NLO+NLL squark and gluino cross-sections with threshold-improved PDFs

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PDF4LHC Working Group
CERN, 26/10/2015

Bonvini, Marzani, JR, Rottoli, Ubiali, Ball, Bertone, Carrazza, Hartland, arXiv:1507.01006
Beenakker, Borschensky, Kramer, Kulesza, Laenen, Marzani, JR, arXiv:1510.00375

Why threshold resummation?

☑ The basic idea of threshold resummation methods is simple. Start from a **factorised cross-section** and transform it to **Mellin (conjugate) space**

$$\sigma(x,Q^2) = x\sum_{a,b}\int_x^1 \frac{dz}{z}\,\mathcal{L}_{ab}\left(\frac{x}{z},\mu_{\rm F}^2\right)\frac{1}{z}\hat{\sigma}_{ab}\left(z,Q^2,\alpha_s(\mu_{\rm R}^2),\frac{Q^2}{\mu_{\rm F}^2},\frac{Q^2}{\mu_{\rm R}^2}\right)$$

$$\sigma(N,Q^2) = \int_0^1 dx\, x^{N-2}\sigma(x,Q^2) = \sum_{a,b}\mathcal{L}_{ab}(N,Q^2)\hat{\sigma}_{ab}\left(N,Q^2,\alpha_s\right)$$

☑ Then, using different techniques, we can computed a **resummed coefficient function** that includes terms or the type $\boldsymbol{\alpha_s^k \ln^p N}$ (corresponding to $\boldsymbol{\alpha_s^k \ln^r (1-x)}$) to **all orders in perturbation theory**

$$\hat{\sigma}_{ab}^{(\rm res)}(N,Q^2,\alpha_s) = \sigma_{ab}^{(\rm born)}(N,Q^2,\alpha_s)\,C_{ab}^{(\rm res)}(N,\alpha_s)$$

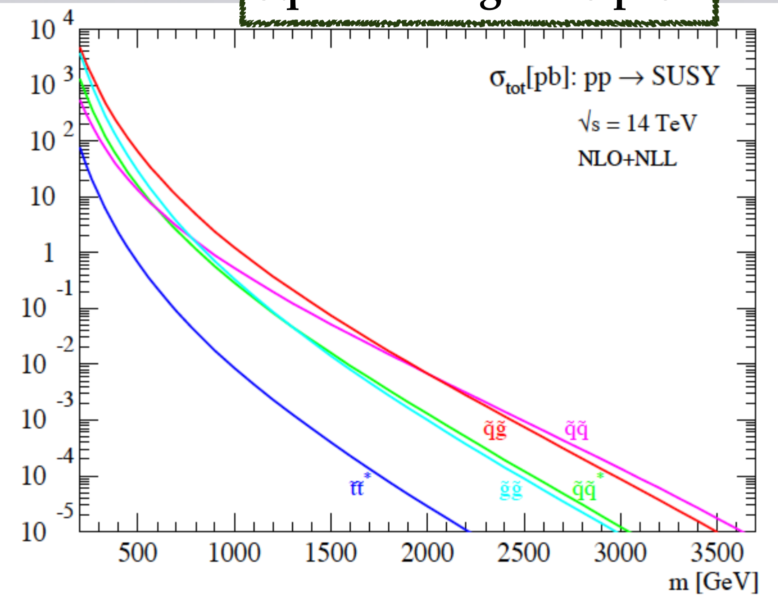
$$\begin{aligned} C^{(N\text{-soft})}(N,\alpha_s) &= g_0(\alpha_s)\exp\mathcal{S}(\ln N,\alpha_s), \\ \mathcal{S}(\ln N,\alpha_s) &= \left[\frac{1}{\alpha_s}g_1(\alpha_s\ln N) + g_2(\alpha_s\ln N) + \alpha_s g_3(\alpha_s\ln N) + \ldots\right] \end{aligned}$$

☑ These terms are numerically large near the **partonic threshold x -> 1 (N -> ∞)**, and thus their resummation **improves the perturbative expansion**, reduces scale uncertainties and allows to **construct approximate higher-order results**

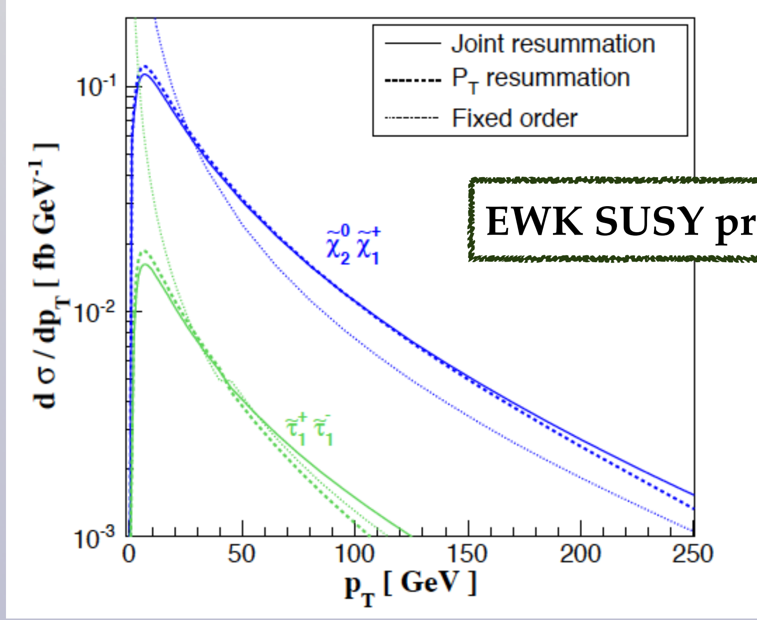
Why threshold resummation?

