Dark scalars and ALPs at Belle II

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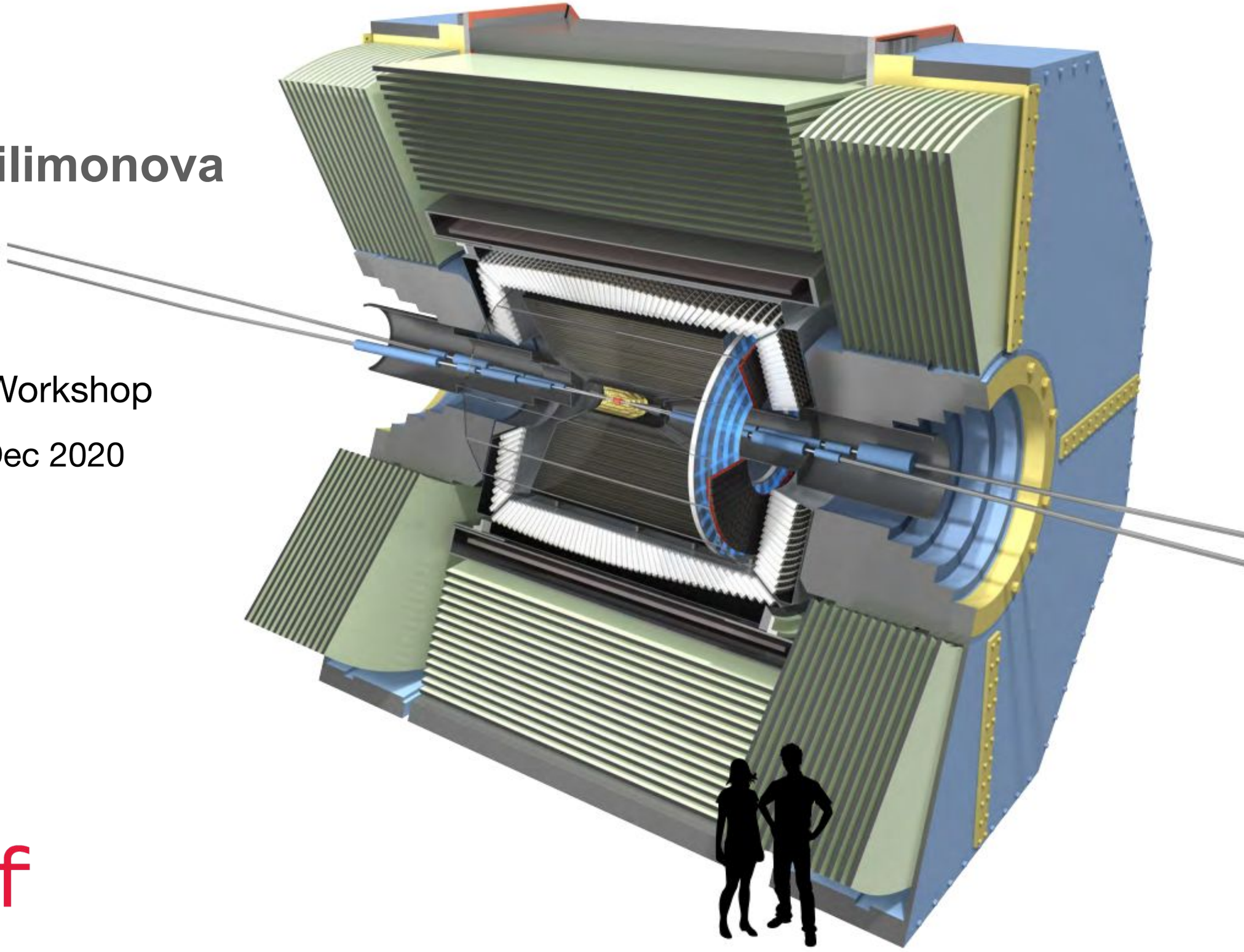
FSP Workshop

11 Dec 2020



Nikhef

Dark (pseudo)scalars

Scalar portal

$$-(\mu\phi + \lambda\phi^2)|H|^2$$

Axion portal

$$e^2 C_{\gamma\gamma}\frac{a}{\Lambda}F\tilde{F} + \frac{\partial_\mu a}{\Lambda}\sum_\alpha \bar{\psi}_\alpha\gamma_\mu\gamma_5\psi$$

Motivation: see talk by Kai/Camilo

Light scalars @ Belle II

$$\mathcal{L} = -\tfrac{1}{2}m_\phi^2\phi^2 - \mu|H|^2\phi - y_\chi\bar{\chi}\chi\phi - \tfrac{1}{2}m_\chi\bar{\chi}\chi$$

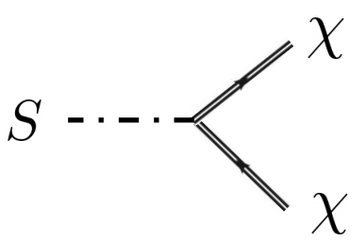
Can play role of DM candidate

Search regions

$$\Gamma_S = c_\theta^2\,\Gamma_{\chi\bar{\chi}} + s_\theta^2\,\Gamma_{\mathrm{SM}}$$

