Could HERA results have been predicted from semileptonic meson decays

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Abstract

The anomalous value of the tensor form factor in the kaon decay $K^+ \to \pi^0 e^+ \nu$ and the destructive interference in pion decay $\pi^- \to e^- \bar{\nu} \gamma$ can be simultaneously described by admixture of a tensor interaction in the standard $V-A$ one. It is shown that the same tensor interaction can describe recent HERA data at very large $Q^2$. 

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In the last years precision electroweak tests were performed at LEP, SLC and Tevatron. The announcements about deviations from the Standard Model (SM) have given rich possibility for theorists to speculate about the existence of a new physics. Unfortunately, the anomalies seem to have disappeared after taking into account the systematic errors more precisely [1] and appropriately modifying the structure functions [2]. Although some contradictions between the experimental data and the SM predictions exist, they are not paid a great attention. Nevertheless, the recent HERA results of H1 [3] and ZEUS [4] Collaborations have been met with a considerable interest.

Now there are lots of theoretical works explaining the events excess at HERA by some new physics. In our work we will present an explanation of the deviation from the SM, observed in deep-inelastic scattering (DIS), by introducing a new effective (non contact) interaction present in the $t$-channel. Usually such interaction appears from the exchange of a new intermediate boson with a large mass $M > M_W/Z$, which is almost negligible for small momentum transfers. However, if the new boson has approximately the same coupling constant with the fermions as $\gamma$, $W$ and $Z$ ones, then at high momentum transfer the strength of the new interaction will be comparable with the usual electroweak interactions. In case of $e^+p \rightarrow e^+X$ DIS at large $Q^2$, there exists a destructive interference between $\gamma$ and $Z$ exchange amplitudes and the expected cross section is substantially reduced. Therefore, in this case the additional contribution from the new interaction may be more definitely observed than in $e^-p \rightarrow e^-X$ DIS.

Another characteristic feature of our approach is the suggestion about the existence of new vector bosons, different from the gauge ones $W'$ and $Z'$, and inducing the new interaction. The new vector particles are described by antisymmetric second-rank tensor field $T_{\mu\nu}$ [5], and not by the vector $A_\mu$. They correspond to the representation of the Lorentz group $(1,0) + (0,1)$ in contrast to the widely used one $(1/2,1/2)$ for the vector particles. As far as both of these nonequivalent representations for the description of vector particles exist in the Lorentz group on the same footing, we will assume, that besides the gauge bosons, there exists another kind of vector particles in Nature.

Due to the particular Lorentz indices structure, the new vector bosons couple to the tensor currents $\bar{\Psi}_R\sigma_{\mu\nu}\Psi_L$, $\bar{\Psi}_L\sigma_{\mu\nu}\Psi_R$, while the usual gauge bosons interact with the vector currents $\bar{\Psi}_L\gamma_\mu\Psi_L$, $\bar{\Psi}_R\gamma_\mu\Psi_R$. This determines their main differences in the interactions with fermions. Note, that while the gauge bosons conserve the chiralities of the fermions, the new vector particles change fermion chiralities. This feature allows to distinguish their presence on the background of the standard electroweak interactions in polarization experiments and by analyzing the angular distributions.

The helicity dependence of DIS cross section is parameterized by the variable $y$. As far as at large $Q^2$ the contribution of the sea quarks into the cross section is negligible, and scattering occurs mainly on the valence quarks, the cross section of the charged-current (CC) process $e^+p \rightarrow \bar{\nu}X$ is suppressed by a factor $(1 - y)^2$ in comparison with $e^-p \rightarrow \nu X$ due to chirality considerations. Therefore, the events excess, observed by H1 Collaboration [3] at large $y$, may indicate in favor of the presence of the new interactions leading to leptons and quarks spin flip.

