Effective squarks/chargino/neutralino couplings: MadGraph Implementation

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Eur. Phys. J. C (2013) 73: 2368, arXiv:1209.5214 [hep-ph]

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V CPAN Days

Squark decay into charginos/neutralinos (*inos*) in the MSSM

- In this work we focussed on squark-quark-*inos* vertexes and decays like $\tilde{q} \to q' \tilde{\chi}^{0,\pm}$
- if squarks exist, some of their decay channel into *inos* are always open.
- Previous computations: Full one-loop QCD and EW corrections are available, for instance
  - S. Kraml et al., Phys. Lett. B386 (1996) 175, hep-ph/9605412.
  - A. Djouadi, W. Hollik, C. Jünger, Phys. Rev. D55 (1997) 6975, hep-ph/9609419.
  - J. Guasch, Ph.D. Thesis, UAB 1999.
  - J. Guasch, W. Hollik, J. Solà, Phys.Lett. B437(1998)88, hep-ph/9802329, JHEP 0210 (2002) 040, hep-ph/0207364
  - J. Guasch, S. Peñaranda, R. Sánchez-Florit, JHEP 0904:016,2009, arXiv:0812.1114

$\Longrightarrow$ large corrections

- To compare with experiments we need precision predictions AND good approximations.
- The best situation arises if these approximations are simple to introduce into simulation codes.

PRESENT WORK

A. A., J. Guasch, S. Peñaranda and R. Sanchez-Florit. Eur. Phys. J. C (2013) 73: 2368

- Recompute the QCD corrections to squarks decays at the one-loop level and all leading corrections proportional to $\log m_{\tilde{g}}$
- Full one-loop corrections were calculated using FeynArts/FormCalc/LoopTools packages

  FeynArts/FormCalc/LoopTools : http://www.feynarts.de/
- We implement in MadGraph the effective approach of squarks interactions with charginos and neutralinos (*inos*)

  MadGraph : http://madgraph.hep.uiuc.edu/
- We cross checked the agreement of the partial decay widths of squark decaying into *inos* between both computation methods.
- For the first time we compute the cross-section of processes $pp \to \tilde{t} \to q\bar{q}'\chi\chi'$ where $\chi = \chi_1^0$, $\chi' = \chi_2^0(\chi_1^{\pm})$, and $q(q') = t(b)$ using our effective approximation of squarks interactions.

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Details of $\tilde{\chi}\tilde{f}f$ lagrangian

fermion-sfermion-chargino/neutralino interaction term in the Lagrangian reads

$$\mathcal{L}_{\chi\tilde{f}f'} = \sum_{a=1,2}\sum_{r}\mathcal{L}_{\chi_r\tilde{f}_a f'} + \text{ h.c. },$$
$$\mathcal{L}_{\chi_r\tilde{f}_a f'} = -g\,\tilde{f}_a^*\bar{\chi}_r\left(A^{(f)}_{+ar}P_L + A^{(f)}_{-ar}P_R\right)f' \;.$$

$r = 1,2$ for charginos ($\tilde{\chi}^{\pm}_r$) and $r = 1...4$ for neutralinos ($\tilde{\chi}^0_r$)

$$A^{(t)}_{+ai} = R^{(t)}_{a1}V^*_{i1} - \lambda_t R^{(t)}_{a2}V^*_{i2}\,,$$
$$A^{(t)}_{-ai} = -\lambda_b R^{(t)}_{a1}U_{i2}$$

check full list of couplings in back-up slide 26.

- U, V: complex matrices diagonalizing chargino mass-matrix
- R: sfermion rotation matrix
- $\lambda_t = m_t/(\sqrt{2}M_W \sin\beta)$ and $\lambda_b = m_b/(\sqrt{2}M_W \cos\beta)$: Yukawa couplings for the top and bottom quarks.

