Neutrinos in Global SU(5) F-theory Model

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Corfu 2022
Workshop on the Standard Model and Beyond
September 7, 2022

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DEPARTMENT OF PHYSICS

Outline

- Brief outline of the model
- Low energy theory
- Neutrinos
- Radiative corrections
- Phenomenology

The Model

H. Clemens & Stuart Raby

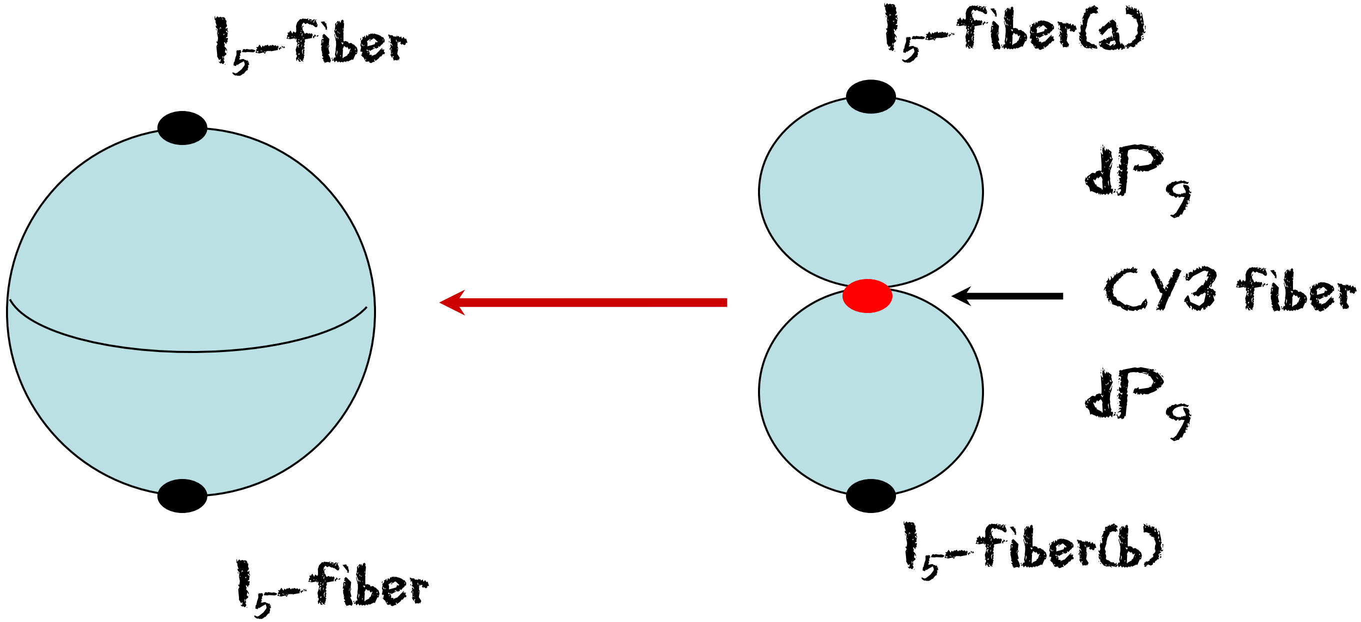
arXiv:1906.07238 (hep-th)	Adv. In Theor. Math. Phys.	
arXiv:1908.01110 (hep-th)	"	
arXiv:1908.01913 (hep-th)	JHEP	The Model
arXiv:1912.06902 (hep-th)	"	Scales
arXiv:2001.10047 (hep-th)	"	RH neutrinos

Heterotic side

- E8 x E8 on elliptically fibered CY_3
  - Torus fibered over base B_2
- E8 broken to $(SU(5)xU(1)\_X)_{gauge}$ by $(SU(4)xU(1)\_X)_{Higgs}$ vector bundle
- Freely acting Z_2 involution (preserving the gauge symmetry) $\pi_1(CY_3) = Z_2$
- Wilson line wraps non-contractible cycle, breaks $SU(5)_{gauge}$ to SM
- Higgs data in semi-stable degeneration limit $dP_9 \cup dP_9$ connected along elliptic fiber
  - Defines the spectral cover

F theory

Heterotic theory



$$\times B_2$$

$$CY_4$$

$$V_3 = CY_3$$

F theory side

Build CY_4 = elliptic fiber over base B_3

$$\begin{array}{ccc} B_3 & = & \mathbb{P}^1 \\ & & \downarrow \\ & & B_2 \end{array}$$

Given by **Tate form** of Weierstrass function

$$\omega y^2 = x^3 + a_5\, \omega x y + a_4\, z \omega x^2 + a_3\, z^2 \omega^2 y + a_2\, z^3 \omega^2 x + a_0\, z^5 \omega^3$$

$$\varsigma(b_3) = \{[\omega, x, y] = [0,0,1]\} \quad \text{first section}$$

F theory side

Build CY_4 = elliptic fiber over base B_3

$$B_3 = \begin{array}{c}\mathbb{P}^1 \\ \downarrow \\ B_2\end{array}$$ with 2 sections

Given by **Tate form** of Weierstrass function

$$\omega y^2 = x^3 + a_5\,\omega\,x\,y + a_4\,z\,\omega\,x^2 + a_3\,z^2\omega^2 y + a_2\,z^3\omega^2 x + a_0\,z^5\omega^3$$

$$\varsigma(b_3) = \{[\omega, x, y] = [0, 0, 1]\}$$ first section

Tate form

$\omega, y, x =$ elliptic fiber (torus)

$z = 0 \;\Rightarrow\; S_{GUT} \;\Rightarrow$ descriminant vanishes

z, a_j functions on B_3

Choose $\quad a_5 + a_4 + a_3 + a_2 + a_0 = 0$

$a_5 s^5 +$

$\tau(b_3) = \{[\omega, x, y] = [1, z^2, z^3]\}$ second section

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Let $\quad \omega = 1,\ y = t^3, x = t^2,\ s = z/t$

$$C \equiv a_5 + a_4 s + a_3 s^2 + a_2 s^3 + a_0 s^5 \quad - \text{spectral cover}$$

$$= \left(a_5 + a_{54} s - a_{20} s^2 - a_0 s^3 - a_0 s^4\right)\left(1 - s\right) \quad 4+1 \text{ split}$$

The Model

- Heterotic – F theory duality
- 4 + 1 split $(SU(4)xU(1)_X)_{Higgs}$
- Z_2 freely acting on B_2 => S_{GUT} = Enriques
- $SU(5) \times U(1)_X$ w/Wilson line GUT breaking
- NO Vector-like exotics

