Signals of ALP-Mediated Dark Matter and its UV Completions

University of Victoria

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TRIUMF

Motivation

- Direct Detection experiments' rates for pseudoscalar particles are suppressed
- Can DM be mediated by a naturally light pseudoscalar?
- We assume the ALP is the only particle which allows DM to interact with the SM via Yukawa couplings

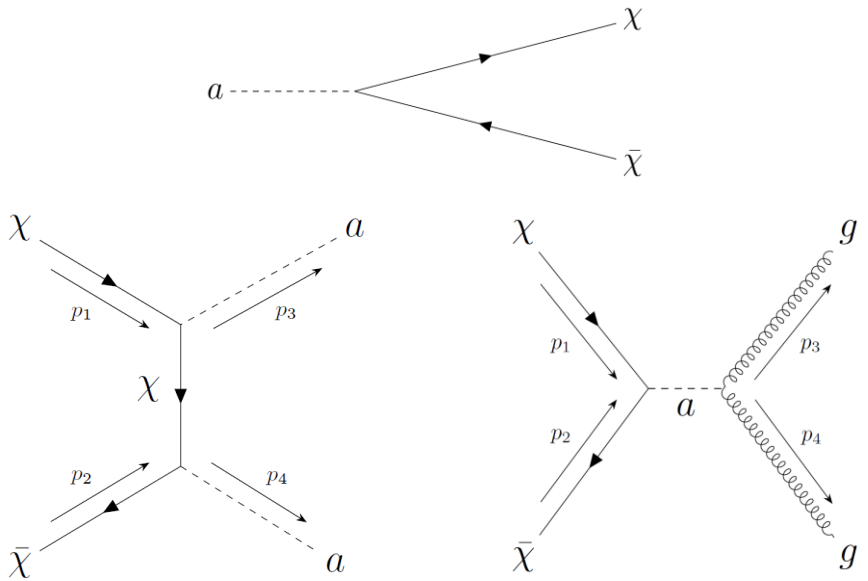
$$m_\chi \frac{a}{f} \chi \gamma^5 \bar{\chi}$$

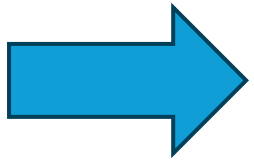
- The ALP couples predominately to gluons (KSVZ type)

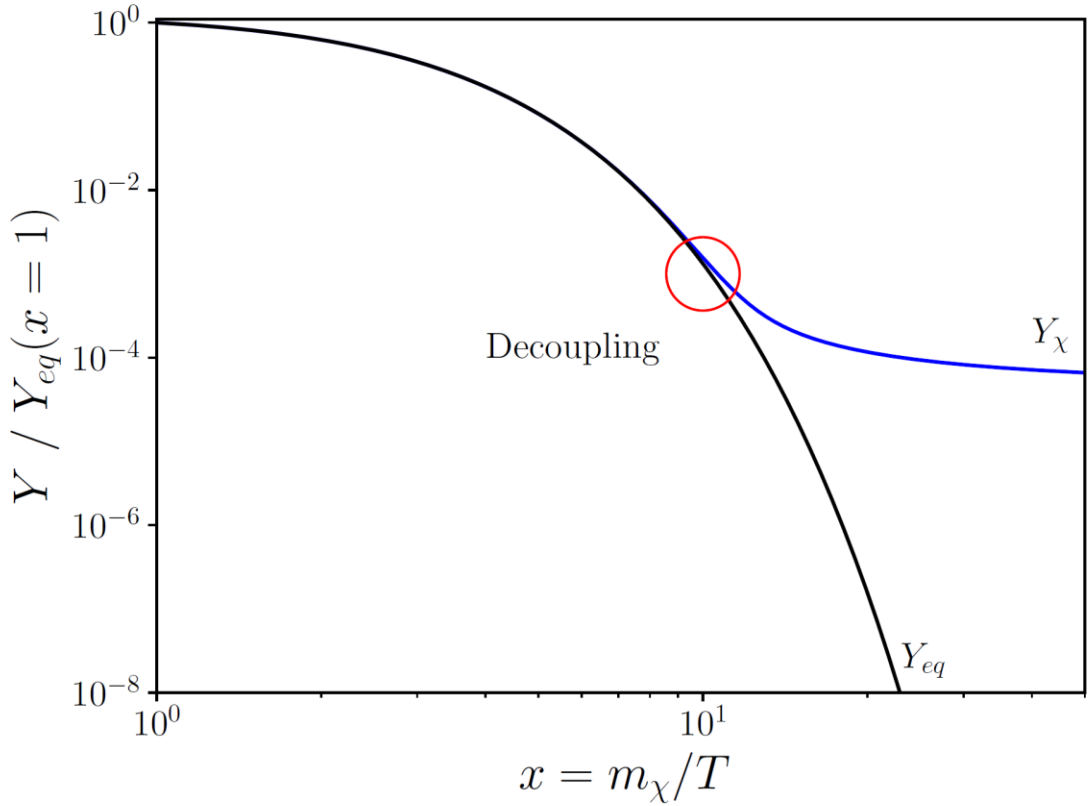
$$i \frac{\alpha_s}{4\pi} c_{gg} \frac{a}{f} G^a_{\mu\nu} \tilde{G}^{\mu\nu,a}$$

