Relaxing Cosmological Constraints on the $U(1)_{L_\mu - L_\tau}$ Model with One-Loop Corrections

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Intro: Zeros in neutrino mass matrix

The SM can not explain neutrino mass

- Adding Majorana mass term m_ν
- \# observed parameter $\theta_{12},\ldots <$ # m_ν parameter
- Assuming **some zeros** in m_ν → m_1, m_2, m_3 can be determined

without UV parameters

$$\text{case } B_5: \quad \mathcal{M}_\nu^{-1} \sim \begin{pmatrix} \times & 0 & \times \\ 0 & \times & \times \\ \times & \times & 0 \end{pmatrix},$$

$$\text{case } B_6: \quad \mathcal{M}_\nu^{-1} \sim \begin{pmatrix} \times & \times & 0 \\ \times & 0 & \times \\ 0 & \times & \times \end{pmatrix},$$

$$\text{case } D: \quad \mathcal{M}_\nu^{-1} \sim \begin{pmatrix} \times & \times & \times \\ \times & 0 & \times \\ \times & \times & 0 \end{pmatrix},$$

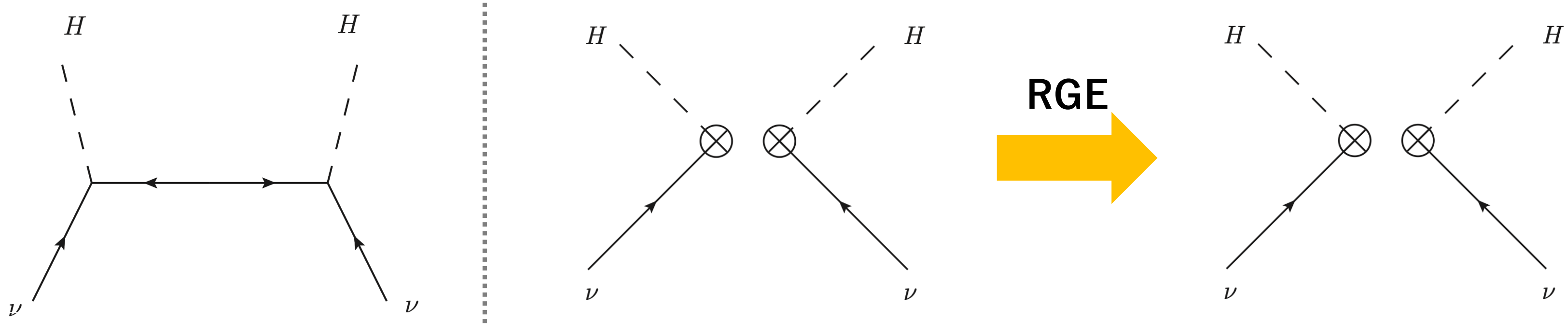
$\boldsymbol{U(1)_{L_\mu - L_\tau}}$ is case D

L. Lavoura 0411232

Intro: Type-I SeeSaw

Adding Right-handed neutrino in the SM

$$\mathcal{M}_\nu^{-1} \sim \begin{pmatrix} \times & \times & \times \\ \times & 0 & \times \\ \times & \times & 0 \end{pmatrix}$$



RGE(SM) keeps zero minors

$-\kappa_\ell \, L_\ell \tilde{H} \, \bar{N}_\ell$ $\quad$ $C_{\ell\ell'}(L_\ell \tilde{H})(L_{\ell'} \tilde{H})$ $\quad$ $C_{\ell\ell'}(L_\ell \tilde{H})(L_{\ell'} \tilde{H})$

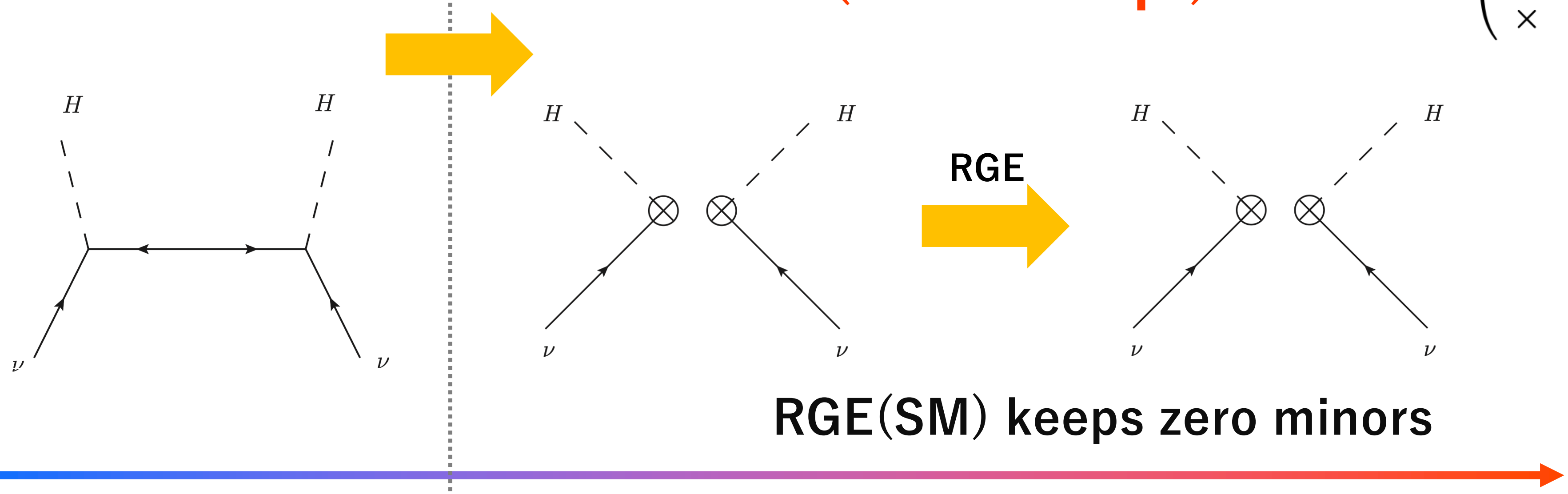
$\sim 10^{14}$GeV

After EW SSB turns to Majorana mass

$\sim 10^{2}$GeV

Intro: Type-I SeeSaw

How about Threshold Effect (One Loop) ? $\mathcal{M}_\nu^{-1} \sim \begin{pmatrix} \times & \times & \times \\ \times & 0 & \times \\ \times & \times & 0 \end{pmatrix}$



