Search for RPV Stops in Multi-jet Events

G Moultaka

L2C-Montpellier

Top-LHC France 2017, Marseille 4-5 May '17

Based partly on: arXiv:1611.05850
+ ongoing collab: PESBLADe

S Diglio, L Feligioni, GM,
R Kukla, A Calandri, N Desai, N Nguyen

Where is –Is there– (TeV) New Physics ??

Where is –Is there– (TeV) New Physics ??

- No TNP discovered so far, where contemporary paradigm expects it!

Where is –Is there– (TeV) New Physics ??

- No TNP discovered so far, where contemporary paradigm expects it!

$1 \rightarrow$ TNP realized in a more complex way? more data? different signatures? more data?

OR

Where is –Is there– (TeV) New Physics ??

- No TNP discovered so far, where contemporary paradigm expects it!

$1 \rightarrow$ TNP realized in a more complex way? more data? different signatures? more data?

OR

$2 \rightarrow$ is the paradigm *half* wrong? ...TNP there but too heavy to be discovered at present energy frontiers? indirect glimpses from "low energy" observables?

Where is –Is there– (TeV) New Physics ??

- No TNP discovered so far, where contemporary paradigm expects it!

$1 \rightarrow$ TNP realized in a more complex way? more data? different signatures? more data?

OR

$2 \rightarrow$ is the paradigm *half* wrong? ...TNP there but too heavy to be discovered at present energy frontiers? indirect glimpses from "low energy" observables?

OR

...

Where is –Is there– (TeV) New Physics ??

- No TNP discovered so far, where contemporary paradigm expects it!

$1 \rightarrow$ TNP realized in a more complex way? more data? different signatures? more data?

OR

$2 \rightarrow$ is the paradigm *half* wrong? ...TNP there but too heavy to be discovered at present energy frontiers? indirect glimpses from "low energy" observables?

OR

...

$3 \rightarrow$ is the paradigm *totally* wrong?

Where is –Is there– (TeV) New Physics ??

- No TNP discovered so far, where contemporary paradigm expects it!

$1 \rightarrow$ TNP realized in a more complex way? more data? different signatures? more data?

OR

$2 \rightarrow$ is the paradigm *half* wrong? ...TNP there but too heavy to be discovered at present energy frontiers? indirect glimpses from "low energy" observables?

OR

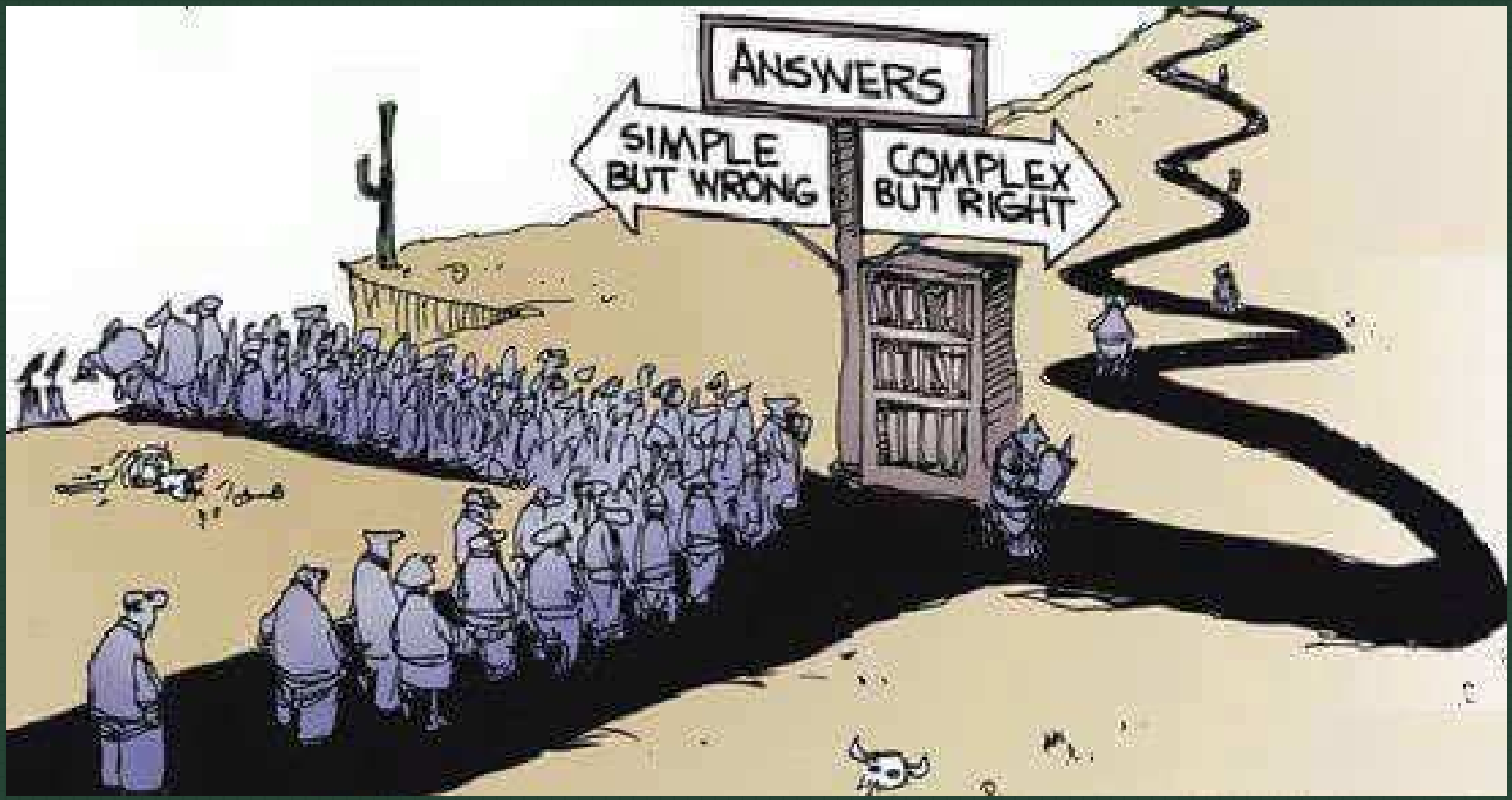
...

