Some Z' and W' Models facing current LHC Searches

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We present the implications of data collected by ATLAS and CMS in 2011 on some classes of Z' and W' models. We remark how the strongest bounds, coming for example from searches in final states containing leptons, do not apply to some theoretically well-motivated resonances, and discuss where signals from such states would appear.

1 Introduction and summary

Heavy vectors appear in an extremely large variety of New Physics models, with very different motivations, properties, and signatures. This implies that many interesting cases need to be left out of this short review, including all colored states. In this contribution we will discuss the implications of the data recorded by ATLAS and CMS in 2011[1] on some classes of Z' and W', which can be broadly defined as color-neutral spin-1 states with electric charge zero and one respectively.

The absence of any signal in data (except perhaps the hints of a Higgs boson with mass around 125 GeV, see Refs. [1, 2]) implies that strong bounds can be set on some models. An example is given by heavy vectors that are sizably coupled to light quarks and decay into experimentally straightforward final states, such as $\ell^+\ell^-$ or $\ell\,\nu\,(\ell = e, \mu)$. We will discuss in Sec. 2 a class of models, known as *minimal* Z' [3], which satisfy these conditions and point out that, in agreement with the estimate of Refs. [4, 5], the LHC has already started probing regions of its parameter space which are allowed by Electroweak Precision Tests (EWPT) and at the same time are compatible with a Grand Unified Theory (GUT) origin of the Z'. While this type of Z' appears in many motivated New Physics models, including GUTs and string constructions with intersecting D-branes, in these theories there is no compelling reason that forces the resonances to be at the TeV scale. This is not the case in strongly-coupled extensions of the Standard Model (SM), where a new strong interaction is involved in the breaking of the EW symmetry. An interesting possibility is that the Higgs be a pseudo-Goldstone boson of a spontaneously broken global symmetry in the strong sector, as this would explain the Little Hierarchy between the scale of the strong sector and the Higgs mass. See Ref. [6] for an introduction and an extensive list of references. In this framework, naturalness forces the scale of resonances to be not too far from the EW scale, otherwise the fine-tuning in the Higgs mass becomes inacceptable. Although these are welcome news for the LHC, the properties of vectors arising as resonances of a strong sector are very different from those of the "standard" weakly

[1]We will sometimes use the self-explanatory abbreviations LHC7, LHC8 and LHC14 in this note.

coupled Z' and W' (of which minimal Z' are an example), and make their discovery challenging. In fact, following the idea of partial compositeness the couplings of composite resonances to light fermions are expected to be small, since the latter, being light, are mostly elementary states. This implies that the Drell-Yan production of composite Z' and W' is suppressed, while the main decay channels contain Goldstone bosons (the Higgs and the longitudinal polarizations of W and Z) and third-generation fermions, for example for a neutral resonance $Z' \to Z_L h, W_L^+ W_L^-, t\bar{t}$ typically dominate. In addition the electroweak S parameter constrains such resonances to be heavier than about 2.5 TeV, placing them out of the reach of the first two runs of the LHC. Dedicated studies [7, 8, 9] show that these resonances can be discovered at LHC14 with large luminosity up to masses of roughly 3 TeV.

Still keeping the compositeness idea in mind, it is interesting to ask whether there could be resonances light enough to give signals at LHC7/8, while at the same time satisfying all current electroweak and collider bounds. In Sec. 3 we discuss an example, a *weakly constrained* W' [10], whose main manifestation would be the observation of a bump in the dijet invariant mass spectrum. While in Ref. [10] the phenomenology of this resonance was discussed adopting an effective, model-independent approach, we notice an interesting similarity with the phenomenological implications of a flavor-symmetric strong sector, which was proposed in Ref. [11]. In this case Minimal Flavor Violation can be implemented, alleviating the tension with flavor bounds that is generically present in composite Higgs models with partial compositeness. This in turn implies that some chiralities of light quarks are largely composite and thus sizably coupled to resonances, giving rise for example to large Drell-Yan production of spin-1 composites and subsequent decay into the dijet final state.

