Heavy QCD Axion in $\boldsymbol{b \to s}$ transition

Pheno 2021

Speaker: Vazha Loladze

arXiv:2102.04474 Sabyasachi Chakraborty, Manfred Kraus, **Vazha Loladze** ,
Takemichi Okui, Kohsaku Tobioka

Axion

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The Extension of the original model is needed!

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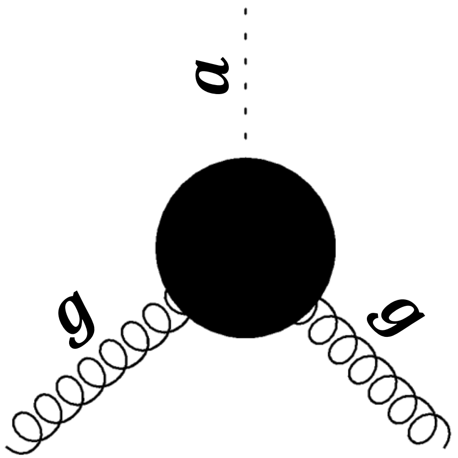
Heavy QCD Axion

1. Is heavy $m_a \sim \mathrm{GeV} \gg m_\pi f_\pi / f_a$=>
   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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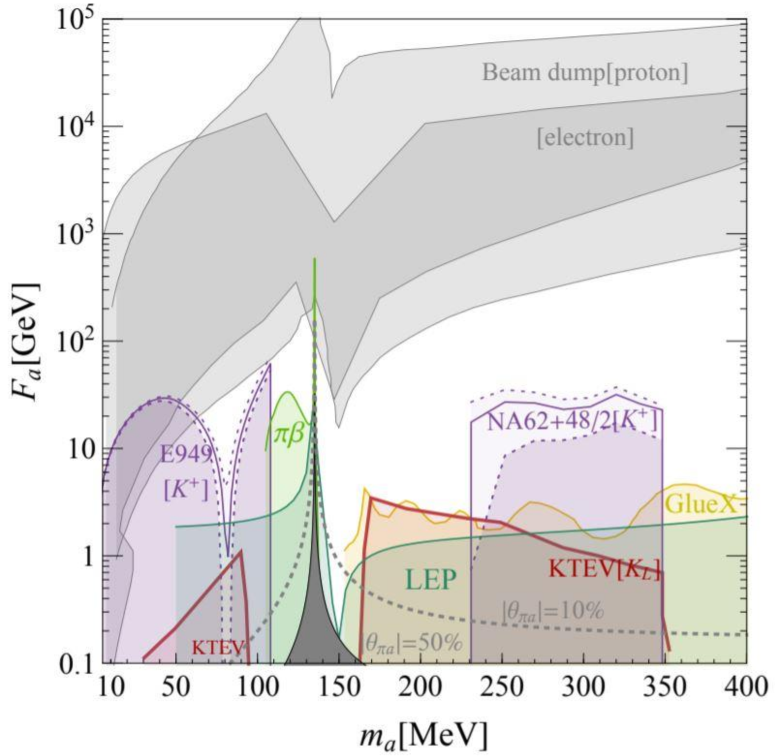
3. The dominant coupling to SM through gluons

Many models can reproduce this scenario:

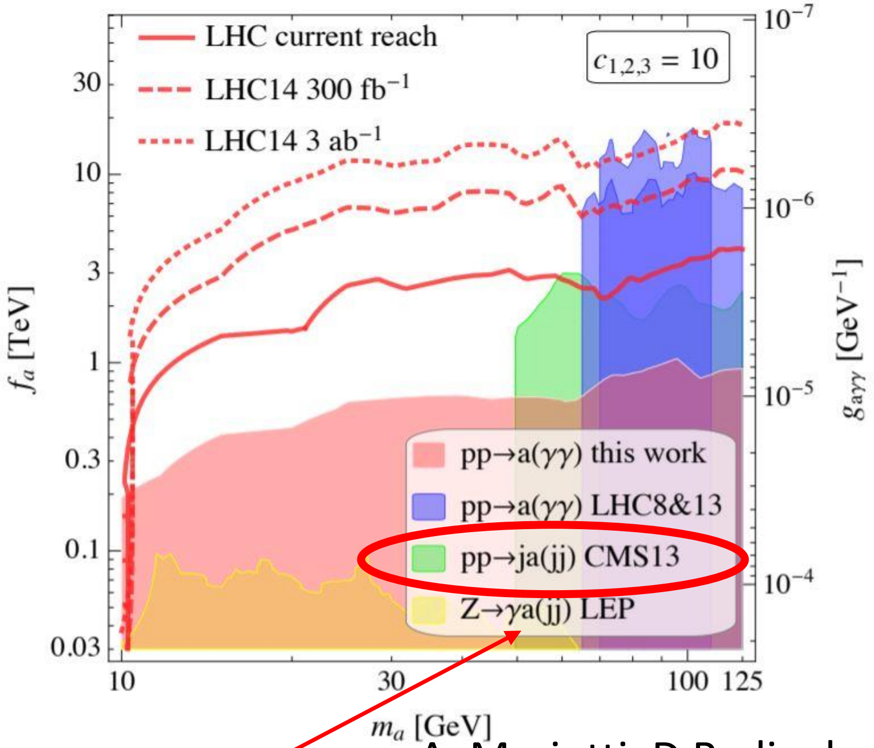
- **H. Fukuda, K. Harigaya, M. Ibe, T. T. Yanagida** arXiv: 1504.06084
- **P. Agrawal, K. Howe** arXiv: 1710.04213
- **P. Agrawal, G. Marques-Tavares, W. Xue** arXiv: 1708.05008
- **M.K. Gaillard, M.B. Gavela, R. Houtz, P. Quilez, R. del Rey** arXiv: 1805.06465
- **T. Gherghetta, V. V. Khoze, A. Pomarol,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

