Reinterpretation of novel CMS analysis in low-mass LLP models

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based on 21xx.xxxx with Michele Papucci and Christina Wang

INTRODUCTION

- current ATLAS/CMS searches for light LLPs limited by
  - SM backgrounds (calorimeter not thick enough to veto SM)
  - LLPs decay to few charged particles (# tracks controlled by $m_{\rm LLP}$)

- recent CMS search looking for clusters in the endcap muon detector system ameliorates these problems
  - Steel $\rightarrow$ LLPs decay products can shower
  - Shower $\rightarrow$ signature tracks $E_{\rm LLP}$ rather than $m_{\rm LLP}$
  - Steel $\rightarrow$ exceptional shielding from SM backgrounds

- we use <u>public data</u> to recast the analysis for
  - ***Higgs decays into scalar/dark photon*** (closest to the model considered in the original CMS analysis, decoupled production and decay channels)
  - ***Inelastic Dark Matter*** (decouples $E_{\rm LLP}$ from MET)
  - ***Axion-like particles*** (production and decay channels controlled by the same parameter, enhanced production at high $E_{\rm LLP}$)
  - ***Dark showers*** (studies the impact of isolation cuts)

RECAST STRATEGY

Event Generation

MadGraph + **Pythia8** generate the hard processes, shower, and hadronize them

loose generator level cuts (MET cut, isolation veto, ecc..) are applied to increase statistics

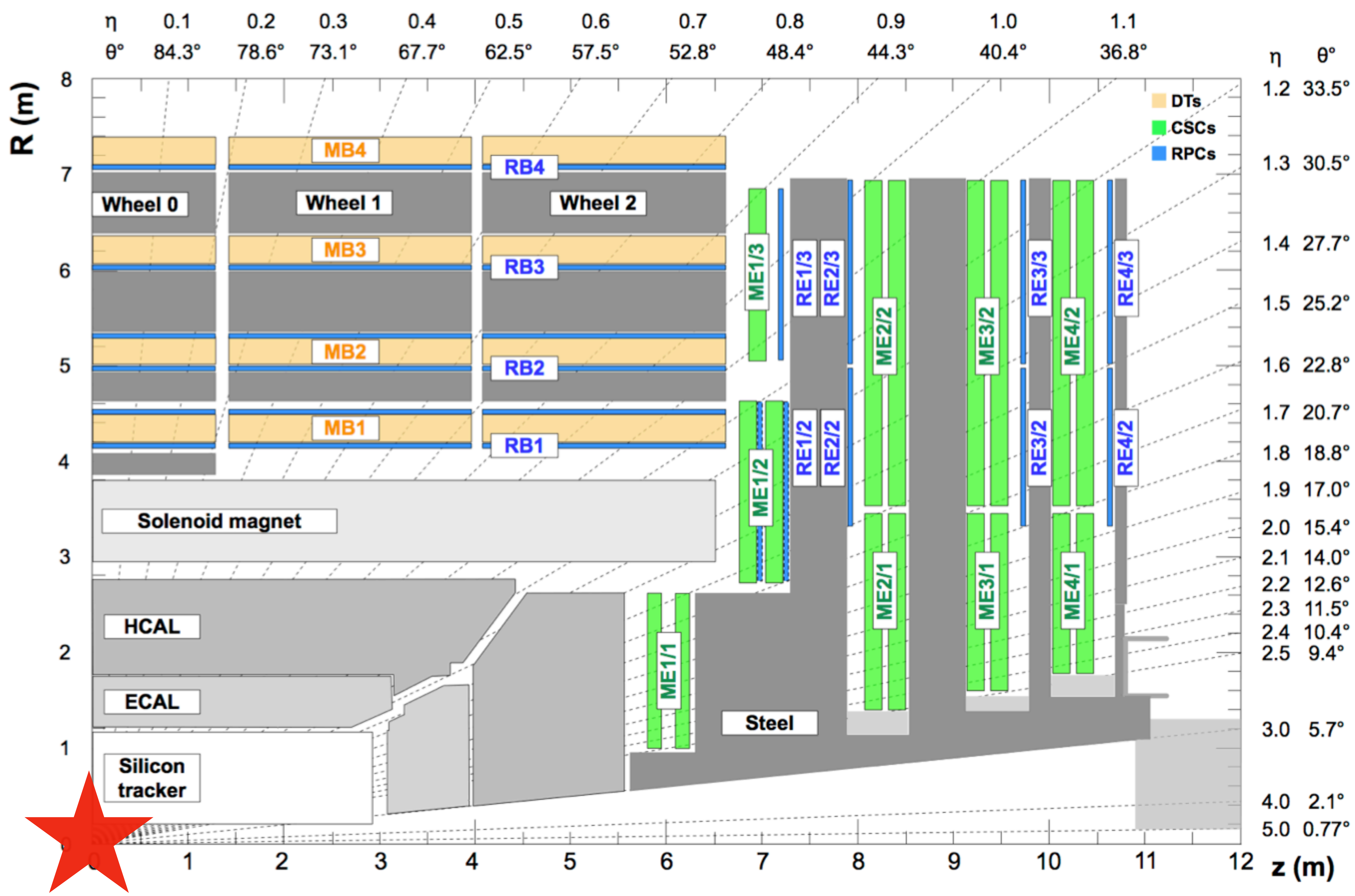
Custom Decayer

given LLP lifetime and energy derive the probability to decay in each detector region

by using Pythia8 **generates a decay event in each detector region** and weights it with the probability to decay in that region

Detector simulation

uses Delphes, with the publicly available module to take to account **cluster** and **cut-based ID** efficiencies for LLPs decays



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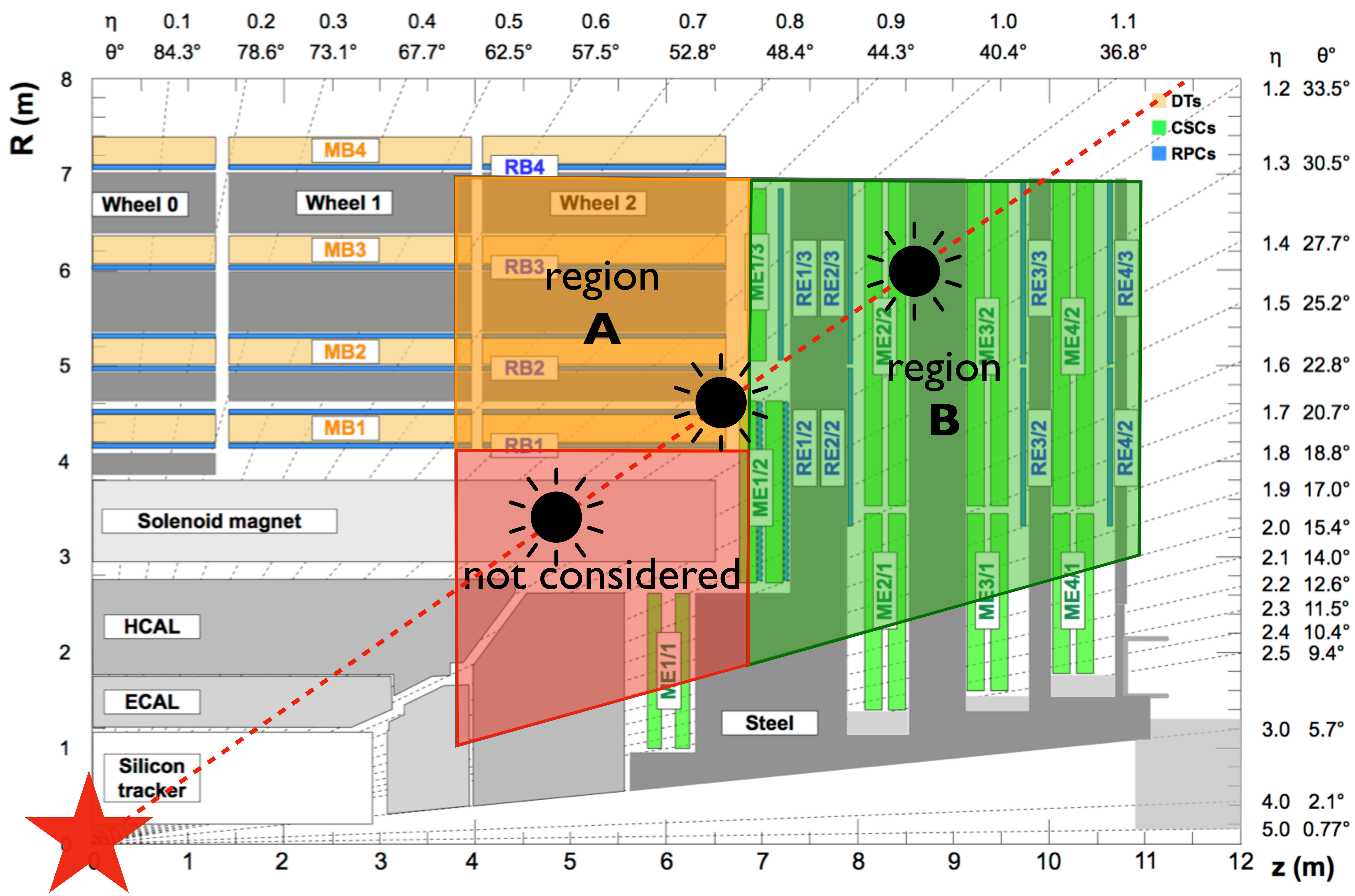

