

# A Critical Look at FCNC Decays of the Top Quark

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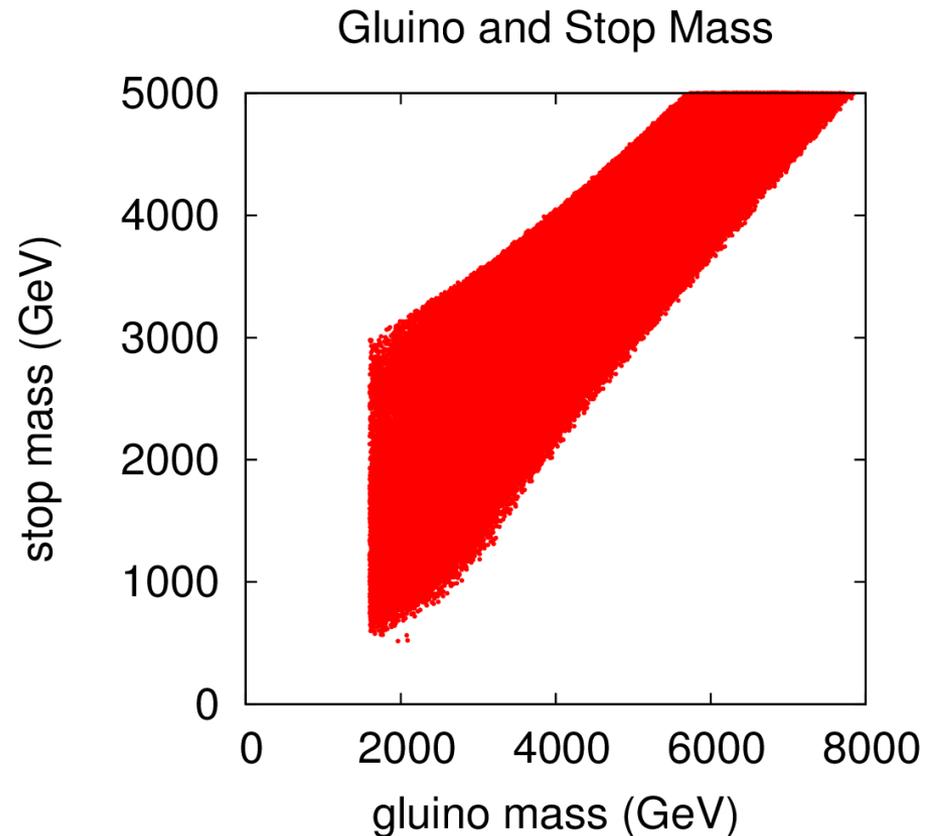
Free Meson Seminar

27/08/2015

# Why FCNCs?

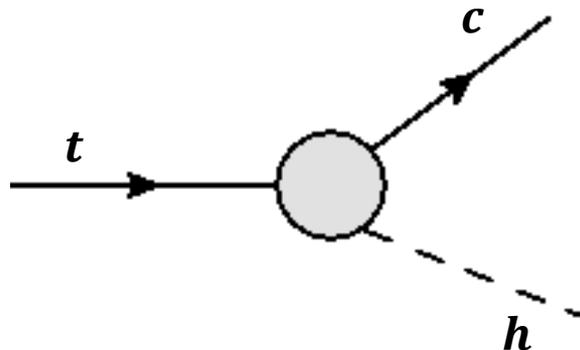
- No SUSY particles from LHC Run-I
- These new particles might be too heavy to produce on-shell – direct searches fail
- Consider the indirect effects of these particles through loop contributions
- Find a rare SM process and find enhancements -  $t \rightarrow ch$

**SuSpect v2.3;  
cMSSM framework**



# Top Quark Exotic Decays: Introduction

- The top quark decays before hadronisation due to its very large mass
- The decay thus doesn't involve non-perturbative processes such as parton showering
- Dominant decay mode:  $t \rightarrow b W$
- Interesting to see FCNC decays – rare decays of the top like  $t \rightarrow c h$
- GIM suppressed processes



# Literature on the subject

- Quite a lot of literature available on FCNC decays of the top
- Most of it is quite nebulous; some quote extremely optimistic values
- **SM predictions (BR ( $t \rightarrow ch$ )):**
  - $10^{-7}$  Eilam et al. [Phys Rec D44 \(1991\) 1473](#)
  - $10^{-7}$  Jin Min Yang et al. [Phys Rec D49 \(1994\) 3412](#)
- **MSSM predictions (BR ( $t \rightarrow ch$ )):**
  - $10^{-5}$  ( by Guasch, [hep-ph/9710267](#) )
  - $10^{-3}$  (by Cordero-Cid et al. [hep-ph/0407127](#) )

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- CMS Collaboration places a 95% CL using Run-I data

$$\mathbf{BR}(t \rightarrow ch) < 5.6 \times 10^{-3}$$

- Sensitivity may improve up to  $10^{-5}$  in Run – II

# Outline

- Standard Model Process
- Analysis using a toy model
- Process in cMSSM
- Process in RPV SUSY

# Top FCNC Decay in the SM

$$t(\mathbf{p}) \rightarrow c(\mathbf{p} + \mathbf{k}) + h(-\mathbf{k})$$

$$\text{Scalar : } iM = \bar{c}(\mathbf{p} + \mathbf{k}) i\Gamma t(\mathbf{p})$$

- Calculated the process  $t \rightarrow c h$  with generic couplings in the Feynman gauge. Form factors have been used:

- Contribution to effective vertex of the  $n$ th diagram is:

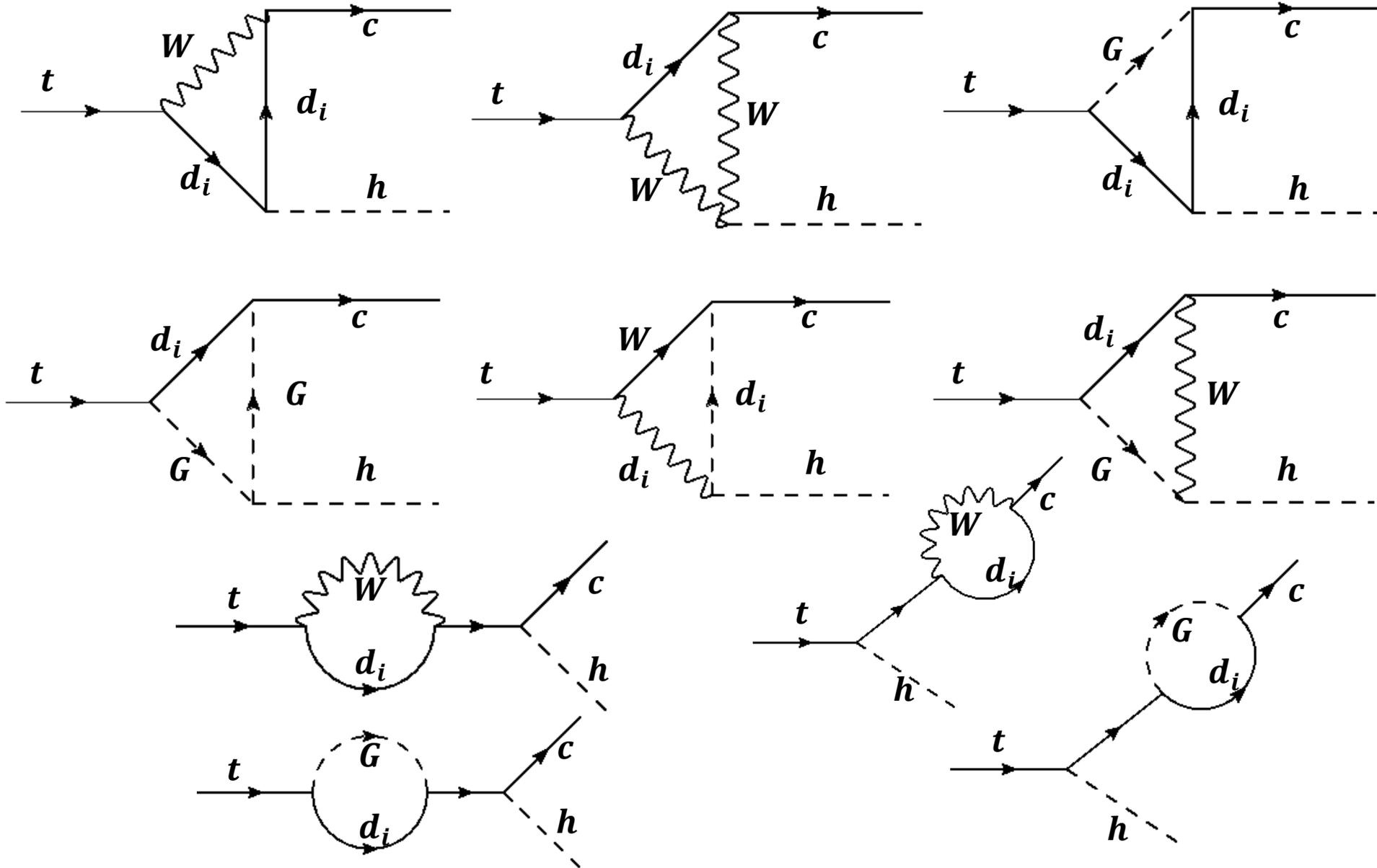
$$i \Gamma_n = \frac{ig^3}{16\pi^2} \sum_{i=1}^3 \lambda_i \left( F_{1i}^{(n)} P_L + F_{2i}^{(n)} P_R \right)$$

