UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

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One-Loop Effects in Low-Scale Seesaw

arXiv:2604.06345

(Miele, Morisi, Peinado, Qamar)

Presenter : Kainat Qamar

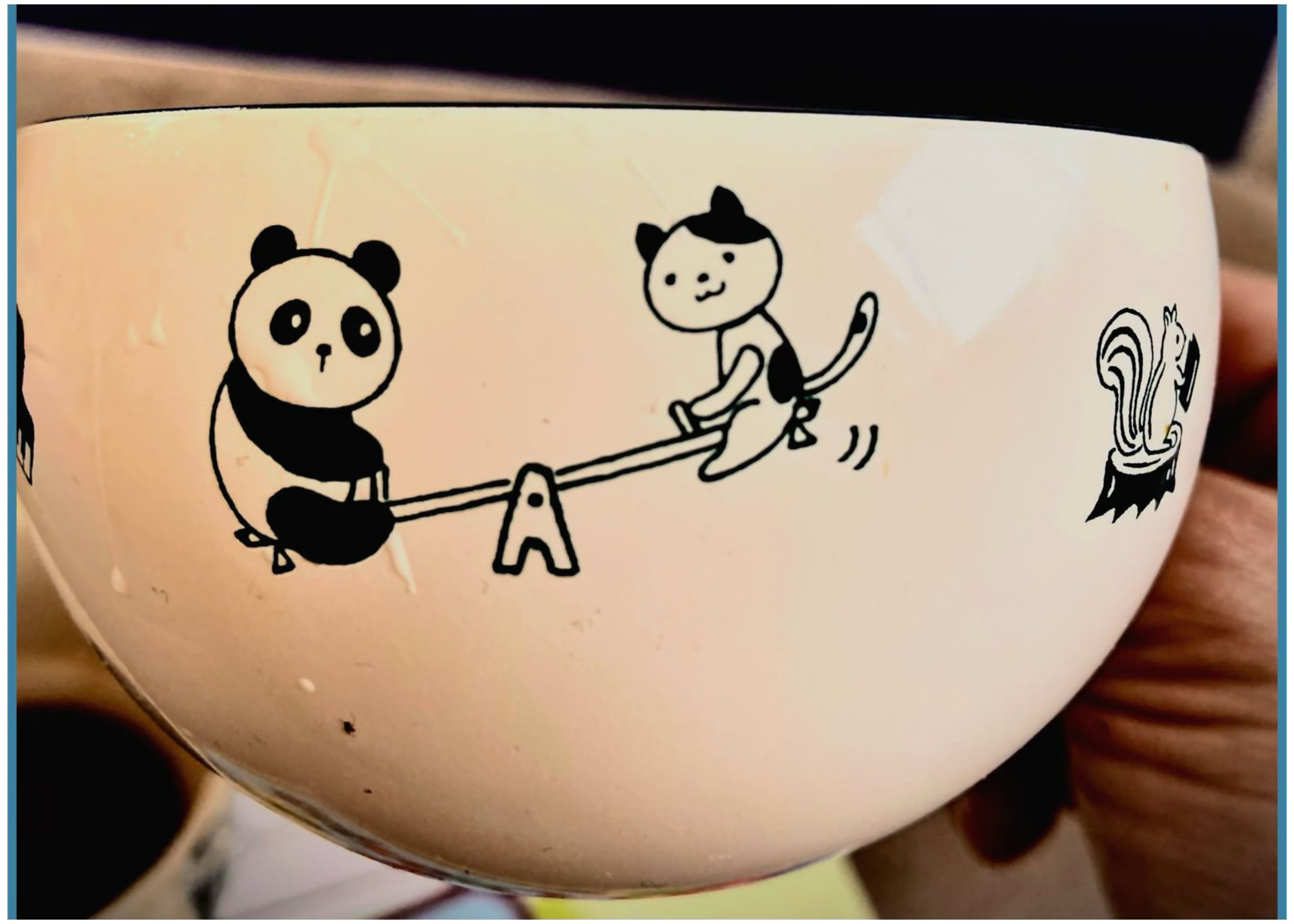
Introduction

- Low-scale Type-I Seesaw viability via radiative stability of m_ν
- 1-loop self-energy & Casas-Ibarra Parametrization
- Prediction of the $Br(\mu \to e\gamma)$ and constraint

Type-1 Seesaw Model

$$\mathscr{L}_{\text{mass}} = -\frac{1}{2}\begin{pmatrix}\overline{\nu_L} & \overline{N_R^c}\end{pmatrix}\begin{pmatrix}0 & M_D \\ M_D^T & M_R\end{pmatrix}\begin{pmatrix}\nu_L^c \\ N_R\end{pmatrix} + \text{h.c.}$$

$$M_{tot} = \begin{pmatrix}0 & M_D \\ M_D^T & M_R\end{pmatrix}$$



THRESHOLD !

under seesaw assumption $\boxed{M_D \ll M_R}$

$$\boxed{m_\nu^{(0)} = -M_D M_R^{-1} M_D^T}$$

Casas-Ibarra Parametrization

$$M_D = i\, U_{PMNS} \sqrt{m_\nu}\, R^T \sqrt{M_R}$$

$$R = \begin{pmatrix} c_2 c_3 & -c_1 s_3 - s_1 s_2 c_3 & s_1 s_3 - c_1 s_2 c_3 \\ c_2 s_3 & c_1 c_3 - s_1 s_2 s_3 & -s_1 c_3 - c_1 s_2 s_3 \\ s_2 & s_1 c_2 & c_1 c_2 \end{pmatrix},$$

$$c_i = \cos\theta_i, \qquad s_i = \sin\theta_i, \qquad \theta_i = x_i + i y_i, \qquad i = 1,2,3$$

$$\cosh y_i,\ \sinh y_i \sim \frac{e^{y_i}}{2}$$

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$$U_{PMNS}^{T}\, m_{\nu}^{(0)}\, U_{PMNS} = m_{\nu}^{(\mathrm{diag})}$$

