Light Scalars Through the Leptonic Higgs Portal

David McKeen
University of Washington

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Based on:
Batell, McKeen, Pospelov & Ritz, arXiv:WXYZ:ABCD

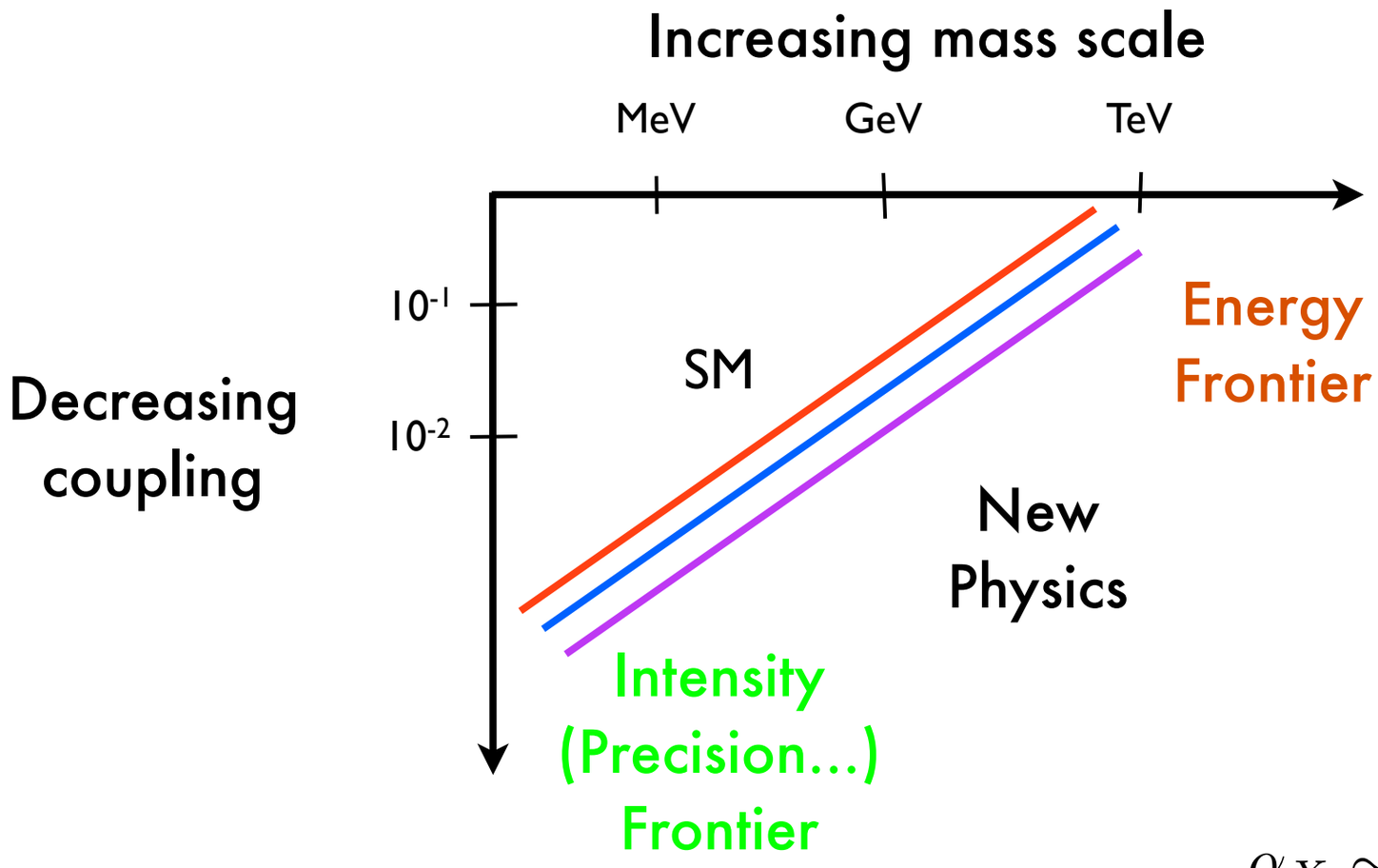
Warning 1: this work is "in progress"

Warning 2: because we're in Victoria we use K, V

Outline

- Lightning "review" of hidden/dark sectors
- g-2
- Vector portal is closing
- Scalars coupled preferentially to leptons can open the door

New Physics Frontiers



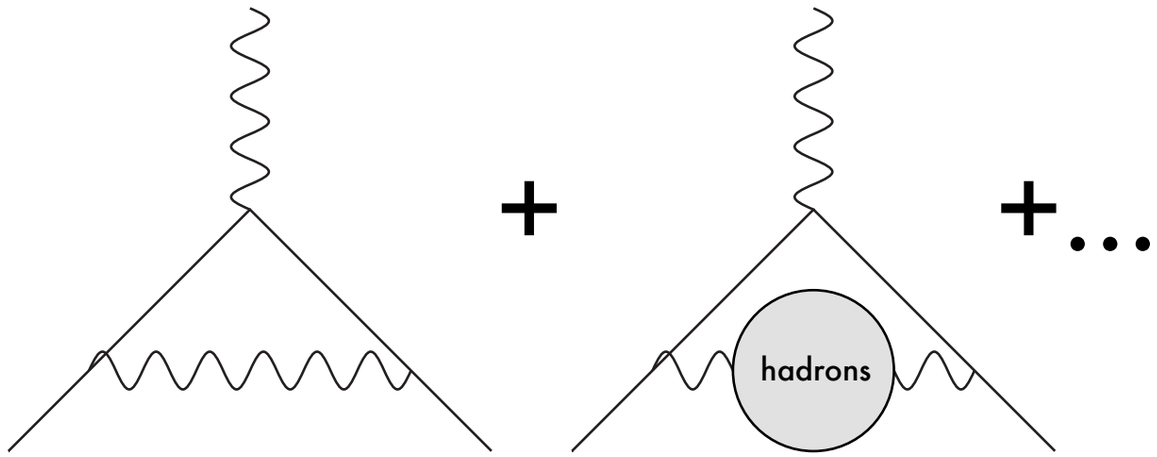
$$V(r) = \frac{\alpha_X}{r} e^{-m_X r} \Rightarrow \text{Amp.} \propto \frac{\alpha_X}{q^2 - m_X^2}$$

$$\begin{cases} \alpha_X \sim \alpha_s \sim 0.1 \\ m_X \sim \text{TeV} \end{cases}$$ in LHC reach

$$\begin{cases} \alpha_X \lesssim 10^{-7} \\ m_X \sim \text{GeV} \end{cases}$$ not

Muon g-2

A nagging disagreement



$$(\Delta a_\mu)_{\rm exp} - (\Delta a_\mu)_{\rm th} \simeq (3 \pm 1) \times 10^{-9}$$

Could be (have been?) a sign of, e.g., SUSY

$$M_{\rm SUSY} \sim 55 \sqrt{\tan\beta}\ {\rm GeV}$$

Czarnecki & Marciano, etc.

