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Abstract

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Single pion production in exclusive neutrino reactions with small momentum transfer to nucleon, induced by neutrino scattering on virtual mesons (reggeons), is considered. In the experimental investigation of such processes the contributions of different mesons may be singled out, thus providing information on the weak meson-pion (reggeon-pion) transitions.

Аннотация

Герштейн С.С., Комаченко Ю.Я., Хлопов М.Ю.
Образование быстрых пионов в эксклюзивных нейтринных процессах. Серпухов, 1980.
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Библиогр. 17.

Рассмотрены процессы образования одиночных пионов в эксклюзивных нейтринных реакциях с *малой передачей импульса нуклону, обусловленные рассеянием нейтрино на виртуальных* мезонах (реджеонах). Экспериментальное изучение таких процессов позволяет в принципе выделить вклады различных мезонов и получить сведения о слабых мезон-пионных (реджеон-пионных) переходах.

1. INTRODUCTION

Rich data, that allow one to study separate exclusive processes, have been accumulated in high energy neutrino experiments. Single fast pion production $\nu_\mu \to \mu^- \pi^+$ and $\bar{\nu}_\mu \to \mu^+ \pi^-$ without visible tracks of recoil proton or of products of target nucleus split have been observed in the experiments at FNAL and CERN. The indicated processes are characterised by small momentum transfer to nucleon (at the recoil proton momentum below 200-300 MeV/c, it can be observed neither in the bubble chambers nor by the balance of transverse momenta of muon and pion). This fact is confirmed by the events with single fast pion and visible slow recoil proton. It is worth noting that in a great number of the events observed pion possesses such large energy (events with 20-30 GeV pion production) that they cannot be explained by neutrino excitation of resonances in πN system.

To interpret the quoted peripheral events it is natural to assume that they take place due to neutrino scattering on virtual mesons in the reaction

$$\nu A \to \mu \pi A \tag{1}$$

where A is a nucleon or the target nucleus (see fig. 1).

On the first sight it seems that the main contribution to reaction (1) is made by the scattering on virtual pions:

$$\nu_\mu (\bar{\nu}_\mu) + \pi^0 \to \mu^{\mp} + \pi^{\pm} . \tag{2}$$

However one should take into consideration that at high energies of pion produced (corresponding to large invariant masses of the πN system) there should take place a transition to Regge asymptotics. In other words, process (2) goes on reggeized pion in this range. Rapid decrease of the contribution from the π-trajectory with energy makes us think that the contribution from scattering on ω, ρ, f-mesons corresponding to the trajectories that fall down less rapidly with energy, as well as scattering on pomeron may turn out to be essential for the description of process (1). The study of such contributions may provide us with the information about unobservable semileptonic decays of mesons (e.g., $\omega \to \pi \mu \nu$) and give us a possibility to investigate the formfactors of the corresponding meson (Reggeon)-pion transitions.

In the present note we estimate the contributions to process (1) made by various virtual mesons (resonances) (§4). Besides we discuss coherent processes of single pion production in nuclei, caused by neutrino scattering on virtual isoscalar mesons (§5).

2. PION PRODUCTION IN NEUTRINO SCATTERING ON VIRTUAL MESONS

Let us treat the class of processes (1) described with the diagram in fig. 1. This diagram with a pion pole in the t-channel is usually considered alongside with the S-channel pole diagrams when reaction (1) is analysed at the threshold /1/. We are interested in the kinematical regions of momentum transfer in high energy processes, where the contribution from the diagram in fig. 1 is dominating*). To calculate the contribution from definite mesons (M) to this diagram we must know the matrix elements of weak transitions $M \to \pi$. Except $M = \pi$ such transitions have not been experimentally observed. Still the theoretical models allow one to give quite reasonable estimates for them.

Since mesons with zero-strangeness have definite G-parity, the selection rules over G-parity (no currents of the second rank) result in the fact, that each transition is either purely vector or purely axial.

*) Neutrino scattering on virtual pions at high energies was considered in refs. /2-4/.

Table 1 gives types of current corresponding to different meson-pion transitions. Note, that pion production processes on isoscalar mesons ω, f, σ (as well as on pomeron) would make a coherent contribution to neutrino production of pions on nuclei*).

As it is also seen from the Table, scattering on virtual η and η' mesons makes no contribution to process (1). Indeed, the selection rules over G-parity demand that $\eta \to \pi$ and $\eta' \to \pi$ transitions should go on at the account of the axial current which, on the other hand is forbidden for the transitions between pseudoscalar mesons.

For completeness we present in Table 1 $M^0 \to \pi^0$ transitions corresponding to the process $\nu A \to \nu\pi^0 A$ at the account of neutral currents. In this case the choice for the type of current is determined by the C-parity selection rules.

The structure and the constants of weak transitions, caused by the vector current, may be obtained, if we proceed from CVC consideration. To estimate the constants of the axial transitions we use the PCAC relation (§3).

The matrix element of reaction (1) is presented in the form:

$$M = \frac{G}{\sqrt{2}} \ell_\mu H_\mu \tag{3}$$

where $\ell_\mu = \bar{u}_2 \gamma_\mu (1+\gamma_5) u_1$ is charged leptonic current, and H_μ is

*) The scattering on σ-meson corresponds to effective description of scattering on isoscalar 2π system with the mass 550 MeV.

the matrix element of weak hadronic current. The set H_μ in the form of a sum of scattering processes of all virtual mesons with pion production:

$$H_\mu = \sum_m T^{(m)} P^{(m)} J_\mu^{(m)} \qquad (4)$$

where $T^{(m)}$ and $P^{(m)}$ denote symbolically the vertex of virtual meson (m) emission by the target nucleon and meson propagator, and $j_\mu^{(m)} = \langle \pi | J_\mu | M \rangle$ is the matrix element of weak hadronic current between virtual meson state (M) and that of pion, corresponds to the diagram in fig. 1.

Nucleon-meson vertices $T^{(m)}$ are defined by the effective constants, used in the models of nuclear potentials of one boson exchange[5] (see § 3).

At sufficiently large invariant masses of the hadronic πN system reggezation of mesons becomes essential for description of process (1). In this case the propagators $P^{(m)}$ should be chosen in accordance with the Regge pole model, and the vertices $T^{(m)}$ are defined by the residues of the corresponding Regge trajectories. Further on we will restrict ourselves with the consideration of the contributions from virtual π, σ, ω, ρ, f-mesons*) In the approximation indicated here the H_μ current has the form:

$$H_\mu = \pm \frac{g_{\pi N}(\bar{u}_2 \gamma_5 u_1)}{t_1 - m_\pi} f_+(t_1, t_2)(p+k)_\mu \phi_\pi^+ +$$

*) Note, that the contribution of axial A_1, D_A -mesons may be neglected owing to smallness of respective constants or Regge residuals[6]. It follows from the quark model that the A_2-nucleon coupling constant is 3 times smaller, than the respective f-meson one. We may thus neglect the contribution of A_2 as compared to the one of f.

