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Prospects for sgoldstino search at the LHC

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Abstract: In this paper we estimate the LHC sgoldstino discovery potential for the signatures with $\gamma\gamma$ and ZZ in a final state.

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It is well known, that exist models of supergravity breaking with relatively light sgoldstinos (scalar S and pseudoscalar P particles — superpartners of goldstino ψ). Such pattern emerges in a number of non-minimal supergravity models [1] and also in gauge mediation models if supersymmetry is broken via non-trivial superpotential (see, ref. [2] and references therein). To the leading order in $1/F$, where F is the parameter of supersymmetry breaking, and to zero order in MSSM gauge and Yukawa coupling constants, the interactions between the component fields of goldstino supermultiplet and MSSM fields have been derived in ref. [3]. They correspond to the most attractive for collider studies processes where only one of these *new* particles appears in a final state. In this case light gravitino behaves exactly as goldstino. For sgoldstinos, as they are R-even, only sgoldstino couplings to goldstino and sgoldstino couplings to SM fields have been included as the most interesting phenomenologically.

All relevant sgoldstino coupling constants presented in ref. [3] are completely determined by the MSSM soft terms and the parameter of supersymmetry breaking F, but sgoldstino masses (m_S, m_P) remain free. If sgoldstino masses are of the order of electroweak scale and $\sqrt{F} \sim 1\,\mathrm{TeV}$ — sgoldstino may be detected in collisions of high energy particles at supercolliders [4, 5].

There are flavor-conserving and flavor-violating interactions of sgoldstino fields. As concerns flavor-conserving interactions, the strongest bounds arise from astrophysics and cosmology, that is $\sqrt{F} \gtrsim 10^6\,\mathrm{GeV}$ [6, 7], or $m_{3/2} > 600\,\mathrm{eV}$, for models with $m_{S(P)} <$ 10 keV and MSSM soft flavor-conserving terms being of the order of electroweak scale. For the intermediate sgoldstino masses (up to a few MeV) constraints from the study of SN explosions and reactor experiments lead to $\sqrt{F} \gtrsim 300\,\mathrm{TeV}$ [7]. For heavier sgoldstinos, low energy processes (such as rare decays of mesons) provide limits at the level of $\sqrt{F} \gtrsim$ 500 GeV [7].

The collider experiments exhibit the same level of sensitivity to light sgoldstinos as rare meson decays. Indeed the studies [8, 9, 10, 11] of the light sgoldstino ($m_{S,P} \lesssim a\ few\,\mathrm{MeV}$) phenomenology based on the effective low-energy lagrangian derived from N=1 linear supergravity yield the bounds: $\sqrt{F} \gtrsim 500\,\mathrm{GeV}$ (combined bound on $Z \to S\bar{f}f, P\bar{f}f$ [10]; combined bound on $e^+e^- \to \gamma S, \gamma P$ [9]) at $M_{soft} \sim 100\,\mathrm{GeV}$, $\sqrt{F} \gtrsim 1\,\mathrm{TeV}$ [11] (combined bound on $p\bar{p} \to gS, gP$) at gluino mass $M_3 \simeq 500\,\mathrm{GeV}$. Searches for heavier sgoldstinos at colliders, though exploiting another technique, results in similar bounds on the scale of supersymmetry breaking. Most powerful among the operating machines, LEP and Tevatron, give a constraint of the order of 1 TeV on supersymmetry breaking scale in models with light sgoldstinos. Indeed, the analysis carried out by DELPHI Collaboration [12] yields the limit $\sqrt{F} > 500 \div 200\,\mathrm{GeV}$ at sgoldstino masses $m_{S,P} = 10 \div 150\,\mathrm{GeV}$ and $M_{soft} \sim 100\,\mathrm{GeV}$. The constraint depends on the MSSM soft breaking parameters. In particular, it is stronger by about a hundred GeV in the model with degenerate gauginos. At Tevatron, a few events in $p\bar{p} \to S\gamma(Z)$ channel, and about 10^4 events in $p\bar{p} \to S$ channel would be produced at $\sqrt{F} = 1\,\mathrm{TeV}$ and $M_{soft} \sim 100\,\mathrm{GeV}$ for integrated luminosity $\mathcal{L} = 100\ \mathrm{pb}^{-1}$ and sgoldstino mass of the order of 100 GeV [5]. This gives rise to a possibility to detect sgoldstino, if it decays inside the detector into photons and $\sqrt{F}$ is not larger than $1.5 \div 2\,\mathrm{TeV}$.

In this note we estimate the LHC sgoldstino discovery potential using as a signature the decay of sgoldstino into two photons or(and) two Z-bosons.

