Portals and the Hidden Sector with Neutrino Experiments

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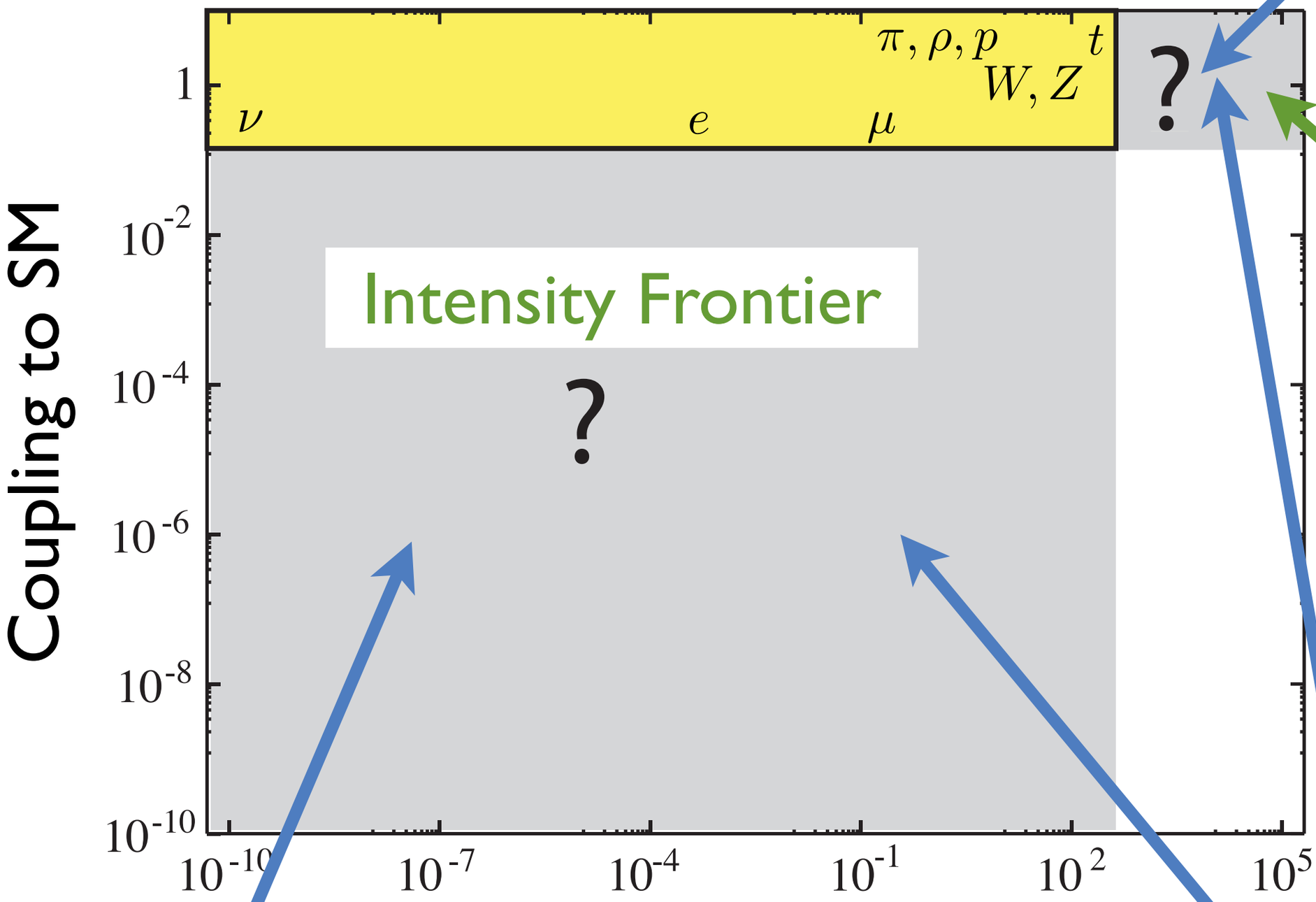
Plan

- Motivation for a hidden sector
- Communicating with portals
- Basic experimental setup; Rate estimates
- Current limits/sensitivities:
  - Dark photons, axions, dark higgs, dark matter ...
- Outlook: prospects for Project X

Where are the new particles?

EWSB, Hierarchy



Energy Frontier

Hidden Sector

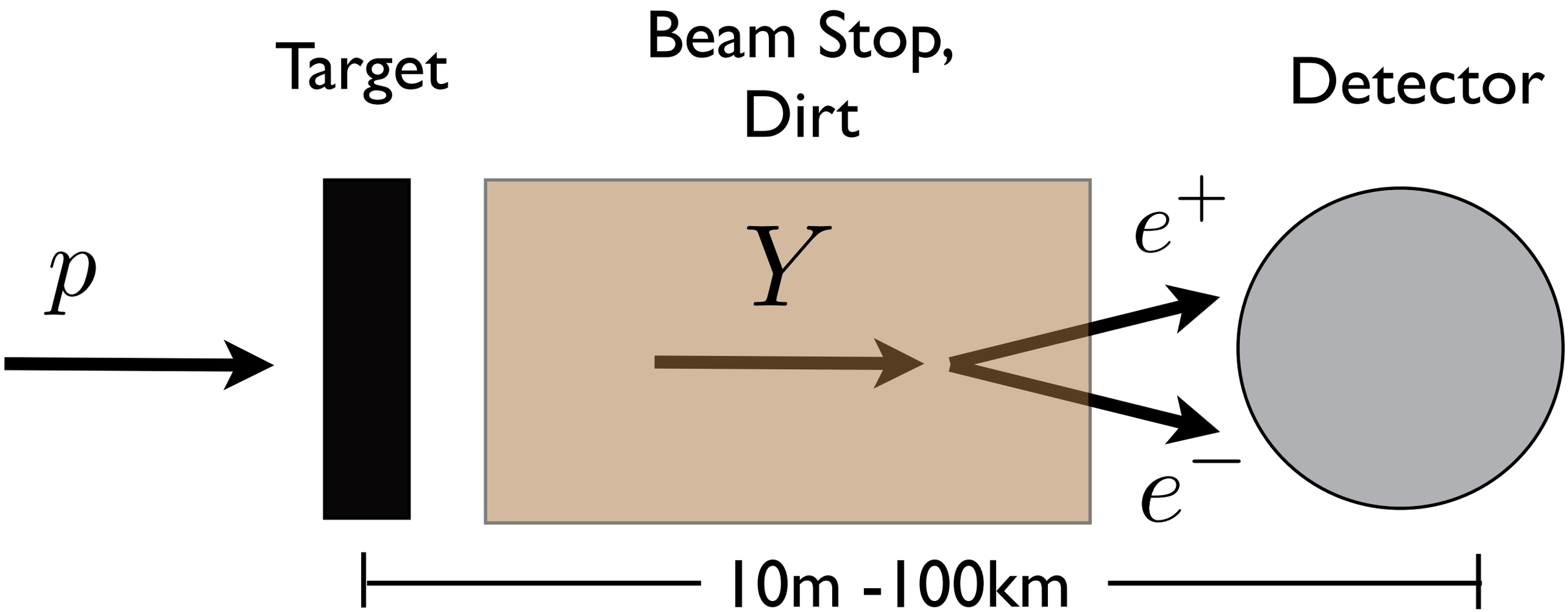
Dark Matter

A Light Hidden Sector?

- Light SM gauge singlet matter and new forces weakly coupled to ordinary matter largely unconstrained
- Singlets exist in SM: L, e_R, d_R, u_R, H, N
- Many possibilities for very weak interactions
- Could address various experimental & observational anomalies
- Predicted in many BSM & top-down scenarios
- Discover new principles in unexpected places!