$$+ \frac{g_{\sigma N}(t_1)(\bar{u}_2 u_1)}{t_1 - m_\sigma^2} f_\sigma(t_1, t_2)(p+k)_\mu \phi_\pi^+ + \tag{5}$$

$$+ \frac{g_{\omega N}(t_1)(\bar{u}_2 \gamma_\nu u_1)}{t_1 - m_\omega^2} f_\omega(t_1, t_2)\varepsilon_{\mu\nu\lambda\rho} q_\lambda k_\rho \phi_\pi^+ \pm$$

$$\pm \frac{g_{\rho N}(t_1)(\bar{u}_2 \gamma_\nu u_1)}{t_1 - m_\rho^2} [f_{1\rho}(t_1, t_2) g_{\mu\nu} + f_{2\rho}(t_1, t_2)(p+q)_\nu k_\mu] \phi_\pi^+ +$$

$$+ \frac{g_{fN}(t_1)(\bar{u}_2 \gamma_\nu u_1)(p_1+p_2)_\lambda P^{\nu\lambda}_{\sigma\tau} h_{\mu\sigma\tau}(t_1, t_2)\phi_\pi^+}{t_1 - m_f^2},$$

where

$$h_{\mu\sigma\tau}(t_1, t_2) = f_{1f}(t_1, t_2)[g_{\mu\sigma}(p+q)_\tau + g_{\mu\tau}(p+q)_\sigma] + $$
$$+ f_{2f}(t_1, t_2)(p+k)_\mu (p+q)_\sigma (p+q)_\tau$$

and we omit the terms proportional to q_μ which when being convoluted with the leptonic current gives us leptonic mass, the terms corresponding to the vector meson couplings of the form $\frac{f_v}{2m_N}\bar{u}_2 \sigma_{\mu\nu} k_\nu u_1$ as well as the terms corresponding to tensor-gradient coupling of f meson with nucleon*). Note that the terms corresponding to isovector π^0 and ρ^0 meson exchange have opposite signs at ν and $\bar{\nu}$ scattering: it is "+" for π^+ production and "−" for π^- production. In formula (5) $g_{MN}(t_1)$ are formfactors of the corresponding meson-nucleon couplings, that will be taken at zero momentum transfer; k_1, k_2, p, p_1, p_2 are 4-momenta of neutrino, muon, pion, incident and final nucleon respectively $k_1 - k_2 = q$, $p_1 - p_2 = k$ (see fig. 1) f_+, f_σ, f_ω, $f_{1\rho}$, $f_{2\rho}$, f_{1f}, f_{2f} are formfactors of weak transitions $\nu M \to \mu\pi$. Their changes due to off-

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*) There are indications in literature that the constant of this coupling is small.

mass-shell effects will be neglected and we will assume that $f(t_1, t_2) \approx f(0, t_2) \approx f(m_M^2, t_2)$. The projection operator $P^{\nu\lambda}_{\sigma\tau}$ of the tensor 2^+ meson has the form:

$$P^{\nu\lambda}_{\sigma\tau} = \frac{1}{2}(\bar{g}_{\nu\sigma}\bar{g}_{\lambda\tau} + \bar{g}_{\nu\tau}\bar{g}_{\lambda\sigma} - \frac{2}{3}\bar{g}_{\nu\lambda}\bar{g}_{\sigma\tau}), \quad \bar{g}_{\nu\lambda} = g_{\nu\lambda} - \frac{k_\nu k_\lambda}{M^2}$$

and satisfies the conditions:

$$k_\nu P^{\nu\lambda}_{\sigma\tau} = k_\lambda P^{\nu\lambda}_{\sigma\tau} = k_\sigma P^{\nu\lambda}_{\sigma\tau} = k_\tau P^{\nu\lambda}_{\sigma\tau} = 0, \quad P^{\lambda\lambda}_{\sigma\tau} = P^{\lambda\nu}_{\sigma\sigma} = 0.$$

It is also symmetric with respect to $\nu \to \lambda$, $\sigma \to \tau$ $(\nu\lambda) \to (\sigma\tau)$ permutations (see e.g.,[8]). Having introduced the formfactors $F_{1f} = 4(p_1 + p_2, q)\frac{g_{fN} f_{1f}}{t_1 - m_f^2}$, $F_{2f} = 4(p_1 + p_2, q)\frac{g_{fN} f_{2f}}{t_1 - m_f^2}$ we shall present the term, corresponding to f meson in formula (5) in the form:

$$H^f_\mu = \frac{F_{1f}}{2}[\bar{u}_2 \gamma_\mu u_1 + \frac{(\bar{u}_2 \hat{q} u_1)}{(p_1 + p_2, q)}(p_1 + p_2)_\mu] + F_{2f}(\bar{u}_2 \hat{q} u_1)(p + k)_\mu .$$

Note that high spin (2^+) exchange results in appearance of multipliers in the effective F_{2f} and F_{2f} formfactors that grow with energy.

Account for the reggezation of mesons results , generally speaking, in great changes in presentation of formula (6). The σ-meson contribution to the Regge domain is inessential[6]. On the other hand at high energies there may take place processes of pion production in neutrino scattering on pomeron, caused by the axial current according to the G-parity selection rule. In each term (but that corresponding to f meson) pole expressions $F_M = \frac{g_{MN} f_{M\pi}}{t_1 - m_M^2}$ and in the case with f meson effective formfactors F_{1f} and F_{2f} transform into $\Phi_R(t_1, t_2, s_2) = \Phi_R^o(t_1, t_2, s_2)\eta_M(\frac{s_1}{s_o})^{a_M(0)-1}$ where η_M and a_M are signatures and trajectories of the corresponding Reggeon; $\Phi_R^o(t_1, t_2, s_2)$ is the function defining weak Regge-pion transition, and s_o is the energy-scale parameter, $s_o = 2M_N E_o$, $E_o \approx 1\,GeV$. In the transitions caused by the axial current, covariant structures change too, and each term in H_μ corresponding to ρ, f and P trajectory generally speaking should be presented as a sum

$$\Phi_1 (p + k)_\mu + \Phi_2 p_{1\mu} + \Phi_3 q_\mu .$$

At small momentum transfers to nucleon the quantity $p_1 q$ is practically independent of the azimuthal. Treiman-Yang angle and for $s \gg M_N^2$, M_N nucleon mass, is equal to:

$$p_1 q \approx - \frac{s t_2}{2 s_2} \tag{6}$$

where invariant variables $s = (k_1 + p_1)^2$, $s_1 = (q + p_1)^2 = (p_2 + p)^2$, $s_2 = (k_2 + p)^2$, $t_1 = k^2$, $t_2 = q^2$ have been introduced (see fig. 1).

In the terms of the quoted variables differential cross section for reaction (1) has the form (at $s \gg M_N^2$; s_2, $|t_2| \gg |t_1|$, m_π^2, m_μ^2; $|t_1| \ll m_\sigma^2$, m_ω^2, m_ρ^2, m_f^2):

$$\frac{d^4\sigma}{dt_1 dt_2 ds_2 d\phi} = \frac{|M|^2}{(2\pi)^4\, 32 (s - M_N^2)^2 (s_2 - t_1)} = \frac{G^2}{(2\pi)^4\, 8 s^2 s_2} \{ -2 t_1 s_2^2 (1 + \frac{t_2}{s_2}) |F_\pi|^2$$

$$+ 2(1 + \frac{t_2}{s_2}) s^2 (1 - \frac{s_2}{s}) | \pm F_\rho + F_f |^2 + 2(1 + \frac{t_2}{s_2}) s_2^2 |F_\sigma|^2 - \tag{7a}$$

$$-2M_N^2 s_2^2 t_2 \left(1+\frac{t_2}{2s_2}\right)^2 |F_\omega|^2 [+\ 4\left(1+\frac{t_2}{s_2}\right) s s_2 \left(1-\frac{s_2}{2s}\right) \mathrm{Re} F_\sigma^+ (\pm F_\rho + F_f) \ +$$

$$+\ 8\left(1+\frac{t_2}{2s_2}\right) s \left(1-\frac{s_2}{2s}\right) \{k_1 p_1 qk\} \mathrm{Re} F_\omega^+ (\pm F_\rho + F_f) \ + \quad (7b)$$

$$+\ 8\left(1+\frac{t_2}{2s_2}\right) s_2 \{k_1 p_1 qk\} \mathrm{Re} F_\omega^+ F_\sigma [\pm \{k_1 p_1 qk\} \mathrm{Im} [\pm \frac{2s_2}{2s-s_2} F_{1\rho} F_{1f}^+ \mp \quad (7c)$$

$$\mp\ 8\frac{t_2}{s_2}\left(s-\frac{s_2}{2}\right) F_{1\rho} F_{2f}^+ \pm 8\frac{t_2}{s_2}\left(s-\frac{s_2}{2}\right) F_{2\rho} F_{1f}^+ + 4(F_{1f} \pm F_{1\rho}) F_\sigma^+] \ \pm$$

