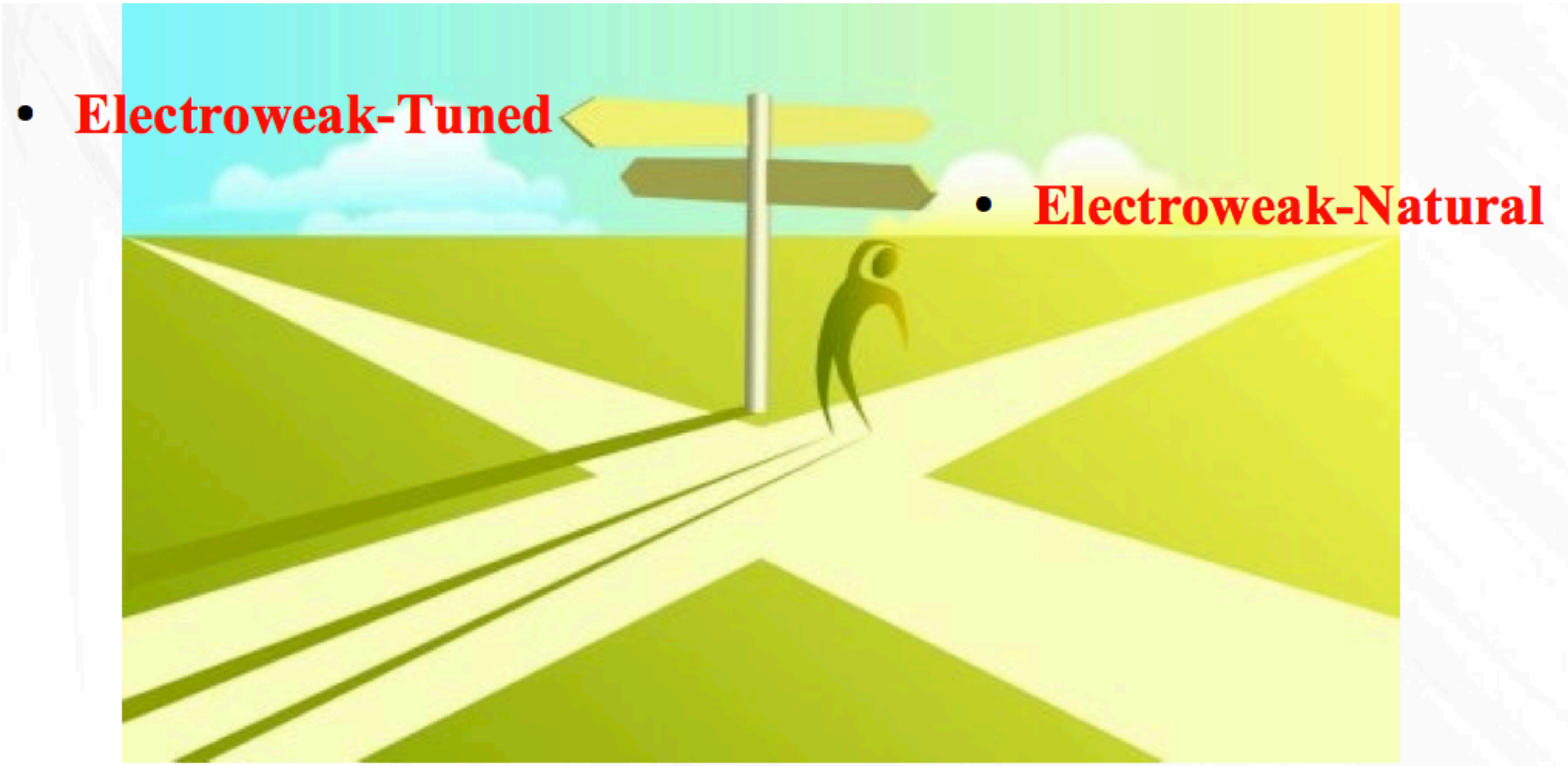
Claudia Frugiuele

Fermilab

R symmetry as the lepton number

Fermilab, 01/10/13

LHC will finally reveal whether or not the electroweak scale is tuned



Supersymmetry (SUSY)

SM particle content (at least) doubled

possibly many new particle to be discovered at the LHC

LHC pheno determined by SUSY breaking terms

MSSM soft terms

1) Mass and mixing term for sleptons, squarks and higgses $b_{ij}\phi_i\phi_j$

2) Majorana mass for the gauginos $\lambda^a\lambda^a$

3) Trilinear couplings $a_{ijk}\phi_i\phi_j\phi_k$

strong flavor constraints on the MSSM soft terms!

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Degenerate squarks and sleptons masses

Lepton and baryon number are not accidental symmetries

Proton instability!

Typical solution:

impose a discrete symmetry called R parity

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

SM particle even under R parity

SUSY partners odd under it

Lightest SUSY particle possible dark matter candidate!

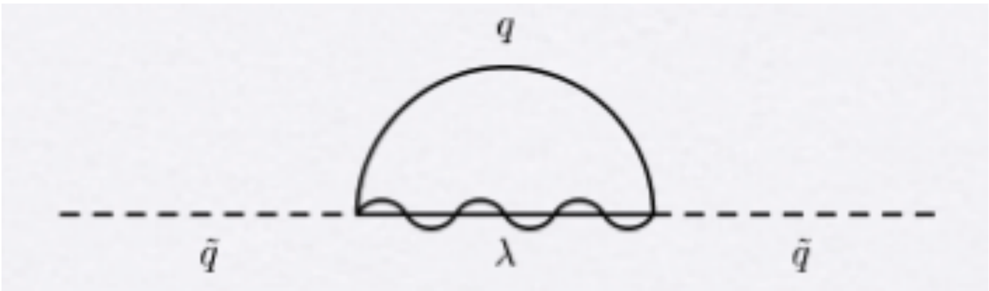
Missing energy signals

SUSY searches at the LHC

no hints of SUSY so far!

- Gluinos and degenerate squarks reached the TeV threshold
- To save naturalness: 1st and 2nd generation heavy
- 3rd generation squark can still be light (?)

..heavy gluino is already in tension with naturalness



log divergent contributions to scalar masses

Lesson from the LHC SUSY searches

SUSY will not show itself in its simplest form

Need to explore different SUSY scenarios/ SUSY breaking mediation mechanism

- flavorful SUSY breaking mediation (to produce minimal natural spectrum)
- hadronic RPV
- stealth supersymmetry
- Dirac gauginos

