Testing supersymmetric neutrino mass models at the LHC

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Overview

- Neutrinos & lepton flavour violation
- Signals in models with
  - Dirac neutrinos
  - Majorana neutrinos in seesaw models
- How to acccess the seesaw scale(s)
- Conclusions

Lepton flavour violation, experimental data

Neutrinos: tiny masses

$\Delta m^2_{atm} \simeq 2.4 \cdot 10^{-3}$ eV^2

$\Delta m^2_{sol} \simeq 7.6 \cdot 10^{-5}$ eV^2

^{3}H decay: $m_\nu \lesssim 2$ eV

Neutrinos: large mixings

$|\tan\theta_{atm}|^2 \simeq 1$

$|\tan\theta_{sol}|^2 \simeq 0.4$

$|U_{e3}|^2 \lesssim 0.05$

strong bounds for charged leptons

$BR(\mu \to e\gamma) \lesssim 1.2 \cdot 10^{-11}$

$BR(\mu^- \to e^- e^+ e^-) \lesssim 10^{-12}$

$BR(\tau \to e\gamma) \lesssim 1.1 \cdot 10^{-7}$

$BR(\tau \to \mu\gamma) \lesssim 4.5 \cdot 10^{-8}$

$BR(\tau \to l l l') \lesssim O(10^{-8})$ $(l, l' = e, \mu)$

$$|d_e| \lesssim 10^{-27}\, e\, cm,\ |d_\mu| \lesssim 1.5 \cdot 10^{-18}\, e\, cm,\ |d_\tau| \lesssim 1.5 \cdot 10^{-16}\, e\, cm$$

SUSY contributions to anomalous magnetic moments

$$|\Delta a_e| \leq 10^{-12},\ \ 0 \leq \Delta a_\mu \leq 43 \cdot 10^{-10},\ \ |\Delta a_\tau| \leq 0.058$$

	Standard Model		MSSM
matter:	e d d d ν_e u u u	$\Leftrightarrow$	$\tilde{e}$ $\tilde{d}$ $\tilde{d}$ $\tilde{d}$ $\tilde{\nu}_e$ $\tilde{u}$ $\tilde{u}$ $\tilde{u}$
gauge sector:	γ Z^0 $W^\pm$ g	$\Leftrightarrow$	$\tilde{\gamma}$ $\tilde{z}^0$ $\tilde{w}^\pm$ $\tilde{g}$
Higgs sector:	h^0 H^0 A^0 $H^\pm$	$\Leftrightarrow$	$\tilde{h}^0_d$ $\tilde{h}^0_u$ $\tilde{h}^\pm$

assume at the moment conserved R-Parity: $(-1)^{(3(B-L)+2s)}$

$(\tilde{\gamma}, \tilde{z}^0, \tilde{h}^0_d, \tilde{h}^0_u) \rightarrow \tilde{\chi}^0_i$, $(\tilde{w}^\pm, \tilde{h}^\pm) \rightarrow \tilde{\chi}^\pm_j$

Dirac neutrinos

analog to leptons or quarks

$$Y_\nu \, H \, \bar{\nu}_L \, \nu_R \to Y_\nu \, v \, \bar{\nu}_L \, \nu_R = m_\nu \, \bar{\nu}_L \, \nu_R$$

requires $Y_\nu \ll Y_e$

$\Rightarrow$ no impact for present or future collider experiments

Exception: $\tilde{\nu}_R$ is LSP and thus a candidate for dark matter
$\Rightarrow$ long lived NLSP, e.g. $\tilde{t}_1 \to l^+ b \tilde{\nu}_R$

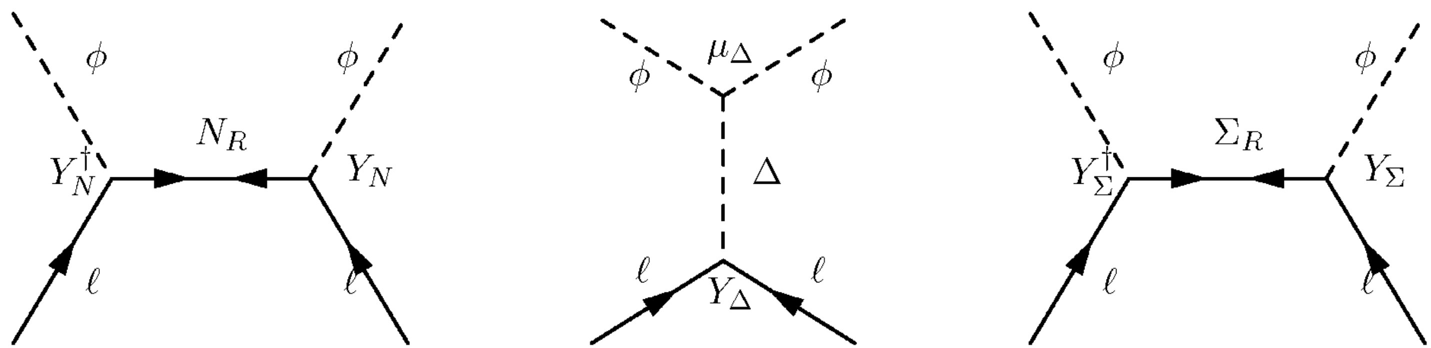
Remark: $m_{\tilde{\nu}_R}$ hardly runs $\Rightarrow$ e.g. $m_{\tilde{\nu}_R} \simeq m_0$ in mSUGRA
$m_{\tilde{\nu}_R} \simeq 0$ in GMSB

S. Gopalakrishna, A. de Gouvea and W. P., JHEP **0611** (2006) 050
S. K. Gupta, B. Mukhopadhyaya, S. K. Rai, PRD **75** (2007) 075007
D. Choudhury, S. K. Gupta, B. Mukhopadhyaya, PRD **78** (2008) 015023

Majorana neutrinos: Seesaw mechanism*

Neutrino masses due to

$$\frac{f}{\Lambda}(HL)(HL)$$



* P. Minkowski, Phys. Lett. B **67** (1977) 421; T. Yanagida, KEK-report 79-18 (1979); M. Gell-Mann, P. Ramond, R. Slansky, in *Supergravity*, North Holland (1979), p. 315; R.N. Mohapatra and G. Senjanovic, *Phys. Rev. Lett.* **44** 912 (1980); M. Magg and C.Wetterich, Phys. Lett. B 94 (1980) 61; G. Lazarides, Q. Shafi and C. Wetterich, Nucl. Phys. B 181 (1981) 287; J. Schechter and J. W. F. Valle, Phys. Rev. **D25**, 774 (1982); R. Foot, H. Lew, X. G. He and G. C. Joshi, Z. Phys. C 44 (1989) 441.

The Setup: GUT scale

Relevant SU(5) invariant parts of the superpotentials at M_{GUT}

- Type-I

$$W_{\mathrm{RHN}} = \mathbf{Y}_N^{\mathrm{I}}\, N^c\, \overline{5}_M \cdot 5_H + \frac{1}{2}\, M_R\, N^c N^c$$

- Type-II

$$W_{15\mathrm{H}} = \frac{1}{\sqrt{2}} \mathbf{Y}_N^{\mathrm{II}}\, \overline{5}_M \cdot 15 \cdot \overline{5}_M + \frac{1}{\sqrt{2}} \lambda_1 \overline{5}_H \cdot 15 \cdot \overline{5}_H + \frac{1}{\sqrt{2}} \lambda_2 5_H \cdot \overline{15} \cdot 5_H$$
$$+ M_{15} 15 \cdot \overline{15}$$

- Type-III

$$W_{24\mathrm{H}} = 5_H 24_M Y_N^{III} \overline{5}_M + \frac{1}{2} 24_M M_{24} 24_M$$

The $SU(5)$-broken phase

Under $SU(3) \times SU_L(2) \times U(1)_Y$

- The **5**, **10** and $\mathbf{5}_H$ contain

$$\overline{5}_M = (\widehat{D}^c, \widehat{L}),\ 10 = (\widehat{U}^c, \widehat{E}^c, \widehat{Q}),\ 5_H = (\widehat{H}^c, \widehat{H}_u),\ \overline{5}_H = (\widehat{\overline{H}}^c, \widehat{H}_d)$$

- The $\mathbf{15}$ decomposes as

$$\mathbf{15} = \widehat{S}(6,1,-\frac{2}{3}) + \widehat{T}(1,3,1) + \widehat{Z}(3,2,\frac{1}{6})$$

- The $\mathbf{24}$ decomposes as

$$\mathbf{24}_M = \widehat{W}_M(1,3,0) + \widehat{B}_M(1,1,0) + \widehat{\overline{X}}_M(3,2,-\frac{5}{6}) + \widehat{X}_M(\overline{3},2,\frac{5}{6}) + \widehat{G}_M(8,1,0)$$

Seesaw I

Postulate very heavy right-handed neutrinos yielding the following superpotential below M_{GUT}:

$$W_I = W_{MSSM} + W_\nu \ ,$$
$$W_\nu = \widehat{N}^c Y_\nu \widehat{L} \cdot \widehat{H}_u + \frac{1}{2} \widehat{N}^c M_R \widehat{N}^c \ ,$$

Neutrino mass matrix

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

Inverting the seesaw equation gives Y_ν a la Casas & Ibarra

$$Y_\nu = \sqrt{2} \frac{i}{v_u} \sqrt{\hat{M}_R} \cdot R \cdot \sqrt{\hat{m}_\nu} \cdot U^\dagger$$

$\hat{m}_\nu$, $\hat{M}_R$ . . . diagonal matrices containing the corresponding eigenvalues
U . . . . neutrino mixing matrix
R . . . . complex orthogonal matrix.

Seesaw II

Below M_{GUT} the superpotential reads

$$
\begin{aligned}
W_{II} &= W_{MSSM} + \frac{1}{\sqrt{2}}(Y_T \widehat{L} \widehat{T}_1 \widehat{L} + Y_S \widehat{D}^c \widehat{S}_1 \widehat{D}^c) + Y_Z \widehat{D}^c \widehat{Z}_1 \widehat{L} \\
&+ \frac{1}{\sqrt{2}}(\lambda_1 \widehat{H}_d \widehat{T}_1 \widehat{H}_d + \lambda_2 \widehat{H}_u \widehat{T}_2 \widehat{H}_u) + M_T \widehat{T}_1 \widehat{T}_2 + M_Z \widehat{Z}_1 \widehat{Z}_2 + M_S \widehat{S}_1 \widehat{S}_2
\end{aligned}
$$

fields with index 1 (2) originate from the 15-plet ($\overline{15}$-plet).

The effective mass matrix is

$$
m_\nu = -\frac{v_u^2}{2} \frac{\lambda_2}{M_T} Y_T .
$$

Note that

$$
\hat{Y}_T = U^T \cdot Y_T \cdot U \ ,
$$

Seesaw III

In the $SU(5)$ broken phase the superpotential becomes

$$\begin{aligned} W_{III} &= W_{MSSM} + \widehat{H}_u(\widehat{W}_M Y_N - \sqrt{\frac{3}{10}}\widehat{B}_M Y_B)\widehat{L} + \widehat{H}_u \widehat{\bar{X}}_M Y_X \widehat{D}^c \\ &+\frac{1}{2}\widehat{B}_M M_B \widehat{B}_M + \frac{1}{2}\widehat{G}_M M_G \widehat{G}_M + \frac{1}{2}\widehat{W}_M M_W \widehat{W}_M + \widehat{X}_M M_X \widehat{\bar{X}}_M \end{aligned}$$

giving

$$m_\nu = -\frac{v_u^2}{2}\left(\frac{3}{10} Y_B^T M_B^{-1} Y_B + \frac{1}{2} Y_W^T M_W^{-1} Y_W\right) \simeq -v_u^2 \frac{4}{10} Y_W^T M_W^{-1} Y_W$$

last step: valid if $M_B \simeq M_W$ and $Y_B \simeq Y_W$
$\Rightarrow$ Casas-Ibarra decomposition for Y_W as in type-I up to factor $4/5$

Effect of heavy particles on MSSM parameters

MSSM: $(b_1, b_2, b_3) = (33/5, 1, -3)$

per 15-plet $\Delta b_i = 7/2$ $\Rightarrow$ type II model $\Delta b_i = 7$

per 24-plet $\Delta b_i = 5$ $\Rightarrow$ type III model $\Delta b_i = 15$

Effect of heavy particles on MSSM parameters

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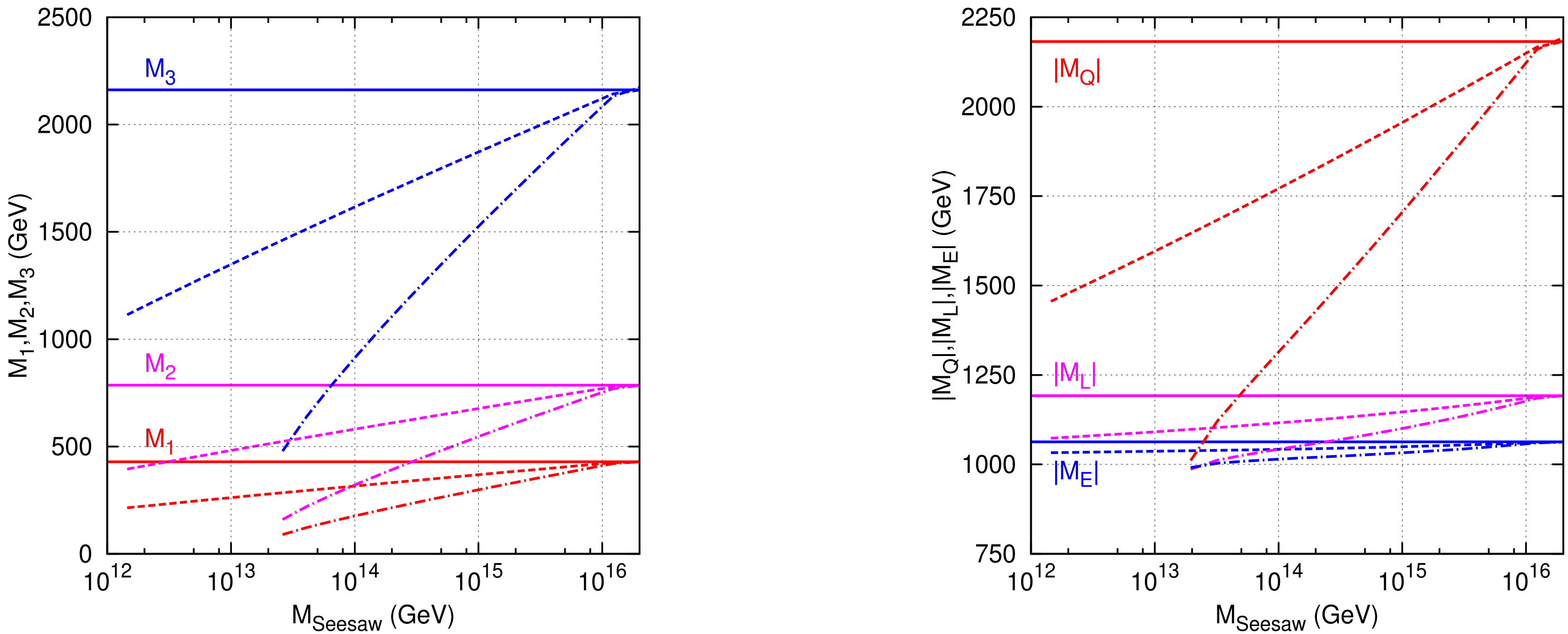