Existing Experimental Search



S. Gori, G. Perez,
K. Tobioka
arXiv: 2005.05170

Gap at few× 100 MeV to 50 GeV



Starts at 50 GeV

A. Mariotti, D.Redigolo,
F. Sala, K. Tobioka
arXiv: 1710.01743

B meson decay

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

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

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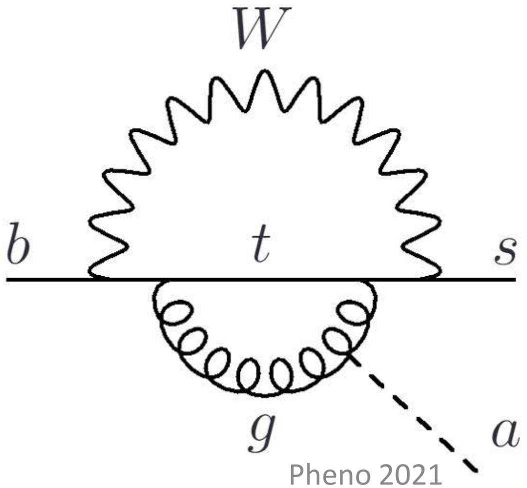
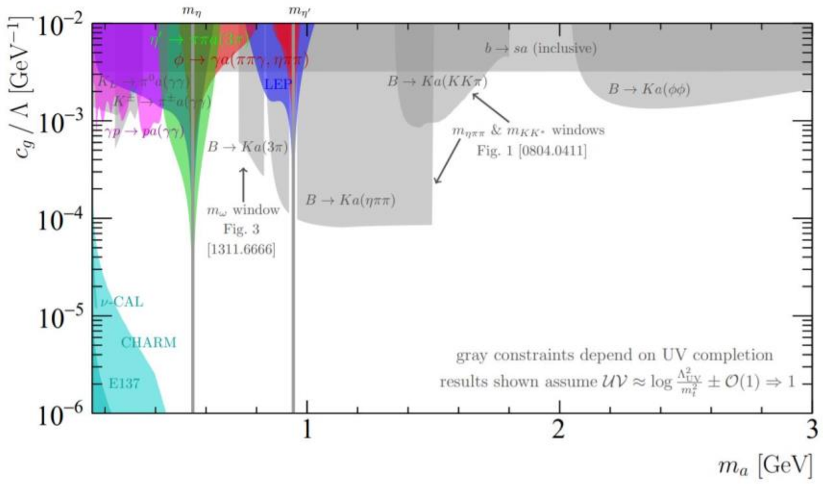
Leading order contribution to $B \to Ka$ comes at two loop level



B meson decay

Previous search relies on order of magnitude estimation of the amplitude!



Daniel Aloni, Yotam Soreq,
Mike Williams

arXiv:1811.03474

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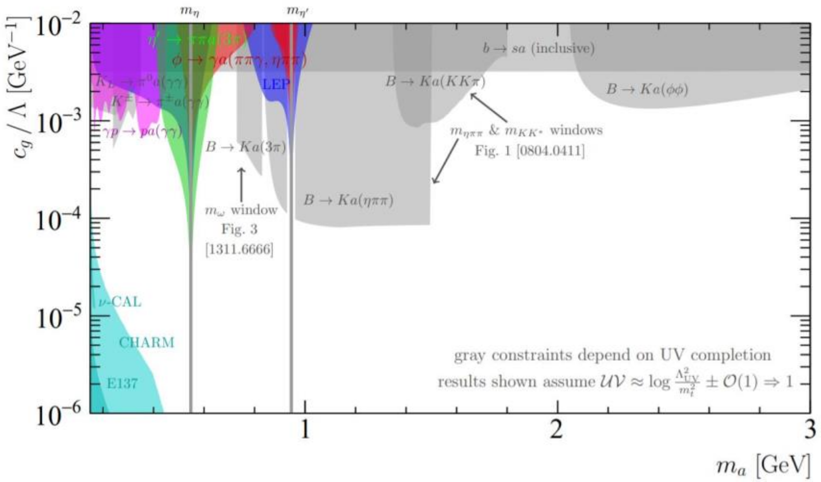

Daniel Aloni, Yotam Soreq, Mike Williams
arXiv:1811.03474

The two loop EFT calculations are needed for $B \to Ka$ process

EFT Framework

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{\boldsymbol{\alpha_s}}{\mathbf{8\pi}}\frac{\boldsymbol{a}}{\boldsymbol{f_a}}\ \boldsymbol{G^a_{\mu\nu}\widetilde{G}^{a\mu\nu}} + \frac{1}{2}\left(\partial_\mu a\right)^2 - \frac{m_a^2}{2}a^2$$

EFT Framework

dim. 5 – non-renormalizable

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The additional operators relevant for $\mathrm{b} \to sa$ phenomenology:

$$\mathcal{L} = \cdots + C_{qq}\sum_q \frac{\partial_\mu a}{f_a}\,\bar{q}\,\gamma^\mu\gamma_5\,q + C_{bs}\frac{\partial_\mu a}{f_a}\bar{s}_L\,\gamma^\mu\gamma_5\,b_L + h.c.$$

EFT Framework

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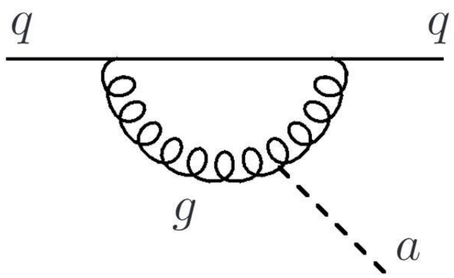
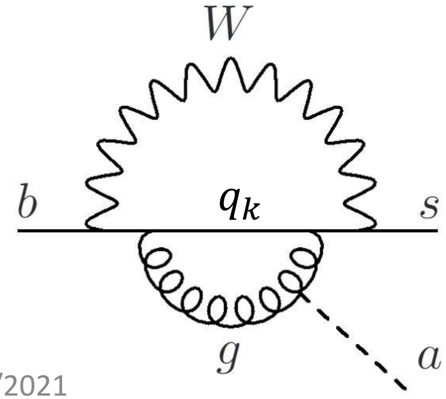


$$\Rightarrow \qquad \boldsymbol{C_{qq}(\Lambda_{UV}) = A\, C_F \left(\frac{\alpha_s}{4\pi}\right)^2}$$



