Leading Logs in QCD Axion EFT

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in collaboration with
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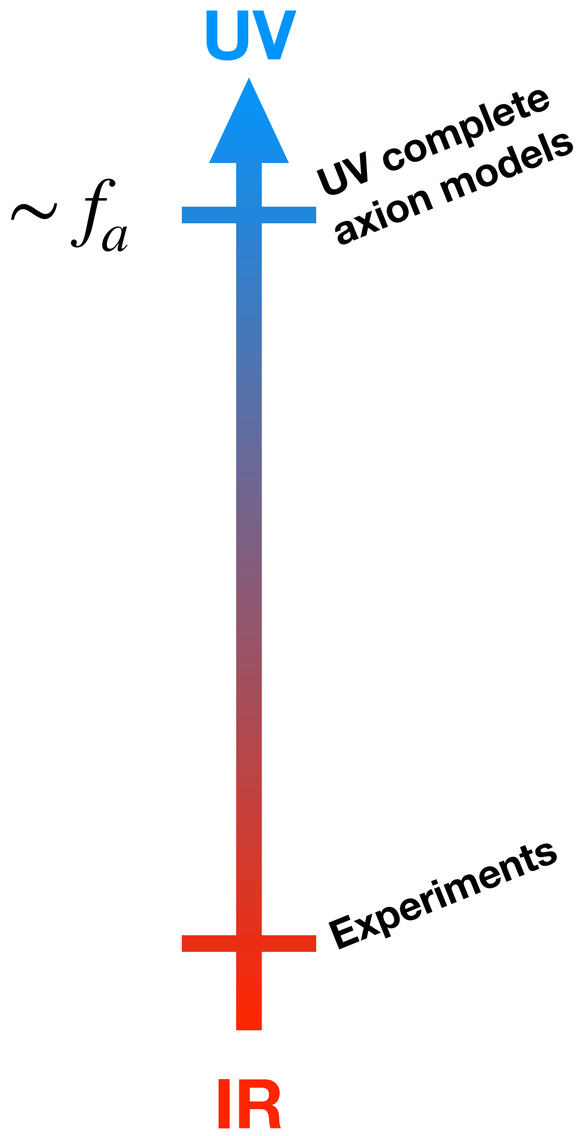
[arXiv:2101.03173]

