Flavor @ FASER: Discovering Light Scalars Beyond Minimal Flavor Violation

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UC Santa Cruz

Based on 2412.15197 (soon in JHEP) with
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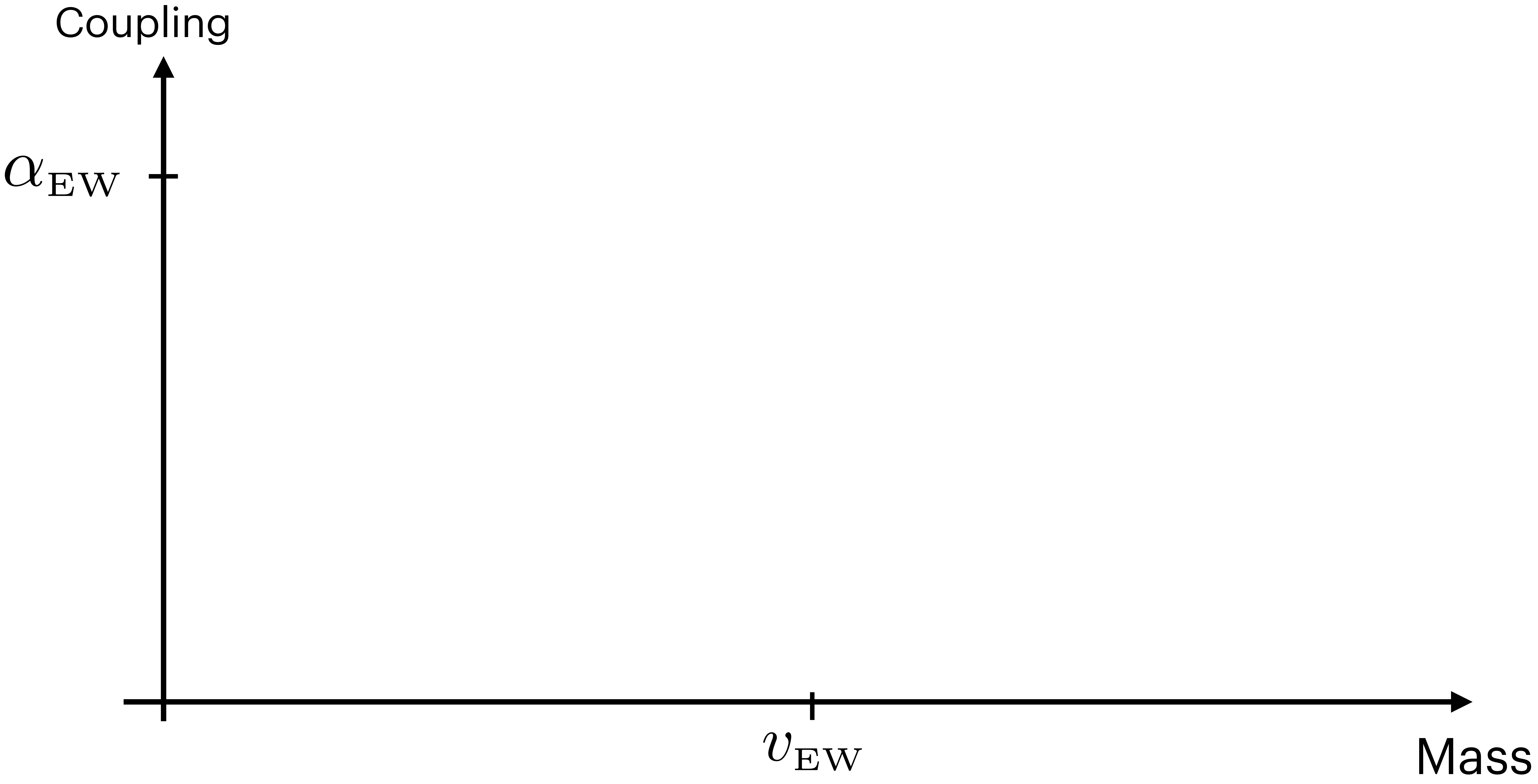
Bay Area Particle Theory Seminar

SCIPP
SANTA CRUZ INSTITUTE FOR PARTICLE PHYSICS
UC SANTA CRUZ

04/04/2025

Motivation



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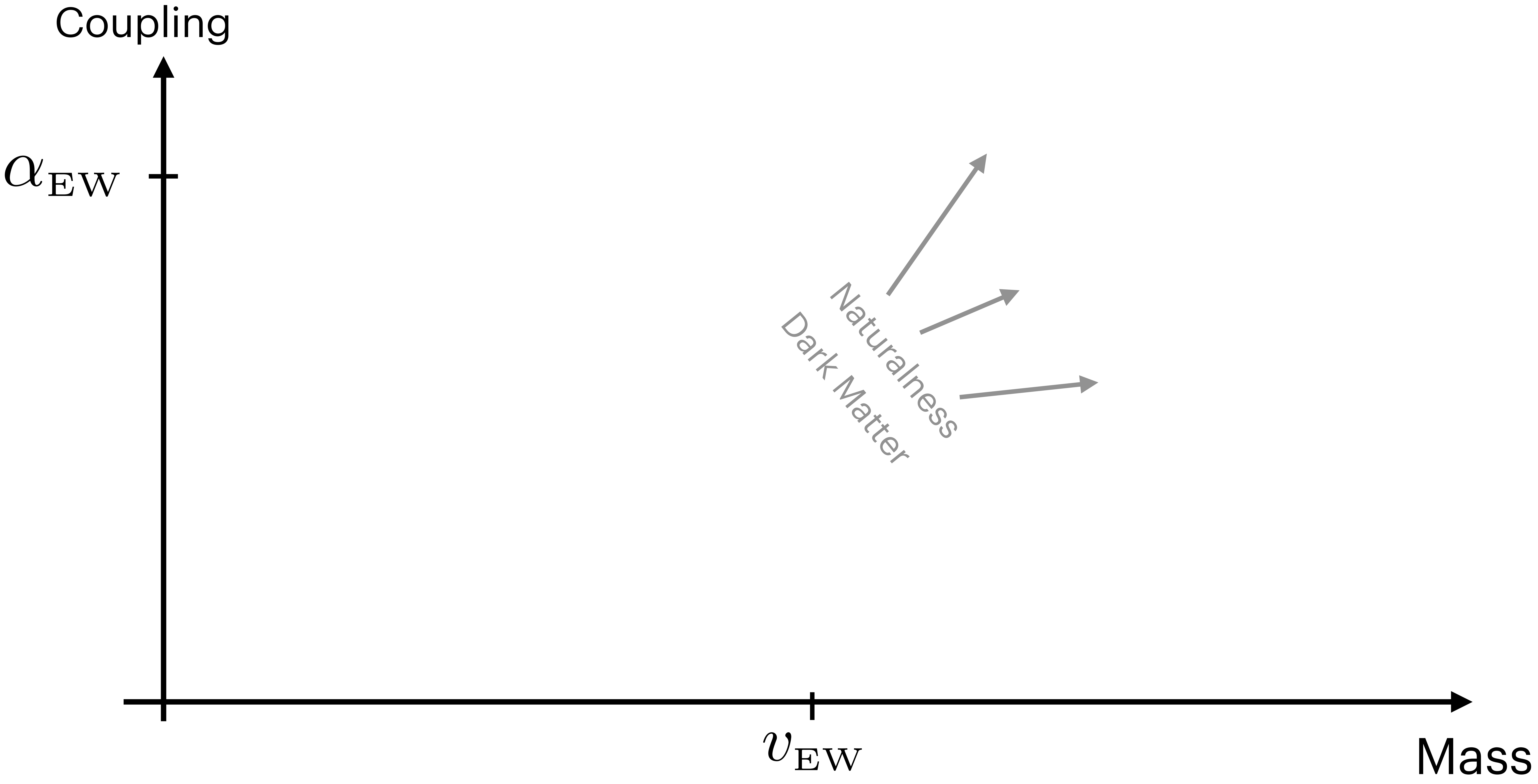

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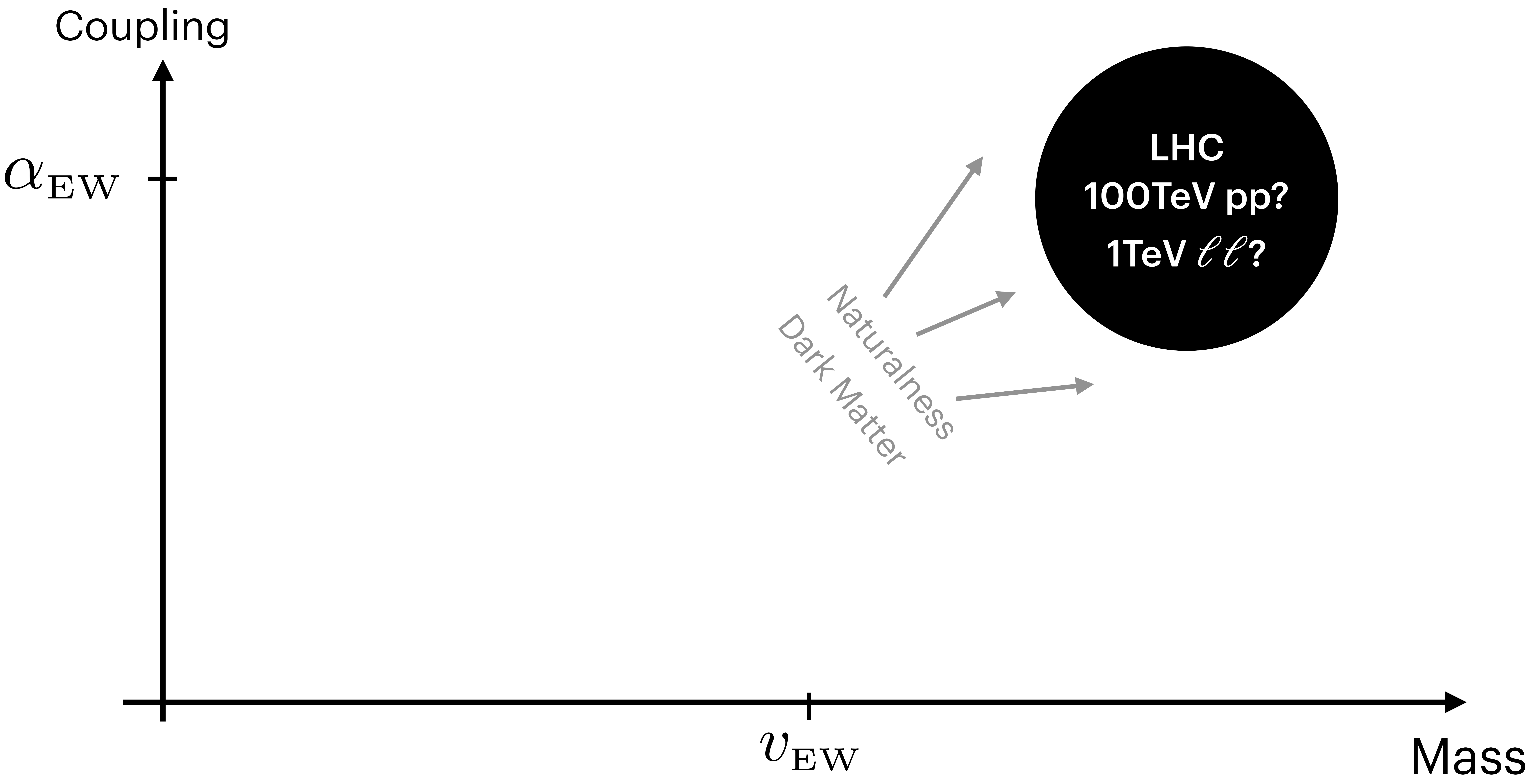
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100TeV pp?
1TeV $\ell\ell$?
Naturalness
Dark Matter
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Mass

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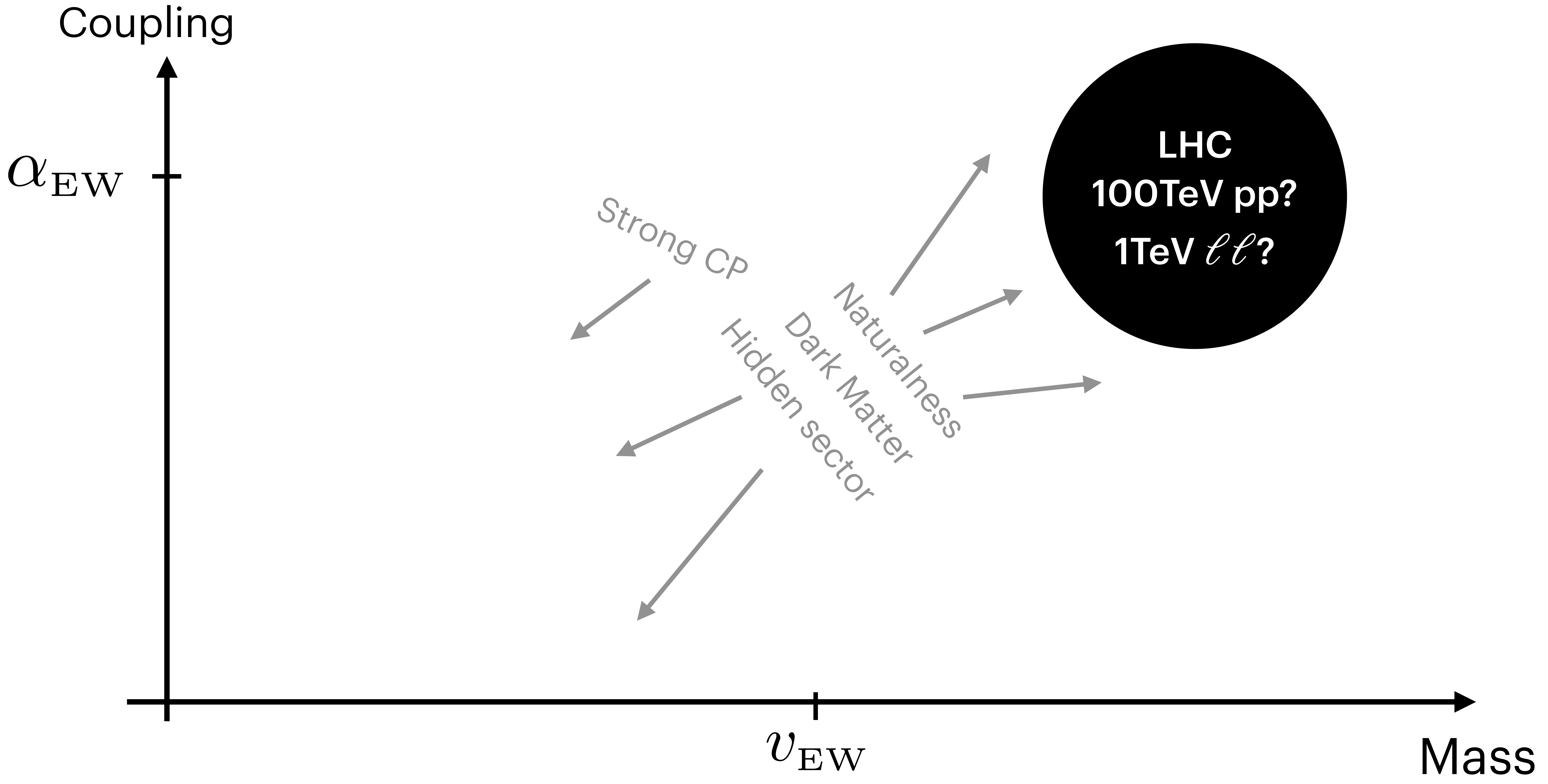
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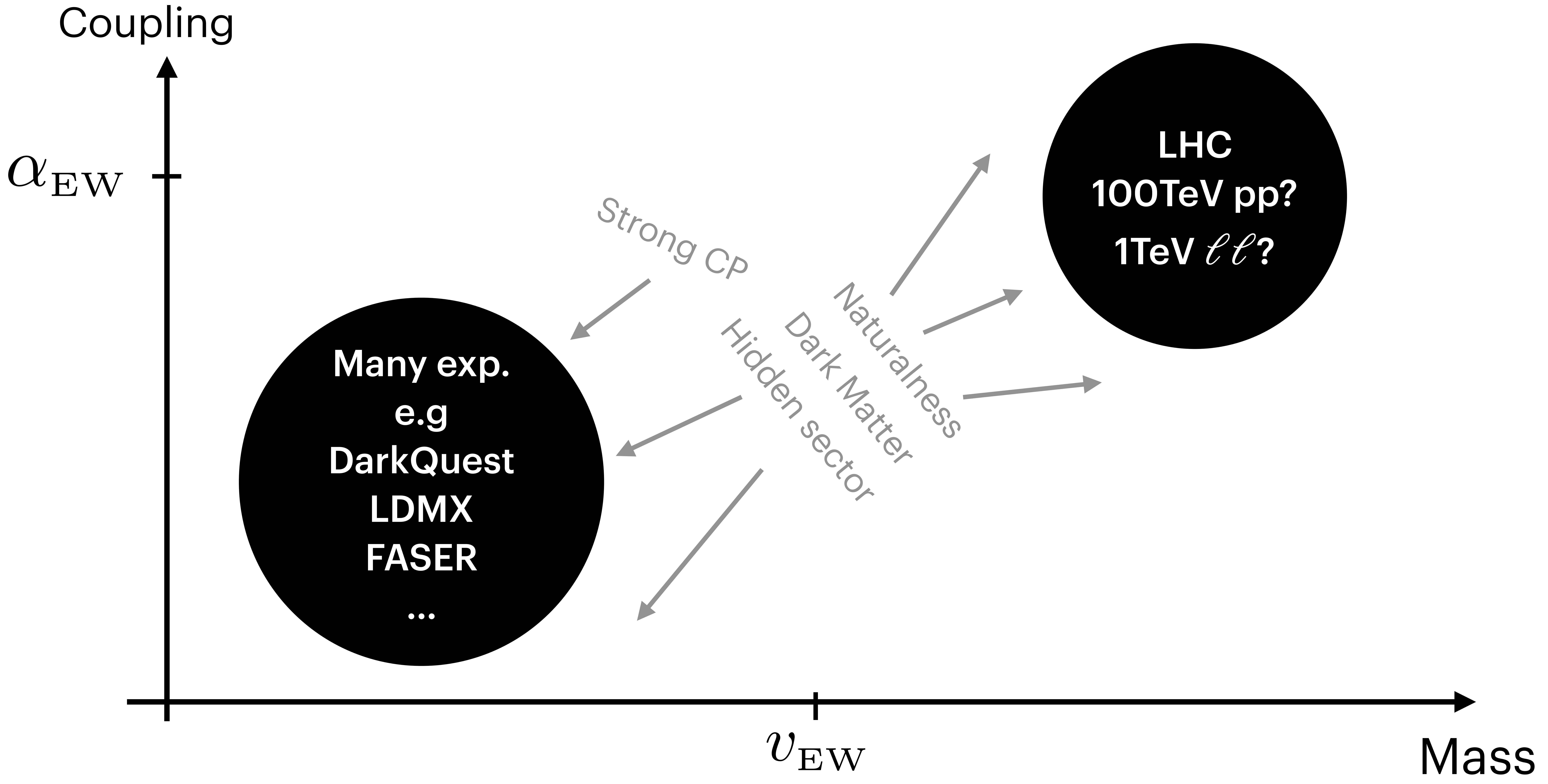

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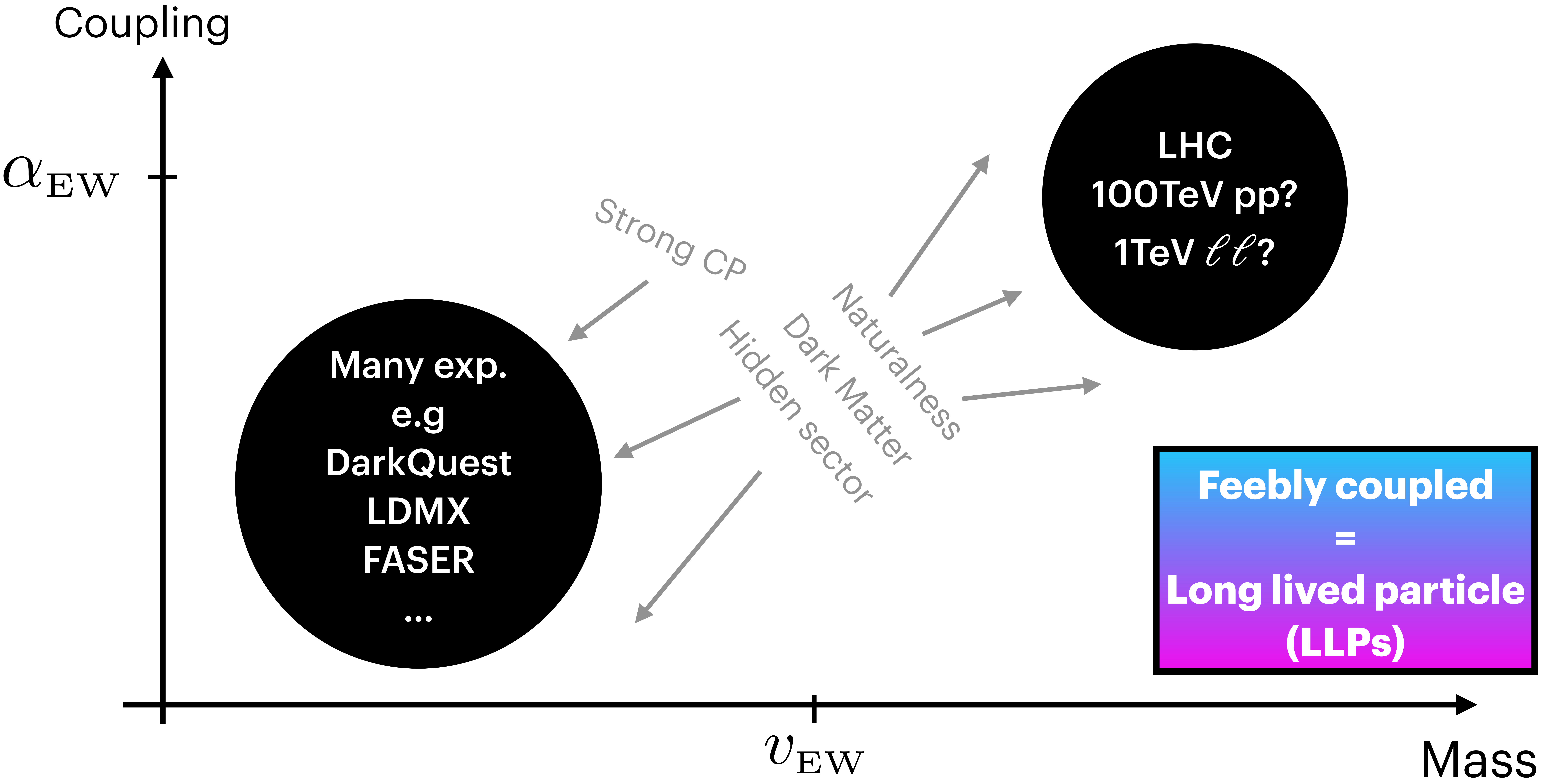
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PBC @ CERN 1901.09966

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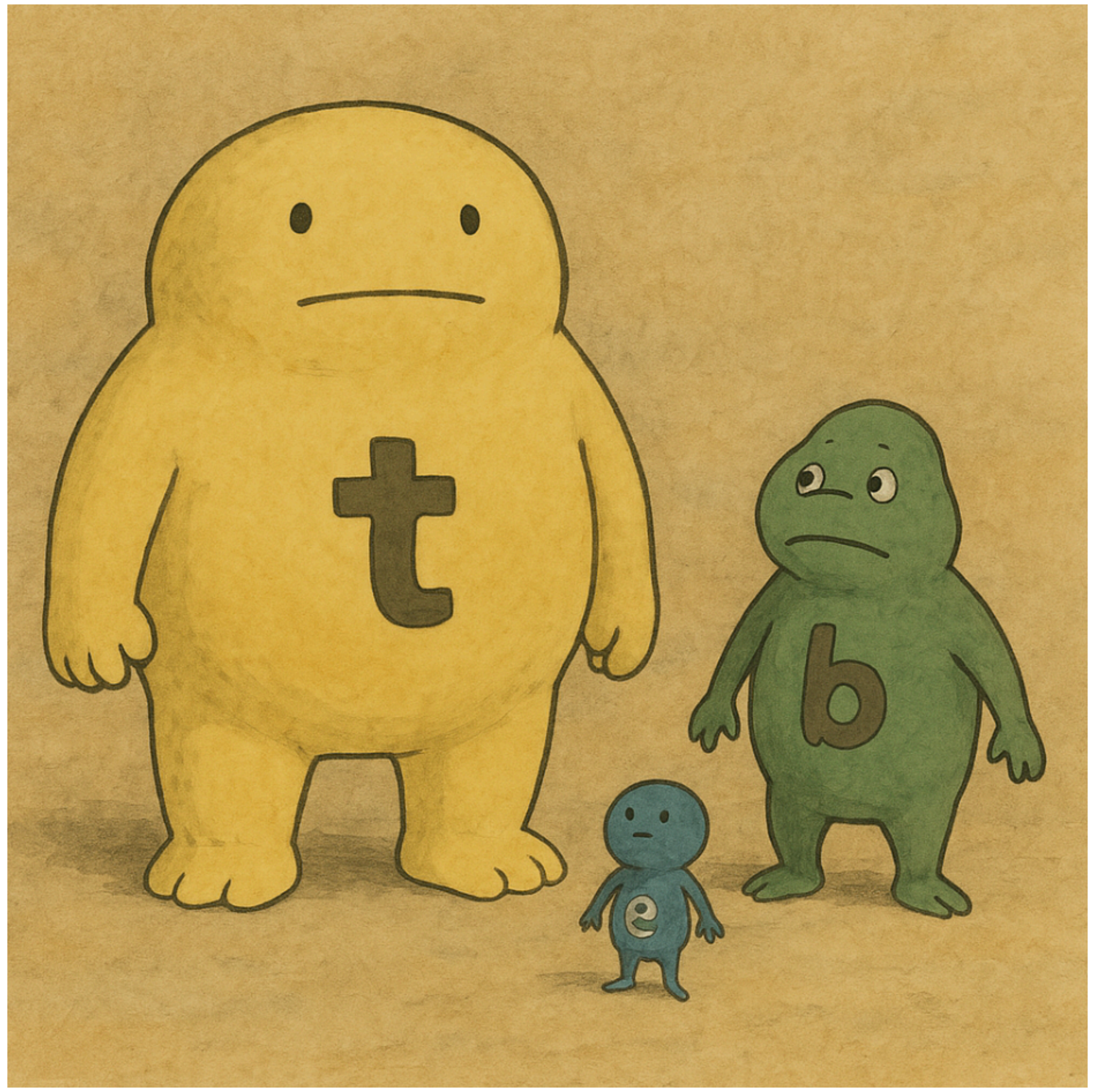

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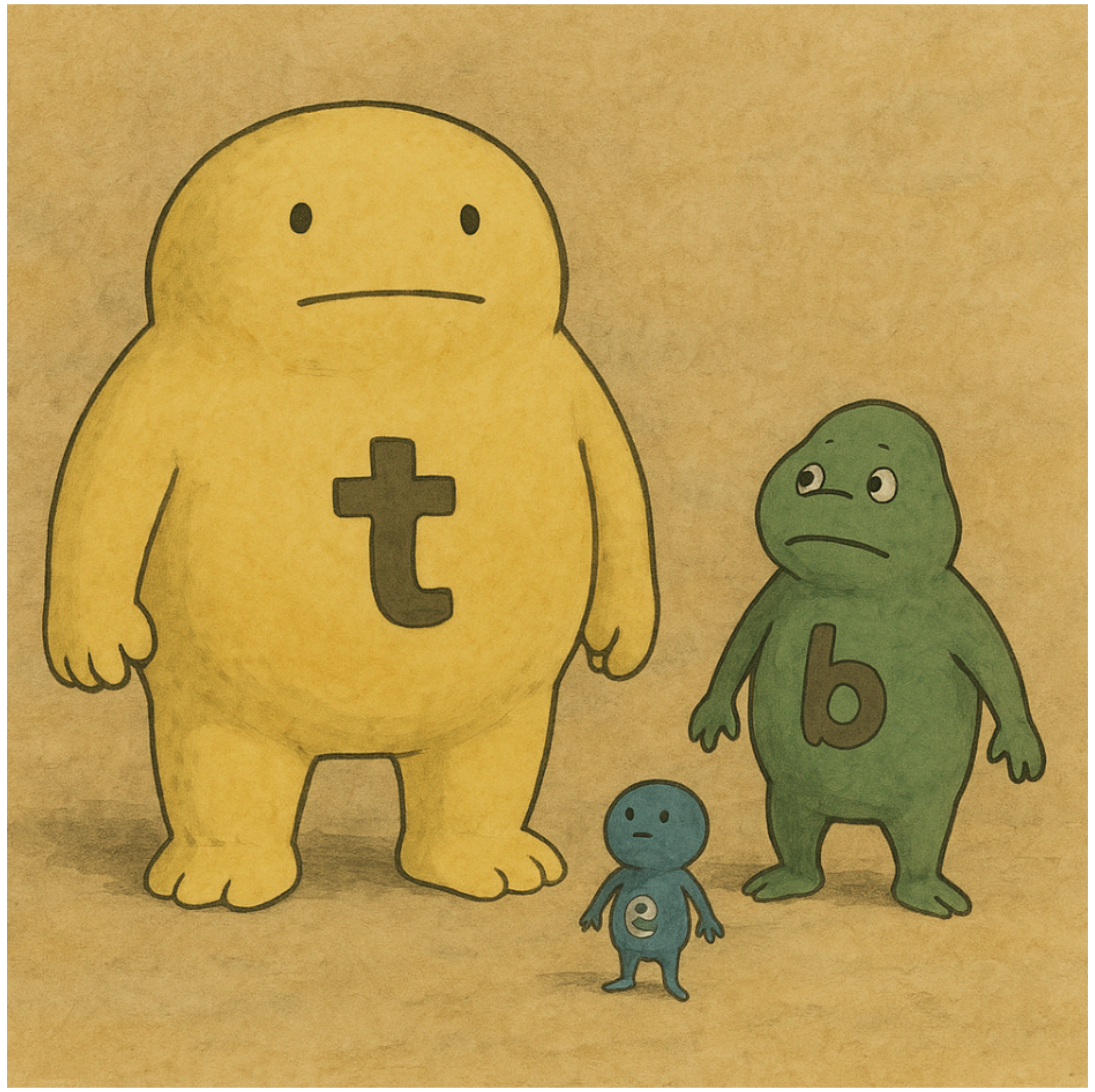

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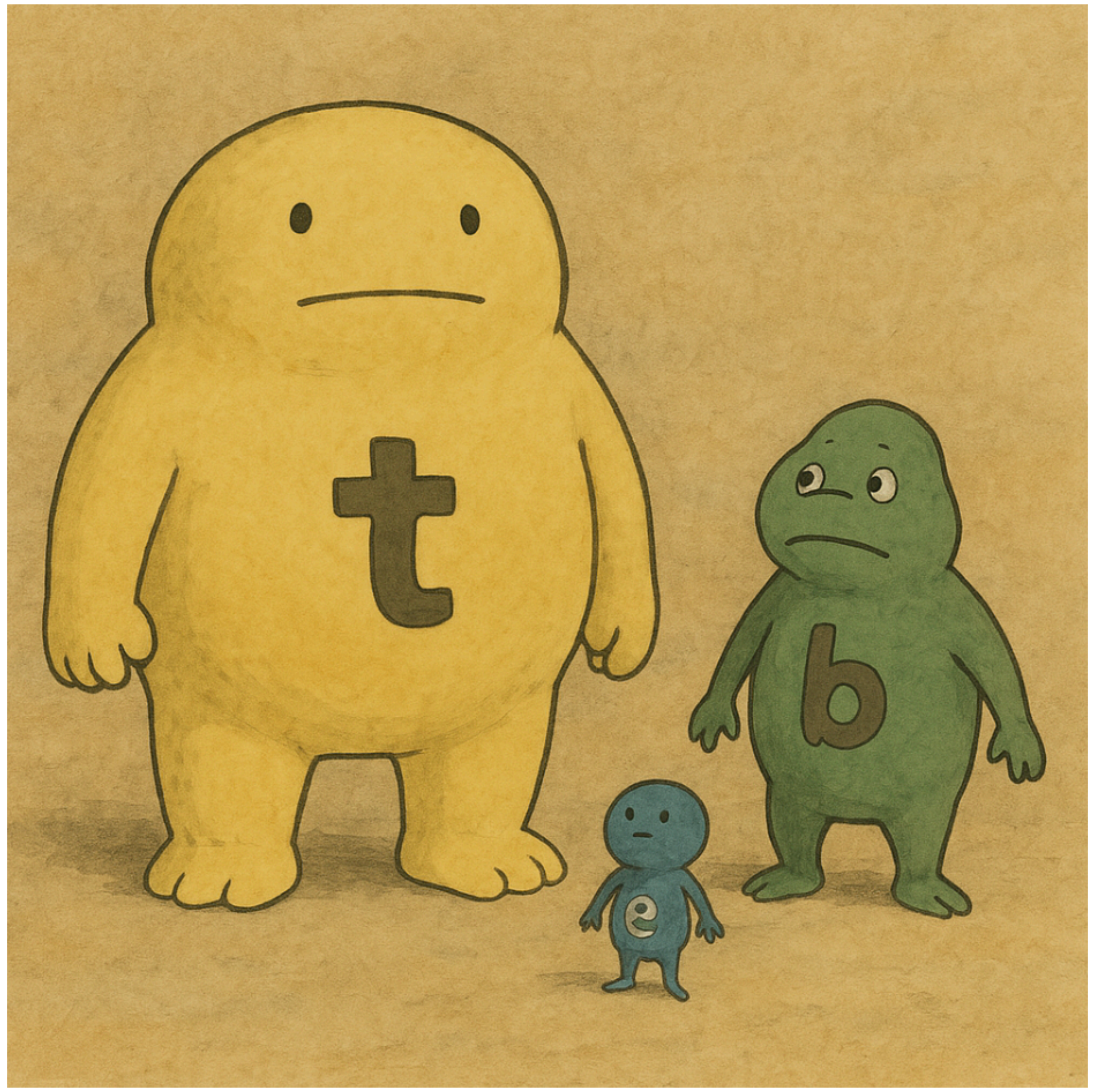

