TeV-scale new physics beyond third-generation-specific textures: a minimal type-II seesaw example

Xiyuan Gao

Karlsruher Institut für Technologie (KIT), Germany

Based on: JHEP 05 (2026) 188 [2511.08679]
with Lorenzo Calibbi and Man Yuan

Nov 14th 2026, Discrete

New Physics at TeV Scale

Karlsruher Institut für Technologie

TeV-Scale NP – motivations and problems

- ✓ Addressing anomalies and conceptual puzzles.

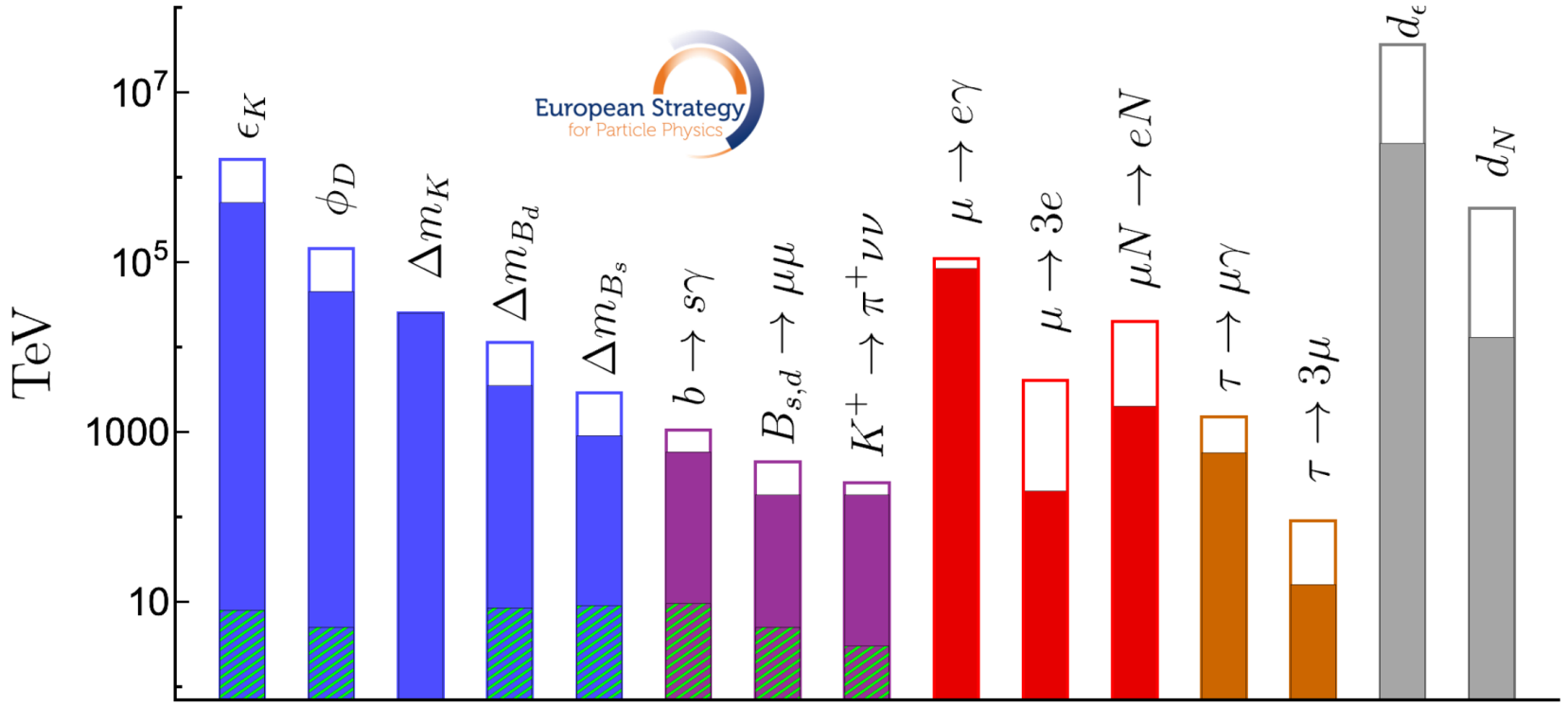
  See e.g. talk by U. Nierste

- ✓ Testable by a broad range of experiments.

- ✗ No observation yet.
- ✗ Many minimal realizations got excluded.

New Physics at TeV Scale

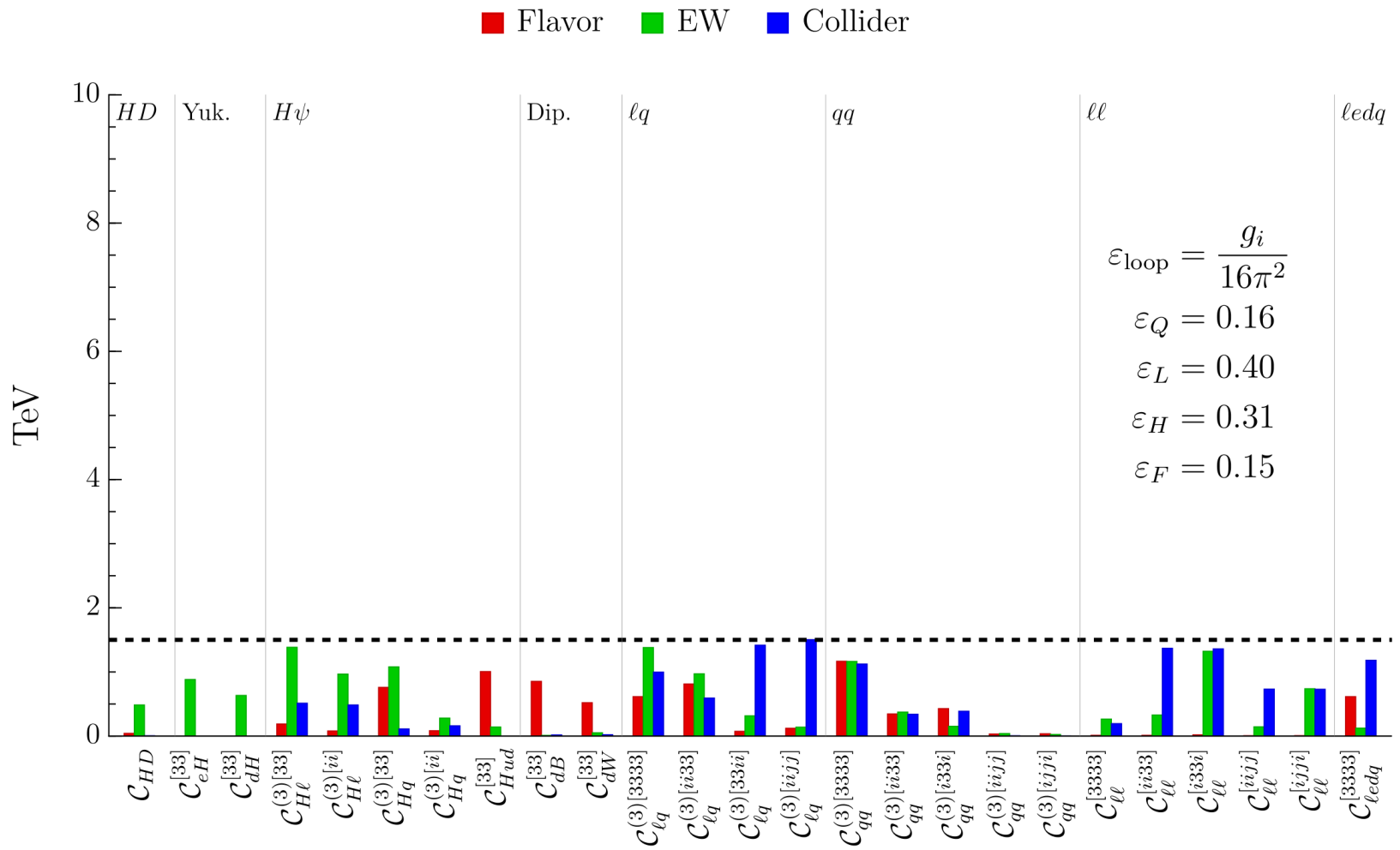
Flavour anarchy assumption excludes TeV-scale NP