Hidden particles	Portal
• Dark photons	$-\frac{\kappa}{2} B_{\mu\nu} V^{\mu\nu}$
• Dark scalars	$(\mu S + \lambda S^2) H^\dagger H$
• Sterile Neutrinos	LHN
• PNGBs	$\frac{\partial_\mu a}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$
• Dark Matter	$\frac{1}{\Lambda^2} \bar{\chi} \chi \bar{q} q + \ldots,$
	$g_\chi \phi \bar{\chi} \chi + g_q \phi \bar{q} q + \ldots$

Proton Beam - Target Setup



Event rate estimates:

$$N_{\text{events}} = N_{\text{prod}} \times P_{\text{det}}$$

Production:

1) Direct production: $N_{\text{prod}} = \sigma(pA \to YX) \times (N_{\text{POT}} n_T L_T)$

2) Decay of hadron: $N_{\text{prod}} = N_H \times \text{Br}(H \to Y + X)$

Detection (via decay to visible matter (e.g. leptons) :

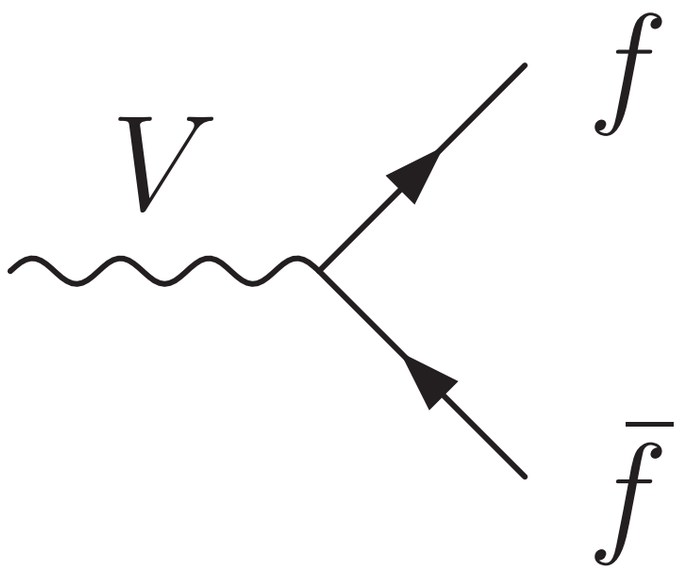
$$P_{\text{det}} \sim \gamma^2 \frac{d\Omega_{\text{lab}}}{4\pi} \left[\exp\left(-\frac{d}{\gamma v \tau}\right) - \exp\left(-\frac{d + R_d}{\gamma v \tau}\right) \right]$$

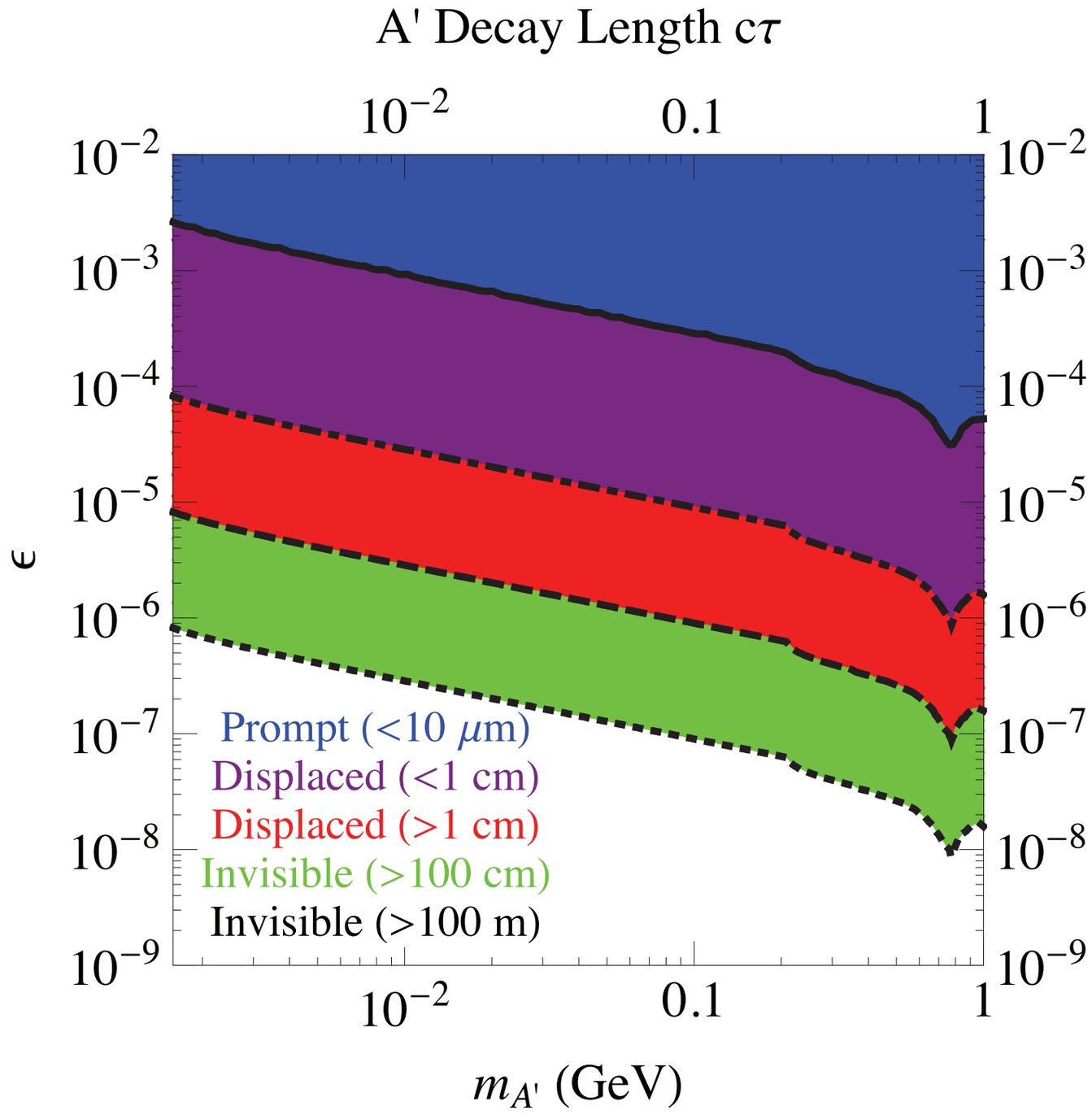
Experiments

Experiment	N_{POT}	Energy	d
CHARM	10^{18}	400 GeV	480 m
LSND	10^{23}	800 MeV	30 m
MiniBooNE	10^{21}	9 GeV	540 m
NuMI/MINOS	10^{20}	120 GeV	1 km

Dark Photons

Essig, Harnik, Kaplan, Toro





$$c\tau \sim 100\text{m} \times \left(\frac{10^{-7}}{\kappa}\right)^2 \left(\frac{100\ \text{MeV}}{m_V}\right)$$

