Pseudoscalar Gluinonia to Diphotons at the LHC

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Abstract

Identifying the diphoton mass excesses reported by ATLAS and CMS as two or more pseudoscalar gluinonia, bound states of two gluinos with $m_{\tilde{g}} \approx 380$ GeV, we perform a scan in Next-to-Minimal Supersymmetry parameter space, fixing $m_{\tilde{g}} \approx 380$ GeV and identifying an experimentally viable point. We generate events, perform fast simulation, and carry out an analysis modeled on the ATLAS search which reproduces the features of the diphoton excess.

1 Introduction

The Standard Model (SM) of particle physics is both a success and a failure. A success because it is a strongly predictive model which no experimental measurement has falsified. A failure because it does not account for Dark Matter, the anomalous muon magnetic moment, the strong CP problem or the hierarchy problem.

Supersymmetry (SUSY) can succeed where the SM fails and embed the SM as a low energy approximation, thus inheriting its successes [1]. ATLAS and CMS have reported possible excesses in the diphoton mass spectrum [2, 3] at the the Large Hadron Collider. The excesses can be explained by gluinonia, bound states of gluinos which have been dubbed the hydrogen atom of SUSY [4].

ATLAS reports a local significance of 3.6σ near 750 GeV, while CMS reports a local significance of 2.6σ near 760 GeV. A diphoton decay strongly indicates decay from either a scalar or pseudoscalar. ATLAS reports a width $\Gamma \approx 40$ GeV for the 750 GeV feature, much larger than the diphoton energy resolution. Assuming a resonance decay, the natural width is unusually large. Alternatively, there may be two or more resonances in close proximity.

The μ-term problem of Minimal SUSY (MSSM) [1, 5, 6] motivates Next-to-Minimal SUSY (NMSSM), which includes a Higgs singlet in addition to the two Higgs doublets of the MSSM [5, 6]. In the study [7] we define a natural NMSSM benchmark h_{60}, characterized by an effective MSSM and a slightly broken PQ symmetry. It features a light pseudoscaler Higgs with $m_{a_1} \approx 10$ GeV and a light scalar with $m_{h_1} \approx 60$ GeV, which can be produced from cascade decay of a light stop with $m_{\tilde{t}_1} \approx 340$ GeV to electroweakinos $\tilde{t}_1 \to \chi^+ b \to \chi_3 W b$, and $\chi_3 \to h_1 \chi_1 \to 2a_1\chi_1$.

2 Pseudoscalar Gluinonia

The benchmark h_{60} features a relatively light gluino with $m_{\tilde{g}} \approx 610$ GeV which has been excluded by ATLAS and CMS. Since the lower energy phenomenology can be decoupled by relaxing the gaugino mass unification constraints, that study simply assumes the gluino mass is $m_{\tilde{g}} \approx 855$ GeV or higher and thus avoids exclusion.

Here we assume, on the contrary, the other possibility: the gluino mass is below threshold for $\tilde{g} \to t\tilde{t}_1$ and $\tilde{g} \to b\tilde{b}_1$ and thus avoids exclusion. Such gluinos can have very small natural widths since they must decay through virtual squarks to electroweakinos. In this case, pair

Parameter	Range/Value	$\tilde{g}_{380}$	h_{60}
λ	Fixed	0.03505	0.03505
κ	Fixed	0.006088	0.006088
m_A	Fixed	1068. GeV	1068. GeV
m_P	Fixed	10.25 GeV	10.25 GeV
μ_{eff}	[150,180] GeV	173.5 GeV	166.7 GeV
$\tan\beta$	[1,25]	6.01	15.49
M_1	Fixed	80.73 GeV	80.73 GeV
M_2	Fixed	161.5 GeV	161.5 GeV
M_3	Fixed	280.0 GeV	484.4 GeV
X_t	$[0, 2X_t^{max}]$	1282. GeV	1378. GeV
$m_{\tilde{Q}3_L}$	[500,600] GeV	546.3 GeV	546.9 GeV
$m_{\tilde{U}3_R}$	m_{Q3}	546.3 GeV	546.9 GeV

Table 1: NMSSM parameter scan ranges together with their values for the benchmark $\tilde{g}_{380}$ and, for comparison, the benchmark h_{60}. Except for M_3, fixed parameters are fixed to their h_{60} values. M_3 is fixed to obtain a 380 GeV gluino.

produced gluinos may form states bound by the strong interaction. Such gluinonia states, the so-called hydrogen atom of SUSY, have been studied in the literature as early as the 1980s [8, 4, 9, 10, 11, 12].

