SU(5) aGUT: a minimal asymptotic grand unification model

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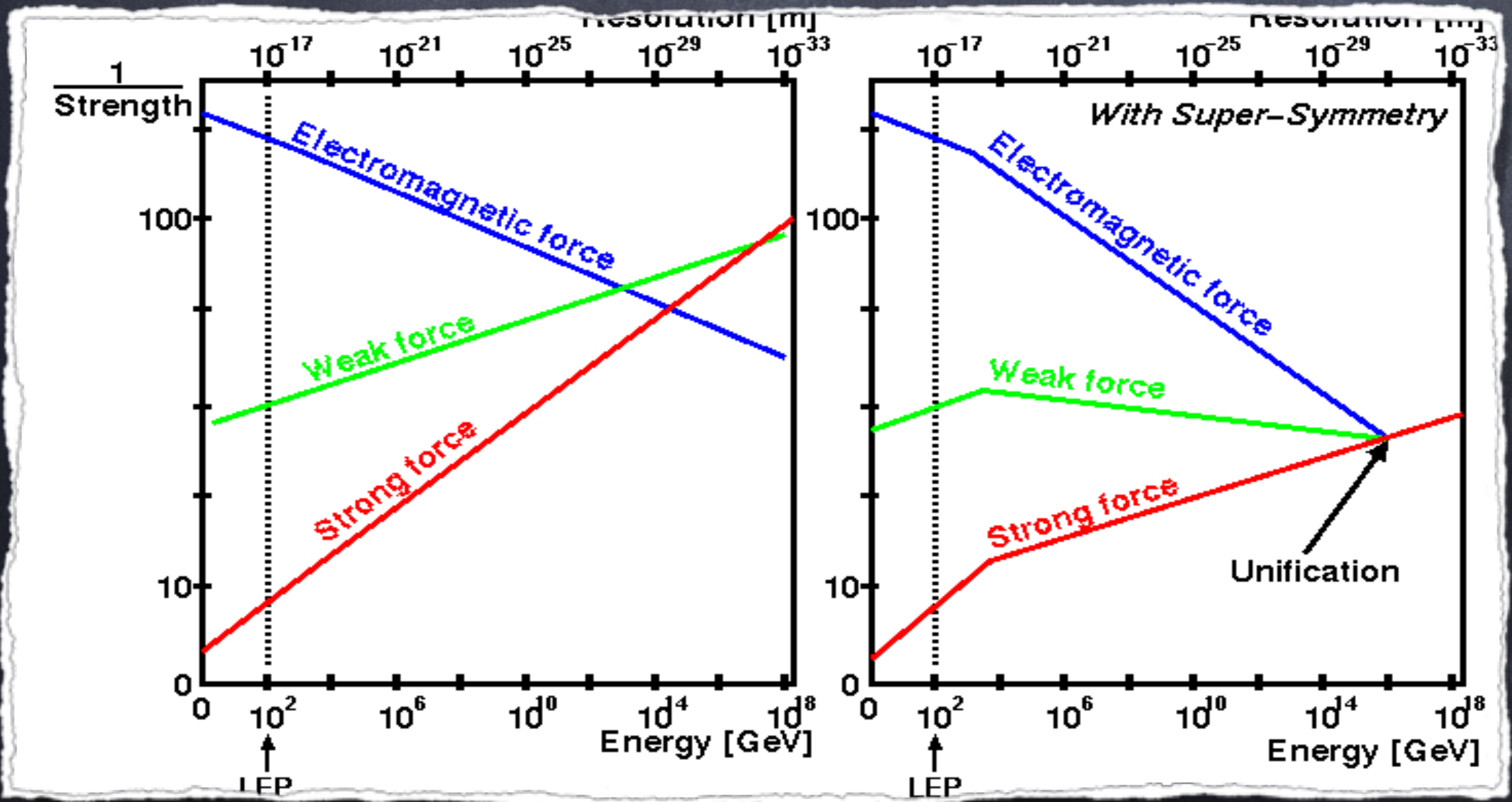
with A. Deandrea, C.Cot, A.Cornell: PRD 104 (2021) 7 [2012.14732]
+ M.Khojali and A.Abdalgabar, work in preparation

Traditional GUTs

- SM gauge couplings expected to be equal at the GUT scale
- supersymmetry helps building "realistic" models
- proton decay inevitable!



