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EXTRA Z′-BOSON IN ELASTIC AND DIFFRACTIVE NEUTRINO SCATTERING

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Introduction

Deriving experimentally checkable predictions from superstrings is a key problem in construction of a unified theory of fundamental interactions. It is clear now that, despite impressive progress in this field, the predictions obtained are far from being reliable. Approaches to the solution of this problem are still dimmed. However, there are reasons to believe that the 10-dimensional heteroidic $E_8 \times E_8'$ superstring leads after compactification to 4-dimensional N=1 supersymmetric theory with the gauge group E_6 /1/. Superfields of matter are grouped into 27-plets E_6 in this case.

An interesting physical consequence of this scheme is that relatively light (the mass is less or near 1 TeV) exotic fermions /2/ and the additional Z'-boson /3/ can exist. The new light fermions from the 27-plet E_6 can probably be two standard-group singlet states: the ν^c belonging to the 16-dimensional representation of SO_{10} and the SO_{10} singlet n /4/. There is a more certain situation with the Z'-boson. It appears practically in all the known schemes of the low-energy limit of superstrings /5/.

Great attention has been recently paid to the study of expected experimental manifestations of the Z'-boson which, if discovered, could indicate the superstring nature of unification of interactions. From this point of view its contribution to deep inelastic processes, $\overset{(-)}{\nu} e$ scattering, e^+e^- annihilation, atomic parity violation and some other processes /5-7/ were theoretically studied. It should be noted, however, that additional neutral bosons can appear in ordinary grand unification schemes as well. So the reliable interpretation of possible deviations from the standard model (SM) as manifestations of the superstring Z' contribution will require a wider class of phenomena to be studied.

We shall calculate and analyse the magnitude and specific features of this contribution to elastic $\overset{(-)}{\nu}N$ scattering, coherent neutrinoproduction of π^0-mesons on nuclei and some diffractive reaction:

$$\overset{(-)}{\nu}N \to \overset{(-)}{\nu}N, \tag{1}$$

$$\overset{(-)}{\nu}A \to \overset{(-)}{\nu}\pi^0 A, \tag{2}$$

$$\overset{(-)}{\nu}N \to \overset{(-)}{\nu}\rho^0(A_1^0)N. \tag{3}$$

Besides, we shall consider once more the process

$$\overset{(-)}{\nu}e \to \overset{(-)}{\nu}e. \tag{4}$$

In Section 1 we make some introductionary remarks on the superstring E_6-model, then write down a Lagrangian of the Z' interaction and the effective neutral current Lagrangian with the Z^0-Z' mixing.

In Section 2 the Z' contribution of processes (1)-(4) is found.

Section 3 contains the results of the quantitative analysis of this contribution. The influence of the Z^0-Z' mixing and the scheme of symmetry breaking at the intermediate scale is studied.

1. Neutral Currents in the Superstring E_6-Model

In the low energy limit of superstrings under consideration the gauge group E_6 breaks down (via flux breaking) to a subgroup of rank 5 or 6 /1,3/

$$G_5 = SU_{3C} \times SU_{2L} \times U_{1Y} \times U_{1\eta} \qquad \text{rank } 5 \tag{5}$$

$$G_6 = SU_{3C} \times SU_{2L} \times U_{1Y} \times U_{1\psi} \times U_{1\chi} \qquad \text{rank } 6 . \tag{6}$$

The subgroup of rank 6 may have other versions, but for our aims it is enough to consider the above one. The subgroup of rank 5 is unique.

Imbedding to E_6 is determined by the subgroup chain:

$$E_6 \supset SO_{10} \times U_{1\psi} \supset SU_5 \times U_{1\chi} \times U_{1\psi}. \tag{7}$$

In this case

$$SU_5 \supset SU_{3C} \times SU_{2L} \times U_{1Y}.$$

Considering the subgroup of rank 6 we obtain two additional neutral bosons Z_ψ and Z_χ. We shall suppose, however, that there is an intermediate scale $M_I \sim 10^{10-11}$ GeV at which the spontaneous breaking of the subgroup G_6 occurs. This breaking can be induced by non-zero VEVs of the scalar superpartners $\tilde{\nu}^c$, $\tilde{n}$ of the fields ν^c and n from the $\underline{27}$ of E_6 (see Table 1) transformed under (SO_{10}, SU_5) as (16,1) and (1,1) respectively. One can show that it results in one "light" Z'-boson /4-6/. The corresponding extra U_1 generator is

$$Q^{Z'}(\theta_{E6}) = Q_\psi \cos\theta_{E6} + Q_\chi \sin\theta_{E6}, \tag{8}$$

Q_ψ and Q_χ are the generators of $U_{1\psi}$ and $U_{1\chi}$. The eigenvalues of $Q_{\psi,\chi}$ for the fields from the $\underline{27}$ are given in Table 1.

Note that $Q_i(\psi_R) = -Q_i(\psi_L^c)$. The angle θ_{E6} is determined by the VEVs $\langle\tilde{n}\rangle$ and $\langle\tilde{\nu}^c\rangle$, i.e. it parametrises the scheme of the symmetry breaking at the intermediate scale. The generator Q_η of the subgroup $U_{1\eta}$ (5) /3,5/

$$Q_\eta = -\sqrt{\tfrac{5}{8}}\, Q_\psi + \sqrt{\tfrac{3}{8}}\, Q_\chi \tag{9}$$

can be considered as a particular case of general formula (8), since $Q_\eta = Q^{Z'}(142.24^\circ)$. Let us write out the neutral current Lagrangian

$$-\mathcal{L}_{NC} = g Z_\mu J^\mu_Z + g' Z'_\mu J^\mu_{Z'}, \qquad (10)$$

where

$$J^Z_\mu = \sum_f \overline{\psi}_f \gamma_\mu Q^Z \psi_f = \frac{1}{2} \sum_f \overline{\psi}_f \gamma_\mu (g^Z_V + g^Z_A \gamma_5) \psi_f,$$

$$J^{Z'}_\mu = \sum_f \overline{\psi}_f \gamma_\mu Q^{Z'}(\theta_{E6}) \psi_f = \frac{1}{2} \sum_f \overline{\psi}_f \gamma_\mu (g^{Z'}_V + g^{Z'}_A \gamma_5) \psi_f. \qquad (11)$$

Summation goes over the fermions from the 27 of E_6. $Q^Z = I_{3L} - x_W Q^{em}$ is the SM "charge" of fermions, $x_W = \sin^2\theta_W$.

