QCD corrections to SUSY particle production at the LHC

Michael Krämer (RWTH Aachen University)

Outline

- Inclusive cross sections at NLO+NLL
- Differential distributions at NLO with parton shower
- Tools
- Outlook

LHC SUSY cross section working group

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections

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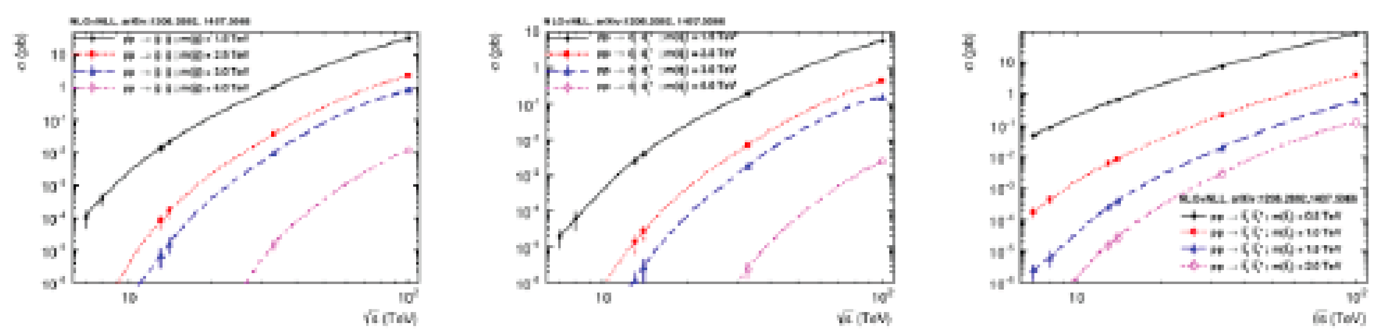
TWiki > LHCPhysics Web > SUSYCrossSections (2015-07-25, SanjayPadhi)

LHC SUSY Cross Section Working Group

Contributors: Christoph Borschensky, Zoltan Gecse, Michael Kraemer, Robin van der Leeuw, Anna Kulesza, Michelangelo Mangano, Sanjay Padhi, Tilman Plehn, Xavier Portell, Sezen Sekmen

Mailing list: lhc-susy-cross-section-wg@cernNOSPAMch, archive.

Overview



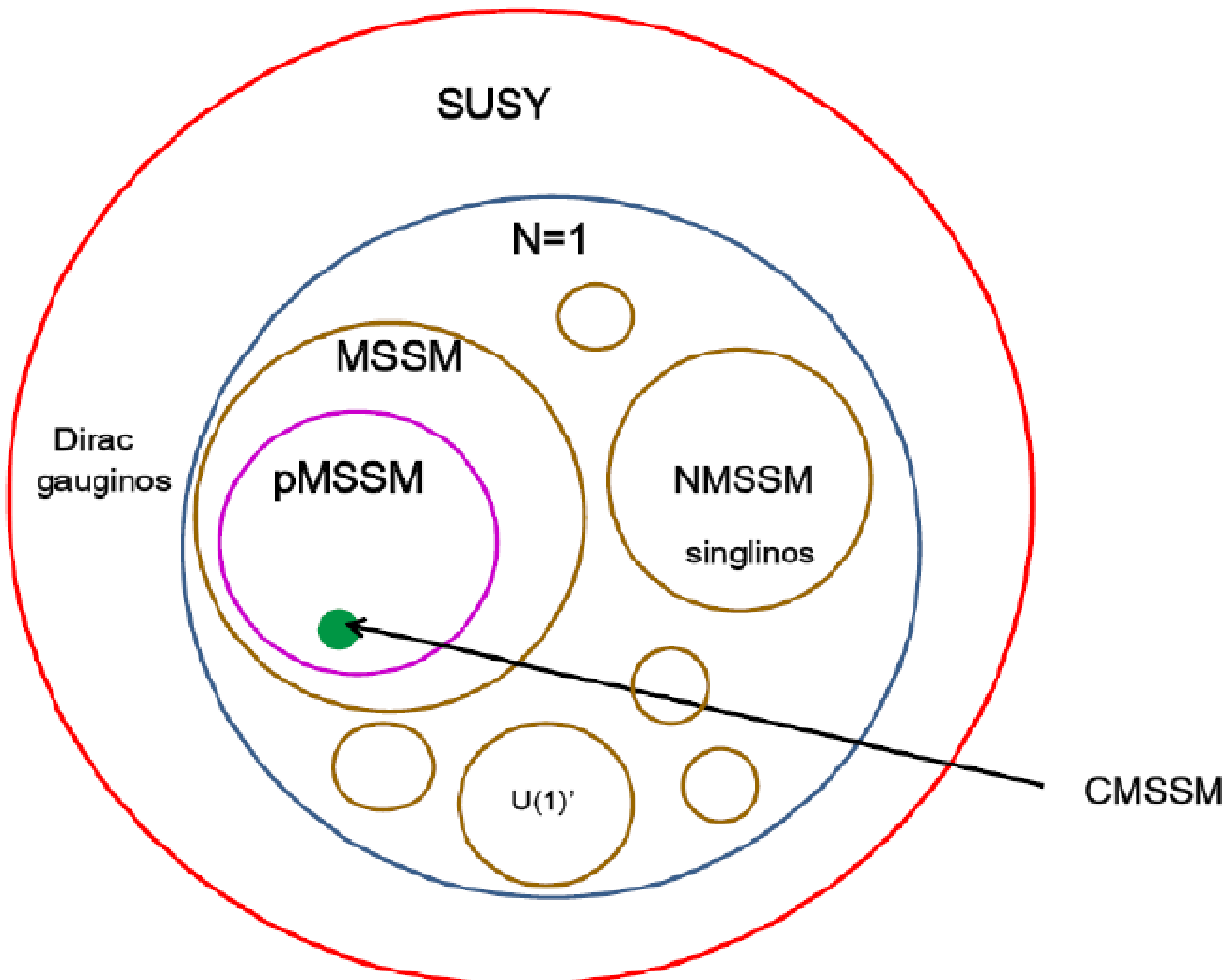
Reference: Squark and gluino production cross sections in pp collisions at \sqrt{s} = 13, 14, 33 and 100 TeV, C. Borschensky, M. Kramer, A. Kulesza, M. Mangano, S. Padhi, T. Plehn, X. Portell, arXiv:1407.5066, Published in Eur.Phys.J. C74 (20

SUSY Cross Sections using 7 TeV pp collisions

Abstract

We summarise the status of the cross section predictions for various supersymmetric processes in pp collisions at sqrt(s)=7 TeV. This document is based on the agreement between the ATLAS and CMS collaborations, as well as with the LPCC SU working group. Calculations including the resummation of soft gluon emission at the next-to-leading logarithmic accuracy are used whenever available. In all other cases we rely on the next-to-leading order in the strong coupling constant. These cr uncertainties are provided for various scale and PDF choices.

The space of SUSY theories…



by Tom Rizzo

The minimal supersymmetric model

Field Content of the MSSM					
Super-Multiplets	Boson Fields	Fermionic Partners	SU(3)	SU(2)	U(1)
gluon/gluino	g	$\widetilde{g}$	8	1	0
gauge/	$W^{\pm}, W^0$	$\widetilde{W}^{\pm}, \widetilde{W}^0$	1	3	0
gaugino	B	$\widetilde{B}$	1	1	0
slepton/	$(\widetilde{\nu}, \widetilde{e}^-)_L$	$(\nu, e^-)_L$	1	2	-1
lepton	$\tilde{e}^-_R$	e^-_R	1	1	-2
squark/	$(\widetilde{u}_L, \widetilde{d}_L)$	$(u, d)_L$	3	2	$1/3$
quark	$\widetilde{u}_R$	u_R	3	1	$4/3$
	$\widetilde{d}_R$	d_R	3	1	$-2/3$
Higgs/	(H^0_d, H^-_d)	$(\widetilde{H}^0_d, \widetilde{H}^-_d)$	1	2	-1
higgsino	(H^+_u, H^0_u)	$(\widetilde{H}^+_u, \widetilde{H}^0_u)$	1	2	1

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Higgs/	(H^0_d, H^-_d)	$(\widetilde{H}^0_d, \widetilde{H}^-_d)$	1	2	-1
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The minimal supersymmetric model

Field Content of the MSSM

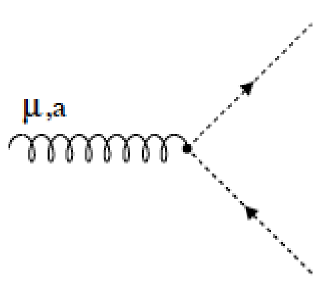
Super-Multiplets	Boson Fields	Fermionic Partners	SU(3)	SU(2)	U(1)
gluon/glu					0
gauge/					0
gaugin					0
slepton					-1
lepton					-2
squark					$1/3$
quark	$\widetilde{u}_R$	u_R	3	1	$4/3$
	$\widetilde{d}_R$	d_R	3	1	$-2/3$
Higgs/	$(H_d^0\,,\ H_d^-)$	$(\widetilde{H}_d^0, \widetilde{H}_d^-)$	1	2	-1
higgsino	$(H_u^+\,,\ H_u^0)$	$(\widetilde{H}_u^+, \widetilde{H}_u^0)$	1	2	1

Squark and gluino production

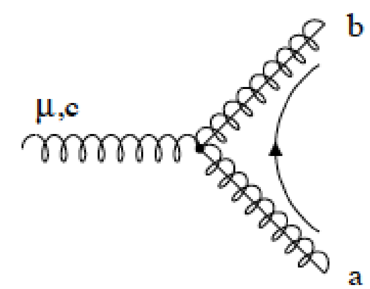
- large cross sections
- largely model-independent
- large higher-order QCD effects

Supersymmetric QCD

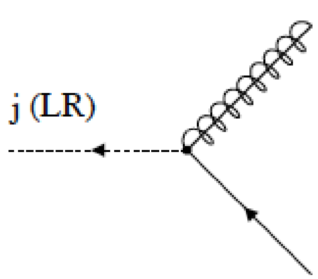
$$
\begin{aligned}
\mathcal{L}_{\mathrm{SUSY-QCD}} = & -\tfrac{1}{4}F^{a}_{\mu\nu}F^{\mu\nu a} + \tfrac{i}{2}\bar{\tilde{g}}^{a}\gamma^{\mu}(\partial_{\mu}\delta^{ac} - g_{\mathrm{s}}f^{abc}g^{b}_{\mu})\tilde{g}^{c} + |D^{\mu}\tilde{q}_{jL}|^{2} + |D^{\mu}\tilde{q}_{jR}|^{2} + i\bar{q}_{j}\gamma^{\mu}D_{\mu}q_{j} \\
& - \tfrac{1}{2}m_{\tilde{g}}\bar{\tilde{g}}^{a}\tilde{g}^{a} - m^{2}_{\tilde{q}_{jL}}\tilde{q}^{*}_{jL}\tilde{q}_{jL} - m^{2}_{\tilde{q}_{jR}}\tilde{q}^{*}_{jR}\tilde{q}_{jR} - \tfrac{1}{2}g^{2}_{\mathrm{s}}(\tilde{q}^{*}_{jL}T^{a}\tilde{q}_{jL} - \tilde{q}^{*}_{jR}T^{a}\tilde{q}_{jR})^{2} \\
& - \sqrt{2}g_{\mathrm{s}}(\bar{q}_{jL}T^{a}\tilde{g}^{a}\tilde{q}_{jL} + \tilde{q}^{*}_{jL}\bar{\tilde{g}}^{a}T^{a}q_{jL} - \tilde{q}^{*}_{jR}\bar{\tilde{g}}^{a}T^{a}q_{jR} - \bar{q}_{jR}\tilde{g}^{a}T^{a}\tilde{q}_{jR})
\end{aligned}
$$