Anarchy: NP interacts with all SM fermions via $\mathcal{O}(1)$ couplings. (no hierarchy)

New Physics at TeV Scale

Third-gen specific texture saves it



MFV, U(2), and variations:

Barbieri, Isidori, Jones-Perez, Lodone and Straub ’11; Isidori and Straub ’12; Barbieri, Buttazzo, Sala and Straub. ’12; Blankenburg, Isidori and Jones-Perez. ’12; Faroughy, Isidori ’20; Allwicher, Cornella, Isidori and Stefanek. ’23 (**the plot**); Allwicher, Isidori and Pesut, ’25; and many more…

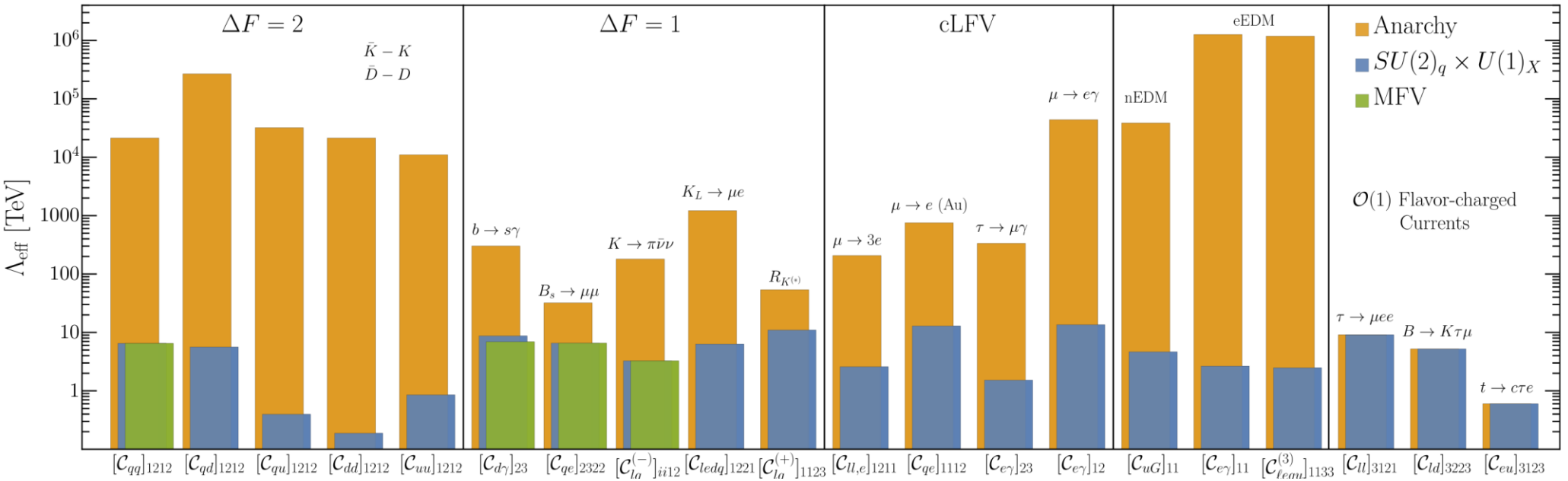
New Physics at TeV Scale

More diverse textures with symmetry protection

- Selection rules from discrete symmetries: $A_4, Z_3, \ldots$

  e.g. Moreno-Sánchez and Palavrić. ’25, Calibbi, et al. ’25 (see also talk by C. Hagedorn)

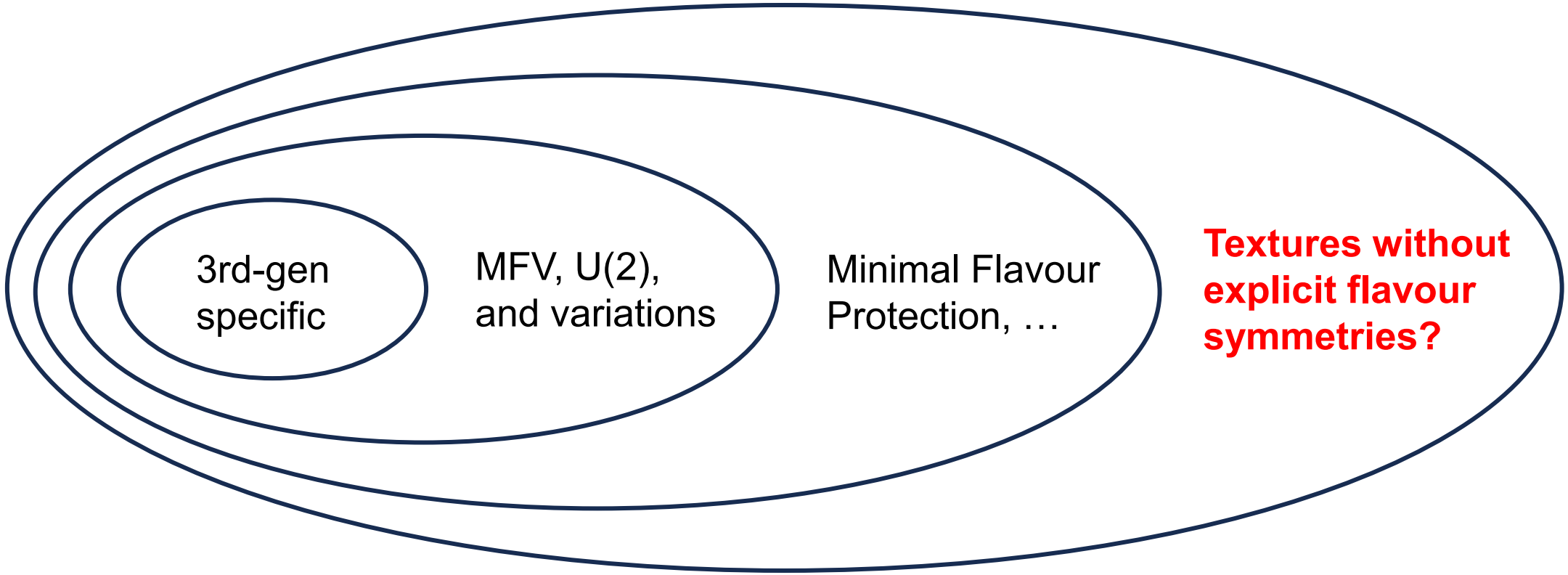
- Minimal flavour protection: $SU(2)_q \times U(1)_X$ Greljo, Palavrić, Stefanek, [2512.04159]



New Physics at TeV Scale

Karlsruher Institut für Technologie

Can we go more general?