Pass through these "portals" from the SM to the Dark Side

- Kinetic Mixing: $F_{\mu\nu}V^{\mu\nu}$ $\left[B_{\mu\nu}V^{\mu\nu}\right]$
- The Higgs Portal: $H^\dagger H\left(\lambda S^2 + AS\right)$
- Neutrino Portal: LHN
- Axion Portal: $J^A_\mu \dfrac{\partial^\mu a}{F_a}$
- Stueckelberg Portal: $J^i_\mu A^\mu$

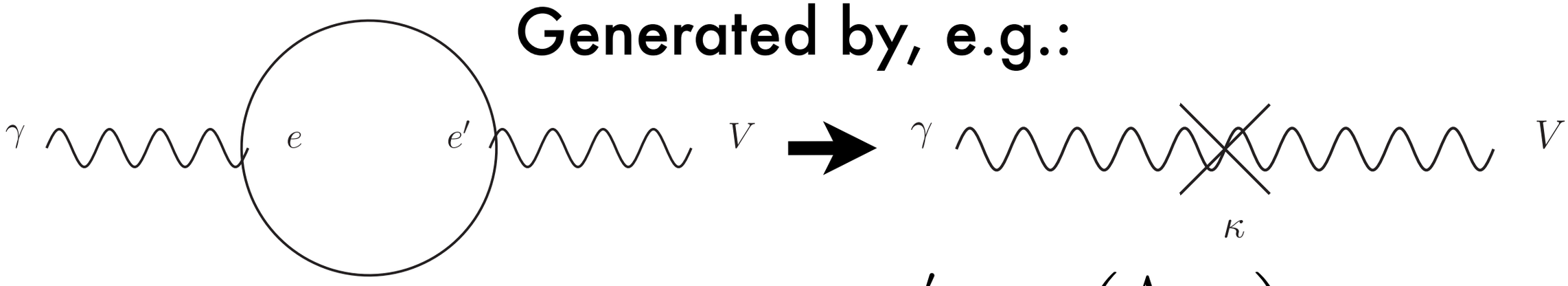
Early work by Holdom; Okun

Kinetic Mixing

New U(1)′ V given mass by Higgs h′

$$\mathcal{L} = -\frac{1}{4}V_{\mu\nu}^2 - \frac{\kappa}{4}V_{\mu\nu}F^{\mu\nu} + \left|D_\mu\phi\right|^2 - V\left(\phi\right) + \mathcal{L}_{\rm SM}$$

Generated by, e.g.:



Does not decouple with heavy scale:

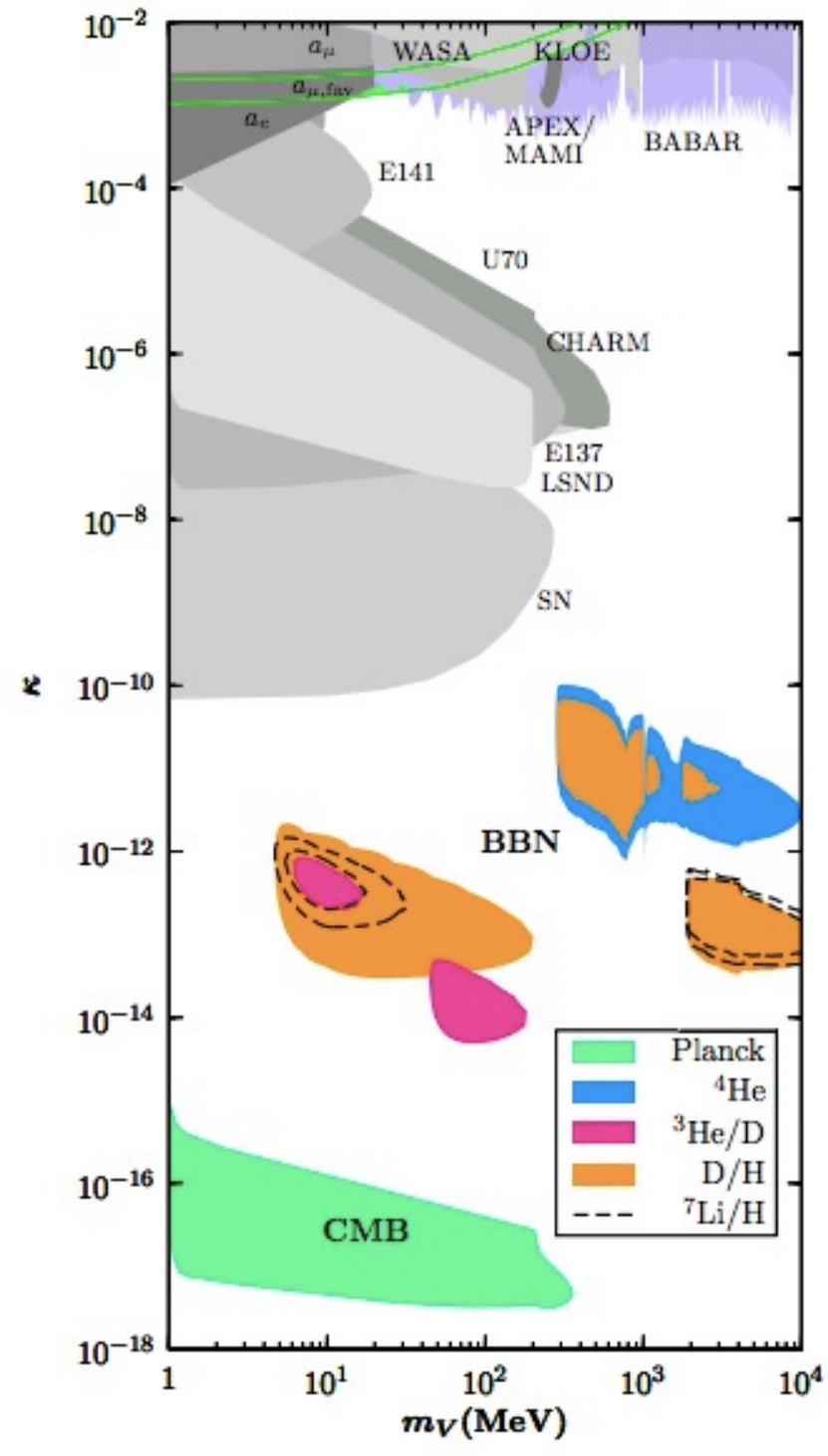
$$\kappa \sim \frac{ee'}{12\pi^2}\log\left(\frac{\Lambda_{\rm UV}}{\Lambda}\right)$$
$$m_V \sim e'\kappa m_Z$$

