Soft gluon resummation for squark and gluino pair production at hadron colliders

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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

AK and L. Motyka, Phys. Rev. Let. **102**, 111802 (2009)

AK and L. Motyka, arXiv:0905.4749 [hep-ph], to appear in Phys. Rev. D

W. Beenakker, S. Brensing, M. Krämer, AK, E. Laenen and I. Niessen, arXiv:0909.4418 [hep-ph]

RADCOR 2009, 25-30 October 2009, Ascona, Switzerland

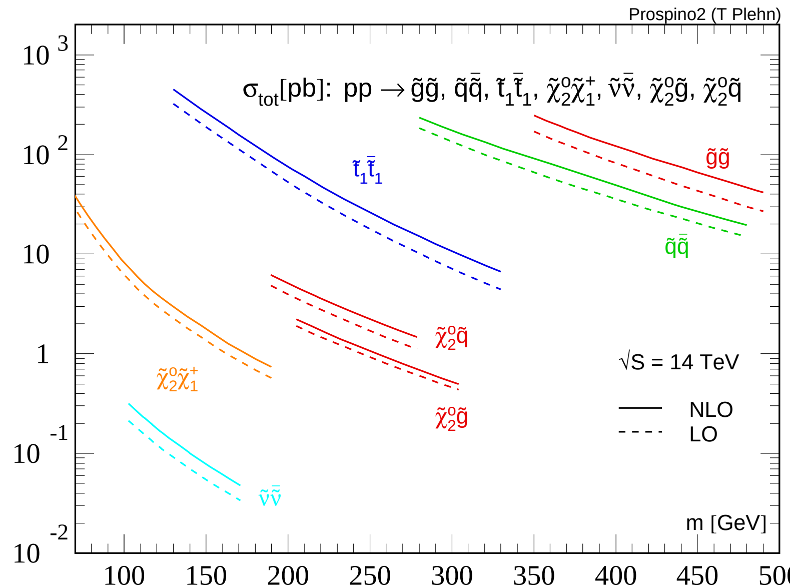
Overview

- Motivation
  - Importance of squark and gluino pair production processes at hadron colliders
- Threshold resummation of soft gluon correction
  - The role of soft gluon effects
  - One-loop soft anomalous dimensions
- Numerical predictions for the resummed total cross sections for stop, squark and gluino pair production at the LHC and the Tevatron
- Conclusions

SUSY particle pair-production at the LHC

- MSSM: minimal content of SUSY particles + $R-$parity conservation
- At the LHC coloured sparticle production dominates

$$pp \to \tilde{t}_i\bar{\tilde{t}}_i,\ \tilde{q}\bar{\tilde{q}},\ \tilde{q}\tilde{q},\ \tilde{q}\tilde{g},\ \tilde{g}\tilde{g}$$

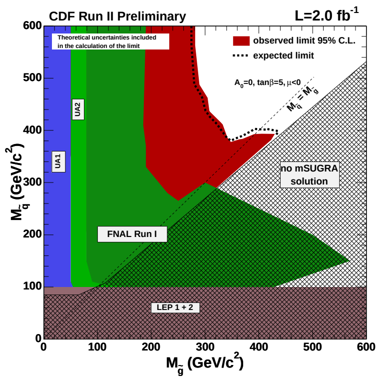


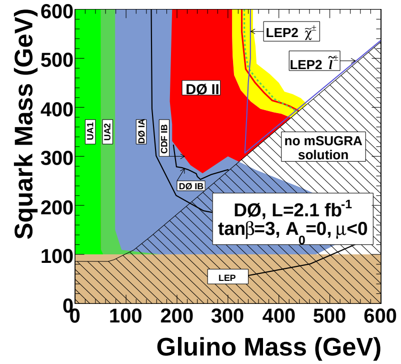
[*Plehn, Prospino2*]

- Production cross sections large ⇒ "easy" SUSY discovery

Experimental searches at the Tevatron

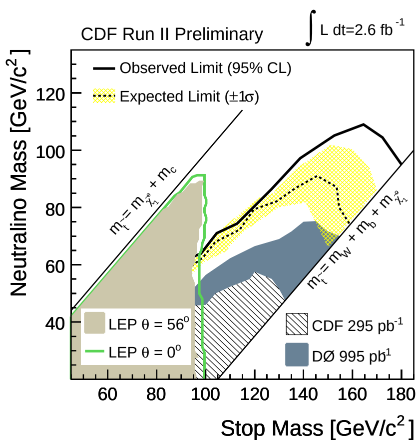
- Limits on squark and gluino masses





CDF [*PRL 102, 121801 (2009)*] D0 [*Phys. Lett. B 660, 449 (2008)*]

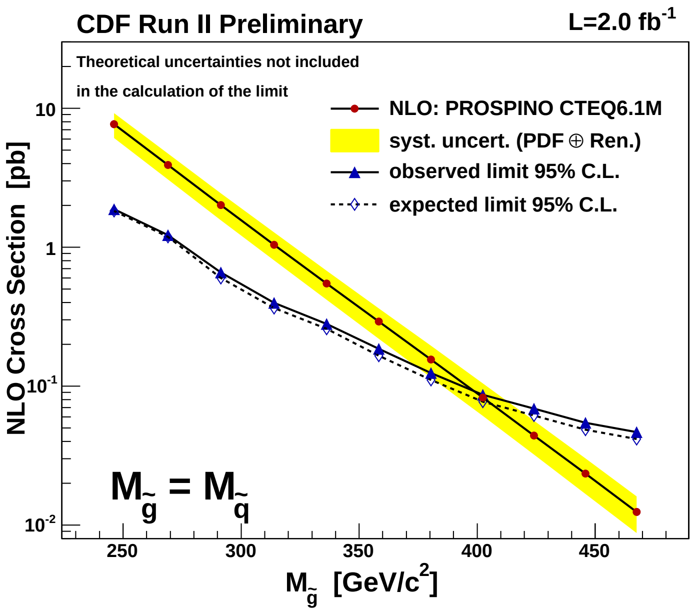
- Limits on stop masses, e.g. from $\tilde{t}_1 \to c\tilde{\chi}^0$



[*CDF Note 9834*]

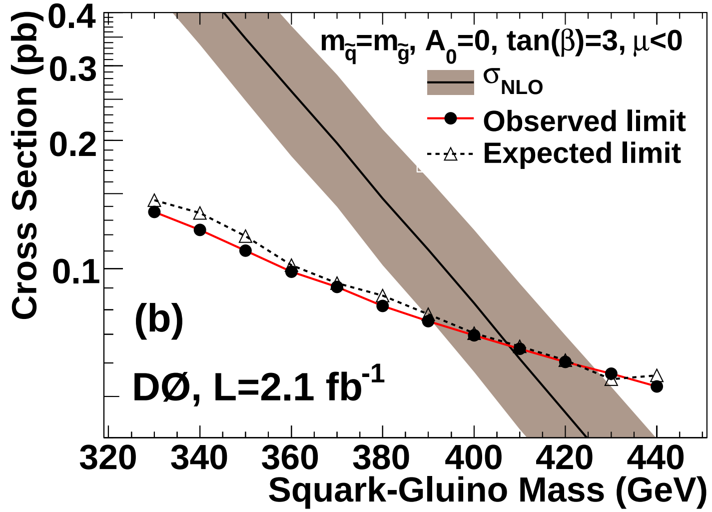
Total cross sections

[*PRL 102, 121801 (2009)*]



$(A_0 = 0, sgn(\mu) = -1, \tan\beta = 5)$

[*Phys. Lett. B 660, 449 (2008)*]



Total cross sections: crucial for determination of exclusion limits

Theoretical status

- Leading order = $\mathcal{O}(\alpha_s^2)$ [*Kane, Leveille'82*][*Harrison, Llewellyn Smith'84*][*Dawson, Eichten, Quigg'85*]
- Fixed-order corrections to $\mathcal{O}(\alpha_s^2)$ processes
  - NLO SUSY-QCD corrections $\longrightarrow \mathcal{O}(\alpha_s^3)$ [*Beenakker, Höpker, Spira, Zerwas'96*]
    - For $\tilde{q}\bar{\tilde{q}}$ production: dominant NNLO contributions (NNLL-NNLO, Coulomb, scale dependence) $\longrightarrow \mathcal{O}(\alpha_s^4)$ [*Langenfeld, Moch'09*]
  - EW corrections $\longrightarrow \mathcal{O}(\alpha_s^2\alpha)$ [*Hollik, Kollar, Trenkel'07*][*Hollik, Mirabella'08*][*Hollik, Mirabella, Trenkel'08*][*Beccaria et al.'08*][*Mirabella'09*][*Germer et al.'09*]

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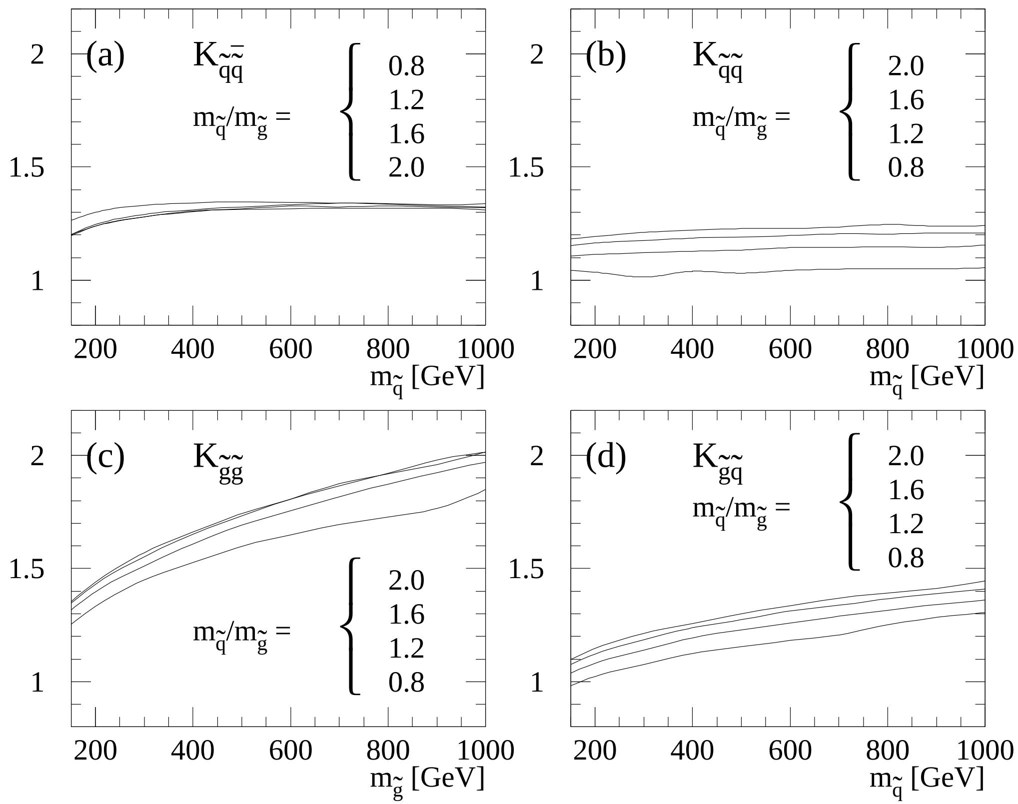
- Tree-level EW effects of $\mathcal{O}(\alpha\alpha_s)$ and $\mathcal{O}(\alpha^2)$
  - QCD-EW interference and photon-induced contributions, tree-level EW [*Bornhauser et al.'07*] [*Alan, Cankocak, Demir'07*][*Hollik, Kollar, Trenkel'07*][*Hollik, Mirabella'08*][*Hollik, Mirabella, Trenkel'08*][*Bozzi, Fuks, Klasen'05*][*Germer et al.'09*]
- Bound-state effects in $\tilde{g}\tilde{g}$ production (NLO QCD potential) [*Hagiwara, Yokoya'09*], gluinonia production and decay (NLO) and energy levels (NNLO QCD potential) [*Kauth, Kühn, Marquard, Steinhauser'09*]

Coloured sparticle production at NLO (SUSY-QCD)

[*Beenakker, Höpker, Spira, Zerwas'96*][*Beenakker, Krämer, Plehn, Spira, Zerwas'98*]

LHC

$$K_{ij} = \sigma_{ij}^{\mathrm{NLO}} / \sigma_{ij}^{\mathrm{LO}}$$



$\Rightarrow$ Significant NLO SUSY-QCD corrections (can be $\sim 100\%$!)

