

Electroweak superpartner production with Resummino at 13.6 TeV

[2304.11915] [2202.13416]

A. Feike¹, J. Fiaschi², B. Fuks³, M. Klasen⁴, A. Neuwirth⁵

¹alex.feike@uni-muenster.de

²juri.fiaschi@unimib.it

³fuks@lpthe.jussieu.fr

⁴michael.klasen@uni-muenster.de

⁵alexander.neuwirth@uni-muenster.de



Outline

Motivation

Resummation

Results

Conclusion

Codes

Outline

Motivation

Resummation

Results

Conclusion

Codes

Motivation

- ▶ In the MSSM R-Parity implies production of SUSY particles in even numbers
- ▶ R-Parity prevents LSP from decaying $\implies$ neutralino is a DM candidate
- ▶ Expect dominant production of squark pairs and gluino pairs
- ▶ But, production at the LHC might be restricted by heavy masses
 - ▶ Electroweak production of slepton pairs or electroweakino pairs
 - ▶ Semi strong production of electroweakino-squark or electroweakino-gluino
- ▶ Electroweak regime has more interesting parameters to study (masses and couplings)

Outline

Motivation

Resummation

Results

Conclusion

Codes

Threshold Resummation of soft gluons

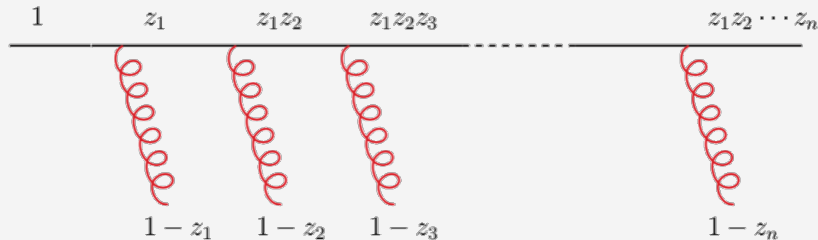
- ▶ Massive particles are mostly produced close to threshold ($M^2/s = z \rightarrow 1$)⁶
- ▶ Perturbative expansion in α_s is spoiled by

Large Sudakov logarithms ($m \leq 2n - 1$)

$$\left(\frac{\alpha_s}{2\pi}\right)^n \frac{\log^m(1-z)}{1-z}$$

$$\left(\frac{\alpha_s}{2\pi}\right)^n \log^m\left(\frac{M^2}{p_T^2}\right)$$

- ▶ Solution: Resummation of all soft emitted gluons



⁶Catani, S. & Trentadue, L. *Nucl. Phys. B* **327**, 323–352 (1989).

Threshold Resummation of soft gluons

► Transforming to Mellin space

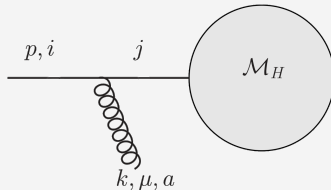
$$F(N) = \int_0^1 dy y^{N-1} F(y) \quad \Rightarrow \quad \left[\frac{\log^m(1-z)}{1-z} \right]_+ \xrightarrow{F} \sim \log^{m+1} N + \dots$$

factorizes the phase space

$$\int dz z^{N-1} d\phi_{2+n}(z) \approx d\phi_2 \times d\phi_n(N)$$

► Dynamical Factorisation is achieved by the eikonal approximation

$$\Gamma_{\text{eik}}^\mu = g_s T^j \frac{\Delta_i v^\mu}{\delta_i v \cdot k + i\epsilon}$$



Threshold Resummation of soft gluons

- ▶ From factorization theorem we split hard and long distance behaviour

$$\sigma(M^2, m^2) = \mathcal{H}(M^2/\mu_F^2) \mathcal{S}(m^2/\mu_F^2)$$

- ▶ Require independence on scale μ_F

$$\sigma(M^2, m^2) = \mathcal{H}(1) \mathcal{S}(1) \exp \left[- \int_{m^2}^{M^2} \frac{dk}{k^2} \gamma_s(k^2) \right]$$

- ▶ From applying the RGEs we get⁷:

$$\sigma^{\text{Res.}}(N, M^2, \mu_R^2, \mu_F^2) = \mathcal{H}_{ab}(M^2, \mu_R^2, \mu_F^2) \exp [G_{ab}(N, M^2, \mu_R^2, \mu_F^2)] + \mathcal{O} \left(\frac{1}{N} \right)$$

with

$$G_{ab}(N, M^2, \mu_R^2, \mu_F^2) = \underbrace{LG_{ab}^{(1)}(N)}_{\text{Leading Log } \sim \log^2(N)} + \underbrace{G_{ab \rightarrow ij}^{(2)}(N, M^2, \mu_F^2, \mu_R^2)}_{\text{Next-to-Leading Log } \sim \log(N)} + \dots$$

⁷Kidonakis, N. et al. [Nucl. Phys. B 525, 299–332. arXiv: hep-ph/9801268 \(1998\).](#)

Matching

- Fixed order calculation with CS-dipole subtraction⁸:

$$\sigma^{\text{NLO}} = \int_3 \left[d\sigma^{\text{R}} - d\sigma^{\text{A}} \right]_{\epsilon=0} + \int_2 \left[d\sigma^{\text{V}} + \int_1 d\sigma^{\text{A}} \right]_{\epsilon=0} + \int_0^1 dx \int_2 \left[d\sigma^{\text{B}}(xp) \otimes (\mathbf{P} + \mathbf{K})(x) \right]_{\epsilon=0}$$

- Hard matching coefficients $C_{ab \rightarrow ij}^{(i)}(M^2, \mu_F^2, \mu_R^2)$

- LO: $C^{(0)} = 1$

$$\mathcal{H}_{ab \rightarrow ij}^{(0)}(M^2, \mu_F^2, \mu_R^2) = \sigma_{ab \rightarrow ij}^{(0)}(M^2)$$

- NLO: compute $C^{(1)} = \sigma_{ab \rightarrow ij}^{(1)}(M^2) / \sigma_{ab \rightarrow ij}^{(0)}(M^2)$ with suppressed 3 particle phase space contributions

$$\mathcal{H}_{ab \rightarrow ij}^{(1)}(M^2, \mu_F^2, \mu_R^2) = \sigma_{ab \rightarrow ij}^{(0)}(M^2) C_{ab \rightarrow ij}^{(1)}(M^2, \mu_F^2, \mu_R^2)$$

⁸Catani, S. et al. *Nucl. Phys. B* **627**, 189–265. [arXiv: hep-ph/0201036](https://arxiv.org/abs/hep-ph/0201036) (2002).