Can easily have $\kappa \sim 10^{-(3-4)},\ m_V \sim \mathrm{MeV} - \mathrm{GeV}$

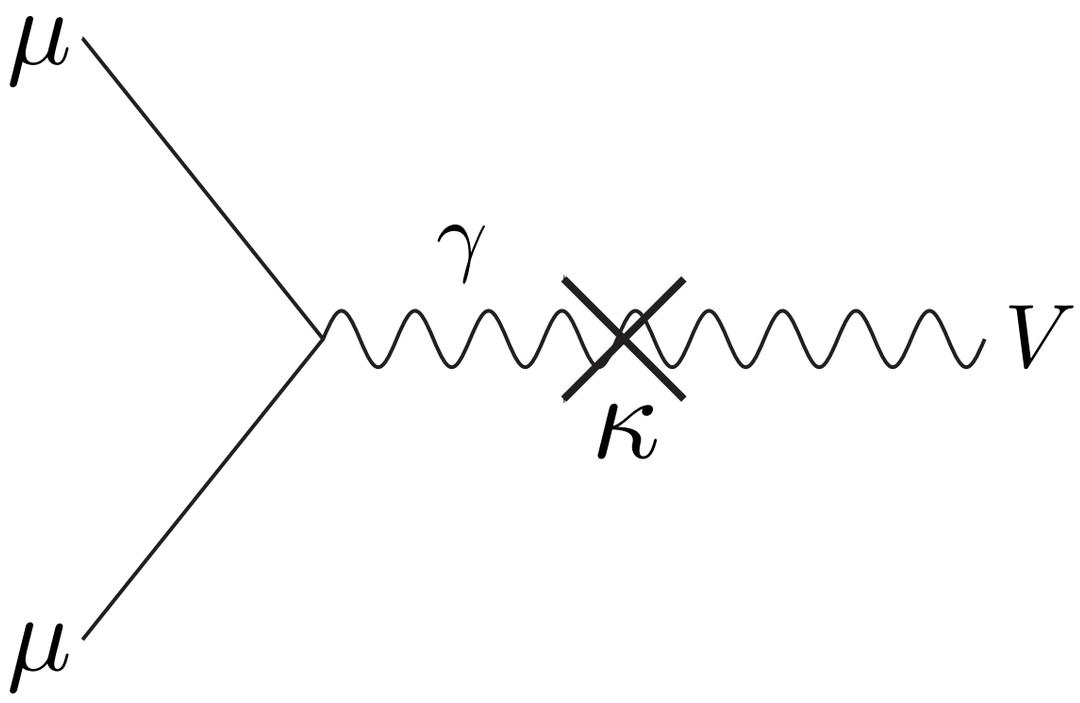
Kinetic Mixing

Has gotten a huge amount of attention

Plot stolen from Fradette, Pospelov, Pradler, & Ritz

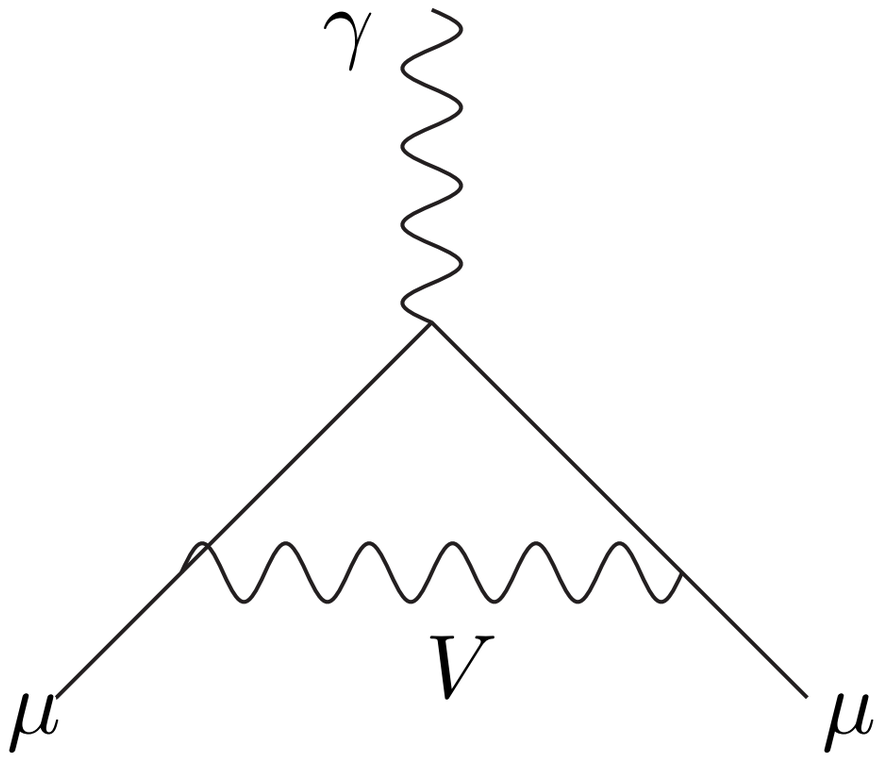


V's couplings to SM fermions

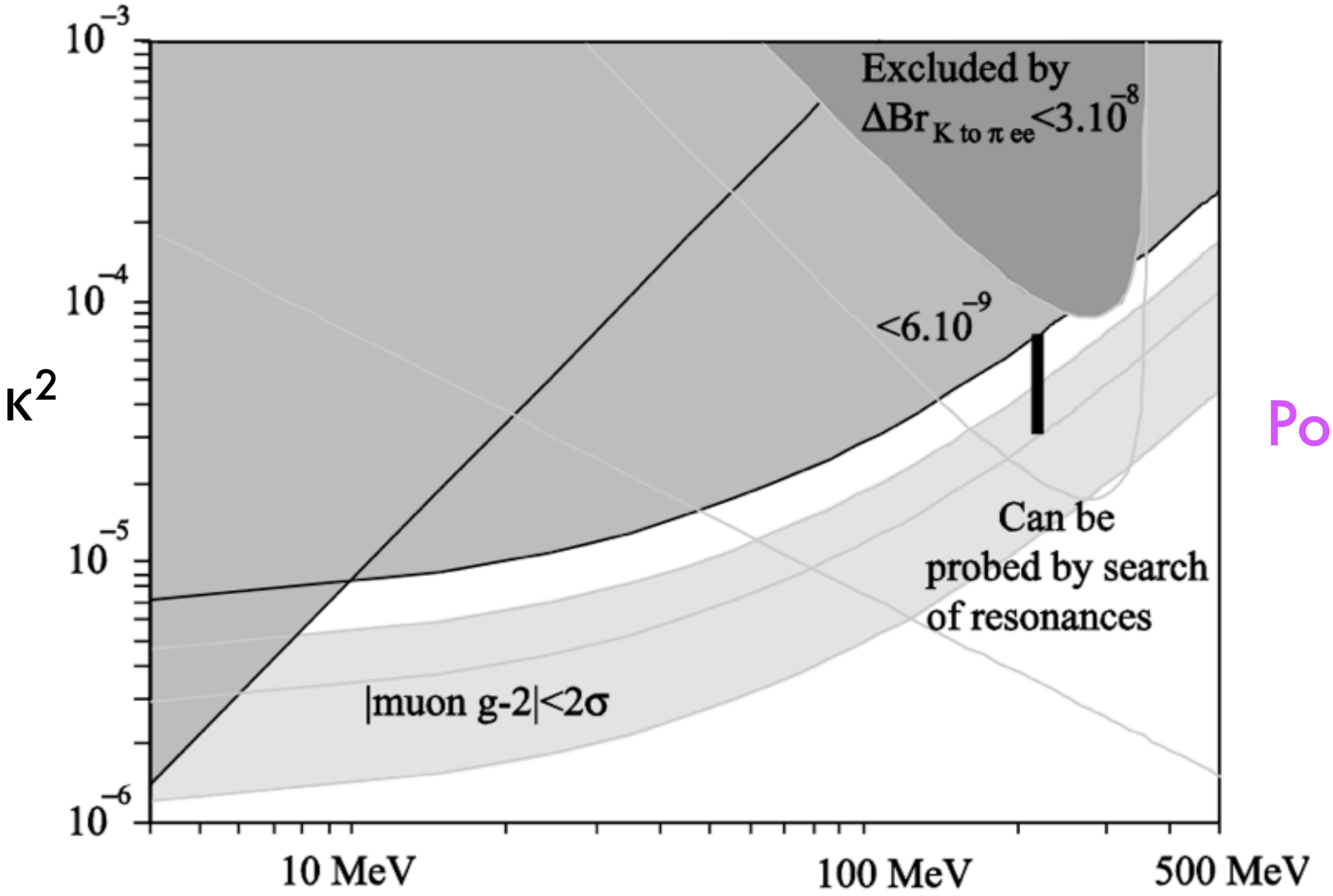


SM gets "dark millicharge"