Those interactions can be chosen in the form

$$L_T = \frac{g}{2\sqrt{2}} \left[ (\bar{\nu}e)L_\sigma^{\alpha\beta}e_R + (\bar{u}d)_L\sigma^{\alpha\beta}d_R \right] \left( T^+_{\alpha\beta} T^0_{\alpha\beta} \right) + \frac{g}{2\sqrt{2}} (\bar{u}d)_L\sigma^{\alpha\beta}u_R \left( \frac{U^0_{\alpha\beta}}{U_{\alpha\beta}} \right) + \text{h.c.} \quad (1)$$

Unfortunately, ZEUS Collaboration has not announced its CC data.
Here we have introduced two doublets of the new vector particles with opposite hypercharges, which are described by antisymmetric second-rank tensor fields. These interactions conserve $SU(2)_L \times U(1)_Y$ symmetry of the electroweak interactions. For definiteness we choose the coupling constant of the new interactions equal to the gauge coupling constant of the $SU(2)$ group. As usual, all particles are introduced massless and the Lagrangian for the new particles reads

$$\mathcal{L}_0 = \frac{1}{4}(\partial_\mu T_{i\nu}^{\mu\nu})\partial^\lambda T_{i\nu}^{\mu\nu} - (\partial_\mu U_{i\nu}^{\mu\nu})\partial^\nu T_{i\nu}^{\mu\nu} \pm \frac{1}{4}(\partial_\mu U_{i\nu}^{\mu\nu})\partial^\nu U_{i\nu}^{\mu\nu},$$

where $T_{i\nu}^{\mu\nu}$ and $U_{i\nu}^{\mu\nu}$ are real fields with weak isospin index $i = 1, 2$. The quantization of these fields was described in [6]. The chiral charged fields in (2) are expressed through the latter ones as $T_{i\nu}^{\mu+} = (T_{i\nu}^{\mu1} + iT_{i\nu}^{\mu2})/\sqrt{2}$, $T_{i\nu}^{\mu0} = (T_{i\nu}^{\mu1} - iT_{i\nu}^{\mu2})/\sqrt{2}$, $U_{i\nu}^{\mu+} = (U_{i\nu}^{\mu1} + iU_{i\nu}^{\mu2})/\sqrt{2}$, $U_{i\nu}^{\mu0} = (U_{i\nu}^{\mu1} - iU_{i\nu}^{\mu2})/\sqrt{2}$, where $T_{i\nu}^{\mu} = \frac{1}{2} \epsilon_{\mu\alpha\beta} T^{\alpha\beta}$, $U_{i\nu}^{\mu} = \frac{i}{2} \epsilon_{\mu\alpha\beta} U^{\alpha\beta}$ are dual tensors. The requirement for cancellation of anomalies can be fulfilled by introducing also two doublets of the scalar Higgs fields $H_1 = (H_1^0, H_1^-)$ and $H_2 = (H_2^+, H_2^0)$ with opposite hypercharges.

After the spontaneous symmetry breaking, the new fields acquire masses, and mixing of the fields may result. In this case the propagators for the charged fields $T_{\mu\nu}$ and $U_{\mu\nu}$ will have the form [7]

$$\mathcal{P}_{\mu\nu\alpha\beta}(q) = \frac{4i}{\Delta(q)} \begin{pmatrix} <T(T_{\mu\nu}^0 T_{\alpha\beta}^0)>_0 & <T(T_{\mu\nu}^0 U_{\alpha\beta}^0)>_0 \\ <T(U_{\mu\nu}^- T_{\alpha\beta}^0)>_0 & <T(U_{\mu\nu}^- U_{\alpha\beta}^0)>_0 \end{pmatrix} = \frac{4i}{\Delta(q)} \begin{pmatrix} (q^2 - m^2)\Pi_{\mu\nu\alpha\beta}^-(q) & \mu_{\mu\nu\alpha\beta}^+(q) \\ \mu_{\mu\nu\alpha\beta}^-(q) & (q^2 - M^2)\Pi_{\mu\nu\alpha\beta}^+(q) \end{pmatrix},$$

where $\Delta(q) = (q^2 - m^2)(q^2 - M^2) - \mu^4, 1^{\pm\mu\nu\alpha\beta} = (g_{\mu\alpha}g_{\nu\beta} - g_{\mu\beta}g_{\nu\alpha} \mp \epsilon_{\mu\nu\alpha\beta})/4, \Pi^\pm(q) = 1^{\pm\mu\nu\alpha\beta}(q) = \Pi(q)1^{\pm\mu\nu\alpha\beta}$.

