A tale of EFTs or a place or two to look at

Joerg Jaeckel

G. Alonso[1], F. Ertas[2], F. Kahlhoefer[2] and L. Thormaehlen[3] + Many More

[1]McGill, [2]RWTH Aachen, [3]U. Heidelberg

A tale of EFTs or a place or two to look at (some preliminary thoughts)

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Let‘s Talk about cutoffs…

EFTs are great

- We are interested in ALPs

➔ ALP EFT

$$\mathcal{L} \supset \frac{\partial_\mu a}{2f_a} c_q \sum_{f=u,d} \bar{f}\gamma^\mu \gamma_5 f + \frac{\partial_\mu a}{2f_a} c_l \sum_{f=\ell,\nu} \bar{f}\gamma^\mu \gamma_5 f$$

$$\sim \sum a \frac{m_f}{f_a} \bar{f}\gamma^5 f$$

Yukawa type interactions

https://arxiv.org/pdf/2101.03173.pdf

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$$\sim \sum a \frac{m_f}{f_a} \bar{f}\gamma^5 f$$

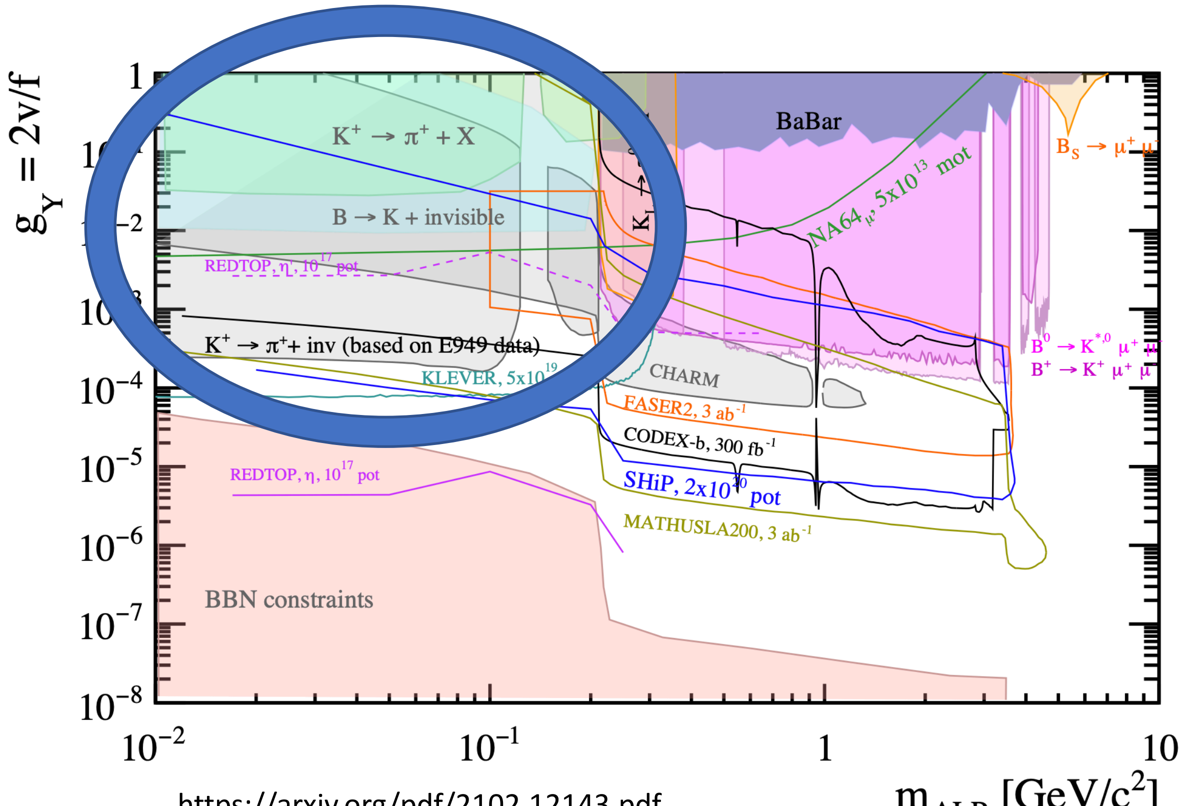
Yukawa type interactions

- ... but care needs to be taken when considering loop-processes
- Especially when divergences affect the result

