REF.TH.3395-CERN

COMPOSITE MODELS, W DOMINANCE AND WEAK BOSON
MASS BOUNDS

M. Kuroda ^{*)}

Department of Theoretical Physics,
University of Bielefeld.

and

D. Schildknecht ⁺⁾

CERN -- Geneva

ABSTRACT

Weak interactions are considered as residual forces between composite leptons and quarks, mediated by composite bosons. The masses of the least massive charged and neutral bosons are bounded by $65 \text{ GeV} \leq m_W \leq 95 \text{ GeV}$, and $75 \text{ GeV} \leq m_Z \leq 110 \text{ GeV}$, respectively.

^{*)}Supported by Deutsche Forschungsgemeinschaft.

⁺⁾Permanent address: Department of Theoretical Physics, University of Bielefeld, F.R.G.

The hypothesis that weak interactions between leptons and quarks may be mediated, in a vague analogy to strong interactions, by a spectrum of vector bosons^{1),2)} seems natural if one speculates on the possibility that vector bosons, leptons and quarks form composite objects [for recent reviews on compositeness, see Ref. 3)]. In particular, we expect the hypothesis to be true if weak interactions are residual effects of some underlying confining hypergluon force, much like the nuclear forces in QCD [cf. Refs. 4)-8) for various specific variants of this conjecture]. Mixing between the photon and neutral W bosons, originally introduced^{1),9)} phenomenologically as an alternative explanation of the observed neutral current structure, is interpreted as a consequence¹⁰⁾⁻¹²⁾ of composite boson structure.

If the weak interaction is a residual interaction, and the (elementary) photon couples to subconstituents of leptons and quarks, we expect^{12),13)} the weak as well as the full electromagnetic interaction between these particles in the low-energy approximation to be described by the (schematic) diagrams of Fig. 1 [supplemented by higher order γW mixing contributions¹²⁾]. These diagrams closely resemble hadron interactions at low energies (e.g., pion-pion scattering). Kogerler and one of the present authors¹²⁾, and also Fritzsche, Kogerler and one of the present authors¹³⁾, recently considered the approximation in which the spectral function of the exchanged system in Fig. 1 is dominated by the least massive W (and Y) boson. This "W dominance" approximation of the quark and lepton electromagnetic form factors^{*)} has been found¹²⁾ to imply specific predictions for the charged and neutral boson masses $M_W^2 = \alpha\pi/\sqrt{2} G_F \sin^2\theta_W \approx (79 \text{ GeV})^2$ and $M_Z = M_W/\cos\theta_W \approx 90 \text{ GeV}$, which coincide with the canonical values¹⁵⁾. In contradistinction to the standard approach, however, these mass formulas are of dynamical origin (W dominance approximation) rather than being a consequence of a spontaneously broken $SU(2) \times U(1)$ gauge symmetry¹⁵⁾ or an asymptotic $SU(2) \times U(1)$ symmetry principle^{1),9)}.

In the present work we wish to examine the question of how strongly the W dominance predictions for the masses of the W and Z bosons are affected by the presence of more massive contributions to the spectral weight function, which we expect to be present in any composite model. For definiteness we will describe

*) It is precisely the photon lepton (quark) interaction via electromagnetic form factors (generated by the weak interaction) with respect to which we differ from the general electroweak mixing scheme^{1),9),14)} with independent point-like photon lepton (quark) couplings.^{12),13)}

the exchanged system (see Fig. 1) by a series of charged and neutral vector bosons. This ansatz approximates the general situation in which a continuum, or a pole and a continuum, or several poles and a continuum, may be present. Later on, we shall concentrate on two isovector bosons W and W' , and a single more massive isoscalar Y boson. The W' may be thought of as effectively parametrizing a higher mass continuum.

At low energies, the charged current weak interaction is then described by an effective Lagrangian which contains the exchange of a series of W bosons. The couplings g_{W_i} of these bosons of masses m_{W_i} have to fulfil the normalization sum rule

$$\sum_i \frac{g_{W_i}^2}{m_{W_i}^2} = \frac{8 G_F}{\sqrt{2}} \quad (1)$$

where G_F denotes the Fermi coupling.