More General Textures: A Simple Example

Karlsruher Institut für Technologie

Minimal Type-II seesaw:

- Very Minimal extension to SM.
- Y_Δ directly correlates to M_ν.
- Vacuum suppressed neutrino mass.
- Charged lepton flavor violation beyond SM.

$$\Delta \equiv \begin{pmatrix} \Delta^-/\sqrt{2} & \Delta^0 \\ \Delta^{--} & -\Delta^-/\sqrt{2} \end{pmatrix} .$$

$$M^\nu = \sqrt{2} Y_\Delta v_\Delta = \mu_\Delta Y_\Delta \frac{v^2}{m_\Delta^2} .$$

$$\delta\mathcal{L}^{\mathrm{d}=6}_{\mathrm{tree}} = \frac{1}{2m_\Delta^2} Y_{\Delta jl} Y^*_{\Delta ik} (\overline{\ell_i} \gamma_\mu P_L \ell_j)(\overline{\ell_k} \gamma^\mu P_L \ell_l) ,$$

Magg and Wetterich. ’80; Schechter and Valle. ’80; Lazarides, Shafi and Wetterich ’81; Mohapatra and Senjanovic. ’81; Gelmini and M. Roncadelli. ’81. See also talk by S. Saha.

More General Textures: A Simple Example

Karlsruher Institut für Technologie

Anarchic texture for leptons:

$$M_\ell = \frac{m_\tau}{3} \times \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}, \qquad M_\nu = \begin{pmatrix} m_{\nu_1} & 0 & 0 \\ 0 & m_{\nu_2} & 0 \\ 0 & 0 & m_{\nu_3} \end{pmatrix}.$$

Fritzsch and Xing. '95; Harrison, Perkins and Scott. '02; Xing. '02; He and Zee. '03.

$$\theta_{12} = \arctan \frac{1}{\sqrt{2}}, \theta_{23} = \frac{\pi}{4}, \theta_{13} \ll \theta_{12}, \theta_{23}$$ 'Tri-bi-maximal mixing'

When M_ℓ diagonal, how M_ν looks like?

- Maybe remain anarchic.
- Not-so anarchic? **Two-zeros at most**.

Frampton, Glashow and Marfatia'02; Xing '02; Kageyama, Kaneko, Shimoyama and Tanimoto. '02; Frigerio and Smirnov. '02; Desai, Roy and Vaucher '03; Guo and Xing. '03.

More General Textures: A Simple Example

Karlsruher Institut für Technologie

Two-zero textures for $M_\nu \sim Y_\Delta$:

$$\mathbf{A_1}: \begin{pmatrix} 0 & 0 & a \\ 0 & y & c \\ a & c & z \end{pmatrix}, \quad \mathbf{A_2}: \begin{pmatrix} 0 & b & 0 \\ b & y & c \\ 0 & c & z \end{pmatrix}, \quad \mathbf{B_1}: \begin{pmatrix} x & b & 0 \\ b & 0 & c \\ 0 & c & z \end{pmatrix}, \quad \mathbf{B_2}: \begin{pmatrix} x & 0 & a \\ 0 & y & c \\ a & c & 0 \end{pmatrix},$$

$$\mathbf{B_3}: \begin{pmatrix} x & 0 & a \\ 0 & 0 & c \\ a & c & z \end{pmatrix}, \quad \mathbf{B_4}: \begin{pmatrix} x & b & 0 \\ b & y & c \\ 0 & c & 0 \end{pmatrix}, \quad \mathbf{C}: \begin{pmatrix} x & b & a \\ b & 0 & c \\ a & c & 0 \end{pmatrix}.$$

- A_1, A_2, B_2, B_3 implies no **tree-level** $\mu \to e$ transition.

  See, Chun, Lee, Park, 03'; Akeroyd, Aoki, Sugiyama, 09'; Kitabayashi, 20'; Ardu, Davidson, Lavignac, 24', for related discussions.

- No symmetry protection: $\mu \to e$ at one loop.

  Also, no consistent zero texture at all scales (see back-up).

More General Textures: A Simple Example

Lowest possible cut-off scale: $\Lambda_\Delta \equiv m_\Delta/(2|Y_{\Delta\mu\tau}|)$ (in TeV)

	$\mathbf{A_1}$	$\mathbf{A_2}$	$\mathbf{B_1}$	$\mathbf{B_2}$	$\mathbf{B_3}$	$\mathbf{B_4}$	$\mathbf{C}$
$\mu \to \bar{e}ee$	$8.3^{+0.6}_{-0.5}$	$10.1^{+0.8}_{-0.9}$	22^{+7}_{-9}	$3.3^{+0.7}_{-0.8}$	$3.1^{+0.5}_{-0.6}$	20^{+5}_{-9}	75^{+49}_{-58}
$\mu \to e\gamma$	$28.0^{+2.3}_{-1.9}$	$29.4^{+2.9}_{-4.0}$	$9.3^{+2.8}_{-4.0}$	$9.8^{+3.5}_{-5.0}$	$8.9^{+2.6}_{-4.0}$	$9.5^{+3.3}_{-5.0}$	38^{+18}_{-35}
$\tau \to \bar{\mu}\mu\mu$	$6.1^{+0.7}_{-0.7}$	$6.0^{+0.4}_{-0.4}$	$0.5^{+0.2}_{-0.2}$	$2.9^{+0.9}_{-1.3}$	$0.2^{+0.2}_{-0.2}$	$2.7^{+0.8}_{-1.3}$	$0.4^{+0.5}_{-0.3}$
$\tau \to \bar{\mu}ee$	$0.64^{+0.04}_{-0.06}$	$0.63^{+0.05}_{-0.06}$	$5.7^{+0.2}_{-0.2}$	$5.7^{+0.2}_{-0.2}$	$5.7^{+0.2}_{-0.2}$	$5.7^{+0.2}_{-0.2}$	$6.4^{+1.5}_{-1.7}$

- 3σ uncertainties from neutrino oscillation data;
- Λ_Δ possibly low as $5 \sim 6$ TeV, as good as $U(2)^5$.

