Revisiting $K \to \pi a$ decay

A. Guerrera [1] S. Rigolin [1]

[1]Università degli studi di Padova and INFN, sezione di Padova

Axion-Like Particles in flavour physics

Light pseudoscalars particles arise naturally of any BSM model with a global $U(1)$ symmetry spontaneously broken at some high scale f_a. These class of pNGBs are different from QCD axion since they escape the well-known constraint $m_a f_a \sim m_\pi f_\pi$. Assuming Minimal Flavour Violation and considering only ALP-fermions interactions one gets a dimension five effective Lagrangian

$$\delta\mathcal{L}_{\rm eff} = i\frac{a}{f_a}\sum_{i=quarks} c_i m_i \overline{\psi}_i \gamma_5 \psi_i .$$

in the "Yukawa" basis derived from the "derivative" basis via the conservation of the vector fermionic current.

All the flavour violating effects arise at loop level and will be proportional to the relevant CKM quark mixing.

Contributions

Under these assumptions what are the relevant contributions in a FCNC decay such as $K^+ \to \pi^+ a$?
Do we need anything else beside the famous "penguin"?

Analysis

- *Claim*
  Lower order contribution might be relevant in the MFV picture with separate ALP-fermion couplings. E.g. consider an interference between a top ALP emission and a strange one, to be relevant in the signal economy $\frac{c_t}{c_s} \sim \frac{A_s}{A_t}$.
- *Result*
  There might be more information inside the experimental data than a single coupling.

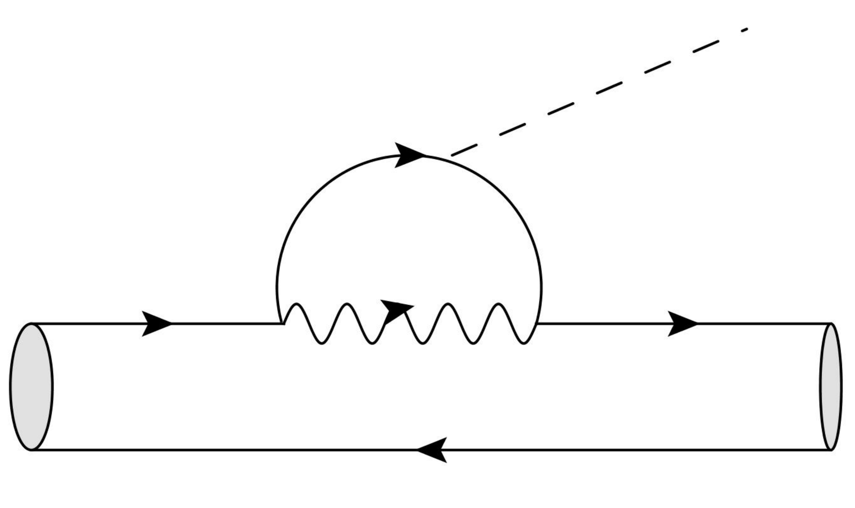

Figure 1: Hadronized penguin diagram, well known contribution proportional to c_t

