CBPF-NF-033/81

WEAK INTERACTIONS INVOLVING SPIN 3/2 LEPTONS

by

J. Leite Lopes[1,2], D. Spehler[2] and J.A. Martins Simões[3]

[1]Centro Brasileiro de Pesquisas Físicas - CBPF/CNPq
Av. Wenceslau Braz, 71, fundos
22290 - Rio de Janeiro - R.J. - BRASIL

[2]Centre de Recherches Nucleaires - CRN
Université Louis Pasteur
Strasbourg - FRANCE

[3]Instituto de Física
Departamento de Física Teórica
Universidade Federal do Rio de Janeiro - BRASIL

ABSTRACT

Weak interaction processes are discussed which involve spin 3/2 charged leptons and spin 3/2 massless neutrinos; predictions for production and decay properties of these particles are given for several phenomenological charged and neutral weak current couplings.

In particular, 3μ events are predicted as a result of possible production and decay of spin 3/2 leptons. Neutrino - electron inelastic scattering with production of spin 3/2 neutrinos might be detected by a distinctive angular distribution of the outgoing electron or muon.

In two previous papers, we have investigated some consequences of the hypothesis of the existence of spin 3/2 leptons[1] and of spin 3/2 quarks[2]. The experimental discovery of effects which might be ascribed to such particles would certainly contribute to a better understanding of the presently known families of fundamental particles and might shed light on recent speculation on a possible internal structure of leptons and quarks[3].

Our preceding analysis was based on the assumption that only charged spin 3/2 leptons would exist in each of the known lepton families and that they would couple to the spin 1/2 neutrino of their own family in order to generate charged weak currents. This is the case indicated in the column (II) of Table I.

It is the aim of this note to present the results of calculations of processes which involve both charged spin 3/2 leptons and spin 3/2 neutrinos assumed to exist according to column (III) of Table I. This completes our phenomenological investigation initiated in Refs. 1 and 2. Massless spin 3/2 neutrinos are taken here according to the orthodox view, as having only a maximal, helicity 3/2 state[4]. The possibility of non-maximal helicity $\frac{1}{2}$ states, as recently suggested by D.H. Miller[5], will not be considered here.

Table I. Possible spin 3/2 leptons.

Leptonic numbers			Basic spin 1/2 leptons (I)		Possible spin 3/2 leptons either (II)	or (III)	
L_e	L_μ	L_τ	ν_ℓ	ℓ	L	ν_L	L
1	0	0	ν_e	e	ε	ν_ε	ε
0	1	0	ν_μ	μ	M	ν_M	M
0	0	1	ν_τ	τ	T	ν_T	T

The following reactions have accordingly been studied:

$$\nu_\mu + e \longrightarrow \nu_M + e \quad (1)$$

$$M^- \longrightarrow \mu^- + e^- + e^+ \quad (2a)$$

$$M^- \longrightarrow \mu^- + \mu^- + \mu^+ \quad (2b)$$

which are governed by neutral weak current couplings, and

$$L \longrightarrow \nu_L + \pi \quad (3)$$

$$L^- \longrightarrow \nu_L + e^- + \bar{\nu}_e \quad (4)$$

$$\nu_\mu + e^- \longrightarrow \mu^- + \nu_\varepsilon \quad (5)$$

$$\bar{\nu}_e + e \longrightarrow \bar{\nu}_L + L \quad (6)$$

which take place through charged weak current interactions.

As no gauge field theory for spin 3/2 fields is known, which would fix their interactions, our analysis will necessarily be based on phenomenological currents and amplitudes. The coupling constant will be denoted f.

