SPIN AND ELECTROWEAK EFFECTS IN e^+e^- PAIR NEUTRINO ANNIHILATION

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ABSTRACT

Differential and integrated cross section, as well as, integral forward-backward asymmetries of the $e^+e^- \to \bar{\nu}\nu$ annihilation are studied for different e^+e^- beams polarizations. Particularly it is shown that variation of the charged and neutral currents relative contributions is manifested in anomalous decrease of the cross section for $e^+_R e^-_L \to \bar{\nu}_e \nu_e$ annihilation in the region $\sqrt{s} < M_z$.

At higher energies this cross section extends to Plateau so that $e^+e^- \to \bar{\nu}_e \nu_e$ channel prevails over that of $\bar{\nu}_\mu \nu_\mu$ or $\bar{\nu}_\tau \nu_\tau$ pairs production.

ملخص

تتناول هذه الدراسة إيجاد المقاطع العرضية التفاضلية وتكاملاتها واستخدام علاقة اللاتماثل (اللاتناظر) الأمامي- الخلفي التكاملية واعتمادها على الطاقة في تفاعل إنتاج الزوج (نيوترينو – نيوترينو مضاد) من جراء فناء الزوج (إلكترون – بوزيترون). تم تبيان دور الإسهامات النسبية للتيارين المختلفين: المشحون والحيادي في إظهار الانخفاض الشاذ لقيمة مقطع التشتت في التفاعل: $e^+_R e^-_L > \bar{\nu}_e \nu_e$ في المجال $\sqrt{s} < M_z$. كما تبين كذلك أنه عند الطاقات العالية يزداد المقطع العرضي للتفاعل اتساعاً لدرجة يصبح فيها تخليق الزوج ($\bar{\nu}_e \nu_e$) هو السائد على إنتاج أي من الزوجين ($\bar{\nu}_\mu \nu_\mu$) أو ($\bar{\nu}_\tau \nu_\tau$).

IINTRODUCTION

Information is lacking about the properties of neutrino, in spite of the fact that they were introduced into physics about 67 years ago. The sun a particular strong source of neutrinos, and for this reason has been used for pertinent experiments.

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The neutrino has been in the news recently, with reports that Superkamiokande collaboration- which operates a 50000- ton detector of ultra pure water isolated deep wjthin the Japanese mine Kamiokande-has found evidence of a non zero neutrino mass [1-4].

Neutrino is a ghostly particle, which can easily pass through the entire earth without interacting. [5-6]

Pure leptonic electron-positron processes allow one to study directly nature of the electro-weak interaction, non-complicated by strong interaction effects.

As it is known at present a wide range of the processes being under experimental study are well described by the standard electro-weak interaction model of Glashow-Weinberg-Salam (GWS). In many cases, however, the achieved accuracy of experimental data assumes noticeable deviation from the standard model. Also within limits of this model some difference in mixing parameter $x = \sin^2 \theta_w$ values, extracting from semileptonic and pure leptonic processes, remains.

To a certain degree the nature of neutrino is still unknown, namely in what concerns its mass, helicity behavior and electromagnetic properties. The study of the neutrino's electromagnetic interaction is very important for astrophysics, particularly, in calculation of the neurino luminosity of stellar objects, since the underlooked solar election neutrino flux is several times less than that calculated on the basis of standard thermonuclear solar model.

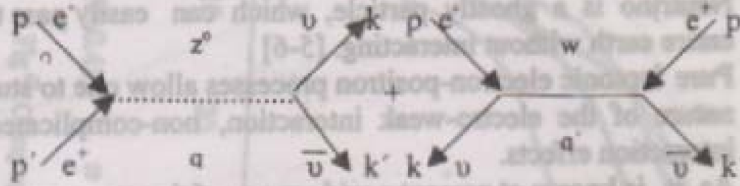
This work develops [7-10] and investigates spin and interference effects, caused by:

i) The weak and electromagnetic interaction in electron-positron pair annihilation process.
ii) The deviation of the neutrino mass from zero in this process.
iii) The interaction of charged currents (CC) and neutral current (NC) in $e^+ e^- \rightarrow \bar{\nu}\nu$.

