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L.A. Grigoryan, V.A. Shakhbazyan

EIKONAL AND QUASI-EIKONAL MODELS OF COMPLEX MOMENTA THEORY FOR π-MESON ELASTIC SCATTERING AND ρ^0-PHOTOPRODUCTION ON ^{4}He

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Л.А.ГРИГОРЯН, В.А.ШАХБАЗЯН

ЭЙКОНАЛЬНАЯ И КВАЗИЭЙКОНАЛЬНАЯ МОДЕЛИ ТЕОРИИ КОМПЛЕКСНЫХ МОМЕНТОВ ДЛЯ УПРУГОГО РАССЕЯНИЯ π-МЕЗОНА И ФОТОРОЖДЕНИЯ ρ^0-МЕЗОНА НА ЯДРЕ ^4He

Получены формулы для упругого рассеяния π-мезона на ядре ^4He в теории комплексных моментов в рамках предположений эйкональной и квазиэйкональной моделей теории комплексных моментов. Показано, что эффекты ливневого усиления в области энергий налетающей частицы $E_{лаб}$=20 ÷ 100 Гэв, описываемые с помощью постоянных коэффициентов, эффективно учитывают неупругую экранировку при перерассеяниях на разных нуклонах ядра. Величины дифференциальных сечений уже в области квадратов передаваемых импульсов 0÷0,3 (Гэв/с)^2 весьма чувствительны к значениям параметров обеих моделей и открывают возможность их гораздо более точного определения. Показано также, что те же эффекты получаются и для фоторождения ρ^0-мезона на ядре ^4He.

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EIKONAL AND QUASI-EIKONAL MODELS OF COMPLEX MOMENTA THEORY FOR π^0- MESON ELASTIC SCATTERING AND ρ^0 - PHOTOPRODUCTION ON ^{4}He

In the framework of the assumptions of eikonal and quasi-eikonal models of complex momenta theory the formulae for the elastic scattering of a π-meson on ^{4}He nucleus are obtained. It was shown that at energies of an incident particle E_{lab}= 20 ÷ 100 GeV, the shower enhancement effects as specified by constant coefficients effectively allow for the inelastic screening at the rescatterings on different nucleons of the nucleus. The values of differential cross sections are highly sensitive to the values of the parameters of both the models already in the (0 ÷ 0.3) $(GeV/c)^2$ range of transferred momenta and thus render possible their more accurate determination. It was shown also, that the same effects occur in the process of ρ^0-meson photoproduction on ^{4}He nucleus.

Yerevan Physics Institute
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I. INTRODUCTION

The consideration of complex momenta theory models for the ^4He nucleus has a number of advantages. As was pointed out in Refs. [1,2] , the number of reggeon exchanges turns out to be minimum owing to the quantum numbers of the ^4He nucleus. In particular, in the elastic $\pi\,^4He$ scattering and the coherent photoproduction of ρ^0-mesons only and P' Regge trajectory exchanges are possible.

At the energies of incident particles equal to several ten GeV the contribution of P' trajectory is small and we have practically only the pomeron exchanges. Therefore it becomes possible to study the purely pomeron exchanges at attainable energies, namely, in the (20 ÷ 100) GeV laboratory energy range. Further, the consideration of the nuclear size and structure allows one to develop the complex momenta theory for an actual composite system. It turns out then that the effects of the rescatterings on different nucleons of a nucleus insert their intrinsic features into the behaviour of both the differential and the total cross sections. They turn to be considerably more sensitive to the values of parameters of different reggeon models in comparison with the case of the target nucleon.