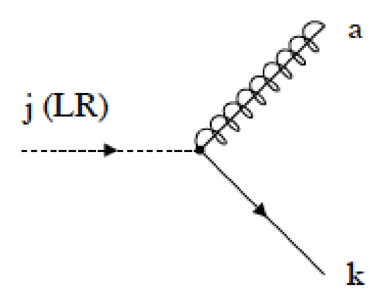
$-ig_s\, T^{a}_{kj}\, (p_j - p_k)^{\mu}$



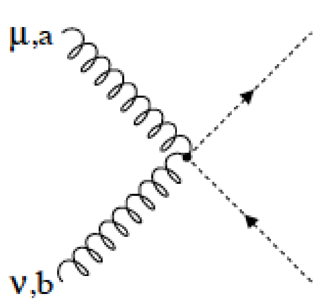
$-g_s\, f_{abc}\, \gamma^{\mu}$



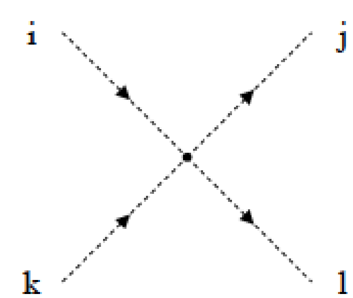
$-ig_s\sqrt{2}\, T^{a}_{jk}\, (\pm P_{LR})$



$-ig_s\sqrt{2}\, T^{a}_{kj}\, (\pm P_{RL})$



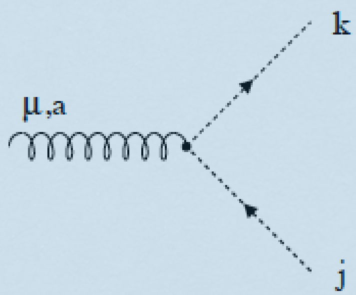
$ig^{2}_{s}\, \{T^{a}, T^{b}\}\, g^{\mu\nu}$



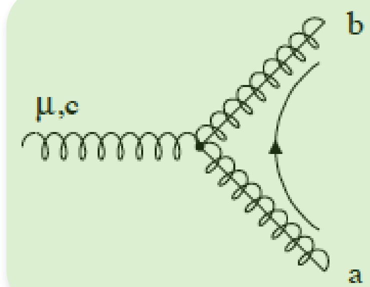
$ig^{2}_{s}\, \dfrac{S_{ijkl}}{2}$

Supersymmetric QCD

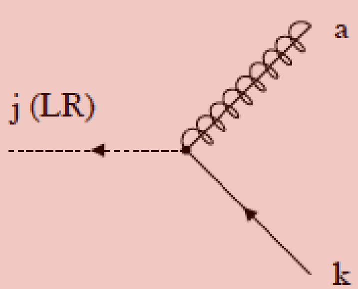
$$\begin{aligned}\mathcal{L}_{\mathrm{SUSY-QCD}} = &-\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu a} + \frac{i}{2}\bar{\tilde{g}}^a\gamma^\mu(\partial_\mu\delta^{ac} - g_s f^{abc} g^b_\mu)\tilde{g}^c + |D^\mu\tilde{q}_{jL}|^2 + |D^\mu\tilde{q}_{jR}|^2 + i\bar{q}_j\gamma^\mu D_\mu q_j \\ &- \frac{1}{2}m_{\tilde{g}}\bar{\tilde{g}}^a\tilde{g}^a - m^2_{\tilde{q}_{jL}}\tilde{q}^*_{jL}\tilde{q}_{jL} - m^2_{\tilde{q}_{jR}}\tilde{q}^*_{jR}\tilde{q}_{jR} - \frac{1}{2}g_s^2(\tilde{q}^*_{jL}T^a\tilde{q}_{jL} - \tilde{q}^*_{jR}T^a\tilde{q}_{jR})^2 \\ &- \sqrt{2}g_s(\bar{q}_{jL}T^a\tilde{g}^a\tilde{q}_{jL} + \tilde{q}^*_{jL}\bar{\tilde{g}}^a T^a q_{jL} - \tilde{q}^*_{jR}\bar{\tilde{g}}^a T^a q_{jR} - \bar{q}_{jR}\tilde{g}^a T^a\tilde{q}_{jR})\end{aligned}$$



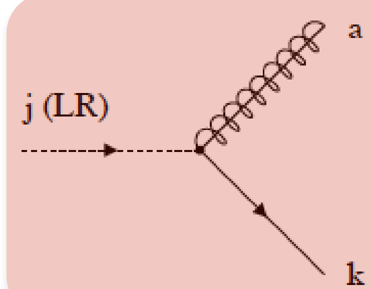
$-ig_s\, T^a_{kj}\, (p_j - p_k)^\mu$



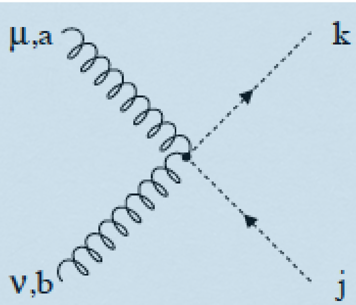
$-g_s\, f_{abc}\, \gamma^\mu$



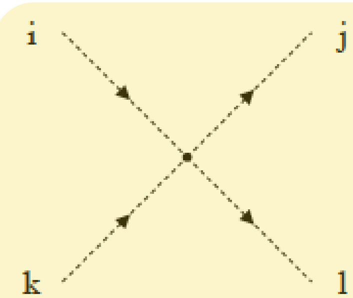
$-ig_s\sqrt{2}\, T^a_{jk}\, (\pm P_{LR})$



$-ig_s\sqrt{2}\, T^a_{kj}\, (\pm P_{RL})$



$ig_s^2\, \{T^a, T^b\}\, g^{\mu\nu}$



$ig_s^2\, \frac{S_{ijkl}}{2}$

Supersymmetric QCD

$$\mathcal{L}_{\text{SUSY-QCD}} = -\tfrac{1}{4}F^a_{\mu\nu}F^{\mu\nu a} + \tfrac{i}{2}\bar{\tilde{g}}^a\gamma^\mu(\partial_\mu\delta^{ac} - g_s f^{abc} g^b_\mu)\tilde{g}^c + |D^\mu\tilde{q}_{jL}|^2 + |D^\mu\tilde{q}_{jR}|^2 + i\bar{q}_j\gamma^\mu D_\mu q_j$$
$$- \tfrac{1}{2}m_{\tilde{g}}\bar{\tilde{g}}^a\tilde{g}^a - m^2_{\tilde{q}_{jL}}\tilde{q}^*_{jL}\tilde{q}_{jL} - m^2_{\tilde{q}_{jR}}\tilde{q}^*_{jR}\tilde{q}_{jR} - \tfrac{1}{2}g_s^2(\tilde{q}^*_{jL}T^a\tilde{q}_{jL} - \tilde{q}^*_{jR}T^a\tilde{q}_{jR})^2$$
$$- \sqrt{2}g_s(\bar{q}_{jL}T^a\tilde{g}^a\tilde{q}_{jL} + \tilde{q}^*_{jL}\bar{\tilde{g}}^aT^aq_{jL} - \tilde{q}^*_{jR}\bar{\tilde{g}}^aT^aq_{jR} - \bar{q}_{jR}\tilde{g}^aT^a\tilde{q}_{jR})$$

We assume R-parity conservation

→ $\cancel{\mathcal{W} = \lambda''_{ijk}U^c_iD^c_jD^c_k}$ etc.

→ sparticles are produced in pairs;
the LSP is stable

Supersymmetric QCD

$$\mathcal{L}_{\text{SUSY-QCD}} = -\frac{1}{4}F^a_{\mu\nu}F^{\mu\nu a} + \frac{i}{2}\bar{\tilde{g}}^a\gamma^\mu(\partial_\mu\delta^{ac} - g_s f^{abc} g^b_\mu)\tilde{g}^c + |D^\mu\tilde{q}_{jL}|^2 + |D^\mu\tilde{q}_{jR}|^2 + i\bar{q}_j\gamma^\mu D_\mu q_j$$
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$$- \sqrt{2}g_s(\bar{q}_{jL}T^a\tilde{g}^a\tilde{q}_{jL} + \tilde{q}^*_{jL}\bar{\tilde{g}}^aT^aq_{jL} - \tilde{q}^*_{jR}\bar{\tilde{g}}^aT^aq_{jR} - \bar{q}_{jR}\tilde{g}^aT^a\tilde{q}_{jR})$$

Squarks mix to form mass eigenstates

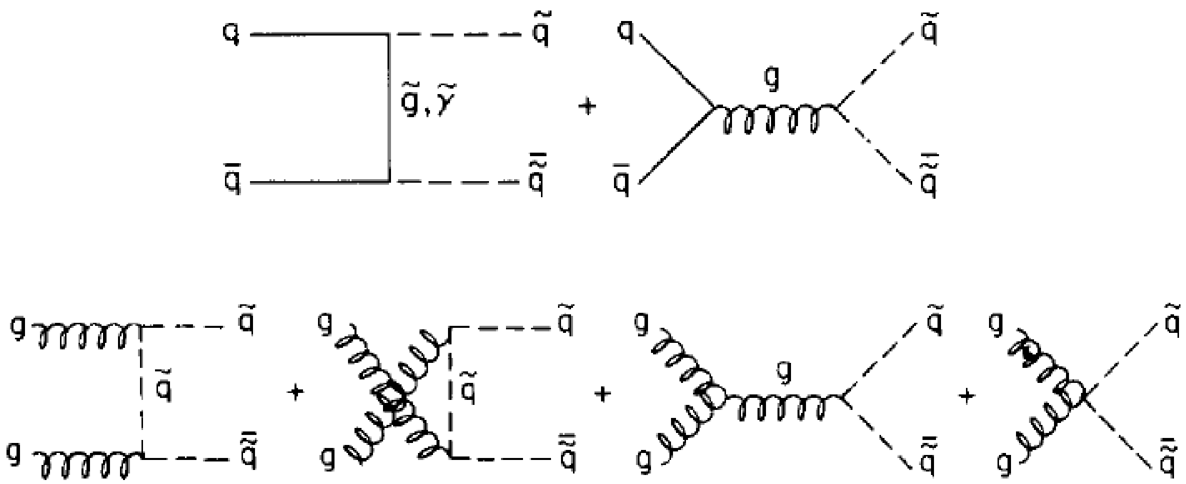
$$\mathcal{M}^2 = \begin{pmatrix} m_Q^2+m_q^2+\left(\frac{1}{2}-\frac{2}{3}s_w^2\right)m_Z^2\cos(2\beta) & -m_q\left(A_q+\mu\cot\beta\right) \\ -m_q\left(A_q+\mu\cot\beta\right) & m_U^2+m_q^2+\frac{2}{3}s_w^2 m_Z^2\cos(2\beta) \end{pmatrix}$$

→ the mixing is proportional to the quark mass

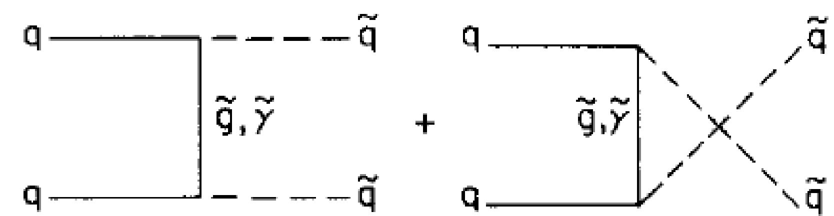
→ mixing is relevant for the 3rd generation