$-\kappa_\ell \, L_\ell \tilde{H} \, \bar{N}_\ell$ $\quad C_{\ell\ell'}(L_\ell \tilde{H})(L_{\ell'} \tilde{H})$ $\quad C_{\ell\ell'}(L_\ell \tilde{H})(L_{\ell'} \tilde{H})$

$\sim 10^{14}\mathrm{GeV}$

Our Result

1. **Threshold Effects (SM one loop) generally breaks minor structure; this is not specific to $U(1)_{L_\mu - L_\tau}$**

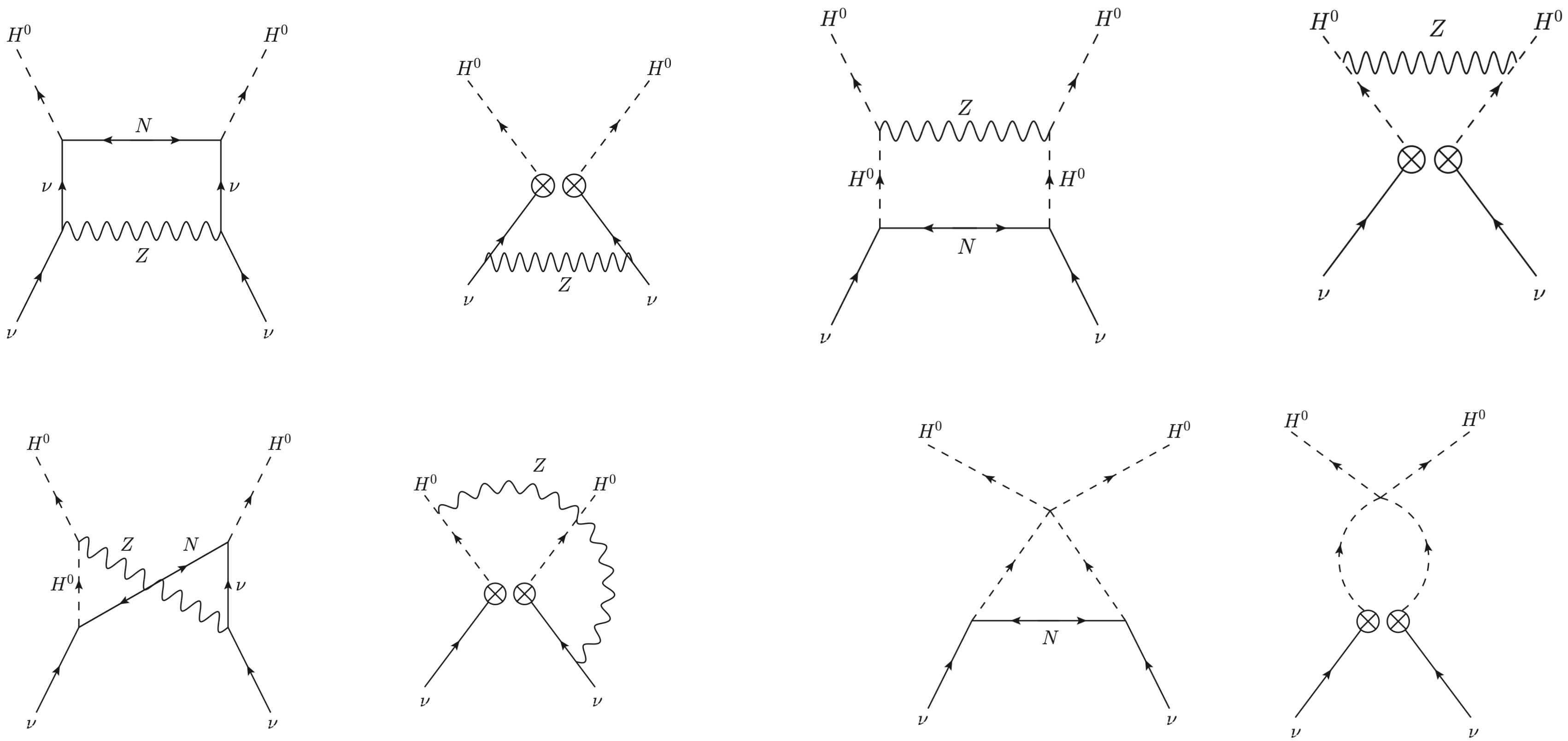
2. **Additional BSM correction can also break the minor structure in $U(1)_{L_\mu - L_\tau}$**

Part I

1. Threshold effects (SM one loop) breaks minor structure

One loop matching of Wilson coefficient
of Weinberg Operator

Diagrams



H^0 H^0 N ν ν Z ν ν
H^0 H^0 Z ν ν
H^0 H^0 Z H^0 H^0 N ν ν
H^0 Z H^0 ν ν
H^0 H^0 Z N H^0 ν ν ν
H^0 Z H^0 ν ν
H^0 H^0 N ν ν
H^0 H^0 ν ν

