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We estimate the production rates of supersymmetric particles in central heavy-ion collisions at LHC. The parton cascade model is used to seek for possible collective phenomena which enlarge the production probability of very heavy particles. Even if there is some indication of such cooperative effects, higher energy and higher luminosity of proton beams at LHC disfavor heavy-ion reactions in the search for supersymmetric particles.

I. INTRODUCTION

The Standard Model (SM) of elementary particle physics is experimentally verified to a large extent; only the existence of the Higgs boson remains still to be validated. On the other hand, the SM does not provide a fundamental unified description of the world since it contains too many and unexplained parameters. Among the major tasks of the future Large Hadron Collider (LHC) at CERN there are attempts to find experimental evidence for the Higgs boson and also to look for new phenomena indicating physics beyond the SM. One prominent candidate for such an extension of the SM is the Minimal Supersymmetric Standard Model (cf. [1] for a recent survey). The search for supersymmetric (SUSY) particles in proton-proton collisions with beam energies of 7 GeV is therefore an important project at the LHC.

Besides proton-proton collisions there is also planned to collide ^{208}Pb with ^{208}Pb with beam energies of 2.76 TeV per nucleon. Here one is predominantly interested in the Quark Gluon Plasma which is rather likely to be formed in such high-energy collisions. If the lightest strongly interacting SUSY particle has a rest mass below 1 TeV [2], the available energy in lead-lead collisions should also be high enough to produce such supersymmetric particles. The lower energies per nucleon and the smaller luminosity for lead beams, compared to proton beams, seem to reduce the possibility to find SUSY particles in lead-lead collisions in relation to proton-proton collisions. However, cooperative effects in heavy-ion collisions could enlarge the rates of SUSY particles. Therefore one should investigate whether collective effects can enhance the production of very heavy particles near or slightly above the threshold. Such effects have proven important in intermediate-energy heavy-ion collisions in the so-called subthreshold production of hadrons [3].

In this paper, we examine the possibility of collective effects and estimate the expected production rates for supersymmetric particles in central collisions of heavy nuclei at LHC energies. Our calculations are based on the parton cascade model (PCM) [4–7].

Our paper is organized as follows. In Section 2 we recall the basic features of the PCM. The cross sections for the production of SUSY particles in proton-proton collisions are

presented in Section 3. Section 4 contains the PCM results for lead-lead collisions at LHC. Our conclusions can be found in Section 5.

II. THE MODEL

The PCM is well documented in several publications [4–7], therefore, here we would like to recall only the basic features. The PCM is a model which describes nuclear collisions on the parton level. In the initialization stage, the nuclei are resolved into their constituent partons at a certain low-energy scale Q_0. The subsequent kinetics of the two colliding bunches of partons is described by a set of coupled quasi-classical transport equations of the Boltzmann type

$$p^\mu \partial_\mu F_a(p, r) = \sum_k I_a^k(p, r), \qquad (1)$$

where $F_a(p, r)$ is the phase-space density of partons of flavor a at momentum p and position r. The left hand side of this equation describes the propagation. On the right hand side, $I_a^k(p, r)$ describes the interaction kernel where partons of flavor a are involved. Possible interactions are elementary processes between two partons in first order of perturbative Quantum Chromo Dynamics (QCD) and parton emission or absorption processes. The explicit form of $I_a^k(p, r)$ can be expressed as

$$\sum_k I_a^k(p, r) = \sum_{b,c,d} J_{abcd}(p_a, r) + \sum_{bc} K_{abc}(p_a, r), \qquad (2)$$

where

$$J_{abcd}(p_a, r) = -\frac{1}{2} \frac{1}{S_{ab}} \frac{1}{S_{cd}} \int \frac{d^3 p_b}{(2\pi)^3 2E_b} \int \frac{d^3 p_c}{(2\pi)^3 2E_c} \int \frac{d^3 p_d}{(2\pi)^3 2E_d} (2\pi)^4 \delta^{(4)}(p_1 + p_b - p_c - p_d)$$

$$\times \left(F_a F_b [1 \pm F_c][1 \pm F_d] |\mathcal{M}_{ab \to cd}|_{\text{eff}}^2 - F_c F_d [1 \pm F_a][1 \pm F_b] |\mathcal{M}_{cd \to ab}|_{\text{eff}}^2 \right) \qquad (3)$$

and

$$K_{abc}(p_a, r) = -\frac{1}{2} \frac{1}{S_{ab}} \int \frac{d^3 p_b}{(2\pi)^3 2E_b} \int \frac{d^3 p_c}{(2\pi)^3 2E_c} (2\pi)^4 \delta^{(4)}(p_1 + p_b - p_c - p_d)$$

$$\times \left(F_a F_b [1 \pm F_c] |\mathcal{M}_{ab \to c}|_{\text{eff}}^2 - F_c [1 \pm F_a][1 \pm F_b] |\mathcal{M}_{c \to ab}|_{\text{eff}}^2 \right) \qquad (4)$$

(we use units with $\hbar = c = 1$). The factors $S_{ab} \equiv 1 + \delta_{ab}$ serve for the correct statistics in case of identical particles. The effective matrix elements $|\mathcal{M}_{...}|_{\text{eff}}^2$ are weighted with the particle densities $F_{...}$ of the incoming particles and are integrated over their momenta. The factors of the form $[1 \pm F_{...}]$ describe either Bose enhancement (with + sign) or Fermi suppression (with − sign) of the outgoing particles, respectively.

The effective matrix elements are corrected afterwards with respect to the virtuality of the partons. They exhibit the form, e.g., for the process $ab \to cd$

$$|\mathcal{M}_{ab \to cd}|_{\text{eff}}^2 = S_a(p_a; Q^2, Q_0^2) S_b(p_b; Q^2, Q_0^2) \left| \mathcal{M}_{ab \to cd}(Q^2) \right|^2 T_c(p_c; Q^2, \mu_0^2) T_d(p_d; Q^2, \mu_0^2), \quad (5)$$

where $\mathcal{M}$ stands for the lowest order QCD matrix element, and $S_{...}(p_{...}; Q^2, Q_0^2)$ is the Sudakov form factor for space-like branchings [8]. The latter one is operative only for primary

partons which did not yet participate in any interaction process. This factor evolves the initialization energy scale Q_0 to the scale Q of the first interaction of the primary partons. It accounts in such a way for the possible primary emissions of partons. The outgoing particles are excited and can emit further partons. This is described by the Sudakov form factor for time-like partons $T_{...}(p_{...}; Q^2, \mu_0^2)$, where μ_0 is a bound for the energy scale. Below this scale perturbative QCD becomes unreliable and a phenomenological hadronization scheme has to be employed.

In the PCM, Eq. (1) is solved within a test-particle formalism utilizing Monte Carlo techniques. Besides the interaction kernel several quantum mechanical corrections are implemented [7]. Our calculations are based on the PCM version VNI-2.0+. This is a corrected version [9] of K. Geigers original code VNI-2.0 [7]. The very recent PCM version VNI-3.1 [10] seems not yet be sufficiently tested so that we prefer to employ our well tested version VNI-2.0+.

III. PRODUCTION OF SUSY PARTICLES IN NUCLEON COLLISIONS

Let us first consider the inclusive production of SUSY particles in nucleon-nucleon collisions

$$\mathrm{N} + \mathrm{N}' \rightarrow \tilde{\mathrm{c}} + \tilde{\mathrm{d}} + \mathrm{X}, \tag{6}$$

where N and N$'$ denote the two nucleons, $\tilde{\mathrm{c}}$ and $\tilde{\mathrm{d}}$ are two supersymmetric particles with masses $m_{\tilde{c}, \tilde{d}}$, and X is an arbitrary number of hadrons. When taking only the first-chance collisions of partons, the total cross section for the process (6) can be calculated by

$$\sigma_{\mathrm{NN}' \rightarrow \tilde{c}\tilde{d}\mathrm{X}} = \frac{1}{s} \sum_{a,b=g,q,\bar{q}} \int_{s_{\min}}^{s} d\bar{s} \int_{\hat{s}/s}^{1} dx \, F_a^{\mathrm{N}}(x) \, F_b^{\mathrm{N}'} \left(\frac{\hat{s}}{sx} \right) \frac{1}{x} \, \sigma_{ab\tilde{c}\tilde{d}}(\hat{s}), \tag{7}$$

where $s_{\min} \equiv (m_{\tilde{c}} + m_{\tilde{d}})^2$, and $F_a^{\mathrm{N}}(x)$ denotes the parton distribution function of flavors a of the nucleon N. We denote the cross section (7) as Drell-Yan like cross section. Later we shall compare this cross section with results of the PCM. It is important to distinguish between the Mandelstam variables s and $\hat{s}$: s is always the squared invariant mass of the two nucleons resp. nuclei, while $\hat{s}$ denotes the squared invariant mass of an elementary parton-parton subprocess. We use the notion $M^2 \equiv \hat{s}$.

