Compositeness from particle collisions to space

Giacomo Cacciapaglia
IP2I Lyon, France
(with Aldo Deandrea and Benjamin Fuks)

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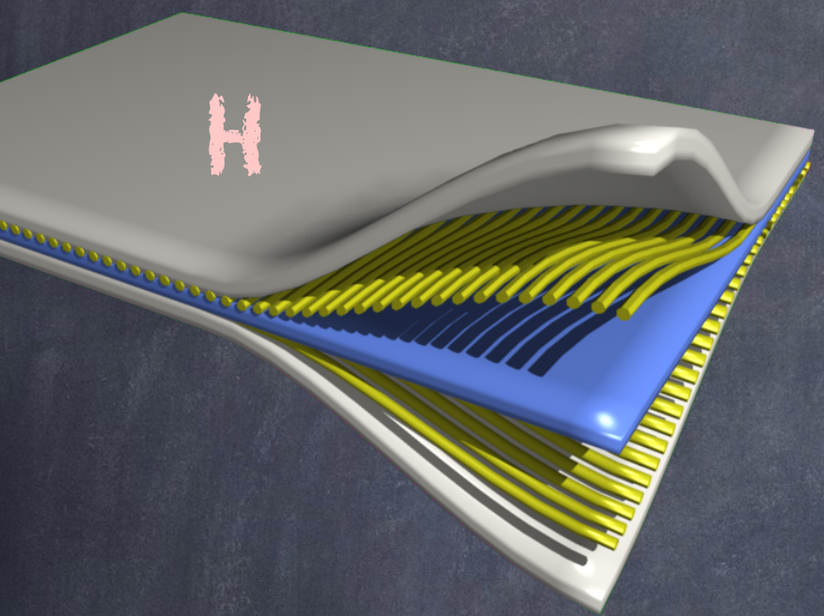
Why compositeness?



- A scalar field may be made of more fundamental fields

- We have seen this in Nature: low-energy QCD!
- Symmetries can be broken dynamically without generating hierarchies of scales!
- Very simple models can be built. (With caveats...)

Composite Higgs models 101

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

Scales:

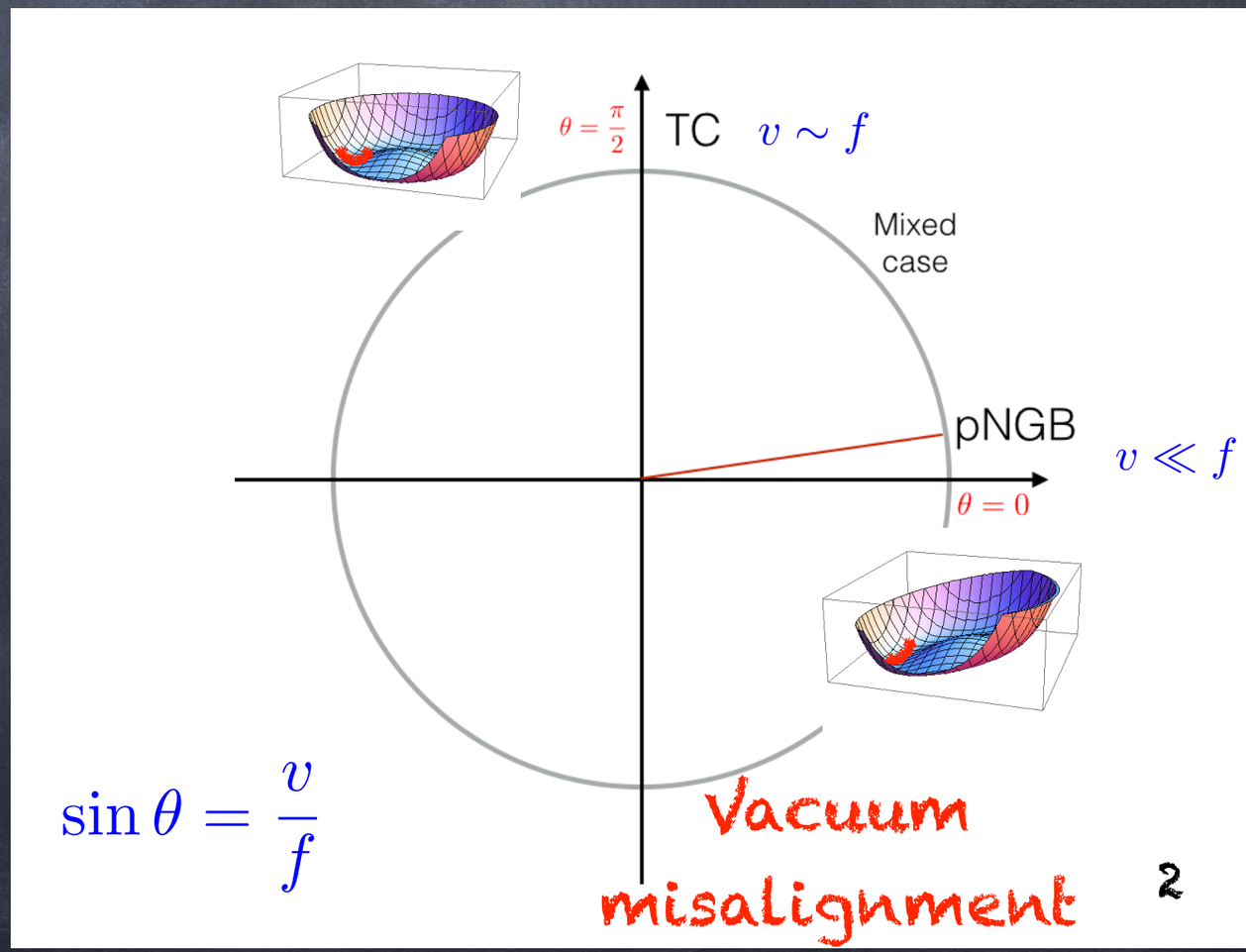
f : Higgs decay constant

v : EW scale

$m_\rho \sim 4\pi f$

EWPTs + Higgs coupl. limit:

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



Composite Higgs models 101

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

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

The EW symmetry is embedded in the global flavour symmetry SU(4) !