Patras Workshop
15/6/2021

Axion EFT

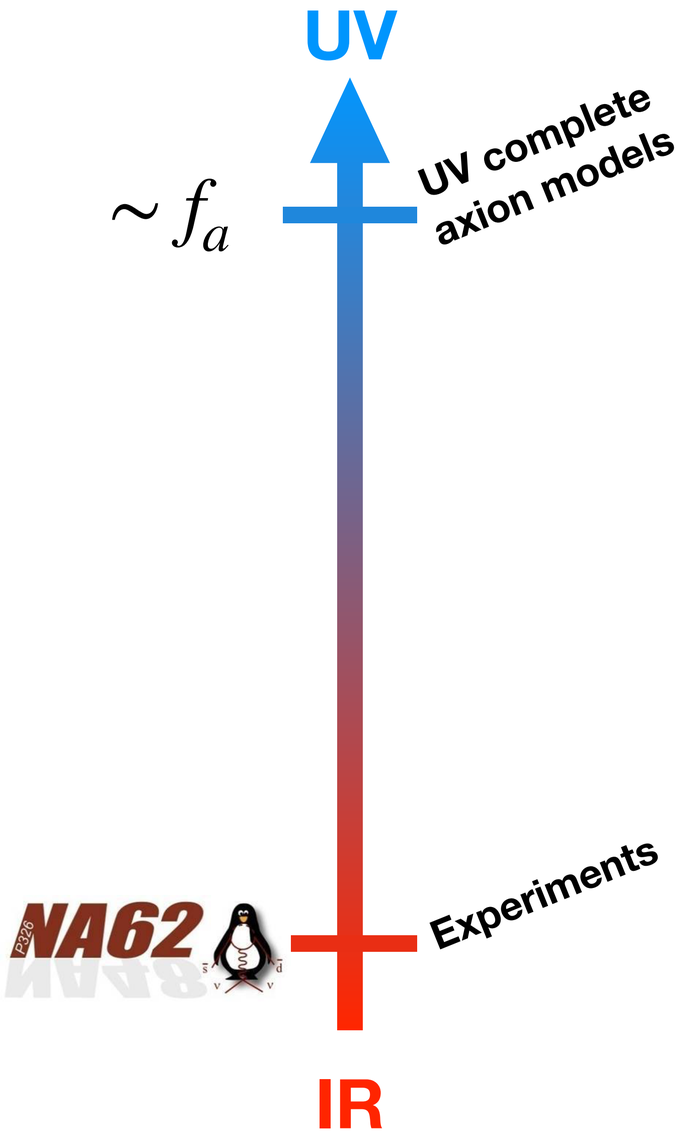


Large separation of scales → Effective field theory description

$$\mathscr{L} = -\frac{1}{f_a}\sum_F c_{FF}\frac{\alpha_F}{8\pi}\, a\, F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{1}{f_a}\sum_f c_f \frac{\partial_\mu a}{2}\,\bar{f}\gamma^\mu\gamma_5 f$$

- Symmetries:
  - Shift symmetry $a \to a + \text{const}$
  - SM gauge symmetries

Axion EFT



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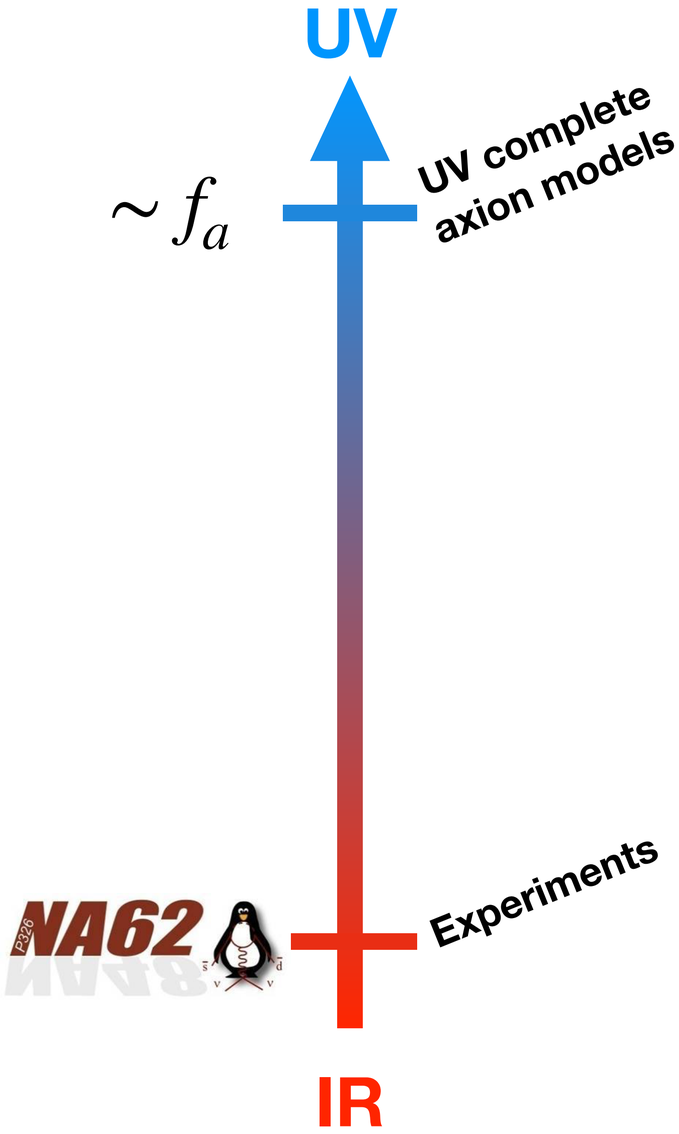
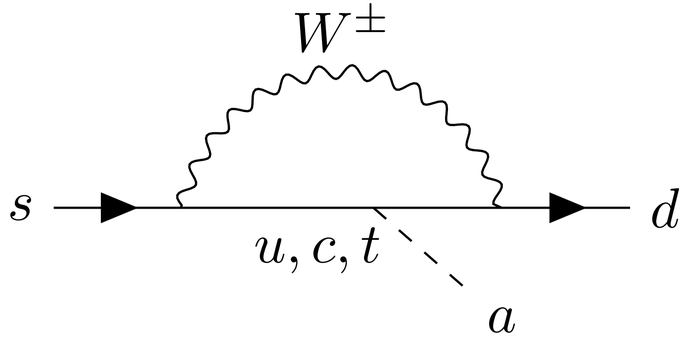
We can calculate observables using the EFT

- For example: rate of $K \to \pi + a$ in NA62
- NA62 is expected to improve sensitivity to $K \to \pi +$ inv by an order of magnitude

