Squark and gluino production at the LHC

Anna Kulesza RWTH AACHEN

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

AK and L. Motyka, arXiv:0905.4749 [hep-ph]

W. Beenakker, S. Brensing, M. Krämer, AK, E. Laenen and I. Niessen, in preparation

The 2009 Europhysics Conference on High Energy Physics

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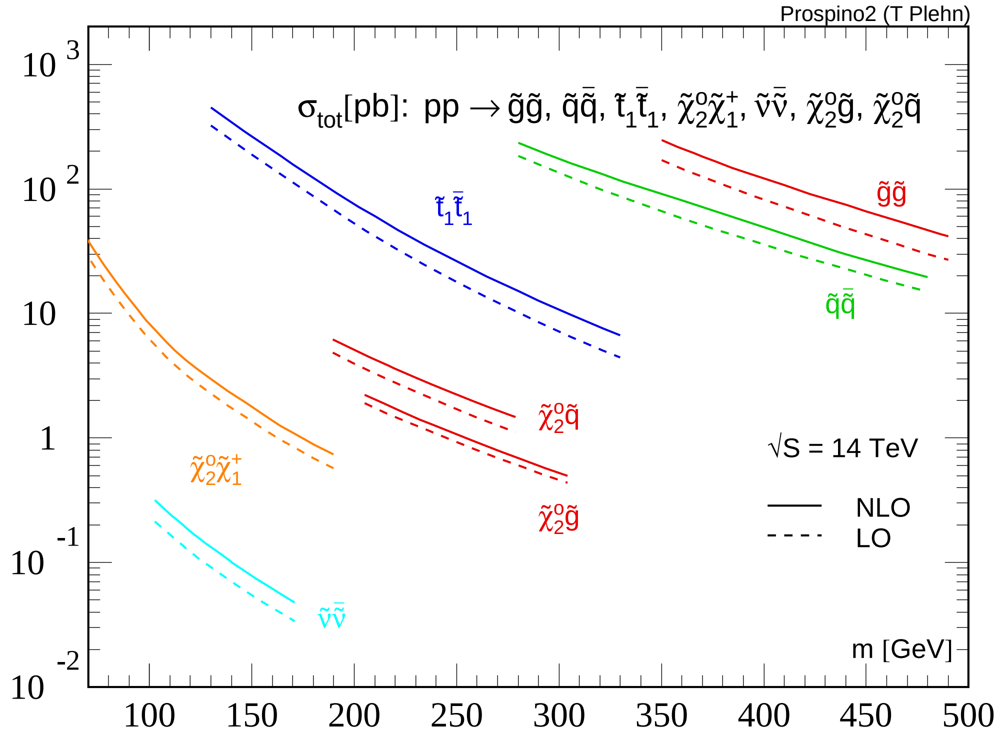
SUSY particle pair-production at the LHC

- 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)

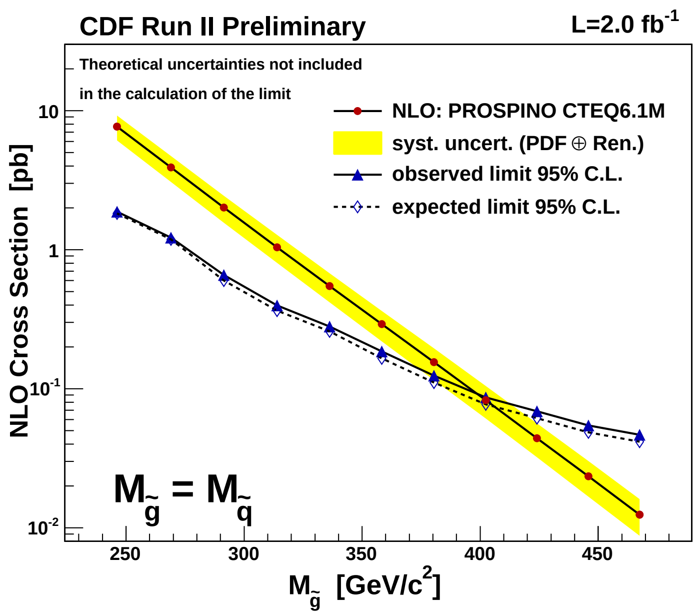


[*Plehn, Prospino2*]

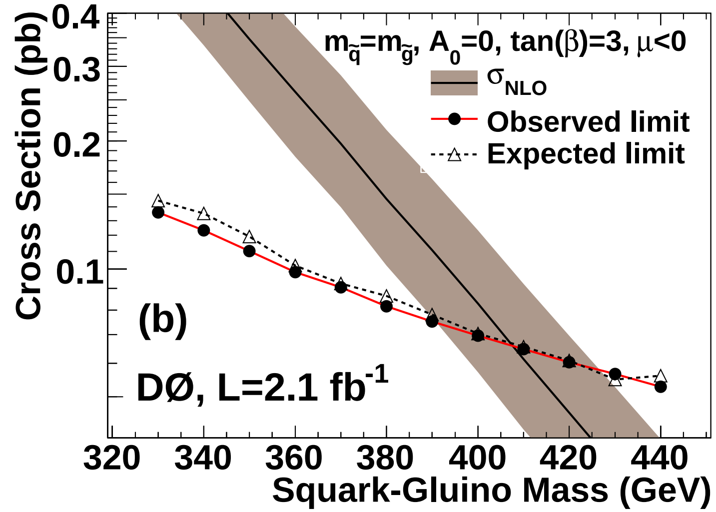
- Production cross sections large ⇒ "easy" SUSY discovery

Total cross sections

- Total cross sections: crucial for exclusion limits / useful for mass determination in case of discovery