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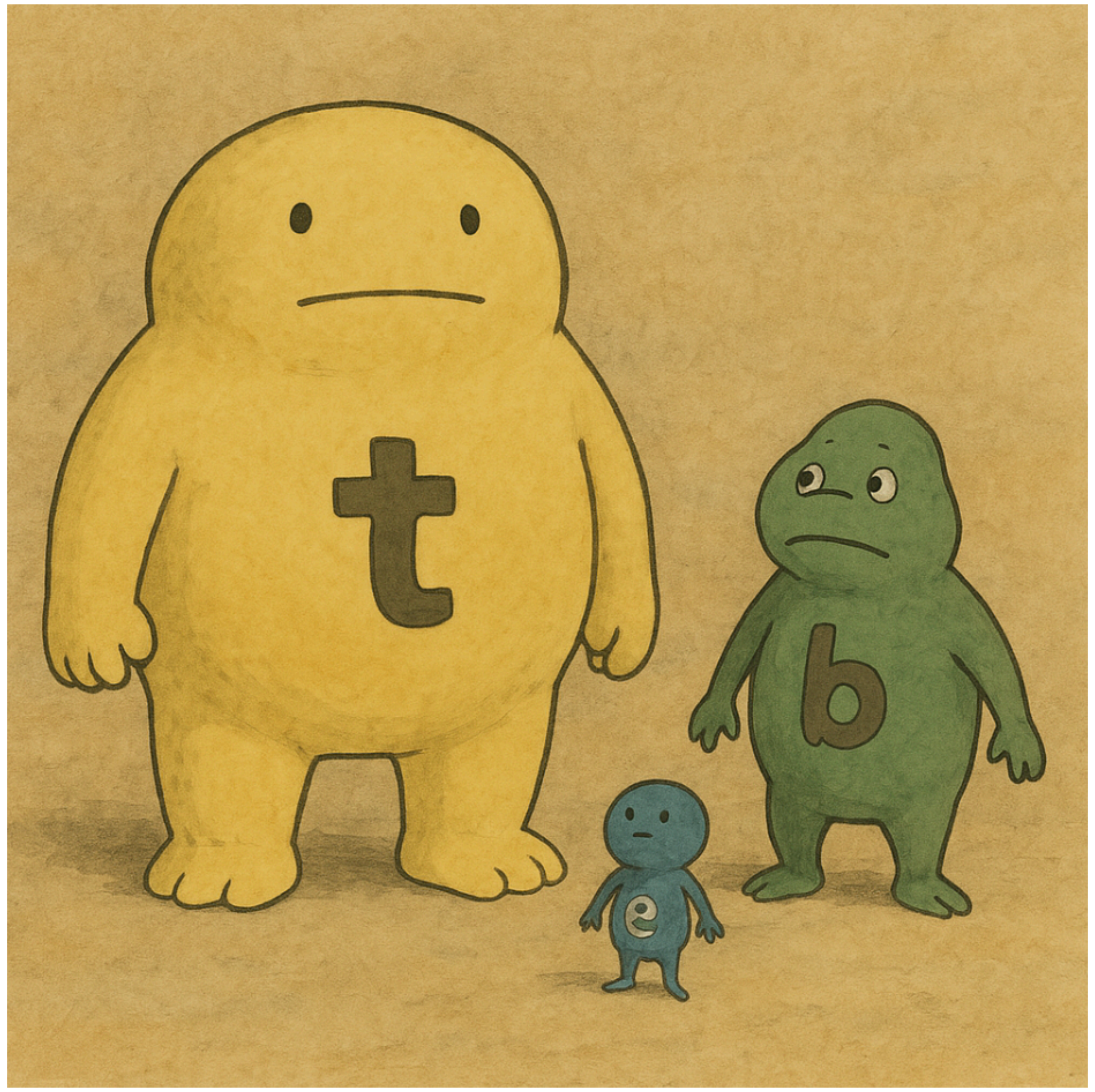

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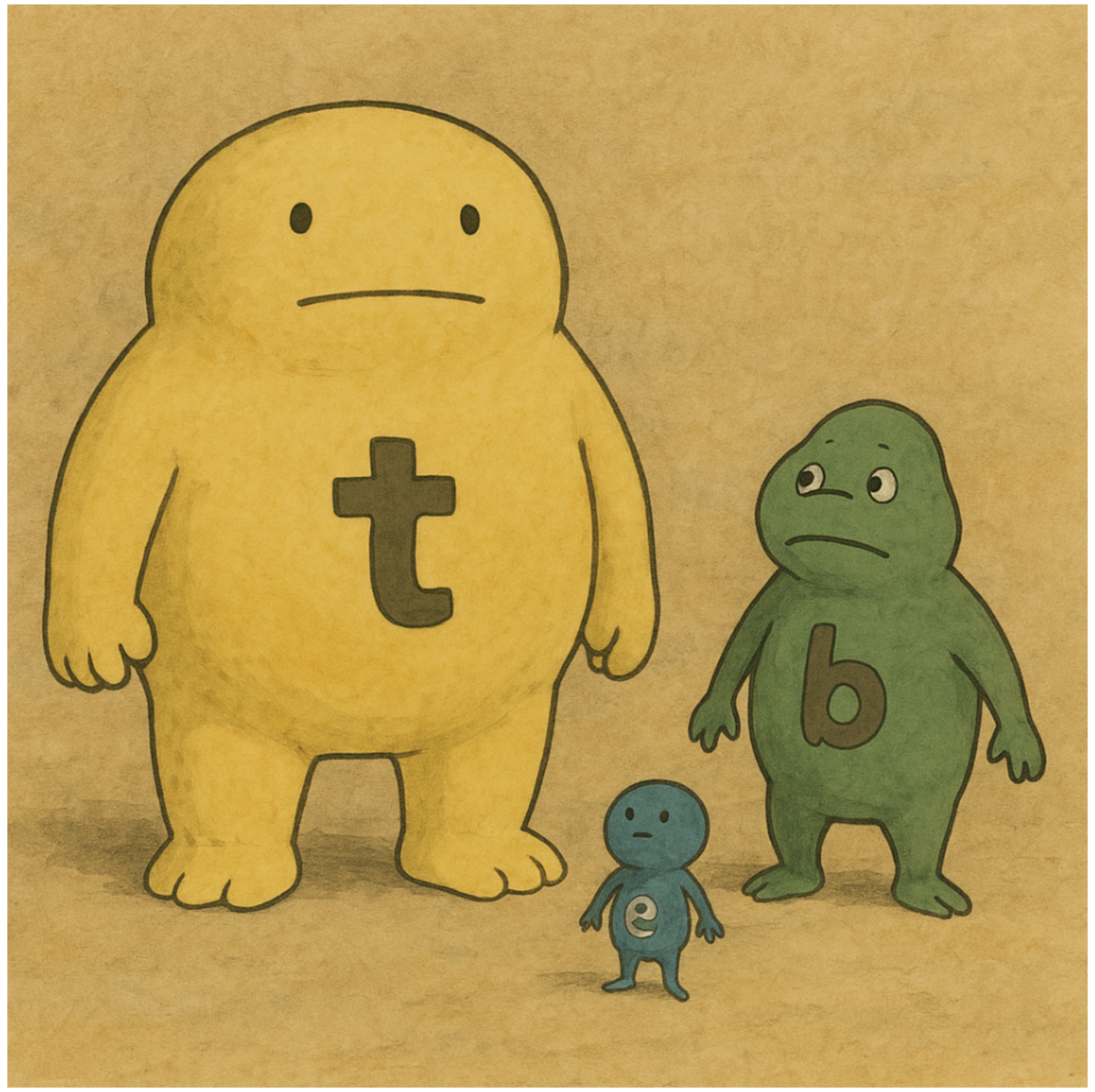

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See Camalich et al. 2002.04623
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- Discovery could also shed light on the Flavor puzzle!

Outline

1. Flavored scalar model
2. Phenomenology
3. Experimental signals @ FASER
4. Model-independent approach
5. Conclusions

Flavored scalar models

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"Dark Higgs": $\varepsilon \to \theta$ $\qquad h = \cos\theta h_{\rm phys} + \sin\theta \phi_{\rm phys}$

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↑ Generated at 1-loop in Dark Higgs models

Beyond MFV : alignment

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hep-ph/9304307
Shadmi & Szabo hep-ph/1103.0292
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$$\lambda \approx 0.2$$

Beyond MFV : alignment

Leurer, Nir, Seiberg hep-ph/9212278
hep-ph/9304307
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Abdullah et al. 1209.4904

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Lepton sector -
more symmetries are needed!
Grossman, Nir, Shadmi hep-ph/9808355

$$c^\ell = \mathrm{diag}(m_e, m_\mu, m_\tau)/v$$

FN and FNU models

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W @ 1-loop →
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Pheno : Production

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$$\mathrm{Br}(D \to \pi\ \phi) \approx \frac{\varepsilon^2 m_c |c^u_{uc}|^2}{32\pi\Gamma_{D^0}} F\left[\frac{m_u}{m_c}, \frac{m_\phi}{m_c}\right] \approx 10^{-11} \left(\frac{10^{10}\ \mathrm{GeV}}{\Lambda}\right)^2 \left(\frac{|c^u_{uc}|}{\lambda^4}\right)^2 \left(\frac{F}{1}\right)$$

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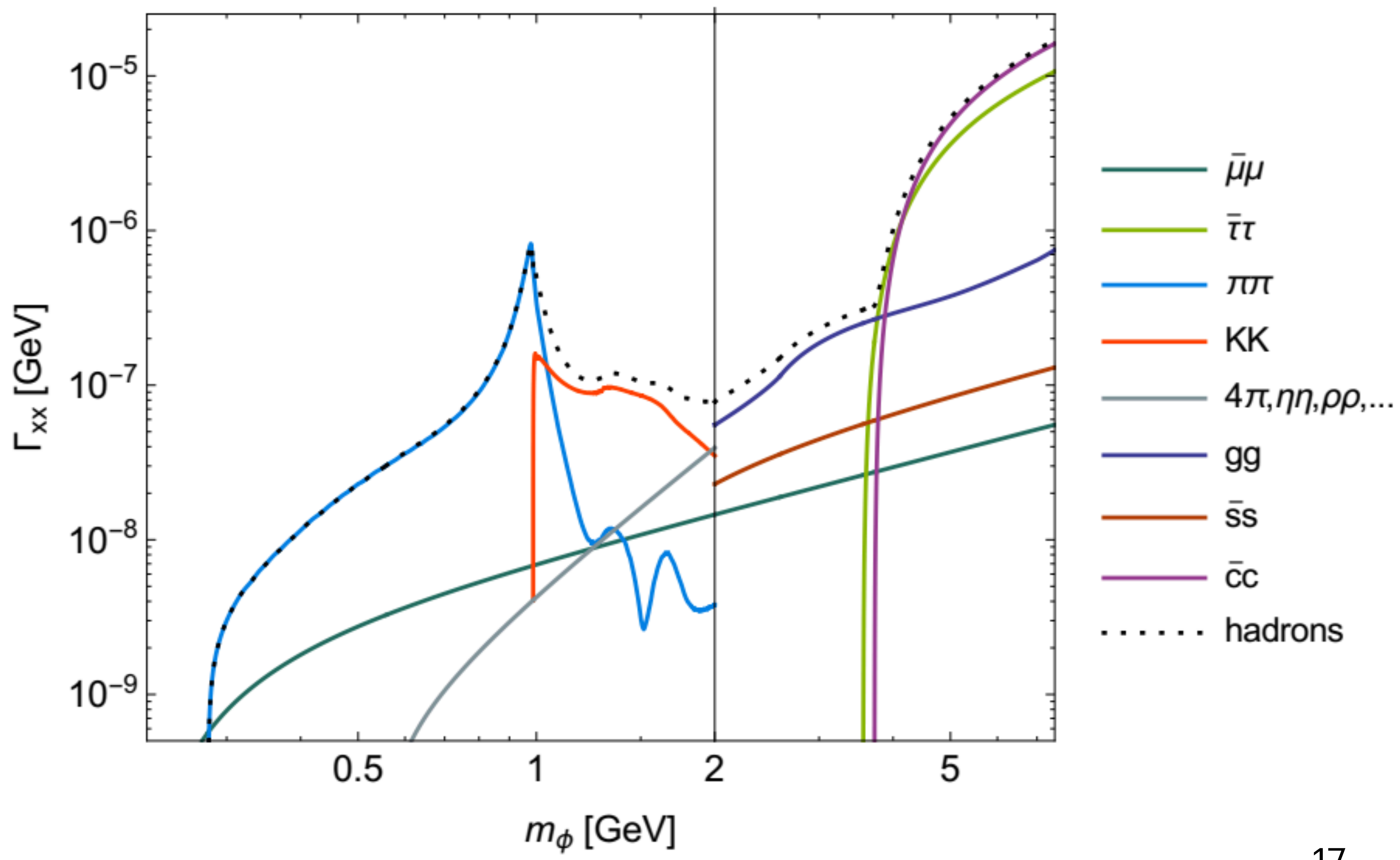
Winkler 1809.01876



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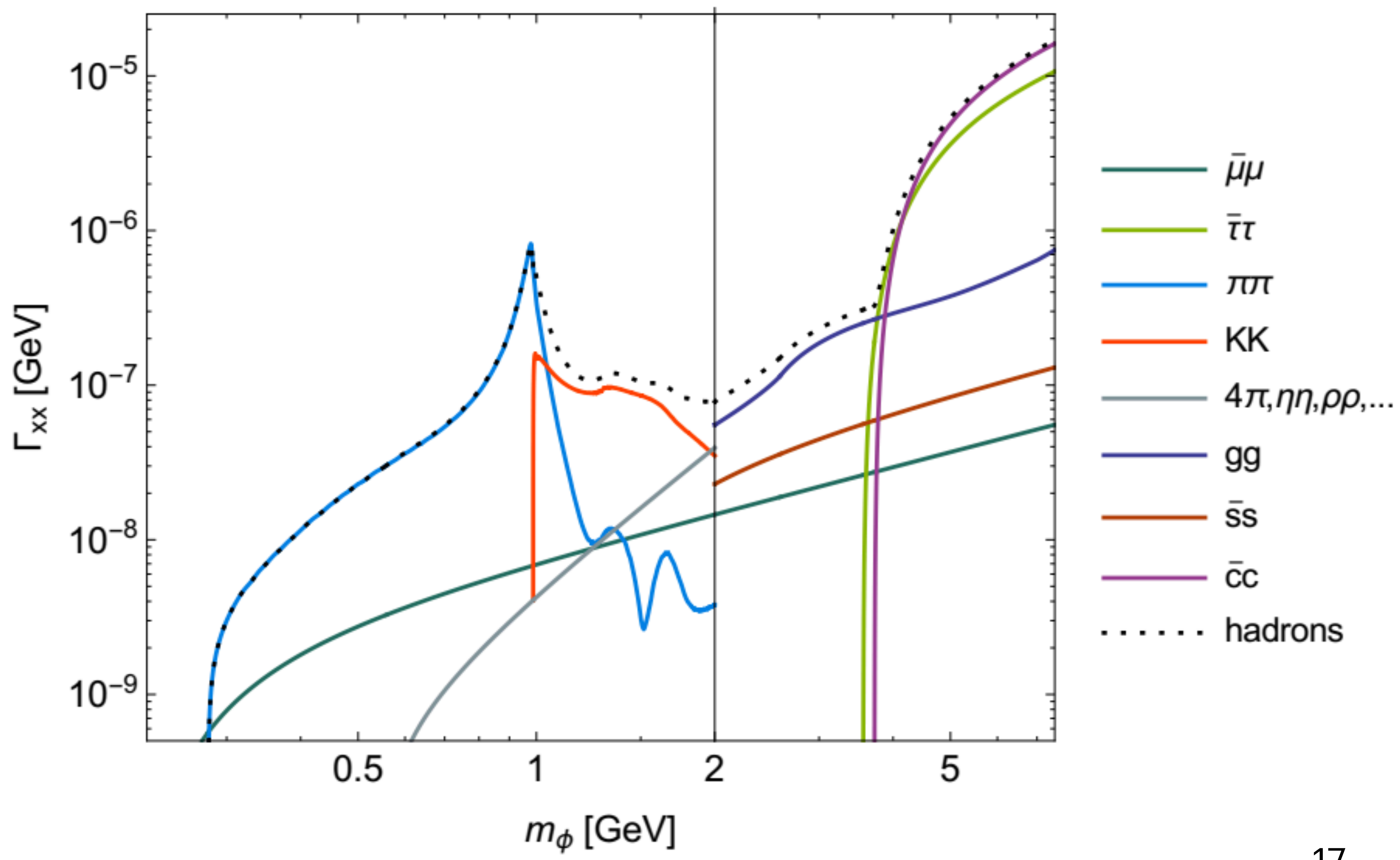
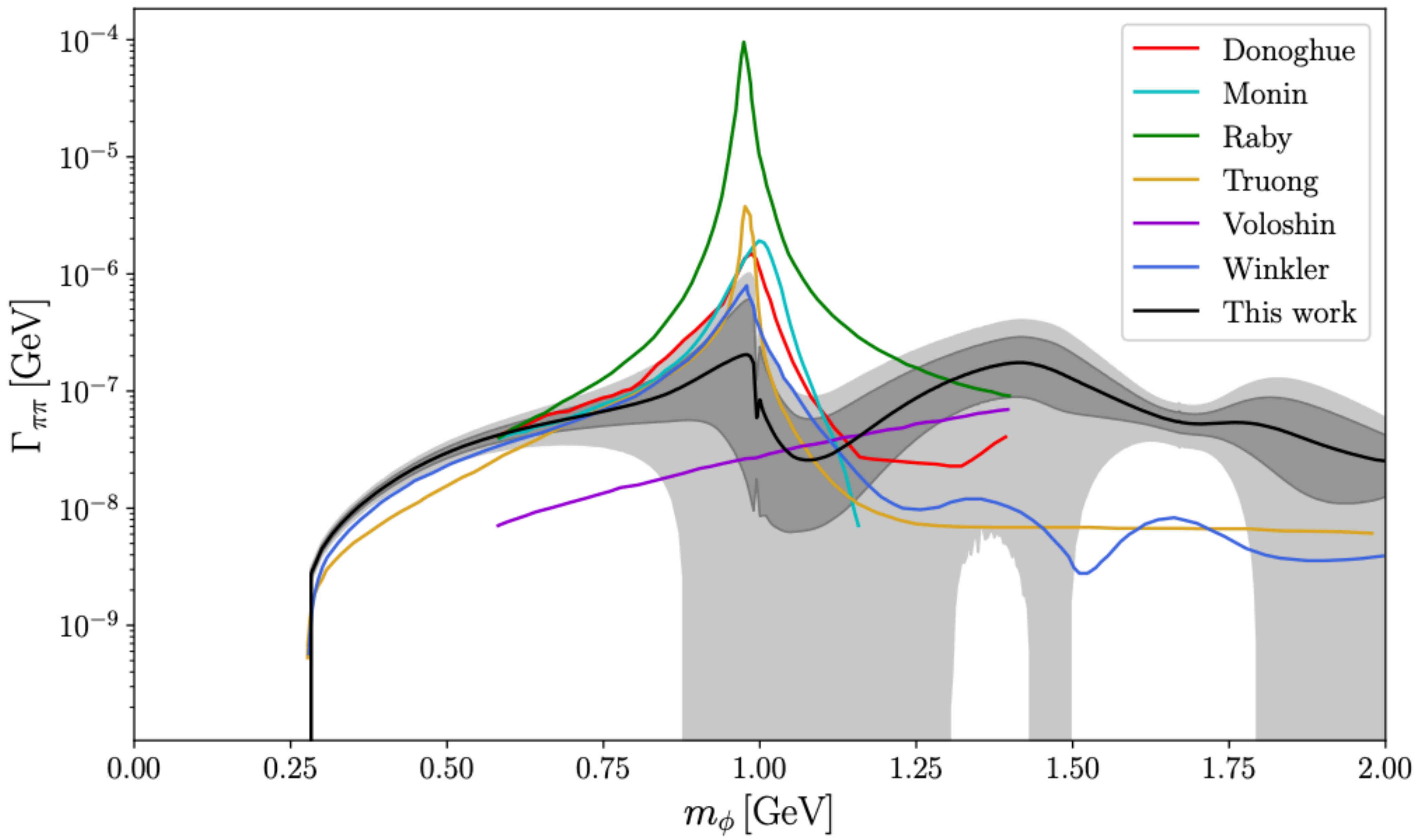
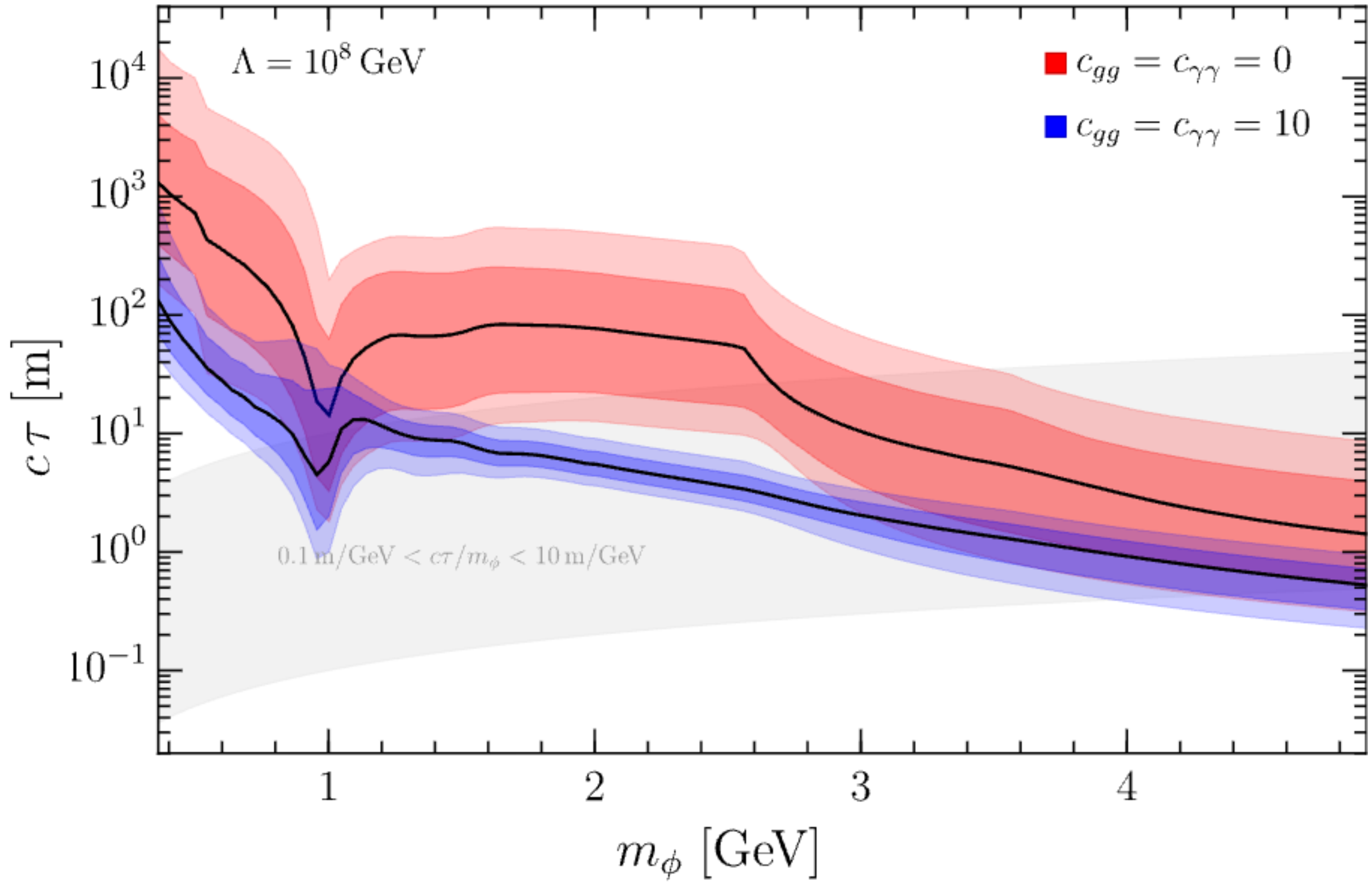


Blackstone et al. 2407.13587



Pheno : Lifetime

RB, Burger, Feng, Shadmi 2412.15197



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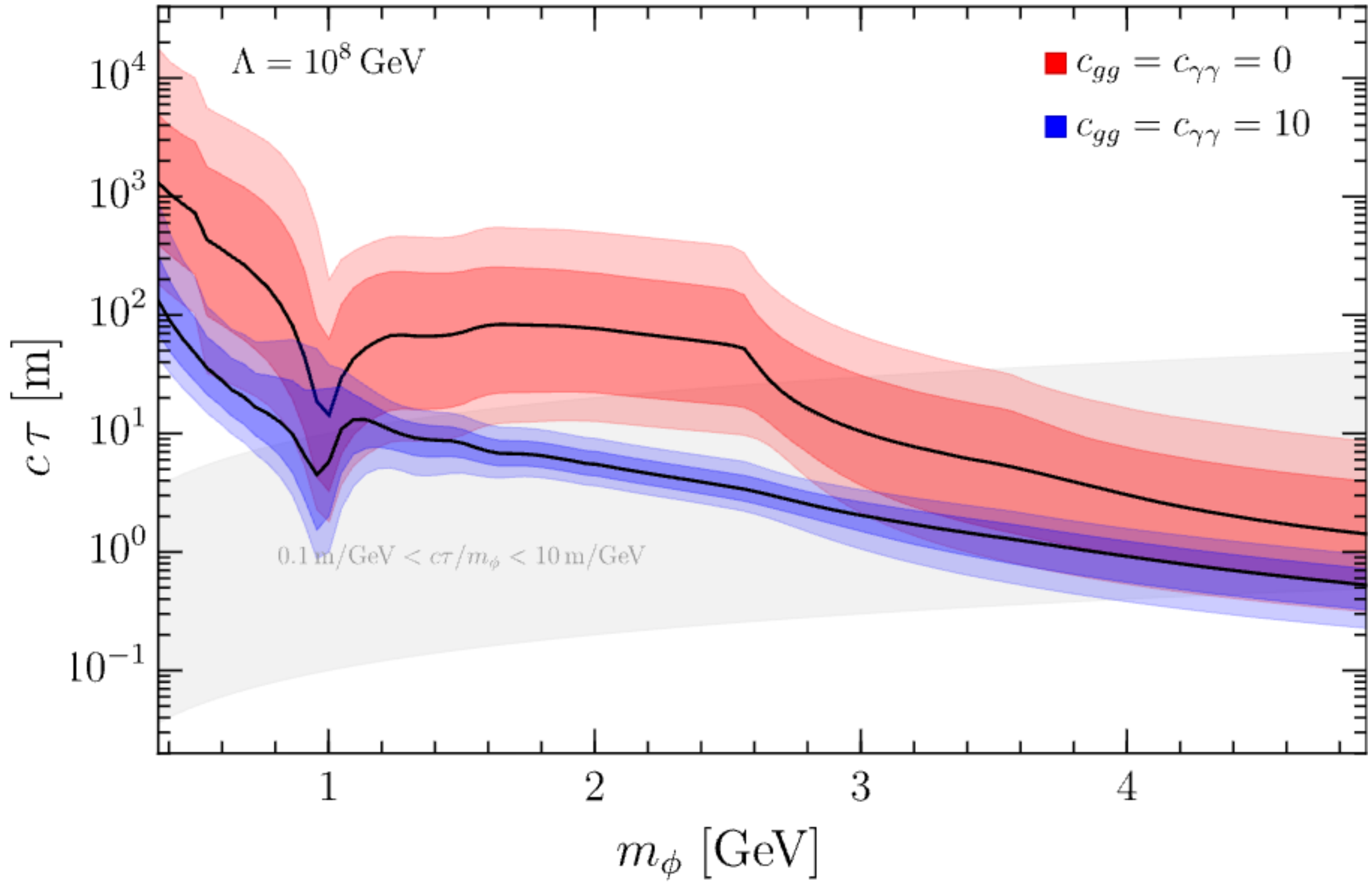

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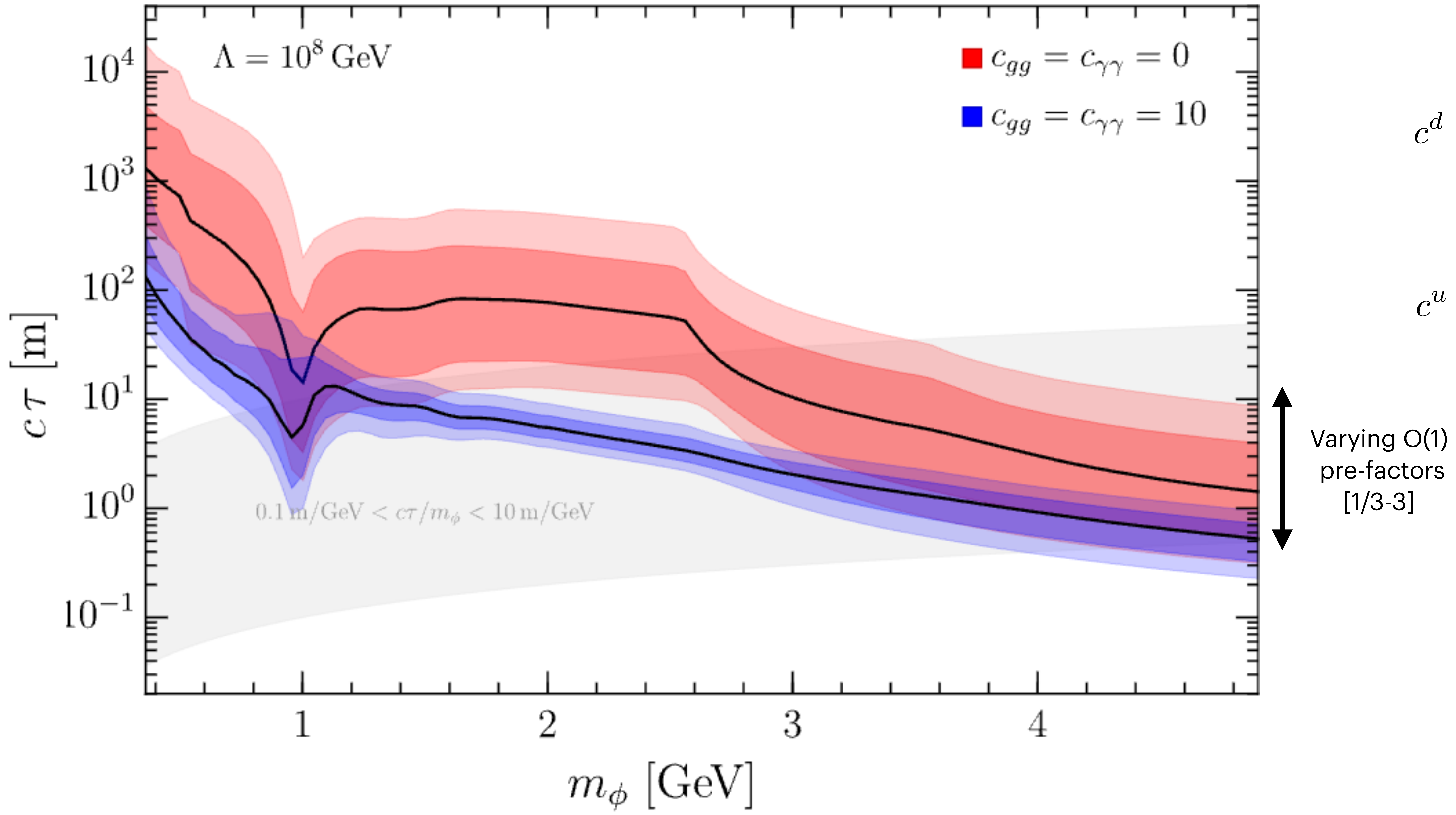

