Probing hidden sectors via the U(1) portal

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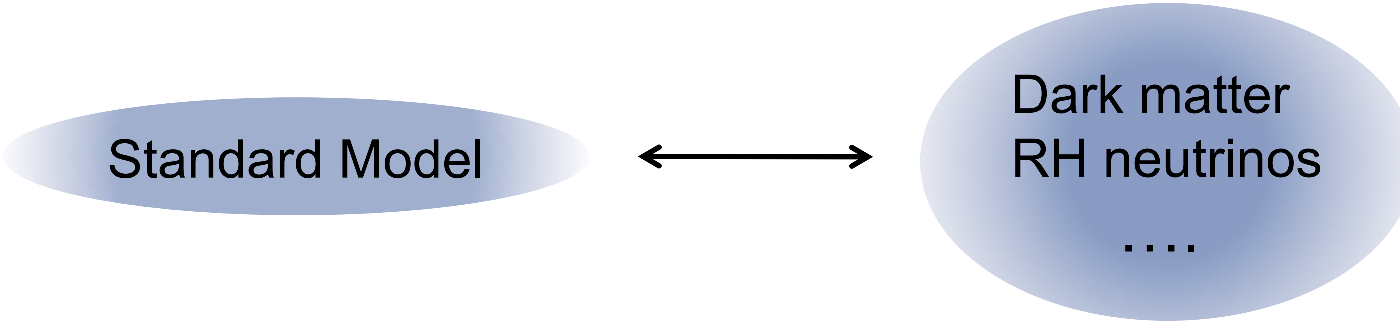
New physics in a hidden sector

Empirical evidence for new physics does not always point to the EW scale and above, but rather to a hidden sector that may also contain “light” states



Any “light” states should be neutral under SM gauge group

In particular, there are motivations for exploring dark matter as part of a larger (interacting, multi-component) hidden sector:

- a more generic setting to explore experimental sensitivity
- allows for possible enhancement/suppression, that could explain existing (astrophys) anomalies: DAMA, PAMELA, etc.

Probing a hidden (dark) sector

Standard Model ⟷ Hidden Sector

$$\mathcal{L}_{med} = \sum_{n,k,l}^{n=k+l-4} \frac{O_k^{(SM)} O_l^{(med)}}{\Lambda^n}$$

Generic interactions are irrelevant (dimension > 4), but there are three renormalizable "portals"

- Vector portal: $\mathcal{L} = -\frac{\kappa}{2} V^{\mu\nu} B_{\mu\nu}$
- Higgs portal: $\mathcal{L} = (-\lambda S^2 + \xi S) H^\dagger H$
- Neutrino portal: $\mathcal{L} = -y_{ij} \bar{L}_i H N_j$

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NB: The vector mediator V can naturally be light ($M \ll M_Z$)

A secluded U(1)

$$\mathcal{L} = -\frac{1}{4}V_{\mu\nu}^2 - \frac{\kappa}{2}V_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 - V(\phi)$$ [Holdom '86]

$$\Downarrow$$

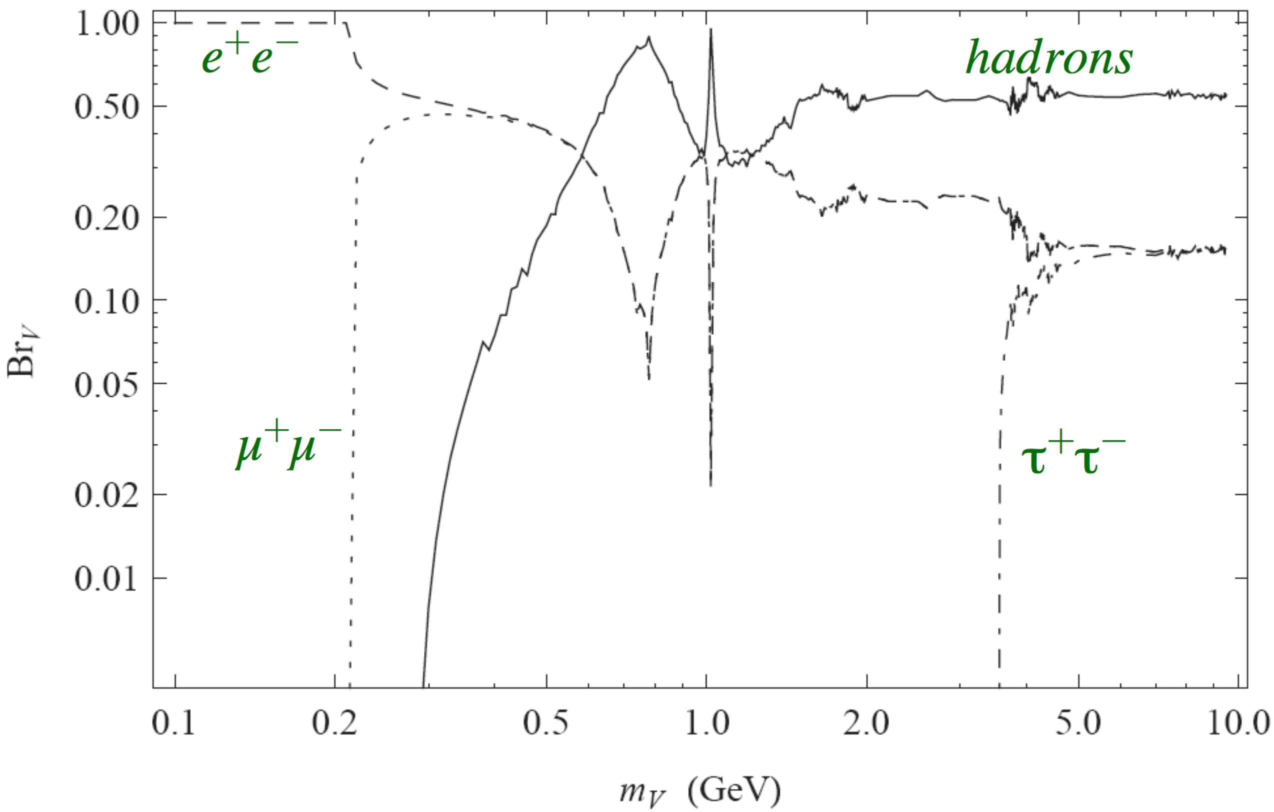
$$\mathcal{L}_{int} = -\kappa e V_\mu J^\mu_{em} + \frac{m_V^2}{v'}h' V_\mu V^\mu$$