$$R_{ij} \sim e^{\pm \mathrm{Im}(\theta_k)}$$

Entries Cancellation

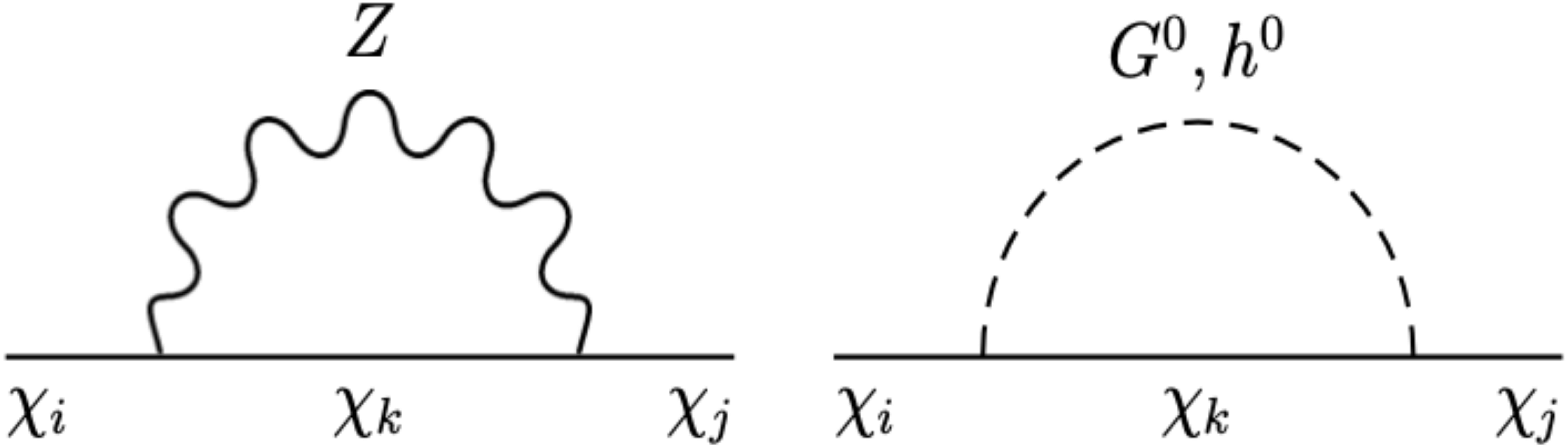
$$m_{\nu}^{(\mathrm{diag})} = \begin{pmatrix} m_1 & 0 & 0 \\ 0 & \sqrt{m_1^2 + \Delta m_{sol}^2} & 0 \\ 0 & 0 & \sqrt{m_1^2 + \Delta m_{atm}^2} \end{pmatrix}$$

$$U_{\mathrm{PMNS}} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \cdot \mathrm{diag}(e^{-i\alpha_1}, e^{-i\alpha_2}, 1)$$

1-loop correction

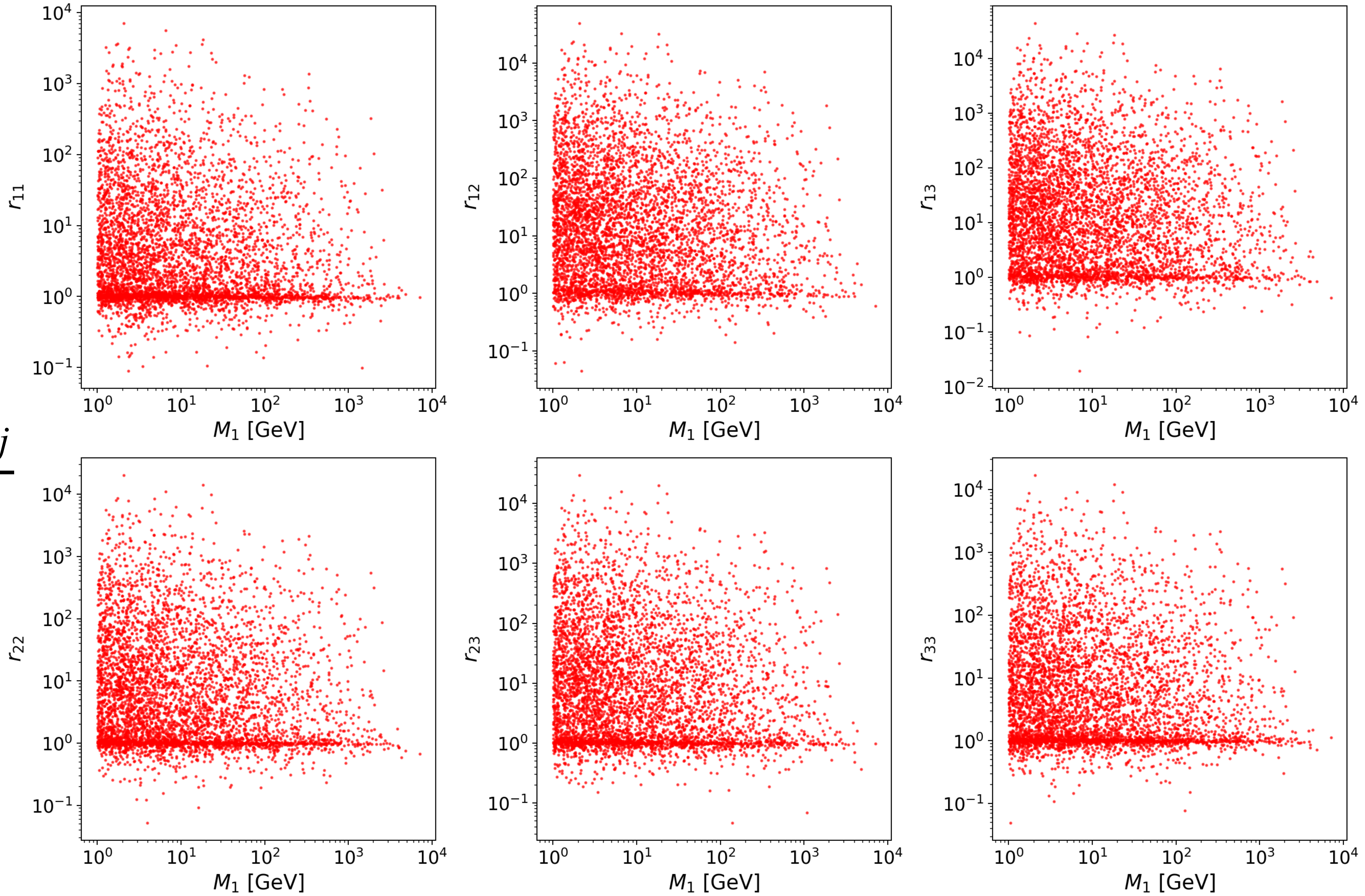
$$\delta M = M_D^T\ M_R^{-1}\ \Sigma_1 M_D = m_\nu^{(1)}$$

$$\Sigma_1 = \frac{g^2}{64\pi^2 M_W^2}\left[m_H^2\ \ln\!\left(\frac{M_R^2}{m_H^2}\right)\ +\ 3\,m_Z^2\ \ln\!\left(\frac{M_R^2}{m_Z^2}\right)\right].$$



