University of Glasgow

Flavour deconstruction: From the electroweak scale to the GUT scale

Invisibles24,
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Based on:

MFN, Stephen F. King, [2305.07690] hep-ph, JHEP 08 (2023) 020
MFN, Stephen F. King and Avelino Vicente, [2311.05683] hep-ph, JHEP 05 (2024) 130
MFN, Stephen F. King and Avelino Vicente, [2404.12442] hep-ph, to appear in JHEP

Tri-hypercharge: an example of flavour deconstruction

- Flavour deconstruction: SM is embedded in a gauge symmetry that contains a separate factor for each fermion family:

$$G_{\text{universal}} \times G_1 \times G_2 \times G_3$$

[Salam 79', Rajpoot 81', Li and Ma 81', Georgi 82' … Craig et al 11', Bordone et al 17', Greljo et al 18', Fuentes-Martín et al, 20', Davighi et al 23' …]

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A simple example:

$$SU(3)_c \times SU(2)_L \times U(1)_{Y_1} \times U(1)_{Y_2} \times U(1)_{Y_3} \longrightarrow Y_{\text{SM}} \equiv Y = Y_1 + Y_2 + Y_3$$

Field	$U(1)_{Y_i}$
q_i	$1/6$
u_i^c	$-2/3$
d_i^c	$1/3$
ℓ_i	$-1/2$
e_i^c	1

q_1	q_2	q_3
u_1^c	u_2^c	u_3^c
d_1^c	d_2^c	d_3^c
ℓ_1	ℓ_2	ℓ_3
e_1^c	e_2^c	e_3^c
		H_3

- Light families are massless in first approximation:

$$\mathcal{L} = y_t q_3 H_3 u_3^c + y_b q_3 H_3 d_3^c + y_\tau \ell_3 H_3 e_3^c + \text{h.c.}$$

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		$H_3^{u,d}$

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$+\text{h.c.}$

- Type II 2HDM can take care of $m_{b,\tau}/m_t$ hierarchies via

$$\tan\beta = v_u/v_d \approx \lambda^{-2} \simeq 20$$

Tri-hypercharge: EFT

$$\mathcal{L}_d = \begin{pmatrix} q_1 & q_2 & q_3 \end{pmatrix} \begin{pmatrix} \approx 0 & \approx 0 & \approx 0 \\ \approx 0 & \approx 0 & \approx 0 \\ \approx 0 & \approx 0 & 1 \end{pmatrix} \begin{pmatrix} d_1^c \\ d_2^c \\ d_3^c \end{pmatrix} H_3^d$$

- E.g. $q_2 H_3^d d_2^c \sim (0, \frac{1}{2}, -\frac{1}{2})$ and $q_2 H_3^d d_3^c \sim (0, \frac{1}{6}, -\frac{1}{6})$ are forbidden by tri-hypercharge (gauge) symmetry

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- Add "23 hyperons" $\phi_{\ell 23} \sim (0, -\frac{1}{2}, \frac{1}{2})$ and $\phi_{q23} \sim (0, -\frac{1}{6}, \frac{1}{6})$ $\quad U(1)_{Y_1} \times U(1)_{Y_2} \times U(1)_{Y_3}$

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- Add "12 hyperons" $\phi_{\ell 12} \sim (-\frac{1}{2}, \frac{1}{2}, 0)$ and $\phi_{q12} \sim (-\frac{1}{6}, \frac{1}{6}, 0)$

$$U(1)_{Y_1} \times U(1)_{Y_2} \times U(1)_{Y_3}$$

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- When these four hyperons (scalars) get VEVs, SM flavour structure is dynamically generated (also in up and charged lepton sectors)

Neutrino masses and mixings also included!

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Heavy messengers needed for Λs!

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Example model

$$Y_d = \begin{pmatrix} c^d_{11}\frac{\phi_{\ell 12}}{M_{D_{13}}}\frac{\phi_{\ell 23}}{M_{D_{12}}} & c^d_{12}\frac{\phi_{q12}}{M_{D_{13}}}\frac{\phi_{\ell 23}}{M_{D_{23}}} & c^d_{13}\frac{\phi_{q12}}{M_{D_{13}}}\frac{\phi_{q23}}{M_{D_{23}}} \\ c^d_{21}\frac{\phi_{\ell 12}}{M_{D_{12}}}\frac{\tilde{\phi}_{q12}}{M_{D_{13}}}\frac{\phi_{\ell 23}}{M_{D_{23}}} & c^d_{22}\frac{\phi_{\ell 23}}{M_{D_{23}}} & c^d_{23}\frac{\phi_{q23}}{M_{D_{23}}} \\ \approx 0 & \approx 0 & c^d_{33} \end{pmatrix}$$

$$Y_u = Y_d(d \to u, D \to U) \qquad Y_e = Y_d(d \to e, q \to \ell, D \to E)$$

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$$\boxed{\frac{\langle\phi_{23}\rangle}{\langle\phi_{12}\rangle} \sim \lambda^3 \approx 0.01} \longrightarrow \text{Highly non-generic}$$

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Spectrum up to $\mathcal{O}(1)$ variations

E

$\mathcal{O}(10^4\ \text{TeV})$ — $M_{U_{12,13},D_{12,13},E_{12,13}}$

$SU(3)_c \times SU(2)_L \times U(1)_{Y_1} \times U(1)_{Y_2} \times U(1)_{Y_3}$

Z'_{12} ↓

$\mathcal{O}(1000\ \text{TeV})$ — $v_{12} \sim \langle \phi_{q12} \rangle, \langle \phi_{\ell 12} \rangle, M_{U_{23},D_{23},E_{23}}$

$SU(3)_c \times SU(2)_L \times U(1)_{Y_{12} \equiv Y_1 + Y_2} \times U(1)_{Y_3}$

Z'_{23} ↓

$\mathcal{O}(10\ \text{TeV})$ — $v_{23} \sim \langle \phi_{q23} \rangle, \langle \phi_{\ell 23} \rangle$