V - production through mixing with EM current: $O(\kappa^2)$

h' - production through higgs'strahlung: $O(\kappa^2)$

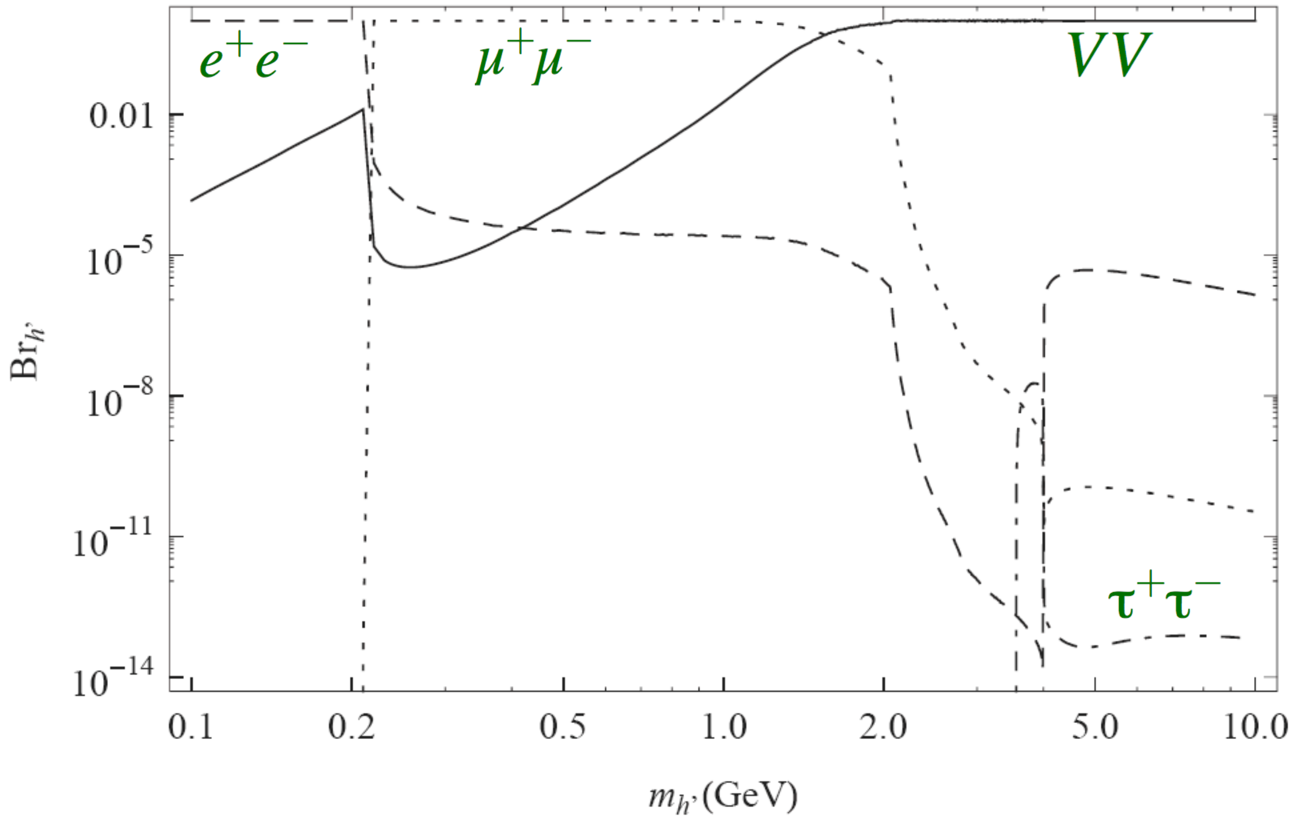
- Weak-scale states charged under $U(1)_S$ are WIMP dark matter candidates [Pospelov, AR, Voloshin '07], which can have enhanced galactic annihilation rates if V is light [Arkani-Hamed et al '08, Pospelov & AR '08]
- If kinetic mixing arises from integrating out heavy charged states at 1-loop $\Rightarrow \kappa \sim 10^{-3}$, SUSY D-terms then imply $m_V \sim O(\text{GeV})$ [Arkani-Hamed & Weiner '08, Baumgart et al '09; Cheung et al '09; Katz & Sundrum '09]
- We will take the secluded U(1) coupling $\alpha' = \alpha$, so the parameter space = $\{m_V, m_{h'}, \kappa\}$