Dirac gauginos

New Adjoints superfields for each SM gauge group

$$\psi_{\tilde{B}} \quad \psi_{\tilde{W}} \quad \psi_{\tilde{g}}$$

Supersoft SUSY breaking

$$\int \frac{d^2\theta}{M} W'_\alpha W_i^\alpha \psi_i$$

$$W'_\alpha \sim D\theta_\alpha$$

D term spurion

Fox,Nelson,Weiner,2002

supersoft=no log divergent gauginos contributions to scalar masses

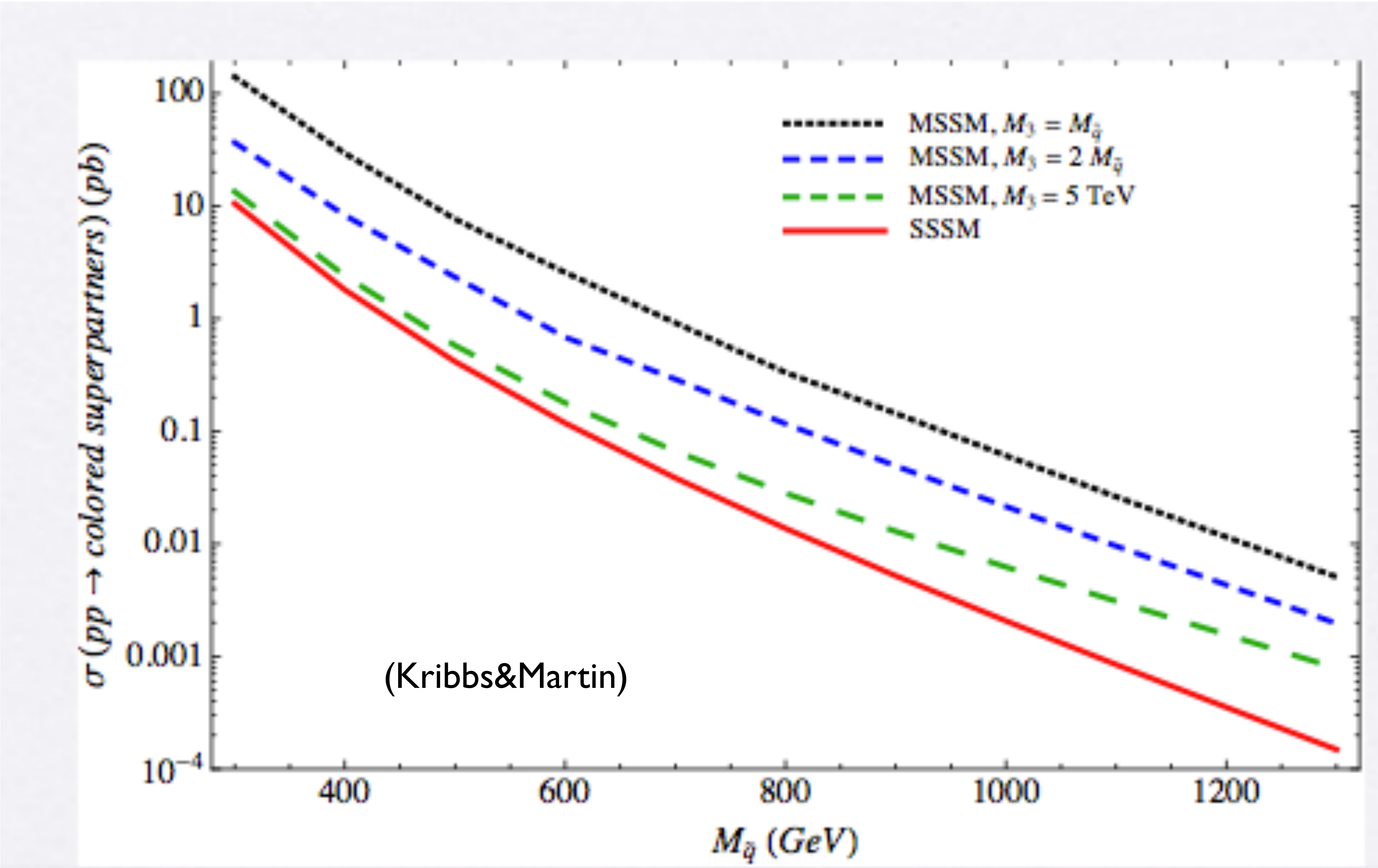
Supersofteness

No log divergent contributions to the scalar masses

scalar adjoint

Few TeV Dirac gluinos are natural!

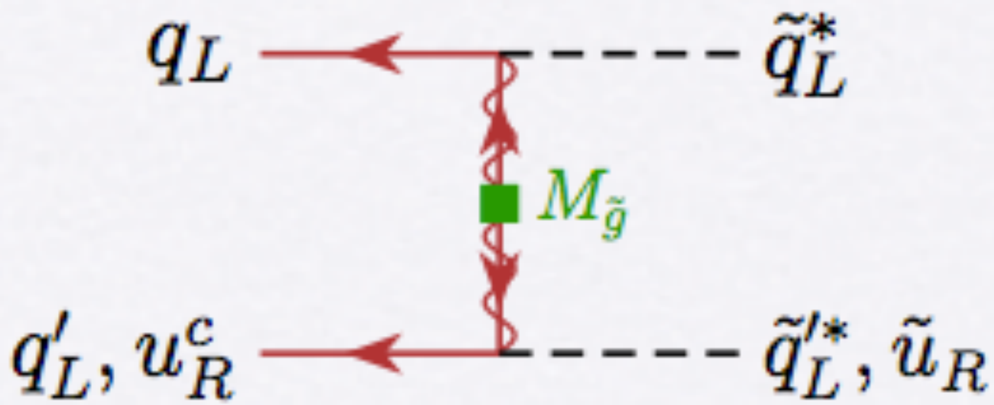
Smaller squarks productions



1st & 2nd generation bounds lowered, 600-700 GeV

Smaller squarks cross section

Majorana mass insertion



$$\propto \frac{M_{\tilde{g}}}{m^2_{\tilde{g}}}$$

no $\tilde{q}\tilde{q}'$ production of same chirality squarks

$$\sigma\left(qq' \to \tilde{q}_L\tilde{q}'_L\right) = \sigma\left(qq' \to \tilde{q}_R\tilde{q}'_R\right) = 0 \quad \& \quad \sigma\left(q\bar{q}' \to \tilde{q}_L\tilde{q}'^*_R\right) = 0$$

$$\sigma^{\text{Tot}}_{\text{Dirac}}\left(\tilde{q}\tilde{g}\right) = \sigma^{\text{Tot}}_{\text{Majorana}}\left(\tilde{q}\tilde{g}\right)$$

$$\sigma^{\text{Tot}}_{\text{Dirac}}\left(gg \to \tilde{g}\tilde{g}\right) = \mathbf{2}\,\sigma^{\text{Tot}}_{\text{Majorana}}\left(gg \to \tilde{g}\tilde{g}\right)$$

$U(1)_R$ symmetry

it acts differently on the bosonic and on the fermionic component of a superfield

chiral superfield R

scalar component R

fermionic component R-1

vector superfield R=0

gauge boson R=0

gaugino R=1

$U(1)_R$ symmetry

- Majorana gaugino masses
- Trilinear scalar interaction
- Standard mu term

→ no left right mixing

Larger flavor and CP violation compatible with experimental bounds

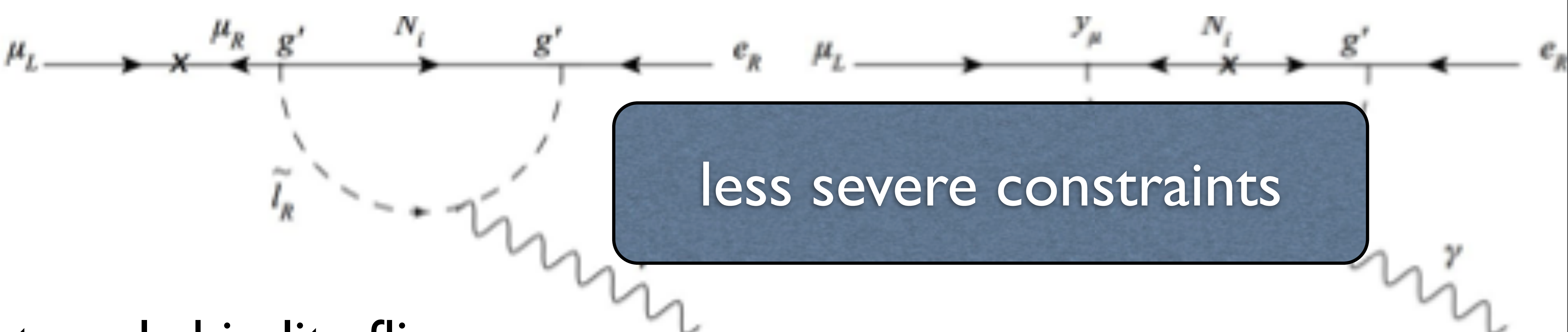
Kribbs, Poppitz, Weiner 07

R symmetry and Flavor

Most of the SUSY flavor problem arise from R violating interactions

e.g. $\mu \longrightarrow e\gamma$

no chirality flip from Majorana mass insertion or μ term



less severe constraints

external chirality flip

suppressed by Yukawa coupling

Larger squark and slepton mixing allowed in R symmetric models

Flavor universality in danger from the LHC searches

might be easier to build UV completion for LHC viable spectrum

MRSSM

Weiner, Poppitz& Kribbs '07

(Minimal R symmetry SUSY extension of the SM)

Standard R charge assignment:
all SM particle are neutral under it
all the BSM are charged under it

Enlarged Higgs sector, two new doublets R_u R_d

Adjoint superfields to have Dirac gauginos

SuperField	R-charge
H_u	0
H_d	0
R_u	2
R_d	2
$\psi_{\tilde{W}}$	0
$\psi_{\tilde{B}}$	0
$\psi_{\tilde{G}}$	0

Enlarged Higgs sector

$$\mathrm{R}(\mathrm{H}_u) = R(H_d) = 0$$

$\mu H_u H_d$ forbidden by the R symmetry

MRSSM solution: add to extra inert doublets

$$\mu_1 H_u R_d + \mu_2 R_u H_d$$

Is the MRSSM the minimal model?

