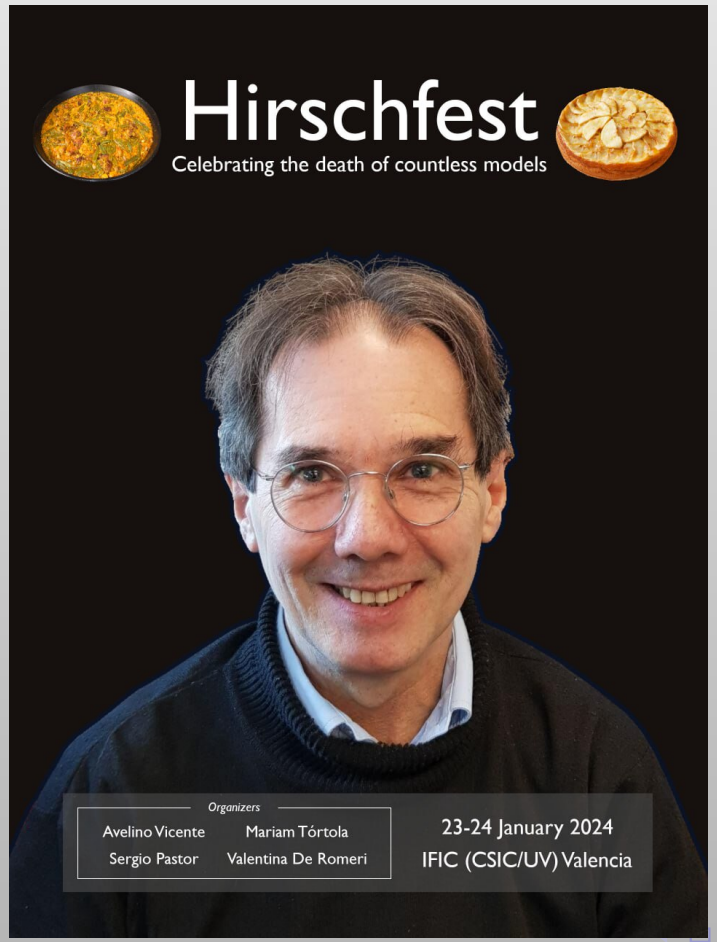
Signatures of neutrino mass models at the LHC

Werner Porod

(Uni. Würzburg)



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"Never do anything more complicated than diagonalising a 2×2 matrix"

"a real and symmetric 2×2 matrix at tree-level"

having recently started to work on

$$W = \varepsilon_{ab}\left[h_U^{ij}\widehat{Q}_i^a\widehat{U}_j\widehat{H}_u^b + h_D^{ij}\widehat{Q}_i^b\widehat{D}_j\widehat{H}_d^a + h_E^{ij}\widehat{L}_i^b\widehat{R}_j\widehat{H}_d^a - \mu\widehat{H}_d^a\widehat{H}_u^b + \epsilon_i\widehat{L}_i^a\widehat{H}_u^b\right]$$

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- actually it was a slightly larger matrix: 3×3 neutrino mass matrix as part of a 7×7 mass matrix

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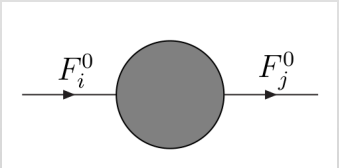

$(F_i = \nu_i, \tilde{\chi}_i)$

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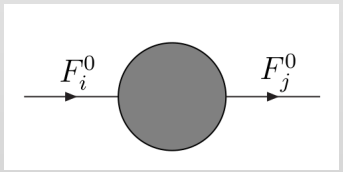
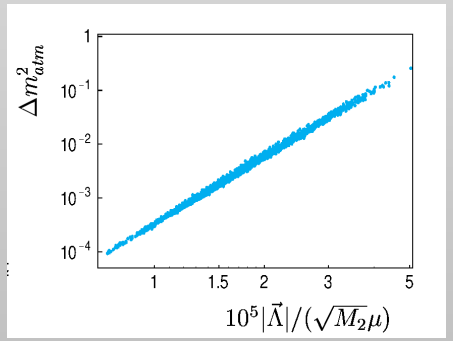
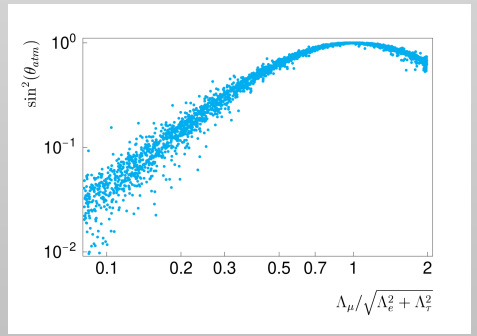


