Title
SIGNATURES FOR STRONGLY INTERACTING W'S AND Z'S

Author
Gaillard, M.K.

Publication Date
1985-09-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

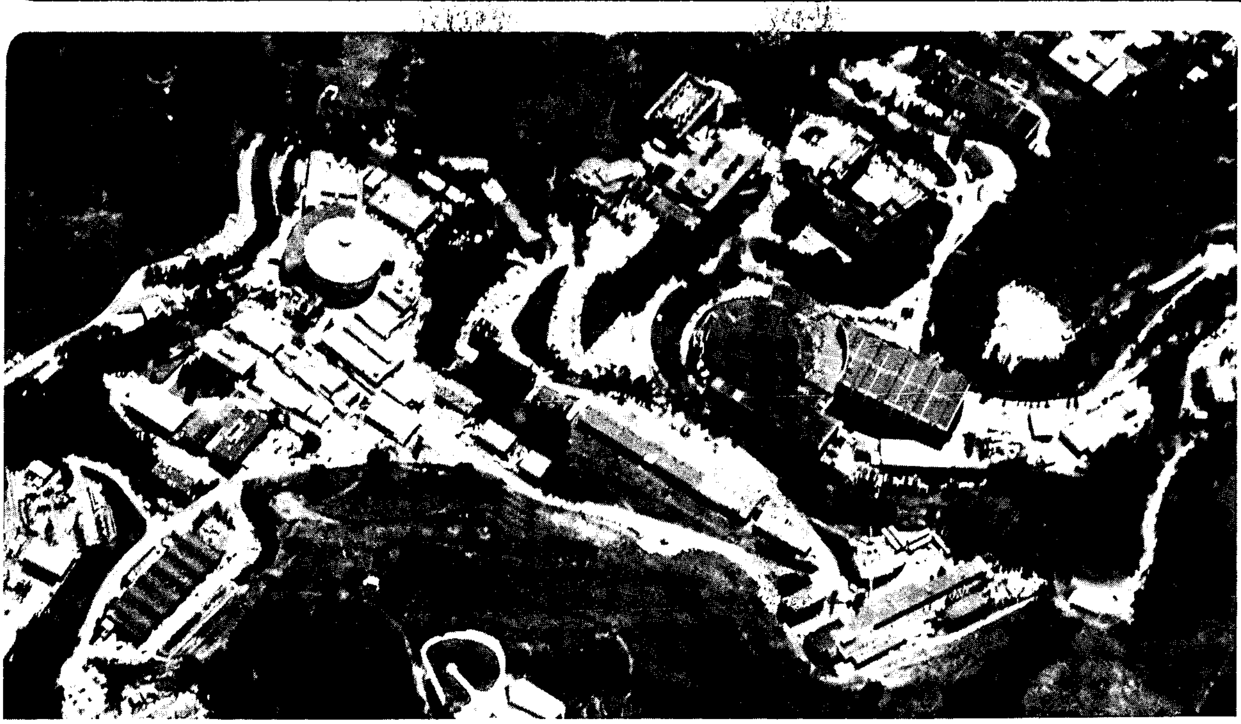
Physics Division

Presented at the International Europhysics Conference on High Energy Physics, Bari, Italy, July 18-24, 1985; and to be published in the Proceedings

SIGNATURES FOR STRONGLY INTERACTING W'S AND Z'S

M.K. Gaillard

September 1985



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

September 1985

LBL-20232
UCB-PTH-85/37

SIGNATURES FOR STRONGLY INTERACTING W'S AND Z'S*,**

Mary K. Gaillard***

Lawrence Berkeley Laboratory
and
Department of Physics
University of California
Berkeley, CA 94720

*To appear in the proceedings of the International Europhysics Conference on High Energy Physics.

**Work done in collaboration with M.S. Chanowitz

***Work supported 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 and in part by the National Science Foundation under Research Grant No. PHY-84-06608.

