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W-Boson Mass Anomaly from a General $SU(2)_L$ Scalar Multiplet

We explain the W-boson mass anomaly by introducing an $SU(2)_L$ scalar multiplet with general isospin and hypercharge in the case without its vacuum expectation value. It is shown that the dominant contribution from the scalar multiplet to the W-boson mass arises at one-loop level, which can be expressed in terms of the electroweak (EW) oblique parameters T and S at the leading order. We firstly rederive the general formulae of T and S induced by a scalar multiplet of EW charges, confirming the results in the literature. We then study several specific examples of great phenomenological interest by applying these general expressions. As a result, it is found that the model with a scalar multiplet in an $SU(2)_L$ real representation with $Y = 0$ cannot generate the required M_W correction since it leads to vanishing values of T and S. On the other hand, the cases with scalars in a complex representation under $SU(2)_L$ with a general hypercharge can explain the M_W excess observed by CDF-II due to nonzero T and S. We further take into account the strong constraints from the perturbativity and the EW global fit of the precision data, and vary the isospin representation and hypercharge of the additional scalar multiplet, in order to assess the extent of the model to solve the W-boson mass anomaly. It turns out that these constraints play important roles in setting limits on the model parameter space. We also briefly describe the collider signatures of the extra scalar multiplet, especially when it contains long-lived heavy highly charged states.

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