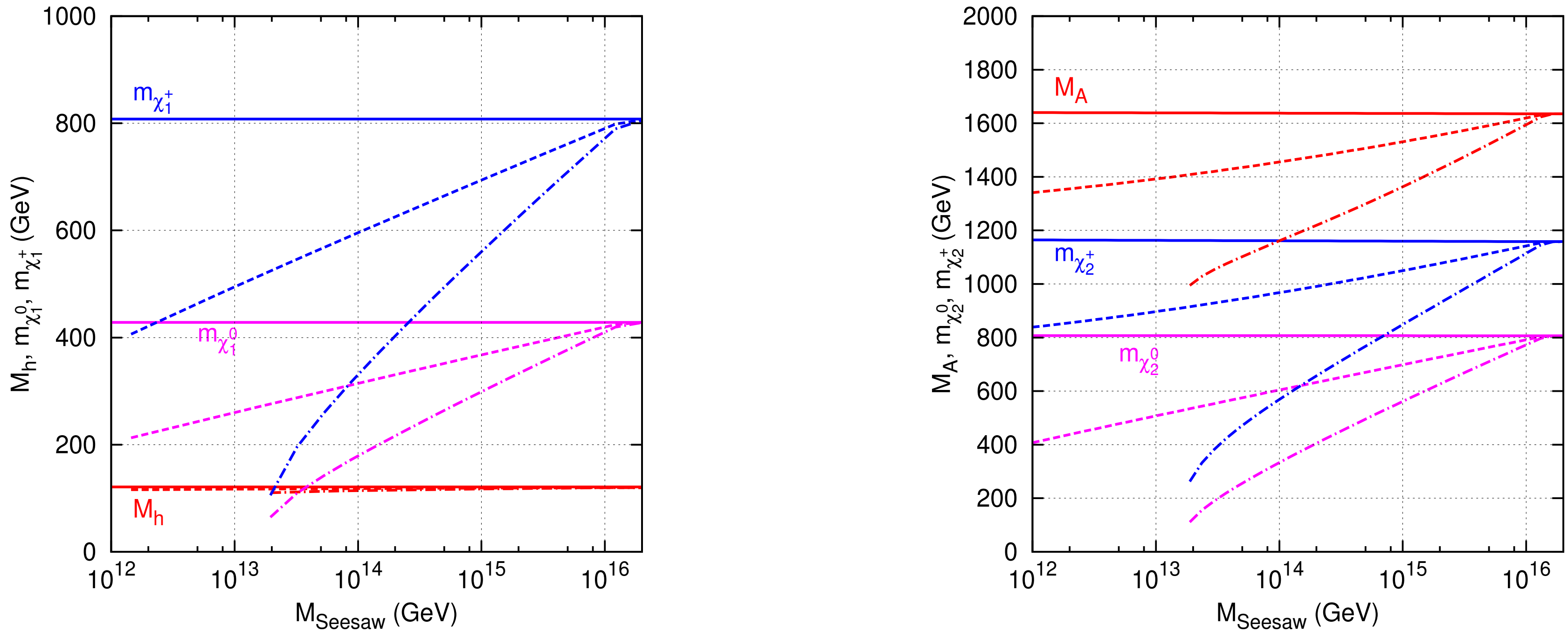
$Q = 1$ TeV, $m_0 = M_{1/2} = 1$ TeV, $A_0 = 0$, $\tan\beta = 10$ and $\mu > 0$

Full lines . . . seesaw type I, dashed lines . . . type II, dash-dotted lines . . . type III

degenerate spectrum of the seesaw particles

J. N. Esteves, M. Hirsch, W.P., J. C. Romao, F. Staub, Phys. Rev. D**83** (2011) 013003

Effect on heavy particles on MSSM spectrum, I

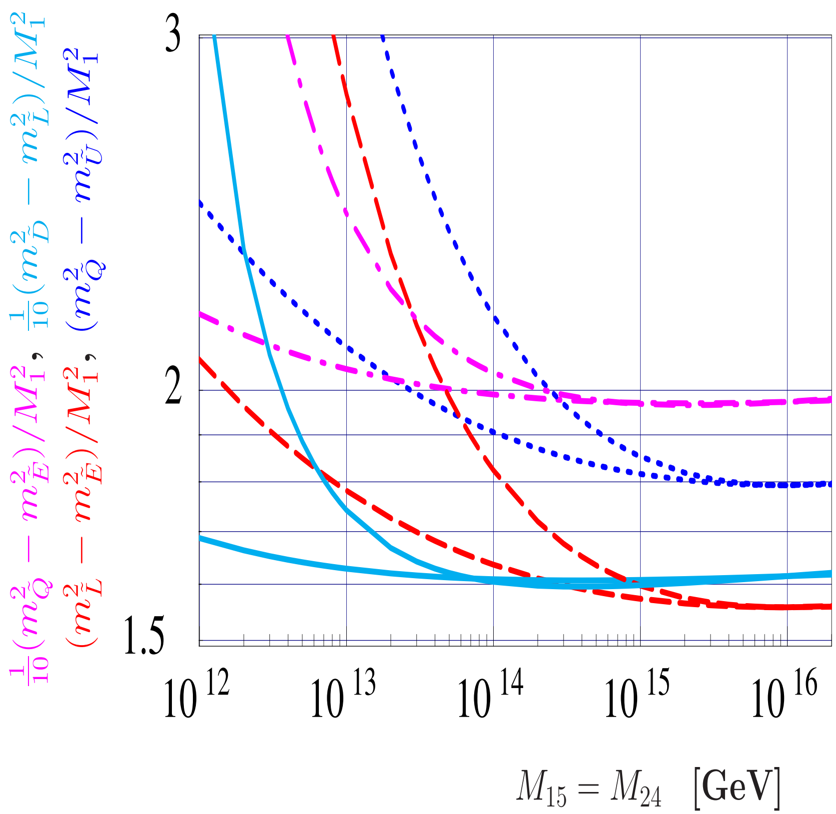


$m_0 = M_{1/2} = 1$ TeV, $A_0 = 0$, $\tan\beta = 10$ and $\mu > 0$

Full lines . . . seesaw type I, dashed lines . . . type II, dash-dotted lines . . . type III
degenerate spectrum of the seesaw particles

J. N. Esteves, M. Hirsch, W.P., J. C. Romao, F. Staub, Phys. Rev. D**83** (2011) 013003

"Invariants"



Seesaw I ($\simeq$ MSSM)

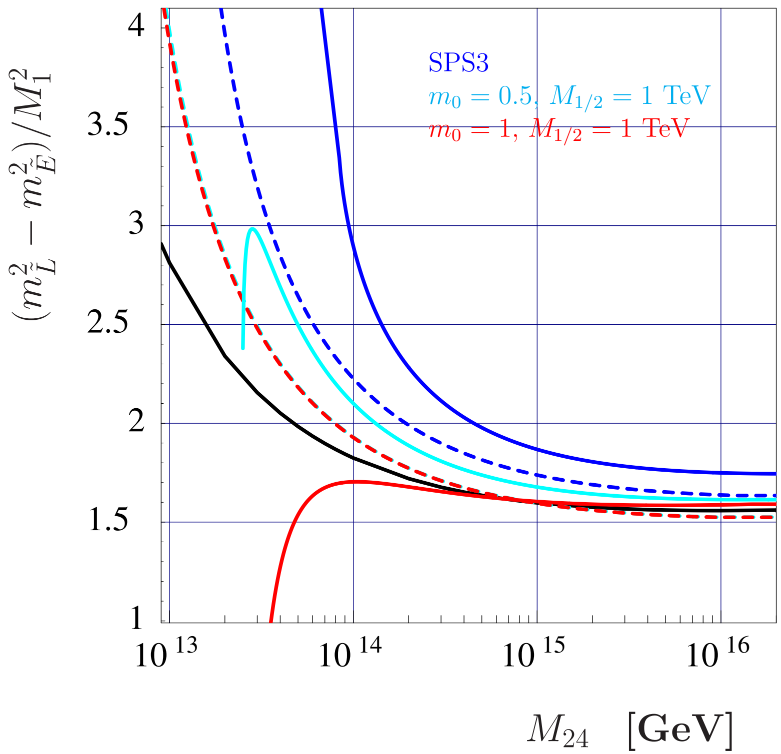
$\frac{m^2_Q - m^2_E}{M^2_1} \simeq 20$, $\frac{m^2_D - m^2_L}{M^2_1} \simeq 18$

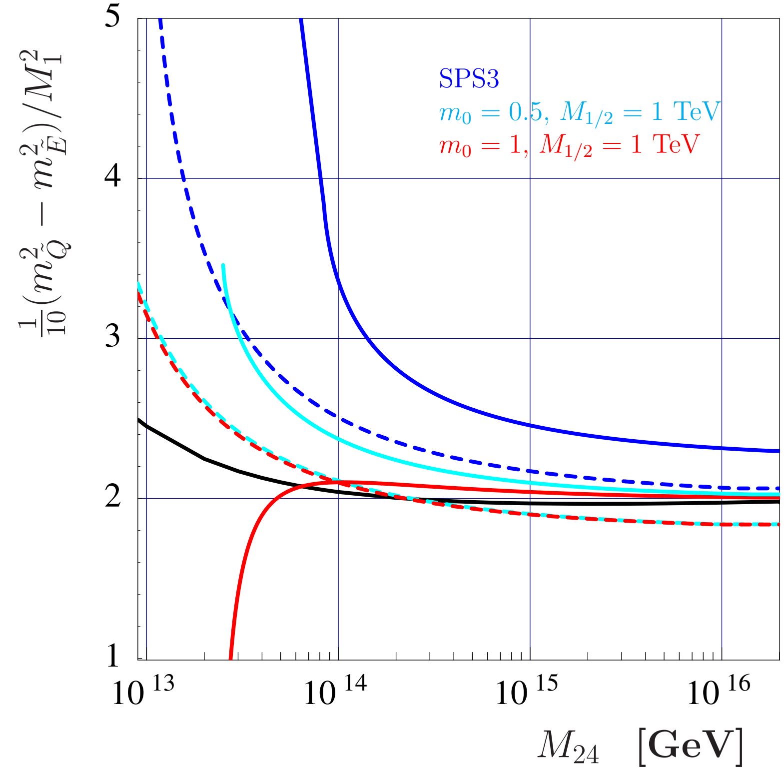
$\frac{m^2_L - m^2_E}{M^2_1} \simeq 1.6$, $\frac{m^2_Q - m^2_U}{M^2_1} \simeq 1.55$

(solution of 1-loop RGEs)

M. Hirsch, S. Kaneko, W. P., Phys. Rev. D **78** (2008) 093004
J. Esteves, M.Hirsch, J. Romão, W. P., F. Staub, Phys. Rev. D**83** (2011) 013003

"Invariants", limits for seesaw type-III models





blue lines . . . SPS3

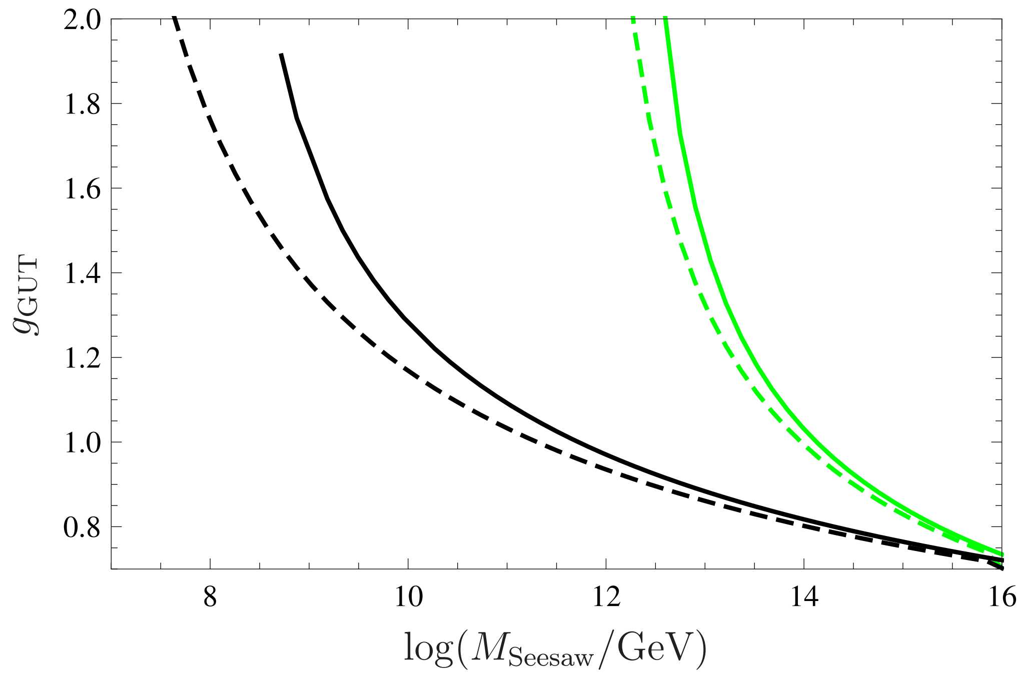
light blue lines . . . $m_0 = 500$ GeV and $M_{1/2} = 1$ TeV

red lines . . . $m_0 = M_{1/2} = 1$ TeV

black line . . . analytical approximation

full (dashed) lines . . . 2-loop (1-loop) results

Landau Poles



$m_0 = M_{1/2} = 1$ TeV, $A_0 = 0$, $\tan\beta = 10$ and $\mu > 0$
$M_{GUT} = 2 \times 10^{16}$ GeV
black lines . . . seesaw type-II
green lines . . . seesaw type-III with three **24**-plets with degenerate mass spectrum
full (dashed) lines . . . 2-loop (1-loop) results

