

Electroweakino pair production at the LHC in NLO+NLL with resummation-improved PDFs

Michael Klasen

Institute for Theoretical Physics, University of Münster

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Work done with J. Fiaschi



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References

- J. Fiaschi, MK
Slepton pair production at the LHC in NLO+NLL with resummation-improved parton densities
JHEP 1803 (2018) 094 [1801.10357]

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- J. Fiaschi, MK
Neutralino-chargino pair production at NLO+NLL with resummation-improved parton density functions for LHC Run II
Phys. Rev. D 98 (2018) 055014 [1805.11322]

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Neutralino-chargino pair production at NLO+NLL with resummation-improved parton density functions for LHC Run II
Phys. Rev. D 98 (2018) 055014 [1805.11322]
- J. Fiaschi, MK, M. Sunder
Beyond the SM Physics at the HL-LHC and HE-LHC
WG3 of the CERN Workshop, 1812.07831

Motivation

Supersymmetry:

- High scale: Poincaré symmetry, supergravity, string theory
- Weak scale: Hierarchy problem, unification, dark matter
- Simplified: Prototype for many more minimal BSM theories
- Actively searched for by ATLAS and CMS → Runs 3 and 4

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Theoretical calculations:

- NLO+(N)NLL for squarks, gluinos; sleptons, gauginos
- Public code RESUMMINO
- Total cross sections increased, scale dependence reduced
- PDF uncertainty still NLO, not reduced

Resummation-improved parton densities (NNPDF3.0)

M. Bonvini et al., JHEP 1509 (2015) 191

NLO+NLL calculations not available for all processes.

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Analysis with reduced data set:

- Deep-inelastic scattering
- Drell-Yan production
- Top-pair production

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Also NLO analysis with identical data set.

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Particularities:

- Replica method problematic in Mellin space (need all x)
- Outliers produce unphysical (e.g. negative) cross sections
- Larger, not smaller uncertainty than in global analysis

NLO+NLL cross sections with global NLO+NLL PDFs

W. Beenakker et al., Eur. Phys. J. C 76 (2016) 53

K-factor:

$$K = \frac{\sigma(\text{NLO} + \text{NLL})_{\text{NLO global}}}{\sigma(\text{NLO})_{\text{NLO global}}} \cdot \frac{\sigma(\text{NLO} + \text{NLL})_{\text{NLO+NLL reduced}}}{\sigma(\text{NLO} + \text{NLL})_{\text{NLO reduced}}}$$

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(Approximate) NLO+NLL cross sections with NLO+NLL PDFs:

$$\sigma(\text{NLO} + \text{NLL})_{\text{NLL+NLO global}} = K \cdot \sigma(\text{NLO})_{\text{NLO global}}$$

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$$\sigma(\text{NLO} + \text{NLL})_{\text{NLL+NLO global}} = K \cdot \sigma(\text{NLO})_{\text{NLO global}}$$

(Approximate) **NLO+NLL global PDF error**:

- Vary NLO global PDFs in $\sigma(\text{NLO})_{\text{NLO global}}$
- Eliminate replicas with unphysical behaviour
- Vary scales with 7-point method directly in $\sigma(\text{NLO} + \text{NLL})$
- Add in quadrature for total uncertainty

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Similar definition for $d\sigma/dM_{\tilde{\ell}\tilde{\ell}}$.

Application to electroweak SUSY searches at the LHC

Minimal Supersymmetric Standard Model:

- Universality of soft SUSY-breaking masses (pMSSM)
- Natural SUSY spectrum → Higgsino masses below 1 TeV
- Compressed spectrum ($m_{\tilde{\chi}_1^\pm} \simeq m_{\tilde{\chi}_2^0} \simeq m_{\tilde{\chi}_1^0}$)

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Processes in RESUMMINO:

- $pp \rightarrow \tilde{\ell}\tilde{\ell}^*$ ($\ell = e, \mu$), $\tilde{\tau}_R\tilde{\tau}_R^*$, $\tilde{\tau}_1\tilde{\tau}_1^*$
- $pp \rightarrow \tilde{\chi}_i^\pm\tilde{\chi}_j^\mp$, $\tilde{\chi}_i^\pm\tilde{\chi}_j^0$, $\tilde{\chi}_i^0\tilde{\chi}_j^0$ ($i, j = 1, 2$)
- Also $pp \rightarrow \tilde{g}\tilde{\chi}_j^{\pm,0}$, $\tilde{q}_i\tilde{\chi}_j^{\pm,0}$ (in progress), $pp \rightarrow Z' \rightarrow \ell\bar{\ell}$