In what follows we assume that the strong coupling constant α_S is the same for coupling to SM particles as well as for coupling to SUSY particles. The dependence of α_S on the energy scale Q is accounted for up to the second order in $\ln(Q^2)^{-1}$ by [11]

$$\alpha_S(Q^2) = \frac{4\pi}{\beta_0 \ln(Q^2/\Lambda^2)} \left(1 - \frac{2\beta_1}{\beta_0^2} \frac{\ln[\ln(Q^2/\Lambda)]}{\ln(Q^2/\Lambda^2)} \right), \tag{8}$$

where $\beta_0 = 11 - \frac{2}{3} n_f$ and $\beta_1 = 51 - \frac{1}{9} 3 n_f$; n_f is the number of quark flavors with masses below Q. If the energy scale $Q = \sqrt{\hat{s}}$ is chosen, α_S varies from 0.094 to 0.067 in the relevant region for $Q = 0.3 \ldots 14$ TeV.

The CTEQ4M parametrization [12] from CERN PDFLIB (version 7.07) is employed for the parton distribution functions F_a^{N}.

The various cross sections of reactions, where SUSY particles are involved, can be found in Ref. [13]. We recalculated and confirmed these results.

We assume that the R parity is conserved in strong interactions and that left and right chiral squarks display the same mass. Precise values of masses are still lacking, of course. Some actual mass limits are listed in Tab. I (cf. [1,11]).

Total cross sections for SUSY particle production are displayed in Fig. 1 as a function of the available center-of-mass system (CMS) energy $\sqrt{\hat{s}}$ of the incoming partons. In Fig. 1 the mass for the lightest squark are taken as $m_{\tilde{q}} = 230$ GeV and the gluino mass is $m_{\tilde{g}} = 160$ GeV. These masses are close to the lower limits for the case $m_{\tilde{g}} \leq m_{\tilde{q}}$. The cross sections calculated with these values therefore serve as upper limits. One observes that the cross sections have their maximum slightly above the threshold and then decrease as $\propto \hat{s}^{-1}$. The reaction $gg \rightarrow \tilde{g}\tilde{g}$ has the largest cross section. All the displayed cross sections depend sensitively on the unknown SUSY particle masses. Below we discuss the dependence of the production rates on these masses.

Fig. 2 depicts the individual cross sections for SUSY particle production in proton-proton collisions in dependence on the CMS energy $\sqrt{s}$ of the protons. The figure covers the complete energy domain $\sqrt{s} \leq 14\,\text{TeV}$ which is available at LHC. The various combinations of outgoing strongly interacting SUSY particles are separately displayed. The gluino-gluino production dominates, followed by gluon-squark and squark-anti-squark production. The dominant parton processes are $gg \rightarrow \tilde{g}\tilde{g}$, $gq \rightarrow \tilde{g}\tilde{q}$, and $q_i\bar{q}_j \rightarrow \tilde{q}_i\tilde{\bar{q}}_j$.

Fig. 3 shows the summed cross sections for the production of $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$ and $\tilde{q}\tilde{q}$. As to be expected from inspecting Fig. 2, the relation $\sigma_{\tilde{g}\tilde{g}} > \sigma_{\tilde{g}\tilde{q}} > \sigma_{\tilde{q}\tilde{q}}$ holds.

As mentioned above, the masses of the SUSY particles represent the largest uncertainties since only lower bounds are known. To illustrate the effect of a change of the SUSY particle masses we depict in Fig. 4 the cross sections for gluino-pair production in dependence on the gluino mass. The mass of the lightest squark is set equal to the gluino mass, i.e., $m_{\tilde{g}} = m_{\tilde{q}}$, although the process $q\bar{q} \rightarrow \tilde{g}\tilde{g}$ can almost be neglected. The gluino mass is chosen to be $m_{\tilde{g}} = 50, 100, 250$ and 500 GeV. The cross sections for $m_{\tilde{g}} = 50, 100\,\text{GeV}$ serve only for comparative purposes, since they are already ruled out by the experiment. If $\sqrt{s}$ is large the cross sections fall by more than one order of magnitude when one doubles the gluino mass. If the invariant mass fulfills $\sqrt{s} < 500$ GeV, the threshold energy $2m_{\tilde{g}}$ becomes important. If $\sqrt{s}$ is ten times larger than the gluino mass, the cross section is large enough to produce SUSY particles in nucleon-nucleon collisions. Here we have assumed that a cross section of 10^{-4} nb is just sufficient to be verified in experiments. For gluino masses of 1 TeV and $\sqrt{s} = 14$ TeV the cross sections is indeed slightly above 10^{-4} nb.

The relation of the gluino mass to the lightest squark mass has also a strong influence on the dominating elementary parton process. To illustrate this effect we display in Fig. 5 the cross sections for the case $m_{\tilde{g}} > m_{\tilde{q}}$ with $m_{\tilde{g}} = 220$ GeV and $m_{\tilde{q}} = 180$ GeV. Again, the masses are just above the actual lower boundaries for this case. For $\sqrt{s} < 800$ GeV the $\tilde{q}\tilde{q}^{(*)}$ production becomes dominant, while above 7.5 TeV the $\tilde{g}\tilde{q}$ production is most important. The figure indicates that for $\sqrt{s}$ above $14\,\text{TeV}$ the $\tilde{g}\tilde{g}$ production becomes the dominant process, as in Fig. 3. This behavior follows from the form of the parton distribution functions. The gluon distribution dominates the quark distributions, but is concentrated at low momenta. The valence quark distributions have contributions at significantly higher momenta. Gluon-gluon interactions take place much more often than gluon-quark or quark-quark interactions, since there are by far more gluons than quarks. Otherwise, the CMS energy $\sqrt{\hat{s}}$ of the gluon-gluon interaction processes is much smaller. Since the masses of

supersymmetric particles are large, large values of $\sqrt{\hat{s}}$ are needed. Therefore, quark-quark interactions are much more efficient for SUSY particle production than gluon-gluon interactions. Gluon-quark interactions are somewhere in between gluon-gluon and quark-quark interactions.

IV. PRODUCTION OF SUSY PARTICLES IN NUCLEAR COLLISIONS

To calculate the SUSY particle production cross sections in nuclear collisions, we extrapolate appropriately the cross sections (7). The difference between nucleons and protons can be neglected because of the large energies which diminish the difference between u and d quarks. We consider symmetric heavy-ion collisions where each nucleus consists of A nucleons. From parton cascade calculations (see below) we know the dependence of the nuclear cross section on the nucleon number,

$$\sigma^{\text{AA}}_{\text{tot}}(s_A) = A^{4/3}\,\sigma^{\text{pp}}_{\text{tot}}(s_A) \, , \tag{9}$$

where $\sqrt{s_A}$ is the CMS energy per nucleon of both nuclei.

Now we want to compare this SUSY particle production cross sections with results of the PCM. The cross sections for SUSY particle production are relatively small compared to the elementary QCD cross sections. It is therefore a good assumption that the cascade will not be disturbed significantly if some SUSY particles are produced. R parity conservation ensures that no created SUSY particle will be lost by decay or interactions, though the original flavor may change.

The number $N_{\tilde{c}\tilde{d}}$ of produced pairs of SUSY particles $\tilde{c}\tilde{d}$ can be estimated by

$$N_{\tilde{c}\tilde{d}} = \sum_{a,b} \int_0^\infty dM \, \frac{\hat{\sigma}_{ab \to \tilde{c}\tilde{d}}}{\sum_{c,d} \hat{\sigma}_{ab \to cd}} \sum_{c,d} \frac{dn_{ab \to cd}(M)}{dM}, \tag{10}$$

where $\hat{\sigma}_{ab \to cd}$ is the total cross section of an elementary two-parton process. $dn_{ab \to cd}(M)/dM$ denotes the differential rate for processes of the type $ab \to cd$. It is extracted from our PCM calculation. This quantity describes the distribution of binary parton collisions as a function of $M \equiv \sqrt{\hat{s}}$. For heavy particle production, the distribution at very large values of $\sqrt{\hat{s}}$ is important. One intriguing question is now to investigate whether the distribution changes with the size of the system. It should be noted that at LHC the beam energies depend on the nuclei to be accelerated since the beam energy per unit charge is constant. This implies the following beam energies (in TeV) for various nuclei: ^{16}O, ^{32}S: 3.5, ^{56}Fe: 3.25, ^{208}Pb: 2.76.