Contributes to g-2



Kinetic Mixing

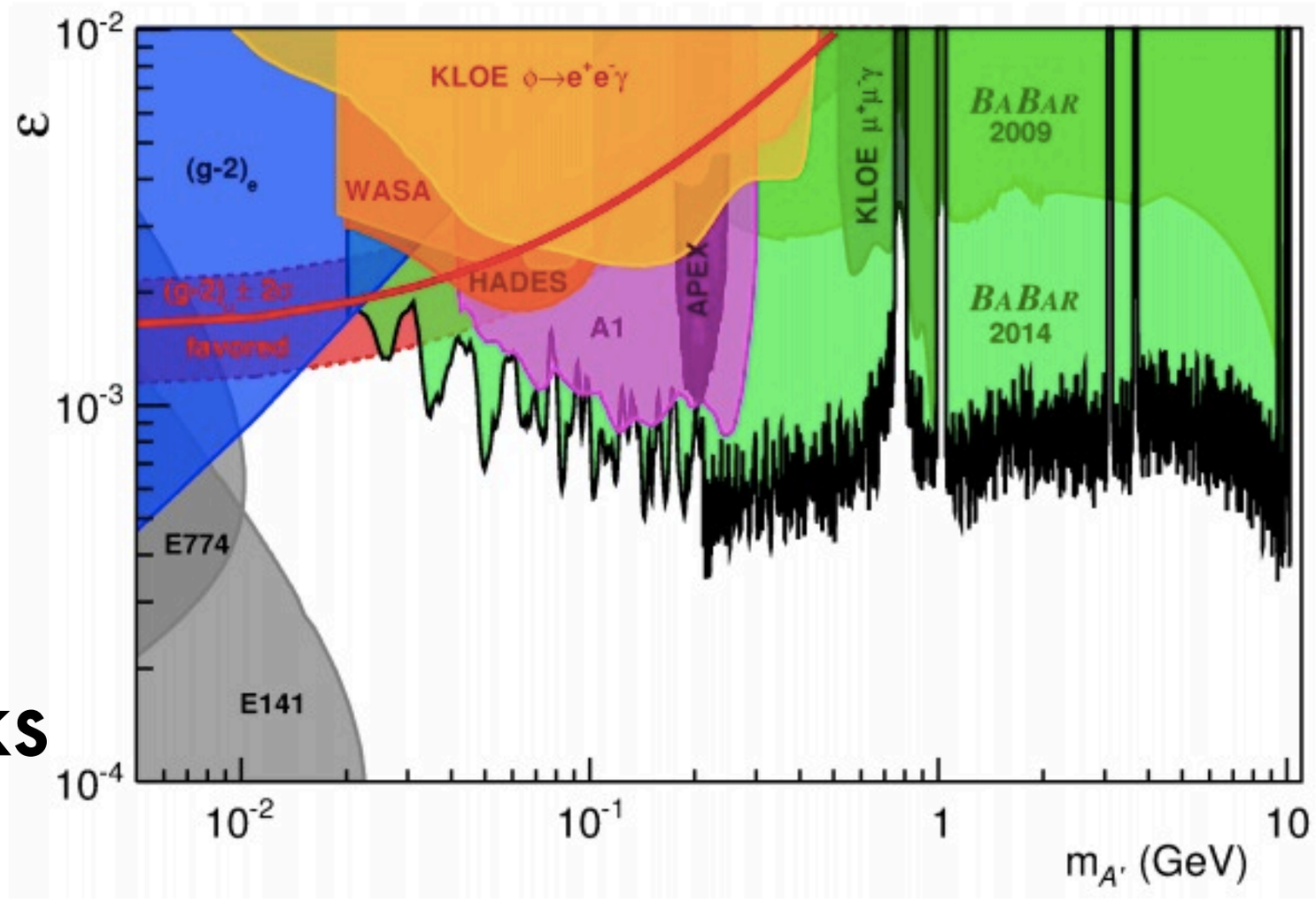


Pospelov ('08)

Kinetic Mixing

But…

See also Philip's and Bertrand's talks



BaBar, 1406.2980

Kinetic Mixing

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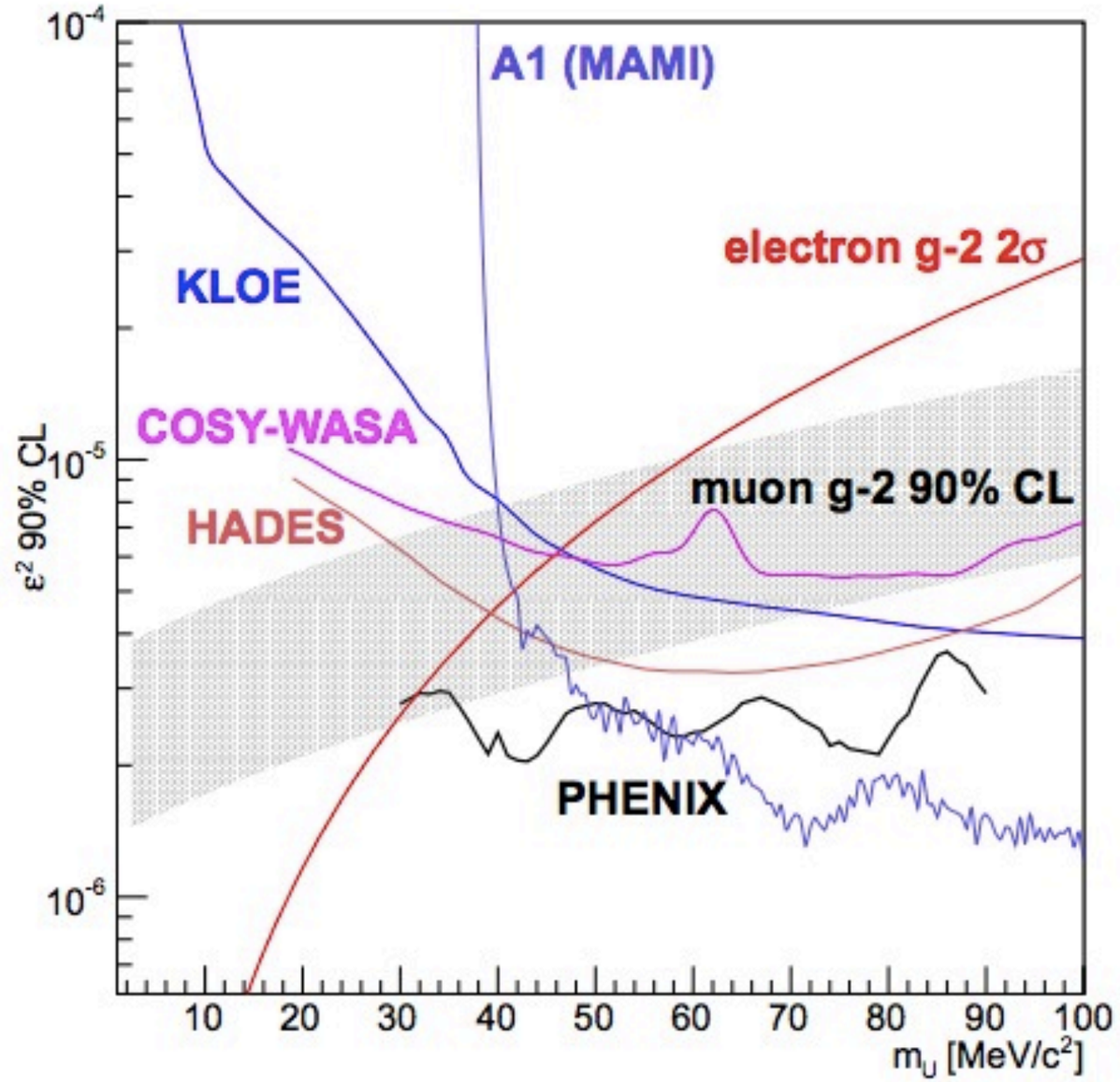


