LFV Higgs decays:
a window to heavy SUSY

María José Herrero

IFT-UAM/CSIC - Instituto de Física Teórica and Dpto. de Física Teórica,
Universidad Autónoma de Madrid

`maria.herrero@uam.es`

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References

Work based on:

- M. Arana-Catania, E. Arganda and M. J. Herrero, "Non-decoupling SUSY in LFV Higgs decays: a window to new physics at the LHC", arXiv:1304.3371 [hep-ph], JHEP 1309 (2013) 160.
- M. Arana-Catania, S. Heinemeyer and M. J. Herrero, "New Constraints on General Slepton Flavor Mixing", arXiv:1304.2783 [hep-ph], Phys.Rev. D88 (2013) 015026.
- E. Arganda, M. J. Herrero, R. Morales and A. Szynkman, "On the use of the MIA for LFV Higgs decays in SUSY", Work in progress 2014.

Motivation

- Lepton Flavor Violation (LFV) occurs in Nature:
  Seen in neutral leptons: Neutrino oscillations ⇒ LFV.
- LFV rates in SM extremely supressed:
  zero if massless neutrinos, tiny with present massive neutrinos.
- If LFV exists in neutral sector why not in charged sector.
  Intense present and future programs for exp. LFV searches.
- LFV opens a new window to look for BSM physics: in particular SUSY.
- Higgs boson seen at the LHC, with $m_H \simeq 125$ GeV, opens new channels for LFV searches.
- SUSY not seen yet at LHC (m_{SUSY} into multi-TeV range?).
- Higgs physics/mediated processes very sensitive to SUSY.

Here: LFV Higgs decays induced by SUSY at one loop:
sizeable even at very heavy $m_{\mathsf{SUSY}} \simeq \mathcal{O}(5\ \text{TeV})$.

Present Status: LFV in Neutrino oscillations

- Neutrino oscillations imply non-vanishing ν mass differences $\Delta m^2_{kj} = m^2_k - m^2_j$ and mixings θ_{ij}

- Best fit (nu-fit.org) (NuFit 1.3 (2014)

$$\begin{aligned}
\sin^2\theta_{12} &= 0.304^{+0.012}_{-0.012}\,, & \Delta m^2_{21} &= 7.50^{+0.19}_{-0.17}\times 10^{-5}\ \mathrm{eV}^2\,,\\
\sin^2\theta_{23} &= 0.451^{+0.001}_{-0.001}\,, & \Delta m^2_{31} &= 2.458^{+0.002}_{-0.002}\times 10^{-3}\ \mathrm{eV}^2\,(\mathrm{NH}),\\
\sin^2\theta_{13} &= 0.0219^{+0.0010}_{-0.0011}\,, & \Delta m^2_{32} &= -2.448^{+0.047}_{-0.047}\times 10^{-3}\ \mathrm{eV}^2\,(\mathrm{IH}).
\end{aligned}$$

Therefore, large flavor mixings (i.e. large LFV in ν sector)

solar	$\theta_{12} \simeq 33.5^o$	large
atmospheric	$\theta_{23} \simeq 42.2^o$	almost maximal
reactor	$\theta_{13} \simeq 8.5^o$	not small

- Interesting connections between LFV and neutrino oscillations in specific models. Particularly via Y_ν if Seesaw Mechanism: Seesaw Models (I, II, III, Linear, Inverse, non-SUSY, SUSY...)

LFV Present Bounds versus Future Sensitivities

(c)LFV not seen yet. Intense program.

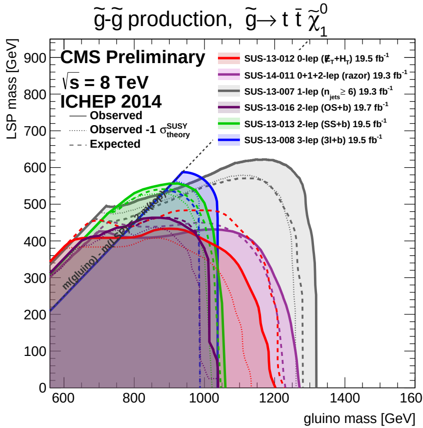
LFV process	Present bound ($90\% CL$)	Future sensitivity (?)
BR($\mu \to e\,\gamma$)	5.7×10^{-13} (MEG 2013)	5×10^{-14} MEGup
BR($\tau \to e\,\gamma$)	3.3×10^{-8} (BaBar 2010)	3×10^{-9} SuperB
BR($\tau \to \mu\,\gamma$)	4.4×10^{-8} (BaBar 2010)	2.4×10^{-9} SuperB
BR($\mu \to e\,e\,e$)	1×10^{-12} (SINDRUM 1988)	10^{-16} Mu3E (PSI)
BR($\tau \to e\,e\,e$)	2.7×10^{-8} (Belle 2010)	$10^{-9,-10}$ Belle2, SuperB
BR($\tau \to \mu\,\mu\,\mu$)	2.1×10^{-8} (Belle 2010)	$10^{-9,-10}$ Belle2, SuperB
BR($\tau \to \mu\eta$)	2.3×10^{-8} (Belle 2010)	$10^{-9,-10}$ Belle2, SuperB
CR($\mu - e, \mathrm{Au}$)	7.0×10^{-13} (SINDRUM2 2006)	
CR($\mu - e, \mathrm{Al}$)		3.1×10^{-15} COMET-I (J-PARC) 2.6×10^{-17} COMET-II (J-PARC) 2.5×10^{-17} Mu2E (Fermilab)
CR($\mu - e, \mathrm{Ti}$)	4.3×10^{-12} (SINDRUM2 2004)	10^{-18} PRISM (J-PARC)

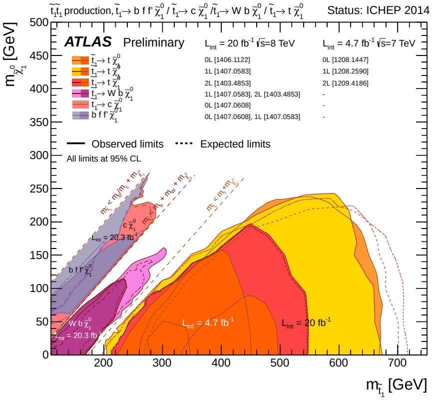
LFV Higgs decays: $\mathrm{Br}(H \to \tau\mu) < 1.57\%$ $(95\% CL)$ LHC New! [CMS, 2014]

(?) = Future sensitivities are under discussion
(updated here as reported in presentations at ICHEP 2014)

Present Status: SUSY searches

SUSY not seen Yet.
Lower bounds for strongly interacting SUSY particles above ∼ 1.2 TeV
Exception: squarks of third generation: limits above ∼ 600 GeV





EW sparticles less constrained: inos above ∼ 500 GeV, sleptons above ∼ 300 GeV

Our proposal and work

- Present data suggests soft masses above TeV scale.
- Accept the tension between this heavy SUSY $\gtrsim \mathcal{O}(1\,\mathrm{TeV})$ and the SUSY solution to the hierarchy problem with $\lesssim \mathcal{O}(1\,\mathrm{TeV})$.
- Look for specific observables where there are relevant contributions from SUSY, even if heavy.
- Look at Higgs observables to one-loop since Higgs couplings to all particles grow with the particle mass:
  hence more sensitive to 'internal' Sparticles in the loops.
- Full 1-loop computation of LFV Higgs decay rates with internal sleptons ($\tilde{l}$, $\tilde{\nu}$) and inos ($\tilde{\chi}^0$,$\tilde{\chi}^\pm$).
- Work within the MSSM with general slepton flavor mixing.
- Focus on LFV Higgs decays with taus: $\phi \to \tau\mu$ ($\phi = h, H, A$)
  $\phi \to \mu e$ rates suppressed by $(m_\mu/m_\tau)^n$
  $\phi \to \tau e$ rates similar to $\tau\mu$ with close detection prospects.
- Impose all the present constraints: both on LFV and SUSY

The MSSM with general slepton mixing

We use a low energy parametrization for general slepton mixing:
Model Independent Approach
LFV is orginated from the off-diagonal δ_{ij}^{AB}'s via loops of SUSY.
Model parameters: MSSM + slepton flavor mixing parameters δ_{ij}^{AB}(real).

$$m_{\tilde{L}}^2 = \begin{pmatrix} m_{\tilde{L}_1}^2 & \delta_{12}^{LL} m_{\tilde{L}_1} m_{\tilde{L}_2} & \delta_{13}^{LL} m_{\tilde{L}_1} m_{\tilde{L}_3} \\ \delta_{21}^{LL} m_{\tilde{L}_2} m_{\tilde{L}_1} & m_{\tilde{L}_2}^2 & \delta_{23}^{LL} m_{\tilde{L}_2} m_{\tilde{L}_3} \\ \delta_{31}^{LL} m_{\tilde{L}_3} m_{\tilde{L}_1} & \delta_{32}^{LL} m_{\tilde{L}_3} m_{\tilde{L}_2} & m_{\tilde{L}_3}^2 \end{pmatrix},$$

$$v_1 \mathcal{A}^l = \begin{pmatrix} m_e A_e & \delta_{12}^{LR} m_{\tilde{L}_1} m_{\tilde{E}_2} & \delta_{13}^{LR} m_{\tilde{L}_1} m_{\tilde{E}_3} \\ \delta_{21}^{LR} m_{\tilde{L}_2} m_{\tilde{E}_1} & m_\mu A_\mu & \delta_{23}^{LR} m_{\tilde{L}_2} m_{\tilde{E}_3} \\ \delta_{31}^{LR} m_{\tilde{L}_3} m_{\tilde{E}_1} & \delta_{32}^{LR} m_{\tilde{L}_3} m_{\tilde{E}_2} & m_\tau A_\tau \end{pmatrix},$$

$$m_{\tilde{E}}^2 = \begin{pmatrix} m_{\tilde{E}_1}^2 & \delta_{12}^{RR} m_{\tilde{E}_1} m_{\tilde{E}_2} & \delta_{13}^{RR} m_{\tilde{E}_1} m_{\tilde{E}_3} \\ \delta_{21}^{RR} m_{\tilde{E}_2} m_{\tilde{E}_1} & m_{\tilde{E}_2}^2 & \delta_{23}^{RR} m_{\tilde{E}_2} m_{\tilde{E}_3} \\ \delta_{31}^{RR} m_{\tilde{E}_3} m_{\tilde{E}_1} & \delta_{32}^{RR} m_{\tilde{E}_3} m_{\tilde{E}_2} & m_{\tilde{E}_3}^2 \end{pmatrix}.$$

Hermiticity of $\mathcal{M}_{\tilde{l}}^2$ and $\mathcal{M}_{\tilde{\nu}}^2$ and $SU(2)_L$ invariance $\Rightarrow$ 12 independent δ_{ij}^{AB}'s.