$m_S > 2m_\chi$

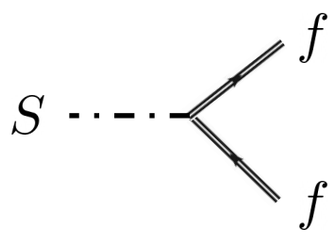
Invisible decays dominate



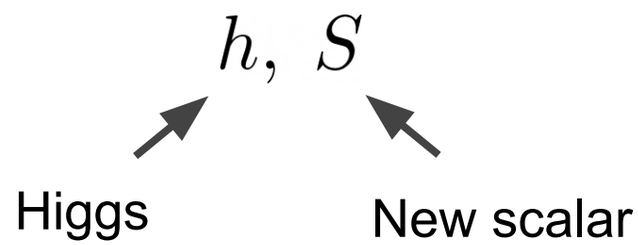
Missing energy

$m_S < 2m_\chi$

Visible decays only



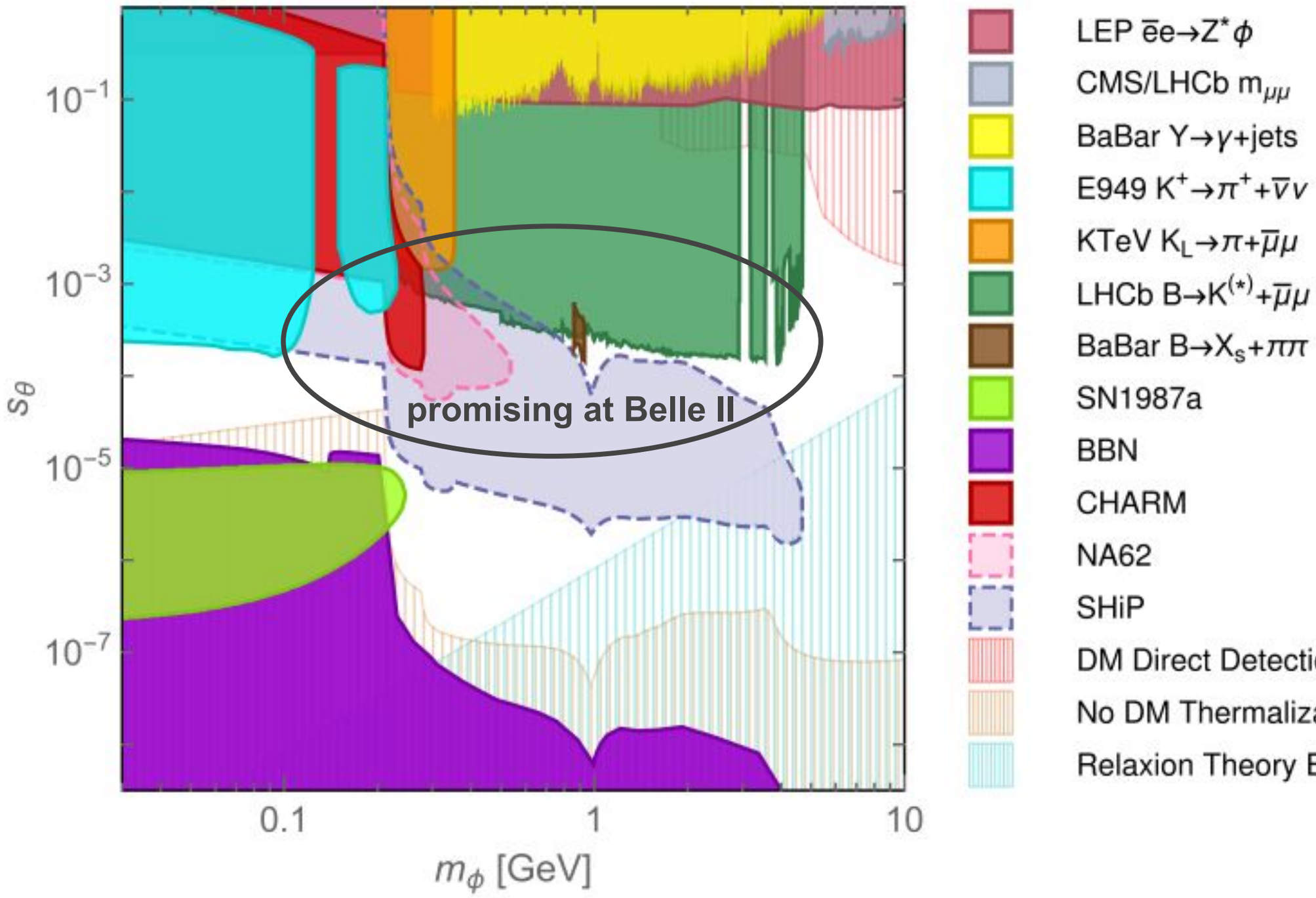
Displaced searches



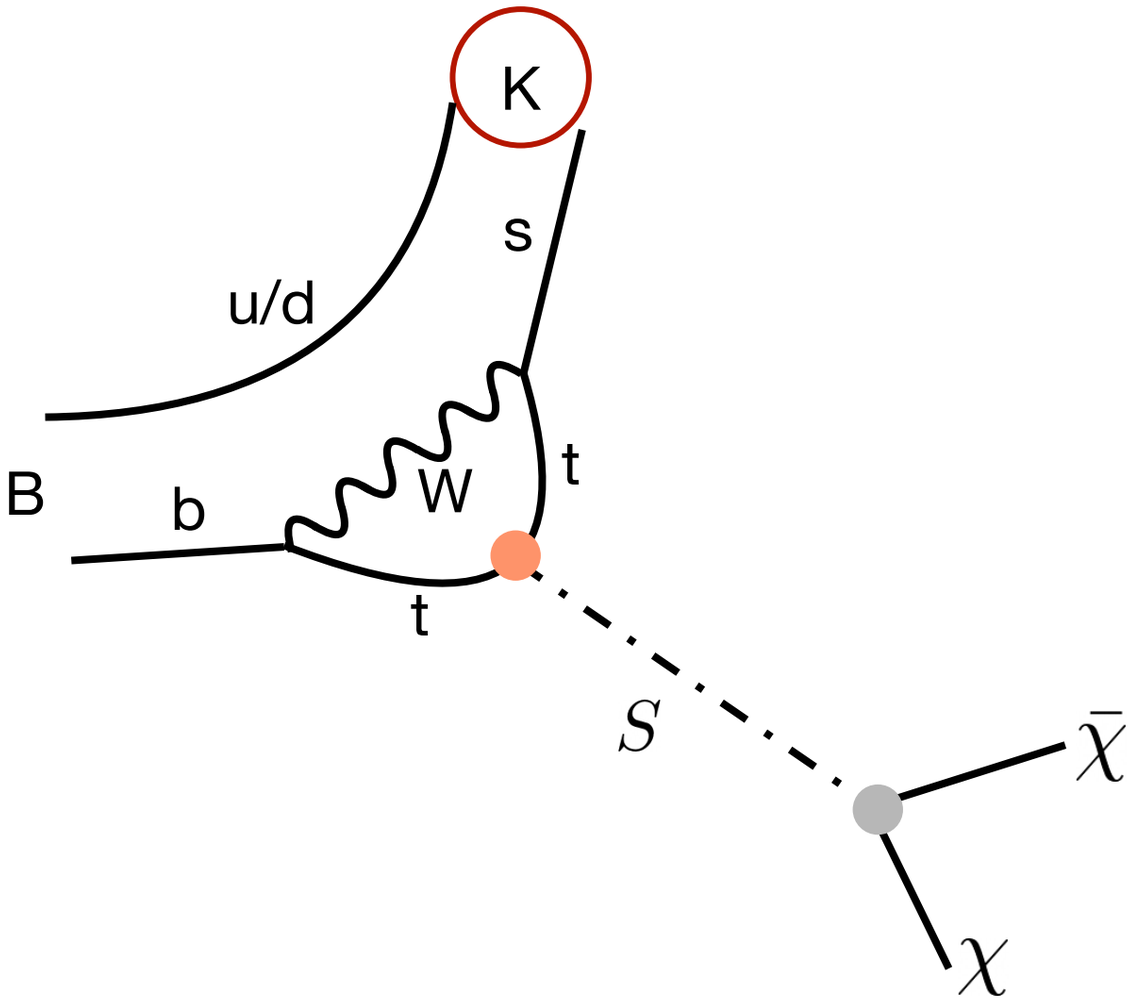
One new coupling

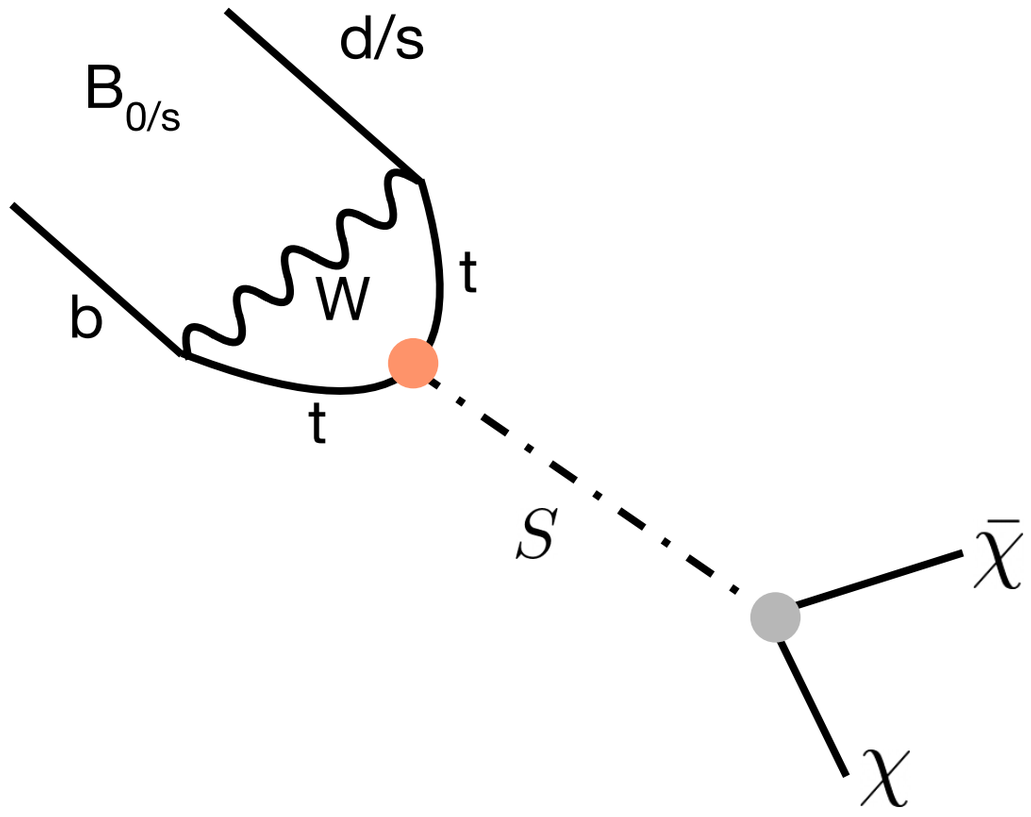
M. Winkler [1809.01876]

