Low energy imprints of (Higgs) compositeness

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Orsay 2023 W mass workshop

Motivation

- Composite models 'solve' the Hierarchy problem...
- with new scale in the multi-TeV!

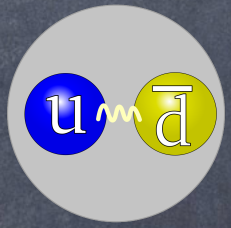
multi-TeV mountain

- What are we looking for?

-> Precision EW + Higgs observables
-> light composite scalars
-> multi-TeV resonances (top partners, pNGBs, spin-1)

Composite Higgs models 101

- Symmetry broken by a condensate (of TC-fermions)
- Higgs and longitudinal Z/W emerge as mesons (pions)



Scales:

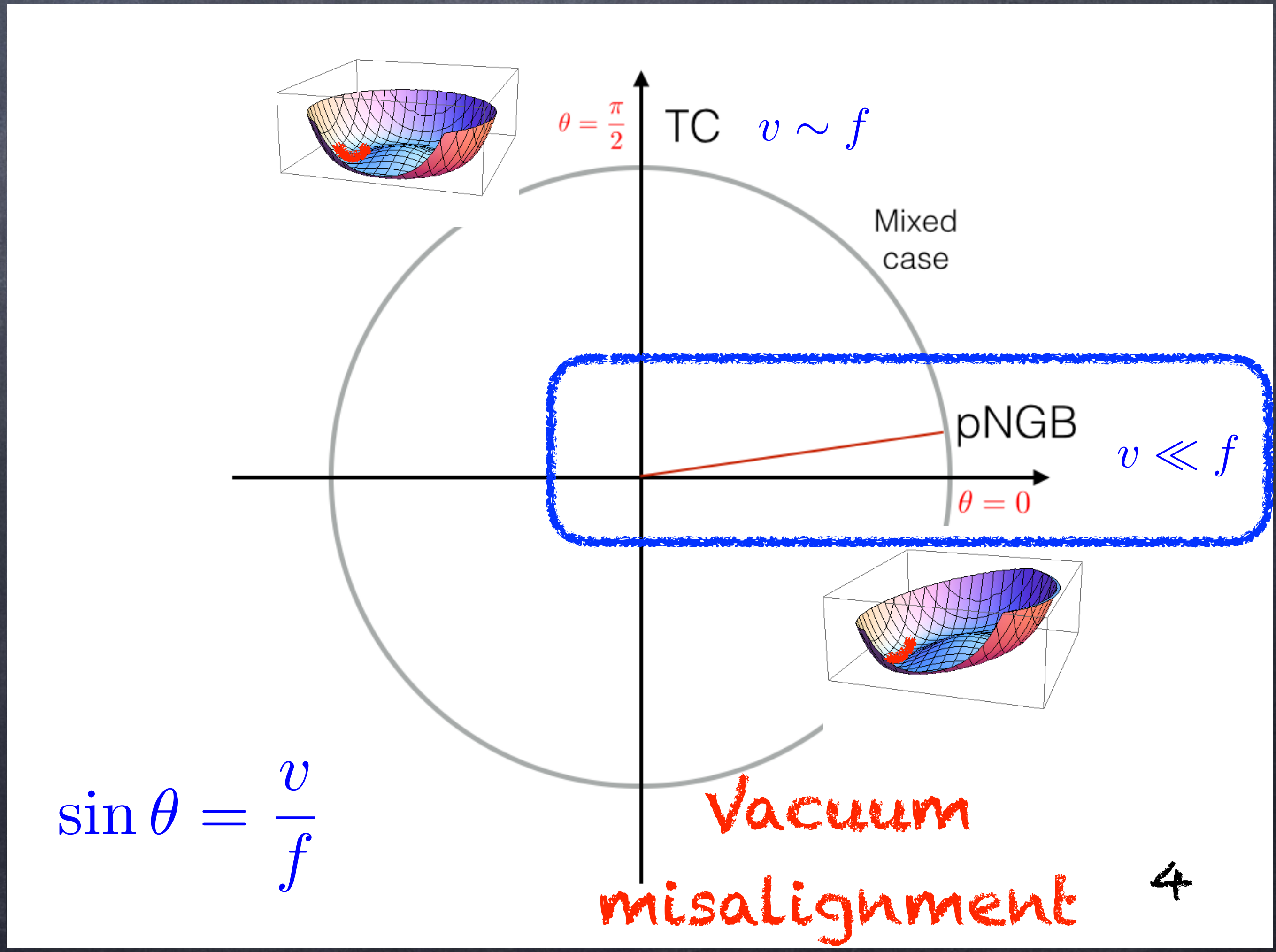
f : Higgs decay constant

v : EW scale

$m_\rho \sim 4\pi f$

EWPTs + Higgs coupl. limit:

$$f \gtrsim 4v \sim 1 \text{ TeV}$$



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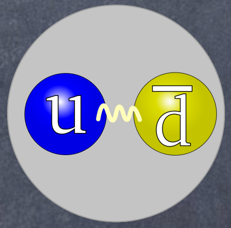
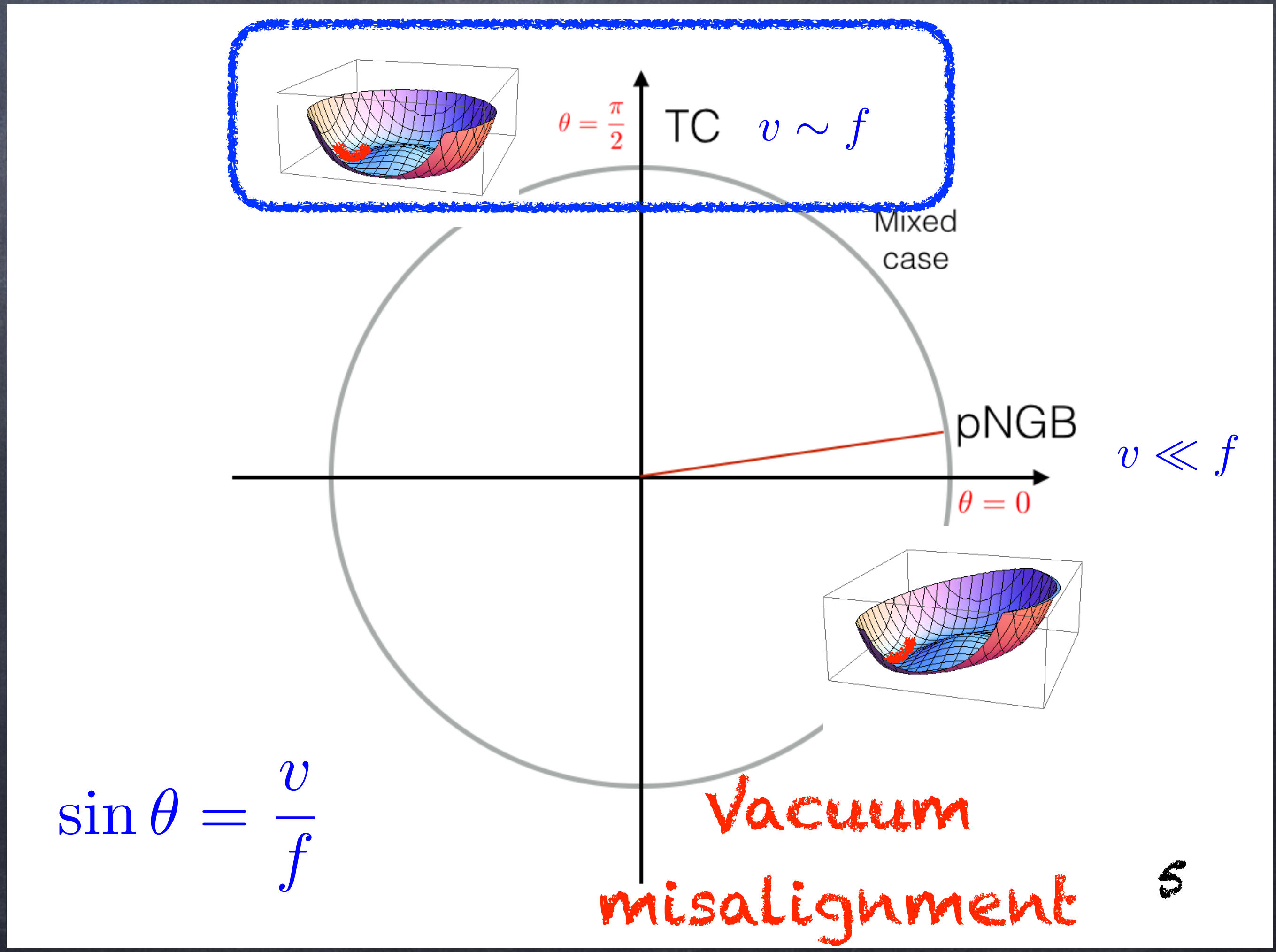


In the TC limit:

$$f = v$$

The Higgs is a light scalar resonance (dilaton?)

$m_\rho \sim 4\pi f$ ~ 2 TeV



A minimal case

T.Ryttov, F.Sannino 0809.0713
Galloway, Evans, Luty, Tacchi 1001.1361

	$SU(2)_{TC}$	$SU(4)_\psi$	$SU(2)_L$	$U(1)_Y$
$\begin{pmatrix}\psi^1\\ \psi^2\end{pmatrix}$	$\square$	$\square$	**2**	0
ψ^3	$\square$		**1**	-1/2
ψ^4	$\square$		**1**	1/2

This theory is Asymptotic Free and confines in the IR!