All squarks ($\tilde{q}_L$,$\tilde{q}_R$) mass degenerate apart from stops $\tilde{t}_1$, $\tilde{t}_2$

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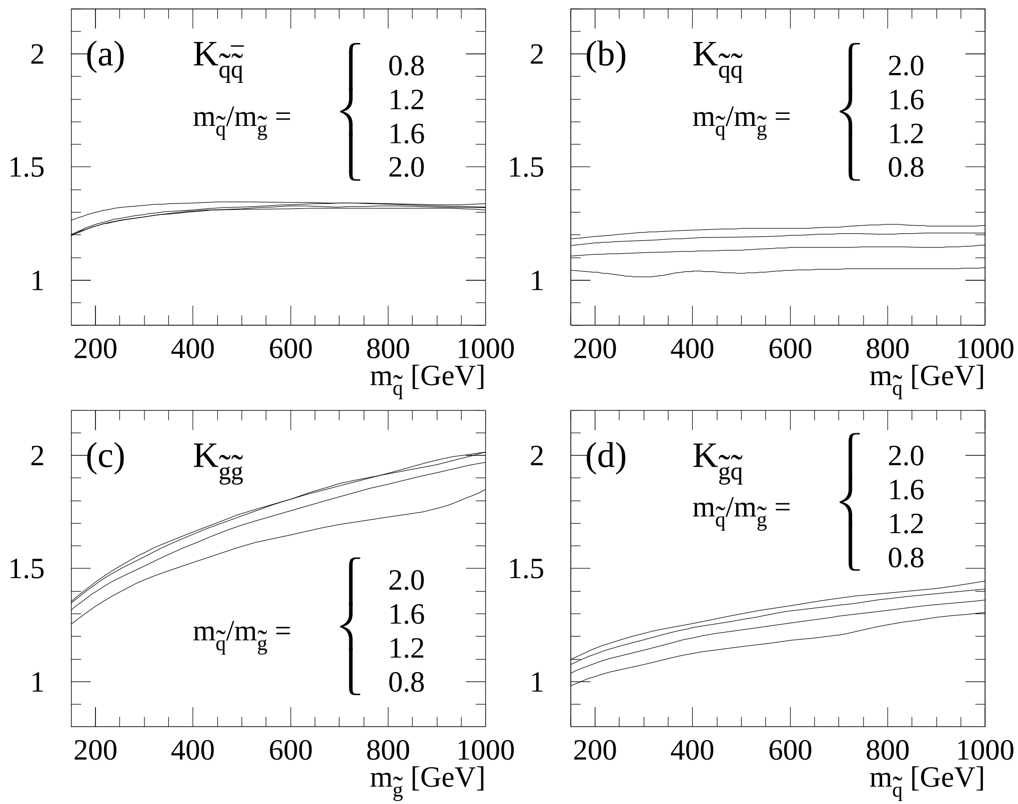

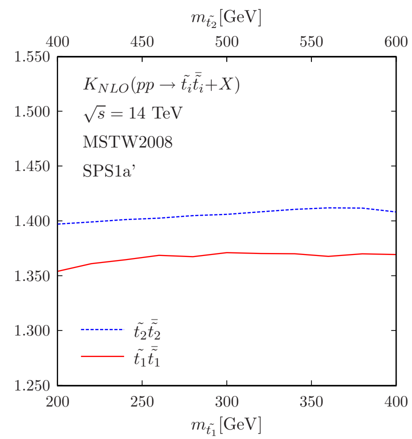

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Higher-order soft gluon effects

- Large masses of squarks and gluons
  $\Rightarrow$ often production close to threshold $\hat{s} \sim 4m^2$ ($m = \frac{m_{\tilde{q}} + m_{\tilde{g}}}{2}$ for $\tilde{q}\tilde{g}$ production)

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- NLO: threshold limit $\beta \to 0$, $\beta^2 \equiv 1 - \frac{4m^2}{\hat{s}}$ of the contribution to $\tilde{g}\tilde{g}$ production from the gg channel [*Beenakker, Höpker, Spira, Zerwas'96*]

$$\Delta\hat{\sigma}^{\mathrm{NLO}}_{gg\to\tilde{g}\tilde{g}} \sim 4\pi\alpha_{\mathrm{s}}\hat{\sigma}^{\mathrm{LO}}_{gg\to\tilde{g}\tilde{g}}\left\{\frac{3}{2\pi^2}\log^2(8\beta^2)-\frac{29}{4\pi^2}\log(8\beta^2)-\frac{3}{2\pi^2}\log(8\beta^2)\log\left(\frac{\mu}{m_{\tilde{g}}}\right)+\frac{1}{16}\frac{1}{\beta}\right\}$$

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- Soft/collinear gluon emission

  $\alpha_{\rm s}\log^2(\beta^2),\ \alpha_{\rm s}\log^2(\beta^2)$

- Exchange of Coulomb gluons

  $\alpha_{\rm s}/\beta$

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- Exchange of Coulomb gluons

  $\alpha_{\rm s}/\beta$

- Both types of corrections can be resummed to all-orders

Here: NLL resummation of soft gluon corrections

- LO Coulomb corrections $\alpha_{\rm s}^n/\beta^n$ resummed for $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production [AK, Motyka'09]
- boundstate corrections (Green's function) for $\tilde{g}\tilde{g}$ [Hagiwara, Yokoya'09]
- Resummation of soft and Coulomb corections together [Beneke, Falgari, Schwinn'09]

Threshold resummation

Resummation of soft gluon corrections performed in the space of Mellin moments N taken wrt. $\rho \equiv \frac{4m^2}{S}$ [Sterman'87][Catani,Trentadue'89]

$$\sigma^{(N)}_{h_1 h_2 \to kl}(\{m^2\}) = \sum_{i,j} f^{(N+1)}_{i/h_1}(\mu^2) f^{(N+1)}_{j/h_2}(\mu^2) \hat{\sigma}^{(N)}_{ij}(\{m^2\}, \mu^2)$$

with

$$\hat{\sigma}^{(N)}_{ij \to kl}(\{m^2\}, \mu^2) = \int_0^1 d\hat{\rho}\, \hat{\rho}^{N-1}\, \hat{\sigma}_{ij \to kl}(\hat{\rho}, \{m^2\}, \mu^2)$$

$$\hat{\rho} = \frac{4m^2}{\hat{s}} = 1 - \beta^2 \qquad \log(1-\hat{\rho}) = \log(\beta^2) \longleftrightarrow \log(N)$$

The logarithmic terms exponentiate

$$\hat{\sigma}^{(N)} = \hat{\sigma}^{(N)}_0 \mathcal{C} \exp(\mathcal{S})$$

($\mathcal{C}$ contains finite contributions)

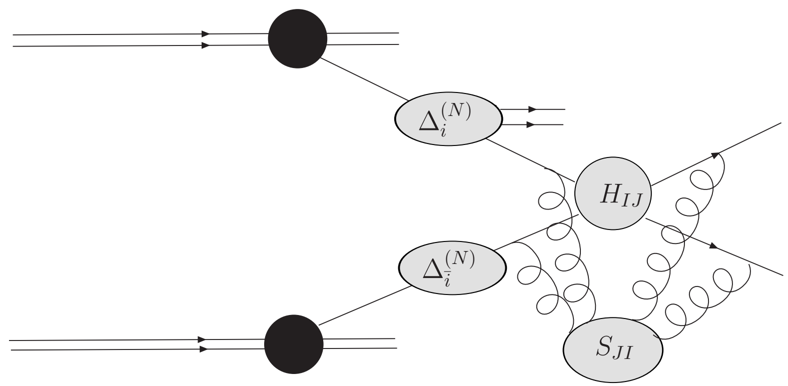
$$\mathcal{S} = L f_1(\alpha_s L) + f_2(\alpha_s L) + \alpha_s f_3(\alpha_s L) + \ldots \qquad L = \log(N)$$

$$LL \qquad NLL \qquad NNLL \qquad \ldots$$

Resummation for $2 \to 2$ with colour and masses

$2 \longrightarrow 2$ with colour flow and massive final state particles

[Kidonakis, Sterman'96-97][Kidonakis, Oderda, Sterman'98][Bonciani et al.'03]



$$\hat{\sigma}^{(\mathrm{res},N)}_{ij\to kl} = \underbrace{H^{(N)}_{ij\to kl,IJ}} \times \underbrace{\Delta_i^{(N)}\Delta_j^{(N)}} \times \underbrace{S^{(N)}_{ij\to kl,JI}}$$

hard function — soft-collinear radiation — soft wide-angle emission

process-dependent — universal factors; KNOWN — process-dependent

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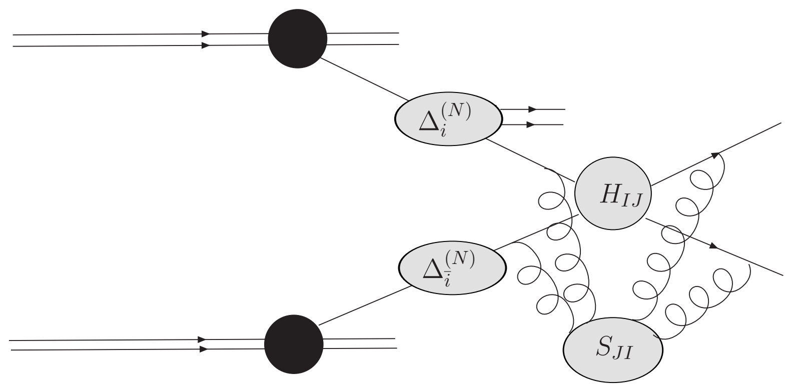

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$$\Delta_i^{(N)} = \exp\left\{\int_0^1 dz\,\frac{z^{N-1}-1}{1-z}\int_{\mu_F^2}^{(1-z)^2Q^2}\frac{d\mu^2}{\mu^2}A_i(\alpha_s(\mu^2))\right\}$$

$A_i = \sum_k \left(\frac{\alpha_s}{\pi}\right)^k A_i^{(k)}$ $\longrightarrow A_i^{(1)}, A_i^{(2)}$ coefficients at NLL [Kodaira,Trentadue'82] [Catani, d'Emilio,Trentadue'88]

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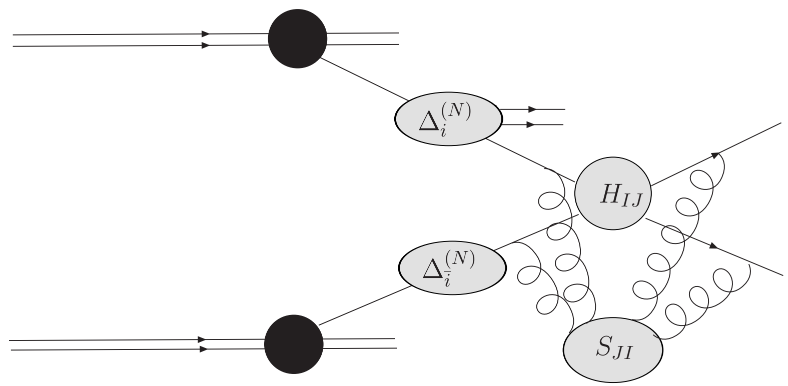

