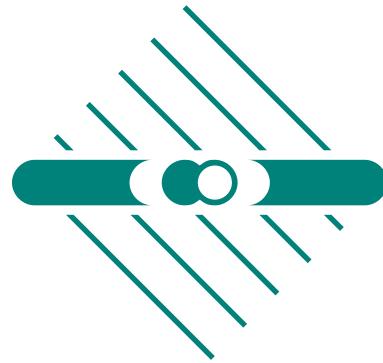

Neutrino masses and LHC

Thomas Schwetz



Max-Planck-Institute for Nuclear Physics, Heidelberg

Introduction

Within the Standard Model neutrinos are massless.

We know from oscillation experiments that neutrinos do have mass.

⇒ Neutrino mass implies physics beyond the SM.

Introduction

Within the Standard Model neutrinos are massless.

We know from oscillation experiments that neutrinos do have mass.

⇒ Neutrino mass implies physics beyond the SM.

Can we learn something about the new physics responsible for neutrino mass at LHC?

A random selection of references on this topic:

- G. Senjanovic, J. Phys. Conf. Ser. **136** (2008) 022039. A. Datta and S. Poddar, 0901.1619 .
Z. Z. Xing, 0901.0209 S. Blanchet, Z. Chacko and R. N. Mohapatra, 0812.3837 P. Fileviez Perez,
T. Han, T. Li and M. J. Ramsey-Musolf, 0810.4138 F. del Aguila and J. A. Aguilar-Saavedra,
Phys. Lett. B **672** (2009) 158 T. Ibrahim and P. Nath, Phys. Rev. D **78** (2008) 075013 P. Fileviez
Perez, T. Han, G. y. Huang, T. Li and K. Wang, Phys. Rev. D **78** (2008) 015018 S. Gabriel,
B. Mukhopadhyaya, S. Nandi and S. K. Rai, Phys. Lett. B **669** (2008) 180 F. de Campos *et al.*
Phys. Rev. D **77** (2008) 115025 P. Fileviez Perez, T. Han, G. Y. Huang, T. Li and K. Wang, Phys.
Rev. D **78** (2008) 071301 S. Bar-Shalom, G. Eilam, T. Han and A. Soni, Phys. Rev. D **77** (2008)
115019 A. G. Akeroyd, M. Aoki and H. Sugiyama, Phys. Rev. D **77** (2008) 075010 J. Garayoa and
T. Schwetz, JHEP **0803** (2008) 009 C. S. Chen, C. Q. Geng, J. N. Ng and J. M. S. Wu, JHEP **0708**
(2007) 022 T. Han, B. Mukhopadhyaya, Z. Si and K. Wang, Phys. Rev. D **76** (2007) 075013
J. Kersten and A. Y. Smirnov, Phys. Rev. D **76** (2007) 073005 A. Hektor, M. Kadastik, M. Muntel,
M. Raidal and L. Rebane, Nucl. Phys. B **787** (2007) 198 F. M. L. de Almeida *et al.*, Phys. Rev. D **75**
(2007) 075002 S. Bray, J. S. Lee and A. Pilaftsis, Nucl. Phys. B **786** (2007) 95 L. D. Ninh and
L. N. Hoang, Phys. Rev. D **72** (2005) 075004 W. Porod and P. Skands, hep-ph/0401077.
S. N. Gninenko, M. M. Kirsanov, N. V. Krasnikov and V. A. Matveev, hep-ph/0301140. A. Ali,
A. V. Borisov and N. B. Zamorin, Eur. Phys. J. C **21** (2001) 123 E. Fernandez, Nucl. Phys. Proc.
Suppl. **31** (1993) 326. A. Datta, M. Guchait and D. P. Roy, Phys. Rev. D **47** (1993) 961
J. N. Esteves *et al.* 0903.1408 A. Villanova del Moral, 0810.3270 I. Gogoladze, N. Okada and
Q. Shafi, Phys. Lett. B **672**, 235 (2009) F. del Aguila and J. A. Aguilar-Saavedra, Nucl. Phys. B
813, 22 (2009) M. Hirsch, S. Kaneko and W. Porod, Phys. Rev. D **78**, 093004 (2008) M. Hirsch *et*
al., Phys. Rev. D **78**, 013006 (2008) I. Gogoladze, N. Okada and Q. Shafi, Phys. Rev. D **78**,
085005 (2008) B. Bajc, M. Nemevsek and G. Senjanovic, Phys. Rev. D **76**, 055011 (2007)
B. Bajc and G. Senjanovic, JHEP **0708**, 014 (2007) E. Ma, Mod. Phys. Lett. A **21** (2006) 1777
E. Ma, 0904.4450 K. S. Babu, S. Nandi and Z. Tavartkiladze, 0905.2710

A random selection of references on this topic:

G. Senjanovic, J. Phys. Conf. Ser. **136** (2008) 022039. A. Datta and S. Poddar, 0901.1619 .
Z. Z. Xing, 0901.0209 S. Blanchet, Z. Chacko and R. N. Mohapatra, 0812.3837 P. Fileviez Perez,
T. Han, T. Li and M. J. Ramsey-Musolf, 0810.4138 F. del Aguila and J. A. Aguilar-Saavedra,
Phys. Lett. B **672** (2009) 158 T. Ibrahim and P. Nath, Phys. Rev. D **78** (2008) 075013 P. Fileviez
Perez, T. Han, G. y. Huang, T. Li and K. Wang, Phys. Rev. D **78** (2008) 015018 S. Gabriel,
B. Mukhopadhyaya, S. Nandi and S. K. Rai, Phys. Lett. B **669** (2008) 180 F. de Campos *et al.*
Phys. Rev. D **77** (2008) 115025 P. Fileviez Perez, T. Han, G. Y. Huang, T. Li and K. Wang, Phys.
Rev. D **78** (2008) 071301 S. Bar-Shalom, G. Eilam, T. Han and A. Soni, Phys. Rev. D **77** (2008)
115019 A. G. Akeroyd, M. Aoki and H. Sugiyama, Phys. Rev. D **77** (2008) 075010 J. Garayoa and
T. Schwetz, JHEP **0803** (2008) 022 T. Han, B. Mukhopadhyaya, Phys. Rev. D **76** (2007) 075013
J. Kersten and A. Y. Smirnov, Phys. Rev. D **76** (2007) 073005 Á. Hektor, M. Kadastik, M. Muntel,
M. Raidal, I. I. Bigi, Nucl. Phys. B **55** (2007) 439 E. Ma, J. A. Aguilar-Saavedra, Phys. Rev. D **76** (2007)

there is a huge literature

I will be very sloppy with citations and apologize for omissions

L. N. Hoang, Phys. Rev. D **72** (2005) 075004 W. Porod and P. Skands, hep-ph/0401077.
S. N. Gninenko, M. M. Kirsanov, N. V. Krasnikov and V. A. Matveev, hep-ph/0301140. A. Ali,
A. V. Borisov and N. B. Zamorin, Eur. Phys. J. C **21** (2001) 123 E. Fernandez, Nucl. Phys. Proc.
Suppl. **31** (1993) 326. A. Datta, M. Guchait and D. P. Roy, Phys. Rev. D **47** (1993) 961
J. N. Esteves *et al.* 0903.1408 A. Villanova del Moral, 0810.3270 I. Gogoladze, N. Okada and
Q. Shafi, Phys. Lett. B **672**, 235 (2009) F. del Aguila and J. A. Aguilar-Saavedra, Nucl. Phys. B
813, 22 (2009) M. Hirsch, S. Kaneko and W. Porod, Phys. Rev. D **78**, 093004 (2008) M. Hirsch *et
al.*, Phys. Rev. D **78**, 013006 (2008) I. Gogoladze, N. Okada and Q. Shafi, Phys. Rev. D **78**,
085005 (2008) B. Bajc, M. Nemevsek and G. Senjanovic, Phys. Rev. D **76**, 055011 (2007)
B. Bajc and G. Senjanovic, JHEP **0708**, 014 (2007) E. Ma, Mod. Phys. Lett. A **21** (2006) 1777
E. Ma, 0904.4450 K. S. Babu, S. Nandi and Z. Tavartkiladze, 0905.2710

Seesaw

Weinberg 1979: there is one dim-5 operator in the SM, which will lead to a Majorana mass term for neutrinos after EWSB:

$$Y^2 \frac{L^T \tilde{\phi}^* \tilde{\phi}^\dagger L}{\Lambda} \quad \longrightarrow \quad m_\nu \sim Y^2 \frac{v^2}{\Lambda}$$

This implies that the physics responsible for neutrino masses lives at the very high scale

$$\Lambda \sim 10^{14} \text{ GeV}$$

which is impossible to probe at LHC or any other imaginable collider experiment.

Neutrino masses from the TeV scale

Maybe the BSM physics expected^a around TeV and searched for at LHC can also be responsible for the generation of neutrino masses:

⇒ TeV scale neutrino mass models

Generically in such models seesaw suppression is not sufficient, one needs additional means to obtain small neutrino masses:

- putting small numbers by hand
- cancellations between large terms
- radiative neutrino masses
- ...

^astabilizing the Higgs mass, Dark Matter,...

Type I, II, III seesaw

3 realizations of the Weinberg operator:

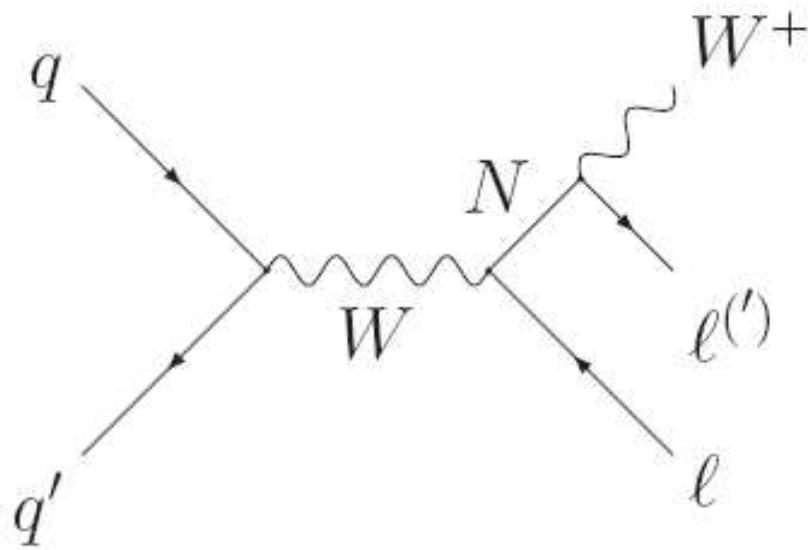
UV completion by

- Type I: fermionic singlet (right-handed neutrinos)
- Type II: scalar triplet
- Type III: fermionic triplet

What happens if these new particles do not have masses of order 10^{14} GeV but only few 100 GeV, within the LHC reach?

Type I seesaw at LHC

e.g., Han, Zhang, 06; Del Aguila, Aguilar-Saavedra, Pittau 07; Kersten Smirnov 07; ...



