Heavy QCD Axion at Belle II: Displaced and Prompt Signals

LLPX

Speaker: Vazha Loladze

arXiv:2108.10331 Emilie Bertholet, Sabyasachi Chakraborty, Vazha Loladze , Takemichi Okui, Abner Soffer, Kohsaku Tobioka

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- Standard QCD Axion - compelling solution for **Strong CP** problem
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- For $f_a > 10$ TeV QG ruins PQ mechanism (Quality Problem)

Heavy QCD Axion

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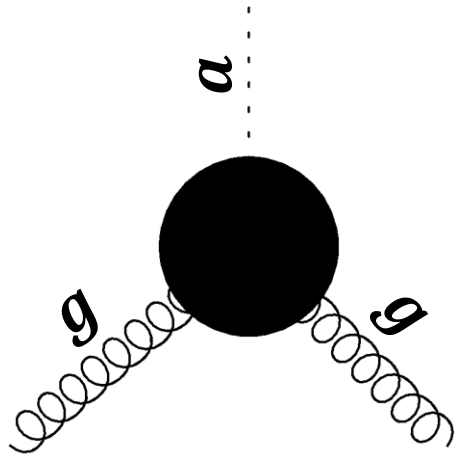
   large parameter space is experimentally allowed! (f_a <10 TeV allowed => **No QP!**)

2. Solves strong CP problem

3. The dominant coupling to SM



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3. The dominant coupling to SM through gluons

Many models can reproduce this scenario:

- **H. Fukuda, K. Harigaya, M. Ibe, T. T. Yanagida**
  arXiv: 1504.06084
- **P. Agrawal, K. Howe**
  arXiv: 1710.04213
- **P. Agrawal, G. Marques-Tavares, W. Xue**
  arXiv: 1708.05008
- **M.K. Gaillard, M.B. Gavela, R. Houtz, P. Quilez, R. del Rey**
  arXiv: 1805.06465
- **T. Gherghetta, V. V. Khoze, A. Pomarol, Y. Shirman**
  arXiv: 2001.05610
- **R.S. Gupta, V.V. Khoze, M. Spannowsky**
  arXiv: 2012.00017

m_a~GeV scale axion

$B \to K^{(*)} a$ - unique probe at $m_a \sim$ GeV:

1. **The correct mass!**
2. **Huge statistics (BABAR, BELLE, LHCb, BELLE II)**

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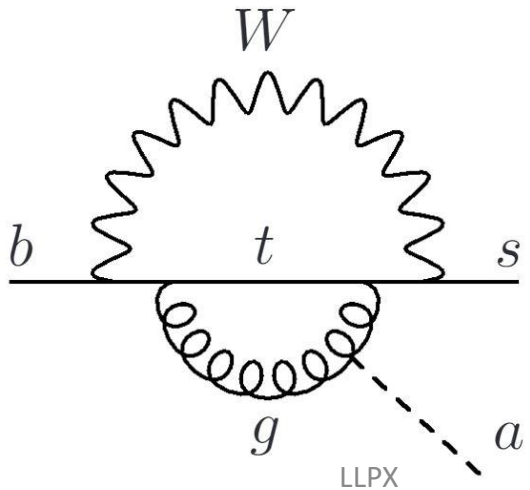
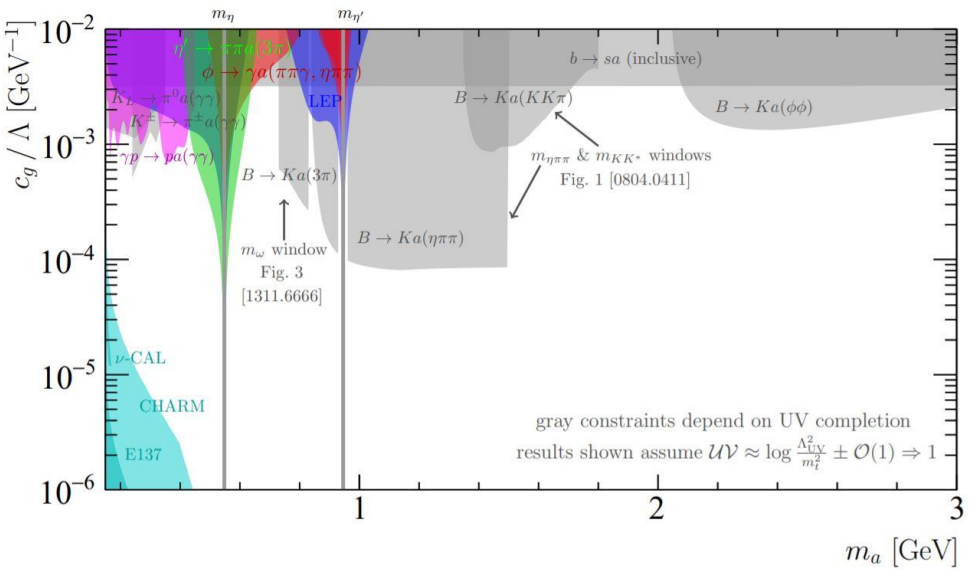
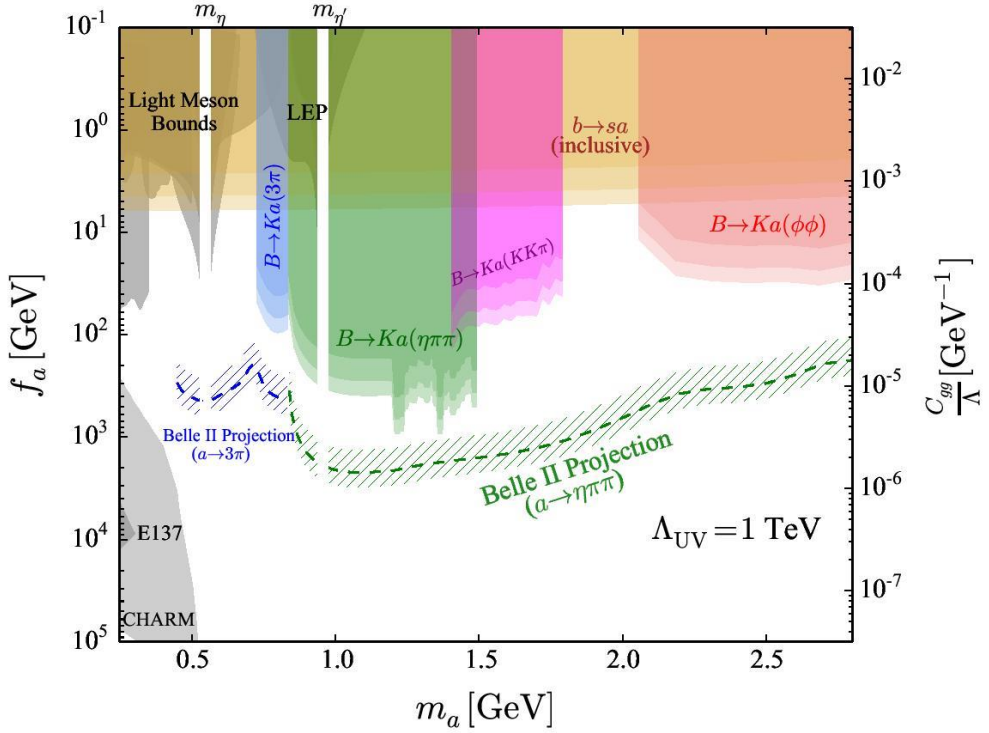
Leading order contribution to $B \to Ka$ comes at two loop level



