Neutrino - LHC working group

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Lepton flavour violation, experimental data

Neutrinos: tiny masses + large mixings

$\Delta m^2_{atm} \simeq 3 \cdot 10^{-3}$ eV^2 $\quad |\tan\theta_{atm}|^2 \simeq 1$

$\Delta m^2_{sol} \simeq 7 \cdot 10^{-5}$ eV^2 $\quad |\tan\theta_{sol}|^2 \simeq 0.4$

^{3}H decay: $m_\nu \lesssim 2$ eV $\quad |U_{e3}|^2 \lesssim 0.05$

strong bounds for charged leptons

$BR(\mu \to e\gamma) \lesssim 1.2 \cdot 10^{-11}$ $\quad BR(\mu^- \to e^- e^+ e^-) \lesssim 10^{-12}$

$BR(\tau \to e\gamma) \lesssim 1.1 \cdot 10^{-7}$ $\quad BR(\tau \to \mu\gamma) \lesssim 6.8 \cdot 10^{-8}$

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

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

SUSY contributions to anomalous magnetic moments

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

Seesaw mechanism*

Neutrino masses due to

$$\frac{f}{\Lambda}(H_u L)(H_u L)$$

Seesaw I: postulates very heavy ν_R:

$$\begin{aligned} m_\nu &\simeq -(Y_\nu^T v_u) M_R^{-1} (Y_\nu v_u) \\ \hat{m}_\nu &= U^T \cdot m_\nu \cdot U \end{aligned}$$

expect: 10^7 GeV $\lesssim M_{R_i} \lesssim 10^{14}$ GeV.

much more parameters than observables in ν-sector

* 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).

Seesaw

Superpotential

$$W = Y_e^{ji} \widehat{L}_i \widehat{H}_d \widehat{E}_j^c + Y_\nu^{ji} \widehat{L}_i \widehat{H}_u \widehat{N}_j^c + M_i \widehat{N}_i^c \widehat{N}_i^c$$

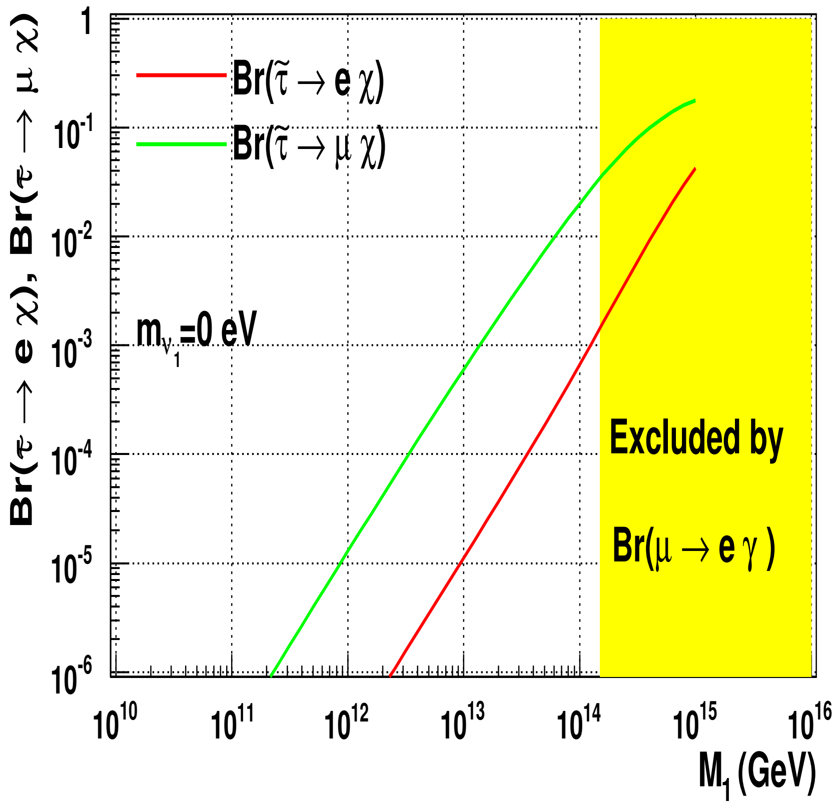
RGE running with mSUGRA boundaries:

$$\begin{aligned}
(\Delta M^2_{\tilde{L}})_{ij} &= -\frac{1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger L Y_\nu)_{ij} \\
(\Delta A_l)_{ij} &= -\frac{3}{8\pi^2} A_0 Y_{l_i} (Y_\nu^\dagger L Y_\nu)_{ij} \\
(\Delta M^2_{\tilde{E}})_{ij} &= 0 \\
L_{kl} &= \log\left(\frac{M_X}{M_{R_k}}\right)\delta_{kl}
\end{aligned}$$

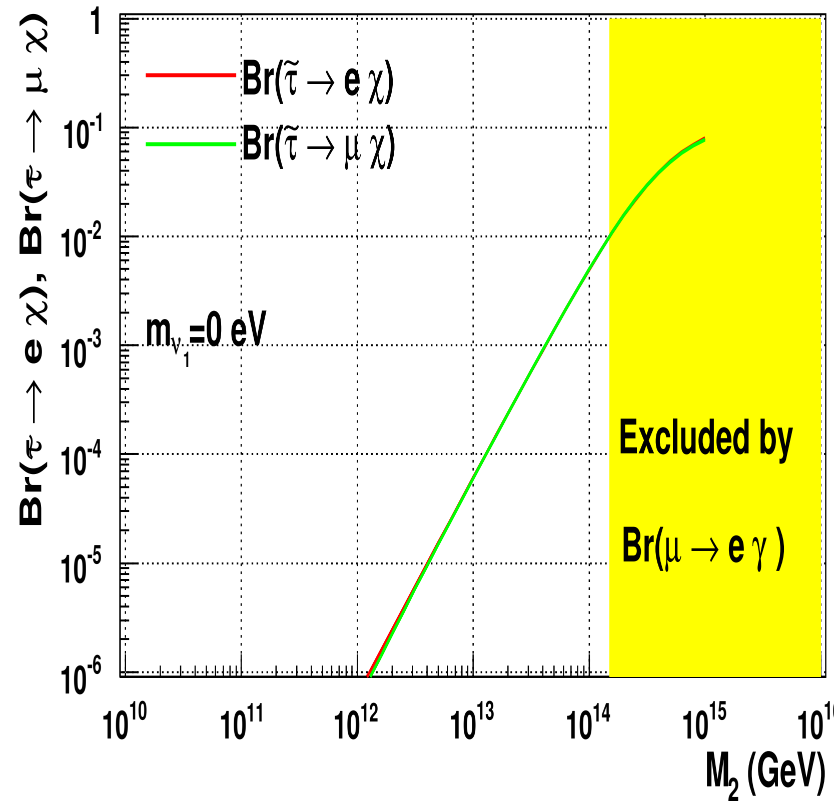
Consequence

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

Seesaw I



degenerate ν_R



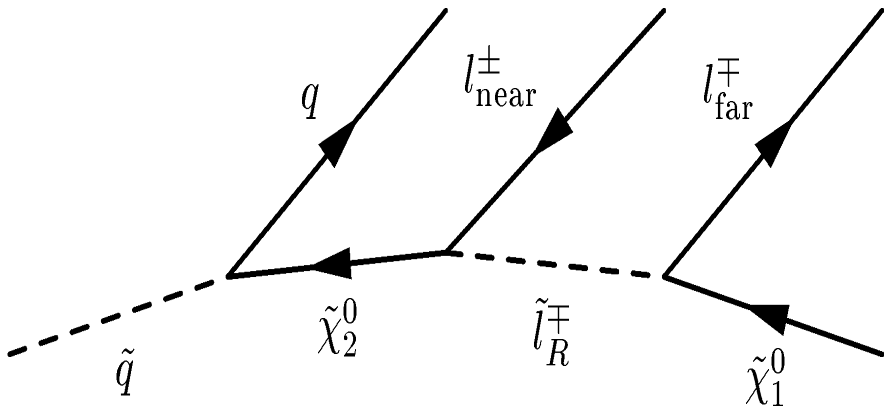
hierarchical ν_R

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

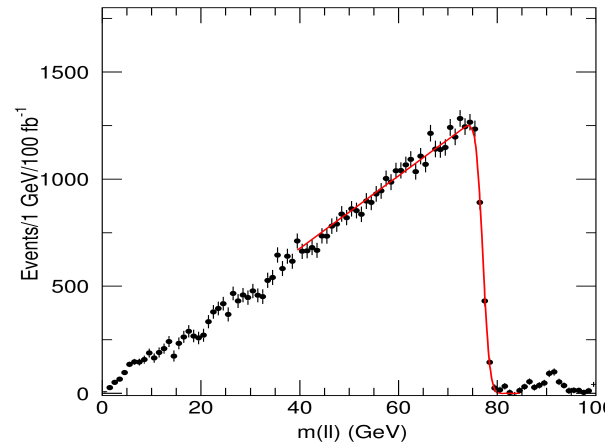
SPS3 ($M_0 = 90$ GeV, $M_{1/2} = 400$ GeV, $A_0 = 0$ GeV, $\tan\beta = 10$, $\mu > 0$)