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

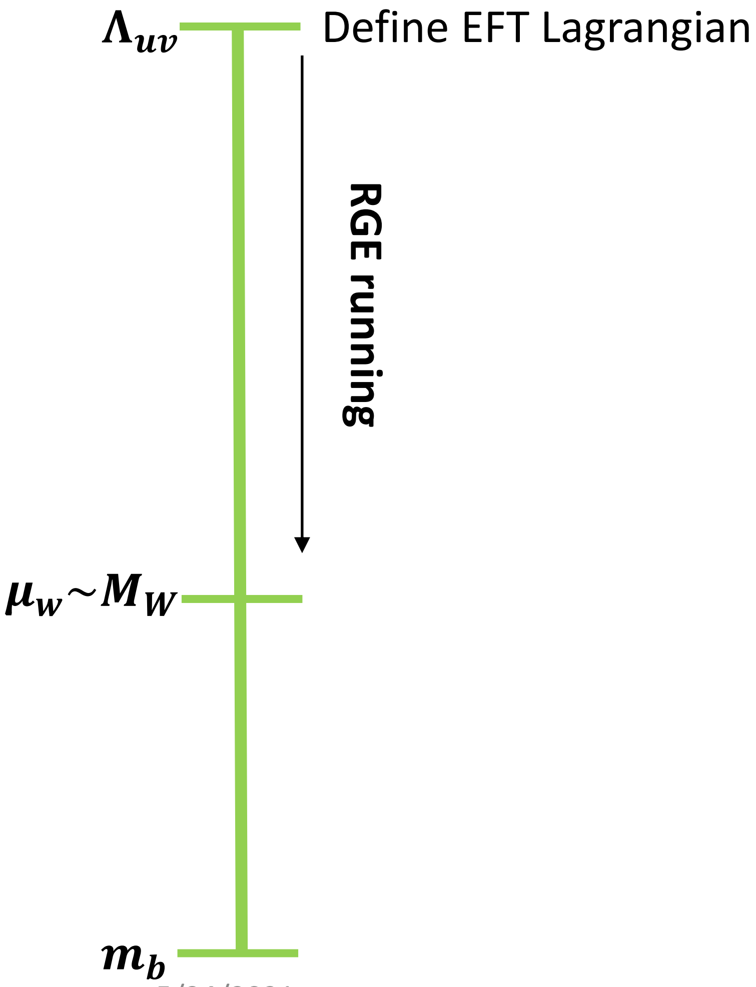
RGE running

Λ_{uv} Define EFT Lagrangian

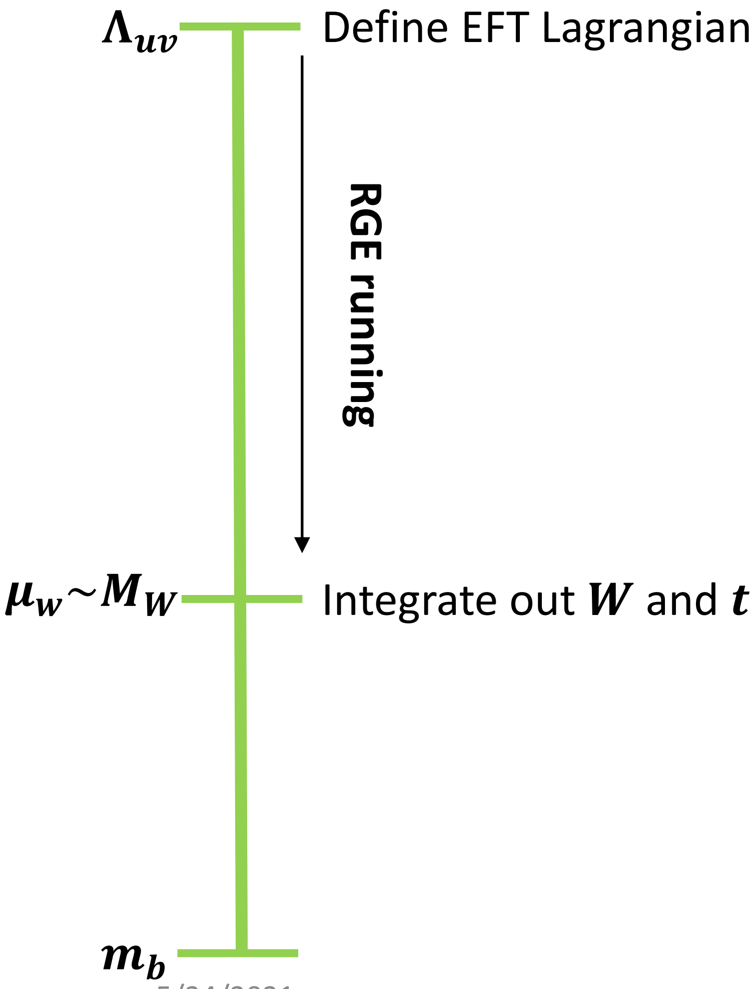
$\mu_w \sim M_W$

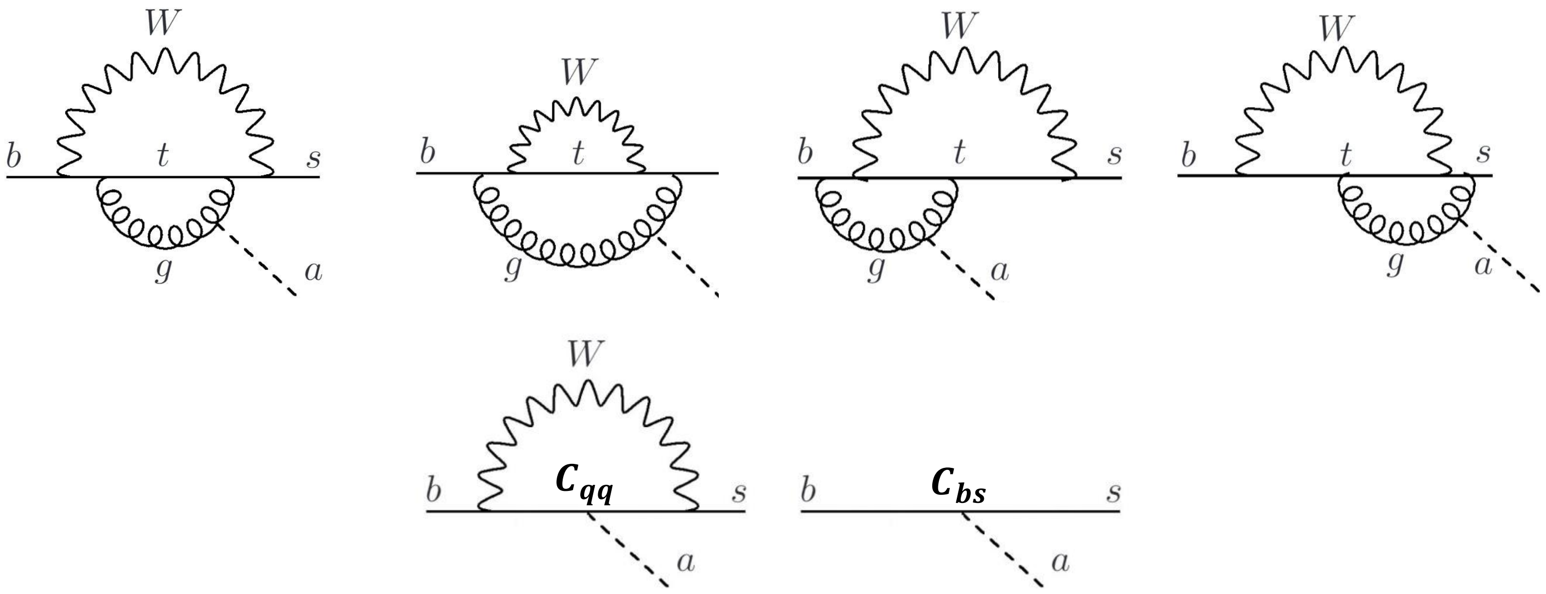
m_b

RGE running



RGE running

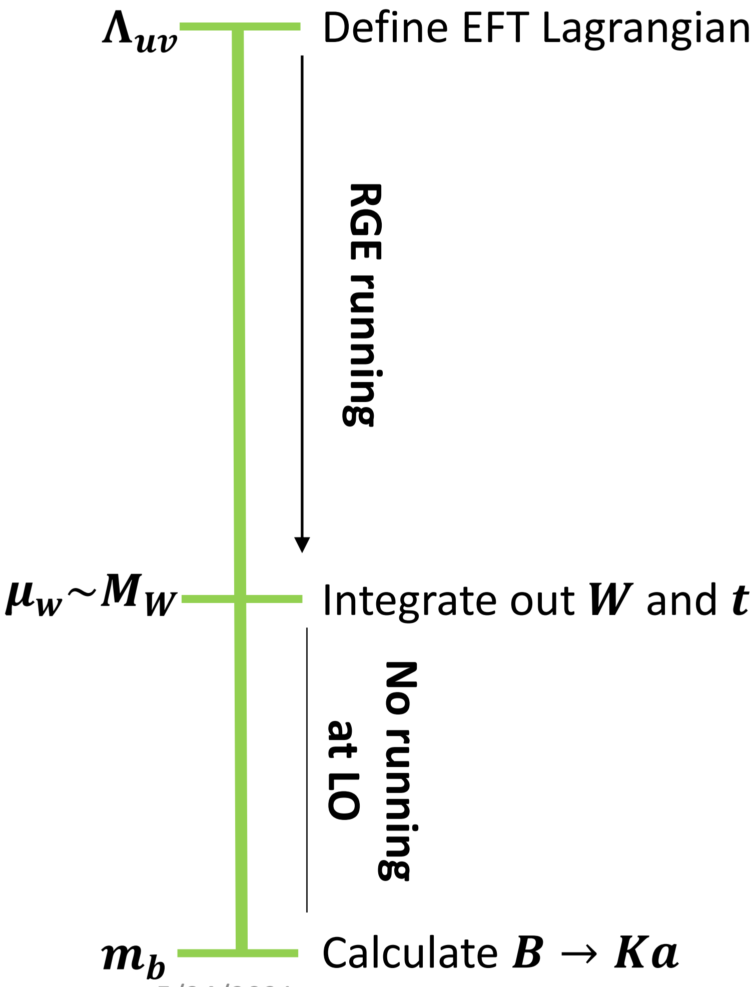