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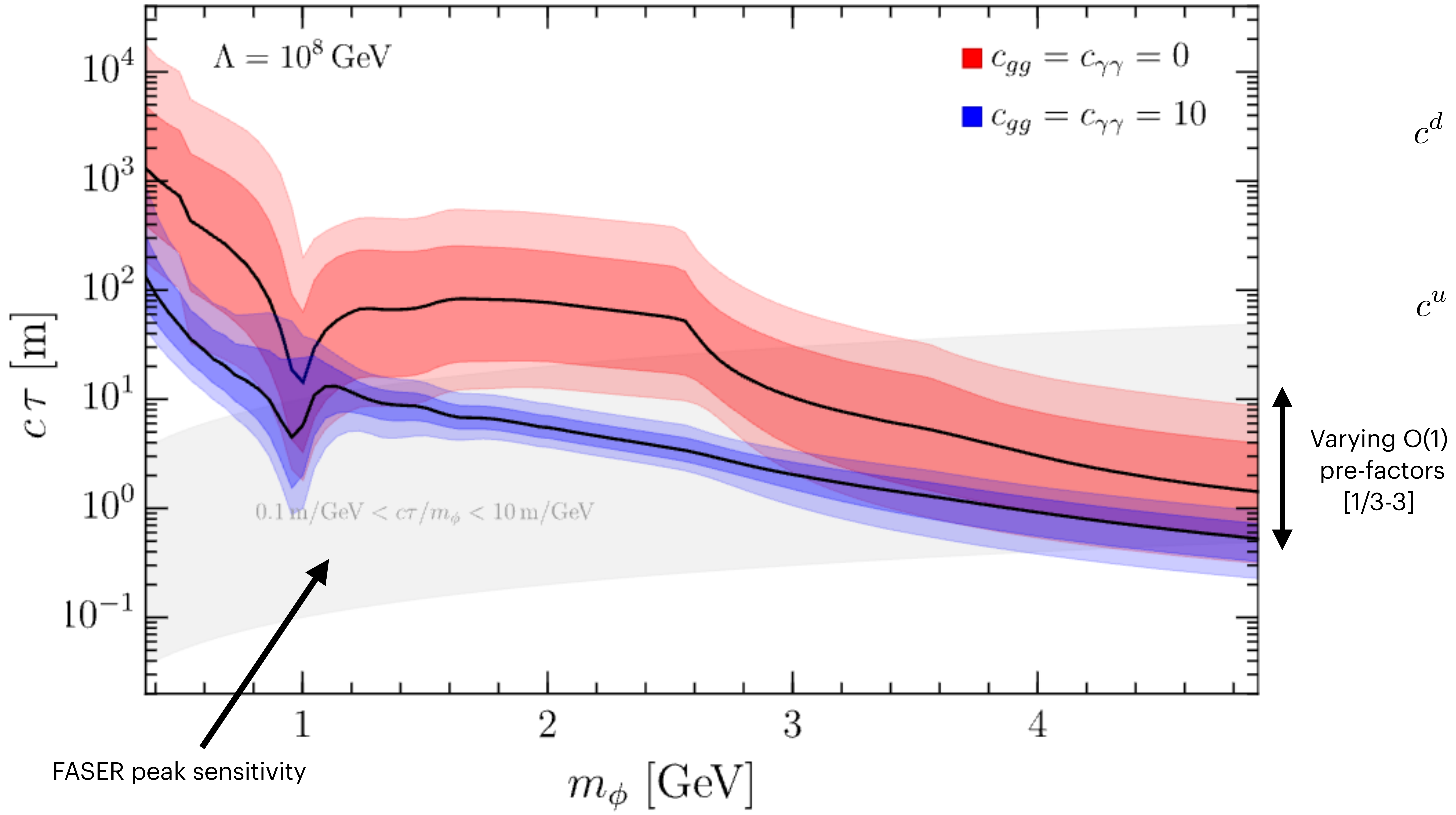

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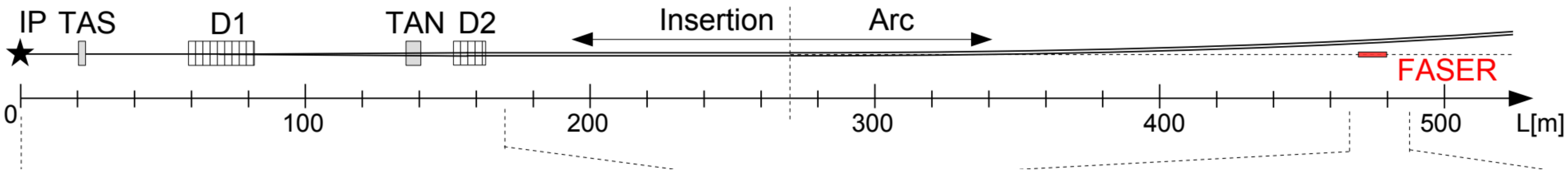
FASER



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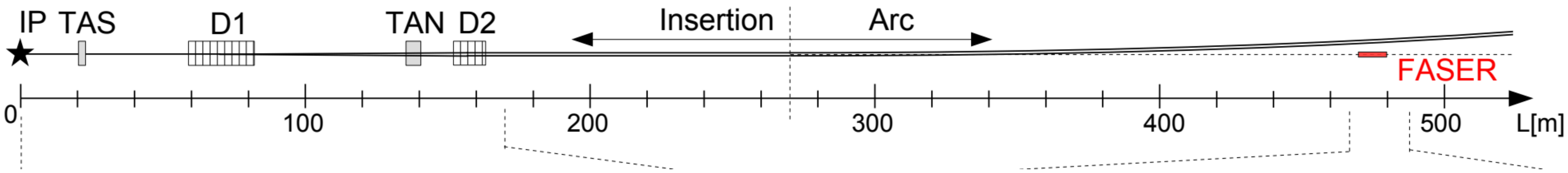

FASER Detector

Experiment built from existing spare parts as well as some dedicated new components

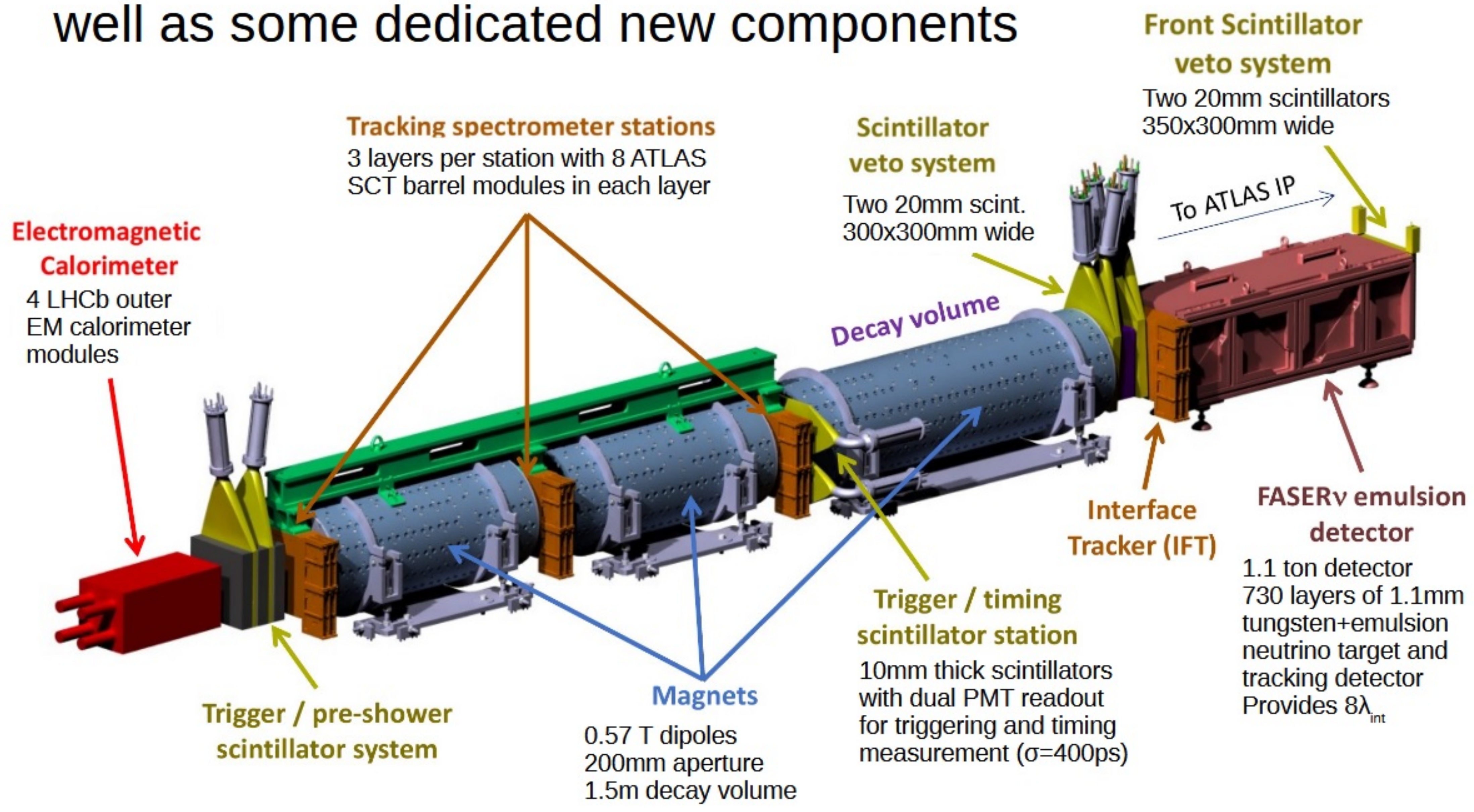

Image taken from Brian Petersen – The FASER Collaboration

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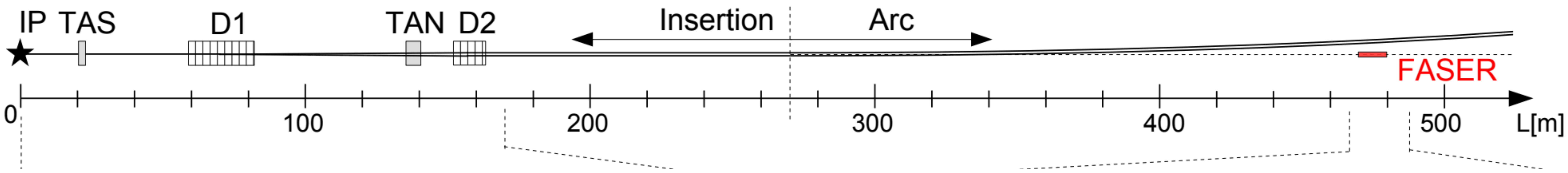

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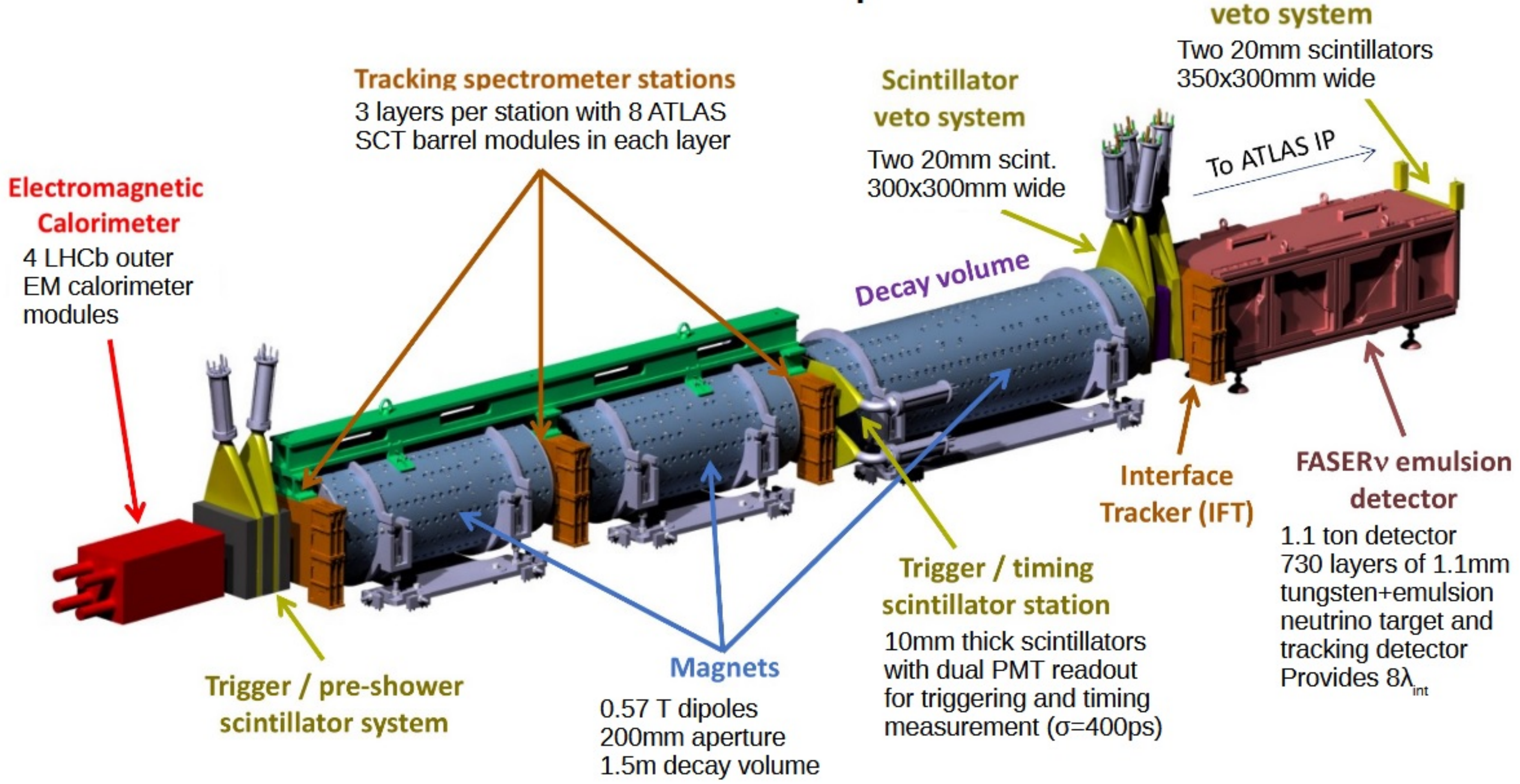

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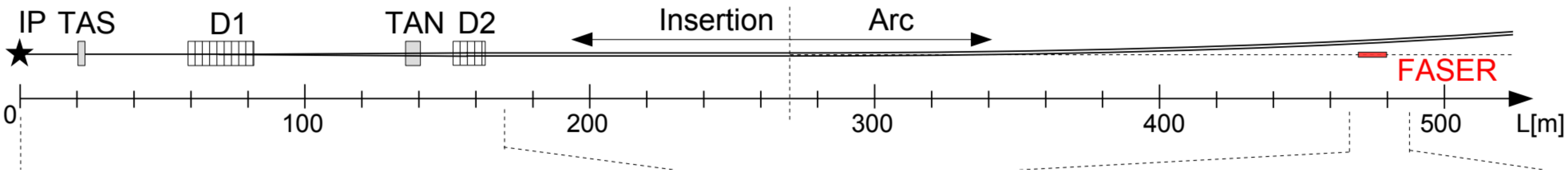
FASER LOI : NOV 2018

FASER



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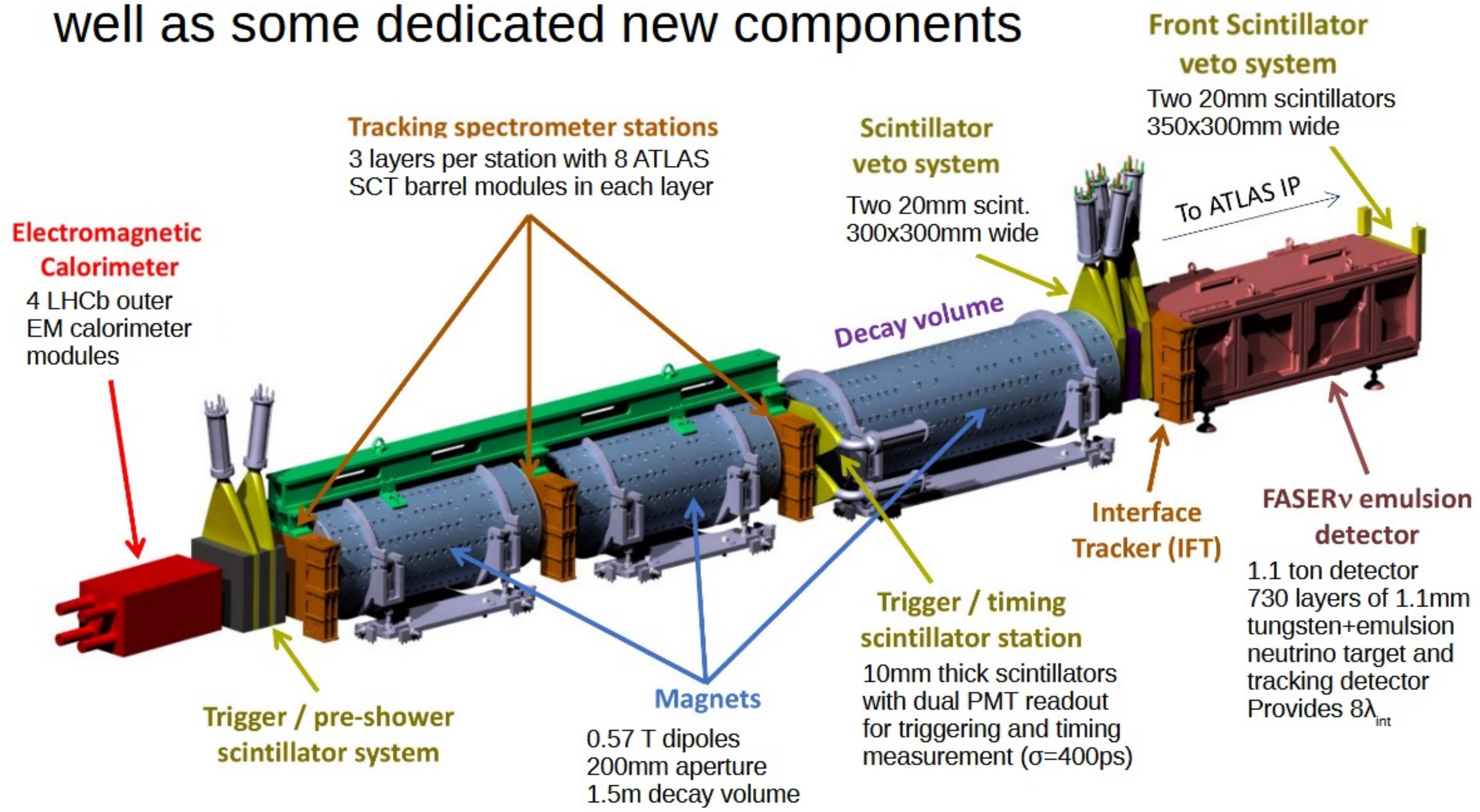

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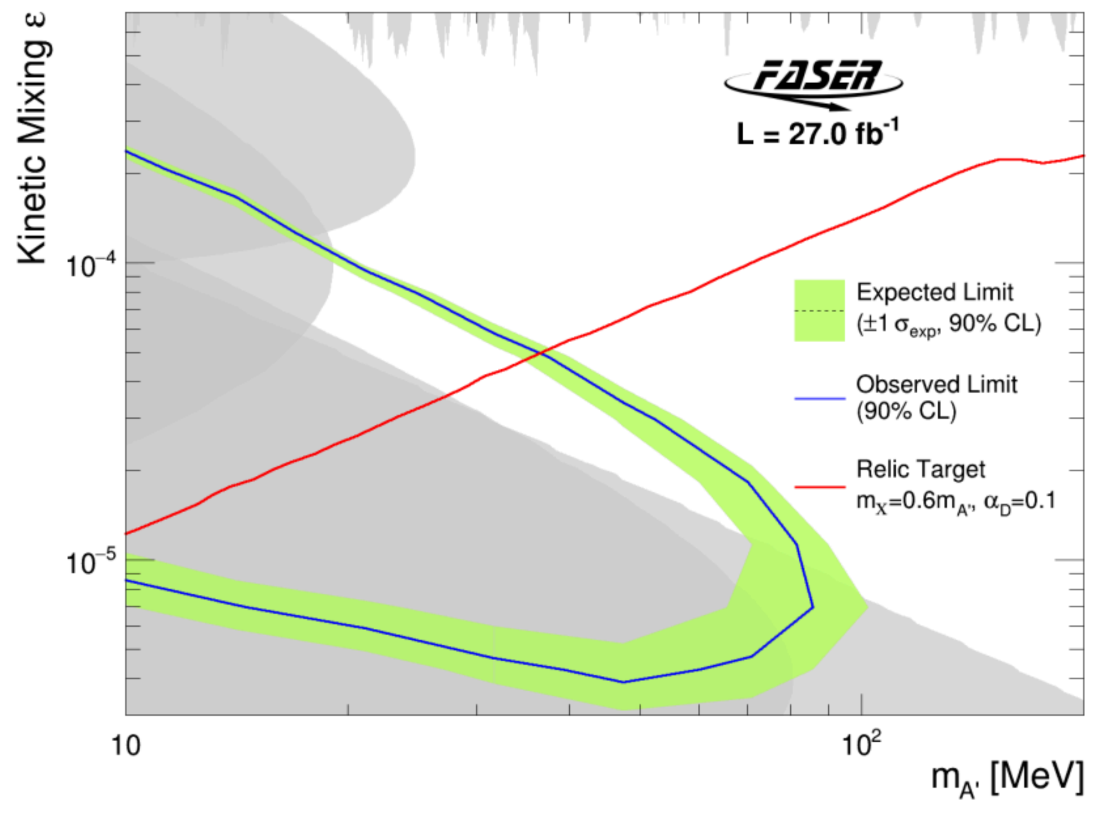
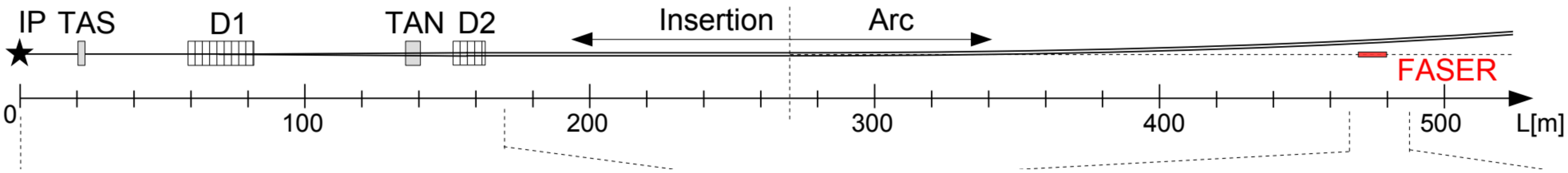


(a)

FASER collaboration **23**08.05587

FASER



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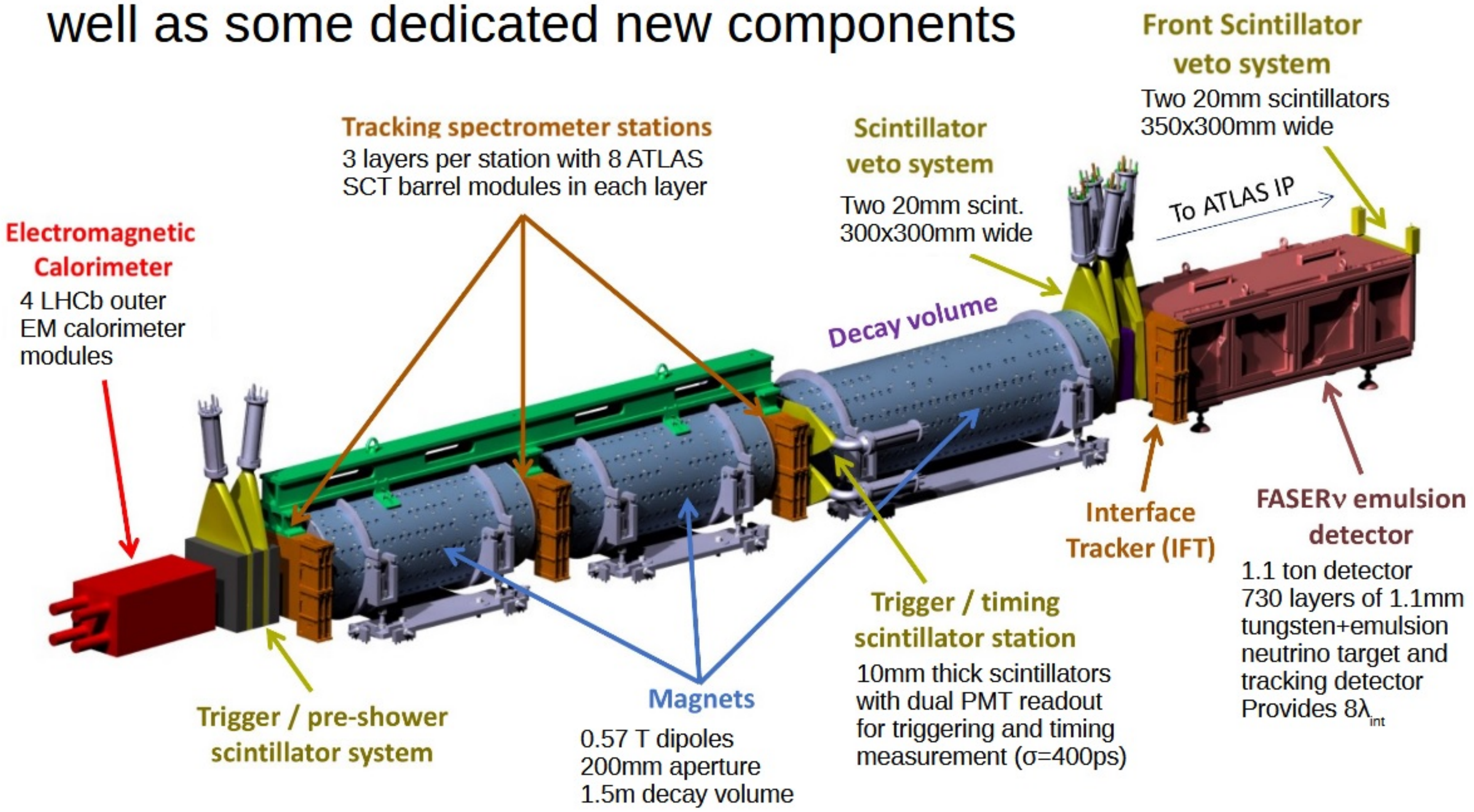

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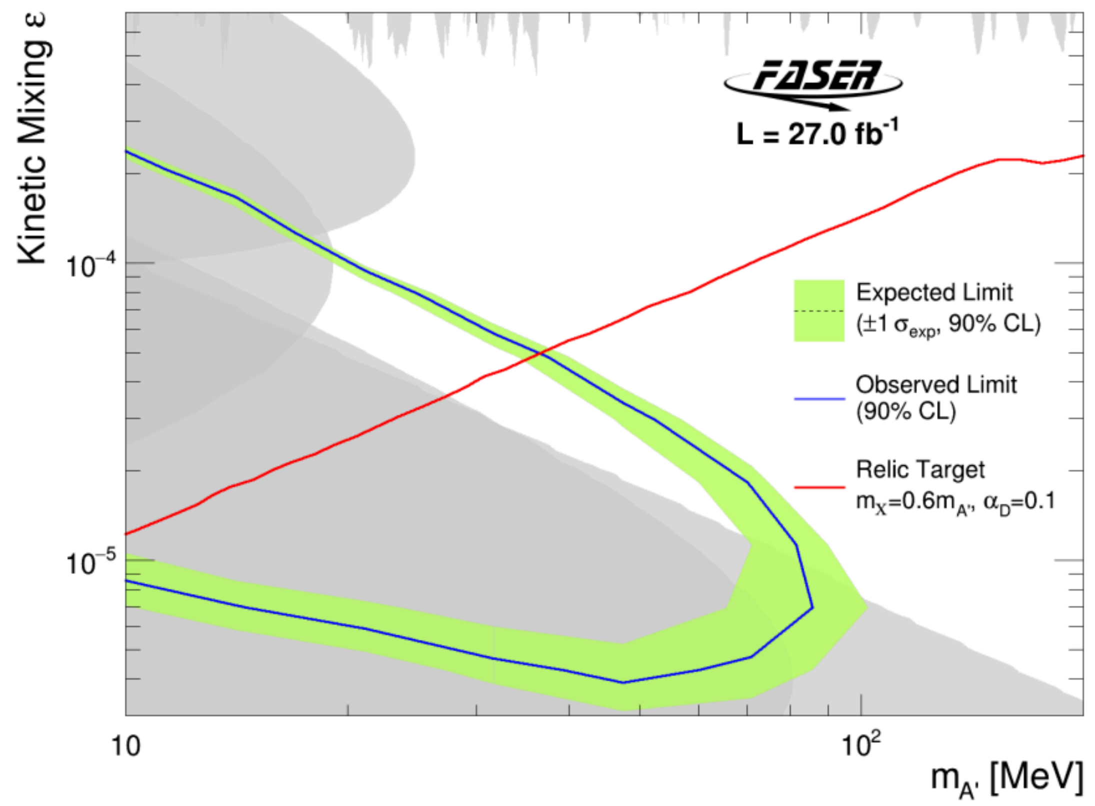

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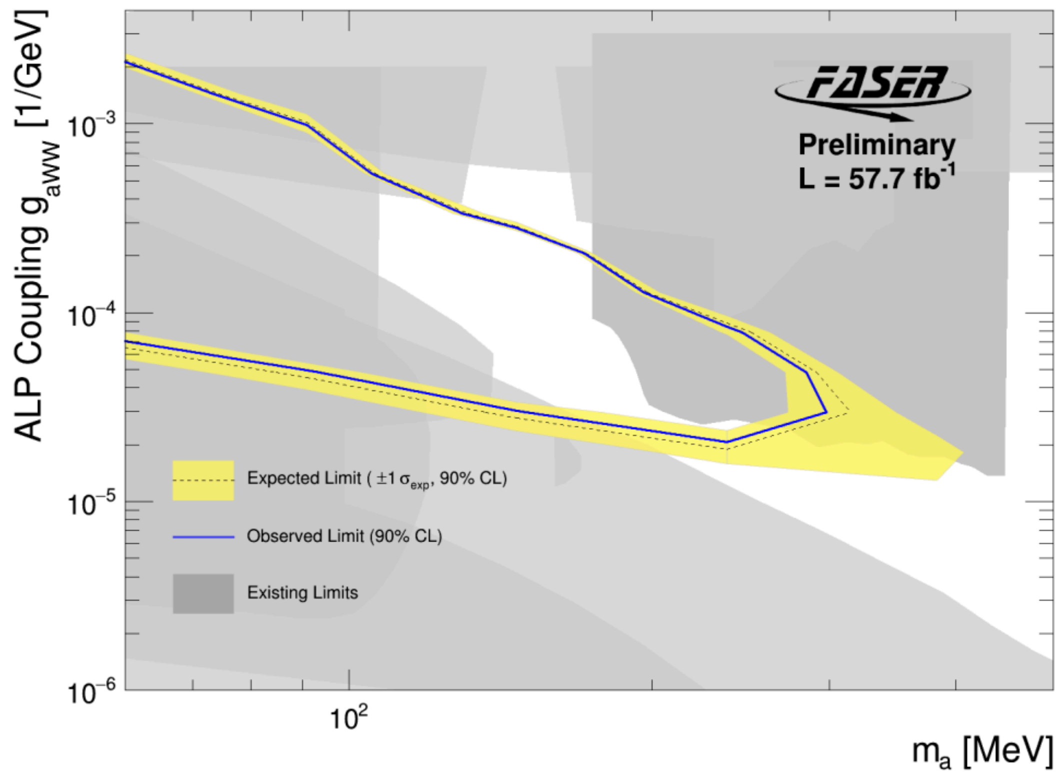