In terms of $\mathrm{SU}(3)_c \times \mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ fields the sgoldstino effective lagrangian reads [3]:

$$\begin{aligned}
\mathcal{L}_S =& - \sum_{\substack{\text{all gauge}\\ \text{fields}}} \frac{M_\alpha}{2\sqrt{2}F} S \cdot F^\alpha_{a\ \mu\nu} F^{\alpha\ \mu\nu}_a - \frac{\mathcal{A}^L_{ab}}{\sqrt{2}F} y^L_{ab} \cdot S \left(\epsilon_{ij} l^j_a e^c_b h^i_D + \text{h.c.}\right) - \\
& - \frac{\mathcal{A}^D_{ab}}{\sqrt{2}F} y^D_{ab} \cdot S \left(\epsilon_{ij} q^j_a d^c_b h^i_D + \text{h.c.}\right) - \frac{\mathcal{A}^U_{ab}}{\sqrt{2}F} y^U_{ab} \cdot S \left(\epsilon_{ij} q^i_a u^c_b h^j_U + \text{h.c.}\right), \\
\mathcal{L}_P =& \sum_{\substack{\text{all gauge}\\ \text{fields}}} \frac{M_\alpha}{4\sqrt{2}F} P \cdot F^\alpha_{a\ \mu\nu} \epsilon^{\mu\nu\lambda\rho} F^\alpha_{a\ \lambda\rho} - i \frac{\mathcal{A}^L_{ab}}{\sqrt{2}F} y^L_{ab} \cdot P \left(\epsilon_{ij} l^j_a e^c_b h^i_D - \text{h.c.}\right) - \\
& - i \frac{\mathcal{A}^D_{ab}}{\sqrt{2}F} y^D_{ab} \cdot P \left(\epsilon_{ij} q^j_a d^c_b h^i_D - \text{h.c.}\right) - i \frac{\mathcal{A}^U_{ab}}{\sqrt{2}F} y^U_{ab} \cdot P \left(\epsilon_{ij} q^i_a u^c_b h^j_U - \text{h.c.}\right). \\
\mathcal{L}_{\psi,S,P} =& \, i\partial_\mu \bar{\psi} \bar{\sigma}^\mu \psi + \frac{1}{2} \partial_\mu S \partial^\mu S - \frac{1}{2} m_S^2 S^2 + \frac{1}{2} \partial_\mu P \partial^\mu P - \frac{1}{2} m_P^2 P^2 + \\
& + \frac{m_S^2}{2\sqrt{2}F} S \left(\psi\psi + \bar{\psi}\bar{\psi}\right) - i \frac{m_P^2}{2\sqrt{2}F} P \left(\psi\psi - \bar{\psi}\bar{\psi}\right).
\end{aligned}$$

where M_α are gaugino masses and $A_{\alpha\beta} y_{\alpha\beta}$ are soft trilinear coupling constants. In this letter we consider $\mathcal{A}_{ab} = A$ and Yukawas $y_{ab} \propto \delta_{ab}$ as in SM.

At hadron colliders sgoldstinos will be produced mostly by gluon resonant scattering $gg \to S(P)$ [5]. The associated production $gg \to S(P)g$ has several times smaller cross section than resonant production and the corresponding discovery potential (in analogy with SM Higgs boson case) is expected to be weaker than the discovery potential for the resonant mode $gg \to S(P)$.

One has to consider the subsequent decay of the sgoldstino inside the detector. Indeed, for the range of parameters that are relevant for this study, sgoldstinos are expected to decay inside the detector, not far from the collision point. Then, assuming that the supersymmetric partners (others than the gravitino $\tilde{G}$) are too heavy to be relevant for the sgoldstino decays, the main decay channels are:

$$S(P) \to gg,\ \gamma\gamma,\ \tilde{G}\tilde{G},\ f\bar{f},\ \gamma Z,\ WW,\ ZZ\,.$$

The corresponding widths have been calculated in refs. [4, 5].[1]

For a sgoldstinos decaying into pairs of massless gauge bosons, one has

$$\Gamma(S(P) \to \gamma\gamma) = \frac{M_{\gamma\gamma}^2 m_{S(P)}^3}{32\pi F^2}\,, \qquad \Gamma(S(P) \to gg) = \frac{M_3^2 m_{S(P)}^3}{4\pi F^2}\,,$$

where $M_{\gamma\gamma} = M_1 \cos^2\theta_W + M_2 \sin^2\theta_W$, and θ_W is the electroweak mixing angle. Note that for $M_{\gamma\gamma} \sim M_3$ gluonic mode dominates over the photonic one due to the color factor enhancement.

[1] There is an additional parameter μ_a in sgoldstino decay widths into weak bosons presented in ref. [4]; this parameter is absent in the minimal model considered in this letter, see ref. [3].

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Model	M_1	M_2	M_3	A
I	100 GeV	300 GeV	500 GeV	300 GeV
II	300 GeV	300 GeV	300 GeV	300 GeV

Table 1: The sets of parameters which the LHC sensitivity is presented for.

