\alpha,\alpha')\Omega_{\pi\to\psi}(\alpha,\alpha',E_0)\times$$
$$\times e^{i\alpha b n x}\frac{1}{\sigma_\pi-\omega_{\pi\pi}(\alpha,\alpha')}\left[N\left(0,\sigma_N-\omega_{NN}(\alpha,\alpha')\right)-N\left(\sigma_N-\omega_{NN}(\alpha,\alpha'),\sigma_\pi-\omega_{\pi n}(\alpha,\alpha')\right)\right] \quad (8)$$

Thus, the cross section of the process $NA \to J/\psi X$ is defined as the sum of Eqs.(4) and (8) taking into account the contibutions from all π-mesons in (8). The calculations were performed under following assumptions. For the cross section of the processes $NN \to J/\psi X$ and $\pi N \to J/\psi X$ the following parametrization was taken

$$x\frac{d\sigma}{dx}(E,x)=\frac{\pi A}{6B^2}(1-x)^C\left(1-\frac{6}{\sqrt{E}}\right) \quad (9)$$

with the parameters A,B,C from Ref. 10.

In the above expressions we have assumed the J/ψ production cross section on neutrons to be equal to that on protons. This is due to the fact that the parametrization (9) was recalculated on a nucleon from the data for the isotopsymmetrical nucleus C^{12} divided by the atomic number.

The simplest energy dependence in Eq.(9) describes the energy behaviour of the total cross sections [6,7] of the processes $pN \to J/\psi X$ and $\pi N \to J/\psi X$ in the energy range from 40 to 300 GeV. The cross sections of the processes $NN \to NX$ and $\pi N \to \pi X$ were parametrized in the form

$$\frac{d\sigma}{dx}(NN\to NX)=const\ ,\quad x\frac{d\sigma}{dx}(\pi N\to\pi X)=const$$

The structure functions for the process $NN \to \pi X$ were taken in the form of $x\frac{d\sigma}{dx} = B(1-x)^n$ with the parameters B and n taken from the Ref. 11 . At last, for the calculation of the effective nucleon numbers $N(\sigma_1, \sigma_2)$, we have used the nucleon distribution in the form

$$\rho(r) = \frac{\rho_0}{1 + \exp\left(\frac{r-R}{c}\right)} \qquad \text{where } R = 1{,}12\,A^{1/3} \text{ and } C = 0{,}5 \text{ f}$$

It turned out, that the index α in the A dependence of the cross section of the process $NA \to J/\psi X$ within the incident nucleon fragmentation region (expressions (4) and (8) were integrated over X between the limits 0,2 (0,25) and 1) takes the values in the interval 0,84 - 0,91 in terms of the choice of the parameters in the cross sections of the elementary processes, which agrees with the experimental data [2,3] . The contribution, due to the accounting of the intermediate channels to the cross section, reaches 40% and influences strongly on the dependence on the atomic number. (Without respect to the intermediate channels the index α does not exceed the value 0,8).

Let us consider now the dimuon production within the mass region corresponding to ρ, ω, φ -mesons. Within this region, it is necessary to take into account the rescatterings of the produced vector meson. Since in this mass region for the cross section of the process $NN \to \mu^+\mu^- X$ the approximate scaling takes place, the cross section of the process $NA \to \mu^+\mu^- X$ takes the form

$$x\frac{d\sigma}{dx} = \frac{1}{2\pi}\int d^2B\,d\alpha\,\omega_{NV}(\alpha)\,e^{i\alpha \ln x}\,N\left(\sigma_{NN}-\omega_{NN}(\alpha), \sigma_{VN}-\omega_{VN}(\alpha)\right) \qquad (10)$$

In this expression $\omega_{xy}(\alpha) \equiv \omega_{xy}(x,b)$, the latter being defined according to Eq.(6), and σ_{VN} are total cross sections of interaction of vector mesons ρ, ω, φ with nucleons. The calculation

performed using Eq.(10) shows that within the region of dimuon masses corresponding to the production of ρ, ω, φ -mesons, the index α takes the values in the interval 0,52 - 0,6 which does not contradict with the experimental data [2,3].

Within the region of the continuum dimuon masses one may use Eqs.(4) and (6) as well. However, at present there are no reliable data within this region on the energy dependence of the cross section of the process $NN \to \mu^+\mu^- X$, and we did not carry out such a calculation.

The analogous situation takes place also in the case of muon pairs production by π -mesons. In Ref. 3 the dependence was presented of the index α on the invariant mass of the pair produced by π^+-mesons with E_π=225GeV. The obtained value of the index α within the region of the J/ψ resonance proved to be smaller than in the case of production by nucleons ($\alpha_\pi \approx 0{,}8$). In the frame of the picture discussed above, this is caused by the smallness of the intermediate channels contribution to the cross section of the process $\pi + A \to J/\psi X$.

On the other hand, for the pair produced within the continuum region, the index α takes the value $\simeq 1$ [3] for the pair mass $\simeq$ 2,5GeV. We suppose, this is direct consequence of the contribution of the process $\pi^+ \to \pi^- \to \mu^+\mu^-$, since within this mass region the cross section of the production of dimuons by π^- -mesons is roughly two times greater than that by $\pi^\pm$ -mesons [3,9].

Unfortunately, there are no data on the A dependence for the π^--meson beams.

The picture of the interaction proposed above being valid, the value of α for the mass region $M_{\mu^+\mu^-}$ = 2-3 GeV should be appreciably smaller than the analogous value for $\pi^\pm$ -mesons.

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ЛЕПТОННЫХ ПАР НУКЛОНАМИ ПРИ ВЫСОКИХ ЭНЕРГИЯХ

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