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Constraints on the mass and mixing of Z' bosons

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Abstract

We tested several models in which the Standard Model (SM) gauge group is extended by an additional $U(1)$ gauge symmetry against available electroweak precision data to impose limits on the mass of the neutral Z' boson, $M_{Z'}$, predicted in all such models, and on the $Z - Z'$ mixing angle, $\theta_{ZZ'}$, at 95% C.L. We found lower limits on $M_{Z'}$ of order 1 TeV in most cases, while $\theta_{ZZ'}$ was found to be constrained to very small values.

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PACS: 2.60.Cn Extensions of electroweak gauge sector, 14.70.Pw Other gauge bosons

1 Introduction

One of the best motivated extensions of the SM is a neutral gauge sector with an extra $U(1)$ symmetry in addition to the SM hypercharge $U(1)_Y$ and an associated Z' gauge boson, predicted in most Grand Unified Theories (GUTs) such as $SO(10)$ or E_6 [1]. There is an extensive range of models with such an additional $U(1)$ symmetry (for reviews, see [2, 3, 4] and references therein). Among these, models based on the E_6 GUT group and left-right symmetry groups have been extensively pursued in the literature and are particularly significant from the point of view of LHC phenomenology. Here we summarize the analysis done in [5] of various Z' models, which include E_6 based $Z\chi$, Z_ψ, Z_η [6, 7, 8, 9], Z_N [10, 11] and Z_R [12] bosons, a Z_{LR} boson appearing in models with left-right symmetry (reviewed in Ref. [13]), a sequential Z_{SM} boson and a family non-universal Z_{string} boson [14].

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2 Mixing and Parameters

The mixing between the mass eigenstates of Z' and the Z is given by,

$$\tan^2\theta_{ZZ'} = \frac{M_0^2 - M_Z^2}{M_{Z'}^2 - M_0^2}, \tag{1}$$

where M_0 is the mass of Z boson in the absence of $Z - Z'$ mixing and is given as

$$M_0 = \frac{M_W}{\sqrt{\rho_0}\cos\theta_W}; \qquad \rho_0 \equiv \frac{\sum_i (t_i^2 - t_{3i}^2 + t_i)|\langle\phi_i\rangle|^2}{\sum_i 2t_{3i}^2|\langle\phi_i\rangle|^2}. \tag{2}$$

We set $\rho_0 = 1$ here, which corresponds to a Higgs sector with only $SU(2)$ doublets and singlets. Furthermore, if the $U(1)'$ charge assignments of the Higgs fields, Q'_i, are known in a specific model, then there exists an additional constraint [15],

$$\theta_{ZZ'} = C\ \frac{g_2}{g_1}\frac{M_Z^2}{M_{Z'}^2}, \tag{3}$$

where $g_1 = g_L/\cos\theta_W$ and where $g_2 = \sqrt{5/3}\ g_1 \sin\theta_W\sqrt{\lambda}$ is the $U(1)'$ gauge coupling. The latter is given in terms of λ whose value is conventionally set to 1 here. C is a function of vacuum expectation values (VEVs) of the Higgs fields and the Q'_i,

$$C = -\frac{\sum_i t_{3i}Q'_i|\langle\phi_i\rangle|^2}{\sum_i t_{3i}^2|\langle\phi_i\rangle|^2}. \tag{4}$$

For E_6 based models one may restrict oneself to the case where the Higgs fields arise from a **27** representation. The $U(1)'$ quantum numbers are then predicted and eq. 4 receives contributions from the VEVs of three Higgs doublets, $x \equiv \langle\phi_\nu\rangle$, $v \equiv \langle\phi_N\rangle$ and $\bar{v} \equiv \langle\phi_{\bar{N}}\rangle$, respectively, in correspondence with the standard lepton doublet, as well as the two doublets contained in the **10** of $SO(10) \subset E_6$. They satisfy the sum rule, $|v|^2 + |\bar{v}|^2 + |x|^2 = (\sqrt{2}\ G_F)^{-1} = (246.22\ \text{GeV})^2$, and we introduce the ratios,

$$\tau = \frac{|\bar{v}|^2}{|v|^2 + |\bar{v}|^2 + |x|^2}, \quad \omega = \frac{|x|^2}{|v|^2 + |\bar{v}|^2 + |x|^2}; \quad (0 \le \tau, \omega \le 1), \tag{5}$$

resulting in different expressions and ranges for C in different models [5].

3 Results

We used the special purpose FORTRAN package GAPP [16] dedicated to the Global Analysis of Particle Properties, wherein the effects of the Z' bosons are taken into account as first order perturbations to the SM expressions. The most stringent indirect constraints on $M_{Z'}$ come from low-energy weak neutral current (WNC) experiments, while the size of the mixing angle $\theta_{ZZ'}$ is strongly constrained by the very high precision Z-pole experiments at LEP and SLC. For details on the data, input parameters and analysis, see [5].