Freeze-out

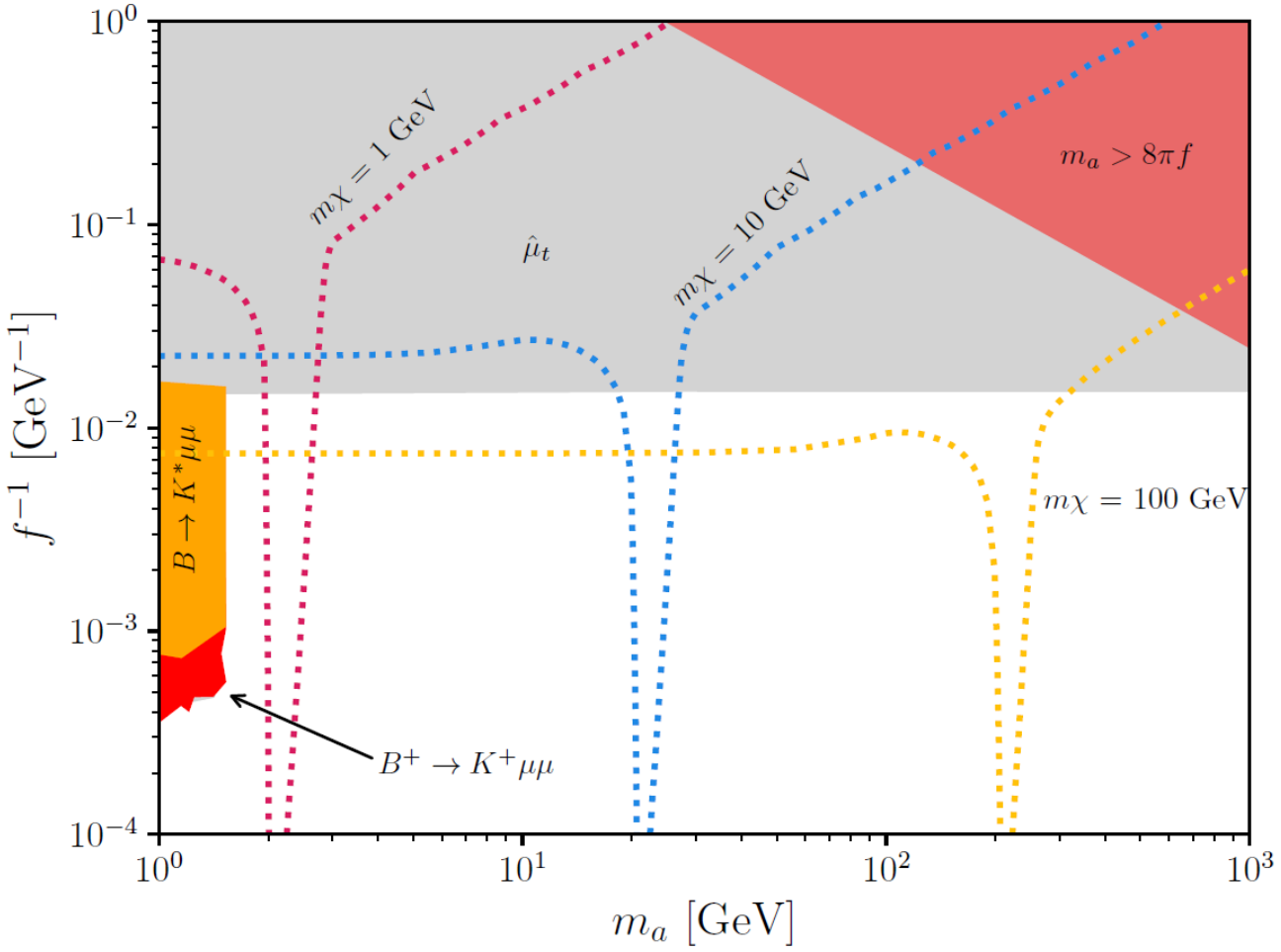
- The relevant processes for the EFT freeze-out are







