

Axion-like particles at flavour experiments

Sophie Renner
SISSA

Based on work with M. Bauer, M. Neubert, M. Schnubel and A. Thamm

Anomalies and precision in the Belle II era, 8th September 2021

Why axion like particles (ALPs)?

Any dynamics with a spontaneously broken approximate global symmetry will produce light spinless particles

Analogy: QCD pions

Λ_{QCD} ————— p, n, \dots

m_π = = = = π

Pions are pseudo goldstone bosons of an approximate spontaneously broken symmetry

BSM physics

Λ_{UV} ————— ??

m_a ————— a

ALP is a pseudo goldstone boson

Mass much below scale of BSM physics

ALP effective field theory

Don't need to know the details of the BSM physics to study the ALP

ALP couplings to SM fields begin at dimension 5, suppressed by the UV scale

$$\Lambda_{UV} = 4\pi f$$

$F = Q, u, d, L, e$

$$\begin{aligned}\mathcal{L}_{\text{eff}}^{D \leq 5} = & \frac{1}{2} (\partial_\mu a) (\partial^\mu a) - \frac{m_{a,0}^2}{2} a^2 + \frac{\partial^\mu a}{f} \sum_F \bar{\psi}_F \mathbf{c}_F \gamma_\mu \psi_F \\ & + c_{GG} \frac{\alpha_s}{4\pi} \frac{a}{f} G_{\mu\nu}^a \tilde{G}^{\mu\nu,a} + c_{WW} \frac{\alpha_2}{4\pi} \frac{a}{f} W_{\mu\nu}^A \tilde{W}^{\mu\nu,A} + c_{BB} \frac{\alpha_1}{4\pi} \frac{a}{f} B_{\mu\nu} \tilde{B}^{\mu\nu}\end{aligned}$$

Assume the ALP mass is a free parameter (depends on unknown aspects of UV Lagrangian)

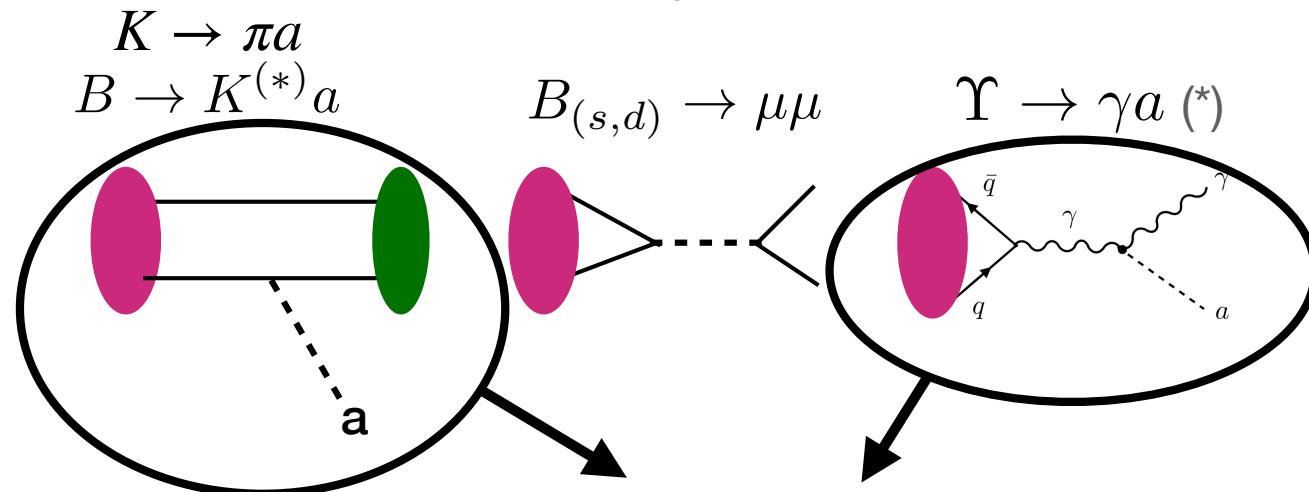
Then the parameter space of the model depends on

$$f, m_a, c_{XX}, \mathbf{c}_F$$

matrices in flavour space

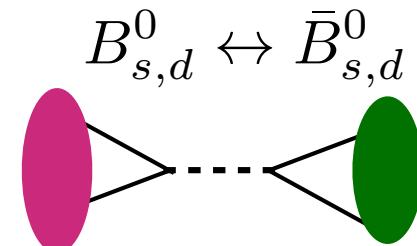
ALPs in flavour

Meson decays



(*actually flavour conserving but important in the same mass range)

