Split supersymmetry, stable gluino, and gluinonium

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In the scenario recently proposed by Arkani-Hamed and Dimopoulos, the supersymmetric scalar particles are all very heavy, at least of the order of 10^9 GeV but the gauginos, Higgsinos, and one of the neutral Higgs bosons remain under a TeV. The most distinct signature is the metastable gluino. However, the detection of metastable gluino depends crucially on the spectrum of hadrons that it fragments into. Instead, here we propose another unambiguous signature by forming the gluino-gluino bound state, gluinonium, which will then annihilate into $t\bar{t}$ and $b\bar{b}$ pairs. We study the sensitivity of such signatures at the LHC.

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I. INTRODUCTION

Supersymmetry (SUSY) is one of the most elegant solutions, if not the best, to the gauge hierarchy problem. It also provides a dynamical mechanism for electroweak symmetry breaking, as well as a viable candidate for dark matter (DM). However, the fine-tuning arguments restrict SUSY to be in TeV scale, otherwise the fine-tuning problem returns. Theorists for the past two decades have been plugging holes that the weak scale SUSY model may fall into. Recently, Arkani and Dimopoulos [1] adopted a rather radical approach to SUSY; essentially they discarded the hierarchy problem and accepted the fine-tuning solution to the Higgs boson mass. They argued that the much more serious problem, the cosmological constant problem, needs a much more serious fine-tuning that one has to live with, and so why not let go of the much less serious one, the gauge hierarchy problem.

Once we accept this proposal the finely tuned Higgs scalar boson is not a problem anymore. The issue of more concern is to a find a consistent set of parameters so as to satisfy the observations. (i) The result of the Wilkenson microwave anisotropy probe (WMAP) [2] has refined the DM density to be $\Omega_{\rm DM}h^2 = 0.094 - 0.129$ (2σ range), (ii) neutrino mass, and (iii) cosmological constant. The last one is accepted by the extremely fine-tuned principle. The second observation requires heavy right-handed neutrinos of mass scale of 10^{11-13} GeV, so that it does not have appreciable effects on electroweak scale physics. The first observation, on the other hand, requires a weakly interacting particle of mass $\lesssim 1$ TeV, in general. It is this requirement which affects most of the parameter space of the finely tuned SUSY scenario.

Such a finely tuned SUSY scenario was also named "split supersymmetry" [3], which can be summarized by the following:

(1) All the scalars, except for a CP-even Higgs boson, are all super heavy that their common mass scale $\tilde{m} \sim 10^9$ GeV $- M_{\rm GUT}$. The scenario will then be safe with flavor-change neutral currents, CP-violating processes, e.g., electric dipole moment (EDM).

(2) The gaugino and the Higgsino masses are relatively much lighter and of the order of TeV, because they are protected by a R symmetry and a Peccei-Quinn symmetry, respectively.

(3) A light Higgs boson, very similar to the SM Higgs boson.

(4) The μ parameter is relatively small due to the requirement of DM. This is to make sure that there are sufficient mixings in the neutralino sector such that the lightest neutralino can annihilate efficiently to give the correct DM density.

(5) This scenario still allows gauge-coupling unification.

An important difference between split SUSY and the usual minimal supersymmetric standard model (MSSM) is, as already pointed out by a number of authors [1,3,4], that the gaugino-Higgsino-Higgs couplings are no longer the same as the corresponding gauge couplings at energies below the SUSY breaking scale $M_{\rm SUSY}$, although they are the same at the scale $M_{\rm SUSY}$ and above. We need to evolve the gaugino-Higgsino-Higgs couplings down from $M_{\rm SUSY}$ using the renormalization group equations involving only gauginos and Higgsinos.

