Soft gluon resummation for gaugino-gluino production

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Work done in collaboration with B. Fuks and M. Rothering

DFG

Graduiertenkolleg 2149
Research Training Group

GEFÖRDERT VOM
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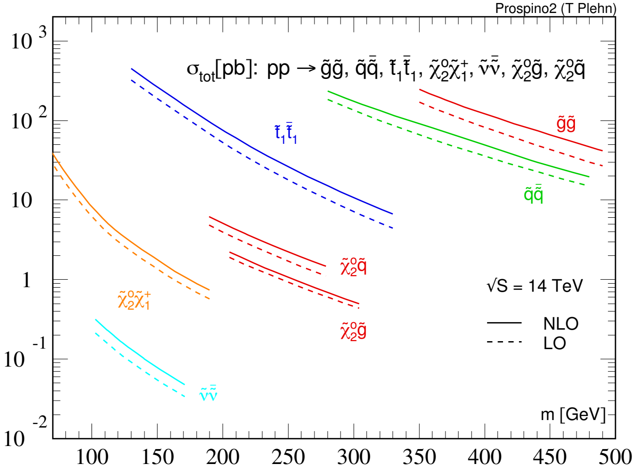
für Bildung
und Forschung

Cross sections for SUSY particles at the LHC

T. Plehn, http://www.thphys.uni-heidelberg.de/˜plehn/index.php?show=prospino&visible=tools



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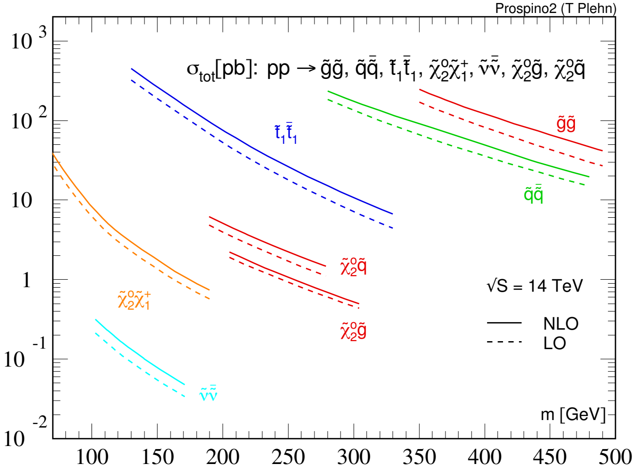

$\tilde{\chi}^0_i \tilde{g}$ channels subdominant, but maybe the only chance for heavy gluinos

References

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- W. Beenakker, C. Borschensky, M. Krämer, A. Kulesza, E. Laenen
  NNLL-fast: Predictions for coloured supersymmetric particle production at the LHC with threshold and Coulomb resummation
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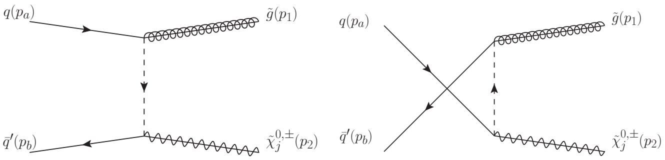
  Soft gluon resummation for associated gluino-gaugino production at the LHC
  JHEP 1607 (2016) 053 [arXiv:1604.01023]

Gaugino-gluino production at leading order in QCD

Feynman diagrams:



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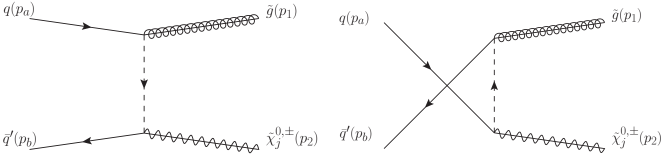