Effective Field Theory Result



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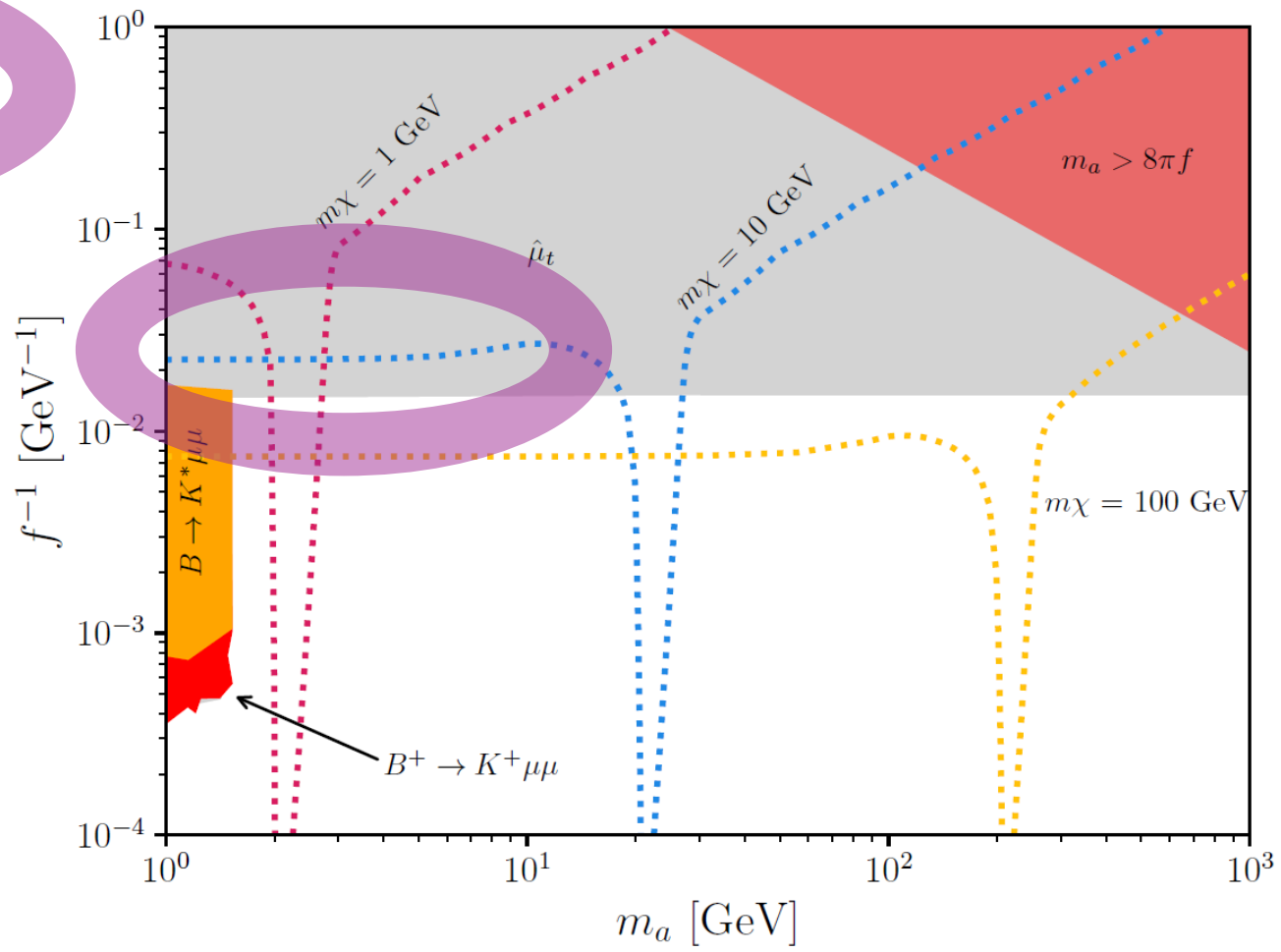
Effective Field Theory Result

$m_\chi < m_a$: $\langle \sigma v \rangle_{\chi\bar{\chi} \to aa}$



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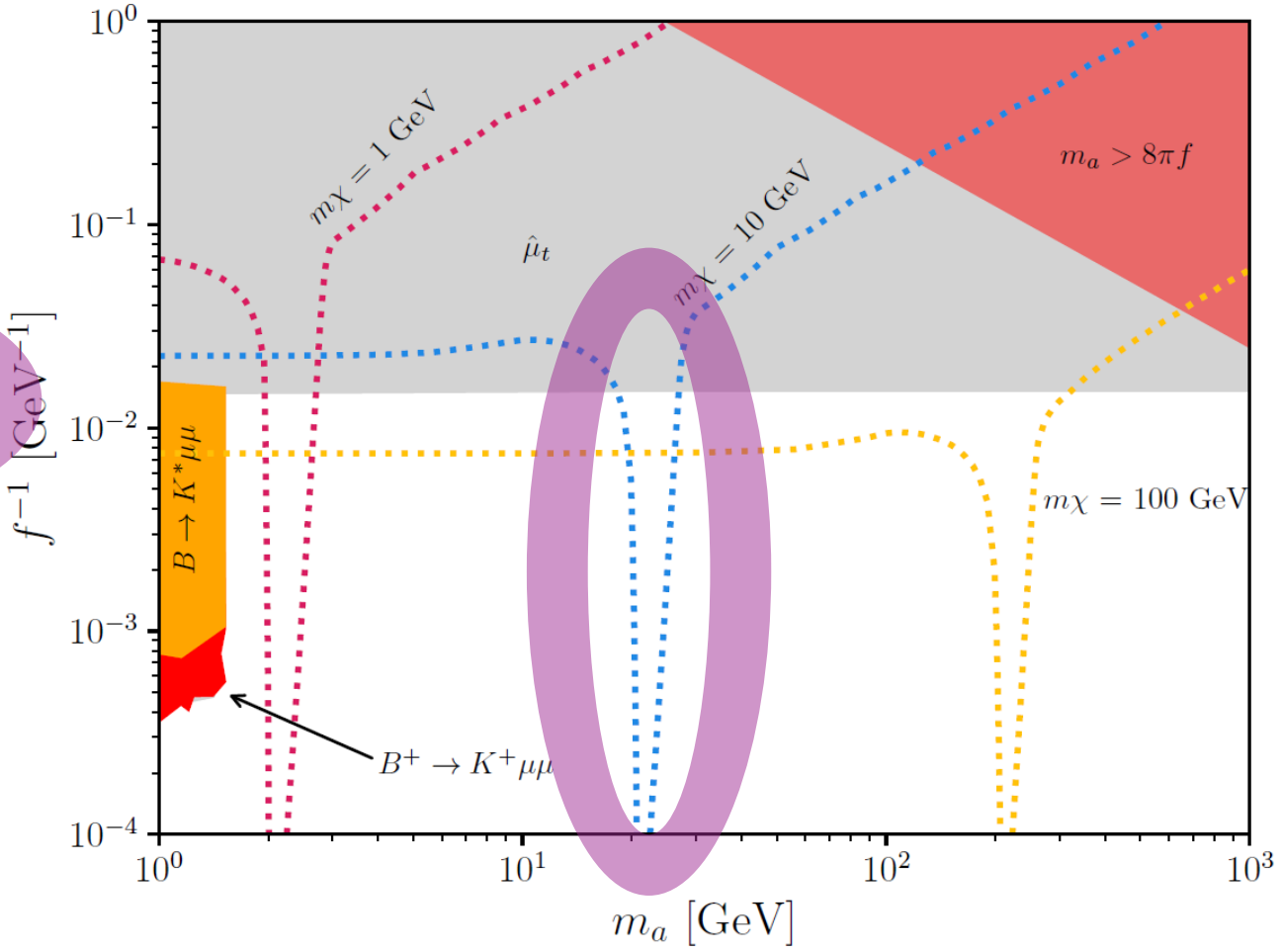
$m_\chi \simeq 2m_a$: $\langle \Gamma \rangle_{a \to \chi\bar{\chi}}$