6 charged sleptons and 3 sneutrinos with intergenerational mixing

One example: SUSY-Seesaw with heavy ν_R (N_i)

Slepton flavor mixing δ_{ij}^{AB} generated radiatively.

[Borzumati,Masiero,1988; Hisano et al,1996; Hisano,Nomura,1999]

Connection between LFV and neutrino physics comes via Y_ν.
RGE running from $M_X = 2 \times 10^{16}$ GeV down to m_{N_i}:

$$\begin{aligned}
\delta_{ij}^{LL} &= -\frac{1}{8\pi^2}\frac{(3M_0^2 + A_0^2)}{M_{\rm SUSY}^2}(Y_\nu^+ L Y_\nu)_{ij} \\
\delta_{ij}^{LR} &= -\frac{3}{16\pi^2}\frac{A_0 v_1 Y_{l_i}}{M_{\rm SUSY}^2}(Y_\nu^+ L Y_\nu)_{ij} \\
\delta_{ij}^{RR} &= \mathcal{O}(\frac{m_l^2}{M_{\rm SUSY}^2}) \simeq 0 \; ; \; L_{ii} \equiv \log\left(\frac{M_X}{m_{N_i}}\right) ; \; (\text{LLog Approx})
\end{aligned}$$

Large δ_{32}^{LL} for $m_{N_i} \sim 10^{14} - 10^{15}$ GeV $\Rightarrow |\delta_{32}^{LL}| \sim 0.1 - 10$ $(|\delta_{12}^{LL}| < 10^{-3})$

Perturbativity: $|\frac{Y_\nu^2}{4\pi}| < 1.5 \Rightarrow$ SUSY-Seesaw I: $|\delta_{23}^{LL}| < 0.5$ [M.J.H et al 2009..]

Larger δ_{32}^{LL} $(\sim \times 6)$ and LFV rates in low scale SUSY-Seesaw models, like SUSY-ISS

[Deppisch,Valle,2005; Hirsch et al,2010; Abada et al 2012; Ilakovac et al,2012...]

Updated constraints on general slepton mixing

(M.Arana-Catania,S.Heinemeyer and M.J.H, PRD 88(2013)015026)

Systematic study of constraints on all δ_{ij}^{AB} slepton mixing parameters from selected LFV processes:

- Radiative LFV decays: $\mu \to e\gamma$, $\tau \to e\gamma$ and $\tau \to \mu\gamma$
- Leptonic LFV decays: $\mu \to 3e$, $\tau \to 3e$ and $\tau \to 3\mu$
- Semileptonic LFV tau decays: $\tau \to \mu\eta$ and $\tau \to e\eta$
- Conversion of μ into e in heavy nuclei

And requiring present experimental LFV bounds on their BRs.

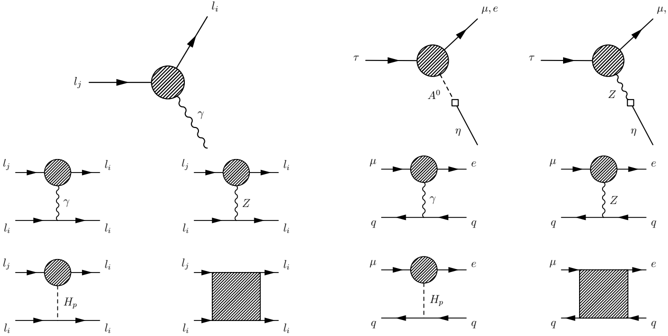
The first are usually the most constraining, but the others can be mediated by Higgs bosons, then access to different δ_{ij}^{AB}'s

Framework for computation of selected LFV processes

MSSM spectra with Spheno code [W.Porod]

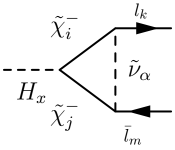
Full 1-loop calculation using a FORTRAN code by E. Arganda and M.J.H

- Radiative LFV decays: $\mu \to e\gamma$, $\tau \to e\gamma$ and $\tau \to \mu\gamma$ [Hisano et al, 1996]
- Leptonic LFV decays: $\mu \to 3e$, $\tau \to 3e$ and $\tau \to 3\mu$ [Arganda, M.J.H, 2006]
- Semileptonic LFV τ decays: $\tau \to \mu\eta$ and $\tau \to e\eta$ [Arganda, M.J.H, Portoles, 2008]
- Conversion of μ into e in heavy nuclei [Arganda, M.J.H, Teixeira, 2007]



One-loop LFV SUSY-induced Higgs decay diagrams

We work with MSSM particle content and explore, either 1) selected MSSM points, or 2) simple MSSM scenarios with few parameters. [Arana-Catania,Arganda,M.J.H,2013] [Arganda et al,2005]



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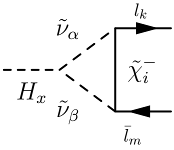

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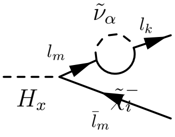

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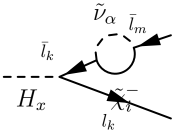

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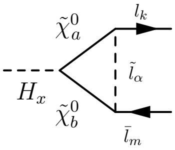

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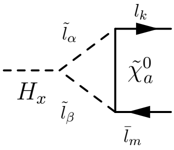

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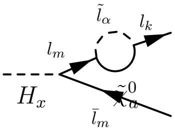

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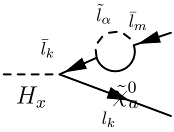


(8)

Selected MSSM points allowed by present data

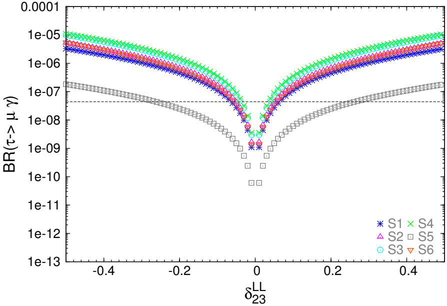
[Arana-Catania, Heinemeyer, M.J.H, 2013]

	S1	S2	S3	S4	S5	S6
$m_{\tilde{L}_{1,2}}$	500	750	1000	800	500	1500
$m_{\tilde{L}_3}$	500	750	1000	500	500	1500
M_2	500	500	500	500	750	300
A_τ	500	750	1000	500	0	1500
μ	400	400	400	400	800	300
$\tan\beta$	20	30	50	40	10	40
M_A	500	1000	1000	1000	1000	1500
$m_{\tilde{Q}_{1,2}}$	2000	2000	2000	2000	2500	1500
$m_{\tilde{Q}_3}$	2000	2000	2000	500	2500	1500
A_t	2300	2300	2300	1000	2500	1500
$m_{\tilde{l}_1} - m_{\tilde{l}_6}$	489-515	738-765	984-1018	474-802	488-516	1494-1507
$m_{\tilde{\nu}_1} - m_{\tilde{\nu}_3}$	496	747	998	496-797	496	1499
$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_2^\pm}$	375-531	376-530	377-530	377-530	710-844	247-363
$m_{\tilde{\chi}_1^0} - m_{\tilde{\chi}_4^0}$	244-531	245-531	245-530	245-530	373-844	145-363
M_h	126.6	127.0	127.3	123.1	123.8	125.1
M_H	500	1000	999	1001	1000	1499
M_A	500	1000	1000	1000	1000	1500
$M_{H^\pm}$	507	1003	1003	1005	1003	1502
$m_{\tilde{u}_1} - m_{\tilde{u}_6}$	1909-2100	1909-2100	1908-2100	336-2000	2423-2585	1423-1589
$m_{\tilde{d}_1} - m_{\tilde{d}_6}$	1997-2004	1994-2007	1990-2011	474-2001	2498-2503	1492-1509
$m_{\tilde{g}}$	2000	2000	2000	2000	3000	1200

Heavy SUSY ok with LHC, h identified with observed Higgs ($M_h \in (123, 127)$ GeV), $(g-2)_\mu$ OK with data.

