Weak Scalar Boson and Vector Boson Phenomenology

Current Phenomenological Status of Higgs Physics and Technicolor

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Although we know that spontaneous symmetry breaking occurs, because $M_{W^\pm}$, $M_Z \neq 0$, we do not yet know the underlying physics or understand what happens. So far, no reasonably attractive theoretical picture has emerged at all, let alone been tested by experiment. Essentially no experiment has put significant constraints on the existence or masses or interactions of scalar or pseudoscalar bosons, and very few experiments are planned for the near future that could change this.

Here I will review the current situation concerning present experimental constraints on Higgs physics [it is useful to use this name for scalar or pseudoscalar bosons of either fundamental or dynamical origin].

First, there are the two major possibilities. I am supposed to concentrate on phenomenological questions, leaving discussion of model building to other speakers.[1]

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Fundamental Higgs Bosons

- This alternative has been introduced in an ad hoc manner. It requires introducing a new fundamental coupling apparently not derivable from a gauge principle.

- It is not clear whether a scalar mass on the scale of a few GeV can be maintained in the presense of radiative corrections.

- No clear experimental predictions.

- If these scalars were part of a bigger theory, such as a supersymmetric one, the objections would presumably be removed, but there are so far no realistic examples of this.

Dynamical Bosons

[Technicolor (TC) + Extended Technicolor (ETC) or Hypercolor + Sideways]

- So far there is no nice model.

- In principle everything is calculable here.

- Probably some reliable and testable predictions.

- Maybe conflicts with experiment already at a detailed level.

Possible experimental predictions will mainly be of two kinds, either new particle states, or scalar or pseudoscalar interactions. First consider the particles.

Expected spectrum

Fundamental Higgs

Minimal SU(2)⊗U(1)

- 1 Higgs doublet

- 1 neutral scalar boson h° expected, with mass $m \gtrsim$ few GeV.

- Its fermion coupling will be $g_f = g\ m_f/m_W$.

2 or more doublets

- This seems the more likely alternative since it would be required to calculate quark mixing angles, to get CP violation via the Higgs sector, if Higgs arose from supersymmetric theories, etc.

- Charged and neutral bosons $h^{\pm}$, h° are expected, with arbitrary masses and arbitrary couplings to fermions and other bosons.

- Scalar and pseudoscalar neutrals occurs.

- In most supersymmetric approaches $m_h \simeq m_W$.

It could happen that m_h, $\Gamma_h \sim 1$ TeV and no simple experimental signatures occur. Then it would be necessary to find new interactions on the TeV scale, but so far there is no clear understanding of what effects would occur.

Dynamical Theories

In TC and ETC particles arise naturally [2-8] at three mass scales: (i) $\Lambda_T \simeq$ 1 TeV, the basic scale of the theory, set to get $m_{W^\pm}$, m_Z correct; (ii) about 250 GeV, set by $m^2 \sim \alpha_s \Lambda_T^2$ for pseudoscalars that would be massless but get mass through color interactions; and (iii) a few GeV, with $m^2 \sim \alpha^2 \Lambda_T^2$, for pseudoscalars that would be massless but get mass from electroweak interactions or the even weaker ETC interactions. The last category can be split into two parts. Charged particles get mass (about 7 GeV) from electroweak interactions -- this should be reliably calculated. Both neutral and charged particles get mass from the ETC interactions. At present the best calculation that can be done in practice with the ETC interactions is to put an upper limit on their contribution, which comes out around 2 GeV, a reasonable result for a very short range force.

In essentially any dynamical theory in which quarks get masses by coupling to new colored fermions, Goldstone bosons which carry color will appear, and will get mass on the scale of 250 GeV; the occurrence of such states will be natural. Similarly, the uncolored states will generally appear and will be in the few GeV region. It would be surprising if the very short range electroweak interaction gave even as much mass as the electroweak interaction.

