COMPOSITE ALTERNATIVES TO THE STANDARD MODEL: EXPERIMENTAL SIGNATURES

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ABSTRACT

We consider experimental signatures of models with composite $W^{\pm}$, Z^0 and composite quarks and leptons. Properties of the composite Z^0 are discussed in detail. In addition to the $W^{\pm}$ and Z^0, many new composite bosons are expected to appear as distinct, narrow resonances in pp, $\bar{p}p$, ep and $\bar{e}e$ interactions.

It is possible that the bosons responsible for the weak interactions are composite.[1] In this report we will consider the experimental signatures of models of this type. Much of our analysis is model independent, however when a specific model is considered we will use the realistic example of reference 2. In this model the known fermions are correctly described in terms of light bound states, and the weak interactions are the result of residual strong interactions between their constituents. (The gluons and the photon are elementary particles.) The low-energy ($E \ll G_F^{-1/2}$) properties of this composite model agree with those of the standard model, but at higher energies new and different phenomena are predicted. We will discuss how the predictions of the standard model are modified in models with composite W's and Z and analyze the new physics which can be investigated at present and future accelerators. There are three main topics: 1) modification of mass, and production and decay properties for a composite Z^0, 2) deviations from the standard model in e^+e^- collisions below the Z mass and 3) predictions of a rich spectrum of new heavy particles.

An excellent confirmation of the standard model would be the discovery of W and Z^0 resonances with the predicted masses and widths. However, if such resonances do not appear as predicted, it is likely that these vector bosons are composite instead. We expect composite W's to be more massive than the fundamental vectors in the standard model. Their mass[3] should be somewhere in the range of 100-170 GeV. The composite Z^0 is expected to be somewhat heavier than the W's. As in the standard model these composite vector particles will decay into pairs of fermions. Because of the underlying strong interaction involving constituents, the composite vectors can also decay into four or more fermions but such decays are highly suppressed by multibody phase space factors. The vector boson width goes like g^2M where M is the vector mass and g its coupling to fermions. In order to get the correct strength for the weak interactions we require that $g^2/8M^2 = G_F/(2)^{1/2}$ so the width is proportional to $G_F M^3$. Thus, the composite vector width can be related to the widths predicted in the standard model by

$$\Gamma_{composite} = \left(\frac{M}{M_{stand.}}\right)^3 \Gamma_{stand.} \qquad (1)$$

where $M_{stand.}$ and $\Gamma_{stand.}$ are the vector mass and width in the standard model. For a composite Z^0 boson of mass 150 GeV, this gives a decay width of around 12 GeV. The branching ratio into electron or muon pairs is 0.03 for 3 families, as in the standard model.

The production cross section for a composite Z^0 in hadron-hadron collisions can be obtained from the Z^0 production cross section in the standard model by adjusting for the stronger coupling and higher mass. See Fig. 1 for the production cross sections[4] at various machines as a function of Z^0 mass. For example,

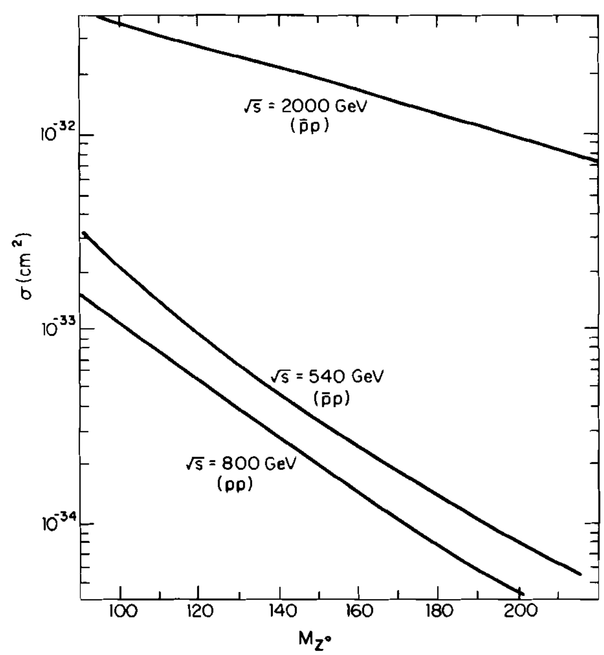

Fig. 1. Composite Z^0 Production Cross Sections as a Function of Mass

at the CERN collider energy of 540 GeV the production cross section for a composite Z^0 of mass 150 GeV is 0.3 nB, or about 1/7 of the standard model's cross section. At higher energies and/or for a lighter composite Z^0, when the production occurs at lower x, we expect the ratio of this composite Z^0 cross section to the standard model cross section to be closer to 1.

In e^+e^- collisions, the Z^0 will appear as a peak in the cross section for $e^+e^- \to \mu^+\mu^-$ for example. At the peak this cross section goes like $g^4/\Gamma^2 \propto 1/m_Z^2$. Thus, the ratio R of this cross section to the photon mediated μ-pair cross section will be the same for a composite Z^0 as in the standard model, independent of the mass of Z^0.