$(F_i = \nu_i, \tilde{\chi}_i)$

- with beautiful results $(\Lambda_i = v_d\epsilon_i + \mu v_i)$

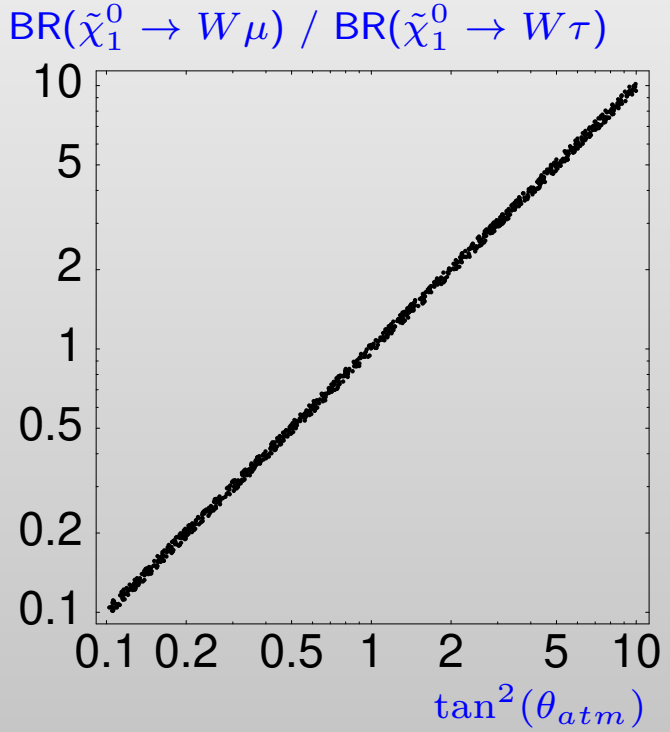


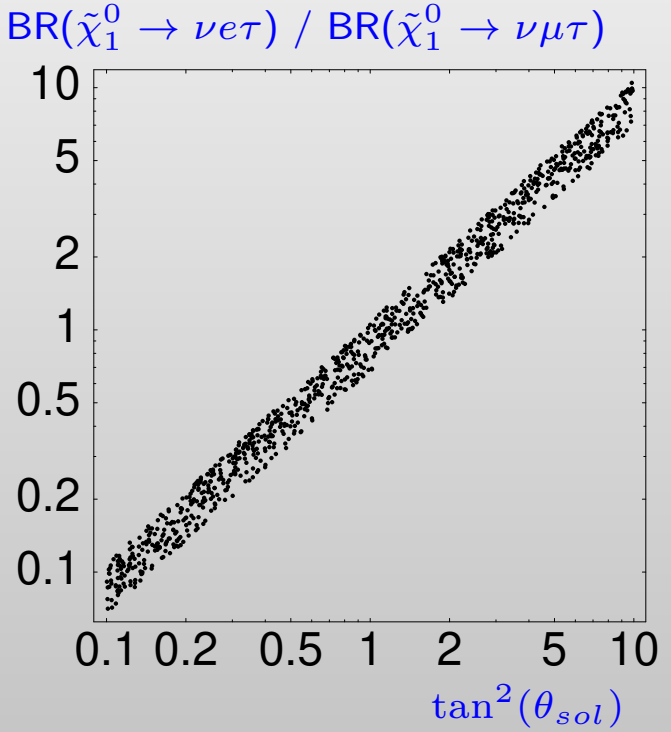


M. Hirsch, M. A. Díaz, W. P., J. C. Romão and J. W. F. Valle, PRD **62** (2000), 113008

Martin: "A good model has to be falsifiable"

$\Rightarrow$ Series of papers with LHC prediction on correlations, e.g.

