Transverse-momentum, threshold and joint resummation for slepton-pair production at hadron colliders

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SUSY 07
Karlsruhe (Germany), July 27, 2007

Outline

1. Introduction and motivations
2. Resummation formalisms
   - Main features of the resummation
   - The resummed component
   - Matching procedure
3. Applications
   - q_T-distribution
   - Invariant-mass distribution
   - Total cross sections
4. Summary and outlook

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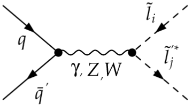
Slepton-pair production at hadron colliders

- Drell-Yan like process



$$q\bar{q} \to \gamma, Z^0 \to \tilde{l}_i \tilde{l}_j^* \qquad \text{and} \qquad q\bar{q}' \to W^{\mp} \to \tilde{l}_i \tilde{\nu}_l^* + c.c.$$

- Sleptons are often light $\Rightarrow$ decays into LSP + SM lepton $\Rightarrow$ clean signal.
- Cross sections given by

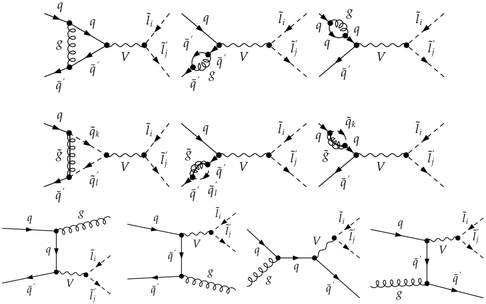
$$\sigma = \sum_{a,b} \int_{\tau}^{1} \mathrm{d}x_a \int_{\tau/x_a}^{1} \mathrm{d}x_b \, f_{a/h_1}(x_a, \mu_F) \;\; f_{b/h_2}(x_b, \mu_F) \, \hat{\sigma}_{ab}(z, M; \alpha_s(\mu_R), \tfrac{M}{\mu_F}, \tfrac{M}{\mu_R})$$

where $\hat{\sigma}_{ab}$ is computed perturbatively

$$\hat{\sigma}_{ab}(z, M; \alpha_s(\mu_R), \tfrac{M}{\mu_F}, \tfrac{M}{\mu_R}) = \sum_{n=0}^{\infty} \left(\frac{\alpha_s(\mu_R)}{\pi} \right)^n \hat{\sigma}_{ab}^{(n)}(z, M; \tfrac{M}{\mu_F}, \tfrac{M}{\mu_R}) \; .$$

Next-to-leading order calculations

- Feynman diagrams:



- Squark mixing included in the SUSY-loops.
- Partonic invariant-mass and transverse-momentum distributions at $\mathcal{O}(\alpha_s)$:

$$\frac{\mathrm{d}\hat{\sigma}_{ab}}{\mathrm{d}M^2} = \hat{\sigma}^{(0)}_{ab}(M)\,\delta(1-z) + \frac{\alpha_s}{\pi}\,\hat{\sigma}^{(1)}_{ab}(M,z) + \mathcal{O}(\alpha_s^2),$$

$$\frac{\mathrm{d}^2\hat{\sigma}_{ab}}{\mathrm{d}M^2\,\mathrm{d}q_T^2} = \hat{\sigma}^{(0)}_{ab}(M)\,\delta(q_T^2)\delta(1-z) + \frac{\alpha_s}{\pi}\,\hat{\sigma}^{(1)}_{ab}(M,z,q_T) + \mathcal{O}(\alpha_s^2),$$

where $z = M^2/s$.

q_T and invariant-mass distributions

- Soft and collinear radiations:
  - $\frac{\alpha_s^n}{q_T^2} \ln^m \frac{M^2}{q_T^2}$ or $\alpha_s^n \left(\frac{\ln^m(1-z)}{1-z}\right)_+$ terms in the distributions ($m \leq 2\,n-1$).
  - Large at small q_T or $z \lesssim 1$.
  - Fixed-order theory unreliable in these kinematical regions.
  - Resummation to all orders needed.
    $\Rightarrow$ q_T-resummation.
    $\Rightarrow$ Threshold resummation.
    $\Rightarrow$ Joint resummation.

