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Squark and gluino production at the LHC

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In this talk I report on recent results for resummed total cross sections in squark and gluino hadroproduction. In the limit of production threshold, the emission of soft gluons results in the appearence of large logarithmic corrections in the theoretical expressions. These corrections are resummed at next-to-leading-logarithmic accuracy and their effect on the predictions for squark and gluino production at hadron colliders is studied.

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1. Introduction

The searches for signals of supersymmetry (SUSY) are currently carried out by the Tevatron experiments and in the coming years will be undertaken by the experiments at the Large Hadron Collider (LHC). Within the Minimal Supersymmetric Standard Model (MSSM) [1], the dominant production processes of sparticles at the LHC are those involving pairs of coloured particles, i.e. squarks and gluinos, in the final state. Depending on the outcome of the experimental searches, predictions for the total rates for these production processes are either used to draw the exclusion limits for the mass parameters or will help to determine the masses of the sparticles.

There are four pair-production processes of squarks and gluinos in hadronic collisions: $p\overset{(-)}{p} \to \tilde{q}\bar{\tilde{q}}, p\overset{(-)}{p} \to \tilde{q}\tilde{q}, p\overset{(-)}{p} \to \tilde{g}\tilde{g}, p\overset{(-)}{p} \to \tilde{q}\tilde{g}$. The next-to-leading order (NLO) SUSY-QCD corrections [2, 3] to all hadroproduction processes are known to be positive. Depending on the process and the masses of sparticles considered, they can be large. As pointed out in [3], an important part of the contributions to the hadronic cross sections comes from the energy region near the partonic production threshold, reached when the square of the partonic center-of-mass (c.o.m.) energy squared $\hat{s}$ approaches $4m^2$, where m is the average mass of produced particles. In this region, two types of corrections dominate: the Coulomb corrections, due to exchange of gluons between slowly moving massive particles, and the soft-gluon corrections, due to emission of low-energetic gluons off the coloured initial and final states. The large size of the soft-gluon emission contributions can be traced down, for the perturbative n-th order correction, to the logarithmic terms of the form $\alpha_{\rm s}^n \log^k(\beta^2)$ where $k = 2n, \ldots, 0$ with $\beta \equiv 1 - 4m^2/\hat{s}$. The effects of the soft-gluon emission are taken into account to all orders in perturbation theory by performing resummation of the threshold logarithms.

Here we review calculations of the resummed total cross sections for the squark and gluino hadroproduction presented in [4, 5, 6]. The LO Coulomb corrections to $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production have been resummed in [5]. Recently, a general formalism allowing for simultaneous resummation of threshold and Coulomb corrections has been presented and applied to $\tilde{q}\bar{\tilde{q}}$ production [7].

2. NLL threshold resummation

The resummation of threshold logarithms is performed in the space of Mellin moments N, taken at the partonic level with respect to the variable $\rho \equiv 4m^2/\hat{s}$. For the partonic processes $ij \to kl$ with massive final states k, l and all four particles carrying colour, the resummed cross section in N-space reads, up to next-to-leading-logarithmic (NLL) accuracy [8, 9, 10, 11, 12, 13],

$$\sigma^{\rm (res)}_{ij\to kl}(N,\{m^2\}) = \sum_{i,j}\sum_{I} \tilde{\hat{\sigma}}^{(0)}_{ij\to kl,I}(N,\alpha_{\rm s}(\mu^2)) \times \Delta_i(N+1,Q^2,\mu^2)\Delta_j(N+1,Q^2,\mu^2)\Delta^{\rm (int)}_{ij\to kl,I}(N+1,Q^2,\mu^2)\,, \tag{2.1}$$

where $\{m^2\}$ represents all masses entering theoretical expressions. We keep the factorization scale μ_F here equal to renormalization scale $\mu_R^2 = \mu_F^2 = \mu$. The sums in (2.1) are over the contributions given by various initial-state partons i, j (gluons and quark flavours) and contributions from different colour states I, considered in the s-channel. The functions $\Delta_i(N+1,Q^2,\mu^2)$ resumming the collinear or soft and collinear radiation from the incoming partons are universal and their form can be found e.g. in [5]. The new elements which have to be calculated in order to obtain the resummed predictions from (2.1) are the contributions to the LO partonic cross-section in N-space from the colour exchange channel I, $\tilde{\hat{\sigma}}^{(0)}_{ij\to kl,I}(N,\alpha_s(\mu^2))$, and the soft function $\Delta^{(\rm int)}_{ij\to kl,I}(N+1,Q^2,\mu^2)$ describing large angle-soft gluon emission. The soft function depends on the colour configuration of all four particles participating in the reaction $ij \to kl$ and is given by

$$\ln\Delta^{(\rm int)}_{ij\to kl,I,N} = \int_0^1 dz \frac{z^{N-1}-1}{1-z} D_{ij\to kl,I}(\alpha_s(4m^2(1-z)^2)).$$

The coefficients $D_{ij\to kl,I}$ are related to the threshold limit $\beta \to 0$ of the one-loop anomalous dimension matrices $\Gamma_{ij\to kl}$, calculated in the s-channel orthogonal colour basis. In this limit, the matrices become diagonal and each diagonal element $\Gamma_{ij\to kl,II}$ contributes to the corresponding $D_{ij\to kl,I}$ coefficient. The expressions for $\Gamma_{ij\to kl}$ in the case $kl = \tilde{q}\bar{\tilde{q}}$ can be found in [11], $kl = \tilde{g}\tilde{g}$ in [4, 5] and $kl = \tilde{q}\tilde{q}, \tilde{q}\tilde{g}$ in [6]. The corresponding expressions for the LO N-space colour contributions and the $D_{ij\to kl,I}$ coefficients have been calculated in [4, 5] and in [6] for the $\tilde{q}\bar{\tilde{q}}$, $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{q}$,$\tilde{q}\tilde{g}$ production, respectively.