Re-expansion

- To avoid double counting in:

$$\sigma_{ab} = \sigma_{ab}^{\text{NLO}} + \underbrace{\sigma_{ab}^{\text{Res.}} - \sigma_{ab}^{\text{Exp.}}}_{\sigma_{ab}^{\text{NLL}}}$$

- Subtract expansion in α_s :

$$\begin{aligned} \sigma_{ab}^{\text{Exp.}} &= \mathcal{H}_{ab \rightarrow ij}^{(0)}(M^2, \mu^2) + \frac{\alpha_s}{2\pi} \mathcal{H}_{ab \rightarrow ij}^{(1)}(M^2, \mu^2) + \frac{\alpha_s}{2\pi} \mathcal{H}_{ab \rightarrow ij}^{(0)}(M^2, \mu^2) \\ &\quad \times \left(\left(A_a^{(1)} + A_b^{(1)} \right) \left(\log \bar{N} + \log \frac{\mu_F^2}{s} \right) - 2D_{ab \rightarrow ij}^{(1)} \right) \log \bar{N} \end{aligned}$$

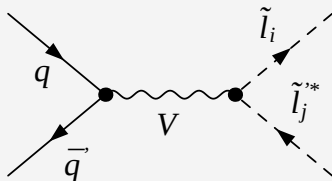
- PDFs fitted in Mellin space

- Inverse Mellin transformation with the integration contour following the principal value procedure and minimal prescription:

$$M^2 \frac{d\sigma_{AB}}{dM^2}(\tau) = \frac{1}{2\pi i} \int dN \tau^{-N} M^2 \frac{d\sigma_{AB}}{dM^2}(N).$$

Resummed approximate Next-to-Next-to-Leading Order

- ▶ NNLO+NNLL resummation for Drell-Yan process requires:
 - ▶ Extra NNLL terms⁹ to universal expansion of the Sudakov exponential G
 - ▶ Hard matching coefficients¹⁰ C to NNLO



- ▶ Supported in Resummino for Drell-Yan like process, i.e. slepton-pair or electroweakino-pair
 - ▶ But no fixed-order NNLO calculation is available to match against
 - ▶ $\implies$ SUSY-QCD (squark-gluino loop) corrections are only matched at NLO
 - ▶ Valid approximation since SUSY-QCD corrections are subdominant due to the large squark and gluino masses

⁹Vogt, A. *Phys. Lett. B* **497**, 228–234. arXiv: [hep-ph/0010146](#) (2001), Moch, S. et al. *Nucl. Phys. B* **726**, 317–335. arXiv: [hep-ph/0506288](#) (2005).

¹⁰Kidonakis, N. *Int. J. Mod. Phys. A* **19**, 1793–1821. arXiv: [hep-ph/0303186](#) (2004), Kidonakis, N. *Phys. Rev. D* **77**, 053008. arXiv: [0711.0142 \[hep-ph\]](#) (2008).

Outline

Motivation

Resummation

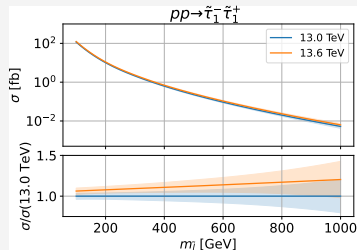
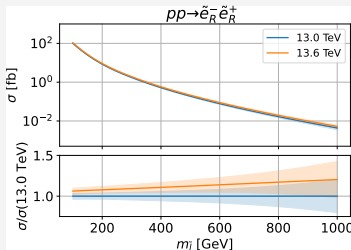
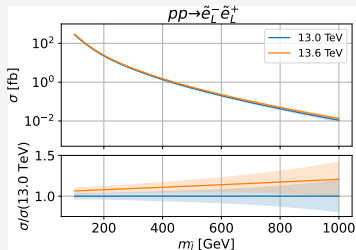
Results

Conclusion

Codes

Sleptons

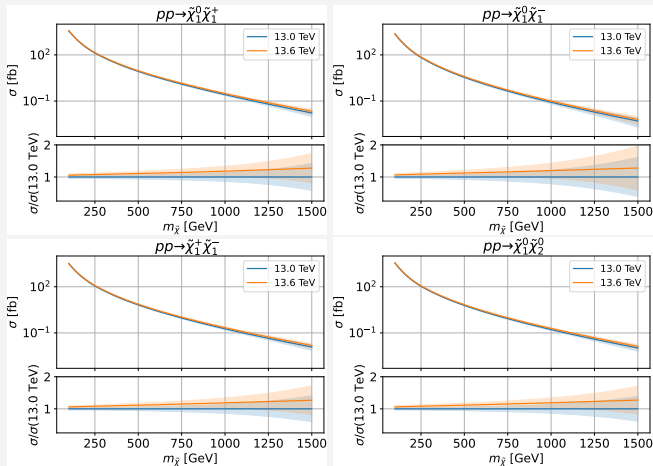
- ▶ $\tilde{e}_{L,R}$ any single generation of sleptons
- ▶ $\tilde{\tau}_1$ maximally mixed sleptons ($\theta_\tau = \frac{\pi}{4}$)
- ▶ All slepton masses $m_{\tilde{l}}$ are varied simultaneously in the simplified model
- ▶ Total cross sections for the slepton production processes $pp \rightarrow \tilde{l}^+ \tilde{l}^-$:



- ▶ Up to 20% increase in the cross section at 13.6 TeV compared to 13 TeV
- ▶ Seven-point-scale uncertainty lower than $\pm 2\%$
- ▶ PDF4LHC21 uncertainty of $\pm 18\%$ for $m_{\tilde{l}} = 1 \text{ TeV}$ is 5% lower at 13.6 TeV than at 13.0 TeV

Electroweakinos~Higgsinos

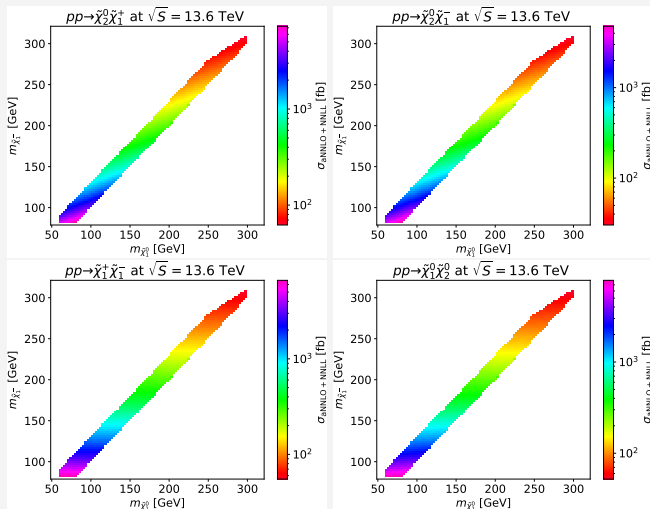
- ▶ All higgsino masses $m(\tilde{\chi}) = m(\tilde{\chi}_{1,2}^0) = m(\tilde{\chi}_1^\pm)$ are varied simultaneously in the simplified model
- ▶ Total cross sections for the degenerate hino production processes $pp \rightarrow \tilde{\chi}\tilde{\chi}$:



- ▶ At $m_{\tilde{\chi}} = 0.5 \text{ TeV}$:
 - ▶ Up to 29% increase of the cross section
 - ▶ PDF4LHC21 uncertainties of $\pm 35\%$, again 5% lower than 13.0 TeV
 - ▶ Scale uncertainties lower than $\pm 1.2\%$

