Threshold resummation for squark-antisquark and gluino-pair production at the LHC

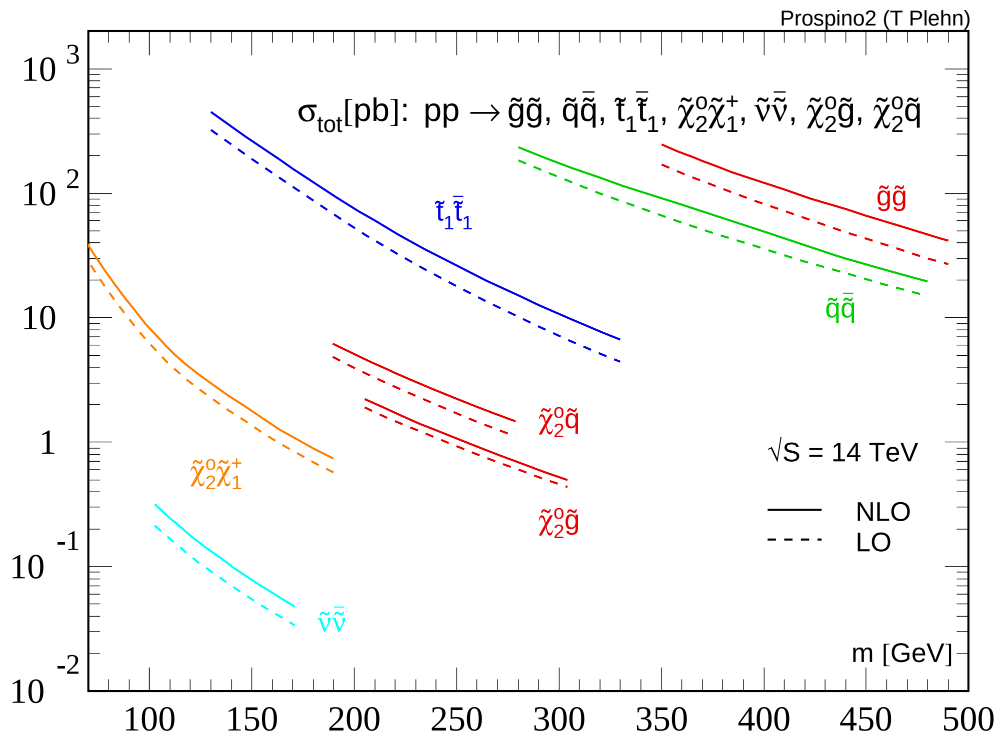
Anna Kulesza

based on work in collaboration with L. Motyka, arXiv:0807.2405 [hep-ph]

Helmholtz Alliance Workshop, Aachen, 27.11.2008

SUSY particle pair-production at the LHC

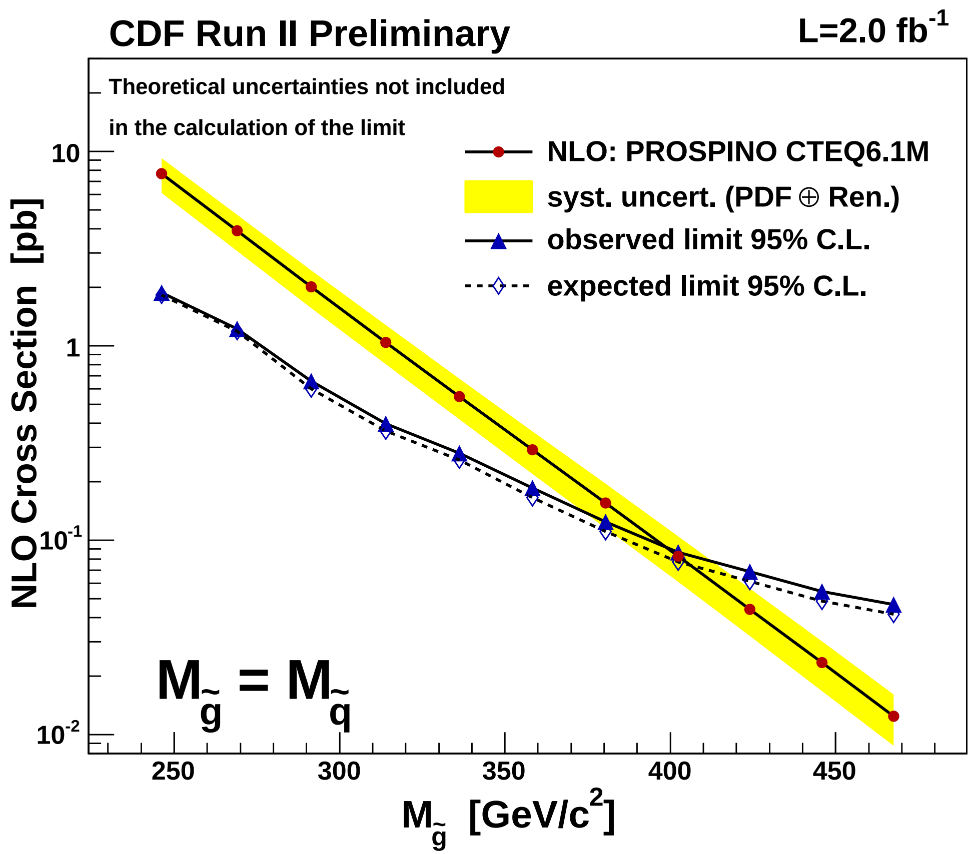
- MSSM: minimal content of SUSY particles + $R-$parity conservation
- At the LHC dominant sparticle production channels involve squarks ($\tilde{q}$) and gluinos ($\tilde{g}$) in the final state ($\tilde{q}\bar{\tilde{q}}$, $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$, $\tilde{g}\tilde{g}$ pairs)



[*Plehn, Prospino2*]

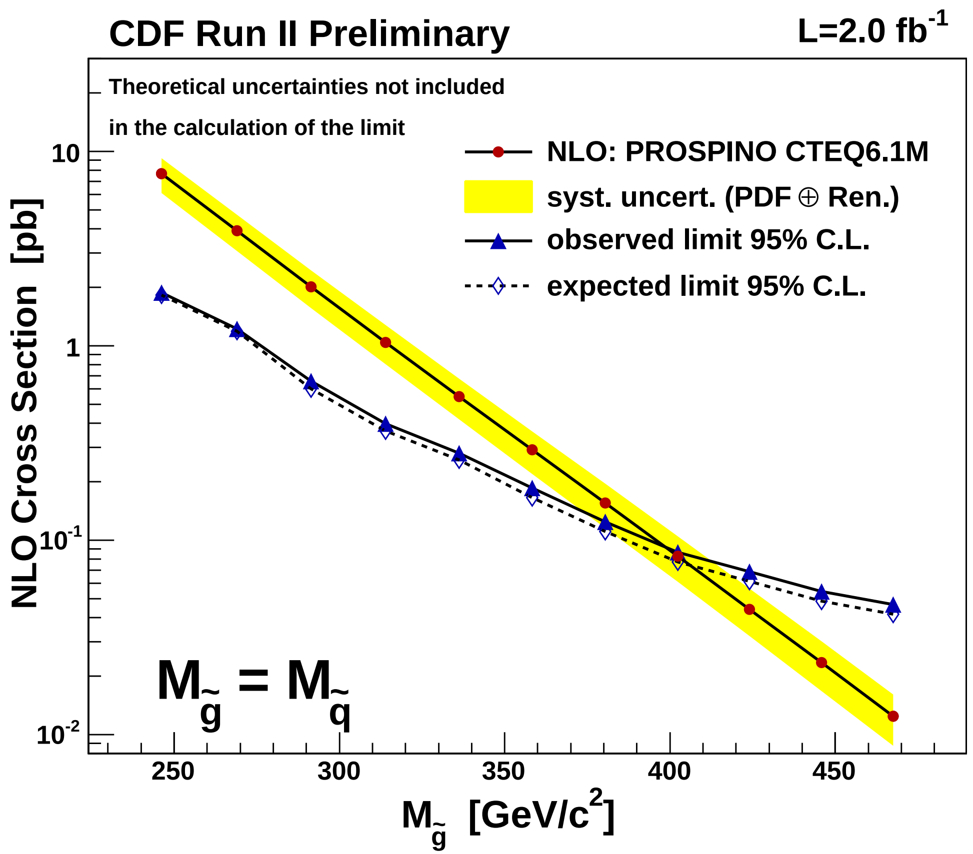
- squarks and gluino discovery possible for masses up to $\sim$ 2 TeV

Gluino mass exclusion limits



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

Gluino mass exclusion limits



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

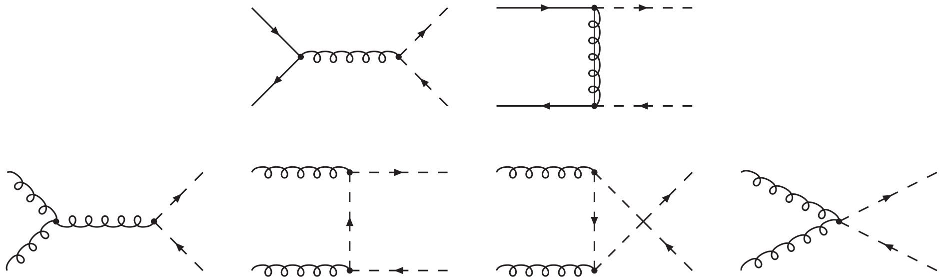
- Predictions for total cross sections can be also useful for mass determination in case of discovery [*Baer et al'07*]