Bounds from other experiments



Missing energy signatures

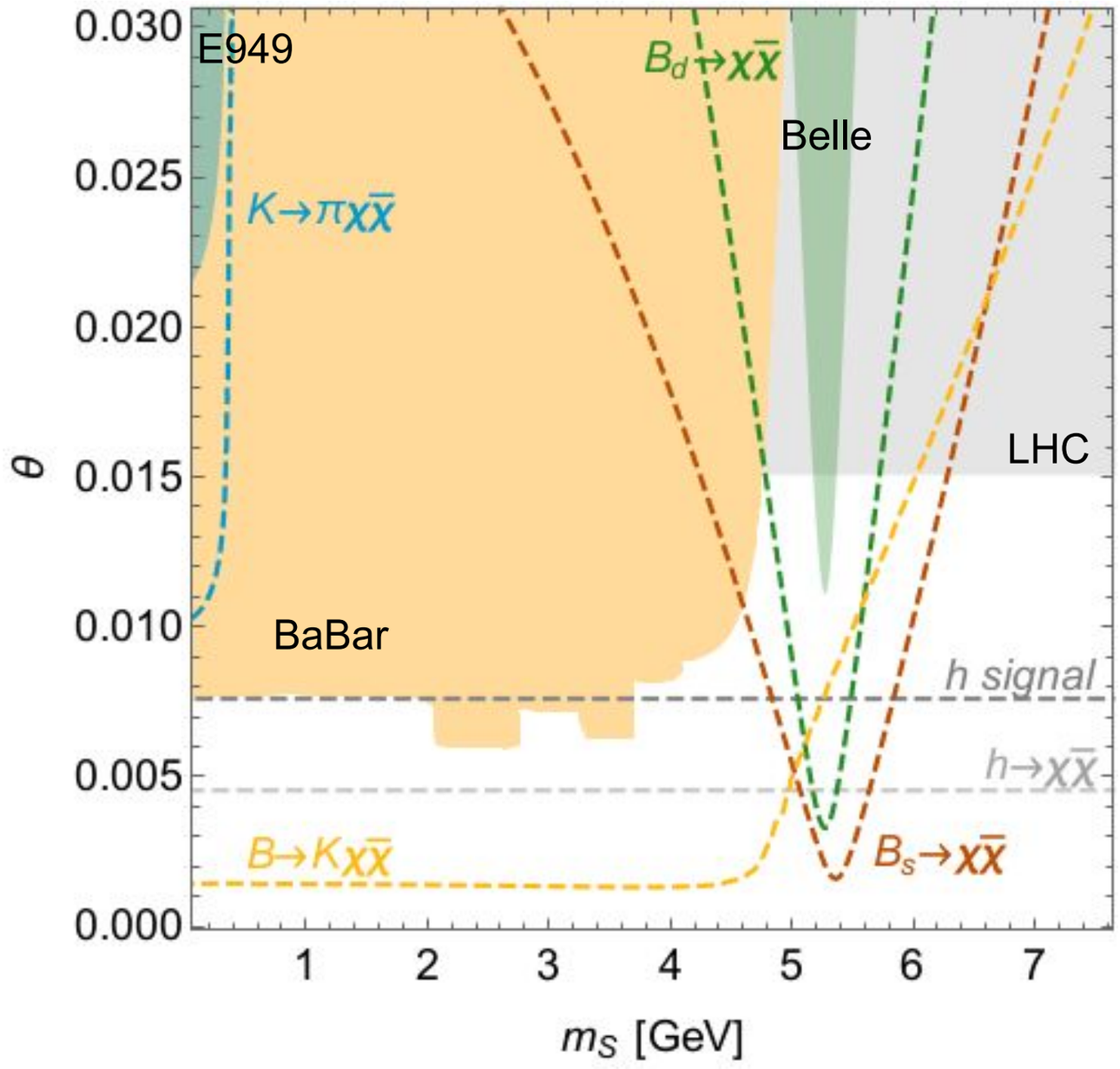




- $\frac{m_t}{v} s_\theta$

AF, R. Schäfer, S. Westhoff [1911.03490]

Missing energy @ Belle II

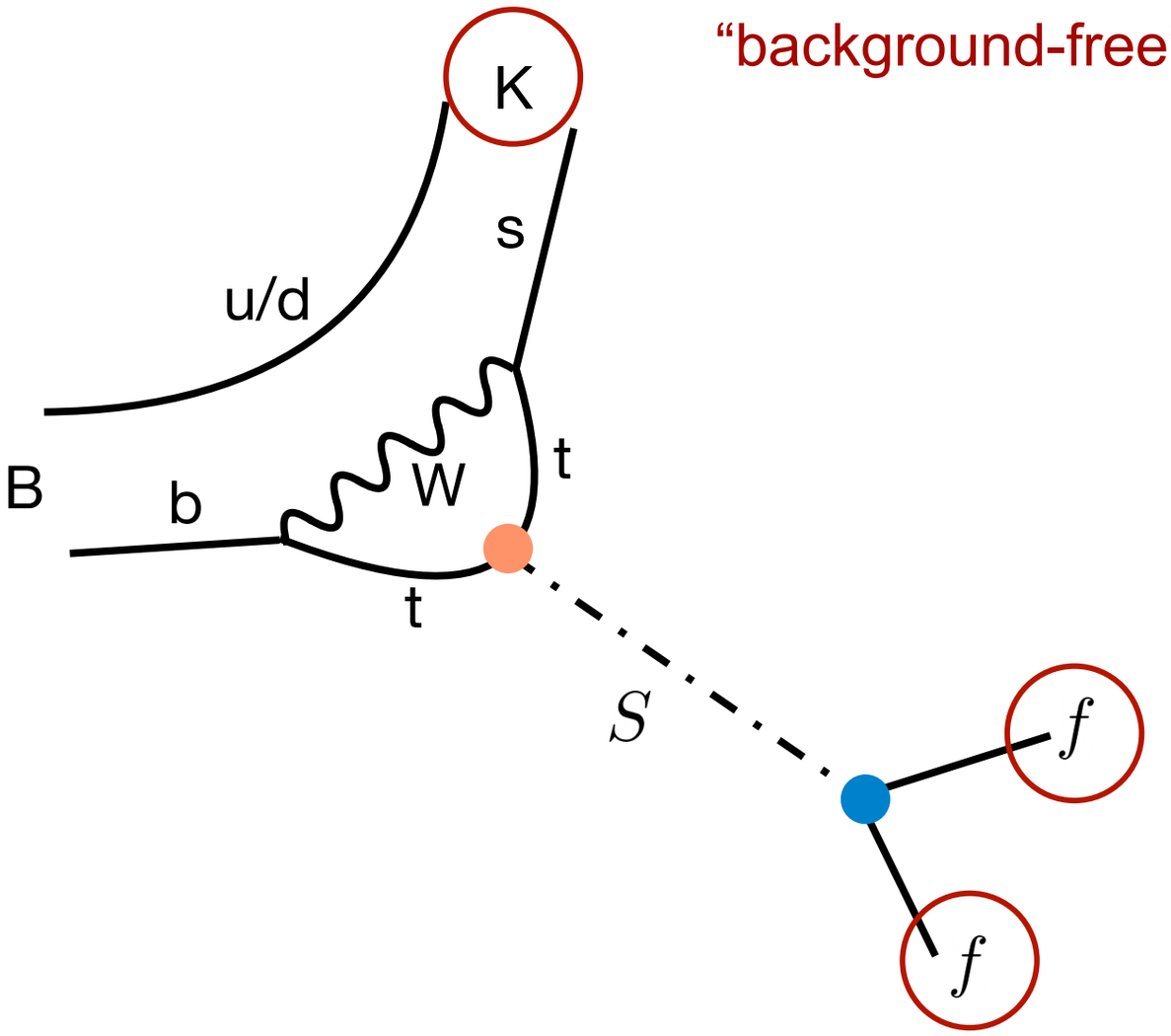


Belle II projections:

Can exclude mixings down to 10^{-3}

AF, R. Schäfer, S. Westhoff [1911.03490]