Squared matrix elements:

$$
\begin{aligned}
\mathcal{M}_t\mathcal{M}_{t_c}^* &= \frac{C_A C_F\, e\, g_s(\mu_r)}{(m_{\tilde{q}}^2-t)(m_{\tilde{q}_c}^2-t)}(\mathcal{L}'\mathcal{L}_c'+\mathcal{R}'\mathcal{R}_c')(LL_c+RR_c)(m_{\tilde{g}}^2-t)(m_{\tilde{\chi}}^2-t),\\
\mathcal{M}_u\mathcal{M}_{u_c}^* &= \frac{C_A C_F\, e\, g_s(\mu_r)}{(m_{\tilde{q}}^2-u)(m_{\tilde{q}_c}^2-u)}(\mathcal{L}\mathcal{L}_c+\mathcal{R}\mathcal{R}_c)(L'L_c'+R'R_c')(m_{\tilde{g}}^2-u)(m_{\tilde{\chi}}^2-u),\\
\mathcal{M}_t\mathcal{M}_{u_c}^* &= \frac{C_A C_F\, e\, g_s(\mu_r)}{(m_{\tilde{q}}^2-t)(m_{\tilde{q}_c}^2-u)}\Big[\Big(-s^2+t^2+u^2+(m_{\tilde{\chi}}^2+m_{\tilde{g}}^2)(s-t-u)+2m_{\tilde{g}}^2 m_{\tilde{\chi}}^2\Big)\\
&\times \Big(LL_c\mathcal{L}'\mathcal{L}_c'+RR_c\mathcal{R}'\mathcal{R}_c'\Big)+2m_{\tilde{g}}m_{\tilde{\chi}}s(\mathcal{R}R_c\mathcal{L}'L_c'+\mathcal{L}L_c\mathcal{R}'R_c')\Big].
\end{aligned}
$$

Total cross section up to NLO QCD

Partonic cross section:

$$d\sigma_{ab}^{(0)} = \int_2 d\sigma^B = \int \frac{1}{2s} \frac{1}{4C_A^2} \sum_{\tilde{q},\tilde{q}_c} \left(\mathcal{M}_t \mathcal{M}_{t_c}^* + \mathcal{M}_u \mathcal{M}_{u_c}^* - 2\,\mathrm{Re}(\mathcal{M}_t \mathcal{M}_{u_c}^*) \right) \mathrm{dPS}^{(2)}$$

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Hadronic cross section:

$$\begin{aligned}\sigma_{AB} \;=\; \int M^2 \frac{\mathrm{d}\sigma_{AB}}{\mathrm{d}M^2}(\tau) \quad &= \quad \sum_{a,b} \int_0^1 \mathrm{d}x_a\, \mathrm{d}x_b\, \mathrm{d}z [x_a f_{a/A}(x_a, \mu_f^2)][x_b f_{b/B}(x_b, \mu_f^2)] \\ &\times \quad [z\, \mathrm{d}\sigma_{ab}(z, M^2, \mu_r^2, \mu_f^2)]\, \delta(\tau - x_a x_b z)\end{aligned}$$

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NLO cross section:

$$\mathrm{d}\sigma_{ab}^{(1)} = \sigma^{\{3\}} + \sigma^{\{2\}} + \sigma^C = \int_3[\mathrm{d}\sigma^R - \mathrm{d}\sigma^A]_{\epsilon=0} + \int_2[\mathrm{d}\sigma^V + \int_1 \mathrm{d}\sigma^A]_{\epsilon=0} + \sigma^C$$

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Agrees with E. Berger, MK, T. Tait, Phys. Rev. D 62 (2000) 095014.

Threshold resummation formalism

Large logarithms:

$$z = \frac{M^2}{s} \to 1 \qquad \Rightarrow \qquad \left(\frac{\alpha_s}{2\pi}\right)^n \left[\frac{\ln^m(1-z)}{1-z}\right]_+$$

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Resummed cross section:

$$\mathrm{d}\sigma^{(\mathrm{res.})}_{ab\to ij}(N, M^2, \mu^2) \quad = \quad \sum_I \mathcal{H}_{ab\to ij,I}(M^2, \mu^2)\, \Delta_a(N, M^2, \mu^2)\, \Delta_b(N, M^2, \mu^2) \Delta_{ab\to ij,I}(N, M^2, \mu^2)$$

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Soft-collinear/soft functions:

$$\Delta_a \Delta_b \Delta_{ab\to ij,I} = \exp\left[L G^{(1)}_{ab}(\lambda) + G^{(2)}_{ab\to ij,I}(\lambda, M^2/\mu^2) + \ldots\right]$$