$\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production at LO

[*Dawson, Eichten, Quigg'85*]

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

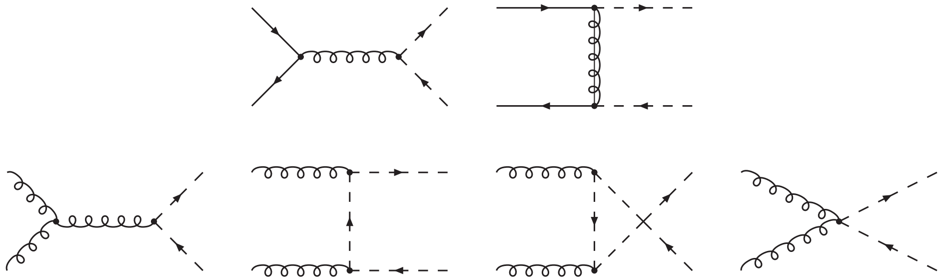
  LO partonic level: $q\bar{q} \to \tilde{q}\bar{\tilde{q}}$, $\bar{q}q \to \tilde{q}\bar{\tilde{q}}$, $gg \to \tilde{q}\bar{\tilde{q}}$



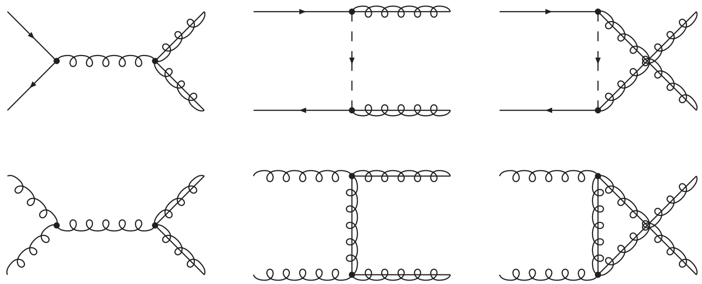
$\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production at LO

[*Dawson, Eichten, Quigg'85*]

- $pp \to \tilde{q}\bar{\tilde{q}}$
  LO partonic level: $q\bar{q} \to \tilde{q}\bar{\tilde{q}}$, $\bar{q}q \to \tilde{q}\bar{\tilde{q}}$, $gg \to \tilde{q}\bar{\tilde{q}}$



- $pp \to \tilde{g}\tilde{g}$
  LO partonic level: $q\bar{q} \to \tilde{g}\tilde{g}$, $\bar{q}q \to \tilde{g}\tilde{g}$, $gg \to \tilde{g}\tilde{g}$



Beyond $\mathcal{O}(\alpha_s^2)$

- NLO corrections
  - SUSY-QCD corrections $\longrightarrow \mathcal{O}(\alpha_s^3)$ [*Beenakker, Höpker, Spira, Zerwas'96*]
  - EW corrections $\longrightarrow \mathcal{O}(\alpha_s^2\alpha)$ [*Hollik, Kollar, Trenkel'07*][*Hollik, Mirabella'08*]

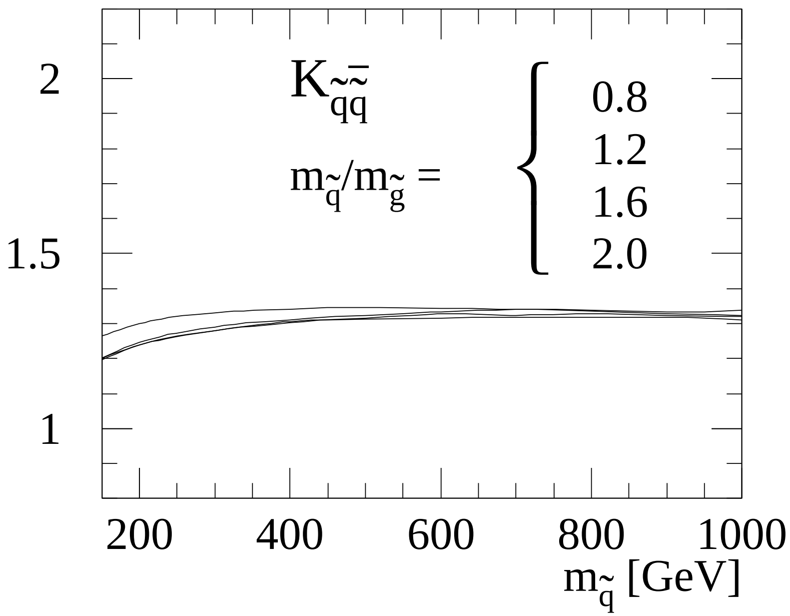
Beyond $\mathcal{O}(\alpha_s^2)$

- NLO corrections
  - SUSY-QCD corrections $\rightarrow \mathcal{O}(\alpha_s^3)$ [*Beenakker, Höpker, Spira, Zerwas'96*]
  - EW corrections $\rightarrow \mathcal{O}(\alpha_s^2\alpha)$ [*Hollik, Kollar, Trenkel'07*][*Hollik, Mirabella'08*]
- For squark production, tree-level EW effects:
  - Tree-level QCD-EW interference $\rightarrow \mathcal{O}(\alpha\alpha_s)$ [*Bornhauser et al.'07*] [*Alan, Cankocak, Demir'07*]
  - Tree-level photon-induced ($\gamma g \rightarrow \tilde{q}\bar{\tilde{q}}$) contributions $\rightarrow \mathcal{O}(\alpha\alpha_s)$ [*Hollik, Kollar, Trenkel'07*]
  - Tree-level EW $\rightarrow \mathcal{O}(\alpha^2)$ [*Bornhauser et al.'07*] [*Alan, Cankocak, Demir'07*]

$\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production at NLO (SUSY-QCD)

[*Beenakker, Höpker, Spira, Zerwas'96*]

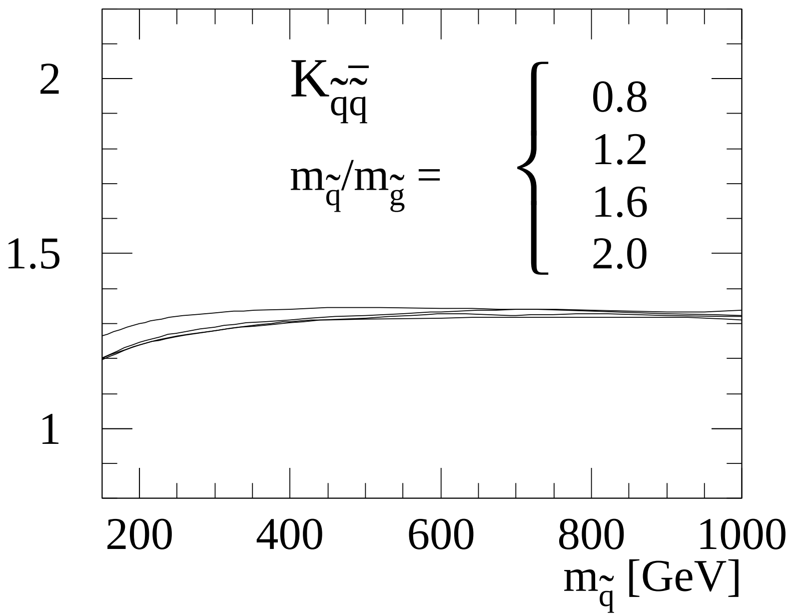
$$K_{ij} = \sigma_{ij}^{\mathrm{NLO}} / \sigma_{ij}^{\mathrm{LO}}$$

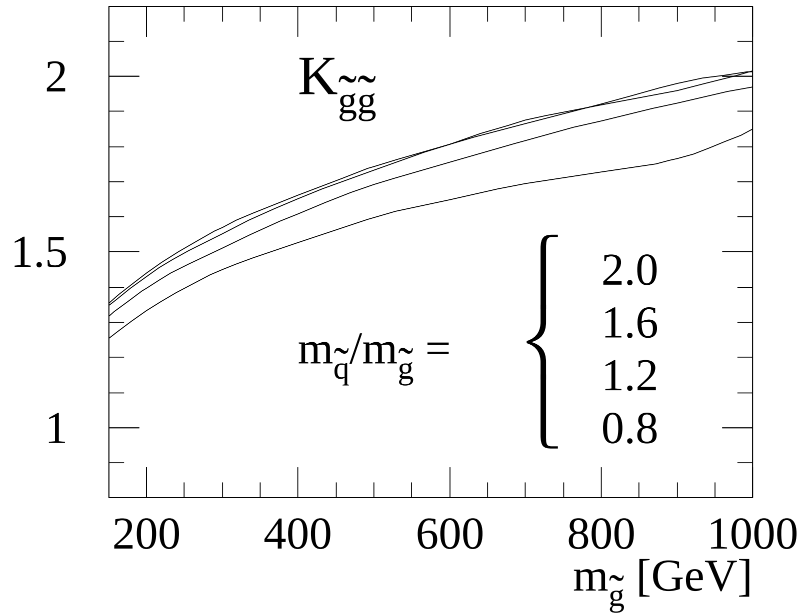


$\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production at NLO (SUSY-QCD)

[*Beenakker, Höpker, Spira, Zerwas'96*]