For the values of $\sqrt{F}$ we are interested in, gravitino is very light, with mass in the range $m_{\tilde{G}} = \sqrt{8\pi/3}\, F/M_{Pl} \simeq 10^{-3} \div 10^{-1}$ eV. Then, the sgoldstino decay rates into two gravitinos are given by

$$\Gamma(S(P) \to \tilde{G}\tilde{G}) = \frac{m_{S(P)}^5}{32\pi F^2},$$

and become comparable with the rate into two photons for heavy sgoldstinos, such that $m_{S(P)} \sim M_{\gamma\gamma}$. Sgoldstinos can also decay into fermion pairs, with rates

$$\Gamma(S \to f\bar{f}) = N_C \frac{A^2 m_f^2 m_S}{32\pi F^2} \left(1 - \frac{4m_f^2}{m_S^2}\right)^{3/2},$$

$$\Gamma(P \to f\bar{f}) = N_C \frac{A^2 m_f^2 m_P}{32\pi F^2} \left(1 - \frac{4m_f^2}{m_P^2}\right)^{1/2},$$

where m_f is fermion mass, and $N_C = 3$ for quarks and $N_C = 1$ for leptons. One can see that, far from the threshold, the fermionic branching ratios are suppressed by a factor m_f^2/m_S^2 in general. Hence, the decay $S(P) \to f\bar{f}$ can be relevant for large trilinear couplings and/or if the sgoldstino mass happens to be not too far from m_f. Finally, sgoldstinos lighter than the top quark can decay into massive vector bosons states. For $m_{S(P)} > M_Z$, $m_{S(P)} > 2M_W$ and $m_{S(P)} > 2M_Z$ the $Z\gamma$, W^+W^- and ZZ channels open up, respectively. The corresponding rates read

$$\Gamma(S(P) \to \gamma Z) = \frac{M_{\gamma Z}^2 m_{S(P)}^3}{16\pi F^2} \left(1 - \frac{M_Z^2}{m_{S(P)}^2}\right)^3,$$

$$\Gamma(P \to W^+W^-) = \frac{M_2^2 m_P^3}{16\pi F^2} \left(1 - \frac{4M_W^2}{m_P^2}\right)^{3/2},$$

$$\Gamma(S \to W^+W^-) = \frac{M_2^2 m_S^3}{16\pi F^2} \left(1 - 4\frac{M_W^2}{m_S^2} + 6\frac{M_W^4}{m_S^4}\right) \sqrt{1 - \frac{4M_W^2}{m_S^2}},$$

$$\Gamma(P \to ZZ) = \frac{M_{ZZ}^2 m_P^3}{32\pi F^2} \left(1 - \frac{4M_Z^2}{m_P^2}\right)^{3/2},$$

$$\Gamma(S \to ZZ) = \frac{M_{ZZ}^2 m_S^3}{32\pi F^2} \left(1 - 4\frac{M_Z^2}{m_S^2} + 6\frac{M_Z^4}{m_S^4}\right) \sqrt{1 - \frac{4M_Z^2}{m_S^2}},$$

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

We will present the estimates for the LHC sensitivity to the scale of supersymmetry breaking for two sets of MSSM soft parameters shown in table 1.

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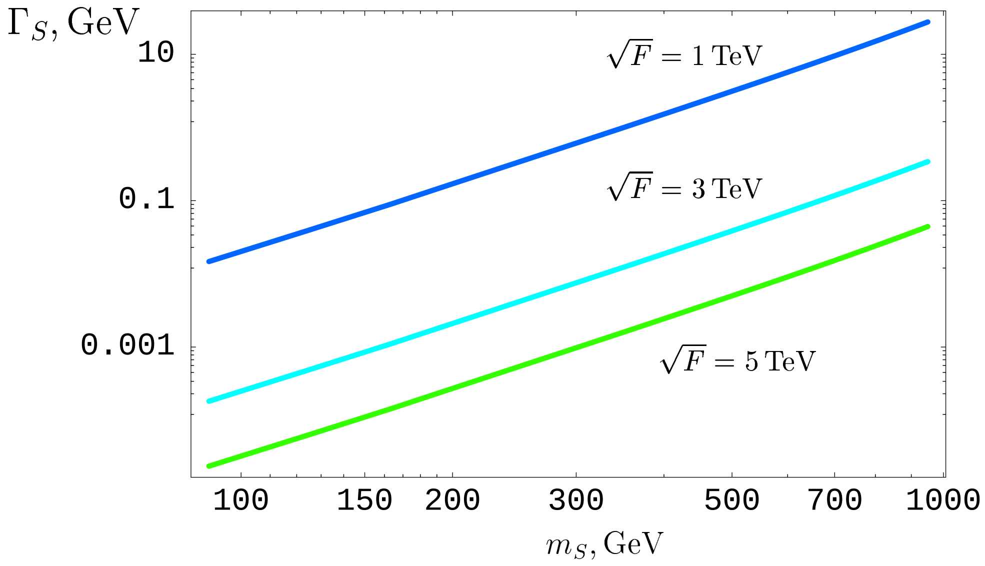

Figure 1: Total decay width of sgoldstino Γ_S as a function of its mass m_S for the model I.