2 Minimal Z'

This class of models is based on a minimal extension of the SM gauge group, consisting in an extra $U(1)'$ factor, and of the SM matter content, which is enlarged to include one right-handed neutrino per family (this allows the implementation of the see-saw mechanism for neutrino masses at the renormalizable level). It can be easily seen that with the specified fermion content all anomalies cancel, provided the generator of $U(1)'$ is a linear combination of Y and $B-L$. The class of models thus defined "continuously interpolates" among several specific models frequently discussed in the literature, such as Z'_χ, which arises from $SO(10)$ grand unification, Z'_{3R}, which appears in Left-Right models, and Z'_{B-L}, the 'pure $B-L$' model. Following the notation of Ref. [4], the coupling of the mass-eigenstate Z' to fermion $f = u_L, d_L, u_R, \dots$ reads

$$\mathcal{L} \,=\, g_Z \sum_f Q_{Z'}(f) \bar{f} \gamma^\mu f \, Z'_\mu \,,$$

$$Q_{Z'}(f) = \sin\theta' [T_{3L}(f) - \sin^2\theta_W Q(f)] + \cos\theta' [\widetilde{g}_Y Y(f) + \widetilde{g}_{BL}(f)] \,, \qquad \left(\tan\theta' \simeq -\widetilde{g}_Y \frac{M_{Z^0}^2}{M_{Z'}^2} \right) .$$

θ' is the Z-Z' mixing angle, and we defined $\widetilde{g}_{Y,BL} \equiv g_{Y,BL}/g_Z$ and $M_{Z^0}^2 = g_Z^2 v^2/4$. In first approximation, the three parameters $M_{Z'}$, $\widetilde{g}_Y, \widetilde{g}_{BL}$ are sufficient to describe the phenomenology of the Z'. In Ref. [4] a comparison of the LHC7 reach with the strong bounds coming from EWPT and with the constraints imposed by a GUT origin of the Z' was performed. Here we update such comparison making use of the results of the ATLAS [12] and CMS [13] searches for resonances in the dilepton final state, based on $\sim 5\,\text{fb}^{-1}$ of LHC collisions at 7 TeV. As can be seen from the left panel of Fig. 1, for a relatively light Z' with mass of 1 TeV the current LHC constraints are much more powerful than those coming from EWPT. On the other hand, for larger masses the LHC has started probing regions of parameter space that were both allowed by EWPT and GUT-compatible, represented by the orange region in the right panel of Fig. 1.

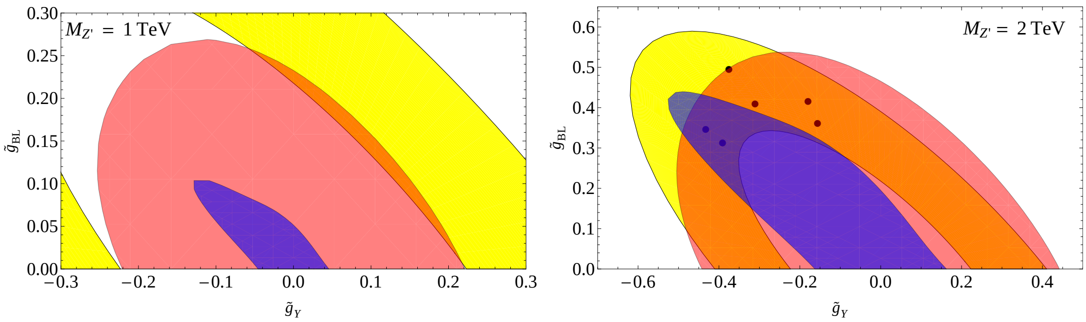

Figure 1: Comparison of the region allowed by LHC7 with $\sim 5\text{fb}^{-1}$ (blue) with those compatible with EWPT (red) and with GUTs (yellow), in the plane $(\widetilde{g}_Y, \widetilde{g}_{BL})$. The black dots appearing in the right panel are specific supersymmetric GUT models, see Ref. [4].