Squark and gluino production

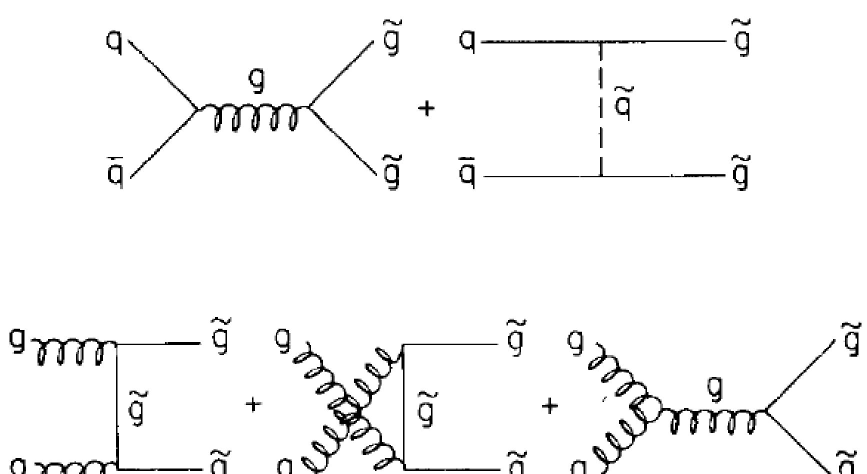
squark-antisquark



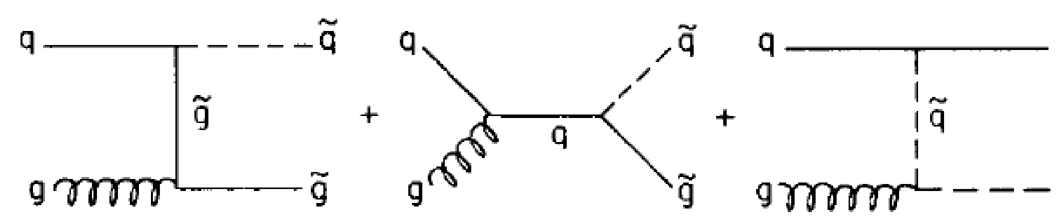
squark-squark



gluino pairs



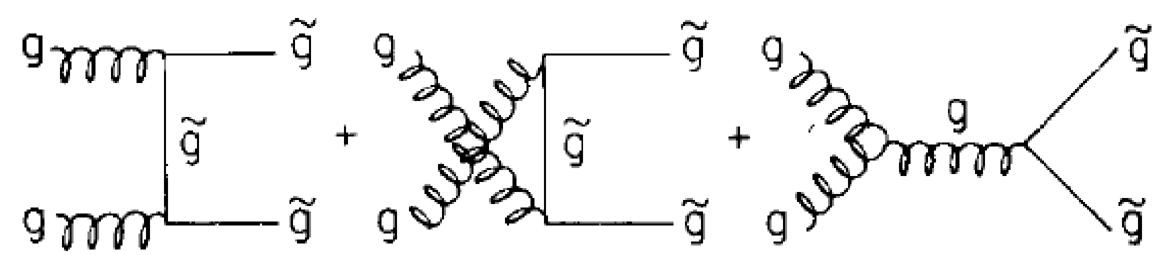
squark-gluino



Squark and gluino production

The cross sections only depend on the SUSY masses

e.g. gluino pair production

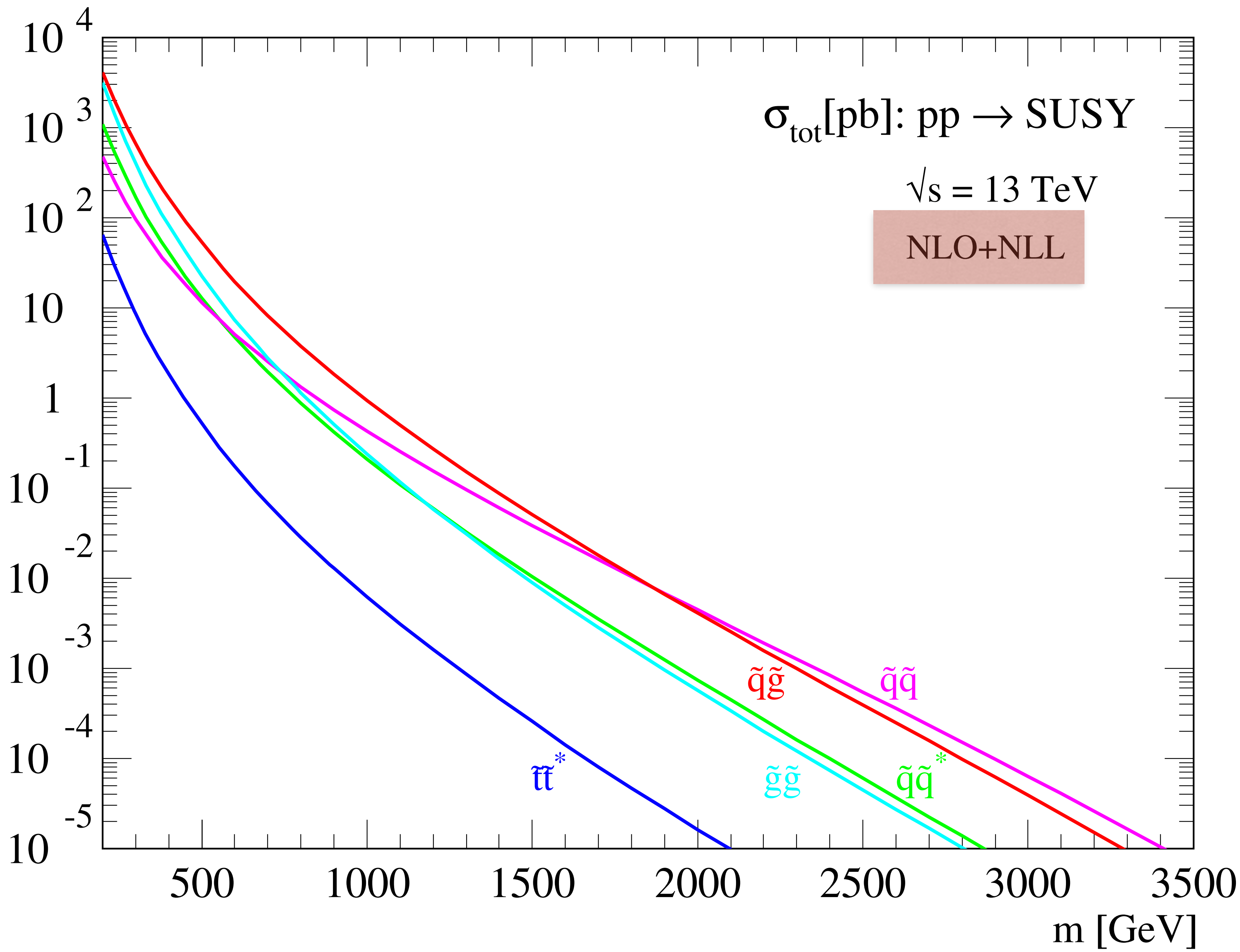


$$\sigma^B(gg \to \tilde{q}\bar{\tilde{q}}) \quad = \quad \frac{n_f \pi \alpha_s^2}{s}\left[\beta_{\tilde{q}}\left(\frac{5}{24}+\frac{31 m_{\tilde{q}}^2}{12 s}\right)+\left(\frac{4 m_{\tilde{q}}^2}{3 s}+\frac{m_{\tilde{q}}^4}{3 s^2}\right)\log\left(\frac{1-\beta_{\tilde{q}}}{1+\beta_{\tilde{q}}}\right)\right]$$

where $\beta_{\tilde{g}} = \sqrt{1-4m_{\tilde{g}}^2/s} \to 0$ at threshold

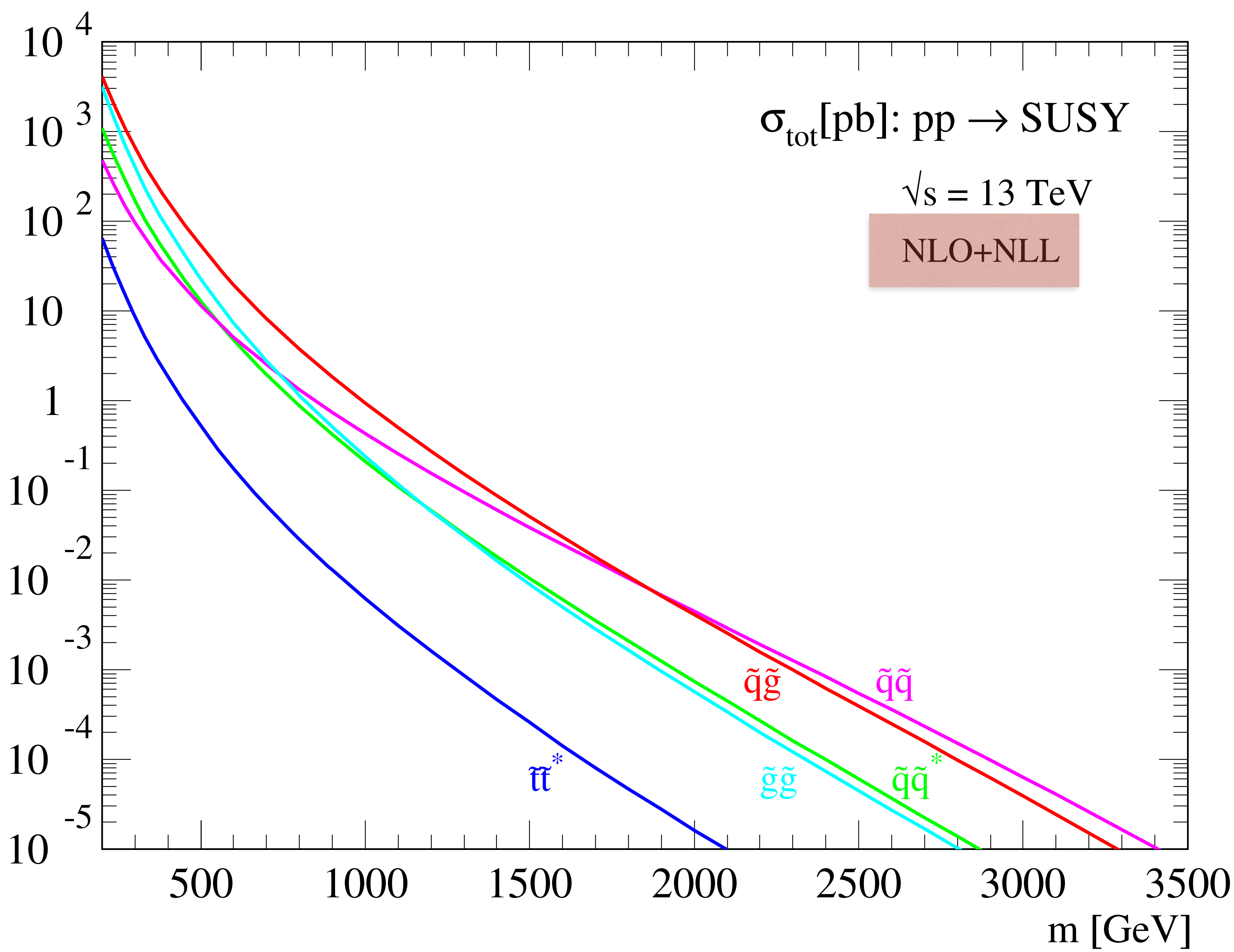
Kane, Leveille; Harrison, Llewellyn Smith, Reya, Roy; Dawson, Eichten, Quigg; Baer, Tata ('82-'85)

Squark and gluino production: NLO+NLL



Borschensky, MK, Kulesza, Mangano, Padhi, Plehn, Portell (1407.5066 [hep-ph])