  Involution includes a translation by

  $$\xi(b_3) - \tau(b_3)$$

- R parity / $\mathbb{Z}_4^R$ symmetry

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$U(1)_X$ due to 4 + 1 split

$$\omega = 1,\ y = t^3, x = t^2,\ s = t/z$$

$$C = \left(a_5 s^4 + a_{54} s^3 - a_{20} s^2 - a_0 (s+1)\right)(s-1) \quad 4+1 \text{ split}$$

Intersection of 3 matter curves
= cubic coupling

$$10^{-1}{}_m\ ,\ \bar{5}^{+3}{}_m\ ,\ 5^{+2}{}_h + \bar{5}^{-2}{}_h$$

$$10_m\ \bar{5}_m\ \bar{5}_h\ ,\ 10_m\, 10_m\, 5_h \quad \text{but NOT} \quad 10_m\ \bar{5}_m\ \bar{5}_m$$

Right-handed Neutrinos

arXiv:2001.10047 (hep-th)

$$\Gamma^{-5} \equiv 1^{-5}{}_{m}, \quad \Lambda^{+10}$$

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$\Gamma^{-5}{}_{m} \ \bar{5}^{+3}{}_{m} \ 5_{h}{}^{+2}$ Dirac neutrino mass allowed

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Under the $\mathbb{Z}_2$ involution, $U(1)_X \to \mathbb{Z}_2$ matter parity

Relative Scales – Visible vs. Hidden sector

arXiv:2001.10047 (hep-th)

$$S_{EH} \sim M_*^8 \int_{\mathbb{R}^{3,1}\times B_3} R\sqrt{-g_\delta}\, d^{10}x$$

$$M_{Pl}^2 \simeq M_*^8 \cdot Vol\,(B_{3,\delta})$$

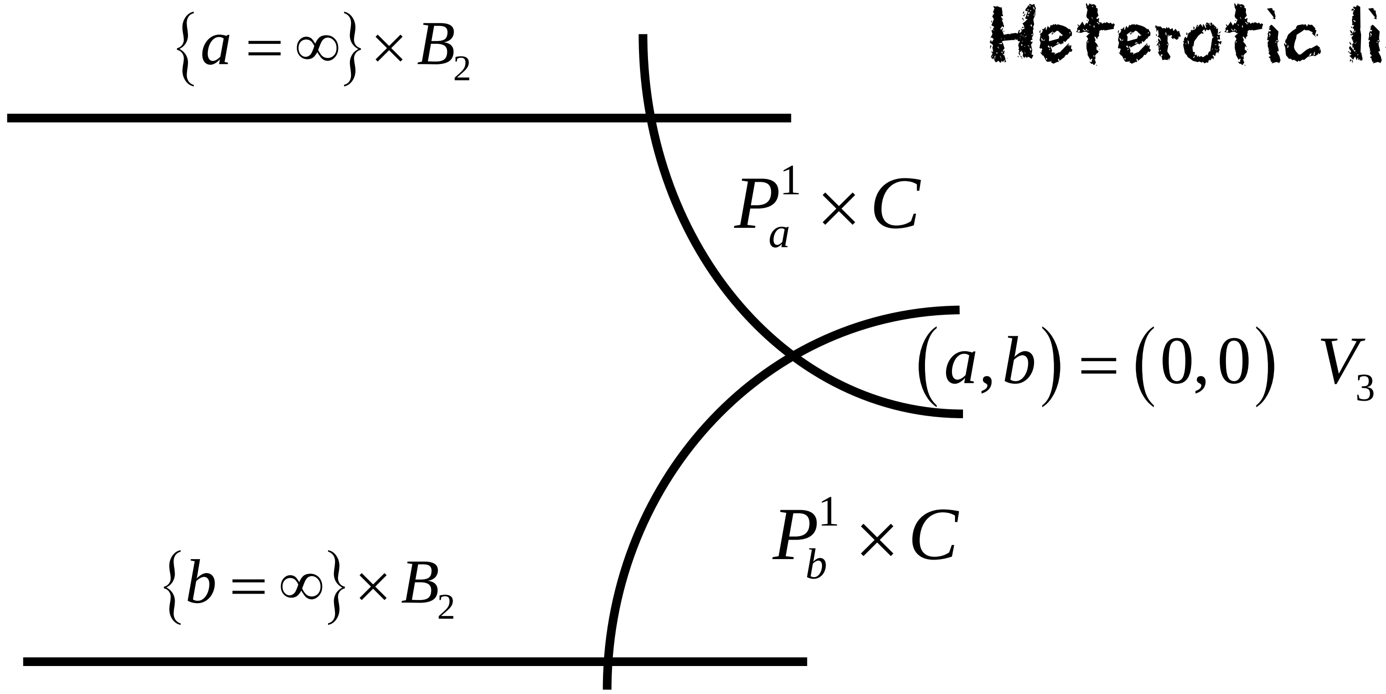
$$S_{guage} \sim -M_*^4 \int_{R^{3,1}\times S_i} \left(Tr(F_1^2)\sqrt{-g_1} + Tr(F_2^2)\sqrt{-g_2}\right) \delta^2(z_0)\; d^{10}x$$

$$\alpha_G^{-1} \sim M_*^4\; Vol(S_i)$$

$$M_G(i)^{-4} \sim Vol(S_i)$$

Two SU(5) gauge groups in the Heterotic limit

Heterotic limit



$$B_{3,0} = B_3^{(1)} \bigcup B_3^{(2)} = P_a^1 \times B_2 \bigcup P_b^1 \times B_2$$

$$S_1 = \left(\{a=\infty\}\times B_2\right) \bigcup (P_a^1 \times C)$$

$$S_2 = \left(\{b=\infty\}\times B_2\right) \bigcup (P_b^1 \times C)$$

$$m_i = Vol(P_i^1),\ i=a,b,\quad Vol(C) = \int_{B_2} |q|^2$$

$$Vol(S_i) = Vol(B_2) + m_i Vol(C), \quad m_i = Vol(P_i^1), \ i = a, b$$

$$\alpha_G(i) M_{Pl} \sim \frac{\sqrt{(m_1 + m_2)\, Vol(B_2)}}{Vol(B_2)(1 + K\, m_i)}$$

Eg.

