Future Searches at Proton Accelerators for New Particles

Brian Batell
The Enrico Fermi Institute
The University of Chicago

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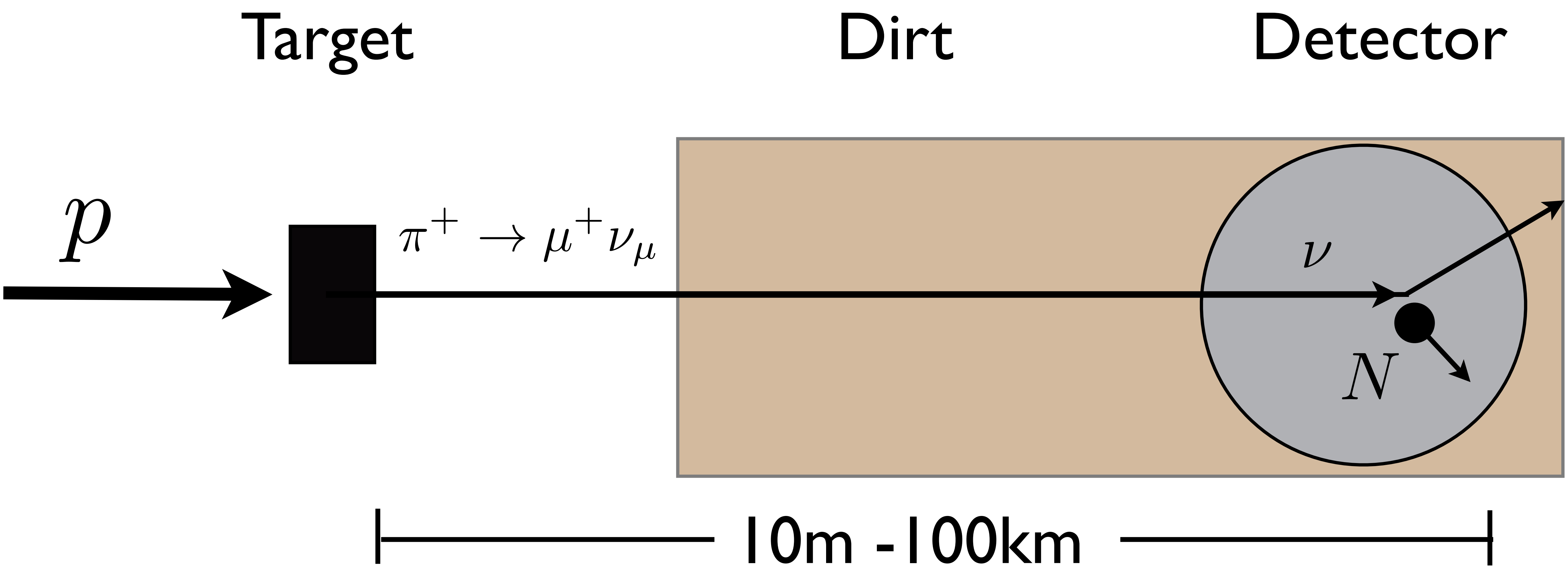
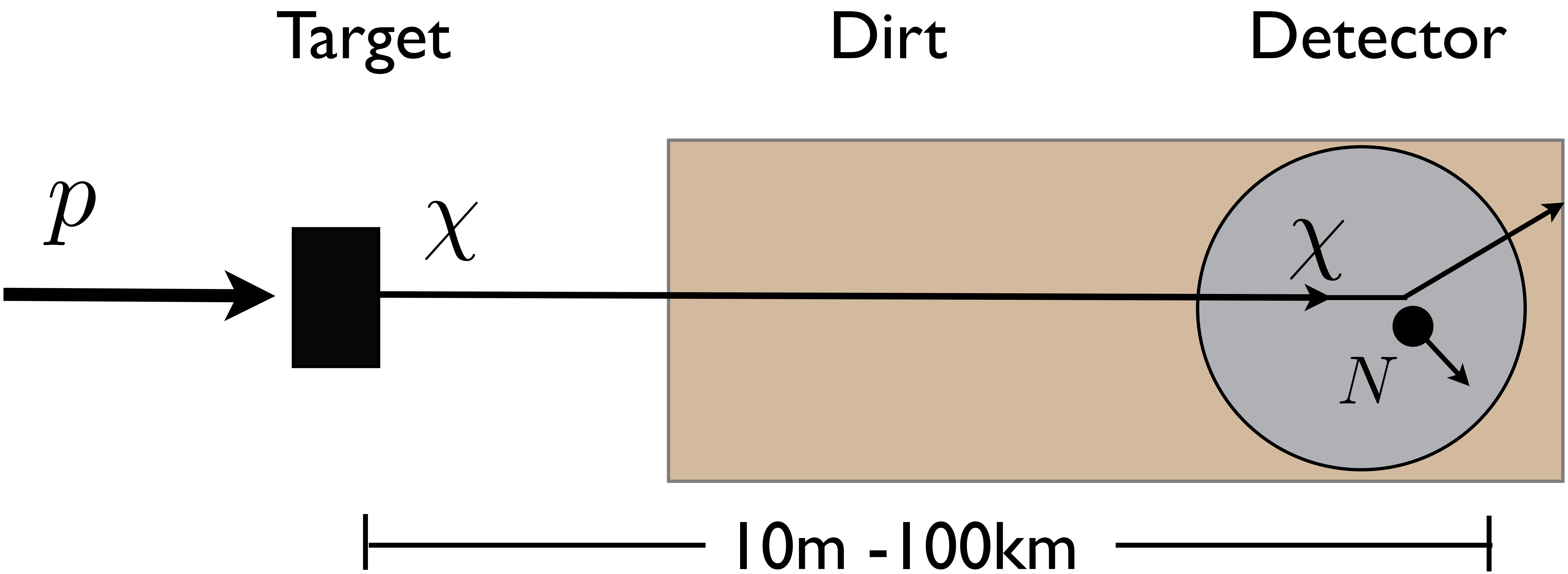
Hidden particles	Portal
Dark photons	$-\frac{\kappa}{2}B_{\mu\nu}V^{\mu\nu}$
Dark scalars	$(\mu S + \lambda S^2)H^\dagger H$
Sterile Neutrinos	LHN
PNGBs	$\frac{\partial_\mu a}{f_a}\bar{\psi}\gamma^\mu\gamma^5\psi$
Dark Matter	$\frac{1}{\Lambda^2}\bar{\chi}\chi\bar{q}q + \ldots,$ $g_\chi\phi\bar{\chi}\chi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