$$\Gamma = \sum_n \Gamma_n$$

- GIM suppression comes from the factor:

$$\lambda_i = V_{ci} V_{ti}^*$$

# Top Quark FCNC Decay Diagrams (in SM)



# Top Quark FCNC Decay Diagrams (in SM)

In the SM

$$BR(t \rightarrow ch) \sim 10^{-15}$$

No way of seeing  
a SM signal

## Three Reasons:

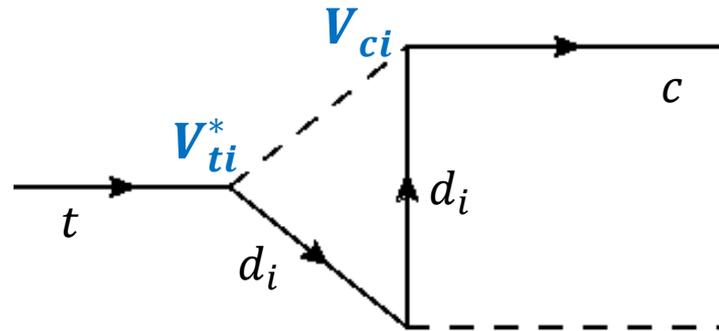
1. GIM Cancellation
2. MFV structure of the quark sector
3. Low value of the coupling constant

Study the relaxation of each of these factors one-by-one

- Use a toy model

# GIM Suppression

- First proposed by Glashow, Iliopoulos and Miani to explain the suppression of the FCNC decay amplitudes seen in  $\Delta S = 2$  decays
- Led to the prediction of the *charm* quark
- Directly related to the unitarity of the CKM matrix



- The FCNC amplitude is of the form

$$\mathcal{A} = C \left[ \sum_i \lambda_i A(x_i) \right]$$

$$x_i = \left( \frac{m_i}{M_W} \right)^2$$

$$\lambda_i = V_{ti}^* V_{ci}$$

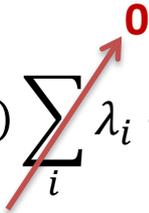
- Unitarity Condition:  $\sum_i \lambda_i = \sum_i V_{ti}^* V_{ci} = 0$

# GIM Suppression

- Taylor expand the amplitude in  $x_i$ 's since they are small numbers

$$A(x_i) = A(0) + x_i A'(0) + \dots$$

- Put this back:

$$\left[ \sum_i \lambda_i A(x_i) \right] = A(0) \sum_i \lambda_i + A'(0) \sum_i \lambda_i x_i \quad \text{Unitarity}$$


- Thus the leading amplitude is proportional to  $x_i$ 's

## GIM Violation

- If FC coupling depends on the mass, we can violate GIM

$$\left[ \sum_i \lambda_i \mathbf{m}_i A(x_i) \right] = A(0) \sum_i \lambda_i \mathbf{m}_i + A'(0) \sum_i \lambda_i \mathbf{m}_i x_i$$

# MFV structure of the Quark sector

- **MFV hypothesis:** Yukawas are the only source of flavour violation in the SM and in any BSM models

R.S. Chivukula, H. Georgi, Phys. Lett. B 188, 99 (1987)

- Yukawas might have a high energy dynamical origin

## Implications:

- SM flavour structure is all that there is
- Produces additional suppression for NP flavour transitions
- Inherits the hierarchical nature of the CKM matrix

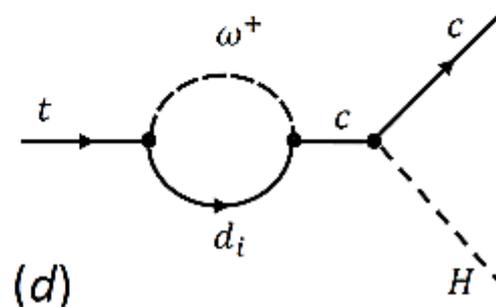
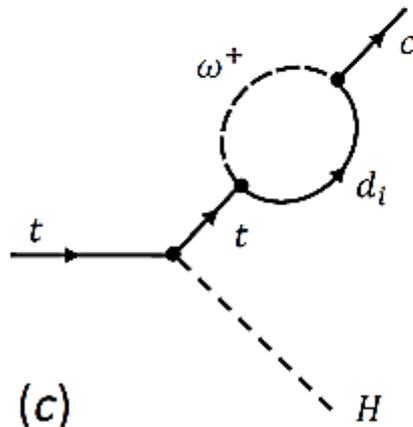
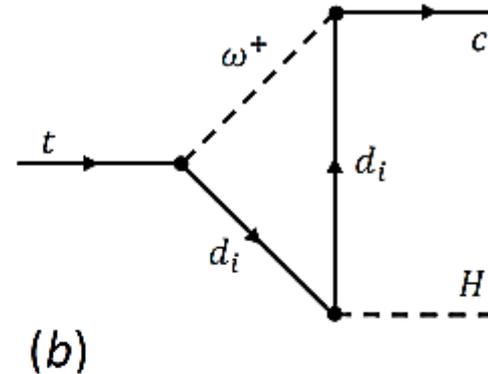
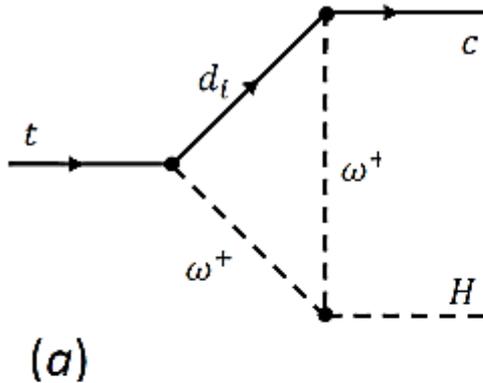
$$CKM \approx \begin{pmatrix} 1 & \lambda & A\lambda^3 \\ -\lambda & 1 & A\lambda^2 \\ A\lambda^3 & -A\lambda^2 & 1 \end{pmatrix} \approx \begin{pmatrix} 1 & 0.2 & 0.003 \\ 0.2 & 1 & 0.04 \\ 0.008 & 0.04 & 1 \end{pmatrix}$$

More 

# Toy Model

- Introduce a scalar – something like a scalar version of the  $W$ - boson

$$\mathcal{L}_{int} = \xi \omega^+ \omega^- h + \sum_{i,j=1}^3 \eta V_{ij} \bar{u}_i P_L d_j \omega^+ + h.c.$$