Fig. 7 shows the scaled production rate dn/dM, averaged over impact parameters and for different nuclei for LHC energies. Since the cross section σ is given by

$$\sigma = \pi b^2_{\text{max}} \int dM \, \frac{dn}{dM} \tag{11}$$

we are going to depict the pure rate dn/dM multiplied by the factor πb^2_{max} . The maximum impact parameter b_{max} is chosen to be twice the radius of the colliding nuclei. Therefore, b_{max} depends on the specific nuclei.

As seen in Fig. 7, the rate is rapidly increasing with growing nucleon number A. For given nucleon number A, in the intermediate energy region (say 200 - 1000 MeV) the rate

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drops roughly exponentially, and at $\sqrt{\hat{s}} > 1$ TeV it flattens out. In the case of large values of M (say $M > 1500$ GeV), the total number of interactions is in the order of unity. This explains the large fluctuations in this region. As mentioned above, the values displayed in Fig. 7 are for fixed beam energies per charge unit. In despite of the caused variation of beam energies, the flattening of the rate dn/dM sets in at $M \sim 1$ TeV. Limited statistics does not allow to draw firm conclusions on a larger interval of accessible large-M collisions in lead-lead reactions in comparison with pp reactions. Nevertheless, it is fair to say, when inspecting Fig. 7, that in collisions of heavy nuclei a similar range of M is accessible as in collisions of protons, even if $\sqrt{s}$ is only $\frac{1}{3}$ of the latter one. The scaled rate at $M \sim 1$ TeV is in AA collisions by a factor of 10^4 larger than in pp reactions.

For the calculation of SUSY particle production rates we need dn/dM separately for each individual pair of initial particles. These rates are depicted in Fig. 8. Gluon-gluon and gluon-quark processes occur most often, since the number of gluons exceeds the number of quarks. For a large invariant masses $M > 500$ GeV the gluon-quark interactions dominate. This corresponds to the effect discussed above, which is caused by the large momenta of the valence quarks. The number of quarks is not high enough to lead to a significant contribution of quark-quark interactions. It is a remarkable result that gq processes seems to be most important for production of heavy particles in central nuclear collisions.

Since we have calculated the distribution dn/dM for various nuclei we can proceed and calculate the dependence of the interaction rate on the nucleon number A. We have to integrate the distributions over M weighted with $\pi b_{\max}^2$. Fig. 9 depicts the result in comparison with different fit functions depending on the nucleon number A. Obviously, the data points are approximated best by a function of the type $a_0 A^{4/3}$. This result justifies our approach leading to Eq. (9).

Besides the cross sections for SUSY particles production, the total cross sections for gluon and quark reactions of the SM enter into Eq. (10). Some of these cross section are infrared divergent and have to be regularized. For consistency, we employ the same regularization as in the PCM. Fig. 10 depicts the regularized total cross sections for various parton reactions in the relevant energy region.

By means of Eq. (10) the SUSY production rate $N_{\tilde{c}\tilde{d}}$ can be calculated. The production cross section $\sigma_{\tilde{c}\tilde{d}}$ then yields $\sigma_{\tilde{c}\tilde{d}} = \pi b_{\max}^2 N_{\tilde{c}\tilde{d}}$. The results for two different mass scenarios of SUSY particles are listed in Tab. II. The VNI-2.0+ parton cascade calculation is compared with the Drell-Yan like rates at fixed beam energies per charge unit. One reveals from Tab. II two interesting features. First, for proton-proton collisions, VNI-2.0+ delivers cross sections which are at least by a factor $\frac{1}{3}$ smaller than the Drell-Yan like rates. Second, for nuclear collisions, VNI-2.0+ delivers at least three times more SUSY particles than the extrapolated Drell-Yan like rate predicts. The latter one is the wanted collective effect. When normalizing the VNI-2.0+ pp result to the Drell-Yan like rate, the corresponding VNI-2.0+ results for lead-lead collisions would be a factor 30 or more larger than the extrapolated Drell-Yan like rate. Even if one takes these numbers with some caution, it appears that, due to secondary parton interactions, the high-energy subprocesses are noticeably amplified in nuclear collisions.

To understand these effects better, one should keep in mind that in the Drell-Yan like calculations only reactions between primary partons (i.e., such ones which did not yet suffer an interaction) are considered. In the parton cascade calculations also the reactions with secondary partons (i.e., such ones which already suffer an interaction) are taken into account. This leads generally to larger rates. The effect is the stronger the heavier the nuclei are,

since the density grows with the number of nucleons per nucleus. The energies of the secondary partons are lower compared to the primary partons. As stated above, the process $gq \to \tilde{g}\tilde{q}$ is the most dominant reaction for SUSY particle production for low invariant masses just above the threshold. Therefore, the process $gq \to \tilde{g}\tilde{q}$ becomes dominant if the secondary interactions become important. This is to be contrasted with the Drell-Yan like rates (compare Tab. II, top rows) where the $\tilde{g}\tilde{g}$ channel for $m_{\tilde{g}} > m_{\tilde{q}}$ dominates.

It can be observed (compare Tab. II, bottom rows) that $\tilde{g}\tilde{q}$ production is the dominant process in the case of $m_{\tilde{g}} > m_{\tilde{q}}$ in nucleon-nucleon calculations. Extrapolated to nucleus-nucleus collisions, $\tilde{q}\tilde{q}^{(*)}$ production becomes dominant. This is due to the effect that the beam energy per nucleon is lower in nucleus-nucleus collisions. In this case, the higher energy of the quarks is more important than the higher density of the gluons (see also Fig. 5). Secondary interactions, however, change this feature and favor again the $gq \to \tilde{g}\tilde{q}$ channel.

Finally let us comment on the different results of Drell-Yan like estimates and VNI-2.0+ calculations for pp collisions. Partially we can understand this difference as a result of a non-perfect parton distribution initialization in the PCM [9], and too low phase space occupation even in high-statistics runs. Further, in the parton cascade it is rather likely that a single parton with very high momentum can escape from the interaction region in a proton-proton collision without any interaction at all. This is supposed not to happen not so often in collisions of heavy nuclei because of the much higher particle density. As a result, the PCM rates in proton-proton collision are diminished. This effect is a consequence of the test-particle character of the parton cascade calculation and seems to become severe in extreme regions of the phase space. As a test of our calculation routines we have used the fiducial masses $m_{\tilde{g}} = 10$ GeV and $m_{\tilde{q}} = 20$ GeV and find that, when summing over all channels, the Drell-Yan like rate and the VNI-2.0+ result agree perfectly.

The actual production rate in the experiment is mainly determined by the luminosity of the particle beams. Since the luminosities for proton and lead beams at the LHC will differ by a factor of about 10^7, it is very important to take the luminosity into account if one wants to compare the production rates in proton-proton and lead-lead collisions.

Obviously, Tab. II demonstrates clearly that one can not expect to find signatures for SUSY particle production in collisions of heavy nuclei easier than in proton-proton collisions. The SUSY particle production rates in pp collisions are by a factor of 10^3 (or more) larger than in AA collisions. The larger luminosity and the higher energy per nucleon in proton-proton collisions provides a clear advantage in the search of production of heavy particles. In addition, it can be expected that it is much easier to analyze an experimental event originating from a proton-proton collision rather than from nucleus-nucleus collision since much fewer particles are involved.

The following estimates rely on the design data of LHC which envisage a luminosity (in units of $10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$) of 0.002 of lead beams in contrast to 10^4 for protons; in addition, there will be two beam crossings of protons. The best case scenario is to produce 52 pairs of SUSY particles per second and per beam crossing in proton-proton collision with masses $m_{\tilde{g}} = 160\,\mathrm{GeV}$ and $m_{\tilde{q}} = 230\,\mathrm{GeV}$. In lead-lead collision, only one pair will be produced in 145 seconds. Since it is probable that the masses are higher than assumed here, this can be considered to represent an upper limit. In the case of $m_{\tilde{g}} = m_{\tilde{q}} = 1$ TeV, it can be expected that one pair of SUSY particles will be produced every 24 minutes. Although this seems to be a short period, it should be taken into account that much more than one event is necessary to find a clear evidence for SUSY production experimentally.

V. SUMMARY

In summary we estimate the production rates of supersymmetric particles in central collisions of lead on lead at LHC energies within the parton cascade model and compare with the production rates in pp collisions. We do not find a sufficiently strong cooperative effect in heavy-ion collisions which would allow for more frequent production of SUSY particles. Due to different beam energies and luminosities for proton and lead beams, it is therefore most likely that SUSY particles (provided they exist) will be primarily found in proton-proton collisions at the LHC. Even for such a very high masses of the gluino as $m_{\tilde{g}} = 1$ TeV and of the lightest squark as $m_{\tilde{q}} = 1$ TeV, it can be expected that SUSY particles can be produced with a considerably high rate to be detectable experimentally.