B meson decay



D. Aloni, Y. Soreq, M. Williams
arXiv:1811.03474



S. Chakraborty, M. Kraus, V. Loladze, T. Okui, K.Tobioka arXiv:2102.04474

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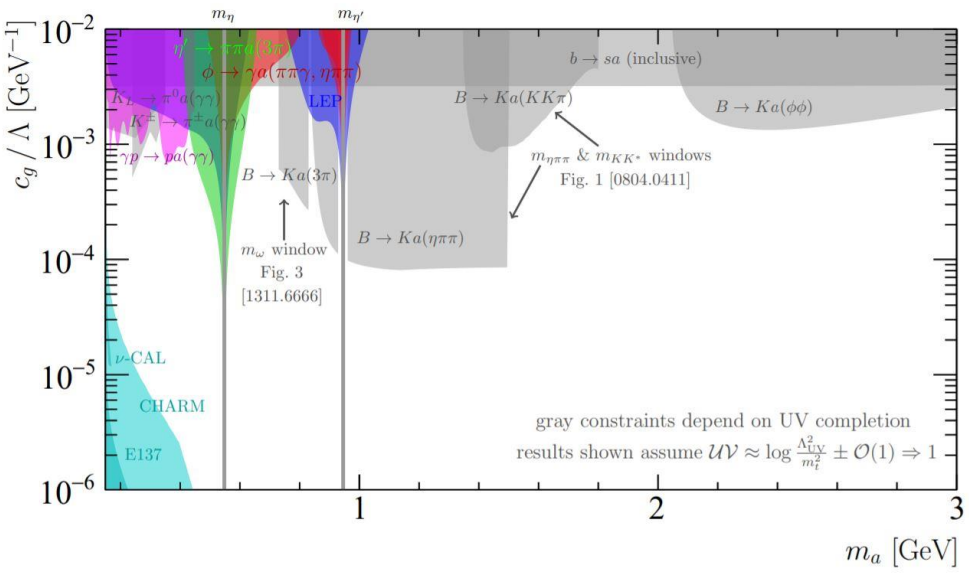

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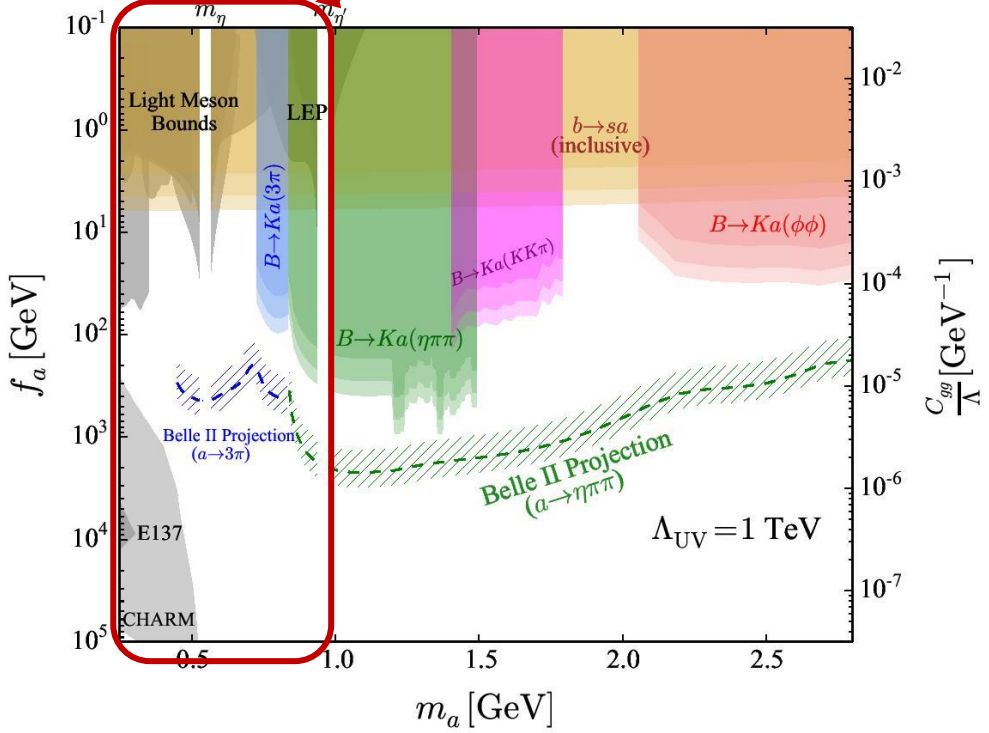
This talk **"LL axion"**