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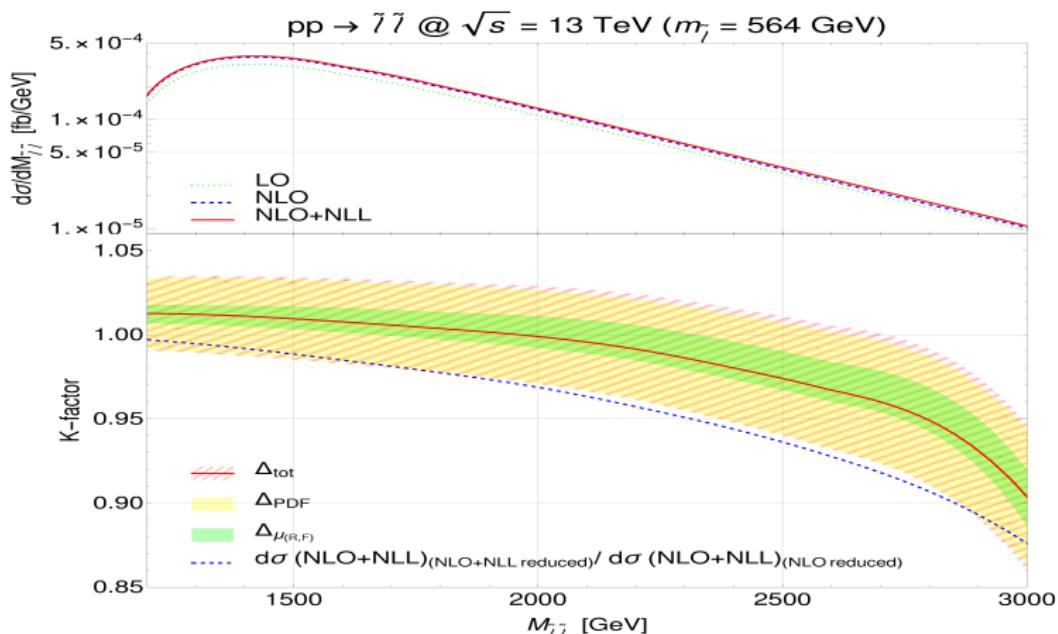
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Experimental signatures:

- $\tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm \rightarrow W^\pm\tilde{\chi}_1^0 \rightarrow \ell\bar{\nu}\tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0 \rightarrow \ell\bar{\ell}\tilde{\chi}_1^0$
- Soft leptons, moderate \cancel{E}_T
- Branching ratios, efficiencies to be added by ATLAS, CMS

Invariant mass distribution for left-handed slepton pairs

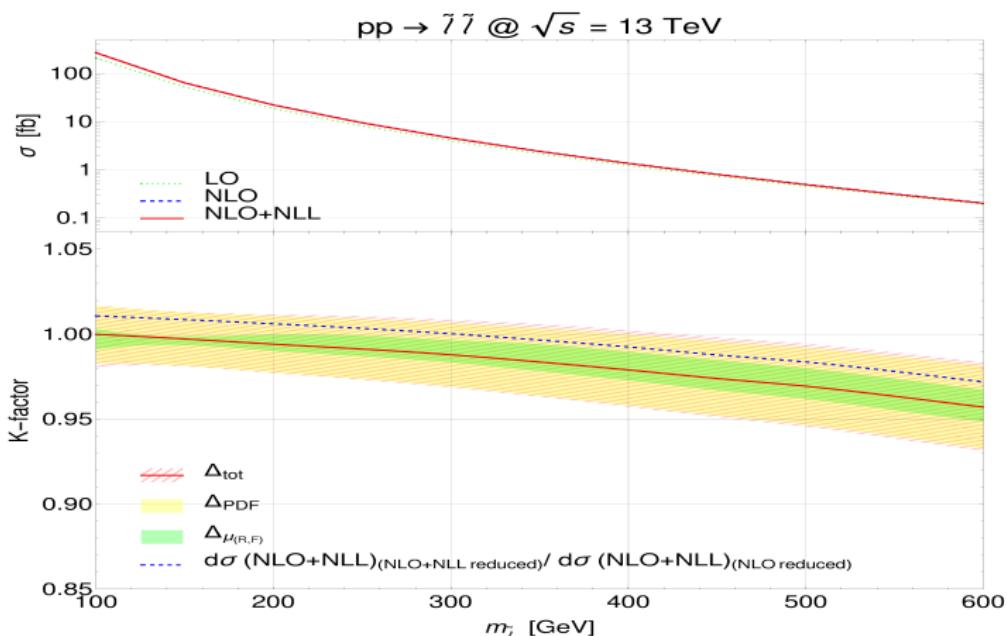
J. Fiaschi, MK, JHEP 1803 (2018) 094



At the peak, NLO increases LO by 16%, NLL in addition by 2-3%.
Red: Full K-factor. Blue: PDFs only, partially compensated by MEs.