Thus we have the predictions:

Mass Range	$\Lambda_T \lesssim 1$ TeV	~250 GeV	~8 GeV	~2 GeV
Mass from	Technicolor Scale	QCD	$SU(2) \otimes U(1)$	Extended Techni-color
Particles	$\rho_T, \omega_T, \ldots$ baryons	η_T^c $\pi_T^{0,\pm c}$ lepton-quark states	$a_T^{\pm}$	$a_T^0, a_T'^0$
Observe	FNAL collider	FNAL collider Isabelle	PEP PETRA in $e^+e^- \to a_T^+ a_T^-$ with 1/4 unit of R	$\psi, \Upsilon \to a_T^0 \gamma$ $KN \to a_T^0\ X$
Main decays	$\rho_T \to GG, W_T^+ W_T^-$ $\to \bar{q}q'$	$\eta_T^c \to t\bar{t}, b\bar{b}, GG, G\gamma, GZ^0$	$a_T^{\pm} \to c\bar{s}, c\bar{b}, \tau\nu$	$a^0 \to \mu^+\mu^-$, $s\bar{s}$ ($\phi\pi$, KK^*, KK) BR($\mu^+\mu^-$) large

Present Knowledge

One could learn about spin zero bosons from either seeing scalar or pseudoscalar currents, or finding actual particles. Assume we can write a Lagrangian for the effective coupling to fermions,

$$\mathcal{L} = g \frac{m_f}{m_W} \bar{f}\left[C_s + C_p\gamma_5\right]f'\phi$$

where ϕ is a fundamental or dynamical boson. This can be written for charged or neutral bosons. Then the most useful present limits are

(a) For charged Higgs, $m_\phi > m_\tau$ since otherwise the τ would decay semiweakly through the Higgs coupling. Similarly, as soon as it is established clearly (as the reports from CESR at this meeting seemed to demonstrate) that the b quark decays normally, then we know $m_\phi > m_b$.

(b) For neutral Higgs only $(g-2)_\mu$ provides[9] a potentially useful limit. For a scalar boson it gives

m_ϕ	C_s
25 MeV	< 1.2
1 GeV	< 6
10 GeV	< 35

For a pseudoscalar the limits on C_p are less good by about a factor 3. For scalar plus pseudoscalar states cancellations can occur; if they are not excluded there is no restriction. The result is

$$a_\mu = \frac{g^2 m_\mu^2}{8\pi^2 m_W^2}\left[C_s^2 A(m_\phi^2) - (C_s^2 + C_p^2) B(m_\phi^2)\right]$$

where A,B are integrals which depend only on m_ϕ^2/m_μ^2. For a wide range of masses B/A is about 1/3.

Possible conflict

There is one possible conflict of Technicolor physics with experiment. Very crudely, the method of giving masses to quarks leads to a result

$$m_q \sim \frac{g_{ETC}^2}{m_{ETC}^2} \Lambda_T^3$$

In general the theory also has flavor changing neutral currents (FCNC), giving a contribution to Δm (K_L-K_S), $K \to \mu e$, etc. Both the quark masses and the FCNC arise from exchange of ETC gauge bosons. The FCNC are of order g_{ETC}^2/m_{ETC}^2 in amplitude. Then the problem is that if g_{ETC}^2/m_{ETC}^2 is large enough to give the heavier lepton and quark masses, it gives too much FCNC (and conversely). Whether this is a basic problem, or just indicates the presence of subtle and interesting mechanisms, is unknown at present.

Conclusion

It is unfortunate that more experimental effort has not gone into establishing useful limits on Higgs physics. In the near future the experiments mentioned for $a_T^\pm$, $a°$, η_T^c should impact greatly on our understanding of spontaneous symmetry breaking -- perhaps a scalar or pseudoscalar boson will be found.

References

1. See other talks at this meeting, such as Beg's, for review of the theory.
2. E. Eichten and K. Lane, Phys. Lett. 90B, 125 (1980).
3. S. Dimopoulos, Nuc. Phys. B168, (1980) 93.
4. M. Peskin, Saclay Preprint, May 1908.
5. J. Preskill, Harvard Preprint, July 1980.
6. V. Baluni, unpublished.
7. J.D. Bjorken, unpublished.
8. S. Dimopoulos, S. Raby, and G.L. Kane, Michigan Preprint UM HE 80-22, to appear in Nuc. Phys. B.
9. J. Leveille, Nuc. Phys. B137, 63 (1978).