Visible sector $\alpha_G(1)^{-1} = 24, \ M_G(1) = 3 \times 10^{16}$ GeV

$$\alpha_G(2) \big/ \alpha_G(1) = \frac{1 + Km_1}{1 + K\, m_2}, \quad M_G(2) \big/ M_G(1) = \left(\frac{1 + Km_1}{1 + K\, m_2} \right)^{1/4}$$

Twin sector, take $M_G(2) = 3.9 \times 10^{16}$ GeV, $\alpha_G(2)^{-1} = 8.7$

or $$\frac{1 + Km_1}{1 + K\, m_2} = 2.8$$

Summary

- Constructed Global SU(5) F theory model with Wilson line breaking
- 3 families and one pair of Higgs doublets + NO vector-like exotics !
- $U(1)_X$ and $\mathbb{Z}_4^R$ symmetry
- $10_M 10_M 5_H$, $10_M \overline{5}_M \overline{5}_H$, $\Gamma_M \overline{5}_M 5_H$, $\Gamma_M \Gamma_M \Lambda$
- Complete twin sector
- Different scales !

Low Energy Theory

- The Wilson line wraps the GUT surface breaking SU(5) -> SM gauge group
- $M_{GUT} = M_C \sim 1/R_{cycle}$
- Non-local GUT breaking - Precise Gauge Coupling Unification
- Complete twin world with scales fixed by the size of the twin manifold
- Twin matter - Dark Matter candidate ?

Low Energy Theory

3 Twin families and one pair of Higgs doublets

$$\langle H'_u \rangle = \begin{pmatrix} 0 \\ v_{H'_u} \end{pmatrix}, \qquad \langle H'_d \rangle = \begin{pmatrix} v_{H'_d} \\ 0 \end{pmatrix}$$

$\Lambda_{QCD'} \; > \; \Lambda_{QCD} \Rightarrow$ heavier twin baryons

$v'_H \; > \; v_H$

$\Rightarrow$ heavier twin Dirac lepton and quark masses

Neutrino Portal

Right-handed neutrino masses

assume i, j = 1, .., 3

$$y_{ij} \langle \Lambda \rangle \Gamma_i \Gamma_j \;\Rightarrow\; M_{ij}\, N_i N_j$$

identical in visible and twin sectors

with one global $U(1)_X$!

$$\Rightarrow \quad W_N = \frac{1}{2} N_i M_{ij} N_j + N_i Y_{ij} \ell_j H_u + N_i Y'_{ij} \ell'_j H'_u$$

Similar to mirror world

An, Chen, Mohapatra & Zhang 0911.4463

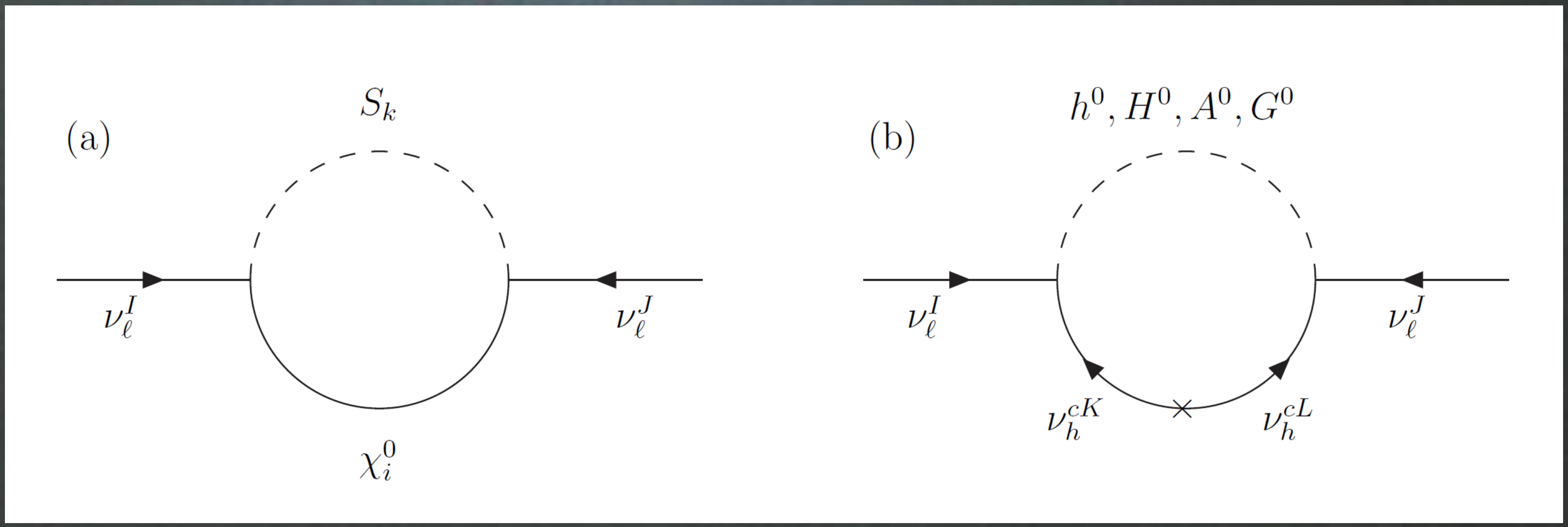
$$M \gg v'_H \geq v_H$$

$$W_{\rm eff} = -\frac{1}{2} \left(\ell Y^T H_u + \ell' Y'^T H'_u \right) M^{-1} \left(Y \ell H_u + Y' \ell' H'_u \right)$$

$\Rightarrow$ 3 massive and 3 massless neutrinos

Radiative neutrino masses

Dedes, Haber & Rosiek 0707.3718



(a) S_K (K=1 , ...,6) light sneutrinos and neutralinos

(b) Higgs, goldstino and heavy neutrinos

Neutrino masses with Rad. corrections

$$\mathcal{M}_{\nu_\ell} = \begin{pmatrix} \delta m_{LL} - m_D^T M^{-1} m_D & -m_D^T M^{-1} m_{D'} \\ -m_{D'}^T M^{-1} m_D & \delta m_{L'L'} - m_{D'}^T M^{-1} m_{D'} \end{pmatrix}$$

In limit $m_{D'} \gg m_D$

$$\mathcal{M}_{\nu_\ell} \sim \begin{pmatrix} \delta m_{LL} & \\ & - m_{D'}^T M^{-1} m_{D'} \end{pmatrix}$$

