Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

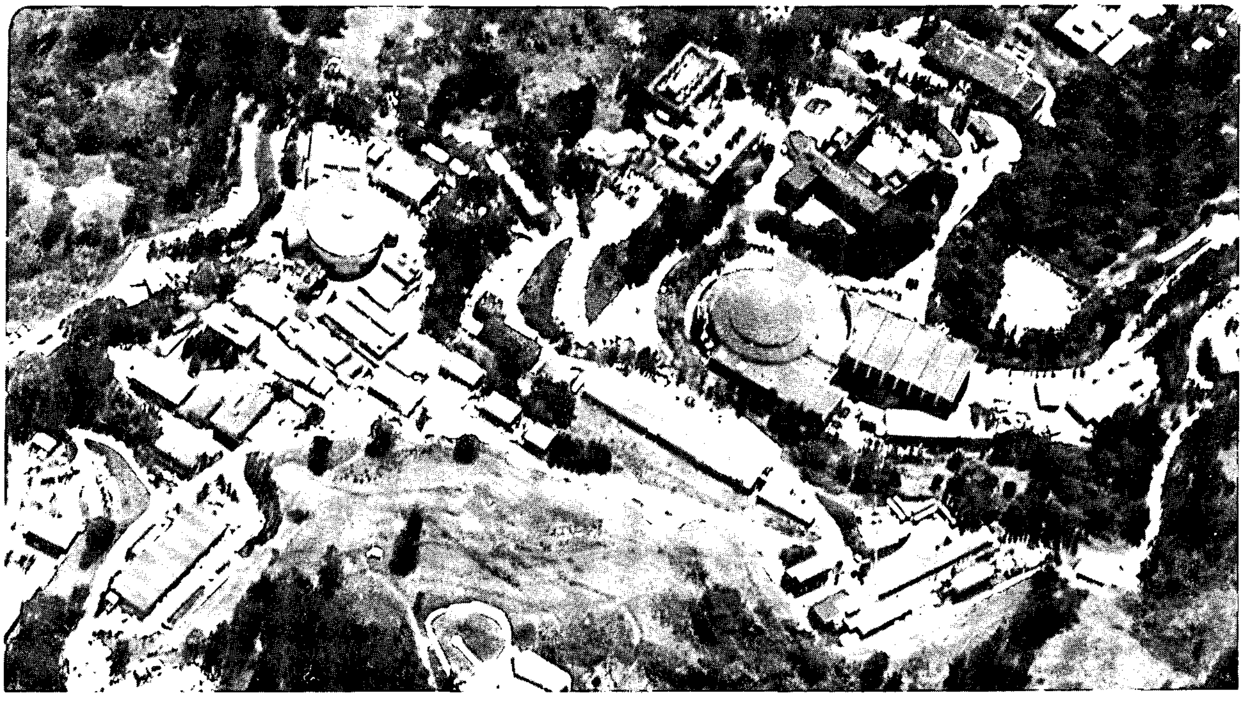
Physics Division

Presented at the Workshop on Colliders to
Super Colliders, Madison, WI,
May 11–22, 1987, and to be published
in the Proceedings

COMPOSITE WEAK BOSONS AT SUPERCOLLIDERS

M. Suzuki

June 1987



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

UCB-PTH-87/26
LBL-23633

COMPOSITE WEAK BOSONS AT SUPERCOLLIDERS

Mahiko Suzuki
Department of Physics and Lawrence Berkeley Laboratory
University of California, Berkeley, California 94720

To be submitted to Proceedings of the Workshop, "Colliders to Super Colliders" at University of Wisconsin, Madison, Wisconsin, 11-22 May, 1987.

Work supported in part by National Science Foundation Research Grant PHY-85-15857 and in part by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics of the U. S. Department of Energy under contract DE-AC03-76SF00098.

June 1987

COMPOSITE WEAK BOSONS AT SUPERCOLLIDERS

Mahiko Suzuki
Department of Physics and Lawrence Berkeley Laboratory
University of California, Berkeley, California 94720

SUMMARY

Following a brief survey of nongauge interactions of composite W and Z from a theoretical viewpoint, we point out some of conspicuous signatures of compositeness at supercolliders, in particular, $W\gamma$ and $Z\gamma$ productions through $q\bar{q}$ by interactions of dimension six. In these processes, a suppression factor $1/\Lambda^2$ due to compositeness scale Λ is largely compensated by longitudinal polarizations of W and Z, allowing us to probe up to high values of Λ.

