Extra Composite W and Z Bosons Implied by Complementarity

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Abstract

It is demonstrated that vector meson dominance (such as Z) of the photon shows up in a gauge model based on $SU(2)^{loc}_{1L} \times SU(2)^{loc}_{2L} \times U(1)^{loc}_{Y}$ with unbroken and confined $SU(2)^{loc}_{1L} \times SU(2)^{loc}_{2L}$. Left - handed quarks ($q^A_i$ for A=1,2,3 and i=1,2) and leptons (ℓ_i) are composites of scalars, $\tilde{w}_{Li}$, carrying the weak charge and spinors, c^α_L (α = 0,1,2,3), carrying the three colors (α = 1,2,3) and B - $L(\alpha = 0)$, as $q^A_{iL} \sim \tilde{w}_{Li}c^A_L$ and $\ell_{iL} \sim \tilde{w}_{Li}c^0_L$. The confined gauge model is shown to be equivalent to the conventional model realized in the Higgs phase as far as the scalar degrees of freedom are frozen.

One of the useful ideas on compositeness of "elementary" particles[1] is the notion of complementarity[2] for a non-abelian gauge theory used as underlying dynamics.[3] When it is applied to weak bosons, the Glashow-Weinberg-Salam (GWS) model based on the spontaneously broken $SU(2)^{loc}_L \times U(1)^{loc}_Y$ symmetry[4] is (almost) equivalent to the model on $U(1)^{loc}_{em}$ with the confined "color" $SU(2)^{loc}_L$ symmetry, *i.e.*, the Bjorken-Hung-Sakurai (BHS) model for the kinetic γ - Z mixing scheme.[5] The weak bosons, $W^\pm$ and Z, are made as[6] $W^\pm_\mu \sim Tr(\tau^{(\pm)}\tilde{w}^\dagger_L D_\mu \tilde{w}_L)$ and $Z_\mu \sim Tr(\tau^{(3)}\tilde{w}^\dagger_L D_\mu \tilde{w}_L)$, where $\tilde{w}_L$ is a scalar carrying the weak charge and is represented by the Higgs scalar ϕ as $\tilde{w}_L = (\phi^G, \phi)$. At the same time, L-handed quarks (q^A_{Li} for A=1,2,3 and i=1,2) and leptons (ℓ_{Li}) are regarded as composites described by $q^A_{Li} = \tilde{w}^a_{Li}c^A_{La}$ and $\ell_{Li} = \tilde{w}^a_{Li}c^0_{La}$. Starting with the lagrangian of the GWS model, one can derive the BHS model with the kinetic mixing parameter, λ, for γ - Z, $\lambda = e/g$ under the constraint of $\tilde{w}^\dagger_L\tilde{w}_L = I$.[7] This equality can be regarded as a result of vector meson (such as Z) dominance of the photon.[8]

One may ask what will happen in QCD, which is realized in the confined color $SU(3)^{loc}_c$ symmetry. Let the flavor group be $SU(3)_f$ for q^i_A (A, i = 1,2,3), *i.e.*, u, d and s. Since there is no scalar, complementarity is only possible if scalar diquarks, $\Phi^A_i = \varepsilon^{ABC}\varepsilon_{ijk}q^j_B q^k_C/f^2_\pi$, are formed.[9] Then QCD gets broken completely as fas as diquarks are condensed to develop $< \Phi_i^A > = f_\pi \delta_i^A$. In this phase, *i.e.*, the Higgs phase of QCD, the gluons, G_A^B, become massive and serve as the octet vector mesons including ρ and quarks act as the octet baryons including P, N and Λ. While, in the confining phase, color-singlet composites are supplied by $\Phi_i^A q_A^j / f_\pi$ ($\sim qqq$ for $\Phi \sim qq$) as the octet baryons and by $\Phi^\dagger i D_\mu \Phi / f_\pi^2$ ($\sim \bar{q}\bar{q}qq$) as the octet vector mesons. Then, the both phases at low-energies contain the octet baryons and vector mesons. The transmutation of gauge bosons (*i.e.*, gluons) into massive vector mesons (*i.e.*, ρ etc.) arises.[10] The similar suggestion has been lately advocated on the basis of the non-linear sigma model with a dummy hidden symmetry,[11] where gauge bosons are regarded as composites and scalar mesons like π are taken into account but without the baryons as qqq. Although it was examined in the Higgs (or broken) phase, the confining (or unbroken) phase is also possible by identifying $\xi_L \sim \exp(i\pi/f_\pi)\Phi$ and $\xi_R \sim \exp(-i\pi/f_\pi)\Phi$.

