SLAC-PUB-3193
August 1983
(T/E)

CAN THE $\xi(2.2)$ BE A TECHNI-PION?

HOWARD E. HABER*

Department of Physics†

University of California, Santa Cruz, California 95064

and

Stanford Linear Accelerator Center

Stanford University, Stanford, California 94305

ABSTRACT

If the new positive parity state $\xi(2.2)$ recently discovered in ψ decay turns out to have zero spin, then it could be a Higgs boson. In the context of technicolor models, (in the absence of CP–violating effects) self-conjugate techni-pions have pseudoscalar couplings and hence cannot be the explanation of the new state. However, a pseudo-Goldstone boson analogue to the K_S^0 (the "techni-K_S") could be a candidate to explain the $\xi(2.2)$. In such a case, we would expect a nearly degenerate state, the "techni-K_L" which would behave like a pseudoscalar and decay into $K^* \bar{K}$.

Submitted to Physics Letters B

---

* This work was supported in part by the Department of Energy, contract DE-AC03-76SF00515, and the National Science Foundation, grant PHY8115541-02.

† Permanent address.

Recently a new state, $\xi(2.2)$, has been announced by the MARK III collaboration;[1] it was observed as follows:

$$\psi \to \gamma + \xi(2.2) \quad \hookrightarrow K_S^0 K_S^0 \,,\; K^+K^- \tag{1}$$

with $m_\xi = 2.22 \pm .02$ GeV, $\Gamma_\xi = 30 \pm 10 \pm 20$ MeV and

$$BR(\psi \to \gamma + \xi(2.2))\, BR(\xi(2.2) \to K^+K^-) = (8.0 \pm 2.0 \pm 1.6) \times 10^{-5} \ . \tag{2}$$

The fact that it decays into $K_S^0 K_S^0$ implies that $\xi(2.2)$ has $J^{PC} = (\text{even})^{++}$. If it turns out to have spin zero then there is an exciting possibility that the $\xi(2.2)$ could be a Higgs boson which is produced as in Fig. 1. Such an interpretation could be suggested to explain the narrow width of the $\xi(2.2)$ (which may be consistent with experimental resolution) and to explain its (preferential?) decay into strange particles.[1] In another paper [2], the possible implications of the $\xi(2.2)$ for Higgs physics will be discussed. In this paper, we shall concentrate on whether the $\xi(2.2)$ could be interpreted in the context of technicolor theories.

Technicolor models [4] are theories which describe the Higgs bosons as composites of new techni-fermions (Q). In such models, the particles analogous to the scalar Higgs of the standard model are the spin zero P-states of the $\bar{Q}\,Q$ system. They are expected to be fairly massive (in the 100 GeV – 1 TeV region). However, technicolor models often predict light pseudoscalars; these are pseudo-Goldstone bosons ("pseudos") of a dynamically broken chiral symmetry which occurs in the techni-fermion world.[5-7] The colorless pseudos are expected to be particularly light [6-8] (with mass ≤ 40 GeV). A simple illustration is given in a toy model by Farhi and Susskind [5] which

[1] The verdict is not in as to whether $\xi(2.2) \to \pi^+\pi^-$ or $\rho\rho$ occurs. Further study of the data is needed before a definitive statement can be made.

contains one weak doublet color triplet of techni-quarks (U_i, D_i) and one weak doublet of techni-leptons (N, E). There is a chiral $SU(8) \times SU(8)$ symmetry which one assumes is dynamically broken to a diagonal $SU(8)$. Three of the resulting Goldstone bosons are eaten by the $W^{\pm}$ and Z^0 leaving 61 pseudos in the physical spectrum (often called techni-pions). The most interesting of these are the color singlets:

$$\begin{aligned} P^{\pm} &= |U\bar{D}\rangle - 3|N\bar{E}\rangle \\ P^0 &= |U\bar{U} - D\bar{D}\rangle_1 - 3|N\bar{N} - E\bar{E}\rangle \\ P'^0 &= |U\bar{U} + D\bar{D}\rangle_1 - 3|N\bar{N} + E\bar{E}\rangle \end{aligned} \tag{3}$$

(the subscript 1 refers to a color singlet; overall normalization factors have been omitted). In eq. (3), the explicit γ_5 has been suppressed; in fact all pseudos are of the form $\bar{Q}\gamma_5 Q$, i.e., they are pseudoscalars in the presence of technicolor (as well as color and electromagnetic) forces.