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

Masses at LHC



G. Polesello



5 kinematical observables depending on 4 SUSY masses

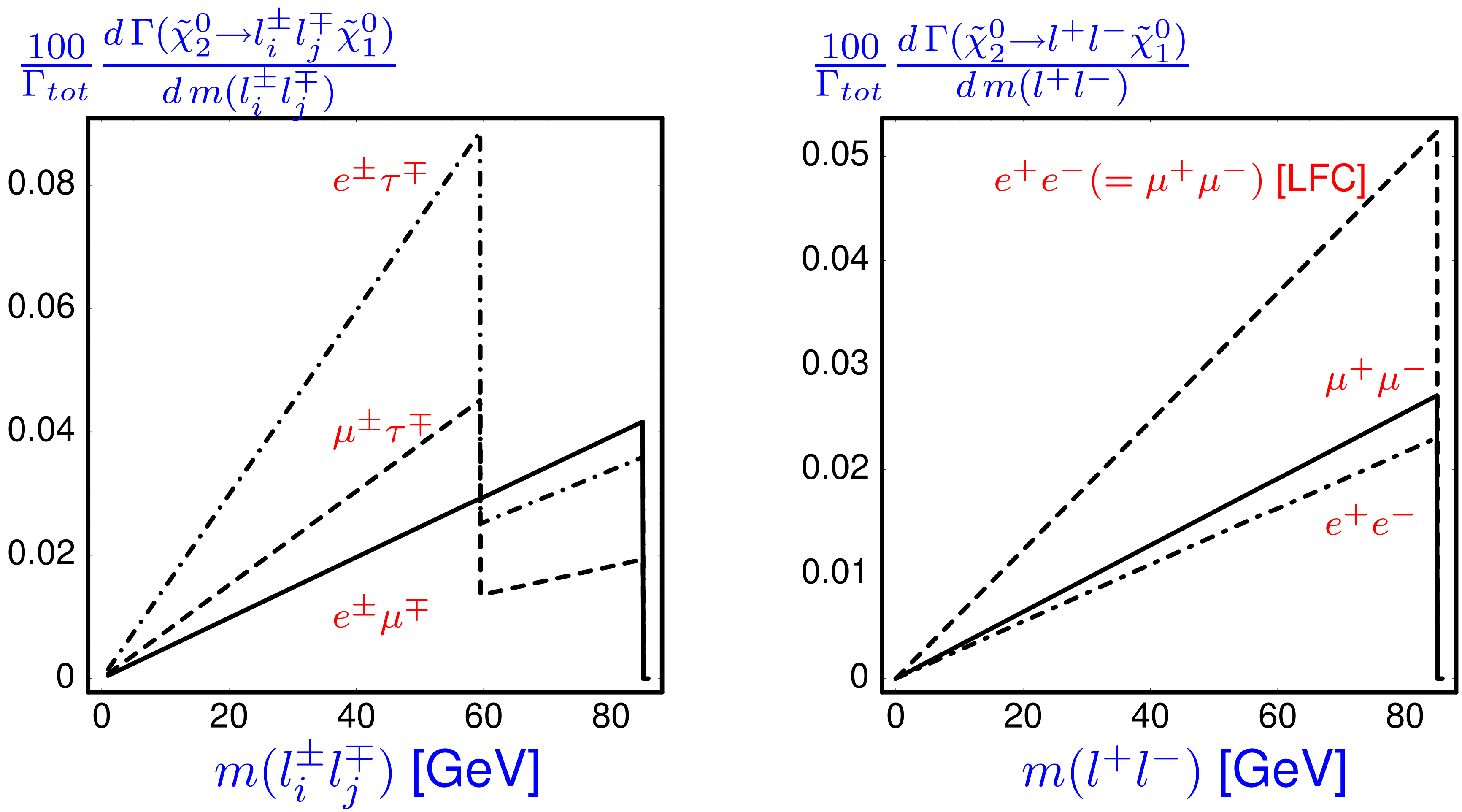
e.g.: $m(ll) = 77.02 \pm 0.05 \pm 0.08$

$\Rightarrow$ mass determination within 2-5%

For background suppression

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

Flavour mixing and edge variables



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

R-parity violation

R-parity: $(-1)^{3(B-L)+2S}$

bilinear R-parity violation:

$$W = W_{MSSM} + \epsilon_i \widehat{L}_i \widehat{H}_u$$

$\Rightarrow$ mixings between SM and SUSY particles

Gravitino as dark matter*

generic prediction of GMSB : light Gravitino LSP

NLSP: $\tilde{\chi}^0_1$ oder $\tilde{l}_R$ ($l = e, \mu, \tau$)

*S. Borgani, A. Masiero, M. Yamaguchi, PLB **386** (1996) 189
F. Takayama and M. Yamaguchi, PLB **485** (2000) 388