Displaced semi-leptonic decays



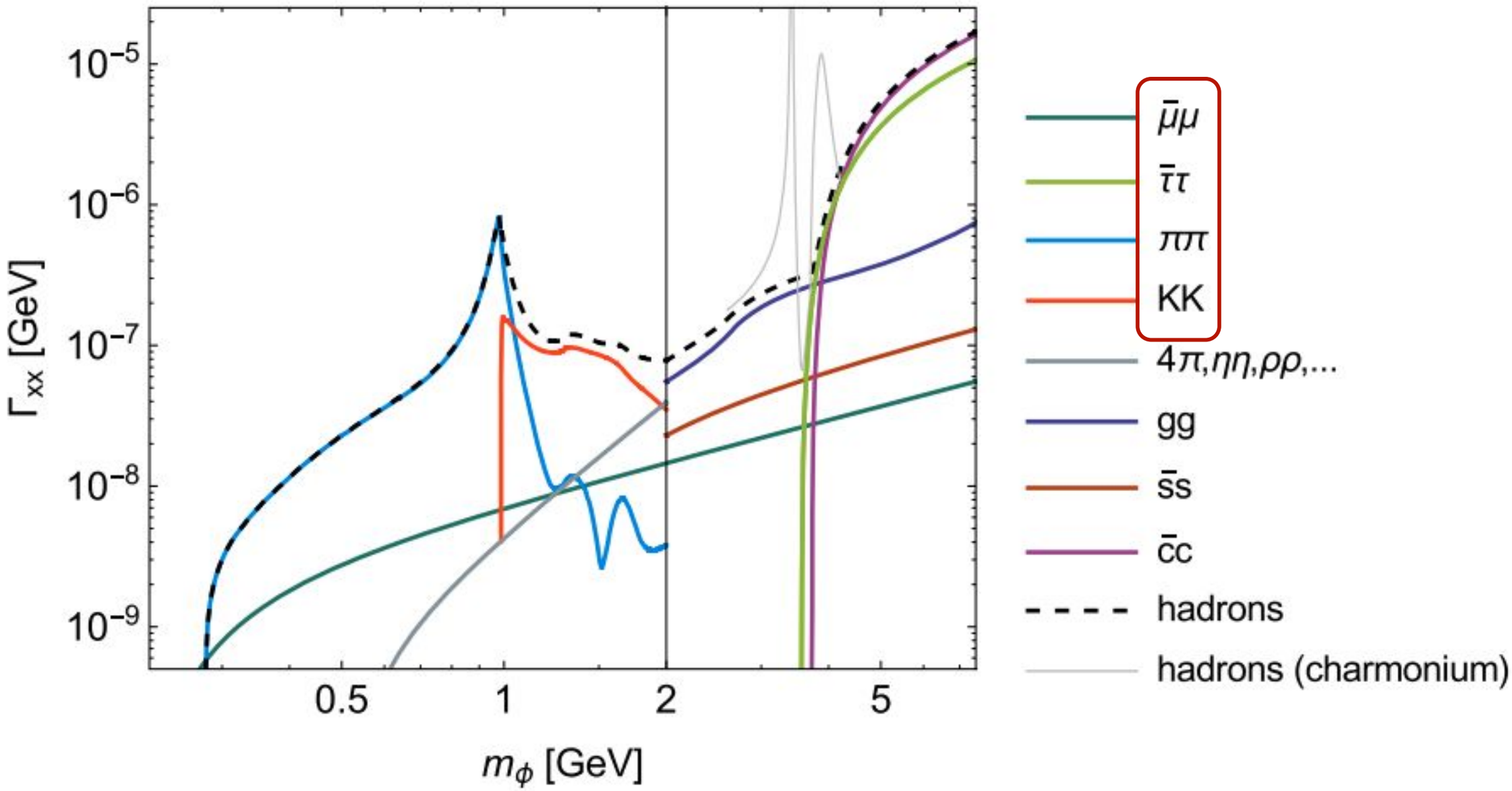
"background-free"

- $\frac{m_t}{v} s_\theta$
- $\frac{m_f}{v} s_\theta$

Displaced decays for decent rate due to mass hierarchy

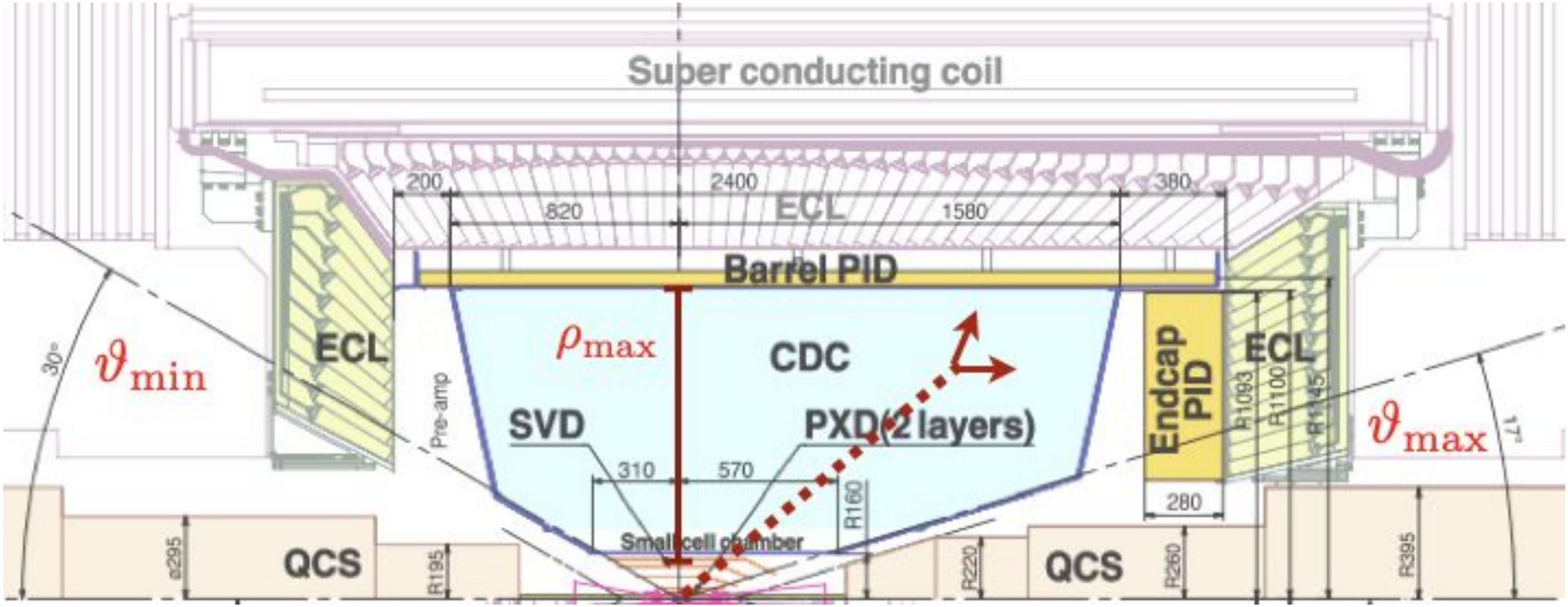
M. Winkler [1809.01876]

Decay modes



AF, R. Schäfer, S. Westhoff [1911.03490]

Displaced signatures @ Belle II



$$N_{f\bar{f}} = N_{B\bar{B}} \times 1.93\,\mathcal{B}(B \to KS)\mathcal{B}(S \to \mu\bar{\mu})$$
$$\times \int_{r_{\min}}^{r_{\max}} \frac{r^2 dr}{2d_S^3} \int_{\vartheta_{\min}}^{\vartheta_{\max}} \frac{d\vartheta}{2\sin^2\vartheta} e^{-\frac{r/\sin\vartheta}{d_S}}$$

AF, R. Schäfer, S. Westhoff [1911.03490]