Whereas the experimental detection of reaction (6) depends on the value of the mass of the charged spin 3/2 leptons L, which would certainly be high, reactions (1) and (5) do not depend on such a mass. The forward-backward asymmetry of the outgoing charged spin 1/2 leptons, as compared to the isotropy of the corresponding processes involving only spin $\frac{1}{2}$ particles, would give an indication of the existence of spin 3/2 neutrinos. Charged spin 3/2 leptons could be detected by means of the decay processes (2a) and (2b). In particular, the 3μ events predicted by reaction (2b) have distinctive features in comparison with 3μ events in neutrino-nucleon reactions associated with charmed quark production:

$$\nu_\mu + N \longrightarrow M^- + X$$
$$\quad\quad\quad \hookrightarrow \mu^- \; e^- \; e^+$$
$$\quad\quad\quad\quad \mu^- \; \mu^- \; \mu^+$$

Reaction (1). We take an amplitude of the form:

$$M^{(1)} = \frac{f}{\sqrt{2}} (\bar{u}(p_e')\gamma^\alpha(1+a\gamma^5)u(p_e))(\bar{u}_\alpha(p_{\nu_M})(1+b\gamma^5)u(p_{\nu_\mu}))$$

The first parenthesis contains an electron-electron neutral current for which we shall pose a=-8 as suggested by the Salam-Weinberg model. The second parenthesis is a phenomenological neutral current constructed with the spin 3/2 neutrino ν_M and the spin 1/2 neutrino ν_μ. The differential cross section for reaction (1) is then:

$$\frac{d\sigma^{(1)}(\theta)}{d\Omega} \equiv \frac{d\sigma}{d\Omega}(\nu_\mu e \rightarrow \nu_M e) = \frac{f^2}{G^2}\frac{d\sigma}{d\Omega}(\nu_\mu e \rightarrow \nu_\mu e)(1+\cos\theta) \cdot \left\{\frac{65}{16}(1+b^2)(1+\cos\theta) + 4b\right\}$$

where θ is the scattering angle in the center-of-mass system,

$$\frac{d\sigma}{d\Omega}(\nu_\mu e \longrightarrow \nu_\mu e) = \frac{G^2}{4\pi^2} s$$

is the isotropic differential cross section for the reaction $\nu_\mu e \longrightarrow \nu_\mu e$. The total cross section is

$$\sigma(\nu_\mu e \rightarrow \nu_M e) = \frac{f^2}{12G^2}\left[65(1+b^2) + 48b\right]\sigma(\nu_\mu e \longrightarrow \nu_\mu e)$$

and is therefore proportional to the elastic scattering cross section for the indicated spin $\frac{1}{2}$ leptons.

The forward-backward asymmetry, as defined by the equation:

$$A(\theta) = \frac{1}{\sigma(\nu_\mu e \longrightarrow \nu_M e)}\left[\frac{d\sigma^{(1)}(\theta)}{d\Omega} - \frac{d\sigma^{(1)}(\pi-\theta)}{d\Omega}\right] \qquad (7)$$

is of the form:

$$A(\theta) = \frac{1}{4\pi} \frac{\left[195(1+b^2) + 96b\right] \cos\theta}{65(1+b^2) + 48b}$$

The asymmetry of the outgoing electrons in reaction (1) is therefore an experimental test for this process. The plot of $A(\theta)$ would determine the parameter b. This angular distribution is to be compared with the asymmetry of the electrons of the elastic scattering $\nu_\mu e \rightarrow \nu_\mu e$, which is isotropic in first approximation but which has also a small θ-dependence due to radiative corrections.

Reaction (2a): The two decay processes (2a), (2b) differ from one another by the occurrence of two identical muons in (2b). A Vector-axial-Vector current amplitude of the form

$$M_1^{(2)} = \frac{f}{\sqrt{2}} \left(\bar{u}(p_\mu)(1+b\gamma^5)u_\alpha(p_M)\right)\left(\bar{u}(p_e')\gamma^\alpha(1+a\gamma^5)v(p_e)\right)$$

leads to the following spectral distribution of the positron in reaction (2a) (masses of the final leptons neglected):

$$\frac{1}{\Gamma_1} \frac{d\Gamma_1}{dx}(M \rightarrow \mu + 2e) = \begin{cases} \frac{1}{78} x^2(537 - 456x + 65x^2) & \text{for } b = 1 \\ \frac{1}{78} x^2(633 - 584x + 65x^2) & \text{for } b = -1 \end{cases}$$

where $a = -8$, $x = \frac{2E}{M}$, M is the mass of the spin 3/2 lepton $\mathcal{M}$, E is the energy of the outgoing positron (Fig. 1).

