Single top-quark production by direct supersymmetric FCNC at the LHC

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J.G., W. Hollik, J. Solà, S. Peñaranda, hep-ph/0601218

Outline

- Minimal Supersymmetric Standard Model $\bigoplus$ flavour mixing mass terms in the Left-Left sector

MSSM without mixing terms

- Assuming Alignment at $\mu_0 \sim \Lambda$ $\Rightarrow$ RGE generates unalignment at $\mu_0 \sim 100\,\mathrm{GeV}$ in the LL sector

  M.J. Duncan, **Nucl. Phys. B** 221, 285 (1993)

- Assuming Alignment: $\Gamma(\tilde{t} \to c\chi^0)$ is divergent (!)

  K.Hikasa, M.Kobayashi **Phys. Rev. D** 36, 724 (1987);

  G.Jahn, ITP-Karlsruhe Diplomarbeit (1998)

- One-loop FCNC: $H^\pm$, $\chi^\pm$

With flavour mixing terms

- giving up Alignment
  - $\delta_{ij} = m_{ij}^2/(\tilde{m}_i\tilde{m}_j)$ $i \neq j$
  - δ_{ij} constrained (mass insertion approximation)

$$\begin{array}{lll} \delta_{12} & \lesssim & .1\,\sqrt{m_{\tilde{u}}\,m_{\tilde{c}}}/500\,\mathrm{GeV} \\ \delta_{13} & \lesssim & .098\,\sqrt{m_{\tilde{u}}\,m_{\tilde{t}}}/500\,\mathrm{GeV} \\ \delta_{23} & \lesssim & 8.2\,m_{\tilde{c}}\,m_{\tilde{t}}/(500\,\mathrm{GeV})^2 \end{array}$$

  F. Gabbiani *et. al.* **NPB** 477, 321 (1996)

  - $B(b \to s\gamma)$: additional contstraints

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$$

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  - $B(b \to s\gamma)$: additional contstraints

Contstraints

- The Flavour-Changing terms are communicated from the up- to the down-sector by CKM

  e.g. M.Misiak, S.Pokorski, J. Rosiek, Adv.Ser.Direct.High Energy Phys.15:795-828,1998, hep-ph/9703442

$$\begin{array}{ccccc} (M^d_{LL})^2 & = CKM^\dagger \times & (M^u_{LL})^2 & \times CKM \\ \not\parallel & & \not\parallel & \\ (M^d_{LL})^2_{\mathrm{DIAG}} & & \mathbb{1}\,\tilde{M}^2 & \end{array}$$

  $\Rightarrow$ top-charm FCNC are constrained by $B(b \to s\gamma)$

- $BR^{exp}(b \to s\gamma) = (3.3 \pm 0.4) \times 10^{-4}$

  CLEO+ALEPH+BELLE+BABAR $\to$ Particle Data Group

- $BR^{SM}(b \to s\gamma) = (3.29 \pm 0.33) \times 10^{-4}$

  K. Chetyrkin, M. Misiak, M. Münz, Phys. Lett. B **400** (1997) 206 [Erratum-ibid. B **425** (1998) 414], hep-ph/9612313;
  A. J. Buras, A. Kwiatkowski and N. Pott, Phys. Lett. B **414** (1997) 157 [Erratum-ibid. B **434** (1998) 459], hep-ph/9707482;
  A. L. Kagan and M. Neubert, Eur. Phys. J. C **7** (1999) 5, hep-ph/9805303;

  $+ \cdots$

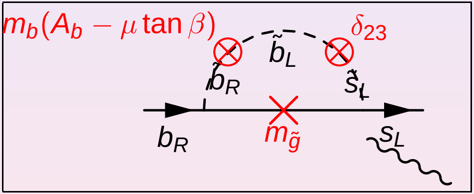
$B(b \to s\gamma)$

Borzumati **ZPC63** (1994) 291, hep-ph/9310212; Borzumati, Greub, Hurt, Wyler, **PRD62** (2000) 075005, hep-ph/9911245.