Loops in the EFT



$K \to \pi + a$ **is induced at loop level**



Calculation gives log-divergent result

$$\Gamma \propto \left| \frac{c_q}{f_a} \cdot \log\left(\frac{\Lambda^2}{m_q^2}\right) \right|^2$$

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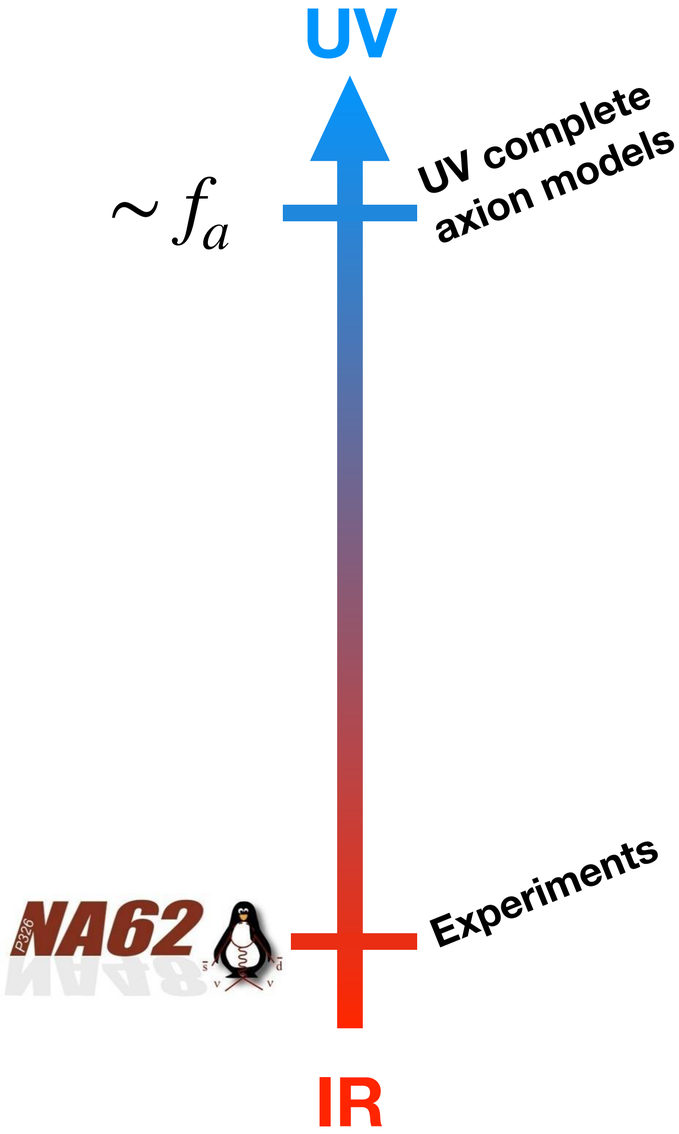

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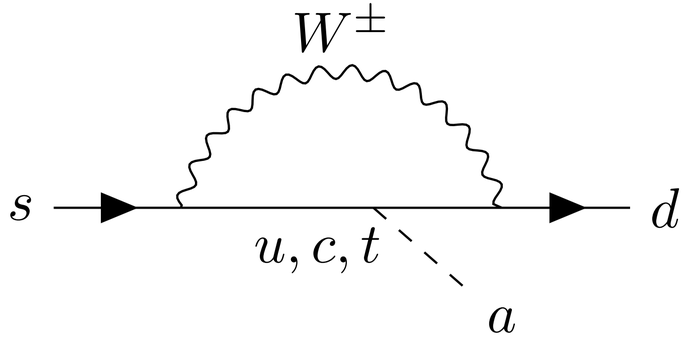