Effective Description of Yukawa interactions

M. Carena et al., Nucl. Phys. B577, 88-120 (2000),arXiv:hep-ph/9912516

We assume the resummation of all $\tan^n \beta$ terms with:

$$\lambda_b^{eff} \equiv \frac{m_b^{eff}}{v_1} \equiv \frac{m_b(Q)}{v_1(1+\Delta m_b)}, \qquad \lambda_t^{eff} \equiv \frac{m_t^{eff}}{v_2} \equiv \frac{m_t(Q)}{v_2(1+\Delta m_t)}$$

where $m_q(Q)$ is the running quark mass and Δm_q is the finite threshold correction. The SUSY-QCD contributions to Δm_q are

$$\begin{aligned} \Delta m_b^{SQCD} &= \frac{2\alpha_s}{3\pi} m_{\tilde{g}} \mu \tan\beta \, I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}}), \\ \Delta m_t^{SQCD} &= \frac{2\alpha_s}{3\pi} m_{\tilde{g}} \frac{\mu}{\tan\beta} \, I(m_{\tilde{t}_1}, m_{\tilde{t}_2}, m_{\tilde{g}}) \end{aligned} \tag{1}$$

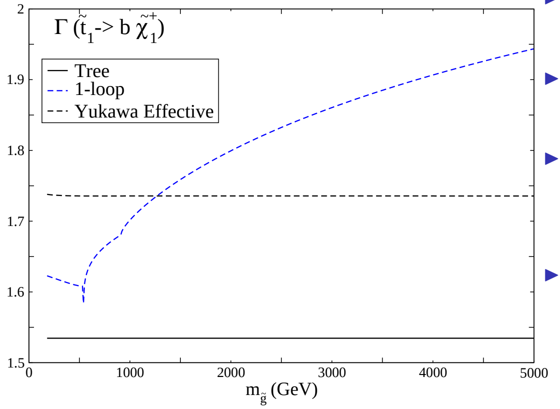
$$I(a,b,c) = \frac{a^2b^2\ln(a^2/b^2) + b^2c^2\ln(b^2/c^2) + a^2c^2\ln(c^2/a^2)}{(a^2-b^2)(b^2-c^2)(a^2-c^2)}$$

To calculate the partial decay width, $\Gamma[\tilde{q} \to q'\chi]$, in squark-*inos* couplings, we substitute

$$\lambda_{t,b} \to \lambda_{b,t}^{eff} \implies \Gamma^{Effective} = \Gamma^{Tree}(\lambda_{b,t}^{eff})$$

Numerical Analysis: Effective Lagrangian Description

arXiv:0812.1114 [hep-ph] and 1209.5214 [hep-ph]



- Tree-level calculation does not depend on $m_{\tilde{g}}$
- one-loop calculation has a $\log m_{\tilde{g}}$ dependence with $m_{\tilde{g}}$
- Notice there is no $\log m_{\tilde{g}}$ terms arising for the Yukawa Effective description.
- We consider an effective theory with the inclusion of both terms: $\log m_{\tilde{g}}$ and $\lambda_{b,t}^{eff}$

Yukawa Effective Description: New Approach

A new effective description: Renormalization Group Analysis to the couplings in $\mathcal{L}_{\chi\tilde{f}f'}$

Jaume Guasch, Siannah Peñaranda, Raül Sánchez-Florit, JHEP 0904:016,2009, arXiv:0812.1114

$A(Q) = A(m_{\tilde{g}}) \left(\frac{\alpha_s(Q)}{\alpha_s(m_{\tilde{g}})}\right)^{2/\beta_0}$ where β_0: QCD β-functions

$A(m_{\tilde{g}}) = H(m_{\tilde{g}}) + G(m_{\tilde{g}})$ (i.e. $A^{(t)}_{+ai} = -\lambda_t R^{(t)}_{a2} V^*_{i2} + R^{(t)}_{a1} V^*_{i1}$)

$H(m_{\tilde{g}})$: Higgs coupling($\lambda_{t,b}$)
run as the quark mass does
$H(Q) \simeq \lambda(Q) \left(1 + \frac{\alpha_s}{\pi} \log \frac{Q}{m_{\tilde{g}}}\right)$

