

SEARCHING FOR SGLUONS IN THE SAME-SIGN LEPTONS FINAL STATE AT THE LHC*

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A simulation of pair production of color-octet scalars (sgluons) decaying into $t\bar{t}$ is presented. Such particles appear in many extensions of the SM, *e.g.* in the R -symmetric SUSY. We search for same-sign dileptons and b -jets signature of sgluons, focusing on events with a large number of “fat” jets and using the sum of jet masses as a selection criterion. The UNLOPS method, as implemented in PYTHIA8, is used to simulate the SM background.

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1. Introduction

With the discovery of the Higgs boson last year [1], the particle content of the Standard Model (SM) has been completed. However, the true nature of the discovered state as well as many shortcomings of the SM are still waiting for an explanation. In particular, the question of stabilization of the Higgs boson mass with respect to the Planck scale has fueled theoretical speculations on beyond the SM physics. Among these, the TeV-scale supersymmetry is one of the most theoretically and experimentally studied options. So far no direct signal of supersymmetry has been observed by the LHC experiments, and only lower mass limits on superpartners have been derived in simplified models. However, the current limits may not be valid in more general supersymmetric scenarios. In particular, dedicated phenomenological studies may be required for some of the final states signatures of non-minimal models. R -symmetric supersymmetric models invariant under a global $U(1)_R$ transformation $\theta \rightarrow e^{i\alpha}\theta$ are particularly well motivated. R -invariance is indeed a symmetry [2] of all basic building blocks of the supersymmetric extension

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of the SM. $U(1)_R$ symmetry forbids not only baryon- and lepton-number changing terms in the superpotential, but also dim-5 operators mediating proton decay. R -symmetry also removes the trilinear A -terms for the scalars, the μ -term and Majorana gaugino masses. The absence of μ - and A -terms ameliorates the flavor problem without the flavor-blind mediation. Although Majorana gaugino masses are forbidden, Dirac masses are perfectly allowed if adjoint chiral superfields for each gauge factor are introduced. Similarly, the Higgs sector is extended by adding multiplets R_u and R_d to generate R -symmetric μ -terms with H_u and H_d , as in the Minimal R -symmetric Supersymmetric Standard Model (MRSSM) [3].

The scalar component of the adjoint $SU(3)$ superfield, a sgluon σ , can be relatively light and thus accessible at the LHC [4]. Note that color-octet scalar states, fundamental or composite, also appear in many different models.

At the LHC, sgluons are produced in pairs and the production cross section is simply determined by their couplings to gluons; a model-dependent single sgluon production might become competitive for heavy states. If squarks and gluinos are too heavy, sgluons will decay to $q\bar{q}$ or gg via their loop-induced couplings. Since the coupling $\sigma q\bar{q}$ is suppressed by the quark mass, as required by chirality arguments, above the top threshold there are essentially two competing decay modes; $\sigma \rightarrow gg$ and $\sigma \rightarrow t\bar{t}$. Both channels have been searched for, and the ATLAS Collaboration excluded sgluon masses below ~ 300 GeV in the gg channel and ~ 800 GeV in the $t\bar{t}$ [5].

In our simulations, we consider a generic scenario with the sgluon mass above 800 GeV assuming $\text{BR}(\sigma \rightarrow t\bar{t}) = 1$ and taking the supersymmetric particles above the current experimental limits. This way we omit specifying a complete model scenario, limiting ourselves to the relevant parameters for our studies. For simplicity, we also consider purely scalar coupling of sgluons to tops. The results can easily be reinterpreted in the context of a particular model that includes color-octet scalars. Since events with same-sign, isolated leptons from SM processes in pp collisions are extremely rare, we perform simulations for final states with same-sign muons and b -jets, with accompanying missing transverse energy \cancel{E}_\perp .

2. Event simulation

2.1. Software set-up

The ME-level samples of signal and background processes have been generated as follows:

- An extension of the SM with a color-octet scalar has been encoded into FeynRules [6]. Signal samples were generated using the MadGraph5 generator [7] at LO. 1M events was generated for each sgluon mass.