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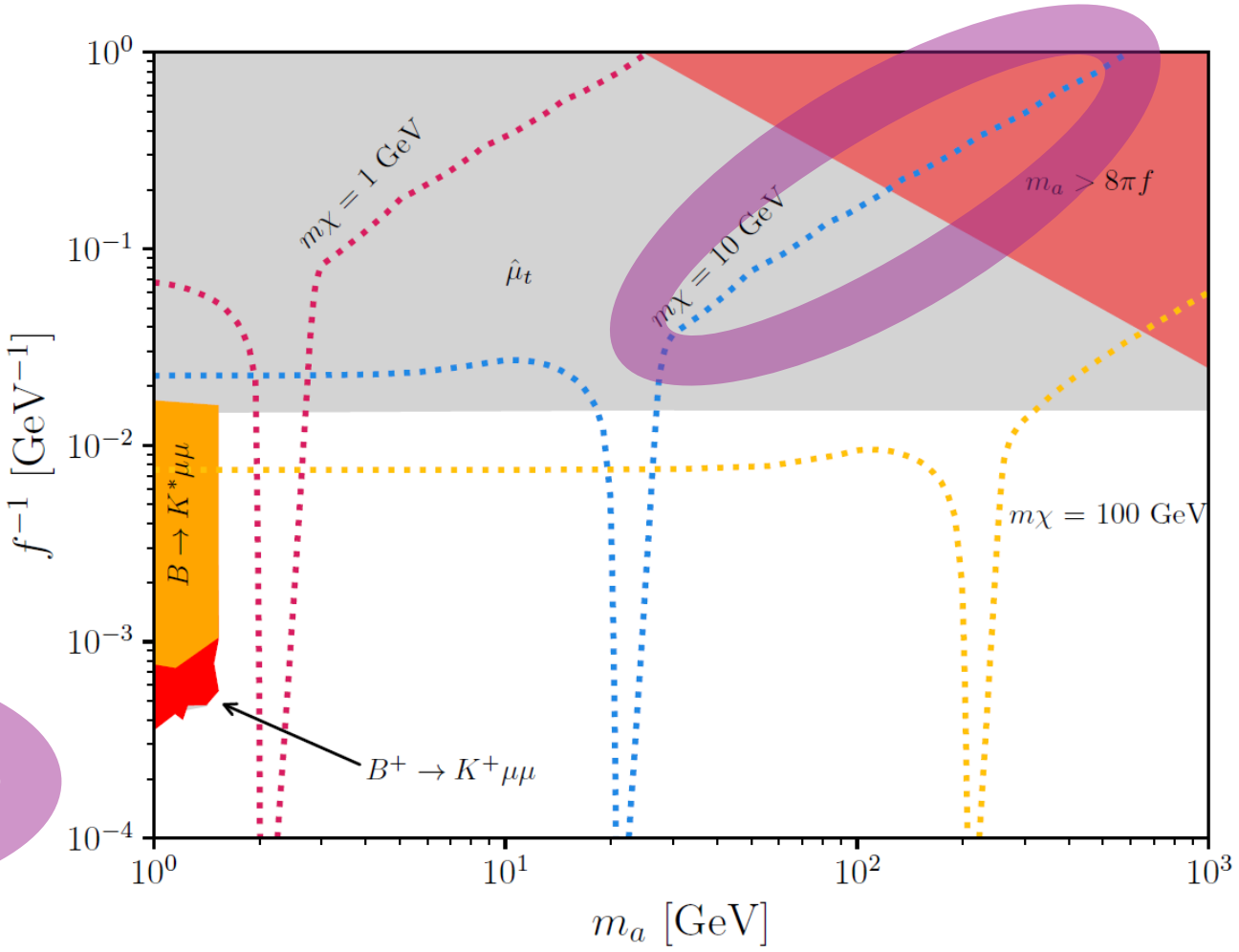
$m_\chi > 2m_a$: $\langle \sigma v \rangle_{\chi\bar{\chi} \to gg}$



