theoretical particle physics @ Vilnius University

The Grimus-Neufeld model:

Restricting Yukawa couplings

with the neutrino sector

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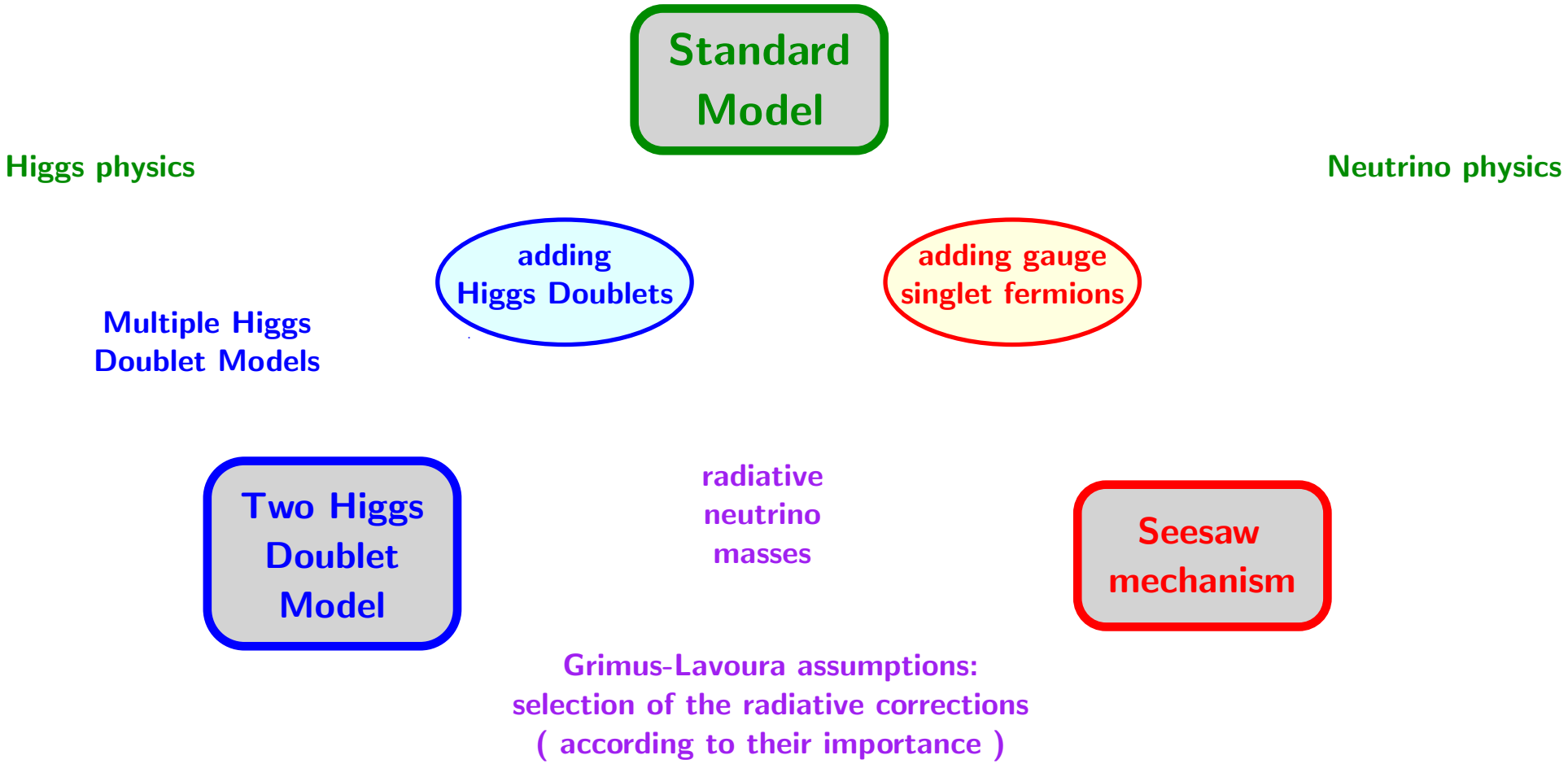
Our model: the 312-νSM (i.e. the Grimus-Neufeld model)

Standard Model (SM) + one fermionic singlet + two Higgs doublets

- is not a new idea: [G-N] W. Grimus and H. Neufeld, Nucl. Phys. B **325** (1989) 18.