Table 1. Quantum members of the fields from the 27-plet E_6

SO_{10}	SU_5	SU_{3C}	Left field	I_{3L}	Q^{em}	Q_η	Q_χ	Q_ψ
16	$\overline{5}$	$\overline{3}$	d^c	0	1/3			
		1	e	-1/2	1	1/6	$1/2\sqrt{3/2}$	
		1	ν_e	1/2	0			
	10	3	d	-1/2	-1/3			
		3	u	1/2	2/3	-1/3	$-1/2\sqrt{1/6}$	$1/6\sqrt{5/2}$
		3	u^c	0	-2/3			
		1	e^c	0	1			
	1	1	ν_e^c	0	0	-5/6	$-5/2\sqrt{1/6}$	
10	$\overline{5}$	$\overline{3}$	h^c	0	1/3			
		1	E	-1/2	-1	1/6	$-\sqrt{1/6}$	
		1	ν_E	1/2	0			
	5	3	h	0	-1/3			$-1/3\sqrt{5/2}$
		1	E^c	1/2	1	2/3	$\sqrt{1/6}$	
		1	N_E^c	-1/2	0			
1	1	1	n	1	0	-5/6	0	$1/3\sqrt{10}$

The standard notation

$$g^i_{V,A} = Q^i_f \mp Q^i_{f^c} \qquad (12)$$

is used in the formulae. Table 2 lists the axial g_A and vector g_V coupling constants of ordinary fermions.

We shall use the following relation for gauge coupling constants:

$$g' = \sqrt{x_W}\, g = \frac{e}{\sqrt{1-x_W}}. \qquad (13)$$

This formula is justified by the renormalization group analysis /8/ and corresponds to the E_6 unification for groups $G_{5,6}(5)$, (6).

The mass matrix of the fields (Z,Z') is non-diagonal in the general case

$$M^2 = \begin{pmatrix} M_0^2 & \delta M^2 \\ \delta M^2 & (M')^2 \end{pmatrix}. \qquad (14)$$

This leads to the Z-Z' mixing. Diagonalising matrix (14) we find the fields $Z_{1,2}$ with a definite mass

$$\begin{pmatrix} Z_1 \\ Z_2 \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} Z \\ Z' \end{pmatrix}. \qquad (15)$$

Table 2. Axial and vector coupling constants of ordinary fermions (The notation $\nu = \frac{1}{6}\sqrt{\frac{5}{2}}\cos\theta_{E6}$; $\xi = \frac{1}{2}\sqrt{\frac{1}{6}}\sin\theta_{E6}$ is introduced)

Field	g^Z_V	g^Z_A	$g^{Z'}_V$ rank 5	$g^{Z'}_V$ rank 6	$g^{Z'}_A$ rank 5	$g^{Z'}_A$ rank 6
u	$1/2-4/3x_W$	1/2	0	0	-2/3	$2(\nu-\xi)$
d	$-1/2+2/3x_W$	-1/2	-1/2	-4ξ	-1/6	$2(\nu+\xi)$
ν	1/2	1/2	1	8ξ	-2/3	$2(\nu-\xi)$
e	$-1/2+2x_W$	-1/2	1/2	4ξ	-1/6	$2(\nu+\xi)$

The masses and the mixing angle are expressed through the initial parameters

$$M_1^2 \simeq M_0^2 - \frac{(\delta M^2)^2}{(M')^2 - M_0^2}, \quad M_2^2 \simeq (M')^2 + \frac{(\delta M^2)^2}{(M')^2 - M_0^2},$$

$$\tan^2\theta = (M_0^2 - M_1^2)/(M_2^2 - M_0^2). \qquad (16)$$

For the models with SU_{2L}-doublet and singlet Higgs fields the following relation is valid:

$$M_0^2 = \frac{M_W^2}{1 - x_W}. \qquad (17)$$

For $x_W = \sin^2\theta_W = 0.233 \pm 0.003 \pm 0.005$ /9/ we find $M_0 = 92.21 \pm 2.45$ GeV. In the superstring E_6 model there are two SU_{2L} doublets (H, $\bar{H}$) and a singlet N of the Higgs fields. In this case

$$\delta M^2 = \sqrt{x_W}\,\frac{4v^2 - \bar{v}^2}{3(v^2 + \bar{v}^2)}, \quad (M')^2 = M_0^2\,\frac{16v^2 + \bar{v}^2 + 25x^2}{9(v^2 + \bar{v}^2)}, \qquad (18)$$

where $v = \langle H^0 \rangle \equiv \langle \tilde{N}_E^c \rangle$, $\bar{v} = \langle \bar{H}^0 \rangle \equiv \langle \tilde{\nu}_E \rangle$, $x = \langle N \rangle \equiv \langle \tilde{n} \rangle$; $\tilde{N}_E^c, \tilde{\nu}_E, \tilde{n}$ are the scalar superpartners of the respective fermions from the 27 (see Table 1).

The effective neutral current Lagrangian with the Z-Z' mixing follows from the initial one (10) and has the form

$$\mathcal{L}_{NC}^{eff} = \frac{4G}{\sqrt{2}}\left(\rho J_Z^2 + \omega J_Z J_{Z'} + \sigma J_{Z'}^2\right), \qquad (19)$$

where

$$\rho = M_0^2/M_1^2 \cos^2\theta + M_0^2/M_2^2 \sin^2\theta,$$

$$\sigma = x_W\left(M_0^2/M_1^2 \sin^2\theta + M_0^2/M_2^2 \cos^2\theta\right),$$

$$\omega = 2\sin 2\theta\sqrt{x_W}\left(M_0^2/M_1^2 - M_0^2/M_2^2\right).$$

Switching to the particular cases of interest we are thus able to find the effective Lagrangians of $\overset{(-)}{\nu}e$ interactions

$$\mathcal{L}_{NC}^{\nu e} = \frac{2G}{\sqrt{2}}\bar{\nu}\gamma_\mu(1+\gamma_5)\nu\,\bar{e}\gamma_\mu\left(g_V^{eff}(e) + g_A^{eff}(e)\gamma_5\right)e \qquad (20)$$

and of neutrino-hadron ($\overset{(-)}{\nu}H$) interactions

$$\mathcal{L}_{NC}^{\nu H} = \frac{2G}{\sqrt{2}}\bar{\nu}\gamma_\mu(1+\gamma_5)\nu\, J_\mu^{eff}(H). \qquad (21)$$

Here the effective quantities are introduced:

$$g_{V,A}^{eff}(e) = a g_{V,A}^{Z}(e) + b g_{V,A}^{Z'}(e),$$

$$J_\mu^{eff}(H) = a J_\mu^{Z}(H) + b J_\mu^{Z'}(H), \qquad (22)$$

where $a = \rho + \omega Q_\nu^{Z'}(\theta_{E6})$, $b = \frac{\omega}{2} + 2\sigma Q_\nu^{Z'}(\theta_{E6})$,

$$Q_\nu^{Z'}(\theta_{E6}) = \frac{1}{6}\sqrt{\frac{5}{2}}\cos\theta_{E6} + \frac{1}{2}\sqrt{\frac{3}{2}}\sin\theta_{E6}.$$

$g_{V,A}^{Z,Z'}(e)$ for $\overset{(-)}{\nu}_\mu e \to \overset{(-)}{\nu}_\mu e$ are given in Table 2, for $\overset{(-)}{\nu}_e e \to \overset{(-)}{\nu}_e e$: $g_{V,A}^{eff}(e,\nu_e) = g_{V,A}^{eff}(e) + 1$. $J_\mu^i(H)$ are the hadronic components of currents; it is suitable to parametrise them displaying their isospin and space-time structure /10/:

$$J_\mu^i(H) = \frac{\alpha^i}{4}(\bar{u}\gamma_\mu u - \bar{d}\gamma_\mu d) + \frac{\beta^i}{4}(\bar{u}\gamma_\mu\gamma_5 u - \bar{d}\gamma_\mu\gamma_5 d) +$$

$$+ \frac{\gamma^i}{4}(\bar{u}\gamma_\mu u + \bar{d}\gamma_\mu d) + \frac{\delta^i}{4}(\bar{u}\gamma_\mu\gamma_5 u + \bar{d}\gamma_\mu\gamma_5 d) + \ldots =$$

$$= \frac{\alpha^i}{2}V_\mu^3 + \frac{\beta^i}{2}A_\mu^3 + \frac{\gamma^i}{2}V_\mu^s + \frac{\delta^i}{2}A_\mu^s + \ldots \qquad (23)$$