$G(m_{\tilde{g}})$: gauge coupling(g)
doesn't run due to QCD
$G(Q) \simeq g \left(1 - \frac{\alpha_s}{\pi} \log \frac{Q}{m_{\tilde{g}}}\right)$

In squark-*inos* couplings where λ_t and λ_b appear, we substitute

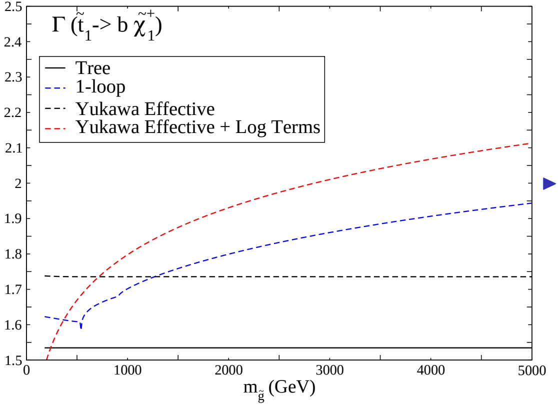
$$\lambda_{t,b} \to \tilde{\lambda}^{eff}_{b,t} = \lambda^{eff}_{b,t}\left(1 + \frac{\alpha_s}{\pi} \log \frac{Q}{m_{\tilde{g}}}\right) \text{ and } g \to g\left(1 - \frac{\alpha_s}{\pi} \log \frac{Q}{m_{\tilde{g}}}\right)$$

$$\Gamma^{Effective} = \Gamma^{Tree}(\tilde{\lambda}^{eff}_{b,t}, g^{eff})$$

Numerical Analysis: Improved Yukawa Effective Description

A. A., J. Guasch, S. Peñaranda and R. Sanchez-Florit. Eur. Phys. J. C (2013) 73: 2368 arXiv:1209.5214 [hep-ph]

J. Guasch, S. Peñaranda and R. Sanchez-Florit. JHEP 0904:016,2009, arXiv:0812.1114



$$Tree \to \Gamma^{Tree}(m_q),\ 1 - Loop \to \Gamma^{1-loop}$$

$$Yukawa\ Effective \to \Gamma^{Tree}(m_q^{eff})$$

$$Yukawa\ Effective\ +\ Log\ Terms :\to \Gamma^{Tree}(\tilde{\lambda}^{eff}_{b,t}, g^{eff})$$

- After the inclusion of $\log m_{\tilde{g}}$ terms in the new effective description we recover the $\log m_{\tilde{g}}$ of the one-loop calculation.

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Monte Carlo Tool

- Monte Carlo Tool
  - MadGraph automatically generates Fortran code to calculate arbitrary tree-level helicity amplitudes for a given model.
  - Implemented models are the SM, Higgs effective couplings, MSSM, the general 2HDM, and several other models, and there is an easy-to-use interface for implementing model extensions.
  - The MadGraph package includes other tools as well: a Pythia module (parton shower); PGS and Delphes (detector simulation), a Root event analysis package, plotting packages, interfaces to other generators and file converters.
  - At present, November 2013, there is a huge effort on including NLO corrections, for instance **aMC@NLO** is being developed under MadGraph 5 framework (`http://amcatnlo.web.cern.ch/amcatnlo/`).

MSSM in MadGraph

- MSSM original implementation has all couplings at tree level.
- We modified all squark-quark-chargino/neutralino couplings substituting $\lambda_{t,b} \to \lambda_{b,t}^{eff} \left(1 + \frac{\alpha_S}{\pi} \log \frac{Q}{m_{\tilde{g}}}\right)$ and $g \to g \left(1 - \frac{\alpha_S}{\pi} \log \frac{Q}{m_{\tilde{g}}}\right)$
- We checked the agreement between FeynArts/FormCalc/LoopTools and MadGraph computations of $\Gamma(\tilde{q} \to q\chi)$ for all third generation squarks at tree and effective level.
- Relative deviations are well below 0.2%

