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WG3 : Beyond the Standard Model Physics

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Abstract

Contents

Some global fixes still missing:

– Notation to refer to the panels of figures: right vs right-hand, top vs upper etc.
– Should we replace everywhere the ugly 3000 fb^{-1} with 3 ab^{-1}?
– We have to uniform notation for MET, PT, KT and all kinematic variables in general;
– For the sections where paragraphs or subsubsections remain uniform the notation;

1 Other BSM signatures

1.1 Spin 0 and 2 resonances

1.2 Spin 1 resonances

*1.2.1 Z' discrimination at HE-LHC in case of an evidence/discovery after HL-LHC [TH]**

Contribution from: C. Helsens, D. Jamin, M. L. Mangano, T. Rizzo, M. Selvaggi

Context of the study

It is legitimate to assume that a heavy resonance could be seen at the end of HL-HLC. If that is the case a new collider with higher energy in the c.o.m. is needed to study its properties as too few events will be available at $\sqrt{s} = 14$ TeV. In this document we present the discrimination potential of a High Energy LHC (HE-LHC) with an assumed c.o.m. energy of 27 TeV. Here we analyzed the capability of the $\sqrt{s} = 27$ TeV HE-LHC with $\mathcal{L} = 15$ ab^{-1} to distinguish among six Z' models. Under the assumption that these Z''s decay only to SM particles, we show that there are sufficient observables to perform this model differentiation in most cases.

Bounds from HL-LHC

As a starting point it is needed to understand what are, for $\sqrt{s} = 14$ TeV, for the typical exclusion/discovery reaches for some standard reference Z' models assuming $\mathcal{L} = 3$ ab^{-1} employing only the e^+e^- and $\mu^+\mu^-$ channels. To address this and the other questions below we will use the same set of Z' models as employed in Ref. [**?**] and mostly in Ref. [**?**], both of which we will refer to frequently. We employ the MMHT2014 NNLO PDF set [**?**] throughout with an appropriate constant K-factor (=1.27) to account for higher order QCD corrections. The production cross section times leptonic branching fraction is shown in Figure 1 (left) for these models at $\sqrt{s} = 14$ TeV in the narrow width approximation (NWA). It has been and will be assumed here that these Z' states only decay to SM particles.

Using the present ATLAS and CMS results at 13 TeV, [**?**] and [**?**], it is straightforward to estimate by extrapolation the exclusion reach at $\sqrt{s} = 14$ TeV using the combined $ee + \mu\mu$ final states. This is given in the first column of Table 1. For discovery, only the ee channel is used due to poor $\mu\mu$-pair invariant mass resolution near $M_{Z'} = 6$ TeV. Estimates of the 3σ evidence and 5σ discovery limits are also given in Table 1. Based on these results, we will assume in our study below that we are dealing with a Z' of mass 6 TeV. Figure 1 (right) shows the NWA cross sections for the same set of models but now at $\sqrt{s} = 27$ TeV with $\mathcal{L} = 15$ ab^{-1}. We note that very large statistical samples will be available for the case of $M_{Z'} = 6$ TeV for each dilepton channel.

Definition of the discriminating variables

The various Z' models can be disentangled with the help of 3 inclusive observables: the production cross section times leptonic branching fraction σB_l, the forward-backward asymmetry A_{FB} and the rapidity ratio r_y. The variable A_{FB} can be seen as an estimate of the charge asymmetry

$$A_{FB} = A_C = \frac{\sigma(\Delta|y| > 0) - \sigma(\Delta|y| < 0)}{\sigma(\Delta|y| > 0) + \sigma(\Delta|y| < 0)}, \tag{1}$$

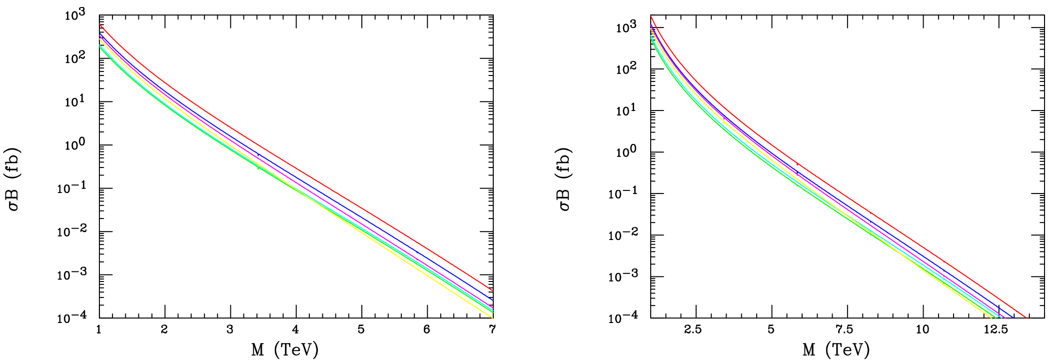

Fig. 1: Left: σB_l in the NWA for the Z' production at the $\sqrt{s}=14$ TeV LHC as functions of the Z' mass: SSM(red), LRM (blue), ψ(green), χ(magenta), η(cyan), I(yellow). (Right) σB_l of Z' in models described in (left) at $\sqrt{s}=27$ TeV.