The work presented deals with the eikonal [3] and the quasi-eikonal [4] models of complex momenta theory for the elastic scattering of π -mesons and the ρ°-meson photoproduction on the ^{4}He nucleus. The differences which stem from the consideration of the nuclear structure of the target effect already the total cross section of π ^{4}He interaction and the zero angle differential cross section of the photoproduction of ρ° - mesons on ^{4}He nucleus. These differences rapidly become all the more pronounced as we pass to larger momentum transfers. If, for example, the zero angle differential cross sections in the eikonal and quasi-eikonal models differ one from the other by $5 \div 10\%$, then already at the transfer of momentum τ =0.18 $(GeV/c)^2$ the differential cross sections differ by more than two times in the energy range from 10 to 100 GeV. Futhermore, the behaviours of the differential cross sections also become noticeably different. The dip in the differential cross section changes its location from τ =0.30 $(GeV/c)^2$ in the eikonal model to the value of τ =0.24 $\div$ 0.26 $(GeV/c)^2$ in quasi-eikonal model. As all these differences are fully measurable, there arise an actual possibility to take into account the effect of the inelastic screening directly in the framework of the quasi-eikonal model without the introduction of supplementary phenomenological parameters. Indeed, as was shown in Ref.[5]. the consideration of the inelastic screening in the case of pomeron exchanges reduces to the taking into account of particleshowers in particle-pomeron vertices. In the same time, such a procedure of the consideration of showers coincides with the analogues procedure in the quasi-eikonal model[4] by means of the introduction of shower enhancement coefficients that is quite correct in the energy range in question. Hence, the formalism of the quasi-eikonal model may be, in such a case, immediately applied to the nucleus.

We consider the energies ranged from 20 to 100 GeV at small momentum transfers $(0 \div 0.3)$ $(GeV/c)^2$. In this region the condition of the applicability of complex momenta theory for nuclei $\frac{s}{m^2} \gg \ln mR$ is fulfilled[6].

It is noteworthy that the results of our consideration of the inelastic screening in the framework of quasi-eikonal model are in a qualitative agreement with the estimates of the effect of inelastic screening made in Ref.[7] for remarkably higher-the laboratory energies in excess of 100 GeV - by means of three-pomeron vertex.

2. REGGEON EIKONAL AND QUASI-EIKONAL MODELS FOR THE ELASTIC SCATTERING OF π-MESONS ON ^{4}He NUCLEUS

Taking into account the rescatterings of the π-meson on all the nucleons of the nucleus the amplitude of the elastic scattering of the π-meson on ^{4}He nucleus could be written in the form[8]:

$$M_{nuclear} = \sum_{i=1}^{4} M^{(i)}_{nuclear} , \tag{1}$$

where $M^{(1)}_{nuclear} = 4\exp\left(-\frac{3q^2R^2}{16}\right) M_{nucleon}(q)$

is the contribution of the impulse approximation,

$$M^{(2)}_{nuclear} = i\,6\exp\left(\frac{q^2R^2}{16}\right)\int \frac{d^2q'}{\pi}\exp\left\{-\frac{R^2}{4}\left[q'^2+(\vec{q}-\vec{q}\,')^2\right]\right\} M_{nucleon}(q')M_{nucleon}(q-q')$$

is the contribution of double rescattering,

$$M^{(3)}_{nuclear} = -4\exp\left(\frac{q^2R^2}{16}\right)\int \frac{d^2q'\,d^2q''}{\pi^2}\exp\left\{-\frac{R^2}{4}\left[q'^2+q''^2+(\vec{q}-\vec{q}\,'-\vec{q}\,'')^2\right]\right\} M_{nucleon}(q')\cdot$$

$$\times M_{nucleon}(q'')M_{nucleon}(q-q'-q'')$$

is the contribution of triple rescatterings,

$$M^{(4)}_{nuclear} = -i\exp\left(\frac{q^2R^2}{16}\right)\int \frac{d^2q'\,d^2q''\,d^2q'''}{\pi^3}\exp\left\{-\frac{R^2}{4}\left[q'^2+q''^2+q'''^2+(q-q'-q''-q''')^2\right]\right\}\times$$

$$\times M_{nucleon}(q')M_{nucleon}(q'')M_{nucleon}(q''')M_{nucleon}(q-q'-q''-q''')$$