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

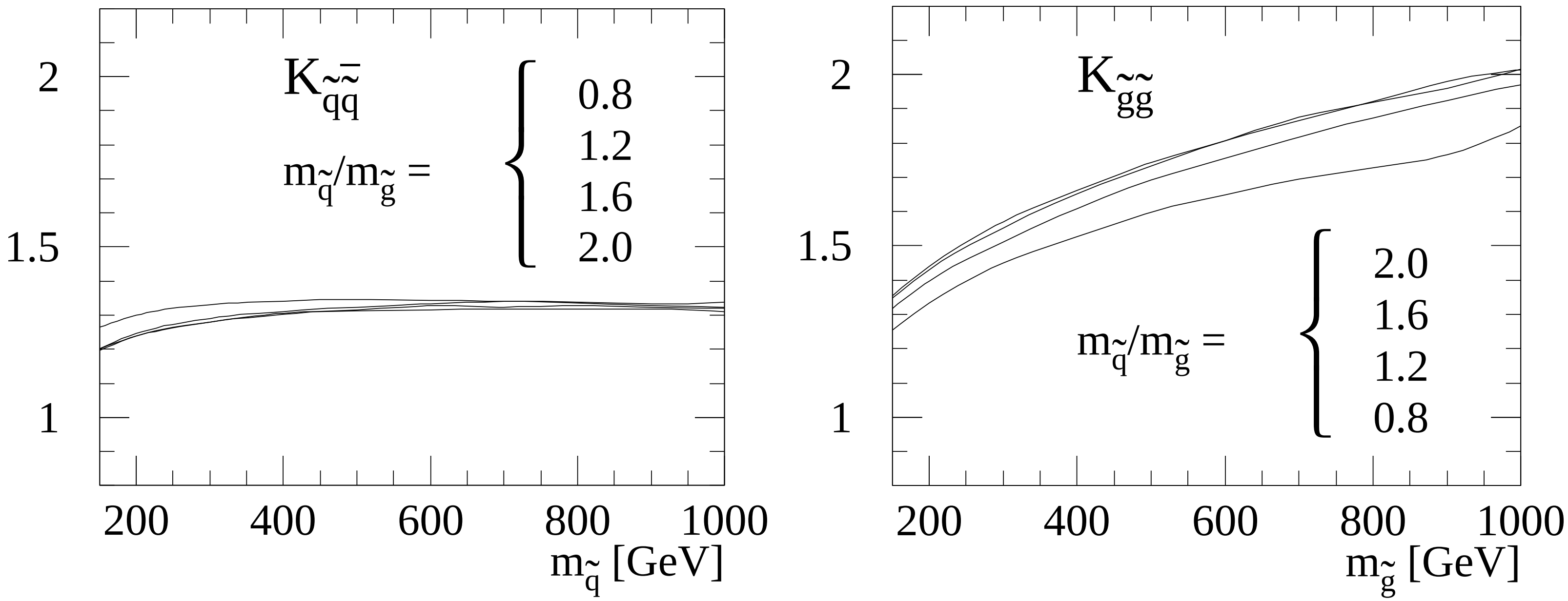




$\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production at NLO (SUSY-QCD)

[*Beenakker, Höpker, Spira, Zerwas'96*]

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



$\Rightarrow$ Increase of the cross sections due to NLO SUSY-QCD corrections over the whole range of masses covered by the LHC, large K-factors for $\tilde{g}\tilde{g}$

Note: assume all squarks ($\tilde{q}_L$,$\tilde{q}_R$) mass degenerate; no final state stops $\Rightarrow$

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

Higher-order effects in $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$

[*Beenakker, Höpker, Spira, Zerwas'96*]

- 100 % correction to $\sigma_{\tilde{g}\tilde{g}}$ at $m_{\tilde{g}} = 1\,\mathrm{TeV}$; 30% correction to $\sigma_{\tilde{q}\bar{\tilde{q}}}$ at $m_{\tilde{q}} = 1\,\mathrm{TeV}$

Higher-order effects in $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$

[*Beenakker, Höpker, Spira, Zerwas'96*]

- 100 % correction to $\sigma_{\tilde{g}\tilde{g}}$ at $m_{\tilde{g}} = 1\,\mathrm{TeV}$; 30% correction to $\sigma_{\tilde{q}\bar{\tilde{q}}}$ at $m_{\tilde{q}} = 1\,\mathrm{TeV}$
- Large masses of squarks and gluons
  $\Rightarrow$ often production close to threshold $\hat{s} \sim 4m^2$
  $\Rightarrow$ real emission forced to be predominantly soft

Higher-order effects in $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$

[*Beenakker, Höpker, Spira, Zerwas'96*]

- 100 % correction to $\sigma_{\tilde{g}\tilde{g}}$ at $m_{\tilde{g}} = 1\,\mathrm{TeV}$; 30% correction to $\sigma_{\tilde{q}\bar{\tilde{q}}}$ at $m_{\tilde{q}} = 1\,\mathrm{TeV}$
- Large masses of squarks and gluons
  $\Rightarrow$ often production close to threshold $\hat{s} \sim 4m^2$
  $\Rightarrow$ real emission forced to be predominantly soft
- Demonstrated by the appearence of terms with powers of $\log\left(1 - \frac{4m^2}{\hat{s}}\right)$ in the expressions for cross sections
  $\rightarrow$ the closer to threshold the more important the logarithmic terms

Higher-order effects in $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$

[*Beenakker, Höpker, Spira, Zerwas'96*]

- 100 % correction to $\sigma_{\tilde{g}\tilde{g}}$ at $m_{\tilde{g}} = 1\,\mathrm{TeV}$; 30% correction to $\sigma_{\tilde{q}\bar{\tilde{q}}}$ at $m_{\tilde{q}} = 1\,\mathrm{TeV}$
- Large masses of squarks and gluons
  $\Rightarrow$ often production close to threshold $\hat{s} \sim 4m^2$
  $\Rightarrow$ real emission forced to be predominantly soft
- Demonstrated by the appearence of terms with powers of $\log\left(1 - \frac{4m^2}{\hat{s}}\right)$ in the expressions for cross sections
  $\longrightarrow$ the closer to threshold the more important the logarithmic terms
- Additionally, for $\tilde{g}\tilde{g}$ production
  - both gg initial state (prevalent contribution) and $\tilde{g}\tilde{g}$ final state radiate strongly: C_A colour charge

$\longrightarrow$ expect a lot of (soft) gluon radiation

Soft-gluon corrections to $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production

- Seen already at NLO: at threshold [*Beenakker, Höpker, Spira, Zerwas'96*]

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

with $\beta^2 = 1 - \frac{4m^2_{\tilde{g}}}{\hat{s}}$ and $\hat{\sigma}^{\rm LO}_{gg\to\tilde{g}\tilde{g}} \sim \frac{27}{64}\alpha_{\rm s}^2\pi\frac{\beta}{m^2_{\tilde{g}}}$

Soft-gluon corrections to $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production

- Seen already at NLO: at threshold [Beenakker, Höpker, Spira, Zerwas'96]

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

with $\beta^2 = 1 - \frac{4m^2_{\tilde{g}}}{\hat{s}}$ and $\hat{\sigma}^{\rm LO}_{gg\to\tilde{g}\tilde{g}} \sim \frac{27}{64}\alpha_{\rm s}^2\pi\frac{\beta}{m^2_{\tilde{g}}}$

- Two types of effects:
  - Soft gluon emission $\to \log^2(\beta^2)$, $\log(\beta^2)$
  - Exchange of long-range Coulomb gluons between the slowly moving massive particles $\to 1/\beta$

Soft-gluon corrections to $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production

- Seen already at NLO: at threshold [Beenakker, Höpker, Spira, Zerwas'96]

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

  with $\beta^2 = 1-\frac{4m_{\tilde{g}}^2}{\hat{s}}$ and $\hat{\sigma}^{\rm LO}_{gg\to\tilde{g}\tilde{g}} \sim \frac{27}{64}\alpha_{\rm s}^2\pi\frac{\beta}{m_{\tilde{g}}^2}$

- Two types of effects:
  - Soft gluon emission $\rightarrow \log^2(\beta^2)$, $\log(\beta^2)$
  - Exchange of long-range Coulomb gluons between the slowly moving massive particles $\rightarrow 1/\beta$

- At n-th order in $\alpha_{\rm s}$ (wrt LO) soft gluon contributions of the form $\alpha_{\rm s}^n \log^m(\beta^2),\ m \leq 2n$

Soft-gluon corrections to $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production

- Seen already at NLO: at threshold [Beenakker, Höpker, Spira, Zerwas'96]

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

with $\beta^2 = 1 - \frac{4m^2_{\tilde{g}}}{\hat{s}}$ and $\hat{\sigma}^{\rm LO}_{gg\to\tilde{g}\tilde{g}} \sim \frac{27}{64}\alpha_{\rm s}^2\pi\frac{\beta}{m^2_{\tilde{g}}}$

- Two types of effects:
  - Soft gluon emission $\to \log^2(\beta^2)$, $\log(\beta^2)$
  - Exchange of long-range Coulomb gluons between the slowly moving massive particles $\to 1/\beta$
- At n-th order in $\alpha_{\rm s}$ (wrt LO) soft gluon contributions of the form $\alpha_{\rm s}^n \log^m(\beta^2),\ m \leq 2n$

In the limit of $\beta \to 0$ convergence of fixed-order expansion spoiled

Threshold resummation

Resummation of threshold logarithms is carried out in the Mellin moment space, where the cross section factorizes:

$\left(g^{(N)} = \int_0^1 dz\, z^{N-1}\, g(z)\right)$

$$\sigma_{h_1h_2}^{(N)} = \sum_{i,j} f_{i/h_1}^{(N+1)}(\mu_F) f_{j/h_2}^{(N+1)}(\mu_F) \hat{\sigma}_{ij}^{(N)}(\mu_F)$$

and the logarithmic terms exponentiate

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

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

$$\mathcal{S} \quad = \quad L f_1(\alpha_s\, L) + f_2(\alpha_s\, L) + \alpha_s f_3(\alpha_s\, L) + ... \qquad\qquad L = \ln(N)$$