Vector decays



Parametrically: $\Gamma_V(V \rightarrow 2l) \sim O(\kappa^2)$

Higgs' decays

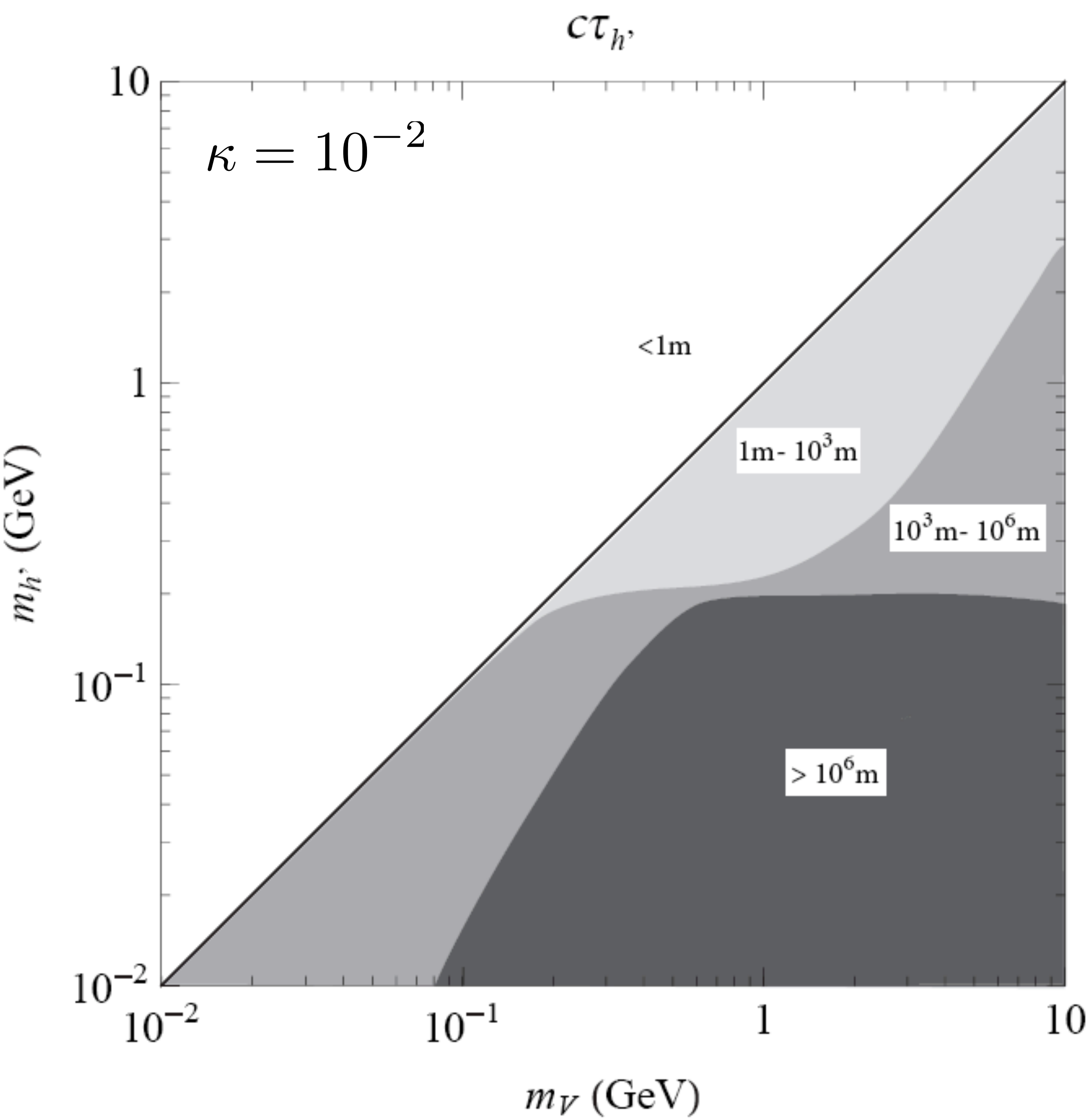


$m_V = 2\,GeV$

When the higgs' is light ($m_{h'} < m_V$), it is parametrically long-lived:

$$\Gamma_{h'}(h' \to 2l) \sim O(\kappa^4)$$

Higgs' decays



Experimental Sensitivity

Luminosity matters!

- Fixed targets (proton & electron beams dumps)

  - up to 10^{23} POT for modern neutrino sources
  - sensitive to long-lived states

- Medium energy colliders (BaBar, Belle)

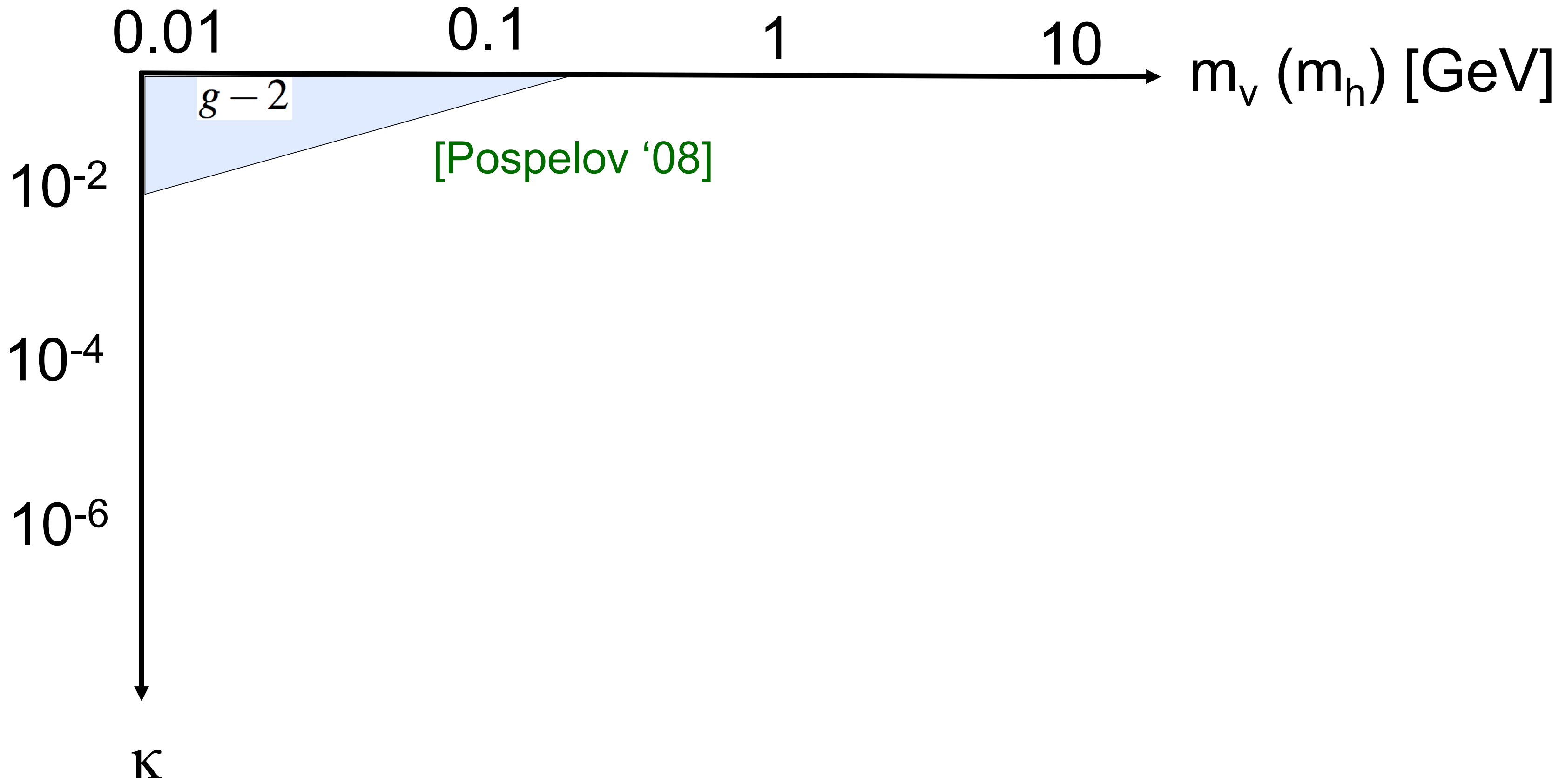
  - large datasets ~ O(1000) fb^{-1}
  - $\sqrt{s}$ ~ 10 GeV