The masses of the new particles are defined through the mass parameters $\mu$, $m$ and $M$:

$$M_L^2 = \frac{M^2 + m^2 - \sqrt{(M^2 - m^2)^2 + 4\mu^4}}{2},$$
$$M_H^2 = \frac{M^2 + m^2 + \sqrt{(M^2 - m^2)^2 + 4\mu^4}}{2}.$$  

Analogous relations can be written also for the neutral particles $T_{\mu\nu}^0$ and $U_{\mu\nu}^0$. Below we will give two arguments, which allow us to fix relations among $\mu$, $m$ and $M$, and to express all quantities through single mass parameter only.

Using (1) and (2), we can write the effective Lagrangian for the CC quark-lepton interaction

$$\mathcal{L}_{cc}^{\text{eff}} = -\frac{g^2}{\Delta(q)} \varepsilon_{RL} \sigma^{\alpha\lambda} \nu_L \frac{g_{\alpha\beta}}{q^2} \bar{u} \sigma_{\beta\lambda}(m^2 - q^2)(1 + \gamma^5) + \mu^2(1 - \gamma^5) |d + \text{h.c.}|$$

Here we have used the identities...
Due to kinematical reasons, the tensor interaction by itself does not contribute into the semileptonic two-particle $\pi$-meson decay $\pi_e\nu$. However, it has been shown [8], that because of electromagnetic radiative corrections to the tensor interaction (6), the pseudotensor term $\bar{u}\sigma_{\mu\nu}\gamma^5d$ generates an interaction between the lepton and pseudoscalar quark currents, to which the pion decay is very sensitive [9]. Our model [7] allows to solve this problem in case the two massive parameters are assumed equal

$$\mu^2 = m^2.$$ (8)

Then, in case of $q^2 \ll m^2$, pseudotensor quark term $\bar{u}\sigma_{\mu\nu}\gamma^5d$ disappears from (8), while tensor term $\bar{u}\sigma_{\mu\nu}d$ does not contribute into the decay of the pseudoscalar pion, because of the parity conservation in the electromagnetic interactions.

Another relation among the mass parameters can be derived analyzing the dependence of the new particles masses on the ratio $m^2/M^2$. A remarkable characteristic of the eqs. 5 at $\mu^2 = m^2$ is the existence of a maximum value for the $M^2_L$, namely for

$$M^2 = 2.5 \ m^2.$$ (9)

In the static limit this corresponds to the minimum of the energy of interaction of the spinor particles, when they interact by exchanging the new vector particle with mass $M_L$. Then the masses of the lighter $M_L = m/\sqrt{2}$ and the heavier $M_H = \sqrt{3}m$ vector particles occur related and can be expressed through the single mass parameter $m$.

In the low-energy limit $q^2 \ll m^2$ the effective interaction (8) takes the form [7]

$$\mathcal{L}_{e\text{f},0}^{CC} = -\frac{G_F}{\sqrt{2}} f_t \bar{e}\sigma^{\alpha\lambda}(1 - \gamma^5)\nu \frac{q_0 q^\beta}{q^2} \bar{u}\sigma_{\beta\lambda}d + \text{h.c.},$$ (10)

where the dimensionless constant

$$f_t = \frac{\sqrt{2}}{G_F} \frac{g^2}{3M^2_L} = \frac{8M^2_W}{3M^2_L}.$$ (11)

describes the strength of the new tensor interaction relative to the ordinary Fermi coupling. The analysis of the anomalies observed in radiative pion decay $\pi^- \rightarrow e^- \bar{\nu}\gamma$ [10] and three particles kaon decay $K^+ \rightarrow \pi^0e^+\nu$ [11] gives self-consistent values of the constant $f_t = 0.39 \pm 0.18$ [7]. From eq. (11) the mass values of the new charged vector bosons can be estimated as follows:

$$M_L = 230 \pm 56 \ \text{GeV}, \quad M_H = 563 \pm 137 \ \text{GeV}.$$ (12)