$e^+ e^-$ pair neutrino annihilation

Together with $\upsilon\, e^-$ – scattering processes it is of interest that the neutrino annihilation of colliding electron- positron beams:

$$e^-(p) + e^+(p') \rightarrow \overline{\upsilon}(k) + \upsilon(k) \qquad (1)$$



$$S = q^2 = (p + p')^2 = (k + k')^2 \; ; \; q^2 << m^2_z$$
$$t = q'^2 = (p - k)^2 = (k' - p')^2 \; ; \; q'^2 << m^2_w$$

The amplitude of the process (1) could be effectively written as:

$$M_{tot} = (G_F / \sqrt{2})\, \bar{u}(p)\, \gamma_\alpha (g_v + g_A \gamma^5)\, u(p)\, \bar{u}_\nu (k')\, \gamma^\alpha (1 + \gamma^5)\, u_\nu (k) = M_z + M_w \qquad (2)$$

The consideration of this process for low energies of the colliding e^+e^- - beams has been done in [10], where the differential and total cross section of the $\overline{\upsilon}_e\, \upsilon_e$ pair production have been given for arbitray spin orientation of e^+ and e^-.

The contribution of the vector bosons in the internneditate states may be taken into account by substitution in (2).

$$g_{v,A} - g_{ve,ae} [1 - s / (M_z^2 - i\Gamma_z / M_z)^{-1}];$$

for NC interaction ($\overline{\upsilon}_\mu\, \upsilon_\mu$, $\overline{\upsilon}_\tau\, \upsilon_\tau$ –pairs in the final state), and

$$g_{v,A} - g_{ve,ae} [1 - s / (M_z^2 - i\Gamma_z / M_z)^{-1}] + [1 + s(1 - \cos\theta) / 2M_w^2]^{-1}$$

for NC and CC interactions ($\overline{\upsilon}_e\, \upsilon_e$ – pair production).

Here

$g_{ve} = -\frac{1}{2} + 2x$ and $g_{ae} = -\frac{1}{2}$ are electron NC constants;

$\sqrt{S} = 2\varepsilon$ is the total energy in center of mass system (CMS); θ – neutrino angel with respect to the electron momentum; M_z and Γ_z are the mass and the total decay width of z^0 boson . We use below the (GWS) –model relation:

$$M_w = M_z \cos\theta_w$$

For w- boson mass; the finite width Γ_w can be neglected, since in this case the transferred momentum is space – like.

While analyzing angular distributions of produced $\overline{\upsilon_e}\,\upsilon_e$ pair let's consider some defiinite cases for electron and positron spins orientations: transverse parallel (^^), transverse antiparallel (˘^) and longitudinal $e_R^- e_L^+$ (RL) and $e_L^- e_R^+$ (LR).

As it has been shown in [10] for transverse orientation of $e^+ e^-$ pair spins the cross section of the process (1) has an azimuthal asymmetry, therefore further let's deal with the case, when electron and positron spins are orthogonal to the reaction plane, i.e. the detector is set up in the plane of storage ring. Then for neutrino angular distribution, we get:

$$(d\sigma_{\uparrow\uparrow} / d\Omega_\nu)_{(\varphi=\pi/2)} = \sigma_0 (D_z)^{-1} \{(g_{ve}\cos\theta + g_{Ae})^2 + D_z (D_w)^{-2} (1+\cos\theta)^2$$

$$+ 2 (D_w)^{-1} (1 - S/(M_z)^2)(g_{ve}\cos\theta + g_{Ae})(1+\cos\theta)\}. \quad (3)$$

$$(d\sigma_{\uparrow\downarrow} / d\Omega_\nu)_{(\varphi=\pi/2)} = \sigma_0 (D_z)^{-1} \{(g_{ve} + g_{Ae}\cos\theta)^2 + D_z (D_w)^{-2} (1+\cos\theta)^2$$

$$+ 2 (D_w)^{-1} (1 - S/(M_z)^2)(g_{ve} + g_{Ae}\cos\theta)(1+\cos\theta)\}. \quad (4)$$

$$(d\sigma_{RL} / d\Omega_\nu)_{(\varphi=\pi/2)} = \sigma_0 (D_z)^{-1} \{(g_{ve} - g_{Ae})^2 + (1-\cos\theta)^2. \quad (5)$$