Along this line for the compositeness of "elementary" particles, a possible new physics beyond the BHS model is investigated by introducing extra W and Z bosons. The simpler extension is to include extra $W^\pm$ and Z as another set of $W^\pm$ and Z. The gauge group is $SU(2)_{1L}^{loc} \times U(1)_Y^{loc} \times SU(2)_{2L}^{loc}$ ($= G^{loc}$). The extra vector bosons in this case are allowed to be as light as 100 GeV that is still consistent with the low-energy weak interaction phenomenology mainly because the couplings to quarks and leptons are of the V - A form, which does not alter low-energy charged-current interactions. The gauge group, G^{loc}, itself is not new and has been discussed by Barger, Keung and Ma and lately by Georgi, Jenkins and Simmons.[12] The lagrangian with extra composite weak bosons is characterized by vector meson dominances, which are described by the kinetic mixing terms among the photon (A^0), W and Z (mainly V_1) and extra W and Z (mainly V_2)[13]

$$\mathcal{L}_{mix} = -\frac{1}{2}\lambda_{12} V_{1\mu\nu}^{(i)} V_2^{(i)\mu\nu} - \frac{1}{2}(\lambda_{\gamma 1} V_{1\mu\nu}^{(3)} + \lambda_{\gamma 2} V_{2\mu\nu}^{(3)}) A^{0\mu\nu}. \tag{1}$$

We will demonstrate how the kinetic mixings are generated in the confining phase of $SU(2)_{1L}^{loc} \times SU(2)_{2L}^{loc}$.

The particles contained are 1) gauge bosons of $(G_{1\mu}^{(i)})_a^b$ (i = 1,2,3; a,b = 1,2), $(G_{2\mu}^{(i)})_{a'}^{b'}$ (a', b' = 1,2) and B_μ; 2) fermions of $c_{La}^{(1)\alpha}$ (α = 0,1,2,3) and $c_{La'}^{(2)\alpha}$: $c_{La}^{(1)\alpha}$ as (1/2, 0; Y) and $c_{La'}^{(2)\alpha}$ as (0, 1/2; Y) and; 3) two sets of scalars of $\tilde{w}_{Li}^{a'}$ as (0, 1/2; $-\tau^{(3)}$) and $\xi_{a'}^a$ as (1/2, 1/2; 0), where three numbers inside the parentheses denote the quantum numbers of ($SU(2)_{1L}^{loc}$, $SU(2)_{2L}^{loc}$; $U(1)_Y^{loc}$). The R - handed fermions are treated as "color"- singlets, $\psi_{Ri}^{(1,2)}$: (0,0; Y_i). The four colors specified by α is the Pati-Salam $SU(4)$ color.[14]

Let us demand that $\mathcal{G}^{loc} = SU(2)_{1L} \times SU(2)_{2L}$ be confined to generate composite particles. To examine this phase, the scalars are subject to the nonlinear realization that is achieved by $\tilde{w}^{a'}_{Li}(\tilde{w}^{\dagger}_{L})^{j}_{a'} = \Lambda^2_{\tilde{w}}\delta^j_i$, $(\tilde{w}^{\dagger}_{L})^{i}_{a'}\tilde{w}^{b'}_{Li} = \Lambda^2_{\tilde{w}}\delta^{b'}_{a'}$, $(\xi^{\dagger})^{a}_{a'}\xi^{b'}_{a} = \Lambda^2_{\xi}\delta^{b'}_{a'}$ and $\xi^{a}_{a'}(\xi^{\dagger})^{b'}_{a} = \Lambda^2_{\xi}\delta^{b'}_{a'}$, which are of course all "color" - singlets. Also defined are "color" - singlet composite fermions for L - handed quarks (q) and leptons (ℓ) and composite vector bosons, V_1 and V_2 for W, Z, W' and Z', according to:

$$\ell^{(1)}_{Li} = \sum_{aa'} \tilde{w}^{a'}_{Li}\xi^{a}_{a'}c^{(1)0}_{La}/\Lambda_{\tilde{w}}\Lambda_{\xi}, \quad q^{(1)A}_{Li} = \sum_{aa'} \tilde{w}^{a'}_{Li}\xi^{a}_{a'}c^{(1)A}_{La}/\Lambda_{\tilde{w}}\Lambda_{\xi}, \tag{2a, b}$$

$$\ell^{(2)}_{Li} = \sum_{a'} \tilde{w}^{a'}_{Li}c^{(2)0}_{La'}/\Lambda_{\tilde{w}}, \quad q^{(2)A}_{Li} = \sum_{a'} \tilde{w}^{a'}_{Li}c^{(2)A}_{La'}/\Lambda_{\tilde{w}}, \tag{2c, d}$$

$$\begin{aligned} f_2(V_{2\mu})^j_i &= -\sum_{aba'b'} \tilde{w}^{a'}_{Li}[\xi^{a}_{a'}(i\partial_\mu + g_1 G_{1\mu})^{b}_{a}(\xi^{\dagger})^{b'}_{b}/\Lambda^2_{\xi} - g_2(G_{2\mu})^{b'}_{a'}](\tilde{w}^{\dagger}_{L})^{j}_{b'}/\Lambda^2_{\tilde{w}}, \\ f(V_{1\mu})^j_i + f_2(V_{2\mu})^j_i &= \sum_{a'b'} \tilde{w}^{a'}_{Li}(i\partial_\mu + g_2 G_{2\mu})^{b'}_{a'}(\tilde{w}^{\dagger}_{L})^{j}_{b'}/\Lambda^2_{\tilde{w}} - g'(\tau^{(3)}/2)^j_i B_\mu. \end{aligned} \tag{2e, f}$$

as well as $f'A^0_\mu = g'B_\mu$. Hereafter, quarks and leptons are denoted by $\psi^{\alpha}_{Li} = \ell_{Li}$ (α=0); $= q^{A}_{Li}$ (α (=A) = 1,2,3).

The "color" - singlet quarks and leptons now come in the two forms: $\psi^{(1)\alpha}_{Li} \sim \tilde{w}_{iL}\xi c^{(1)\alpha}_{L}$ and $\psi^{(2)\alpha}_{Li} \sim \tilde{w}_{iL}c^{(2)\alpha}_{L}$. The extra scalar, ξ, carrying both "colors" yields additional quark - lepton states. These two sets of the quark - lepton states may be regarded as two generations of quarks and leptons. The resulting low-energy phenomenology will be different depending on which states are assigned to "e"- and "μ"- generations. And it can be found that the present phenomenology is consistent if "e" and "μ" are identified with $\psi^{(2)}$ for $(\tilde{w}_L, \xi)$ (thus primarily couples to the extra bosons).[f1] but with $\psi^{(1)}$ (thus does not primarily couple to the extra bosons, V_2) if $\tilde{w}_L$ is replaced by $\tilde{w}'_L$: (1/2, 0, $-\tau^{(3)}$).