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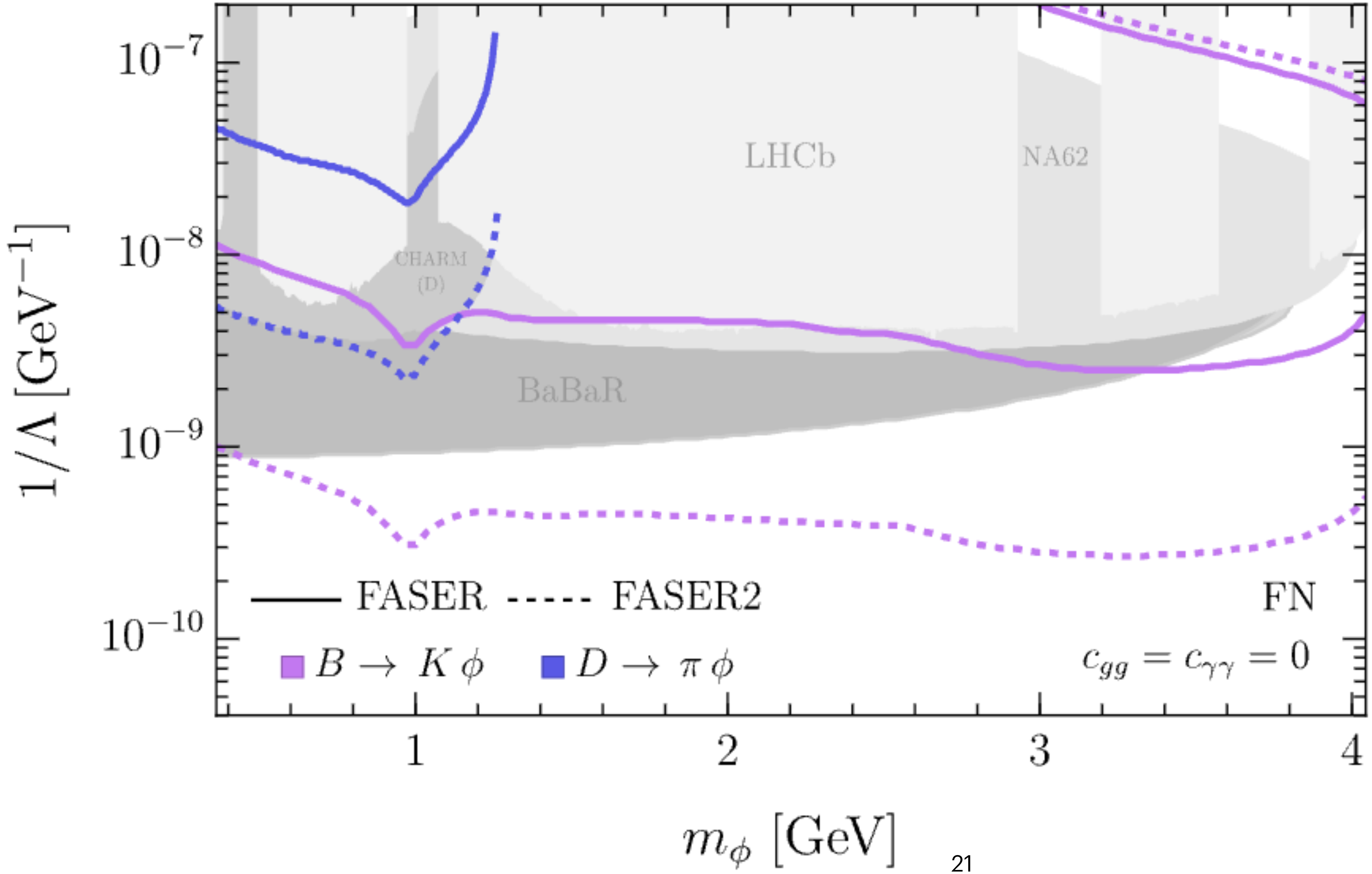
Results - FN models

RB, Burger, Feng, Shadmi 2412.15197



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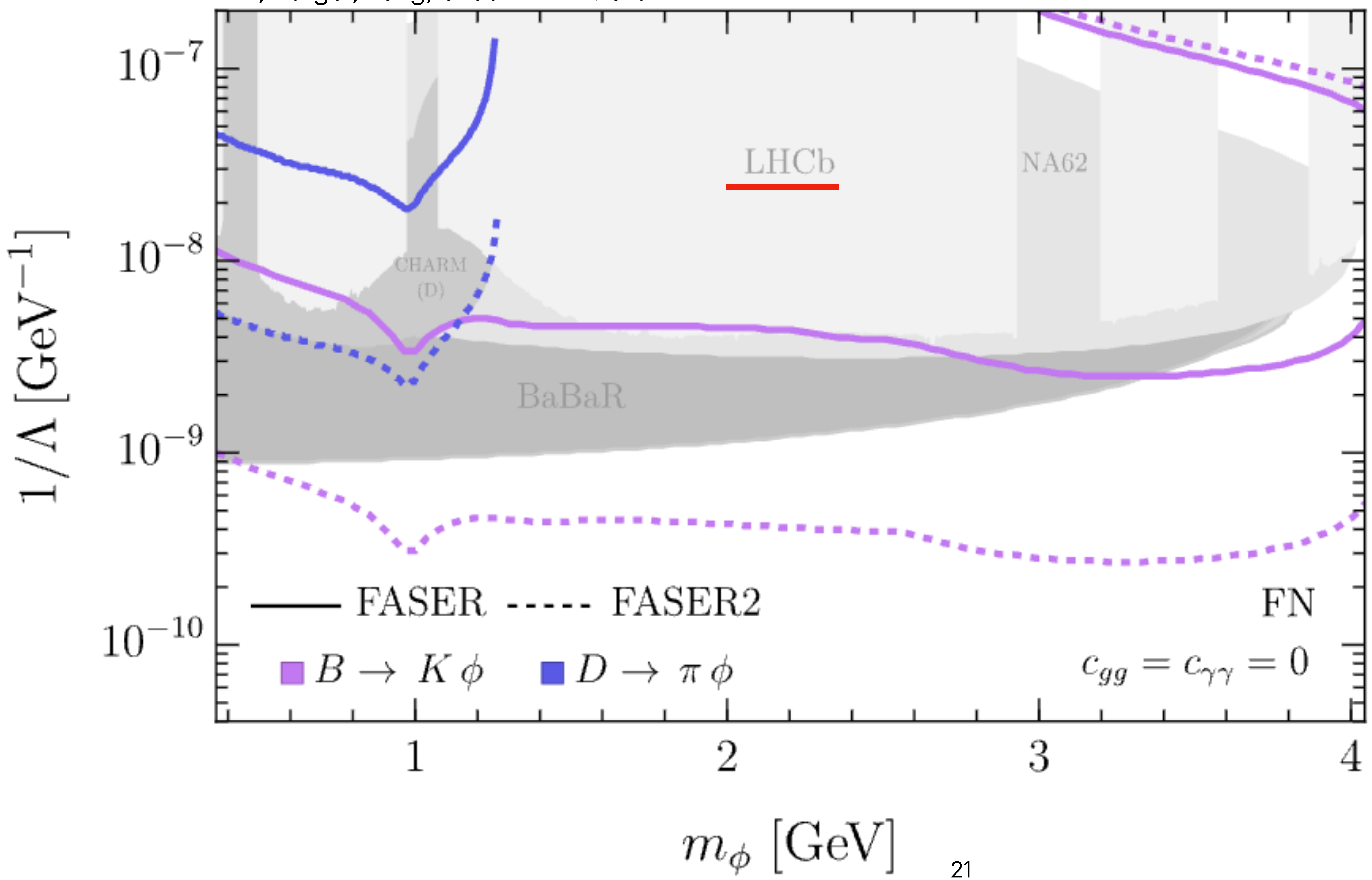

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$$B \to K\phi\,(\phi \to \mu\mu)$$

1508.04094

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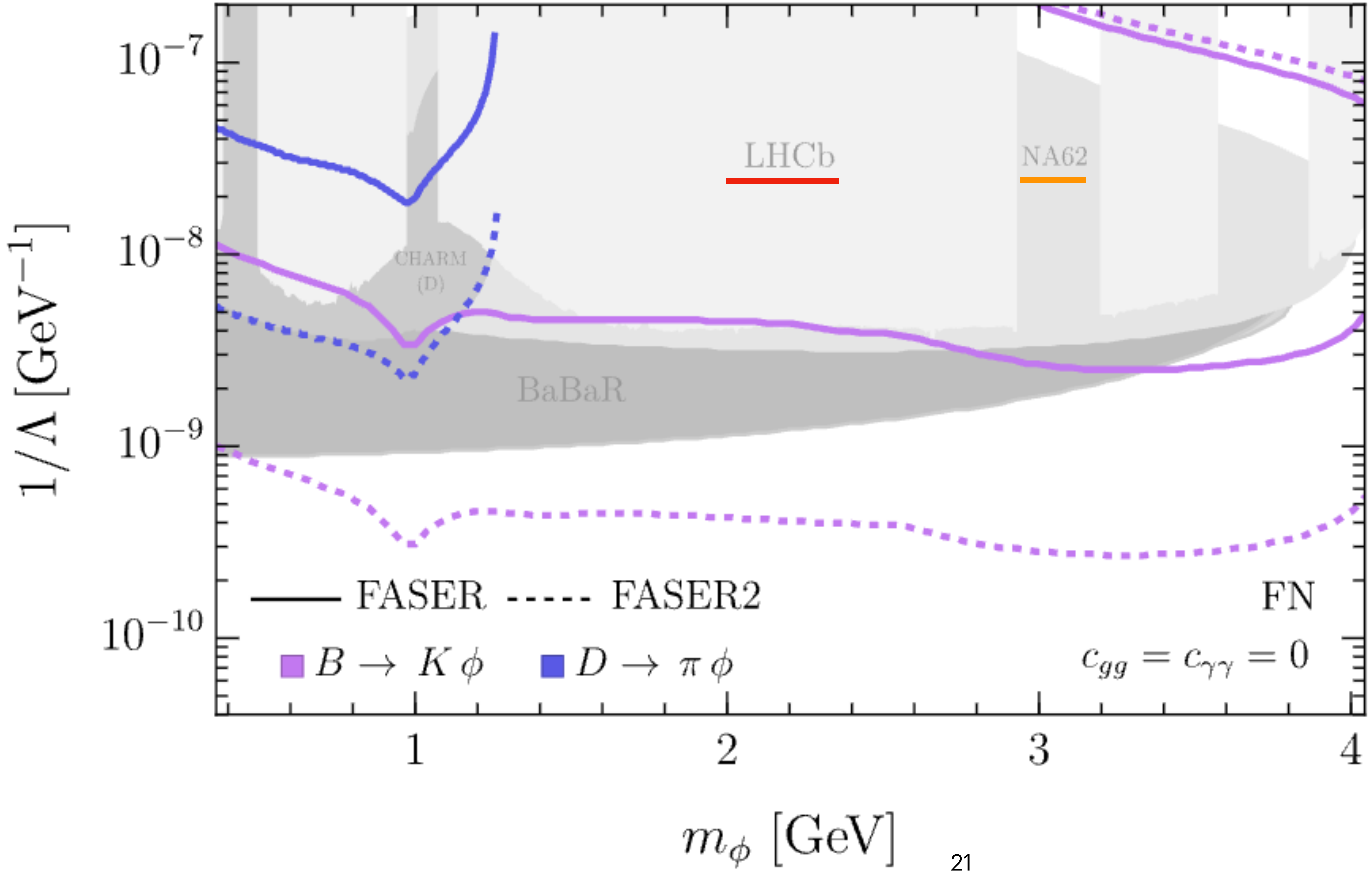

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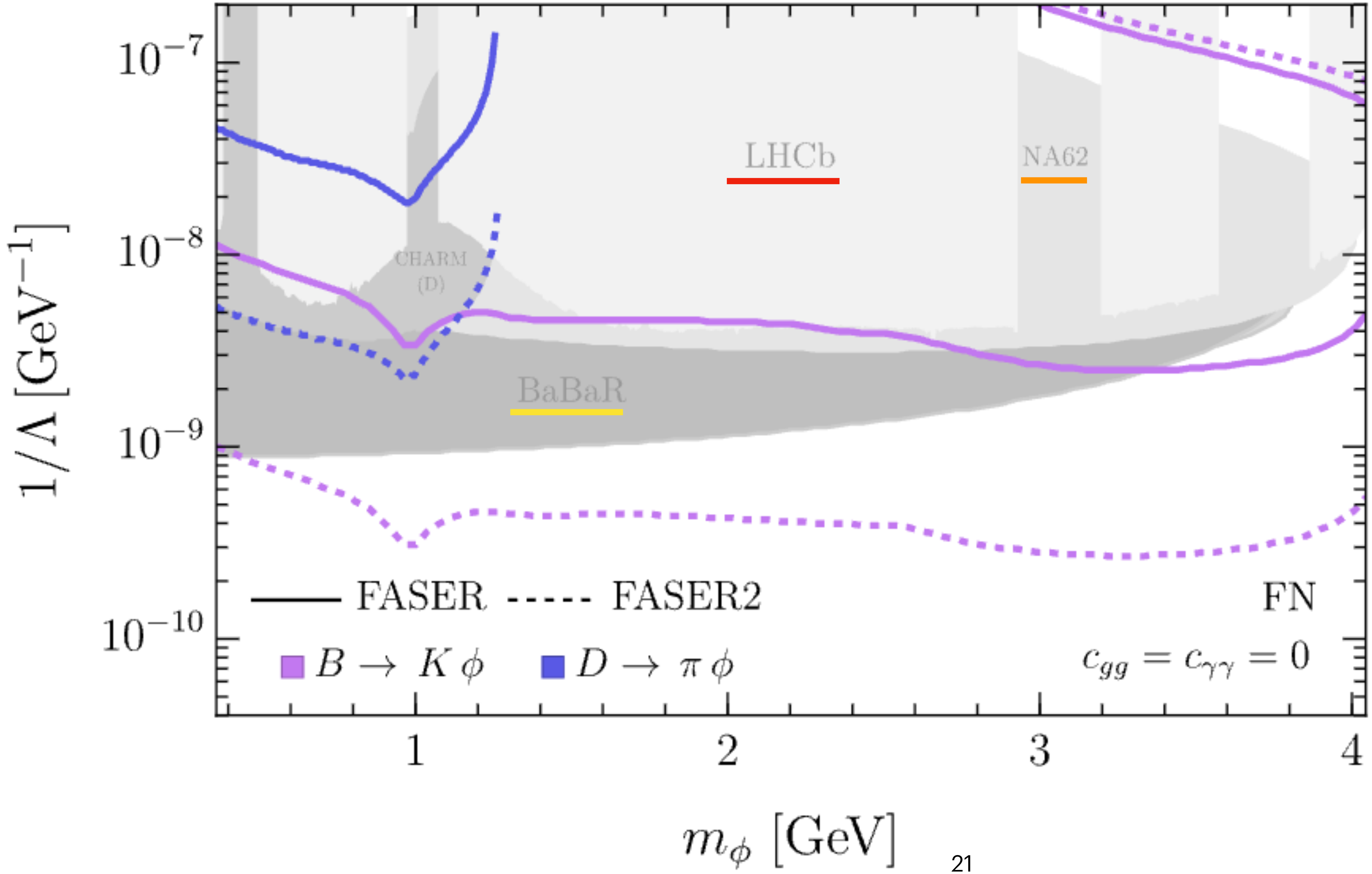

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Camalich et al. 2002.04623

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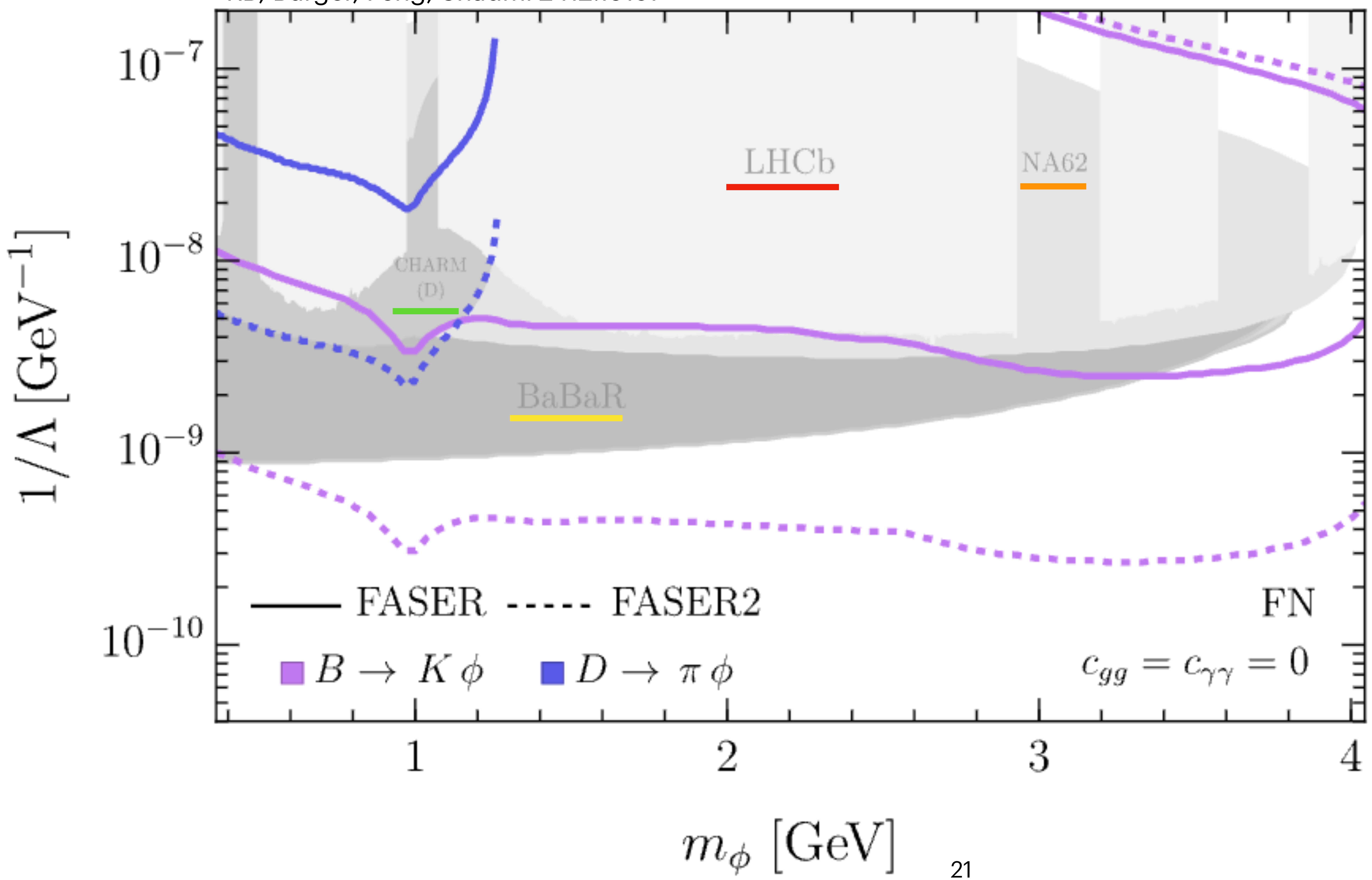

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CHARM

Phys. Lett. B 157 (1985) 458–462

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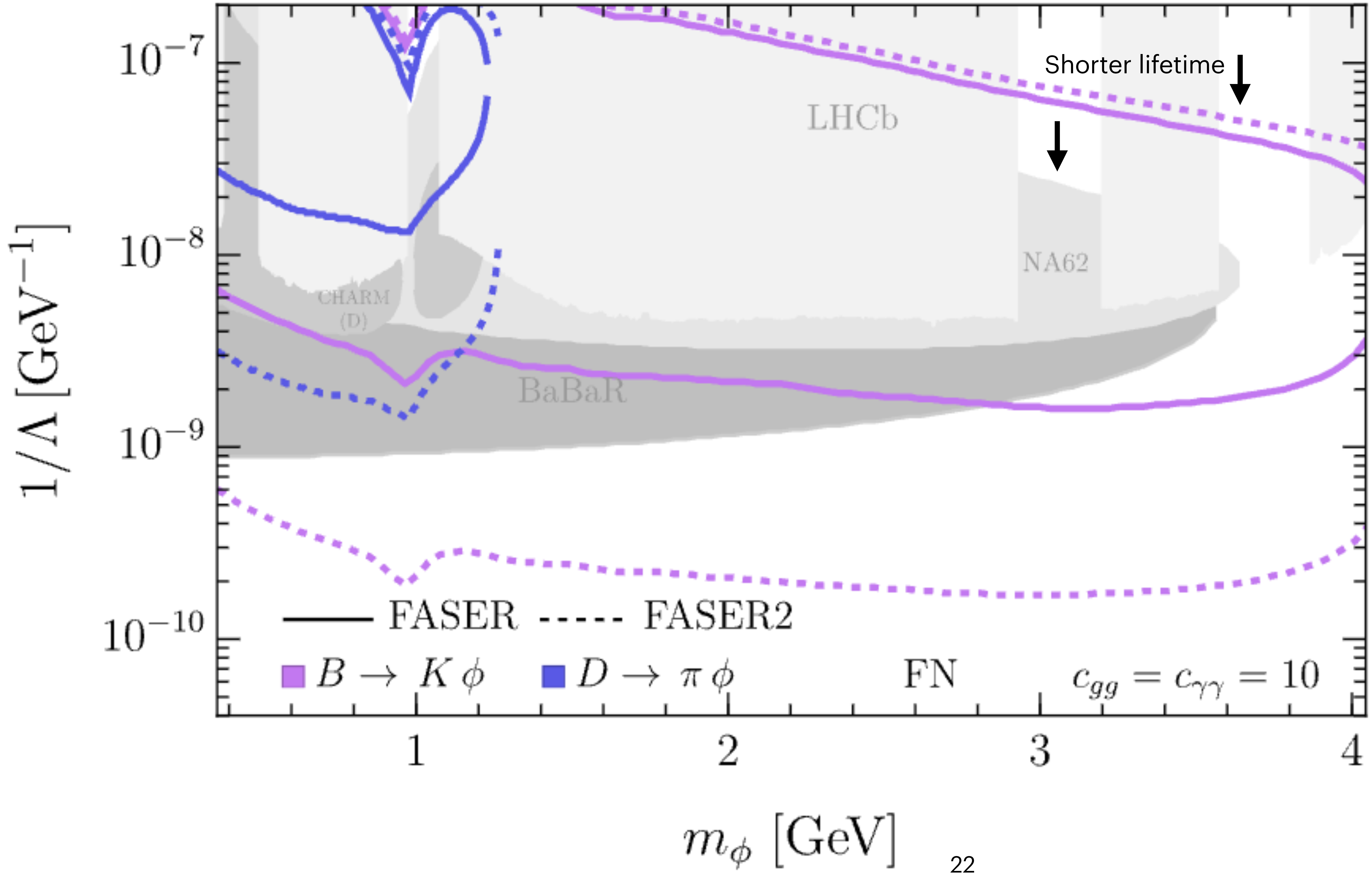

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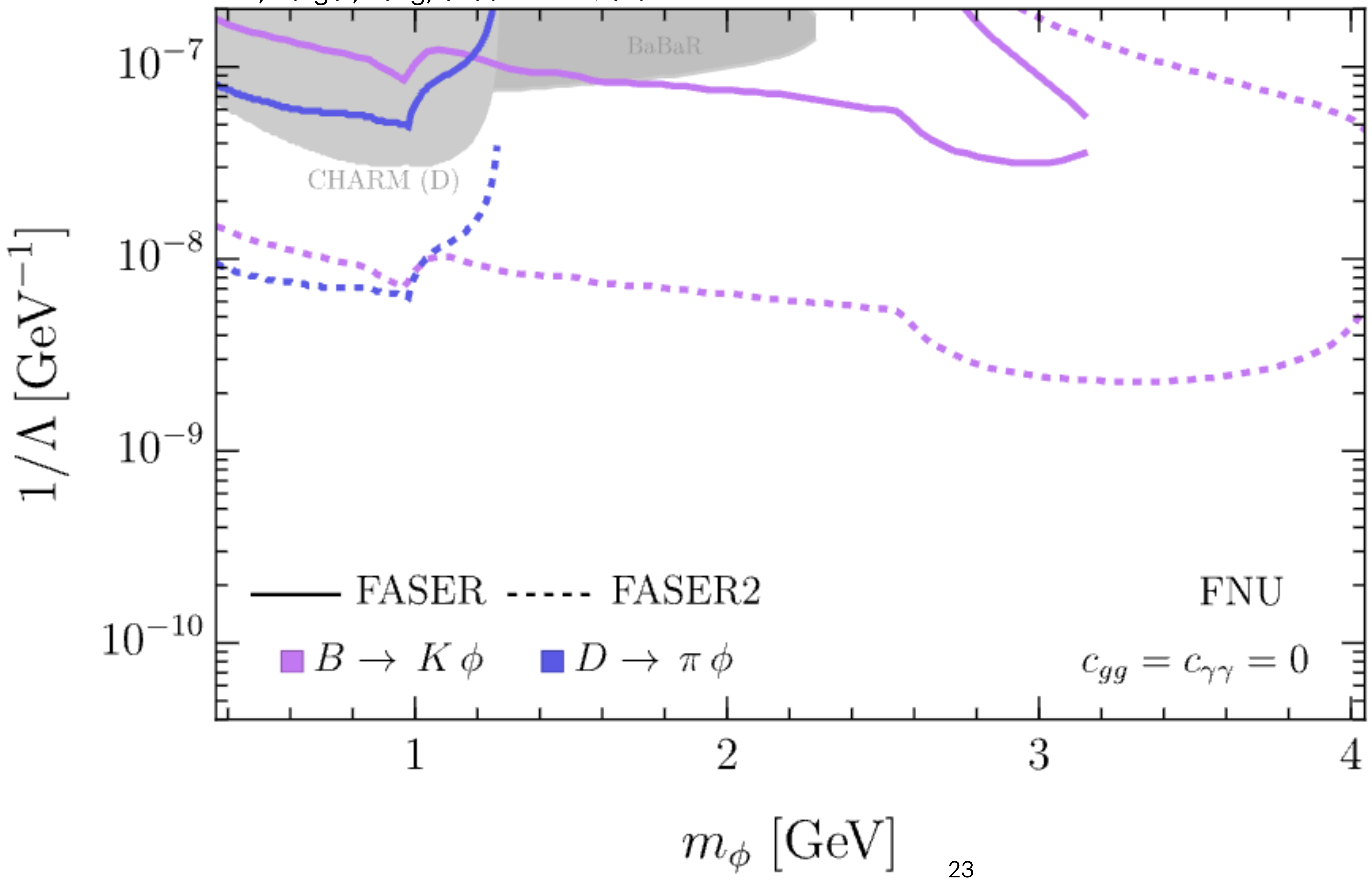

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Br$[\phi \to \mu\mu] \to 0$

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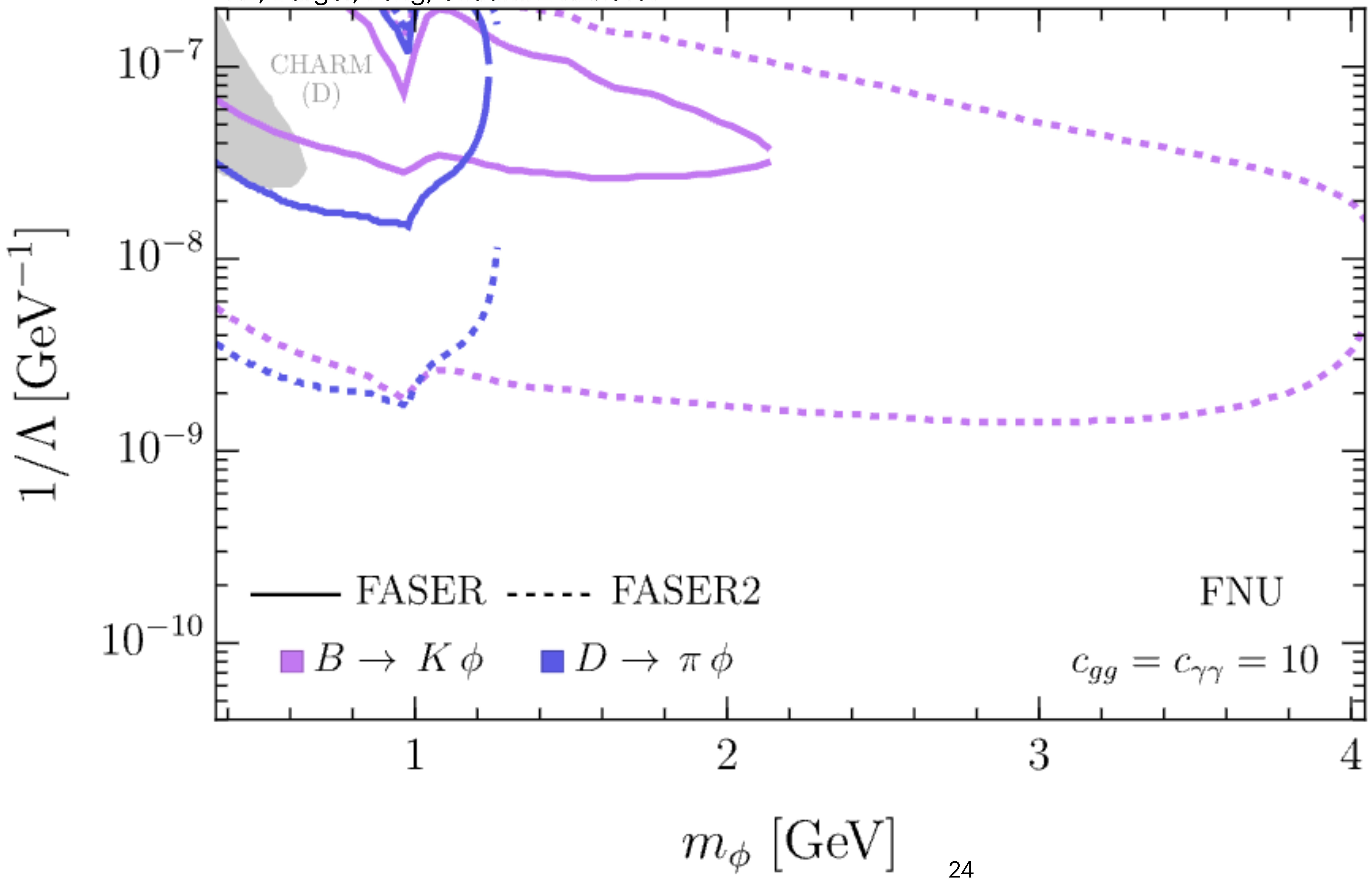

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Too short-lived

CHARM

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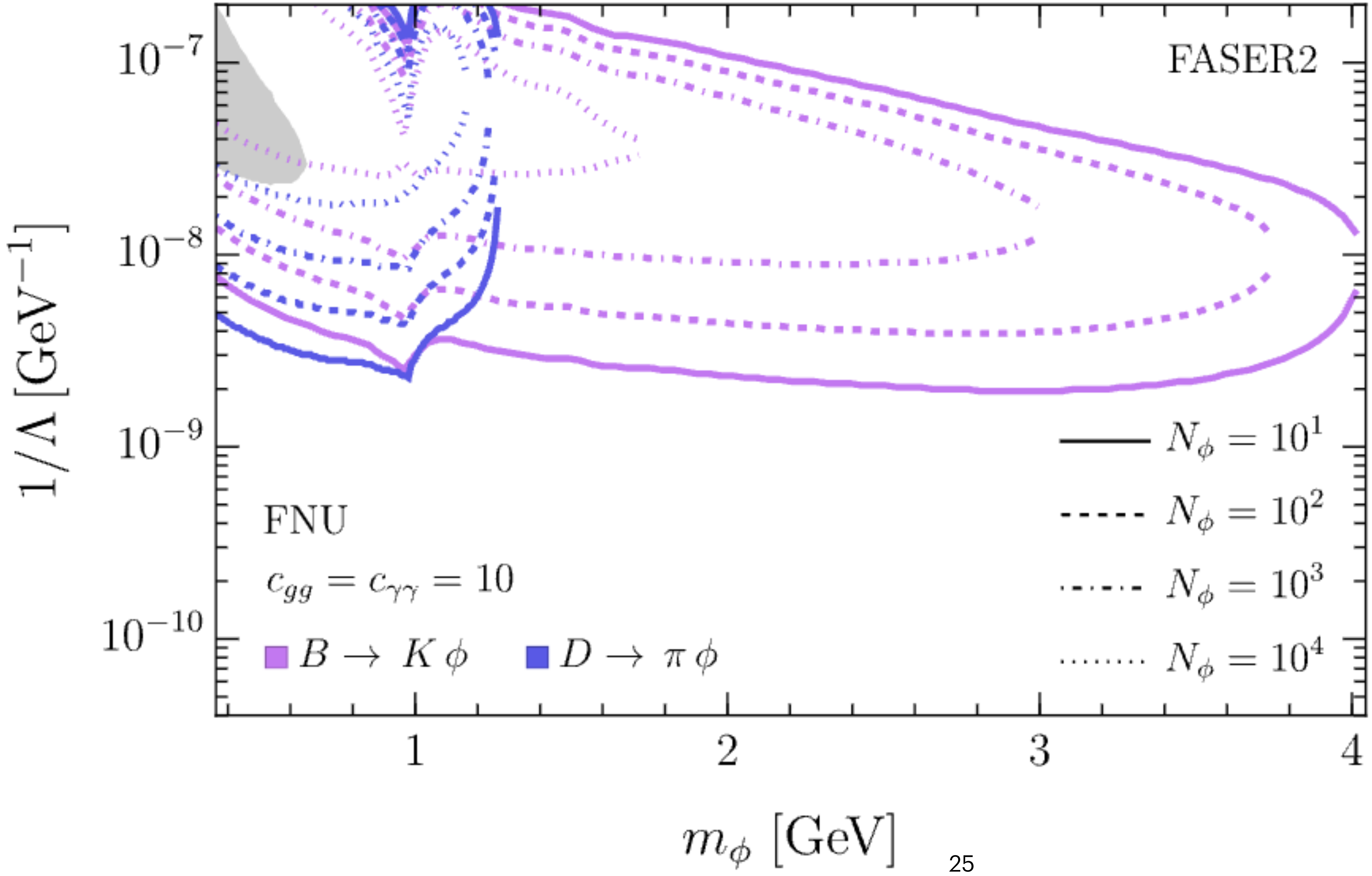
Disentangling Flavor violation