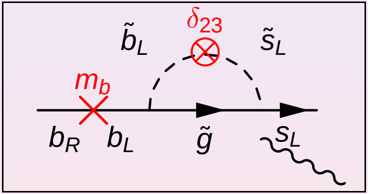
[True for Left-Left mixing only!]

- Relevant Wilson operator in the effective theory: chirality flip

$$O_7 = \frac{e}{16\pi^2}\, m_b\, (\bar{s}_L\, \sigma^{\mu\nu}\, b_R)\, F_{\mu\nu}$$



Leading, Double insertion



Sub-Leading, Single insertion

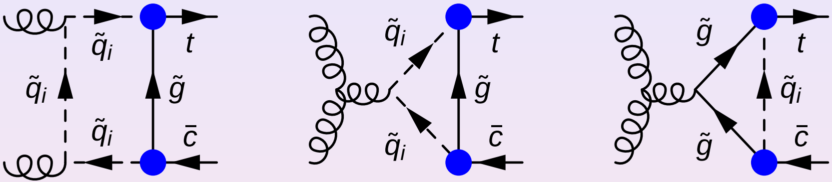
- The Feynman Amplitude:

$$A^{SUSY-QCD}(b \to s\gamma) \sim \delta_{23} \frac{m_b(A_b - \mu \tan\beta)}{M^2_{SUSY}} \times \frac{1}{m_{\tilde{g}}}$$

Similar to $t \to cg$: J.G., J. Solà, **NPB562** (1999) 3, hep-ph/9906268

Direct FCNC production @ LHC

$pp[gg] \longrightarrow tc$



- Previous computation

  J.J. Lui *et al.*, **Nucl. Phys. B** 705 (2005) 3, hep-ph/0404099

  - No complete parameter analysis
  - Main effects from Left-Right mixing

- Newer computation

  G. Eilam, M. Frank, I. Turan, hep-ph/0601253 (Jan. 30)

  - Very recent
  - Mostly agree in the computation

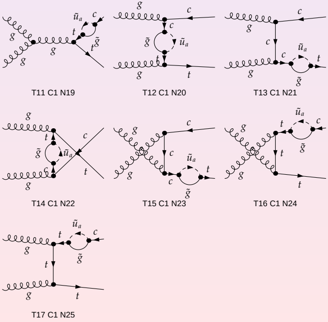
- Computation: FeynArts, FormCalc, LoopTools

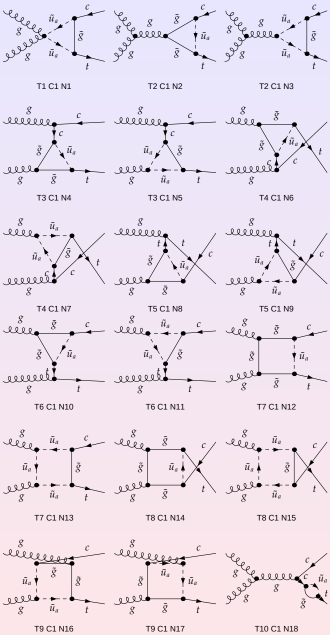
  T. Hahn, W. Hollik, J. I. Illana and S. Peñaranda,

  hep-ph/0512315; http://www.feynarts.de

- Leading terms from Left-Left sector: similar structure to $b \to s\gamma$

$$A(gg \to t\bar{c}) \sim \delta_{23} \frac{m_t(A_t - \mu/\tan\beta)}{M_{SUSY}^2} \times \frac{1}{m_{\tilde{g}}}$$





Comparison with Higgs FCNC

S. Béjar, J.G., J. Solà, JHEP 0510 (2005) 113, hep-ph/0508043;hep-ph/0601191.

- Take parameters of maximum $\sigma(pp \to h \to t\,c)$: Large M_{SUSY} and $m_{\tilde{g}}$

$$\sigma(pp \to H^0 \to t\bar{c} + \bar{t}c) \simeq 2.5 \times 10^{-3}\ \text{pb} \quad [\tan\beta = 5]$$