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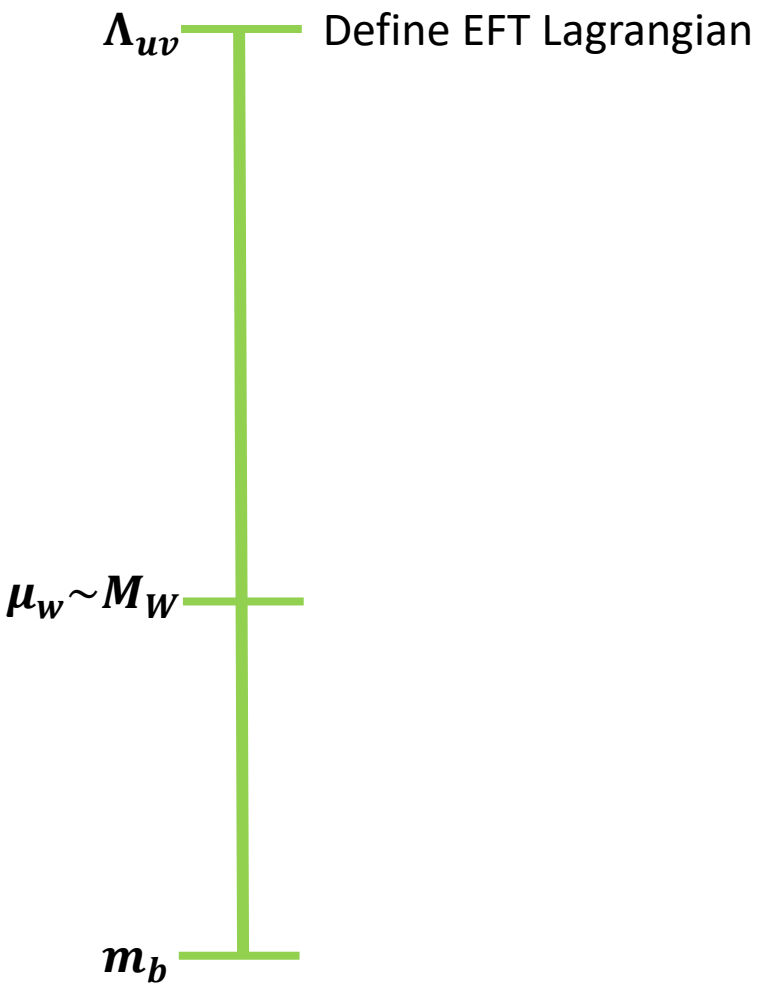
Long Lived Heavy QCD Axion at Belle II

EFT Framework for production



Define EFT Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{\alpha_s}{8\pi}\frac{a}{f_a}\, G^a_{\mu\nu}\tilde{G}^{a\mu\nu} + \frac{1}{2}\left(\partial_\mu a\right)^2 - \frac{m_a^2}{2}a^2 + \boldsymbol{C_{qq}} \sum_q \frac{\partial_\mu a}{f_a}\, \bar{q}\, \gamma^\mu\gamma_5\, q + \boldsymbol{C_{bs}}\frac{\partial_\mu a}{f_a}\bar{s}_L\, \gamma^\mu\gamma_5\, b_L + h.c. + \cdots$$

$$C_{qq}(\Lambda_{UV}) = A\, C_F \left(\frac{\alpha_s}{4\pi}\right)^2 \qquad C_{bs}(\Lambda_{UV}) = B C_F \left(\frac{\alpha_s}{4\pi}\right)^2 \frac{\alpha_w}{4\pi}\sum_k V_{ik}V_{kj}^* \frac{m_k}{M_w}$$

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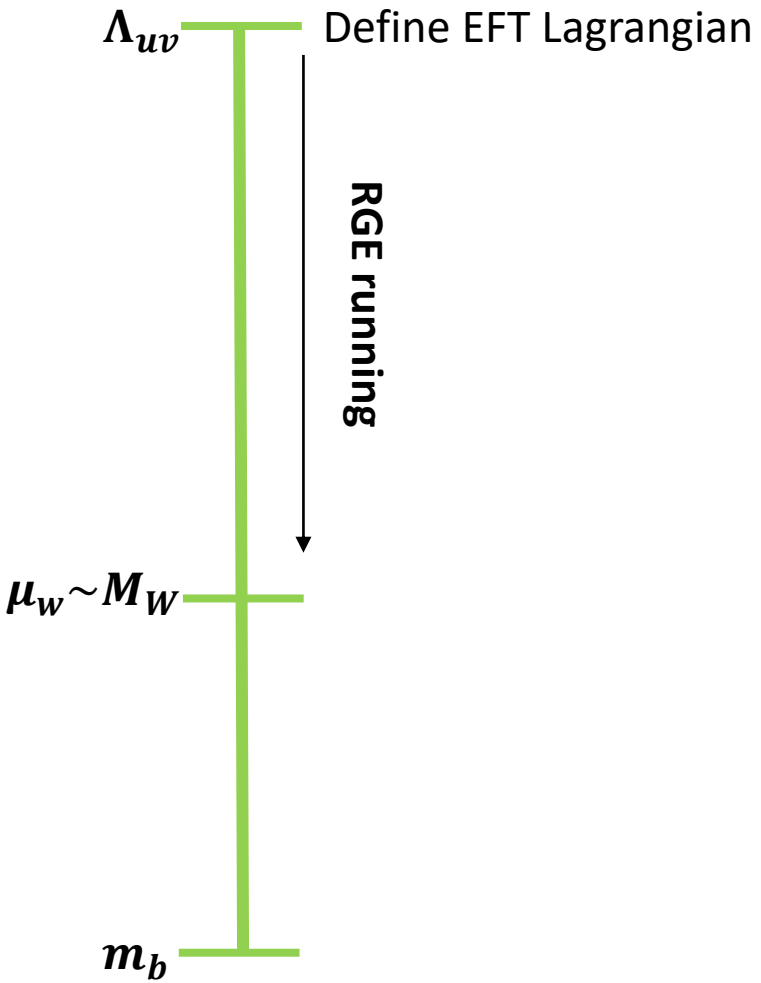