$SU(3)_c \times SU(2)_L \times U(1)_{Y \equiv Y_1 + Y_2 + Y_3}$

$174\ \text{GeV}$ — $v_{\text{SM}} \sim \langle H_3^{u,d} \rangle$

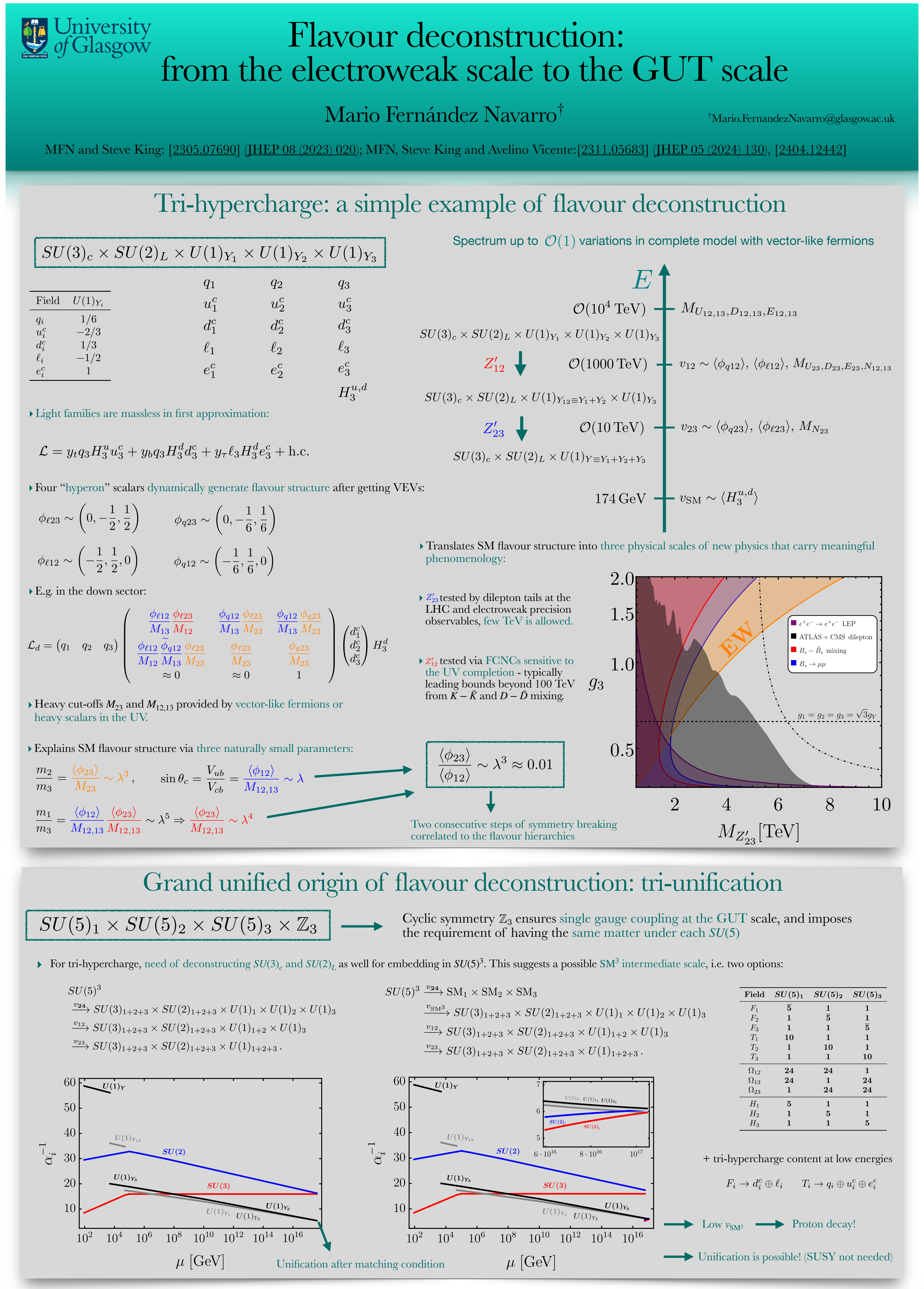
Correlations and lots of pheno!

Take home messages

✓ A simple option for flavour deconstruction is the tri-hypercharge group:

$$SU(3)_c \times SU(2)_L \times U(1)_{Y_1} \times U(1)_{Y_2} \times U(1)_{Y_3}$$

- Translates SM flavour structure into three simple and correlated NP scales that carry meaningful pheno. The lowest scale may be close to TeV.
- Flavour deconstruction may arise from gauge unified frameworks!
- See all this and more in my poster!
- Also CERN BSM forum on 1st August



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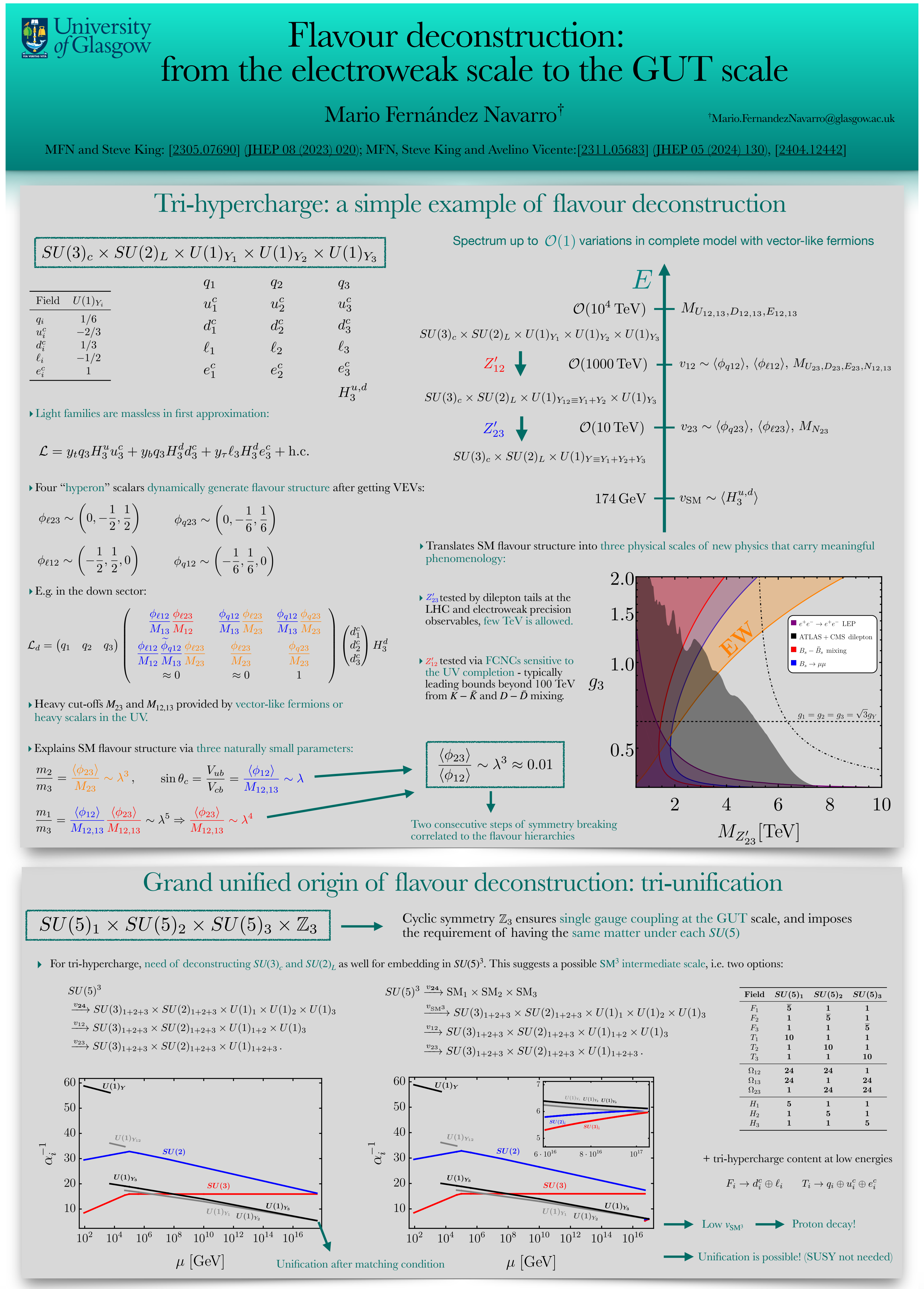