COMMENTATOR

A way to observe the Higgs Boson H^0 in Hadronic Interactions

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With its single parameter $\sin^2\theta_W = .23 \pm .02$, the standard SU(2) × U(1) model has impressively fitted many different types of weak interactions[1]. Though the model has the definite predictions of the intermediate bosons $W^{\pm}$, Z^0, with Masses $M_W \simeq 80$ GeV, $M_Z \simeq 90$ GeV, the mass-generating mechanism of the theory has been obscure. Since we are at the threshold of checking the existence of the predicted $W^{\pm}$ and Z^0 with definite signatures in the next generation accelerators[2], it is of great importance to find ways to check the existence of these mass-generating related bosons. Contrasting to the situation with e^+e^- machines, for which signatures and ways to observe such bosons are rather clear, ways of detecting such bosons have been noticably missing in hadronic scatterings.[3]

Here we point out that the bremsstrahlung of the H^0 by a Z^0, produced in hadronic scattering as shown in the insert of Fig. (1), gives a definite signature[4] of a bump in the dilepton mass Q with a sharp fall at $Q \simeq M_Z - M_H$. The production is calculated using the Drell-Yan model.

In Fig. (1) we show the Q distribution for $\sqrt{s} = 800$ GeV, and various Higgs mass $M_H = 5$ GeV, 10 GeV, 15 GeV and 20 GeV. We see that besides the direct Z^0 peak at $Q = M_Z \simeq 90$ GeV, there is a bump peaks about $Q + M_H \simeq M_Z$. Actually the sharp fall around $Q \simeq M_Z - M_H$ comes from the B-W propagator in $\hat{s}$ and the fall on the lower side of the bump is from the B-W propagator in Q. It is interesting to point out that the top shape of the bump is rather insensitive to the Higgs masses and the Z^0 width. The $M_H = 5$ GeV curve indicates that one must be careful in interpreting the lower secondary peak, whether it is a broad second resonance or it is from the effect of such a massive particle bremsstrahlung.

Now we shall discuss briefly the detectability of the Higgs boson through such a mechanism. In Fig. (1) we also show the Q-distribution of $\ell\bar{\ell}$ from Z^0 without the H^0 emission. Agreeing with Ref. 5, the peak at $Q = M_Z$ with the H^0 emission is about three orders of magnitude below the peak at $Q = M_Z$ without H^0 emission. However, the second bump in Q is enticingly not too far below the background of the Z^0 and the virtual photon γ_V production. With the projected luminosity of ISABELLE 10^{33} cm^{-2} sec^{-1}, there will be about 600 events/year (3.15×10^7 sec) from the bump between 66 GeV $\leq Q \leq$ 76 GeV in the case of $\sqrt{s} = 800$ GeV and $M_H = 15$ GeV. As low as it is, however, it is not completely out of the question to accumulate enough events for its detection in case we can eliminate the background above. To get rid of the background, we propose to trigger a third lepton of relatively low momentum besides the original two fast leptons with momentum $\simeq \frac{1}{2}(M_Z - M_H)$, using the property that the H^0 prefers to couple (with a strength $\propto M_F^2 G$) to the most massive fermion pair allowed, i.e., $\tau\bar{\tau}$ and $c\bar{c}$ for $2M_\tau < M_H < 2M_b$, and $b\bar{b}$ for $2M_b < M_H < 2M_t$. The τ, D have $\sim .15\%$ branching ratio decaying

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into a charged lepton,[5] and the b has even higher portion of its final states having a lepton due to its cascade decay into the charm. Thus by this trigger the bump is reduced less than .30%. However, we anticipate much more reduction for the background from our current understanding of single lepton productions.[6] If the Higgs masses are much bigger than $2M_b$, it may be also triggered by two hadronic jets.

Due to the smallness of the cross section it definitely points to machines with high luminosity besides high energy. Note also that for small M_H, a detector of good mass resolution is needed, in case if the background of the single Z^0 production can be triggered away. In Fig. (2) we show the energy variation of the bump for $M_H = 15$ GeV at $\sqrt{s} = 1000$ GeV, 800 GeV, 600 GeV for pp scattering. In the same figure we also show the $p\bar{p}$ production of H at $\sqrt{s} = 540$ GeV and 2000 GeV. Though the cross section from $\bar{p}p$ is a factor of a few larger than that of pp at the same energy, due to the projected low $\bar{p}$ luminosity ($\simeq 10^{30}$ cm^{-2} sec^{-1}) the Higgs production under the present estimate seems too small to be detected in the next generation $\bar{p}p$ storage rings.