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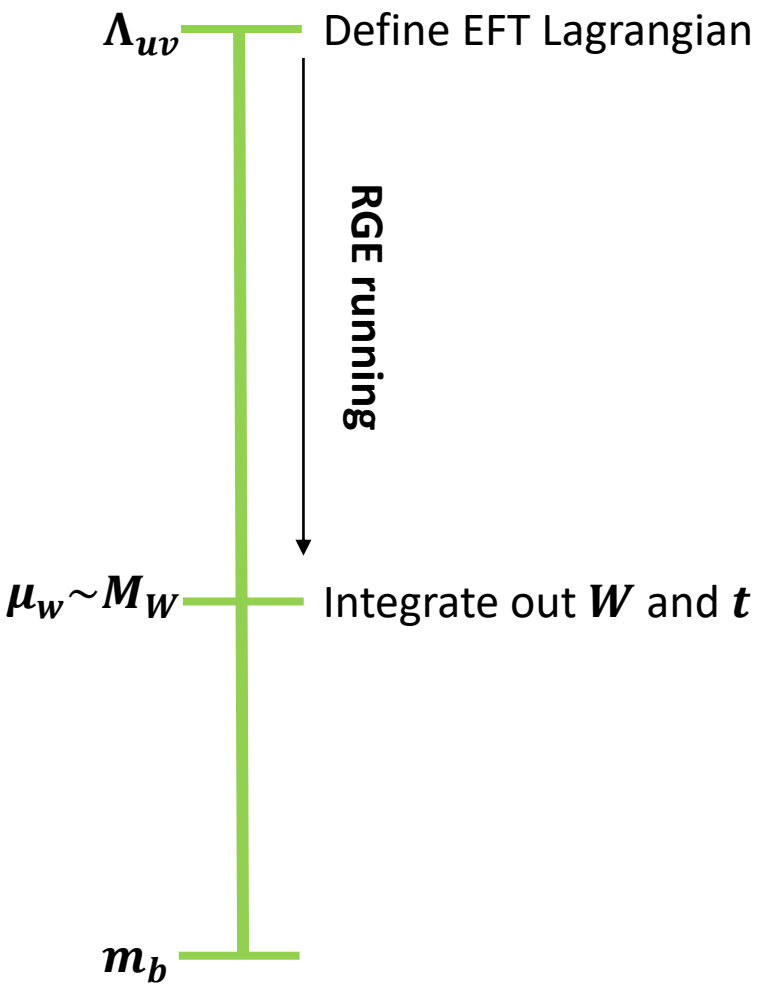

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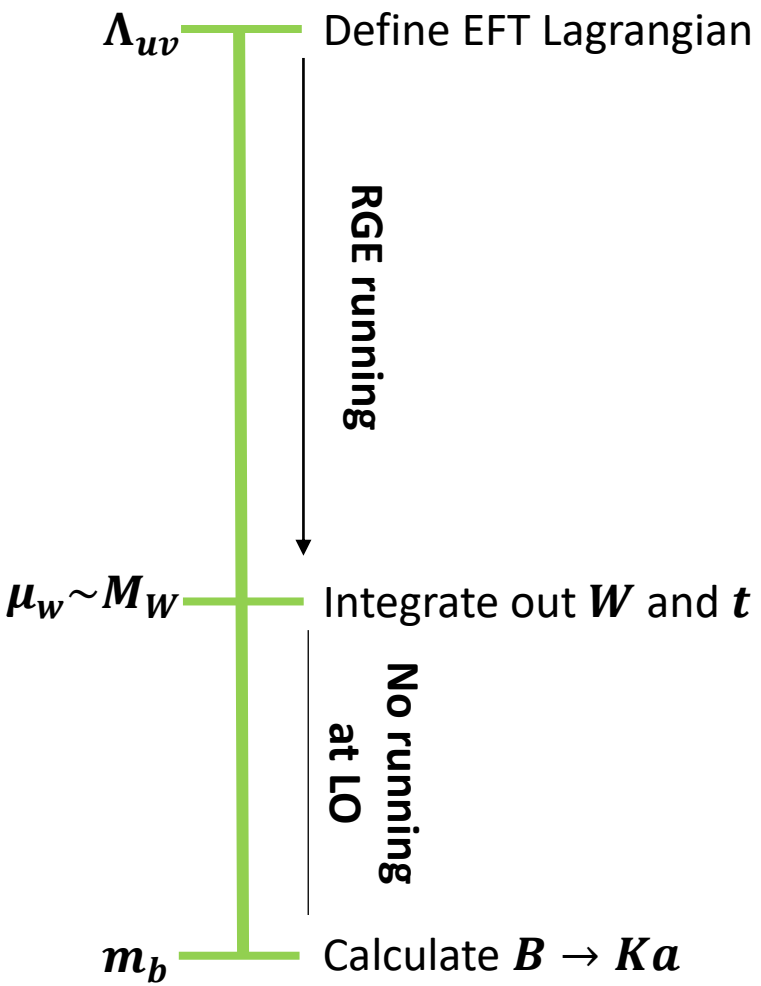

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Hadronic level cross section is calculated using **Light-Cone QCD Sum Rules**

arXiv: hep-ph/0412079, hep-ph/0406232, 0911.4938 ,1611.09355

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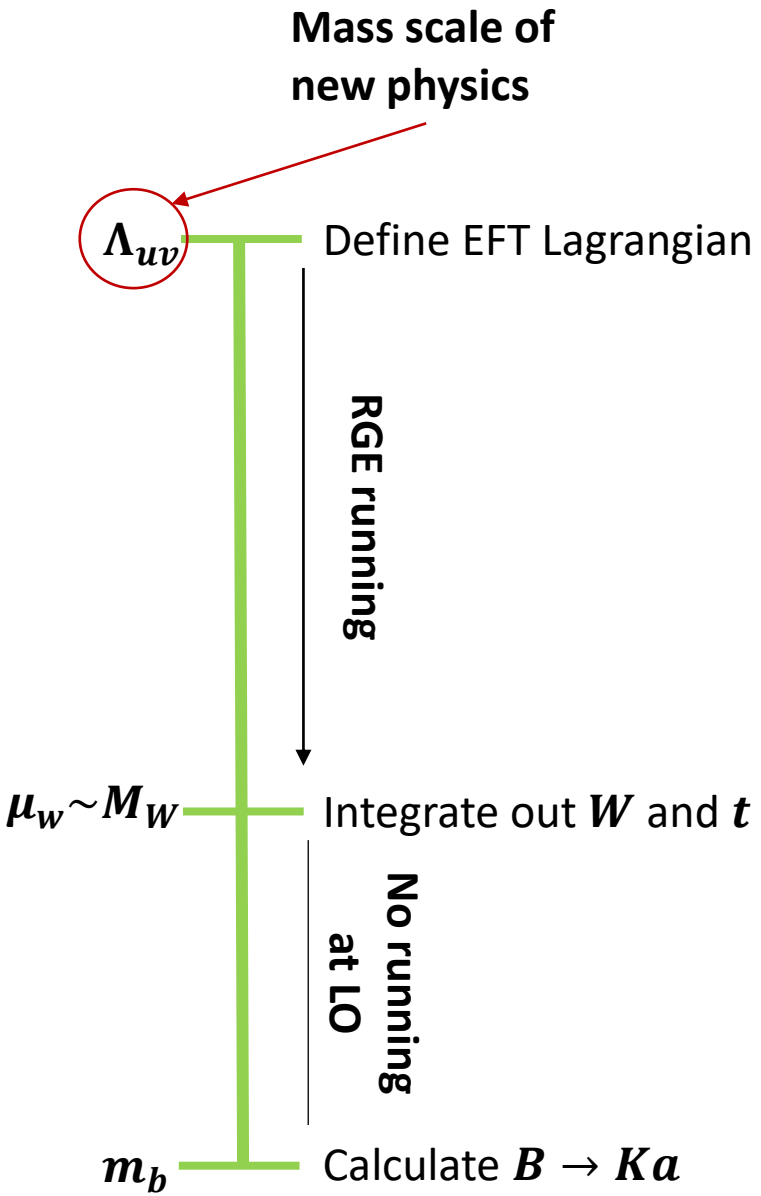