Another possible amplitude, proportional to the momentum transfer $q = p_\mu - p_{\mathcal{M}}$, is the following:

$$M_2^{(2)} = \frac{f}{\sqrt{2}} \left(\bar{u}(p_\mu)\gamma^\alpha(1+b\gamma^5)\frac{q_\lambda}{M} u^\lambda(p_{\mathcal{M}})\right)\left(\bar{u}(p_e')\gamma_\alpha(1+a\gamma^5)v(p_e)\right)$$

which gives rise to the following positron spectral distribution:

$$\frac{1}{\Gamma_2}\frac{d\Gamma_2}{dx}(\mathcal{M} \longrightarrow \mu + 2e) = \begin{cases} \frac{3x^2}{1040}(5370 - 9120x + 5135x^2 - 1142x^3) & \text{for } b = 1 \\ \frac{3x^2}{1040}(6330 - 11680x + 7215x^2 - 1718x^3) & \text{for } b = -1 \end{cases}$$

Reaction (2b). This reaction involves two identical muons in the final state and the amplitudes, similar to $M_1^{(2)}$ and $M_2^{(2)}$ above must be antisymmetrical with respect to the variables of the identical muons.

The spectral distribution of μ^+ for the antisymmetrized amplitude $M_1^{(2)}$ in p_μ and p_μ' has the form:

$$\frac{1}{\Gamma_1}\frac{d\Gamma_1}{dx}(\mathcal{M} \longrightarrow 3\mu) = \frac{20}{3}x^2\left(\frac{x^2}{8} - \frac{3x}{2} + \frac{3}{2}\right)$$

and does not depend on the values of a and b since these constants factorise (the γ^5 - term does not contribute to the interference terms of the antisymmetrised amplitude in M^+M).

The spectral distribution of μ^+ corresponding to the antisymmetrized amplitude $M_2^{(2)}$ is (Fig. 2):

$$\frac{1}{\Gamma_2}\frac{d\Gamma_2}{dx}(M \longrightarrow 3\mu) = \begin{cases} \frac{3x^2}{1432}(8310 - 15000x + 9055x^2 - 2122x^3) & \text{for } b = 1 \\ \frac{3x^2}{1688}(11190 - 21400x + 13695x^2 - 3338x^3) & \text{for } b = -1 \end{cases}$$

Reaction (3). The amplitude:

$$M^{(3)} = \frac{if}{\sqrt{2}} f_\pi(p_\pi) p_\pi^\alpha (\bar{u}^\lambda(p_{\nu_L})(1 + b\gamma^5)\gamma_\alpha u_\lambda(p_L))$$

$$p_\pi = p_L - p_{\nu_L}$$

for the decay of a spin $\frac{3}{2}$ charged lepton with mass M into a pion and a spin $\frac{3}{2}$ massless neutrino gives a transition probability:

$$\Gamma(L \longrightarrow \pi\nu_L) = \frac{1}{32\pi}(fm_p^2)^2\left(\frac{m_\pi}{m_p}\right)^2\left(\frac{M}{m_p}\right)^2 M\left(1 - \frac{m_\pi^2}{M^2}\right)^2$$

which is proportional to the probability for decay into a spin $\frac{1}{2}$ neutrino which was previously given[1]:

$$\Gamma(L \longrightarrow \pi\nu_L) = \frac{6f^2}{G^2}\left(1 - \frac{m_\pi^2}{M^2}\right)^{-2}\Gamma(L \longrightarrow \pi\nu_\ell)$$

A lifetime for the decay (3) is predicted which is about six times shorter than if the decay gives a spin $\frac{1}{2}$ neutrino and if $f^2 \approx G^2$.