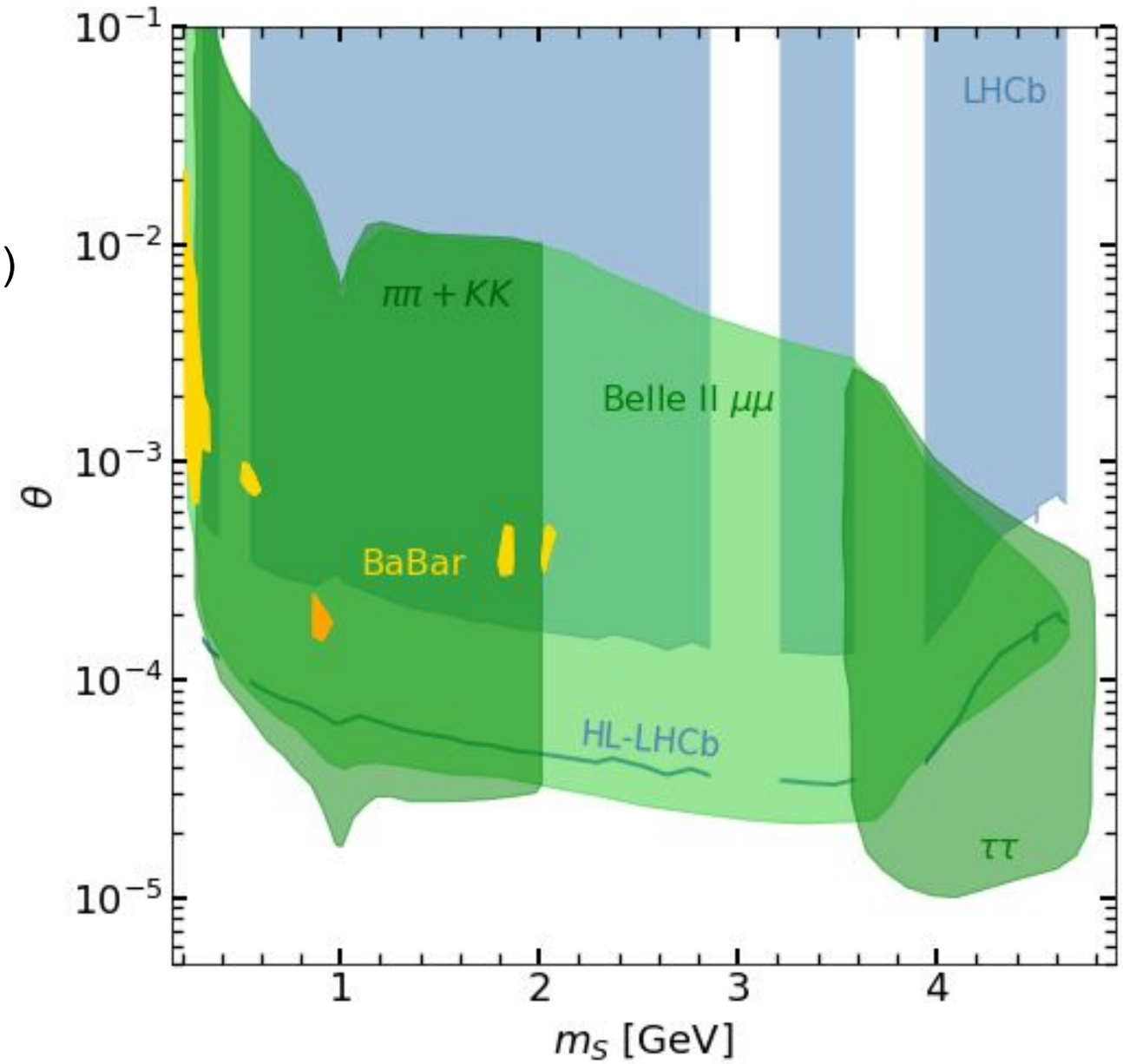
B-factories: comparison

LHCb

decays within 60 cm

Large boost

(particles decay outside)



Belle II

decays within ~113 cm

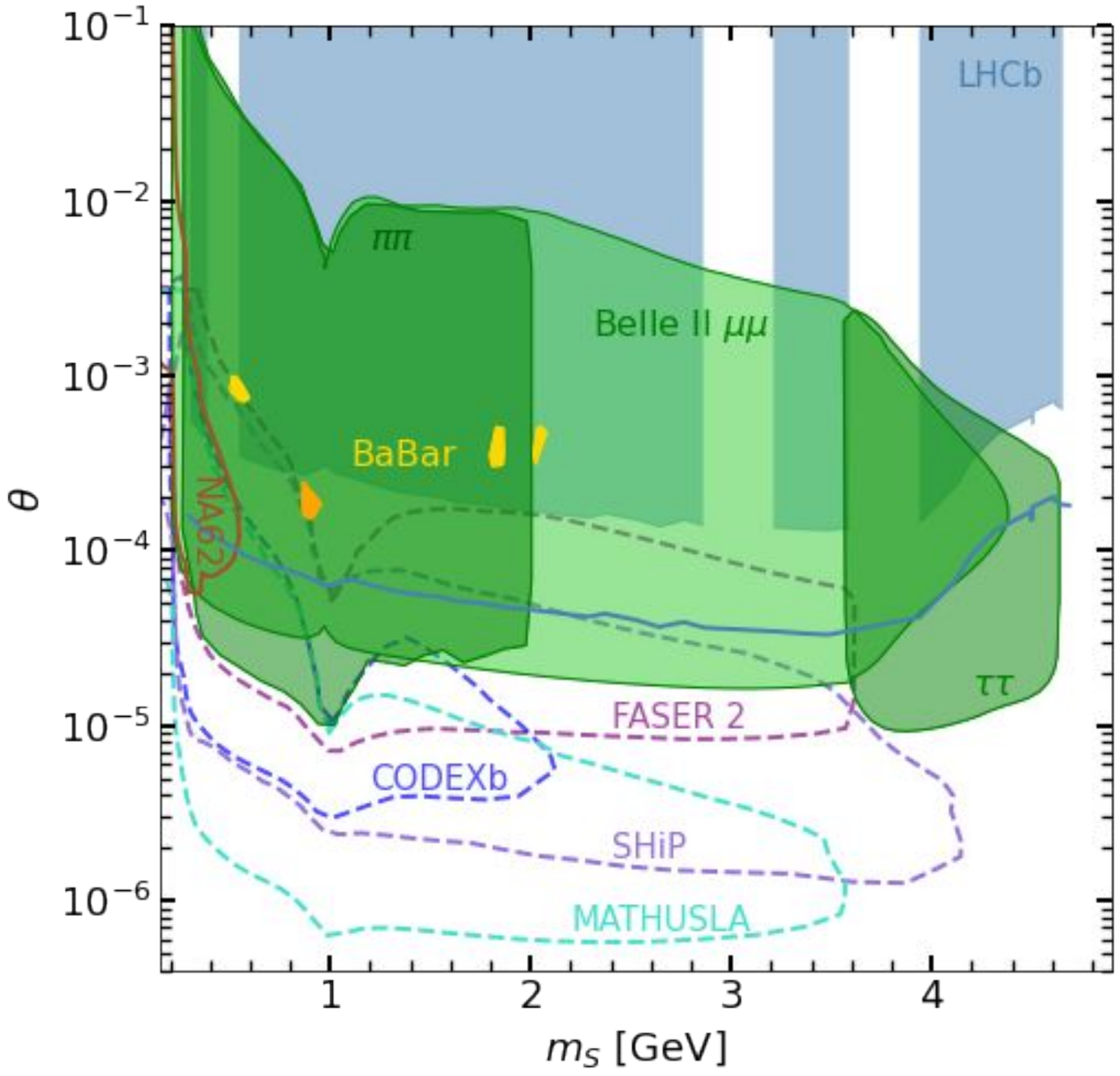
B-s almost at rest

(larger lifetimes probed)

Can exclude mixings down to 10^{-5}

AF, R. Schäfer, S. Westhoff [1911.03490]

Belle II and fixed-target experiments



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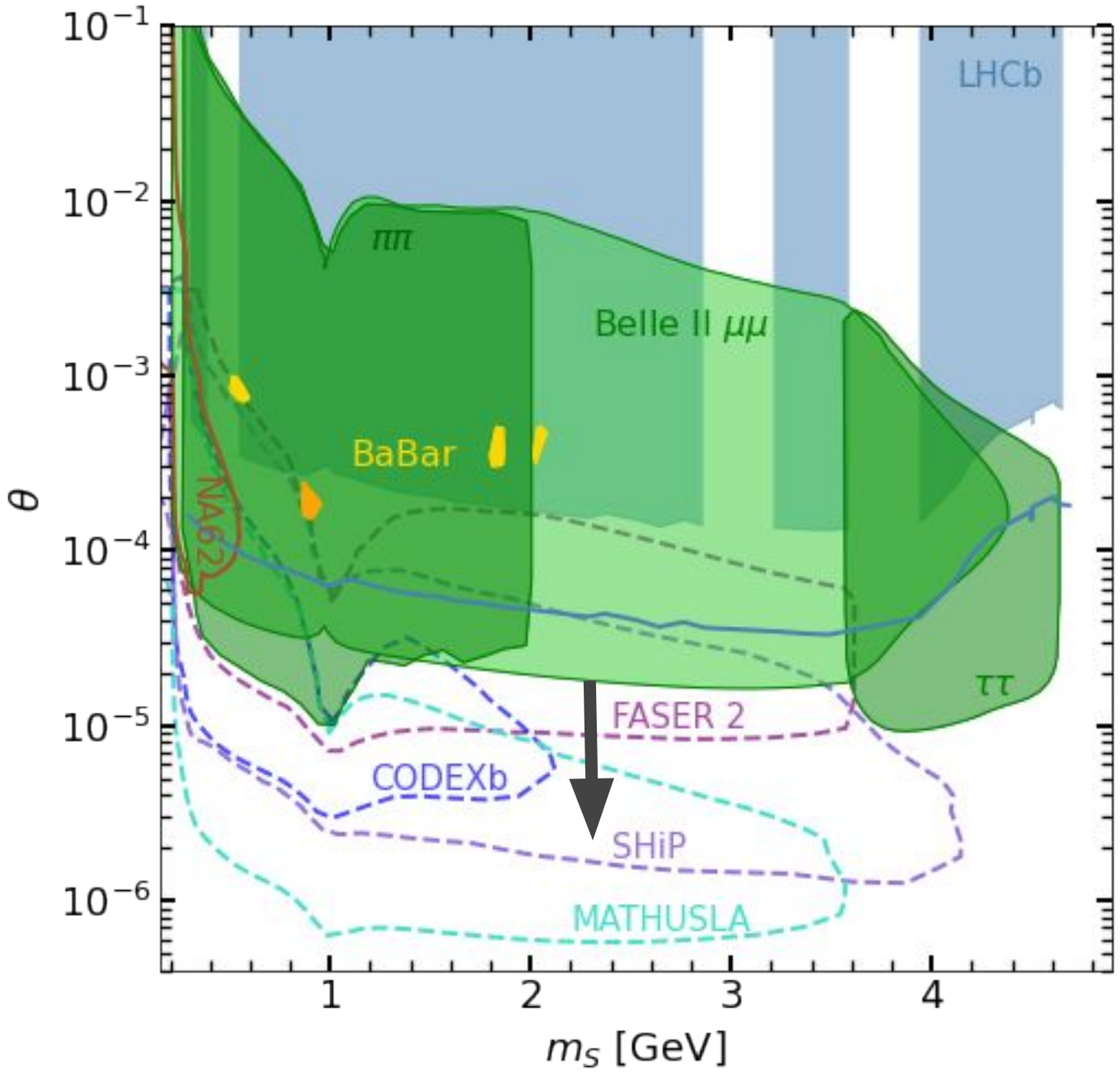


GAZELLE?