Numerical Analysis

- We consider regions of SUSY parameters where the gluino decay channel of squarks is closed ($m_{\tilde{q}} < m_q + m_{\tilde{g}}$)
- In all numerical analysis only $\tan\beta$ and $m_{\tilde{g}}$ were varied
  - $m_{\tilde{g}}$ between [400, 5000] GeV
  - $\tan\beta$ between [3, 50]
- SM Inputs: $m_t = 172\,\text{GeV}$, $m_b = 4.7\,\text{GeV}$, $\alpha_s(M_Z) = 0.1172$, $s_W^2 = 0.221$, $M_Z = 91.1875\,\text{GeV}$, $1/\alpha = 137.035989$.
- MSSM parameters:
  - Special conditions(*Def* in plots)

Jaume Guasch, Siannah Peñaranda, Raül Sánchez-Florit, JHEP 0904:016,2009, arXiv:0812.1114

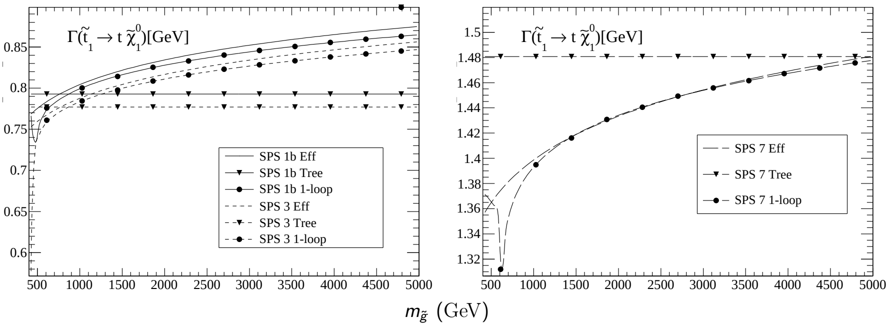
$$\tan\beta = 5,\ \mu = 300\,\text{GeV},\ M = 200\,\text{GeV},\ M_{\tilde{f}_L} = 800\,\text{GeV},$$
$$m_{\tilde{g}} = 3000\,\text{GeV},\ M_{SUSY} \equiv M_{\tilde{f}_R} = 1000\,\text{GeV}\ ,$$
$$A_t = A_b = 2M_{\tilde{f}_L} + \mu/\tan\beta = 1660\,\text{GeV}$$

  - SPS (masses are given in GeV)

SPS	$m_{\tilde{g}}$	μ	$\tan\beta$	M_2	A_t	A_b	$M_{\tilde{f}_L}$	$M_{\tilde{b}_R}$	$M_{\tilde{t}_R}$
1b	916.1	495.6	30	310.9	-729.3	-987.4	762.5	780.3	670.7
3	914.3	508.6	10	311.4	-733.5	-1042.2	760.7	785.6	661.2
7	926.0	300	15	326.8	-319.4	-350.5	836.3	826.9	780.1

Numerical Analysis: Partial Decay Widths

$\tilde{t}_1$ partial decay width as a function of $m_{\tilde{g}}$ for SPS 1b, 3 (left column) and 7 (right column)



- Largest corrections on Γ will show up in higgsino-type coupling in the studied vertex. This depends on the SUSY parameter choice: i.e. in SPS 7, $\tilde{\chi}^{0(+)}_{1,2(1)}$ have mostly higgsino-type couplings to the top-squark.
- Dips found in the one loop calculation of Γ set the applicability limits of the approximation ($m_{\tilde{g}} > 800\,\text{GeV}$)