is the contribution of four-fold rescatterings.
Here $M_{nucleon}(q)$ is the elementary amplitude of the scattering of π -meson on a nucleon normalized as in Refs[3,4], and $R = 44(GeV)^{-2}$ is the square of the helium nucleus radius. The formfactor of the ^4He nucleus is taken in a simple exponential form. The numerical value of the nucleus radius is the same as that in the first term of formula (5) in Ref.[9]. For the squares of momentum transfers ranged from 0 to $0.3(GeV)^2$ the contribution of the second term to the formfactor used in Ref.[9] is negligibly small. Further, the contribution of the nucleon spin flip amplitude likewise turns out negligible due to both the smallness of momentum transfers and the quantum numbers of ^4He nucleus that efficiently retain only P and P' exchanges (the flip amplitudes in the πN -scattering are determined primarily by the ρ -trajectory which doesn't contribute in pole approximation to the elastic $\pi\,^4He$ scattering while the double account of it in the rescatterings is negligibly small at energies under consideration).

To find the amplitude of the elastic $\pi\,^4He$ scattering in the eikonal model[3] of Regge pole theory it will be enough to calculate the contributions of $M^{(i)}_{nucleus}$ in this model taking the account of sufficient number of Reggeon exchanges in the elementary amplitude.

The quasi-eikonal model[4] taking account of the appearance of the showers at multiple rescatterings of an incident particle with the help of constant coefficients of shower enhancement allows also to take into account the inelastic screening originated at high energies from the rescattering on different nucleons of a nucleus.

In what follows we give the values of $M^{(i)}_{nucleus}$ calculated in the framework of quasi-eikonal model.[4]

The eikonal model expressions for these quantities will be obtained taking the coefficients of shower enhancement equal to one.

$$M^{(1)}_{nuclear} = 4i\exp\left(-\frac{3R^2q^2}{16}\right)\sum_{k=1}^{\infty}\sum_{b_k=0}^{k}\left\{\frac{(-1)^{k-1}(i^{-1}\eta_{p'}\varepsilon_{p'})^{b_k}}{(k-b_k)!\,b_k!}\times\right.$$

$$\left.\times\frac{r_p^{k-b_k}\,r_{p'}^{b_k}\,c(b_k)}{\lambda_p^{k-b_k}\cdot\lambda_{p'}^{b_k}\,\Lambda_k}\exp(-q^2\Lambda_k^{-1})\right\}, \qquad (2)$$

where

$$i^{-1}\eta_{p'} = 1 + i\,ctg\frac{\pi\alpha^{\circ}_{p'}}{2}, \quad \varepsilon_{p'} = \exp\left[-(1-\alpha^{\circ}_{p'})\ln\frac{E}{E_o}\right],$$

$$\Lambda_k = \frac{k-b_k}{\lambda_p} + \frac{b_k}{\lambda_{p'}}, \quad c(b_k) = \begin{cases} cc'^{\,k-2} & \text{if } b_k = 0,\ k \geq 2 \\ 1 & \text{" } k = 1, \\ 1 & \text{" } b_k \neq 0. \end{cases}$$

$$M^{(2)}_{nuclear} = i\frac{4!}{2!\,2!}\exp\left(\frac{q^2R^2}{16}\right)\sum_{k,n=1}^{\infty}\sum_{b_k=0}^{k}\sum_{b_n=0}^{n}\left\{(-1)^{k+n-1}\frac{(i^{-1}\eta_{p'}\varepsilon_{p'})^{b_k+b_n}}{(k-b_k)!\,(n-b_n)!\,b_k!\,b_n!}\times\right.$$

$$\left.\times\frac{r^{k+n-b_k-b_n}\,r_{p'}^{b_k+b_n}\,c(b_k,b_n)\exp[-q^2(R_k^{-1}+R_n^{-1})^{-1}]}{\lambda_p^{k+n-b_k\ b_n}\cdot\lambda_{p'}^{b_k+b_n}\cdot\Lambda_k\cdot\Lambda_n R_k R_n (R_k^{-1}+R_n^{-1})}\right\}, \qquad (3)$$

where
$$R_{\kappa,n} = \frac{R^2}{4} + \Lambda^{-1}_{\kappa,n} ,$$

$$\begin{cases} C(b_n) & \text{if } b_\kappa \neq 0, \ b_n = 0, \\ C(b_\kappa) & \text{"} \ b_n \neq 0, \ b_\kappa = 0, \\ 1 & \text{"} \ b_\kappa \neq 0, \ b_n \neq 0, \\ CC'^{n+\kappa-2} & \text{"} \ b_\kappa = 0, \ b_n = 0. \end{cases}$$