☑ **Threshold resummation of partonic cross-sections** extensively used in precision LHC pheno

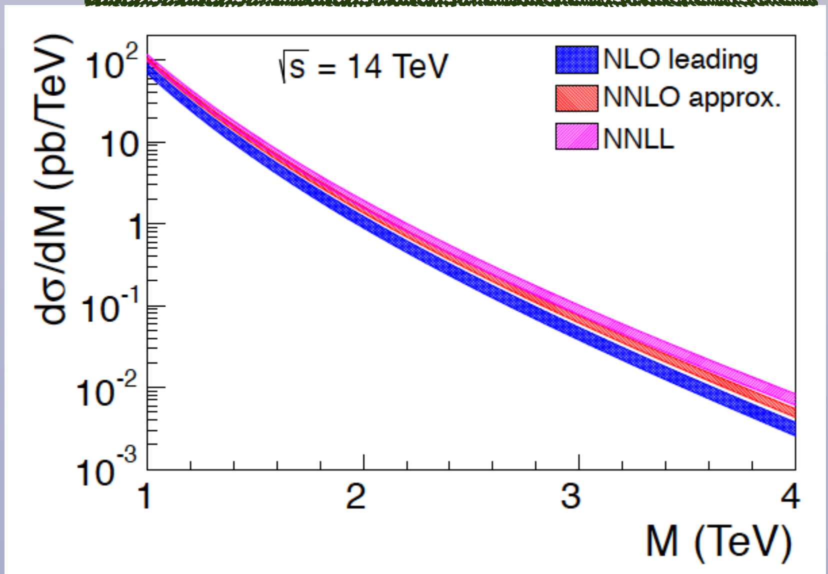
squark and gluino prod



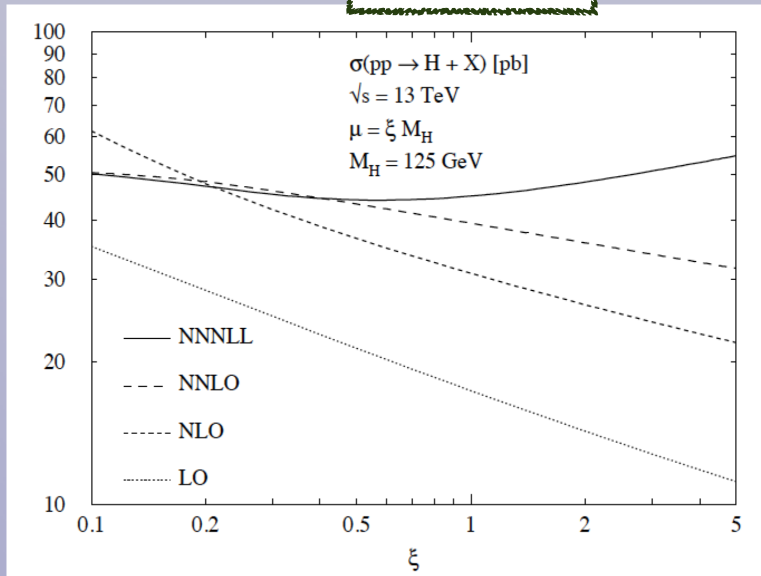
EWK SUSY prod



large mass top quark pair production



gg -> Higgs



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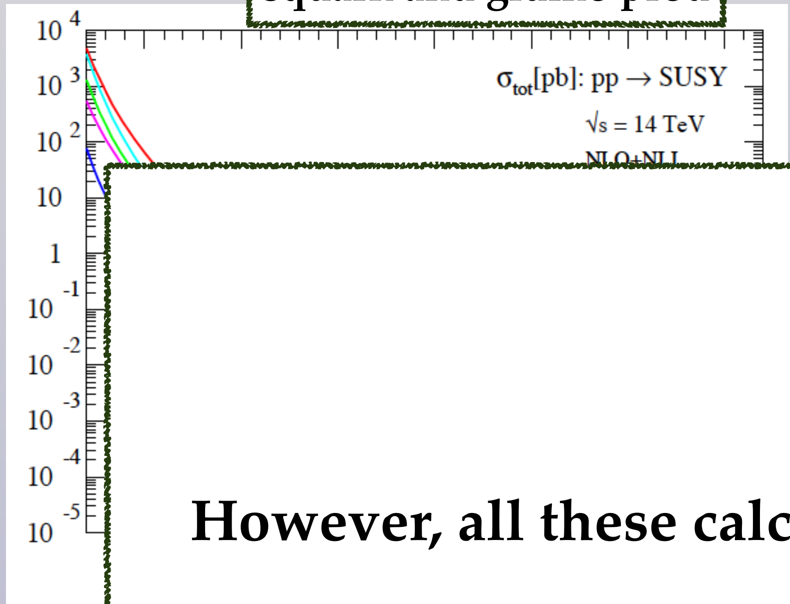
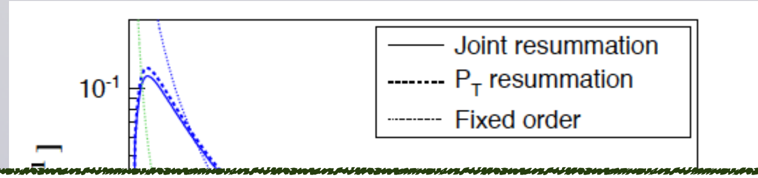
squark and gluino prod



