Slepton and squark pair production at (polarized) hadron colliders

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SUSY 05

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based on the following papers:

hep-ph/0411318 (Phys.Lett.B609 (2005),339)

hep-ph/0507073 (submitted to PRD)

Slepton pair production

- **Slepton pair production at hadron colliders :**

Processes studied : $pp \to \tilde{l}\tilde{l}^*$ **and** $p\bar{p} \to \tilde{l}\tilde{l}^*$

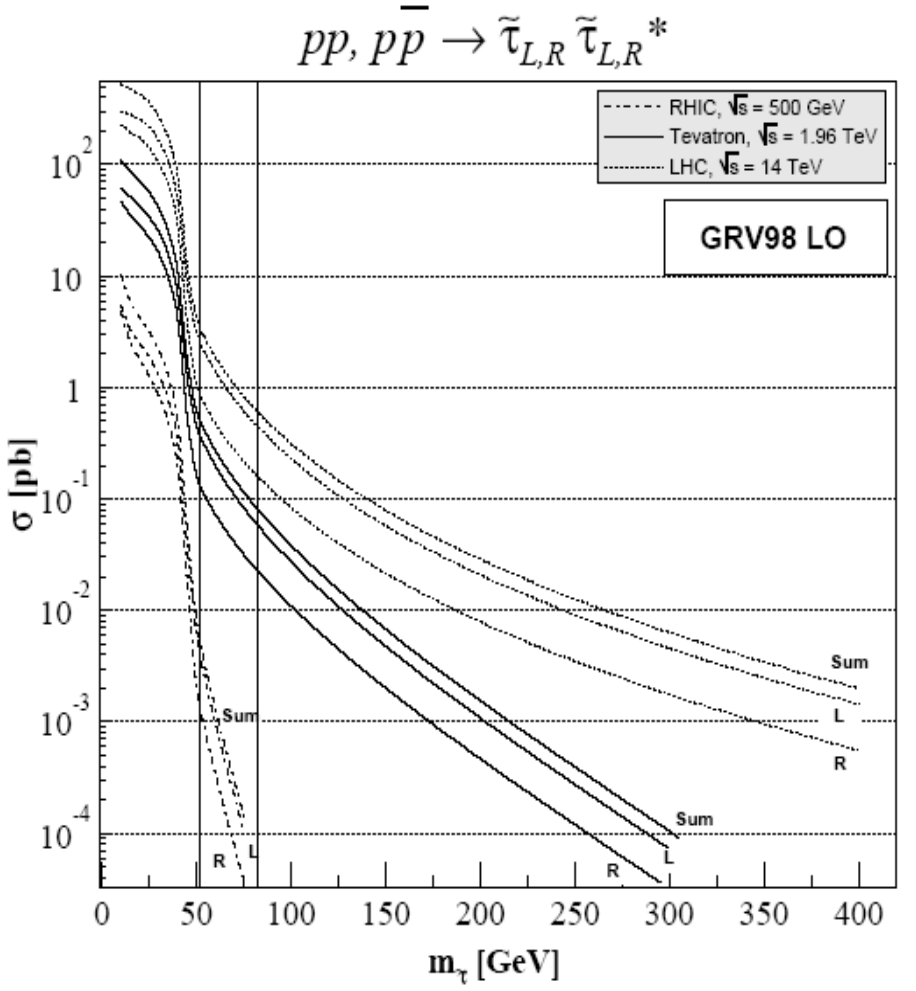
- Unpolarised cross sections well known (both LO and NLO):
  - LO : S.Dawson, E.Eichten and C.Quigg, PRD **31** (1985) 1581
  - LO : H.Baer, C.Chen, F.Paige and X.Tata, PRD **49** (1994) 3283
  - NLO : H.Baer, B.W.Harris and M.H.Reno, PRD **57** (1998) 5871
  - NLO : W.Beenakker, M.Klasen, M.Krämer, T.Plehn, M.Spira and P.M.Zerwas, PRL **83** (1999) 3780

  (NLO enhances LO by ~ 35% at Tevatron and ~20% at LHC
  --> extended discovery reach)
- Polarised cross sections
  - Discrimination between new physics signal and SM background
  - Old paper for old colliders:

    P.Chiappetta, J.Soffer and P.Taxil, PLB **162** (1985) 192
  - No mixing (important, especially for the lightest slepton : $\tilde{\tau}$)

Verify and extend previous polarized calculations, including mixing effects relevant for third generation sleptons

