HOW TO SEARCH FOR HIGGS PHYSICS

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I. INTRODUCTION

Higgs physics is an essential part of the standard model of electroweak interactions, but it is not understood experimentally or theoretically. Because gauge bosons and fermions have mass some new physics must occur. Extending the standard model to grand unification, to include flavor, to be supersymmetric, all may depend crucially on learning to understand Higgs physics. In every approach scalar bosons and/or currents arise (fundamental or dynamical ones) but none have been seen. Apart from axion searches for very light bosons, no limits on Higgs boson masses or couplings are published and almost no dedicated experiments are in progress, in spite of the extreme importance of this area of physics.

The Higgs bosons could be fundamental point particles, or composite states built of new fundamental fermions, as in the dynamical theories (technicolor, hypercolor). We will concentrate here on the experimental search for Higgs physics.[1]

II. EXPECTED SPECTRUM

In the standard model a single Higgs doublet is sufficient to give mass to gauge bosons and fermions. Then a single neutral Higgs particle will exist. Its mass can be given a lower bound of a few GeV, and its fermion couplings are gm_f/m_W for fermion f.

It could happen that the mass and width of the Higgs are both hundreds of GeV and almost no direct signatures occur. We would be forced to this view if no other evidence for scalar interactions was found. Machines with lepton or quark pair energies of order 1 TeV would show strong interaction effects.

The standard model is incomplete. It does not allow us to understand quark mixing angles, why there are flavors, grand unification, the CP problem, the origin of parity violation, etc. For all of these, and for other reasons, it is very likely that whatever the origin of Higgs physics, at least two Higgs doublets are needed to have a theory with which we are satisfied. With two doublets, there are two vacuum expectation values and fermion couplings can be modified by a factor v_1/v_2. There are five physical particles to observe, a charged pair $H^{\pm}$, two neutral scalars, and a neutral pseudoscalar. In dynamical theories such as technicolor essentially an equivalent spectrum emerges.

III. HOW CAN HIGGS PHYSICS BE OBSERVED?

If scalar particles or interactions exist, they will give rise to scalar (or pseudoscalar) currents, usually with an effective strength of order $(m'_f m_f/m_H^2)$ relative to the V-A current (in the

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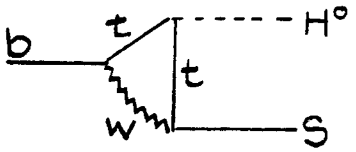
amplitude), for coupling to fermions f and f'. Any decays that could be mediated by a spin zero particle should be examined, such as $\mu\to e\nu\bar{\nu}$, $n\to pe\nu$, $\pi^{\pm}\to\ell^{\pm}\nu$, $\pi^{\circ}\to e^{+}e^{-}$, $\eta\to\mu^{+}\mu^{-}$, $K\to\pi\ell^{+}\ell^{-}$. Violations of μ/e universality might be signals, e.g. $\Gamma(\tau\to\mu\nu\bar{\nu}) \neq \Gamma(\tau\to e\nu\bar{\nu})$. With only minor improvements on present accuracy no effects are expected, but unexpected effects could occur. Both charged and neutral Higgs could show up as scalar current effects.

The easiest Higgs to observe would be charged ones, since they can be produced in $e^{+}e^{-}$ reactions,

$$e^{+}e^{-} \to H^{+}H^{-},$$

with a known cross section (1/4 unit of R), a known production angular distribution ($\sin^{2}\theta$), and a threshold behavior of β^{3} (see below for data). Alternatively, they could appear in decays such as $\tau^{\pm}\to H^{\pm}\nu$ or $b\to H^{-}u$. The Higgs decay would be the dominant mode since it is semiweak. That data from CESR apparently[2] excludes $b\to H^{-}u$ and implies $m_{H^{-}}>m_{b}$. As soon as t quarks are produced we will observe H^{+} or learn $m_{H^{\pm}}>m_{t}-m_{b}$, since the decay $t\to H^{+}b$ will dominate t decay if it is allowed.

Neutral Higgs are extremely hard to find (unless they carry color such as η_{T} below), and are well discussed in the usual literature concerning the standard model, so I will not discuss them further here, except to note one recent point. It has been noted[7] that induced flavor changing decays such as the b decay shown



are allowed under certain conditions in theories with at least two Higgs doublets (which includes technicolor), and should have large branching ratios because they are not Cabibbo suppressed and have only two body phase space. If $m_{H^{\circ}}<2m_{\tau}$ the $\mu^{+}\mu^{-}$ branching ratio will be significant ($\gtrsim$10%) so it should be possible to find such a mode, or exclude $m_{H^{\circ}}$ up to $2m_{\tau}$ from the absence of $B\to K\mu^{+}\mu^{-}$(+ pions). A similar statement can be made for $K\to\pi H^{\circ}$ by replacing b by s, s by d above.