Bounds on δ_{23}^{LL} for selected S1,..,S6 points

[Arana-Catania, Heinemeyer, M.J.H, 2013]

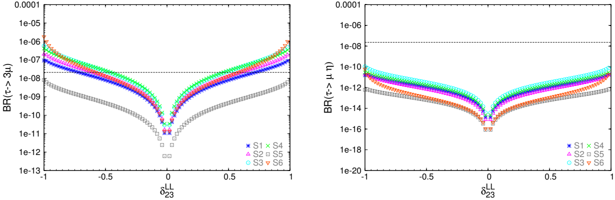


$$|\delta_{23}^{LL}| < \mathcal{O}(10^{-1})$$

$\mathrm{BR}(\tau \to \mu\gamma)$ most restrictive observable

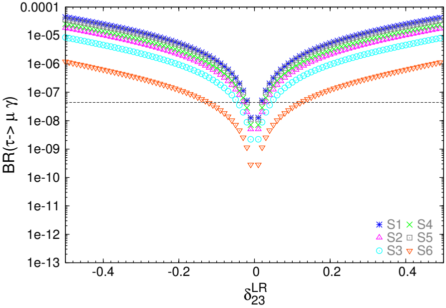
Similar bounds for δ_{13}^{LL}

Higgs mediated $\tau \to 3\mu$ and $\tau \to \mu\eta$ less constraining (even at large $\tan\beta$)



Bounds on δ_{23}^{LR} for selected S1,..,S6 points

[Arana-Catania, Heinemeyer, M.J.H, 2013]

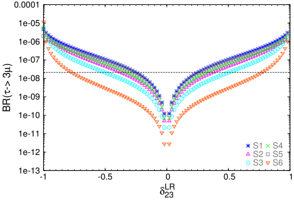


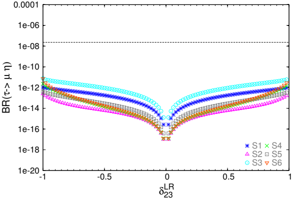
$$|\delta_{23}^{LR}| < \mathcal{O}(10^{-1})$$

$\mathrm{BR}(\tau \to \mu\gamma)$ the most restrictive observable

Similar bounds for δ_{13}^{LR}

Higgs mediated $\tau \to 3\mu$ and $\tau \to \mu\eta$ less constraining





Bounds on δ_{23}^{RR} for selected S1,..,S6 points

[Arana-Catania, Heinemeyer, M.J.H, 2013]

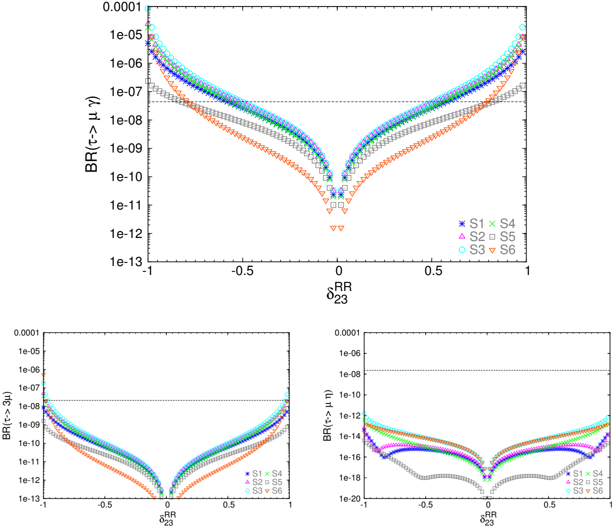
$|\delta_{23}^{RR}| < \mathcal{O}(1)$

The less constrained mixing

$\mathrm{BR}(\tau \to \mu\gamma)$ the most restrictive observable

Similar bounds for δ_{13}^{RR}

Higgs mediated $\tau \to 3\mu$ and $\tau \to \mu\eta$ less constraining



LFV constraints on double delta $(\delta_{23}^{LR}, \delta_{23}^{LL})$

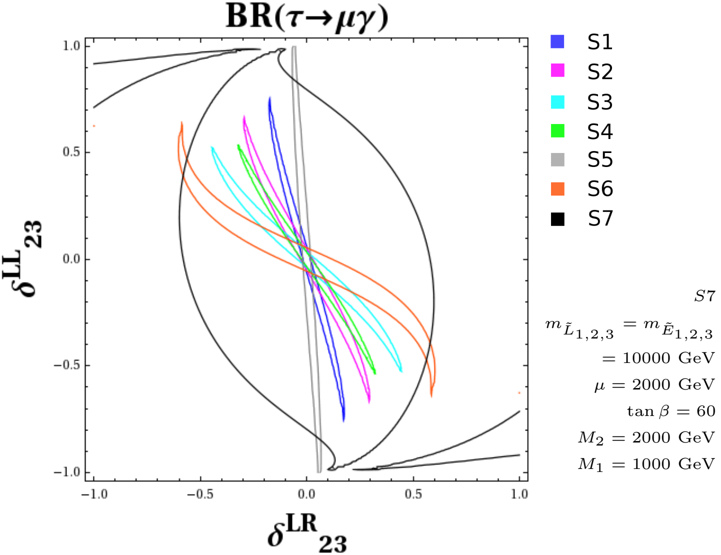
Constructive or destructive interference depending on relative sign of deltas

Allowed areas inside contour lines

Large deltas $\sim \pm 0.5$ still allowed.

Even larger $\sim \pm 0.9$ for S7

Heavy SUSY decoupling in $\tau \to \mu\gamma$



Summary of bounds on δ_{ij}^{AB} for selected points

[See details in: Arana-Catania, Heinemeyer, M.J.H, 2013]

For S1...S6: $500 < m_{\tilde{l},\tilde{\nu}}(\mathrm{GeV}) < 1500$; $300 < m_{\tilde{\chi}}(\mathrm{GeV}) < 900$

$|\delta_{23}^{LL}| < \mathcal{O}(10^{-1})$ $|\delta_{23}^{LR}| < \mathcal{O}(10^{-1})$ $|\delta_{23}^{RR}| < \mathcal{O}(1)$

$|\delta_{13}^{LL}| < \mathcal{O}(10^{-1})$ $|\delta_{13}^{LR}| < \mathcal{O}(10^{-1})$ $|\delta_{13}^{RR}| < \mathcal{O}(1)$

$|\delta_{12}^{LL}| < \mathcal{O}(10^{-4})$ $|\delta_{12}^{LR}| < \mathcal{O}(10^{-5})$ $|\delta_{12}^{RR}| < \mathcal{O}(10^{-3})$

If S7: $m_{\tilde{l},\tilde{\nu}} \sim 10\mathrm{TeV}$, $m_{\tilde{\chi}} \sim 2\mathrm{TeV}$, all $\delta_{23} \lesssim \mathcal{O}(1)$ allowed.

General : Heavy SUSY implies weaker bounds on δ_{ij}^{AB}'s

Results for LFV Higgs decays: BR$(h, H, A \to \tau\mu)$

[Arana-Catania, Arganda, M.J.H, 2013]

- We perform a systematic comparison of full-one loop BR$(\phi \to \tau\mu)$ and BR$(\tau \to \mu\gamma)$, and require BR$(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$.
- No approximation done here
- Earlier estimates of loop-induced LFV Higgs decay rates within MSSM:

  [Brignole, Rossi, 2003], [Diaz-Cruz, 2003], [Kanemura et al 2004], [Arganda, Curiel, M.J.H, Temes, 2005],....
- Recent studies of sensitivity to LFV Higgs decays at LHC:

  [Davidson, Verdier, 2012], [Blankenburg, Ellis, Isidori, 2012]

Work with simple heavy SUSY scenarios

Take all soft-mass parameters relevant for LFV related to just one m_{SUSY}:

$$\begin{aligned} m_{\tilde{L}} &= m_{\tilde{L}_1} = m_{\tilde{L}_2} = m_{\tilde{L}_3} = m_{\mathsf{SUSY}}\,, \\ m_{\tilde{E}} &= m_{\tilde{E}_1} = m_{\tilde{E}_2} = m_{\tilde{E}_3} = m_{\mathsf{SUSY}}\,, \\ \mu &= M_2 = a\, m_{\mathsf{SUSY}} \quad (a = 1/5, 1/3, 1)\;, \end{aligned}$$

with the approximate GUT relation for the gaugino masses:

$$M_2 = 2M_1 = M_3/4\,.$$

($A_\tau = A_\mu = A_e = m_{\mathsf{SUSY}}$, $m_{\tilde{Q}} = m_{\tilde{U}} = m_{\tilde{D}} = A_t = A_b =$ 5 TeV)
(checked that all these provide a m_h prediction close to exp. ± 2 GeV)

$$\mathcal{A}^l_{23} \;=\; \tilde{\delta}^{LR}_{23} m_{\mathsf{SUSY}}\,, \quad \mathcal{A}^l_{32} = \tilde{\delta}^{LR}_{32} m_{\mathsf{SUSY}}\,,$$

Simply related to the previous ones by:

$$\delta^{LR}_{23} = \left(\frac{v_1}{m_{\mathsf{SUSY}}}\right) \tilde{\delta}^{LR}_{23}\,, \quad \delta^{LR}_{32} = \left(\frac{v_1}{m_{\mathsf{SUSY}}}\right) \tilde{\delta}^{LR}_{32}.$$

Input parameters for LFV Higgs decays

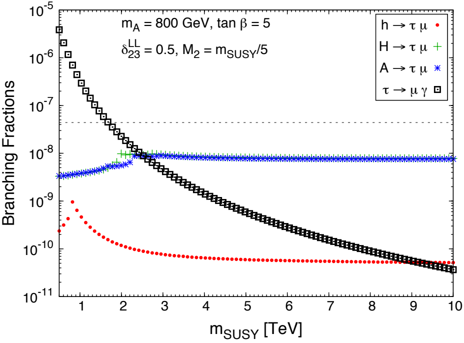
Explore wide intervals:

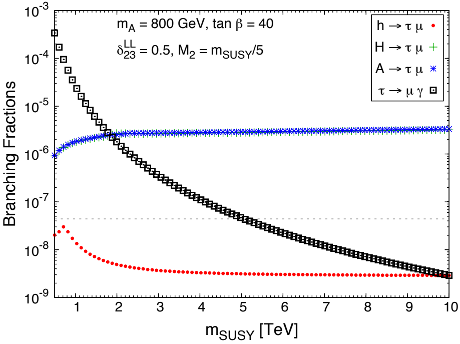
- 200 GeV $\leq m_A \leq$ 1000 GeV,
- 1 $\leq \tan\beta \leq$ 60,
- 0.5 TeV $\leq m_{\mathsf{SUSY}} \leq$ 10 TeV HEAVY SUSY!!,
- $-1 \leq \delta_{23}^{LL}$, $\delta_{23}^{RR} \leq 1$,
- $-5 \leq \tilde{\delta}_{23}^{LR}$, $\tilde{\delta}_{23}^{RL} \leq 5$,
  $(|\delta_{23}^{LR}|, |\delta_{23}^{RL}| \leq 0.0043$ for $m_{\mathsf{SUSY}} =$ 5 TeV and $\tan\beta =$ 40)

Respect constraints from:

1) Experimental bounds on BR($\tau \to \mu\gamma$)
2) LHC direct SUSY searches and $(m_A, \tan\beta)$ plane
3) Vacuum Metastability [Jae-hyeon Park (2011)]

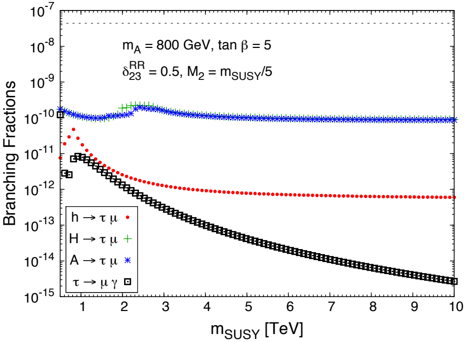
Results: LFV rates versus m_{SUSY} ($\delta_{23}^{LL} = 0.5$)

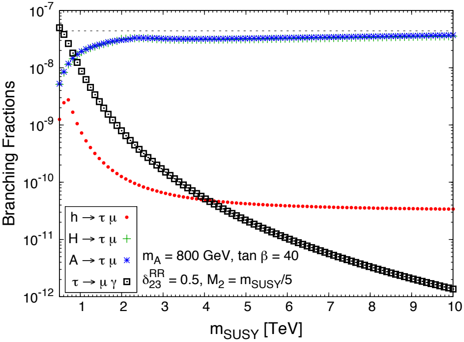




- Constant non-decoupling behavior of BR($\phi \to \tau\mu$) with m_{SUSY}.
- In contrast with decoupling behavior of BR($\tau \to \mu\gamma$) $\sim 1/m_{\text{SUSY}}^4$.
- Large ratios at large $\tan\beta$: BR($\delta_{23}^{LL} \neq 0$) grow with $\tan\beta$
- BR($H, A \to \tau\mu$) close to $\sim 10^{-5}$ for $\tan\beta = 40$ in allowed region ($m_{\rm SUSY} \geq 5\,\rm TeV$) by BR($\tau \to \mu\gamma$) exp. upper bound (dashed line)

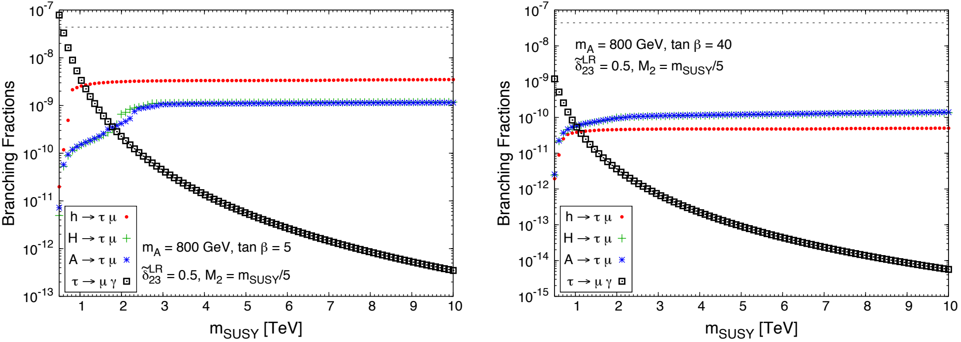
Results: LFV rates versus m_{SUSY} ($\delta_{23}^{RR} = 0.5$)





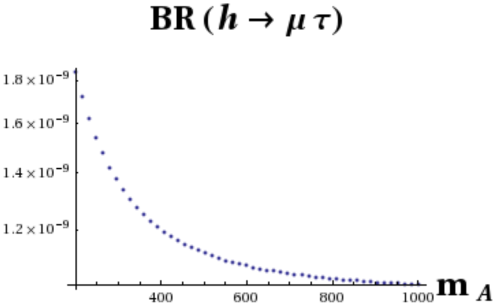
- Similar behavior with m_{SUSY} for δ_{23}^{RR} as for δ_{23}^{LL}
- But lower LFV rates for δ_{23}^{RR} than for δ_{23}^{LL}

Results: LFV rates versus m_{SUSY} ($\tilde{\delta}_{23}^{LR} = 0.5$)



- Again: Non-decoupling constant behaviour of LFV H decays for $\tilde{\delta}_{23}^{LR}$, versus decoupling behaviour of LFV τ decays.
- In contrast: BR($\delta_{23}^{LR} \neq 0$) decrease with $\tan\beta$. Large LFV rates at the low $\tan\beta$ region.

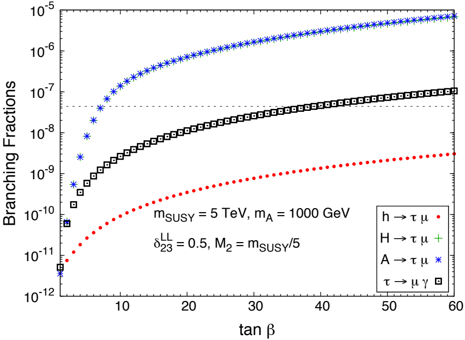
Remark on the 'Decoupling Limit' in LFV Higgs decays

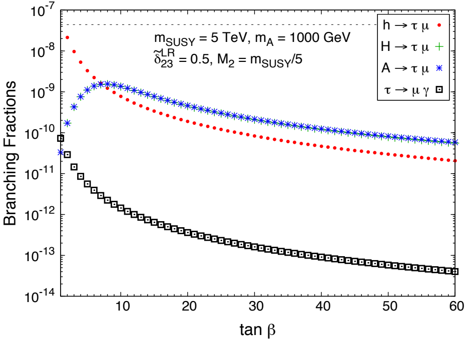


$(\delta_{23}^{LR} = 0.9,\ \delta_{23}^{LL} = \delta_{23}^{RR} = 0,\ m_{\rm SUSY} = 5\ {\rm TeV},\ \tan\beta = 60)$

The LFV ratios for the lightest Higgs boson decays, $h \to \tau\mu$,..,
manifest decoupling behaviour, as expected, for $m_A >> m_Z$
i.e in the so-called decoupling limit: h behaves as $H_{\rm SM}$ (OK!)

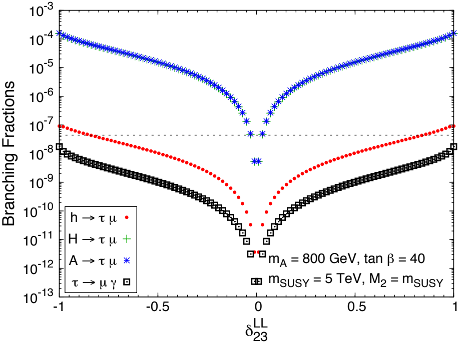
LFV rates as functions of $\tan\beta$

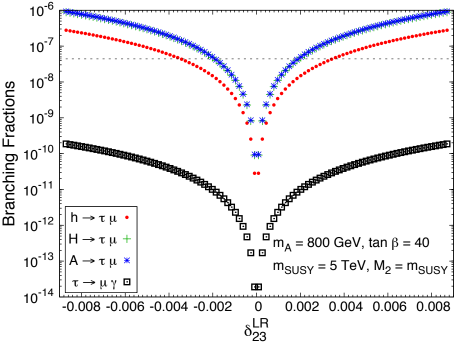




- δ_{23}^{LL} (and δ_{23}^{RR}): Larger ratios at large $\tan\beta$: $\tan\beta = 40$ optimal !
  BR($\delta_{23}^{LL} \neq 0$) $\sim (\tan\beta)^2$ for $\tan\beta \gtrsim 10$.
- δ_{23}^{LR} (and δ_{23}^{RL}): Lower ratios at large $\tan\beta$: $\tan\beta \lesssim 5$ optimal !
  BR($\delta_{23}^{LR} \neq 0$) $\sim (\tan\beta)^{-2}$ for $\tan\beta \gtrsim 10$.