The most distinct feature for this scenario in terms of collider phenomenology is that the gluino now becomes metastable inside collider detectors, because all sfermions are super heavy. This feature is very similar to the gluino-LSP scenario [5,6] as far as gluino collider signatures are concerned. The gluino pair so produced will hadronize into color-neutral hadrons by combining with some light quarks or gluons. Such objects are strongly interacting massive particles, electrically either neutral or charged. If the hadron is electrically neutral, it will pass through the tracker with little trace. If the hadron is electrically charged, it will undergo ionization energy loss in the central tracking system; hence it behaves like a "heavy muon." However, an issue arises when the neutral hadron containing the gluino may convert into a charged hadron when the internal light quark or gluon is knocked off and replaced by another light quark—and vice versa. The probability of such a scattering depends crucially on the mass spectrum of the hadrons formed by the gluino and light quarks and gluons. In reality, we know very little about the spectrum. Some previous estimates [5] assumed a fixed probability that the gluino fragments into a charged hadron. The resulting sensitivity depends crucially on this probability.

In view of such an uncertainty, we propose to look at another novel signature of stable or metastable gluinos. Since the gluinos are produced in pairs and stable, they can form a bound state, called gluinonium by exchanging gluons. In fact, one could talk about the toponium were not if the decay time of the top quark is too short. The potential between two massive gluinos can be very well described by a Coulombic potential. The value of the wave function at the origin can be reliably determined. We will calculate the production rates for the gluinonium at the LHC and at the Tevatron.

The two gluinos within the gluinonium can then annihilate into standard model particles, either gg or $q\bar{q}$, depending on the angular momentum and color of the bound state. Since each gluino is in a color octet $\mathbf{8}$, the gluinonium can be in

$$\mathbf{8} \otimes \mathbf{8} = \mathbf{1} + \mathbf{8}_S + \mathbf{8}_A + \mathbf{10} + \overline{\mathbf{10}} + \mathbf{27}, \tag{1}$$

where the subscript "S" stands for symmetric and "A" for antisymmetric. It was shown that only $\mathbf{1}$, $\mathbf{8}_S$, and $\mathbf{8}_A$ have an attractive potential [8]. Here we only consider S-wave bound states with a total spin $S = 0$ or 1. In order that the total wave function of the gluinonium is antisymmetric, the possible configurations are ${}^1S_0(\mathbf{1})$, ${}^1S_0(\mathbf{8}_S)$, and ${}^3S_1(\mathbf{8}_A)$, the color representations of which are shown in the parentheses. Note that the dominant decay mode of ${}^1S_0(\mathbf{1})$ and ${}^1S_0(\mathbf{8}_S)$ is gg, which would give rise to dijet in the final state. However, the QCD dijet background could easily bury this signal and we have verified that. Therefore, we focus on the ${}^3S_1(\mathbf{8}_A)$ state, which decays into $q\bar{q}$ including light quark and heavy quark pairs. We could then make use of the $t\bar{t}$ and/or $b\bar{b}$ in the final state to search for the peak of the gluinonium in the invariant mass spectrum of the $t\bar{t}$ and/or $b\bar{b}$ pairs. Nevertheless, we shall give the production cross sections for both ${}^1S_0$ and ${}^3S_1$ states.

According to heavy quark symmetry [9], the spin and velocity of a heavy quark inside a heavy-light system will not be affected by the muck (soft gluon radiation, for example). The spin-flip amplitude is proportional to $\Lambda_{\rm QCD}/M_Q$. Therefore, by similar reasons in the heavy gluinonium system the spin structure would not be affected during hadronization. On the other hand, the color structure of gluinonium could be changed by attaching light quarks or gluons to the gluinonium. However, one has to note that the only allowed color state for ${}^3S_1$ is $\mathbf{8}_A$. So the gluinonium has no choice but stay in the $\mathbf{8}_A$ state. But for the ${}^1S_0$ state it has two choices: $\mathbf{1}$ and $\mathbf{8}_S$. Therefore, it can swap between these two color states during hadronization. We, therefore, conclude that the ${}^3S_1(\mathbf{8}_A)$ state of the gluinonium would remain intact during hadronization. Its decay product will continue to be $q\bar{q}$.

The study in this work is not just confined to split SUSY scenario, but also applies to other stable gluino scenarios, e.g., gluino-LSP [5,6], long-lived gluino scenario, etc. Our calculation shows that gluinonium production and its decay can help searching for the stable or metastable gluinos. Although the sensitivity using this signature is in general not as good as the "heavy muon"-like signature, it is, however, free from the uncertainty of the hadronic spectrum of the gluino hadrons.

