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ABSTRACT

In this note we discuss the possibility that new spin 3/2 leptons can occur in nature as a manifestation of a leptonic structure and in multiplets in supersymmetric theories. We postulate a new interaction between spin 1/2 and spin 3/2 particles that maintains the standard $SU(2)_L \otimes U(1)$ local gauge invariance. A comparison with the anomalous $Z^o \to e^+e^-\gamma$ events is made and new decays for the weak bosons are studied.

The repetition of the properties of each of the known fermionic families and the experimental discovery of the tau lepton with a mass higher than that of baryons raises the possibility of a leptonic structure. An evidence for this possibility could be the excitation of the subcomponents and the consequent appearance of spin 3/2 states(1).

In a rather different context supersymmetric theories(2) predict supermultiplets with spin 3/2 particles. A recent study(3) of the renormalization effects in broken supergravity gauge theories concludes that the gravitino (spin 3/2) can have a mass as low as 50 GeV.

These two points suggest that the experimental discovery of a spin 3/2 lepton (or quark) could be a fundamental step to confirm or to rule out a series of models in the present elementary particle physics.

This is particularly difficult since we have no complete theory for interacting spin 3/2 fields. But we may propose phenomenological interactions which can give qualitative properties of spin 3/2 interactions. This is suggested by the effective point-like Fermi's model which is not a consistent theory but gives very useful informations on weak interactions at low energies.

We will consider mainly the possibility of spin 3/2 states as a manifestation of a leptonic structure for a simple reason. If spin 3/2 fields are excited states of the presently known lepton families we can reasonably suppose that their electroweak interactions are the same as in the low lying spin 1/2 states. This hypothesis fixes almost all the parameters in the theory, except, of course, the spin 3/2 mass.

The uniqueness of the Rarita-Schwinger Lagrangian has been reexamined recently[4] and has the form:

$$(1) \quad \mathcal{L}_{free} = - \varepsilon^{\alpha\mu\nu\beta} \bar{\psi}_\alpha \gamma^5 \gamma_\mu (\partial_\nu + i \frac{M}{2} \gamma_\nu) \psi_\beta$$

We can generalize[5] this Lagrangean for the electroweak $SU_L(2) \otimes U(1)$ model by considering spin 3/2 fields with the same quantum numbers as in the spin 1/2 states: a left-handed doublet

$$(2) \quad L^\mu = \begin{pmatrix} N^\mu \\ E^\mu \end{pmatrix}_L$$

and a right-handed isoscalar

$$(3) \quad R^\mu = E^\mu_R$$

The fermionic Lagrangian is

$$(4) \quad \mathcal{L}_{fermionic} = - \varepsilon^{\mu\nu\rho\sigma} (\bar{L}_\mu \gamma_5 \gamma_\nu D_\rho L_\sigma + \bar{R}_\mu \gamma_5 \gamma_\nu D_\rho R_\sigma)$$

where the notation is the same as in reference 6.

We generalize even further the local $SU_L(2) \otimes U(1)$ invariance and include spin 3/2 (L^μ, R^μ) and spin 1/2 (L, R) interactions:

$$(5) \quad \mathcal{L}_{3/2, 1/2} = - K \varepsilon^{\mu\nu\rho\sigma} \left[\bar{L}_\mu \gamma_5 \gamma_\nu D_\rho D_\sigma L + \bar{R}_\mu \gamma_5 \gamma_\nu D_\rho D_\sigma R \right]$$

where K is a constant which behaves like the inverse of a mass.

The above interactions imply several new decays

for the weak bosons. We compute decay probabilities with arbitrary vector (V) and axial-vector (A) couplings which generalize our interaction Lagrangians (4) and (5) to other cases.

We consider several new decays:

DECAY I: $Z^o \to E^+_{3/2}\, e^-_{1/2}$

In this case

$$(6) \quad \Gamma(Z^o \to E^+_{3/2}\, e^-_{1/2}) = \frac{K^2 (V_I^2 + A_I^2)}{48 \pi x (1+x)} M_Z^3 (1-x)^3 (1+2x+3x^2)$$

where $x \equiv M^2_{3/2}/M^2_Z$. In the standard model we have (for $K = \frac{1}{M_{3/2}}$) the following branching ratio

$$(7) \quad \frac{\Gamma(Z^o \to E^+_{3/2}\, e^-_{1/2})}{\Gamma(Z^o \to e^+_{1/2}\, e^-_{1/2})} = \frac{1}{4x^2} \frac{(1-x)^3}{(1+x)} (1+2x+3x^2)$$

DECAY II: $W^+ \to E^+_{3/2}\, \nu_{1/2}$; $W^+ \to e^+_{1/2}\, N_{3/2}$

For a V-A coupling $(V^2_{II} = A^2_{II})$ we have $(y = \frac{M^2_{3/2}}{M^2_W})$

$$(8) \quad \Gamma(W^+ \to E^+_{3/2}\, \nu_{1/2}) = \Gamma(W^+ \to e^+_{1/2}\, N_{3/2}) =$$

$$= \frac{K^2 V^2_{II} M^3_W}{24 \pi y (1+y)} (1-y)(1+2y+3y^2)$$

and in the standard model

(9) $$\frac{\Gamma(W^+ \to E^+_{3/2}\ \nu_{1/2})}{\Gamma(W^+ \to e^+_{1/2}\ \nu_{1/2})} = \frac{1}{4y^2}\ \frac{(1-y)^3}{(1+y)}\ (1+2y+3y^2)$$

