Dark photon bounds in the dark EFT

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FAPESP

IFUSP
Instituto de Física da USP

DESY.

HEFT - Manchester – June 2023

Straight to the point

[Holdom, 1986]

$$\mathscr{L} = \mathscr{L}_{\rm SM} - \frac{1}{4} Z_D^{\mu\nu} Z_{D\mu\nu} + \frac{m_{Z_D}^2}{2} Z_D^{\mu} Z_{D\mu} - \frac{\epsilon}{2 c_W} Z_D^{\mu\nu} B_{\mu\nu}$$

- New light vector field Z_D (*dark photon*)

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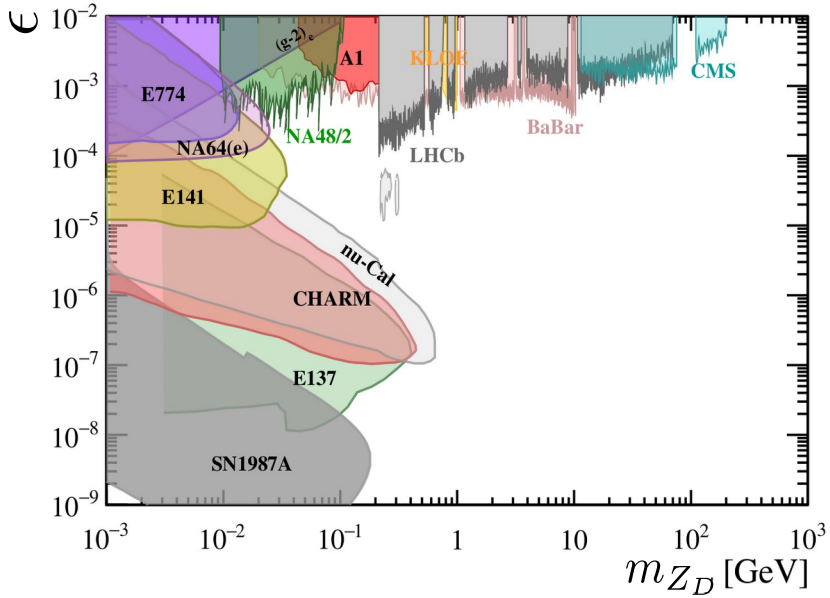

[Fabbrichesi, Gabrielli, Lanfranchi, 2021]

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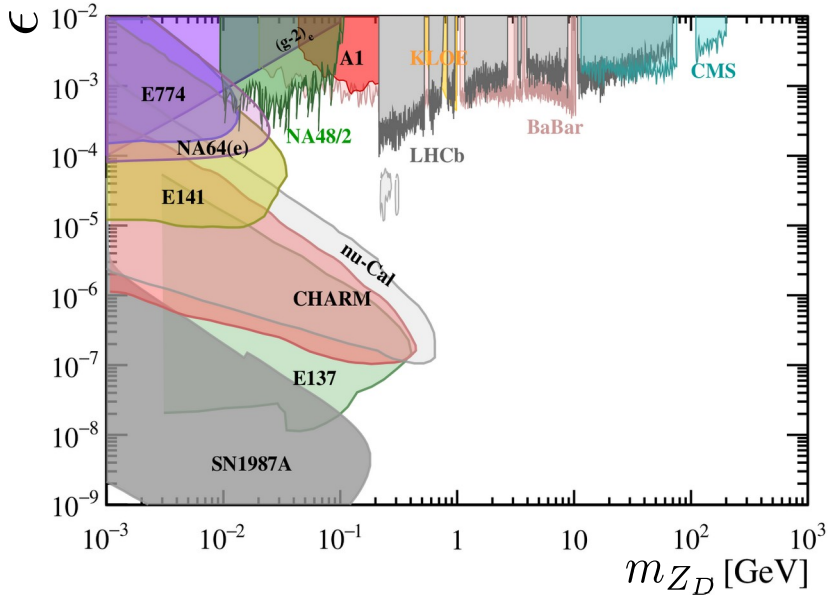

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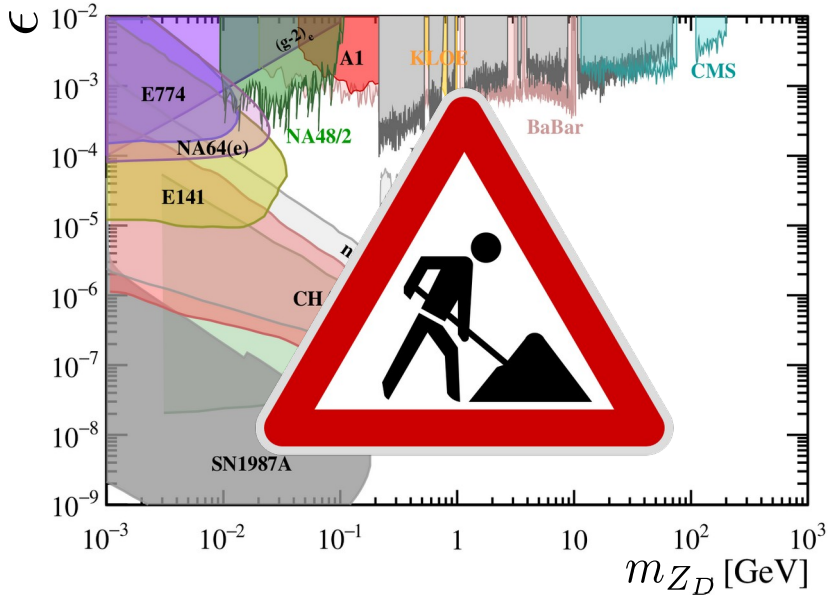

[Fabbrichesi, Gabrielli, Lanfranchi, 2021]