- The global symmetry is broken: SU(4)/Sp(4)

Witten, Kosower

- 5 Goldstones (pions) arise:

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

Higgs — additional singlet

Muon g-2 anomaly

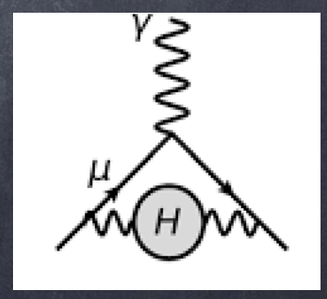
$$\Delta a_\mu = \frac{g_\mu - 2}{2} = \Delta a_\mu|_{QED} + \Delta a_\mu|_{EW} + \Delta a_\mu|_{QCD} + \Delta a_\mu|_{BSM}$$

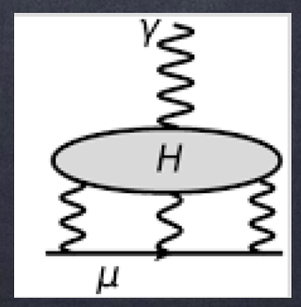
$116584718.9(1) \times 10^{-11}$ 0.001 ppm

$153.6(1.0) \times 10^{-11}$ 0.01 ppm

$6845(40) \times 10^{-11}$ 0.37 ppm

$92(18) \times 10^{-11}$ 0.15 ppm





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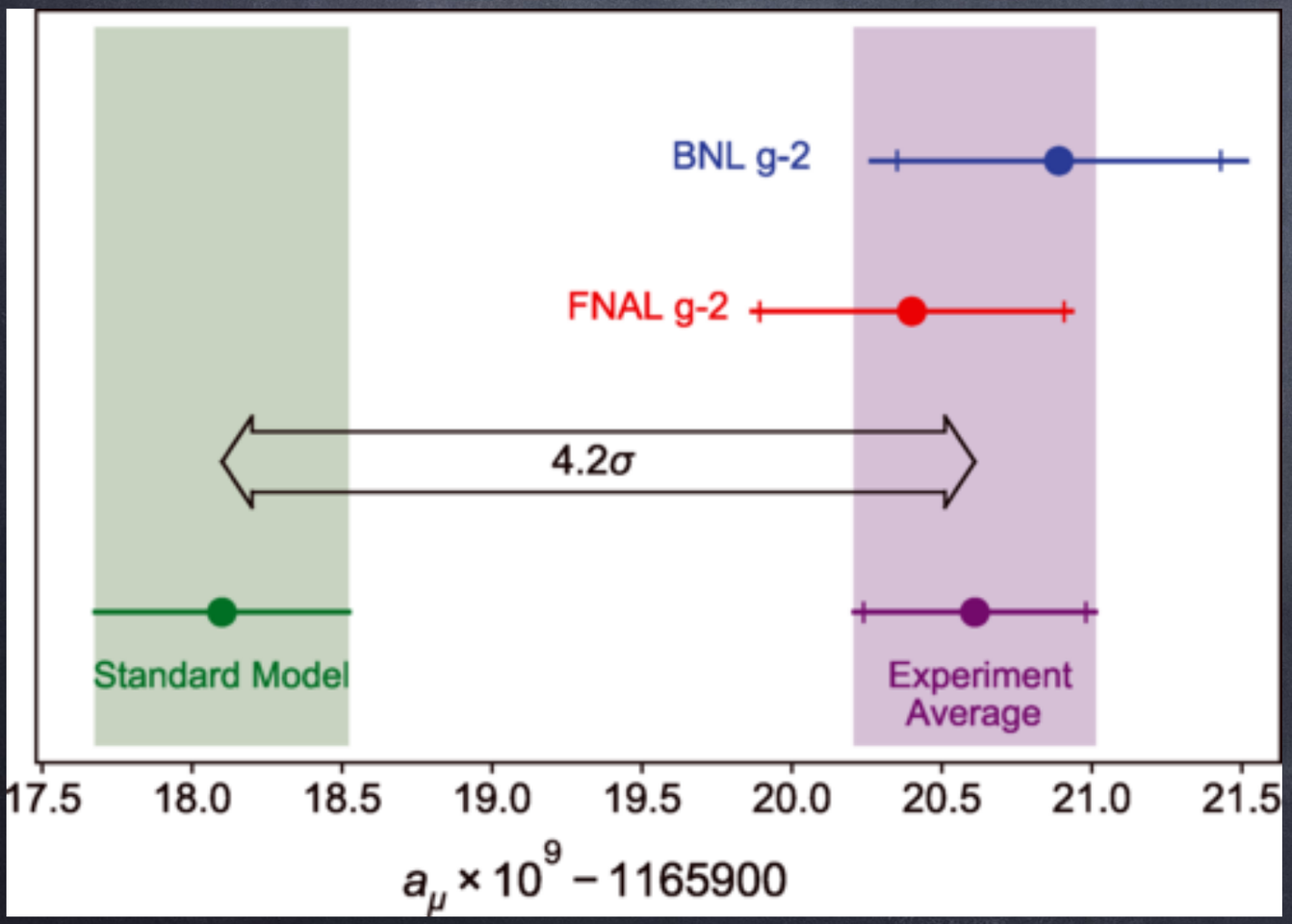

$$\Delta a_\mu|_{BSM} = 251(59) \times 10^{-11}$$

$$\Delta a_\mu|_{BSM} \approx \frac{m_\mu^2}{\Lambda^2}$$

$$\Lambda \approx 2 \text{ TeV} \approx 4\pi v$$

Anomaly point to the most natural scale of Technicolor! (compositeness at the EW scale)