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The soft function S given by a solution of renormalization group equation

$$\left(\mu\frac{\partial}{\partial\mu} + \beta(g)\frac{\partial}{\partial g}\right) S^{(N)}_{JI} = -\Gamma^{\dagger}_{JK} S^{(N)}_{KI} - S^{(N)}_{JL}\Gamma_{LI}$$

$\longrightarrow$ soft anomalous dimension matrices Γ to be calculated

Soft anomalous dimensions

- Need 1-loop anomalous dimension matrices in order to resum up to NLL
  - massless $2 \to n$ QCD processes [*Kidonakis, Oderda, Sterman'98*][*Bonciani et al.'03*][*Mert Aybat, Dixon, Sterman'06*]
  - massive case: heavy quark $Q\bar{Q}$ production [*Kidonakis, Sterman'96*][*Bonciani et al.'98*]
- Calculation of 1-loop soft anomalous dimension matrices Γ_{IJ} for $2 \to 2$ processes with nontrivial colour structure and massive particles in the final state

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$$
\begin{array}{llcc}
\tilde{q}\bar{\tilde{q}} & \mathbf{3} \otimes \bar{\mathbf{3}} & = & \mathbf{1} \oplus \mathbf{8} \\
\tilde{q}\tilde{q} & \mathbf{3} \otimes \mathbf{3} & = & \bar{\mathbf{3}} \oplus \mathbf{6} \\
\tilde{q}\tilde{g} & \mathbf{3} \otimes \mathbf{8} & = & \mathbf{3} \oplus \bar{\mathbf{6}} \oplus \mathbf{15} \\
\tilde{g}\tilde{g} & \mathbf{8} \otimes \mathbf{8} & = & \mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{27}
\end{array}
$$

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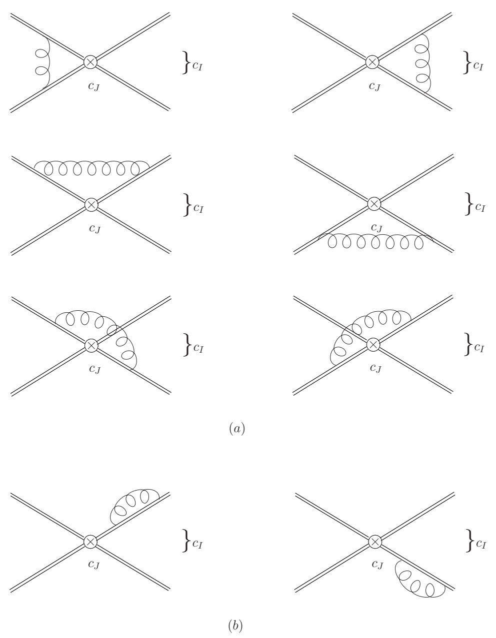

- $\Gamma(g) = -\frac{g}{2}\frac{\partial}{\partial g}\mathrm{Res}_{\epsilon\to 0} Z(g,\epsilon)$
  Z = renormalization constant for S
- one-loop integrals in the eikonal approximation
  $\longrightarrow$ equal masses [Kidonakis, Sterman'96]
  $\longrightarrow$ unequal masses ($\tilde{q}\tilde{g}$) [Beenakker, Brensing, Krämer, AK, Laenen, Niessen'09]
  combined with appropriate colour structures
  $\Rightarrow$ one-loop Γ_{IJ} for $\tilde{q}\bar{\tilde{q}}$, $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$, $\tilde{g}\tilde{g}$

Resummation for $2 \to 2$ with colour and masses (II)

Threshold limit $\beta \to 0$

- Γ_{IJ} matrices calculated in the s-channel colour basis become diagonal
  $\longrightarrow$ to all orders: [*Beneke, Falgari, Schwinn'09*]
- In orthogonal basis in colour space for which Γ_{IJ} is diagonal the resummed partonic cross section reads up to NLL [*Kidonakis, Sterman'96-97*][*Bonciani, Catani, Mangano, Nason'98*]

$$\tilde{\sigma}^{(\mathrm{res},N)}_{ij\to kl} = \sum_I \tilde{\sigma}^{(0,N)}_{ij\to kl,I}\, \Delta_i^{(N)}\, \Delta_j^{(N)}\, \Delta^{(\mathrm{soft},N)}_{ij\to kl,I}$$

$$\Delta^{(\mathrm{soft},N)}_{ij\to kl,I} = \exp\left[\int_\mu^{Q/N} \frac{dq}{q}\, \frac{\alpha_\mathrm{s}(q)}{\pi}\, D^{(1)}_{ij\to kl,I}\right], \quad D^{(1)}_{ij\to kl,I} = \lim_{\beta\to 0} \frac{\pi}{\alpha_\mathrm{s}}\, 2\,\mathrm{Re}\,(\bar{\Gamma}_{II})$$

$\longrightarrow$ I corresponds to different colour channels (singlet, octet, etc.)

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- Full set of $D^{(1)}$-coefficients for $\tilde{q}$ and $\tilde{g}$ production processes

$$\begin{array}{ll}
D^{(1)}_{q\bar{q}\to\tilde{q}\bar{\tilde{q}},\,I} = \{0,-3\} & I = \{\mathbf{1},\mathbf{8}\} \\
D^{(1)}_{gg\to\tilde{q}\bar{\tilde{q}},\,I} = \{0,-3\} & I = \{\mathbf{1},\mathbf{8}\} \\
D^{(1)}_{q\bar{q}\to\tilde{g}\tilde{g},\,I} = \{0,-3,-3\} & I = \{\mathbf{1},\mathbf{8_S},\mathbf{8_A}\} \\
D^{(1)}_{gg\to\tilde{g}\tilde{g},\,I} = \{0,-3,-3,-6,-8\} & I = \{\mathbf{1},\mathbf{8_S},\mathbf{8_A},\mathbf{10}\oplus\overline{\mathbf{10}},\mathbf{27}\} \\
D^{(1)}_{qq\to\tilde{q}\tilde{q},\,I} = \{-4/3,-10/3\} & I = \{\bar{\mathbf{3}},\mathbf{6}\} \\
D^{(1)}_{qg\to\tilde{q}\tilde{g},\,I} = \{-4/3,-10/3,-16/3\} & I = \{\mathbf{3},\bar{\mathbf{6}},\mathbf{15}\}
\end{array}$$

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- Full set of $D^{(1)}$-coefficients for $\tilde{q}$ and $\tilde{g}$ production processes
- $D^{(1)}$ correspond to values of the quadratic Casimir operators for the SU(3) representations for the outgoing state $\longrightarrow$ soft gluon radiation from the total colour charge of the heavy-particle pair produced at threshold

Resummation-improved NLL+NLO total cross section

NLL resummed expression has to be matched with the full NLO result

$$\sigma^{(\text{match})}_{h_1 h_2 \to kl}(\rho, \{m^2\}, \mu^2) = \sum_{i,j=q,\bar{q},g} \int_{C_{\text{M}P}-i\infty}^{C_{\text{M}P}+i\infty} \frac{dN}{2\pi i}\, \rho^{-N}\, f^{(N+1)}_{i/h_1}(\mu^2)\, f^{(N+1)}_{j/h_2}(\mu^2)$$

$$\times \left[\hat{\sigma}^{(\text{res},N)}_{ij\to kl}(\{m^2\}, \mu^2) - \hat{\sigma}^{(\text{res},N)}_{ij\to kl}(\{m^2\}, \mu^2)\Big|_{\text{NLO}} \right]$$

$$+ \sigma^{\text{NLO}}_{h_1 h_2 \to kl}(\rho, \{m^2\}, \mu^2)\,,$$

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$$\times \left[\hat{\sigma}^{\rm (res,N)}_{ij\to kl}(\{m^2\}, \mu^2) - \hat{\sigma}^{\rm (res,N)}_{ij\to kl}(\{m^2\}, \mu^2) \Big|_{\rm NLO} \right]$$

$$+ \sigma^{\rm NLO}_{h_1 h_2 \to kl}(\rho, \{m^2\}, \mu^2)\,,$$

- Inverse Mellin transform evaluated using a contour in the complex N space according to 'Minimal Prescription' [*Catani, Mangano, Nason Trentadue'96*]
- NLO cross sections evaluated with publicly available code PROSPINO

[*Beenakker, Hoepker, Krämer, Plehn, Spira, Zerwas*]

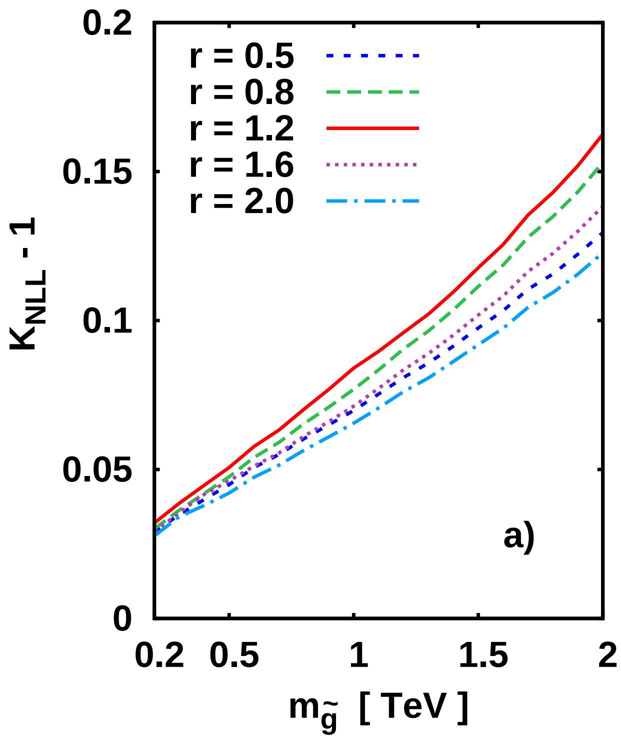
[*http://www.thphys.uni-heildelberg.de/plehn/prospino/*]

The NLL K-factors at the LHC

[*AK, Motyka'09*]

$$K^{\mathrm{NLL}} - 1 = \frac{\sigma^{\mathrm{match}} - \sigma^{\mathrm{NLO}}}{\sigma^{\mathrm{NLO}}}$$

$pp \to \tilde{g}\tilde{g} + X$



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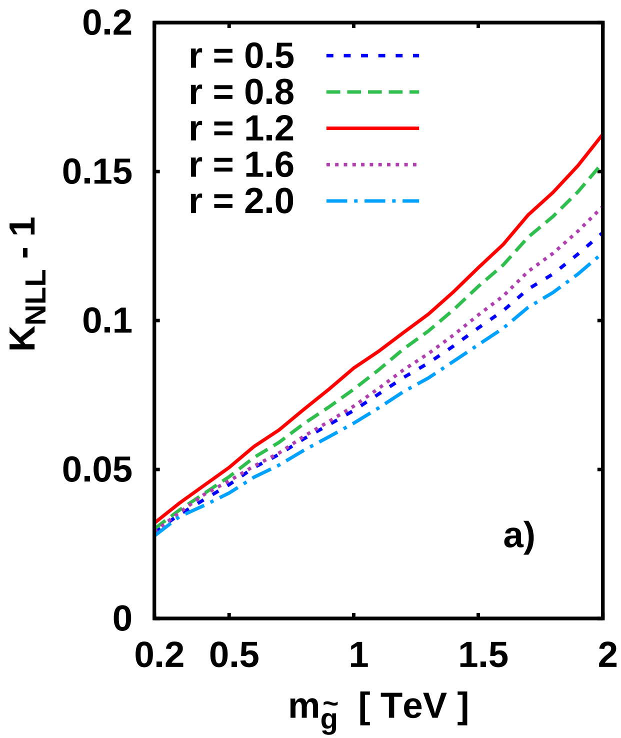