https://arxiv.org/pdf/2101.03173.pdf

Process we are interested in

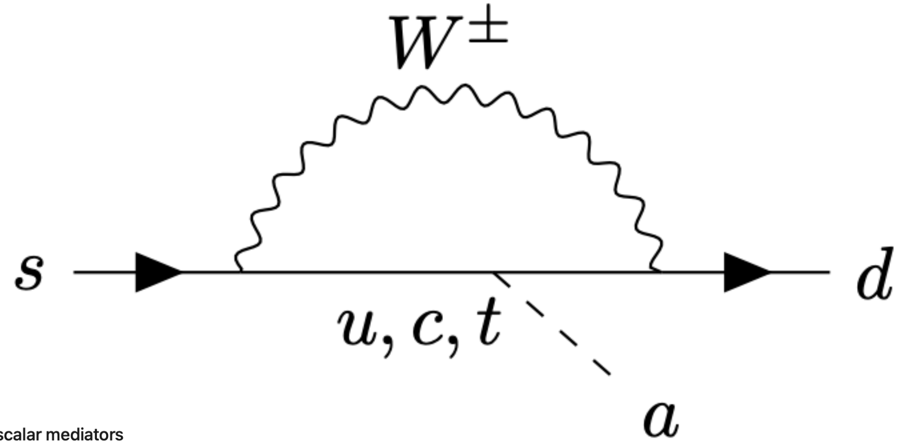
- Flavor violating Meson decays provide some of the strongest bounds



https://arxiv.org/pdf/2102.12143.pdf

These are indeed loop processes

- E.g. $K^+ \to \pi^+ + a.$



A taste of dark matter: Flavour constraints on pseudoscalar mediators

Matthew J. Dolan (SLAC), Felix Kahlhoefer (DESY), Christopher McCabe (U. Amsterdam, GRAPPA), Kai Schmidt-Hoberg (DESY) (Dec 16, 2014)

Published in: *JHEP* 03 (2015) 171, *JHEP* 07 (2015) 103 (erratum) • e-Print: 1412.5174 [hep-ph]

- Standard Result features log

$$\Gamma(K^+ \to \pi^+ + a) \sim \left[\log\left(\frac{\Lambda}{m_t}\right)\right]^2$$

https://arxiv.org/pdf/2101.03173.pdf

What is the cutoff?

- In axion EFTs cutoff is usually identified with f_a
- This is suggested by the higher dimensional operators in the Lagrangian

$$\mathcal{L} \supset \frac{\partial_\mu a}{2f_a} c_q \sum_{f=u,d} \bar{f}\gamma^\mu\gamma_5 f + \frac{\partial_\mu a}{2f_a} c_l \sum_{f=\ell,\nu} \bar{f}\gamma^\mu\gamma_5 f$$

- But is this correct?

https://arxiv.org/pdf/2101.03173.pdf

Example: DSFZ type models

- 2 Higgs-doublet models
- Results in Yukawa type couplings for up type quarks

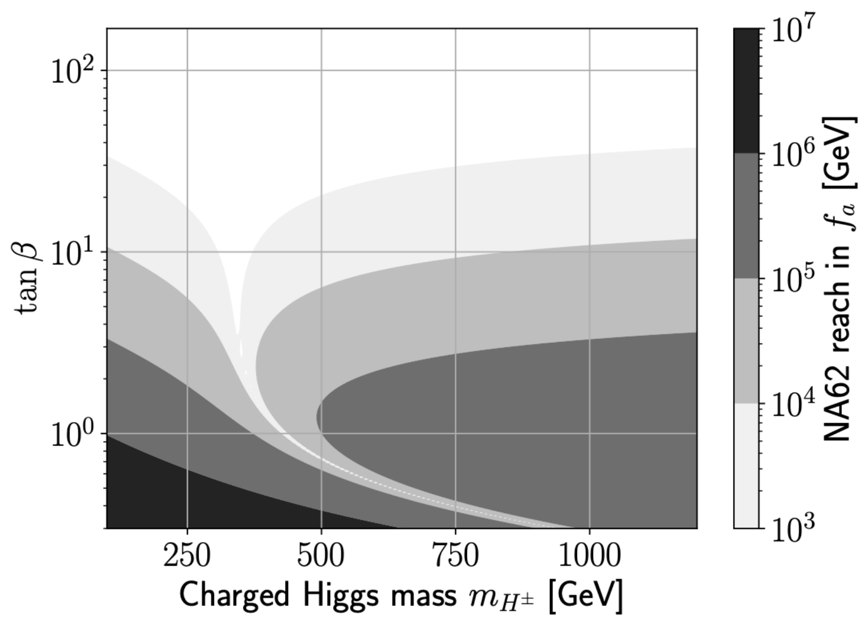
$$\sim \frac{m_f}{f_a} \cos^2(\beta) \qquad \tan(\beta) = \frac{v_u}{v_d}$$

