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

Why study slepton production ?

- Due to their purely electroweak couplings, sleptons are among the lightest SUSY particles in many SUSY-breaking scenarios.

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- 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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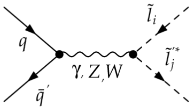

$q\bar{q} \longrightarrow \tilde{l}_i \tilde{l}_j^*$:

- slepton-pair production
- neutral current

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

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- charged current

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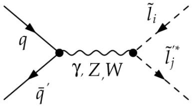

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Third generation slepton and sneutrino properties

- 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
$\Rightarrow$ only important for third generation.
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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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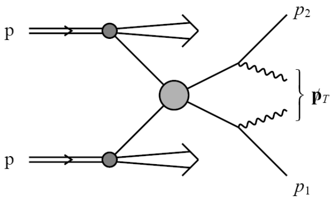
Importance of transverse-momentum distribution

- 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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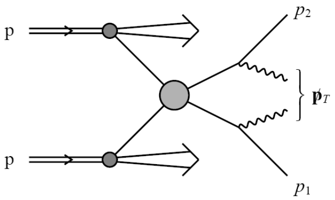

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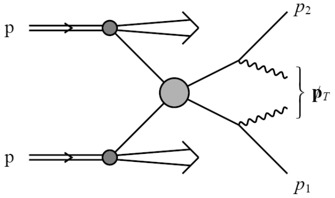

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Transverse mass variables

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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Outline

LO cross section and mixing effects for $h_1 h_2 \to \tilde{l}_i \tilde{l}_j^*$

$$\frac{\mathrm{d}\hat{\sigma}_{h_a,h_b}}{\mathrm{d}t} = \frac{4\pi\alpha^2}{3s^2}\left[\frac{u\,t - m_i^2 m_j^2}{s^2}\right]\Bigg[e_q^2\, e_l^2 (1 - h_a h_b)\, \frac{\delta_{ij}}{2}$$

$$+ \frac{e_q\, e_l\, \mathrm{Re}(L_l + R_l)\, [(1-h_a)\,(1+h_b)\, L_q + (1+h_a)\,(1-h_b)\, R_q]\, \delta_{ij}}{8\, x_W\, (1-x_W)\,(1-m_Z^2/s)}$$

$$+ \frac{|L_l + R_l|^2 [(1-h_a)\,(1+h_b)\, L_q^2 + (1+h_a)\,(1-h_b)\, R_q^2]}{64\, x_W^2 (1-x_W)^2 (1-m_Z^2/s)^2}\Bigg],$$

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 $S_{ij} = 0$).
- For charged current, all right couplings and electric charges are set to zero, and L_l is set to $\sqrt{2}\cos\theta_W\, S_{i1}$.

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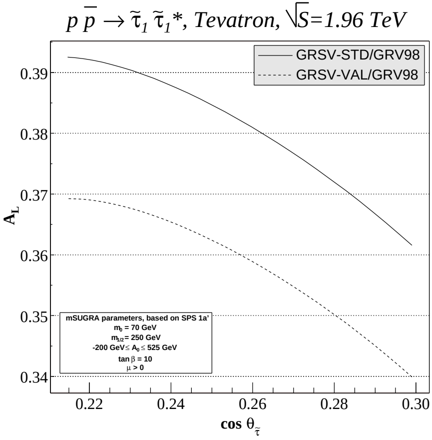
Leading order: Single-spin asymmetry and mixing effects



- 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.
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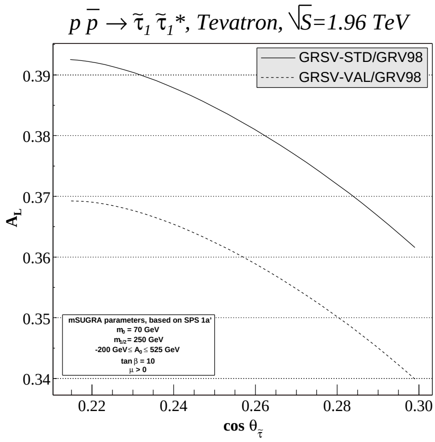

