Lepton flavour violation and dark matter in a SUSY Left-Right model

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Based on work in collaboration with

J. Esteves, M. Hirsch, W. Porod, J. Romão and F. Staub

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[arXiv:1109.6478]

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Introduction

Motivation

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- The extension must account for the **smallness of neutrino masses**

$\longrightarrow$ Seesaw mechanism

- And lead to **new predictions**!

$\longrightarrow$ Seesaw models:

  - No chance for direct production
  - Only indirect tests are possible

Motivation

In Supersymmetry, **R-parity** is usually introduced **by hand**, without any theoretical argument supporting it.

Idea: R-parity is the remnant subgroup after the breaking of a continuous $U(1)_{B-L}$ gauge symmetry

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Idea: R-parity is the remnant subgroup after the breaking of a continuous $U(1)_{B-L}$ gauge symmetry

- **Left-Right symmetry :** $\mathbf{SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}}$
  - $\star$ Restoration of parity at high energies
  - $\star$ Natural framework for the seesaw mechanism $\rightarrow$ neutrino masses
  - $\star$ Provides technical solutions to SUSY and strong CP problems
  - $\star$ Gives an understanding for the $U(1)$ charges
  - $\star$ Can be easily embedded in $SO(10)$ GUTs

Basic setup

Indirect tests of physics at high energies are possible thanks to the **RGE running**.

- Universal (and flavour diagonal) soft terms at the GUT scale
  - ⋆ CMSSM-like boundary conditions
- RGE running from GUT to SUSY/EW scale

$$m_{GUT} \longrightarrow \text{Intermediate scales} \longrightarrow m_{SUSY}$$

- The SUSY spectrum gets deformed (w.r.t. the CMSSM) and LFV is induced

Left vs Right

In minimal seesaw models LFV is generated **only for the left-handed sleptons**.

- ⋆ **Example:** Type-I seesaw. e^c only couples through the flavour diagonal charged lepton Yukawa Y_e.
- ⋆ No chances to observe LFV in the **right slepton sector**.

However, in a LR extended version of the seesaw, $L^c = (e^c, \nu^c)$ couples exactly like the left-handed doublet $L = (\nu, e)$.

The model

Omega LR

Aulakh *et al*, Phys. Rev. Lett. 79, 2188 (1997)
Aulakh *et al*, Phys. Rev. D 58, 115007 (1998)

Besides the usual MSSM representations:

	$SU(3)_c$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$	
Δ	1	3	1	2	
Δ^c	1	1	3	-2	$\Rightarrow f L^c \Delta^c L^c$
$\bar{\Delta}$	1	3	1	-2	$\Downarrow$
$\bar{\Delta}^c$	1	1	3	2	$\mathbf{f\, v_{BL}\, \nu^c \nu^c}$
Ω	1	3	1	0	RH neutrinos mass
Ω^c	1	1	3	0	**Seesaw mechanism**

The $B - L = 0$ triplets have important contributions to the **tree-level scalar potential**, allowing for **R-parity conservation**, without the necessity of higher order corrections (Kuchimanchi, Mohapatra, 1993 and Babu, Mohapatra, 2008).

Symmetry breaking

$$\mathbf{SU(2)_R \times U(1)_{B-L}}$$

$$\downarrow$$

$$\langle \Omega^c \rangle = \frac{v_R}{\sqrt{2}}$$

Parity breaking scale

$$\mathbf{U(1)_R \times U(1)_{B-L}}$$

$$\downarrow$$

$$\langle \Delta^c \rangle = \langle \bar{\Delta}^c \rangle = \frac{v_{BL}}{\sqrt{2}}$$

Seesaw scale

$$\mathbf{U(1)_Y}$$

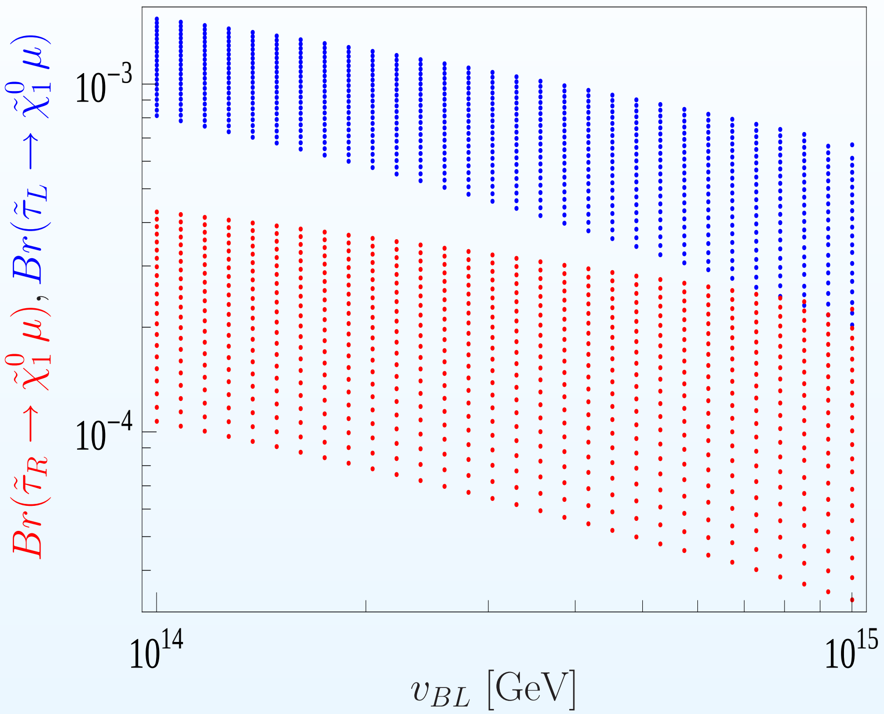
Lepton Flavor Violation

Left vs Right

SPS3 benchmark point

Y_ν fit

$M_S = 10^{13}$ GeV , $v_R \in [10^{15}, 5 \cdot 10^{15}]$ GeV



- There are regions of parameter space with observable rates for LFV in the right-handed slepton sector
- Closer $v_{BL} - v_R$ implies closer $Br(\tilde{\tau}_L) - Br(\tilde{\tau}_R)$
- Indirect hint on the ratio v_{BL}/v_R

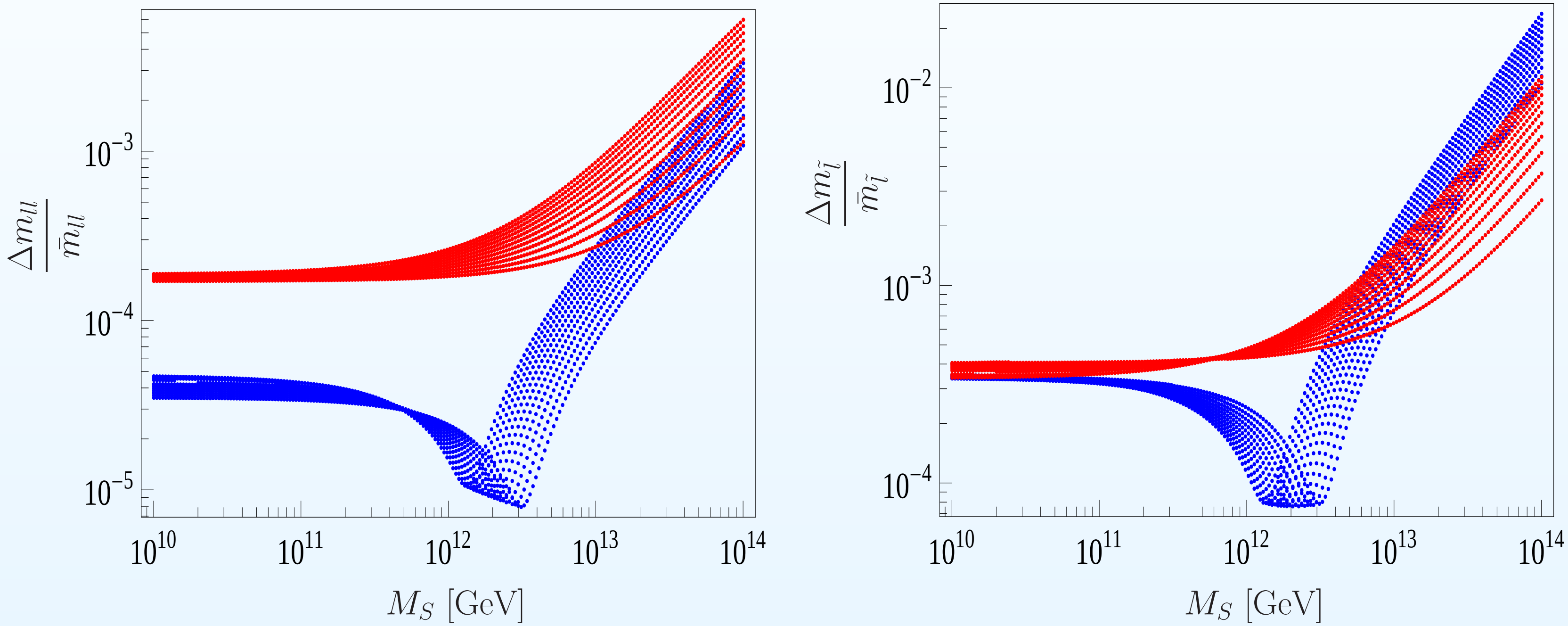
$\tilde{e} - \tilde{\mu}$ mass splitting

SPS3 benchmark point

Y_ν fit

$v_{BL} = 10^{15}$ GeV , $v_R \in [10^{15}, 10^{16}]$ GeV

$$\tilde{\chi}_2^0 \to \tilde{l}^\pm l^\mp \to \tilde{\chi}_1^0 l^\pm l^\mp$$



- Sizeable splittings $m_{\tilde{e}} - m_{\tilde{\mu}}$ due to RGE running in the **L** and **R** sectors.
- Sensitivities around 10^{-3} can be reached at the LHC.

