Composite Dark Matter (and the Higgs)

DMI2019

Mainz

References

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- G.Cacciapaglia, T.Ma, B.Zhang, Y.Wu, "Composite Dark Matter and the Higgs", JHEP 1711 (2017) 058 (arXiv:1703.06903)

- G.Ballestreros, A.Carmona, M.Chala, "Exceptional Composite Dark Matter", EPJC 77 (2017) no.7, 468 (arXiv:1704.07388) -> see also arXiv:1201.6208

- R.Balkin, M.Ruhdorfer, E.Salvioni, A.Weiler, "Charged Composite Scalar Dark Matter", JHEP 1711 (2017) 094 (arXiv:1707.07685)

- C.Cai, G.Cacciapaglia, H.H.Zhang, "Vacuum alignment in a composite 2HDM", JHEP 1901 (2019) 130 (arXiv:1805.07619)

The cosets

Coset	N pNGB	Higgses	DM states	U(1) or Z2
SU(4)/Sp(4)	5	1	Singlet	Z2
SU(4)xSU(4)/SU(4)	15	2	Doublet + Triplet + Singlets	Z2
SU(6)/Sp(6)	14	2	Doublet + Singlets Doublet + Triplet	U(1) Z2
SO(7)/SO(6)	6	1	Singlets	U(1)
SO(7)/G2	7	1	Triplet or Singlets	Z2

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A composite 2HDM

$SU(3)_{\mathrm{HC}}$

G.C., T.Ma
1508.07014

	SU(N)	SU(2)$_L$	U(1)$_Y$
$\psi_L = \begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix}$	$\square$	**2**	0
$\psi_R = \begin{pmatrix} \psi_3 \\ \psi_4 \end{pmatrix}$	$\square$	**1** **1**	1/2 -1/2

$$SU(4) \times SU(4) \to SU(4)$$

Triplet

Complex bi-doublet
(2HDM)

$$\Pi = \frac{1}{2} \begin{pmatrix} \sigma_i \Delta^i + s/\sqrt{2} & -i\Phi_H \\ i\Phi_H^\dagger & \sigma_i N^i - s/\sqrt{2} \end{pmatrix}$$

SU(2)R Triplet

A composite 2HDM

$SU(3)_{\mathrm{HC}}$

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Is it there a parity stabilising the pions?

$$\Sigma = e^{\frac{i}{f}\Pi} \qquad \Sigma \to P \cdot \Sigma^T \cdot P \qquad P = \begin{pmatrix} \sigma^2 & 0 \\ 0 & -\sigma^2 \end{pmatrix}$$

$$\left.\begin{array}{l} s \to s \\ H_1 \to H_1 \end{array}\right\} \text{Mimics the minimal case}$$