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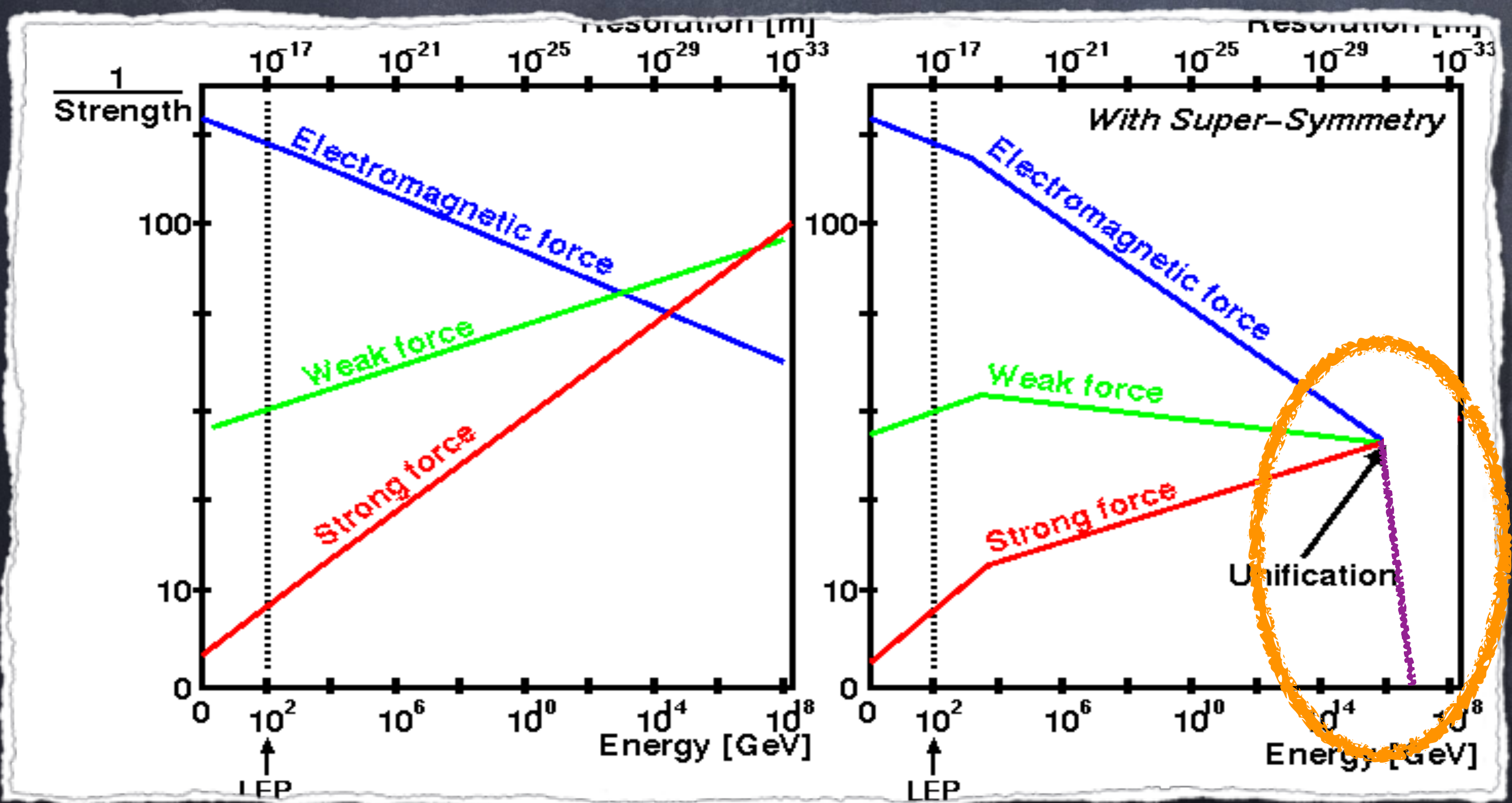
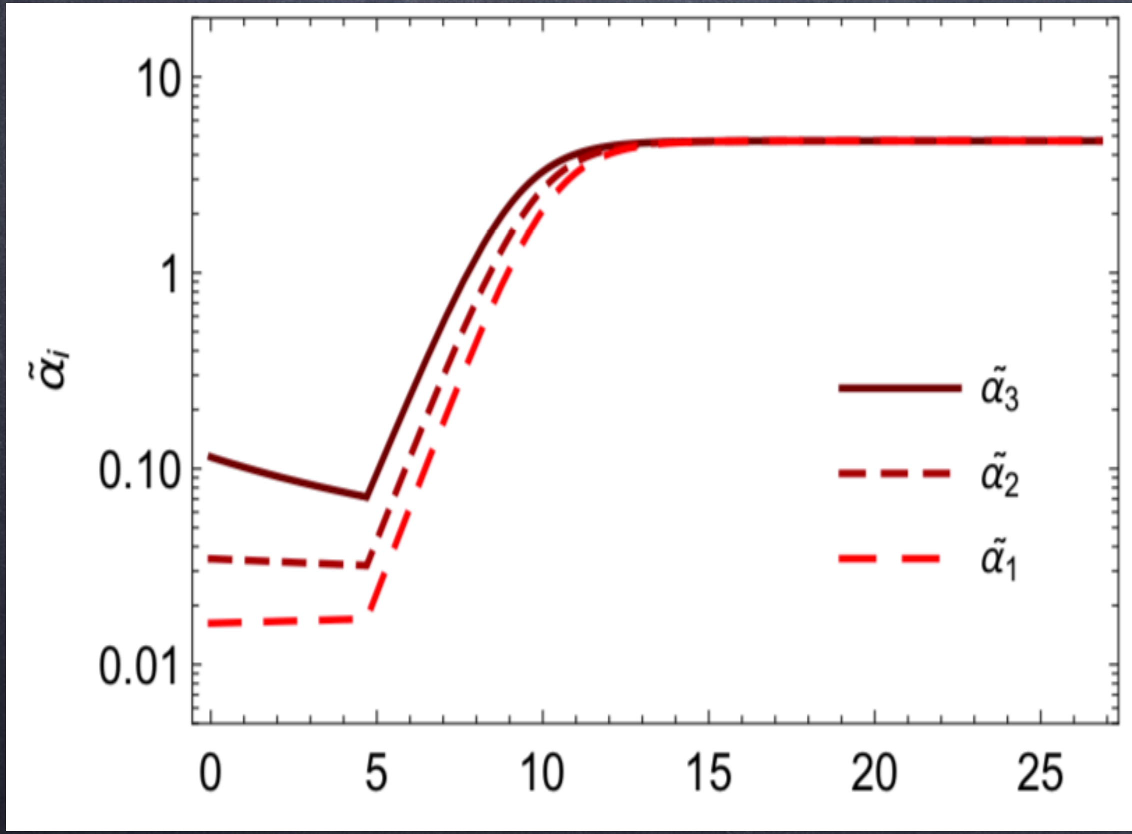


However:

- Large matter representations needed to break the gauge symmetry!
- Landau pole!!!!

asymptotic GUT (aGUT)

- Gauge couplings are never equal, but tend to the same UV fixed point!