  $\Rightarrow$ a **LC** can do much better! ($\sim 10^{-5} - 10^{-4}$)
- Deviations from the mSUGRA prediction ($m_{\tilde{e}} \simeq m_{\tilde{\mu}}$) can be measurable.

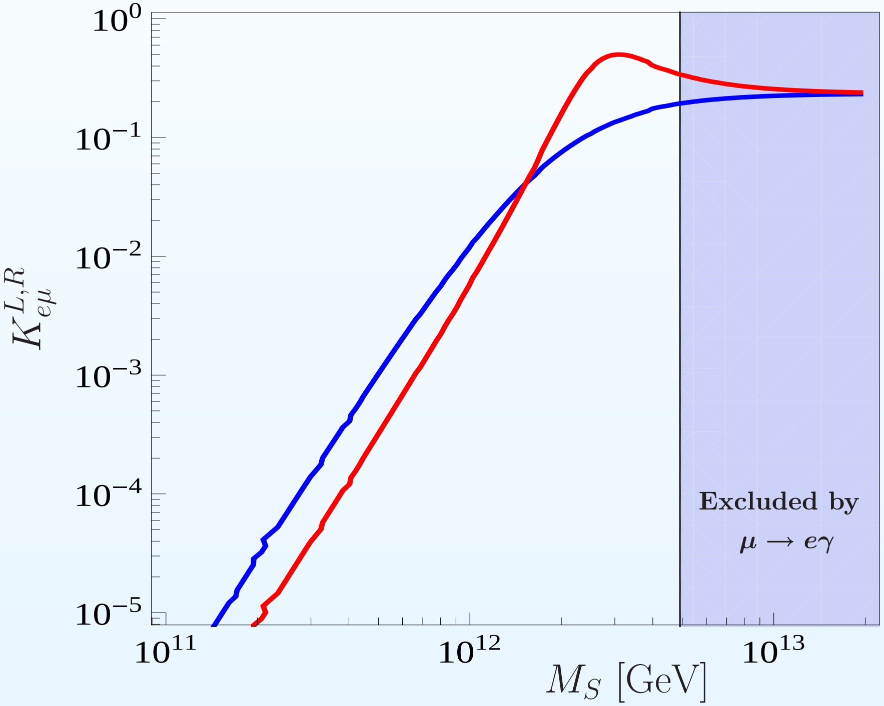
$\tilde{\chi}_2^0$ decays and LFV

SPS3 benchmark point

f fit

$v_{BL} = 10^{15}$ GeV , $v_R = 5 \cdot 10^{15}$ GeV

$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \, l_i \, l_j \text{ with } i \neq j$$



$K_{e\mu}$ defined as

$$\frac{Br(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 e\mu)}{Br(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 ee) + Br(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \mu\mu)}$$

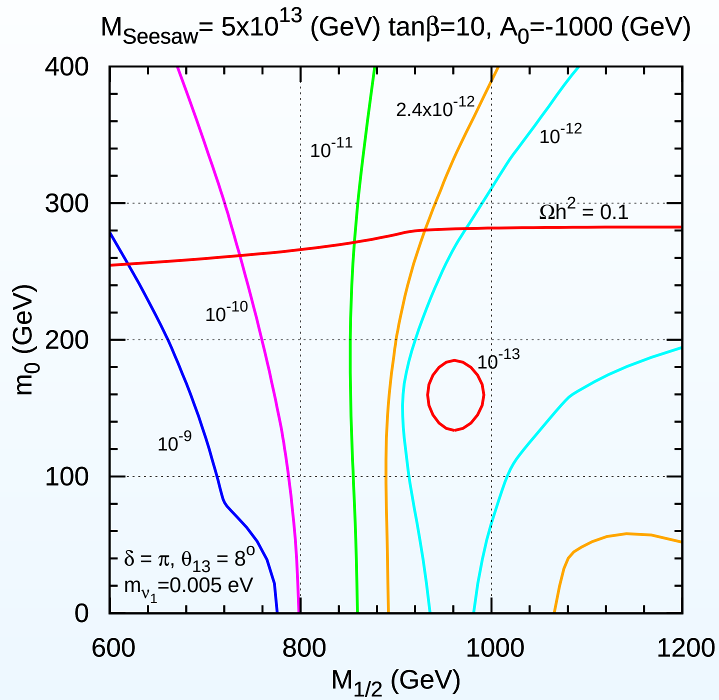
If the intermediate L and R sleptons are on-shell (as in SPS3) one can distinguish between $K_{e\mu}^L$ and $K_{e\mu}^R$ and find LFV in both sectors

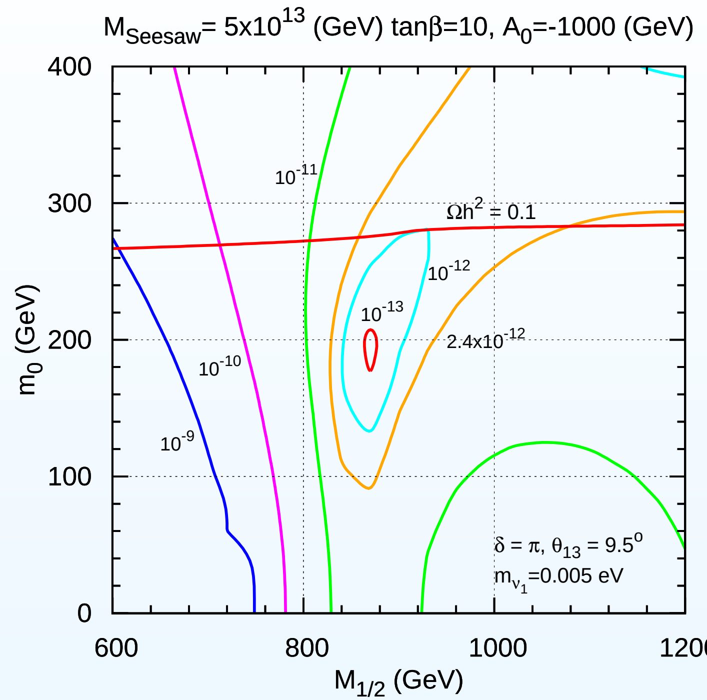
This signal can be discovered at the LHC if $K_{e\mu} \geq 0.04$

See Andreev et al., Phys. Atom. Nucl. 70 (2007) 1717

Dark Matter

Flavoured coannihilation





Flavoured coannihilation:

- $\tilde{\tau}_R$ mass: $m(\tilde{\tau}_R) = m(\tilde{\tau}_R)_{CMSSM} + \Delta_{flavour}$
- Flavour processes contributing to the determination of the **relic abundance**