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

Resummation for colour singlet production

Drell-Yan, Higgs, ... [*Catani, Trentadue'89*] [*Sterman'87*]

$$\sigma_{ij}^{(N)} = \hat{\sigma}_{0,\,ij}^{(N)} C_{ij} \Delta_i^{(N)} \Delta_j^{(N)} \Delta_{\mathrm{int},ij}^{(N)}$$

Resummation for colour singlet production

Drell-Yan, Higgs, ... [*Catani, Trentadue'89*] [*Sterman'87*]

$$\sigma_{ij}^{(N)} = \hat{\sigma}_{0,\, ij}^{(N)} C_{ij} \Delta_i^{(N)} \Delta_j^{(N)} \Delta_{\mathrm{int},ij}^{(N)}$$

$\Delta_i^{(N)}$ soft gluons collinear to initial state partons (universal)

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

Resummation for colour singlet production

Drell-Yan, Higgs, ... [Catani, Trentadue'89] [Sterman'87]

$$\sigma_{ij}^{(N)} = \hat{\sigma}_{0,\,ij}^{(N)} C_{ij} \Delta_i^{(N)} \Delta_j^{(N)} \Delta_{\mathrm{int},ij}^{(N)}$$

$\Delta_i^{(N)}$ soft gluons collinear to initial state partons (universal)

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

$\Delta_{\mathrm{int}}^{(N)}$ large-angle soft gluons (process-dependent)

$$\Delta_{\mathrm{int,ij}}^{N} = \exp\left\{ \int_0^1 dz \frac{z^{N-1}-1}{1-z} D_{ij}(\alpha_{\mathrm{s}}((1-z)^2 Q^2)) \right\}$$

Resummation for colour singlet production

Drell-Yan, Higgs, ... [*Catani, Trentadue'89*] [*Sterman'87*]

$$\sigma_{ij}^{(N)} = \hat{\sigma}_{0,\,ij}^{(N)} C_{ij} \Delta_i^{(N)} \Delta_j^{(N)} \Delta_{\mathrm{int},ij}^{(N)}$$

$\Delta_i^{(N)}$ soft gluons collinear to initial state partons (universal)

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

$\Delta_{\mathrm{int}}^{(N)}$ large-angle soft gluons (process-dependent)

$$\Delta_{\mathrm{int,ij}}^{N} = \exp\left\{ \int_0^1 dz \frac{z^{N-1}-1}{1-z} D_{ij}(\alpha_s((1-z)^2 Q^2)) \right\}$$

A_i,D_{ij} perturbative functions $\longrightarrow$ Up to NLL, need to know $A_i^{(1)}$, $A_i^{(2)}$, $D_{ij}^{(1)}$ coefficients of the α_s expansion

Resummation for colour singlet production

Drell-Yan, Higgs, ... [Catani, Trentadue'89] [Sterman'87]

$$\sigma_{ij}^{(N)} = \hat{\sigma}_{0,\,ij}^{(N)} C_{ij} \Delta_i^{(N)} \Delta_j^{(N)} \Delta_{\mathrm{int},ij}^{(N)}$$

$\Delta_i^{(N)}$ soft gluons collinear to initial state partons (universal)

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

$\Delta_{\mathrm{int}}^{(N)}$ large-angle soft gluons (process-dependent)

$$\Delta_{\mathrm{int,ij}}^{N} = \exp\left\{ \int_0^1 dz \frac{z^{N-1}-1}{1-z} D_{ij}(\alpha_s((1-z)^2 Q^2)) \right\}$$

A_i,D_{ij} perturbative functions $\rightarrow$ Up to NLL, need to know $A_i^{(1)}$, $A_i^{(2)}$, $D_{ij}^{(1)}$ coefficients of the α_s expansion

Also process dependent:

C_{ij} N-independent finite coefficients

$\hat{\sigma}_{0,\,ij}^{(N)}$ LO partonic cross sections in N space

Resummation for non-trivial colour flow

[*Kidonakis, Sterman'96-97*][*Kidonakis, Oderda, Sterman'98*]

- Soft wide-angle gluon emission sensitive to colour flow of the underlying hard-scattering
  - for $\geq$ 4 partons: $\hat{\sigma}_0^{(N)} \Delta_{\rm int}^{(N)}$ has to be replaced by $\sum_{IJ} H_{0,IJ}^{(N)} S_{JI}^{(N)}$

  I,J : different colour structures

Resummation for non-trivial colour flow

[*Kidonakis, Sterman'96-97*][*Kidonakis, Oderda, Sterman'98*]

- Soft wide-angle gluon emission sensitive to colour flow of the underlying hard-scattering
  - for $\geq$ 4 partons: $\hat{\sigma}_0^{(N)} \Delta_{\rm int}^{(N)}$ has to be replaced by $\sum_{IJ} H_{0,IJ}^{(N)} S_{JI}^{(N)}$

  I,J : different colour structures
- Resummation of the soft emission from solving the RGE

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

Resummation for non-trivial colour flow

[*Kidonakis, Sterman'96-97*][*Kidonakis, Oderda, Sterman'98*]

- Soft wide-angle gluon emission sensitive to colour flow of the underlying hard-scattering
  - for ≥ 4 partons: $\hat{\sigma}_0^{(N)} \Delta_{\rm int}^{(N)}$ has to be replaced by $\sum_{IJ} H_{0,IJ}^{(N)} S_{JI}^{(N)}$

  I,J : different colour structures

- Resummation of the soft emission from solving the RGE

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

- The general solution for the soft function $S_{JI}^{(N)}$

$$\begin{aligned}\mathrm{Tr}\left(H^{(N)}\left(\frac{Q}{\mu}\right)S^{(N)}\left(\frac{Q}{\mu}\right)\right) = \quad & \mathrm{Tr}\quad\left[H^{(N)}(\frac{Q}{\mu})\bar{P}\exp\left(\int_{\mu}^{Q/N}\frac{dq}{q}\Gamma^{\dagger}(\alpha_{\rm s}(q^2))\right)\right.\\ & \times\quad \left. S^{(N)}(1)P\exp\left(\int_{\mu}^{Q/N}\frac{dq}{q}\Gamma(\alpha_{\rm s}(q^2))\right)\right]\end{aligned}$$

with $\Gamma(g) = -\frac{g}{2}\frac{\partial}{\partial g}\mathrm{Res}_{\epsilon\to 0}Z(g,\epsilon)$ $\qquad$ Z = renormalization constant for S

Resummation for $2 \to 2$ with colour flow

Simplification:

In orthogonal basis in colour space for which $\Gamma^{ij\to kl}$ is diagonal [*Kidonakis, Sterman'96-97*][*Bonciani, Catani, Mangano, Nason'98*]

$$\hat{\sigma}^{(N)}_{ij\to kl} = \sum_I \hat{\sigma}^{(N)}_{0,ij\to kl,I}\, \widetilde{C}_{ij\to kl,I}\, \Delta^i_{(N+1)}\, \Delta^j_{(N+1)}\, \Delta^{(N+1)}_{\rm (int),ij\to kl,I}$$

→ I corresponds to different colour channels

→ assume massive final state (no final state jet functions)

Resummation for $2 \to 2$ with colour flow

Simplification:

In orthogonal basis in colour space for which $\Gamma^{ij\to kl}$ is diagonal [*Kidonakis, Sterman'96-97*][*Bonciani, Catani, Mangano, Nason'98*]

$$\hat{\sigma}^{(N)}_{ij\to kl} = \sum_I \hat{\sigma}^{(N)}_{0,ij\to kl,I}\, \widetilde{C}_{ij\to kl,I}\, \Delta^i_{(N+1)}\, \Delta^j_{(N+1)}\, \Delta^{(N+1)}_{\mathrm{(int),ij\to kl,I}}$$

→ I corresponds to different colour channels

→ assume massive final state (no final state jet functions)

Radiative factor for soft non-collinear emission

$$\Delta^{(N+1)}_{\mathrm{(int),ij\to kl,I}} = \exp\left\{ \int_0^1 dz \frac{z^{N-1}-1}{1-z} D_{ij\to kl,I}(\alpha_{\mathrm{s}}((1-z)^2Q^2)) \right\}$$

related to Γ by

$$D_{ij\to kl,I} = 2\mathrm{Re}(\lambda_I) \qquad \text{for } \Gamma^{ij\to kl} = \mathrm{diag}(\lambda_1, \ldots)$$

Resummation for $2 \to 2$ with colour flow

Simplification:

In orthogonal basis in colour space for which $\Gamma^{ij\to kl}$ is diagonal [*Kidonakis, Sterman'96-97*][*Bonciani, Catani, Mangano, Nason'98*]

$$\hat{\sigma}^{(N)}_{ij\to kl} = \sum_I \hat{\sigma}^{(N)}_{0,ij\to kl,I}\, \widetilde{C}_{ij\to kl,I}\, \Delta^i_{(N+1)}\, \Delta^j_{(N+1)}\, \Delta^{(N+1)}_{\mathrm{(int),ij\to kl,I}}$$

→ I corresponds to different colour channels

→ assume massive final state (no final state jet functions)

Radiative factor for soft non-collinear emission

$$\Delta^{(N+1)}_{\mathrm{(int),ij\to kl,I}} = \exp\left\{\int_0^1 dz \frac{z^{N-1}-1}{1-z} D_{ij\to kl,I}(\alpha_\mathrm{s}((1-z)^2Q^2))\right\}$$

related to Γ by

$$D_{ij\to kl,I} = 2\mathrm{Re}(\lambda_I) \qquad \text{for } \Gamma^{ij\to kl} = \mathrm{diag}(\lambda_1,\dots)$$