The dark EFT

- Operators up to dim 6 with the dark photon
- Only field strengths

$\psi^2 HX$	$X^2 H^2$
$\bar{Q}\sigma^{\mu\nu}\tilde{H}u_R Z_D^{\mu\nu}$	$H^\dagger H Z_D^{\mu\nu} Z_D^{\mu\nu}$
$\bar{Q}\sigma^{\mu\nu}H d_R Z_D^{\mu\nu}$	$H^\dagger H Z_D^{\mu\nu} B^{\mu\nu}$
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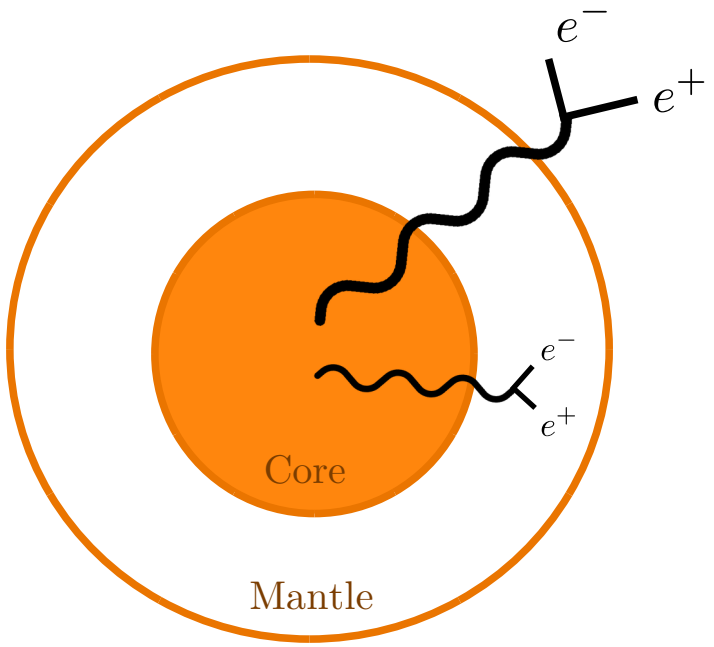
- For our purposes $\rightarrow$ Electron dark dipole:

$$\mathscr{L} \supset -\epsilon Z_D^\mu \bar{e}\gamma^\mu e + \frac{d_e v}{16\pi^2\Lambda^2} Z_D^{\mu\nu}\bar{e}\sigma^{\mu\nu}e$$

ϵ and d_e/Λ^2 independent

Phenomenology - Supernova

[Burrows, Lattimer, 1987]
[Raffelt, 1996]
[Denton, Ferrer, Krauss, 2012]
[Kazanas et al, 2014]



- Constraints from:
  - Escaping dark photons
  - Earlier explosion
- # of $Z_D \sim \epsilon^2 P_{\text{decay}}(\epsilon, \Lambda)$

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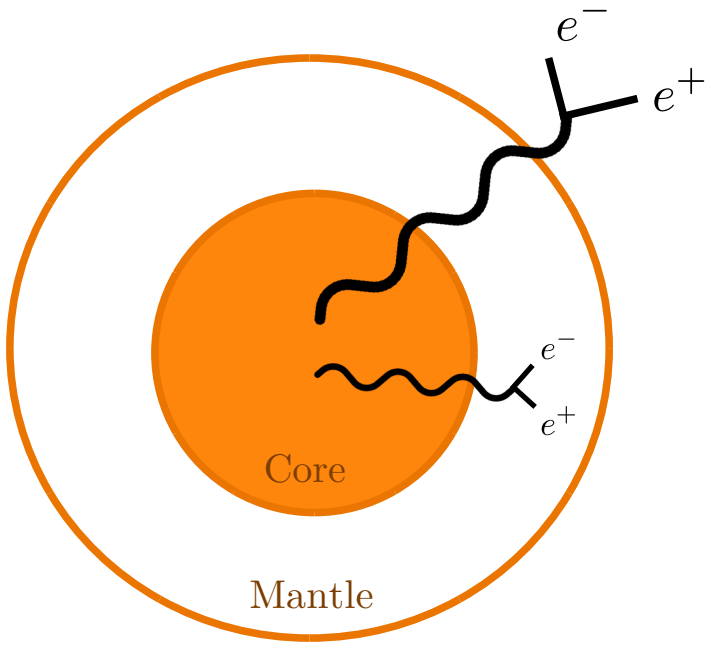

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$$\Gamma(Z_D \to e^- e^+) \supset \frac{m_{Z_D}^3 v^2 d_e^2}{1536\pi^5 \Lambda^4} \left(1 + 8\frac{m_e^2}{m_{Z_D}^2}\right) \sqrt{1 - \frac{4m_e^2}{m_{Z_D}^2}}$$

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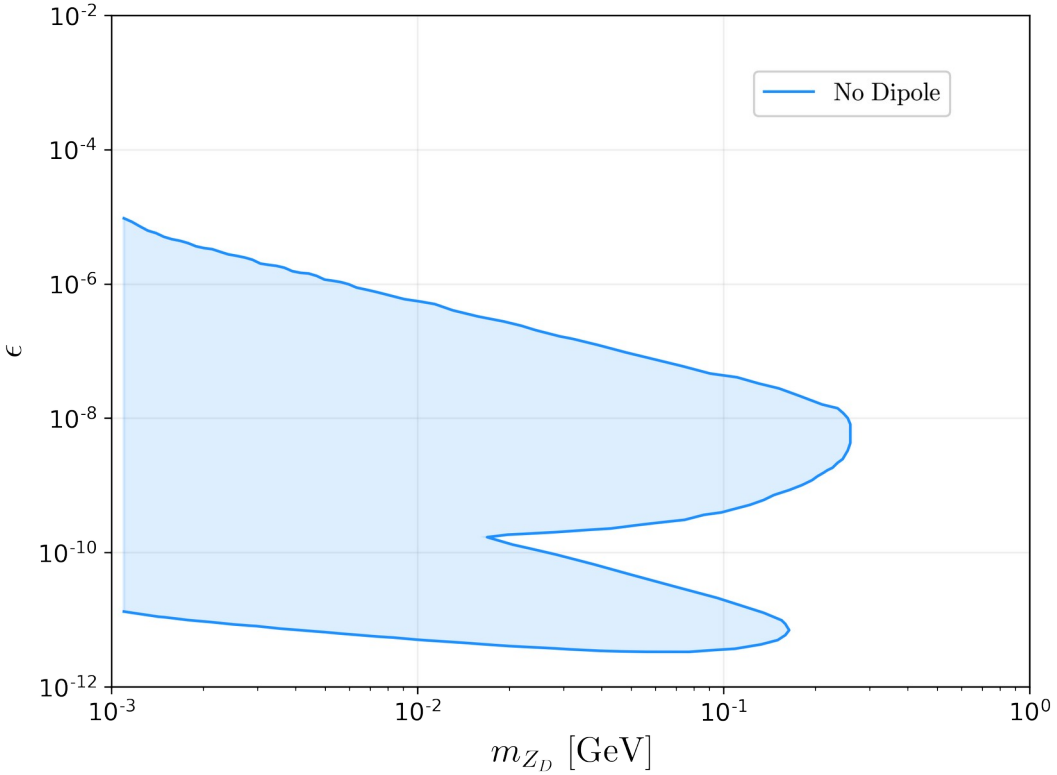