⇒ dilepton (or multi-lepton) events, e.g.:

lepton number violating: $\ell^\pm \ell^\pm + \text{jets}$ or

lepton flavour violating: $\ell_\alpha^\pm \ell_\beta^\mp + \text{jets}$

Type I seesaw at LHC

$$m_{\alpha\beta}^\nu = v^2 \sum_i \frac{Y_{\alpha i} Y_{\beta i}}{M_i}$$

If heavy neutrino masses M_i are not so heavy there are two possibilities to obtain small neutrino masses:

1. small Yukawas $Y_{\alpha i} \sim 10^{-6}$ (electron Yukawa)
2. cancellations in the sum over N_i

Buchmüller, Wyler, 1990; Pilaftsis, 1992

Type I seesaw at LHC

$$m_{\alpha\beta}^\nu = v^2 \sum_i \frac{Y_{\alpha i} Y_{\beta i}}{M_i}$$

If heavy neutrino masses M_i are not so heavy there are two possibilities to obtain small neutrino masses:

1. small Yukawas $Y_{\alpha i} \sim 10^{-6}$ (electron Yukawa)
2. cancellations in the sum over N_i

add 1: since N_i are SM singlets they interact only via Yukawas \Rightarrow tiny Yukawas imply negligible production rate at LHC.

Type I seesaw at LHC

$$m_{\alpha\beta}^\nu = v^2 \sum_i \frac{Y_{\alpha i} Y_{\beta i}}{M_i}$$

If heavy neutrino masses M_i are not so heavy there are two possibilities to obtain small neutrino masses:

1. small Yukawas $Y_{\alpha i} \sim 10^{-6}$ (electron Yukawa)
2. cancellations in the sum over N_i

add 2: cancellations could be motivated by symmetries, but decouple LHC signatures from light neutrino mass matrix Kersten, Smirnov, 07

Seesaw at LHC with tiny Yukawas

Way out: give N_i gauge interaction, such that new production channels at LHC open:

- Low scale Left-Right symmetry

$$q\bar{q} \rightarrow W_R \rightarrow N\ell \rightarrow \ell\ell + \text{jets}$$

e.g., Keung, Senjanovic, 1983

- Type II seesaw: $N \rightarrow \Delta$ scalar triplet

$$q\bar{q} \rightarrow Z^0(\gamma) \rightarrow \Delta^{--}\Delta^{++} \rightarrow \ell^-\ell^-\ell^+\ell^+$$

see below

- Type III seesaw: $N \rightarrow T$ fermionic triplet

$$q\bar{q} \rightarrow W^- \rightarrow T^-T^0 \rightarrow \ell^-\ell^- + \text{jets}$$

Foot et al., 89; Ma, 98; Bajc, Senjanovic, 07; Franceschini, Hambye, Strumia, 08; ...

- provide some new BSM interaction for N

One specific example:

The Higgs triplet model and LHC

(I prefer not to call it Type-II seesaw)

based on J. Garayoa and T. Schwetz, JHEP **0803** (2008) 009 [0712.1453]

other recent works:

- A. Hektor et al., Nucl. Phys. B **787** (2007) 198 [0705.1495].
- T. Han, B. Mukhopadhyaya, Z. Si and K. Wang, Phys. Rev. D **76** (2007) 075013 [0706.0441].
- A. G. Akeroyd, M. Aoki and H. Sugiyama, Phys. Rev. D **77** (2008) 075010 [0712.4019].
- M. Kadastik, M. Raidal and L. Rebane, Phys. Rev. D **77** (2008) 115023 [0712.3912].
- P. Fileviez Perez et al., Phys. Rev. D **78** (2008) 015018 [0805.3536].

The model

add a triplet Δ under $SU(2)_L$ to the SM:

$$\mathcal{L}_\Delta = f_{ab} L_a^T C^{-1} i\tau_2 \Delta L_b + \text{h.c.},$$

$$\Delta = \begin{pmatrix} H^+/\sqrt{2} & H^{++} \\ H^0 & -H^+/\sqrt{2} \end{pmatrix}$$

The VEV of the neutral component $\langle H^0 \rangle \equiv v_T/\sqrt{2}$ induces a Majorana mass term for the neutrinos:

$$\frac{1}{2} \nu_{La}^T C^{-1} m_{ab}^\nu \nu_{Lb} + \text{h.c.} \quad \text{with} \quad m_{ab}^\nu = \sqrt{2} v_T f_{ab}$$

Neutrino masses

$$m_{ab}^\nu = \sqrt{2} v_T f_{ab} \lesssim 10^{-10} \text{ GeV}$$

Neutrino masses are small because of

- a small triplet VEV v_T
- small Yukawas f_{ab}
- or a combination of these two

Neutrino masses

$$m_{ab}^\nu = \sqrt{2} v_T f_{ab} \lesssim 10^{-10} \text{ GeV}$$

Lepton number violating term in Higgs potential: $\mu \phi^\dagger \Delta \tilde{\phi}$
minimisation of the potential gives

$$v_T \sim \mu \frac{v^2}{M_\Delta^2}$$

Neutrino masses

$$m_{ab}^\nu = \sqrt{2} v_T f_{ab} \lesssim 10^{-10} \text{ GeV}$$

Lepton number violating term in Higgs potential: $\mu \phi^\dagger \Delta \tilde{\phi}$
minimisation of the potential gives

$$v_T \sim \mu \frac{v^2}{M_\Delta^2}$$

Type II seesaw: heavy triplet

$$\mu \sim M_\Delta \sim 10^{14} \text{ GeV} \quad \Rightarrow \quad v_T \sim m^\nu, \quad f_{ab} \sim \mathcal{O}(1)$$