Electroweakinos~Higgsinos

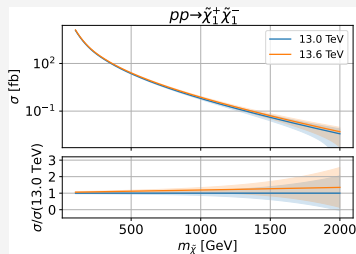
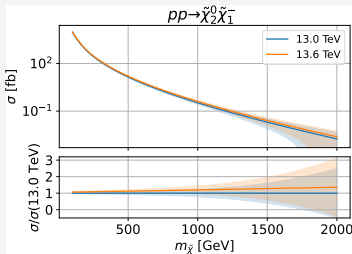
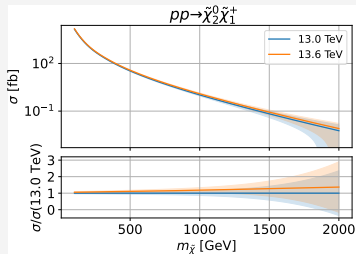
- ▶ Higgsinos of different mass with chargino in between $m(\tilde{\chi}_1^\pm) = \frac{m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)}{2}$
- ▶ Total cross sections for the non-degenerate hino production processes $pp \rightarrow \tilde{\chi}\tilde{\chi}$:



- ▶ With increasing final state mass the
 - ▶ PDF4LHC uncertainties rise from $\pm 2.5\%$ to $\pm 5\%$
 - ▶ scale uncertainties fall from $\pm 3\%$ to $\pm 0.6\%$

Electroweakinos~Winos

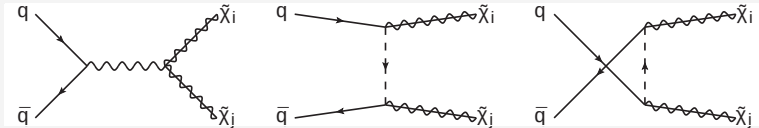
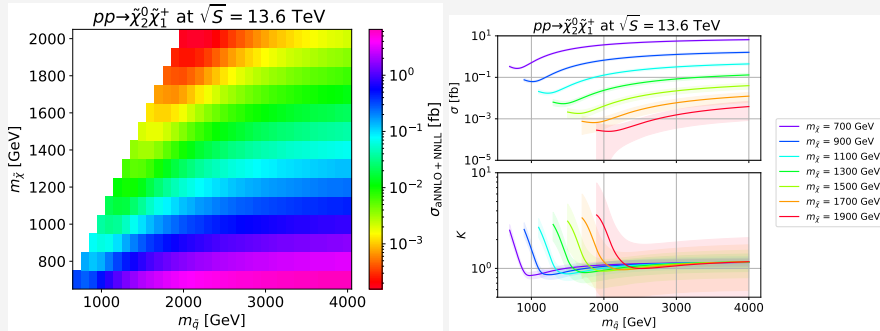
- ▶ All wino masses $m(\tilde{\chi}) = m(\tilde{\chi}_2^0) = m(\tilde{\chi}_1^\pm)$ are varied simultaneously in the simplified model
- ▶ Total cross sections for the wino production processes $pp \rightarrow \tilde{\chi}\tilde{\chi}$:



- ▶ At $m_{\tilde{\chi}} = 2 \text{ TeV}$:
 - ▶ The cross section is 60% larger compared to 13.0 TeV
 - ▶ Scale uncertainties lower than $\pm 0.1\%$
- ▶ PDF4LHC21_40 uncertainties get quite large for wino masses near 2 TeV

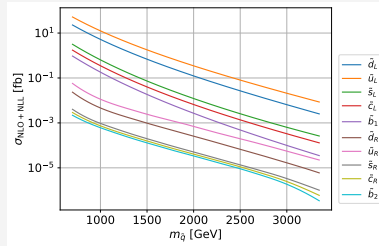
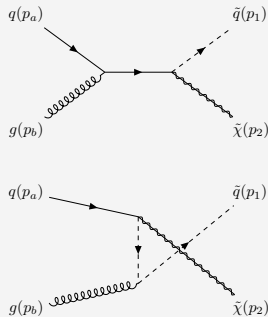
Squark mass dependence on wino production

- ▶ 8 squark masses $m(\tilde{u}_{L,R}) = m(\tilde{d}_{L,R}) = m(\tilde{s}_{L,R}) = m(\tilde{c}_{L,R})$ are varied.
- ▶ Lower squark masses reduce the cross section due to interference
- ▶ Rise in K-factor at low squark mass due to shifted minimum (LO minimum at $m_{\tilde{\chi}} = m_{\tilde{q}}$)
- ▶ Large squark masses decouple and the K-factor becomes independent of squark mass

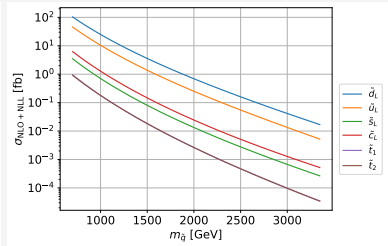


Single squark production

- ▶ Simplified Wino scenario with fixed mass $m_{\tilde{\chi}} = 500$ GeV
- ▶ Stop $\tilde{t}$ and sbottom $\tilde{b}$ maximally mixed
- ▶ Total cross sections for the gaugino-squark production processes $pp \rightarrow \tilde{\chi} \tilde{q}$:



(a) $pp \rightarrow \tilde{\chi}_2^0 \tilde{q}$ @ 13.6 TeV

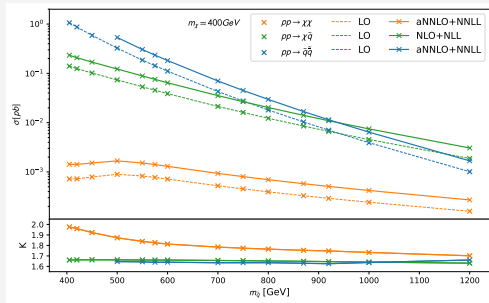


(b) $pp \rightarrow \tilde{\chi}_1^\pm \tilde{q}$ @ 13.6 TeV

- ▶ Ordering of cross sections determined by quark PDFs
- ▶ Stop only produced with chargino since there is no top quark in standard PDFs

Combined production channels

- ▶ Combination of $pp \rightarrow \tilde{u}_R \tilde{u}_R, \tilde{B}_0 \tilde{u}_R, \tilde{B}_0 \tilde{B}_0$ @ 13 TeV
- ▶ Simplified diagonal neutralino mixing scenario
- ▶ Uninvolved particles decoupled via large masses