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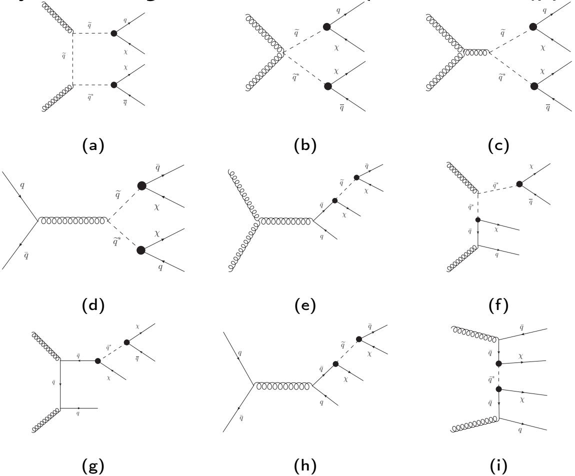
Cross section Calculation: $\sigma(pp \to [\tilde{t}_i] \to q\tilde{\chi}\bar{q}\tilde{\chi})$ at 14 TeV

- For the first time we compute the cross-section of processes $pp \to \tilde{t} \to q\bar{q}'\chi\chi'$:
  - $pp \to [\tilde{t}_1] \to (b\chi_1^0)(\bar{t}\chi_1^0)$
  - $pp \to [\tilde{t}_2] \to (b\chi_1^0)(\bar{t}\chi_1^0)$
  - $pp \to [\tilde{t}_1] \to (b\chi_2^0)(\bar{t}\chi_1^0)$
  - $pp \to [\tilde{t}_2] \to (b\chi_2^0)(\bar{t}\chi_1^0)$
  - $pp \to [\tilde{t}_1] \to (b\chi_1^+)(\bar{t}\chi_1^0)$
  - $pp \to [\tilde{t}_2] \to (b\chi_1^+)(\bar{t}\chi_1^0)$
- $t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$: searches of heavy quarks + missing energy
- $t\bar{t}\tilde{\chi}_2^0\tilde{\chi}_1^0$, $t\bar{b}\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$: searches of heavy quarks+leptons+missing energy
- $q\tilde{q}\chi$ coupling scale (Q) fixed at the physical mass of the squark, $\tilde{t}_i$

Cross section: Feynman Diagrams

Feynman diagrams for the computation of $\sigma(pp \to [\tilde{q}_i] \to (q\tilde{\chi})(\bar{q}\tilde{\chi}))$

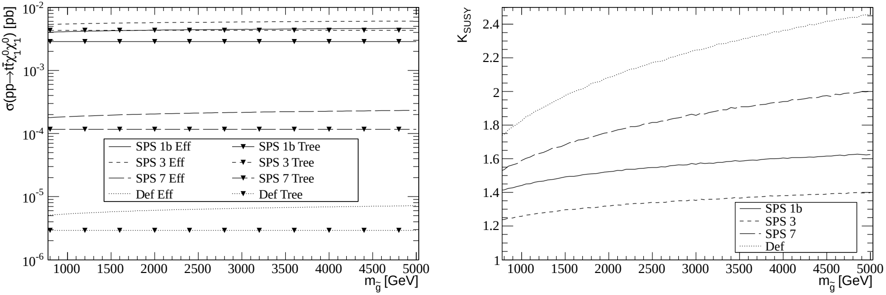


(a)-(d) double resonant diagrams ($\sigma(pp \to \tilde{q}_a \tilde{q}_a^* \to (q\chi)(\bar{q}\chi))$), **(e)-(h)** single resonant diagrams, **(i)** non-resonant diagram.

- One-loop effects, our effective theory, are accounted at marked vertexes.
- Notice: depending on the SUSY parameterization, diagram (i) may become the dominant one (only one squark propagator).

Numerical Analysis: Cross section and K_{SUSY} Plots

$\sigma(pp \to [\tilde{t}_1] \to t\tilde{\chi}_1^0 \bar{t}\tilde{\chi}_1^0)$ and $K_{SUSY} = \sigma_{eff}/\sigma_{tree}$, as a function of $m_{\tilde{g}}$



- $\sigma(pp \to [\tilde{t}_1] \to t\tilde{\chi}_1^0 \bar{t}\tilde{\chi}_1^0)$ ranges from 10^{-6} to $10^{-2} pb$
- $K_{SUSY} > 2$ for *Def* parameterization with $m_{\tilde{g}} > 1.6\,TeV$ ($m_{\tilde{t}_1} = 720$ GeV, $\tan\beta = 5$)
- $\log m_{\tilde{g}}$ terms of the effective approximation are noticeable for all SUSY parameterization studied ($m_{\tilde{g}} \gtrsim 1\,TeV$ and $m_{\tilde{q}} > 600$ GeV), giving a $K_{SUSY} > 1.2$.

