Hadrons production off nuclei in multiple scattering theory.

Sergey Gevorkyan
Joint Institute for Nuclear Research
Yerevan Physics Institute

Incoherent hadron scattering on nuclei

$pA \to pA'$

$$\frac{d\sigma}{dt} = \frac{1}{4\pi}\int e^{i\vec{q}\vec{\rho}}\, d^2\rho\, d^2B\, e^{-\sigma T(B)}\left[e^{\Omega(\rho)T} - 1\right]$$

$$T(B) = \int \rho(B,z)\,dz \qquad t = -q_\perp^2$$

$$\sigma \equiv \sigma^{tot}(pN)$$

$$\Omega(\rho) = \int \frac{d^2\Delta}{k^2}\, e^{i\vec{\Delta}\vec{\rho}}\, \frac{d\sigma^{el}}{d\Omega}$$

Expanding in Ω/σ :

$$\frac{d\sigma}{dt} = \frac{1}{4\pi}\sum_1^A \frac{1}{n!}\int d^2b\, e^{-\sigma T(B)}\, T^n(B)\, \delta(\vec{q}_\perp - \sum_1^n \vec{\Delta}_i)\prod_1^n \frac{d\sigma}{d^2\Delta_i} d^2\Delta_i$$

$$= N_1(\sigma)\frac{d\sigma_0}{dt} + N_2(\sigma)\int \frac{1}{\sigma}\frac{d\sigma_0}{dt}(\Delta)\,\frac{d\sigma_0}{dt}(\vec{q}-\vec{\Delta})\,d^2\Delta + \dots$$

$$N_n(\sigma) = \frac{1}{\sigma n!}\int (\sigma T(B))^n e^{-\sigma T(B)}\, d^2B$$

$$\Sigma N_n(\sigma) = N(0,\sigma) = \int \frac{1-e^{-\sigma T(b)}}{\sigma} d^2b$$

$$P_n = \frac{\sigma_{NN}^{inel}}{\sigma_{NA}^{in}} N_n(\sigma^{in}) \qquad \sum P_n = 1$$

Inclusive production off nuclei

$pA \to pX$

$$\frac{d\sigma}{dE' d^2q} = \frac{1}{4\pi} \sum_{n=1}^{A} \frac{1}{n!} \int T^n(b)\, e^{-\sigma T(b)} d^2b$$

$$\prod_1^n \frac{d\sigma_0}{d^2q_i\, dM_i^2} \left(\bar{q}_i, M_i, E - \sum_1^{i-1} \frac{q_k^2 + M_k^2 - m^2}{2m}\right)$$

$$\delta\left(\bar{q} - \sum_1^n \bar{q}_i\right) \delta\left(E - E' - \sum_1^n \frac{q_i^2 + M_i^2 - m^2}{2m}\right) d^2q_i\, d^2M_i$$

Feynman scaling $\quad E' \frac{d\sigma}{d^3p}(q, x, E) = f(q, x)$

$$x \frac{d\sigma}{dx\, d^2q} = \frac{1}{(2\pi)^3} \int d^2B\, d^2b\, d\lambda \exp\left(i\bar{q}\bar{b} + i\lambda \ln x\right) \cdot$$

$$e^{-\sigma T(B)} \left[e^{\omega(\lambda, b) T(B)} - 1 \right]$$

$$\omega(\lambda, \bar{b}) = \int \frac{d\sigma_0}{d^2q\, dx} e^{-i\bar{q}\bar{b} - i\lambda \ln x} dx\, d^2q$$

If elementary invariant cross section $pN \to pX$ is in the form:

$$E\frac{d\sigma_0}{d^3p} = f(p_\perp, x) = \frac{\sigma^{in}}{2\pi} B^2 \ell x^\ell \exp(-Bp_\perp)$$

B - slope $\quad \ell = \frac{1-K}{K} \quad K$ - inelasticity

$$E\frac{d\sigma}{d^3p} = E\frac{d\sigma_0}{d^3p} e^{Bp_\perp} \sum_{1}^{A} \frac{N_n(\sigma)}{\Gamma(n)\Gamma(\frac{3}{2}n)} \left(\frac{Bp_\perp}{2}\right)^{\frac{3}{2}n-1}$$

$$\left(\ell \ln \tfrac{1}{x}\right)^{n-1} K_{\frac{3}{2}n-1}(Bp_\perp)$$

$\sigma \equiv \sigma^{inel}$

Cronin et al. (1975)