(see talks by Torben & Michele)

ALPs @ Belle II

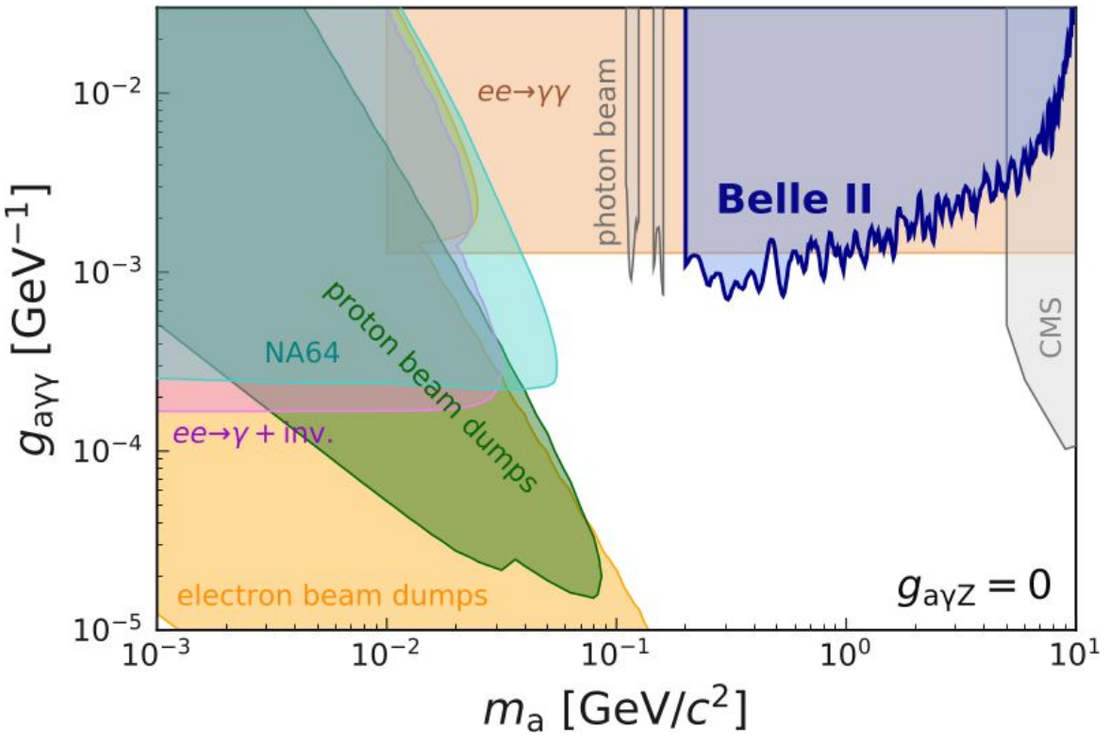
$$\mathcal{L}_{\text{eff}}^{D\leq 5} \supset \partial^\mu a \sum_F \bar{\psi}_F \frac{\hat{C}_{FF}}{\Lambda} \gamma_\mu \psi_F + g_s^2 \frac{C_{GG}}{\Lambda} a\, G^A_{\mu\nu} \tilde{G}^{\mu\nu,A} + e^2 \frac{C_{\gamma\gamma}}{\Lambda} a\, F_{\mu\nu} \tilde{F}^{\mu\nu}$$
$$+ \frac{2e^2}{s_w c_w} \frac{C_{\gamma Z}}{\Lambda} a F_{\mu\nu} \tilde{Z}_{\mu\nu} + \frac{e^2}{s_w^2 c_w^2} \frac{C_{ZZ}}{\Lambda} a Z_{\mu\nu} \tilde{Z}_{\mu\nu}$$

Production and decay might be completely independent

ALP-photon coupling

$$\mathcal{L} \supset -\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}_{\mu\nu}$$

Recent Belle II search



$\mathcal{L}$ = 455 pb^{-1}

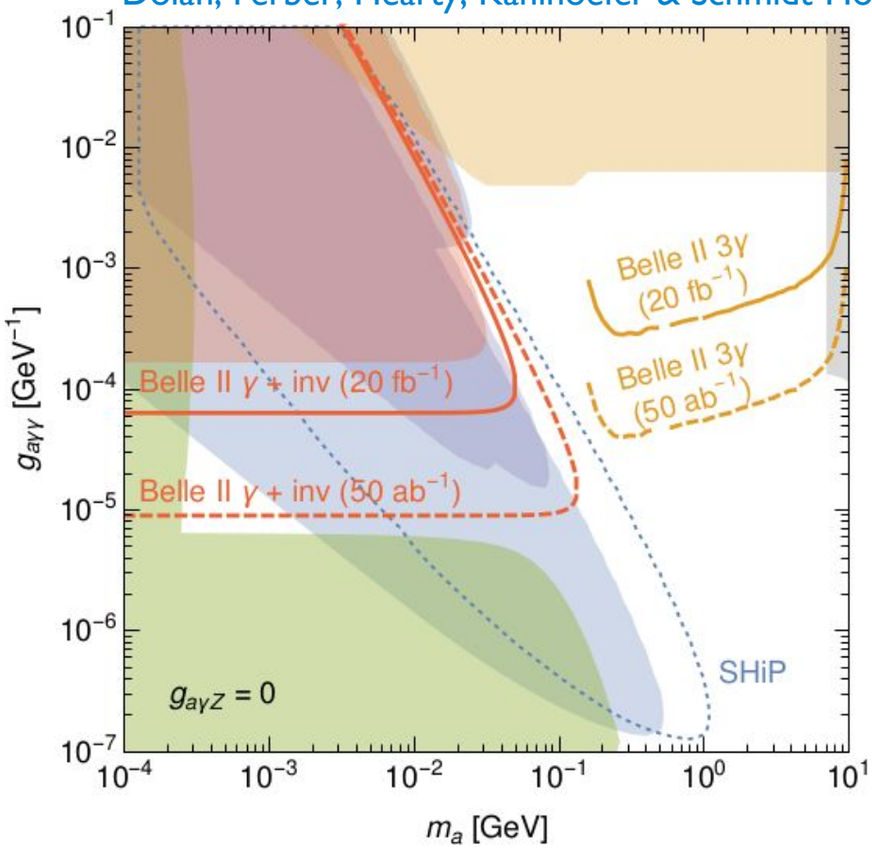
$e^+ e^- \to \gamma a$, $a \to \gamma\gamma$

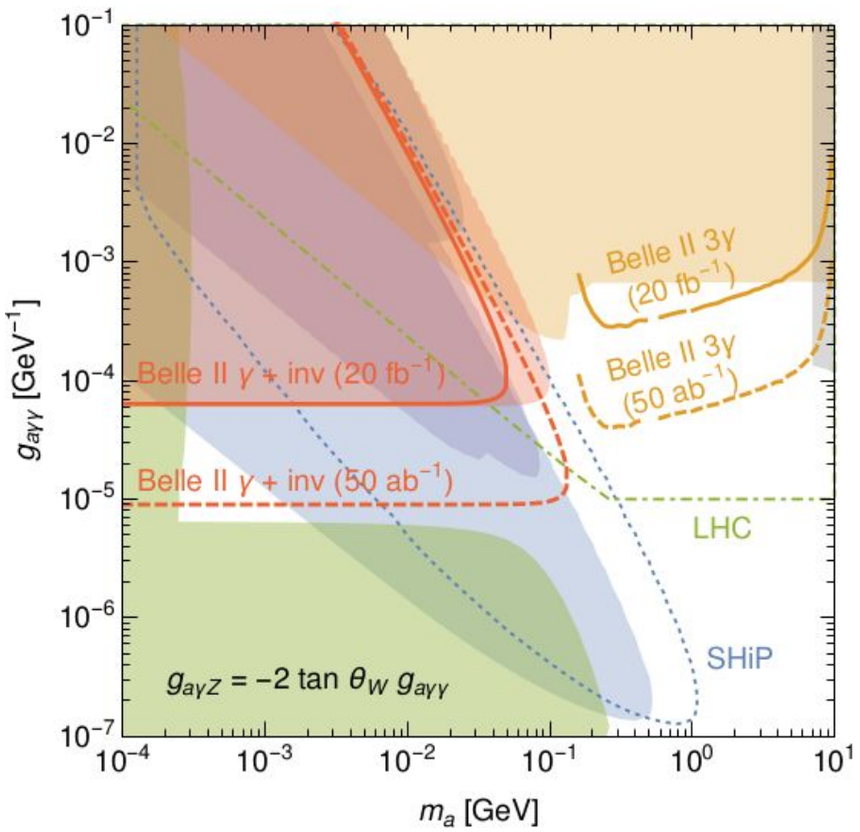
Already exceeds LEP constraints

Belle II Collaboration [2007.13071]