NONGAUGE INTERACTIONS AND THEIR DIMENSIONS[1)]

Nongauge interactions of W and Z have dimensions four and more. While interactions of dimension higher than four are suppressed by inverse powers of the compositeness scale Λ, it is not so obvious how the nongauge interactions of dimension four are related to Λ. A dimensional argument does not always apply to dimension-four interactions; if nongauge couplings suggested by a naive dimension counting are correct, loop effects involving such interactions would generate unacceptably large corrections in many cases.[2)] In order to examine the nongauge interactions of dimension four, we must have an explicit model of composite W and Z.

A few dynamical mechanisms have been proposed to ensure the approximate gauge invariance in composite models. In the "strongly coupled standard model"[3)], for instance, the $SU(2)_L$ gauge symmetry is realized by requiring that the preon sector is heavy and weakly coupled. We recently constructed a dynamical toy model of composite W and Z. In this model[4)], all dimension-four interacrions approach the gauge couplings in the limit that the binding force is infinitely strong and the mass ratios of weak bosons to preons approach zero. All higher dimensional interactions are suppressed, in agreement with a naive expectation, by inverse powers of compositeness scale Λ, which is equal to the preon mass of the model. Although the model is unrenormalizable and unconfining, it seems to possess all other desirable dynamical features. The electroweak SU(2) gauge symmetry results from global SU(2) symmetry of the preons in the limit of tight binding. The γW^0 mixing leads us automatically to $m_Z^2 \cos^2\theta_W/m_W^2 = 1$ and the resulting low energy effective Lagrangean is identical with that of the standard theory with an infinite Higgs mass. We extract general features from such models.

THREE-BODY SELF-COUPLINGS

The three-body self-couplings of dimension four and six are written following the notation of Hagiwara et al as[5)]

$$L_{int}/g_{WWV} = ig_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{i\lambda_V}{m_W^2} W^\dagger_{\lambda\mu}W^\mu_\nu V^{\nu\lambda}, \qquad (1)$$

where V^μ = Z or γ field, $W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu$, and $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$. Since the binding force conserves C and P in our model, we have suppressed four additional terms which violate C and/or P. The interactions of (1) arise from the diagrams of Fig.1. By computing them explicitly, we find for the deviations of g_1^V and κ_V from their gauge limits and for λ_V

$$\left.\begin{aligned} g_1^V &= 1 + \Delta g_1^V, \quad \kappa_V = 1 + \Delta\kappa_V; \\ \Delta g_1^V &= c_1\, p^2/\Lambda^2, \\ \Delta\kappa_V &= c_2\, p^2/\Lambda^2, \\ \lambda_V &= c_3\, m_W^2/\Lambda^2, \end{aligned}\right\} (2)$$

where p^2 is the largest of external momenta squared and $c_{1,2,3}$ are constants of O(1) which do not contain the gauge coupling g nor $1/16\pi^2$.[6)] In spite that the interactions of g_1^V and κ_V are of dimension four, their deviations from the gauge limits are suppressed by $1/\Lambda^2$ and actually of dimension six, not four. This $1/\Lambda^2$ suppression ensures that loop corrections be under control in composite models. Without it, we need to keep fine tuning parameters each time higher loops are computed. We therefore believe that the behaviors in (2) are general characteristics of composite models.

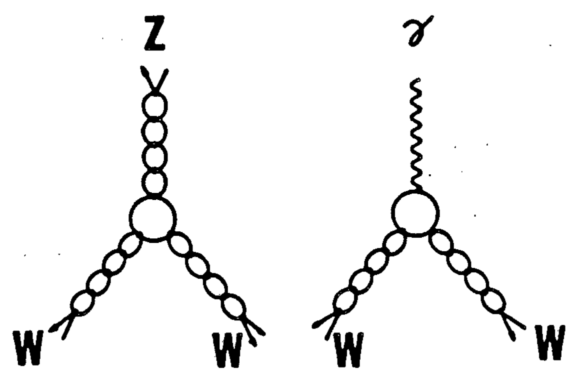


Fig.1. ZWW and γWW couplings. Bubbles mean an infinite series of them.

