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[#]Presented by J.A. Martins Simões to the XXII International Conference on High Energy Physics - Leipzig - July 1984

POSSIBLE SPIN 3/2 QUARKS IN NEUTRINO REACTIONS#

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ABSTRACT

In this paper we discuss the hypothesis that quarks are composite objects and that excited states with spin 3/2 can be produced in neutrino reactions. Experimental consequences are analysed. The most relevant ones are scaling violations of a particular type and a consistent rate for same-sign dileptons.

Key-words: Elementary particles; Quarks; Leptons; Spin 3/2 particles.

1 INTRODUCTION

Models for lepton and/or quark sub-structure are very popular at present. However, they are so far difficult to be submitted to experimental tests.

Some time ago it was suggested [1,2,3] that we should look for indirect evidences for such a structure and thus obtain information on the dynamics of the sub-components of leptons and quarks.

The simplest consequence of a fermionic substructure is the excitation of states of higher spin in particular of spin 3/2.

We may then have several possibilities: a) doublets of spin 3/2 fermions corresponding to each family of the usual spin 1/2 quarks and leptons; b) new sequential spin 3/2 fermions; c) supersymmetric multiplets with different spin values, among others.

We must decide between these alternatives by comparing their predictions with experiment. This is particularly difficult, since even for electromagnetic interactions there is no complete theory for spin 3/2 fields. For example, the "minimal" electromagnetic coupling $A_\mu \bar{\psi}^\alpha \gamma^\mu \psi_\alpha$ implies that the cross section (4) for $e^+e^- \to \bar{f}_{3/2} f_{3/2}$ violates unitarity at energies very close to the threshold value. Then we simply do not know [5] what is to be expected for the real, physical electromagnetic production of spin 3/2 fermions.

A similar problem occurs for the weak interactions of spin 3/2 fermions. But here we can take advantage of the fact that unitarity is violated at higher energies relative to a typical threshold value. By employing phenomenological interactions we can, at least qualitatively, make predictions for the behaviour of spin 3/2 fermions. Of course, our results can not be extrapolated at higher energies, but we hope that close to thresholds they work. This is the spirit of the succesfull Fermi's approximation for weak interactions.

The leptonic case was discussed in references [1,3]. In this paper we consider the phenomenological implications of the weak interactions for spin 3/2 quarks. The most appropriate physical process for this study is neutrino-nucleon collision.

2 SCALING VIOLATIONS

If we suppose [2] that there is a link between quarks with spin 1/2 and 3/2 we must consider transitions between spin 1/2 $\leftrightarrow$ spin 3/2 quarks.

In the usual Rarita-Schwinger formalism the simplest V ± A currents are

$$\text{(I)}\quad J^{\alpha}_{I} = \bar{\mu}^{\alpha}(p, s = 3/2)(1 + a\gamma^5)\mu(p', s = 1/2)$$

$$\text{(II)}\quad J^{\alpha}_{II} = \frac{1}{M_{3/2}}\bar{\mu}^{\lambda}(p, s = 3/2)q_{\lambda}\gamma^{\alpha}(1 + a\gamma^5)\mu(P', s = 1/2)$$

where μ^{α} is a vector-spinor, "a" is a constant equal to ± 1 and $q = p - p'$.

We have other possibilities besides (I) and (II) but with the same difficulties. As we are interested in estimates for physical processes we take only the above expressions, which are the least divergent.

The most important result in this model is a particular scaling violation for the usual spin 1/2 partons.

The weak transition spin 1/2 → spin 3/2 is indicated in the diagram (see Fig. 1).

With the standard techniques of the parton model, the first interaction implies the following relations for the structure functions for spin 3/2 production

$$2F_1(x) = F_3(x)$$

$$F_2(x,Q^2) = \frac{xQ^2}{2M^2_{3/2}} F_1(x)$$

In terms of the usual structure functions for spin 1/2 partons we have

$$F_1(x,3/2) = \frac{2}{3} F_1(x,1/2)$$

$$F_2(x,Q^2,3/2) = \frac{Q^2}{6M^2_{3/2}} F_2(x,1/2)$$

$$F_3(x,3/2) = \frac{2}{3} F_3(x,1/2)$$

The cross section for this process is

$$\frac{d^2\sigma^{\nu}_{\bar{\nu}}}{dx\,dy} = \frac{G^2ME}{\pi}\left[xy^2\frac{2}{3}F_1(x,1/2) + (1-y)\frac{Q^2}{6M^2_{3/2}}F_2(x,1/2) \pm (1-y/2)xy\frac{2}{3}F_3(x,1/2)\right]$$

where we consider a coupling equal to $G/\sqrt{2}$ and the approximation $M^2_{3/2} << M^2_W$.