Hadronic cross sections



- $\tilde{\tau}_L$ and $\tilde{\tau}_R$ supposed degenerate in mass (no mixing here)
- **LHC** : visible in the entire mass range
- **Tevatron** : visible in a restricted mass range
- **RHIC** : difficult !
- **Background** : σ ~10 nb (3 to 6 orders of magnitude higher)

Spin asymmetry

- **Introduction of the mixing angle θ**

  (Mass eigenstates $\tilde{\tau}_1$ and $\tilde{\tau}_2$)

- **Cross sections**

  - $\sigma = \dfrac{\sigma_{1,1} + \sigma_{1,-1} + \sigma_{-1,1} + \sigma_{-1,-1}}{4}$

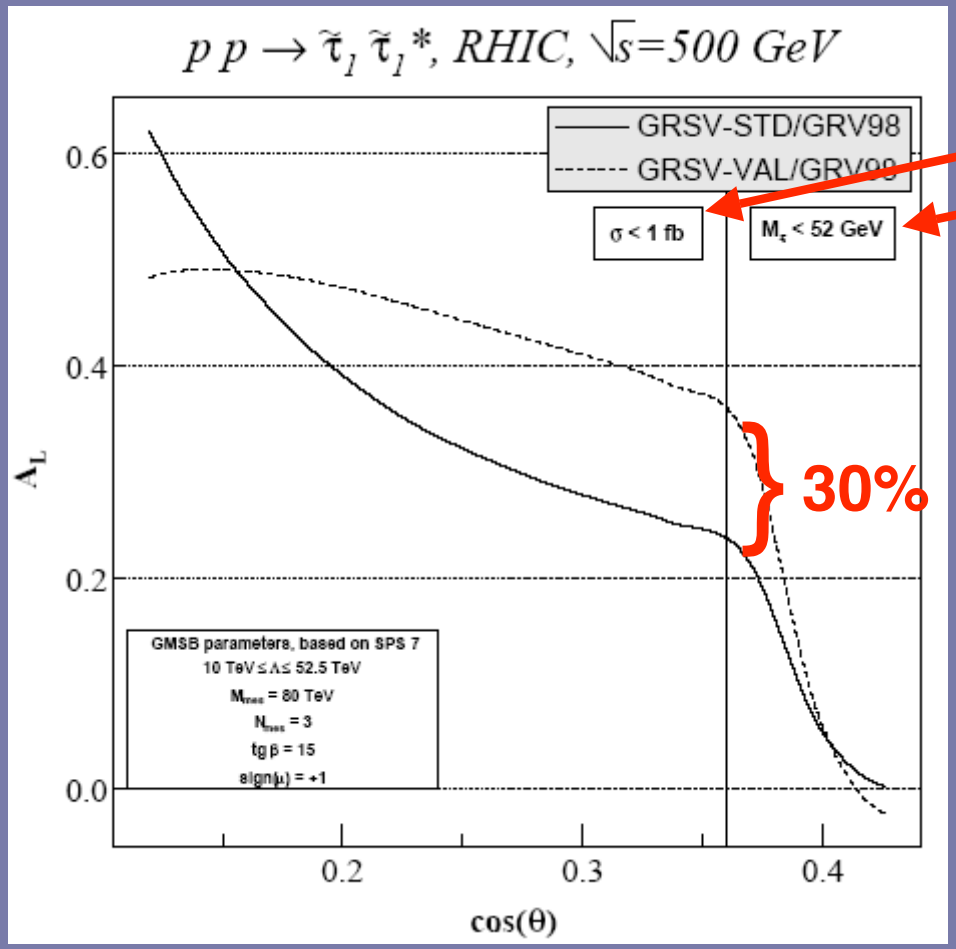
  - $\Delta\sigma_L = \dfrac{(\sigma_{1,1} + \sigma_{1,-1}) - (\sigma_{-1,1} + \sigma_{-1,-1})}{4}$ *and* $\Delta\sigma_{LL} = \dfrac{(\sigma_{1,1} + \sigma_{-1,-1}) - (\sigma_{1,-1} + \sigma_{-1,1})}{4}$

  - $A_{LL} = \dfrac{\Delta\sigma_{LL}}{\sigma} = -1$ *and* $A_L = \dfrac{\Delta\sigma_L}{\sigma}$ (no photon contribution here)

- Polarised PDF used : **GRSV2000LO** (standard and valence)