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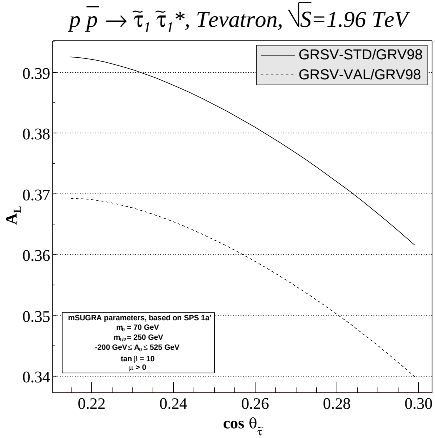

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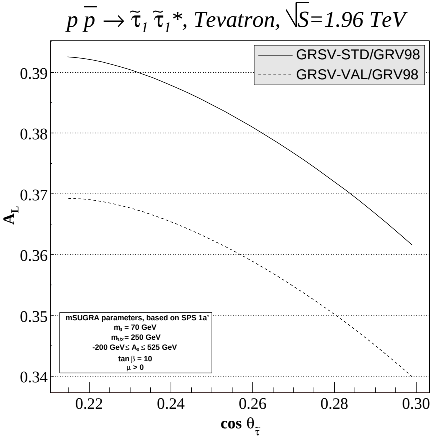

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Next-to-leading order K factor

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

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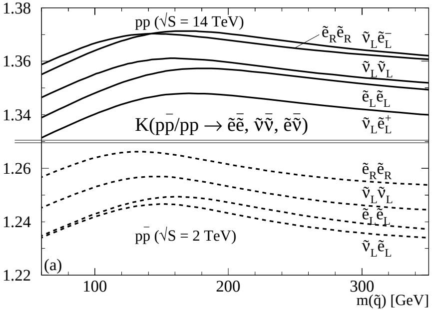

- K factors for slepton-pair in NLO SUSY-QCD not too different from QCD only.
- NLO contributions not negligible ($\sim$ 35% for the LHC and $\sim$ 25% for Tevatron)

Importance of higher order calculations.

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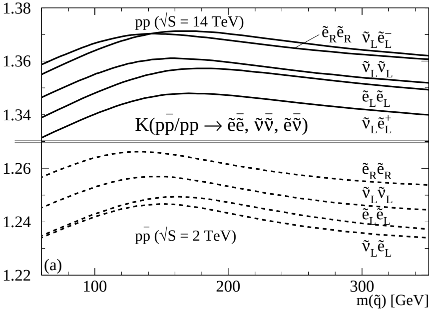

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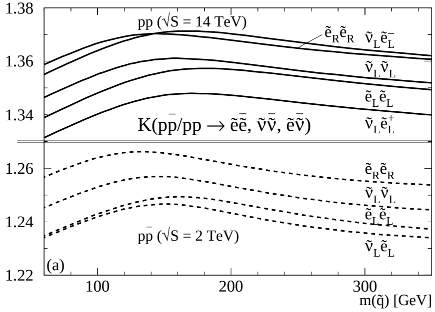

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Main features

- Fixed order failure at low q_T:

  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 $q_T \to 0$.
  - Real and virtual contributions highly unbalanced.
  - Resummation to all orders needed for reliable perturbative results.

- 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 logarithmically-enhanced contributions at small q_T and the terms proportional to $\delta(q_T)$, resummed to all orders in α_s, which exponentiate $\Rightarrow$ finite term.
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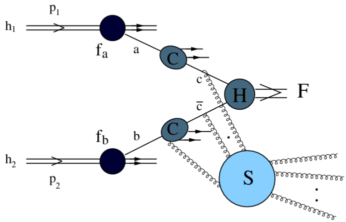
Universal resummation formalism developed by Bozzi, Catani, de Florian, Grazzini. [Catani, de Florian, Grazzini, Nucl. Phys. **B 596**, 299 (2001)]



- **process-independent** coefficient functions C_{ac} (collinear radiation at very low q_T),
- **process-independent** Sudakov form factor S_c (soft radiation, and collinear radiation at intermediate q_T),
- **process-dependent** factor H_c^F (hard contributions at $q_T \sim Q$).

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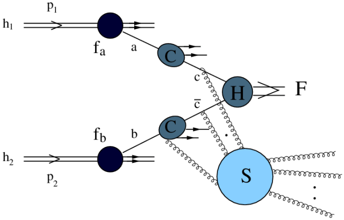

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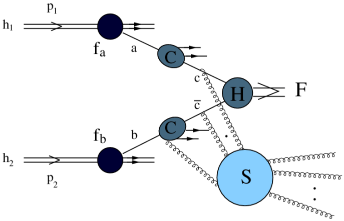

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The resummed component

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

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Remark: PDFs evaluated at factorization scale rather than at b_0/b.