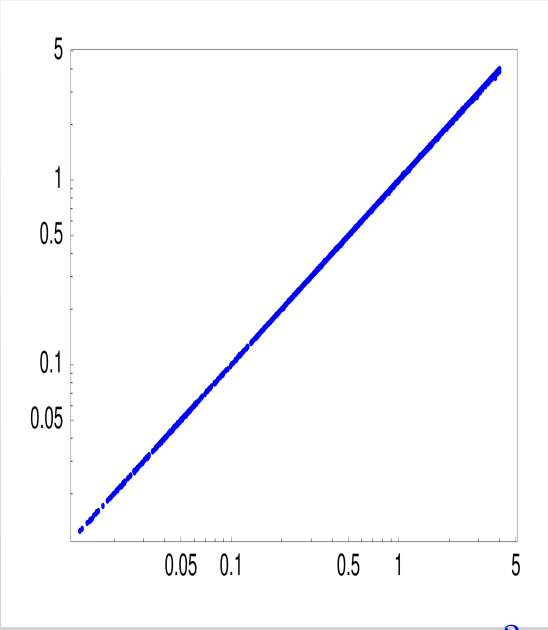




W. P., M. Hirsch, J. Romão and J. W. F. Valle, PRD **63** (2001), 115004

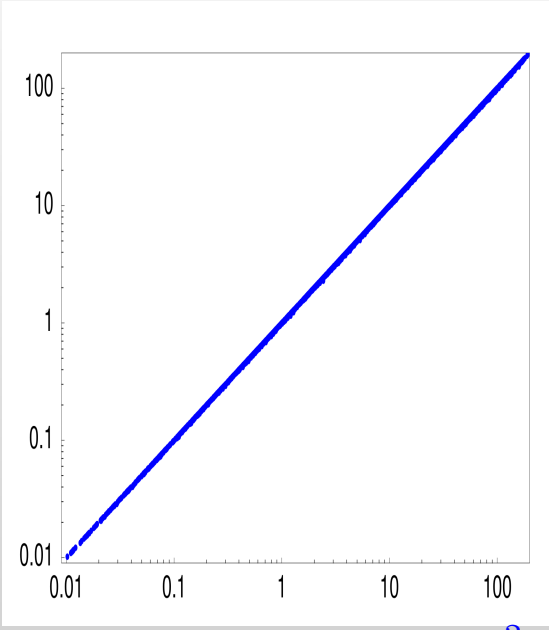
continued by other LSP candidates, e.g. $\tilde{l}_1$

$\mathrm{BR}(\tilde{e}_1 \to \mu\nu_i)/\ \mathrm{BR}(\tilde{e}_1 \to \tau\nu_i)$



$(\epsilon_2/\epsilon_3)^2$

$\mathrm{BR}(\tilde{\mu}_1 \to e\nu_i)/\ \mathrm{BR}(\tilde{\mu}_1 \to \tau\nu_i)$



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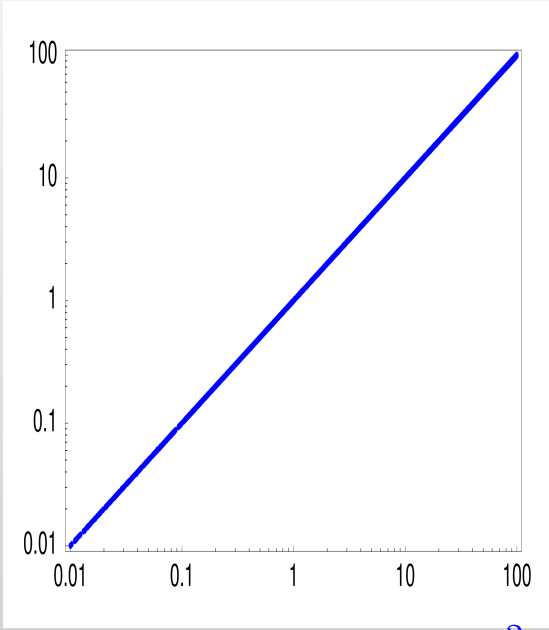

$(\epsilon_1/\epsilon_2)^2$

Cross check possible: $(\epsilon_1/\epsilon_3)^2/(\epsilon_1/\epsilon_2)^2 \equiv (\epsilon_2/\epsilon_3)^2 \Rightarrow$ Measure 2 ratios, 3rd is fixed.
M. Hirsch, W. P., J. C. Romão and J. W. F. Valle, PRD **66** (2002), 095006

+ M. Hirsch and W. Porod, PRD **68** (2003), 115007 for all other possibilities

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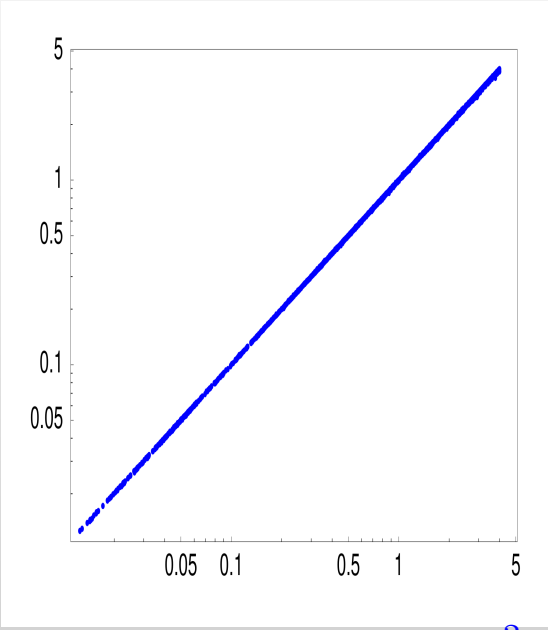

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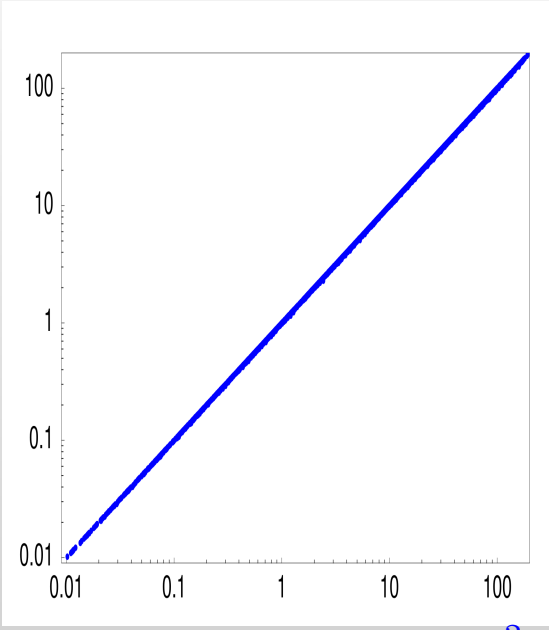