Meson mixing



On-shell signatures:

Long lived ALP: missing energy, monoenergetic final state meson/photon

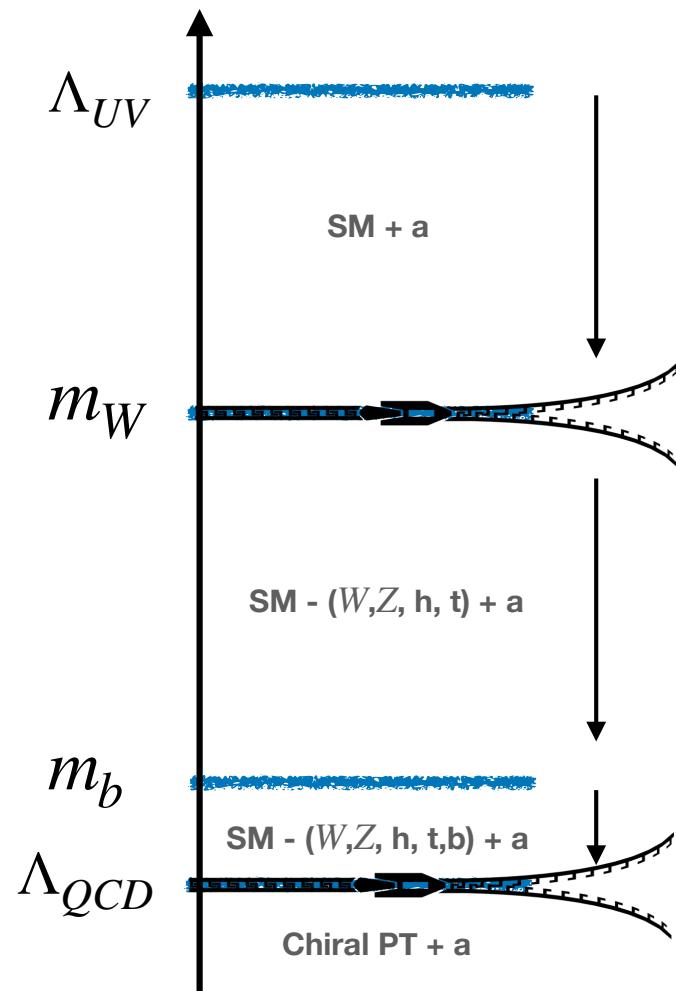
Decaying ALP: narrow resonance in decay products (+ poss displaced vertex)

Since ALP couplings are suppressed by heavy scale, ALPs can have long decay lengths

From the EFT to observables

Bauer, Neubert, SR, Schnubel, Thamm 2012.12272

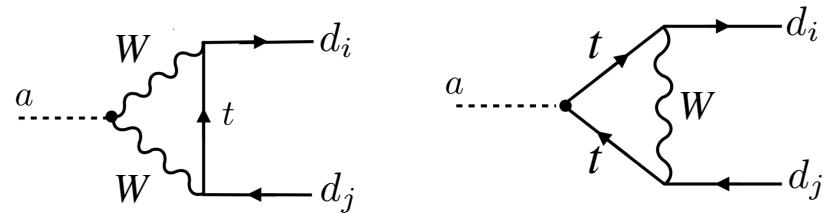
Chala, Guedes, Ramos, Santiago, 2012.09017



ALP couplings determined by physics at Λ

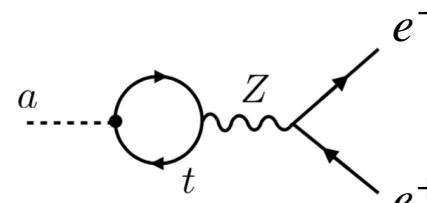
To make connection with observables, need to run and match to scale of measurement