More General Textures: A Simple Example

Karlsruher Institut für Technologie

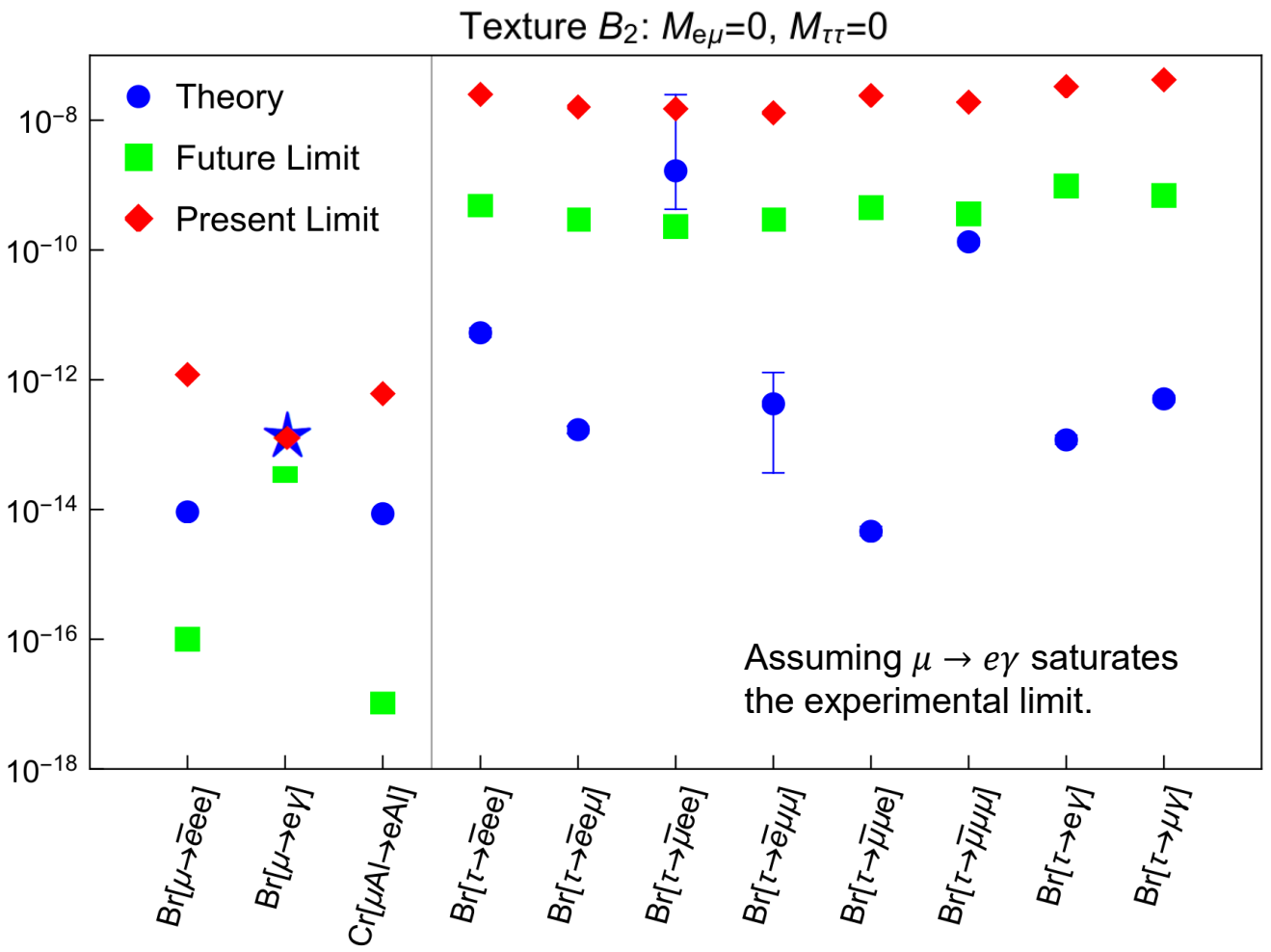
Key predictions:

- Smoking gun signature:
- Same for B_3.
- Other textures: only $\mu \to e$.
- Compare with $U(2)^5$ EFT:

Covone, Morell, and Tinari. ’25

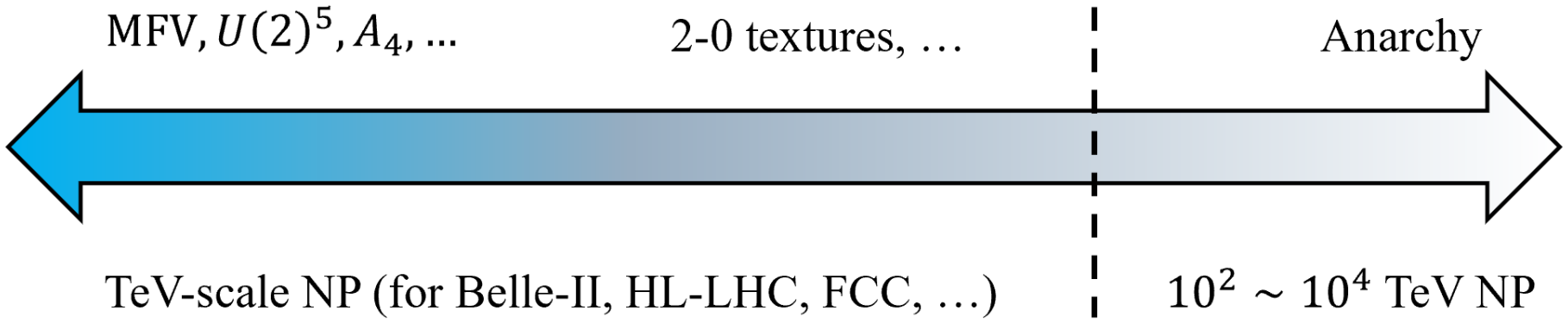
$\mathcal{B}(\tau \to \mu\bar{e}e)$	$< 7.6 \times 10^{-10}$
$\mathcal{B}(\tau \to \mu\bar{\mu}\mu)$	$< 1.2 \times 10^{-9}$

(Opposite Sign)



Conclusion and Outlook

- Motivating rare tau decay search with same sign electrons.
- Demonstrating diverse flavor textures for TeV NP.
- Diversity → New organizing principles? e.g. minimal GUT.



Karlsruher Institut für Technologie

Thanks

Additional Slides

Particle	BESIII	STCF (1 ab^{-1})	Belle II (50 ab^{-1} on $\Upsilon(4S)$)	LHCb (300 fb^{-1})	CEPC (TDR)
$\tau^+\tau^-$	3.6×10^8	3.6×10^9	4.5×10^{10}		1.2×10^{11}

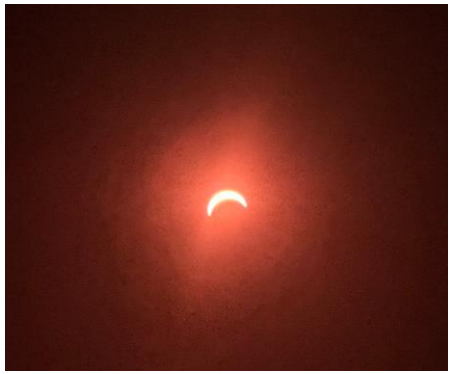
Measurement	Current	Belle II	FCC	CEPC prelim.
$BR(\tau \to \mu\mu\mu)$	$< 2.1 \times 10^{-8}$	3.6×10^{-10}	1.4×10^{-11}	10^{-10}
$BR(\tau \to \mu\gamma)$	$< 4.4 \times 10^{-8}$	6.9×10^{-9}	1.2×10^{-9}	10^{-10}

CEPC white paper 2412.19743

- # of τ: Belle II $\gg$ BESIII or Super Tau-Charm Factory (STCF).
- CEPC can do a little bit better.
- Large improvements only on FCC-ee, but not by orders of magnitude.

