Phenomenology of gluino pair production at the LHC

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Gluino pair production at the LHC

Current exclusion limits on SUSY particles are based on the **inclusive hadronic production cross sections**. At the partonic level we know:

- Cross section at NLO (fixed order) [Beenakker, Hopker, Spira, Zerwas, 1997]
- Threshold limit with resummed threshold logarithms to NLL accuracy [Kulesza, Montyka, 2008,2009]
- Bound-state effects at LO and NLO [Hagiwara,Yokaja,2009] [Kauth, Kühn, Marquard, Steinhauser, 2011]

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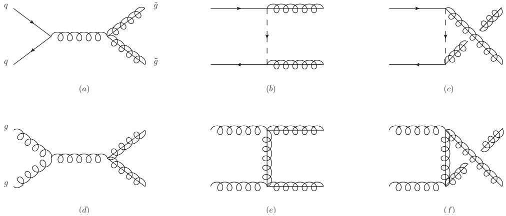
recent improvements:

- Combined soft and Coulomb resummation at NLL [Falgari, Schwinn, Wever, 2012]
- Resummation of threshold logarithms to NNLL accuracy / approximated NNLO fixed order cross section [Langenfeld, Moch, TP, 2012]
- Extended discussion of finite-width effects in the presence of NLL resummation [Falgari, Schwinn, Wever, 2012]

Kinematics

$$\rho = \frac{4m_{\tilde{g}}^2}{\hat{s}}\,, \qquad \beta = \sqrt{1-\rho}\,, \qquad r = \frac{m_{\tilde{q}}^2}{m_{\tilde{g}}^2}$$

- Simplifying assumption: mass degeneracy among the squarks
- Threshold limit: $\beta \to 0$
- LO Feynmangraphs:



At NLO, there is also gq channel, which is suppressed compared to the gg and $q\bar{q}$ channel near the threshold.

Partonic NLO cross section at the threshold

• Born cross section factores out

• **Soft and colinear gluon radiation** gives rise to **threshold enhanced logarithms** $\ln^k(\beta)$

• **Soft-gluon exchange** between the **final-state particles** gives rise to **Coulomb corrections** $1/\beta^l$

- NLO: $k \leq 2\,,\quad l = 1$
- NNLO: $k \leq 4\,,\quad l \leq 2$

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Consider production channel ij near the threshold:

$$\sigma_{ij}^{\rm NLO}(\mu = m_{\tilde{g}}) = \sigma_{ij}^{\rm Born}\left(1 + \alpha_s\left[A_{ij}\ln^2(\beta) + B_{ij}\ln(\beta) + \frac{C_{ij}}{\beta} + C_1^{ij} + \mathcal{O}(\beta)\right]\right)$$

- The $\mathcal{O}(\beta)$-terms are neglected near the threshold, however

$$\beta \ll 1 \qquad \Rightarrow \qquad \alpha_s\ln(\beta) \approx 1 \qquad \frac{\alpha_s}{\beta} \approx 1$$

Threshold resummation

Threshold logarithms can be resummed to all orders in perturbation theory. This can be done in **Mellin space** for instance [Sterman 1987; Catani, Trentadue, 1989]

$$\hat{\sigma}(N, m_{\tilde{g}}^2) = \int_0^1 d\rho\, \rho^{N-1}\, \hat{\sigma}(\hat{s}, m_{\tilde{g}}^2)\,, \qquad \hat{\sigma}_{ij\to\tilde{g}\tilde{g}} = \sum_{\mathbf{I}} \hat{\sigma}_{ij,\mathbf{I}}$$

- The threshold limit $\beta \to 0$ corresponds to $N \to \infty$.
- The resummation requires a decomposition of the amplitude into all possible $SU(3)$ color configurations $\mathbf{I}$ of the final-state gluino pair.