Predicted reach of Belle II

Dolan, Ferber, Hearty, Kahlhoefer & Schmidt-Hoberg [1709.00009]





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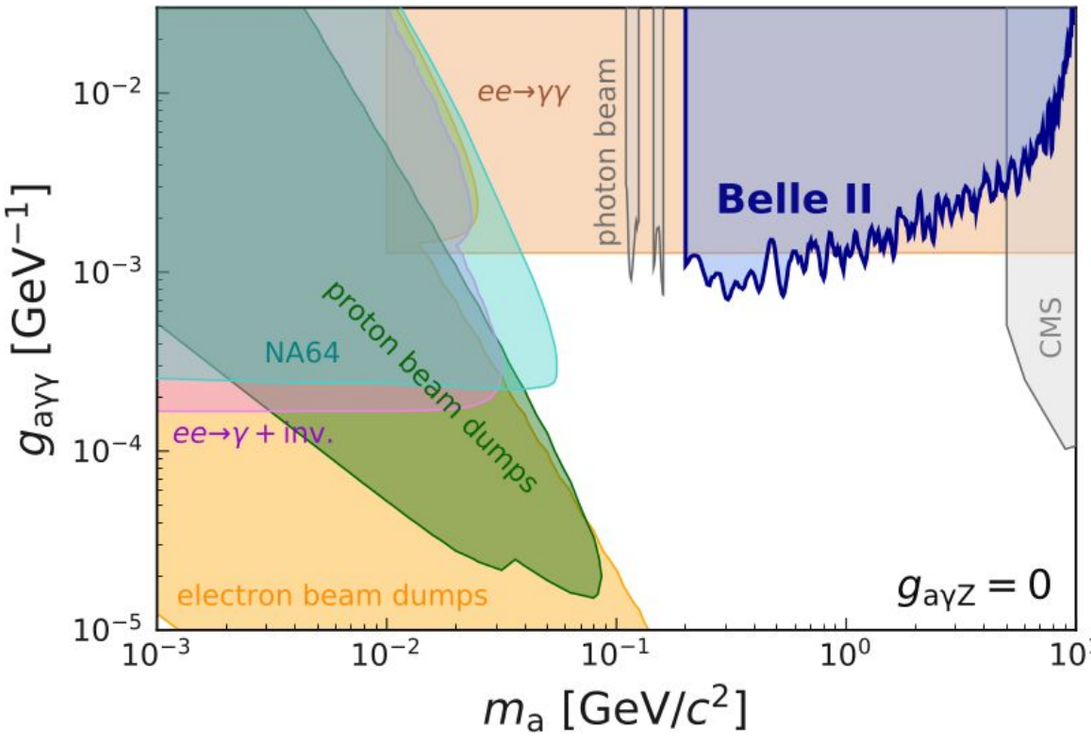

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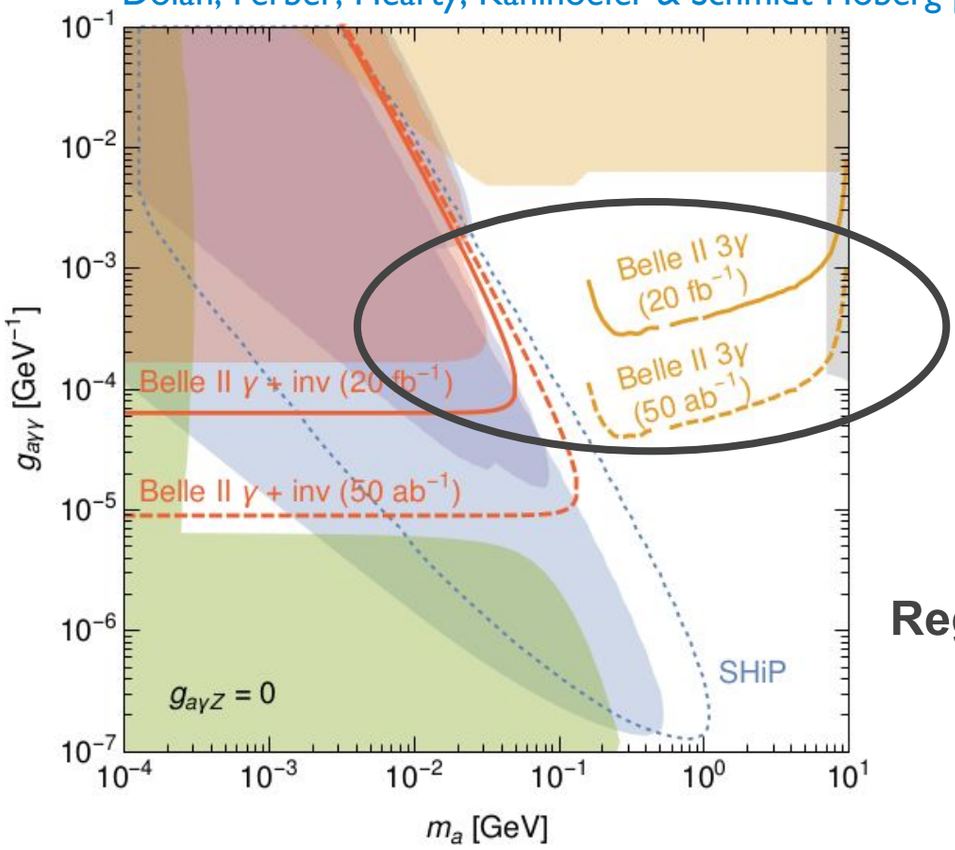
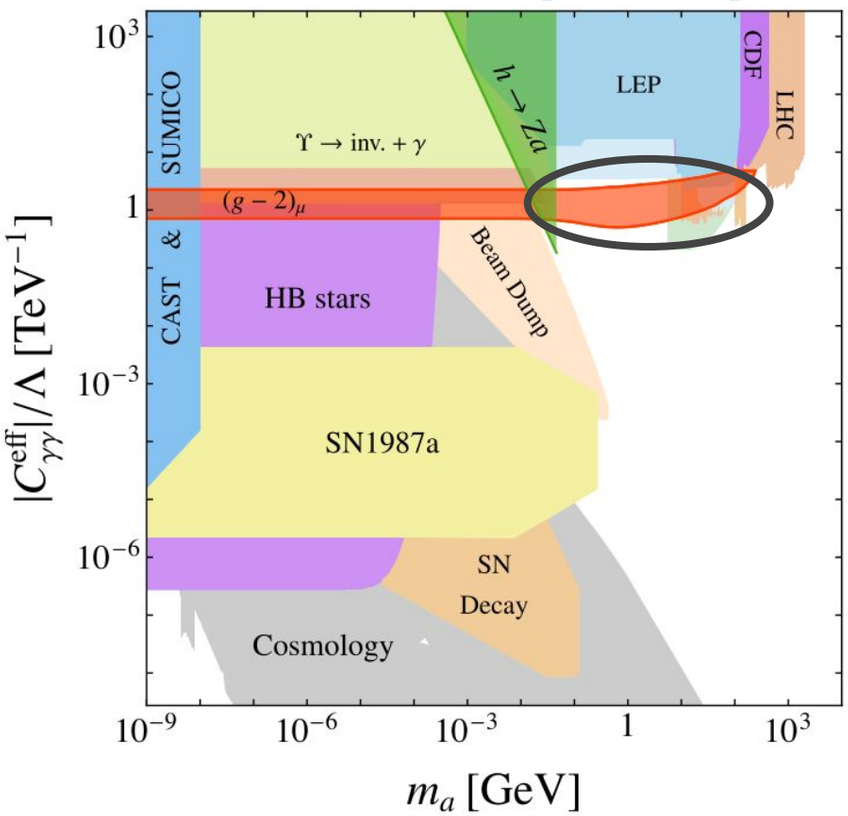


Region of $(g-2)_\mu$

Bauer, Neubert, Thamm [1708.00443]