According to Fig. 1, the neutral current interaction contains a weak boson exchange as well as a photon exchange piece. Besides the neutral component of the weak isovector current, $j^{(3)}$, an additional (isoscalar) current must be present which has to coincide¹²⁾ with the usual hypercharge current. The weak, as well as the full electromagnetic interaction between two composite quarks or leptons in the low-energy approximation, is then described by

$$\begin{aligned} -2L_{\text{eff}}^{NC} = & \sum_i \frac{g_{W_i}^2}{q^2 - m_{W_i}^2} j^{(3)2} + \sum_i \frac{g_{Y_i}^2}{q^2 - m_{Y_i}^2} j^{(Y)2} \\ & + D(q^2) \left(\sum_i g_{W_i} \tilde{\lambda}_{W_i} \frac{m_{W_i}^2}{q^2 - m_{W_i}^2} j^{(3)} + \sum_i g_{Y_i} \tilde{\lambda}_{Y_i} \frac{m_{Y_i}^2}{q^2 - m_{Y_i}^2} j^{(Y)} \right)^2 \end{aligned} \quad (2)$$

The photon propagator has been denoted by $D(q^2)$, and the (non-renormalized) $\gamma W^{(0)}$ and γY couplings have been called $\tilde{\lambda}_{W_i}$ and $\tilde{\lambda}_{Y_i}$. According to Fig. 1 and formula (2), the photon interacts in a point-like manner with subconstituents, which form bound state W (and Y) bosons such that the full photon lepton (quark) interaction is effectively described by a multi-boson dominated lepton (quark) form factor^{*}). The photon boson couplings (being analogous to the $\gamma\rho^0$

*) We exclude the case where compositeness (conjectured to be realized by a confining gauge theory) leads to photon lepton (quark) interactions which have no resemblance whatsoever to the analogous situation in hadron physics (QCD).

junction in hadron physics) have their origin in the composite nature of the vector bosons and lead to mixing. This is reflected in the form of $D(q^2)$ which, upon summation over all orders in $\tilde{\lambda}$, is given by [e.g., Ref. 12)]

$$D(q^2) = \frac{1}{q^2} \left(1 - \sum_i \frac{\tilde{\lambda}_i^2 m_i^2}{q^2 - m_i^2} \right)^{-1} \quad (3)$$

$$\cong \frac{1}{q^2} \left(1 + \sum_i \tilde{\lambda}_i^2 \right)^{-1} \left(1 - q^2 \left(1 + \sum_i \tilde{\lambda}_i^2 \right)^{-1} \sum_i \frac{\tilde{\lambda}_i^2}{m_i^2} + \dots \right).$$

We have dropped the indices W and Y to facilitate notation; the sums run over all W and Y bosons. As in the general electroweak mixing scheme^{1),2),9)}, photon boson mixing shifts the neutral boson masses relative to the unmixed states. The corresponding eigenvalue equation for the neutral boson masses, $q^2 \equiv m^2$, obtained by putting the denominator of (3) equal to zero, takes the form

$$1 + \sum_i \lambda_i^2 \left(\frac{m_i^2}{q^2} - 1 \right)^{-1} = 0. \quad (4)$$

(4) has been written in terms of the renormalized photon boson couplings λ_i ,

$$\lambda_i^2 \equiv \tilde{\lambda}_i^2 \left(1 + \sum_k \tilde{\lambda}_k^2 \right)^{-1} \quad (5)$$

which are required to fulfil

$$\sum_i \lambda_i^2 < 1, \quad (6)$$

in order to guarantee real eigenvalues to be obtained from (4).