It is expected at LEP that g_1^V, κ_V, and λ_V will be measured with the accuracy of 10 %.[5)] Since $p^2 \simeq (2m_W)^2$ in $e^+e^- \to W^+W^-$ at LEP, it means that LEP will probe compositeness scale Λ up to roughly 0.5 TeV. Accuracy of measurement for g_1^V and κ_V will not be competitive at SSC. However, if the deviations really grow with squared momenta, as indicated in (2), their effects will be much larger at SSC than at LEP. In fact, it has been observed [7)] that λ_V may be probed with an accuracy significantly better at SSC because of the singular nature of dimension-six interactions.

FOUR-BODY SELF-COUPLINGS OF WEAK BOSONS

Some of four-body interactions of dimension four are allowed as gauge interactions, while others are forbidden. An example of the former is $g^2_{WWZ}\, a W^{\dagger}_{\mu} W^{\mu} Z_{\nu} Z^{\nu}$ and an example of the latter is $b Z_{\mu} Z^{\mu} Z_{\nu} Z^{\nu}$. We find from the diagrams of Fig.2 that for allowed couplings, deviations from their gauge limits behave as

$$a = 1 + O(1) \times (s,t \text{ or } u)/\Lambda^2, \tag{3}$$

while for forbidden couplings, their magnitudes are suppressed just like dimension-six interactions,

$$b = O(1) \times (s,t \text{ or } u)/\Lambda^2 \,. \tag{4}$$

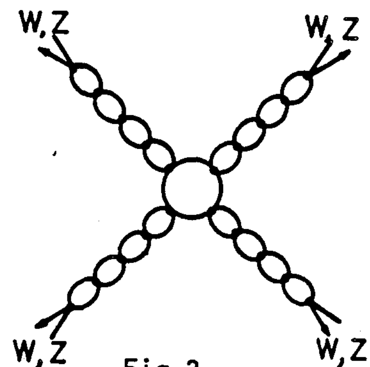


Fig.2.

Four-body self-coupling.

Here (s,t,u) are the Mandelstam variables. As before, any deviation from its gauge limit must be suppressed by powers of $1/\Lambda$ even though an interaction is of dimension four. It is this feature that warrants self-consistency of composite models beyond the lowest order processess.

It was suggested in some composite pictures [8)] that effective couplings like $Z\gamma gg$ and $Zggg$ may be much larger for composite Z than for elementary Z because gauge bosons interact among themselves directly through preons. Our finding is in disagreement with such a speculation. Gauge invariance with respect to γ and g forces those interactions to have dimension eight. Therefore, the associated couplings are suppressed by $1/\Lambda^4$ and very likely to be smaller than the effective interactions through light fermion loops unless Λ is comparable with m_Z. In particular, existence of direct couplings like $Z\gamma gg$ and $Zggg$ are highly model dependent.

Production of ZZ through WW by the nongauge interaction of (3), $WW \to ZZ$, is given by

$$\frac{d\hat{\sigma}}{d\hat{t}} \approx \frac{\pi}{4} \alpha_2^2 \frac{\hat{s}^4}{\Lambda^4 \, m_{WZ}^8} \,, \tag{5}$$

when the all bosons are longitudinally polarized. The steep $\hat{s}$ dependence in (5) arises because there is no compensating Higgs diagram for nongauge contributions. This singular $\hat{s}$ dependence may overcome the small $SU(2)_L$ coupling α_2 to allow detection of the nongauge contribution at energies of $\hat{s} > (\Lambda^4 m_{WZ}^6)^{1/5}$. For processes induced by nongauge interactions which grow steeply with energy, SSC will have a clear advantage over LEP. We ought to go after such processes in order to probe compositeness at SSC.

Although our toy model has not really incorporated successfully the light chiral fermions because of known outstanding difficulties,[1] we can make a reasonable guess on possible nongauge interactions which can arise in dynamically natural composite models. First of all, in models where W, Z and light fermions are all composite, left-handed quarks and leptons must contain at least one preon which is found in W and Z. Otherwise, there would not be an $SU(2)_L$ interaction. Quarks must also contain one preon or more that carry the QCD colors, but the colored preon need not be the same preon that enters W and Z. This is the reason why existence of the direct couplings like $Z\gamma gg$ are model dependent.