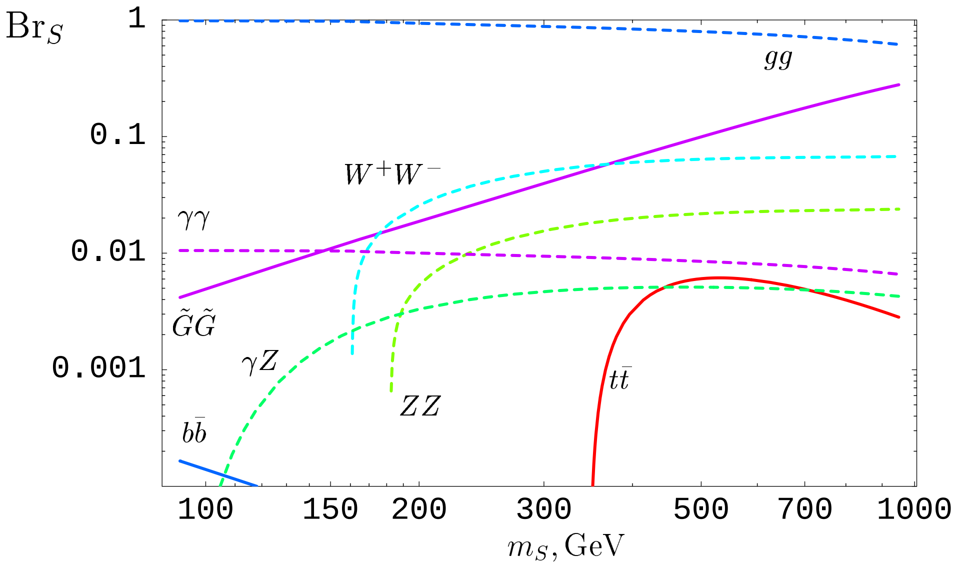

Figure 2: Sgoldstino branching ratios Br_S as functions of its mass m_S for the model I.

For these sets of parameters we calculate sgoldstino width (see figures 1, 3) and branching ratios (see figures 2, 4). In fact, only gg, $\gamma\gamma$, ZZ, W^+W^- and $\tilde{G}\tilde{G}$ modes are relevant in our study.

For $\gamma\gamma$ mode the simulations of the CMS detector [13] lead for the Higgs boson masses $m_h = 100, 110, 130$ GeV to the mass resolutions $\Delta M = 0.78, 0.87, 0.96$ GeV (high luminosity $L = 10^{34}$ cm^{-2}s^{-1}). So, to estimate the diphoton mass resolution we shall use the simplest parametrisation

$$\frac{\Delta M}{M} = 0.008\,.$$

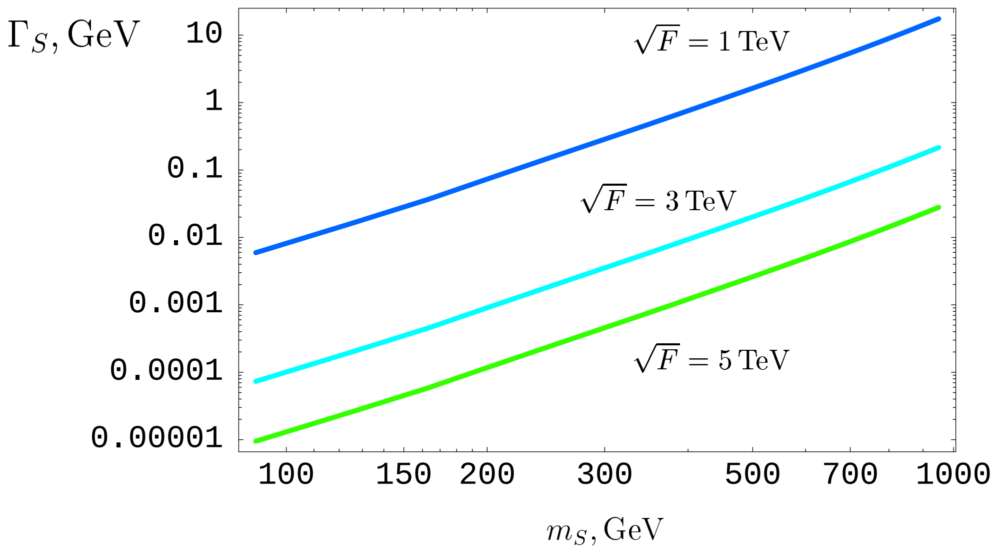

Figure 3: Total decay width of sgoldstino Γ_S as a function of its mass m_S for the model II.

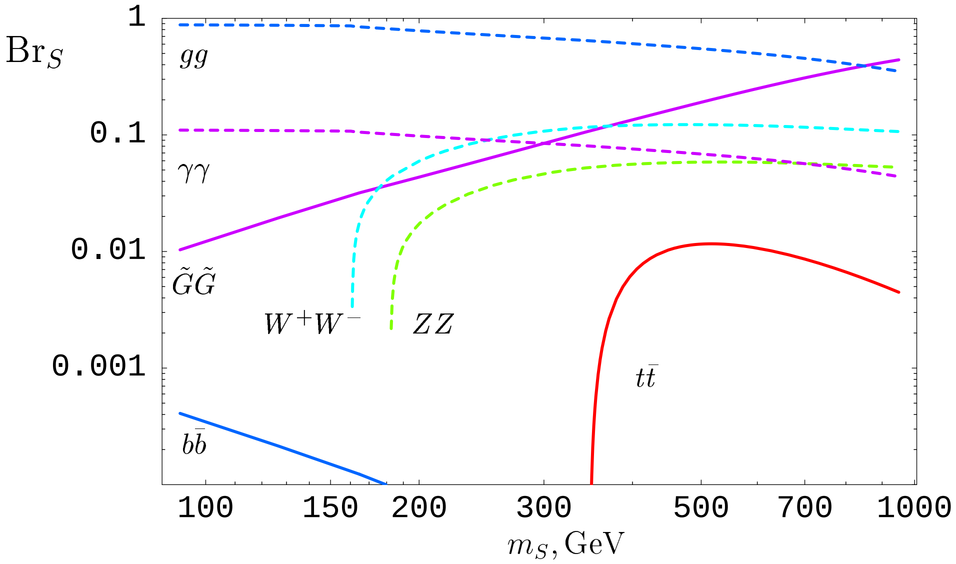

Figure 4: Sgoldstino branching ratios Br_S as functions of its mass m_S for the model II.