Backup: Phenomenology

$$SU(3)_c \times SU(2)_L \times U(1)_{Y_1} \times U(1)_{Y_2} \times U(1)_{Y_3}$$
$$\xrightarrow{v_{12}} SU(3)_c \times SU(2)_L \times U(1)_{Y_1+Y_2} \times U(1)_{Y_3} + Z'_{12}$$
$$\xrightarrow{v_{23}} SU(3)_c \times SU(2)_L \times U(1)_{Y_1+Y_2+Y_3} + Z'_{23} + Z'_{12}$$

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- Z'_{23} is lighter and protected by accidental $U(2)^5$ symmetry

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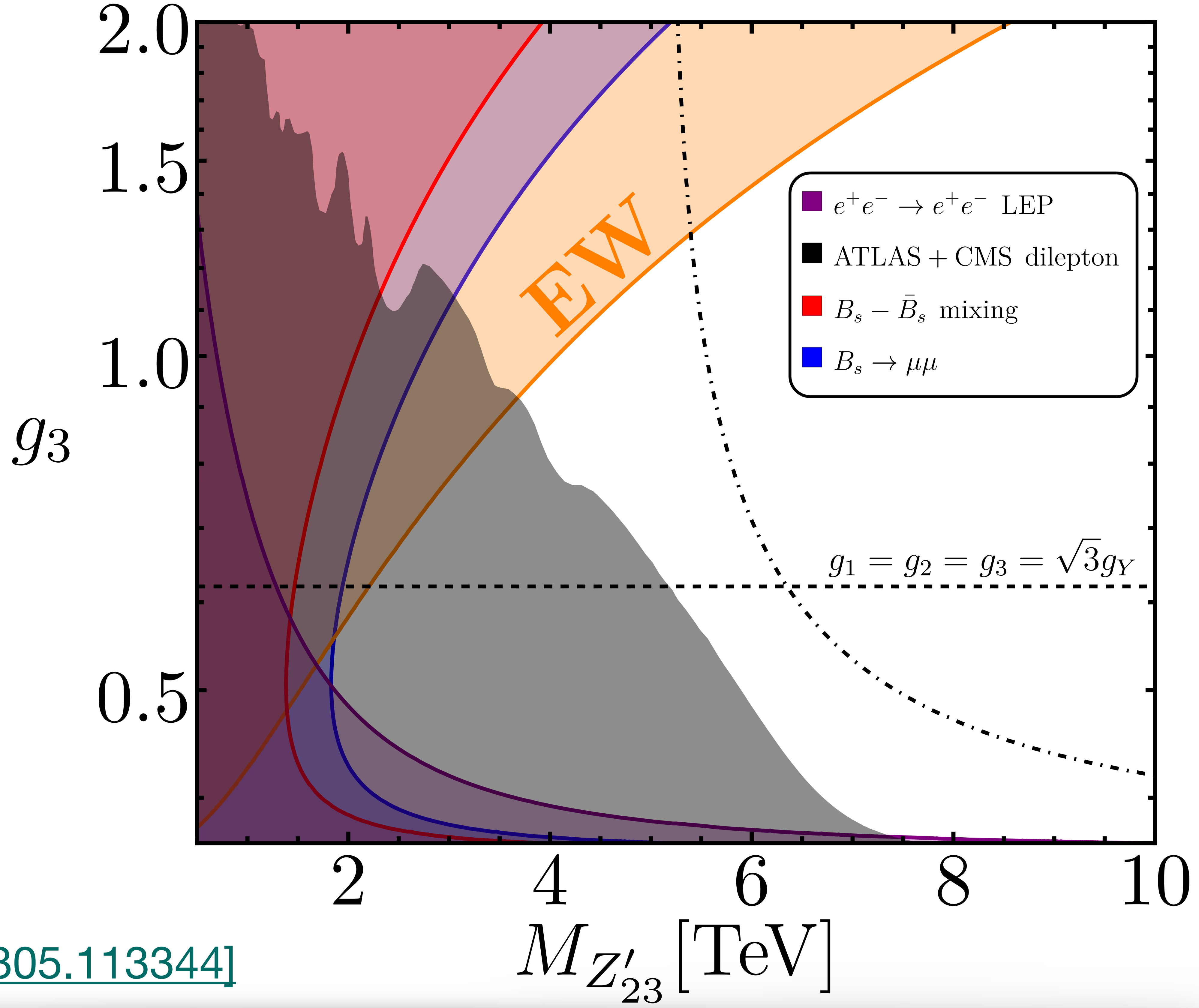
- Z'_{23} is lighter and protected by accidental $U(2)^5$ symmetry
  - Tested by dilepton tails at hadron colliders or EWPOs (independent of UV-completion) - bounds of order TeV

$$g_{12} = \frac{g_1 g_2}{\sqrt{g_1^2 + g_2^2}} \qquad g_Y = \frac{g_{12} g_3}{\sqrt{g_{12}^2 + g_3^2}} \simeq 0.36\,(M_Z)$$