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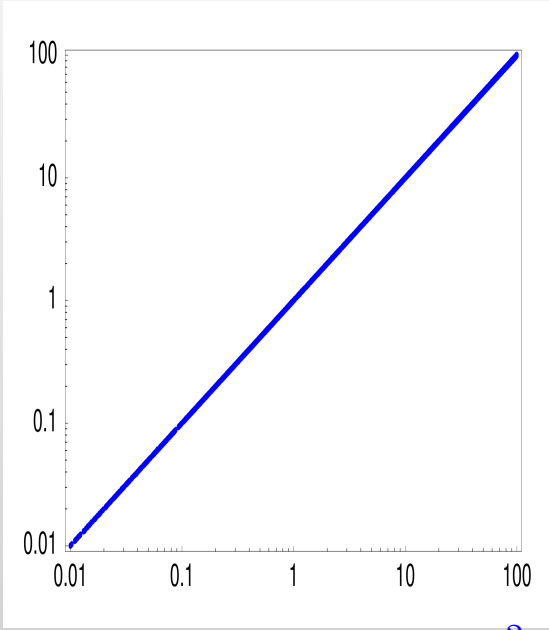

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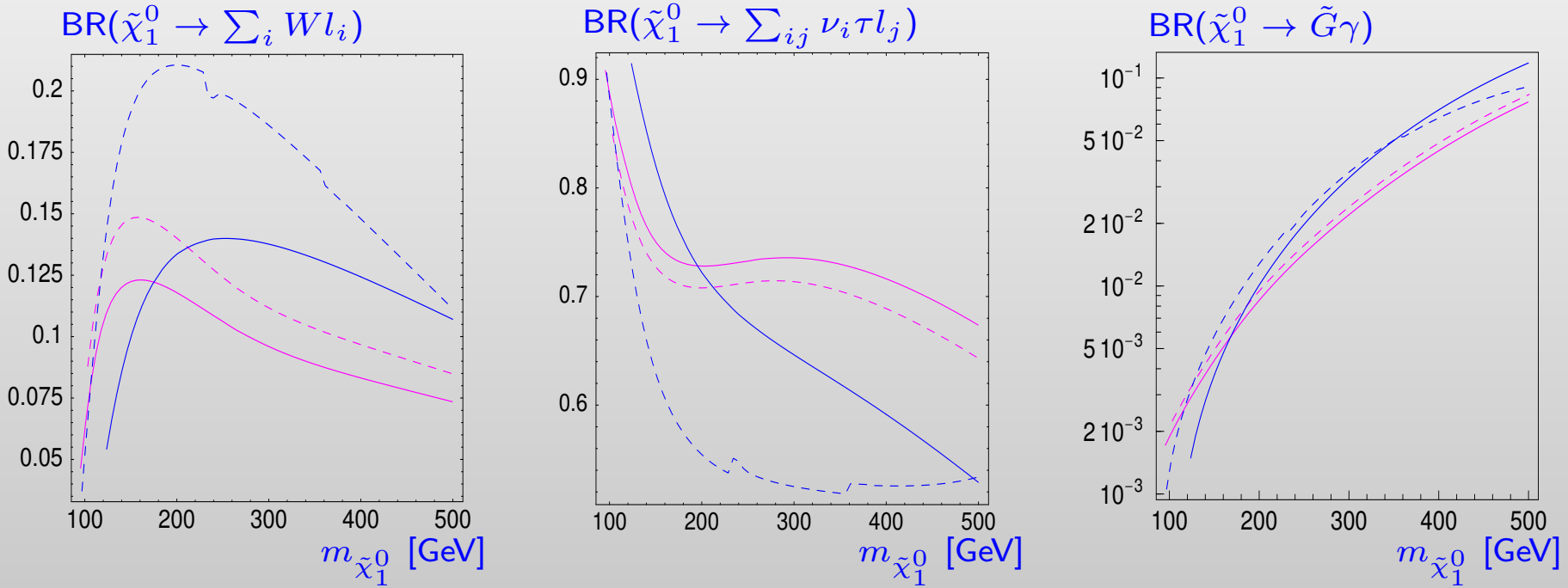
In

- M. Hirsch, T. Kernreiter and W. P., JHEP **01** (2003), 034
  left the realm of real matrices and investigated CP-phases
- included also trilinear RPV-couplings in
  - A. Bartl, M. Hirsch, T. Kernreiter, W. P. and J. W. F. Valle, JHEP **11** (2003), 005
  - D. Aristizabal Sierra, M. Hirsch and W. P., JHEP **09** (2005), 033

