Polarization and resummation for slepton-pair hadroproduction

Benjamin Fuks (LPSC Grenoble)

in collaboration with Giuseppe Bozzi and Michael Klasen

[Phys. Lett. **B609**, 339 (2005) and hep-ph/0603074]

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Outline

The Minimal Supersymmetric Model

Main features

- High energy extension to Standard Model.
- Symmetry between fermions and bosons.
- One SUSY partner for each SM particle.
- 5 Higgs bosons.
- R-parity conservation.

Advantages

- Gauge couplings unification at Planck scale.
- Possible inclusion of gravity.
- Solution to hierarchy problem.
- Dark matter candidate.
- New CP-violation phases.

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Why study slepton production ?

- Due to their purely electroweak couplings, sleptons are among the lightest SUSY particles in many SUSY-breaking scenarios.
  [Allanach *et al.*, Eur. Phys. J. **C25**, 113 (2002)]
- Often directly decays into the lightest SUSY particle (LSP) plus the corresponding standard model partner (lepton or neutrino).
- Clean signal with a highly energetic lepton and missing energy.

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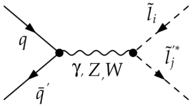
Slepton production at hadron colliders



$q\bar{q} \to \tilde{l}_i \tilde{l}_j^*$:

- slepton-pair production
- neutral current

$q\bar{q}' \to \tilde{l}_i \tilde{\nu}_l^* + \tilde{l}_i^* \tilde{\nu}_l$

- slepton-sneutrino associated production
- charged current

We focus on tau slepton and sneutrino. **Why?**

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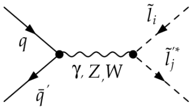

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Third generation slepton and sneutrino properties

- In general SUSY-breaking models, interaction eigenstates are not identical to mass eigenstates

$$\begin{pmatrix} \tilde{l}_1 \\ \tilde{l}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\tilde{l}} & \sin\theta_{\tilde{l}} \\ -\sin\theta_{\tilde{l}} & \cos\theta_{\tilde{l}} \end{pmatrix} \begin{pmatrix} \tilde{l}_L \\ \tilde{l}_R \end{pmatrix} ,$$

where

$$\tan 2\theta_{\tilde{l}} = \frac{2\, m_l\, m_{LR}}{m_{LL}^2 - m_{RR}^2} \ .$$

[Haber, Kane, Phys. Rept. **117**, 75 (1985)]

- Mixing proportional to corresponding lepton mass
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Are tau sleptons detectable ?

Tau slepton often decays in one tau lepton plus one neutralino
$\Rightarrow$ tau tagging at hadron colliders ?

- Leptonic decays (35%): isolated muons or electrons plus $\not{E}_T$
  $\Rightarrow$ Limited use (origin of the lepton unknown).
- Hadronic decays (65%): narrow isolated jet with low track multiplicity and invariant mass, plus $\not{E}_T$.
- Require significant q_T.

Atlas: [Hinchliffe, Nucl. Phys. Proc. Suppl. **123**, 229 (2003)]

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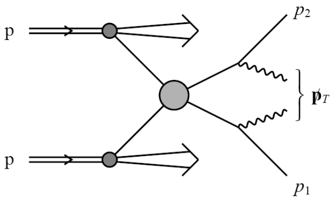
Importance of transverse-momentum distribution

- Slepton-pair production signal made of two SM leptons and large missing energy due to two massive unobserved LSPs.



- Longitudinal momentum balance unknown in hadronic collision
  $\Rightarrow$ importance of a precise knowledge of the q_T-balance.
- Can be used to distinguish SUSY signals from SM background (lepton-pairs from WW or $t\bar{t}$ decays have a different q_T-shape)
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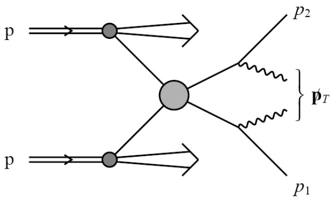

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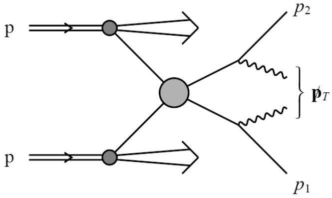

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Transverse mass variables

Problem: We have two massive particles carrying missing momentum.