Results

$$\mathcal{L} = \mathcal{L}_{\rm SM} + i\, N_\ell^\dagger \bar{\sigma}^\mu \partial_\mu N_\ell$$
$$- \kappa_\ell\, L_\ell \tilde{H}\, \bar{N}_\ell - \frac{1}{2} M_{\ell\ell'}\, N_\ell N_{\ell'} + \text{h.c.}$$

Type-I seesaw

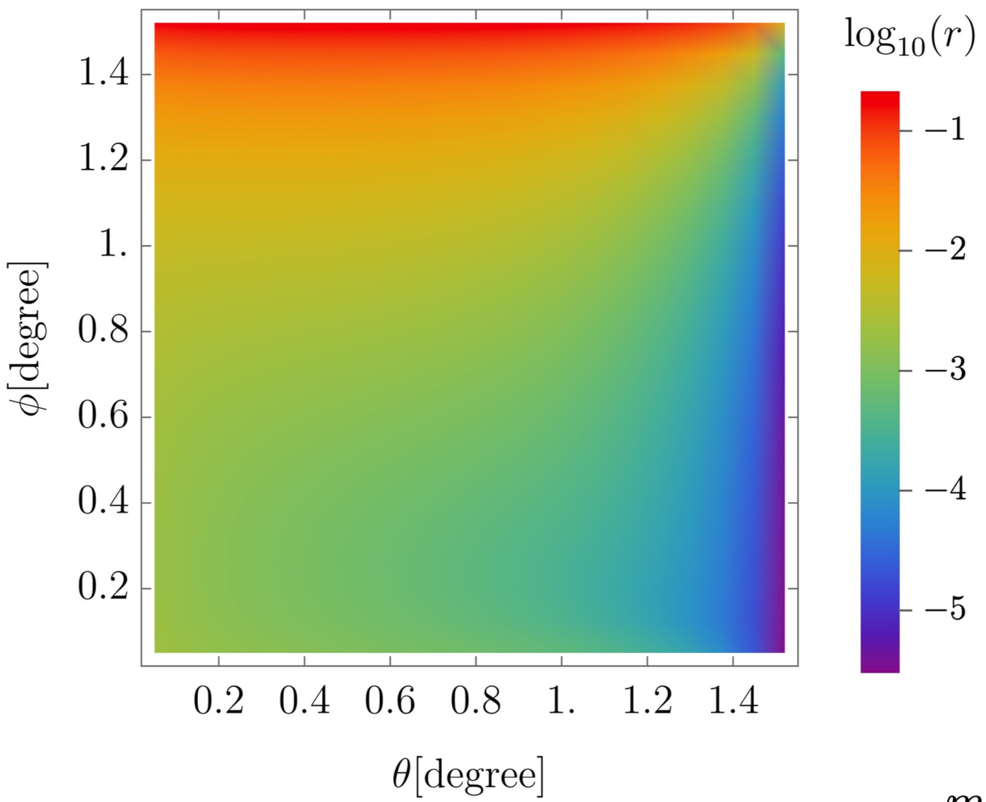
$$\mathcal{L}_{\rm EFT} = \mathcal{L}_{\rm SM} + C_{\ell\ell'} (L_\ell \tilde{H})(L_{\ell'} \tilde{H}) \qquad C^{\rm tree} = Y^D \frac{1}{\hat{M}} (Y^D)^T = \kappa M^{-1} \kappa^T$$

$$C(\mu_{\rm UV}^2)^{\rm one-loop}$$
$$= \frac{m_Z^2}{16\pi^2 v_{\rm EW}^2} Y^D \frac{1}{\hat{M}} \left(-3 \ln \frac{\hat{M}^2}{\mu_{\rm UV}^2} + 1 \right) (Y^D)^T$$
$$+ \frac{m_h^2}{16\pi^2 v_{\rm EW}^2} Y^D \frac{1}{\hat{M}} \left(- \ln \frac{\hat{M}^2}{\mu_{\rm UV}^2} + 1 \right) (Y^D)^T$$

At NLO, there is no need of Right-handed neutrino mass M!!

Breaking down of minors

$r = (C^{-1})_{\mu\mu}/(C^{-1})_{ee}$



$r = 0$, if minor is hold

$$(\kappa_e, \kappa_\mu, \kappa_\tau) = \kappa(\cos\theta, \sin\theta\cos\phi, \sin\theta\sin\phi)$$

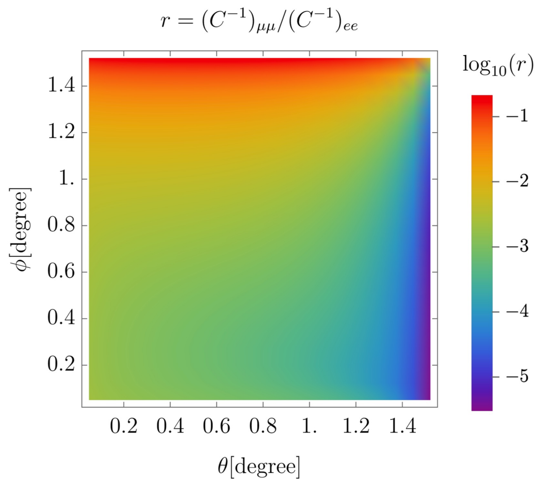
$$m_\nu = -v_{\rm EW}^2 Y^D \hat{M}^{-1}(Y^D)^T - v_{\rm EW}^2 C(v_{\rm EW}^2; \hat{M})^{\rm one-loop}$$

Short summary I

Zero minors are broken by SM One Loop Threshold Effects

The deviation can be evaluated by Yukawa couplings as new parameter (No need of RH neutrino mass)