[see EW global fit and FCC-ee projections in Davighi and Stefanek, 2305.113344]

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$\overset{v_{12}}{\to} SU(3)_c \times SU(2)_L \times U(1)_{Y_1+Y_2} \times U(1)_{Y_3} + Z'_{12}$

$\overset{v_{23}}{\to} SU(3)_c \times SU(2)_L \times U(1)_{Y_1+Y_2+Y_3} + Z'_{23} + Z'_{12}$

- Z'_{12} is heavier and tested via FCNCs sensitive to the different complete models - bounds typically beyond 100 TeV

Model	Observable	Mediator	Bound (TeV)
1	$K-\bar{K}$ (Re)	Z'_{12}	$M_{Z'_{12}}/g_1 > 340 \times \lvert\mathrm{Re}\begin{bmatrix} c^d_{12} & c^d_{21} \\ c^d_{22} & c^d_{22}\end{bmatrix}\rvert$
	$K-\bar{K}$ (Im)	Z'_{12}	$M_{Z'_{12}}/g_1 > 3\cdot 10^3 \times \lvert\mathrm{Im}\begin{bmatrix} c^d_{12} & c^d_{21} \\ c^d_{22} & c^d_{22}\end{bmatrix}\rvert$
	$\mu \to e\gamma$	Z'_{12}	$M_{Z'_{12}}/g_1 > 30 \times \lvert c^e_{12}/c^e_{22}\rvert$
		Z'_{23}	$M_{Z'_{23}}/g_3 > 8 \times \lvert y^e_{62}(y^e_{65}y^e_{15})^*\rvert$
	$\mu \to 3\,e$	Z'_{12}	$M_{Z'_{12}}/g_1 > 30 \times \lvert c^e_{12}/c^e_{22}\rvert$
2	$D-\bar{D}$ (Re)	Z'_{12}	$M_{Z'_{12}}/g_1 > 150 \times \lvert\mathrm{Re}\begin{bmatrix} c^u_{12} & c^u_{21} \\ c^u_{22} & c^u_{22}\end{bmatrix}\rvert$
	$D-\bar{D}$ (Im)	Z'_{12}	$M_{Z'_{12}}/g_1 > 500 \times \lvert\mathrm{Im}\begin{bmatrix} c^u_{12} & c^u_{21} \\ c^u_{22} & c^u_{22}\end{bmatrix}\rvert$

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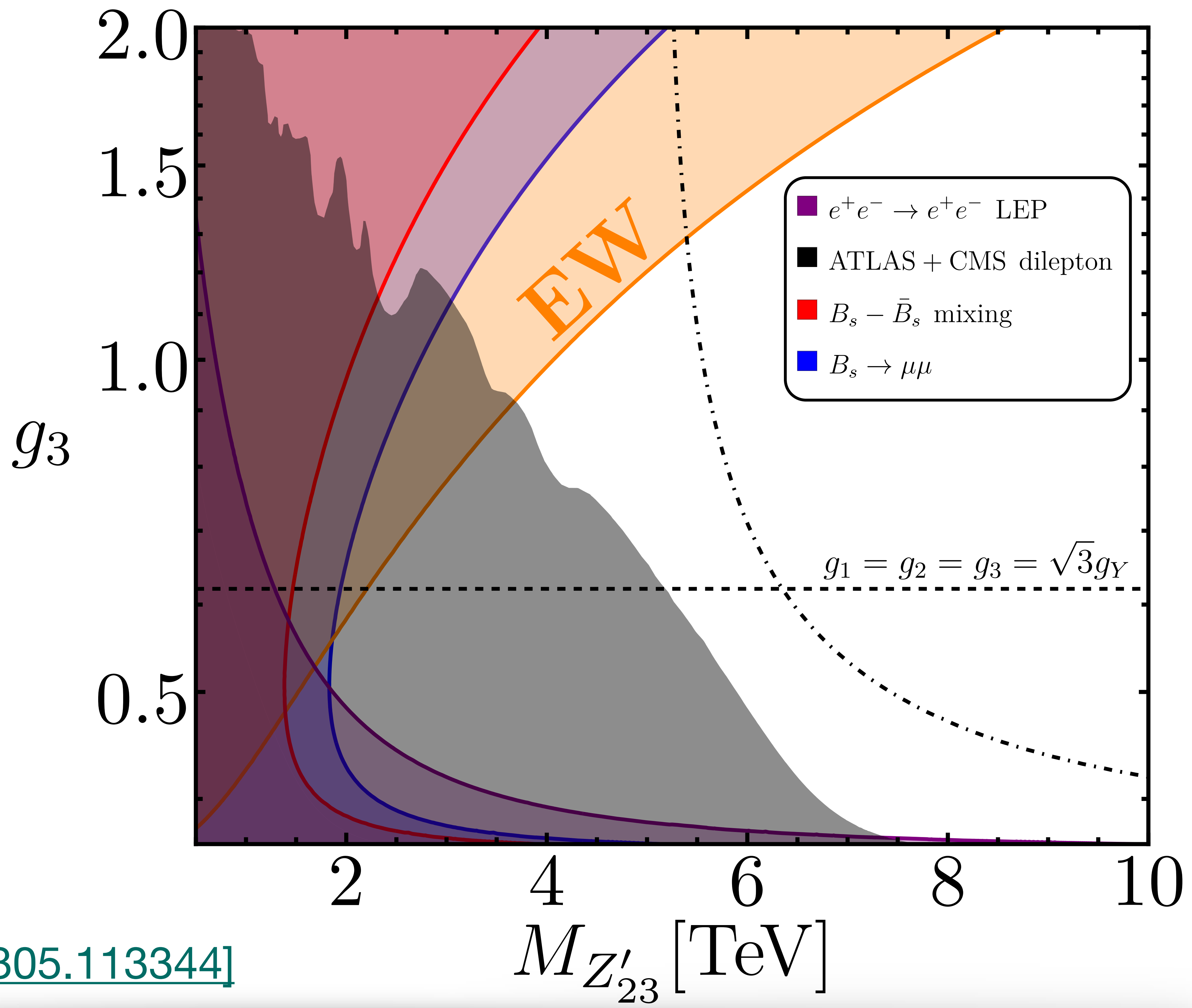
  - Tested by dilepton tails at hadron colliders or EWPOs (independent of UV-completion) - bounds of order TeV

$$g_{12} = \frac{g_1 g_2}{\sqrt{g_1^2+g_2^2}} \qquad g_Y = \frac{g_{12} g_3}{\sqrt{g_{12}^2+g_3^2}} \simeq 0.36\,(M_Z)$$