- $M_{SUSY} \simeq m_{\tilde{g}} \simeq 880\,\text{GeV}$, $\mu \simeq -700\,\text{GeV}$, $\delta_{23} \simeq 10^{-0.1} \simeq 0.79$

$$\boxed{\sigma(pp[gg] \to t\bar{c}) \simeq 1.8 \times 10^{-3}\ \text{pb}}$$

$\Rightarrow$ Same order of magnitude as Higgs-mediated FCNC

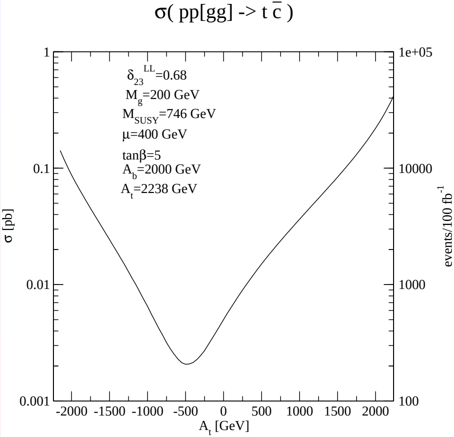
Maximum rates

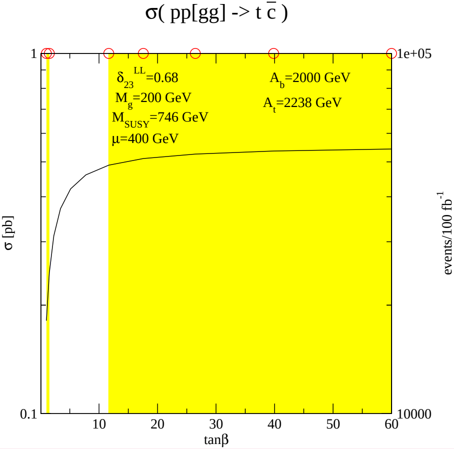
$$A(gg \to t\bar{c}) \sim \delta_{23} \frac{m_t(A_t - \mu/\tan\beta)}{M^2_{SUSY}} \times \frac{1}{m_{\tilde{g}}}$$

- Large rates $\Longrightarrow$ Large δ_{23} and Large $(A_t - \mu/\tan\beta)$
  - $\Rightarrow$ high sensitivity to A_t
  - $\Rightarrow$ Left-Left flavour mixing $\bigoplus$ Left-Right stop mixing $\Longrightarrow$ similar to Left-Right flavour mixing
    - $\Rightarrow$ Similar analysis of $B(b \to s\gamma)$
- Analytical approximation to maximization:
  - Find the maximum value of: $\delta_{23} \times (A_t - \mu/\tan\beta)$
  - Physical mass constraints: upper limit on: $\delta_{23}^2 + (A_t - \mu/\tan\beta)^2$
  - Non-colour breaking vauca: additional contstraints on A_t
  - Low value of M_{SUSY}
  - Similar analytical expressions to find the contstraints from $B(b \to s\gamma)$

$\Rightarrow$ $\tan\beta = 5$, $\mu = 400\,\mathrm{GeV}$, $A_t = 2238\,\mathrm{GeV}$, $A_b = 2000\,\mathrm{GeV}$,

$\Rightarrow$ $\delta_{23} = 0.68$, $M_{SUSY} = 750\,\mathrm{GeV}$, low $m_{\tilde{g}}$