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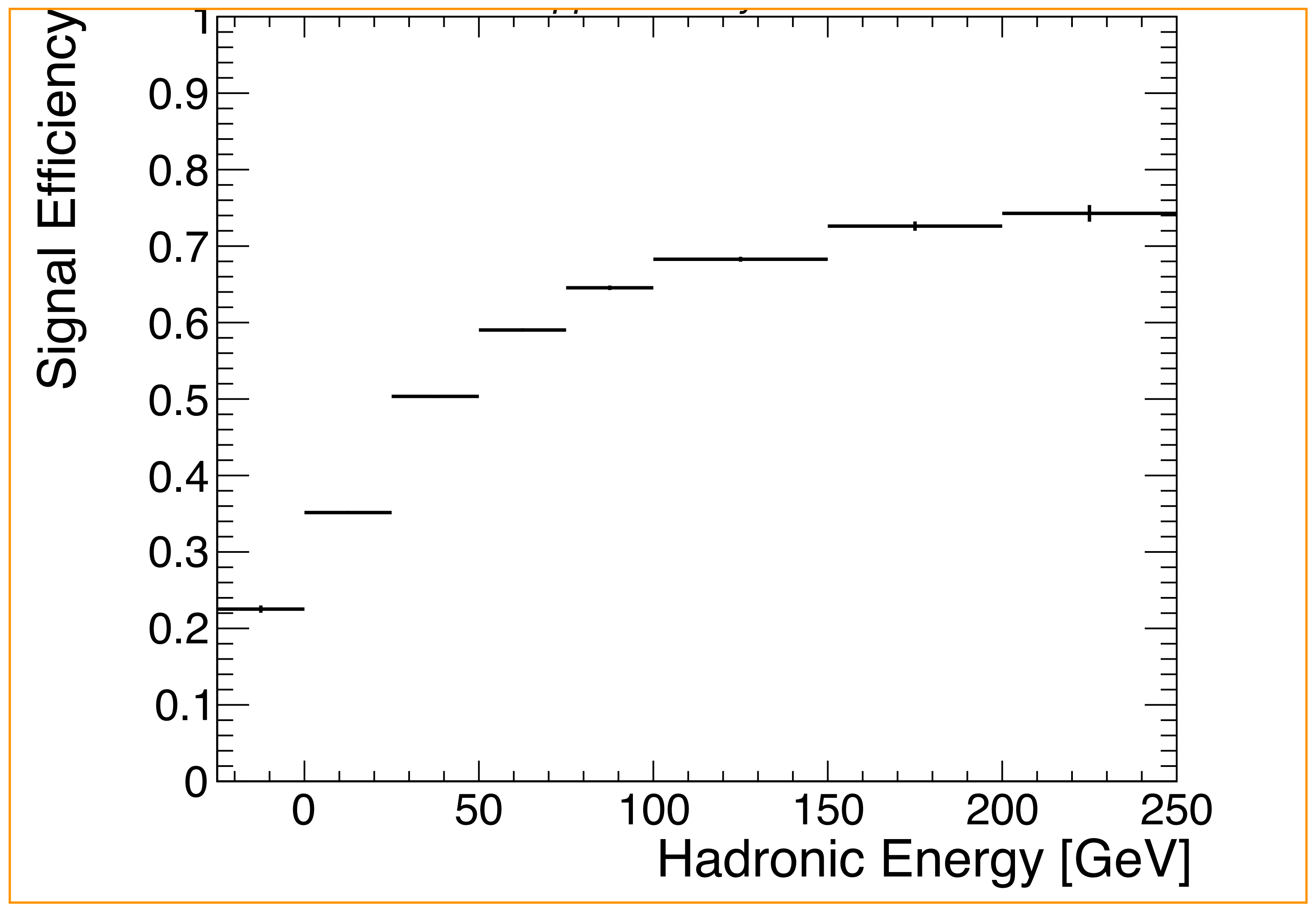
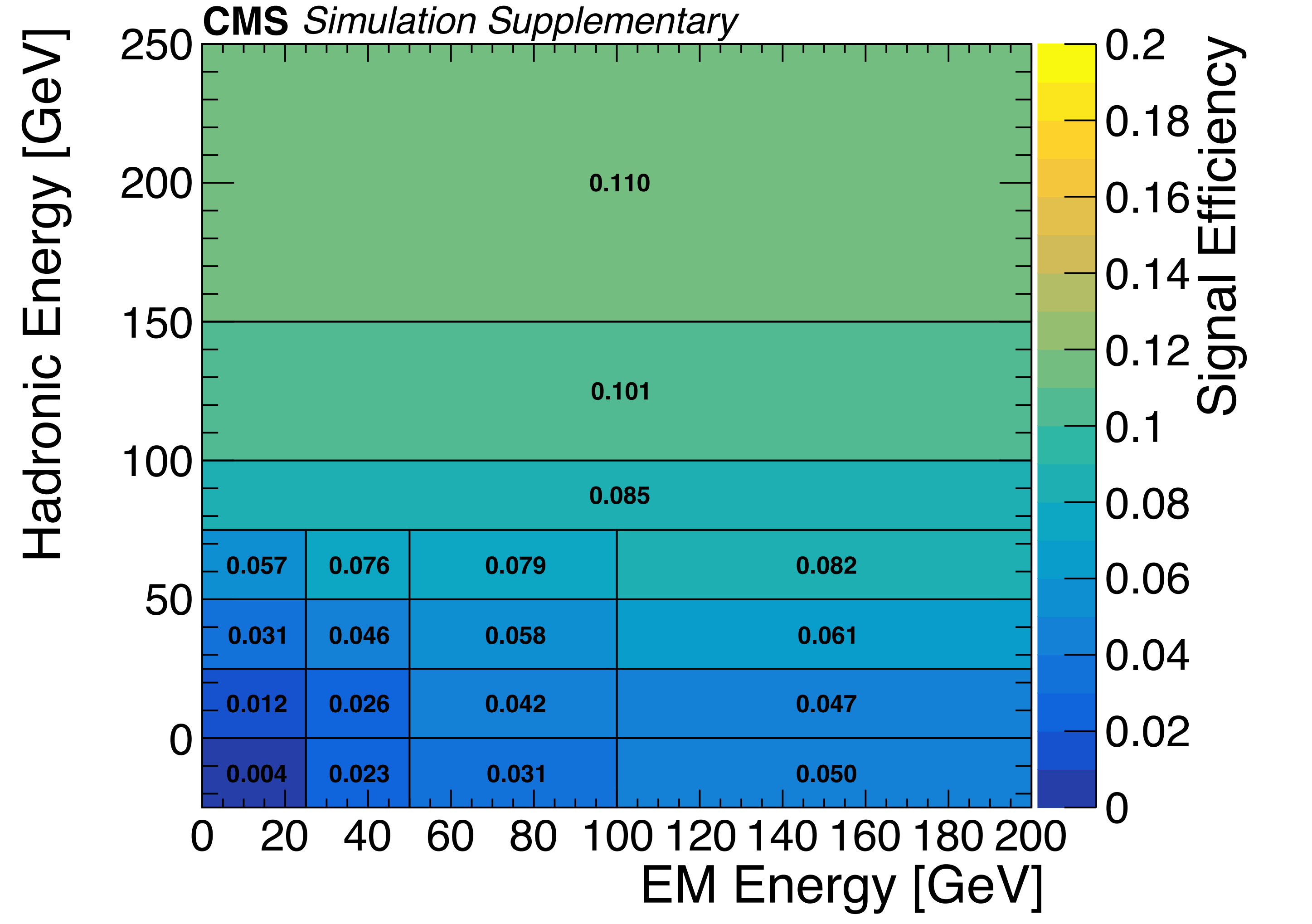
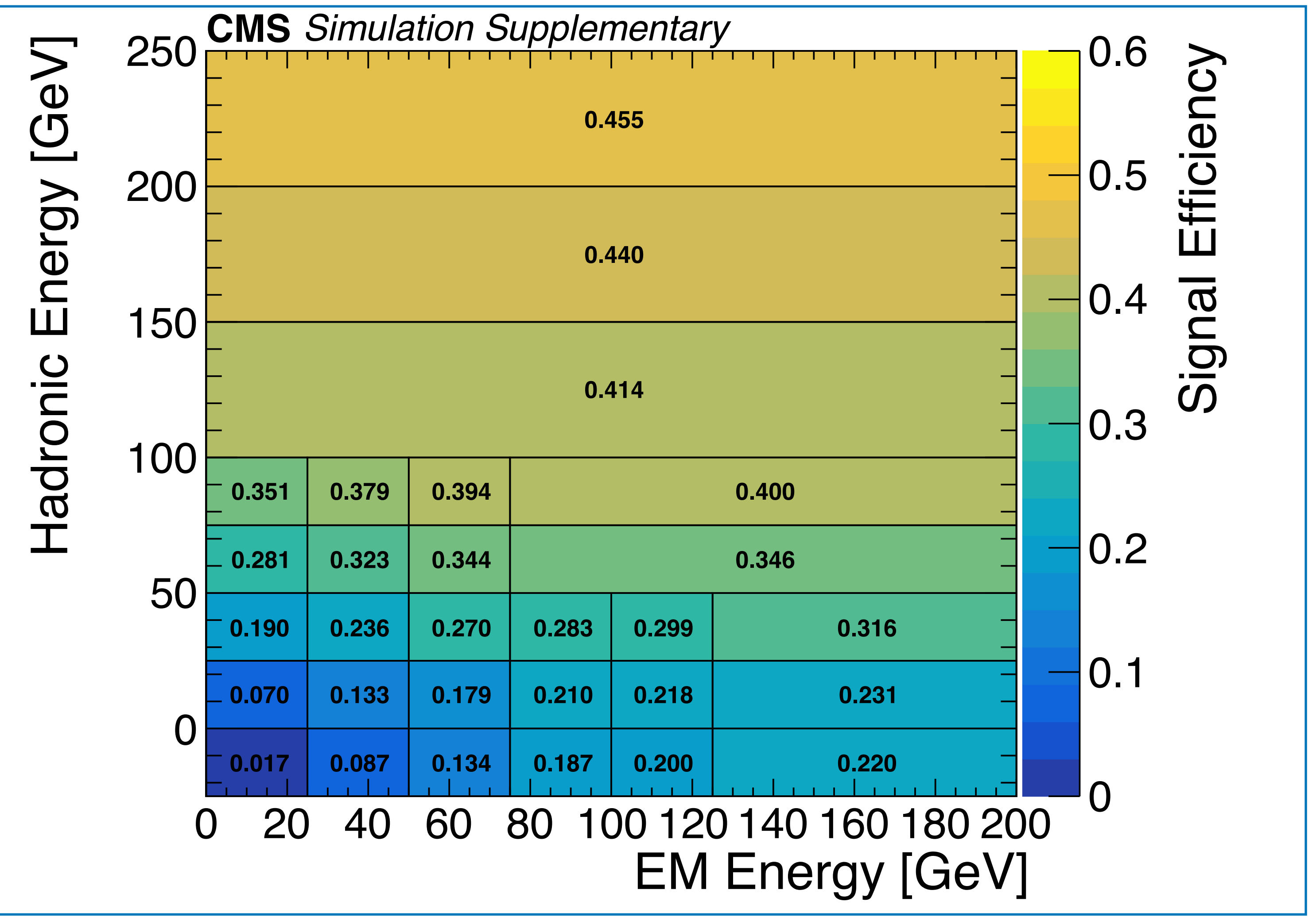
cut-based ID for region B



cluster efficiency region A



cluster efficiency region B



RESULTS FOR BENCHMARK MODELS

LIGHT SCALAR

$$\mathcal{L}_{SH} = \mathcal{L}_{\rm SM} + \overbrace{\frac{1}{2}\partial_\mu \hat{S}\,\partial^\mu \hat{S} - \frac{\mu_S^2}{2}\hat{S}^2}^{\mathcal{L}_{\rm DS}} - \overbrace{\left(A_{HS}\,\hat{S} + \lambda_{HS}\,\hat{S}^2\right)\hat{H}^\dagger \hat{H}}^{\text{Higgs portal}}$$