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



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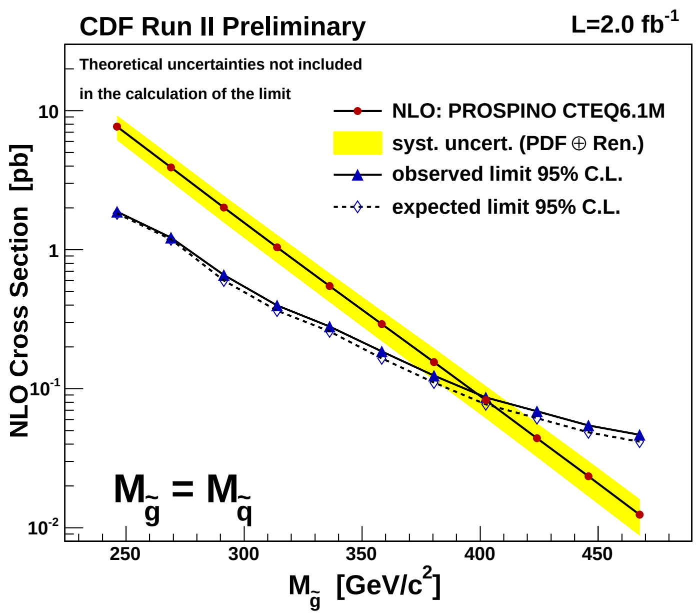

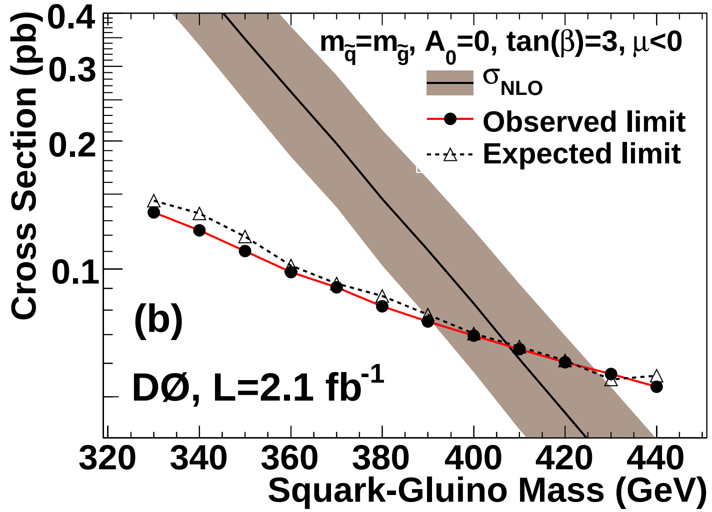

$(A_0 = 0, sgn(\mu) = -1, \tan\beta = 5)$

- Important to know total cross sections with high precision

Theoretical status

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

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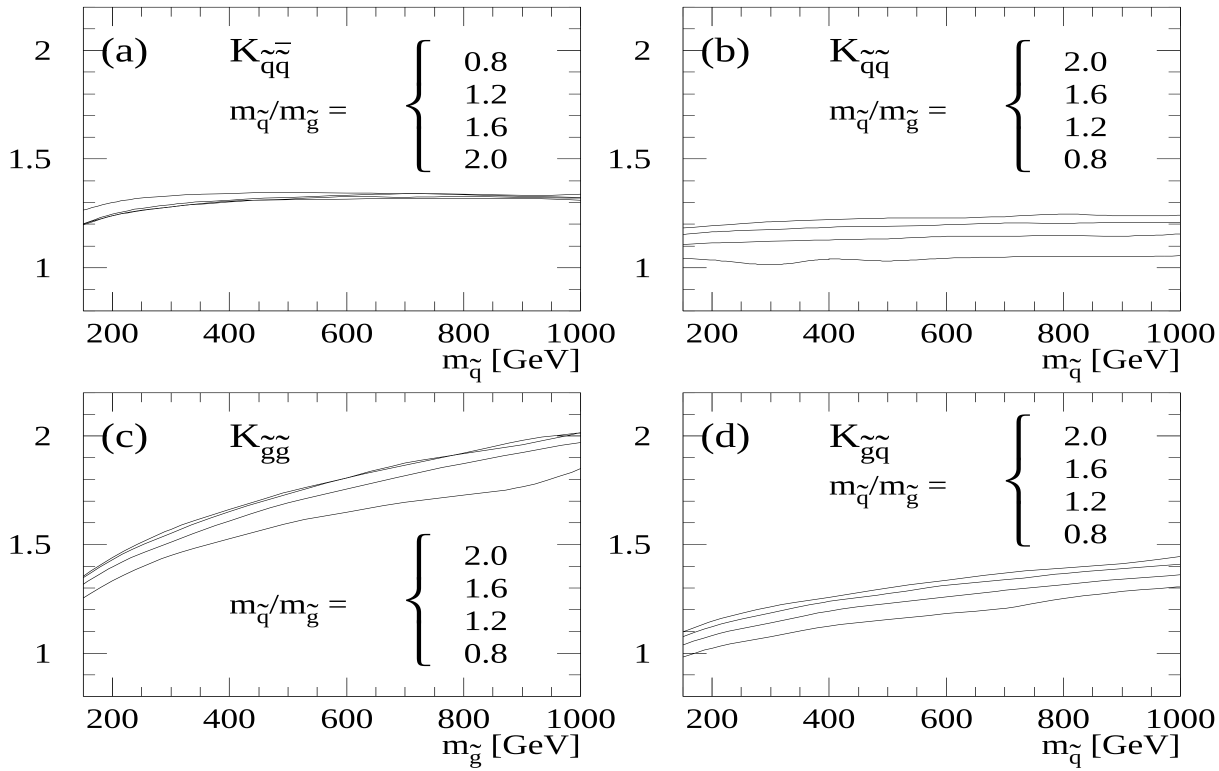
- Tree-level EW effects of $\mathcal{O}(\alpha\alpha_s)$ and $\mathcal{O}(\alpha^2)$
  - QCD-EW interference and photon-induced contributions, tree-level EW [Bornhauser et al.'07] [Alan, Cankocak, Demir'07][Hollik, Kollar, Trenkel'07][Hollik, Mirabella'08][Hollik, Mirabella, Trenkel'08][Bozzi, Fuks, Klasen'05]