Z'	$M_{Z'}$ [GeV]				$\sin\theta_{ZZ'}$			$\chi^2_{\rm min}$
	EW (this work)	CDF	DØ	LEP 2	$\sin\theta_{ZZ'}$	$\sin\theta^{\rm min}_{ZZ'}$	$\sin\theta^{\rm max}_{ZZ'}$	
Z_χ	1,141	892	640	673	−0.0004	−0.0016	0.0006	47.3
Z_ψ	147	878	650	481	−0.0005	−0.0018	0.0009	46.5
Z_η	427	982	680	434	−0.0015	−0.0047	0.0021	47.7
Z_N	623	861			−0.0004	−0.0015	0.0007	47.4
Z_R	442				−0.0003	−0.0015	0.0009	46.1
Z_{LR}	998	630		804	−0.0004	−0.0013	0.0006	47.3
Z_{SM}	1,403	1,030	780	1,787	−0.0008	−0.0026	0.0006	47.2
Z_{string}	1,362				0.0002	−0.0005	0.0009	47.7
SM	∞				0			48.5

Table 1: 95% C.L. lower mass limits on extra Z' bosons for various models from EW precision data and constraints on $\sin\theta_{ZZ'}$. For comparison, we show also (where applicable) the limits obtained by CDF, DØ and LEP 2.

In Table 1 we present our limits on the Z' parameters for the models listed in the introduction. Also shown in Table 1 are the current limits on various Z' boson masses from the Tevatron and LEP 2. The mass limits at the Tevatron assume that no decay channels into exotic fermions or superpartners are open to the Z'; otherwise the limits would be moderately weaker. The Table shows that the mass limits from the EW precision data are generally competitive with and in many cases stronger than those from colliders.

Figures 1 and 2 show 90% C.L. exclusion contours for all models. The solid lines specify use of the constraint $\rho_0 = 1$ while the dashed lines are for ρ_0 free. We also show the extra constraints for the specific Higgs sectors discussed above. These are represented by the dotted and long-dashed lines. The numbers in the plots refer to the values of τ or ω, from ranges given in eq. 5. The best fit locations are indicated by an "x". The lower limits from CDF (dot-dashed), DØ (double-dot-dashed) and LEP 2 (dot-double-dashed) given in Table 1 are also shown.

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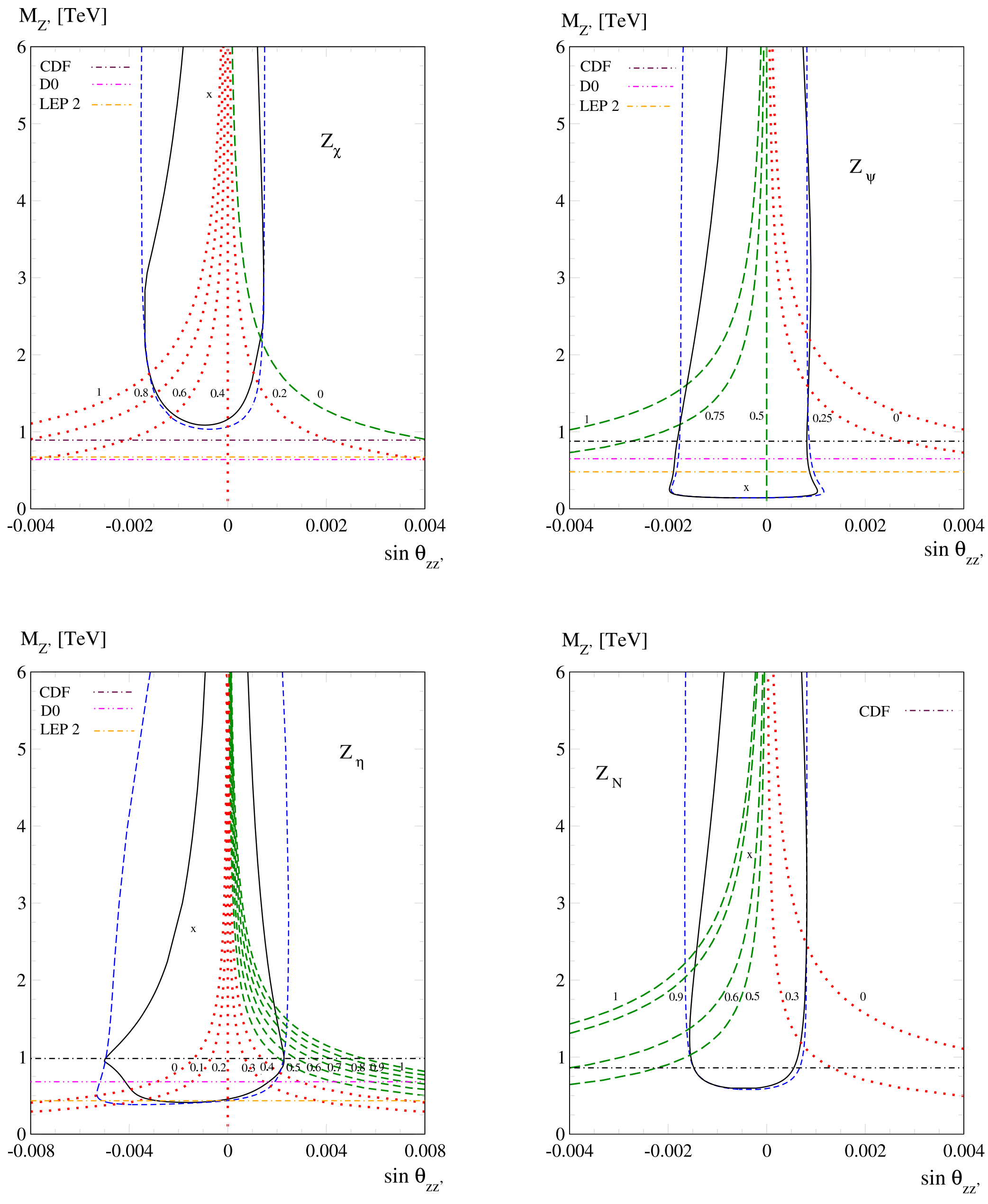