RB, Burger, Feng, Shadmi 2412.15197



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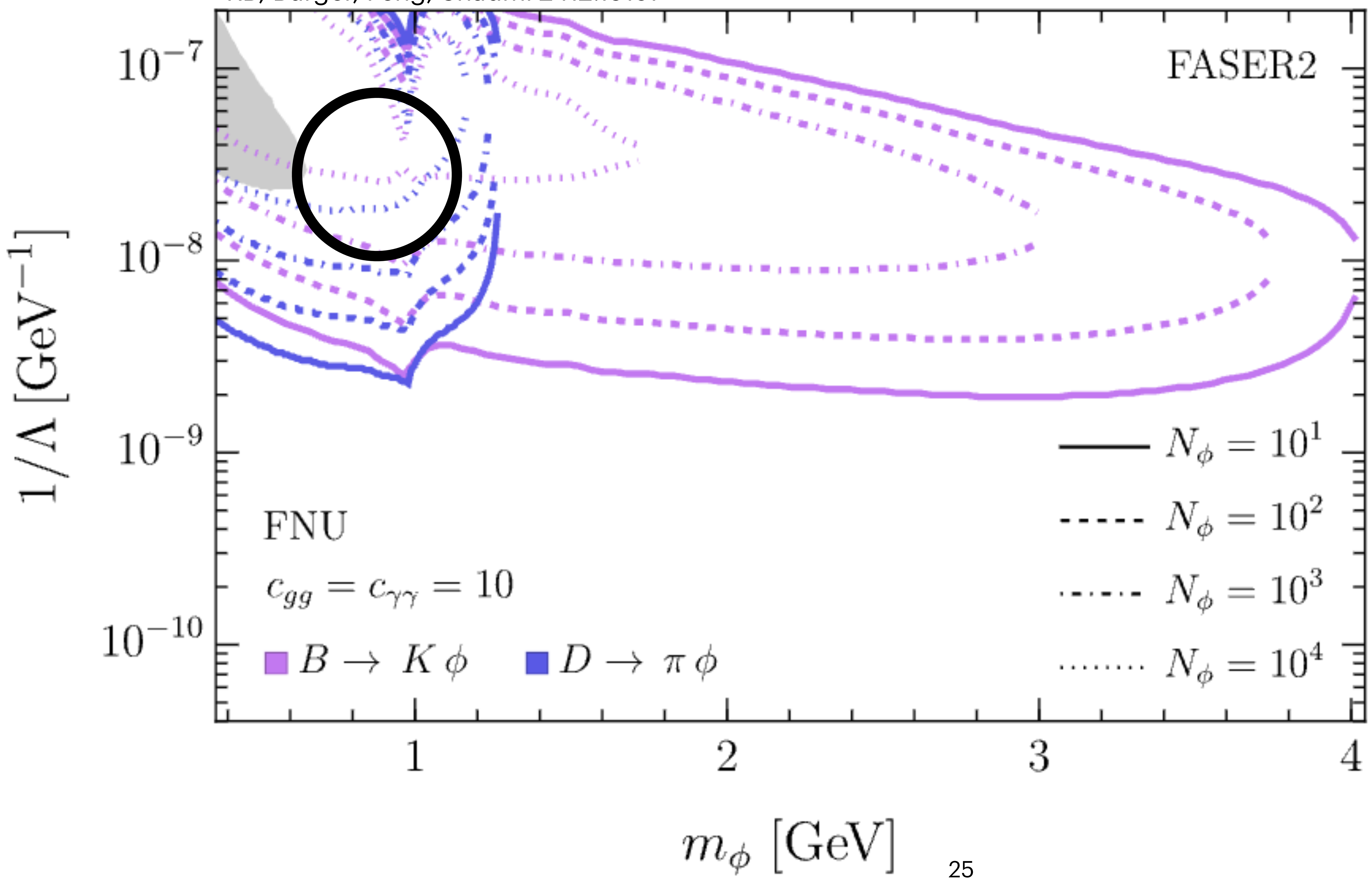

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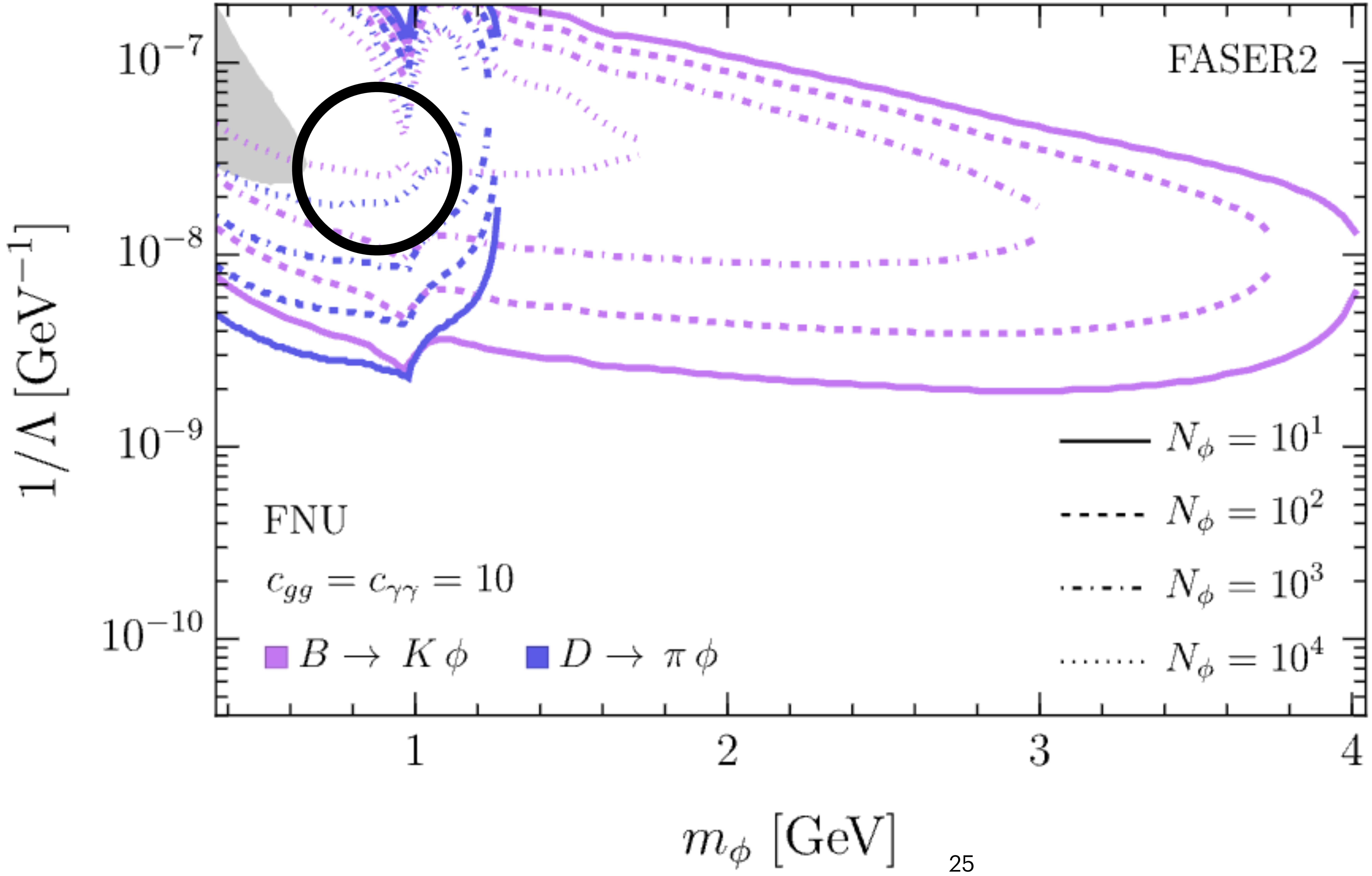

Comparable or dominating D decays = Clear indication of Non-MFV theory

Disentangling Flavor violation

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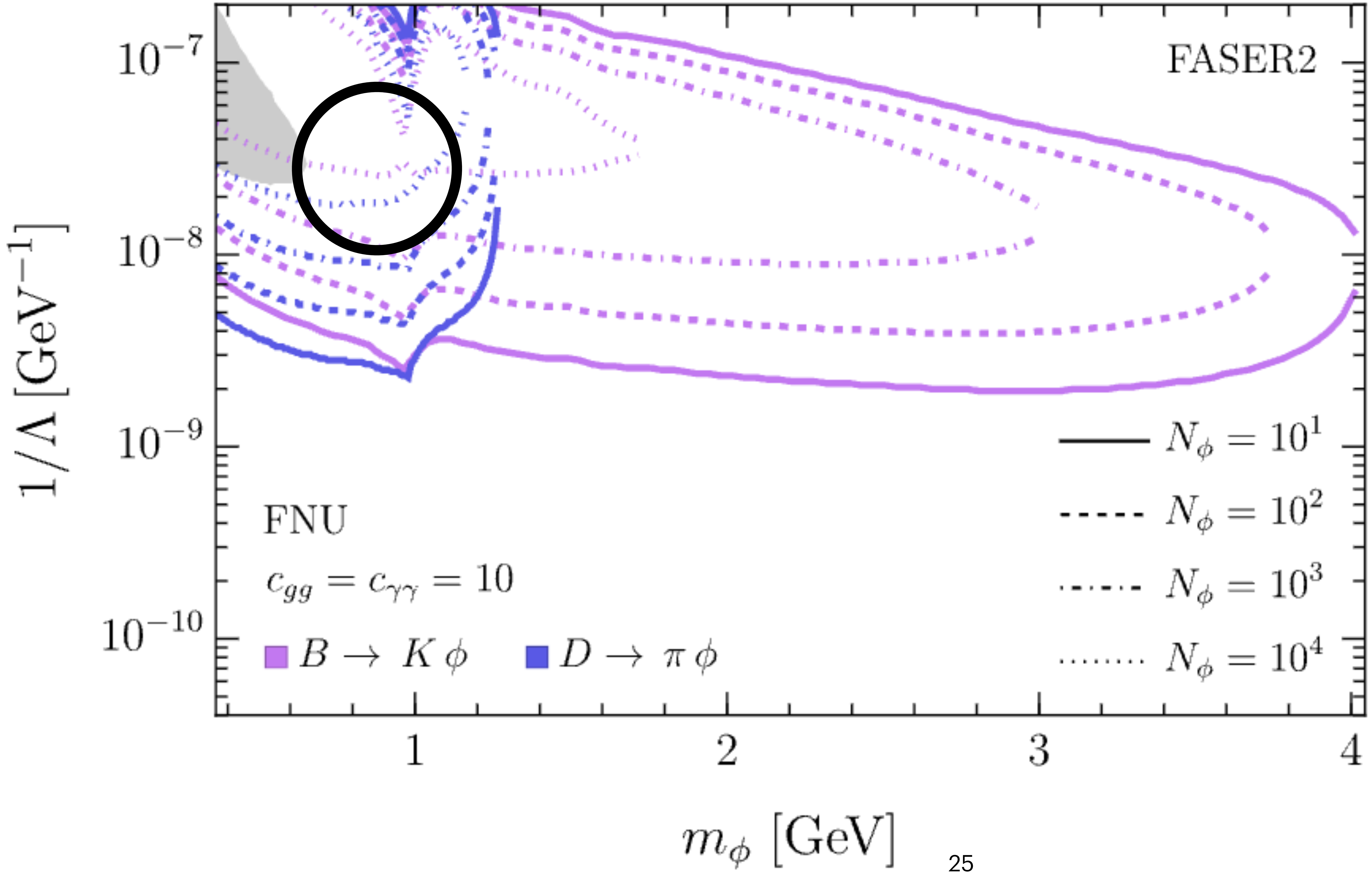
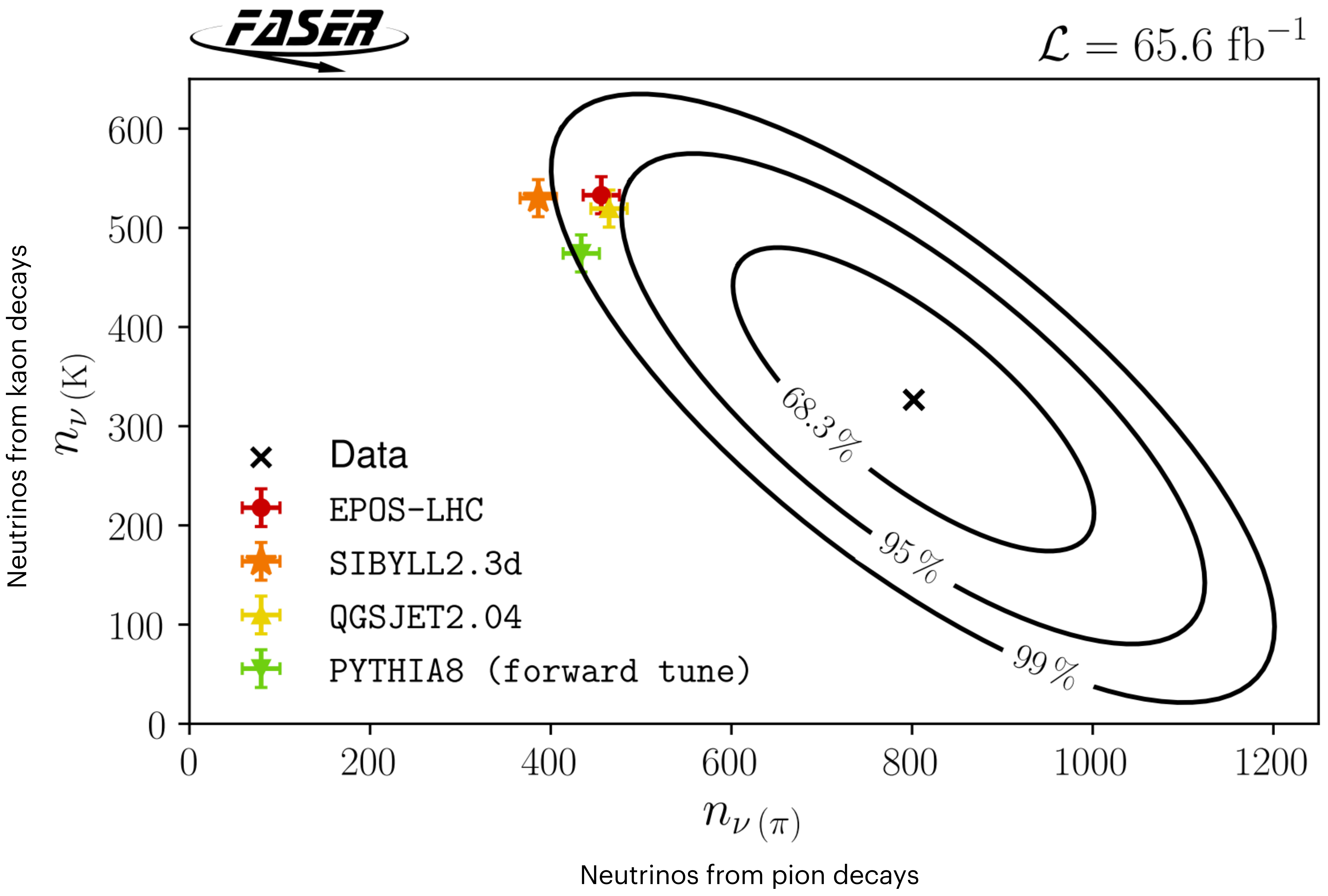


Comparable or dominating D decays
=
Clear indication of Non-MFV theory

Can D and B decay be disentangled?

Disentangling Flavor violation



Proof of concept

FASER collaboration
2412.03186

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$$\{m_\phi, \Lambda, c\} \to \{m_\phi, \tau_\phi, \mathrm{Br}[M \to M'\phi]\}$$

Model-independent approach

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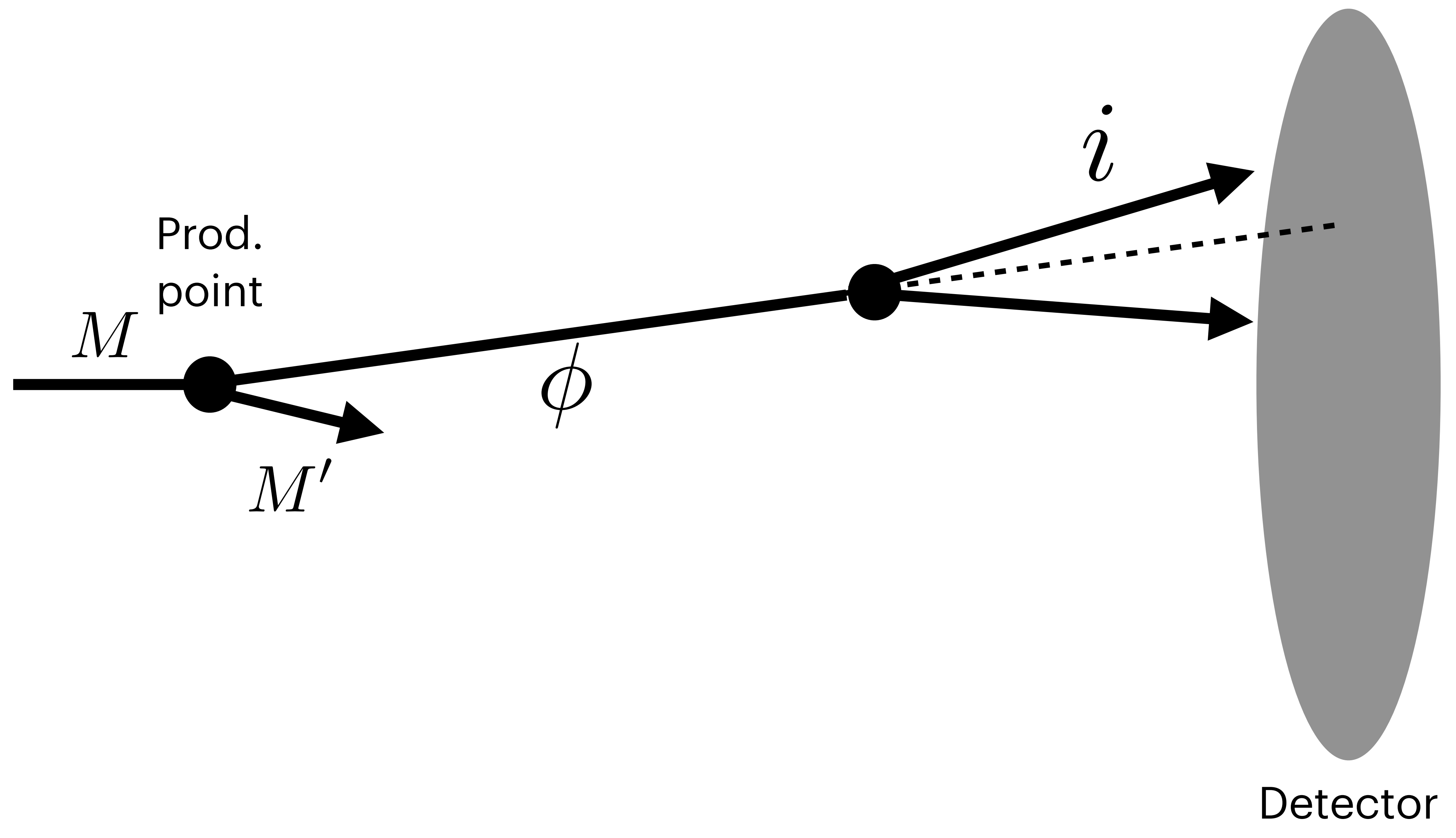
$$M \;\to\; M'\,\phi$$

Model-independent approach

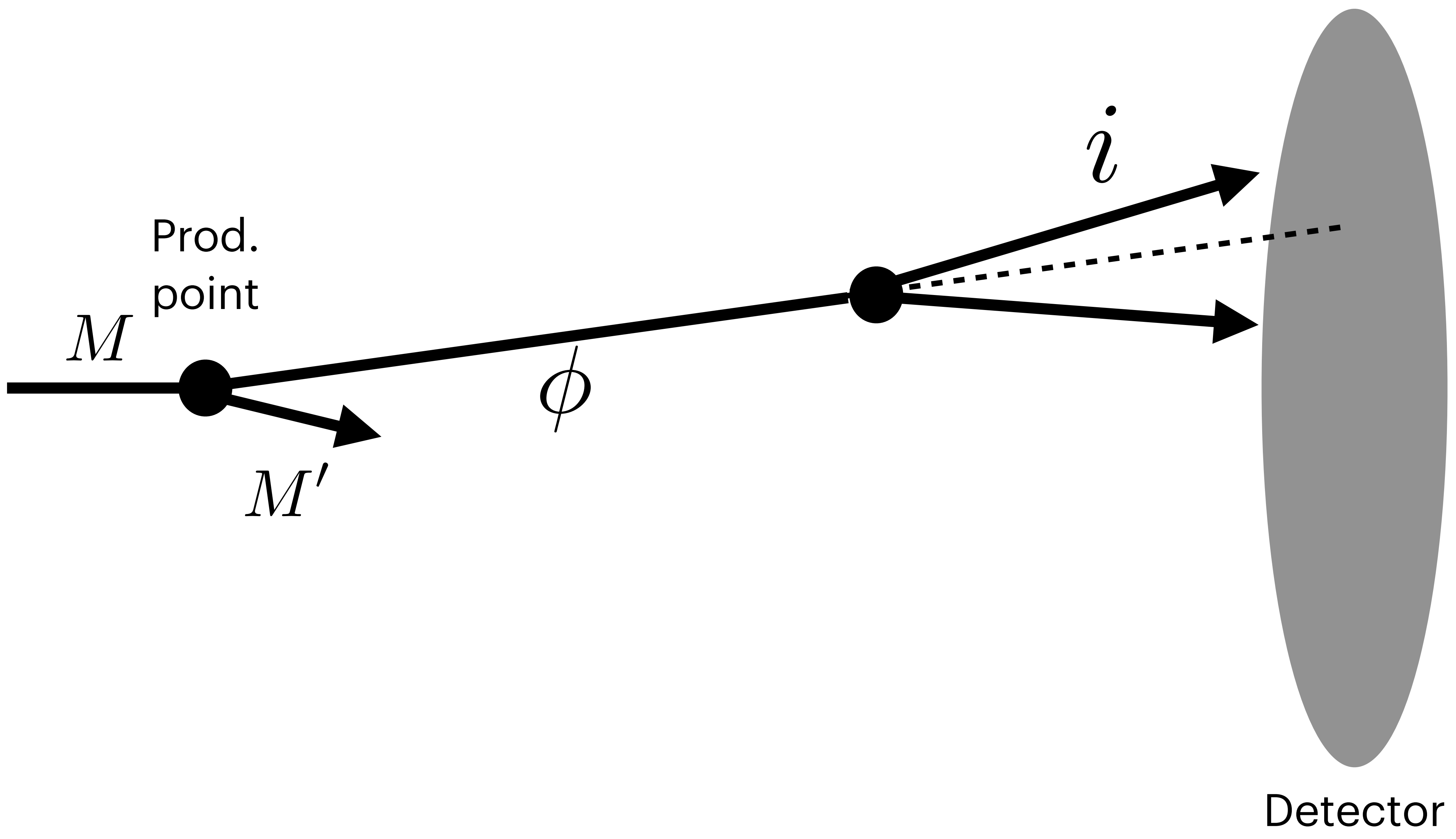
$$M \to M' \, \phi$$



Model-independent approach

$$M \to M' \phi$$

$$N_\phi \sim N_M \cdot \mathrm{Br}(M \to M' \phi) \cdot \mathcal{A}(m_\phi) \cdot P_{\mathrm{decay}}(\tau_\phi / m_\phi) \sum_{i \in \mathrm{visible}} \mathrm{Br}(\phi \to i) \cdot \epsilon_i$$



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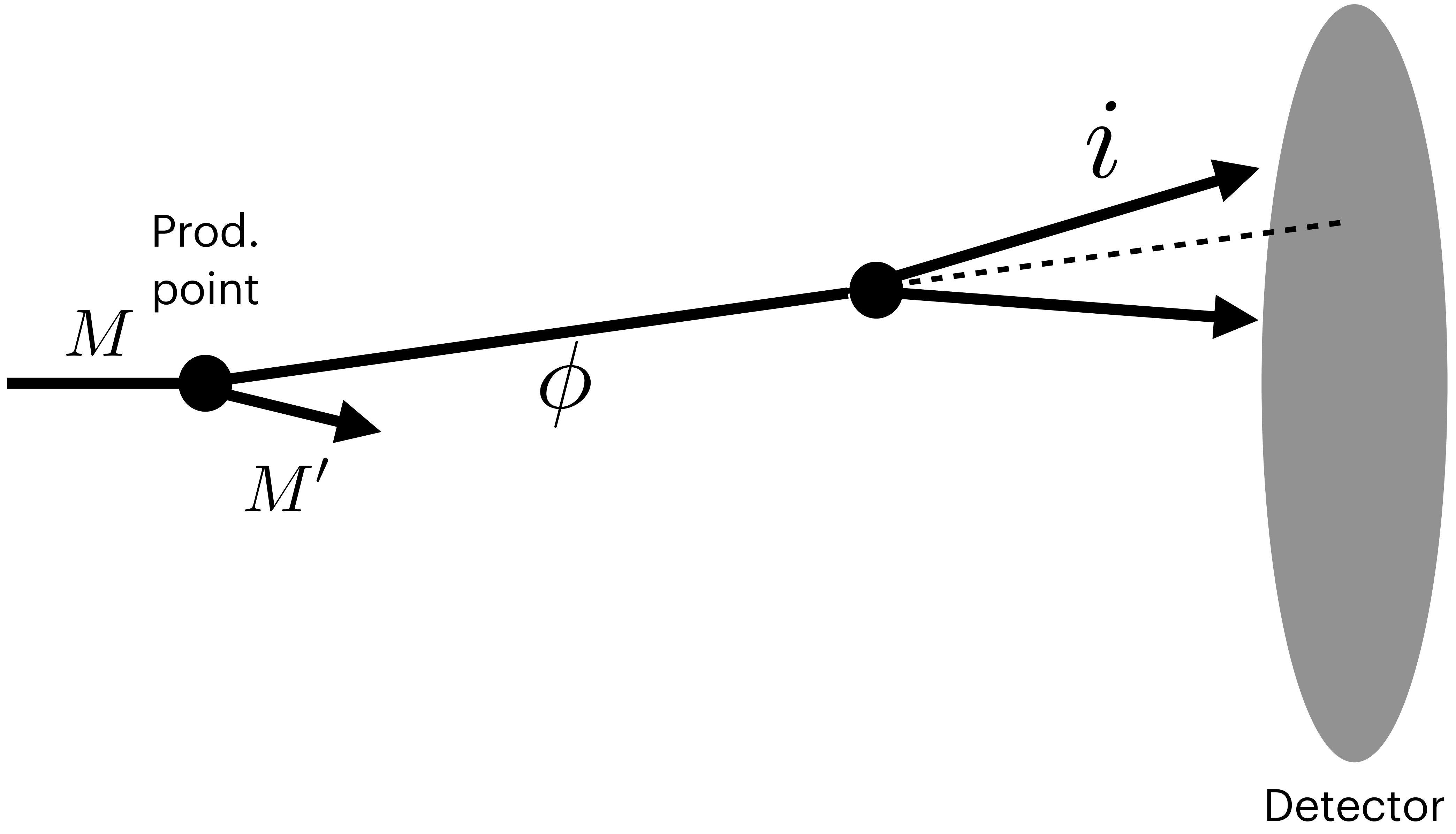
Total yield of M meson



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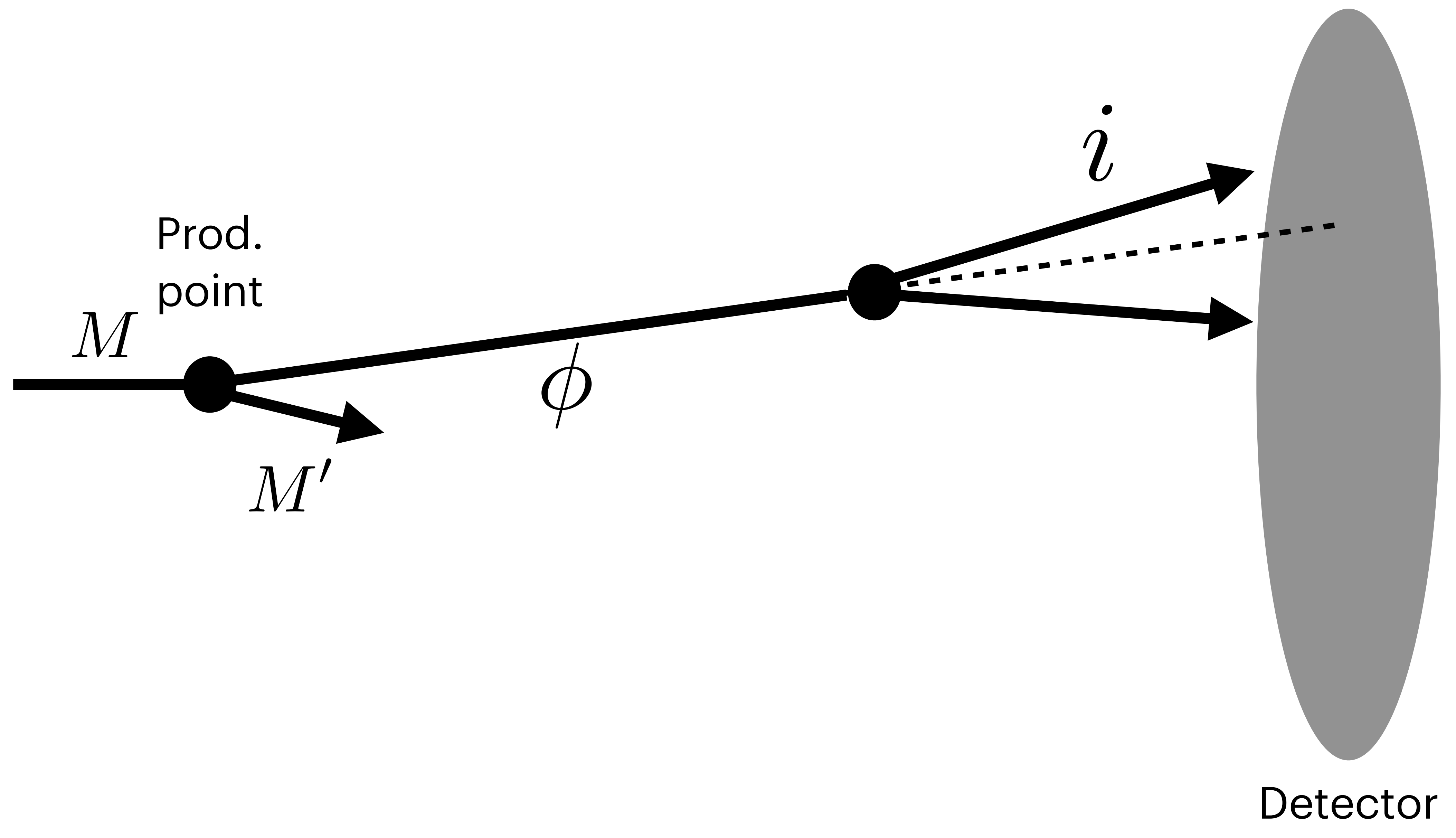