Neutrino masses

$$m_{ab}^\nu = \sqrt{2} v_T f_{ab} \lesssim 10^{-10} \text{ GeV}$$

Lepton number violating term in Higgs potential: $\mu \phi^\dagger \Delta \tilde{\phi}$
minimisation of the potential gives

$$v_T \sim \mu \frac{v^2}{M_\Delta^2}$$

if we want to see the triplet at LHC we need a **light triplet**:

$$M_\Delta \sim v \sim 100 \text{ GeV} \Rightarrow v_T \sim \mu$$

light neutrinos require a small μ

put “by hand” (technically natural \rightarrow Lepton number)

The triplet at LHC

$$pp \rightarrow Z^*(\gamma^*) \rightarrow H^{++}H^{--} \rightarrow \ell^+\ell^+ \ell^-\ell^-$$

doubly charged component of the triplet:

$$\Delta = \begin{pmatrix} H^+/\sqrt{2} & H^{++} \\ H^0 & -H^+/\sqrt{2} \end{pmatrix}$$

very clean signature:

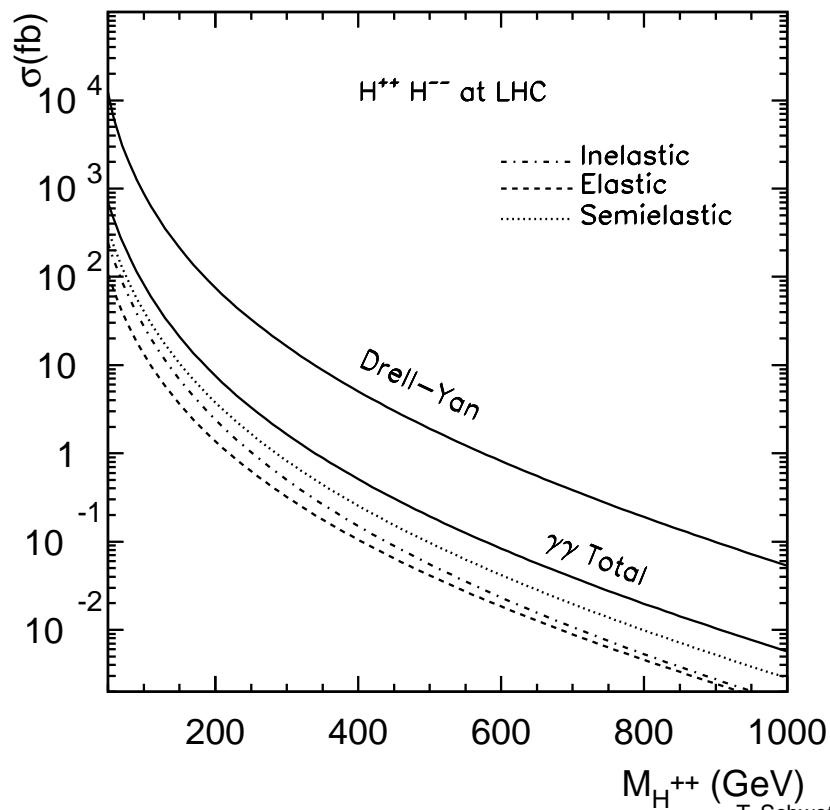
two like-sign lepton pairs with the same invariant mass and no missing transverse momentum

practically no SM background

The triplet at LHC

$$pp \rightarrow Z^*(\gamma^*) \rightarrow H^{++}H^{--} \rightarrow \ell^+\ell^+ \ell^-\ell^-$$

promising production rate: Han, Mukhopadhyaya, Si, Wang, 0706.0441



Decays of the triplet

remember: $\mathcal{L}_\Delta = f_{ab} L_a^T C^{-1} i\tau_2 \Delta L_b$, $m_{ab}^\nu = \sqrt{2} v_T f_{ab}$

$$\Gamma(H^{++} \rightarrow \ell_a^+ \ell_b^+) = \frac{1}{4\pi(1 + \delta_{ab})} |f_{ab}|^2 M_{H^{++}},$$

⇒ Decays of doubly charged Higgs are proportional to the elements of the neutrino mass matrix!

Range for Yukawas and triplet VEV

$$4 \times 10^{-7} \left(\frac{M_{H^{++}}}{100 \text{ GeV}} \right)^{1/2} \lesssim f_{ab} \lesssim 5 \times 10^{-4} \left(\frac{M_{H^{++}}}{100 \text{ GeV}} \right)$$

and with $v_T f_{ab} \sim 0.1 \text{ eV}$:

$$0.2 \text{ keV} \left(\frac{M_{H^{++}}}{100 \text{ GeV}} \right)^{-1} \lesssim v_T \lesssim 0.2 \text{ MeV} \left(\frac{M_{H^{++}}}{100 \text{ GeV}} \right)^{-1/2}$$

bounds on LFV constrain triplet Yukawas f_{ab}
most stringent from $\mu \rightarrow eee$ (tree level in this model)