Basic proton beam - target -detector setup

Neutrino beam

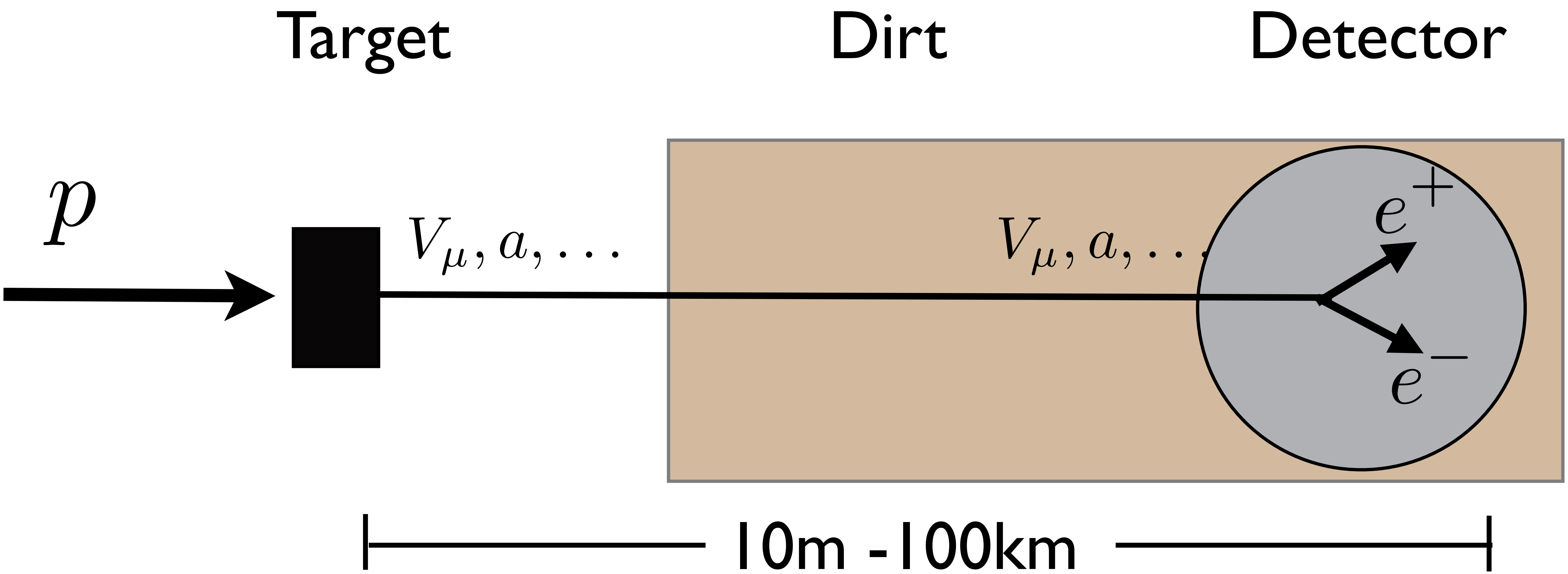


A dark matter beam!



[BB, Pospelov, Ritz '09]

Dark photon, dark Higgs, axion, ...



[BB, Pospelov, Ritz 2009]
[Essig, Harnik, Kaplan, Toro ’10]

I’ll focus in this talk on new developments
in searches for light Dark Matter

However, proton beam - target setups can
probe many other NLWCP...

No time to cover here, but see my talk at
Rockville Intensity Frontier Workshop, and
references therein:

https://twindico.hep.anl.gov/indico/conferenceOtherViews.py?view=standard&confId=751

A dark matter beam

Based on:

BB, Pospelov Ritz; arXiv:0906.5614

deNiverville, Pospelov Ritz; arXiv:1107.4580

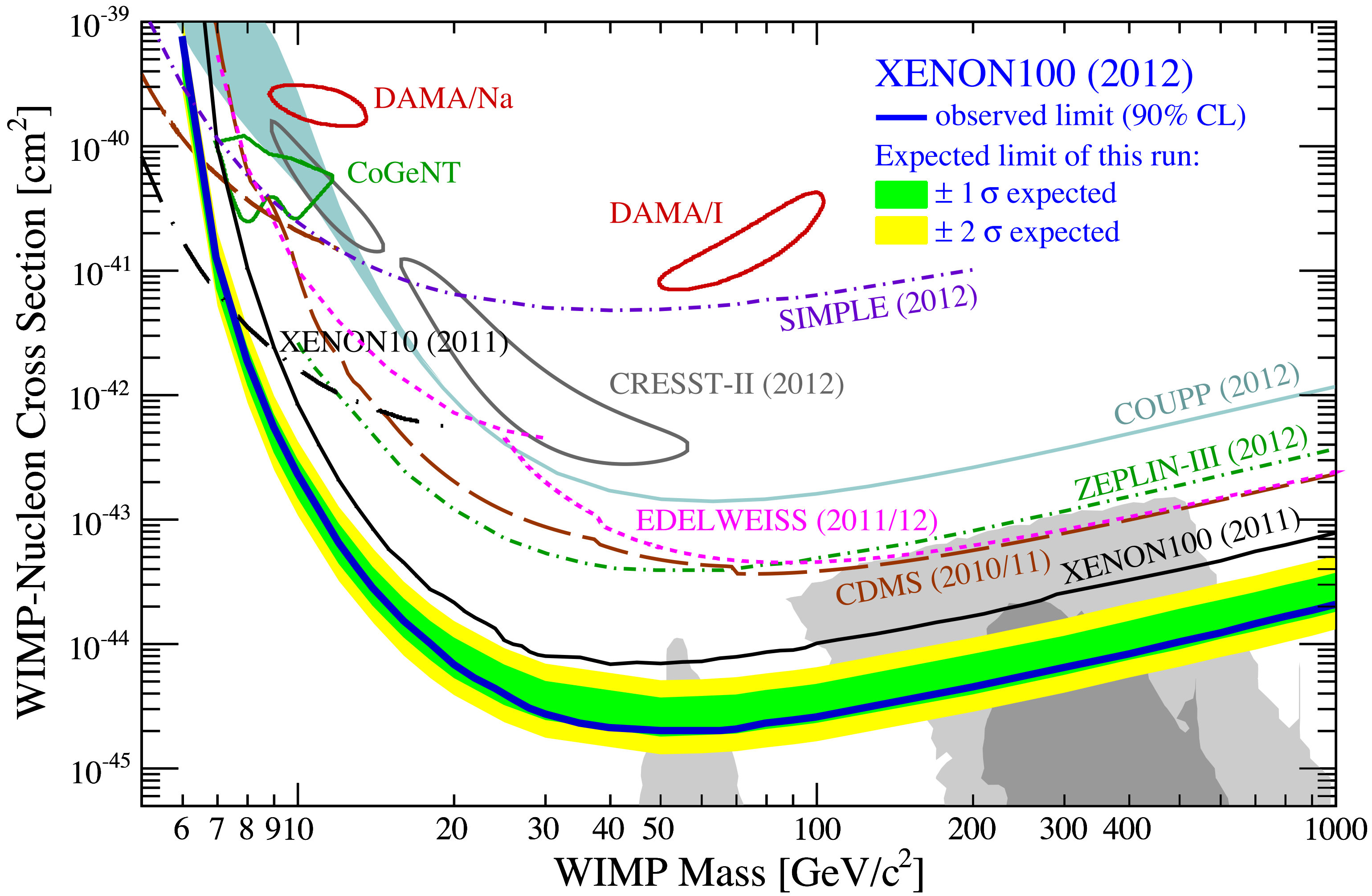
deNiverville, McKeen Ritz; arXiv:12005.3499

