Hunting ALPs in Meson Decays

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44TH COURSE OF THE INTERNATIONAL SCHOOL OF NUCLEAR PHYSICS

Set 22, 2023

MENU

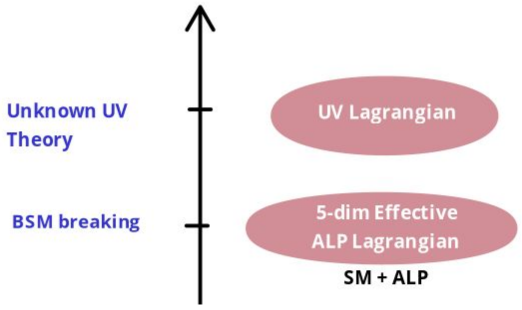
- Axion-Like Particles
- ALPs in Kaon decays
- ALPS in B meson decays
- Conclusions

Axion-Like Particles (ALPs)

- Pseudo Goldstone Boson from global symmetries breaking

Peccei-Quinn Symmetry	QCD Axion
Lepton Number Symmetry	Majoron
Flavor Symmetry	Flavon
...	...

- Potential dark matter candidate [Preskill, Wise, Wilczek (1983)]
- Enjoy a shift symmetry.



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

[H. Georgi, D. B. Kaplan, L. Randall (1986)]

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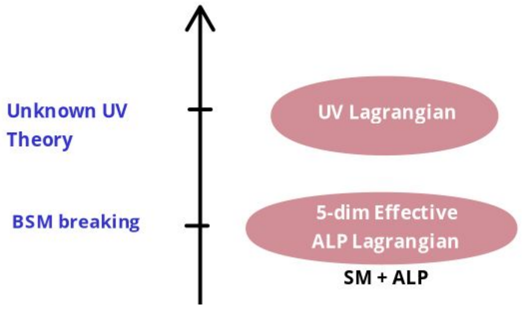

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field redefinition

$$\mathcal{L}^{D=5\,\prime}_{\rm SM+ALP} = C_{GG}\,\frac{a}{f}\,G^a_{\mu\nu}\,\tilde{G}^{\mu\nu,a} + C_{WW}\,\frac{a}{f}\,W^I_{\mu\nu}\,\tilde{W}^{\mu\nu,I} + C_{BB}\,\frac{a}{f}\,B_{\mu\nu}\,\tilde{B}^{\mu\nu} - \frac{a}{f}\left(\bar{Q}\tilde{H}\widetilde{\mathbf{Y}}_u u_R + \bar{Q}H\widetilde{\mathbf{Y}}_d d_R + \bar{L}H\widetilde{\mathbf{Y}}_e e_R + \text{h.c.}\right)$$

$\psi_F \to \psi_F + i\,\frac{a}{f}\,\mathbf{c}_F\,\psi_F$

flavor universal ALP: $\widetilde{\mathbf{Y}}_u \equiv i\,\mathbf{Y}_u\,C_u\,,\quad \widetilde{\mathbf{Y}}_d \equiv i\,\mathbf{Y}_d\,C_d\,,\quad \widetilde{\mathbf{Y}}_e \equiv i\,\mathbf{Y}_e\,C_e$

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K→ pi a phenomenology

- Matching the ALPs into the Chiral Lagrangian

- The degrees of freedom is the hadron

$$\boldsymbol{\Sigma}(x) = \exp\left[\frac{i\sqrt{2}}{f_\pi}\lambda^a\pi^a(x)\right]$$

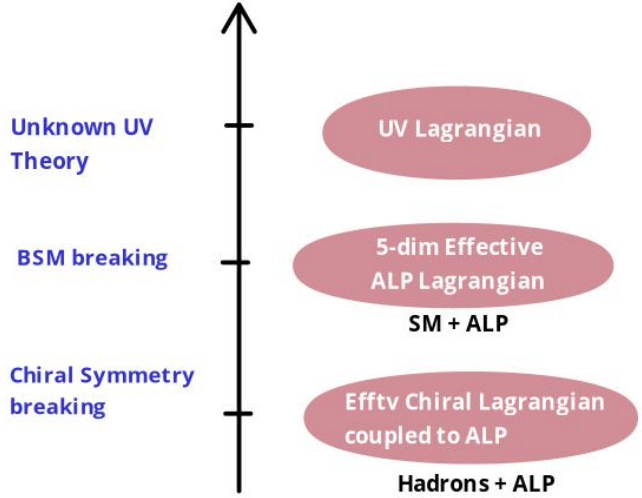
- Leading order effective Chiral Lagrangian:

$$\mathcal{L}^{\chi}_{\rm eff} = \frac{f_\pi^2}{8}\mathrm{Tr}[\mathbf{D}^\mu\boldsymbol{\Sigma}\,(\mathbf{D}_\mu\boldsymbol{\Sigma})^\dagger] + \frac{f_\pi^2}{4}B_0\,\mathrm{Tr}\left[\hat{\mathbf{m}}_q(a)\boldsymbol{\Sigma}^\dagger + \text{h.c.}\right]$$
$$+\frac{1}{2}\,\partial^\mu a\,\partial_\mu a - \frac{m_{a,0}^2}{2}\,a^2 + \hat{c}_{\gamma\gamma}\,\frac{\alpha}{4\pi}\,\frac{a}{f}\,F_{\mu\nu}\,\tilde{F}^{\mu\nu},$$

where,

$$iD_\mu\boldsymbol{\Sigma} = i\partial_\mu\boldsymbol{\Sigma} + e\,A_\mu\,[\boldsymbol{Q},\boldsymbol{\Sigma}] + \frac{\partial_\mu a}{f}\left(\hat{\boldsymbol{k}}_Q\boldsymbol{\Sigma} - \boldsymbol{\Sigma}\,\hat{\boldsymbol{k}}_q\right)$$

$$\hat{\boldsymbol{m}}_q(a) = \exp\left(-2i\boldsymbol{\kappa}_q\,c_{GG}\,\frac{a}{f}\right)\boldsymbol{m}_q$$



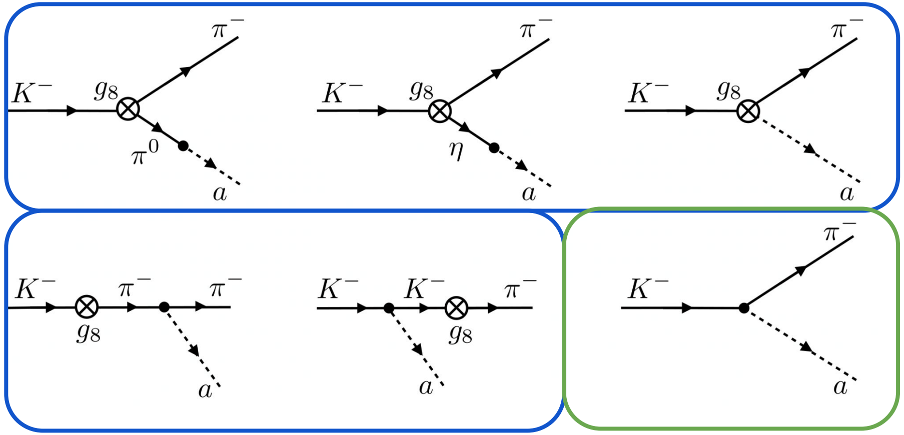
K→ pi a phenomenology

M. Bauer, M. Neubert, et al, arXiv:2102.13112

- Flavor changing s→d

$$K^- \longrightarrow \pi^- + \text{ALP}$$

$$m_a \leq m(K^-) - m(\pi^-) \approx 350\text{MeV}$$



- The amplitude is

$$i\mathcal{A}(K^- \longrightarrow \pi^- + a) \approx -1.12 \times \mathbf{10^{-4}GeV}\left[\frac{1TeV}{f}\right][k_d + k_D]_{12} + \mathbf{10^{-11}GeV}\left[\frac{1TeV}{f}\right]$$
$$[3.50C_{GG} + 0.86\,(2c_{uu} + c_{dd} + c_{ss}) + 1.01\,([k_d + k_D]_{11} - [k_d + k_D]_{22})]$$

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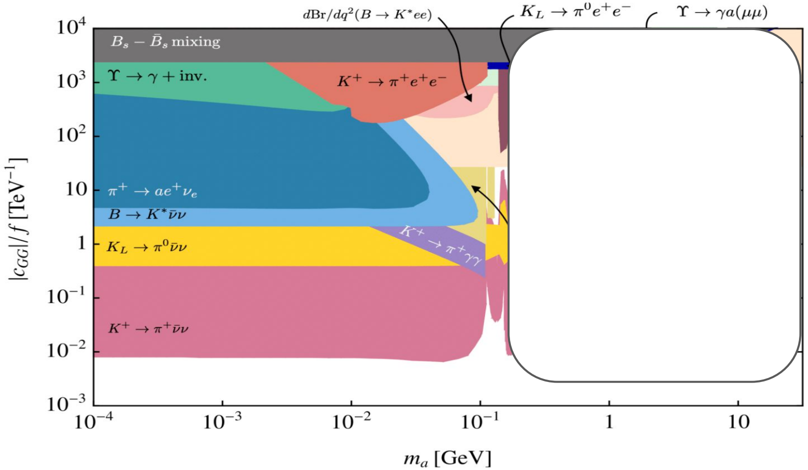