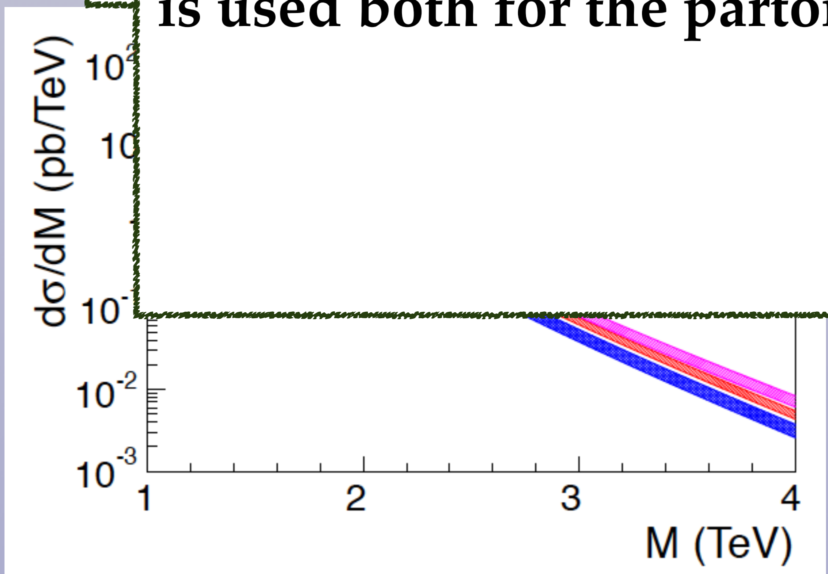


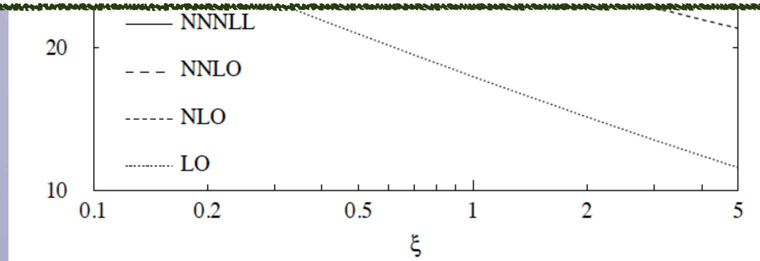
However, all these calculations use fixed-order NLO PDFs!

What happens if exactly the same theory (NLO+NLL)

is used both for the partonic matrix elements and for the PDFs?

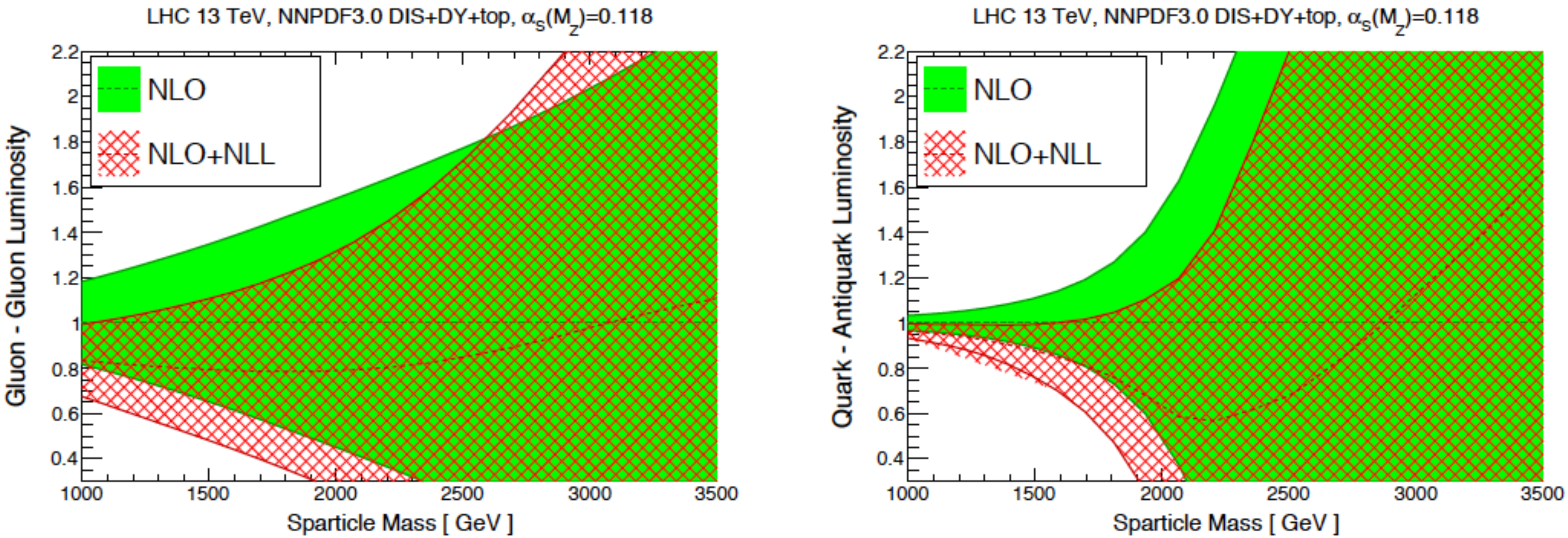
la





PDFs with threshold resummation

☑ To determine the relevance of calculations where resummation is included **both** for partonic matrix-elements and the PDFs, we have produced for the first time **threshold-improved PDFs at NLO+NLL and NNLO+NNLL** using a **variant of the NNPDF3.0 fit**