Proposal to search for light DM with MiniBooNE

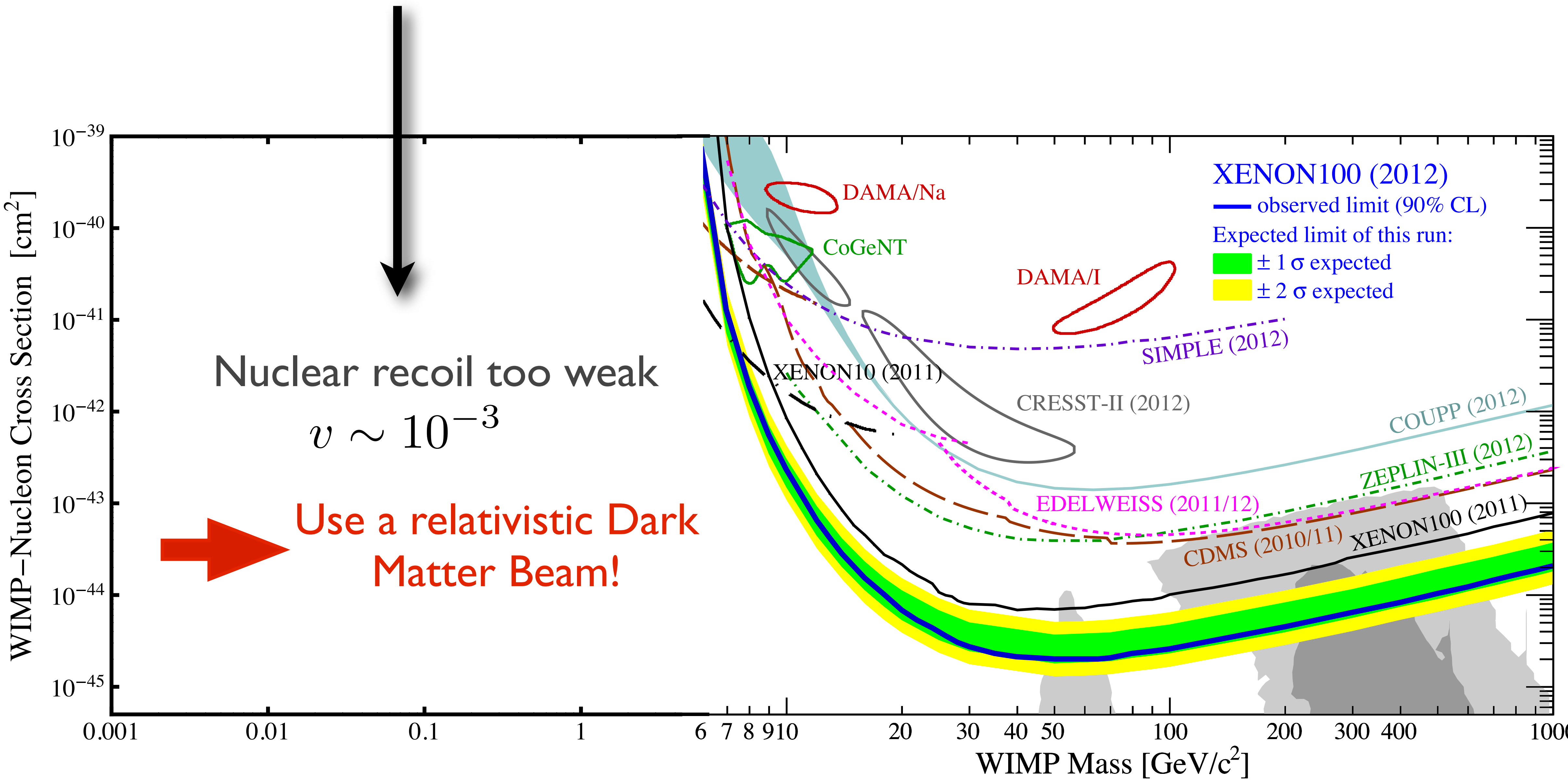
Aguilar-Arevalo et al.; arXiv:1211.2258

See also next talk by R. Van de Water

Direct Detection of Dark Matter



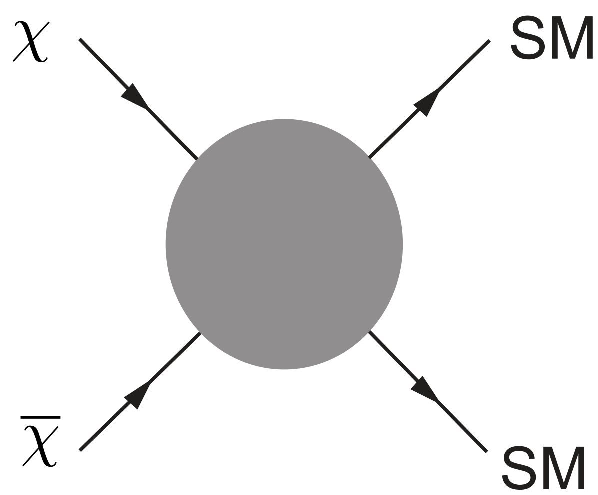
What about here?

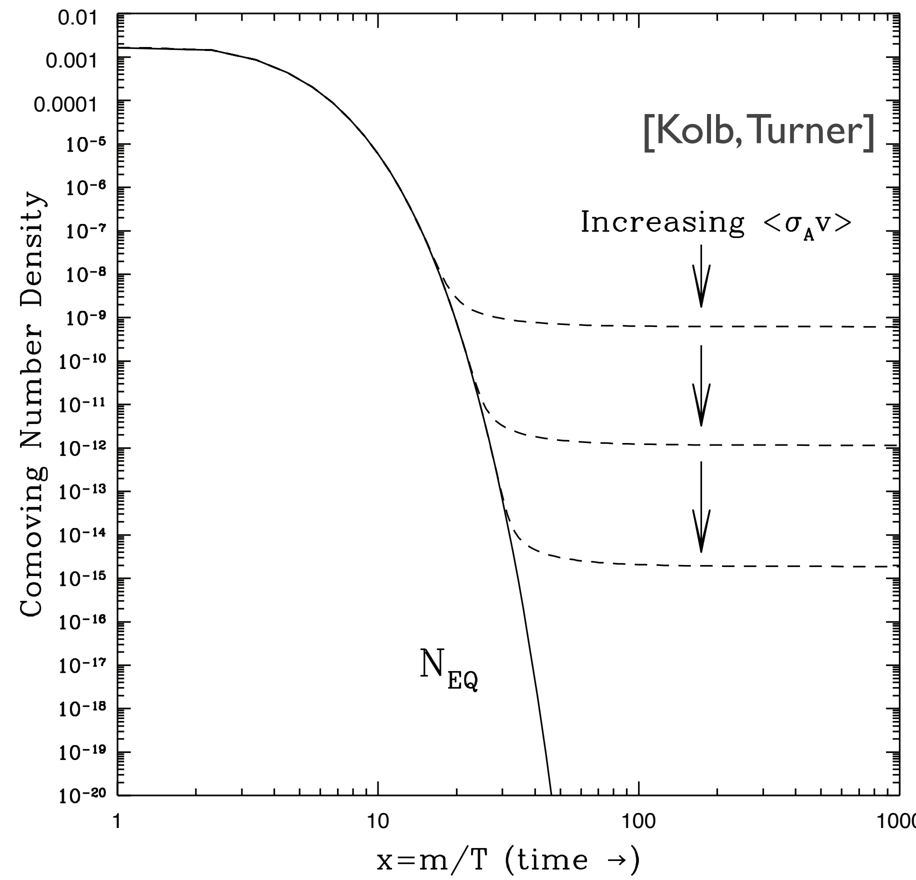


For complementary approaches to light DM, see

[Essig, Mardon, Volansky '11]
[Kahn, Thaler '12]

Light Dark Matter?