Now we already have everything necessary to determine the contribution of the effective tensor interaction into the CC DIS cross section. Neglecting the sea quarks, in the lowest order of the parton model, the cross section can be simplified to
where $Y_{\pm}(y) = 1 \pm (1 - y)^2$ reflect the helicity dependence of electroweak interactions and

$$F_W(Q^2) = \left[ \frac{M_W^2}{(M_W^2 + Q^2)} \right]^2, \quad F_T(Q^2) = \left( 4M_L^4 + 2M_L^2Q^2 + \frac{1}{2}Q^4 \right) \left[ \frac{3M_L^2}{(M_L^2 + Q^2)(6M_L^2 + Q^2)} \right]^2,$$

are the form factors, which appear due to the finite masses of the intermediate bosons, and are normalized as $F_W(0) = F_T(0) = 1$; $u(x, Q^2)$ and $d(x, Q^2)$ are the quark densities of the proton.

At large momentum transfer ($Q^2 > 15000$ GeV$^2$) with a total $e^+p$ integrated luminosity of 14.2 pb$^{-1}$, we predict $5.75 \pm 2.65$ events \[4\] versus 4 events, observed by H1 Collaboration, where $1.77 \pm 0.87$ are expected. Probably, the number of CC events, observed by ZEUS Collaboration with total luminosity of 20.1 pb$^{-1}$, should fall into the interval $8.05 \pm 3.75$.

In fig. 1 the plots of $x$ and $y$ distributions of the CC cross sections, for $Q^2 > 15000$ GeV$^2$ and a fixed value $f_t = 0.28$, are presented in comparison with the SM. For this value of $f_t$ we obtain the total cross section of the $e^+p \to \bar{\nu}X$ scattering $\sigma_{tot} = 0.28$ pb, which gives 4 events at the total luminosity of 14.2 pb$^{-1}$. The considerable events excess for large $Q^2$ is due to the chiral suppression of the processes $e^+p \to \bar{\nu}X$ in the SM. In the case of $e^-p \to \nu X$ scattering, at $Q^2 > 15000$ GeV$^2$, we have obtained a total cross section equal to $4.9 \pm 0.7$ pb in comparison with the expected in the SM \[3\] $3.8 \pm 0.3$ pb. Therefore, the contribution of the tensor interaction into the CC electron DIS will be negligible compared to the standard one.

In order to estimate the effect of the new tensor interactions into the neutral-current (NC) DIS, it is necessary to obtain analogous formulae for the NC lepton-quark effective interactions. In contrast to the CC processes, NC interactions at low energy are screened by the electromagnetic ones. Moreover, as will be shown underneath, the NC tensor interactions are parity-conserving and do not contribute into the $P$ asymmetries. Obviously, due to that, the admixture of the tensor forces have not yet been observed in NC interactions. We have not a direct experimental estimation for the NC tensor coupling constant $f_t^{NC}$, in contrast to the CC case. However, as far as both charged and neutral fields are components of one and the same $SU(2)$ multiplet, their masses should not differ noticeably, just like the case of $W$ and $Z$ bosons. Moreover, at space like momentum transfer $q^2 < 0$, in the $t$-channel, the form factors have a smooth dependence on the intermediate boson masses. Therefore, for our NC cross section estimations we will use the same mass values \[12\] and the same propagators \[3\] as for charged particles case.

The effective Lagrangian for the NC tensor interactions between leptons and quarks has the form:

$$\mathcal{L}_{eff}^{NC} = -\frac{g^2}{2\Delta(q)} \bar{e} \sigma^{\alpha \beta} e \left[ (q^2 - m^2) \Pi_{\alpha \beta \mu \nu}(q) \right] \overleftrightarrow{d} \sigma^{\mu \nu} d + \mu^2 \bar{u} \sigma_{\alpha \beta} u].$$
Those interactions are parity conserving. Hence, they are not constrained from atomic parity violation measurements. Using the identities (10), the Lagrangian (15) can be rewritten in the chiral form