- Expressing the ALPs in terms of the coupling at the UV scale

$$|\mathcal{A}(K^- \longrightarrow \pi^- + a)| \approx 10^{-11} GeV \left[\frac{1TeV}{f}\right] \cdot [(3.58C_{GG} + 1.79C_{uu}(\Lambda) + 1.81C_{dd}(\Lambda)) + (-65.8C_{uu}(\Lambda) + 0.32C_{dd}(\Lambda) + 0.21C_{GG} + 0.38C_{WW}) - 1.12 \cdot 10^7 \kappa_D^{12}(\Lambda)]$$

- Using the NA62 upper limit Br(K → pi X) < 2.0 10^{-10} (90% CL)

C_{ii}	C_{GG}	C_{WW}	C_{uu}	C_{dd}	κ_D^{12}
(upper limit [TeV])$^{-1}$	61.3	6.5	1126	31.0	$1.9 \cdot 10^8$

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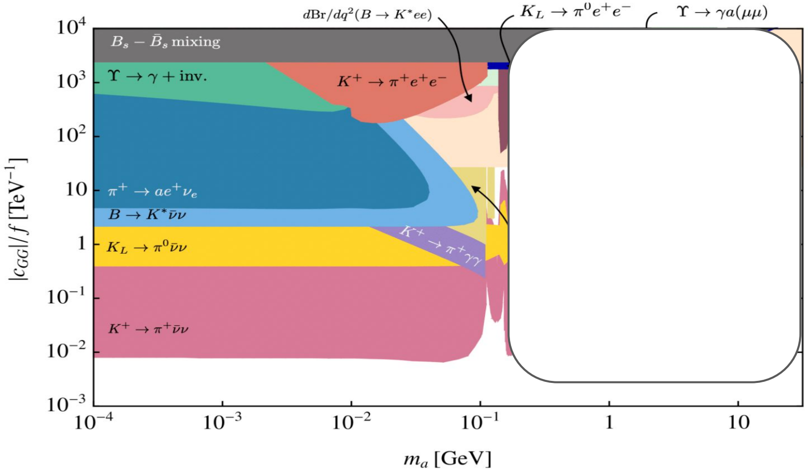

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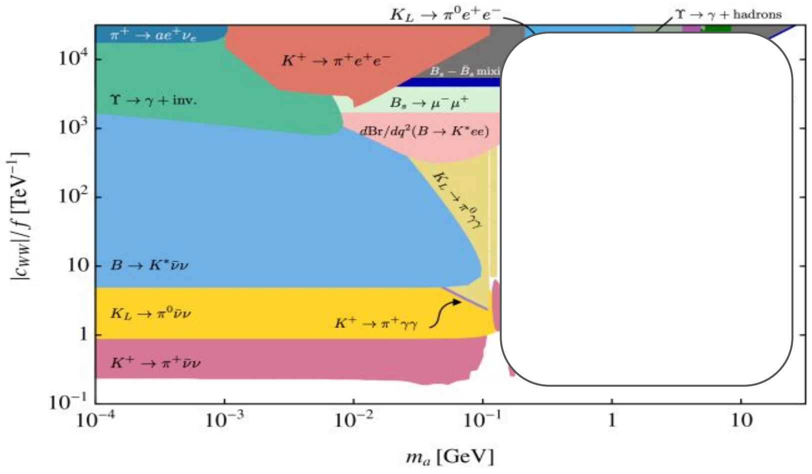

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B→ K a phenomenology

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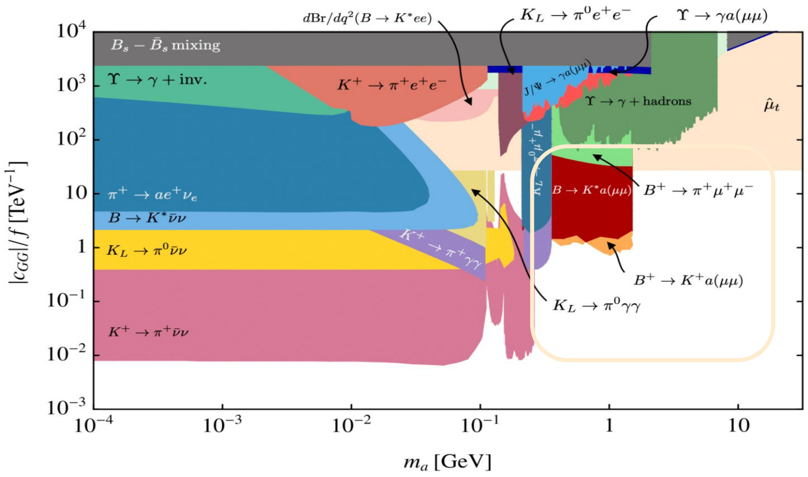
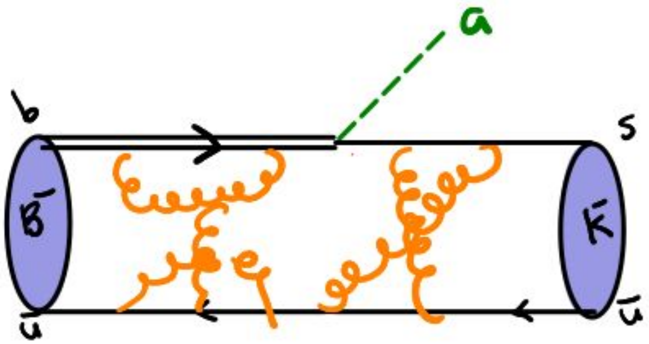