σ(pp[gg] -> t c̄)
δ23LL=0.68
Mg=200 GeV
MSUSY=746 GeV
μ=400 GeV
tanβ=5
Ab=2000 GeV
At=2238 GeV
σ [pb]
events/100 fb-1
At [GeV]
1
0.1
0.01
0.001
1e+05
10000
1000
100
-2000 -1500 -1000 -500 0 500 1000 1500 2000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σ [pb]
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1
0.1
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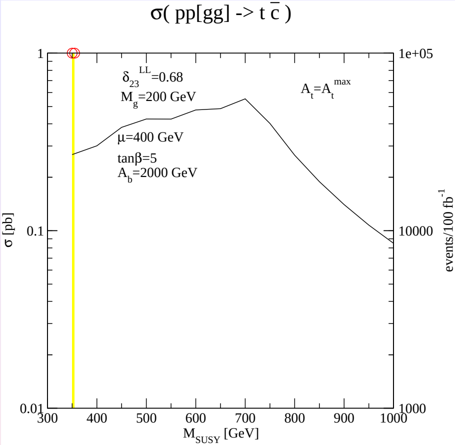
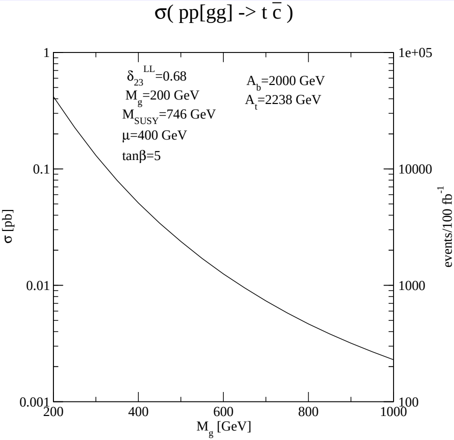
10000
10 20 30 40 50 60





- $\Rightarrow$ Cross-sections $\sim$ 0.5 pb possible
- $\Rightarrow$ $\sim 100,000$ events$/100$ fb^{-1} for $t\bar{c}$ processes
- $\Rightarrow$ Only with Left-Left intergenerational mixing

Conclusions & Outlook

- Direct production is competitive to Higgs-mediated processes
  - $\Rightarrow$ **Direct process can give much larger rates**

Parameter	Higgs-mediated	Direct production
$\tan\beta$	Decreases fast	insensitive
M_{A^0}	Decreases fast	insensitive
M_{SUSY}	Prefers large	Decreases fast
A_t	insensitive	very sensitive
δ_{23}	Moderate	Moderate

- Reproduce previous results
- Left-Left flavour mixing gives large rates
- Analytical approximation to maximization
  - Maximal possible value of $\delta_{23} \times (A_t - \mu/\tan\beta)$
- Low sensitivity to $\tan\beta$

- $\sigma(pp[gg] \to t\bar{c}) \sim 0.5$ pb $\Longrightarrow 10^5$ events$/100$ fb^{-1} $[m_{\tilde{g}} \sim 200\,\mathrm{GeV}]$
  - SM: $\sigma^{SM}(pp[gg] \to t\bar{c} + \bar{t}c) \sim 7 \times 10^{-7}$ pb
    $\Rightarrow$ 7 orders of magnitude larger than SM!
  - 2–3 orders of magnitude larger than Higgs-mediated
- Experimental issues:
  - Signal: single top-quark + light c-jet
    $\Rightarrow$ Evidence of new physics
    - Direct production in SUSY
    - Higgs-mediated production in SUSY
      S. Béjar, J.G., J. Solà, JHEP 0510 (2005) 113, hep-ph/0508043;hep-ph/0601191.
    - Higgs-mediated production in 2HDM
      S. Béjar talk. S. Béjar, J.G., J. Solà, **NPB675** (2003) 270, hep-ph/0307144.
  - single top quark @ LHC: $t + W$, $t + b$, $\ldots$: ~ 300 pb
- Request: can be separated from backgrounds?