$$\pm\ 4M_N^2 t_2 s_2 \left(1+\frac{t_2}{2s_2}\right) \mathrm{Im} F_\omega^+ (F_{1f} \pm F_{1\rho}), \quad (7d)$$

where ϕ is the Treiman-Yang angle, $\{k_1 p_1 qk\} \equiv \varepsilon_{\mu\nu\lambda\sigma} k_{1\mu} p_{1\nu} q_\lambda k_\sigma$,

$$F_\pi = \frac{g_{\pi N} f_t}{t_1 - m_\pi^2}, \quad F_\sigma = \frac{2M_N g_{\sigma N} f_\sigma}{m_\sigma^2}, \quad F_\omega = \frac{g_{\omega N} f_\omega}{m_\omega^2}, \quad F_{1,2\rho} = \frac{g_{\rho N} f_{1,2\rho}}{m_\rho^2}$$

$$F_{1,2f} = 4(p_1 + p_2, q) \frac{g_{fN} f_{1,2f}}{m_f^2}; \quad F_\rho = F_{1\rho} - q^2 F_{2\rho}, \quad F_f = F_{1f} - q^2 F_{2f}. \quad (8)$$

It should be noted that in the case of scattering on nonpolarized target pion amplitude does not interfere with other amplitudes.

In (7) the term (7b) corresponds to P-odd effects, caused by interference of vector and axial hadronic currents. The indicated effects manifest themselves in the asymmetry on the Treiman-Yang angle. In the lab. system this term defines the correlation $([\vec{p}\vec{k}_2]\vec{p}_2)$ which manifests itself in the angular asymmetry between the planes $(\vec{p}, \vec{k}_2)$ and $(\vec{p}, \vec{p}_2)$ where pion $(\vec{p})$ and muon $(\vec{k}_2)$ and pion ($\vec{p}$) and recoil nucleon momenta ($\vec{p}_2$) lie. For the investigation of the given effects we need recoil nucleon to be detected.

The terms (7c) and (7d) correspond to the interference of leptonic vector and axial currents and have opposite signs in the case of neutrino (Upper sign) and antineutrino (lower sign). The term (7c) corresponds to the asymmetry in the Treiman-Yang angle. The term 7d corresponds also to the interference between hadronic vector and axial currents and does not vanish when averaging over the Treiman-Yang angle. The upper signs in formula (7) here ν and $\bar{\nu}$ further on relate to neutrino scattering and the lower ones to antineutrino.

Selection of the difference between neutrino and antineutrino cross sections for fast pion production allow us to obtain information concerning the relative signs of different transitions. The Regge pole theory predicts quite a definite relations between real and imaginary parts of the amplitudes. Note that the difference of ν and $\bar{\nu}$ cross sections is rather sensitive for the presence of imaginary parts of the amplitudes not connected with the Regge behaviour: if non-Regge amplitudes are real, the terms (7c) and (7d) vanish in the non-Regge domain.

Differential cross section (7) integrated over the Treiman-Yang angle and over small t_1 momentum transfers is of interest as far as analysis of the experimental data is concerned. If the recoil proton momentum is limited by the condition $|\vec{p}_2| \leqslant a M_N$ $(a<1)$ then integration over t_1 whould be performed within the limits

$$\frac{M_N^2 s_2^2}{s^2} \leqslant |t_1| \leqslant 2(\sqrt{a^2+1}-1)M_N^2 \approx a^2 M_N^2 \quad (a \ll 1).$$

Differential cross section obtained characterises then both process (1) with observable slow recoil nucleon and processes where the energy of recoil proton is below the detection threshold. General form of the indicated cross section becomes simpler, if we preceed to standart variables, used for description of deep inelastic scattering $x = -\frac{q^2}{2(p_1q)}$, $y = \frac{p_1q}{p_1k_1}$. In the plane of the variables (x, y) the conditions for application of the one meson and Regge pole exchange models become evident. Taking into account relation (6) we have:

$$x \approx \frac{s_2}{s}; \quad y \approx -\frac{t_2}{s_2} \approx \frac{2p_1q}{s} \approx \frac{s_1}{s}. \tag{9}$$

Fig. 2 presents the plane of the variables x and y. Since $(s_2)_{max} = \frac{s}{M_N}\sqrt{|t_1|_{max}} \approx a s$ then to the kinematic range of reaction (1) there will be a corresponding strip $0 \leqslant y \leqslant 1$ and $0 \leqslant x \leqslant a$ at $|t_1| \leqslant a^2 M_N^2$. Hyperbolas $xy = -q^2/s$ in fig. 2 correspond to fixed q^2 and hyperbolas $y(1-x) \approx \frac{s_1}{s}$ correspond to fixed s_1.

Hyperbola (A): $xy = \frac{\Lambda^2}{s}$ where $\Lambda^2 \approx 1$ GeV^2 conditionally divides the (x, y) plane into the ranges of large q^2 (Above from hyperbola (A) through which the effects of virtual meson structure (q^2-dependence of the formfactors) manifest themselves in reaction (1) and the range of small q^2, where these effects are inessential.

Hyperbola (B): $y(1-x)=\frac{M_R^2}{s}$ where $M_R^2 \approx 2$-3 GeV^2, separates the range (below hyperbola (B)) where reaction (1) goes on due to the neutrino excitation of the resonances in πN system. So as to select experimentally scattering processes on virtual mesons one should choose the range of reaction (1) that would lie above hyperbola (B).

Uncertainties in theoretical predictions concerning the transition to the Regge behaviour of the amplitude do not permit to indicate in fig. 2 an unambigous bound for meson and Regge domains. For certain we may say that at sufficiently large $y=\frac{s_1}{s} \gtrsim \gtrsim \frac{s_R}{s}=y_R$, $s_R \approx 20$ GeV^2 Regge description is by no means valid. If such a description is valid even at the values considerably lower than y_R (upto the domain of S-channel nucleon resonances), then at kinematical removal the resonances from the contribution in the πN system reaction (1) will be defined by neutrino scattering on Reggeons. However it is possible that Regge asymptotics takes place quite late, so that at $y<y_M=\frac{s_M}{s}$, $s_M \approx 15$ GeV^2 our notion about scattering on virtual mesons is quite valid. Characteristic domains, into which one may divide conditionally the kinematic domain of reaction (1) above nucleon resonance domain (hyperbola B)

are given in fig. 2. At $\frac{s_M}{s} \lesssim y \lesssim \frac{s_R}{s}$ a transition from meson description to Regge one takes place. It is of interest to investigate experimentally this transition range, which would provide us with valuable physical information about physical nature of the transition to the Regge asymptotics.

Domain 1 in Fig. 2 $\left(0 < x < \frac{\Lambda^2}{sy}\right.$ and $\left.\frac{M_R^2}{s(1-x)} \leqslant y \leqslant \frac{s_M}{s}\right)$ corresponds to the scattering on virtual structureless mesons.

In domain III it is very important to take into account the structure of virtual mesons. It should be noted that the existence of domain III is conditioned by the relation between the parameters Λ^2 and s_M: $\Lambda^2 \leqslant a s_M$, at $a s_M < \Lambda^2$ the kinematic domain III is absent in reaction (1).

Regge domain is also divided into the domain of scattering on structureless reggeons (domain II: $s_R/s = y_R \lesssim y \lesssim 1$) and domain IY, where the account for the q^2 dependence the formfactors of Regge-pion transitions is essential.