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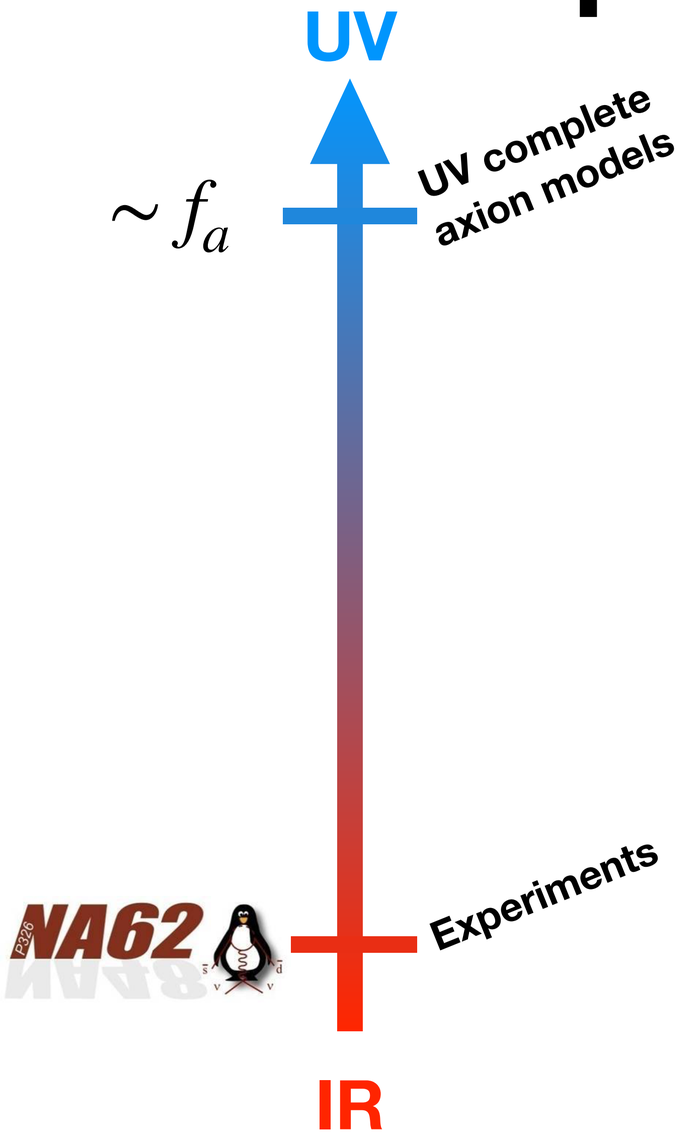
$\Rightarrow$ **If cut-off** $\Lambda \sim f_a$ **:** **large log enhancement** $\to$ ***Leading Log***

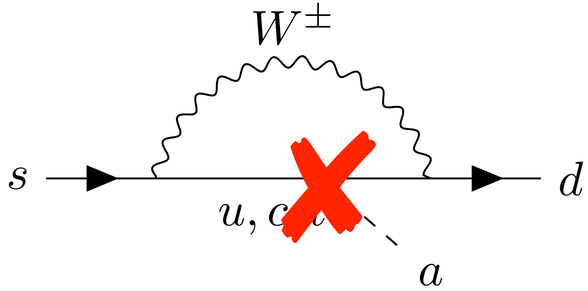
$$\log\left(\frac{f_a^2}{m_t^2}\right) \sim 22 \quad \text{for } f_a = 10^7\,\text{GeV}$$

Loops in QCD axion models



Benchmark model 1: KSVZ

No PQ-charge of SM fermions → no tree-level axion coupling to SM quarks



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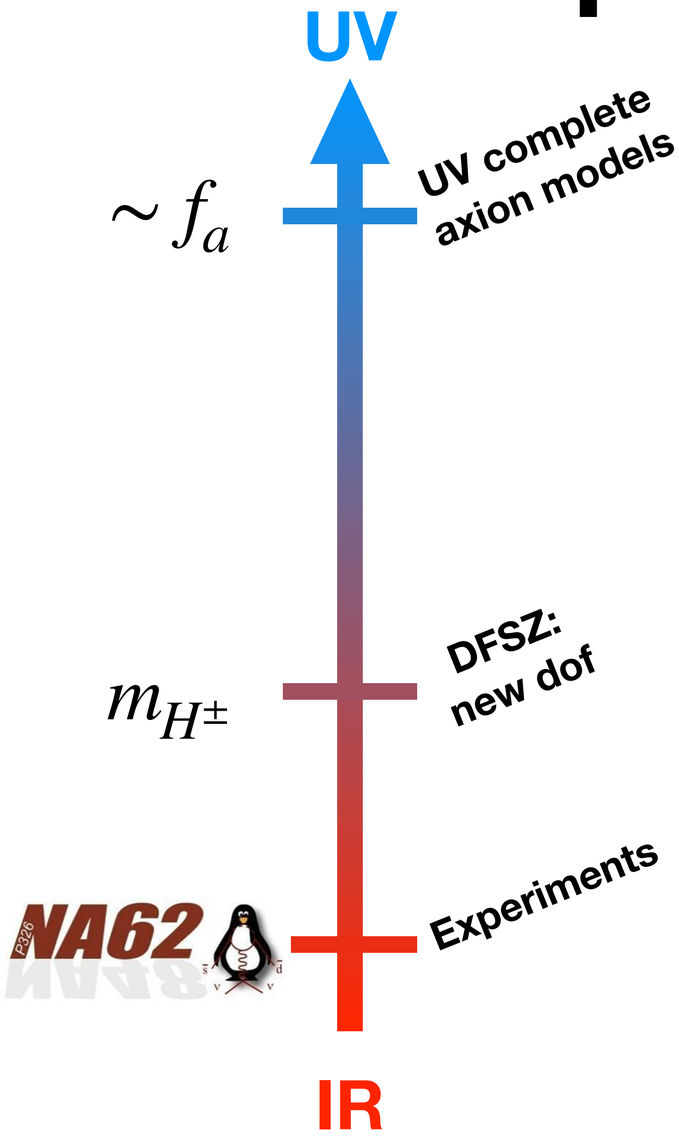