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Finding the maximum

- Define: $\delta_{33}^{LR} = \frac{m_t(A_t - \mu/\tan\beta)}{M_{SUSY}^2}$
- $\sigma = (\delta_{23})^2(\delta_{33}^{LR})^2$ =constant defines an hyperbola in the $\delta_{23} - \delta_{33}^{LR}$ plane
- Mass (approximation):

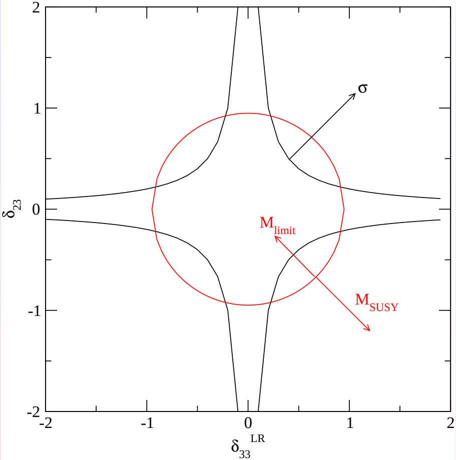
$$m_{\tilde{q}}^2 = M_{SUSY}^2 \left(\begin{array}{c|ccc} & c_L & t_L & t_R \\ \hline c_L & 1 & \delta_{23} & 0 \\ t_L & \delta_{23} & 1 & \delta_{33}^{LR} \\ t_R & 0 & \delta_{33}^{LR} & 1 \end{array} \right)$$

- lightest mass:

$$m_q^2 = M_{SUSY}^2 \left(1 - \sqrt{(\delta_{23})^2 + (\delta_{33}^{LR})^2} \right) > M_{\text{limit}}^2 \; .$$

Experimental limit defines a circle in $\delta_{23} - \delta_{33}^{LR}$ plane:

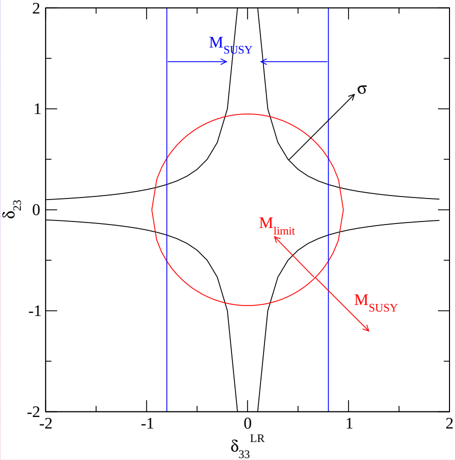
$$(\delta_{23})^2 + (\delta_{33}^{LR})^2 < \left(1 - \frac{M_l^2}{M_{SUSY}^2} \right)^2 \equiv R^2$$



Maximum at:

$$\delta_{23} = \delta_{33}^{LR} = \frac{R}{\sqrt{2}} = \frac{1}{\sqrt{2}}\left(1 - \frac{M_l^2}{M_{SUSY}^2}\right) \to \frac{1}{\sqrt{2}}\ .$$

$M_{SUSY} \to \infty$



non-colour breaking vacua:
$|A_t| \sim< 3M_{SUSY}$

$$|\delta_{33}^{LR}| <\sim \frac{3m_t}{M_{SUSY}}$$

The maximum is obtained when:

- the diagonal: $\delta_{23} = \delta_{33}^{LR}$
- the limit mass circle
- the limit from A_t

cross in a single point

Exact equations

$$
\begin{aligned}
\delta_{23} &= \delta_{33}^{LR} \\
\delta_{33}^{LR} &= \frac{m_t\,(3M_{SUSY} - \mu/\tan\beta)}{M_{SUSY}^2} \\
(\delta_{23})^2 + (\delta_{33}^{LR})^2 &= \left(1 - \frac{M_l^2}{M_{SUSY}^2}\right)^2
\end{aligned}
$$

setting:

$m_t = 175\,\mathrm{GeV}$, $M_l = 150\,\mathrm{GeV}$, $\mu = 400\,\mathrm{GeV}$, $\tan\beta = 5$ (by $b \to s\gamma$)

$$
\begin{aligned}
\delta_{33}^{LR} = \delta_{23} &= 0.678525 \\
M_{SUSY} &= 746.082\,\mathrm{GeV} \\
A_t &= 2238.25\,\mathrm{GeV}
\end{aligned}
$$