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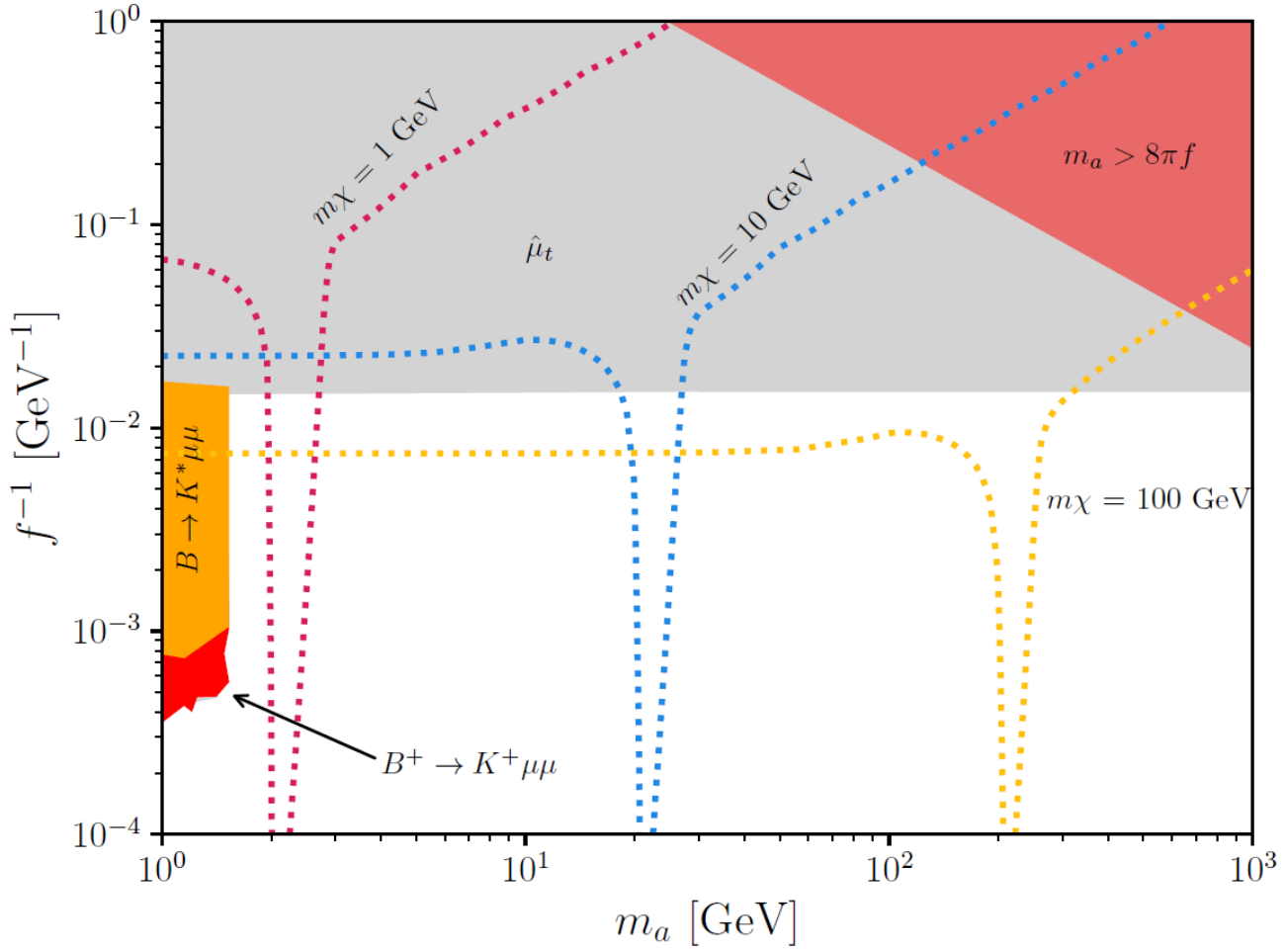

Where does the EFT become invalid?
$m_a > 8\pi f$?

Previously shown by 2306.03128

Effective Field Theory from UV

- The standard approach is to take a wine-bottle potential for a complex scalar and spontaneously break it

$$V(|\Phi|) = \lambda_\Phi \left(|\Phi|^2 - \frac{f^2}{2} \right)^2 \rightarrow \Phi = \frac{f}{\sqrt{2}} \left(1 + \frac{r}{f} \right) e^{ia/f}$$

- The SSB creates a scalar, r, and a pseudoscalar, a, in which r receives a mass that depends on the decay constant f, while a does not

- Weakly interacting implies large f values

UV Completion

- We use a KSVZ UV completion and include r

- Let's examine the interaction terms

$$\mathcal{L}_{int} \supset \frac{m_r}{2f} r^3 + \frac{r}{f}(\partial a)^2 + \frac{r^2}{2f^2}(\partial a)^2 + \frac{\lambda_\Phi}{4} r^4$$
$$-m_\chi \frac{r}{f} \bar{\chi}\chi + \frac{\alpha_s}{6\pi} c_{gg} \frac{r}{f} G^a_{\mu\nu} G^{\mu\nu,a}$$
$$-m_\chi \frac{a}{f} \bar{\chi}\gamma^5\chi + \frac{\alpha_s}{4\pi} c_{gg} \frac{a}{f} G^a_{\mu\nu} \tilde{G}^{\mu\nu,a}$$