M. Hirsch, W. P., D. Restrepo, JHEP **0503**, 062 (2005)

R-parity violation

Neutrino physics*:

- neutrino masses via ν-$\tilde{\chi}_i^0$ mixing
- neutrino mixing angles in terms of R-parity violating couplings

Neutralino decays:

- dominant R-parity violating decays: $\tilde{\chi}_1^0 \to W^\pm l_i^\mp$, $\tilde{\chi}_1^0 \to Z\nu_i$, $\tilde{\chi}_1^0 \to \nu\tau^+ l_i^-$
- R-parity conserving decay: $\Gamma(\tilde{\chi}_1^0 \to \tilde{G}\gamma) \propto \left(\frac{m_{\tilde{\chi}_1^0}}{100 \ \mathrm{GeV}}\right)^5 \left(\frac{100 \ \mathrm{eV}}{m_{3/2}}\right)^2$
- $\Gamma(\tilde{\chi}_1^0) \simeq (10^{-4}–10^{-2})$ eV $\Rightarrow$ decay length of O(10 μm) – O(1 mm)

Gravitino:

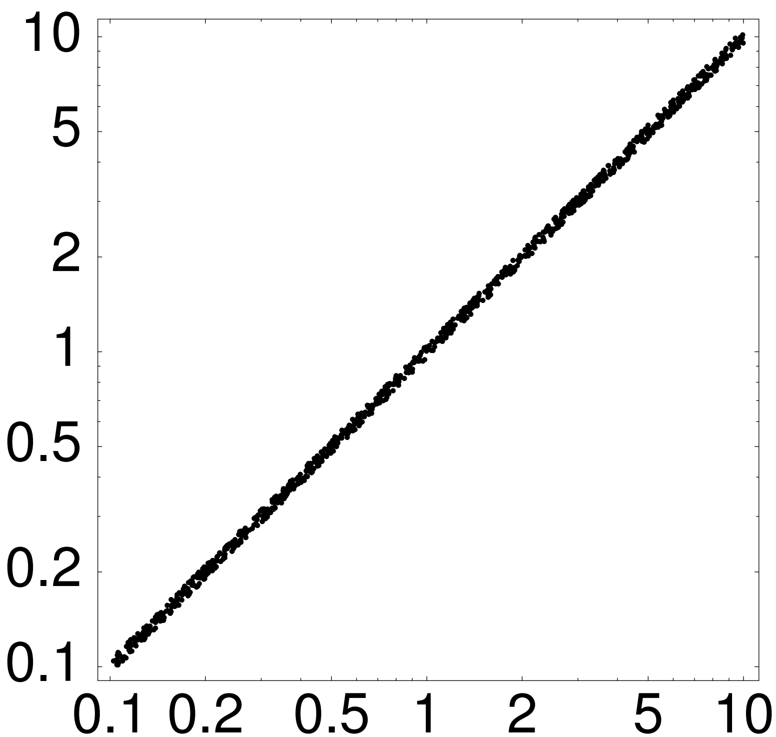
- $\tilde{G}$ eventually decays into $\nu\gamma$
  but: $\tau(\tilde{G}) \sim O(10^{30})\cdot$ life time of the universe