In order to estimate the 4 lepton mass resolution $ZZ \to 4$ *leptons* we use the parametrisation

$$\frac{\Delta M}{M} = 0.02\,.$$

Defining a signal significance as

$$\Sigma = \frac{N_{\rm S}}{\sqrt{N_{\rm B}}} = \frac{\sigma_{\rm S}}{\sqrt{\sigma_{\rm B}}}\sqrt{\mathcal{L}^{-1}_{\rm LHC}}\,,$$

where $\mathcal{L}^{-1}_{\rm LHC}$ is the integrated luminosity of LHC, we estimate the signal significance for

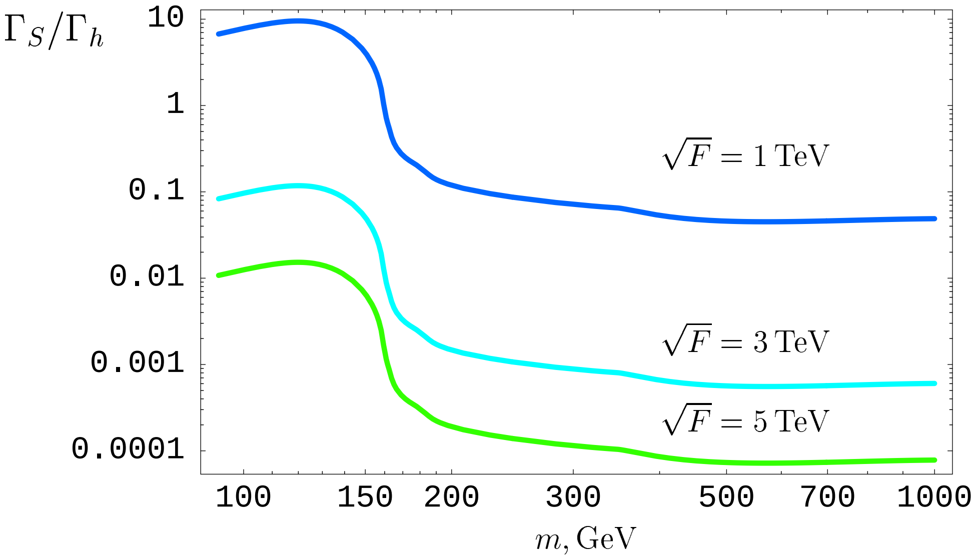

Figure 5: The ratio of sgoldstino width Γ_S and Higgs width Γ_h as a function of mass m at various $\sqrt{F}$ for the model I.

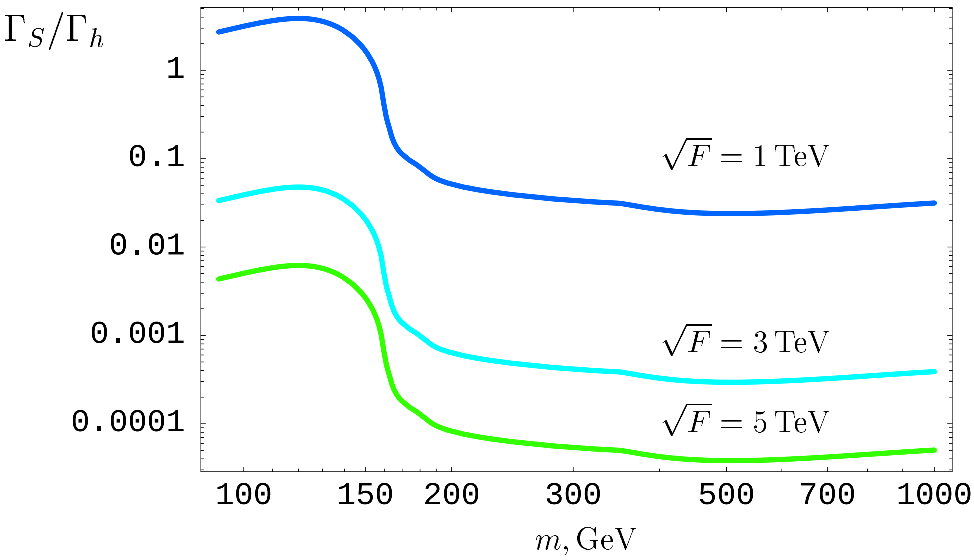

Figure 6: The ratio of sgoldstino width Γ_S and Higgs width Γ_h as a function of mass m at various $\sqrt{F}$ for the model II.

