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NEUTRAL CURRENT COUPLINGS OF HIGHER GENERATIONS

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ABSTRACT

We show that longitudinal polarization of the outgoing lepton in $e^+e^- \to \mu^+(\tau^+)\mu^-(\tau^-)$ is expected at the energies of a vector meson resonance $(\Psi, T, T, \dots)$. On the basis of the standard SU(2)×U(1) theory, this parity violating observable is already appreciable (~3%) for the T, and it becomes ~9% for a T at 30 GeV.

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1 - One of the outstanding questions in Physics is the determination of weak neutral couplings of leptons and quarks. Intense recent activity[1)] has established the effective couplings of the first generation of fermions, with the result of their compatibility with the standard $SU(2)\times U(1)$ theory[2)] of weak and electromagnetic interactions for a value of the weak mixing angle $\sin^2\theta_W = 0.230 \pm 0.015$. An experimental determination of the neutral current properties of the muon (tau) and of heavy quarks is still lacking. Proposed experiments[*)] are the measurements of the forward-backward asymmetry in the process $e^+e^- \to \mu^+(\tau^+)\mu^-(\tau^-)$ and the parity violating effect inducing lepton helicity from unpolarized beams[4)]. Similar considerations have been made for quark jets in the final state.

On the basis of the standard theory and the "¼ effect", one expects that parity violating effects in $e^+e^- \to \mu^+\mu^-$, if any, should be very small. One is left with the charge asymmetry induced by the axial couplings to electrons and muons, but here the problem is masked by the 2γ exchange contribution[5)]. It would be interesting to envisage the study of parity violating effects in processes which are being seen at present energies. In this note we concentrate our considerations to the analysis of the outgoing lepton helicity produced from unpolarized e^+e^- machines at incident energies corresponding to the formation of a vector resonance $(\Psi, T, T, \ldots)$, as suggested by R. Koniuk et al.[6)]. As we are going to see below, the combination of couplings to the γ and Z mediating the interaction is now favourable to induce a parity violating effect.

2 - The dominant diagrams which contribute to the process $e^+e^- \to$ $\to \mu^+(\tau^+)\mu^-(\tau^-)$ on a vector resonance are given in Fig. 1. In view of the possible importance of the outgoing lepton mass for $\tau^+\tau^-$ production at the region of the T resonance, we are going to keep this mass in calculating all observables, such as the angular distribution and the longitudinal polarization of the outgoing lepton. At energies below the mass of the Z boson, we can neglect the Z-Z diagram, so that we calculate the parity violating effects to order $G_F s/\alpha$. Furthermore, the Z-Z contribution has the same disease as the background term, corresponding to direct Z exchange, of lacking a parity violating coupling between electrons and muons (taus) in the standard theory (assuming the "¼ effect"). On the other hand, the background γ and Z exchanges are neglected, as well as their interference with the diagrams in Fig. 1. In order to illustrate the effects that are proposed here we calculate them in the standard theory, leaving a more

[*)] The suggestion to look for parity violating effects in muonic atoms should be mentioned here[3)].

detailed discussion in other theories, the effects of including the background terms of direct γ and Z exchanges and of going to LEP energies[7)] for a forthcoming publication[8)].

To the order considered in this note, when sitting on the vector resonance and keeping the diagrams of Fig. 1, no charge asymmetry is left. So we study the outgoing lepton helicity induced by parity violation. The origin of the longitudinal polarization has different mechanisms in diagrams 1b) and 1c). Diagram 1b) produces the resonance with a parity conserving (P.C.) interaction and it is its parity violating (P.V.) decay which originates a longitudinal polarization. In the absence of P.V. vector polarization in the intermediate stage, the answer from this piece to the final lepton helicity presents angular symmetry. The situation is different for the contribution coming from diagram 1c). Here the P.V. production mechanism of the resonance is able to induce vector polarization, so that the subsequent P.C. decay gives an helicity to the final lepton with angular asymmetry for the longitudinal polarization distribution. With all these general considerations in mind, we proceed to the explicit calculation of these effects.