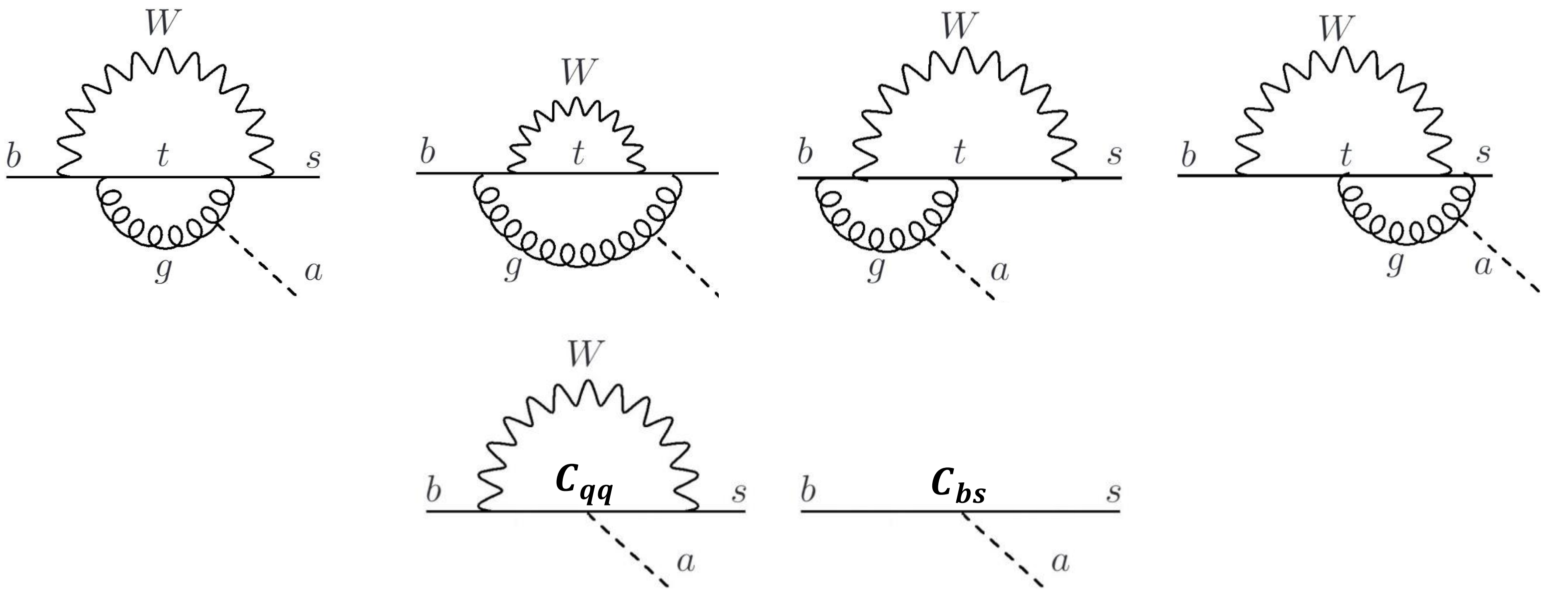


$$\mathcal{L}_{bsa} = C_W \frac{\partial_\mu a}{f_a} \, \bar{s}_L \, \gamma^\mu \gamma_5 \, b_L + h.c.$$

$$C_W = C_{bs}(\mu_w) + \frac{\alpha_w}{4\pi} \, C_{qq}(\mu_w) \, g(\mu_w) + \frac{1}{2}\frac{\alpha_w}{4\pi}\left(\frac{\alpha_s}{4\pi}\right)^2 f(\mu_w)$$