$3 \rightarrow$ is the paradigm *totally* wrong?

could be a double-edged razor:

Let us bet on 1:

Let us bet on 1:



RPV-MSSM

$\rightarrow$ add to the MSSM superpotential

$$W_{\not L} = \frac{1}{2}\lambda_{ijk}\hat{L}_i \cdot \hat{L}_j \, \hat{E}^c_k + \lambda'_{ijk}\hat{L}_i \cdot \hat{Q}_j \, \hat{D}^c_k + \mu_i \hat{L}_i \cdot \hat{H}_2$$

$$W_{\not B} = \frac{1}{2}\lambda''_{ijk}\hat{U}^{\alpha c}_i \hat{D}^{\beta c}_j \hat{D}^{\gamma c}_k \epsilon_{\alpha\beta\gamma}$$

$\rightarrow$ extra $\mathcal{O}(45)$ new (free) parameters!
$\rightarrow$ other sources for RPV: e.g. non-holomorphic contributions (arXiv:1502.03096)
$\rightarrow$ further (free) parameters in the soft SUSY breaking sector
$\rightarrow$ no stable SUSY particle (perhaps meta-stable).

stop pair production and decays

QCD driven: direct, $pp \to \tilde{t}\bar{\tilde{t}}$. or from gluino decays, $pp \to \tilde{g}\tilde{g}$.

$\to$ in this presentation, a simplified assumption, $m_{\tilde{g}} \gg m_{\tilde{t}}, \sigma_{\tilde{g}\tilde{g}} \ll \sigma_{\tilde{t}\bar{\tilde{t}}}$.

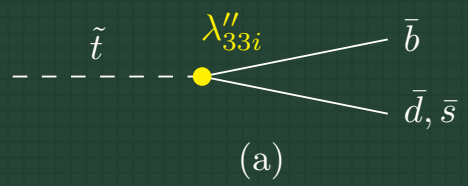
$\Rightarrow$ a working assumption: reduced fine-tuning in ensuring REWSB and a 125 GeV Higgs:

$\to$ light stop, light Higgsino-like chargino/neutralino.

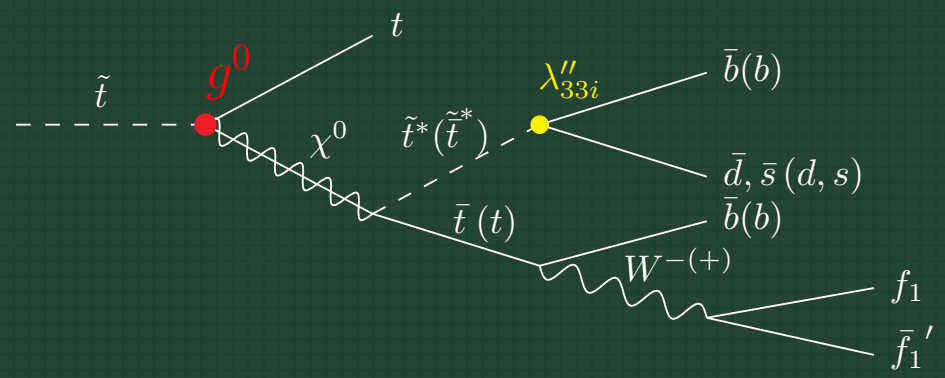
- stop MSSM-LSP
OR
- $m_{\tilde{t}} > m_{\chi^+}, m_{\chi^0}$ MSSM-LSP

$\Rightarrow$ $\lambda''_{33i} \neq 0$, $(i{=}1{,}2)$ $\to$ stop, chargino, neutralino unstable, decaying to SM particles.