Gravitino dark matter



— $\tan\beta = 10,\ \mu > 0$, - - $\tan\beta = 10,\ \mu < 0$, — $\tan\beta = 35,\ \mu > 0$, - - $\tan\beta = 35,\ \mu < 0$

M. Hirsch, W. P. and D. Restrepo, JHEP **0503**, 062 (2005)

Several papers on further RPV models

- Spontaneous R-parity violating
  - playing Hide and Seek 😇, M. Hirsch and W. Porod, PRD **74** (2006), 055003)
  - studying $\tilde{\chi}_1$ decays, M. Hirsch, A. Vicente and W. P., PRD **77** (2008), 075005
  - $\mu \to eJ$ and $\tau \to \mu J$, eJ decays, M. Hirsch, A. Vicente, J. Meyer and W. Porod, PRD **79** (2009), 055023
- $\mu\nu$SSM, with expected 😀 and unexpected 🤔 correlations
  A. Bartl, M. Hirsch, A. Vicente, S. Liebler and W. P., JHEP **05** (2009), 120

with up to 14×14 mass matrices 😱

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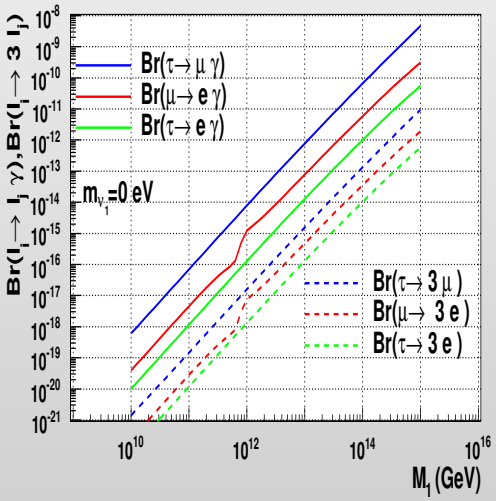
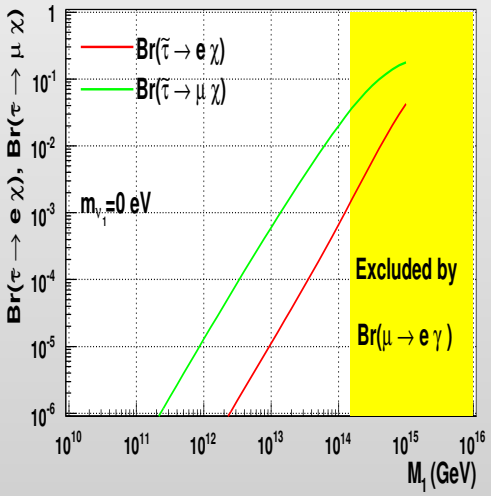
But, there is also a SUSY world with conserved R-parity explaining ν-data 😉

- started with Seesaw I





degenerate ν_R, SPS3

M. Hirsch, J.W.F. Valle, W. P., J. C. Romão, A. Villanova del Moral, PRD **78** (2008), 013006

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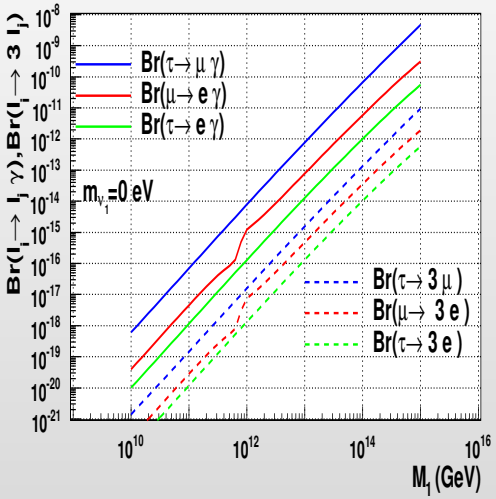