Antisymmetric matrix

$$\langle\psi^i\psi^j\rangle = \Sigma_0$$

Under the global symmetry SU(4):

$$\Sigma_0 \to U\cdot\Sigma_0\cdot U^T$$

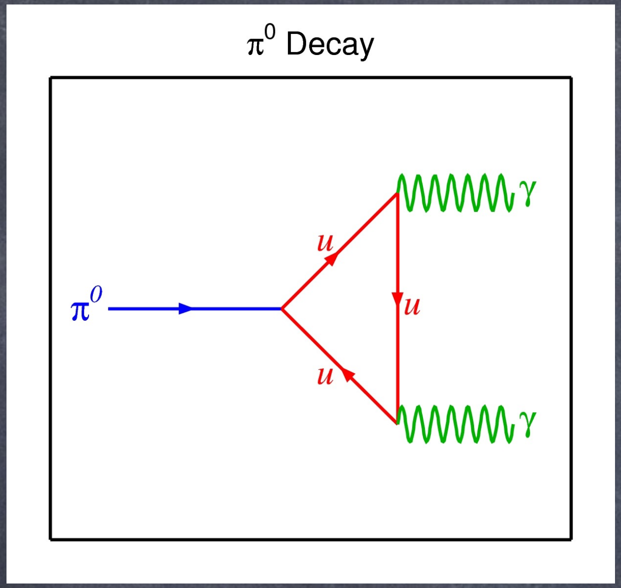
SU(4) -> Sp(4)

$$5_{\mathrm{Sp}(4)} \to (2,2)\oplus(1,1)$$

Higgs

DM?

WZW matters!



In QCD, coupling of the pions to EW gauge bosons are generated by (global) anomalies!

$$\mathcal{L}_{WZW} = \frac{d_\psi}{64\pi^2}\frac{\eta}{f}\left(g^2 W_{\mu\nu}\tilde{W}^{\mu\nu} - g'^2 B_{\mu\nu}\tilde{B}^{\mu\nu}\right)$$

$d_\psi = 2$

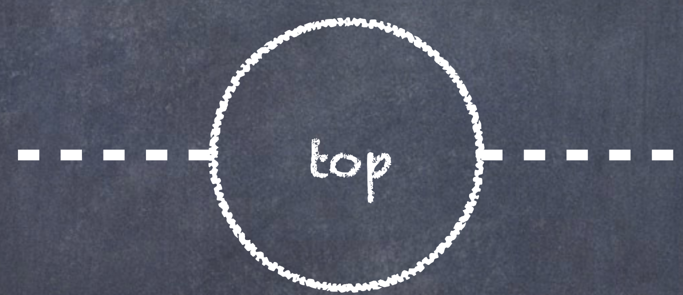
Dimension of TC rep

- Predictive power!
- Coupling to 2 photons vanishes!

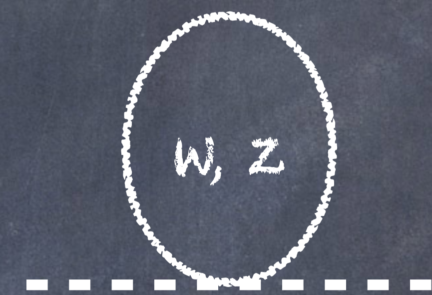
Composite Higgs models 101

How can light states emerge?

Top loops



Gauge loops



TC-fermion masses

	Top loops	Gauge loops	TC-fermion masses
ϕ	$\sim y_t^2 f^2$	$\sim g^2 f^2$	$\sim m_\psi f$
h (h massless for vanishing v)	$\sim y_t^2 f^2 s_\theta^2 = y_t^2 v^2$	$\sim g^2 f^2 s_\theta^2 = g^2 v^2$	X
a	X	X	$\sim m_\psi f$ This can be small!

The partial compositeness paradigm

Kaplan Nucl.Phys. B365 (1991) 259

$$\frac{1}{\Lambda_{\text{fl.}}^{d-1}} \mathcal{O}_H q_L^c q_R \qquad \Delta m_H^2 \sim \left(\frac{4\pi f}{\Lambda_{\text{fl.}}}\right)^{d-4} f^2$$

Both irrelevant if

we assume: $d_H > 1$ $\quad d_{H^2} > 4$

Let's postulate the existence of fermionic operators:

$$\frac{1}{\Lambda_{\text{fl.}}^{d_F-5/2}} (\tilde{y}_L\, q_L \mathcal{F}_L + \tilde{y}_R\, q_R \mathcal{F}_R)$$

This dimension is not related to the Higgs!

$$\Downarrow$$

$$f(y_L\, q_L Q_L + y_R\, q_R Q_R)$$

with

$$y_{L/R} f \sim \left(\frac{4\pi f}{\Lambda_{\text{fl.}}}\right)^{d_F-5/2} 4\pi f$$

Sequestering QCD in Partial compositeness

$\mathcal{G}_{\rm TC}$: rep R rep R′

G.Ferretti, D.Karateev
1312.5330, 1604.06467

Q χ $T' = QQ\chi$ or $Q\chi\chi$

SM : EW colour + hypercharge

global : $\langle QQ \rangle \neq 0$ a) $\langle \chi\chi \rangle \neq 0$

↓

pNGB Higgs
DM?