W. Grimus and L. Lavoura , 2002

$$r_{ij} \equiv \frac{(m_\nu^{(0)} + m_\nu^{(1)})_{ij}}{(m_\nu^{(0)})_{ij}}$$



Reproduced Result of Aristizabal & Yaguna, 2011

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Usual Type-1 Seesaw

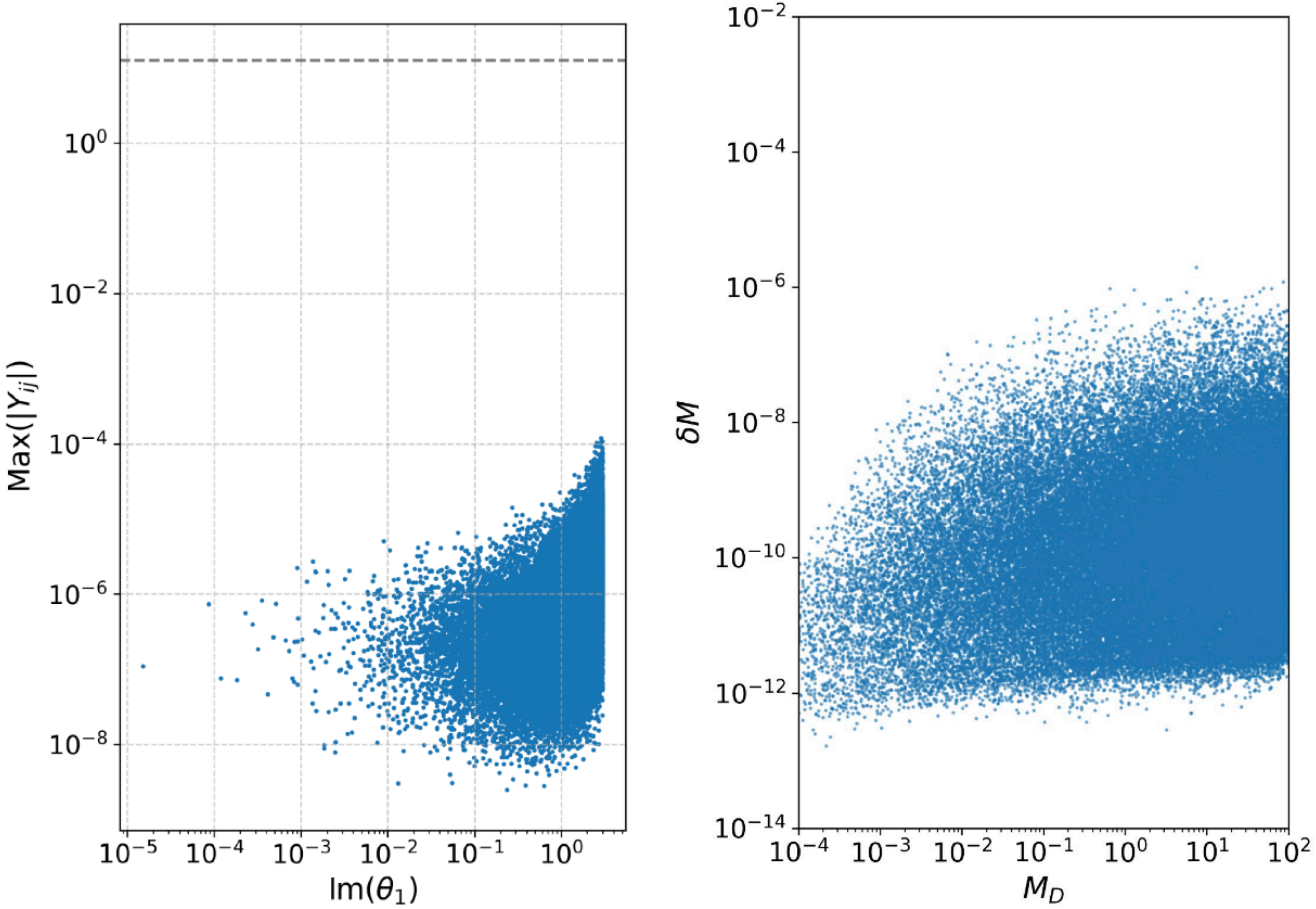
$$m_\nu^{(0)} = -M_D M_R^{-1} M_D^T \;\Rightarrow\; M_D = Y\frac{V}{\sqrt{2}} \;\Rightarrow\; m_\nu \simeq \frac{Y_\nu^2 v^2}{M_R}$$