Hadronization

- *Tree-Level*
  Brodsky/Lepage approach
- *Loop*
  LQCD factorization

Techinique

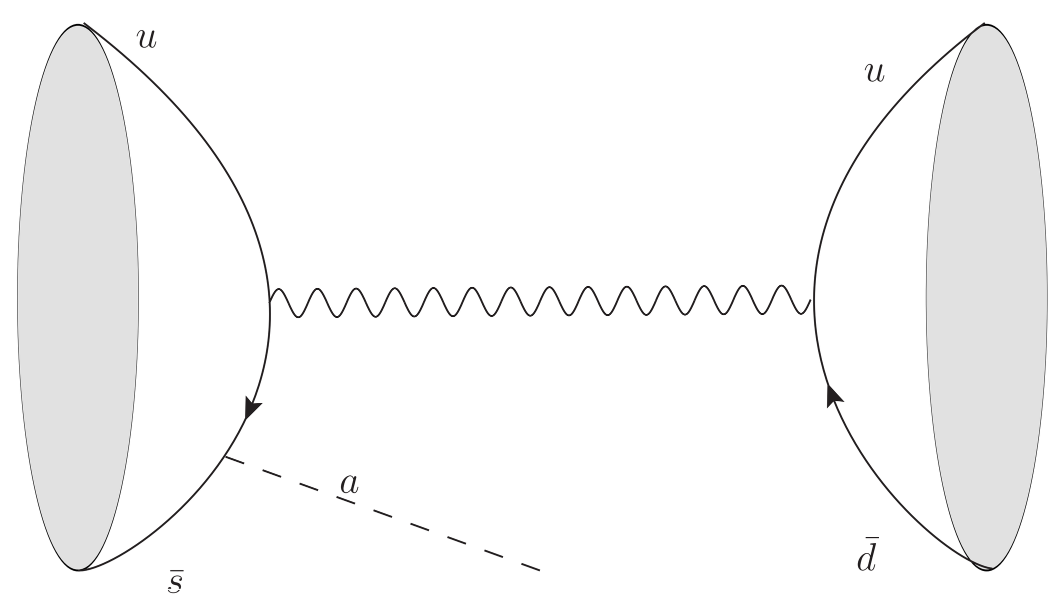

Figure 2: Hadronized tree-level emission by the $\bar{s}$ quark. All other partons can in principle participate in the interaction, although only the Kaonic ones will contribute.

The hadronic process can be factorized as $\langle \pi^+ | \bar{d}\,\Gamma_{(\pi)}\, u\, |0\rangle \langle 0 | \bar{s}\,\Gamma_{(K)}\, u\, | K^+ \rangle$ with the operator insertion $\Gamma_{(\pi)} \otimes \Gamma_{(K)}$ being $\gamma^\mu P_L \otimes \Gamma_\mu$ or $\Gamma'_\mu \otimes \gamma^\mu P_L$ depending if the ALP is emitted by the initial or final meson. The relevant operator Γ_M is computed as a skeleton diagram and the hadronization is achived using the algebric rule

$$\langle 0 | \bar{Q}\, \Gamma^\mu\, q\, | M \rangle \equiv i f_M \int_0^1 dx\, {\rm Tr}\left[\Gamma^\mu \Psi_M(x)\right] ,$$

where $\Psi_M(x) = \frac{1}{12}\phi_M(x)\gamma^5(\not{P}_M + g_M(x) M_M)$, is the meson's wavefunction, describing the spin contraction and the momentum distribution via ϕ. The loop hadronization is instead rather simple and relies on the LQCD parametrization

$$\langle P | \bar{q}_1 \gamma^\mu Q_2 | M \rangle = f_+(k^2)(P_M + P_P)^\mu + f_0(k^2) k^\mu$$

provided you have the effective ALP coupling mediating the FCNC.

Phenomenology

As a case study we exclude the loop and focus on the tree-level signal, fitting it to the data from NA62 and E949 on the allowed mass spectum for the ALP