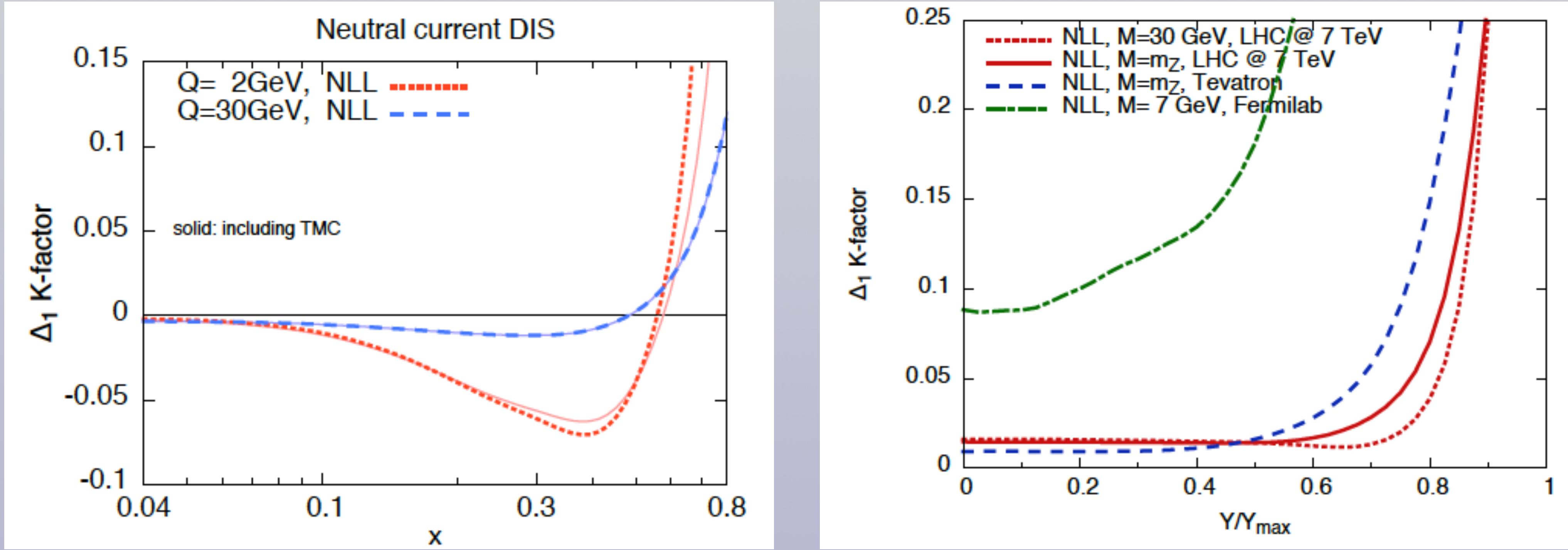


☑ **Threshold-improved PDFs** can differ substantially wrt fixed-order PDFs: **up to -20% for gg luminosity and -40% for quark-antiquark luminosity,** in the high-mass region relevant for new BSM heavy particles

PDFs with threshold resummation

☑ The **suppression** observed at **large-x in the resummed PDFs** as compared to the FO ones can be traced back to the **enhancement due to NLO+NLL** used in the fit for DIS structure functions and DY distributions

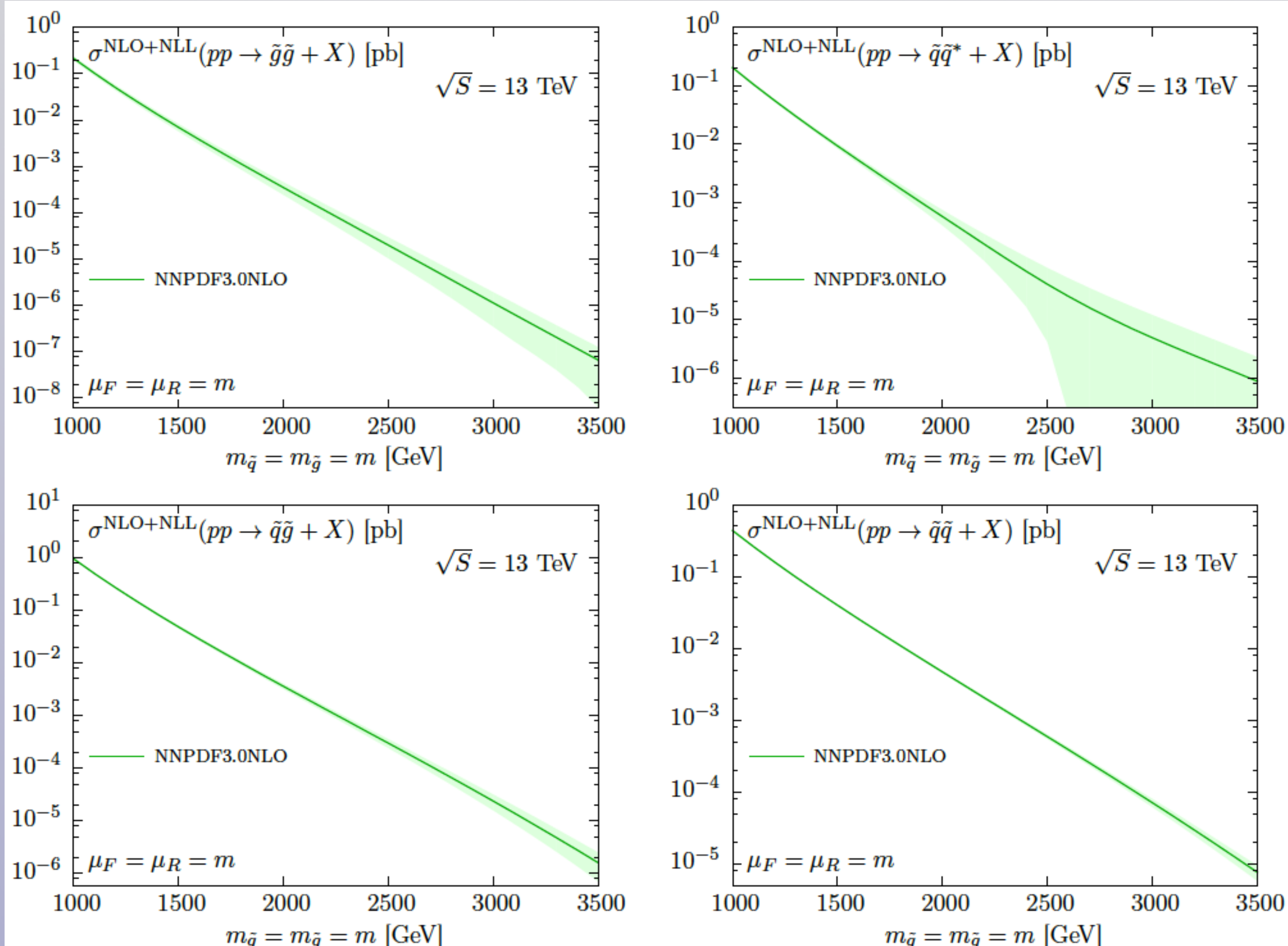
$$\sigma_{\mathrm{N}^j\mathrm{LO}+\mathrm{N}^k\mathrm{LL}} = \sigma_{\mathrm{N}^j\mathrm{LO}} + \sigma_{\mathrm{LO}} \times \Delta_j K_{\mathrm{N}^k\mathrm{LL}}$$



☑ **Phenomenologically most relevant:** this suppression will partially or totally compensate enhancements in partonic cross-sections for new processes (SUSY, Higgs, ttbar differential)