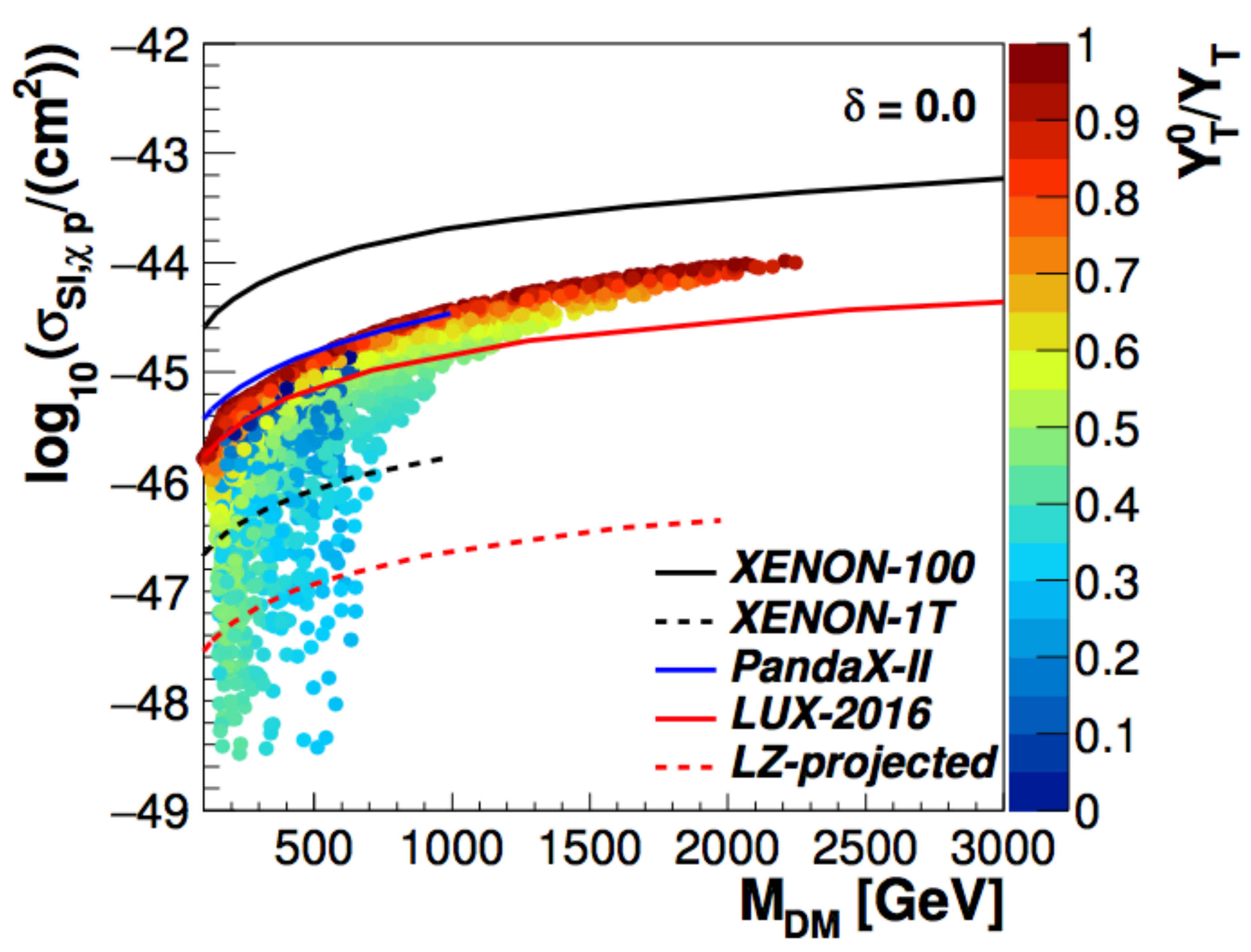
$$\left.\begin{array}{l} H_2 \to -H_2 \\ \Delta \to -\Delta \\ N \to -N \end{array}\right\} \text{Dark Sector!}$$