The lagrangian for the gauge theory evaluated in the confining phase, $\mathcal{L}_{conf}$, is found to be

$$\mathcal{L}_{conf} = -\frac{1}{2g_1^2}Tr(v_{1\mu\nu}v_1^{\mu\nu}) - \frac{1}{2g_2^2}Tr(v_{2\mu\nu}v_2^{\mu\nu}) - \frac{e^2}{g'^2}A^0_{\mu\nu}A^{0\mu\nu} + i\overline{\psi^{(1)}_L}\gamma^\mu(\partial_\mu$$

$f1$) In the Georgi-Jenkins-Simmons assignment (for the case of $(\tilde{w}_L, \xi)$), quarks turn out to be $\psi^{(1)}$ that couples only to V_1 and leptons, $\psi^{(2)}$ that couples to V_2 as well as V_1 in the confining phase.

$$- if_1 V_{1\mu} - ieQ_{em}A^0_\mu)\psi^{(1)}_L + i\overline{\psi^{(1)}_R}\gamma^\mu(\partial_\mu - ieQ_{em}A^0_\mu)\psi^{(1)}_R$$
$$+ i\overline{\psi^{(2)}_L}\gamma^\mu(\partial_\mu - if_1 V_{1\mu} - if_2 V_{2\mu} - ieQ_{em}A^0_\mu)\psi^{(2)}_L + i\overline{\psi^{(2)}_R}\gamma^\mu(\partial_\mu$$
$$- ieQ_{em}A^0_\mu)\psi^{(2)}_R + \frac{1}{2}\Lambda^2_{\tilde{\omega}}(f_1 V^{(i)}_{1\mu} + f_2 V^{(i)}_{2\mu})^2 + \frac{1}{2}(f_2\Lambda_\xi)^2 V^{(i)}_{2\mu} V^{(i)\mu}_2, \qquad (2)$$

where

$$v_{1\mu} = f_1 V_{1\mu} + f'\frac{\tau^{(3)}}{2}A^0_\mu, \qquad v_{2\mu} = f_1 V_{1\mu} + f_2 V_{2\mu} + f'\frac{\tau^{(3)}}{2}A^0_\mu. \qquad (3a, b)$$

We find that $1/f_1^2 = 1/g_1^2 + 1/g_2^2$, $1/f'^2 = 1/f_1^2 + 1/g'^2$ ($\equiv 1/e^2$) and $f_2 = g_2$ for canonical kinetic terms of $V_{1,2}$ and A^0. The couplings of f', f_1 and f_2, respectively, turn out to be nothing but the electromagnetic charge, e, g_L of the diagonal subgroup of $SU(2)_{1L} \times SU(2)_{2L}$ and g_2 of $SU(2)_{2L}$, defined in the Higgs phase. For "color" singlet composites, the unbroken $U(1)^{loc}_Y$ symmetry is coincident with the $U(1)^{loc}_{em}$ symmetry. The third - isospin is provided through the $U(1)^{loc}_Y$ charge of $\tilde{w}_L$, which ensures $Q_{em} = (\tau^{(3)} + Y)/2$.The kinetic mixings are now characterized by f_1/f_2 ($= \lambda_{12}$) for V_1 and V_2, $e/f_{1,2}$ ($= \lambda_{\gamma 1,2}$) for A^0 and $V_{1,2}$. The kinetic mixings cause the following field - redefinition:

$$\mathcal{V}^{(3)}_{1\mu}(\equiv Z^0_\mu) = \sqrt{1-\lambda^2_{\gamma 1}}(V^{(3)}_{1\mu} + \lambda_{12}V^{(3)}_{2\mu}), \quad \mathcal{V}^{(3)}_{2\mu} = \sqrt{1-\lambda^2_{12}}V^{(3)}_{2\mu}, \qquad (4a, b)$$
$$\mathcal{V}^{(\pm)}_{1\mu} = V^{(\pm)}_{1\mu} + \lambda_{12}V^{(\pm)}_{2\mu}, \qquad \mathcal{V}^{(\pm)}_{2\mu} = \sqrt{1-\lambda^2_{12}}V^{(\pm)}_{2\mu}, \qquad (4c, d)$$
$$A_\mu = A^0_\mu + \lambda_{\gamma 1}V^{(3)}_{1\mu} + \lambda_{\gamma 2}V^{(3)}_{2\mu}. \qquad (4e)$$

Note that $V^{(i)}_1$ describe the weak bosons, $W^\pm$ and Z, in the limit of $\lambda_{12} \to 0$. The difference between $\psi^{(1)}$ and $\psi^{(2)}$ becomes now manifest: $\psi^{(1)}$ couples to V_1 and A^0 while $\psi^{(2)}$ couples to the extra bosons, V_2, as well as V_1 and A^0.