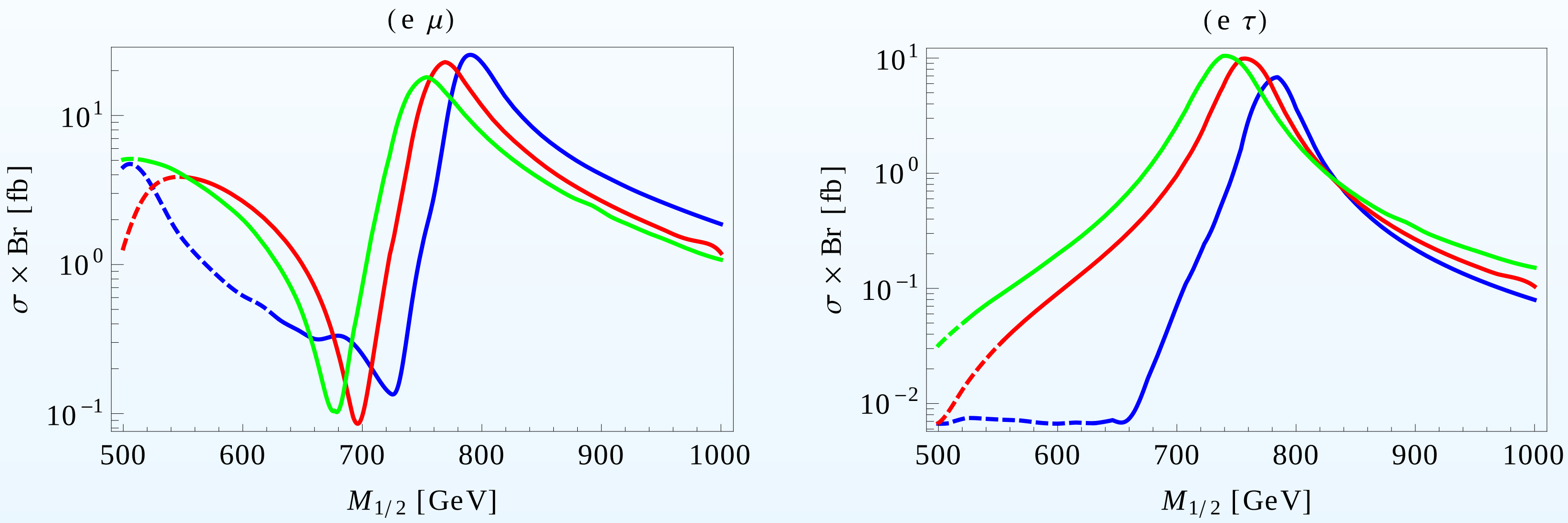
Possible thanks to flavour violation in the **R slepton sector**

(see Choudhury et al. arXiv:1104.4467)

Flavoured coannihilation at colliders

$\sqrt{s} = 14$ TeV
$m_0 = 100$ GeV, $A_0 = 0$, $\tan\beta = 10$
$v_{BL} = v_R = \{10^{14}, 5 \cdot 10^{14}, 10^{15}\}$ GeV

$$\mathbf{pp \to \tilde{\chi}_2^0 X \to \tilde{\chi}_1^0 l^{\pm} l^{\mp} X}$$



(Similar results in the $\mu\tau$ channel)

- Large LFV signals are found in regions with **flavoured coannihilation** ($\sigma \times$ BR can go up to $\sim 10 - 30$ fb)
- Good perspectives for the LHC

Summary and conclusions

Summary

- ⋆ SUSY Left-Right models are well motivated extensions of the MSSM, with automatic R-parity conservation and seesaw mechanism.
- ⋆ Contrary to minimal seesaw implementations, there are regions of parameter space where LFV is also observable in the R sector. Such observation would clearly point to an underlying Left-Right symmetry.
- ⋆ In addition, dark matter phenomenology can clearly depart from the CMSSM expectations.

Backup slides

Neutrino data

Parameter	Best fit	2σ	3σ
Δm^2_{21} $[10^{-5}\text{eV}^2]$	$7.59^{+0.23}_{-0.18}$	7.22–8.03	7.02–8.27
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\text{eV}^2]$	$2.40^{+0.12}_{-0.11}$	2.18–2.64	2.07–2.75
$\sin^2\theta_{12}$	$0.318^{+0.019}_{-0.016}$	0.29–0.36	0.27–0.38
$\sin^2\theta_{23}$	$0.50^{+0.07}_{-0.06}$	0.39–0.63	0.36–0.67
$\sin^2\theta_{13}$	$0.013^{+0.013}_{-0.009}$	$\leq$ 0.039	$\leq$ 0.053

Taken from Schwetz *et al*, New J. Phys. 10 (2008) 113011 *[arXiv:0808.2016v3]*

- Hierarchy between atmospheric and solar mass scales
- Two large mixing angles
- One small (maybe zero?) mixing angle

CMSSM benchmark points

Point	m_0	$M_{1/2}$	A_0	$\tan\beta$	$sign(\mu)$
SPS1a'	70 GeV	250 GeV	-300 GeV	10	+
SPS3	90 GeV	400 GeV	0 GeV	10	+
SPS4	400 GeV	300 GeV	0 GeV	50	+
SPS5	150 GeV	300 GeV	-1000 GeV	5	+
SU4	200 GeV	160 GeV	-400 GeV	10	+
Om1	280 GeV	250 GeV	-500 GeV	10	+
LM1	60 GeV	250 GeV	0 GeV	10	+

LR models - Case 1: Doublet models

R. N. Mohapatra and G. Senjanovic, Phys. Rev. D 12, 1502 (1975)

In the **first LR models** doublets were chosen to break the LR symmetry.

	$SU(3)_c$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$
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χ^c	1	1	2	-1

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However . . .

- R-parity gets broken unless additional discrete symmetries are imposed by hand
- There is no seesaw mechanism

LR models - Case 2: MSUSYLR

M. Cvetic and J. C. Pati, Phys. Lett. 135, 57 (1984)

The so-called **Minimal SUSY Left-Right** (MSUSYLR) model breaks the LR symmetry with **triplets** instead of doublets.

	$SU(3)_c$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$
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RH neutrinos mass

Seesaw mechanism

However . . .

- A detailed analysis of the scalar potential shows that **R-parity gets broken by $\langle \tilde{\nu}^c \rangle \neq 0$**. Kuchimanchi, Mohapatra, PRD 48, 4352 (1993).

  $\rightarrow$ This is **controversial** : 1-loop corrections must be taken very seriously.

How to break the LR symmetry

$$\mathbf{SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}}$$
$$\downarrow$$
$$\mathbf{SU(3)_c \times SU(2)_L \times U(1)_Y}$$

Requirements:

- Automatic conservation of R-parity
- Seesaw mechanism
- Parity conservation at high energies
- Cancellation of anomalies

Omega LR: Superpotential and soft terms

$$\begin{aligned}
\mathcal{W} &= Y_Q Q \Phi Q^c + Y_L L \Phi L^c - \frac{\mu}{2}\Phi\Phi + f L \Delta L + f^* L^c \Delta^c L^c \\
&+ a \Delta \Omega \bar{\Delta} + a^* \Delta^c \Omega^c \bar{\Delta}^c + \alpha \Omega \Phi \Phi + \alpha^* \Omega^c \Phi \Phi \\
&+ M_\Delta \Delta \bar{\Delta} + M_\Delta^* \Delta^c \bar{\Delta}^c + M_\Omega \Omega \Omega + M_\Omega^* \Omega^c \Omega^c
\end{aligned}$$

$$\begin{aligned}
-\mathcal{L}_{soft} &= m_Q^2 \tilde{Q}^\dagger \tilde{Q} + m_{Q^c}^2 \tilde{Q^c}^\dagger \tilde{Q^c} + m_L^2 \tilde{L}^\dagger \tilde{L} + m_{L^c}^2 \tilde{L^c}^\dagger \tilde{L^c} \\
&+ m_\Delta^2 \Delta^\dagger \Delta + m_{\bar{\Delta}}^2 \bar{\Delta}^\dagger \bar{\Delta} + m_{\Delta^c}^2 \Delta^{c\dagger} \Delta^c + m_{\bar{\Delta}^c}^2 \bar{\Delta}^{c\,\dagger} \bar{\Delta}^c \\
&+ m_\Phi^2 \Phi^\dagger \Phi + m_\Omega^2 \Omega^\dagger \Omega + m_{\Omega^c}^2 \Omega^{c\dagger} \Omega^c \\
&+ \frac{1}{2}\Big[M_1 \tilde{B}^0 \tilde{B}^0 + M_2 (\tilde{W}_L \tilde{W}_L + \tilde{W}_R \tilde{W}_R) + M_3 \tilde{g}\tilde{g} + h.c.\Big] \\
&+ \Big[T_Q \tilde{Q} \Phi \tilde{Q^c} + T_L \tilde{L} \Phi \tilde{L^c} + T_f \tilde{L} \Delta \tilde{L} + T_f^* \tilde{L^c} \Delta^c \tilde{L^c} + T_a \Delta \Omega \bar{\Delta} \\
&+ T_a^* \Delta^c \Omega^c \bar{\Delta}^c + T_\alpha \Omega \Phi \Phi + T_\alpha^* \Omega^c \Phi \Phi + B_\mu \Phi \Phi \\
&+ B_{M_\Delta} \Delta \bar{\Delta} + {B_{M_\Delta}}^* \Delta^c \bar{\Delta}^c + B_{M_\Omega} \Omega \Omega + {B_{M_\Omega}}^* \Omega^c \Omega^c + h.c.\Big]
\end{aligned}$$

A comment on bidoublets

In LR models the MSSM Higgses are introduced as **bidoublets**

$$\Phi = \begin{bmatrix} H_d^0 & H_u^+ \\ H_d^- & H_u^0 \end{bmatrix} \quad : \quad (2,2,0) \text{ under } SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