In conclusion the bremsstrahlung of a Higgs boson H^0 by the Z^0 produced in the nucleon-nucleon reactions will produce a bump structure in the dilepton invariant mass Q with a sharp fall around $Q \simeq M_Z - M_H$. To sweep away the background of $\ell\bar{\ell}$ system from other sources ($\gamma_V + Z^0$ without H^0), we suggest a trigger of detecting a third lepton (or jets) from the dominant decay channels of the H^0. Since the mechanism discussed here is a kinematic one, similar effects should exist for any emission of massive particle by a resonance. Thus this phenomena provides a means to discover particles in the cases when the coupling strength of the emission is large enough. Further, the Higgs-boson bremsstrahlung mechanism discussed here provides an explicit example that the detecting of the tri-lepton or dilepton plus jets might be the way for future experiments to discover new particles, in addition to the historically successful method of detecting the dilepton system.

References

1. See review talk by C. Baltay, Proceedings of the XIXth International Conference on High Energy Physics, Tokyo, Aug. 1978. J.K. Kim, P. Langacker, M. Levine and H.H. Williams, University of Pennsylvania preprint, UPR-158T (submitted to Rev. of Mod. Phys.)
2. R.F. Peierls, T.L. Trueman, L.-L. Wang, Phys. Rev. D16, 1397 (1977); F.E. Paige "Updated estimates of W production in pp and $\bar{p}p$ interactions," Proceedings of Workshop on Production of new particles in super high energy collisions, Madison, Wisconsin, 1979; and a review by L.-L. Chau Wang, "Theoretical Implications on ISABELLE Physics," Lecture at the 1980 Erice Summer School.
3. The production of the H^0 and an on-shell Z^0 in hadronic scattering was calculated by S.L. Glashaw, D.V. Nanopoulos, A. Yildiz, Phys. Rev. D18, 1724 (1978).

4. Details see L.-L. Chau Wang "Signature of the Bremsstrahlung of a Higgs Boson by the Z^0 in Hadronic Reactions," Brookhaven preprint #
5. For leptonic decay branching ratios for the τ and the b, see M. Perl, The Tau Lepton, SLAC preprint, SLAC-PUB-2446 (Dec. 1979) (submitted to Ann. Rev. Nucl. Part. Sci.). B. Gittelman's talk at the XXth Int. Conf. on High Energy Physics.
6. For review on the status of prompt lepton production, see talk by H. Wachsmuth, Proceedings of the 1979 Int. Sym. on Lepton and Photon Interactions at High Energies.