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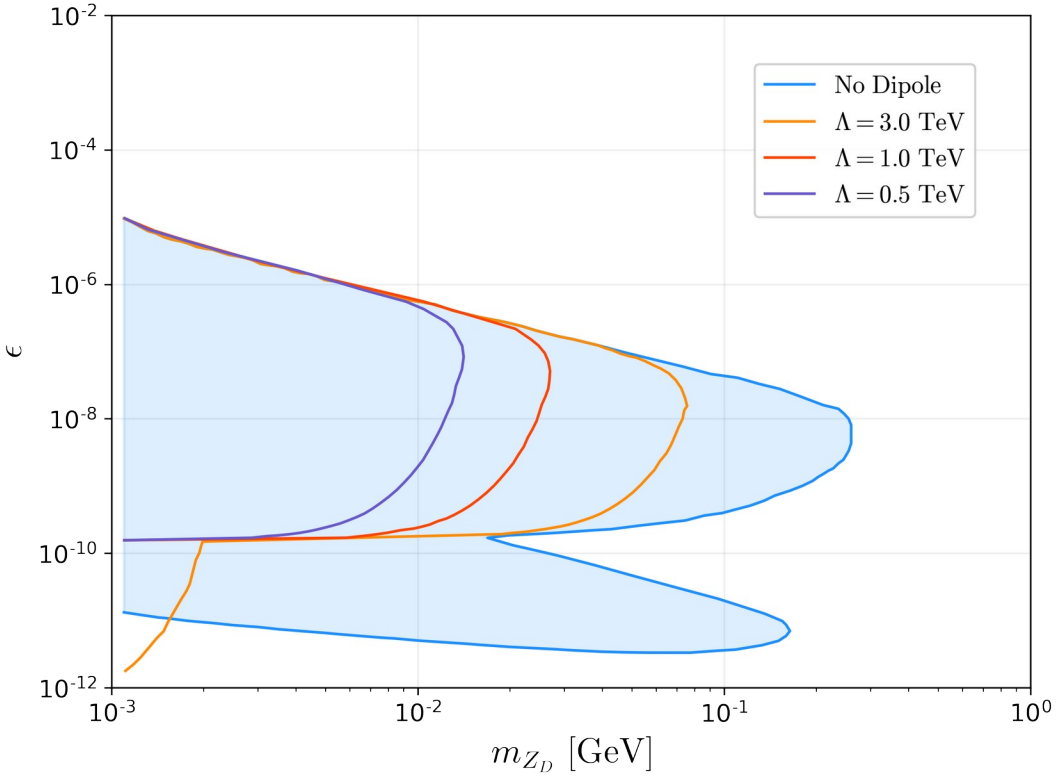

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Phenomenology - E137

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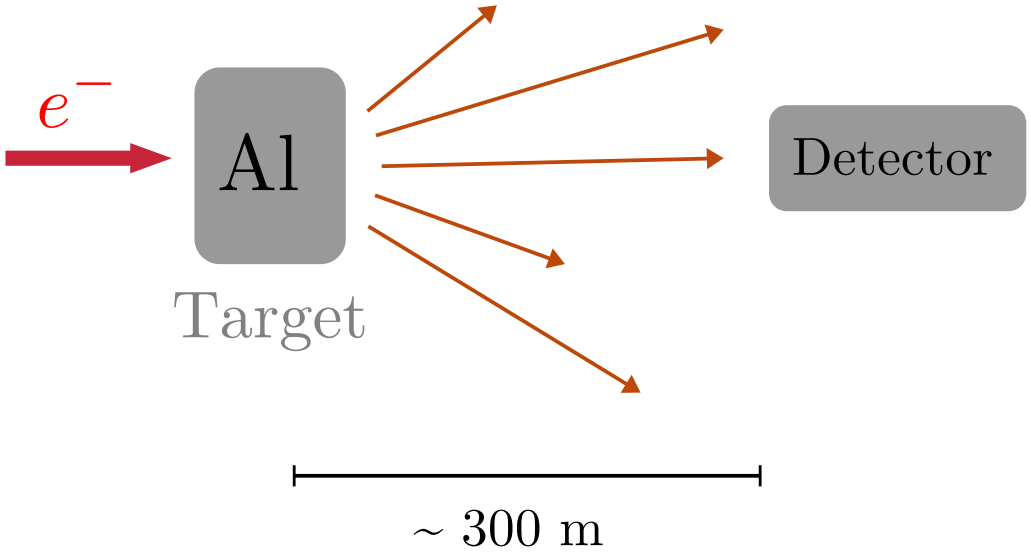

- Old beam-dump:
  - 20 GeV electron beam
  - ~ 300 m baseline
- # of Z_D
  $\sim f_{\text{prod}}(\epsilon, \Lambda) P_{\text{decay}}(\epsilon, \Lambda)$

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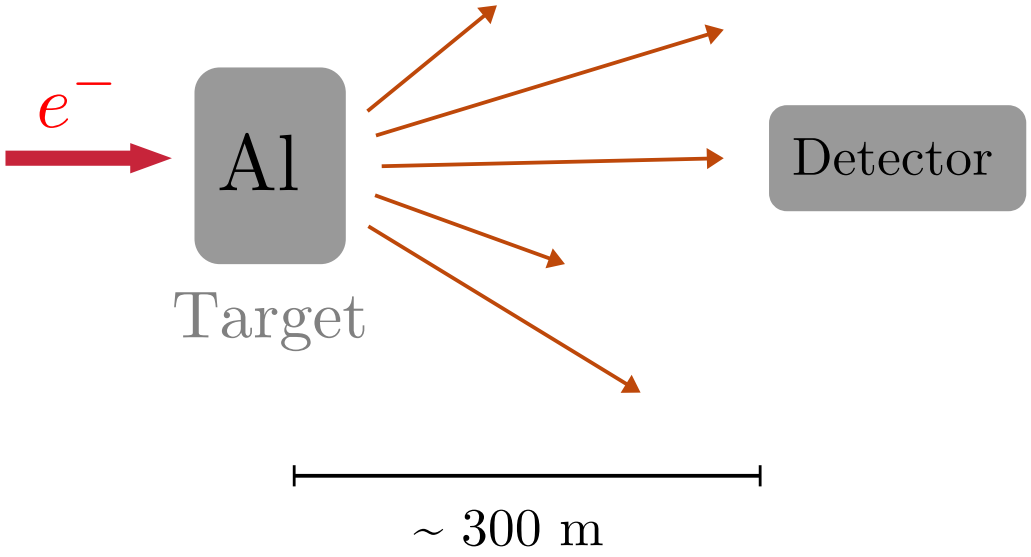

