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UPDATED CONSTRAINTS ON Z'AND W' BOSONS DECAYING INTO BOSONIC AND LEPTONIC FINAL STATES USING RUN 2 ATLAS DATA AT LARGE HADRON COLLIDER

Introduction

One of the main goals of the physics programme at the Large Hadron Collider (LHC) is to search for new phenomena that become visible in high-energy proton-proton collisions [1]. A possible signature of such new phenomena would be the production of a heavy resonance with its subsequent decay into a final state consisting of a pair of leptons or vector bosons. Many new physics scenarios beyond the Standard Model (SM) predict such a signal. Possible candidates are charged and neutral heavy gauge bosons. In the simplest models these particles are considered copies of the SM W and Z bosons and are commonly referred to as W' and Z' bosons [1–5]. In the Sequential Standard Model (SSM) the W'_{SSM} and Z'_{SSM} bosons have couplings to fermions that are identical to those of the SM W and Z bosons, but for which the trilinear couplings $W'WZ$ and $Z'WW$ are absent. The SSM has been used as a reference for experimental W' and Z' boson searches for decades, the results can be reinterpreted in the context of other models of new physics, and it is useful for comparing the sensitivity of different experiments.

At the LHC, such heavy W' and Z' bosons could be observed through their single production as s-channel resonances with subsequent leptonic decays

$$pp \to W'X \to l\nu X, \quad (1)$$

$$pp \to Z'X \to l^+l^-X \quad (2)$$

respectively, where in what follows, $l = e, \mu$ unless otherwise stated. The production of W' and Z' bosons at hadron colliders is expected to be dominated by the process $q\bar{q}'/q\bar{q} \to W'/Z'$. Leptonic final states provide a low-background and efficient experimental signature that results in excellent sensitivity to new phenomena at the LHC.

Heavy resonances that can decay to gauge boson pairs are predicted in many scenarios of new physics, including extended gauge models (EGM), models of warped extra dimensions, technicolour models associated with the existence of technirho and other technimesons, more generic composite Higgs models, and the heavy vector-triplet model [2–5], which generalises a large number of models that predict spin-1 charged (W') and neutral (Z') resonances etc. Searches for exotic heavy particles that decay into WZ or WW pairs are complementary to searches in the leptonic channels $l\nu$ and l^+l^- of the processes (1) and (2). Moreover, there are models in which new gauge boson couplings to SM fermions are suppressed, giving rise to a fermiophobic W' and Z' with an enhanced coupling to electroweak gauge bosons. It is therefore important to search for *W'* and *Z'* bosons also in the WZ and WW final states.

After the discovery of *Z'* and *W'* bosons at the LHC via the dilepton process (1) and (2), some diagnostics of its couplings, *Z-Z'* and *W-W'* mixings need to be performed in order to identify the underlying theoretical framework. In this note we investigate the implications of the ATLAS Run2 data in the diboson production channels

$$pp \to W'X \to WZX, \tag{3}$$
$$pp \to Z'X \to WWX \tag{4}$$

to probe the *Z'* and *W'* bosons that arise, e.g., in popular models with extended gauge sector EGM. The presented analysis is based on pp collision data at a center-of-mass energy 13 TeV, collected by the ATLAS at Run2 (with time-integrated luminosity of 139 fb^{-1}) experiment at the LHC [4, 5]. In particular, the data is used to probe the *Z-Z'* and *W-W'* mixing.

1. Diboson resonances and their decays into electroweak bosons

We will consider a new physics model where *Z'* interacts with light quarks and charged gauge bosons $Z' \to WW$ via their mixing with the SM *Z* assuming that the *Z'* couplings exhibit the same Lorentz structure as those of the SM. In particular, in the present analysis we will focus on a gauge boson of the EGM. In the simple reference EGM model, the couplings of the *Z'* boson to fermions (quarks, leptons) and *W* bosons are a direct transcription of the corresponding standard-model couplings.