Solution: use of the Cambridge *stransverse mass* M_{T2}^2

$$m_T^2(\mathbf{q}_T^l, \mathbf{q}_T^{\tilde\chi}) = m_l^2 + m_{\tilde\chi}^2 + 2\left(E_T^l\, E_T^{\tilde\chi} - \mathbf{q}_T^l \cdot \mathbf{q}_T^{\tilde\chi}\right)$$

$$m_{T2}^2 = \min_{\not{q}_1 + \not{q}_2 = \not{q}_T} \left[\max\left\{ m_T^2(\mathbf{q}_T^{l^-}, \mathbf{q}_T^1), m_T^2(\mathbf{q}_T^{l^+}, \mathbf{q}_T^2)\right\}\right]$$

$$m_{T2}^2 \leq m_{\tilde l}^2$$

- Optimistic: $\tilde\chi_1^0$ mass is known, slepton mass can be deduced.
- More realistic: relationship between neutralino and slepton masses.

  [Lester, Summers, Phys. Lett. **B463**, 99 (1999)]
- Bonus: can be used for spin determination.

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   - The Minimal Supersymmetric Model
   - Slepton production at hadron colliders
   - Tau slepton identification
   - Importance of transverse-momentum distribution
2. Fixed order calculations
   - Leading order
   - Next-to-leading order
   - Fixed order failure
3. Transverse-momentum resummation
   - Main features
   - The resummed component
   - The finite component
   - Non-perturbative effects
   - q_T-resummation for slepton-pair production at the LHC
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LO cross section and mixing effects for $h_1\, h_2 \to \tilde{l}_i\, \tilde{l}_j^*$

$$\frac{\mathrm{d}\hat\sigma_{h_a,h_b}}{\mathrm{d}t} = \frac{4\pi\alpha^2}{3s^2}\left[\frac{u\,t - m_i^2 m_j^2}{s^2}\right]\left[e_q^2\, e_l^2 (1 - h_a h_b)\,\frac{\delta_{ij}}{2} + \frac{e_q\, e_l\, \mathrm{Re}(L_l + R_l)\,[(1-h_a)\,(1+h_b)\,L_q + (1+h_a)\,(1-h_b)\,R_q]\,\delta_{ij}}{8\,x_W\,(1-x_W)\,(1-m_Z^2/s)} + \frac{|L_l + R_l|^2 [(1-h_a)\,(1+h_b)\,L_q^2 + (1+h_a)\,(1-h_b)\,R_q^2]}{64\,x_W^2 (1-x_W)^2 (1-m_Z^2/s)^2}\right],$$

with

$$L_l = (2\,T_f^3 - 2\,e_f\,x_W)\,S_{i1}\,S_{j1}^* \quad \text{and} \quad R_l = (-2\,e_f\,x_W)\,S_{i2}\,S_{j2}^* \ .$$

- No mixing matrix S for sneutrino ($S_{11} = 1$, and all others $S_{ij} = 0$).
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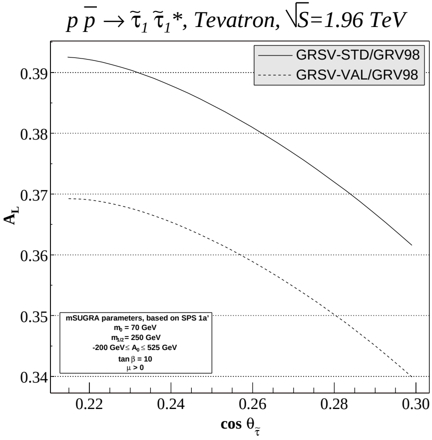
Leading order: Single-spin asymmetry and mixing effects



