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DYNAMICAL SYMMETRY BREAKING AND THE STANDARD MODEL OF ELECTROWEAK INTERACTIONS

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In a version of the standard model the Higgs boson is replaced by a doublet (B^+, B^0) of vector bosons, and the masses of gauge bosons and fermions are generated by the dynamical breaking of the gauge group. In this note it is shown that B^+ and B^0 are heavy particles: $m_{B^+} \approx 0.9 m_{B^0}$, $m_{B^0} \gtrsim 42.73$ GeV. Production of B particles is studied in $e^+e^- \to B^0\overline{B^0}$, B^+B^-, $ZB^0\overline{B^0}$, ZB^+B^-. In particular, $B^0\overline{B^0}$ has a large cross section in Z-resonance region. The B^+B^- production is a factor of $\cos^2 2\theta_W$ smaller than that of $B^0\overline{B^0}$.

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The Higgs boson is not yet seen and there exists a motivation for alternative symmetry breakings [1].

In a recent paper [2] a self-interacting doublet B_μ of vector bosons was introduced in the standard model instead of a scalar Higgs. B_μ has an invariant interaction with usual gauge vector fields $A_{i\mu}$, C_μ:

$$
\begin{aligned}
L_0(DB) &= -\tfrac{1}{2}\left(D_\mu B_\nu - D_\nu B_\mu\right)^+\left(D^\mu B^\nu - D^\nu B^\mu\right), \\
D_\mu &= \partial_\mu - \tfrac{1}{2} i g \tau_j A_{j\mu} - \tfrac{1}{2} i g' C_\mu ,
\end{aligned} \tag{1}
$$

where

$$
B_\mu = \begin{pmatrix} B_\mu^{(+)} \\ B_\mu^{(0)} \end{pmatrix} \tag{2}
$$

is a $Y = 1$ doublet. By assuming the formation of a condensate,

$$
\begin{aligned}
\langle B_\mu^{(0)+} B_\nu^{(0)} \rangle_0 &= g_{\mu\nu} d, \quad d \neq 0, \\
\langle B_\mu^{(+)+} B_\nu^{(+)} \rangle_0 &= 0,
\end{aligned} \tag{3}
$$

one gets mass terms for W and Z. $(-d)^{1/2}$ plays the role of the vacuum expectation value of the Higgs field,

$$d = -\left(6(2)^{1/2} G_F\right)^{-1}. \tag{4}$$

The photon remains massless and $\rho_{\text{tree}} = 1$. Fermions can be made massive by introducing an interaction between fermion pairs and $B^{(0)}$ pairs [2] respecting the Kobayashi–Maskawa mechanism, too. The coupling strength turns to be $3(2)^{-1/2} m_f G_F$.

In general, the model has a low momentum scale $\Lambda \lesssim 2.6$ TeV, and it can be considered as an effective field theory.

In the present note we would like to point out that the B boson is a heavy particle and $m_{B^+} \approx 0.9 m_{B^0}$, as well as $m_{B^0} \gtrsim 42.73$ GeV. Furthermore, in e^+e^- annihilation there exists a large cross section for $B^0\overline{B^0}$ pairs in the Z-resonance region. At higher energies the cross section is still a few pbs for $m_{B^0} = (46 - 48)$ GeV. The amplitude for B^+B^- production is a factor of $\cos 2\theta_W$ smaller than that of the $B^0\overline{B^0}$ final state. $B^0\overline{B^0}Z$ has a cross section which is smaller than 0.01 pb at the LEP 200 region and $(0.1 - 0.2)$ pb at $\sqrt{s} = 500$ GeV.

First of all, the vector condensate generates the mass of B^0. In a self--consistent approximation

$$m_{B^0}^2 = -10 d\lambda, \tag{5}$$

coming from the self-interaction $-\lambda(B_\nu^+ B^\nu)^2$ added to (1), $\lambda > 0$. Since the field $B_\mu^{(+)}$ cannot be transformed out, it represents a physical field which gets its mass from the self-interactions of B_ν,

$$m_{B^+}^2 = -8\lambda d, \quad \left(\frac{m_{B^+}}{m_{B^0}}\right)^2 = \frac{4}{5}. \tag{6}$$

From the momentum scale $\Lambda \lesssim 2.6$ TeV we have $m_{B^0} \lesssim 2.6$ TeV [2].

