Minimal three-loop neutrino mass models and charged lepton flavour violation

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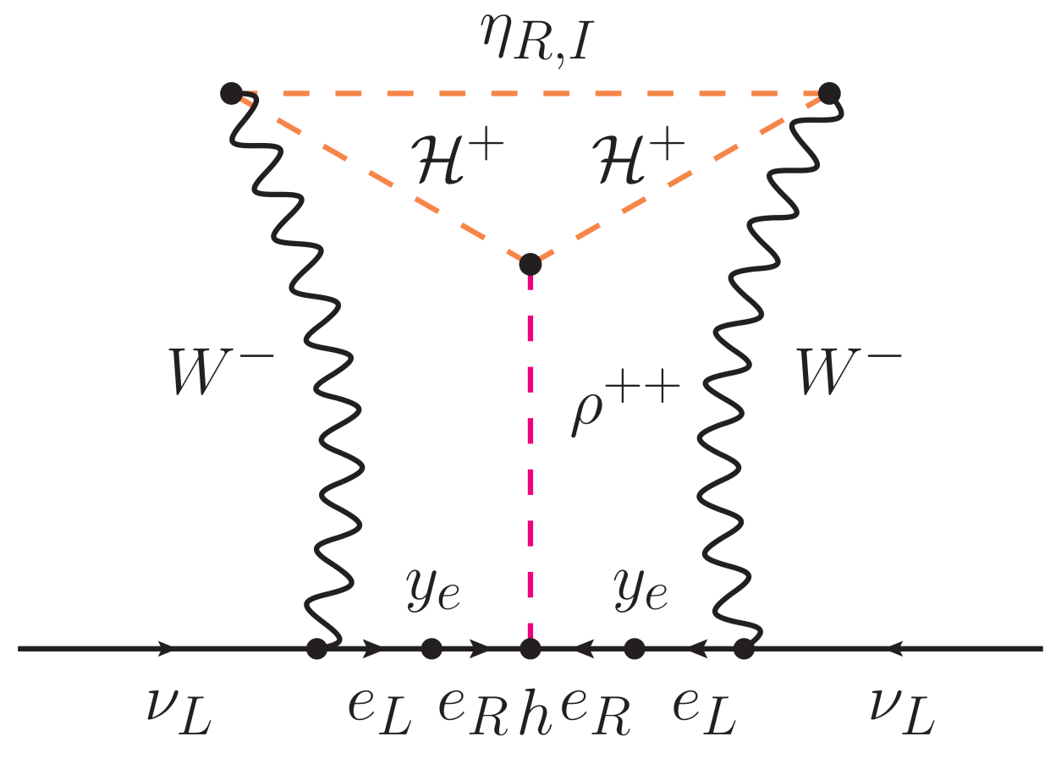
COCKTAIL MODEL [1]



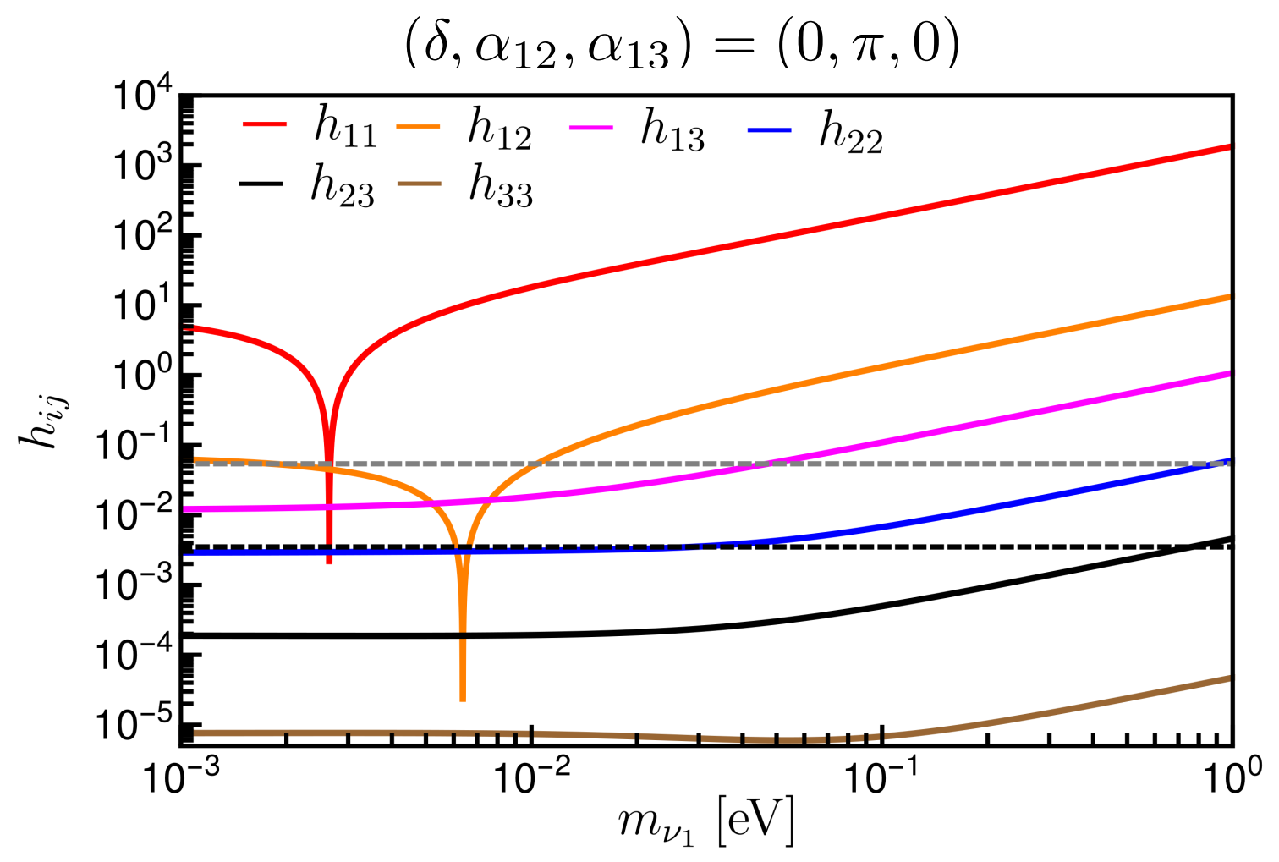
New particles in the cocktail model with respect to the SM.