A) Realised in asympt. safe theories (via large Nf resum)

(Intermediate Pati-Salam unification needed)

Molinaro et al, PRD 98 (2018) 11

asymptotic GUT (aGUT)

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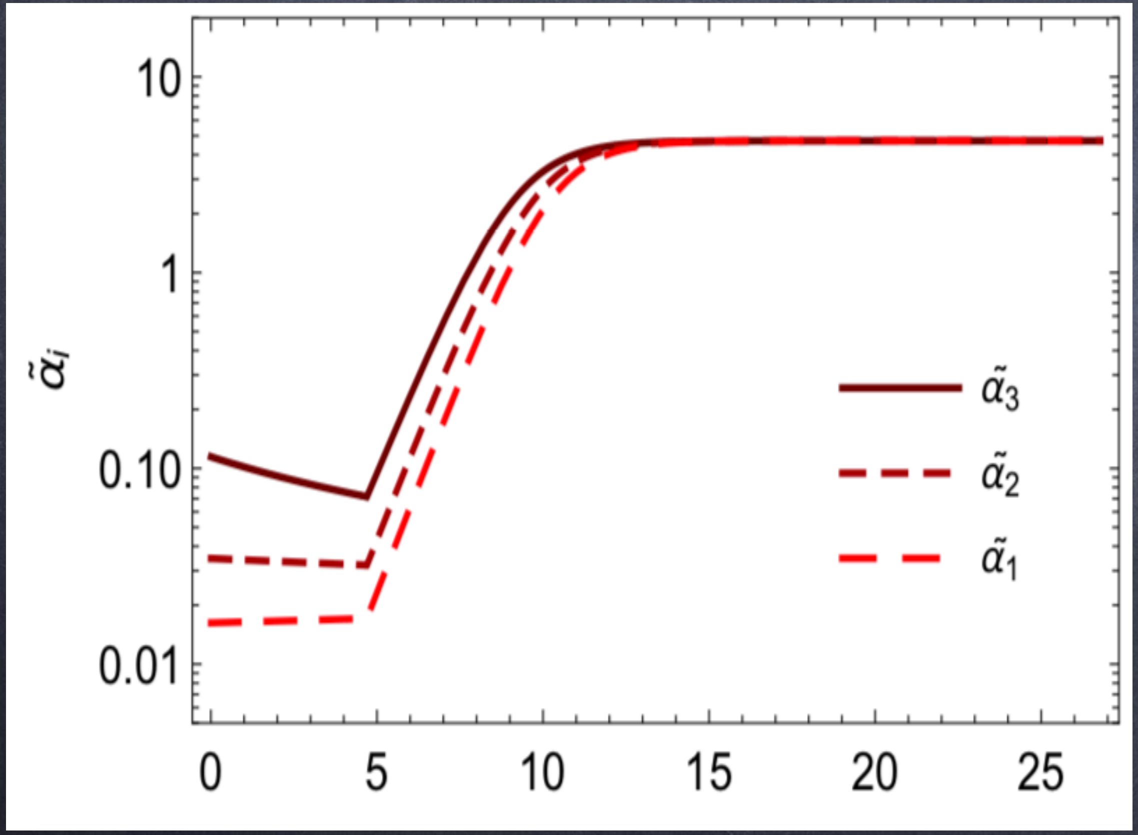


B) Extra compact dimensions

$$2\pi \frac{d\alpha}{d\ln\mu} = \mu R\, b_5\, \alpha^2$$

$\tilde{\alpha} = \mu R\, \alpha$ ('t Hooft coupling in 5D)

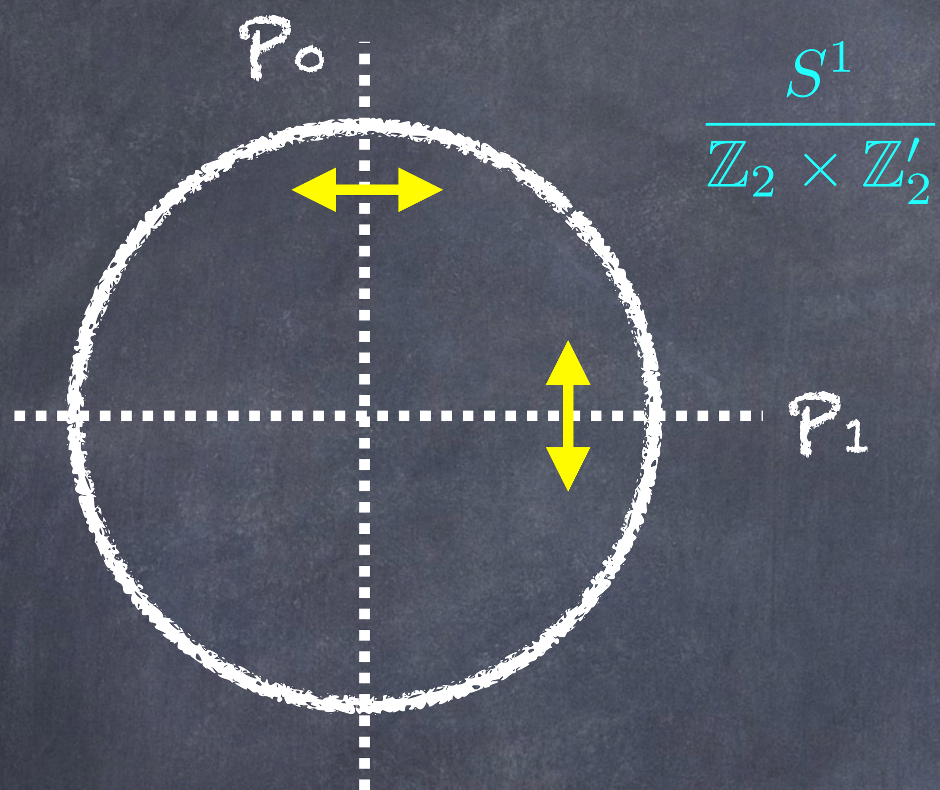
$$2\pi \left(\tilde{\alpha} + \frac{d\tilde{\alpha}}{d\ln\mu} \right) = b_5\, \tilde{\alpha}^2$$

$$\tilde{\alpha}_{UV} = -\frac{2\pi}{b_5}$$

Gies, PRD 68 (2003)
Morris, JHEP 01 (2005) 002

Minimal SU(5) aGUT

Cacciapaglia et al, PRD 104 (2021) 7



$$(P_0) \Rightarrow \begin{cases} A^a_\mu(x,-y) = P_0 A^a_\mu(x,y) P_0^\dagger\,, \\ A^a_y(x,-y) = -P_0 A^a_y(x,y) P_0^\dagger\,, \end{cases}$$

$$(P_1) \Rightarrow \begin{cases} A^a_\mu(x,\pi R - y) = P_1 A^a_\mu(x,y) P_1^\dagger\,, \\ A^a_y(x,\pi R - y) = -P_1 A^a_y(x,y) P_1^\dagger\,, \end{cases}$$