At this point, the theory cannot as yet explain (ordinary) fermion masses, nor the coupling of pseudos to ordinary quarks and leptons. For this, one must introduce extended technicolor [6,9] (ETC) gauge bosons which connect techni-fermions to ordinary fermions.[2] Using the diagram shown in fig. 2, the fermions get a mass when $\langle \bar{F}F\rangle_0$ gains a vacuum expectation value. By the same diagram, fermions couple to the pseudos whose techni-fermion content is $\bar{F}\gamma_5 F$. In some models the P^0 and P'^0 are expected to have mass in the 2-3 GeV range [7,8] so one could ask — can the $\xi(2.2)$ be a techni-pion (either P^0 or P'^0)?

[2] Although the model described above is not realistic, it contains features that are expected to persist in more realistic models. However, one should be aware of the various phenomenological problems with ETC models, namely flavor changing neutral currents which are too large [10] and masses for the pseudos $P^{\pm}$ which may be too light [8] (so that they should have been seen at PEP and PETRA). In more complicated models, one might hope these problems could be solved [11], although no compelling model exists at present.

At first, it seems that the answer is obviously no! Since $\xi(2.2) \rightarrow K_S^0 K_S^0$, the $\xi(2.2)$ must have positive parity, whereas the techni-pions are pseudoscalars. However, there is a subtlety here — the techni-pions are pseudoscalar under parity conserving technicolor and color interactions. The ordinary fermions couple to techni-pions through ETC interactions which must be parity *nonconserving*[3] (as shown in fig. 2). Thus *a priori*, it is possible for techni-pions to have a 0^{++} component in their interactions with fermions.[12,13]

In the sample technicolor model described above, this in fact cannot occur as we now show. Observe from eq. (3) that the neutral techni-pions P^0 and P'^0 are self-conjugate bosons (i.e., they are real fields). Hence, if CP is conserved,[4] then P^0 and P'^0 must have pure pseudoscalar interactions with fermions. This can be understood as follows: from Table 1, we see that $\bar{f} f$ and $i \bar{f} \gamma_5 f$ have opposite CP quantum numbers (note that the factor of i is required by hermiticity). Hence, if CP is conserved, a neutral self-conjugate scalar can couple either to $\bar{f} f$ or $i \bar{f} \gamma_5 f$ but not both. The assumption here that the scalar is self-conjugate is crucial. For example, if the two fermions are different, $\bar{f}_1 (a + b\gamma_5) f_2 + h.c.$ does not violate either hermiticity or CP invariance. Of course, the scalar boson which couples to it cannot be self-conjugate. We can deduce this result directly from fig. 2 as follows. For the self-conjugate techni-pion, the two techni-fermions in fig. 2 have the same flavor (i.e., $i = j$). For simplicity, we perform the following calculation as if the techni-pion consisted of one flavor of techni-fermions. Hence, in the local limit, the interaction of fig. 2 is:

---

[3] If all ETC interactions were parity conserving then up- and down-type quarks would be mass degenerate in pairs [6,12].