However, at least **two bidoublets** are needed to produce a non-trivial V_{CKM} at tree-level.

$$Y_Q^{(i)} Q \Phi_i Q^c \Rightarrow \text{The misalignment } Y_Q^{(1)} - Y_Q^{(2)} \text{ generates } V_{CKM}$$

At the v_R scale one of these two bidoublets dicouples while the orthogonal combination leads to the MSSM two Higgs doublets. Therefore, the **low-energy Yukawa parameters** are rotations of the original ones. In the leptonic sector:

$$\begin{aligned} Y_e &= Y_L^1 \cos\theta_1 - Y_L^2 \sin\theta_1 \\ Y_\nu &= -Y_L^1 \cos\theta_2 + Y_L^2 \sin\theta_2 \end{aligned}$$

Renormalization Group Equations

- **From the GUT scale to the $\mathbf{v_R}$ scale**

$$
\begin{aligned}
16\pi^2 \frac{d}{dt} m_L^2 \quad = \quad & 6 f f^\dagger m_L^2 + 12 f m_L^2 f^\dagger + 6 m_L^2 f f^\dagger + 12 m_\Delta^2 f f^\dagger \\
& + 2 Y_L^{(k)} Y_L^{(k)\,\dagger} m_L^2 + 2 m_L^2 Y_L^{(k)} Y_L^{(k)\,\dagger} + 4 Y_L^{(k)} m_{L^c}^2 Y_L^{(k)\,\dagger} \\
& + 4 (m_\Phi^2)_{mn} Y_L^{(m)} Y_L^{(n)\,\dagger} + 12 T_f T_f^\dagger + 4 T_L^{(k)} T_L^{(k)\,\dagger} \\
& - (3 g_{BL}^2 |M_1|^2 + 6 g_2^2 |M_2|^2 + \frac{3}{2} g_{BL}^2 S_1) \mathcal{I}_3
\end{aligned}
$$

$$
\begin{aligned}
16\pi^2 \frac{d}{dt} m_{L^c}^2 \quad = \quad & 6 f^\dagger f m_{L^c}^2 + 12 f^\dagger m_{L^c}^2 f + 6 m_{L^c}^2 f^\dagger f + 12 m_{\Delta^c}^2 f^\dagger f \\
& + 2 Y_L^{(k)\,\dagger} Y_L^{(k)} m_{L^c}^2 + 2 m_{L^c}^2 Y_L^{(k)\,\dagger} Y_L^{(k)} + 4 Y_L^{(k)\,\dagger} m_L^2 Y_L^{(k)} \\
& + 4 (m_\Phi^2)_{mn} Y_L^{(m)\,\dagger} Y_L^{(n)} + 12 T_f^\dagger T_f + 4 T_L^{(k)\,\dagger} T_L^{(k)} \\
& - (3 g_{BL}^2 |M_1|^2 + 6 g_2^2 |M_2|^2 - \frac{3}{2} g_{BL}^2 S_1) \mathcal{I}_3
\end{aligned}
$$

Renormalization Group Equations

- **From the $\mathbf{v_R}$ scale to the $\mathbf{v_{BL}}$ scale**

$$
\begin{aligned}
16\pi^2 \frac{d}{dt} m_L^2 \quad = \quad & 2 Y_e m_{\tilde{e}^c}^2 Y_e^\dagger + 2 m_{H_d}^2 Y_e Y_e^\dagger + 2 m_{H_u}^2 Y_\nu Y_\nu^\dagger + m_L^2 Y_e Y_e^\dagger \\
& + Y_e Y_e^\dagger m_L^2 + m_L^2 Y_\nu Y_\nu^\dagger + Y_\nu Y_\nu^\dagger m_L^2 + 2 Y_\nu m_{\tilde{\nu}^c}^2 Y_\nu^\dagger \\
& + 2 T_e T_e^\dagger + 2 T_\nu T_\nu^\dagger - (3 g_{BL}^2 |M_1|^2 + 6 g_L^2 |M_L|^2 + \frac{3}{4} g_{BL}^2 S_2) \mathcal{I}_3
\end{aligned}
$$

$$
\begin{aligned}
16\pi^2 \frac{d}{dt} m_{\tilde{e}^c}^2 \quad = \quad & 2 Y_e^\dagger Y_e m_{\tilde{e}^c}^2 + 2 m_{\tilde{e}^c}^2 Y_e^\dagger Y_e + 4 m_{H_d}^2 Y_e^\dagger Y_e + 4 Y_e^\dagger m_L^2 Y_e \\
& + 4 T_e^\dagger T_e - (3 g_{BL}^2 |M_1|^2 + 2 g_R^2 |M_R|^2 - \frac{3}{4} g_{BL}^2 S_2 - \frac{1}{2} g_R^2 S_3) \mathcal{I}_3
\end{aligned}
$$

RGEs: Approximated expressions

- **From the GUT scale to the $\mathbf{v_R}$ scale**

$$\Delta m_L^2 = -\frac{1}{4\pi^2}\left(3ff^\dagger + Y_L^{(k)}Y_L^{(k)\,\dagger}\right)(3m_0^2 + A_0^2)\ln\left(\frac{m_{GUT}}{v_R}\right)$$

$$\Delta m_{L^c}^2 = -\frac{1}{4\pi^2}\left(3f^\dagger f + Y_L^{(k)\,\dagger}Y_L^{(k)}\right)(3m_0^2 + A_0^2)\ln\left(\frac{m_{GUT}}{v_R}\right)$$

- **From the $\mathbf{v_R}$ scale to the $\mathbf{v_{BL}}$ scale**

$$\Delta m_L^2 \sim -\frac{1}{8\pi^2}Y_\nu Y_\nu^\dagger\left(3m_L^2|_{v_R} + A_e^2|_{v_R}\right)\ln\left(\frac{v_R}{v_{BL}}\right)$$

$$\Delta m_{e^c}^2 \sim 0$$

Basic setup

J. N. Esteves, M. Hirsch, J.C. Romão, W. Porod, F. Staub and A. Vicente
JHEP 12, 077 (2010)

- mSUGRA boundary conditions
- 2-loop RGEs
  - ⋆ Analytical computation with *Sarah*

    F. Staub, Comput. Phys. Commun. 181, 1077 (2010)

  - ⋆ Numerical implementation with *SPheno*

    W. Porod, Comput. Phys. Commun. 153, 275 (2003)

- Threshold corrections at intermediate scales
- Two types of fit to neutrino oscillation parameters
  - ⋆ Y_ν fit : Flavour in $Y_\nu L H_u \nu^c \supset Y_L L \Phi L^c$
  - ⋆ f fit : Flavour in $f L \Delta L$

Left vs Right: types of fit

$\mathbf{Y}_\nu$ fit	$\mathbf{f}$ fit
GUT scale : $\mathbf{m_L^2 = m_E^2 = m_0^2 \, \mathcal{I}_3}$	**GUT scale :** $\mathbf{m_L^2 = m_E^2 = m_0^2 \, \mathcal{I}_3}$
$\downarrow$	$\downarrow$
$\mathbf{v_R}$ **scale :** $\mathbf{m_L^2 = m_E^2}$	$\mathbf{v_R}$ **scale :** $\mathbf{m_L^2 = m_E^2}$
due to parity conservation	**due to parity conservation**
off-diagonal m_E^2 stop running	off-diagonal m_E^2 and m_L^2 stop running
$\downarrow$	$\downarrow$
$\mathbf{v_{BL}}$ **scale :** $\mathbf{m_L^2 \neq m_E^2}$	
off-diagonal m_L^2 stop running	
$\downarrow$	
SUSY scale : $\mathbf{m_L^2 \neq m_E^2}$	**SUSY scale :** $\mathbf{m_L^2 \neq m_E^2}$

⋆ Large LFV entries in both sectors.

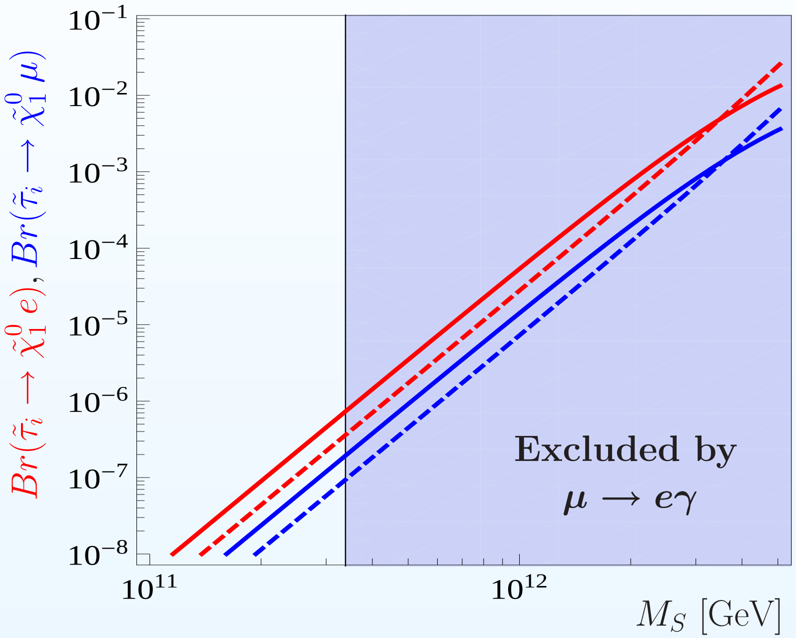
⋆ In case of the Y_ν fit, the L-R difference is sensitive to the $\mathbf{v_{BL} - v_R}$ difference.