(i = Z, Z', eff). The dots correspond to the contribution of heavy quarks. It follows from (22), (23) that

$$(\alpha^{eff}, \beta^{eff}, \gamma^{eff}, \delta^{eff}) = a(\alpha^Z, \beta^Z, \gamma^Z, \delta^Z) + b(\alpha^{Z'}, \beta^{Z'}, \gamma^{Z'}, \delta^{Z'}). \qquad (24)$$

Now a way of taking into account the Z' contribution in $\overset{(-)}{\nu}e$ and $\overset{(-)}{\nu}H$ NS interactions is given by the substitutions

$$g_{V,A}(e) \to g_{V,A}^{eff}; \quad \alpha, \beta, \gamma, \delta \to \alpha^{eff}, \beta^{eff}, \gamma^{eff}, \delta^{eff} \qquad (25)$$

in the relevant formulae obtained within the SM. The parameters $\alpha^{z,z'}, \beta^{z,z'}, \gamma^{z,z'}, \delta^{z,z'}$ are in Table 3. In the Appendix there is a list of some useful relations between the neutral current parameters.

Table 3. Isospin structure parameters of the hadronic current. (The notation $\nu = \frac{1}{6}\sqrt{\frac{5}{2}}\cos\theta_{E6}$; $\xi = \frac{1}{2}\sqrt{\frac{1}{6}}\sin\theta_{E6}$ is introduced)

Parameter	Z	Z'	
		rank 5	rank 6
α	$1 - 2X_W$	1/2	4ξ
β	1	-1/2	-4ξ
γ	$-2/3X_W$	-1/2	-4ξ
δ	0	-5/6	4ν

2. Elastic Form Factors of Nucleons

To calculate elastic $\overset{(-)}{\nu} N$ scattering one must specify the matrix element of the current J_μ^{eff} entering into Lagrangian (21):

$$\langle p,n | J_\mu^{eff}(0) | p,n\rangle = \bar{u}(k_2)\Big[\gamma_\mu F^{eff}_{V(p,n)}(Q^2) - \frac{\sigma_{\mu\nu}q^\nu}{2M} F^{eff}_{M(p,n)}(Q^2) + \gamma_\mu\gamma_5 F^{eff}_{A(p,n)}(Q^2)\Big] u(k_1). \qquad (26)$$

The problem is to find form factors (FF) F_i^{eff}. We establish their relation with electromagnetic FF $F_{1,2}$ and the axial FF F_A^{CC} of the charged current. The standard definitions are

$$\langle p,n | J_\mu^{em}(0) | p,n\rangle = \bar{u}(k_2)\Big[\gamma_\mu F_1^{p,n}(Q^2) - \frac{\sigma_{\mu\nu}q^\nu}{2M} F_2^{p,n}(Q^2)\Big] u(k_1),$$

$$\langle p | A_\mu^{1+i2}(0) | n\rangle = \bar{u}(k_2)\gamma_\mu\gamma_5 u(k_1) F_A^{CC}(Q^2), \qquad (27)$$

$$\langle N | A_\mu^{s}(0) | N\rangle = \bar{u}(k_2)\gamma_\mu\gamma_5 u(k_1) F_A^{s}(Q^2).$$

One can write down on the basis of the CVC hypothesis and isospin symmetry considerations:

$$\langle p | V_\mu^3(0) | p\rangle = -\langle n | V_\mu^3(0) | n\rangle = \frac{1}{2}\Big[\langle p | J_\mu^{em}(0) | p\rangle - \langle n | J_\mu^{em}(0) | n\rangle\Big], \qquad (28)$$

$$\langle p,n | A_\mu^3(0) | p,n\rangle = \pm\frac{1}{2}\langle p | A_\mu^{1+i2}(0) | n\rangle.$$

For the hadronic current J_μ^i (23) we find from (26)-(28) the following relations:

$$F^i_{V,M(p,n)}(Q^2) = \frac{1}{4}(\alpha^i + 3\gamma^i)F^{p,n}_{1,2}(Q^2) - \frac{1}{4}(\alpha^i - 3\gamma^i)F^{n,p}_{1,2}(Q^2),$$

$$F^i_{A(p,n)}(Q^2) = \pm\frac{1}{4}\beta^i F_A^{CC}(Q^2) + \frac{\delta^i\epsilon}{2}F_A^s(Q^2). \qquad (29)$$

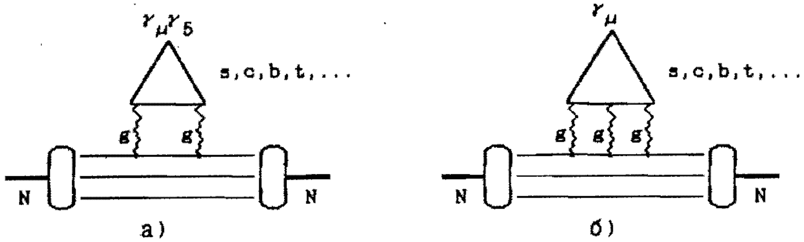


Fig. 1. Contribution of heavy quarks to axial (a) and vector (b) currents. An example of the lowest order diagrams.

The correction ϵ is due to the contribution of heavy quarks to the axial current /11/. The corresponding diagram of a lower order is given in Fig. 1a. According to Wolfenstein's estimations /12/ $\epsilon = 0.1 \pm 0.15$. A similar contribution to vector currents is small $O(\alpha_s^3) \lesssim 10^{-3}$, since in a lowest order it is determined by the three-gluon exchange diagram (Fig. 1b). To determine the Q^2-dependence of FF, we use the relation:

$$G_{E_p}(Q^2) \simeq G_{M_p}(Q^2)/\mu_p \simeq G_{M_n}(Q^2)/\mu_n, \quad G_{E_n}(Q^2) \simeq 0, \tag{30}$$

$$F_A^S(Q^2) \simeq \frac{\lambda}{2} F_A^{CC}(Q^2), \tag{31}$$

$\mu_p = 2.79$, $\mu_n = -1.91$ are the proton and neutron magnetic moments. Relations (30) are well known. Now we explain formula (31). In the region of small and moderate Q^2 it can be justified from different points of view. In particular, the coincidence of the Q^2-dependence of F_A^S and F_A^{CC} follows from the hypothesis of A_1-meson dominance in axial current. Preliminary estimations in the approach based on local duality in QCD /13/ also indicate that this formula is a good approximation in the Q^2 region considered. Slight deviations from (31) result in negligible corrections to (29) because of δ and ϵ are small. Thus for our estimations the accuracy of relations (30), (31) is quite sufficient.