Figure 1: 90% C.L. contours in $M_{Z'}$ vs. $\sin\theta_{ZZ'}$ for various models. See the text for details.

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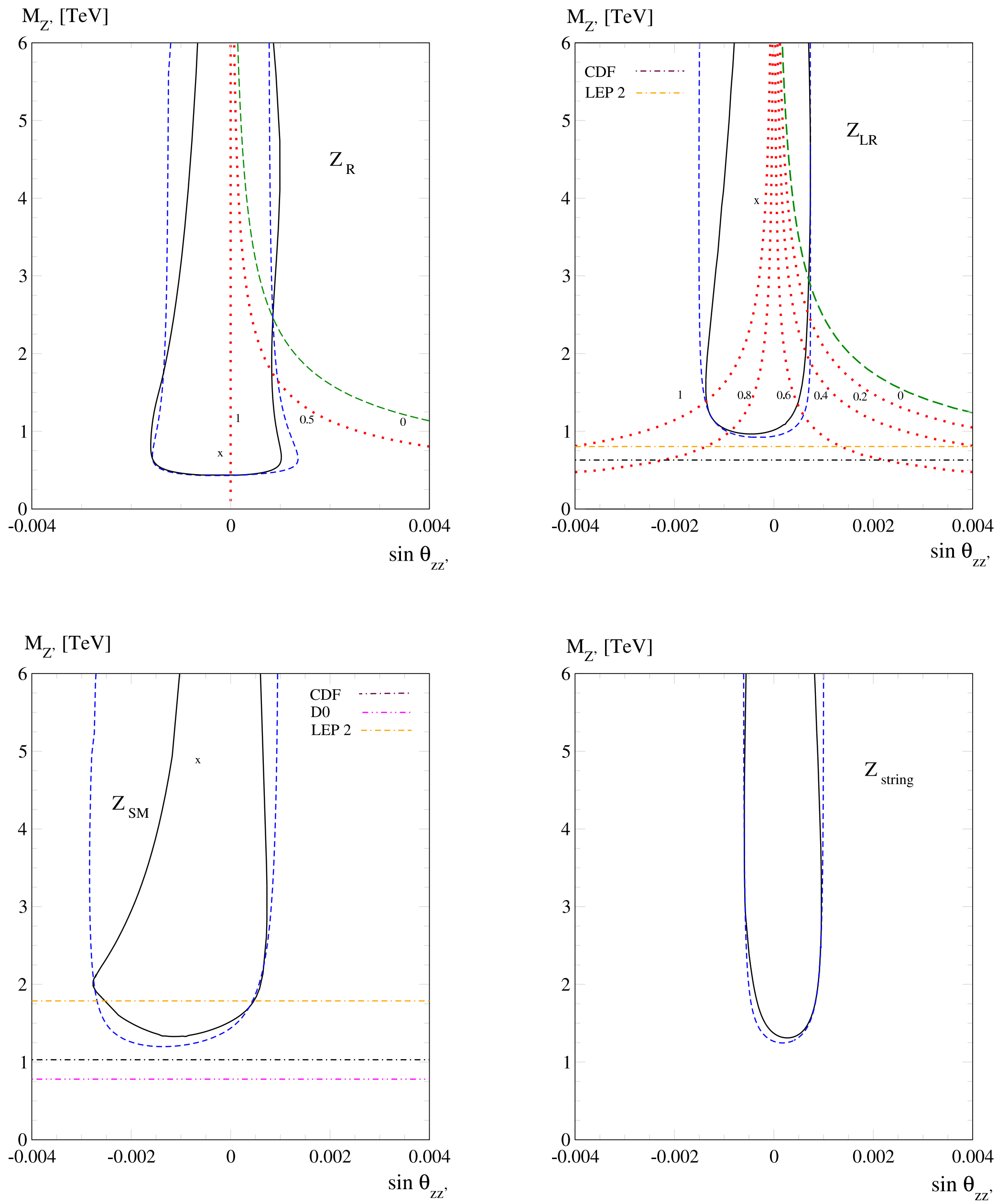

Figure 2: 90% C.L. contours in $M_{Z'}$ vs. $\sin\theta_{ZZ'}$ for various models. See the text for details.

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