Stop decay channels



(a)



If $m_{\tilde{t}} - m_{\chi^0} > m_t$

Naively

$\Gamma_{(a)} > \Gamma$

Further assumptions for this workshop

→ all MSSM susy particles decoupled from LHC except for one $\tilde{t}$, one χ^+, two χ^0.

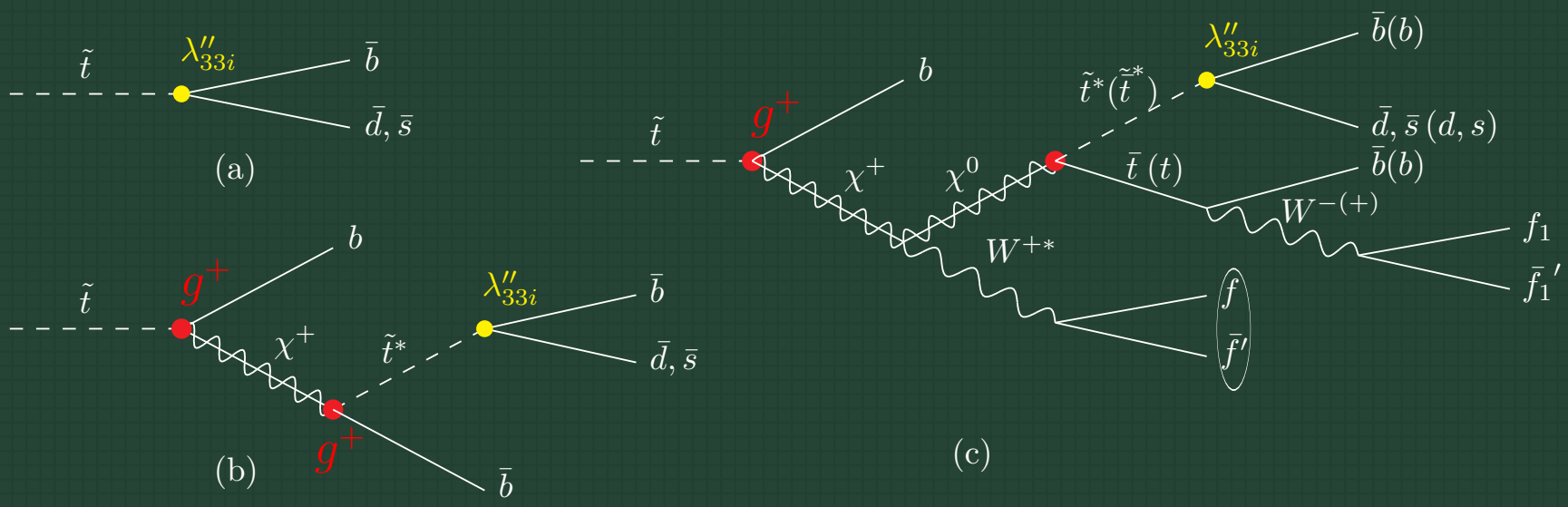
→ $m_{\tilde{t}} \gtrsim m_{\chi_2^0} \gtrsim m_{\chi^+} \gtrsim m_{\chi^0} > m_t$

$m_{\tilde{t}} - m_{\chi^0} < m_t$

$m_{\tilde{t}} - m_{\chi^+} > m_b$

→ no tops from direct stop decays! somewhat provocative for a top-LHC workshop...

Stop decay channels



Naively $\Gamma_{(a),(b),(c)} \sim \lambda''^{\,2}_{33i}$ and $\Gamma_{(a)} \gg \Gamma_{(b)} > \Gamma_{(c)}$ unless $m_{\tilde{t}} \gg m_{\chi^+}$

Usually, consider one final state in a time, assuming 100% branching ratio
$\rightarrow$ exp. limits on $\tilde{t}$ mass.

In fact, cascades and branching ratios $\rightarrow$ much different sensitivities to λ''_{33i}!

$\bar{\tilde{t}}$ \ $\tilde{t}$	$\tilde{\mathbf{t}}$-RPV	χ-RPV	RPC-like
$\tilde{\mathbf{t}}$-RPV	$2b2j$	$4b2j$	$1t3b2j$
χ-RPV		$6b2j$	$1t5b2j$
RPC-like			$2t4b2j$

$$r_1 = \frac{\Gamma_1(\tilde{t} \to \bar{b}\bar{s})}{\Gamma(\tilde{t} \to \chi^+ b)} \, , r_2 = \frac{\Gamma_1(\chi^+ \to \bar{b}\bar{s}\bar{b})}{\Gamma(\chi^+ \to \chi^0 f \bar{f}')}$$