Relic density and DD: eff. Yukawas

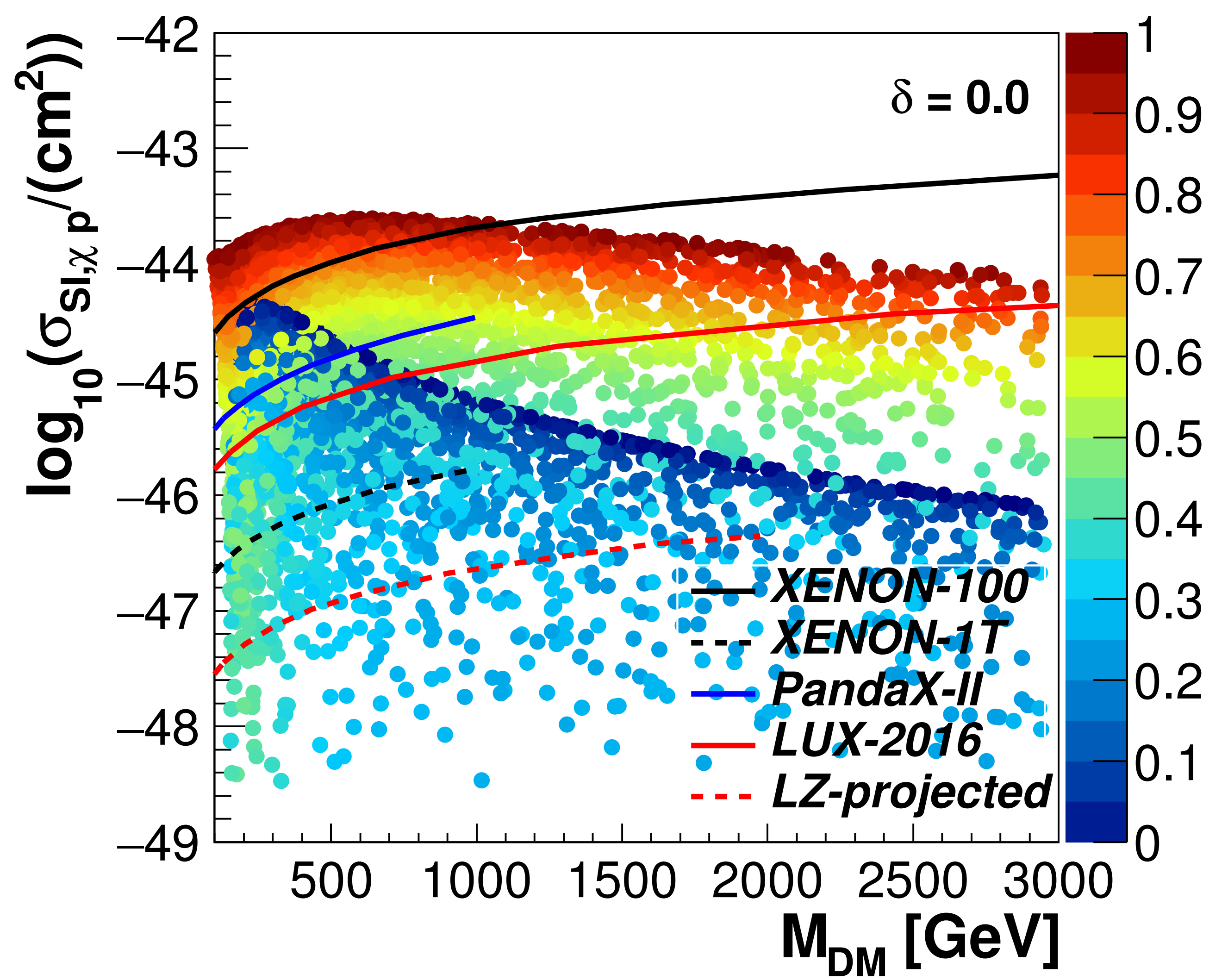
Direct Detection

G.C., T.Ma, Y.Wu, B.Zhang
1703.06903

Thermal relic



Fixing DM relic



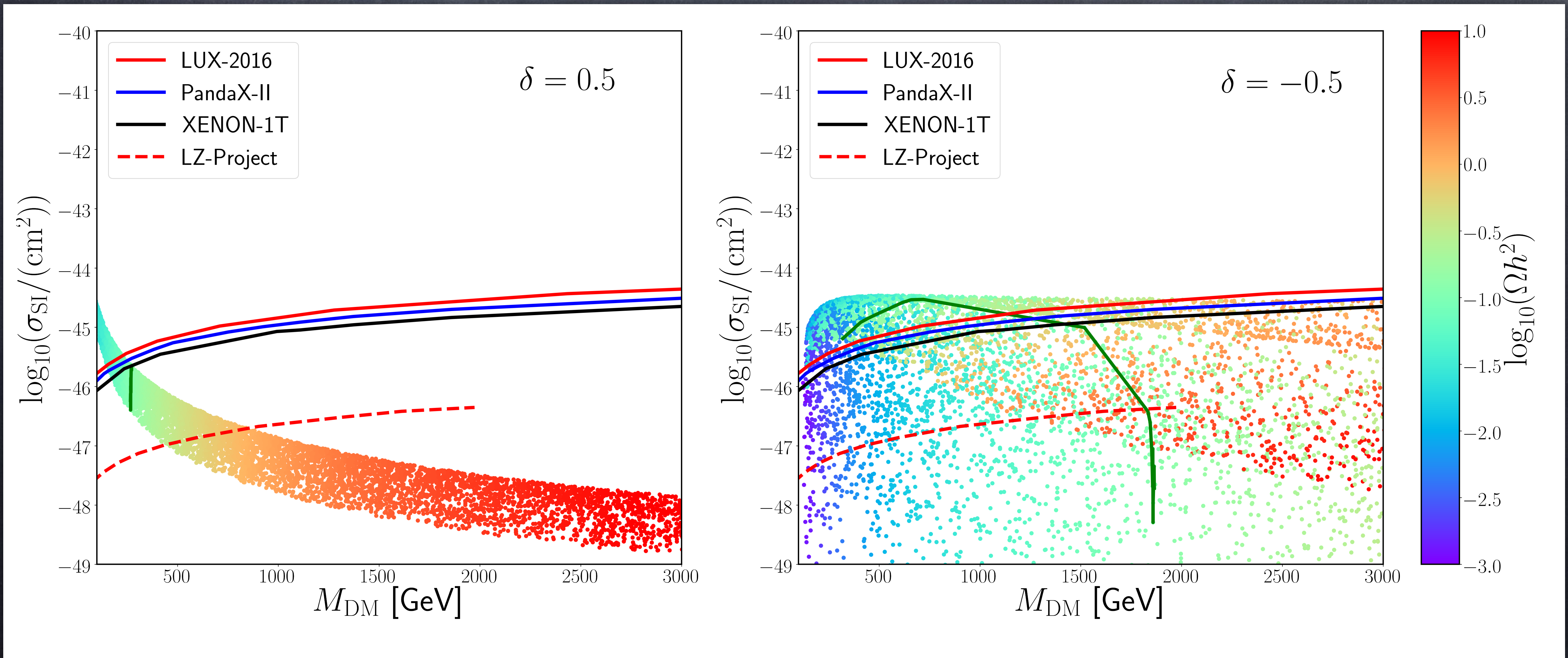
Relic density and DD: partial compositeness