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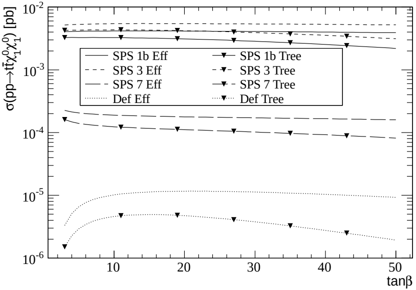
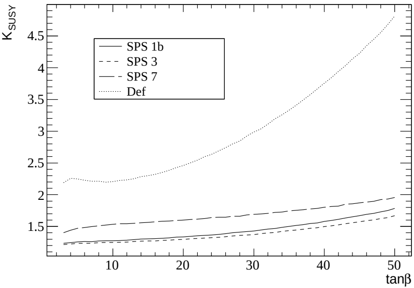
$\sigma(pp \to [\tilde{t}_1] \to t\tilde{\chi}_1^0\bar{t}\tilde{\chi}_1^0)$ and $K_{SUSY} = \sigma_{eff}/\sigma_{tree}$, as a function of $\tan\beta$

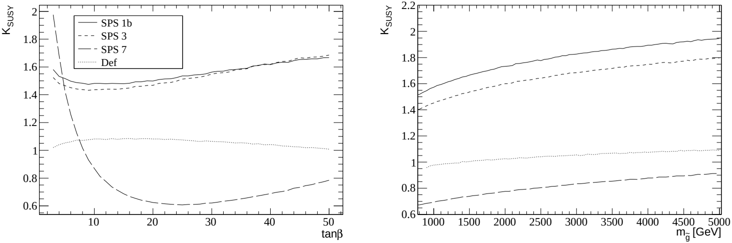




- $\sigma(pp \to [\tilde{t}_1] \to t\tilde{\chi}_1^0\bar{t}\tilde{\chi}_1^0)$ ranges from 10^{-6} to $10^{-2} pb$
- For certain SUSY parameters the effective approximation gave a considerable increase to the cross section for instance, the *Def* parameterization ($m_{\tilde{g}} = 3\,TeV$, $m_{\tilde{t}_1} = 720\,\text{GeV}$) at $\tan\beta = 50$ $K_{SUSY} = 4.5$.
- For the SPS the increase is noticeable as well, K_{SUSY} always above 1. $K_{SUSY} \approx 2$ for SPS 7 at $\tan\beta = 50$.

Numerical Analysis: K_{SUSY} Plots

K_{SUSY} plots for $\sigma(pp \to [\tilde{t}_2] \to b\tilde{\chi}_1^+ \bar{t}\tilde{\chi}_1^0)$, as a function of $m_{\tilde{g}}$ and $\tan\beta$



- $\sigma(pp \to [\tilde{t}_2] \to b\tilde{\chi}_1^+ \bar{t}\tilde{\chi}_1^0)$ ranges from 10^{-6} to $10^{-4} pb$
- SPS 7 (long dashed line) shows how the inclusion of radiative corrections may decrease the cross section as well. In this case due to the large shrink found for the partial decay width of the $\tilde{t}_2 \to b\tilde{\chi}_1^+$ as a function of $m_{\tilde{g}}$ and $\tan\beta$
- For the rest of the SUSY parameterizations the effective approximation yield a net increase of the cross section ($K_{SUSY} > 1$ for $m_{\tilde{g}} > 1 TeV$ in SPS 1b and 3 and special conditions).