$$M^{(3)}_{nuclear} = i\,\frac{4!}{3!}\exp\left(\frac{q^2R^2}{16}\right)\sum_{\kappa,n,\ell=0}^{\infty}\ \sum_{b_\kappa=0}^{\kappa}\ \sum_{b_n=0}^{\ell}\ \sum_{b_\ell=0}^{\ell}\left\{(-1)^{\kappa+n+\ell-1}\right. \times \tag{4}$$

$$\times \frac{(i^{-1}\eta_{p'}\varepsilon_{p'})^{b_\kappa+b_n+b_\ell}\cdot\eta_p^{\kappa+n+\ell-b_\kappa-b_n-b_\ell}\cdot\eta_{p'}^{b_\kappa+b_n+b_\ell}\cdot C(b_\kappa,b_n,b_\ell)}{\lambda_p^{\kappa+n+\ell-b_\kappa-b_n-b_\ell}\cdot\lambda_{p'}^{b_\kappa+b_n+b_\ell}\cdot\Lambda_\kappa\,\Lambda_n\cdot\Lambda_\ell\ R_\kappa R_n R_\ell}\times$$

$$\times\left.\frac{\exp[-q^2(R_\kappa^{-1}+R_n^{-1}+R_\ell^{-1})^{-1}]}{(R_\kappa^{-1}+R_n^{-1}+R_\ell^{-1})}\right\},$$

where

$$C(b_\kappa,b_n,b_\ell) = \begin{cases} C(b_\kappa,b_n) & \text{if } \ b_\ell \neq 0, \\ C(b_\kappa)C(b_\ell) & \text{"} \ b_n \neq 0, \\ C(b_n,b_\ell) & \text{"} \ b_\kappa \neq 0, \\ CC'^{\kappa+n+\ell-2} & \text{"} \ b_\kappa = b_n = b_\ell = 0. \end{cases}$$

$$M^{(4)}_{nuclear} = i\exp\left(\frac{q^2R^2}{16}\right)\sum_{\kappa,n,m,\ell=1}^{\infty}\ \sum_{b_\kappa=0}^{\kappa}\ \sum_{b_n=0}^{n}\ \sum_{b_\ell=0}^{\ell}\ \sum_{b_m=0}^{m}\left\{\ \ ^{\kappa+n+m+\ell-1}\right.\times$$

$$\times \frac{(i^{-1}\eta_{P'}\xi_{P'})^{b_k+b_n+b_l+b_m}\cdot \tau_P^{k+n+l+m-b_k-b_n-b_l-b_m}\cdot \tau_{P'}^{b_k+b_n+b_l+b_m}}{\lambda_P^{k+n+l+m-b_k-b_n-b_l-b_m}\cdot \lambda_{P'}^{b_k+b_n+b_l+b_m}\Lambda_k\cdot\Lambda_n\cdot\Lambda_l\cdot\Lambda_m}\times$$

$$\times \frac{C(b_k,b_n,b_l,b_m)\exp\left[-q^2(R_k^{-1}+R_n^{-1}+R_l^{-1}+R_m^{-1})^{-1}\right]}{R_k R_n R_l R_m (R_k^{-1}+R_n^{-1}+R_l^{-1}+R_m^{-1})}\Bigg\}, \qquad (5)$$

where

$$C(b_k,b_n,b_l,b_m)=\begin{cases} C(b_k,b_n,b_l) & \text{if } b_m\neq 0,\\ C(b_k,b_n)C(b_m) & \text{"} \ b_l\neq 0,\\ C(b_k)C(b_l,b_m) & \text{"} \ b_n\neq 0,\\ CC^{k+n+l+m-2} & \text{"} \ b_k=b_n=b_l=b_m=0,\\ C(b_n,b_l,b_m) & \text{"} \ b_k\neq 0. \end{cases}$$

In formulae (2) - (5) τ_P and $\tau_{P'}$ everywhere designate the residues of P and P' trajectories in the elastic πN scattering,

$$\lambda_P=R_P^2+\alpha_P'\left(\ln\frac{E}{E_0}-\frac{i\pi}{2}\right),\quad \lambda_{P'}=R_{P'}^2+\alpha_{P'}'\left(\ln\frac{E}{E_0}-\frac{i\pi}{2}\right).$$

In accordance with Ref.[4], the conditions on shower enhance - ment coefficients are specified so as all the elementary πN - amplitudes not contain the shower coefficients if they involve at least one ρ'-trajectory. This requirement is necessary since any elementary amplitude is expressed as an infinite series in reggeon exchanges.