This theory can be generalized on inclusive production. Gevorgyan et al. 1987

$$hA \to h'X \qquad h, h' = \text{HADRON, PHOTON}$$

$$\frac{d\sigma}{dx} = \sum_{n=1}^{A} N_n(\sigma)\, \phi_n(x)$$

$$N_n(\sigma) = \frac{1}{\sigma n!} \int (\sigma T)^n e^{-\sigma T} d^2 b$$

$$\phi_n(x) = \int \cdots \int \frac{1}{\sigma} \frac{d\sigma}{dx_1}(hN \to HX) \frac{1}{\sigma} \frac{d\sigma}{dx_2}(HN \to HX)$$

$$\cdots \frac{d\sigma}{dx_n}(HN \to h'X)\, \delta(x - x_1 \ldots x_n)\, dx_1 \ldots dx_n$$

$$\int \frac{d\sigma}{dx}(hN \to HX)\, dx = \int \frac{d\sigma}{dx}(HN \to HX)\, dx =$$

$$= \sigma^{inel}(hN) - \sigma_{diff} = \sigma$$

Experiment data Barton et al. (1983)

Fermilab $E_0 = 100$ GeV $\quad 0.3 \le x \le 0.88$

$hA \to h'X \qquad p_\perp = 0.3$ and 0.5

$h = p, \pi, K$

$h' = p, \bar{p}, \pi^{\pm}, K^{\pm}$

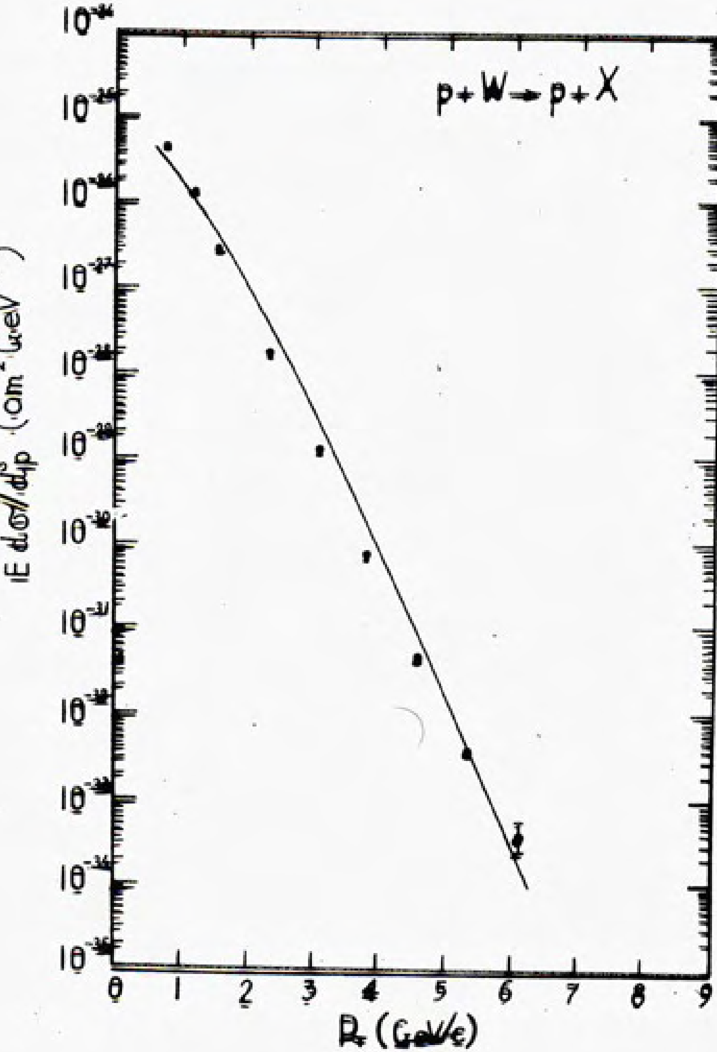


Fig. 1 Invariant cross section of the p + W → p + anything reaction versus P_T at incident energy E_0 = 300 GeV and the laboratory frame detection angle θ_L = 77 mrad.