Standard Model
Higgs physics
Neutrino physics
adding Higgs Doublets
adding gauge singlet fermions
Multiple Higgs Doublet Models
Two Higgs Doublet Model
radiative neutrino masses
Seesaw mechanism
Grimus-Lavoura assumptions:
selection of the radiative corrections
(according to their importance)

The 312-νSM has parameters additionally to the "original" SM

- the singlet Majorana mass term M_R
- the neutrino Yukawa coupling of the first Higgs doublet

  $(Y_N^{(1)})_j := \widetilde{Y}^1_{Lj} = \frac{\sqrt{2}}{v}(M_D)_j$ ... the "Dirac mass" term

- the Yukawa couplings of the second Higgs doublet

  $(Y_E^{(2)})_{jk} := Y^2_{Ljk}$ to lepton doublets and charged lepton singlets ℓ_{Rj}

  $(Y_N^{(2)})_j := \widetilde{Y}^2_{Lj}$ to lepton doublets and neutral fermionic singlet N_R

- additional parameters in the Higgs sector

  [H-ON] H. E. Haber and D. O'Neil, Phys. Rev. D **83** (2011) 055017 [arXiv:1011.6188 [hep-ph]]

  - $m^2_{H_2}$, $m^2_{H_3}$, $m^2_{H^\pm}$ masses of the additional Higgs bosons
  - θ_{12}, θ_{13} mixing angles between the neutral Higgs fields

    assuming CP conservation forces the mixing to the pseudo-scalar A^0 to zero: $\theta_{13} = 0$
  - Z_2, Z_3, Z_7 ... parameters of the Higgs potential,

    not fixed by tree level mass relations

312-νSM generic model predictions

- additional Higgses: $H^{\pm}, H^{0}_{(1,)\,2,3}$ (like the generic 2HDM)

  $\Rightarrow$ generic 2HDM phenomenology

- one heavy fermionic singlet (''heavy neutrino'')
  - most probably invisible @ colliders (like a neutrino)

- only one seesaw neutrino at tree level
- one light neutrino gets a radiative mass at one-loop level
- the third light neutrino can get a radiative mass at 2 or 3-loop level

  ! we have only a single mass difference at tree level !

  $\Rightarrow$ we need the one-loop level to determine parameters

Using the Grimus-Lavoura procedure (i.e. approximation)

[G-L] W. Grimus and L. Lavoura, JHEP **0011** (2000) 042 [arXiv:hep-ph/0008179].

allows to determine the "light" neutrino masses $\tilde{m}_j$ analytically :

$$\tilde{m}_o = 0 \quad \text{and} \quad \tilde{m}_{r,s} = \tilde{m}_{r,s}\left[m_h^2, m_H^2, m_A^2, \theta_{12}, v^2, \tilde{m}_4, m_D^2, d, d' = |d'|e^{i\phi'}\right]$$

- we can invert these relations and determine (with $d' = |d'|e^{i\phi'}$)

$$\begin{aligned} d^2 &= d^2\left[m_h^2, m_H^2, m_A^2, \theta_{12}, v^2, \tilde{m}_r, \tilde{m}_s, \tilde{m}_4, m_D^2\right] \\ |d'| &= |d'|\left[m_h^2, m_H^2, m_A^2, \theta_{12}, v^2, \tilde{m}_r, \tilde{m}_s, \tilde{m}_4, m_D^2, \phi'\right] \end{aligned}$$

- which fully determine the Yukawa couplings:

$$(Y_N^{(1)})_k = \frac{\sqrt{2}m_D}{v} u_{ks} \qquad (Y_N^{(2)})_k = d\, u_{kt} + d' u_{ks}$$

  - when we express the $u_{k\alpha}$ by U_{PMNS} and the mixing of the states

$\Rightarrow$ possible predictions

Comparison with SPheno and FlexibleSUSY

[Drau] ⟨http://talpykla.elaba.lt/elaba-fedora/objects/elaba:29420143/datastreams/MAIN/content⟩

- S. Draukšas implemented the GN model in SPheno and FlexibleSUSY
  - the code generation worked
  - SPheno could not reproduce the small neutrino masses
  - FlexibleSUSY gave qualitatively an expected spectrum

Plans

- We want a full renormalization of the GN model
  - giving us an estimate of the size of the GL approximation
- We want to extend the comparison with SPheno and FlexibleSUSY
- FlexibleSUSY allows predictions for leptonic rare processes
  - like: $\mu \to e\gamma$, $\mu \to eee$, ...
  - when the parameters are constrained by other "normal" measurements