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PHYSICS POSSIBILITIES AT TRISTAN

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In this talk, I was asked to review theoretical expectations at TRISTAN.[§] Unfortunately, the Z boson is predicted to have a mass of 93 GeV by the Weinberg-Salam model and it will not be produced at TRISTAN. Is it possible that we may still discover a neutral gauge boson? How must we modify the standard model in order to have a light neutral gauge boson without violating any of the low energy experimental constraints? What is the possibility of producing toponium, Θ , at TRISTAN? If Θ is produced, does it decay weakly? Can effects of Z boson be revealed by observing weak decays of Θ ? If B mesons are produced in weak decay products of Θ , can we learn anything new about B's. Is B^0 meson more interesting than T^0 mesons? I would like to discuss these questions.

Many authors have studied the possibility of modifying the standard model in preparation for a possibility that the Z boson is not found at the mass predicted by the standard model¹⁻⁴. In particular, Ref.2 gives a general discussion with a conclusion that there is no absolute upper bound on the lightest neutral gauge boson mass. Here we shall discuss some models with light neutral gauge boson which might be produced at TRISTAN. In order to satisfy the low energy experimental constraints, we start with a gauge group

$$SU(2) \times U(1) \times G$$

§ Is it really true that TRISTAN cannot produce the Z? See note added.

where known quarks, leptons, and the Higgs doublet $\begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$ are singlets under G. So far the model is identical to the standard model. For definiteness, let G be SU(2)' and U(1)' as discussed in Refs. 3 and 4 respectively. Now, in order to change the masses of gauge bosons, we introduce a Higgs boson multiplet which carry both SU(2)xU(1) and G quantum numbers. For example,

$$\begin{array}{c} \leftarrow \text{SU(2)'} \rightarrow \\ \Phi = \begin{pmatrix} \eta^0 & \chi^+ \\ \eta^- & \chi^0 \end{pmatrix} \begin{array}{c} \uparrow \text{SU(2)} \\ \downarrow \end{array}, \end{array}$$

doublet in both SU(2) and SU(2)' as in Ref. 3. When η^0 and χ^0 acquire vacuum expectation values, the neutral components of SU(2), U(1), and SU(2)' mix to form γ , Z_1 , Z_2 . For example,

$$\mathcal{L}_\Phi = \int d^4x \left\{ \left[\partial_\nu - i \left(g_1 T^3 A_{3\nu} + g_2 Y B_\nu + g_3 \tilde{T}_3 W_{3\nu} \right) \right] \Phi \right\}^2$$

(T^3 , T_3 , and Y are SU(2), SU(2)', and U(1) charge operators, respectively) gives rise to mass mixing terms like

$$A_3 W_3 \langle \eta^0 \rangle \langle \chi^0 \rangle.$$

As it is well known, a mass matrix

$$\begin{pmatrix} m_1 & C \\ C & m_2 \end{pmatrix}$$

gives a spectrum

and the lighter one is the light Z.

An effective interaction of \$Z_1\$ and \$Z_2\$ can be obtained from examining the fermion sector of the Lagrangian

$$\begin{aligned} \mathcal{L}_f &= \bar{\psi} \not{D} \psi \\ &= \bar{\psi} [\not{D} - ieQ\not{A} - i \sum_{j=1,2} (c_j T^3 + c'_j Q + c''_j \tilde{T}^3) \not{Z}_j] \psi. \end{aligned}$$

Giving an appropriate definition of \$\sin\theta_w\$ in terms of \$c_j\$, \$c'_j\$, and \$c''_j\$, we can write an effective Hamiltonian for the neutral current interaction

$$H_{\text{eff}} = \frac{4G_F}{\sqrt{2}} \left[(j_\nu^3 - \sin^2\theta_w j_\nu^{em})^2 + C (j_\nu^{em})^2 \right]$$

where the first term is identical to the interaction term of the standard model and the second term is an extra term resulting from the introduction of G, Φ , and a new light Z boson. The best constraint on C comes from Z_1 and Z_2 's contribution to $e^+e^- \rightarrow$ hadron cross section.