Total cross section for left-handed slepton pairs

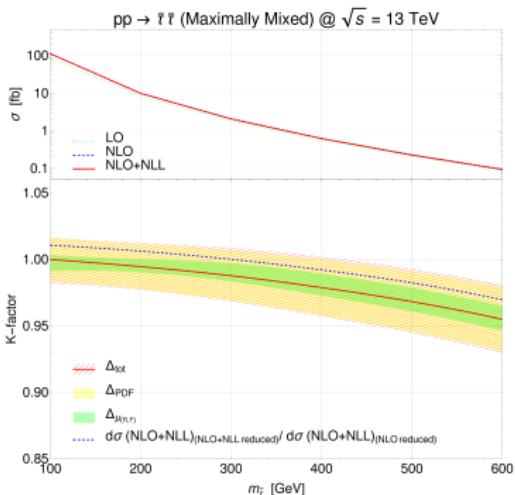
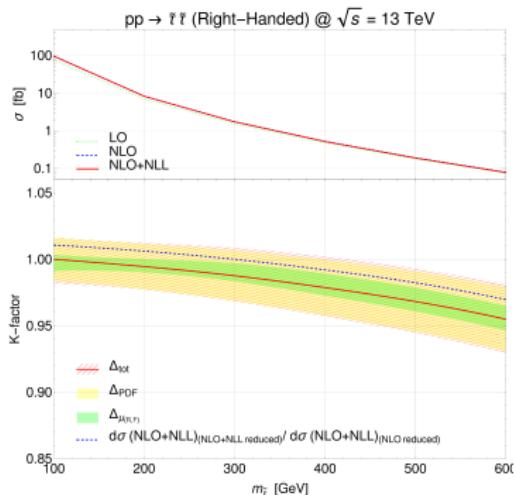
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ATLAS/CMS limits ($\mathcal{L} = 35 - 50 \text{ fb}^{-1}$): $m_{\tilde{\ell}_{L(R)}} > 400 \text{ (290) GeV}$.
NLO+NLL cross sections with NLO+NLL PDFs smaller by $\sim 4\%$.