Besides scaling violation, we have a Q^2 dependence on the y distributions and deviations of the Callan-Gross relations.

For the other interaction we have the following structure functions

$$\Gamma_i'(x,Q^2,3/2) = \frac{1}{12}\frac{Q^4}{M^4_{3/2}}\ F_i(x,1/2)$$

This case presents the same Callan-Gross relation as for spin 1/2 but a linear rise in Q^4, quite different from the Q.C.D. prediction. Of course, this must happen only at energies near the threshold for spin 3/2 production.

The cross section for this interaction form is given by

$$\frac{d^2\sigma_{\nu}^{\nu}}{dxdy} = \frac{G^2ME}{\pi}\frac{1}{12}\frac{Q4}{M^4_{3/2}}\left[xy^2F_1(x,1/2) + (1-y)F_2(x,1/2) \pm (1-y/2)xyF_3(x,1/2)\right]$$

The order of magnitude of these cross sections must be taken with caution. We have considered the current-current coupling for spin 1/2 → spin 3/2 transitions of the order of Fermi's constant. Besides propagator effects for heavy quarks, mixing between quarks can reduce this value.

3 THE SAME-SIGN DILEPTON PUZZLE

The same sign dilepton events produced in neutrino-nucleon reactions is one of the very few experiments which, so far, are not included in the standard $SU(3) \otimes SU_L(2) \otimes U(1)$ model. The most promising mechanism [8], bottom excitation, is at least one order of magnitude below the data. Q.C.D. corrections seems to be unable to improve this.

It was recently suggested [9] that a possible mechanism for these events is the production of a heavy spin 3/2 quark.

For simplicity we consider an excited state of an "u" quark which we call $\mathcal{U}$ but other states are also possible. This quark state can be recombined with an "u" quark and form a neutral vector meson $\mathcal{U}$ (Spin 1).

If we recall Bjorken's argument for the fragmentation function for a heavy quark this implies a delta function $\delta(z-z^0)$. But our final result is practically independent of the z^0 value.

The main feature of this meson is the oscillation $\mathcal{U}\bar{u} \Leftrightarrow \mathcal{U}\bar{u}$ via a flavour conserving neutral current. This effect can be quite large and we estimate 50% as a reasonable upper bound.

Finally, the semi-leptonic decay spectrum for the first interaction is given by

$$\frac{1}{\Gamma_I} \frac{d\Gamma_I}{\frac{d^3P_{1/2}}{2p_o}} = \frac{3}{\pi M^2_{3/2}} x \{15 - 40x + 30x^2 - 8x^2\}$$

and for the second

$$\frac{1}{\Gamma_{II}} \frac{d\Gamma_{II}}{\frac{d^3 p_{1/2}}{2p_0}} = \frac{40}{3\pi M^2_{3/2}} x\{3 - 6x + x^2\}$$

where $x \equiv \frac{P_{3/2} \cdot P_{1/2}}{M^2_{3/2}}$ and $P_{1/2}$ refers to the charged lepton.

Using the FHOPRW [10] parametrization for the quark distributions in nuclei our results are shown in Figures II and III.

The theoretical uncertainties for spin 3/2 fields do not allow us to extract a sharp value for the mass. But as two independent interaction forms give practically the same result we conclude that a possible mechanism for the same sign dilepton events is the production of a spin 3/2 quark with a mass in the 10 GeV region.

The spin 3/2 production will contribute to other processes such as opposite sign dileptons, but with a small rate relative to the dominant charm production. Neutral current decays as $\mathcal{U} \to \ell^+ \ell^- u$ can also contribute to trilepton events.

4 CONCLUSIONS

The hypothesis of spin 3/2 quarks has several implications - scaling violations, deviation from Callan-Gross relation. Q^2 dependence on y distributions, large oscillations for vector mesons and a compatible rate for same sign dilepton events.

These are the indirect consequences of a quark substructure which we think that deserves more theoretical and experimental investigation.

A recent paper by Fleury and Leite Lopes proposes a Pauli-type interaction between spin - 1/2 and spin 3/2 fields with production or absorption of γ, W or Z particles. This interaction allows for the decay of a Z meson into a pair $e^-_{3/2}$ and $e^+_{1/2}$ and subsequent decay of $e^-_{3/2}$ into $e^-_{1/2}$ and a γ, which could account for the recent observations at CERN by the NA1 collaboration. Calculations on this problem will be published elsewhere.