coloured pNGBs
di-boson

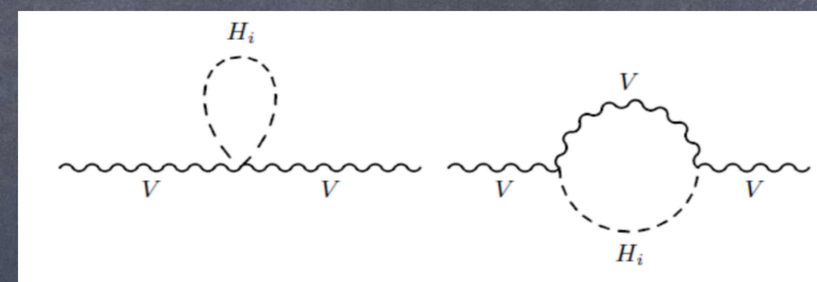
b) $\langle \chi\chi \rangle = 0$

light top partners
from t Hooft anomaly
conditions?

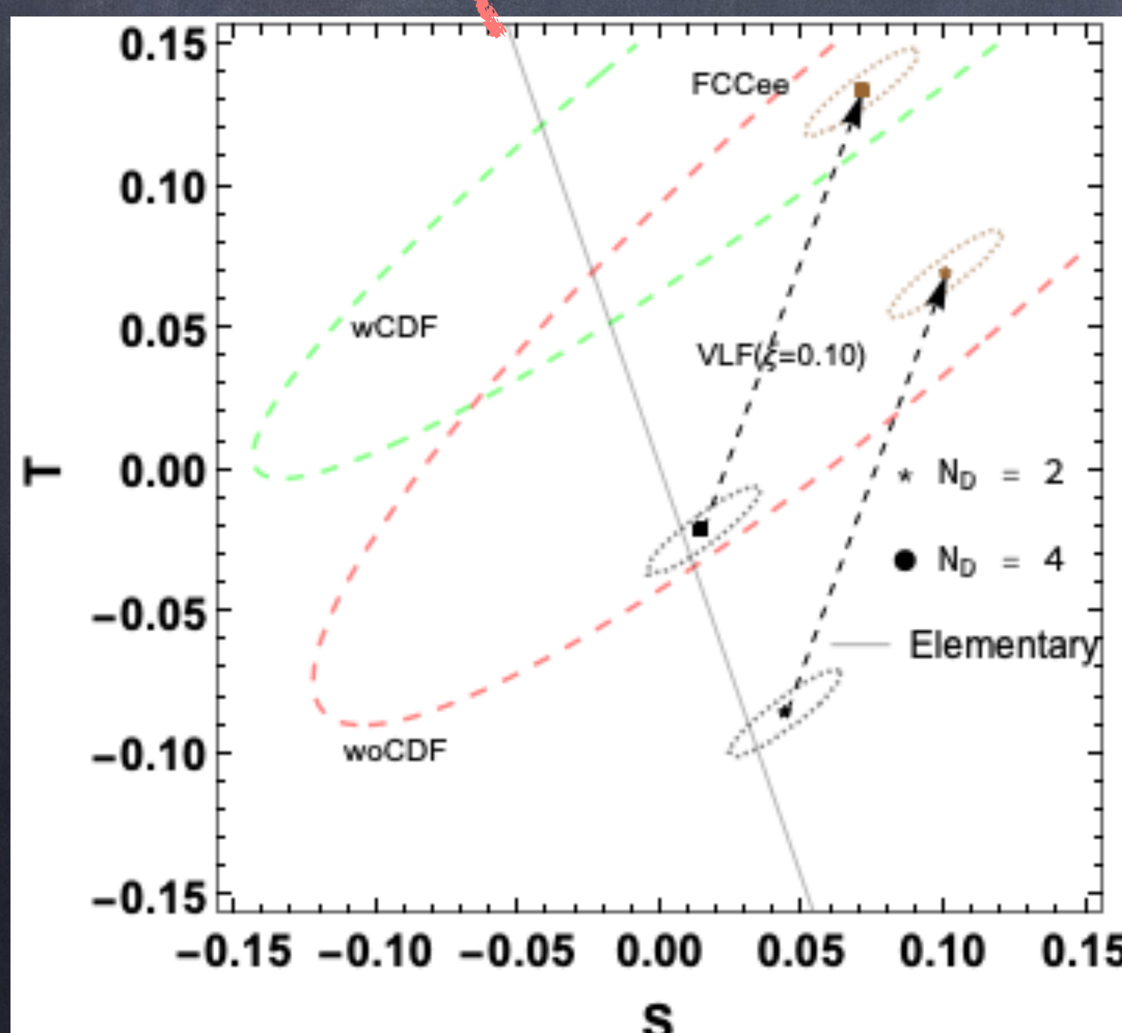
Starting with misalignment models

- Effect expressed in terms of oblique parameters: S & T

Effects from H loops



composite case: see 1502.04718



$$\Delta T = -\frac{3}{16\pi c_W^2}\sin^2\theta\ln\frac{\Lambda^2}{m_h^2}$$

$$\Delta S = \frac{1}{12\pi}\sin^2\theta\ln\frac{\Lambda^2}{m_h^2} + S_{\rm UV}\sin^2\theta$$

Arrows: naive contribution of top partner loops.