The correlation with Leptogenesis may be interesting



$$C(\mu_{\rm UV}^2)^{\rm one-loop} = \frac{m_Z^2}{16\pi^2 v_{\rm EW}^2} Y^D \frac{1}{\hat{M}} \left(-3\ln\frac{\hat{M}^2}{\mu_{\rm UV}^2} + 1\right) (Y^D)^T + \frac{m_h^2}{16\pi^2 v_{\rm EW}^2} Y^D \frac{1}{\hat{M}} \left(-\ln\frac{\hat{M}^2}{\mu_{\rm UV}^2} + 1\right) (Y^D)^T$$

Part II

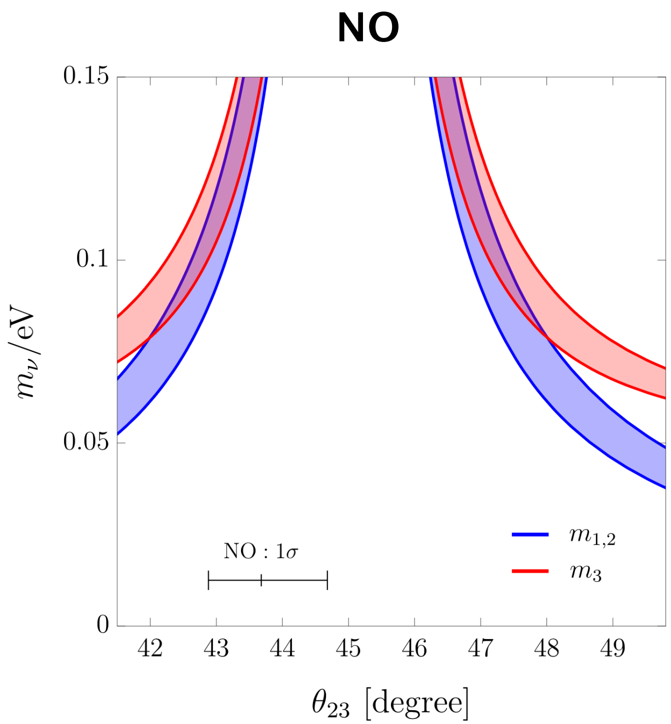
2. Additional BSM correction also breaks in $U(1)_{L_\mu - L_\tau}$

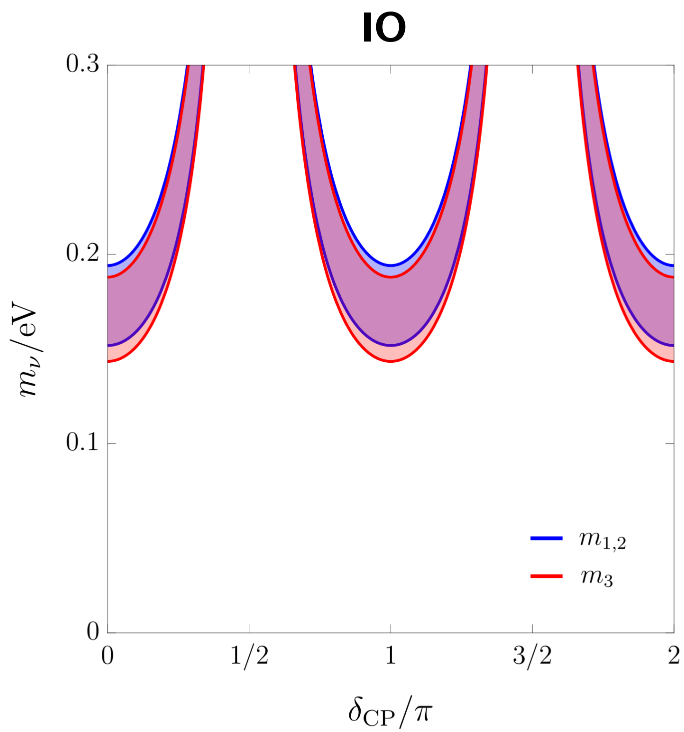
SM couplings are small

So, BSM loop contribution is important!!

(Much more diagrams contribute)

Motivation





But…

$\boldsymbol{U(1)_{L_\mu - L_\tau}}$ **$\sum m_\nu$ at least ~ 0.3 eV, Latest cosmology bound $\sum m_\nu$ < 0.2 eV**