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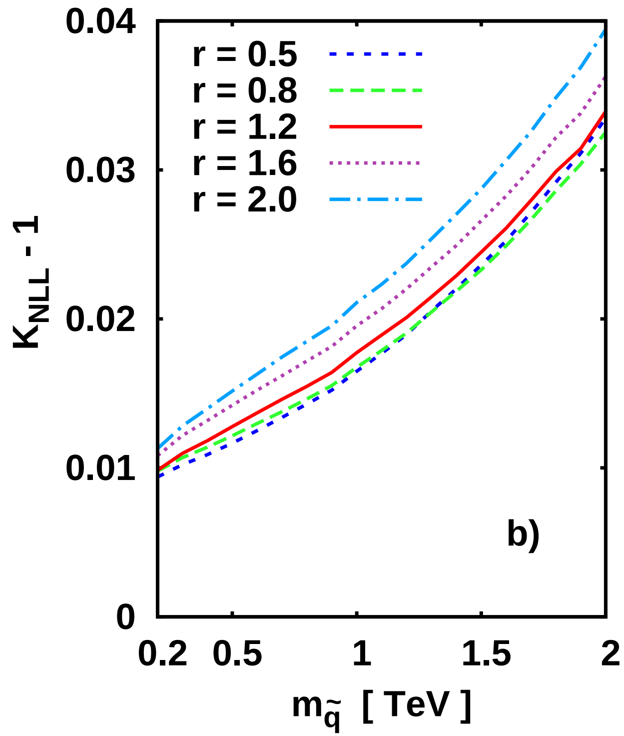
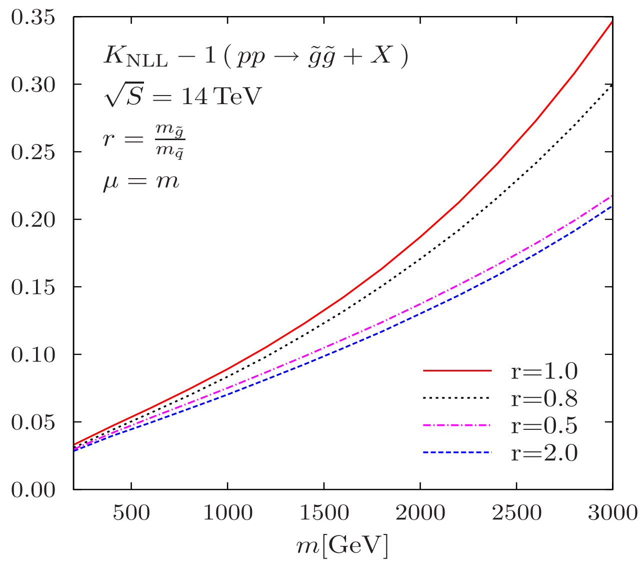


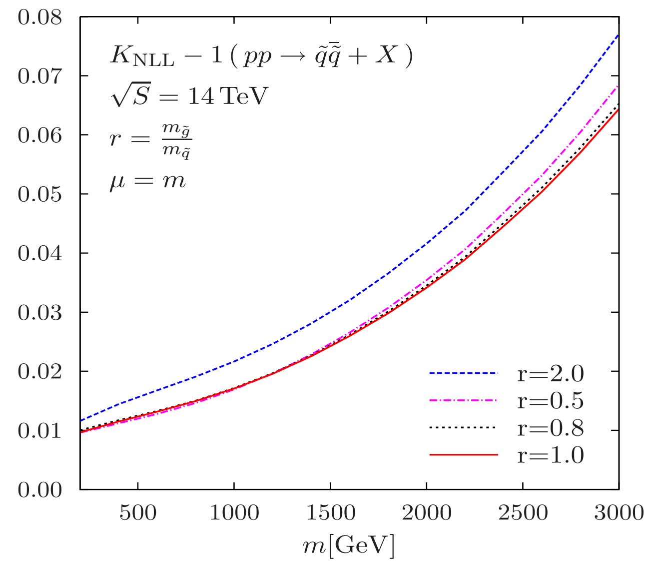
$r = \frac{m_{\tilde{g}}}{m_{\tilde{q}}}$, $\mu_F = \mu_R = m$, CTEQ6M pdfs

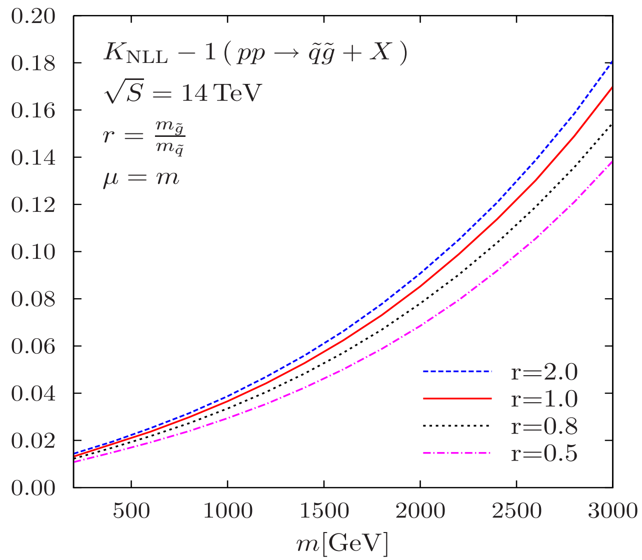
The NLL K-factors at the LHC cntd.

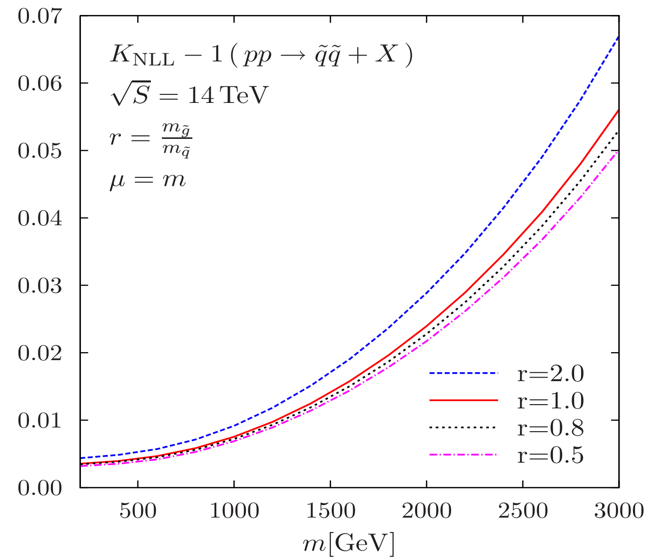
$$K_{\mathrm{NLL}} - 1 = \frac{\sigma^{\mathrm{match}} - \sigma^{\mathrm{NLO}}}{\sigma^{\mathrm{NLO}}}$$

[Beenakker, Brensing, Krämer, AK, Laenen, Niessen'09]







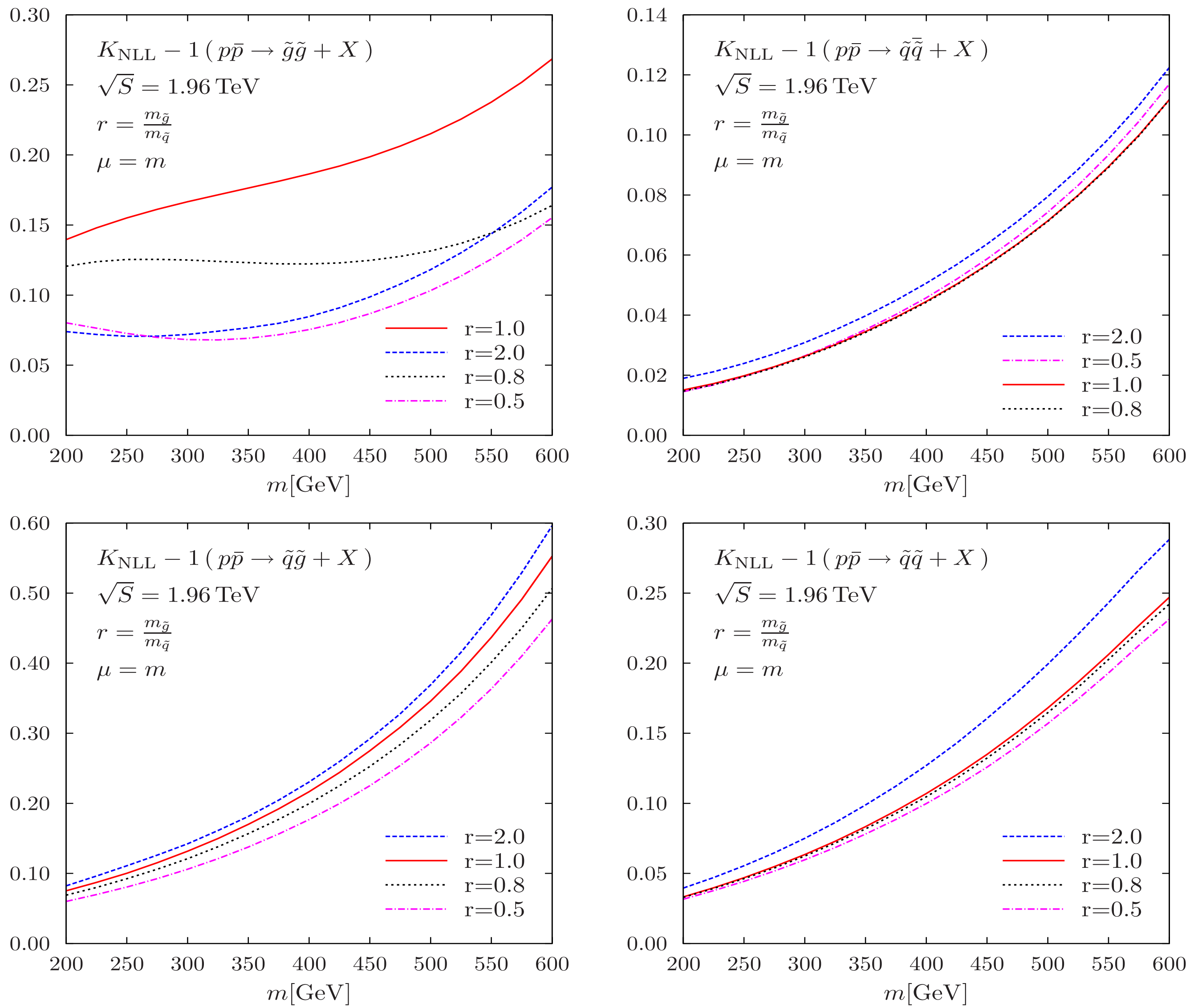


MSTW 2008

The NLL K-factors at the Tevatron

$$K_{\rm NLL} - 1 = \frac{\sigma^{\rm match} - \sigma^{\rm NLO}}{\sigma^{\rm NLO}}$$

[Beenakker, Brensing, Krämer, AK, Laenen, Niessen’09]