# Toy Model

“SM Like” amplitudes

$$\mathcal{M} = \sum_i \lambda_i \mathcal{A}_i (m_i, X)$$

$$\lambda_i = V_{ti}^* V_{ci}$$

Break GIM

$$\mathcal{M} = \sum_i \lambda_i \mathcal{A}_i (m_i, X) \times \left( \frac{m_i}{m_b} \right)^2$$

$$m_i = (m_d, m_s, m_b)$$

Go beyond MFV

$$V'_{CKM} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \theta & \sin \theta \\ 0 & -\sin \theta & \cos \theta \end{pmatrix}$$

$$\text{For } \theta = \frac{\pi}{4}; \quad \lambda = \left( 0, -\frac{1}{2}, \frac{1}{2} \right)$$

Maximize coupling

$$g \rightarrow 1$$

# Toy Model

- Used helicity amplitude techniques to calculate the Branching Ratios
- Amplitudes for each helicity combination of top, charm:  $\mathcal{A}_i(h_c, h_t)$
- Only two combinations non-zero:  $\mathcal{A}_i(+, +)$ ;  $\mathcal{A}_i(-, -)$

## GIM Relaxation:

- Gives us an enhancement of  $\sim \left[ \left( \frac{m_b}{M_\omega} \right)^2 \right]^{-1} \approx 10^2 - 10^4$

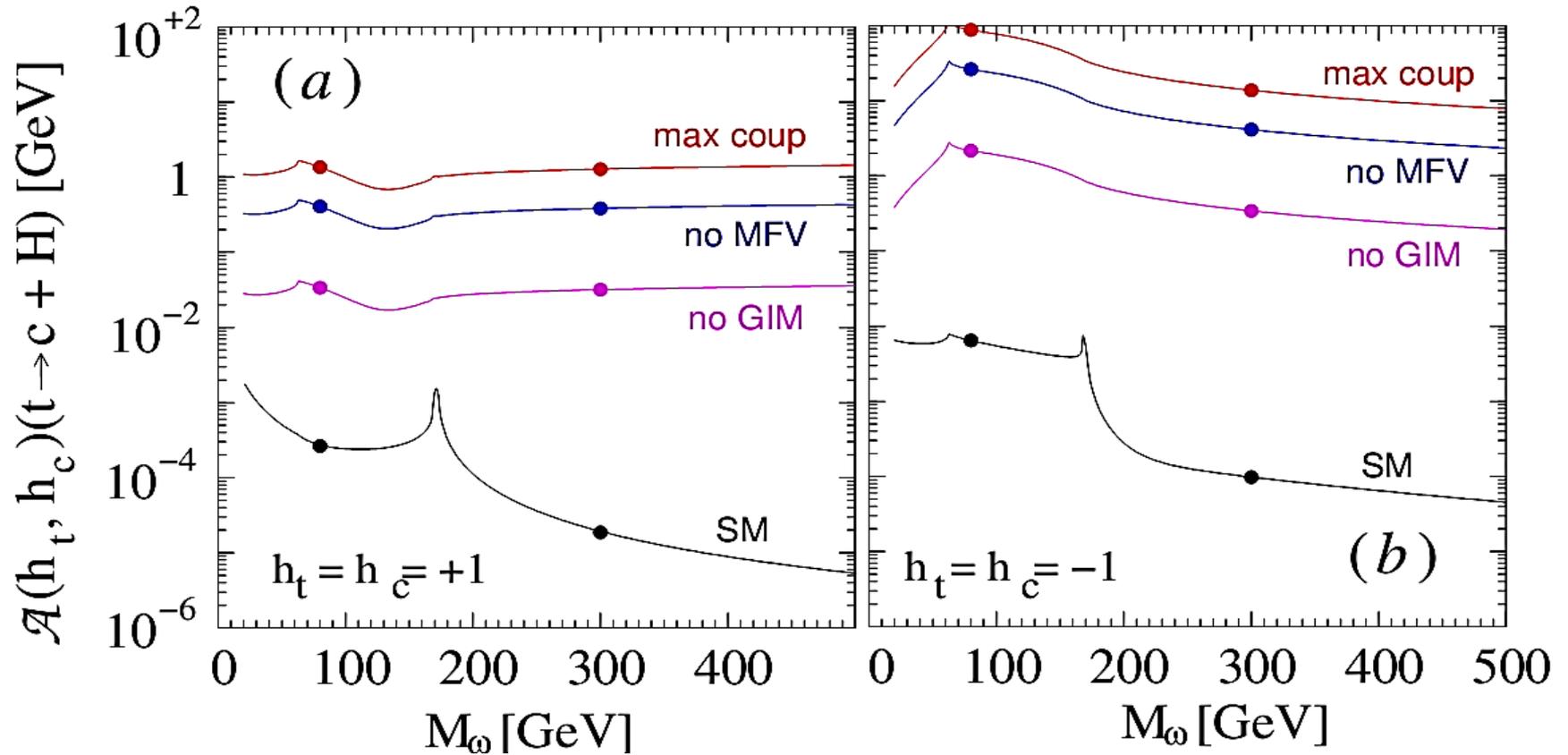
## Departure from MFV:

- Gives us an enhancement of 1 to 2 orders of magnitude

## Maximal couplings:

- Factor of 3 - 5

# Toy Model

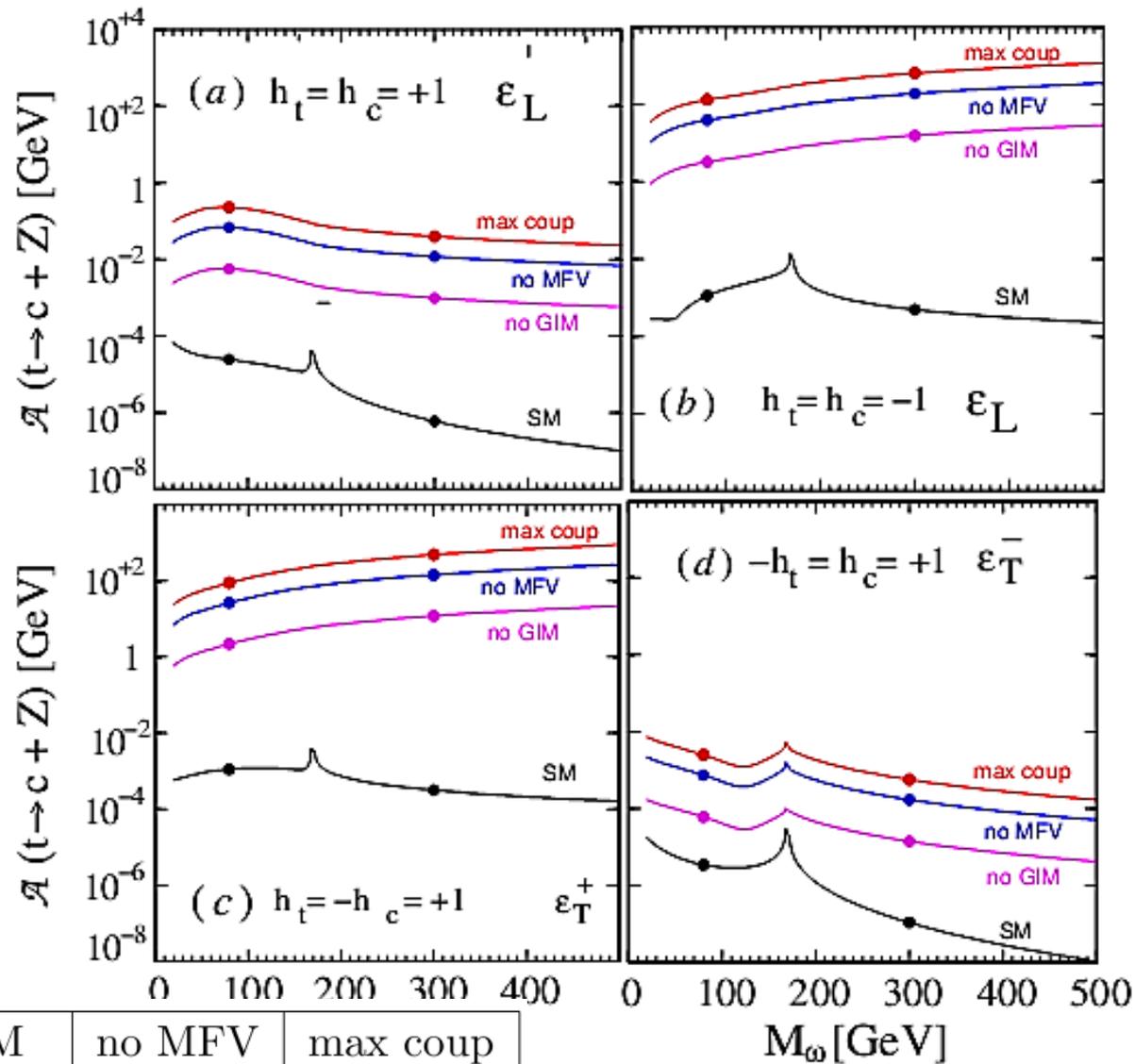


**Branching  
Ratio**

$M_\omega$	SM	no GIM	no MFV	max coup
80 GeV	$8.8 \times 10^{-10}$	$9.9 \times 10^{-5}$	$1.5 \times 10^{-2}$	$1.6 \times 10^{-1}$
300 GeV	$2.1 \times 10^{-13}$	$2.5 \times 10^{-6}$	$3.6 \times 10^{-4}$	$4.1 \times 10^{-3}$

# Toy Model — for $t \rightarrow c Z$

- Similar results – 4 combinations survive out of 12



$M_\omega$	SM	no GIM	no MFV	max coup
80 GeV	$7.4 \times 10^{-10}$	$7.3 \times 10^{-3}$	0.52	0.92
300 GeV	$1.7 \times 10^{-10}$	$1.6 \times 10^{-1}$	0.97	0.99

# The cMSSM

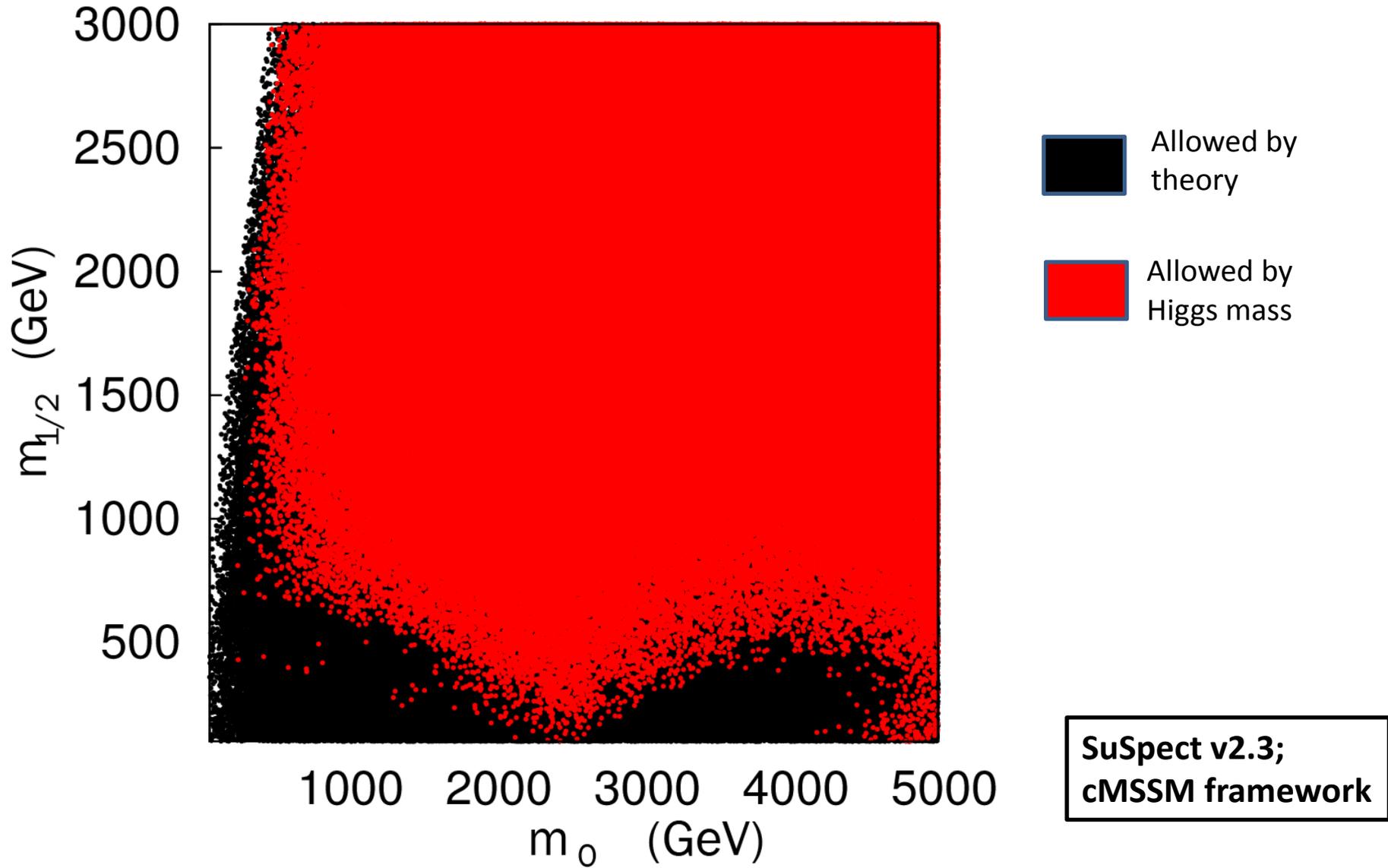
- The simplest version of the MSSM
- cMSSM contains 5 free parameters –  $m_0$ ,  $m_{1/2}$ ,  $A_0$ ,  $\tan \beta$ ,  $\text{sgn}(\mu)$
- GIM would be broken by the charged Higgs
- MFV structure retained
- Couplings similar to those of the SM particles, scaled by factors like  $\tan \beta$

# cMSSM

- Theory Constraints
  - Issues like vacuum stability, proper LSP etc.
- Higgs Mass constraint
  - light Higgs mass taken between 124 to 127 ( $2\sigma$  interval)
  - Constraints  $m_0$  values  $\Rightarrow$  charged Higgs mass is large
- Direct mass constraints
  - Latest results by ATLAS ATLAS SUSY Searches Summary, July 2015
  - $m_{\tilde{g}} > 1.6 \text{ TeV}$  ;  $m_{\tilde{q}} > 800 \text{ GeV}$  ;  $m_{\tilde{t}}(b\chi^+) > 460 \text{ GeV}$
- Flavour Physics constraints
  - FCNC processes involving  $b$ -quark are also GIM-violating
  - $B \rightarrow K^*\gamma$  and  $B_s \rightarrow \mu^+\mu^-$  are measured very close to SM
  - Values taken at a  $2\sigma$  level LHCb: 1211.2674; Belle: 1208.4678
  - Constraints on GIM-violation effects :  $M(H^+)$ ,  $\tan\beta$