LFV in the slepton sector: approximate formulas, I

one-step integration of the RGEs assuming mSUGRA boundary

$$\Delta M^2_{L,ij} \simeq -\frac{a_k}{8\pi^2}\left(3m_0^2 + A_0^2\right)\left(Y_N^{k,\dagger} L Y_N^k\right)_{ij}$$

$$\Delta A_{l,ij} \simeq -a_k \frac{3}{16\pi^2} A_0 \left(Y_e Y_N^{k,\dagger} L Y_N^k\right)_{ij}$$

$$\Delta M^2_{E,ij} \simeq 0$$

$$L_{ij} = \ln(M_{GUT}/M_i)\delta_{ij}$$

for $i \neq j$ with Y_e diagonal

$$a_I = 1 \;,\; a_{II} = 6 \text{ and } \; a_{III} = \frac{9}{5}$$

LFV in the slepton sector: approximate formulas, II

$(\Delta M^2_{\tilde{L}})_{ij}$ and $(\Delta A_l)_{ij}$ induce

$$\begin{aligned} l_j &\rightarrow l_i\gamma\ ,\ l_i l_k^+ l_r^- \\ \tilde{l}_j &\rightarrow l_i\tilde{\chi}^0_s \\ \tilde{\chi}^0_s &\rightarrow l_i\tilde{l}_k \end{aligned}$$

Neglecting L-R mixing:

$$\begin{aligned} Br(l_i \rightarrow l_j\gamma) &\propto \alpha^3 m^5_{l_i} \frac{|(\delta m^2_L)_{ij}|^2}{\widetilde{m}^8} \tan^2\beta \\ \frac{Br(\tilde{\tau}_2 \rightarrow e + \chi^0_1)}{Br(\tilde{\tau}_2 \rightarrow \mu + \chi^0_1)} &\simeq \left(\frac{(\Delta M^2_L)_{13}}{(\Delta M^2_L)_{23}}\right)^2 \end{aligned}$$

Moreover, in most of the parameter space

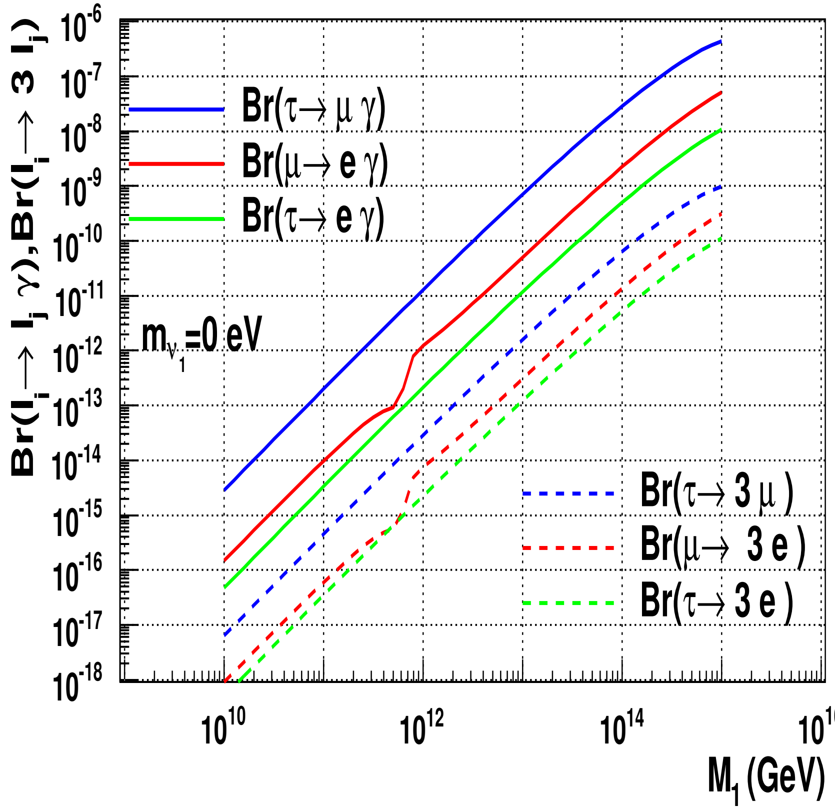
$$\frac{\mathrm{Br}(l_i \rightarrow 3l_j)}{\mathrm{Br}(l_i \rightarrow l_j + \gamma)} \simeq \frac{\alpha}{3\pi}\left(\log\left(\frac{m^2_{l_i}}{m^2_{l_j}}\right) - \frac{11}{4}\right)$$

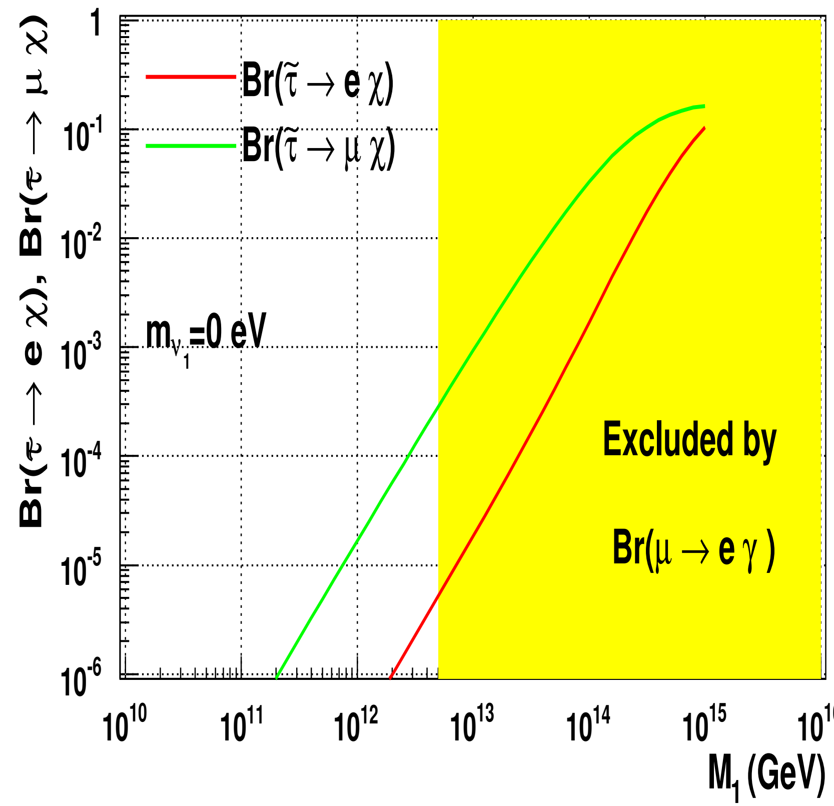
take all parameters real

$$U = U_{\text{TBM}} = \begin{pmatrix} \sqrt{\frac{2}{3}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{1}{\sqrt{6}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

$$R = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Use 2-loop RGEs and 1-loop corrections including flavour effects



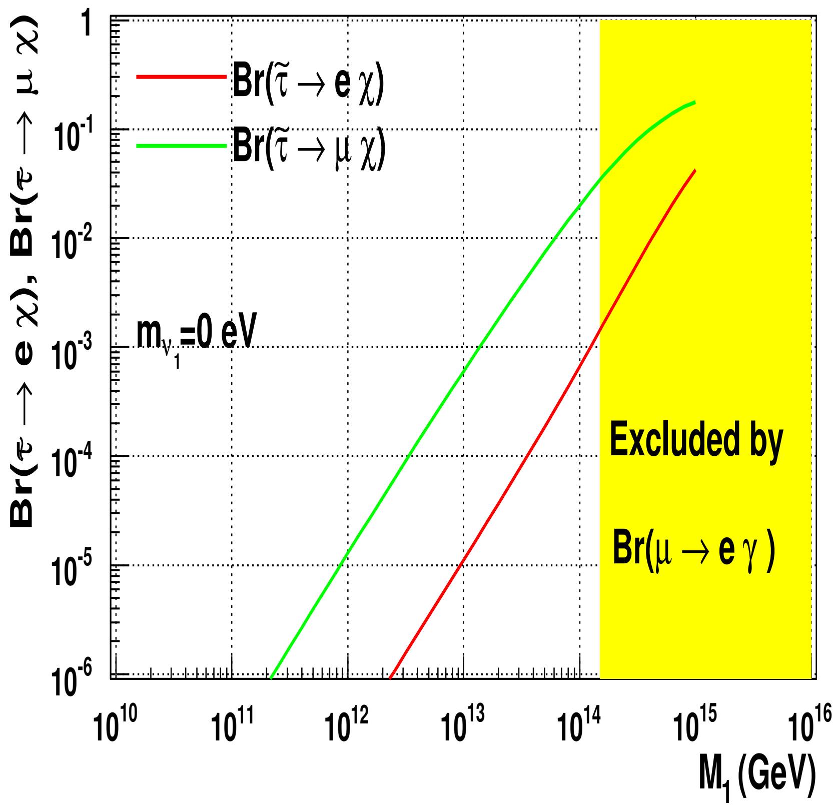


degenerate ν_R

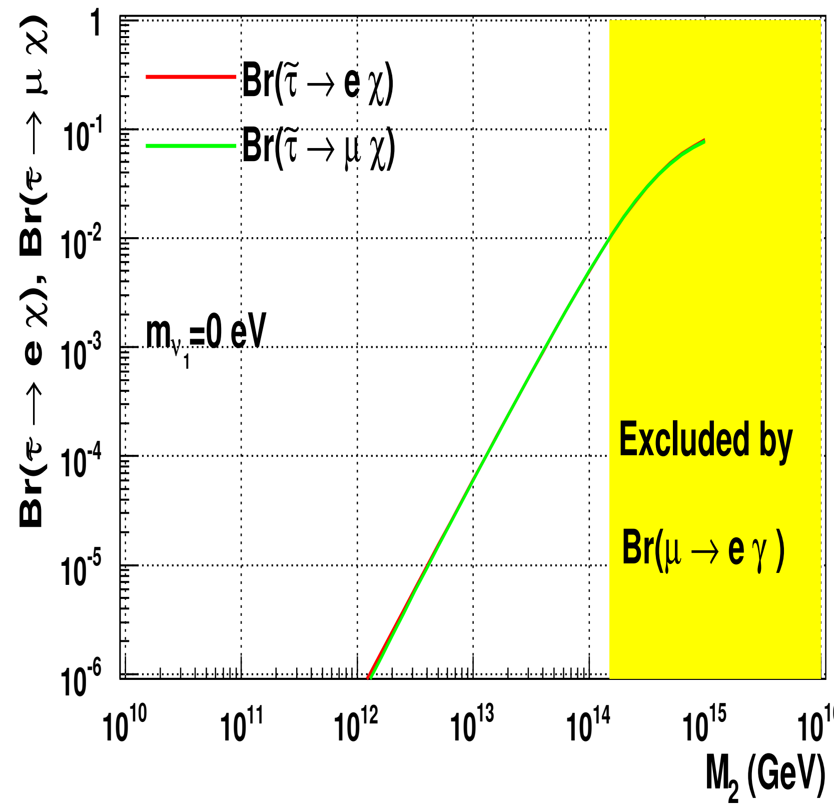
SPS1a' ($M_0 = 70$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -300$ GeV, $\tan\beta = 10$, $\mu > 0$)

M. Hirsch et al. Phys. Rev. D **78** (2008) 013006

Seesaw I



degenerate ν_R



hierarchical ν_R

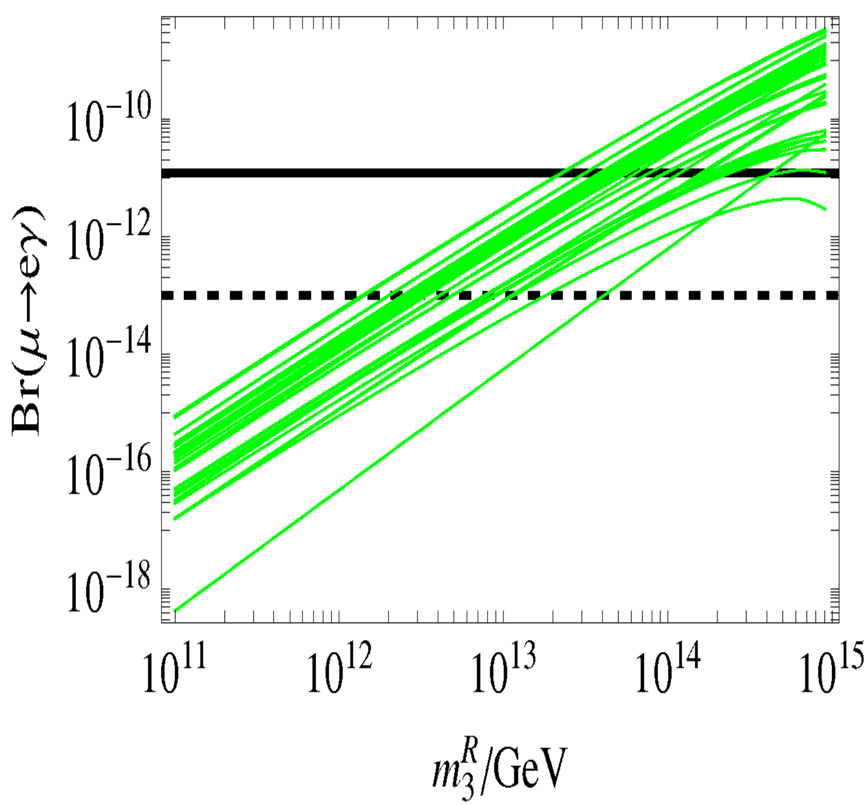
($M_1 = M_3 = 10^{10}$ GeV)

SPS3 ($M_0 = 90$ GeV, $M_{1/2} = 400$ GeV, $A_0 = 0$ GeV, $\tan\beta = 10$, $\mu > 0$)

