# $Z'$ Searches at the LHC: Some QCD Precision Studies in Drell-Yan

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**Abstract**

Discovery potentials for extra neutral interactions at the Large Hadron Collider in forthcoming experiments are analyzed in Drell-Yan. For this purpose we use high precision next-to-next-to-leading order (NNLO) determination of the invariant mass distributions and of the total cross sections in the kinematic region around 1 TeV. In this region we explore the possibility to make a preliminary distinction between different anomaly-free extensions of the Standard Model.

# 1 Introduction

Searching for extra neutral interactions at the Large Hadron Collider involves a combined effort from two sides: precise determination of the signal, which should allow a discrimination of any specific model, and precise determination of the SM background, which is a very difficult task at a hadron collider due to the presence of the QCD effects in hadronization. Extra $Z'$ come from different extensions of the Standard Model like in left-right symmetric models, in Grand Unified Theories (GUTs) and in string inspired constructions. It has also been suggested that the existence of a low scale $Z'$ may account for the suppression of proton decay mediating operators (free fermionic models) in supersymmetric theories and otherwise [1] [2]. Some of these U(1) could also be anomalous, and invoke a mechanism of cancelation of the anomalies that requires an axion [3] [4] [5] [6] [7] [8].

# 2 The interaction Lagrangian

In our analysis we have decided to compare our results for a string-inspired $Z'$ with a series of models studied in [9]. We just mention that the construction of models with extra $Z'$ using a bottom-up approach is, in general, rather straightforward, being based mostly on the principle of cancelation of the gauge cubic $U(1)^3_{Z'}$ and the mixed and gravitational anomalies.

After the diagonalization of the mass matrix we obtain the physical masses of the gauge bosons

$$M_Z^2 = \frac{g^2}{4\cos^2\theta_W}(v_{H_1}^2 + v_{H_2}^2)\left[1 + O(\varepsilon^2)\right]; \quad M_{Z'}^2 = \frac{g_z^2}{4}(z_{H_1}^2 v_{H_1}^2 + z_{H_2}^2 v_{H_2}^2 + z_\phi^2 v_\phi^2)\left[1 + O(\varepsilon^2)\right]. \tag{1}$$

where $\varepsilon$ is defined as a mixing-perturbative parameter ($\varepsilon \approx 10^{-3}$) and $v_{H_i}, v_\phi$ are the expectation values of the two Higgses of the theory, while $z_{H_i}, z_\phi$ denote their charges.

The colour-averaged inclusive differential cross section for the reaction $P + P \to l_1 + l_2 + X$, is given by

$$\frac{d\sigma}{dQ^2} = \tau\sigma_V(Q^2, M_V^2)W_V(\tau, Q^2) \qquad \tau = \frac{Q^2}{S}, \tag{2}$$

where all the hadronic initial state information is contained in the hadronic structure function $W_V(\tau, Q^2)$ which is defined in [10] while all the information regarding the $Z'$ interactions with the quarks and the leptons is contained in the point like cross section defined as

$$\sigma_{Z'}(Q^2) = \frac{\pi\alpha_{em}}{4M_{Z'}\sin^2\theta_W\cos^2\theta_W N_c}\frac{\Gamma_{Z'\to\bar{l}l}}{(Q^2 - M_{Z'}^2)^2 + M_{Z'}^2\Gamma_{Z'}^2}. \tag{3}$$

Here $\Gamma_{Z'}$ and $\Gamma_{Z'\to\bar{l}l}$ are respectively the total and the partial decay rate of the $Z'$.

Our results for the NLO total cross sections are listed in Tab. 1.

# 3 Discussion

While the analysis of the invariant mass distributions shows in general an overlap between the various models in both the NLO and NNLO cases that we have studied [2], the differences among the predictions seem to be different if we look at observables like the total cross section, which is obtained by integrating the invariant mass distributions over $\pm 3\Gamma_{Z'}$ around the peak. This feature depends on the fact that in this interval all the models exhibit differences in their shape, width and in their peak values. Therefore, by focusing the attention near the resonance one can hope to better distinguish among the various models.

| $\sigma_{tot}^{nlo}$ [fb], $\sqrt{S} = 14$ TeV, $M_{Z'} = 1.2$ TeV, $\tan\beta = 40$, Candia evol. | | | | | |
|---|---|---|---|---|---|
| $g_z$ | Free Ferm. | $U(1)_{B-L}$ | $U(1)_{q+u}$ | $U(1)_{10+\bar{5}}$ | $U(1)_{d-u}$ |
| 0.1 | 0.572 | 1.620 | 1.224 | 0.367 | 0.309 |
| | 0.146 | 0.160 | 0.213 | 0.079 | 0.027 |
| | 0.008 | 0.202 | 0.114 | 0.010 | 0.013 |
| 0.3 | 5.418 | 15.559 | 12.412 | 3.281 | 2.427 |
| | 1.314 | 1.439 | 1.916 | 0.715 | 0.240 |
| | 0.074 | 1.936 | 1.160 | 0.091 | 0.101 |
| 0.5 | 14.316 | 40.465 | 30.535 | 9.149 | 6.741 |
| | 3.650 | 3.997 | 5.323 | 1.987 | 0.667 |
| | 0.195 | 5.036 | 2.853 | 0.255 | 0.279 |
| 0.7 | 28.077 | 79.270 | 59.836 | 17.915 | 13.212 |
| | 7.154 | 7.833 | 10.433 | 3.894 | 1.307 |
| | 0.383 | 9.865 | 5.591 | 0.498 | 0.547 |
| 1.0 | 57.394 | 161.625 | 121.921 | 36.556 | 26.959 |
| | 14.600 | 15.986 | 21.292 | 7.946 | 2.667 |
| | 0.783 | 20.114 | 11.392 | 1.017 | 1.117 |

Table 1: Total cross sections at NLO, $M_{Z'} = 1.2$ TeV.

# 4 Conclusions

The possibility of discovering extra $Z'$ at the LHC is realistic, being they common both in GUTs and string-inspired models. Therefore, precision determinations of the QCD background are necessary to identify them at the LHC. Some golden-plated processes like $Z \to \gamma\gamma$ or $Z \to l\bar{l}l\bar{l}$ and Drell-Yan are the best place to search for new signals. From the string theory side, the family of free fermionic models is one of the most phenomenologically attractive, because it addresses quite successfully the issue of proton stability [1].

Since the V-A structure of the couplings is different in each model, a measurement of forward-backward asymmetries and/or of charge asymmetries could be helpful [11] for their detection, but this can happen only if the gauge coupling is sizeable. However, discriminating among the models remains a difficult issue for which NNLO QCD determinations, at least in leptoproduction, though useful, do not seem to be necessary in the immediate future - for such large values of the mass of the extra $Z'$ -, while the NLO effects remain important for the reduction of the renormalization/factorization scale dependence of the cross sections.

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