- Explicit UV complete (renormalizable) model allows direct calculation without EFT

https://arxiv.org/pdf/2101.03173.pdf

DSFZ ➔ effective cutoff is lower!

- Actually the Higgses enter the game
- Their mass also acts as a cutoff! ➔ much lower!
- Sensitivity of flavor decays reduced!



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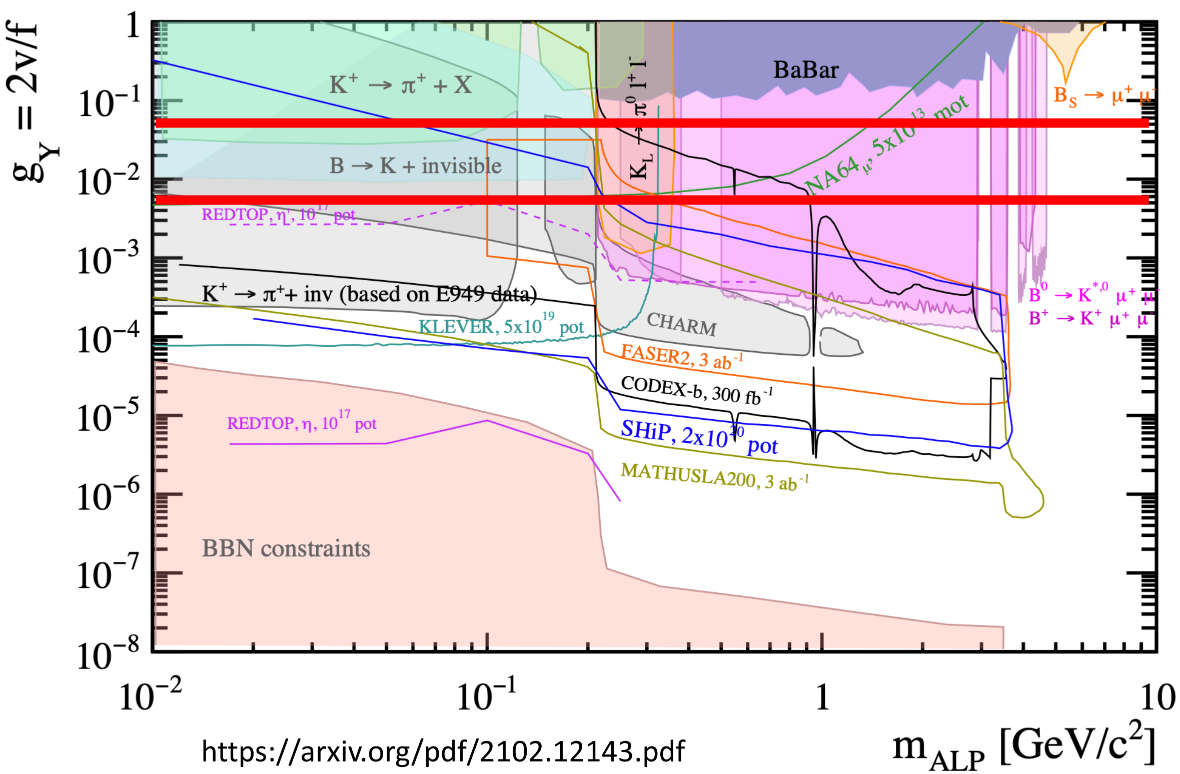
Opening up parameter space