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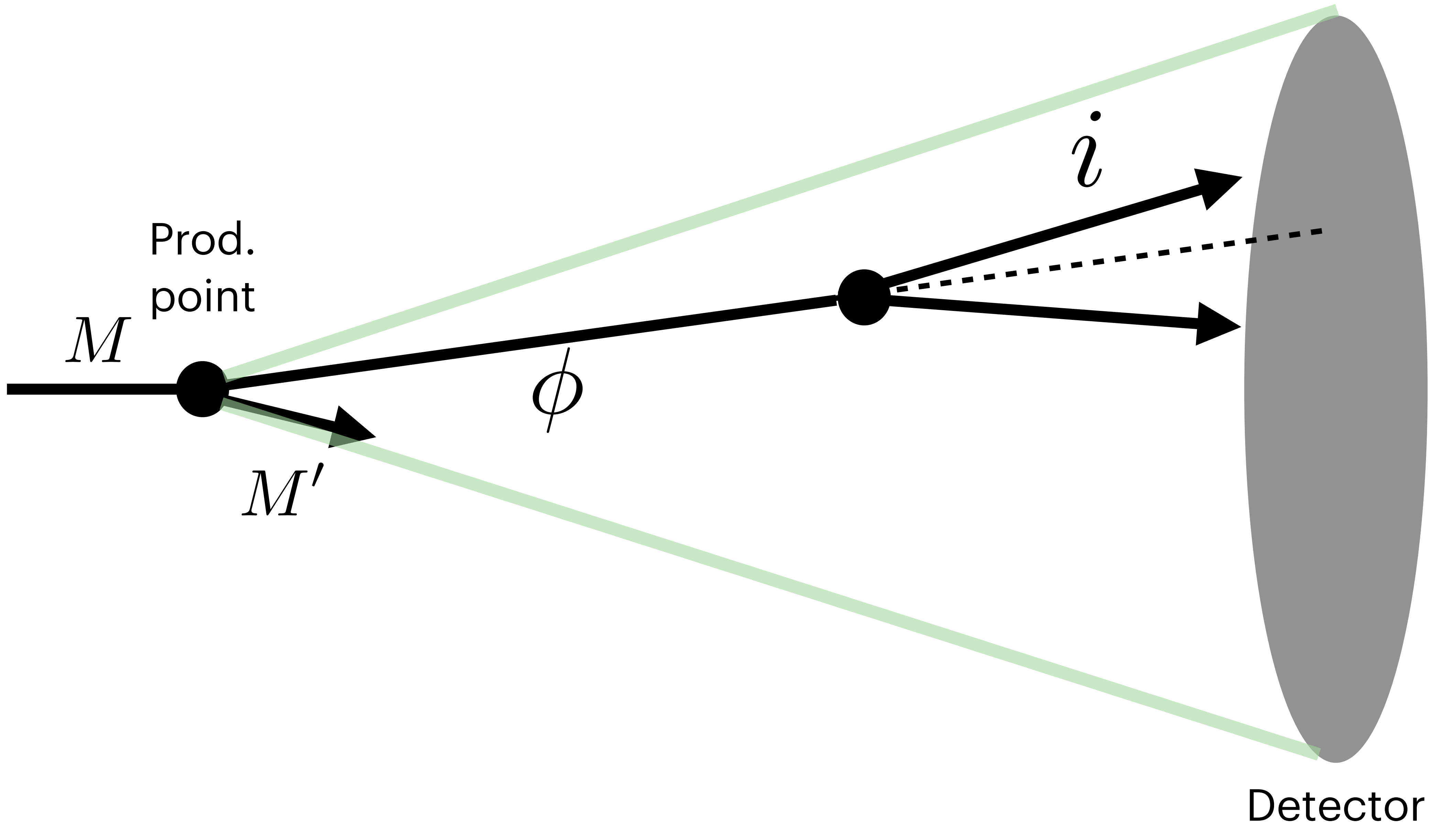
Branching ratio

Geometrical acceptance



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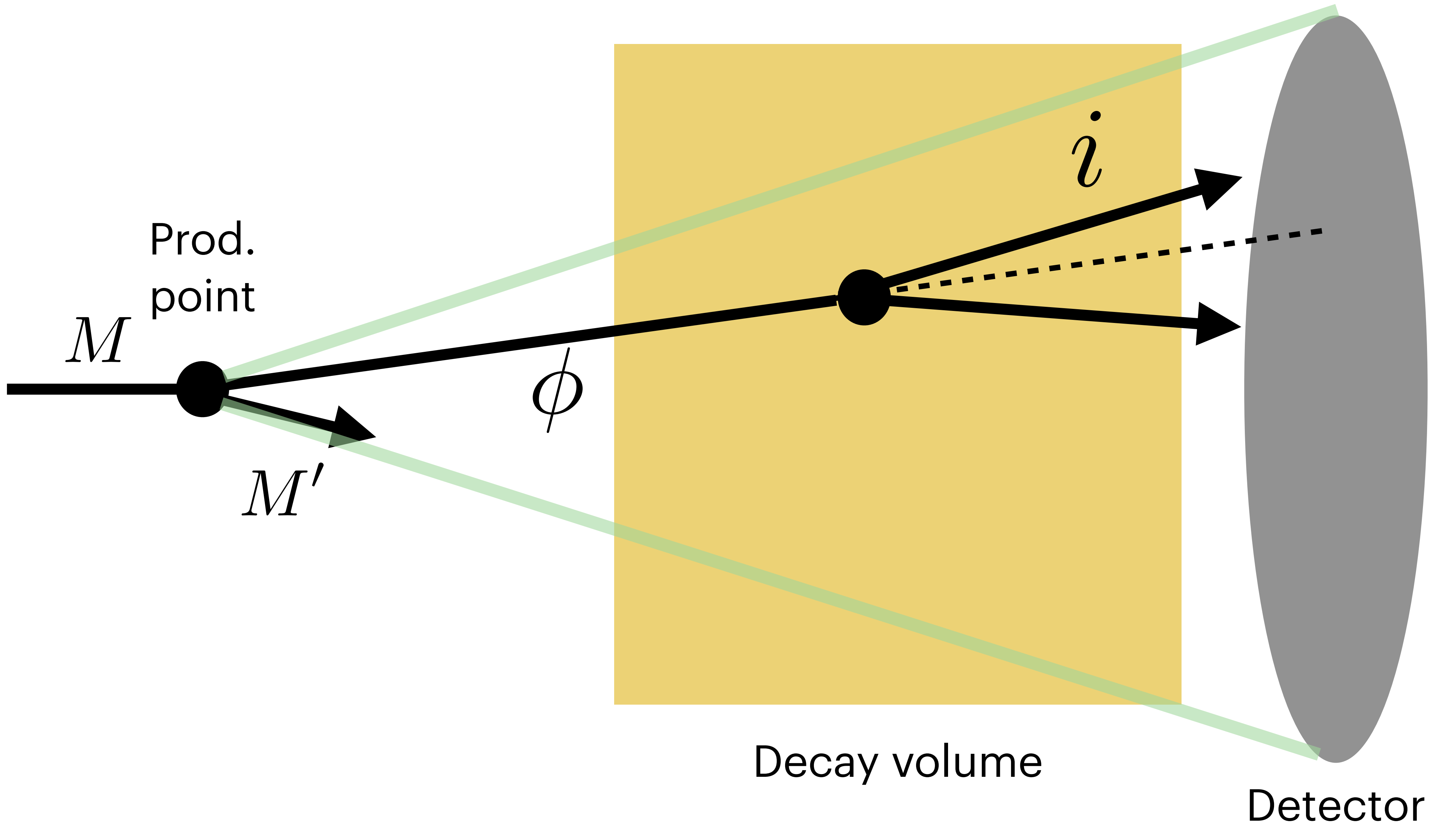
Total yield of M meson

Branching ratio

Geometrical acceptance

Decay probability



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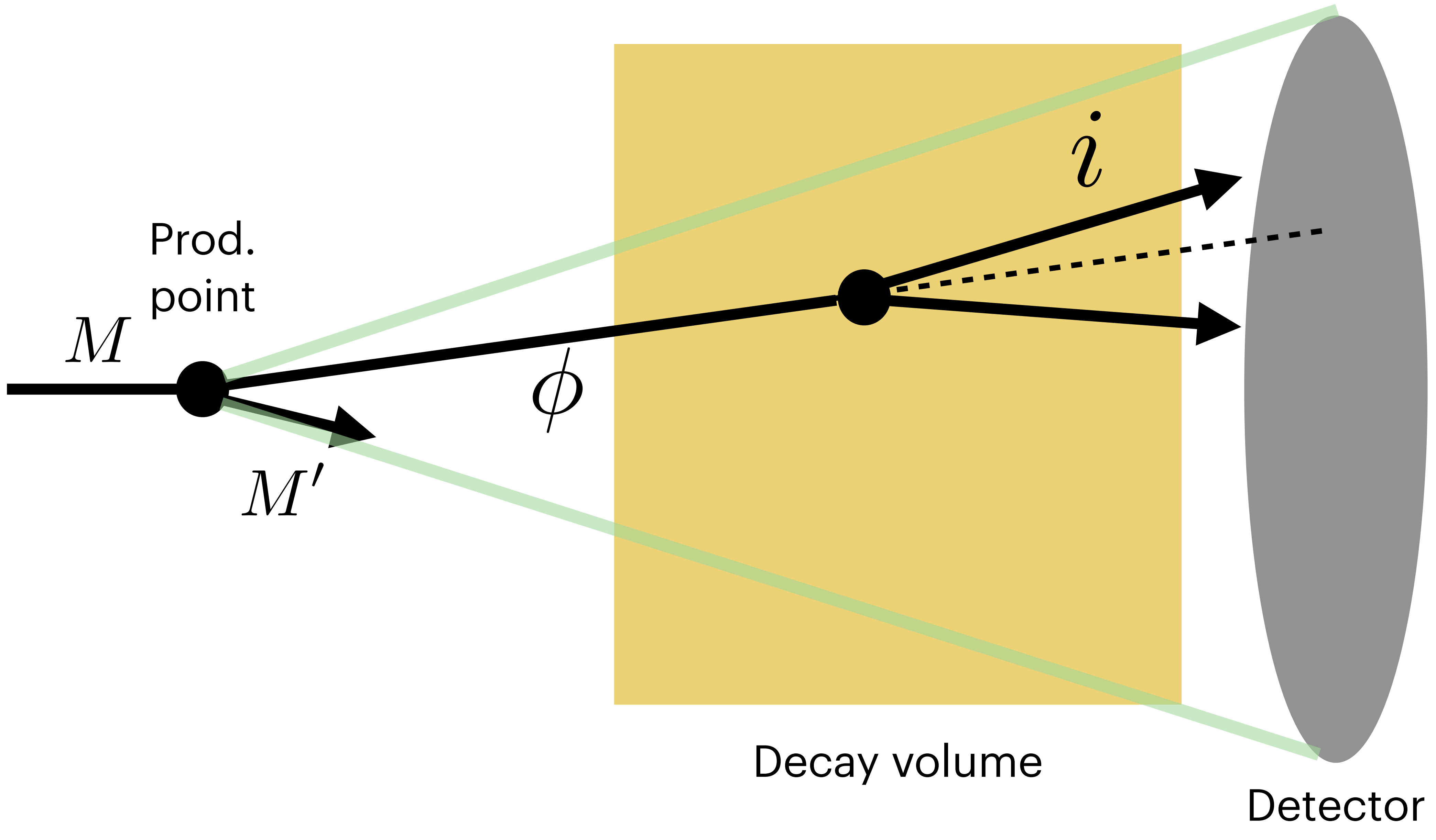
Total yield of M meson

Branching ratio

Geometrical acceptance

Decay probability

Detection efficiency



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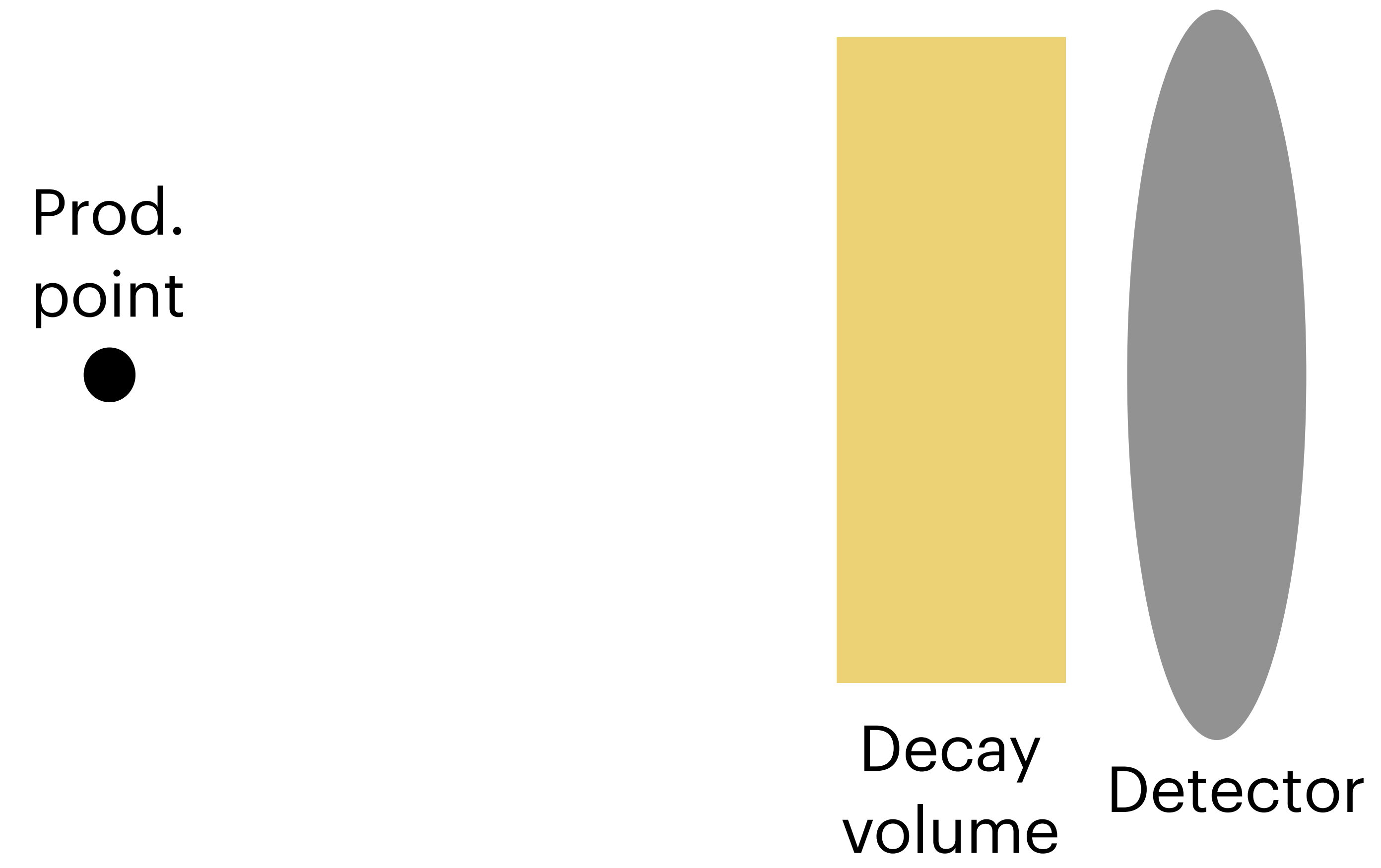
$$P_{\mathrm{decay}}(\tau_\phi / m_\phi) \approx \exp(-L/d_{\mathrm{lab}}) \, [1 - \exp(-\Delta/d_{\mathrm{lab}})]$$



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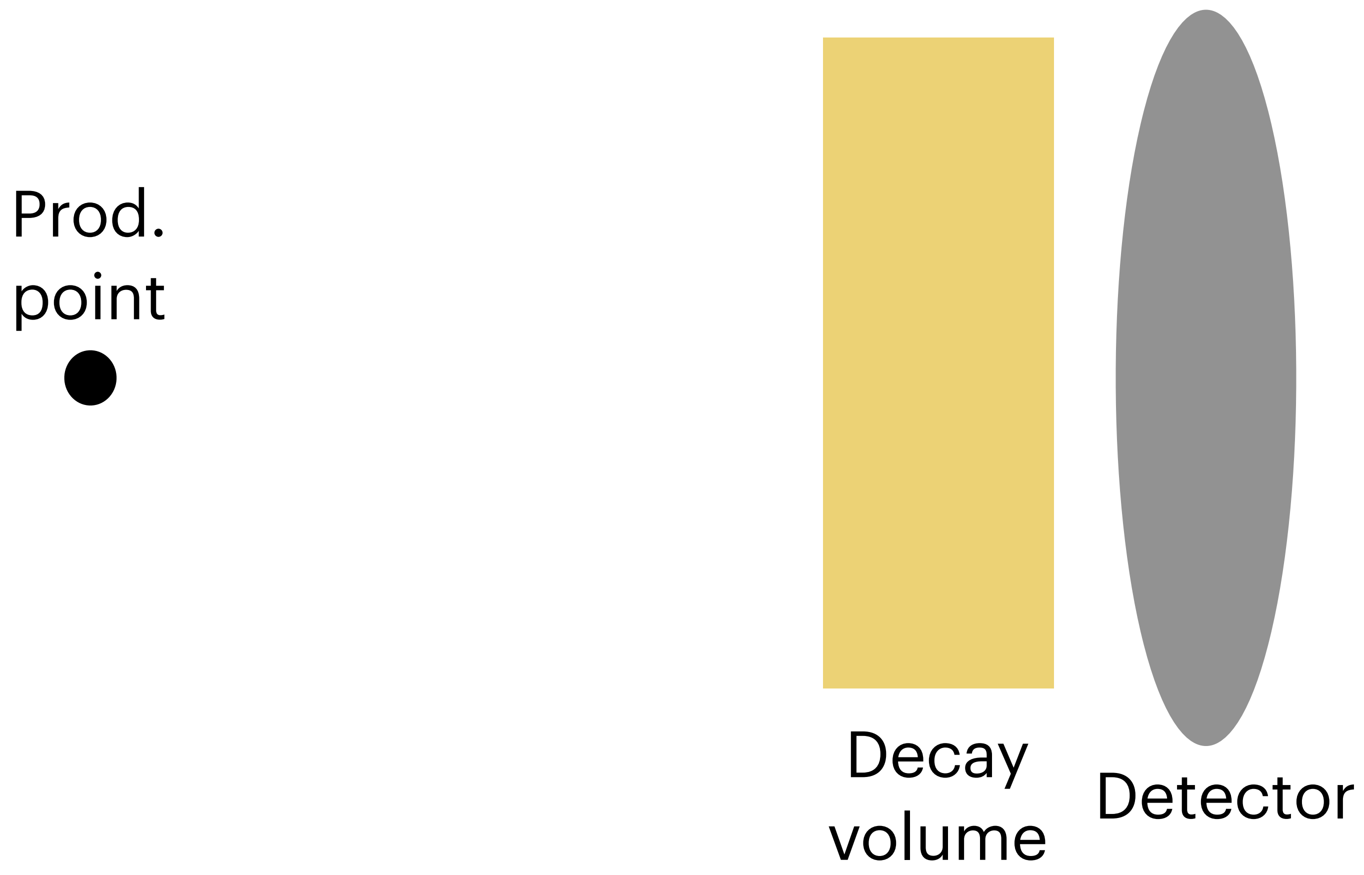

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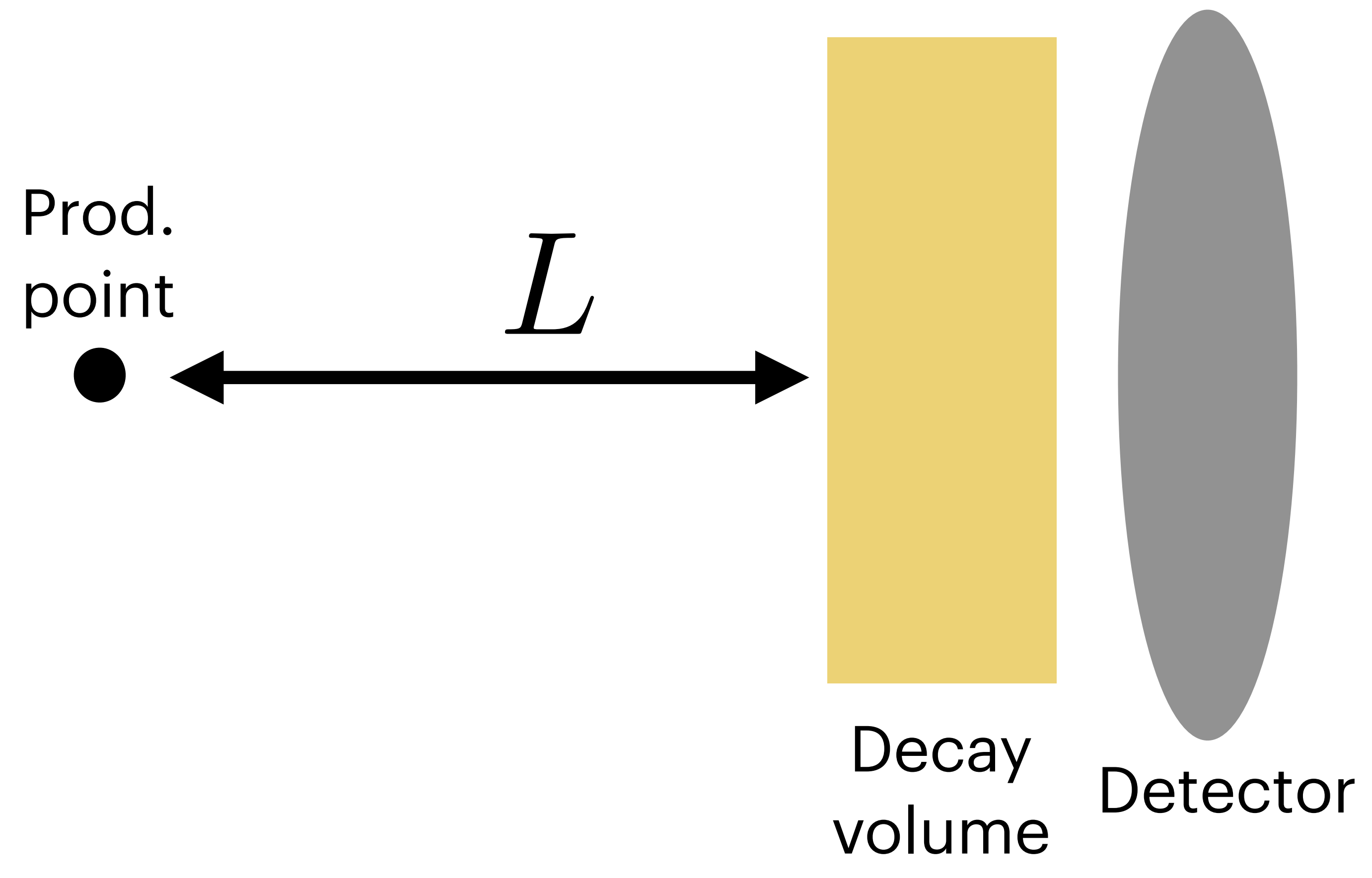

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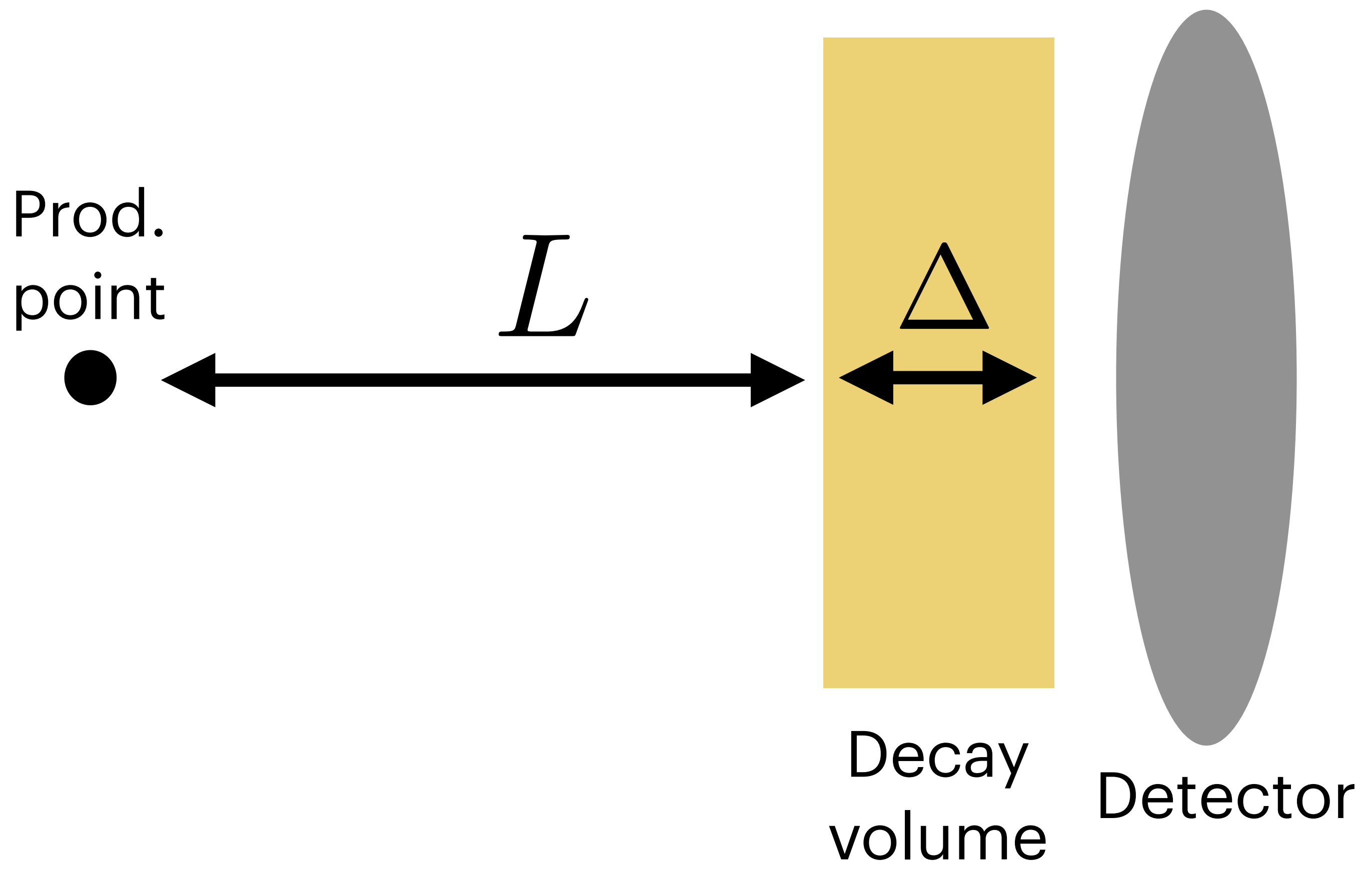

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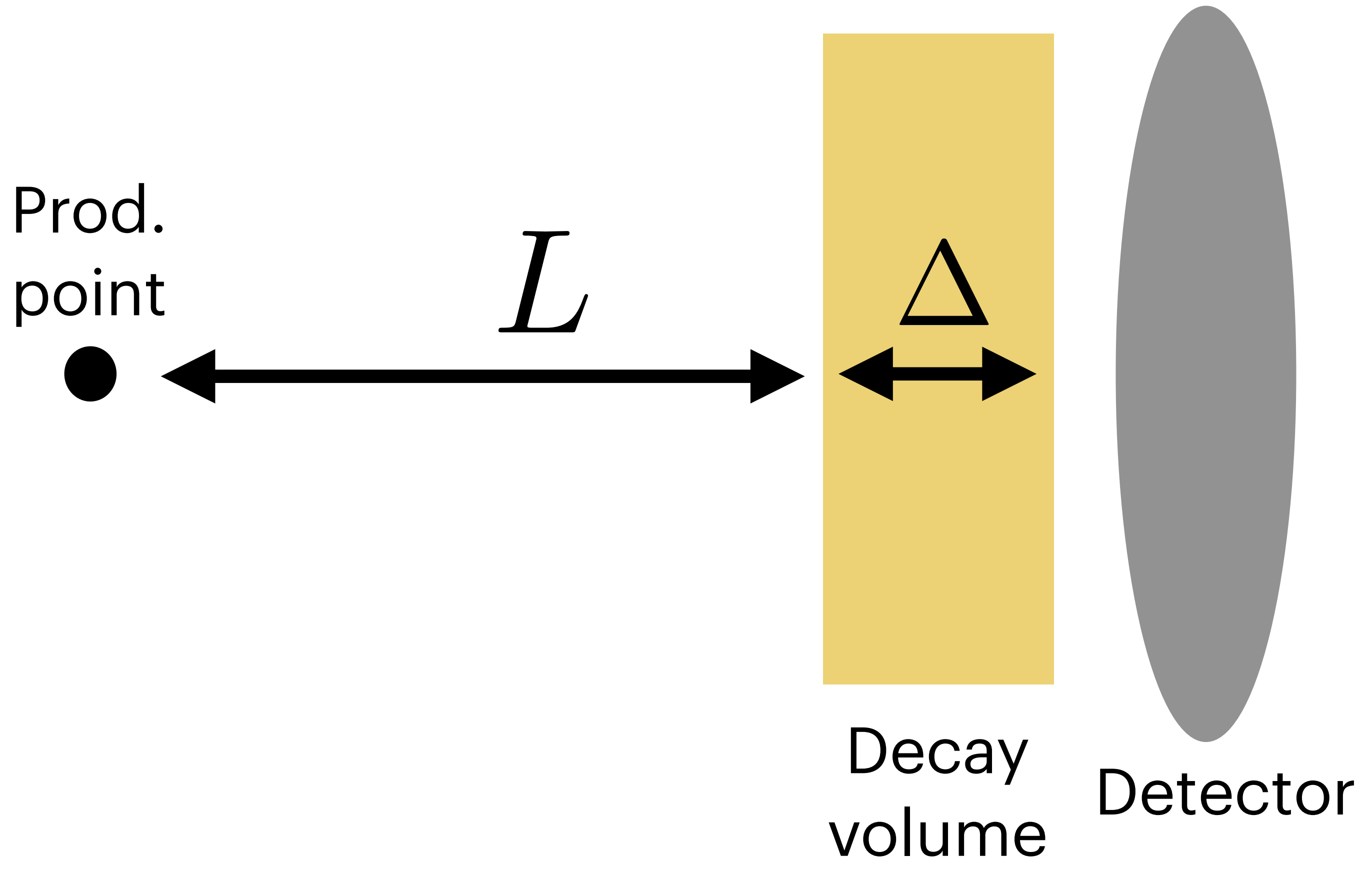

Model-independent approach

- Sensitivity peaks at $$\frac{c\tau_\phi}{m_\phi} \sim \frac{L}{\langle p_\phi \rangle} \qquad (\text{for } \Delta \ll L)$$

Particle physics

Depends on the experiment

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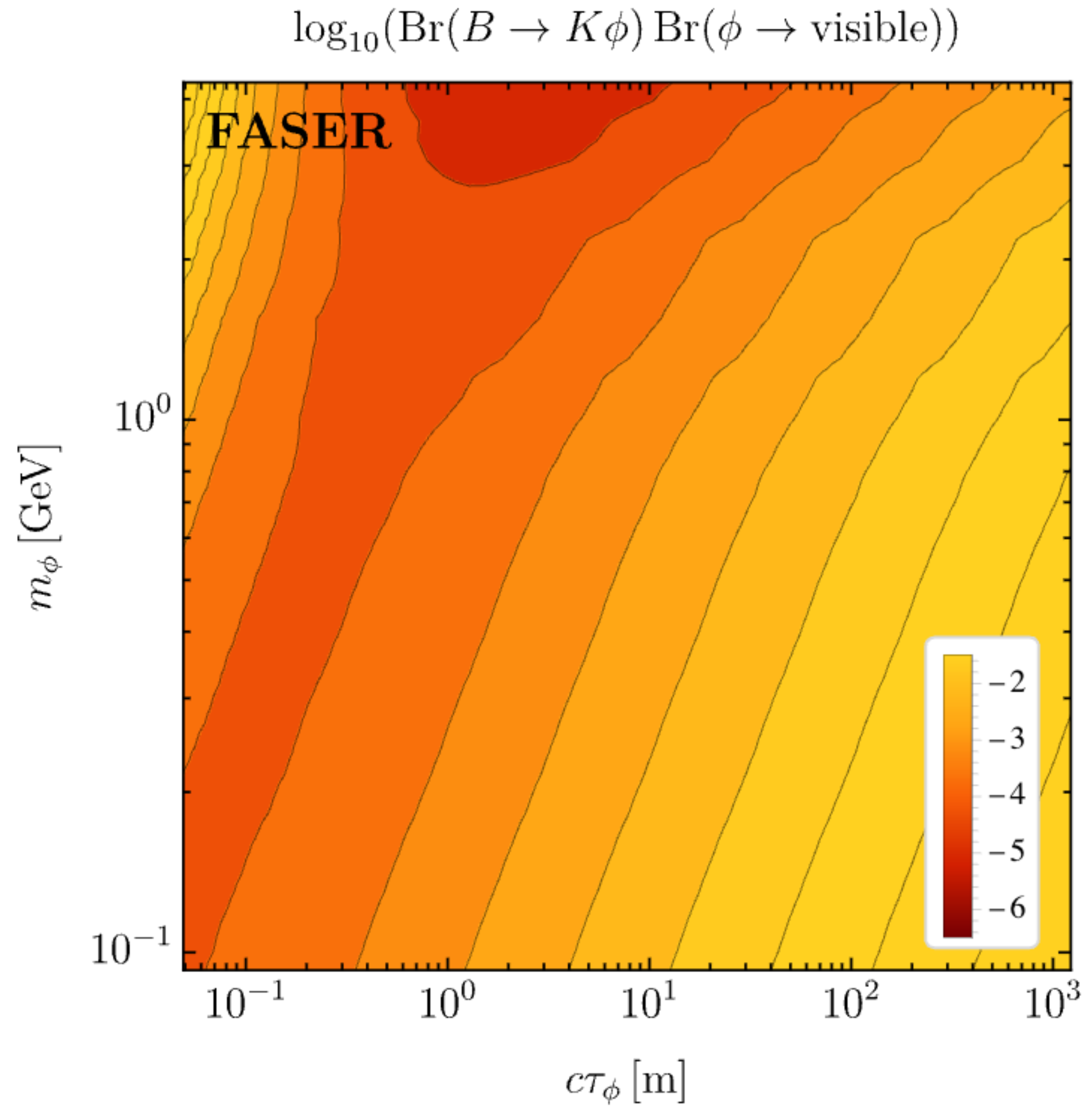