[4] We assume throughout most of this paper that CP–violating effects are small and can be neglected in the above discussions.

$$\bar{F}\,\gamma_\mu(a+b\gamma_5)f\,\frac{1}{M_{ETC}^2}\,\bar{f}\,\gamma^\mu(a+b\gamma_5)F \quad . \tag{4}$$

To identify the coupling of the techni-pion (Π_T) to $f\,\bar{f}$ [15], we first note that current algebra and PCAC imply:

$$\langle 0|\,\bar{F}\,\gamma_\mu\gamma_5 F|\Pi_T\rangle = iF_\pi p_\mu \tag{5}$$

$$\langle 0|\,\bar{F}\,\gamma_5 F|\Pi_T\rangle = \frac{-iM_\pi^2 F_\pi}{2M_F} \quad . \tag{6}$$

It is convenient to rewrite eq. (6) using

$$M_\pi^2 F_\pi^2 = 2M_F\langle\bar{F}\,F\rangle_0 \tag{7}$$

thereby obtaining

$$\langle 0|\,\bar{F}\,\gamma_5 F|\Pi_T\rangle = \frac{-i\langle\bar{F}\,F\rangle_0}{F_\pi} \quad . \tag{8}$$

Roughly, one expects $\langle F\,\bar{F}\rangle_0$ to be of order F_π^3. Applying a Fierz transformation to eq. 4 (see Appendix), we obtain

$$\frac{1}{M_{ETC}^2}\,i\,\bar{f}\,\gamma_5 f\Pi_T\left[m_f F_\pi(a^2+b^2)+\frac{\langle\bar{F}\,F\rangle_0}{F_\pi}(a^2-b^2)\right] \tag{9}$$

which demonstrates the pure pseudoscalar coupling of the techni-pion.

From this discussion, it is clear how to avoid such a result — namely construct a technicolor model with non-self-conjugate pseudos. Consider, for example, a model with two generations of colored techni-quarks; (U_i, D_i), (C_i, S_i). Then among the many pseudos, we find non-self-conjugate bosons such as $\bar{D}\,S$, $\bar{S}\,D$, etc. These bosons are the analogues of ordinary K-mesons so we shall call them by the generic name of techni-kaons (K_T). Indeed, techni-kaons can have both scalar and pseudoscalar couplings to ordinary fermions. The relevant interaction from fig. 2 is now:

$$\bar{F}_1\,\gamma_\mu(a_1+b_1\gamma_5)f\,\frac{1}{M_{ETC}^2}\,\bar{f}\,\gamma^\mu(a_2+b_2\gamma_5)F_2 + h.c. \quad . \tag{10}$$

Applying a Fierz transformation and using equations analogous to eqs. 5-8, we find

$$\frac{1}{M^2_{ETC}}\left\{i\bar{f}\gamma_5 fK_T\left[m_f F_K(a_1a_2+b_1b_2)+\frac{\langle\bar{F}F\rangle_0}{F_K}(a_1a_2-b_1b_2)\right]\right.$$
$$\left.\frac{i\langle\bar{F}F\rangle_0}{F_K}(a_2b_1-a_1b_2)\bar{f}fK_T+h.c.\right\} \tag{11}$$

where we have assumed that $\langle\bar{F}_iF_j\rangle_0\equiv\delta_{ij}\langle\bar{F}F\rangle_0$. As advertised, K_T exhibits both scalar and pseudoscalar couplings.

As in the ordinary K-system, it is convenient to define CP-eigenstates P^0_S ($CP=+1$) and P^0_L ($CP=-1$). Then, in its coupling to $f\bar{f}$, P^0_S behaves as 0^{++} and P^0_L behaves as 0^{-+}. Thus, we may answer the question posed in the title of this paper. The $\xi(2.2)$ cannot be a (self-conjugate) techni-pion, but it could be a techni-kaon, P^0_S.