Increasing the LFV rates with δ_{23}^{LL} and δ_{23}^{LR}



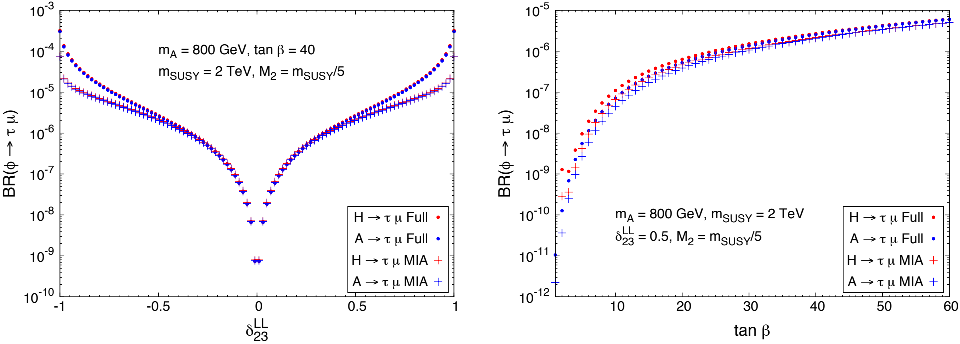


- Found growing behaviour as BR $\sim |\delta_{23}^{AB}|^2$, as expected.
- $|\delta_{23}^{LL}| \leq 1$ allowed by $\tau \to \mu\gamma$. Going to max.rates for:
  $\tan\beta = 40$ we get BR$(h \to \tau\mu) \sim 10^{-7}$, BR$(H, A \to \tau\mu) \sim 10^{-4}$.
- $|\tilde{\delta}_{23}^{LR}| \leq 5$ (or $|\delta_{23}^{LR}| \leq 0.0043$) allowed by $\tau \to \mu\gamma$. Going to max.rates, for:
  $|\tilde{\delta}_{23}^{LR}| = |\tilde{\delta}_{23}^{RL}| = 5$ and $\tan\beta = 5$, we get BR$(h, H, A \to \tau\mu) \sim 10^{(-5,-4)}$
- Switching both δ_{23}^{LL} and δ_{23}^{LR}: $\mathrm{BR}_{\max} \sim 10^{-4}$ for all ϕ; both large/low $\tan\beta$

Comparing full versus MIA approximation results I

We also compute simple MIA formulas for the LFV Higgs form factors as functions of δ_{23}^{AB} $(AB = LL, RR, LR, RL)$. Very usefull for future experimental analysis.

[Arganda, M.J.H, Morales, Szynkman, in progress 2014]



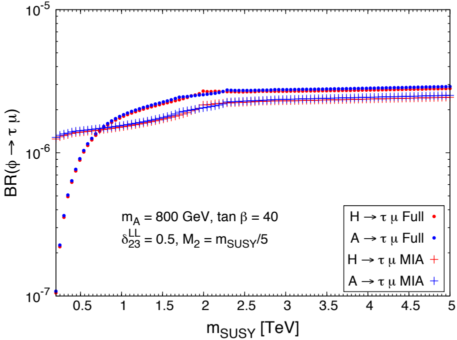
We find MIA a good approximation to full results:
For LL: precision better that $\sim 10\%$ for $|\delta_{23}^{LL}| \leq 0.5$ and $5 \leq \tan\beta \leq 60$ checked!!.

For RR and LR/RL cases work in progress

Comparing full versus MIA approximation results II

We also confirm the non-decoupling constant behaviour with large $m_{\rm SUSY}$ using the MIA simple formulas. The form factors $F^{\phi\tau\mu}$ tend to a constant at large $m_{\rm SUSY}$!

[Arganda, M.J.H, Morales, Szynkman, in progress 2014]



$$F_L^{H\tau\mu} \simeq -\frac{g^3}{16\pi^2}\frac{m_\tau}{m_W}\delta_{23}^{LL}\left[\frac{1}{8}(1+\tan^2\beta)+\frac{1}{24}\tan^2\theta_W(1+2\tan\beta-3\tan^2\beta)\right]$$

(constant with $m_{\rm SUSY}$ for $m_{\rm SUSY} >> m_W$!!)

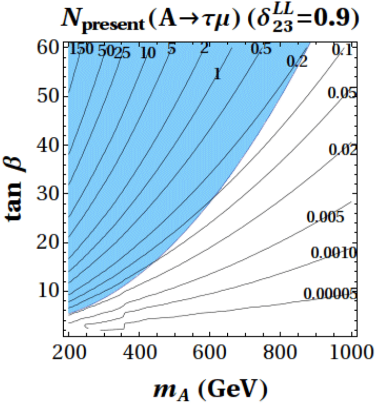
Results for the LFV Higgs mediated event rates at the LHC

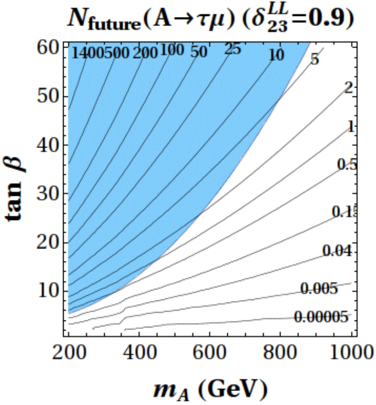
- Focus on largest rates allowed by $\tau \to \mu\gamma$
  We chose: $m_{\mathsf{SUSY}} \gtrsim 5$ TeV, $M_2 = m_{\mathsf{SUSY}}$, $\delta_{23}^{LL} = 0.9$ and $\tilde{\delta}_{23}^{LR} = \tilde{\delta}_{23}^{RL} = \pm 5$. Predictions for other choices easily derived from previous plots.
- Low $\tan\beta$: $\sigma(h, H, A)$ dominated by gluon fusion.
- Large $\tan\beta$ ($\gtrsim 10$): $\sigma(H, A)$ dominated by bottom-antibottom quark annihilation.
- We use FeynHiggs to compute the Higgs cross sections.

Phases of the LHC

- Present: $\sqrt{s} = 8$ TeV and $\mathcal{L} = 25$ fb^{-1}.
- Future: $\sqrt{s} = 14$ TeV and $\mathcal{L} = 100$ fb^{-1}.

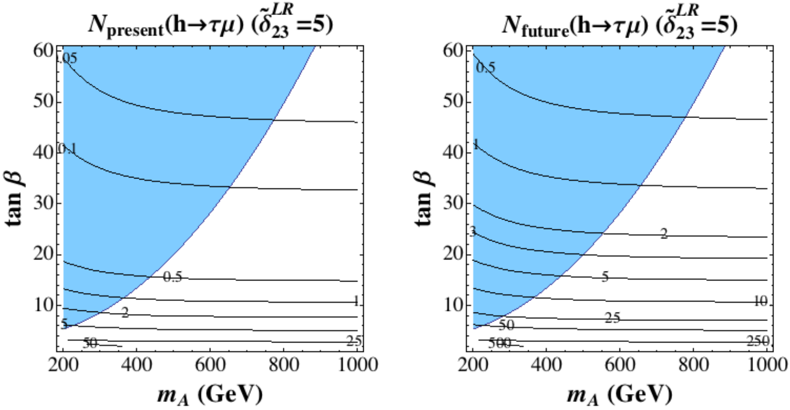
Predictions in $(m_A, \tan\beta)$ plane for LL mixing





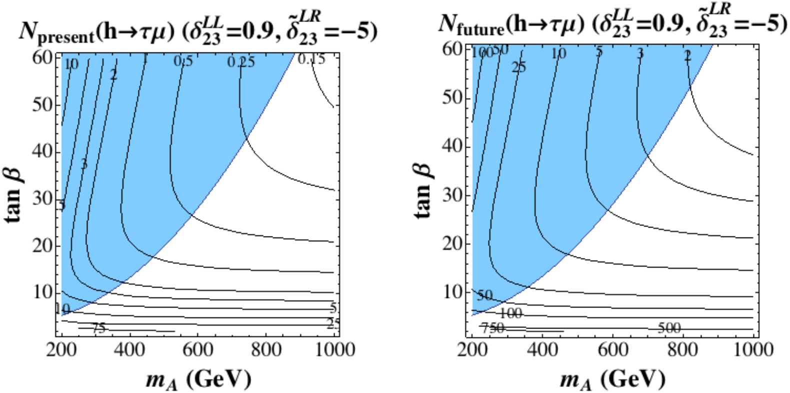
- The needed large $\tan\beta$ is excluded (blue area) by present LHC searches. No LFV mediated $A\,(\sim H)$ events in present phase of LHC if δ_{23}^{LL} responsible for $\tau - \mu$ transitions. Worse for h.
- Better expectations in future phase: up to $A\,(\sim H)$ 5 events for large $\tan\beta \gtrsim$ 50 and $800 < m_A(\mathrm{GeV}) < 1000$

Predictions in $(m_A, \tan\beta)$ plane for LR mixing



- Maximum allowed number of events are obtained in the low $\tan\beta$ region, softly dependent on m_A.
- For instance: 25 (250) LFV events in the present (future) LHC phase for $\tan\beta \sim 3$ and all $200 < m_A(\text{GeV}) < 1000$.

Predictions in $(m_A, \tan\beta)$ plane for LL-LR mixing



- Maximum rates predicted when combining both LL and LR deltas.
- For instance: 50 (500) LFV h events in the present (future) LHC phase for low $\tan\beta \sim 3$ and all $200 < m_A(\mathrm{GeV}) < 1000$
- Conclusions apply to both choices for the sign of LR/RL mixings, i.e. here for ± 5.

Conclusions

If m_{SUSY} is too heavy, as the present experiments are pointing out, and the SUSY particles cannot be directly reachable at the present or next future LHC energies, LFV Higgs decays could provide an unique window to explore new physics and to find some hint of very heavy SUSY at the LHC.

If LFV Higgs decays not seen at the LHC, then extract new bounds on slepton δ_{ij}^{AB} mixings, some more restrictive than from other LFV processes

Backup slides

Future work

- Analytical formulas from mass insertion approximation (MIA) in order to understand better the non-decoupling behavior of LFVHD.
- Search strategies for $\phi \to \tau\mu$ processes at the LHC, especially for the LFV decays of the heavy Higgs boson states, $H \to \tau\mu$ and $A \to \tau\mu$.