Acknowledgements

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VI. TABLES

SUSY particle	mass limit [GeV]	condition
squark $\tilde{q}$	> 224	$m_{\tilde{g}} \le m_{\tilde{q}}$
	> 176	$m_{\tilde{g}} < 300\,\text{GeV}$
gluino $\tilde{g}$	> 154	$m_{\tilde{g}} < m_{\tilde{q}}$
	> 212	$m_{\tilde{g}} \ge m_{\tilde{q}}$

TABLE I. Strongly interacting supersymmetric particles and their mass limits. $\tilde{q}$ denotes the lightest squark. The mass limits depend on the mass relation of the gluino to the lightest squark.

SUSY masses		SUSY pair	Drell-Yan like		VNI-2.0+	
			p	^{208}Pb	p	^{208}Pb
		$\tilde{g}\tilde{g}$	3.68	345	0.365	1030
	σ_{tot} [nb]	$\tilde{g}\tilde{q}$	1.14	153	0.374	2000
$m_{\tilde{g}} = 160\,\text{GeV}$		$\tilde{q}\tilde{q}^{(*)}$	0.367	66.9	0.0309	425
$m_{\tilde{q}} = 230\,\text{GeV}$		$\tilde{g}\tilde{g}$	36.8	6.90×10^{-4}	3.65	0.00206
	Rate [s^{-1}]	$\tilde{g}\tilde{q}$	11.4	3.06×10^{-4}	3.74	0.004
		$\tilde{q}\tilde{q}^{(*)}$	3.67	1.34×10^{-4}	0.309	8.5×10^{-4}
		$\tilde{g}\tilde{g}$	0.797	56.2	0.119	338
	σ_{tot} [nb]	$\tilde{g}\tilde{q}$	0.852	112	0.298	1580
$m_{\tilde{g}} = 220\,\text{GeV}$		$\tilde{q}\tilde{q}^{(*)}$	0.699	140	0.0455	688
$m_{\tilde{q}} = 180\,\text{GeV}$		$\tilde{g}\tilde{g}$	7.97	1.12×10^{-4}	1.19	6.76×10^{-4}
	Rate [s^{-1}]	$\tilde{g}\tilde{q}$	8.52	2.24×10^{-4}	2.98	0.00316
		$\tilde{q}\tilde{q}^{(*)}$	6.99	2.80×10^{-4}	0.455	0.00138

