QCD resummations for gaugino-pair hadroproduction

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Minimal Supersymmetric Standard Model

Main features

- High-energy extension of the Standard Model
- Symmetry between bosons and fermions
- Each SM particle has one SUSY partner

Some advantages

- Solution to the hierarchy problem
- Gauge coupling unification
- *R*-parity: Lightest SUSY particle stable
  $\Rightarrow$ dark matter candidate (can be the lightest neutralino)

Neutralinos and charginos

- Gauginos: $\tilde{W}^{\pm}$, $\tilde{W}^0$, $\tilde{B}$
- Higgsinos: $\widetilde{H}_2^+$, $\widetilde{H}_2^0$, $\tilde{H}_1^0$, $\tilde{H}_1^-$

- EWSB $\rightarrow$ Mixings $\rightarrow$ Neutralinos and charginos

$$\begin{pmatrix} \tilde{\chi}_1^0 \\ \tilde{\chi}_2^0 \\ \tilde{\chi}_3^0 \\ \tilde{\chi}_4^0 \end{pmatrix} = N \begin{pmatrix} -i\tilde{B}^0 \\ -i\tilde{W}^0 \\ \tilde{H}_2^0 \\ \tilde{H}_1^0 \end{pmatrix}$$

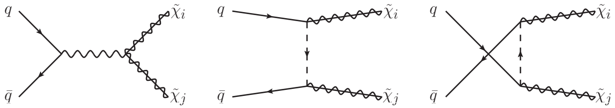
$$\begin{pmatrix} \tilde{\chi}_1^- \\ \tilde{\chi}_2^- \end{pmatrix} = U \begin{pmatrix} -i\tilde{W}^- \\ \tilde{H}_1^- \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} \tilde{\chi}_1^+ \\ \tilde{\chi}_2^+ \end{pmatrix} = V \begin{pmatrix} -i\tilde{W}^+ \\ \tilde{H}_2^+ \end{pmatrix}$$

Motivation for gaugino study

- Need accurate values for masses and mixings
  - Hints on SUSY-breaking mechanism
  - DM calculations strongly rely on these parameters

- Among the lightest SUSY particles in many SUSY-breaking scenarios
  $\Rightarrow$ May be produced at current hadron colliders

- Can decay into the LSP and leptons
- Clean signal: leptons + large $\not{E}_T$
- Tevatron searches for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to l^{\pm}l^+l^- + \not{E}_T$ [CDF(2008)], [D0(2006)]



Fixed-order calculation

- Partonic M- and p_T-distributions at $\mathcal{O}(\alpha_s)$: $\qquad z = \frac{M^2}{\hat{s}}$

$$\frac{d\hat{\sigma}}{dM^2} = \hat{\sigma}^{(0)}(M)\delta(1-z) + \alpha_s \hat{\sigma}^{(1)}(z, M)$$
$$\frac{d\hat{\sigma}}{dM^2 dp_T^2} = \hat{\sigma}^{(0)}(M)\delta(1-z)\delta(p_T^2) + \alpha_s \hat{\sigma}^{(1)}(z, M, p_T)$$

- Cancellation of IR singularities leaves terms of the form

$$\alpha_s^n \left(\frac{\ln^m(1-z)}{1-z} \right)_+ \quad \text{and} \quad \frac{\alpha_s^n}{p_T^2} \ln^m \frac{M^2}{p_T^2} \qquad (m < 2n)$$

- Large at $z \approx 1$ or small p_T
- Convergence of the perturbative expansion is spoiled

- These contributions must be summed to all order in α_s
  $\Rightarrow$ Gain reasonable control over these terms

Resummation formalisms

- Threshold resummation: [Sterman (1987)]
- p_T-resummation: [Collins, Soper, Sterman (1985)]

- Work in conjugate spaces:
  - Mellin transform: N variable conjugate to z
  - Fourier transform: impact parameter b conjugate to p_T
  - The large terms become large logarithms: $L \equiv \ln N$ or $\ln(bM)$

- The resummed cross section can be written in an exponential form:

$$\hat{\sigma}^{(\mathrm{res})}(M, L) = \mathcal{H}(M) \exp[\mathcal{G}(L)]$$

- The $\mathcal{H}$-coefficient contains all the non-singular terms
  $\Rightarrow$ Can be computed perturbatively
- The Sudakov exponent $\mathcal{G}$ contains all the large logs which are resummed in the exponential

Matching to the fixed order

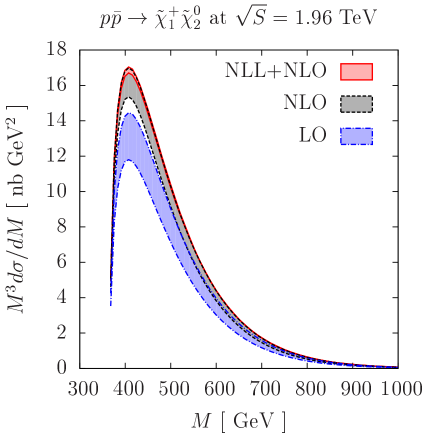
- Close to the critical kinematical regions:
  Perturbation theory spoiled → Resummation needed