3. Numerical results

In this analysis we consider production of any squark flavour apart from top squarks. Left- and right-handed squarks are assumed to be mass degenerate. The most accurate theoretical description of the squark and gluino pair production processes is obtained through matching the NLL resummed predictions with the existing NLO results in the following way

$$\begin{aligned}\sigma^{(\rm match)}_{p\overset{(-)}{p}\to kl}(\rho,\{m^2\},\mu^2) &= \sigma^{(\rm NLO)}_{p\overset{(-)}{p}\to kl}(\rho,\{m^2\},\mu^2) \\ &+ \sum_{i,j=q,\bar{q},g} \int_{C_{\rm MP}-i\infty}^{C_{\rm MP}+i\infty} \frac{dN}{2\pi i}\, \rho^{-N}\, f^{(N+1)}_{i/p}(\mu^2)\, f^{(N+1)}_{j/\overset{(-)}{p}}(\mu^2) \\ &\times \left[\hat{\sigma}^{(\rm res)}_{ij\to kl,N}(\{m^2\},\mu^2) - \hat{\sigma}^{(\rm res)}_{ij\to kl,N}(\{m^2\},\mu^2)\,|_{\scriptscriptstyle(NLO)}\right],\end{aligned} \tag{3.1}$$

where $\hat{\sigma}^{(\rm res)}_{ij\to kl,N}\,|_{\scriptscriptstyle(NLO)}$ represents the perturbative expansion of the resummed in N-space cross section for the partonic process $ij \to kl$, $\hat{\sigma}^{(\rm res)}_{ij\to kl,N}$, truncated at NLO. The moments of the parton distribution functions (pdfs) $f_{i/h}(x,\mu^2)$ are defined in the standard way $f^{(N)}_{i/h}(\mu^2) \equiv \int_0^1 dx x^{N-1} f_{i/h}(x,\mu^2)$. The inverse Mellin transform (3.1) is evaluated numerically using a contour in the complex-N space according to the "Minimal Prescription" method developed in Ref. [14] and the NLO cross sections are evaluated using PROSPINO [15].

The NLL corrections to hadroproduction of squarks and gluinos are positive and lead to higher predictions for the total cross sections compared to the NLO results. In general, we observe that the most significant effects arise for processes characterised by high contributions from gluon initial states and the presence of gluinos in the final states. This is to be expected due to high colour charge, and correspondingly, values of the Casimir invariants, which are involved. At the LHC, the effect of the soft gluon corrections is the most prominent for the gluino-pair production and can reach up to 16% at $m_{\tilde{g}} = 2$ TeV, see Fig. 1a, and up to 35% at $m_{\tilde{g}} = 3$ TeV. In the range of the sparticle masses considered here, the distance from the threshold is on avarage smaller for the processes at

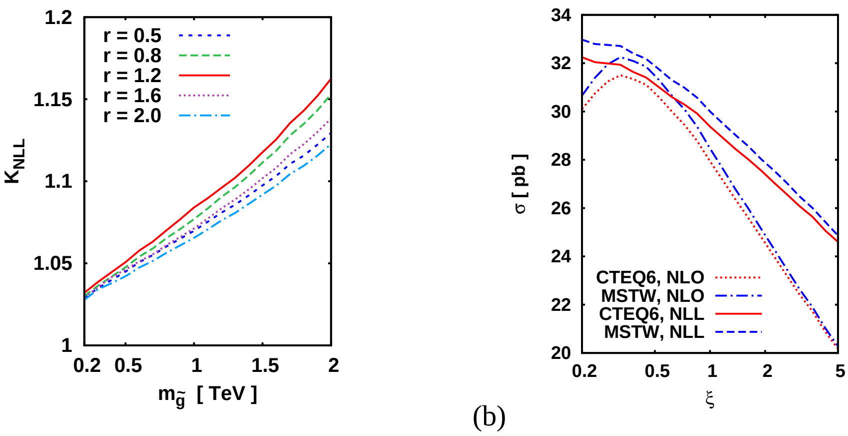

Figure 1: (a) The K factor, $K_{NLL} = \sigma^{(\text{match})}/\sigma^{(\text{NLO})}$ for $\tilde{g}\tilde{g}$ production at the LHC as a function gluino mass $m_{\tilde{g}}$ for different ratios $r = m_{\tilde{g}}/m_{\tilde{q}}$. (b) The dependence of the matched NLL and NLO total cross sections on $\xi = \mu/m_{\tilde{g}}$ for $\tilde{g}\tilde{g}$ production at the LHC with $m_{\tilde{g}} = 500$ GeV.

the Tevatron than at the LHC, leading to higher soft gluon corrections. Since the partonic processes involving quark initial states are in general more important at the Tevatron than at the LHC, the $\tilde{q}\tilde{g}$ production receives the largest soft gluon correction, which can be close to 40% for the average sparticle mass of 500 GeV. For all processes, the NLL resummed results, matched with the NLO predictions show reduced factorization and renormalization scale dependance in comparison with the NLO predictions, as illustrated in Fig. 1b for the $\tilde{g}\tilde{g}$ production at the LHC with $m_{\tilde{g}} = 500$ GeV.

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