Dark Photons

BB, Pospelov, Ritz

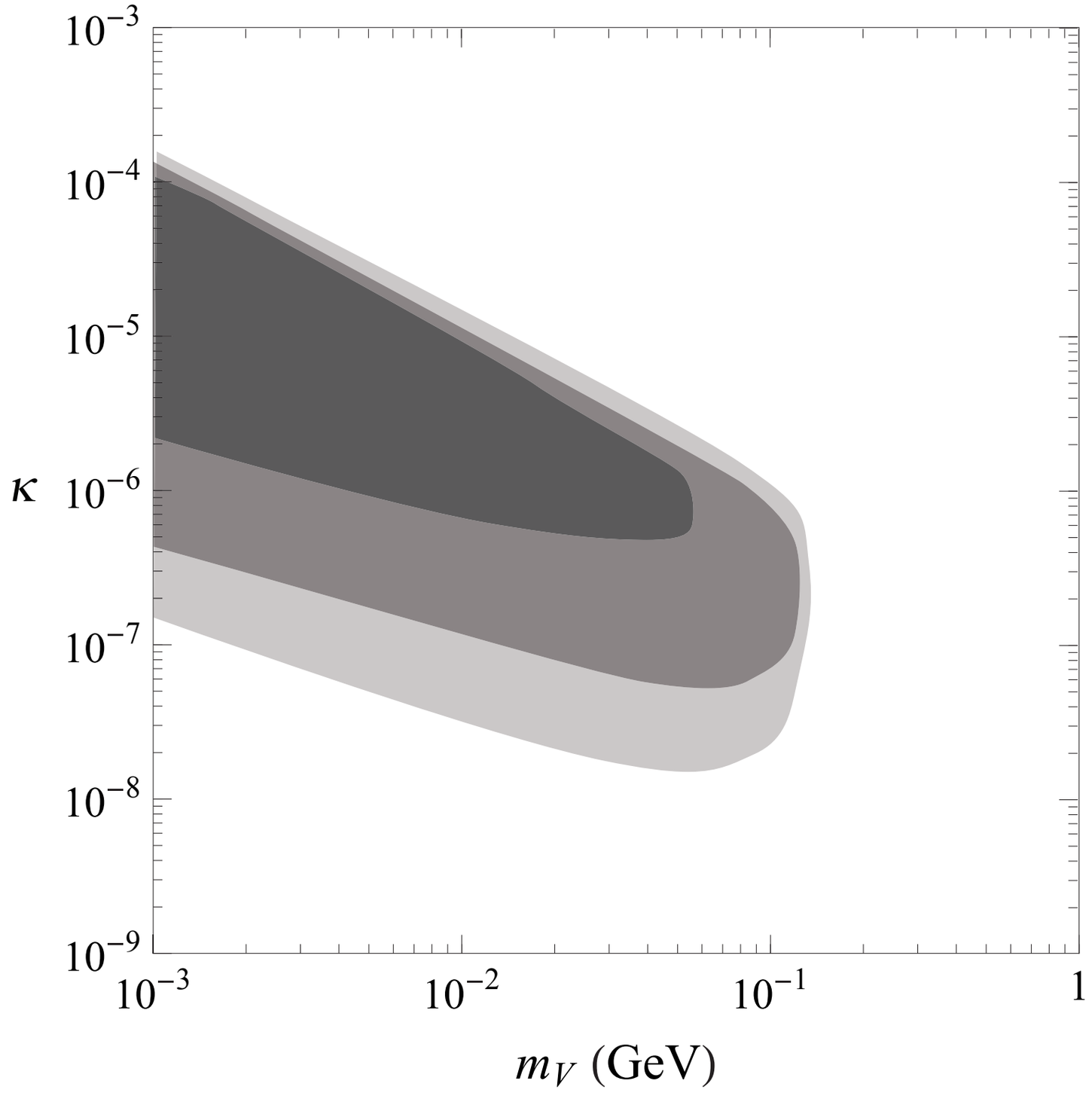
LSND

Production via

$$p + A \to \pi^0 + X$$

followed by

$$\pi^0 \to \gamma V \to \gamma e^+ e^-$$