- potential for S chosen such that S does not develop a vev
- $m_S \sim \mu_S^2 + \lambda_{HS} v^2 \ll m_H$

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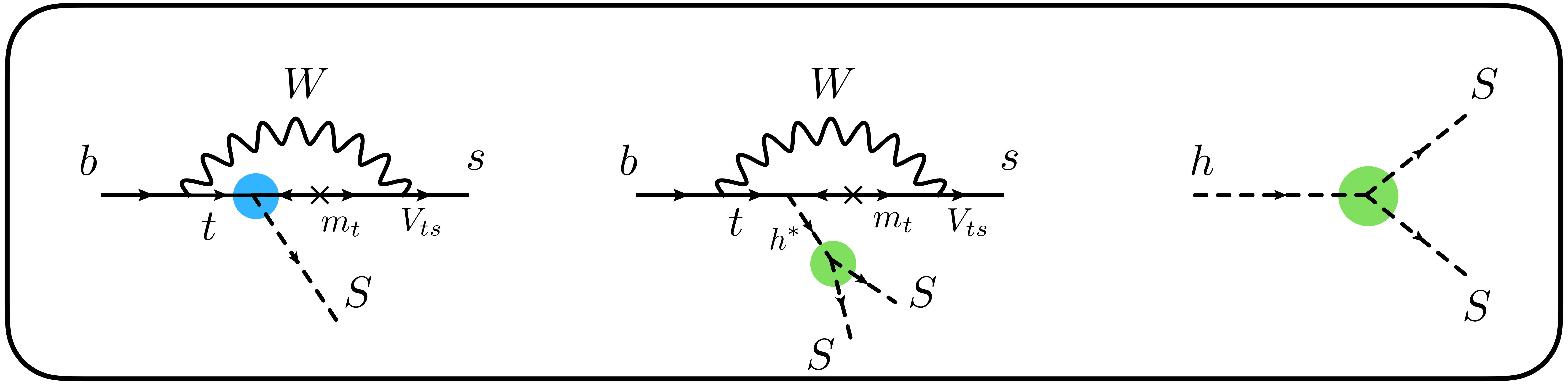
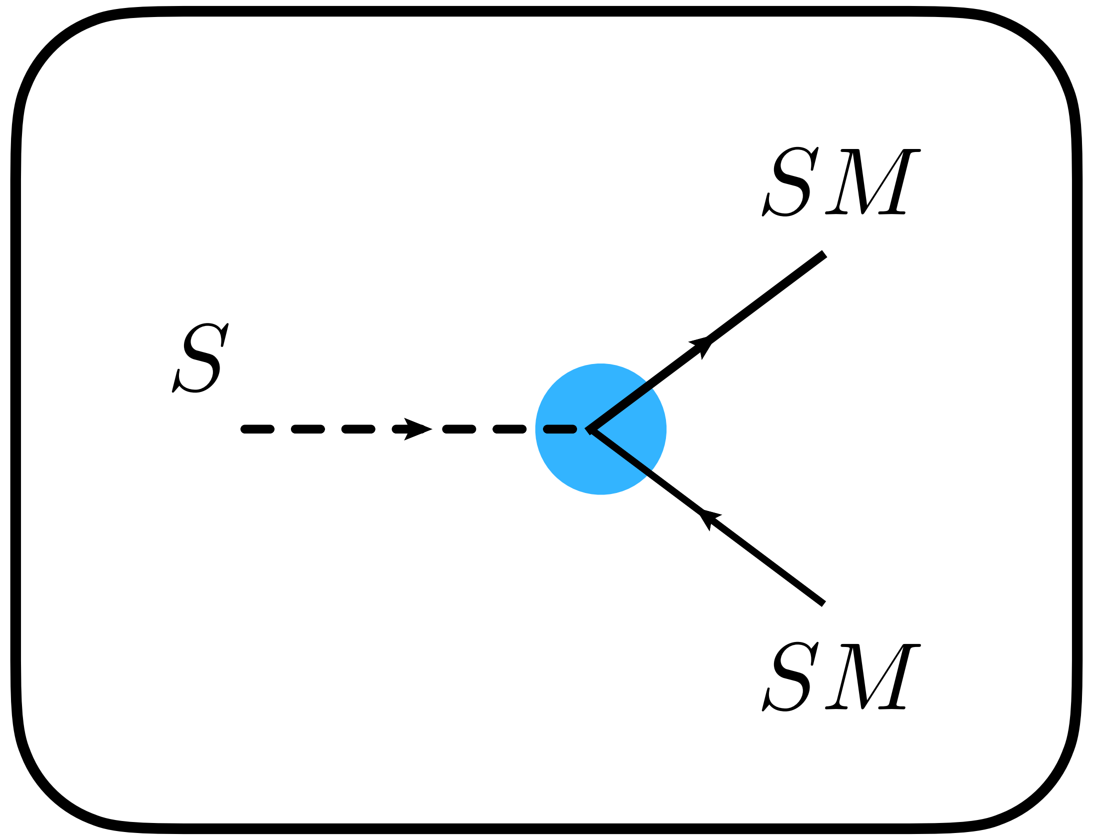
A_{HS}: controls the $\hat{H} - \hat{S}$ mixing

λ_{HS}: controls $Br(H \to SS)$

production



decay



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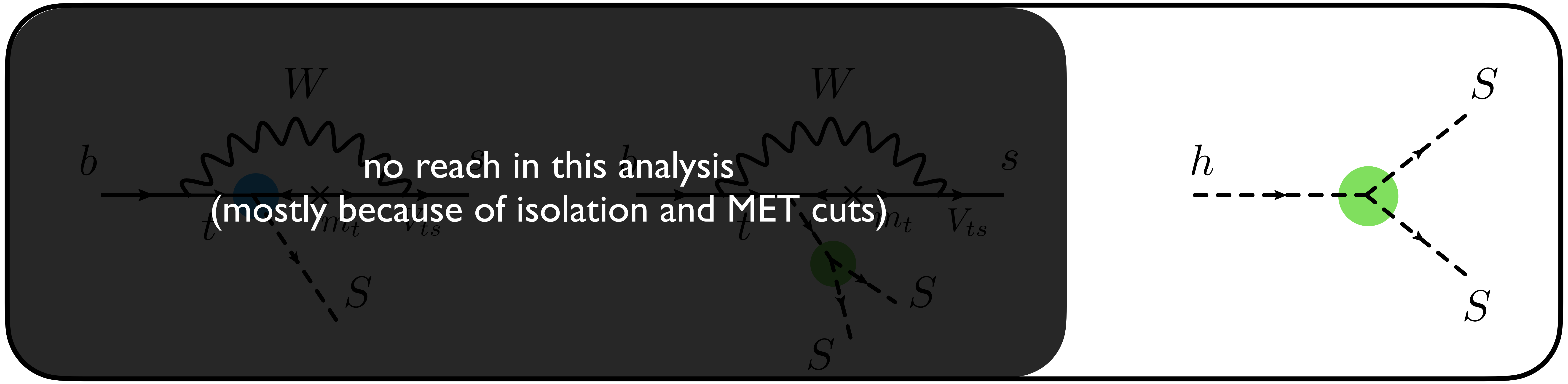

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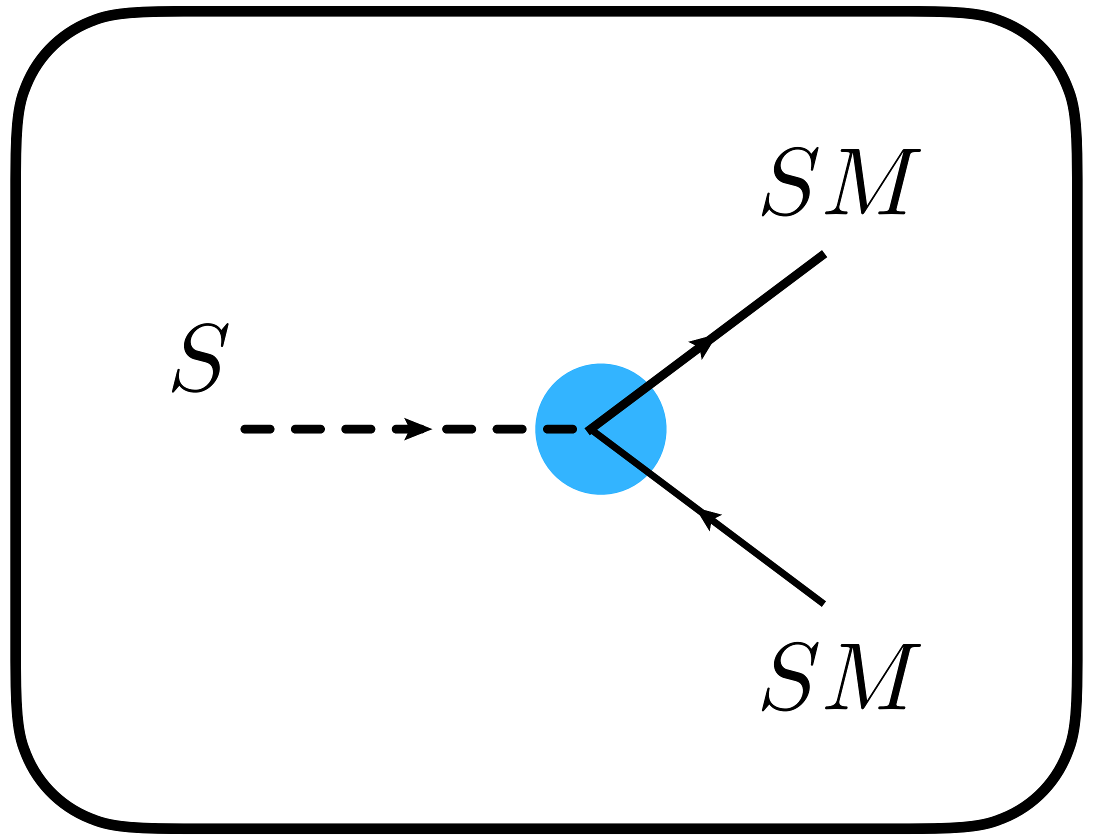