II. PRODUCTION OF GLUINONIUM

In calculating gluinonium production we will encounter the spinor combination $u(P/2)\bar{v}(P/2)$, where P is the 4-momentum of the gluinonium. We can replace it by, in the nonrelativistic approximation,

$$\begin{aligned}
{}^3S_1(\mathbf{8}_A):\ & u(P/2)\bar{v}(P/2) \longrightarrow \frac{1}{\sqrt{2}}\frac{R_8(0)}{2\sqrt{4\pi M}} \times \frac{1}{\sqrt{3}} f^{hab} \not{\epsilon}(P)(\not{P} + M),\\
{}^1S_0(\mathbf{8}_S):\ & u(P/2)\bar{v}(P/2) \longrightarrow \frac{1}{\sqrt{2}}\frac{R_8(0)}{2\sqrt{4\pi M}}\sqrt{\frac{3}{5}} d^{hab}\gamma^5(\not{P} + M),\\
{}^1S_0(\mathbf{1}):\ & u(P/2)\bar{v}(P/2) \longrightarrow \frac{1}{\sqrt{2}}\frac{R_1(0)}{2\sqrt{4\pi M}}\frac{1}{\sqrt{8}} \delta^{ab}\gamma^5(\not{P} + M),
\end{aligned} \tag{2}$$

where the color factors $(1/\sqrt{3})f^{\rm hab}$, $\sqrt{3/5}d^{\rm hab}$, and $(1/\sqrt{8})\delta^{ab}$ are the color representations of $\mathbf{8}_A$, $\mathbf{8}_S$, and $\mathbf{1}$, respectively. The $\epsilon(P)$ is the polarization 4-vector for the gluinonium of momentum P. The values of the color octet and singlet wave functions at the origin are given by the Coulombic potential between the gluinos, with one-gluon approximation [8],

$$|R_8(0)|^2 = \frac{27\alpha_s^3(M)M^3}{128}, \tag{3}$$

$$|R_1(0)|^2 = \frac{27\alpha_s^3(M)M^3}{16}. \tag{4}$$

There is an additional factor of $1/\sqrt{2}$ in Eqs. (2) because of the identical gluinos in the wave function of the gluinonium.

In the calculation of ${}^3S_1(\mathbf{8}_A)$, the lowest order process is a $2 \rightarrow 1$ process:

$$q\bar{q} \rightarrow {}^3S_1(\mathbf{8}_A). \tag{5}$$

The next order $2 \rightarrow 2$ processes include

$$q\bar{q} \to {}^3S_1(\mathbf{8}_A) + g, \tag{6}$$

$$qg \to {}^3S_1(\mathbf{8}_A) + q, \tag{7}$$

$$gg \to {}^3S_1(\mathbf{8}_A) + g \tag{8}$$

which would give a p_T to the gluinonium. Representative Feynman diagrams are shown in Fig. 1. Naively, one would expect the gg fusion in Eq. (8) has a large cross section because of the high gg luminosity and fragmentation type diagrams. However, when other nonfragmentation type diagrams are included, we found that the cross section is extremely small for heavy gluinos. On the other hand, the processes in Eqs. (6) and (7) give a small correction to the process in Eq. (5). Nevertheless, one also has to consider similar or even larger corrections to the $t\bar{t}$ background. Therefore, we only use the lowest order process of Eq. (5) and $t\bar{t}$ background in the signal-background analysis.

The cross section for $q\bar{q} \to {}^3S_1(\mathbf{8}_A)$ is given by

$$\hat{\sigma} = \frac{16\pi^2\alpha_s^2}{3}\frac{|R_8(0)|^2}{M^4}\delta(\sqrt{\hat{s}} - M). \tag{9}$$

After folding with the parton distribution functions, the total cross section is given by

$$\sigma = \frac{32\pi^2\alpha_s^2}{3s}\frac{|R_8(0)|^2}{M^3}\int f_{q/p}(x)f_{\bar{q}/p}(M^2/sx)\frac{dx}{x}, \tag{10}$$

where s is the square of the center-of-mass energy of the colliding protons and we sum over all possible initial partons $q = u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}, b, \bar{b}$.