Numerical Analysis: Cross section Resume Table

Effects of the radiative corrections to production cross-sections in the effective approximation, K_{SUSY}, for SPS1b, SPS3, SPS7 and *Def* SUSY parameters choice at different $\tan\beta$.

K_{SUSY}	SPS7 $m_{\tilde{g}} = 926.0$ GeV			*Def* $m_{\tilde{g}} = 1$ TeV			*Def* $m_{\tilde{g}} = 3$ TeV		
	10	30	50	10	30	50	10	30	50
$pp \to [\tilde{t}_1] \to (t\chi_1^0)(\bar{t}\chi_1^0)$	1.53	1.69	1.95	1.83	2.46	3.91	2.20	2.98	4.81
$pp \to [\tilde{t}_1] \to (t\chi_2^0)(\bar{t}\chi_1^0)$	1.27	1.38	1.60	1.66	2.32	3.71	1.94	2.70	4.40
$pp \to [\tilde{t}_1] \to (b\chi_1^+)(\bar{t}\chi_1^0)$	1.24	1.25	1.27	1.77	1.62	1.62	2.15	1.93	2.00
$pp \to [\tilde{t}_2] \to (t\chi_1^0)(\bar{t}\chi_1^0)$	1.28	2.00	3.31	1.20	1.28	1.40	1.37	1.47	1.62
$pp \to [\tilde{t}_2] \to (t\chi_2^0)(\bar{t}\chi_1^0)$	1.06	1.57	2.59	1.05	1.11	1.22	1.15	1.22	1.34
$pp \to [\tilde{t}_2] \to (b\chi_1^+)(\bar{t}\chi_1^0)$	0.87	0.62	0.78	0.99	0.98	0.93	1.08	1.06	1.01

	SPS1b $m_{\tilde{g}} = 916.1$ GeV			SPS3 $m_{\tilde{g}} = 914.3$ GeV		
$pp \to [\tilde{t}_1] \to (t\chi_1^0)(\bar{t}\chi_1^0)$	1.27	1.42	1.78	1.24	1.37	1.66
$pp \to [\tilde{t}_1] \to (t\chi_2^0)(\bar{t}\chi_1^0)$	1.16	1.30	1.63	1.13	1.25	1.52
$pp \to [\tilde{t}_1] \to (b\chi_1^+)(\bar{t}\chi_1^0)$	1.14	1.22	1.37	1.11	1.18	1.29
$pp \to [\tilde{t}_2] \to (t\chi_1^0)(\bar{t}\chi_1^0)$	1.46	1.86	2.66	1.42	1.81	2.58
$pp \to [\tilde{t}_2] \to (t\chi_2^0)(\bar{t}\chi_1^0)$	1.45	1.88	2.69	1.42	1.84	2.62
$pp \to [\tilde{t}_2] \to (b\chi_1^+)(\bar{t}\chi_1^0)$	1.48	1.56	1.66	1.44	1.55	1.69

Conclusions

- We analyze the $\log m_{\tilde{g}}$ resummation in the effective approximation of squarks interactions, which correctly describes the one-loop behavior of $\Gamma(\tilde{q} \to q\chi)$; and the changes it introduces in $\sigma(pp \to [\tilde{t}_i] \to q\tilde{\chi}\bar{q}\tilde{\chi})$ computation.
- We successfully implement the effective description of squarks interactions into MSSM of MadGraph .
  - easy to use in Monte Carlo simulation.
  - the code is available under request
- The radiative corrections to $\tilde{q}q\tilde{\chi}$ vertexes are noticeable
- $\sigma(pp \to [\tilde{t}_i] \to q\tilde{\chi}\bar{q}\tilde{\chi})$ (q: third generation, $\tilde{\chi} = \tilde{\chi}^{0(\pm)}_{1,2(1)}$) ranges from 10^{-6} to $10^{-2} pb$
- In general, we obtain an increase in $\sigma_{eff}(pp \to [\tilde{t}_i] \to q\tilde{\chi}\bar{q}\tilde{\chi})$ with respect to tree level calculations for most of the analyzed SUSY parameter space.
- the improved MSSM in MadGraph should be very helpful for experimentalist at the LHC.