\[
\mathcal{L}_{\text{eff}}^{\text{NC}} = - \frac{2g^2}{\Delta(q)} \bar{e}_L \sigma^{\alpha\lambda} e_R \frac{q_0 q_3}{q^2} [(m^2 - q^2) \bar{d}_R \sigma_{\beta\lambda} d_L + \mu^2 \bar{u}_L \sigma_{\beta\lambda} u_R] \\
- \frac{2g^2}{\Delta(q)} \bar{e}_R \sigma^{\alpha\lambda} e_L \frac{q_0 q_3}{q^2} [(m^2 - q^2) \bar{d}_L \sigma_{\beta\lambda} d_R + \mu^2 \bar{u}_R \sigma_{\beta\lambda} u_L].
\]

(16)

In the parton model the Born cross section for the NC scattering of leptons on the valence quarks are

\[
\frac{d^2}{dx dy} \left[ \frac{\sigma_{\text{NC}}^{\text{e}^- p}}{\sigma_{\text{NC}}^{\text{e}^+ p}} \right] = \frac{2\pi\alpha^2 s}{Q^4} \sum_{q=u,d} \left\{ Y_+(y) C_2^q(Q^2) \pm Y_-(y) C_3^q(Q^2) + (1 - \frac{y}{2})^2 C_T^q(Q^2) \right\} q(x, Q^2),
\]

(17)

where the form factors, \(C_2^q\), \(C_3^q\) and \(C_T^q\) are given by

\[
C_2^q(Q^2) = e_q^2 - 2e_q v_a \chi_Z + (v_a^2 + a_i^2)(v_a^2 + a_i^2) \chi_Z^2 \\
C_3^q(Q^2) = -2e_q a_a \chi_Z + (2v_a a_q)(2v_a a_q) \chi_Z^2 \\
C_T^q(Q^2) = \left[ \frac{\mu^2}{Q^2 + 2M_Z^2} \right] \chi_T^2, \quad C_T^d(Q^2) = \chi_T^2
\]

(18)

with

\[
\chi_Z = \frac{1}{4 \sin^2 \theta_W \cos^2 \theta_W} \frac{Q^2}{Q^2 + M_Z^2}, \quad \chi_T = \frac{1}{\sin^2 \theta_W} \frac{2Q^2(Q^2 + 2M_L^2)}{Q^2 + 6M_L^2}.
\]

(19)

In eqs. (18) and (19), \(e_q\) is the quark charge in units of \(e\); \(v_i\) and \(a_i\) are the vector and axial couplings of the fermions to \(Z^0\); \(\theta_W\) is the weak mixing angle. In the region of large \(Q^2\) the contribution from the parity-violating term substantially reduces the \(e^+p\) cross section. Therefore, for positron scattering the events excess over the SM prediction is more significant. The number of the observed and the predicted NC positron events, including tensor interaction, above \(Q_{\text{min}}^2\) thresholds for the two experiments, are given in the table 1.

| \(Q_{\text{min}}^2\) [GeV²] | \(N_{\text{obs}}\) | \(N_T\) |
|-----------------|----------------|----------|
| 15000           | 24             | 30.7 ± 10.4 |
| 20000           | 10             | 12.9 ± 4.7  |
| 25000           | 6              | 5.7 ± 2.1   |
| 30000           | 4              | 2.6 ± 0.9   |
| 35000           | 2              | 1.1 ± 0.4   |

**Table 1:** The number of the observed \((N_{\text{obs}})\) and the predicted \((N_T)\) NC positron events, including tensor interaction, above \(Q_{\text{min}}^2\) thresholds for the two experiments.

The differential cross sections with \(Q^2 > 15000\) GeV² cut for NC DIS are presented in fig. 2 for masses of the new particles.
which correspond to $f_t = 0.28$ (see eq. [1]). For comparison the corresponding curves for the SM expectations are plotted also. The experimental data from the two experiments for positron scattering are shown in the figure as well.