One can also estimate the decay width of the gluinonium by adding all partial widths into $u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}, b\bar{b}, t\bar{t}$:

$$\Gamma({}^3S_1(\mathbf{8}_A)) = \sum_{Q=u,d,s,c,b,t}\alpha_s^2\frac{|R_8(0)|^2}{M^4}(M^2 + 2m_Q^2) \times\sqrt{1 - 4m_Q^2/M^2}. \tag{11}$$

When the gluinonium mass is 1 TeV or above, the branching ratio into $t\bar{t}$ is $1/6$. We note that the formulas for ${}^3S_1(\mathbf{8}_A)$ production and decay width differ from those given in Refs. [10] that our results are smaller by a factor of 2.

For completeness we also give the formulas for ${}^1S_0(\mathbf{1})$ and ${}^1S_0(\mathbf{8}_S)$:

$$\begin{aligned}
\Gamma({}^1S_0(\mathbf{1})) &= 18\alpha_s^2\frac{|R_1(0)|^2}{M^2},\\
\Gamma({}^1S_0(\mathbf{8}_S)) &= \frac{9}{2}\alpha_s^2\frac{|R_8(0)|^2}{M^2},\\
\sigma(pp \to {}^1S_0(\mathbf{1})) &= \frac{9\pi^2\alpha_s^2}{4s}\frac{|R_1(0)|^2}{M^3}\\
&\quad\times\int f_{g/p}(x)f_{g/p}(M^2/sx)\frac{dx}{x},\\
\sigma(pp \to {}^1S_0(\mathbf{8}_S)) &= \frac{9\pi^2\alpha_s^2}{2s}\frac{|R_8(0)|^2}{M^3}\\
&\quad\times\int f_{g/p}(x)f_{g/p}(M^2/sx)\frac{dx}{x}.
\end{aligned} \tag{12}$$

Note that our singlet ${}^1S_0(\mathbf{1})$ production and decay width formulas agree with Ref. [8], but the octet ${}^1S_0(\mathbf{8}_S)$ production and decay width formulas differ from those in Ref. [8] that our results are smaller by a factor of 8.

We show the production cross section for ${}^3S_1(\mathbf{8}_A)$ and ${}^1S_0(\mathbf{1})$ and ${}^1S_0(\mathbf{8}_S)$ at the Tevatron and the LHC in Fig. 2. Note that we have included a factor of $\zeta(3) \simeq 1.2$ because of the sum of all radial excitations $\sum_n(1/n^3)$ [8]. The strong coupling constant is evaluated at the scale of gluinonium mass M at the one-loop level. At the Tevatron, the $q\bar{q}$ luminosity dominates and so the vector gluinonium is more important. On the other hand, at the LHC, the pseudoscalar gluinonium has larger production cross sections until $M \approx 3$ TeV, because of the large gg initial parton luminosity at small x. However, it is noted that the dijet background is far more serious than the $t\bar{t}$ background, and so in the next section we focus on ${}^3S_1(\mathbf{8}_A)$ signal and $t\bar{t}$ background.

III. BACKGROUND ANALYSIS

The ${}^3S_1(\mathbf{8}_A)$ gluinonium decays into light quark and heavy quark pairs. The signal of light quark pairs would be easily buried by QCD dijet background. Thus, we focus on top-quark pair. Irreducible backgrounds comes from QCD $t\bar{t}$ production. We take the advantage that the t and