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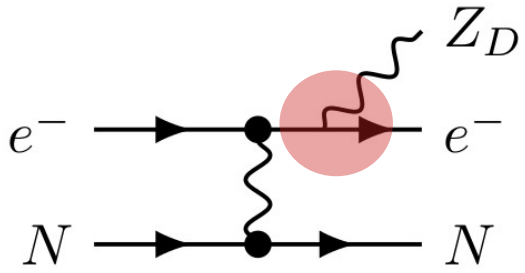

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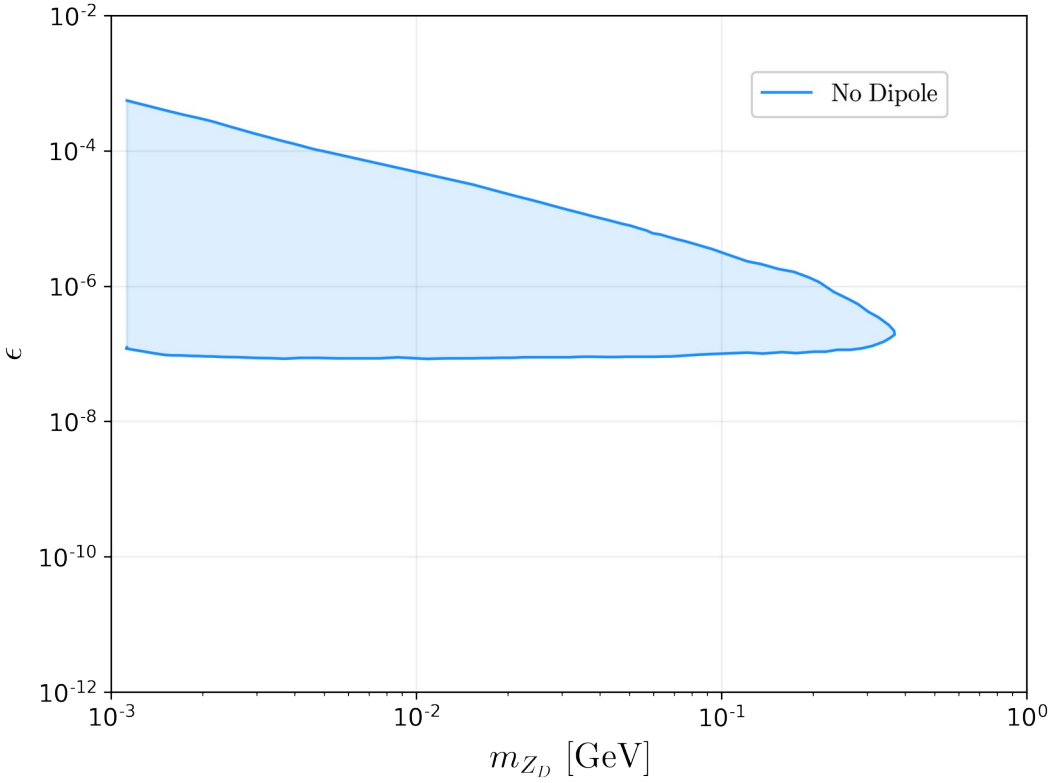

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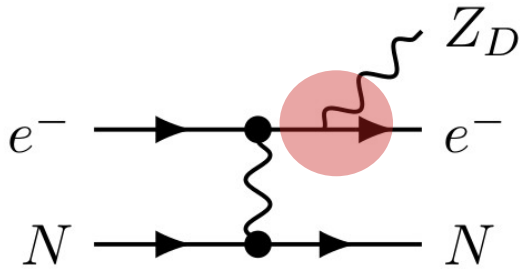

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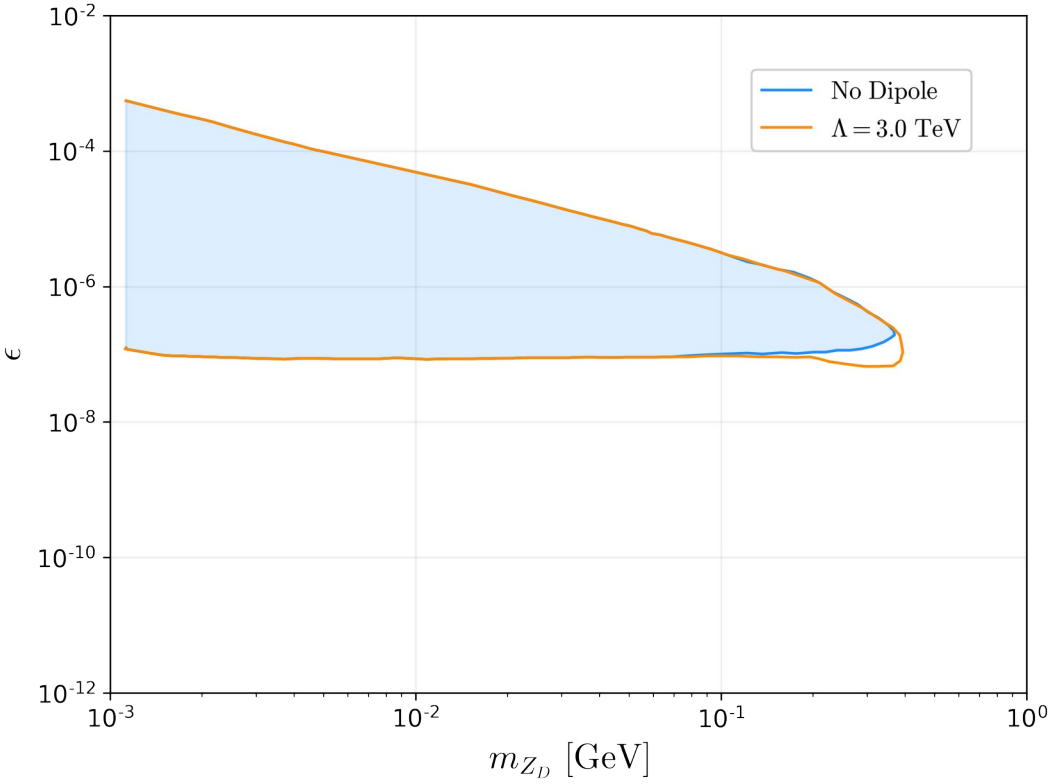