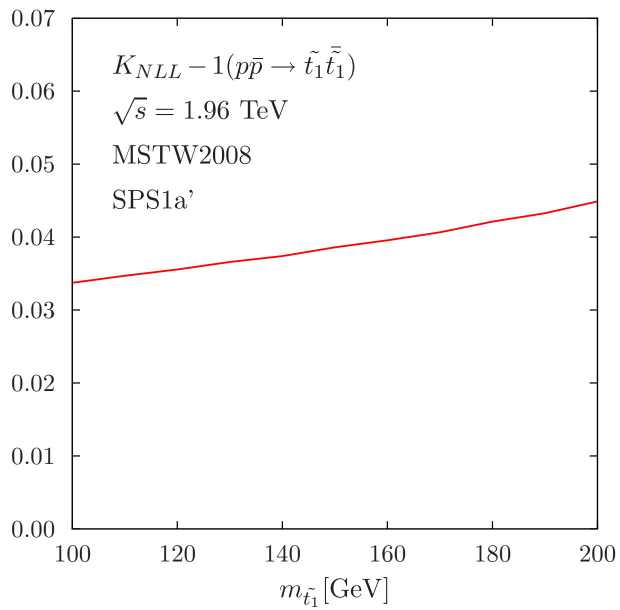
MSTW 2008

Stop production at hadron colliders

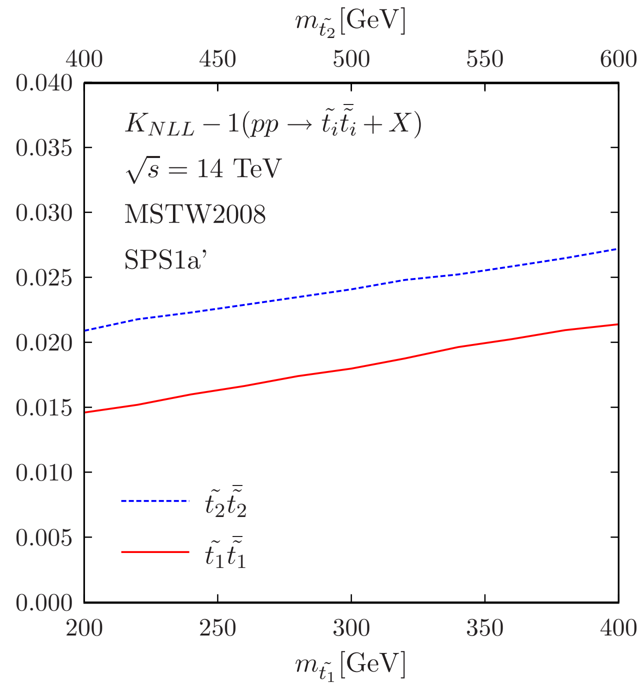
[*Beenakker, Brensing, Krämer, AK, Laenen, Niessen, in preparation*]

$$K^{NLL} - 1 = \frac{\sigma^{match} - \sigma^{NLO}}{\sigma^{NLO}}$$

Tevatron



LHC



SPS 1a' ($m_{\tilde{t}_1} = 153$ GeV, $m_{\tilde{t}_2} = 582$ GeV, $m_{\tilde{g}} = 605$ GeV, $m_{\tilde{q}} = 546$ GeV, $\sin(2\theta) = 0.926$)

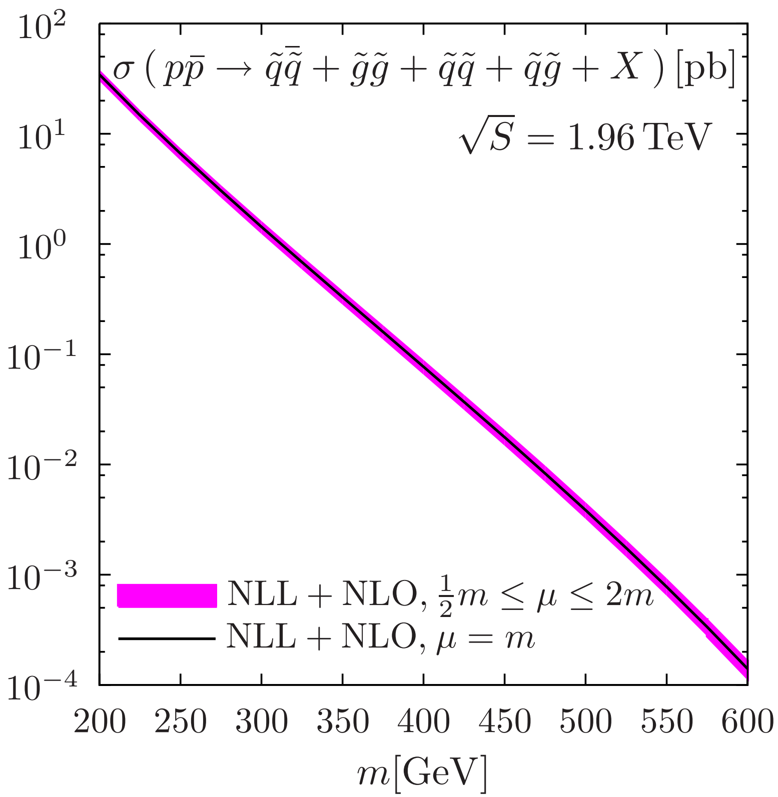
[PRELIMINARY] MSTW2008

Squark and gluino production at hadron colliders

[*Beenakker, Brensing, Krämer, AK, Laenen, Niessen'09*]

Most accurate theoretical predictions currently available

Tevatron



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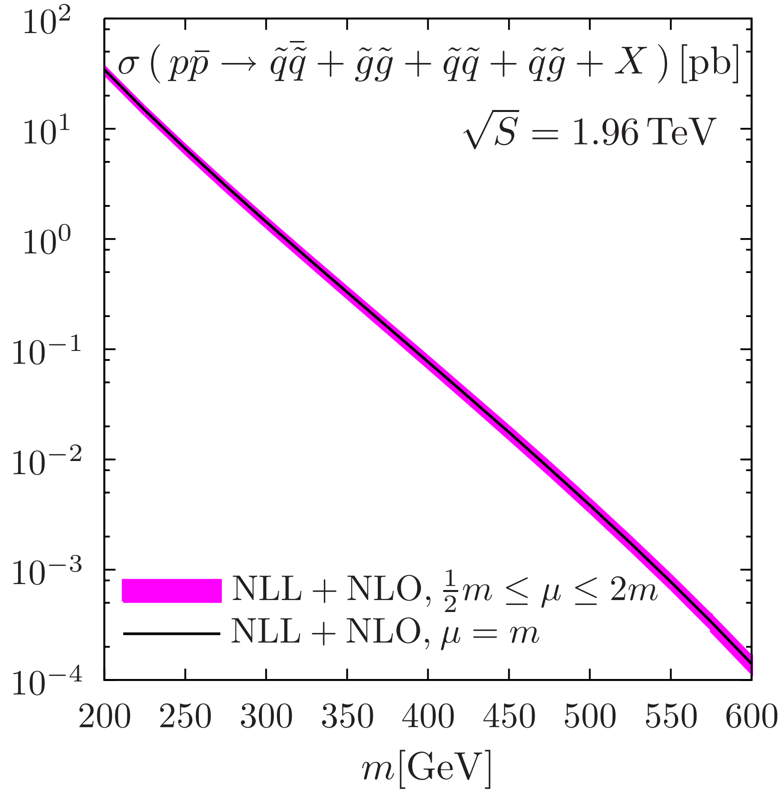

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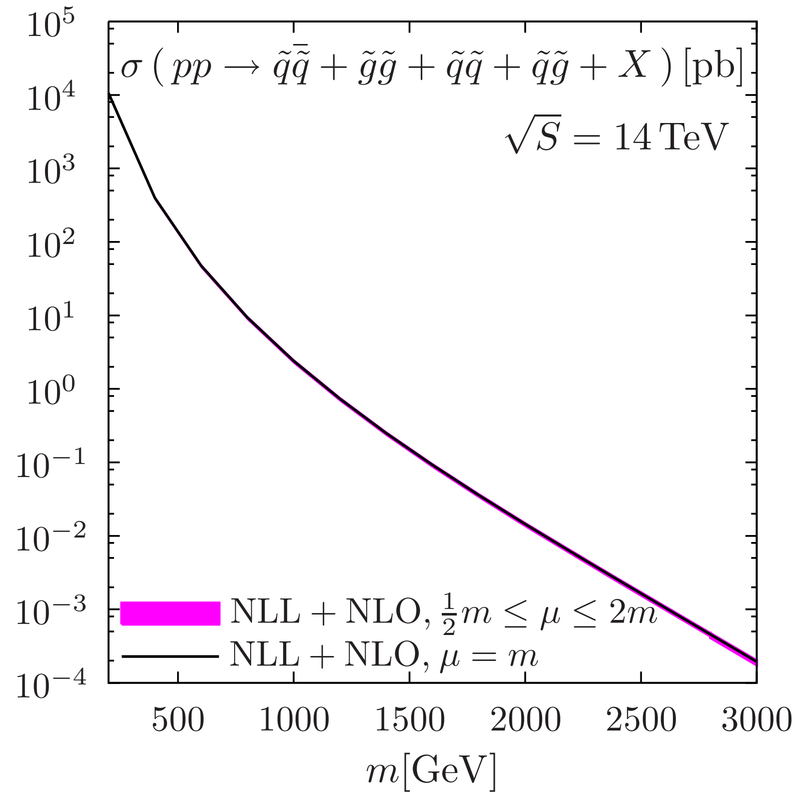
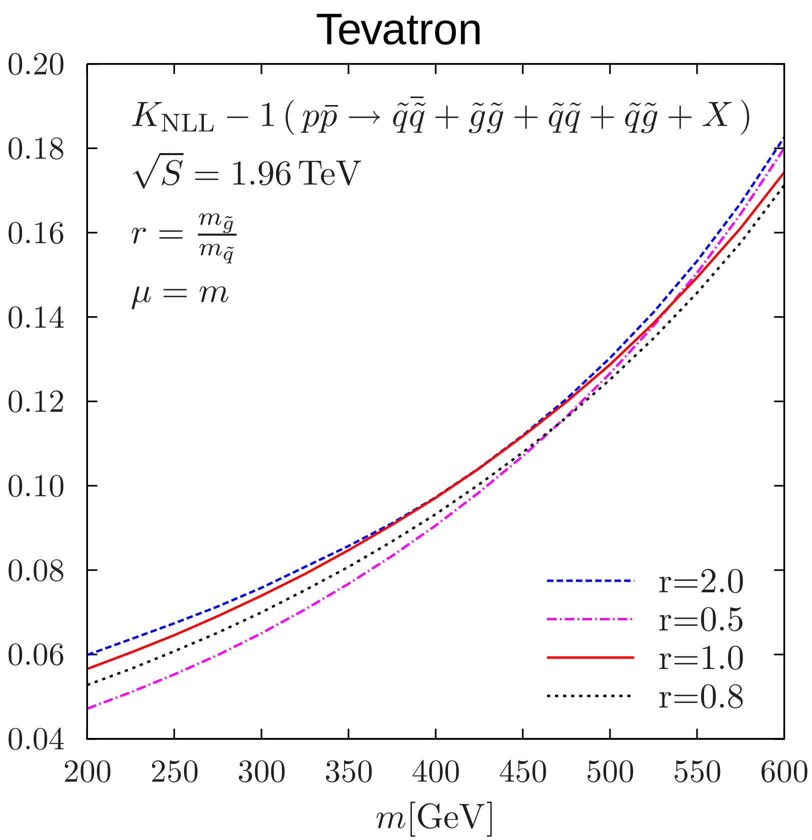


$m_{\tilde{q}} = m_{\tilde{g}}$, MSTW2008

NLL K-factor for $\tilde{q}$ and $\tilde{g}$ production at hadron colliders

[*Beenakker, Brensing, Krämer, AK, Laenen, Niessen'09*]

- Total cross section for production of $\tilde{q}$ and $\tilde{g}$ through all four processes
  $\Rightarrow$ different processes provide different weight to the combined NLL correction



