PROCEEDINGS OF SCIENCE

Z' production at LHC in an extended MSSM

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Searching for heavy neutral gauge bosons Z', predicted in extensions of the Standard Model based on a $U(1)'$ gauge symmetry, is among the main new physics investigations undertaken by the experiments at the Tevatron and at the Large Hadron Collider. The Z' phenomenology at hadron colliders according to several $U(1)'$-based models and in the Sequential Standard Model is studied. In particular, as far as its decay is concerned, including the Z' decays into supersymmetric particles, besides the Standard Model modes, so far investigated.
The new features of the MSSM, once it is extended by means of a $U(1)'$ group are considered. As for Z' decays into sfermions, the D-term contribution, due to the breaking of $U(1)'$, to slepton and squark masses is accounted.
The Z' phenomenology is studied in few benchmarks points in the parameter space. Results on branching ratios are presented with a special attention to the decays into neutralinos, charginos and charged-slepton pairs. The Z' cross sections for all considered models at LHC center-of-mass energies, $\sqrt{s}$= 8,14 TeV, is presented and their values folded with branching ratio into lepton final states are shown.
The feasibility to discover supersymmetry through these channels at the LHC is studied in two different center-of-mass energy and integrated luminosity scenarios.

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1. Introduction

An heavy neutral gauge boson, namely Z' is predicted by extension of Standard Model based on one extra string-inspired $U(1)'$ gauge symmetry, in in TeV mass range [1]. Moreover, another model, the Sequential Standard Model ($Z'_{\rm SSM}$), *i.e.* a heavy gauge boson with the same couplings to fermions and gauge bosons as the Z of the SM, has been investigated. The experimental searchs at Tevatron [2, 3] and LHC experiments excluded Z' with mass below 1.79 $\div$ 1.97 TeV(ATLAS) [4] (according various models) with mass below 2 TeV(CMS) [5](according a specific model) for string-inspired models and 2.33 TeV(CMS) and 2.22 TeV(ATLAS) in the SSM case. All these bounds on the Z' mass, $m_{Z'}$, rely on the assumption that the Z' decays into Standard Model particles, with branching ratios depending on its mass and, in the string-like case, on the parameters characterizing the specific $U(1)'$ model. But, there is no actual reason to exclude Z' decays into channels beyond the SM [6], such as its supersymmetric extension, the Minimal Supersymmetric Standard Model (MSSM). This new physics contributions to the Z' width significantly decreases the branching ratios into SM particles, and therefore the mass limits quoted by the experiments may have to be revisited. In this framework a D-term correction has to be included, due, to the extra $U(1)'$ group, to sfermion masses. This D-term can be large and negative implying in some cases unphysical sfermion masses. The supersymmetric particle masses are obtained in this work by diagonilazing the correspondenting mass matrices.

Here, of the phenomenology of Z' bosons at the LHC, is invistigated, assuming that decays into both SM and supersymmetric particles, as in the MSSM. The Z' decays into supersymmetric particles, if existing, represent an excellent tool to investigate the electroweak sector at the LHC in a phase-space corner that cannot be explored by employing the usual techniques. Through this work, particular care will be taken about the decay of the Z' into leptonic final state. Here, only the main points are summarized referring to the original paper for a more extensive description [7].

2. $\mathbf{Z'}$ production and decay

Among the $U(1)'$ gauge models, special attention has been paid to those coming from the breaking of a grand unified gauge group $\rm E_6$, having rank 6, as, $\rm E_6 \to SO(10)\times U(1)'_\psi$, followed by $\rm SO(10) \to SU(5)\times U(1)'_\chi$. The neutral vector bosons associated with the $U(1)'_\psi$ and $U(1)'_\chi$ groups are named Z'_ψ and Z'_χ respectively. Any other model is characterized by an angle θ and leads to a Z' boson which can be expressed as:

$$Z'(\theta) = Z'_\psi \cos\theta - Z'_\chi \sin\theta. \tag{2.1}$$

Each value of the mixing angle θ corresponds to a $U(1)'$ group and leads to a different Z' phenomenology. The most widely used models, with their corresponding mixing angle, are: Z'_η ($\arccos\sqrt{5/8}$), Z'_ψ (0), $Z'_{\rm N}$ ($\arctan\sqrt{15}-\pi/2$), $Z'_{\rm I}$ ($\arccos\sqrt{5/8}-\pi/2$), $Z'_{\rm S}$ ($\arctan(\sqrt{15}/9)-\pi/2$), Z'_χ ($-\pi/2$).