1) Flavour changing effects



ALP production, eg $B \rightarrow K a$

2) Flavour conserving effects



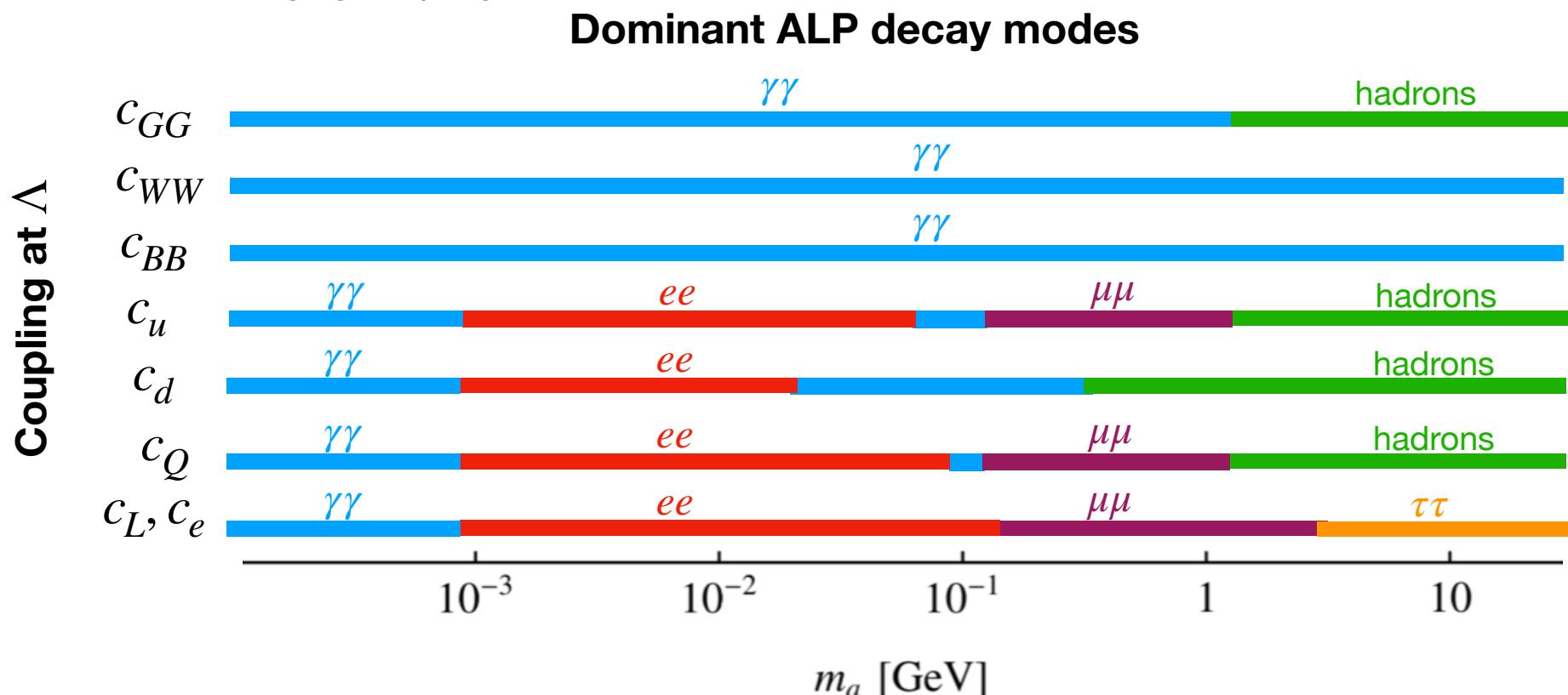
ALP decay, eg $a \rightarrow e e$

Production & decay in flavour processes

Simplifying assumption: flavour diagonal & universal couplings at $\Lambda = 4\pi$ TeV