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

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The finite component

- Logarithmic terms and contributions proportional to $\delta(q_T)$ are included in the resummed component.
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$$\left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\rm fin} = \left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\rm f.o.} - \left[\frac{\mathrm{d}\sigma}{\mathrm{d}q_T^2}\right]_{\rm res}\Bigg|_{\rm f.o.} .$$

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- Transverse-momentum distribution is affected by non-perturbative (NP) effects which are important in the large-b region.
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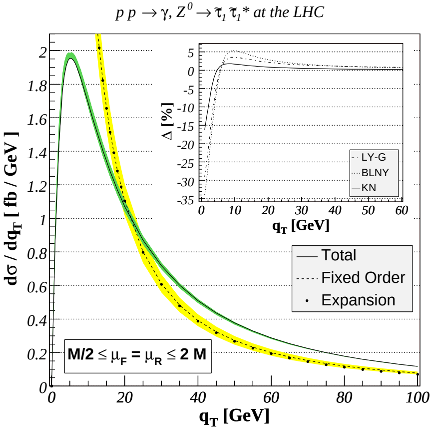

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NLL + LO $\mathcal{O}(\alpha_s)$ results for SPS 7

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

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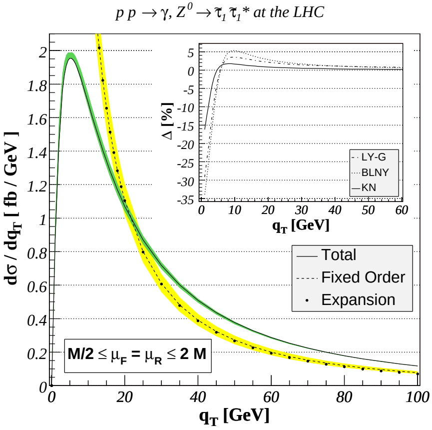

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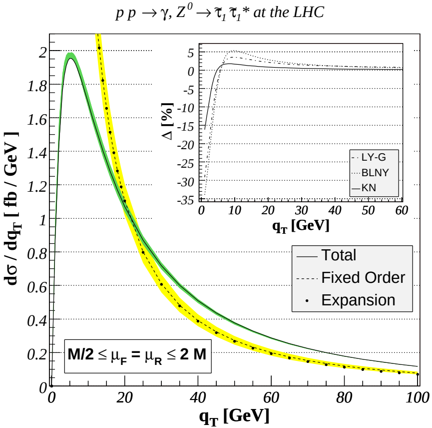

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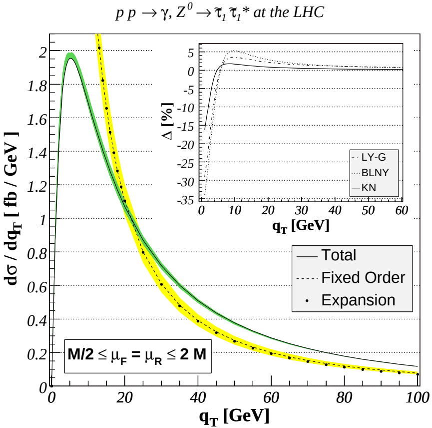

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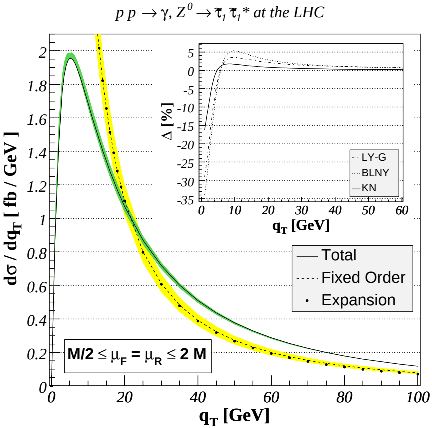

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Summary

- Slepton-pair hadroproduction
  - Unpolarized cross sections known at NLO
  - Polarized cross sections known at LO with sfermion mixing.
  - Beam polarization and sfermion mixing correlated.
- q_T-resummation for sleptons
  - Accurate q_T-spectrum needed by experiment
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