Reaction (4). For the decay of a spin $\frac{3}{2}$ charged lepton with mass M into a spin $\frac{3}{2}$ neutrino and a pair electron, antineutrino, we have tried amplitudes constructed with scalar and tensor currents and two forms of vector-axial-vector currents. The spectral distribution of the outgoing electron has the following forms:

(i). Scalar - pseudoscalar currents:

$$M_S^{(4)} = \frac{f}{\sqrt{2}} (\bar{u}^{\lambda}(p_{\nu_L}) u_{\lambda}(p_L)) (\bar{u}(p_e)(c + d\gamma^5) v(p_{\nu_e}))$$

$$\frac{1}{\Gamma_S} \frac{d\Gamma_S}{dx} = 4x^2 \left(\frac{3}{2} - x\right)$$

where $0 \leqq x \leqq 1$; $x = 2\frac{E_e}{M}$

(ii). Tensor currents

$$M_T^{(4)} = \frac{f}{\sqrt{2}} (\bar{u}^{\lambda}(p_{\nu_L}) u^{\mu}(p_L)) (\bar{u}(p_e) \sigma_{\lambda\mu} v(p_{\nu_e}))$$

$$\frac{1}{\Gamma_T} \frac{d\Gamma_T}{dx} = \frac{20}{59} x^2 (x^2 - 33x + 33)$$

(iii) Vector, axial-Vector currents:

$$M^{(4)}_{V_1} = \frac{f}{\sqrt{2}} (\bar{u}^{\alpha}(p_{\nu_L})\gamma^{\lambda}(1+b\gamma^5)u_{\alpha}(p_L))(\bar{u}(p_e)\gamma_{\lambda}(1-\gamma^5)v(p_{\nu_e}))$$

$$\frac{1}{\Gamma_{V_1}}\frac{d\Gamma_{V_1}}{dx} = \begin{cases} x^2(9-8x) & \text{for } b = 1 \\ 12x^2(1-x) & \text{for } b = -1 \end{cases}$$

$$M^{(4)}_{V_2} = \frac{f}{\sqrt{2}} (\bar{u}^{\lambda}(p_{\nu_L})(1 + b\gamma^5)\frac{q^{\alpha}}{M}u_{\alpha}(p_L))(\bar{u}(p_e)\gamma_{\lambda}(1-\gamma^5)v(p_{\nu_e}))$$

$$q = p_{\nu_L} - p_L$$

$$\frac{1}{\Gamma_{V_2}}\frac{d\Gamma_{V_2}}{dx} = \begin{cases} 15x^2(3-8x+7x^2-2x^3) & \text{for } b = 1 \\ \frac{3}{2}x^4(5-2x) & \text{for } b = -1 \end{cases}$$

The corresponding curves for $\frac{1}{\Gamma}\frac{d\Gamma}{dx}$ are shown in Fig. 3

Reaction (5). This is an alternative to reaction (1) above and to the reaction denoted (2) in Ref. 1. With the amplitude:

$$M^{(5)} = \frac{f}{\sqrt{2}} (\bar{u}^{\lambda}(p_{\nu_{\varepsilon}})(1+b\gamma^5)u(p_e))(\bar{u}(p_{\mu})\gamma_{\lambda}(1-\gamma^5)u(p_{\nu_{\mu}}))$$

we obtain the differential and total cross sections below:

$$\frac{d\sigma}{d\Omega}(\nu_\mu e \longrightarrow \mu\nu_\varepsilon) = \frac{d\sigma}{d\Omega}(\nu_\mu e \longrightarrow \mu\nu_e)\,\frac{f^2}{G^2}\,\cdot$$

$$\cdot\,\frac{1}{s}\left\{(1+b^2)\,\frac{s+m_\mu^{\,2}}{8} + \frac{b}{2}\,(s-m_\mu^{\,2}) + \right.$$

$$+\cos\theta\left[(1+b^2)\frac{s}{4} + \frac{b}{4}\left(2s + m_\mu^{\,2} - \frac{m_\mu^4}{s}\right)\right] +$$

$$\left. + \cos^2\theta\left[\frac{1+b^2}{8}\,(s-m_\mu^2) + \frac{b}{2}\,m_\mu^{\,2}\right]\right\},$$

$$\sigma(\nu_\mu e \longrightarrow \mu\nu_\varepsilon) = \sigma(\nu_\mu e \longrightarrow \mu\nu_e)\,\frac{1}{12s}\left[2s\,(1+b^2+3b) + m_\mu^2\,(1+b^2-4b)\right]$$