  M. Glück, E. Reya, M. Stratmann and W. Vogelsang, PRD **63** (2001) 094005

Spin Asymmetry @ RHIC

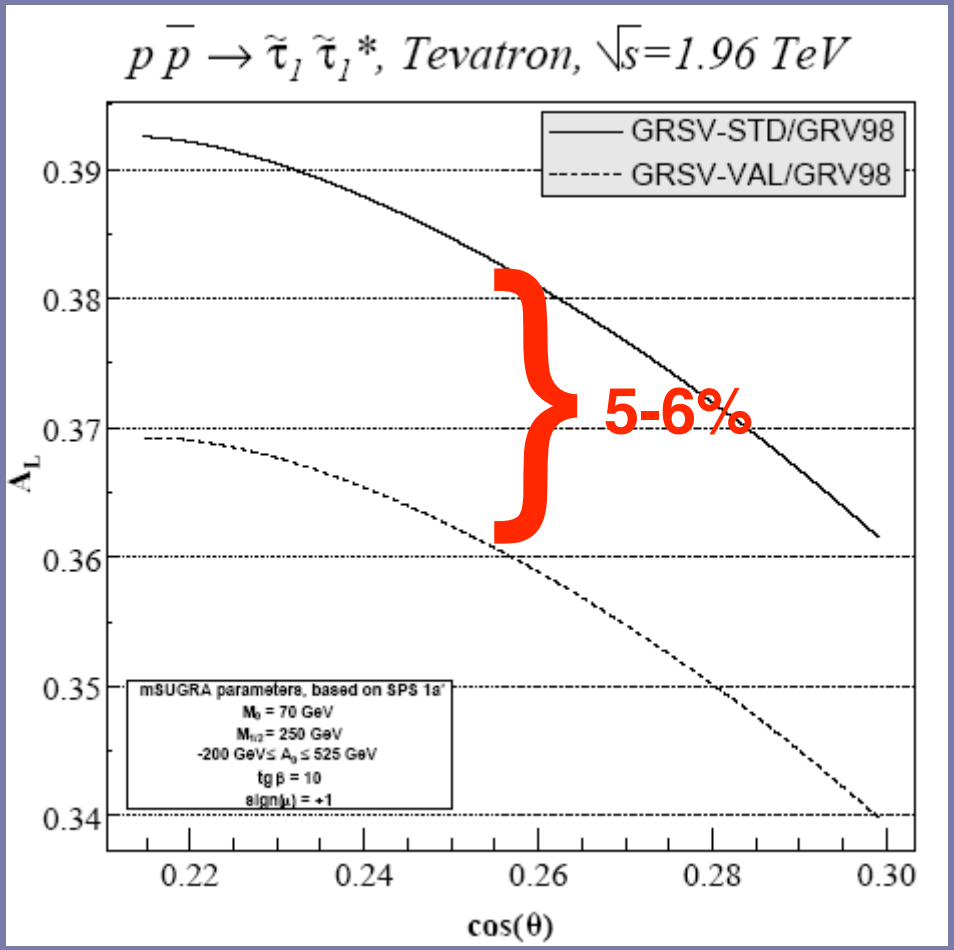


- **Only a small area of interest :**
  - Invisible cross section
  - Mass exclusion domain (LEP)
  - Physical constraints on SUSY parameters
- **Large PDF uncertainties** (large Bjorken-x)
- **Sensitive to the mixing: constraints on SUSY parameters?**
- **Background: A_L = –0.1 … –0.04** (after invariant mass cut at $\hat{s}/2$ ≈ 52 GeV)

--> **Discrimination SUSY/SM**

Scenario: GMSB SPS7 (lightest $\tilde{\tau}_1$)

