Soft-gluon resummation for squark and gluino hadroproduction

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and work in preparation

Outline

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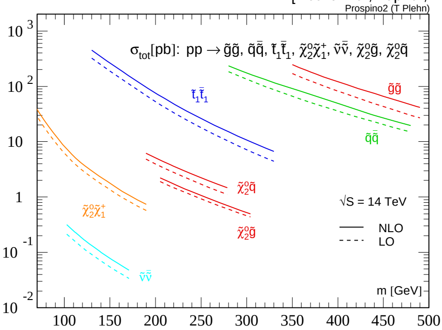
Framework: MSSM with R-parity conservation

LHC: [Beenakker,Höpker,Krämer,Plehn,Spira,Zerwas'96-'98]

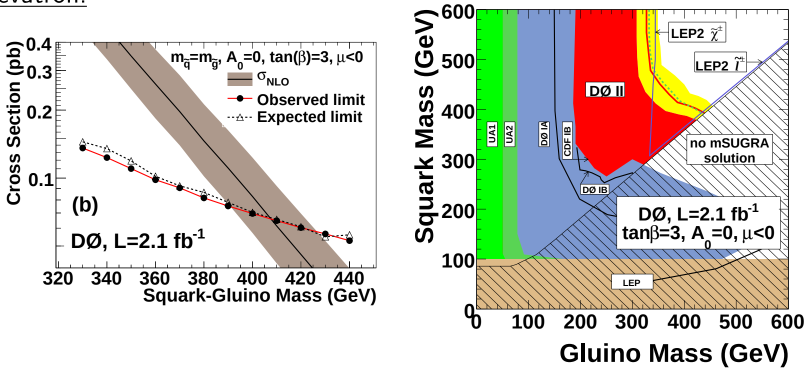


- dominated by processes involving coloured particles in the final state: $\tilde{q}\bar{\tilde{q}}, \tilde{q}\tilde{q}, \tilde{g}\tilde{g}, \tilde{q}\tilde{g}$ and $\tilde{t}_1\bar{\tilde{t}}_1$
  Note: Assume all squarks $\tilde{q} = (\tilde{q}_L, \tilde{q}_R)$ with $\tilde{q} \neq \tilde{t}$ mass degenerate
  - $\tilde{t} = (\tilde{t}_L, \tilde{t}_R)$ mix to form mass eigenstates $\tilde{t}_1, \tilde{t}_2 \rightarrow$ potentially small $m_{\tilde{t}_1}$
- total cross sections are used to determine the masses in case of discovery

- total cross sections are used to derive exclusion limits

[D0, PL B660, 449, '08]

Tevatron:



⇒ precise theoretical predictions are needed

Introduction

Squark and gluino production at hadron colliders

- NLO SUSY-QCD corrections [Beenakker et al.'96][Beenakker et al.'97]
- NLL-resummed corrections ($\tilde{q}\bar{\tilde{q}}, \tilde{g}\tilde{g}$) [Kulesza, Motyka '08,'09]
- combined (soft-gluon & Coulomb) NLL-resummed corrections ($\tilde{q}\bar{\tilde{q}}$) [Beneke, Falgari, Schwinn '09,'10]
- approximate NNLO contributions ($\tilde{q}\bar{\tilde{q}}$) [Langenfeld, Moch '09]

- NLO EW corrections [Beccaria et al. '07,'08][Hollik, Kollar, Trenkel '07][Hollik, Mirabella '08] [Hollik, Mirabella, Trenkel '08][Mirabella '09][Germer et al. '10]
- LO EW and QCD-EW interference [Bozzi, Fuks, Klasen '05][Alan, Cankocak, Demir '07] [Bornhauser et al '07][Hollik, Kollar, Trenkel '07][Hollik, Mirabella '08][Hollik, Mirabella, Trenkel '08][Germer et al. '10]

- bound state effects in $\tilde{g}\tilde{g}$-production (NLO QCD potential) [Hagiwara, Yokoya '09]
- gluinonia production and decay (NLO QCD) and energy levels (NNLO QCD potential) [Kauth et al. '09]

Introduction

NLO SUSY-QCD calculation

[Beenakker et al. '96]