	generations	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	$\mathbb{Z}_2$
S	1	**1**	**1**	1	−
ρ	1	**1**	**1**	2	+
η	1	**1**	**2**	1/2	−

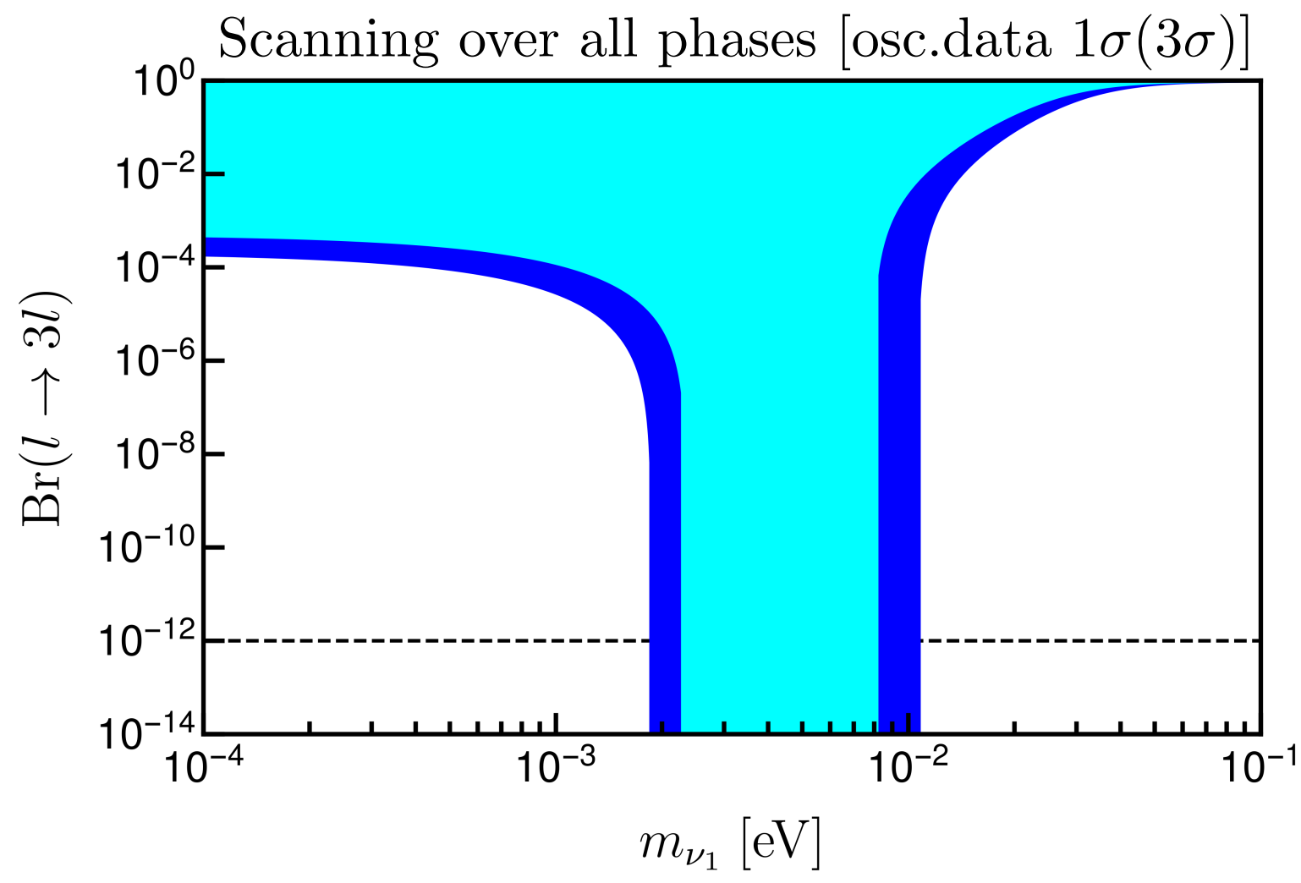
Mass eigenstates:

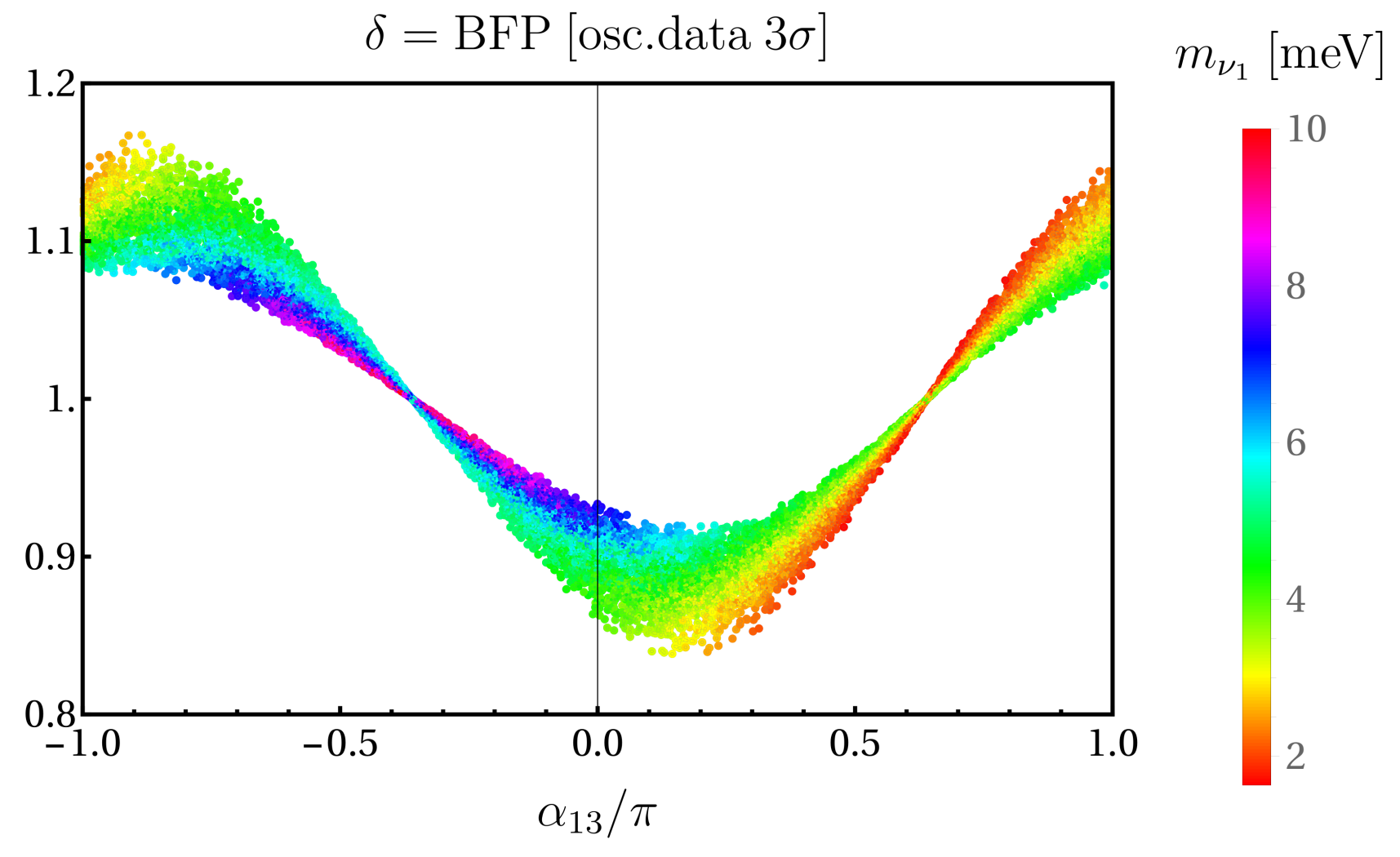
- $\eta^0 = \frac{1}{\sqrt{2}}(\eta_R + i\,\eta_I)$, due to λ_5.
- $\mathcal{H}^+ \equiv \mathcal{H}^+_{1,2} \to$ mass matrix of $\{S^+, \eta^+\}$.

Neutrino mass: $(\mathcal{M}_\nu)_{ij} = \frac{\lambda_5}{(16\pi^2)^3} \frac{m_i\, h_{ij}\, m_j}{m_{\rho^{++}}} F_{\text{loop}}$, where $m_{i,j}$ are SM charged lepton masses.