- Rare decays

  - high statistics e.g. for kaon decays

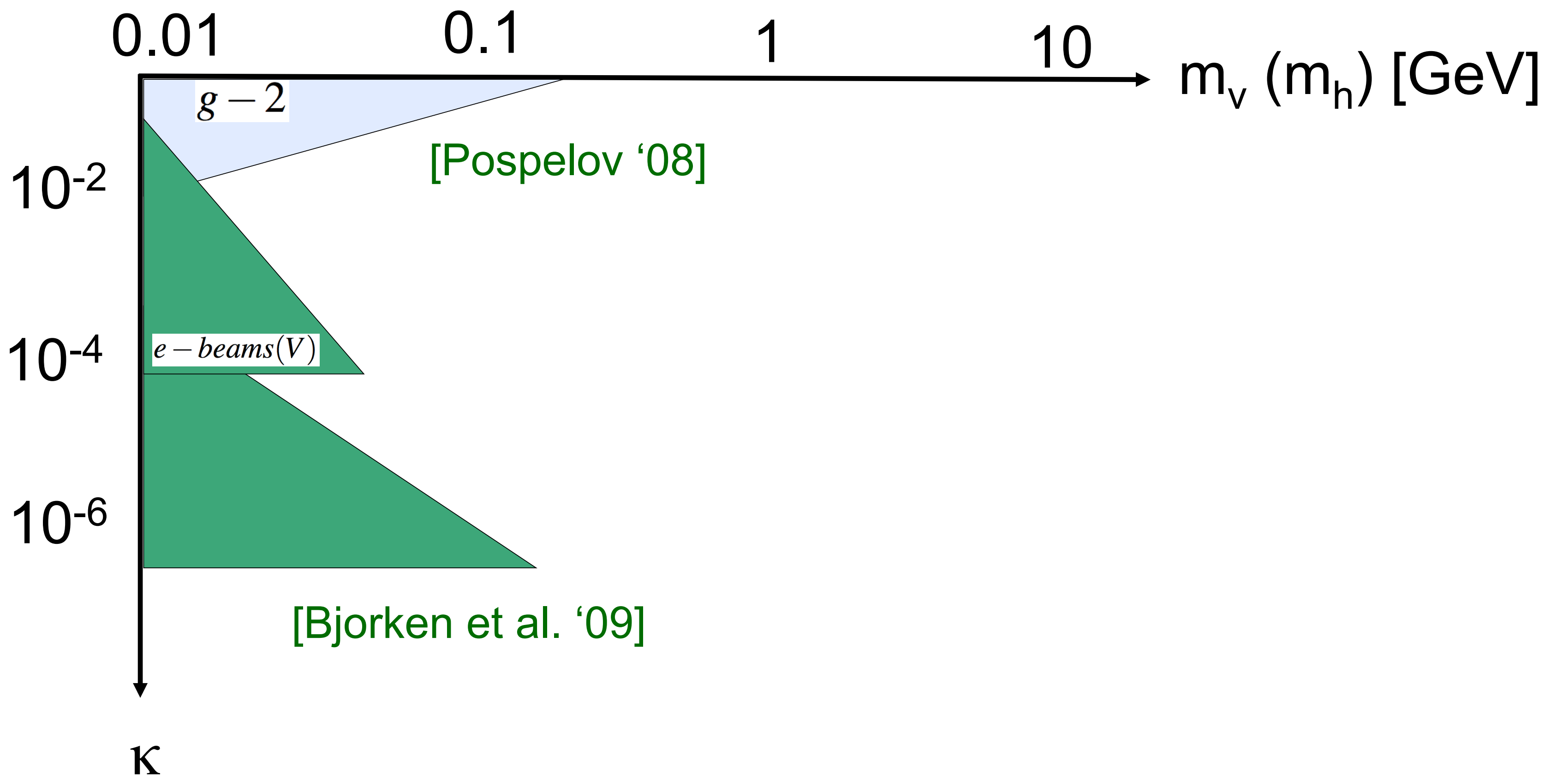
Experimental Sensitivity

In pictorial form



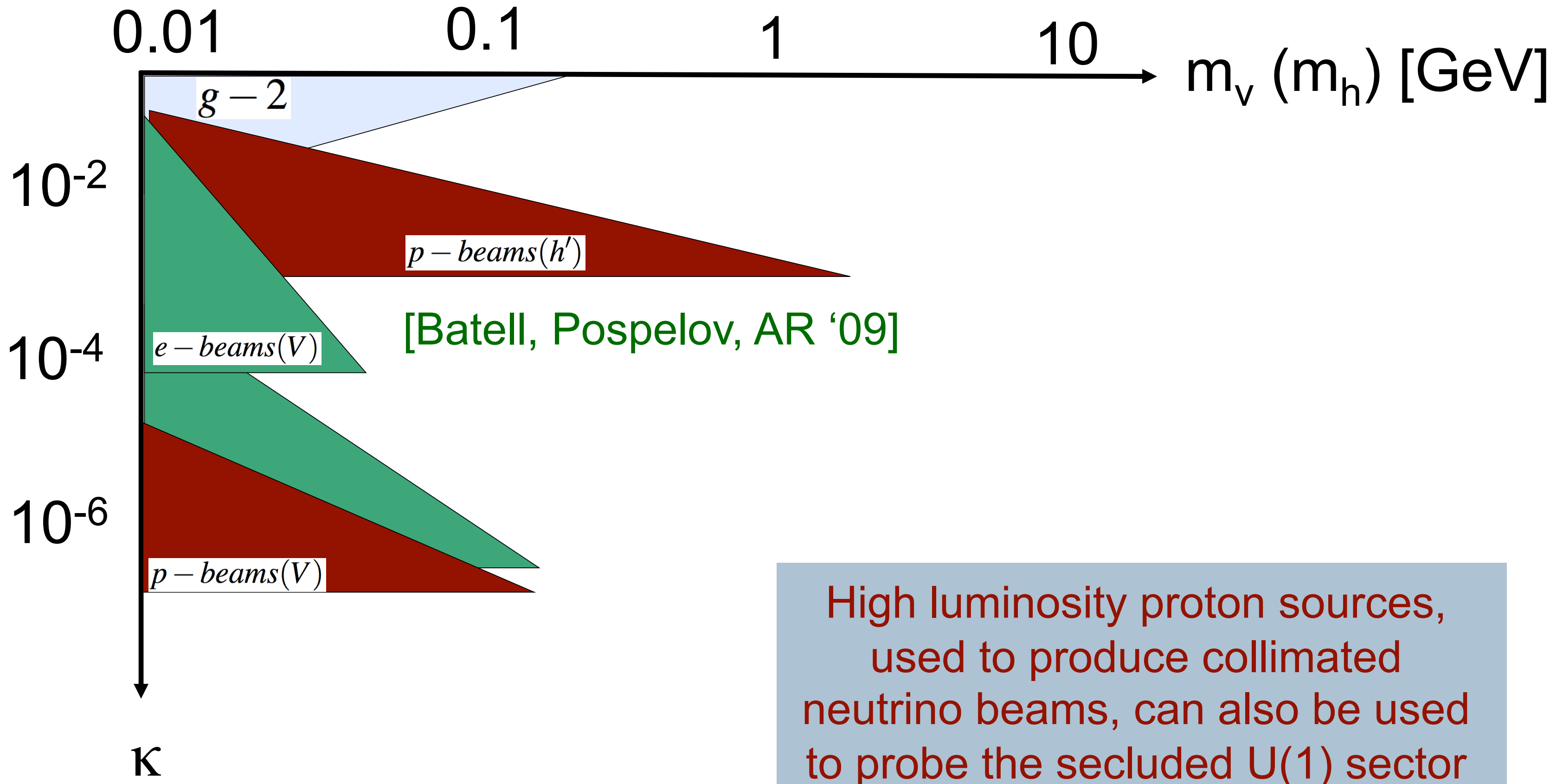
Experimental Sensitivity

In pictorial form