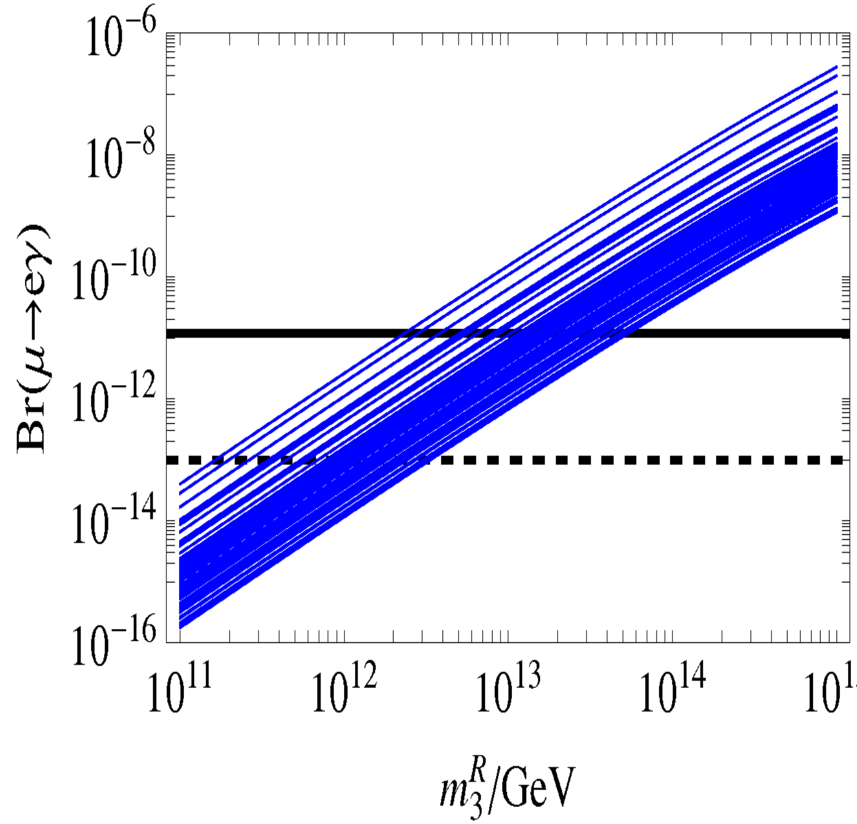
M. Hirsch et al. Phys. Rev. D **78** (2008) 013006

Texture models, hierarchical ν_R

real textures



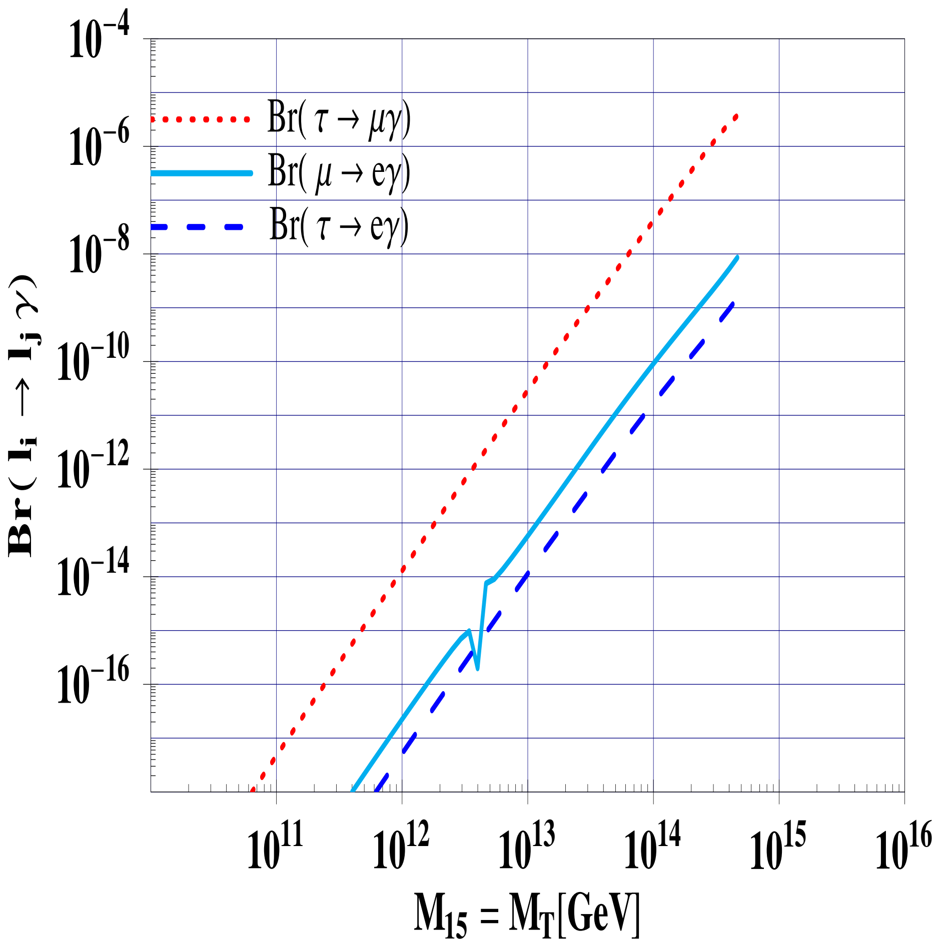
"complexification" of one texture

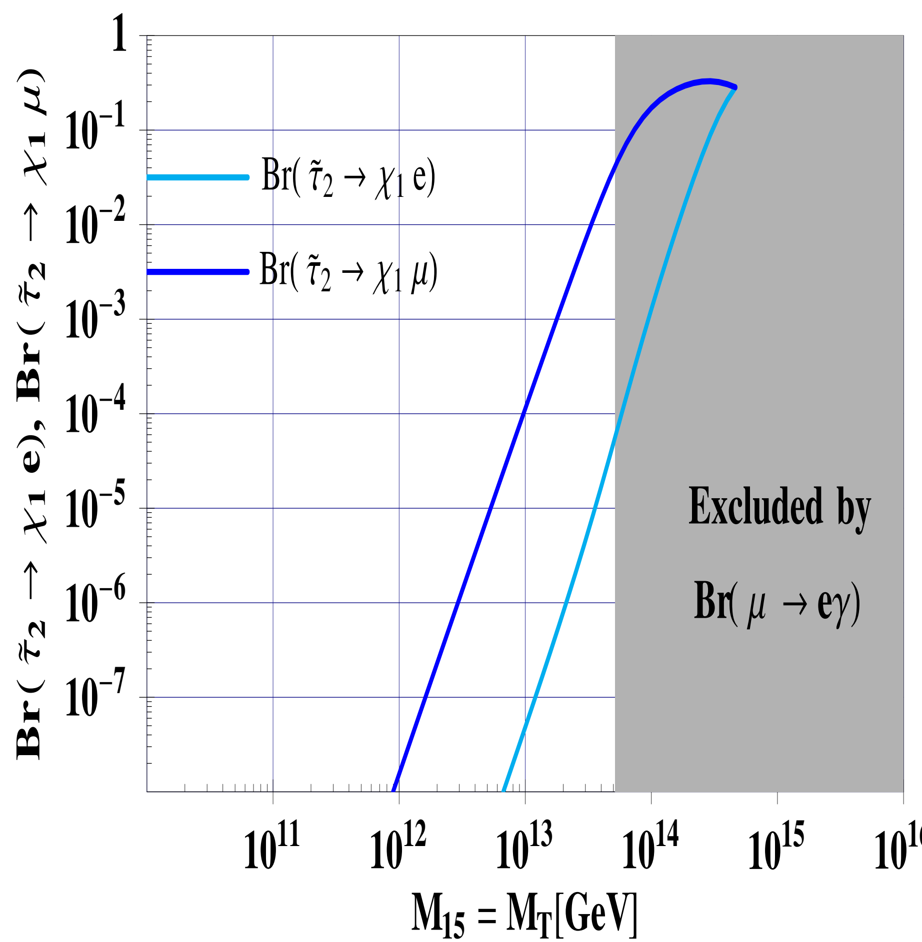


SPS1a' ($M_0 = 70$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -300$ GeV, $\tan\beta = 10$, $\mu > 0$)

F. Deppisch, F. Plentinger, G. Seidl, JHEP **1101** (2011) 004

Seesaw II with a pair of 15-plets



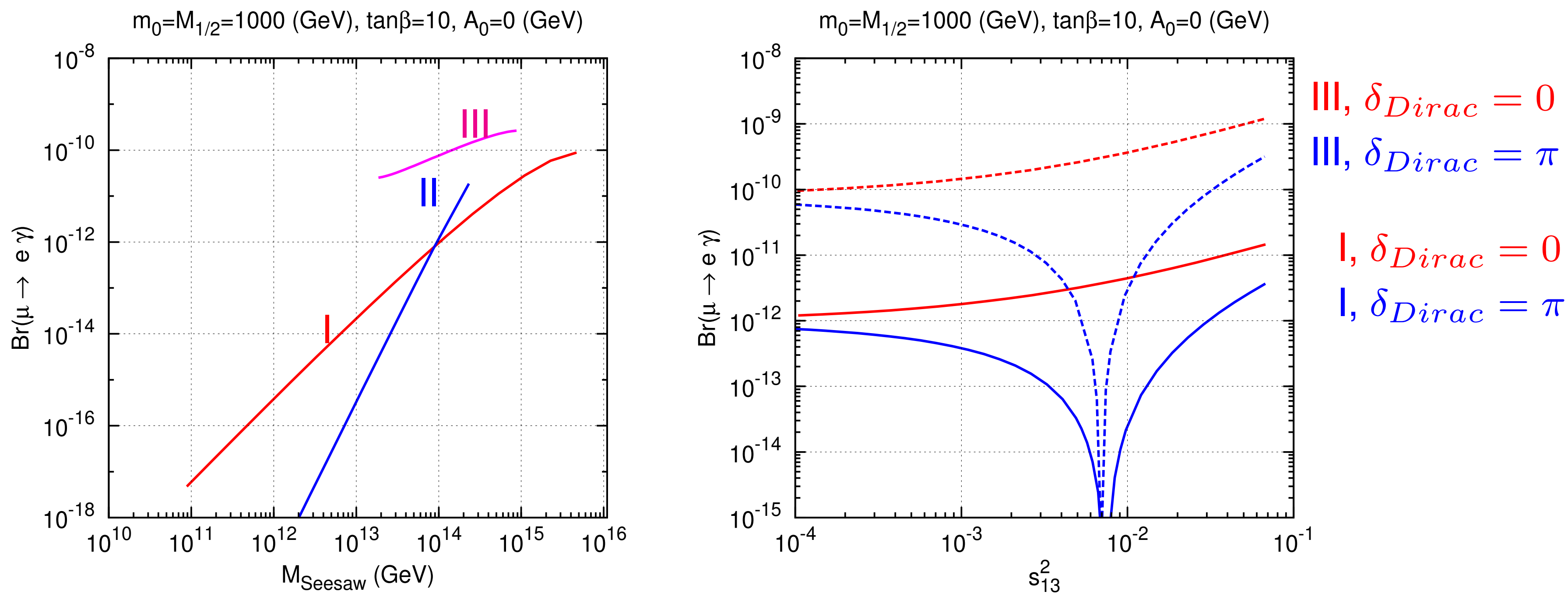


$\lambda_1 = \lambda_2 = 0.5$

SPS3 ($M_0 = 90$ GeV, $M_{1/2} = 400$ GeV, $A_0 = 0$ GeV, $\tan\beta = 10$, $\mu > 0$)

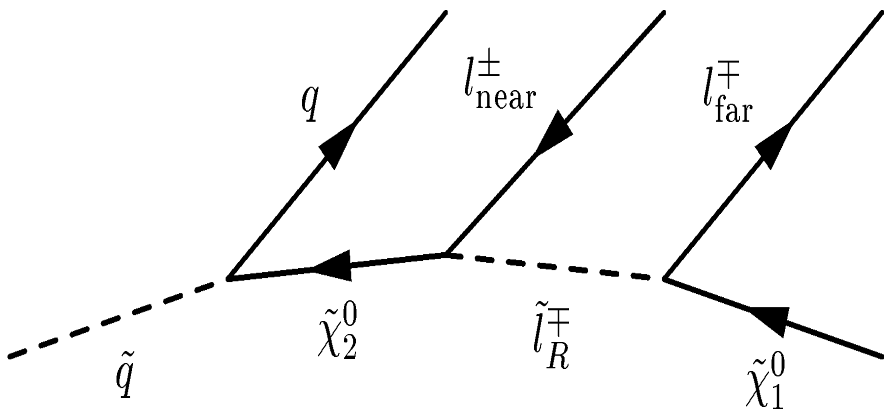
M. Hirsch, S. Kaneko, W. P., Phys. Rev. D **78** (2008) 093004.