- Advantages of resummation:
  - Reliable perturbative results.
  - Correct quantification of these radiations (even far from critical regions).
  - Accurate invariant-mass and q_T spectra.

  q_T-distribution $\Rightarrow$ stransverse mass $\Rightarrow$ spin and mass determination.
  [Lester, Summers (1999); Barr (2006)]
  M-distribution and total cross section $\Rightarrow$ accurate mass determination.
  [Bozzi, BF, Klasen (2007)]

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Main features of the resummation

Reorganization of the cross section

$$\mathrm{d}\sigma = \mathrm{d}\sigma^{(\mathrm{res})} + \mathrm{d}\sigma^{(\mathrm{fin})}\ .$$

- $\mathrm{d}\sigma^{(\mathrm{res})}$
  - * Contains all the logarithmic terms.
  - * Resummed to all orders in α_s.
  - * Exponentiation (Sudakov form factor).
- $\mathrm{d}\sigma^{(\mathrm{fin})}$
  - * Remaining contributions.

The resummed component: conjugate spaces

- Conjugate spaces: Mellin, impact-parameter $\Rightarrow$ kinematics naturally factorizes.
- Factorization of the hadronic cross sections:

$$\frac{\mathrm{d}\sigma^{(\mathrm{res})}}{\mathrm{d}M^2}(\tau,M)=\sum_{a,b}\int_\tau^1 \mathrm{d}x_a \int_{\tau/x_a}^1 \mathrm{d}x_b\, f_{a/h_1}(x_a,\mu_F)\, f_{b/h_2}(x_b,\mu_F)\, \hat\sigma^{(\mathrm{res})}_{ab}(z;\alpha_s(\mu_R),\tfrac{M}{\mu_F},\tfrac{M}{\mu_R})$$

$$\Downarrow$$

$$\frac{\mathrm{d}\sigma^{(\mathrm{res})}}{\mathrm{d}M^2}(N,M)=\sum_{a,b} f_{a/h_1}(N+1,\mu_F)\, f_{b/h_2}(N+1,\mu_F)\, \hat\sigma^{(\mathrm{res})}_{ab}(N;\alpha_s,\tfrac{M}{\mu_R},\tfrac{M}{\mu_F}),$$

and

$$\frac{\mathrm{d}^2\sigma^{(\mathrm{res})}}{\mathrm{d}M^2\mathrm{d}q_T^2}(\tau,M,q_T)=\sum_{a,b}\int_\tau^1 \mathrm{d}x_a \int_{\tau/x_a}^1 \mathrm{d}x_b\, f_{a/h_1}(x_a,\mu_F)\, f_{b/h_2}(x_b,\mu_F)\, \hat\sigma^{(\mathrm{res})}_{ab}(z,q_T;\alpha_s(\mu_R),\tfrac{M}{\mu_F},\tfrac{M}{\mu_R})$$

$$\Downarrow$$

$$\frac{\mathrm{d}^2\sigma^{(\mathrm{res})}}{\mathrm{d}M^2\mathrm{d}q_T^2}(N,M,q_T)=\sum_{a,b} f_{a/h_1}(N+1,\mu_F)\, f_{b/h_2}(N+1,\mu_F) \int \tfrac{b}{2}\,\mathrm{d}b\, J_0(b\,q_T)\, \mathcal{W}^F_{ab}(N,b;\alpha_s,\tfrac{M}{\mu_R},\tfrac{M}{\mu_F}).$$

- The logarithms are included in the functions $\hat\sigma^{(\mathrm{res})}$ and $\mathcal{W}^F$:

$$\left(\frac{\ln(1-z)}{1-z}\right)_+ \to \ln^2\bar N \quad \text{with} \quad \bar N = N\,\exp[\gamma_E] \qquad\qquad \frac{1}{q_T^2}\ln\frac{M^2}{q_T^2}\to \ln\bar b^2 \quad\text{with}\quad \bar b=\frac{b\,M}{2}\exp[\gamma_E]$$

The resummed component: the partonic cross section

- The process-dependence is factorized outside the exponent:

$$\mathcal{W}^F_{ab}(N,b) = \mathcal{H}^F_{ab}(N) \exp\left\{\mathcal{G}(N,b)\right\},$$
$$\hat\sigma^{(\rm res)}_{ab}(N) = \sigma^{(LO)}\, \tilde C_{ab}(N;\alpha_s)\, \exp\left\{\mathcal{G}(N,L)\right\}.$$

- $\mathcal{H}^F$- and $\tilde C$-functions:
  * Can be computed perturbatively and are process-dependent.
  * Contain real and virtual collinear radiation, and hard contributions.

