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Z-Z' Mixing Effects at the Large Hadron Collider

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We discuss the expected sensitivity to Z' boson effects in the $W^{\pm}$ boson pair production process at the Large Hadron Collider (LHC). The results of a model-dependent analysis of Z' boson effects are presented as constraints on the Z-Z' mixing angle ϕ and Z' boson mass.

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1. Introduction

Although the Standard Model (SM) of the electroweak and strong interactions describes nearly all experimental data available today [1], it is widely believed that it is not the ultimate theory. Grand Unified Theories (GUT), eventually supplemented by Supersymmetry to achieve a successful unification of the three gauge coupling constants at the high scale, are one of the main candidates for physics beyond the SM. Many of these GUTs predict the existence of new neutral gauge bosons, which might be light enough to be accessible at current and/or future colliders [2–5].

Search for Z' particles is an important aspect of the experimental physics program of current and future high-energy colliders. In this paper we study the potential of the Large Hadron Collider (LHC) to discover Z-Z' mixing in

$$pp \to W^+W^- + X \tag{1}$$

and compare it with that expected at the International Linear Collider (ILC).

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2. Cross sections and results

There are many theoretical models which predict Z' with mass possibly in the TeV range. Popular classes of models are represented by E_6-motivated models, the Left-Right Symmetric Model (LR), Z' in an ‘alternative’ left-right scenario and the Sequential Standard Model (SSM), which has a heavier boson with couplings like those of the SM Z. Detailed description of these models and Z-Z' mixing aspects can be found in [6].

The parton model cross section for the process (1) from initial quark-antiquark states can be written as

$$\frac{d\sigma_{q\bar{q}}}{dM\,dy\,dz} = K\frac{2M}{s}\sum_q [f_{q|P_1}(\xi_1)f_{\bar{q}|P_2}(\xi_2) + f_{\bar{q}|P_1}(\xi_1)f_{q|P_2}(\xi_2)]\,\frac{d\hat{\sigma}_{q\bar{q}}}{dz}. \tag{2}$$

Here, s is the proton-proton center-of-mass energy squared; $z = \cos\theta$ with θ the W^--boson–quark angle in the W^+W^- center-of-mass frame; y is the diboson rapidity; M is diboson invariant mass; $f_{q|P_1}(\xi_1, M)$ and $f_{\bar{q}|P_2}(\xi_2, M)$ are parton distribution functions in the protons P_1 and P_2, respectively, with $\xi_{1,2} = (M/\sqrt{s})\exp(\pm y)$ the parton fractional momenta; finally, $d\hat{\sigma}_{q\bar{q}}/dz$ is the partonic differential cross section, explicit form of which is presented in Ref. [6]. In (2), the K factor accounts for next-to-leading order QCD contributions [7, 8].

The resonant Z' production cross section of process (1) needed in order to estimate the expected number of Z' events, can be derived from (2) by integrating its right-hand-side over z, the rapidity of the $W^{\pm}$-pair y and invariant mass M around the resonance peak $(M_R - \Delta M/2, M_R + \Delta M/2)$:

$$\sigma(pp \to W^+W^- + X) = \int_{M_R-\Delta M/2}^{M_R+\Delta M/2} dM \int_{-Y}^{Y} dy \int_{-z_{\rm cut}}^{z_{\rm cut}} dz \frac{d\sigma_{q\bar{q}}}{dM\, dy\, dz} \,. \tag{3}$$