Present Status: LFV experimental searches

(c)LFV not seen yet. Intense program. Present (90%CL) bounds:

- Radiative decays,
  $\mathrm{Br}(\mu \to e\gamma) < 5.7 \times 10^{-13}$ [MEG, 2013]

  $\mathrm{Br}(\tau \to \mu\gamma) < 4.4 \times 10^{-8}$, $\mathrm{Br}(\tau \to e\gamma) < 3.3 \times 10^{-8}$ [BaBar, 2010]
- 3-body lepton decays,
  $\mathrm{Br}(\mu \to 3e) < 1.0 \times 10^{-12}$ [SINDRUM, 1988]

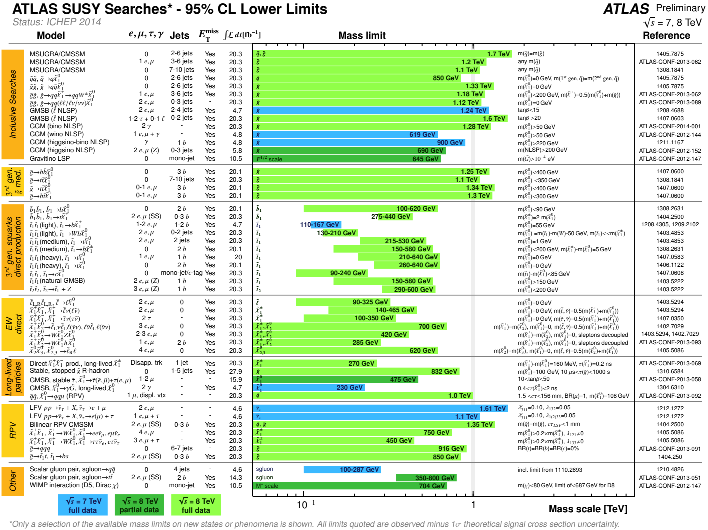
  $\mathrm{Br}(\tau \to 3\mu) < 2.1 \times 10^{-8}$, $\mathrm{Br}(\tau \to 3e) < 2.7 \times 10^{-8}$ [Belle, 2010]
- Semileptonic tau decays,

  $\mathrm{Br}(\tau \to \mu\eta) < 2.3 \times 10^{-8}$, $\mathrm{Br}(\tau \to e\eta) < 4.4 \times 10^{-8}$ [Belle, 2010]
- muon-electron conversion in heavy nuclei,

  $\mathrm{CR}(\mu - e, \mathrm{Au}) < 7.0 \times 10^{-13}$ [SINDRUM II, 2006]
- Meson decays, $\mathrm{Br}(B_d^0 \to e\mu) < 2.8 \times 10^{-9}$ [LHCb, 2013]
- Z decays, $\mathrm{Br}(Z \to \mu e) < 1.7 \times 10^{-6}$ [OPAL, 1995]
- H decays, $\mathrm{Br}(H \to \tau\mu) < 1.57\%$ $(95\% CL)$ LHC New! [CMS, 2014]
  Estimated $(8\,\mathrm{TeV}, 20\,\mathrm{fb}^{-1})$ sensitivity 4.5×10^{-3}[Davidson,Verdier 1211.1248]

Present Status: SUSY searches (summary)

SUSY not seen yet. Present (95% CL) bounds (similar in ATLAS and CMS):



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary

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

	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[fb^{-1}]$	Mass limit			Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q},\tilde{g}$	1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	1405.7875
	MSUGRA/CMSSM	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$	850 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$	1.33 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^{\pm}\to qqW^{\pm}\tilde{\chi}_1^0$	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$	1.18 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^{\pm})=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20.3	$\tilde{g}$	1.12 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e,μ	2-4 jets	Yes	4.7	$\tilde{g}$	1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$	1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$	1.28 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e,\mu+\gamma$	-	Yes	4.8	$\tilde{g}$	619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$	900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$	690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale	645 GeV	$m(\tilde{G})>10^{-4}$ eV	ATLAS-CONF-2012-147
3rd gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$	1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$	1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$	1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$	100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^{\pm}$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$	275-440 GeV	$m(\tilde{\chi}_1^{\pm})$=2 $m(\tilde{\chi}_1^0)$	1404.2500
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$	110-167 GeV	$m(\tilde{\chi}_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$	130-210 GeV	$m(\tilde{\chi}_1^0)$ =$m(\tilde{t}_1)$-$m(W)$-50 GeV, $m(\tilde{t}_1)$<<$m(\tilde{\chi}_1^{\pm})$	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e,μ	2 jets	Yes	20.3	$\tilde{t}_1$	215-530 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^{\pm}$	0	2 b	Yes	20.1	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^{\pm})$-$m(\tilde{\chi}_1^0)$=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e,μ	1 b	Yes	20	$\tilde{t}_1$	210-640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1407.0583
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{t}_1$	260-640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1406.1122
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$	90-240 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$	150-580 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$	290-600 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$	90-325 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$	140-465 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	100-350 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1407.0350
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$	700 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^{\pm})+m(\tilde{\chi}_1^0))$	1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$	420 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$	1 e,μ	2 b	Yes	20.3	$\tilde{\chi}_1^{\pm},\tilde{\chi}_2^0$	285 GeV	$m(\tilde{\chi}_1^{\pm})=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$	620 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^{\pm}$	270 GeV	$m(\tilde{\chi}_1^{\pm})$-$m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^{\pm})$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$	832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$	475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$	230 GeV	0.4<$\tau(\tilde{\chi}_1^0)$<2 ns	1304.6310
	$\tilde{q}\tilde{q}$, $\tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$	1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$	1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$	1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$	1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	750 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^{\pm})$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$	450 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^{\pm})$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$	916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$	850 GeV		1404.250
Other	Scalar gluon pair, sgluon→$q\bar{q}$	0	4 jets	-	4.6	sgluon	100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon→$t\bar{t}$	2 e,μ (SS)	2 b	Yes	14.3	sgluon	350-800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale	704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

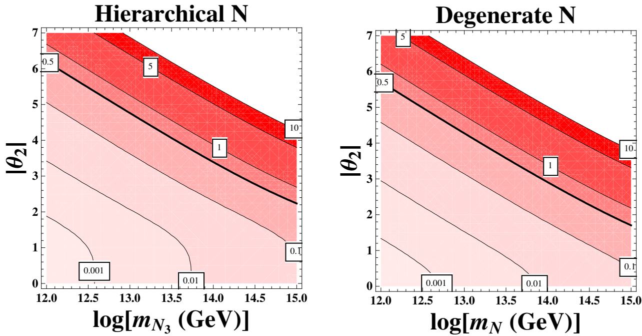
🟦 $\sqrt{s}$ = 7 TeV full data
🟩 $\sqrt{s}$ = 8 TeV partial data
🟩 $\sqrt{s}$ = 8 TeV full data

**Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.*

Size of δ_{32}^{LL} in SUSY-Seesaw

M.J.H, J.Portoles, A.Rodriguez-Sanchez, PRD80(2009)015023, (Seesaw I)

Contour lines of δ_{32}^{LL} for heavy N_i (full 1-loop RGE and compatibility with ν data)



Hierarchical N

Degenerate N

arg$(\theta_2) = \pi/4$

Large δ_{23}^{LL} for $m_{N_i} \sim 10^{14} - 10^{15}$ GeV $\Rightarrow |\delta_{32}^{LL}| \sim 0.1 - 10$ $(|\delta_{12}^{LL}| < 10^{-3})$

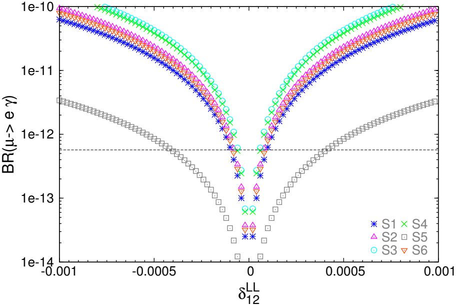
Perturbativity constraints (solid line): $|\frac{Y_\nu^2}{4\pi}| < 1.5 \Rightarrow |\delta_{23}^{LL}| < 0.5$

Larger δ_{32}^{LL} ($\sim \times 6$) and LFV rates in low scale SUSY-Seesaw models, like SUSY-ISS

[Deppisch,Valle,2005; Hirsch et al,2010; Abada et al 2012; Ilakovac et al,2012...]

Bounds on δ_{12}^{LL} for selected S1,..,S6 points

[Arana-Catania, Heinemeyer, M.J.H, 2013]

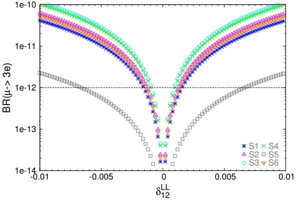


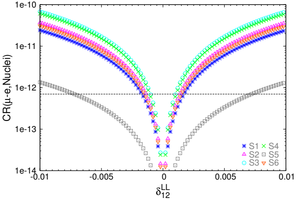
$$|\delta_{12}^{LL}| < \mathcal{O}(10^{-4})$$

All 12 mixings are strongly restricted

$\mathrm{BR}(\mu \to e\gamma)$ the most restrictive observable at present

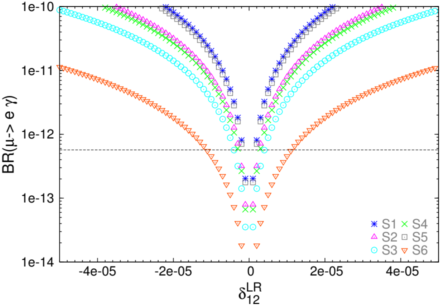
$\mu - e$ conversion also competitive, with best future prospects





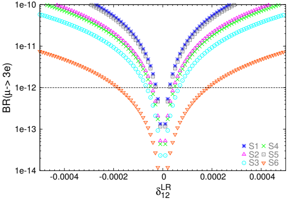
Bounds on δ_{12}^{LR} for selected S1,..,S6 points

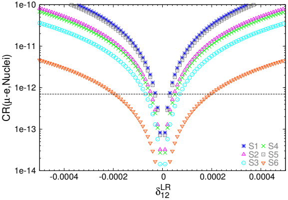
[Arana-Catania, Heinemeyer, M.J.H, 2013]



$|\delta_{12}^{LR}| < \mathcal{O}(10^{-5})$

δ_{12}^{LR} highly restricted !!