Muon g-2 anomaly

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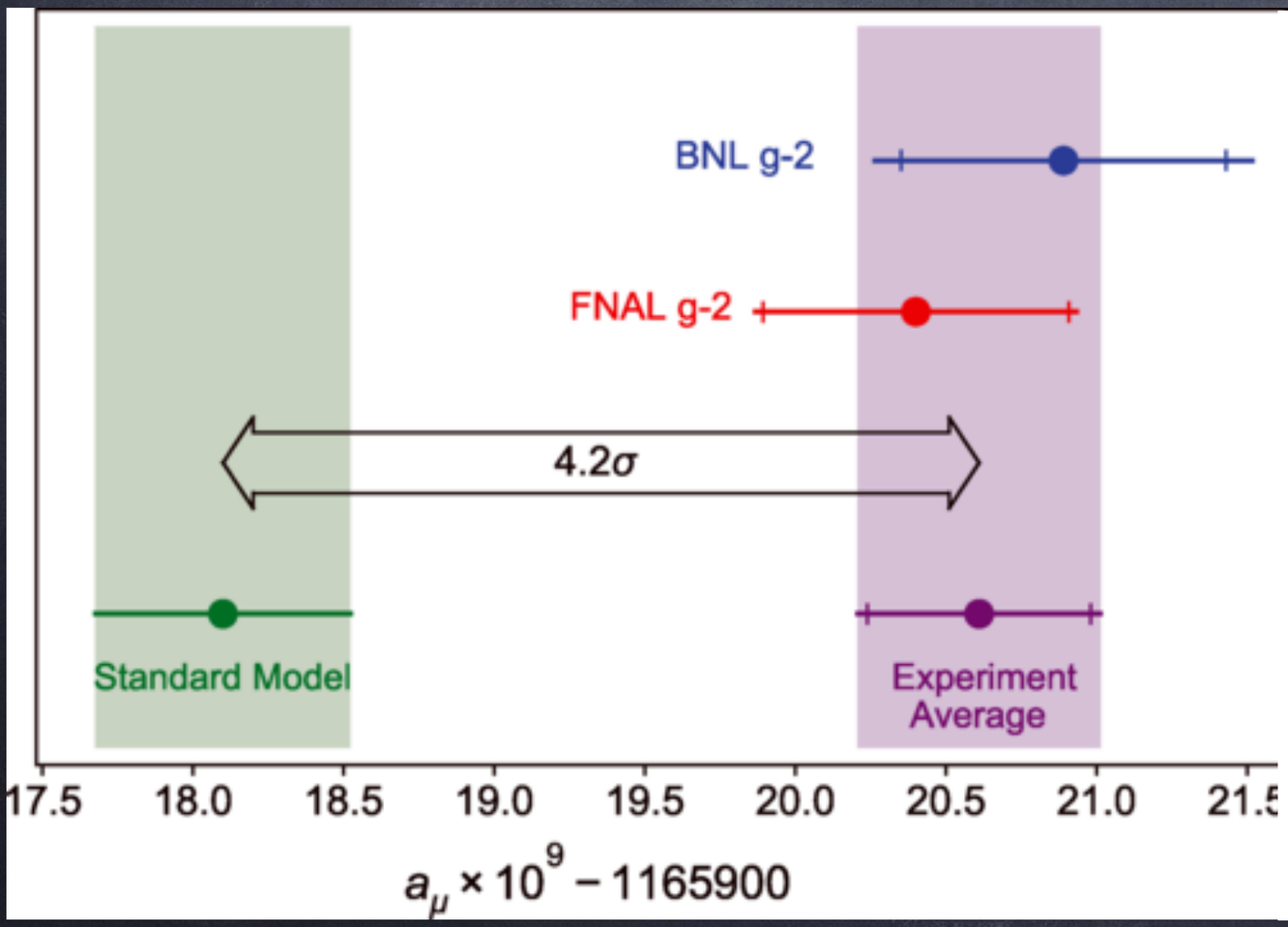
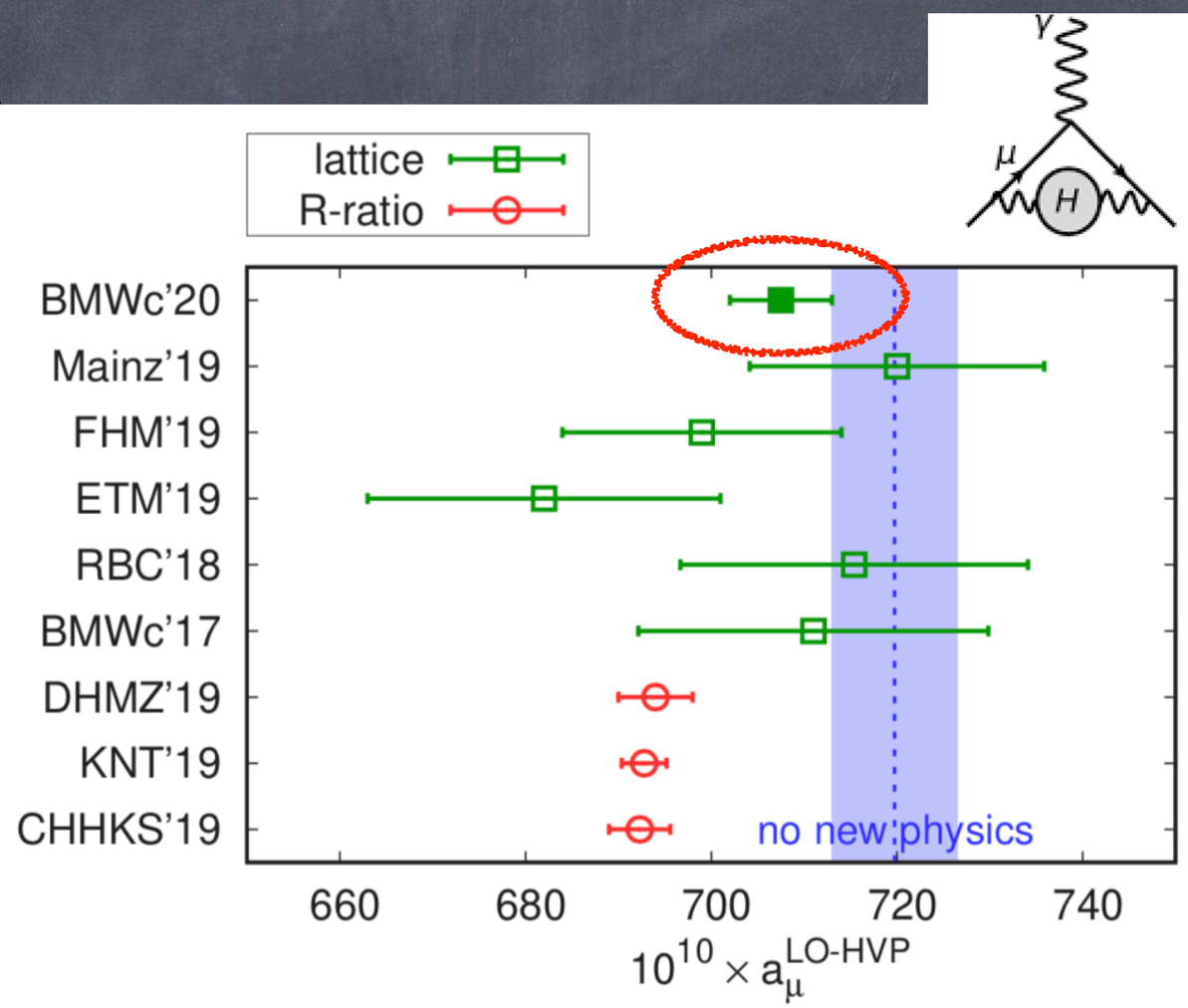
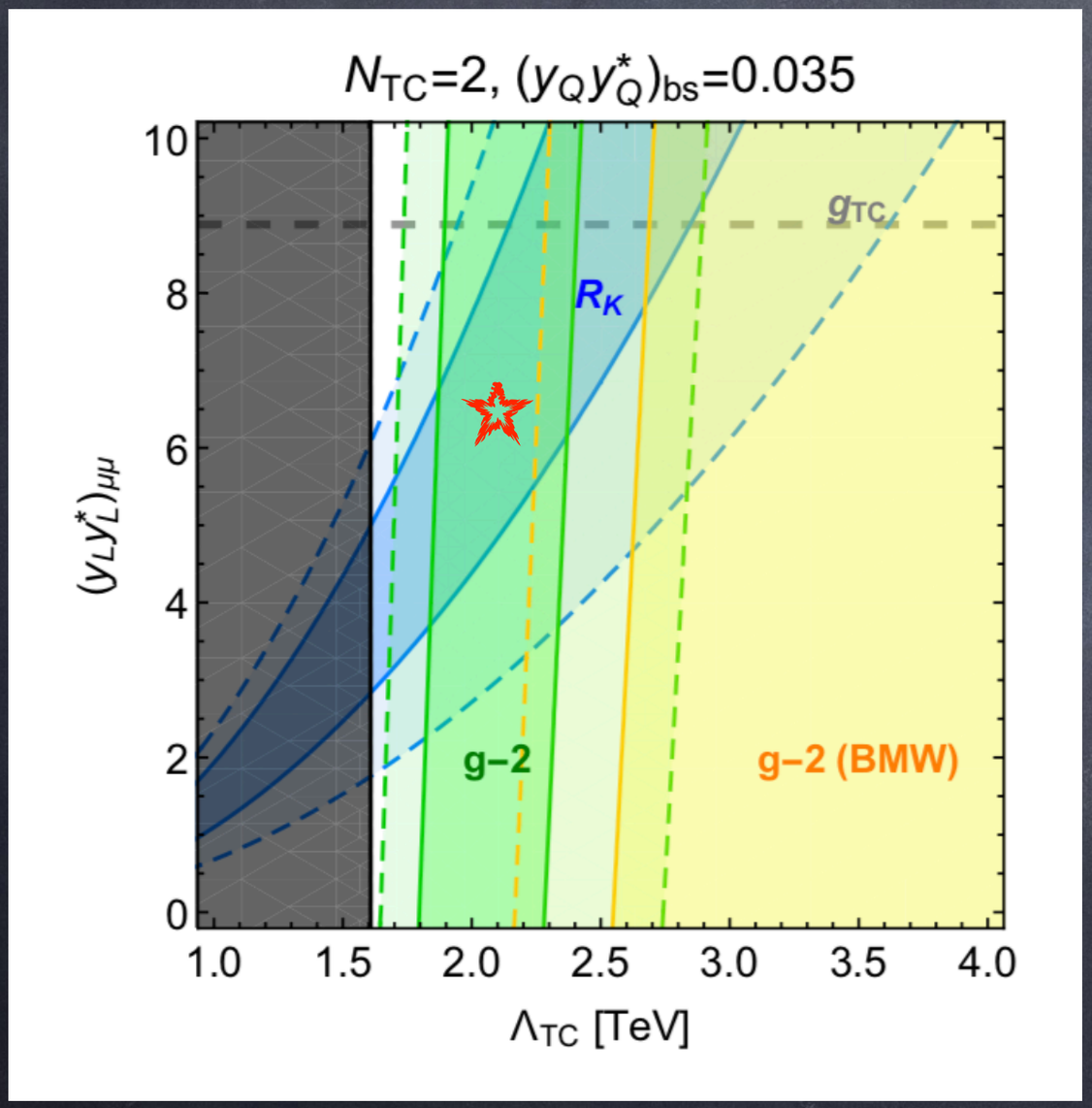