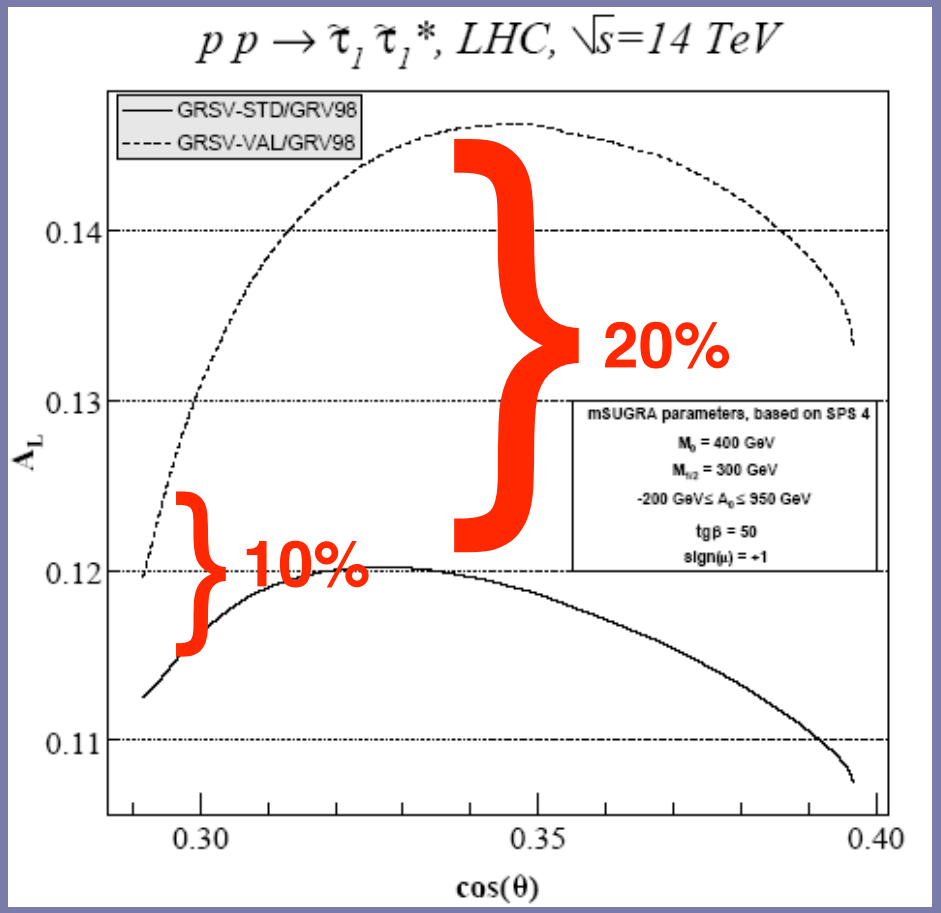
Spin Asymmetry @ Tevatron



- **Physical constraints on SUSY parameters**
  (cos θ from 0.21 to 0.30)
- **Small PDF dependence**
  (well known Bjorken-x range)
- **Sensitive to the mixing:**
  Constraints on SUSY parameters?
- **Background: A_L = –0.09 … –0.08**
  (after invariant mass cut)
  --> Discrimination SUSY/SM

Scenario: mSUGRA SPS1a' (standard choice)

Spin Asymmetry @ LHC



- **Physical constraints on SUSY parameters**
  (cos θ is going from 0.29 to 0.40)
- **Large PDF uncertainties**
  (small Bjorken-x)
- **Sensitive to the mixing:**
  Constraints on SUSY parameters?
- **Background: A_L = –0.025 … –0.015**
  (after invariant mass cut)

--> **Discrimination SUSY/SM**

Scenario: mSUGRA SPS4 (allows for heavy $\tilde{\tau}_1$)

Squark pair production

- **Stop and sbottom sectors of MSSM :**
  - **Lightest** particles of the squark sector in most SUSY scenarios
  - Large Yukawa coupling between Higgs and heavy quarks
    ⟹ **Large mixing** for the mass eigenstates
  - **Non-diagonal and mixed** squark pair production could provide constraints on SUSY parameters, mixing angles or SUSY CKM matrix
  - **We calculated squared helicity amplitudes for diagonal, non-diagonal and mixed squark pair production at hadron colliders**

Squark pair production

- **Diagonal pair production :**
  - ***QCD*** : ***qq*** channel and ***gg*** channel
  - Unpolarised result:

    W.Beenakker, M.Krämer, T.Plehn, M.Spira, P.M.Zerwas, Nucl.Phys. B515 (1998) 3
  - Polarised result:

    T.Gehrmann, D.Maître, D.Wyler, Nucl.Phys.B703 (2004) 147

    --> Extended to include squark mixing effects!
- **Non-diagonal pair production :**
  - ***QCD : gg*** channel (tree level: t-channel gluino exchange)
    - Unpolarised result: 1-loop level: **we added sbottom loop contribution**

      W.Beenakker, M.Krämer, T.Plehn, M.Spira, P.M.Zerwas, Nucl.Phys. B515 (1998) 3
    - Polarised result:

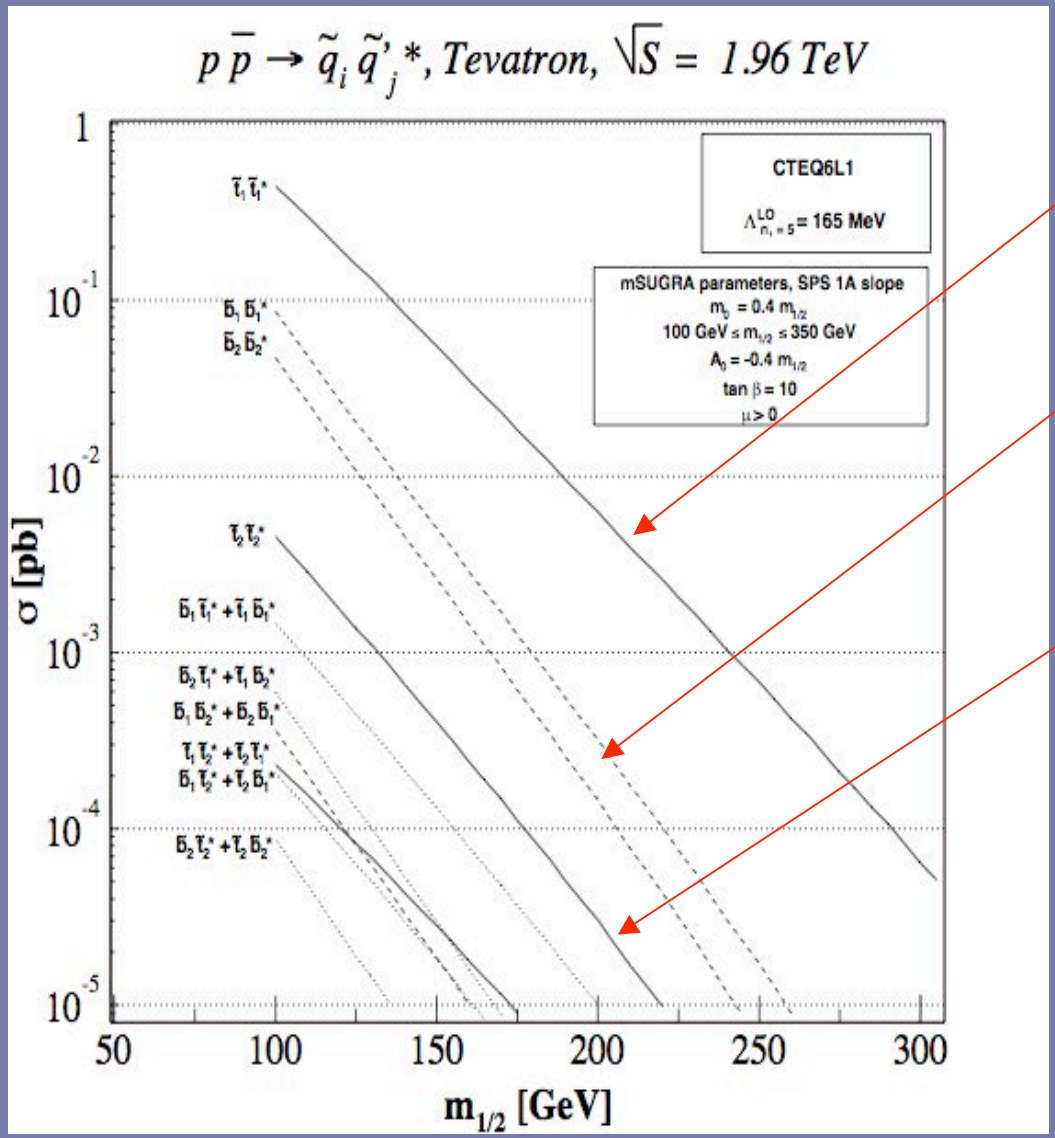
$$A_{LL} = 1$$
$$A_L = 0$$

  - ***Electroweak : qq*** channel (via s-channel Z + t-channel neutralino exchanges)
    - Unpolarised result: **-->first time calculation!**
    - Polarised :

$$A_{LL} = -1$$
$$A_L = -\frac{L_q^2 - R_q^2}{L_q^2 + R_q^2}$$

--> Independent of the mixing angle (unfortunately)
- **Mixed pair production :**
  - ***Electroweak***: ***qq*** channel (via W exchange) **-->first time calculation!**

