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SUPERSTRING INSPIRED NEUTRAL GAUGE BOSON IN ELASTIC ep-ASYMMETRIES

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The neutral extra gauge Z′-boson with mass below 1 TeV is today one of the most widely discussed low energy concequences of superstring theory [1,2]. Since there is no yet unambiguous scheme of the low energy limit of superstrings, the experimental determination of the Z′-boson parameters,such as mass, its mixing with the standard Z- boson and couplings with fermions can help to reduce this uncertainty and give necessary information about E6 gauge symmetry breaking at the intermediate scale.

The experimental investigation of possible Z′-boson manifestations can be done in two directions which complement each other. First, the obvious observations of Z′-boson creation and decay in high energy colliders [3]. Secondly, indirect manifestations by little deviations of experimental results from standard model (SM) predictions in precise measurements [4]. In the former case the energy must be as high as possible, in the latter case the main problem is not the energy but the high accuracy.

This significant increase in precision will be obtained on the Continuous Electron Beam Accelerator Facility (CEBAF) where luminosity will be about 10^{38} cm^{-2}/sec [5]. In this case, for instance, 1-2% level of accuracy has to be reached in parity violating elastic polarized electron - nucleon asymmetries [6]:

$$A(e_L^- - e_R^-) = \frac{\frac{d\sigma}{dQ^2}(e_L^- N \to e^- N) - \frac{d\sigma}{dQ^2}(e_R^- N \to e^- N)}{\frac{d\sigma}{dQ^2}(e_L^- N \to e^- N) + \frac{d\sigma}{dQ^2}(e_R^- N \to e^- N)} . \qquad (1)$$

This accuracy gives a good oppotunity to extract the most strong restrictions on the above-mentioned Z′-boson parameters: M_2 - Z′ mass, θ - Z-Z′ mixing angle and θ_{E6} angle which is determined by symmetry breaking at the intermadiate scale.

In Ref.[7] we found that for high energy collisions (HERA, UNK,etc) in elastic ep-scatering the Z′-boson can give up to 20 per cent deviation from SM. Unfortunately, while writing our paper [7] we did not have any information about CEBAF and the planned precise measurements, therefore we concluded that elastic ep-scatering cannot impose more restrictions on M_2 and θ, as compared, for instance, with deep inelastic ep-scattering (HERA) [4] or collider experiments.

Now taking into account the CEBAF high accuracy we discuss the same question but in intermediate energy and Q^2 domain.

The neutral current cross section of polarized electron - nucleon elastic scattering which take place in P-odd asymmetry (1) can be expressed in the form ($\lambda=\pm1$ for L,R):

$$\frac{d\sigma}{dQ^2}(e_\lambda^- N) = \frac{G^2}{2\pi} \sum_{i=1}^{4} k_i \varphi_i(N,Q^2,\lambda), \qquad (2)$$

where $y=\frac{Q^2}{2pk}$ and $k_1=y\frac{M^2}{pk}$, $k_2=2y-y^2$, $k_3=1-y-y\frac{M^2}{2pk}$, $k_4=y^2/2$ are kinematic factors. Structure functions φ_i may be expressed through the effective neutral currentform factors A_λ,V_λ,M_λ ($\tau = Q^2/4m_p^2$):

$$\begin{aligned}
&\varphi_1(N,Q^2,\lambda) = (A_\lambda)^2, \\
&\varphi_2(N,Q^2,\lambda) = -\lambda A_\lambda(V_\lambda+M_\lambda), \\
&\varphi_3(N,Q^2,\lambda) = (A_\lambda)^2+(V_\lambda)^2+\tau(M_\lambda)^2, \\
&\varphi_4(N,Q^2,\lambda) = (A_\lambda)^2+(V_\lambda+M_\lambda)^2.
\end{aligned} \qquad (3)$$

These effective form factors A_λ,V_λ,M_λ can be connected with the standard defined electromagnetic $G_E^p(Q^2)$ and charged current axial $F_A(Q^2)$ proton form factors [8] (in calculations we used dipole parametrisation):

$$\begin{aligned}
A_\lambda^{p,n}(Q^2) &= \{\pm\beta^{ef} + \varkappa\,\delta^{ef}\}\,\frac{F_A(Q^2)}{4}, \\
V_\lambda^{p,n}(Q^2) &= \pm\{r_\pm^{ef}(1+\tau\mu_p) - r_\mp^{ef}\tau\mu_n\}\,\frac{G_E^p(Q^2)}{2(1+\tau)}, \\
M_\lambda^{p,n}(Q^2) &= \pm\{r_\pm^{ef}\,(\mu_p-1) - r_\mp^{ef}\,\mu_n\}\,\frac{G_E^p(Q^2)}{2(1+\tau)}.
\end{aligned} \qquad (4)$$