-5-

pA → h'X

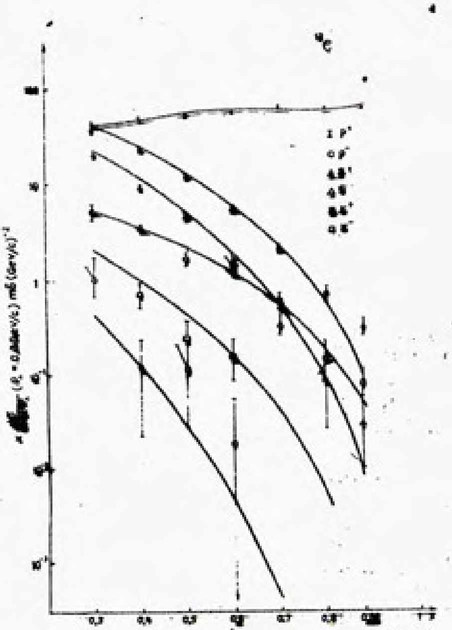
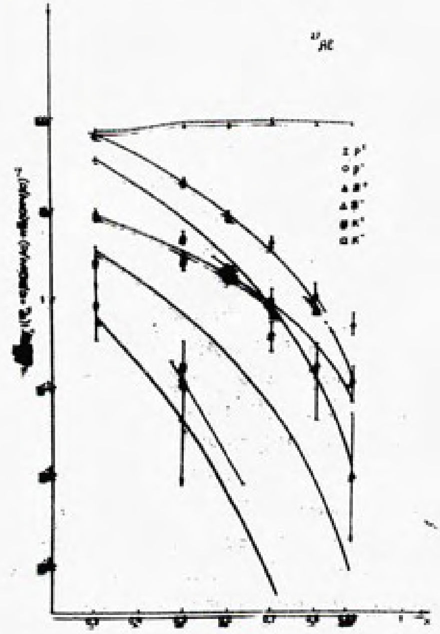


Рис.1



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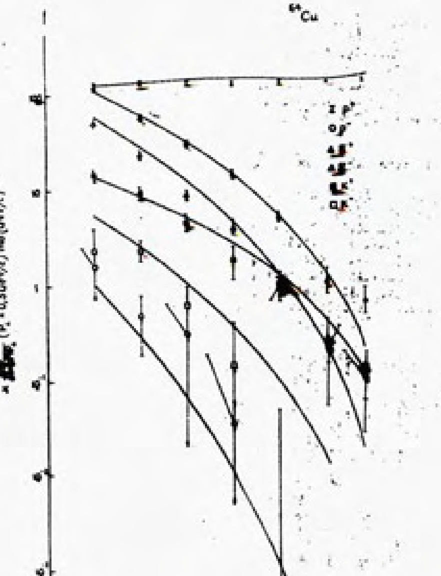

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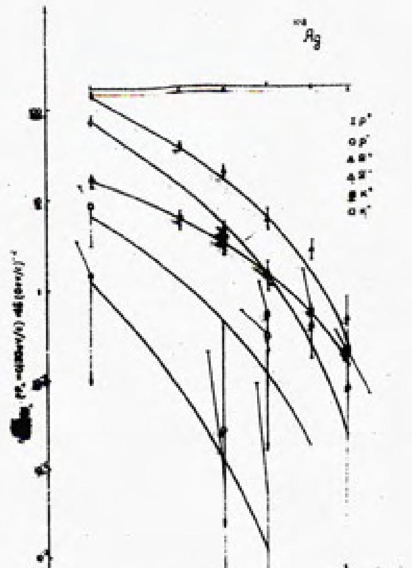