Lee-Weinberg bound: $m_\chi \gtrsim \mathcal{O}(\mathrm{GeV})$

Assumes Dark Matter annihilates via Standard Model interactions

New forces ⇨ viable light thermal relic dark matter!

A Minimal Model

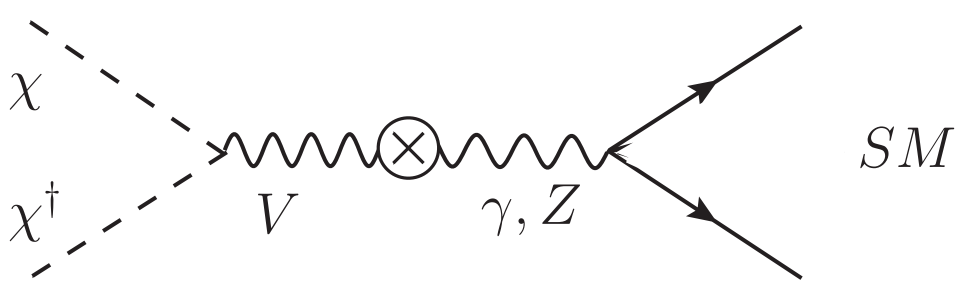
$$\mathcal{L} \supset |D_\mu \chi|^2 - m_\chi^2 |\chi|^2 - \frac{1}{4} V_{\mu\nu}^2 + \frac{1}{2} m_V^2 V_\mu^2 - \frac{\kappa}{2} B_{\mu\nu} V^{\mu\nu} + \ldots$$