Range for Yukawas and triplet VEV

$$4 \times 10^{-7} \left(\frac{M_{H^{++}}}{100 \text{ GeV}} \right)^{1/2} \lesssim f_{ab} \lesssim 5 \times 10^{-4} \left(\frac{M_{H^{++}}}{100 \text{ GeV}} \right)$$

and with $v_T f_{ab} \sim 0.1 \text{ eV}$:

$$0.2 \text{ keV} \left(\frac{M_{H^{++}}}{100 \text{ GeV}} \right)^{-1} \lesssim v_T \lesssim 0.2 \text{ MeV} \left(\frac{M_{H^{++}}}{100 \text{ GeV}} \right)^{-1/2}$$

v_T should not be too large in order to maintain
 $\Gamma(H^{++} \rightarrow W^+ W^+) \lesssim \Gamma(H^{++} \rightarrow \ell_a^+ \ell_b^+)$
→ save from LEP EW precision tests

The branchings $H^{++} \rightarrow \ell_a^+ \ell_b^+$

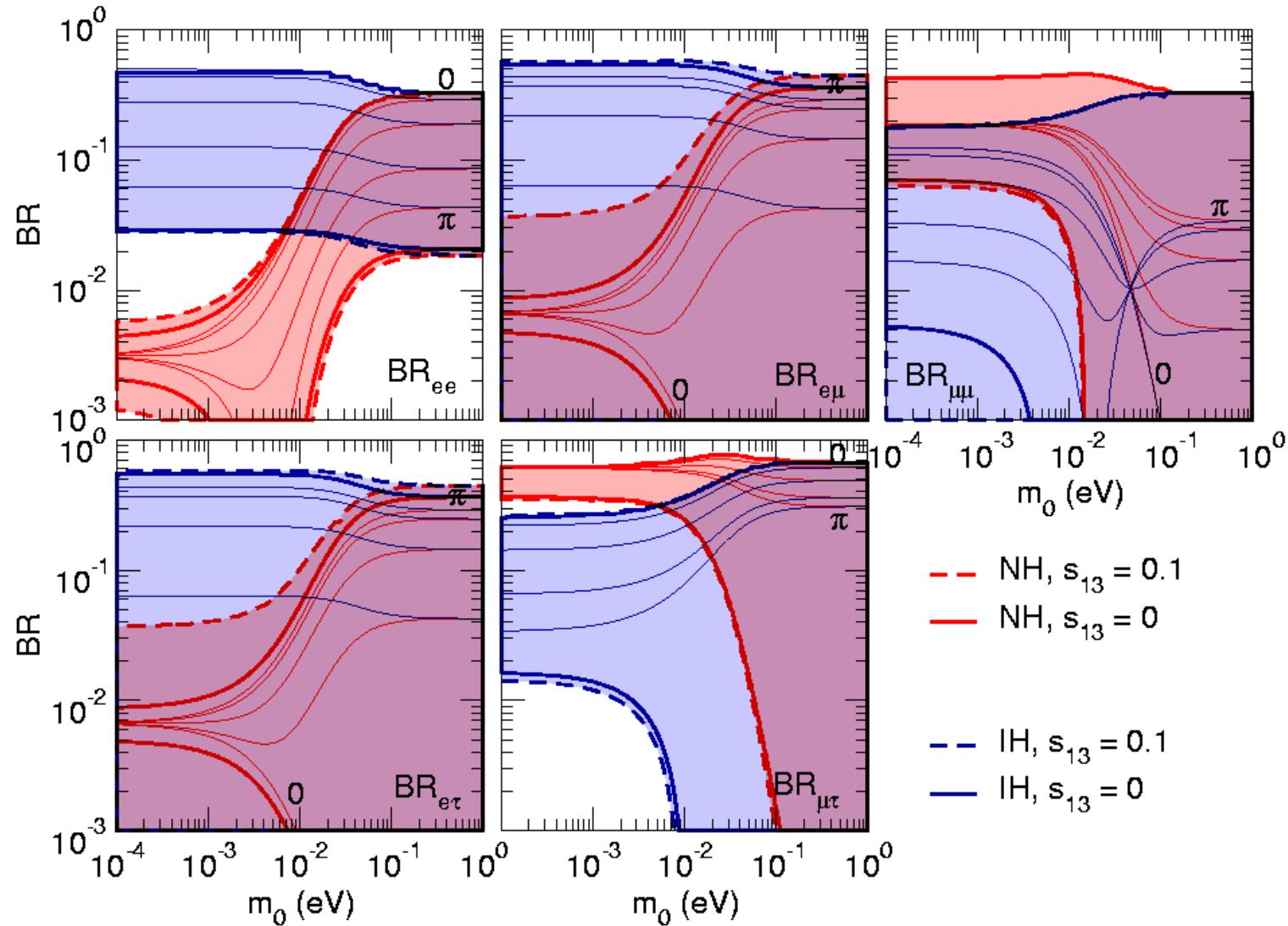
the branchings

$$\text{BR}_{ab} = \frac{2}{(1 + \delta_{ab})} \frac{|M_{ab}|^2}{\sum_{i=1}^3 m_i^2}$$

depend on

- the lightest neutrino mass m_0
- the type of the neutrino mass ordering (NH/IH)
- Majorana CP phases