In this case we obtain from (29)-(31)

$$F^i_{V(p,n)}(Q^2) = \pm\left[r^i_{\pm}(1+\mu_p\tau) - r^i_{\mp}\mu_n\tau\right] G_{E_p}(Q^2)/(1+\tau), \tag{32}$$

$$F^i_{M(p,n)}(Q^2) = \pm\left[r^i_{\pm}(\mu_p - 1) - r^i_{\mp}\mu_n\right] G_{E_p}(Q^2)/(1+\tau),$$

$$F^i_{A(p,n)}(Q^2) = \frac{1}{4}\left[\lambda(\delta^i + \epsilon) \pm \beta^i\right] F_A^{CC}(Q^2),$$

where $r^i_{\pm} = \frac{1}{4}(\alpha^i \pm 3\gamma^i)$; $\tau = Q^2/4M^2$; M is the nucleon mass. The normalisation constant λ can be calculated in the non-relativistic SU_6-model: $\lambda = 3/5$.

3. Manifestations of Z'-Boson

To estimate the Z' contribution to processes (1)-(3) properly, it is desirable to represent the result in the form weakly depending on uncertainties aroused by the nucleon and nuclear structures.

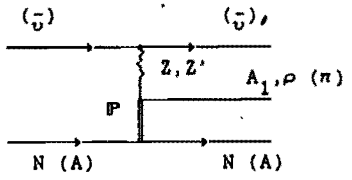


Fig. 2. Diagram of diffractive (coherent) neutrinoproduction of $A_1^0, \rho^0(\pi^0)$-mesons.

The processes of coherent neutrinoproduction of π^0-mesons on nuclei (2) and diffractive neutrinoproduction of ρ^0, A_1^0-mesons on nucleons (3) are described by pomeron-exchange diagrams (Fig. 2). Ratios of their cross sections to cross sections of the corresponding charged current processes are simply expressed through the parameters of the hadronic current $J^i_\mu(H)$ /10/:

$$R^{coh}_{\pi^0} = \frac{\sigma(\overset{(-)}{\nu}A \to \overset{(-)}{\nu}\pi^0 A)}{\sigma(\overset{(-)}{\nu}A \to \mu^{\mp}\pi^{\pm}A)} = \frac{(\beta^i)^2}{2}, \tag{33}$$

$$R^{diffr}_{A_1} = \frac{\sigma(\overset{(-)}{\nu}N \to \overset{(-)}{\nu}A_1^0 N)}{\sigma(\overset{(-)}{\nu}N \to \mu^{\mp}A_1^{\pm}N)} = \frac{(\beta^i)^2}{2}, \tag{34}$$

$$R^{diffr}_{\rho^0} = \frac{\sigma(\overset{(-)}{\nu}N \to \overset{(-)}{\nu}\rho^0 N)}{\sigma(\overset{(-)}{\nu}N \to \mu^{\mp}\rho^{\pm}N)} = \frac{(\alpha^i)^2}{2}. \tag{35}$$

Cancellation of dependence on the structure of nucleons and nuclei participating in the scattering is due to the hypothesis of pomeron exchange dominance.

Cross sections for elastic $\overset{(-)}{\nu}$N scattering (1) are determined by FF of the same current $J^i_\mu(H)$:

$$\frac{d\sigma^{\pm}_{p,n}}{dQ^2} = \frac{G^2}{\pi}\Big\{\Big(\frac{F^i_{V(p,n)} \pm F^i_{A(p,n)}}{2}\Big)^2 + (1-y)\Big(\frac{F^i_{V(p,n)} \mp F^i_{A(p,n)}}{2}\Big)^2 + y\frac{M}{4E}\Big[\big(F^i_{A(p,n)}\big)^2 - \big(F^i_{V(p,n)}\big)^2\Big] + \frac{y}{2}\Big[(1-y)\frac{E}{2M}F^i_{M(p,n)} + y\Big(F^i_{V(p,n)} + \frac{1}{4}F^i_{M(p,n)} \mp F^i_{A(p,n)}\Big) \pm 2F^i_{A(p,n)}\Big]F^i_{M(p,n)}\Big\}, \tag{36}$$

where E is the neutrino energy, $y=\frac{\nu}{E}$, ν is the energy transfer to a nucleon of mass M.

On studying manifestations of the Z'-boson it is suitable to analyse the quantity

$$\Delta_{p,n}=\frac{\frac{d\sigma^{+NC}_{p,n}}{dQ^2}-\frac{d\sigma^{-NC}_{p,n}}{dQ^2}}{\frac{d\sigma^{+CC}_{p,n}}{dQ^2}-\frac{d\sigma^{-CC}_{p,n}}{dQ^2}}=\frac{\sigma^{+NC}_{p,n}-\sigma^{-NC}_{p,n}}{\sigma^{+CC}_{p,n}-\sigma^{-CC}_{p,n}}=\frac{(r_{\pm}\mu_{p,n}-r_{\mp}\mu_{n,p})}{\cos^2\theta_c\,(\mu_p-\mu_n)}\times \tag{37}$$

$$\times(\lambda(\delta+e)\pm\beta).$$

This formula follows from (32), (36) and is an analogue of the well-known Paschos-Wolfenstein relation for deep inelastic $\overset{(-)}{\nu}N$ scattering [14]. The basic property of this relation is that it connects the combination of $\overset{(-)}{\nu}N$ scattering cross sections with the neutral current J^i_μ parameters, in particular, with $\sin^2\theta_W$, this connection weakly depending on the model uncertainties aroused by the nucleon structure [15].

Let the relative value of the Z' contribution be given by the function

$$\tau(A)=\frac{A(Z+Z')-A(Z)}{A(Z)}, \tag{38}$$

where A(Z+Z') and A(Z) is the characteristic A calculated with and without the Z' contribution. If A is measured with a relative error δA smaller than $\tau(A)$, a manifestation of the Z'-boson can be observed.

We obtain from (32)-(38)

$$\tau(\pi^0)\equiv\tau(R^{coh}_{\pi^0})=\frac{(\beta^{eff})^2}{(\beta^Z)^2}-1;\quad \tau(A_1)\equiv\tau(R^{diff.}_{A_1})=\tau(\pi^0) \tag{39}$$

$$\tau(\rho^0)\equiv\tau(R^{diff.}_{\rho^0})=(\alpha^{eff})^2/(\alpha^Z)^2-1.$$

$$\tau(F_{V_p})=\frac{r_+^{eff}(1+\mu_p\tau)-r_-^{eff}\mu_n\tau}{r_+^Z(1+\mu_p\tau)-r_-^Z\mu_n\tau}-1, \tag{40}$$

$$\tau(F_{M_p})=\frac{r_+^{eff}(\mu_p-1)-r_-^{eff}\mu_n}{r_+^Z(\mu_p-1)-r_-^Z\mu_n}-1,$$

$$\tau(F_{A_p})=\frac{\lambda(\delta^{eff}+\epsilon)+\beta^{eff}}{\lambda\epsilon+1}-1 \tag{41}$$

$$\tau(\Delta_p)=4\,\frac{(r_+^{eff}\mu_p-r_-^{eff}\mu_n)(\lambda(\delta^{eff}+e)+\beta^{eff})}{[(1-4x_W)\mu_p-\mu_n](\lambda\epsilon+1)}-1.$$

For the reasons mentioned above the given estimations weakly depend on a model of the nucleon and nuclear structure.