Experimental Sensitivity

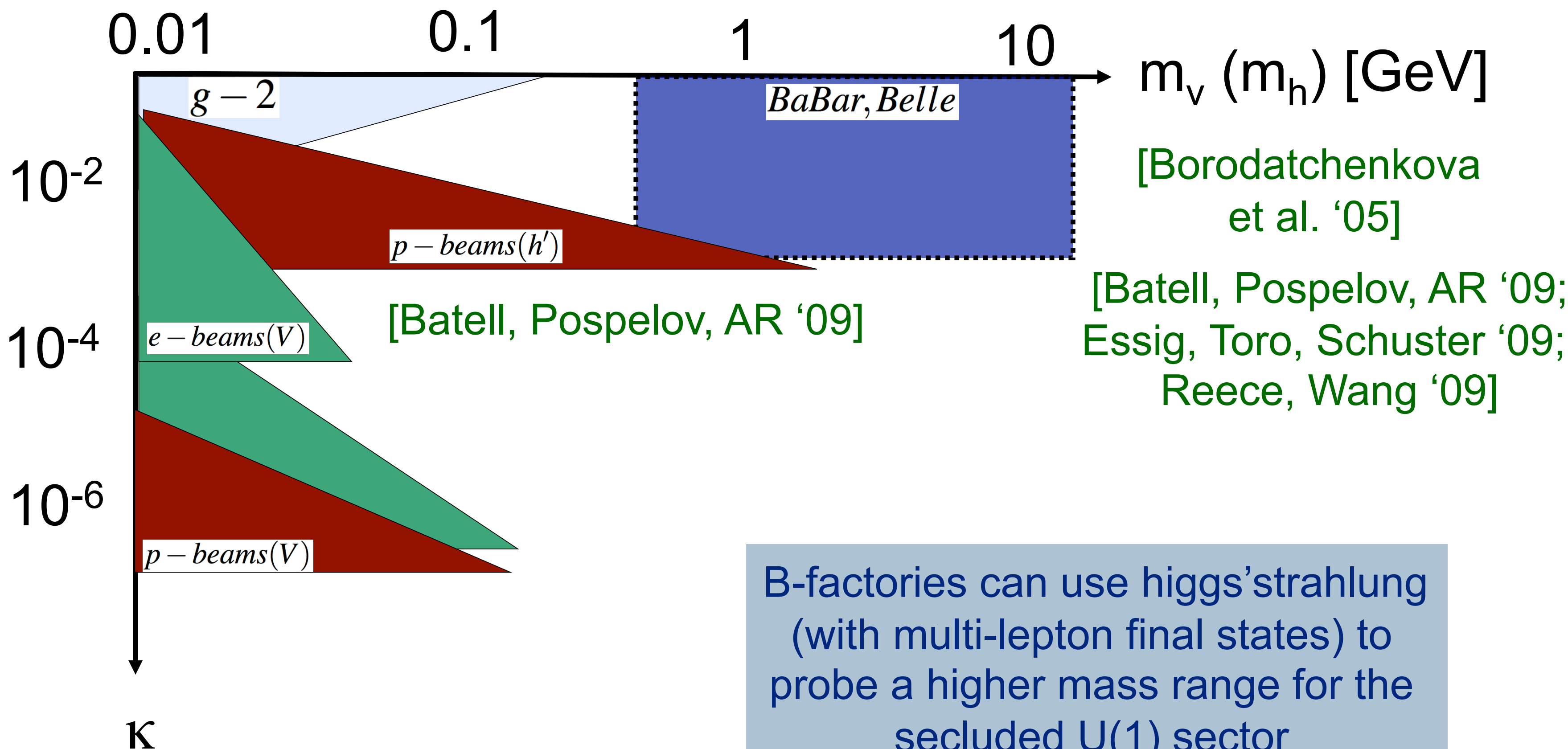
In pictorial form



High luminosity proton sources, used to produce collimated neutrino beams, can also be used to probe the secluded U(1) sector