For the B mass there exists a lower bound following from the Lagrangian (1) and the precision measurements of the Z parameters [3]. From (1) we see that the Z couplings contributing to the Z decays are $ZB^0\overline{B^0}$, ZB^+B^-, $Z\gamma B^+B^-$ if B is light enough. The coupling $Z\gamma B^+B^-$ is 0.6 times the ZB^+B^- coupling which is 0.54 times the $ZB^0\overline{B^0}$ coupling, therefore, $Z\gamma B^+B^-$ can be neglected. The remaining interactions have the form

$$L\left(B^{(0)}\right) = \frac{ig}{2\cos\theta_W} \partial^\mu B^{(0)\nu+} \left(Z_\mu B_\nu^{(0)} - Z_\nu B_\mu^{(0)}\right) + \text{h.c.},$$
$$L\left(B^+B^-Z\right) = \cos 2\theta_W \, L\left(B^{(0)} \to B^{(+)}\right). \tag{7}$$

The partial width of $Z \to B^0\overline{B^0}$ is obtained as

$$\Gamma(Z \to B^0\overline{B^0}) = \left(\frac{g}{2\cos\theta_W\, m_Z m_{B^0}}\right)^2 \frac{\left(m_Z^2 - 4m_{B^0}^2\right)^{3/2}\left(m_Z^2 + 3m_{B^0}^2\right)}{48\pi}, \tag{8}$$

shown in Fig. 1. Before the kinematical limit the width is not very sensitive to changing m_{B^0}. For instance, for $m_{B^0} = 42\,\mathrm{GeV} \to 43.5\,\mathrm{GeV}$, $\Gamma = 35\,\mathrm{MeV} \to 15\,\mathrm{MeV}$.

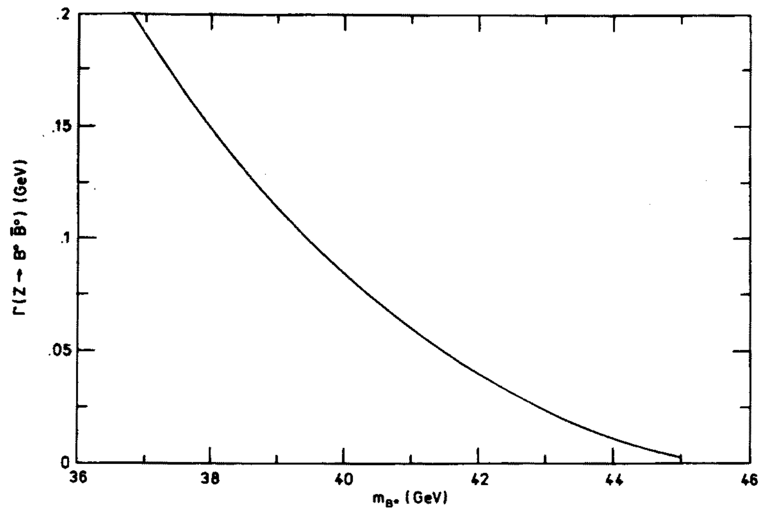

Fig. 1. The width of $Z \to B^0\overline{B^0}$ as the function of m_{B^0}.

We take the average LEP Z parameters [3]

$$\begin{aligned} m_Z &= (91.175 \pm 0.021)\,\mathrm{GeV} \\ \Gamma_Z^{\mathrm{exp}} &= (2.487 \pm 0.010)\,\mathrm{GeV}, \end{aligned} \tag{9}$$

as well as we use $\sin^2\theta_W = 0.2300 \pm 0.0064$ [4]. The maximum value of Γ_Z^{exp} is compared to the minimum value of $\Gamma_Z^{\mathrm{theory}}$ belonging to known Z-decays into leptons and quarks at maximum $\sin^2\theta_W$, minimum m_Z^2 and $\alpha_s = 0.110$ [5]. This yields

$$\begin{aligned} &\Gamma_Z^{\mathrm{theory}} \geq 2.465\,\mathrm{GeV}, \\ &1.29\Gamma(Z \to B^0\overline{B^0}) \lesssim 32\,\mathrm{MeV}, \end{aligned} \tag{10}$$

giving $m_{B^0} \gtrsim 42.73\,\mathrm{GeV}$. We have neglected a small effect generated by the $B^+ - B^0$ mass difference.