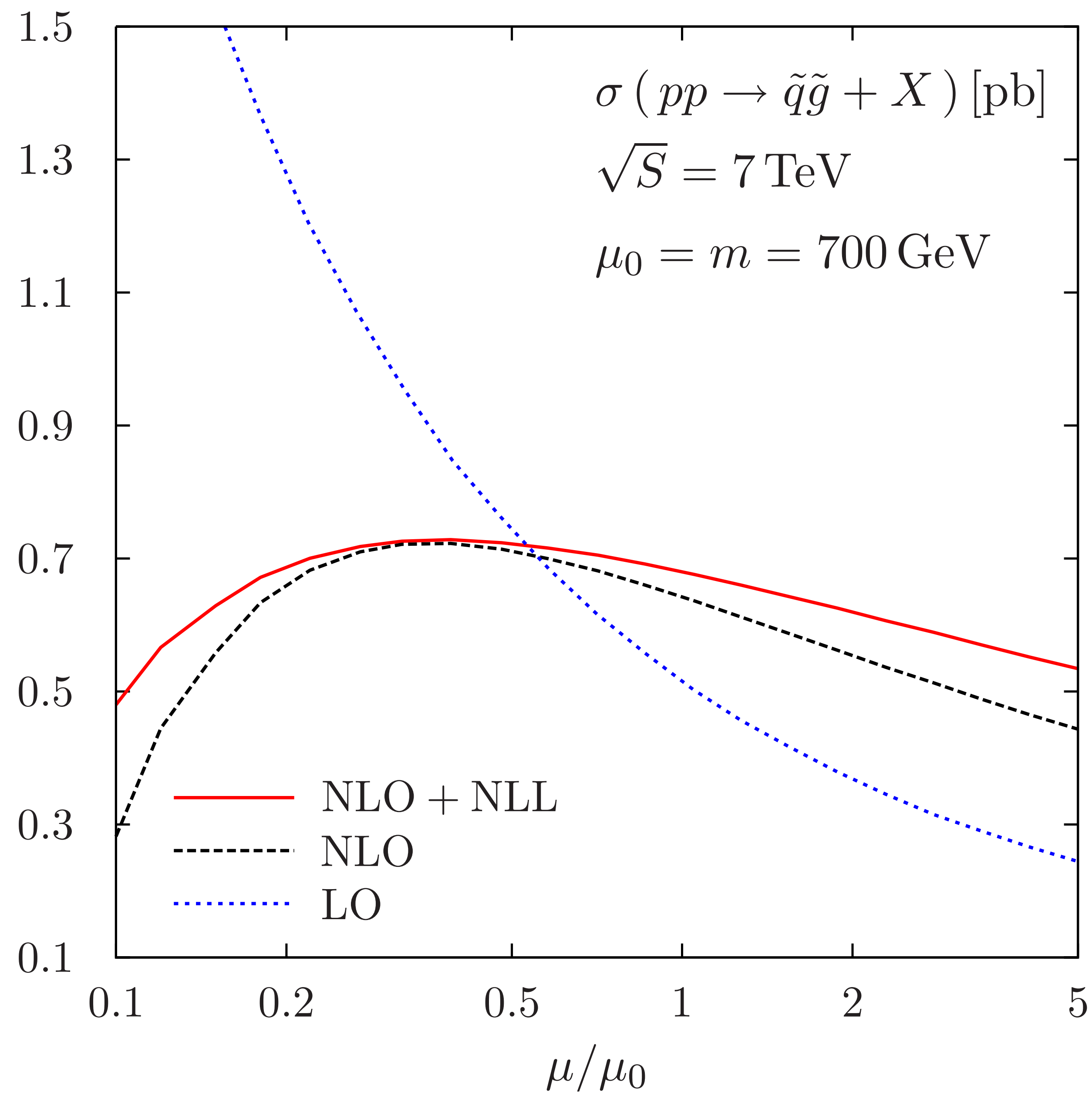
Squark and gluino production: NLO+NLL



based on **Prospino** and **NLL-fast**

Squark and gluino production: NLO+NLL

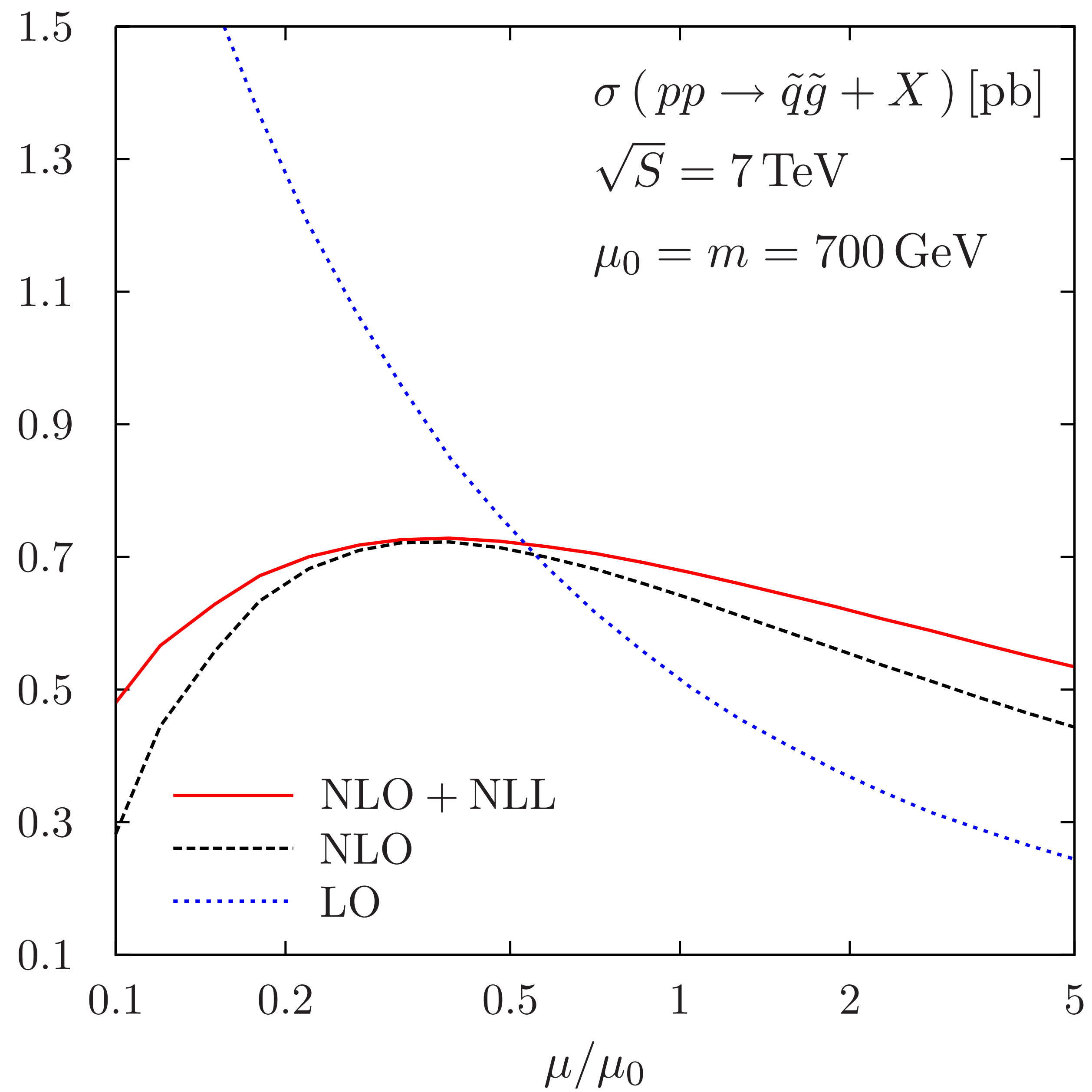
renormalization and factorization scale dependence



Beenakker, Brensing, MK, Kulesza, Laenen, Motyka, Niessen ('09-'11)

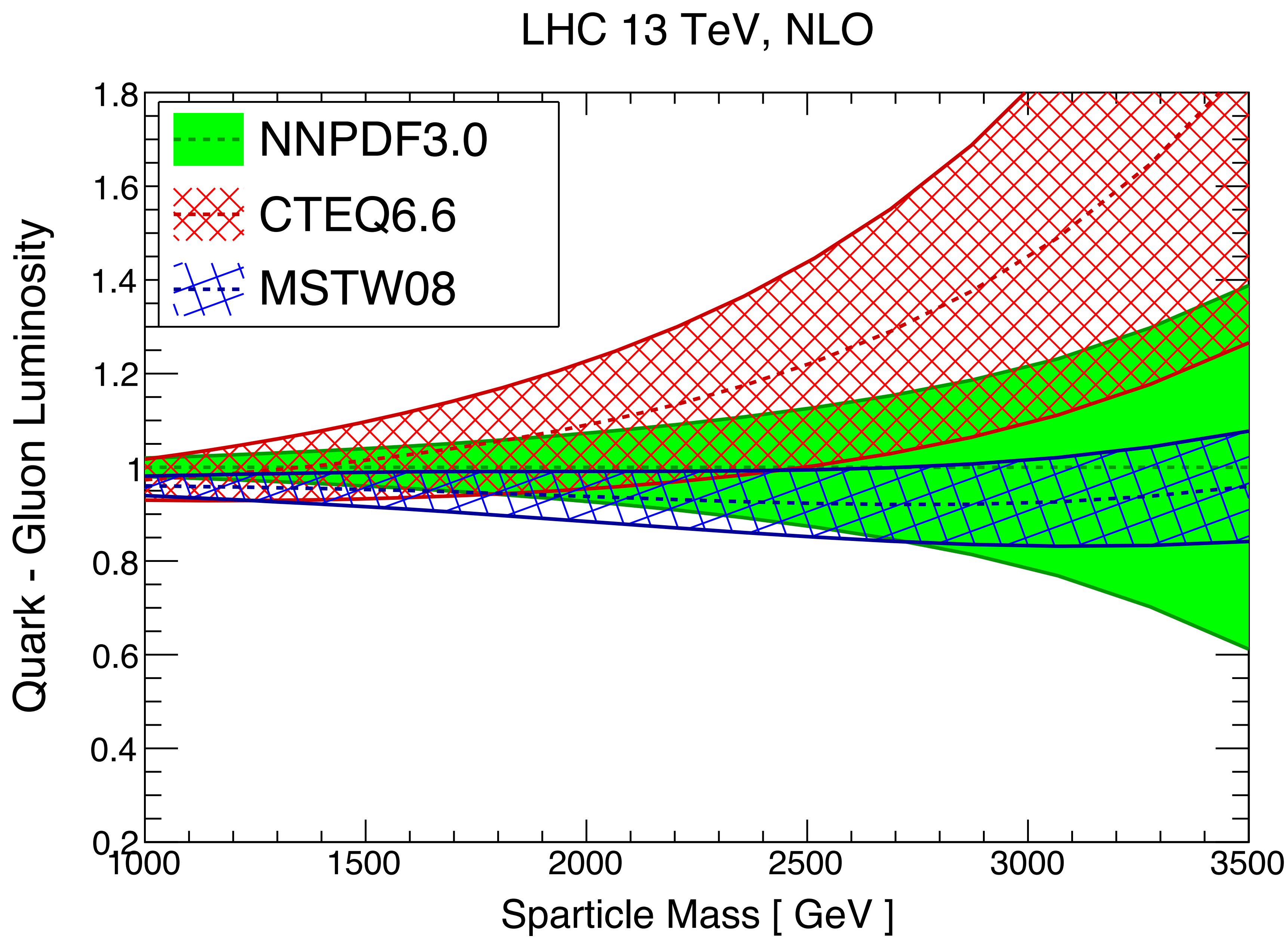
Squark and gluino production: NLO+NLL

renormalization and factorization scale dependence



cf. Langenfeld, Moch, Pfoh; Beneke, Falgari, Schwinn, Wever; Kauth, Kress, Kühn; Broggio et al.