production and decay channels are ***decoupled***

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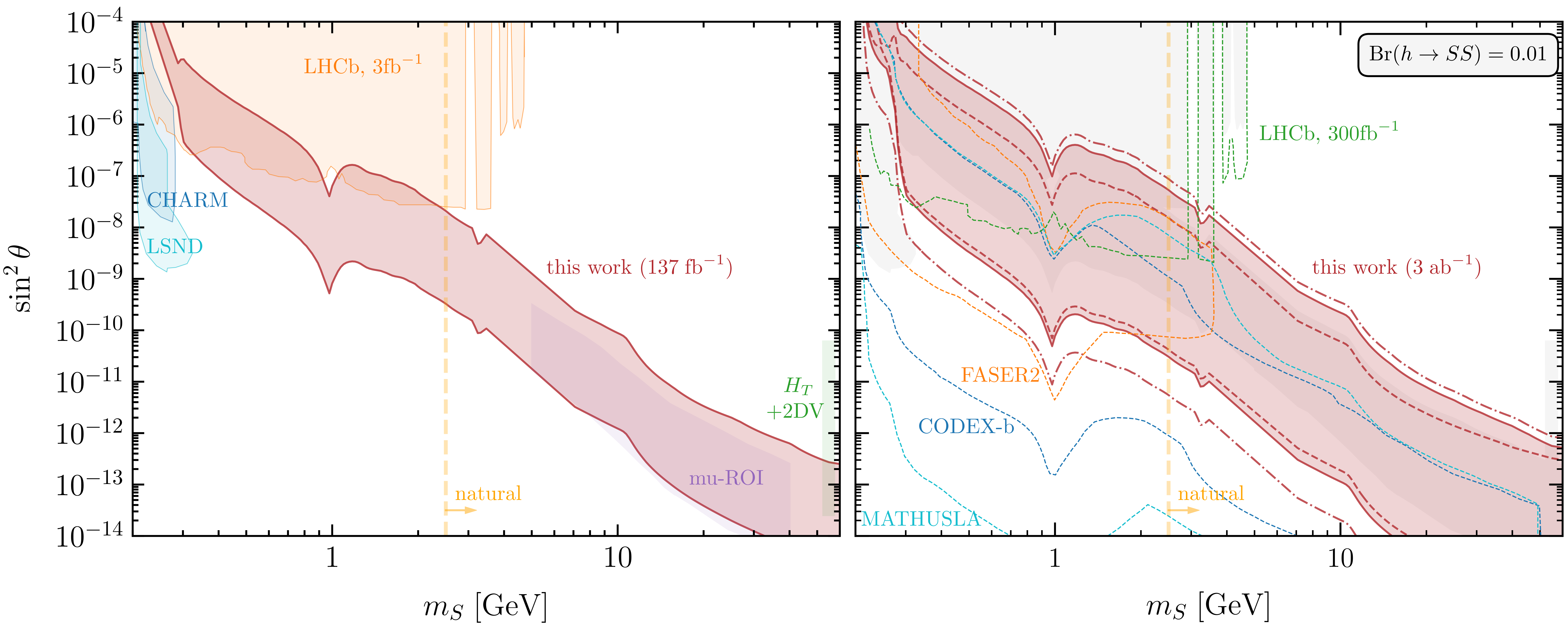
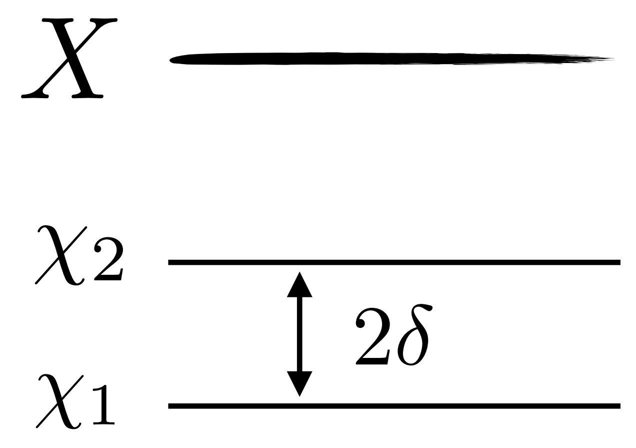


INELASTIC DM

$$\mathcal{L} = \mathcal{L}_{\rm SM} + i e_D \hat{X}^{\mu} \bar{\chi}_1 \gamma^{\mu} \chi_2 - \frac{\epsilon}{2\cos\theta_W} \hat{X}_{\mu\nu} \hat{B}^{\mu\nu}$$

the mass hierarchy of the model is



$$\Delta \equiv \frac{2\delta}{m_1}$$

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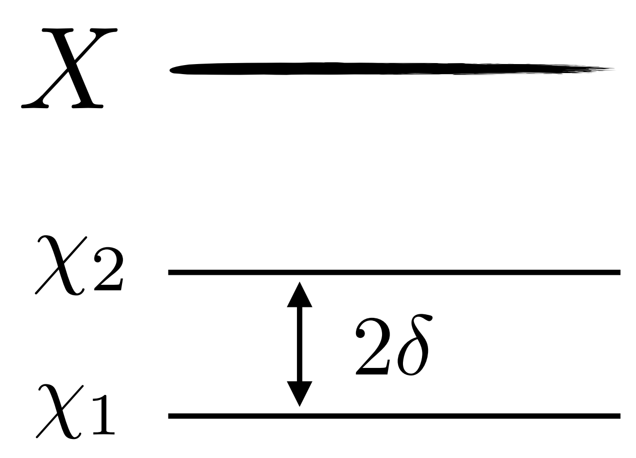

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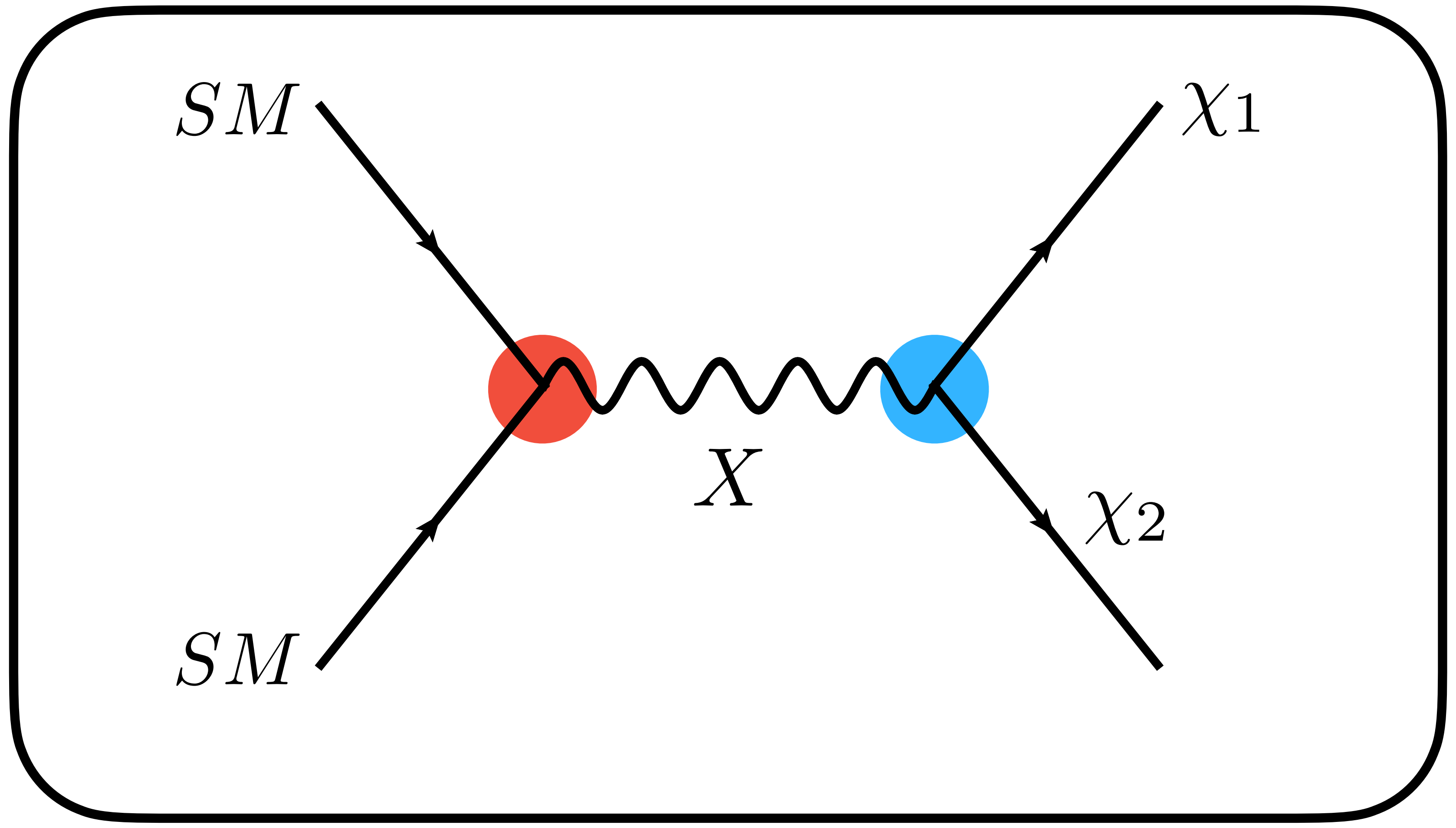

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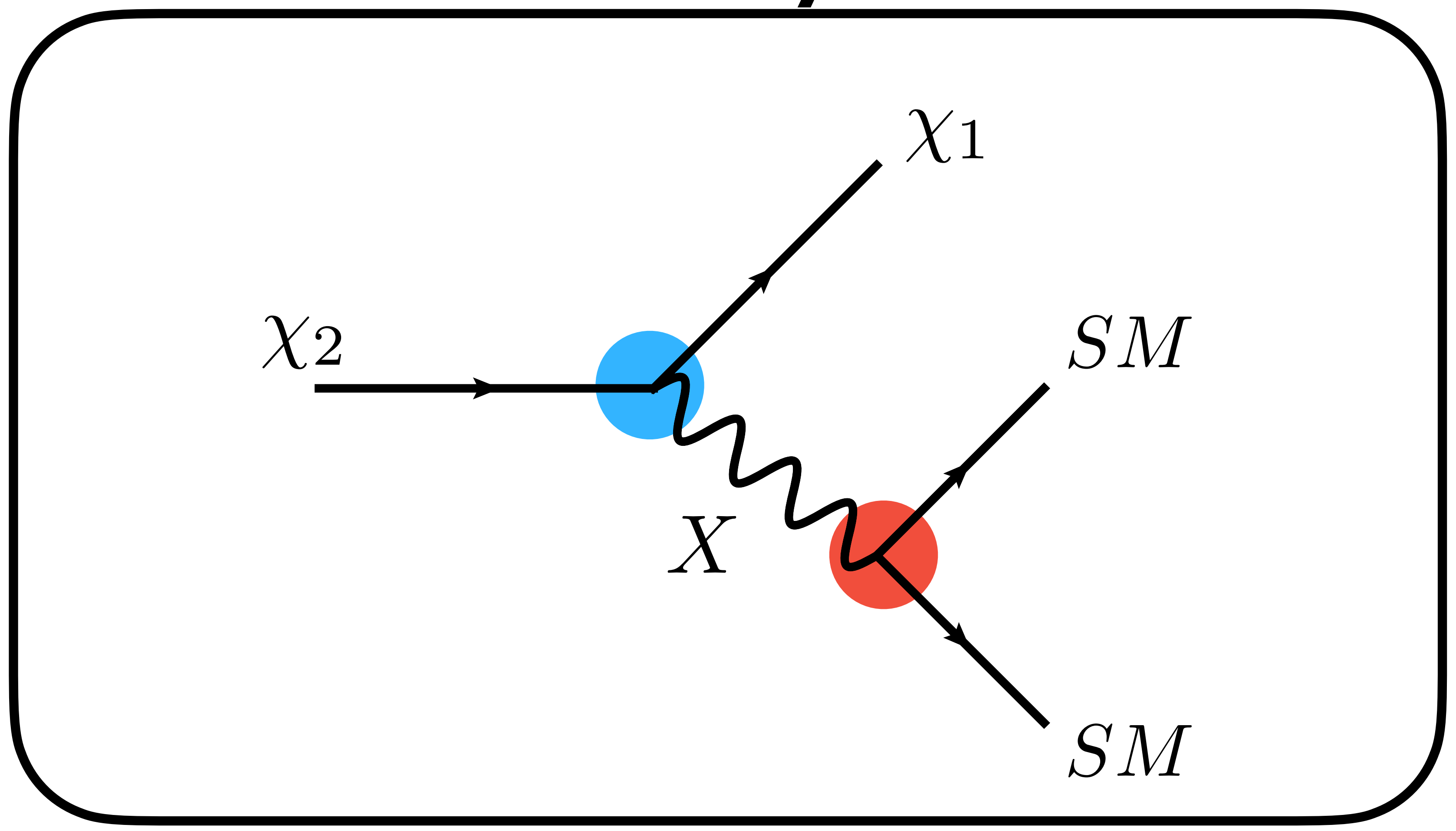