$$P_0 = \left(+ + + - -\right), \quad P_1 = \left(+ + + + +\right).$$

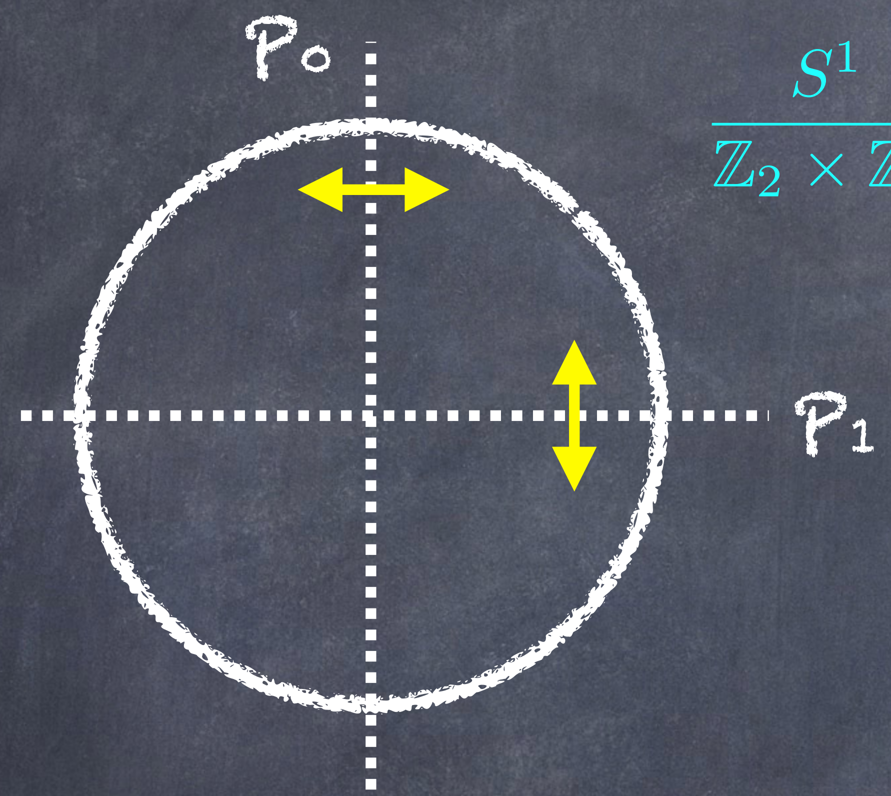
$$\psi_5 = \begin{pmatrix} B^c \\ l \end{pmatrix} \quad \begin{matrix} (- +) \\ (+ +) \end{matrix} \quad \begin{matrix} \\ \text{Lh zero} \end{matrix}$$

$$\psi_5 = \begin{pmatrix} b \\ L^c \end{pmatrix} \quad \begin{matrix} (- -) \\ (+ -) \end{matrix} \quad \begin{matrix} \text{Rh zero} \\ \end{matrix}$$

- SU(5) broken in y=0 to the SM by boundary conditions
- SM fermions cannot be embedded in complete multiplets of SU(5)!!!

Minimal SU(5) aGUT

Cacciapaglia et al, PRD 104 (2021) 7



$$\frac{S^1}{\mathbb{Z}_2 \times \mathbb{Z}_2'}$$

$$(P_0) \Rightarrow \begin{cases} A^a_\mu(x,-y) = P_0 A^a_\mu(x,y) P_0^\dagger\,, \\ A^a_y(x,-y) = -P_0 A^a_y(x,y) P_0^\dagger\,, \end{cases}$$

$$(P_1) \Rightarrow \begin{cases} A^a_\mu(x,\pi R - y) = P_1 A^a_\mu(x,y) P_1^\dagger\,, \\ A^a_y(x,\pi R - y) = -P_1 A^a_y(x,y) P_1^\dagger\,, \end{cases}$$

$$P_0 = \big(+\,+\,+\,-\,-\big)\,, \qquad P_1 = \big(+\,+\,+\,+\,+\big)\,.$$

$$\psi_{1_{L/R}} = N\,, \quad \psi_{5_{L/R}} = \begin{pmatrix} b \\ L^c \end{pmatrix}_{L/R}, \quad \psi_{\overline{5}_{L/R}} = \begin{pmatrix} B^c \\ l \end{pmatrix}_{L/R},$$

$$\psi_{10_{L/R}} = \frac{1}{\sqrt{2}} \begin{pmatrix} T^c & q \\ & \mathcal{T}^c \end{pmatrix}_{L/R}, \quad \psi_{\overline{10}_{L/R}} = \frac{1}{\sqrt{2}} \begin{pmatrix} t & Q^c \\ & \tau \end{pmatrix}_{L/R},$$