PDF uncertainties



Beenakker, Borschensky, MK, Kulesza, Laenen, Marzani, Rojo (1510.00375 [hep-ph])

Beyond Prospino/NNL-fast

NLO-QCD corrections for generic MSSM spectra

→ Effect of O(10%) on σ x BR for generic MSSM benchmark scenarios

Hollik, Lindert, Pagani; Goncalves-Netto, Lopez-Val, Mawatari, Plehn, Wigmore; Gavin, Hangst, MK, Mühlleitner, Pellen, Popenda, Spira

Beyond Prospino/NNL-fast

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EWK corrections (EWK loops, EWK x QCD, γ-induced processes)

→ model dependent

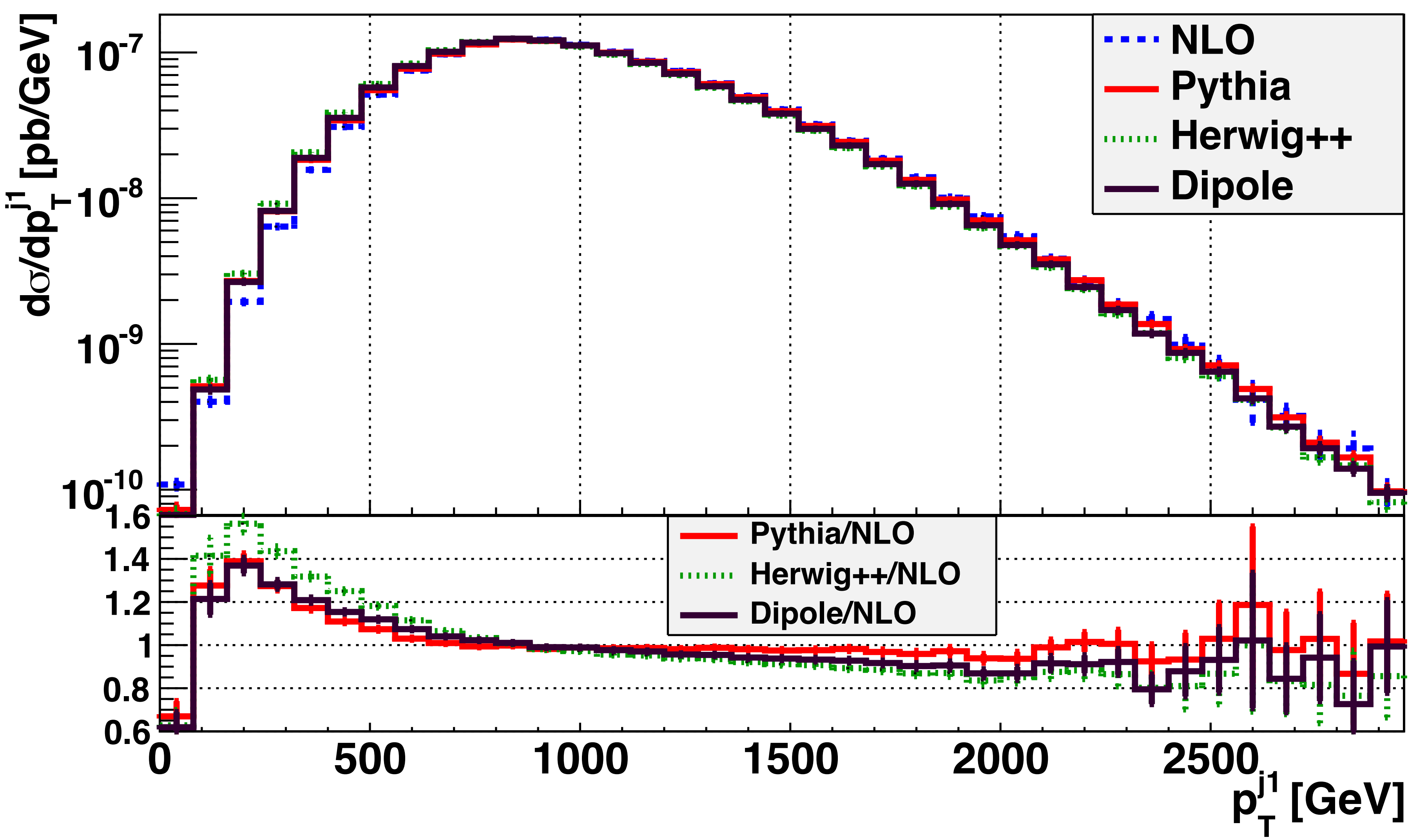
→ O(few %) for inclusive cross sections

→ more significant for specific processes and large Q^2

see e.g. Hollik, Lindert, Mirabella, Pagani (1506.01052 [hep-ph]) and references therein

Squark and gluino production and decay

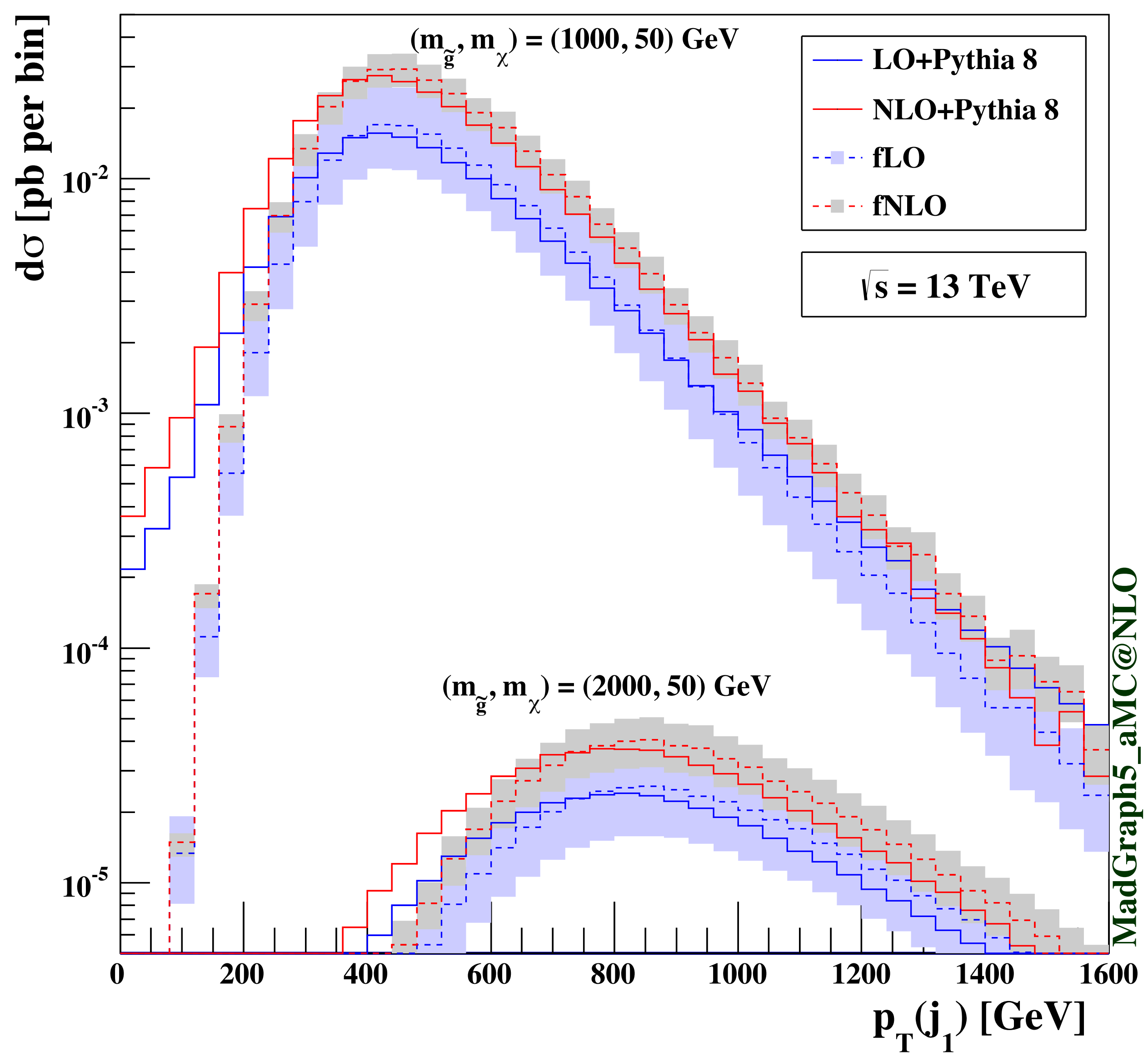
NLO differential distributions with parton showers



Gavin, Hangst, MK, Mühlleitner, Pellen, Popenda, Spira;
cf. Hollik, Lindert, Pagani; Boughezal, Schulze

Squark and gluino production and decay

NLO differential distributions with parton showers



Degrande, Fuks, Hirschi, Proudhom, Shao (1510.00391[hep-ph])

Squark and gluino production: tools

Prospino, NLL-fast, MadGolem, sPOWHEG,
MadGraph5_aMC@NLO, …

Squark and gluino production: tools

Prospino, NLL-fast, MadGolem, sPOWHEG, MadGraph5_aMC@NLO, …

Prospino: http://www.thphys.uni-heidelberg.de/~plehn/index.php?show=prospino&visible=tools

Our 20 year old warhorse, a bit worn down but still useful

Beenakker, Höpker, Klasen, MK, Plehn, Spira, Zerwas ('94-'??)

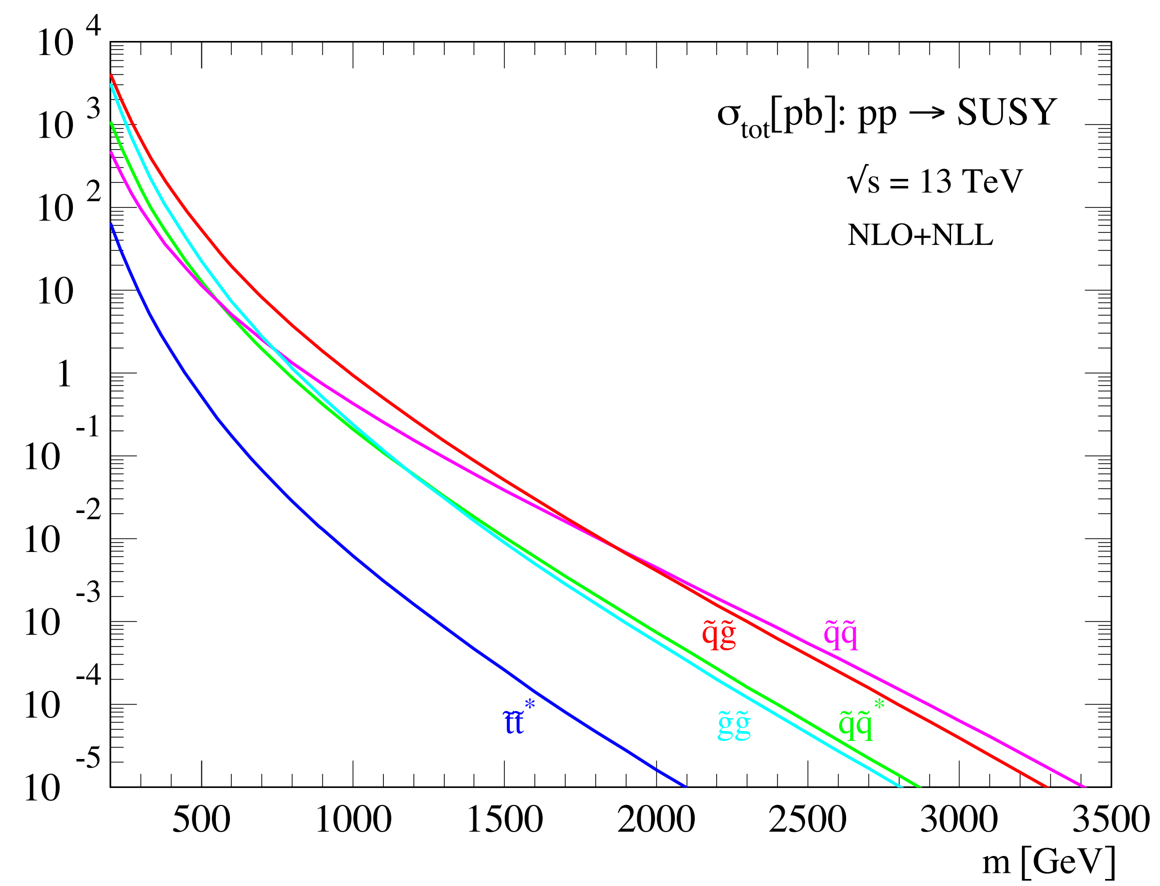
Squark and gluino production: tools

Prospino, **NLL-fast**, MadGolem, sPOWHEG, MadGraph5_aMC@NLO, …

NLL-fast: http://pauli.uni-muenster.de/~akule_01/nllwiki/index.php/NLL-fast

The current standard tool for inclusive NLO+NLL cross section calculations

Beenakker, Borschensky, MK, Kulesza, Laenen, Motyka, Niessen, Thewes ('09-'14)