In this study we consider a natural NMSSM benchmark $\tilde{g}_{380}$ with the low energy phenomenology of h_{60} but with a different spectrum for the gluino, stop and sbottom. We take the 750 GeV LHC diphoton excess to be two or more pseudoscalar gluinonia states, and the gluino mass to be $m_{\tilde{g}} \approx 380$ GeV.

We consider two pseudoscalar gluinonia states, the color singlet ${}^1S_0(1)$ with color factor 3, and the color octet ${}^1S_0(8)$ with color factor $\frac{3}{2}$. Both states have been studied in the literature [9, 10, 11, 12] with consistent results. For $m_{\tilde{g}} \approx 380$ GeV, their widths are $\Gamma_1 \approx 320$ MeV and $\Gamma_8 \approx 10$ MeV respectively. The binding energy of the color singlet is $E_b^1 \approx 20$ GeV, while for the color octet this is reduced by the square of their color factor ratio, $E_b^8 = \frac{1}{4}E_b^1$. The difference in binding energies, together with detector resolution, can account for the large width of approximately 40 GeV reported by ATLAS since their masses are $2M_{\tilde{g}} - E_b$. The LHC production cross section at $\sqrt{s} = 14$ TeV for the color singlet is approximately $\sigma_1 = 2$ pb, while for the color octet this is reduced by the square of their color factor ratio $\sigma_8 = \frac{1}{4}\sigma_1$.

Diphoton decays of these states are suppressed relative to digluon decays by $R_{\gamma\gamma} \approx 10^{-5}$ for the processes considered in [10], but we consider that some mechanism has enhanced production of the diphoton final state either through additional gluinonia states, enhanced cross section, enhanced branching ratio, gluoinonia pair production, or some combination of these possibilities.

3 NMSSM Benchmark $\tilde{g}_{380}$

We perform a NMSSM scan similar to the scan which produced h_{60}. We use NMSSM-Tools4.8.2 [13, 14, 15, 16, 17, 18] and impose the full set of experimental constraints. Unlike the h_{60} scan, however, we use Higgs mass precision 1 rather than 2 in order to expedite the scan.

We fix the doublet-singlet coupling λ, the singlet self interaction coupling κ, the doublet scalar mass m_A, and the doublet pseudoscalar mass m_P to their h_{60} values. We target a 380 GeV gluino by relaxing the unification constraint for the gaugino masses $M_3 = 3M_2$ and directly fix the mass $M_3 = 280$ GeV. The other gaugino masses are fixed to the h_{60} values $M_2 = 161.5$ GeV and $M_1 = \frac{1}{2}M_2$.

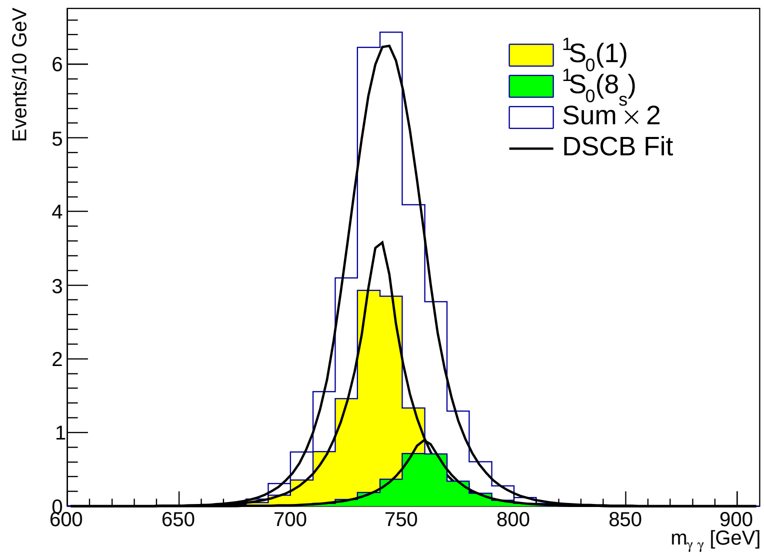

Figure 1: The diphoton spectrum obtained with Pythia8 assuming pseudoscalar gluinonia color singlet with mass $m_1 = 740$ GeV and color octet with mass $m_8 = 760$ GeV. The branching ratio to diphotons is assumed to be 0.4%. The full width at half maximum of the sum is approximately 40 GeV.

We scan four parameters close to their h_{60} values with 10^8 random points: third generation squark mass m_{Q_3}, stop mixing X_t, the effective μ-term μ_{eff}, and the ratio of doublet VEVs $\tan\beta$. All other squark and soft trilinear parameters are fixed to 1500 GeV. The slepton mass parameters are fixed to 300 GeV. See Table 1 for the scan parameter values and ranges.