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Minimal SU(5) aGUT

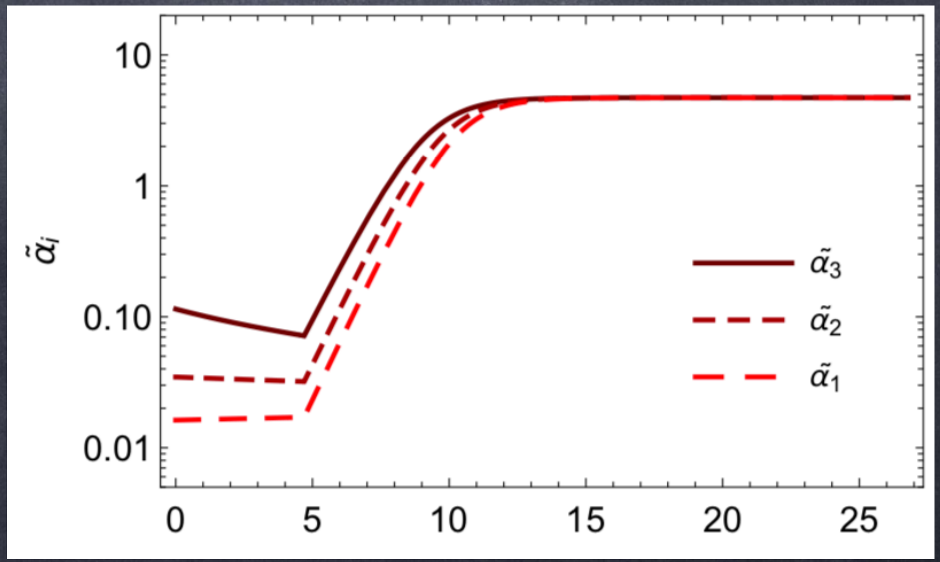
Cacciapaglia et al, PRD 104 (2021) 7

Field	$(\mathbb{Z}_2, \mathbb{Z}_2')$	SM	zero mode?	KK mass
l	$(+,+)$	$(\mathbf{1},\mathbf{2},-1/2)$	$\surd$	$2/R$
L	$(+,-)$		$-$	$1/R$
τ	$(-,-)$	$(\mathbf{1},\mathbf{1},-1)$	$\surd$	$2/R$
$\mathcal{T}$	$(-,+)$		$-$	$1/R$
N	$(-,-)$	$(\mathbf{1},\mathbf{1},0)$	$\surd$	$2/R$
q	$(+,+)$	$(\mathbf{3},\mathbf{2},1/6)$	$\surd$	$2/R$
Q	$(+,-)$		$-$	$1/R$
t	$(-,-)$	$(\mathbf{3},\mathbf{1},2/3)$	$\surd$	$2/R$
T	$(-,+)$		$-$	$1/R$
b	$(-,-)$	$(\mathbf{3},\mathbf{1},-1/3)$	$\surd$	$2/R$
B	$(-,+)$		$-$	$1/R$
ϕ_h	$(+,+)$	$(\mathbf{1},\mathbf{2},1/2)$	$\surd$	$2/R$
H	$(-,+)$	$(\mathbf{3},\mathbf{1},-1/3)$	$-$	$1/R$
B_μ	$(+,+)$	$(\mathbf{1},\mathbf{1},0)$	$\surd$	$2/R$
W^a_μ		$(\mathbf{1},\mathbf{3},0)$		
G^i_μ		$(\mathbf{8},\mathbf{1},0)$		
A^μ_X	$(-,+)$	$(\mathbf{3},\mathbf{2},-5/6)$	$-$	$1/R$

$$b_5 = -\frac{52}{3} + \frac{16}{3} n_{\text{gen}}$$

$$b_5 < 0 \quad \text{for} \quad n_{\text{gen}} \leq 3$$

- UV fixed point for 3 or less bulk generations!!!



$$t = \ln \frac{\mu}{m_Z}$$

Indalo states

The most general bulk Lagrangian reads:

$$\mathcal{L}_{SU(5)} = -\frac{1}{4}F^{(a)}_{MN}F^{(a)MN} - \frac{1}{2\xi}(\partial_\mu A^\mu - \xi\partial_5 A_y)^2 + i\overline{\psi_5}\not{D}\psi_5 + i\overline{\psi_{\overline{5}}}\not{D}\psi_{\overline{5}} + i\overline{\psi_{10}}\not{D}\psi_{10}$$
$$+ i\overline{\psi_{\overline{10}}}\not{D}\psi_{\overline{10}} - \left(\sqrt{2}Y_\tau\,\overline{\psi_{\overline{5}}}\psi_{\overline{10}}\phi_5^* + \sqrt{2}Y_b\,\overline{\psi_5}\psi_{10}\phi_5^* + \frac{1}{2}Y_t\,\epsilon_5\,\overline{\psi_{\overline{10}}}\psi_{10}\phi_5 + \text{h.c.}\right)$$
$$+ |D_M\phi_5|^2 - V(\phi_5) + i\overline{\psi_1}\not{\partial}\psi_1 - \left(Y_\nu\,\overline{\psi_1}\psi_{\overline{5}}\phi_5 + \text{h.c.}\right),$$

- Yukawas DO NOT unify!
- Baryon and lepton numbers can be defined (no proton decay processes)

Indalo states

Multiplets	Fields	L	B	Q	Q_3
$\psi_{\bar{5}}$	B_R^c	1/2	1/6	1/3	0
	$\boxed{\tau_L}$	1	0	-1	-1
	$\boxed{\nu_L}$	1	0	0	1
ψ_5	$\boxed{b_R}$	0	1/3	-1/3	0
	$\mathcal{T}_L^c$	-1/2	1/2	1	1
	$\mathcal{N}_L^c$	-1/2	1/2	0	-1
ψ_{10}	T_R^c	1/2	1/6	-2/3	0
	$\mathcal{T}_R^c$	-1/2	1/2	1	0
	$\boxed{t_L}$	0	1/3	2/3	1
	$\boxed{b_L}$	0	1/3	-1/3	-1
$\psi_{\overline{10}}$	$\boxed{t_R}$	0	1/3	2/3	0
	$\boxed{\tau_R}$	1	0	-1	0
	T_L^c	1/2	1/6	-2/3	-1
	B_L^c	1/2	1/6	1/3	1
ψ_1	N	1	0	0	0
ϕ_5	H	1/2	-1/6	-1/3	0
	$\boxed{\phi^+}$	0	0	1	1
	$\boxed{\phi_0}$	0	0	0	-1
A_X	X	1/2	-1/6	-4/3	-1
	Y	1/2	-1/6	-1/3	1

- Non-SM components carry unusual B and L charges
- Hence, they cannot decay into SM states
- States with mass 1/R stable

 = Indalo

- Prehistoric symbol found in Almería caves, Spain
- It means "creation" or "nature" in Zulu