$E_{\rm LLP}$ **and MET are decoupled**

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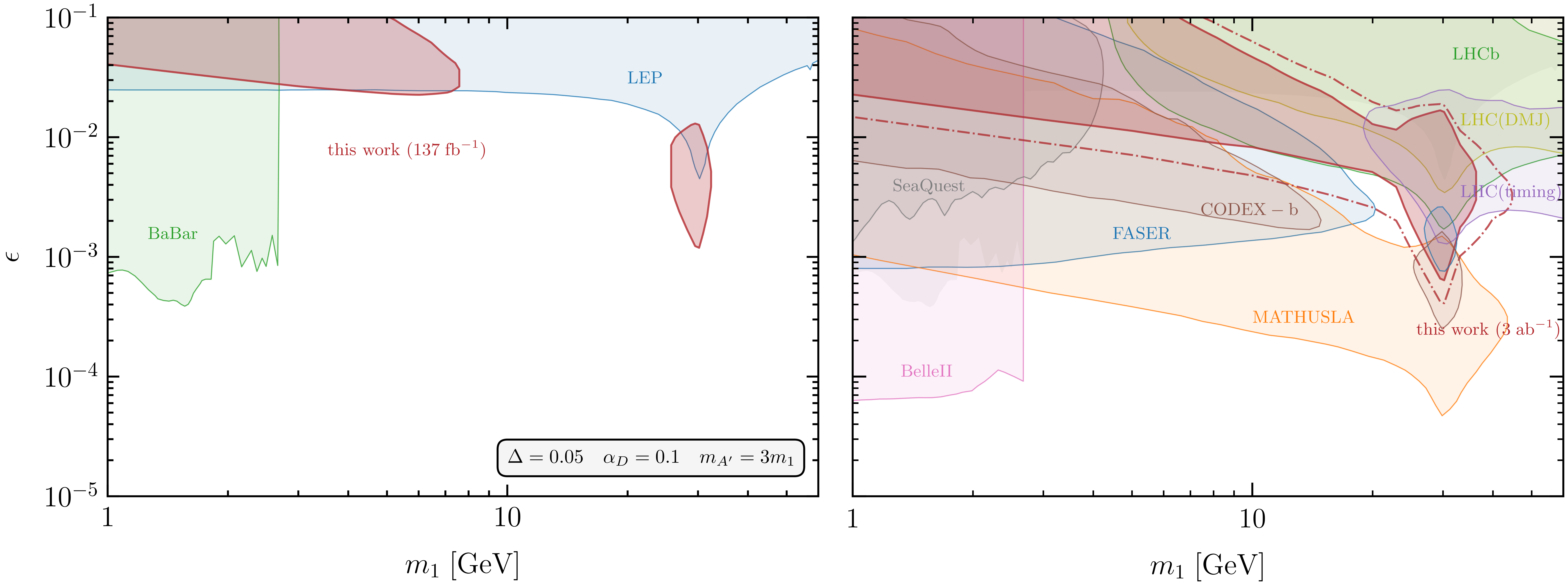
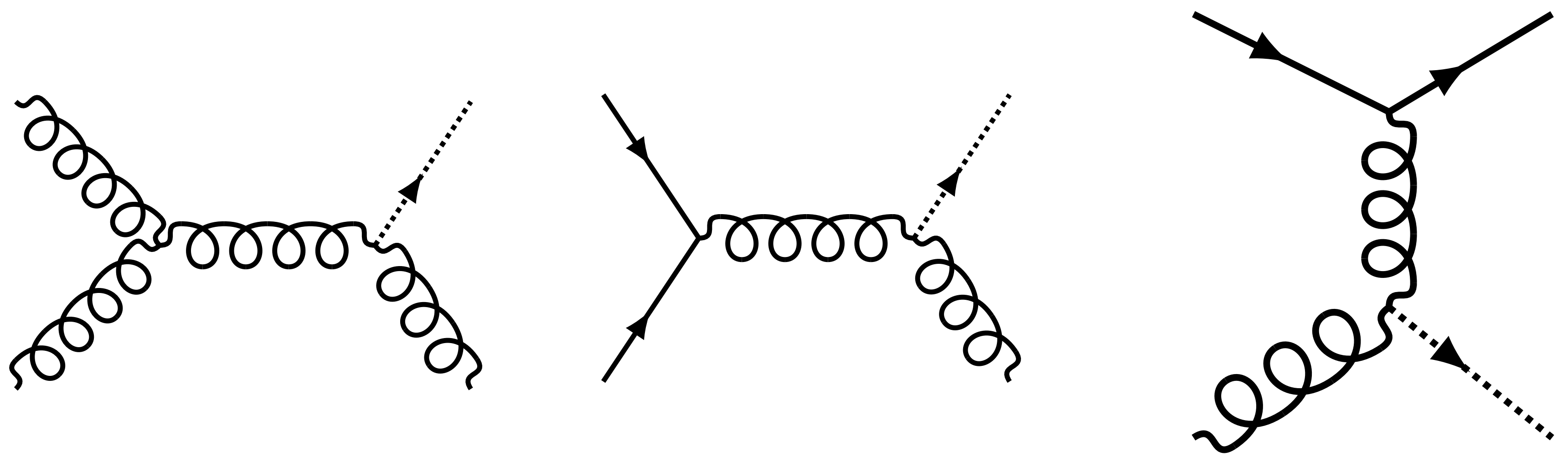


ALP

$$\mathcal{L} = \frac{1}{2}\left(\partial_\mu a\right)^2 + \frac{a}{4\pi f_a}\left(\alpha_s c_{GG}\, G^a_{\mu\nu}\,\widetilde{G}^{a,\mu\nu} + \alpha_2 c_{WW}\, W^a_{\mu\nu}\widetilde{W}^{a,\mu\nu} + \alpha_1 c_{BB}\, B_{\mu\nu}\widetilde{B}^{\mu\nu}\right) + \ldots$$

gluon-coupled ALP
($c_{GG} \neq 0$, $c_{BB} = c_{WW} = 0$)



main production channels

$a \to \gamma\gamma$

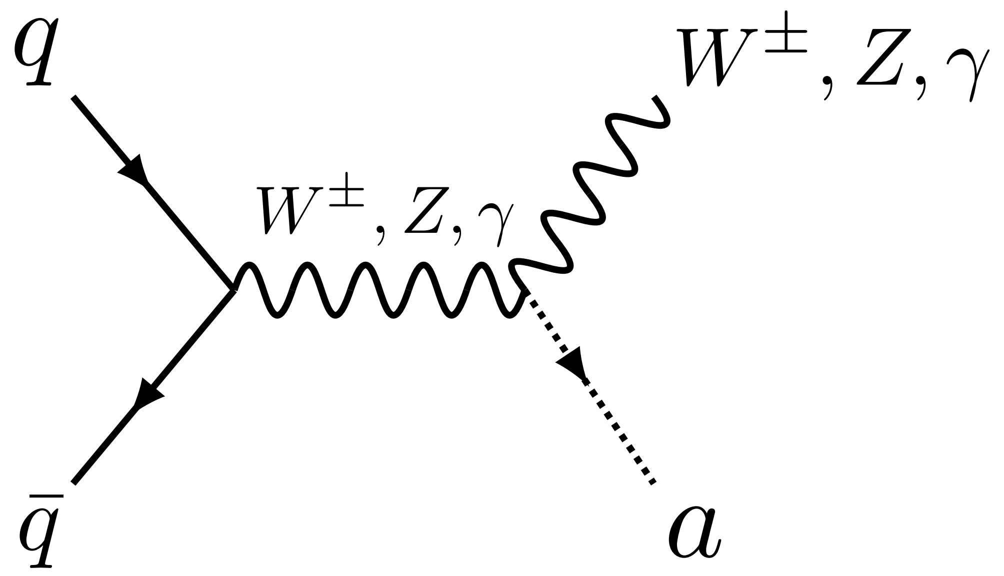
$a \to 3\pi$

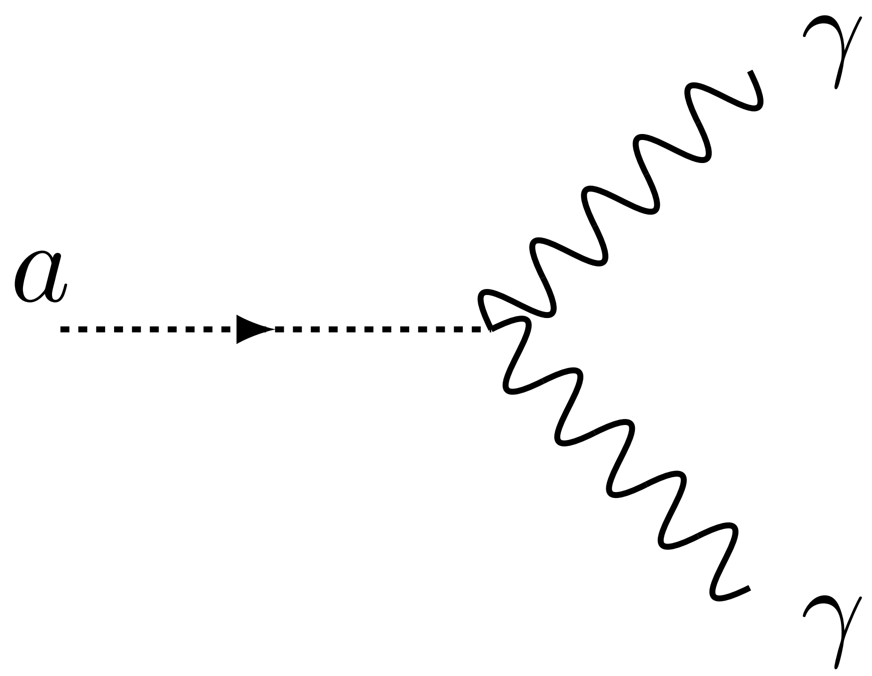
$a \to \eta\pi\pi$

$a \to \pi\pi\gamma$

main decay channels for current reach

photon-coupled ALP
($c_{GG} \neq 0$, $c_{BB} = c_{WW} = 0$)