In many extended gauge models, while the couplings to fermions are not much different from those of the SM, the $Z'WW$ coupling is substantially suppressed with respect to that of the SM. In fact, in an extended gauge model the standard-model trilinear gauge boson coupling strength, $g_{WWZ}(=\cot\theta_W)$, is replaced by $g_{WWZ} \to \xi_{Z-Z'} \cdot g_{WWZ}$, where $\xi_{Z-Z'} = C \cdot (M_W / M'_Z)^2$ is the mixing factor and C the coupling strength scaling factor.

Figure 1 shows the observed 95% C.L. upper limits on the production cross section times the branching fraction as a function of *Z'* mass, $M_{Z'}$. The intersection points of the observed upper limits on the production cross section with these theoretical cross sections for various $\xi_{Z-Z'}$ give the corresponding lower bounds on ($M_{Z'}$, $\xi_{Z\text{-}Z'}$) displayed in figure 2.

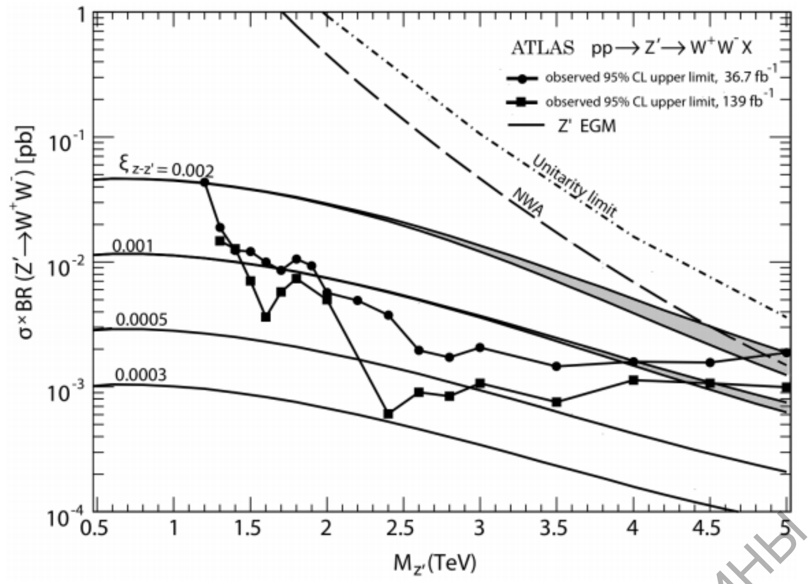

Figure 1 – Observed 95% C.L. upper limits on the production cross section times the branching fraction for $Z' \to WW$ as a function of Z' mass, showing ATLAS data of the fully hadronic final states for 36,7 fb^{-1} and 139 fb^{-1}. Theoretical production cross sections $\sigma(pp \to Z') \times Br(Z' \to WW)$ are calculated from PYTHIA 8, and given by thin solid curves which correspond to values of the $Z - Z'$ mixing factor $\xi_{Z-Z'}$ from 0,0003 to 0,002