Modification of two-zero minor

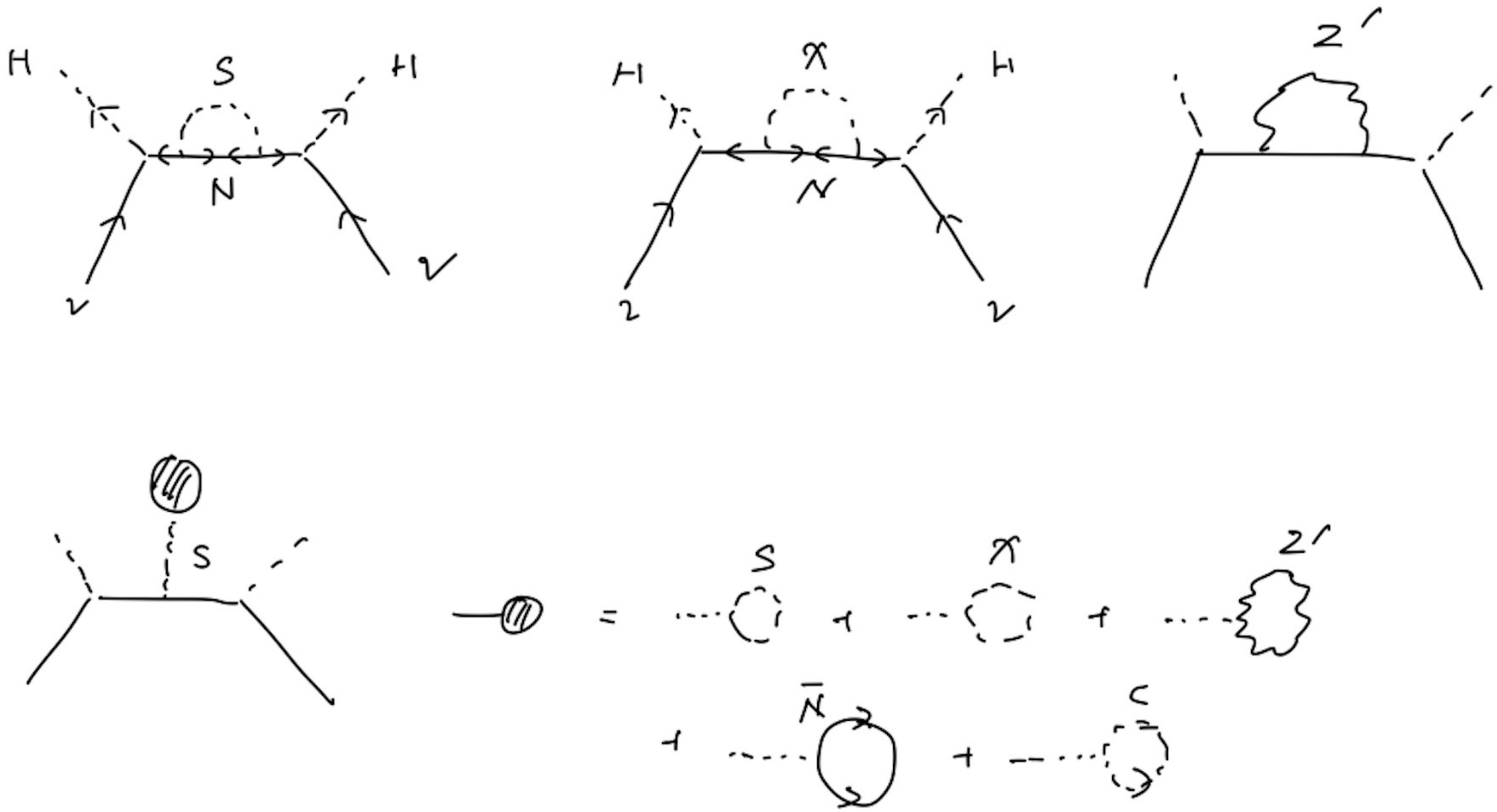
$$U_{\mu 1}^2 + \frac{U_{\mu 2}^2}{r_{21}} + \frac{U_{\mu 3}^2}{r_{31}} = 0,$$
$$U_{\tau 1}^2 + \frac{U_{\tau 2}^2}{r_{21}} + \frac{U_{\tau 3}^2}{r_{31}} = 0.$$

$$m_\nu^{-1} = -m_D^{T-1}(M + \Delta M)\, m_D^{-1}$$

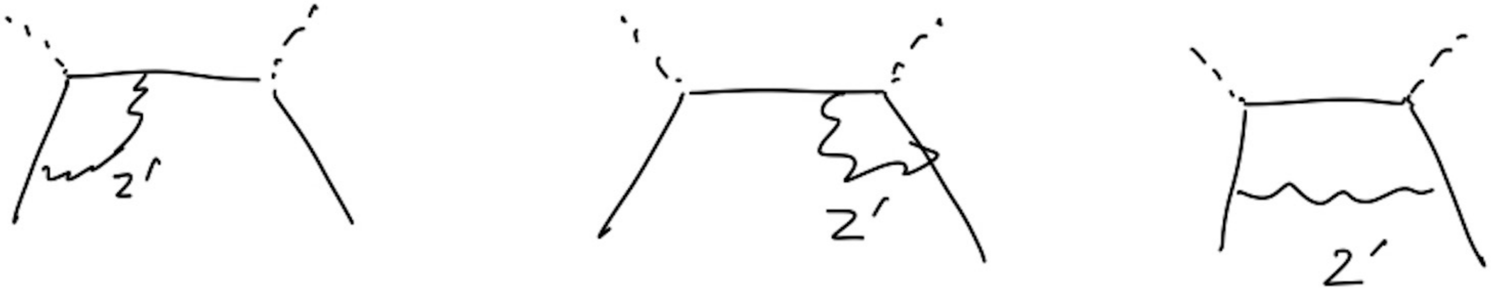
modified radiatively

$$U_{\mu 1}^2 + \frac{U_{\mu 2}^2}{r_{21}} + \frac{U_{\mu 3}^2}{r_{31}} = \epsilon e^{2i\eta_1},$$
$$U_{\tau 1}^2 + \frac{U_{\tau 2}^2}{r_{21}} + \frac{U_{\tau 3}^2}{r_{31}} = \epsilon' e^{2i\eta_1},$$

Diagrams



Diagrams



Z' : $U(1)_{L_\mu - L_\tau}$ gauge boson

$$\phi = \frac{1}{\sqrt{2}}\left(v_{\mu-\tau} + s + i\chi\right)$$

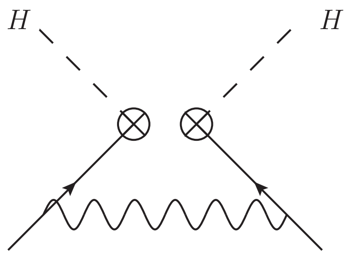
Results ΔM_{22} and ΔM_{33}

$$\begin{pmatrix} 0 & M_{e\mu} & M_{e\tau} \\ M_{e\mu} & 0 & 0 \\ M_{e\tau} & 0 & 0 \end{pmatrix} U_R \left(\frac{m_s^2}{m_{Z'}^2} \frac{\hat{M}}{\hat{M}^2 - m_s^2} \ln \frac{\hat{M}^2}{m_s^2} \right) U_R^T \begin{pmatrix} 0 & M_{e\mu} & M_{e\tau} \\ M_{e\mu} & 0 & 0 \\ M_{e\tau} & 0 & 0 \end{pmatrix}$$