The derived lagrangian is the generalization of the γ - Z mixing model for W and Z.[5] The condition of e/f_1 ($= \cos\theta$) to yield $m_W = \cos\theta m_Z$ is enlarged to $m_W m_{W'} = \cos\theta m_Z m_{Z'}$.[15] [16] The less-model dependent symmetry-argument based on the asymptotic symmetry[16] also leads to the extended mass relation. It is not difficult to show the equivalence of the interactions in the confining and Higgs phase as far as the scalar degrees freedom are frozen.[17] One can observe that complementarity is respected in a way that the $SU(2)^{loc}_{1L} \times U(1)^{loc}_Y \times SU(2)^{loc}_{2L}$ model provides the same physics both in the Higgs phase (with the mass mixing) and in the confining phase (with the kinetic mixing).[f2] As predictions, we show $\Gamma(Z \rightarrow \text{all})$ (in *Fig*.1) and $\Gamma(Z \rightarrow e^+e^-)$ (in *Fig*.2) calculated from $\mathcal{L}_{conf}$, (2), whose magnitudes are lower than the standard model predictions.[20]

One may wish to introduce extra bosons with the vector coupling to fermions (such as the ρ - like meson) instead of the V - A coupling discussed here. From the present discussions, it is expected that the ρ analogue is associated with $\mathcal{G}^{loc} = SU(2)^{loc}_{1L} \times SU(2)^{loc}_{V}$ with, say, $c_{La'}$: (0, 1/2; Y) and $c_{Ra'}$: (0, 1/2; Y).[21] However, if one demands complementarity, it turns out to be unsuccessful because the same "flavor" - interactions are generated for both L- and R- handed ("color"-singlet) fermions, namely no L - handed weak interactions are generated. The consistent realization is obtained if an additional A_1 - like meson (with the axial coupling to fermions) is present.[22] Then, the "color" confining group for the ρ- and A_1- like mesons is given by $\mathcal{G}^{loc} = SU(2)^{loc}_{1L} \times SU(2)^{loc}_{V} \times SU(2)^{loc}_{A}$. Correspondingly, three kinds of the scalars are necessary.

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$f2)$ It is also possible to show the equivalence of the model in the case of $\mathcal{G}^{loc} = SU(2)^{loc}_{2L}$.[18] The similar argument can be applied to models with an extra Z bosons based on $\mathcal{G}^{loc} = SU(2)^{loc}_{L} \times U(1)^{loc}$.[19]

