PHYSICAL REVIEW D VOLUME 42, NUMBER 9 1 NOVEMBER 1990

Addendum to "Seeking signs of a second Z"

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(Received 29 May 1990)

We constrain our previous double-Z model using available data. We show that it cannot lead to new physics in present or near-future experiments. We consider herein only Z'-related phenomena, mainly low-energy induced interactions and modifications at the Z peak but also $p\bar{p}$ scattering measured by the Collider Detector at Fermilab and the forward-backward (or charge) lepton asymmetry in electron-positron annihilation.

We show that the model containing two Z bosons which we studied in our previous work[1] produces no detectable effects at low energies. We first compare low-energy scattering data with the effective four-fermion interactions of this model. The close agreement of this data, and of precision measurements of M_W and M_Z, with the standard-model predictions requires the Z' to be far heavier than the Z. This constraint is stronger than those arising from the CERN e^+e^- collider LEP or the Collider Detector at Fermilab, and restricts any signs of such a second Z to lie beyond the range of currently accessible energies.

Calculations for this model (exhibited in previous work[1]) are summarized here. The standard model (SM) is extended by the addition of a right-handed "neutrino" $\tilde{\nu}_R$, an extra U(1)$'$ gauge boson W_5 coupling to a quantum number $Y'=5(B-L)-4Y$, and an extra Higgs singlet χ^0 which has a vacuum expectation value (VEV) $v/\sqrt{2}$ greater than the SM Higgs-doublet VEV $u/\sqrt{2}$. The electric charge is given by $Q=T_3+Y$ where T_3 is normalized to $\frac{1}{2}$ for the SU(2)$_L$ doublets and Y is the weak hypercharge. The gauge couplings g and g' are defined as in the SM, whereas the gauge coupling g_2 of W_5 to the fermions is related to g' by the requirement of unifiability. The model is parametrized by the ratio

$$\lambda \equiv \frac{3}{50\sin^2\theta_W}\frac{u^2}{v^2}=(M_Z/M_{Z'})^2 , \qquad (1)$$

where the second equality (valid to lowest order in u/v) is an adequate approximation. Relevant experimental predictions of our model are stated in terms of λ.

The strongest bounds on λ follow from low-energy determinations of $\sin^2\theta_W$ (Ref. 2) combined with accurate determinations of the W and Z masses.[3,4] We have already described[1] the effects of nonzero λ on deep-inelastic neutrino scattering and on electron-quark scattering, and have given the dependence of the low-energy parameters $\epsilon_{L,R}(u,d)$ on $\sin^2\theta_W$ and λ. The best experimental limits are on the combinations $\theta_{L,R}\equiv\arctan\, \epsilon_{L,R}(u)/\epsilon_{L,R}(d)$ and $g^2_{L,R}\equiv\epsilon^2_{L,R}(u)+\epsilon^2_{L,R}(d)$. The predictions depend not only on $\sin^2\theta_W$ and λ but also on radiative corrections, which depend in turn on the uncertain masses of the top quark and Higgs boson. For given values of λ and m_{Higgs}, we calculate the ranges of values of $\sin^2\theta_W$ and m_t which gives agreement with each of the above experimental values. If these ranges do not overlap for some value of λ then that value is ruled out.

The quantity θ_R does not depend on $\sin^2\theta_W$, nor does its measurement place a competitive limit on λ. The experimental value of θ_L is in tolerable disagreement with the rest of the data even in the SM ($\lambda=0$), but the experimental uncertainty is so large that we will henceforth ignore this quantity. As is by now conventional, we *define* $\sin^2\theta_W\equiv 1-M_W^2/M_{Z^0}^2$. Thus, the measured ratio M_W/M_Z directly determines θ_W as a function of λ independently of radiative correction. The Z mass is predicted in terms of the top mass and λ. Recent precise determinations of M_Z at LEP (Ref. 4) yield the most severe restriction on the parameter space. In Fig. 1 we plot the $\chi^2=4.5$ contours outside of which the parameter values are excluded with 90% confidence. (The allowed region is an envelope of the allowed regions for Higgs-boson masses in the range 10–1000 GeV.) The