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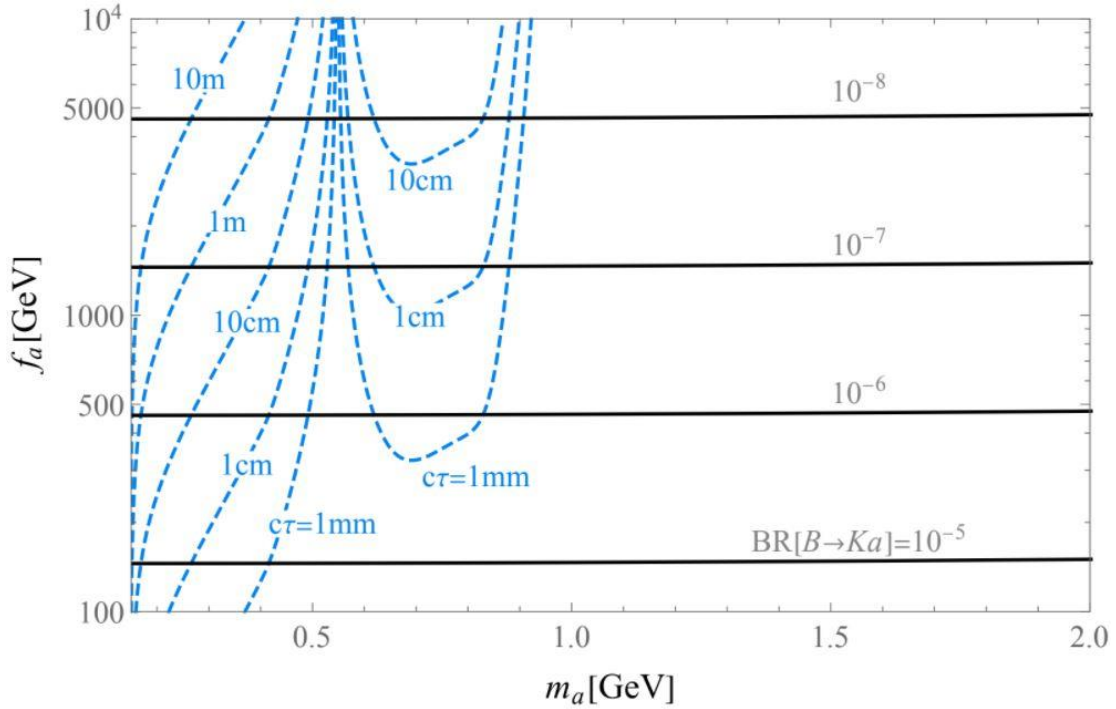
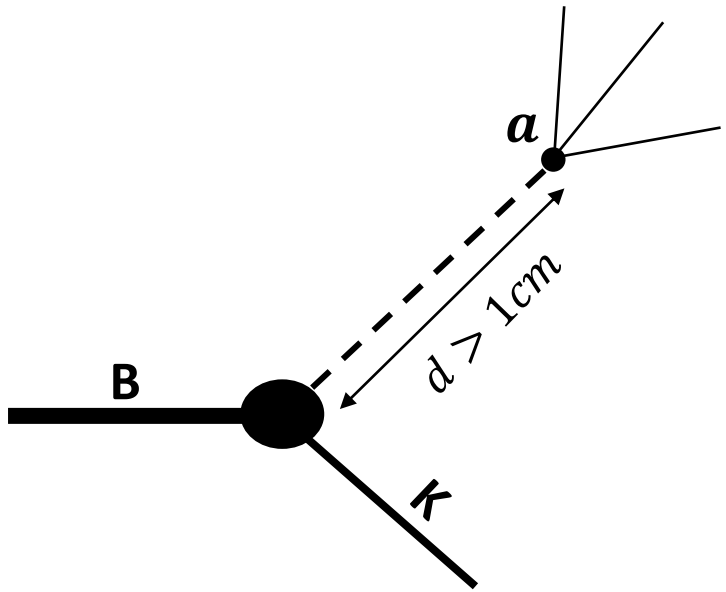
Not very important

displaced decay of axion





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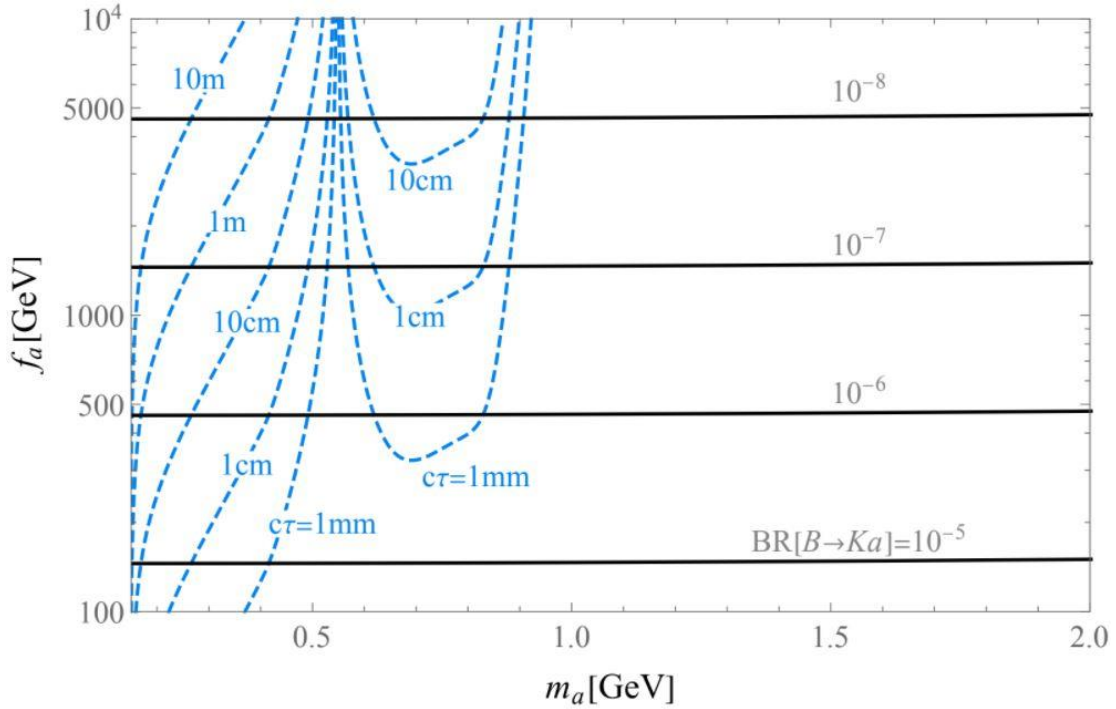