10^4 GeV

10^5 GeV

https://arxiv.org/pdf/2102.12143.pdf

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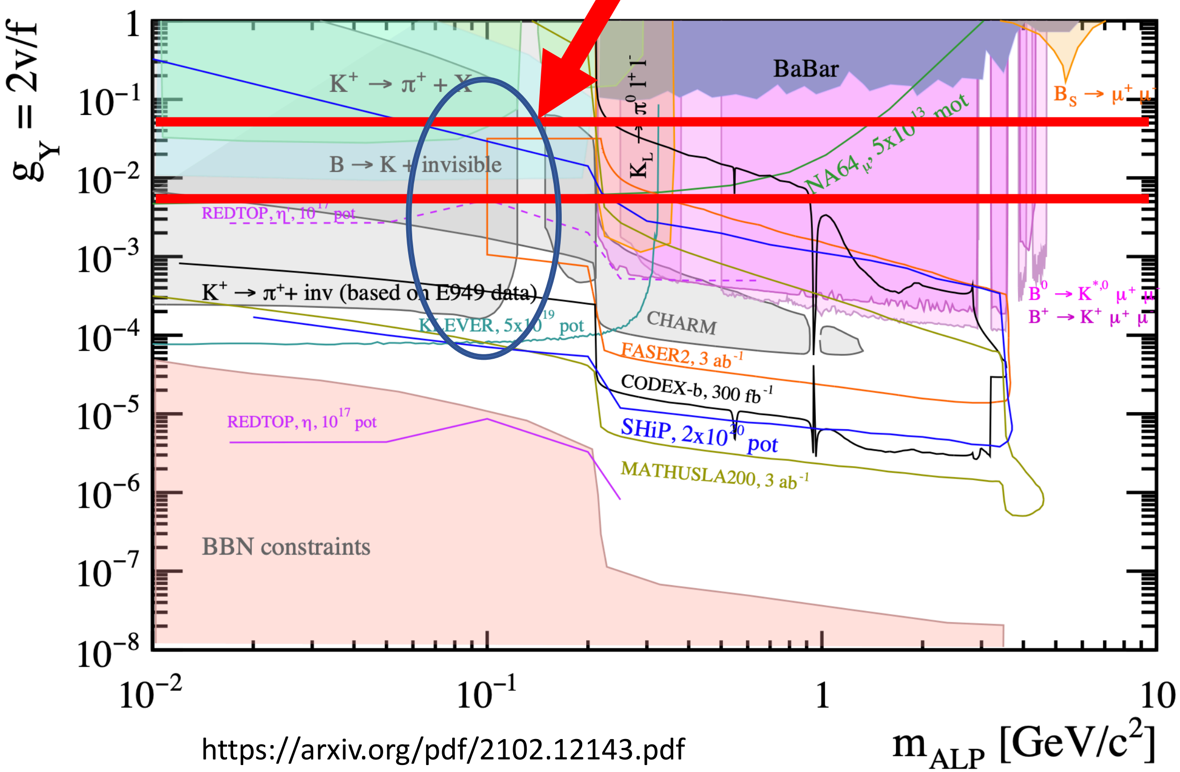
Under-tested parameter space

Region might be interesting to test with FASER



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How generic?

- Probably quite:
  - KSVZ models do not have suitable effective fermion couplings

  - Models with high effective cutoff and suitable fermion couplings not easy to construct
  - These models usually feature flavor changing couplings already at tree-level

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How generic?

- Probably quite:
  - KSVZ models do not have suitable effective fermion couplings
  - Models with high effective cutoff and suitable fermion couplings not easy to construct
  - These models usually feature flavor changing couplings already at tree-level
- Smells of a field theoretic Axion-Marshland conjecture

Marsh[2]: https://arxiv.org/abs/1903.12643

https://arxiv.org/pdf/2101.03173.pdf

Let‘s Talk about masses…

Super-Naively

- Lagrangian

$$\mathcal{L} = \frac{1}{2}(\partial_\mu a)^2 + \frac{1}{2}m_a^2 a^2 + \frac{\lambda}{4!}a^4 + \sum_\psi c_\psi \frac{1}{f_a}(\bar{\psi}\gamma_\mu\gamma_5\psi)\partial^\mu a - \frac{1}{4}\, g_{a\gamma} F_{\mu\nu}\tilde{F}^{\mu\nu} a$$

- With $\frac{m_a^2}{f_a^2} \sim 10^{-14}\left(\frac{m_a}{100\ \mathrm{MeV}}\right)^2\left(\frac{10^6\mathrm{GeV}}{f_a}\right)^2 \sim \lambda$

- This looks badly finetuned...