$$D_\mu = \partial_\mu - i e' V_\mu$$

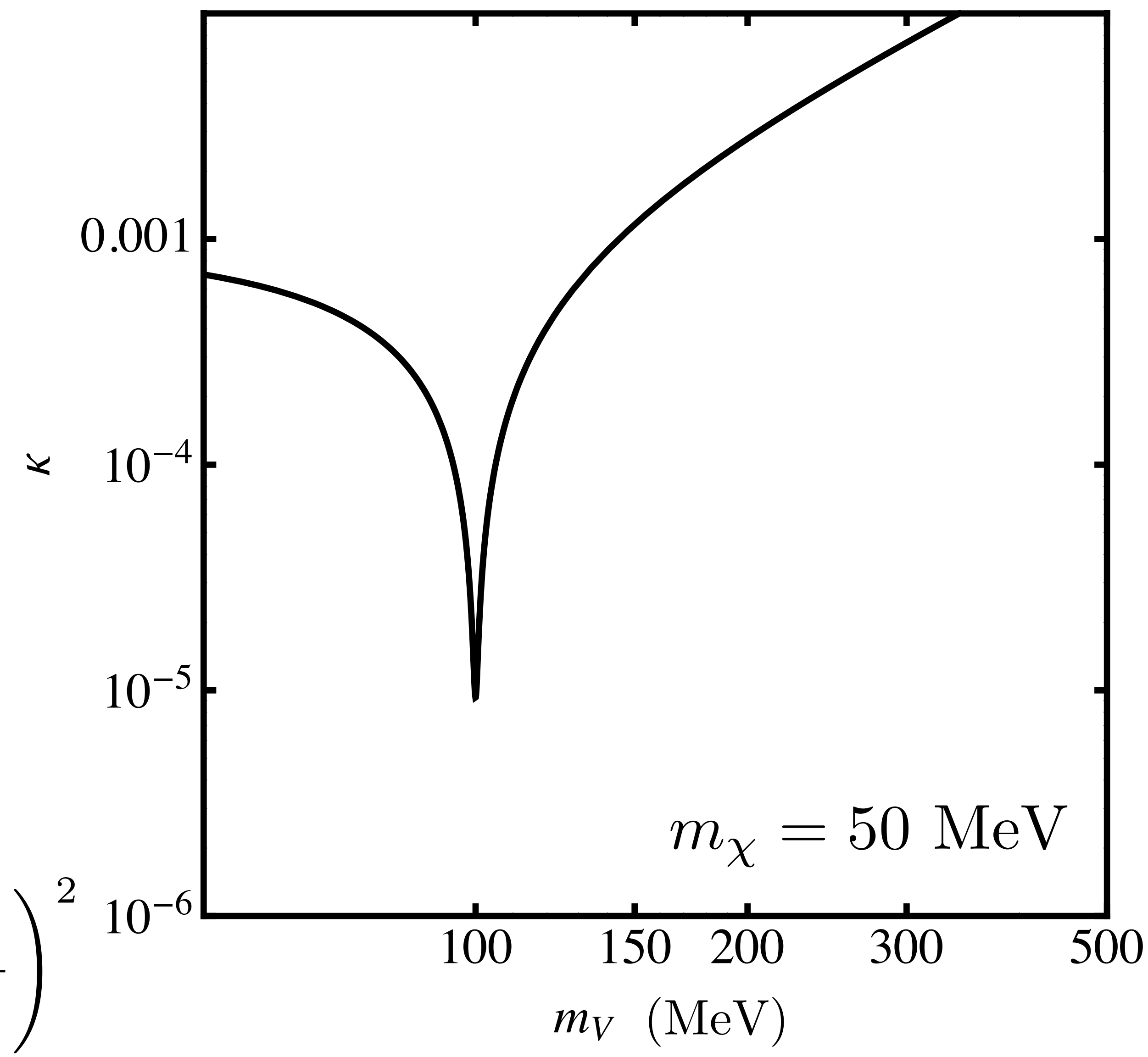
4 new parameters:

$$m_\chi, m_V, \kappa, \alpha'$$

Relic abundance fixes one relation among parameters



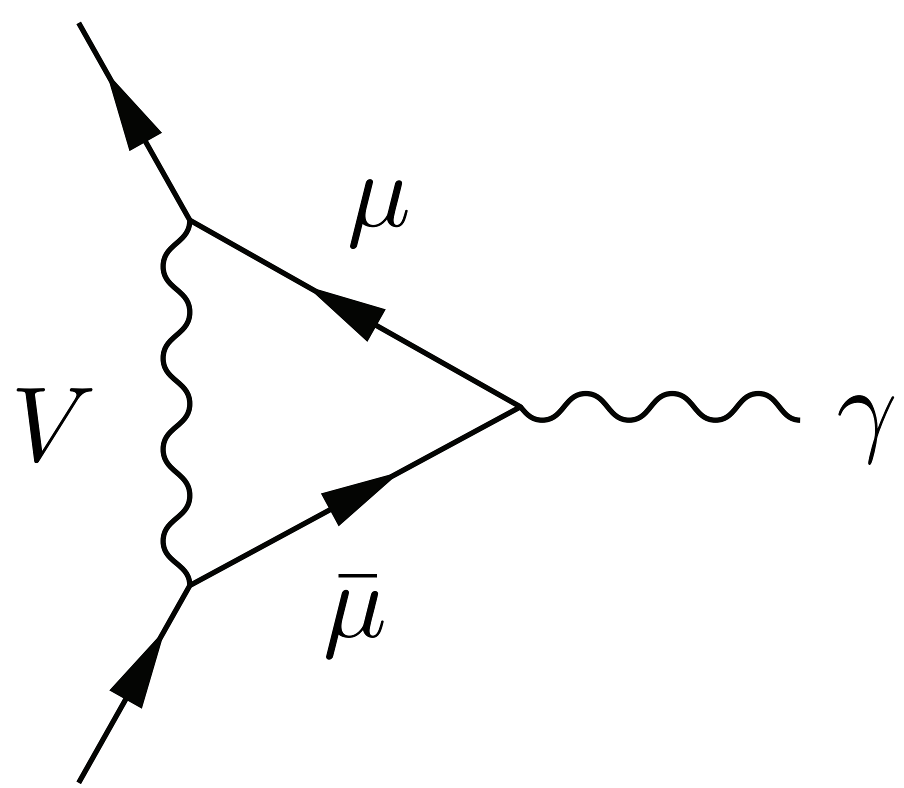
$$\langle \sigma v \rangle = 1 \text{ pb} \left(\frac{\kappa^2 \alpha'}{\alpha} \langle v^2 \rangle \right) \times \left(\frac{m_\chi}{\text{MeV}} \right)^2 \left(\frac{4 m_\chi^2}{(4 m_\chi^2 - m_V^2)} \right)^2$$

