An ALP Portal to GeV-Scale Dark Matter

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Axions++

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Why axions at the MeV scale?

- Strong-CP problem?

- Interesting region of the parameter space

- $(g-2)_\mu$

- ALP mediators to Dark Sectors have sparked recent interest
  [Dror et al, '23; Fitzpatrick et al, '23]

Why axions at the MeV scale?

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Model

- Write down a general Lagrangian for an axion-like particle a that couples to Standard Model (SM) fermions ψ

$$\mathcal{L} \supset \frac{\partial_\mu a}{2f_a} c_\psi \bar{\psi}\gamma^\mu\gamma_5\psi \quad \longleftrightarrow \quad \mathcal{L} \supset -iag_\psi\bar{\psi}\gamma_5\psi, \quad g_\psi = \frac{c_\psi m_\psi}{f_a}$$

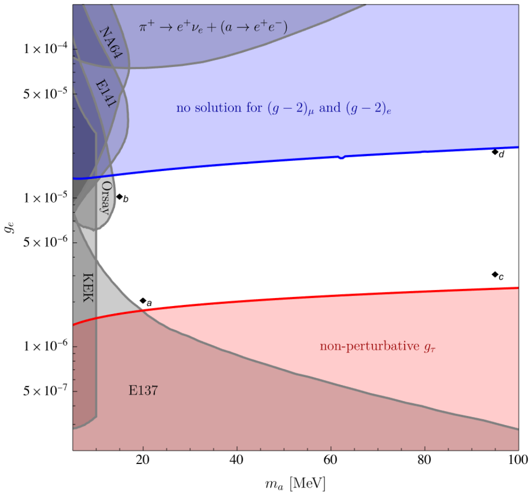
- $m_a \sim$ MeV implies constraints from beam dump experiments

- Constrain couplings to leptons further using $(g-2)_e$ and $(g-2)_\mu$

$$\Delta a_e = 34(16) \times 10^{-14} \quad \Delta a_\mu^{\mathrm{BMW}} = 105(61) \times 10^{-11}$$

Model	m_a[MeV]	$g_e/10^{-5}$	$g_\mu/10^{-4}$	g_τ	$\mathrm{BR}_{\gamma\gamma}$[%]	τ_a[ps]
a	20	0.20	0.29	2.6	99	1.4
b	15	1.0	1.7	0.50	11	9.8
c	95	0.30	0.37	2.4	100	0.01
d	95	2.0	3.5	0.36	39	0.26

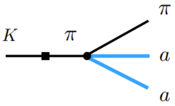
Model



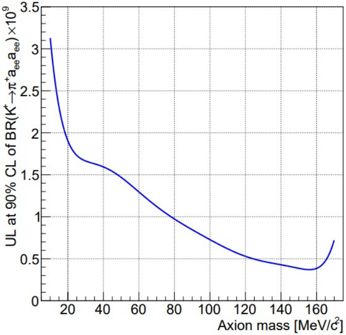
$\pi^+ \to e^+\nu_e + (a \to e^+e^-)$
NA64
E141
no solution for $(g-2)_\mu$ and $(g-2)_e$
Orsay
KEK
E137
non-perturbative g_τ
a
b
c
d
1×10^{-4}
5×10^{-5}
1×10^{-5}
5×10^{-6}
1×10^{-6}
5×10^{-7}
g_e
20
40
60
80
100
m_a [MeV]

QCD Axion

- QCD axion at the MeV scale?
- Previously considered realisable with very stringent constraints
  [Alves and Weiner, '17; Alves, '20; Liu et al, '20]
- Recently excluded by NA62 looking for $K^+ \to \pi^+ e^+ e^- e^+ e^-$
  [Hostert and Pospelov, '20; NA62 Collaboration, '23]



$$\mathcal{B}(K^+ \to \pi^+ aa) \simeq 1.7 \times 10^{-5}$$



Dark Matter

- Let the ALP couple also to a DM fermion χ

$$\mathcal{L} \supset \sum_{i=\chi,e,\mu,\tau} -iag_i\bar{\psi}_i\gamma_5\psi_i - m_\chi\bar{\chi}\chi$$