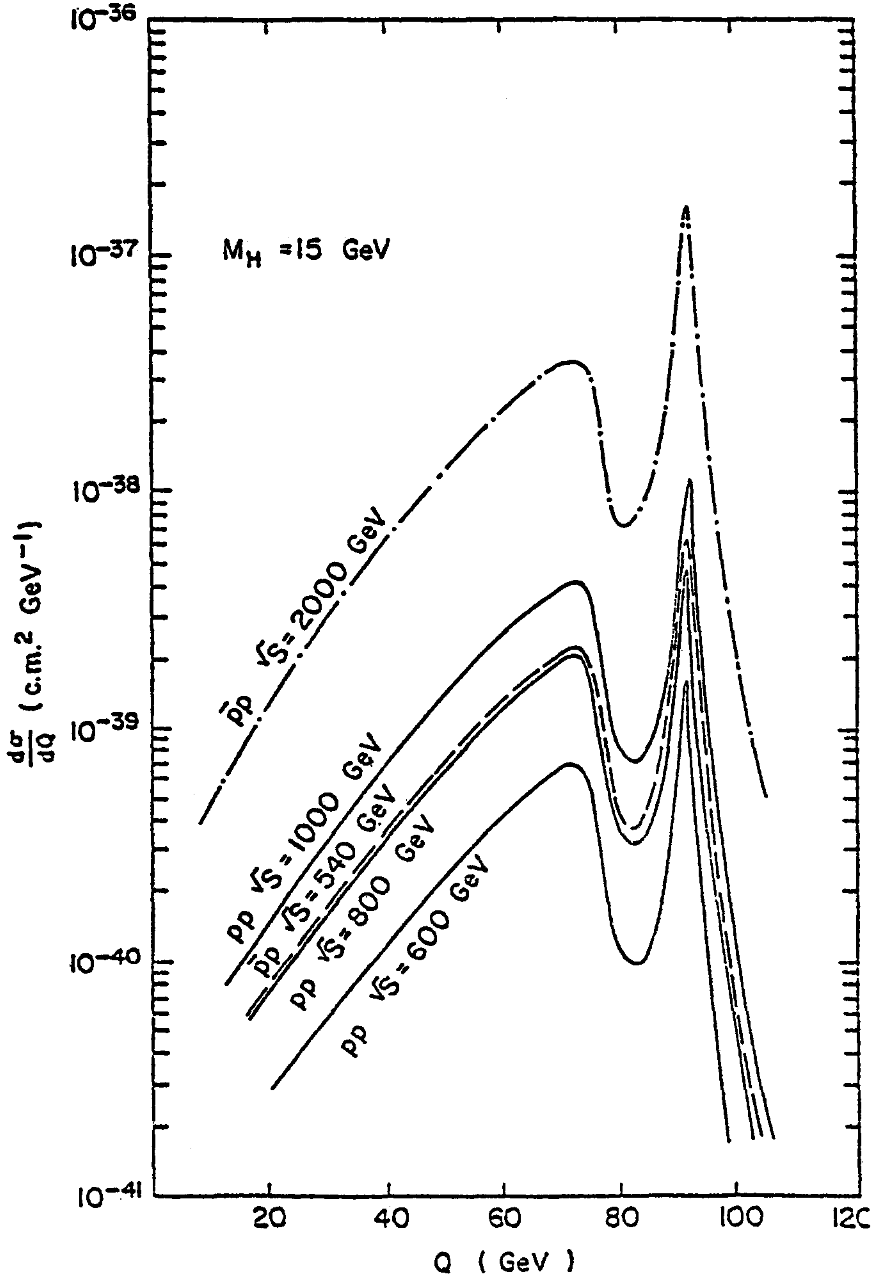

Fig. (1)

Fig. (1). Dilepton mass Q distribution for the bremsstrahlung of a H^0 by a Z^0 produced in pp $\to XZ^0 \to XZ^0H^0 \to \ell\bar{\ell}H^0$ at $\sqrt{s}$ = 800 GeV, and Higgs boson mass m_H = 5, 10, 15, 20 GeV, and for pp $\to X(Z^0 + \gamma_v) \to X\ell\bar{\ell}$ at the same energy.

