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τ-CHARM, B, ... FACTORIES AND QUARKONIUM DECAYS INTO ν-$\bar{\nu}$ PAIRS

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Recently experiments were initiated at SLC and LEP facilities one of the main aims of which being the determination of the number of the neutrino types existing in nature. There are known at least two types of neutrinos (ν_e, ν_μ). A third type of neutrinos ν_τ is also generally assumed to exist, but the evidence for its existence, however, is not direct. The LEP experiments [1], in which the width of Z°-boson was measured, allow to exclude the existence of a fourth neutrino type. It should be emphasized, however, that the experiments mentioned above in no way exclude the decay of Z° into relatively heavy neutral particles other than neutrinos[1] (for example, supersymmetric particles, heavy neutral leptons,... [2]). From this point of view it would be important to perform experiments in which decays of virtual Z° are investigated (and not only decays of real Z° as it is being done presently at LEP). In other words it would be of interest to investigate processes in which the invisible Z°-decay products have different energies.

In this note we shall consider[2] decays into neutrino- antineutrino pairs of the ground states of quarkonium (J/Ψ, Υ, $(T\bar{T})$). A method of detecting the decay $J/\Psi \longrightarrow \nu\bar\nu$ was considered in [5], where it was proposed to investigate the decay sequence

$$\Psi' \longrightarrow J/\Psi + \pi\pi \quad , \qquad J/\Psi \longrightarrow \nu\bar\nu$$

1 For convenience, we call neutrinos only light neutral leptons (with mass, say, less than the electron mass).

2 The decays of quarkonium states into neutrino-antineutrino pairs were discussed in [3,4], but in ref. [4] the decay width $\Gamma(\Upsilon \longrightarrow \nu\bar\nu)$ in our opinion was seriously underestimated.

in which J/Ψ is "tagged" by measuring the momenta of pions[3]. Obviously such a method can be used also for other decay chains such as

$$\Upsilon' \longrightarrow \Upsilon + \pi\pi \quad , \qquad \Upsilon \longrightarrow \nu\bar{\nu}$$

etc.

At present projects of relatively low energy high luminosity e^+e^- colliders (so called τ-charm, B-factories) are widely considered [6,7]. It is interesting to discuss the possibilities of observing decays of quarkonium into neutrino-antineutrino pairs at these facilities.

Let us consider the decays of quarkonium ground states $(J/\psi, \Upsilon, ..)$ into $\nu\bar{\nu}$ pairs in the framework of the standard theory. The interaction Hamiltonian has the form

$$\mathcal{H}_I = ie\, j^{\gamma}_{\alpha} A_{\alpha} + i \frac{e}{2\sin\theta_W \cos\theta_W} j^{Z}_{\alpha} Z_{\alpha} \, , \qquad (1)$$

where θ_W is the weak mixing angle,

$$j^{\gamma}_{\alpha} = \sum_l (-1)\, \bar{l}\gamma_{\alpha} l + \sum_q e_q\, \bar{q}\, \gamma_{\alpha} q \, , \qquad (2)$$

is the electromagnetic current (e_q is the quark electrical charge),

$$j^{Z}_{\alpha} = \sum_l \bar{\nu}_l \gamma_{\alpha} \frac{1}{2}(1+\gamma_5)\nu_l + \sum_l \bar{l}\gamma_{\alpha}(g_V + g_A\gamma_5) l$$

$$+ \sum_q \bar{q}\gamma_{\alpha}(v_q + a_q\gamma_5) q \qquad (3)$$

is the neutral current and

$$g_V = -\frac{1}{2} + 2\sin^2\theta_W \, , \quad g_A = \frac{1}{2} \, , \qquad (4)$$

3 As a matter of fact, when the paper [5] was being written the quarkonium nature of J/Ψ was not entirely understood and the proposal at issue was made with the aim of clearing it up.

$$v_q = I_3^q - 2\sin^2\theta_W e_q \, , \qquad a_q = I_3^q \, , \qquad (5)$$

where I_3^q is the third component of the weak quark isospin. The ratio of the width of the decay of quarkonium ground state $(Q\bar{Q})_o$ into one neutrino-antineutrino pair $\nu_l\bar{\nu}_l$ ($l = e, \mu, \tau$) to the width of the decay into lepton-antilepton pair $l\bar{l}$ is

$$R_q = \frac{\Gamma(\, (Q\bar{Q})_o \longrightarrow \nu\bar{\nu}\,)}{\Gamma(\, (Q\bar{Q})_o \longrightarrow l\bar{l}\,)} = \frac{1}{32} \frac{M^4}{(M_Z^2 - M^2)^2} \frac{v_q^2}{\sin^4\theta_W \cos^4\theta_W} \times \qquad (6)$$

$$\times \left[e_q^2 + \frac{g_V e_q v_q}{2\sin^2\theta_W \cos^2\theta_W} \frac{M^2}{(M_Z^2 - M^2)} + \frac{(g_V^2 + g_A^2)\, v_q^2}{16\sin^4\theta_W \cos^4\theta_W} \frac{M^4}{(M_Z^2 - M^2)^2} \right]^{-1} ,$$

where M is the quarkonium mass, and M_Z is the mass of Z°-boson. Let us note that in the expression of R_q the masses of final leptons were neglected.