The interaction (7) results in $B^0\overline{B^0}$, B^+B^- pairs in e^+e^- annihilation, $e^+e^- \to B^0\overline{B^0}$, B^+B^-. The cross sections are as follows

$$\sigma(e^+e^- \to B^0\overline{B^0}) = g^4(s-4m_{B^0}^2)^{3/2}(s+3m_{B^0}^2) \times \frac{(4\sin^2\theta_W-1)^2+1}{3072\pi s^{1/2}m_{B^0}^2\cos^4\theta_W\left(\left(s-m_Z^2+\frac{\Gamma_Z^2}{4}\right)^2+m_Z^2\Gamma_Z^2\right)},$$

$$\sigma(e^+e^- \to B^+B^-) = 0.29\sigma(e^+e^- \to B^0\overline{B^0})_{m_{B^0}\to m_{B^+}}. \qquad (11)$$

The cross section of the $B^0\overline{B^0}$ production is shown in Figs 2, 3 as the function of the total centre of mass energy $s^{1/2}$ at various m_{B^0}'s. For $m_{B^0} < m_Z/2$ the cross section is large also beyond the Z resonance region (Fig. 2). For $m_{B^0} > m_Z/2$ Z cannot decay into $B^0\overline{B^0}$ but the cross section is still a few pbs for $s^{1/2} \approx 100$ GeV, $m_{B^0} = (46-48)$ GeV (Fig. 3).

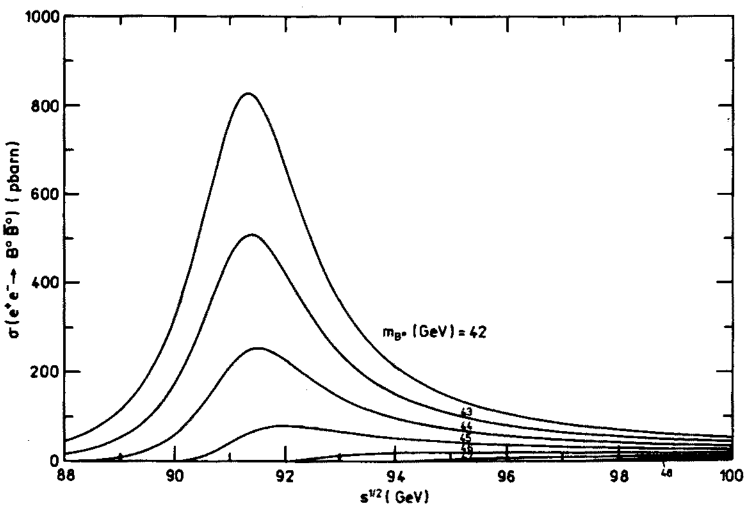

Fig. 2. The total cross section of $e^+e^- \to B^0\overline{B^0}$ as the function of the total centre of mass energy $s^{1/2}$ at various m_{B^0}'s and $m_Z = 91.175$ GeV, $\Gamma_Z = 2.487$ GeV, $\sin^2\theta_W = 0.23$.

From the Lagrangian (7) the associated production of Z and $B^0\overline{B^0}$ is possible, too. However, the chain $e^+e^- \to Z^* \to B^0\overline{B^0}Z$ is more probable, as is shown by a calculation. The corresponding Lagrangian is obtained from (1)

$$L = \frac{g^2}{4\cos^2\theta_W}\left(-Z_\mu Z^\mu B_\nu^{(0)+}B^{(0)\nu} + Z_\nu Z^\mu B_\mu^{(0)+}B^{(0)\nu}\right). \qquad (12)$$