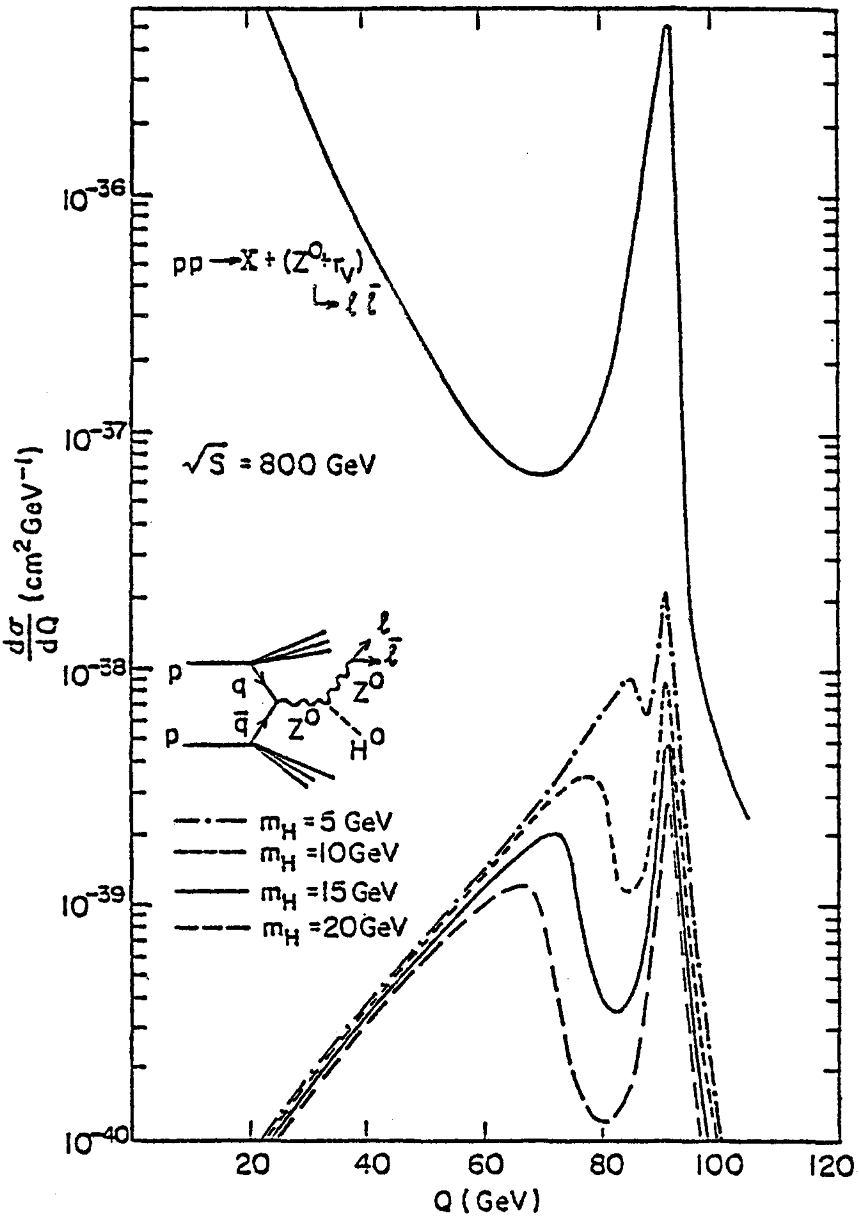

Fig. (2)

Fig. (2). Same as Fig. (1) but for m_H = 5 GeV, in pp scattering with $\sqrt{s}$ = 600, 800, 1000 GeV and in $\bar{p}p$ scattering with $\sqrt{s}$ = 540, 2000 GeV.

DISCUSSION

LANDE: Suppose one tried, in the pre-Isabelle and pre-Fermilab collider days, to look at very high energy cosmic ray interactions. What are the signatures one would look for in these things?

KANE: Well, the first comment is that the cross sections are too small to produce them that way. The heavy ones, the 200 GeV sort of things, for example, will have typically two kinds of dominant decay modes. One is pairs of gluons jets each with half the energy. The other is fermion pairs, $t\bar{t}$ for example. Some of the other states will decay into W and a gluon jet or a Z and a gluon jet. So events with multiple W's, multiple Z's, one or two hundred GeV gluon jets or heavy quark jets would be the typical signatures.

The light ones in the dynamical theory have only $s\bar{s}$ and μ pair decay modes, so they decay essentially completely into these, and they have a large branching ratio for μ pairs. All statements about decay branching ratios of any of these things are model-dependent much more than anything else I've said. The charged ones have essentially $c\bar{s}$ and $\tau\nu$ decays, and depending whether they are fundamental or not, the $c\bar{s}$ or the $\tau\nu$ will dominate.

LANDE: I should point out that the muon pairs are a very good, very easily recognized signature of the cosmic ray situation.

KANE: Sure, and at the accelerators, too. For example, an experiment with a K^+ beam is probably the optimum experiment that Fermilab could do to find μ pairs. Since you annihilate strange quarks, which are heavier, the signal-to-noises is within the limits of experimentaly possibility, but not with any other accelerators.

TYE: Just checking a point with the technicolor people. Is it true that in all technicolor models, the processes that L.L. Wang talked about would not occur? If H^o is a technicolor Higgs, you cannot couple to the Z-pair.

KANE: I believe that's correct. (See Bég's talk).

TYE: So the question is, if you don't see it, can you make a clear statement?

KANE: If you are sure you could have distinguished it from the background, yes. There are a number of ways to distinguish pseudo-scalar Higgs from scalar Higgs. First you should see them and then worry about distinguishing them.