Seesaw scale determination

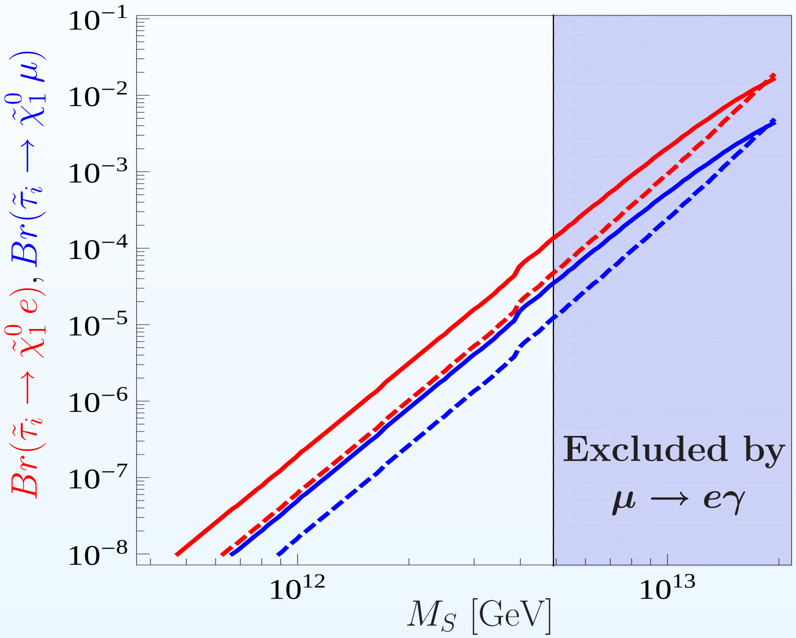
Y_ν fit

$v_{BL} = 10^{15}$ GeV, $v_R = 5 \cdot 10^{15}$ GeV

SPS1a'



SPS3



$$m_\nu = -\frac{v_u^2}{2} \, Y_\nu^T \cdot M_R^{-1} \cdot Y_\nu$$

The absolute value of LFV BR's is linked to the Seesaw scale.

$\tilde{e} - \tilde{\mu}$ mass splitting

SPS1a' benchmark point

Y_ν fit

$v_{BL} = 10^{15}$ GeV , $v_R \in [10^{15}, 10^{16}]$ GeV

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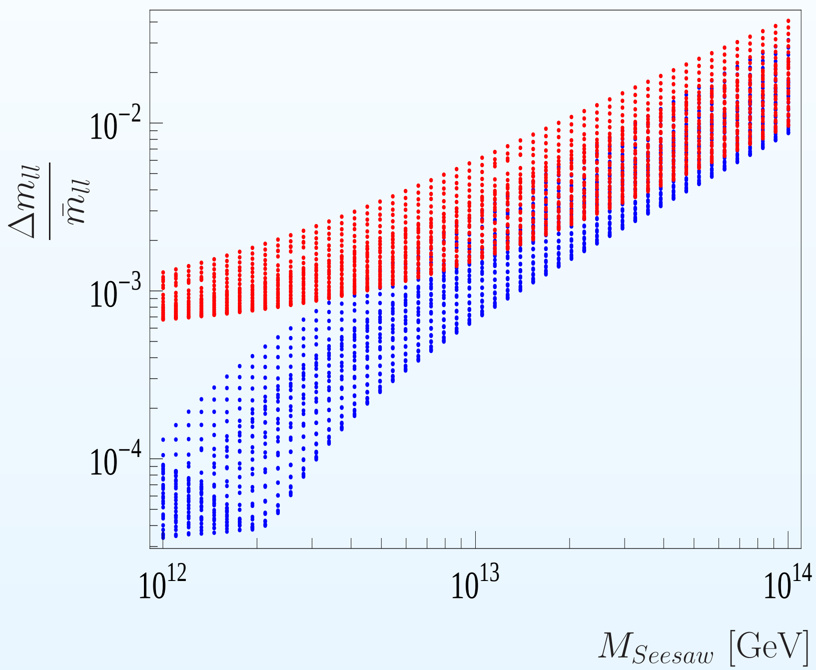
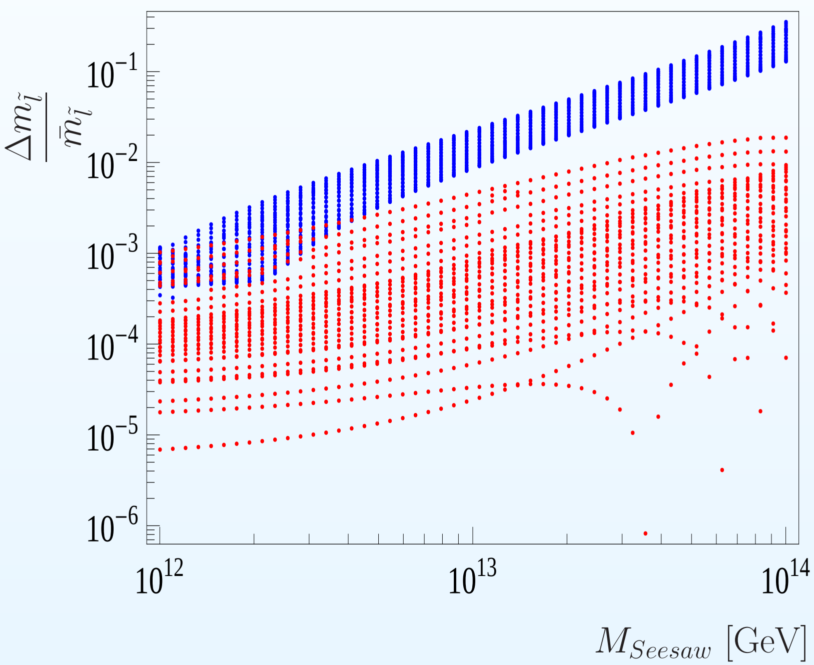
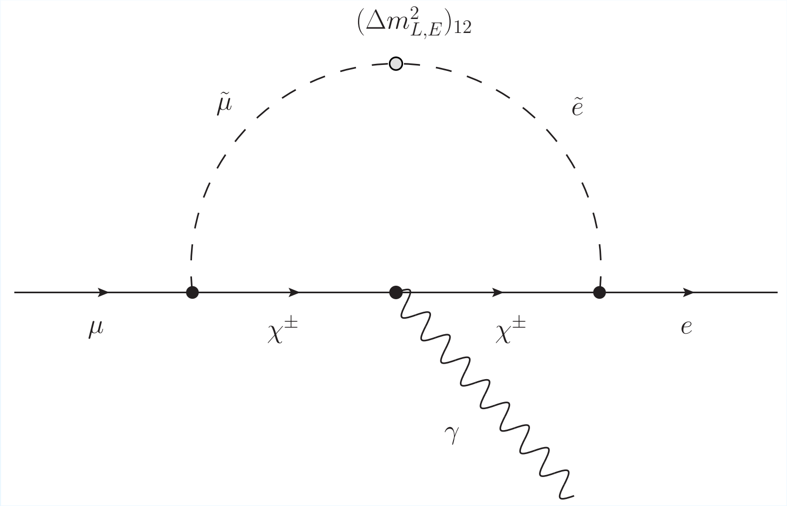


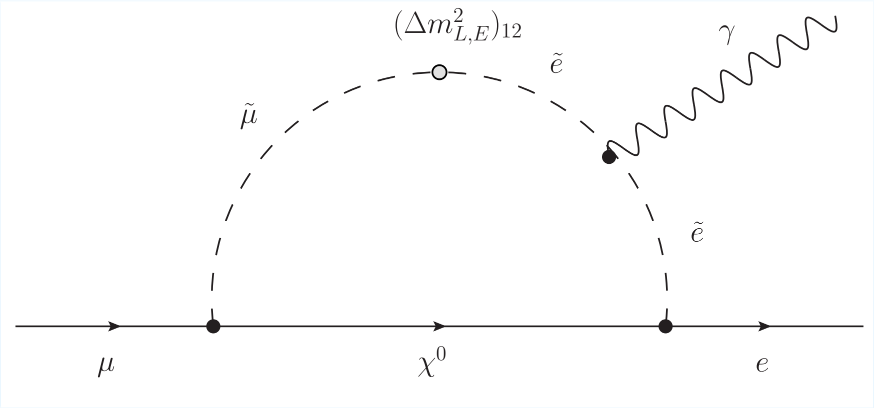


Large splittings $m_{\tilde{e}} - m_{\tilde{\mu}}$ are produced by RGE running in the **L** and **R** sectors.