3. PHOTOPRODUCTION OF ρ°-MESON ON NUCLEUS AS A WHOLE

To obtain the results on the ρ°-meson photoproduction on ^{4}He nucleus we shall avail ourselves of the Ref.[10] approach in which the amplitude of ρ°-meson photoproduction on a nucleon is expressed according to Ref.[11] as

$$M_{\gamma p\to\rho^{\circ}p}=X_{\rho}a_{\pi p}+X_{\omega}(a_{Kp}-a_{Kn})+\frac{1}{3}A_{\pi}(\gamma p\to\omega p), \qquad (6)$$

where

$$a_{\pi p}=\frac{1}{2}(a_{\pi^+p}+a_{\pi^-p}),$$

$$a_{Kp}=\frac{1}{2}(a_{K^+p}+a_{K^-p}),$$

$$a_{Kn}=\frac{1}{2}(a_{K^+n}+a_{K^-n}),$$

$$\frac{X_{\omega}^2}{X_{\rho}^2}=\frac{1}{9}\xi_{\omega}^2, \quad X_{\rho}^2=\frac{\alpha\pi}{\gamma_{\rho}^2}\approx\frac{1}{300}$$

A_{π} is the contribution of π-meson trajectory.

It should be remembered while extending the results to the case ρ° photoproduction on the ^{4}He nucleus as a whole, that to the difference $a_{Kp}-a_{Kn}$ only the A_2 trajectory contributes[10] which can't make a contribution to the ρ°-

photoproduction on ^4He. Likewise, the ... term in the formula (6) doesn't contribute to the process under consideration as the contribution of π- meson trajectory is also forbidden.

Thus we come to the very simple approximate formula:

$$M_{\gamma p \to \rho^\circ p} \approx X_\rho a_{\pi p} \qquad (7)$$

This approximation is sufficiently accurate as all the plausible contributions of A_2 and π -trajectories to non-pole terms of ρ° photoproduction on ^4He nucleus are small and quickly vanish with energy[10].

Thus, we obtain the following relation:

$$\frac{d\sigma(\gamma\,^4He \to \rho^\circ\,^4He)}{dt} \approx X_\rho^2 \frac{d\sigma(\pi\,^4He \to \pi\,^4He)}{dt} \qquad (8)$$

The formula (8) allows us to find the cross sections of ρ° -meson photoproduction on ^4He directly from the cross section of the elastic scattering of the π- meson on ^4He by the multiplication of the latter by a constant factor X_ρ^2

4. THE DISCUSSION OF RESULTS

In Figs 1,2,3 are plotted the curves of differential cross sections of the elastic π ^4He scattering $\left(\text{or } \frac{1}{X_\rho^2} \times \frac{d\sigma(\gamma\,^4He \to \rho^\circ\,^4He)}{dt}\right)$ at laboratory enrgies of the incident π -meson (or a γ -quantum) equal to 17.8, 30 and 41 GeV calculated by formulae (1) - (5). The numerical values of parameters in the quasi-eikonal (solid lines) and the eikonal (dashed lines) models were taken from Refs [4] and [3] respectively. One can see from these curves that there is a rather large discrepancy between the predictions of these models both by the values of differential cross sections and the position of the dip. For eikonal model it is located at 0.30 $(GeV/c)^2$ and for quasi-eikonal model it is in the (0.24 - 0.26) $(GeV/c)^2$ interval.

In Fig.4 the total cross section of the $\pi\,{}^4He$ reaction and the zero angle differential cross section of ρ^0-meson photoproduction on the ^4He nucleus are given.