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Neglecting Coulomb terms, the general resummation formula reads:

$$\boxed{\hat{\sigma}_{ij,\mathbf{I}}(N, m_{\tilde{g}}^2) = \hat{\sigma}^B_{ij,\mathbf{I}}(N, m_{\tilde{g}}^2)\; g^0_{ij,\mathbf{I}}(m_{\tilde{g}}^2)\; \exp\Big[G_{ij,\mathbf{I}}(N+1)\Big] + \mathcal{O}(N^{-1} \ln^n N)}$$

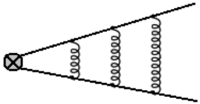
$$G_{ij,\mathbf{I}}(N) = \underbrace{\ln(N) \cdot g^1_{ij}(\lambda)}_{\text{LL}} + \underbrace{g^2_{ij,\mathbf{I}}(\lambda)}_{\text{NLL}} + \underbrace{a_s\, g^3_{ij,\mathbf{I}}(\lambda)}_{\text{NNLL}} + \dots\,, \qquad \lambda = \frac{\alpha_s}{4\pi}\beta_0 \ln N$$

Coulomb corrections

• Coulomb corrections **can not be summed in Mellin-space** and have to be **included at fixed order**:

⇒ The matching constant in the resummation formula depends on N:
$g^{0}_{ij,\text{I}}(m^2_{\tilde{g}}) \to g^{0}_{ij,\text{I}}(N, m^2_{\tilde{g}})$

• Pure Coulomb corrections can be summed in momentum (β)-space to all orders by means of NRQCD ($\to$ Sommerfeld factor). [Fadin, Khoze,Sjostrand, 1990]



• Starting from NNLO, there is also **interference of soft and Coulomb corrections**. $\to$ Combined soft and Coulomb resummation required.
[Beneke, Falgari, Schwinn, 2010; 2011]

• At NNLO the non-relativistic potential also exhibits further spin-dependent contributions $\propto \ln(\beta)$. [Beneke, Czakon, Falgari, Mitov, Schwinn, 2009]

Approximated NNLO cross section

The following **fixed order NNLO** pieces are known:

• All **scale-dependent corrections**, which depend on $\ln\left(\mu_r^2/m_{\tilde{g}}^2\right)$, can be calculated exactly by means of renormalization-group methods.

[van Neerven, A. Vogt, 2000; Kidonakis, Laenen, Moch, R. Vogt, 2001]

• All contributions arising from the non-relativistic Coulomb potential and their interference with soft corrections are known for arbitrary color representations.

[Beneke, Czakon, Falgari, Mitov, Schwinn, 2009]

If the NLO cross section is known in color-decomposed form, one can **construct all threshold-enhanced logarithms at NNLO by expanding the resummation formula** to $\mathcal{O}(\alpha_s^2)$.

→ The color-decomposed fixed order NLO cross section at the threshold (including all constant terms) has been presented for gluinonium production.

[Kauth, Kühn, Marquard, Steinhauser, 2011]

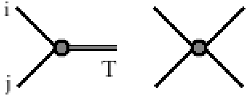
→ Construct the color-decomposed cross section for gluino pair production from the latter result!

Approximated NNLO cross section

General color-decomposed threshold formula (color index **I**):

$$\sigma^{\mathrm{NLO}}_{ij,\mathbf{I}} = \sigma^{\mathrm{Born}}_{ij,\mathbf{I}} \left(1 + \alpha_s \left[\underbrace{A_{ij} \ln^2(\beta) + (B^1_{ij} + B^2_{ij,\mathbf{I}}) \ln(\beta) + \frac{C_{ij,\mathbf{I}}}{\beta} + C^{ij}_{1,\mathbf{I}}}_{\text{independent of kinematics}} + \mathcal{O}(\beta) \right] \right)$$

- Only the Born term and the neglected $\mathcal{O}(\beta)$-terms distinguish between bound-state production and pair production!



$\rightarrow$ Take result from bound-state production and replace the Born term.