$$+ 3 \begin{pmatrix} 0 & M_{e\mu} & -M_{e\tau} \\ M_{e\mu} & 0 & 0 \\ -M_{e\tau} & 0 & 0 \end{pmatrix} U_R \left(\frac{\hat{M}}{\hat{M}^2 - m_{Z'}^2} \ln \frac{\hat{M}^2}{m_{Z'}^2} \right) U_R^T \begin{pmatrix} 0 & M_{e\mu} & -M_{e\tau} \\ M_{e\mu} & 0 & 0 \\ -M_{e\tau} & 0 & 0 \end{pmatrix}$$

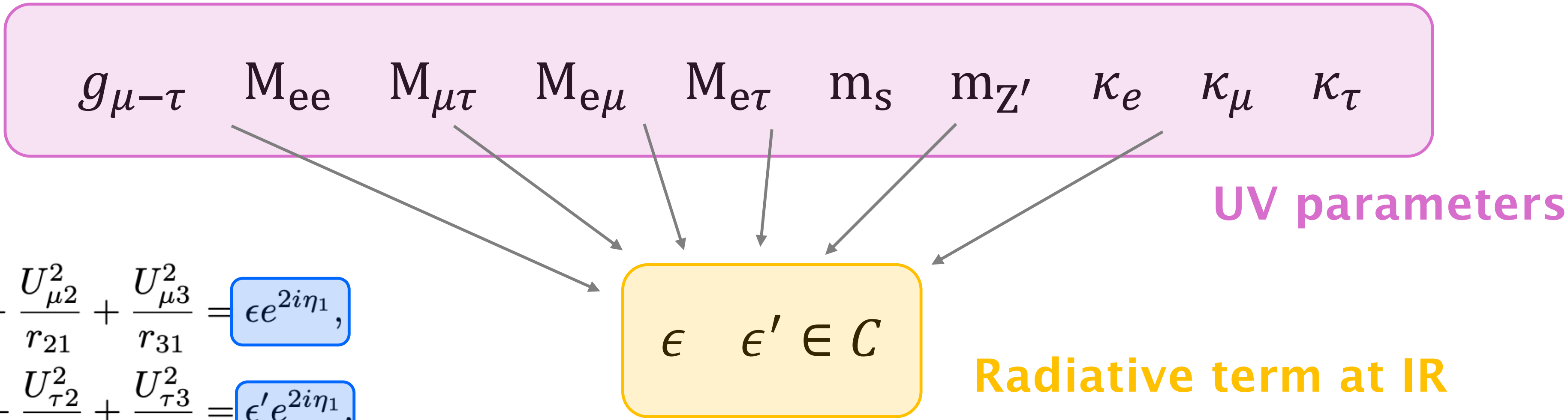
Renormalization scale μ free, No gauge dependence ξ

Second term also arises from EFT side !!



$$U_R^T M U_R = \hat{M} = \mathrm{diag}(M_1,\, M_2,\, M_3)$$

UV parameters degeneration



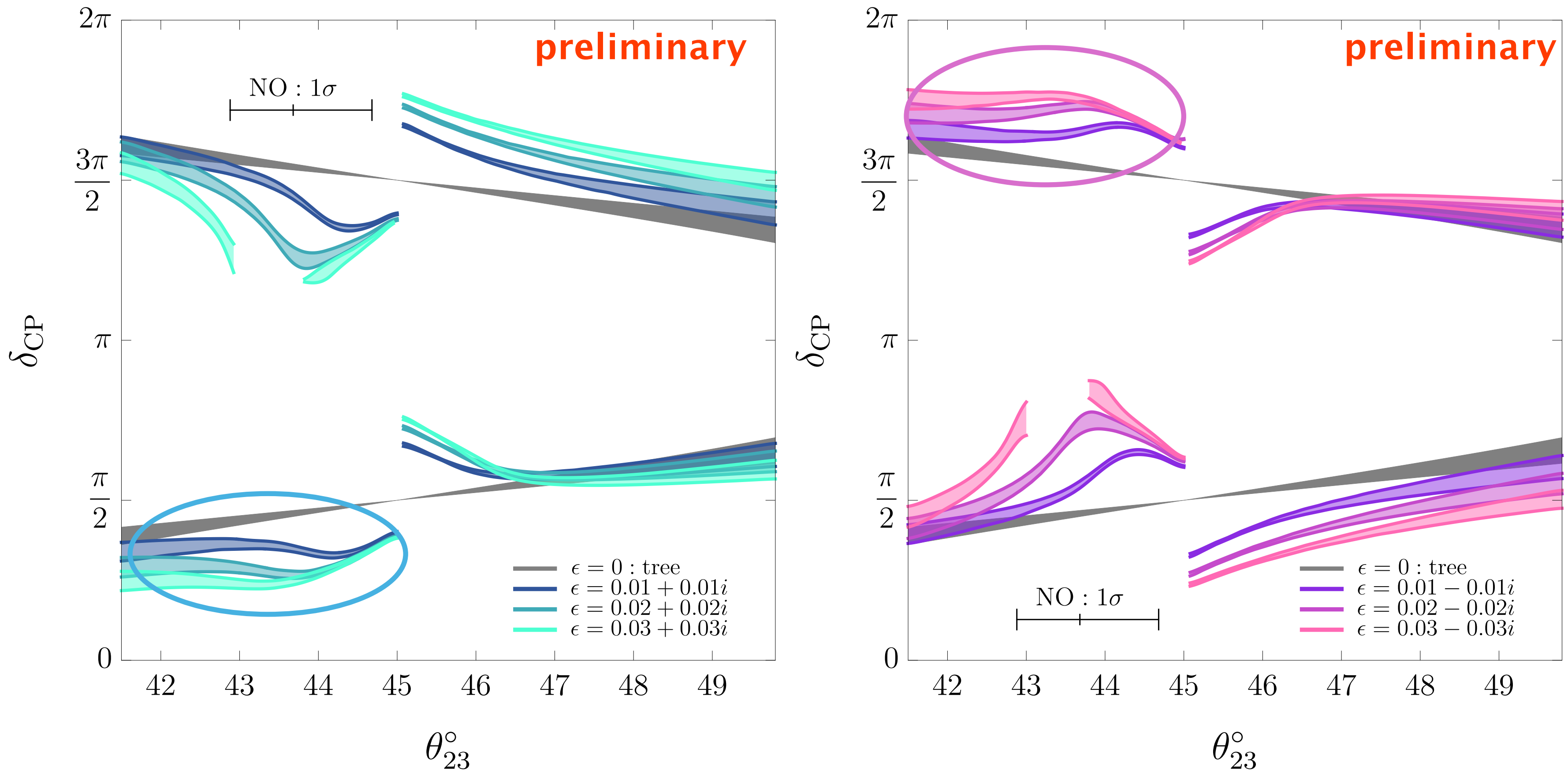
$$U_{\mu 1}^2 + \frac{U_{\mu 2}^2}{r_{21}} + \frac{U_{\mu 3}^2}{r_{31}} = \epsilon e^{2i\eta_1},$$