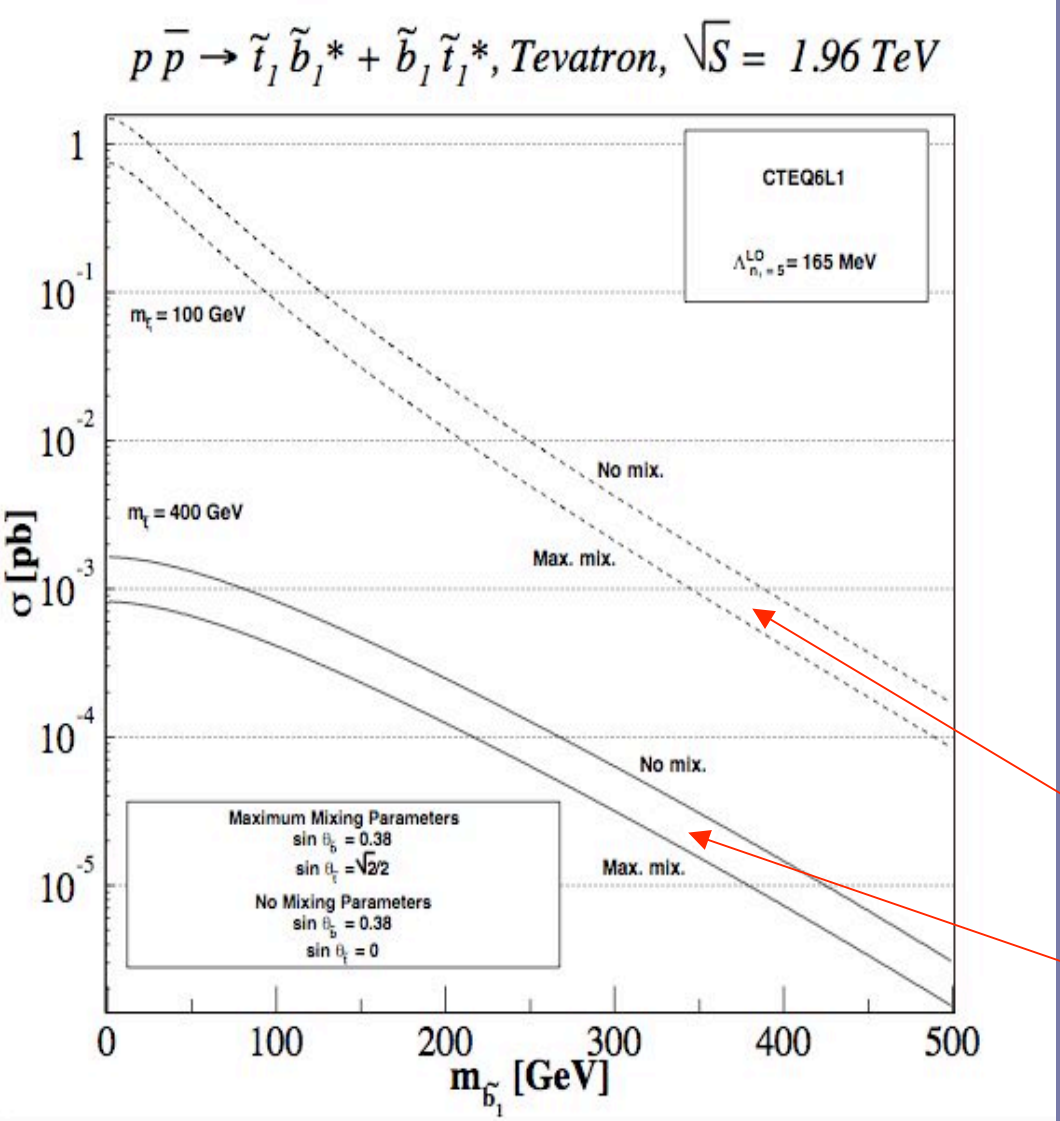
Tevatron - All processes



- Only diagonal production of lighter stop pair visible in the full region
- Diagonal sbottom pair production visible in the region $m_{1/2} < 225$ GeV
- Non-diagonal and mixed pair production visible only if $m_{1/2} \sim 100$ GeV
- As expected, qq annihilation is dominant with respect to gg channel (at most 15% of total cross section)