The $q^2 \rightarrow 0$ form of the neutral current interaction (2) is now easily obtained by substituting the low q^2 expansion (3) for the propagator $D(q^2)$. One finds

$$2\mathcal{L}_{\text{eff}}^{NC}(q^2 \rightarrow 0) = -\frac{e^2}{q^2} j_{em}^2$$

$$+ G_W \left((j^{(3)})^2 - S_W^2 j_{em}^2 + C_W j_{em}^2 \right)$$

$$+ G_Y \left((j^{(Y)})^2 - S_Y^2 j_{em}^2 + C_Y j_{em}^2 \right). \quad (7)$$

In (7) we have identified the photon pole contribution with the electromagnetic interaction

$$j_{em} \equiv j^{(3)} + j^{(Y)} \quad (8)$$

and, consequently, we had to introduce the requirement

$$\sum_i \lambda_{W_i} g_{W_i} = \sum_i \lambda_{Y_i} g_{Y_i} = e, \quad (9)$$

where e denotes the unit of electric charge. Relation (9) is a consequence of the composite nature of leptons, quarks and vector bosons as incorporated in our ansatz (2) for the electroweak interaction. It may be called the "compositeness condition" or "saturation condition", as the interaction of the photon via intermediate boson states has to fully saturate the electric charge e^* .

The other constants in (7) are given by

$$\begin{aligned} G_W &\equiv \sum \frac{g_{W_i}^2}{m_{W_i}^2}, \\ S_W^2 &\equiv \frac{e}{G_W} \sum_i \frac{g_{W_i} \lambda_{W_i}}{m_{W_i}^2}, \\ C_W &\equiv \frac{e^2}{G_W} \sum_i \frac{\lambda_{W_i}^2}{m_{W_i}^2} - S_W^4 \geq 0. \end{aligned} \quad (10)$$

and the analogous expressions for G_Y , S_Y and C_Y [obtained by replacing W by Y in (10)].

Using (8) to eliminate $j^{(Y)}$, the effective low q^2 Lagrangian (7) may be cast into a form in which the parameters are directly related to the known empirical constants G_F , $\sin^2 \theta_W$, ρ and C . One finds

*) Condition (9) may also be introduced within the framework of the general electroweak mixing scheme by the additional postulate^{1),2),9)} of unification in the sense of asymptotic $SU(2) \times U(1)$ symmetry.

$$2 \mathcal{L}_{\text{eff}}^{NC}(q^2 \rightarrow 0) = - \frac{e^2}{q^2} j_{\text{em}}^2 + \rho \frac{8G_F}{\sqrt{2}} \left((j^{(3)} - \sin^2 \theta_W j_{\text{em}})^2 + C j_{\text{em}}^2 \right), \quad (11)$$

where the charged current normalization (1) has been inserted and ρ , $\sin^2 \theta_W$ and C are given by

$$\rho \equiv 1 + \sqrt{2} G_Y / 8G_F \geq 1, \quad (12)$$

$$\sin^2 \theta_W \equiv \rho^{-1} (S_W^2 + (\rho - 1)(1 - S_Y^2)),$$

$$\rho \cdot C \equiv C_W + (\rho - 1)C_Y + (\rho - 1)\rho^{-1}(1 - S_W^2 - S_Y^2)^2 \geq C_W.$$

The empirical value¹⁶⁾ of $\rho = 1 \pm 0.03$ shows that the isoscalar contribution G_Y is much suppressed relative to G_F . The spectrum of the isoscalar states thus has to set in at masses which are several times larger than the lowest isovector boson mass m_W .

Specializing to a single W boson, and putting $\rho \approx 1$, we obtain the W dominance approximation suggested and examined recently^{12),13)}. In this case $C_Y = C_W = C = 0$, and the normalization (1), together with the saturation condition (9) and the eigenvalue equation (4), imply the canonical mass relations $m_W = M_W \approx 79 \text{ GeV}$ and $m_Z = M_Z \approx 90 \text{ GeV}$.

Let us now investigate the stability of these mass formulas if higher mass contributions are taken into account. For this purpose we approximate the isoscalar (hypercharge) contribution, which sets in at much higher masses than the isovector one, by a simple pole. Examining (10) [with $W \rightarrow Y$] then shows $C_Y = 0$ and $S_Y^2 \equiv \lambda_Y^2$. Assuming that the γY transition strength λ_Y is approximately given by $\lambda_Y^2 \approx \sin^2 \theta_W \approx 0.23$ (in analogy to $\lambda_W \approx 0.23$ in the W dominance case), and using $\rho \leq 1.03$, we obtain

$$S_W^2 \approx \sin^2 \theta_W, \quad (13)$$

which we will use in our subsequent analysis of the isovector case.