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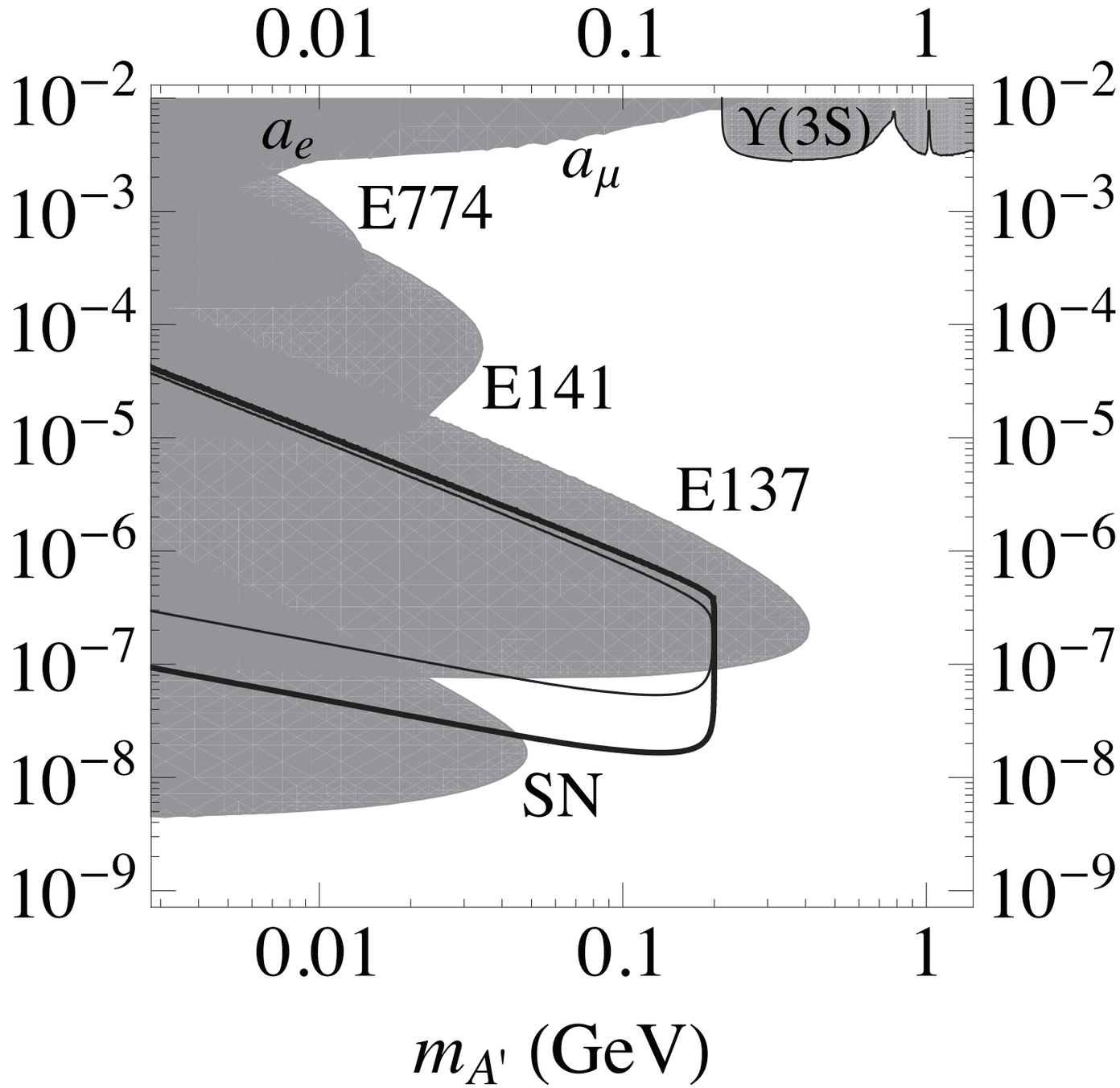
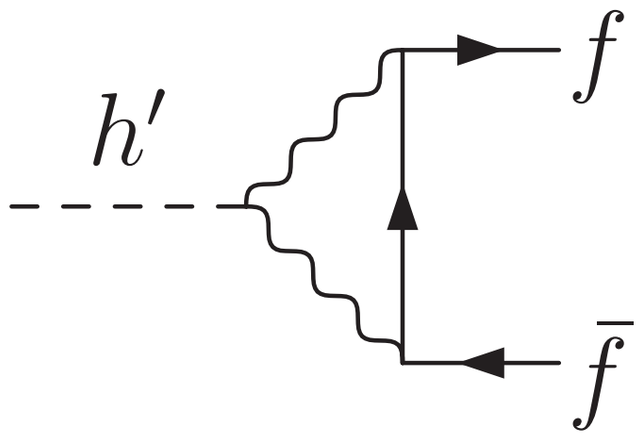
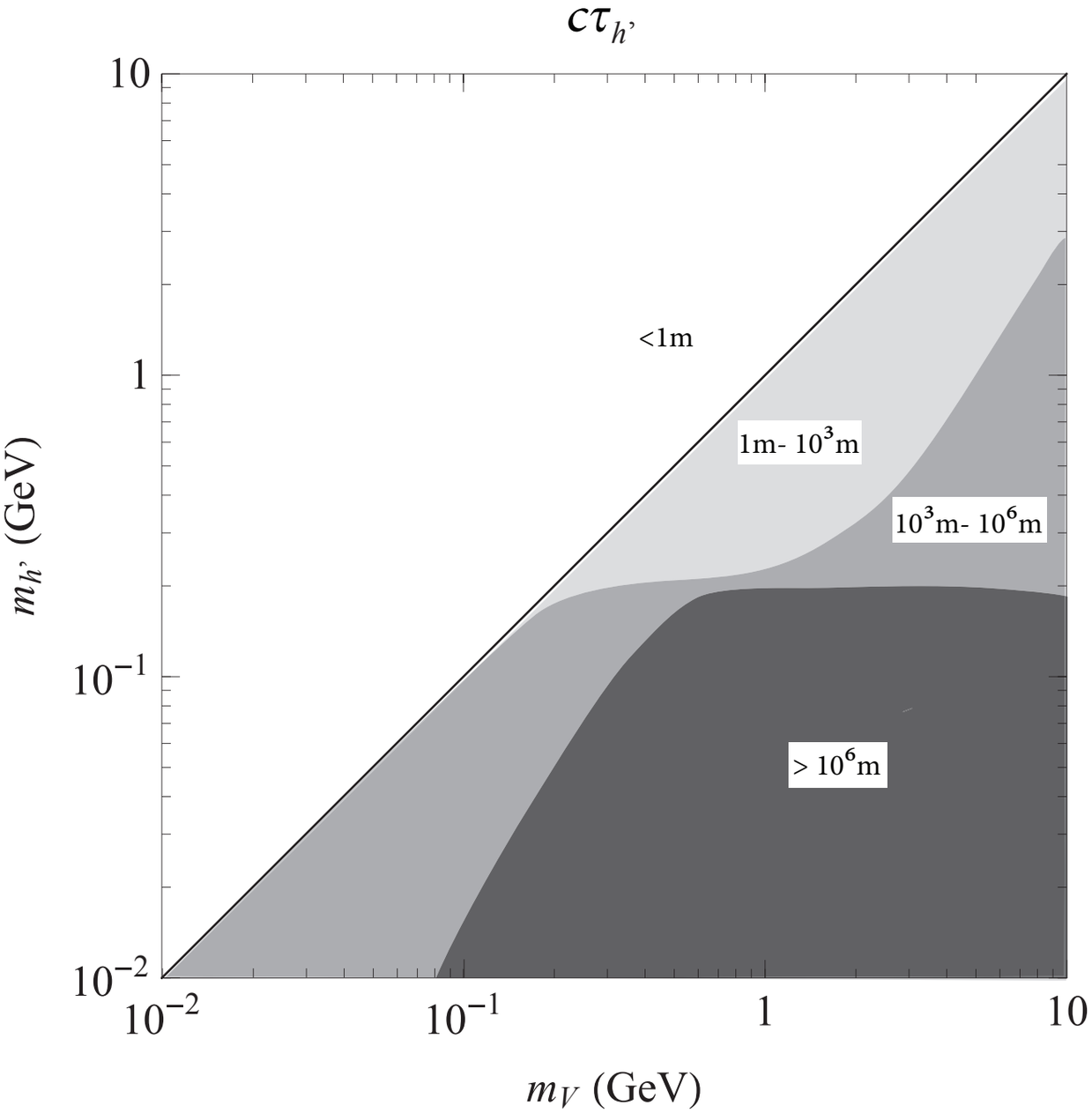