* M. Hirsch, et al. Phys. Rev. D **62**, 113008 (2000)

R-parity violation

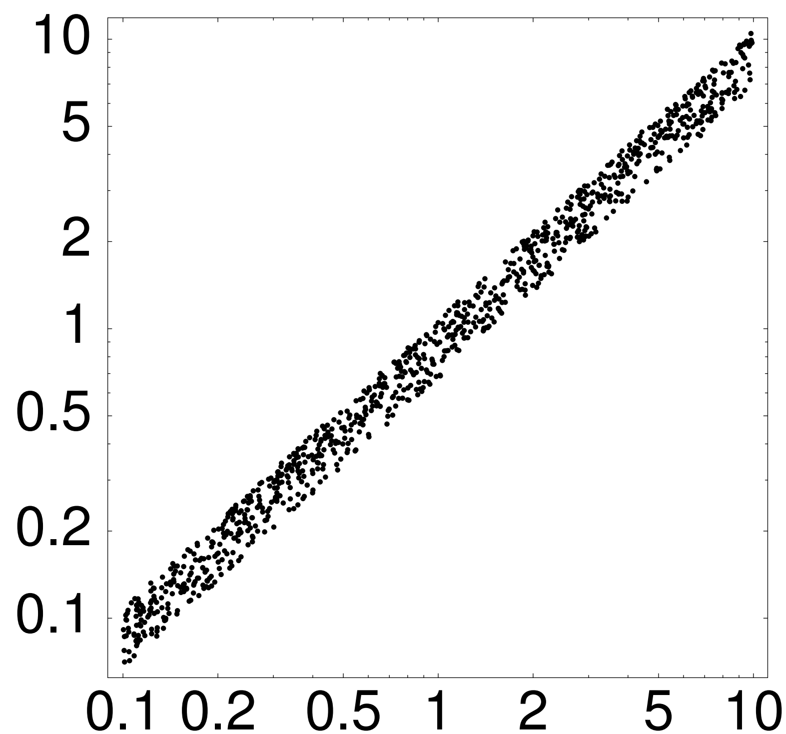
Correlations

BR($\tilde{\chi}_1^0 \to W\mu$) / BR($\tilde{\chi}_1^0 \to W\tau$)



$\tan^2(\theta_{atm})$

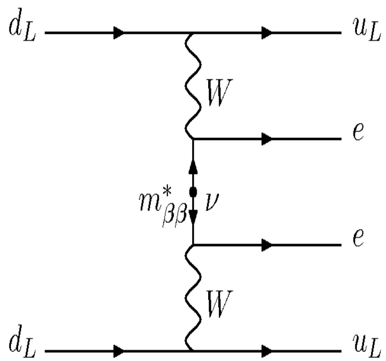
BR($\tilde{\chi}_1^0 \to \nu e\tau$) /BR($\tilde{\chi}_1^0 \to \nu\mu\tau$)