New lattice results reduce tension: stay tuned!

There's something about Muons



$$R_K = \frac{\mathrm{BR}\,(B^+ \to K^+\mu^+\mu^-)}{\mathrm{BR}\,(B^+ \to K^+e^+e^-)} = 0.846^{+0.044}_{-0.041}$$

- g-2 fixes the scale of new physics
- natural values for TC-like theories!
- RK requires large muon couplings (attainable in strong dynamics)

These anomalies will be further probed in the near future!

Perspectives: low energy

- A complete scenario motivated by the muon anomalies can be constructed.
- The Higgs must be a light dilaton-like composite resonance.
- Low scale => testable at the LHC and future colliders.
- BSM lattice studied can point towards the correct underlying theory (model building)

Light composite resonances

How can light states emerge?

	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)	$\sim y_t^2 f^2 s_\theta^2 = y_t^2 v^2$	$\sim g^2 f^2 s_\theta^2 = g^2 v^2$	✗
a	✗	✗	$\sim m_\psi f$ This can be small!

Composite ALP Lagrangian:

$$\mathcal{L}_{\rm eff}^{D\leq 5} = \frac{1}{2}\,(\partial_\mu a)(\partial^\mu a) - \frac{m_{a,0}^2}{2}\,a^2 + \frac{\partial^\mu a}{\Lambda}\sum_F \bar{\psi}_F\,\boldsymbol{C}_F\,\gamma_\mu\,\psi_F$$
$$+ g_s^2\,C_{GG}\,\frac{a}{\Lambda}\,G^A_{\mu\nu}\,\tilde{G}^{\mu\nu,A} + g^2\,C_{WW}\,\frac{a}{\Lambda}\,W^A_{\mu\nu}\,\tilde{W}^{\mu\nu,A} + g'^2\,C_{BB}\,\frac{a}{\Lambda}\,B_{\mu\nu}\,\tilde{B}^{\mu\nu}\,,$$

Composite Higgs scenario:

$$\frac{C_{WW}}{\Lambda} \sim \frac{C_{BB}}{\Lambda} \sim \frac{N_{\rm TC}}{64\sqrt{2}\,\pi^2 f}$$

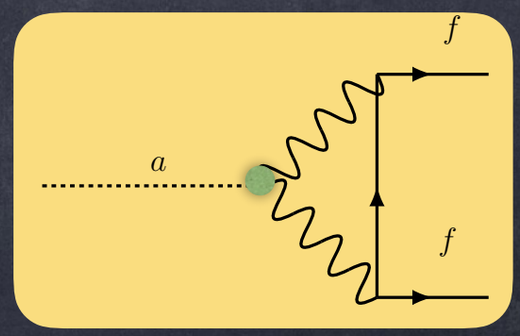
$$\frac{C_{GG}}{\Lambda} = 0$$

(Poor bounds at the LHC)

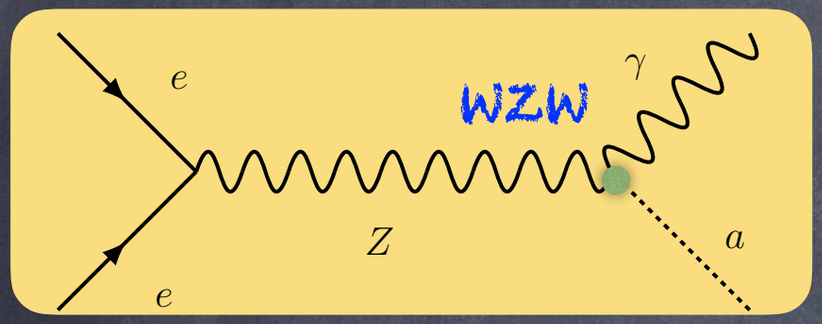
$$(C_{\gamma\gamma} = C_{WW} + C_{BB})$$

$\mathbf{C}_F$ is loop-induced:

M.Bauer et al, 1708.00443



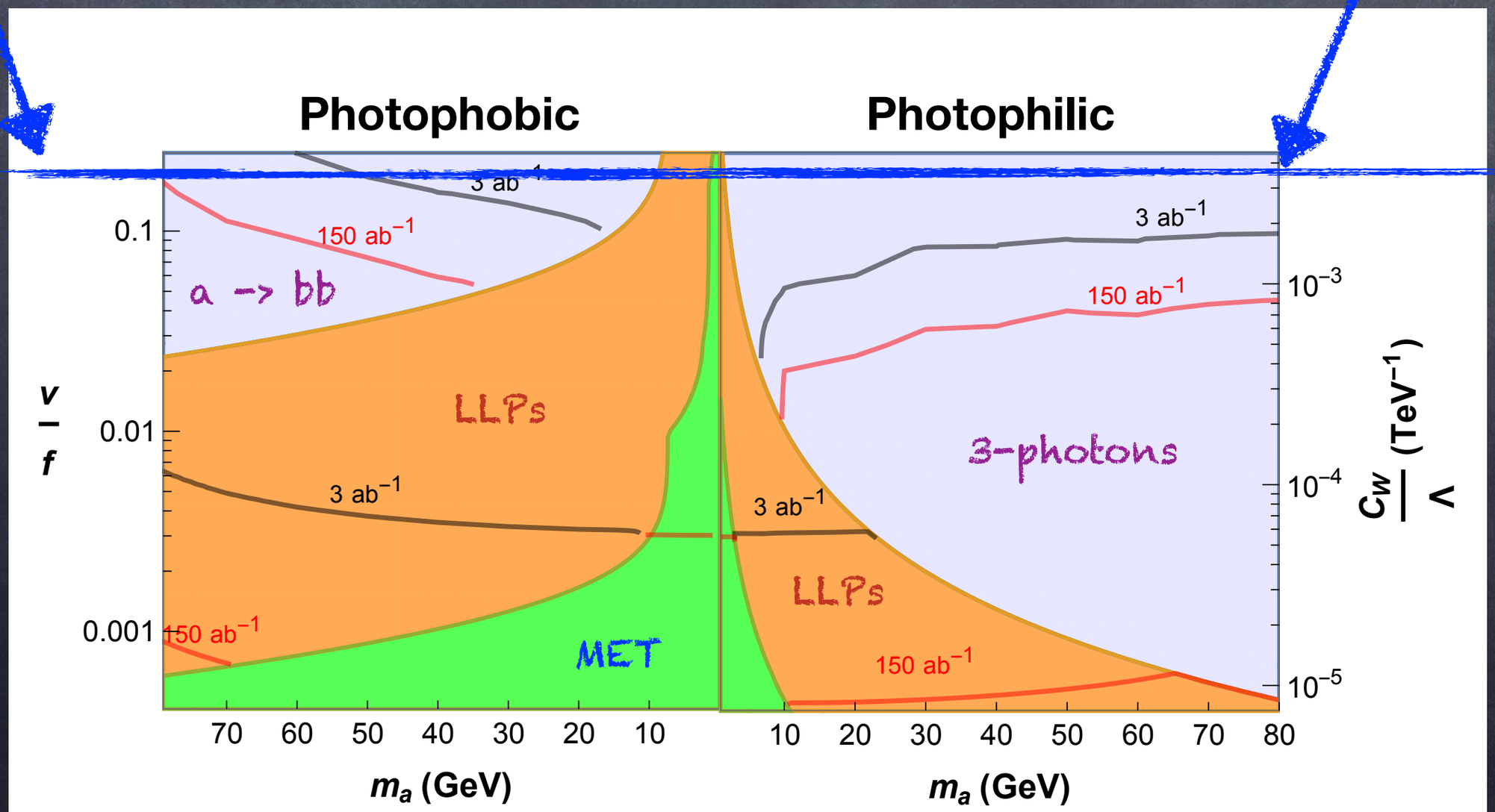
Tera-Z portal to compositeness (via ALPs)



Typical EWPT bound

This process is always associated with a monochromatic photon.

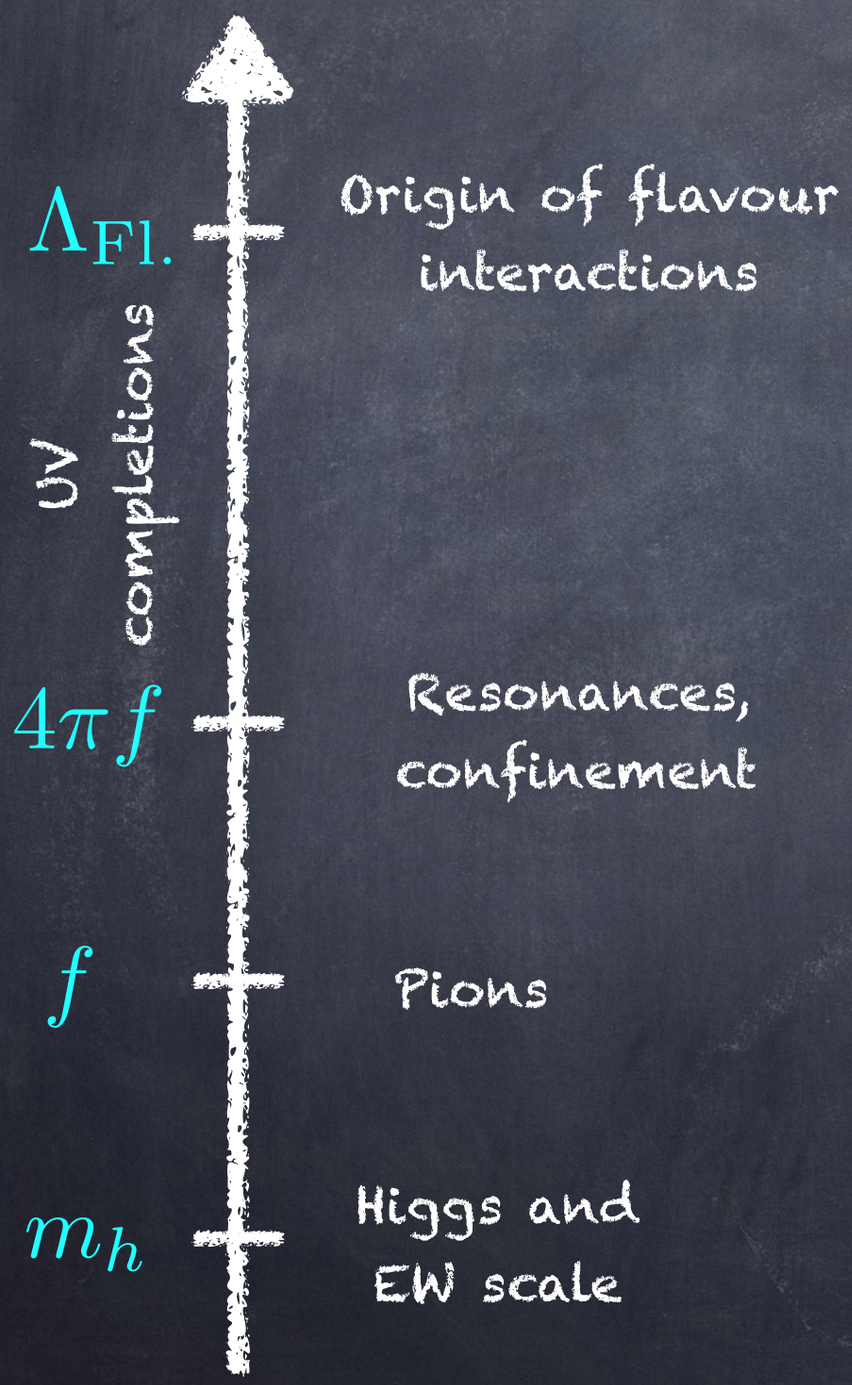
Too small to explain the muon g-2 anomaly!
M.Bauer et al, 1704.08207