The mass of the Z^0 in the standard model can be determined from propagator effects in e^+e^- collisions even before the Z^0 threshold has been reached. In composite models, effects of order Q^2/Λ^2 are expected with Λ on the order of the mass of the composite Z^0. Hence high precision measurements will be informative. Another effect which might be seen in high precision e^+e^- experiments or in deep inelastic neutrino scattering experiments is the presence of an isoscalar neutral current interaction which is expected to occur due to other composite vector bosons.

In addition to the composite W's and Z^0, there will be in general a rich spectrum of new heavy particles. In the model of Ref. 2 the left-handed fermions are bound states of a fermionic and a scalar preon. The binding force is confining and is due to the gauge group $SU(2)_L$. Two scalar preons can combine to form spin one bound states and these are identified as the $W^\pm$ and Z which form a triplet under a global SU(2) group. The global SU(2) singlet partner of the $W^\pm$ and Z is a neutral spin 0 particle which shares most of the decay characteristics of the standard model's neutral Higgs. Its mass should roughly be comparable to the W and Z masses.

The fermionic preons can combine to form integer spin bound states. Each fermionic preon carries lepton number or baryon number (with QCD color) and a generation index. We call the leptonic preons ℓ_i (i = electron, muon, tau) and the baryonic preons q_i^a(a = red, green, blue; i = 1,2,3). In Table I we list some of the expected spin 0 and spin 1 bound states and their associated quantum numbers. These bosons are not present in the standard model.

Table I. Bosonic Bound States in the Model of Ref. 2

Type	Charges	Baryon #	Lepton #	Color	Total #
Spin 0 bound states of two fermionic preons					
$\ell_i\ell_j$	-1	0	2	1	3
$\ell_i q_j^a$	-1/3	1/3	1	3	27
$q_i^a q_j^b$	1/3	2/3	0	$\overline{3}$,6	36
					66
Spin 1 bound states of two fermionic preons					
$\ell_i^*\ell_j$	0	0	0	1	9
$\ell_i^* q_j^a$	2/3	1/3	-1	3	27
$\ell_i q_j^{a*}$	-2/3	-1/3	1	$\overline{3}$	27
$q_i^{a*} q_j^b$	0	0	0	8 + 1	81
					144

One might think that the exchange of these particles would lead to exotic unobserved currents at low energy. However one can show[2] that there are nearly exact symmetries of the theory which guarantee that the effective four-fermion interaction which results from the exchange of these bosons can be Fierz transformed into the isoscalar neutral current discussed above. An additional term of this type in the neutral current has not yet been observed at the 5% level. Therefore we conclude

$$G_V = \frac{g_V^2}{4\sqrt{2}M_V^2} < \frac{1}{20}\left(\frac{g_Z^2}{4\sqrt{2}M_Z^2}\right) = \frac{1}{20} G_F. \tag{2}$$

where g_V and M_V are the common coupling and mass of the two fermion vector bound states and g_Z and M_Z are the composite Z^0 coupling and mass. The decay rate of any individual spin-1 V boson can be compared to the decay rate of the Z^0,

$$\frac{\Gamma_V}{\Gamma_Z} \simeq \frac{g_V^2 M_V N_V}{g_Z^2 M_Z N_Z}, \tag{3}$$

where we have included factors N_V and N_Z, the number of final-state fermion-antifermion pairs available to the meson in its decay. N_Z = 8N for N families. Using Eqs. (2) and (3), we get

$$\Gamma_V < \frac{N_V}{160N}\left(\frac{M_V}{M_Z}\right)^3 \Gamma_Z. \tag{4}$$

For $M_V \sim 200$ GeV, $M_Z \sim 150$ GeV and three families, $\Gamma_Z \sim 12$ GeV and $N_V = 2$, we have $\Gamma_V < 0.1$ GeV, which is surprisingly narrow. In fact, the widths of these states will in general be less than their mass splittings. The mass splittings are due to QCD, electromagnetic effects, and Yukawa couplings. These can split the states by a few GeV, so we have a series of well-defined narrow resonances.

The states listed in Table 1 can be produced in various collider facilities. In Table 2 we list the dominant single particle production mode for each type of collider.

Table II.

States Produced in Various Particle Collisions

Collisions	Single Bound States Produced
$\bar{e}e$	Z^0, $\ell_i^*\ell_j$,
pp	$q_i q_j$
$\bar{p}p$	Z^0, $q_i^* q_j$,
ep	$\ell_i q_j$

In addition $q_i^* q_j$ color singlet states can be produced in $\bar{e}e$ collisions and $\ell_i^*\ell_j$ in $\bar{p}p$ because of mixing. However these cross sections are expected to be quite small. The presence of resonances in ep channels is an interesting feature of composite models.

We also expect excited states of all the composite bosons which we have discussed as well as excited states of composite fermions. However these heavy bound states are broad and hence difficult to observe. In conclusion, if the $W^\pm$ and Z^0 are found to be composite, physics above 100 GeV will be very rich and exciting.

References

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2) L. Abbott and E. Farhi, Phys. Lett. 101B (1981) 69; Nucl. Phys. B189 (1981) 547.

3) Early analyses of non-standard W's and Z's which share several of the features of composite W's and Z's given here can be found in J. D. Bjorken, Phys. Rev. D19, 335 (1979); P. Q. Hung and J. J. Sakurai, Nucl. Phys. B143 (1978) 81.

4) These cross sections are based on calculations by F. Paige and by G. Kane and J. Leveille.