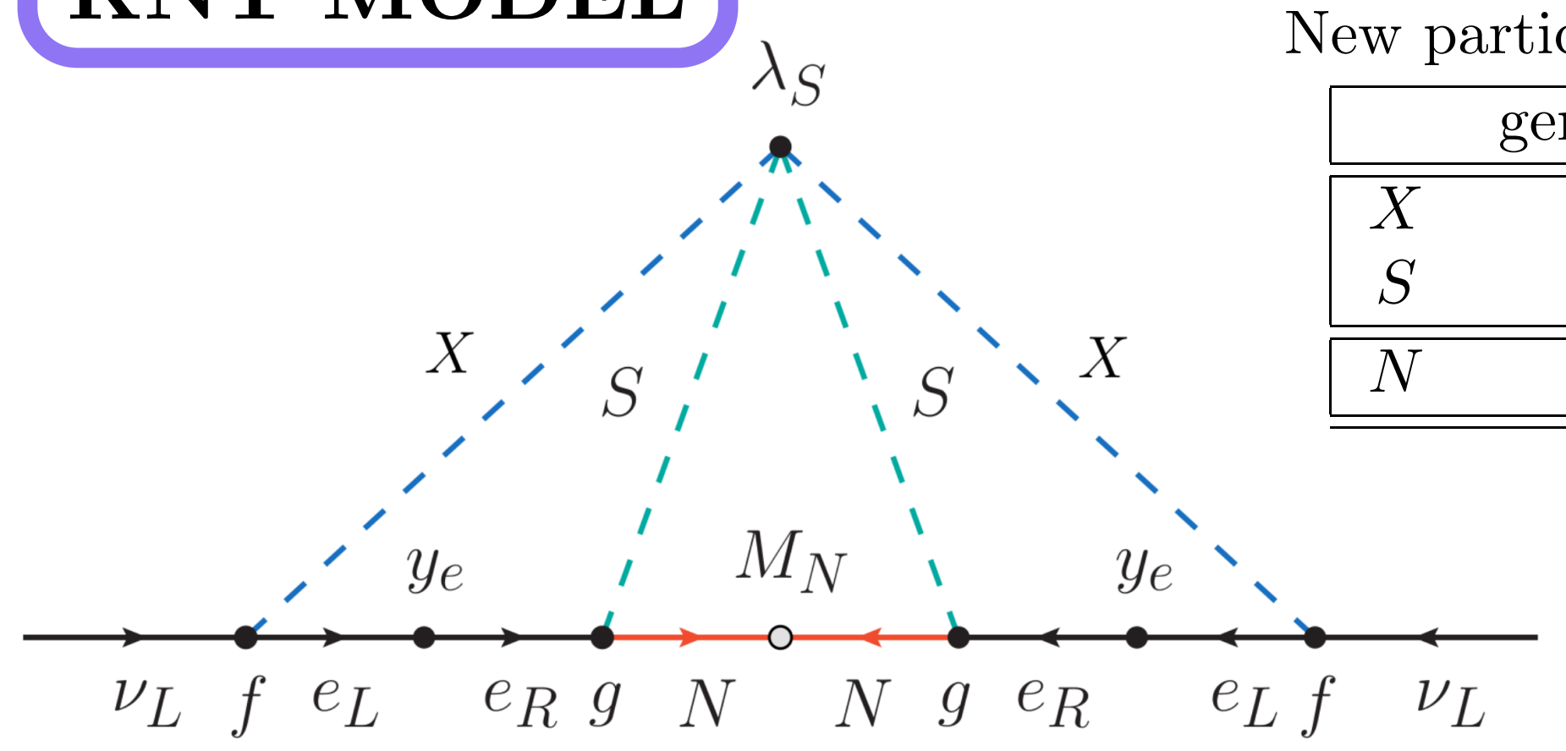


- Yukawa h is non-perturbative except for specific values of the phases and m_{ν_1} ⇒ fine-tuning.
- The most severe constraint comes from $\mu \to 3e$ at tree-level mediated by $m_{\rho^{++}}$.
- The model can fulfill the constraint from $\mathrm{Br}(\mu \to 3e)$ only in a very narrow range of phases.
- The model fixes $m_{\nu_1} \sim (2-10)$ meV.





KNT MODEL [3]

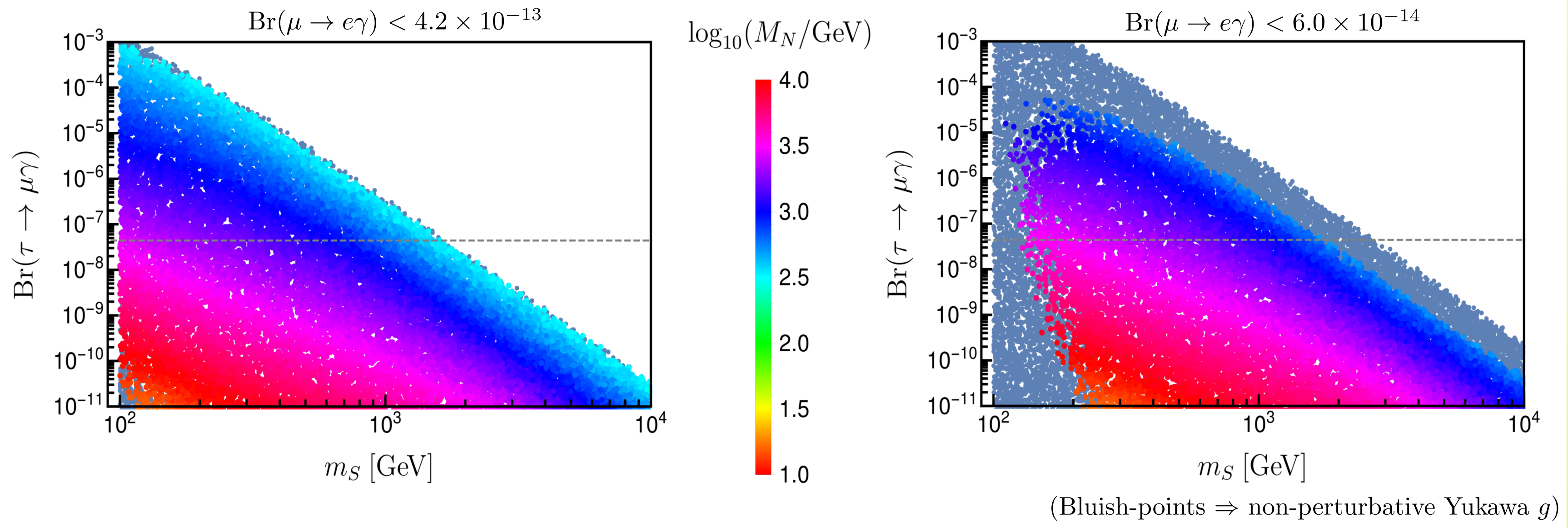


New particles in the KNT model with respect to the SM.

	generations	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	$\mathbb{Z}_2$
X	1	**1**	**1**	1	+
S	1	**1**	**1**	1	−
N	3	**1**	**1**	0	−

Neutrino mass: $(\mathcal{M}_\nu)_{ij} = \frac{2\lambda_S}{(16\pi^2)^3} \sum_{\alpha,\beta,a} \frac{m_\alpha m_\beta}{M_{N_a}} f_{i\alpha} f_{j\beta} g_{\alpha a} g_{\beta a}\, F_{\text{loop}}$

Yukawa f is antisymmetric ⇒ neutrino fit: osc. data (2 mass splittings, 3 angles and a phase) + 6 complex equations



(Bluish-points ⇒ non-perturbative Yukawa g)