Seesaw III in comparison

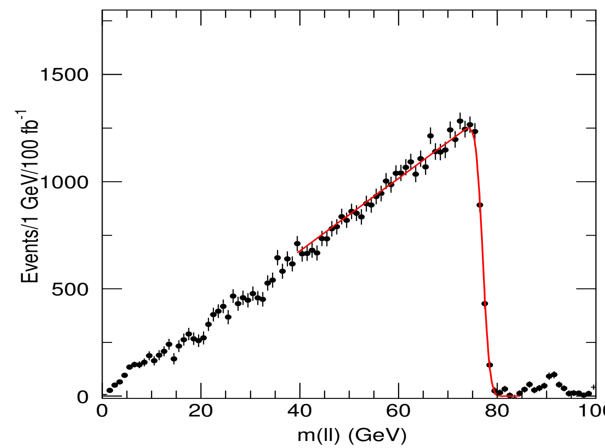


degenerate spectrum of the seesaw particles, $M_{seesaw} = 10^{14}$ GeV

J. Esteves, M.Hirsch, J. Romão, W.P., F. Staub, Phys. Rev. D**83** (2011) 013003



G. Polesello



5 kinematical observables depending on 4 SUSY masses

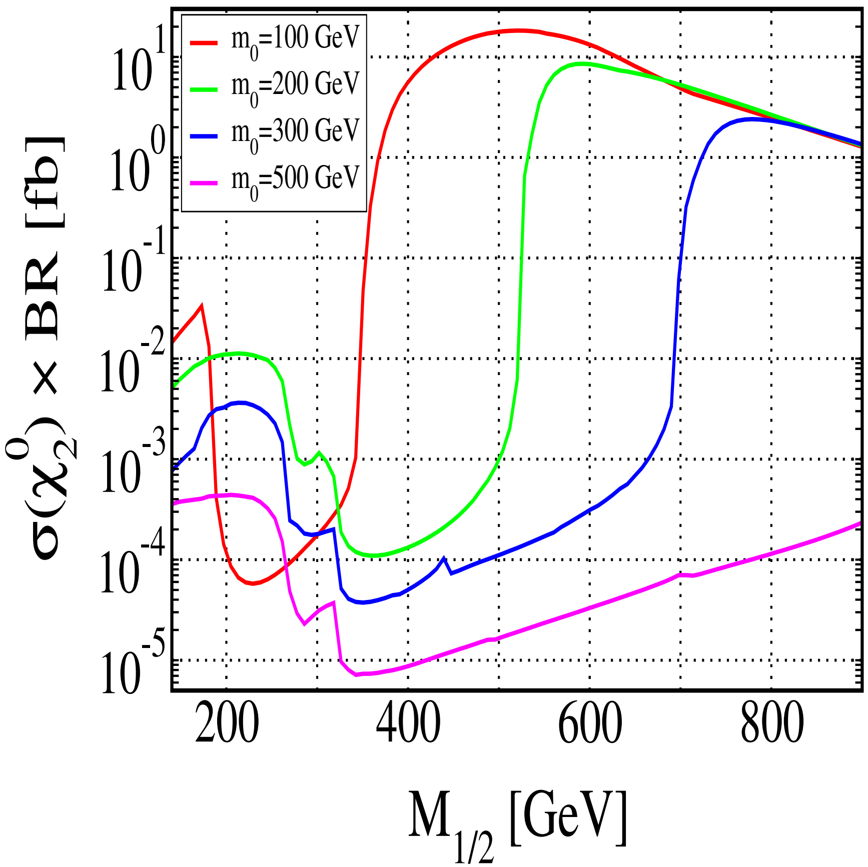
e.g.: $m(ll) = 77.02 \pm 0.05 \pm 0.08$

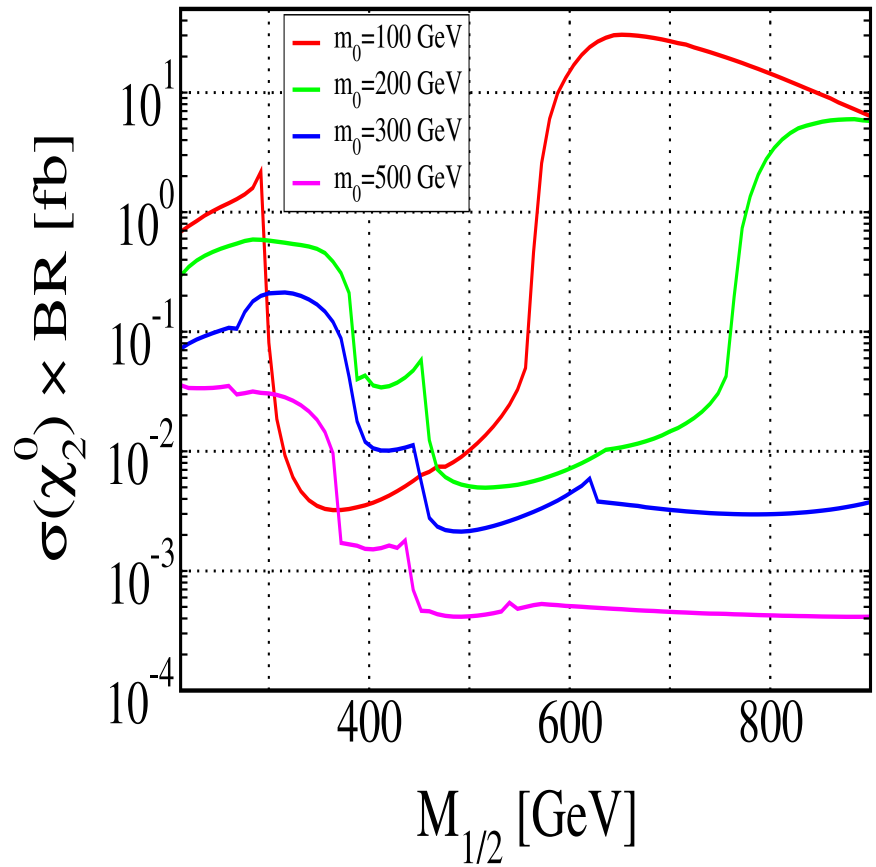
$\Rightarrow$ mass determination within 2-5%

For background suppression

$$N(e^+e^-) + N(\mu^+\mu^-) - N(e^+\mu^-) - N(\mu^+e^-)$$

Seesaw I + II, signal at LHC





$\sigma(pp \to \tilde{\chi}_2^0) \times BR(\chi_2^0 \to \sum_{i,j} \tilde{l}_i l_j \to \mu^\pm \tau^\mp \tilde{\chi}_1^0)$

$A_0 = 0$, $\tan\beta = 10$, $\mu > 0$ (Seesaw II: $\lambda_1 = 0.02$, $\lambda_2 = 0.5$)

J.N. Esteves et al., JHEP **0905**, 003 (2009)

Exp. input:

- MEG, BELLE, . . . : BR($\mu \to e\gamma$), . . .
- LHC: mass differences , edge variables (including LFV signals)
- ILC/CLIC: mass spectrum, LFV branching ratios, cross sections

Theo. input

- High scale model, e.g. mSUGRA, GMSB
- Seesaw type

Expected experimental accuaracies

	Mass, ideal	"LHC"	"LC"	"LHC+LC"
h^0	116.0	0.25	0.05	0.05
H^0	425.0		1.5	1.5
$\tilde{\chi}_1^0$	97.7	4.8	0.05	0.05
$\tilde{\chi}_2^0$	183.9	4.7	1.2	0.08
$\tilde{\chi}_4^0$	413.9	5.1	3-5	2.5
$\tilde{\chi}_1^\pm$	183.7		0.55	0.55
$\tilde{e}_R$	125.3	4.8	0.05	0.05
$\tilde{e}_L$	189.9	5.0	0.18	0.18
$\tilde{\tau}_1$	107.9	5-8	0.24	0.24
$\tilde{q}_R$	547.2	7-12	-	5-11
$\tilde{q}_L$	564.7	8.7	-	4.9
$\tilde{t}_1$	366.5		1.9	1.9
$\tilde{b}_1$	506.3	7.5	-	5.7
$\tilde{g}$	607.1	8.0	-	6.5

$m_0 = 70$ GeV

$m_{1/2} = 250$ GeV

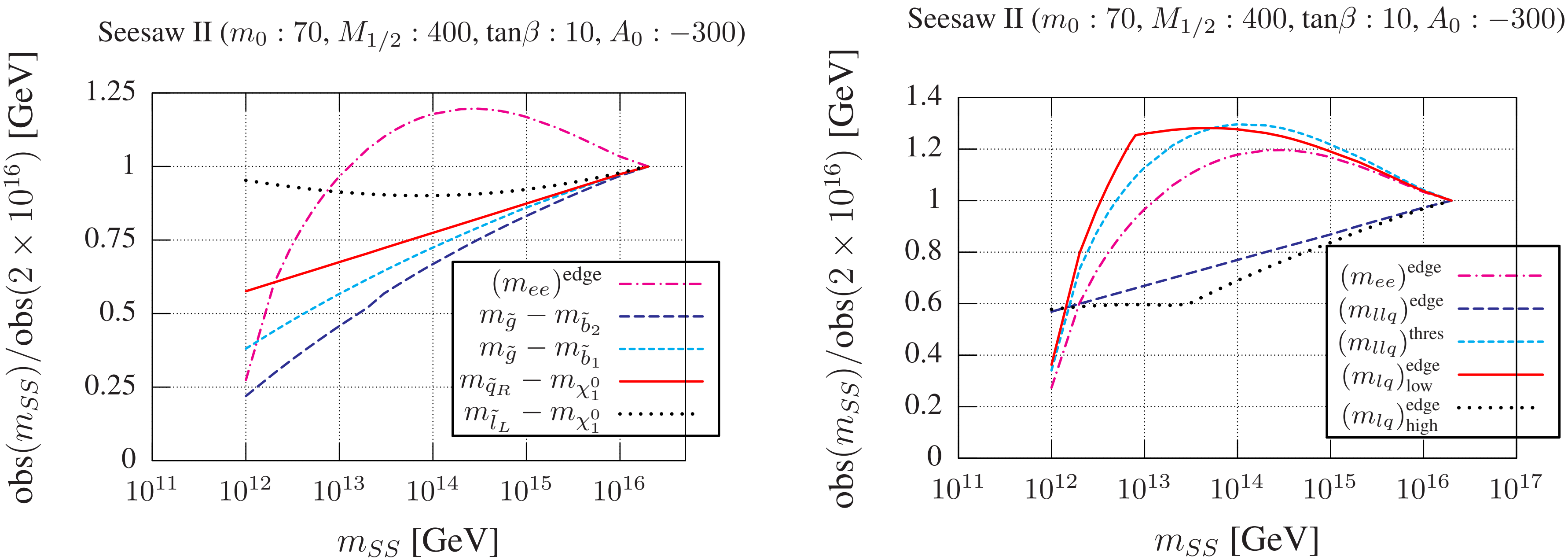
$A_0 = -300$ GeV

$\tan\beta = 10$

sign$(\mu) = +$

G. Weiglein *et al.*, Phys. Rept. **426** (2006) 47; J.A. Aguilar-Saavedra *et al.*, EPJC **46** (2006) 43

Dependence of LHC observables



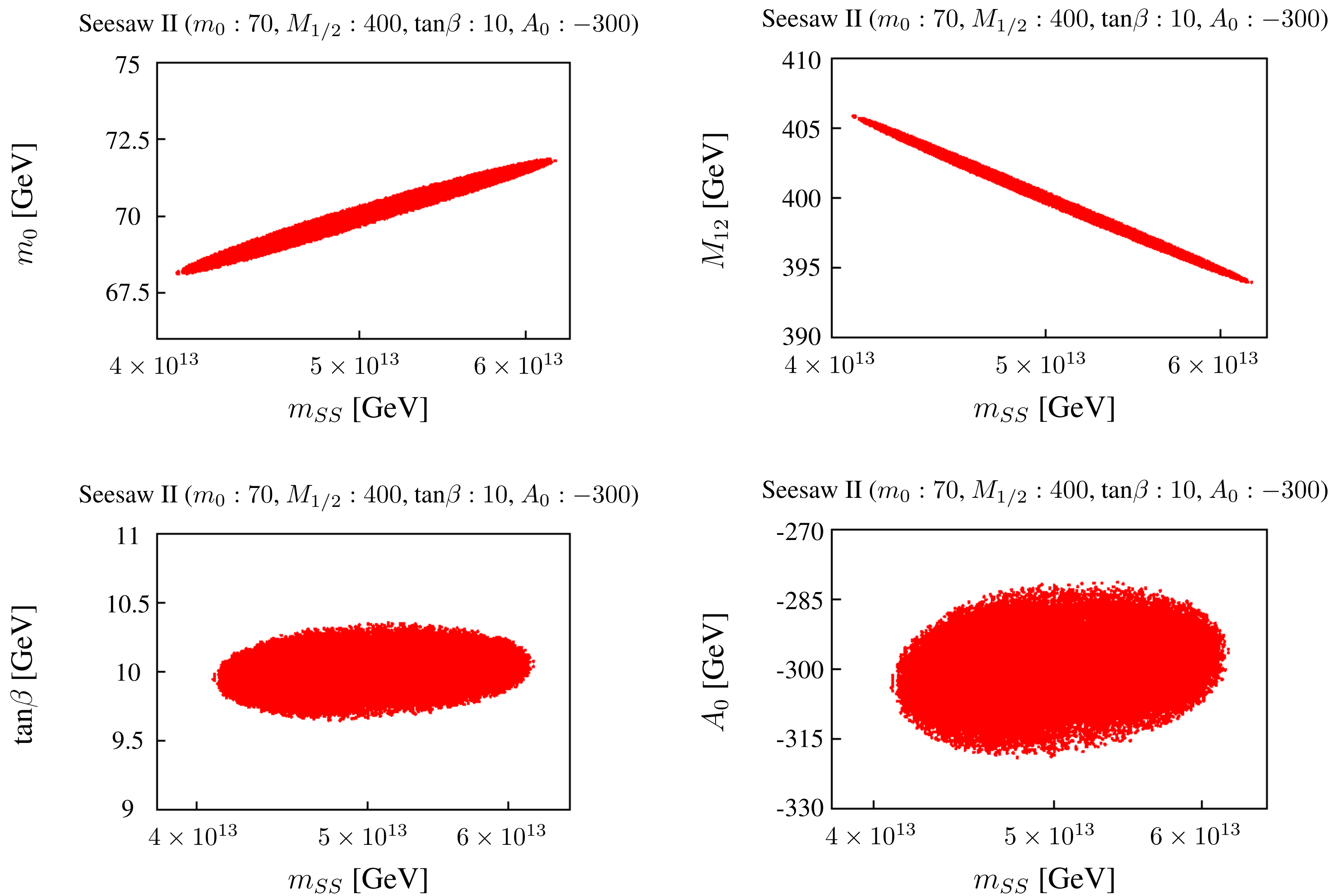
Kinks

$$(m_{lq})^{\text{edge}}_{\text{high}} = \max[(m^{\text{max}}_{l_{\text{near}}q})^2, (m^{\text{max}}_{l_{\text{far}}q})^2]$$

$$(m_{lq})^{\text{edge}}_{\text{low}} = \min[(m^{\text{max}}_{l_{\text{near}}q})^2, (m^2_{\tilde q} - m^2_{\chi^0_2})(m^2_{\tilde l_R} - m^2_{\chi^0_1})/(2m^2_{\tilde l_R} - m^2_{\chi^0_1})]$$

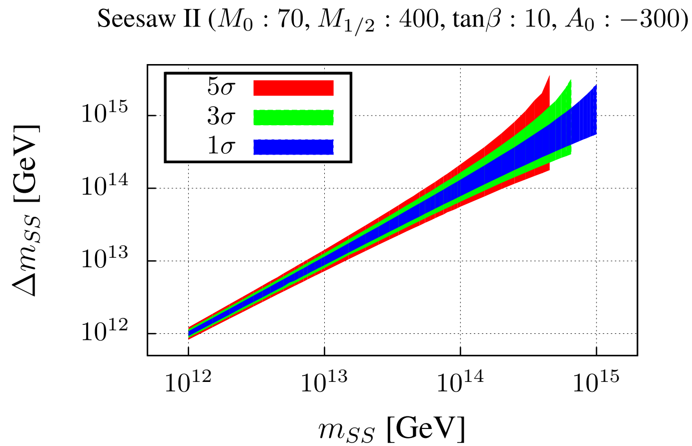
M. Hirsch, W.P., L. Reichert, arXiv:1101.2140 [hep-ph]

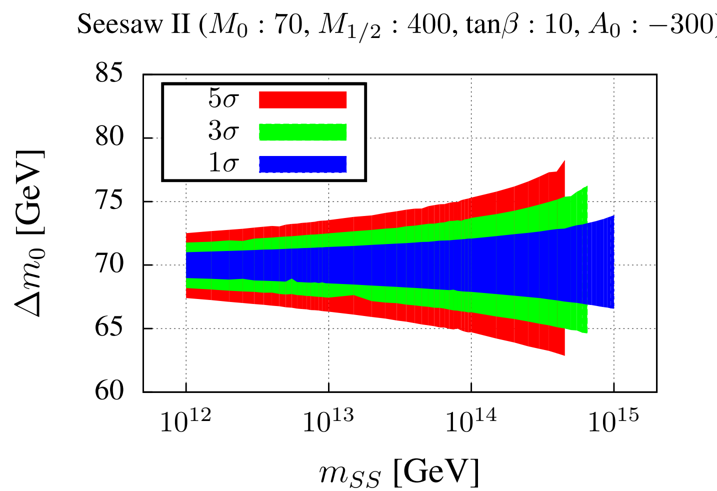
Results of a MC random walk, LHC+ILC, without Yukawas