In general need to know $\hat{\sigma}^{(N)}_{0,ij\to kl}$, $D^{(1)}_{ij\to kl}$, $\widetilde{C}_{ij\to kl}$ coefficients in each colour channel

Resummation for $\tilde{q}\bar{\tilde{q}}$ production

Colour structure same as for the heavy quark production $\Rightarrow \Gamma^{ij\to\tilde{q}\bar{\tilde{q}}} = \Gamma^{ij\to Q\bar{Q}}$

Resummation for $\tilde{q}\bar{\tilde{q}}$ production

Colour structure same as for the heavy quark production $\Rightarrow \Gamma^{ij\to\tilde{q}\bar{\tilde{q}}} = \Gamma^{ij\to Q\bar{Q}}$

- Coefficients $D^{(1)}_{ij\to Q\bar{Q},I}$ known [*Kidonakis, Sterman'96-97*][*Bonciani, Catani, Mangano, Nason'98*]

Resummation for $\tilde{q}\bar{\tilde{q}}$ production

Colour structure same as for the heavy quark production $\Rightarrow \Gamma^{ij\to\tilde{q}\bar{\tilde{q}}} = \Gamma^{ij\to Q\bar{Q}}$

- Coefficients $D^{(1)}_{ij\to Q\bar{Q},I}$ known [*Kidonakis, Sterman'96-97*][*Bonciani, Catani, Mangano, Nason'98*]
  - Singlet: $D^{(1)}_{ij\to\tilde{q}\bar{\tilde{q}},\mathbf{1}} = 0$
  - Octet: $D^{(1)}_{ij\to\tilde{q}\bar{\tilde{q}},\mathbf{8}} = -C_A$

Resummation for $\tilde{q}\bar{\tilde{q}}$ production

Colour structure same as for the heavy quark production $\Rightarrow \Gamma^{ij\to\tilde{q}\bar{\tilde{q}}} = \Gamma^{ij\to Q\bar{Q}}$

- Coefficients $D^{(1)}_{ij\to Q\bar{Q},I}$ known [Kidonakis, Sterman'96-97][Bonciani, Catani, Mangano, Nason'98]
  - Singlet: $D^{(1)}_{ij\to\tilde{q}\bar{\tilde{q}},\mathbf{1}} = 0$
  - Octet: $D^{(1)}_{ij\to\tilde{q}\bar{\tilde{q}},\mathbf{8}} = -C_A$
- Need $\hat{\sigma}^{(N)}_{0,ij\to\tilde{q}\bar{\tilde{q}},\mathbf{1}}$,$\hat{\sigma}^{(N)}_{0,ij\to\tilde{q}\bar{\tilde{q}},\mathbf{8}}$

Resummation for $\tilde{q}\bar{\tilde{q}}$ production

Colour structure same as for the heavy quark production $\Rightarrow \Gamma^{ij\to\tilde{q}\bar{\tilde{q}}} = \Gamma^{ij\to Q\bar{Q}}$

- Coefficients $D^{(1)}_{ij\to Q\bar{Q},I}$ known [*Kidonakis, Sterman'96-97*][*Bonciani, Catani, Mangano, Nason'98*]
  - Singlet: $D^{(1)}_{ij\to\tilde{q}\bar{\tilde{q}},\mathbf{1}} = 0$
  - Octet: $D^{(1)}_{ij\to\tilde{q}\bar{\tilde{q}},\mathbf{8}} = -C_A$
- Need $\hat{\sigma}^{(N)}_{0,ij\to\tilde{q}\bar{\tilde{q}},\mathbf{1}}$,$\hat{\sigma}^{(N)}_{0,ij\to\tilde{q}\bar{\tilde{q}},\mathbf{8}}$
- $C_{ij\to\tilde{q}\bar{\tilde{q}}}$ coefficients contain N-independent terms and Coulomb corrections (also possible to resum); for this calculation keep $\widetilde{C}^{(1)}_{ij\to\tilde{q}\bar{\tilde{q}},I} = 1$

Anomalous dimension for massive colour-octet pair

NLL anomalous dimensions known for all $2 \to 2$ massless QCD processes

[*Kidonakis, Oderda, Sterman'98*][*Bonciani, Catani, Mangano, Nason'03*]

Anomalous dimension for massive colour-octet pair

NLL anomalous dimensions known for all $2 \to 2$ massless QCD processes

[*Kidonakis, Oderda, Sterman'98*][*Bonciani, Catani, Mangano, Nason'03*]

Gluino production $ij \to \tilde{g}\tilde{g}$: massive colour-octet particles $\Rightarrow$ same colour structure as $ij \to gg$

Anomalous dimension for massive colour-octet pair

NLL anomalous dimensions known for all $2 \to 2$ massless QCD processes

[*Kidonakis, Oderda, Sterman'98*][*Bonciani, Catani, Mangano, Nason'03*]

Gluino production $ij \to \tilde{g}\tilde{g}$: massive colour-octet particles $\Rightarrow$ same colour structure as $ij \to gg$

- Analogously to $ij \to gg$, in the space of colour exchanges
  - $qq \to \tilde{g}\tilde{g}$ colour basis c_I consists of 3 tensors $\Rightarrow \Gamma^{q\bar{q}\to\tilde{g}\tilde{g}}$ is a 3×3 matrix
  - $gg \to \tilde{g}\tilde{g}$ colour basis c_I consists of 8 tensors $\Rightarrow \Gamma^{gg\to\tilde{g}\tilde{g}}$ is a 8×8 matrix

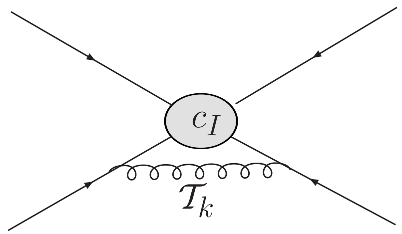
Anomalous dimension for massive colour-octet pair

NLL anomalous dimensions known for all $2 \to 2$ massless QCD processes

[*Kidonakis, Oderda, Sterman'98*][*Bonciani, Catani, Mangano, Nason'03*]

Gluino production $ij \to \tilde{g}\tilde{g}$: massive colour-octet particles $\Rightarrow$ same colour structure as $ij \to gg$

- Analogously to $ij \to gg$, in the space of colour exchanges
  - $qq \to \tilde{g}\tilde{g}$ colour basis c_I consists of 3 tensors $\Rightarrow \Gamma^{q\bar{q}\to\tilde{g}\tilde{g}}$ is a 3×3 matrix
  - $gg \to \tilde{g}\tilde{g}$ colour basis c_I consists of 8 tensors $\Rightarrow \Gamma^{gg\to\tilde{g}\tilde{g}}$ is a 8×8 matrix
- Evaluation of $\Gamma^{ij\to\tilde{g}\tilde{g}}$ requires one-loop integrals for gluon exchanges between all legs (vertex corrections) + self-energies; calculated in the eikonal approximation [*Kidonakis, Sterman'96*]
  Schematically:



$$\Gamma_{JI} = \sum_k \mathcal{T}_k(c_I)c_J^\dagger \left(-\frac{g}{2}\frac{\partial}{\partial g} I_k\Big|_{\frac{1}{\epsilon}\ \text{pole}}\right)$$

Example: anomalous dimension $\Gamma^{q\bar{q}\to\tilde{g}\tilde{g}}$

[*AK, L.Motyka'08*]

- Orthogonal s-channel basis ($\{c_I^q\}$ correspond to $\mathbf{1}$, $\mathbf{8}_S$ and $\mathbf{8}_A$ representations)

$$c_1^q = \delta^{\alpha_1\alpha_2}\,\delta^{a_3 a_4}, \quad c_2^q = T^b_{\alpha_2\alpha_1} d^{b a_3 a_4}, \quad c_3^q = iT^b_{\alpha_2\alpha_1} f^{b a_3 a_4},$$

Example: anomalous dimension $\Gamma^{q\bar{q}\to\tilde{g}\tilde{g}}$

[*AK, L.Motyka'08*]

- Orthogonal s-channel basis ($\{c_I^q\}$ correspond to $\mathbf{1}$, $\mathbf{8}_S$ and $\mathbf{8}_A$ representations)

$$c_1^q = \delta^{\alpha_1\alpha_2}\,\delta^{a_3a_4}, \quad c_2^q = T^b_{\alpha_2\alpha_1} d^{ba_3a_4}, \quad c_3^q = iT^b_{\alpha_2\alpha_1} f^{ba_3a_4},$$

- In this basis

$$\Gamma^{q\bar{q}\to\tilde{g}\tilde{g}} = \frac{\alpha_s}{\pi}\left[\begin{pmatrix} 6\bar{S} & 0 & -\Omega \\ 0 & 3\bar{S}+\frac{3}{2}\Lambda & -\frac{3}{2}\Omega \\ -2\Omega & -\frac{5}{6}\Omega & 3\bar{S}+\frac{3}{2}\Lambda \end{pmatrix} - \frac{4}{3}i\pi\,\hat{\mathbf{I}}\right]$$

$$\text{with} \quad \Lambda \equiv \bar{T}+\bar{U} \qquad \Omega \equiv \bar{T}-\bar{U}$$

$$\bar{T} \equiv \ln\left(\frac{m^2-\hat{t}}{\sqrt{m^2\hat{s}}}\right) - \frac{1-i\pi}{2}, \qquad \bar{U} \equiv \ln\left(\frac{m^2-\hat{u}}{\sqrt{m^2\hat{s}}}\right) - \frac{1-i\pi}{2}, \qquad \bar{S} \equiv -\frac{L_\beta+1}{2}$$

$$\hat{s} = (p_1+p_2)^2, \quad \hat{t} = (p_1-p_3)^2, \quad \hat{u} = (p_1-p_4)^2, \quad L_\beta = \frac{1}{\beta}(1-2m^2/\hat{s})\left(\ln\frac{1-\beta}{1+\beta} + i\pi\right)$$