The charge of a field Φ is expressed through the same mixing angle θ as: $Q'(\Phi) = Q_\psi(\Phi)\cos\theta - Q_\chi(\Phi)\sin\theta$. with Q_ψ and Q_χ charge values for standard and supersymmetric particles as Ref. [6].

Extending the MSSM with the Z' boson, two extra neutralinos, (in total six neutralinos) and an extra neutral Higgs (in total six Higgs) are required. These additional particle masses are in general so heavy that or Z' decays into them are prevented or their contribution to total branching fraction is neglegible.

In conclusion, the $U(1)'$ group addition implies: an additional heavy Higgs, H', two extra neutralinos and as for the sfermions, an extra contribution, the so-called D-term, to squark and slepton masses, depending on the $U(1)'$ sfermion charges and Higgs vacuum expectation values. This D-terms has a crucial impact on sfermion masses and, whenever large and negative, they lead to discarding some MSSM/$U(1)'$ scenarios.

3. Representative Point and Z′ decays into final states with leptons

A specific configuration of the parameter space, the so-called 'Representative Point', is considered [7] to study the Z' phenomenology with non-zero branching ratios in the more relevant SM and MSSM decay channels. Then, each parameter is varied individually, fixing the others to the following values:

$$m_{Z'} = 3 \text{ TeV} \,,\ \theta = \arccos\sqrt{\frac{5}{8}} - \frac{\pi}{2}, \mu = 200 \,,\ \tan\beta = 20 \,,\ A_q = A_\ell = A_f = 500 \text{ GeV} \,,$$
$$m^0_{\tilde{q}_L} = m^0_{\tilde{q}_R} = m^0_{\tilde{\ell}_L} = m^0_{\tilde{\ell}_R} = m^0_{\tilde{\nu}_L} = m^0_{\tilde{\nu}_R} = 2.5 \text{ TeV}, M_1 = 100 \text{ GeV} \,,\ M' = 1 \text{ TeV}.$$

where by q and ℓ denote any possible quark and lepton flavor, respectively. $A_q = A_\ell = A_f$ are the fermion coupling constants. The gaugino masses M_1, M_2, M', satisfy, within very good accuracy, the GUT-inspired relation: $\frac{M_1}{M_2} = \frac{5}{3}\tan^2\theta_W$.The Beyond-Standard-Model (BSM) particle masses with Eq. (3.1) setting are summarized in Tab. 1. A study of parameter dependence is in Ref. [7].

Table 1: Masses in GeV of non Standard Model particles in the MSSM/$U(1)'$ scenarios, at Reference Point.

$m_{\tilde{u}_1}$	$m_{\tilde{u}_2}$	$m_{\tilde{d}_1}$	$m_{\tilde{d}_2}$	$m_{\tilde{\ell}_1}$	$m_{\tilde{\ell}_2}$	$m_{\tilde{\nu}_1}$	$m_{\tilde{\nu}_2}$
2499.4	2499.7	2500.7	1323.1	3279.0	2500.4	3278.1	3279.1
$m_{\tilde{\chi}^0_1}$	$m_{\tilde{\chi}^0_2}$	$m_{\tilde{\chi}^0_3}$	$m_{\tilde{\chi}^0_4}$	$m_{\tilde{\chi}^0_5}$	$m_{\tilde{\chi}^0_6}$	$m_{\tilde{\chi}^\pm_1}$	$m_{\tilde{\chi}^\pm_2}$
94.6	156.5	212.2	260.9	2541.4	3541.4	154.8	262.1
m_h	m_A	m_H	$m_{H'}$	$m_{H^\pm}$			
90.7	1190.7	1190.7	3000.0	1193.4			