$l_i \to l_j\gamma$

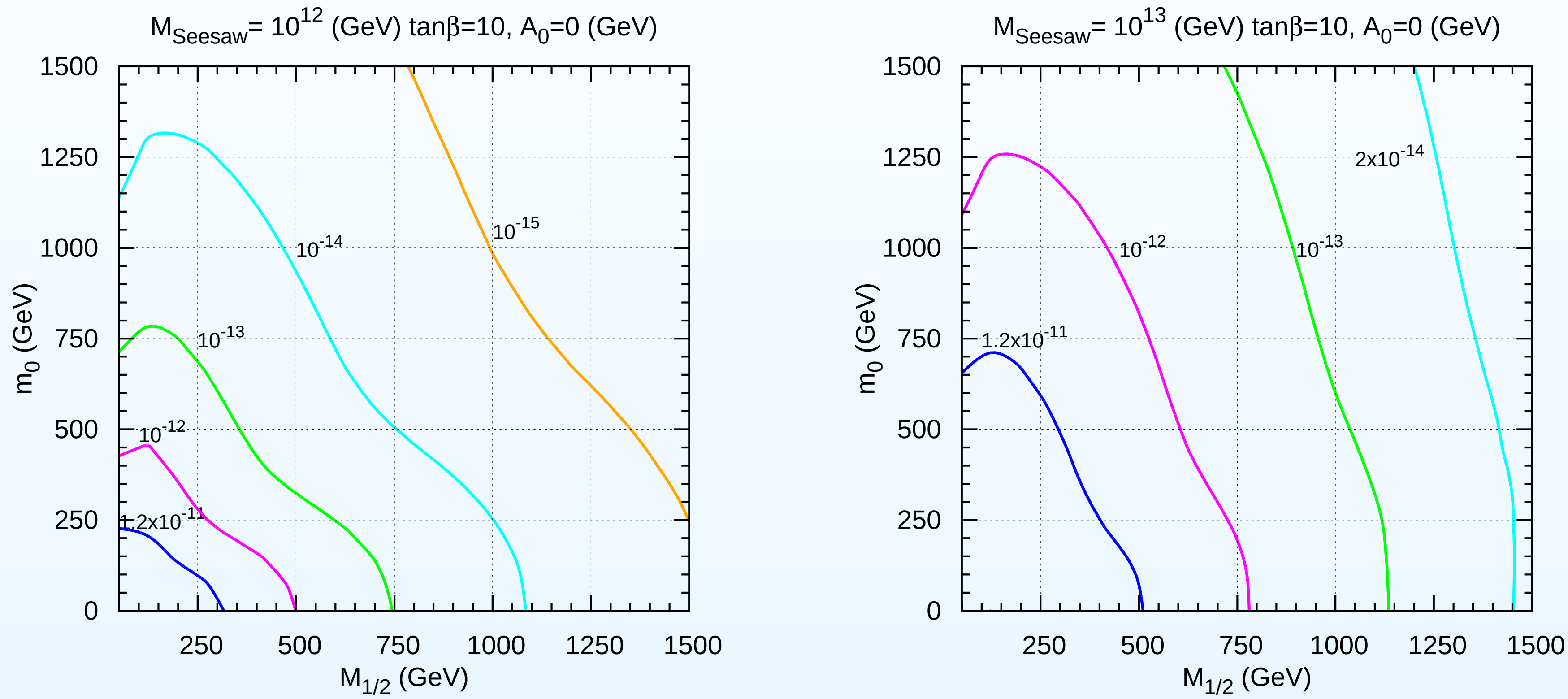
$l_i \to l_j\gamma$ processes are enhanced by **off-diagonal Δm_L^2 and Δm_E^2**. For example, in the case of $\mu \to e\gamma$:





$$Br(\mu \to e\gamma) \propto \Delta(m^2_{L,E})^2_{12}$$

$\mu \to e\gamma$

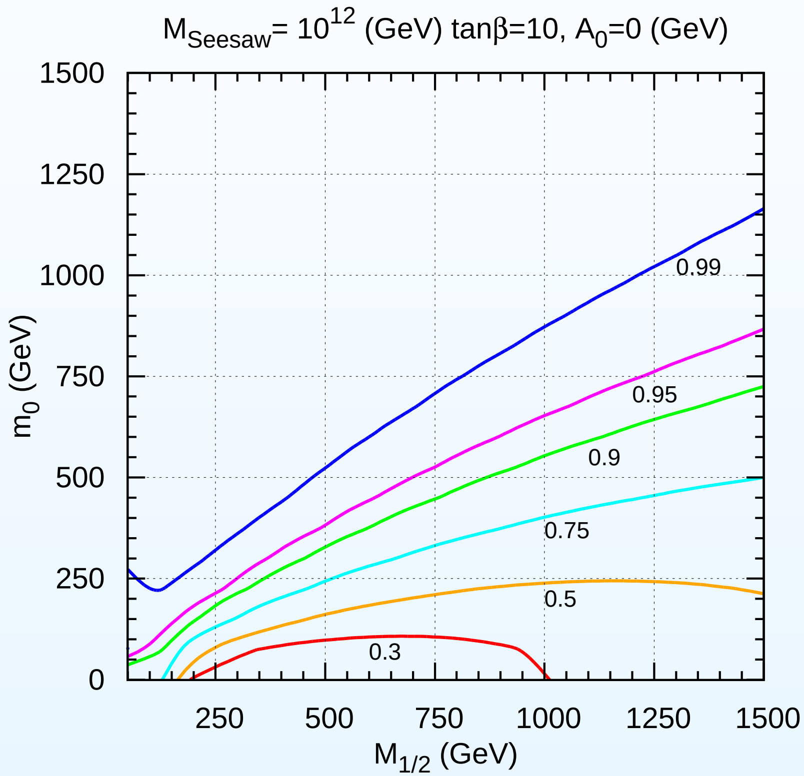


$\mathbf{M_{Seesaw} = 10^{12}}$ **GeV** $\mathbf{M_{Seesaw} = 10^{13}}$ **GeV**

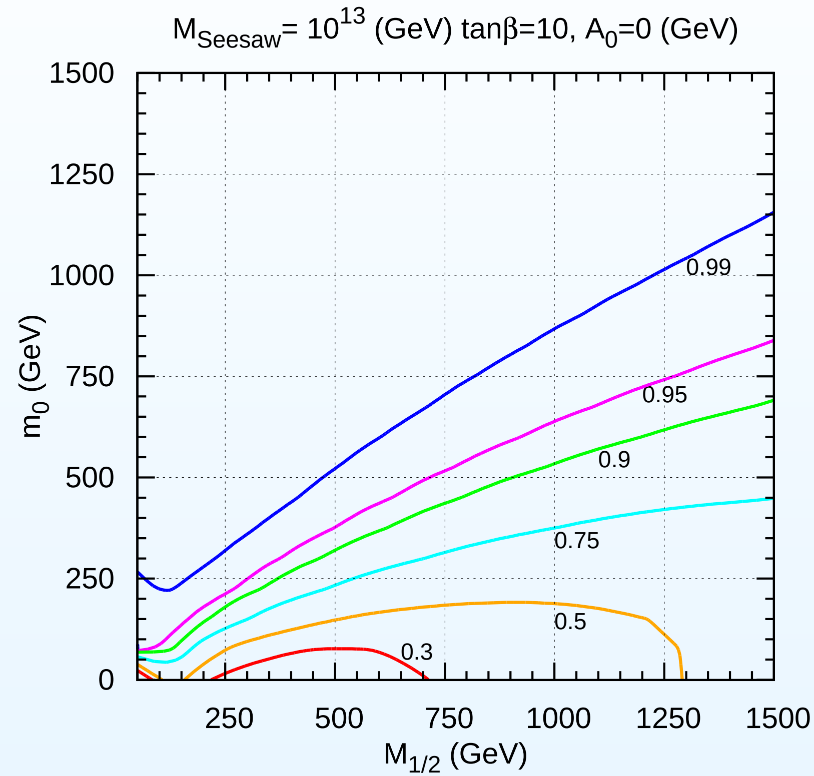
Non-negligible right-handed contribution