Additional Slides

Examples



$$\frac{R_{\rm sun}}{D_{\rm sun}} = \frac{6.955\times10^{8}\ \text{m}}{(1.496\pm0.025)\times10^{11}\ \text{m}} = 0.00465 \pm 0.00008$$

$$\frac{R_{\rm moon}}{D_{\rm moon}} = \frac{1.738\times10^{6}\ \text{m}}{(3.844\pm0.214)\times10^{8}\ \text{m}} = 0.00452 \pm 0.00028$$

Eclipses happen.

Argument from S. Martin pre-SUSY 2021

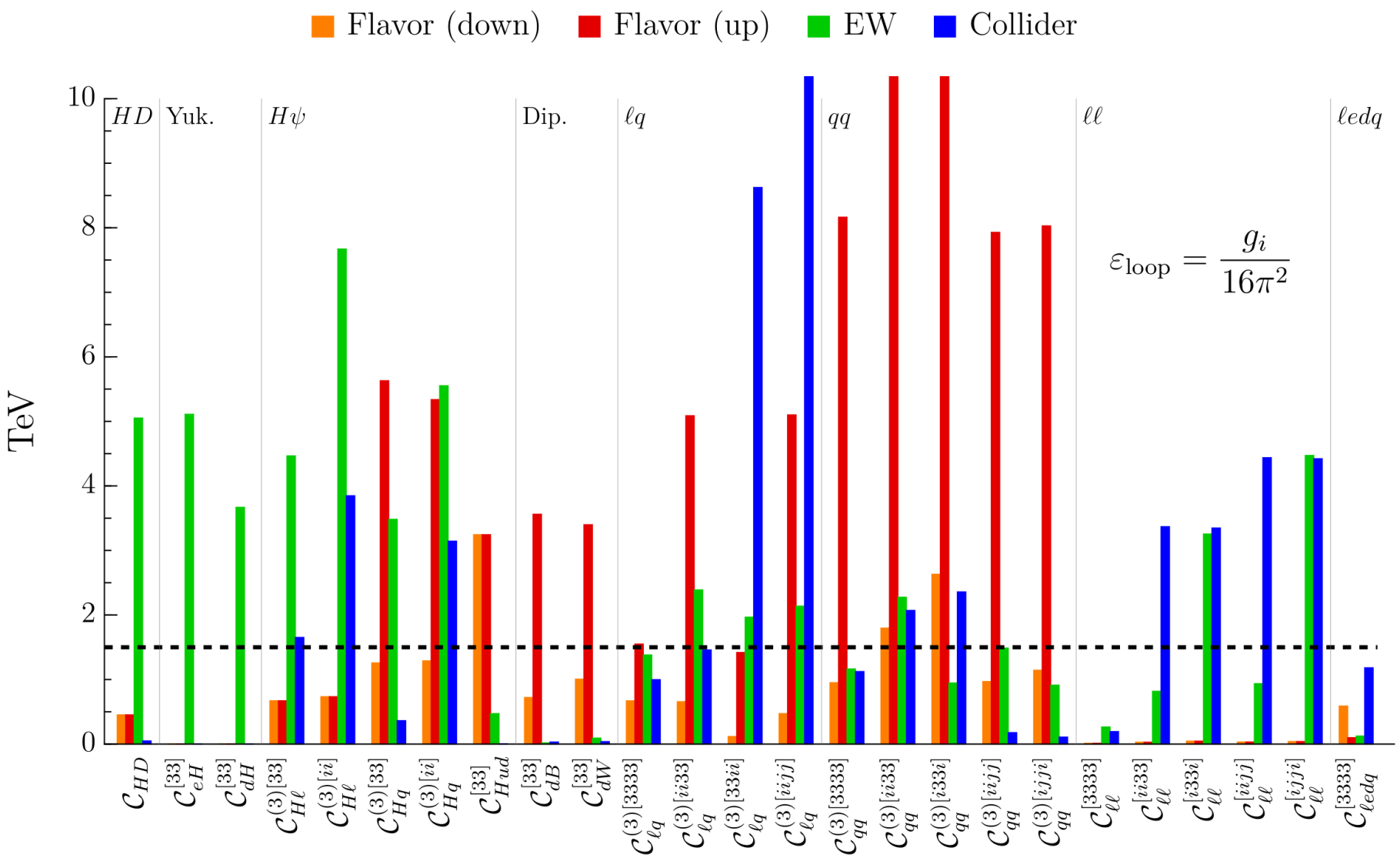
$$\theta_c = \arctan\sqrt{\frac{m_d}{m_s}} - \arctan\sqrt{\frac{m_u}{m_c}}$$

Weinberg. '77; De Rujula, Georgi and Glashow. '77; Wilczek and Zee. '77; Fritzsch. '77.

$$M_D = \begin{pmatrix} 0 & \sqrt{m_d m_s} \\ \sqrt{m_d m_s} & m_s \end{pmatrix}, \quad M_U = \begin{pmatrix} 0 & \sqrt{m_u m_c} \\ \sqrt{m_u m_c} & m_c \end{pmatrix}.$$

Sym protected only after extending the SM

Additional Slides



Additional Slides

Collider search:

$$pp \to \Delta^{++}(\to \ell^+\ell^+)\Delta^{--}(\to \ell^-\ell^-).$$

$$\mu^+\mu^- \to \mu^-\ell^-\Delta^{++}$$

$$\mu^+\mu^+ \to \Delta^{++}(\gamma)$$

$$\mu^+\mu^+ \to \ell_i^+\ell_j^+ \quad \text{(high } p_T \text{ tail)}$$

Tailor made for μTRISTAN

Additional Slides

Minimal Type-II seesaw:

$$\mathcal{L} = \mathcal{L}_{\rm SM} + {\rm Tr}\left[(D_\mu\Delta)^\dagger(D^\mu\Delta)\right] - m_\Delta^2 {\rm Tr}(\Delta\Delta^\dagger) - V^{(4)}(H,\Delta)$$
$$- \left(Y_\Delta \overline{\ell_L}\Delta i\tau_2 \ell_L^c - \mu_\Delta H^T i\tau_2 \Delta H + {\rm h.c.}\right),$$

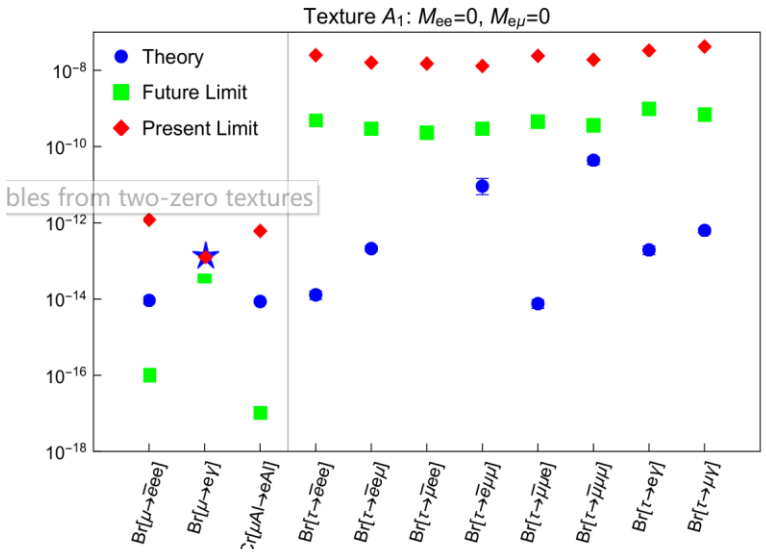
- Very Minimal extension to SM.
- Y_Δ directly correlates to M_ν.
- Vacuum suppressed neutrino mass.
- Charged lepton flavor violation beyond SM.