3 - The vertices of the diagrams in Fig. 1 are extracted from the Lagrangian density

$$L(x) = e\,Q_f\,\bar{f}(x)\,\gamma^\lambda f(x)\,A_\lambda(x) + g_Z\,\bar{f}(x)\,\gamma^\lambda(v_f + a_f\gamma_5)\,f(x)\,Z_\lambda(x) + \dots \tag{1}$$

with the neutral current coupling normalization $g_Z^2 = G_F^2 M_Z^2/2\sqrt{2}$. The matrix element of the neutral (vector) current operator between the 1^- meson (supposed to be a $q\bar{q}$ composite system) and the vacuum is written as

$$\langle 0 \,|\, \bar{q}(0)\,\gamma^\lambda q(0)\,|\, 1^-(q)\rangle = \xi^\lambda(q)\,F_V \tag{2}$$

where ξ^λ is the polarization vector and the vector meson decay constant F_V is related to its electron-electron width by $|F_V|^2 = 3M^3\Gamma_{ee}/\left[4\pi(\alpha Q_q)^2\right]$. Because of the single coupling present in Eq.(2), our results for the longitudinal polarization of the outgoing lepton are independent on the value of F_V.

The invariant T matrix element is given by

$$T = -\frac{1}{s^2}\frac{1}{s-M_V^2+iM_V\Gamma} e^4 Q_\mu Q_e Q_q^2 |F_V|^2 \bar{u}(p_f)\gamma^\lambda v(p_f')\bar{v}(p_i')\gamma_\lambda u(p_i)$$

$$-\frac{1}{s(s-M_Z^2)}\frac{1}{s-M_V^2+iM_V\Gamma} e^2 g_Z^2 Q_e Q_q v_q |F_V|^2 \bar{u}(p_f)\gamma^\lambda(v_\mu + a_\mu\gamma_5)v(p_f')\bar{v}(p_i')\gamma_\lambda u(p_i)$$

$$-\frac{1}{s(s-M_Z^2)}\frac{1}{s-M_V^2+iM_V\Gamma} e^2 g_Z^2 Q_\mu Q_q v_q |F_V|^2 \bar{u}(p_f)\gamma^\lambda v(p_f')\bar{v}(p_i')\gamma_\lambda(v_e + a_e\gamma_5)u(p_i)$$

(3)

where $p_i(p_i')$ refer to $e^-(e^+)$ and $p_f(p_f')$ to the final lepton (antilepton). The subindex μ must be replaced by τ when considering heavy lepton production.

Consistently with our previous discussion, we keep in the T matrix element squared only the square of 1a) and the interferences of 1a) with 1b) and 1c), respectively. We calculate the angular distribution, with respect to the incident e^- beam, of events with a $\mu^-(\tau^-)$ helicity λ. It is given by

$$\left.\frac{d\sigma}{d\Omega}\right|_\lambda = \frac{9\, x\, \Gamma_{ee}^2}{8\left[(s-M_V^2)^2 + M_V^2\Gamma^2\right]}\Bigg\{ 1 + \frac{4m^2}{s} + x^2\cos^2\theta$$

$$+ \frac{v_q}{Q_q}\frac{G_F\, s}{4\pi\alpha\sqrt{2}}\frac{1}{1-\frac{s}{M_Z^2}}\Big[2\, v\left(1 + \frac{4m^2}{s} + x^2\cos^2\theta\right)$$

$$-\lambda\, a\left(x(1+\cos^2\theta) + 2\cos\theta\right)\Big]\Bigg\} \qquad (4)$$

where $x \equiv (1-4m^2/s)^{\frac{1}{2}}$ and m is the mass of the muon (tau). One notices that mass effects are the same for the parity conserving interference as for the dominant angular distribution, but they are very different in the parity violating term inducing outgoing lepton helicity. In the above given expression (4) we have assumed universality to write $v \equiv v_e = v_\mu = v_\tau$ and $a \equiv a_e = a_\mu = a_\tau$. In the standard theory with $\sin^2\theta_W = \frac{1}{4}$, one has $v=0$, $a=-1$.