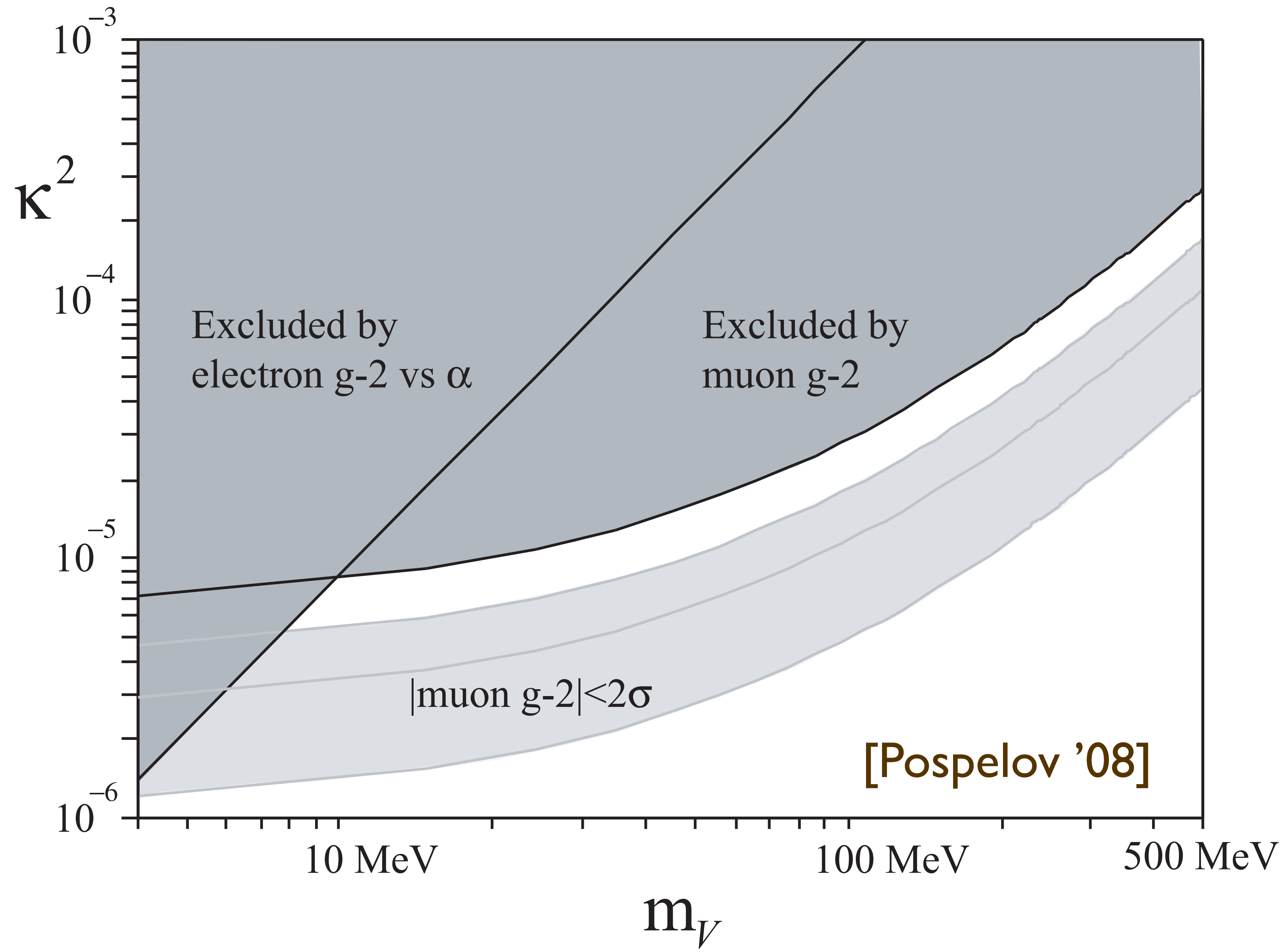


Scalar DM: p-wave annihilation (CMB ok), flavor safe - viable!

$(g-2)_\mu$ $\sim 3\sigma$ discrepancy

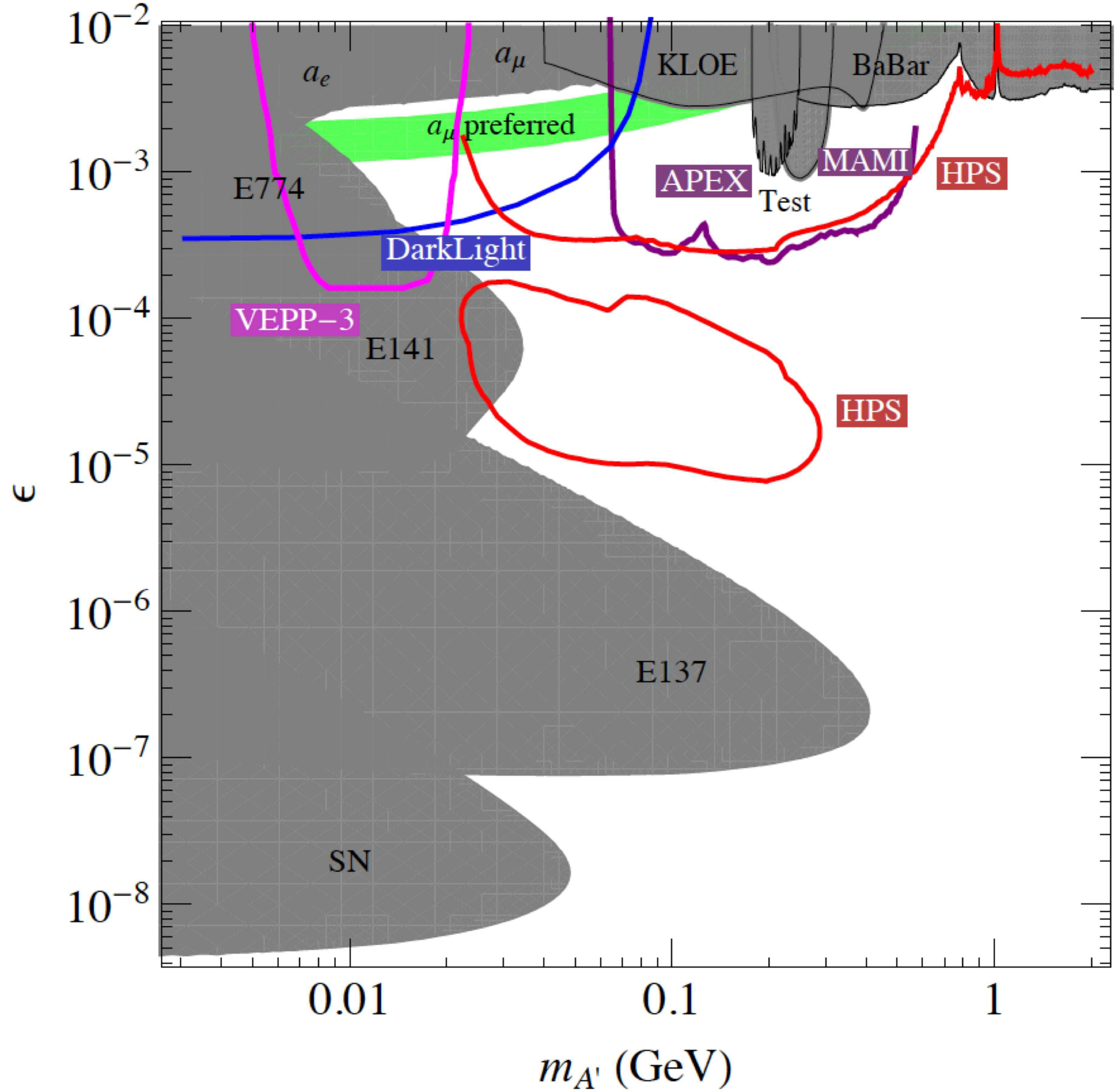
Kinetically mixed vector can help!