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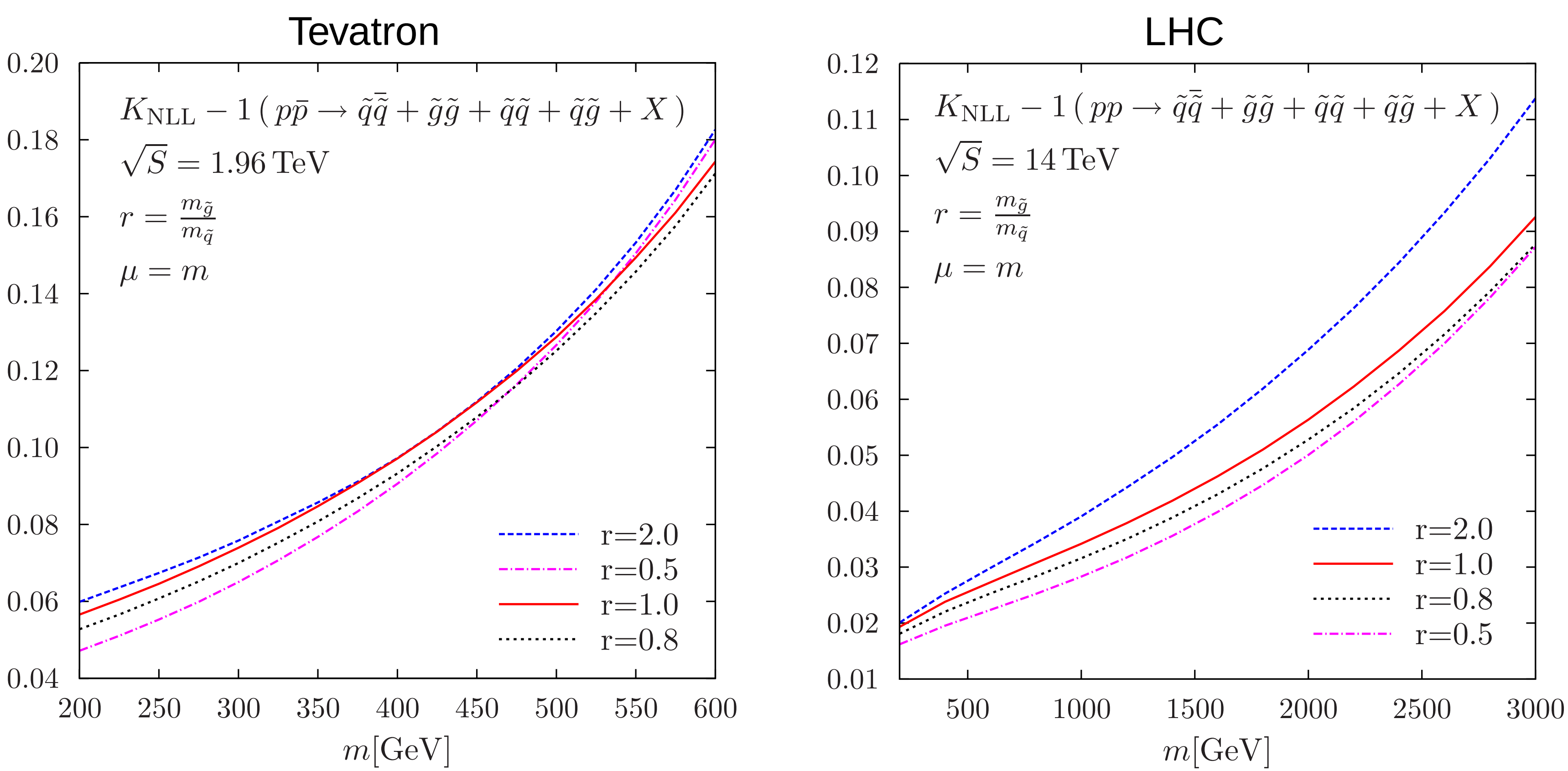
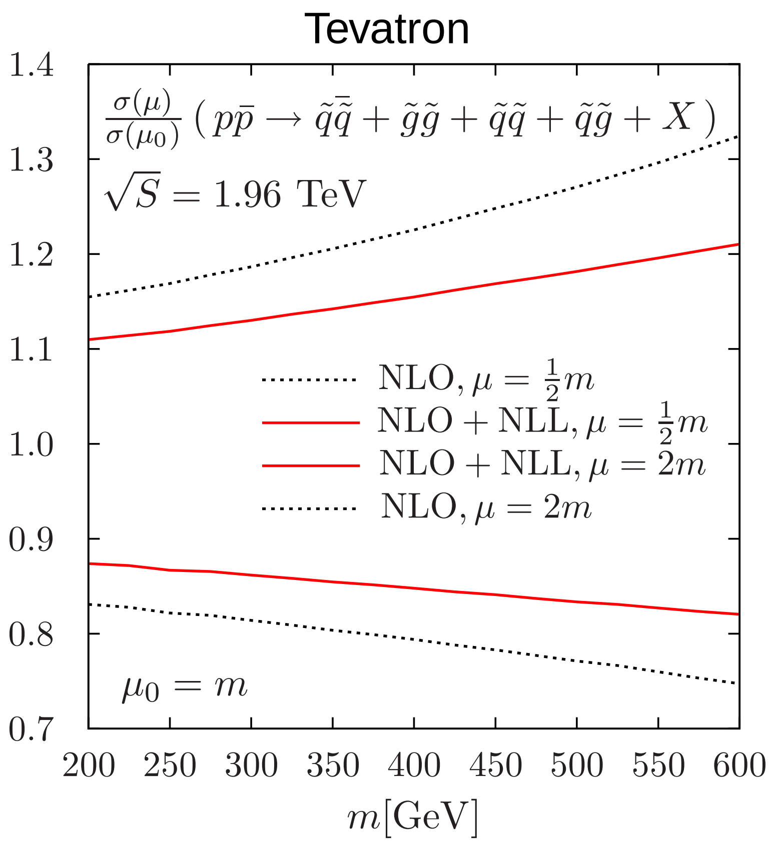


MSTW2008

Scale dependence for $\tilde{q}$ and $\tilde{g}$ hadroproduction

[*AK, Motyka'09*] [*Beenakker, Brensing, Krämer, AK, Laenen, Niessen'09*]

- Reduction of scale dependence observed individually for each process
- For all four processes together:



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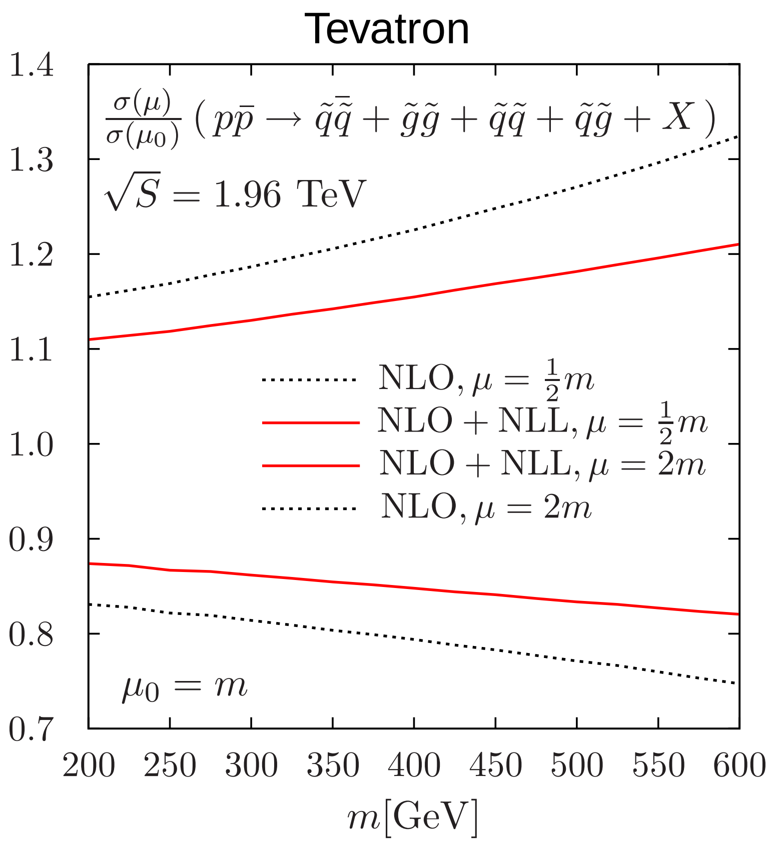

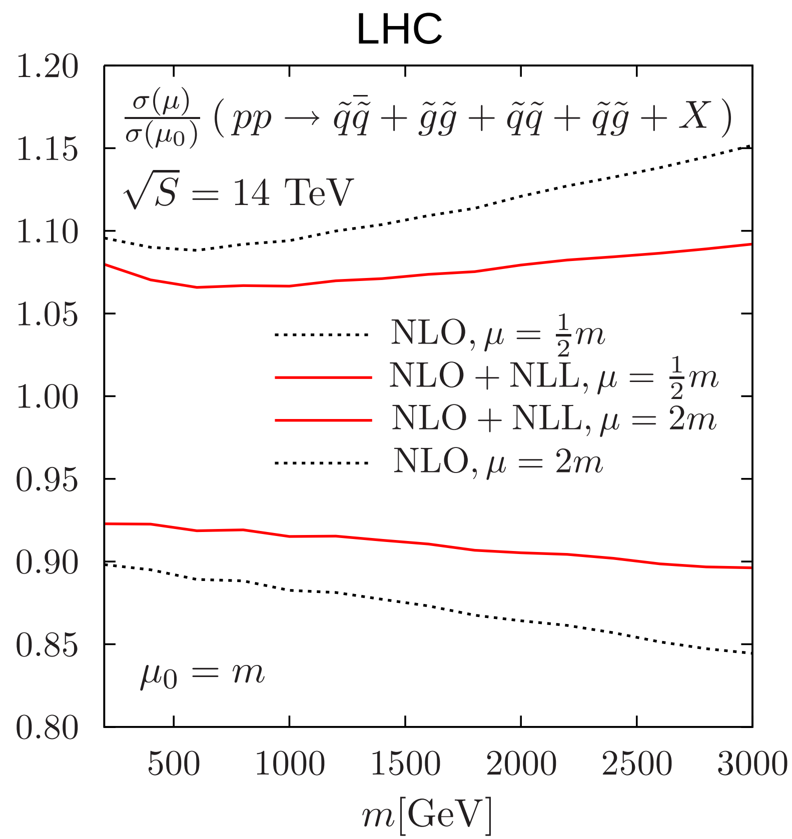

$m_{\tilde{q}} = m_{\tilde{g}}$, MSTW2008

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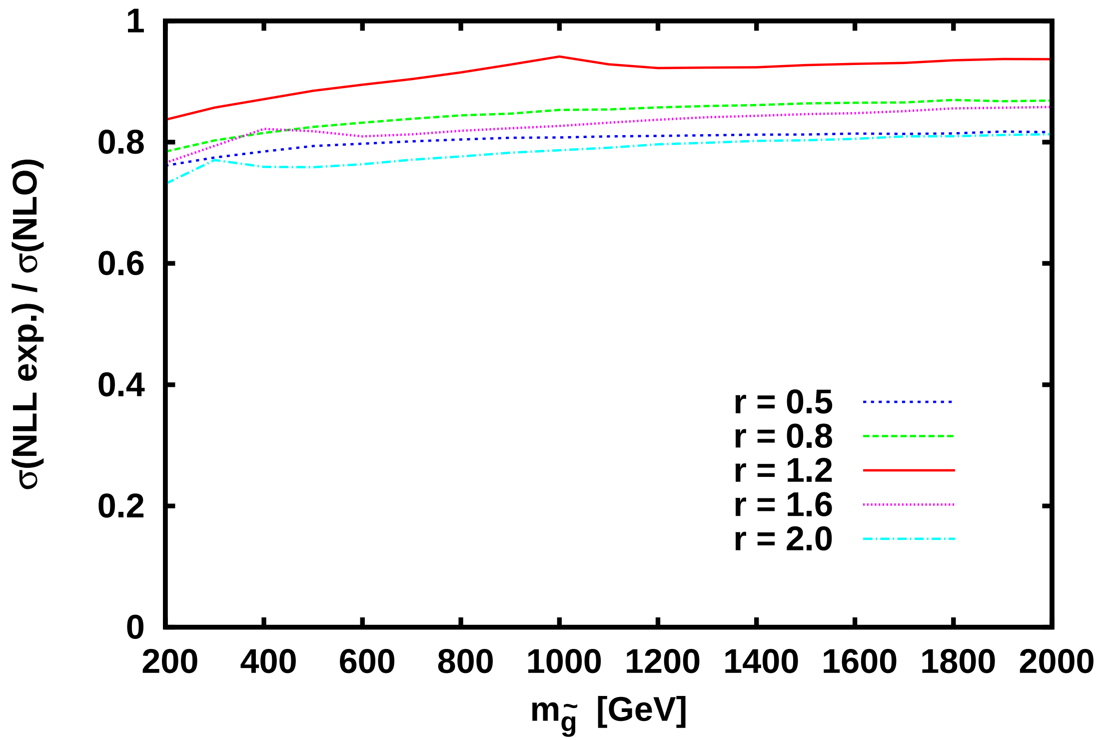
- Corrections due to NLL threshold resummation highest for processes with gluons in the initial state and gluinos in the final state.
  - $\sim 15\%$ correction for $m_{\tilde{g}} \sim 2\,\mathrm{TeV}$ for $\tilde{g}\tilde{g}$ production at the LHC
  - $\sim 40\%$ correction for at $0.5(m_{\tilde{q}} + m_{\tilde{g}}) \sim 500\,\mathrm{GeV}$ for $\tilde{q}\tilde{g}$ production at the Tevatron
- Significant reduction of the theoretical error due to scale variation