In general, diagonalizing the neutrino mass matrix

$$u_\ell^T \mathcal{M}_{\nu_\ell} u_\ell = \mathrm{diag}\,(m_{\nu_1}, m_{\nu_2}, m_{\nu_3}, m_{s_1}, m_{s_2}, m_{s_3}) =: \begin{pmatrix} d_\nu & 0 \\ 0 & d_s \end{pmatrix}$$

The extended PMNS matrix

$$\mathcal{L}_W = \frac{g}{\sqrt{2}} W_\mu^- \overline{\psi}_e \gamma^\mu P_L a_L \begin{pmatrix} \nu_a \\ \nu_s \end{pmatrix}, \quad u_\ell =: \begin{pmatrix} a_L \\ a_{L'} \end{pmatrix}$$

$$a_L =: \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} & U_{e4} & U_{e5} & U_{e6} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} & U_{\mu 4} & U_{\mu 5} & U_{\mu 6} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} & U_{\tau 4} & U_{\tau 5} & U_{\tau 6} \end{pmatrix}$$

Phenomenology

Neutrino masses and mixing angles in simplified analysis

$Y' = Y,\ Y'_e = Y_e\ ,\ m_H, m_A \gg m_h$ decoupling limit

$\tan\beta' \neq \tan\beta,\ v'_H \neq v_H\ , M_N = 10^{12}$ GeV+ …

Normal Hierarchy

$$\Delta m^2_{12} = (7.55 \pm 0.20) \times 10^{-5}\ \text{eV}, \quad \Delta m^2_{23} = (2.424 \pm 0.030) \times 10^{-3}\ \text{eV},$$

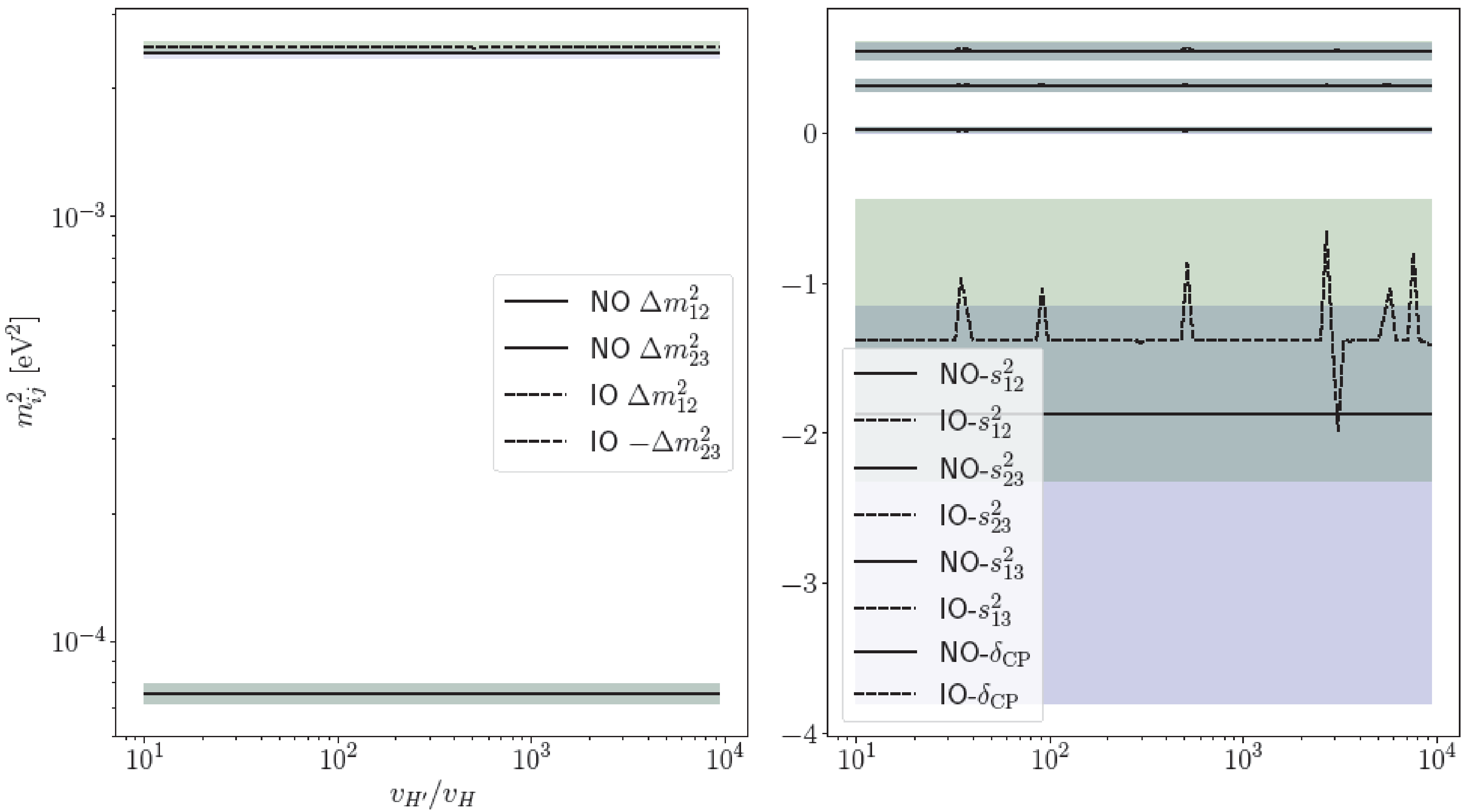
$$s^2_{12} = 0.32 \pm 0.02, \quad s^2_{23} = 0.547 \pm 0.03, \quad s^2_{13} = 0.0216 \pm 0.0083, \quad \delta_{\text{CP}} = 218 \pm 38\ \text{deg}$$

Inverted Hierarchy

$$\Delta m^2_{12} = (7.55 \pm 0.20) \times 10^{-5}\ \text{eV}, \quad \Delta m^2_{23} = (-2.50 \pm 0.040) \times 10^{-3}\ \text{eV},$$

$$s^2_{12} = 0.32 \pm 0.02, \quad s^2_{23} = 0.5551 \pm 0.03, \quad s^2_{13} = 0.0220 \pm 0.0076, \quad \delta_{\text{CP}} = 281 \pm 27\ \text{deg}$$

