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On sgoldstino interpretation of the diphoton excess

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We point out that the diphoton excess at about 750 GeV recently discovered by the LHC experiments can be explained within supersymmetric models with low scale supersymmetry breaking with sgoldstino as a natural candidate. We discuss phenomenological consequences of this scenario describing possible signatures to test this hypothesis.

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1. Introduction. The first results obtained by the ATLAS and CMS collaborations in proton-proton collisions at $\sqrt{s} = 13$ TeV at LHC Run-II have been recently revealed [1]. Among them there has been highlighted a small excess in searches for diphoton resonances [2, 3]. Although its local significance is not very high, 3.9σ for ATLAS and 2.6σ for CMS, it is most exciting that both experiments observed the excess at the same diphoton invariant mass around 750 GeV, and it is tempting to interpret it as a signal from long-awaited new physics. Several studies have already been performed in this direction [4] and among them are explanations within a low scale supersymmetry framework [5, 6]. In this class of models (see, e.g., [7–10]) apart from usual superpartners of the Standard Model particles, the low energy theory contains also a part of the sector responsible for supersymmetry breaking. In a minimal scenario, this part contains Goldstone fermion – goldstino – and its superpartners dubbed sgoldstinos. Interactions of the latter with the Standard Model particles are determined by soft supersymmetry breaking parameters and suppressed by the supersymmetry breaking scale $\sqrt{F}$. Collider phenomenology of sgoldstinos with masses of order electroweak scale have been discussed for instance in [10–18]. In Refs. [5, 6] it has been proposed that sgoldstino (scalar, pseudoscalar or both) is responsible for the diphoton excess at 750 GeV. In this note we further discuss phenomenological implications of this proposal pointing out at particular signatures which can be used to verify this scenario.

2. Exploring the model. The scalar S sgoldstino interactions with photons and gluons are governed by the following effective lagrangian (see, e.g., Ref. [19])

$$\mathcal{L}_1 = -\frac{M_3}{2\sqrt{2}F} S G^a_{\mu\nu} G^{a\mu\nu} - \frac{M_{\gamma\gamma}}{2\sqrt{2}F} S F_{\mu\nu} F^{\mu\nu}, \qquad (1)$$

where $M_{\gamma\gamma} = M_1 \cos^2\theta_W + M_2 \sin^2\theta_W$ and $M_{1,2,3}$ are soft gaugino masses of a supersymmetric extension of the Standard Model. The dominating production mechanism of sgoldstino at high energy pp collisions is gluon-gluon fusion [11, 12] for typical hierarchy of soft supersymmetry breaking parameters: gluino is the heaviest gaugino while the soft trilinear couplings are of the same size as M_i. The production cross section σ_S is related to the decay of sgoldstino to gluons $\Gamma(S \to gg) = \frac{M_3^2 m_S^3}{4\pi F^2}$ which is typically the main decay channel for $\sqrt{F}$ at TeV scale and $m_S < \sqrt{F}$ which we will assume in what follows. The width of sgoldstino decay into photons is given by $\Gamma(S \to \gamma\gamma) = \frac{M_{\gamma\gamma}^2 m_S^3}{32\pi F^2}$. Apart from gg and $\gamma\gamma$ the most important decay modes of sgoldstino relevant for our study are into WW, ZZ, and $Z\gamma$. Corresponding interactions are

$$\mathcal{L}_2 = -\frac{M_2}{\sqrt{2}F} S W^{\mu\nu} W_{\mu\nu} - \frac{M_{ZZ}}{2\sqrt{2}F} S Z^{\mu\nu} Z_{\mu\nu} - \frac{M_{Z\gamma}}{\sqrt{2}F} S Z^{\mu\nu} F_{\mu\nu} \qquad (2)$$

with $M_{ZZ} = M_1 \sin^2\theta_W + M_2 \cos^2\theta_W$ and $M_{Z\gamma} = (M_2 - M_1)\sin\theta_W \cos\theta_W$.