$\bar{\tilde{t}}$ \ $\tilde{t}$	$\tilde{\mathbf{t}}$**-RPV**	$\boldsymbol{\chi}$ **-RPV**	**RPC-like**
$\tilde{\mathbf{t}}$**-RPV**	$2b2j$	$4b2j$	$1t3b2j$
$\boldsymbol{\chi}$ **-RPV**		$6b2j$	$1t5b2j$
RPC-like			$2t4b2j$

$$r_1 = \frac{\Gamma_1(\tilde{t} \to \bar{b}\bar{s})}{\Gamma(\tilde{t} \to \chi^+ b)} \, , r_2 = \frac{\Gamma_1(\chi^+ \to \bar{b}\bar{s}\bar{b})}{\Gamma(\chi^+ \to \chi^0 f \bar{f}')}$$

$\bar{\tilde{t}}$ \ $\tilde{t}$	$\tilde{\mathbf{t}}$**-RPV**	$\boldsymbol{\chi}$**-RPV**	**RPC-like**
$\tilde{\mathbf{t}}$**-RPV**	$2b2j$	$4b2j$	$1t3b2j$
$\boldsymbol{\chi}$**-RPV**		$6b2j$	$1t5b2j$
RPC-like			$2t4b2j$

NWA

$$\sigma(2b2j) \simeq \sigma_{\tilde{t}\bar{\tilde{t}}} \times \frac{r_1^2 \times (\lambda''_{33i})^4}{(1 + r_1 \times (\lambda''_{33i})^2)^2}$$

$$\sigma(4b2j) \simeq \sigma_{\tilde{t}\bar{\tilde{t}}} \times \frac{2 r_1 r_2 \times (\lambda''_{33i})^4}{(1 + r_1 \times (\lambda''_{33i})^2)^2 (1 + r_2 \times (\lambda''_{33i})^2)}$$

$$\sigma(6b2j) \simeq \sigma_{\tilde{t}\bar{\tilde{t}}} \times \frac{r_2^2 \times (\lambda''_{33i})^4}{(1 + r_1 \times (\lambda''_{33i})^2)^2 (1 + r_2 \times (\lambda''_{33i})^2)^2}$$

$$\sigma(1t5b2j) \simeq \sigma_{\tilde{t}\bar{\tilde{t}}} \times \frac{2 r_2 \times (\lambda''_{33i})^2}{(1 + r_1 \times (\lambda''_{33i})^2)^2 (1 + r_2 \times (\lambda''_{33i})^2)^2}$$

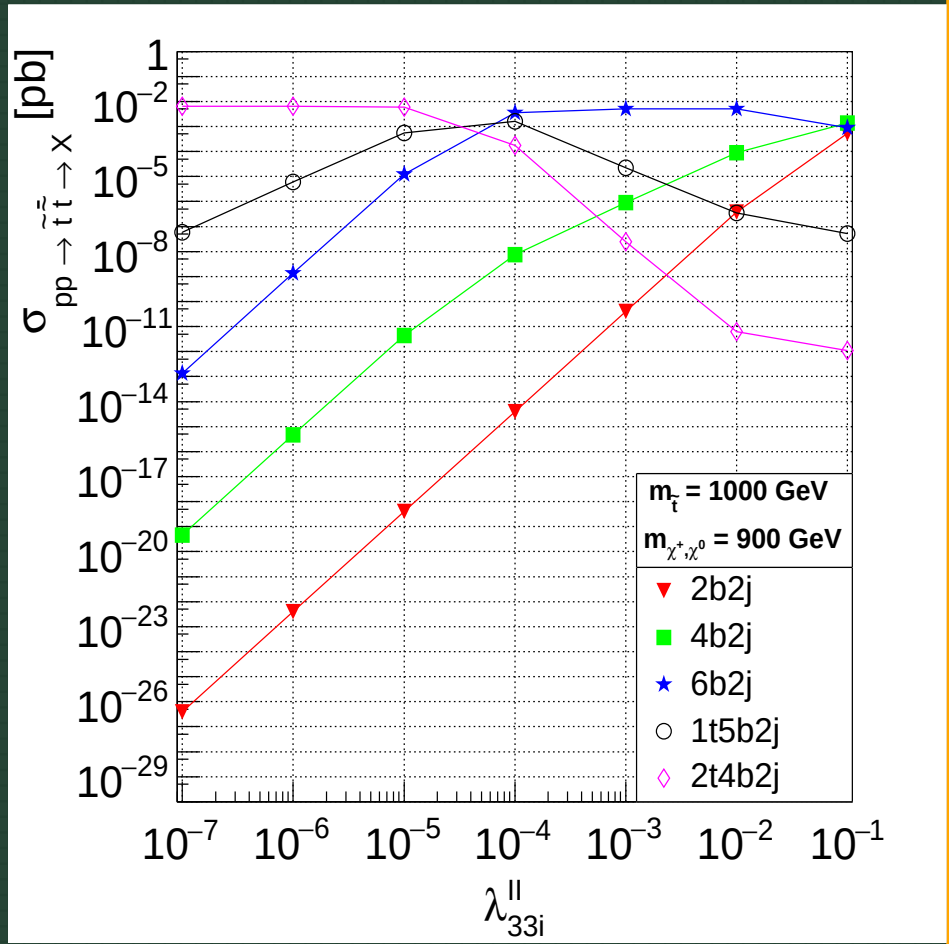
$$\sigma(2t4b2j) \simeq \sigma_{\tilde{t}\bar{\tilde{t}}} \times \frac{1}{(1 + r_1 \times (\lambda''_{33i})^2)^2 (1 + r_2 \times (\lambda''_{33i})^2)^2}$$