$$[k_D(m_t)]_{ij}^{\text{univ}} \simeq 10^{-5} V_{ti}^* V_{tj} \left[-6.1 c_{GG} - 2.8 c_{WW} - 0.02 c_{BB} + 1926 c_u(\Lambda) - 9.2 c_d(\Lambda) - 1905 c_Q(\Lambda) - 0.05 c_e(\Lambda) + 4.2 c_L(\Lambda) \right]$$

induced flavour changing coupling



Simplified scenario: coupling to SU(2) gauge bosons

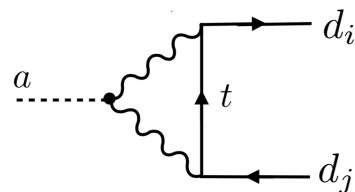
Bauer, Neubert, SR, Schnubel, Thamm, preliminary

see also: Gavela, Houtz, Quilez, del Rey, Sumensari (2019)

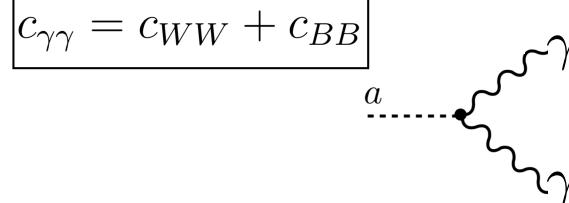
Izaguirre, Lin, Shuve (2016); Gori, Perez, Tobioka (2020)

**Flavour
change:**

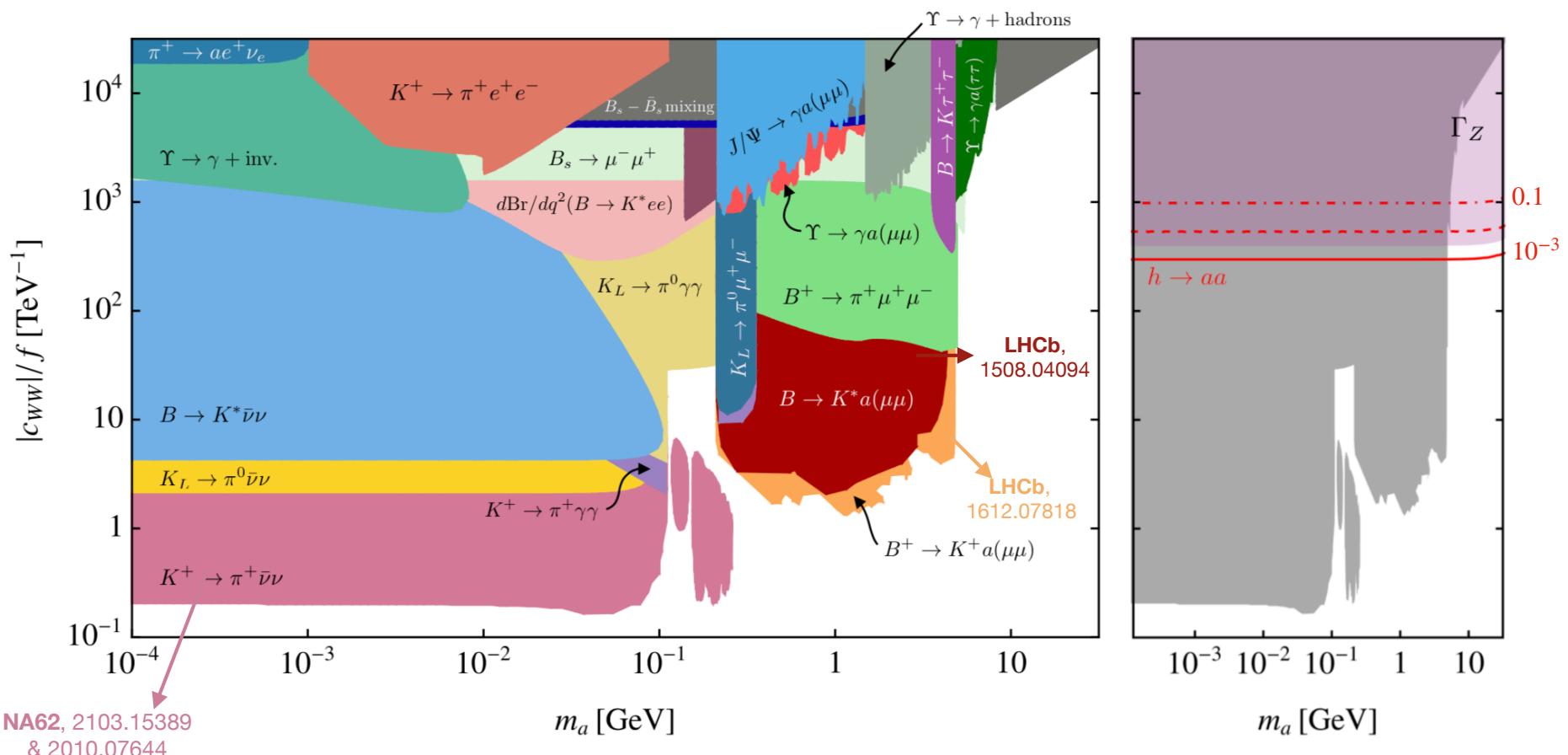
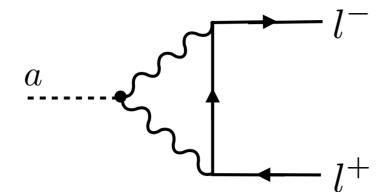
$$c_{WW} \frac{\alpha_2}{4\pi} \frac{a}{f} W_{\mu\nu}^A \tilde{W}^{\mu\nu,A}$$