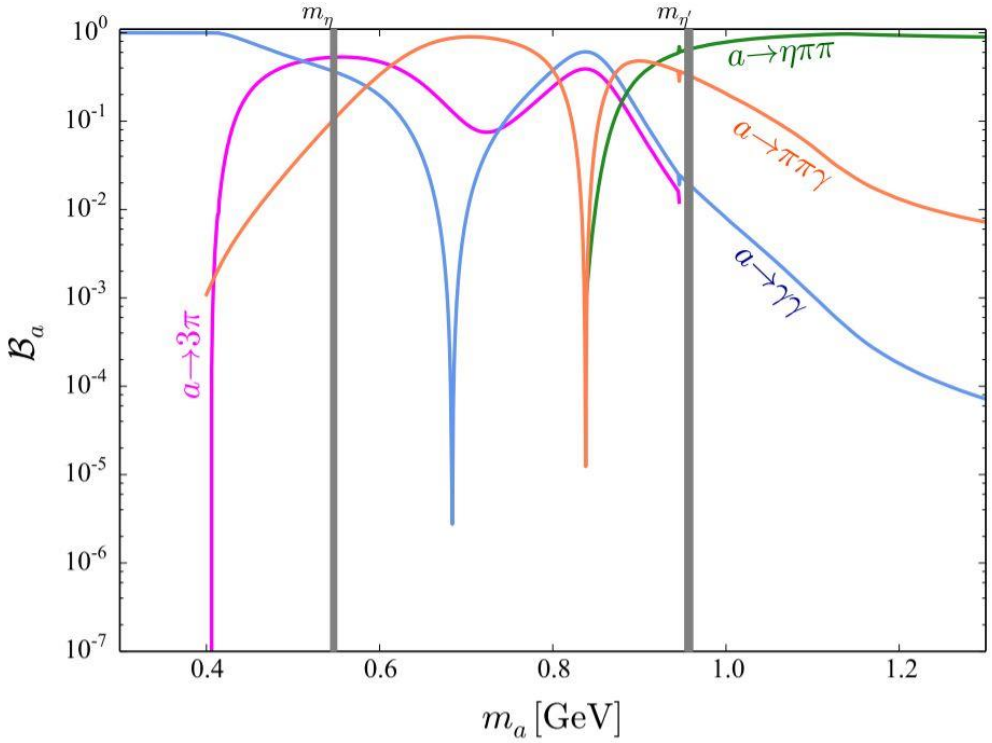

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$a \rightarrow 3\pi$

- Signal: **B**$\rightarrow Ka(\rightarrow \pi^0\pi^+\pi^-)$
- **We can resolve displaced vertex!**

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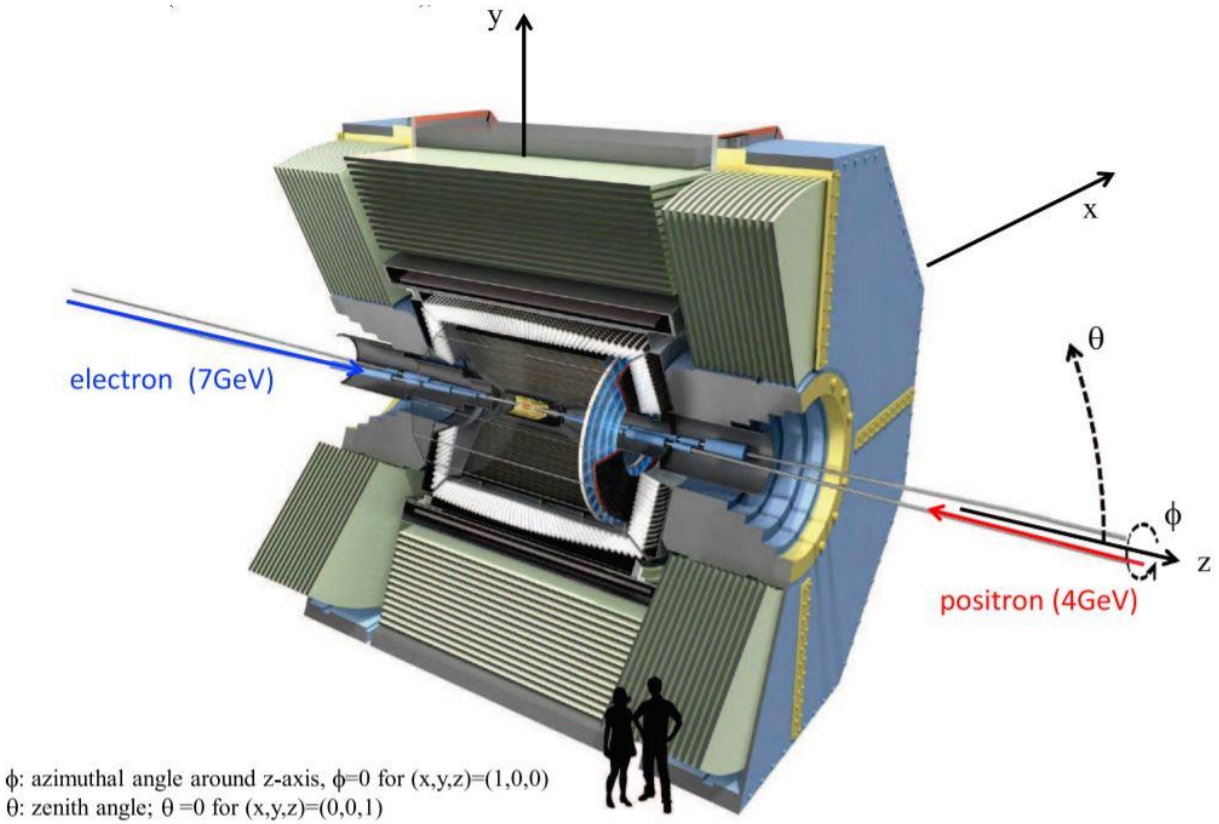
- **DV cut:**