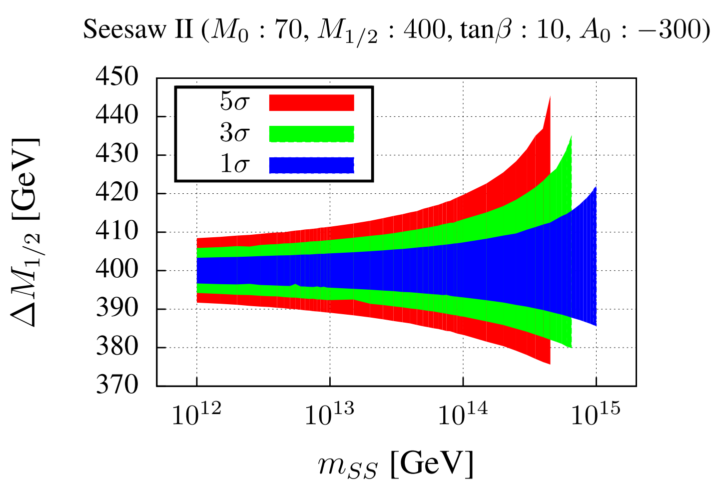


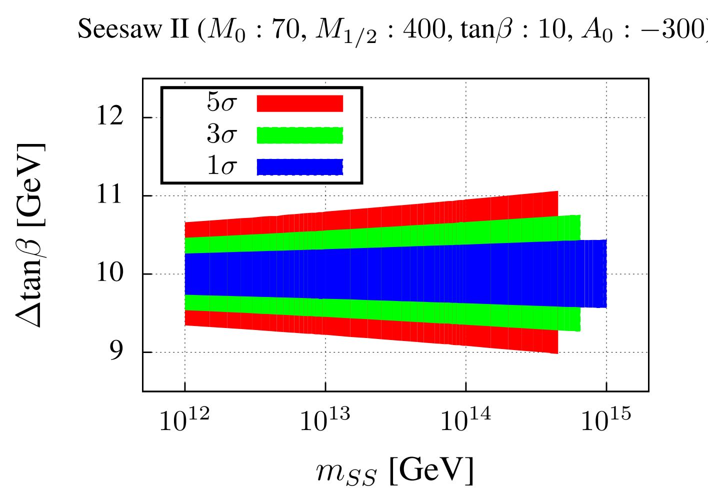
original scale 5×10^{13} GeV; M. Hirsch, W.P., L. Reichert, arXiv:1101.2140 [hep-ph]

Results of MC random walk, LHC + ILC observables

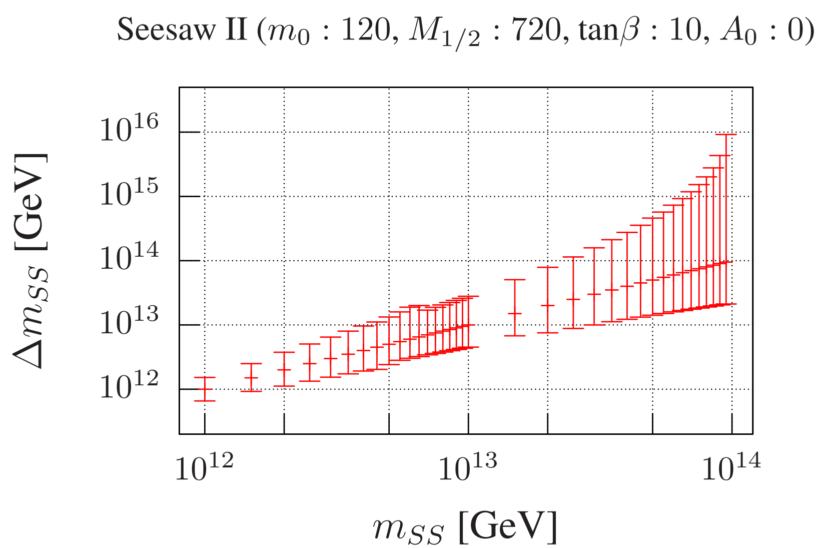


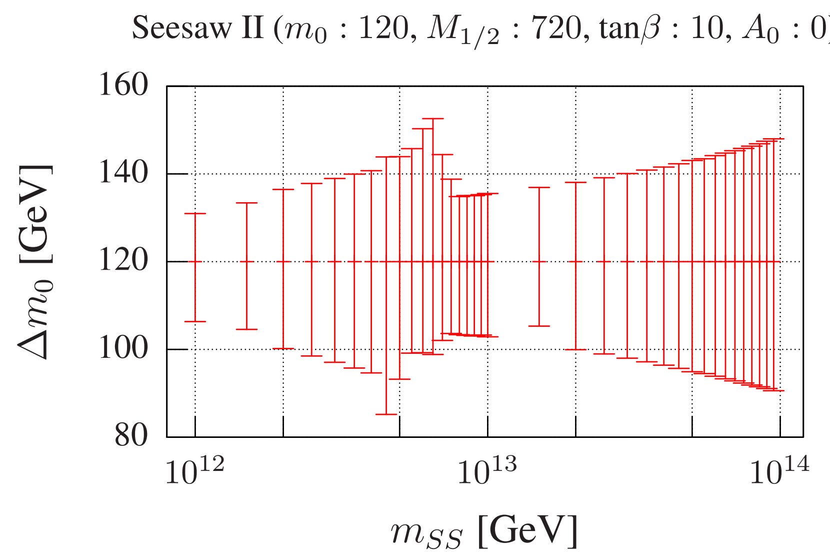


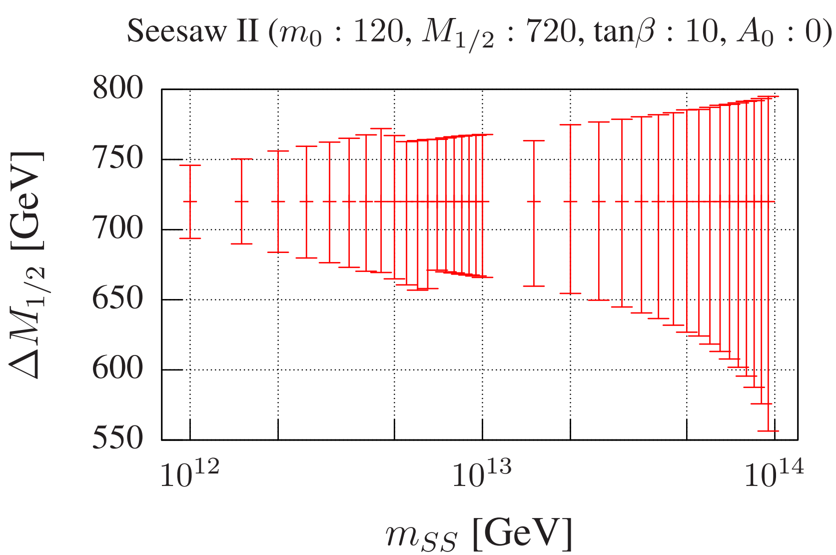




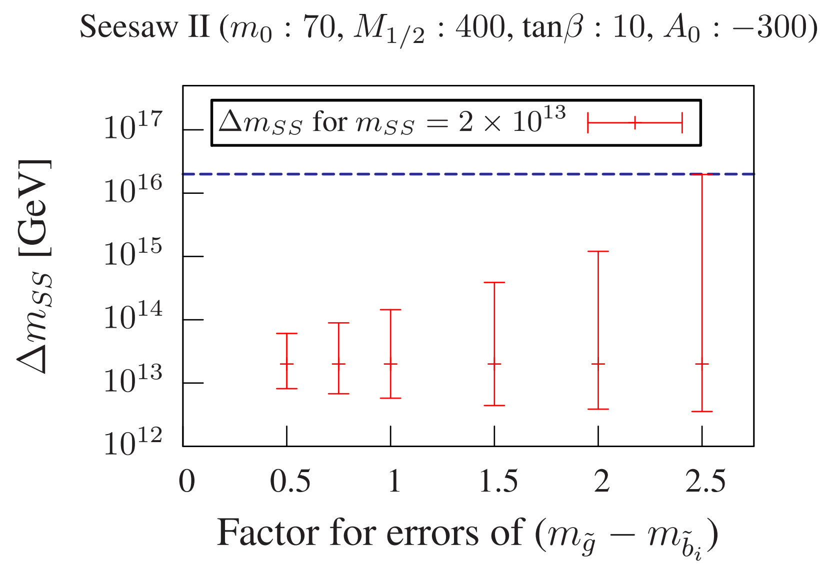
Results of MC random walk, LHC observables only