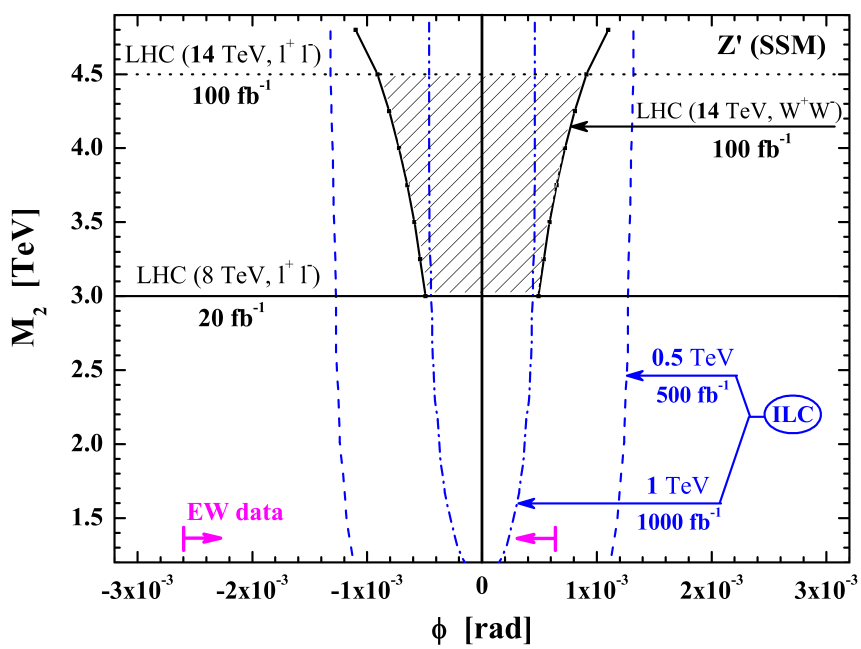

FIG. 1. Reach (95% C.L.) on Z-Z' mixing and M_2 mass for $Z'_{\rm SSM}$ model obtained from the process $pp \to WW \to l\nu l'\nu'$ $(l, l' = e, \mu)$ at the LHC. (In colour)

We adopt the parametrization of the experimental mass resolution ΔM in reconstructing the invariant mass of the W^+W^- system, ΔM vs. M [9].

We need to mention that in order to analyse process (1) one has to take into account background processes for different decay modes of final $W^{\pm}$ bosons, perform the analysis of experimental cuts and their influence on both signal and background. A comprehensive analysis of these aspects can be found in [6].

In our analysis, we denote by $N_{\rm SM}$ and $N_{Z'}$ the numbers of 'background' and 'signal' events, and we adopt the criterion $N_{Z'} = 2\sqrt{N_{\rm SM}}$ or 3 events, whichever is larger, as the minimum signal for discovery at the 95% C.L. [6].

In Fig. 1 we depict the region in parameter space to which the LHC will be able to constrain Z-Z' mixing angle ϕ for an integrated luminosity of 100 fb^{-1}. The allowed domain in ϕ and M_2 (Z_2 boson mass) is depicted as the hatched line. Current limit on M_2 for $Z'_{\rm SSM}$ derived from the Drell–Yan (l^+l^-) process at the LHC (8 TeV) is shown as horizontal solid line. 'Typical' mass limits expected at the LHC (14 TeV) is presented as horizontal dotted line. Limits on the Z-Z' mixing angle from electroweak precision data and those expected from $W^\pm$ pair production at the ILC with polarized beams are displayed as well.

As a conclusion, we should say that if a new Z' boson exists in the mass range $\sim$ 3–4.5 TeV, its discovery is possible in the Drell–Yan channel. Moreover, the detection of the $Z' \to W^+W^-$ mode is eminently possible and gives valuable information on Z-Z' mixing. It might be the only mode other than the dileptonic one, $Z' \to l^+l^-$, that is accessible. Our results demonstrate that it might be possible to detect a new heavy Z' boson and measure (or constrain) the Z-Z' mixing from the totally leptonic or semileptonic WW channels at the LHC.

Additional numerical results and detailed conclusions can be found in Ref. [6].

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References

[1] J. Beringer *et. al.* (Particle Data Group). Phys. Rev. D **86**, 010001 (2012).

[2] J. L. Hewett and T. G. Rizzo. Phys. Rept. **183**, 193 (1989).

[3] P. Langacker. Rev. Mod. Phys. **81**, 1199-1228 (2009), arXiv:0801.1345 [hep-ph].

[4] A. Leike. Phys. Rept. **317**, 143-250 (1999), arXiv:9805494 [hep-ph].

[5] A. Gulov and V. Skalozub. Int. J. Mod. Phys. A **25**, 5787 (2010), arXiv:1009.2320 [hep-ph].

[6] V.V. Andreev, G. Moortgat-Pick, P. Osland, A.A. Pankov, N. Paver. arXiv:1406.6776 [hep-ph].

[7] J. M. Campbell and R. K. Ellis. Phys. Rev. D **60**, 113006 (1999), arXiv:9905386 [hep-ph].

[8] J. M. Campbell, R. K. Ellis and C. Williams. JHEP **1107**, 018 (2011), arXiv:1105.0020 [hep-ph].

[9] ATLAS Collaboration. Reports No. CERN-LHCC-99-14, CERN-LHCC-99-15.