To explain the diphoton excess we require that the mass of sgoldstino is equal to 750 GeV and

$$3 \text{ fb} \lesssim \sigma_{\gamma\gamma} \lesssim 13 \text{ fb at } 13 \text{ TeV}, \qquad (3)$$

where we define

$$\sigma_{\gamma\gamma} \equiv \sigma_S \mathrm{Br}(S \to \gamma\gamma) \qquad (4)$$

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and as gg decay mode is dominant,

$$\mathrm{Br}(S \to \gamma\gamma) = \frac{\Gamma(S \to \gamma\gamma)}{\Gamma(S \to gg)}. \quad (5)$$

The information about the width of this resonance is still quite uncertain and we will not be focusing on it in the present study. One should check that this scenario is phenomenologically viable and passes all constraints obtained in previous collider searches. Let us discuss the compatibility of new diphoton excess with the ATLAS and CMS results at $\sqrt{s} = 8$ TeV. The strongest bound $\sigma_{\gamma\gamma} \lesssim 1.5$ fb at this collision energy was obtained by the CMS [20] while somewhat weaker constraints come from ATLAS data [21]. The ratio of the production cross sections for sgoldstino case of $\sqrt{s} = 8$ and 13 TeV is almost independent on parameters of the model and is found to be $\frac{\sigma_S(\sqrt{s}=13\,\mathrm{TeV})}{\sigma_S(\sqrt{s}=8\,\mathrm{TeV})} \approx 5$. The excess (3) requires $0.6\,\mathrm{fb} \lesssim \sigma_{\gamma\gamma}(\sqrt{s} = 13\,\mathrm{TeV}) \lesssim 2.6\,\mathrm{fb}$ which seems to be still allowed partly by the present bounds. The dominating decay into gluon pairs reveals itself in a dijet signature. The strongest present bound from the searches for dijet resonances is $\sigma_S \mathrm{Br}(S \to gg) \lesssim 30$ pb [22]. Searches for resonances decaying into pair of massive vector bosons WW, ZZ have been performed at the LHC Run-I [23, 24] and the strongest limits look

$$\sigma_{WW} \lesssim 0.03\,\mathrm{pb}, \quad \sigma_{ZZ} \lesssim 0.012\,\mathrm{pb} \quad \text{at } 8 \text{ TeV} \quad (6)$$

with the definitions of σ_{WW} and σ_{ZZ} similar to (4). It is important to note that the couplings of sgoldstino to Z and W bosons are not independent from that of to photons, see Eqs. (1) and (2). Thus, in general one expects that sgoldstino interpretation of the diphoton resonance will result in certain predictions with the diboson (WW, ZZ, or $Z\gamma$) signatures. We explore this possibility by performing a scan over relevant parameter space. Namely we fix the supersymmetry breaking scale $\sqrt{F} = 5$ or 7 TeV while take gaugino masses randomly in the following ranges: $0.2\,\mathrm{TeV} < M_{1,2} < \sqrt{F}$ and $1.7\,\mathrm{TeV} < M_3 < \sqrt{F}$. The upper bounds in these intervals come from perturbative unitarity constraints of the effective sgoldstino interactions while the lower bounds are inspired by results of the direct searches[2)] for gauginos. For each model characterized by chosen set of parameters $M_{1,2,3}, F$ we calculate sgoldstino production cross section and its relevant decay widths using formulas of Refs. [26] and [12]. Then, we select phenomenologically accepted models which predict diphoton rate in the interval (3) and also satisfy the experimental constraints from searches for resonances in dijets, diphotons and double massive vector bosons we described above.

The results of the scan are presented in Figs. 1–4. In Fig. 1 we show the parameters $M_{1,2}$ of the selected models for different values of supersymmetry breaking scale $\sqrt{F}$. As expected, larger $\sqrt{F}$ require an increase of gaugino masses $M_{1,2}$ because sgoldstino couplings behave as M_i/F. Similar correlation is found for M_3. Diphoton and $pp \to S \to ZZ$ cross sections calculated at different $\sqrt{F}$ are shown in Fig. 2. We see that the bound on diphoton cross section obtained by CMS in the Run-I effectively cuts all the models with $\sigma_{\gamma\gamma} \gtrsim 7.6$ fb. At the same time predicted values for the resonance cross section with ZZ final state σ_{ZZ} reach values about 17 and 26 fb for $\sqrt{F} = 5$ and 7 TeV, respectively. In Figs. 3