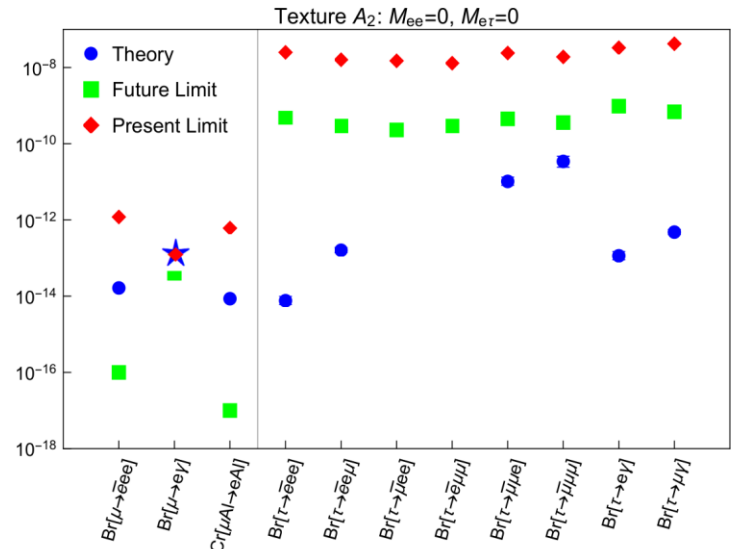
$$\Delta \equiv \begin{pmatrix} \Delta^-/\sqrt{2} & \Delta^0 \\ \Delta^{--} & -\Delta^-/\sqrt{2} \end{pmatrix}.$$

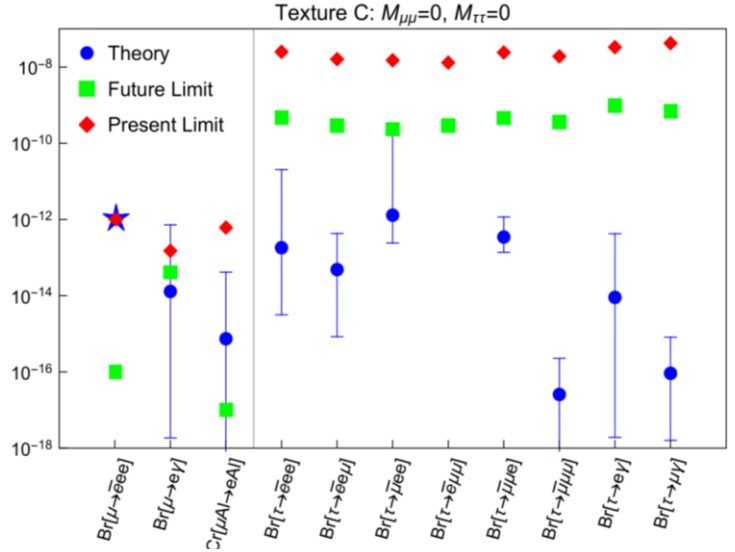
$$M^\nu = \sqrt{2} Y_\Delta v_\Delta = \mu_\Delta Y_\Delta \frac{v^2}{m_\Delta^2}.$$

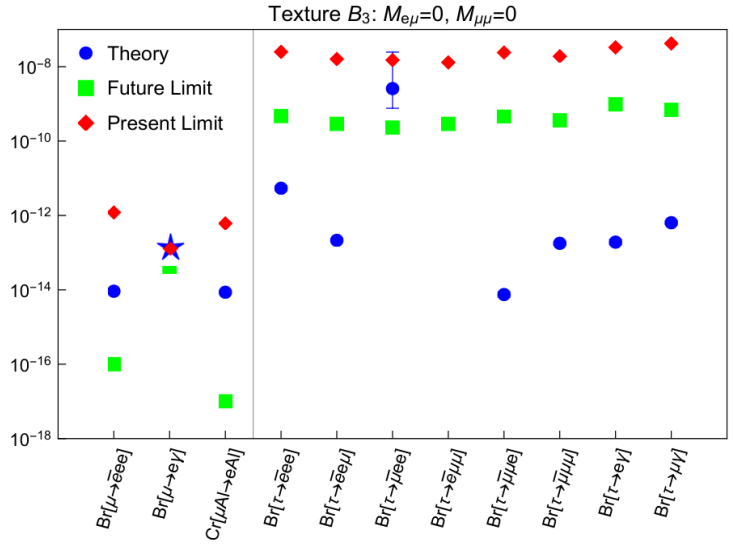
$$\delta\mathcal{L}^{\rm d=6}_{\rm tree} = \frac{1}{2m_\Delta^2} Y_{\Delta jl} Y^*_{\Delta ik} (\overline{\ell_i}\gamma_\mu P_L \ell_j)(\overline{\ell_k}\gamma^\mu P_L \ell_l),$$

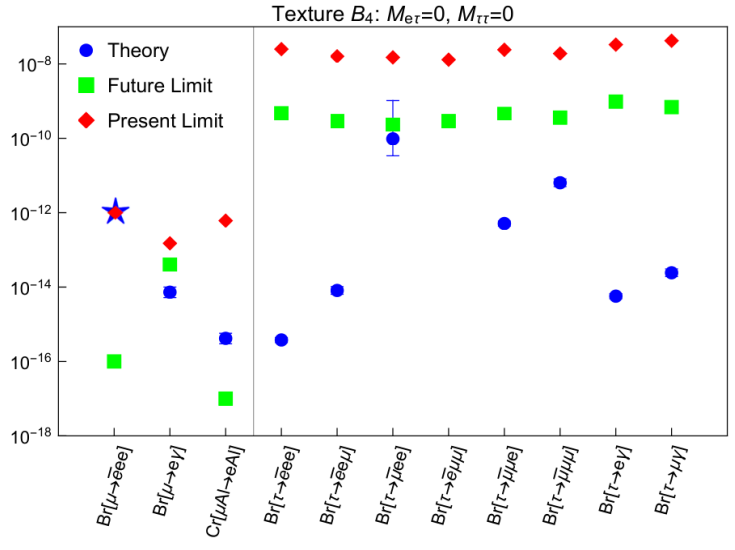
Additional Slides

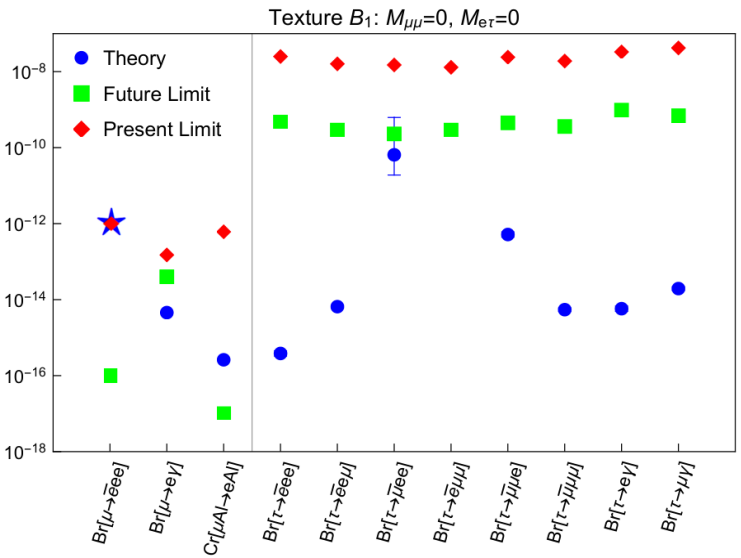












Additional Slides

EFT and matching:

$$\delta\mathcal{L}^{\rm d=6}_{\rm tree} = \frac{1}{2m_\Delta^2} Y_{\Delta jl} Y^*_{\Delta ik} (\overline{\ell_i}\gamma_\mu P_L \ell_j)(\overline{\ell_k}\gamma^\mu P_L \ell_l)\,,$$

$$\delta\mathcal{L}^{\rm d=6}_{\rm FV} = \mathcal{C}^{ik}_{\rm dipole}\left(\overline{\ell_i}\sigma^{\mu\nu} P_R \ell_k\right) F_{\mu\nu} + \mathcal{C}^{ik}_{\rm penguin}(\overline{\ell_i}\gamma_\mu P_L \ell_k)\left(\overline{\ell_l}\gamma^\mu \ell_l + \frac{2}{3}\overline{u_l}\gamma^\mu u_l - \frac{1}{3}\overline{d_l}\gamma^\mu d_l\right)$$
$$+\ \mathcal{C}^{ijkl}_{\rm box}(\overline{\ell_i}\gamma_\mu P_L \ell_j)(\overline{\ell_k}\gamma^\mu P_L \ell_l)\,,$$

$$\mathcal{C}^{ik}_{\rm penguin} = \frac{e^2}{12\pi^2 m_\Delta^2} Y_{\Delta\, ij} Y^*_{\Delta\, kj}\left(\frac{1}{12} + f\left(\frac{q^2}{m_\Delta^2}, \frac{m_j^2}{m_\Delta^2}\right)\right),$$

$$\mathcal{C}^{ik}_{\rm dipole} = \frac{3e}{64\pi^2 m_\Delta^2}(Y_\Delta Y_\Delta^\dagger)_{ik} m_k\,.$$

$$\mathcal{C}^{ijkl}_{\rm box} = -\frac{1}{32\pi^2 m_\Delta^2}(Y_\Delta Y_\Delta^\dagger)_{ij}(Y_\Delta Y_\Delta^\dagger)_{kl} - \frac{1}{8\pi^2 m_\Delta^2}(Y_\Delta Y_\Delta^\dagger)_{il}(Y_\Delta Y_\Delta^\dagger)_{kj}\,,$$

Additional Slides

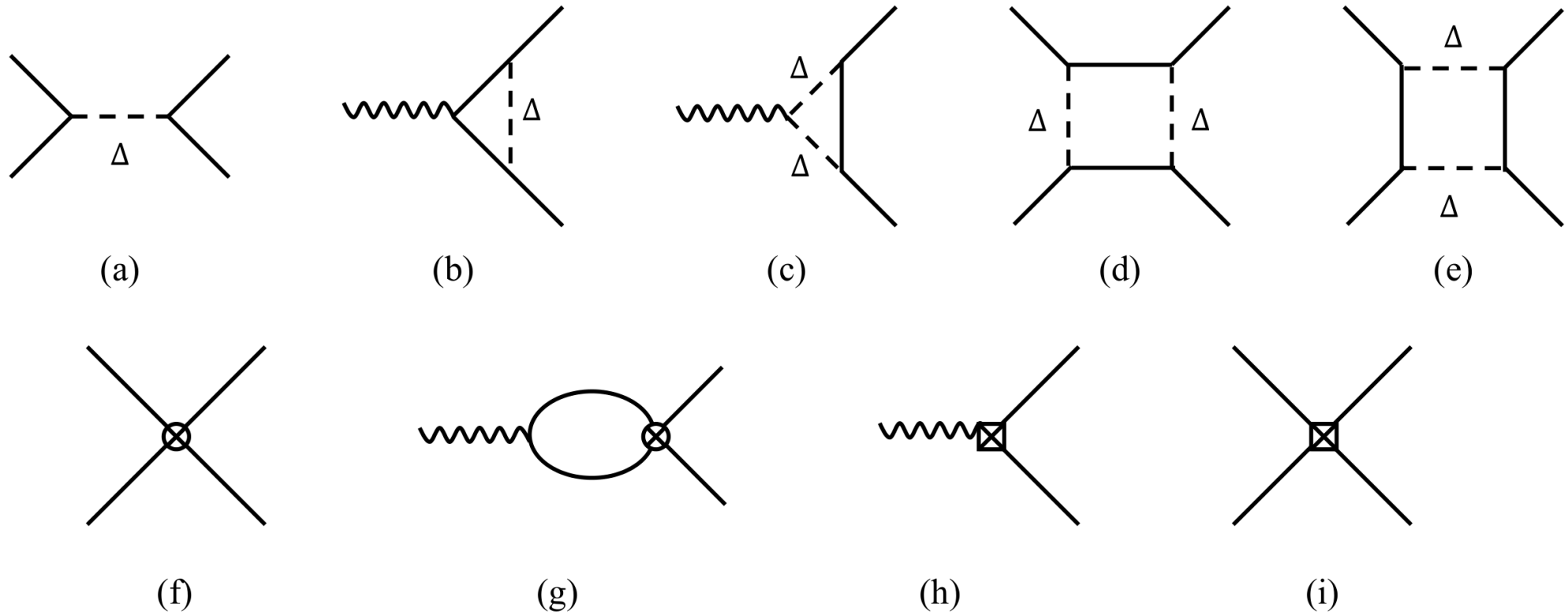
Two-zero textures for $M_\nu \sim Y_\Delta$:

$$\mathbf{A_1}: \begin{pmatrix} 0 & 0 & 0.43 \\ 0 & 1.07 & 1 \\ 0.43 & 1 & 1.12 \end{pmatrix}, \quad \mathbf{A_2}: \begin{pmatrix} 0 & 0.45 & 0 \\ 0.45 & 1.15 & 1 \\ 0 & 1 & 1.09 \end{pmatrix}, \quad \mathbf{B_1}: \begin{pmatrix} 0.83 & 0.10 & 0 \\ 0.10 & 0 & 1 \\ 0 & 1 & 0.42 \end{pmatrix}, \quad \mathbf{B_2}: \begin{pmatrix} 0.87 & 0 & 0.07 \\ 0 & 0.31 & 1 \\ 0.07 & 1 & 0 \end{pmatrix},$$

$$\mathbf{B_3}: \begin{pmatrix} 0.84 & 0 & 0.07 \\ 0 & 0 & 1 \\ 0.07 & 1 & 0.38 \end{pmatrix}, \quad \mathbf{B_4}: \begin{pmatrix} 0.87 & 0.06 & 0 \\ 0.06 & 0.29 & 1 \\ 0 & 1 & 0 \end{pmatrix}, \quad \mathbf{C}: \begin{pmatrix} 0.74 & 0.06 & 0.40 \\ 0.06 & 0 & 1 \\ 0.40 & 1 & 0 \end{pmatrix}.$$