SIGNATURES FOR STRONGLY INTERACTING W'S AND Z'S*

Mary K. Gaillard
Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, CA 94720

The observed structure of the electroweak interactions is understood in terms of a spontaneously broken gauge theory. Although we have as yet no experimental indication as to the nature of the phenomenon responsible for symmetry breaking, general theoretical arguments set an upper limit of 1 or 2 TeV on the energy scale at which some manifestation of this phenomenon must occur. This scale defines a target for the effective hard collision energy that should be achieved in the next accelerator facility; the work [1] reported here was aimed at sharpening this requirement by studying the minimal manifestations of electroweak symmetry breaking that can be expected to occur in the TeV energy region if a Higgs particle with $m_H < 1TeV$ is not found. While we used the minimal Higgs model as a guide, the results obtained are of far more general validity. Our analysis relied on three tools, briefly discussed below.

1. VECTOR-SCALAR EQUIVALENCE. At high energies, $E >> m_{w,z}$, longitudinally polarized W's and Z's are equivalent [2], up to corrections of order $m_{w,z}/E_{w,z}$, to their scalar counterparts, the would-be Goldstone bosons $w^{\pm}$ and z, that develop strong interactions [3] if $m_H < 1TeV$. This statement can be made mathematically precise [1] to all orders of perturbation theory in a general R_ξ gauge. It allows us to infer the physics of strongly interacting W's and Z's by studying the strongly coupled scalar sector of the theory.

2. SYMMETRIES OF THE SCALAR SECTOR. In the minimal model the scalar Lagrangian is specified by the potential:

$$V = \frac{m_H^2}{2} H^2 + \frac{1}{2}\frac{m_H^2}{v}(|\vec{\phi}|^2) + \frac{m_H^2}{8v}(|\vec{\phi}|^2 + H^2)^2 \tag{1}$$

where the triplet of Goldstone bosons $\vec{\phi} = (w^+, z, w^-)$ is related to the standard complex Higgs doublet by

$$\Phi^T = (\Phi^+, \Phi^0) = (-iw^+,\ (H + v - iz)/\sqrt{2})\ . \tag{2}$$

The potential (1) is parity invariant with H defined as a scalar and the ϕ_i as pseudoscalars. It is further invariant under chiral $SU(2) \times SU(2)$ with ϕ_i a vector and H a singlet of the diagonal $SU(2)$ subgroup, and

$$\delta H = \vec{\alpha} \cdot \vec{\phi},\ \delta\,\vec{\phi} = \vec{\alpha}\,(H + v) \tag{3}$$

under "axial" $SU(2)$ transformations with parameters $|\ \alpha_i\ | << 1$. Invariance under (3) implies the usual Ward identities relating correlation functions of the conserved axial vector currents to S-matrix elements with external w's and z's; these determine uniquely the low energy scattering amplitudes that are identical to the $\pi - \pi$ scattering amplitudes (in the limit $m_\pi \to 0$) as determined twenty years ago by Weinberg [4] with the replacement $f_\pi \to v$. It follows that the tree approximation to any Lagrangian with the correct symmetries, in particular that of the minimal model, Eq. (1), will give the correct w, z scattering amplitudes over some energy region $m_{w,z}^2 << s \leq \Lambda$.

---

*Work done in collaboration with M.S. Chanowitz.

Here Λ is the scale of new physics, such as the mass region of resonances (possibly, but not necessarily, a heavy Higgs) that form the spectrum of a strongly interacting scalar sector. The low energy amplitude is the same for any model in which this sector possesses a global chiral $SU(2)$ symmetry; as far as is known this is the only class of models that insures the relation $m_W = m_Z \cos\theta_w$. These low energy theorems determine the way in which scattering amplitudes approach the regime of new physics, and therefore represent minimal expectations, as any resonance production would enhance the predicted yields. The extrapolated low energy amplitude for the $I = J = 0$ channel violates tree unitarity for $\sqrt{s} \geq 1.8\,TeV$, so this energy defines the scale at which some deviation from the tree approximation to the standard model must occur if there is no light Higgs particle.