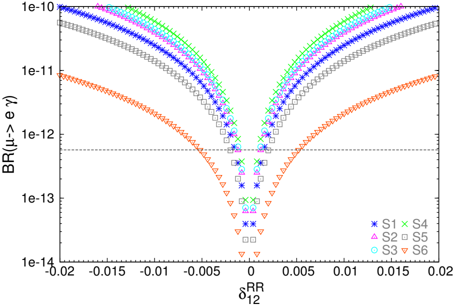


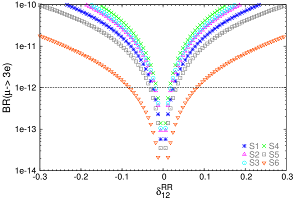


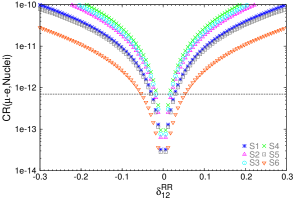
Bounds on δ_{12}^{RR} for selected S1,..,S6 points

[Arana-Catania, Heinemeyer, M.J.H, 2013]

$$|\delta_{12}^{RR}| < \mathcal{O}(10^{-3})$$







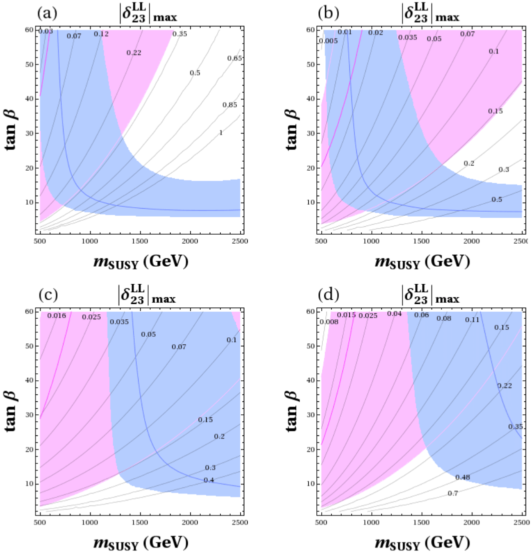
$|\delta_{23}|_{\rm max}$ in $(m_{SUSY}, \tan\beta)$ plane, versus $(g-2)_\mu$ and m_h

Max allowed by $\tau \to \mu\gamma$

Tension in MSSM versus data

$(g-2)_\mu$ requires a light SUSY-EW sector and large $\tan\beta$; m_h requires a heavy SUSY-QCD sector.

$|\delta_{23}^{LL}|_{\rm max} \sim \mathcal{O}(10^{-1})$



$m_{\tilde L} = m_{\tilde E} = m_{\rm SUSY-EW}$
$m_{\tilde Q} = m_{\tilde U} = m_{\tilde D} = m_{\rm SUSY-QCD}$

a) $M_2 = m_{\rm SUSY-EW}$
$A_t = 1.3\, m_{\rm SUSY-QC}$
$m_{\rm SUSY-QCD} = 2\, m_{\rm SUSY-EW}$

b) $M_2 = m_{\rm SUSY-EW}/5$
$A_t = m_{\rm SUSY-QCD}$
$m_{\rm SUSY-QCD} = 2\, m_{\rm SUSY-EW}$

c) $M_2 = 300$ GeV
$A_t = m_{\rm SUSY-QCD}$
$m_{\rm SUSY-QCD} = m_{\rm SUSY-EW}$

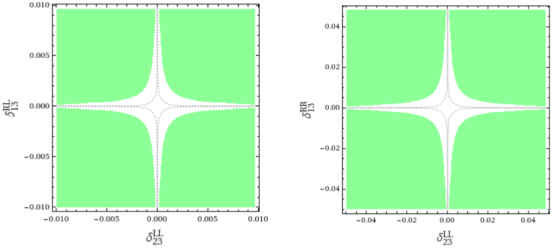
d) $M_2 = m_{\rm SUSY-EW}/3$
$A_t = m_{\rm SUSY-QCD}$
$m_{\rm SUSY-QCD} = m_{\rm SUSY-EW}$

Pink area allowed by $(g-2)_\mu$

Blue area allowed by m_h

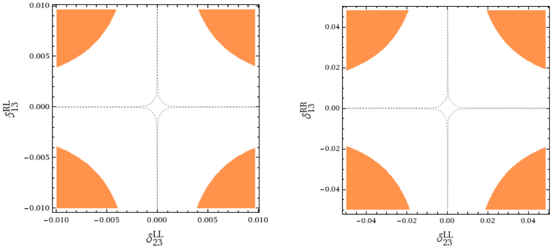
LFV constraints on double delta

More stringent bounds than single delta case.



Disallowed by $\mathrm{BR}(\mu \to e\gamma)$

Same conclusions for $(\delta_{13}^{LL}, \delta_{23}^{LL})$ and $(\delta_{13}^{RR}, \delta_{23}^{RR})$.



Disallowed by $\mu - e$ conversion

(Meta)stability bounds on $\mathcal{A}^l_{ij}$

If $\mathcal{A}^l_{ij}$ too large, MSSM scalar potential develops charge and/or colour breaking (CCB) minimum deeper than SM-like local minimum or unbounded from below (UFB) directions

[Casas, Dimopoulos (1996)]

$$|\mathcal{A}^l_{23}| \leq y_\tau \sqrt{m^2_{\tilde{L}_2} + m^2_{\tilde{E}_3} + m^2_1}\,, \text{ with } \quad y_\tau = \frac{g m_\tau}{\sqrt{2} M_W \cos\beta}$$

In our simplified SUSY scenarios:

$$|\delta^{LR}_{23}| \leq \frac{m_\tau}{m_{\mathsf{SUSY}}} \sqrt{2 + \frac{m_1^2}{m^2_{\mathsf{SUSY}}}}\,, \quad |\tilde{\delta}^{LR}_{23}| \leq y_\tau \sqrt{2 + \frac{m_1^2}{m^2_{\mathsf{SUSY}}}}\,.$$

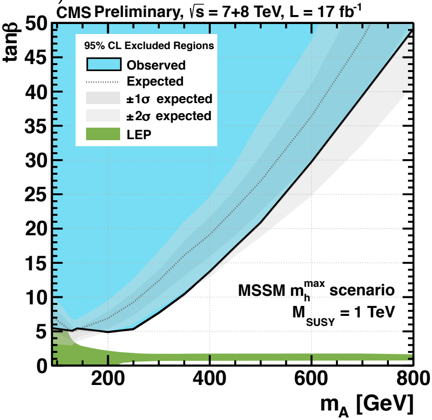
- **Stability:** for $m_{\mathsf{SUSY}} = m_A = 1$ TeV, $|\tilde{\delta}^{LR}_{23}| \lesssim \mathcal{O}(0.1)$ $(\tan\beta \simeq 5)$ and $|\tilde{\delta}^{LR}_{23}| \lesssim \mathcal{O}(1)$ $(\tan\beta \simeq 50)$.
- **Metastability:** for $3 \leq \tan\beta \leq 30$ and $m_{\mathsf{SUSY}} \leq 10$ TeV, $|\tilde{\delta}^{LR}_{23}| \leq 5$ [Jae-hyeon Park (2011)]. Weaker × factor $\sim (4-8)$.

Experimental constraints over the parameter space

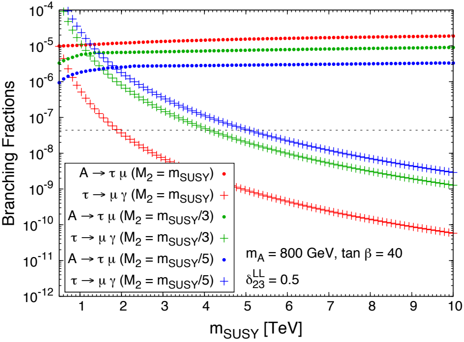
- B. Aubert *et al.*, [BABAR Collaboration], Phys. Rev. Lett. **104**, 021802 (2010) [arXiv:0908.2381 [hep-ex]]:

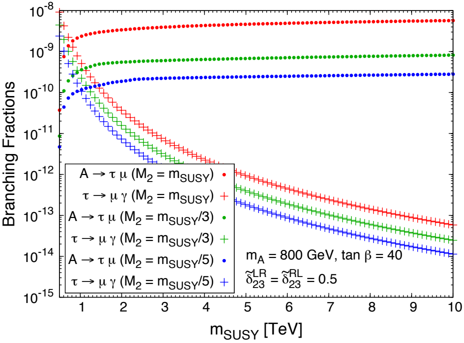
$$\text{BR}(\tau^{\pm} \to \mu^{\pm}\gamma) < 4.4 \times 10^{-8}\,.$$

- Searches for MSSM neutral Higgs bosons decaying to τ pairs in pp collisions (CMS-PAS-HIG-12-050).



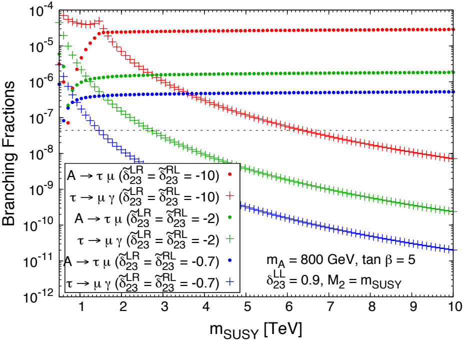
LFV rates as functions of m_{SUSY} $(M_2 = a\, m_{\text{SUSY}})$

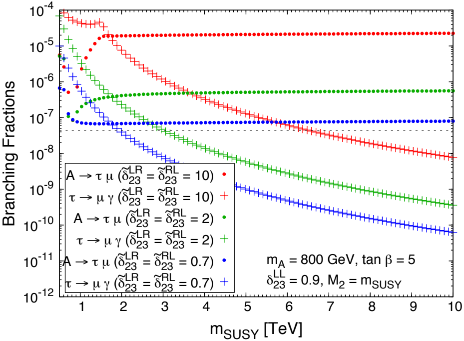




- LL case: the larger M_2 is, the larger the LFV Higgs branching ratios are and the lower BR$(\tau \to \mu\gamma)$ is.
- LR case: BR$(h, H, A \to \tau\mu)$ rise as a grows but BR$(\tau \to \mu\gamma)$ increases too.
- $M_2 = m_{\text{SUSY}}$ in order to obtain the largest LFVHD rates.