Indalo-genesis

Multiplets	Fields	L	B	Q	Q_3
$\psi_{\bar{5}}$	B_R^c	1/2	1/6	1/3	0
	$\boxed{\tau_L}$	1	0	-1	-1
	$\boxed{\nu_L}$	1	0	0	1
ψ_5	$\boxed{b_R}$	0	1/3	-1/3	0
	$\mathcal{T}_L^c$	-1/2	1/2	1	1
	$\mathcal{N}_L^c$	-1/2	1/2	0	-1
ψ_{10}	T_R^c	1/2	1/6	-2/3	0
	$\mathcal{T}_R^c$	-1/2	1/2	1	0
	$\boxed{t_L}$	0	1/3	2/3	1
	$\boxed{b_L}$	0	1/3	-1/3	-1
$\psi_{\overline{10}}$	$\boxed{t_R}$	0	1/3	2/3	0
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	T_L^c	1/2	1/6	-2/3	-1
	B_L^c	1/2	1/6	1/3	1
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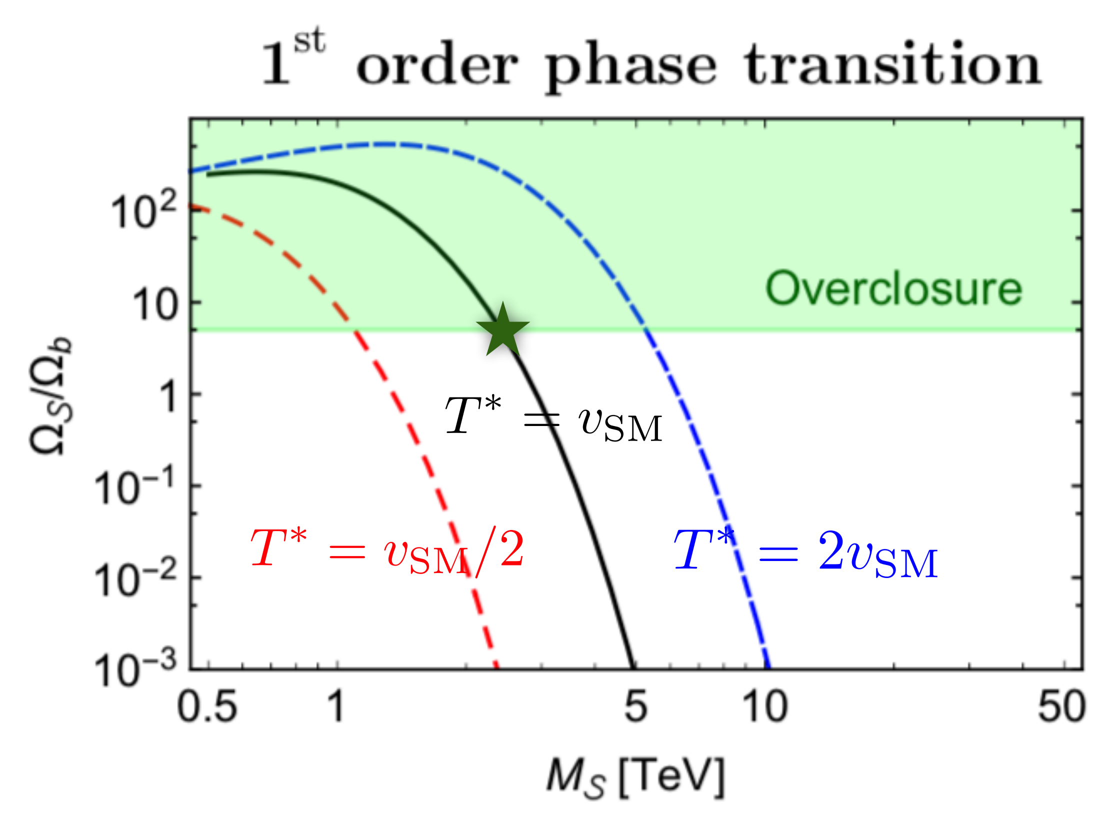
ϕ_5	H	1/2	-1/6	-1/3	0
	$\boxed{\phi^+}$	0	0	1	1
	$\boxed{\phi_0}$	0	0	0	-1
A_X	X	1/2	-1/6	-4/3	-1
	Y	1/2	-1/6	-1/3	1

- Baryogenesis could also produce an asymmetric abundance of Indalo states

Dark Matter candidate!

$1/R = 2.4\ TeV$



The Yukawa sector

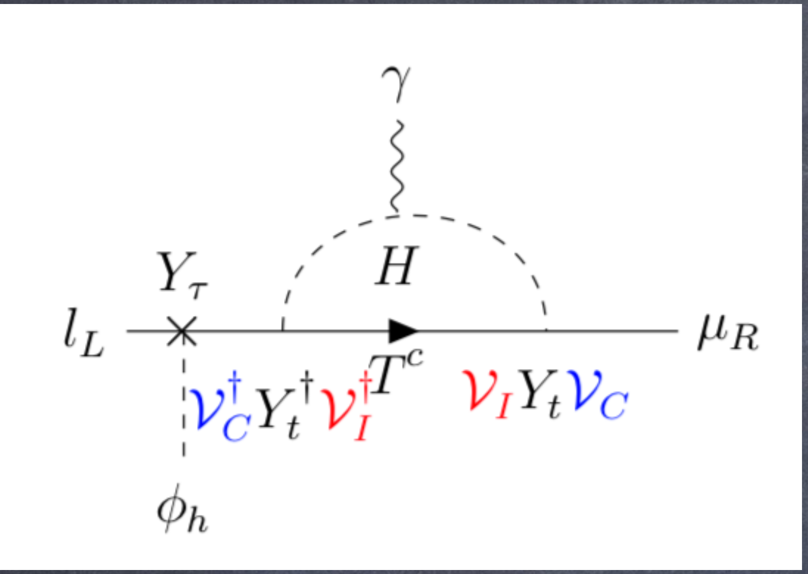
- In components, diagonalising the flavour matrices:

$$
\begin{aligned}
Y_b :& \bar{b}\hat{Y}_b q\phi_h^* - \overline{L}^c\hat{Y}_b qH^* - \overline{L}^c\hat{Y}_b\mathcal{T}^c\phi_h^* + \epsilon_3\bar{b}\hat{Y}_b T^c H^* \,, \\
Y_\tau :& -\bar{\tau}\hat{Y}_\tau l\phi_h^* - \overline{Q}^c\hat{Y}_\tau lH^* + \overline{Q}^c\hat{Y}_\tau B^c\phi_h^* - \epsilon_3\bar{t}\mathcal{V}_I^T\hat{Y}_\tau B^c H^* \,, \\
Y_t :& \bar{t}\hat{Y}_t\mathcal{V}_C q\phi_h + \bar{t}\hat{Y}_t\mathcal{V}_C\mathcal{T}^c H + \bar{\tau}\mathcal{V}_I\hat{Y}_t\mathcal{V}_C T^c H + \overline{Q^c}\mathcal{V}_I\hat{Y}_t\mathcal{V}_C T^c\phi_h + \epsilon_3\overline{Q}^c\mathcal{V}_I\hat{Y}_t\mathcal{V}_C qH \,,
\end{aligned}
$$

CKM matrix

- Besides the CKM matrix, a new mixing matrix is predicted.
- It only appears in couplings with Indalo states.
- Example: bounds from leptonic sector.