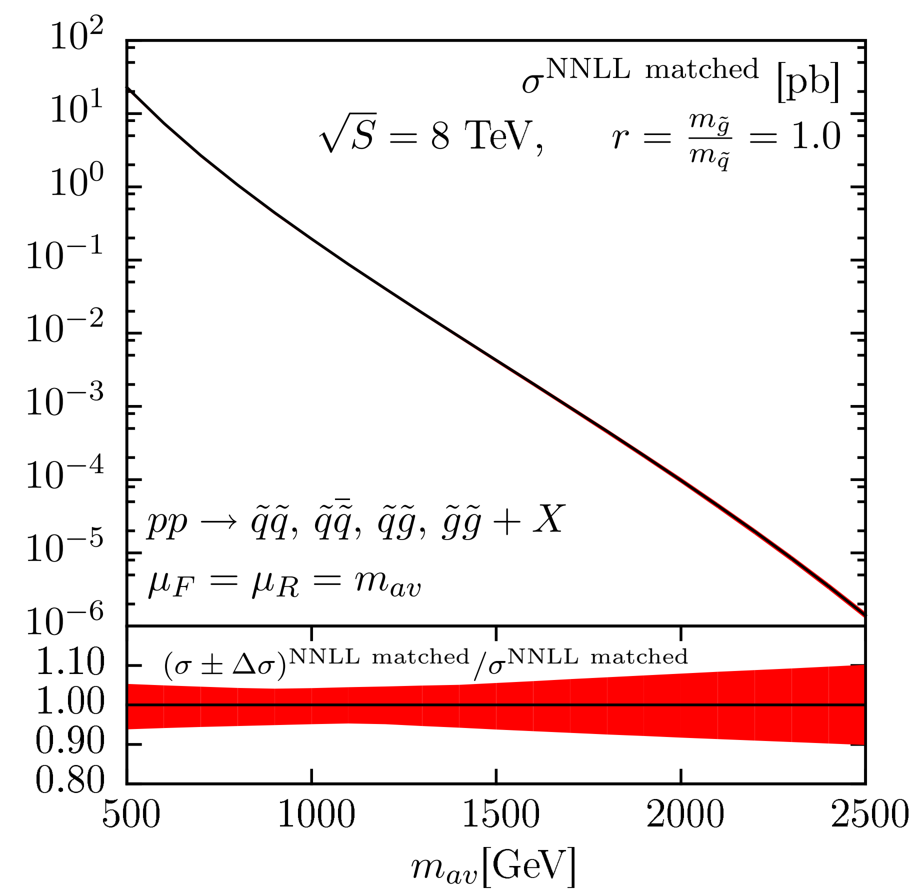
Squark and gluino production: tools

Prospino, **NLL-fast**, MadGolem, sPOWHEG, MadGraph5_aMC@NLO, …

NLL-fast: http://pauli.uni-muenster.de/~akule_01/nllwiki/index.php/NLL-fast

NNLL-fast is on its way

Beenakker, Borschensky, MK, Kulesza, Laenen Theeuwes, Thewes, in preparation



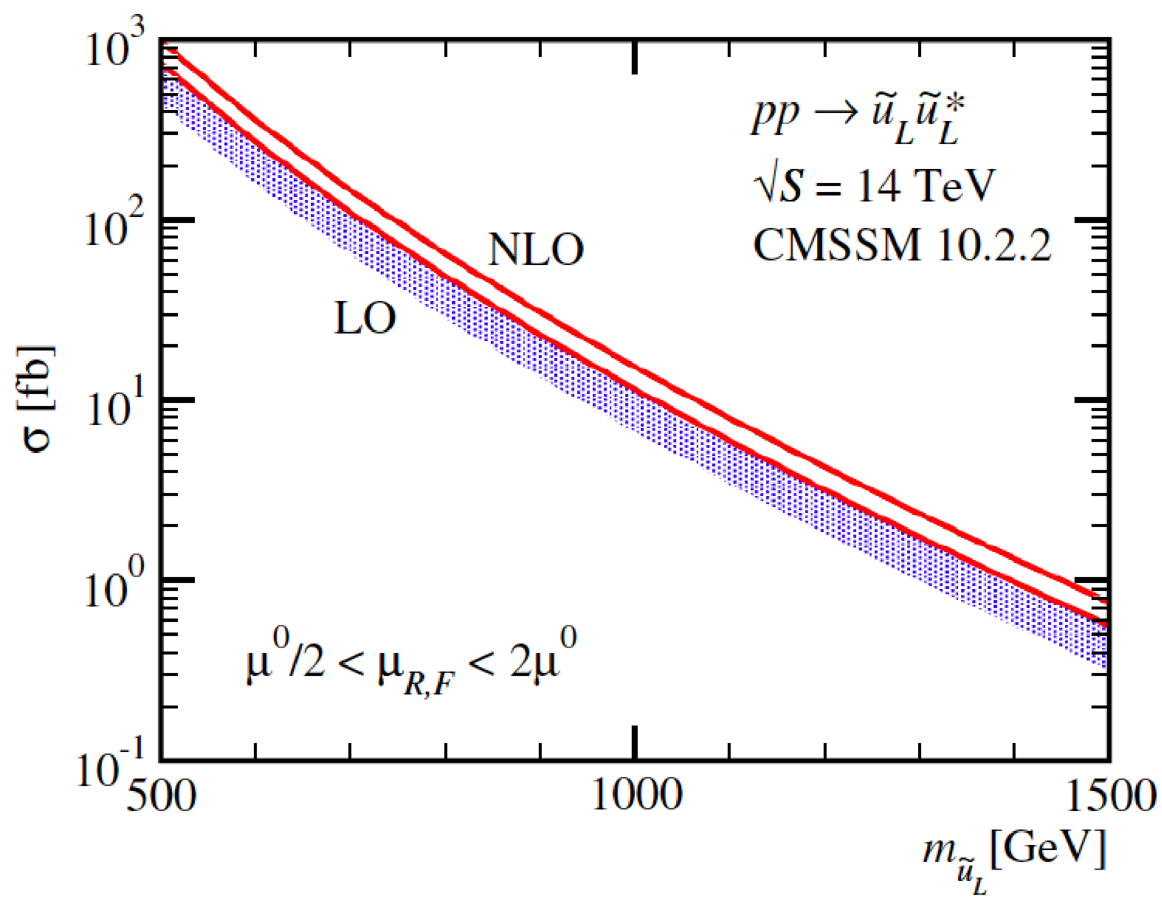
Squark and gluino production: tools

Prospino, NLL-fast, **MadGolem**, sPOWHEG, MadGraph5_aMC@NLO, …

MadGolem: code available from authors

NLO squark and gluino production for generic MSSM spectra

Goncalves-Netto, Lopez-Val, Mawatari, Plehn, Wigmore ('13)



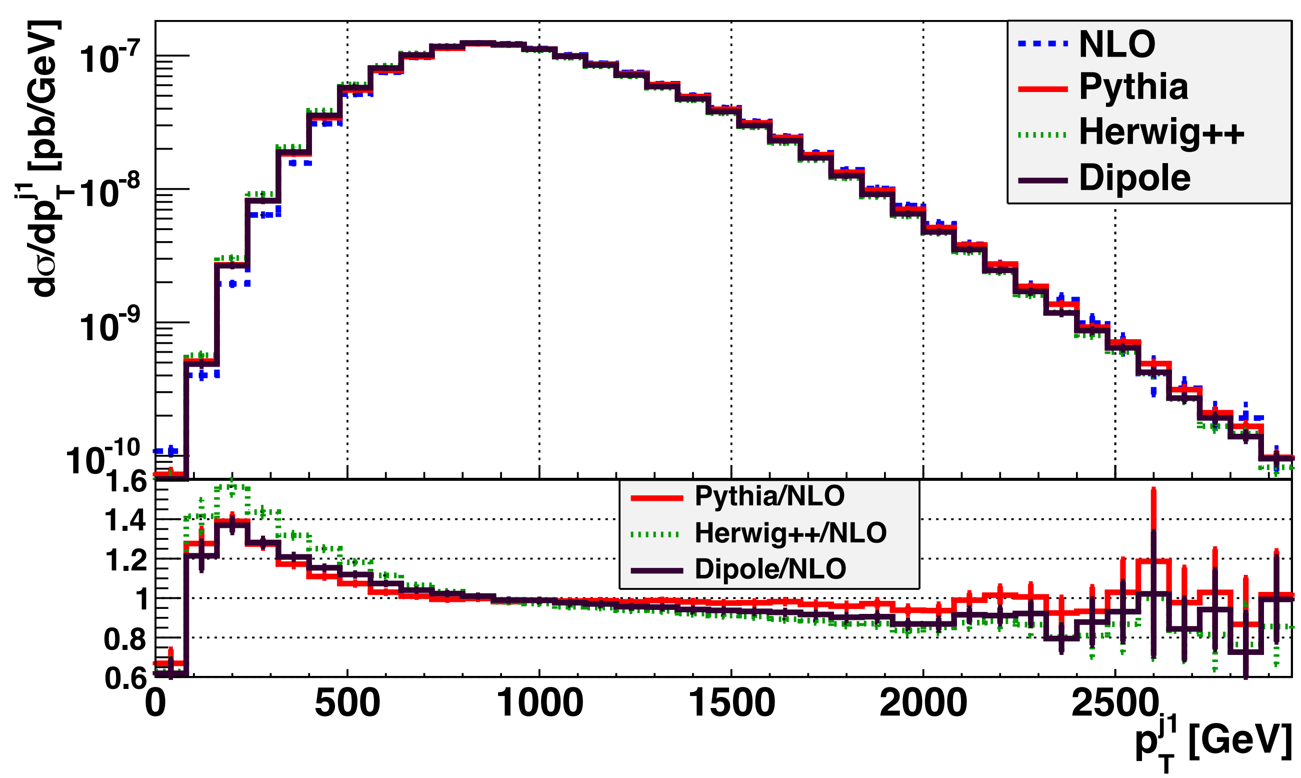
Squark and gluino production: tools

Prospino, NLL-fast, MadGolem, **sPOWHEG**, MadGraph5_aMC@NLO, …

sPOWHEG: http://powhegbox.mib.infn.it

NLO squark production and decay matched to parton showers

POWHEG team + Gavin, Hangst, MK, Mühlleitner, Pellen, Popenda, Spira ('14)