Note that at small momentum transfers to nucleon the y variable is connected with the observed final pion energy $y = \frac{E_\pi}{E_\nu}$. Double differential cross section for reaction (1) $\frac{d^2\sigma}{dxdy}$ has the form:

$$\frac{d^2\sigma}{dxdy} = \frac{G^2 M_N^2 (a^2 - x^2) s}{32\pi^3} \{ (1-y) |F_A|^2 + M_N^2 x^3 y s \left(1 - \frac{y}{2}\right)^2 |F_\omega|^2 +$$

$$\frac{x^2(1-y)}{(a^2-x^2)M_N^2}\left[\ell n\frac{a^2+\frac{m_\pi^2}{M_N^2}}{x^2+\frac{m_\pi^2}{M_N^2}}-\frac{m_\pi^2(a^2-x^2)}{M_N^2(a^2+\frac{m_\pi^2}{M_N^2})(x^2+\frac{m_\pi^2}{M_N^2})}\right]g_{\pi N}^2 f_+^2 \mp \tag{10}$$

$$\mp 2M_N^2 x^2 y(1-\frac{y}{2})\,\mathrm{Im}F_\omega^+(F_{1f}\pm F_{1\rho}),$$

at $s_2 \ll s$, where the transitions, caused by the axial hadronic current, reveal themselves as a combination

$$F_A = F_f \pm F_\rho + xF_\sigma \tag{11}$$

here the effective formfactors, corresponding to $f\pi$ and $\rho\pi$ transitions are in form (8).

In expression (10) the contributions from $\pi\pi$ and $\omega\pi$ transitions and sets of meson-pion transitions caused by axial hadronic current are separated.

Transition to Regge asymptotics is realized through the replacement

$$F_\pi \to \Phi_{\pi R}; \quad F_\omega \to \Phi_{\omega R}$$

and instead of (11) for F_A we will have

$$F_A \to \pm \Phi^o_{\rho R}\eta_\rho\left(\frac{s_1}{s_0}\right)^{\alpha_\rho(0)-1} + \Phi^o_{fR}\eta_f\left(\frac{s_1}{s_0}\right)^{\alpha_f(0)-1} + \Phi_P\eta_P. \tag{12}$$

In expression (12) the term $\Phi_P\eta_P$ ($\eta_P = i$ is the signature of pomeron) is added. This term corresponds to pion production in neutrino scattering on pomeron. The contribution from the σ-trajectory, rapidly decreasing with energy has been omitted. The extraction of the combination (11)-(12) in expression (10) can easily be understood in the framework of the formalism developed in ref[10]. Indeed at small momentum transfers the main contribution to the matrix element of the axial current is made by the term

$$(u_2 \gamma_\nu'' u_1) g_{\mu\nu} (\pm\Phi_\rho + \Phi_f + \Phi_P) = \frac{2}{s_1} (u_2 \hat{q} u_1)\ p_{1\mu} (\pm\Phi_\rho + \Phi_f + \Phi_P) \sim F_A (p_1 + p_2)_\mu \quad (13)$$

which corresponds in expression (5) to the contribution $F_{1\rho}$ of ρ-meson and to F_{1f} of f meson.

3. TRANSITION CONSTANTS AND AMPLITUDES

a) Meson-nucleon interaction constants. The values for the constants that characterize the vertices of meson-nucleon interaction, in the expression for the current H_μ (5), are well known for π and σ mesons. They are $\frac{g^2_{\pi N}}{4\pi} \approx 15$ and $\frac{g^2_{\sigma N}}{4\pi} \approx 6$. The accuracy for the constants of vector mesons is somewhat worse. We will deal with the maximum value for $g_{\rho N}$ which obtained under assumption of total dominance of ρ meson in isovector nucleon formfactor $g_{\rho N} = g_{\rho\pi\pi} = g_\rho$, $g_{\rho\pi\pi}$ is the constant of the $\rho^\circ \to \pi^+\pi^-$ decay. (see ref.[11]). For the constant of ω-nucleon coupling we have from the quark model $g_{\omega N} = 3 g_{\rho N}$ that gives us $\frac{g^2_{\omega N}}{4\pi} \approx 25$. To estimate tensor f meson interaction with nucleon we shall use the ideas of the quark model and the data on the $f \to 2\pi$ decay probability. The amplitude of the $f^\circ \to \pi^+\pi^-$ decay has the form:

$$M_{f \to \pi^+\pi^-} = g_{f\pi^+\pi^-} Q_\mu Q_\nu \phi_1^+ \phi_2^+ F_{\mu\nu} \quad (14)$$

where $Q_\mu = k_{1\mu} - k_{2\mu}$, $\phi_1^+(k_1)$, $\phi_2^+(k_2)$ are the wave functions (momenta) of pions. For matrix element (14) the probability of the $f \to \pi^+ \pi^-$ decay is defined by the formula:

$$\Gamma(f \to \pi^+\pi^-) = \frac{g^2_{f\pi^+\pi^-} m_f^3}{120\pi}, \tag{15}$$

whereof, using

$\Gamma_{f\to\pi^+\pi^-} = \frac{2}{3}\Gamma^{tot}_{f\to 2\pi} \approx 96$ MeV, we will obtain $g^2_{f\pi^+\pi^-}/4\pi \approx \frac{3}{2M_N^2}$. Considering that the constants $g_{f\pi^-\pi^+}$ and g_{fN} are defined by coherent emission of f-mesons by quarks, constituing π-meson and nucleon, we shall get $g_{fN} = \frac{3}{2} g_{f\pi^+\pi^-}$, $\frac{g^2_{fN}}{4\pi} = \frac{27}{8M_N^2}$ or for a dimensionless constant $\tilde{g}_{fN} = 2M_N g_{fN}$; $\frac{\tilde{g}^2_{fN}}{4\pi} \approx 14$ which agrees with the results on analysing the contribution from f-meson to πN and NN scattering at low energies /7/.

<u>b) Weak meson-pion transition constants.</u> The quantity $f_+(0)$ is defined from the probability of the $\pi^+ \to \pi^0 e\nu$ decay and is equal to $\sqrt{2}$. The constant $f_\omega(0)$ may be related to the constant of the $\omega \to \pi\gamma$ decay through the CVC hypothesis. We have

$$f_\omega(0) = \frac{\sqrt{2}}{e} g_{\omega\pi\gamma} \tag{16}$$

where $g_{\omega\pi\gamma}$ is the constant characterising the matrix element of the $\omega \to \pi\gamma$ decay

$$M_{\omega\to\pi\gamma} = g_{\omega\pi\gamma}\,\varepsilon_{\mu\nu\lambda\rho} k_\mu \psi_\nu q_\lambda \varepsilon_\rho .$$

The probability for the $\omega \to \pi\gamma$ decay has the form

$$\Gamma_{\omega\to\pi\gamma} = \frac{g^2_{\omega\pi\gamma} m_\omega^3}{96\pi}$$

whereof

$$f_\omega^2(0) = \frac{192\pi\Gamma_{\omega\to\pi\gamma}}{e^2 m_\omega^3}. \tag{17}$$

(Some information about q^2 dependence $f_\omega(q^2)$ in the time-like domain may be derived from the experimental data on electromagnetic $\omega^o \to \pi^o \mu^+ \mu^-$ decay/12/).

The constant of axial $\rho\pi$ transition may be obtained on the basis of PCAC. Within the limits of soft pion we have the following expression for the matrix elements of weak current:

$$<\pi^+|A^+_\mu|\rho^o> \underset{p_\pi \to 0}{\to} \frac{i}{f_\pi} <0|[Q^-_s, A^+_\mu]|\rho^o> = \frac{2i}{f_\pi} <0|V_{3\mu}|\rho^o> = \frac{2im^2_\rho}{f_\pi g_\rho} \rho_\mu \qquad (18)$$

whereof

$$f_{1\rho}(0) = \frac{2m^2_\rho}{f_\pi g_\rho} \qquad (19)$$

where $f_\pi \approx m_\pi$ is the constant of the $\pi \to \mu\nu$ decay.