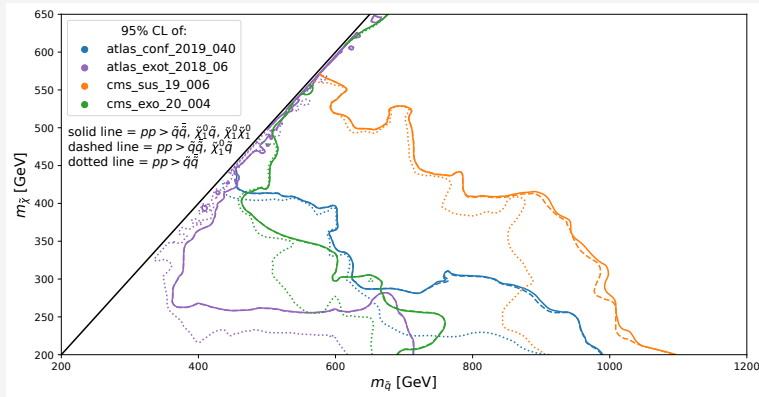
- ▶ For given scenario $\tilde{\chi}\tilde{q}$ can exceed $\tilde{q}\tilde{q}$
- ▶ Large K -factors

$$pp \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 : \quad \sigma = \sigma(\text{LO})_{\text{LO}}^{\text{MG}} \frac{\sigma(\text{aNNLO+NNLL})_{\text{NLO}}^{\text{RS}}}{\sigma(\text{LO})_{\text{LO}}^{\text{RS}}}, \quad (2.1)$$

$$pp \rightarrow \tilde{\chi}_1^0 \tilde{q} : \quad \sigma = \sigma(\text{LO})_{\text{LO}}^{\text{MG}} \frac{\sigma(\text{NLO+NLL})_{\text{NLO}}^{\text{RS}}}{\sigma(\text{LO})_{\text{LO}}^{\text{RS}}}, \quad (2.2)$$

$$pp \rightarrow \tilde{q}\tilde{q} : \quad \sigma = \sigma(\text{LO})_{\text{LO}}^{\text{MG}} \frac{\sigma(\text{NLO})_{\text{NLO}}^{\text{nllfast}}}{\sigma(\text{LO})_{\text{LO}}^{\text{nllfast}}} \frac{\sigma(\text{aNNLO+NNLL})_{\text{NNLO}}^{\text{nllfast}}}{\sigma(\text{NLO})_{\text{NLO}}^{\text{nllfast}}}. \quad (2.3)$$

Combined production channels



- ▶ CKKW-L matched MadGraph events with cross section scaled to (aN)NLO+(N)NLL
- ▶ MadAnalysis recast analyses
- ▶ Despite same analysis quite some gain on the exclusions by adding $\tilde{\chi}\tilde{q}$ to $\tilde{q}\tilde{q}$
- ▶ Combining analyses will give better exclusions (WiP)

Outline

Motivation

Resummation

Results

Conclusion

Codes

Conclusion

► Electroweak production cross sections for simplified models

final state particle mass	1 TeV	1.5 TeV	2 TeV
$\sigma(13.6 \text{ TeV})/\sigma(13.0 \text{ TeV})$	~ 1.2	~ 1.3	~ 1.6
PDF4LHC21 uncertainty	13-20%	35-60%	>100 %
scale uncertainty	<0.3%	<0.2%	<0.1%

- Resummation typically reduces the scale dependence
from 20% (LO) to 10% (NLO) to <5% (NLO+NLL) to <1% (aNNLO+NNLL)
- While PDF and scale uncertainties are of same order at low masses, the
PDF uncertainties dominate at high masses

Outline

Motivation

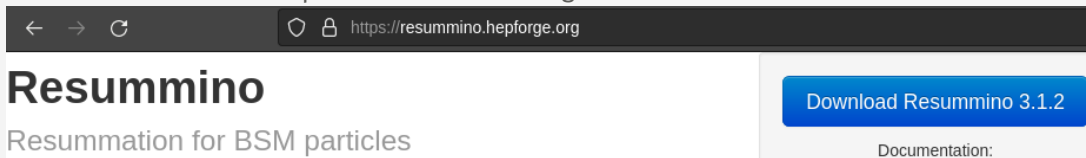
Resummation

Results

Conclusion

Codes

- ▶ Resummino 3.1.2 code published on HEPForge:



- ▶ Approximate NNLO+NNLL for slepton-pair¹¹, electroweakino-pair¹², Z' and W' ¹³ production
- ▶ NLO+NLL for electroweakino-gluino¹⁴ and electroweakino-squark¹⁵ production
- ▶ New in 3.1.2: Apptainer and Docker images¹⁶

¹¹Fiaschi, J. et al. *JHEP* **04**, 049. arXiv: 1911.02419 [hep-ph] (2020).

¹²Fiaschi, J. & Klasen, M. *Phys. Rev. D* **102**, 095021. arXiv: 2006.02294 [hep-ph] (2020).

¹³Jezo, T. et al. *JHEP* **12**, 092. arXiv: 1410.4692 [hep-ph] (2014).

¹⁴Fuks, B. et al. *JHEP* **07**, 053. arXiv: 1604.01023 [hep-ph] (2016).

¹⁵Fiaschi, J. et al. *JHEP* **06**, 130. arXiv: 2202.13416 [hep-ph] (2022).

¹⁶Fiaschi, J. et al. *Eur. Phys. J. C* **83**, 707. arXiv: 2304.11915 [hep-ph] (2023).

HEPi

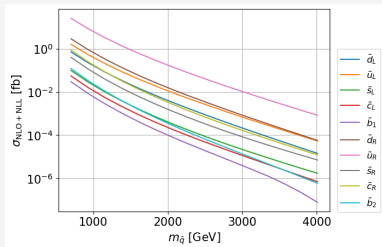
Python interface to Resummino and others ((N)NLL-fast, SPheno, SoftSusy, Prospino2, FeynHiggs, MadGraph)

- ▶ Scan masses
- ▶ Scan PDFs and scales and combine them to uncertainty bands
- ▶ Generate Resummino run files for distribution across clusters
- ▶ Collect results into a single json file¹⁷ and plot them
- ▶ Interpolate 1D and 2D json scans (hepi-fast)
- ▶ Install with “pip install hepi”
- ▶ Binder for simple calculations
- ▶ <https://github.com/APN-Pucky/HEPi>
- ▶ <https://hepi.readthedocs.io/en/latest/>

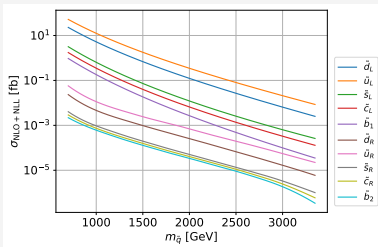
¹⁷Following: <https://github.com/fuenfundachtzig/xsec>

Thank you!