$$U_{\tau 1}^2 + \frac{U_{\tau 2}^2}{r_{21}} + \frac{U_{\tau 3}^2}{r_{31}} = \epsilon' e^{2i\eta_1},$$

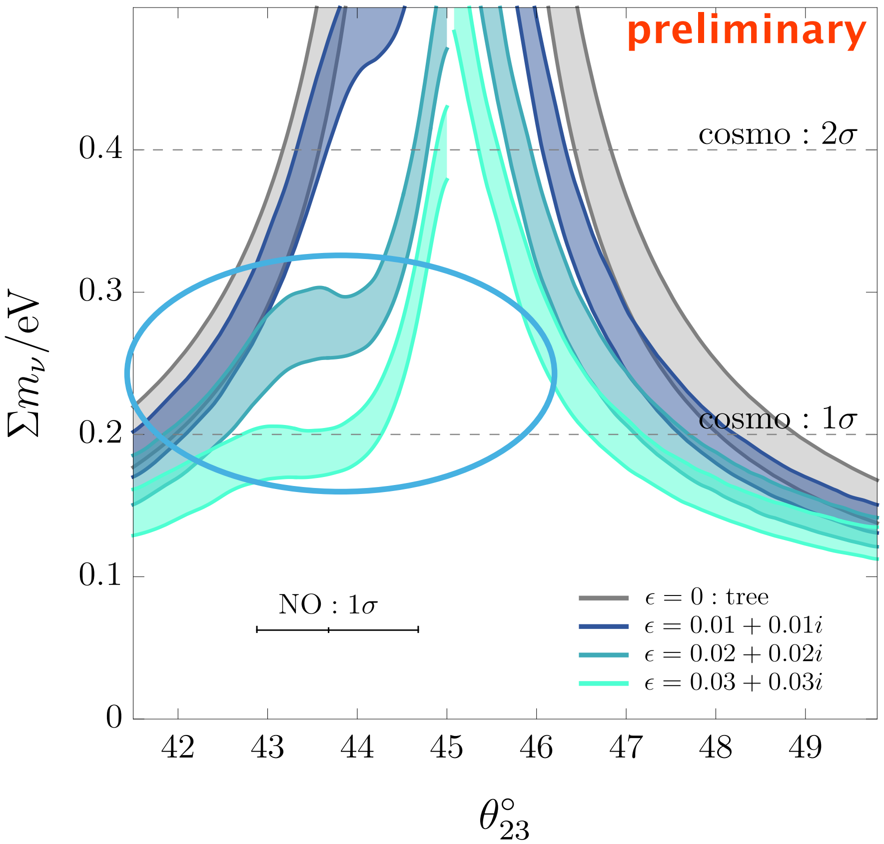
ϵ/ϵ' is determined only IR observables θ_{23} etc.