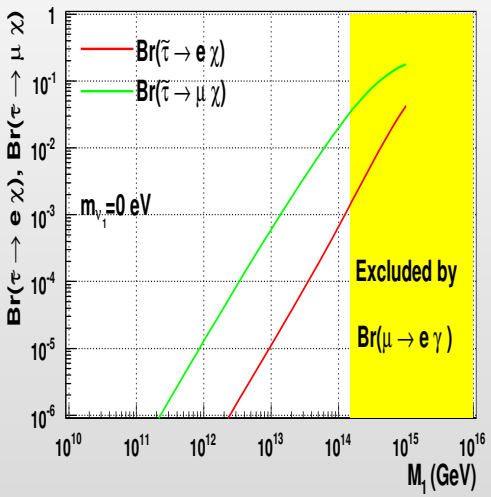

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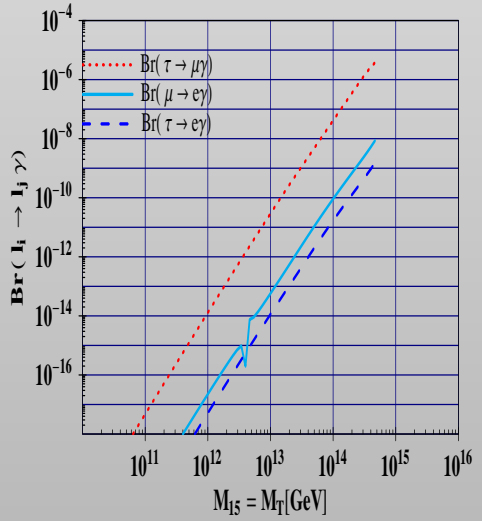
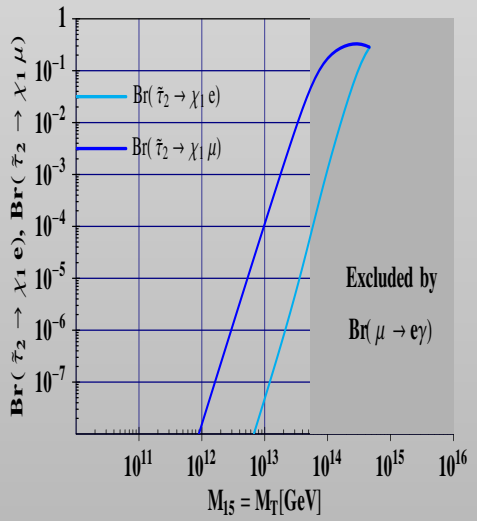
M. Hirsch, J.W.F. Valle, W. P., J. C. Romão, A. Villanova del Moral, PRD **78** (2008), 013006

- continued with Seesaw II

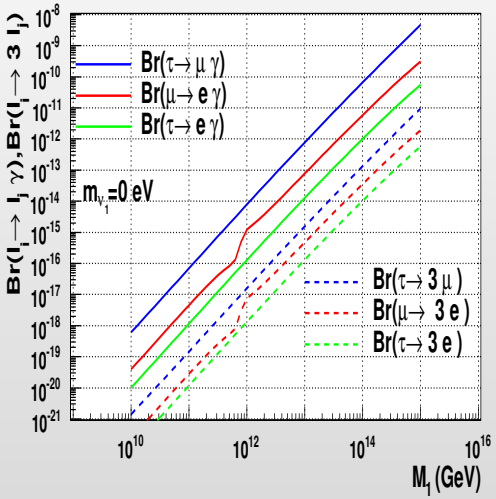


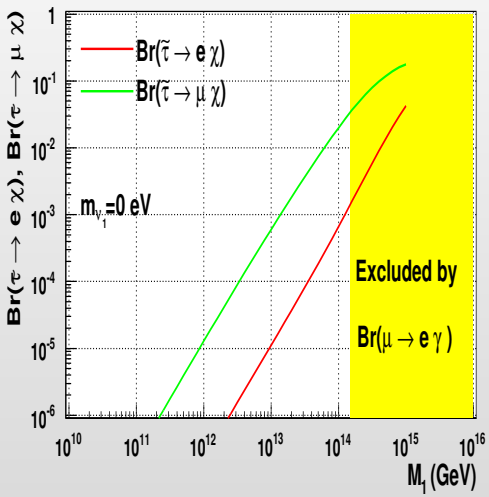


$\lambda_1 = \lambda_2 = 0.5$, SPS3

M. Hirsch, S. Kaneko, W. P., PRD **78** (2008) 093004

- started with Seesaw I





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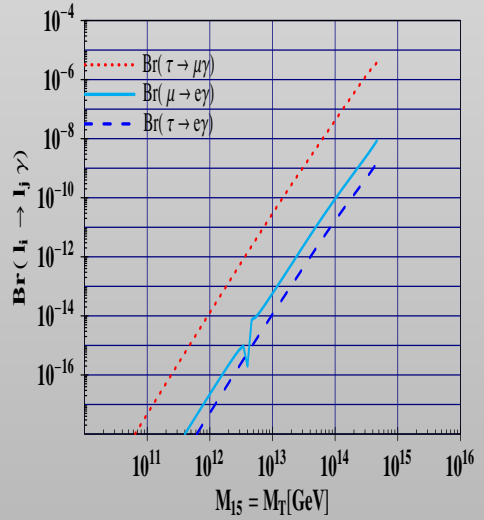
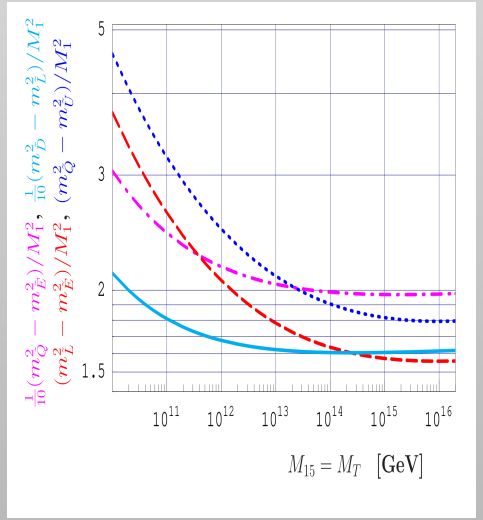