Bino vs Wino



(a) Bino: $pp \rightarrow \tilde{\chi}_1^0 \tilde{q}$ @ 13.6 TeV

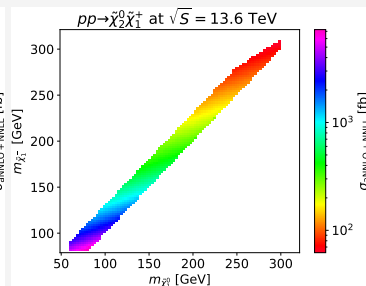
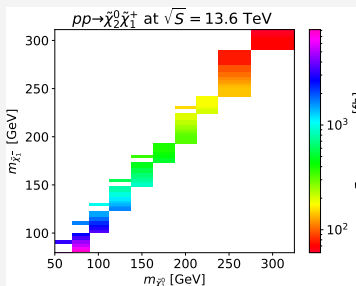
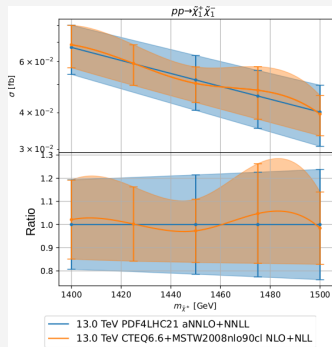


(b) Wino: $pp \rightarrow \tilde{\chi}_2^0 \tilde{q}$ @ 13.6 TeV

► Bino is suppressed by one order of magnitude compared to Wino

Interpolation

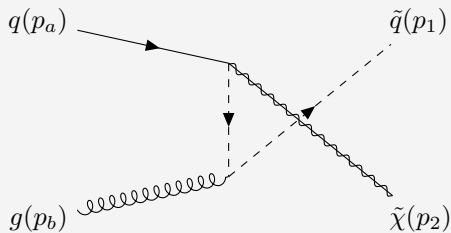
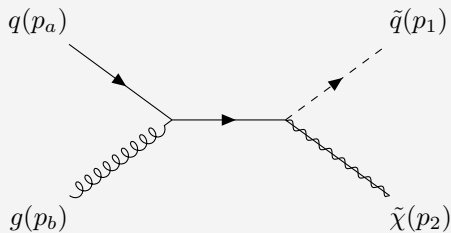
- ▶ Interpolate in Log-space since mass dependence often results in a power law
- ▶ Spline in 1D and LinearND¹⁸ in 2D yield reliable results
- ▶ PDF4LHC21 is better interpolated, but has larger uncertainties in the high mass regime



¹⁸Virtanen, P. et al. *Nature Methods* **17**, 261–272 (2020), Barber, C. B. et al. *ACM Trans. Math. Softw.* **22**, 469–483. ISSN: 0098-3500. <https://doi.org/10.1145/235815.235821> (Dec. 1996).

Squark and Electroweakino Production

- ▶ In the MSSM R-Parity implies production of SUSY particles in even numbers
- ▶ Expect dominant production of squark pairs and gluino pairs
- ▶ Production at the LHC might be restricted by heavy masses



- ▶ Squark and (lighter) electroweakino better LHC production candidate
- ▶ LO¹⁹ and NLO²⁰ corrections are known

¹⁹Dawson, S. et al. *Phys. Rev. D* **31**, 1581 (1985).

²⁰Binoth, T. et al. *Phys. Rev. D* **84**, 075005. [arXiv: 1108.1250 \[hep-ph\] \(2011\)](#), Frixione, S. et al. *JHEP* **12**, 008. [arXiv: 1907.04898 \[hep-ph\] \(2019\)](#), Baglio, J. et al. *JHEP* **12**, 020. [arXiv: 2110.04211 \[hep-ph\] \(2021\)](#).

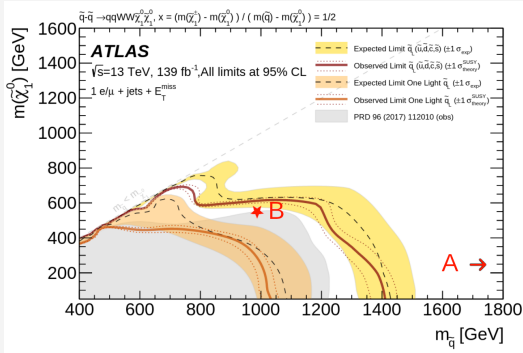
Scenarios

pMSSM-11 scenario A [TeV]		
M_1 0.25	M_2 0.25	M_3 −3.86
$M_{(U,D,Q)_{1,2}}$ 4.0	$M_{(U,D,Q)_3}$ 1.7	μ 1.33
$M_{(L,E)_{1,2}}$ 0.35	$M_{(L,E)_3}$ 0.47	$\tan \beta$ 36
M_A 4.0	A_0 2.8	
$m_{\tilde{\chi}_1^0}$ 0.249	$m_{\tilde{u}}$ 4.07	$m_{\tilde{g}}$ 3.90

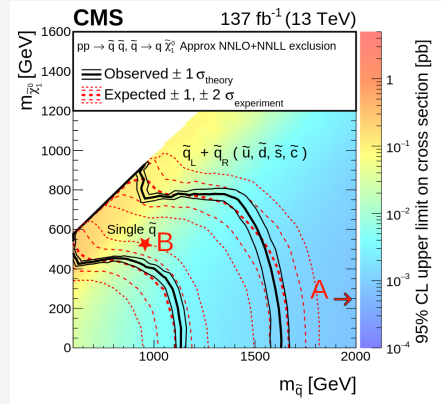
pMSSM-11 scenario B [TeV]		
M_1 0.51	M_2 0.48	M_3 3.00
$M_{(U,D,Q)_{1,2}}$ 0.9	$M_{(U,D,Q)_3}$ 2.0	μ −9.4
$M_{(L,E)_{1,2}}$ 1.85	$M_{(L,E)_3}$ 1.33	$\tan \beta$ 33
M_A 3.0	A_0 −3.4	
$m_{\tilde{\chi}_1^0}$ 0.505	$m_{\tilde{u}}$ 0.96	$m_{\tilde{g}}$ 2.94

Current Limits

ATLAS²¹



CMS²²

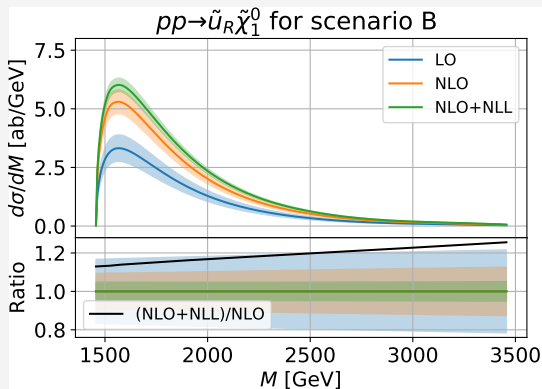
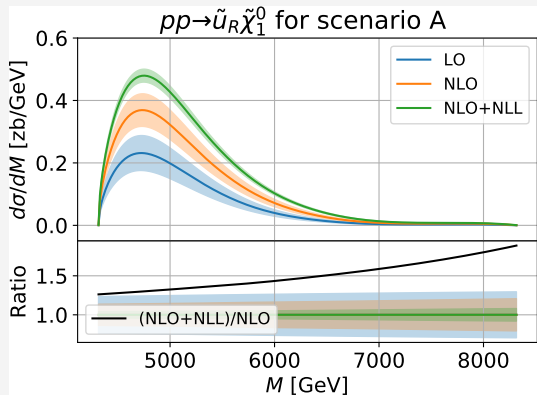


²¹Aad, G. et al. *Eur. Phys. J. C* **81**. [Erratum: *Eur.Phys.J.C* 81, 956 (2021)], 600. arXiv: 2101.01629 [hep-ex] (2021).

²²Sirunyan, A. M. et al. *JHEP* **10**, 244. arXiv: 1908.04722 [hep-ex] (2019).