[see EW global fit and FCC-ee projections in Davighi and Stefanek, 2305.113344]

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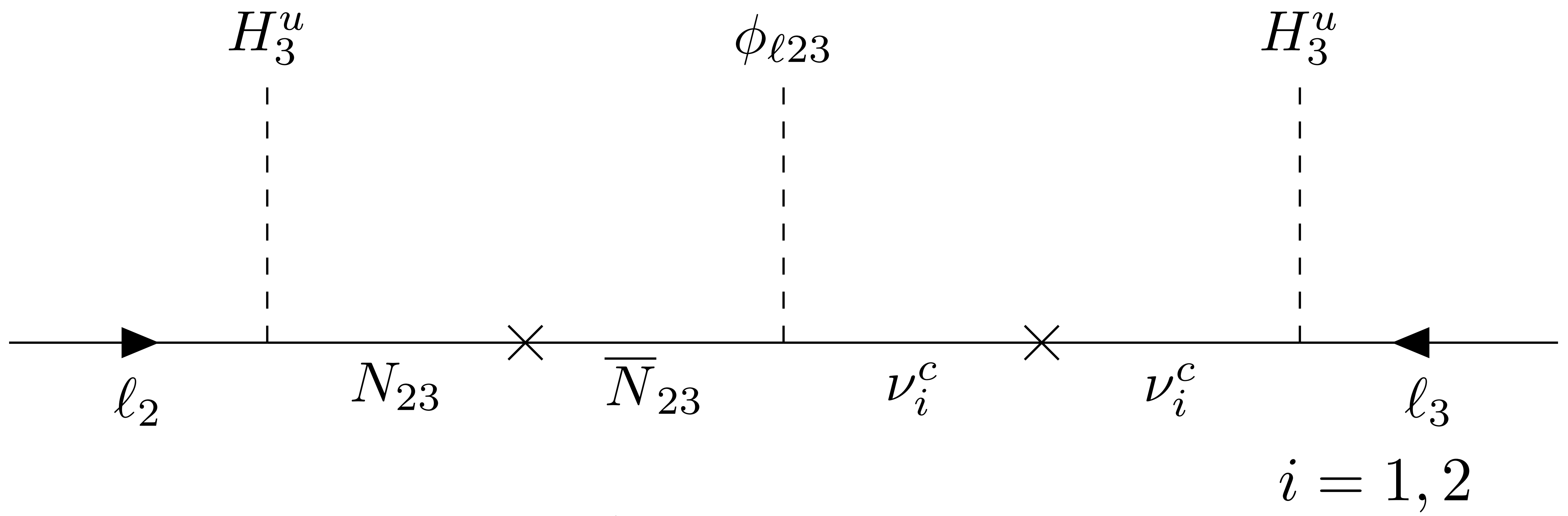

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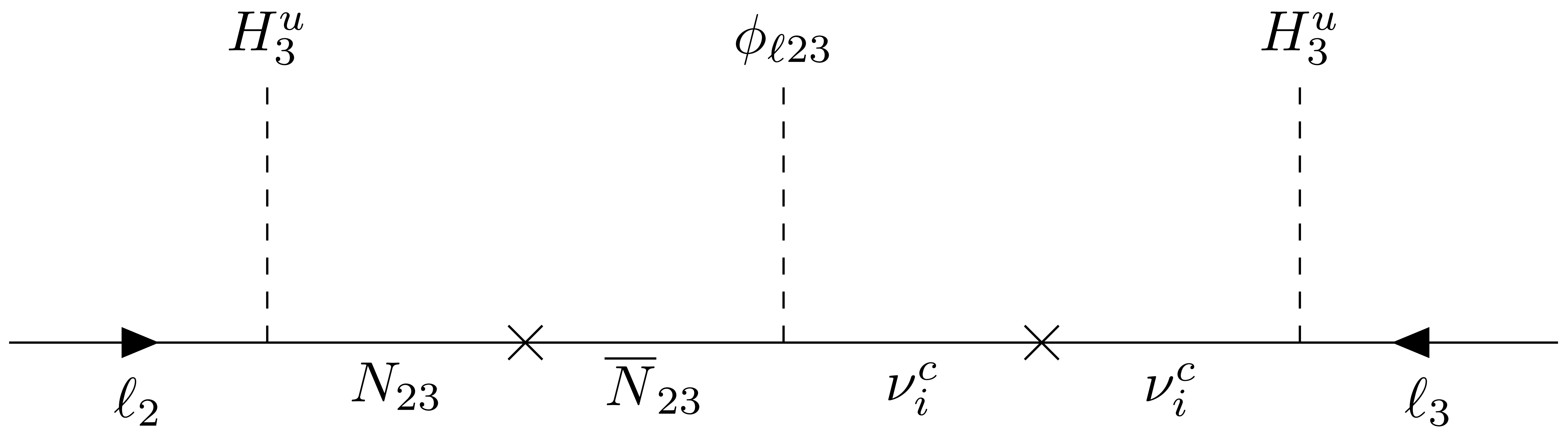