Here μ_p= 2,79, μ_n=-1.91 are the proton and neutron magnetic moments; $\varkappa = 2F_A^s(0)/C_A$= 0.3 determines normalization of weak isoscalar axial form factor $F_A^s(Q^2)$ in non-relativistic SU(6)- quark model, $C_A = F_A(0)$ = 1.25 ± 0.06 [9]; $r_\pm^{ef} = \frac{1}{2}(\alpha^{ef} \pm 3\gamma^{ef})$.

The effective parameters α^{ef}, β^{ef}, γ^{ef}, δ^{ef} set the time-space and isospin structure of the full (γ- and Z^0- and Z′-) neutral current [10]

$$J_\mu^{nc} = \frac{\alpha^{ef}}{2} V_\mu^3 + \frac{\beta^{ef}}{2} A_\mu^3 + \frac{\gamma^{ef}}{2} V_\mu^s + \frac{\delta^{ef}}{2} A_\mu^s \;\ldots = \qquad (5)$$

and have the form:

$$\begin{aligned}
\alpha^{ef} &= \frac{\sqrt{2}}{4G}\sum_1^2 \frac{\alpha_i\varepsilon_i(e_\lambda^-)}{M_i^2} - \chi\frac{m_p^2}{Q^2}, \qquad \beta^{ef} = \frac{\sqrt{2}}{4G}\sum_1^2 \frac{\beta_i\varepsilon_i(e_\lambda^-)}{M_i^2}, \\
\gamma^{ef} &= \frac{\sqrt{2}}{4G}\sum_1^2 \frac{\gamma_i\varepsilon_i(e_\lambda^-)}{M_i^2} - \frac{\chi}{3}\frac{m_p^2}{Q^2}, \qquad \delta^{ef} = \frac{\sqrt{2}}{4G}\sum_1^2 \frac{\delta_i\varepsilon_i(e_\lambda^-)}{M_i^2},
\end{aligned} \qquad (6)$$

where $\chi = 2\pi\alpha\sqrt{2}/Gm_p^2 \approx 0.6\cdot10^4$, m_p is the proton mass, and for $f_{1,2}^{Z,Z'} = [\alpha, \beta, \gamma, \delta, \varepsilon(e_\lambda^-)]_{1,2}^{Z,Z'}$ we define

$$f_1 = g^Z f^Z \cos\theta + g^{Z'} f^{Z'} \sin\theta,$$
$$f_2 = g^{Z'} f^{Z'} \cos\theta - g^Z f^Z \sin\theta. \qquad (7)$$

Values of these parameters for Z- and Z′-bosons as functions of ϑ_{E6} angle are given in the Table. For Z-Z mixing angle one has the relation $tg^2\theta = (M_o^2-M_1^2)/(M_2^2-M_o^2)$, where M_1 and M_2 are the physical Z- and Z′- masses.

Table

($\nu = \sqrt{5/2}\,\cos\vartheta_{E6}/6$, $\xi = \sqrt{1/6}\,\sin\vartheta_{E6}/2$)

parameter	Z^o	Z'
g	$e(\cos\theta_W \sin\theta_W)^{-1}$	$e(\cos\theta_W)^{-1}$
$\varepsilon(e_L^-)$	$-1/2+\sin^2\theta_W$	$3\xi+\nu$
$\varepsilon(e_R^-)$	$\sin^2\theta_W$	$\xi-\nu$
α	$1-2\sin^2\theta_W$	4ξ
β	1	-4ξ
γ	$-2\sin^2\theta_W/3$	-4ξ
δ	$0 + \hat{\xi}^{*)}$	4ν

*) Correction $\hat{\xi}$ [11] results from the heavy quark contribution to the isoscalar part of the weak axial hadron current (with s,b,t-quarks $\hat{\xi}$ = 0.06 [8]).