Specializing the normalization condition (1), the NC constraint in (10) with (13), and the compositeness constraint (9) to the two boson W, W' case, we have

$$\begin{aligned}
 g_W/m_W^2 + g_W'^2/m_W'^2 &= 8G_F/\sqrt{2}, \\
 \lambda_W g_W/m_W^2 + \lambda_W' g_W'/m_W'^2 &= 8G_F \sin^2 \theta_W / e\sqrt{2}, \quad (14) \\
 \lambda_W g_W + \lambda_W' g_W' &= e
 \end{aligned}$$

as a starting point for our subsequent analysis. In addition, let us make use of the duality relationship between transitions to vector bosons and haplon-antihaplon pairs [in the terminology of Ref. 6)], which has recently been employed^{11),12)} to estimate the W, W' level spacing from the number of hypercolours and the empirical value of $\sin^2 \theta_W$. Similar to the case of photon vector meson couplings in e^+e^- annihilation, the duality relationship implies

$$\lambda_W' = \lambda_W m_W / m_W'. \quad (15)$$

We thus have four relations (14), (15) between the six parameters m_W, m_W', g_W, g_W' and λ_W, λ_W' . It is convenient to choose the smaller W mass, m_W , and the ratio $r \equiv m_W'/m_W$ as the two remaining independent parameters. We note that from recent considerations^{11),12)} a value of $r \approx 5$ may be more realistic than a value of $r \approx 1$.

While m_W and r are free parameters, there are nevertheless restrictive bounds on m_W as a function of r , which are displayed in Fig. 2. Let us now turn to a derivation of these bounds which, together with the bounds on the neutral boson mass, constitute the main result of the present paper.

The most conservative bound is obtained from the requirement (6) that the neutral boson masses resulting from mixing should be real. In the present case we have, from (6),

$$\lambda_W^2 + \lambda_W'^2 < 1 \quad (16)$$

Using (14) and (15), this relation is converted into a bound on m_W as a function of $x \equiv 1/r$. With $M_W^2 = \alpha\pi/\sqrt{2}G_F \sin^2 \theta_W \approx (79 \text{ GeV})^2$, it is given by

$$\left. \frac{m_W^2}{M_W^2} \right|_{\text{Max}}^{\text{Min}} = \frac{1}{2} (1+x^2) \left(1 + \frac{(1-x^2)^2}{(1+x^2)^2 2 \sin^2 \theta_W} \right) \quad (17)$$

$$\pm \frac{(1-x^2)}{(1+x^2) 4 \sin^2 \theta_W} \left(4 \sin^2 \theta_W \cos^2 \theta_W (1+x^2)^2 + (1-x^2)^2 \right)^{\frac{1}{2}}.$$

It is displayed in Fig. 2. An absolute upper bound is obtained in the limit of large level spacing, $r = 1/x \rightarrow \infty$, which reads

$$m_W^2 \leq M_W^2 \left(1 + 2 \sin^2 \theta_W + (1 + 4 \sin^2 \theta_W \cos^2 \theta_W)^{\frac{1}{2}} \right) / 4 \sin^2 \theta_W \quad (18)$$

$$\cong (135 \text{ GeV})^2.$$

This bound on the lowest charged boson mass is more stringent than the bound $m_W \leq M_W / \sin \theta_W \cong 165 \text{ GeV}$ first obtained by Bjorken¹⁾. The difference is due to the assumption of composite quarks and leptons as embodied in the form factors in (2) and leading to (9), together with the duality constraint (15). We will come back to (18) in connection with the neutral boson mass.