More minimal models

Just two Higgs doublets model as in the MSSM if..

- One Higgs doublet model,
  Davies,March-Russell,McCullogh
- Sneutrino as the down type Higgs,
  CF&T.Grègoire

even more minimal model

The sneutrino is the only Higgs!

Biggio, Pomarol, Riva
2012

R symmetry as the lepton number

Non standard R symmetries

	Q_i	U_i^c	D_i^c	L_i	E_i^c	H_u	H_d	R_u	R_d	S	T	O
$U(1)_{R_1=R_0-L}$	1	1	1	0	2	0	0	2	2	0	0	0
$U(1)_{R_2=R_0+B}$	4/3	2/3	2/3	1	1	0	0	2	2	0	0	0
$U(1)_{R_3=R_0+L}$	1	1	1	2	0	0	0	2	2	0	0	0

They all guarantee proton stability

if the R symmetry is the lepton number then

The sneutrino does not carry R charge/lepton number

a sneutrino VeV does not break lepton number

No Majorana mass for the neutrino induced if the R symmetry is the lepton number then

The sneutrino does not carry R charge/lepton number

a sneutrino VeV does not break lepton number

No Majorana mass for the neutrino induced

Sneutrino can play the role of the down type Higgs H_d

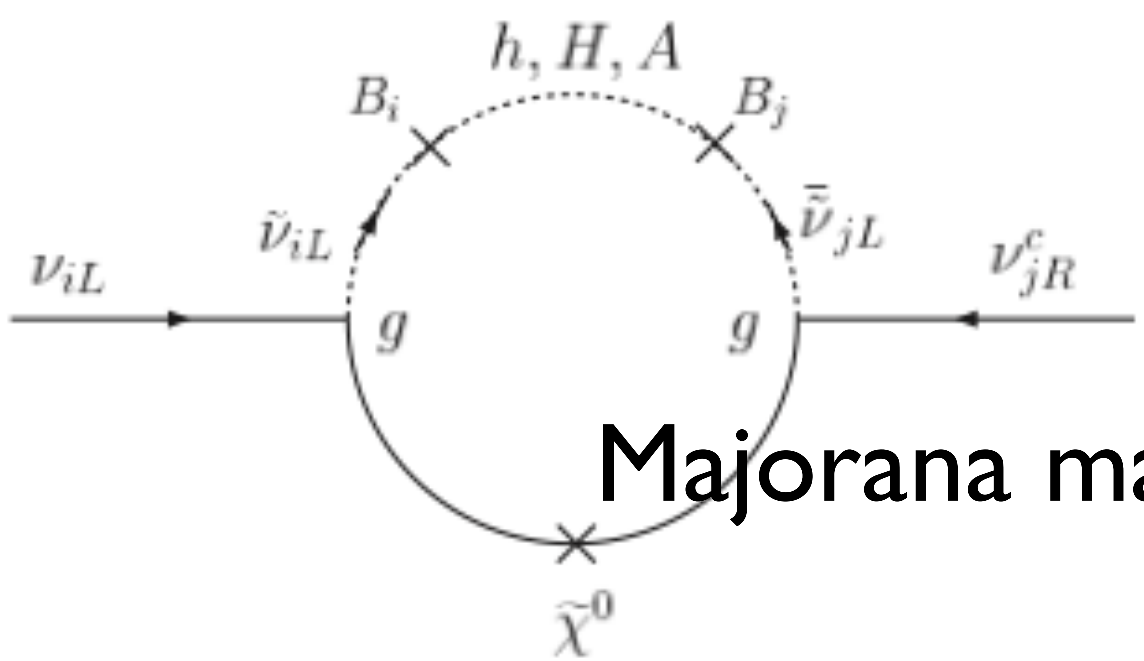
More minimal particle content than in the MRSSM

two higgs doublets instead of four!

Large sneutrino vev

$\mathrm{B}_i h_u \tilde{l}_i$ bilinear RPV

In the MSSM neutrino mass at one loop



Majorana mass insertion necessary!

No neutrino mass generated in our case!

Bounds on the sneutrino vev

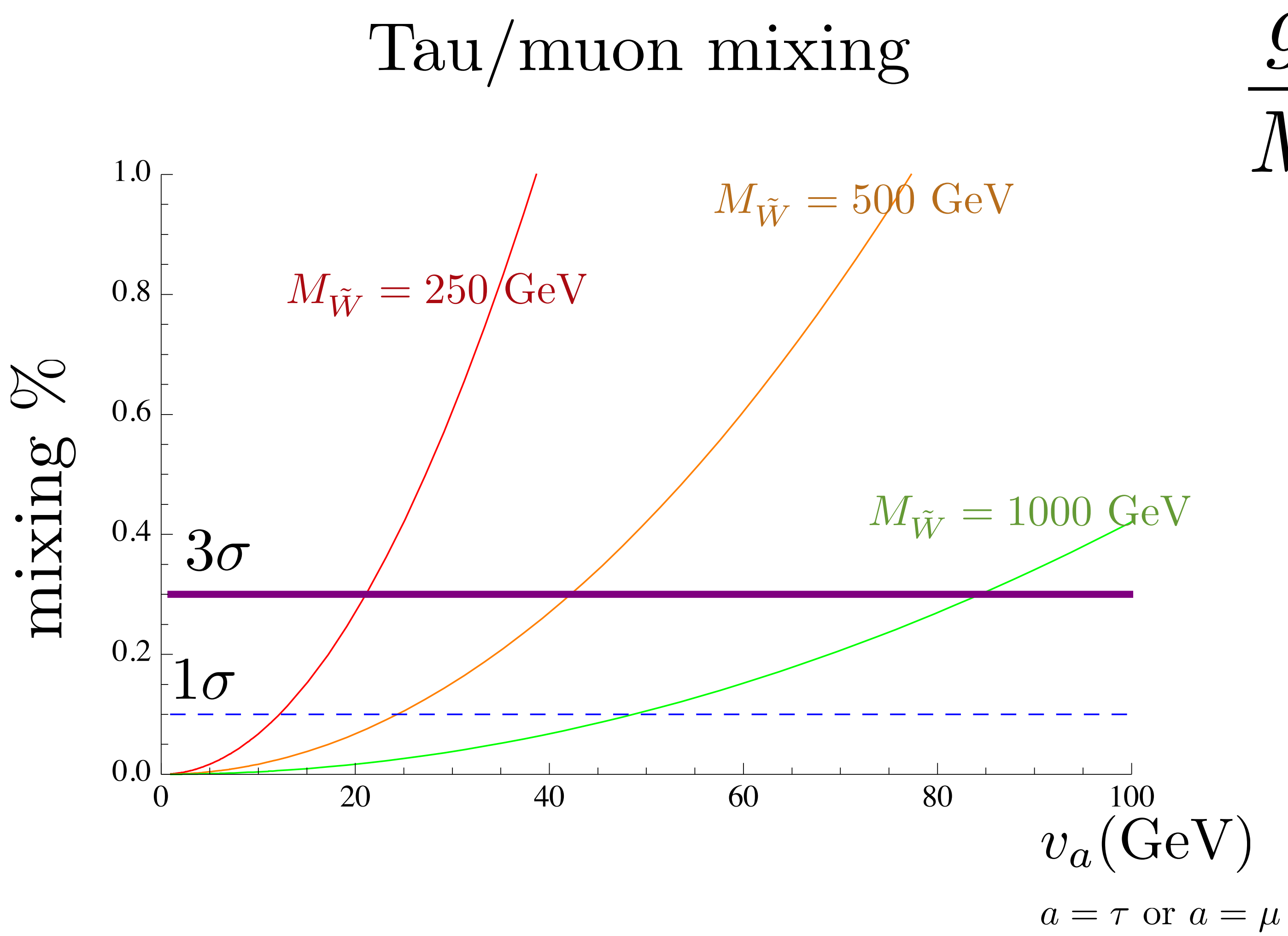
Leptons as the lightest charginos and neutralinos