TABLE II. Cross sections and production rates for SUSY particle production for different masses of the gluino and the lightest squark.
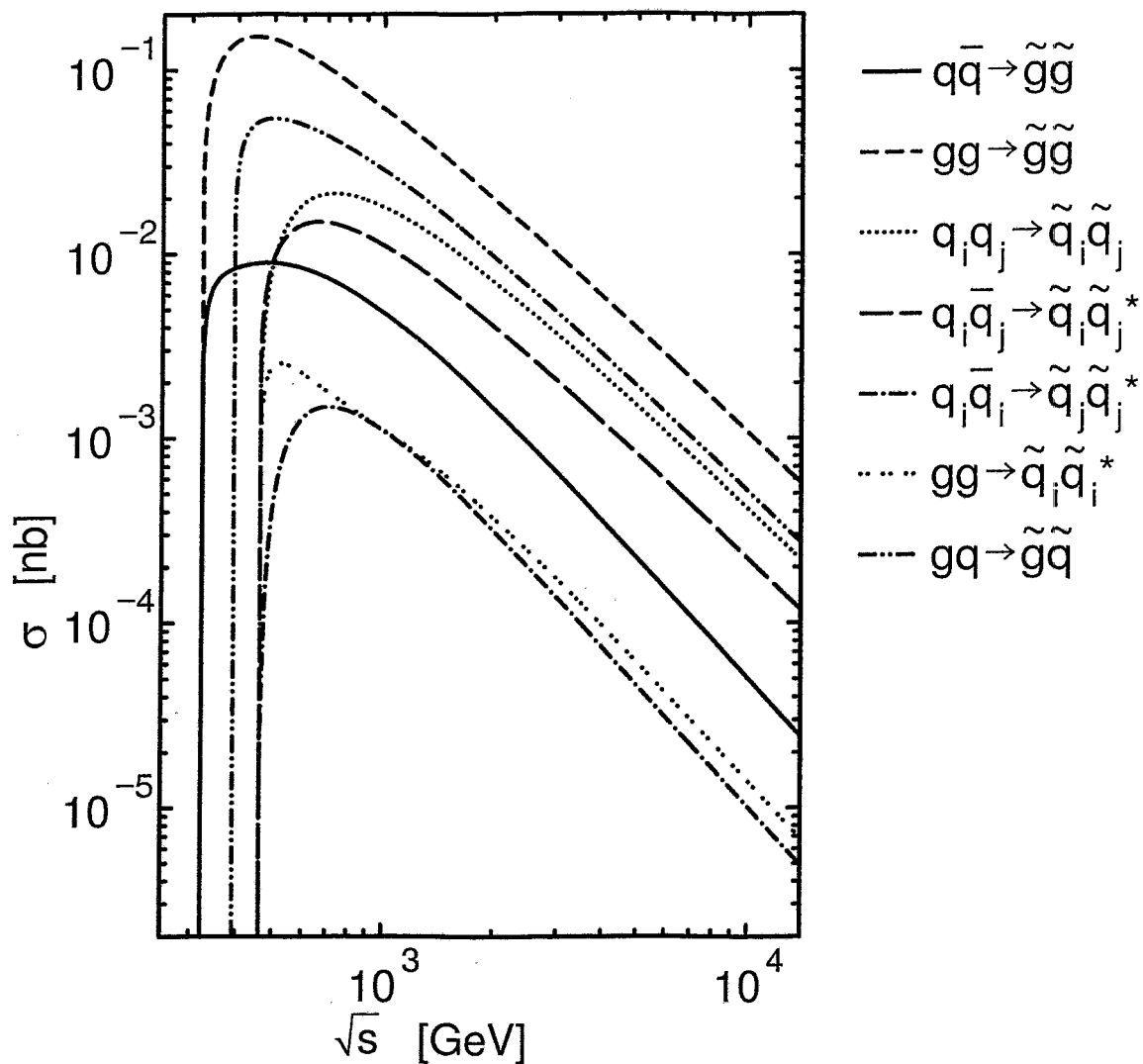
FIG. 1. Total cross sections of seven fundamental SUSY particle production processes as a function of the CMS energy $\sqrt{\hat{s}}$. The masses are chosen to be $m_{\tilde{q}} = 230$ GeV for the lightest squark, and $m_{\tilde{g}} = 160$ GeV for the gluino.
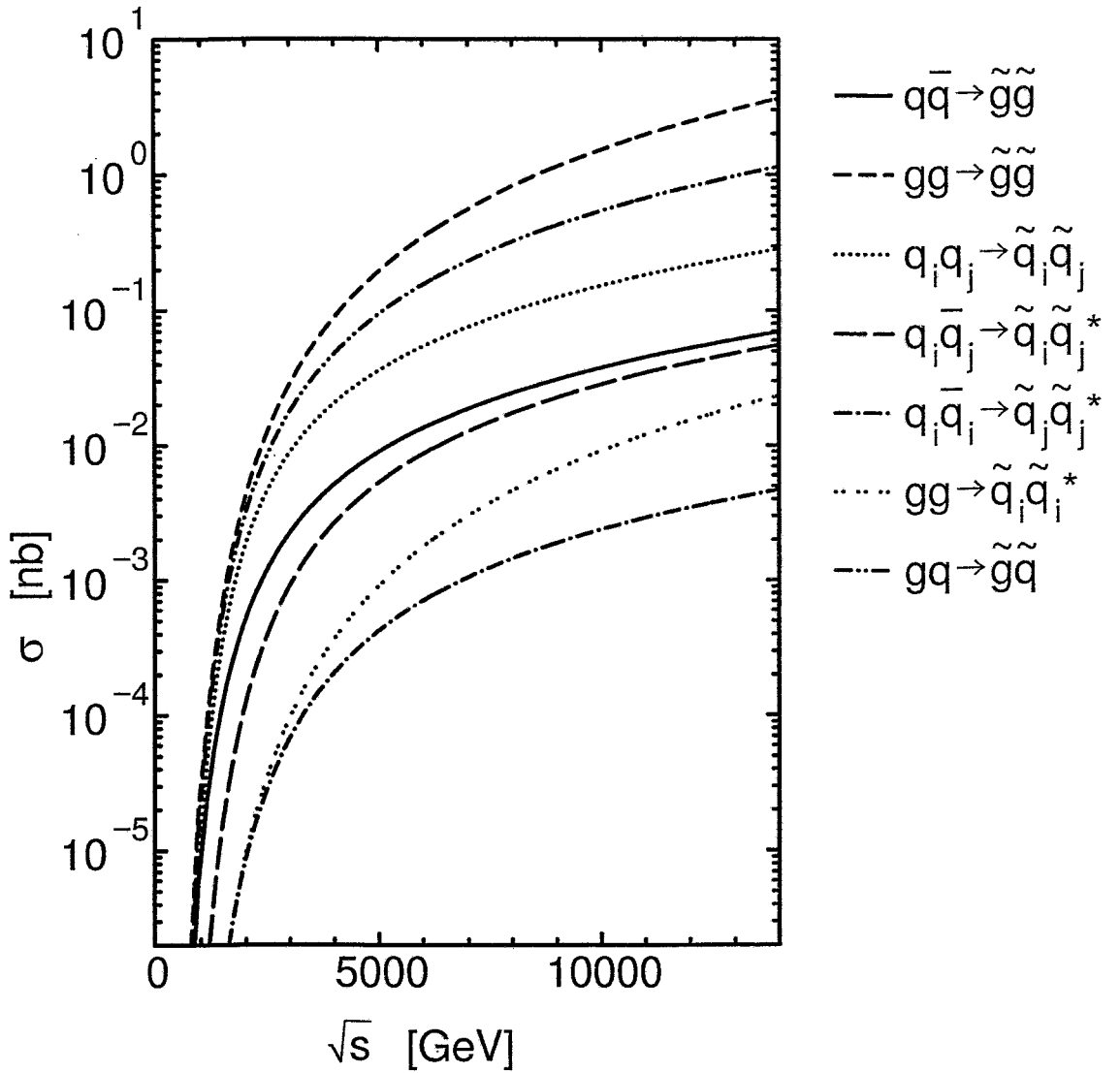
FIG. 2. Drell-Yan like production of SUSY particles in proton-proton collisions. The cross sections of individual subprocesses are depicted separately. The masses of the SUSY particles are $m_{\tilde{q}} = 230$ GeV and $m_{\tilde{g}} = 160$ GeV.