We will be interested in the regime $m_V > 2m_\chi$ ➡ $V \to \chi\chi^*$

Note: other regime is the "dark force" model ➡ $V \to \ell^+\ell^-$



Low Mass WIMP Searches with a Neutrino Experiment: A Proposal for Further MiniBooNE Running

Presented to the FNAL PAC Oct 15, 2012

The MiniBooNE Collaboration

R. Dharmapalan, S. Habib, C. Jiang, & I. Stancu
University of Alabama, Tuscaloosa, AL 35487

R. A. Johnson & D.A. Wickremasinghe
University of Cincinnati, Cincinnati, OH 45221

F.G. Garcia , R. Ford, T. Kobilarcik, W. Marsh,
C. D. Moore, D. Perevalov, & C. C. Polly
Fermi National Accelerator Laboratory, Batavia, IL 60510

J. Grange & H. Ray
University of Florida, Gainesville, FL 32611

R. Cooper & R. Tayloe
Indiana University, Bloomington, IN 47405

G. T. Garvey, W. Huelsnitz, W. Ketchum, W. C. Louis, G. B. Mills,
J. Mirabal, Z. Pavlovic, & R. Van de Water,
Los Alamos National Laboratory, Los Alamos, NM 87545

B. P. Roe
University of Michigan, Ann Arbor, MI 48109

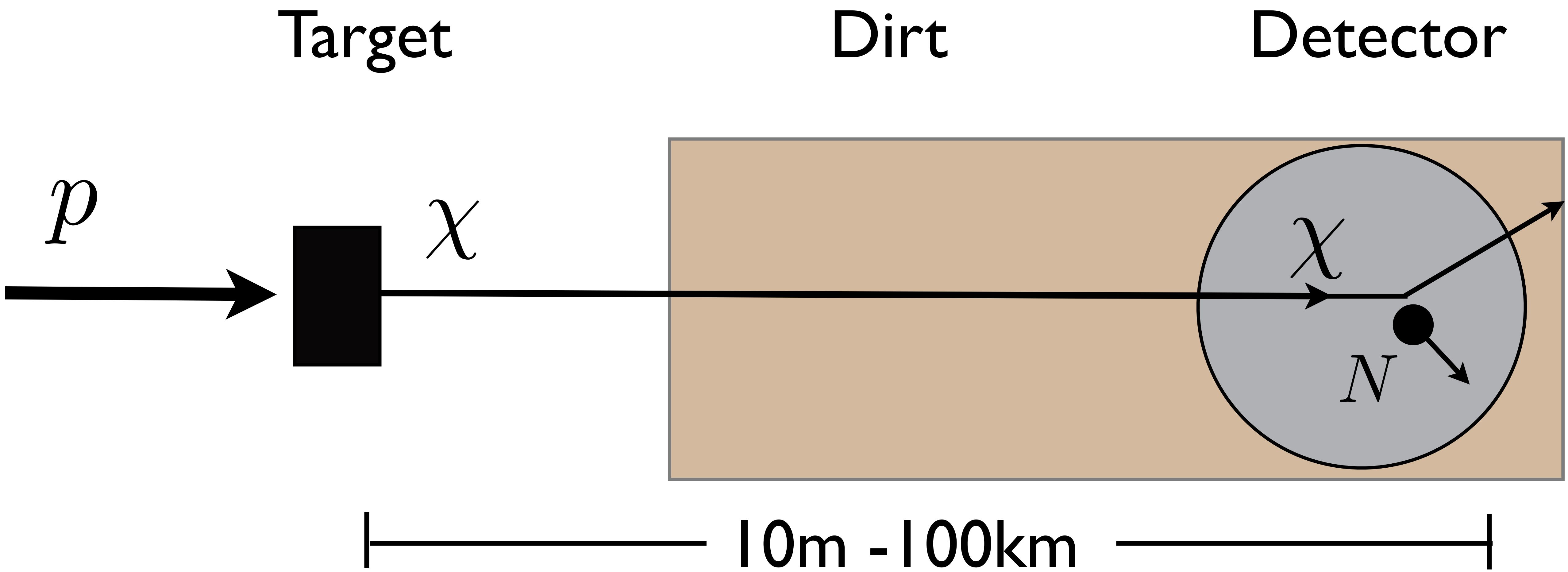
A. A. Aguilar-Arevalo
Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, D.F. México