$\Rightarrow$ **Larger Br's w.r.t. stardard seesaw**

$\mathcal{A}(\boldsymbol{\mu}^+ \to \mathbf{e}^+\boldsymbol{\gamma})$



$\mathbf{M_{Seesaw}} = \mathbf{10^{12}}$ **GeV**



$\mathbf{M_{Seesaw}} = \mathbf{10^{13}}$ **GeV**

Strong dependence on m_0 due to slepton masses

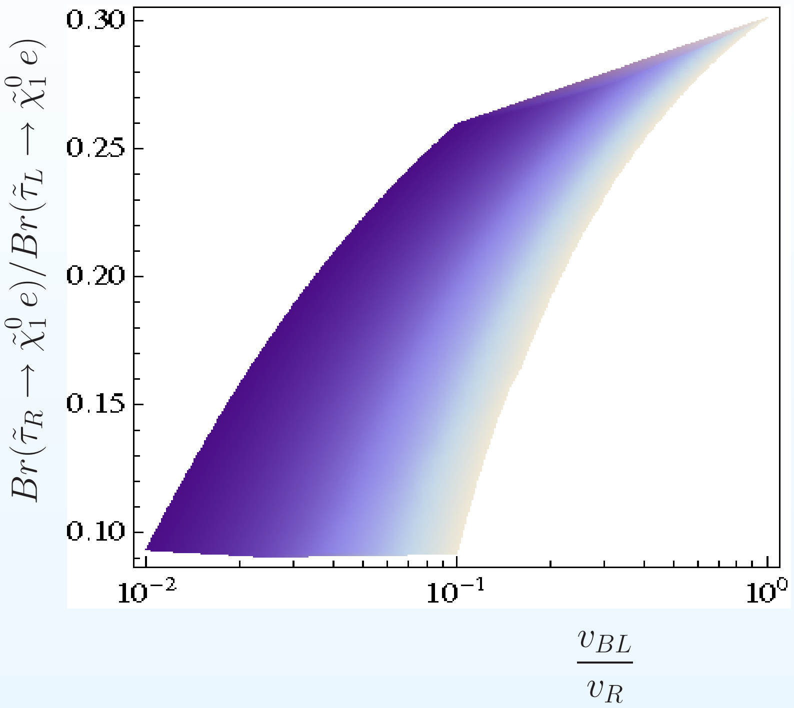
- Large m_0: Comparable **L** and **R** slepton masses, LFV in the **L** sector dominates
- Small m_0: Lighter **R** sleptons compensate the additional LFV in the **L** sector

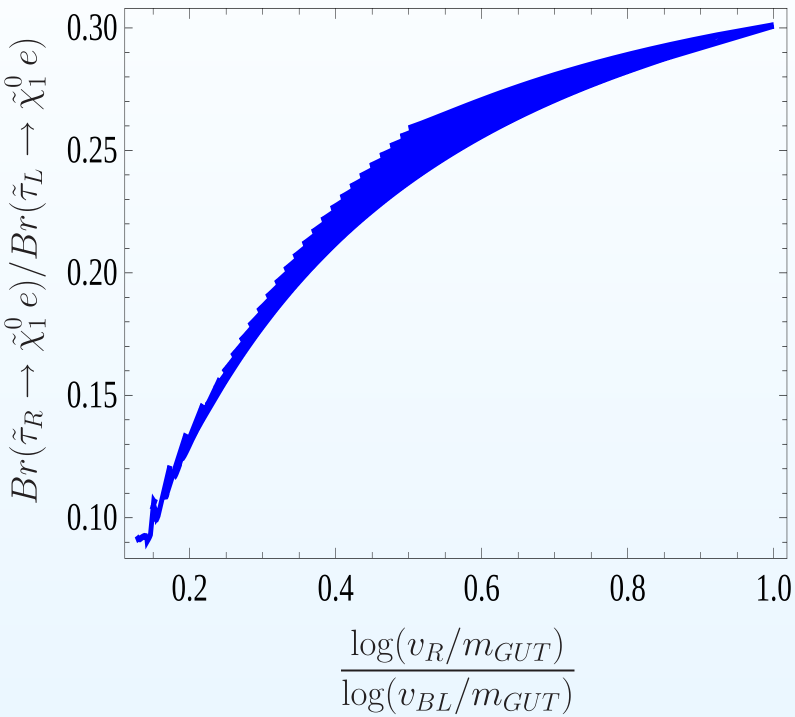
Left vs Right

SPS3 benchmark point

Y_ν fit

$M_S = 10^{13}$ GeV, $v_{BL} \in [10^{14}, 10^{15}]$ GeV, $v_R \in [10^{15}, 10^{16}]$ GeV





- By measuring **left- and right-handed LFV** the ratio v_{BL}/v_R can be constrained
- However, there is a slight dependence on M_S and m_{GUT}
- More information (e.g. other LFV decays) is required

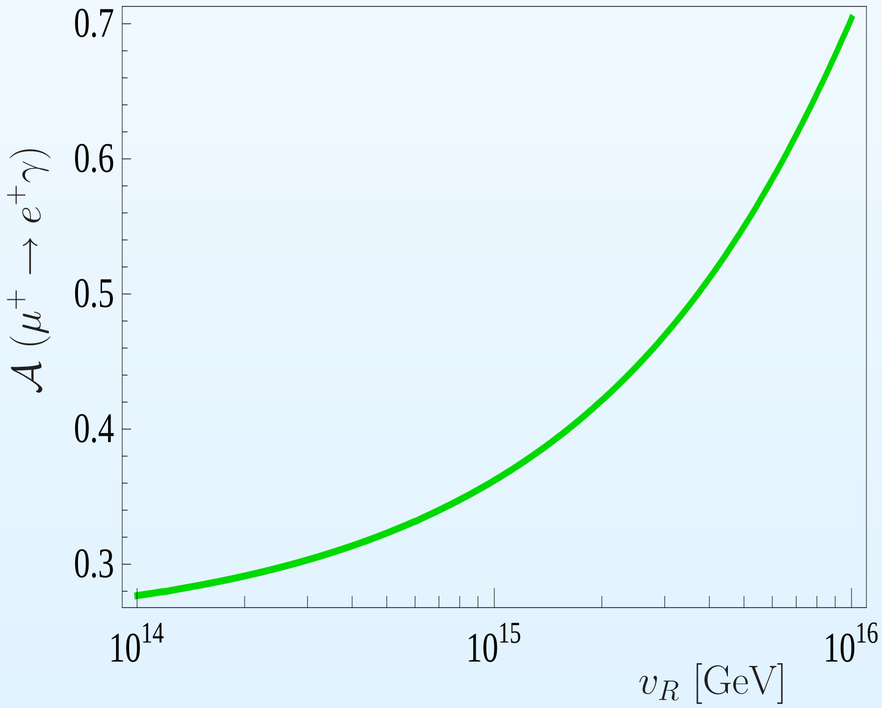
$\mu^+ \to e^+\gamma$: Positron polarization asymmetry

$$\mathcal{L}_{eff} = e\frac{m_i}{2}\bar{l}_i\sigma_{\mu\nu}F^{\mu\nu}(A_L^{ij}P_L + A_R^{ij}P_R)l_j + h.c.$$

Positron polarization asymmetry

$$\mathcal{A}(\mu^+ \to e^+\gamma) = \frac{|A_L|^2 - |A_R|^2}{|A_L|^2 + |A_R|^2}$$

SPS3 benchmark point, Y_ν fit, $v_{BL} = 10^{14}$ GeV



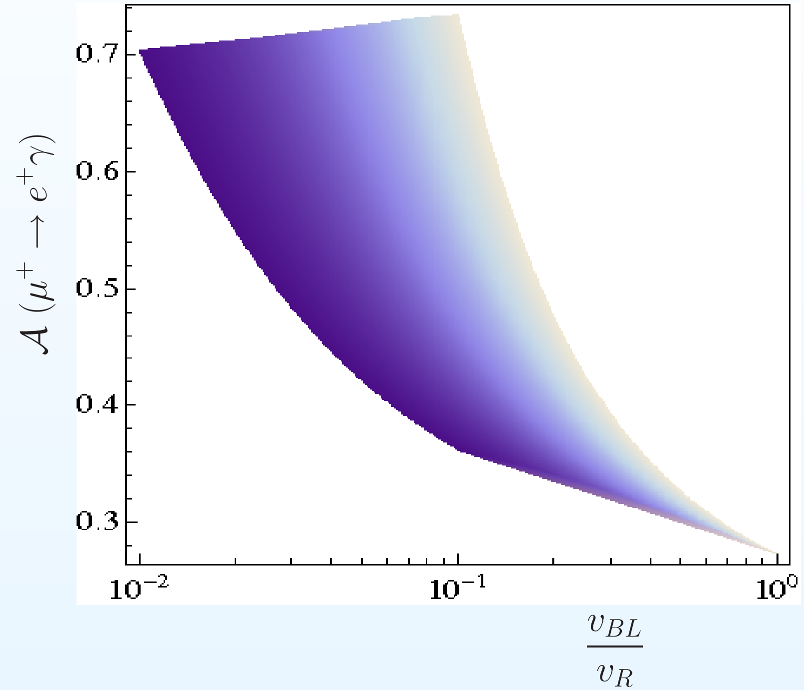
- In minimal seesaw models $\mathcal{A} \simeq 1$ is expected
- In this case large departures from $\mathcal{A} = 1$ can be found
- This observable is very sensitive to the high energy scales