$$(d\sigma_{LR} / d\Omega_\nu)_{(\varphi=\pi/2)} = \sigma_0 (D_z)^{-1} \{(g_{ve} + g_{Ae})^2 + 4 D_z (D_w)^{-2} + 4 (D_w)^{-1} (1 - S/(M_z)^2)$$

$$\times (g_{ve} + g_{Ae})\}(1+\cos\theta)^2. \quad (6)$$

Here some abbreviations are accepted:

$$\sigma_0 = (G_F)^2 S / 32\pi, \quad D_z = (1 - S/(M_z)^2)^2 + (\Gamma_Z)^2/(M_Z)^2, \quad D_W = 1 + S(1-\cos\theta)/2(M_w)^2$$

From (3) – (6) it is seen, that for $\bar{\upsilon}_\mu \upsilon_\mu$ and $\bar{\upsilon}_\tau \upsilon_\tau$ - pairs production the shape of angular distribution is indepndent on energy and determined only by g_{Ve} and g_{Ae} constants.

The same is true of $d\sigma_{RL} / d\Omega_\nu$ for any type of neutrino in final state. For $\bar{\upsilon}_e \upsilon_e$ – pair production the behavior pattern of angular distributions are complicated because of variations of charged and neutral currents relative contributions.

The integral characteristic of neutrino angular distribution is given by forward- backward asymmetry relation:

$$A = [\int_0^{\pi/2} (d\sigma/d\Omega_\nu)\sin\theta\, d\theta - \int_{\pi/2}^{\pi} (d\sigma/d\Omega_\nu)\sin\theta\, d\theta] / \int_0^{\pi} (d\sigma/d\Omega_\nu)\sin\theta\, d\theta \qquad (7)$$

In the case of $\bar{\upsilon}_\mu \upsilon_\mu$ and $\bar{\upsilon}_\tau \upsilon_\tau$ pairs production we have

A ^^ = -0.080; A "^ = - 0.236; $A_{LR} = 0.750$; $A_{RL} = - 0.750$

for the values of parameters:

$x = 0.23$, M_z ? 93 GeV, $\Gamma_z = 3$GeV, M_w ? 80GeV.

Fig. (1) : shows plots of $\bar{\upsilon}_e \upsilon_e$ – pair production asymmetry as a function of electron beam energy E.

When E = . 30 – 35 GeV ($\sqrt{s} < M_z$) the asymmetries for spin configurations, ^^, "^, and LR of annihilating electrons and positrons have quasi – resonance behavior and whenever there are transverse polarization, ^^ and "^ the neutrino production momentum prevails in the direction opposite to electron momentum. For ($\sqrt{s} > M_z$) the asymmetries A ^^, A "^, and A_{LR} are near to the unity because of the small suppression of w- exchange contributions when $\theta > 0$.

The variation of the relative CC and NC contributions is manifested also in energy dependence of the annihilation integral cross section, given in Fig. (2) while the cross sections of the $e^+ e^- \to \bar{\upsilon}_\mu \upsilon_\mu, \bar{\upsilon}_\tau \upsilon_\tau$

annihilation at the expense of NC have the same form for different $e^+ e^-$ spins orientation and differ only in modulus. The $e^+e^- \to \upsilon_e\upsilon_e$ annihilation cross section has two regions of anomalous behavior:

1) For $\sqrt{s} = 60 - 80$ GeV the growth rate of cross section decreases and even there a local minimum appears in LR configuration;

2) For $\sqrt{s} > M_z$ the σ_{--}, σ_{+-} and σ_{LR} cross section the extend to a plateau. This is explained by the prevailing contribution of w-exchange. Thus for the reaction of $e^+ e^-$ annihilation in high energy region the channel of electron neutrino- antineutrino pair production predominates. Its cross section is constant, whereas those of annihilation to $\overline{\upsilon}_\mu \upsilon_\mu$ and $\overline{\upsilon}_\tau \upsilon_\tau$ -pair's decrease like s^{-1}.