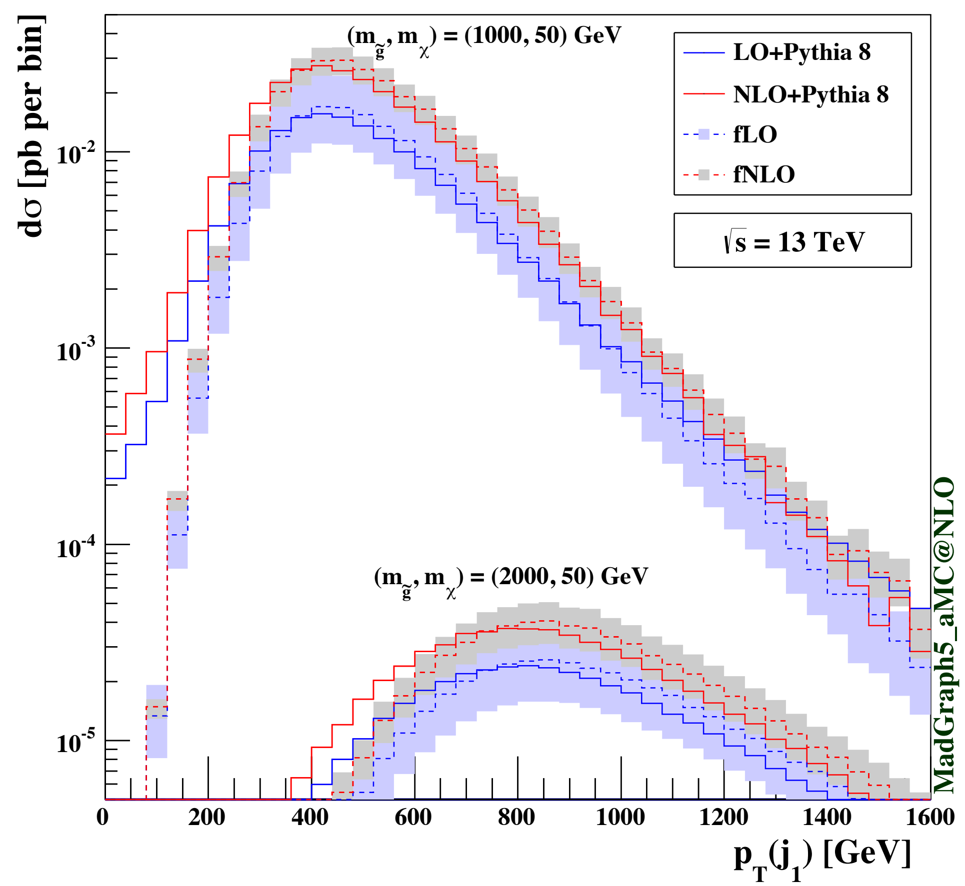
Squark and gluino production: tools

Prospino, NLL-fast, MadGolem, sPOWHEG,
MadGraph5_aMC@NLO, …

MadGraph5_aMC@NLO: https://launchpad.net/mg5amcnlo

NLO squark & gluino production and decay matched to parton showers

Degrande, Fuks, Goncalves Netto, Hirschi, Lopez-Val, Mawatari, Pagani, Proudom, Shao, Zaro, in preparation



The LHC SUSY cross section working group

will

- provide an update of the SUSY cross section recommendation at NNLL, and including recent pdfs;
- quantify the difference between Mellin space $\leftrightarrow$ SCET resummation;
- collect benchmark results for EWK corrections;
- provide links to NLO SUSY tools, together with benchmark results for validation.

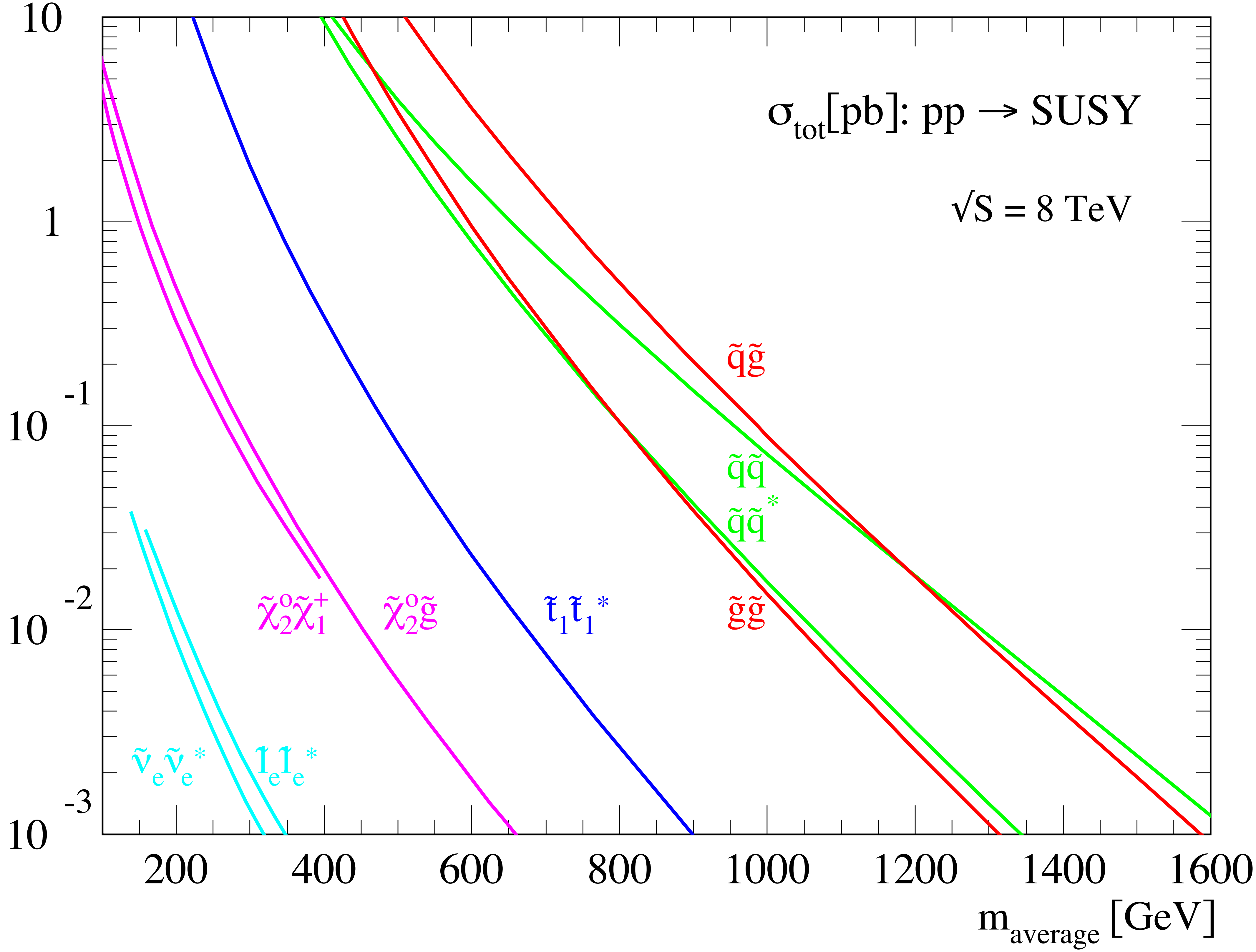
Squark and gluino production

A lot of effort (> 20 years) went into calculating higher-order QCD corrections for squark and gluino production

The theoretical uncertainty for inclusive cross sections is $\lessapprox$ 15%,
and is now dominated by the pdf error

In the future, we need to work towards automated NLO calculations for more generic models, including NLL resummation

Thank you!


σ_{tot}[pb]: pp → SUSY
√S = 8 TeV
10
1
10^{-1}
10^{-2}
10^{-3}
200
400
600
800
1000
1200
1400
1600
$m_{average}$ [GeV]
$\tilde{q}\tilde{g}$
$\tilde{q}\tilde{q}$
$\tilde{q}\tilde{q}^*$
$\tilde{g}\tilde{g}$
$\tilde{t}_1\tilde{t}_1^*$
$\tilde{\chi}_2^o\tilde{\chi}_1^+$
$\tilde{\chi}_2^o\tilde{g}$
$\tilde{\nu}_e\tilde{\nu}_e^*$
$\tilde{l}_e\tilde{l}_e^*$

Squark and gluino production

Why do we bother to go beyond NLO?

$$\sigma^{(1,\mathrm{thr})}_{gg\to\tilde{t}\bar{\tilde{t}}} = \frac{\pi\alpha_s^2(\mu^2)}{16m^2}\,\frac{N_c^2-2}{N_c(N_c^2-1)}\,\beta\left(1+4\pi\alpha_s(\mu^2)\left\{\frac{2C_F-\frac{N_c^2-4}{N_c^2-2}C_A}{16\beta}-\frac{N_c^2-4}{N_c^2-2}\,\frac{C_A}{4\pi^2}\log(8\beta^2)\right.\right.$$
$$\left.\left.+\frac{2C_A}{4\pi^2}\left[\log^2(8\beta^2)-4\log(8\beta^2)-\log(8\beta^2)\log\left(\frac{\mu^2}{m^2}\right)\right]\right\}\right).$$

Higher-order corrections introduce large logarithms

These logarithms can be summed to all orders

Squark and gluino production

Threshold resummation

$$\sigma = \sigma_0 \left[\alpha_s \left(L^2 + L + 1\right) + \alpha_s^2 \left(L^4 + L^3 + L^2 + L + 1\right) + \ldots\right]$$