DECAY III: $Z^0 \to N_{3/2}\ \bar{\nu}_{1/2}$

For this reaction

(10) $$\Gamma(Z^0 \to N_{3/2}\ \bar{\nu}_{1/2}) = \frac{K^2(A_{III} - V_{III})^2}{96\,\pi\, x(1+x)}\ M_Z^3 (1-x)^3\ (1+2x+3x^2)$$

and the branching ratio is

(11) $$\frac{\Gamma(Z^0 \to N_{3/2}\ \bar{\nu}_{1/2})}{\Gamma(Z^0 \to e^+_{1/2}\ e^-_{1/2})} = \frac{1}{2(a^2+v^2)}\ \frac{(1-x)^3}{x^2(1+x)}\ (1+2x+3x^2)$$

where $a^2 = 1$ and $v^2 = (1 - 4\,\mathrm{sen}^2\theta_W)$

DECAY IV: $Z^0 \to N_{3/2}\ \bar{N}_{3/2}$

This decay is an example of pair production of spin 3/2 fermions. These cases can all be supressed if $M_{3/2} > \frac{1}{2} M_Z$. The neutral massive pair production gives

(12) $$\Gamma(Z^0 \to N_{3/2}\ \bar{N}_{3/2}) = \frac{(V^2_{IV} + A^2_{IV})}{144\,\pi\, x}\ M_Z\ (1-4x)(3-14x+38x^2)$$

and the branching ratio in the standard model is

(13) $$\frac{\Gamma(Z^0 \to N_{3/2}\ \bar{N}_{3/2})}{\Gamma(Z^0 \to e^+\ e^-)} = \frac{8}{3(a^2+v^2)}\ \frac{(1-4x)}{x}\ (3-14x+38x^2)$$

The interaction form (5) implies that the dominant decay of the charged spin 3/2 fermion is electromagnetic

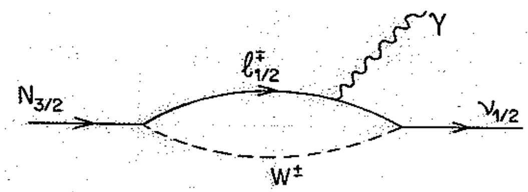
(14) $$E_{3/2} \to e_{1/2} + \gamma$$

with a branching ratio of practically one. The contributions of this coupling to other processes like the Compton effect or the Thomson cross section were discussed in references 5.

We have also the possibility of neutral decays

(15) $$N_{3/2} \to \nu_{1/2} + \gamma$$

via higher order contributions like



We turn now our attention to the anomalous $Z^0 \to e^+e^-\gamma$ events observed in the UA_1 experiment[7]. Even if we have a limited statistics for these events the agreement with the standard electroweak theory seems very difficult.

In our model, this decay can proceed through the chain

$$Z^0 \to E^+_{3/2}\ e^-_{1/2}$$
$$\quad\ \ \llcorner\!\!\longrightarrow e^+_{1/2}\ \gamma$$

with a branching ratio of twice our equation 7.

We also have decays like

$$W^+ \rightarrow E^+_{3/2}\ \nu_{1/2}$$
$$\quad \llcorner\!\!\longrightarrow e^+_{1/2}\ \gamma$$

which are not, so far, detected. A large mass for the spin 3/2 charged lepton can suppress this channel. We compare both predictions in Table I where we consider $M_W = 80$ GeV, $M_Z = 90$ GeV and different values for $M_{3/2}$ (in GeV).

$M_{3/2}$	65	70	75
$\dfrac{\Gamma(Z^o \rightarrow E^+_{3/2}\ e^-_{1/2})}{\Gamma(Z^o \rightarrow e^+_{1/2}\ e^-_{1/2})}$	.19	.09	.03
$\dfrac{\Gamma(W^+ \rightarrow E^+_{3/2}\ \nu_{1/2})}{\Gamma(W^+ \rightarrow e^+_{1/2}\ \nu_{1/2})}$	.05	.01	.001

TABLE I

which shows clearly the suppression of the charged boson decay.

We note that the hypothesis of excited spin 1/2 leptons, with a non-renormalized phenomenological interaction[8] leads to a mass value similar to the spin 3/2 case to fit the $Z^o \rightarrow e^+e^-\gamma$ events.

The decay III also implies a very definite signature. If the branching ratio for $N_{3/2} \rightarrow \nu_{1/2}\gamma$ is one, we have a decay $Z^o \rightarrow \nu\bar{\nu}\gamma$ with a branching ratio that can be obtained

from our equation (11) and recognized by a very energetic single gamma event plus missing energy.

If the neutral $N_{3/2}$ satisfies $M_{3/2} < \frac{M_Z}{2}$ decay IV implies events with two energetic gammas and a branching ratio given by equation (13).

In conclusion, production and decay of spin 3/2 leptons appears as a very usefull test for leptonic structure and/or supersymmetric models. The present experimental investigation of the W's and Z^o decays is shown to be consistent with the production of heavy spin 3/2 leptons, but we still need more detailed experiments.

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