$$R_{Z_1 Z_2} = \frac{\sigma(e^+e^- \rightarrow Z_1, Z_2 \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

$$= - \frac{G_F Q^2}{\sqrt{2} \pi \alpha} g_v^2$$

$$\text{where } g_v = \frac{1}{4} [(1 - 4\sin^2\theta_w)^2 + 16C].$$

Note that the smallness of $1 - 4\sin^2\theta_w$ and the factor of 16 makes this contribution very sensitive to C. The data from PETRA gives⁵

$$0 < C < .033$$

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$$.027$$

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where the lower limit is deduced from the theoretical expression for C. In terms of Z boson masses M_{Z_1} , M_{Z_2} , and $M_Z = 93\text{GeV}$, the value of Z boson mass predicted by the standard model,

$$C = \frac{(M_{Z_1}^2 - M_Z^2)(M_{Z_2}^2 - M_Z^2)}{M_{Z_1}^2 M_{Z_2}^2} \times \begin{cases} \sin^2\theta_w & \text{Ref 3} \\ \cos^2\theta_w & \text{Ref 4} \end{cases}$$

The expression for C derived in Ref. 4 leads to an unnaturally small mass differences and it seems quite unlikely that this model is realized in nature. Experimental constraints on Z boson masses for both Ref.3, and Ref.4 are shown below. As it is seen from the figure, the lighter Z boson can have a mass within the energy range of TRISTAN.

An optimist should be reminded, however, that many modifications of the standard model have been proposed in the past. But so far nature seems to have chosen the simplest version. It will be surprising indeed if she breaks the pattern now.

Probably a more realistic consideration is to discuss whether the toponium states or $t\bar{t}$ continuum states can be excited at TRISTAN. There have been many guesses for the t quark mass from structures of quark mass matrices. Some of them have already ^{been} ruled out by PETRA experiments. A most reasonable guess for the mass, in my opinion, is that recently proposed by Buras⁶. An upper limit for the t quark

mass comes from combining gauge theory calculation of $K_L \rightarrow \mu^+ \mu^-$ rate^{7,8} and $K_L - K_S$ mass difference⁸. Within a context of gauge theory, quark diagrams contributing to $K_L \rightarrow \mu^+ \mu^-$ decay are:

(a)

(b)

(c)

(d)

Strong interaction corrections to Figs.(a)-(c) can be estimated since the major contribution to the decay comes from the short distance region. Fig.(d), on the other hand, gets contribution from the long distance region and it requires more consideration. Note that the absorptive part of Fig. (d) can be computed from known rates for $K_L \rightarrow \gamma\gamma$ and $\gamma\gamma \rightarrow \mu^+\mu^-$ as shown below.

The size and the sign of the real part can not be computed. A guess based on quark diagrams show that the real part of Fig.(d) is much smaller than the imaginary part⁹. Subtracting the absorptive part of Fig.(d), we obtain the bound on the amplitude:

$$|A(a) + (b) + (c)| < 5.6 \times 10^{-9}$$

Aside from the uncertainty introduced by the real part of Fig.(d), the bound is free of unsubstantiated assumptions. Going from quark diagrams to $K_L \rightarrow \mu^+\mu^-$ decay amplitude is less of a problem here since the amplitude can be related to the K decay constant obtained from $K^+ \rightarrow e^+\nu$ decay rate.

Gauge theory computation of Fig.(a-c) enables us to convert

the above bound to a bound involving quark masses⁷

$$| C_2 (C_2 C_1 - S_2 t_3 C_8) m_c^2 + S_2 (C_1 S_2 + C_2 t_3 C_8) m_t^2 | \leq 57 \text{ GeV}^2$$

where s_1, s_2, s_3 , and s_8 are the Kobayashi-Maskawa mixing parameters.

It is clear that m_c^2 term can be ignored and the bound on m_t can be obtained if s_2 is known. Some information on the lower limit of s_2 can be obtained from following considerations¹⁰. Interactions responsible for $K_L - K_S$ mass difference are given by the following diagrams:

The mass difference is given by

$$m_{K_L} - m_{K_S} \sim \langle K_0 | H_a | \bar{K}_0 \rangle + \langle K_0 | H_b | \bar{K}_0 \rangle$$

and

$$\langle K_0 | H_a | \bar{K}_0 \rangle \sim \frac{.4}{R} \frac{m_c^2}{m_K} (U_{cs} U_{cd}^*)^2$$

$$\langle K_0 | H_b | \bar{K}_0 \rangle \sim \frac{.4}{R} \frac{m_t^2}{m_K} (U_{ts} U_{td}^*)^2$$

where R is a parameter expressing the ambiguity associated with evaluating $K^0 - \bar{K}^0$ matrix elements from quark diagrams. Two methods give different results¹¹:

R=1 for MIT bag model

R=.4 Vacuum saturation.