Dark Higgs

BB, Pospelov, Ritz





$$c\tau_{h'} \sim 100\,\mathrm{m} \times \left(\frac{\alpha'}{\alpha}\right) \left(\frac{\kappa^2}{10^{-5}}\right)^{-2} \left(\frac{m_{h'}}{\mathrm{GeV}}\right)^{-1} \left(\frac{m_V}{2m_f}\right)^2$$

Dark Higgs

BB, Pospelov, Ritz

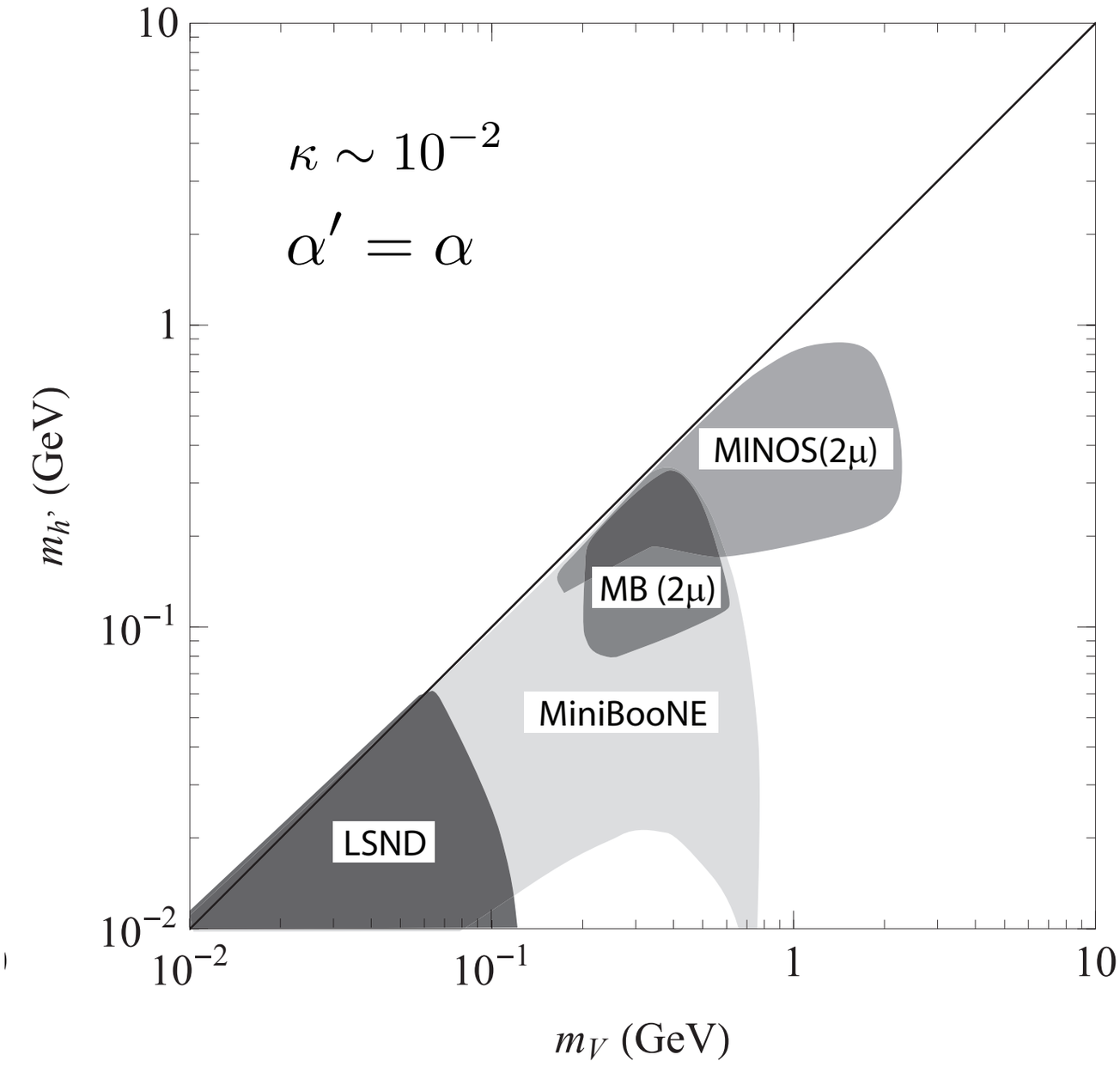
LSND: $\pi_0 \to \gamma V h'$

MiniBooNE: $\rho, \omega \to V h'$

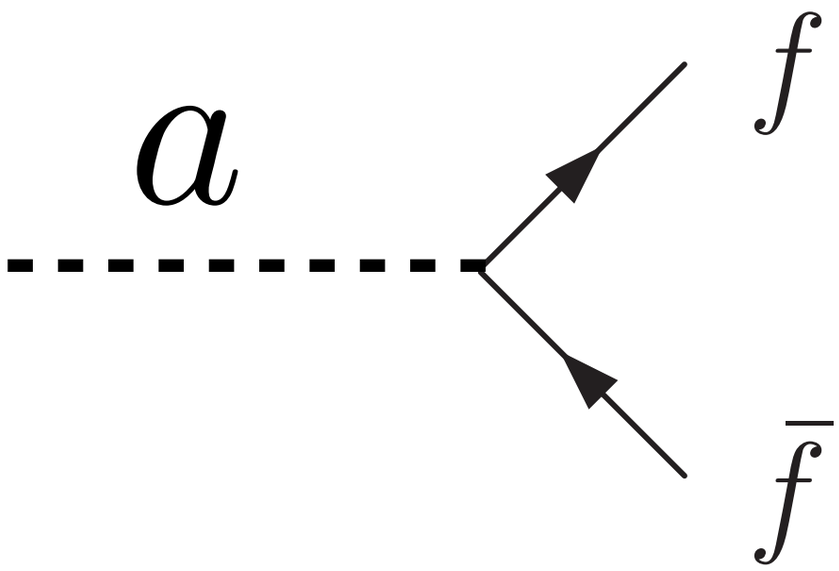
NuMi/MINOS $pA \to V h'$

followed by

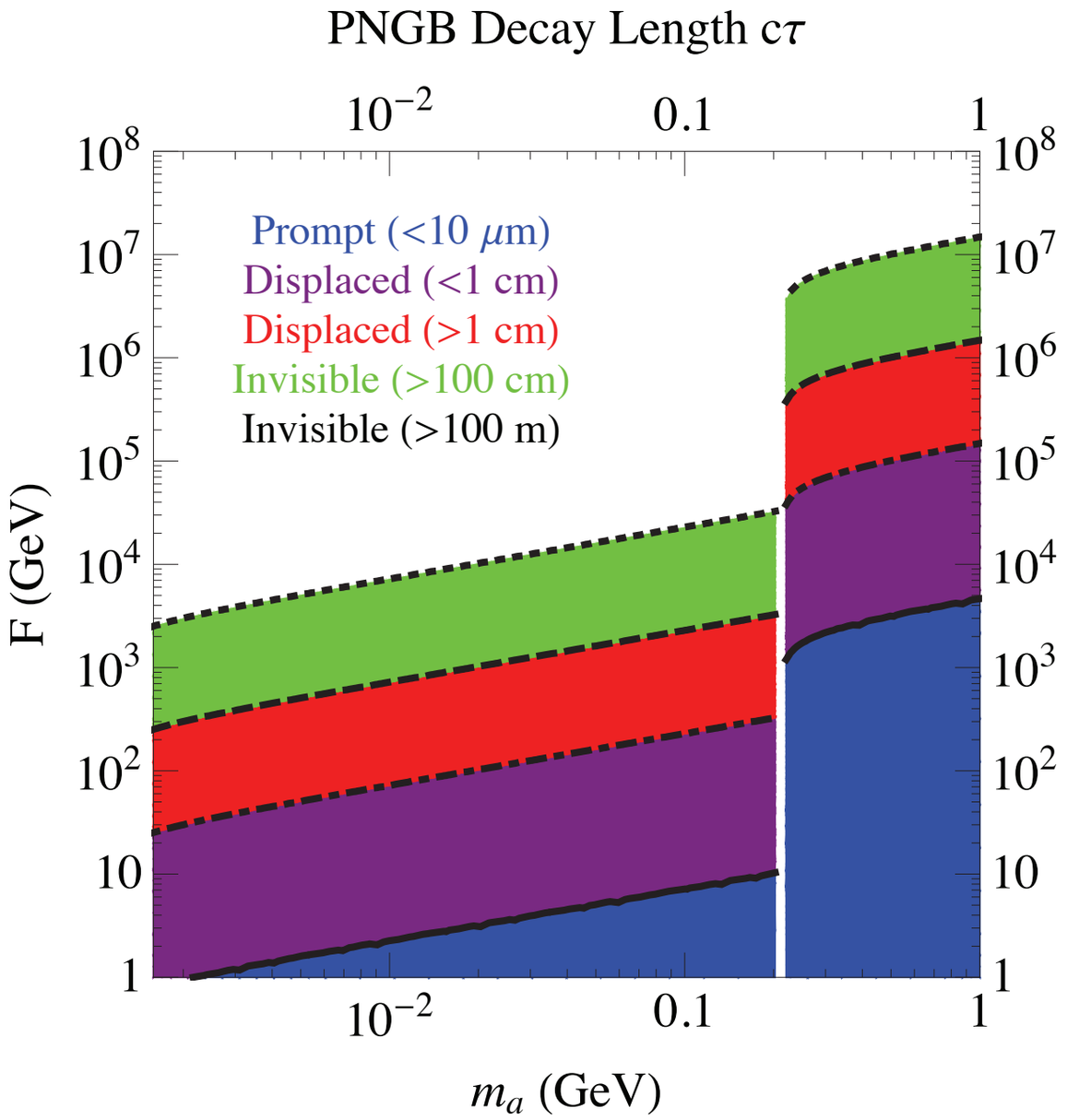
$$h' \to \ell^+ \ell^-$$



Pseudo-Nambu Goldstone Bosons



Essig, Harnik, Kaplan, Toro



$$c\tau \sim 20\text{m} \times \left(\frac{100\ \text{MeV}}{m_a}\right)\left(\frac{F}{10^4\ \text{GeV}}\right)^2$$