sgoldstino events:

$$\Sigma_S = \Sigma_h \cdot \frac{\Gamma(S \to gg)}{\Gamma(h \to gg)} \frac{\mathrm{Br}_S^{\gamma\gamma(ZZ)}}{\mathrm{Br}_h^{\gamma\gamma(ZZ)}} \sqrt{\frac{\max(\Gamma_S, \Delta M)}{\max(\Gamma_h, \Delta M)}}\,, \tag{1}$$

with Σ_h being the signal significance for SM Higgs boson. We will exploit only $\gamma\gamma$ and ZZ channels. In what follows we will use $\Sigma_h(m_h)$ presented by CMS Collaboration in refs. [14, 15] for $\gamma\gamma$ and ZZ channels, respectively. Note that partial width for both

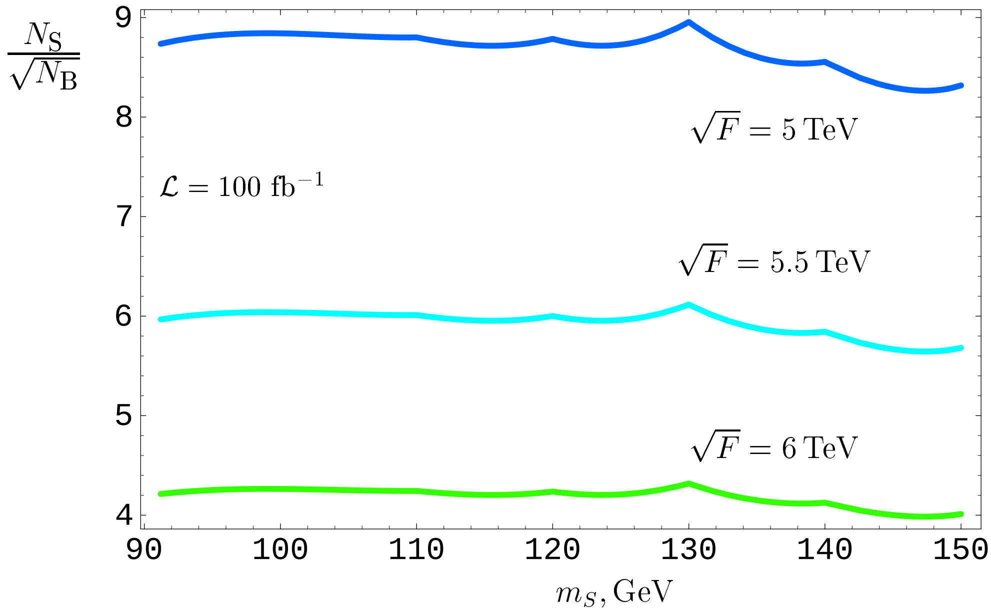

Figure 7: Signal significance of $\gamma\gamma$ channel as a function of sgoldstino mass m_S for the model I.

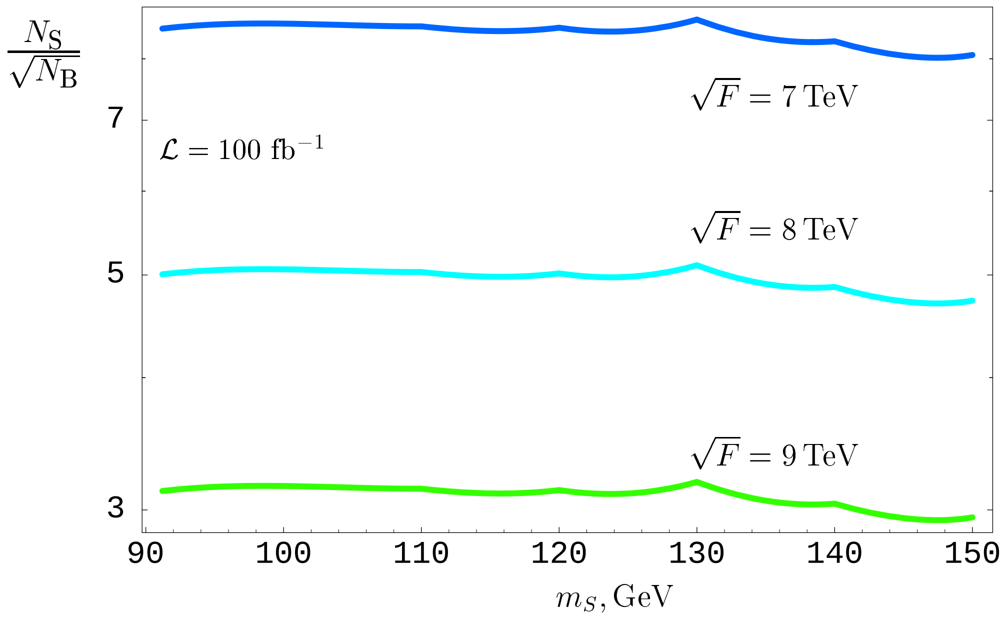

Figure 8: Signal significance of $\gamma\gamma$ channel as a function of sgoldstino mass m_S for the model II.

scalars (sgoldstino and Higgs boson) should be calculated either in the leading order or with account of electroweak/strong corrections. The results coincide, since the relevant corrections for any neutral scalar SM singlet are the same.