Extra slides

Importance of the NLL terms

[*AK, Motyka'09*]

Expanded NLL-resummed cross section up to $\mathcal{O}(\alpha_s^3)$ vs. NLO



$pp \rightarrow \tilde{g}\tilde{g}$ at the LHC

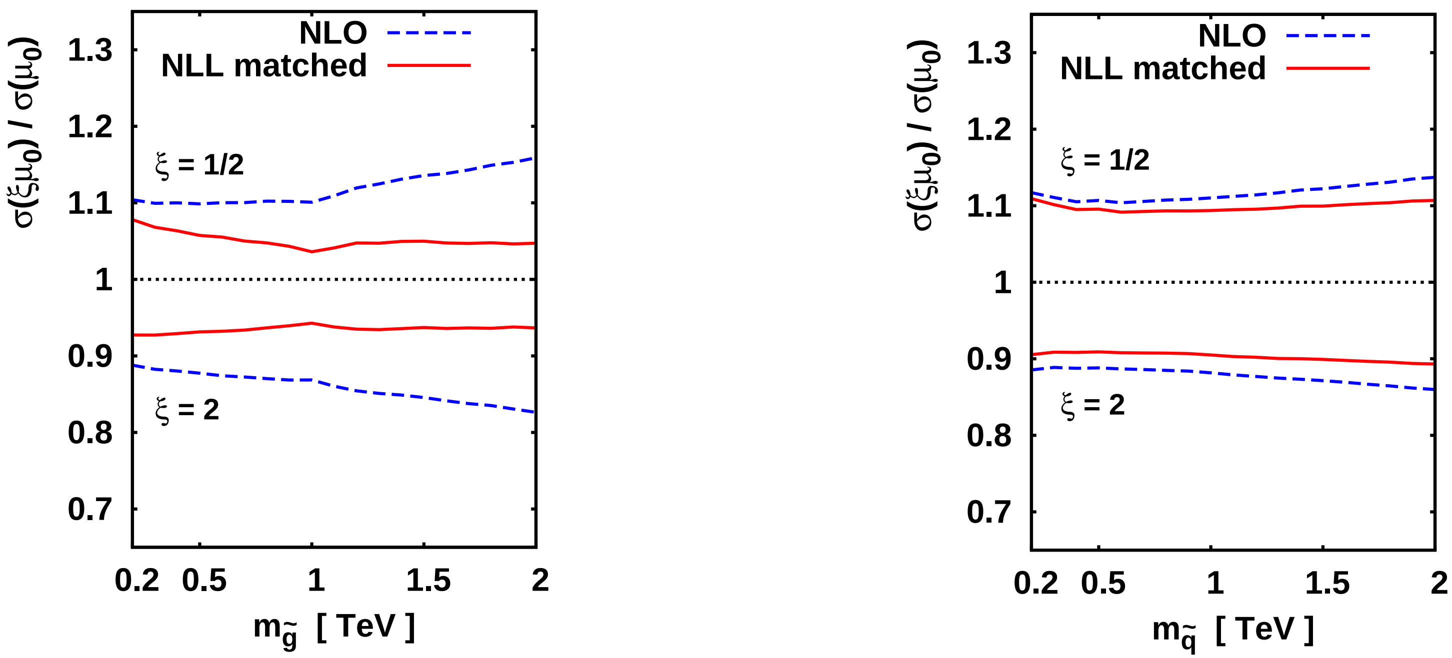
$r = \frac{m_{\tilde{g}}}{m_{\tilde{q}}}$ ($\mu_F = \mu_R = m_{\tilde{g}}$, CTEQ6M)

The scale dependence

$$\frac{\sigma^{\rm NLO}(\mu=\xi m_{\tilde q})}{\sigma^{\rm NLO}(\mu=m_{\tilde q})} \text{ vs. } \frac{\sigma^{\rm (match)}(\mu=\xi m_{\tilde q})}{\sigma^{\rm (match)}(\mu=m_{\tilde q})}$$

[*AK, Motyka'08*]

$pp \to \tilde g \tilde g$ $\qquad\qquad$ $pp \to \tilde q \bar{\tilde q}$



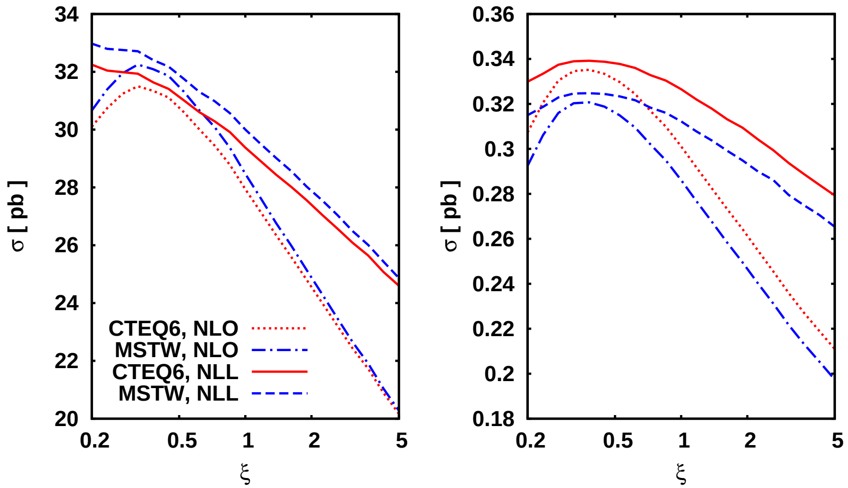
$r = \frac{m_{\tilde g}}{m_{\tilde q}} = 1.2$, $\mu_F = \mu_R$, CTEQ6M pdfs

The scale dependence

[AK, Motyka'09]

$$\xi = \mu/m,\ \mu = \mu_F = \mu_R,\ r = \frac{m_{\tilde{g}}}{m_{\tilde{q}}} = 1.2$$

$$pp \to \tilde{g}\tilde{g}$$



$m_{\tilde{g}} = 500$ GeV $\qquad$ $m_{\tilde{g}} = 1$ TeV

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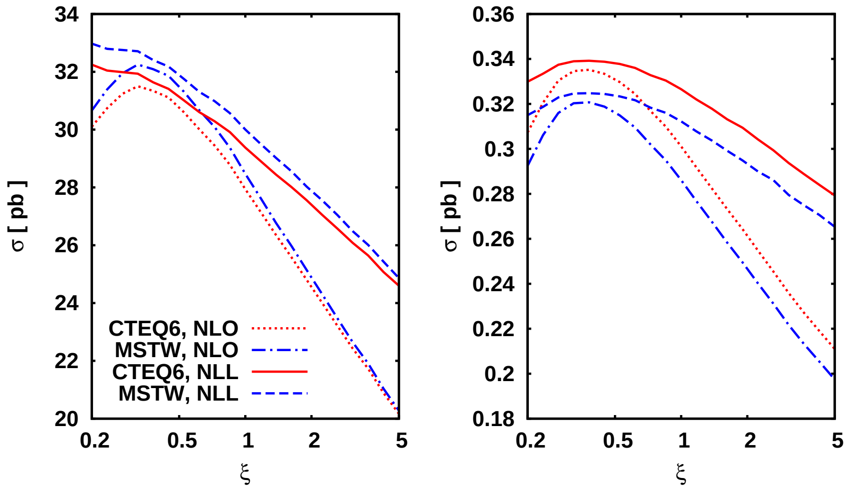

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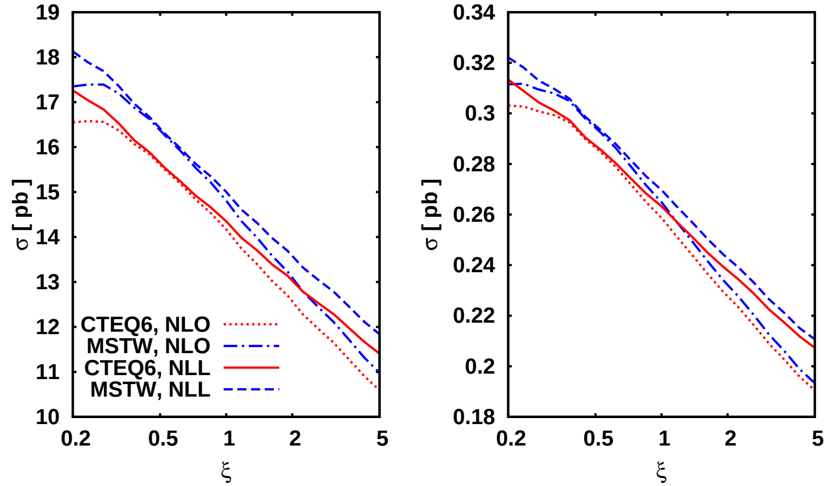
$pp \to \tilde{q}\bar{\tilde{q}}$