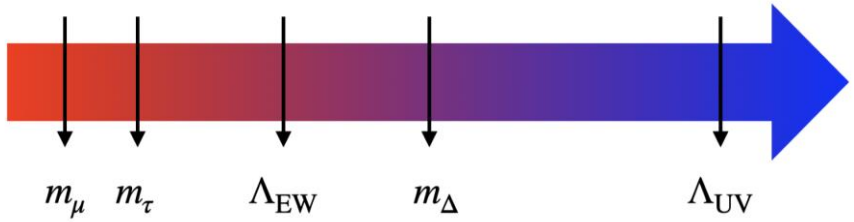
Additional Slides

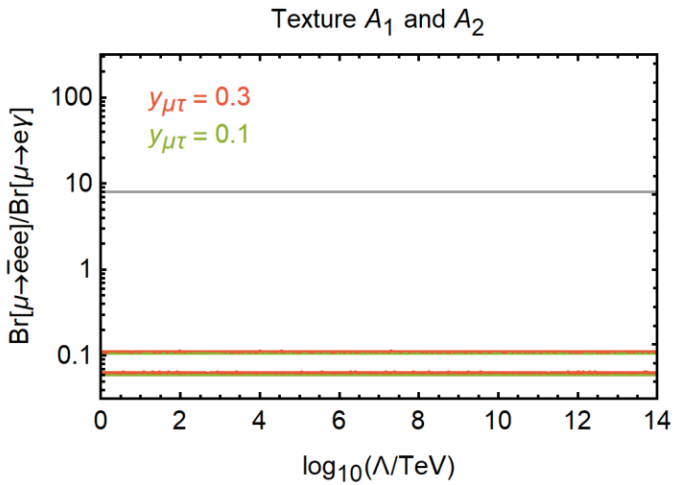
EFT and matching:

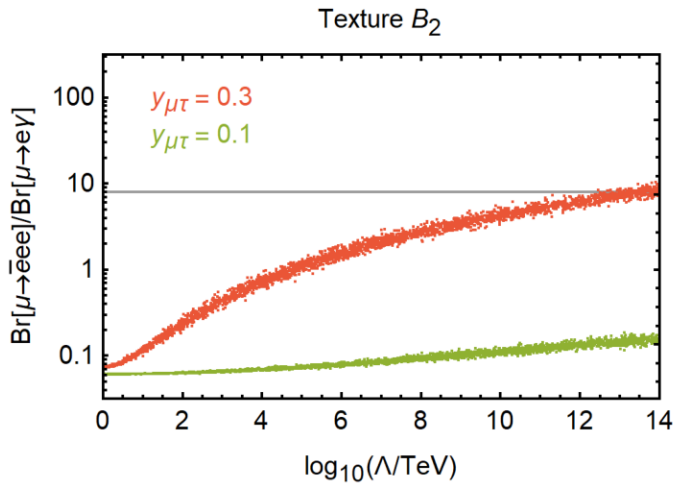


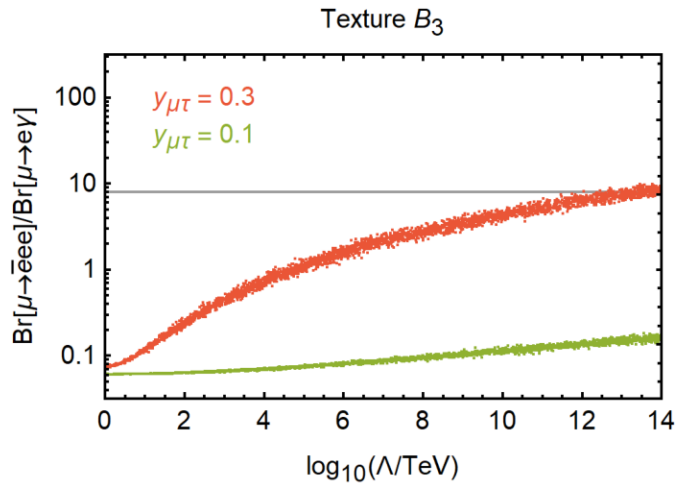
Additional Slides

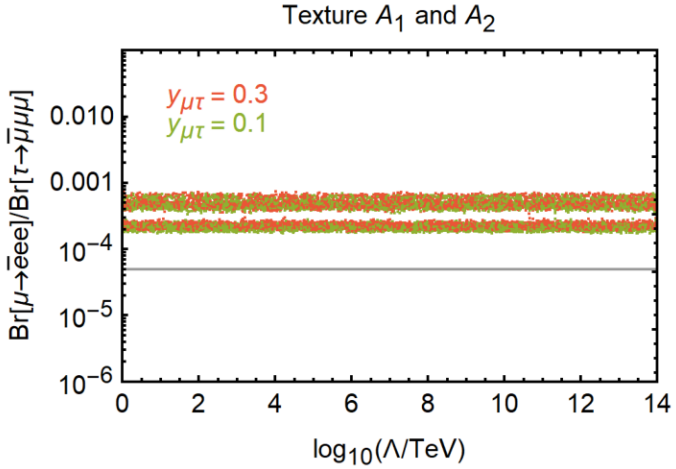
Running above m_Δ

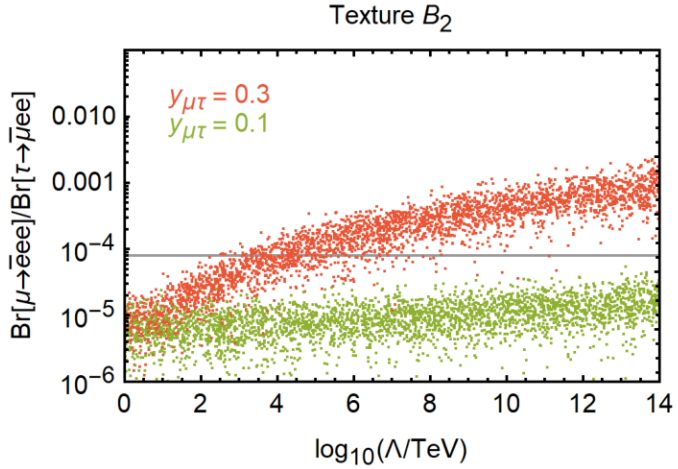


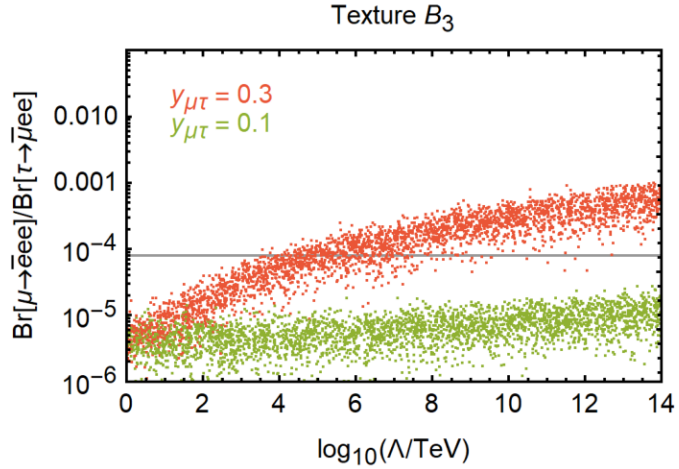












Additional Slides