Total cross sections for right-handed and max. mixed staus

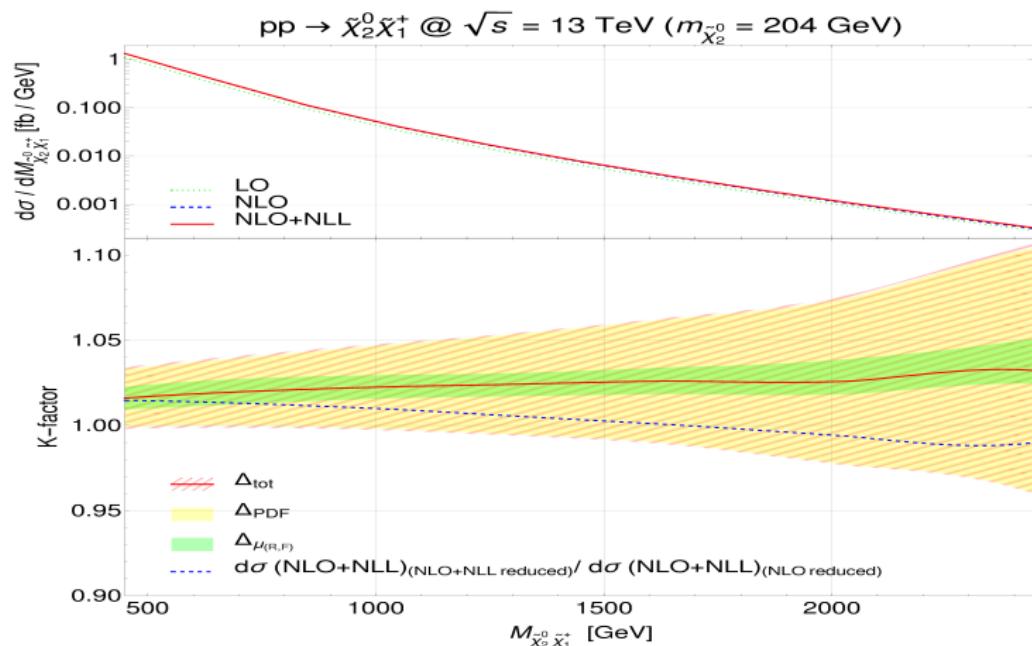
J. Fiaschi, MK, JHEP 1803 (2018) 094



Right-handed staus: Smaller by almost a factor 3.
 Maximally mixed staus: Smaller by about a factor 2.
 Similar behaviour of higher-order corrections.

Invariant mass distribution for light higgsinos

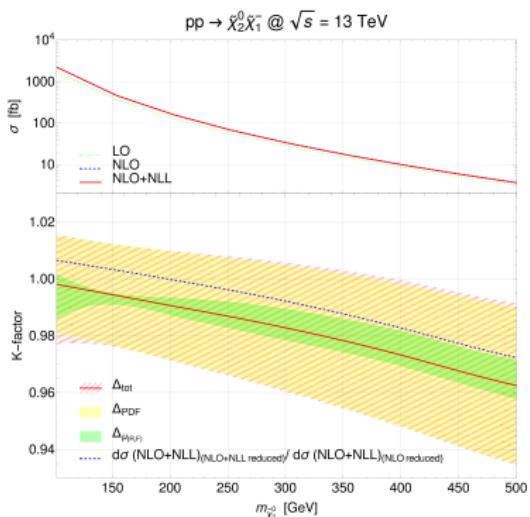
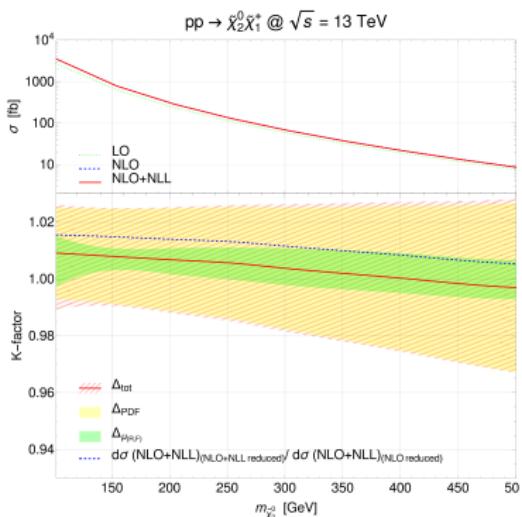
J. Fiaschi, MK, PRD 98 (2018) 055014



$\mu = 200 \text{ GeV} < M_{1,2} = 1 \text{ TeV}$, $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^\pm} \approx m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \approx 5 \text{ GeV}$.
At low $M_{\tilde{\chi}\tilde{\chi}}$, NLO increases LO by 20%, NLL in addition by 1-4%.