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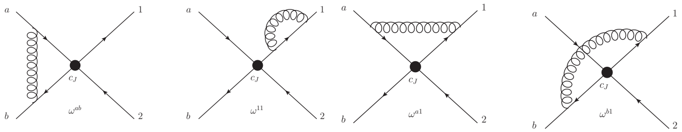
Leading/next-to-leading logarithms:

$$\begin{aligned} G^{(1)}_{ab}(\lambda) &= g^{(1)}_a(\lambda) + g^{(1)}_b(\lambda), \\ G^{(2)}_{ab\to ij}(\lambda) &= g^{(2)}_a(\lambda, M^2, \mu_r^2, \mu_f^2) + g^{(2)}_b(\lambda, M^2, \mu_r^2, \mu_f^2) + h^{(2)}_{ab\to ij,I}(\lambda). \end{aligned}$$

Soft anomalous dimension

Feynman diagrams:



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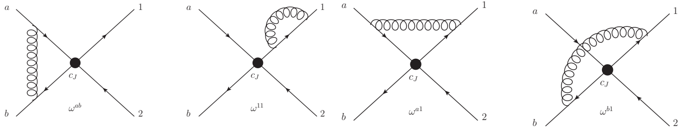

Calculation in axial gauge:

$$\omega^{ab} = S_{ab}\frac{\alpha_s}{\pi\epsilon}\left[-\ln\left(\frac{v_a\cdot v_b}{2}\right)+\frac{1}{2}\ln\left(\frac{(v_a\cdot n)^2}{|n|^2}\frac{(v_b\cdot n)^2}{|n|^2}\right)+i\pi-1\right],$$

$$\omega^{a1} = S_{a1}\frac{\alpha_s}{\pi\epsilon}\left[-\frac{1}{2}\ln\left(\frac{(v_a\cdot v_1)^2 s}{2m_{\tilde{g}}^2}\right)+L_1+\frac{1}{2}\ln\left(\frac{(v_a\cdot n)^2}{|n|^2}\right)-1\right],$$

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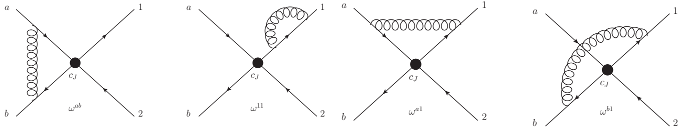

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Total one-loop result:

$$h^{(2)}_{ab\to ij,I}(\lambda) = \frac{2\pi}{\alpha_s}\frac{\ln(1-2\lambda)}{2\beta_0}\,\mathrm{Re}\left\{\frac{\alpha_s}{2\pi}C_A\left[\ln 2+i\pi-1+\ln\left(\frac{m_{\tilde{g}}^2-t}{\sqrt{2}m_{\tilde{g}}\sqrt{s}}\right)+\ln\left(\frac{m_{\tilde{g}}^2-u}{\sqrt{2}m_{\tilde{g}}\sqrt{s}}\right)\right]\right\}$$

Hard matching coefficient

Perturbative expansion of the hard function:

$$\mathcal{H}_{ab\to ij,I}(M^2,\mu^2) = \sigma^{(0)}_{ab\to ij}(M^2)\left\{1 + \frac{\alpha_s(\mu^2)}{2\pi}C^{(1)}_{ab\to ij}(M^2,\mu^2) + \cdots\right\}$$

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Hard matching coefficient $C^{(1)}_{ab\to ij}(M^2,\mu^2)$:

- N-independent terms of the full NLO corrections in Mellin space
- $\mathrm{d}\sigma^V$ and $\int_1 \mathrm{d}\sigma^A \propto \delta(1-z)$, therefore constant in N

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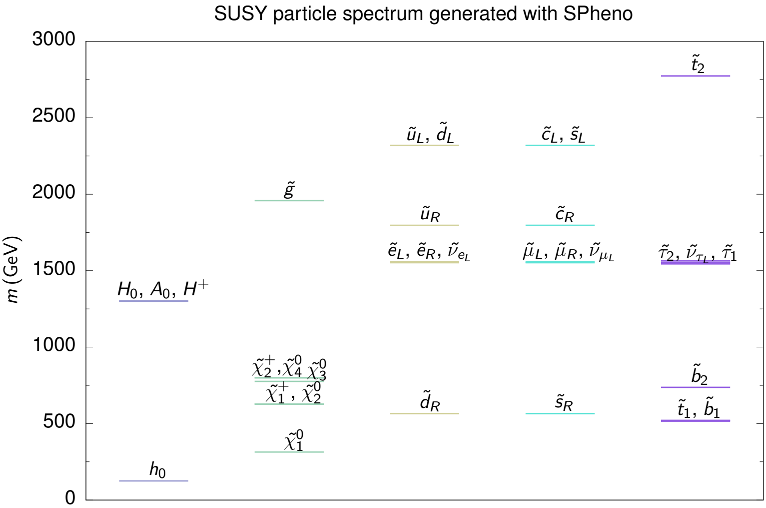
Collinear remainder:

$$\begin{aligned}
\sigma^C &= \sum_{a'}\int_0^1 \mathrm{d}x \int_2 [\mathrm{d}\sigma^{(0)}_{a'b}(xp_a,p_b)\otimes\langle a'|\mathbf{P}+\mathbf{K}|a\rangle(x)+(a\leftrightarrow b)]_{\epsilon=0},\\
\langle\mathbf{P}(N)\rangle &= \frac{\alpha_s}{2\pi}\left[(2C_F-C_A)\ln\frac{\mu_f^2}{s}+C_A\ln\frac{\mu_f^2}{m_{\tilde g}^2-t}\right]\left[\ln\bar N-\frac{3}{4}\right]+\mathcal{O}\left(\frac{1}{N}\right),\\
\langle\mathbf{K}(N)\rangle &= \frac{\alpha_s}{2\pi}\left\{2C_F\ln^2\bar N+C_A\left[\ln\frac{m_{\tilde g}^2}{m_{\tilde g}^2-t}+1\right]\ln\bar N+\frac{\pi^2}{2}C_F-\gamma_q-K_q\right.\\
&+\frac{C_A}{4}\left[1+4\,\mathrm{Li}_2\frac{2m_{\tilde g}^2-t}{m_{\tilde g}^2}+\left(1+4\ln\frac{m_{\tilde g}^2}{m_{\tilde g}^2-t}+2\frac{m_{\tilde g}^2}{m_{\tilde g}^2-t}\right)\ln\frac{m_{\tilde g}^2}{2m_{\tilde g}^2-t}\right.\\
&\left.\left.+3\ln\left(1+\frac{2m_{\tilde g}}{m_{\tilde g}^2-t}\left(m_{\tilde g}-\sqrt{2m_{\tilde g}^2-t}\right)\right)+6\frac{m_{\tilde g}}{m_{\tilde g}+\sqrt{2m_{\tilde g}^2-t}}-3\right]\right\}+\mathcal{O}\left(\frac{1}{N}\right).
\end{aligned}$$

pMSSM-13 benchmark scenario



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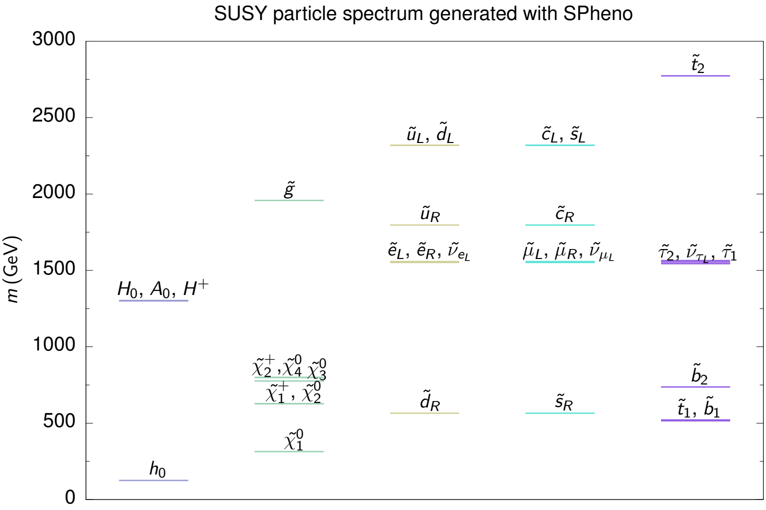
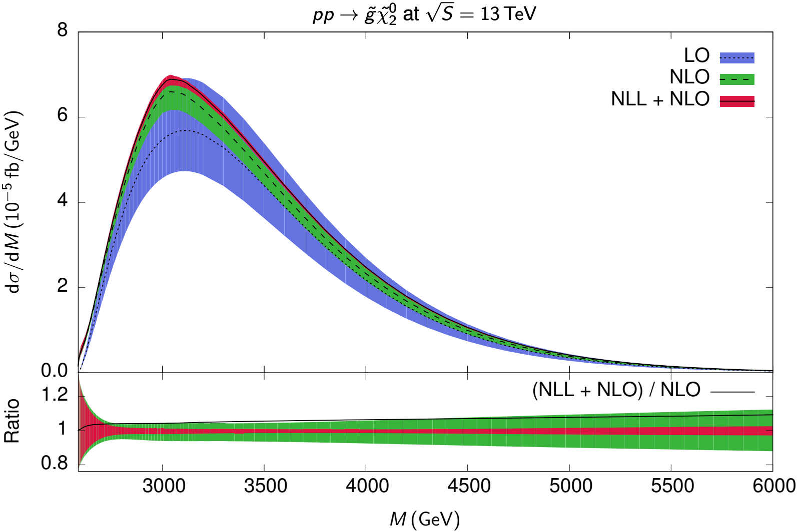