Considering $\overset{(-)}{\nu}_e e$, $\overset{(-)}{\nu}_\mu e$ scattering we shall study the functions

$$\tau(\overset{(-)}{\nu}_{\mu,e}e)=\tau(\sigma_{\overset{(-)}{\nu}_{\mu,e}e});$$

$$\tau(\nu_\mu-\bar\nu_\mu)=\tau(\sigma_{\nu_\mu e}-\sigma_{\bar\nu_\mu e}),\ \tau(\nu_e-\bar\nu_e)=\tau(\sigma_{\nu_e e}-\sigma_{\bar\nu_e e}) \tag{42}$$

Let us refer to the results of the quantitative analysis of the Z' contribution to processes (1)-(4). In Figs.3-7 the dependence of functions (39)-(42) on the Z_2 mass M_2 and the Z-Z' mixing angle θ are plotted for three values of the angle θ_{E_6}: $0°$, $142.24°$, $\pi/2$.

Now we describe some general properties of the curves in Figs. 3-7.

1. If $M_1=M_2=M_0$, there is no dependence on the Z-Z' mixing angle θ and all curves plotted for its different values intersect in one point. As seen from (19), in this limiting case $\rho=1$, $\omega=0$, $\sigma=x_W$ for any θ.

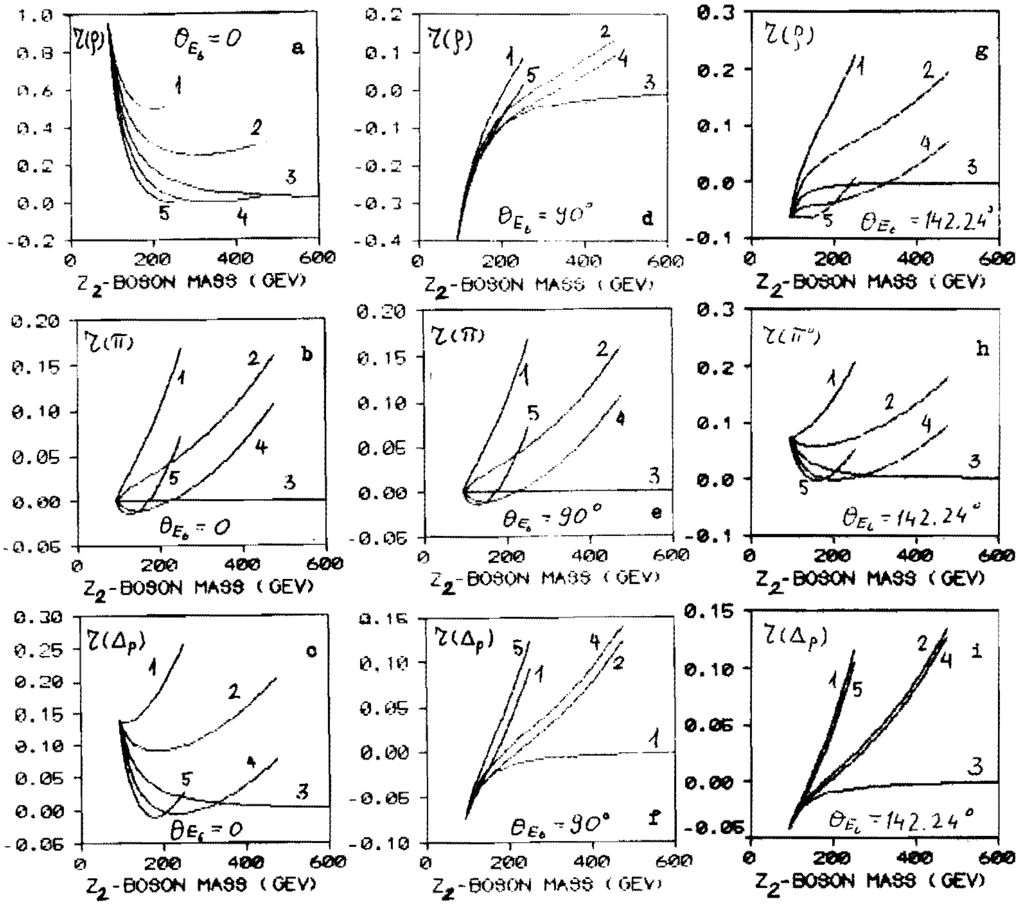


Fig.3. Deviation from the standard model as a function of the Z_2 mass at the Z-Z'mixing angles -0.1,-0.05, 0, 0.05, 0.1 rad (curves 1-5 respectively) plotted for $\tau(\rho)$, $\tau(\pi)$ and $\tau(\Delta_p)$.

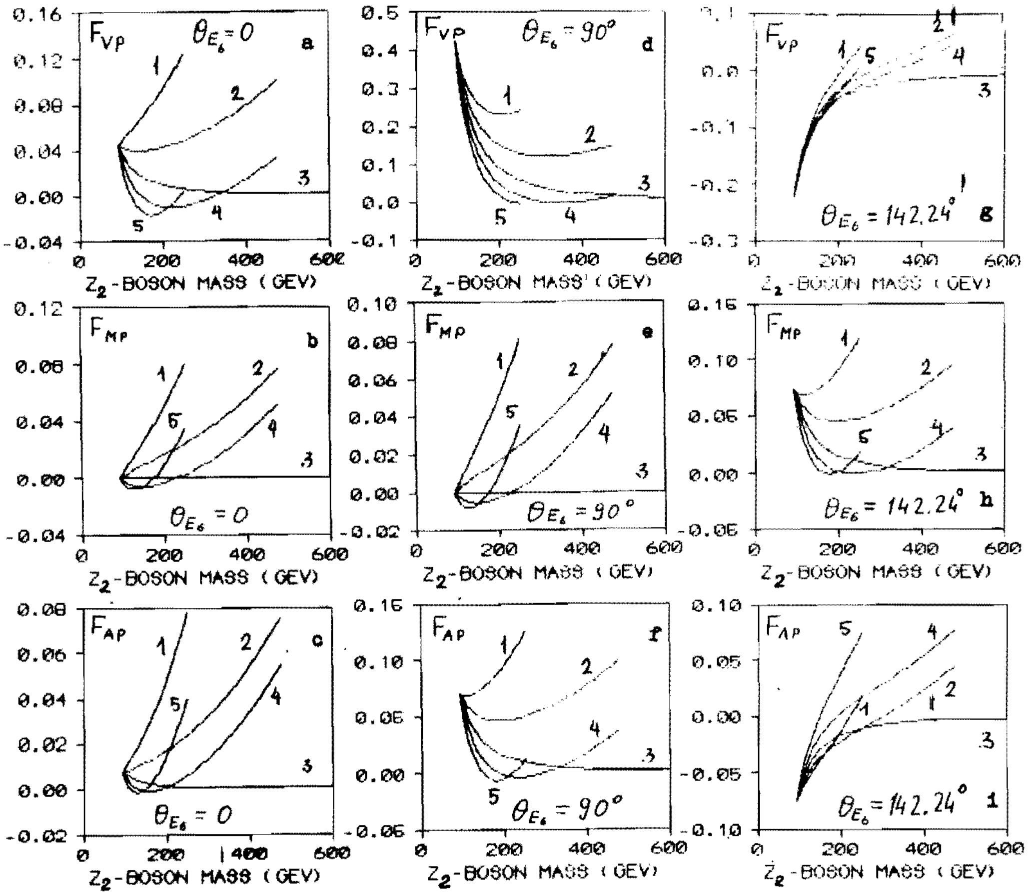


Fig. 4. The same as in Fig. 3, but for $\tau(F_{V(p)})$, $\tau(F_{MP})$, $\tau(F_{AP})$.