Preliminary



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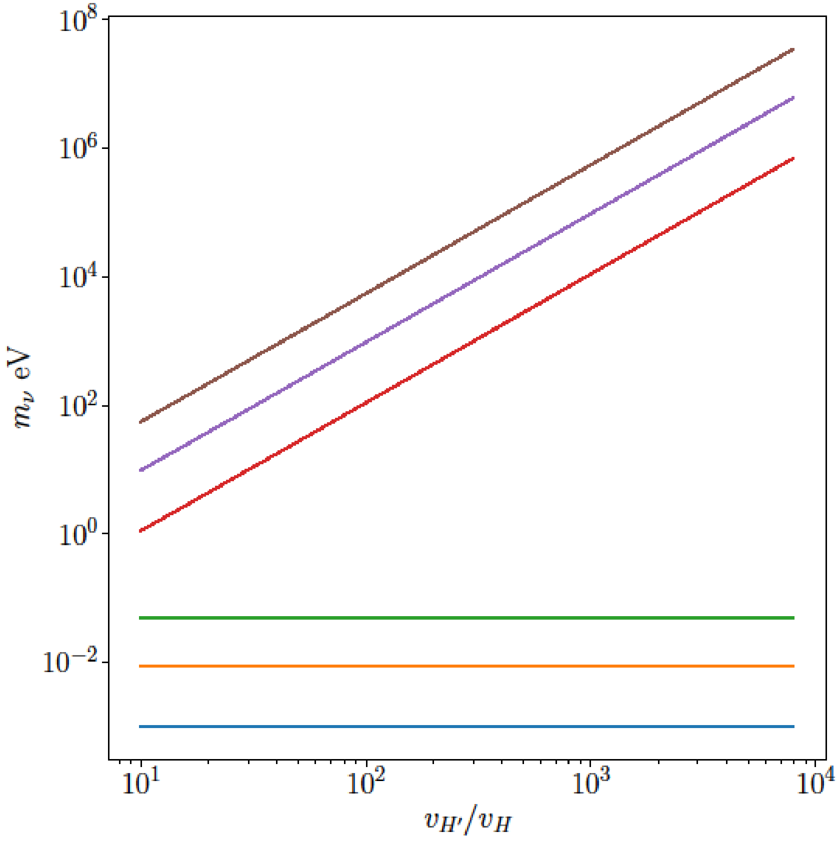
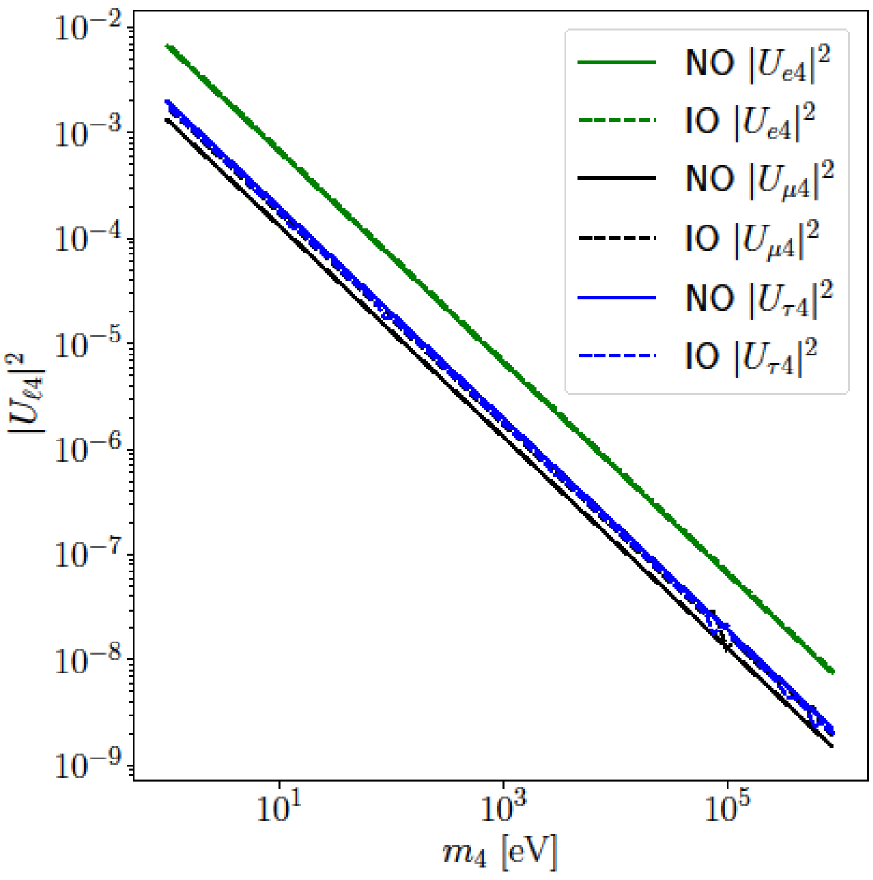
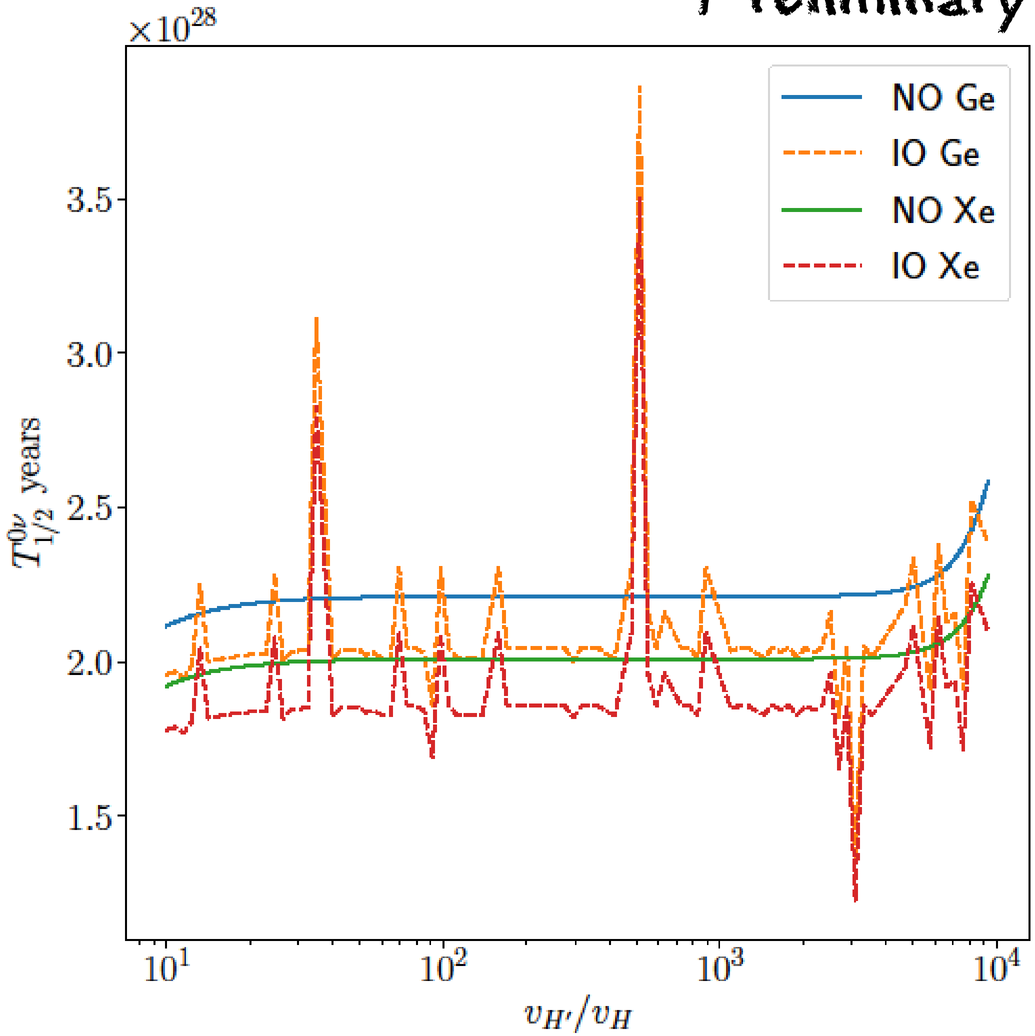