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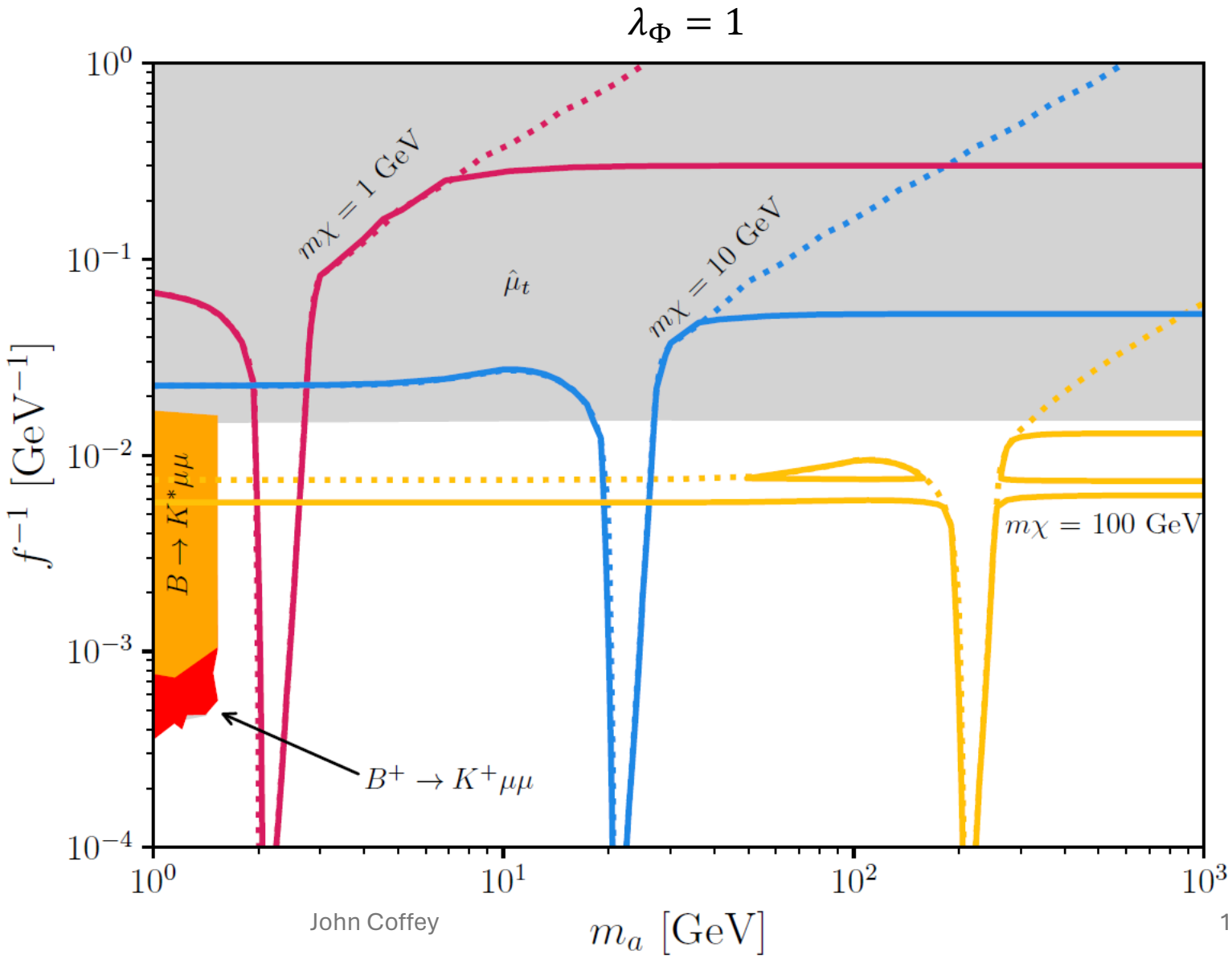
UV effects

$$-m_\chi \frac{a}{f} \bar{\chi}\gamma^5\chi + \frac{\alpha_s}{4\pi} c_{gg} \frac{a}{f} G^a_{\mu\nu} \tilde{G}^{\mu\nu,a}$$