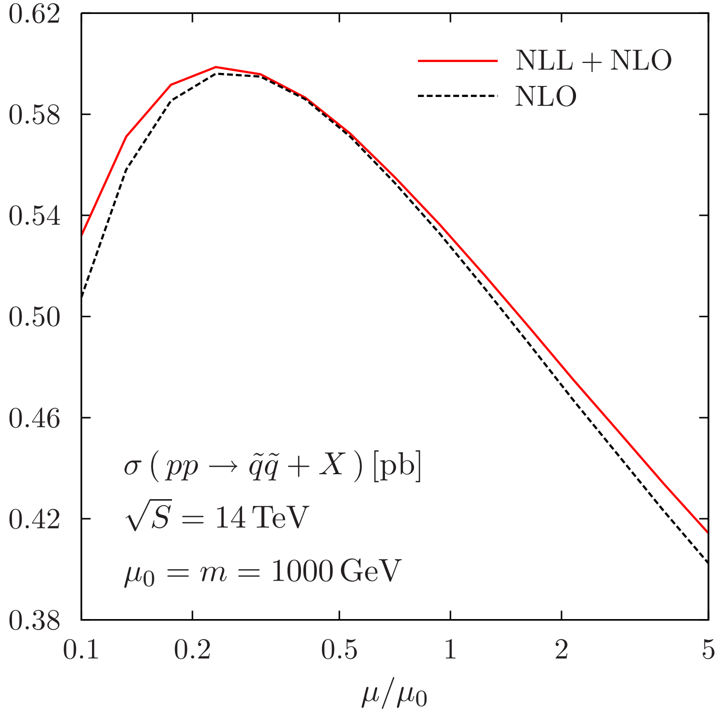


$m_{\tilde{q}} = 500$ GeV $\qquad m_{\tilde{q}} = 1$ TeV

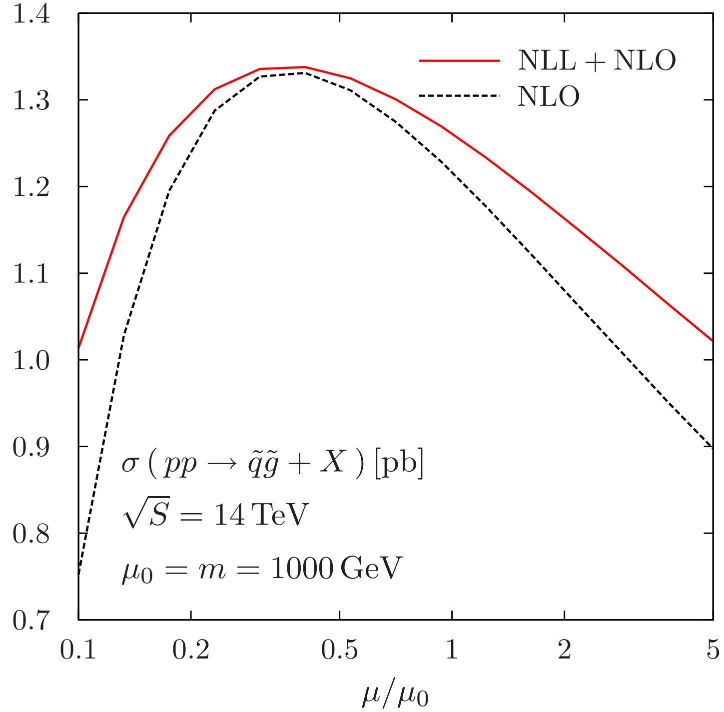
The scale dependence cntd.

[*Beenakker, Brensing, Krämer, AK, Laenen, Niessen'09*]

$pp \longrightarrow \tilde{q}\tilde{q}$

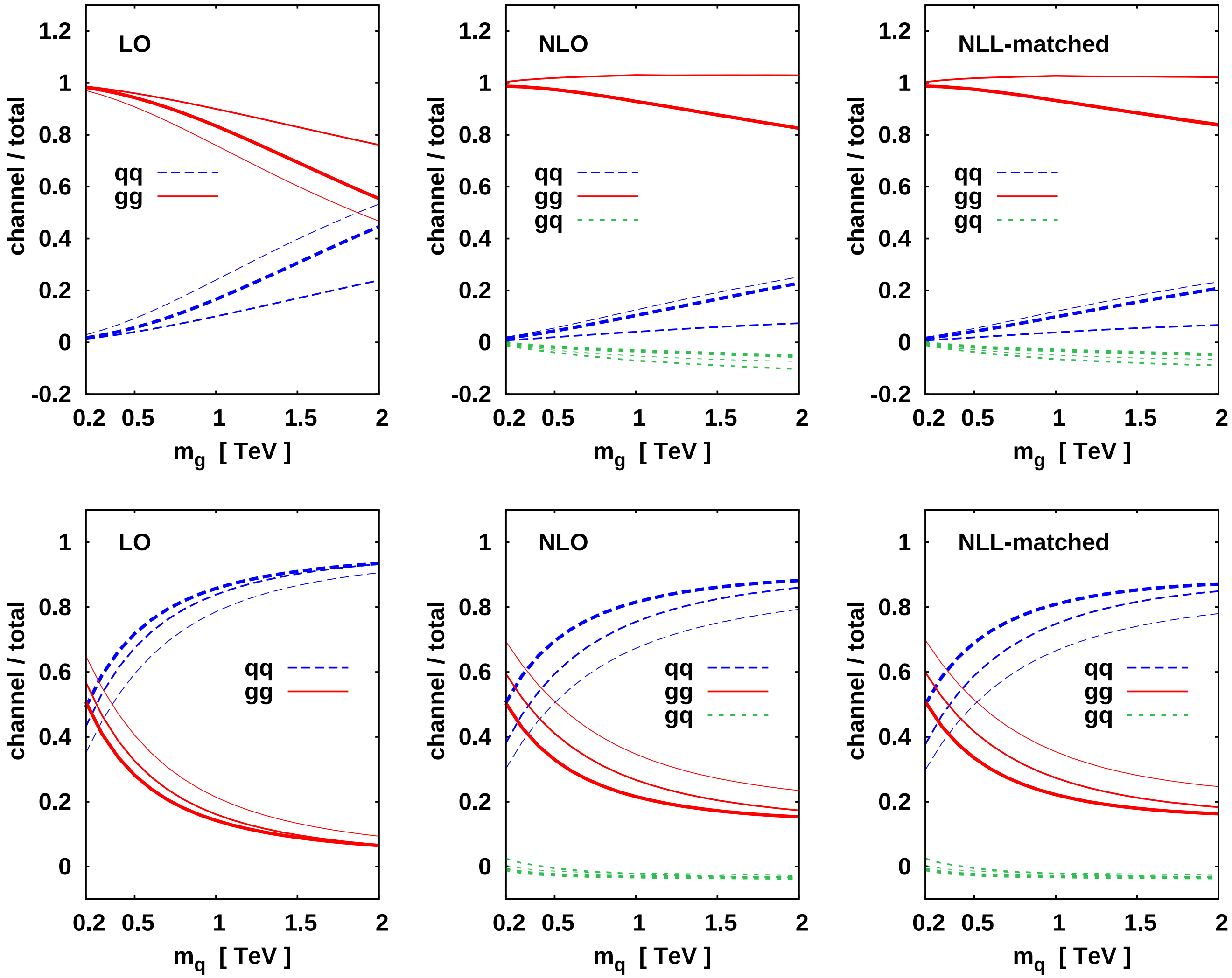


$pp \longrightarrow \tilde{q}\tilde{g}$



Squark and gluino production at the LHC

$pp \to \tilde{g}\tilde{g}$: [AK, L. Motyka'09]



$pp \to \tilde{q}\bar{\tilde{q}}$:

(thick line: $m_{\tilde{g}}/m_{\tilde{q}} = 0.5$, medium: $m_{\tilde{g}}/m_{\tilde{q}} = 1.2$, thin: $m_{\tilde{g}}/m_{\tilde{q}} = 2$)

Coulomb corrections

Leading Coulomb corrections

$$\alpha_{\mathrm{s}}^n/\beta^n \qquad \text{wrt. LO}$$

can also be resummed [Fadin, Khoze, Sjöstrand' 90] [Catani, Mangano, Nason, Trentadue'96]

$$\hat{\sigma}^{\mathrm{Coul}}_{ij\to kl} = \sum_I \hat{\sigma}^{\mathrm{LO}}_{ij\to kl,\ I}\ \frac{X_{ij\to kl,\ I}}{1-\exp(-X_{ij\to kl,\ I})}$$

$$X_{ij\to kl,\ I} = \pi\alpha_{\mathrm{s}} C_{ij\to kl,\ I}\ /\beta$$

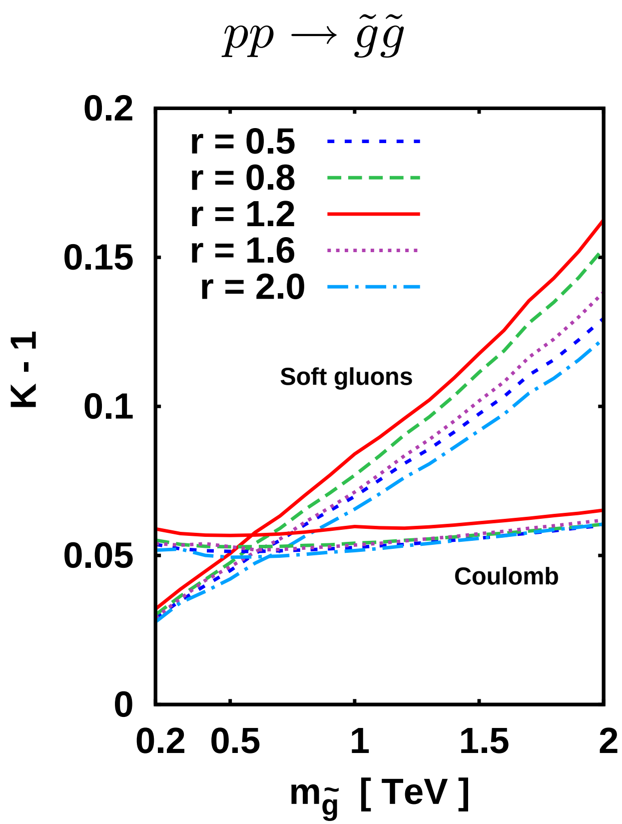
$C_{ij\to kl,\ I}$ are appropriate colour factors

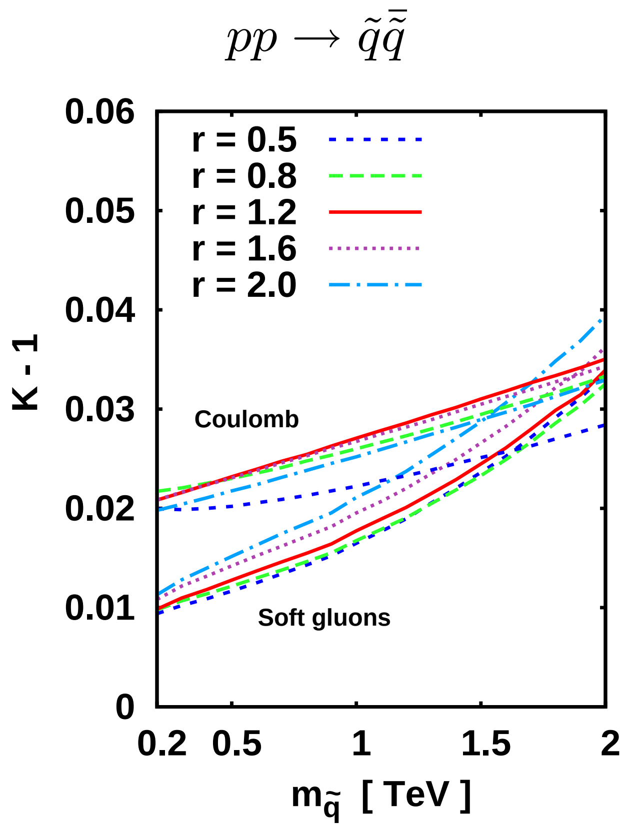
Define the “Coulomb K-factor” as

$$K^{\mathrm{Coul}}_{ij\to kl} = \frac{\hat{\sigma}^{\mathrm{Coul}}_{ij\to kl} - \hat{\sigma}^{\mathrm{Coul}}_{ij\to kl}|_{\mathrm{NLO}}}{\sigma^{\mathrm{NLO}}_{ij\to kl}}$$

Threshold effects for $\tilde{g}\tilde{g}$ and $\tilde{q}\bar{\tilde{q}}$ production at the LHC

[AK, L. Motyka'09]





Threshold effects for $\tilde{g}\tilde{g}$ and $\tilde{q}\bar{\tilde{q}}$ production at the LHC

[*AK, Motyka'09*]

Soft + Coulomb corrections

$pp \rightarrow \tilde{g}\tilde{g}$ $\qquad$ $pp \rightarrow \tilde{q}\bar{\tilde{q}}$