Example: anomalous dimension $\Gamma^{q\bar{q}\to\tilde{g}\tilde{g}}$

[AK, L.Motyka'08]

- Orthogonal s-channel basis ($\{c_I^q\}$ correspond to $\mathbf{1}$, $\mathbf{8}_S$ and $\mathbf{8}_A$ representations)

$$c_1^q = \delta^{\alpha_1\alpha_2}\,\delta^{a_3a_4}, \quad c_2^q = T^b_{\alpha_2\alpha_1} d^{ba_3a_4}, \quad c_3^q = iT^b_{\alpha_2\alpha_1} f^{ba_3a_4},$$

- In this basis

$$\Gamma^{q\bar{q}\to\tilde{g}\tilde{g}} = \frac{\alpha_s}{\pi}\left[\begin{pmatrix} 6\bar{S} & 0 & -\Omega \\ 0 & 3\bar{S}+\frac{3}{2}\Lambda & -\frac{3}{2}\Omega \\ -2\Omega & -\frac{5}{6}\Omega & 3\bar{S}+\frac{3}{2}\Lambda \end{pmatrix} - \frac{4}{3} i\pi\,\hat{\mathbf{I}}\right]$$

$$\text{with} \quad \Lambda \equiv \bar{T}+\bar{U} \qquad \Omega \equiv \bar{T}-\bar{U}$$

$$\bar{T} \equiv \ln\left(\frac{m^2-\hat{t}}{\sqrt{m^2\hat{s}}}\right) - \frac{1-i\pi}{2}, \qquad \bar{U} \equiv \ln\left(\frac{m^2-\hat{u}}{\sqrt{m^2\hat{s}}}\right) - \frac{1-i\pi}{2}, \qquad \bar{S} \equiv -\frac{L_\beta+1}{2}$$

$$\hat{s} = (p_1+p_2)^2, \quad \hat{t} = (p_1-p_3)^2, \quad \hat{u} = (p_1-p_4)^2, \quad L_\beta = \frac{1}{\beta}(1-2m^2/\hat{s})\left(\ln\frac{1-\beta}{1+\beta}+i\pi\right)$$

- Similar procedure to obtain $\Gamma^{gg\to\tilde{g}\tilde{g}}$

Threshold limit for $\Gamma^{ij\to\tilde{g}\tilde{g}}$

- At the threshold $\hat{s} \to 4m^2$, $\Gamma^{ij\to\tilde{g}\tilde{g}}$ matrices for the s-channel colour bases become diagonal

$$\Gamma^{gg\to\tilde{g}\tilde{g}} \quad \to \quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^g,\,\gamma_2^g,\,\ldots,\,\gamma_8^g)\,,$$

$$\Gamma^{q\bar{q}\to\tilde{q}\tilde{q}} \quad \to \quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^q,\,\gamma_2^q,\,\gamma_3^q)$$

Threshold limit for $\Gamma^{ij\to\tilde{g}\tilde{g}}$

- At the threshold $\hat{s} \to 4m^2$, $\Gamma^{ij\to\tilde{g}\tilde{g}}$ matrices for the s-channel colour bases become diagonal

$$\begin{aligned}\Gamma^{gg\to\tilde{g}\tilde{g}} &\quad\to\quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^g,\,\gamma_2^g,\,\ldots,\,\gamma_8^g)\,,\\ \Gamma^{q\bar{q}\to\tilde{q}\bar{q}} &\quad\to\quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^q,\,\gamma_2^q,\,\gamma_3^q)\end{aligned}$$

- The resummation formula simplifies with [*Kidonakis, Oderda, Sterman'98*]

$$\begin{aligned}D^{(1)}_{gg\to\tilde{g}\tilde{g},\,I} &= 2\mathrm{Re}(\gamma_I^g)\\ D^{(1)}_{q\bar{q}\to\tilde{g}\tilde{g},\,I} &= 2\mathrm{Re}(\gamma_I^q)\end{aligned}$$

Threshold limit for $\Gamma^{ij\to\tilde{g}\tilde{g}}$

- At the threshold $\hat{s}\to 4m^2$, $\Gamma^{ij\to\tilde{g}\tilde{g}}$ matrices for the s-channel colour bases become diagonal

$$\Gamma^{gg\to\tilde{g}\tilde{g}} \quad\to\quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^g,\,\gamma_2^g,\,\ldots,\,\gamma_8^g)\,,$$
$$\Gamma^{q\bar{q}\to\tilde{q}\tilde{q}} \quad\to\quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^q,\,\gamma_2^q,\,\gamma_3^q)$$

- The resummation formula simplifies with [*Kidonakis, Oderda, Sterman'98*]

$$D^{(1)}_{gg\to\tilde{g}\tilde{g},\,I} \quad=\quad 2\mathrm{Re}(\gamma_I^g)$$
$$D^{(1)}_{q\bar{q}\to\tilde{g}\tilde{g},\,I} \quad=\quad 2\mathrm{Re}(\gamma_I^q)$$

  - $\{D^{(1)}_{q\bar{q}\to\tilde{g}\tilde{g},\,I}\}=\{0,-3,-3\}$
  - $\{D^{(1)}_{gg\to\tilde{g}\tilde{g},\,I}\}=\{0,-3,-3,-6,-8;-3,-3,-6\}$

Threshold limit for $\Gamma^{ij\to\tilde{g}\tilde{g}}$

- At the threshold $\hat{s} \to 4m^2$, $\Gamma^{ij\to\tilde{g}\tilde{g}}$ matrices for the s-channel colour bases become diagonal

$$\Gamma^{gg\to\tilde{g}\tilde{g}} \quad \to \quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^g,\, \gamma_2^g,\, \ldots,\, \gamma_8^g)\,,$$
$$\Gamma^{q\bar{q}\to\tilde{q}\tilde{q}} \quad \to \quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^q,\, \gamma_2^q,\, \gamma_3^q)$$

- The resummation formula simplifies with [*Kidonakis, Oderda, Sterman'98*]

$$D^{(1)}_{gg\to\tilde{g}\tilde{g},\,I} \quad = \quad 2\mathrm{Re}(\gamma_I^g)$$
$$D^{(1)}_{q\bar{q}\to\tilde{g}\tilde{g},\,I} \quad = \quad 2\mathrm{Re}(\gamma_I^q)$$

  - $\{D^{(1)}_{q\bar{q}\to\tilde{g}\tilde{g},\,I}\} = \{0, -3, -3\}$
  - $\{D^{(1)}_{gg\to\tilde{g}\tilde{g},\,I}\} = \{0, -3, -3, -6, -8; -3, -3, -6\}$

- Values of the quadratic Casimir operators for the SU(3) representations for the outgoing state $\to$ soft gluon radiation from the total colour charge of the heavy-particle pair produced at threshold

Threshold limit for $\Gamma^{ij\to\tilde{g}\tilde{g}}$

- At the threshold $\hat{s} \to 4m^2$, $\Gamma^{ij\to\tilde{g}\tilde{g}}$ matrices for the s-channel colour bases become diagonal

$$\Gamma^{gg\to\tilde{g}\tilde{g}} \quad \to \quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^g,\, \gamma_2^g,\, \ldots,\, \gamma_8^g)\,,$$
$$\Gamma^{q\bar{q}\to\tilde{q}\tilde{q}} \quad \to \quad \frac{\alpha_s}{\pi}\,\mathrm{diag}\,(\gamma_1^q,\, \gamma_2^q,\, \gamma_3^q)$$

- The resummation formula simplifies with [*Kidonakis, Oderda, Sterman'98*]

$$D^{(1)}_{gg\to\tilde{g}\tilde{g},\, I} \quad = \quad 2\mathrm{Re}(\gamma_I^g)$$
$$D^{(1)}_{q\bar{q}\to\tilde{g}\tilde{g},\, I} \quad = \quad 2\mathrm{Re}(\gamma_I^q)$$

  - $\{D^{(1)}_{q\bar{q}\to\tilde{g}\tilde{g},\, I}\} = \{0, -3, -3\}$
  - $\{D^{(1)}_{gg\to\tilde{g}\tilde{g},\, I}\} = \{0, -3, -3, -6, -8; -3, -3, -6\}$

- Values of the quadratic Casimir operators for the SU(3) representations for the outgoing state $\to$ soft gluon radiation from the total colour charge of the heavy-particle pair produced at threshold
- Need $\hat{\sigma}^{(N)}_{0,ij\to\tilde{g}\tilde{g},I}$, coefficient $\widetilde{C}^{(1)}_{ij\to\tilde{g}\tilde{g},I} = 1$