CONCLUSION

Differential cross section for annihilation processes $e^+ e^- \to \overline{\upsilon}_e\upsilon_e$, $\overline{\upsilon}_\mu \upsilon_\mu$, $\overline{\upsilon}_\tau \upsilon_\tau$ were calculated in the framework of GWS – model for several polarization of the $e^+ e^-$ beams.

The paper discusses some anomalies in the neutrino angular distributions caused by variation of the relative contributions of the charged and neutral currents interactions for various polarization channels below and over z^0 – resonance region.

It is concluded that for $\sqrt{s} > M_z$ cross section for electron neutrino pair production prevails significantly over that for $\overline{\upsilon}_\mu \upsilon_\mu$ or $\overline{\upsilon}_\tau \upsilon_\tau$ pairs production.

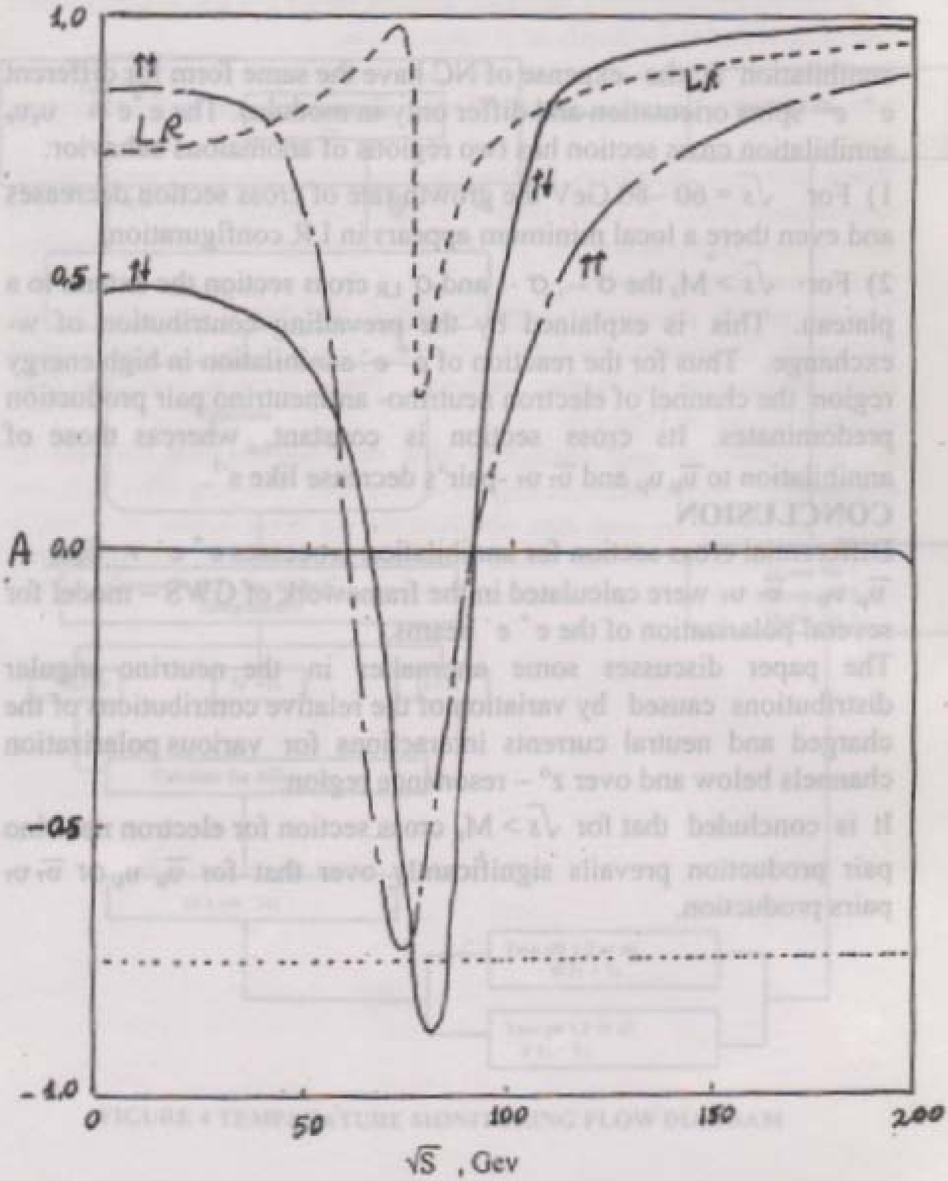


Fig .(1) : Energy dependences of the forward – backward asymmetries A in $e^+ e^- \longrightarrow \overline{\upsilon}_e \upsilon_e$ annihilation for e+ e- polarization.