An empirical bound on m_W within the present framework is implied by the PETRA bound¹⁷⁾ on the low-energy parameter C . With $\rho \cong 1$, we have, from (10) and (13),

$$C_W = \frac{e^2 12}{8 G_F} \left(\frac{I_W^2}{m_W^2} + \frac{I_W'^2}{m_W'^2} \right) - \sin^2 \theta_W \leq C \leq C_{\text{exp}} \quad (19)$$

where C_{exp} is the empirical bound from $e^+e^- \rightarrow \mu^+\mu^-$. Again, using (14) and (15), the restriction (19) is converted into

$$\left. \frac{m_W^2}{M_W^2} \right|_{\text{Max}}^{\text{Min}} = M_W^2 \frac{(1+x^4)(1+x^2 \pm (1-x^2)\sqrt{C_{\text{exp}}/\sin^2 \theta_W})}{(1+x^2)^2 - (1-x^2)^2 C_{\text{exp}}/\sin^4 \theta_W}. \quad (20)$$

For $r \equiv 1/x \rightarrow \infty$ we obtain the absolute bound

$$\left. \frac{m_W^2}{M_W^2} \right|_{\text{Max}}^{\text{Min}} = M_W^2 \frac{\sin^4 \theta_W \pm \sin^2 \theta_W \sqrt{C_{\text{exp}}}}{\sin^4 \theta_W - C_{\text{exp}}}. \quad (21)$$

Inserting the experimental bound¹⁷⁾ $C \leq C_{\text{exp}} = 0.021$, yields $62 \text{ GeV} \leq m_W \leq 127 \text{ GeV}$. In Fig. 2 we plot the boundary for the more restrictive value of $C \leq 0.01$, which is within experimental reach and leads to $65 \text{ GeV} \leq m_W \leq 105 \text{ GeV}$.

If we allow for additional theoretical input, an even more restrictive bound on m_W is obtained. The couplings of the ground state W and the excited state W' have been denoted by g_W and g'_W . It is reasonable to expect the inequality

$$|g'_W| \leq |g_W|, \quad (23)$$

which is valid, for example, in bound state models for the binding. Again employing (14) and (15) we find from (23)

$$M_W^2 \frac{(1+x^3)}{(1+x)} \leq m_W^2 \leq M_W^2 \frac{(1-x^3)}{(1-x)}. \quad (24)$$

This restriction on m_W is also shown in Fig. 2. Writing the saturation condition (9) in the form

$$\lambda_W g_W (1 + \lambda'_W g'_W / \lambda_W g_W) \equiv \lambda_W g_W (1 + \varepsilon) = e, \quad (25)$$

ε denotes the relative contribution of W' and may be calculated as a function of m_W and r . A point belonging to a 20% contribution from W' is indicated in Fig. 2.

Let us finally turn to the neutral boson masses. The position of the neutral masses relative to the unmixed (charged) ones is determined by the eigenvalue equation (4). We start by assuming that m'_W [i.e., r] and the lowest isoscalar (Y) boson mass are sufficiently large, such that their contributions to the eigenvalue equation are negligible as far as the determination of the smallest neutral boson mass is concerned. Under this assumption, (4) reduces to the simple mass relation

$$m_Z^2 = \frac{m_W^2}{1 - \lambda_W^2}, \quad (26)$$

where λ_W is to be expressed in terms of m_W and r by using (14) and (15), and the limit $r \rightarrow \infty$ is to be taken. One finds

$$\lambda_W^2 = \frac{\sin^2 \theta_W}{m_W^2 M_W^2} \left((m_W^2 - M_W^2)^2 + m_W^4 \right). \quad (27)$$

For the limiting value of $\lambda_W = 1$, we recover the bound (18) implying $m_W \leq 135$ GeV. Our mass relation (26), (27) for the least massive neutral boson of mass, m_Z , in terms of the charged boson mass, m_W (under the assumption of large level spacing, $r \rightarrow \infty$) is plotted in Fig. 3. For comparison, we also show the mass relation of Bjorken¹⁾ and Hung and Sakurai⁹⁾ based on $\gamma_W^{(0)}$ mixing and an independent point-like γ lepton (quark) interaction, for which (27) must be replaced by