Model	95% C.L.	3σ	5σ
SSM	6.62	6.09	5.62
LRM	6.39	5.85	5.39
ψ	6.10	5.55	5.07
χ	6.22	5.68	5.26
η	6.15	5.59	5.16
I	5.98	5.45	5.05

Table 1: Mass reach for several Z' models at $\sqrt{s}=14$ TeV with $\mathcal{L}=3$ ab^{-1}.

where $\Delta|y|=|y_l|-|y_{\bar{l}}|$. It has been checked that this definition is equivalent to defining

$$A_{FB}=\frac{\sigma_F-\sigma_B}{\sigma_F+\sigma_B}, \tag{2}$$

with $\sigma_F=\sigma(cos\theta^*_{cs})>0$ and $\sigma_B=\sigma(cos\theta^*_{cs})<0$ where θ^*_{cs} is the Collins-Soper frame angle. The variable r_y is defined as the ratio of central over forward events:

$$r_y=\frac{\sigma(|y_{Z'}|<y_1)}{\sigma(y_1<|y_{Z'}|<y_2)}, \tag{3}$$

where $y_1=0.5$ and $y_2=2.5$.

Model discrimination

The model discrimination presented in this section has been performed assuming the HE-LHC detector parametrisation [**?**] in DELPHES [**?**]. In such a detector, muons at $\eta\approx 0$ are assumed to be reconstructed with a resolution $\sigma(p)/p\approx 7\%$ for $p_T = 3$ TeV.

Leptonic final states The potential for discriminating various Z' models is first investigated using the leptonic ee and $\mu\mu$ final states only. The signal samples for the 6 models and the Drell-Yan backgrounds have been generated with PYTHIA 8.230 [**?**] assuming including the interference between the signal and background. The Z' decays assume lepton flavour universality. For a description of the event selection and a discussion of the discovery potential in leptonic final states for the list of Z'

models being discussed here, the reader should refer to Section [?]. We simply point out here that with $\mathcal{L} = 15$ ab^{-1} , all Z' models with $m_{Z'} \lesssim 10$ TeV can be excluded at $\sqrt{s} = 27$ TeV.

Figure 2 (left) shows the correlated predictions for the A_{FB} and the rapidity ratio r_y observables defined previusly for these six models given the above assumptions. Here we see that apart from a possible near degeneracy in models ψ and η, a reasonable Z' model separation is indeed achieved.

Using a profile likelihood technique, the signal strength μ, or equivalently, σB_l, can be fitted together with its corresponding error using the the di-lepton invariant mass shape. The quantity σB_l and its total estimated uncertainty is shown in Figure 2 (center) as a function of the integrated luminosity. The σB_l measurement seems to be able to resolve the degeneracy between the ψ and η models with $\mathcal{L} = 15$ ab^{-1}. It should be noted however that since the cross-section can easily be modified by an overall rescaling of the couplings, further handles will be needed for a convincing discrimination. (RT)

RT: in plot right FCC Simulation -> HE-LHC simulation. Plot style can also be improved, line instead of boxes in legends. Increase line thickness in for better visibility.

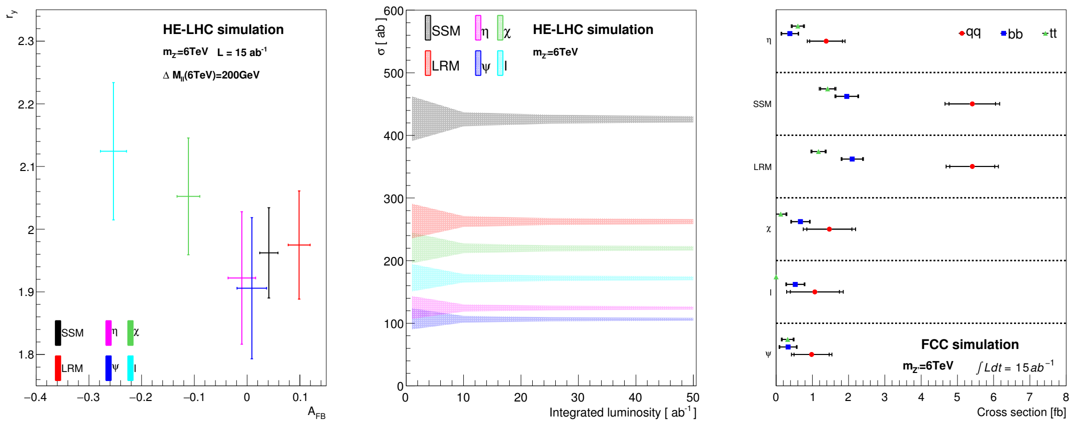

Fig. 2: Left: Scatter plot of r_y versus A_{FB} with 200 GeV and mass window. The full interference is included. Center: Fitted signal cross-section together with its corresponding error versus integrated luminosity. Right: Fitted cross-section of the three hadronic analyses. Statistical and full uncertainties are shown on each point.

Hadronic final states Model discrimination can be improved by including an analysis involving three Z' addition hadronic final states: $t\bar{t}$, $b\bar{b}$ and $q\bar{q}$, where $q = u, d, c, s$. The sample production and event selection for the $t\bar{t}$, $q\bar{q}$ final states has been described to some extent in Section [?]. We simply remind here that the analysis involves requiring the presence of two central high p_T jets. In order to ensure complete orthogonality between the various final states jets are required to be tagged as follows. In the $Z' \to t\bar{t}$ analysis both jets should be *top-tagged*. For the $Z' \to b\bar{b}$ final state both jets are required to be *b-tagged* and we veto events containing at least one top-tagged jet. Finally, in the $Z' \to q\bar{q}$ analysis, we veto events that contain at least one b-tagged or top-tagged jet.

Figure 2 (right) summarise the discrimination potential in terms of fitted cross-section of the different models considering the three aforementionned hadronic decays, $t\bar{t}$, $b\bar{b}$ and $q\bar{q}$. An good overall discrimination among the various models can be achieved using all possible final states. We note however that the degeneracy between η and Ψ can only be partially resolved resolved at $\approx 1\,\sigma$ by exploiting the difference in $t\bar{t}$ yield.

Conclusion

1.3 Spin 1/2 resonances

1.4 Signature based analyses

References