It is useful to remind ourselves that values $m_c = 2\text{GeV}$, $U_{cs} U_{cd}^* = \sin\theta_c \cos\theta_c$, $U_{ts} U_{td}^* = 0$, and $R=.4$ give a correct result for the mass difference (In fact this is how m_c was predicted⁸ to be 2GeV). Naturally, then, if one trusts the MIT bag model and set $R=1$, contribution from the top quark is needed to fill in the decreased value for the charm contribution. This requires $U_{ts} U_{td}^* \neq 0$. A detailed analysis gives

$$S_2 \gtrsim S_{2LB}(R) ; (S_{2LB}(1) = .2) .$$

With this bound on s_2 , we can obtain a bound on m_t shown below.⁶

Unfortunately, the figure does not extend to $R=.4$, the number corresponding to the vacuum saturation approximation. Noting that

U_{ts}^U can not vanish, we can still obtain an upper limit for m_t :

$$m_t < 80 \text{ GeV} \quad \text{for } R=.4.$$

(A. Buras, private communication)

If this analysis is correct, chances of discovering $\oplus$ at TRISTAN are very good.

What can we learn from $\oplus$, once it is produced at TRISTAN?

If $\oplus$ had a mass

$$40 \text{ GeV} < m_{\oplus} < 60 \text{ GeV},$$

the resonance to continuum ratio is¹²

$$1 < R_{\text{peak}}/R_{\text{cont.}} < 5.$$

Thus there may be substantial gain in event rate by sitting on the resonance.

There have been many studies on weak decays of quarkonium.

Some of previous estimates, however, must be modified since the values of α_s determined at Υ seems to be some what smaller than we have expected.¹³ ($\Lambda_{\overline{MS}}$ determined by $\Gamma(\Upsilon \rightarrow \text{had})/\Gamma(\Upsilon \rightarrow \mu^+\mu^-)$ is $\sim 100 \text{ MeV}$).

This modification reduces $\Gamma(\Theta \rightarrow 3gluon)$ by roughly a factor of 2, and thus increases other branching ratios. Roughly we obtain

$$\Gamma(\Theta \rightarrow b\bar{b}) \cong .2 \Gamma(\Theta \rightarrow 3gluon)$$

where the left hand side includes γ , Z, and W contributions, (Widths for $\Theta \rightarrow u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}$ are ofcourse comparable in magnitude). A detail theoretical study on the possibility of observing asymmetries associated with weak decays of Θ seems to be worth while. It is quite possible that new information on W and Z can be deduced from parity violating asymmetries in the decay products of Θ .

While decays of D mesons are extreemly interesting, unlike K meson decays, they do not show any sign of $D^0-\bar{D}^0$ mixing¹⁴. This is probably because the life time of D^0 meson is much shorter than the characteristic time required for mixing. The shortness of the life time is due to the fact that c quark is the heavier of the two members of the weak isospin doublet. Corresponding qualitative statement for the weak isospin doublet (t, b) is that we do not expect $T^0-\bar{T}^0$ mixing while $B^0-\bar{B}^0$ mixing is possible¹⁵. It should then be extreemly interesting to make a detail study of B decays. Such a study is under way at CESR. Can TRISTAN compete with CESR in B meson physics? If Θ is produced at TRISTAN, we expect a finite branching ratio for

$$\Gamma(\Theta \rightarrow B\bar{B} + X).$$

Also, there will be considerable difference between $B\bar{B}$ events from Υ_{4S} and $\Upsilon(4S)$ decays. At CESR, $B\bar{B}$ are practically at rest while at TRISTAN, the pair will be energetic. Therefore, the possibility of TRISTAN making a substantial contribution to B meson physics should not be ruled out. Such considerations, however, depends crucially on various resonance parameters.

In designing TRISTAN detectors, it is important to learn from difficulties experienced by others. After over a year of running, CESR has less than 20 events in which two electrons, two muons, or an electron and muon are identified. There are less than 100 events in which two K mesons are identified. Note that almost all $B\bar{B}$ decays contain two K mesons. It is very hard to ask a detailed question about B decays under such circumstances. A detector with good efficiencies in identifying μ , e and K particles is the key to success of TRISTAN.

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