Vary $M_1 \simeq M_2/2$ and M_3, impose m_{h^0}, FCNC, LHC, and DM constraints.

Invariant mass distribution



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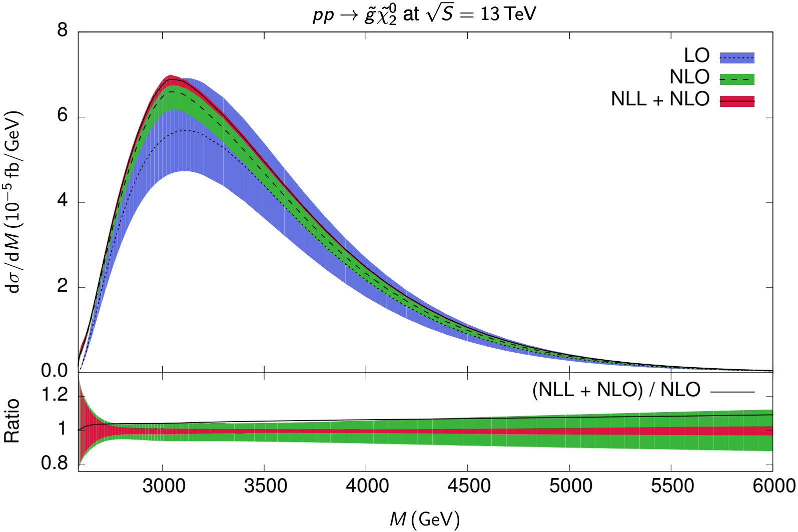
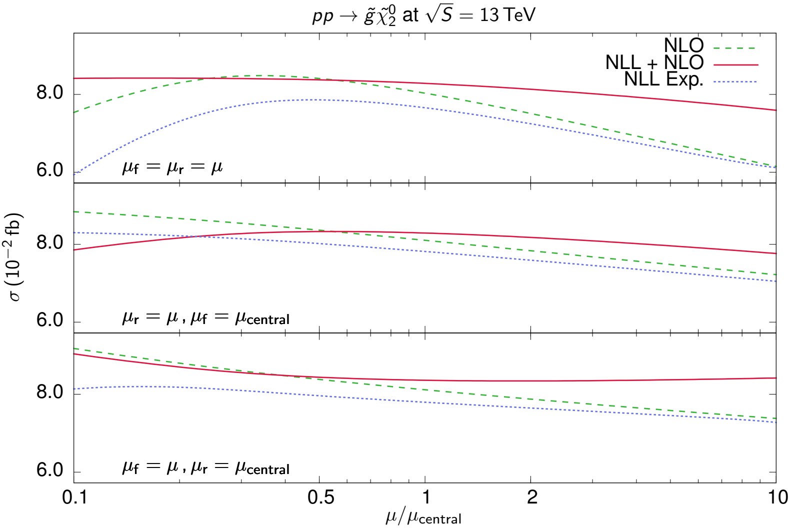


Additional radiation shifts maximum, reduces scale dependence.