On the other hand, on the basis of the PCAC hypothesis we may connect the divergence of the matrix element of weak $\rho\pi$ transition with the amplitude of the $\rho \to 2\pi$ decay:

$$i q_\mu <\pi^+|A^+_\mu|\rho^o> = i f_\pi <\pi\pi|\rho> = i f_\pi g_{\rho\pi\pi} Q_\nu \rho_\nu, \qquad (20)$$

whereof

$$f_\rho(0) = f_{1\rho}(0) = 2 f_\pi g_{\rho\pi\pi}.$$

Under assumption that $g_\rho \to g_{\rho\pi\pi}$ from relations (19) and (20) we obtain a well known KCRF relation/13/

$$f^2_\pi = \frac{m^2_\rho}{g^2_\rho}.$$

Thus the estimate of the formfactor $f_\rho(0)$ is selfconsistent in the framework of the PCAC hypothesis.

The ideas of the PCAC allow us also to obtain restrictions for the value of the constant of the f_π transition by relating this transition to the amplitude of the $f \to \pi^+\pi^-$ decay. Indeed, according to the PCAC

$$i q_\mu < \pi^+ | A_\mu^+ | f > = f_\pi < \pi^+ \pi^- | f >,$$

whereof we obtain

$$f_{1f}(0) = f_\pi g_{f\pi^+\pi^-} . \qquad (21)$$

When making estimations for the case with σ-meson we will assume that $f_\sigma(0) = 1$*).

c) Amplitude in the Regge domain. The estimate of the amplitude in the Regge domain made independent of the assumptions on the residues is of interest. The quantity $\Phi_{\pi R}$ may be connected with the use of CVC with the amplitude of photoproduction of charged pions at small momentum transfers/14/. Then for the quantity $\Phi_{\pi R}$ we obtain

$$\Phi_{\pi R} = F_\pi \left(\frac{s_1}{s_0}\right)^{a_\pi(0)-1} .$$

Due to a rapid decrease of the scattering amplitude on reggeized pion with energy, its contribution (as well as that of σ) to differential cross section (10) is negligible in the Regge domain).

The amplitude $\Phi_{\omega R}$ characterising the contribution from the ω trajectory may be connected with a strong amplitude for the reaction $\pi N \to \rho N$ at high energies with the help of the hypothesis on vector dominance.

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*) In the case of $\sigma\pi$ transition the relationship similar to (20) does not provide the estimation of $f_\sigma(0)$ owing to ambiguity in the width of σ meson.

The amplitude $\pi N \to \rho N$ has the form:

$$A(\pi N \to \rho N) = \rho_\mu \varepsilon_{\mu\nu\lambda\rho}(u_2 \gamma_\nu u_1) q_\lambda k_\rho \Phi^\omega_{\pi\rho} \qquad (22)$$

then as a consequence of the vector dominance

$$\Phi_{\omega R} = \frac{\sqrt{2}}{g_\rho} \Phi^\omega_{\pi\rho} \,. \qquad (23)$$

For matrix element (22) differential cross section of reaction $\pi N \to \rho N$ has the form:

$$\frac{d\sigma}{dt}(\pi N \to \rho N) = \frac{t}{16\pi} |\Phi^\omega_{\pi\rho}|^2 .$$

Experimental data [15] on the reaction $\pi N \to \rho N$ at small angle on Cu^{64}-nuclei at $E_\pi = 150$ GeV will allow us to obtain information about the value for the quantity $|\Phi^\omega_{\pi\rho}|^2$. According to the results from [15] the main contribution to the strong amplitude is made by the ω trajectory. For the quantity

$$\frac{|\Phi^o_{\pi\rho}|^2}{16\pi} = \frac{|\Phi^\omega_{\pi\rho}|^2}{16\pi} \cdot \frac{s}{s_o}$$

we have

$$\frac{|\Phi^o_{\pi\rho}|^2}{16\pi} \approx \frac{8 \cdot 10^4}{A^{\varkappa}} \; \frac{mb}{(GeV/c)^4} \,. \qquad (24)$$

The quantity $\varkappa$ characterises the screening effects for nucleons and for meson absorption in nucleus. When these effects are absent $\varkappa = 2$. Account for the quoted effects whould bring us to $\varkappa < 2$. As quite a reasonable estimate we may take $\varkappa = 4/3$ [16]. The relations of PCAC permit to connect the combination F_A (11) - (12)

caused by axial hadronic current, with the amplitude of elastic scattering. According to (13)

$$q_\mu <\pi N| A_\mu | N> = q_\mu F_A (p_1 + p_2)_\mu \sim s_1 F_A = f_\pi T_{\pi N} \tag{25}$$

where $T_{\pi N}$ is the amplitude of the πN scattering, which defines differential cross section of elastic πN scattering

$$\frac{d\sigma}{dt} = 4\pi \left| \frac{T_{\pi N}}{8\pi s_1} \right|^2.$$

From relation (25) we obtain

$$F_A = \frac{f_\pi}{s_1} T_{\pi N}. \tag{26}$$

4. NUMERICAL ESTIMATES

a) Event density in the (x, y) plane and estimate of cross section for pion production on virtual mesons. The estimates for the constants and amplitudes obtained above allow us to obtain distribution of the events with single pion in the (x, y) plane. In the region of one meson exchange from formula (10) we obtain for differential cross section (at $x \ll 1$ and $y < \frac{s_M}{s} \ll 1$) the following expression:

$$\frac{d\sigma}{dxdy} = \frac{G^2 M_N^2 (a^2 - x^2) s}{32\pi^3} \{ | \pm F_\rho(0) \tilde{F}_\rho(q^2) + x F_\sigma(0) \tilde{F}_\sigma(q^2) + y s \phi_f(0) \tilde{\phi}_f(q^2)]^2 + M_N^2 x^3 y s F_\omega^2(0) \tilde{F}_\omega^2(q^2) + x^2 B(a, \beta, x) \phi_\pi^2(0) \tilde{\phi}_\pi^2(q^2) \} \tag{27}$$

where according to relations (15, 16, 17, 19, 20 and 21):

$$F_\rho(0) = \frac{2}{f_\pi}, \quad \phi_f(0) = \frac{480\pi f_\pi \Gamma^{tot}_{f\to 2\pi}}{m_f^5}, \quad F_\omega^2(0) = \frac{192\pi\Gamma_{\omega\to\pi\gamma}g^2_{\omega N}}{e^2 m_\omega^7},$$

$$B(\alpha,\beta,x) = \frac{1}{\alpha^2 - x^2}\ell n\frac{\alpha^2+\beta^2}{x^2+\beta^2} - \frac{\beta^2}{(\alpha^2+\beta^2)(x^2+\beta^2)}, \quad \beta = \frac{m_\pi}{M_N}, \quad \phi_\pi^2(0) = \frac{2g^2_{\pi N}}{M_N^2}.$$

At $x\to 0$ in formula (27) there remain contributions only for ρ and f mesons:

$$\frac{d\sigma}{dxdy} \underset{x\to 0}{\to} \frac{G^2 M_N^2 \alpha^2 s}{32\pi^3}\left(\pm\frac{2}{f_\pi} + \frac{480\pi f_\pi \Gamma_{f\to 2\pi}}{m_f^5} ys\right)^2. \qquad (28)$$

The contribution from each meson is characterized in formula (27) by a definite dependence on x and y, which gives us a principle possibility to select scattering effects on each virtual meson and to investigate q^2 dependences of the corresponding meson-pion transitions.

It will be interesting to check energy dependences of the scattering processes on vector and tensor mesons. The growth of cross-sections with $s_1 = ys$ obtained in formulae (27) and (28) is caused by the spin exchange effects in the t-channel. The relation of the vector dominance and PCAC connect F_A and F_ω with the corresponding hadronic processes, where no growth with energy is observed. Therefore experimental study of domains I and II in fig. 2 at $s_1 < s_M \sim 15$ GeV^2 will make it possible to investigate spin effects in the t-channel and to check the relation of the vector dominance and PCAC in the kinematic domain under consideration.