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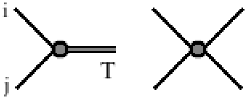

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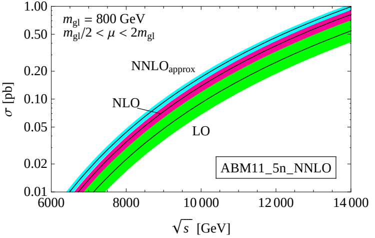
In summary we have all information to write down the **full threshold-enhanced part of the NNLO cross section** [Langenfeld, Moch, TP, 2012]

Def.: $\sigma_{\mathrm{approx}}^{\mathrm{NNLO}} = \sigma_{\mathrm{exact}}^{(\mathrm{LO})} + \sigma_{\mathrm{exact}}^{(\mathrm{NLO})} + \sigma_{\mathrm{th.enh.}}^{(\mathrm{NNLO})}$

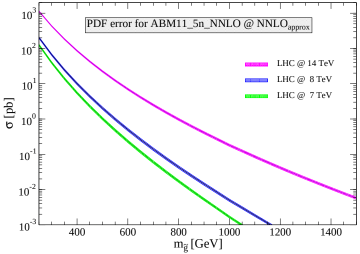
(The exact NLO part can be computed with PROSPINO)

Hadronic cross section

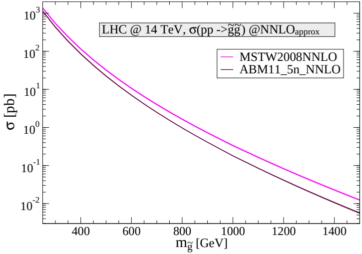
hadronic cross section as a function of the hadronic cms energy $\sqrt{s}$

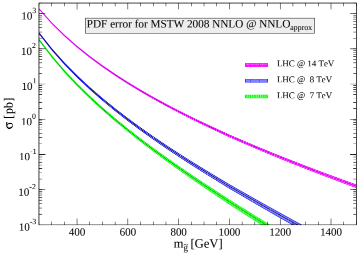


PDF errors:



Comparison of MSTW and ABM11 PDF sets as a function of $m_{\tilde{g}}$





Hadronic cross section

Example for $m_{\tilde{g}} = 800\,\text{GeV}$, $\sqrt{s} = 7\,\text{TeV}$:

gg-channel: $\approx$ 99%
$q\bar{q}$-channel: $\approx$ 1%
gq-channel: $\approx$ 1% (negative contribution)

2 reasons for the dominance of the **gluon-fusion channel**:

- partonic cross section: $\hat{\sigma}_{gg}/\hat{\sigma}_{q\bar{q}} = \mathcal{O}(10)$
- dominance of gluon- over quark PDFs at high energies

$\Rightarrow$ The cross section is more or less **independent of the choice of** $m_{\tilde{q}}$ because

- $\hat{\sigma}_{gg}^{\mathrm{Born}}$ does not depend on $m_{\tilde{q}}$ at all.
- at NLO, only constant and β-suppressed terms are affected.

NNLO threshold contribution:

threshold logs	soft/Coulomb terms	spin-dependent
$\mathcal{O}(70\%)$	$\mathcal{O}(25\%)$	$\mathcal{O}(5\%)$

• Effects of joined soft and Coulomb NLL resummation including corrections due to a finite gluino width: $\rightarrow$ Talk of Christian Schwinn

Summary

- We have derived analytic results for the color-decomposed NLO and approximated NNLO cross section of gluino-pair production near the threshold.
- The resummation of threshold logarithms has been performed in Mellin space to NNLL accuracy. Alternatively, one could resum in β-space [Becher, Neubert, 2006], where general results for a combined soft- and Coulomb resummation are given in the literature. [Beneke, Falgari, Schwinn, 2010]
- The resummation formula has been used to derive the approximated NNLO cross section at fixed order.
- At the scale $\mu = m_{\tilde{g}}$, the approximated NNLO cross section increases the NLO result of about $15 - 20\%$.The results are rather stable in the range $\mu \in [\frac{1}{2} m_{\tilde{g}}, 2m_{\tilde{g}}]$.
- Concerning the inclusive production cross section, bound-state effects play a minor role, thus the fixed order NNLO approximation provides a good improvement, which is easy to implement.
- The dominant source of uncertainty comes from the non-perturbative input. This should be kept in mind in forthcoming investigations.

Thank you for your attention!