In Fig.5 the energy dependence of the differential cross section of elastic $\pi\,{}^4He$ scattering (or $\frac{1}{X_\rho^2}\frac{d\sigma(\gamma\,{}^4He \to \rho^0\,{}^4He)}{dt}$) at the fixed momentum transfer, 0.18 $(GeV/c)^2$, in the (10 ÷ 100) GeV range is given for illustration. It is seen that already at such small momentum transfers the discrepancy between the predictions of these models exceeds the factor of two.

Thus, these calculations evidence the feasibility of an independent experimental determination of the quasi-eikonal model parameters at Serpukhov energies. With sufficiently good experimental data on the elastic $\pi\,{}^4He$ scattering (or the ρ^0-meson photoproduction on ^4He nucleus as a whole) such a determination may be considerably more precise than those made up to now.

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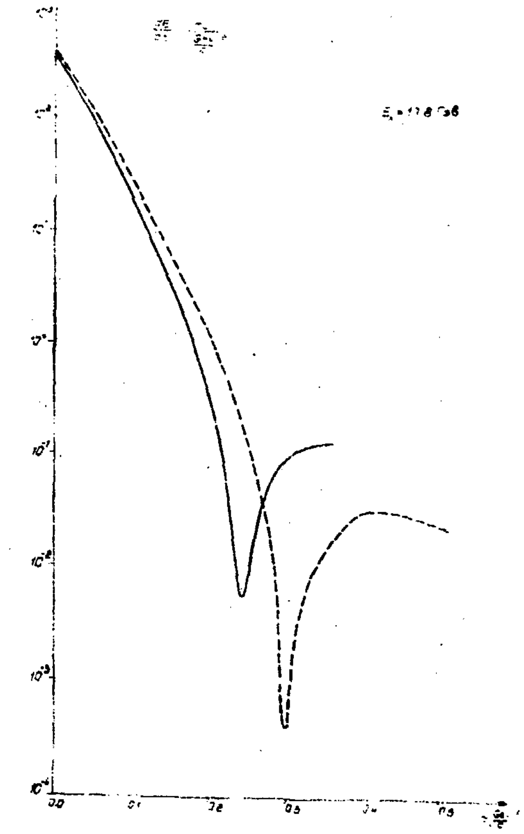