- large positive corrections $K_{\rm NLO} = \frac{\sigma_{\rm NLO}}{\sigma_{\rm LO}} \sim 1.0 - 1.9$ depending on process and on m_q, m_g
- significant part can be attributed to threshold region $\hat{s} \sim 4m^2$
- threshold behaviour of NLO partonic cross section: $\beta = \sqrt{1-\hat{\rho}} \rightarrow 0$ with $\hat{\rho} = \frac{4m^2}{\hat{s}}$

$$\hat{\sigma}^{\rm NLO} \propto \hat{\sigma}^{\rm LO} \left\{ \frac{\alpha_s}{\pi} \left(a \log^2(\beta^2) + b \log(\beta^2) + c \log(\beta^2) \log\left(\frac{\mu^2}{m^2}\right) + d \frac{1}{\beta} \right) \right\}$$

  - logarithmic terms $\log^i \beta^2 (i = 1, 2)$ result from soft-gluon emission and become large at threshold
  - $1/\beta$-term: Coulomb corrections

$\rightarrow$ can be taken into account to all orders in perturbation theory by means of threshold resummation

Outline

1. Introduction
2. Soft-gluon resummation
   - Introduction
   - Numerical results for squark and gluino pair-production processes
     - total cross sections
   - Numerical results for stop pair-production
     - total cross sections
     - p_T-distributions
3. Summary

Soft-gluon resummation
Introduction

schematic perturbative expansion ($L = \log\left(\beta^2\right)$)

$$
\begin{aligned}
d\sigma = 1 \\
&+ \alpha_s(L^2 + L + 1) \\
&+ \alpha_s^2(L^4 + L^3 + L^2 + L + 1) \\
&\vdots \\
&+ \alpha_s^n(\underbrace{L^{2n}}_{\text{LL}} + \underbrace{L^{2n-1}}_{\text{NLL}} + \cdots)
\end{aligned}
$$

$\rightarrow$ even for small α_s convergent behaviour spoiled

Resummation=organisation of large logs in perturbative expansions

$$\sigma^{\text{res}} = \sigma^{\text{LO}} \exp\left(\underbrace{L g_1(\alpha_s L)}_{\text{LL}} + \underbrace{g_2(\alpha_s L)}_{\text{NLL}} + \ldots\right) + \text{suppressed terms}$$

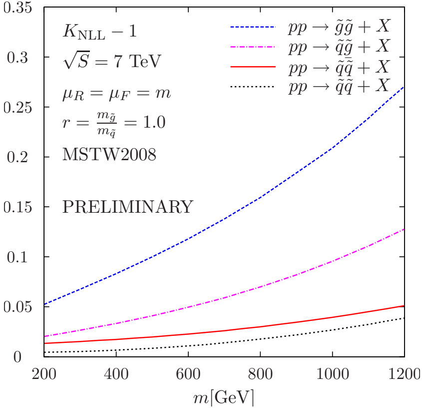
- summation of these logs to all orders

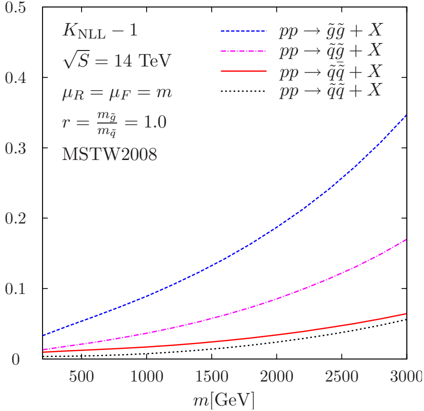
Numerical results

for all possible squark and gluino pair-production processes

$$K_{\mathrm{NLL}} = \frac{\sigma^{\mathrm{NLL+NLO}}}{\sigma^{\mathrm{NLO}}}$$

[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen '09]



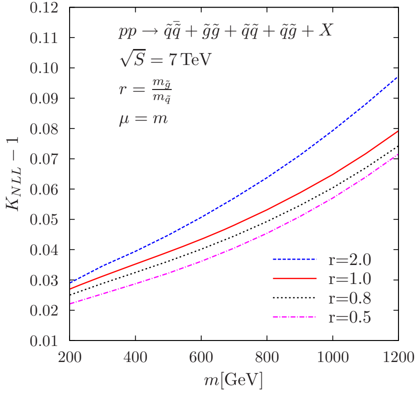


- calculated numerical results for various mass ratios: r=0.5..2.0, here shown for r=1.0
- large effects for processes involving large colour charge, i.e. initial state gluons and final state gluinos