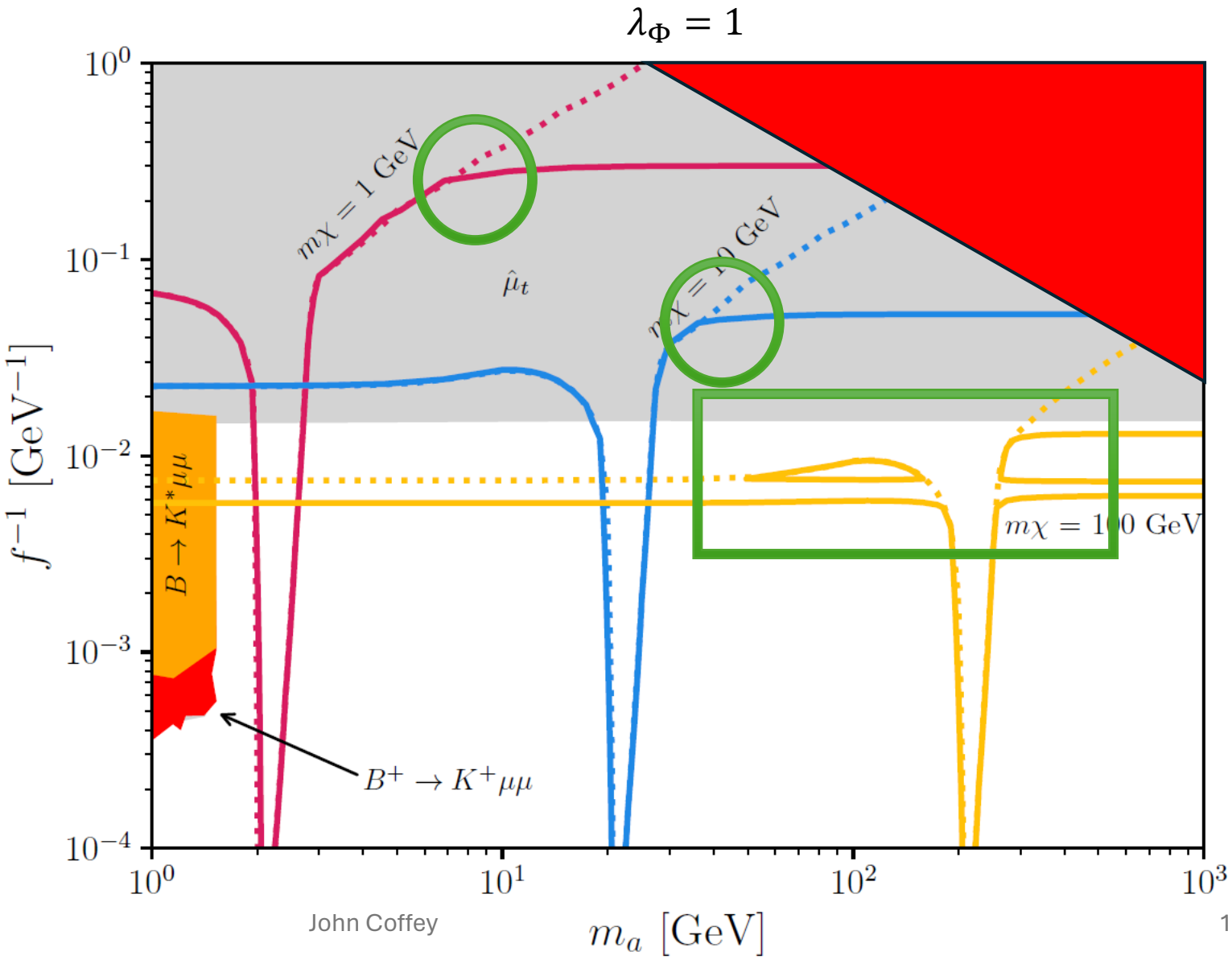
EFT

UV Results


$\lambda_\Phi = 1$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
f^{-1} [GeV^{-1}]
$m\chi = 1$ GeV
$\hat{\mu}_t$
$m\chi = 10$ GeV
$m\chi = 100$ GeV
$B \to K^* \mu\mu$
$B^+ \to K^+ \mu\mu$
10^0
10^1
10^2
10^3
m_a [GeV]

UV Results

UV effects turn on much sooner than previously thought!



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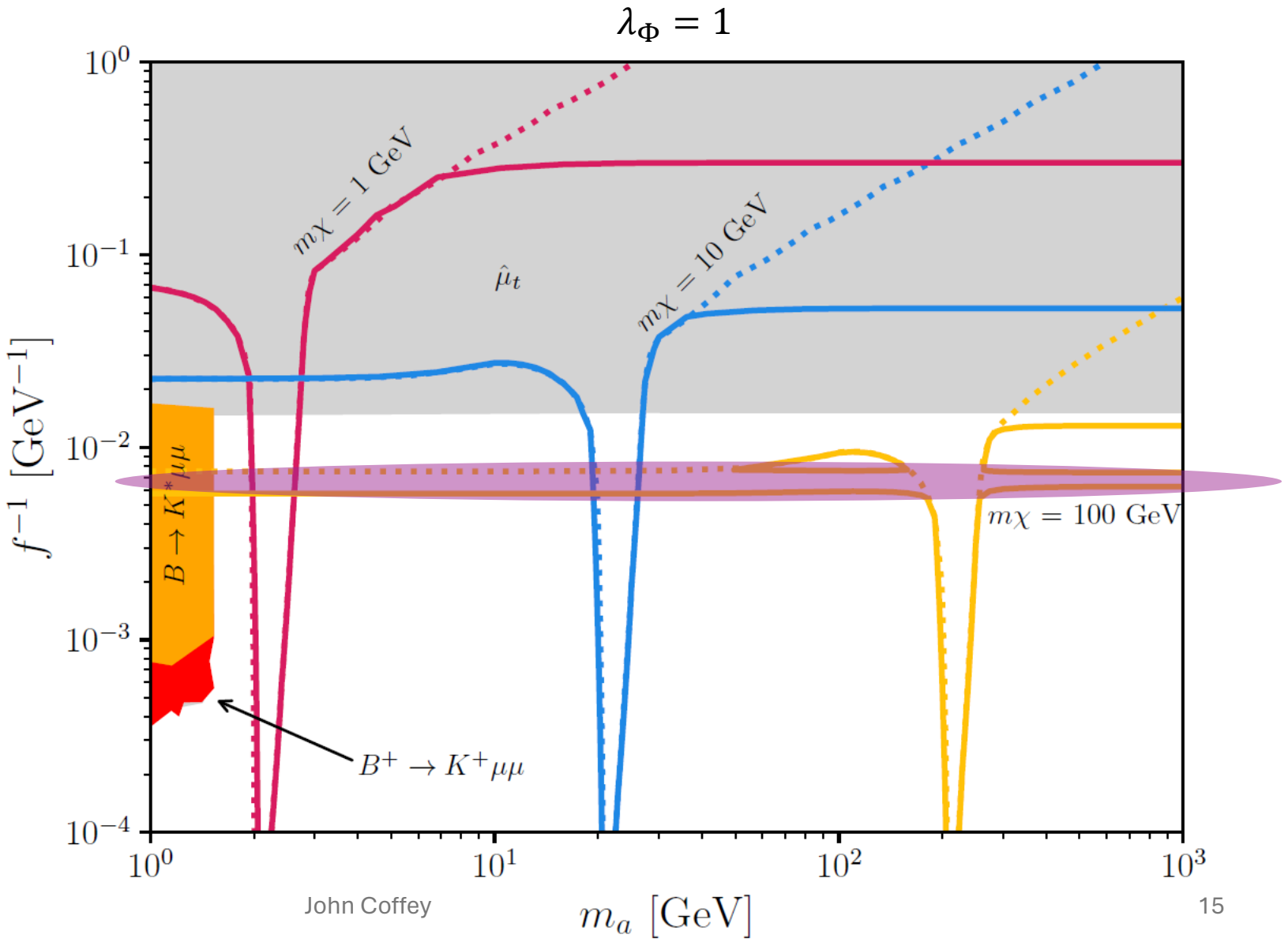
Since m_χ is on the order of f, and $m_r = \sqrt{2\lambda_\Phi} f$