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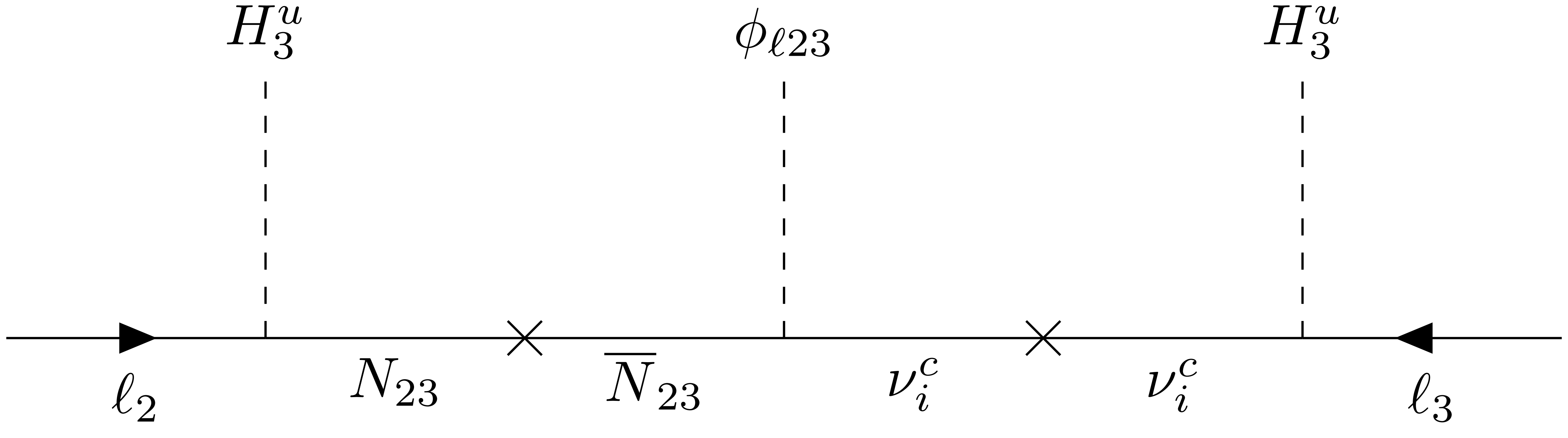

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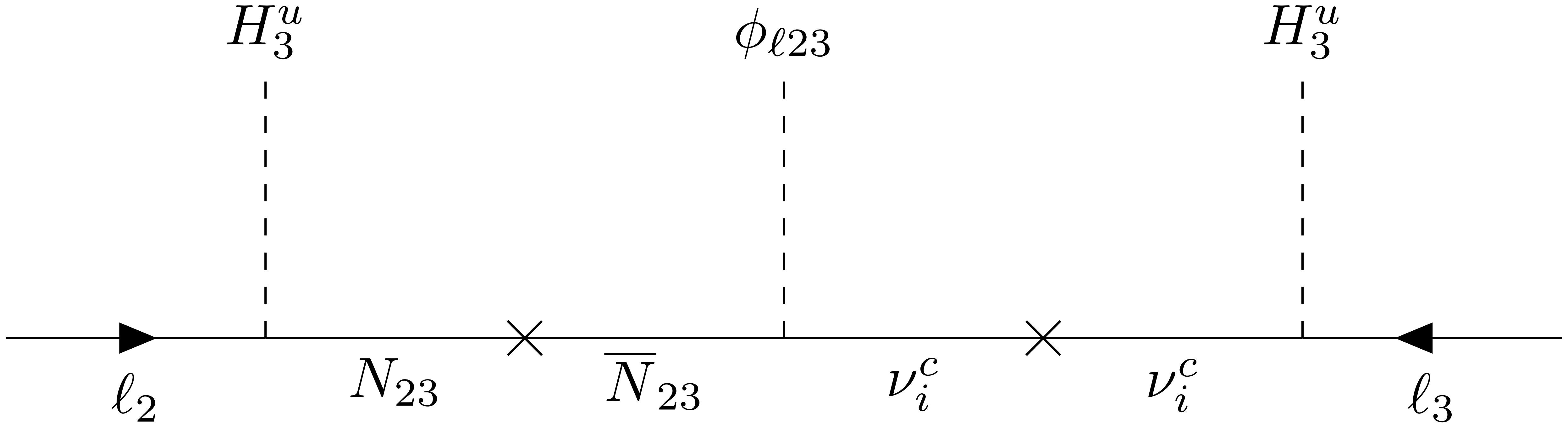

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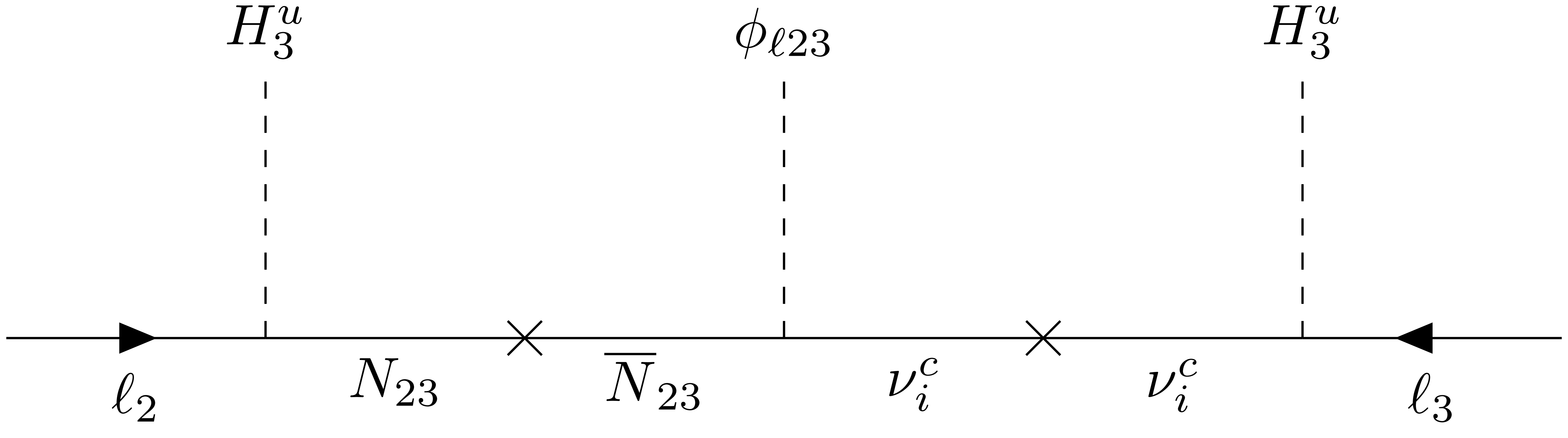

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- ✓ $M \approx 10^{15}$ GeV
- ✓ No need of small couplings nor $v_{12},\ v_{23}$ being very heavy
- ✓ No need of adding extra scalars
- ✓ $M_{N_{23}} \approx v_{23} \gtrsim \mathcal{O}(10\ \text{TeV})$

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[This talk]

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[Li and Ma, PRL 81'; Muller and Nandi, hep-ph/9602390 … Chiang *et al*, 0911.1480; Allwicher *et al*, 2011.01946; Davighi *et al* 2312.13346; Capdevila *et al*, 2401.00848 …]

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$$\boxed{SU(5)_1 \times SU(5)_2 \times SU(5)_3 \times \mathbb{Z}_3}$$

[Salam 79', Rajpoot 81', Georgi 82', de Rújula, Georgi, Glashow 84', $SU(3)_c \times SU(3)_L \times SU(3)_R \times \mathbb{Z}_3$ …]

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✓ Deconstructed GUTs may be the origin of low energy flavour deconstructed models.