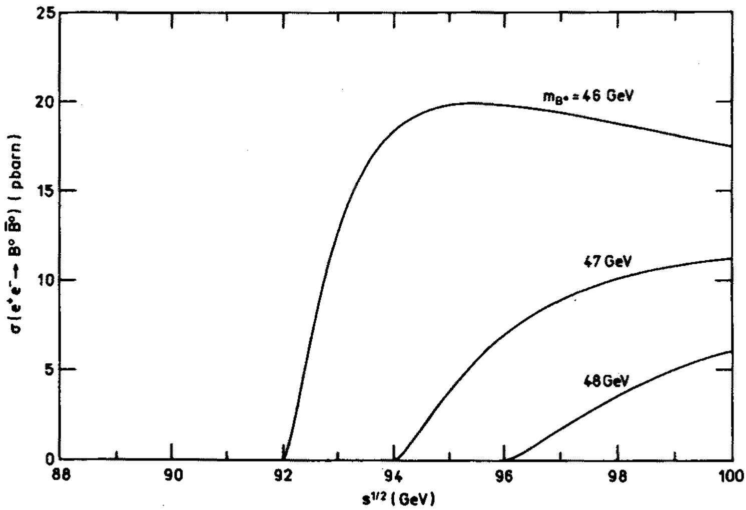

Fig. 3. The same as Fig. 2 at $m_{B^0} = 46$, 47, 48 GeV.

The resulting total cross section has a long analytic form which is plotted against $s^{1/2}$ in the LEP 200 region for $m_{B^0} = (42 - 48)$ GeV in Fig. 4. Fig. 5 shows the same at higher energies. At about $s^{1/2} = 200$ GeV the cross section does not reach 0.01 pb, in particular, it is small at higher m_{B^0}. At an integrated luminosity of 1 pb^{-1} (for one day) this provides a small yield of $B^0\overline{B^0}$ pairs. The situation changes at higher energies, for instance at $s^{1/2} = 500$ GeV a cross section of (0.1–0.2) pb emerges.

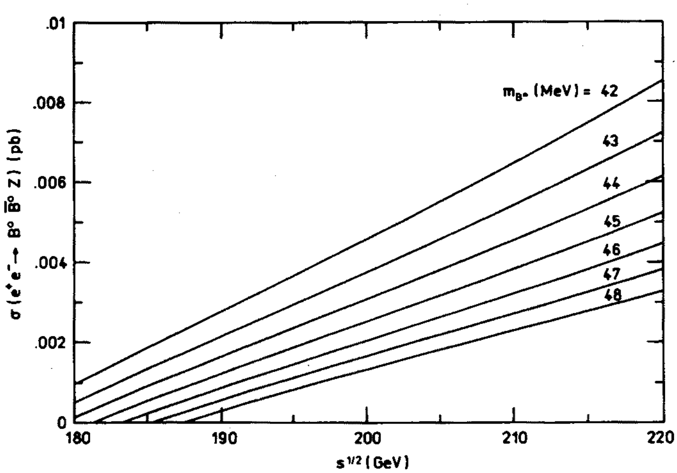

Fig. 4. The total cross section of $e^+e^- \to B^0\overline{B^0}Z$ versus $s^{1/2}$ at $m_{B^0} = (42 - 48)$ GeV using the same input parameters as in Fig. 2.

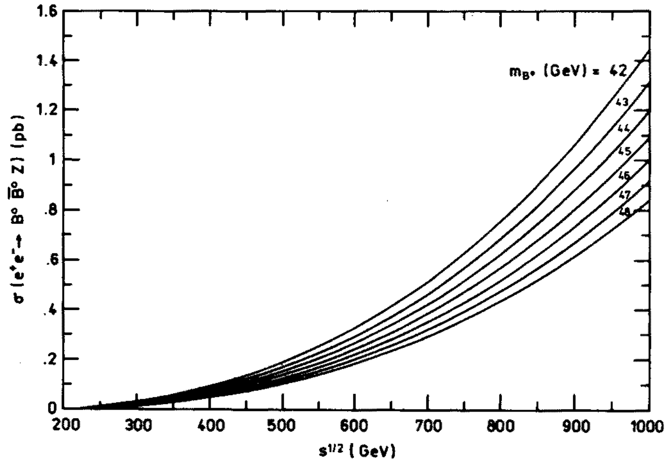

Fig. 5. The same as in Fig. 4 at higher energies.

In conclusion, one can break dynamically the standard model gauge group leading to spin-one massive B particles. These are heavy objects, $m_{B^0} \gtrsim 42.73$ GeV and they could possibly be seen in e^+e^- annihilation.

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