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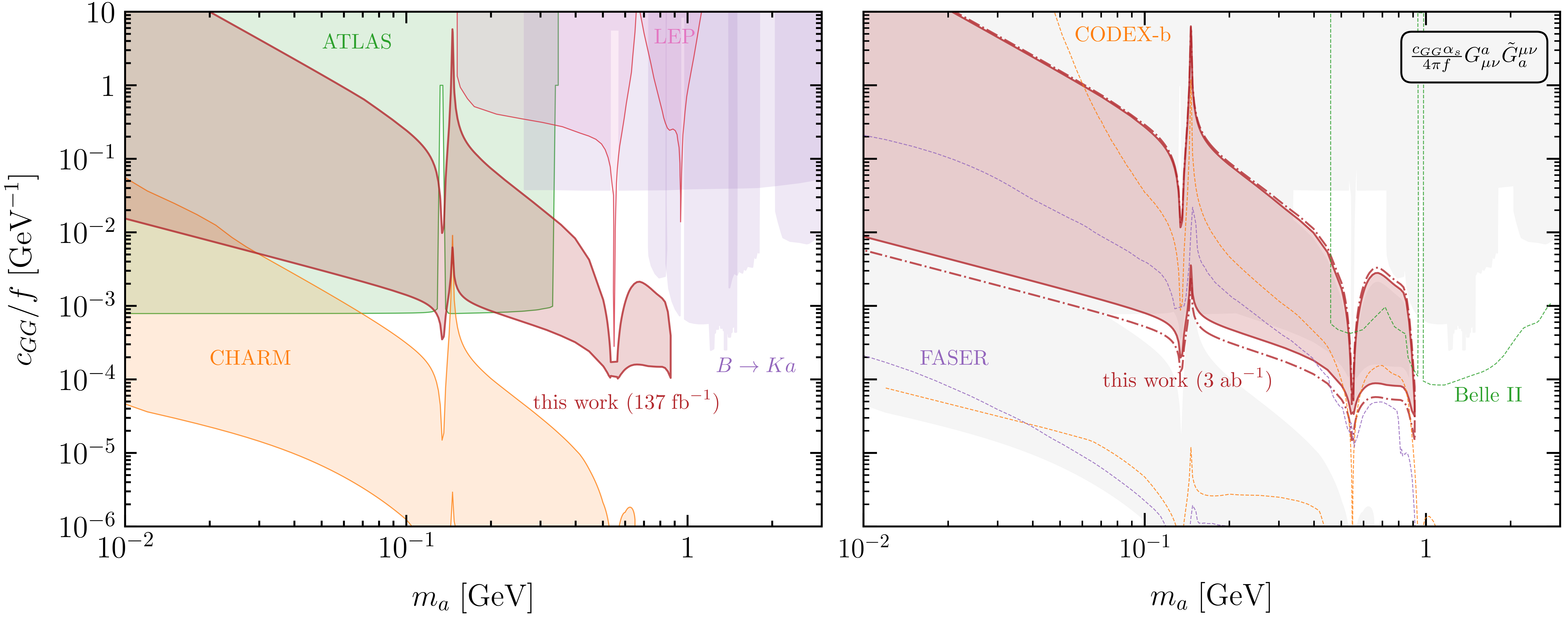

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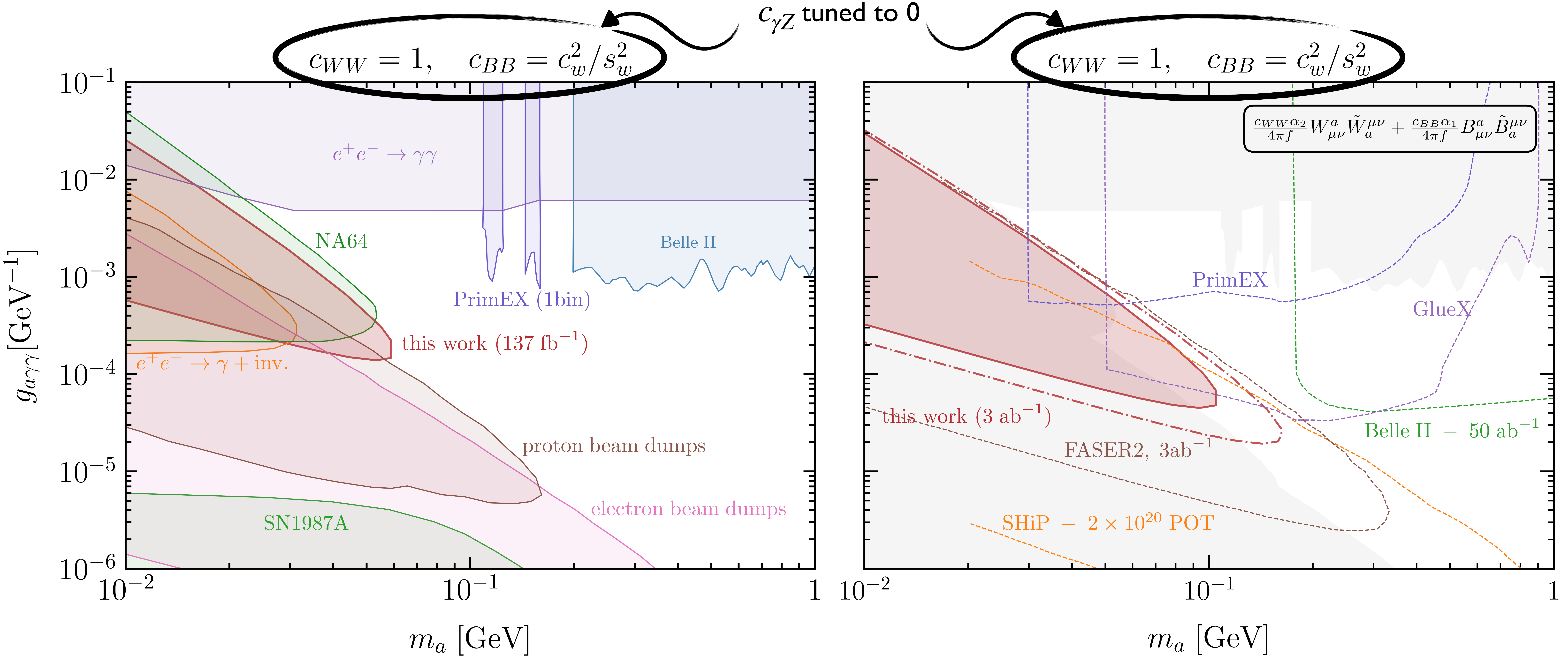
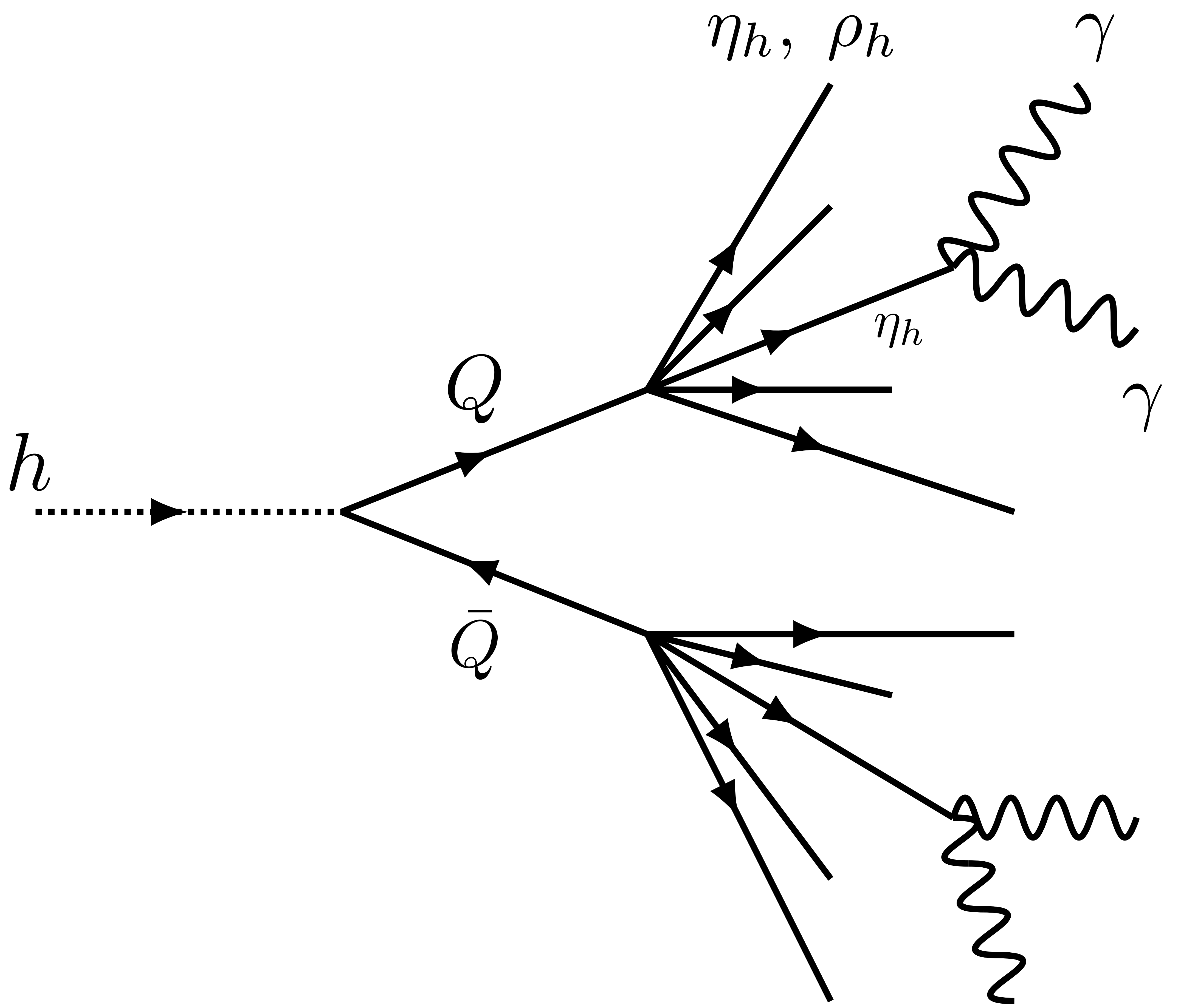
$c_{\gamma Z}$ tuned to 0