Updated NLO+NLL cross-sections with NNPDF3.0NLO

- **Previous NLL-fast calculations** at 13 TeV based on CTEQ6.6 and MSTW08 NLO sets
- **NLL-fast version 3.1** has now been updated to **NLO+NLL cross-sections with NNPDF3.0NLO**



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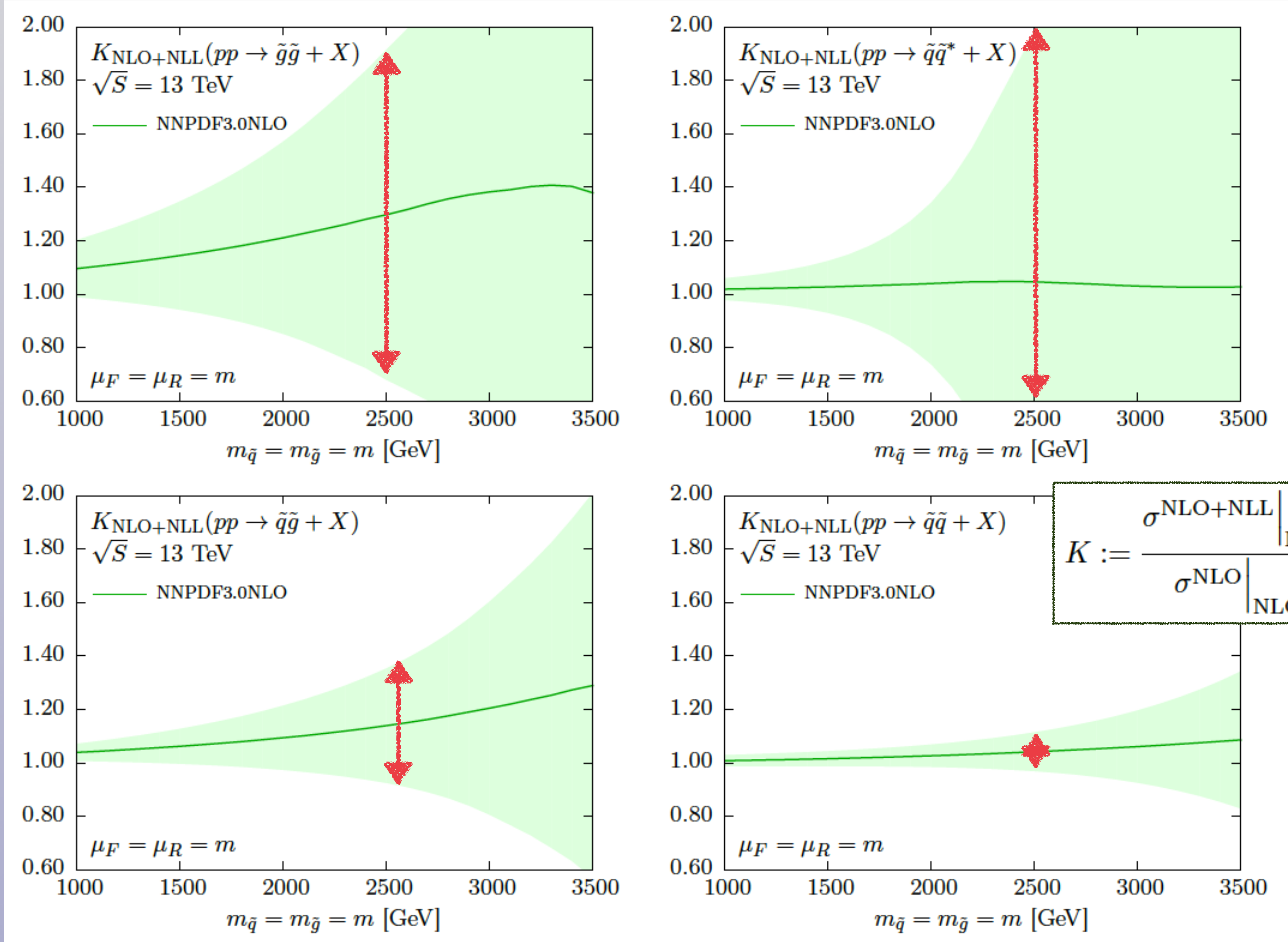

$$K := \frac{\sigma^{\mathrm{NLO+NLL}}\Big|_{\mathrm{NLO\ global}}}{\sigma^{\mathrm{NLO}}\Big|_{\mathrm{NLO\ global}}}.$$