Benchmark points	1	2
$\tan\beta$	10	
M_1	2.5 TeV	
M_2	1.5 TeV	
M_3	1.7 TeV	
$(m_{\tilde{Q}})_{33}$	2 TeV	
$(m_{\tilde{U}})_{33}$	570 GeV	964 GeV
$(m_{\tilde{D}})_{33}=(m_{\tilde{U}})_{ii}=(m_{\tilde{D}})_{ii}=$ $(m_{\tilde{E}})_{ii}=(m_{\tilde{Q}})_{ii}=(m_{\tilde{L}})_{ii},\ i=1,2$	3 TeV	
$(T^u)_{33}$	-2100 GeV	-2150 GeV
m_A	2.5 TeV	
μ	400$-$650 GeV	750-10^3 GeV
$\lambda''_{33i}\equiv\sqrt{(\lambda''_{332})^2+(\lambda''_{331})^2}$	$10^{-7}-10^{-1}$	
$T^l, T^d, (T^u)_{ij}, (m_{\tilde{Q},\tilde{U},\tilde{D},\tilde{L},\tilde{E}})_{ij}, T''_{33i}$ $i\neq j=1,2,3,\ (T^u)_{ii}, i=1,2$	0	

Benchmark points	1	2
$m_{\tilde{t}}$	$\sim$600 GeV	$\sim$1 TeV
m_{χ^+}	$\sim$400$-$650 GeV	$\sim$750$-$1000 GeV
$m_{\chi^+} - m_{\chi^0}$	$\sim$1.5$-$2.5 GeV	
$m_{\tilde{t}} - m_{\chi^+}$	~ -45 $-$ 200 GeV	$\sim$1 - 245 GeV
$m_{\chi_2^0} - m_{\chi^+}$	$\sim$4$-$5 GeV	
$m_{\chi_3^0} \sim m_{\chi_2^+}$, $m_{\chi_4^0}$	$\sim$1.5 TeV, $\sim$2.5 TeV	
m_{h^0}	$\sim$125 GeV	
$m_A \approx m_{H^0} \approx m_{H^\pm}$	$\sim$2.5 TeV	
$M_{\tilde{g}}$	$\sim$1.87 TeV	
$M_{\tilde{t}2} \approx M_{\tilde{b}1}$	$\sim$2 TeV	
$M_{\tilde{b}2} \approx M_{\tilde{u}1,2} \approx M_{\tilde{d}1,2}$	$\sim$3 TeV	
$M_{\tilde{l}1,2}, M_{\tilde{\nu}1,2}$	$\sim$3 TeV	
$(g-2)_\mu^{\rm SUSY}$	3$-$3.3 $\times 10^{-11}$	3.2$-$3.3 $\times 10^{-11}$
$\delta\rho^{\rm SUSY}$	5.7$-$5.9 $\times 10^{-5}$	$\sim$5.5 $\times 10^{-5}$
$BR(B \to X_s\gamma)/BR(B \to X_s\gamma)^{SM}$	0.89$-$0.92	0.95$-$0.96
$BR(B_s^0 \to \mu\mu)$	3.36$-$3.39 $\times 10^{-9}$	3.38$-$3.40 $\times 10^{-9}$
$BR(B_d^0 \to \mu\mu)$	1.08$-$1.09 $\times 10^{-10}$	$\sim$1.09 $\times 10^{-10}$