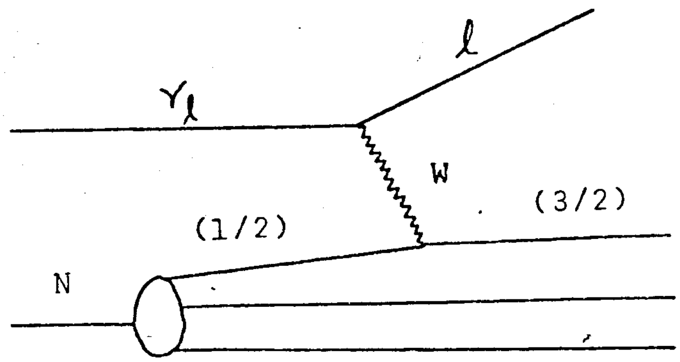

FIGURE I

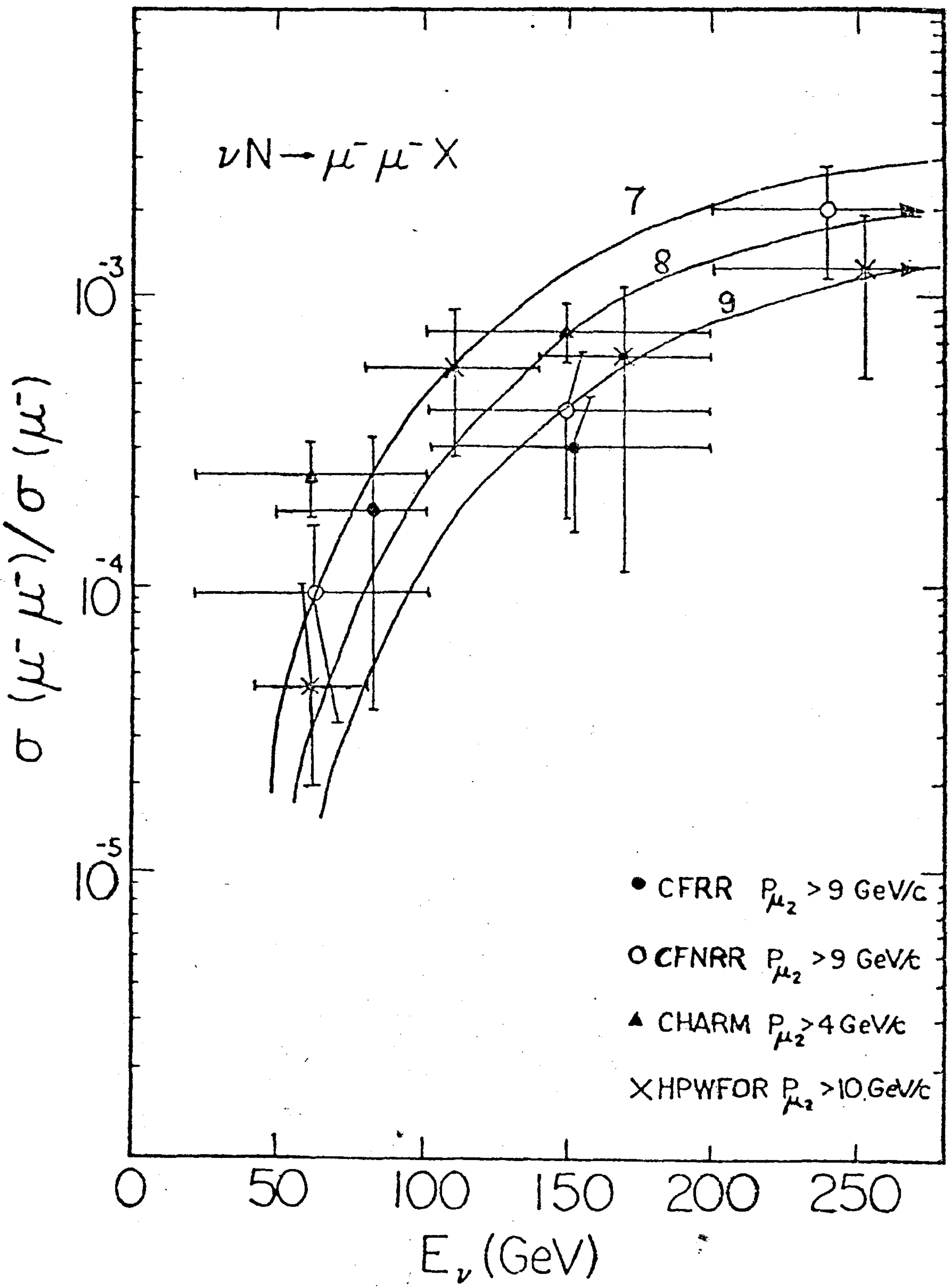

FIGURE II

Same sign dilepton rates for the first interaction. The curves correspond to different values for the spin 3/2 quark mass and a cut in E_{min} = 9 GeV.