Resummation-improved NLL+NLO total cross section

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

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

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

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

Resummation-improved NLL+NLO total cross section

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

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

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

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

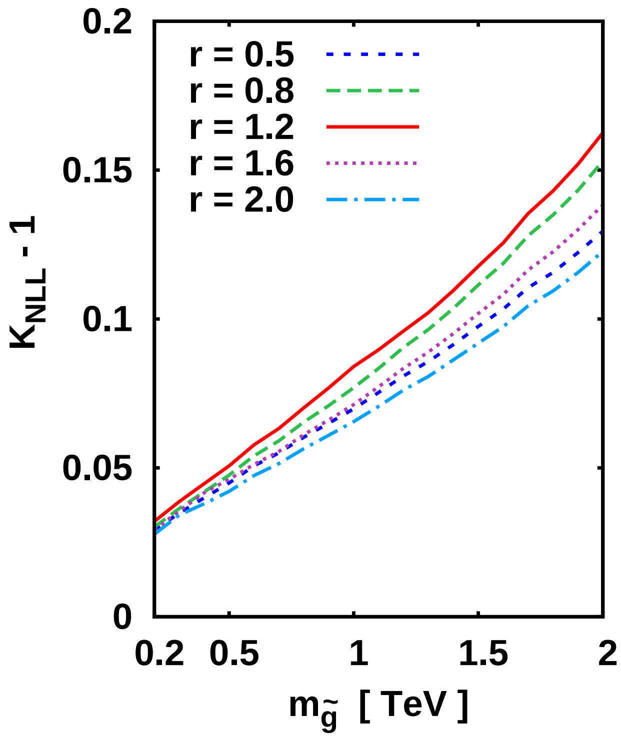
- Inverse Mellin transform evaluated using a contour in the complex N space according to 'Minimal Prescription' [Catani, Mangano, Nason Trentadue'96]
- NLO cross sections evaluated with publicly available code PROSPINO

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

[Plehn, http://www.ph.ed.ac.uk/ tplehn/prospino/]

NLL gluino-pair production at the LHC

[*AK, L. Motyka'08*]



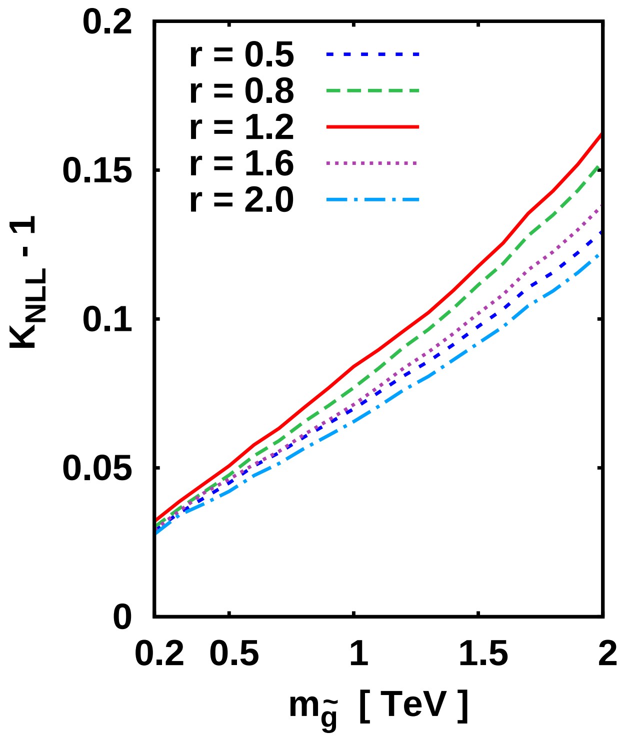
$$\mathrm{K}^{\mathrm{NLL}} = \frac{\sigma^{\mathrm{match}}}{\sigma^{\mathrm{NLO}}}$$

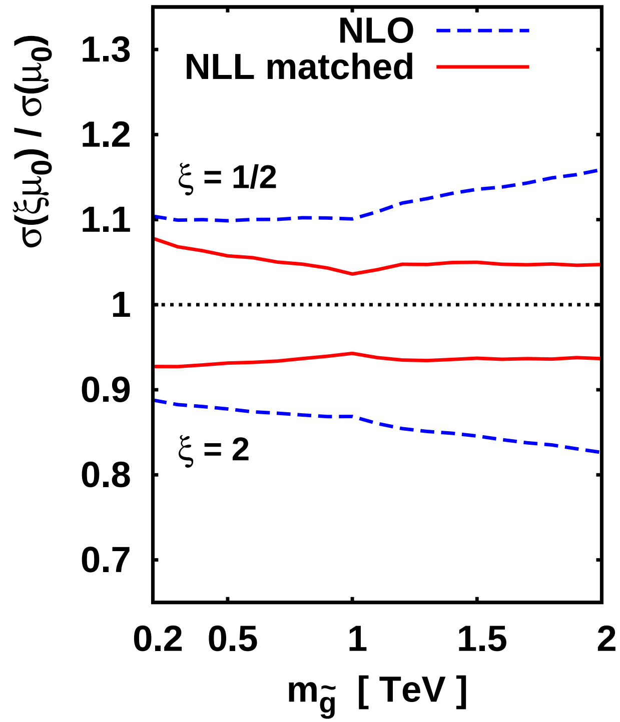
$$r = \frac{m_{\tilde{g}}}{m_{\tilde{q}}}$$

$$(\mu_F = \mu_R = m_{\tilde{g}})$$

NLL gluino-pair production at the LHC

[*AK, L. Motyka'08*]





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

$$r = \frac{m_{\tilde{g}}}{m_{\tilde{q}}}$$

$$(\mu_F = \mu_R = m_{\tilde{g}})$$

$$\sigma^{\mathrm{NLO}}(\mu = \xi m_{\tilde{g}})/\sigma^{\mathrm{NLO}}(\mu = m_{\tilde{g}})$$

vs.

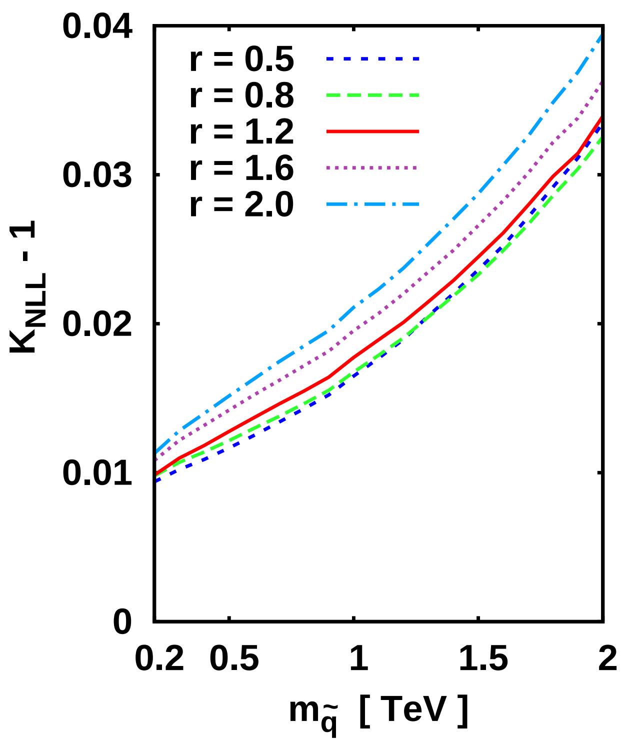
$$\sigma^{(\mathrm{match})}(\mu = \xi m_{\tilde{g}})/\sigma^{(\mathrm{match})}(\mu = m_{\tilde{g}})$$

for $\xi = 0.5$ and $\xi = 2$

$$(\mu = \mu_F = \mu_R; r = 1.2)$$

NLL squark-antisquark production at the LHC

[*AK, L. Motyka'08*]



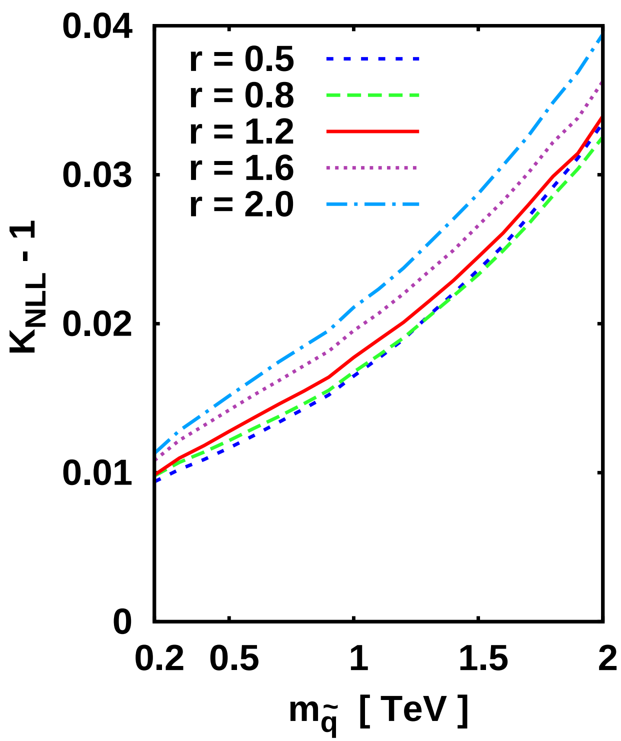
$$\mathrm{K}^{\mathrm{NLL}} = \frac{\sigma^{\mathrm{match}}}{\sigma^{\mathrm{NLO}}}$$