The decay $\psi\to P^0+\gamma$ may occur via the "Wilczek mechanism" [3] (see fig. 1) resulting in a decay rate of

$$\frac{\Gamma(\psi\to P^0+\gamma)}{\Gamma(\psi\to\mu^+\mu^-)}=\frac{x^2G_Fm^2_\psi}{4\sqrt{2}\,\pi\alpha}\left(1-\frac{m^2_P}{m^2_\psi}\right) \quad . \tag{12}$$

The factor x is defined so that the $P^0f\bar{f}$ coupling is $xgm_f/2m_W$.[5] If we interpret the $\xi(2.2)$ as a pseudo P^0, the experimental result [eq. (2)] suggests $x\gtrsim 3$ [2]. In technicolor models, the parameter x depends on the highly model dependent ETC sector (see refs. [12] and [15]). Admittingly, it would take a fairly baroque model of technicolor where the P^0_S would be the first pseudo to be detected experimentally.[6] However, let me give some amusing tests should it turn out that the $\xi(2.2)$ has spin zero.

[5] Note the $x=1$ in the minimal electroweak model with one Higgs doublet.
[6] Note that the decay $P^0_S\to s\bar{s}$ would require a techni-flavor changing neutral current. One would have to assume that the decay $P^0_S\to\Pi^0_T\Pi^0_T$ was kinematically forbidden.

First, I suspect that the P_S^0 and P_L^0 would be rather close in mass, presumably within the experimental energy resolution of the MARK III detector. The CP–even state P_S^0 could decay into $K\bar{K}$ (in an $\ell = 0$ state) and $K^*\bar{K}^*$ (in an $\ell = 0$ or 2 state) but cannot decay into $K^*\bar{K}$. On the other hand, the CP–odd state P_L^0 is forbidden to decay into $K\bar{K}$ but can decay into $K^*\bar{K}^*$ (in an $\ell = 1$ state) or into $K^*\bar{K}$ (in an $\ell =$ 1 state). These conclusions are easily reached by assuming that C and P are separately conserved. However, these results are also true in more general CP–conserving theories for the following reason. Using eq. 11, it is clear that P_L^0 and P_S^0 are defined so that their couplings to ordinary fermions are parity conserving. Therefore, as an example, the decay $P_L^0 \to K^*\bar{K}$ occurs via $P_L^0 \to s\bar{s}$ followed by the production of $u\bar{u}$ and $d\bar{d}$ out of the vacuum. Both of these processes (and the formation of the K–mesons) conserve parity, and hence the decays of the techni-kaons into ordinary mesons must be P–conserving. Thus, in the absence of CP–violation, the above analysis gives the correct selection rules for techni–kaon decays.[7]

Note, however that a 2^{++} meson can decay strongly into both $K\bar{K}$ and $K^*\bar{K}$ (in each case in an $\ell = 2$ state). Thus, if both $\xi(2.2) \to K_S^0 K_S^0$ and $\bar{K}^0 K^{*0}$ were observed, the natural explanation (assuming only one state were present) would be that $\xi(2.2)$ has quantum numbers J^{++} with $J \geq 2$ and even. If, in addition, a spin analysis revealed that $J = 0$, then a two-state interpretation (or parity–violation) would be necessary. In addition, if a $K^*\bar{K}^*$ signal were seen, by measuring final state correlations one could determine whether the final state particles were emitted in an ℓ–even or ℓ–odd final state. As argued above, the detection of both ℓ–even and ℓ–odd states could indicate the presence of two nearly degenerate states with opposite CP quantum numbers.

---

[7] In this argument ordinary weak interaction corrections are neglected. For example, the $K^*\bar{K}$ state can have 0^{--} quantum numbers which by a weak interaction process can connect to P_S^0. Clearly, such effects will be numerically negligible.

Finally, consider what would happen if there were large CP–violating effects in the extended technicolor interactions. In this case, even (self–conjugate) techni–pions could exhibit both scalar and pseudoscalar couplings to ordinary fermion pairs. Consequently, it would then be possible to have both the decays $\Pi_T^0 \to K\bar{K}$ and $K^*\bar{K}$. From an experimental point of view, this would be similar to the existence of two definite CP–eigenstates which were too close in mass to be resolved. Therefore, one should search for a resonance signal in both $K\bar{K}$ and $K^*\bar{K}$ at 2.2 GeV (in addition to the spin measurement); the result of which will be important in elucidating the nature of the $\xi(2.2)$.