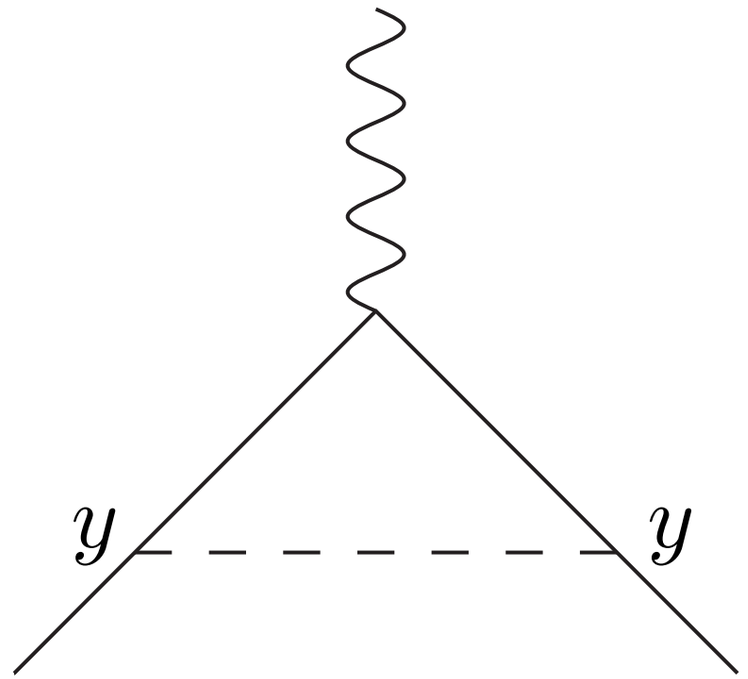
PHENIX, 1409.0851

What about a scalar?

Also contributes to g-2

$$\Delta a_\mu \sim \frac{y^2}{8\pi^2} \simeq 3 \times 10^{-9} \left(\frac{y}{m_\mu/v}\right)^2$$

for a scalar not much heavier than the muon



However, meson decays limit $y_q \lesssim 10^{-3} \frac{m_q}{v}$

$$K \to \pi h \to \pi \ell^+ \ell^-$$
$$B \to K h \to K \ell^+ \ell^-$$

Is there a way to suppress couplings to quarks and not to leptons?

L2HDM

2HDM where one doublet couples to quarks and the other to leptons

$$-\mathcal{L}_{\rm Yuk} = \bar{L} Y_\ell H_\ell \ell_R + \bar{Q} Y_d H_q d_R + \bar{Q} Y_u \tilde{H}_q u_R + \text{h.c.}$$

ψ \ ϕ	h_ℓ	h
ℓ	$-s_\alpha/c_\beta$	c_α/c_β
q	c_α/s_β	s_α/s_β
$W,\, Z$	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$

$$-\mathcal{L}_{\rm Yuk} \to \xi \frac{m_\psi}{v} \phi \bar{\psi} \psi$$

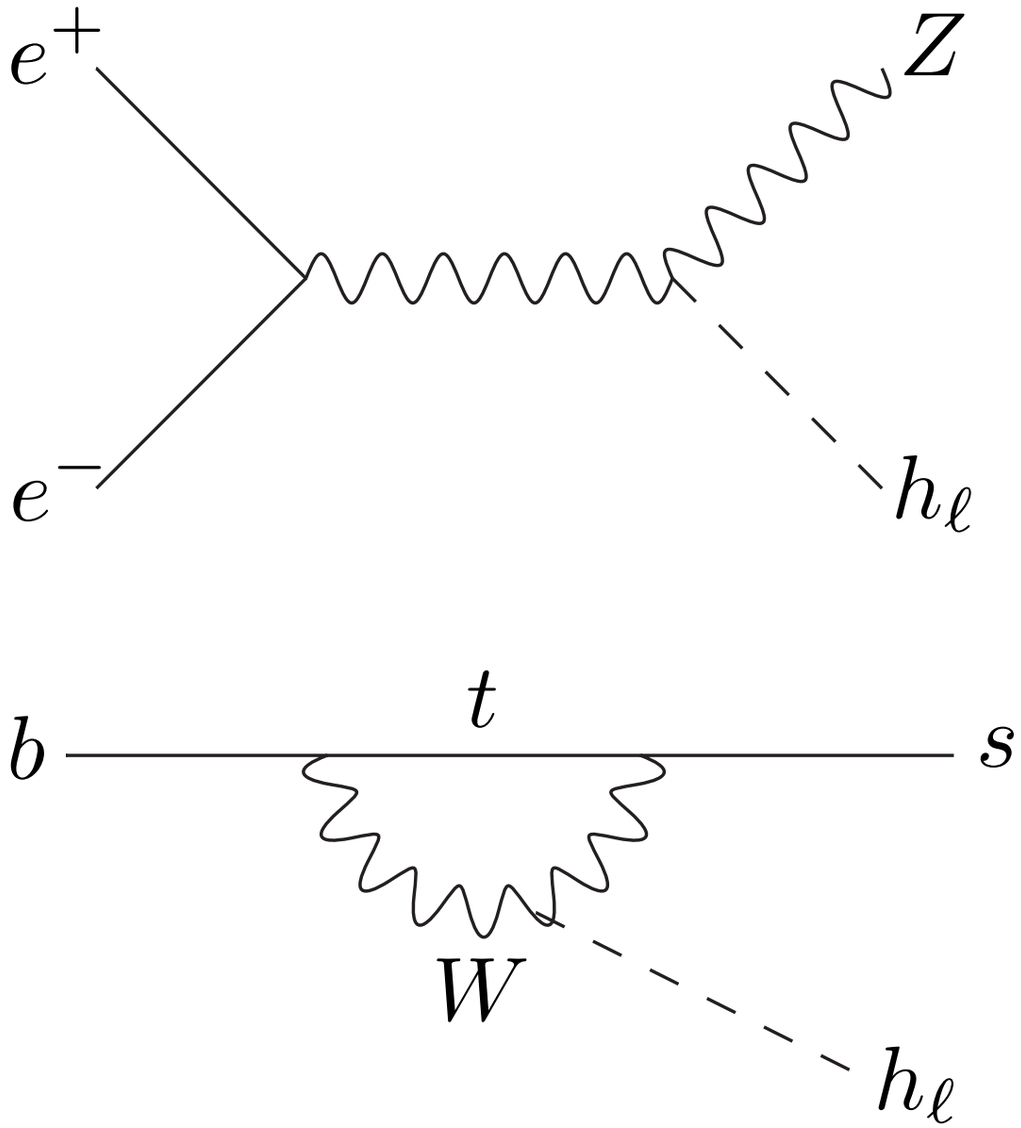
ξ is the coupling in units of the SM Higgs Yukawa