fig.1

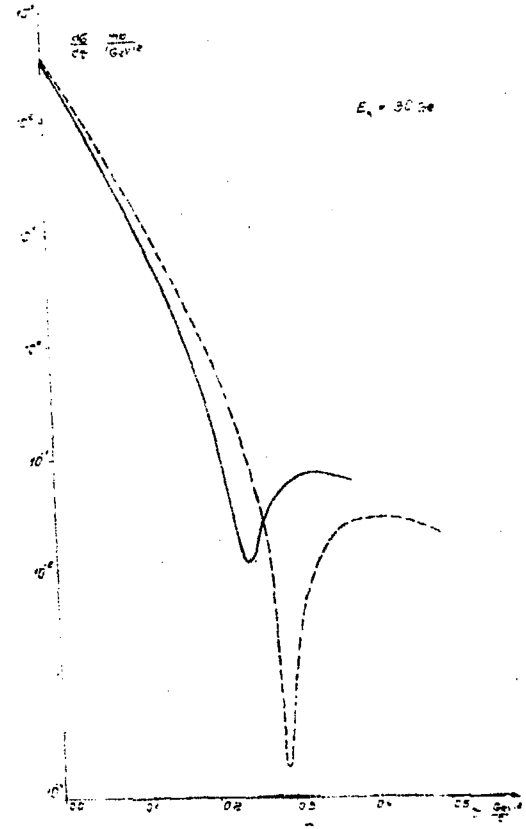


Fig.2

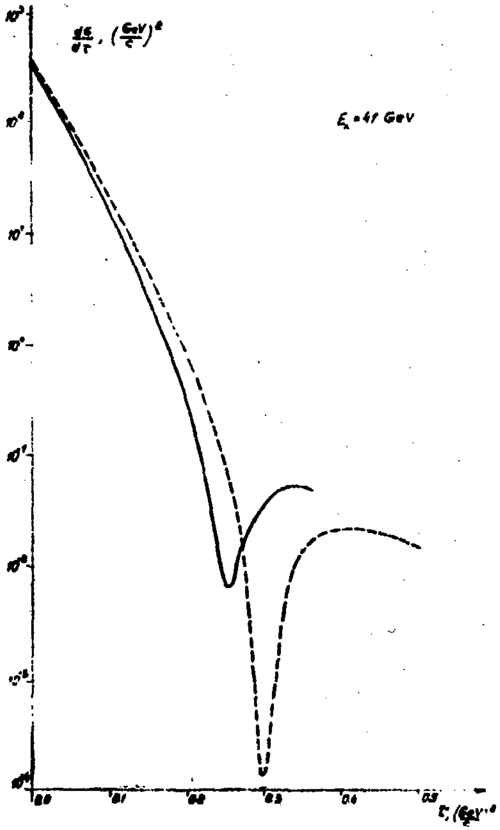


Fig.3

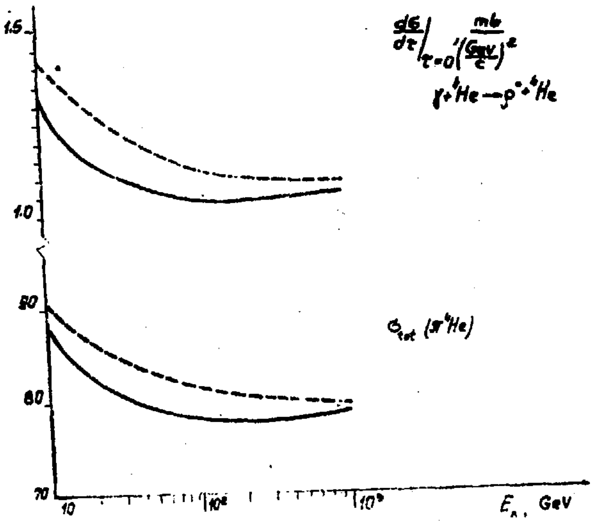
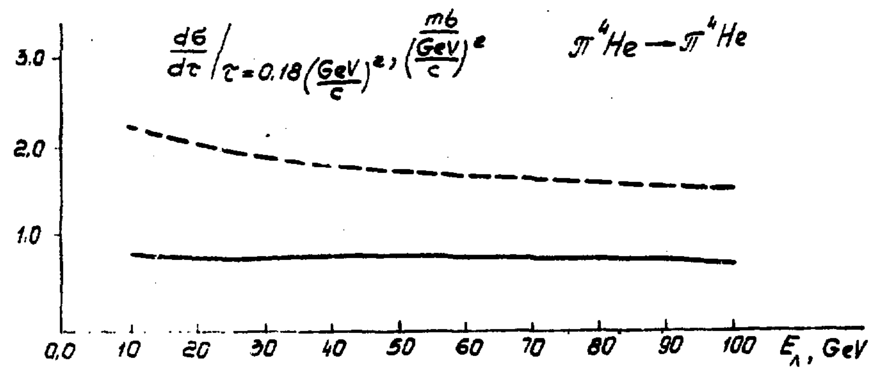


Fig 4.



$\frac{d\sigma}{d\tau}\Big/_{\tau=0.18\left(\frac{GeV}{c}\right)^2}, \left(\frac{mb}{\left(\frac{GeV}{c}\right)^2}\right)$
$\pi\,^4He \to \pi\,^4He$
3.0
2.0
1.0
0.0
10
20
30
40
50
60
70
80
90
100
E_Λ, GeV

Fig.5

R E F E R E N C E S

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ЭЙКОНАЛЬНАЯ И КВАЗИЭЙКОНАЛЬНАЯ МОДЕЛИ ТЕОРИИ КОМПЛЕКСНЫХ МОМЕНТОВ ДЛЯ УПРУГОГО РАССЕЯНИЯ π-МЕЗОНА И ФОТОРОЖДЕНИЯ ρ^0-МЕЗОНА НА ЯДРЕ ^{4}He

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