The asymmetry $A(\theta)$ similar to the one defined in equation (7) is in this case

$$A(\theta) = \frac{3}{2\pi}\,\frac{(1+b^2)\,s+b\left(2s+m_\mu^2 - \frac{m_\mu^{\,4}}{s}\right)}{2\,(1+b^2+3b)\,s + (1+b^2-4b)\,m_\mu^2}\,\cos\theta$$

<u>Reaction (6)</u>. We give finally the cross section for the reaction in which electronic antineutrinos react with electrons to produce a pair formed of a spin 3/2 negative lepton and its antineutrinos. The amplitude:

$$M^{(6)} = \frac{f}{\sqrt{2}}\,(\bar{u}^\lambda(p_L)\,\gamma^\alpha(1+b\gamma^5)\,v_\lambda(p_{\bar{\nu}_L}))\,(\bar{v}(p_{\bar{\nu}_e})\,\gamma_\alpha(1-\gamma^5)\,u(p_e))$$

gives the following cross sections in the c.m system:

$$\frac{d\sigma}{d\Omega}(\bar{\nu}_e e \longrightarrow \bar{\nu}_L L) = \frac{f^2}{G^2}\frac{d\sigma}{d\Omega}(\bar{\nu}_e e \longrightarrow \bar{\nu}_\ell \ell)\frac{2}{3s} \cdot$$

$$\{\frac{1}{4}(s+3m^2_L)(1+b^2)-bs\cos\theta + (s-3m_L^2)(1+b^2)\frac{\cos^2\theta}{4}\} \cdot$$

$$\frac{d\sigma}{d\Omega}(\bar{\nu}_e e \longrightarrow \bar{\nu}_\ell \ell) = \frac{G^2}{4\pi^2}\frac{(s-m_\ell^2)^2}{s} \cdot$$

$$\sigma(\bar{\nu}_e e \longrightarrow \bar{\nu}_L L) = \frac{f^2}{G^2}\sigma(\bar{\nu}_e e \longrightarrow \bar{\nu}_\ell \ell)\frac{1+b^2}{3s}\left(\frac{2s}{3} + m_L^2\right)$$

$$\sigma(\bar{\nu}_e e \longrightarrow \bar{\nu}_\ell \ell) = \frac{G^2}{\pi}\frac{(s-m_\ell^2)^2}{s} \cdot$$

The above calculations can be easily generalised to take into account the propagator of the intermediate vector fields in the case of amplitudes constructed with Vector-axial-Vector currents if one assumes that the corresponding interactions involving spin 3/2 leptons[1] are also mediated by the W and Z vector fields.

We emphasize once more that the discovery of spin 3/2 heavy leptons and massless (or very light) spin 3/2 neutrinos might constitute an important step for a deeper understanding of the presently known lepton families. A search for these particles and events is therefore urged.

Acknowledgments - We are grateful to M. Abud for stimulating discussions and suggestions. One of us (J.A.M.S.) is indebted to the National Council for Scientific and Technological Development of Brazil (CNPq) for a research fellowship; another of us (D.S) whishes to express her gratitude to the Centro Brasileiro de Pesquisas Físicas and its Director, Prof. Roberto Lobo, for their kind hospitality.