- Reproduce relic abundance through thermal freeze-out

- Annihilation channels:

$\bar{\chi}\chi \to \ell^+\ell^-$	s-wave
$\bar{\chi}\chi \to \gamma\,\gamma$	s-wave
$\bar{\chi}\chi \to a\,a$	p-wave

- Couplings to leptons and photons (through loops of leptons) yield bounds from CMB ($e^\pm$, $\mu^\pm, \gamma$) and X-ray searches ($\tau^\pm$)

Model	m_a[MeV]	$g_e/10^{-5}$	$g_\mu/10^{-4}$	g_τ
a	20	0.20	0.29	2.6
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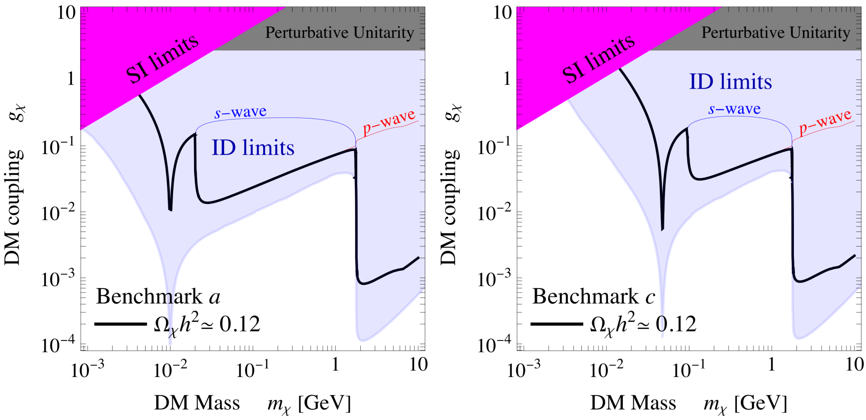
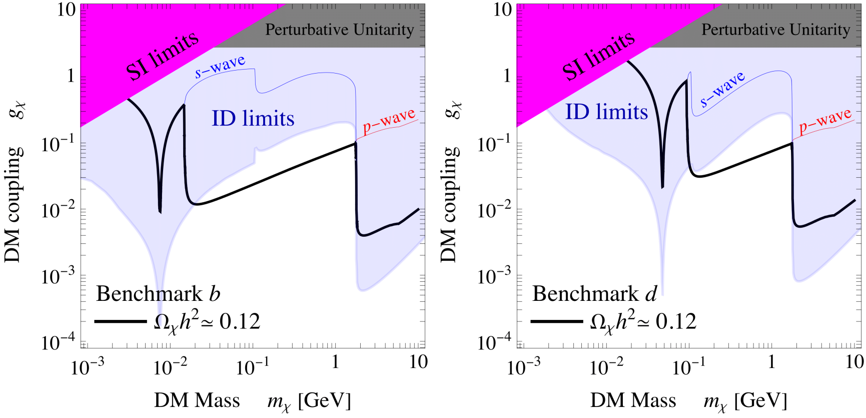


Model	m_a[MeV]	$g_e/10^{-5}$	$g_\mu/10^{-4}$	g_τ
b	15	1.0	1.7	0.50
d	95	2.0	3.5	0.36



Conclusion

- An ALP with $m_a \sim$ MeV has connections with different branches of particle physics
- Constraints to couplings to SM leptons from beam dump experiments and $(g-2)_{e/\mu}$
- Couple ALP to DM fermion $\rightarrow$ reproduce right relic abundance through thermal freeze-out
- Constraints from CMB and X-ray searches
- Sweet spot for $m_\chi \sim \mathcal{O}(0.1-1)$GeV and $g_\chi \sim 10^{-2} - 10^{-1}$