Invariant Mass

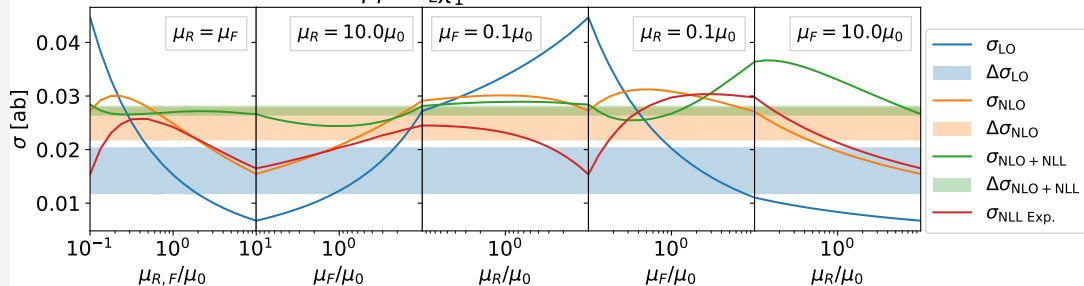
- ▶ $\sqrt{S} = 13$ TeV and MSHT20 PDF



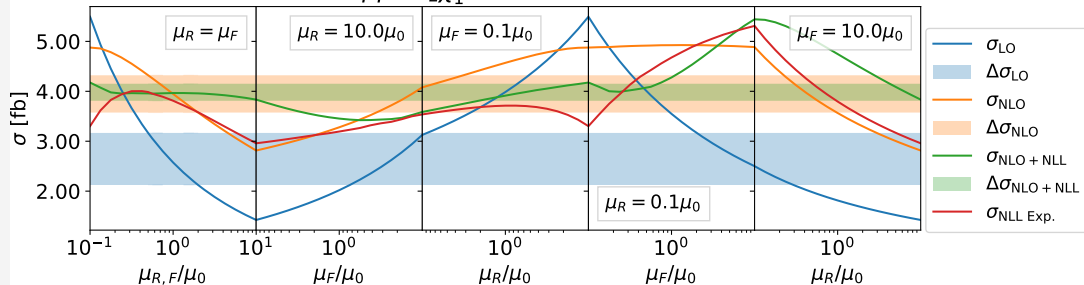
- ▶ Large resummation contributions very close to threshold
- ▶ Seven-point method around scale $\mu = M$ to estimate scale uncertainties

Scale Variation

$pp \rightarrow \tilde{u}_L \tilde{\chi}_1^0$ for scenario A

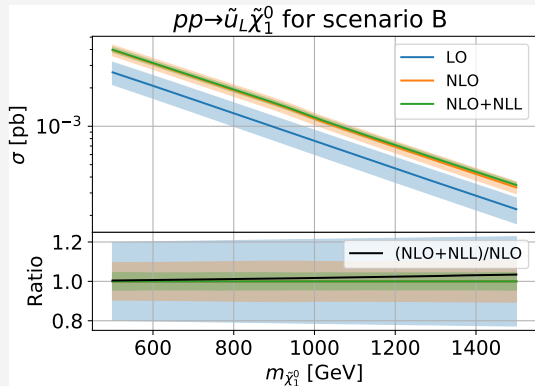
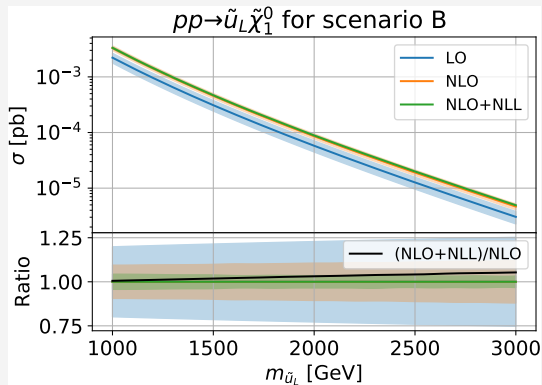


$pp \rightarrow \tilde{u}_L \tilde{\chi}_1^0$ for scenario B



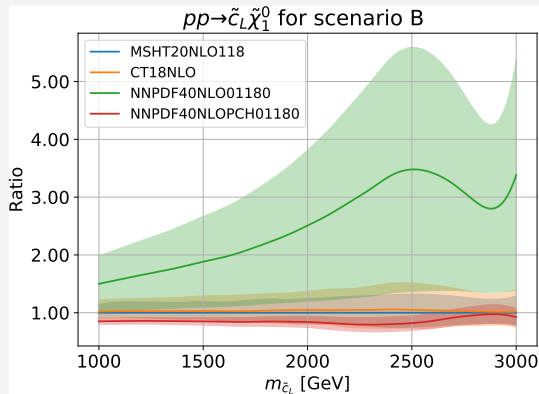
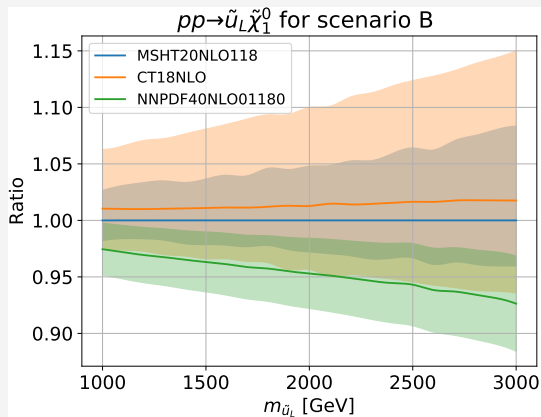
Note: panels 2 and 3 are inverted.

Total Cross sections



- ▶ NLL contributions of up to 6%
- ▶ Scale uncertainty reduced to $<5\%$

Parton density uncertainties

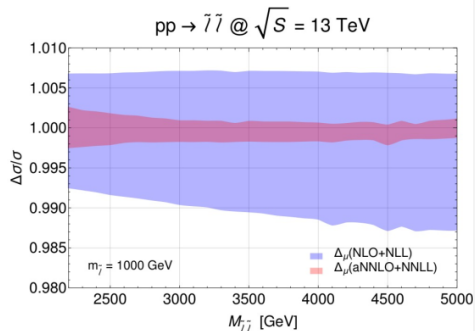
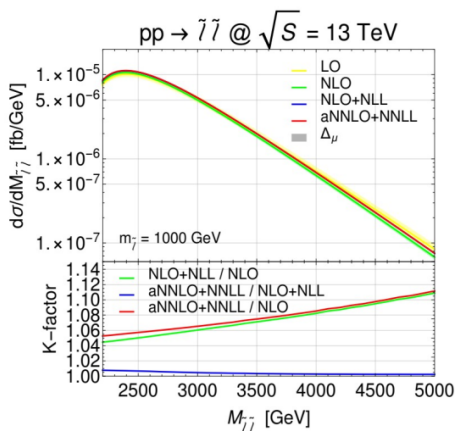


- ▶ Up-PDF uncertainties at 90% CL are consistent
- ▶ For 2 TeV up-squarks they range from $\pm 4\%$ to $\pm 7\%$
- ▶ Difference in NNPDF40's fitted charm and perturbative charm treatment.