HIDDEN VALLEY

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \lambda h \bar{Q} Q$$



- we treat the η_h lifetime as a free parameter
- we take $\mathrm{Br}(\eta_h \to \gamma\gamma) = 1$ (hard to probe with other searches)
- we assume ρ_h to decay into $\eta_h \eta_h$ to maximize self-veto effects
- we implement the dark shower with Pythia treating η_h as a pion

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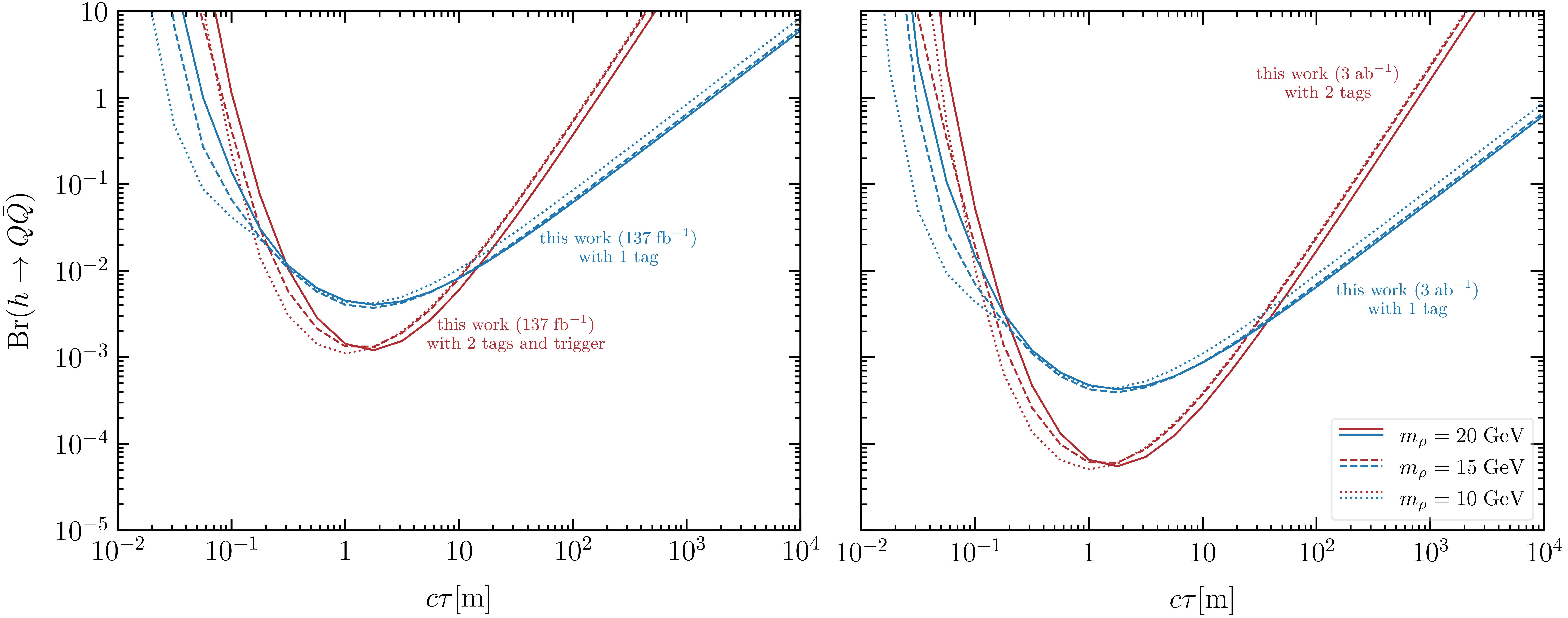

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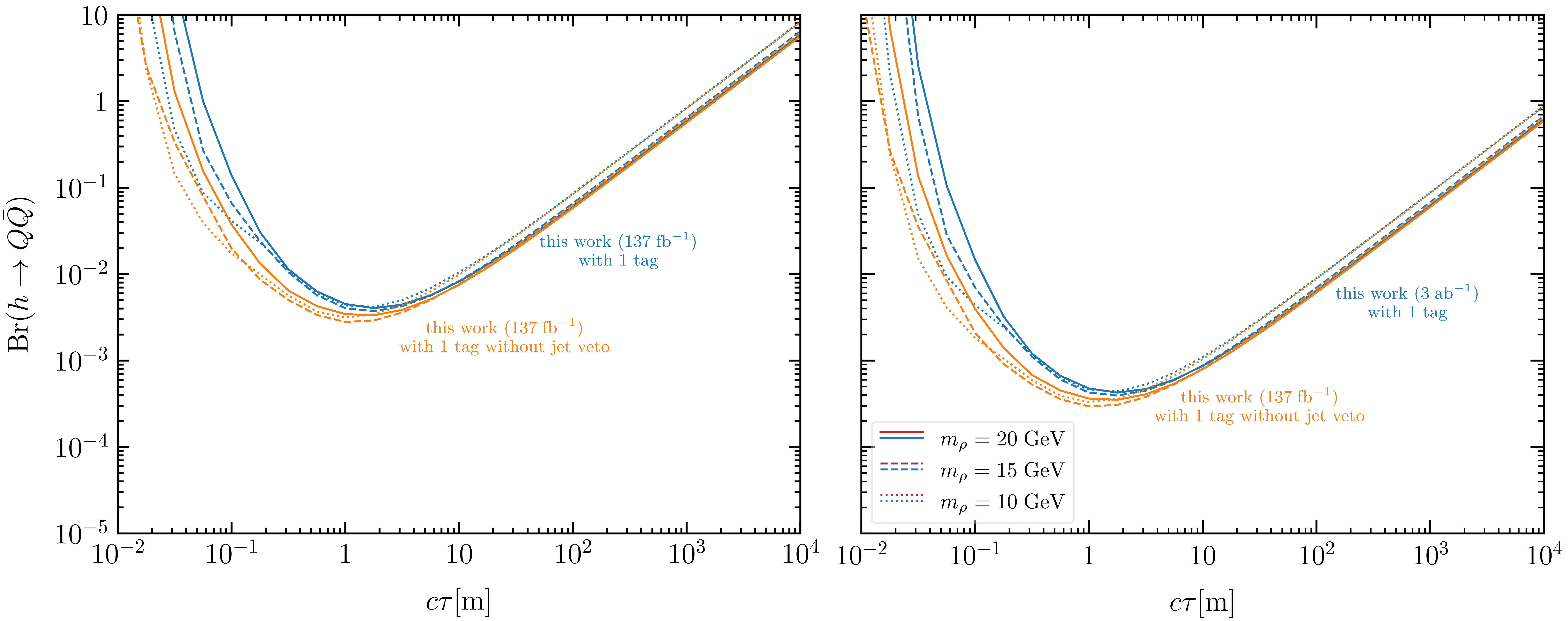

TAKEAWAYS

- for most of the benchmark models, *the* ***analysis covers previously unconstrained regions of the parameter space***

- ***MET cut boon and bane***:
    - allows to probe lower lifetimes
    - reduces cross-section
    - sensitivity could be improved by using model-specific techniques to suppress the backgrounds

- Isolation cuts reduce sensitivity for models where multiple LLPs are produced in the same direction (e.g. hidden valley)

BACKUP SLIDES

DARK PHOTON

Higgs portal / vector portal

$$\mathcal{L}_{SH} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm DS} - \underbrace{\lambda_{HS}\,\hat{S}^2\hat{H}^\dagger\hat{H}}_{\text{Higgs portal}} - \underbrace{\frac{\epsilon}{2\cos\theta_W}\hat{X}_{\mu\nu}\hat{B}^{\mu\nu}}_{\text{vector portal}}$$

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- dark scalar breaks $\mathrm{U}(1)$ and gives a mass to the dark photon
- $m_S \sim \mu_S^2 + \lambda_{HS}v^2 \gg m_H$