Coloured sparticle production at NLO (SUSY-QCD)

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

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



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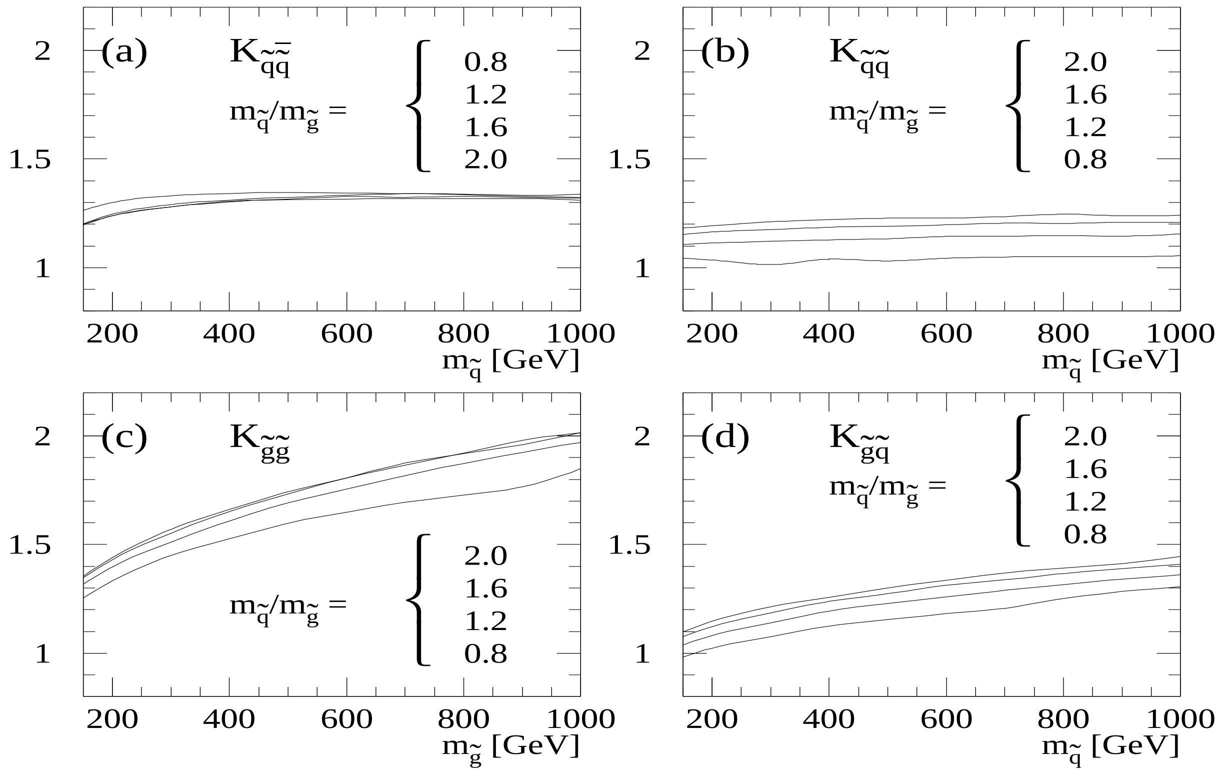

$\Rightarrow$ Increase of the cross sections due to NLO SUSY-QCD corrections

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 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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- At n-th order in α_s (wrt. LO) soft gluon contributions of the form

$$\alpha_\mathrm{s}^n \log^m(\beta^2),\ m \leq 2n \qquad\qquad \beta^2 = 1 - \frac{4m^2}{\hat{s}}$$

  - the closer to threshold the more important the logarithmic terms
    $\rightarrow$ expect large contributions from soft gluon radiation

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

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$$+ \alpha_s \left(c_{12} \log^2 \left(\beta^2\right) + c_{11} \log \left(\beta^2\right) + c_{10} \right) \quad \longleftarrow \text{NLO}$$

$$+ \alpha_s^2 \left(c_{24} \log^4 \left(\beta^2\right) + c_{23} \log^3 \left(\beta^2\right) + c_{22} \log^2 \left(\beta^2\right) + \ldots \right) \quad \longleftarrow \text{NNLO}$$

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$$\hat{\sigma} \sim \mathcal{C}(\alpha_{\rm s}) \exp \left(L g_1(\alpha_{\rm s} L) + g_2(\alpha_{\rm s} L) + \alpha_{\rm s} g_3(\alpha_{\rm s} L) + \ldots \right)$$

$$LL \qquad NLL \qquad NNLL \qquad \ldots \qquad\qquad L = \log(\ldots)$$

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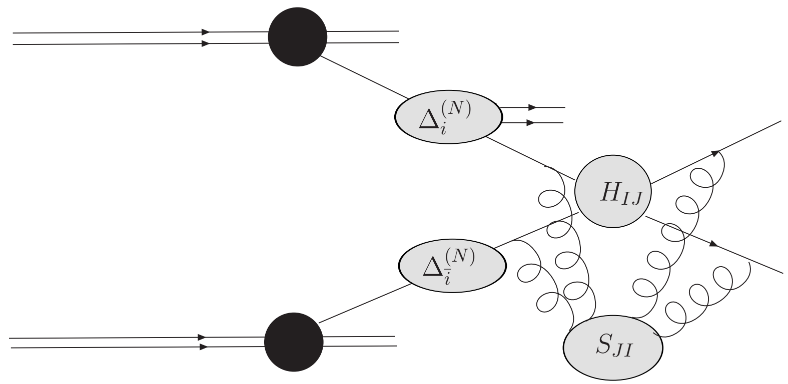
$$LL \qquad NLL \qquad NNLL \qquad \ldots \qquad L = \log(\ldots)$$