- Background samples at the NLO QCD accuracy were generated using the POWHEG-BOX [8] and PowHel programs [9]. Samples with additional jets at the LO accuracy needed for the UNLOPS method [10] were generated using, as in the case of the signal, MadGraph5. Processes with extra jets were regularized using a k_{\perp} measure of 20 GeV.

Exclusive samples for the background were combined using the UNLOPS methods in PYTHIA8 with the merging scale $t_{\text{MS}} = 40$ GeV. Such a choice is best suited for “fat” jet analysis, which we are conducting. Numbers in parentheses following UNLOPS tags in Table I denote number of jets at NLO and LO accuracy, respectively, that were generated. For example, UNLOPS(0,3) means that only the core process was generated at the NLO accuracy and that samples with up to 3 partons at the LO accuracy were used. For every process in Table I, we generated 1M events for the core process, 2M events with one additional parton above the resolution scale and 3.5M events for processes with two partons. Size of samples with more than 2 partons varied depending on the complexity of the core process.

TABLE I

Analysis summary for signal and relevant background processes at the 8 TeV LHC. Last column gives number of expected events per 19.5/fb of integrated luminosity passing final selection criteria. Numbers of background events correspond to 3 sets of cuts, optimized for $m_{\sigma} = 750, 900$ and 1000 GeV, respectively. The meaning of an UNLOPS tag is explained in the text.

Process	Method	σ [fb]	$\sigma \times \text{BR}$ [fb]	Event number
$W^{\pm}Z$	UNLOPS(0,3)	—	86.4	0
ZZ	UNLOPS(0,3)	—	55.1	0
$t\bar{t}$	UNLOPS(1,3)	247×10^3	50.5×10^3	0
$t\bar{t}W^{\pm}$	UNLOPS(0,3)	209	2.44	0.21/0.16/0.16
$t\bar{t}Z$	UNLOPS(0,3)	219	7.58	0.35/0.26/0.26
$m_{\sigma} = 750$ GeV	no-matching	65.4	1.52	7.4
$m_{\sigma} = 900$ GeV	no-matching	10	0.232	1.1
$m_{\sigma} = 1000$ GeV	no-matching	5.29	0.123	0.5

Processes at the NLO order were generated using the MSTW2008nlo PDF with 4 active flavors. LO samples used in the UNLOPS method were generated using the same set to ensure smooth matching. For signal simulation, we used 4-flavor MSTW2008lo PDF. All samples were passed through the full event simulation using the PYTHIA8 SMC generator.

2.2. Signal and background processes

Table I shows a list of MC samples generated for this simulation. We only generated processes with at least two prompt leptons. The treatment of processes with lower lepton's multiplicities is briefly discussed below. We assume for the signal that $t\bar{t}\bar{t}\bar{t}$ from sgluons do decay to at least two same-sign muons and that tops decay exclusively into b -quarks and W bosons with a branching ration of W into the single flavor of leptons of 0.108. This gives a total BR of 2.3×10^{-2} for this process. At 8 TeV LHC the SM 4 top-quarks production, which is an irreducible background, can be neglected compared to the signal up to $m_\sigma \lesssim 1$ TeV [11], and therefore not included in Table I. The signal cross section was normalized to the NLO accuracy according to [12].

SM processes with same-sign prompt and non-prompt leptons (*i.e.* leptons from heavy flavor decays, kaon/pion decays), like from $t\bar{t}$ production, are suppressed by requiring isolated leptons. Events with one or two objects misidentified as leptons were not taken into account in this analysis.

3. Detector's response parametrization

The Delphes [13] fast-simulation framework was used to simulate the LHC detector response and reconstruction resolutions. The default settings for the CMS detector were used with a slightly increased muon reconstruction efficiency and changed isolation criteria¹ to better match the latest public CMS results on tracking performance. Since the b -tagging is also an important element of this analysis, a working point with true b -quark efficiency $\epsilon_b = 0.5$ and $\epsilon_c = 0.1$ was chosen, according to ROC curves for 2012 data published by the CMS Collaboration. The pile-up was not simulated in this analysis.