Leptonic final states are typically the golden channels for the LHC experimental searches. Therefore, the decays of the Z' into supersymmetric particles, leading to final states with charged leptons and missing energy, due to the presence of neutralinos or neutrinos are investigated.
The two charged lepton final state may originate from primary decays $Z' \to \tilde{\ell}^+\tilde{\ell}^-$ followed by $\tilde{\ell}^\pm \to \ell^\pm\tilde{\chi}^0_1$ or from chargino chain decays $Z' \to \tilde{\chi}^\pm_2\tilde{\chi}^\mp_2$ with a subsequently decay of $\tilde{\chi}^\pm_2 \to W^\pm\tilde{\chi}^0_1 \to \nu(\bar{\nu})\tilde{\chi}^0_1$. The four charged lepton final state is originated from sneutrino, $\tilde{\nu}$, decays or $Z' \to \tilde{\nu}_2\tilde{\nu}^*_2$ with a subsequent decay chain $\tilde{\nu}_2 \to \tilde{\chi}^0_2\nu$, and $\tilde{\chi}^0_2 \to \tilde{\ell}^+\tilde{\ell}^-\tilde{\chi}^\pm_1$ and finally $\tilde{\ell}^\pm \to \ell^\pm\tilde{\chi}^0_1$. At same four lepton final is contributing as well the Z' decays into neutralino. The SUSY decay chain is $Z' \to \tilde{\chi}^0_2\tilde{\chi}^0_2$ with subsequent $\tilde{\chi}^0_2 \to \tilde{\ell}^\pm\tilde{\ell}^\mp$ and $\tilde{\ell}^\pm \to \ell^\pm\tilde{\chi}^0_1$ processes.

The study of Z' decays into leptonic final states for a given set of the MSSM and $U(1)'$ parameters, in the Z'_ψ model, varying $m^0_{\tilde{\ell}}$, the initial common slepton mass, at various $m_{Z'}$ values. The same set of parameters as eq. (3.1), but $m_{\tilde{q}}$ = 5 TeV and M_1 = 150 TeV are used.

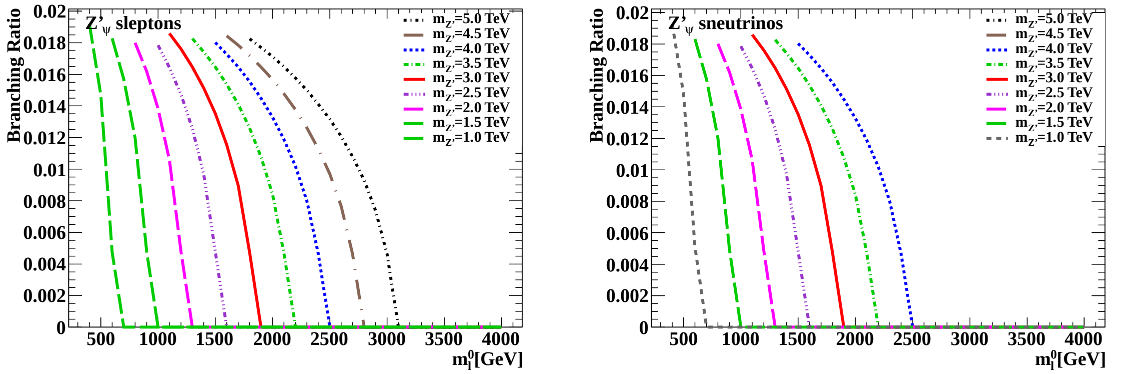

Figure 1: Branching ratio of the Z'_ψ boson into charged slepton (left) sneutrino (right) pairs as a function of the initial condition for the slepton mass, $m^0_{\tilde{\ell}}$, and for several values of $m_{Z'}$.