The Yukawa sector



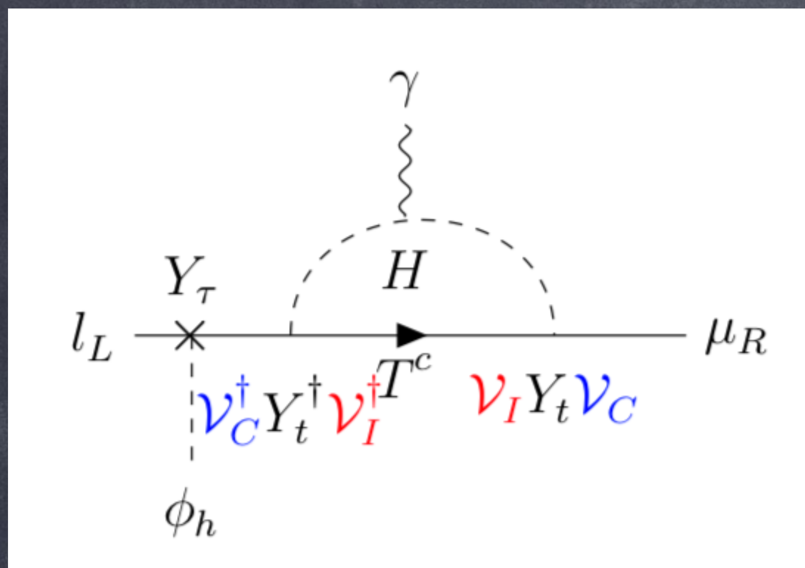
- Potentially large effects involving the top Yukawa and the new mixing matrix

$$\begin{aligned}
\Delta a_\mu &= \frac{m_\mu^2}{1536\ M_{KK}^2}\left(13\sum_{q=u,c,t}\frac{m_q^2}{\langle\phi_h\rangle^2}|(\mathcal{V}_I)^{\mu q}|^2+\frac{m_\mu^2}{\langle\phi_h\rangle^2}\right)\\
&= 1.4\times 10^{-11}\left(\frac{2.4\mathrm{TeV}}{M_{KK}}\right)^2\left(|(\mathcal{V}_I)^{\mu t}|^2+\frac{m_c^2}{m_t^2}|(\mathcal{V}_I)^{\mu c}|^2+\frac{m_u^2}{m_t^2}|(\mathcal{V}_I)^{\mu u}|^2+\frac{1}{13}\frac{m_\mu^2}{m_t^2}\right).
\end{aligned}$$

This factor is < 1

- Right sign, but too small to reduce the anomaly significantly.

The Yukawa sector



- Potentially large effects involving the top Yukawa and the new mixing matrix

$$\frac{\mathrm{BR}(l \to l'\gamma)}{\mathrm{BR}(l \to l'\nu\nu)} = 8.4\times 10^{-8}\left(\frac{2.4\ \mathrm{TeV}}{M_{KK}}\right)^4 \left|(\mathcal{V}_I)^{lt}(\mathcal{V}_I{}^\dagger)^{tl'} + \frac{m_c^2}{m_t^2}(\mathcal{V}_I)^{lc}(\mathcal{V}_I{}^\dagger)^{cl'} + \frac{m_u^2}{m_t^2}(\mathcal{V}_I)^{lu}(\mathcal{V}_I{}^\dagger)^{ul'}\right|^2$$

$$\begin{array}{lcll}
\mathrm{BR}(\mu \to e\gamma) & < & 4.2\times 10^{-13} & (5\times 10^{-14}) \\
\mathrm{BR}(\tau \to \mu\gamma) & < & 4.4\times 10^{-8} & (10^{-9}) \\
\mathrm{BR}(\tau \to e\gamma) & < & 3.3\times 10^{-8} & (5\times 10^{-9})
\end{array}$$

- Enough to suppress electron mixing to top: 10^-3

The Yukawa sector

- Asymptotic GUT is a novel paradigm, avoiding many shortcomings of traditional GUTs.
- We present a minimal realistic SU(5) model in 5D
- Indalo states (mass 1/R) provide accidental DM candidates - protected by Baryon number
- Indalo-genesis requires masses in the TeV range
- A single new flavour mixing matrix is predicted, with mild bounds