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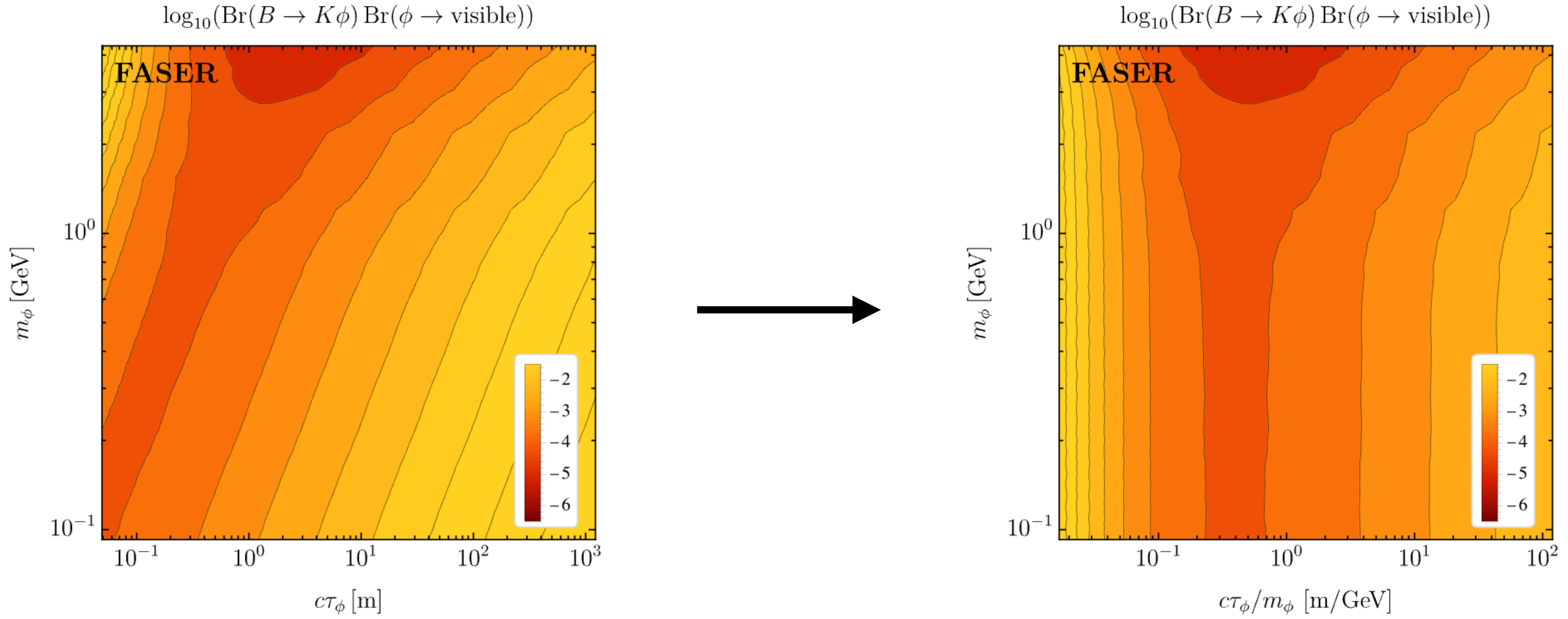

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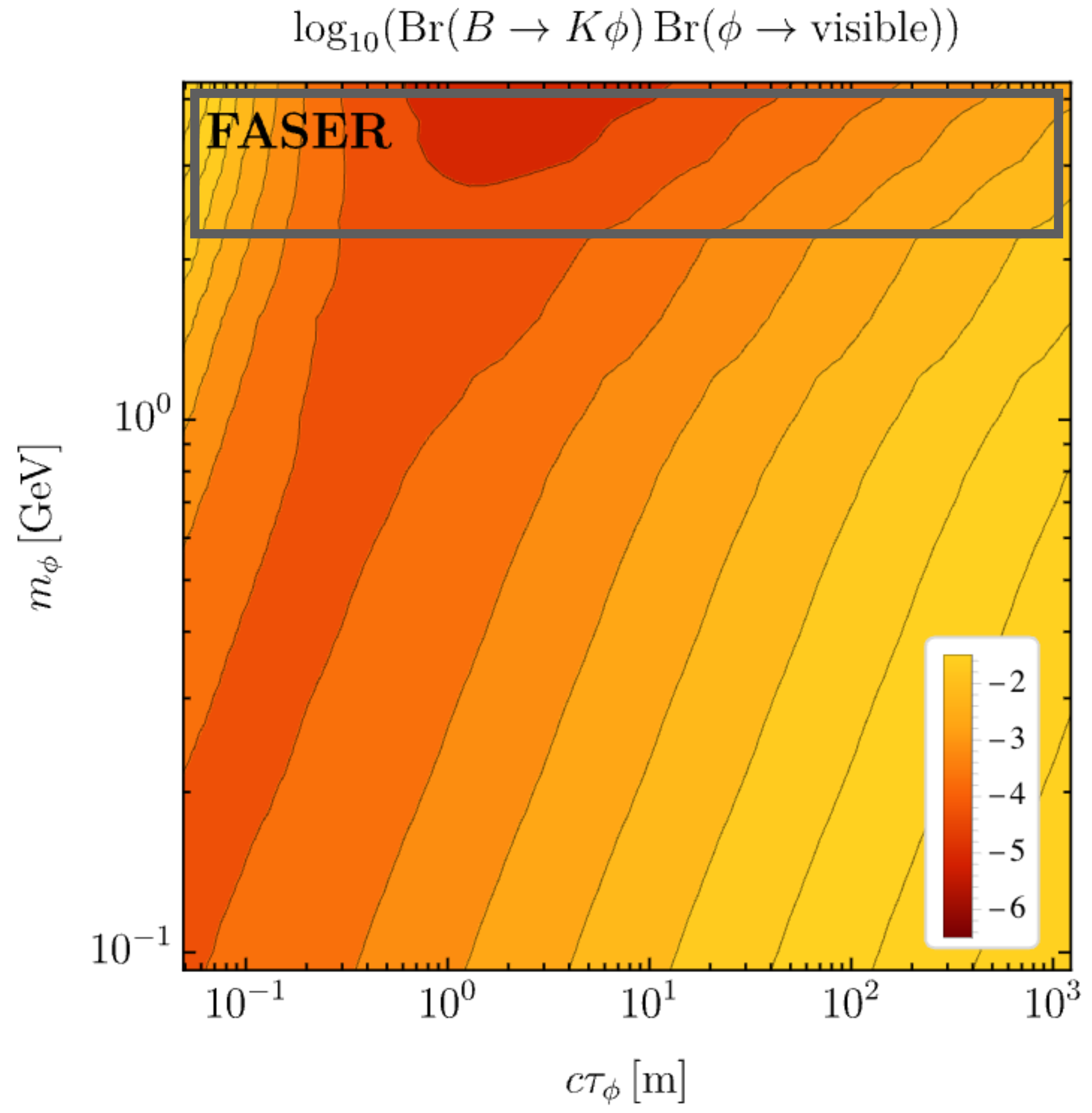
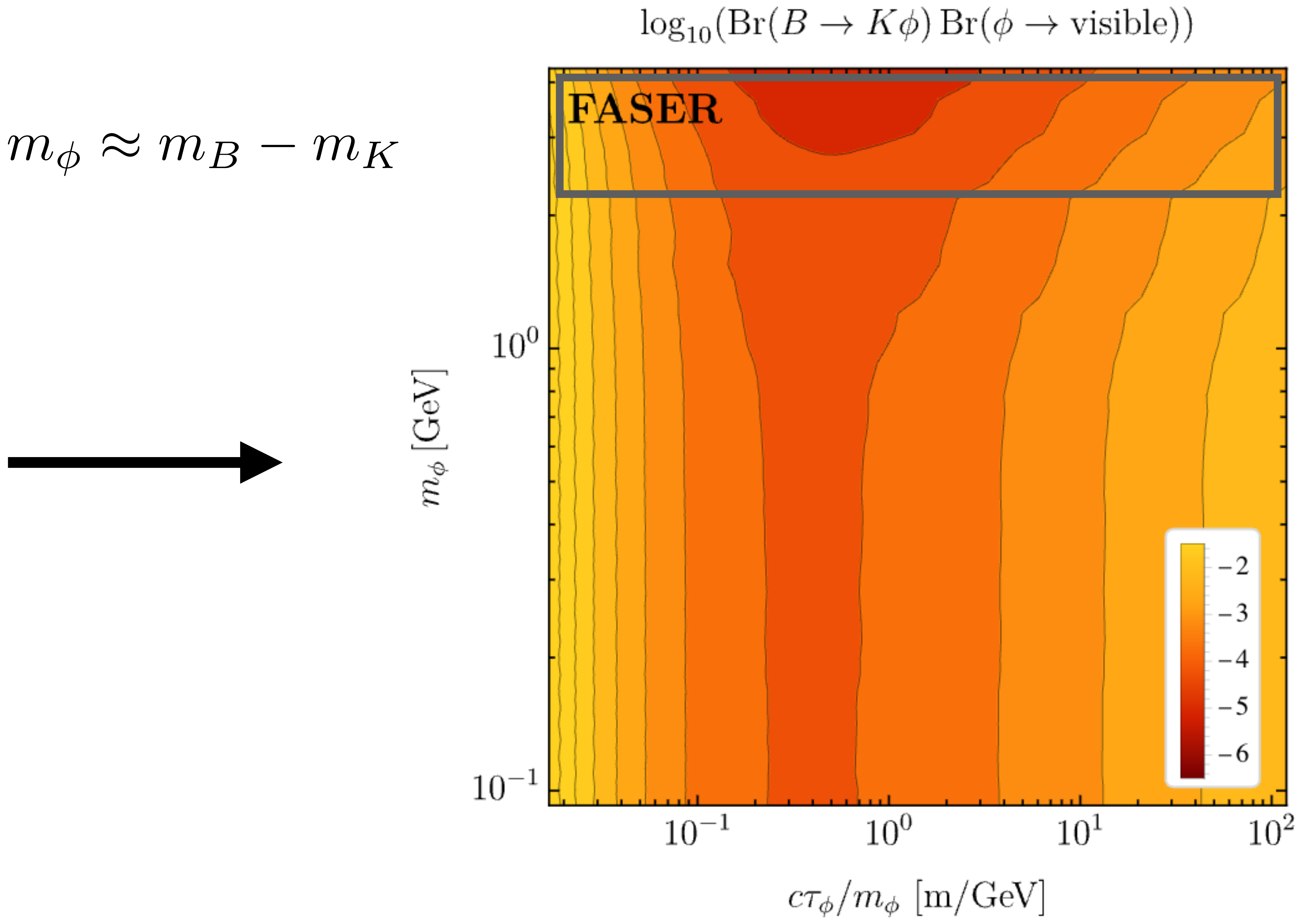


$m_\phi \approx m_B - m_K$



Model-independent approach

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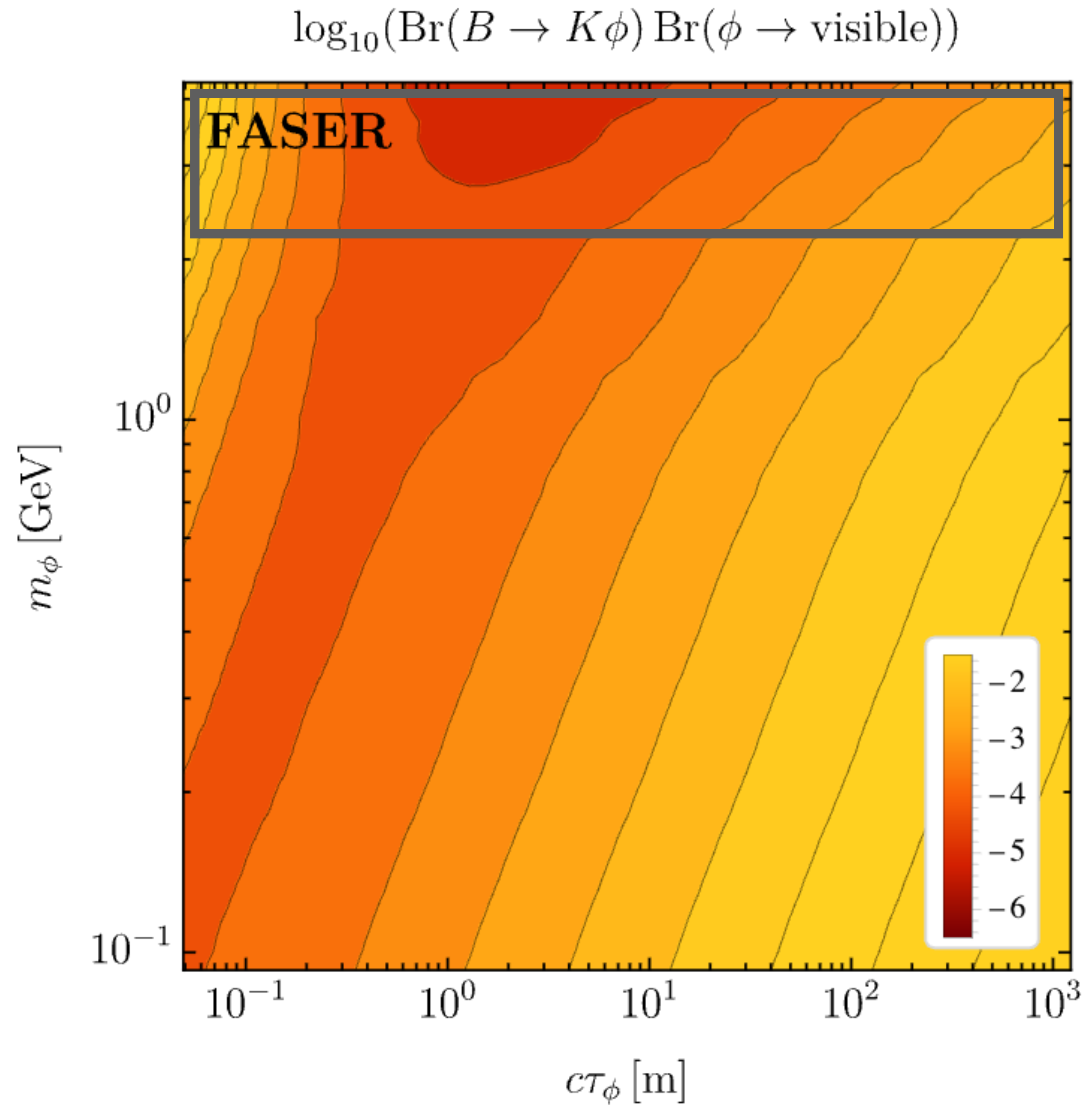
Particle physics

Depends on the experiment



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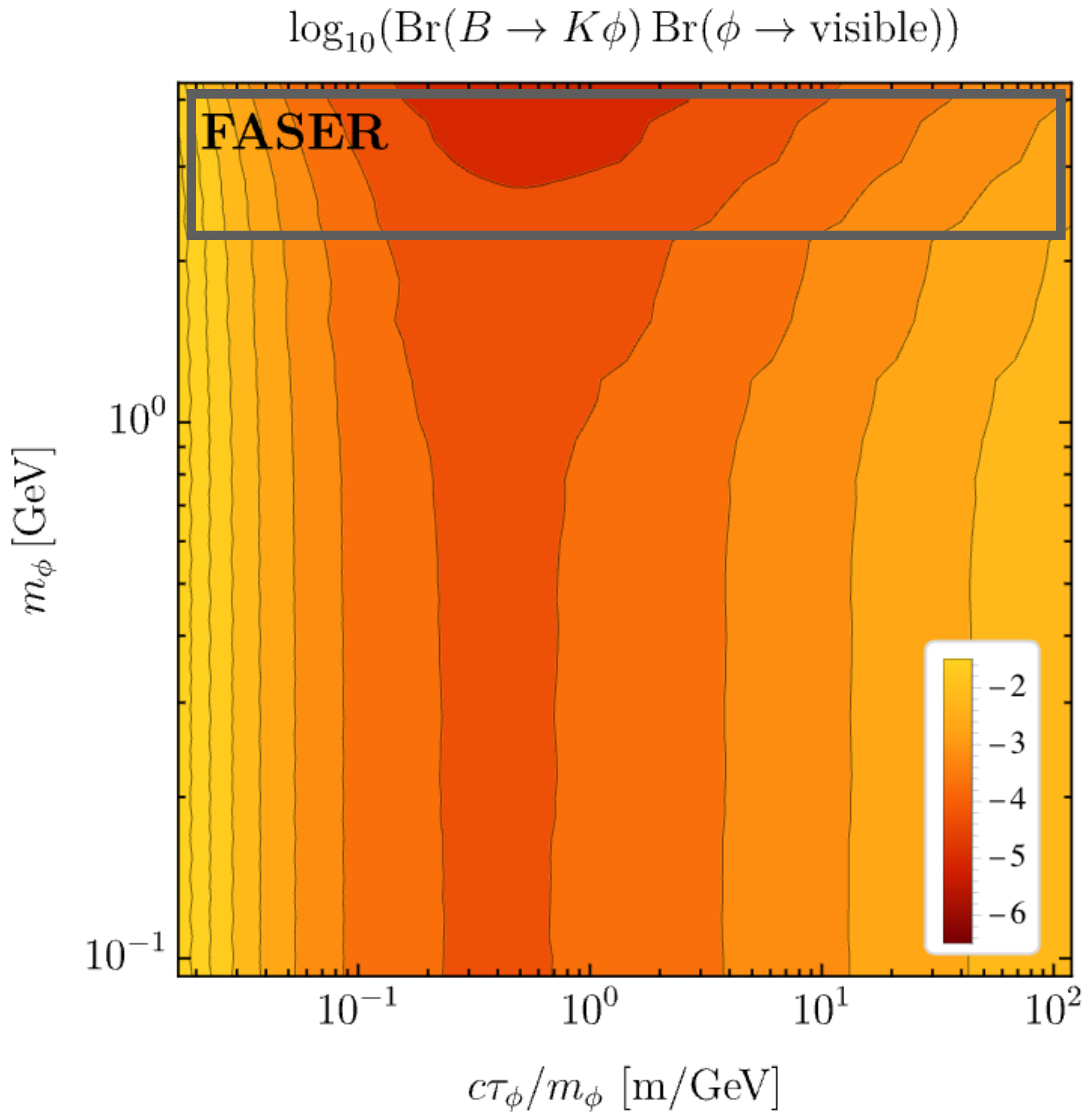

Less momentum in rest frame

Model-independent approach

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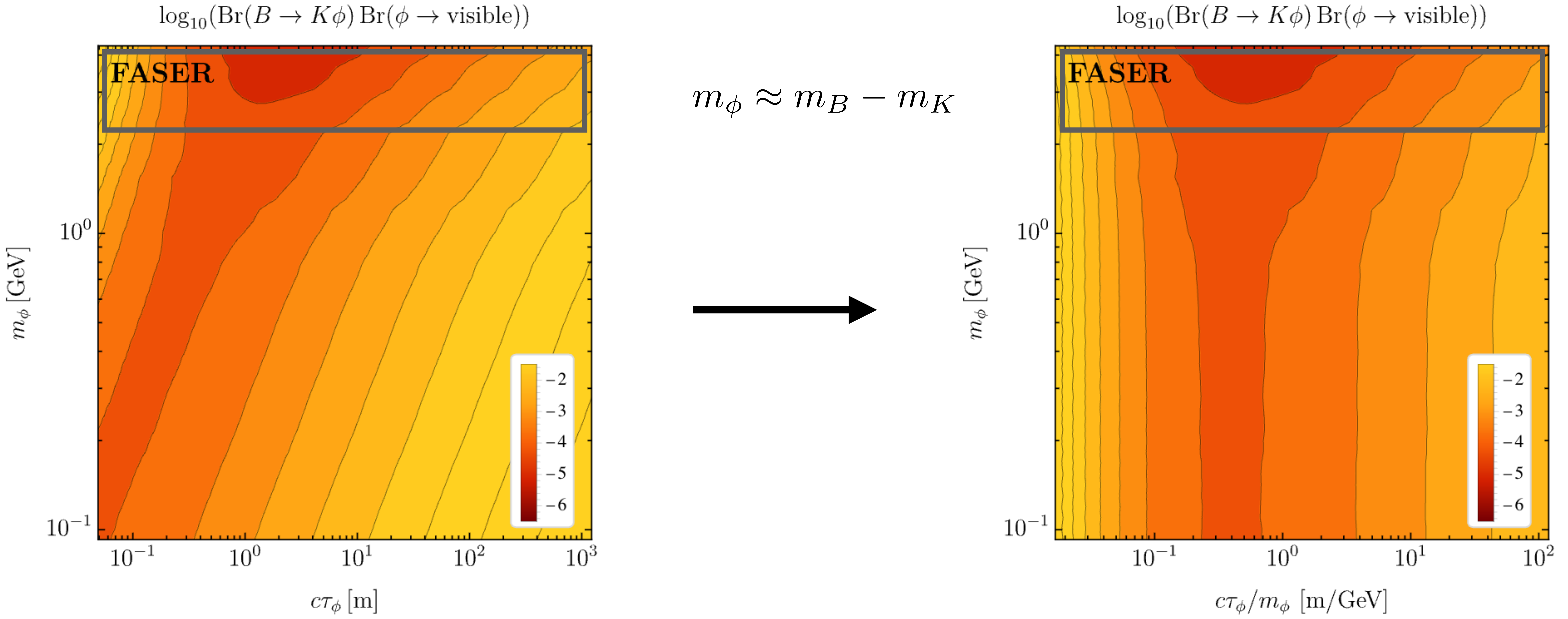
Particle physics — Depends on the experiment



Less momentum in rest frame

↓

More colinear with forward decaying particle

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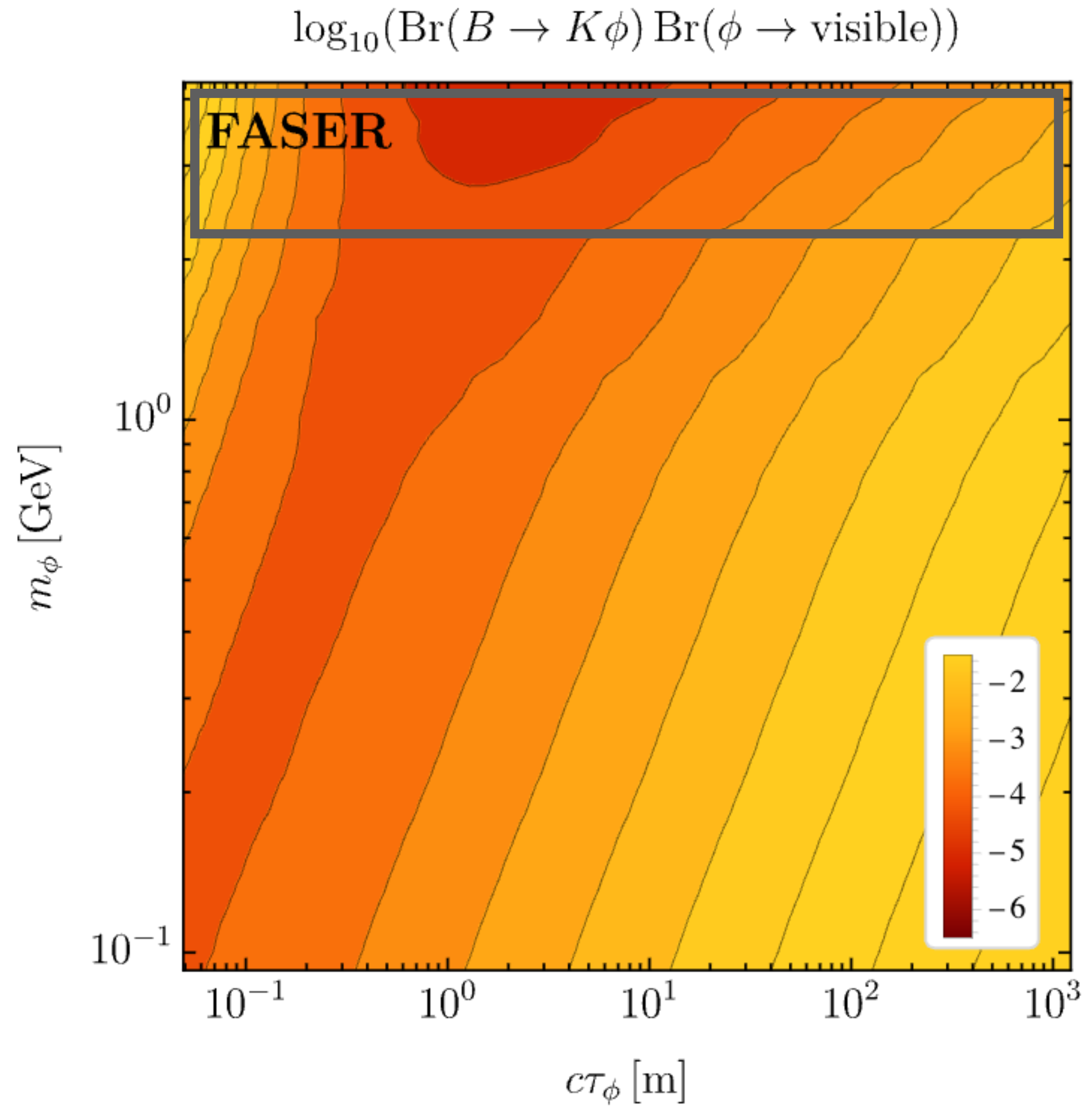

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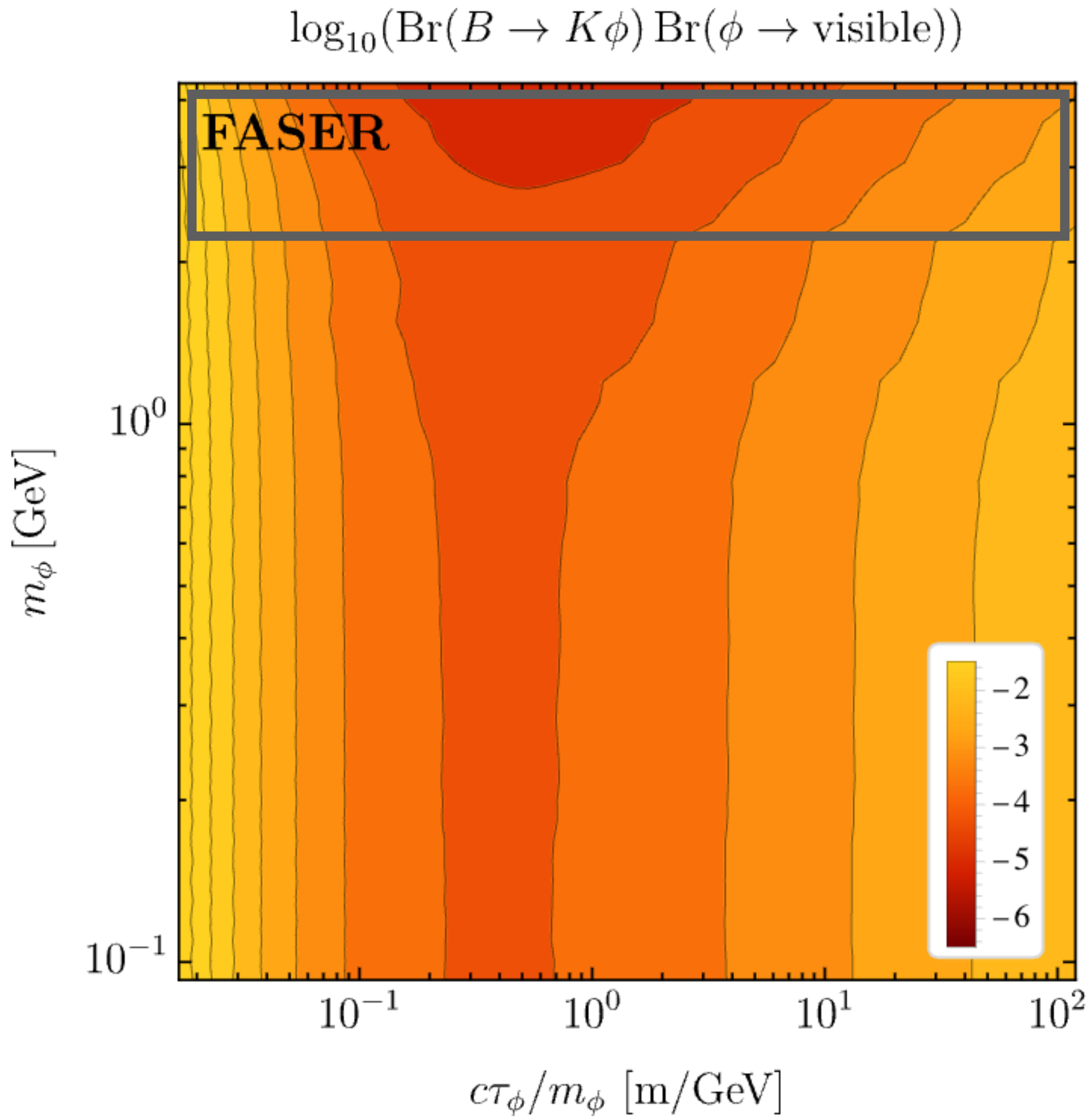

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↓

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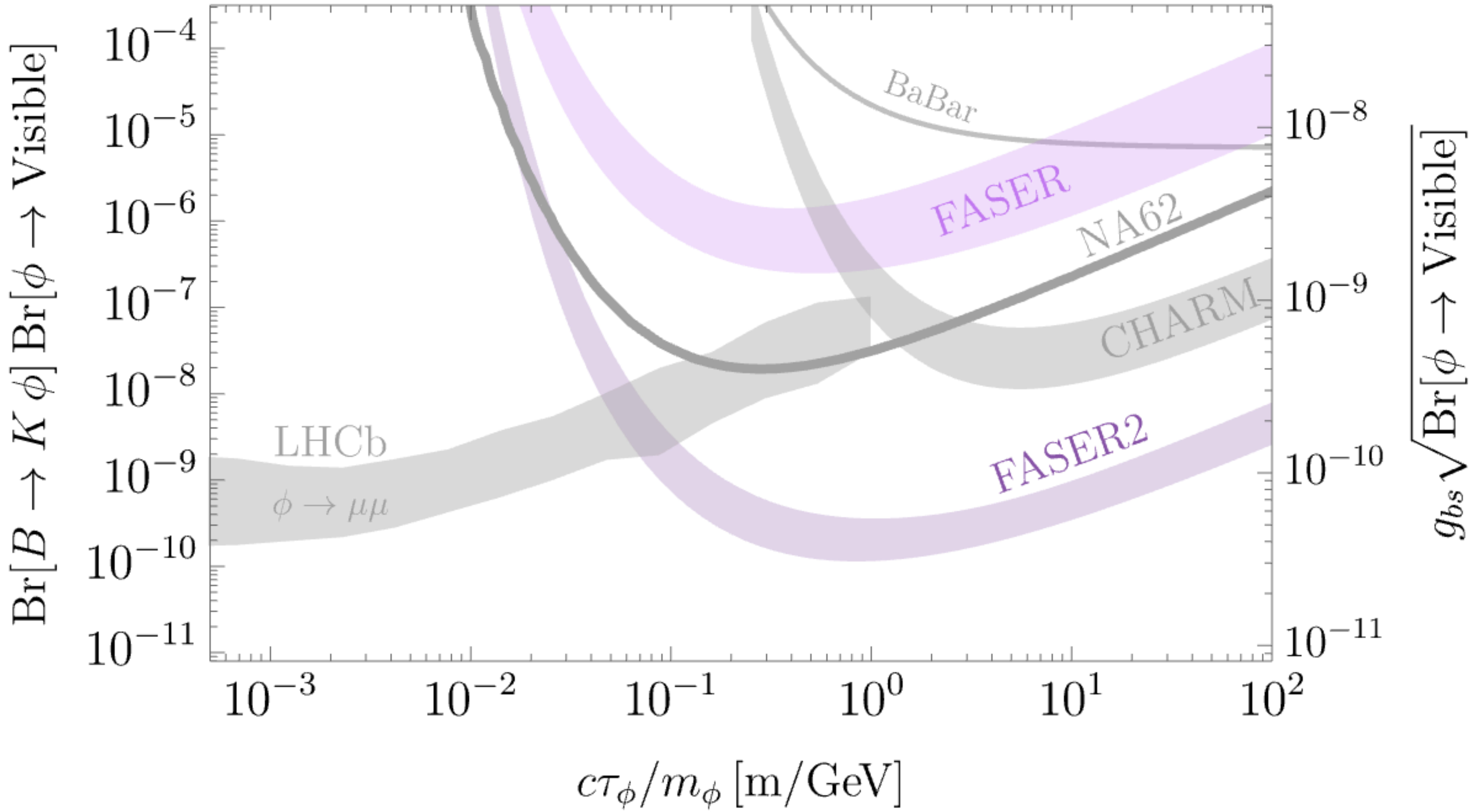
↓