But: Pseudo-Goldstone

- Goldstone of U(1)

$$\mathcal{L} \supset |\partial_\mu \phi|^2 - V(|\phi|) \qquad \langle \phi \rangle \sim f_a \neq 0$$

$$\phi = f_a \exp\left(i \frac{a}{f_a} \right) \quad \Rightarrow \quad m_a = 0 \qquad \lambda = 0$$

- Pseudo-Goldstone → explicit U(1) breaking

$$\Delta V \sim \Lambda^{4-n} \phi^n + h.c.$$

$$m_a^2 \sim \Lambda^{4-n} f_a^{n-2} \qquad \frac{m_a^2}{f_a^2} \sim \Lambda^{4-n} f^{n-4} \sim \left(\frac{\Lambda}{f_a} \right)^{4-n} .$$

Examples

- We always need $\Lambda \ll f_a$!

$$\frac{m_a^2}{f_a^2} \sim \left(\frac{\Lambda}{f_a}\right)^{4-n} .$$

- n=1

$$m_a^2 \sim \frac{\Lambda^3}{f_a} \ll \Lambda^2$$

See-saw type smallness!

- Stops already at n=2

$$m_a^2 \sim \Lambda^2 \sim \Lambda^2$$

Anomalous/Non-perturbative breaking

- Luckily many models (e.g. QCD axion) do not take Λ as an input parameter.
- The symmetry breaking arises from anomaly

$$\Lambda \sim M_0 \exp\left(-\frac{8\pi^2}{g^2}\right)$$

$g \sim 0.1 - 1$ Can generate tiny values of Λ

Essentially any mass can be motivated

Planck scale opportunities

Planck scale corrections to axion models
Stephen M. Barr (Delaware U., Bartol Inst.), D. Seckel (Delaware U., Bartol Inst.) (Feb, 1992)
Published in: Phys.Rev.D 46 (1992) 539-549

Planck scale physics and the Peccei-Quinn mechanism
Marc Kamionkowski (Princeton, Inst. Advanced Study), John March-Russell (Princeton U.) (Jan, 1992)
Published in: Phys.Lett.B 282 (1992) 137-141 • e-Print: hep-th/9202003 [hep-th]

Solutions to the strong CP problem in a world with gravity #1
Richard Holman (Santa Barbara, KITP and Carnegie Mellon U.), Stephen D.H. Hsu (Santa Barbara, KITP and Harvard U.), Thomas W. Kephart (Vanderbilt U.), Edward W. Kolb (Santa Barbara, KITP and Fermilab and Chicago U., Astron. Astrophys. Ctr. and Chicago U., EFI), Richard Watkins (Fermilab and Chicago U., Astron. Astrophys. Ctr. and Chicago U., EFI) et al. (Jan, 1992)
Published in: Phys.Lett.B 282 (1992) 132-136 • e-Print: hep-ph/9203206 [hep-ph]

- Quantum gravity may (!!! or not) feature symmetry violation of the type

$$\Delta V \sim M_P^{4-n}\phi^n + h.c. \quad n \gtrsim 4$$

$$m_a^2 \sim f_a^2 \left(\frac{f_a}{M_P}\right)^{n-4} \qquad \frac{m_a^2}{f_a^2} \sim \left(\frac{f_a}{M_P}\right)^{n-4} .$$

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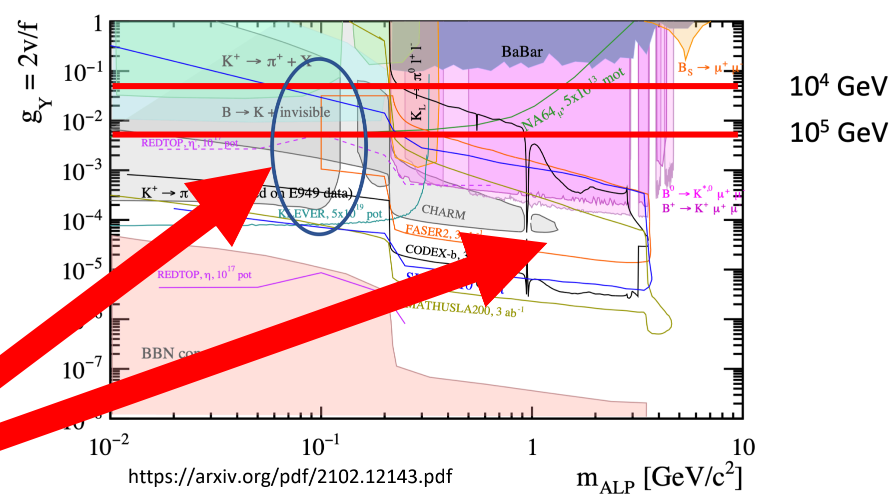
See-saw the other way around

$$n = 5$$

$$m_a^2 \sim (100\,\mathrm{MeV})^2\left(\frac{3\times 10^5\mathrm{GeV}}{f_a}\right)$$