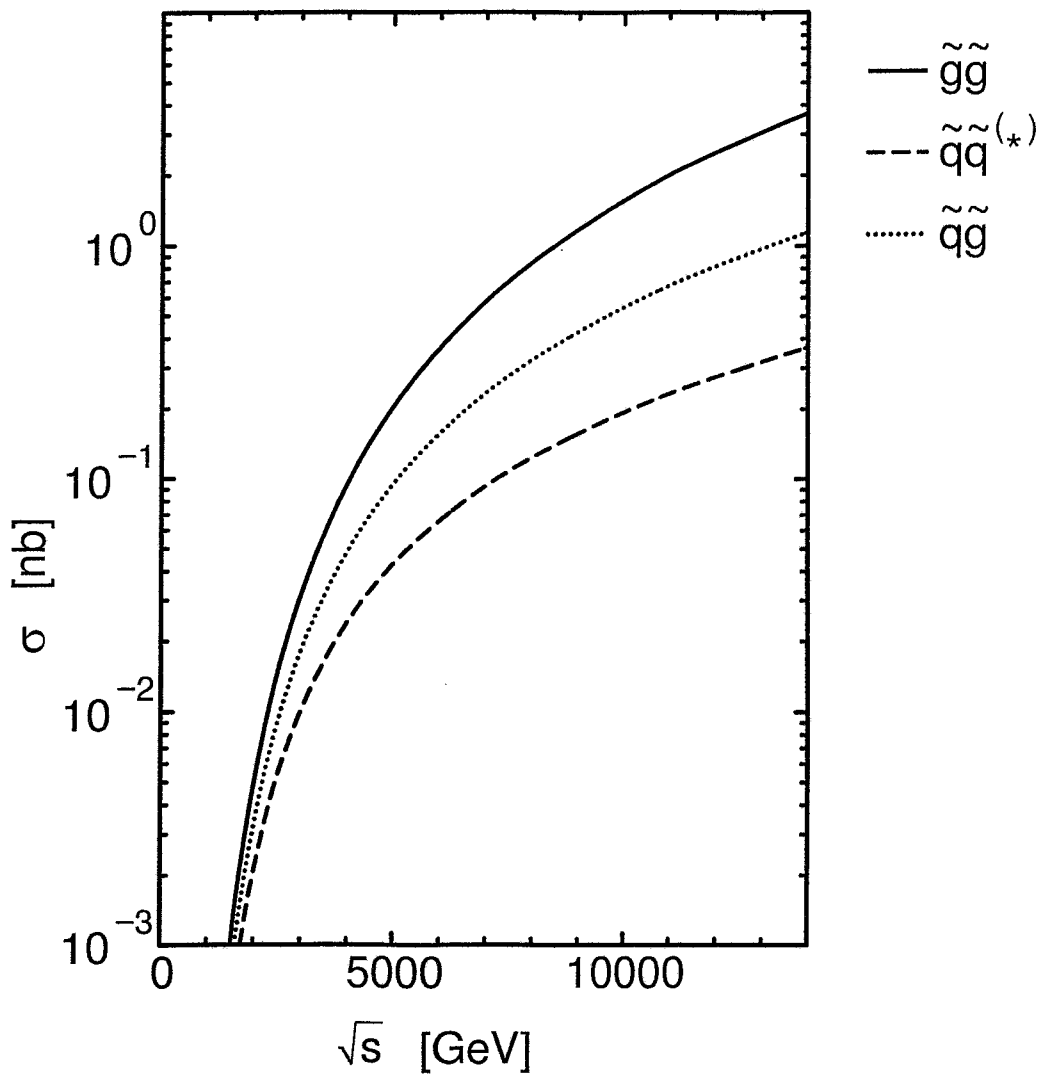
FIG. 3. As in fig. 2, but summed over all processes with the same final SUSY particle pair.
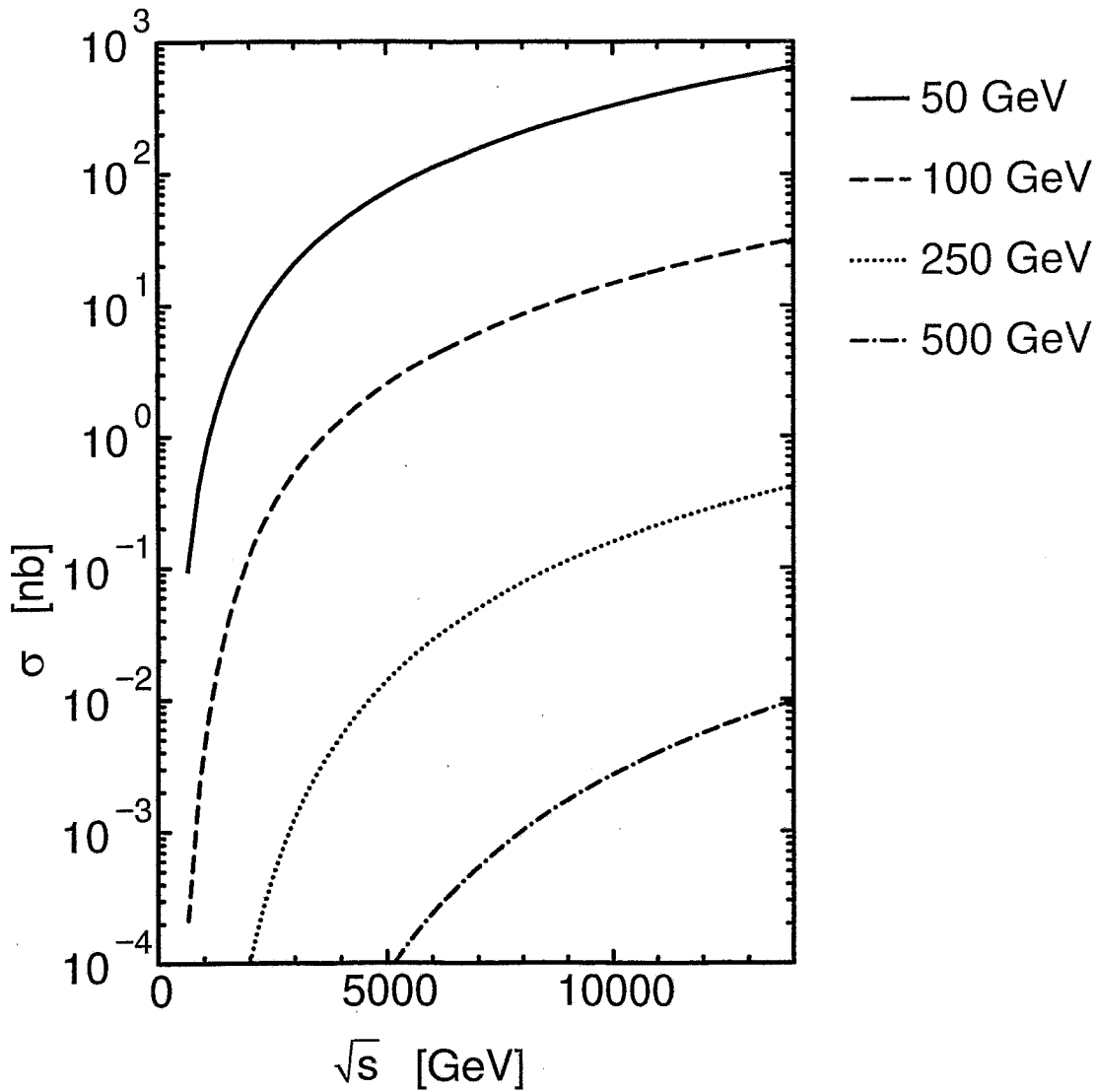
FIG. 4. Drell-Yan like production of gluino pairs in proton-proton collisions for various assumptions on the gluino mass. We use $m_{\tilde{g}} = m_{\tilde{q}}$.
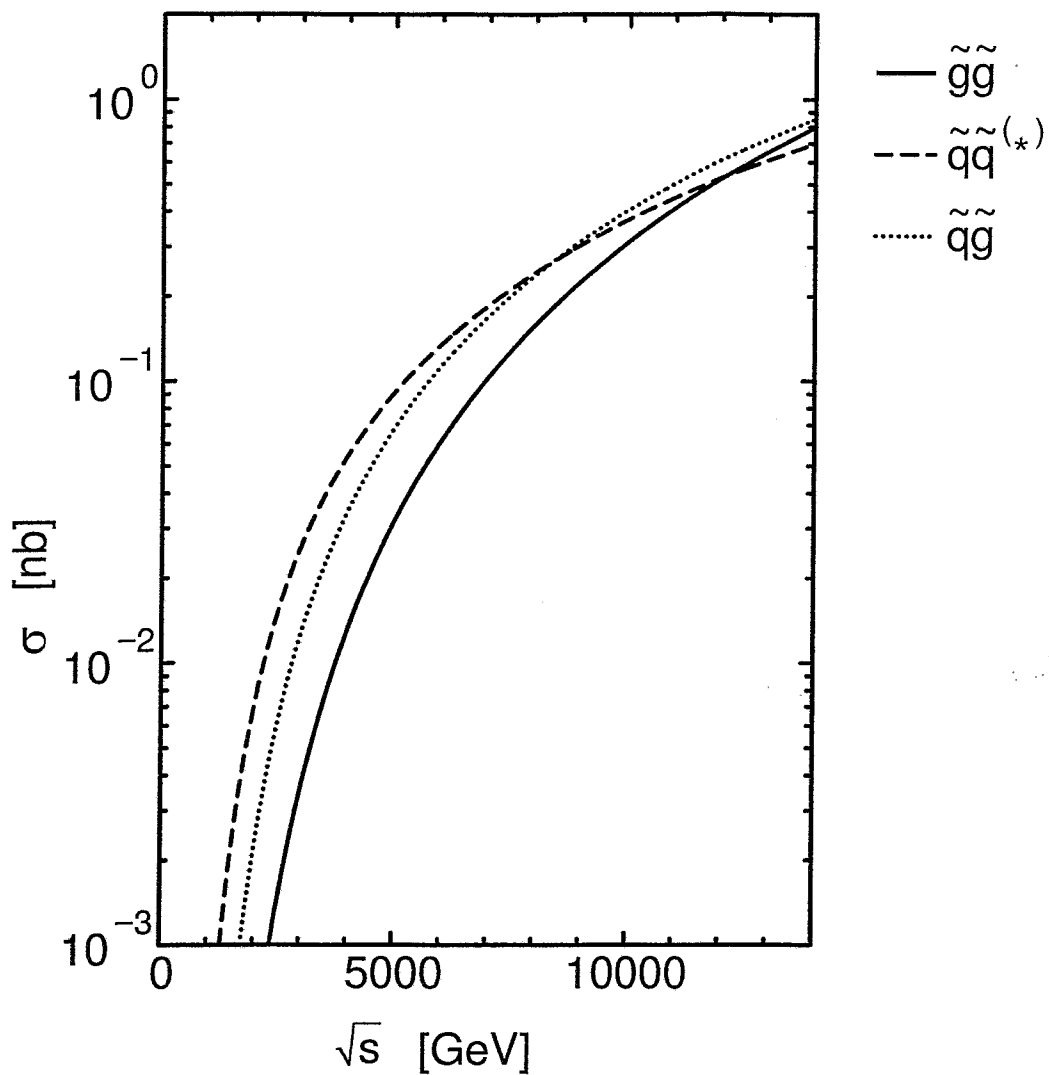
FIG. 5. The same as in Fig. 3 for the case $m_{\tilde{g}} > m_{\tilde{q}}$. The lightest squark mass is $m_{\tilde{q}} = 180$ GeV, while the gluino mass is $m_{\tilde{g}} = 220$ GeV.
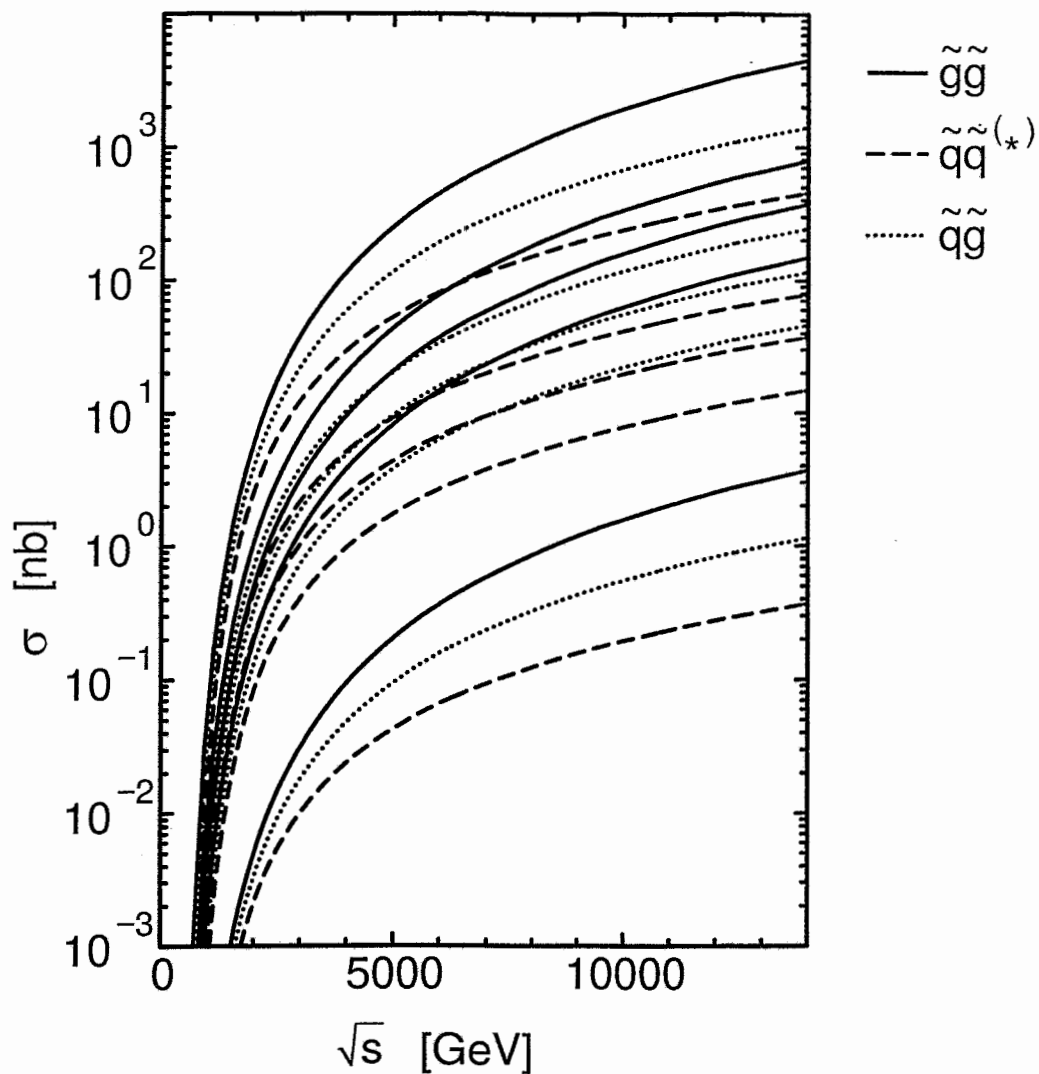