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- Sensitive to the mixing angle (7% – 8%).
- PDF uncertainties are still large (5% – 6%).
- Lepton-pair production: $A_L \approx -0.09$ $\Rightarrow$ discrimination SUSY/SM.
- Missing: an upgraded Tevatron with one polarized beam. [SPIN collaboration, 10th Topical Workshop on Proton-Antiproton Collider Physics (1995)]

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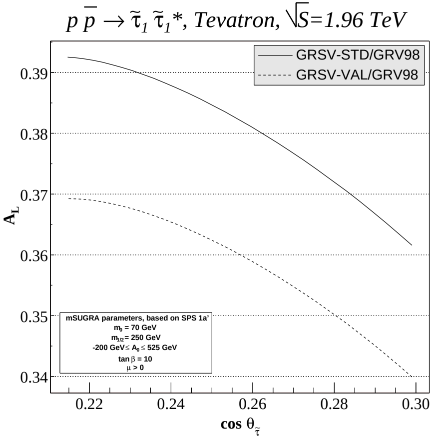

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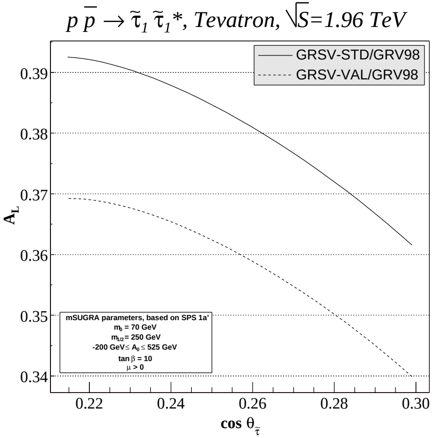

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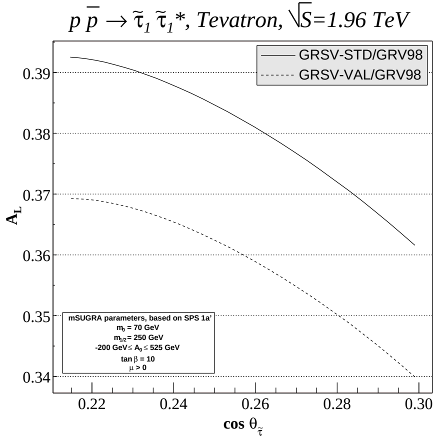

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Next-to-leading order K factor

QCD: [Baer, Harris, Reno, Phys. Rev. **D 57**, 5871 (1998)]

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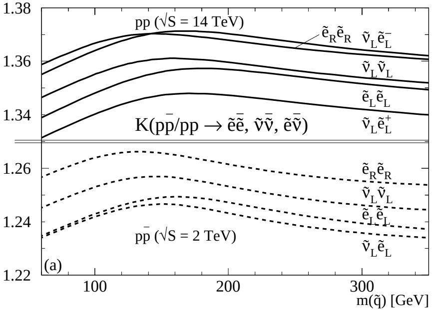

- K factors for slepton-pair in NLO SUSY-QCD not too different from QCD only.
- NLO contributions not negligible ($\sim$ 35% for the LHC and $\sim$ 25% for Tevatron)

Importance of higher order calculations.

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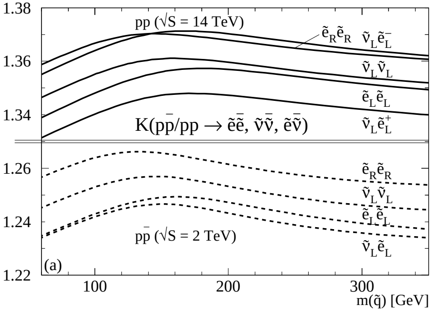

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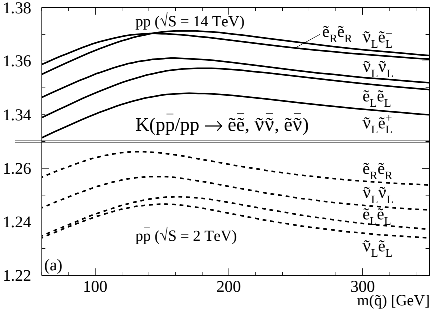

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Fixed order failure at low q_T

q_T-distribution features.