Conclusion

- ▶ Production of squark/gluino with gaugino relevant if squark and gluino pair production are too heavy for the LHC
- ▶ We computed QCD-NLO corrections with CS-dipoles and OS-subtraction for the NLL matching of soft gluon emissions
- ▶ Resummation increases the σ_{tot} by 2% to 6% for squark masses ranging from 1 TeV to 3 TeV
- ▶ Renormalisation and Factorisation scale dependence is reduced from 20% (LO) to 10% (NLO) to <5% (NLO+NLL)
- ▶ Current PDF uncertainties are of the same order as scale uncertainties after Resummation

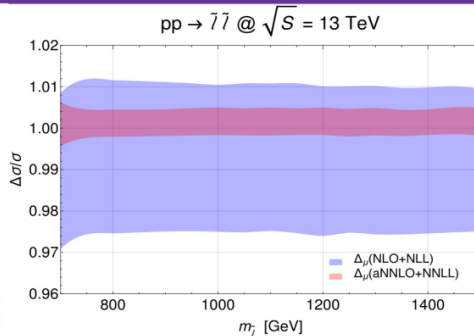
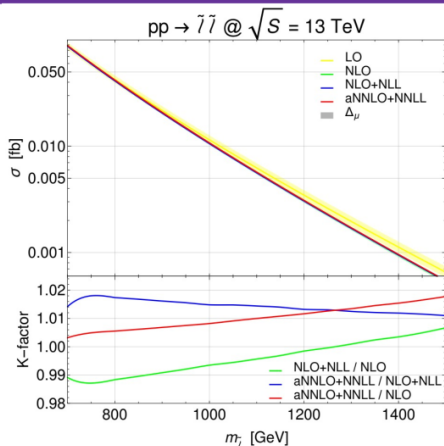
Slepton pair production



➤ Visible reduction of scale uncertainty
from about 1% to about 0.1%.

- Resummation effects at NLL are more important at production threshold.
- K-factor increases from 4.5% to 11%
- The increase from NLO+NLL to aNNLO+NNLL is about 1%

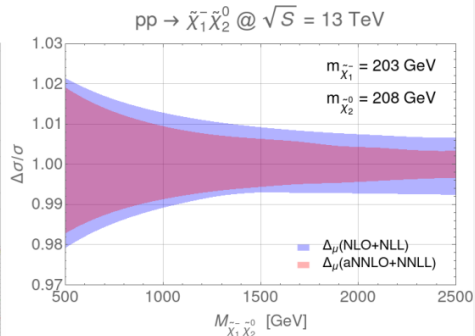
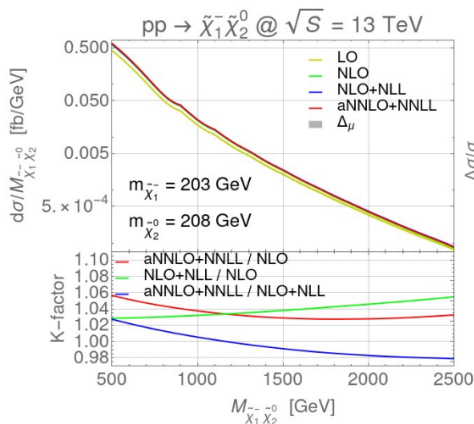
Slepton pair production



➤ Visible reduction of scale uncertainty from few % to few 0.1%.

- These cross sections correspond to:
 - more than 10 events at 700 GeV at current integrated luminosity of 139 fb^{-1} ;
 - 3 events at 1 TeV for LHC Run 3 goal of 300 fb^{-1} ;
 - Few events at 1.5 TeV for HL-LHC goal of 3 ab^{-1}
- aNNLO(+NNLL) corrections increase the NLO(+NNLL) prediction by 1% - 2%.

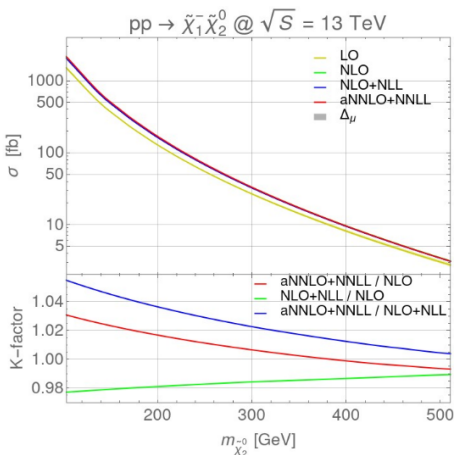
Mostly Higgsino Electroweakinos



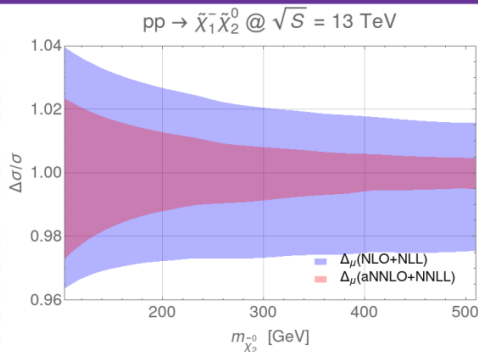
- Visible reduction of scale uncertainty from about from $\pm 2.1\%$ to $\pm 1.8\%$ ($\pm 0.6\%$ to $\pm 0.4\%$) at low (large) invariant masses.

- NLO corrections enhance the LO cross section by about 30%.
- NLL corrections enhance the NLO cross section by another 3-5%.
- aNNLO+NNLL give another $\pm 2\%$ correction to the NLO+NLL cross section.

Mostly Higgsino Electroweakinos



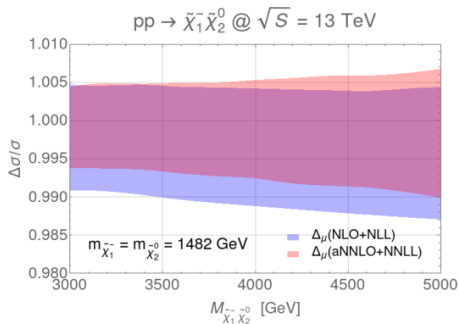
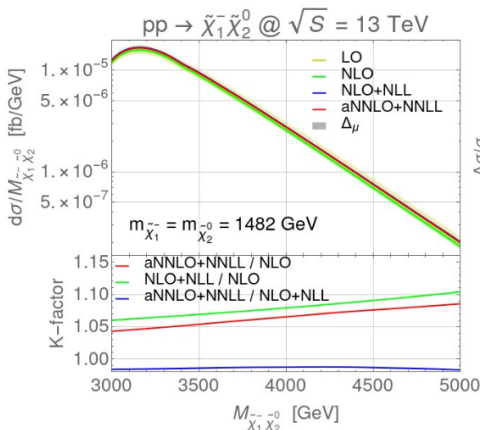
- NLL corrections reduce the NLO cross section by 1% to 2%.
- aNNLO+NNLL corrections increase the NLO+NLL cross section by up to 5% for low higgsino masses.