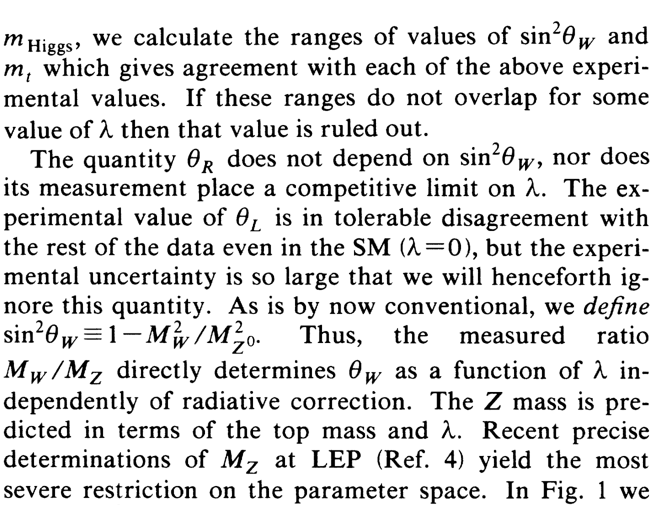

FIG. 1. $\chi^2=4.5$ contours in the $(m_t,\sin^2\theta_W)$ parameter space for the SM ($\lambda=0$) and for our model with $\lambda=0.015$. The figures show the ("allowed") regions not excluded at the 90% confidence level by low-energy scattering measurements and by the W and Z mass determinations. The allowed regions incorporate Higgs-boson masses from 10 to 1000 GeV. For $\lambda\geq 0.02$ the contours disappear.

(unmodified) SM favors a top mass of under 150 GeV, which maximal mass decreases further as λ increases. The allowed contours shrink as λ increases, disappearing entirely when $\lambda \simeq 0.02$ for any reasonable value of the Higgs-boson mass. For larger λ's all of the parameter space is excluded with 90% confidence. We may conclude

$$M_{Z'} \gtrsim 650-750 \text{ GeV} . \qquad (2)$$

Next, we consider the Z boson and its various partial widths. We have previously calculated[1] the effects of λ on the Z widths and its peak cross section. The bound derived in Eq. (2) is too strict for the effects of finite λ to be seen at LEP with its present sensitivity.

Can the Z' reveal itself at CDF? We examine its effect upon the lepton-pair cross section integrated above a certain invariant mass. We employ the modified coupling constants of the Z and Z' bosons, assume no new channels are open (if exotic quark channels are open to the Z', their effect is only to diminish our result), and use the EHLQ (Ref. 5) structure functions for the quark content of the proton and antiproton to compute $\int d\sigma(p\bar{p} \to \{Z, Z', \gamma\} \to \mu^+\mu^-)$ integrated over $\mu^+\mu^-$ energies above 200 GeV. We choose this value because we are informed[6] that this integrated cross section has been established, with 95% confidence, to be no greater than a picobarn, at a center-of-mass energy of 1.8 TeV. The CDF bounds restrict λ to be less than ~ 0.05, corresponding to $M_{Z'} > 400$ GeV, but this cannot compete with the low-energy limit set by Eq. (2).

Another constraint on two Z models can come from the leptonic forward-backward asymmetry in $e^+e^- \to \mu^+\mu^-$ via γ, Z, and Z' exchange. For our model this effect is negligible at energies far from the Z' peak, and hence at all LEP energies, given the lower bound in Eq. (2).

We are indebted to Langacker for providing us with his preliminary summary of the latest low-energy neutral-current data as well as tables of radiative corrections and helpful comments. We also thank E. Simmons and K. Lane for the Eichten-Hinchliffe-Lane-Quigg structure function programs. This research was supported in part by the National Science Foundation under Grant No. PHY-87-14654.

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