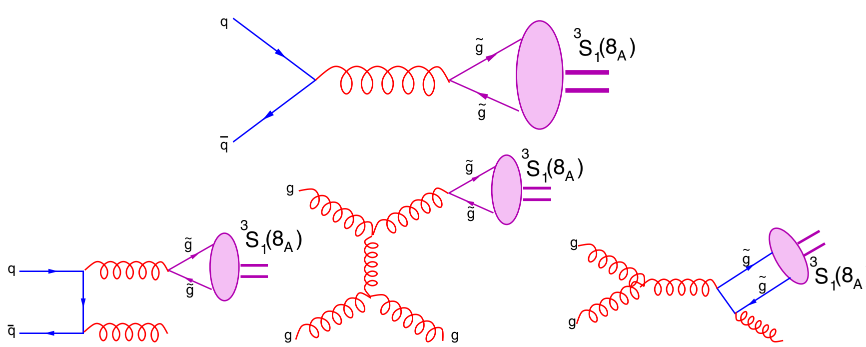

FIG. 1 (color online). Representative Feynman diagrams for $q\bar{q} \to {}^3S_1(\mathbf{8}_A)$, $q\bar{q} \to {}^3S_1(\mathbf{8}_A) + g$, and $gg \to {}^3S_1(\mathbf{8}_A) + g$.

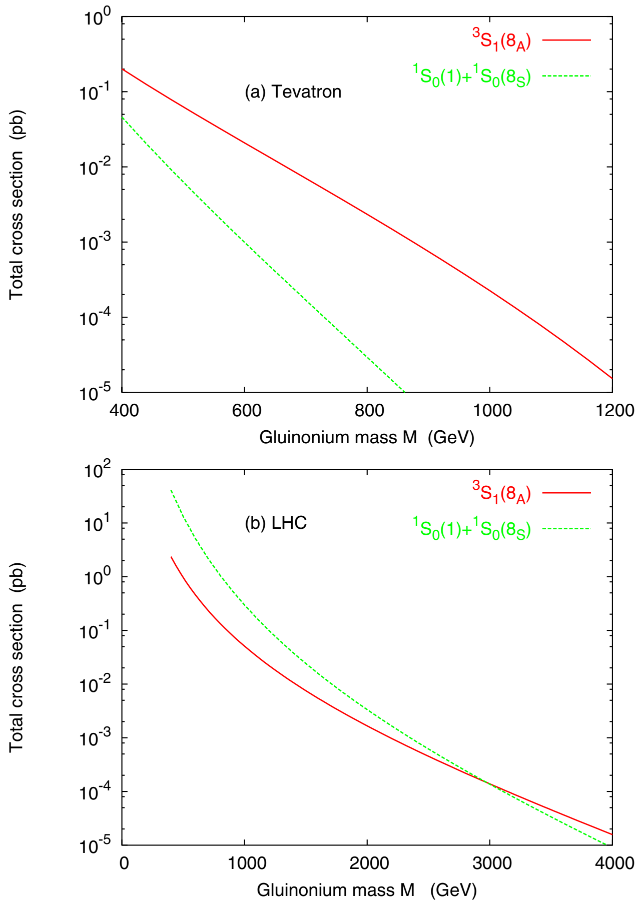

FIG. 2 (color online). Total production cross sections for gluinonium in $^3S_1(\mathbf{8}_A)$ and in $^1S_0(\mathbf{1}) + {}^1S_0(\mathbf{8}_S)$ states at the (a) Tevatron and (b) LHC

$\bar{t}$ coming from the heavy gluinonium would have a very large p_T, typically of order of the mass of the gluino, while the t and $\bar{t}$ from the background are not. We impose a very large p_T cut as follows

$$p_T(t),\ p_T(\bar{t}) > \frac{3}{4} m_{\tilde{g}} \quad \text{for} \quad M \geq 1\ \text{TeV},$$
$$p_T(t),\ p_T(\bar{t}) > 100\ \text{GeV} \quad \text{for} \quad M < 1\ \text{TeV}. \qquad (13)$$

The background has a continuous spectrum while the signal plus background should show a small bump right at the gluinonium mass, provided that the signal is large enough. Since the intrinsic width of the gluinonium is very small, of the order of 1 GeV, the width of the observed bump is determined by experimental resolution. We have adopted a simple smearing of the top-quark momenta: $\delta E/E = 50\%/\sqrt{E}$. We summarize the cross sections at the LHC for the signal and background in Table I. One could also include using $b\bar{b}$ in the final state. The branching ratios of the gluinonium into $b\bar{b}$ and $t\bar{t}$ are the same for such heavy gluinonia. Naively, one would expect the QCD background of $b\bar{b}$ production to be roughly the same as $t\bar{t}$ production at such high invariant mass region. Therefore,

TABLE I. Cross sections at the LHC for the gluinonium signal into $t\bar{t}$ with mass M and the continuum $t\bar{t}$ background between $M - 50$ GeV and $M + 50$ GeV. If including $b\bar{b}$ in the final state the significance $S/\sqrt{B}$ would increase by a factor of $\sqrt{2}$.