$$l'^{\pm}_a = \cos\phi \; l^{\pm}_a + \sin\phi \; \psi^{\pm}_{\tilde{W}},$$

$$\nu'_a = c_\nu \nu_a + c_{\tilde{B}} \psi_{\tilde{B}} + c_{\tilde{W}} \psi_{\tilde{W}},$$

$$a = e, \mu, \tau$$

Constraints from gauge bosons coupling to leptons



$$\frac{g v_a}{M_{\tilde{W}}}$$ → mixing

Heavier wino larger sneutrino VeV

no stringent bounds from lepton universality violation

More minimal particle content

single vev basis: just one sneutrino acquires vev

$$H_d \longrightarrow L_a$$

$$a = e \text{ or } \mu \text{ or } \tau$$

higgsino mass

$$W = \mathbf{y}_u \bar{u} Q H_u - \mathbf{y}_d \bar{d} Q L_a - y_l l^c L L_a + \boxed{\mu H_u R_d}$$

$$R(H_u) = 0 \qquad R(R_d) = 2$$ inert doublet

Minimal particle content just two higgs doublets!

Trilinear RPV

$$W_{Yukawa} = y_b^a L_a L_b e_b^c + y_c^a L_a L_c e_c^c + y_{di}^a L_a Q_i d_i^c,$$

down type Yukawa couplings RPV couplings

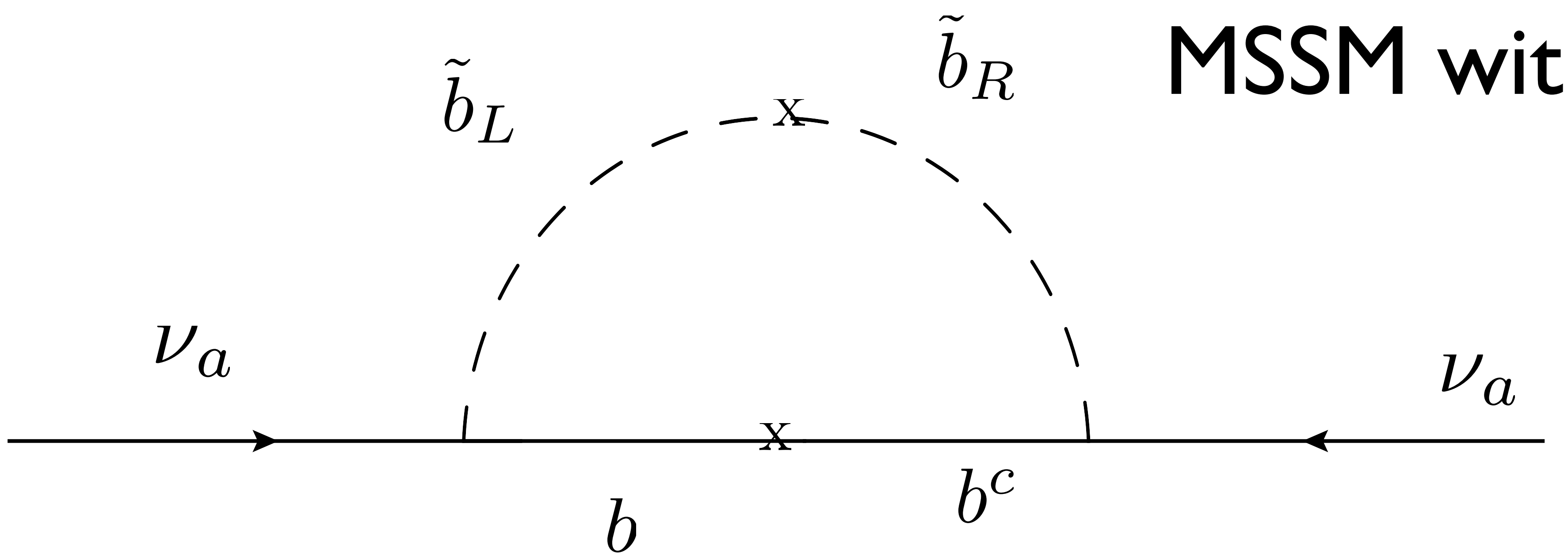
$$W_{trilinear} = \sum_{i=a,b,c} \lambda_{bci} L_b L_c e_i^c + \sum_{ij} (\lambda'_{bij} L_b Q_i d_j^c + \lambda'_{cij} L_c Q_i d_j^c),$$

RPV is violated since standard lepton number is violated

but different constraints:
no bounds from neutrino physics!

Larger trilinear RPV couplings

MSSM with leptonic RPV



left right mixing

In the R symmetric limit the neutrino remain massless

no neutrino bounds on the trilinear couplings

Leptoquarks(LQ)

R symmetry
lepton number

$\lambda'_{i33} \sim 1$ RPV MSSM $\lambda'_{i33} \sim 10^{-3}$

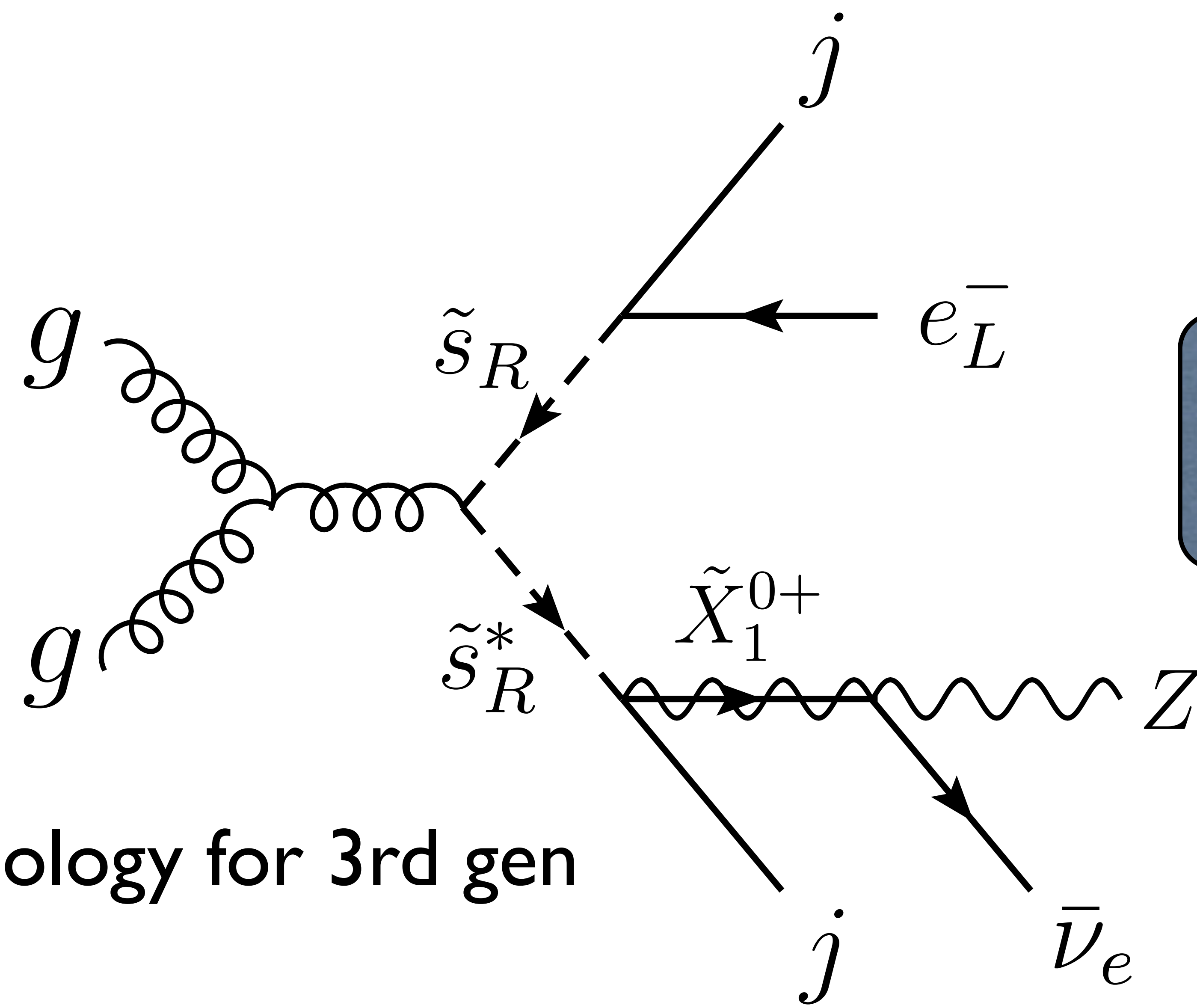
Leptoquarks signals are generic LHC signatures!

