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Nuclear Shadowing Effect in Photoproduction Process at LHC

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Abstract In the paper we give some results about nuclear shadowing of real photon at LHC. We show that shadowing grows strong with the increasing of photon energy E_γ. The CMS energy dependence of total cross sections of production of ρ, ω and ϕ in the process $\gamma + A \rightarrow V + A$ is also given. The results show that there is a critical energy point, above which the nuclear shadowing is strong enough to be observed.

Key words elastic photoproduction process, nuclear shadowing, vector mesons

Nuclear shadowing effect in deep-inelastic scattering off nuclei is a hot topic for the last two decades[1]. The experimental result implies that the total $\sigma(\gamma^* A)$ on a nucleus (with mass number A) at small Bjorken x ($x < 0.01$) is less than A times the total cross section $\sigma_{\mathrm{tot}}(\gamma^* \mathrm{N})$ on a nucleon. Many theoretical efforts have been devoted to understand this phenomenon quantitatively, among which a very intuitive picture arises in the rest frame of the nucleus, where shadowing may be understood in the following way: The virtual photon fluctuates into a hadronic state that interacts with the nucleus at it's surface and the nucleons inside have less chances to interact with the photon, thus the total cross section is less than expected naively. This idea leads to the vector meson dominance model. The fluctuation extends over a distance called coherence length

$$\lambda = \frac{2E_\gamma}{Q^2 + M_{\mathrm{X}}^2}, \tag{1}$$

where M_{X} is the invariant mass of the fluctuation, E_γ is the energy of the photon and Q^2 is the virtuality of the photon which is related to the size R_{A} of the nucleus by $Q^2 \leqslant 1/R^2$. The shadowing correction is given by[2]

$$\sigma_{\mathrm{tot}}^{\gamma^* \mathrm{A}} = A\sigma_{\mathrm{tot}}^{\gamma^* \mathrm{N}} - A\langle T\rangle \int \mathrm{d}^2 b \int \mathrm{d}M_{\mathrm{X}}^2 \left.\frac{\mathrm{d}^2\sigma(\gamma^* \mathrm{N}\rightarrow \mathrm{XN})}{\mathrm{d}t\mathrm{d}M_{\mathrm{X}}^2}\right|_{t=0} F_{\mathrm{A}}^2(\lambda, b), \tag{2}$$

where the nuclear form factor is

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$$F_A^2(\lambda,\ b) = \frac{1}{A\langle T\rangle}\left|\int_{-\infty}^{+\infty} dz\rho_A(b,z)\exp(iz/\lambda)\right|^2, \tag{3}$$

$$\langle T\rangle = \frac{1}{A}\int d^2bT^2(b), \tag{4}$$

where the nuclear thickness $T(b) = \int dz\rho_A(b,z)$ is the integral of the nuclear density over the direction of the incident photon and b is the impact parameter. We choose the nuclear density as the Gaussian $\rho_A(r) = A(\pi R_A^2)^{-3/2}\exp(-r^2/R_A^2)$. The radius of a nucleus is given approximately by $R_A = 1.2A^{1/3}$, where A is the nucleon number.

From the above equations we obtain

$$\sigma_{tot}^{\gamma^*A} = A\sigma_{tot}^{\gamma^*N}\left[1 - \frac{2A^{1/3}}{a^2}\frac{1}{\sigma_{tot}^{\gamma^*N}}\int dM_X^2\frac{d^2\sigma(\gamma^*N\to XN)}{dtdM_X^2}\bigg|_{t=0}\exp\left(-\frac{a^2A^{2/3}}{2\lambda^2}\right)\right], \tag{5}$$

where $a \simeq 1.2$fm.

In the theory of lepton-nucleus interactions there is a close relation between nuclear shadowing and diffractive scattering which has been tested by E665 Collaboration[3]. This means one can take the Regge theoretical diffractive result, the double differential cross section for the process $\gamma^* + N\to X + N$

$$\frac{d^2\sigma^D(\gamma^*N\to XN)}{dtdM_X^2} \sim \left(\frac{1}{M_X^2}\right)^{\alpha P(0)}(W^2)^{2\alpha P(0)-2}e^{b|t|} \tag{6}$$

into Eq.(5) to get the shadowing result.