- Threshold corrections exponentiate in the space of Mellin moments taken wrt. $z \equiv \frac{4m^2}{\hat{s}} = 1 - \beta^2$ [Sterman'87][Catani,Trentadue'89]

$$f^{(N)} = \int_0^1 dz\, z^{N-1} f(z) \qquad \Rightarrow \qquad \log(\beta^2) = \log(1-z) \longleftrightarrow \log(N)$$

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

$2 \to 2$ with colour flow [Kidonakis, Sterman'96-97][Kidonakis, Oderda, Sterman'98][Bonciani et al.'03]



Up to NLL:

$$\hat{\sigma}^{(N)}_{ij\to kl} = \underbrace{H^{(N)}_{ij\to kl,IJ}}_{\text{hard function}} \times \underbrace{\Delta_i^{(N)}\Delta_j^{(N)}}_{\text{soft-collinear radiation}} \times \underbrace{S_{ij\to kl,JI}}_{\text{soft wide-angle emission}}$$

universal factors; KNOWN

process-dependent

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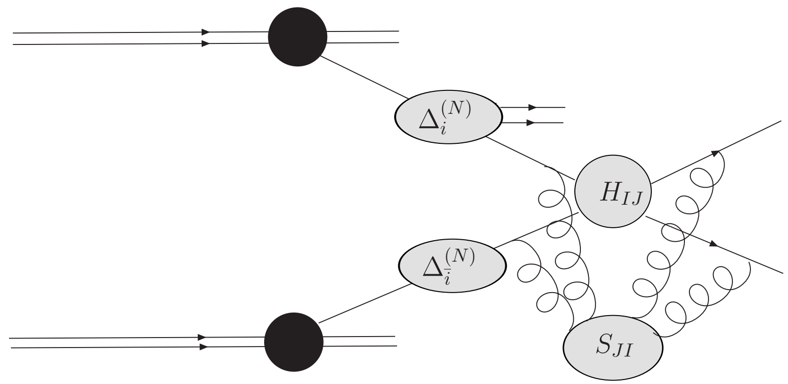

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hard function — soft-collinear radiation: universal factors; KNOWN — soft wide-angle emission: process-dependent

S_{JI} from solving renormalization group equation

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

Anomalous dimensions

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

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- Threshold limit $\hat{s} \to 4m^2$
  - Γ_{JI} matrices calculated in the s-channel colour basis become diagonal
  - Coefficients governing the soft radiation factors correspond to the values of the quadratic Casimir operators for the SU(3) representations

> 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

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

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

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

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- 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*]

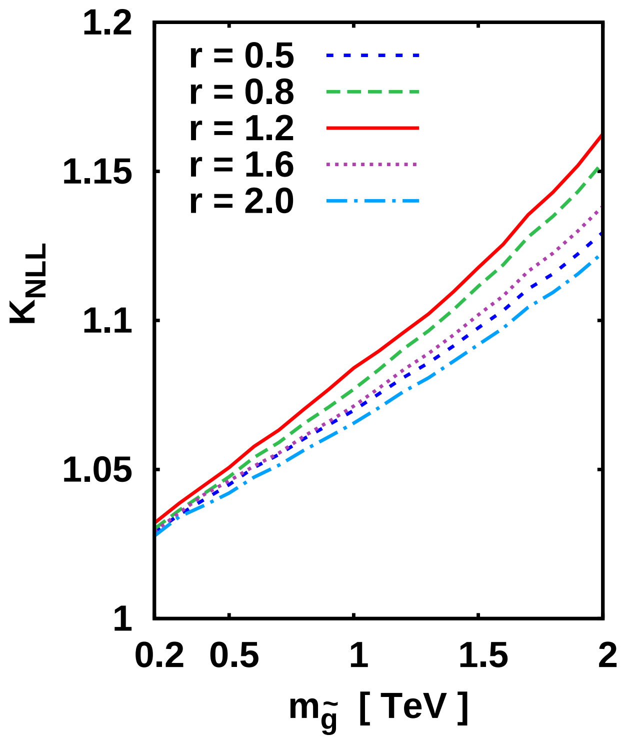
[*Plehn, http://www.ph.ed.ac.uk/ tplehn/prospino/*]

The NLL K-factors at the LHC

[*AK, Motyka'08*]