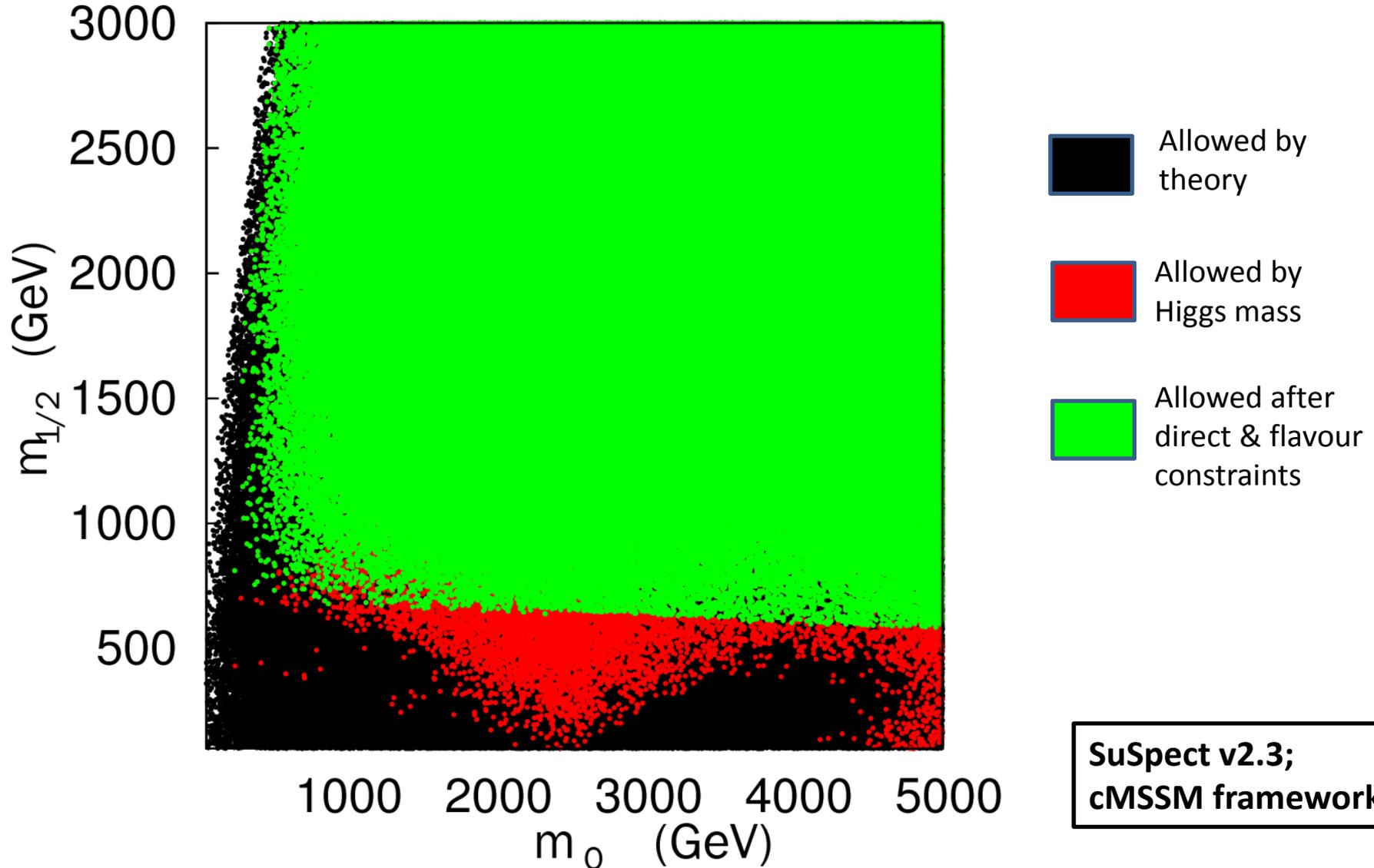
# cMSSM

## Higgs Constraints



# cMSSM

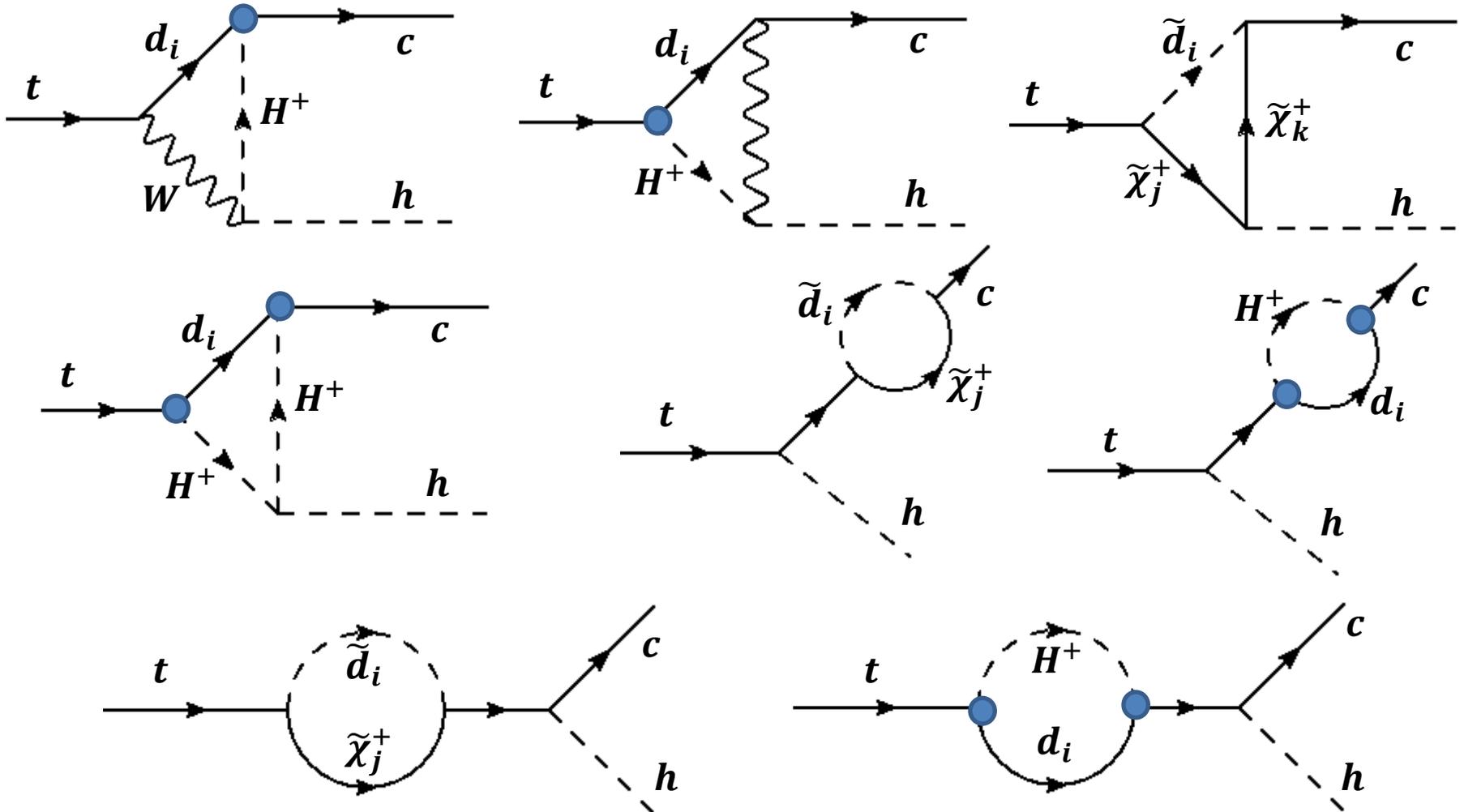
## Higgs + Flavour and Direct Constraints