Рис.4

$pPb \to h'X$

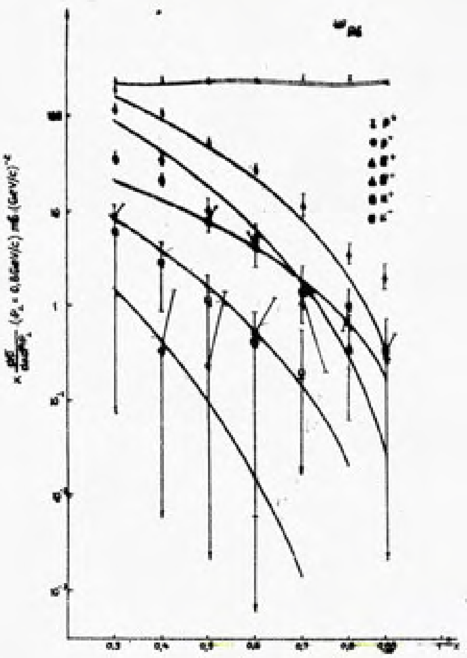
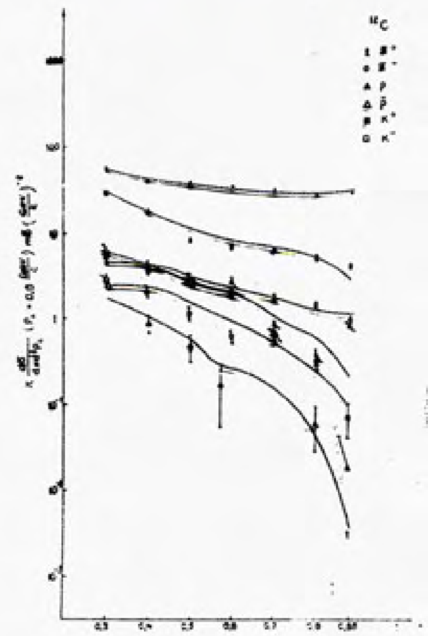


Рис.5

$\pi A \to h'X$



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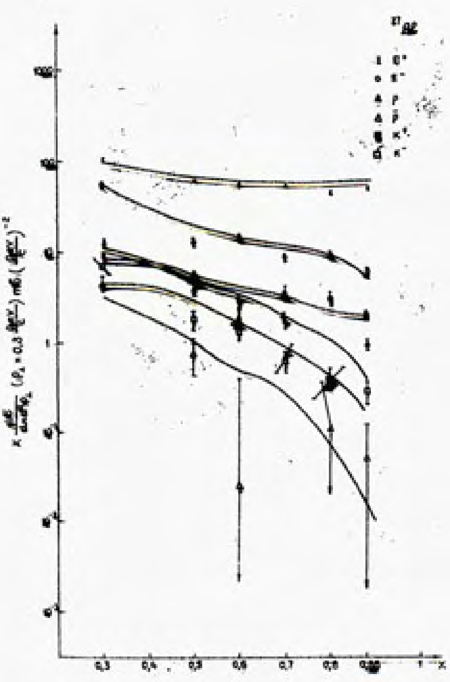

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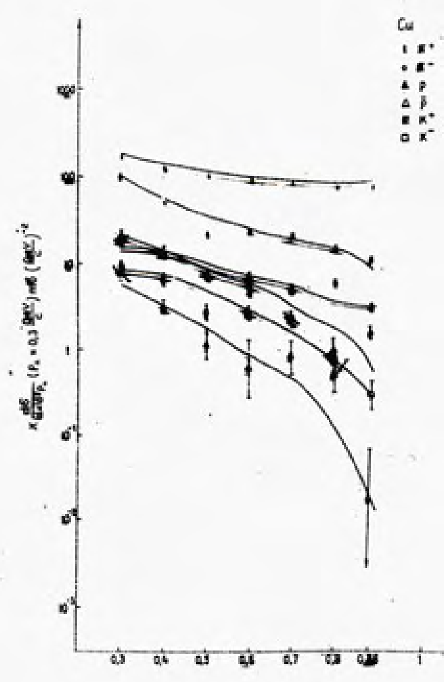
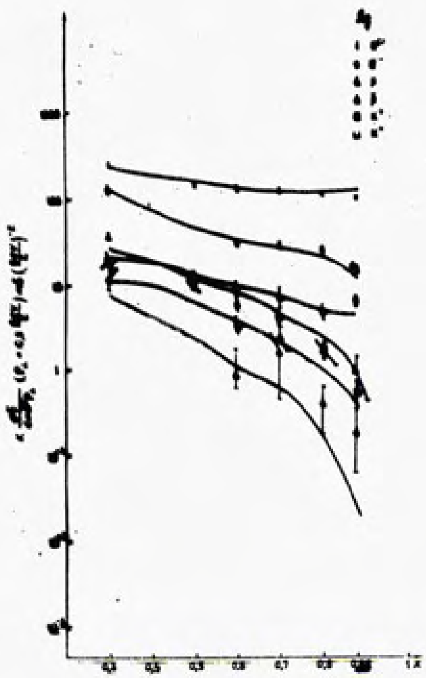