It is easy to extrapolate the above results to the real photonic shadowing phenomenon in the limit $Q^2\to 0$. Keeping the real photon massless, shadowing still occurs via the above physical picture. The coherence length of hadronic states of mass M_X, produced by a real photon of energy E_γ is

$$\lambda = \frac{2E_\gamma}{M_X^2}. \tag{7}$$

We therefore expect that the total cross section $\sigma_{tot}(\gamma A) < A\sigma_{tot}(\gamma N)$. To discuss the photonuclear effects it is also useful to define the effective number of nucleons in the nucleus by

$$\frac{A_{eff}}{A} = \frac{\sigma(\gamma A)}{A\sigma(\gamma N)}, \tag{8}$$

$$\frac{A_{eff}}{A} = 1 - \frac{2A^{1/3}}{a^2}\frac{1}{\sigma_{tot}^{\gamma N}}\int dM_X^2\frac{d^2\sigma^D(\gamma N\to XN)}{dtdM_X^2}\bigg|_{t=0}\exp\left(-\frac{a^2A^{2/3}}{2\lambda^2}\right). \tag{9}$$

Using HEAR diffractive photoproduction results[4] for the above equations, we obtain the shadowing ratio $\frac{A_{eff}}{A}$ for Pb and Ca nuclei in the photonuclear process at LHC, which is shown in Fig. 1. In the LHC process $\gamma A\to XA$ the maximum energy of photon E_γ may arrive to 80GeV for Pb and 180GeV for Ca respectively. Fig. 1 shows that shadowing grows stronger for higher photon energy E_γ, eventually approaching some saturation value. This is due to the fact that the coherence length govern scattering processes. This can be easily understand from Eq. (9), taking the limit $\lambda\to\infty$ one can obtain

$$\frac{\sigma(\gamma A)}{A\sigma(\gamma P)}=1-\frac{2A^{1/3}}{a^2}\frac{1}{\sigma(\gamma P)}\left.\frac{d\sigma^D(\gamma P\to XP)}{dt}\right|_{t=0}. \tag{10}$$

It is also interesting to study elastic vector meson photoproduction in the processes A + A→V + A + A, (V = ρ, ω, ϕ) at LHC. The equivalent photon spectrum function[5] is given by

$$n(E_\gamma)\approx\frac{2Z^2\alpha}{\pi E_\gamma}\ln\left(\frac{\gamma_1}{RE_\gamma}\right), \tag{11}$$

where $R=b_{min}$ (b_{min} is the cut-off of impact). γ_1 is Lorentz factor of nuclei. The production cross section of a photon fusion a parton in the nucleus in the collision of heavy-ion is given by

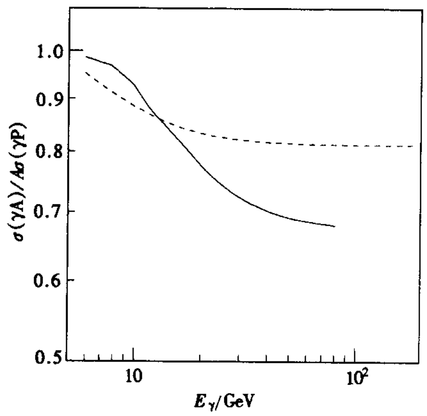

Fig. 1 The shadowing ratio for the absorption of real photons on nuclei as a function of photon energy E_γ, solid line for Pb and dashed line for Ca

$$\sigma_{tot}(AA\to AAV)=\int dE_\gamma n(E_\gamma)\sigma_{tot}(\gamma A\to VA), \tag{12}$$