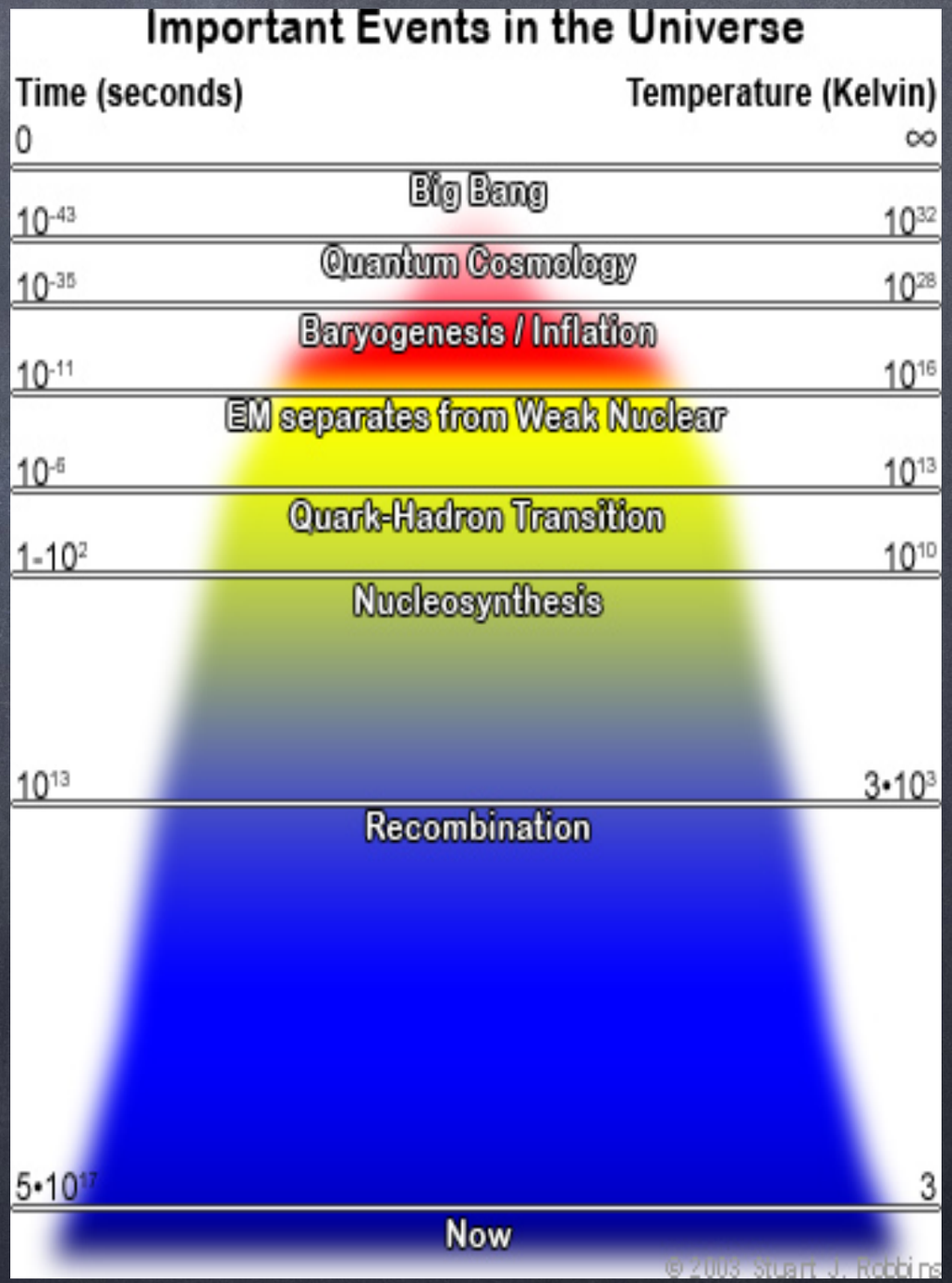


Perspectives: light composites

- Composite (Higgs) models naturally feature very light (pseudo)scalars
- Ideal Physics case for FCC-ee (FCC-France initiative)
- Exotic decays of top parters: systematic study at the LHC, "Master" UFO model files @ NLO
- If below MeV, they can produced inside stars, and affect the Cosmological evolution

Composite (Higgs) in space!





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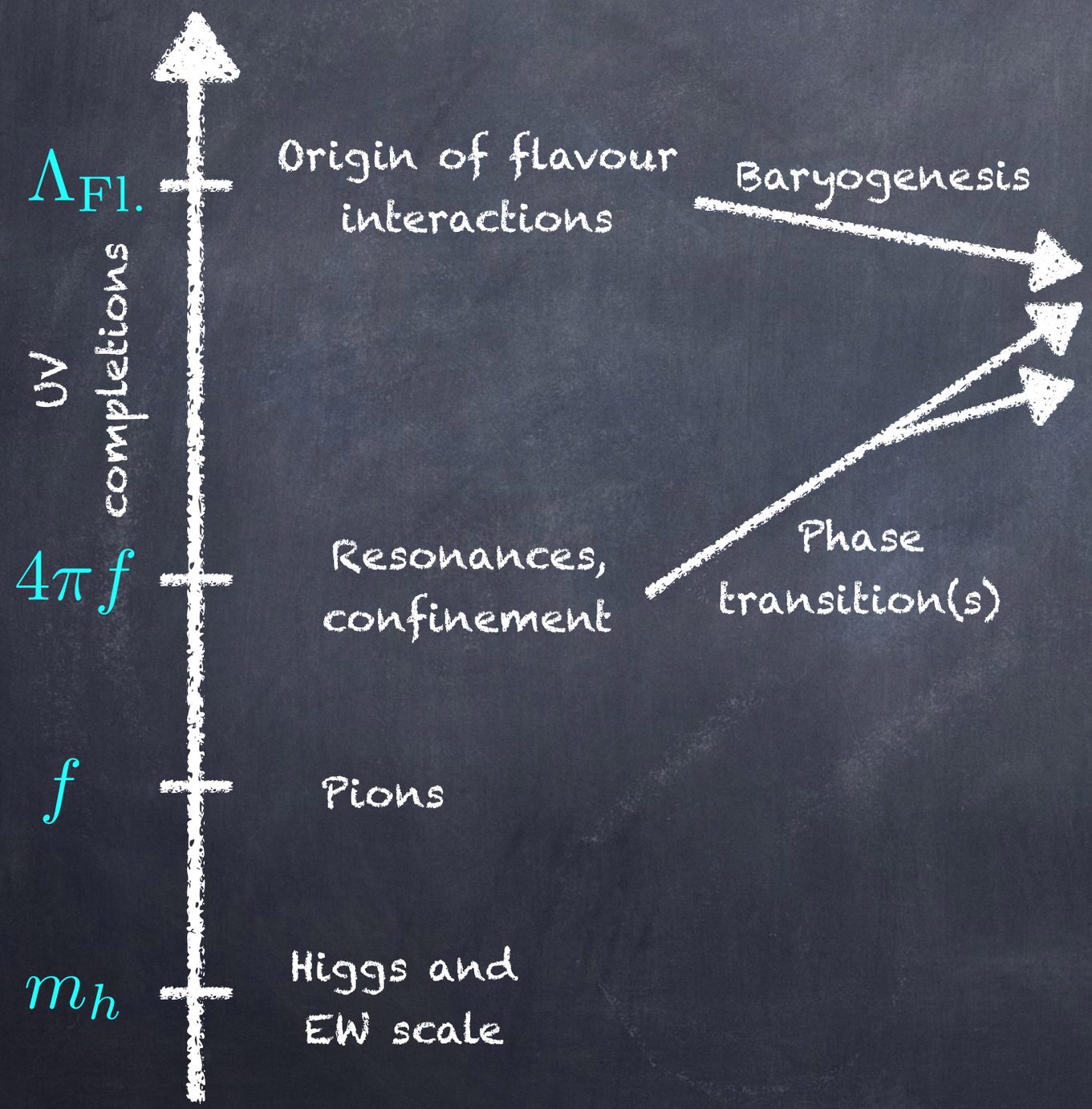