Since, as noted in [7], a stop lighter than the one in h_{60} can explain the CMS dilepton excess [19], we seek the benchmark $\tilde{g}_{380}$ among the points surviving the scan constraints with the lowest stop mass which is still consistent with the lower energy phenomenology of h_{60}. These criteria yield the point $\tilde{g}_{380}$ with $m_{\tilde{g}} = 381.7$ GeV, $m_{\tilde{t}_1} = 324.0$ GeV and $m_{\tilde{b}_1} = 527.8$ GeV. See Table 1 for the parameter values in $\tilde{g}_{380}$ and, for comparison, h_{60}.

4 LHC Diphoton Signature of $\tilde{g}_{380}$

We use Pythia8.205 [20, 21] to simulate gluon fusion production and diphoton decay of pseudoscalar color singlet and color octet bound states of two gluinos: $gg \to \tilde{g}\tilde{g} \to^1 S_0(1) \to \gamma\gamma$ and $gg \to \tilde{g}\tilde{g} \to^1 S_0(8) \to \gamma\gamma$.

The center of mass energy is set to $\sqrt{s} = 13$ TeV with pp beams. Gluon fusion production of the pseudoscalar Higgs A is employed to mimic the pseudoscalar gluinonia production. The decay $A \to \gamma\gamma$ is required, and two masses are specified: $m_A = 740$ GeV to mimic the $^1S_0(1) \to \gamma\gamma$ decay and $m_A = 760$ GeV to mimic the $^1S_0(8) \to \gamma\gamma$ decay. In both cases the width is set to $\Gamma_A = 1$ MeV.

Fast detector simulation is carried out with Delphe3.2.0 [22] using the Delphes3 ATLAS card with pileup suitable for $\sqrt{s} = 13$ TeV. The ATLAS diphoton search selection is reproduced as far as this is possible with fast simulation. Photons are required to satisfy $|\eta_\gamma| < 2.37$, excluding the region $1.37 < |\eta_\gamma| < 1.52$. Photon isolation requires

$E_{cal}^{0.4}/E_\gamma < 0.022$ where $E_{cal}^{0.4}$ is the calorimeter energy in a cone of radius $\Delta R = 0.4$ around (but excluding) the photon. The analysis requirements are these:

- at least two isolated photons with $E_T^\gamma > 30$ GeV
- at least one isolated photon with $E_T^\gamma > 40$ GeV
- leading photon satisfies $E_T^\gamma/m_{\gamma\gamma} > 0.4$
- subleading photon satisfies $E_T^\gamma/m_{\gamma\gamma} > 0.3$

where $m_{\gamma\gamma}$ is the mass of the leading and subleading photons. After full signal selection, the signal efficiency is approximately 40% for both signal samples.

We assume an integrated luminosity $\int dt\mathcal{L} = 3.2$ fb^{-1} and cross sections for $gg \to^1 S_0(1)$ of $\sigma_1 = 2$pb and for $gg \to^1 S_0(8)$ of $\sigma_8 = \frac{1}{4}\sigma_1$. We assume a branching ratio to diphotons of 0.4%, which , though in conflict with [10], is required to yield approximately 10 events after full selection.

The $m_{\gamma\gamma}$ distributions for the ${}^1S_0(1)$, the ${}^1S_0(8)$, and their sum are fit with a double sided Crystal Ball (DSCB) as defined in the ATLAS search [3]. See Figure 1 for the diphoton mass distributions $m_{\gamma\gamma}$ and their fits after full signal selection. The $m_{\gamma\gamma}$ sum distribution full width at half maximum is approximately 40 GeV.

5 Conclusion

We have identified pseudoscalar gluinonia, bound states of gluinos with $m_{\tilde{g}} \approx 380$ GeV, as an explanation for the diphoton excesses reported by ATLAS and CMS. A light gluino below the threshold for decay to stop or sbottom has a small width beacause it must decay via virtual squarks, allowing two gluinos to form bound states with widths larger than the gluino width.

A color singlet with mass $m_{{}^1S_0(1)} = 740$ GeV and a color octet with mass $m_{{}^1S_0(8)} =$ 760 GeV can explain the large width reported by ATLAS if there exist more gluinonia states, the production cross section is enhanced, the diphoton branching ratio is enhanced, gluinonia are pair produced, or some combination of these possibilities. Only the ground states of pseudoscalar color singlet and octet have been considered here, for example.

A scan is performed in NMSSM parameter space with NMSSMTools4 to identify a benchmark point $\tilde{g}_{380}$ consistent with the benchmark h_{60} [7] featuring $m_{\tilde{g}} \approx 380$ GeV which survives experimental constraints. An analysis based on the ATLAS diphoton search is carried out with events generated by Pythia8 with Delphes3 detector simulation which reproduces the important features of the diphoton excess in the $\sqrt{s} = 13$ TeV data.

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