- Invisible width of the Z is unchanged for SM
- Neutrinoless double beta decay bounds > 10^{25} y

No problem

Preliminary



Sterile Neutrino Bounds
see Dentler et al. 1803.10661

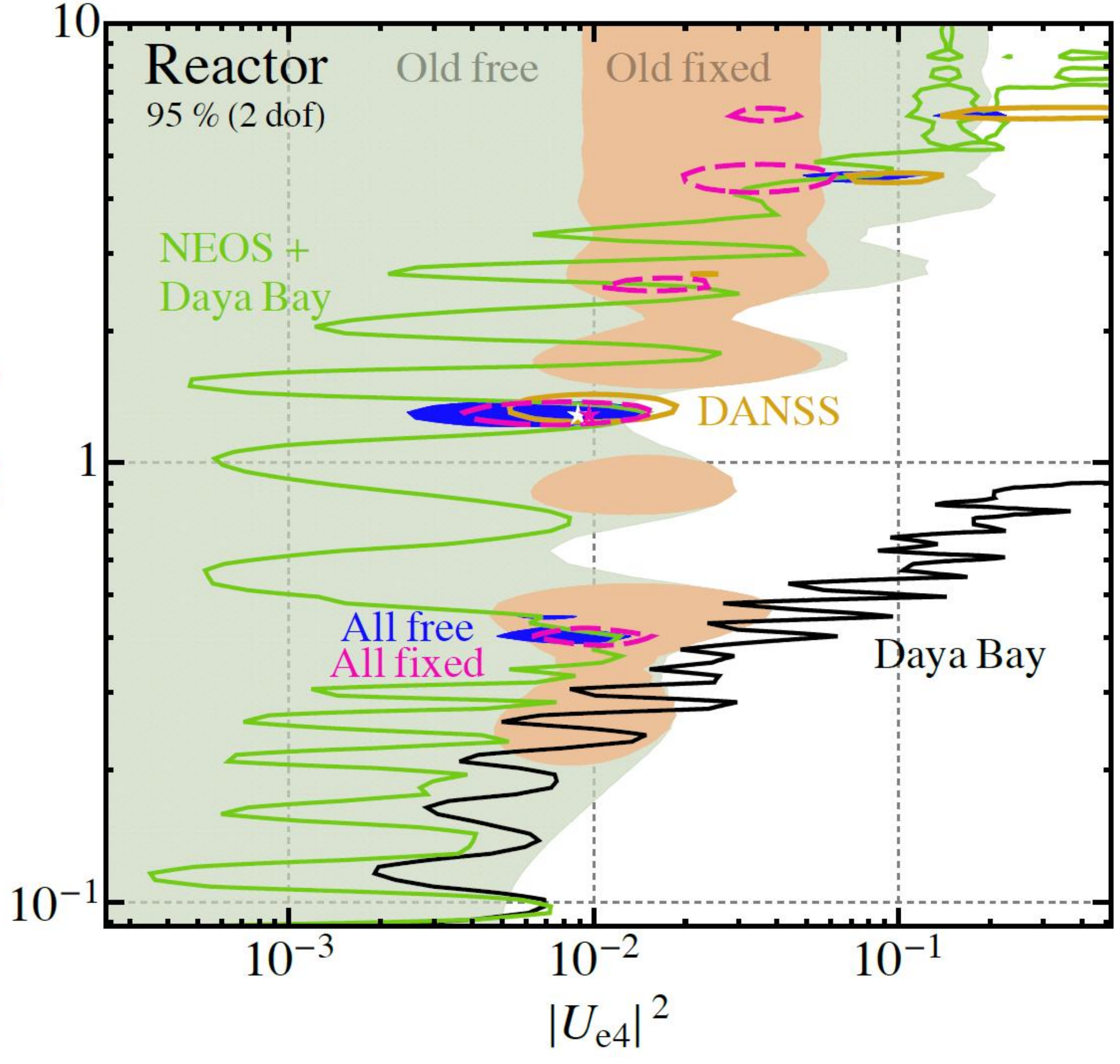
- ✓ Reactor experiments on ν_e disappearance
  DayaBay, NEOS place upper bounds on $|U_{e4}|^2$
  DANSS reports an excess
  All 3 consistent with $\Delta m^2_{14} \approx 1.3 \text{ eV}^2, |U_{e4}| \approx 0.1$

- ✓ Bounds on ν_μ disappearance
  MINOS+, IceCube

- ❖ All data are inconsistent with $\nu_\mu \to \nu_e$
  LSND anomaly excluded at 4.7 σ

Dentler et al. 1803.10661

Best fit point $\Delta m_{41}^2 = 1.29\,\text{eV}^2$, $\sin^2\theta_{14} = 0.0089$