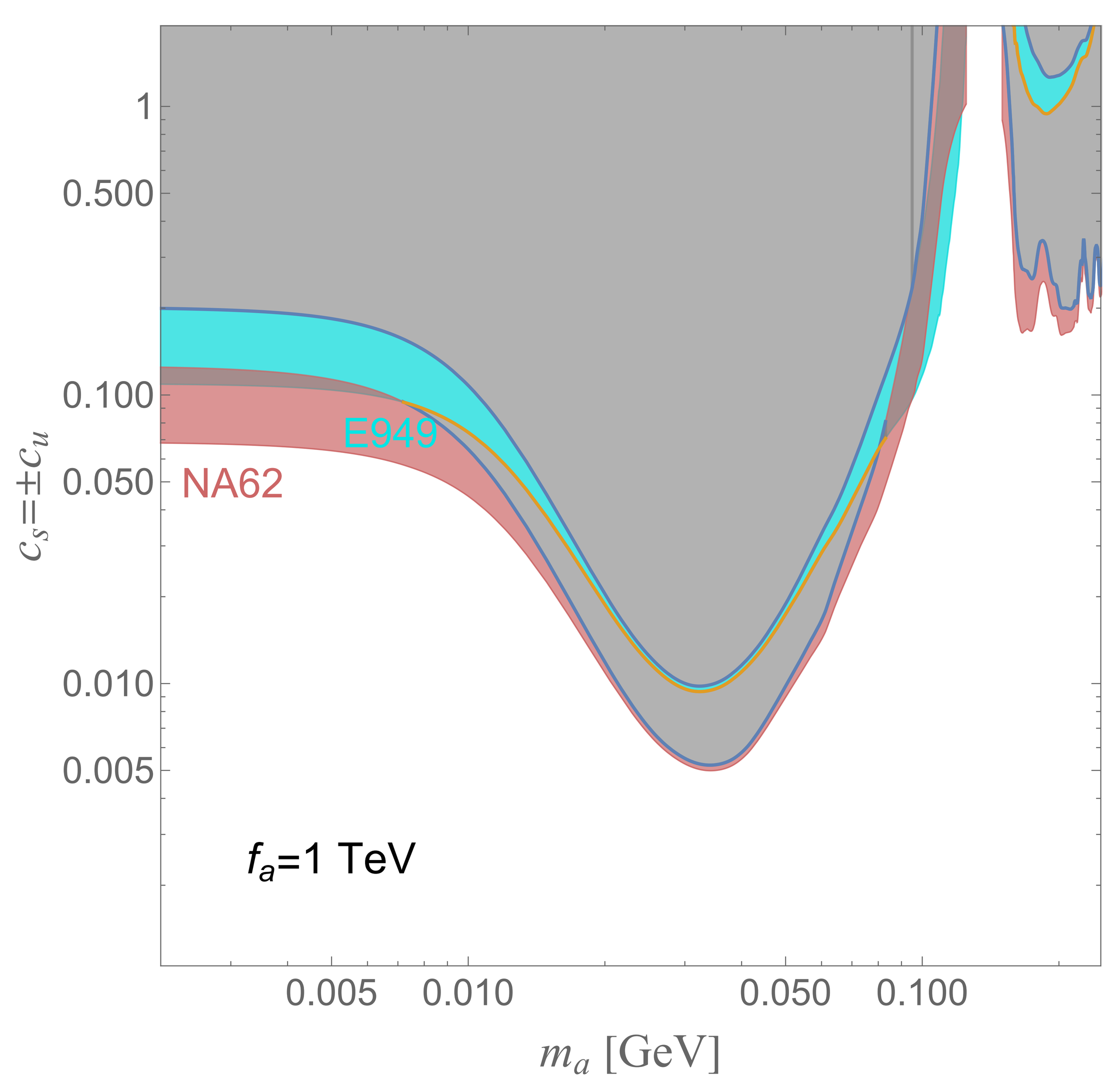

Figure 3: The highlighted regions show how the signals strenght varies when one scans the parameter region $|c_s/c_u| < 1$.

Surprisingly one obtains the strongest limit on down quarks-ALP interactions from flavour physiscs, to the authors knowledge, from the tree level alone. The next step is to include tree level and loop in a complete analysis of the signal.

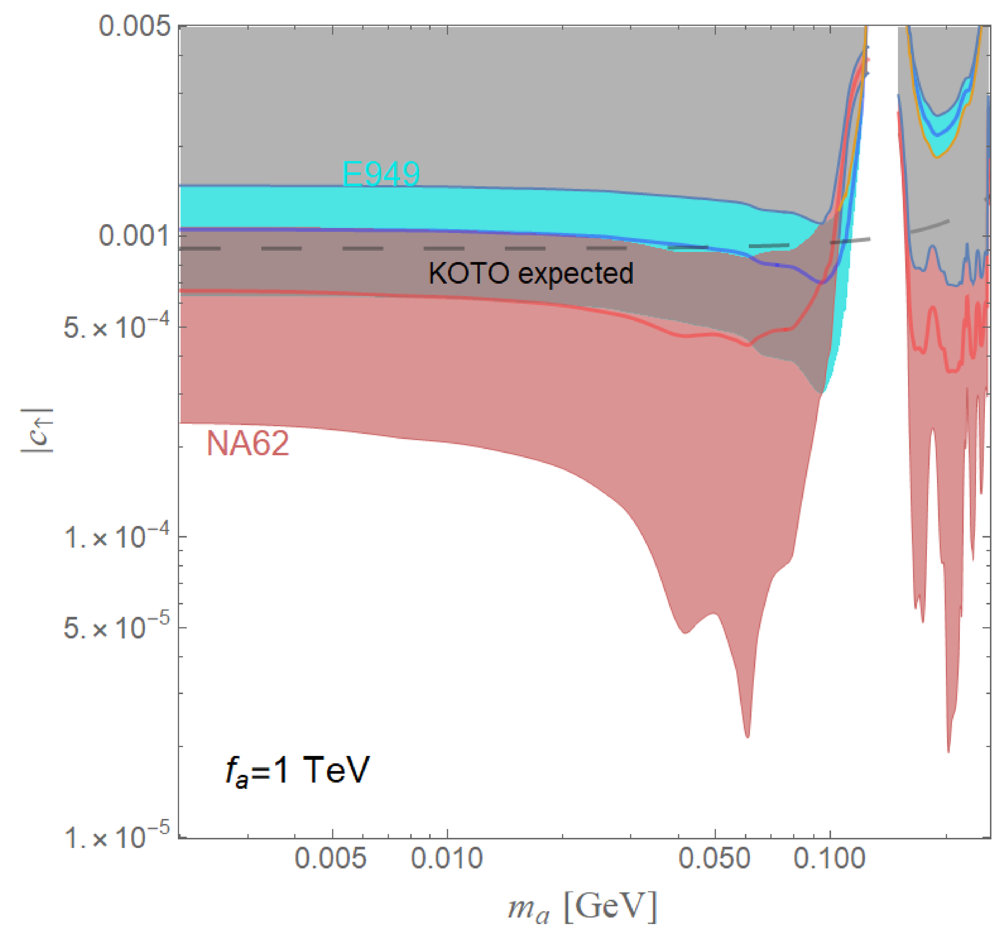

Figure 4: Admissible $c_\uparrow$ regions when $c_\downarrow$ varies between $\pm 3 \cdot 10^{-1}$. This value is a "token" value justified by recent evaluation of the parameter. The bold lines indicate a purely loop signal.