To study manifestations of the Z′-boson, one usually analyses the relative deviation from SM

$$r(e_L^- - e_R^-) = \frac{A(Z+Z')-A(Z)}{A(Z)}, \qquad (8)$$

where A(Z+Z′) is the asymmety with the Z′-contribution and A(Z) is the asymmetry in SM. The quantity $r(e_L^- - e_R^-)$ is interesting from two points of view. First, a lot of uncontrolled hadron structure systematic uncertainties are cancelled in it, secondly the direct

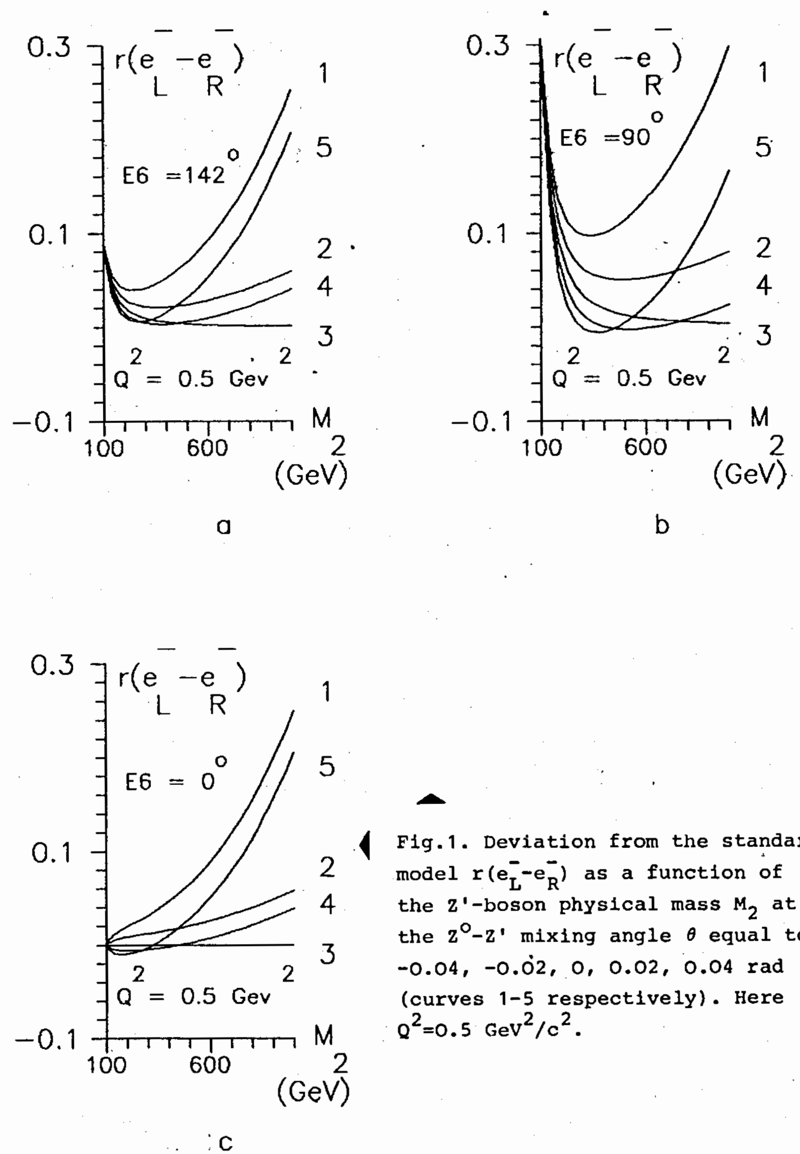

Fig.1. Deviation from the standard model $r(e_L^- - e_R^-)$ as a function of the Z'-boson physical mass M_2 at the Z^o-Z' mixing angle θ equal to -0.04, -0.02, 0, 0.02, 0.04 rad (curves 1-5 respectively). Here Q^2=0.5 GeV^2/c^2.

comparison of $r(e_L^- - e_R^-)$ with the experimental accuracy answers the question about possibility of indirect observation of the Z′-boson. In calculations we restrict ourselves to polarized electron-proton scattering, similar results can be easily obtained from formulae (1)-(6) for electon-neutron scattering, etc.