Рис.8



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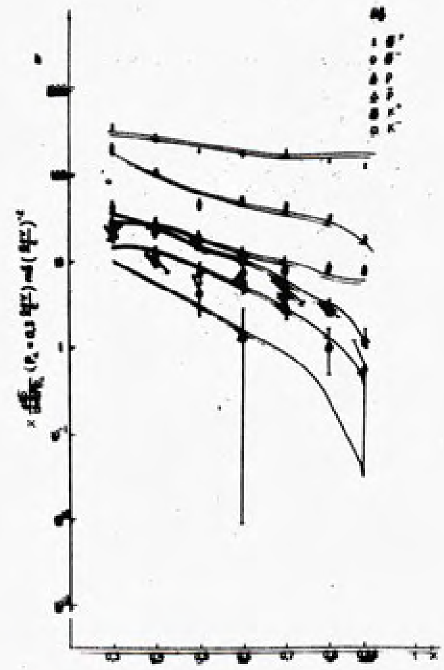


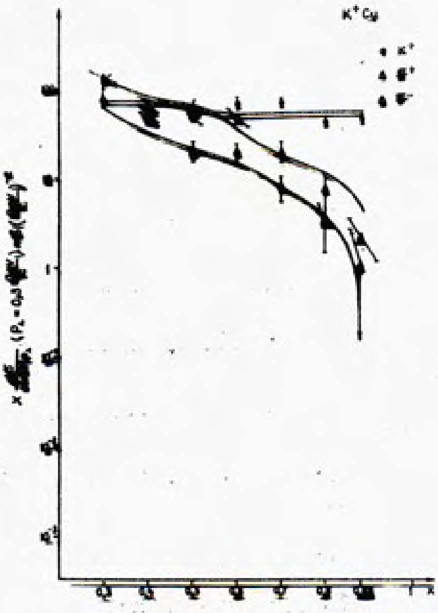
Рис.10

$K^+A \to h'X$

Рис.II

Рис.I2

$KA \to h'X$



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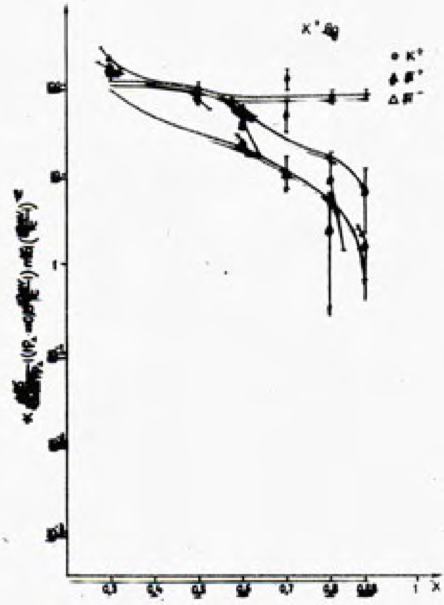

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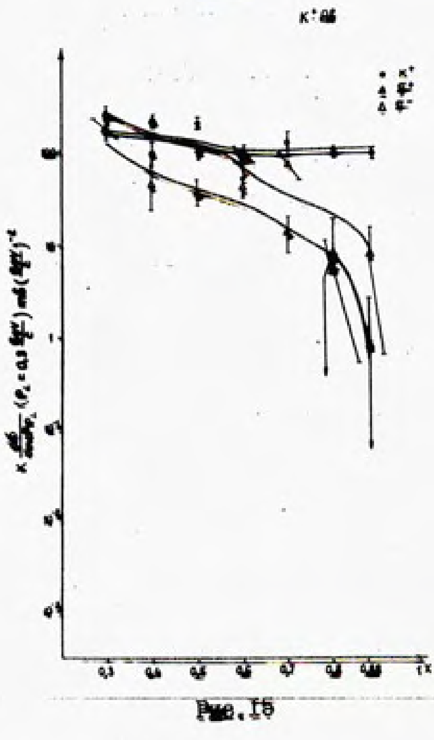