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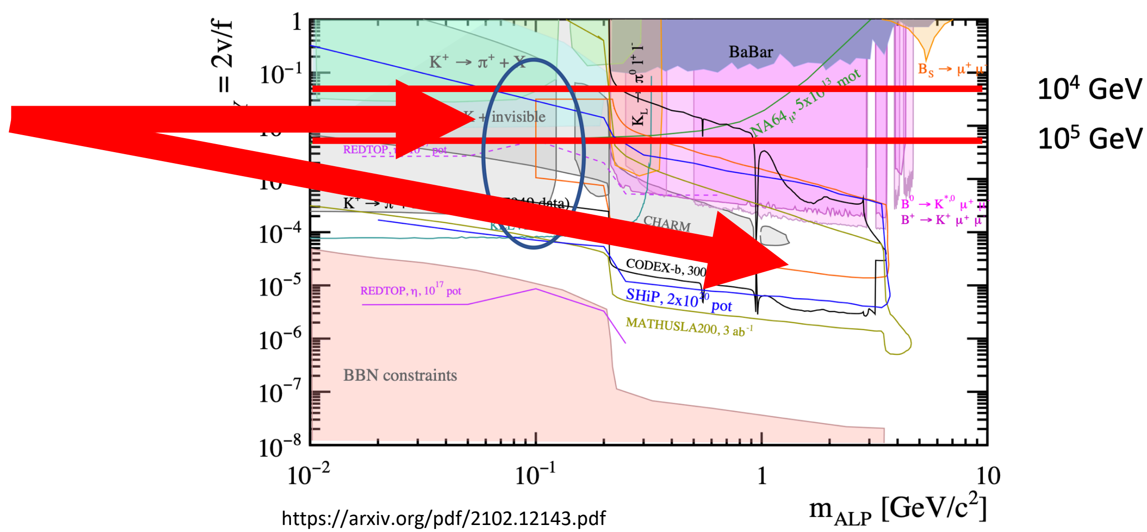
→ Might be interesting

Conclusions

- Constraints on ALPs based on loop-level EFT calculations may need extra care (lower cutoff due to extra particles)

➔ Regions of parameter space may be open for direct tests

- Planck scale symmetry violation may be within reach ;-).



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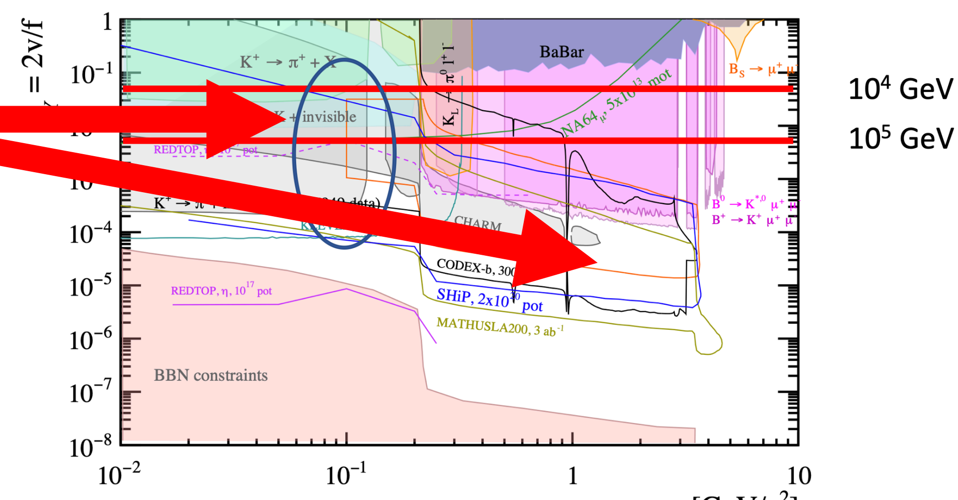
General messages

- Re-think constraints
- Use high-scale info on EFTs



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- Cosmic Frontier CF2: Wave-like Dark Matter

➔ i.e. sub-eV dark matter

It‘s cool, too ;-).