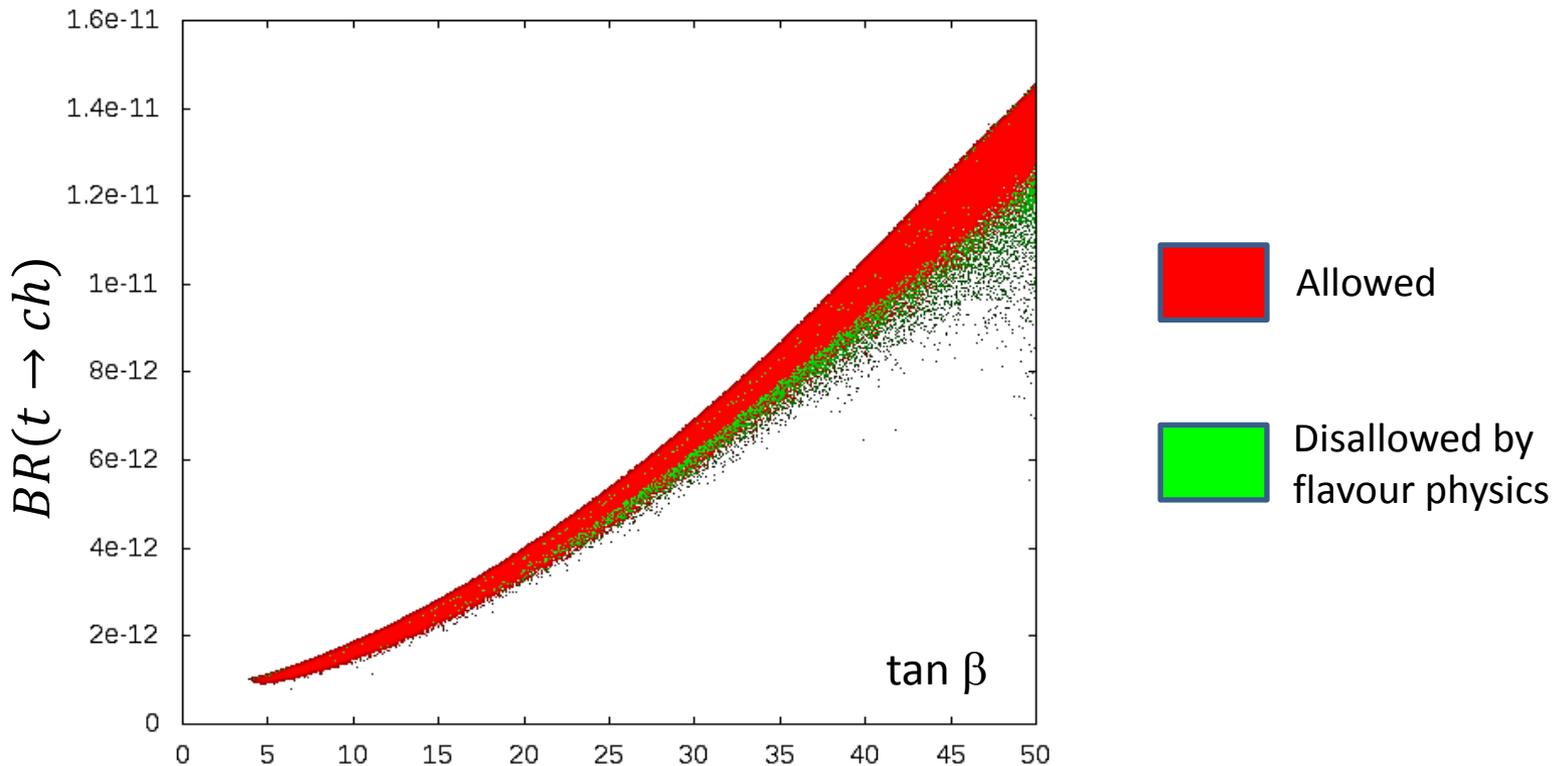


# SUSY Contributions

- Additional diagrams with (a) **charged Higgs bosons** (b) **charginos**

(c) **d-squarks**





- GIM would be broken by the charged Higgs, but not by other sparticles
- The charged Higgs sector is MFV
- Suppression due to large SUSY particle masses in cMSSM

**cMSSM doesn't do it**

# R-Parity Violating SUSY

- R-parity is a  $\mathbb{Z}_2$  symmetry which differentiates between SM and SUSY particles

$$R = (-1)^{2s+3B+L}$$

- R-parity conservation gives a viable dark matter candidate, the LSP
- R-parity violating SUSY superpotential -

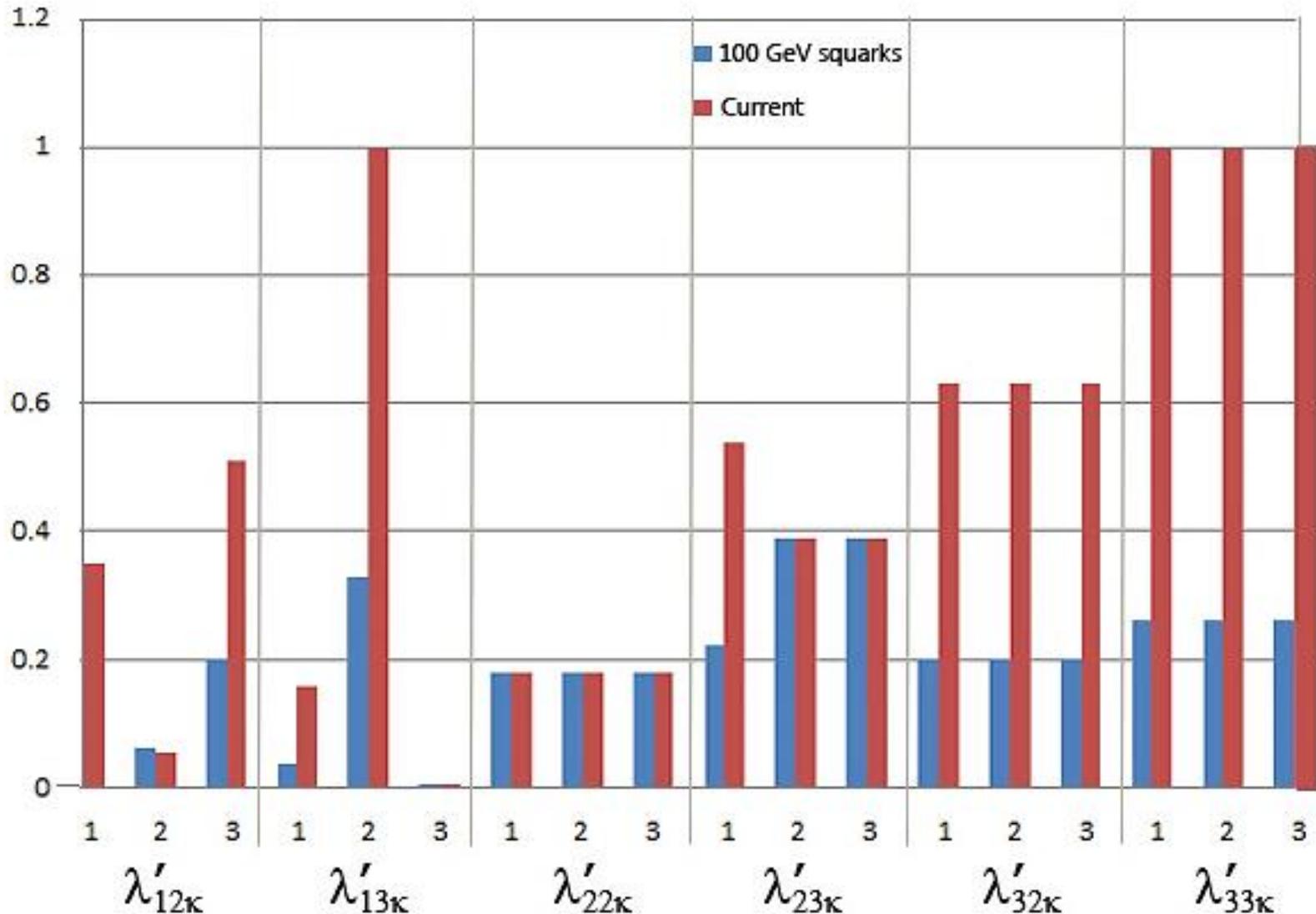
$$W_{RPV} = \mu_i H_u L_i + \frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c$$

- LQD - Lagrangian

$$\mathcal{L}_{LQD} = -\lambda'_{ijk} (\tilde{\nu}_{iL} \bar{d}_{kR} d_{jL} + \tilde{d}_{jL} \bar{d}_{kR} \nu_{iL} + \tilde{d}_{kR}^* \bar{\nu}_{iR}^c d_{jL} - (v_L \rightarrow l_L, d_L \rightarrow u_L)) + h.c.$$