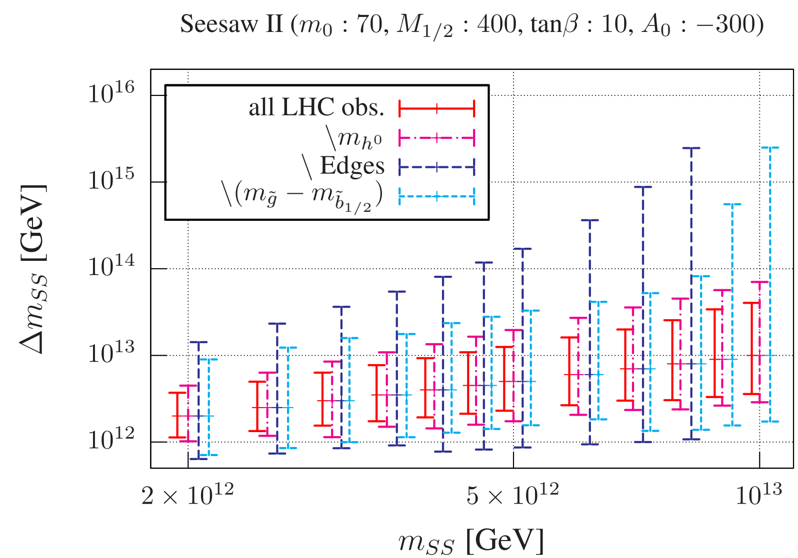


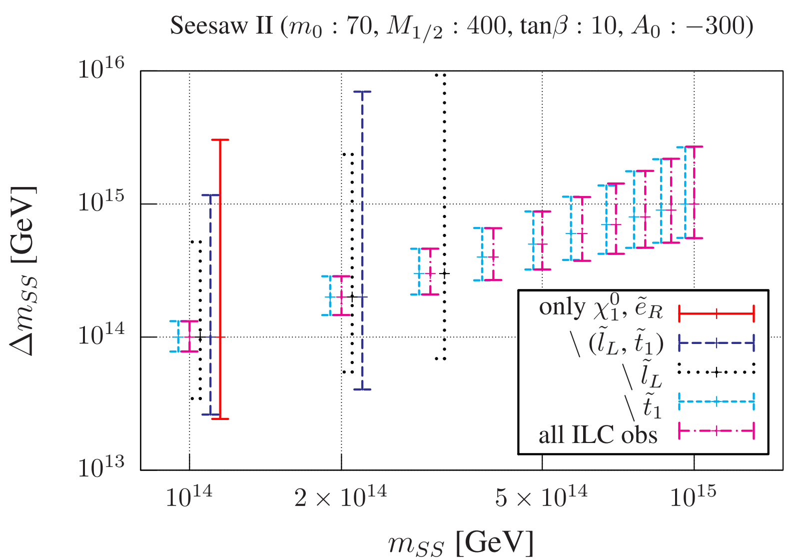


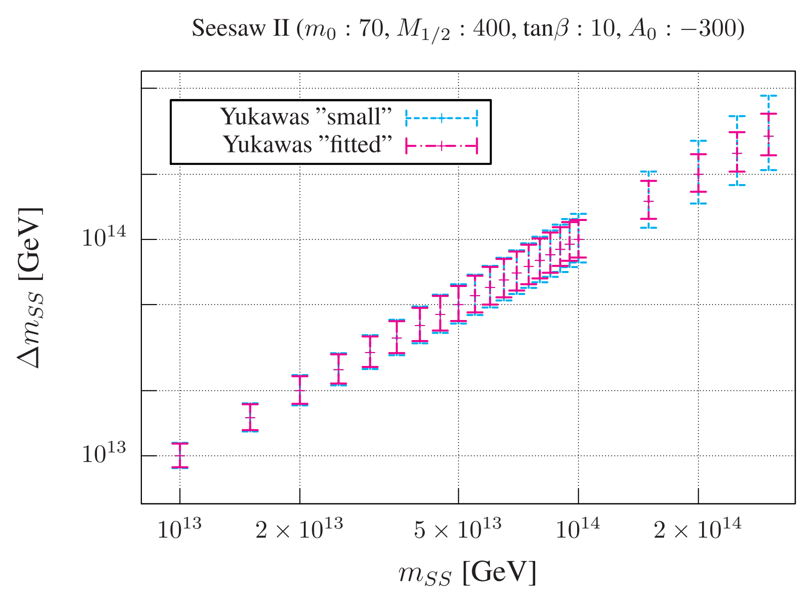


Results of MC random walk, varying assumptions





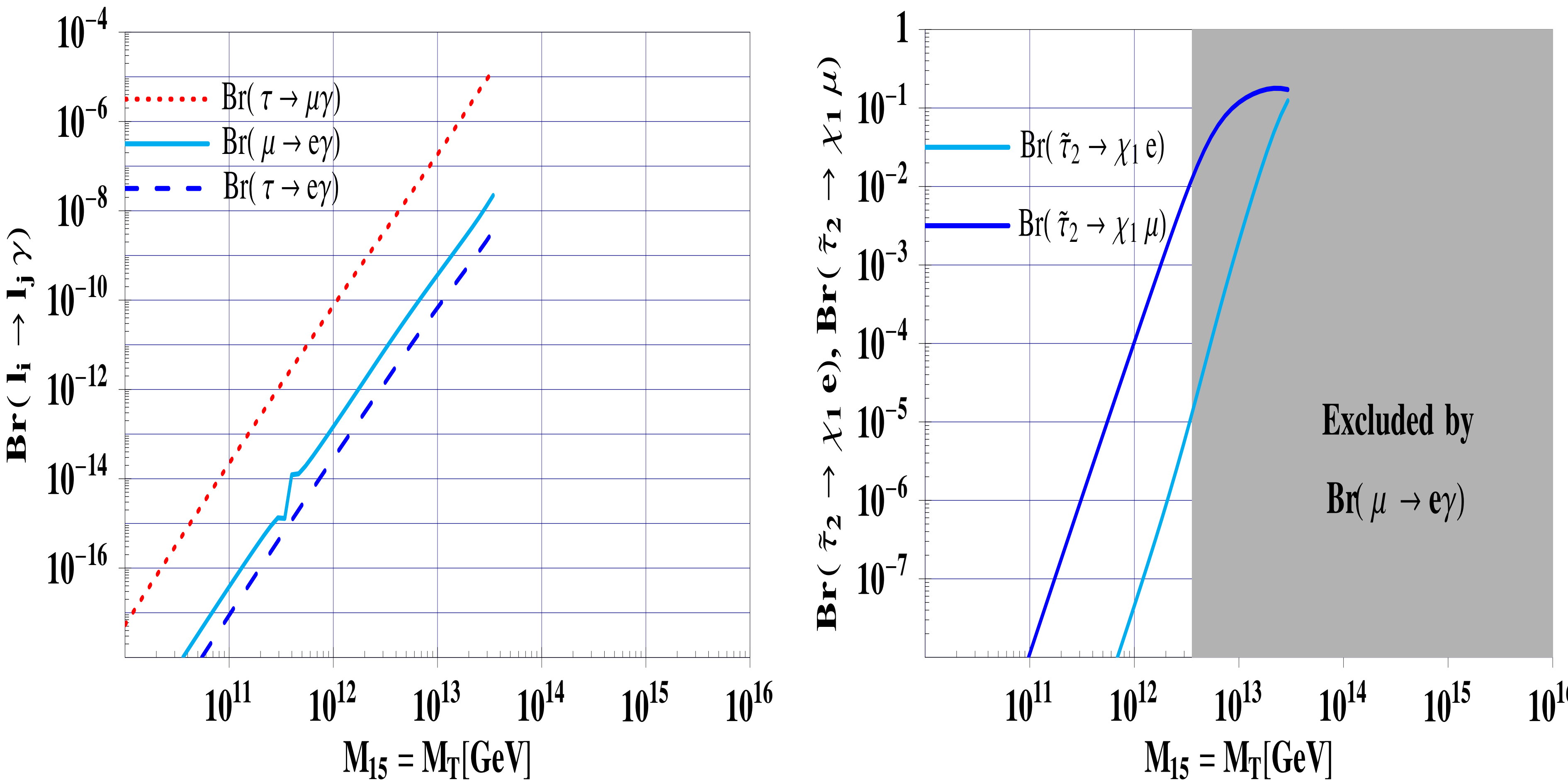




Conclusions

- Dirac neutrinos: displaced vertices if $\tilde{\nu}_R$ LSP, e.g. $\tilde{t}_1 \to lb\tilde{\nu}_R$ (but NMSSM: $\tilde{t}_1 \to lb\nu\tilde{\chi}^0_1$)
- Seesaw models:
  - in case of seesaw II, III: different mass ratios
  - promosing: $\tilde{\tau}_2$ decays
  - LFV signals difficult to test at LHC, of O(10 fb) or below
- Model reconstruction for seesaw II, III
  - LHC: possible in favourable parts of parameter space; might improve if additional observables can be used, e.g. lepton and jet spectra
  - LHC+ILC: possible for large part of parameter space, however still some model dependence
  - to disthinguish between type II and III: need in addition LFV signals

Seesaw II with 15-plets

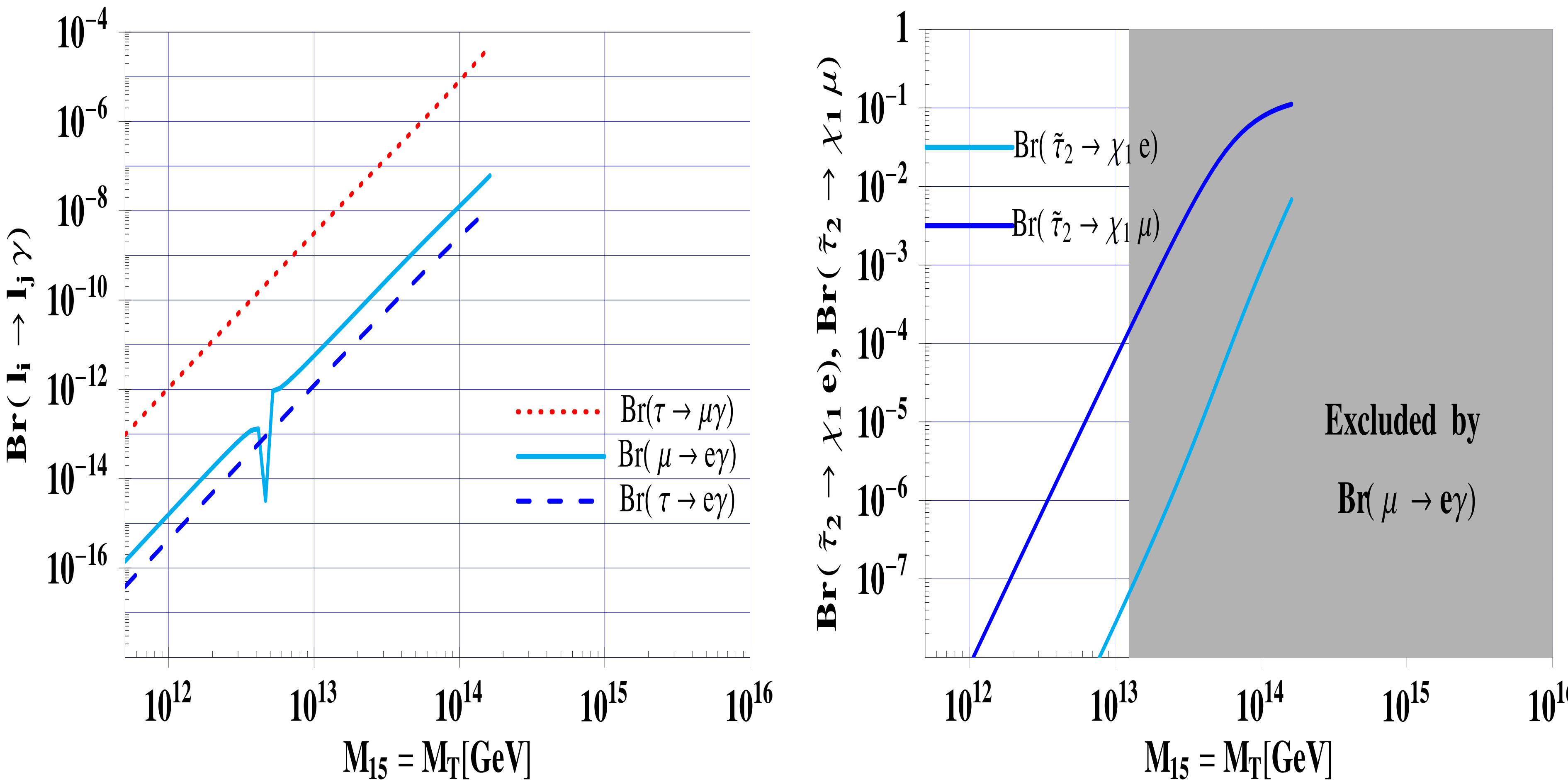


$\lambda_1 = \lambda_2 = 0.05$

SPS3 ($M_0 = 90$ GeV, $M_{1/2} = 400$ GeV, $A_0 = 0$ GeV, $\tan\beta = 10$), $\mu > 0$

M. Hirsch, S. Kaneko, W. P., Phys. Rev. D **78** (2008) 093004.

Seesaw II with 15-plets

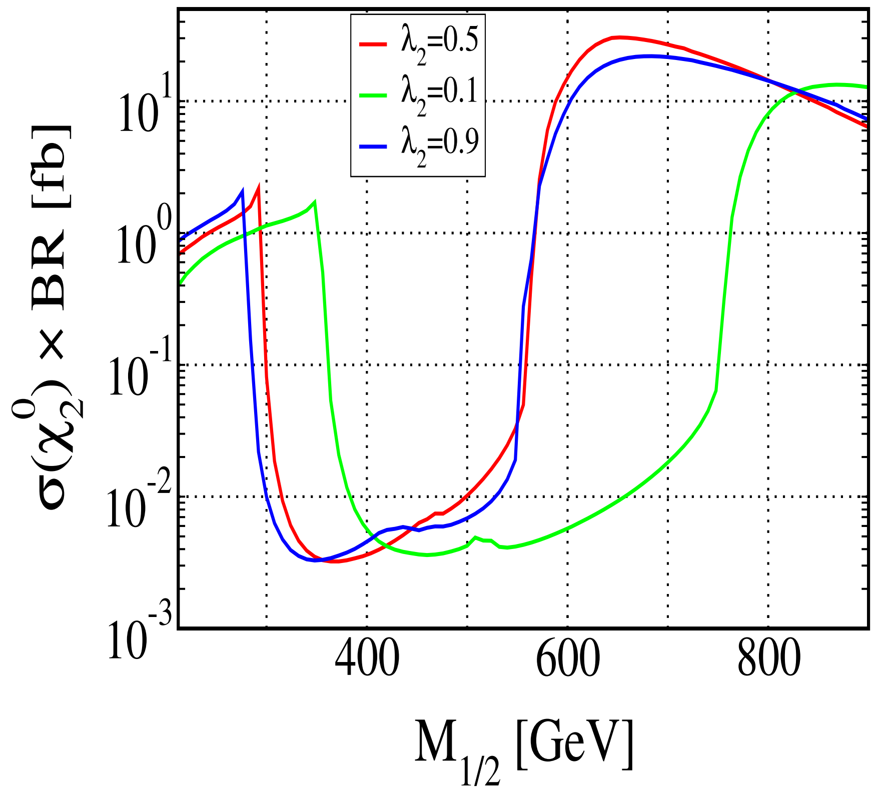


$\lambda_1 = \lambda_2 = 0.5$

SPS1a' ($M_0 = 70$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -300$ GeV, $\tan\beta = 10$), $\mu > 0$

M. Hirsch, S. Kaneko, W. P., Phys. Rev. D **78** (2008) 093004.

Seesaw II, signal at LHC



$\sigma(pp \to \tilde{\chi}_2^0) \times BR(\chi_2^0 \to \sum_{i,j} \tilde{l}_i l_j \to \mu^\pm \tau^\mp \tilde{\chi}_1^0)$

$m_0 = 100$ GeV $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$, $\lambda_1 = 0.02$

J.N. Esteves et al., JHEP **0905**, 003 (2009)

SUSY masses at LHC

talk by I. Borjanovic at 'Flavour in the era of LHC', Nov.'05, CERN

L=**100 fb^{-1}**

Fit results

Edge	Nominal Value	Fit Value	Syst. Error Energy Scale	Statistical Error
$m(ll)^{\rm edge}$	77.077	77.024	0.08	0.05
$m(qll)^{\rm edge}$	431.1	431.3	4.3	2.4
$m(ql)^{\rm edge}_{\rm min}$	302.1	300.8	3.0	1.5
$m(ql)^{\rm edge}_{\rm max}$	380.3	379.4	3.8	1.8
$m(qll)^{\rm thres}$	203.0	204.6	2.0	2.8

Mass reconstruction

5 endpoints measurements, 4 unknown masses

$$\chi^2 = \sum \chi_j^2 = \sum \left[\frac{E_j^{\rm theory}(\vec{m}) - E_j^{\rm exp}}{\sigma_j^{\rm exp}}\right]^2$$

$$E_j^i = E_j^{\rm nom} + a_j^i \sigma_j^{\rm fit} + b^i \sigma_j^{Escale}$$

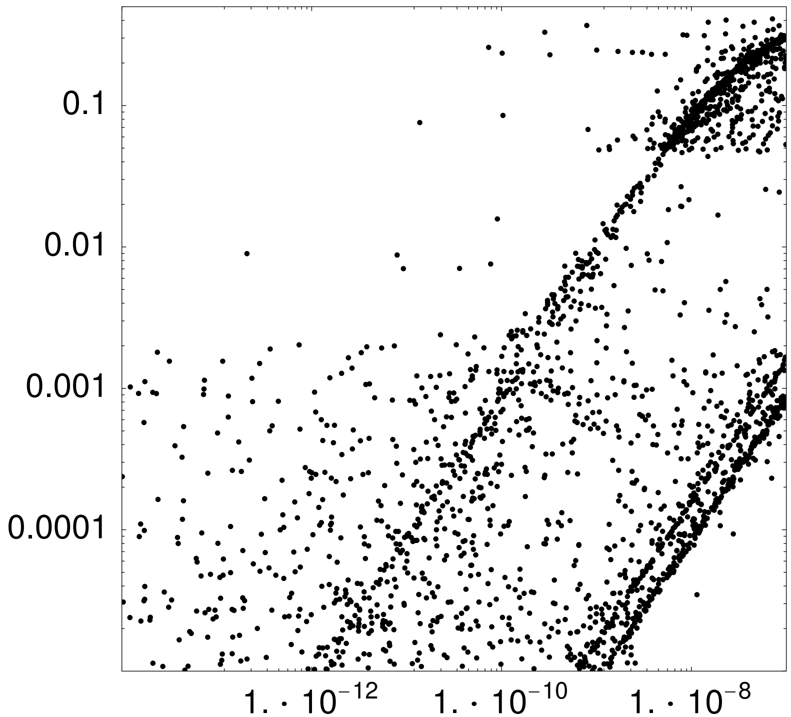
$m(\chi_1^0) = 96$ GeV
$m(l_R) = 143$ GeV
$m(\chi_2^0) = 177$ GeV
$m(q_L) = 540$ GeV

$\Delta m(\chi_1^0) = 4.8$ GeV, $\Delta m(\chi_2^0) = 4.7$ GeV,
$\Delta m(l_R) = 4.8$ GeV, $\Delta m(q_L) = 8.7$ GeV