From the expression (6) of R_q it is seen that in the decay probability of quarkonium into a lepton-antilepton pair the exchange of γ as well as the exchange of Z° has been taken into account.

It is clear that the exchange of Z° might be of importance in the decay of the toponium, the mass of which must be larger then 150 GeV [8]. Numerically, however, the contribution of the Z°-exchange to the ratio R_q is quite small and even in the toponium decay turns out to be about 5 % for toponium masses ≃ 250 GeV.

In addition to the quarkonium mass and to various standard model parameters, in the probabilities of decays $(Q\bar{Q})_o \longrightarrow \nu\bar{\nu}$ and $(Q\bar{Q})_o \longrightarrow l\bar{l}$ there is entering also the squared modulus of the wave function of quarkonium at the origin $|\Psi(o)|^2$. The value of $|\Psi(o)|^2$ strongly depends upon the quark-quark potential (see, for example [9]). Let us stress, however, that the ratio R_q does not depend on $|\Psi(o)|^2$ and consequently in the ratio R_q there are no ambiguities associated with the quark potential.

In the Table the values of the ratio R_q are given for various quarkonium states.

TABLE

The ratio $R_q = \Gamma(Q\bar{Q})_0 \longrightarrow \nu\bar{\nu})/\Gamma(Q\bar{Q})_0 \longrightarrow l\bar{l})$ (one neutrino type) for various quarkonium states ($\sin^2\theta_W = 0.230$, $M_Z = 91.10$ GeV)

Quarkonium state	Mass (GeV)	R_q
ϕ	1.019	$1.7\ 10^{-8}$
J/Ψ	3.097	$1.1\ 10^{-7}$
Υ	9.460	$1.3\ 10^{-4}$
toponium	150	$1.8\ 10^{-1}$
	200	$1.2\ 10^{-1}$
	250	$1.0\ 10^{-1}$
	300	$9.4\ 10^{-2}$
	400	$8.6\ 10^{-2}$

The results presented in the Table will be discussed below. Clearly

$$B((Q\bar{Q})_0 \longrightarrow \nu_x\bar{\nu}_x) = R_q N_\nu\, B((Q\bar{Q})_0 \longrightarrow l\bar{l}) \ , \qquad (7)$$

where N_ν is the number of neutrino types, $B((Q\bar{Q})_0 \longrightarrow \nu_x\bar{\nu}_x)$ and $B((Q\bar{Q})_0 \longrightarrow l\bar{l})$ are the fractions of decays of quarkonium, correspondingly, into neutrino-antineutrino and lepton-antilepton pairs.

As far as the ϕ-particle is concerned, the $B(\phi \longrightarrow \nu_x\bar{\nu}_x)$ is too small ($B(\phi \longrightarrow \nu_x\bar{\nu}_x)=1.6\ 10^{-11}$) to be of interest here.

As for the J/Ψ quarkonium state, making use of the known experimental value $B(J/\Psi \longrightarrow l\bar{l})=6.9\ 10^{-2}$ and R_c given in the Table, we get $B((Q\bar{Q})_0 \longrightarrow \nu_x\bar{\nu}_x)=2.3\ 10^{-8}$. It is expected that about $6\ 10^9$ Ψ'-particles will be produced per year at the so-called τ-charm

factories [6]. Taking into account that $B(\Psi' \longrightarrow J/\Psi\ \pi\pi) \simeq 0.5$, we conclude that in such colliders about 70 decays $J/\Psi \longrightarrow \nu_x\bar{\nu}_x$ per year could be observed (for three types of neutrinos).

In the B-factories about 10^8 Υ'-particles per year could be produced. Taking into account that $B(\Upsilon \longrightarrow l\bar{l})=2.6\ 10^{-2}$ and $B(\Upsilon' \longrightarrow \Upsilon\pi\pi)=27.3\ 10^{-2}$, we conclude that about 300 decays $\Upsilon \longrightarrow \nu_x\bar{\nu}_x$ could be observed per year at B-factory facilities, which implies a statistical accuracy of about $\Delta N_\nu=0.2$ in the measurements of N_ν[4].

In future e^+e^- experiments high accuracy in the value N_ν will be achieved. Clearly by using such value of N_ν it is possible from the decay width $\Gamma(\Upsilon \longrightarrow \nu_x\bar{\nu}_x)$ to get the magnitude of the constant v_b, characterizing the vector neutral current of b-quarks. The measurement of the width of the decay $\Upsilon \longrightarrow \nu_x\bar{\nu}_x$ at B-factory facilities would allow to get a value of v_b with an accuracy $\Delta v_b = 2\ 10^{-25}$.