As a final note the authors want to highlight the correlation present in the measure and the neutral channel for the decay studied

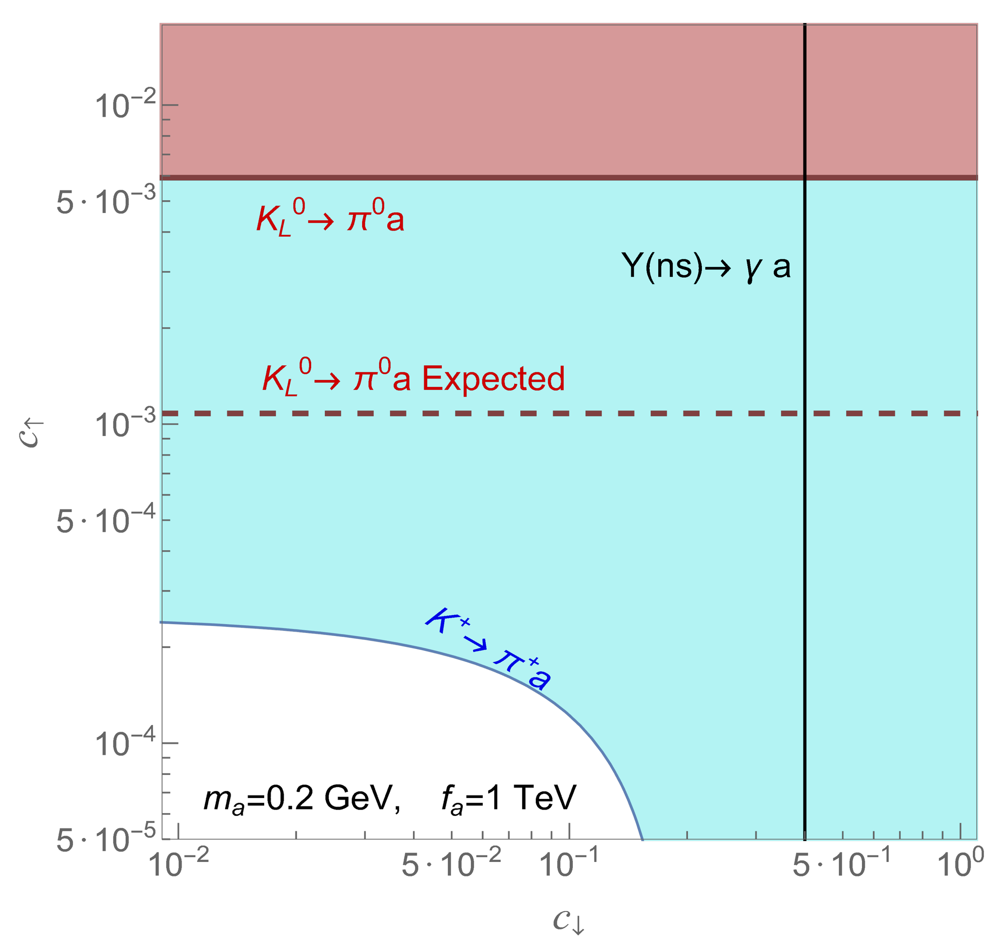

Figure 5: Correlation plot including KOTO data and future predictions.

Conclusion

$K \to \pi a$ decay admits sizeable interference with tree-level contributions ignored up until now.

(1)M.B. Gavela,et al. Flavor constraints on electroweak ALP couplings. Eur. Phys. J. C, 79(5):369, 2019
(2)Y.G. Aditya et al. Searching for super-WIMPs in leptonic heavy meson decays. Phys. Lett. B, 710:118–124, 2012
(3) A. V. Artamonov et al. Study of the decay K+ → π+νν¯ in the momentum region 140 < Pπ < 199 MeV/c. Phys. Rev. D, 79:092004, 2009
(4) Eduardo Cortina Gil et al. Measurement of the very rare K+ → π+νν¯ decay. 3 2021
(5)J.K. Ahn et al. Search for the KL → π0νν and KL → π0X0 decays at the J-PARC KOTO experiment. Phys. Rev. Lett., 122(2):021802, 2019