$$c_{\gamma\gamma} = c_{WW} + c_{BB}$$



Decays:

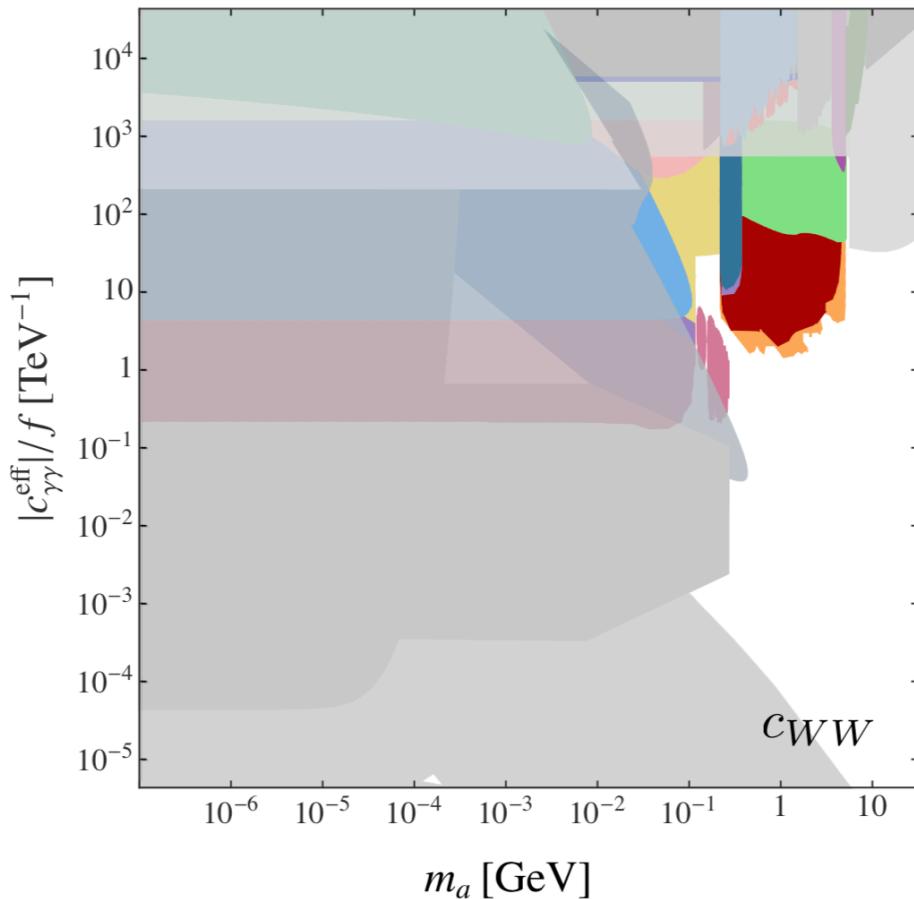
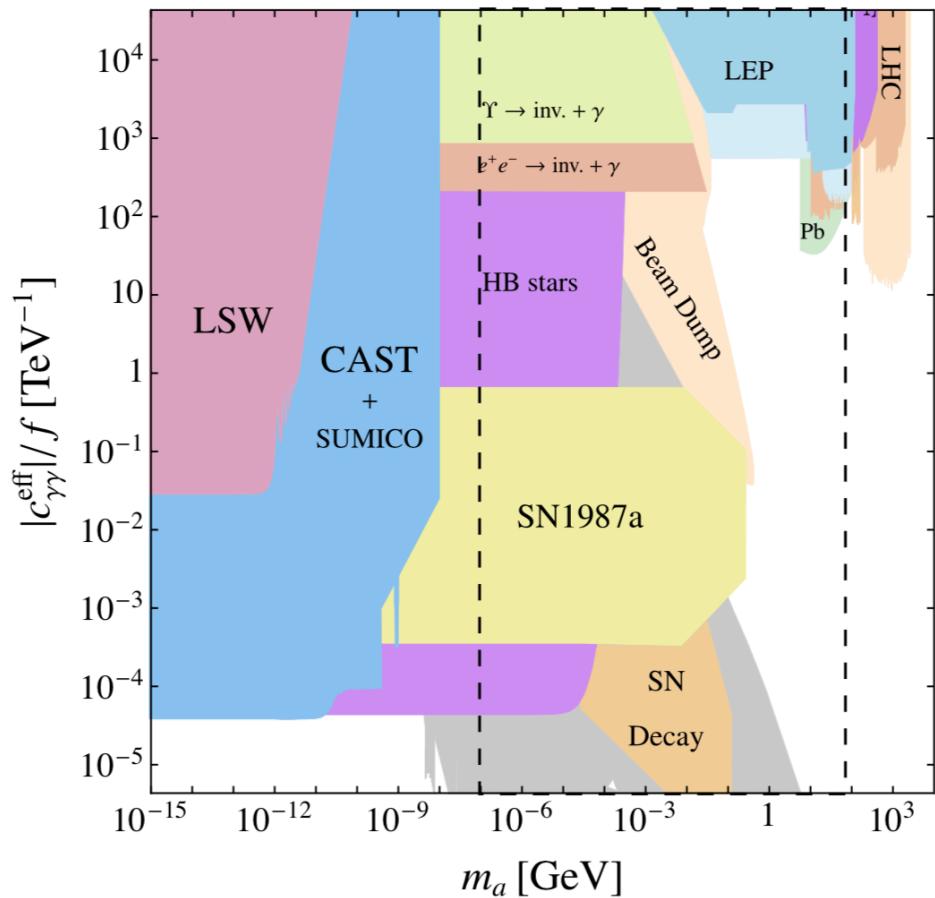