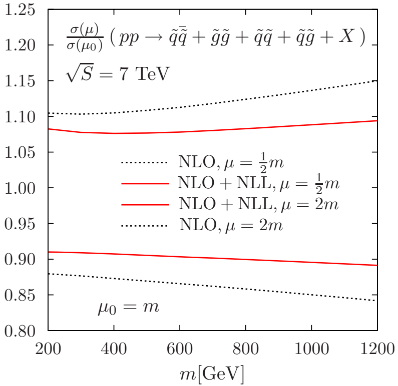
Numerical results

for inclusive squark and gluino production

K_{NLL} for $p\bar{p}/pp \to \tilde{q}\bar{\tilde{q}} + \tilde{q}\tilde{q} + \tilde{q}\tilde{g} + \tilde{g}\tilde{g} + X$



[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen, in prep.]
[PRELIMINARY]



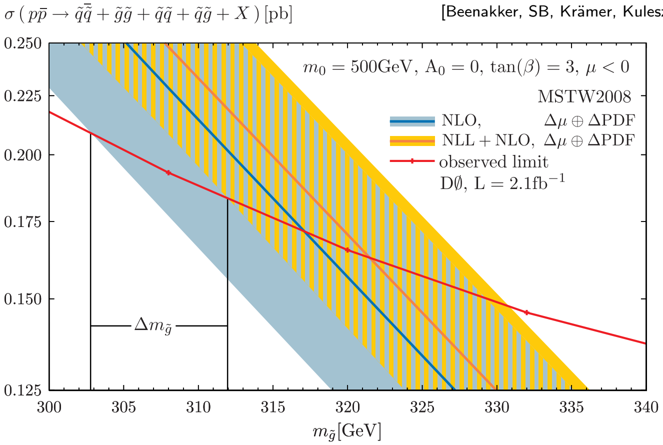
- significant reduction of theoretical uncertainty due to scale variation
- reduced scale sensitivity for each single process $p\bar{p}/pp \to \tilde{q}\bar{\tilde{q}}, \tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g} + X$

Numerical results

for inclusive squark and gluino production

- $\sigma^{\text{NLO+NLL}}$ most accurate theoretical prediction currently available
- can e.g. be used to improve Tevatron sparticle bounds (reanalysis of data currently ongoing)

[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen, in prep.]

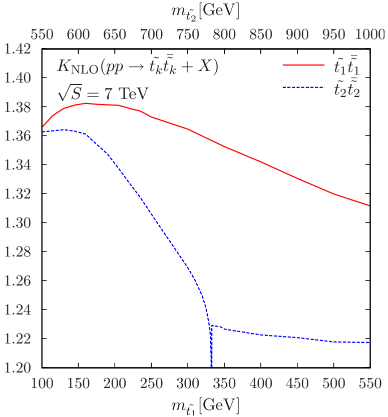


Numerical results

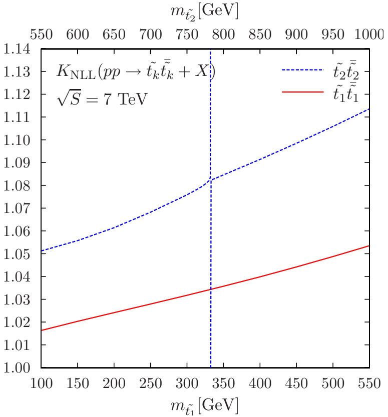
for stop pair-production

K-factors:

[Beenakker et al.,'97]PROSPINO



[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen, '10]



SPS1a': $m_{\tilde{t}_1} = 367\mathrm{GeV}$, $m_{\tilde{t}_2} = 590\mathrm{GeV}$, $m_{\tilde{q}} = 560\mathrm{GeV}$, $m_{\tilde{g}} = 610\mathrm{GeV}$, $\sin(2\Theta) = 0.932$