For two sets of the MSSM soft breaking terms shown in table 1 we present plots with lines of the LHC sensitivities to sgoldstinos of various masses.

First, we present the plots 5, 6 with the ratios of sgoldstino-to-Higgs widths. One can see, that for the relevant region in $(m_{S(P)}, \sqrt{F})$ space, sgoldstino width is more narrow.

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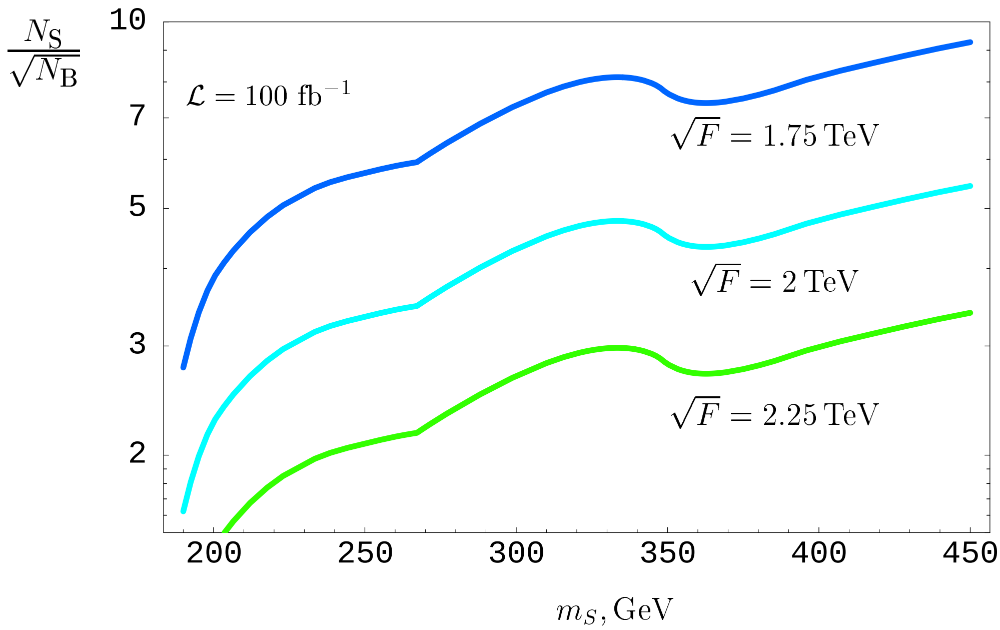

Figure 9: Signal significance of ZZ channel as a function of sgoldstino mass m_S for the model I.

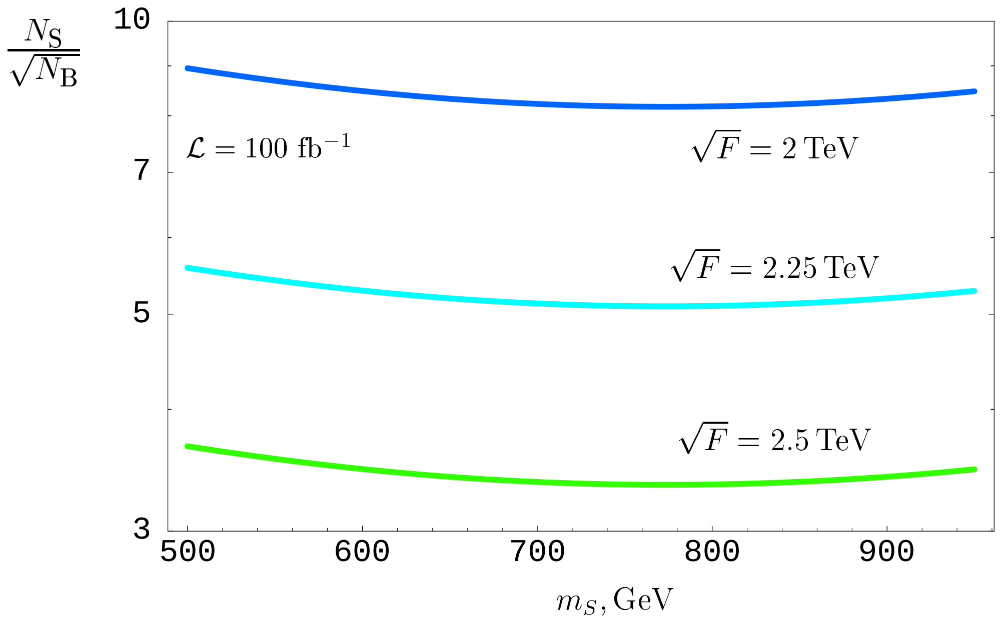

Figure 10: Signal significance of ZZ channel as a function of sgoldstino mass m_S for the model I.

Our main results are the plots 7–12 with the LHC sensitivity to the scale of supersymmetry breaking estimated by making use of eq. (1): figures 7, 8 refer to two-photon channel, figures 9, 11 correspond to ZZ channel and $M_S < 500$ GeV, figures 10, 12 concern ZZ channel and $M_S > 500$ GeV.