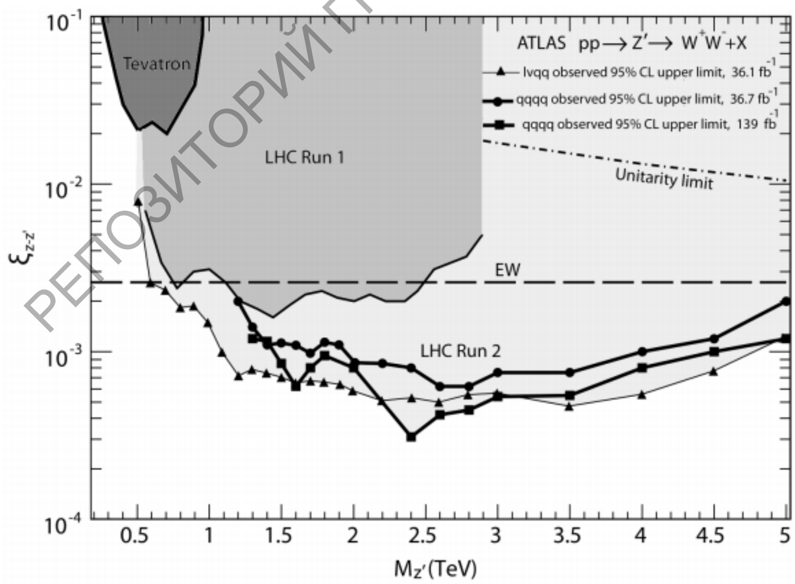

Figure 2 – Z' exclusion regions in the two-dimensional plane of ($M_{Z'}$, $\xi_{Z-Z'}$) obtained from CDF and D0 collaborations at Tevatron and LHC data at different energies and luminosities (Run1 and Run2). Also, unitarity and narrow width approximation (NWA) constraints are displayed

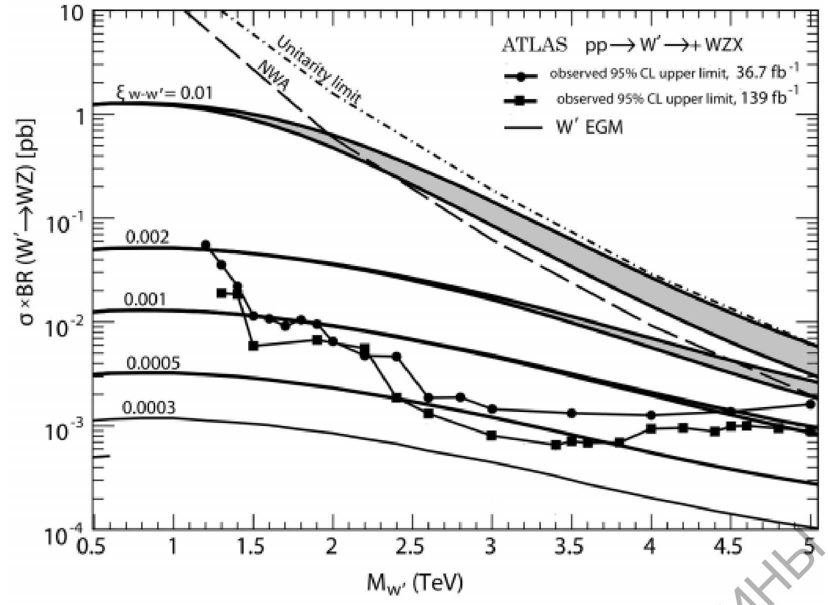

Figure 3 – Observed 95% C.L. upper limits on the production cross section times the branching fraction for as a function of *W'* mass showing ATLAS data of the fully hadronic final states $W' \to WZ$ for 36,7 fb^{-1} and 139 fb^{-1}. Theoretical production cross sections $\sigma(pp \to W') \times Br(W' \to WZ)$ are given by thin solid curves which correspond to values of the *W*-*W'* mixing factor from 0,0003 to 0,01