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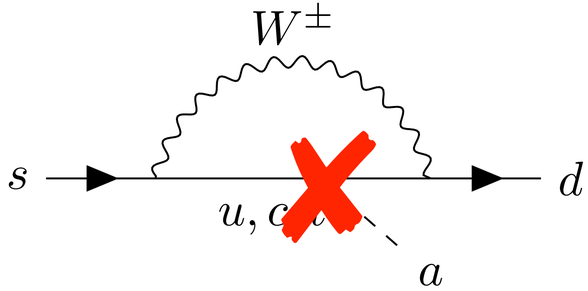


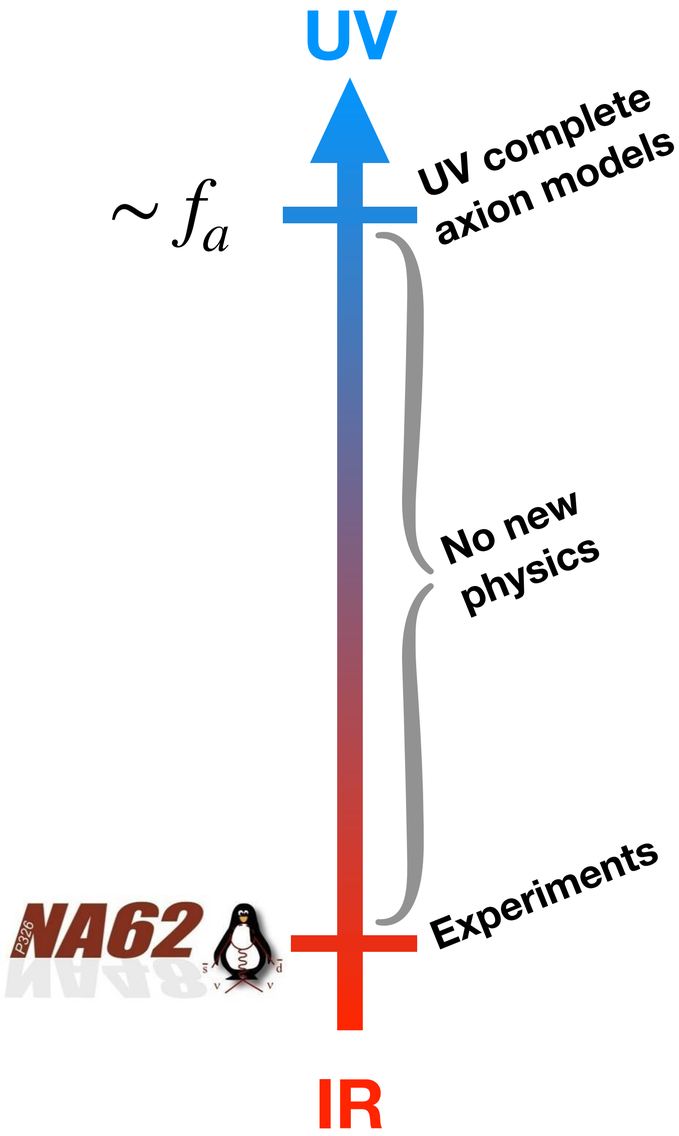
Benchmark model 2: DFSZ

Contains 2HDM → new degrees of freedom below f_a .