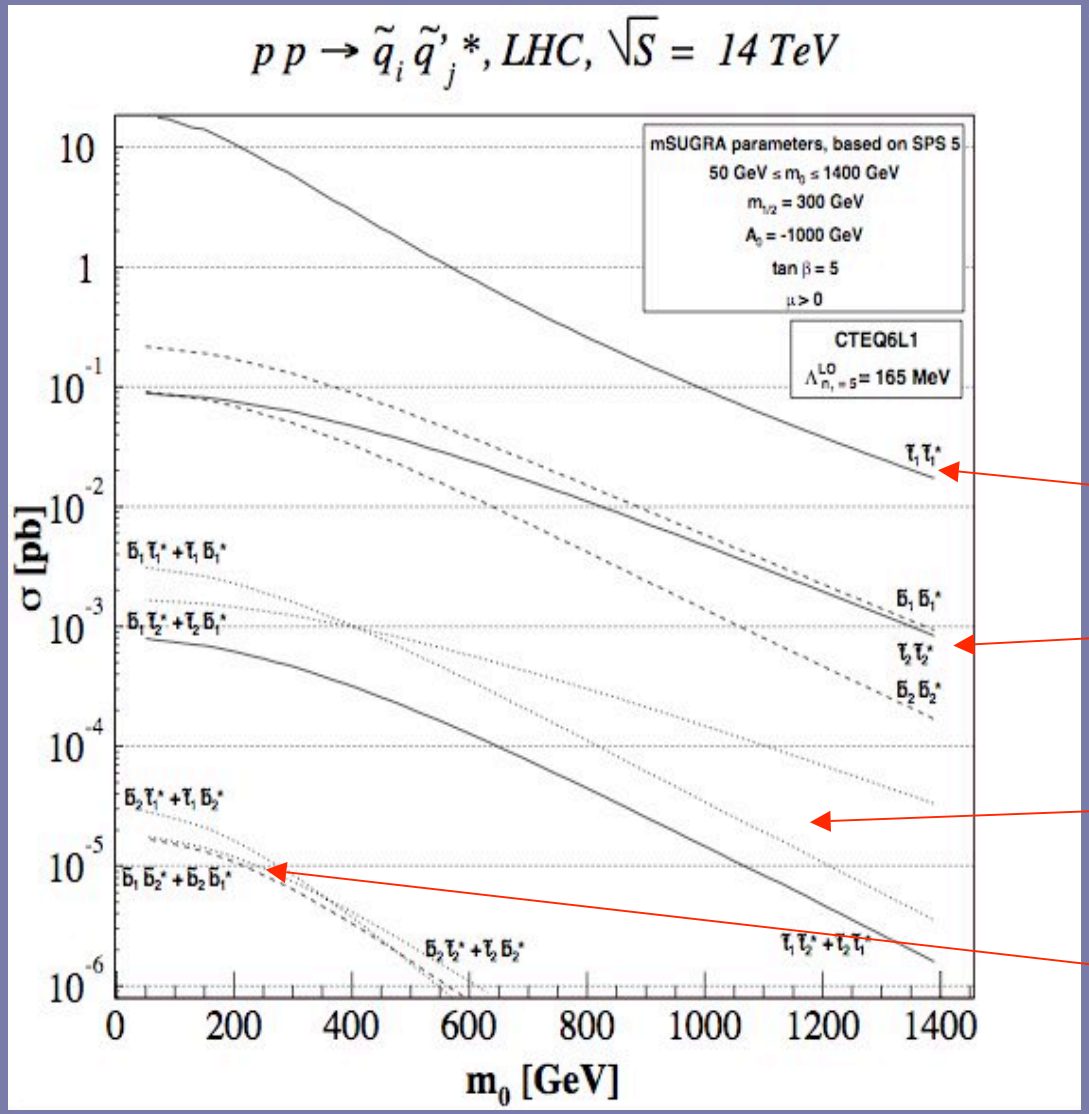
Scenario: mSUGRA SPS1a (standard choice)

Tevatron - Decoupled sbottom



- Fixed $\sin\theta_b$=0.38 (reduced Z coupling, not W)
- $0 < \sin\theta_t < 1/\sqrt{2}$ (no mixing and maximum mixing values for stops)
- Bands of small (constant) width --> small dependence on stop mixing angle (sbottom mass)
- Two different values for stop mass:
  - For m_t=100 GeV, we can exclude m_b < 500 GeV
  - For m_t=400 GeV, we can exclude m_b < 250 GeV