$(b_1, b_2, b_3)^{MSSM} = (\frac{33}{5}, 1, -3)$
$(b_1, b_2, b_3)^{T_1+T_2} = (\frac{18}{5}, 4, 0)$
$(b_1, b_2, b_3)^{\overline{15}+15} = (7, 7, 7)$

Seesaw I ($\simeq$ MSSM)

$\frac{m_Q^2 - m_E^2}{M_1^2} \simeq 20, \quad \frac{m_D^2 - m_L^2}{M_1^2} \simeq 18$

$\frac{m_L^2 - m_E^2}{M_1^2} \simeq 1.6, \quad \frac{m_Q^2 - m_U^2}{M_1^2} \simeq 1.55$

M. Hirsch, S. Kaneko, W. P., PRD **78** (2008) 093004

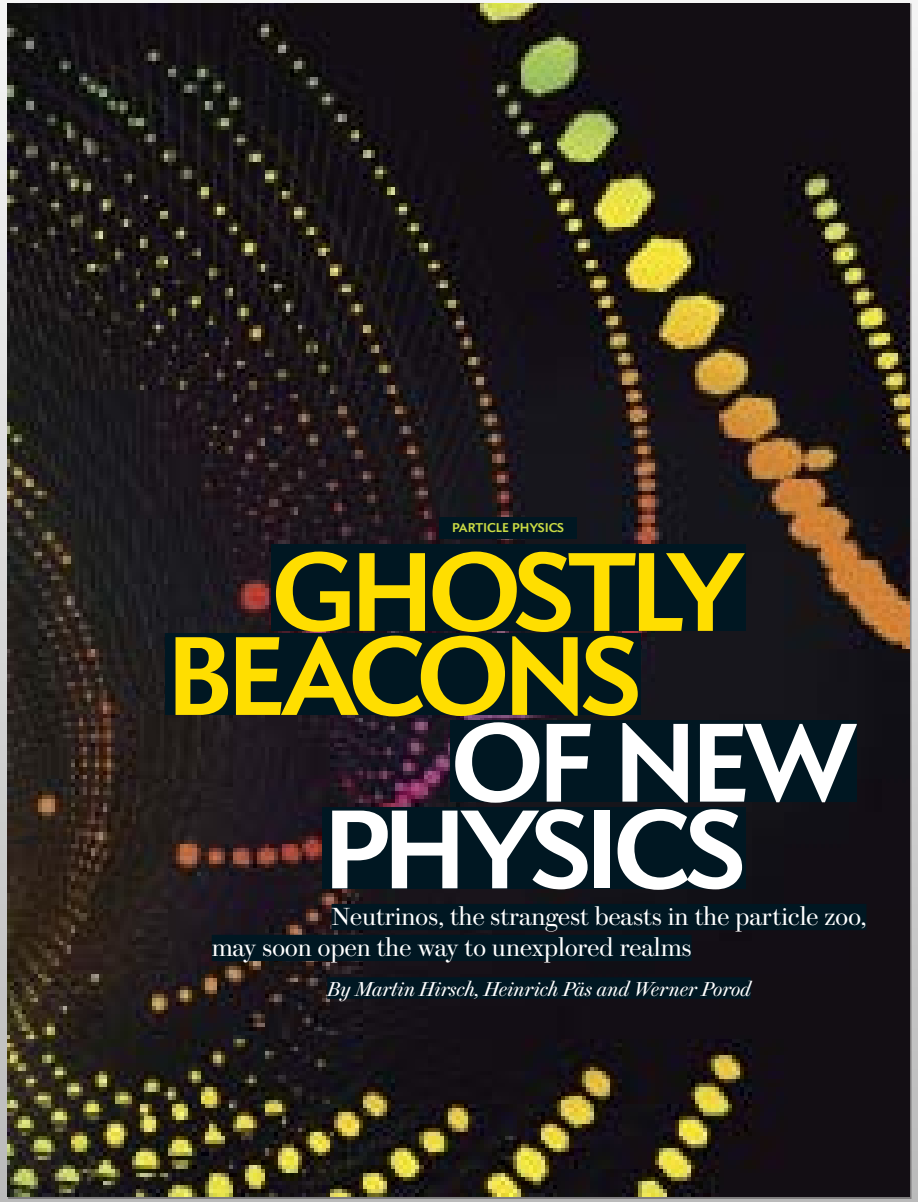
Do things systematically

And went on to

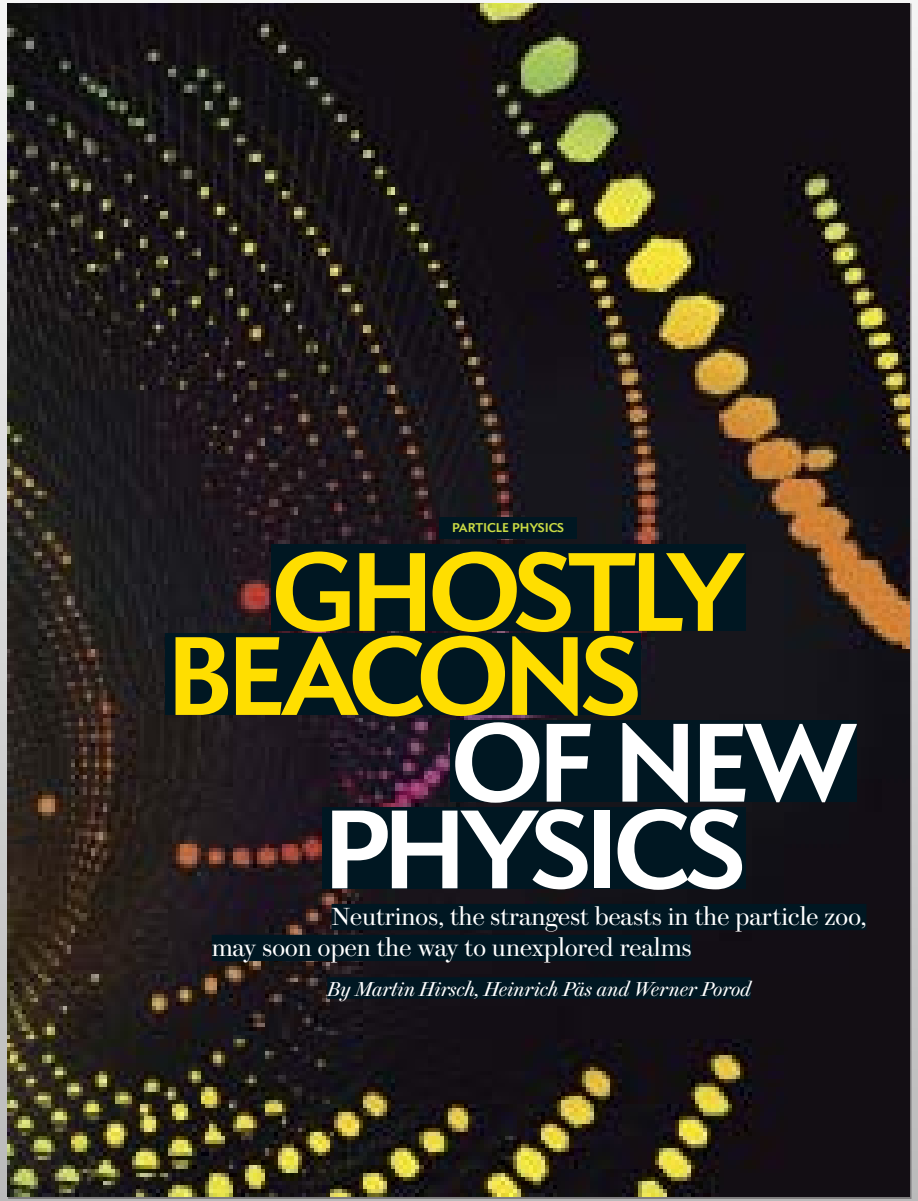
- Seesaw III 🤫
  J.N. Esteves, J.C. Romão, M. Hirsch, F. Staub and W. P., PRD **83** (2011), 013003
  M. Hirsch, W. P., C. Weiss and F. Staub, PRD **87** (2013) no.1, 013010
- Left-right symmetric models 🤗
  J. N. Esteves, J.C. Romão, M. Hirsch, A. Vicente, W. P. and F. Staub, JHEP **12** (2010), 077
  J.N. Esteves, J.C. Romão, M. Hirsch, W. P., F. Staub and A. Vicente, JHEP **01** (2012), 095

Attempted to understand why Higgs mass larger than naive MSSM expectations

- Use extra D-term contributions from larger gauge symmetries 😌
  M. Hirsch, M. Malinský, W. P., L. Reichert and F. Staub, JHEP **02** (2012), 084
- and its tests at LHC ☺️
  M. Hirsch, W. Porod, L. Reichert and F. Staub, PRD **86** (2012), 093018


PARTICLE PHYSICS
GHOSTLY BEACONS OF NEW PHYSICS
Neutrinos, the strangest beasts in the particle zoo, may soon open the way to unexplored realms
By Martin Hirsch, Heinrich Päs and Werner Porod

Why 33+1 papers?



Other physics: stability (or Martin's hidden interest)

Sand castles: the aim

Sand castles: still a long way to go

Sand castles: but intermediate goal, tower's height $\geq$ children's height ✓

Martin

Martin

- founded a new tradition:

The Monday Cake 

Martin

- founded a new tradition:

The Monday Cake  potentially based on 

Martin

- founded a new tradition:

The Monday Cake  potentially based on

- implemented a German tradition in Spain: Feuerzangenbowle

Last but not least

Success is not only citations and H-index, but ...

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also forging the next generation

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Happy Anniversary and many more interesting things to discover