$$\lambda_W^2 = \frac{m_W^2}{M_W^2} \sin^2 \Theta_W. \quad (28)$$

Both relations, i.e., (26) with either (27) or (28), coincide for $m_W \equiv M_W \equiv 79$ GeV, but yield different results for other values of m_W . In particular, our mass relation (26) with (27) implies the more restrictive upper bound $m_W \leq 135$ compared with $m_W \leq 165$ GeV from (26) with (28). The difference is due to the compositeness assumption for weak bosons as well as leptons and quarks, which implies both the duality relationship (15) characteristic of point-like γ haplon interactions, and the saturation condition (9). Both relations conspire in such a manner that even in the limit of large level splitting between W and W' ($r \rightarrow \infty$, i.e., $r \gtrsim 5$ in practice), the mass relations are different from those in the photon single weak boson mixing scheme not explicitly incorporating a composite structure for leptons and quarks. Nevertheless, in the mass interval, $70 \text{ GeV} \leq m_W \leq 100 \text{ GeV}$ ($80 \text{ GeV} \leq m_Z \leq 130 \text{ GeV}$), which is the most relevant one according to Fig. 2, the difference between (27) and (28) does not lead to dramatically different results.

In order to see how strongly our conclusions on m_Z are dependent on the assumptions $r \rightarrow \infty$ and $m_Y \rightarrow \infty$, we also calculated m_Z as a function of m_W for finite values of $r \equiv m'_W/m_W$ and $m_Y \rightarrow \infty$, as well as for finite r and $m_Y = m'_W$ and $\lambda_Y = \lambda_W$. For $m_Y \rightarrow \infty$, in Fig. 4 we plot the mass shift $m_Z - m_W$ in the relevant interval of m_W . For $r \equiv 5$, the curve is found to practically coincide with the one for $r \rightarrow \infty$. For $r = 2$, there are deviations as indicated, in particular for $m_W > M_W$. Similar results are obtained for $m_Y = m'_W$ and $\lambda_Y = \lambda_W$, but we refrain from showing them.

In Fig. 5 we show the bounds on the neutral boson mass, m_Z , obtained for $C = 0.01$ and $g'_W = g_W$ as a function of r . They result from combining the bounds on m_W in Fig. 2 with the mass shifts in Figs. 3 and 4. For $C = 0.01$, we note the absolute restriction $72 \text{ GeV} \leq m_Z \leq 145 \text{ GeV}$, while for $r = 5$, we have $72 \text{ GeV} \leq m_Z \leq 130 \text{ GeV}$.

To summarize, we consider weak interactions as residual forces between composite leptons and quarks mediated by composite bosons (in the low-energy approximation). The composite nature of fermions and bosons implies photon vector boson mixing, as well as photon interactions with leptons (quarks) via electromagnetic form factors (Fig. 1). The $q^2 \rightarrow 0$ effective interaction (11) is consistent with experiment. The first charged and neutral bosons are predicted to lie in the intervals $65 \text{ GeV} \lesssim m_W \lesssim 95 \text{ GeV}$ and $75 \text{ GeV} \lesssim m_Z \lesssim 110 \text{ GeV}$, respectively. An absolute bound on m_W is given by $m_W \lesssim 135 \text{ GeV}$. The single W dominance result^{12),13)} $m_W = M_W = 79 \text{ GeV}$, and $m_Z = M_Z = 90 \text{ GeV}$, is thus little affected (by approximately $\pm 20\%$) by more massive contributions. Should the least massive bosons be found outside the above intervals, the present concept of compositeness, which is largely based on intuition gained from QCD and hadron physics, will clearly be ruled out [as well as the $SU(2) \times U(1)$ gauge theory]. A more radical view of compositeness (or something else?) will then be needed.

As the present predictions for the boson masses do not violently differ from the $SU(2) \times U(1)$ standard model ones¹⁵⁾ ($M_W = 82 \pm 2.4 \text{ GeV}$, $m_Z = 93 \pm 2.0 \text{ GeV}$ when radiative corrections¹⁸⁾ are included), it may take a long time to find out whether leptons, quarks and weak bosons are indeed of a composite nature. Apart from (obviously) desirable information in the TeV energy range, above the threshold for multilepton production precise measurements of all W and Z decay modes may help¹⁹⁾ us to decide on this important issue.

ACKNOWLEDGMENT

It is a pleasure to thank Reinhardt Kögerler for numerous useful discussions.