Scale dependence



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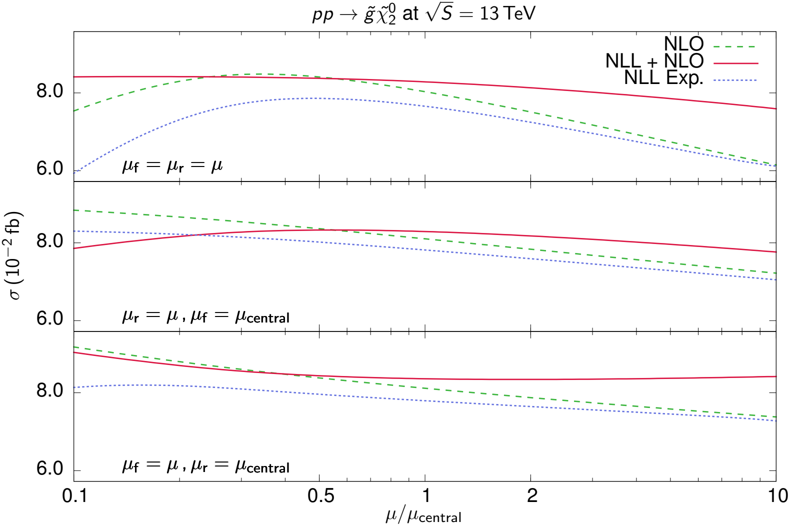
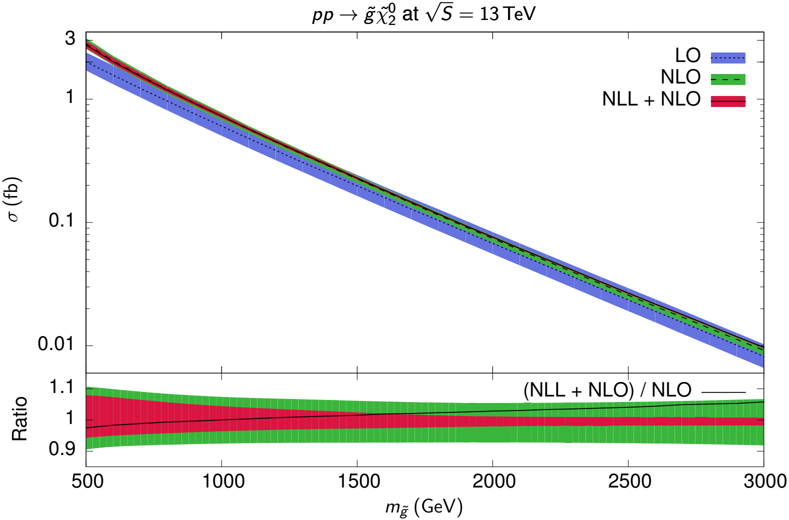


Stable predictions at NLL+NLO, expansion of NLL approximates NLO.

Gluino mass dependence



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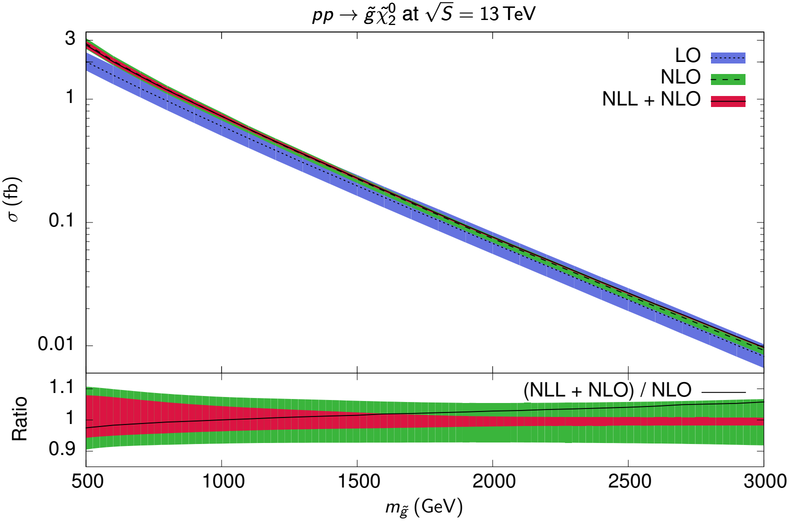
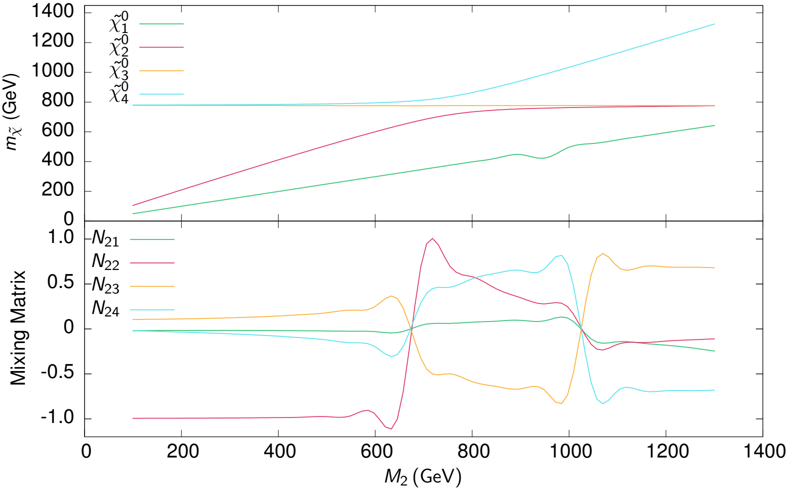