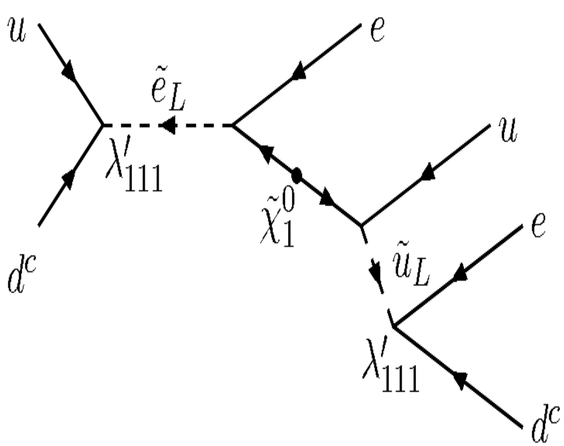


$\tan^2(\theta_{sol})$

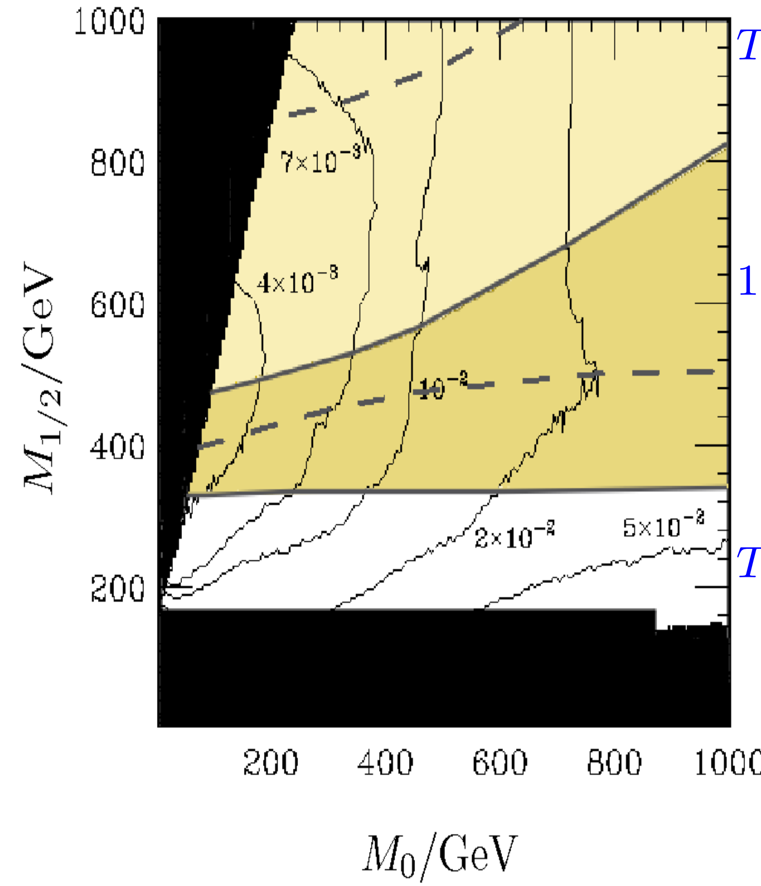
W. P. et al., Phys. Rev. D **63**, 115004 (2001)

R-parity, $0\nu\beta\beta$, single slepton production





regions for 5σ discovery



$T^{0\nu\beta\beta}_{1/2} > 1 \times 10^{27}$yrs

$100 > T^{0\nu\beta\beta}_{1/2}/10^{25}$yrs > 1.9

$T^{0\nu\beta\beta}_{1/2} < 1.9 \cdot 10^{25}$yrs

$L = 10$ fb^{-1} at 14 TeV, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$