- The Sudakov form factor contains the soft-collinear radiation:
  * Can be computed perturbatively and is process-independent.

- Used formalisms:
  * Universal q_T-resummation. [Catani, de Florian, Grazzini (2001); Bozzi, Catani, de Florian, Grazzini (2006)]
  * Threshold resummation including collinear radiation. [Sterman (1987); Catani, Trentadue (1989, 1991); Krämer, Laenen, Spira (1998); Catani, de Florian, Grazzini (2001)]
  * Universal joint resummation. [Laenen, Sterman, Vogelsang (2001); Kulesza, Sterman, Vogelsang (2002, 2004); Bozzi, BF, Klasen (*in prep.*)]

The finite component: matching procedure

- Fixed-order theory
  - * Reliable far from the critical kinematical regions ($z \ll 1$, $q_T \gg 0$).
  - * Spoiled in the critical regions ($z \sim 1$, $q_T \sim 0$).
- Resummation
  - * Needed in the critical regions.
  - * Not justified far from the critical regions.
- Both contributions important in the intermediate kinematical regions.

- Information from both fixed-order and resummation needed.
- Need to avoid double-counting.

- Consistent matching procedure required:

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

Summary: complete resummation formulae

- Invariant-mass spectrum

$$\frac{\mathrm{d}\sigma}{\mathrm{d}M^2}(\tau,M) = \frac{\mathrm{d}\sigma^{(\mathrm{F.O.})}}{\mathrm{d}M^2}(\tau,M) + \oint_{C_N} \frac{\mathrm{d}N}{2\pi i}\,\tau^{-N}\left[\frac{\mathrm{d}\sigma^{(\mathrm{res})}}{\mathrm{d}M^2}(N,M) - \frac{\mathrm{d}\sigma^{(\mathrm{exp})}}{\mathrm{d}M^2}(N,M)\right].$$

- Transverse-momentum spectrum

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}M^2\,\mathrm{d}q_T^2}(\tau,M,q_T) = \frac{\mathrm{d}^2\sigma^{(\mathrm{F.O.})}}{\mathrm{d}M^2\,\mathrm{d}q_T^2}(\tau,M,q_T) + \oint_{C_N} \frac{\mathrm{d}N}{2\pi i}\,\tau^{-N}\int \frac{b\,\mathrm{d}b}{2}\,J_0(q_T\,b)\left[\frac{\mathrm{d}^2\sigma^{(\mathrm{res})}}{\mathrm{d}M^2\,\mathrm{d}q_T^2}(N,b) - \frac{\mathrm{d}^2\sigma^{(\mathrm{exp})}}{\mathrm{d}M^2\,\mathrm{d}q_T^2}(N,b)\right].$$

  * Far from the critical regions, $\mathrm{d}\sigma^{(\mathrm{res})} \approx \mathrm{d}\sigma^{(\mathrm{exp})}$ $\Rightarrow$ Perturbative theory.
  * In the critical regions, $\mathrm{d}\sigma^{(\mathrm{F.O.})} \approx \mathrm{d}\sigma^{(\mathrm{exp})}$ $\Rightarrow$ Pure resummation.
  * In the intermediate regions $\Rightarrow$ Consistent matching.