REFERENCES

- 1) J.D. Bjorken, Phys. Rev. D19 (1979) 335;
E.H. de Groot and D. Schildknecht, Zeit. für Physik C10 (1981) 55.
- 2) D. Schildknecht, Erice Lecture (1980), preprint BI-TP81/12; Proceedings to be published, ed. A. Zichichi, and Proceedings of the 1981 ISABELLE Workshop, Vol. 2 p. 492 (BNL 51443).
- 3) M.E. Peskin, Proceedings of the 1981 International Symposium on Lepton and Photon Interactions at High Energies, Bonn, ed. W. Pfeil, p. 880;
H. Harari, Weizmann Institute preprint WIS-82/1/Jan-ph;
R. Gatto, UGVA-DPT 1982/06-351.
- 4) H. Harari and N. Seiberg, Phys. Lett. 98B (1981) 269.
- 5) O.W. Greenberg and J. Sucher, Phys. Lett. 99B (1981) 339.
- 6) H. Fritzsch and G. Mandelbaum, Phys. Lett. 102B (1981) 319.
- 7) L. Abbott and E. Farhi, Phys. Lett. 101B (1981) 69.
- 8) R. Barbieri, R.N. Mohapatra and A. Masiero, Phys. Lett. 105B (1981) 369.
- 9) P.Q. Hung and J.J. Sakurai, Nucl. Phys. B143 (1978) 81;
J.J. Sakurai, Schladming Lecture 1982, MPI-PAE-PTh22/82 (1982).
- 10) H. Fritzsch and G. Mandelbaum, Phys. Lett. 109B (1982) 224.
- 11) P. Chen and J.J. Sakurai, Phys. Lett. 110B (1982) 481.
- 12) R. Kögerler and D. Schildknecht, CERN preprint TH-3231 (1982), to be published.
- 13) H. Fritzsch, D. Schildknecht and R. Kögerler, Phys. Lett. 114B (1982) 157.
- 14) M. Kuroda and D. Schildknecht, BI-TP81/22, Phys. Rev., in press;
N. Wright, UCLA preprint UCLA/81/TEP/14 (1981).
- 15) S.L. Glashow, Nucl. Phys. 22 (1961) 579;
S. Weinberg, Phys. Rev. Lett. 19 (1967) 1264;
A. Salam, Elementary Particle Theory, ed. N. Svartholm (Åmquist and Wiksell, Stockholm, 1968) p. 367.
- 16) F. Dydak, Proceedings of the International Conference on High Energy Physics, Geneva (1979) p. 25.
- 17) M. Davier, Report at the Paris Conference (1982).
- 18) W.J. Marciano and A. Sirlin, Nucl. Phys. B189 (1981) 442;
C.H. Llewellyn Smith and J.F. Wheeler, Phys. Lett. 105B (1981) 486.
- 19) F.M. Renard, CERN preprint TH-3304 (1982).

FIGURE CAPTIONS

- Figure 1 : In Fig. 1a the weak interactions between composite leptons and quarks due to composite W exchange (in the low-energy approximation) are shown. The dashed lines denote further lepton (quark) constituents which are not constituents of the W . In Fig. 1b the electromagnetic interaction (weak isovector part) is shown.
- Figure 2 : Various bounds on the mass of the charged W , m_W , as a function of the ratio $r \equiv m'_W/m_W$, where m'_W denotes a more massive contribution to the weak spectral function. Three different bounds are shown, based on the mixing condition (16), the constant C , and the dynamical requirement (23).
- Figure 3 : The neutral boson mass m_Z , as a function of the charged one, m_W for the case of large level spacing ($r \rightarrow \infty$).
- Figure 4 : The mass shift $(m_Z - m_W)$ as a function of m_W in the relevant m_W range for different assumptions on the level spacing, i.e., $r \equiv m'_W/m_W$.
- Figure 5 : Bounds on the mass of the neutral boson, m_Z , as a function of $r \equiv m'_W/m_W$.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Handwritten text, likely bleed-through from the reverse side of the page. The text is arranged in several paragraphs, with some lines appearing as lists or bullet points. The handwriting is cursive and somewhat faded.