Composite Weak Bosons at the LHC

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Abstract

In a composite model of the weak bosons the excited bosons, in particular the p-wave bosons, are studied. The state with the lowest mass is identified with the boson, which has been discovered recently at the "Large Hadron Collider" at CERN. Specific properties of the excited weak bosons are studied, in particular their decays into weak bosons and into photons.

In the Standard Model of the electroweak interactions the masses of the weak bosons and of the leptons and quarks are generated by a spontaneous breaking of the electroweak symmetry. Besides the weak bosons a scalar boson must exist ("Higgs boson"). Recently one has discovered a new scalar boson with a mass of about 126 GeV (ref.(1,2)), which might be the Higgs boson.

Here I discuss the possibility that the weak bosons are composite particles. The new scalar boson, observed at the LHC, would be an excited Z-boson.

In the Standard Theory the masses of the weak bosons, leptons and quarks are generated by the spontaneous symmetry breaking. A doublet of scalar fields is introduced, which breaks the weak isospin symmetry spontaneously and develops a non-zero vacuum expectation valus. The weak bosons absorb three of the four scalar fields and obtain a mass, which is proportional to the vacuum expectation value. The remaining neutral scalar boson is the "Higgs" boson.

In QCD the three ρ-mesons are degenerate in mass, if the electromagnetic interaction is switched off and the two light quark masses are zero. Once the electromagnetic interaction is introduced, the charged mesons receive an additional small contribution to the mass, which is due to the Coulomb self energy. In addition the neutral ρ-meson mixes with the photon and its mass increases. This mass shift can be calculated. It depends on a mixing parameter μ, which is determined by the electric charge, the decay constant F_ρ and the mass of the ρ-meson:

$$\mu = e\frac{F_\rho}{M_\rho} \ . \tag{1}$$

The mass shift due to the mixing is given by:

$$M_{\rho^0}^2 = M_{\rho^+}^2 \left(\frac{1}{1-\mu^2} \right) \ . \tag{2}$$

The decay constant is measured to about 220 MeV - it is about equal to the QCD scale parameter Λ_c. One obtains $\mu \approx 0.09$ - it leads to a mass shift of about 3 MeV.

We assume that the weak bosons are composite particles. They consist of a lefthanded fermion and its antiparticle, which are denoted as "haplons". A theory of this type was proposed in 1981 (see ref.(3) and ref.(4,5,6,7,8)). The new confining chiral gauge theory is denoted as QHD. The QHD mass scale is given by a mass parameter Λ_h, which determines the size of the weak bosons. The haplons interact with each other through the exchange of massless gauge bosons.

Two types of haplons are needed as constituents of the weak bosons, denoted by α and β. Their electric charges in units of e are:

$$h = \begin{pmatrix} +\frac{1}{2} \\ -\frac{1}{2} \end{pmatrix} . \tag{3}$$

The three weak bosons have the following internal structure:

$$\begin{aligned} W^+ &= \overline{\beta}\alpha \, , \\ W^- &= \overline{\alpha}\beta \, , \\ W^3 &= \frac{1}{\sqrt{2}} \left(\overline{\alpha}\alpha - \overline{\beta}\beta \right) . \end{aligned} \tag{4}$$

In the absence of electromagnetism the weak bosons are degenerate in mass. If the electromagnetic interaction is introduced, the mass of the neutral boson increases due to the mixing with the photon (ref. (9,10)).

In the Standard Theory the mixing is generated by the scalar fields. Both the photon and the Z-boson are mixtures of the $SU(2)$ and $U(1)$ gauge bosons. Here the mixing is a dynamical mixing, analogous to the mixing of ρ - mesons. It is described by the mixing parameter m, determined by the decay constant of the weak boson:

$$m = e\frac{F_W}{M_W} \ . \tag{5}$$

One finds for the mass difference beween the charged and the neutral weak boson:

$$M_Z^2 \ = \ M_{W^+}^2 \left(\frac{1}{1-m^2} \right) \ . \tag{6}$$

In the standard electroweak theory there is a similar equation - the mixing parameter m must be replaced by $\sin\theta_w$. According to the experiments the mixing parameter m is about 0.485, i. e. about five times larger than the mixing paramter for the ρ-mesons. Using the experimental value, one can determine the decay constant for the weak bosons:

$$F_W \approx 125\, GeV. \tag{7}$$

As in QCD it is expected that the decay constant of the weak boson and the QHD mass scale are related. The decay constant of the ρ-meson and the QCD mass scale are about the same - in QHD the weak decay constant and Λ_h should be of the same order of magnitude. Details will depend in particular on the gauge group of QHD. We expect that Λ_h is in the range between 0.12 TeV and 1 TeV.