From formula (27) we have for the effect of charge asymmetry in the one meson domain:

$$\frac{d\sigma^{\nu}}{dxdy} - \frac{d\sigma^{\bar{\nu}}}{dxdy} = \frac{120\,G^2 M_N^2 s^2 \Gamma^{tot}_{f\to 2\pi}}{\pi^2 m_f^5}(\alpha^2 - x^2)\, y\, \tilde{F}_\rho(q^2)\,\tilde{\phi}_f(q^2), \quad (29)$$

Energy growth $\propto ys$ in (29) is also connected with the t-channel spin effects.

Total cross section for fast pion production is a sum $\sigma^{tot} = \sigma_\pi + \sigma_\sigma + \sigma_\omega + \sigma_\rho + \sigma_f \pm \sigma_{\rho f}$ where $\sigma_{f\rho}$ is the term, corresponding to the ρ and f meson interference. This term defines the difference of neutrino and antineutrino cross sections $\sigma^{\nu} - \sigma^{\bar{\nu}} = 2\sigma_{\rho f}$ (the interference of ρ and f with σ-meson will be neglected). Assuming universal q^2 dependence of all formfactors

$$\tilde{F}_M(q^2) = \frac{1}{1 - q^2/\Lambda^2} \quad (30)$$

where $\Lambda^2 \approx 1\ GeV^2$ we will obtain in the limits of small and large $\gamma = \frac{\alpha s_M}{\Lambda^2}$ the following simple asymptotic expressions for total cross sections:

$$\sigma^{tot}(\gamma \ll 1) = \frac{G^2 M_N^2}{32\pi^3}\Big\{ s_M \alpha^3 \phi_\pi^2(0)\Big[\frac{2}{9} - \frac{\beta^2(4\alpha^2 + 5\beta^2)}{3\alpha^2(\alpha^2+\beta^2)} + \frac{5}{3}\frac{\beta^3}{\alpha^3}\,\mathrm{arctg}\frac{\alpha}{\beta}\Big] + \frac{2}{15} s_M \alpha^5 F_\sigma^2(0) + \frac{s_M^2 M_N^2 \alpha^6}{24} F_\omega^2(0) + \frac{2}{3} s_M \alpha^3 F_\rho^2(0) + \frac{2}{9} s_M^3 \alpha^3 \phi_f^2(0) \pm \frac{2}{3} s_M^2 \alpha^3 F_\rho(0)\phi_f(0)\Big\}, \quad (31)$$

$$\sigma^{tot}(\gamma \gg 1) = \frac{G^2 M_N^2}{32\pi^3}\left\{ \frac{\Lambda^2 \alpha^2 \phi_\pi^2(0)}{2}\left(\frac{\alpha^2+2\beta^2}{\alpha^2+\beta^2} - 2\frac{\beta^2}{\alpha^2}\ln\frac{\alpha^2+\beta^2}{\beta^2}\right) + \right.$$

$$+ \frac{\Lambda^2\alpha^4}{4} F_\sigma^2(0) + \frac{\Lambda^4\alpha^4}{4} M_N^2 F_\omega^2(0)\left[\ln(1+\gamma) - \frac{\gamma}{1+\gamma} - \frac{3}{4}\right] +$$

$$+ \Lambda^2\alpha^2 F_\rho^2(0)\left[\ln(1+\gamma) - \frac{1}{2}\right] + \tag{32}$$

$$\left. + \frac{\Lambda^2 s_M^2 \alpha^2}{2}\phi_f^2(0) \pm 2\Lambda^2 s_M \alpha^2 F_\rho(0)\phi_f(0)\right\}.$$

Table 2 contains numerical estimates of the cross sections at different sets of the parameter s_M and at maximum momentum $|t_1|_{max} \approx \approx (1\div 2)m_\pi^2$ transfered to nucleon, which corresponds to $\alpha \simeq \frac{1}{7}\div\frac{1}{5}$.

Though the differential cross section (27) grows with energy $\propto s$ the sizes of domains I and II become smaller as 1/s. Therefore total cross section is constant*) and its value, as well as the ratio of the contributions from different mesons are essentially determined by the values the parameters s_M, Λ^2.
The relative value for the cross section difference $A = \frac{\sigma^\nu - \sigma^{\bar\nu}}{\sigma^\nu + \sigma^{\bar\nu}}$ of reaction (1) in ν and $\bar\nu$ beams is defined in domains I and III practically only by the parameter s_M.

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*) Note that for the total cross sections this asymptotics takes place at the energies of the incoming neutrino $E_\nu \gg s_M/2M_N$.

b) Cross section of pion production on reggeons.

In the Regge domain, we shall derive from formula (10) using relation (23) and (25) the following one:

$$\frac{d\sigma}{dxdy} = \frac{G^2 M_N^2(\alpha^2 - x^2)s}{32\pi^3}\{16\pi f_\pi^2 (1-y)(\frac{d\sigma^\pm}{dt}|_{t=0})\tilde{\Phi}_A^2(q^2) + M_N^2 x^3 ys(1-\frac{y}{2})^2 \frac{2}{g_\rho^2}|\Phi^\omega_{\pi\rho}|^2 \tilde{\Phi}^2_\omega(q^2) \mp \tag{33}$$

$$\mp 2M_N^2 x^2 y(1-\frac{y}{2})\frac{\sqrt{2}}{g_\rho} f_\pi \, \mathrm{Re}\,\Phi^\omega_{\pi\rho}\sigma_{tot}^{\pi^\pm N}\tilde{\Phi}_A(q^2)\tilde{\Phi}_\omega(q^2)\}$$

where $\frac{d\sigma^\pm}{dt}|_{t=0}$ is differential cross section of $\pi^\pm N$ scattering

$$\frac{d\sigma^\pm}{dt}|_{t=0} = 4\pi|\gamma_P\eta_P + \gamma_f\eta_f(\frac{ys}{s_0})^{\alpha_f(0)-1} \mp \gamma_\rho\eta_\rho(\frac{ys}{s_0})^{\alpha_\rho(0)-1}|^2$$

γ, η, $\alpha(0)$ is a residue, signature and the value for $\alpha(0)$ at P, f and ρ trajectories. For the axial combination Φ_A there is assumed a unified dependence of the formfactor

$$\tilde{\Phi}_A(q^2) = \frac{\Phi_A(q^2)}{\Phi_A(0)}.$$

From numerical calculations it is clear that the main contribution to the Regge domain at $\frac{s_R}{s} < y < 1$ is made by the axial transitions, where weak pomeron-pion transition is dominating. From formula (33) it is seen, that at $y \to 1$ the contribution from the (ω)-trajectory becomes dominating in differential cross section. Thus a study of the y-distribution in the Regge domain allows one in principle to select the contribution from the vector and axial currents.

At $x \to 0$ which corresponds to domain II in fig. 2 we have:

$$\frac{d\sigma}{dx\,dy} = \frac{G^2 M_N^2 \alpha^2 s}{32\pi^3} 16\pi f_\pi^2 (1-y) \left(\frac{d\sigma^{\pm}}{dt}\Big|_{t=0} \right). \qquad (34)$$

In the Regge domain the difference of the cross sections for ν and $\bar{\nu}$ is defined both by the asymmetry caused by ρ-pomeron interference and by P-odd asymmetry, connected with the interference between leptonic and hadronic vector and axial currents. For the $\bar{\nu}$ and ν cross section difference we have:

$$\frac{d\sigma^{\bar{\nu}}}{dx\,dy} - \frac{d\sigma^{\nu}}{dx\,dy} = \frac{G^2 M_N^2 (\alpha^2 - x^2) s}{32\pi^3} \Big\{ 16\pi f_\pi^2 (1-y) \times \qquad (35)$$

$$\times \left(\frac{d\sigma^-}{dt} - \frac{d\sigma^+}{dt}\Big|_{t=0} \right) \tilde{\Phi}_A^2(q^2) + 2M_N^2 x^2 y \left(1 - \frac{y}{2}\right) \frac{\sqrt{2}}{g_\rho} \mathrm{Re}\, \Phi_{\pi\rho}^{\omega} (\sigma^+_{tot} + \sigma^-_{tot}) \tilde{\Phi}_A(q^2) \tilde{\Phi}_\omega(q^2) \Big\}.$$

The study of the q^2 dependence for differential cross sections (33) and (35) allows us to study the formfactors of weak Reggeon-pion transitions.