- Soft and collinear radiation enhance the cross section by powers of logarithmic terms $\propto \frac{\alpha_s^n}{q_T^2} \log^m \frac{Q^2}{q_T^2}$ $(m \leq 2\,n - 1)$.
- Cross section diverges as $q_T \longrightarrow 0$.
- Higher order contributions increase the divergence.
- Fixed order theory convergence definitely spoiled.

Why ?

- Real and virtual contributions highly unbalanced.
- Cancellation does not occur order by order.

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Main features

Reorganization of the cross section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2} = \left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\mathrm{res}} + \left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\mathrm{fin}} .$$

- $\left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\mathrm{res}}$
  - Contains all the logarithmic terms.
  - Contains all the terms proportional to $\delta(q_T)$.
  - Resummation to all orders in α_s.
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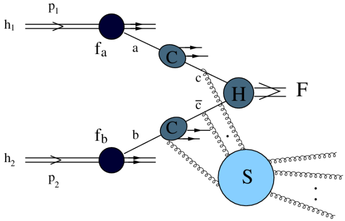
Universal resummation formalism developed by Bozzi, Catani, de Florian, Grazzini. [Catani, de Florian, Grazzini, Nucl. Phys. **B 596**, 299 (2001)]



- **process-independent** coefficient functions C_{ac} (collinear radiation at very low q_T),
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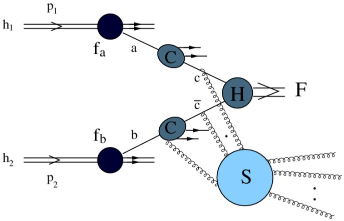

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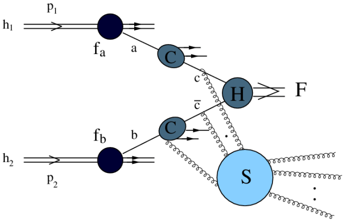

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The resummed component

$$\left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\mathrm{res}}(q_T, Q, s) = \sum_{a,b}\int_0^1 \mathrm{d}x_1 \int_0^1 \mathrm{d}x_2\, f_{a/h_1}(x_1, \mu_F)\, f_{b/h_2}(x_2, \mu_F) \times \left[\frac{\mathrm{d}\sigma_{ab}}{\mathrm{d}q_T^2}\right]_{\mathrm{res}}(q_T, Q, \hat{s}; \mu_R, \mu_F)$$

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$\mathcal{W}_{ab}^F$ contains all previously cited contributions, plus PDFs evolution.

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N-space and exponentiation

Computation of $\mathcal{W}^F_{ab}$ in N-space $\Rightarrow$ exponentiation.

$$\mathcal{W}^F_{ab,\,N}(b,Q;\mu_R,\mu_F) = \mathcal{H}^F_{ab,\,N}(Q;\frac{Q^2}{\mu_R^2},\frac{Q^2}{\mu_F^2})\exp[\mathcal{G}_N(L\equiv\log\frac{Q^2\,b^2}{b_0^2};\frac{Q^2}{\mu_R^2})]$$

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The finite component

- Logarithmic terms and contributions proportional to $\delta(q_T)$ are included in the resummed component.

  $\Rightarrow \left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\rm fin}$ can be computed by

$$\left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\rm fin} = \left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\rm f.o.} - \left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\rm res}\Bigg|_{\rm f.o.} .$$

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Summary

- At small q_T, the resummed component dominates, and the finite term is small.
- At intermediate q_T, both contributions are consistently matched and double-counting of any term is prevented.
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Non-perturbative effects

- Transverse-momentum distribution is affected by non-perturbative (NP) effects which are important in the large-b region.
- For Drell-Yan like processes, we multiply the previously cited $\mathcal{W}_{ab}^F$ function by a NP form factor obtained through experiment.