The branchings $H^{++} \rightarrow \ell_a^+ \ell_b^+$



Numerical analysis

Assume two cases: $\epsilon N_{2H} = 100$ or 1000

ϵ : detection efficiency

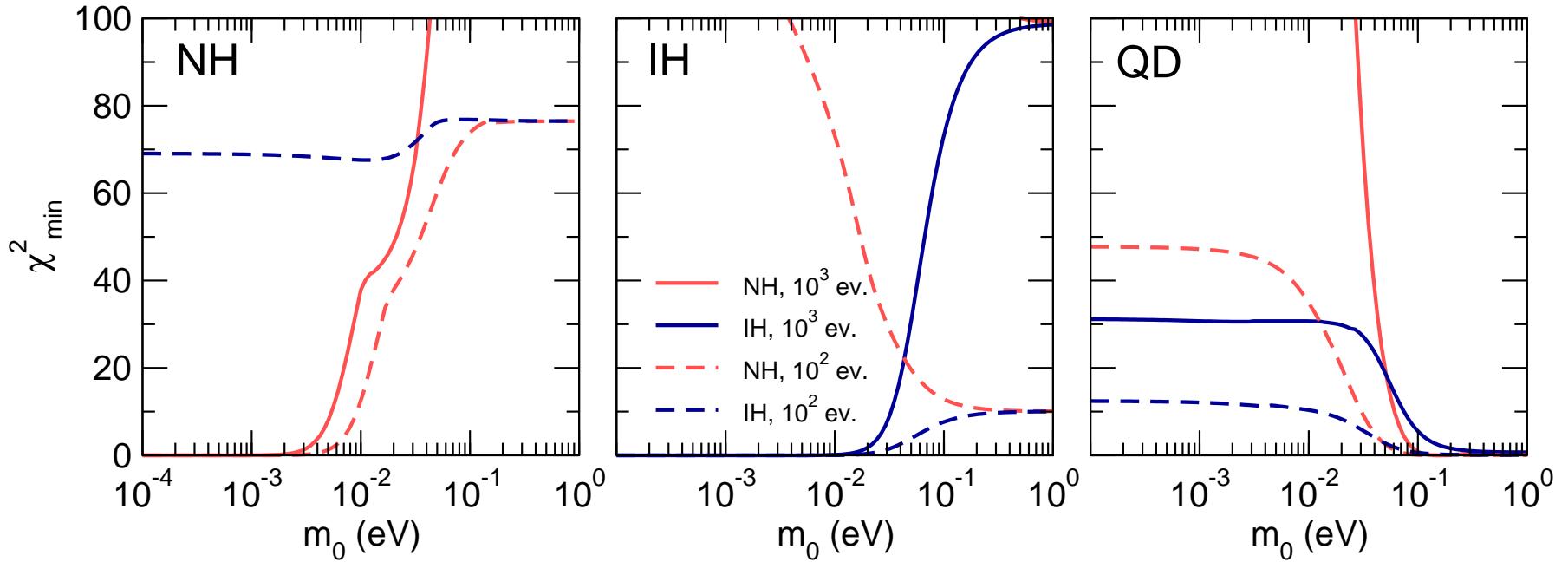
N_{2H} : total number of doubly charged Higgs decaying to 4ℓ

for 100 fb^{-1} at LHC we will have roughly 1000 (100) events for $M_{H^{++}} \simeq 350 \text{ GeV}$ (600 GeV).

consider all possible flavour combinations of 4 lepton events allowing for at most one τ among the 4 leptons

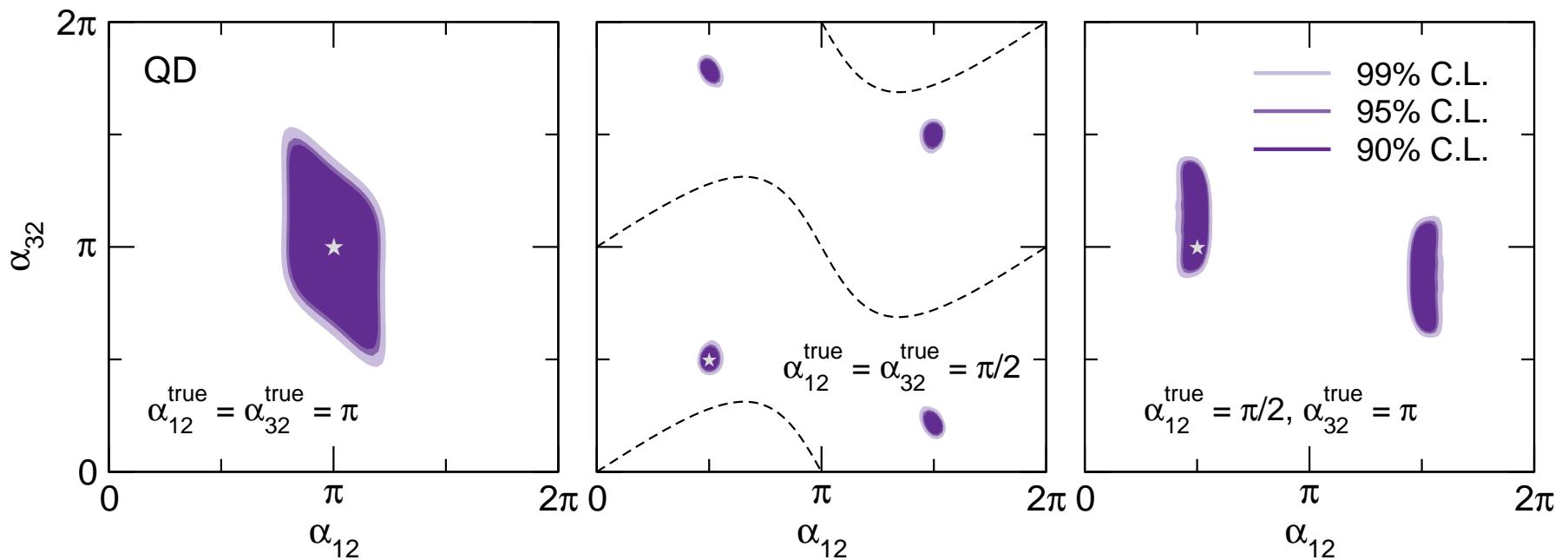
perform a χ^2 fit for the 5 observables corresponding to the number of like-sign lepton pairs with the flavour combinations (ee) , $(e\mu)$, $(\mu\mu)$, $(e\tau)$, $(\mu\tau)$.