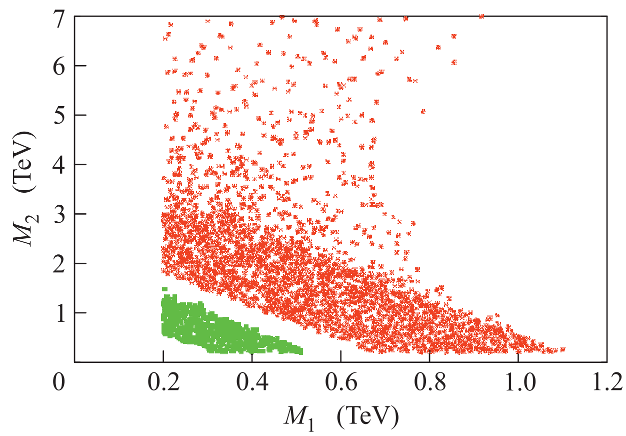

Fig. 1. (Color online) Scatter plot in (M_1, M_2) plane for $\sqrt{F} = 5$ TeV (green/light gray) and $\sqrt{F} = 7$ TeV (red/dark gray)

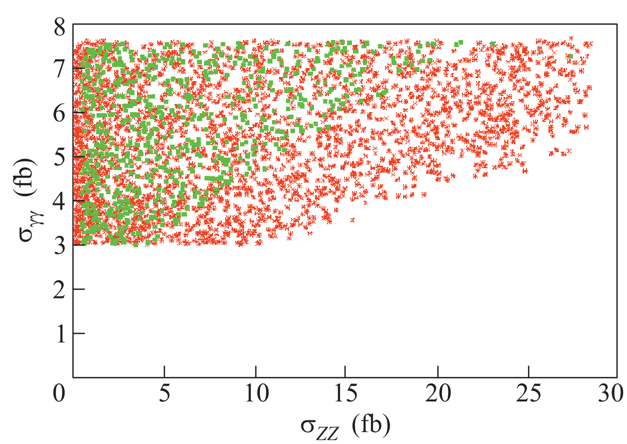

Fig. 2. (Color online) Diphoton cross section versus ZZ cross section for $\sqrt{F} = 5$ TeV (green) and $\sqrt{F} = 7$ TeV (red); we set $\sqrt{s} = 13$ TeV

[2)] Here we conservatively assume strong bound on gluino mass, see the latest results [1]. Note, however, that it can be somewhat relaxed for considered class of models with gravitino as the lightest supersymmetric particle when gluino undergoes multistage decays, see, e.g., [25].

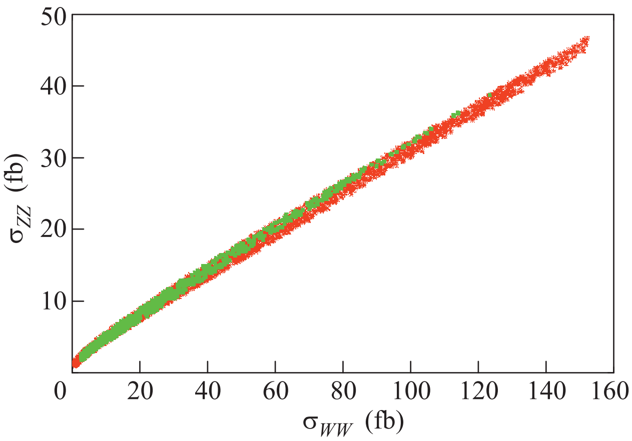

Fig. 3. (Color online) ZZ and WW cross sections for $\sqrt{F} = 5$ TeV (green) and 7 TeV (red); we set $\sqrt{s} = 13$ TeV