RGE running





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$\boldsymbol{B \to Ka}$ rate

Using Light-Cone QCD Sum Rules:

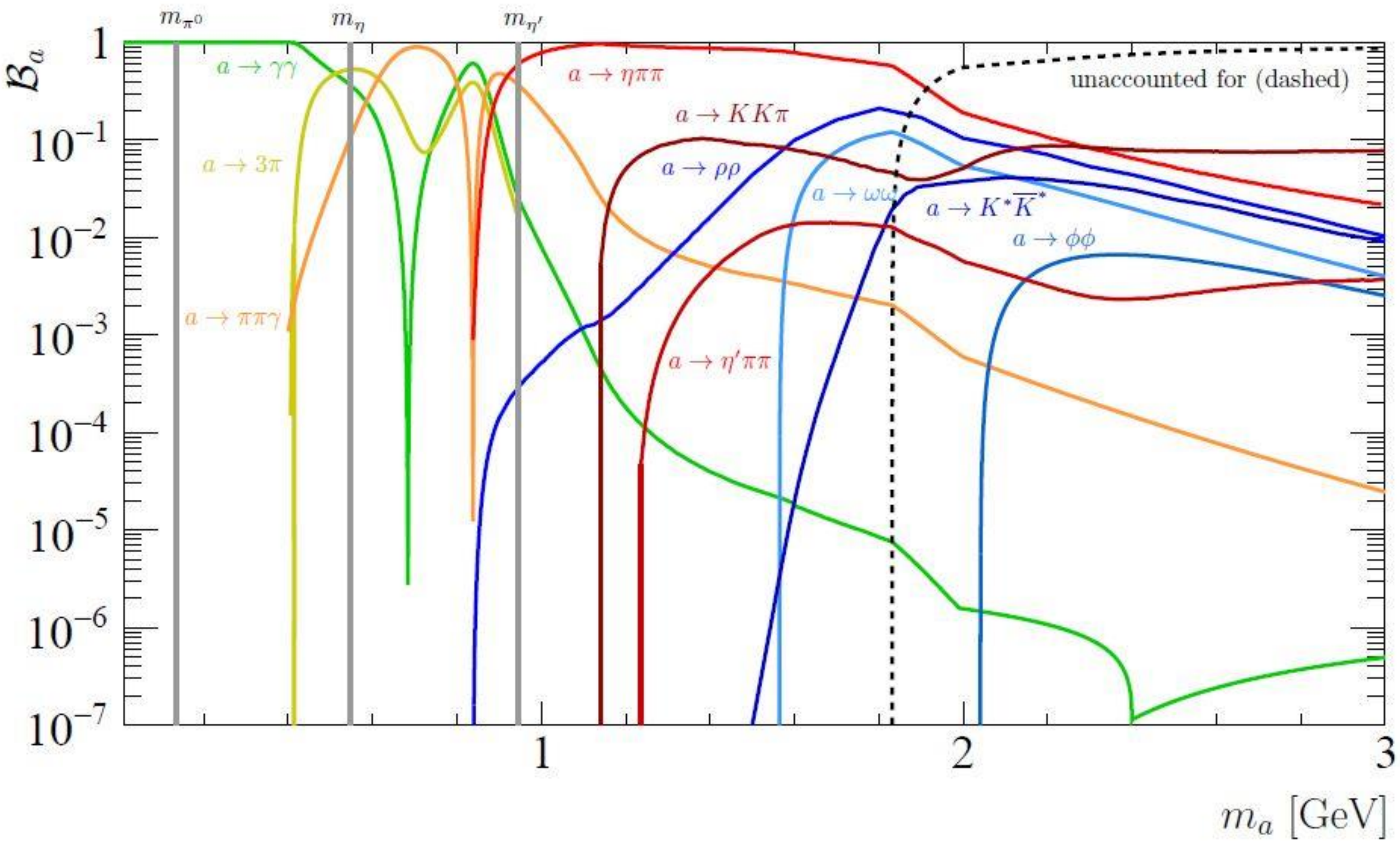
$$\Gamma_{B\to Ka} = |\boldsymbol{C_W}|^2 \frac{m_B^3}{64\pi f_a^2}\left(1 - \frac{m_K^2}{m_B^2}\right)^2 \lambda_{Ka}[\,f_0(m_a^2)]^2$$