$$\Gamma \propto \log\left(\frac{m_{H^\pm}^2}{m_q^2}\right) \lesssim 3.5$$

⇒ **No large log in *typical* QCD axion models**

New Model

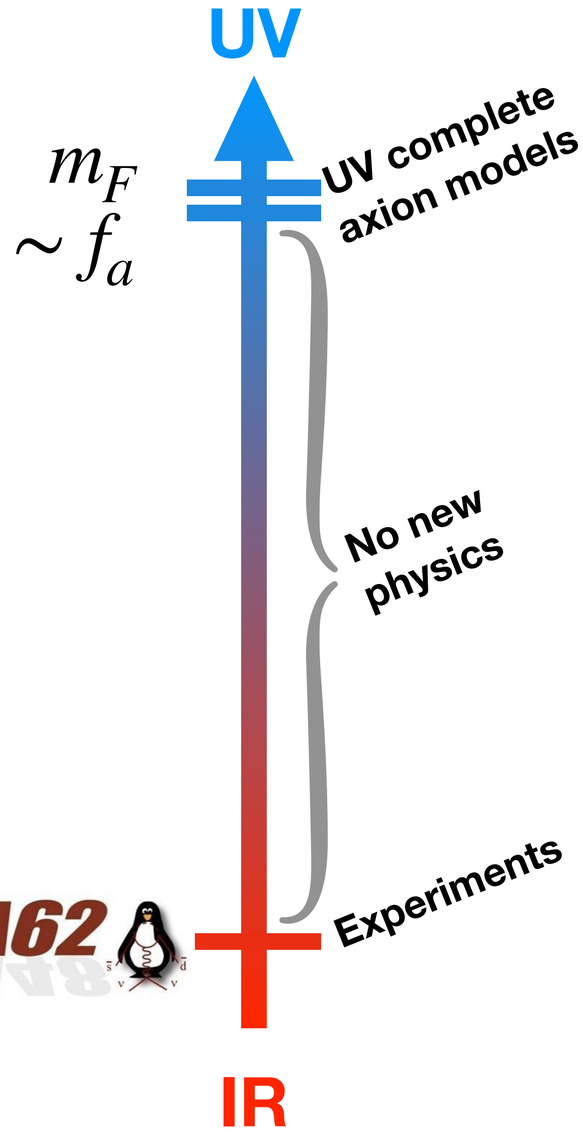


Is there a QCD axion model with a large log??

- Requirements: axion-quark coupling + no new physics below f_a

$$\mathscr{L} \supset -\frac{\Phi}{\Lambda} H \bar{Q}_L q_R + \text{h.c.} \xrightarrow[\text{SSB}]{\text{PQ}} -Y e^{i\frac{a}{f_a}} H \bar{Q}_L q_R + \text{h.c.}$$

New Model



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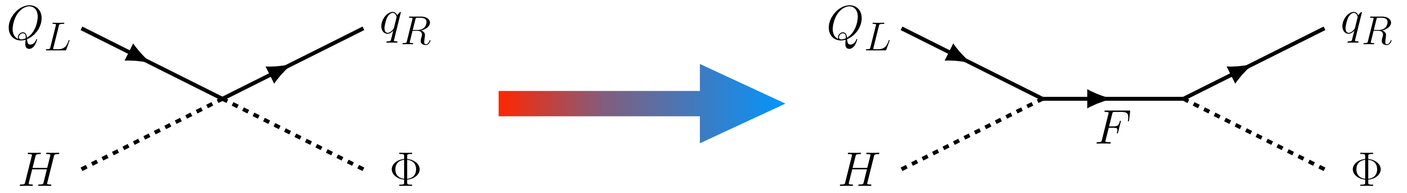
This still needs to be UV completed →new heavy *F-quarks* with $m_F \gtrsim f_a$



Calculation of Kaon decay rate gives

$$\Gamma \propto \left| \log\left(\frac{m_F^2}{m_q^2}\right) \right|^2 \gtrsim \left| \log\left(\frac{f_a^2}{m_q^2}\right) \right|^2$$

good sensitivity of NA62!!!

Conclusion

The QCD axion EFT is a powerful tool for model independent analyses

Careful with UV sensitive observables like $K \to \pi + a$!

- Total event rate depends strongly on the UV cut-off Λ of the divergent loop process
- Λ is not generically given by f_a !!

QCD axion models

- Typical benchmark QCD axion models do not feature a large log enhancement.
- Building a model that does is highly non trivial and requires tuning

  $\Rightarrow$ Does every QCD axion EFT have a UV completion?

Look at our paper (arXiv:2101.03173) for

- Details on the new UV model
- Phenomenology of the new model in NA62 and (baby)IAXO
- More thoughts on potential issues that can arise when UV completing axion EFTs