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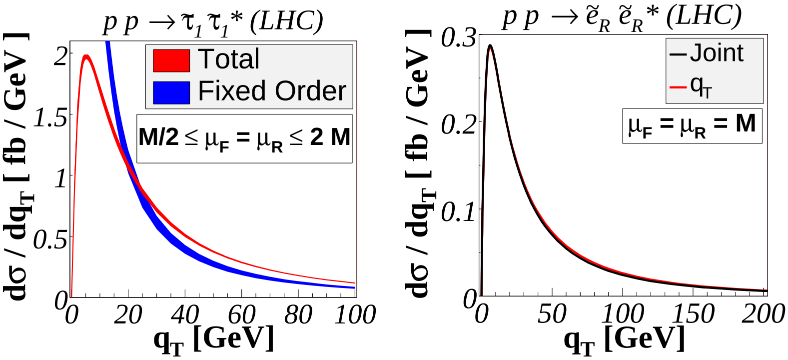
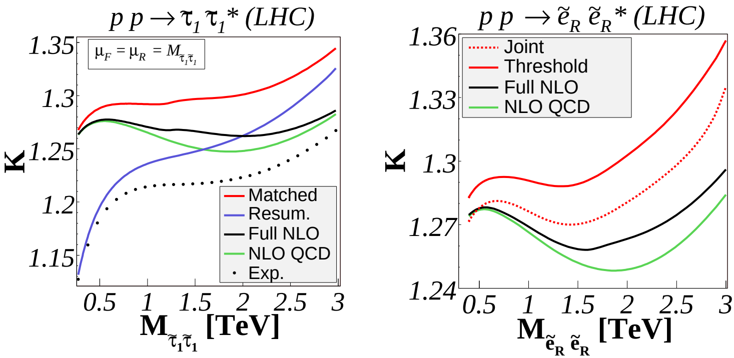
q_T-distribution at the LHC



[Bozzi, BF, Klasen (2006; *in prep.*)]

- SPS1a and BFHK-B SUSY scenarios (slepton masses ≈ 100-200 GeV).
- Finite results at small q_T; enhancement at intermediate q_T; finite total σ.
- Improvement of scale dependences: (NLL+F.O. $\lesssim$ 5%; F.O. 10%).
- Effects of the threshold-enhanced contributions in the intermediate-q_T region.

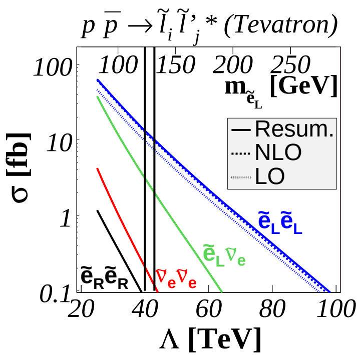
Invariant-mass distribution at the LHC

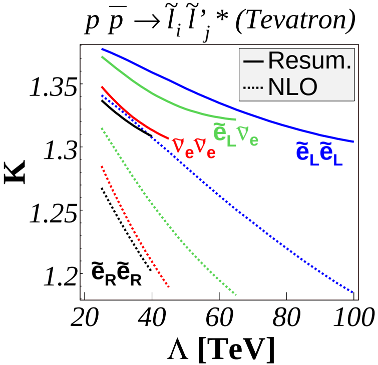


[Bozzi, BF, Klasen (2007; *in prep.*)]

- SPS1a and BFHK-B SUSY scenarios (slepton masses ≈ 100-200 GeV).
- Normalization to LO cross section.
- Small M: $\mathrm{d}\sigma^{(\mathrm{res})} \approx \mathrm{d}\sigma^{(\mathrm{exp})}$; Large M: $\mathrm{d}\sigma^{(\mathrm{F.O.})} \approx \mathrm{d}\sigma^{(\mathrm{exp})}$.
- Reduced SUSY-loop effects.
- Joint-exponent reproduces q_T-exponent.
  ⇒ some differences with threshold-resummation (however under control).

Threshold-resummed total cross sections at the Tevatron





[Bozzi, BF, Klasen (2007)]

* SPS7 slope.
* NLO and threshold-resummation effects important.
* Resummation more important for heavier sleptons.
* Shift in $m_{\tilde{e}_L}$ if deduced from total σ measurement.

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Conclusion and outlook

- Full NLO SUSY-QCD calculations, including squark mixing.
- Threshold, q_T and joint resummations.
- Comparison with the Monte Carlo approach.
- Study of other SUSY particle production processes.