Transverse-momentum resummation for gaugino-pair production at hadron colliders

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Outline

Introduction
- Motivation
- Neutralinos/Charginos

p_T-spectrum of neutralino/chargino-pair in hadron collisions
- Fixed order calculations
- p_T-resummation formalism
- Numerical results

Conclusion

Outline

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

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

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

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

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 scenarii
  $\Rightarrow$ Can be produced at current colliders

- Can decay into the LSP and leptons
- Clean signal: 2 leptons + large $\not{E}_T$
- Tevatron searches for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to 3l^{\pm} + \not{E}_T$ [D0 (2006-2007)]

- R-parity: Production of SUSY-particle pairs at colliders
- Precision calculations of the p_T spectrum of the gaugino pairs

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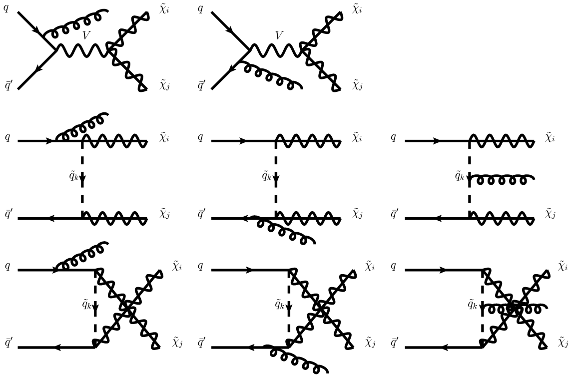
LO partonic cross section at $O(\alpha^2 \alpha_S)$

- $q\bar{q} \longrightarrow \tilde{\chi}\tilde{\chi} + g$



- $qg \longrightarrow \tilde{\chi}\tilde{\chi} + q$ and $g\bar{q} \longrightarrow \tilde{\chi}\tilde{\chi} + \bar{q}$

QCD-factorization theorem

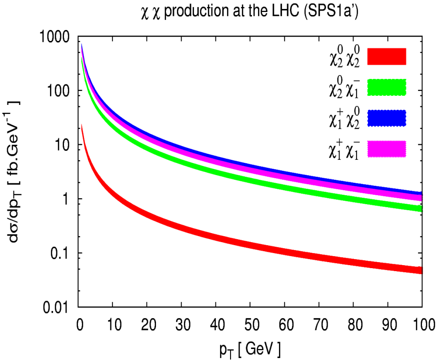
- Hadronic cross section:

$$\frac{d\sigma_{AB}}{dp_T} = \sum_{a,b} \int dx_a \, dx_b \, f_{a/A}(x_a, \mu_F^2) \, f_{b/B}(x_b, \mu_F^2) \, \frac{d\hat{\sigma}_{ab}}{dp_T}$$

with:

- $f_{a/A}$, $f_{b/B}$: parton distribution functions
- $x_{a,b}$: longitudinal momentum fractions
- μ_F: factorization scale
- $\hat{\sigma}_{ab}$: partonic cross section

p_T-spectrum at the LHC



- SPS1a': $m_0 = 70$ GeV, $m_{1/2} = 250$ GeV, $A_0 = -300$ GeV $\tan\beta = 10$, $\mu > 0$
- mSUGRA RGE: SuSpect2.3
- PDF set: CTEQ6

- $\bar{m}_{\tilde{\chi}} \approx 183$ GeV
- $\bar{m}_{\tilde{\chi}}/2 \le \mu_R = \mu_F \le 2\bar{m}_{\tilde{\chi}}$
- Diverge at $p_T = 0$ GeV
- Soft/collinear parton emission

$$\frac{M^2 d\sigma}{dM^2 dp_T^2} \sim \sigma_0 \frac{\alpha_s}{p_T^2} \ln \frac{M^2}{p_T^2}$$

- Fixed order calculation leads to unreliable results at small p_T
- All order resummation of the logs

Resummation formalism

- p_T resummation formalism
  [Collins, Soper, (Sterman) (1981(5))]
- Formally decomposed into two parts

$$\frac{d\sigma}{dM^2 dp_T^2} = \frac{d\sigma^{(res.)}}{dM^2 dp_T^2} + \frac{d\sigma^{(fin.)}}{dM^2 dp_T^2}$$

- $\frac{d\sigma^{(res.)}}{dM^2 dp_T^2}$: includes all the singular terms
  - terms propotionnal to $\delta(p_T^2)$
  - terms propotionnal to $p_T^{-2} \ln^n \frac{M^2}{p_T^2}$
- $\frac{d\sigma^{(fin.)}}{dM^2 dp_T^2}$: includes all the regular terms

Resummation formalism

- p_T-resummation is formulated in inverse space

$$W(b^2, M^2 b^2) = \int d^2 p_T \, e^{-i\mathbf{b}.\mathbf{p_T}} \, \frac{d\sigma^{(res.)}}{dM^2 dp_T^2} \quad \Rightarrow \quad \ln \frac{M^2}{p_T^2} \to \ln M^2 b^2$$

- C.S.S. found the evolution equation of W

$$\frac{\partial}{\partial \ln M^2} W(b^2, M^2 b^2) = -\gamma_W(M^2, M^2 b^2) \, W(b^2, M^2 b^2)$$

- The solution leads to the exponentiation of the large logs

$$W(b^2, M^2 b^2) = W(b^2, 1) \exp \underbrace{\left[- \int_{1/b^2}^{M^2} \frac{dq^2}{q^2} \gamma_W(q^2, q^2 b^2) \right]}_{\text{Sudakov exponent}}$$

