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

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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 $\longrightarrow$ Mixings $\longrightarrow$ Neutralinos and charginos

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

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

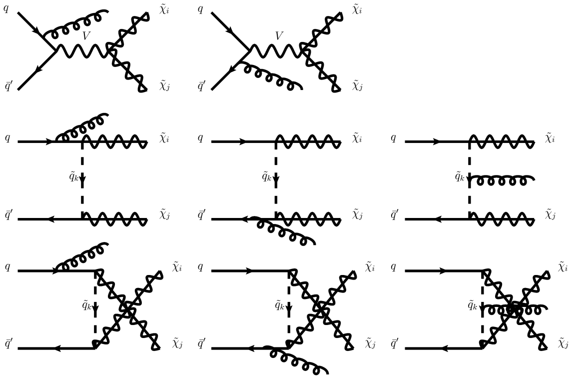
Motivation for gaugino study

- 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 $\Rightarrow$ May be produced at current colliders
- Can decay into the LSP and leptons
- Clean signal: leptons + large $\not{E}_T$
- Tevatron researches for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to l^\pm l^+ l^- + \not{E}_T$ [CDF(2008), D0(2006)]
- Precision calculation for the p_T-spectrum of the gaugino pairs

Outline

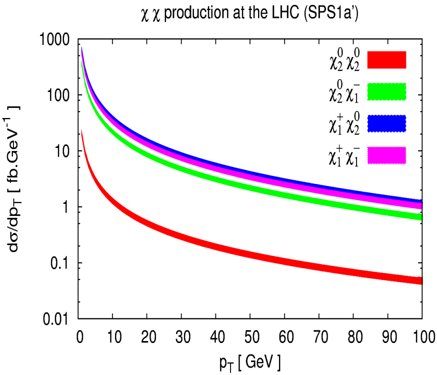
LO partonic cross section at $O(\alpha^2\alpha_S)$

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



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

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
- $\bar{m}_{\tilde{\chi}}/2 \leq \mu_R = \mu_F \leq 2\bar{m}_{\tilde{\chi}}$
- Divergent 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))], [Bozzi, Catani, de Florian, Grazzini (2006)]
- Cross section 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 $\delta(p_T^2)$ (Born, One-loop)
  - terms propotionnal to $p_T^{-2} \ln^n \frac{M^2}{p_T^2}$ (Real emission)
- $\frac{d\sigma^{(fin.)}}{dM^2 dp_T^2}$: includes all the regular terms

Resummation formalism [Singular part]

- p_T-resummation is formulated in inverse space

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

- 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 [Regular part]

- For the finite component, we use direct matching

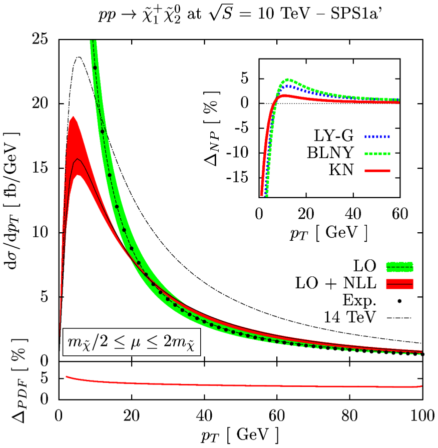
$$\left.\frac{d\sigma^{(fin.)}}{dM^2 dp_T^2}\right|_{LO} = \left.\frac{d\sigma}{dM^2 dp_T^2}\right|_{LO} - \left.\frac{d\sigma^{(res.)}}{dM^2 dp_T^2}\right|_{LO}$$

- And we get

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

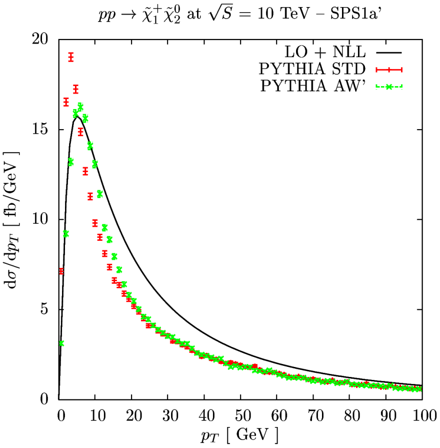
- p_T-distribution is affected by NP effects in the small p_T-region: Universal for DY-like processes and obtained with DY data
- 3 parametrizations are investigated: [Konychev, Nadolsky (2006)], [Landry, Brock, Nadolsky, Yuan (2003)], [Ladinsky, Yuan (1994)]

Numerical results



- Get finite results for small p_T
- Scale dependence improved
- PDF uncertainties $\sim 5\%$
- NP important for small p_T but $< 5\%$ for $p_T > 5$ GeV

Numerical results



- 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

- p_T-spectrum of neutralino/chargino pairs at hadron colliders
  - Usual fixed-order calculation leads to incorrect predictions at small values of p_T
  - 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
  - Studies of PDF uncertainties and the NP effects
  - vs PYTHIA