3 A weakly constrained W'

In Ref. [10] an isospin-singlet W' was studied in a model-independent approach, by writing an effective Lagrangian containing all the dimension-four operators compatible with the SM gauge symmetry and involving the SM fields plus the resonance. The absence of an associated neutral resonance in the effective theory implies that the bounds on Z' from EW data and from colliders can be avoided. Furthermore, gauge invariance forces the W' to be leptophobic, its dominant couplings to fermions being

$$\mathcal{L} = \frac{g_q}{\sqrt{2}}(V_R)_{ij}\overline{u}^i_R\gamma^\mu d^j_R W'^{+}_\mu + \text{h.c.}\,,$$

where $i, j = 1, 2, 3$ are flavor indexes and V_R is a matrix that in the effective approach is arbitrary. For suitable choices of V_R, constraints from flavor data are very weak. In Ref. [10] the LHC phenomenology of the resonance was discussed assuming the least constrained among these special forms, namely $(V_R)_{ij} = \delta_{ij}$. If the W-W' mixing is neglected, only two parameters are relevant, the mass $M_{W'}$ and coupling to quarks g_q . The null results of LHC searches in the dijet final state then place bounds on these parameters, as shown in the left panel of Fig. 2 (see also Ref. [16]). We make use of the latest searches for resonances in the dijet invariant mass spectrum [14, 15], and of the CMS search for quark compositeness in dijet angular distributions [17]. The bound from the latter is obtained applying the results of Ref. [18] [2], and is more relevant for strongly coupled resonances. In the right panel of Fig. 2 we compare the discovery prospects for the W' at LHC8 with the current exclusion from LHC7 (based on 1 fb^{-1} of data [3]),

[2] We thank J. Serra for providing the update of the numerical bounds given in Ref. [18].

[3] Rescaling the exclusion to the full $\sim 5\,\text{fb}^{-1}$ luminosity collected in 2011 increases the bound to about $M_{W'} \gtrsim 2\,\text{TeV}$.

assuming a coupling $g_q = g$. We find that a W' with mass up to 2.2 TeV can be discovered with 15 fb^{-1}. See Ref. [10] for details on how this estimate was derived.

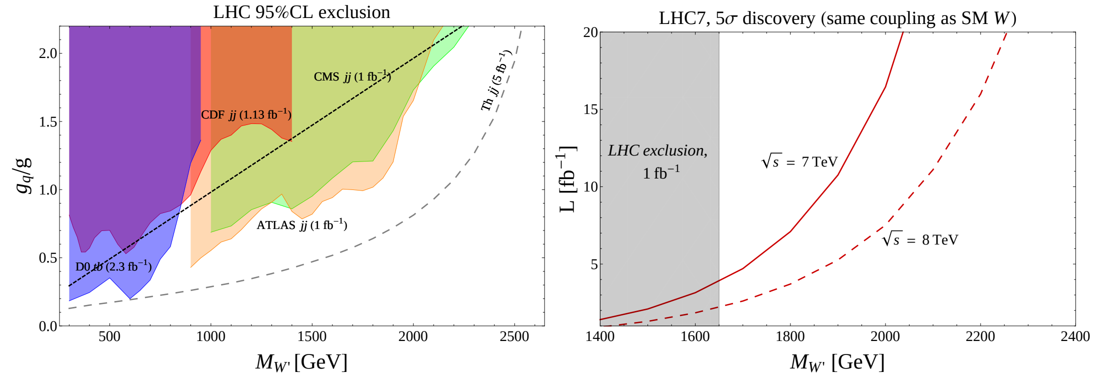

Figure 2: (*Left panel*) Current bounds in the plane $(M_{W'}, g_q/g)$ from Tevatron searches in the *tb* (blue) and dijet channel (red), from LHC searches for resonances decaying into dijets (brown and pink) and from LHC searches for quark compositeness (dashed straight line, corresponding to $M_{W'}/g_q > (2.2\,\text{TeV})/\sqrt{2}$). The exclusion expected from LHC dijet resonance searches after 5 fb^{-1}, computed in Ref. [10], is also shown as a dashed line. (*Right panel*) Discovery luminosity as a function of the W' mass, assuming a coupling $g_q = g$, at LHC7 and LHC8.

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