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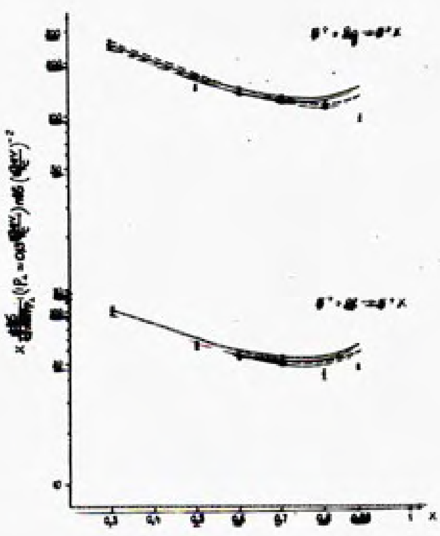

Рис.16

For photoproduction

$\gamma A \to h X$

$$x \frac{d\sigma}{dx\, d^2p} = \frac{1}{(2\pi)^2} \int d^2b\, d\alpha\, e^{i\bar{p}\bar{b} + i\alpha \ln x}\, \Omega_{\gamma h}(\alpha, \bar{b})$$

$$\times N(0, \tilde{\sigma})$$

$$N(0,\sigma) = \int \frac{1 - e^{-\sigma T(B)}}{\sigma}\, d^2B$$

$$\tilde{\sigma} = \sigma^{tot}_{hN} - \Omega_{hh}(\alpha, b)$$

$hN \to h' X$

$$\Omega_{hh}(\alpha, b) = \int \frac{d\sigma_{hh}}{dx\, d^2p}\, e^{-i\bar{p}\bar{b} - i\alpha \ln x}\, d^2p\, dx$$

$\gamma N \to h X$

$$\Omega_{\gamma h}(\alpha, b) = \int \frac{d\sigma_{\gamma h}}{dx\, d^2p}\, e^{-i\bar{p}\bar{b} - i\alpha \ln x}$$

$$\frac{d\sigma^{\gamma A \to hX}}{dx} = \frac{d\sigma^{\gamma N \to hX}}{dx} N(0,\sigma) + \sum_{n=1}^{A} \frac{M_n(\sigma)}{(n-1)!} \int_x^1 \frac{d\sigma^{\gamma N \to hX}}{dx_1} \left(\ln \frac{x_1}{x}\right)^{n-1} \frac{dx_1}{x_1}$$

$$M_n(\sigma) = N(0,\sigma) - N_1(\sigma) - \dots N_n(\sigma)$$

$\gamma\, Kr \to \pi^+ X$

$$R_A = \frac{\frac{1}{A}\frac{d\sigma^A}{d^2p}}{\frac{d\sigma^N}{d^2p}}$$

He
Ne

HERMES $\quad \gamma\, Kr \to \pi^{\pm},\ K^{\pm},\ p, \bar{p}$

All above consideration is strictly speaking true for structureless particles.

What happened when one account the complex structure of hadrons or even photon?

Total cross sections

$$\sigma_{tot}(hA) = 2\int \left(1 - e^{-\frac{\sigma T}{2}}\right) d^2b$$

$$\sigma_{tot}(hA) = 2\int |\psi(r)|^2 \left(1 - e^{-\frac{\sigma(r) T(b)}{2}}\right) d^2b\, d^2r$$

$\sigma(r) = c\, r^2$ dipole cross section

$\psi(r)$ - hadron wave function

$$\sigma_{tot}(\gamma A) = 2\int |\psi_\gamma(r)|^2 \left(1 - e^{-\frac{\sigma(r) T}{2}}\right) d^2b\, d^2r$$

The same is true for exclusive processes i.e.

$\gamma A \to \rho A$; $\gamma A \to \rho A'$

The complex structure of hadrons becomes important for hard processes as hadron production with high p_T, jets, DIS, central nucleus-nucl. collisions and so on.

Conclusions

1. Multiple scattering theory work for soft interactions with nuclei not only for exclusive processes (coherent and incoherent) but even for inclusive one.

2 As we see above multiple inelastic collisions lead to correct dependence on Z. The scattering of complex system (guands, gluons) have