PNGBs

CHARM, LSND,
MiniBoone, MINOS

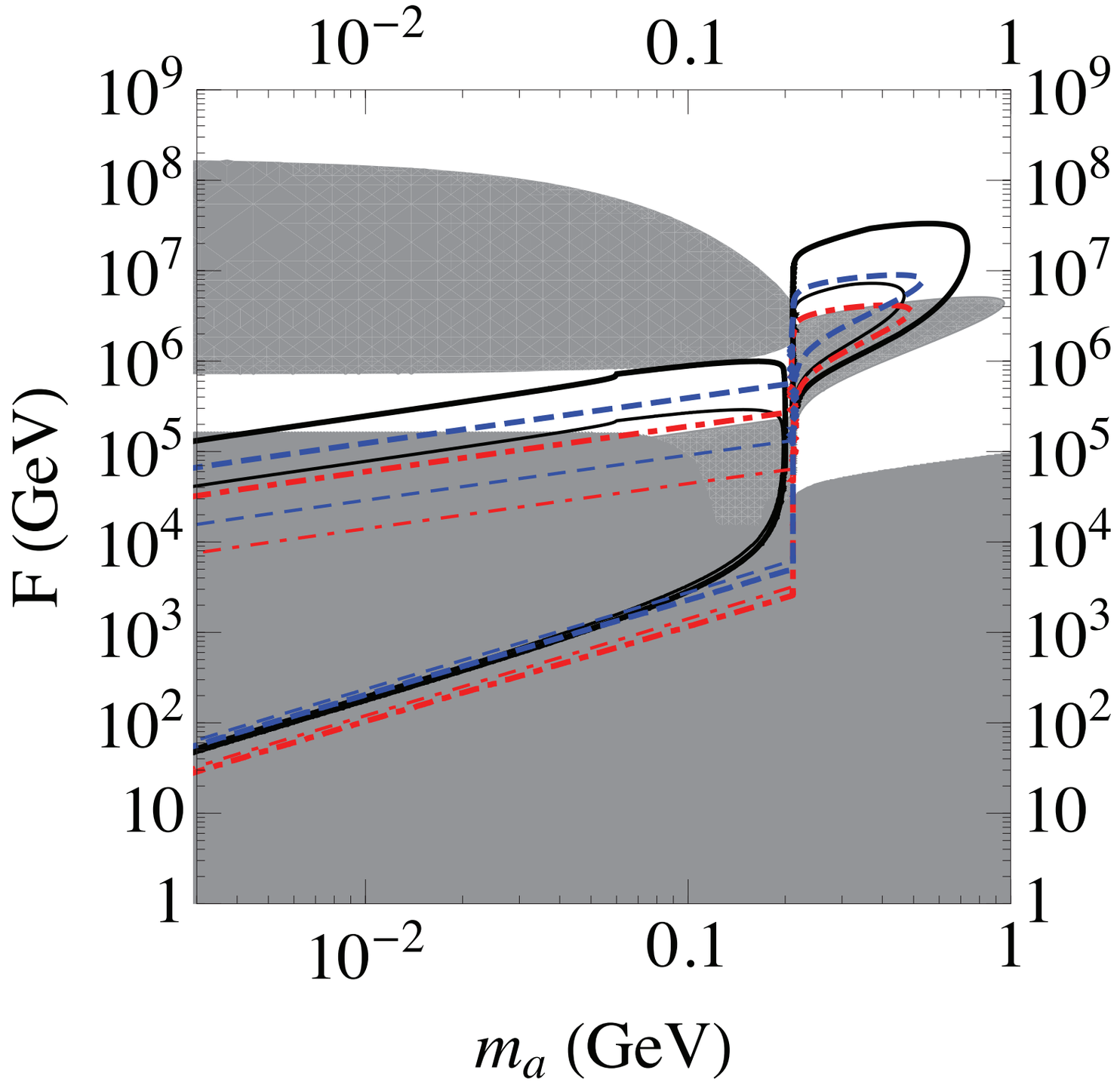
Production via

$$p + A \to a + X$$

followed by

$$a \to \ell^- \ell^+$$

Essig, Harnik, Kaplan, Toro



Dark matter beam

BB, Pospelov, Ritz

Dark matter produced in decay of light mediator

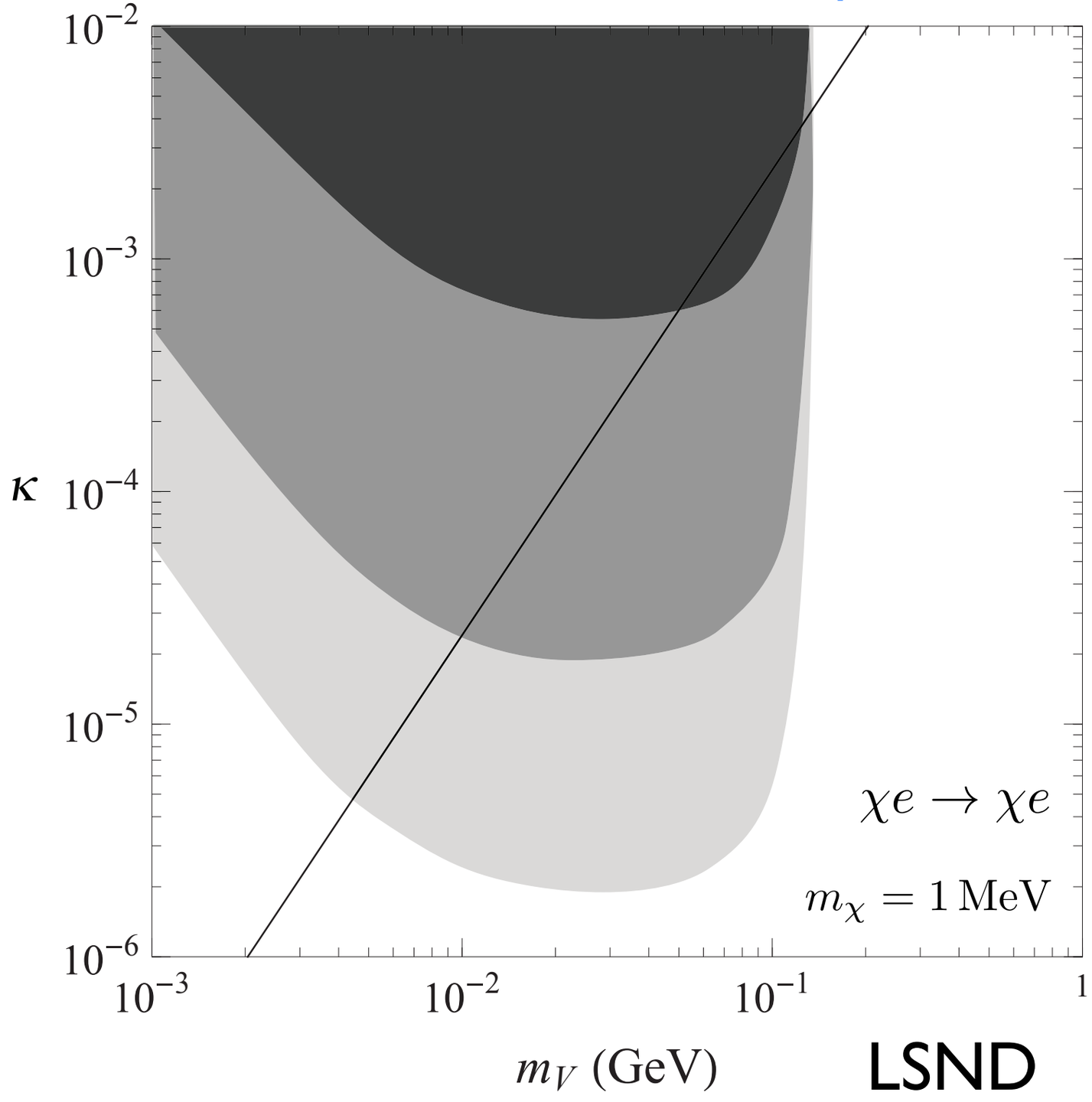
$$\pi_0, \eta \to \gamma V$$

$$V \to \bar{\chi}\chi$$

Neutral current-like event:

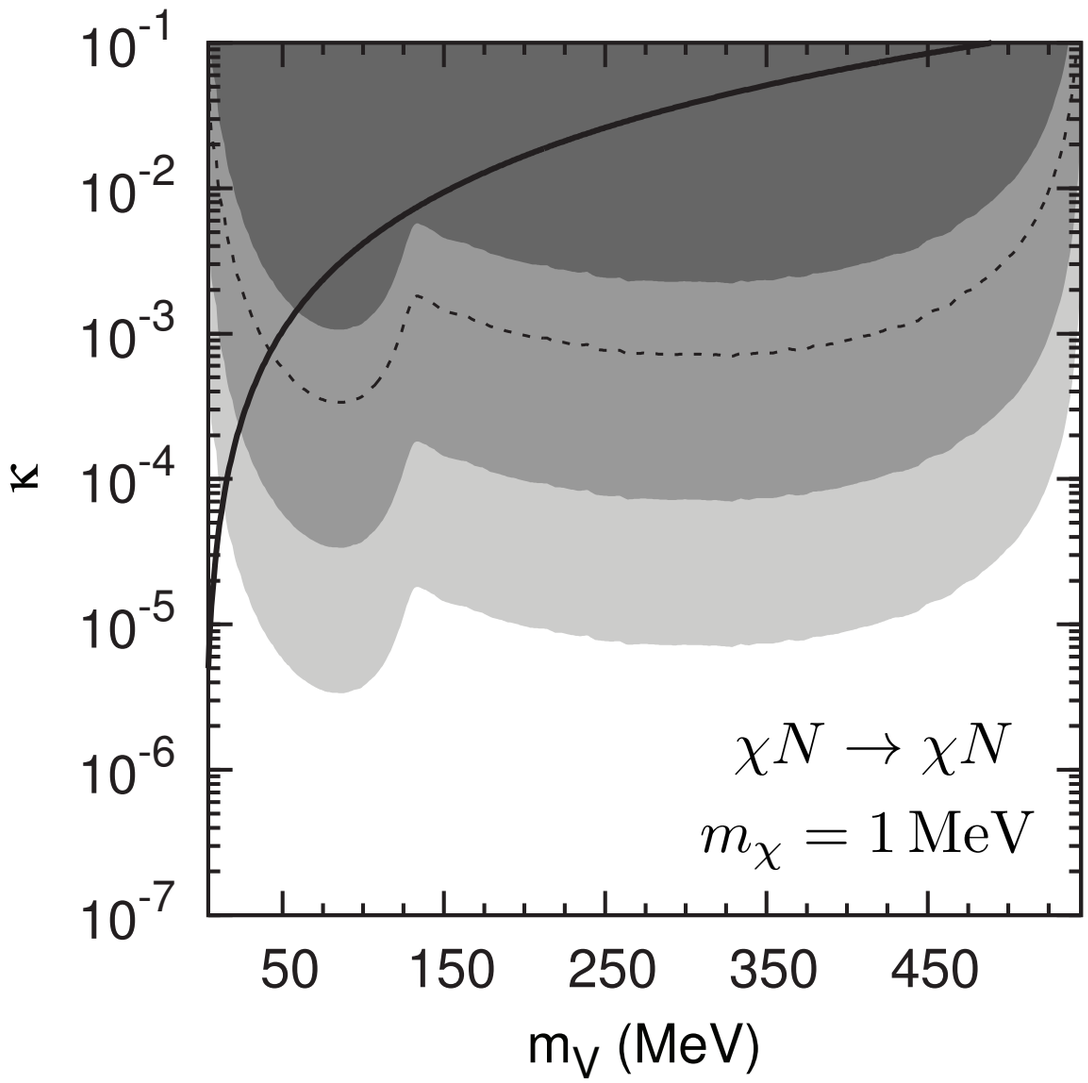
$$\chi e \to \chi e$$

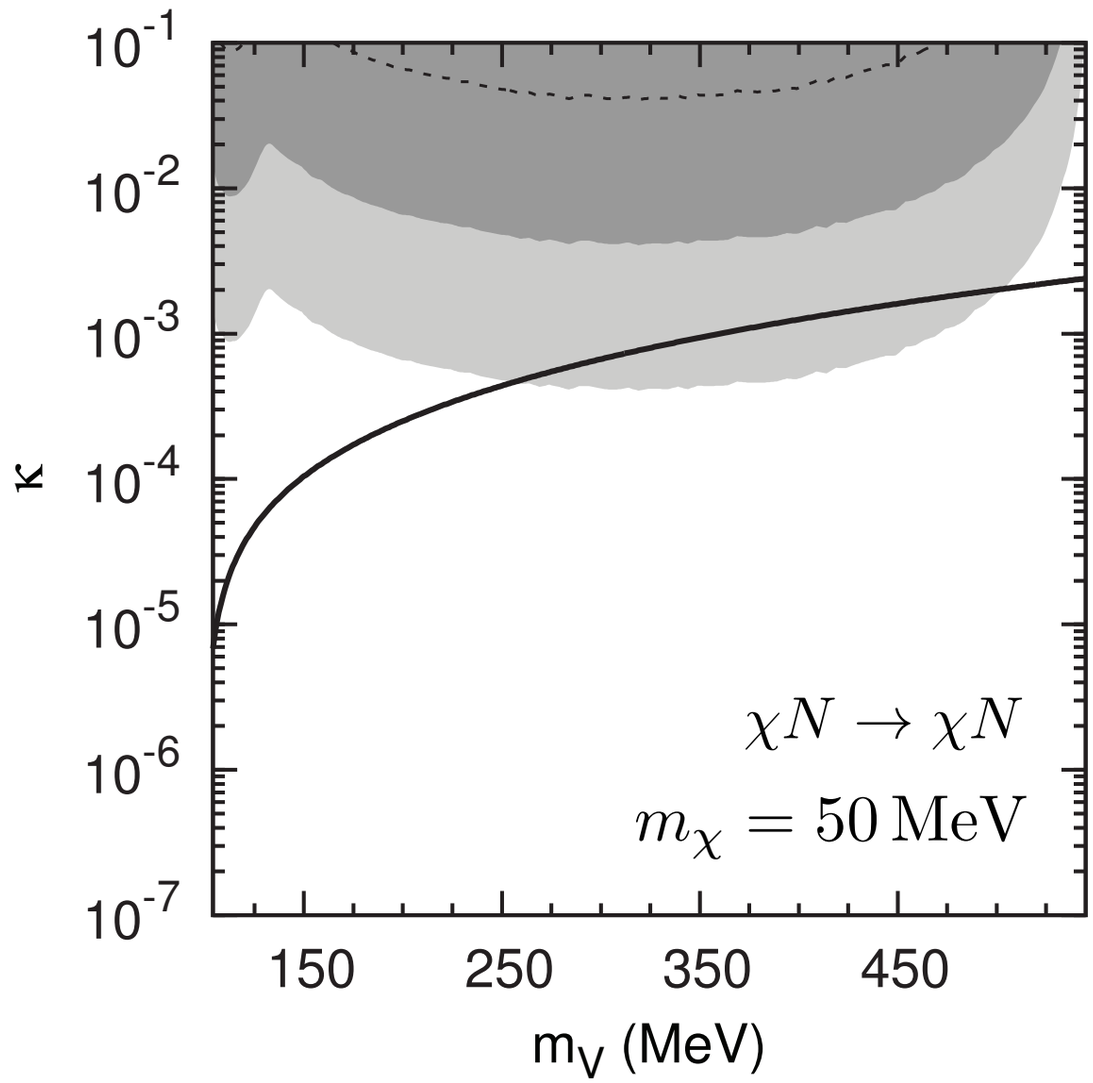
$$\chi N \to \chi N$$



Dark matter beam

deNiverville, Pospelov, Ritz



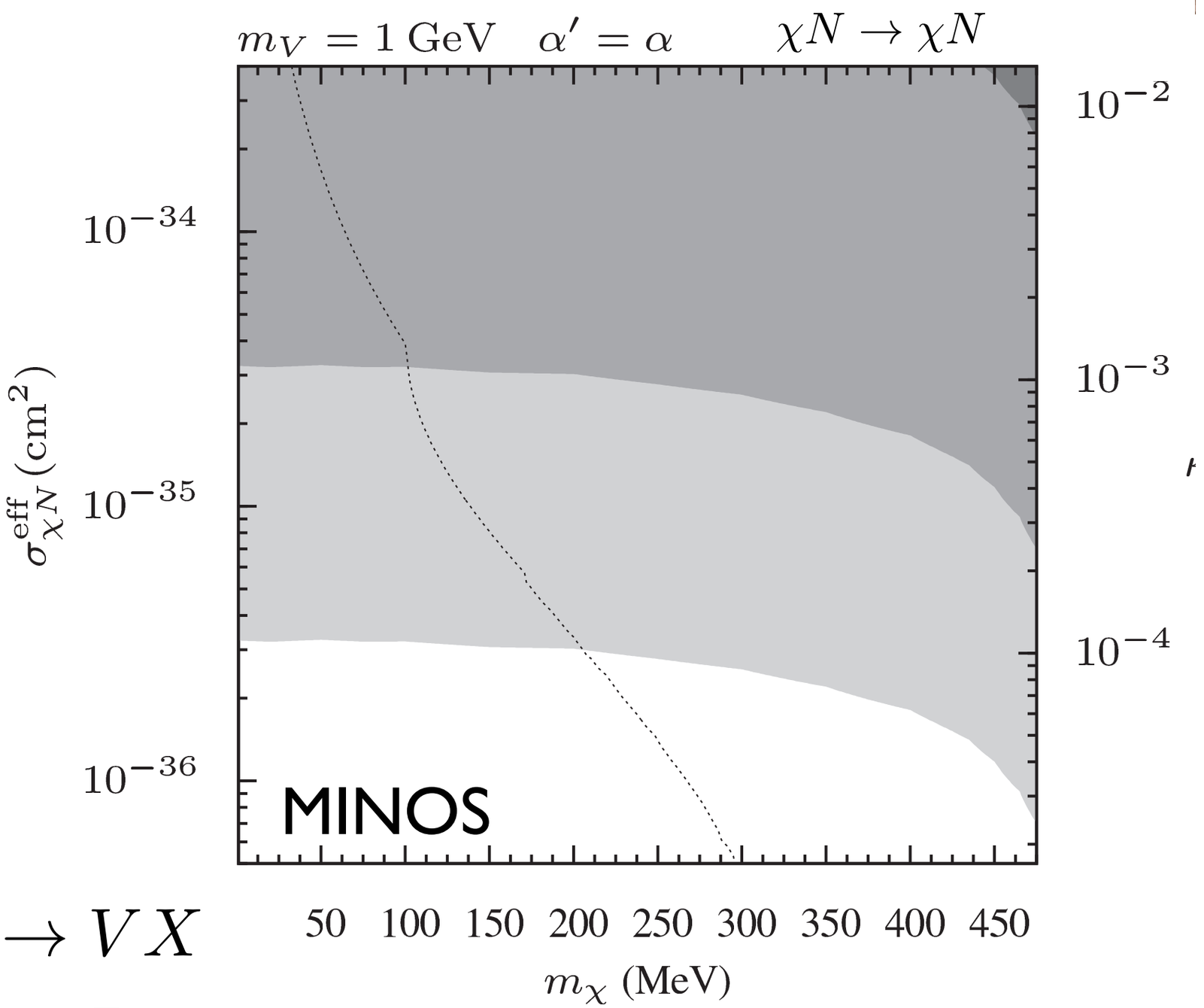


$$\pi_0, \eta \to \gamma V$$
$$V \to \bar{\chi}\chi$$

MiniBooNE

Dark matter beam

deNiverville, McKeen, Ritz

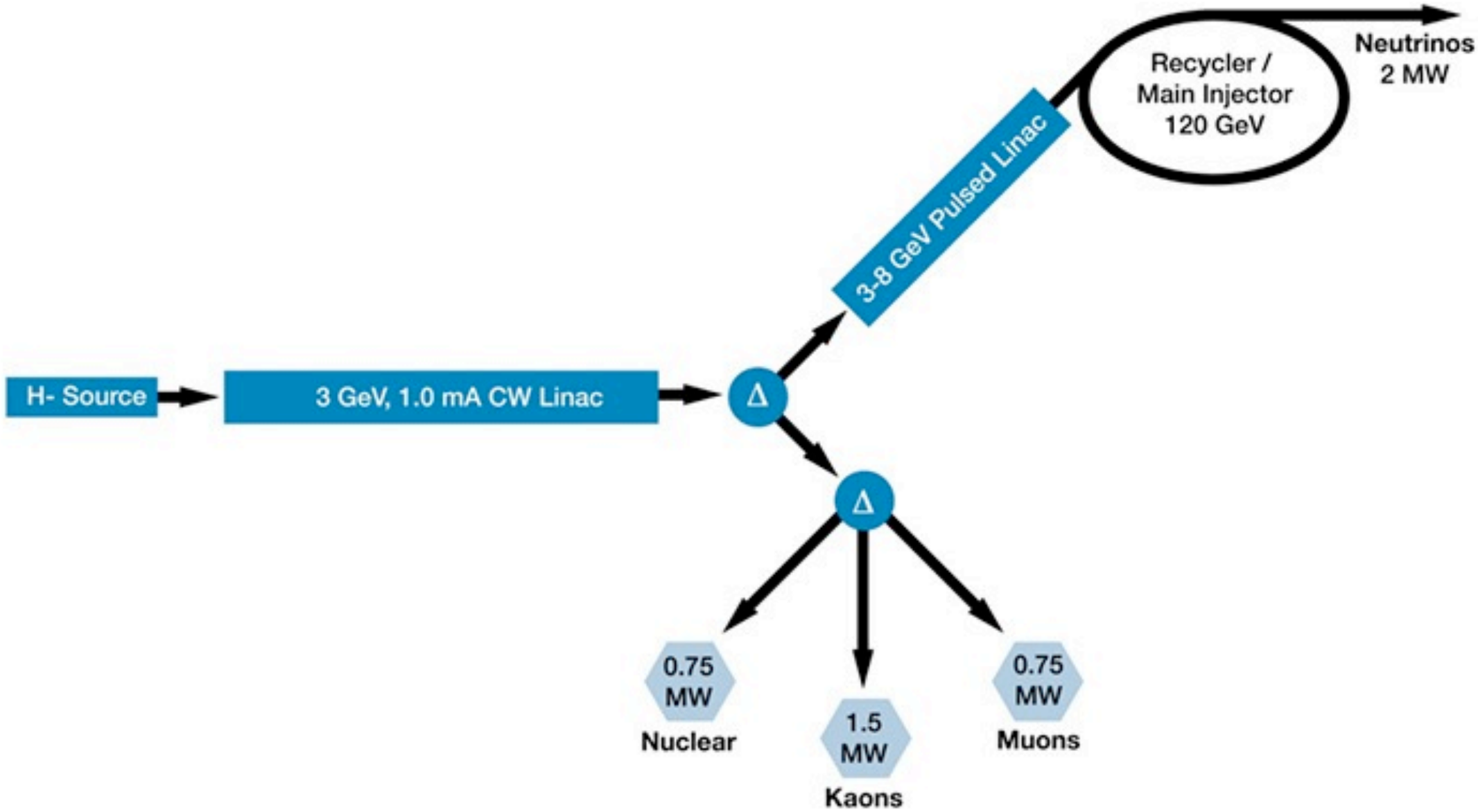


$$pA \to VX$$

$$V \to \bar{\chi}\chi$$

Project X: New high-intensity proton source

3 MW at 3 GeV ⇒ potential for $\sim 10^{23}\ \frac{\mathrm{POT}}{\mathrm{yr}}$



Closing thoughts

- Weakly-coupled, light particles are a generic & exciting possibility for physics beyond the Standard Model

- Can be systematically explored via portals

- Proton Beam-target experiments offer complementary sensitivity to other probes

- Provide another physics rationale for the experimental program at the intensity frontier

Question:

What is the best way to utilize/expand existing experimental infrastructure for a more comprehensive physics program?

Especially in the context of Project X?