If the spin of the $\xi(2.2)$ is found to be zero, it will also be important to search for the rarer $\mu^+\mu^-$ decay mode in order to see whether the Higgs/techni-kaon interpretation is tenable. In summary, we have shown that although the recently discovered $\xi(2.2)$ cannot be a self-conjugate techni-pion, the possibility of it being a (CP-even) techni-kaon P_S^0 cannot as yet be excluded. In the latter case, a pseudoscalar P_L^0 should be nearby perhaps nearly degenerate in mass. Note that should a Higgs-like interpretation be borne out, then it should be possible to confirm or rule out the technicolor scenario since if the P_L^0 were not found (as well as no CP–violation), one would have to interpret the $\xi(2.2)$ as an "ordinary" scalar Higgs. In such a case, technicolor models would be ruled out since they cannot tolerate light scalar Higgs bosons.

If the spin of the $\xi(2.2)$ is measured to be zero, then there could be exciting Higgs/Technicolor physics to be uncovered in ψ decays. If the spin turns out to be ≥ 2, then we are left with a puzzle of an unusually narrow state, the physics of which would clearly lie elsewhere.

—

ACKNOWLEDGEMENTS

I would like to thank Estia Eichten, Dan Caldi, David Dorfan, Terry Goldman, Ian Hinchliffe, Bob Holdom, Gordon Kane, and Boris Kayser for useful discussions. I am also grateful to John Ellis whose advocacy of the Higgs interpretation of the $\xi(2.2)$ inspired much of this work.

Appendix: Fierz Identity

We have used the following identity in this paper:

$$
\begin{aligned}
\gamma_\mu(a_1 + b_1\gamma_5) \otimes \gamma^\mu(a_2 + b_2\gamma_5) \\
&= (a_1a_2 - b_1b_2)(I \times I - \gamma_5 \times \gamma_5) \\
&\quad + (a_1b_2 - b_1a_2)(\gamma_5 \times I - I \times \gamma_5) \\
&\quad - \frac{1}{2}(a_1a_2 + b_1b_2)(\gamma^\alpha \times \gamma_\alpha + \gamma^\alpha\gamma_5 \times \gamma_\alpha\gamma_5) \\
&\quad - \frac{1}{2}(a_1b_2 + a_2b_1)(\gamma^\alpha \times \gamma_\alpha\gamma_5 + \gamma^\alpha\gamma_5 \times \gamma_\alpha) \quad .
\end{aligned}
$$

References

1. Walter Toki, seminar given at the 1983 SLAC Summer Institute on Particle Physics.
2. Howard E. Haber and Gordon L. Kane, SLAC–PUB–3209 (1983).
3. F. Wilczek, Phys. Rev. Lett. 39 (1977) 1304.
4. S. Weinberg, Phys. Rev. D 13 (1976) 974 and D 19 (1979) 1277; L. Susskind, Phys. Rev. D 20 (1979) 2619; E. Farhi and L. Susskind, Phys. Rep. 74C (1981) 277.
5. E. Farhi and L. Susskind, Phys. Rev. D 20 (1979) 3404.
6. E. Eichten and K. Lane, Phys. Lett. 90B (1980) 125.
7. M.A.B. Beg, H. D. Politzer and P. Ramond, Phys. Rev. Lett. 43 (1979) 1701; S. Dimopoulos, Nucl. Phys. B168 (1980) 69; M. E. Peskin, Nucl. Phys. B175 (1980) 197; J. P. Preskill, Nucl. Phys. B177 (1981) 21.
8. S. Dimopoulos, S. Raby and G. L. Kane, Nucl. Phys. B182 (1981) 77; S. Chadha and M. E. Peskin, Nucl. Phys. B185 (1981) 61 and B187 (1981) 541; P. Binétruy, S. Chadha and P. Sikivie, Phys. Lett. 107B (1981) 425 and Nucl. Phys. B207 (1982) 505.
9. S. Dimopoulos and L. Susskind, Nucl. Phys. B155 (1979) 237.
10. S. Dimopoulos and J. Ellis, Nucl. Phys. B168 (1980) 69.
11. R. Holdom, Phys. Rev. D 24 (1981) 157; A. Masiero, E. Papantonopoulos and T. Yanagida, Phys. Lett. 115B (1982) 229; A. J. Buras, S. Dawson and A. N. Schellekens, Phys. Rev. D 27 (1983) 1171; A. J. Buras and T. Yanagida,