The longitudinal polarization is immediately obtained, with the result

$$P_L(\cos\theta) = H(s)\,\frac{x(1+\cos^2\theta) + 2\cos\theta}{1 + \frac{4m^2}{s} + x^2\cos^2\theta}$$

$$H(s) = \frac{v_q}{Q_q}\,\frac{G_F s}{4\pi\alpha\sqrt{2}}\,\frac{1}{1 - \frac{s}{M_Z^2}} \quad ; \quad s = M_V^2 \tag{5}$$

The dominant features of this result are worth discussing. Apart from its mass $s=M_V^2$, all the ingredient of the vector meson 1^- appearing in $H(s)$ is the ratio v_q/Q_q. In the standard theory with $\sin^2\theta_W = \frac{1}{4}$, this ratio is $+2$ ($+\frac{1}{2}$) for lower (upper) quark flavours, independently of the generation. The angular distribution of the longitudinal polarization shows the two mechanisms discussed above, corresponding to diagrams 1b) and 1c), respectively.

In Fig. 2 we give numerical results for μ^- and τ^- at incident energy corresponding to the Υ (9.46 GeV) resonance. Appreciable effects, of the order of 3%, are obtained in the forward region. A measurement of this observable seems feasible in available machines. The method to determine the polarization of outgoing muons and taus has been discussed in Ref. 7). For muons, it involves stopping muons in iron and measuring the asymmetry in the decay electrons. For τ's, one can use the leptonic decay modes or the $\pi\nu$ decay, the spectrum of the pion depending on the τ polarization. As observed in Eq. (5), the shape of $P_L(\cos\theta)$ versus $\cos\theta$ is universal when the final lepton mass can be neglected. For the Ψ (3.097 GeV), the longitudinal polarization of μ^- is, however, slightly less than 1‰.

If a new vector meson resonance were found with a mass around 30 GeV, we would expect longitudinal polarization effects of the order of 9% for a $t\bar{t}$ bound state (toponium), as shown in Fig. 2, 36% if it were a new $b'\bar{b}'$ bound state. The results at this energy are insensitive to the final lepton mass.

4 - To conclude, we have shown that parity violating effects inducing final lepton helicity in e^+e^- machines are expected in the standard theory for energies corresponding to the formation of a vector meson resonance. The calculation of that observable becomes independent of the strong interaction dynamics of the resonance, and it is only sensitive to the flavour properties of the corresponding quark. The angular distribution of longitudinal polarization has been calculated from the diagrams shown in Fig. 1, which are the dominant ones at present energies. Whereas the calculated effects are still very small ($\sim 1‰$) for the Ψ resonance, they are already $\sim 3\%$ for the Υ region, and $\sim 9\%$ for a T at 30 GeV. A more detailed study of these problems, including background diagrams as well as the possibility to go to higher energies, is in preparation.

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FIGURE CAPTIONS

Fig. 1 - Dominant diagrams for $e^+e^- \to \mu^+(\tau^+)\ \mu^-(\tau^-)$ at energies sitting on a vector meson resonance.

Fig. 2 - The angular distribution of longitudinal polarization for the μ^- and τ^- at the Υ (9.46 GeV) resonance. The μ curve gives the distribution for μ^- and τ^- at a 30 GeV Υ resonance, with the scale indicated by the ordinate on the right.