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

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



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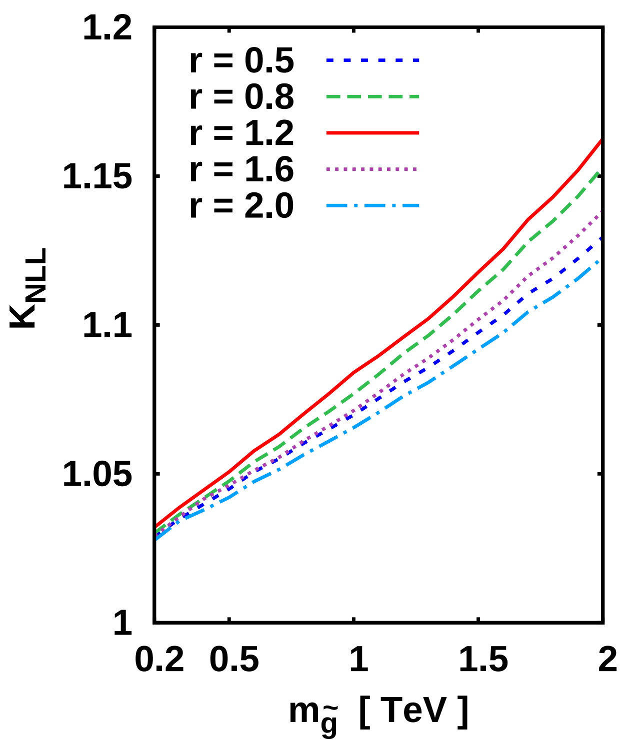
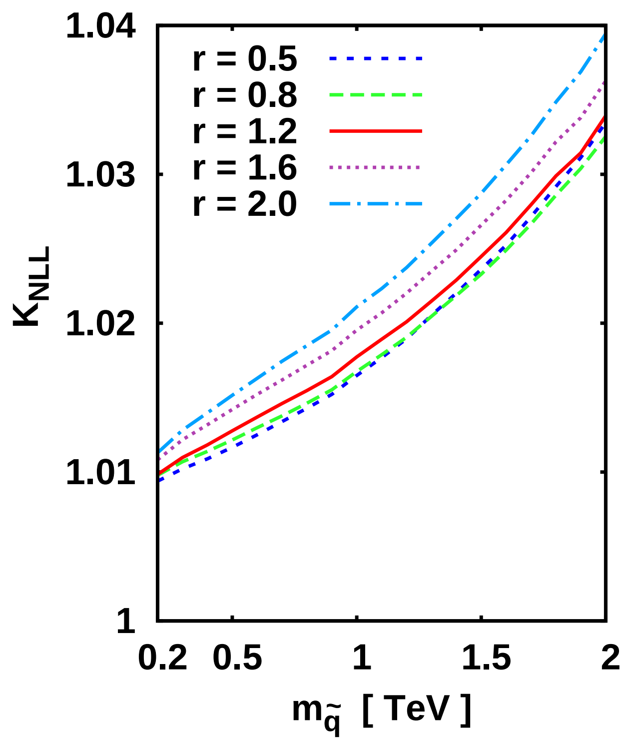


$pp \to \tilde{q}\bar{\tilde{q}}$



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

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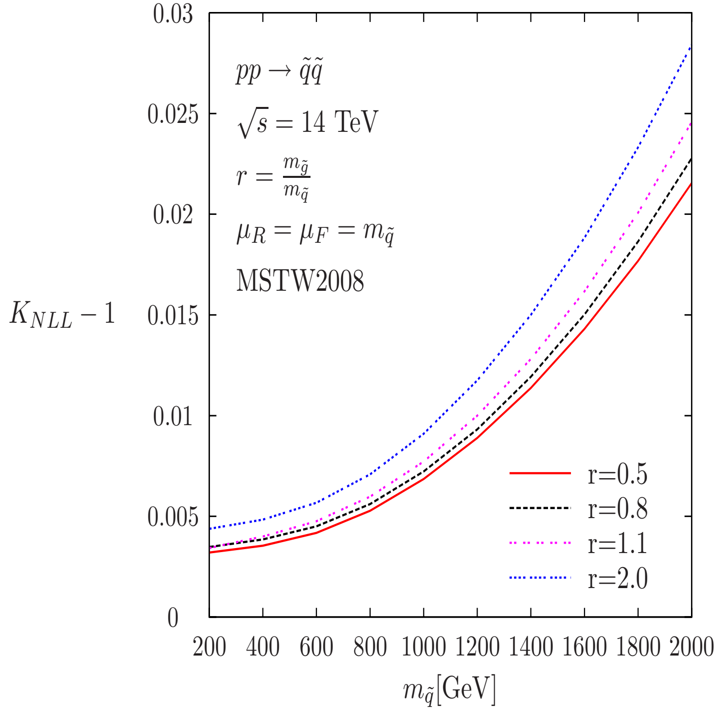

[PRELIMINARY]

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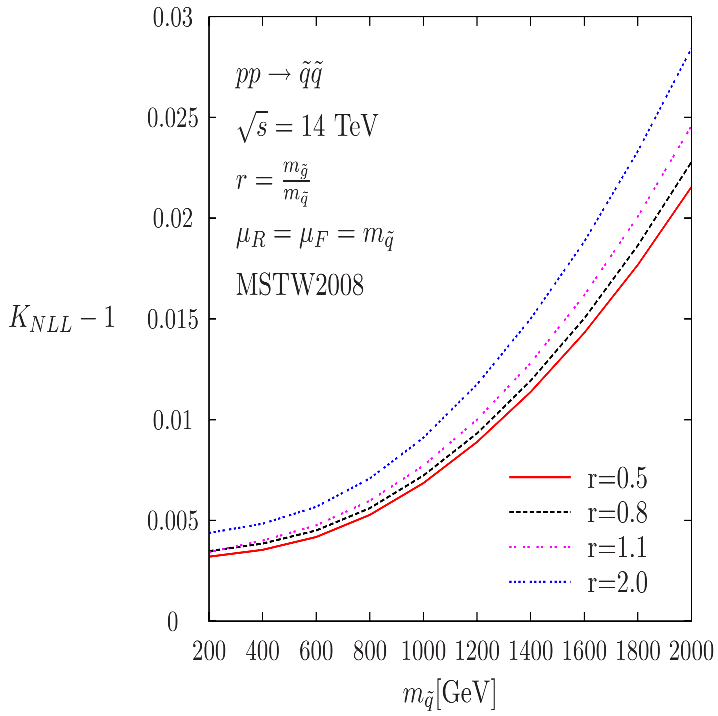