Contribution of top partners

- Top-partners are baryons of the new strong sector:

EW gauge Interactions

$$\mathcal{L}_{\rm composite} = tr\left[\bar{\psi}_A\, i\, \not{D}\, \psi_A\right] - M_A\, tr\left[\bar{\psi}_A \psi_A\right] + tr\left[\bar{\psi}_1\, i\, \not{D}\, \psi_1\right] - M_1\, tr\left[\bar{\psi}_1 \psi_1\right] + \tag{2.12}$$

- Effect of mixing with the top/bottom fields usually considered:

$$\begin{aligned}\mathcal{L}_{\rm mix} = & \, y_{L1} f\ tr\left[A_L^\dagger \gamma_0 U_\Pi \psi_5 U_\Pi^T\right] + y_{R1} f\ tr\left[A_R^\dagger \gamma_0 U_\Pi \psi_5 U_\Pi^T\right] \\ & + y_{L2} f\ tr\left[A_L^\dagger \gamma_0 U_\Pi \psi_1 U_\Pi^T\right] + y_{R2} f\ tr\left[A_R^\dagger \gamma_0 U_\Pi \psi_1 U_\Pi^T\right] \\ & + y'_R f\ tr\left[A_R^{(2)\dagger} \gamma_0 U_\Pi \psi_5 U_\Pi^T\right] + \text{h.c.}\,,\end{aligned}$$

$$A_L = \begin{pmatrix} 0 & 0 & \frac{t_L}{\sqrt{2}} & 0 \\ 0 & 0 & \frac{b_L}{\sqrt{2}} & 0 \\ -\frac{t_L}{\sqrt{2}} & -\frac{b_L}{\sqrt{2}} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

Mixing angles: $\sin[\phi_L] \propto y_L$ $\quad \sin[\phi_R] \propto y_R$ $\quad Y_{\rm top} \propto \sin[\phi_L]\ \sin[\phi_R]\,\frac{f}{M_T}$

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- Additional couplings in the strong sector: generate corrections to the W/Z coupling via misalignment

$$d_\mu = -\frac{\sqrt{2}}{f}\partial_\mu \left(h X^4 + \sum_{a=5}^{dim(\mathcal{G}/\mathcal{H})} \eta^a X^a \right) + \frac{\sin\alpha}{\sqrt{2}} \sum_{i=1}^{3} \left(g_2 W_\mu^i - g_1 B_\mu \delta^{i3} \right) X^i + \cdots$$