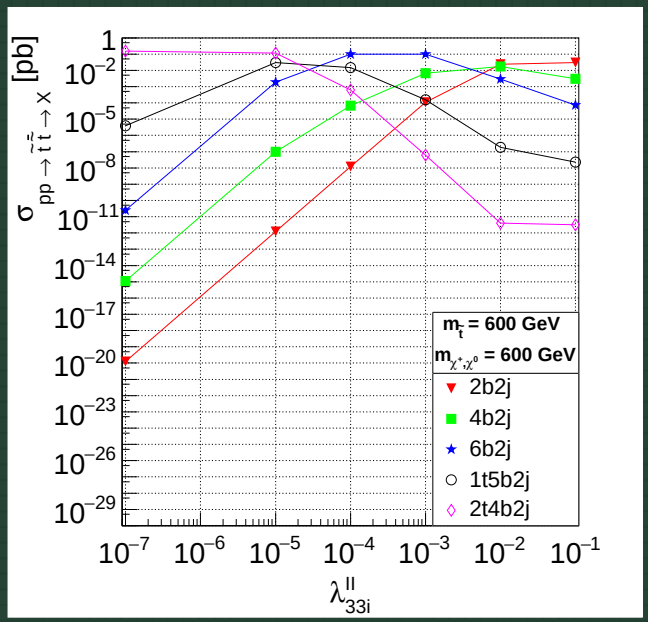
Sensitivity to λ''_{332}

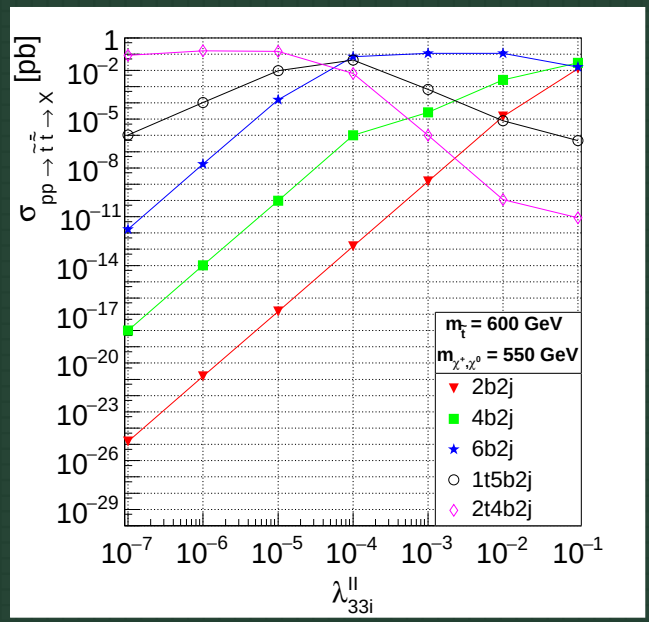
$$BR\left(\chi^0 \to \tilde{t}^* \bar{t} (\tilde{\bar{t}}^* t) \to \bar{b} d_i \bar{b} (b d_i b) f_1 \bar{f}'_1\right) \approx 1$$

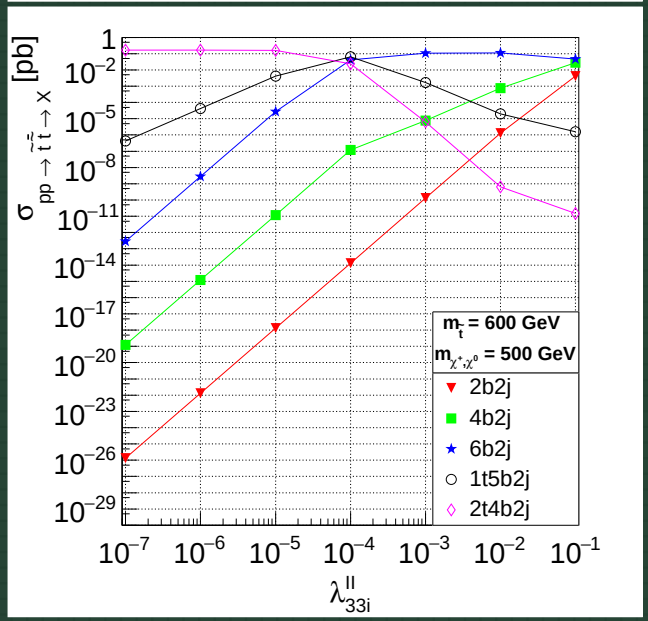


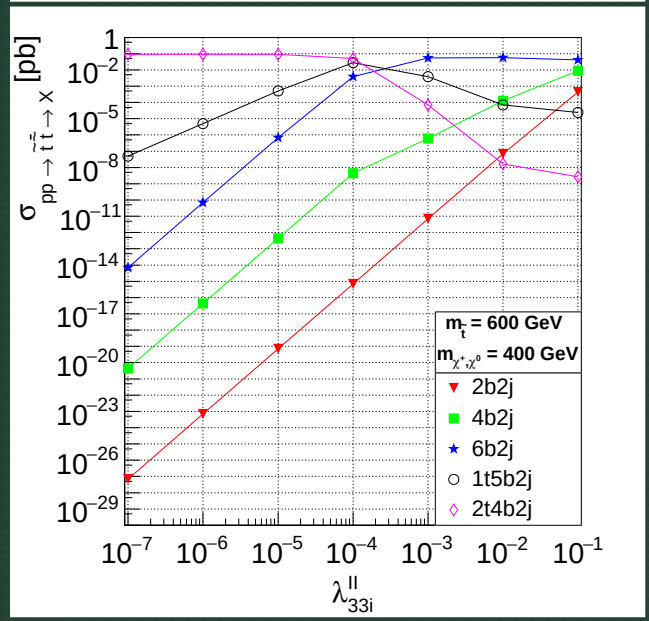
Diglio *et al* arXiv:1611.05850

Sensitivity to λ''_{332} (Diglio *et al* arXiv:1611.05850)