Cross sections will soon be observable at the LHC with $\mathcal{L} = 100$ fb^{-1}.

Gaugino decomposition



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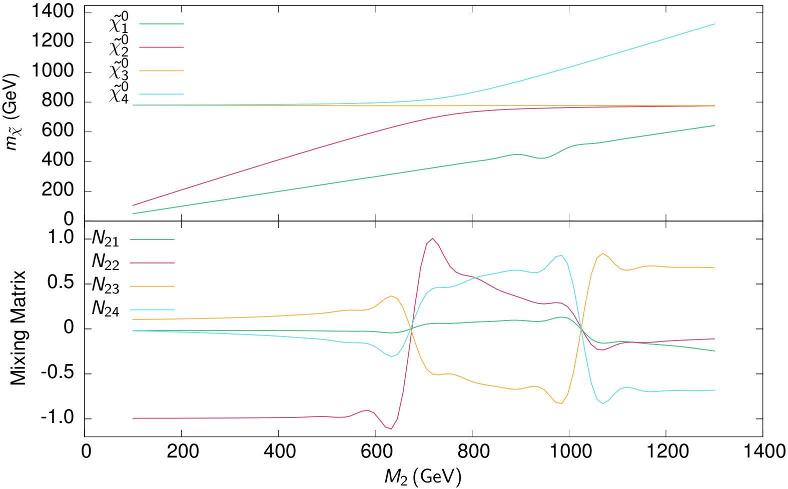
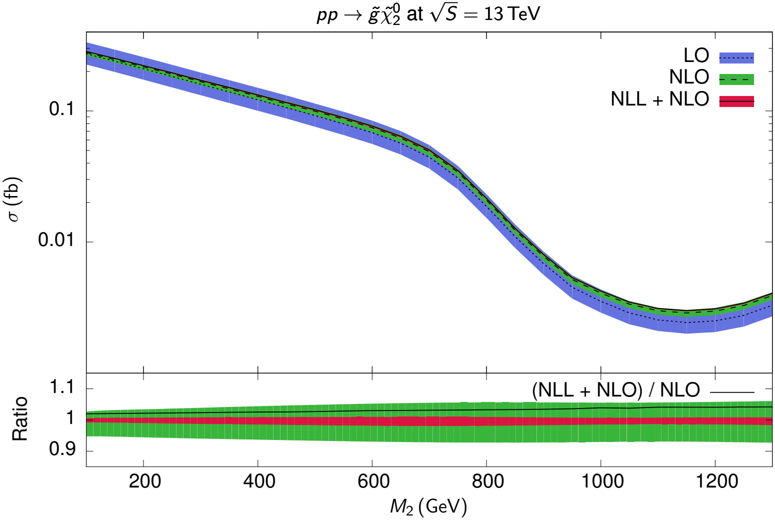


Avoided crossings at $M_2 = \mu = 773$ GeV (also for charginos).