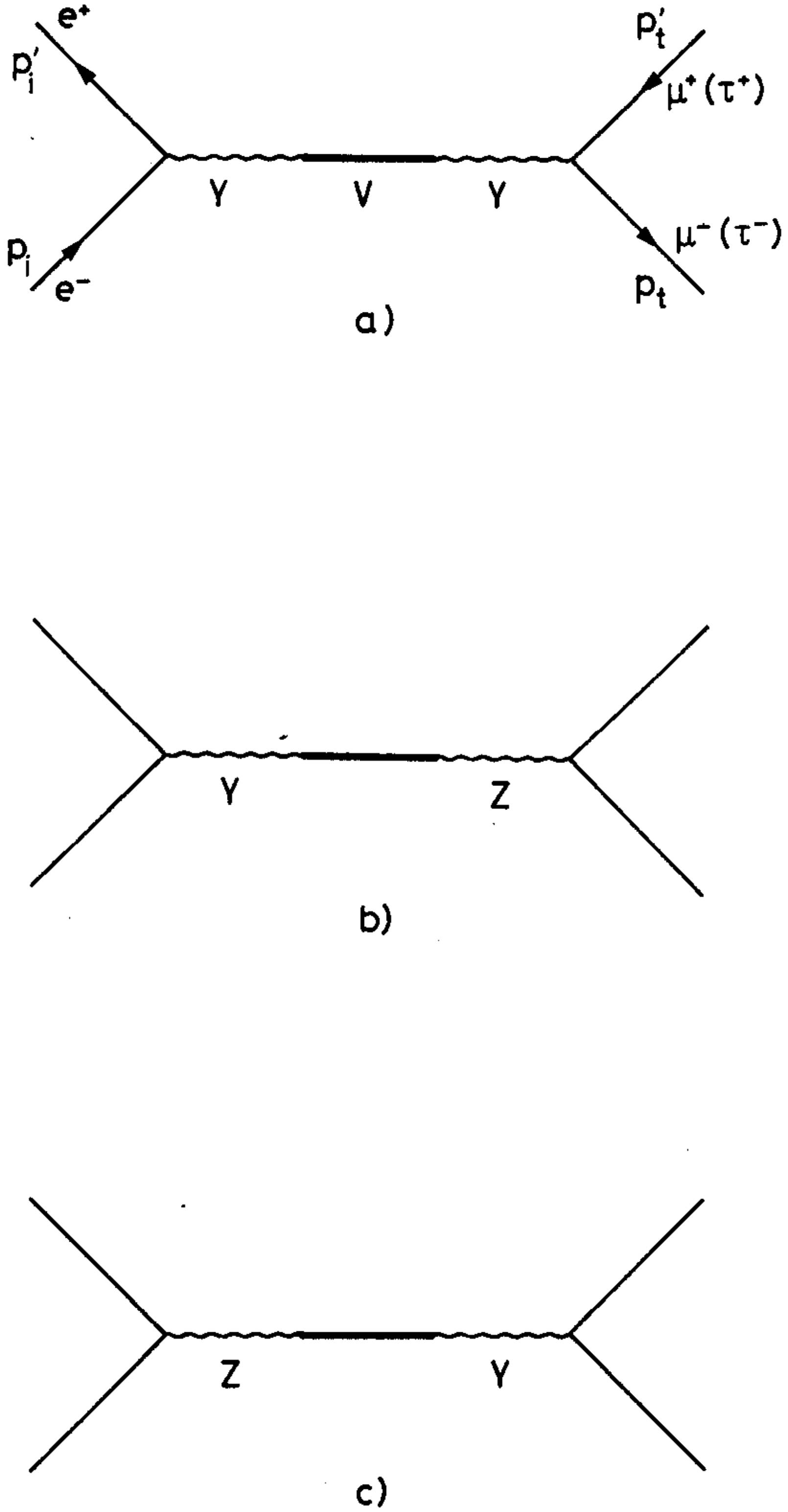

FIG.1