3. VECTOR BOSON FUSION. In spite of the fact that the equivalent scalars w, z decouple from the (quasi) massless quarks that constitute hadrons, it turns out that fast hadrons (or leptons) provide reasonably intense beams of longitudinally polarized W's and Z's. This is because, in contrast with transversely polarized vector bosons, their emission is not suppressed in the forward direction. As a result, the familiar $ln\,(s/m^2)$ enhancement of the Weissacker-Williams approximation is replaced by an s/m^2 enhancement that exactly compensates the m^2/s suppression of the squared emission amplitude, due to vector-scalar equivalence. Therefore, the vector boson fusion process, first studied [5] as a mechanism for Higgs production, provides a significant source of longitudinally polarized bosons that can subsequently rescatter through their conjectured strong interactions.

In the analysis of Ref. 1, yields of longitudinally polarized W's and Z's were estimated using unitarized Born approximations to the standard model with $m_H = 1\,TeV$ and $m_H \to \infty$. The w, z scattering cross-sections were folded into the effective W_L, Z_L luminosities [1],[6] in pp collisions as determined by the fusion mechanisms [5], using the parton distribution functions [7] of EHLQ. We found a significant enhancement of diboson production over $q\bar{q}$ annihilation background in the high invariant mass tail, $\hat{s}_{VV} > 1/2\,TeV$ for proton collisions at 40 TeV center-of-mass energy, while energies below 20 TeV would not provide a sufficient signal for detection. Even at the highest energies the signal is not overwhelming, and the highest achievable luminosities are desirable. The prospects for using non-leptonic W, Z decays in the presence of a large QCD jet background are the object of on-going studies [8]. With a center-of-mass energy of 40 TeV and an integrated luminosity of $10^{40}\,cm^{-1}$, one could also expect a handful of spectacularly signed events such as $\mu^{\pm}\nu_{\mu}\mu^{\pm}\nu_{\mu}$ from $w^{\pm}w^{\pm}$ strong rescattering or multi-lepton plus jet events from 2 to 4 body scattering.

The absence of any signatures of strongly interacting W's,and Z's at a facility capable of detecting them would imply the existence of a light Higgs particle that had hitherto escaped detection; for this reason such a facility cannot fail to address the question of the origin of the spontaneous breaking of electroweak symmetry. If the answer involves new strong interactions, high energies and luminosity will be required to study their properties.

ACKNOWLEDGEMENTS

This work supported 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 and in part by the National Science Foundation under Research Grant No. PHY-84-06608.

REFERENCES

[1] M.S. Chanowitz and M.K. Gaillard, Phys. Lett. 142B, 85 (1984); LBL-19470, UCB-PTH-85/19, to be published in Nucl. Phys.

[2] J.M. Cornwall, D.N. Levin and G. Tiktopoulos, Phys. Rev. D10, 1145 (1974); C.E. Vayonakis, Lett. Nuovo Cimento 17, 383 (1976).

[3] M. Veltman, Acta Physica Polonica B8, 475 (1977); B.W. Lee, C. Quigg and N. Thacker, Phys. Rev. D16, 1519 (1977).

[4] S. Weinberg, Phys. Lett. 17, 616 (1966).

[5] D. Jones and S. Petcov, Phys. Lett B84, 440 (1979); R.N. Cahn and S. Dawson, Phys. Lett. 136B, 196 (1984).

[6] S. Dawson, Nucl. Phys. B29, 42 (1985); G.L. Kane, W.W. Repko and W.B. Rolnick, Phys. Lett. 148B, 367 (1984).

[7] E. Eichten, I. Hinchliffe, K. Lane and C. Quigg, Rev. Mod. Phys. 56, 579 (1984).

[8] E. Fernandez et al., Proceedings, DPF Summer Study on the Design and Utilization of the SSC, eds R. Donaldson and J. Morfin (Fermilab, 1985); J.F. Gunion, Z. Kunzt and M. Soldate, Oregon preprint OITS-298, SLAC-PUB-3709, UCD-55-4 (1985); W.J. Stirling, R. Kleiss and S.D. Ellis, CERN prepring TH.4209/85 (1985).