The Z'_ψ modeling, as example, yields branching ratios about 35-40% into BSM particle, and therefore it may look like being a promising scenario to investigate Z' production within the MSSM. Figure 1 finally displays the branching ratios into sneutrinos and charged sleptons as a function of $m^0_{\tilde{\ell}}$ and for several values of $m_{Z'}$.

3.1 Leading order Z′ production cross section

The cross sections is calculated at leading order (LO) with, for consistency, the LO parton distribution functions CTEQ6L. Different LO PDFs have a negligible impact on the cross section results. In the calculations, the factorization is set equal to the Z' mass. As far as the total cross section is concerned, the parton-level process is analogous to Z production, *i.e.* it is the purely SM quark-antiquark annihilation $q\bar{q} \to Z'$. Since the coupling of the Z' to the quarks depends on the specific $U(1)'$ scenario, the production rate is a function of the mixing angle θ, and of the Z' mass, but not of the MSSM parameters.

Figure 2 presents in logarithmic the total cross section for the different models, including the SSM, as a function of $m_{Z'}$ at $\sqrt{s}$= 8 TeV (Fig. 3, left) and 14 TeV (Fig. 3, right). The highest production cross section corresponds to SSM model, whereas the lowest to Z'_ψ model. The others model cross sections are lying between those and are indistinguishable at large $m_{Z'}$ value.
The cross section varies according $m_{Z'}$, center-of-mass energy and model.

The model choice has a more limited impact on the absolute value of cross section, but there are important differences as function of $\sqrt{s}$. The change by several order of magnitudes is present as function of Z' mass. The number of expected events is summarized in Tab. 2, in two scenarios: $\sqrt{s}$=8 TeV with an expected integrated luminosity, $\int \mathscr{L}\,dt$=20 fb^{-1}, as expected in 2012 LHC data taking and a future scenario $\sqrt{s}$=14 TeV with $\int \mathscr{L}\,dt$=100 fb^{-1}.

As final information on th experimental analysis search in dilepton (e, μ) pairs the results in term of the product of Z' production cross section (σ) and branching fraction (BR) at $\sqrt{s}$= 8 TeV is shown in Fig. 3 [8]. In this plot, the results is shown accounting only SM decays (dashed line) and also including the BSM (solid line). This presentation allows a straightforward comparison with the experimental results [5, 4]. Including BSM decays the suppression of σ BR is about 60% for $Z'_{\rm SSM}$, 40 % for Z'_ψ model and 30% for Z'_η and 13 % for $Z'_{\rm I}$. This clearly demonstrate the impact of the inclusion of the supersymmetric contribution to Z'decays.

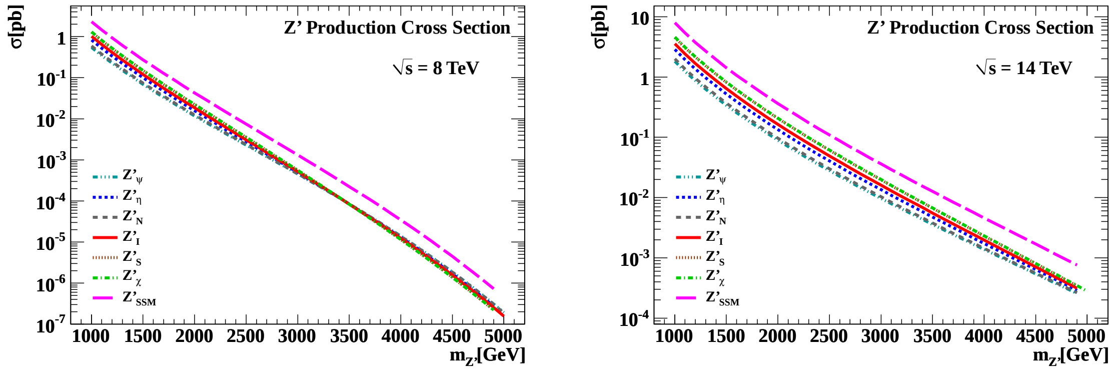

Figure 2: Cross section (logarithmic scale) of Z' production in pp collisions at center-of-mass energy, $\sqrt{s}$= 8 TeV (left) and $\sqrt{s}$= 14 TeV (right), for various models (see text).