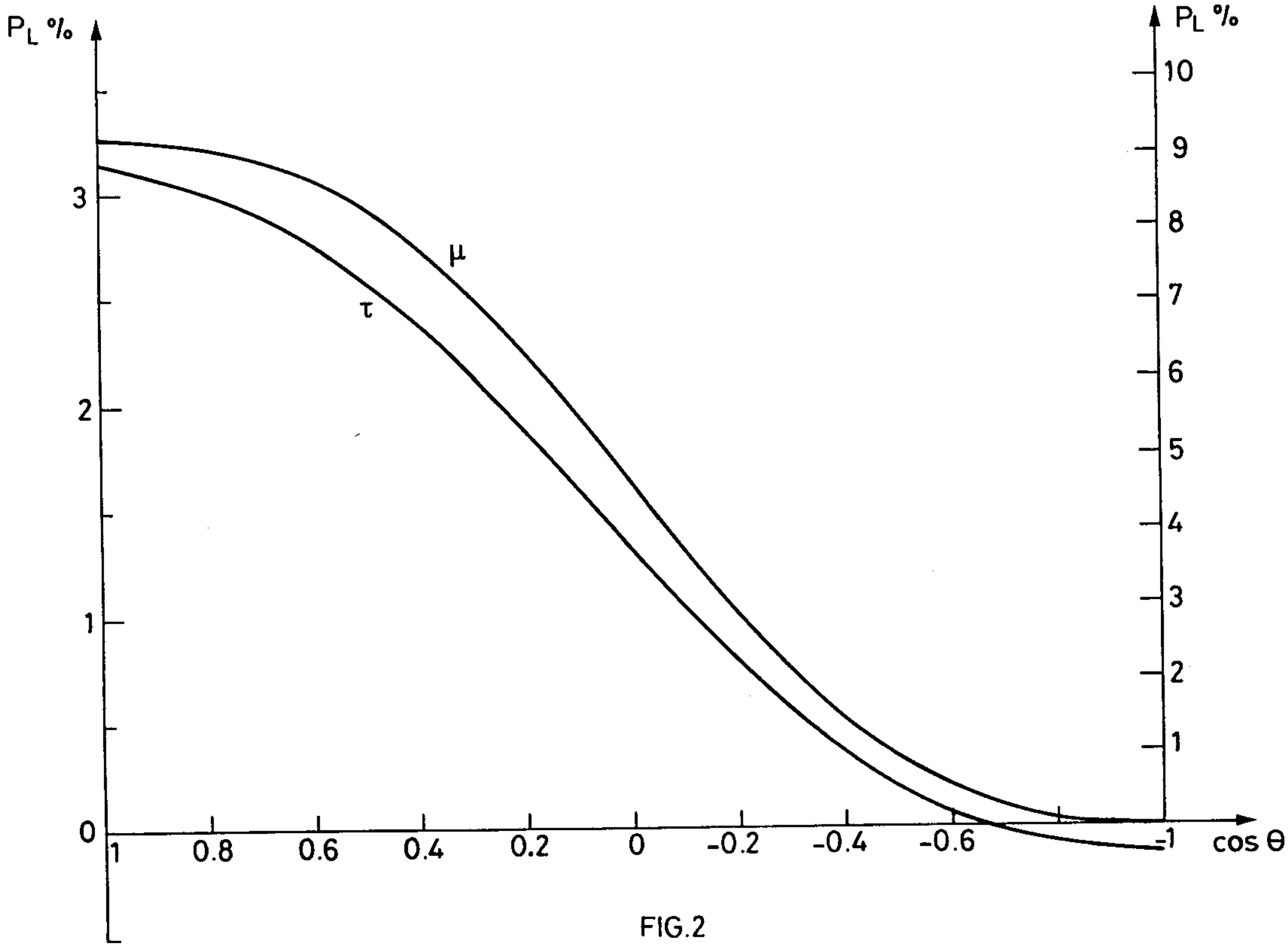

FIG.2