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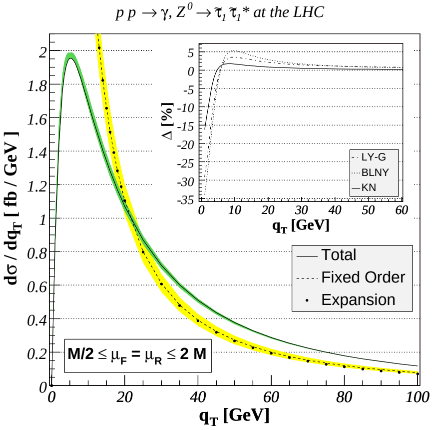
q_T-resummation for slepton-pair production at the LHC



NLL + LO $\mathcal{O}(\alpha_s)$ results for SPS 7

[Bozzi, BF, Klasen, hep-ph/0603074]

- Finite result at small q_T, enhancement at intermediate q_T.
- Improvement of scale dependence (NLL+LO: $\lesssim 5\%$; LO: 10%).
- Non-perturbative effects cannot be neglected at small q_T.
- **Total cross section reproduced after q_T integration.**

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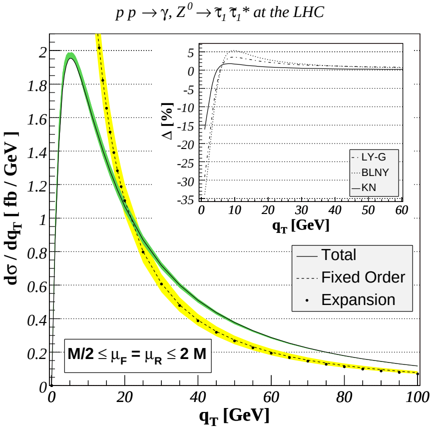

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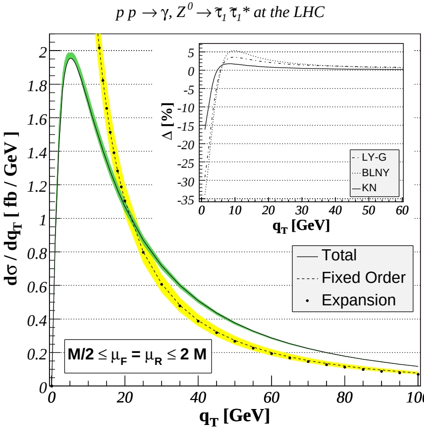

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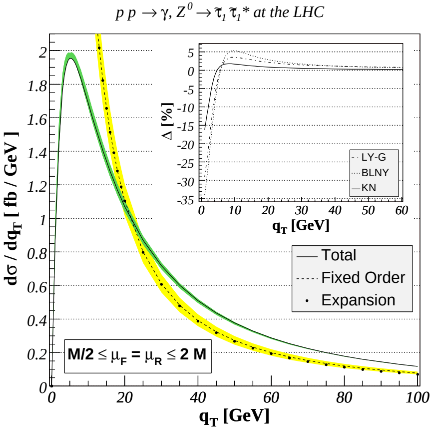

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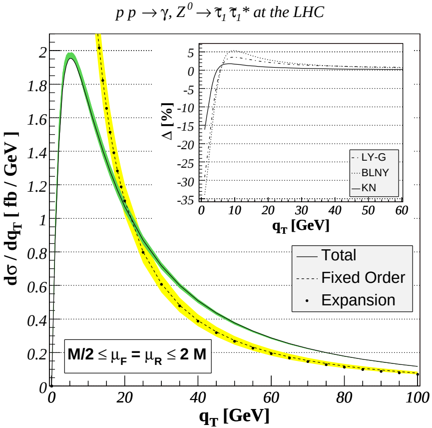

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