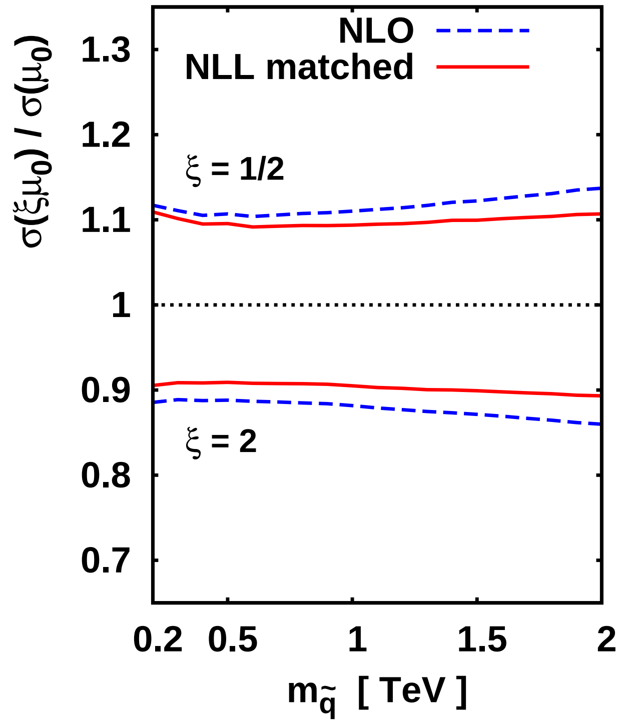
$$r = \frac{m_{\tilde{g}}}{m_{\tilde{q}}}$$

$$(\mu_F = \mu_R = m_{\tilde{q}})$$

NLL squark-antisquark production at the LHC

[*AK, L. Motyka'08*]





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

$$r = \frac{m_{\tilde{g}}}{m_{\tilde{q}}}$$

$$(\mu_F = \mu_R = m_{\tilde{q}})$$

$$\sigma^{\mathrm{NLO}}(\mu = \xi m_{\tilde{q}})/\sigma^{\mathrm{NLO}}(\mu = m_{\tilde{q}})$$

vs.

$$\sigma^{(\mathrm{match})}(\mu = \xi m_{\tilde{q}})/\sigma^{(\mathrm{match})}(\mu = m_{\tilde{q}})$$

for $\xi = 0.5$ and $\xi = 2$

$$(\mu = \mu_F = \mu_R; r = 1.2)$$

Coulomb corrections

Leading Coulomb corrections

$$\alpha_s^n/\beta^n \qquad \text{wrt. LO}$$

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

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

$$X_{ij\to kl,\ I} = \pi\alpha_s C_{ij\to kl,\ I}/\beta$$

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

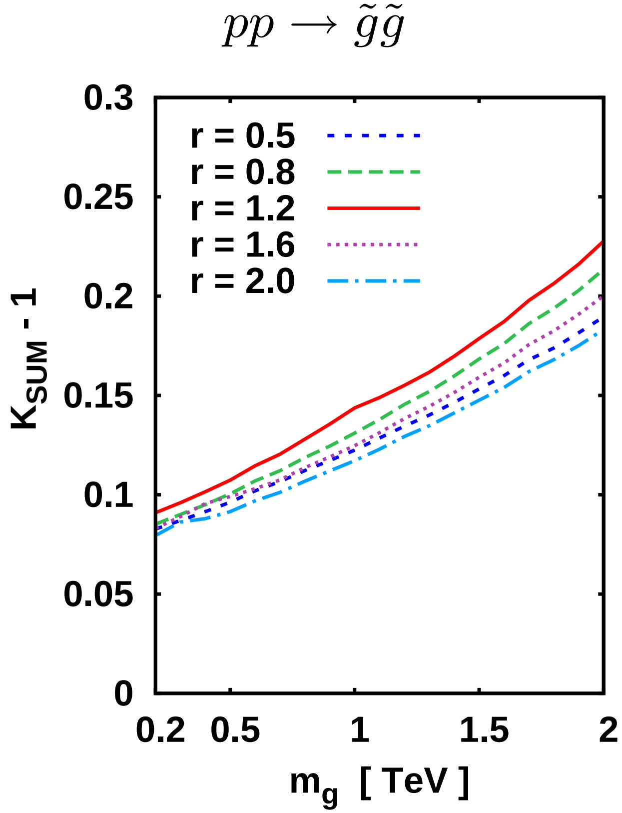
Define the "Coulomb K-factor" as

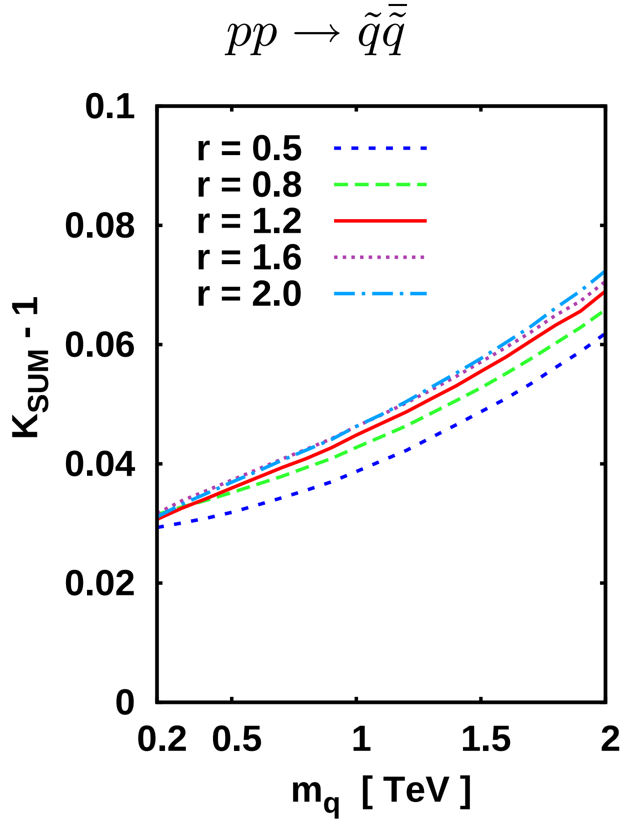
$$K^{\text{Coul}}_{ij\to kl} = \frac{\hat{\sigma}^{\text{Coul}}_{ij\to kl} - \hat{\sigma}^{\text{Coul}}_{ij\to kl}|_{\text{NLO}}}{\sigma^{\text{NLO}}_{ij\to kl}}$$

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

[*AK, L. Motyka, in prep.*]

Soft + Coulomb corrections





Summary

- If SUSY realized in Nature, $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production will be among the most dominant mechanisms of sparticle production at the LHC
  - SUSY discovery through $\tilde{q}$ and $\tilde{g}$ production

Summary

- If SUSY realized in Nature, $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production will be among the most dominant mechanisms of sparticle production at the LHC
  - SUSY discovery through $\tilde{q}$ and $\tilde{g}$ production
- Knowledge of total cross section crucial for establishing exclusion limits, useful for mass determination

Summary

- If SUSY realized in Nature, $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production will be among the most dominant mechanisms of sparticle production at the LHC
  - SUSY discovery through $\tilde{q}$ and $\tilde{g}$ production
- Knowledge of total cross section crucial for establishing exclusion limits, useful for mass determination
- NLL resummed (matched with NLO) predictions for total cross sections in $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ hadroproduction: corrections due to soft gluon emissions above NLO

Summary

- If SUSY realized in Nature, $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production will be among the most dominant mechanisms of sparticle production at the LHC
  - SUSY discovery through $\tilde{q}$ and $\tilde{g}$ production
- Knowledge of total cross section crucial for establishing exclusion limits, useful for mass determination
- NLL resummed (matched with NLO) predictions for total cross sections in $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ hadroproduction: corrections due to soft gluon emissions above NLO
- Anomalous dimension for any $2 \to 2$ process involving pair of massive colour-octet particles in the final state
  - confirms physical picture: at threshold soft gluon radiation from the total charge of the heavy-particle pair

Summary

- If SUSY realized in Nature, $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production will be among the most dominant mechanisms of sparticle production at the LHC
  - SUSY discovery through $\tilde{q}$ and $\tilde{g}$ production
- Knowledge of total cross section crucial for establishing exclusion limits, useful for mass determination
- NLL resummed (matched with NLO) predictions for total cross sections in $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ hadroproduction: corrections due to soft gluon emissions above NLO
- Anomalous dimension for any $2 \to 2$ process involving pair of massive colour-octet particles in the final state
  - confirms physical picture: at threshold soft gluon radiation from the total charge of the heavy-particle pair
- For $\tilde{g}\tilde{g}$ production at the LHC:
  - NLL effects provide $\mathcal{O}(10\%)$ correction for $1\,\mathrm{TeV} \lesssim m_{\tilde{g}} \lesssim 2\,\mathrm{TeV}$.
  - Significant reduction of sensitivity to scale choices

Summary

- If SUSY realized in Nature, $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ production will be among the most dominant mechanisms of sparticle production at the LHC
  - SUSY discovery through $\tilde{q}$ and $\tilde{g}$ production
- Knowledge of total cross section crucial for establishing exclusion limits, useful for mass determination
- NLL resummed (matched with NLO) predictions for total cross sections in $\tilde{q}\bar{\tilde{q}}$ and $\tilde{g}\tilde{g}$ hadroproduction: corrections due to soft gluon emissions above NLO
- Anomalous dimension for any $2 \to 2$ process involving pair of massive colour-octet particles in the final state
  - confirms physical picture: at threshold soft gluon radiation from the total charge of the heavy-particle pair
- For $\tilde{g}\tilde{g}$ production at the LHC:
  - NLL effects provide $\mathcal{O}(10\%)$ correction for $1\,\mathrm{TeV} \lesssim m_{\tilde{g}} \lesssim 2\,\mathrm{TeV}$.
  - Significant reduction of sensitivity to scale choices
- Smaller NLL effects for $\tilde{q}\bar{\tilde{q}}$ at the LHC