Gaugino mass dependence



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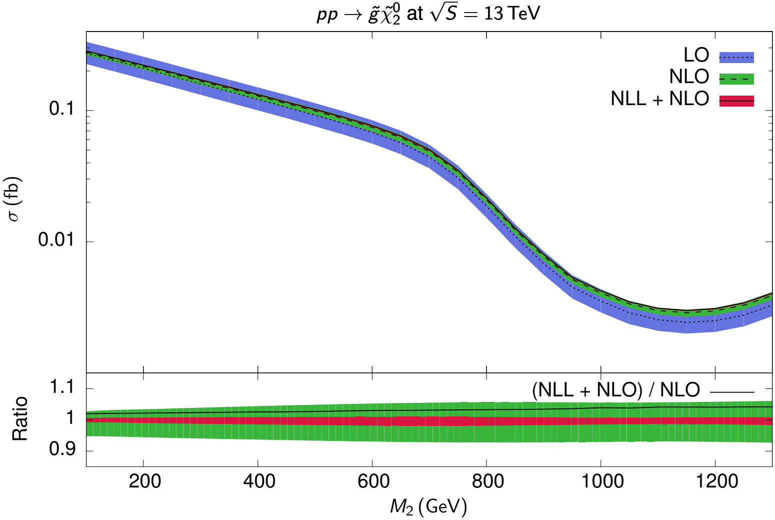
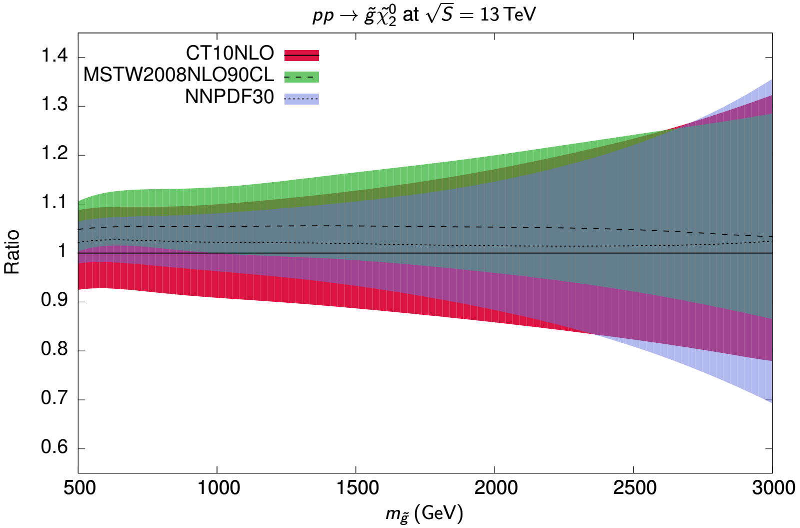


Beyond $M_2 > \mu$, decomposition changes more than the mass.

Relative PDF uncertainties



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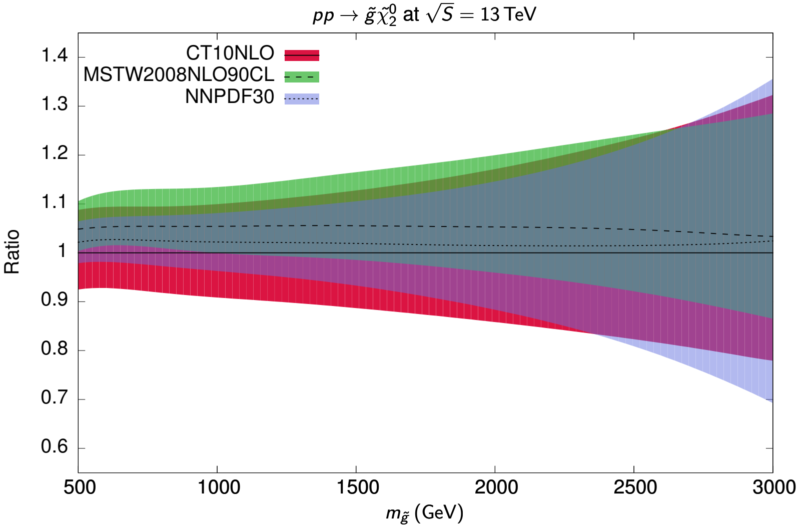

Large uncertainties at large $x \to$ employ threshold improved PDFs.

Conclusion

Motivation:

- Semi-weak process, will become relevant if gluinos are heavy
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Process-dependent calculations:

- Soft anomalous dimension
- Hard matching coefficient
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Results:

- NLL increases NLO invariant mass distribution by up to 10%
- Total scale dependence reduced from 30% to 5%
- PDF uncertainty not reduced, needs threshold-improved PDFs