Gjelsten, Lytken, Miller, Osland, Polesello, ATL-PHYS-2004-007

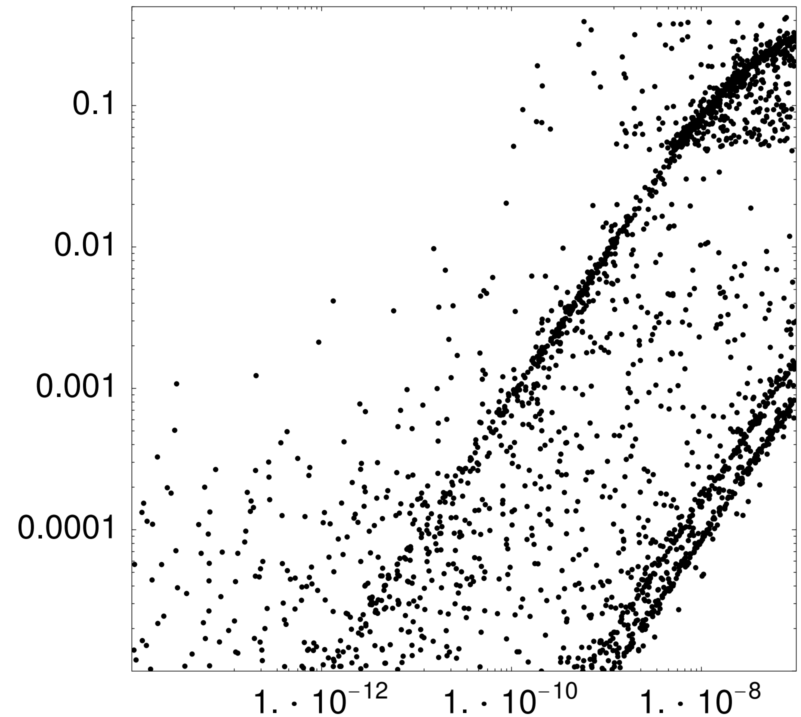
arbitrary $M^2_{E,ij}$, $M^2_{L,ij}$, $A_{l,ij}$: $\tilde{\chi}^0_2 \to \tilde{l}_i l_j \to l_k l_j \tilde{\chi}^0_1$

BR$(\tilde{\chi}^0_2 \to \tilde{\chi}^0_1\, e^\pm\, \tau^\mp)$



BR$(\tau \to e\gamma)$

BR$(\tilde{\chi}^0_2 \to \tilde{\chi}^0_1\, \mu^\pm\, \tau^\mp)$

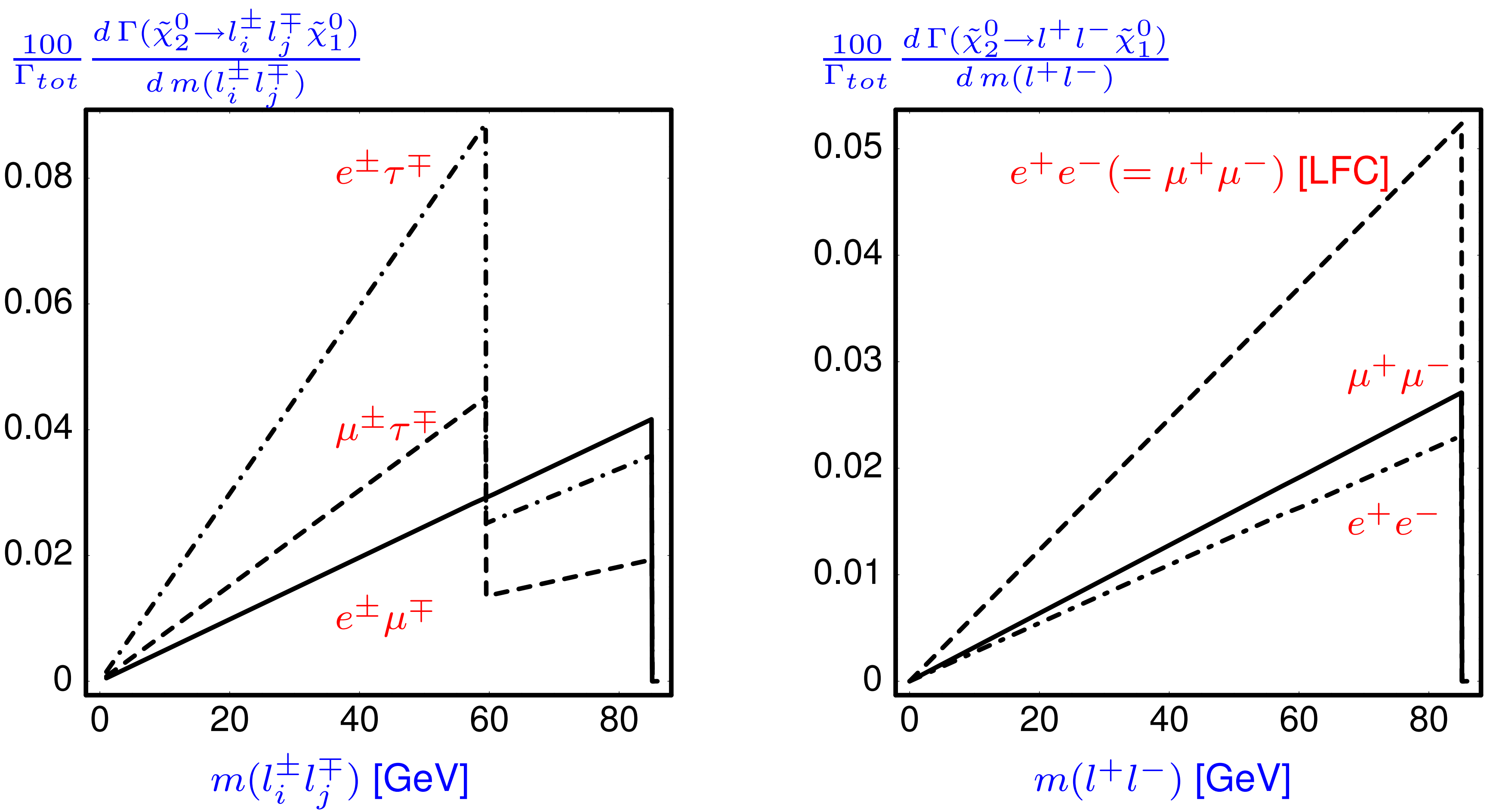


BR$(\tau \to \mu\gamma)$

Variations around SPS1a

($M_0 = 100$ GeV, $M_{1/2} = 250$ GeV, $A_0 = -100$ GeV, $\tan\beta = 10$)

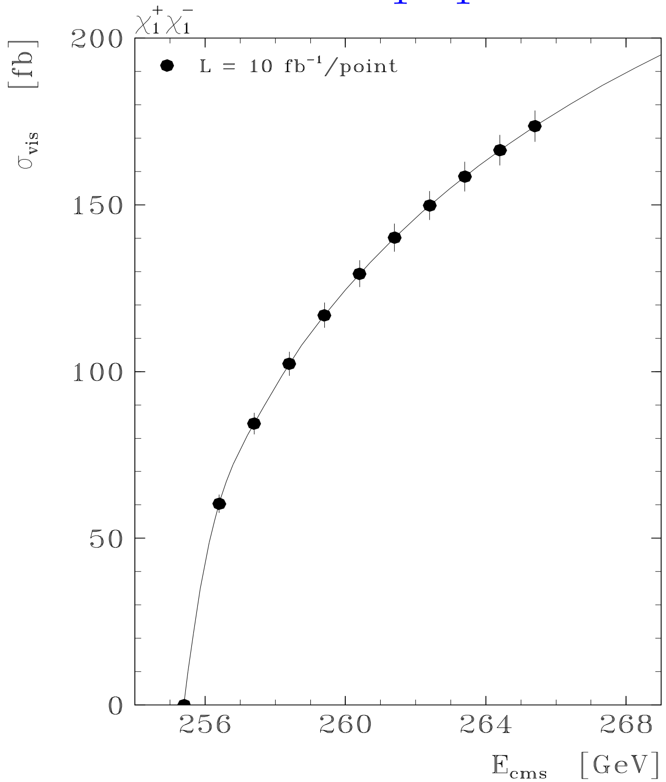
Flavour mixing and edge variables



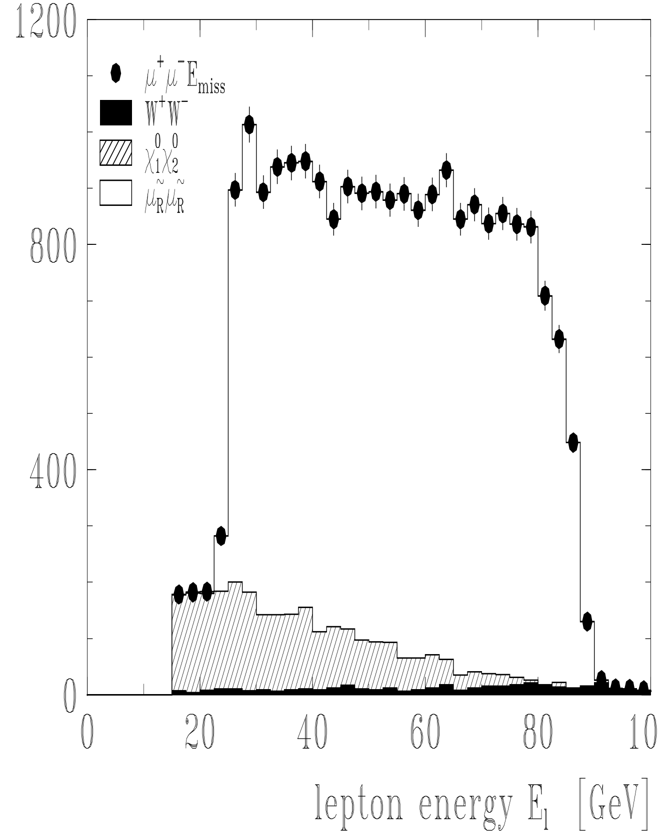
A. Bartl et al., Eur. Phys. J. C **46** (2006) 783

Mass measurements, ILC

$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$

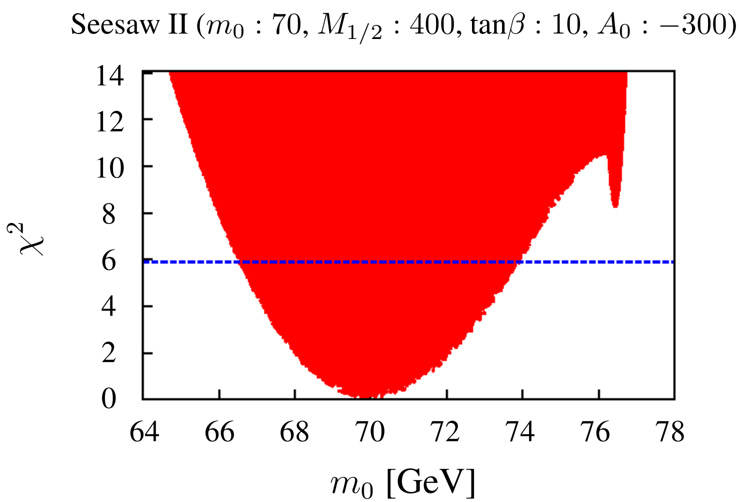


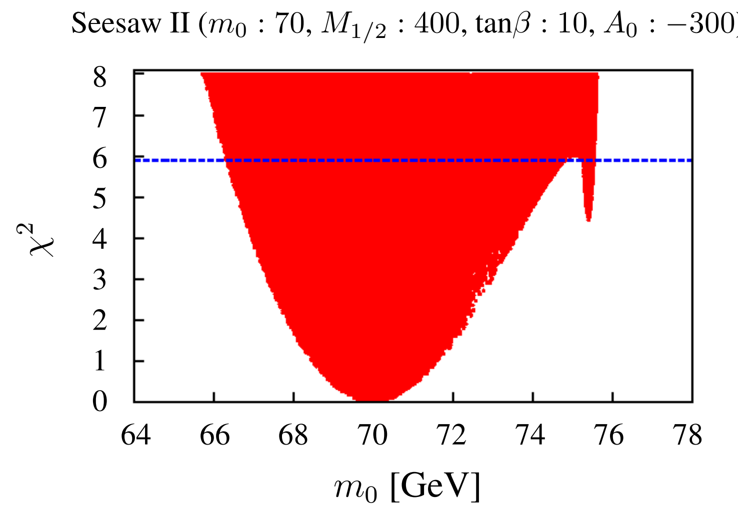
$e^+e^- \to \tilde{\mu}_R^+ \tilde{\mu}_R^- \to \mu^+\mu^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$

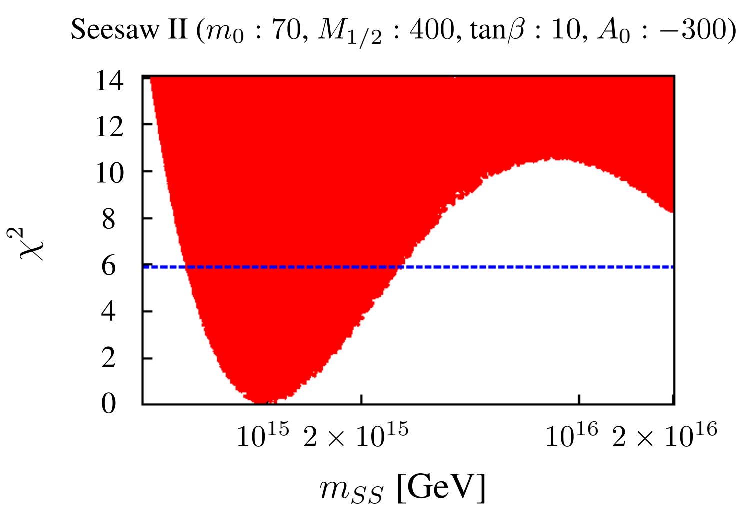


U. Martyn

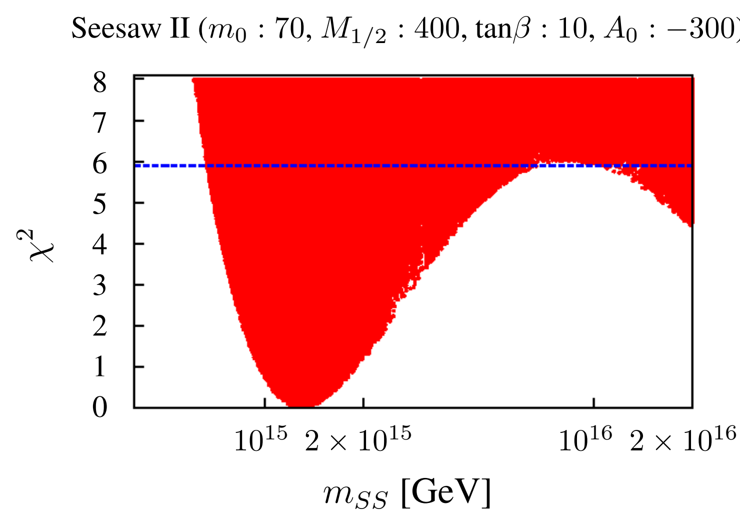
Results of a MC random walk, LHC+ILC







original scale 1×10^{15} GeV



original scale 1.3×10^{15} GeV