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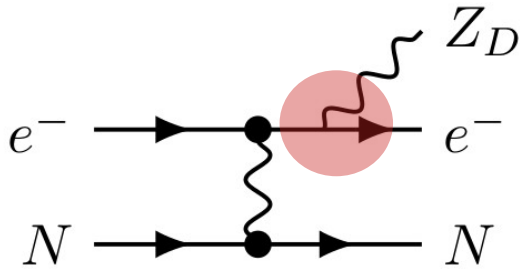

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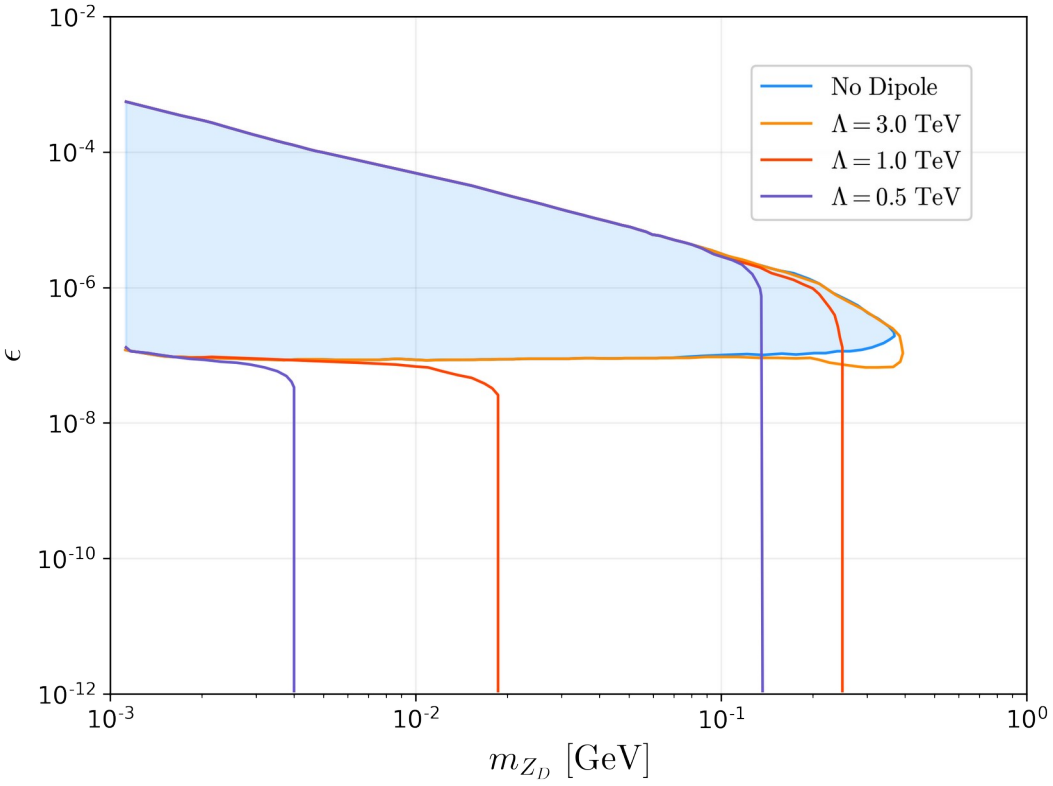

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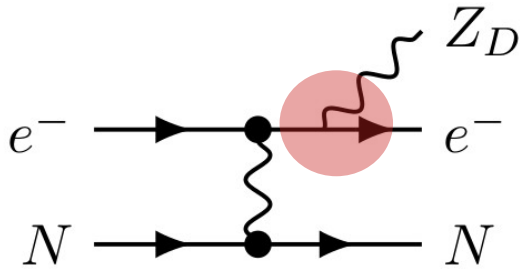

Summary

- Dark photon bounds are in general *not robust* in the presence of effective interactions.

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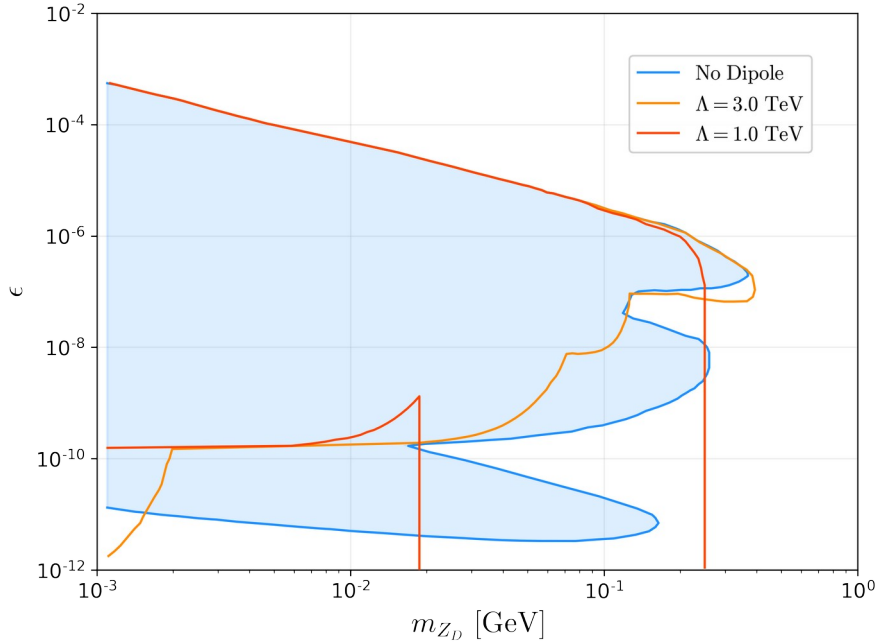