# RPV SUSY Couplings

- Direct squark mass bounds: heavy squarks  $\rightarrow$  weaker constraints



Dreiner.  
[hep-ph/9707435](https://arxiv.org/abs/hep-ph/9707435)

Eilam et al.  
[hep-ph/0102037](https://arxiv.org/abs/hep-ph/0102037)



# RPV SUSY Couplings

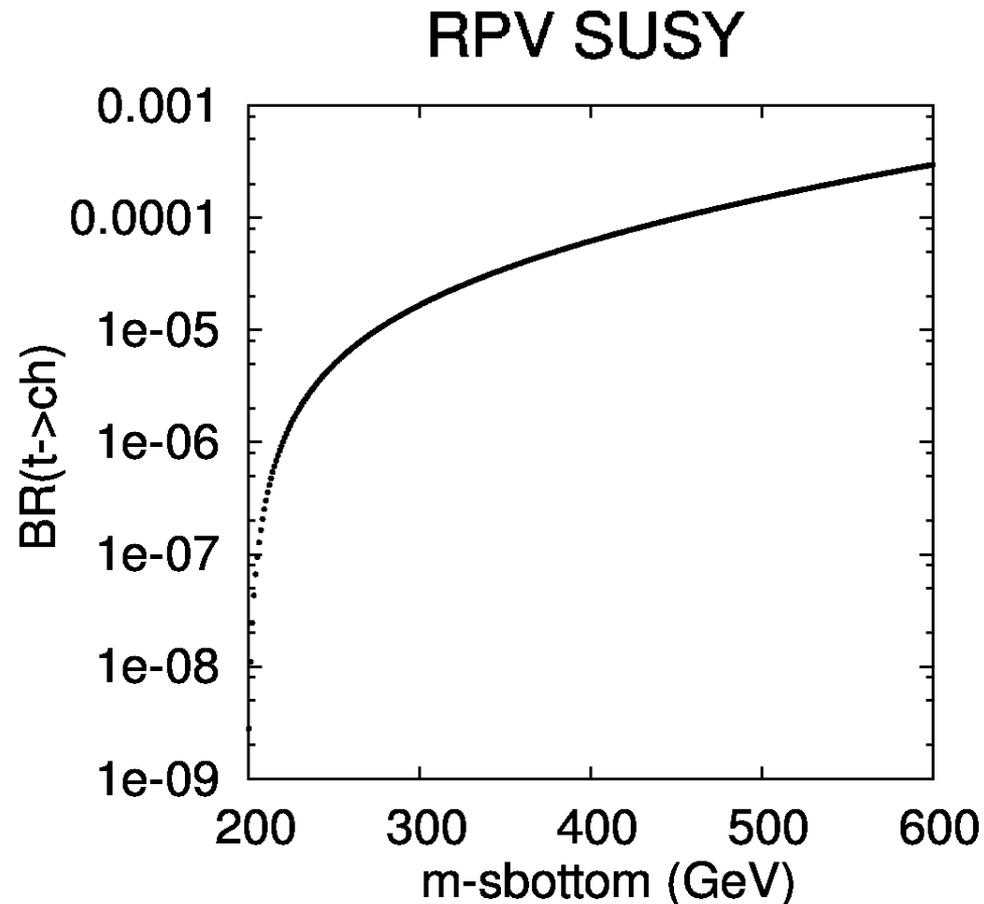
- The couplings occur as:  $\lambda'_{i2k}\lambda'_{i3k}$  and  $\lambda''_{2jk}\lambda''_{3jk}$  combinations
- Most important couplings:  $\lambda'_{323}\lambda'_{333}$
- $\lambda'_{323} = 0.66$  ;  $\lambda'_{333} = 1.0$

## Result :

$$m_{\tilde{q}} = 1 \text{ TeV} ; m_{\tilde{b}} \sim 300 \text{ GeV}$$

$$m_{\tilde{t}} \sim 300 \text{ GeV}$$

$$BR(t \rightarrow ch) \sim 10^{-5}$$



# SUMMARY

- Indirect searches might be the way to go in case SUSY particles are too heavy for direct detection –  $t \rightarrow ch$
- Heavy suppression of BR in SM coming from GIM mechanism, MFV structure and small couplings
- Have to evade all three to get observable signal
- cMSSM doesn't do it; RPV-SUSY might be able to