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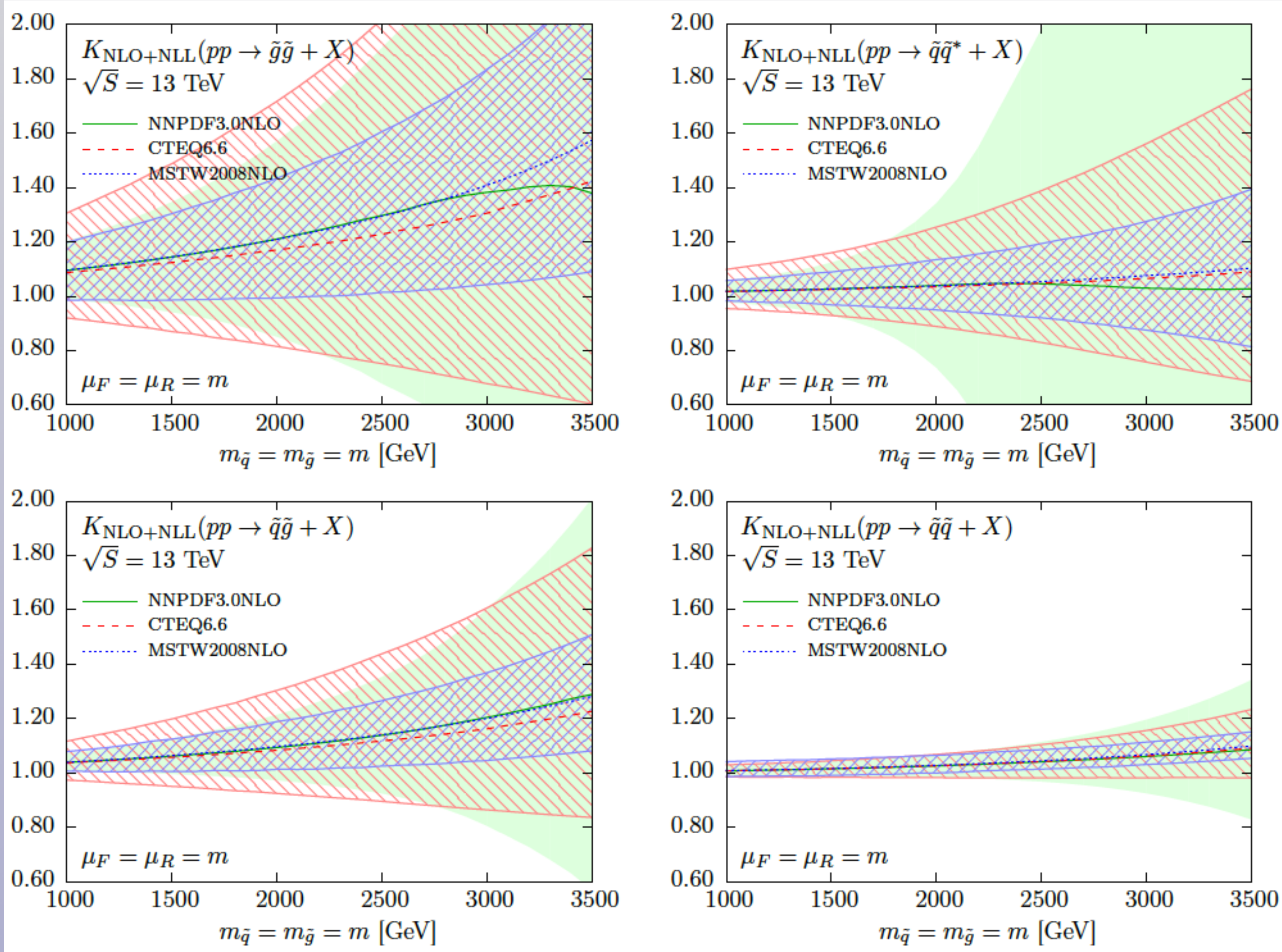
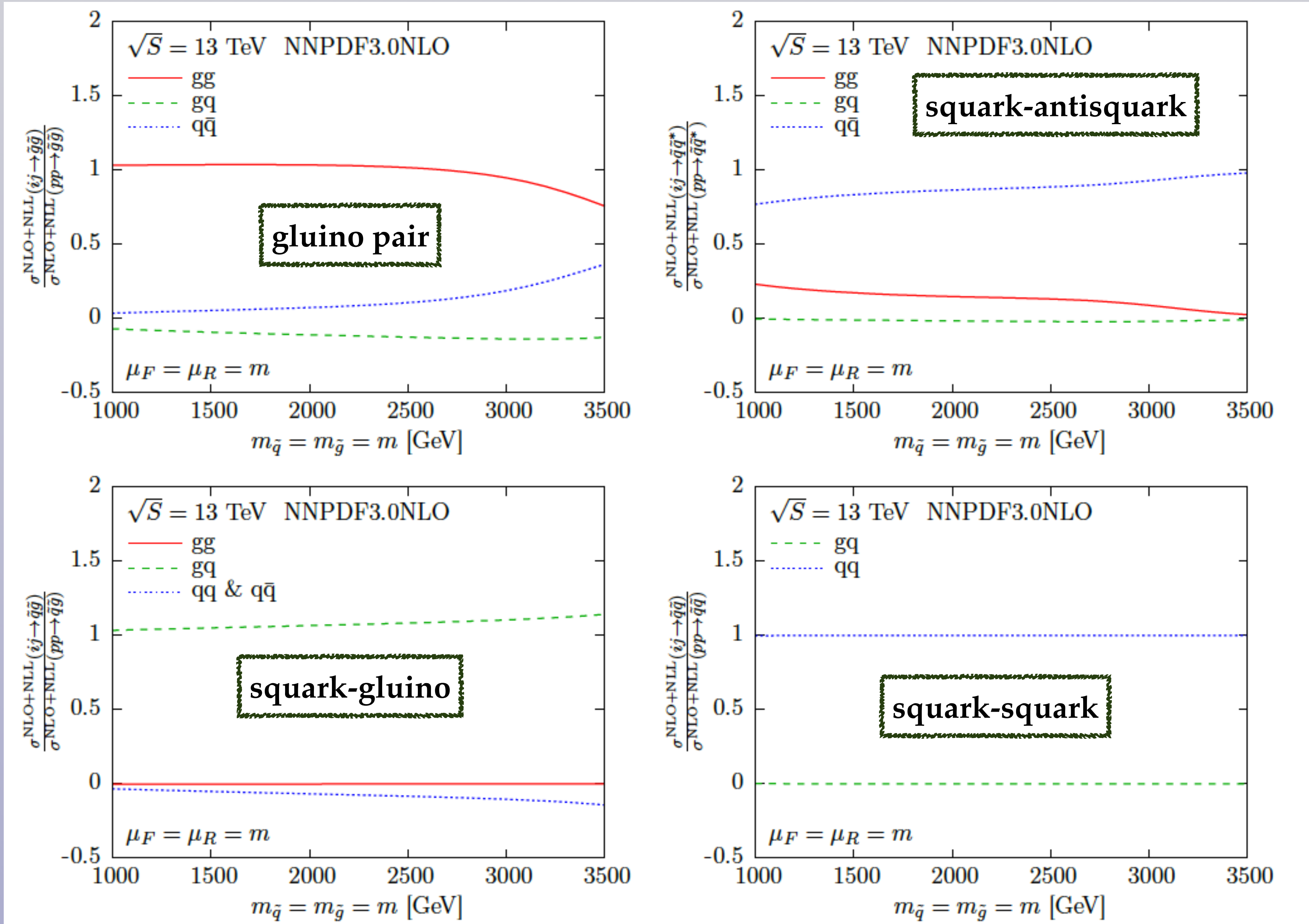