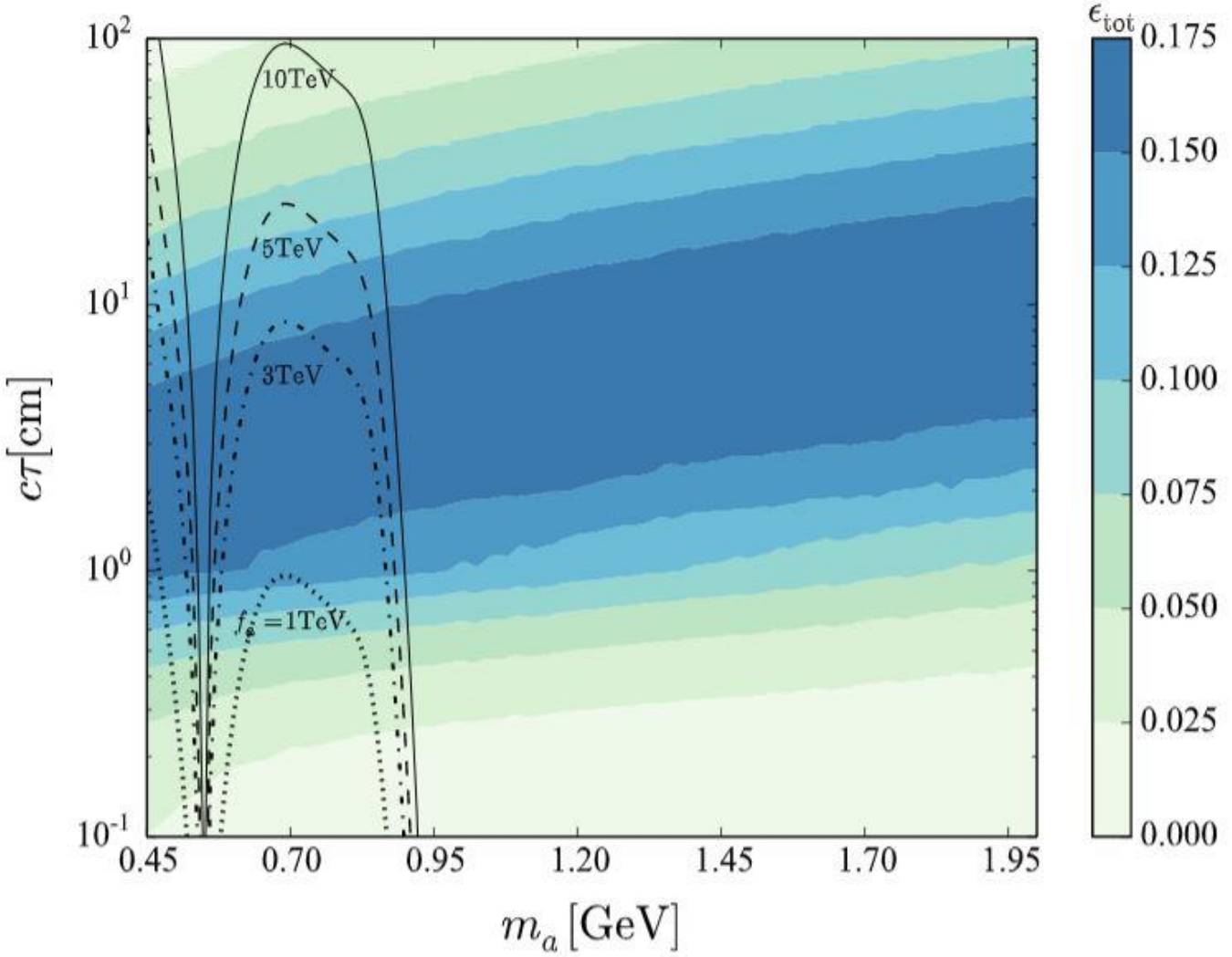
Fiducial volume

$-40 < z < 120$ cm

$1 < r < 80$ cm $\quad (r = \sqrt{x^2 + y^2})$



$a \to 3\pi$ DV efficiency



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4. **B** $\to KK_L\left(\to \pi^0\pi^+\pi^-\right)$ $c\tau_{K_L} \approx 15$ **m is too long** $\Rightarrow$ $N_B \approx 5$ **events around** $m_a = m_{K_L}$