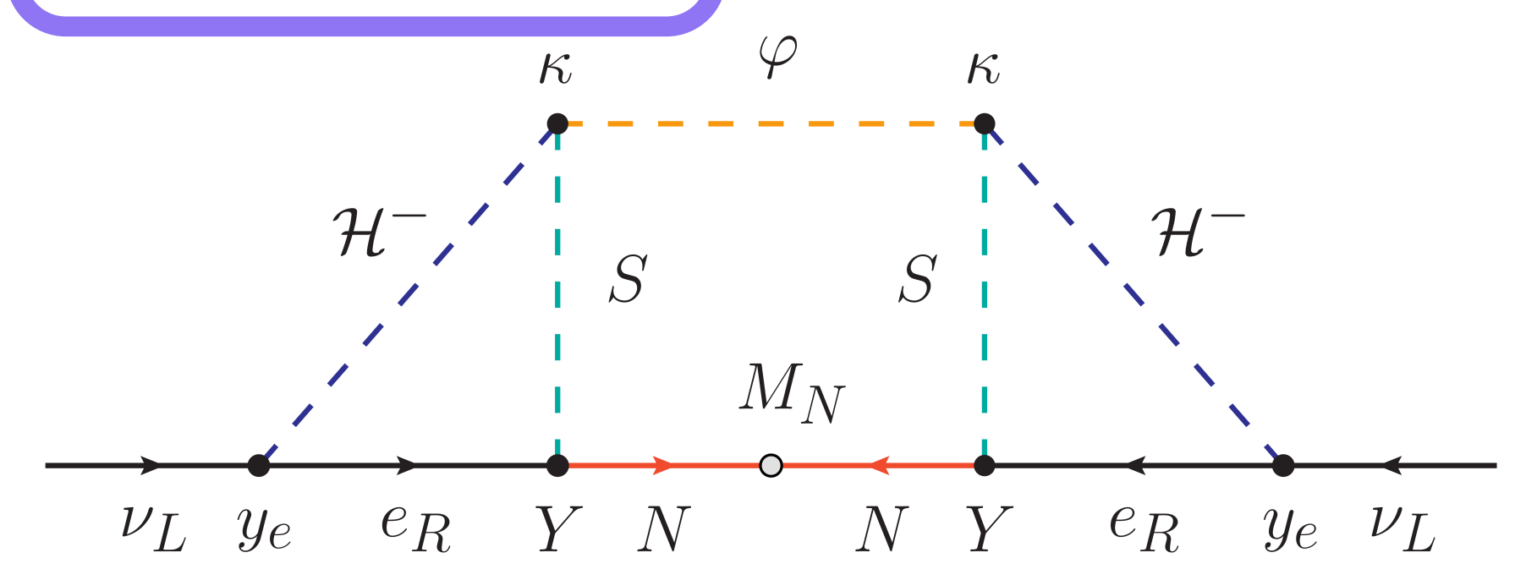
- The most stringent limit comes from $\mu \to e\gamma$, which cannot be 0 due to the antisymmetry of f.
- We maximized f saturating the limit $\mathrm{Br}(\mu \to e\gamma) < 4.2 \times 10^{-13}$ ⇒ minimizes Yukawa g, as given by $\mathcal{M}_\nu$.
- A smaller upper limit on $\mathrm{Br}(\mu \to e\gamma)$ will lead to a larger g ⇒ more stringent constraints from $\tau \to \mu\gamma$.
- Future CLFV searches would put a lower bound on m_S roughly of order 200 GeV (NH) [600 GeV (IH)], stronger for lower values of M_N.

ABSTRACT: We study charged lepton flavor violation for the three most popular three-loop minimal Majorana neutrino mass models. We call these models “minimal” since their particle content correspond to the minimal particle contents for which genuine three-loop models can be constructed. In all the three minimal models the neutrino mass matrix is proportional to some powers of standard model lepton masses, providing additional suppression factors on top of the expected loop suppression. To correctly explain neutrino masses, large Yukawa couplings are needed in these models. We calculate charged lepton flavor violating observables and find that the three minimal models survive the current constraints only in very small regions of their parameter spaces. Only particular choices of the Dirac and Majorana phases survive the current constraints for a narrow range of the lightest neutrino mass.

DISCUSSION:

- In our analysis, scalar couplings of 4π have been allowed. With a more restrictive choice of couplings $\mathcal{O}(1)$, all three models would already be ruled out.
- CLFV alone cannot exclude any of these models, one can always reduce the CLFV rates by tuning the parameters of the model more finely. However, this will slowly push couplings towards a non-perturbative regime, excluding the model.
- Only the KNT model can explain neutrino data for both hierarchies. Neither the cocktail nor the AKS model has acceptable points for inverse hierarchy.
- Since m_{ν_1} and the Majorana phases must be tuned for the models to survive, the effective $0\nu\beta\beta$ neutrino mass m_{ee} becomes strongly constrained and definite predictions for the $0\nu\beta\beta$ rates are obtained for the AKS and KNT models.

AKS MODEL [2]



New particles in the AKS model with respect to the 2HDM (Φ_1, Φ_2)

	generations	$\mathrm{SU}(3)_c$	$\mathrm{SU}(2)_L$	$\mathrm{U}(1)_Y$	$\mathbb{Z}_2$
φ	1	**1**	**1**	0	−
S	1	**1**	**1**	1	−
N	3	**1**	**1**	0	−

