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Gluino pair production at the LHC: The threshold

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Abstract

The next-to-leading order analysis of the cross section of hadronic gluino pair production close to threshold is presented. Within the framework of non-relativistic QCD a significant enhancement compared to fixed order perturbation theory is observed which originates from the characteristic remnant of the $1S$ peak below the nominal pair threshold. This enhancement is similar to the corresponding one for top production. However, as a consequence of the larger color factor of the QCD potential the effect is significantly enhanced. The analysis includes all color configurations of S-wave gluino pairs, i.e. singlet, symmetric and antisymmetric octet, decuplet and twenty-seven representation. Matching coefficients involving real and virtual radiation are separately evaluated for all color and spin configurations and initial states. We concentrate on the case of gluino decay rates comparable to the gluino binding energy. The non-relativistic dynamics of the gluino pair is solved by calculating the Green's function in NLO. Numerical results for the Large Hadron Collider at $\sqrt{s} = 14$ TeV and 7 TeV are presented for various characteristic scenarios.

Keywords: LHC; Gluino pair production; Perturbation theory; Threshold effects

1. Introduction

The search for new particles, predicted in supersymmetric models, is one of the important tasks of the experiments at the Large Hadron Collider (LHC). The detailed determination of particle masses and couplings will be crucial for the discrimination between various manifestations of supersymmetry (SUSY) and alternative models, even more so if one wants to distinguish

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between the different variants of supersymmetric models, to identify the origin of breaking of supersymmetry and to measure the model parameters. One of the SUSY signals will be events with missing energy or missing transverse momentum, resulting from cascade decays of squarks and gluinos into the lightest supersymmetric particle (LSP) which escapes detection. The existence of squarks, gluinos and the LSP is definitely a key prediction of supersymmetry.

Depending on details of the models, in particular the masses of squarks and the LSP, gluinos with masses up to 3 TeV [1] could be detected. The search strategy is quite different if gluinos are heavier than squarks or if they are lighter. In the former case ($m_{\tilde{g}} > m_{\tilde{q}}$) the two-body decay into a squark and an anti-quark (or its charge conjugate) dominates, with the subsequent decay of the squark into a quark plus a chargino or neutralino. In the latter case ($m_{\tilde{g}} < m_{\tilde{q}}$) the two-body channel is kinematically forbidden and the now dominant three-body decay into quark, anti-quark and neutralino or chargino, mediated by the virtual squark, leads to a small decay rate. In the limit of extremely heavy squarks, a scenario denoted Split SUSY, the gluino is quasistable and hadrons composed of gluinos and gluons or quarks may travel macroscopic distances. The search strategies will be markedly different in the various cases.

The importance of squark and gluino searches has motivated a series of detailed studies of hadroproduction cross sections for squarks and gluinos. The lowest order has been evaluated long time ago [2–4]. Subsequently the next-to-leading order (NLO) SUSY-QCD corrections were calculated [5–7], more recently the effect of soft-gluon resummation [8–14] was included. The present paper will be concerned with gluino-pair production close to threshold, which exhibits a number of peculiar features.

As a consequence of their color-octet representation the production cross section of gluinos is large and perturbative corrections are particularly important. Furthermore, the threshold region is strongly affected by final state interaction, which in leading order is related to Sommerfeld rescattering corrections and which, compared to the similar situation in top–anti-top production [15], is amplified by the ratio $(C_A/C_F)^2 = (9/4)^2$.

Corresponding to the different decay modes and rates, two complementary scenarios must be considered: For relatively stable gluinos (corresponding to the case $m_{\tilde{g}} < m_{\tilde{q}}$) gluino pairs may form non-relativistic boundstates, denoted gluinonia, which decay through gluino pair annihilation into a pair of gluon jets or a quark plus an anti-quark jet. This possibility has been described originally in Refs. [16–19] where the basic features like boundstate quantum numbers, leading terms in the potential, spectra and some of the production mechanisms were investigated. More recently this aspect has been studied in Refs. [20–22]. Relatively stable gluinos are motivated by the proposal of Split SUSY [23,24] (see also Refs. [25,26]), which suggests heavy squarks and, correspondingly, long-lived gluinos. A detailed study is presented in [27], which gives the higher order corrections to the potential, to the boundstate energy spectrum and to the production cross section for the boundstate in the color singlet configuration.

The second scenario is relevant for gluinos with a larger decay rate, of order one GeV or higher. In this case the boundstate decay proceeds through the decay of the constituents, and for decay rates of several GeV no well-defined boundstates exist. Even in this case final state interaction leads to a significant lowering of the effective production threshold, an enhancement of the cross section and a strong distortion of the differential cross section, in particular of the distribution in the invariant mass of the gluino, with details depending on the gluino mass and decay rate.

This scenario has many similarities with hadronic top quark production close to threshold [28,29]. In particular the distribution in the invariant mass of the gluino pair can be treated with similar methods. In Ref. [30] the dominant contributions and the leading radiative corrections