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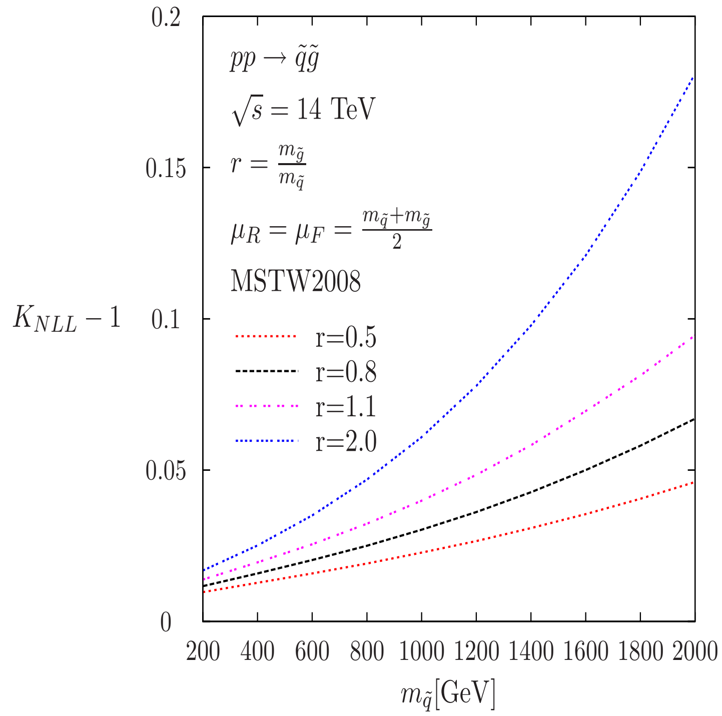

[PRELIMINARY]

The scale dependence

[*AK, Motyka'09*]

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

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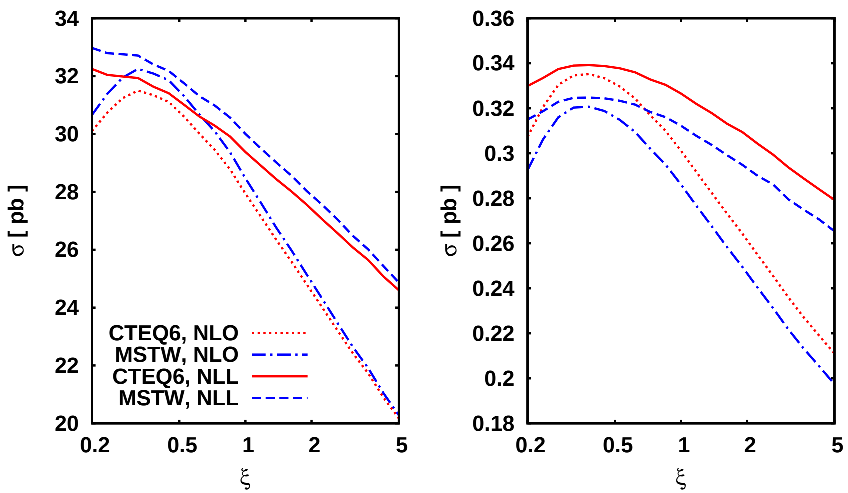

$m_{\tilde{g}} = 500$ GeV $\quad$ $m_{\tilde{g}} = 1$ TeV

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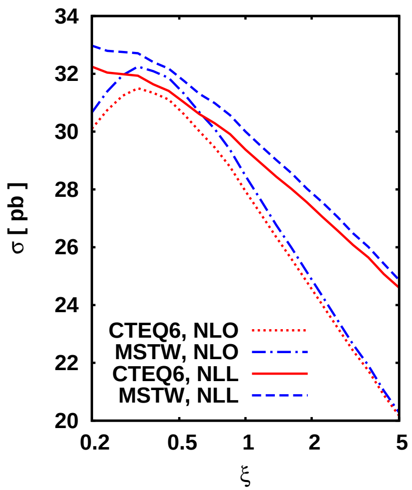

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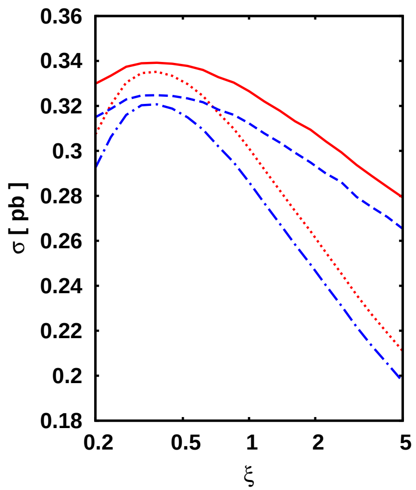

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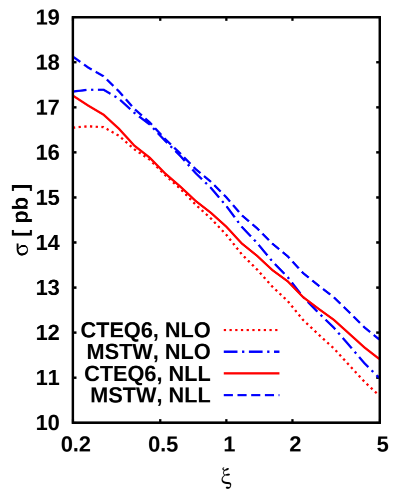

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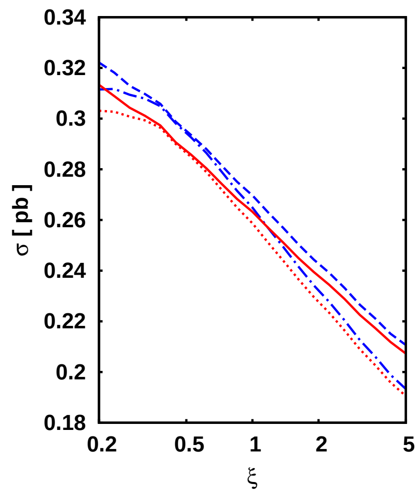

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The scale dependence cntd.