Casas-Ibarra parametrization

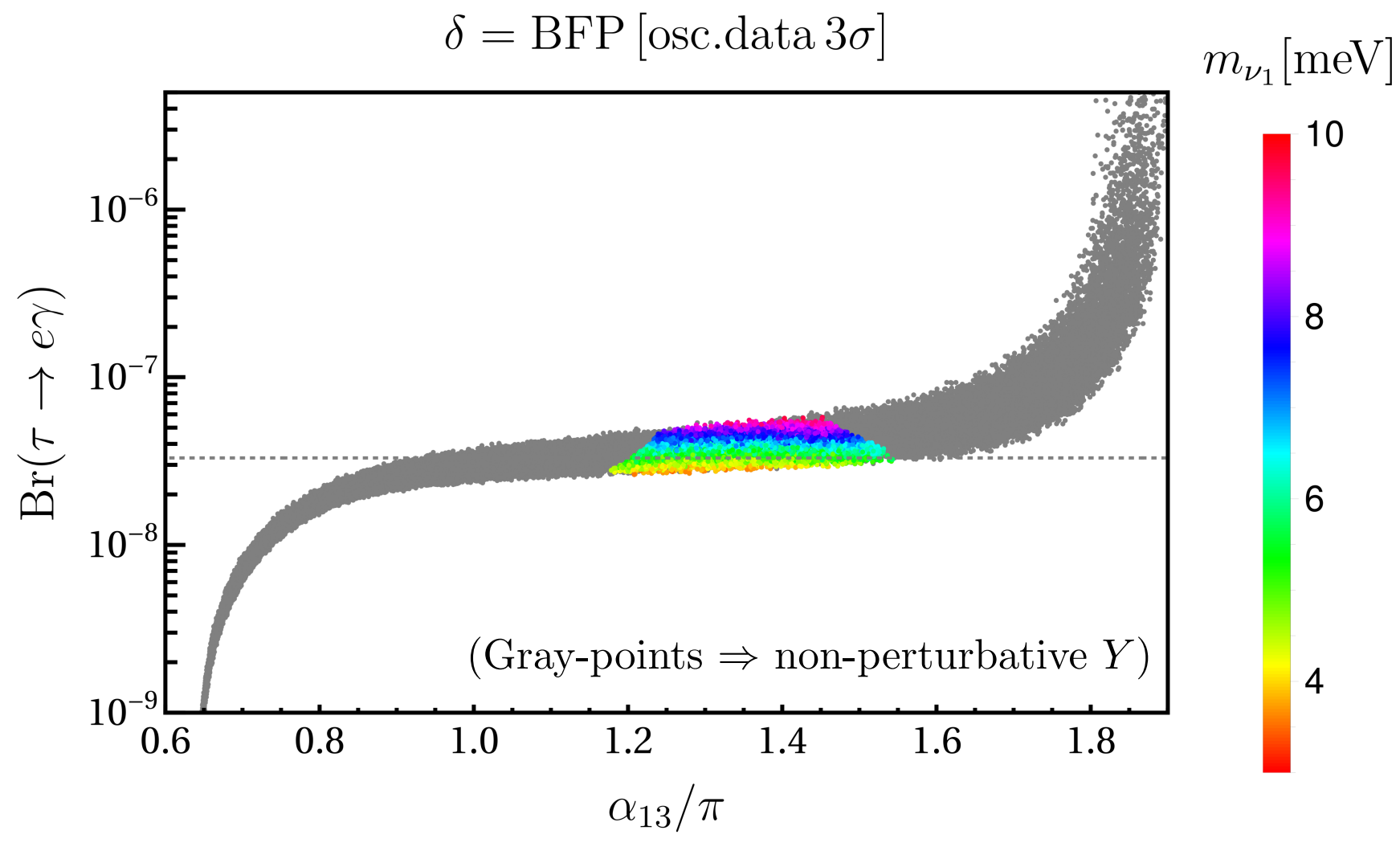
⇑

Neutrino mass: $(\mathcal{M}_\nu)_{ij} = \frac{\kappa^2\, \tan^2\beta}{(16\pi^2)^3} \sum_{\alpha,\beta} \frac{m_i\, Y_{i\alpha} Y_{j\beta}\, m_j}{(M_N)_{\alpha\beta}} F_{\text{loop}}$