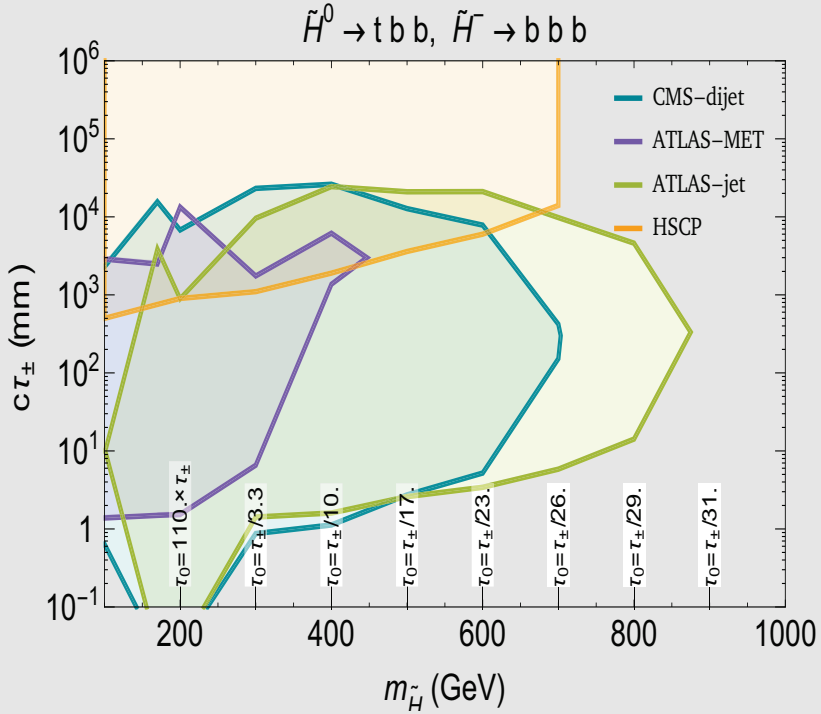




Displaced vertices

Pair produced Higgsino-like electroweakinos

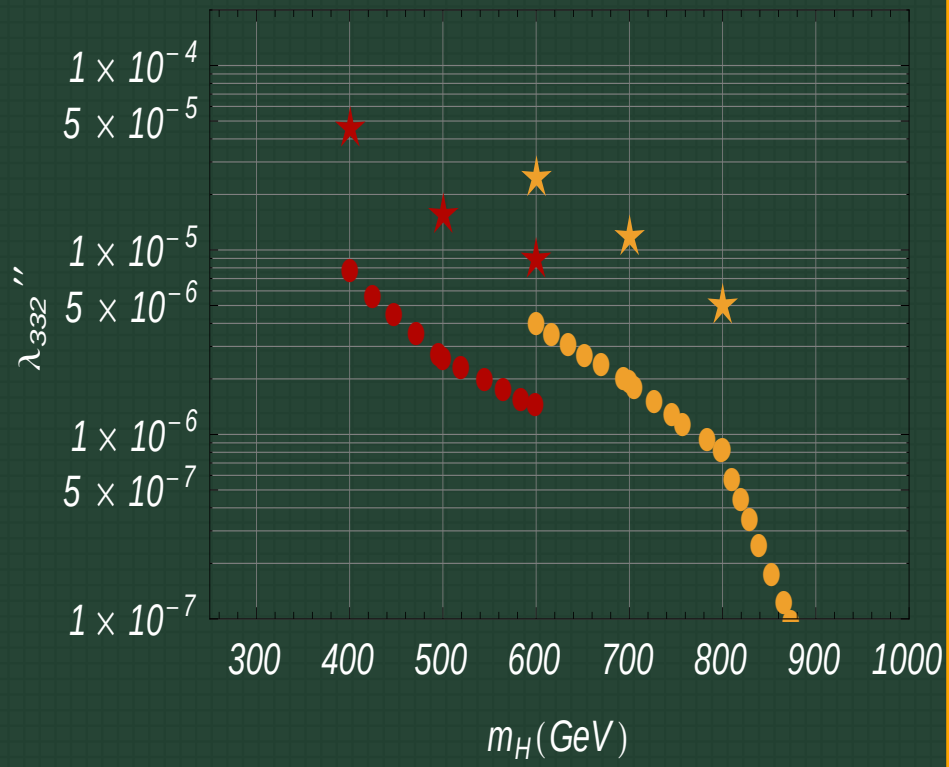
$$pp \to \tilde{H}^0 \tilde{H}^0, \tilde{H}^0 \tilde{H}^+, \tilde{H}^+ \tilde{H}^+$$