$$m_\nu \simeq 0.05\ \text{eV}, \qquad V = 246\ GeV$$

$$M_R = 10^{15}\ \text{GeV} \;\Rightarrow\; Y_\nu \sim 1$$

$$M_R = 1\ \text{GeV} \;\Rightarrow\; Y_\nu \sim 10^{-8}$$

Case 1: $z_1 = z_2 = z_3 = 3$



$z_i \equiv \left| \max\left(\mathrm{Im}(\theta_i)\right) \right|$

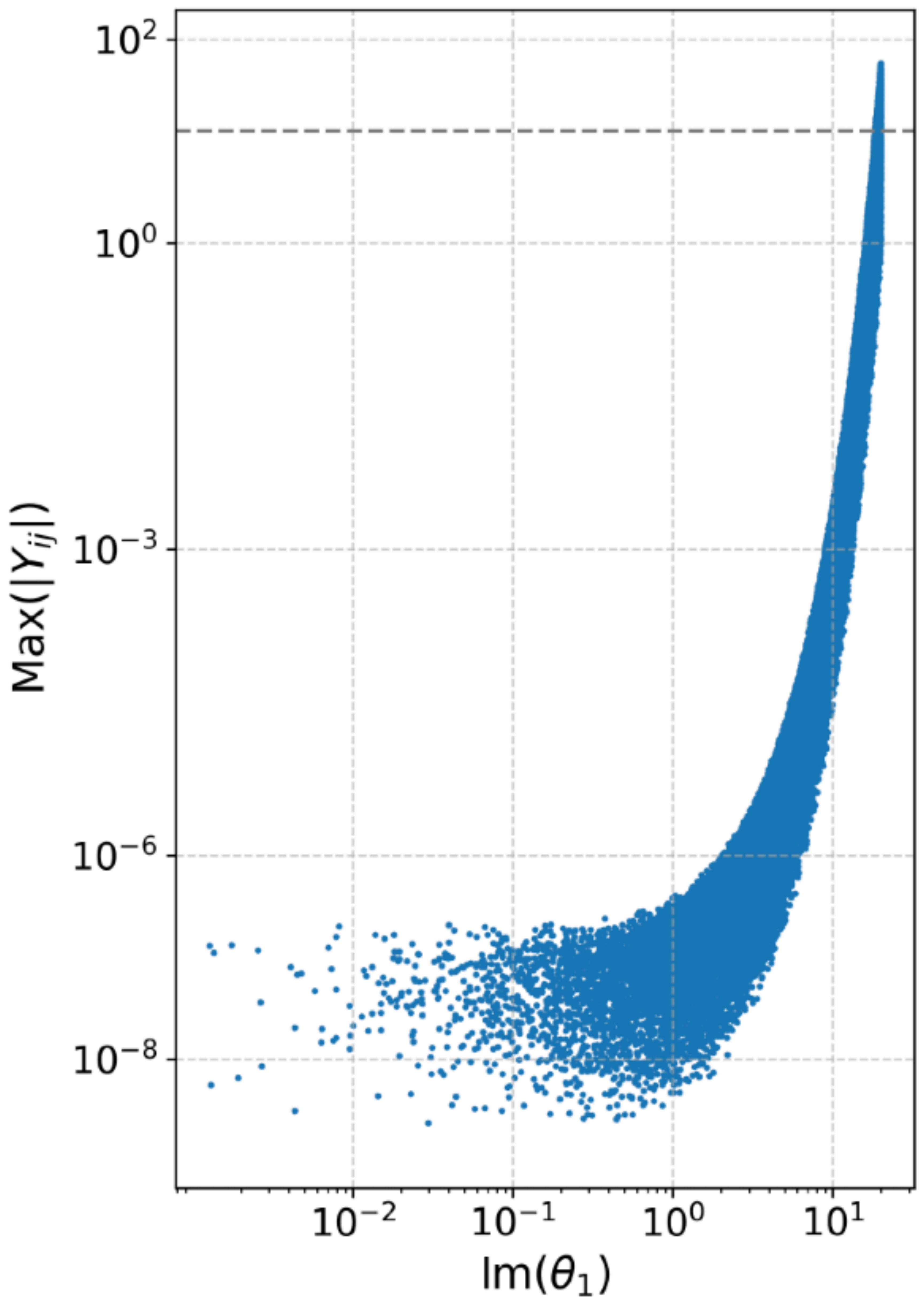
$$M_D = Y \frac{V}{\sqrt{2}}$$

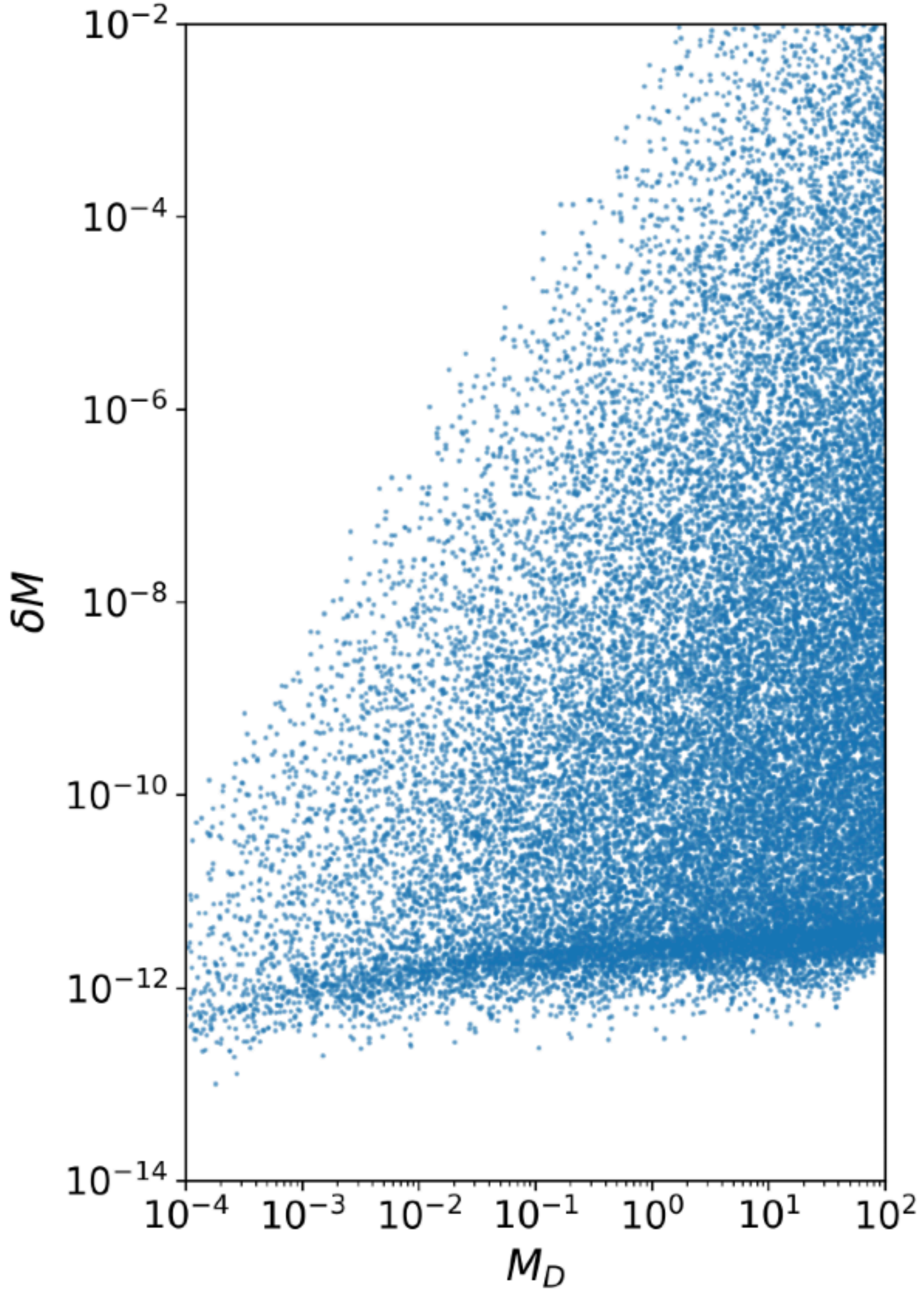
$$R \propto e^{Im(\theta)}$$

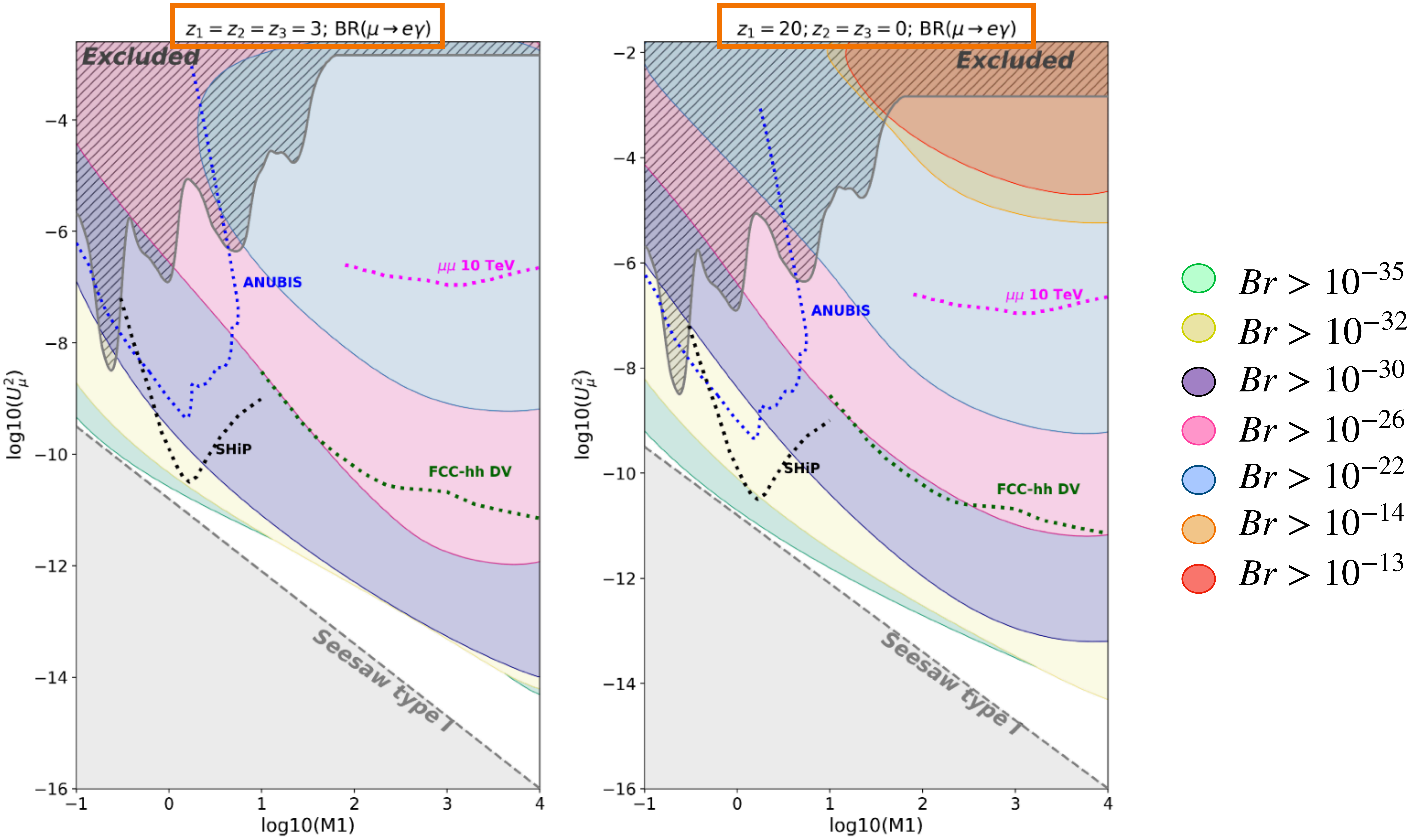
$$M_D \uparrow \Rightarrow \; Y_\nu \uparrow$$

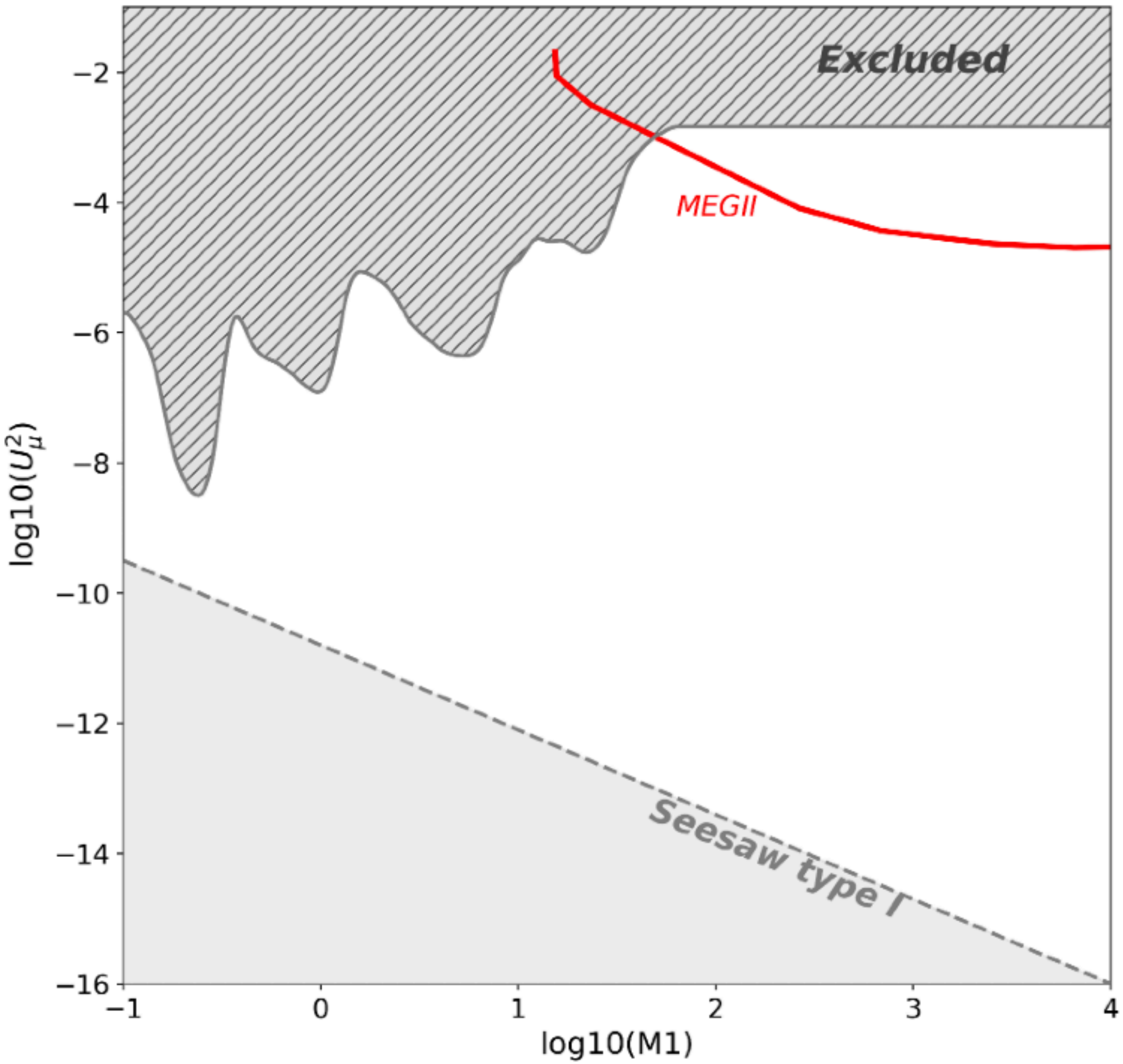
$$U^2 \sim \frac{M_D^2}{M_R^2} \uparrow$$