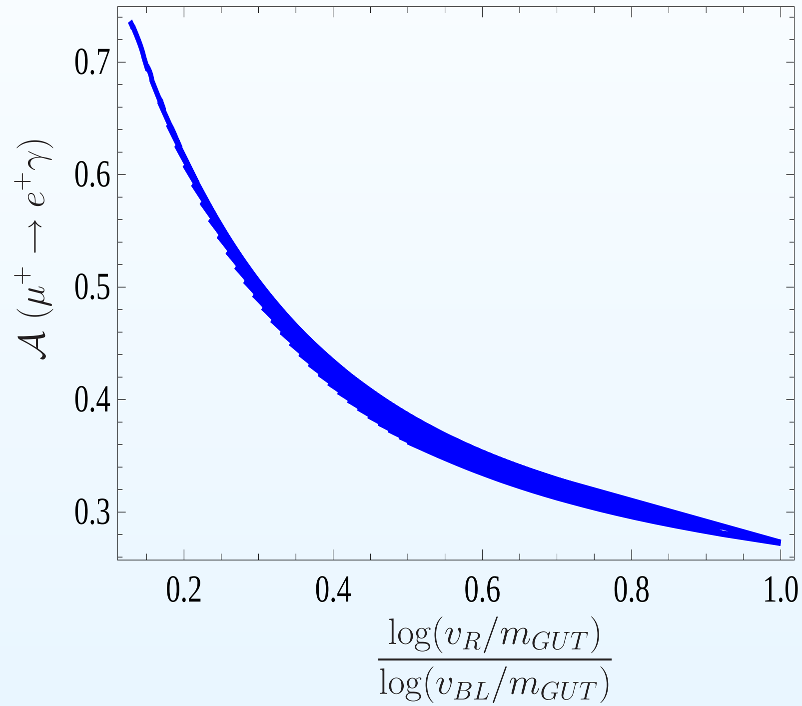
Left vs Right

SPS3 benchmark point

Y_ν fit

$M_S = 10^{13}$ GeV, $v_{BL} \in [10^{14}, 10^{15}]$ GeV, $v_R \in [10^{15}, 10^{16}]$ GeV



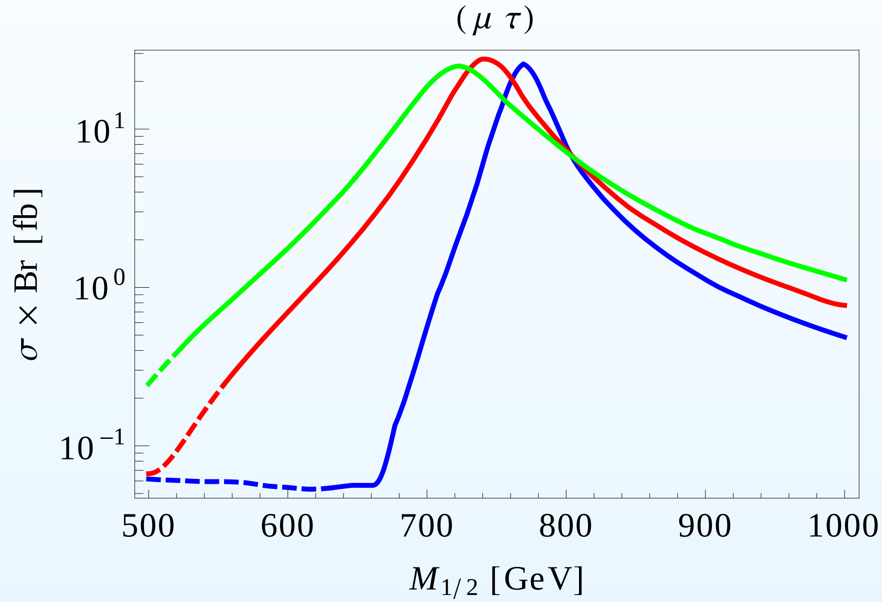


- The polarization asymmetry is strongly dependent on the ratio v_{BL}/v_R
- Again, there is a slight dependence on M_S and m_{GUT}

Flavoured coannihilation at colliders

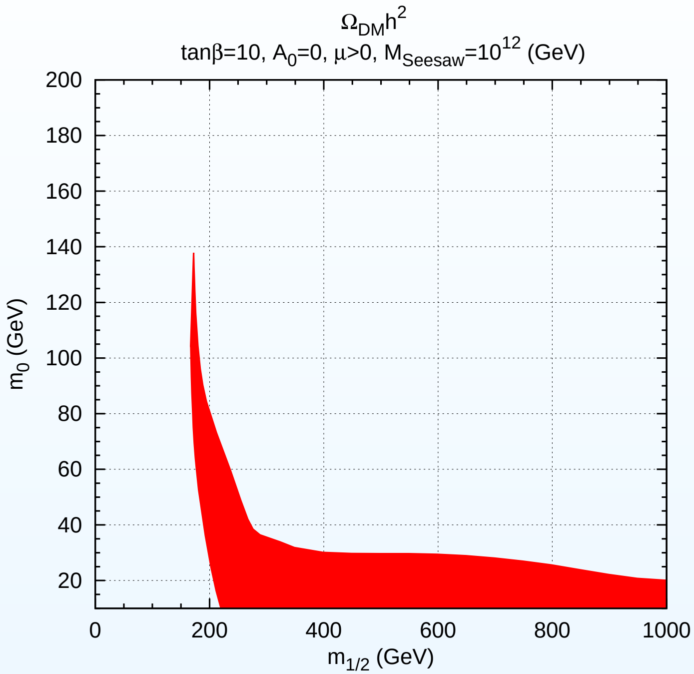
$\sqrt{s} = 14$ TeV
$m_0 = 100$ GeV, $A_0 = 0$, $\tan\beta = 10$
$v_{BL} = v_R = \{10^{14}, 5 \cdot 10^{14}, 10^{15}\}$ GeV

$$\mathbf{pp \to \tilde{\chi}_2^0 X \to \tilde{\chi}_1^0 l^{\pm} l^{\mp} X}$$

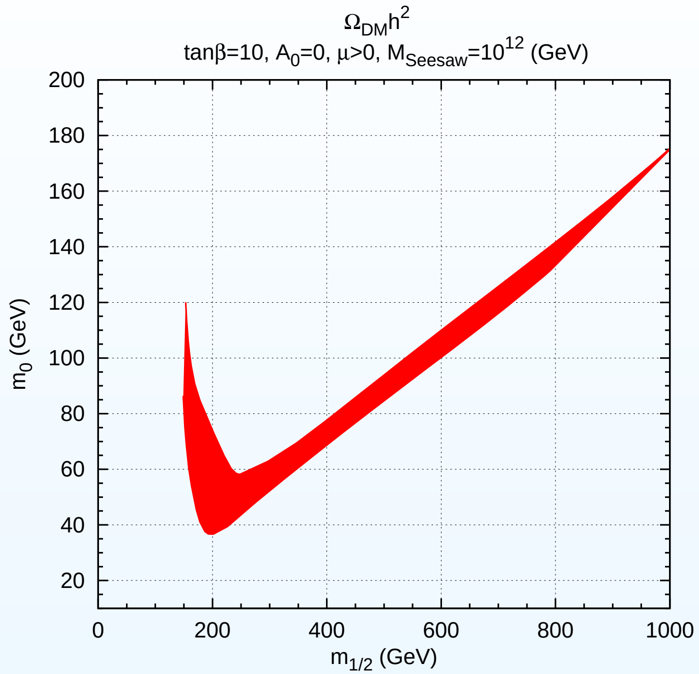


- Large LFV signals are found in regions with **flavoured coannihilation** ($\sigma \times$ BR can go up to $\sim 10 - 30$ fb)
- Good perspectives for the LHC

Stau coannihilation



$v_{BL} = v_R = 1.5 \cdot 10^{15}$ GeV



$v_{BL} = v_R = 10^{16}$ GeV

- The allowed $\tilde{\tau}$ **coannihilation region** ($\Omega h^2 \in [0.10, 0.12]$) depends very strongly on v_{BL} and v_R
- The lower the intermediate scales are, the lower m_0 is. This compensates the running of gaugino masses to lower values
- For low v_{BL} and/or v_R it can even disappear