REFERENCES

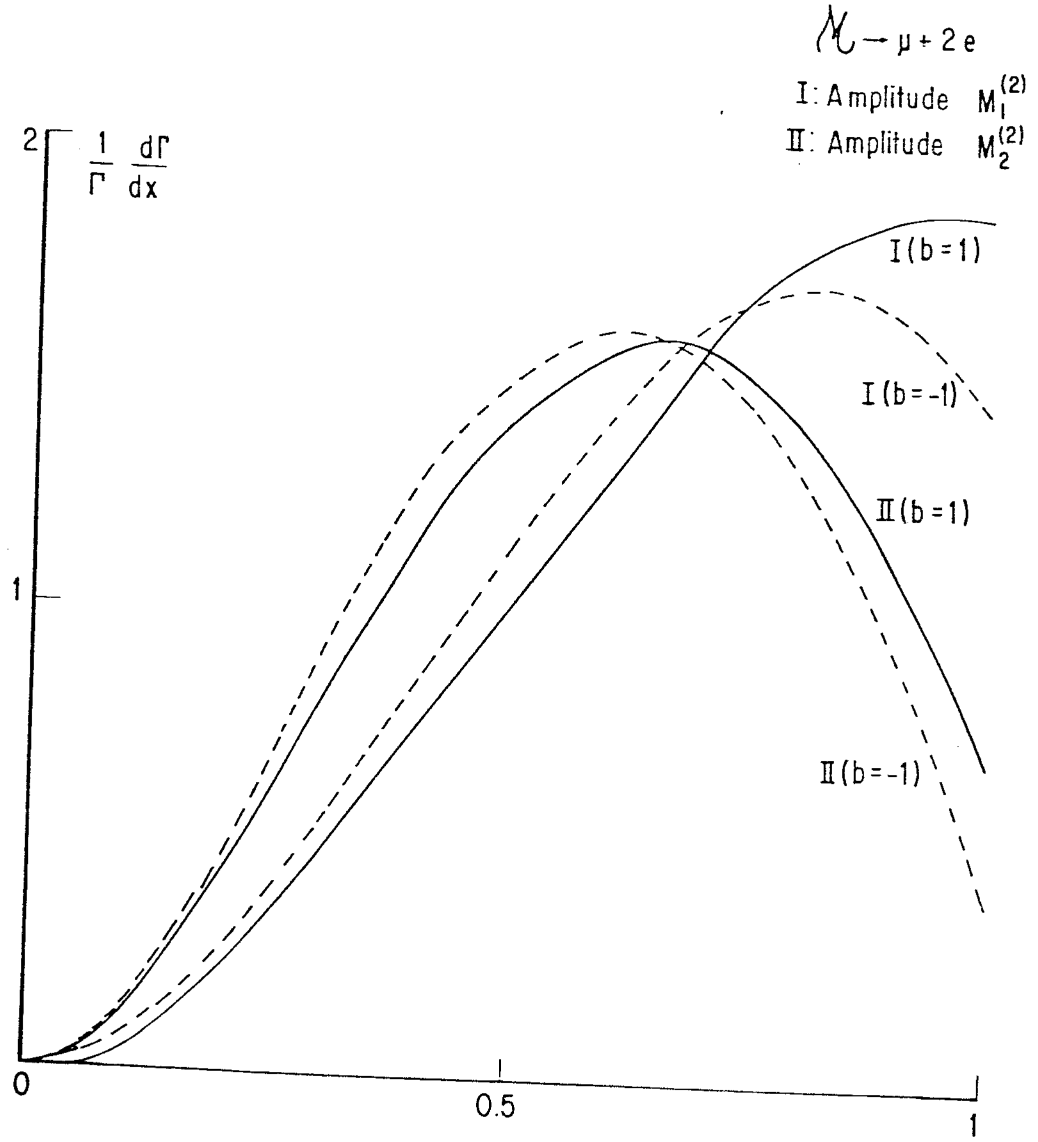
1. J. Leite Lopes, J.A. Martins Simões and D. Spehler, Phys. Lett 94B, 367(1980)