New contribution to S & T

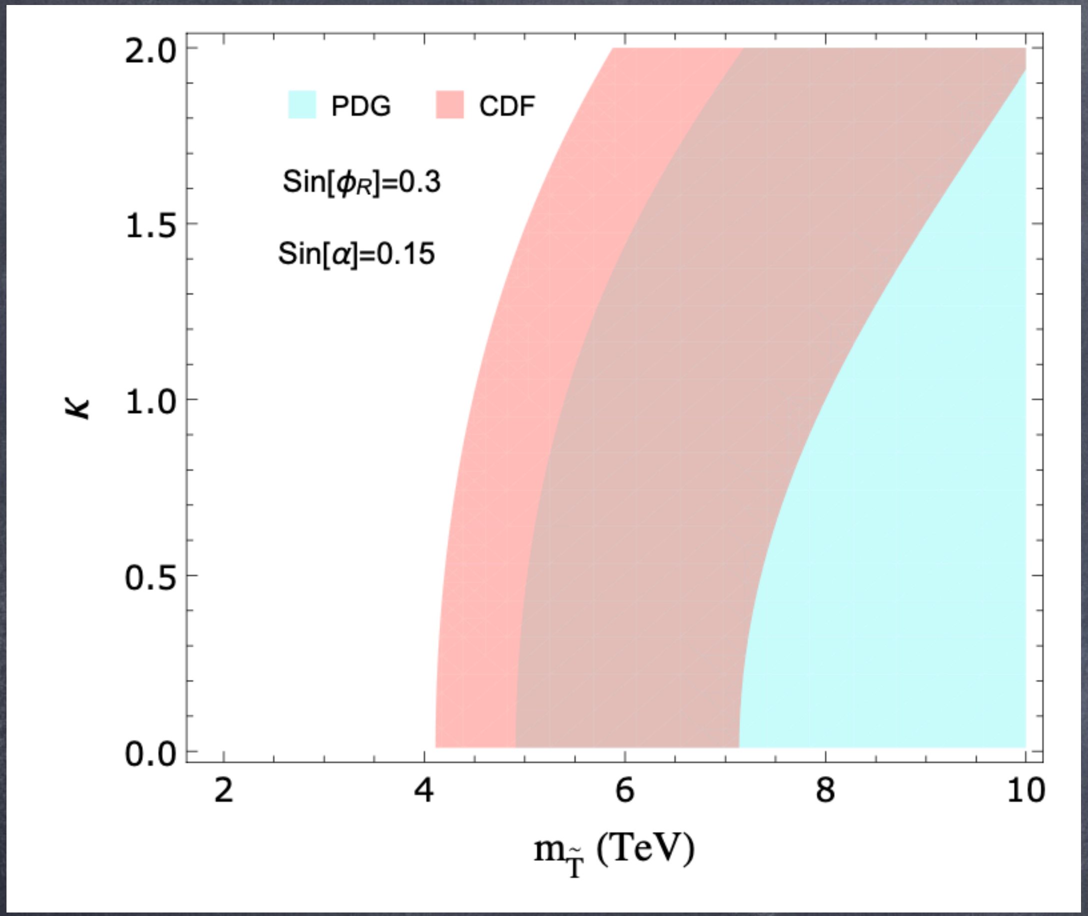
H.Cai, G.C., 2208.04290

Contribution of top partners

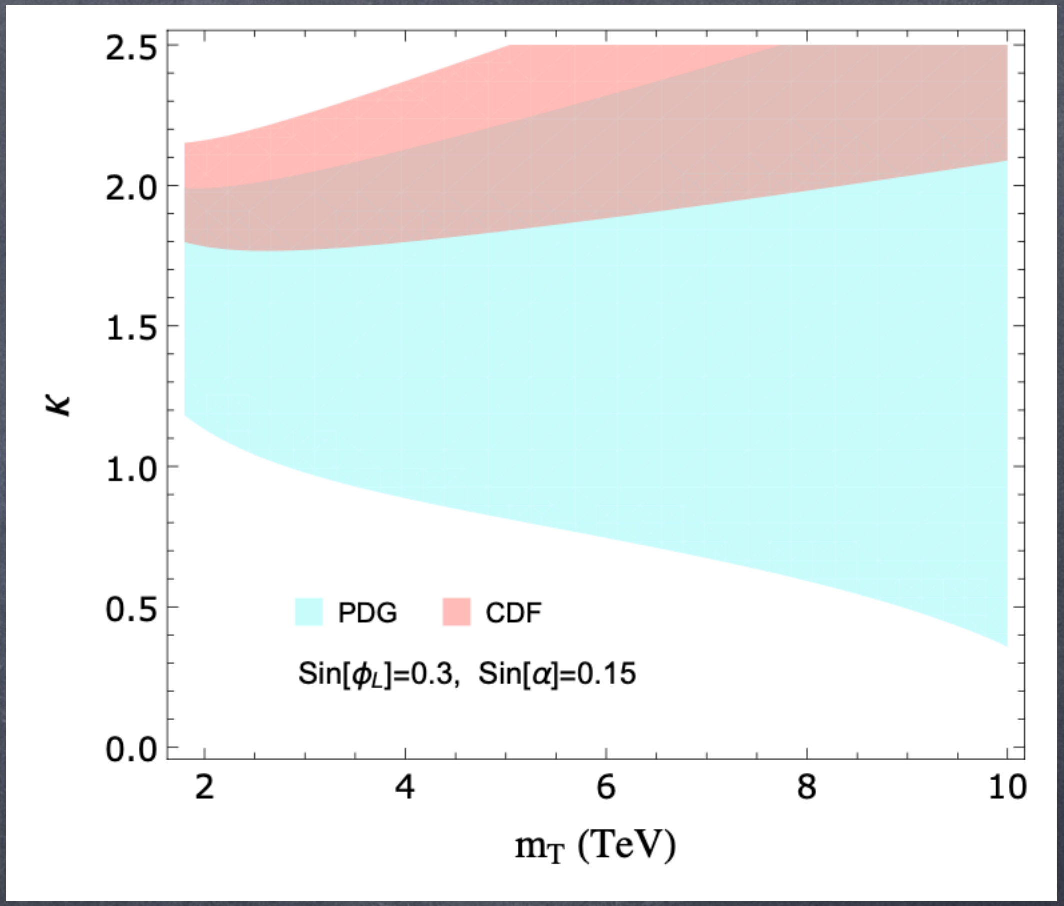
H.Cai, G.C., 2208.04290

SU(4)/Sp(4)

Singlet:



Bi-doublet:



- Top-partner masses in the multi-TeV scale, compatible with lattice results
- New effects crucial in some cases (bi-doublet)

"Technicolor" models

Compositeness scale f=v

- The Higgs arises as a "light" resonance (dilaton-like?)