Simplified scenario: coupling to SU(2) gauge bosons

Bauer, Neubert, SR, Schnubel, Thamm, preliminary

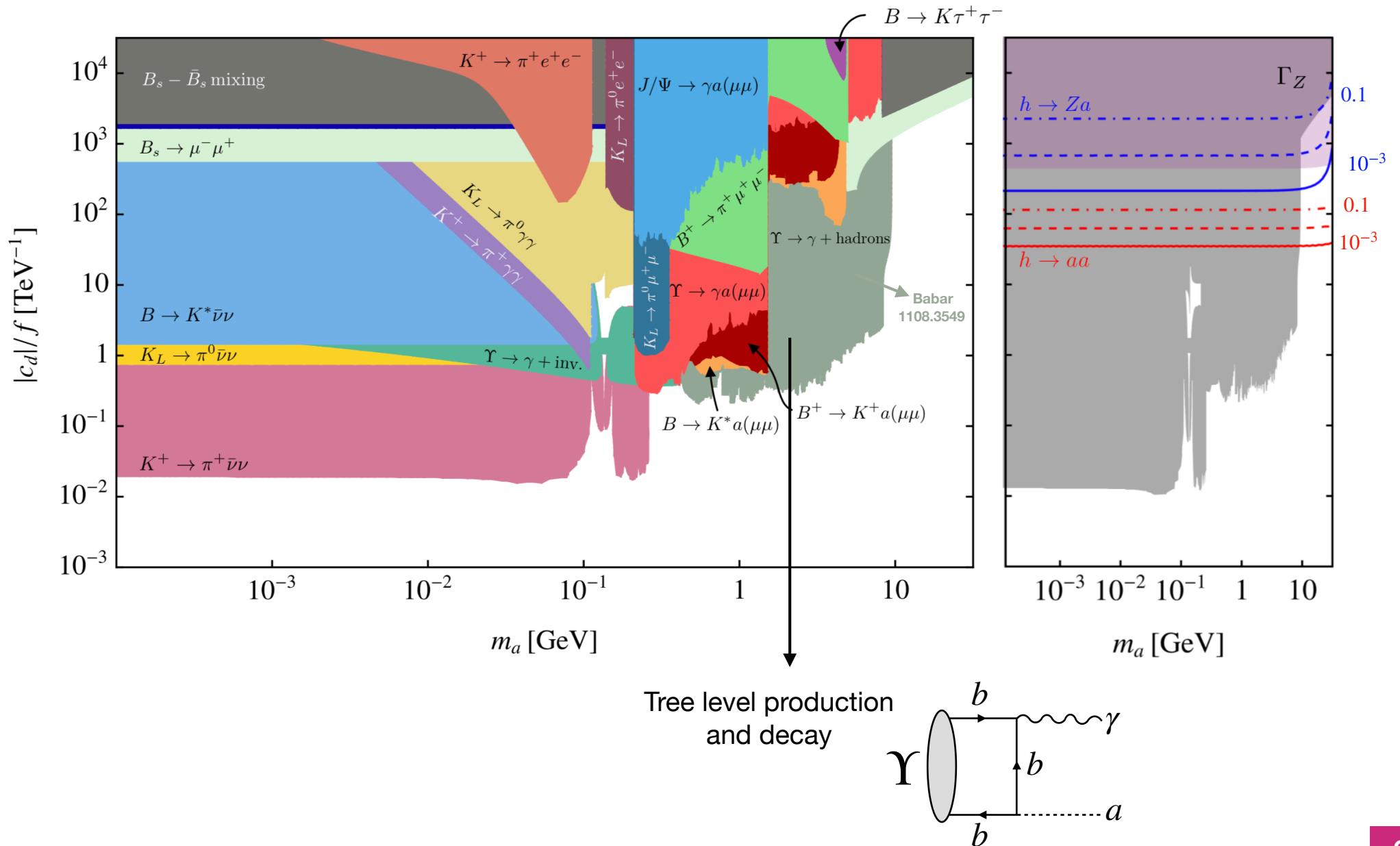
$$c_{\gamma\gamma} = \textcircled{c_{WW}} + c_{BB}$$