It is well known that t-quarks have not yet been discovered. From all available data it follows that 77 GeV < m_t < 200 GeV [8,10]. In the Table the ratios R_t for four values of toponium masses in the interval 150 GeV-400 GeV are presented. As one can see in the Table, the fraction of the toponium decay into a neutrino-antineutrino pairs comparable to the fraction of its decay into a lepton-antilepton pair. When there will be available e^+e^- colliders

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4 From LEP measurements of the Z^0-boson total width it is expected that the value N_ν will be determined with the accuracy $\Delta N_\nu \simeq 0.1$. Let us stress, however, that the experiments we are discussing here are "direct neutrino counting experiments", similar, for example, to the investigations of the process $e^+e^- \longrightarrow \nu\bar{\nu}\gamma$.

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5 Let us notice that recently from the measurement of the width of the decay of Z^0 into $b\bar{b}$-pair it was obtained $v_b^2 = 0.095 \pm 0.047$ [11].

of energy and luminosity sufficient for the observation of the chain

$$(T\bar{T})' \longrightarrow (T\bar{T})_o + \pi\pi$$
$$\hookrightarrow \text{nothing}$$

one could get some information about the existence of "undetectable"particle with masses M_x in the interval $\frac{M_z}{2} < M_x < \frac{M(T\bar{T})}{2}$.

In conclusion it is a pleasure for us to thank B. Pontecorvo for many stimulating and fruitful discussions. We would also like to thank G.Mitselmakher and A.Olshevski for discussions[6].

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References

[1] B. Adeva et al.(The L3 Collaboration), Phys. lett. B231 (1989) 509; D. Decamp et al.(The ALEPH Collaboration), Phys. lett. B231 (1989) 519; M.Z. Akrawy et al.(The OPAL Collaboration), Phys. lett. B231 (1989) 530; P. Aarnio et al.(The DELPHI Collaboration), Phys. lett. B231 (1989) 539.

[2] Komatsu, Phys. Lett. B177 (1986) 201;
J. Ellis, F. Zwirner, preprint CERN-TH-5460/89;
R. Barbieri et al., Phys. Lett. B195 (1987) 500;

[3] J. Ellis, Proc. of Summer Inst. on Particle Physics, SLAC Report N.251, 1978, p.69.

[4] L. Köpke and N. Wermes, Phys. Rep. v.174, N2-3, (1989) p.68.

[5] S.M. Bilenky and B. Pontecorvo, Dubna preprint P2-8576, 1975

[6] Proc. of the Tau-Charm Factory Workshop, SLAC-Report-343, June 1989; J. Kirkby, preprint CERN-EP/89-140, Nov. 1989.

[7] Proposal for e^--e^+ for Heavy Flavour Particle Physics, PSI Report, PR-88-09 (July 1988).

[8] The CDF collaboration, FERMILAB-Pub-89/212-E (1989).

[9] J.D.Jackson, Proc. of Summer Inst. on Particle Physics, SLAC Report N.198, 1976

[10] J. Ellis and G.L. Fogli, preprint CERN-TH.5511/89 (1989).
A. Blondel, preprint CERN-EP/90-10 (1990).

[11]. B. Adeva et al.(The L3 Collaboration), internal L3 preprint #6, Feb. 20, 1990.

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6 After this note has been completed we discovered the paper by L. Bergström and H. Rubinstein (Phys. Lett. B 201, 283 (1988)) who came to conclusions similar to ours. We thank A. Olshevski who drew our attention to this paper.

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τ-C, B, ... фабрики и распад кваркония на пары ν-$\bar{\nu}$

Рассмотрены распады основного состояния кваркония в пару нейтрино-антинейтрино. Наблюдение распада на пару $\nu\bar{\nu}$ "меченных" J/Ψ, Υ (и $(T\bar{T})_0$) на τ-C, B (и T)-фабриках представляется возможным. Сравнение результатов таких экспериментов с результатами опытов по измерению числа типов нейтрино на LEP дало бы возможность ответить на вопрос о том, испускаются ли в распаде Z^0 тяжелые нейтральные (нерегистрируемые) частицы.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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τ-charm, B, ... Factories and Quarkonium Decays into ν-$\bar{\nu}$ Pairs

The decays of quarkonium ground states into neutrino-antineutrino pairs are considered. It is shown the observation of the decays into $\nu\bar{\nu}$ of "tagged" J/Ψ, Υ (and $(TT)_0$) at τ-charm, B (and T)-factories are feasible in principle. Comparison of the results of such experiments with the result of LEP experiments on measurement of the number of neutrino types could answer the question whether heavy neutral (undetectable) particles are emitted in the decay of Z^0.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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