$$\lambda_{Ka} = \left[\left(1 - \frac{(m_K + m_a)^2}{m_B^2}\right)\left(1 - \frac{(m_K - m_a)^2}{m_B^2}\right)\right]^{\frac{1}{2}} \qquad f_0(m_a^2) = \frac{0.330}{1 - \frac{m_a^2}{37.5\ GeV^2}}$$

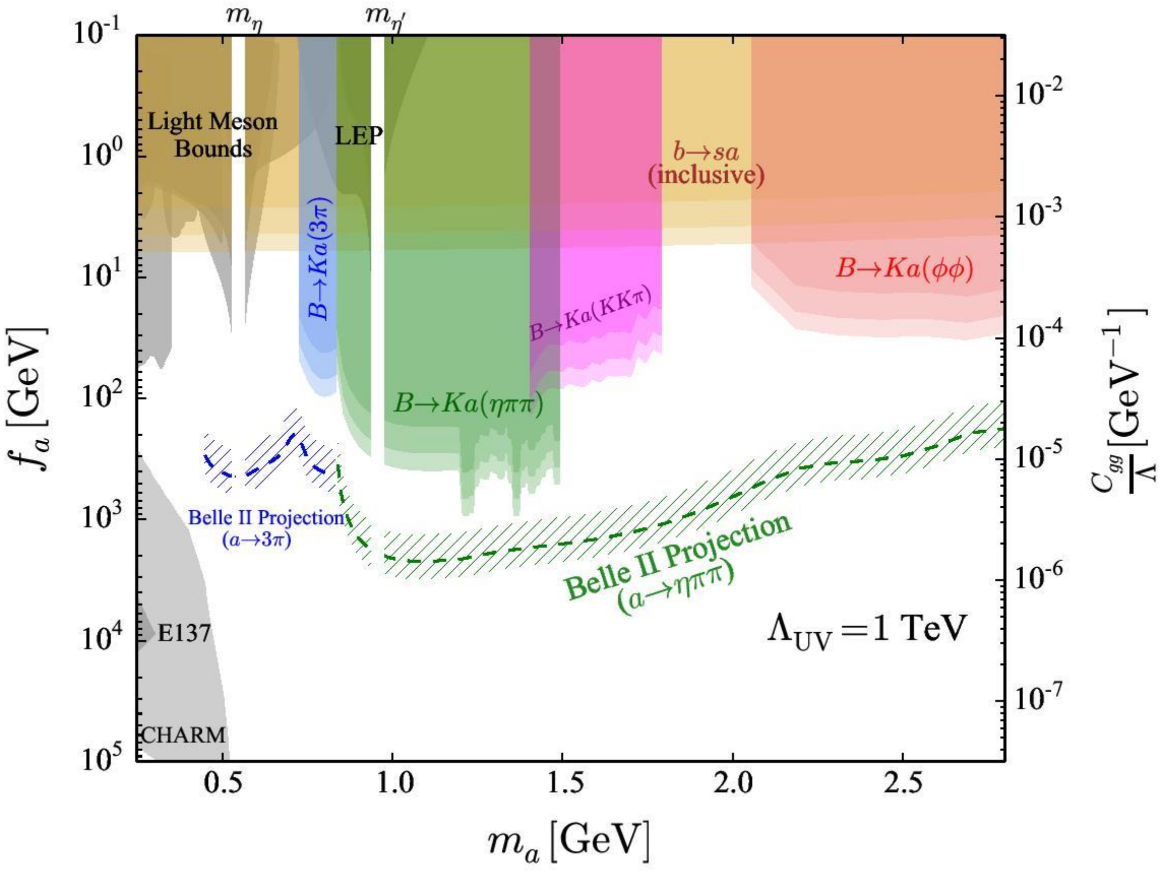
arXiv: hep-ph/0412079, hep-ph/0406232, 0911.4938 ,1611.09355