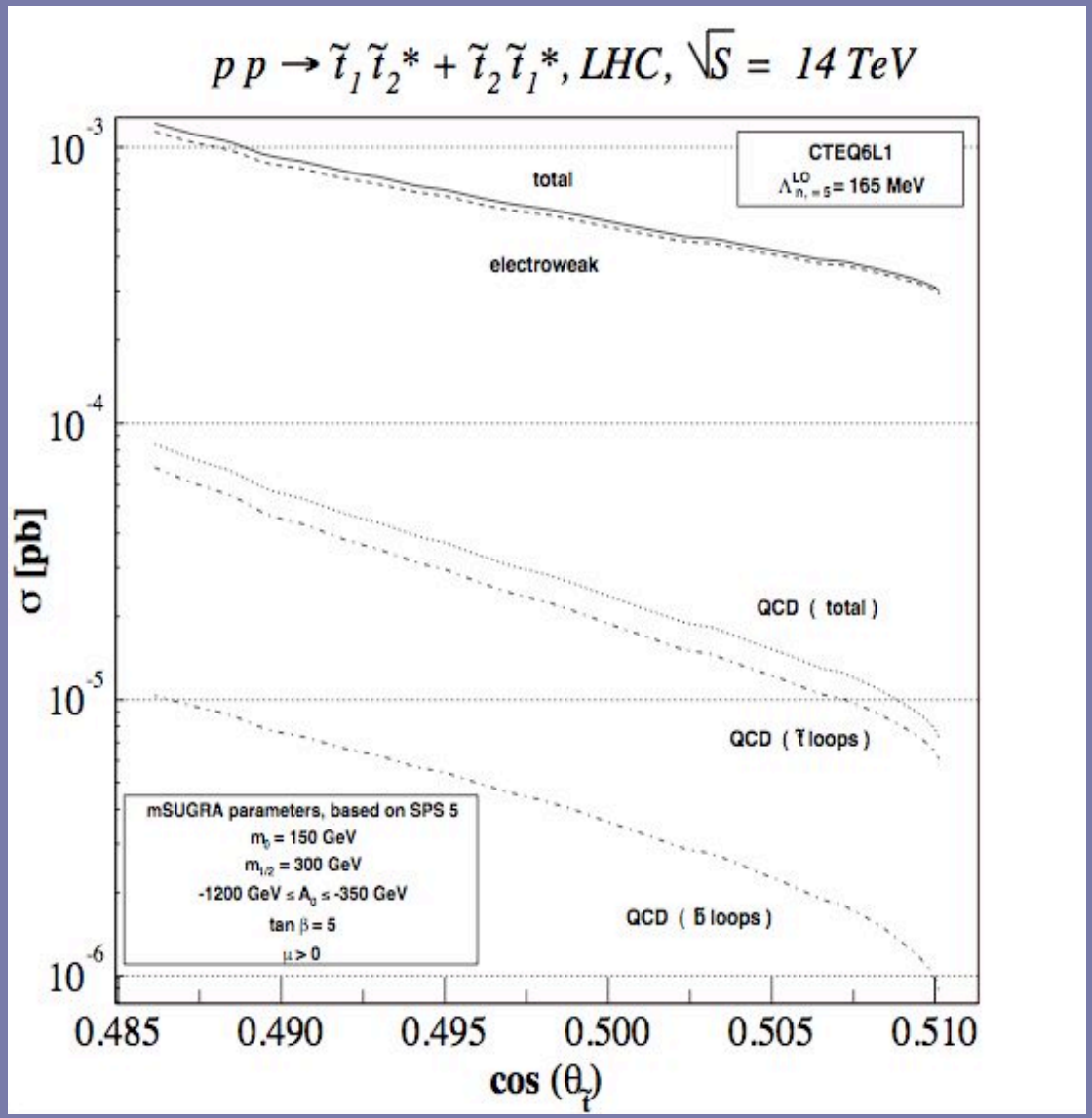
LHC - All processes



- Enough luminosity to detect all possible pair productions
- Hierarchy of different pair production is clearly visible:
  1. Diagonal production of lighter stop
  2. Diagonal production of heavier stop and sbottom
  3. Charged and neutral EW production of pairs with at least 1 light squark
  4. Charged and neutral EW production of heavier squarks (if m_0<600 GeV)

Scenario: mSUGRA SPS5 (allows for large mixing)

LHC - QCD vs. EW contributions



Scenario: mSUGRA SPS5 (allows for large mixing)

- Non-diagonal stop production only
- EW contribution: very large (more than 90% of total cross section)
- QCD contribution:
  - stop and sbottom loops
  - sbottom loops ~ 1 order of magnitude less than stop loops (mixing effects $\propto m_q$!)
  - gluino exchange requires in addition top quark and gluino propagators in the loop --> highly suppressed !
- Small mixing angle dependence: constraints on SUSY parameters ?

Conclusions

- **Slepton pair production:**
  - Differentiation of SM/SUSY processes for all 3 colliders through asymmetry measurements
  - More severe constraints on SUSY parameters ?
    - Tevatron : small PDF uncertainties --> reliable
    - LHC, RHIC : large PDF uncertainties --> more difficult
- **Squark pair production:**
  - Computation of squared helicity amplitudes for diagonal, non-diagonal and mixed squark production at hadron colliders
  - Inclusion of (dominant) EW contributions $O(\alpha^2)$ as well as strong $O(\alpha^4_s)$ processes
  - Numerical studies show that non-diagonal and mixed production can be studied at LHC, possibly allowing for constraints on SUSY masses and mixing angles
  - Mixed stop-sbottom production may allow for confirmation or exclusion of light sbottom scenarios at Tevatron