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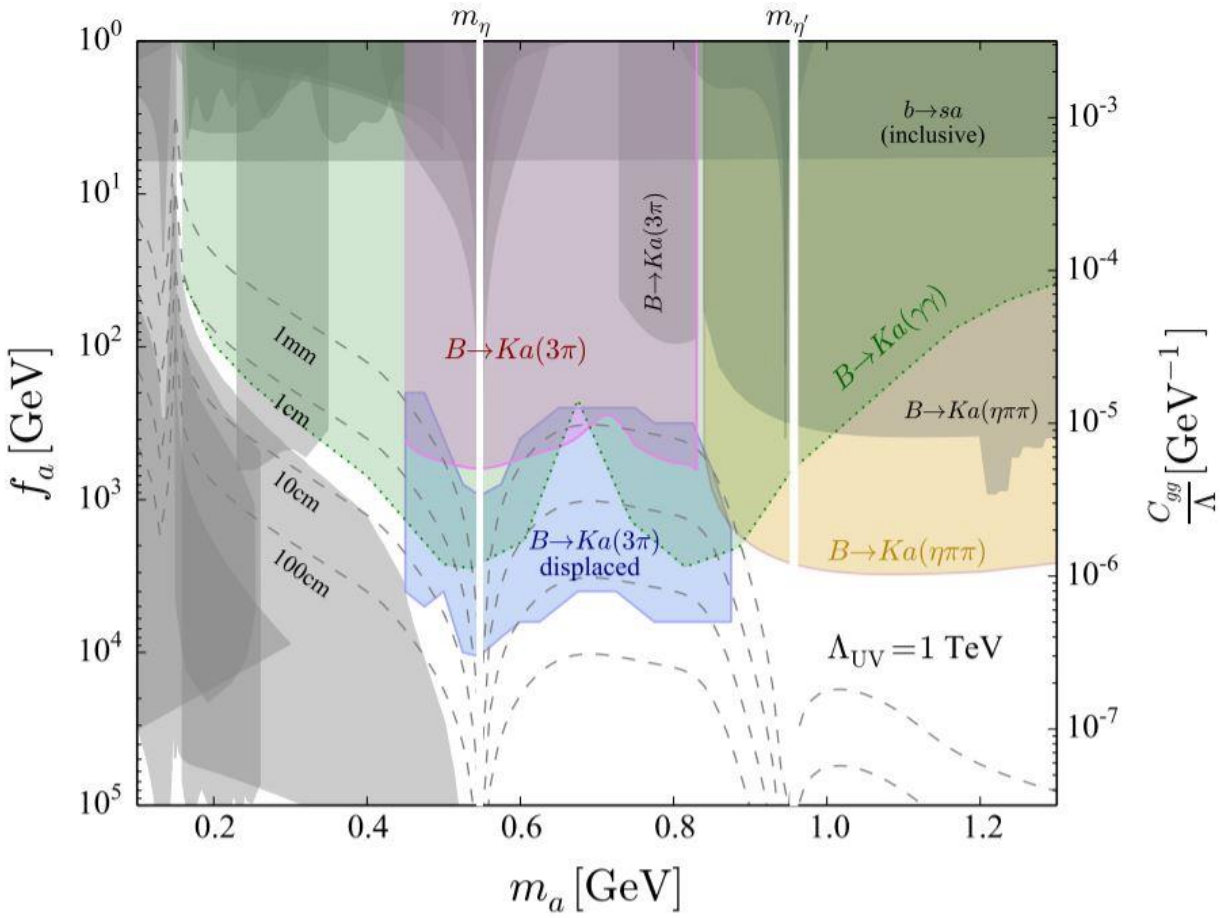
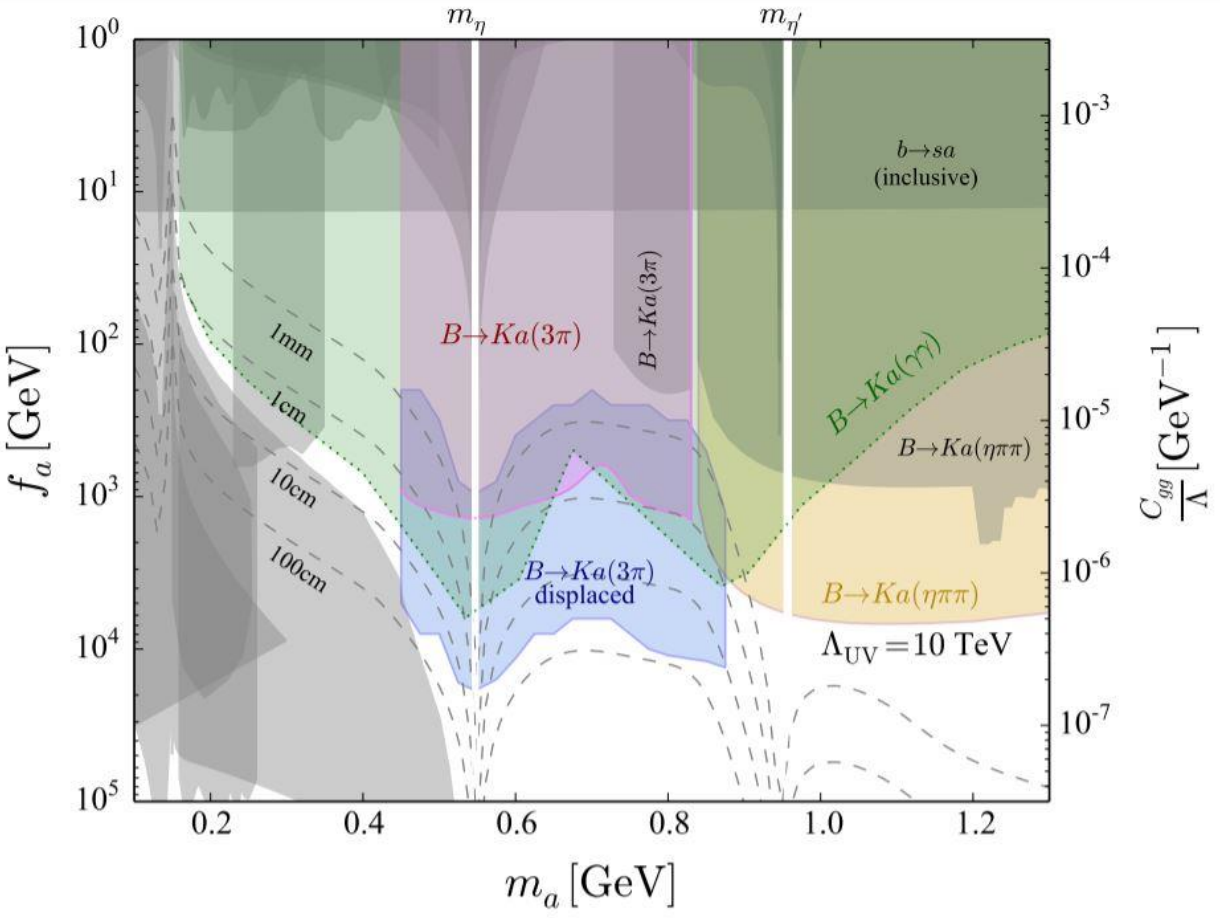
- **We lower our projection to** d_{lab}**=20 cm contour in the** $145 < m_a < 500$ **MeV mass range**

$a \to 3\pi$ & $a \to \gamma\gamma$ projections at Belle II





Summary

- Show displaced $a \to 3\pi$ is almost background free at Belle II
- Study $a \to \gamma\gamma$ at Belle II
- Derive projection of Belle II reach in these two channels

Belle II can even reach axion with $f_a \sim 10$ TeV

Thank you!