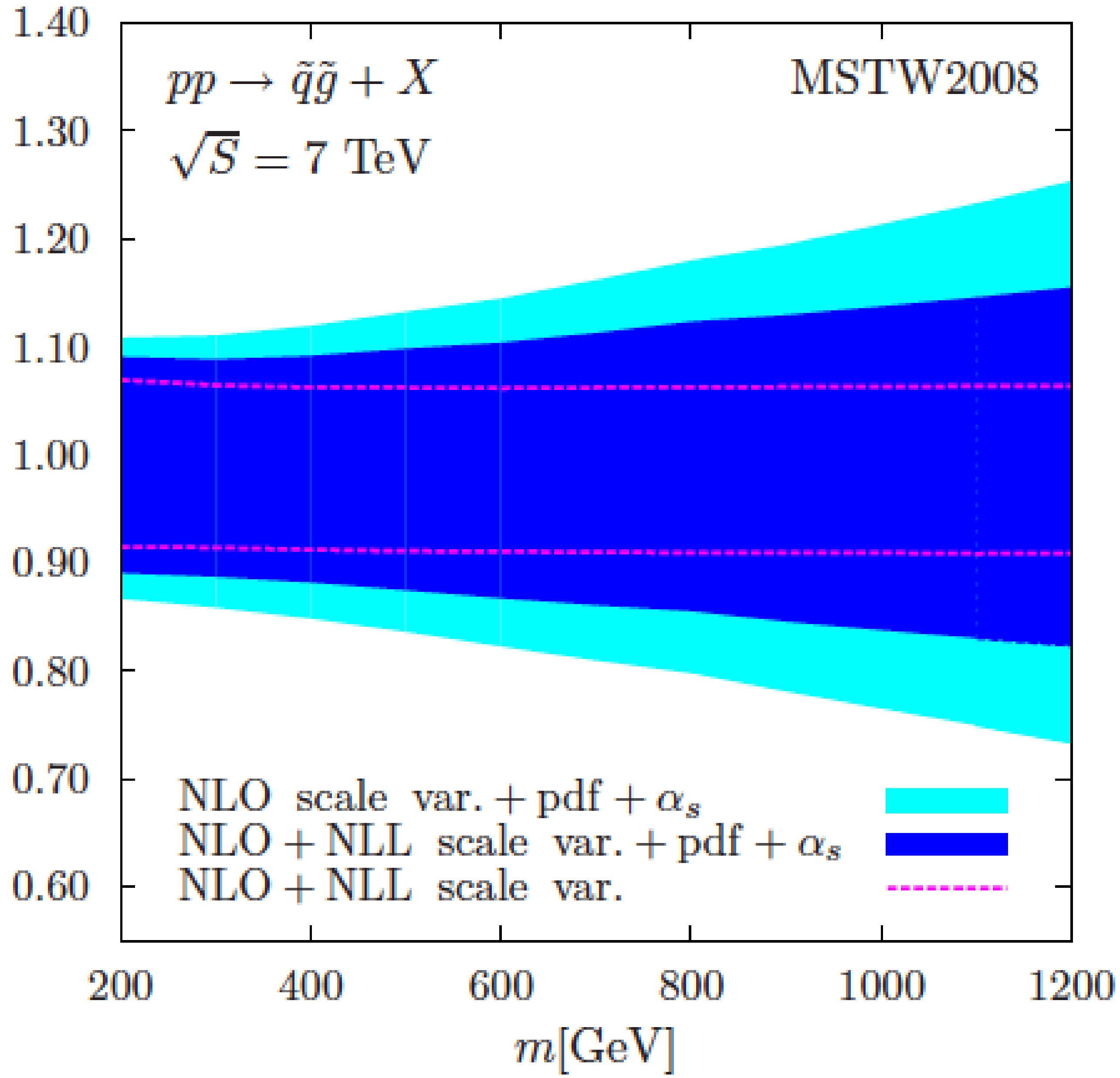
$$= \sigma_0 \exp\Big(\underbrace{\underbrace{\underbrace{L g_1(\alpha_s L)}_{\text{LL}} + g_2(\alpha_s L)}_{\text{NLL}} + \alpha_s g_3(\alpha_s L)}_{\text{NNLL}} + \ldots \Big) \underbrace{C(\alpha_s)}_{\text{constants}}$$

+ suppressed terms

Kidonakis, Sterman; Bonciani, Catani, Mangano, Nason; Kidonakis, Odera, Sterman; Catani, Mangano, Nason, Trentadue ('97-'03)

Squark and gluino production

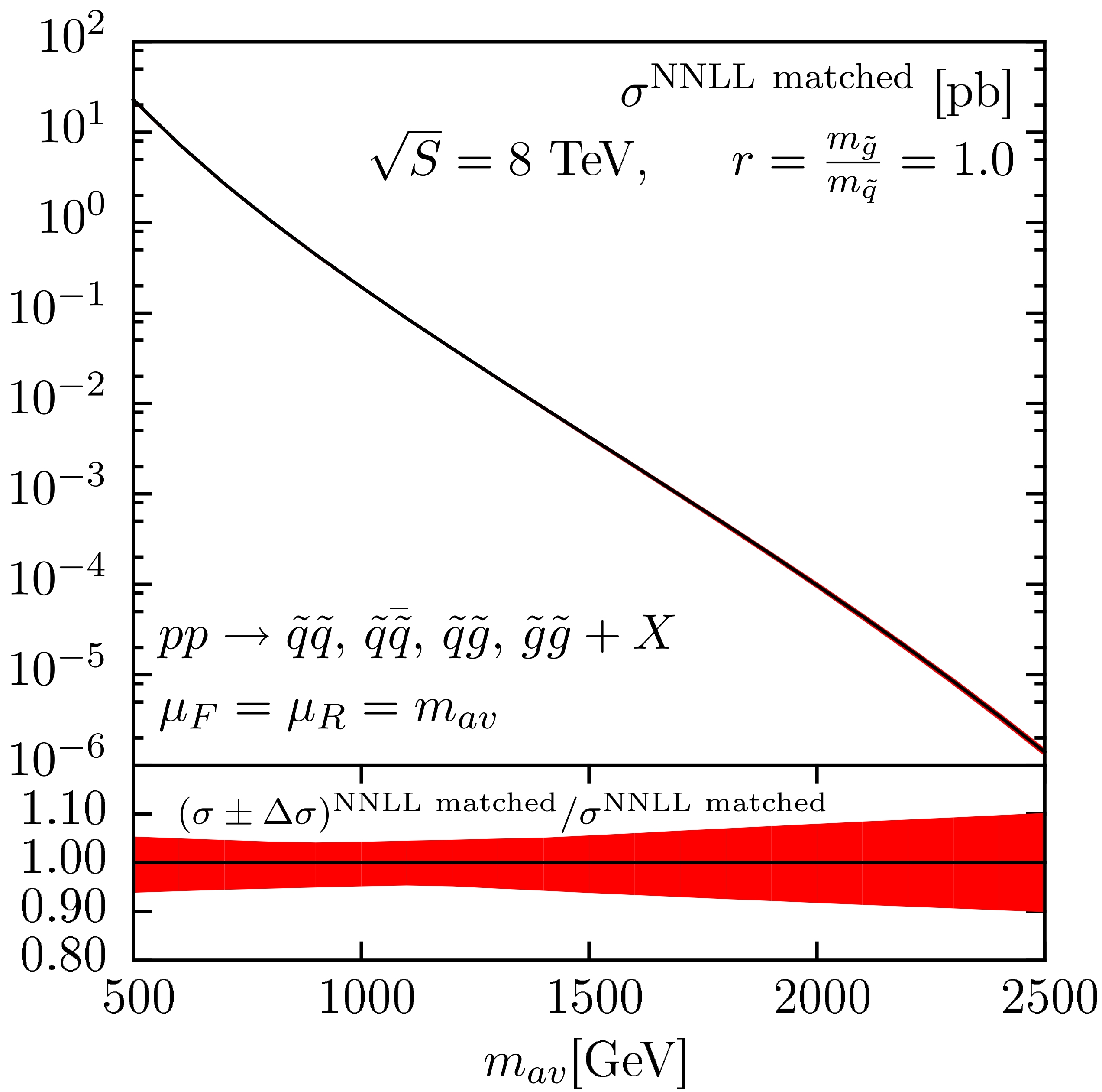
NLL threshold resummation



LHC recommendation: MK, Kulesza, van der Leeuw, Mangano, Padhi, Plehn, Portell (12)

Squark and gluino production

NNLL threshold resummation



Beenakker, Borschensky , MK, Kulesza, Laenen, Theeuwes, Thewes ('14)

Squark and gluino production

So far, to calculate the SUSY-QCD corrections we have assumed that

$u_{\mathrm{L/R}}, d_{\mathrm{L/R}}, s_{\mathrm{L/R}}, c_{\mathrm{L/R}}, b_{\mathrm{L/R}}$ are mass degenerate

and we have summed over a swath of subprocesses

$$q_i \, \bar{q}_j \to \tilde{q}_k^{c1} \, \tilde{q}_l^{* \, c2} \quad \text{and} \quad g \, g \to \tilde{q}_i^{c} \, \tilde{q}_i^{* \, c} \, .$$

How good an approximation is that?

Squark and gluino production

Let us look at a random cMSSM scenario with

$$m_0/m_{1/2}/A_0 = 825/550/0\ \mathrm{GeV}, \tan(\beta) = 10 \text{ and } \mathrm{sgn}(\mu) = +1$$

corresponding to masses

$m_{\tilde{u}_L} = m_{\tilde{c}_L}$	$m_{\tilde{u}_R} = m_{\tilde{c}_R}$	$m_{\tilde{d}_L} = m_{\tilde{s}_L}$	$m_{\tilde{d}_R} = m_{\tilde{s}_R}$	$m_{\tilde{g}}$
1799.53	1760.21	1801.08	1756.40	1602.96

Taking the average squark mass as an input and summing over all subprocesses for squark-antisquark production one gets

K = 1.39

Squark and gluino production

Looking at the individual channels, we find

Process	σ_{LO}[fb]	σ_{NLO}[fb]	K-factor
$\tilde{u}_L\bar{\tilde{u}}_L$	$9.51 \cdot 10^{-2}$	$1.43 \cdot 10^{-1}$	1.50
$\tilde{u}_R\bar{\tilde{u}}_R$	$1.14 \cdot 10^{-1}$	$1.72 \cdot 10^{-1}$	1.51
$\tilde{d}_L\bar{\tilde{d}}_L$	$5.50 \cdot 10^{-2}$	$8.79 \cdot 10^{-2}$	1.60
$\tilde{d}_R\bar{\tilde{d}}_R$	$6.89 \cdot 10^{-2}$	$1.11 \cdot 10^{-1}$	1.61
$\tilde{u}_L\bar{\tilde{u}}_R$	$3.75 \cdot 10^{-1}$	$5.12 \cdot 10^{-1}$	1.37
$\tilde{d}_L\bar{\tilde{d}}_R$	$1.41 \cdot 10^{-1}$	$1.70 \cdot 10^{-1}$	1.21
$\tilde{u}_L\bar{\tilde{d}}_L$	$6.98 \cdot 10^{-2}$	$7.89 \cdot 10^{-2}$	1.13
$\tilde{u}_L\bar{\tilde{d}}_R$	$2.98 \cdot 10^{-1}$	$3.54 \cdot 10^{-1}$	1.19
$\tilde{u}_R\bar{\tilde{d}}_L$	$2.94 \cdot 10^{-1}$	$3.49 \cdot 10^{-1}$	1.19
$\tilde{u}_R\bar{\tilde{d}}_R$	$8.36 \cdot 10^{-2}$	$9.54 \cdot 10^{-2}$	1.14
Sum	1.59	2.07	1.30

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Squark and gluino production

Looking at the cross section x decay we find

$$\sum_{\text{channels}} \sigma_{\text{NLO}} \cdot \text{BR}^{\text{LO}} \left(\tilde{q} \to \tilde{\chi}_0 q\right) \cdot \text{BR}^{\text{LO}} \left(\tilde{q}^* \to \tilde{\chi}_0 \bar{q}\right) = 0.139\,\text{fb}.$$

compared to the approximate (Prospino) calculation

$$\sum_{\text{channels}} \sigma_{\text{LO}} \cdot K^{\text{avg}} \cdot \text{BR}^{\text{LO}} \left(\tilde{q} \to \tilde{\chi}_0 q\right) \cdot \text{BR}^{\text{LO}} \left(\tilde{q}^* \to \tilde{\chi}_0 \bar{q}\right) = 0.126\,\text{fb}.$$

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Squark & gluino production and decay

NLO differential distributions with parton showers

ATLAS analysis

ATLAS-CONF-2013-047

$$p_T^{j_1} > 130\,\mathrm{GeV}, \quad p_T^{j_2} > 60\,\mathrm{GeV}, \quad \not{E}_T > 160\,\mathrm{GeV},$$

$$\frac{\not{E}_T}{m_{\mathrm{eff}}} > 0.2, \quad m_{\mathrm{eff}}^{\mathrm{incl}} > 1\,\mathrm{TeV}, \quad \Delta\phi(j_{1/2}, \vec{\not{E}}_T) > 0.4,$$

$$\text{and } \Delta\phi(j_3, \vec{\not{E}}_T) > 0.4 \quad \text{if} \quad p_T^{j_3} > 40\,\mathrm{GeV}$$

	$\tilde{q}\tilde{q}$	$\tilde{q}\bar{\tilde{q}}$
NLO	0.871 fb	0.0781 fb
PYTHIA	0.883 fb	0.0797 fb
HERWIG++	0.895 fb	0.0807 fb

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