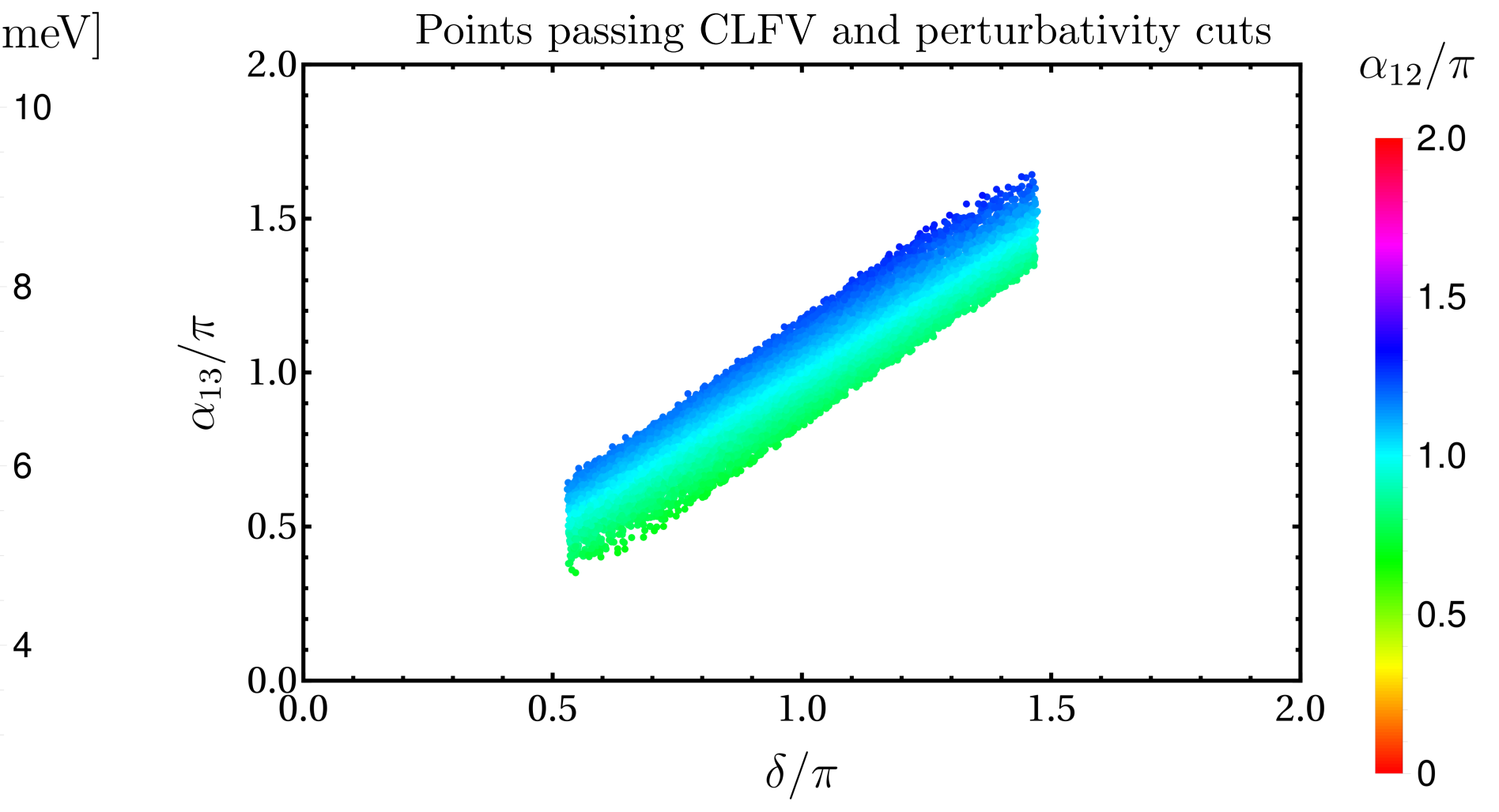
- The most stringent constraints come from $\mu \to e\gamma$ and perturbativity of Y.
- We make $\mathrm{Br}(\mu \to e\gamma) < 4.2 \times 10^{-13}$ with the freedom of the neutrino fit, phases and m_{ν_1} ⇒ fine-tuning.
- All the phases lie between $(\pi/2,\ 3\pi/2)$, while for the lightest neutrino mass, $m_{\nu_1} \sim (4.5-20)$ meV.
- For larger masses the parameter space decreases as F_{loop}/M_N decreases pushing Y towards non-perturbative values.
- Any observation of $0\nu\beta\beta$ decay would definitely rule out the AKS model.

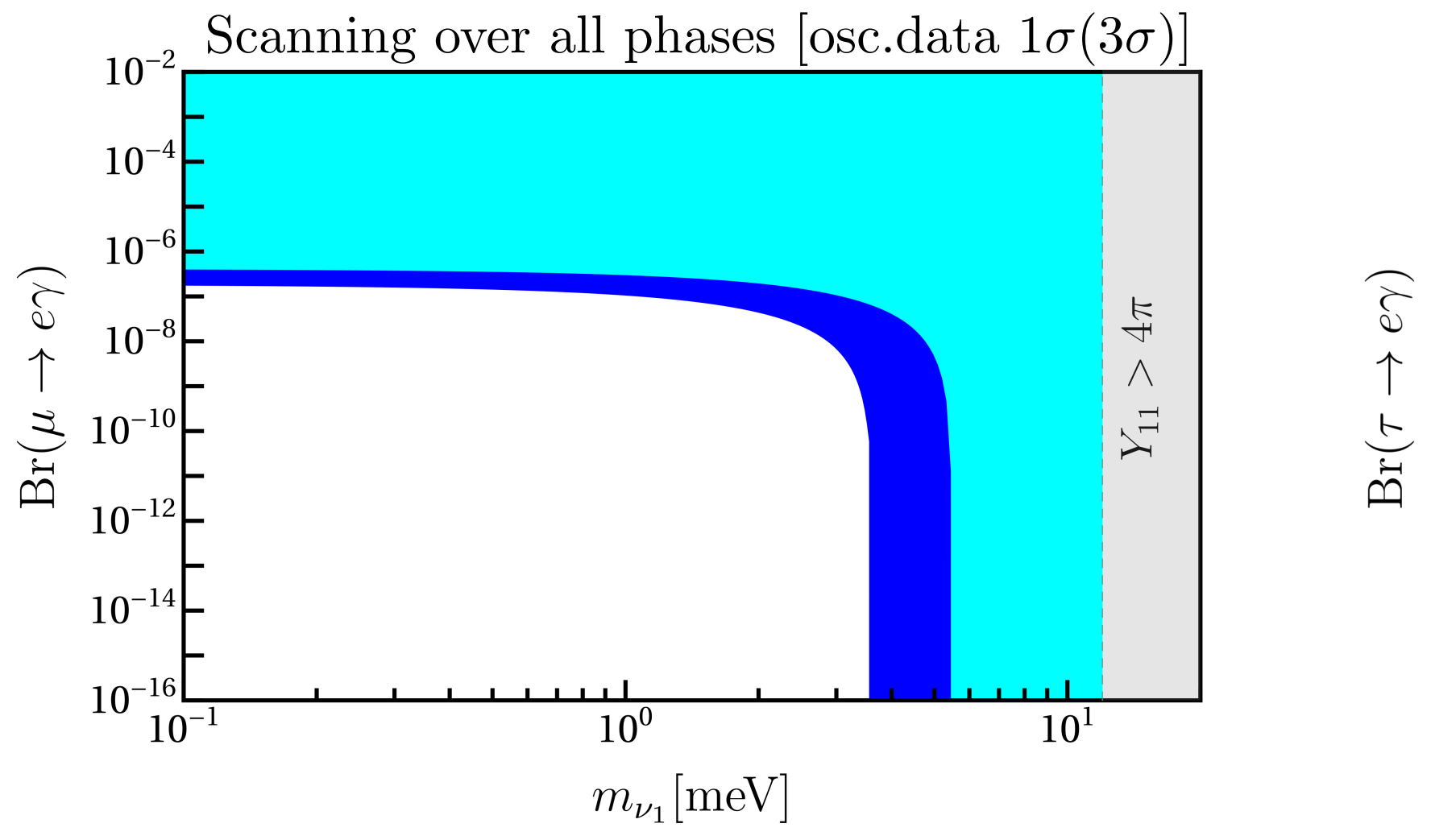
Mass eigenstates: $\mathcal{H}^\pm \to$ mass matrix of $\{\Phi_1^\pm, \Phi_2^\pm\}$.