$$\sigma_{tot}^{\gamma A}=A\sigma_{tot}^{\gamma P}\left[1-\frac{2A^{1/3}}{a^2}\frac{1}{\sigma_{tot}^{\gamma P}}\left.\frac{d\sigma^D(\gamma P\to VP)}{dt}\right|_{t=0}\exp\left(-\frac{a^2A^{2/3}}{2\lambda^2}\right)\right], \tag{13}$$

where

$$\lambda=\frac{2E_\gamma}{Q^2+M_V^2}. \tag{14}$$

Using HEAR diffractive photoproduction results[6] of vector mesons for the above equations, we obtain the total cross section of elastic production of ρ, ω and ϕ in the process γ + A→V + A which are shown in Fig. 2(a) is for the process γ + Pb→V + Pb. When CMS energy of γ-Pb is below 240GeV the total cross section of ρ (the solid line in the figure) shows a very good shape like $\sigma(\gamma Pb)\sim A\sigma(\gamma P)\sim AW^{0.22}$, while $W>$ 240GeV the shadowing effect becomes very strong, here the critical energy point $W=$ 240GeV is correspond to E_γ = 5.0GeV. So do that of ω and ϕ where the critical energy point are $W=$ 292GeV, E_γ = 7.2GeV and $W=$ 339GeV, E_γ = 9.7GeV. Fig. 2(b) is for the process γ + Ca→V + Ca. Here we get the similar results as those in Fig. 2(a). $W=$ 250GeV, E_γ = 4.1GeV for ρ and ω, $W=$ 330GeV, E_γ = 7.2GeV for ϕ.

In conclusion, we have given some results about nuclear shadowing of real phoon at LHC. We show that shadowing grows strong with the increasing of photon energy E_γ. The CMS energy dependence of total cross sections of elastic production of ρ, ω and ϕ in the process γ + A→V + A is also given. The results show that there is a "critical" energy point, above which the nuclear shadowing is strong enough to be observed. So we think that the phenomenology of high energy real photonic nuclear shadowing may be an interesting subject of LHC, which can be studied in detail.

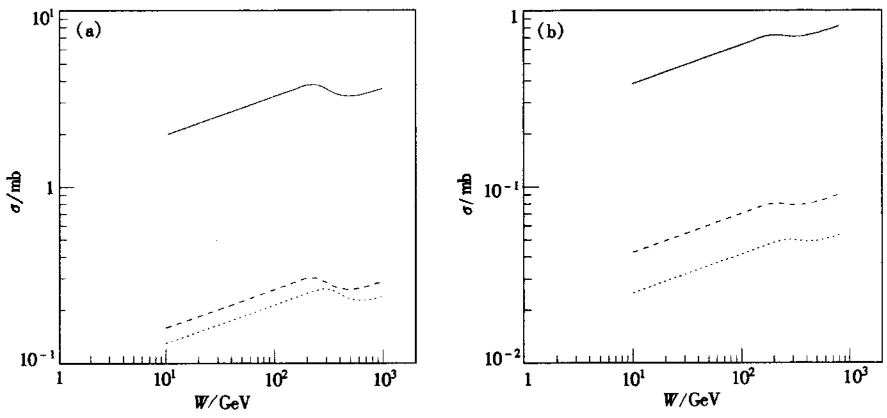

Fig. 2 (a) CMS energy distribution of total cross section of elastic photoproduction of ρ (solid line), ω (dashed line) and ϕ (dotted line) in $\gamma + Pb \rightarrow V + Pb$ processes.
(b) CMS energy distribution of total cross section of elastic photoproduction of ρ(solid line), ω (dashed line) and ϕ (dotted line) in $\gamma + Ca \rightarrow V + Ca$ processes

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LHC 光生过程中的核遮蔽效应

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摘要 给出了关于 LHC 实光子核遮蔽效应的一些结果. 证明了遮蔽随光子能量 E_γ 的增加而变强. 给出了反应过程 $\gamma + A \rightarrow V + A$ 中的ρ, ω, ϕ 总截面对质心系能量的依赖性. 结果表明,存在一个能量的临界点,在该点以上的核遮蔽强到足可以被测到.

关键词 弹性光生过程 核遮蔽 矢量介子

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