FIG. 6. Extrapolated Drell-Yan like production cross sections of SUSY particles in nucleus-nucleus collisions for different nuclei. The masses of the SUSY particles are identical with those in Fig. 3. From bottom to top, the cross sections are shown for protons, ^{16}O, ^{32}S, ^{56}Fe and ^{208}Pb.
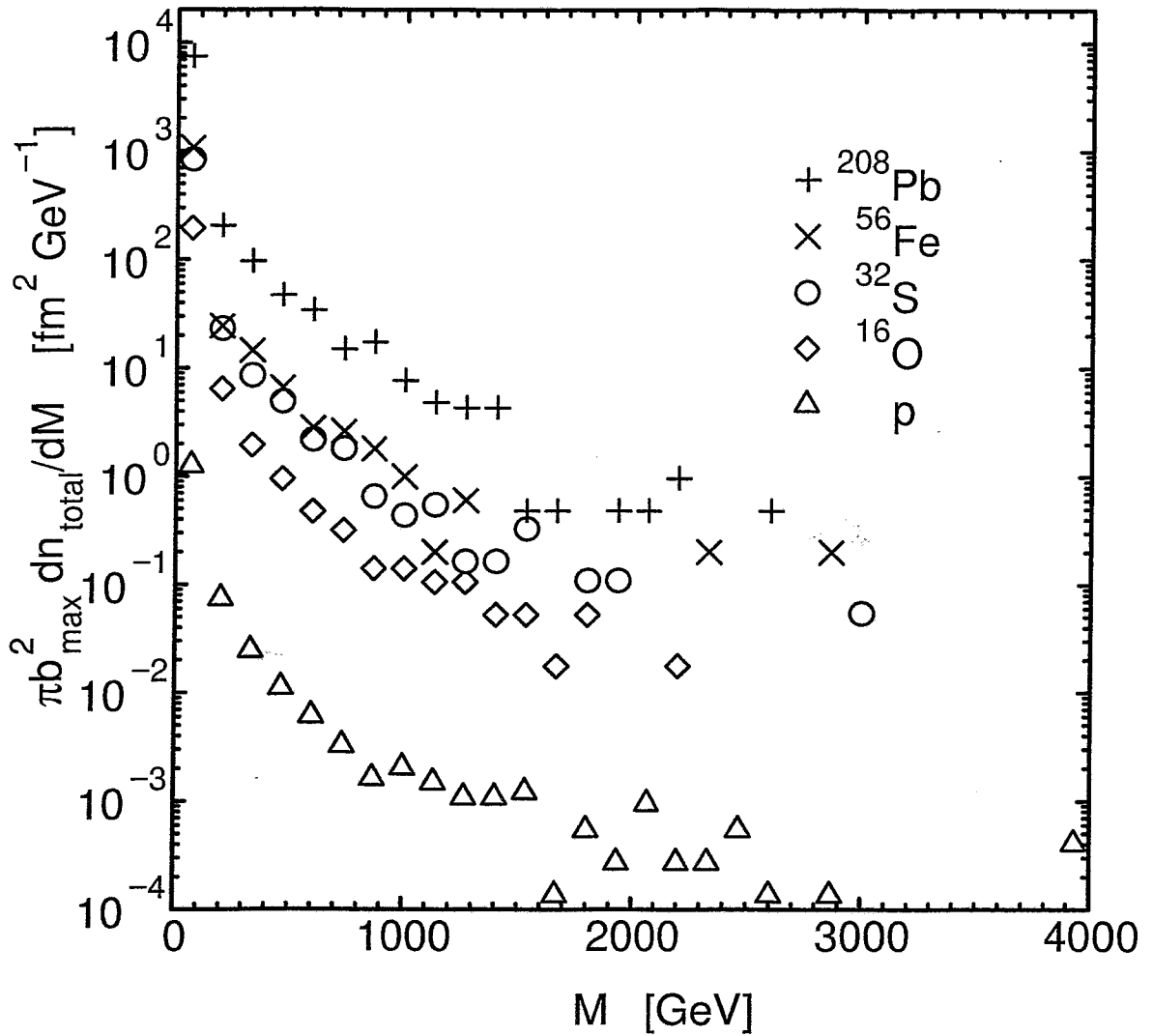
FIG. 7. The total $\pi b_{max}^2 \, dn/dM$ distribution for different nuclei at 7 TeV per charge unit in dependence on the invariant mass $M \equiv \hat{s}^{1/2}$ of the parton-parton process. b_{max} is the maximum impact parameter. The distributions were obtained by averaging over several collisions. The fluctuations in the high M region are due to the low statistics in the high energy tail of the distributions.