The weak bosons consist of pairs of haplons, which are in an s-wave. The spins of the two haplons are aligned, as the spins of the quarks in a ρ-meson. The first excited states are those, in which the two haplons are in a p-wave. We describe the quantum numbers of these states by $I(J)$. The $SU(2)$-representation is denoted by I - the symbol J describes the total angular momentum. There are three $SU(2)$ singlets, which we denote by

S(0), S(1) and S(2), and three triplet states, denoted by T(0), T(1) and T(2).

The boson $S(0)$ is the particle, which has been observed at CERN (ref. (1,2)):

$$M(S(0)) = 126\ GeV. \tag{8}$$

In analogy to QCD we expect that the masses of the other p-wave states are in the range 0.3 - 0.5 TeV. The mass of the $S(1)$ - boson should be just above 0.3 TeV, the mass of the $S(2)$ - boson between 0.4 and 0.5 TeV.

The masses of the $SU(2)$ - triplet bosons T should be larger than the masses of the S - bosons. We compare the spectrum of these bosons with the spectrum of the corresonding mesons in QCD. Thus the mass of the $T(0)$ - boson should be about 0.3 TeV, the mass of the $T(1)$ - boson just above 0.4 TeV, and the mass of the $T(0)$ - boson should be in the range 0.5 - 0.6 TeV.

The $S(0)$ - boson will decay mainly into two charged weak bosons or into two Z-bosons (one of them virtual respectively), into a photon and a Z-boson and into two photons. The Z-boson is the boson W^3, mixed with the photon. The mixing angle is the weak angle, measured to about 28.7 degrees. Using this angle, we can calculate the branching ratios BR for the various decays, taking into accoutn phase space corrections. The branching ratio for the decay into charged weak bosons is denoted by B.

$$S(0) \Longrightarrow (\text{"}W\text{"} + W^{)} \qquad \text{BR} = B,$$

$$S(0) \Longrightarrow (\text{"}Z\text{"} + Z) \qquad \text{BR} \approx 0.55\ B,$$

$$S(0) \Longrightarrow (Z + \gamma) \qquad \text{BR} \approx 0.04\ B,$$

$$S(0) \Longrightarrow (\gamma + \gamma) \qquad \text{Br} \approx 0.05\ B.$$

We would not expect that the decay rates for the decays of $S(0)$ into letons and quarks are given by the mass of the fermion, as they are for the

Higgs boson. The branching ratios for the decays into an electron pair, into a muon pair, into a tau pair or into a neutrino pair should be similar. The decay of the $S(0)$ into a muon pair could be observed in the near future at the LHC.

The bosons $S(1)$ and $S(2)$ have a much higher mass as the $S(0)$ - boson. They will decay mainly into three or four weak bosons. The $SU(2)$ - triplet bosons $T(0)$, $T(1)$ and $T(2)$ will decay mainly into four or five weak bosons or photons. Decays into two weak bosons, a weak boson and a photon or two photons are strongly suppressed.

The properties of the new boson, which has been discovered at the LHC, should be investigated in detail. If the model, discussed here, is correct and the new boson is the state $S(0)$, the other excited bosons $S(1)$, $S(2)$ and $T(0)$ should be discovered soon at the LHC.

References

[1] Atlas collaboration:
arXiv:1202.1414,arXiv:1202.1408, arXiv:1202.1415.

[2] CMS collaboration:
arXiv:1202.1488, arXiv:1202.1489, arXiv:1202.1487.

[3] H. Fritzsch and G. Mandelbaum, Phys. Lett. B102 (1981) 319;
Phys. Lett. B 109 (1982) 224.

[4] R. Barbieri, R. Mohapatra and A. Masiero, Phys. Lett. B 105 (1981) 369.

[5] H. Fritzsch. D. Schildknecht and R. Kogerler, Phys. Lett. B 114 (1982) 157.

[6] L. F. Abbott and E. Farhi, Phys. Lett. B 101, 69 (1981).

[7] T. Kugo, S. Uehara and T. Yanagida, Phys. Lett. B 147, 321 (1984).

[8] S. Uehara and T. Yanagida, Phys. Lett. B 165, 94 (1985).

[9] H. Fritzsch, arXiv:1201.2512

[10] H. Fritzsch, Mod. Phys. Lett. A26, 2305 (2011)