$(4,\bar{4})$

Direct Detection

Thermal relic

G.C., S.Vatani, T.Ma, Y.Wu
1812.04005v1



	Complex	Real	$SU(4)^2/SU(4) \times SU(6)/SO(6)$				
$SO(N_{HC})$	$4 \times (\mathbf{Spin}, \overline{\mathbf{Spin}})$	$6 \times \mathbf{F}$	$N_{HC} = 10$	$\frac{8}{3}$	$2/3$	$N_{HC} = 10$	M10
$SU(N_{HC})$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$6 \times \mathbf{A}_2$	$N_{HC} = 4$	$\frac{2}{3}$	$2/3$	$N_{HC} = 4$	M11
	Complex	Complex	$SU(4)^2/SU(4) \times SU(3)^2/SU(3)$				
$SU(N_{HC})$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$3 \times (\mathbf{A}_2, \overline{\mathbf{A}}_2)$	$N_{HC} \geq 5$	$\frac{4}{3(N_{HC}-2)}$	$2/3$	$N_{HC} = 5$	M12
$SU(N_{HC})$	$4 \times (\mathbf{F}, \overline{\mathbf{F}})$	$3 \times (\mathbf{S}_2, \overline{\mathbf{S}}_2)$	$N_{HC} \geq 5$	$\frac{4}{3(N_{HC}+2)}$	$2/3$	/	
$SU(N_{HC})$	$4 \times (\mathbf{A}_2, \overline{\mathbf{A}}_2)$	$3 \times (\mathbf{F}, \overline{\mathbf{F}})$	$N_{HC} = 5$	4	$2/3$	/	

Underlying models with partial compositeness

- Same low energy effective Lagrangian;
- Different spectrum (masses) and WZW topological anomalies.

Extras

The hot potato: flavour!

100,000 TeV	Λ_{flavour}	Scale of fermion mass generation
		How can this hierarchy be generated?
10 TeV	$\Lambda \sim 4\pi f$	Vector resonances, ...
1 TeV	f	Condensation scale (extra pions)
100 GeV	$v_{\text{SM}} \sim f \sin\theta$	EWSB

Higgs

$$\mathcal{L}_{\text{fermions}} = \frac{1}{\Lambda_{\text{fl.}}^2}(\psi\psi)(q_L^c q_R)$$

$$+\frac{1}{\Lambda_{\text{fl.}}^2}(q_L^c q_R)(q_L^c q_R) + \frac{1}{\Lambda_{\text{fl.}}^2}(\psi\psi)^2$$

FCNCs

Higgs mass

$$m_{\text{top}} \sim \frac{(4\pi f)^3}{\Lambda_{\text{fl.}}^2}\sin\theta$$

Too small!

The hot potato: flavour!

100.000 TeV	Λ_{flavour}	Scale of fermion mass generation
		Intermediate conformal region
10 TeV	$\Lambda \sim 4\pi f$	Vector resonances, ...
1 TeV	f	Condensation scale (extra pions)
100 GeV	$v_{\text{SM}} \sim f \sin\theta$	EWSB

$$(\psi\psi) \to \mathcal{O}_H$$

$$\dim[\mathcal{O}_H] = d_H$$

effective Yukawa:

$$\frac{1}{\Lambda_{\text{fl.}}^{d-1}} \mathcal{O}_H q_L^c q_R$$

$$m_{\text{top}} \sim \left(\frac{4\pi f}{\Lambda_{\text{fl.}}}\right)^{d-1} 4\pi f \sin\theta$$

$$d \sim 1.$$

The hot potato: flavour!