PDFs with threshold resummation

- **PDF uncertainties in high-mass SUSY cross-sections are very large!**
- This is because **large-x PDFs are being probed**, and these are affected by large errors due to the **lack of direct experimental constraints** (can be improved with Run-I and Run-II LHC data)



NLO+NLL susy xsecs with threshold-improved PDFs

- Now include the effect of **NLO+NLL threshold-improved PDF**
- Problem is that **not all processes included in NNPDF3.0** can be consistently resummed, in particular **jets** and **charged current Drell-Yan** missing from NNPDF3.0 NLO+NLL fits

Experiment	Observable	Ref.	NNPDF3.0 global (N)NLO	NNPDF3.0 DIS+DY+top (N)NLO [+(N)NLL]
NMC	$\sigma^{NC}_{\rm dis}$, F_2^d/F_2^p	[124, 125]	Yes	Yes
BCDMS	F_2^d, F_2^p	[126, 127]	Yes	Yes
SLAC	F_2^d, F_2^p	[128]	Yes	Yes
CHORUS	$\sigma^{CC}_{\nu N}$	[129]	Yes	Yes
NuTeV	$\sigma^{\rm CC,charm}_{\nu N}$	[130]	Yes	Yes
HERA-I	$\sigma^{NC}_{\rm dis}$, $\sigma^{CC}_{\rm dis}$	[131]	Yes	Yes
ZEUS HERA-II	$\sigma^{NC}_{\rm dis}$, $\sigma^{CC}_{\rm dis}$	[132–135]	Yes	Yes
H1 HERA-II	$\sigma^{NC}_{\rm dis}$, $\sigma^{CC}_{\rm dis}$	[136, 137]	Yes	Yes
HERA charm	$\sigma^{\rm NC,charm}_{\rm dis}$	[138]	Yes	Yes
DY E866	$\sigma^{NC}_{\rm DY,p}$, $\sigma^{NC}_{\rm DY,d}/\sigma^{NC}_{\rm DY,p}$	[139–141]	Yes	Yes
DY E605	$\sigma^{NC}_{\rm DY,p}$	[142]	Yes	Yes
CDF Z rap	$\sigma^{NC}_{\rm DY,p}$	[143]	Yes	Yes
CDF Run-II k_t jets	$\sigma_{\rm jet}$	[144]	Yes	No
D0 Z rap	$\sigma^{NC}_{\rm DY,p}$	[145]	Yes	Yes
ATLAS Z 2010	$\sigma^{NC}_{\rm DY,p}$	[146]	Yes	Yes
ATLAS W 2010	$\sigma^{CC}_{\rm DY,p}$	[146]	Yes	No
ATLAS 7 TeV jets 2010	$\sigma_{\rm jet}$	[147]	Yes	No
ATLAS 2.76 TeV jets	$\sigma_{\rm jet}$	[148]	Yes	No
ATLAS high-mass DY	$\sigma^{NC}_{\rm DY,p}$	[149]	Yes	Yes
ATLAS W p_T	$\sigma^{CC}_{\rm DY,p}$	[150]	Yes	No
CMS W electron asy	$\sigma^{CC}_{\rm DY,p}$	[151]	Yes	No
CMS W muon asy	$\sigma^{CC}_{\rm DY,p}$	[152]	Yes	No
CMS jets 2011	$\sigma_{\rm jet}$	[153]	Yes	No
CMS $W+c$ total	$\sigma^{\rm NC,charm}_{\rm DY,p}$	[154]	Yes	No
CMS 2D DY 2011	$\sigma^{NC}_{\rm DY,p}$	[155]	Yes	Yes
LHCb W rapidity	$\sigma^{CC}_{\rm DY,p}$	[156]	Yes	No
LHCb Z rapidity	$\sigma^{NC}_{\rm DY,p}$	[157]	Yes	Yes
ATLAS CMS top prod	$\sigma(t\bar{t})$	[158–163]	Yes	Yes

NLO+NLL susy xsecs with threshold-improved PDFs

- Now include the effect of **NLO+NLL threshold-improved PDF**
- Problem is that **not all processes included in NNPDF3.0** can be consistently resummed, in particular **jets** and **charged current Drell-Yan** missing from NNPDF3.0 NLO+NLL fits
- Prescriptions needed to combine **NNPDF3.0NLO (global, fixed-order fit)** with **NNPDF3.0NLL (reduced dataset, resummed)**

Prescription 1

$$K := \frac{\sigma^{\rm NLO+NLL}\Big|_{\rm NLO\ global}}{\sigma^{\rm NLO}\Big|_{\rm NLO\ global}} \times \frac{\sigma^{\rm NLO+NLL}\Big|_{\rm NLL\ DIS+DY+top}}{\sigma^{\rm NLO+NLL}\Big|_{\rm NLO\ DIS+DY+top}} .$$