4. Event selection

By default, Delphes reconstructs only leptons with $p_\perp > 10$ GeV. We select muons with $|\eta| < 2.1$ and veto all events which do not have a same-sign muon pair after this selection. Following Ref. [14], we find the variable M_J a useful tool in discriminating the signal from background. It is defined as a sum of "fat" jet masses $M_J = \sum_{\text{jets}} m_j$, where the fat jets have the cone size of $R = 1.2$ with anti- k_t algorithm and the sum runs over jets satisfying conditions: $p_\perp^j > 50$ GeV, $|\eta^j| < 3.8$. The discriminating power of such an observable is, for typical SUSY signatures, higher than the commonly used H_\perp variable although for this particular case the difference is not very large. Due to a large number of b -quarks and light jets for the signal final state it is advantageous to require at least one b -tagged jet. Large hadronic

¹ We set the DeltaRMax and PTRatioMax parameters in MuonIsolation module to 0.4.

activity is ensured by requiring at least 3 jets in total (together with a b -tagged one) where the leading jet has $p_{\perp} > 120$ GeV. Thus requirement of a large hadronic activity and the presence of b -quarks removes the background due to the di-boson contribution and the main SM background comes from the production of $t\bar{t}$ pairs in association with a vector boson. To cope with this background, we employ cuts in the M_J vs. \cancel{E}_{\perp} plane, which are chosen such that maximize the $S/\sqrt{B+1}$ ratio. Plots of this quantity for $m_{\sigma} = 750$ and 900 GeV are given in Fig. 1. The last column of Table I gives numbers of expected events for signal and background processes after all selection cuts assuming 19.5/fb of integrated luminosity. Thus our analysis shows that $S/\sqrt{B+1} < 5$ is obtained for $m_{\sigma} \geq 800$ GeV, which is consistent with the experimental results of ATLAS experiment during the 8 TeV run of the LHC. Including same-sign electron and electron–muon pairs in addition to requiring same-sign muon pairs might improve the discovery/exclusion reach of our method.

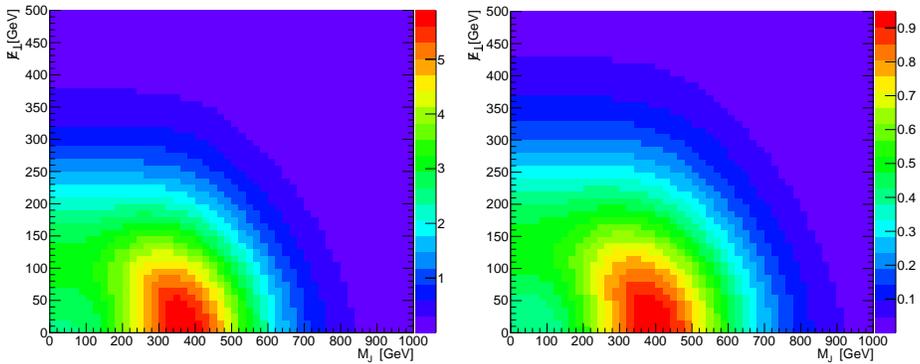


Fig. 1. $S/\sqrt{B+1}$ ratio for a given choice of M_J and \cancel{E}_{\perp} cuts for purely scalar $\sigma t\bar{t}$ coupling for $m_{\sigma} = 0.75$ TeV (left) and 0.9 TeV (right).

5. Conclusions

Experimental signature, similar to the one considered in this paper, was recently investigated by the CMS experiment in Ref. [15] showing no deviation from the SM. Our analysis differs in a few key aspects and focuses on a specific model but agrees well with both ATLAS [5] and CMS [15] searches. Rapid fall-off of the production cross section with the increasing sgluon mass suggest that using the collected 8 TeV data makes pushing the exclusion limit much above 800 GeV rather unlikely, even if same-sign electron and electron–muon samples are added. Nevertheless, the consistency of the results of our pure MC-based analysis with experimental results gives us a confidence in our method and encourages us to pursue a sensitivity study for the 13/14 TeV LHC.

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