Outlook

- Systematic studies: PDF, kinematical cuts, etc.
- We plan to generalize these results to other SUSY processes containing $\tilde{q}q\tilde{\chi}$ couplings

THANKS!!!!

Back Up

Tree Level: Dynamics

$$
\begin{aligned}
A^{(t)}_{+ai} &= R^{(t)}_{a1} V^*_{i1} - \lambda_t R^{(t)}_{a2} V^*_{i2}\,, \\
A^{(t)}_{-ai} &= -\lambda_b R^{(t)}_{a1} U_{i2}\,, \\
A^{(t)}_{+a\alpha} &= \frac{1}{\sqrt{2}} \left(R^{(t)}_{a1} \left(N^*_{\alpha 2} + Y_L t_W N^*_{\alpha 1} \right) + \sqrt{2} \lambda_t R^{(t)}_{a2} N^*_{\alpha 4} \right)\,, \\
A^{(t)}_{-a\alpha} &= \frac{1}{\sqrt{2}} \left(\sqrt{2} \lambda_t R^{(t)}_{a1} N_{\alpha 4} - Y^t_R t_W R^{(t)}_{a2} N_{\alpha 1} \right)\,, \\
A^{(b)}_{+ai} &= R^{(b)}_{a1} U^*_{i1} - \lambda_b R^{(b)}_{a2} U^*_{i2}\,, \\
A^{(b)}_{-ai} &= -\lambda_t R^{(b)}_{a1} V_{i2}\,, \\
A^{(b)}_{+a\alpha} &= -\frac{1}{\sqrt{2}} \left(R^{(b)}_{a1} \left(N^*_{\alpha 2} - Y_L t_W N^*_{\alpha 1} \right) - \sqrt{2} \lambda_b R^{(b)}_{a2} N^*_{\alpha 3} \right)\,, \\
A^{(b)}_{-a\alpha} &= -\frac{1}{\sqrt{2}} \left(-\sqrt{2} \lambda_b R^{(b)}_{a1} N_{\alpha 3} + Y^b_R t_W R^{(b)}_{a2} N_{\alpha 1} \right)
\end{aligned}
$$

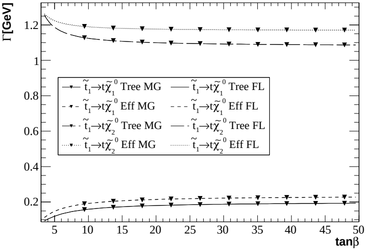
U, V and N: complex matrices diagonalizing chargino and neutralino mass-matrices
R: Sfermion rotation matrix

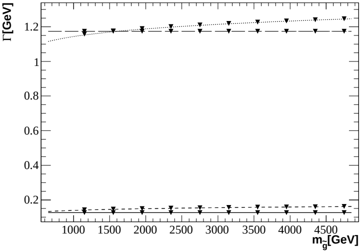
$\lambda_t = m_t/(\sqrt{2} M_W \sin\beta)$ and $\lambda_b = m_b/(\sqrt{2} M_W \cos\beta)$: Yukawa couplings normalized to the $SU(2)_L$ gauge coupling constant g for the top and bottom quarks.

Numerical Analysis: Partial Decay Widths

MadGraph and FeynArts/FormCalc/LoopTools agreement

Partial decay width of $\tilde{t}_1$ decaying into neutralinos as a function of $\tan\beta$ and $m_{\tilde{g}}$ for the special conditions of SUSY parameters ($m_{\tilde{g}} = 3\,\text{TeV},\ \tan\beta = 5$).





The agreement between both computation methods is well bellow 1%

$\delta|_{m_{\tilde{g}}} = \frac{\Gamma^{MG} - \Gamma^{FL}}{\Gamma^{FL}} \times 100 \implies$