$M = 2m_{\tilde{g}}$ (TeV)	$\sigma(^3S_1(\mathbf{8}_A))$ (fb)	$t\bar{t}$ bkgd (fb) (fb)	$S/\sqrt{B}$ for $L = 100$ fb^{-1}
0.5	120	83 000	4.2
0.75	28	19 000	2.0
1	4.9	1150	1.4
1.5	0.78	97	0.79
2.0	0.17	14	0.45
3.0	0.014	0.67	0.17

by including $b\bar{b}$ in the final state, although one does not improve the signal-background ratio, one would, however, improve the significance $S/\sqrt{B}$ of the signal by a factor of $\sqrt{2}$. From the table the sensitivity is only up to about $M = 2m_{\tilde{g}} = 0.5$–0.6 TeV with a luminosity of 100 fb^{-1}.

The $t\bar{t}$ background has some uncertainties due to higher order corrections, structure functions, reconstruction of top-quark momenta, etc. Similar corrections also apply to the signal. The uncertainty of the signal calculation lies in the determination of $|R_8(0)|^2$, which should be small due to the good approximation of Coulombic potential between heavy gluinos.

Since the gluinonium is heavy, its decay product $t\bar{t}$ or $b\bar{b}$ would both be very energetic. So we would expect the top to decay like a cone of jets, which contains one b-jet. One would expect that it is easy to identify such a "fat top-jet." For a full mass reconstruction one may have to rely on the hadronic mode of the W boson. Then there is a factor of 50% for the efficiency. Thus, the significance in the Table I would be reduced by a factor of $\sqrt{2}$. On the other hand, one may also make use of the transverse mass reconstruction or just need one hadronic decay of the top quark only, and so the efficiency increases. Therefore, we leave out the efficiency factor in the Table I. For energetic b-jets the detection efficiency is also very high. Therefore, by including the $b\bar{b}$ final state one could enhance the significance by a factor close to $\sqrt{2}$.

IV. COMPARISON WITH "HEAVY MUON" SIGNATURE

Another important signature of stable or metastable gluinos is that once gluinos are produced they will hadronize into color-neutral hadrons by combining with some light quarks or gluons. Such objects are strongly interacting massive particles, electrically either neutral or charged. If the hadron is electrically neutral, it will pass through the tracker with little trace. However, an issue arises when the neutral hadron containing the gluino may convert into a charged hadron when the internal light quark or gluon is knocked off and replaced by another light quark. The probability of such a scattering depends crucially on the mass spectrum of the hadrons formed by the gluino and light quarks and gluons. In reality, we know very little about the spectrum, so we simply assume a 50% chance that a gluino will hadronize into a neutral or charged hadron. If the hadron is electrically charged, it will undergo ionization energy loss in the central tracking system, hence behaves like a "heavy muon." Essentially, the penetrating particle loses energy by exciting the electrons of the material. Ionization energy loss dE/dx is a function of $\beta\gamma \equiv p/M$ and the charge Q of the penetrating particle [11]. For the range of $\beta\gamma$ between 0.1 and 1 that we are interested in, dE/dx has almost no explicit dependence on the mass M of the penetrating particle. Therefore, when dE/dx is measured in an experiment, the $\beta\gamma$ can be deduced, which then gives the mass of the particle if the momentum p is also measured. Hence, dE/dx is a good tool for particle identification for massive stable charged particles. In addition, one can demand the massive charged particle to travel to the outer muon chamber and deposit energy in it. To do so the particle must have at least a certain initial momentum depending on the mass; typical initial $\beta\gamma = 0.25$–0.5. In fact, the CDF Collaboration has made a few searches for massive stable charged particles [12]. The CDF analysis required that the particle produces a track in the central tracking chamber and/or the silicon vertex detector, and at the same time penetrates to the outer muon chamber. The CDF requirement on $\beta\gamma$ is