We would like to mention that we did not take into account sgoldstino couplings to superpartners. If open (allowed kinematically), new sgoldstino decay channels distort the pattern of sgoldstino branching ratios into SM particles. In a given model the level of

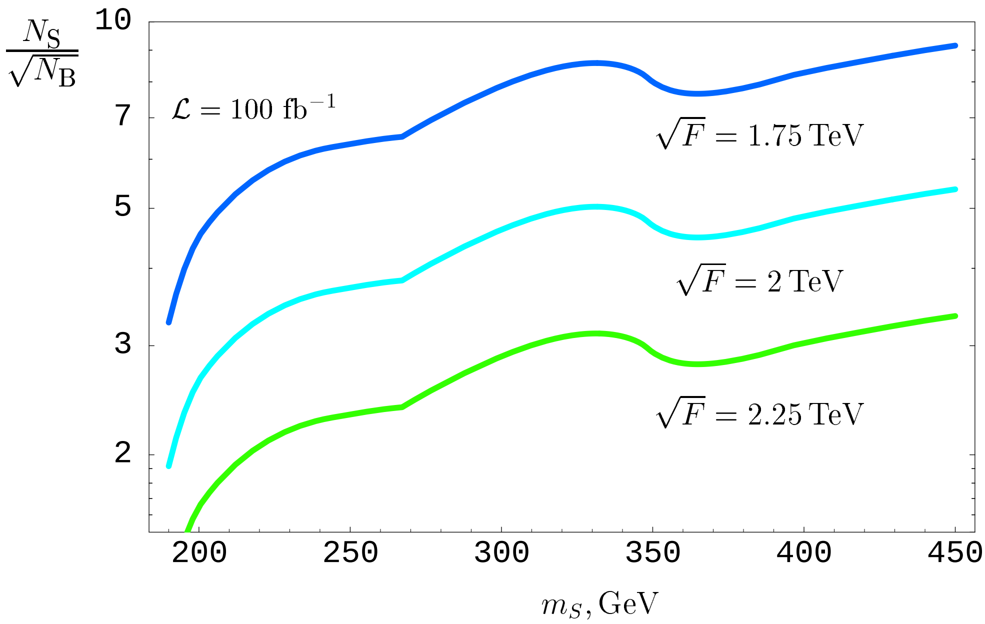

Figure 11: Signal significance of ZZ channel as a function of sgoldstino mass m_S for the model II.

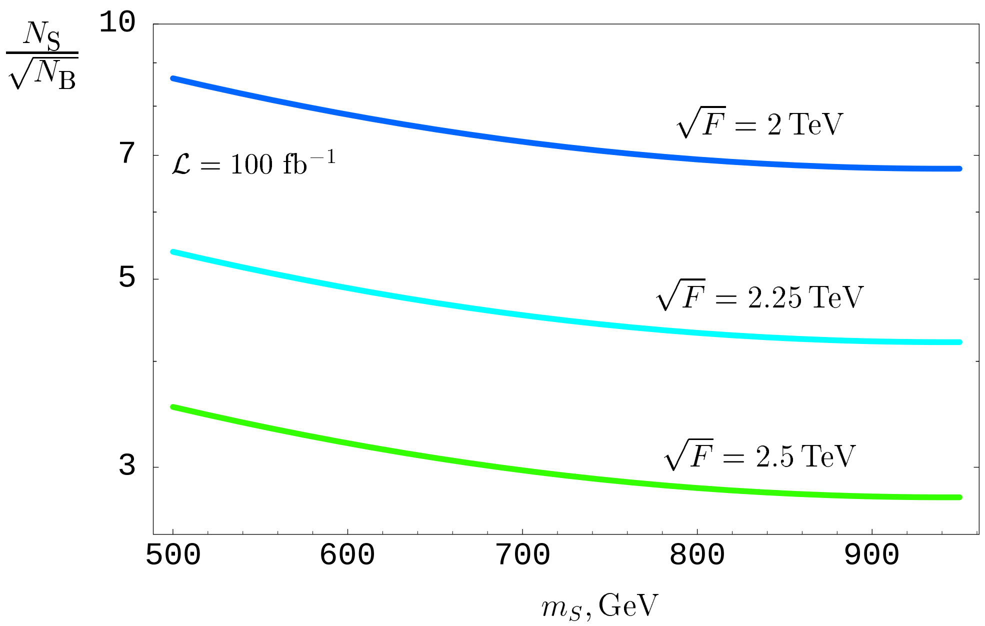

Figure 12: Signal significance of ZZ channel as a function of sgoldstino mass m_S for the model II.

distortion depends on the set of soft supersymmetry breaking masses and sgoldstino masses and effective couplings to superpartners. As clearly seen from eq. (1), the distortion can affect our predictions of LHC sensitivity iff a partial width of some new channel becomes comparable to the partial width of the dominant gluonic channel. The deviation of the predictions may be estimated from eq. (1). In particular, if the total decay rate into superpartners becomes equal to decay rate into two gluons, the sensitivity to $\sqrt{F}$ decreases by 20%.

It should be noted that in ref. [16] by making use of the same method as our the sensitivity of the LHC to the radion has been investigated. Certainly the method is viable for any scalar SM singlet massive field.

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