Among many four-body interactions which conserve chirality and global SU(2), those which can generate hard photons are of particular interest from an experimental viewpoint. An example of such interactions is

$$(e/\Lambda)^2 \, f \, (\bar{q}_L \gamma_\mu q_L) Z_\nu F^{\mu\nu} \, , \tag{6}$$

where $F^{\mu\nu}$ is the field tensor of γ (see Fig.3). We expect in composite models that

$$f = O(1) \tag{7}$$

The Z field may be replaced by the W field in (6). It should be emphasized, however, that a similar interaction with Z replaced by γ or g in (6) is not allowed by gauge invariance required of γ and g.[9] The interaction (6) can exist when the electroweak SU(2) gauge symmetry applies only to dimension-four interactions, not higher-dimensional interactions.

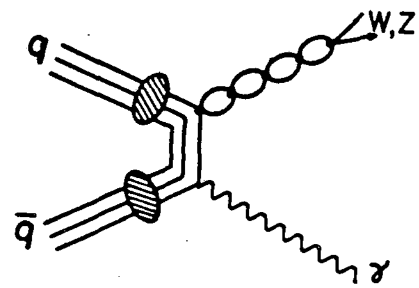


Fig.3. Four-body contact interaction of $Z(W)\gamma q\bar{q}$.

It therefore tests compositeness of light fermions and weak bosons. If the compositeness scales are different for quarks and (W,Z), the scale Λ in (6) represents the largest one of them.

With the interaction (6), the cross section for the process $q\bar{q} \to Z\gamma$ and $\to W\gamma$ due to the contact interaction is given by

$$\frac{d\hat{\sigma}}{d\hat{t}} \approx \frac{\pi}{4}\alpha^2 \frac{\hat{t}\,\hat{u}}{\Lambda^4 m_{WZ}^2 \hat{s}} \, , \tag{8}$$

while the standard theory predicts that the cross section scales as $d\hat{\sigma}/d\hat{t} \sim \pi\alpha^2/\hat{s}^2$.[10] In Eq. (8), $1/m_{WZ}^2$ arises from the longitudinal polarization of the final Z or W. The nongauge cross section (8) dominates over the corresponding standard theory term when $\hat{t}$ and $\hat{u}$ are comparable with $-\hat{s}$ and

$$\hat{s} > (\Lambda^2 m_{WZ})^{2/3} . \qquad (9)$$

For 1 TeV, the right-hand side of (9) is $\sim(0.5\ \text{TeV})^2$. It is worth searching hard photons from contact interactions at SSC. Other interesting processes are $q\bar{q} \to ZZ$ and WZ by interactions like $\bar{q}_L \gamma_\lambda q_L Z_\kappa \partial^\kappa Z^\lambda$. When both polarizations are longitudinal, their cross sections rise even more rapidly with energy than (8).

ACKNOWLEDGEMENT

Illuminating conversations with Ian Hinchliffe and Dieter Zeppenfeld are gratefully acknowledged. The author was supported by DOE contract DE-AC03-76SF00098 and by NSF grant PHY-85-15857.

REFERENCES

1. Peskin, M.E., Proceedings of 1981 International Symposium on Lepton and Photon Interactions at High Energies (Bonn, 1981), p.880; Proceedings of 1985 International Symposium on Lepton and Photon Interactions at High Energies (Kyoto, 1985), p.714 for review.
2. Herzog, F., Phys. Lett. 148B, 355 (1984); (E) 155B, 468 (1985).
   Suzuki, M., Phys. Lett. 153B, 289 (1985).
   Grau, A. and J.A. Grifols, Phys. Lett. 154B, 283 (1985).
   Van der Bij, J.J., Phys. Rev. D35, 1088 (1987).
3. Claudson, M. et al., Phys. Rev. D34, 873 (1986).
   Abbott, L.F. and E. Farhi, Nucl. Phys. B189, 547 (1981).
4. Suzuki, M., to be published.
5. Hagiwara, K. et al., Nucl. Phys. B282, 253 (1987).
6. To be precise, the coefficients $c_{1,2,3}$ involve a cutoff dependence in their denominators in the toy model of Ref. 5. However, presence of cutoff is due to unrenormalizability of the model. In a renormalizable model, this cutoff is expected to disappear.
7. Zeppenfeld, D., in these proceedings.
8. Renard, F.M., Phys. Lett. 116B, 269 (1984).
   Leurer, M. et al., Phys. Lett. 141B, 455 (1984).
9. Owens, J.F. et al., Snowmass 1984.
10. Brown, R.W. and K.O. Mikaelian, Phys. Rev. D19, 922 (1979).

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720