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- Discontinuities due to gauge coupling matching conditions:

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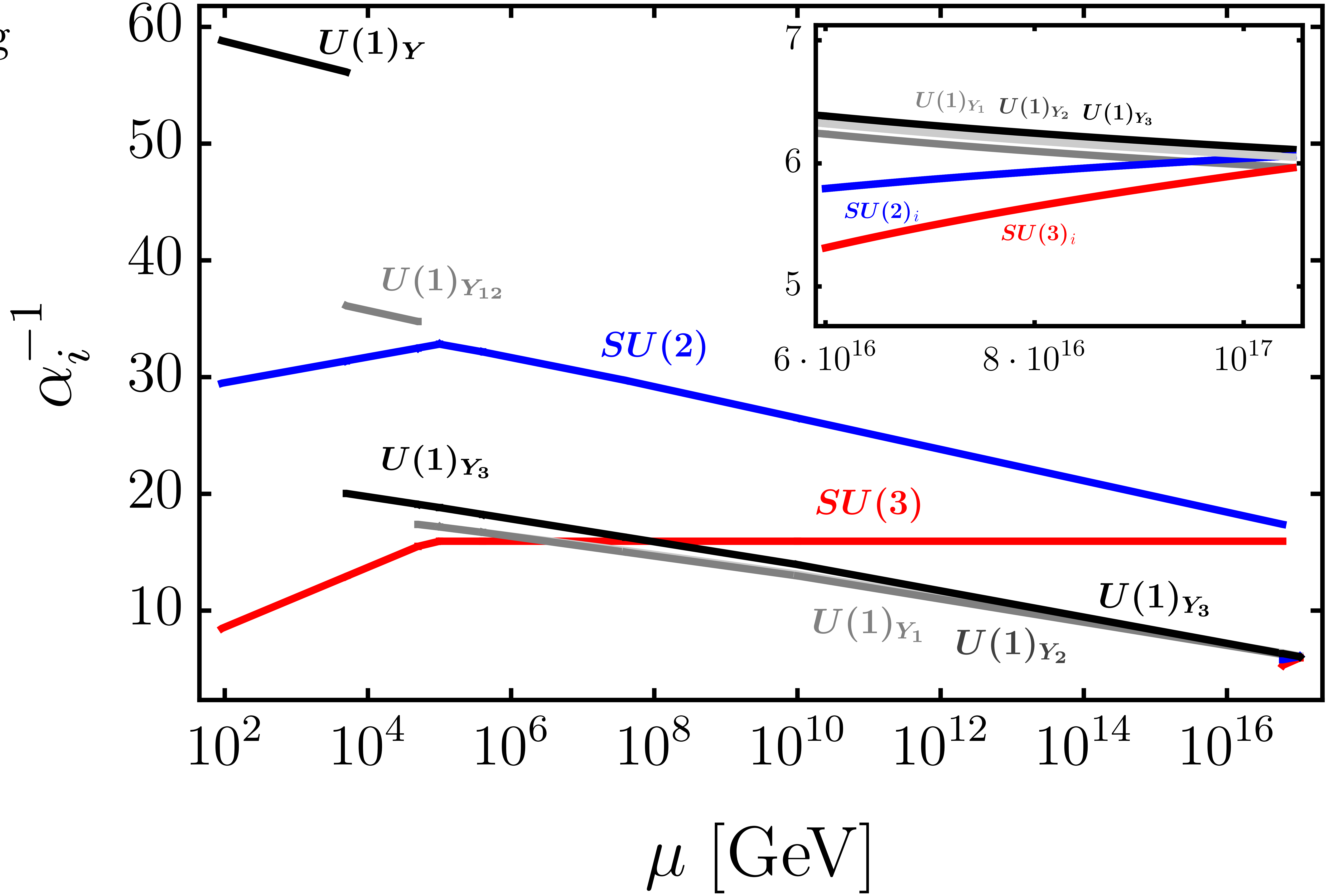