- Visible reduction of scale uncertainty from about from $\pm 4\%$ to $\pm 2.5\%$ (+1.5% and -2.5% to $\pm 0.5\%$) for light (heavy) Higgsinos

(Scale uncertainties are not so small, because of the relatively light Higgsino masses)

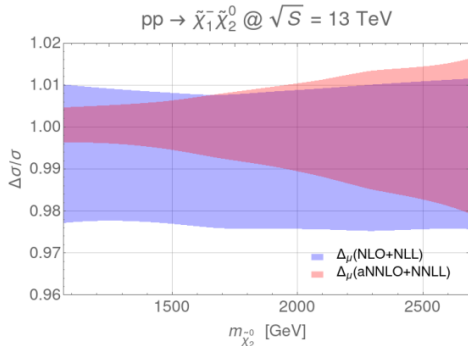
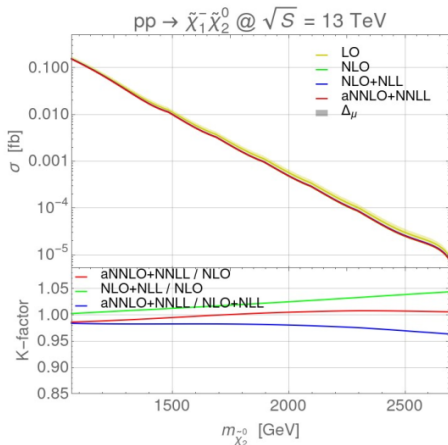
Mostly gauginos Electroweakinos



- Reduction of scale uncertainty on the lower bound from -0.9% to -0.6% at low invariant masses.

- NLL corrections increase the cross section between 5% to 10%.
- A decrease for all invariant masses is observed from NLO+NLL to aNNLO+NNLL.
- This behavior is correlated with large t - and u -channel contributions and large cancellations of the squared s -channel contribution with its interference terms.

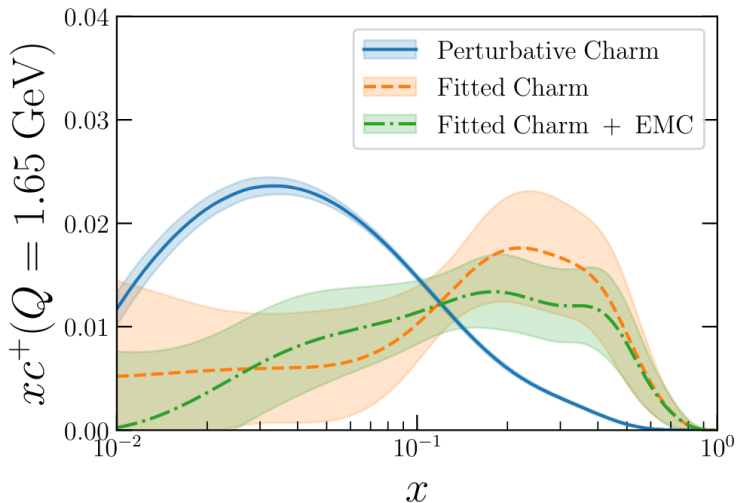
Mostly gauginos Electroweakinos



- Scale uncertainty gets reduced from 3% to about 1% for light gauginos, while it is stable at around 3% for heavy gauginos

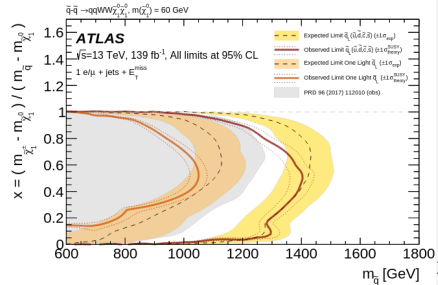
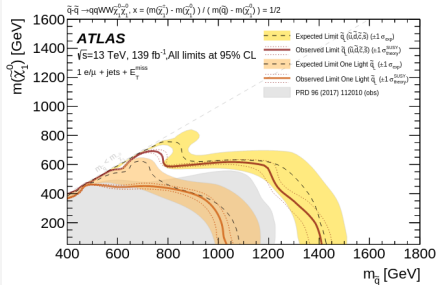
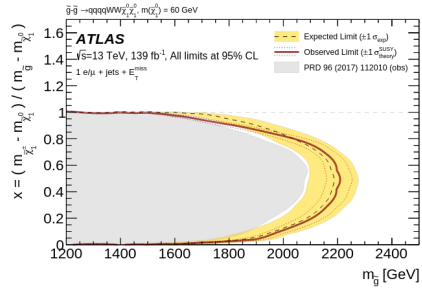
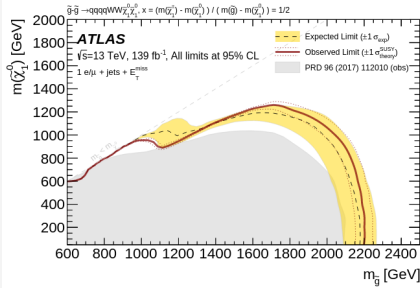
- NLL corrections increase the NLO cross section by up to 5%.
- aNNLO+NNLL corrections reduce the NLO+NLL cross section by up to 4% for high gaugino masses.

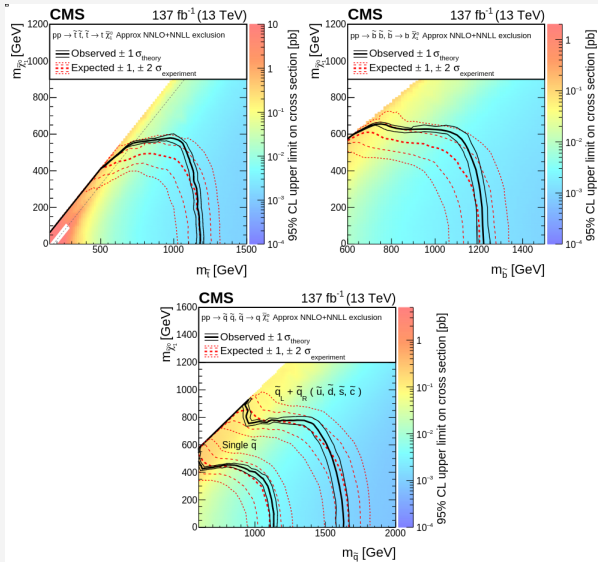
NNPDF40 charm



23

²³Rojo, J. in 55th Rencontres de Moriond on QCD and High Energy Interactions (Apr. 2021). arXiv: 2104.09174 [hep-ph].





PDF fitting

To perform our computation in Mellin space we still need to transform the PDFs. This is achieved by fitting them in x-space to the function used by the MSTW collaboration

$$f(x) = A_0 x^{A_1} (1-x)^{A_2} (1 + A_3 \sqrt{x} + A_4 x + A_5 x^{\frac{3}{2}}) + A_6 x^2 + A_7 x^{\frac{5}{2}},$$

with the analytical result in Mellin space

$$F(x) = A_0 \Gamma(y) B'(A_1 + N, y) + A_3 B'(A_1 + N + \frac{1}{2}, y) + A_4 B'(A_1 + N + 1, y) \\ + A_5 B'(A_1 + N + \frac{3}{2}, y) + A_6 B'(A_1 + N + 2, y) + A_7 B'(A_1 + N + \frac{5}{2}, y)$$

and

$$B'(x, y) = B'(x, A_2 + 1) = B(x, y) / \Gamma(y) = B(x, y) / \Gamma(y).$$