For the fixed electron energy E = 2Gev $r(e_L^- - e_R^-)$ depends on the kinematic variable y (or Q^2) and parameters M_2, θ and ϑ_{E6}. For angle ϑ_{E6} we have taken discrete special values 142.24°, 90° and 0° in correspondence with the most popular low energy limits of superstrings [2-4]. For this angles and Q^2= 0.5 GeV^2/c^2(or y ≈ 0.1) fig.1a,b,c demonstrate the deviation from SM, $r(e_L^- - e_R^-)$, as a function of the Z′-boson physical mass for fixed θ (in radian) equal to -0.04(curve 1), -0.02(2), 0(3), 0.02(4), 0.04(5). It vanishes quickly for $\theta = 0$ and increases with M_2 from fractions of per cent to 25-30% for $\theta \neq 0$. The increase must cut off for larger $|\theta|$ and M_2 because of experimentally measured low mass limit of the ordinary Z-boson. If y differs from 0.1, the main properties of curves 1-5 don′t change very much.

Contours 2(for 1% deviation) and 3(for 2%) in fig.2 illustrate a possibility of obtaining strong restrictions on M_2 and θ for ϑ_{E6}=142.24° in CEBAF presice measurements . For 1% (2%) accuracy M_2 must be larger than 450(320)Gev and $|\theta|$ must be smaller than 0.01(0.03). These contours correspond to y= 0.5, for lesser y the restrictions become softer and for y ≈ 0 the contours go to contour 3 in fig.4, obtained for measurement of deep inelastic νq-scattering with 0.5% accuracy [12]. Contour 1 gives today′s restrictions [13].

Practically, the elastic asymmetry $A(e_L^- - e_R^-)$ gives information only about the vector part of the hadron weak current V_q which appeared in the parity violating effective Lagrangian as a product of V_q times axial lepton current $A_e V_q$. This information is well available today from deep inelastic ep-scattering and P-odd effect atomic physics measurements [4,10]. More information is needed for determination of the axial part of the hadron weak current A_q which appeared in Lagrangian as $V_e A_q$. In the domain where y is not equal 0 or 1, there is an opportunity of studing the axial hadron current A_q in presice measurements of charged asymmetry $A(e_L^- - e_R^+)$, because this asymmetry is directly proportional to the axial vector current parameters β and δ (6) :

$$A(e_L^- - e_R^+) \propto \{\beta^{ef} + \varkappa\delta^{ef}\} \quad k_3\, F_A(Q^2)\, (F_V^{em} + F_M^{em})/\sigma_{em}.$$

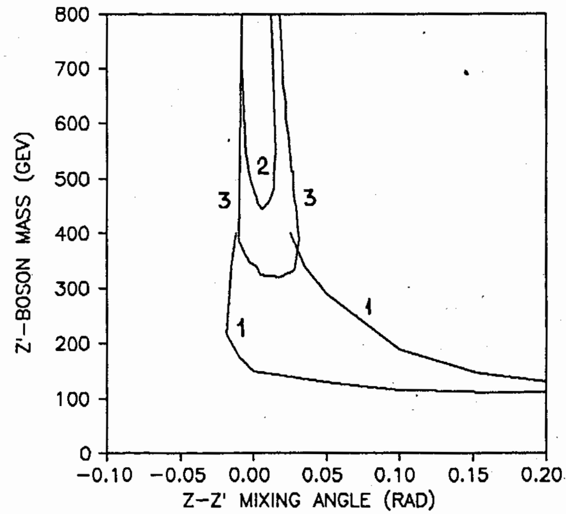

Fig.2 Limits on the Z-Z′ mixing angle θ and Z′ mass M_2 for ϑ_{E6}=142.24°. The permitted regions are inside the contours. 1 - contour obtained in Ref [12]; 2,3 - contours corresponding to $r(e_L^- - e_R^-)$ = 1%, 2%.