The data on diffractive dissociation of pions on nucleons /17/ point to the fact that differential cross section for pion dissociation into hadronic system of the mass M decreases as $1/M^4$ with the growth of M. Reaction (1) in the Regge domain at large q^2 may be treated in the hadronic block as a process inverse to diffraction dissociation of pion into the system with $M = \sqrt{|q^2|}$ and one may take for estimates the q^2 dependence of formfactors in form (30). Then at large $|q^2| = sxy \gg \Lambda^2$ from (33) we obtain:

$$\frac{d\sigma}{dxdy} = \frac{G^2 M_N^2(\alpha^2 - x^2)\Lambda^4}{32\pi^3} \{ \frac{16\pi f_\pi^2}{s x^2 y^2}(1-y)(\frac{d\sigma^\pm}{dt})|_{t=0}) +$$

$$+2M_N^2 \frac{s_o}{s} \frac{x}{y^2}(1-\frac{y}{2})^2 \frac{2}{g_\rho^2} |\Phi^o_{\pi\rho}|^2 \mp 2M_N^2(1-\frac{y}{2}) \frac{\sqrt{2}}{g_\rho} \Phi^o_{\pi\rho} f_\pi \sigma^\pm_{tot} \sqrt{\frac{s_o}{s}} \frac{1}{s y^{3/2}} \}. \tag{36}$$

From comparison of formulae (27), (34) and (36) it follows that the scattering event density in mesons and structurelles reggeons increases with energy $\propto s$ while the density of the events of scattering on structure reggeons decreases with energy as 1/s. However domains I,II and III in fig. 2 decrease with energy, while domain IV increases since the total number of the events in domains I, II, III turns out to be constant and independent of the energy. The total number of neutrino production of pions on pomeron increases as energy logarithm, and the total cross section of other scattering processes on structure reggeons and their interferences are constant and to great extent are defined by the quatity s_R. The total cross section for pion production in the Regge domain (at $\alpha s_R \gg \Lambda^2$) has the form:

$$\sigma^{tot} = \sigma_P + \sigma_\omega \mp \sigma_{\rho P} = \frac{G^2 M_N^2}{32\pi^3} [\Lambda^2 \alpha^2 f_\pi^2 (\sigma^{\pi N}_{tot})^2 (\ell n \frac{s}{s_R} - 1) + \frac{\Lambda^4 \alpha^4 s_o |\Phi^o_{\pi\rho}|^2}{2 g_\rho^2 s_R} \mp 4\Lambda^2 \alpha^2 \sigma^{\pi N}_{tot} \sigma^{\pi N}_\rho (s = s_R)(1 - \sqrt{\frac{s_R}{s}})] \tag{37}$$

where $\sigma_{\rho}^{\pi N}$ is the contribution from the ρ-trajectory to the total cross section for πN scattering

$$\sigma_{tot}^{\pi^- N} - \sigma_{tot}^{\pi^+ N} = 2\sigma_{\rho}^{\pi N}.$$

At $\Lambda^2 \approx 1$ GeV^2, $s = 200$ GeV^2, $s_R = 20$ GeV^2, $a = 1/5$ for separate contributions $\sigma_P \simeq 2 \cdot 10^{-40}$ cm^2, $\sigma_{\omega} \approx 4 \cdot 10^{-42}$ cm^2, $\sigma_{\bar{\nu}} - \sigma_{\nu} \simeq 3 \cdot 10^{-41}$ cm^2. The difference of the total cross sections for single fast pion production in the ν and $\bar{\nu}$ beams changes its sign when passing to the Regge domain. The quoted quantity is determined by the effects of charge asymmetry in domains II and IV, which is caused by ρ and P trajectory interference, and makes up 10-15% of total cross section. The contribution of the interference of vector and axial currents to the cross section difference is small (< 0.1%) and decreases with the energy as 1/S. From formula (37) it is seen that total cross section in Regge domain is defined mainly by neutrino /antineutrino/ scattering on pomeron. Thus a study of reaction (1) provides us with the information about weak interaction of pomeron and its quark structure.

According to formulae (27) (34) and (36) the event density is maximal in the range of transition to Regge asymptotics at $y \sim \frac{s_M}{s} \div \frac{s_R}{s}$ and at $|q^2| \sim \Lambda^2$, therefore the investigation of the event distribution over x and y gives us information about space-time picture of reggeon production (virtual mesons) (see Conclusion). The study of the charge asymmetry effects, manifesting themselves in the difference of neutrino and antineutrino cross sections helps us to define more precisely the parameters s_M and s_{R} determining the transition to the Regge asymptotics on the case of lepton-hadron processes.

5. SINGLE PION PRODUCTION ON NUCLEI

In single pion production processes the scattering on σ, f and pomeron goes on coherently on the whole nucleus at sufficiently small t_1. As for scattering on π and ρ it is defined by the sum of incoherent contributions from nucleus nucleons. In the vertex of ω emission by nucleon $g_\omega \bar{u}_2 \gamma_\mu u_1 \omega_\mu$ interaction with the time component $g_\omega \bar{u}_2 \gamma_0 u_1 \omega_0$ goes into $g_\omega 2M_N \phi_2^+ \phi_1 \omega_0$ (the wave functions $\phi_{1,2}$ are normalized for 1) in nonrelativistic limit) and corresponds to coherent scattering on nucleus. The interaction of nucleons with space component $\vec{\omega}$ is caused by relativistic effects and is inessential in consideration of small momentum transfers to nucleon.

Account for Pauli exclusion principle for nucleons in the final state may greatly influence the ratio of incoherent and coherent contributions from different mesons to the reaction (1) of fast pion production with small momentum transfer to nucleon. A detailed consideration of incoherent processes with account for nuclear effects is therefore a separate problem which involves numerical calculations.*)

Differential cross section of coherent neutrino production of single pions on nuclei is defined in formulae (7), (10) (27) and (36) by the contributions from σ, ω, f and pomeron. In this the relevant cross sections are to be additionally multiplied by $A^{\varkappa}$ where $\varkappa = 2$ for coherent scattering with no account for nucleon screaning and pion absorption in nucleus.

The study of fast pion production on nuclei allows us to select the contributions from ω and f mesons in the mesonic domain and in the P, ω, f trajectories in Regge domain. It is rather interesting that the difference of the ν and $\bar{\nu}$ cross sections for pion production on nuclei caused by the ρ contribution may practically vanish.

6. CONCLUSION. SPACE-TIME PICTURE OF VIRTUAL MESON AND REGGEON FORMATION

The kinematical range of small momentum transfers to nucleon corresponds to scattering on its periphery, which corresponds to the range of small x in the framework of the quark-parton model. No matter that the contribution from the range of small x to the total cross section of deep inelastic scattering is small, still just this region raises our interest from the point of view of

*) The coherent neutrino production of π° mesons on nuclei induced by neutral currents was considered in ref. /16/.

quark interaction at large distances. This is the range of strong correlations between partons and neutrino scattering on virtual mesons treated in this work is manifestation of these correlations.

Our understanding of scattering on virtual mesons as of an effective way of the simplified description of neutrino scattering on quark-antiquark correlations in the peripheral domain of nucleon (in the domain of confinment) makes it necessary to change the description of such correlations with increase of $s_1 \approx 2p_1 q \approx 2M_N q_0$. At characteristic time of scattering $\Delta\tau \sim \frac{1}{q_0} > \frac{1}{M_N}$ the correlations manage so to say to form in virtual meson, on smaller timescales scattering takes place on correlations with quantum numbers of the corresponding mesons but they did not manage to form into such mesons. Regge asymptotics allows one to describe such "short-term" correlations, which manifest themselves as a corresponding Reggeon. In this the parameter S_M (more precisely $\tau_M = \frac{2M_N}{s_M}$) introduced in this work, which defines the transition from meson amplitudes to Regge ones, may be interpreted as the timescale virtual meson formation.