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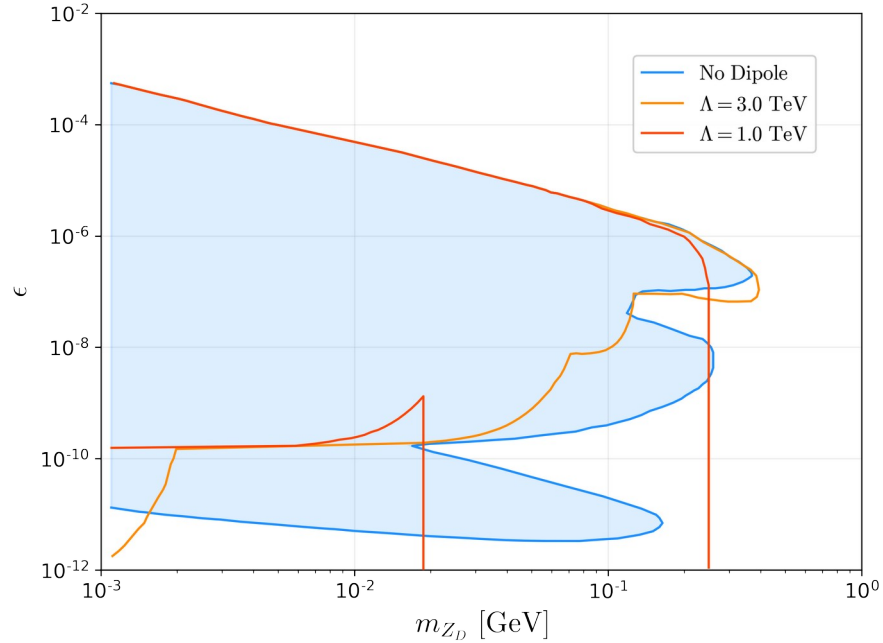


Thank you!

It's time to say goodbye...

Backup

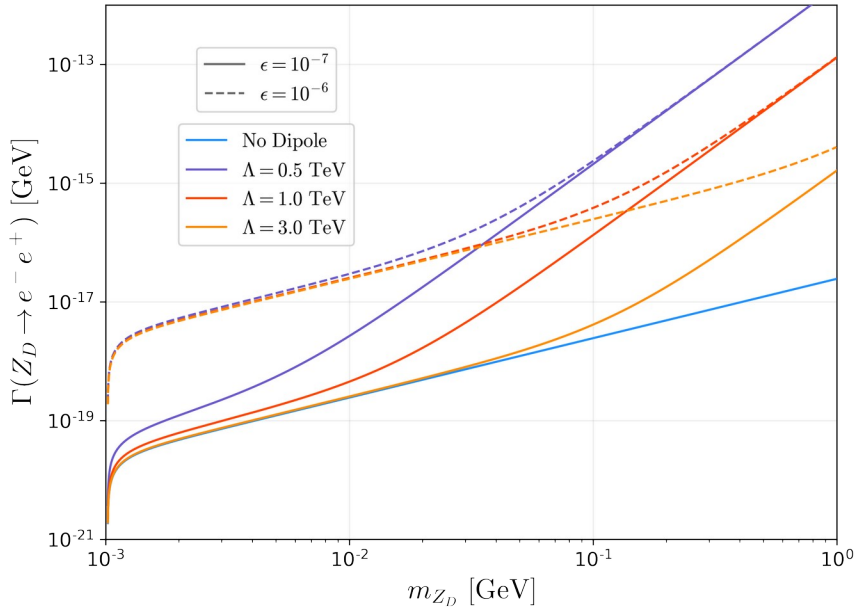
Dark photon width to electrons

$$\Gamma(Z_D \to e^- e^+) =$$

$$\left[\frac{\epsilon^2 \alpha_{\rm EM} m_{Z_D}}{3}\left(1+2\frac{m_e^2}{m_{Z_D}^2}\right)+\frac{\epsilon\sqrt{\alpha_{\rm EM}}d_e}{8\pi^{5/2}}\frac{m_e m_{Z_D} v}{\Lambda^2}+\frac{m_{Z_D}^3 v^2 d_e^2}{1536\pi^5\Lambda^4}\left(1+8\frac{m_e^2}{m_{Z_D}^2}\right)\right]\sqrt{1-\frac{4m_e^2}{m_{Z_D}^2}}$$

- Dipole dominates for

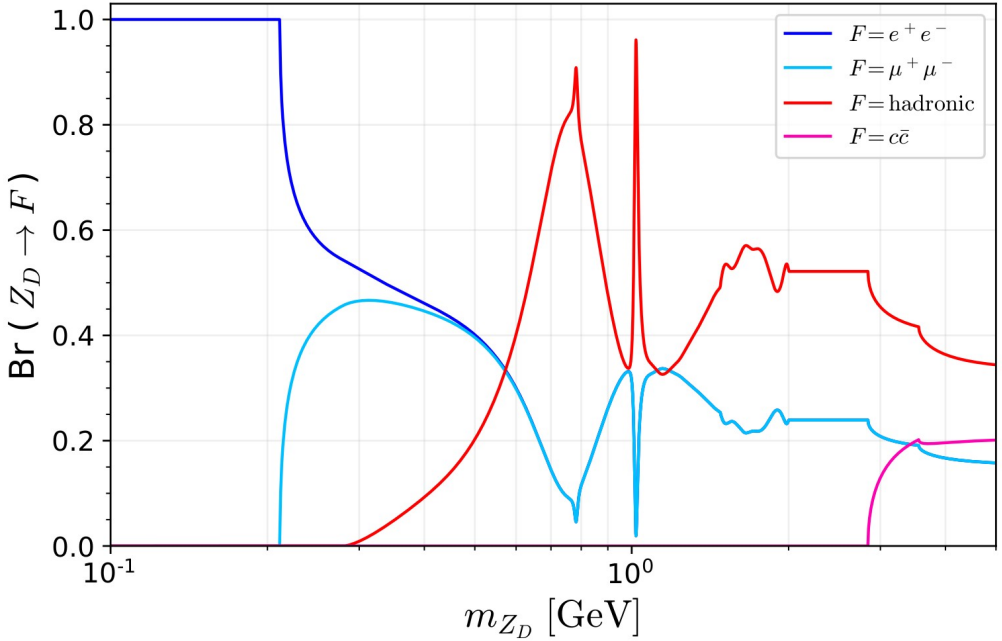
$$(10\ \text{GeV})^2 \times \frac{m_{Z_D}^2 d_e^2}{\epsilon^2 \Lambda^4} \gtrsim 1$$