Csaki *et al* arXiv:1505.00784

$\rightarrow$ bounds on λ''_{33i} from DV limits

[χ^0-LSP becomes detector stable for $|\lambda''_{33i}| \lesssim 10^{-7}$]

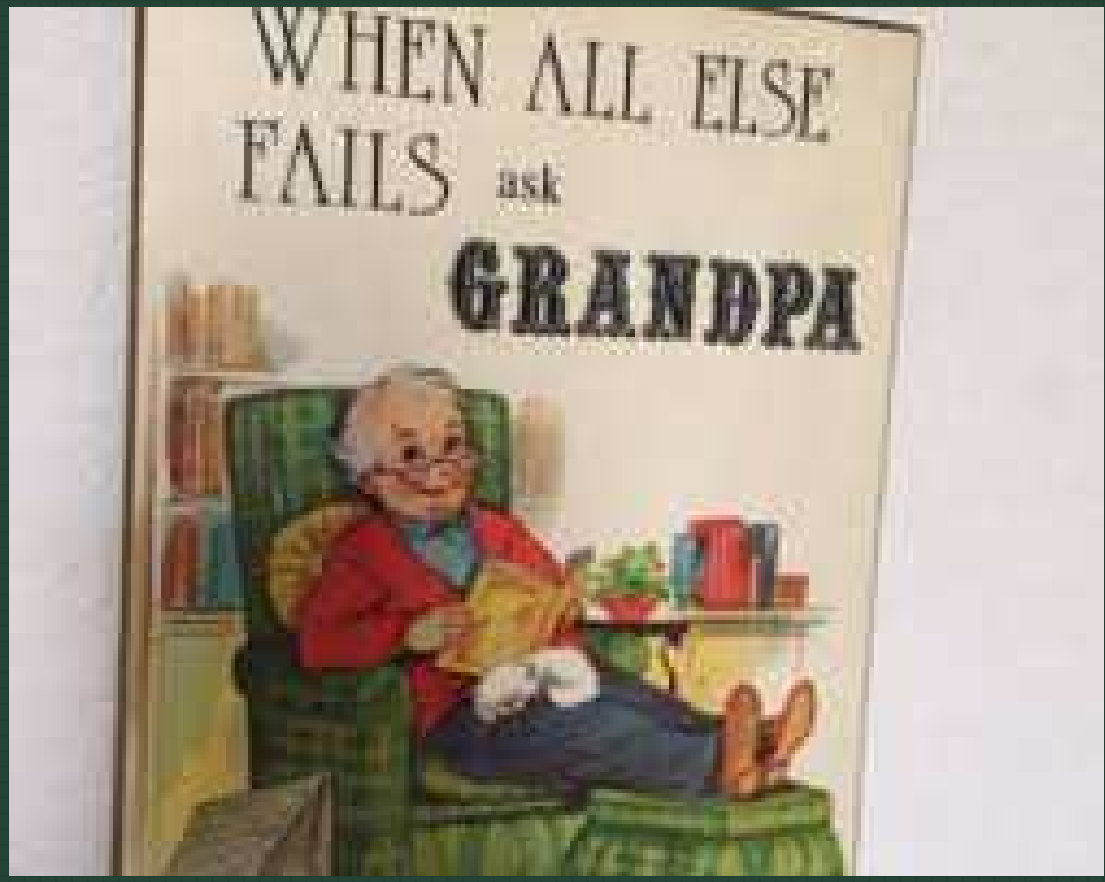


$\tilde{t}$: 600 GeV (red), 1 TeV(yellow), χ^0:star, χ^+:blob

$$c\tau[\mathrm{mm}] \simeq \frac{2.6\times10^{-13}}{|\lambda''_{33i}|^2}\left(\frac{m_{\tilde{t}}}{600\mathbf{GeV}}\right)^4\left(\frac{500\mathbf{GeV}}{m_{\chi^0}}\right)^5 \begin{cases} \Phi(\frac{m_t}{m_{\chi^0}})\ \alpha_{\chi^0}^{-1} & [\chi^0 \to tbd_i] \\ 2\ \alpha_{\chi^+}^{-1} & [\chi^+ \to bbd_i] \end{cases}$$

Conclusion

- RPV is not just a trick to avoid the (ever stronger) limits on signals with $E_{T\text{miss}}$
- We enter the era of experimental searches for RPV @LHC,
  $m_{\tilde{t}} \gtrsim 1$ TeV (all leptonic), $\gtrsim 100 - 400$ GeV (b + 1jet),
  $\gtrsim 1.2$ TeV (simplified model, $2t4b2j$, e.g. ATLAS-CONF-2017-013)
- model-dependence should be considered, sensitivity to RPV couplings triggers the leading final states
- a combined strategy: limits on Xsections, limits from Long-lived particles.


WHEN ALL ELSE
FAILS ask
GRANDPA