- No large logs in W. W and γ_W can be computed perturbatively

Resummation formalism

- Working into Mellin space, we can do even better
  [Bozzi, Catani, de Florian, Grazzini (2006)]
- Collect all the b-dependence in the Sudakov exponent and get a resummed formula at the partonic level

$$\frac{d\hat{\sigma}_{ab}^{(res.)}}{dM^2 dp_T^2}(N) = \int \frac{d^2 b}{(2\pi)^2}\, e^{i\mathbf{b}.\mathbf{p_T}}\, \mathcal{H}_{ab}(N, M^2)\, \exp\left[\mathcal{G}(N, \ln M^2 b^2)\right]$$

- The Sudakov exponent can be systematically expanded as

$$\mathcal{G}(N, L) = L\, g_N^{(0)}(\alpha_S L) + g_N^{(1)}(\alpha_S L) + \alpha_S\, g_N^{(2)}(\alpha_S L) + \cdots$$

- $L\, g_N^{(0)}(\alpha_S L)$ collects the LL, $g_N^{(1)}(\alpha_S L)$ collects the NLL, ...
- $\mathcal{H}$ and $\mathcal{G}$ can be computed pertubatively
  - LL accuracy needs $g^{(0)}$ and $\mathcal{H}$ at $O(\alpha_S^0)$.
  - NLL accuracy needs $g^{(0)}$, $g^{(1)}$ and $\mathcal{H}$ at $O(\alpha_S)$

Resummation formalism

- For the finite component, we use direct matching, that is, at LO

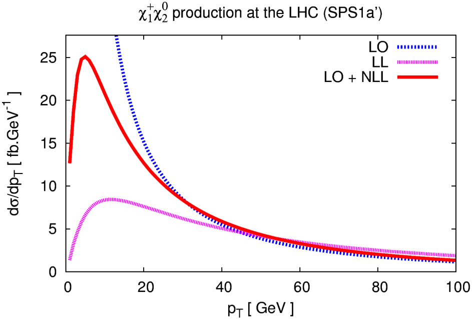
$$\left.\frac{d\sigma^{(fin.)}}{dM^2 dp_T^2}\right|_{LO} = \left.\frac{d\sigma}{dM^2 dp_T^2}\right|_{LO} - \left.\frac{d\sigma^{(res.)}}{dM^2 dp_T^2}\right|_{LO}$$

- And we get

$$\left.\frac{d\sigma}{dM^2 dp_T^2}\right|_{LO+NLL} = \left.\frac{d\sigma}{dM^2 dp_T^2}\right|_{LO} + \left.\frac{d\sigma^{(res.)}}{dM^2 dp_T^2}\right|_{NLL} - \left.\frac{d\sigma^{(res.)}}{dM^2 dp_T^2}\right|_{LO}$$

- Now both contributions (i.e. resummed and fixed order) are consistently matched (avoiding double counting)

Numerical results

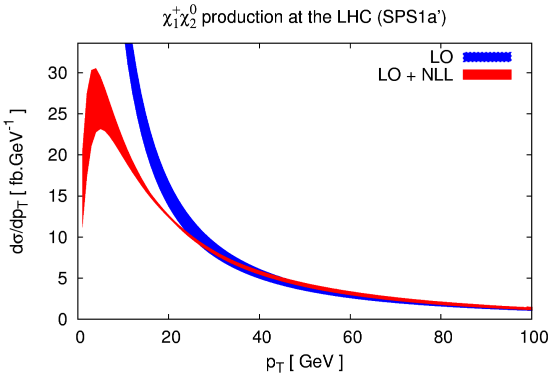


- Get finite results for small p_T
- LL normalization: Born total cross section: $\sigma = 632$ fb
- LO+NLL normalization: One-loop total cross section: $\sigma = 789$ fb

$$\Rightarrow \boxed{K = 1.25}$$

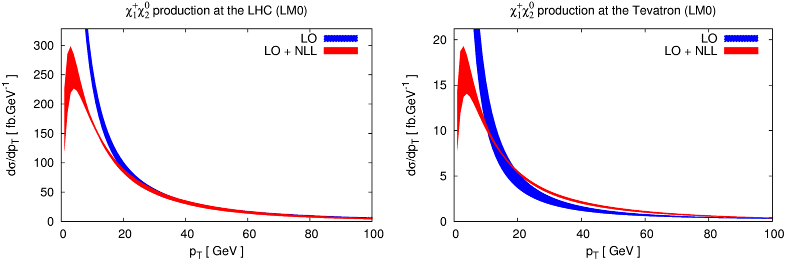
- Different shapes between LL and LO+NLL

Numerical results



- $\bar{m}_{\tilde{\chi}}/2 \leq \mu_R = \mu_F \leq 2\bar{m}_{\tilde{\chi}}$
- Improvement of the scale dependence for the resummed results with respect to the pure fixed order calculation
- p_T-jet $\sim$ 7 GeV: take into account to evaluate $\not{p}_T$

Numerical results



- Common CMS/ATLAS low mass benchmark point - LM0
- LM0: $m_0 = 200$ GeV, $m_{1/2} = 160$ GeV, $A_0 = -400$ GeV $\tan\beta = 10$, $\mu > 0$
- $\bar{m}_{\tilde{\chi}} \approx 113$ GeV just above the current reach of the Tevatron
- Enhancement at the Tevatron for intermediate values of p_T

Conclusion

- p_T-spectrum of neutralino/chargino-pairs at hadron colliders
  - Usual fixed-order calculation leads to incorrect predictions at small p_T values
  - Need to resum the large logs
- p_T-resummation
  - up to NLL accuracy
  - At small p_T: Finite and predictive results
  - At intermediate p_T:
    - Scale dependence is reduced
    - Enhancement at the Tevatron energy
- Outlook
  - Non-perturbative effects at very small p_T
  - PDF-uncertainty study