Bonus tracks

The Yukawa sector runs

Bulk Yukawas

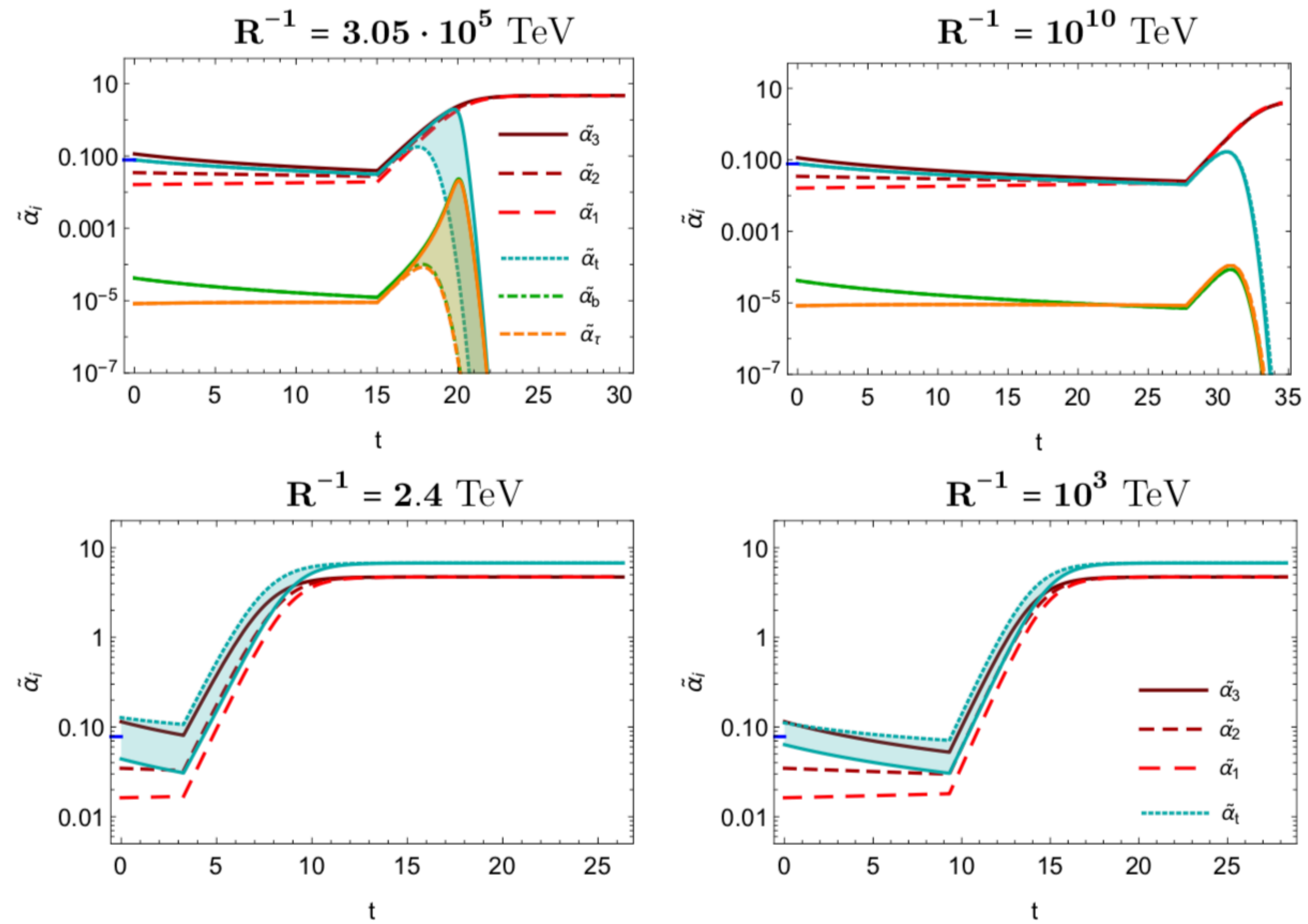


Figure 2. Running of the bulk Yukawas as compared to the gauge couplings. In the top row, we run up from the EW scale for two sample values of compactification scales above the critical value. In the bottom row, we run the top Yukawa down from the UV fixed point (imposed at the 5D Planck scale) for two sample values of the compactification scales below the critical value. The bands indicate the systematic uncertainty from the gauge couplings, while the SM value of the top Yukawa at the EW scale is indicated by the blue tick at $t = 0$. The largest value of t in the plots corresponds to the 5D Planck scale.

The Yukawa sector runs

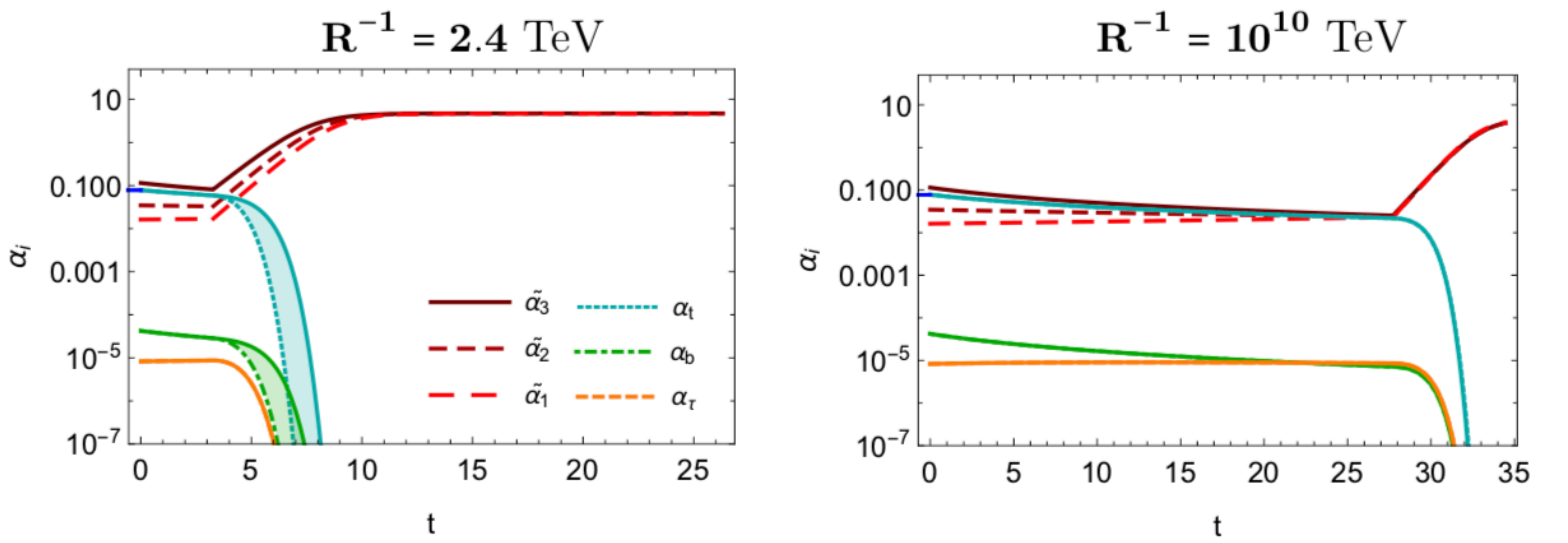


Figure 3. Running of the localized Yukawa couplings compared to the bulk gauge ones for two sample values of the compactification scale. The bands indicate the uncertainty related to KK gauge couplings (see text). The largest value of t corresponds to the 5D Planck mass value.

Localised Yukawas - SU(5) brane