sizeable BR for $\tilde{t}_L \longrightarrow bl$ $\tilde{b}_L \longrightarrow b\nu$ $\tilde{s}_R \rightarrow lj$

Third generation leptoquarks

Mixed topologies

λ' can 'compete' with gauge or large Yukawa couplings



smoking gun signal

same topology for 3rd gen

Different RPV pheno

LHC PHENO

with T. Grègoire,P.Kumar and E.Pontòn

hep-ph1210.5257
hep-ph1210.0541

Benchmark spectrum

- Heavy gauginos (> 1 TeV)
- electron sneutrino as the down type Higgs
- natural spectrum, $\mu < 250\ GeV$
- light sleptons (EW scale)

In our scenario naturalness requires also light sleptons!

typically the higgsino or the sleptons are the LSP

In this talk higgsino LSP

Neutralinos and charginos

the electron and neutrino of flavor a mix with charginos and neutralinos

$$\tilde{\chi}_i^{0+} = V^N_{i\tilde{b}}\, \tilde{b} + V^N_{i\tilde{w}}\, \tilde{w} + V^N_{id}\, \tilde{h}^0_d \,,$$
$$\tilde{\chi}_i^{0-} = U^N_{i\tilde{s}}\, \tilde{s} + U^N_{i\tilde{t}}\, \tilde{T}^0 + U^N_{iu}\, \tilde{h}^0_u + U^N_{i\nu}\, \nu_e \,,$$

higgsino LSP

$$\chi_1^0 \to Z\nu_e$$
$$\chi_1^0 \to h\nu_e$$
$$\chi_1^0 \to We$$
$$\chi_1^\pm \to W\nu_e$$

prompt decays

In the standard RPV scenarios strong bounds on sneutrino vev implies long lived neutralino/chargino or displaced vertex

1st & 2nd generation

no significant BR for leptoquark channels

$$\tilde{q} \rightarrow \chi_1^0 q \qquad \tilde{q} \rightarrow \chi_1^{\pm} q'$$

most sensitive search: ATLAS jet+MET 5.8 fb^-1

multileptons CMS and ATLAS searches

$$\chi_1^0 \rightarrow W e$$

Mass bound around 550-650 GeV

still room for a rich subTeV LHC pheno!

3rd generation

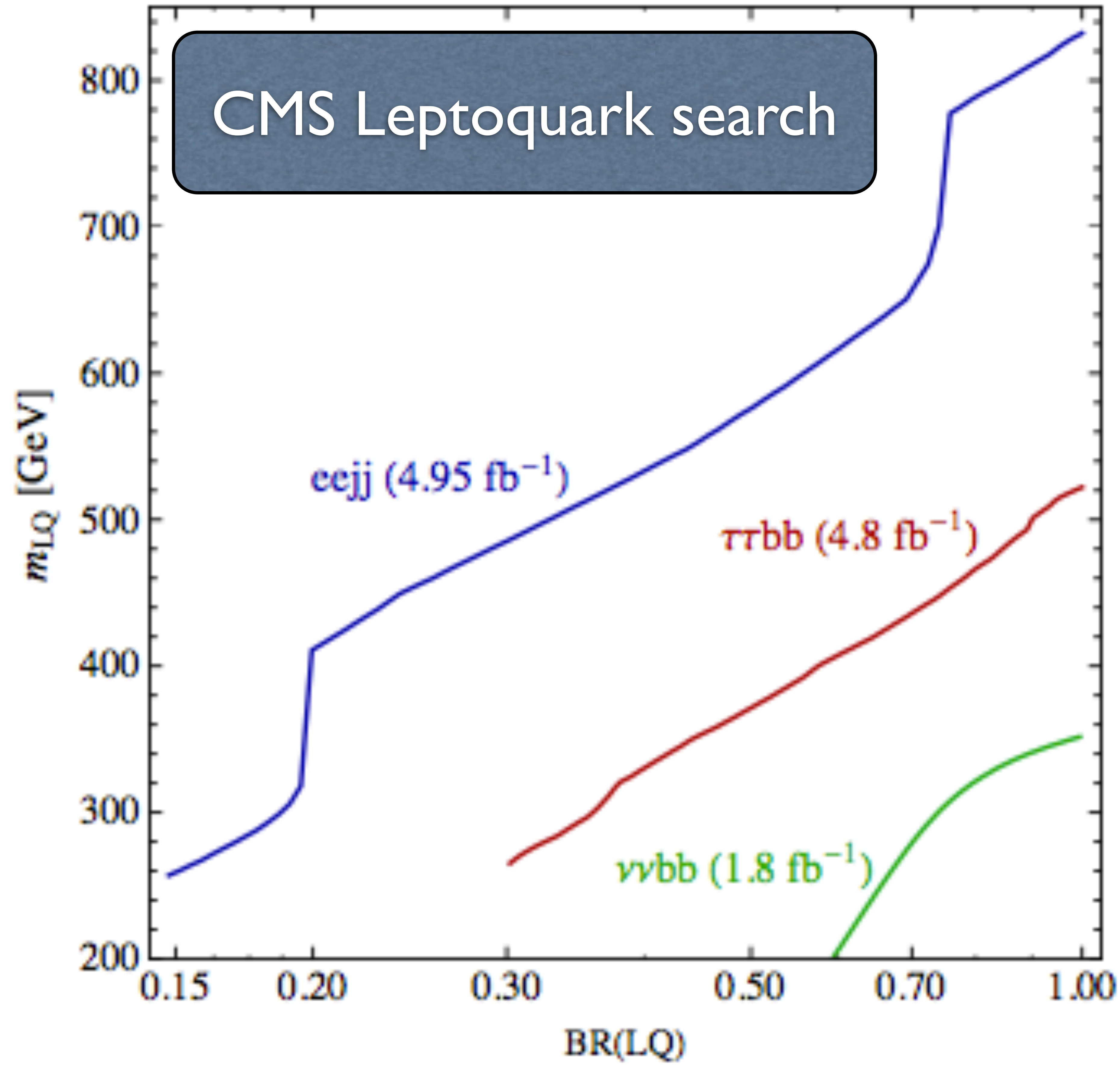
Leptoquark (LQ) signal

- $\tilde{t}_L \to be$ through the bottom yukawa
- $\tilde{t}_L \to \tau b$ through the coupling