Total cross sections for positive and negative higgsinos

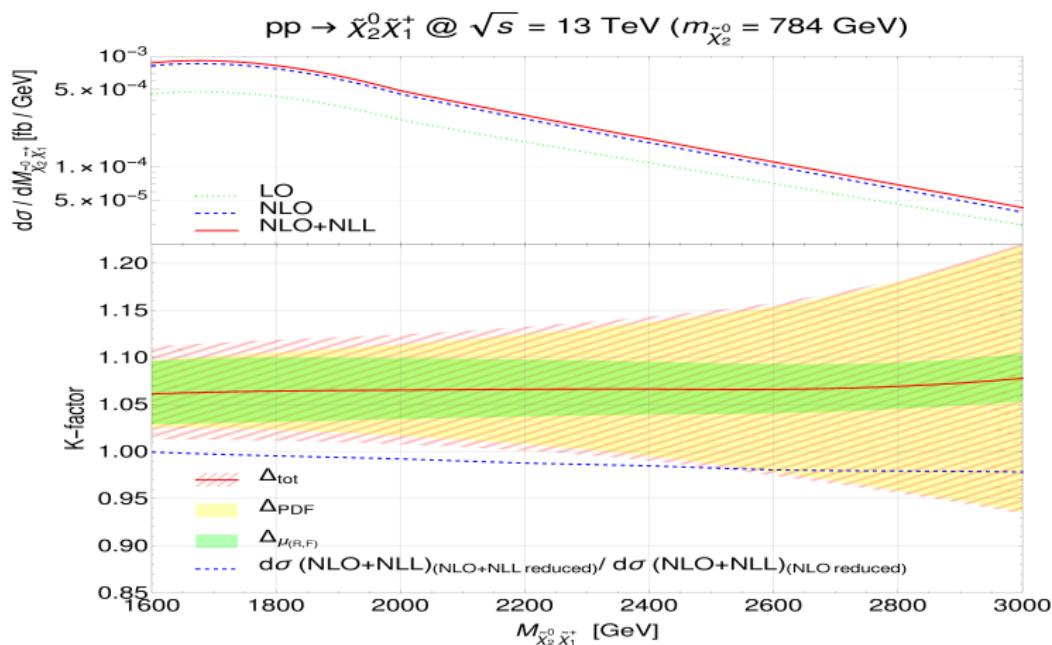
J. Fiaschi, MK, PRD 98 (2018) 055014



Positive charginos have larger σ , increased by NLO+NLL PDFs.
 Negative charginos have smaller σ , reduced by NLO+NLL PDFs.

Invariant mass distribution for heavier gauginos

J. Fiaschi, MK, PRD 98 (2018) 055014

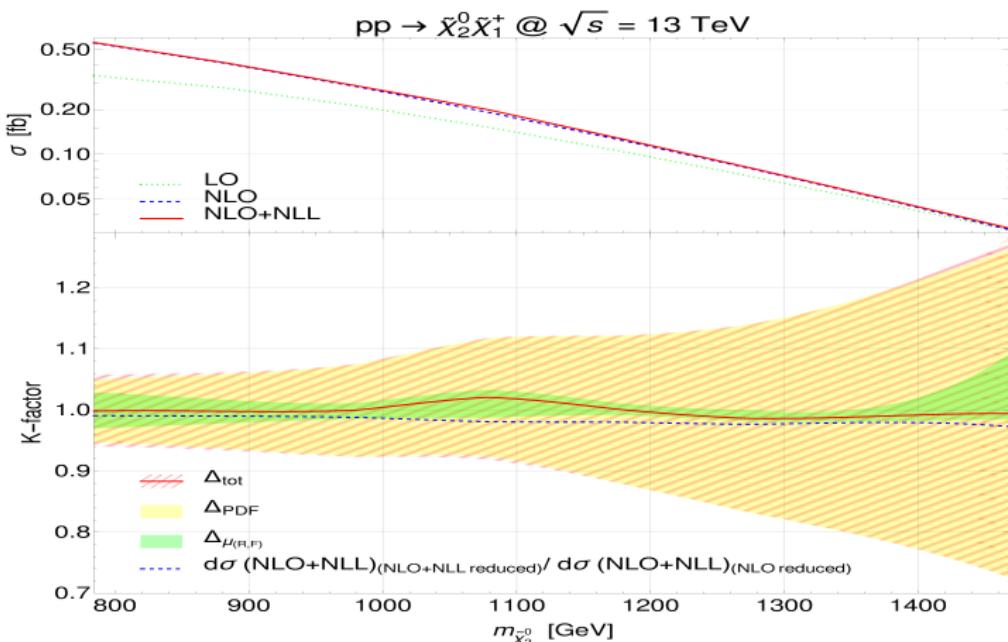


NLO increases LO by 30-80%, NLL in addition by 6-10%.

Winos considerably heavier than higgsinos \rightarrow closer to threshold.

Total cross section for heavier gauginos

J. Fiaschi, MK, PRD 98 (2018) 055014



Small effect from resummation in PDFs.

Summary

- RESUMMINO with new NLO+NLL PDFs [1507.01006]
- Should lead to smaller PDF uncertainties
- Reduced data set leads to larger (!) PDF uncertainties
- Best of both worlds using K -factor prescription [1510.00375]

Summary

- RESUMMINO with new NLO+NLL PDFs [1507.01006]
- Should lead to smaller PDF uncertainties
- Reduced data set leads to larger (!) PDF uncertainties
- Best of both worlds using K -factor prescription [1510.00375]

- Cross sections increase from 7 (8) TeV to 13 (27) TeV [1812.07831]
- Large cross sections for left-handed sleptons/light higgsinos
- Large NLL corrections in particular for heavy winos
- NLL in MEs partially compensated by NLL in PDFs