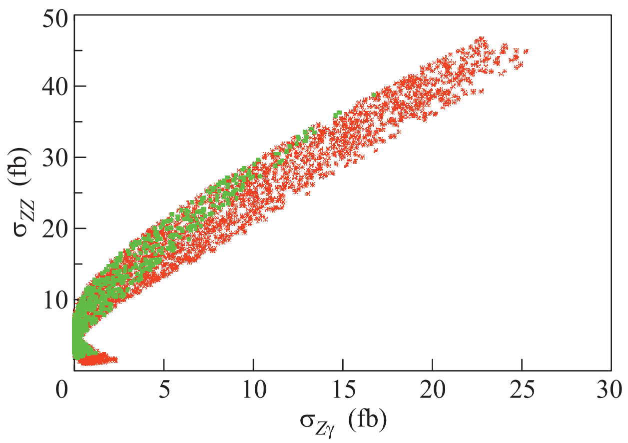

Fig. 4. (Color online) ZZ and $Z\gamma$ cross sections for $\sqrt{F} =$ 5 TeV (green) and 7 TeV (red); we set $\sqrt{s} = 13$ TeV

and 4 we show obtained values of the resonance production cross sections with ZZ, WW, and $Z\gamma$ final states. The cross sections for these channels turn out to be of the sizes reachable at the LHC, Run-II with larger statistics. Moreover, there are correlations between values of these cross sections which appear because of relations between corresponding sgoldstino coupling constants. Thus, the model with sgoldstino can be tested by measuring different diboson cross sections which seems to be within the reach of the Run-II experiments at least for their larger values. At the same time lesser values of the cross sections σ_{ZZ}, σ_{WW}, and $\sigma_{Z\gamma}$ correspond to small values of M_i. Thus, this part of parameter space can be probed by direct searches for light gauginos.

Further, let us mention that we consider here only the case of scalar sgoldstino. Its pseudoscalar partner is also a viable candidate for explanation of the diphoton excess, see also [5, 6]. We can add that if there is a mixing between scalar and pseudoscalar sgoldstinos this will result in changes of angular distribution of decay products, photons or massive vector bosons. Scalar and pseudoscalar sgoldstino couplings to the SM particles and hence the corresponding production cross sections ($\sigma_{\gamma\gamma}$, σ_{ZZ}, etc.) are closely related to each other (see, e.g., [12]). So, if the mixing is reasonably small and their masses are different one expects to observe $\gamma\gamma$-peak at another invariant mass associated with the sgoldstino twin. Similar resonances are expected for other diboson final states.

Here we concentrated mainly on sgoldstino physics related to vector bosons. However, existence of the 750 GeV sgoldstino resonance can have interesting implications related to the SM fermions. In particular, corresponding sgoldstino couplings are determined by soft trilinear coupling constants $A_{ij}^{U,D,L}$ which can have nontrivial flavor structure. Thus, we can expect flavor violating processes mediated by virtual sgoldstino: top-quark or heavy meson decays. Moreover, there can be peaks at 750 GeV invariant mass of fermion-antifermion pair (quarks or leptons) including those of different flavour.

We do not discuss here width of the sgoldstino resonance Γ_S. For considered set of parameters of sgoldstino model its value is always smaller than the GeV scale. Large width $\Gamma_S \sim 46$ GeV which is somewhat favorable by the ATLAS results [2] (but not the CMS) seems not to be allowed within the considered framework. However, in general the width of sgoldstino can be increased to some extent in the case of nonminimal supersymmetric extensions involving light singlet scalar (e.g. in NMSSM). In this case sgoldstino can have a considerable decay rate into pair of the scalars while the hierarchy between branchings of the decays into vectors bosons will be almost unchanged.

3. Discussion and conclusions. To summarize, we argue that sgoldstino with the mass about 750 GeV is a natural candidate for explanation of the small diphoton excess observed recently by the ATLAS and CMS experiments. Typical values of supersymmetry breaking scale and soft gaugino masses required for this explanation are found to be below 10 TeV. We explore possible range of the sgoldstino production cross section with the diboson final states WW, ZZ, and $Z\gamma$ and found that these processes as well as direct searches for gauginos can be used to test the hypothesis about 750 GeV sgoldstino.

Finally, let us note that in the class of models with low scale supersymmetry breaking the lightest supersymmetric particle is gravitino. For values of $\sqrt{F}$ considered in this note its mass is about $m_{3/2} = \sqrt{\frac{8\pi}{3}}\frac{F}{M_{Pl}} \sim$ $\sim (10^{-3}–10^{-2})$ eV. This region is allowed by astrophysical bounds from Supernovae [27] and by cosmological constraints from Big Bang Nucleosynthesis [28].

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