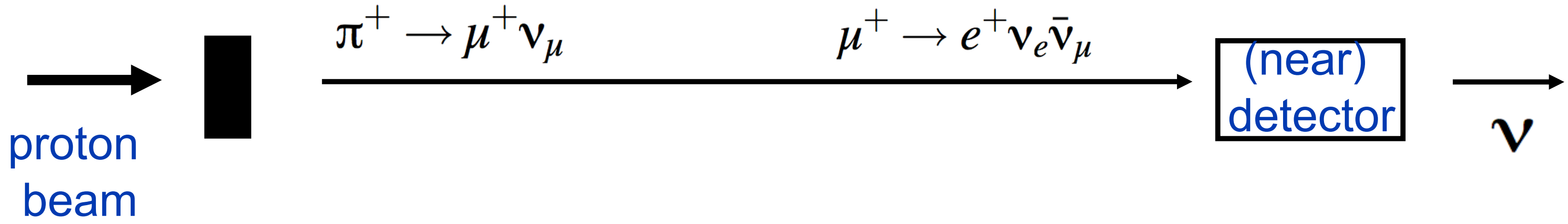
Experimental Sensitivity

In pictorial form

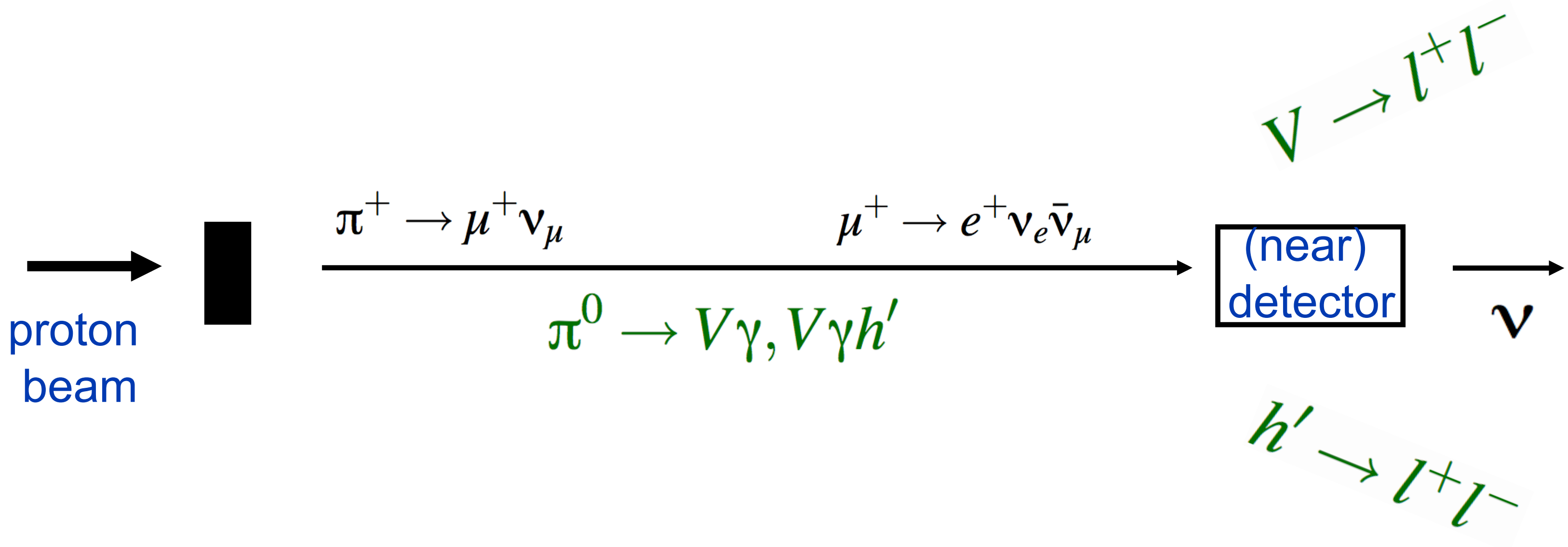


B-factories can use higgs'strahlung (with multi-lepton final states) to probe a higher mass range for the secluded U(1) sector

Fixed target probes - Neutrino Beams



Neutrino Beams

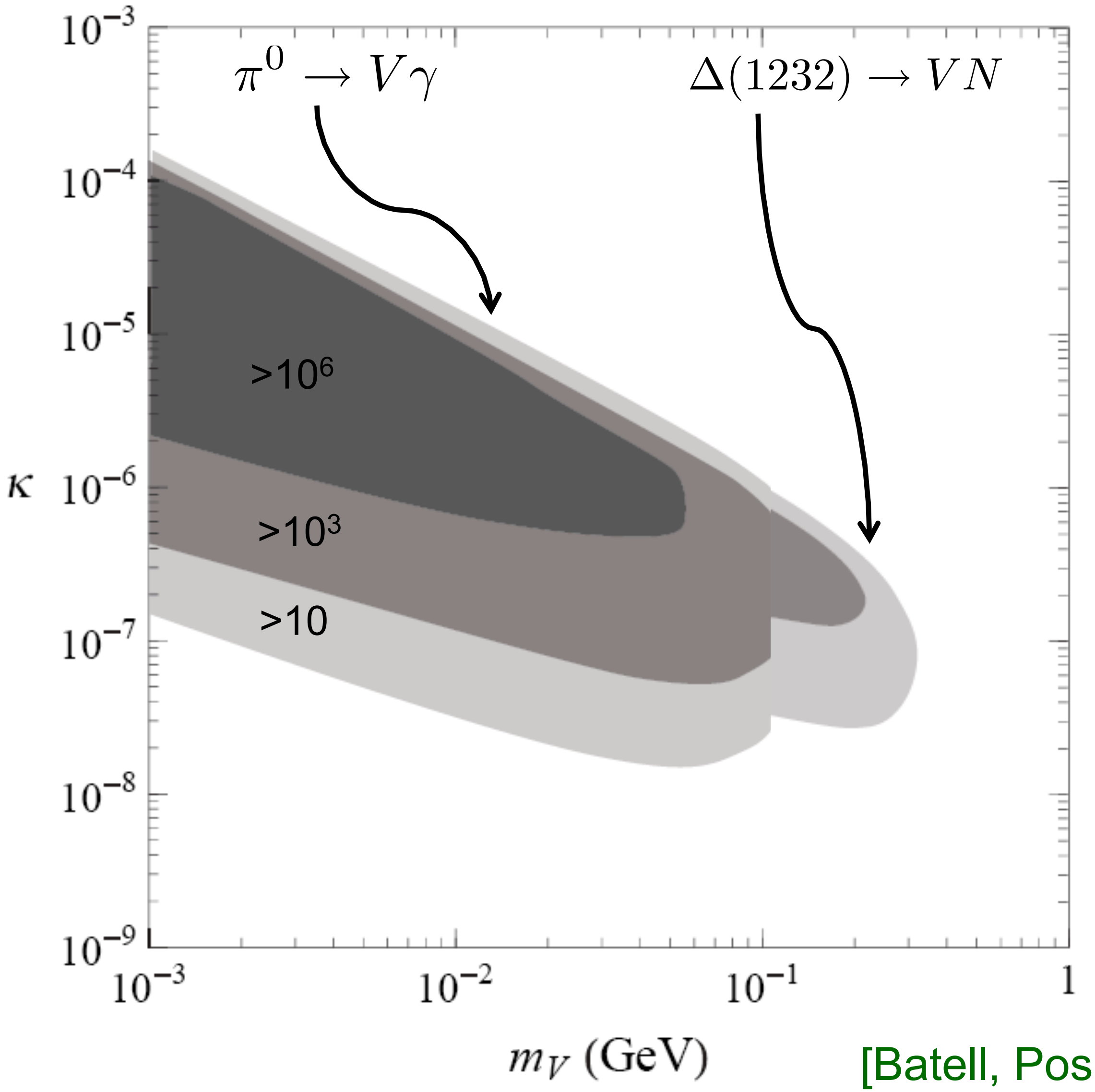


V sensitivity: $\Gamma_V \sim O(100m) \Longrightarrow \kappa \sim 10^{-6} - 10^{-7}$