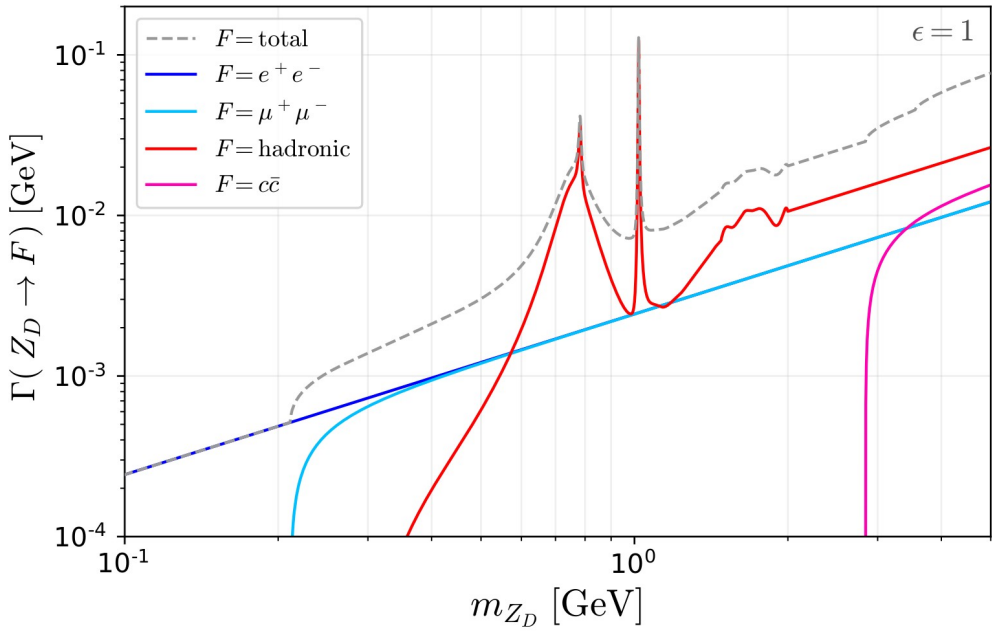


Dark photon widths (No dipole)

[Foguel, GMS, Zukanovich, 2022]

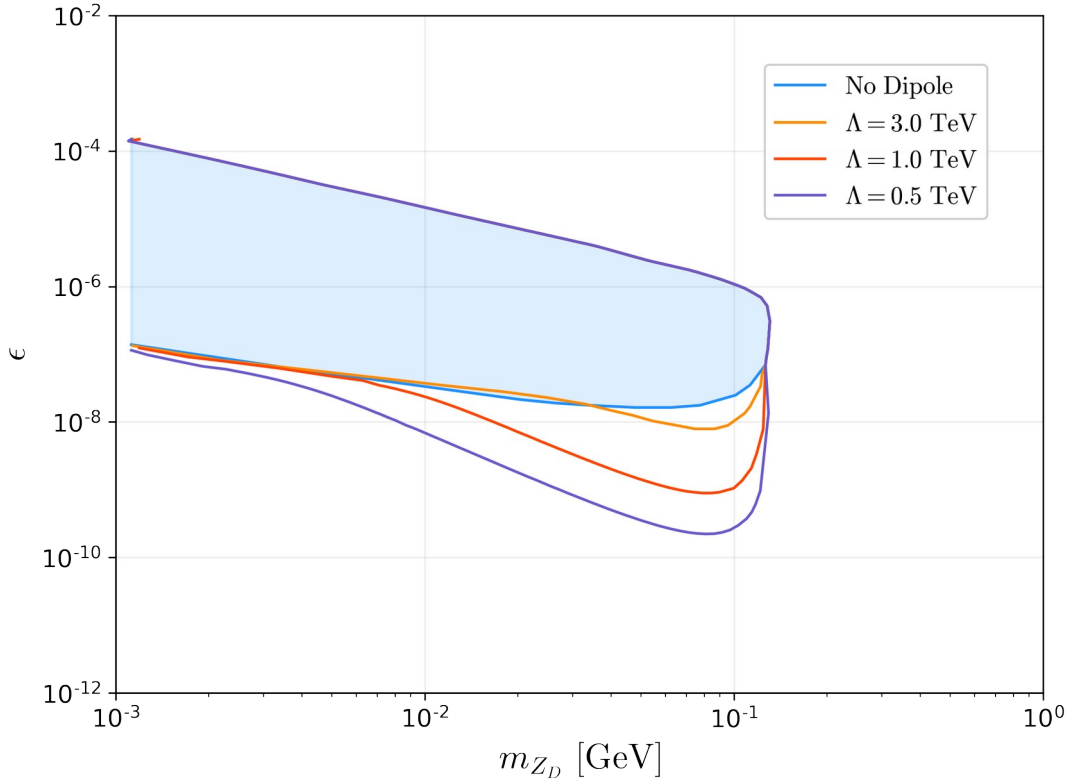
$$\mathscr{L} \supset -\frac{\epsilon}{2c_W} \xrightarrow[\epsilon \ll 1]{\text{rotations}} -\epsilon Z_D^\mu J_{\text{EM},\mu}$$