**Thank You**

**BACKUP SLIDES**

# ATLAS SUSY Searches\* - 95% CL Lower Limits

Status: July 2015

ATLAS Preliminary

$\sqrt{s} = 7, 8$  TeV

Model	$e, \mu, \tau, \gamma$	Jets	$E_T^{miss}$	$\int \mathcal{L} dt [fb^{-1}]$	Mass limit	$\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV
Inclusive Searches	MSUGRA/GMSSM	$0.3 e, \mu / 1.2 \tau$	$2-10$ jets/3b	Yes	20.3	$\tilde{\chi}^0$	1.8 TeV $m(\tilde{g})=m(\tilde{g})$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}k_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}k_1^0$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$	100-440 GeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}(L/\nu)/\nu/\bar{k}_1^0$	$2 e, \mu$ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$	780 GeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}k_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}k_1^0 \rightarrow qqW+k_1^0$	$0-1 e, \mu$	2-6 jets	Yes	20	$\tilde{g}$	1.26 TeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}(L/\nu)/\nu/\bar{k}_1^0$	$2 e, \mu$	0-3 jets	-	20	$\tilde{g}$	1.32 TeV
	GMSB ( $\tilde{L}$ NLSP)	$1-2 \tau + 0-1 \ell$	0-2 jets	Yes	20.3	$\tilde{g}$	1.6 TeV
	GGM (bino NLSP)	$2 \gamma$	-	Yes	20.3	$\tilde{g}$	1.29 TeV
	GGM (higgsino bino NLSP)	$\gamma$	1b	Yes	20.3	$\tilde{g}$	1.3 TeV
GGM (higgsino bino NLSP)	$\gamma$	2 jets	Yes	20.3	$\tilde{g}$	1.25 TeV	
GGM (higgsino NLSP)	$2 e, \mu$ (Z)	2 jets	Yes	20.3	$\tilde{g}$	850 GeV	
Gravitino LSP	0	mono-jet	Yes	20.3	$\tilde{g}$	865 GeV	
3 <sup>rd</sup> gen. $\tilde{g}, \tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\bar{b}k_1^0$	0	3b	Yes	20.1	$\tilde{g}$	1.25 TeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\bar{t}k_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\bar{t}k_1^0$	$0-1 e, \mu$	3b	Yes	20.1	$\tilde{g}$	1.34 TeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\bar{b}k_1^0$	$0-1 e, \mu$	3b	Yes	20.1	$\tilde{g}$	1.3 TeV
3 <sup>rd</sup> gen. squarks direct production	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{b}k_1^0$	0	2b	Yes	20.1	$\tilde{t}_1$	100-620 GeV
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\bar{t}k_1^0$	$2 e, \mu$ (SS)	0-3b	Yes	20.3	$\tilde{t}_1$	275-440 GeV
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{b}k_1^0$	$1-2 e, \mu$	1-2b	Yes	4.7/20.3	$\tilde{t}_1$	110-167 GeV
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\bar{k}_1^0$ or $t\bar{k}_1^0$	$0-2 e, \mu$	0-2 jets/1-2b	Yes	20.3	$\tilde{t}_1$	90-191 GeV
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\bar{t}k_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-240 GeV
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	$2 e, \mu$ (Z)	1b	Yes	20.3	$\tilde{t}_1$	150-580 GeV
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow t_1 + Z$	$3 e, \mu$ (Z)	1b	Yes	20.3	$\tilde{t}_2$	290-600 GeV	
EW direct	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\bar{t}k_1^0$	$2 e, \mu$	0	Yes	20.3	$\tilde{t}_1$	90-325 GeV
	$\tilde{t}_1^+\tilde{t}_1^-, \tilde{t}_1^+ \rightarrow \tilde{\nu}_t(L/\bar{\nu})$	$2 e, \mu$	0	Yes	20.3	$\tilde{t}_1^+$	140-465 GeV
	$\tilde{t}_1^+\tilde{t}_1^-, \tilde{t}_1^+ \rightarrow \tau(\tau\bar{\tau})$	$2 \tau$	-	Yes	20.3	$\tilde{t}_1^+$	100-350 GeV
	$\tilde{t}_1^+\tilde{t}_1^+ \rightarrow \tilde{\nu}_t \nu_t f(L/\bar{f}), f\bar{\nu}_t f(\bar{\nu})$	$3 e, \mu$	0	Yes	20.3	$\tilde{t}_1^+$	700 GeV
	$\tilde{t}_1^+\tilde{t}_1^+ \rightarrow W\tilde{k}_1^0 Z k_1^0$	$2-3 e, \mu$	0-2 jets	Yes	20.3	$\tilde{t}_1^+$	420 GeV
	$\tilde{t}_1^+\tilde{t}_1^+ \rightarrow W\tilde{k}_1^0 k_1^0, h \rightarrow b\bar{b}/WW/\tau\tau/\gamma\gamma$	$e, \mu, \gamma$	0-2b	Yes	20.3	$\tilde{t}_1^+$	250 GeV
	$\tilde{t}_2^+\tilde{t}_2^+, \tilde{t}_2^+ \rightarrow \tilde{t}_1 k_1^0$	$4 e, \mu$	0	Yes	20.3	$\tilde{t}_2^+$	620 GeV
GGM (wino NLSP) weak prod.	$1 e, \mu + \gamma$	-	Yes	20.3	$\tilde{W}$	124-361 GeV	
Long-lived particles	Direct $\tilde{t}_1^+\tilde{t}_1^-$ prod., long-lived $\tilde{t}_1^+$	Disapp trk	1 jet	Yes	20.3	$\tilde{t}_1^+$	270 GeV
	Direct $\tilde{t}_1^+\tilde{t}_1^-$ prod., long-lived $\tilde{t}_1^+$	dE/dx trk	-	Yes	18.4	$\tilde{t}_1^+$	482 GeV
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	832 GeV
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$	1.27 TeV
	GMSB, stable $\tau, \tilde{t}_1^0 \rightarrow \tau(\bar{\nu}_\tau, \bar{\mu}) + \tau(e, \mu)$	$1-2 \mu$	-	-	19.1	$\tilde{t}_1^0$	537 GeV
	GMSB, $\tilde{t}_1^0 \rightarrow \nu\bar{\nu}$ , long-lived $\tilde{t}_1^0$	$2 \gamma$	-	Yes	20.3	$\tilde{t}_1^0$	435 GeV
	$\tilde{g}\tilde{g}, \tilde{t}_1^0 \rightarrow ee/\mu\mu/\mu\mu$	displ. ee/μμ/μμ	-	-	20.3	$\tilde{t}_1^0$	1.0 TeV
GGM $\tilde{g}\tilde{g}, \tilde{t}_1^0 \rightarrow Z\tilde{G}$	displ. $\nu x + \text{jets}$	-	-	20.3	$\tilde{t}_1^0$	1.0 TeV	
RPV	LFV $\tilde{g}\tilde{g} \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e\mu/\tau/\mu/\tau$	$e, \mu, \tau, \mu\tau$	-	-	20.3	$\tilde{g}$	1.7 TeV
	Bilinear RPV CMSSM	$2 e, \mu$ (SS)	0-3b	Yes	20.3	$\tilde{g}$	1.35 TeV
	$\tilde{t}_1^+\tilde{t}_1^-, \tilde{t}_1^+ \rightarrow W\tilde{k}_1^0, \tilde{t}_1^+ \rightarrow \nu\bar{\nu}_\tau, \mu\mu/\bar{\nu}_\tau$	$4 e, \mu$	-	Yes	20.3	$\tilde{t}_1^+$	750 GeV
	$\tilde{t}_1^+\tilde{t}_1^-, \tilde{t}_1^+ \rightarrow W\tilde{k}_1^0, \tilde{t}_1^+ \rightarrow \tau\bar{\nu}_\tau, e\tau/\bar{\nu}_\tau$	$3 e, \mu + \tau$	-	Yes	20.3	$\tilde{t}_1^+$	450 GeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}q$	0	6-7 jets	-	20.3	$\tilde{g}$	917 GeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}k_1^0, \tilde{t}_1^0 \rightarrow qq\bar{q}$	0	6-7 jets	-	20.3	$\tilde{g}$	870 GeV
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t_1\bar{t}_1, \tilde{t}_1 \rightarrow b\bar{t}$	$2 e, \mu$ (SS)	0-3b	Yes	20.3	$\tilde{g}$	850 GeV
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{t}$	0	2 jets + 2b	-	20.3	$\tilde{t}_1$	100-308 GeV	
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow b\bar{t}$	$2 e, \mu$	2b	-	20.3	$\tilde{t}_1$	0.4-1.0 TeV	
Other	Scalar charm, $\tilde{c} \rightarrow c\bar{k}_1^0$	0	2c	Yes	20.3	$\tilde{c}$	490 GeV

$10^{-1}$

1

Mass scale [TeV]

# MFV structure of the Quark sector

- Total SM fermion flavour structure

$$G_f = \mathbf{SU(3)}_q \otimes \mathbf{SU(3)}_U \otimes \mathbf{SU(3)}_D \quad \otimes \mathbf{SU(3)}_l \otimes \mathbf{SU(3)}_E$$

- Introduce spurions like Yukawa fields to break  $G_f^Q$

$$Y_u \sim (3, \bar{3}, 1); \quad Y_d \sim (3, 1, \bar{3})$$

$$\mathcal{L} = \bar{Q} Y_d D \phi + \bar{Q} Y_u U \tilde{\phi} + h.c. \quad \longleftarrow \text{Invariant under } G_f$$

- Source of Yukawa fields – some high energy dynamics
- Dim-5 terms in EFT



# RPV Couplings & Scaling

Coupling	Old Value	Dependence	Mass(GeV)	New Value
$\lambda'_{121}$	0.035	$m_{\tilde{d}}/100 \text{ GeV}$	1000	0.35
$\lambda'_{122}$	0.06	$\sqrt{m_{\tilde{\tau}}/100 \text{ GeV}}$	85	0.05
$\lambda'_{123}$	0.2	$\sqrt{m_{\tilde{b}}/100 \text{ GeV}}$	650	0.51
$\lambda'_{131}$	0.035	$m_{\tilde{\tau}}/100 \text{ GeV}$	450	0.16
$\lambda'_{132}$	0.28	$m_{\tilde{\tau}}/100 \text{ GeV}$	450	1.0
$\lambda'_{133}$	0.002	$\sqrt{m_{\tilde{b}}/100 \text{ GeV}}$	650	0.005
$\lambda'_{221}, \lambda'_{222}, \lambda'_{223}$	0.18	$m_{\tilde{d}}/100 \text{ GeV}$	1000	1.0
$\lambda'_{231}$	0.22	$\sqrt{m_{\tilde{b}}/100 \text{ GeV}}$	650	0.54
$\lambda'_{232}$	0.39	Z Decay	-	0.39
$\lambda'_{233}$	0.39	Neutrino mass	-	0.39
$\lambda'_{321}, \lambda'_{322}, \lambda'_{323}$	0.2	$\sqrt{m_{\tilde{d}}/100 \text{ GeV}}$	1000	0.63
$\lambda'_{331}, \lambda'_{332}, \lambda'_{333}$	0.45	$m_{\tilde{\tau}}/100 \text{ GeV}$	450	1.0
$\lambda''_{2jk}$				1.0
$\lambda''_{3jk}$	0.2	$m_{\tilde{\tau}}/280 \text{ GeV}$	450	0.32