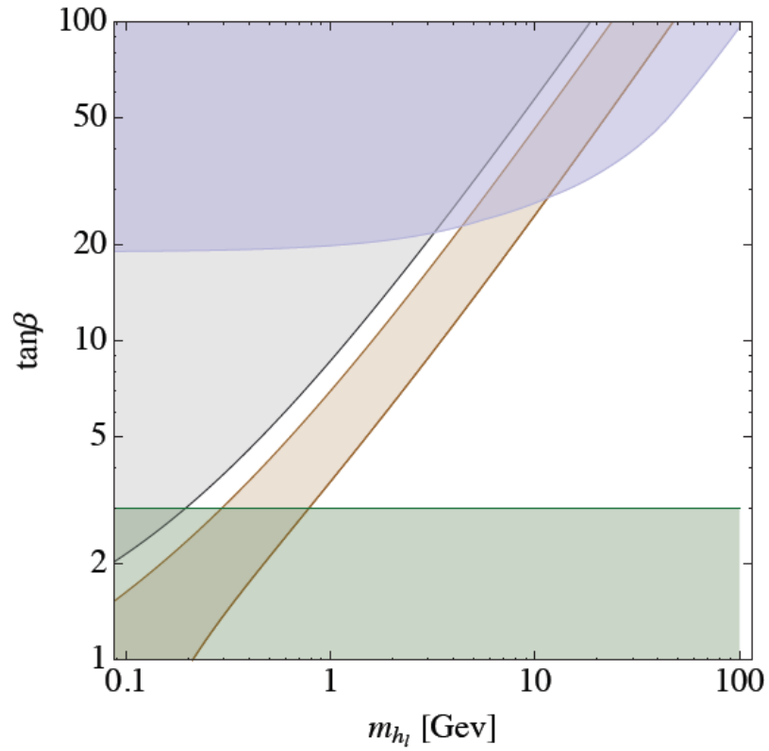
Assume the heavier is SM-like and the lighter dominantly couples to leptons

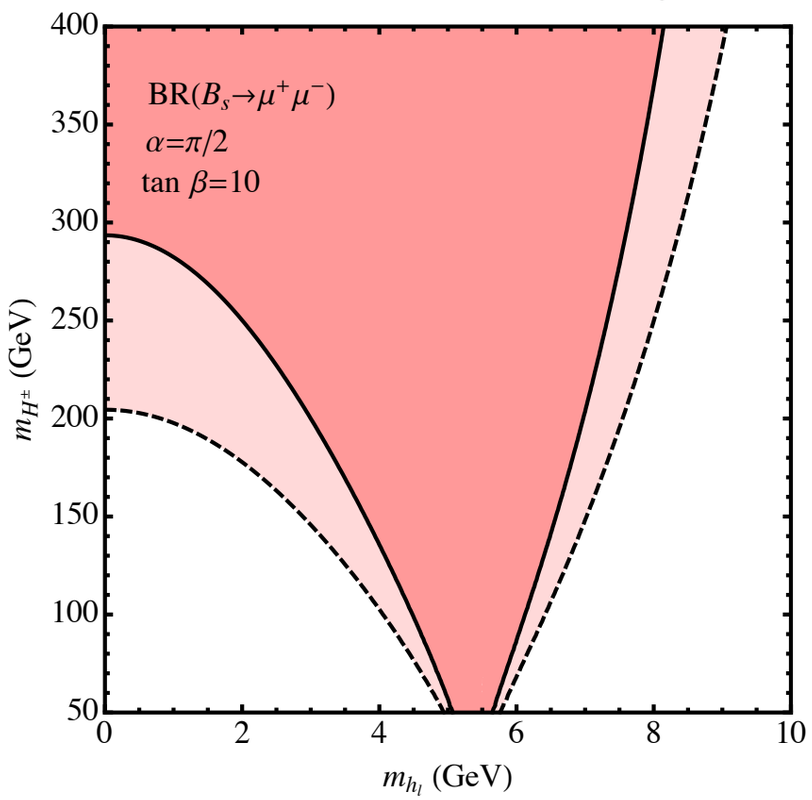
meson decays require $\alpha \simeq \frac{\pi}{2}$

L2HDM

However, even with the coupling to quarks suppressed...







L2HDM+S

Add a singlet coupled through the Higgs Portal

$$V_{\text{portal}} = S\left[A_{11}H_\ell^\dagger H_\ell + A_{22}H_q^\dagger H_q + A_{12}\left(H_\ell^\dagger H_q + H_q^\dagger H_\ell\right)\right]$$

ψ \ ϕ	h_ℓ	h_1	h_2
ℓ	δ_{13}/c_β	$-s_\alpha/c_\beta$	c_α/c_β
q	δ_{23}/s_β	c_α/s_β	s_α/s_β
$W,\ Z$	$\delta_{13}c_\beta + \delta_{23}s_\beta$	$\sin(\beta-\alpha)$	$\cos(\beta-\alpha)$

mixing angles $\delta_{ij} \sim \dfrac{A_{mn}v}{m^2_{h_{1,2}}}$

$$A_{12} \gg A_{11}, A_{22} \Rightarrow \delta_{23} \simeq \frac{\delta_{13}}{\tan\beta}$$