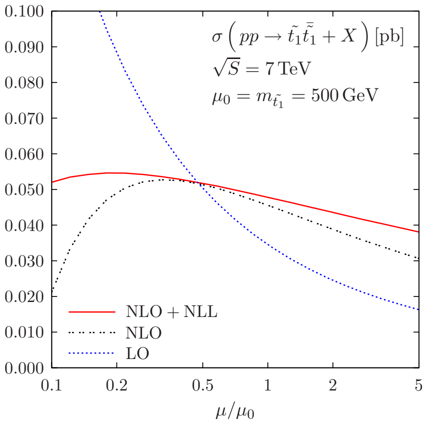
- MSSM parameter dependence numerically small
- also apply to sbottom-pair production (bottom-induced contributions numerically negligible)

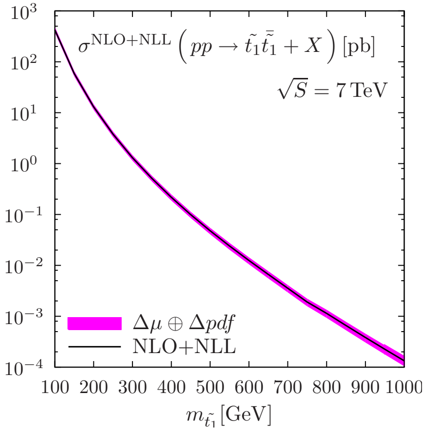
Numerical results

for stop pair-production

[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen, '10]

Scale dependence:



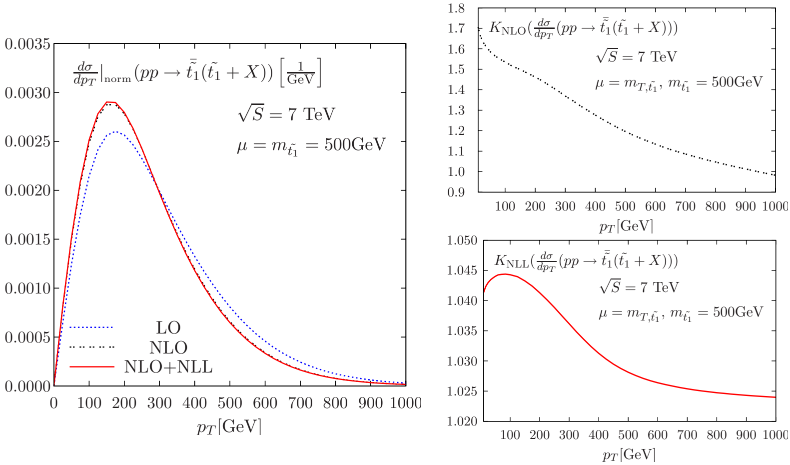


Numerical results

for stop pair-production

Single-particle transverse momentum distribution:

[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen, '10]



Outline

Summary

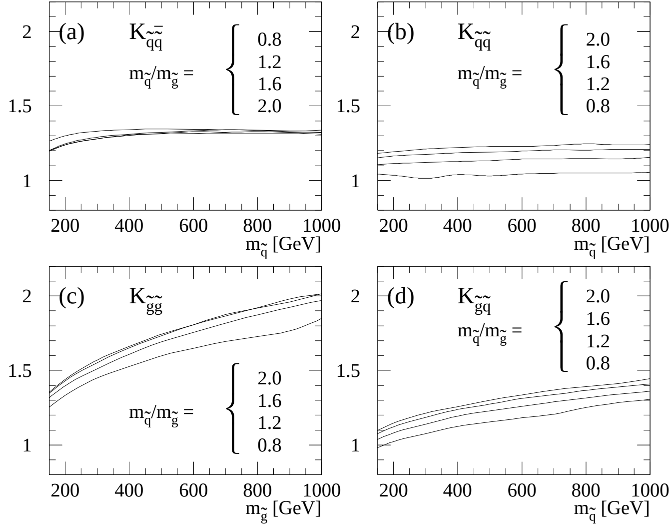
- Squark, gluino and stop production processes are the most dominant channels for sparticle production at the LHC
- NLO+NLL matched predictions for total cross sections for all possible squark and gluino pair-production processes at the Tevatron and the LHC
  - significant enhancement of NLO cross section predictions ($\sim$ 5%-40%)
  - most pronounced for processes involving large colour charge
  - significant reduction of theoretical error due to scale variation
- NLO+NLL matched predictions for stop/sbottom pair-production: total cross sections & p_T-distributions (Tevatron & LHC)
  - enhancement of NLO predictions, K_{NLL} up to 10%
  - reduction of theoretical error due to scale variation
  - SUSY parameter dependence small $\lesssim 2\%$
  - can change the shape of p_T distributions considerably