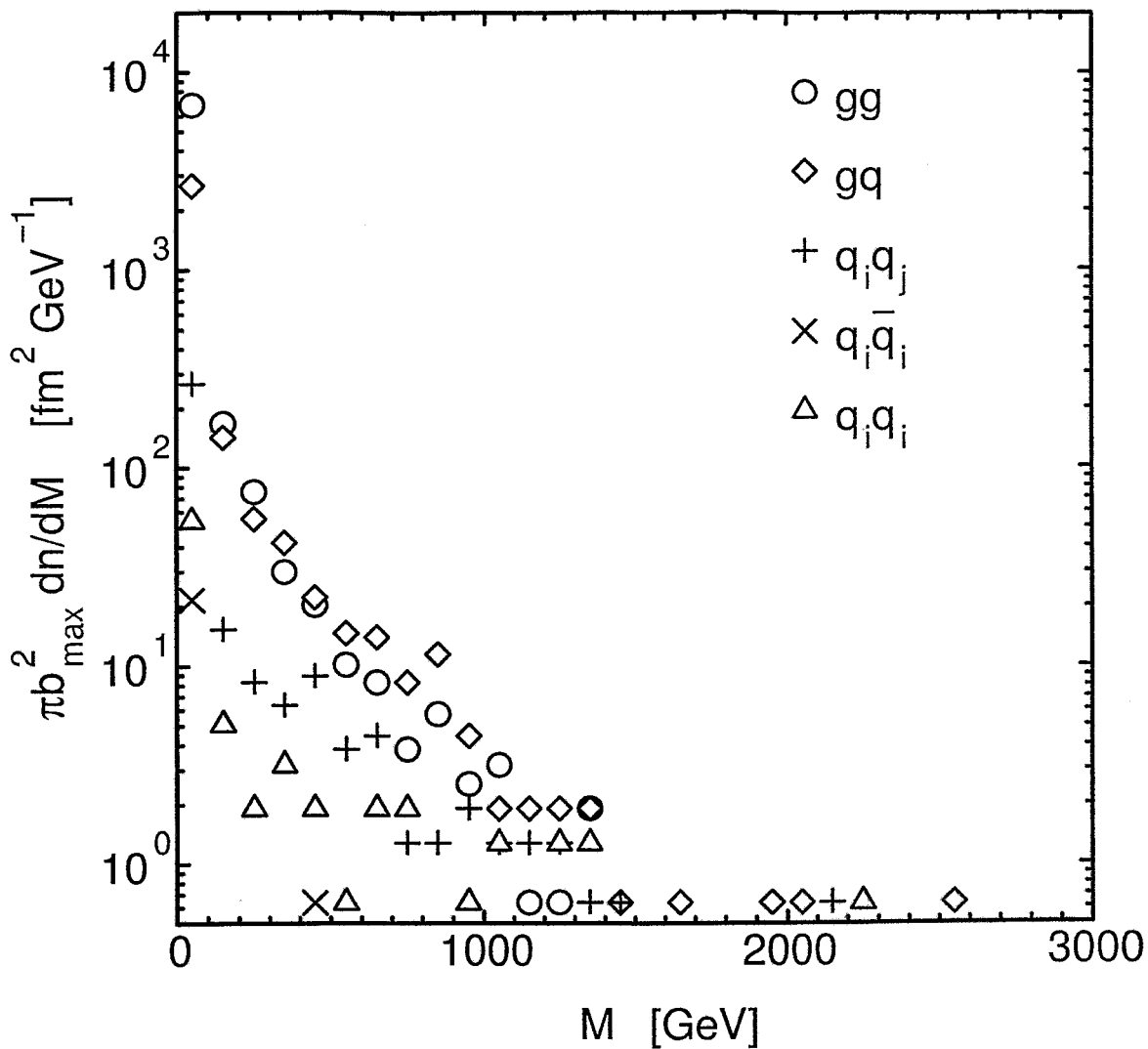
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FIG. 8. The dn/dM distribution for lead-lead collisions at beam energies of 2.76 ATeV. The dn/dM distributions are depicted separately for different combinations of colliding initial partons.
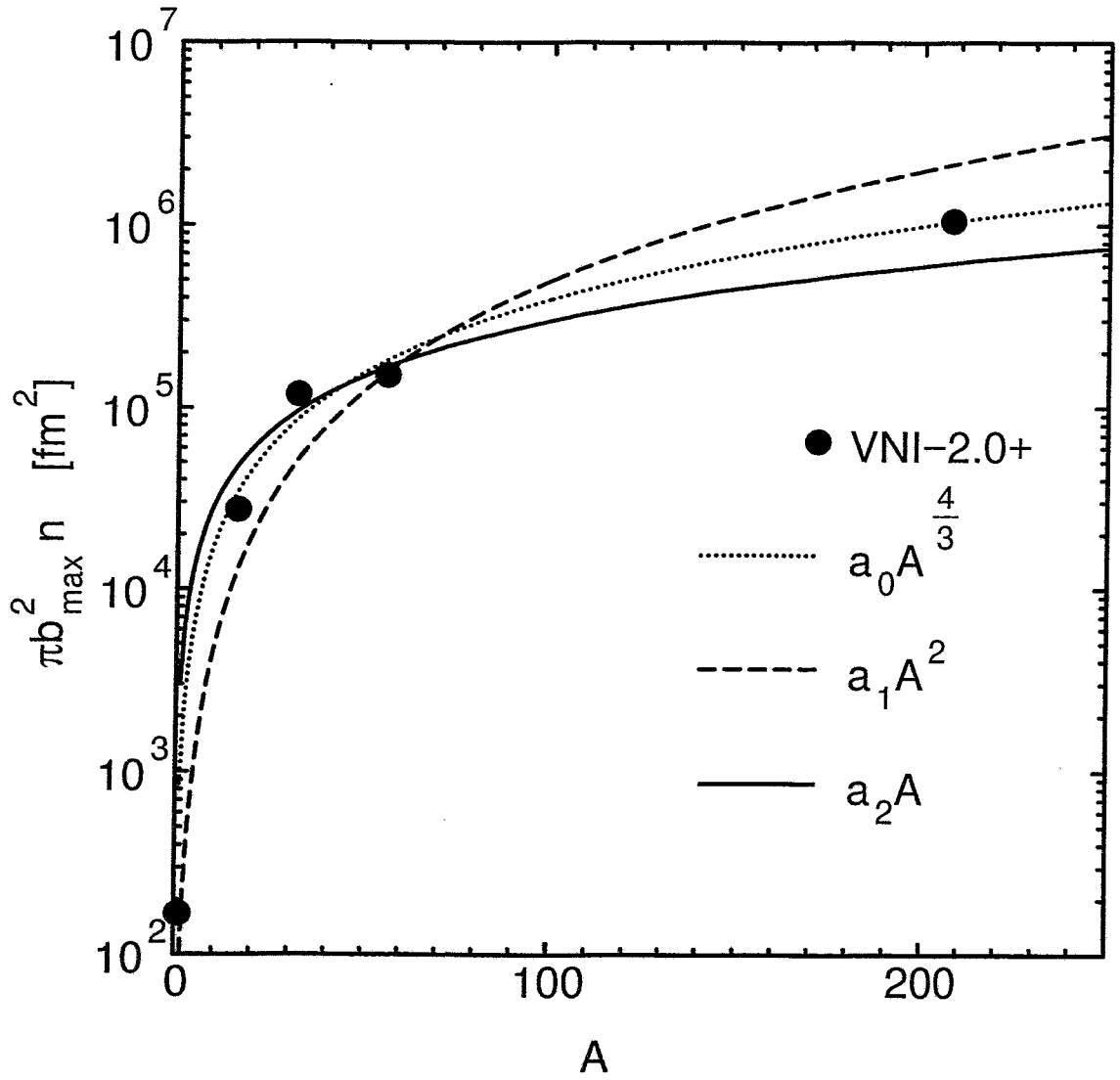
FIG. 9. The integrated binary collision rate as a function of the nucleon number A compared to various fit functions.
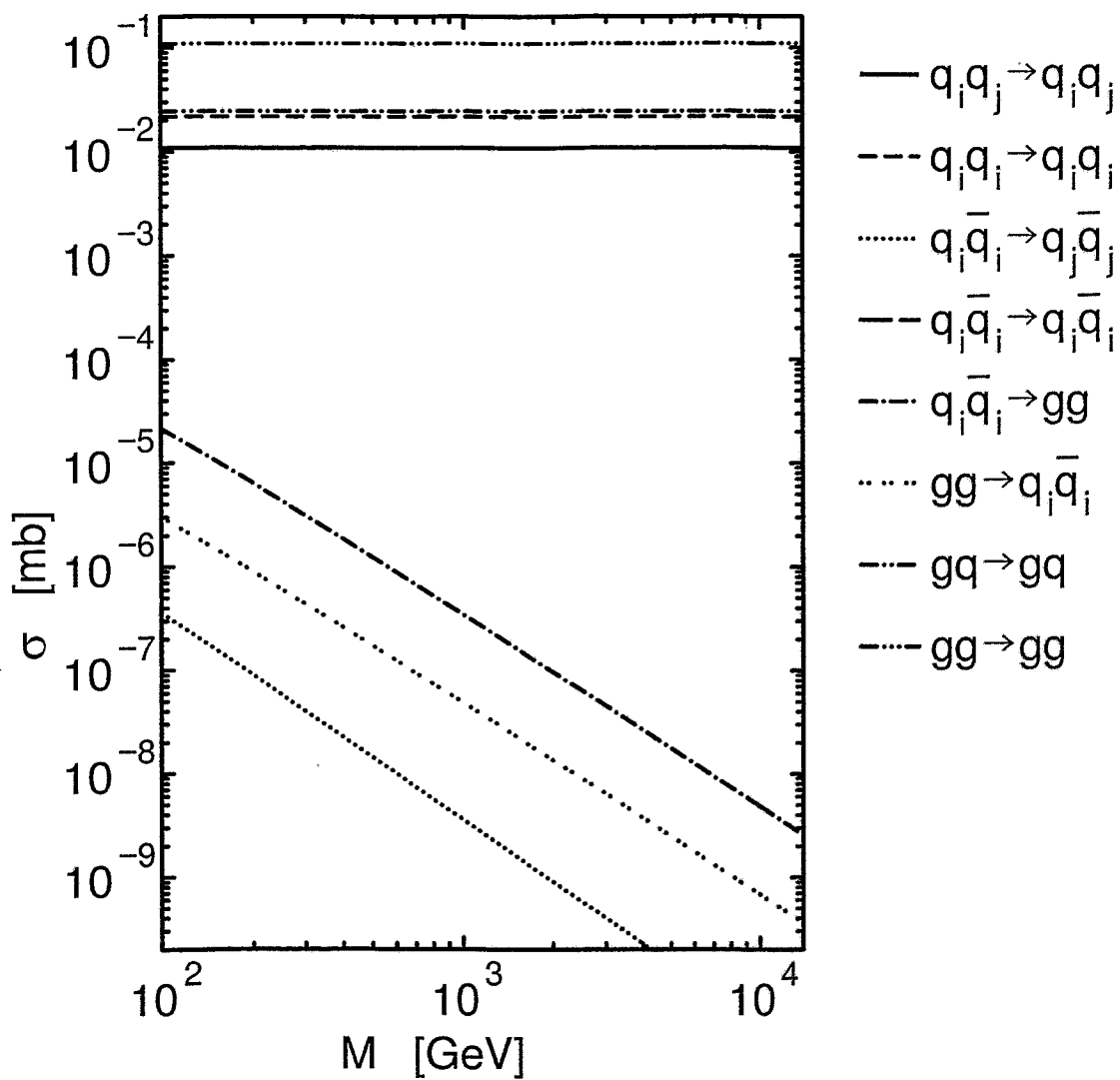
FIG. 10. The total cross sections of the fundamental QCD procesess for massless quarks and gluons.