Table 2: Number of supersymmetric particles (N_{casc}, from SUSY cascade and N_{slep}, from $\tilde{\ell}$ decays) at the LHC, for Z' production in different models as function of $m_{Z'}$ in TeV, at $\sqrt{s}$= 8 TeV, $\int \mathscr{L}\, dt$= 20 fb^{-1}and at $\sqrt{s}$= 14 TeV, $\int \mathscr{L}\, dt$= 100 fb^{-1}.

Model	$m_{Z'}$	$N_{casc}^{\sqrt{s}=8\text{ TeV}}$	$N_{slep}^{\sqrt{s}=8\text{ TeV}}$	$N_{casc}^{\sqrt{s}=14\text{ TeV}}$	$N_{slep}^{\sqrt{s}=14\text{ TeV}}$
Z'_η	1.5	523	–	13650	–
Z'_η	2	55	–	2344	–
Z'_ψ	1.5	599	36	10241	622
Z'_ψ	2	73	4	2784	162
Z'_{N}	1.5	400	17	9979	414
Z'_{N}	2	70	3	2705	104
Z'_{I}	1.5	317	–	8507	–
Z'_{I}	2	50	–	2230	–
Z'_{S}	1.5	30	–	8242	65
Z'_{S}	2	46	–	2146	16
Z'_{SSM}	1.5	2968	95	775715	24774
Z'_{SSM}	2	462	14	19570	606

4. Conclusions

In this paper, the production and decays of new neutral Z' boson, according to new physics models based on a $U(1)'$ gauge group and to the Sequential Standard Model is discussed. Decays in Standard Model and Beyond Standard Model particles are included. In this perspective, all quoted experimental limits have to be revisited.
The extension of the Minimal Supersymmetric Standard Model with $U(1)'$ group implies new features as an extra Higgs boson, two novel neutralinos and a modification of the sfermion mass by a D-term, where the new features are embedded. Only scenarios with all physical sfermion masses are considered. In particularly, the attention is focused to final states with charged leptons and missing energy favorable to experimental detection in hadronic events and can be yielded by intermediate charged sleptons or a SUSY cascade through neutralinos, chargino, sneutrinos.

The production cross sections in all investigated models and the number of expected events at

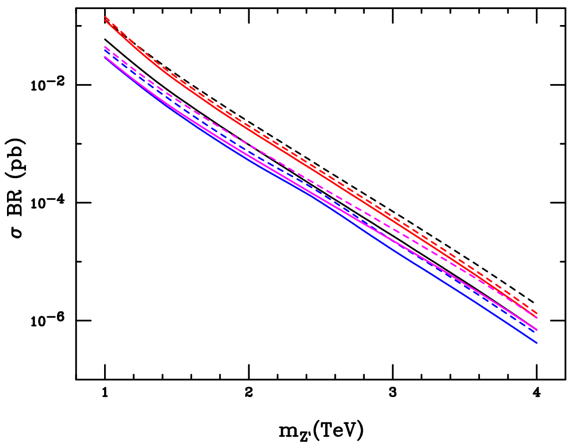

Figure 3: Product of cross section times branching ratio(σ BR) into e^+e^- and $\mu^+\mu^-$ pairs for Z' production in in pp collisions at center-of-mass energy, $\sqrt{s}$= 8 TeV. $Z'_{\rm SSM}$ (black line), Z'_η (blue), $Z'_{\rm I}$ (red) and Z'_ψ (magenta). The solid lines account for BSM decay modes, the dashed for only SM channels [8].

two centre-of-mass energies and integrated luminosities has been provided. For some models and parametrization, $10^4 - 10^5$ events with sparticle production, are expected. The sparticle production impact is more evident observing the product production cross section times branching fraction in electron/muon pair, showing an effect ranging from 40% to 13% neglecting the beyond Standard Model Z' decays.

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