Bauer, Neubert & Thamm, 1708.00443



Simplified scenario: coupling to RH down type quarks

Bauer, Neubert, SR, Schnubel, Thamm, preliminary

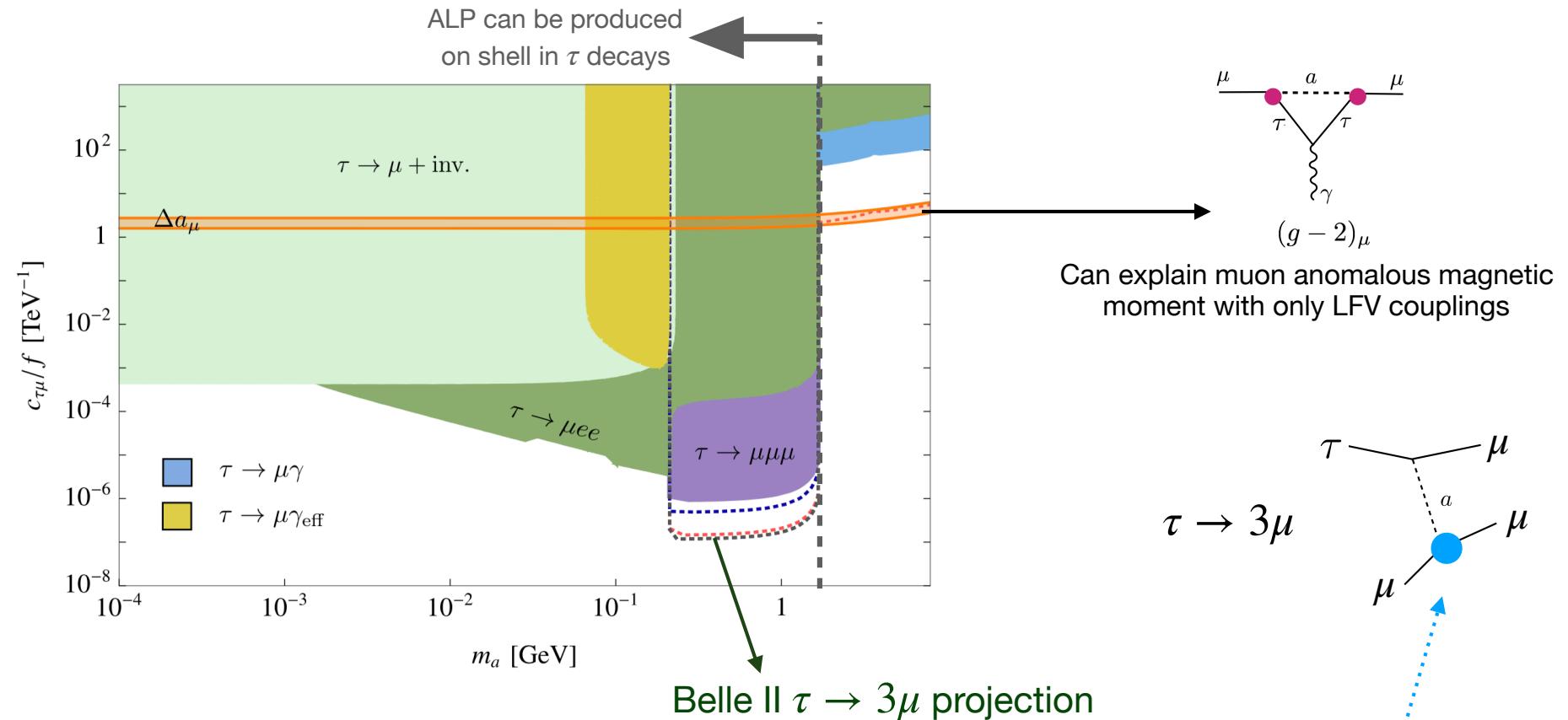


Lepton flavour violating ALPs

Björkeroth, Chun, King, JHEP 08 (2018) 117
 Bauer, Neubert, SR, Schnubel, Thamm, PRL 124 (2020) 21
 Cornella, Paradisi, Sumensari JHEP 01 (2020) 158

$$\mathcal{L}_{\text{eff}}^{\text{LFV}} = \frac{\partial^\mu a}{f} (\bar{\ell}_i(k_E)_{ij} \gamma_\mu P_L \ell_j + \bar{\ell}_i(k_e)_{ij} \gamma_\mu P_R \ell_j)$$

If an ALP has lepton flavour changing couplings (at Λ),
 can be seen in LFV processes



This is assuming that $c_{ee}/f = c_{\mu\mu}/f = c_{\tau\tau}/f = 1 \text{ TeV}^{-1}$

Bounds depend strongly on assumptions made for the flavour diagonal couplings

Summary

- ▶ Axion-like particles are a well motivated option for light new physics, and can be studied independently of their UV completion via EFTs
- ▶ Through running and matching from the UV scale, quark flavour changing effects generically arise
- ▶ ALPs can be searched for in meson decays and tau decays (for LFV couplings)
- ▶ Searches at flavour experiments can provide some of the strongest constraints on ALPs in the MeV-GeV range, even if the fundamental UV couplings are flavour conserving

Thank you!