QCD resummations for gaugino-pair hadroproduction

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La Thuile, Italy
March 18, 2010
Outline

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  Neutralinos and charginos

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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: $\tilde{H}_2^+$, $\tilde{H}_2^0$, $\tilde{H}_1^0$, $\tilde{H}_1^-$

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

\[
\begin{pmatrix}
\tilde{\chi}_0^0 \\
\tilde{\chi}_1^0 \\
\tilde{\chi}_2^0 \\
\tilde{\chi}_3^0 \\
\tilde{\chi}_4^0
\end{pmatrix}
= N
\begin{pmatrix}
-i\tilde{B}_0^0 \\
-i\tilde{W}_0^0 \\
\tilde{H}_2^0 \\
\tilde{H}_1^0
\end{pmatrix}
\]

\[
\begin{pmatrix}
\tilde{\chi}_1^- \\
\tilde{\chi}_2^-
\end{pmatrix}
= U
\begin{pmatrix}
-i\tilde{W}_-^-
\end{pmatrix}
\quad \text{and} \quad
\begin{pmatrix}
\tilde{\chi}_1^+ \\
\tilde{\chi}_2^+
\end{pmatrix}
= V
\begin{pmatrix}
-i\tilde{W}_+^+
\end{pmatrix}
\]
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
  ⇒ May be produced at current hadron colliders

- Can decay into the LSP and leptons
- Clean signal: leptons + large $E_T$
- Tevatron searches for $\tilde{\chi}_1^±\tilde{\chi}_2^0 \rightarrow l^± l^0 l^- + E_T$ [CDF(2008)], [D0(2006)]
Fixed-order calculation

- Partonic $M$- and $p_T$-distributions at $\mathcal{O}(\alpha_s)$: 
  \[
  z = \frac{M^2}{\hat{s}} \\
  \frac{d\hat{\sigma}}{dM^2} = \hat{\sigma}^{(0)}(M)\delta(1 - z) + \alpha_s \hat{\sigma}^{(1)}(z, M) \\
  \frac{d\hat{\sigma}}{dM^2 dp_T^2} = \hat{\sigma}^{(0)}(M)\delta(1 - z)\delta(p_T^2) + \alpha_s \hat{\sigma}^{(1)}(z, M, p_T)
  \]

- Cancellation of IR singularities leaves terms of the form
  \[
  \alpha_s^n \left( \frac{\ln^m(1 - z)}{1 - z} \right) + \frac{\alpha_s^n}{p_T^2} \ln^m \frac{M^2}{p_T^2} \quad (m < 2n)
  \]

- 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 $\alpha_s$
  \(
  \Rightarrow \text{Gain reasonable control over these terms}
  \)
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:
  \[
  \hat{\sigma}^{(\text{res})}(M, L) = \mathcal{H}(M) \exp[\mathcal{G}(L)]
  \]

- 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 $\alpha_s$ of the resummed result
- No double counting of the logarithms

$$d\hat{\sigma} = d\hat{\sigma}^{(\text{res})} + d\hat{\sigma}^{(f.o)} - d\hat{\sigma}^{(\text{exp})}$$
**M-distribution at the Tevatron**

\[ p\bar{p} \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_2^0 \text{ at } \sqrt{S} = 1.96 \text{ TeV} \]

![Graph showing M-distribution](image)

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

- SPS1a': \( m_0 = 70 \text{ GeV}, m_{1/2} = 250 \text{ GeV}, A_0 = -300 \text{ GeV}, \tan \beta = 10, \mu > 0 \)
- mSUGRA RGE: SuSpect2.4
- PDF set: CTEQ6.6M / CTEQ6L1
Resummation effects at the Tevatron and the LHC

$p\bar{p}\ (\sqrt{s} = 1.96 \text{ TeV}) - \text{SPS1a'}$

$pp\ (\sqrt{s} = 7 \text{ TeV}) - \text{SPS1a'}$

$K^{\text{NLL}} = \frac{d\sigma^{\text{NLL+NLO}}}{d\sigma^{\text{NLO}}}$

- 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

- Fixed-order prediction is divergent at $p_T = 0$ GeV
  $\Rightarrow$ Unreliable results

- Applying $p_T$-resummation
  $\Rightarrow$ Get finite results

- Scale dependence improved: $12\% \rightarrow 6\% \ (p_T = 45 \text{ GeV})$

$pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_2^0$ at $\sqrt{S} = 10$ TeV

[JD, Fuks, Klasen (2009)]
Comparison with PYTHIA

$pp \to \tilde{\chi}_1^+ \tilde{\chi}_2^0$ at $\sqrt{S} = 10$ TeV – SPS1a’

- $p_T$-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

[JD, Fuks, Klasen (2009)]
Conclusion

- **Neutralino/chargino pairs at hadron colliders**
  - Usual fixed-order calculations are polluted by large logarithms at the edge of the phase space ($p_T \to 0, \ z \to 1$)
  - 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