- Far from the critical kinematical regions:
  Perturbation theory reliable → Resummation not justified
  ⇒ Information from both calculations required

- Matching procedure:
  - Add both resummation and fixed-order results
  - Substract the expansion in α_s of the resummed result
  - No double counting of the logarithms

$$d\hat{\sigma} = d\hat{\sigma}^{(\mathrm{res})} + d\hat{\sigma}^{(\mathrm{f.o})} - d\hat{\sigma}^{(\mathrm{exp})}$$

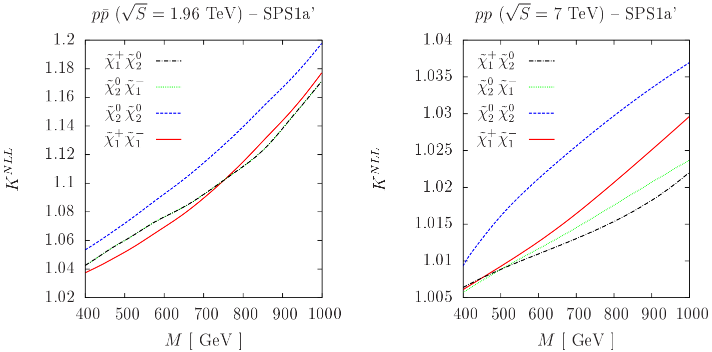
M-distribution at the Tevatron



- SPS1a': $m_0 = 70$ GeV, $m_{1/2} = 250$ GeV, $A_0 = -300$ GeV, $\tan\beta = 10$, $\mu > 0$
- mSUGRA RGE: SuSpect2.4
- PDF set: CTEQ6.6M / CTEQ6L1

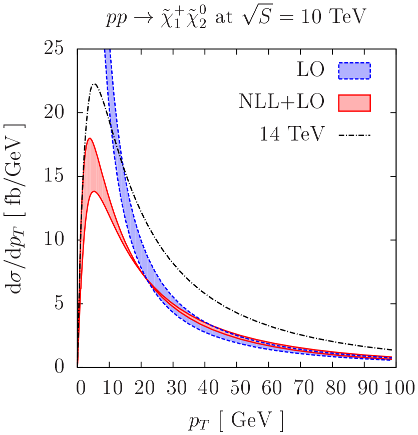
- $M/2 \le \mu_F = \mu_R \le 2M$
- NLO corrections:
  - Large and positive (20-25%)
  - Scale dependence slightly improved
- Resummation effects are important
  - Cross section slightly increased
  - Scale dependence reduced

Resummation effects at the Tevatron and the LHC



- $K^{NLL} = \dfrac{d\sigma^{NLL+NLO}}{d\sigma^{NLO}}$
- NLL contributions: positive and increase with M
- Larger at the Tevatron (5-20 %) than at the LHC (a few percent)

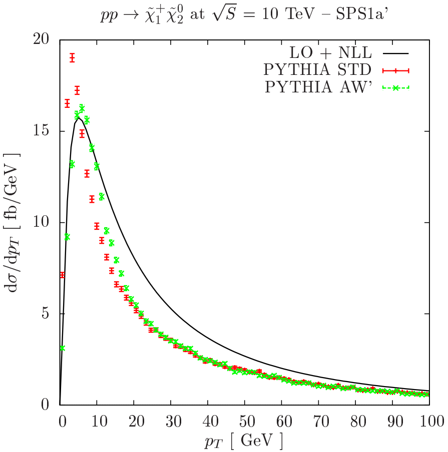
p_T-distribution at the LHC



[JD, Fuks, Klasen (2009)]

- Fixed-order prediction is divergent at $p_T = 0$ GeV
  $\Rightarrow$ Unreliable results
- Applying p_T-resummation
  $\Rightarrow$ Get finite results
- Scale dependence improved:
  12% $\rightarrow$ 6% ($p_T = 45$ GeV)

Comparison with PYTHIA



[JD, Fuks, Klasen (2009)]

- p_T-distribution in PYTHIA comes from parton shower
- PYTHIA STD: Peak at too small values of p_T
- PYTHIA AW': CDF tune for V-boson production [Field (2006)]
- Correct peak but underestimate the intermediate p_T-region

Conclusion

- Neutralino/chargino pairs at hadron colliders
  - Usual fixed-order calculations are polluted by large logarithms at the edge of the phase space ($p_T \longrightarrow 0$, $z \longrightarrow 1$)
  - Leading to incorrect predictions at small values of p_T
  - Need for resummation
- p_T-resummation and Threshold resummation
  - Up to NLL accuracy
  - Reliable results
  - Smaller dependence on the unphysical scales
  - vs PYTHIA