coupling to quarks is suppressed relative to leptons as $\dfrac{1}{\tan^2\beta}$

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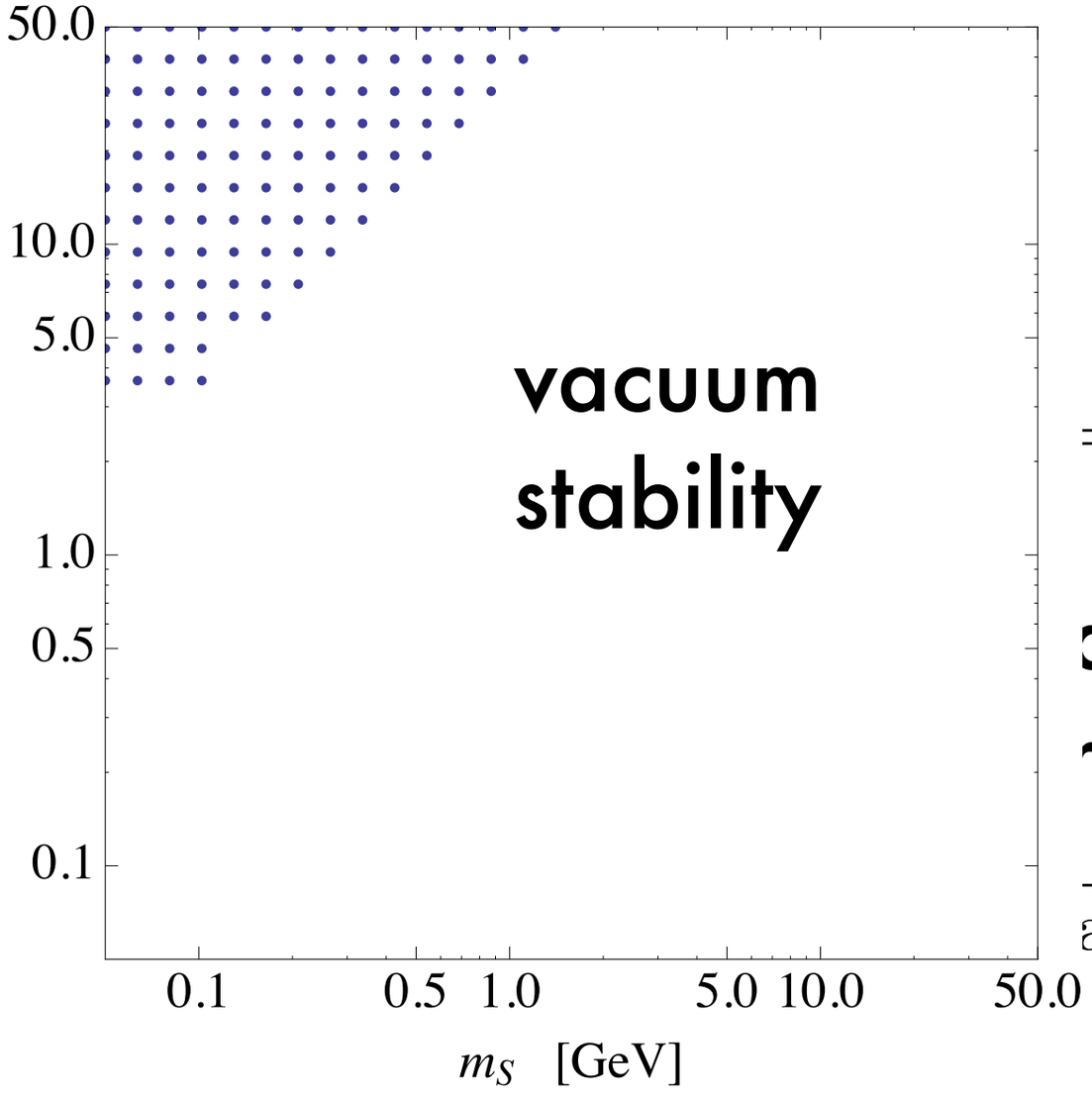
mixing angles



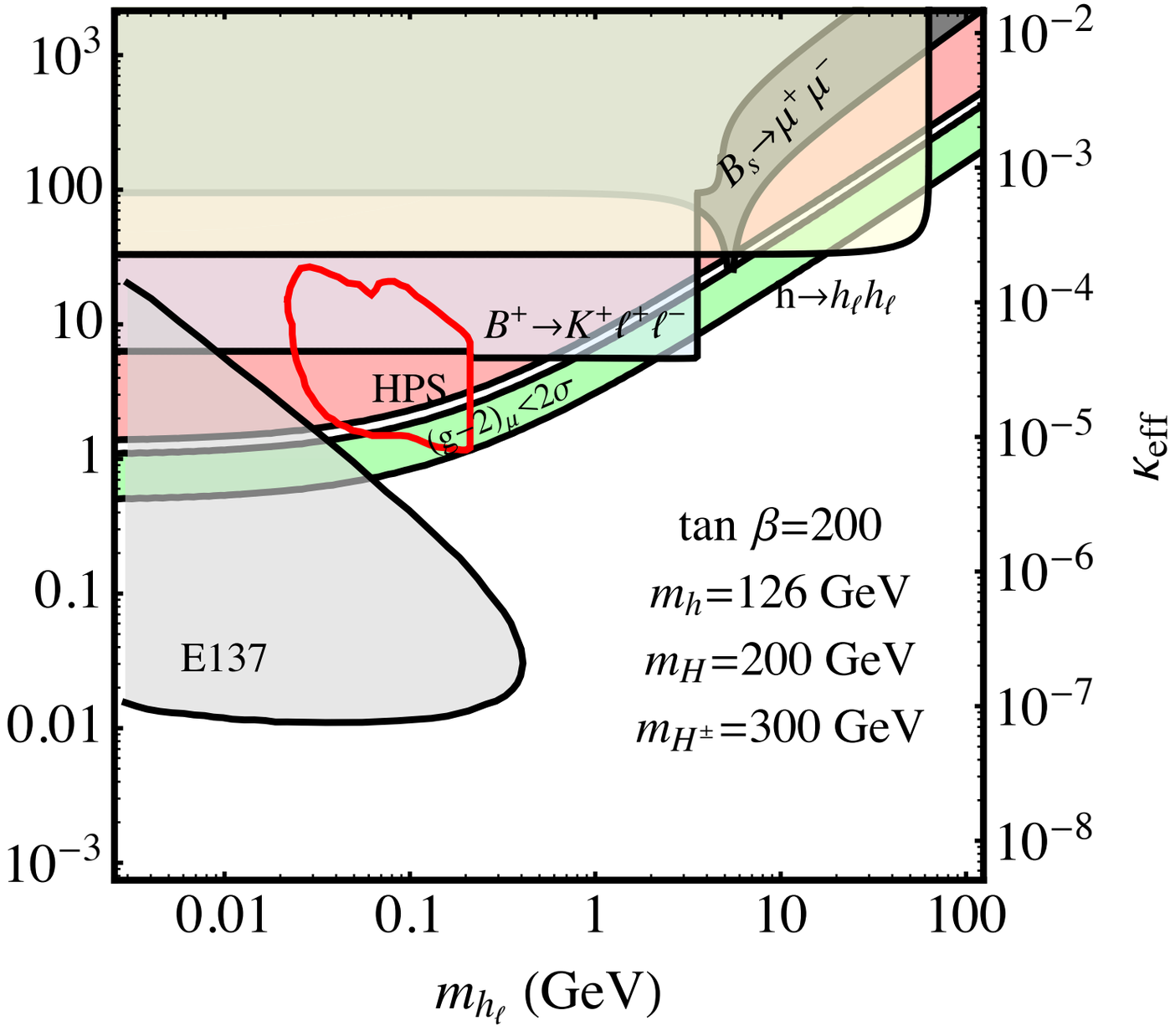
vacuum stability

$$\Rightarrow \delta_{23} \simeq \frac{\delta_{13}}{\tan\beta}$$

quarks is relative to

$$\frac{1}{\tan^2\beta}$$

L2HDM+S



in the vector case:

$$\mathcal{L}_{\rm int} = \kappa e V^\mu \bar{\ell}\gamma_\mu \ell$$

compared to the scalar case:

$$\mathcal{L}_{\rm int} = \xi_\ell \frac{m_e}{v} h_\ell \bar{\ell}\ell$$

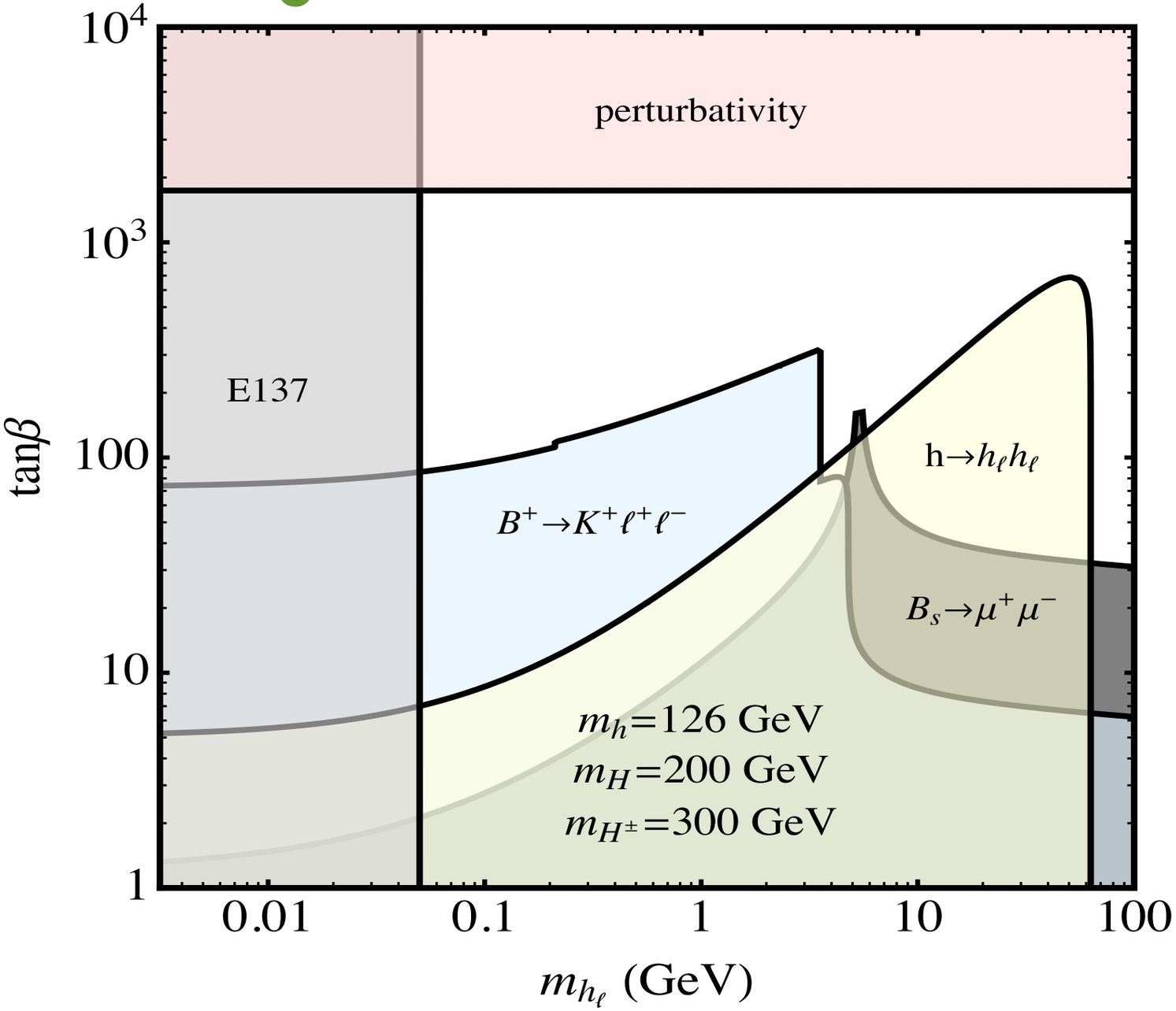
suggests the definition

$$\kappa_{\rm eff} e \equiv \xi_\ell \frac{m_e}{v}$$

g-2 region moves down by a factor of 200

L2HDM+S

g-2<2σ



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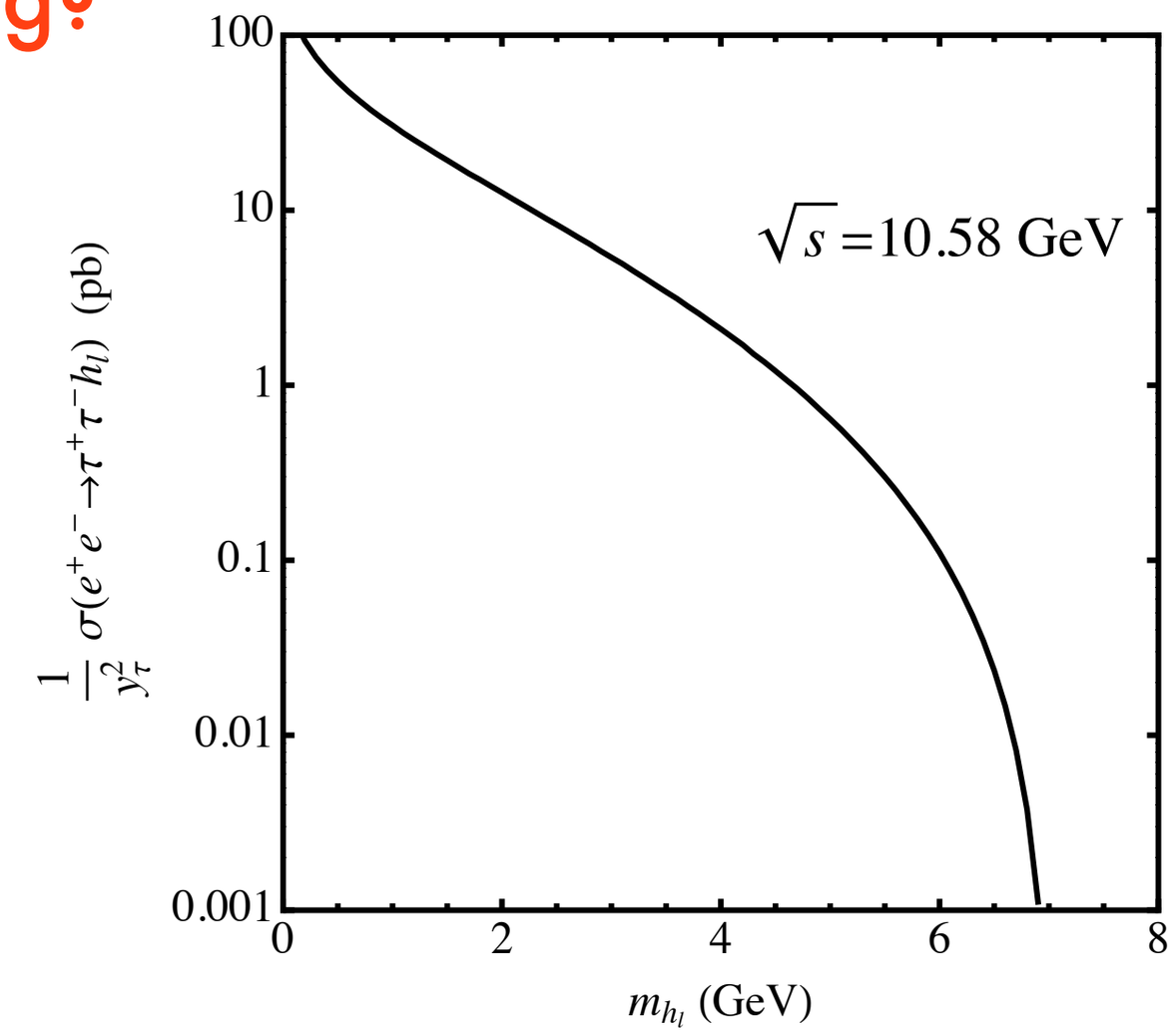
L2HDM+S

How do we find this thing?

Production at a B Factory:

$$\left(y_\tau = \xi_\ell \frac{m_\tau}{v} \simeq 0.007\,\xi_\ell\right)$$



Other ideas?

Conclusions

- Light, kinetically mixed vector is well motivated, well studied
- Hidden scalar gives qualitatively different phenomenology
  - could open up g-2 band
  - requires different searches

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Thanks!