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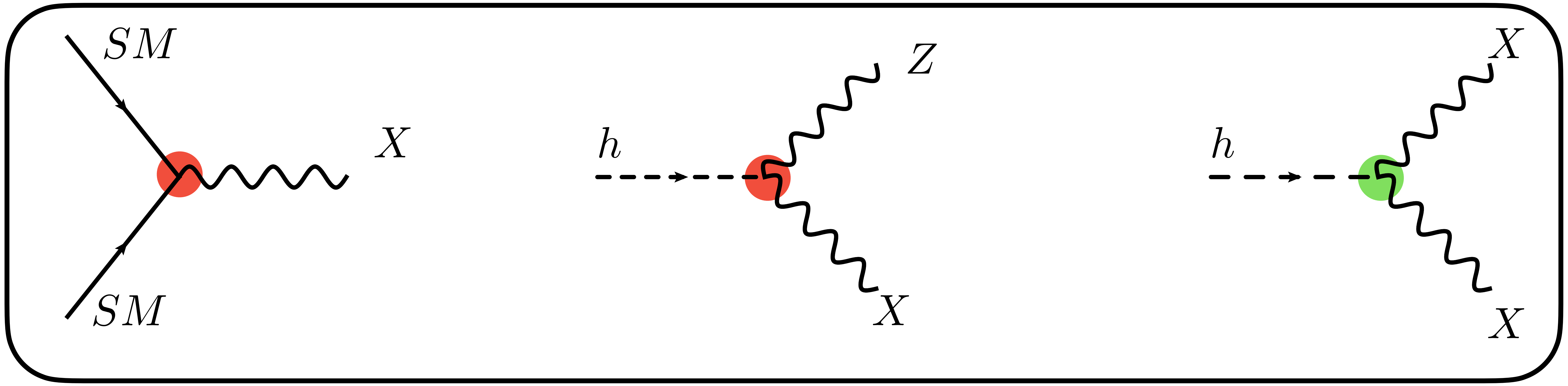
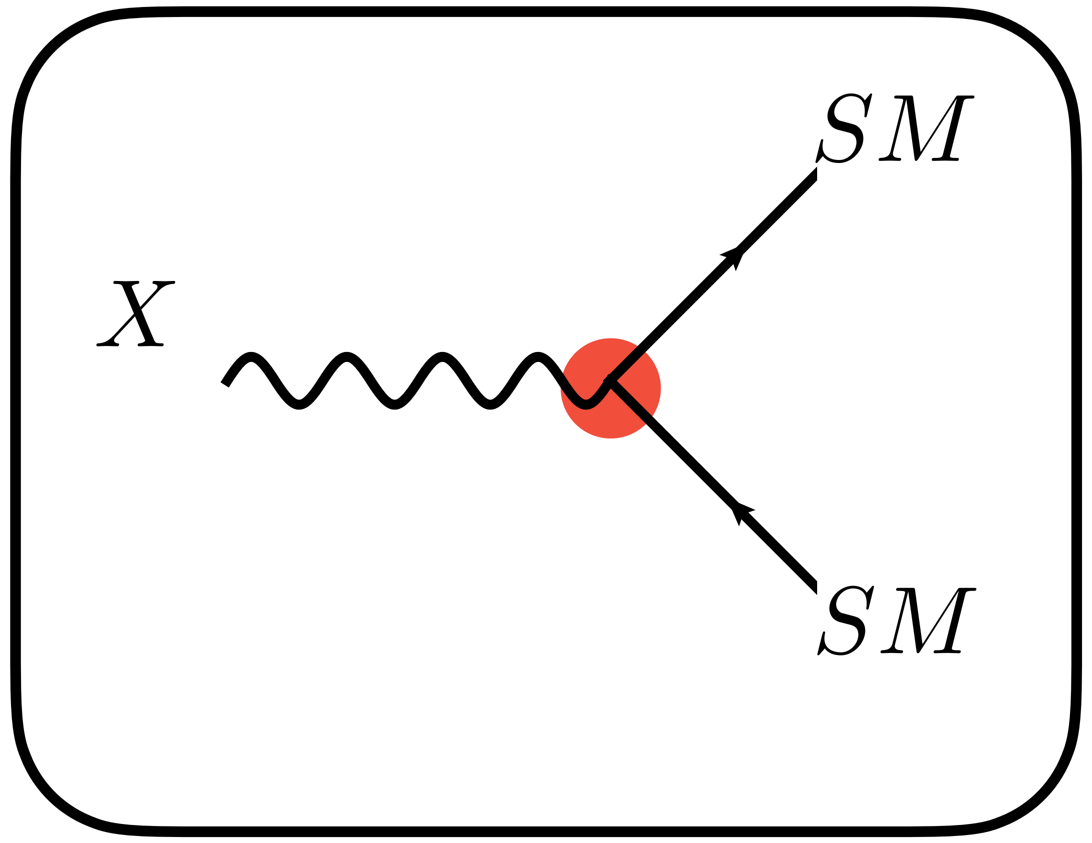


decay



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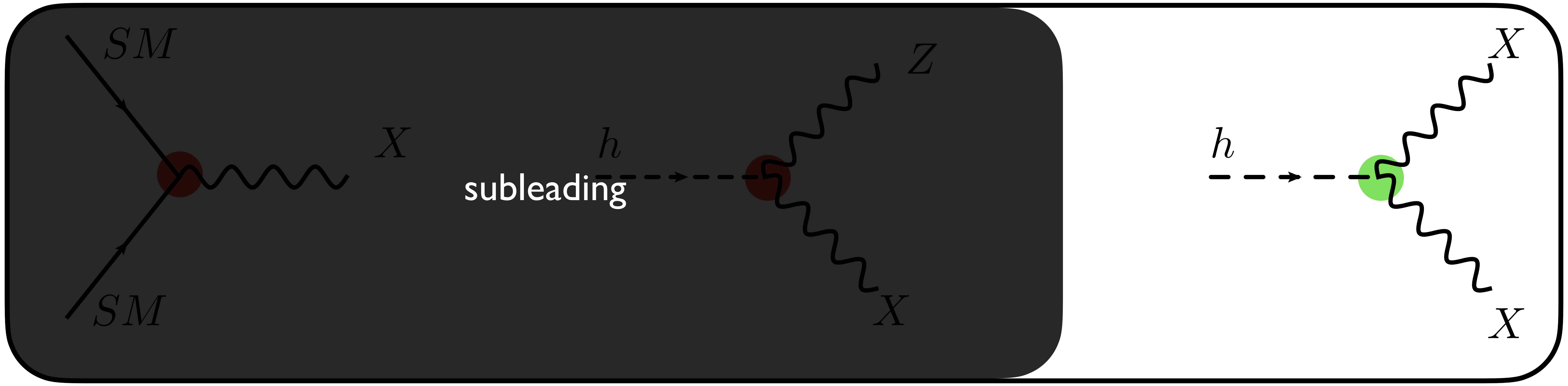

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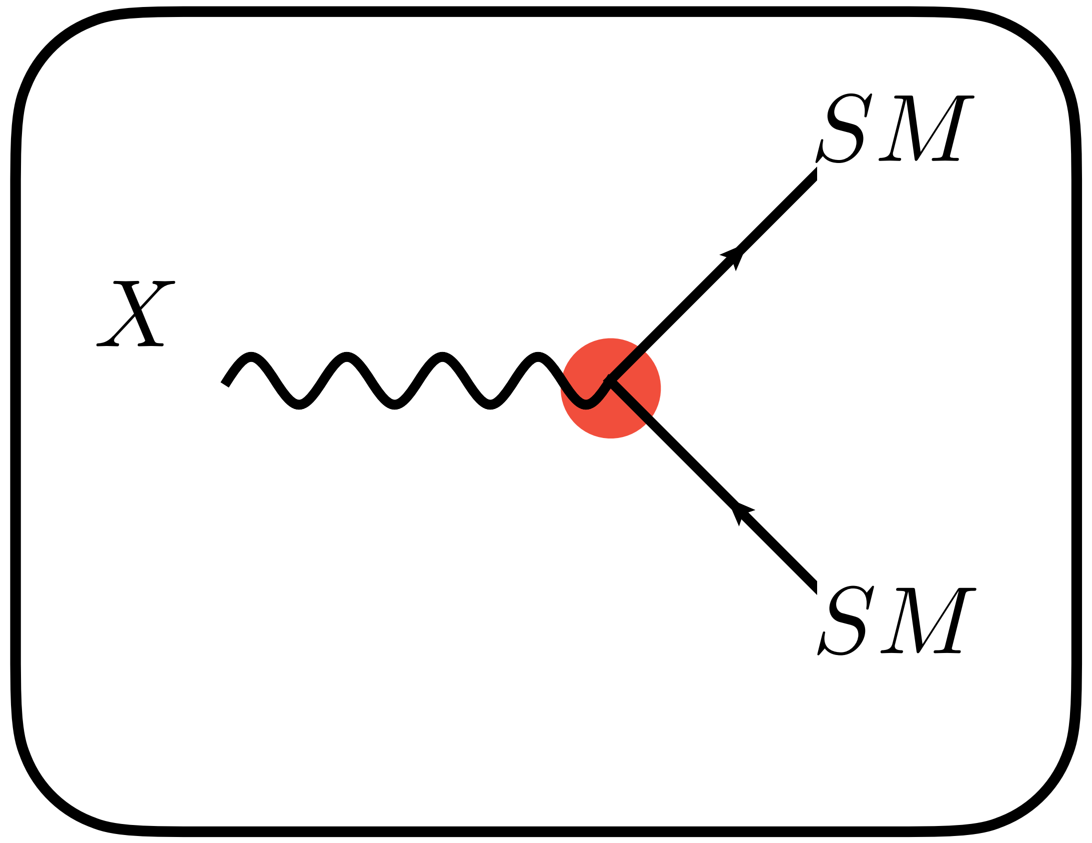

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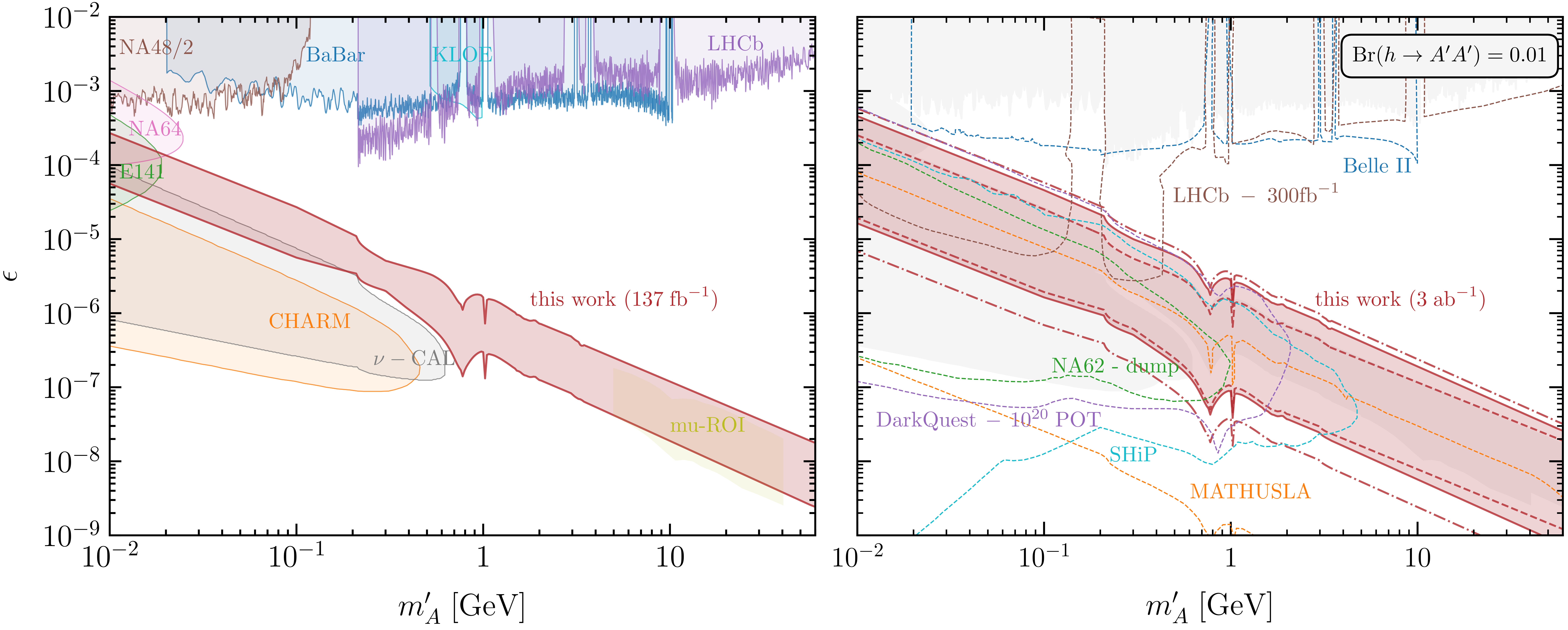

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