Determining the hierarchy

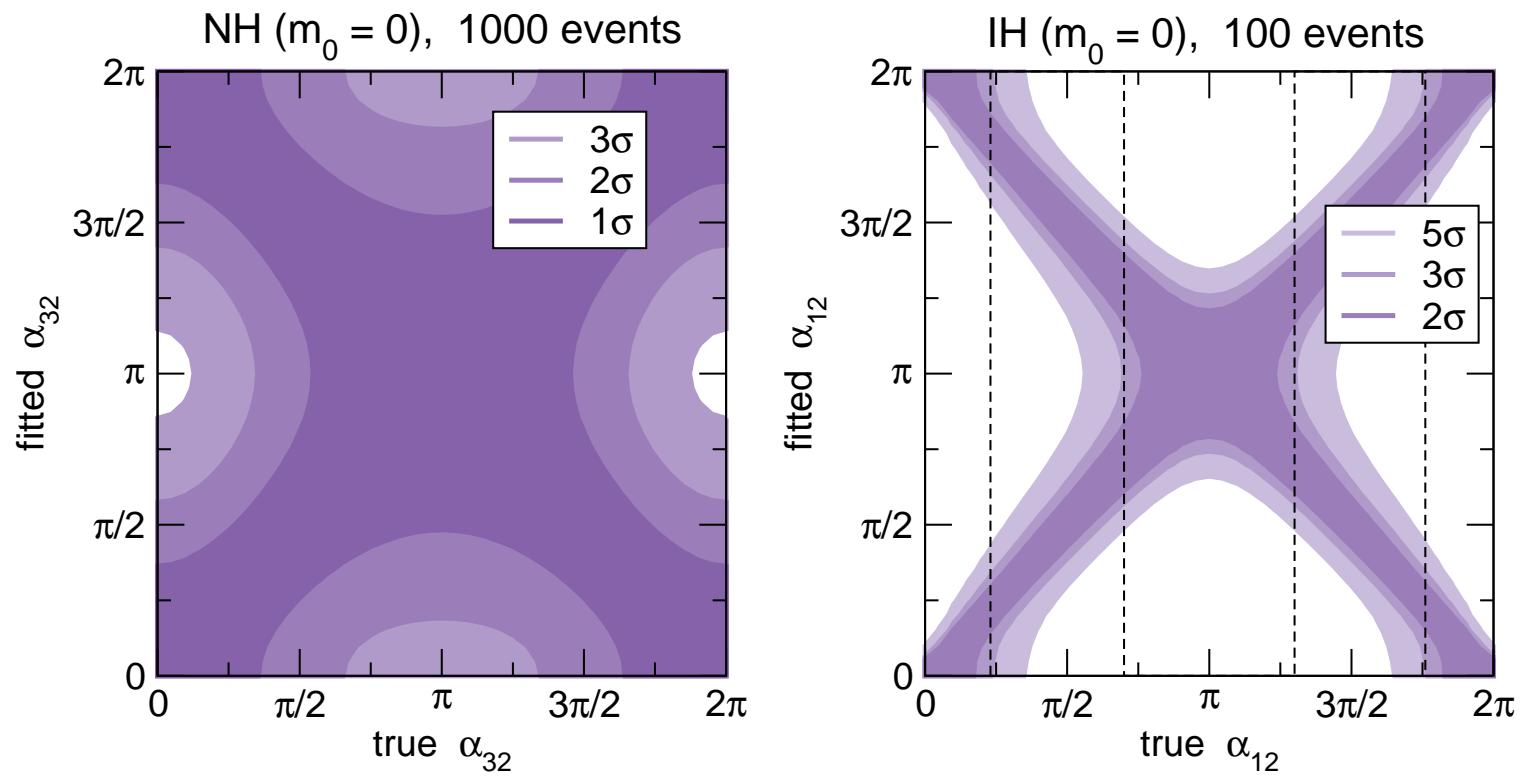


can identify NH vs IH vs QD and obtain some bound
on the lightest neutrino mass m_0

Measuring Majorana phases for QD



Measuring Majorana phases for $m_0 = 0$



Comment on CP violation

there is no CP-odd observable

$$\Gamma(H^{++} \rightarrow \ell_a^+ \ell_b^+) = \Gamma(H^{--} \rightarrow \ell_a^- \ell_b^-) \propto |m_{ab}^\nu|^2$$

⇒ only $\cos(\alpha_{ij})$ can be measured

nevertheless one can (in principle) confine the Majorana phases to CP violating values

(like in neutrino-less double beta decay)