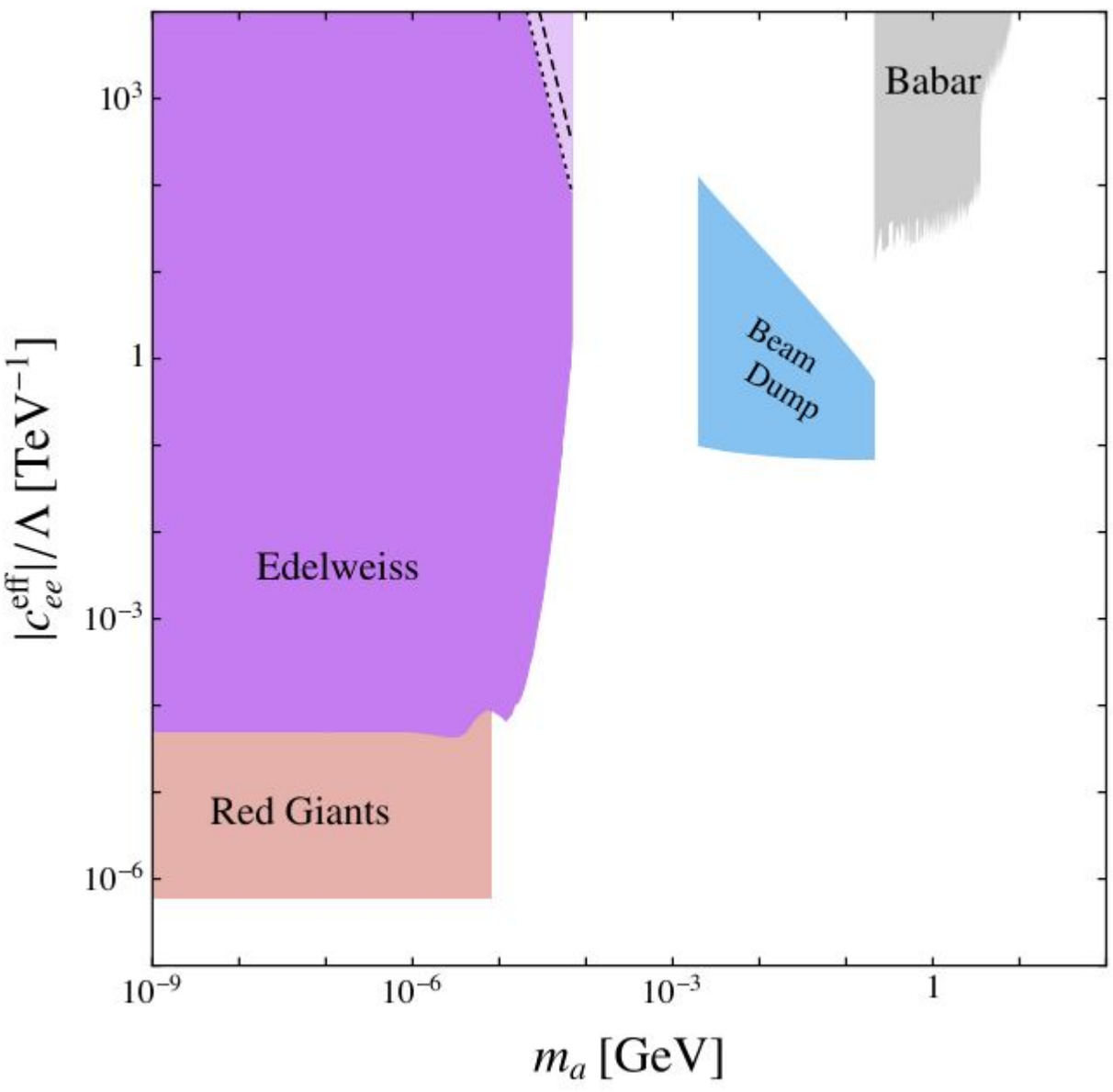
* For recent BaBar results on $B^\pm \to K^\pm a$, $a \to \gamma\gamma$, see talk by Brian Shuve @ ICHEP 2020

ALP-lepton coupling(s)

$$\mathcal{L} \supset \frac{c_{\ell\ell}^{\rm eff}}{2}\frac{\partial^\mu a}{\Lambda}\bar{\ell}\gamma_\mu\gamma_5\ell$$

bound on $c_{\mu\mu}^{\rm eff}$

Bauer, Neubert, Thamm [1708.00443]



Almost unexplored

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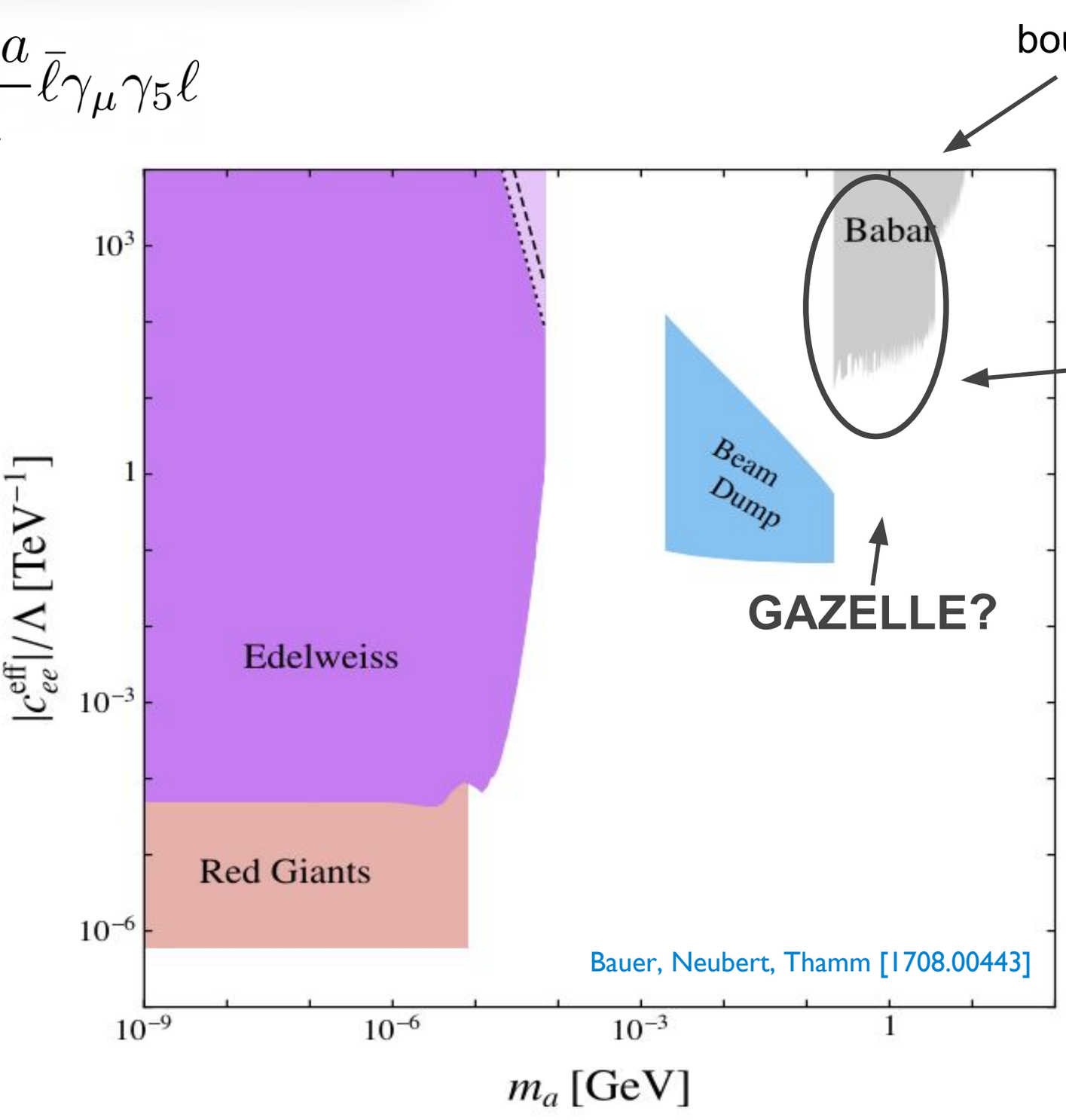

Almost unexplored

Take-home message

- Belle II is a perfect experiment for studying dark sectors at ~GeV scale.

- It is competitive with existing experiments (BaBar, LHCb...) and can help in “closing the gap” between current and future detectors.

- Leptonic (hadronic) final states should be actively searched for. They will probe parameter space that we don’t have access to otherwise.

- The reach of Belle II might be sufficiently extended by an additional father-distanced detector (see GAZELLE talks by Torben and Michele).