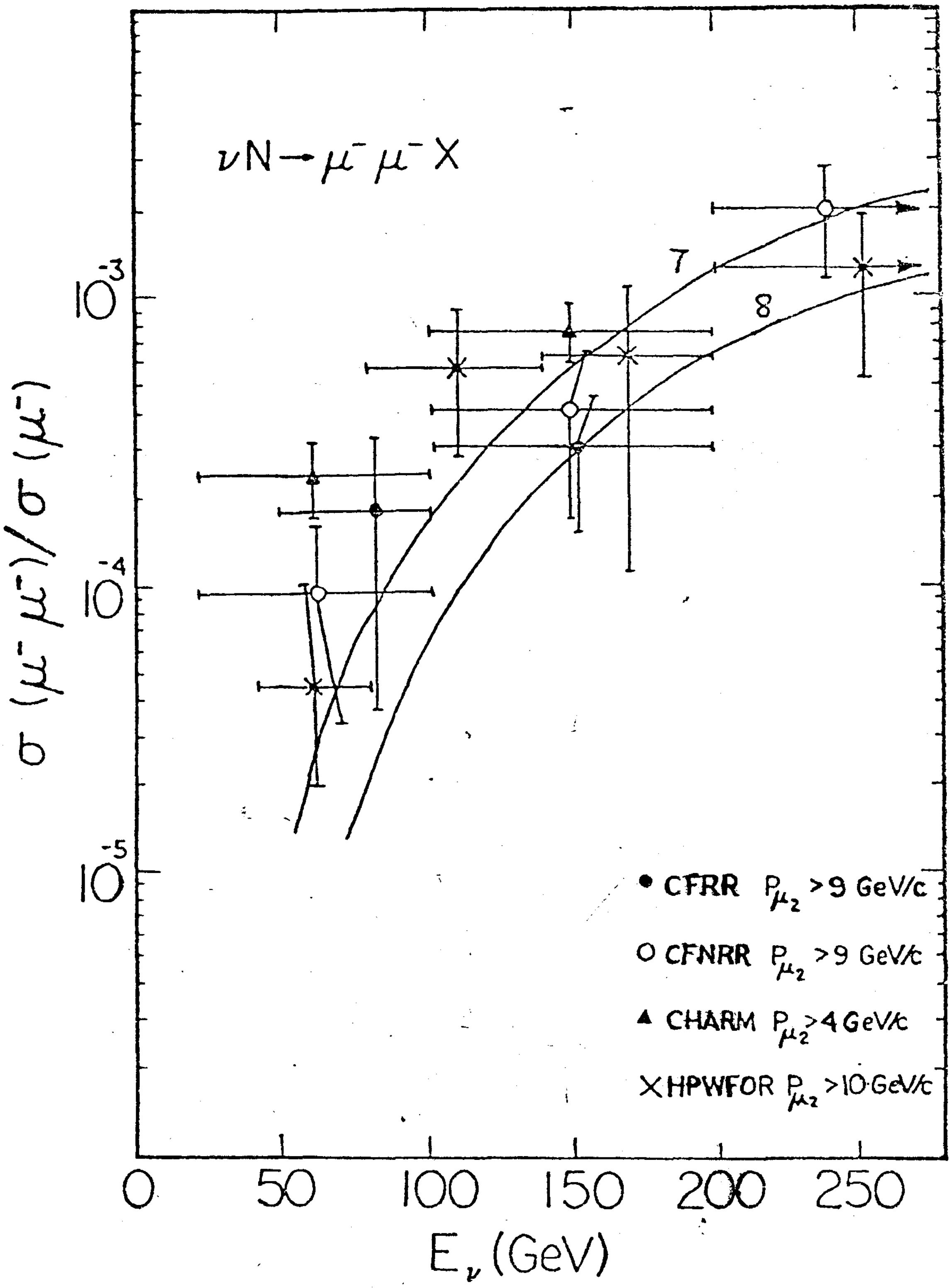

FIGURE III

The same as figure II but for the second interaction.

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