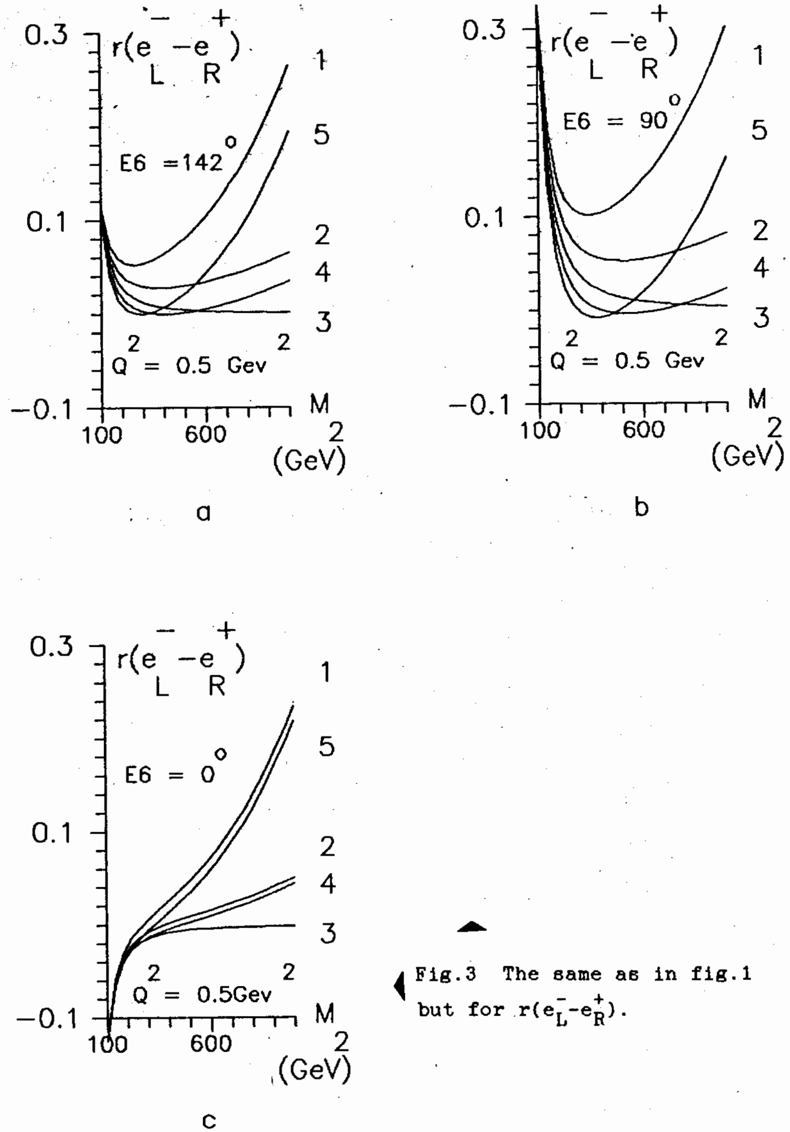

Fig.3 The same as in fig.1 but for $r(e_L^- - e_R^+)$.

The combined results of measurements of $A(e_L^- - e_R^-)$ and $A(e_L^- - e_R^+)$ can fully determine the structure of the parity violating effective Lagrangian. For the discussed ϑ_{E6} angles and $Q^2 = 0.5$ fig.3a,b,c demonstrate the deviation from SM for charged asymmetry $A(e_L^- - e_R^+)$. Curve 2 in fig.4 gives restrictions on parameters M_2 and θ corresponding to the 1% deviation from SM in $A(e_L^- - e_R^+)$.

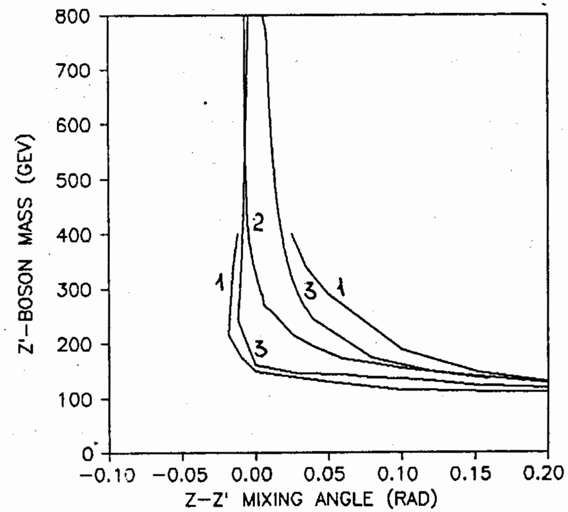

Fig.4 The same as in fig.2 but: 2 - contour corresponding to $r(e_L^- - e_R^+)$ = 1%, 3 - contour corresponding to 0.5% accuracy measurements in deep inelastic $\bar{\nu}$N-scattering [8].

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When this paper was submitted to publication we have received paper by S.J.Pollock [14], where a similar question was studied.

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