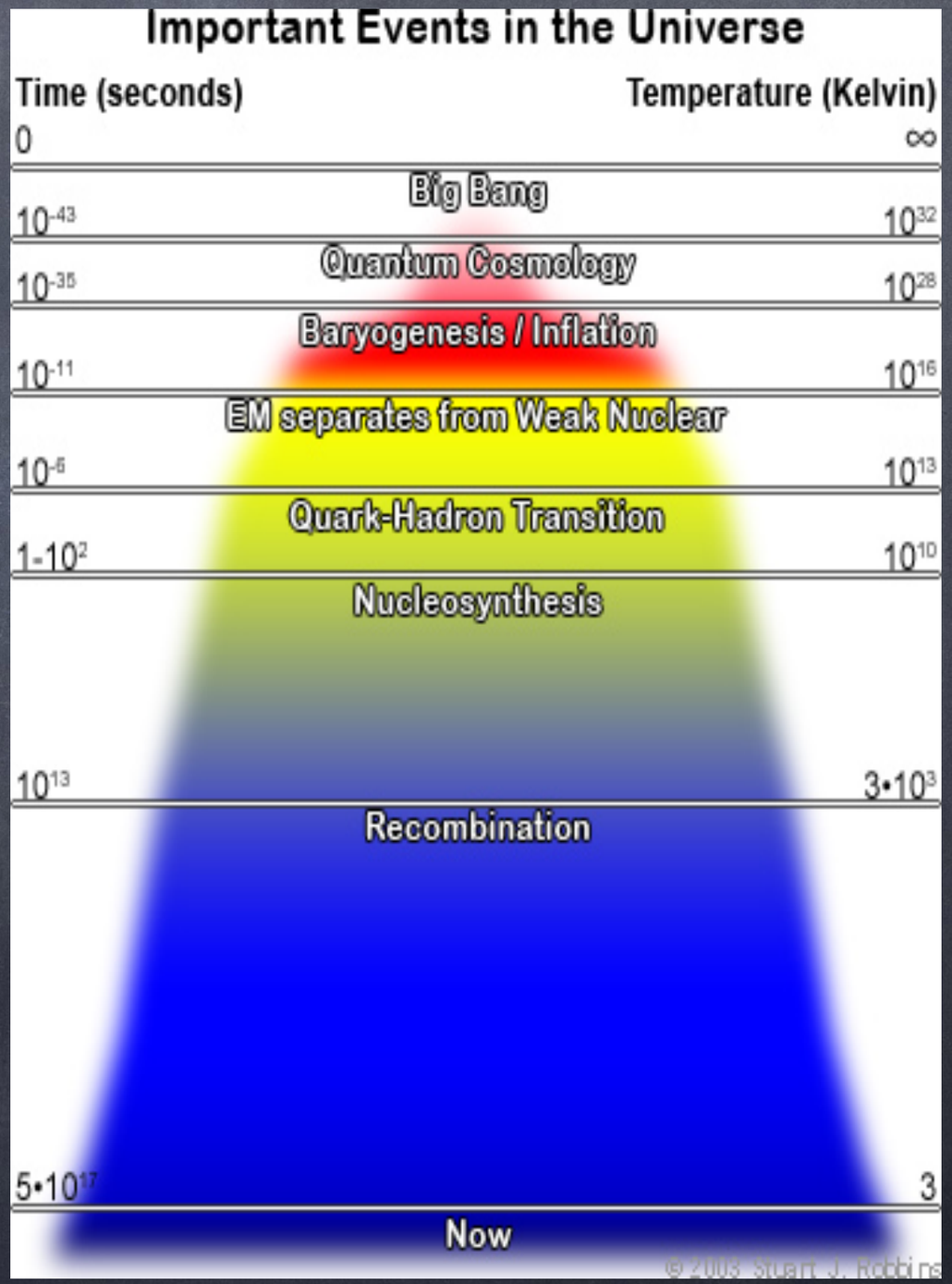

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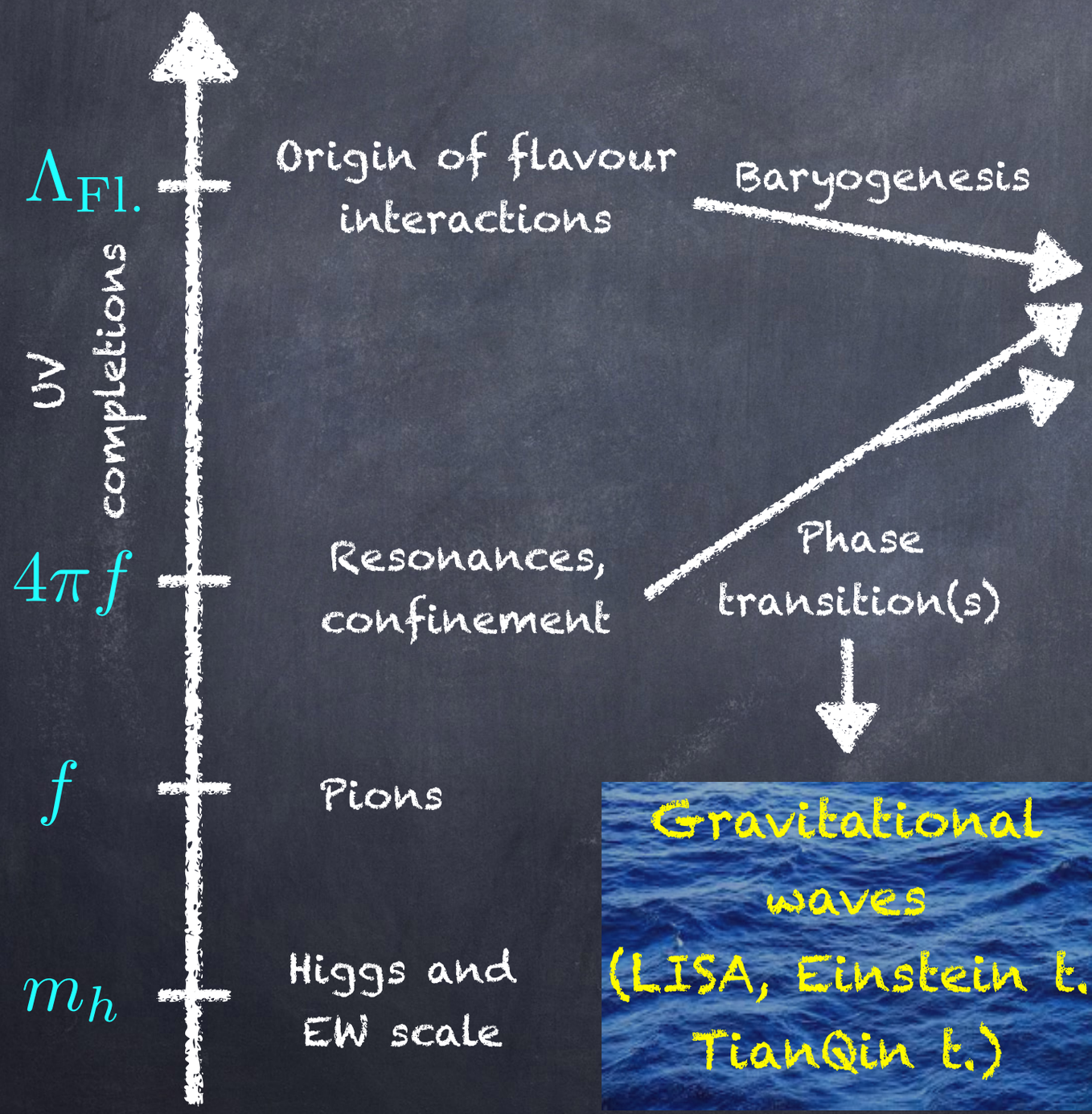

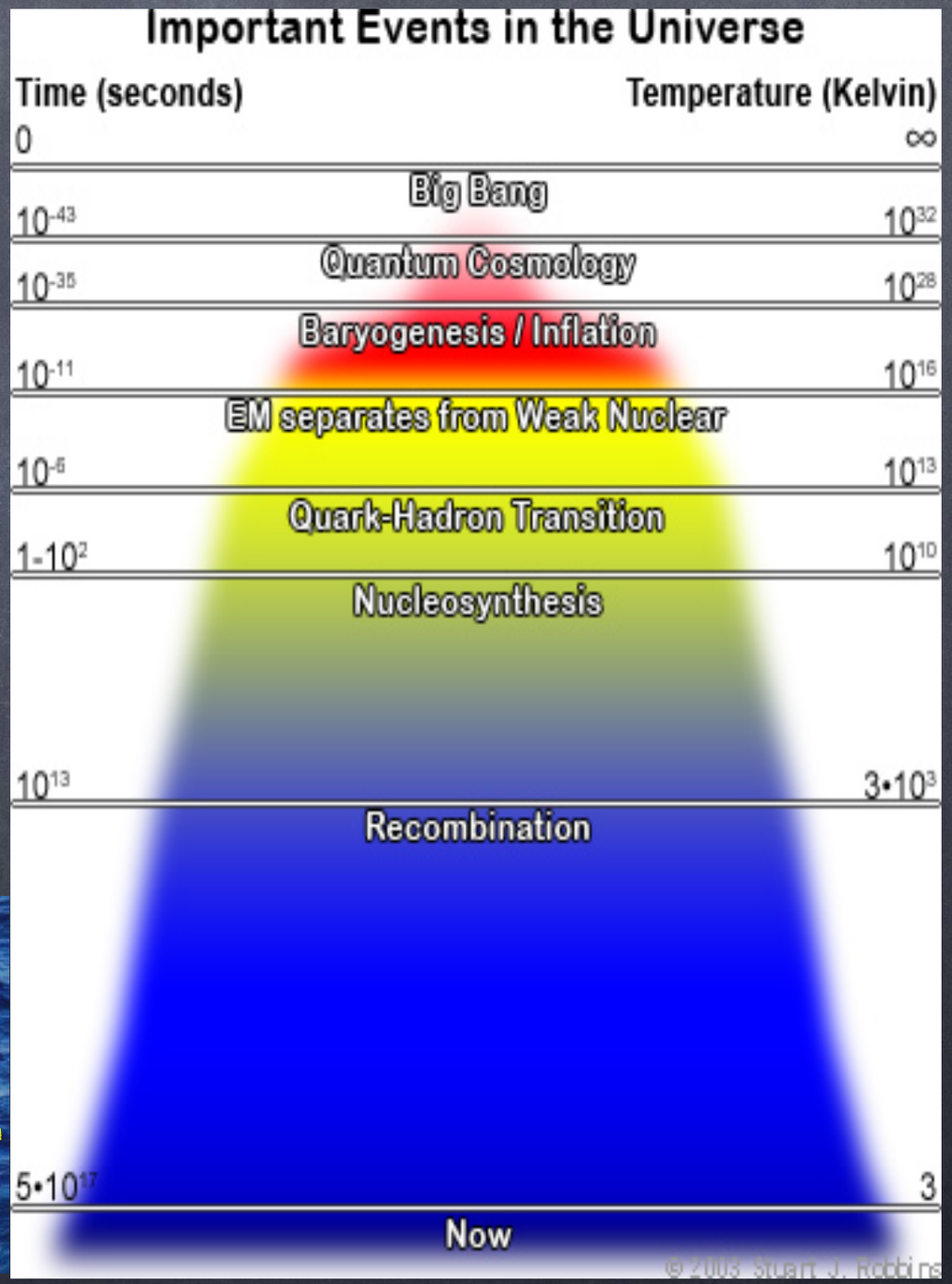

Outlook

- Composite (Higgs or Dark Matter) models are a feasible route for New Physics
- g-2 and R_K explainable via TC-like theories
- Phenomenology at LHC and FCC-ee
- Phase transitions in the early Universe can generate relic gravitational waves
- Interesting and fun physics from low energies to Cosmology!