The two experiments, with combined accumulated luminosity of 34.3 pb$^{-1}$ for positron scattering, have observed 24 events with $Q^2 > 15000$ GeV$^2$ against the SM expectation of $13.4 \pm 1.0$. For such a small number of events it is too early to speak about distributions and the total cross section approach is more appropriate now. Our predictions for total cross sections at $Q^2 > 15000$ GeV$^2$ are $\sigma^{e^-p}_{tot} = 1.7 \pm 0.3$ pb and $\sigma^{e^+p}_{tot} = 0.9 \pm 0.3$ pb. For a total $e^+p$ integral luminosity of 34.3 pb$^{-1}$, the last cross section corresponds to $30.7 \pm 10.4$ events. For our choice of the new particles masses (20), this corresponds to the total cross sections $\sigma^{e^-p}_{tot} = 1.5$ pb and $\sigma^{e^+p}_{tot} = 0.7$ pb (the last one being an exact fit to the observed 24 events).

So, our results on positron DIS are in agreement with anomalous HERA data both for CC and NC channels. They reproduce the main features of the HERA results, but it is too early to speak about fitting various distributions due to the lack of sufficient statistics.

Besides, note that the form of the new interaction was derived only using semileptonic meson decay data. And it is remarkable, that this interaction works in self-consistent manner both at low and high energies. The next step, of course, should be to analyze the eventual contribution from new interaction at hadron (Tevatron) and lepton (LEP) colliders, which lies beyond the scope of the present work. We would like to make just a short comment here. As far as the masses of the new particles (20) are large $M_H > M_L > m_{top}$, it is very difficult to detect them in hadron collisions and a special search for that is needed. However, up till now nobody has searched for such kind of particles and interactions, neither at Tevatron nor at LEP. We hope that more precise analysis of the experimental data will allow to discover the effects of the new tensor interactions at both Tevatron and LEP.

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References

[1] ALEPH Collaboration, Contributed paper PA10-015; SLD Collaboration, Contributed paper PA10-023; DELPHI Collaboration, Contributed paper PA01-061; 
_International Conference on High Energy Physics, Warsaw, 1996._

[2] J. Huston et al., Phys. Rev. Lett. 77 (1996) 444; H. L. Lai et al., Phys. Rev. D55 (1997) 1280.

[3] C. Adloff et al., H1 Collaboration, DESY preprint 97-24, [hep-ex/9702012](http://arxiv.org/abs/hep-ex/9702012).

[4] J. Breitweg et al., ZEUS Collaboration, DESY preprint 97-25, [hep-ex/9702013](http://arxiv.org/abs/hep-ex/9702013).

[5] N. Kemmer, Proc. Roy. Soc. A166 (1938) 127.
[6] L. V. Avdeev and M. V. Chizhov, JINR preprint E2-94-263, hep-th/9407067.

[7] M. V. Chizhov, Mod. Phys. Lett. A8 (1993) 2753.

[8] M. B. Voloshin, Phys. Lett. B283 (1992) 120.

[9] B. A. Campbell and K. A. Peterson, Phys. Lett. B192 (1987) 401;
    O. Shankar, Nucl. Phys. B204 (1982) 375.

[10] V. N. Bolotov et al., Phys. Lett. B243 (1990) 308.

[11] H. Steiner et al., Phys. Lett. B36 (1971) 521;
    S. A. Akimenko et al., Phys. Lett. B259 (1991) 225.

[12] M. Glück, E. Reya, and A. Vogt., Z. Phys. C67 (1995) 433.
FIGURE CAPTIONS

**Figure 1:** The solid curves represent predicted CC differential cross sections for $Q^2 > 15000$ GeV$^2$, accounting for the tensor interaction with $f_t = 0.28$. For a comparison the SM expectation curves are plotted with dashed lines.

**Figure 2:** The solid curves represent NC differential cross sections for $Q^2 > 15000$ GeV$^2$ and for masses of the new particles, correspondingly $M_L = 248$ GeV and $M_H = 607$ GeV. For a comparison the SM expectation curves are plotted with dashed lines. The experimental data from the two experiments for positron scattering are shown with dots.
Fig. 1
Fig. 2