2. J. Leite Lopes, J.A. Martins Simões and D. Spehler, Phys. Rev. D23, 797(1981)

3. See Ref.1 and also H. Terezawa, Phys. Rev. D22, 184(1980)

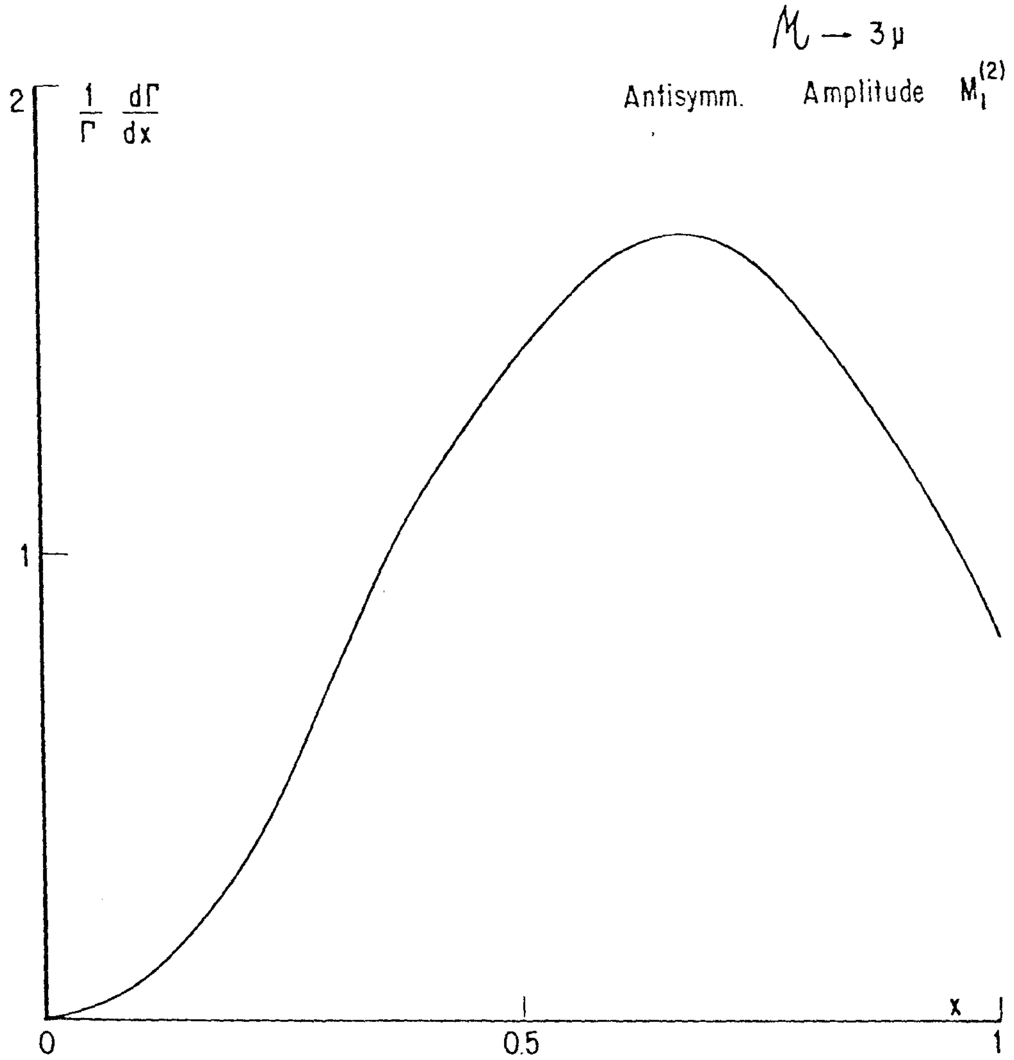
4. D. Lurjé, Particles and fields (Interscience, New York 1968); A. Das and D.Z. Freedman, Nucl. Phys. B114, 271(1976); J. Leite Lopes and D. Spehler, Lett. Nuovo Cimento 26, 567(1979)

5. David H. Miller, SLAC - Pub-2713(1981)



$\mathcal{N} \to \mu + 2e$
I: Amplitude $M_1^{(2)}$
II: Amplitude $M_2^{(2)}$
2
$\frac{1}{\Gamma}\frac{d\Gamma}{dx}$
1
0
0.5
1
I (b = 1)
I (b = -1)
II (b = 1)
II (b = -1)

FIG. 1



$\mathcal{M} \to 3\mu$
Antisymm. Amplitude $M_1^{(2)}$
$\frac{1}{\Gamma}\frac{d\Gamma}{dx}$
2
1
0
0.5
1
x