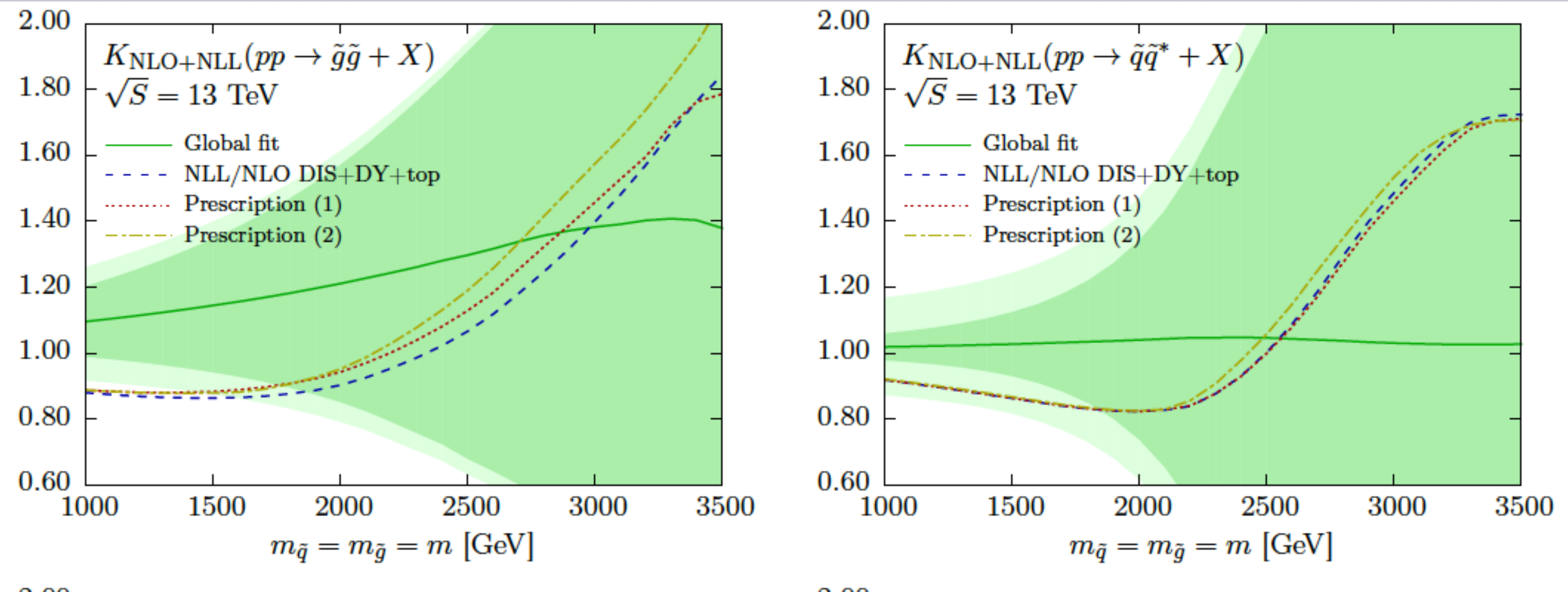
Prescription 2

$$K = \frac{\sigma_{qq}^{\rm NLO+NLL}\Big|_{\rm rescaled} + \sigma_{qg}^{\rm NLO+NLL}\Big|_{\rm rescaled} + \sigma_{gg}^{\rm NLO+NLL}\Big|_{\rm rescaled}}{\sigma^{\rm NLO}\Big|_{\rm NLO\ global}}$$

$$\sigma_{ij}^{\rm NLO+NLL}\Big|_{\rm rescaled} = \sigma_{ij}^{\rm NLO+NLL}\Big|_{\rm NLO\ global} \times \frac{\sigma_{ij}^{\rm NLO+NLL}\Big|_{\rm NLL\ DIS+DY+top}}{\sigma_{ij}^{\rm NLO+NLL}\Big|_{\rm NLO\ DIS+DY+top}}$$

NLO+NLL SUSY xsecs with threshold-improved PDFs

- Now include the effect of **NLO+NLL threshold-improved PDF**
- Substantial shift, **changes qualitatively and quantitatively** the behaviour of NLO+NLL SUSY xsecs
- Shift within total theory band, so **current exclusion limits unaffected**
- But would become crucial if we ever need to **characterise SUSY particles from LHC data**, much in the same way as in the **Higgs sector**



solid band: PDF errors only **lighter band: scales+PDF errors added linearly**

NLL-fast grids

- The **updated NLO+NLL squark and gluino** production cross-sections at the **LHC 13 TeV** using **NNPDF3.0** can be downloaded from the NLL-fast collaboration webpage
- Include a **complete characterisation of theory uncertainties** from PDFs, scales and strong coupling

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

Squark and gluino production:

- Squark and Gluino Production at Hadron Colliders, W. Beenakker, R. Höpker, M. Spira, P.M. Zerwas, Nucl. Phys. B492 (1997) 51-103
- Threshold resummation for squark-antisquark and gluino-pair production at the LHC, A. Kulesza, L. Motyka, Phys. Rev. Lett. 102 (2009) 111802
- Soft gluon resummation for the production of gluino-gluino and squark-antisquark pairs at the LHC, A. Kulesza, L. Motyka, Phys. Rev. D80 (2009) 095004
- Soft-gluon resummation for squark and gluino hadroproduction, Wim Beenakker, Silja Brensing, Michael Krämer, Anna Kulesza, Eric Laenen, Irene Niessen, JHEP 0912 (2009) 041
- Squark and gluino hadroproduction, W. Beenakker, S. Brensing, M. Krämer, A. Kulesza, E. Laenen, L. Motyka, I. Niessen, Int. J. Mod. Phys. A26 (2011) 2637-2664

Stop (sbottom) production:

- Stop Production at Hadron Colliders, W. Beenakker, M. Krämer, T. Plehn, M. Spira, P.M. Zerwas, Nucl.Phys. B515 (1998) 3-14
- Supersymmetric top and bottom squark production at hadron colliders, Wim Beenakker, Silja Brensing, Michael Krämer, Anna Kulesza, Eric Laenen, Irene Niessen, JHEP 1008(2010)098
- Squark and gluino hadroproduction, W. Beenakker, S. Brensing, M. Krämer, A. Kulesza, E. Laenen, L. Motyka, I. Niessen, Int. J. Mod. Phys. A26 (2011) 2637-2664

When using NLL-fast version 3.1, please additionally cite:

- NLO+NLL squark and gluino production cross-sections with threshold-improved parton distributions, W. Beenakker, C. Borschensky, M. Krämer, A. Kulesza, E. Laenen, S. Marzani, J. Rojo

Code

Downloads

NEW: NLL-fast, version 3.1 (LHC @ 13 TeV)

- Main program and grids in one package nllfast-3.1. For grids for stop/sbottom production SUSY parameters other that stop/sbottom masses correspond to CMSSM benchmark point 40.2.5 as
- This version of NLL-fast is an update of version 3.0, now also including predictions with the NNPDF3.0NLO (NNPDF3.0LO for LO) set.
- Please note that the output format for the NNPDF predictions is slightly different, as the PDF and AlphaS error are already given in a combined format.

- In addition, **cross-sections using the threshold-improved NNPDF3.0** sets is available from the authors upon request.
- Important to use **up-to-date theory calculations** for the **interpretation of SUSY searches** at the LHC Run II