$\rightarrow$ should be used to interpret current and future searches for SUSY

Numerical results

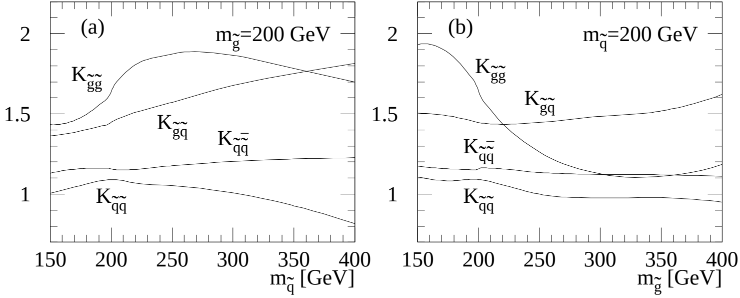
NLO SUSY-QCD calculation

[Beenakker et al. '06]



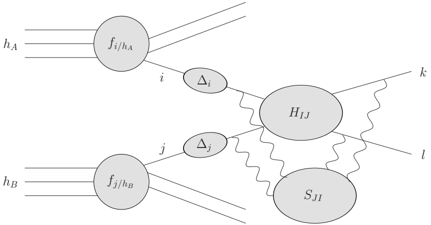
Numerical results
NLO SUSY-QCD calculation

[Beenakker et al. '06]



Threshold resummation for coloured particles

[Contopanagos, Kidonakis, Laenen, Oderda, Sterman '96-'98; Bonciani, Catani, Mangano, Nason '98]



schematically:

$$\hat{\sigma} = \Delta_i \Delta_j \otimes S \otimes H \quad \xrightarrow[\text{Mellin transf.}]{} \quad \hat{\sigma}_N = \overbrace{\Delta_i \Delta_j}^{\text{universal}} \quad \overbrace{\sum_{IJ} H_{IJ} S_{JI}}^{\text{process-dependent}}$$

$$\hat{\sigma}^{\text{res}}_{ij\to kl,N} = \underbrace{\Delta^i_{N+1}\,\Delta^j_{N+1}}_{\text{soft-collinear (universal)}} \sum_I \hat{\sigma}^{\text{LO}}_{ij\to kl,I,N} \underbrace{\Delta^S_{ij\to kl,I,N+1}}_{\text{soft non-collinear (process-dependent)}}$$

I: different colour channels

$$\sigma^{\text{res}}_{h_A h_B\to kl,N} = \sum_{i,j} f^{(N+1)}_{i/h_A} f^{(N+1)}_{j/h_B}\, \hat{\sigma}^{\text{res}}_{ij\to kl,N}$$

$\to$ Calculation of σ^{res} up to NLL accuracy & matching with NLO: $\sigma_{\text{NLL+NLO}}$

Matching with NLO

- matching of NLL-resummed with NLO

$$\sigma^{\mathrm{NLL+NLO}}_{h_A h_B \to kl}(\rho, m^2, \mu_F^2, \mu_R^2) = \sum_{i,j} \overbrace{\int_{C-i\infty}^{C+i\infty} \frac{dN}{2\pi i}\, \rho^{-N}}^{\text{inv. Mellin transf.}} f^{(N+1)}_{i/h_A}(\mu_F^2)\, f^{(N+1)}_{j/h_B}(\mu_F^2)$$