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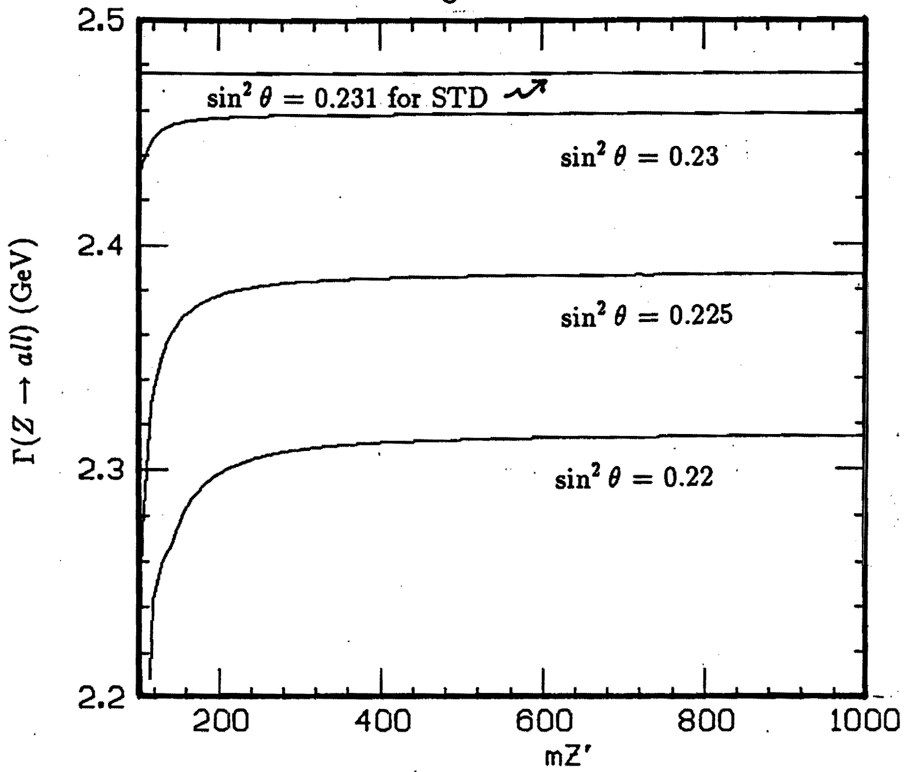
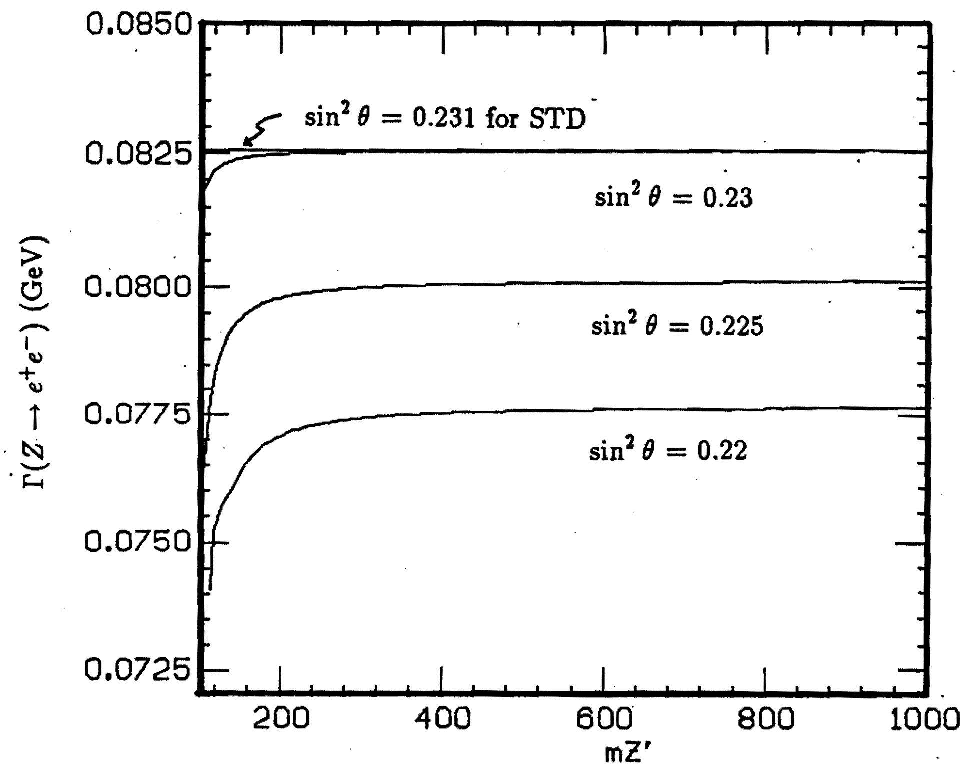
Figure 1



(m_Z, m_t)=(91.1 GeV, 100 GeV)

Figure 2



(m_Z, m_t)=(91.1 GeV, 100 GeV)