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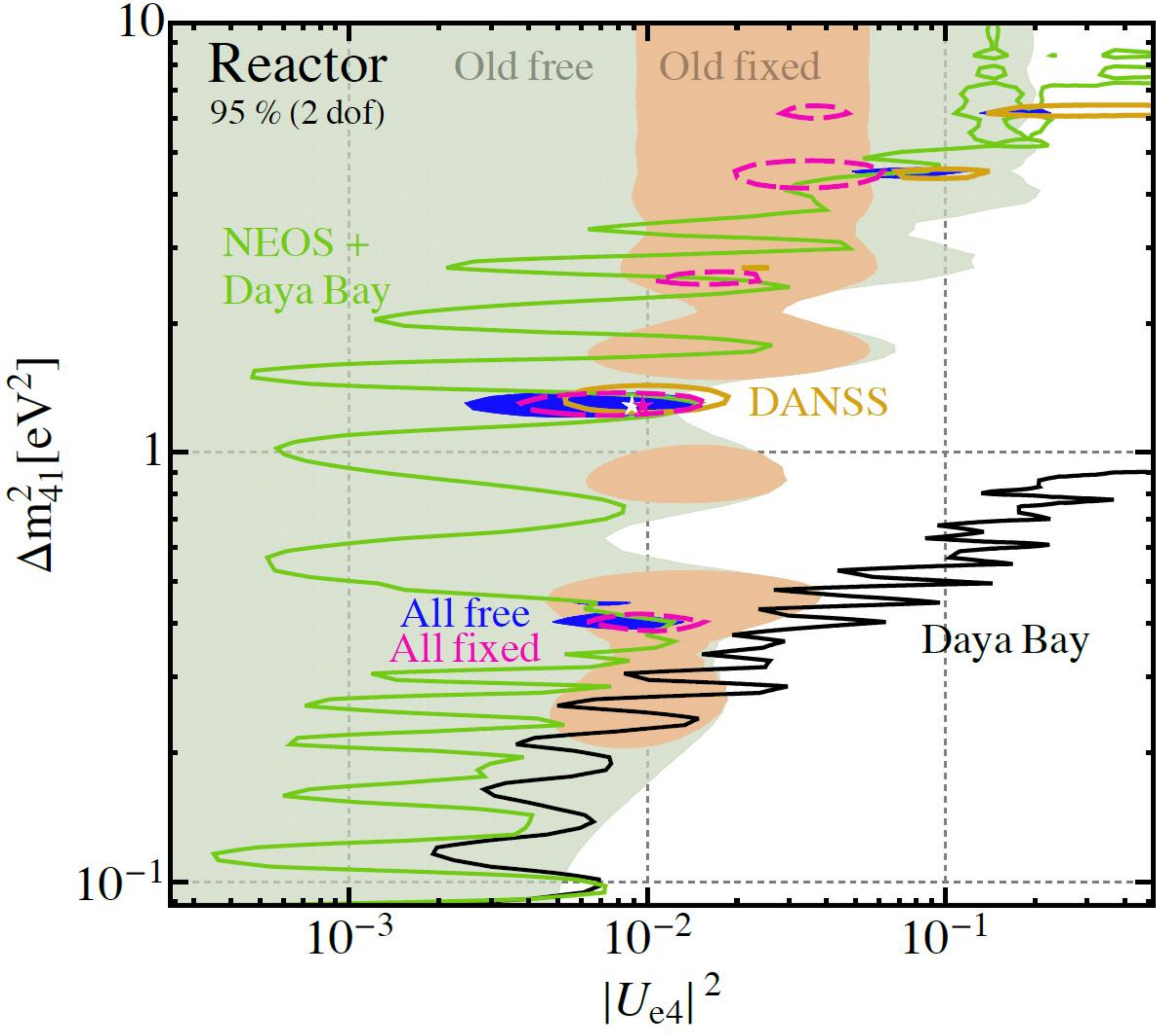