B. C. Allanach, C. H. Kom, H. Päs, arXiv:0903.0347 (hep-ph)

Current activities

Aachen, Dortmund, Würzburg

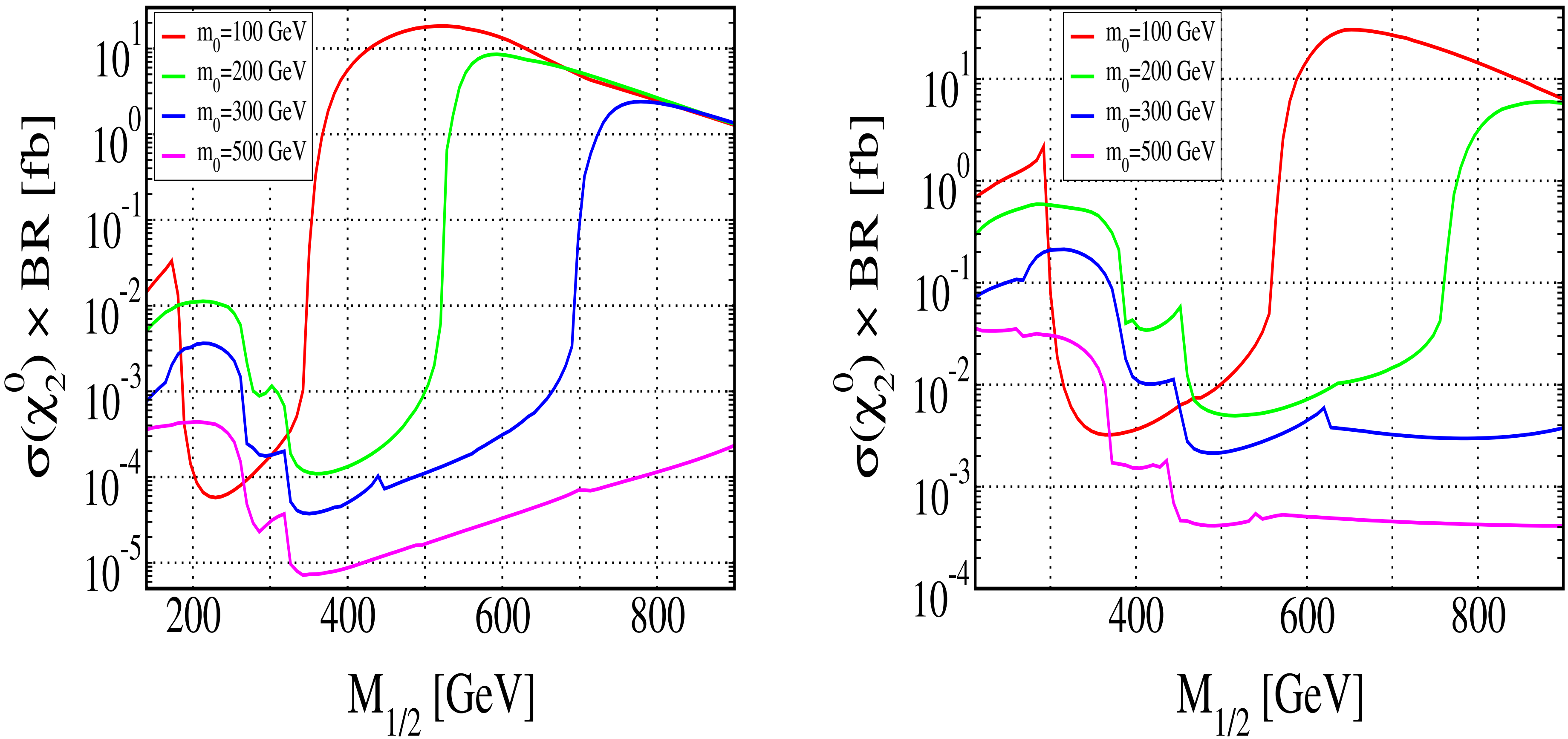
- rare lepton decays at LHC, such as $\tau \to \mu^- \mu^- \mu^+$
- LFV signals at LHC, e.g. cascades containing $\tilde{\chi}_2^0 \to \mu \tau \tilde{\chi}_1^0$
- predictions of ν-mass models for rare lepton decays and properties of new particles (not only SUSY)
- to which extent does a combination of LHC data with data from other experiments allow one to pin down the underlying model?

Kick-off Workshop, 24./25. Nov. in Würzburg

- https://indico.desy.de/conferenceDisplay.py?confId=2403
- www.terascale.de → Schools and workshops

Meeting on Friday at 14:00, 'Großer Gästespeiseraum'

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., arXiv:0903.1408