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

$$+ \sigma^{\mathrm{NLO}}_{h_A h_B \to kl}(\rho, m^2, \mu_F^2, \mu_R^2)$$

with $\rho = \frac{4m^2}{S}$

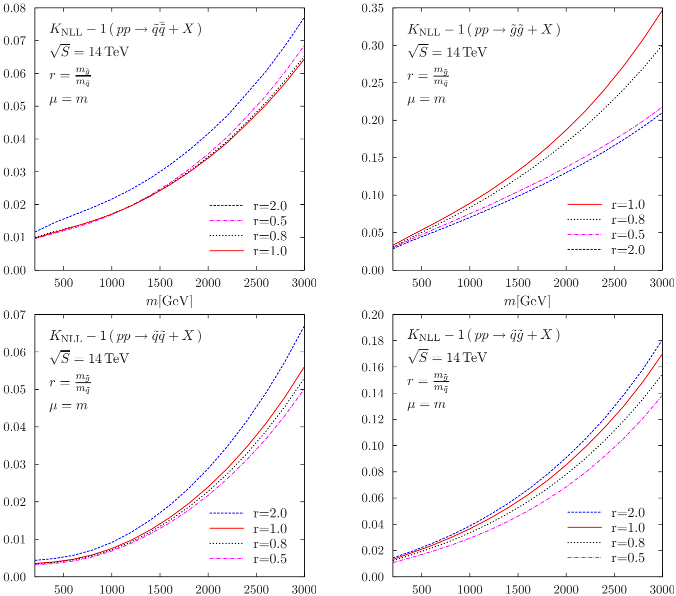
- NLO cross section calculated with PROSPINO

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

Numerical results

K_{NLL}

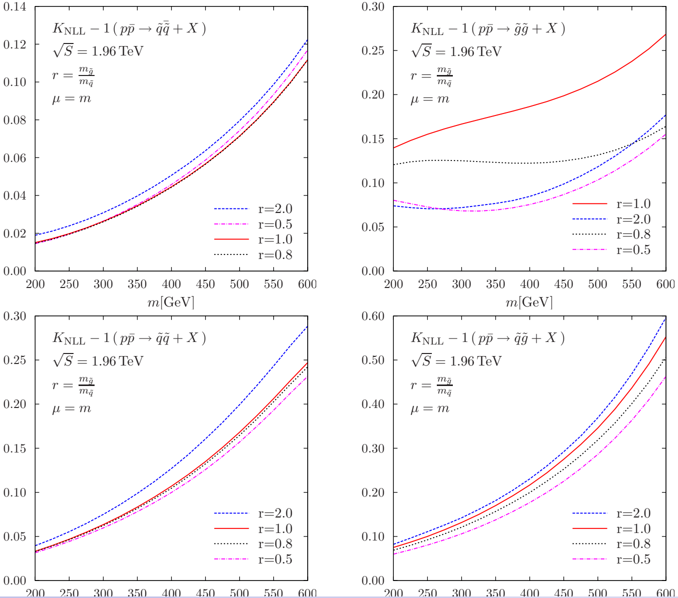
[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen '09]



Numerical results

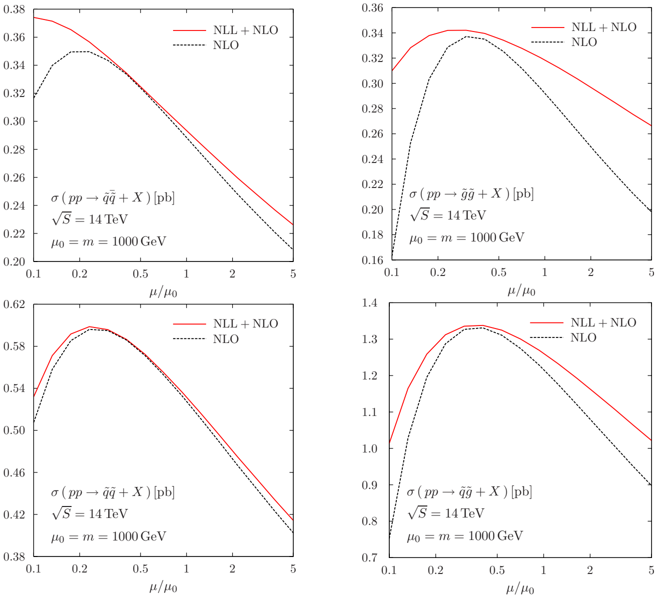
K_{NLL}

[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen '09]



Scale variation

[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen '09]



Numerical results

Scale variation

[Beenakker, SB, Krämer, Kulesza, Laenen, Niessen '09]