Case 2: $z_1 = 20; z_2 = z_3 = 0$



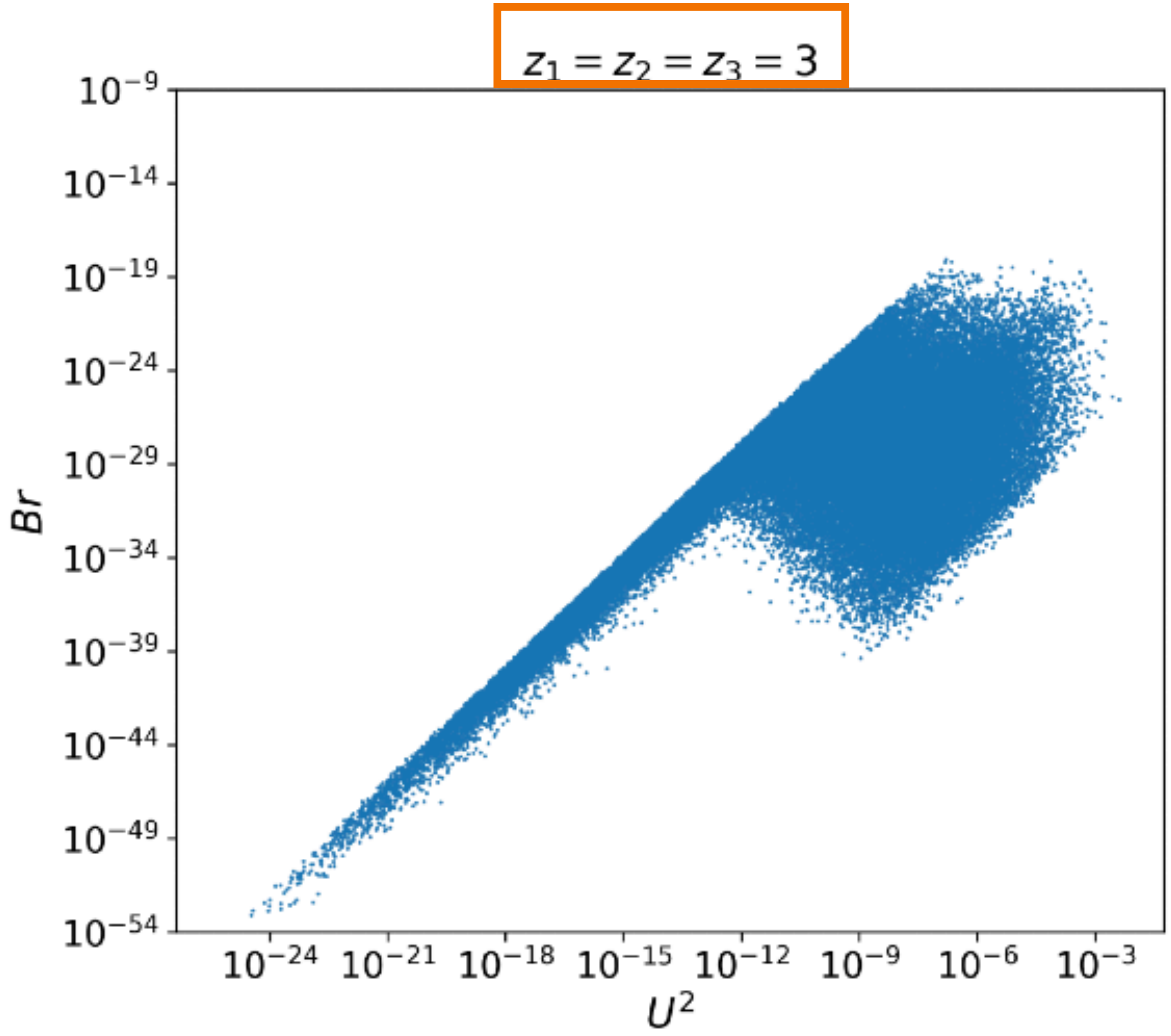


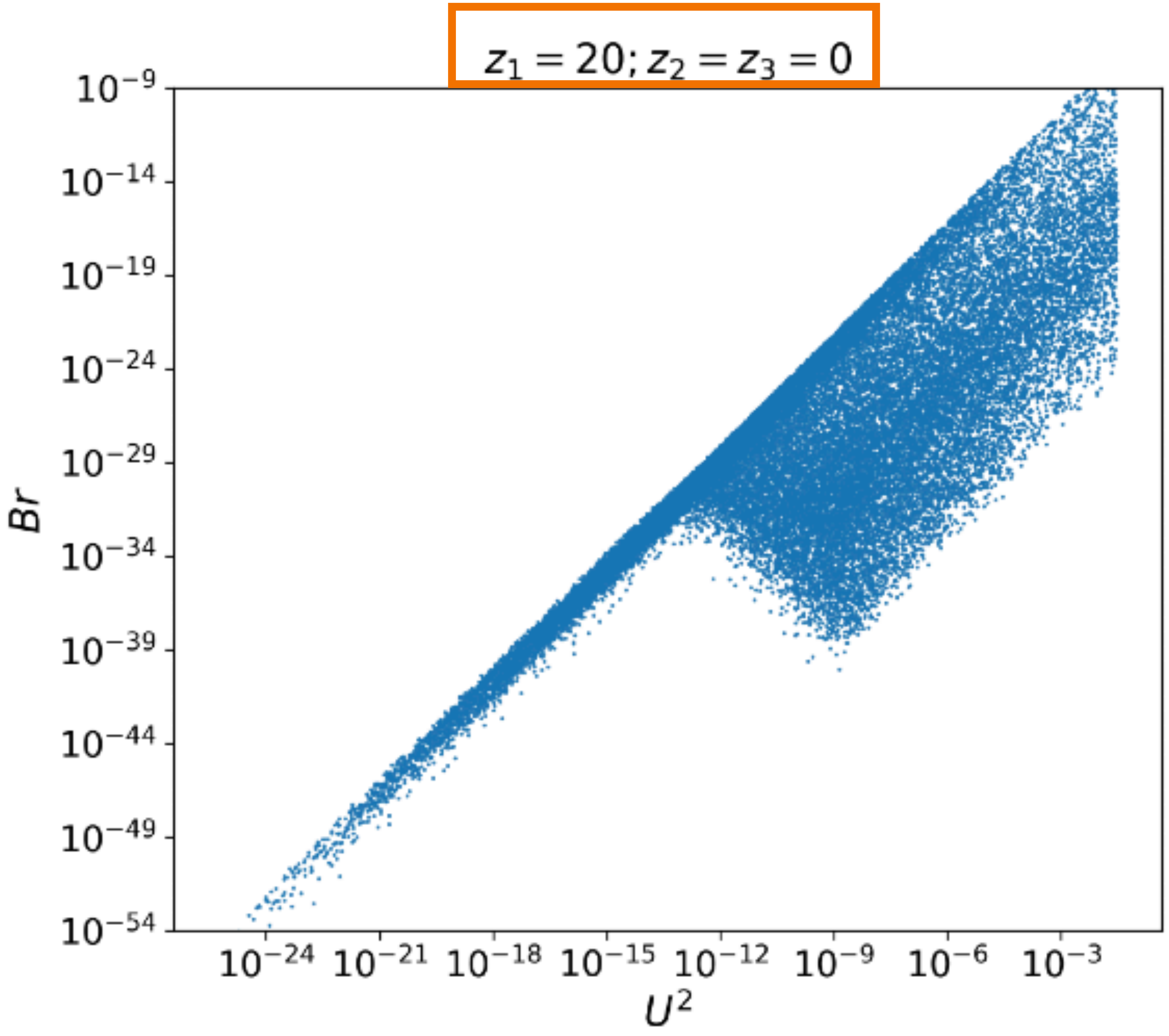

$z_1 = z_2 = z_3 = 3$; BR($\mu \to e\gamma$)
$z_1 = 20$; $z_2 = z_3 = 0$; BR($\mu \to e\gamma$)
Excluded
ANUBIS
$\mu\mu$ 10 TeV
SHiP
FCC-hh DV
Seesaw type I
log10(U_μ^2)
log10(M1)
$Br > 10^{-35}$
$Br > 10^{-32}$
$Br > 10^{-30}$
$Br > 10^{-26}$
$Br > 10^{-22}$
$Br > 10^{-14}$
$Br > 10^{-13}$



Excluded
MEGII
Seesaw type I
log10(U_μ^2)
log10(M1)
−2
−4
−6
−8
−10
−12
−14
−16
−1
0
1
2
3
4

$$U_2 \equiv \sum_{\alpha=e,\mu,\tau} \sum_{i=4}^{6} |U_{\alpha i}|^2$$





$$m_\nu = m_\nu^{(0)} + \delta M \equiv - M_D^{(1)^T} \frac{1}{M_R'} M_D^{(1)}$$

$$\frac{1}{M_R'} = \frac{1}{M_R}(1 - \Sigma_1)$$

$R^T \Sigma_1 R \;\sim\; \sinh^2(\mathrm{Im}\,\theta_i)$

Loop corrections break cancellation → R entries directly affect m_ν structure