The resonance of the s-channel for $\chi\bar{\chi} \to r \to gg$ and the annihilation $\chi\bar{\chi} \to rr$ are important!



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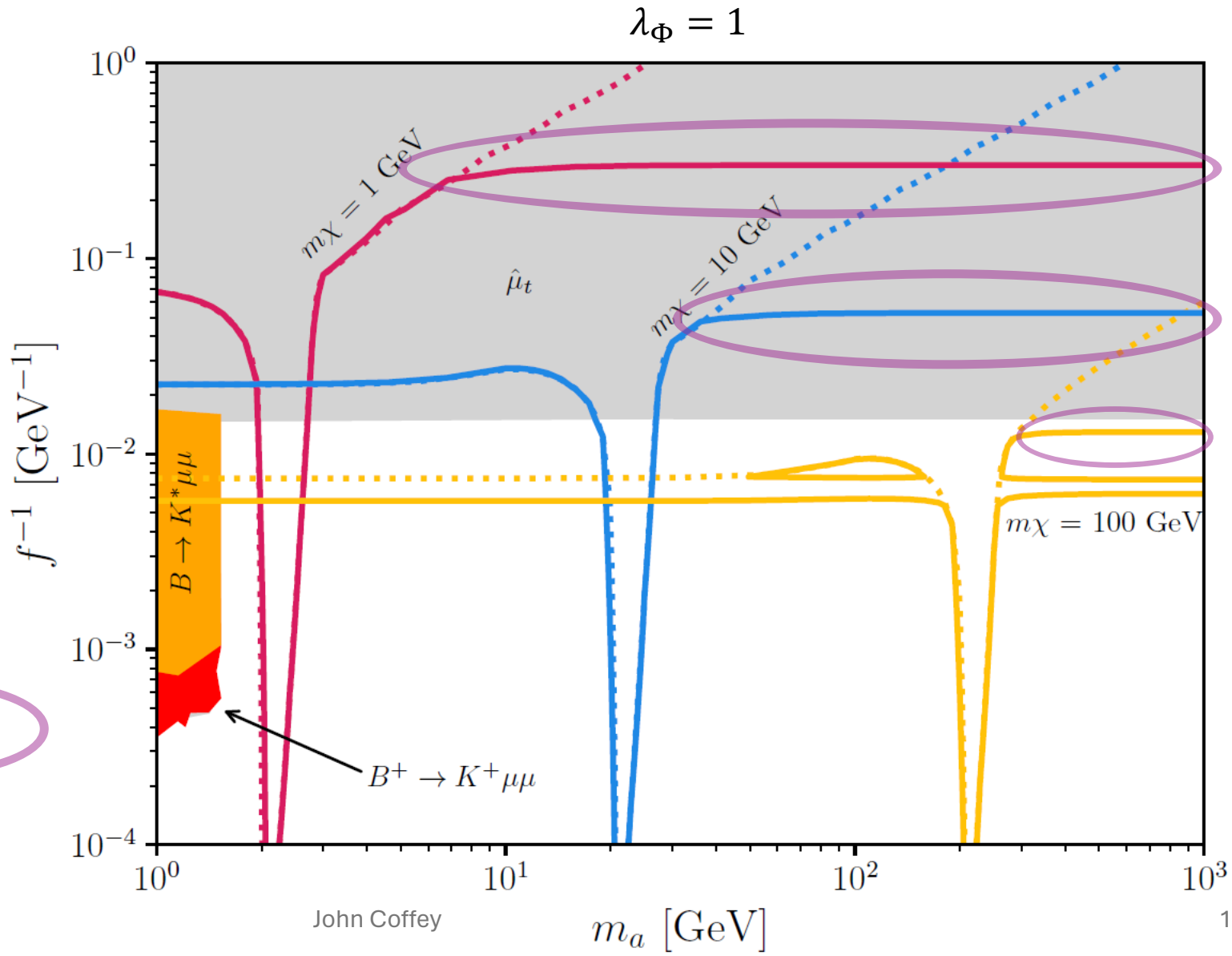

Moving Forward

- Examine the freeze-in scenario, adding in the UV effects
- KSVZ connectors, examining ALPs and quarks interactions
- Add in other vectors bosons channels, $W^+W^-, \mathrm{ZZ}, \gamma\gamma, \gamma Z$, 2405.02403
- Look at Direct Detection with DM and r, bounds from DD and no pseudoscalar suppression

Thank you for your time!

Questions?