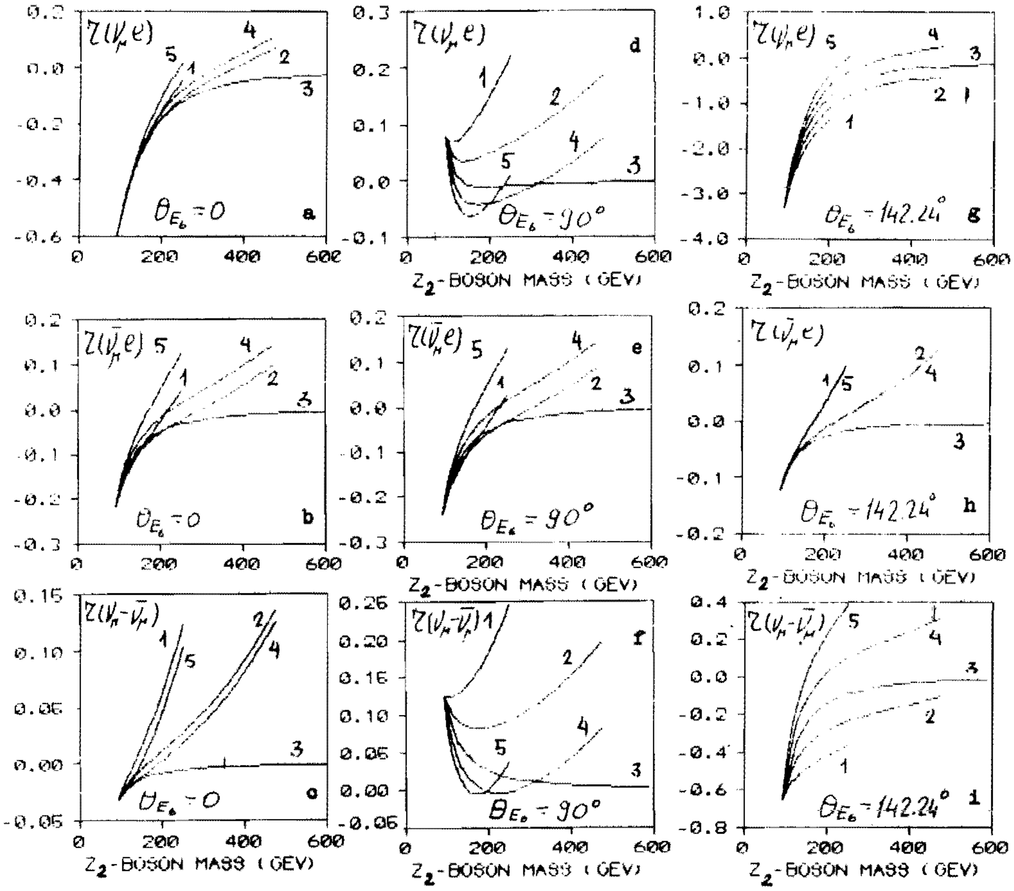


Fig. 5. The same as in Fig. 3, but for $\tau(\nu_\mu e)$, $\tau(\bar{\nu}_\mu e)$, $\sigma(\nu_\mu - \bar{\nu}_\mu)$.

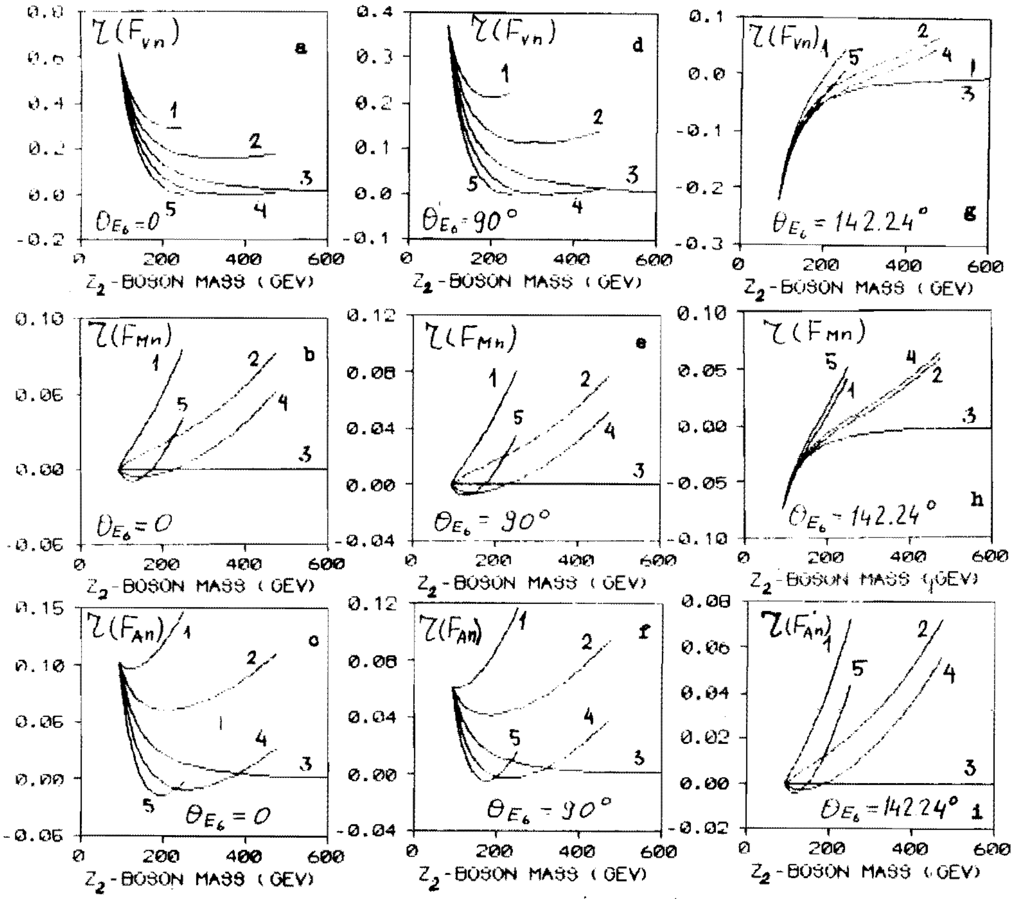
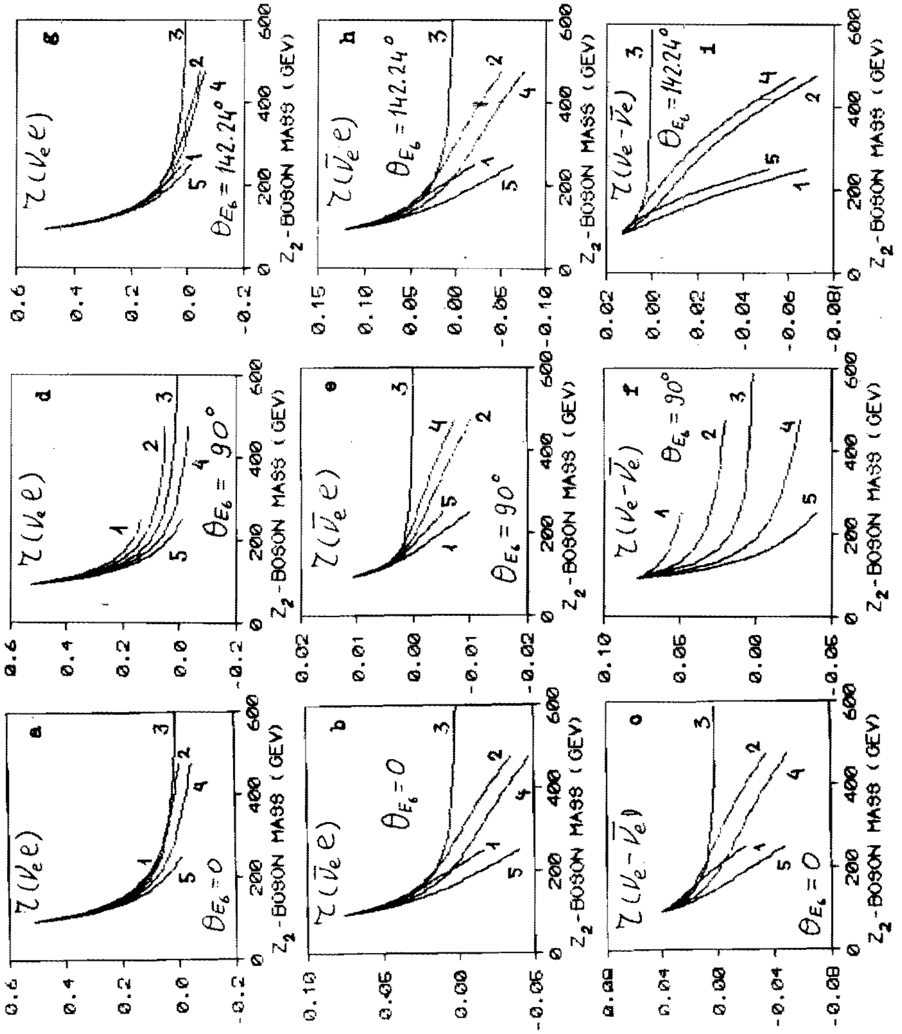