$y_b = \lambda'_{133}$ λ'_{333}

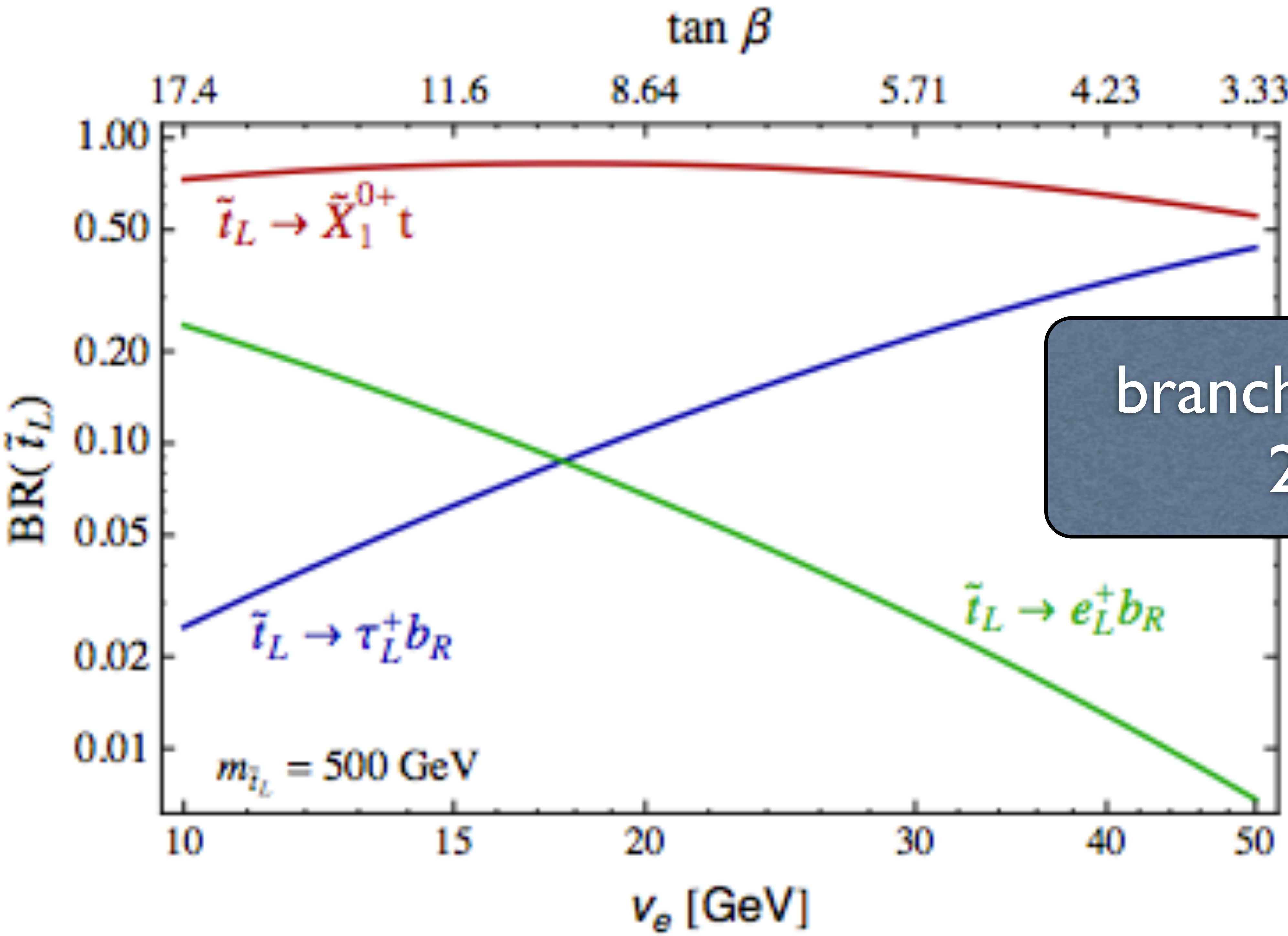
max $\lambda'_{333} \sim\sim \frac{10^{-2}}{y_b}$

b tagging in first gen. LQ searches


CMS Leptoquark search
800
700
600
500
400
300
200
m_{LQ} [GeV]
eejj (4.95 fb^{-1})
ττbb (4.8 fb^{-1})
ννbb (1.8 fb^{-1})
0.15
0.20
0.30
0.50
0.70
1.00
BR(LQ)

no b tag

Still room for a light third generation

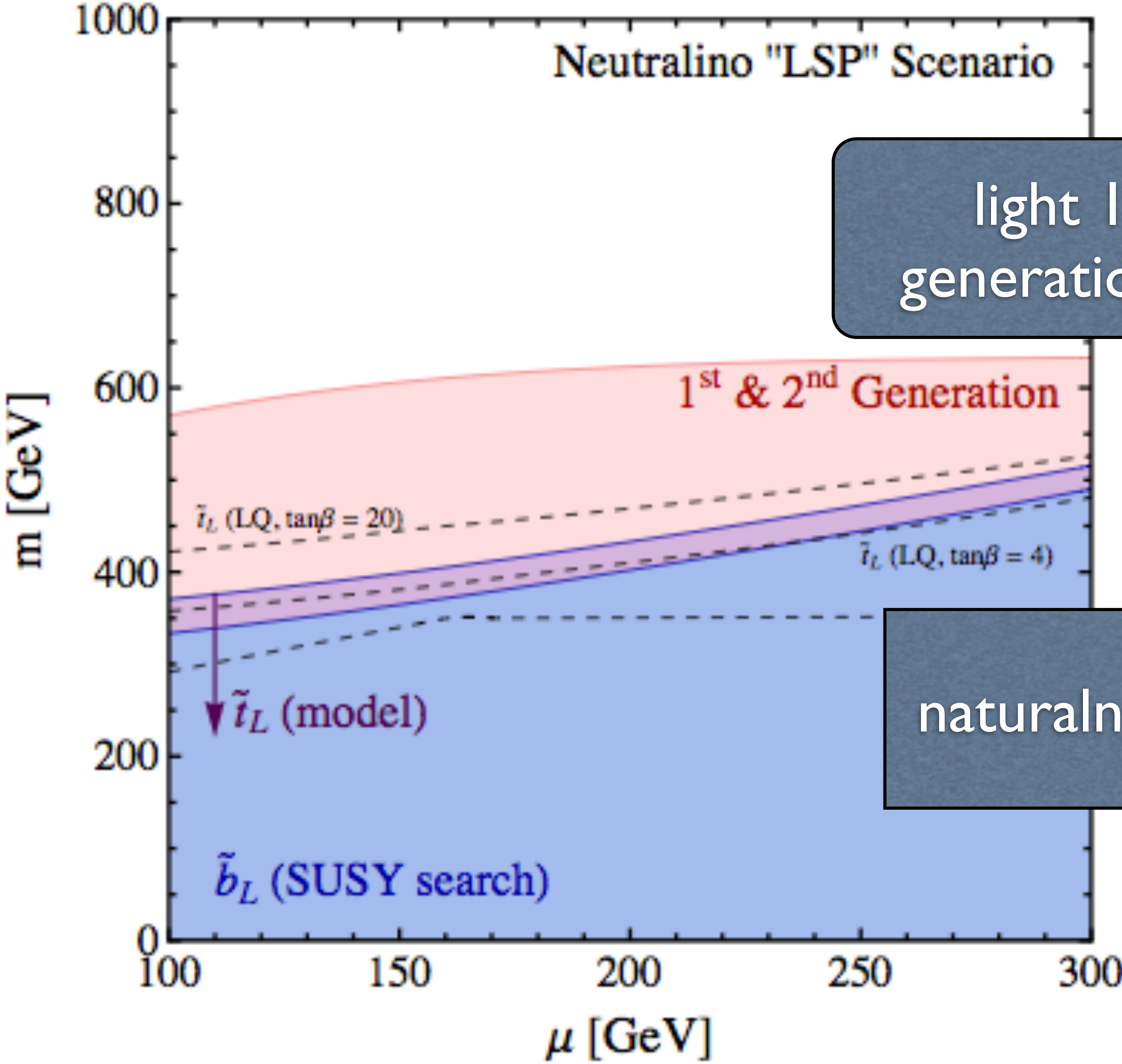


branching ratio
20%

Standard RPV: natural region ruled out

LQ channel visible JUST if the 3rd generation is the LSP

Summary of the bounds



light 1st&2nd generation squarks

naturalness still alive

R breaking and neutrino physics

in collaboration with E. Bertuzzo

hep-ph 1203.5340

Anomaly mediated R breaking

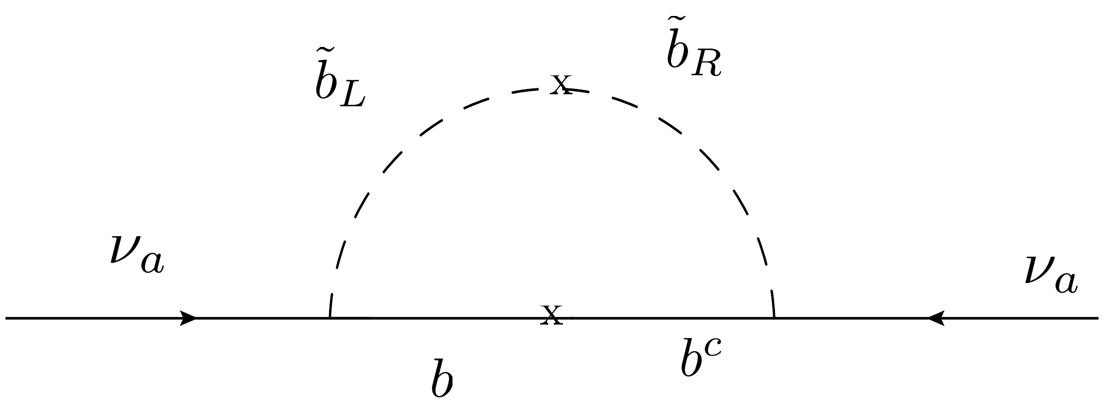
R symmetry is not exact. Broken by gravitino mass