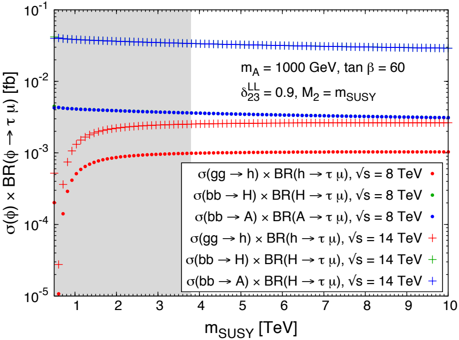
LFV rates combining δ_{23}^{LL} and $\tilde{\delta}_{23}^{LR} = \tilde{\delta}_{23}^{RL}$

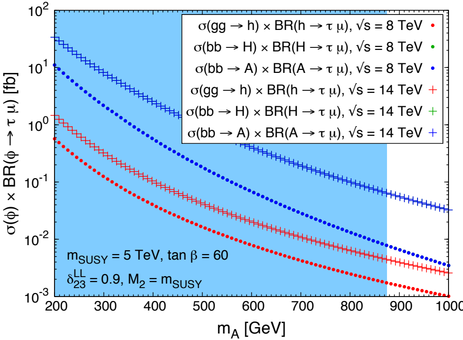




- LFV rates increase as $|\tilde{\delta}_{23}^{LR}| = |\tilde{\delta}_{23}^{RL}|$ grows and slightly higher than for single LL or LR mixings: BR$(h \to \tau\mu) \simeq 10^{-4}$ and BR$(H, A \to \tau\mu) \simeq 3 \times 10^{-5}$.
- LFVHD rates from negative LR mixings slightly larger than positive ones. Opposite behavior for $\tau \to \mu\gamma$.

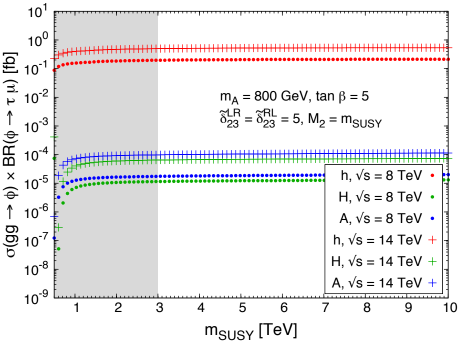
Predictions for single LL mixing

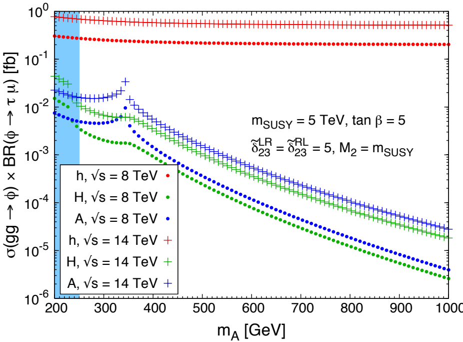




- Shaded gray area excluded by $\tau \to \mu\gamma$ upper bound and shaded blue area excluded by CMS searches.
- $H, A \to \tau\mu$: $\mathcal{L} \gtrsim 100$ fb^{-1} (present) and $\mathcal{L} \gtrsim 20$ fb^{-1} (future).
- $h \to \tau\mu$: $\mathcal{L} \gtrsim 500$ fb^{-1} (present) and $\mathcal{L} \gtrsim 200$ fb^{-1} (future).
- Large m_A and large $\tan\beta$: h behaves as SM-like Higgs with no LFV couplings (decoupling limit).

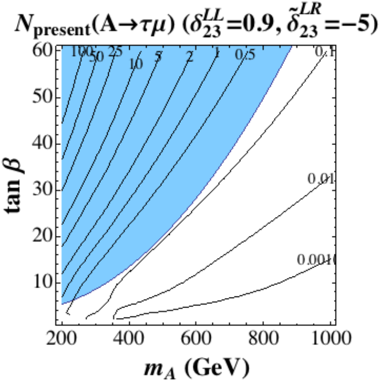
Predictions for single LR mixing

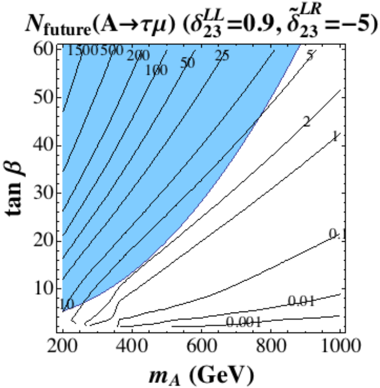




- $\sigma(gg \to h) \times$ BR$(h \to \tau\mu)$ reach values around 0.2 fb in the present LHC phase and up to 0.5 fb in the future one.
- LFV A cross sections of 0.01 fb (0.04 fb) in the present (future) LHC phase ($t\bar{t}$ threshold effect).
- Largest LFV H cross section is 0.004 fb (0.01 fb) in the present (future) phase of the LHC ($m_A \simeq 250$ GeV).

Predictions in $(m_A, \tan\beta)$ plane for LL-LR mixing





- Event rates increase as $\tan\beta$ grows and are reduced as m_A gets bigger.
- Present: no events. Future: up to about 5 LFV events for large $\tan\beta$ and m_A and up to 10 in the low $\tan\beta$ region with $m_A \simeq$ 200 GeV.
- Similar conclusions are found for the case of positive LR.

F_L form factor

$$\begin{aligned} F_L^{(x)} &= \frac{g\tan^2\theta_W}{16\pi^2}\,\Delta_{LL}^{mk}\,\frac{m_{l_k}}{2\sqrt{2}v_1}\left[-\left(\sigma_2^{(x)}+p_x\sigma_1^{(x)}\tan\beta\right)\frac{\mu M_1}{m_L^4}\,f_1(b_L,a_L)\right. \\ &+ \left. 2\sigma_5^{(x)}\,\frac{\mu}{M_1^3}\,f_3(a_L,a_R)+2(A_k-\mu\tan\beta)p_x\sigma_1^{(x)}\,\frac{M_1}{m_L^4}\,f_1(a_L/a_R,a_L)\right] \\ &+ \frac{g}{16\pi^2}\,\Delta_{LL}^{mk}\,\frac{3m_{l_k}}{2\sqrt{2}v_1}\,\frac{\mu M_2}{m_L^4}\,f_1(b_L,a_{L_2})\left(\sigma_2^{(x)}+p_x\sigma_1^{(x)}\tan\beta\right)\,, \end{aligned}$$

where $\Delta_{AB}^{mk}=\delta_{AB}^{mk}m_A m_B$ with $A=L,R$ and $B=L,R$, $p_h=p_H=+1$ and $p_A=-1$,

$$a_L=\frac{M_1^2}{m_L^2}\,,\,a_{L_2}=\frac{M_2^2}{m_L^2}\,,\,a_R=\frac{M_1^2}{m_R^2}\,,\,b_L=\frac{\mu^2}{m_L^2}\,,\,b_R=\frac{\mu^2}{m_R^2}\,,$$

$$f_1(a,b)=\frac{-a(-1+b)^2\log(a)+(-1+a)[-(a-b)(-1+b)+(-1+a)b\log(b)]}{(-1+a)^2(a-b)(-1+b)^2}\,,$$

$$f_3(a,b)=\frac{a^2b[-(-1+b)(-a^2+b)\log(a)+(-1+a)(a-(1+a)b+b^2-(-1+a)b\log(b))]}{(-1+a)^2(a-b)^2(-1+b)}\,,$$

$$\sigma_1^{(x)}=\begin{pmatrix}\sin\alpha\\ -\cos\alpha\\ i\sin\beta\end{pmatrix}\,,\quad \sigma_2^{(x)}=\begin{pmatrix}\cos\alpha\\ \sin\alpha\\ -i\cos\beta\end{pmatrix}\,,\quad \sigma_5^{(x)}=\begin{pmatrix}\cos\alpha\\ \sin\alpha\\ i\cos\beta\end{pmatrix}\,.$$

F_L in the limit of equal soft masses

In the limit of $M_1 = M_2 = \mu = m_L = m_R = m_{\mathsf{SUSY}}$,

$$\begin{aligned}\tilde{F}_L^{(x)} &= \frac{g\tan^2\theta_W}{16\pi^2}\delta_{LL}^{mk}\frac{m_{l_k}}{6\sqrt{2}v_1}\left[-\frac{\sigma_2^{(x)}}{2}+p_x\sigma_1^{(x)}\left(1-\frac{3}{2}\tan\beta\right)+\sigma_5^{(x)}\right]\\ &+ \frac{g}{16\pi^2}\delta_{LL}^{mk}\frac{m_{l_k}}{4\sqrt{2}v_1}\left(\sigma_2^{(x)}+p_x\sigma_1^{(x)}\tan\beta\right)\,,\end{aligned}$$

with

$$\lim_{a,b\to 1} f_1(a,b) = \lim_{a,b\to 1} f_3(a,b) = \frac{1}{6}\,.$$