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

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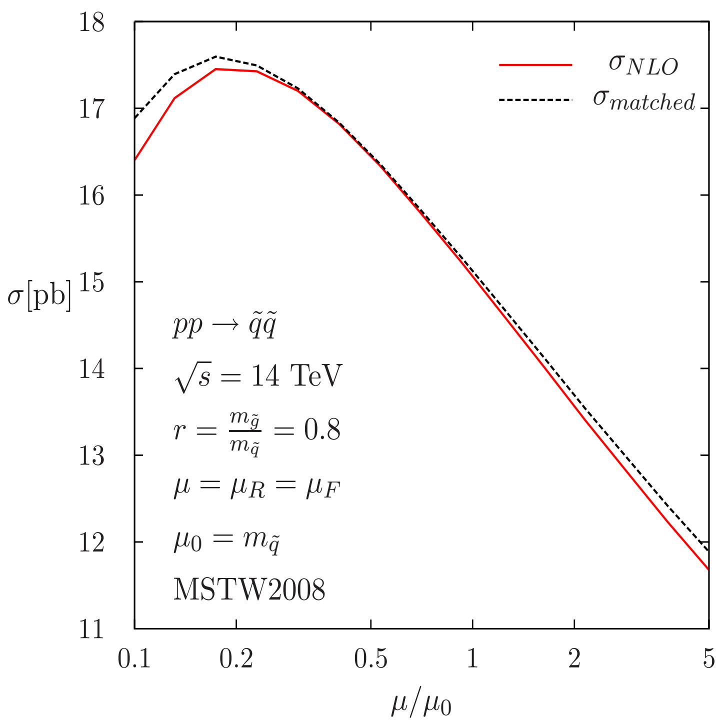

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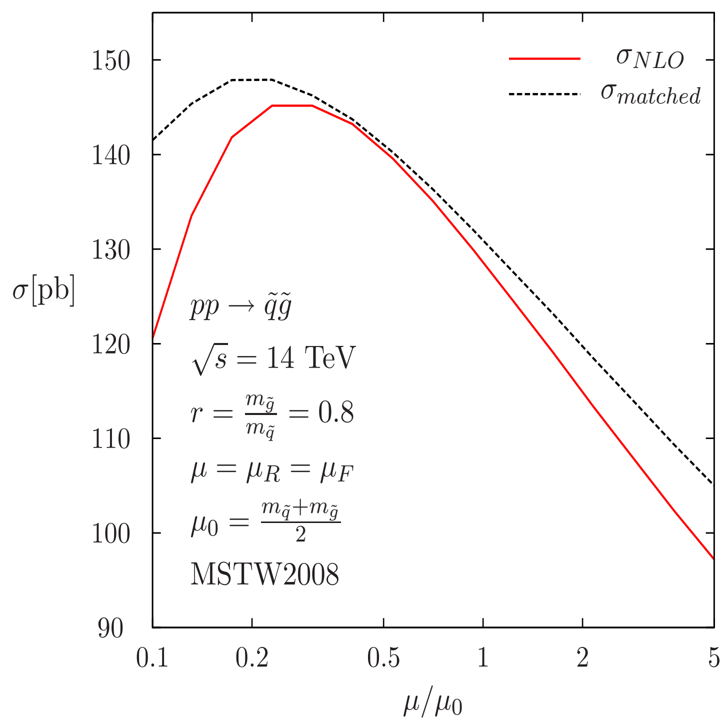


[PRELIMINARY]

The NLL K-factors at the Tevatron

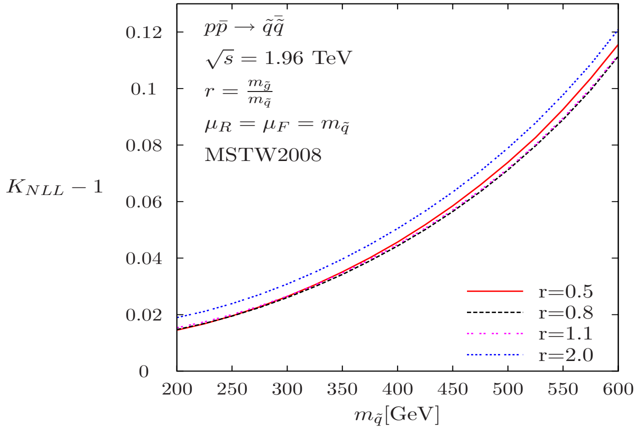
[*Beenakker, Brensing, Krämer, AK, Laenen, Niessen*]

Results for resummed total cross sections available for all four production processes

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

[PRELIMINARY]

$p\bar{p} \longrightarrow \tilde{q}\bar{\tilde{q}}$



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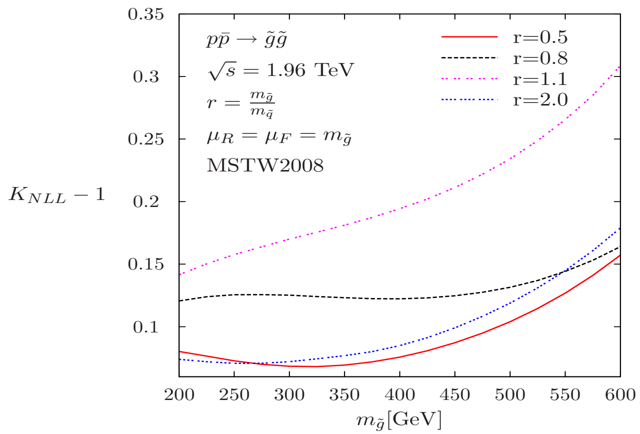