Other examples of TeV scale ν masses

R-parity violating SUSY

neutrino mass generation is related to lepton number violating terms in superpotential \Rightarrow

can study neutrino properties by observing *R*-parity violating decays of the LSP (neutralino) at LHC

e.g.: Hirsch, Porod, Romao, Valle; many many others

see contribution of S. Lavignac

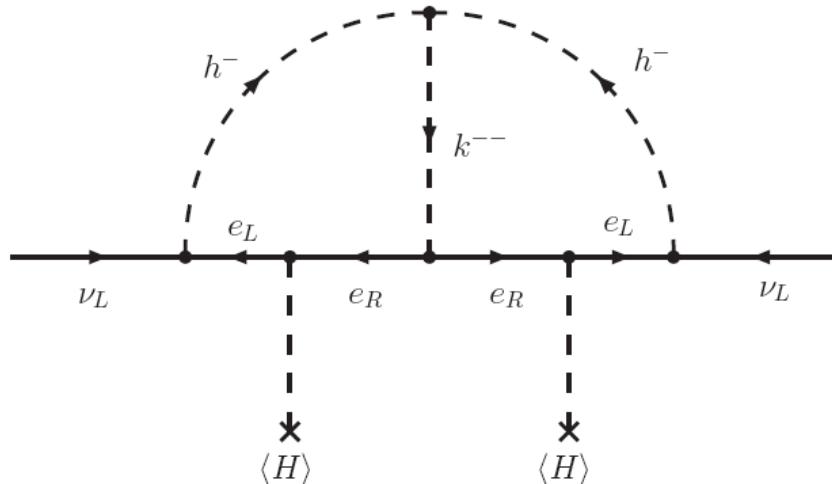
Radiative neutrino mass generation

Example: Zee-Babu model Zee, 85, 86; Babu 88

add two SU(2) singlet scalars: h^+, k^{++}

$$\mathcal{L}_\nu = f_{\alpha\beta} L_\alpha^T C i \sigma_2 L_\beta h^+ + g_{\alpha\beta} \overline{e_{R\alpha}^c} e_{R\beta} k^{++} + \mu h^- h^- k^{++} + \text{h.c.}$$

$$m_\nu \approx \frac{\mu}{48\pi^2 m_k^2} f m_\ell g^* m_\ell f^T$$



Radiative neutrino mass generation

Example: Zee-Babu model Zee, 85, 86; Babu 88

add two SU(2) singlet scalars: h^+, k^{++}

$$\mathcal{L}_\nu = f_{\alpha\beta} L_\alpha^T C i \sigma_2 L_\beta h^+ + g_{\alpha\beta} \overline{e_{R\alpha}^c} e_{R\beta} k^{++} + \mu h^- h^- k^{++} + \text{h.c.}$$

$$m_\nu \approx \frac{\mu}{48\pi^2 m_k^2} f m_\ell g^* m_\ell f^T$$

good prospects to see doubly-charged scalar at LHC →
like-sign lepton events; $\text{BR}(k^{\pm\pm} \rightarrow \ell_\alpha^\pm \ell_\beta^\pm) \propto |g_{\alpha\beta}|^2$
if k^{++} is within reach for LHC the model is tightly constrained by
perturbativity requirements and bounds from LFV

Babu, Macesanu, 02; Aristizabal, Hirsch, 06; Nebot et al., 07

m_ν from a dim-7 operator

Babu, Nandi, Tavartkiladze, 0905.2710

2 fermionic triplets: Σ, Σ' + scalar 4-plet $\Phi = (\Phi^{+++}, \Phi^{++}, \Phi^+, \Phi^0)$

$$\mathcal{L}_\nu = Y L H^* \Sigma + Y' L \Phi \Sigma' + M_\Sigma \Sigma \Sigma' + \lambda H^3 \Phi^* + \text{h.c.}$$

integrate out $\Sigma, \Sigma' \rightarrow$

$$\mathcal{L}_\nu = -\frac{YY'LLH\Phi}{M_\Sigma} \xrightarrow{\text{SB}} m_\nu = \frac{YY'vv_\Phi}{M_\Sigma} = \lambda YY' \frac{v^4}{M_\Sigma M_\Phi^2}$$

(scalar potential minimization gives $v_\Phi = -\lambda v^3/M_\Phi^2$)

correct neutrino mass scale for

$\lambda \sim Y \sim Y' \sim 10^{-3}$ and $M_\Sigma \sim M_\Phi \sim \text{TeV}$

m_ν from a dim-7 operator

Babu, Nandi, Tavartkiladze, 0905.2710

producing Φ^{+++} at LHC:

$$pp \xrightarrow{W^+} \Phi^{+++}\Phi^{--} \quad pp \xrightarrow{Z,\gamma} \Phi^{+++}\Phi^{---}$$

signature:

$$\begin{aligned} \Phi^{+++} &\rightarrow W^+ H^{++*} \\ &\downarrow \\ &W^+ W^+, \ell^+ \ell^+ \end{aligned}$$

final states, e.g.,

$$(W^+ W^+ W^+ W^- W^-), (W^+ W^+ W^+ \ell^- \ell^-), (W^+ \ell^+ \ell^+ \ell^- \ell^-), \dots$$

Summary

Summary

- typical seesaw models for neutrino mass are very hard to test at LHC
- no chance to test neutrino properties at LHC for type-I seesaw even if right-handed neutrinos have TeV masses
- but there are many examples for models where neutrino masses are generated by physics at the TeV scale, testable at LHC
- the typical signature of TeV scale neutrino mass models are like-sign lepton events
- the relation of LHC observables to neutrino properties is very model dependent

Concluding remarks

- The LHC inverse problem: suppose we observe, e.g., like-sign dileptons at LHC, will it be possible to identify the mechanism of neutrino mass generation?

Concluding remarks

- The LHC inverse problem: suppose we observe, e.g., like-sign dileptons at LHC, will it be possible to identify the mechanism of neutrino mass generation?
- For TeV scale neutrino mass models it is often difficult to obtain Leptogenesis.

Concluding remarks

- The LHC inverse problem: suppose we observe, e.g., like-sign dileptons at LHC, will it be possible to identify the mechanism of neutrino mass generation?
- For TeV scale neutrino mass models it is often difficult to obtain Leptogenesis.

Thank you for your attention!