h’ sensitivity: $\Gamma_{h'} \sim O(100m) \Longrightarrow \kappa \sim 10^{-2} - 10^{-3}$

Sensitivity to Vectors

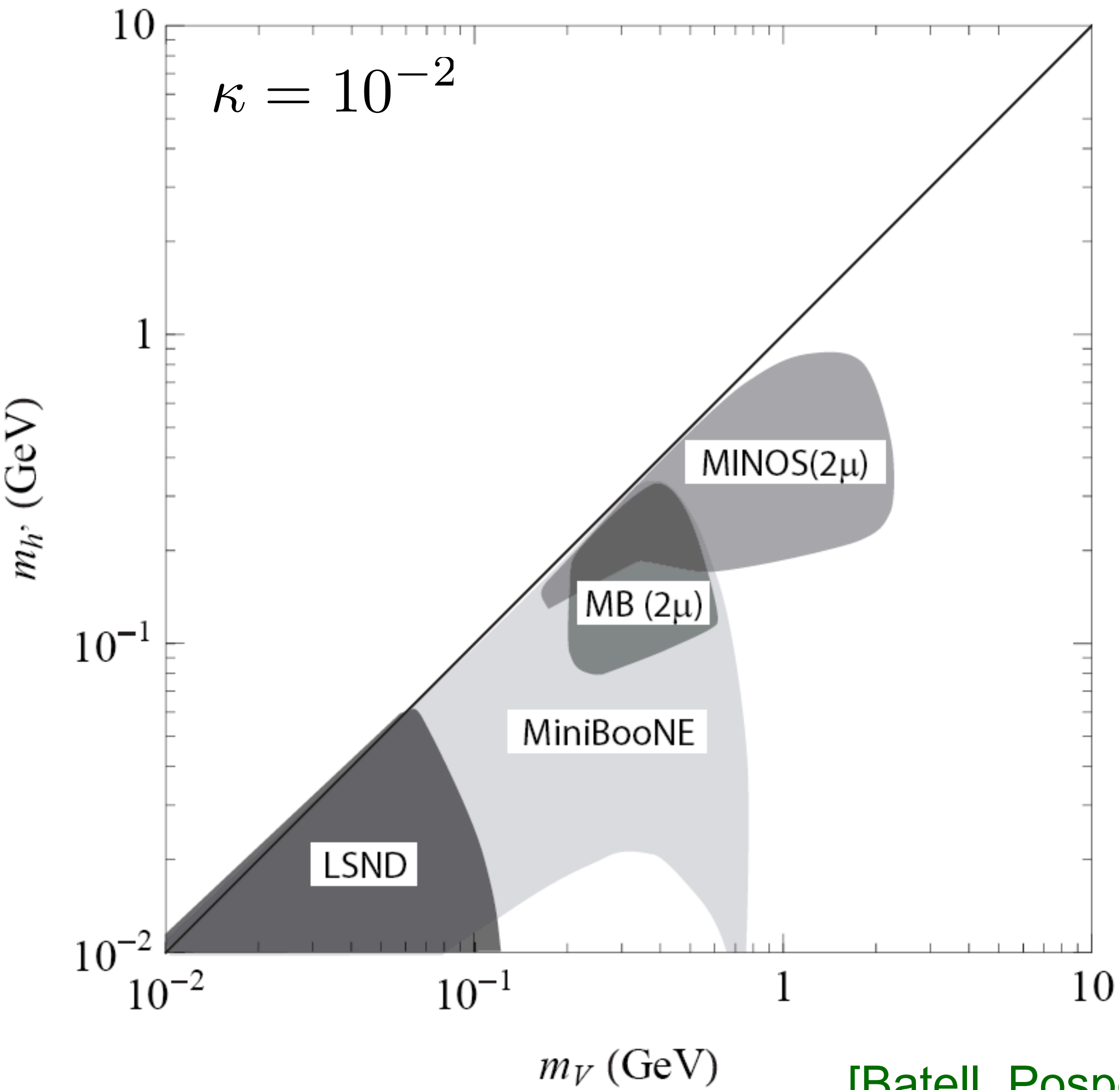
LSND: Distance to detector = 30m, 10^{23} protons on target



[Batell, Pospelov, AR '09]

Sensitivity to Higgs'