Fig. 6. The same as in Fig. 3, but for $\tau(F_{VN})$, $\tau(F_{MN})$, $\tau(F_{AN})$.

Fig. 7. The same as in Fig. 3, but for $\tau(\nu_e e)$, $\tau(\bar{\nu}_e e)$, $\tau(\nu_e - \bar{\nu}_e)$.



2. At some M_2 the curves are cut off. The cut-off value of M_2 is smaller for the larger θ . This is due to the experimental limit on the Z^0-boson mass $M_Z = M_1 = 91.8 \pm 0.9$ /9,16/ ($M_1 > M_{min} \simeq$ 90 GeV) and follows from formulae (16), (17)

$$M_2^2 < \frac{M_W^2}{(1-x_W)\sin\theta} - \frac{M_{min}^2}{\tan^2\theta} . \qquad (43)$$

3. If $\theta = 0$, the Z' contribution grows as M_2 decreases, while the situation can be opposite at $\theta \neq 0$ and sufficiently large M_2.

4. In conclusion, noteworthy is the dependence of the behaviour of the curves on the angle θ_{E_6} parametrising the

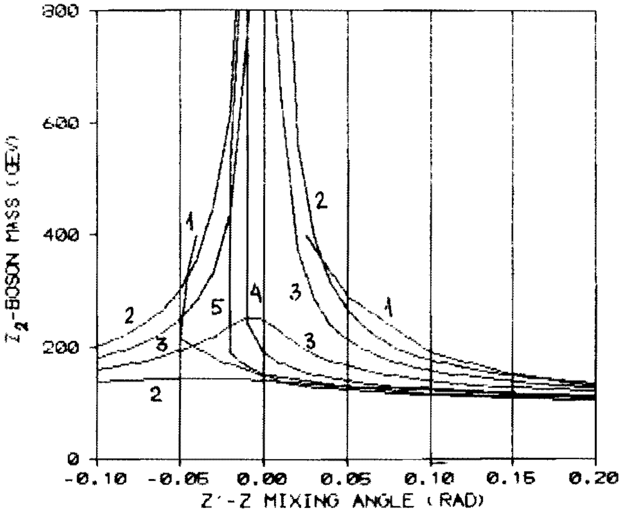


Fig. 8. Limits for the Z-Z' mixing angle and the Z_2 mass M_2 (θ_{E_6} = 142.24). The permitted regions are inside the contours.

1 - contour obtained in Ref. /7/;

2,3 - contours corresponding to $\tau(\pi)$ = 3%, 1% ;

4,5 - contours corresponding to $\tau(p)$ = 3%, 5%.

scheme of symmetry breaking at the intermediate scale. There is a special case $\theta_{E_6} = 0$ when the interaction of the Z'-boson with ordinary matter becomes pure axial.

Figs. 8–10 show the limits in the (M_2, θ) plane expected from measurement of cross sections for processes (1)-(4). For the sake of certainty, the model with the intermediate group of rank 5 is considered, i.e. $\theta_{E_6} = 142.24^{\circ}$. The permissible values of (M_2, θ) are in the regions limited by contours. Each contour corresponds to a certain accuracy of measurement of the quantities given in the graphs. The contour obtained in Ref. /7/ from the analysis of deep inelastic scattering data is shown in these figures for comparison. The comparison shows that the significant narrowing of the region enclosed with the contour requires measurements of the relevant quantities with an accuracy as high as several per cent. It is not a

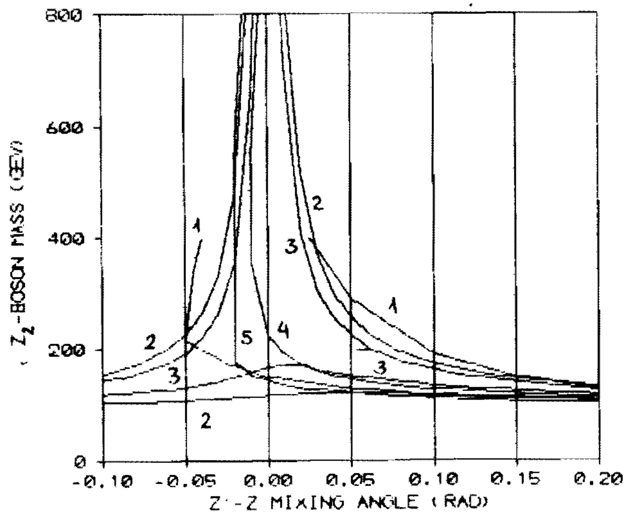


Fig. 9. The same as in Fig. 8, but

2,3 - contours corresponding to $\tau(\nu_\mu e) = 2\%, 1\%$;

4,5 - contours corresponding to $\tau(\bar{\nu}_\mu e) = 2\%, 5\%$.