$$\mathcal{L} = \mathcal{L}_{\overline{\mathrm{SM}}} + \xi_V \left(1 + 2\kappa_V \frac{h}{v} + \kappa_{2V} \frac{h^2}{v^2}\right) \frac{v^2}{4} \mathrm{Tr}\ D_\mu U^\dagger D^\mu U + \frac{1}{2}\partial_\mu h \partial^\mu h - \frac{\tilde{m}_h^2}{2} h^2 \left(1 + V_{0,1}\lambda_{3h}\frac{h}{v}\right)$$

- The couplings of the Higgs stem from the strong dynamics, and they could be larger than the SM ones!

$$T = -\frac{3}{16\pi c_W^2}(1-\kappa_V^2)\ln\frac{\Lambda^2}{m_h^2}\,, \qquad S = \frac{1}{12\pi}(1-\kappa_V^2)\ln\frac{\Lambda^2}{m_h^2} + \Delta S_{\mathrm{UV}}\,,$$

$$\kappa_V > 1 \quad \Rightarrow \quad \Delta T > 0!!!$$

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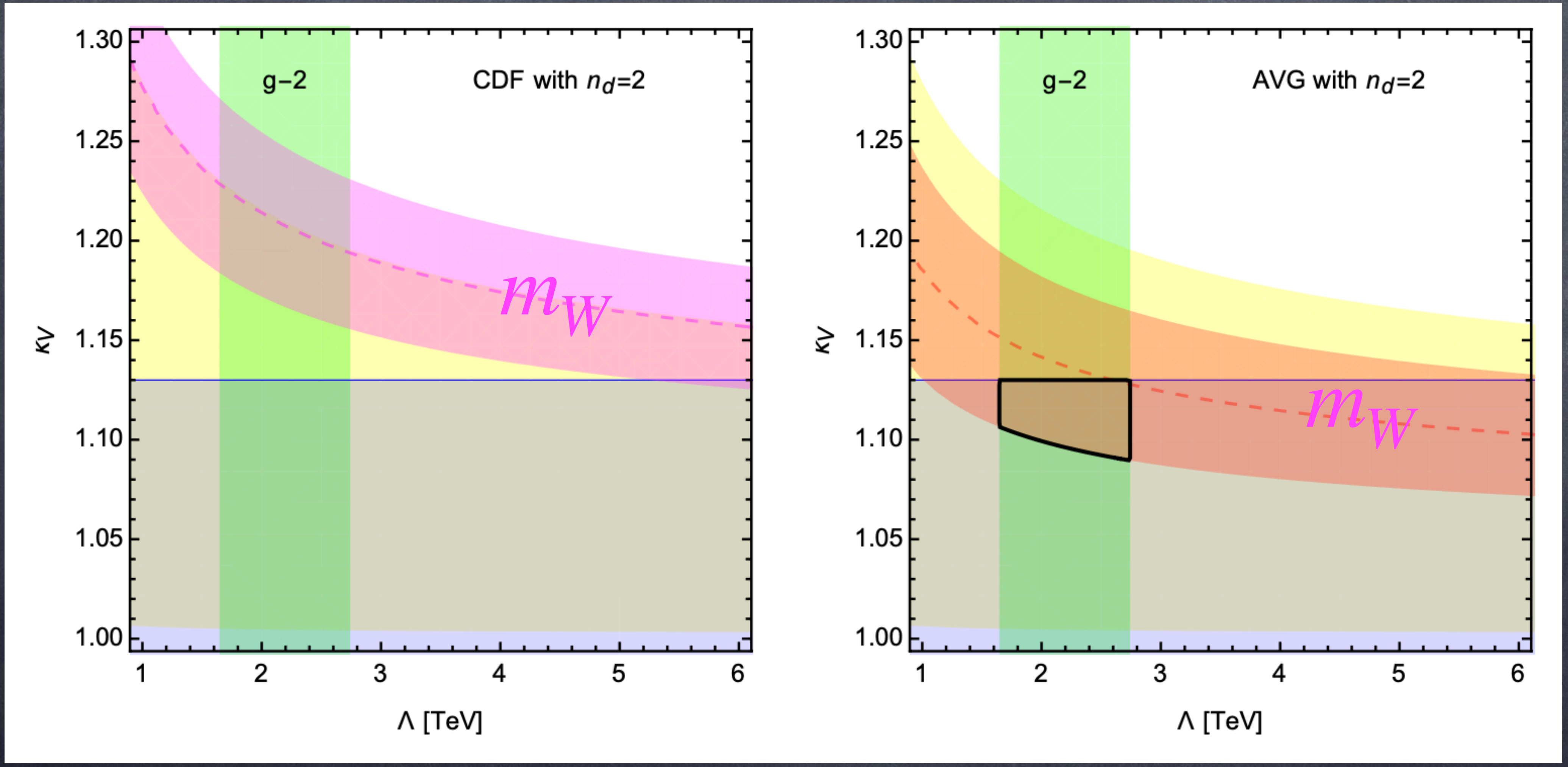
$$\Delta S_{\rm UV} = \frac{n_d}{6\pi}$$

G.C., F.Sannino 2204.04514



- Possible to obtain sizeable shifts in the W mass, contribution from top partners (to be added) can further help!