The high is q^2 the better is the space resolution of parton correlations, and appearance of the q^2 dependence of the formfactors is caused by the transition to distances smaller than the effective sizes of meson. Experimental study of the problem on the q^2 dependence of the formfactors of meson-pion and Regge-pion transitions (weak charge radius of meson and reggeon) is of great interest.

From the estimates made it follows that the value for total cross section for π meson production in neutrino scattering on virtual mesons (reggeons) and the maximum density of the events in the plane (x, y) are very sensitive to the ratio of the parameters $s_M(s_R)$ and Λ^2 i.e., they are essentially defined by the timescale of meson formation in parton correlations and by the space structure of these correlations.

In the framework of the described space-time picture it is of interest to treat the problem on the existence of a kinematic domain for scattering on virtual mesons. The thing is that in this domain the PCAC ratio (25) is greatly violated, if one uses estimates (19) and (20) for F_A , and for $T_{\pi N}$ experimental data on πN scattering. Such a violation may serve as an indication that similarly with the case of hadron-hadron processes the transition to Regge description of reaction (1) takes place right after resonance region, or even earlier, if $s_R < M_R^2$, is characterized by the background part of the amplitude in the resonance region. However, the violation of the PCAC relation may be quite reasonable, reflecting the essential difference between lepton-hadron and hadron-hadron processes in the region of $s_1 < s_M$ if $s_M > M_R^2$). The indicated region is characterized by the time $\Delta\tau > \tau_M = \frac{2M_N}{s_M}$ in the neutrino processes. This time is larger than the one necessary for virtual meson formation in hadron at rest. In collision of two hadrons the processes would look as if virtual meson exchange in both hadrons. But for incident hadron the quoted time increases $\tau_M \to \tau_M' = \tau_M \frac{s_1}{2M_N^2}$ becoming considerably larger than characteristic collision time. This reasoning may serve as a qualitative argument in favour of a more delayed transtion to Regge asymptotics in lepton-hadron proces- ses. Experimental study of reaction (1) charge asymmetry effects in particular, at $s_1 \lesssim 20 \ GeV^2$ will help to check the indicated possibility.

It will be interesting to detect slow recoil nucleon in reaction (1). It would make possible to measure the quantity $|t_1|_{max}$ and thus to investigate the properties of parton correlations depending on x. Detection of recoil nucleon allows one to study P-odd asymmetry (see formula (7)) over the Treiman-Yang angle, which would allow to find out the relative sign of different amplitudes. It seems to be of great importance to develop the methods for slow particle detection in neutrino detectors.

Reaction (1) treated here is the simplest example of a wide class of neutrino processes on the peripheral of nucleon. Investigation of such exclusive and inclusive /8/ processes would provide us with the information about weak meson (reggeon) interaction, quark structure of reggeons and their physical nature. It will also be rather useful for theoretical and experimental study of the properties of quark interactions at large distances.

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Table 1

Transition	J^P I^G of initial meson	Charged current: G-parity of the transition;	type	Neutral current of $C_{0\to0}$-parity of the transition;	type
$\pi^o \to \pi$	0^-, 1^-	+	V	+	no
$\rho^o \to \pi$	1^-, 1^+	-	A	-	V
$\omega^o \to \pi$	1^-, 0^-	+	V	-	V
$\sigma^o \to \pi$	0^+, 0^+	-	A	+	A
$A_1^o \to \pi$	1^+, 1^-	+	V	+	no
$D_A^o \to \pi$	1^+, 0^+	-	A	+	A
$\eta^o \to \pi$ $(\eta' \to \pi)$	0^-, 0^+	-	no	+	no
$A_2^o \to \pi$	2^+, 1^-	+	V	+	no
$f^o \to \pi$	2^+, 0^+	-	A	+	A

Table 2

The contributions of different mesons to total cross section in one meson when different s_M and a parameter choice

σ, cm^2	σ_π	σ_σ	σ_ω	σ_ρ	σ_f	$\sigma_{\rho f}$	$A = \frac{\sigma^\nu - \sigma^{\bar\nu}}{\sigma^\nu + \sigma^{\bar\nu}}$
$s_M = 2$ GeV^2, $a = 1/7$	$5\cdot10^{-42}$	$2\cdot10^{-42}$	$6\cdot10^{-43}$	$3\cdot10^{-41}$	$2\cdot10^{-41}$	$4\cdot10^{-41}$	0.8
$s_M = 20$ GeV^2, $a = 1/5$	$8\cdot10^{-41}$	$6\cdot10^{-41}$	$2\cdot10^{-41}$	$3\cdot10^{-40}$	$2\cdot10^{-38}$	10^{-38}	0.5

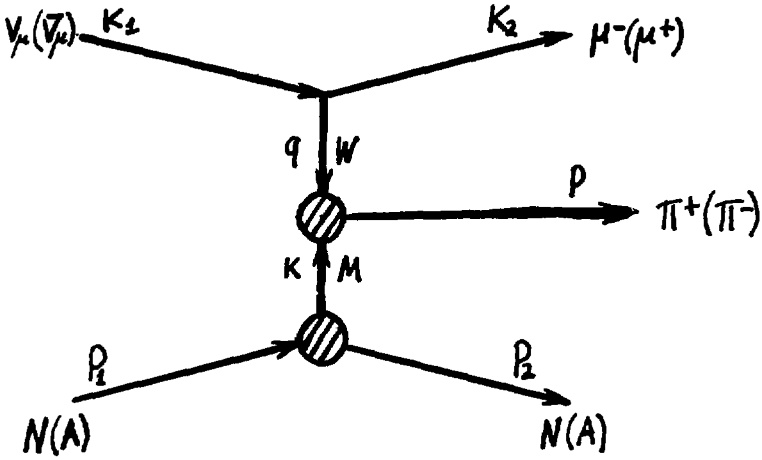
$\nu_\mu(\bar\nu_\mu)$
K_1
K_2
$\mu^-(\mu^+)$
q
W
p
$\pi^+(\pi^-)$
K
M
P_1
P_2
N(A)
N(A)

Fig. 1

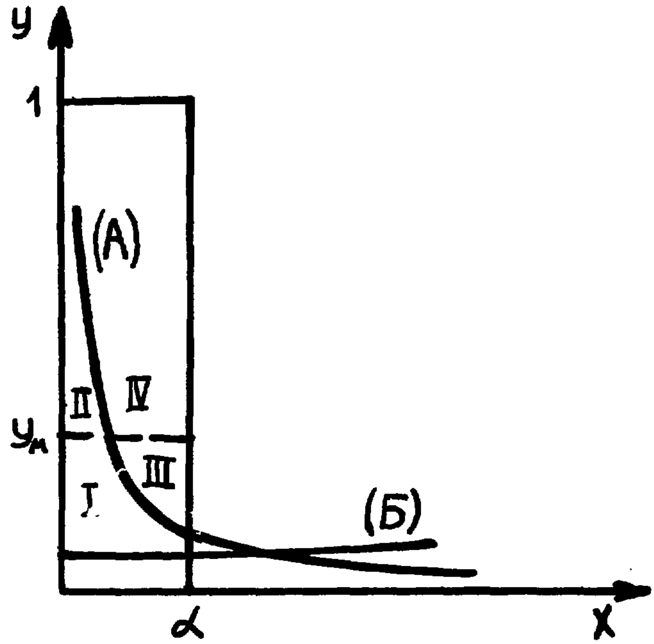
y
1
(A)
II
IV
y_μ
III
I
(Б)
α
x

Fig. 2

Цена 18 коп.

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