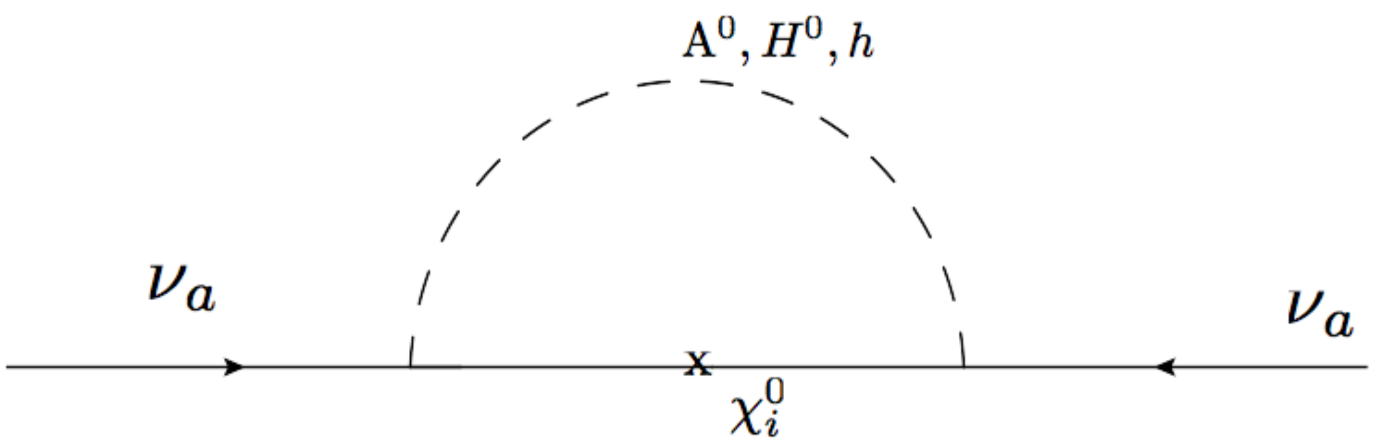
→ R breaking communicated to the visibile sector through anomaly mediation

Majorana mass for gauginos and trilinear coupling generated!

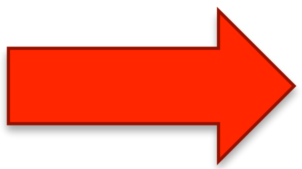
$$\mathcal{L}_{AM} = A^u \tilde{u}_r \tilde{q}_L H_u - A^d \tilde{d}_R \tilde{q}_L \tilde{l}_a - A^l \tilde{l}_a \tilde{l} \tilde{e}_R + M_{\lambda_{\tilde{B}}} \lambda_{\tilde{B}} \lambda_{\tilde{B}} + M_{\lambda_{\tilde{W}}} \lambda_{\tilde{W}} \lambda_{\tilde{W}} + M_{\lambda_{\tilde{g}}} \lambda_{\tilde{g}} \lambda_{\tilde{g}},$$

Neutrino mass generated at one loop!





$$m_{\nu_a} < 1eV$$



Bounds on gravitino mass

$$\mathrm{m}_{3/2} < 100\ MeV$$

Fitting neutrino physics

Neutrino masses and mixings can be introduced without the need of additional degrees of freedom or scale

Normal or inverted hierarchy?

it depends on the sneutrino higgs flavor

electronic inverted hierarchy
muonic both/ taunic none

Gravitino dark matter candidate ?

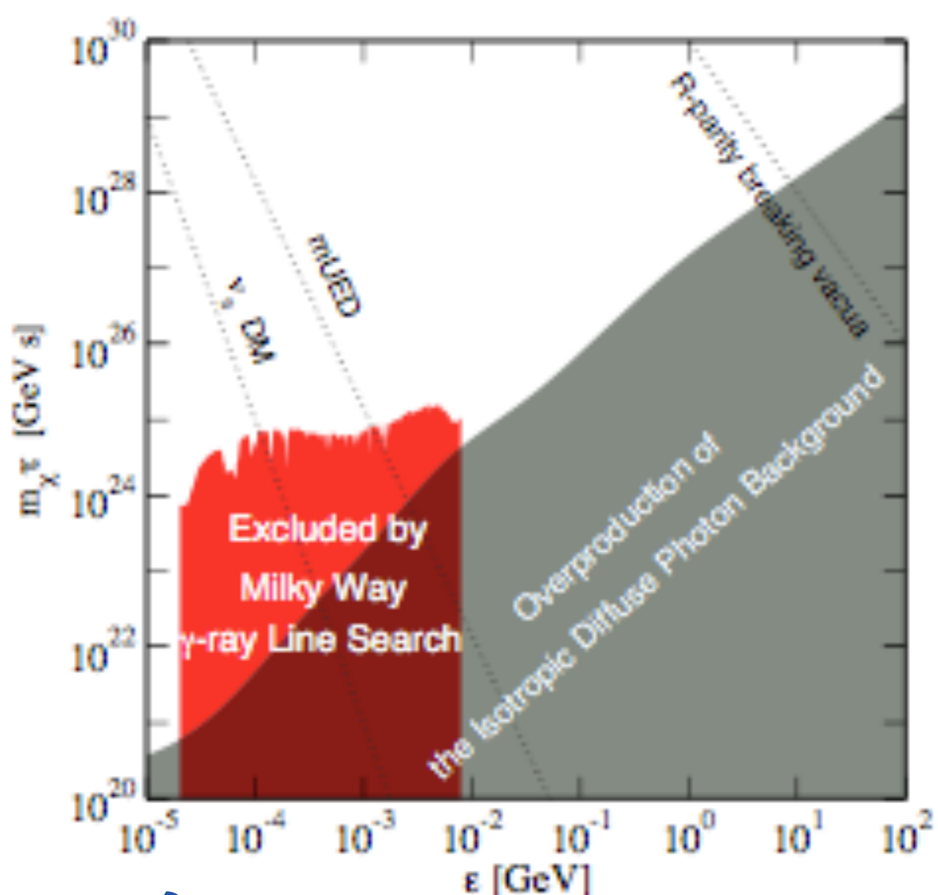
$$1MeV < m_{3/2} < 50MeV$$

$$\tilde{G} \rightarrow \nu_e \gamma$$

$$\tau_{3/2} \sim 10^{28} - 10^{30} s$$

$$\tau > \tau_{universe}$$

life time large enough
to avoid experimental constraints



is it the dominant form of dark matter ?

Conclusions

Summarizing..

- Dirac gauginos well motivated alternative to the MSSM
- Different LHC phenomenology from the MSSM (generic leptoquark signatures- prompt RPV neutralino decays)..but the LHC will not miss it!

Still room for a rich and visible sub TeV LHC pheno!

3rd generation phenomenology and the R symmetry

Some work in progress...