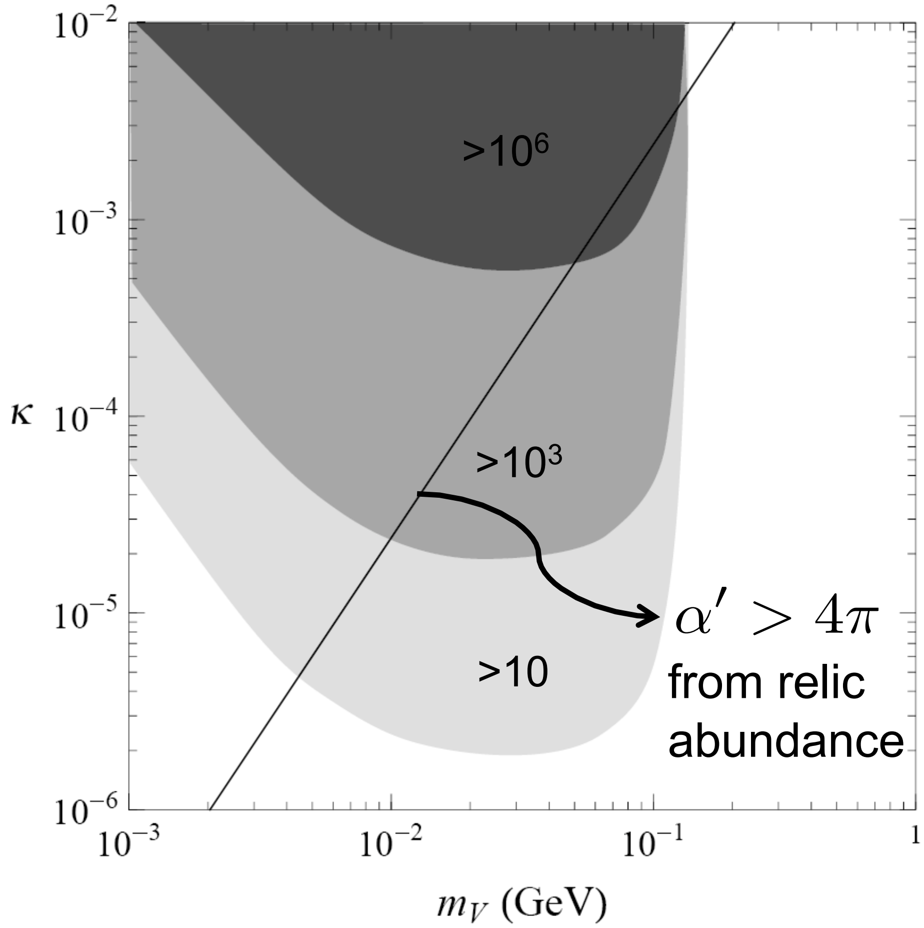
From LSND, MiniBooNE, NuMI/MINOS, …



[Batell, Pospelov, AR '09]

Sensitivity to a “Dark Matter Beam”

If dark matter χ is light (MeV-scale [Boehm et al ‘03, Fayet ’04,’07]), V may decay in the hidden sector ($V \rightarrow \chi\chi$) with NC-like signatures ($\chi + e \rightarrow \chi + e$) in the detector

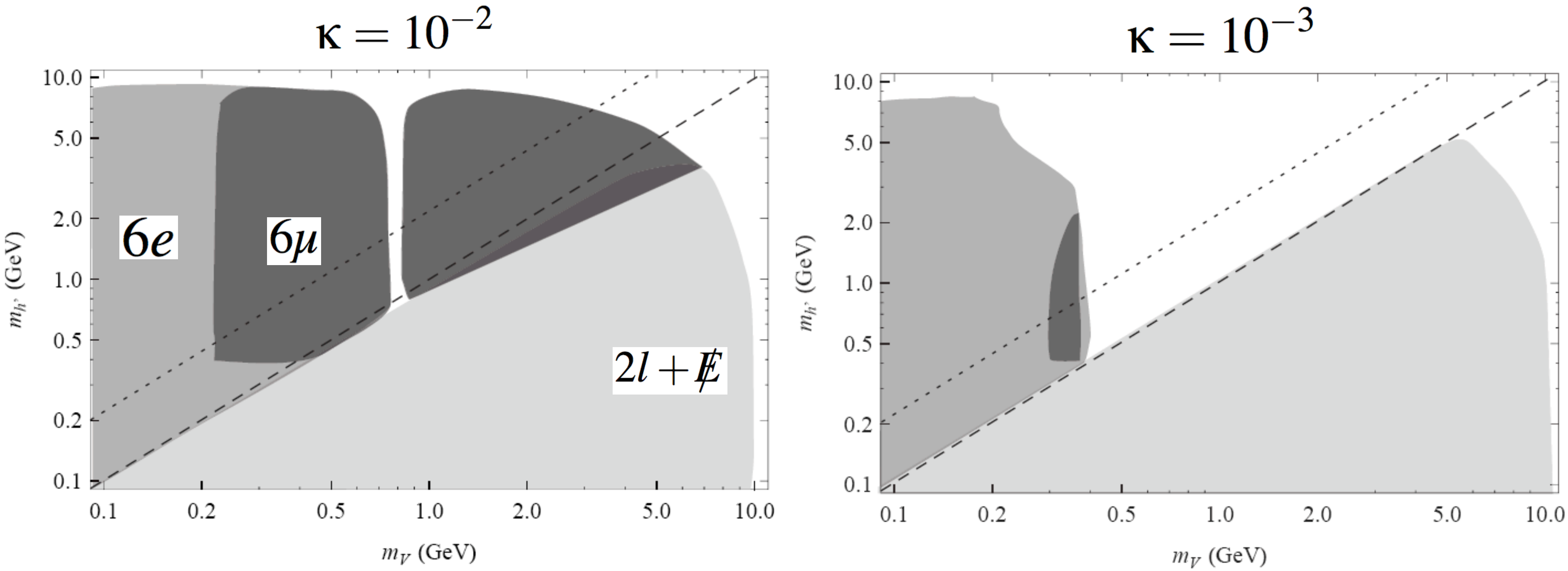


LSND provides the strongest constraints on certain models of MeV-scale DM!

Collider probes - B-factories

Higgs'strahlung: $e^+e^- \longrightarrow Vh' \longrightarrow 6l \;\; (or\; 2l + \not{E})$

NB: primarily continuum V-production, ϒ's give a small correction



[Batell, Pospelov, AR '09]

[see also: Essig et al. '09; Reece & Wang '09]

Probes via Rare Meson Decays

Can also search for resonant structures in rare meson decays with (low mass) sensitivity κ ~ 10^3 - 10^4

- Kaon decays: $$\mathrm{Br}_{K_L \to V\gamma} \simeq 10^{-3} \times \kappa^2 \times \left(1 - \frac{m_V^2}{m_K^2}\right)^3$$

$$\mathrm{Br}_{K_L \to \mu^+\mu^-\gamma} \simeq 3.6 \times 10^{-7}$$ [10^4 events @ KTeV '01]

- Υ(nS) decays: B-factories now providing significant constraints of new light states (but no Vγ decay)

[Babar '09, see talks by Kolomensky & Guido]

Concluding Remarks

- A neutral hidden sector is an intriguing possibility, motivated by dark matter, RH neutrinos, SUSY breaking, …
- Light degrees of freedom may interact with the SM at the renormalizable level via the vector, Higgs, and neutrino portals
- Sensitivity to these portals lies at the luminosity frontier, e.g. medium energy e^+e^- machines (B-factories), rare decays, fixed targets, …
- Significant sensitivity to a secluded U(1) from neutrino sources: LSND, MiniBooNE, NuMI/MINOS, T2K, NOvA, …