Phys. Lett. 121B (1983) 316; M.A.B. Bég, Phys. Lett. 124B (1983) 403; S. Dimopoulos, H. Georgi and S. Raby, Phys. Lett. 127B (1983) 101.

12. K. Lane, in *Proceedings of the 1982 DPF Summer Study on Elementary Particle Physics and Future Facilities*, edited by R. Donaldson, R. Gustafson and F. Paige (American Physical Society, New York, 1983).

13. G. L. Kane, in *Gauge Theories in High Energy Physics*, Les Houches Summer School Proceeding, Vol. 37, edited by M. K. Gaillard and R. Stora (North-Holland Publishing Company, Amsterdam, 1983).

14. C. Itzykson and J.-B. Zuber, *Quantum Field Theory* (McGraw-Hill, New York, 1980).

15. J. Ellis, M. K. Gaillard, D. V. Nanopoulos and P. Sikivie, Nucl. Phys. B182 (1981) 529.

Table 1

	P	C	T
$\bar{f}f$	+1	+1	+1
$i\bar{f}\gamma_5 f$	−1	+1	−1

The transformation properties of scalar bilinear covariants under discrete symmetries. The factor of i is chosen so that the bilinear covariants are hermitian. (For notation, see p. 157 of ref. 14.)

Figure Captions

1. The decay of ψ into a Higgs boson and a photon via the Wilczek mechanism (ref. 3).

2. The coupling of techni-fermions $\bar{F}_i F_j$ to ordinary fermions, f, via the exchange of an extended technicolor (ETC) gauge boson X_{ETC}. Note that the coupling of X_{ETC} to fF_i is in general parity violating with an arbitrary mixture of V and A which is model dependent.

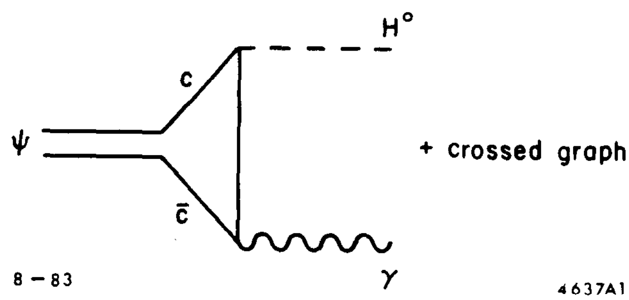
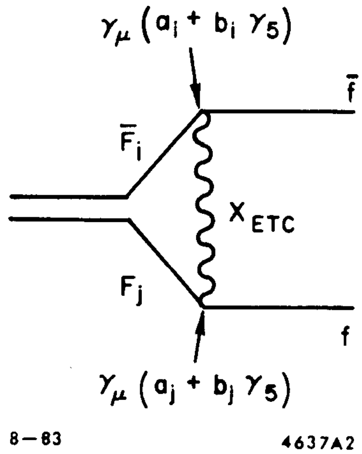


Fig. 1



$\gamma_\mu (a_i + b_i \gamma_5)$
$\bar{f}$
$\bar{F}_i$
X_{ETC}
F_j
f
$\gamma_\mu (a_j + b_j \gamma_5)$
8-83
4637A2

Fig. 2