$$0.26\text{–}0.50 \lesssim \beta\gamma < 0.86.$$

We use a similar analysis for metastable gluinos. We employ the following acceptance cuts on the gluinos

$$p_T(\tilde{g}) > 20 \text{ GeV}, \qquad |y(\tilde{g})| < 2.0, \qquad 0.25 < \beta\gamma < 0.85. \tag{14}$$

It is easy to understand that a large portion of cross section satisfies the cuts—especially the heavier the gluino the closer to the threshold is. In Table II we show the cross sections from direct gluino-pair production with all the acceptance cuts in Eq. (14), for detecting 1 massive stable charged particle (MCP), two MCPs, or at least one MCP in the final state. The latter cross section is the simple sum of the former two. We have used a probability of $P = 0.5$ that the $\tilde{g}$ will hadronize into a charged hadron. Requiring about ten such events as suggestive evidence, the sensitivity can reach up to about $m_{\tilde{g}} \simeq 2.25$ TeV with an integrated luminosity of 100 fb^{-1}. In Table II we also show the cross sections of $\sigma_{\geq 1\text{MCP}}$ for $P = 0.1$ and $P = 0.01$ in the last two columns. As expected the cross section decreases with P, the probability that the gluino hadronizes into a charged hadron. If the probability is only of the order of 10%, the sensitivity will be slightly less than 2 TeV. If the probability is of the order of 1%, the sensitivity will go down to 1.5 TeV. This is the major uncertainty associated with gluino detection using the method of stable charged tracks. Note that the treatment here is rather simple. For more sophisticated detector simulations please refer to Refs. [5,13,14].

V. CONCLUSIONS

The most distinct signature for split SUSY or gluino-LSP scenario is that the gluino is stable or metastable within the detector. Previous studies are based on hadronization of the gluino into $R_{\tilde{g}}$ hadrons, but the detection of such a signature has a large uncertainty due to the unknown spectrum of $R_{\tilde{g}}$ hadrons. We have demonstrated that using the gluinonium is free from this uncertainty, and the decay of gluinonium into a $t\bar{t}$ and/or $b\bar{b}$ pair may provide a signal above the continuum $t\bar{t}$ invariant mass spectrum. However, a rather good resolution of $t\bar{t}$ spectrum and accurate determination of continuum background are necessary to bring out the signal.

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Note added.—During writing other papers on split SUSY appear [15–17].

TABLE II. Cross sections for direct gluino-pair production at the LHC, with the cuts of Eq. (14). Here $\sigma_{1\text{MCP}}$, $\sigma_{2\text{MCP}}$, and $\sigma_{\geq 1\text{MCP}}$ denote requiring the detection of 1, 2, and at least one massive stable charged particles (MCP) in the final state, respectively. Here the probability P that gluinos fragment into charged states is $P = 0.5$. We also show the cross section $\sigma_{\geq 1\text{MCP}}$ for $P = 0.1$ and $P = 0.01$ in the last two columns.

$m_{\tilde{g}}$ (TeV)	$\sigma_{1\text{MCP}}$ (fb) $P = 0.5$	$\sigma_{2\text{MCP}}$ (fb) $P = 0.5$	$\sigma_{\geq 1\text{MCP}}$ (fb) $P = 0.5$	$\sigma_{\geq 1\text{MCP}}$ (fb) $P = 0.1$	$\sigma_{\geq 1\text{MCP}}$ (fb) $P = 0.01$
0.5	4050	620	4670	1040	105
1.0	67	13	80	18	1.9
1.5	3.7	0.91	4.6	1.1	0.11
2.0	0.3	0.09	0.39	0.09	0.0096
2.25	0.092	0.029	0.12	0.029	0.003
2.5	0.028	0.0095	0.038	0.009	0.0009

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