100.000 TeV Λ_{flavour} Light fermions

Conformal region

Λ_{top}

10 TeV $\Lambda \sim 4\pi f$ Vector resonances, ...

1 TeV f Condensation scale (extra pions)

100 GeV $v_{\text{SM}} \sim f \sin\theta$ EWSB

Multi-scale model

$$m_c \sim \left(\frac{4\pi f}{\Lambda_{\text{fl.}}}\right)^{d-1} 4\pi f \sin\theta$$

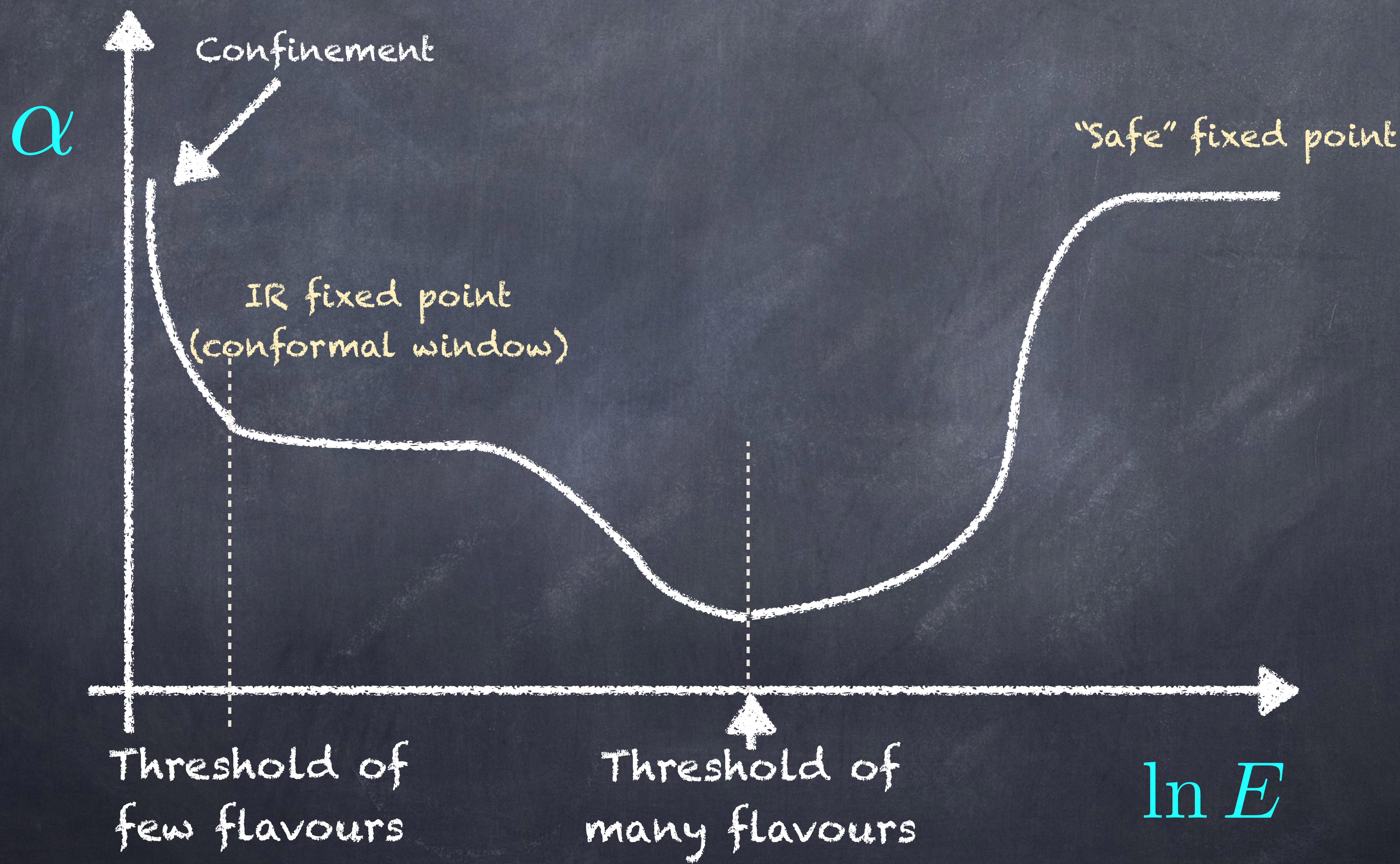
$$\Downarrow$$

$$\sim 0.01 \Rightarrow d \sim 1.5$$

Still, for the top, one would need:

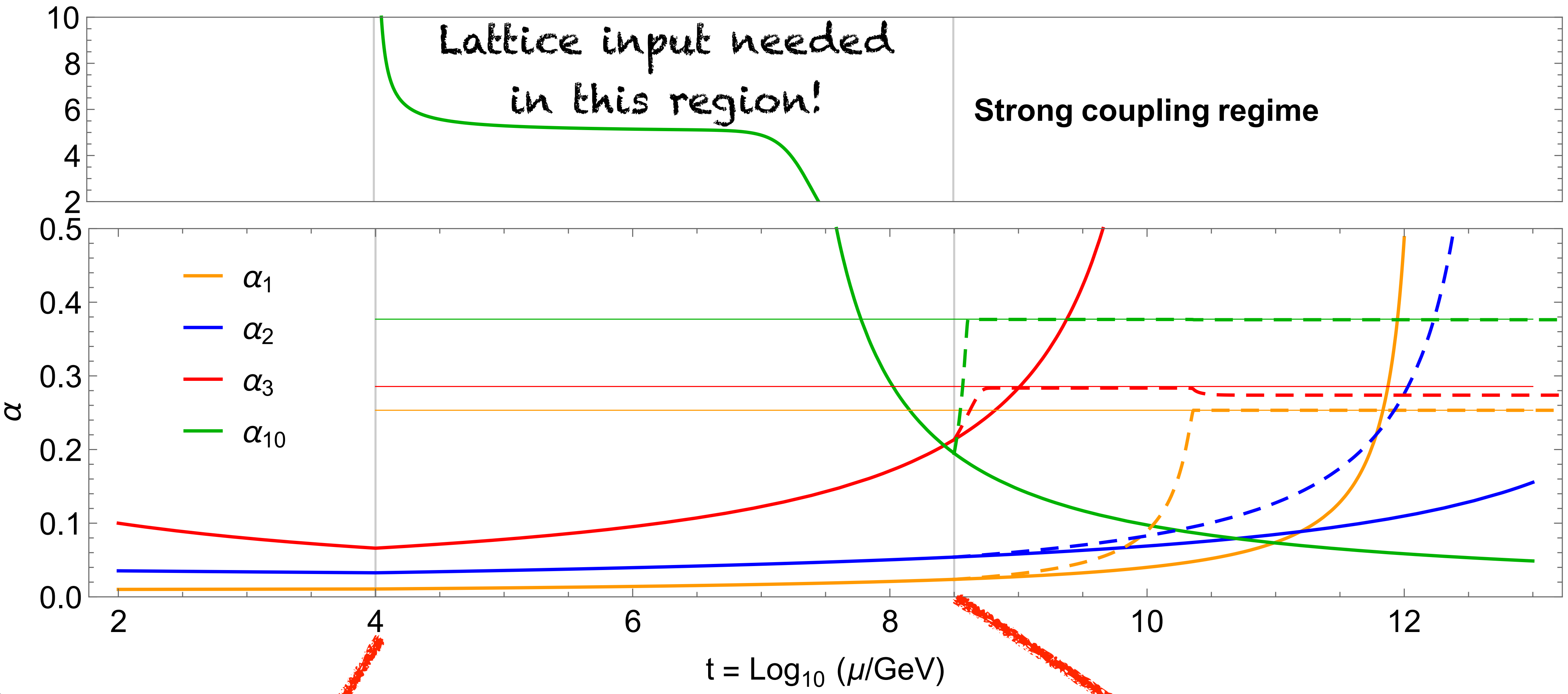
$$\Lambda_{\text{top}} \sim 4\pi f$$

Roads to UV safety



M10 v2.0

G.C., S.Vatani, T.Ma, Y.Wu
1812.04005



At 10 TeV we replace the Higgs with composite theory.

The other fermions can be added at any scale between 10 TeV and 10^9 GeV.