Improved geometrical acceptance

Model-independent approach : B meson decays

Also: Döbrich et al. 1810.11336



$$\mathrm{Br}(M \to M'\phi) \approx \frac{g^2 m_M}{32\pi\Gamma_M}$$

Model-independent approach : B meson decays

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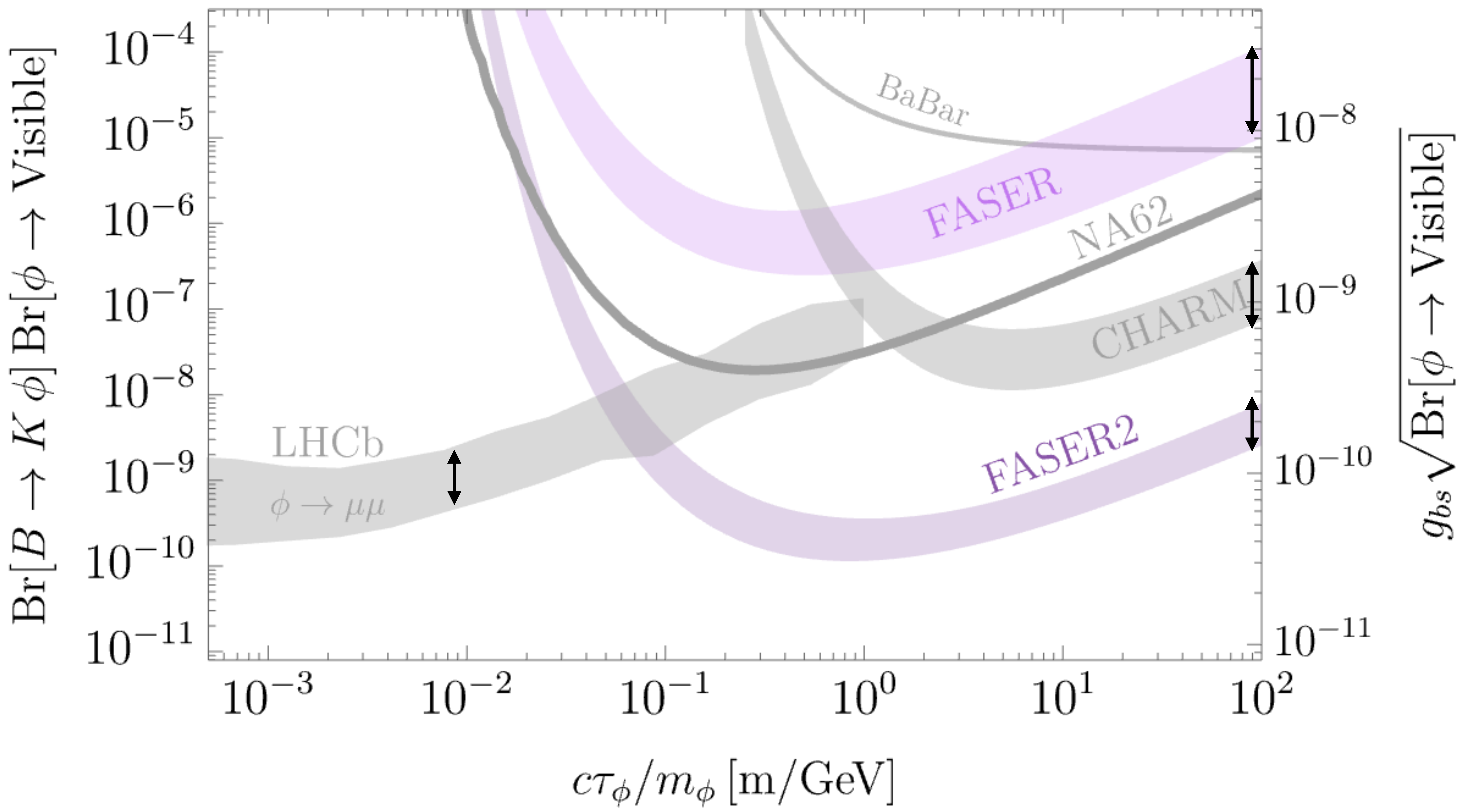

Band width from varying the mass

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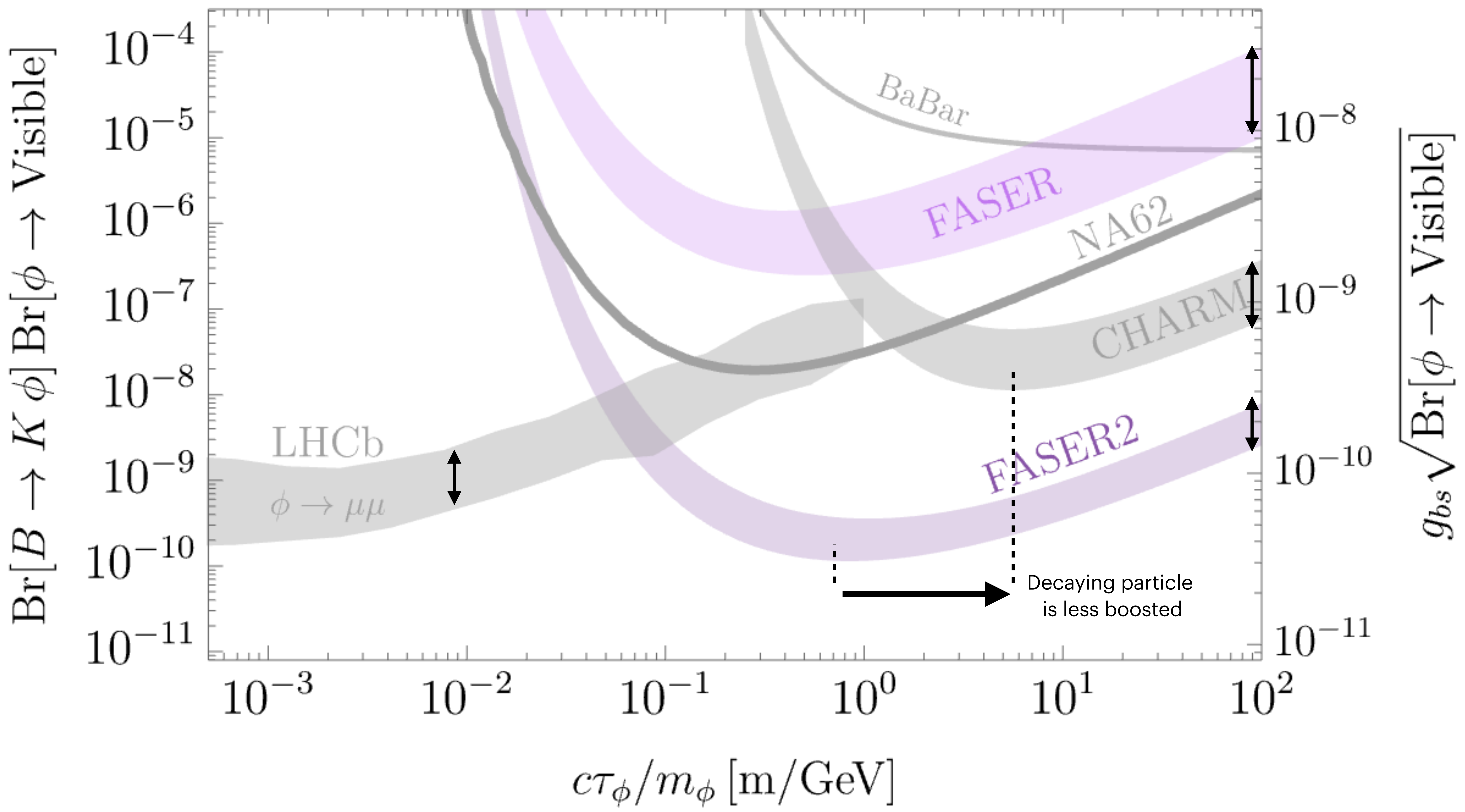

Band width from varying the mass

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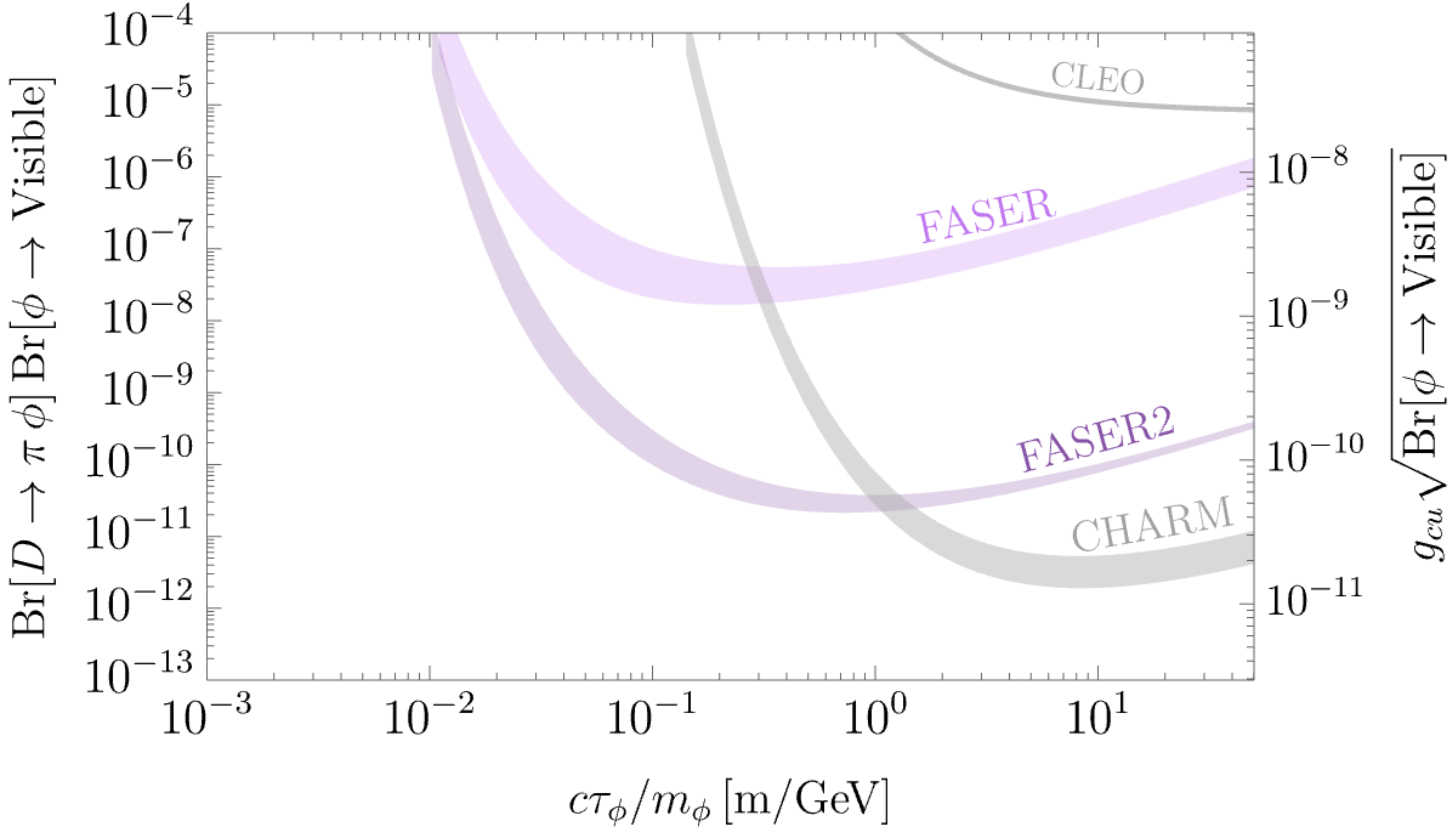
Model-independent approach : D meson decays



First model-independent calculation for D decays

CLEO

$$D^+ \to \mu^+ + \text{missing}$$

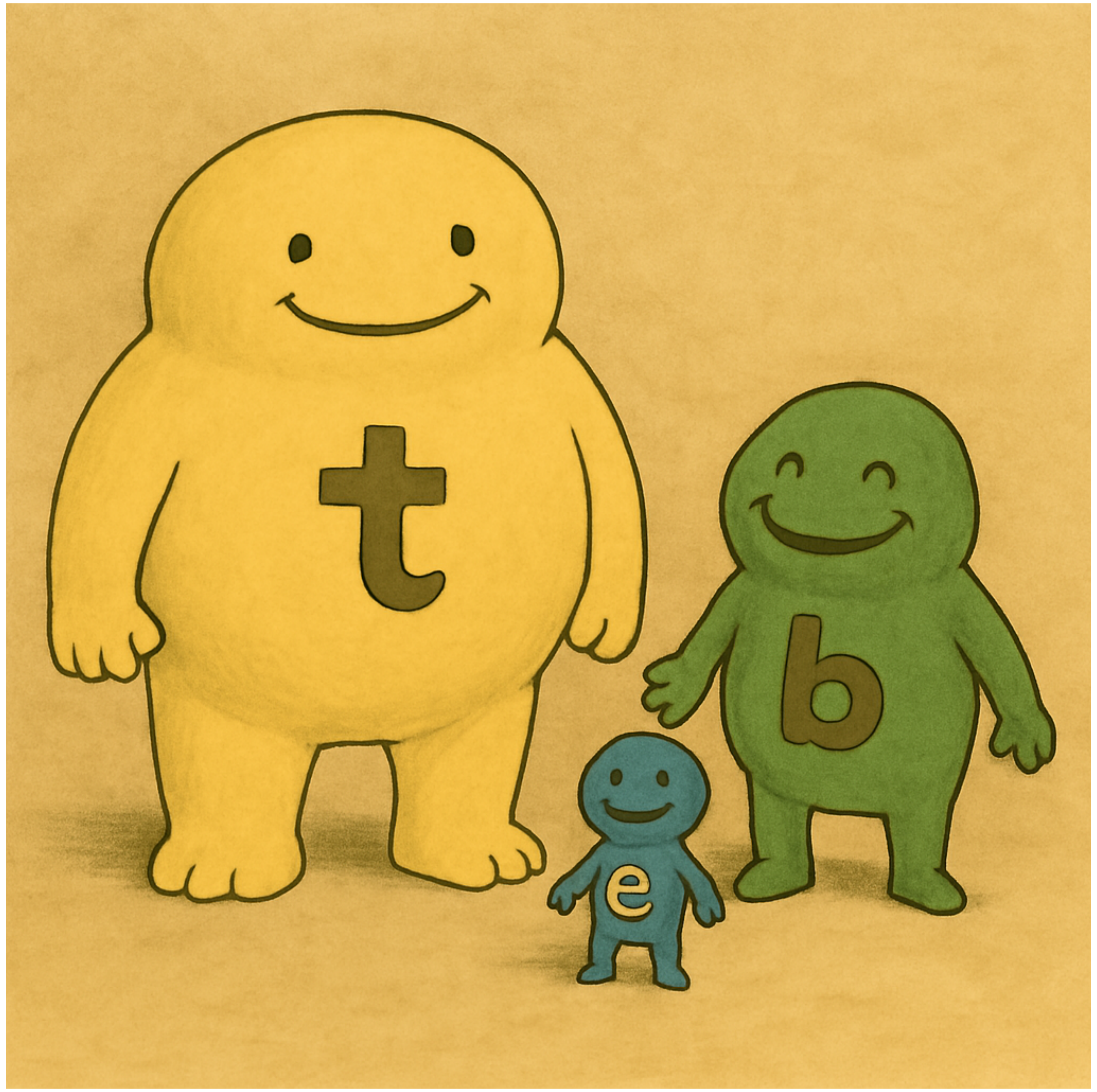
0806.2112
Camalich et al. 2002.04623

$$\mathrm{Br}(M \to M'\phi) \approx \frac{g^2 m_M}{32\pi\Gamma_M}$$

Outline

1. Flavored scalar model ✓
2. Phenomenology ✓
3. Experimental signals @ FASER ✓
4. Model-independent approach ✓
5. Conclusions

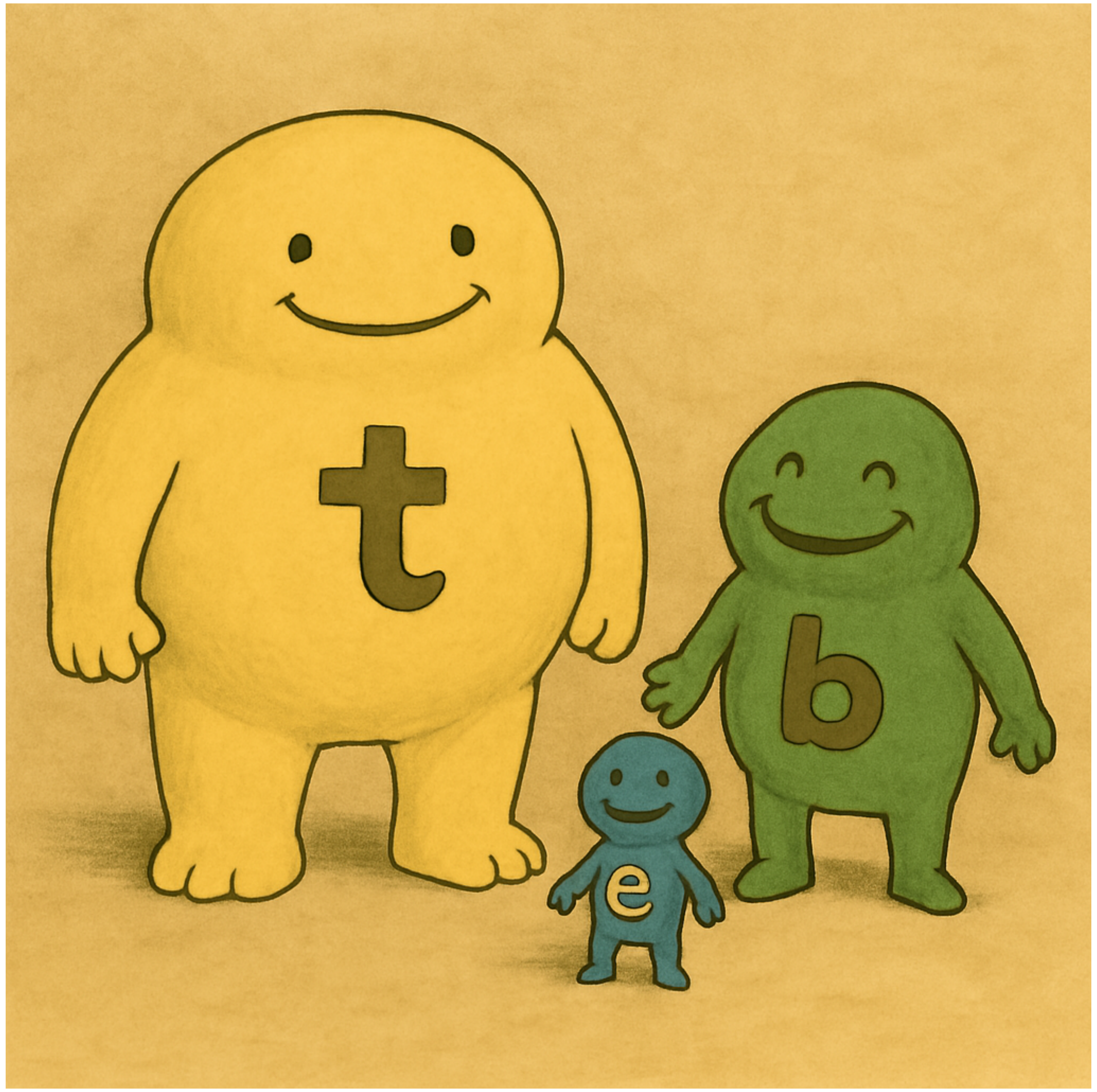
Summary and outlook



Still not to scale

Summary and outlook

- Flavored scalar models are well-motivated and have a rich phenomenology beyond the MFV paradigm.



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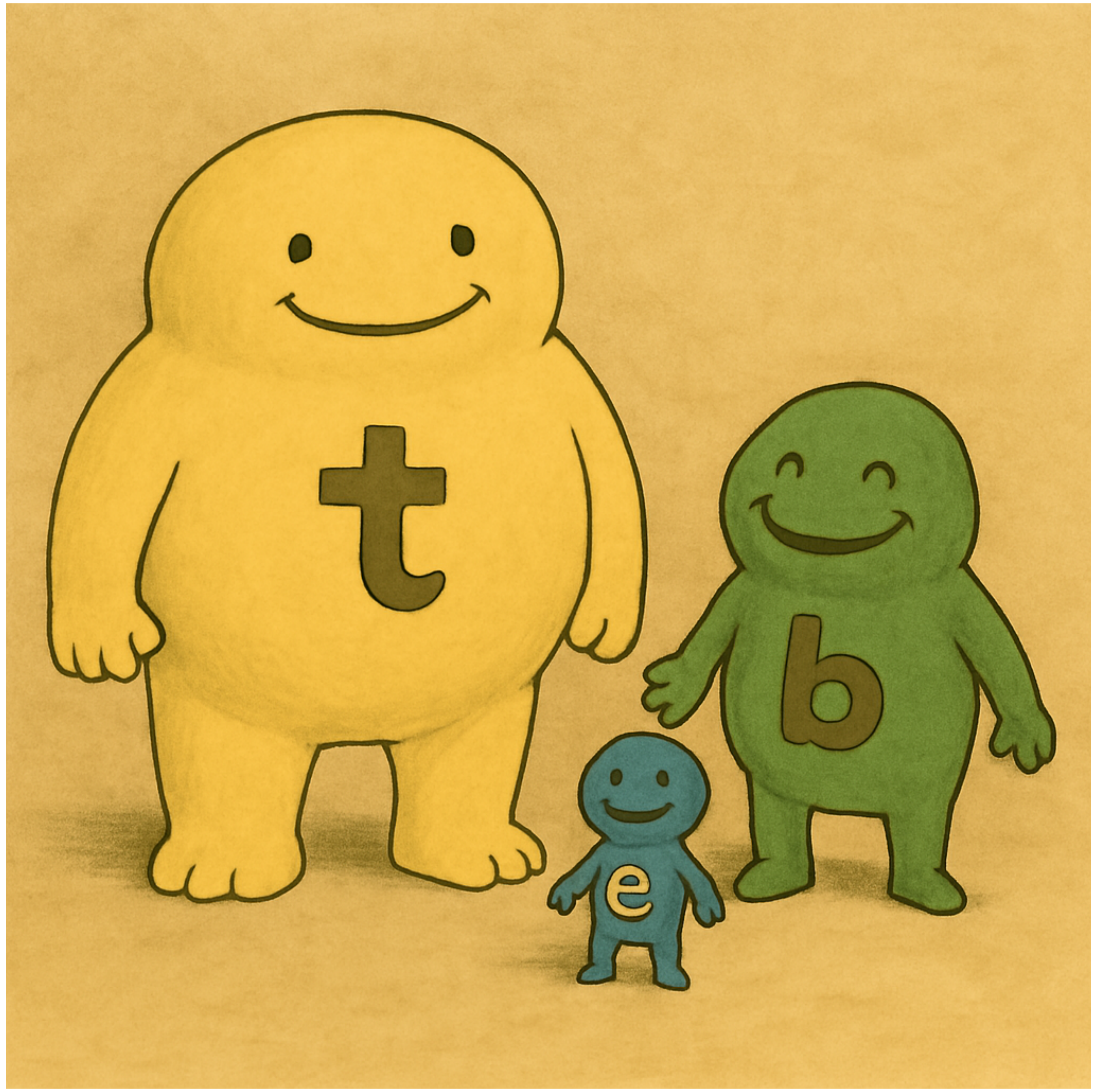
Summary and outlook

- Flavored scalar models are well-motivated and have a rich phenomenology beyond the MFV paradigm.

- FASER/2 can probe unexplored parameter space of such models.



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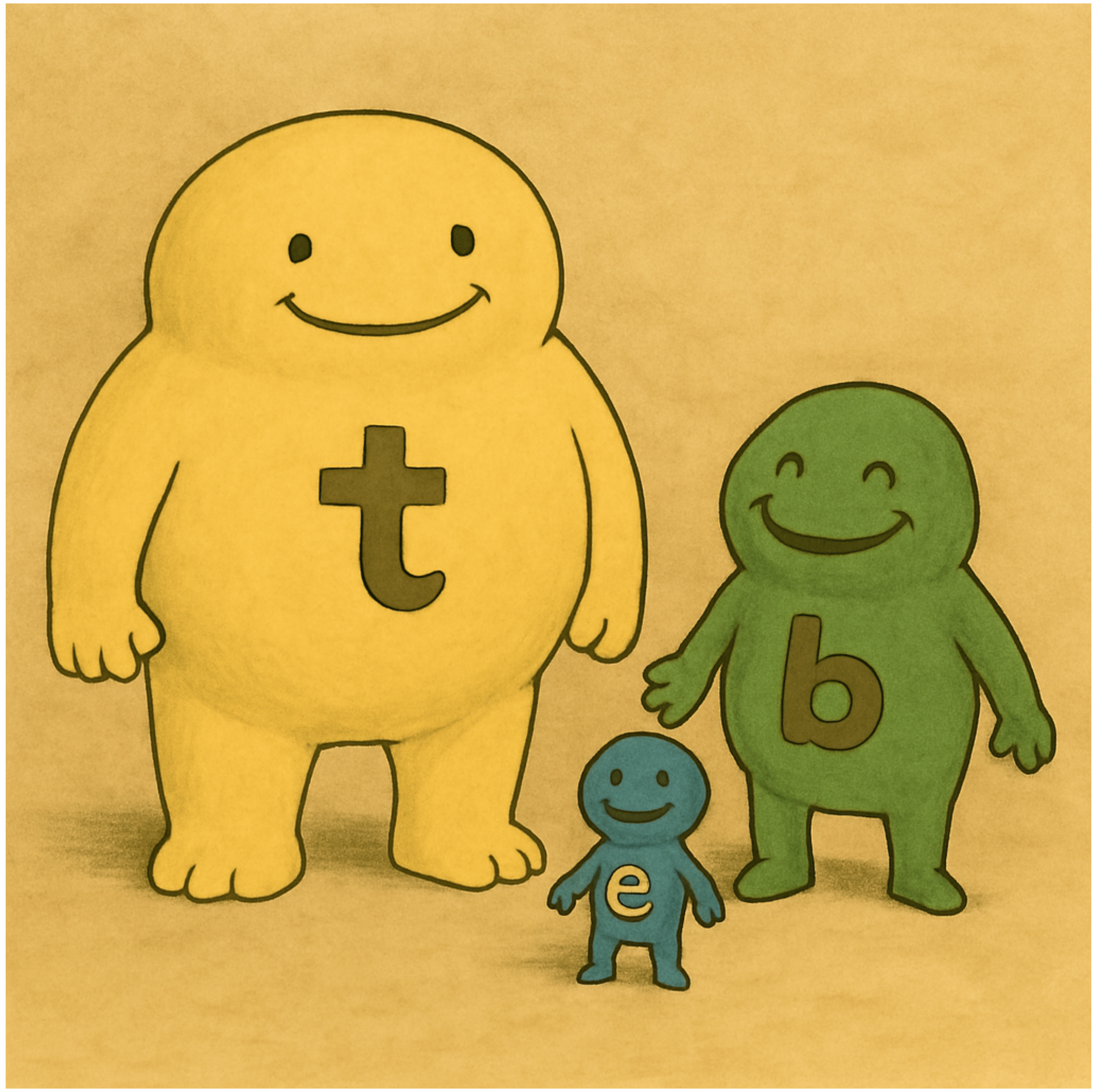

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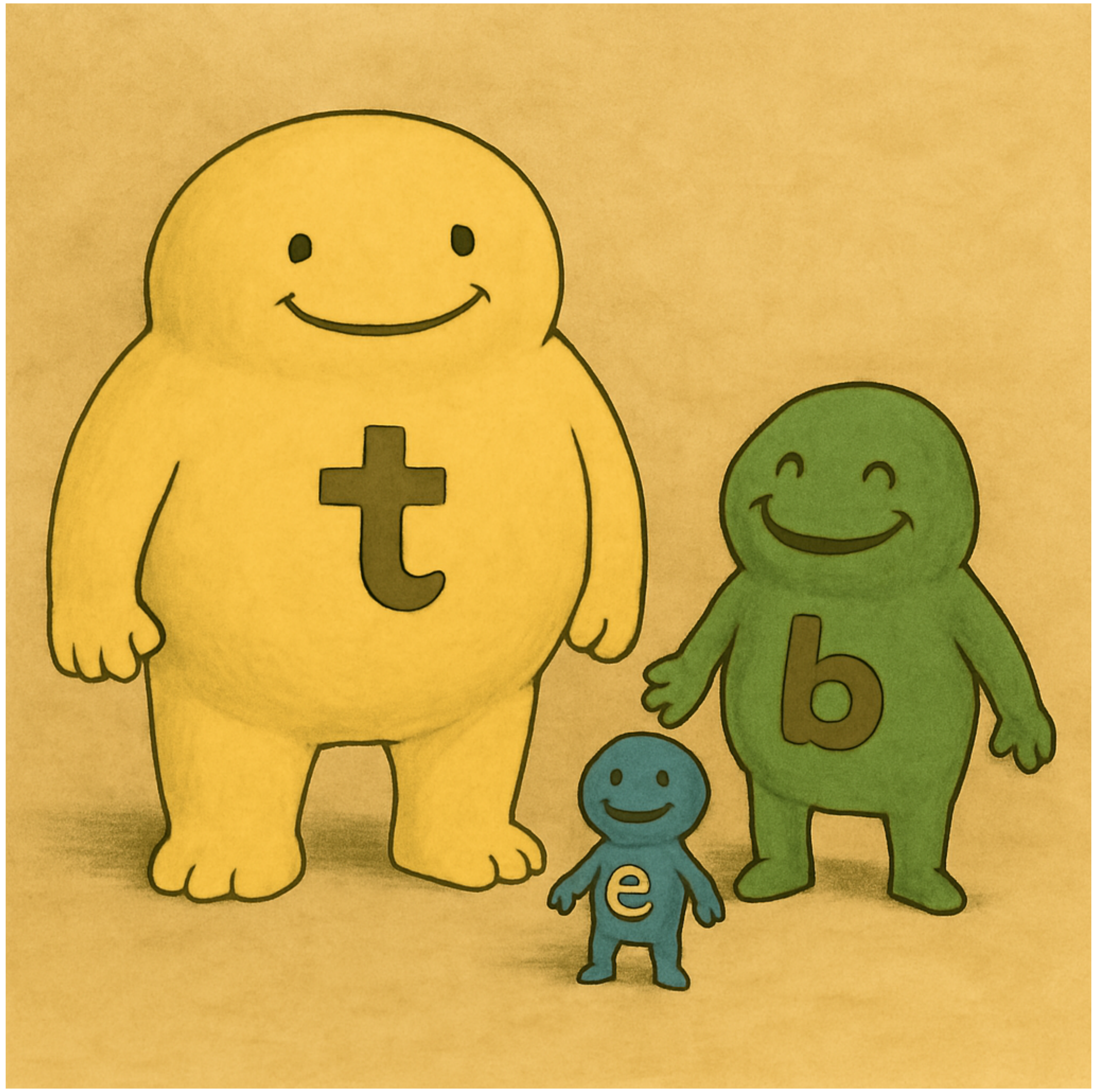
- Given the vast theoretical landscape, a model-independent approach for experimental constraints is a useful way to compare sensitivities.



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BACKUP

Higgs mixing

$$\mathcal{L}^{\theta}_{\phi\bar{f}f} = \frac{\phi^{\text{phys}}}{\sqrt{2}}\left[(\varepsilon c^{u}_{ij} + \theta\hat{Y}^{u}_{ij})\bar{u}_i P_R u_j + (\varepsilon c^{d}_{ij} + \theta\hat{Y}^{d}_{ij})\bar{d}_i P_R d_j + (\varepsilon c^{\ell}_{ij} + \theta\hat{Y}^{\ell}_{ij})\bar{\ell}_i P_R \ell_j + \text{h.c.}\right]$$

Diagonal terms are dominated by dim. 5 operator:

$$\Lambda \ll v/\theta \sim (10^5\,\text{GeV})(10^{-4}/\theta)$$

Transitions in the up sector dominate by dim. 5 operator:

$$\Lambda \ll 10^{14}\,\text{GeV}\left(\frac{10^{-4}}{\theta}\right)\frac{\text{Max}[c^u_{12}, c^u_{21}]}{y_b^2}$$

Transitions in the down sector dominate by dim. 5 operator:

$$\Lambda \ll 10^{10}\,\text{GeV}\left(\frac{10^{-4}}{\theta}\right)\frac{\text{Max}[c^d_{23}, c^d_{32}]}{y_b}$$