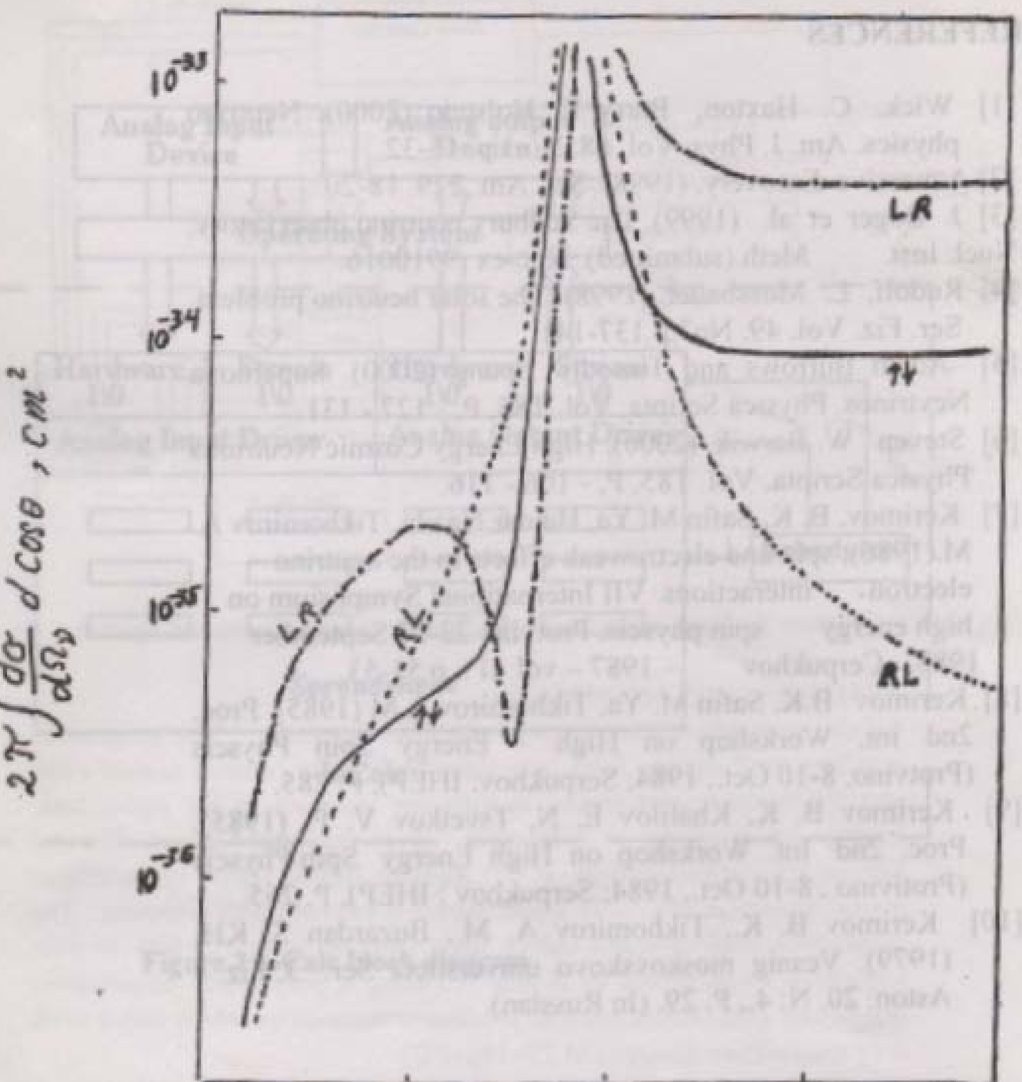


Fig. (2): Energy dependences of the integrated cross sections in $e^+ e^- \longrightarrow \bar{\nu}\nu$ annihilation for $e^+ e^-$ polarization .

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