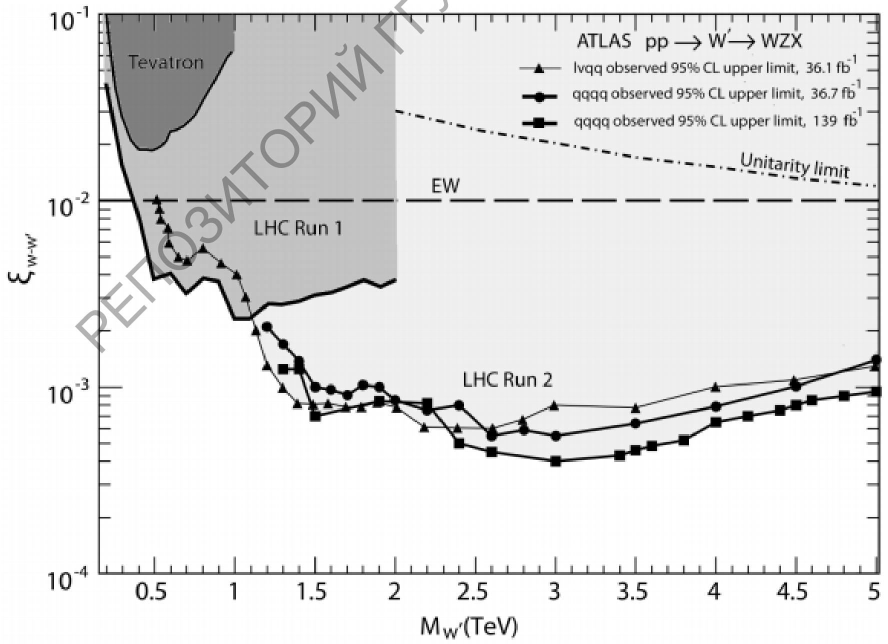

Figure 4 – *W'* exclusion regions in the two-dimensional plane of ($M_{W'}$, $\xi_{W\text{-}W'}$) obtained from Tevatron and LHC data at different energies and luminosities. Also, unitarity and narrow width NWA constraints are displayed

The analysis of a diboson resonance associated with extra charged *W'* boson decaying into *WZ* pair can be performed in the same manner as those for *Z'* and we present it in figure 3 and figure 4. Here, we are making an analysis, employing the most recent measurements of diboson processes provided by the experimental collaboration ATLAS in Run 2 (139 fb^{-1}). In particular, for *W'* we compute the LHC *W'* production cross-section multiplied by the branching ratio into *WZ* bosons, $\sigma(pp \to W') \times Br(W' \to WZ)$ as a function of two parameters ($M_{W'}$, $\xi_{W\text{-}W'}$), and compare it with the limits established by the ATLAS experiment analyzed the *WZ* production in process (1) through the fully hadronic final states. Figure 3 shows the observed 95% C.L. upper limits on the production cross section times the branching fraction for $W' \to W Z$ as a function of *W'* mass. The data analyzed comprises pp collisions at 13 TeV, recorded by the ATLAS (139 fb^{-1}) detector at the LHC. Also shown are theoretical production cross sections, $\sigma(pp \to W') \times Br(W' \to WZ)$, for *W'*, calculated from PYTHIA8 adapted for such kind of analysis.

2. Concluding remarks

In conclusion, the current note presents an analysis of *Z-Z'* and *W-W'* mixing in the process of WW and WZ production, respectively. The analysis is based on pp collision data at a centre-of-mass energy of 13 TeV, collected by the ATLAS experiment at the LHC in Run2 at time-integrated luminosity of 139 fb^{-1}.

We analyzed the popular EGM model and determined limits on its mass of *W'* (*Z'*) as well as on the *W-W'* (*Z-Z'*) mixing factor $\xi_{W\text{-}W'}$ ($\xi_{Z\text{-}Z'}$). We present the *W'* (*Z'*) exclusion region in the $M_{W'} - \xi_{W\text{-}W'}$ ($M_{Z'} - \xi_{Z\text{-}Z'}$) plane for the first time by using these data. The exclusion limits represent a large improvement over previously published results obtained at the Tevatron, and also over precision electroweak data as well as results obtained from proton-proton collisions at the LHC at 7 TeV and 8 TeV in Run1. These are the most stringent exclusion limits to date on the $M_{W'} - \xi_{W\text{-}W'}$ ($M_{Z'} - \xi_{Z\text{-}Z'}$) plane. Further improvement on the constraining of this mixing can be achieved from the analysis of data which will be collected at higher luminosity at Run III and HL-LHC options.

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