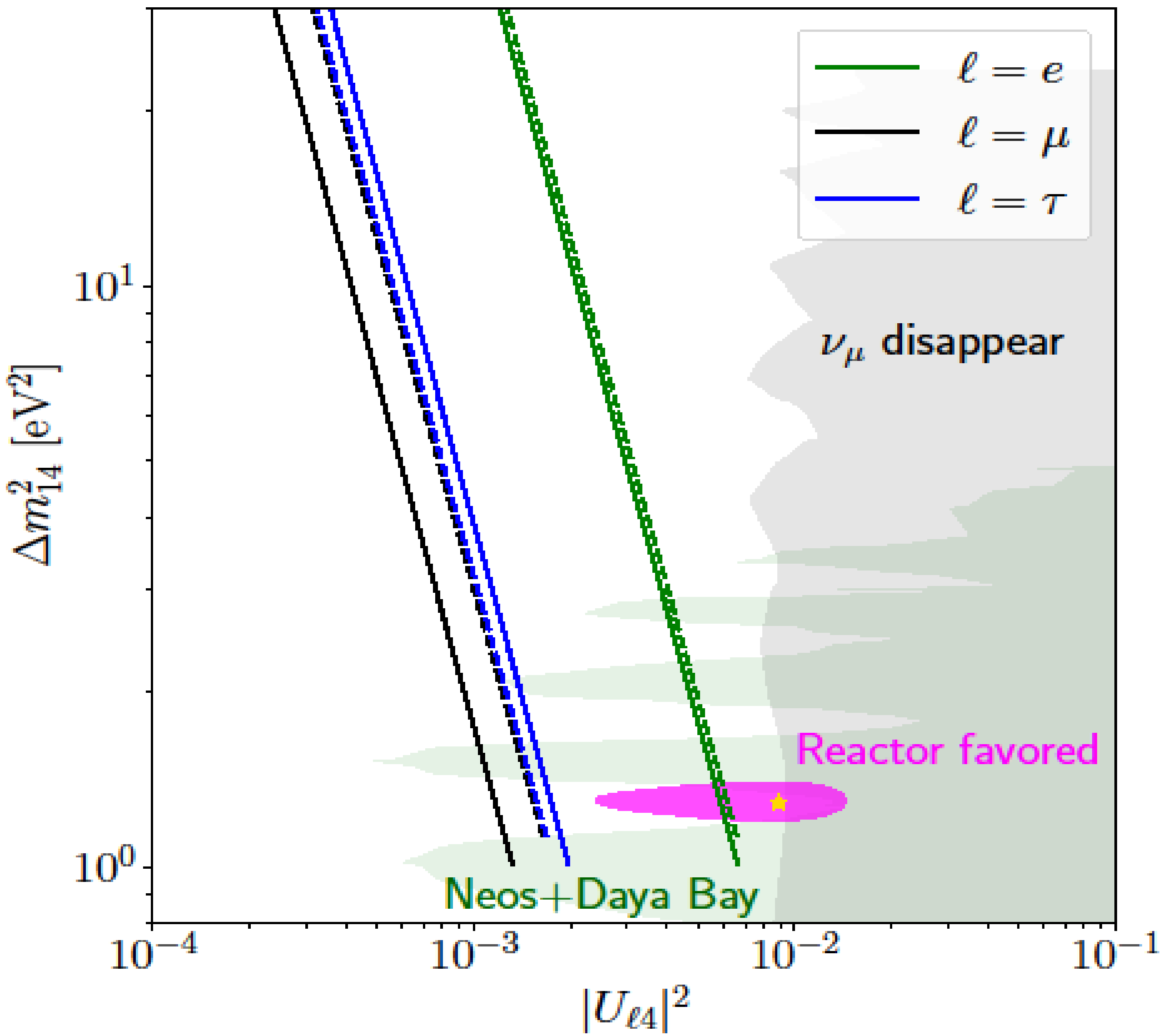

$\ell = e$
$\ell = \mu$
$\ell = \tau$
ν_μ disappear
Reactor favored
Neos+Daya Bay
10^1
10^0
Δm^2_{14} [eV^2]
10^{-4}
10^{-3}
10^{-2}
10^{-1}
$|U_{\ell 4}|^2$

Dentler et al. 1803.10661

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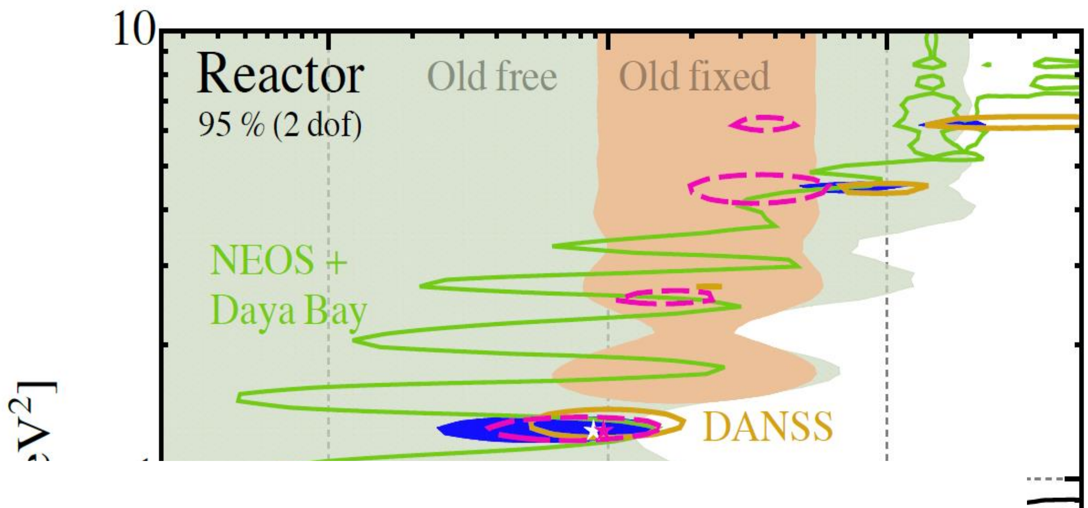

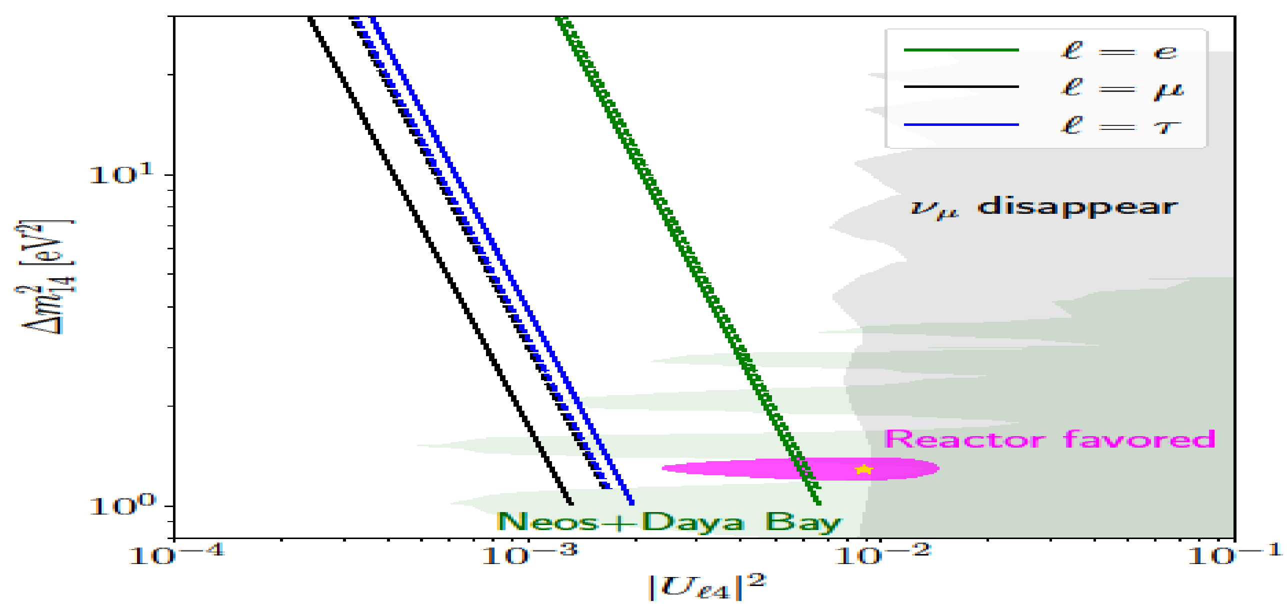

Cosmology

Heavier twin baryons and leptons

Massless twin photon

OPEN QUESTIONS

What is the relation between T' and T ??

Is there inflation, reheat temps, axion, dark matter, baryogenesis, etc.

FUTURE WORK

Thank you

Kinetic mixing suppressed

$$\sim \frac{m_{\nu}\, m_{\nu'}}{\left(16\pi^{2}\right)^{3} M_{W}^{2}} F_{\mu\nu}\, F'^{\mu\nu}$$