IV. TECHNICOLOR PREDICTIONS

Technicolor ideas have been well reviewed recently (see Ref. 1, 4-7) so here we will just examine the main predictions, which are for new pseudoscalar bosons. If technicolor physics is used only to generate masses for gauge bosons, there is no need for new particles to be observed, but if it is also used to give mass to fermions then a large number of particles will appear.

The most important ones for experimental tests are of three kinds.

(a) In any dynamical theory where electrically charged color-singlet Goldstone bosons are formed, they will only get mass from electroweak interactions and any additional as yet unknown interactions, but not from color interactions. From electroweak interactions in most models they get mass of about 7 GeV.[4-7,8,9] It is known that additional interactions must be present for consistency, but their effect is not known. In the cases studied so far they get less mass from the new interactions than from the electroweak interaction, so they should be detectable at PETRA and PEP as charged scalar bosons. So far two groups have reported[10,11] unpublished PETRA results that are negative, covering the mass range of interest.

The theory is not good enough to predict the decay branching ratios into different modes, so experimental searches have to cover all expected alternative modes. Soon it should be clear if the results of Ref. 10,11 can exclude any theory with a charged pseudoscalar of mass $\lesssim$ 15 GeV.

(b) There are also light color-singlet neutrals that do not even get mass from electroweak interactions, so they will be lighter than the charged bosons. Most remarks about observing neutral Higgs apply to these also, and they are so difficult to observe that it is not obvious how to look systematically.

(c) Perhaps most important for testing dynamical theories is the heavier, electrically neutral, color octet pseudo-Goldstone boson. Its mass and cross section are more reliably calculated than the other states, so when machines ave available it will be a more definitive test. Any theory where the new fermions are colored and pseudo-Goldstone bosons arise will have such a particle. It was first discussed in Ref. 12, and its properties and production cross section estimated in detail in Ref. 8. Its mass arises from color so it is larger, about 240 GeV. While this is not precisely calculable, uncertainties such as other interactions have only a small effect. Its cross section should be calculable by the same arguments as the $\pi^\circ \to \gamma\gamma$ rate if the whole dynamical approach makes sense. Further, it will be distinguishable from fundamental Higgs by its cross section and other properties. A recent discussion is given in Ref. 1.

It will mainly decay to $t\bar{t}$, giving t quark jets at very large p_T where there is little QCD background. Identification should not be difficult.

V. DISTINGUISHING TECHNICOLOR?

It will not be easy to distinguish a fundamental Higgs particle from a dynamical, composite one. At sufficiently high energies, of course, one could tell, but well below the TeV scale there is no direct test. That the colored pseudoscalar of $m \simeq 240$ GeV has color and a relatively large production cross section can be determined and are good tests. For the light charged states no test is possible.

For the light neutrals it may be possible. The parity of the light neutrals may be different in the two approaches. Unfortunately, while the light neutrals are pseudoscalars in the technifermion basis, the interaction that mediates their decays to ordinary fermions need not (and in general will not) conserve parity. Then they can appear as any parity mixture for different fermion states (much of the literature is wrong on this point). Still two clues may work. First, decays into gauge bosons such as two photons or two gluons proceed via the technifermions, and must show a pseudoscalar for Technicolor to be valid. Second, with some assumptions a fundamental Higgs theory will not give decays from the same particle to different states of CP, while the technicolor theory can.

First we should find some evidence of Higgs particles. Then sorting out the alternatives will be an exciting challenge.

REFERENCES

1. See G.L. Kane, Proceedings of the 1981 Les Houches School, and preprint UM HE 81-56 for a recent longer review of this area and many references to the literature.
2. D.R.T. Jones, G.L. Kane, and J.P. Leveille, UM HE 81-45. See also the talk of S. Stone in these proceedings.
3. M. Wise and L. Hall, Harvard Preprints
4. M. Peskin and K. Lane, Proceedings of the 1980 Rencontre de Moriond, ed. J. Tran Thanh Van
5. E. Eichten, Proceedings of the 1980 Vanderbilt e^+e^- Conference.
6. E. Fahri and L. Susskind, CERN preprint TH 2975.
7. P. Sikivie, Varenna Lectures, 1980.
8. S. Dimopoulos, S. Raby, and G.L. Kane, Nuc. Phys. B182 (1981) 77.
9. M. Peskin and S. Chadka, CERN preprints TH-3023 and TH-3032 find 10-14 GeV in another class of models.
10. H. Meyer, private communication.
11. P. Duinker, talk at the 1981 Isabelle Summer Study.
12. S. Dimopoulos, B168 (1980) 69.