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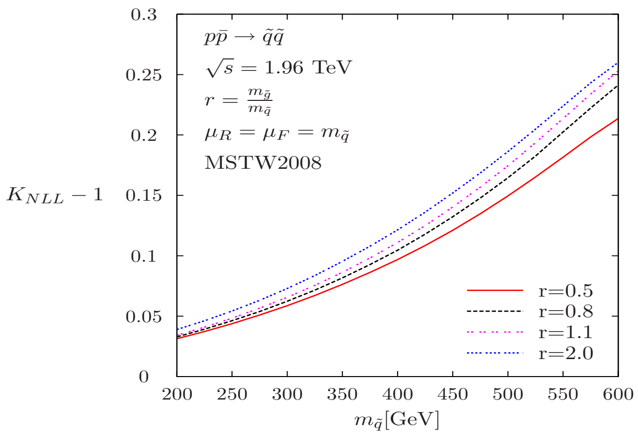
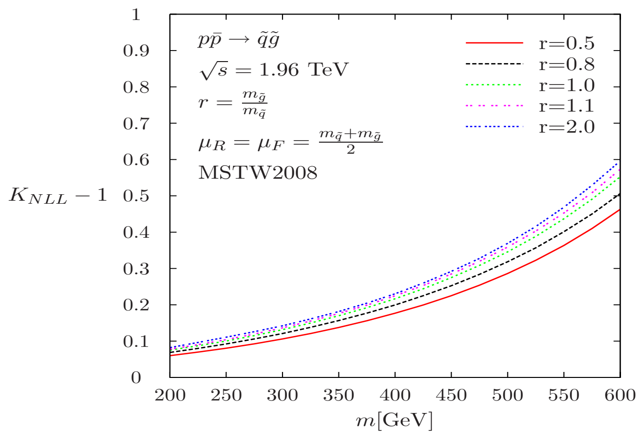


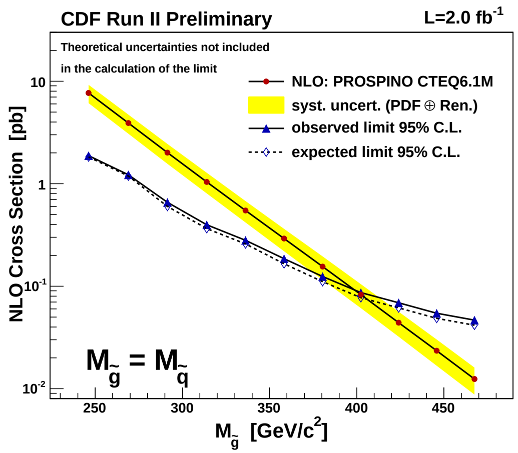
$p\bar{p} \longrightarrow \tilde{q}\tilde{g}$



Limits on squark and gluino masses from the Tevatron

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

Impact on limits on squark and gluino masses under investigation



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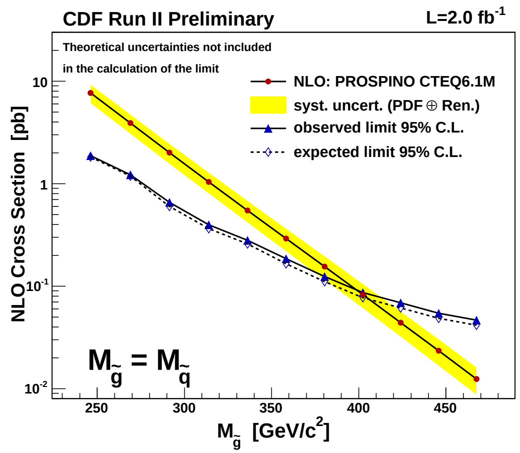
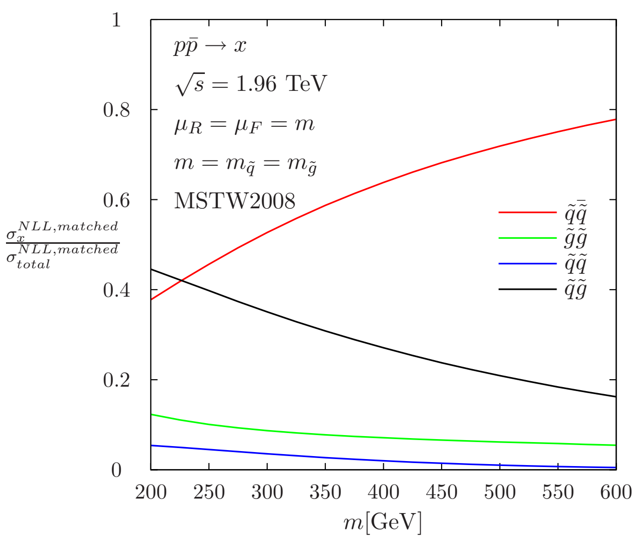
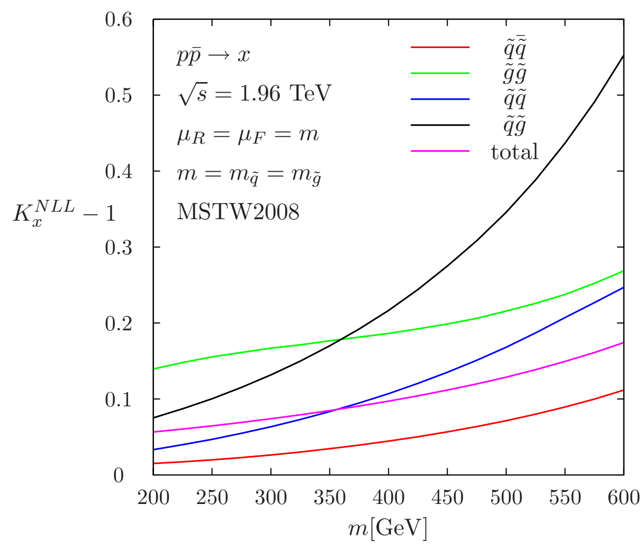




[PRELIMINARY]



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