"Technicolor" models

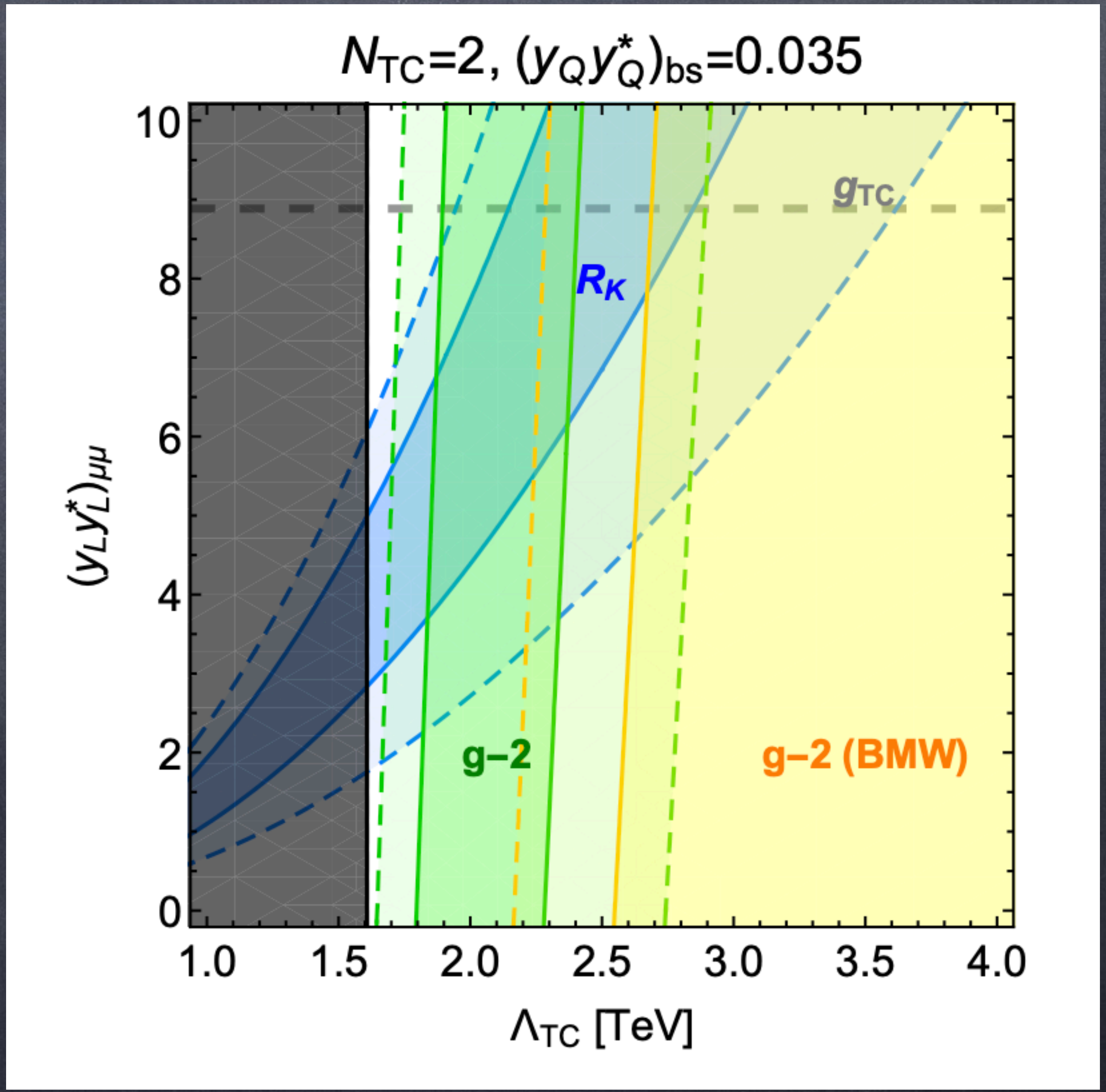
G.C., C.Cot, F.Sannino 2104.08818

- The most intriguing "coincidence" stemming from the anomalous muon g-2 !

$$\Delta a_\mu = \frac{m_\mu^2}{\Lambda_{\rm TC}^2}\left(1 + \frac{(y_L y_L)_{\mu\mu}}{g_{\rm TC}^2}\right)$$

$\Delta a_\mu = 250 \cdot 10^{-11}$ for $\Lambda_{\rm TC} = 2$ TeV $\sim 4\pi v$

Old RK result:



Suppressed in misaligned models:

$$\Delta a_\mu({\rm CGH}) \approx \frac{g_*^2}{(4\pi)^2}\frac{m_\mu^2}{m_*^2} = \frac{v_{\rm SM}^2}{f_{\rm CGH}^2}\frac{m_\mu^2}{\Lambda_{\rm TC}^2}\,,$$