Third generation squarks always decay into third generation quarks

this makes easier to find them: b tagging and/or leptons from top quarks

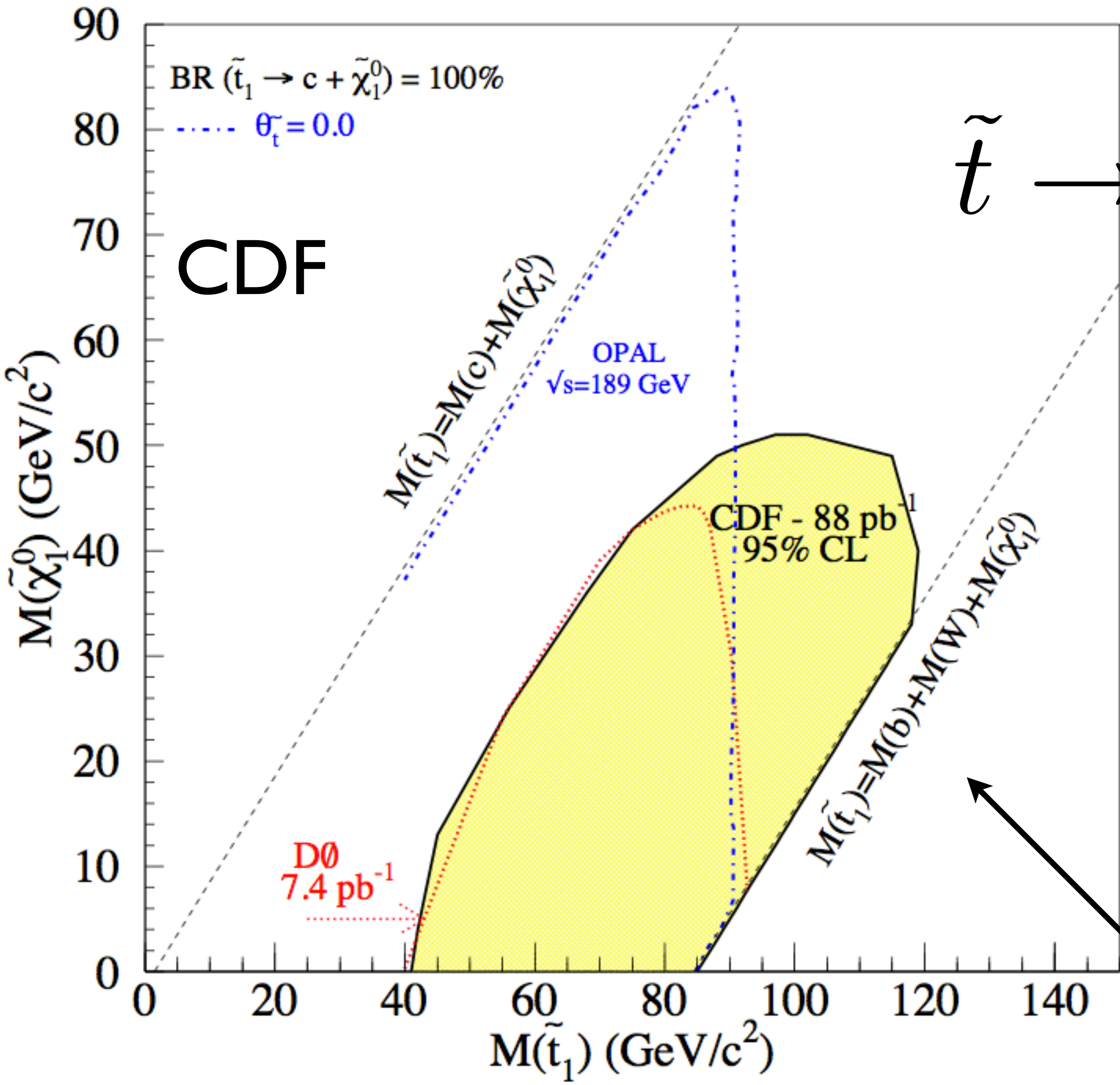
$$\delta \sim \frac{M_{ij}^2}{M_{\tilde{q}}^2} \sim 1$$ Large squark mixing

$$\Rightarrow \quad \tilde{t} \rightarrow j \; LSP$$

$$m_{\tilde{t}} < m_{LSP} + m_t$$

dominant decay mode in a larger region of the parameter space than in the MSSM

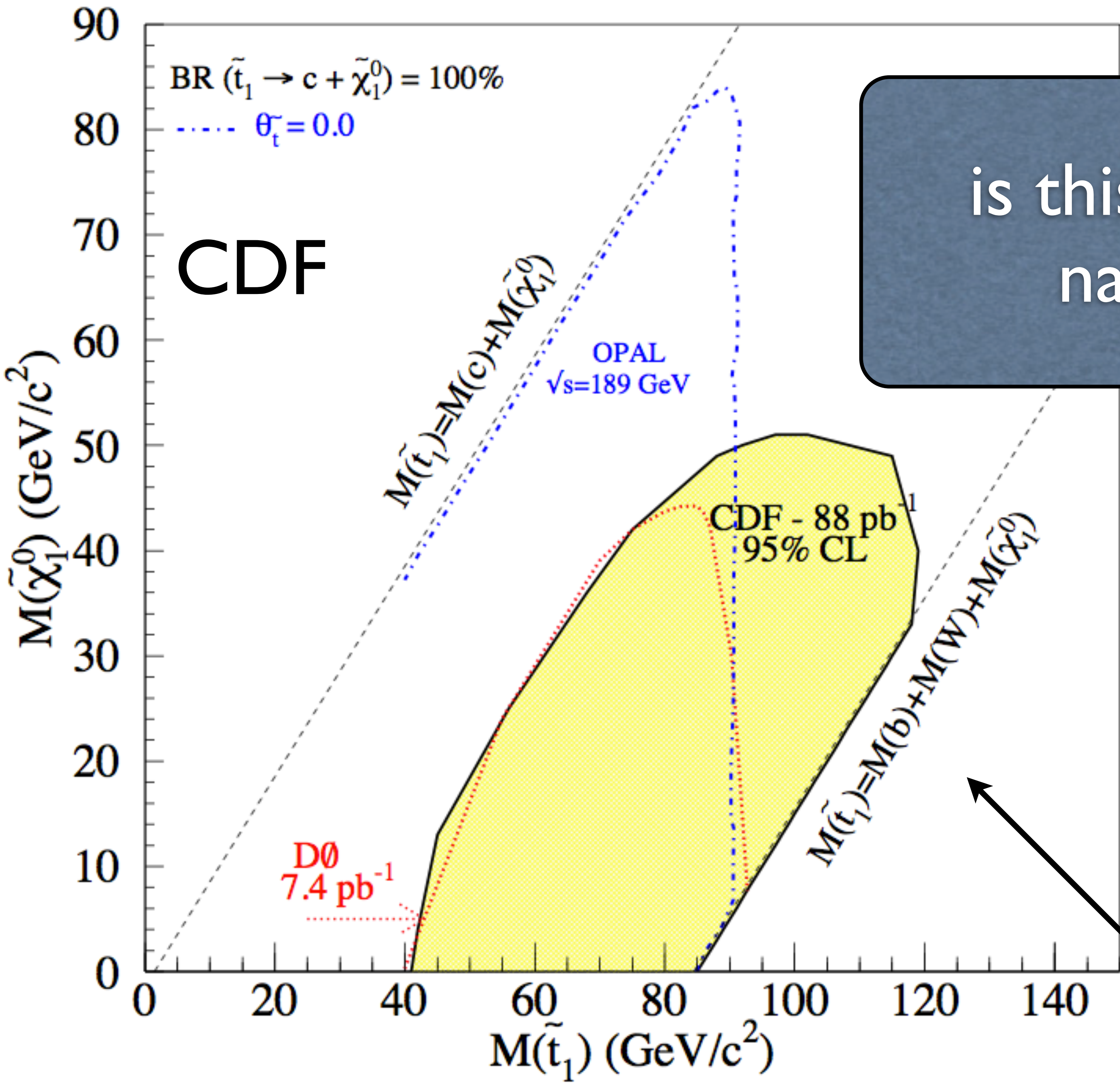
Tevatron covered all the parameter space relevant for the MSSM



$$\tilde{t} \to c\, LSP$$

region significant for us, but not for the MSSM

Tevatron covered all the parameter space relevant for the MSSM



is this a way to hide natural SUSY?

region significant for us, but not for the MSSM no LHC dedicated searches for this topology, but other searches might be sensitive

Monojets searches in the compressed spectrum region

Jet+MET for larger mass splitting

LHC is doing a very good job to look for SUSY beyond the MSSM

However..different interpretation of possible discoveries

b jets or top quark does not mean necessarily 3rd generation squarks

Heavy squarks in channels with heavy quarks does not mean fine tuning!