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- Colour octet $\Theta_i \sim (\mathbf{8},\mathbf{1},0)_i$ from cyclic $\mathbf{24}$ at v_{12} scale to bend SU(3) (non-SUSY).
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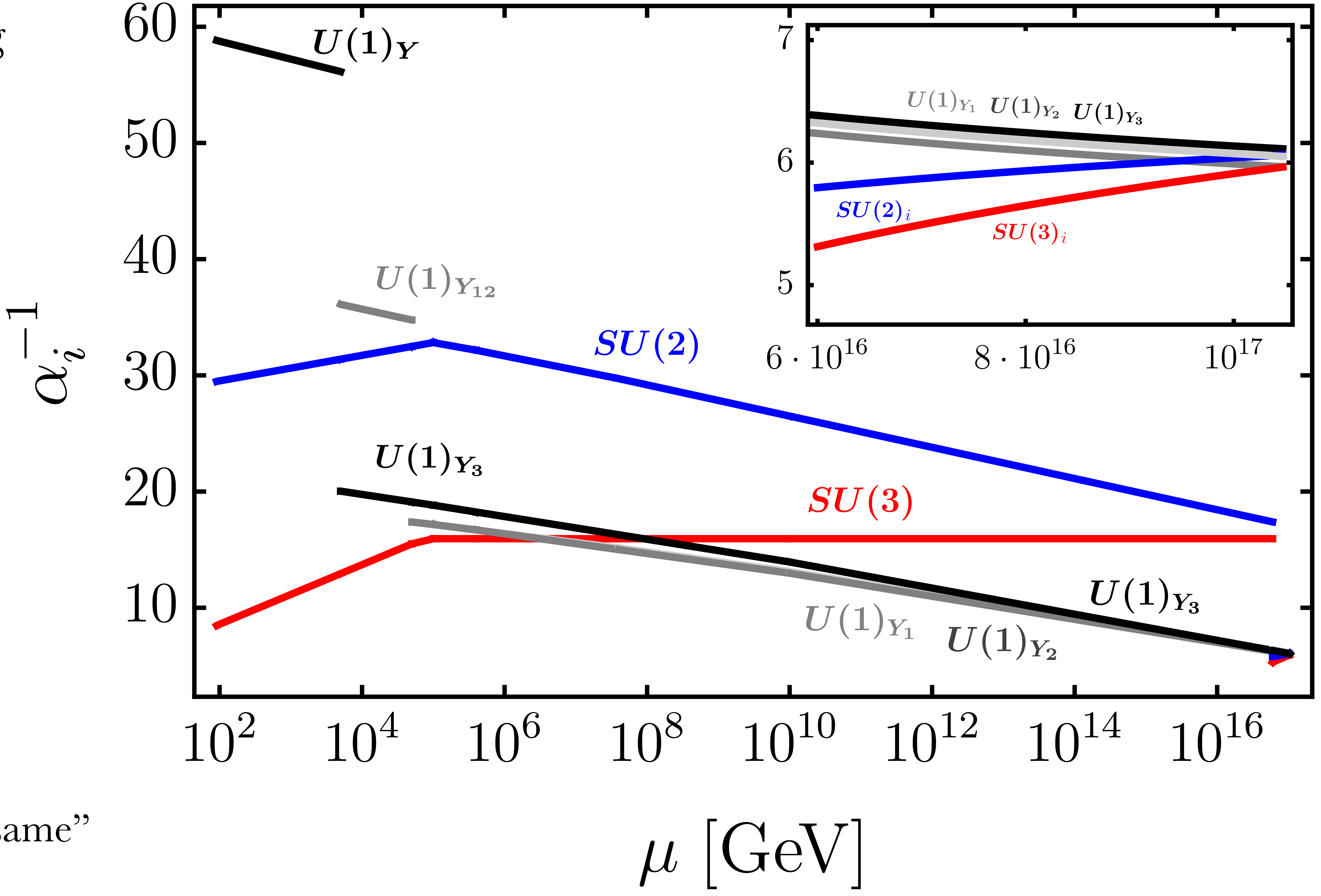

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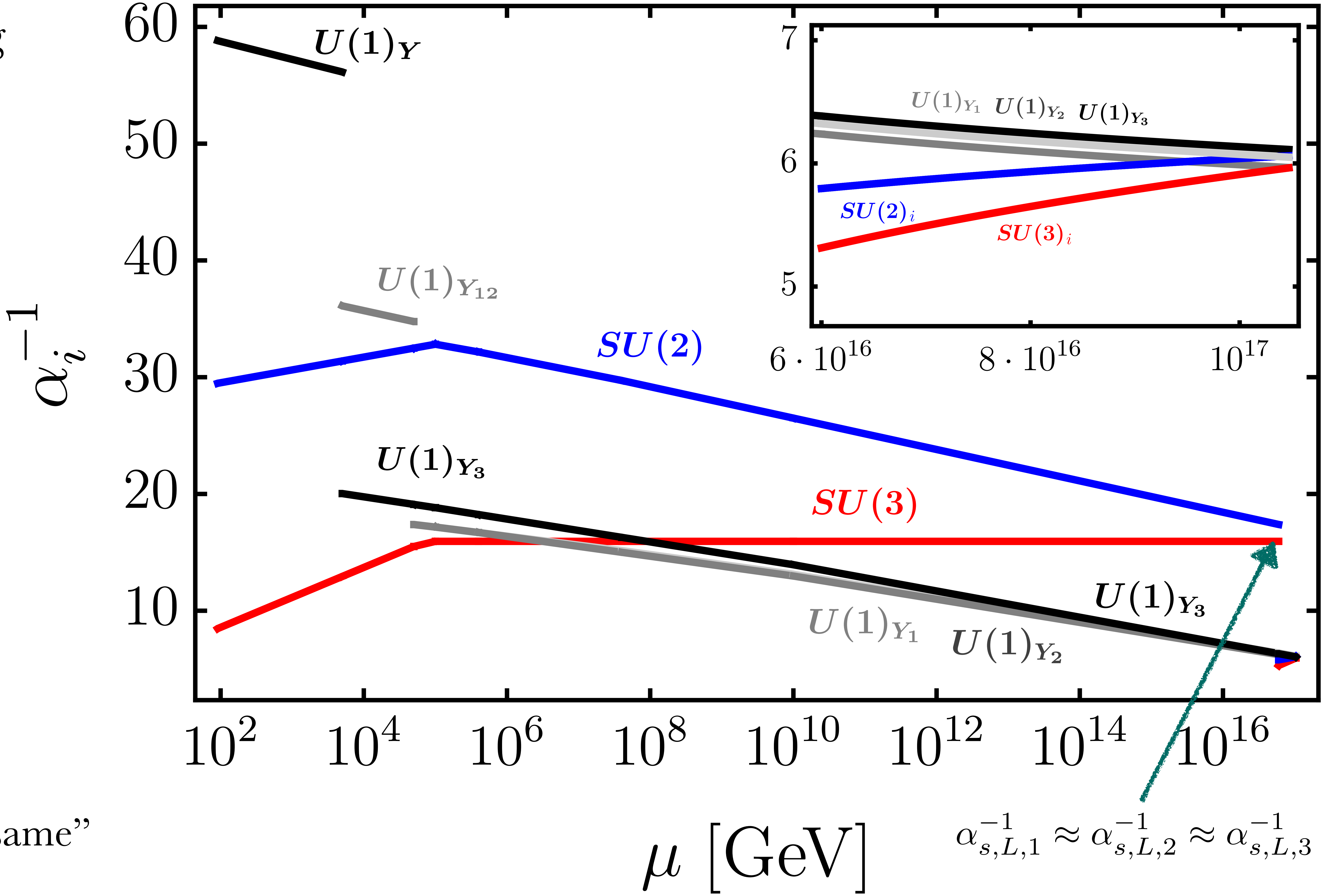

$v_{\mathrm{SM}^3} = 6 \times 10^{16}$ GeV → $M_{\mathrm{GUT}} = 10^{17}$ GeV