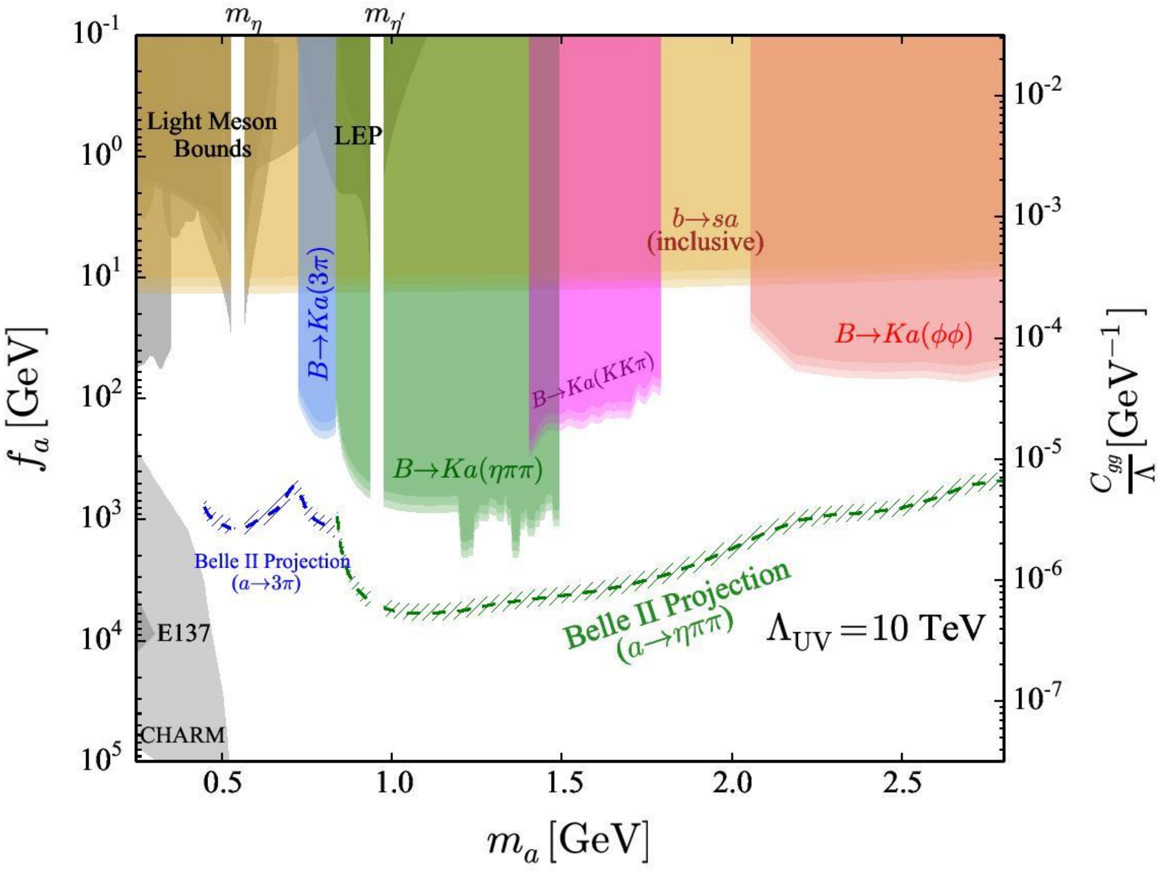
Axion decay

Data driven approach: Daniel Aloni, Yotam Soreq, Mike Williams arXiv:1811.03474

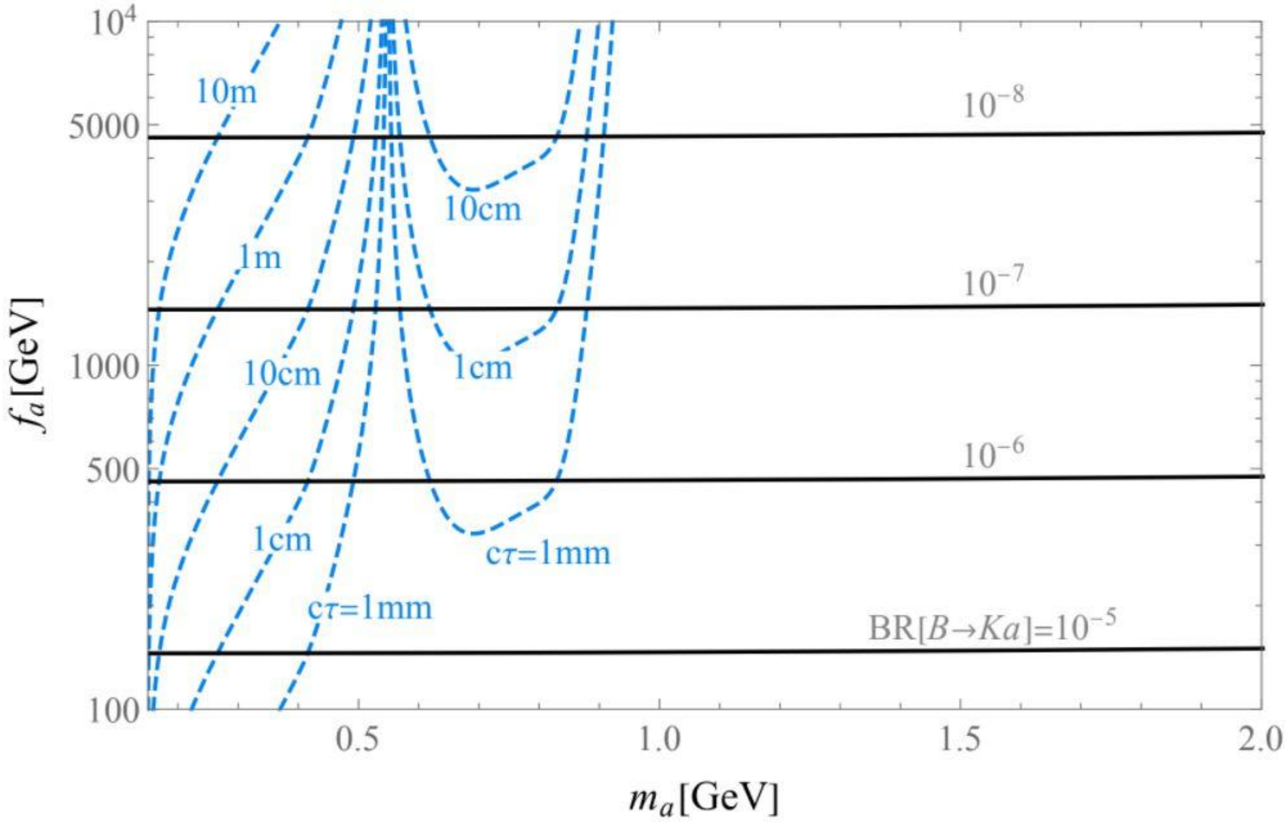


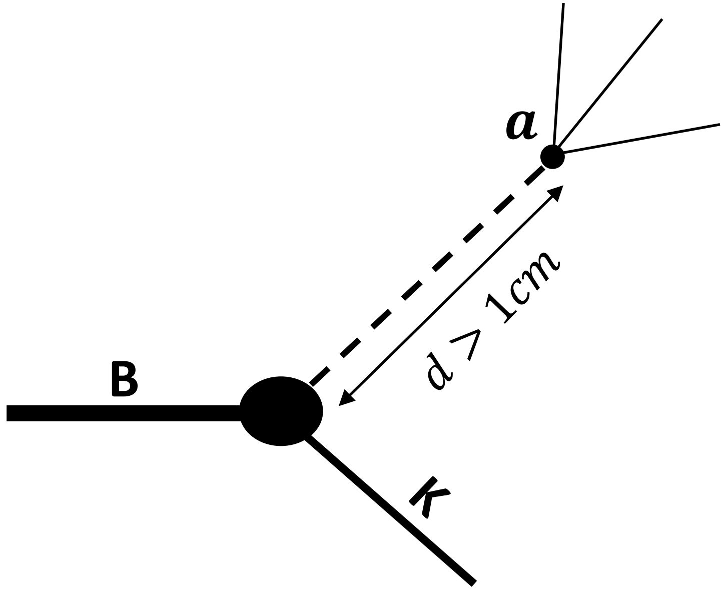
Bounds and Projections





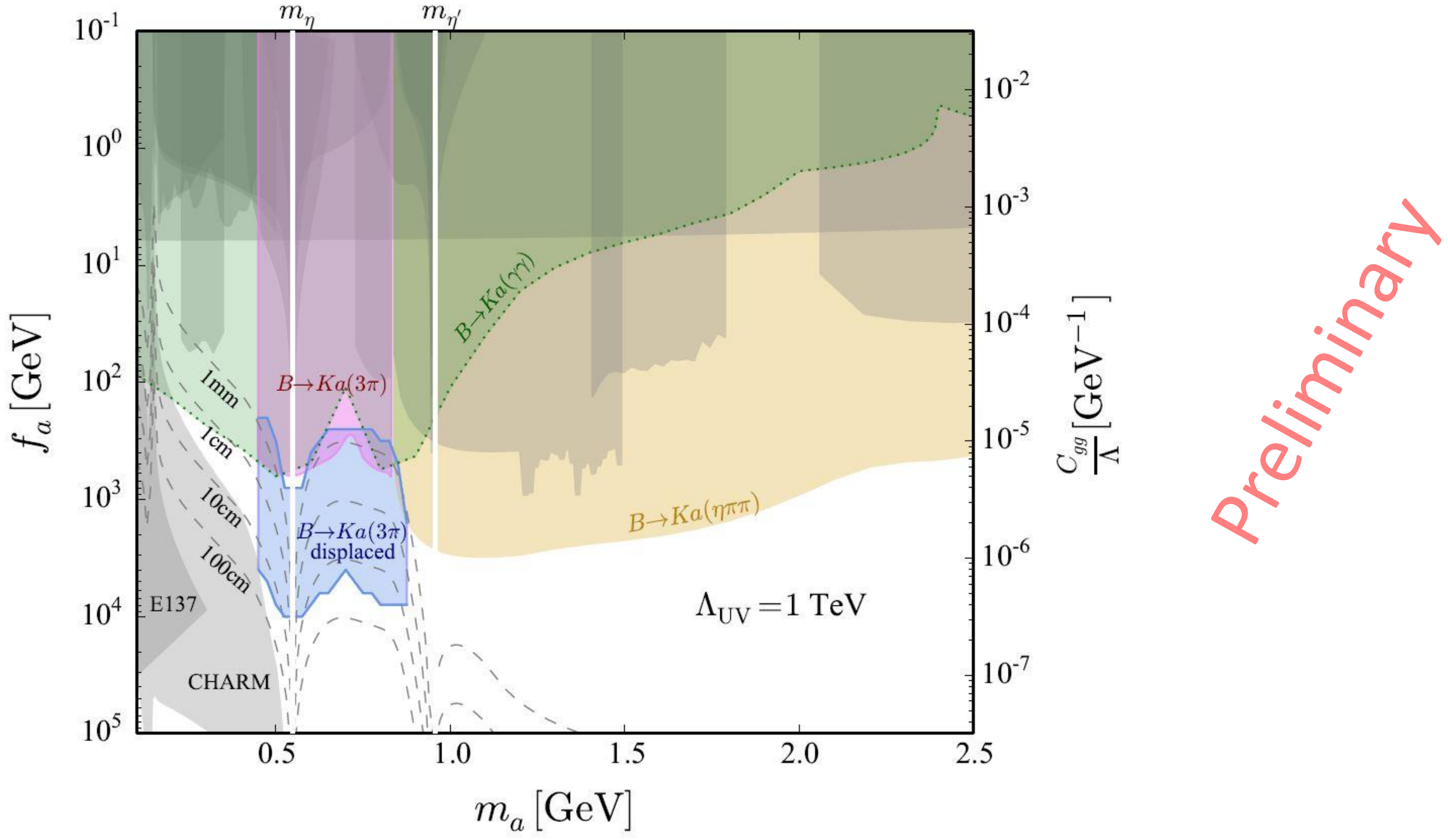
$a \to 3\pi$ displaced vertex





arXiv:XXXX.XXXXX E. Bertholet, S. Chakraborty, **V. Loladze**, T. Okui, A. Soffer, K. Tobioka

$a \to 3\pi$ displaced vertex and $a \to \gamma\gamma$



arXiv:XXXX.XXXXX E. Bertholet, S. Chakraborty, **V. Loladze**, T. Okui, A. Soffer, K. Tobioka

Thank you!