$$M_D^{(1)} = i\sqrt{M_R'}\, R \sqrt{m_\nu}\, U_{PMNS}$$

$$\delta M' = M_D^{(1)\,T} \Sigma_1 M_D^{(1)}$$

$$M'_{tot} = \begin{pmatrix} \delta M' & M_D^{(1)^T} \\ M_D^{(1)} & M_R \end{pmatrix} \longrightarrow U$$

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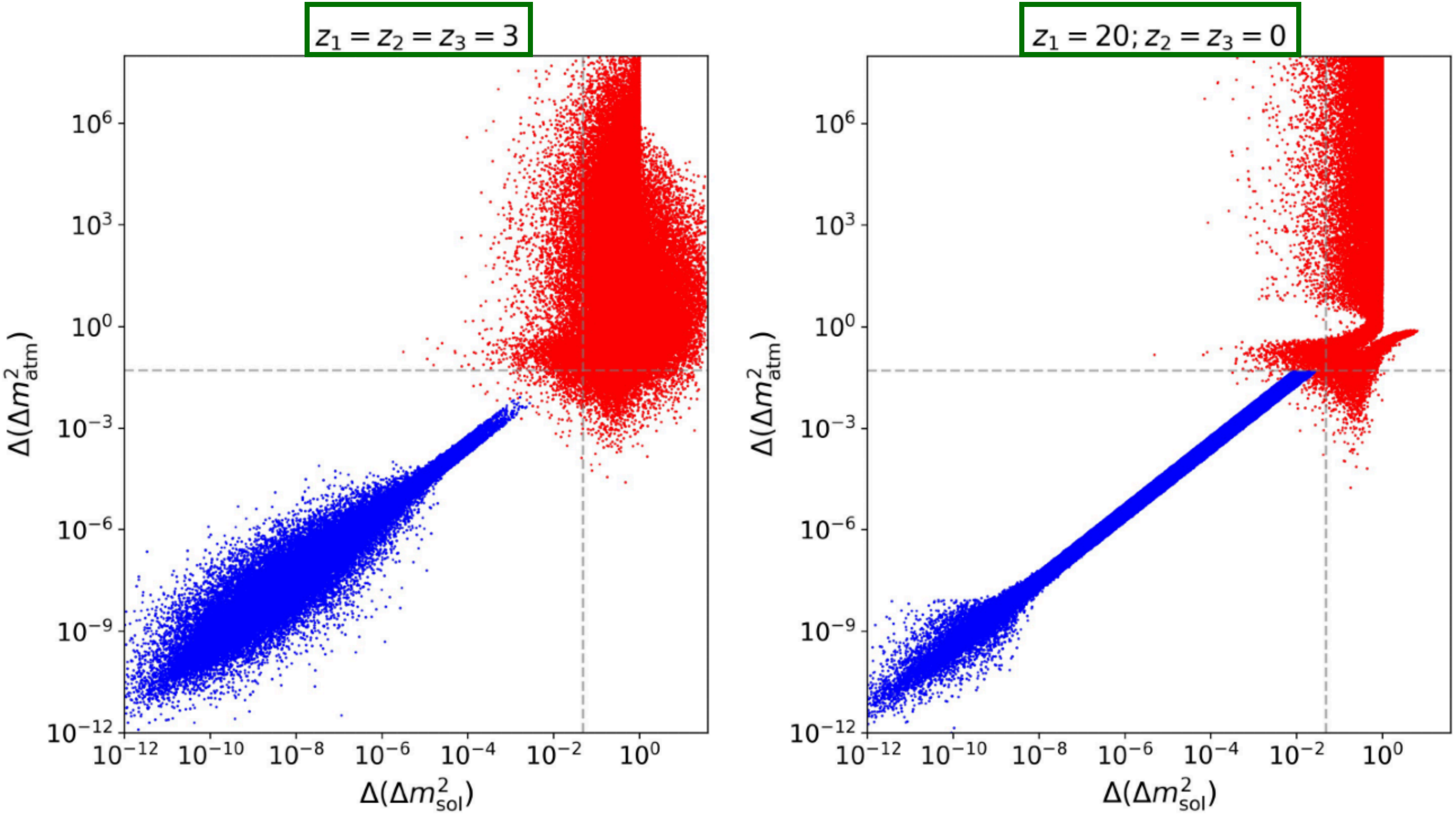
Mass Splitting

$$U^T M_{tot}^{\prime\dagger} M'_{tot} U = \mathrm{diag}(m_1^2, m_2^2, m_3^2, M_4^2, M_5^2, M_6^2)$$

$$\Delta m_{sol}^2 = m_2^2 - m_1^2, \qquad \Delta m_{atm}^2 = m_3^2 - m_1^2$$

$$\Delta(\Delta m_{\mathrm{sol}}^2) = \frac{\Delta m_{sol,\mathrm{rec}}^2 - \Delta m_{sol,\mathrm{exp}}^2}{\Delta m_{sol,\mathrm{exp}}^2},$$

$$\Delta(\Delta m_{\mathrm{atm}}^2) = \frac{\Delta m_{atm,\mathrm{rec}}^2 - \Delta m_{atm,\mathrm{exp}}^2}{\Delta m_{atm,\mathrm{exp}}^2}$$