Phenomenology - LSND

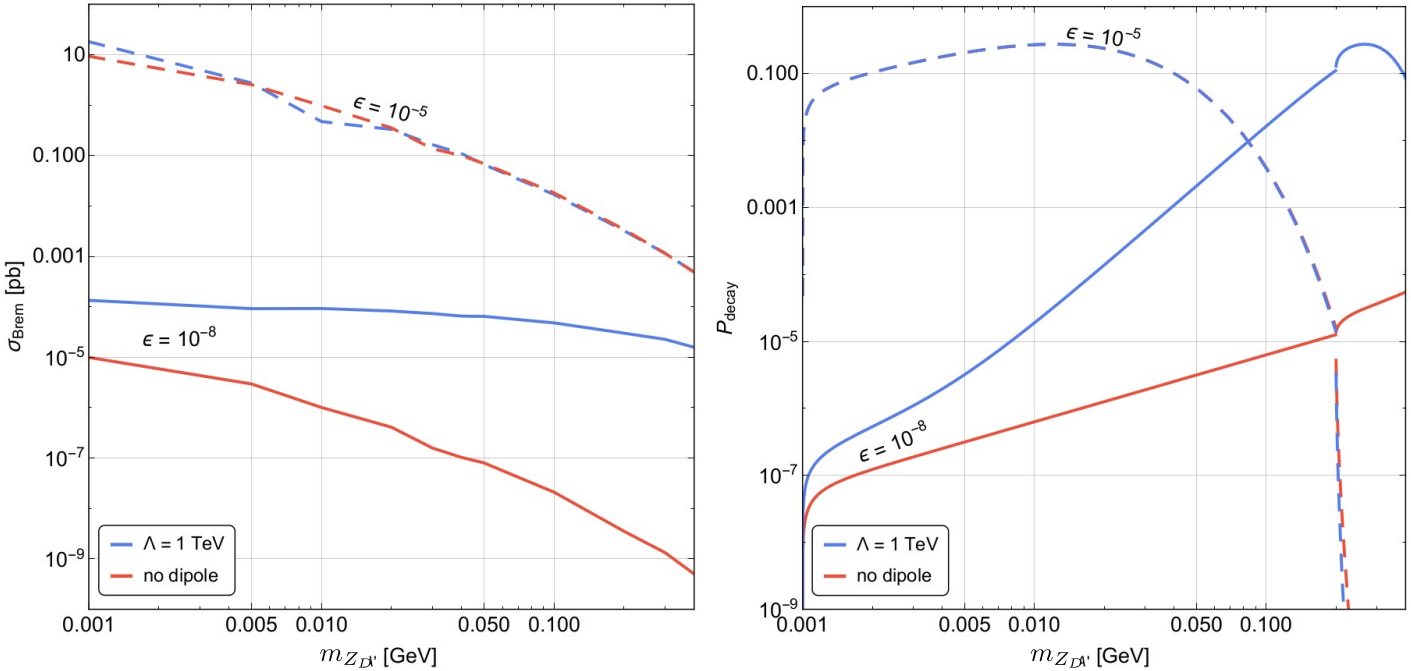
[Batell, Pospelov, Ritz et al, 2009]
[Essig et al, 2010]



- Old neutrino experiment:
  - Proton beam
  - $\sim$ 30 m baseline
- Considerable uncertainties.

Phenomenology - E137

- Cross-section & Decay probability



Toy UV model - Lagrangian

- Vector-like leptons + Scalars

$$\mathscr{L}_{\rm UV} \supset \kappa_L \Phi^\dagger \bar{L} \mathcal{L}_R + \kappa_R \Phi^\dagger \bar{e}_R \mathcal{E}_L$$

$$+ y \bar{\mathcal{L}}_L H \mathcal{E}_R + y' \bar{\mathcal{L}}_R H \mathcal{E}_L + h.c.$$

$$+ \lambda' |H|^2 |S|^2$$

$$\Phi \sim (\mathbf{1}, \mathbf{1}, 0, q)$$

$$\mathcal{L}_{L,R} \sim (\mathbf{1}, \mathbf{2}, -1/2, q)$$

$$\mathcal{E}_{L,R} \sim (\mathbf{1}, \mathbf{1}, -1, q)$$

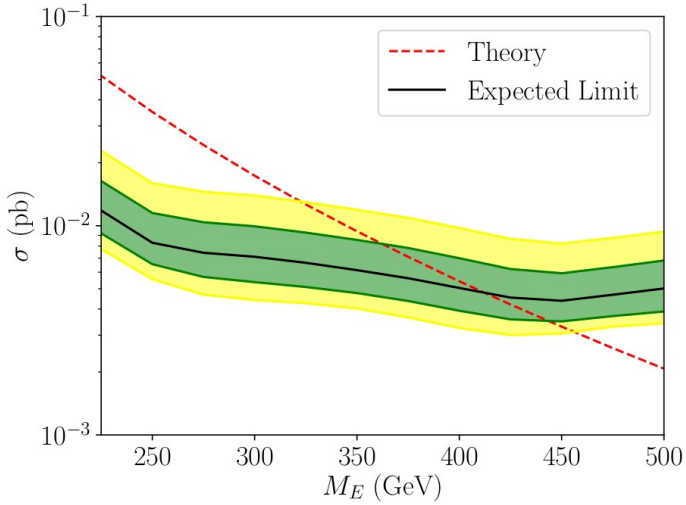
$$S \sim (\mathbf{1}, \mathbf{2}, y_S, q_S)$$

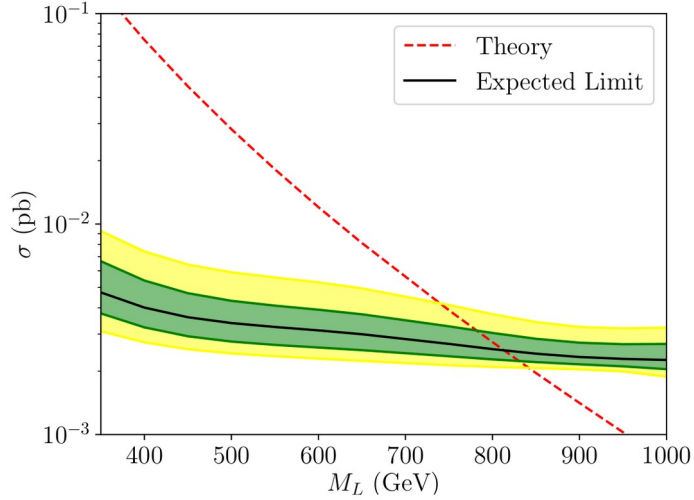
Toy UV model – Existing bounds

[Guedes, Santiago, 2021]

- Improved LHC bounds at 13 TeV
- Depend on precise values of BRs

$$M_E \gtrsim \begin{cases} 405\,\text{GeV}, & [\text{VLL singlet}], \\ 630\,\text{GeV}, & [\text{BR}(E \to \ell Z) = 1], \\ 895\,\text{GeV}, & [\text{BR}(E \to \ell A_H) = 1] \end{cases}$$





Stuckelberg mechanism

[Kribs, Lee, Martin, 2022]

- No $U(1)_D$ gauge symmetry
- Operators built out of Z_D^μ

$$\mathscr{L}_{\text{int}} = \frac{m_{Z_D}^2}{2} Z_D^\mu Z_{D\mu} - \frac{\epsilon}{2c_W} Z_D^{\mu\nu} B_{\mu\nu} + \lambda_4 (Z_D^\mu Z_{D\mu})^2 +$$

$$+ \lambda_H (Z_D^\mu Z_{D\mu}) |H|^2 + Z_D^\mu J_\mu$$

$$J^\mu = \sum_f r_f \bar{f} \gamma^\mu f$$