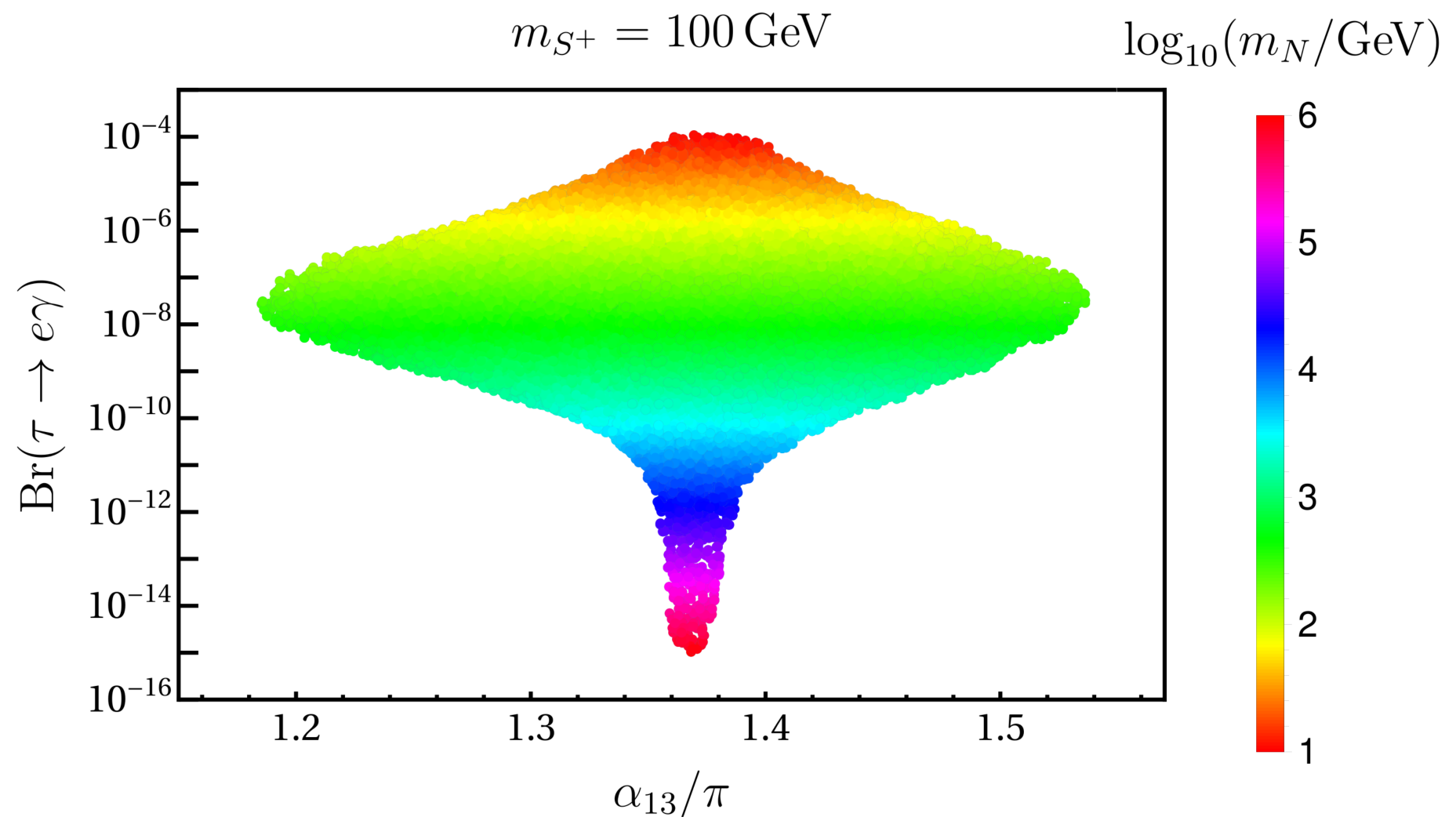
VEVs: $\langle \Phi_i \rangle = v_i$, with the SM VEV $v^2 = v_1^2 + v_2^2$, an the ratio $\tan\beta = v_2/v_1$.



(Gray-points ⇒ non-perturbative Y)







CONCLUSIONS: All the models discussed naturally imply that large Yukawa couplings to reproduce neutrino oscillation data. As a result, perturbativity is typically lost. We showed that one can decrease the Yukawa couplings by tuning some of the free parameters of these scenarios. However, even after these parameters are tuned to recover perturbativity, the resulting CLFV branching ratios tend to largely exceed the existing bounds. In order to reduce the CLFV rates further tuning is needed.

Our main conclusion is that the three models survive only in tiny correlated regions of their parameter spaces.

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[2] Phys.Rev.D67 (2003) 085002
[3] Phys.Rev.Lett. 102 (2009) 051805