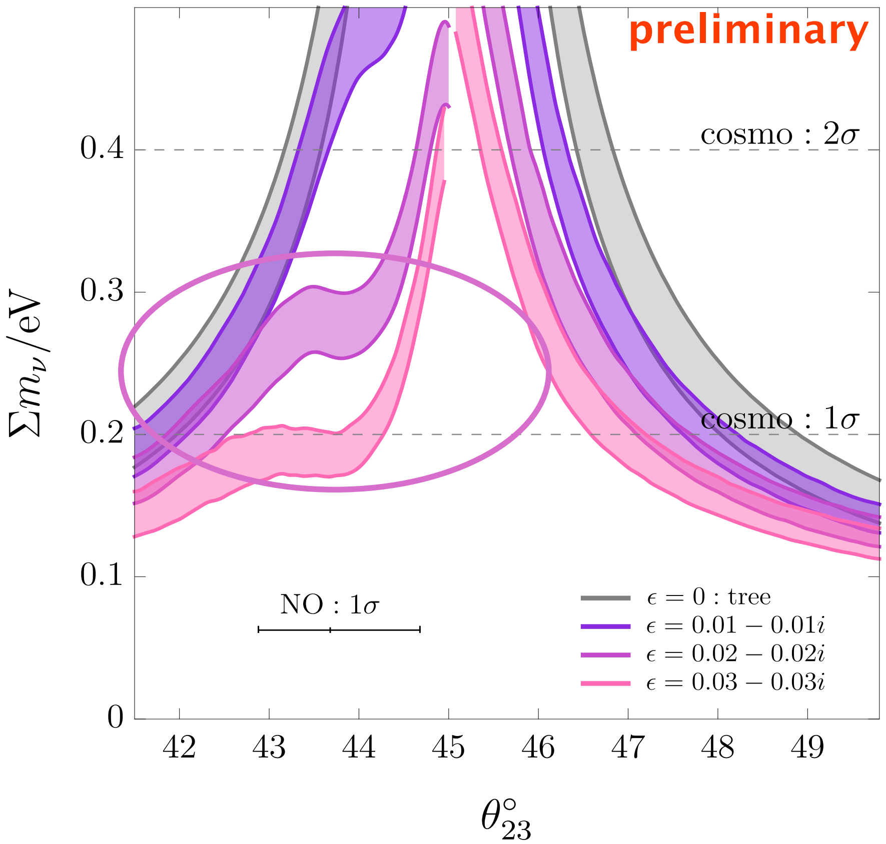
Test using ϵ as 2 parameters UV parameters independently

UV parameters independent predictions I



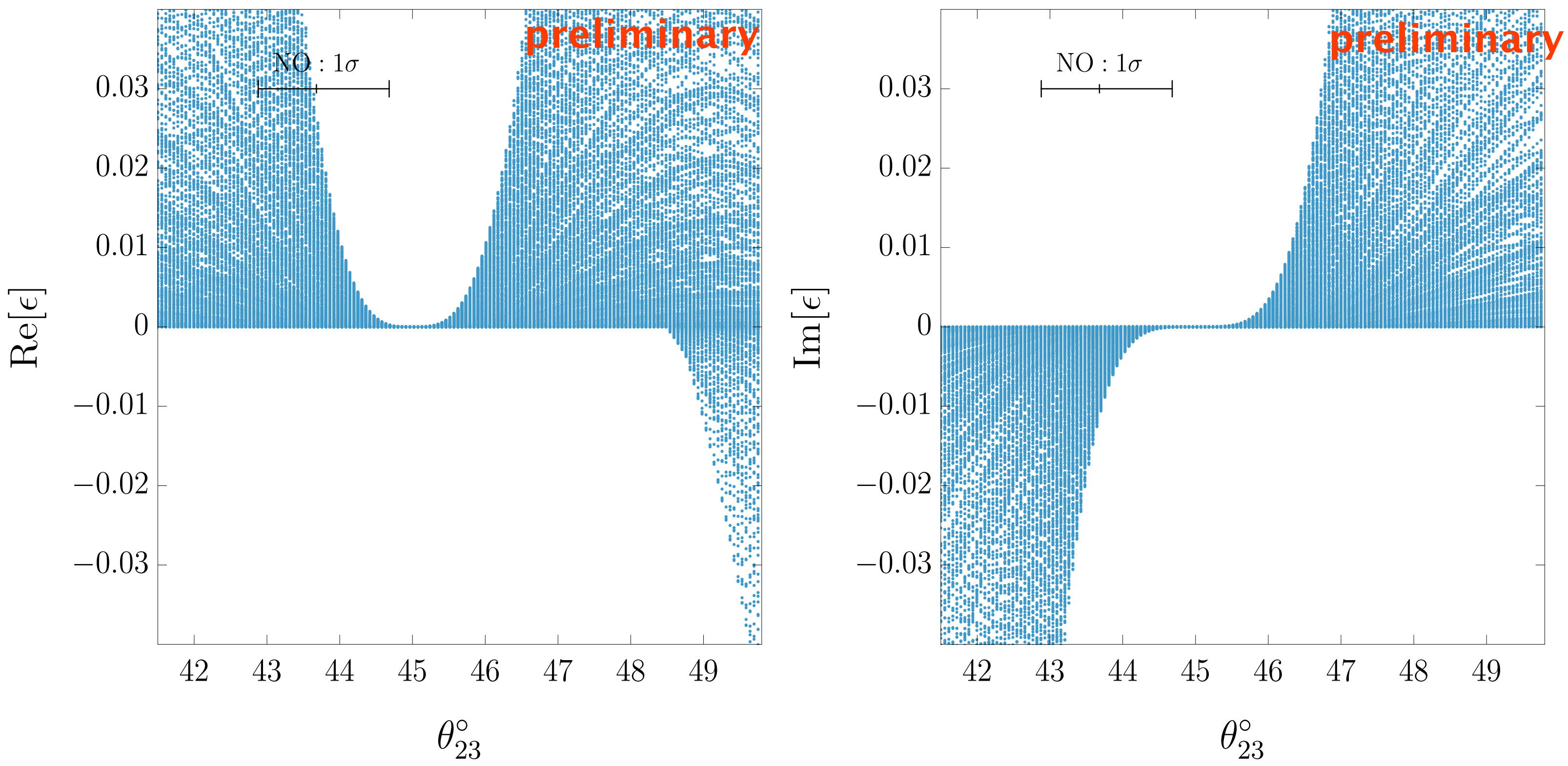
UV parameters independent predictions II





UV parameters $\Longrightarrow \epsilon$

Taking $g_{\mu-\tau} = 1, \ \lambda = 1$



Conclusion and messages

- Threshold corrections can break zero minor even if SM loop contribution
- The impact might be not negligible (but loop suppressed)
- All UV parameters are not needed at NLO because of zero minor holds at LO
- Correlation with Leptogenesis may be interesting since Yukawa couplings are sensitive to the NLO prediction.