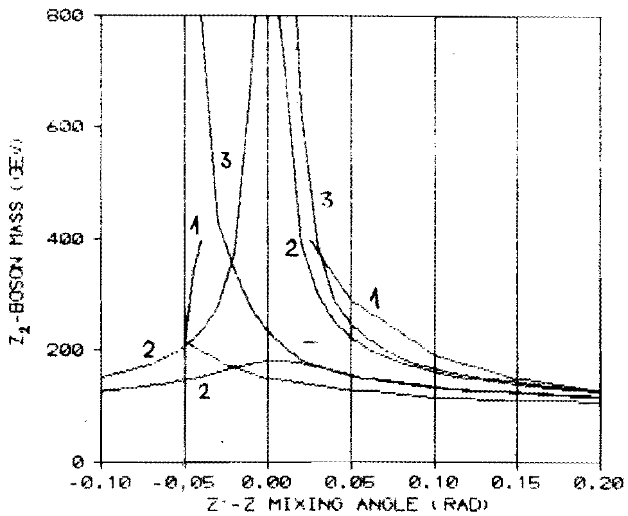


Fig. 10. The same as in Fig. 8, but

2 - contour corresponding to $\tau(\Delta_p) = 1\%$,

3 - contour corresponding to $\tau(\nu_\mu - \bar{\nu}_\mu) = 10\%$.

serious obstacle for studying elastic $\overset{(-)}{\nu}p$, $\overset{(-)}{\nu}e$ scattering. On the other hand, it is a difficult experimental problem to measure cross sections of diffractive (3) and coherent (2) processes with an accuracy, like that. Nevertheless it is desirable to have data provided by measurements with accuracies as those in Fig. 6 if one is going to look for new physics in the region of moderate energies, in particular, to look for manifestations of the superstring Z'-boson. The above analysis clearly shows that the Z'-boson cannot show up at lower accuracies.

Conclusion

The superstring Z' contributions to elastic (1), (4), diffractive (3) and coherent (2) processes can be quite noticeable and does not depend on the neutrino beam energy. So it is possible in principle to study it at comparatively low energies. Unlike deep inelastic $\overset{(-)}{\nu} N$ scattering, the above processes have a selective sensitivity to different Z'-coupling constants. This is important for recognition and identification of Z' contribution when experimental data are analysed. To enhance the reliability of this procedure one will have to study manifestations of the Z'-boson in a maximum wide class of processes and make joint analysis of data. Interesting information can be obtained, for example, from elastic $\overset{(-)}{\nu} d$ - scattering. It should be mentioned that $F_{A(p)} + F_{A(n)} \approx 0$ in the SM (see (24)), so the main contribution to the sum comes from the new physics effects including Z'. The results presented are based on the study of quantities and relations weakly depending on model uncertainties which are due to taking into account the structure of nucleon or nuclear targets. We have obtained relation (37) for elastic $\overset{(-)}{\nu} N$ scattering. It has the property mentioned and is an analogue of the Paschos- Wolfenstein relation /14/ for deep inelastic $\overset{(-)}{\nu} N$ processes.

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APPENDIX

Here we show the relation between different parametrizations of the neutral current J_μ^{NC}.

Alongside the forms (11) and (23) there is a representation of J_μ^{NC} in terms of chiral constants $\epsilon_{L,R}(i)$:

$$J_\mu^{NC} = \sum_f \{ \epsilon_L(f) \bar{\psi}_{fL} \gamma_\mu \psi_{fL} + \epsilon_R(f) \bar{\psi}_{fR} \gamma_\mu \psi_{fR} \}.$$

The relation between parametrizations is expressed in the following ways:

$$\epsilon_L(f) = Q_f; \; \epsilon_R(f) = -Q_f c, \quad Q_f = Q^Z, Q^{Z'}, \dots$$

$$g_{V,A}(f) = \epsilon_L(f) \pm \epsilon_R(f);$$

$$\alpha = \epsilon_L(u) + \epsilon_R(u) - \epsilon_L(d) - \epsilon_R(d) = g_V(u) - g_V(d),$$

$$\beta = \epsilon_L(u) - \epsilon_R(u) - \epsilon_L(d) + \epsilon_R(d) = g_A(u) - g_A(d),$$

$$\gamma = \epsilon_L(u) + \epsilon_R(u) + \epsilon_L(d) + \epsilon_R(d) = g_V(u) + g_V(d),$$

$$\delta = \epsilon_L(u) - \epsilon_R(u) + \epsilon_L(d) - \epsilon_R(d) = g_A(u) + g_A(d).$$

$$\epsilon_L(u) = \frac{1}{4}(\alpha + \beta + \gamma + \delta)$$

$$\epsilon_R(u) = \frac{1}{4}(\alpha - \beta + \gamma - \delta)$$

$$\epsilon_L(d) = \frac{1}{4}(-\alpha - \beta + \gamma + \delta)$$

$$\epsilon_R(d) = \frac{1}{4}(-\alpha + \beta + \gamma - \delta).$$

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Дополнительный Z'-бозон в упругом и дифракционном рассеянии нейтрино

В суперструнной E_6-модели изучен вклад дополнительного Z'-бозона в упругое $\overset{(-)}{\nu}e$-, $\overset{(-)}{\nu}N$-рассеяние, когерентное нейтринорождение π^0-мезонов на ядрах, дифракционные нейтринные реакции с образованием ρ^0 и A_1^0-мезонов. Проанализированы характеристики и соотношения между сечениями, слабо зависящие от структуры нуклонов и ядер. Для упругого $\overset{(-)}{\nu}N$-рассеяния получено соотношение аналогичное соотношению Пашоса-Вольфенштейна для глубоконеупругого рассеяния. Обоснована целесообразность экспериментальных исследований вклада Z'-бозона не только в глубоконеупругих, но и в рассмотренных процессах, которые обладают избирательной чувствительностью к отдельным константам взаимодействия Z' с фермионами. Обсуждается принципиальная возможность таких исследований при сравнительно невысоких энергиях.

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Extra Z'-Boson in Elastic and Diffractive Neutrino Scattering

The contribution of the extra Z'-boson to elastic $\overset{(-)}{\nu}N$, $\overset{(-)}{\nu}e$ scattering, coherent neutrino-production of π^0-mesons on nuclei, diffractive neutrino reactions with ρ^0 and A_1^0-mesons produced have been studied within the superstring inspired E_6-model. Some combinations of charged and neutral current cross sections weakly depending on the nucleon and nuclear structure have been analysed. The conclusion that it is reasonable to study experimentally the Z' contribution not only in deep elastic processes but also in the above ones is substantiated. Possibilities of carrying out these investigations at relatively low energies are discussed.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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