FIG.2

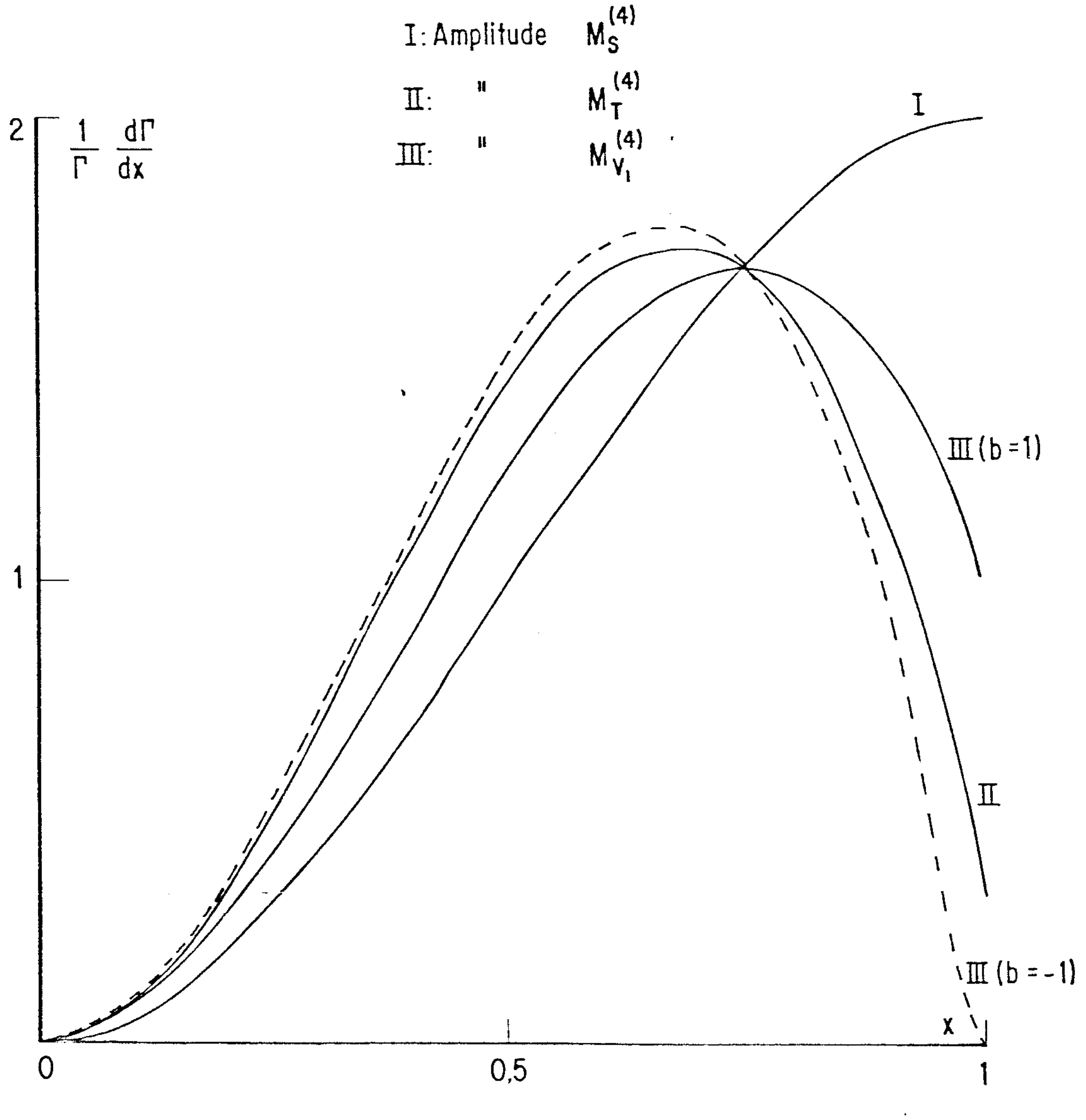

I: Amplitude $M_S^{(4)}$
II: " $M_T^{(4)}$
III: " $M_{V_1}^{(4)}$
2
1
$\frac{1}{\Gamma}\frac{d\Gamma}{dx}$
I
III (b = 1)
II
III (b = -1)
x
0
0,5
1

FIG. 3