- Flavor changing b→s

$$B^- \longrightarrow K^- + \text{ALP}$$

$$m_a \leq m(B^-) - m(K^-) \approx 4.8\text{GeV}$$

- ALP Flavor Changing:



$$\Gamma(B^-\to\pi^-a) = \frac{m_B^3}{64\pi f^2}\,|[k_D+k_d]_{13}|^2\,|F_0^{B\to\pi}(m_a^2)|^2\left(1-\frac{m_\pi^2}{m_B^2}\right)^2\lambda^{1/2}\left(\frac{m_\pi^2}{m_B^2},\frac{m_a^2}{m_B^2}\right),$$

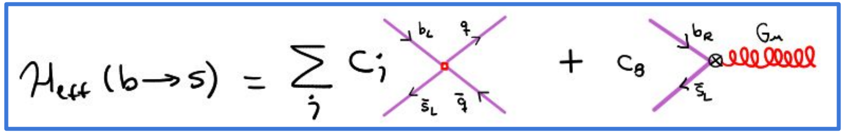
$$\Gamma(\bar{B}^0\to\pi^0a) = \frac{1}{2}\Gamma(B^-\to\pi^-a),$$

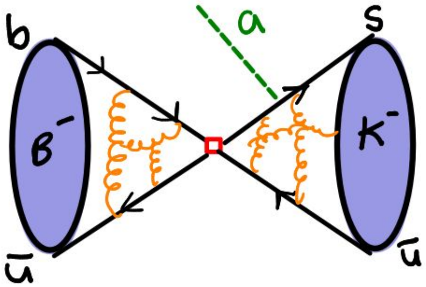
$$\Gamma(B^-\to K^-a) = \frac{m_B^3}{64\pi f^2}\,|[k_D+k_d]_{23}|^2\,|F_0^{B\to K}(m_a^2)|^2\left(1-\frac{m_K^2}{m_B^2}\right)^2\lambda^{1/2}\left(\frac{m_K^2}{m_B^2},\frac{m_a^2}{m_B^2}\right),$$

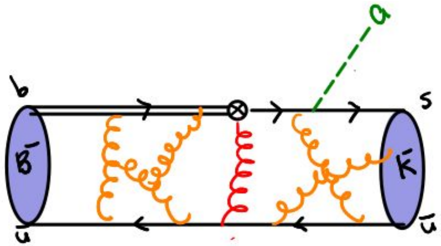
$$\Gamma(B^-\to K^{*-}a) = \frac{m_B^3}{64\pi f^2}\,|[k_D-k_d]_{23}|^2\left|A_0^{B\to K^*}(m_a^2)\right|^2\lambda^{3/2}\left(\frac{m_{K}^{*2}}{m_B^2},\frac{m_a^2}{m_B^2}\right),$$

B→ K a phenomenology

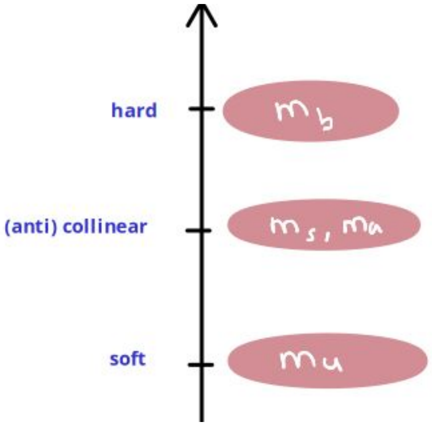
- Flavor-changing by the Weak Interaction and ALP-flavor conserving







- Multi-scale problem



Conclusions

- ALPs can be constrained by meson decays: Kaon and B meson.
- Kaon decays are more sensitive to ALP flavor-changing than flavor-conserving decays
- Flavor-changing in B meson decays given by EW effective interaction are bigger or smaller?

STAY IN TUNE