$z_1 = z_2 = z_3 = 3$
$z_1 = 20; z_2 = z_3 = 0$
10^{6}
10^{3}
10^{0}
10^{-3}
10^{-6}
10^{-9}
10^{-12}
$\Delta(\Delta m^2_{\rm atm})$
10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0}
$\Delta(\Delta m^2_{\rm sol})$

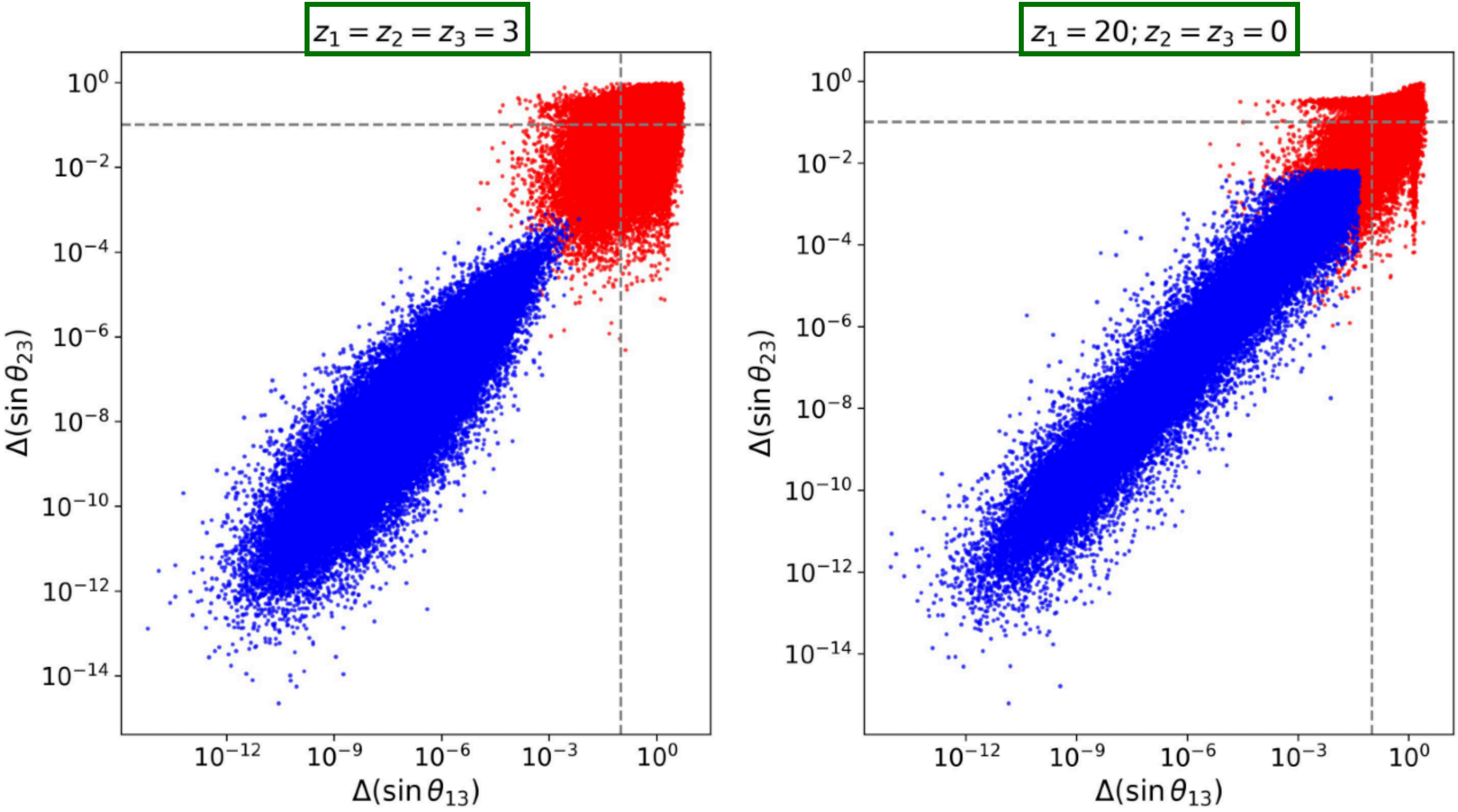
Mixing Angles

$$M'_{\mathrm{tot}} \;\rightarrow\; U \;\rightarrow\; \sin\theta_{ij}^{\mathrm{rec}} \;\rightarrow\; \Delta(\sin\theta_{ij})$$

$$\Delta(\sin\theta_{12}) = \frac{\sin\theta_{12,\mathrm{rec}} - \sin\theta_{12,\mathrm{exp}}}{\sin\theta_{12,\mathrm{exp}}}$$

$$\Delta(\sin\theta_{13}) = \frac{\sin\theta_{13,\mathrm{rec}} - \sin\theta_{13,\mathrm{exp}}}{\sin\theta_{13,\mathrm{exp}}}$$

$$\Delta(\sin\theta_{23}) = \frac{\sin\theta_{23,\mathrm{rec}} - \sin\theta_{23,\mathrm{exp}}}{\sin\theta_{23,\mathrm{exp}}}$$



$z_1 = z_2 = z_3 = 3$
$z_1 = 20; z_2 = z_3 = 0$
$\Delta(\sin\theta_{23})$
$\Delta(\sin\theta_{13})$
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-12}
10^{-9}
10^{-6}
10^{-3}
10^{0}

Conclusions

- Low-energy models are viable alternatives to the standard scale.

- MEGII limits on $Br(\mu \to e\gamma)$ provide competitive constraints for $M_R > 100$ GeV.

- The complex CI is incorrect under loop effects.

Thanks!

Questions?

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Effect of higher order corrections

$$\Sigma_2 = \frac{1}{16\pi^2}\Sigma_1$$

$$\Sigma_3 = \frac{1}{(16\pi^2)^2}\Sigma_1$$