P. Nienaber
Saint Mary's University of Minnesota, Winona, MN 55987

The Theory Collaboration

B. Batell
University of Chicago, Chicago, IL, 60637

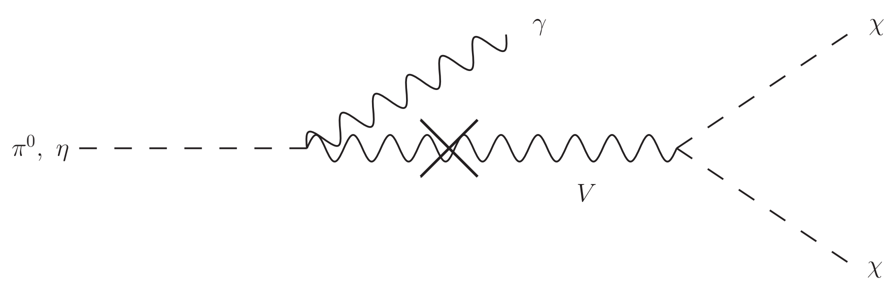
P. deNiverville , D. McKeen, M. Pospelov, & A. Ritz
University of Victoria, Victoria, BC, V8P 5C2



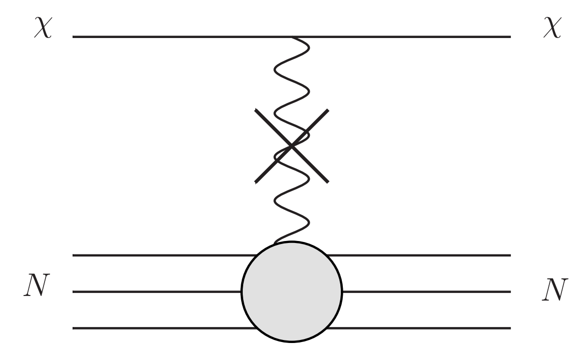
Target
Dirt
Detector
p
χ
χ
N
10m -100km

Signal event rate estimates

(production)



(detection)



$$N_{\pi^+} = \frac{\Phi_\nu A_{\rm det}}{\gamma^2 (d\Omega_{\rm lab}/4\pi)}$$

$$N_{\pi^0} \approx r_{\rm horn} \times N_{\pi^+}$$

$$N_\chi = N_{\pi^0} \times {\rm Br}_{\pi^0 \to \gamma {\rm V}}$$

$$N_{\chi,{\rm det}} = N_\chi \gamma^2 \frac{d\Omega_{\rm lab}}{4\pi}$$

$$\mathcal{L}_{\rm det} = N_{\chi,{\rm det}} n_N L_{\rm det}$$

$$N_S = \sigma_{\chi N \to \chi N} \times \mathcal{L}_{\rm det}$$

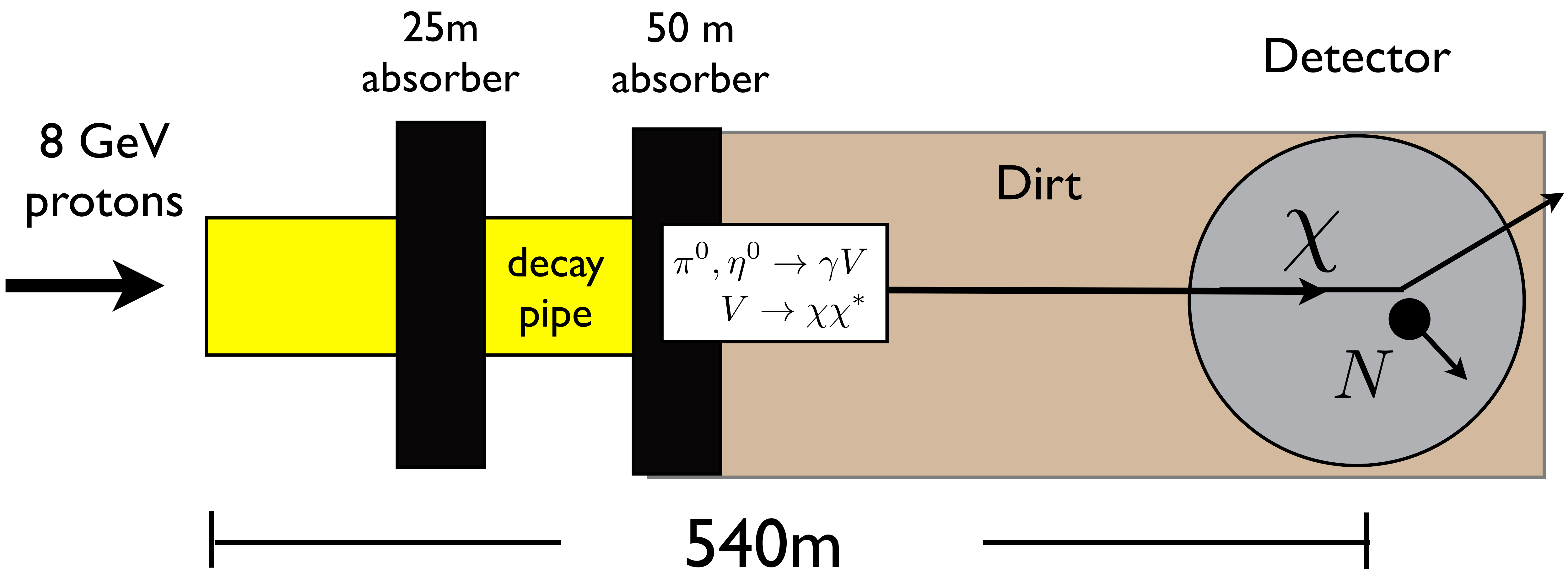
$$N_S \approx 100 \times \left(\frac{\Phi_\nu}{10^{11}\,{\rm cm}^{-2}}\right) \times \left(\frac{V_{\rm det}}{10^9\,{\rm cm}^3}\right) \times \left(\frac{r_{\rm horn}}{1/6}\right) \times \left(\frac{n_N}{10^{23}\,{\rm cm}^{-3}}\right) \times \left(\frac{\sigma_{\chi N \to \chi N}}{10\,{\rm pb}}\right) \times \left(\frac{{\rm Br}_{\pi^0 \to \gamma V}}{10^{-6}}\right)$$

Beating down the neutrino background

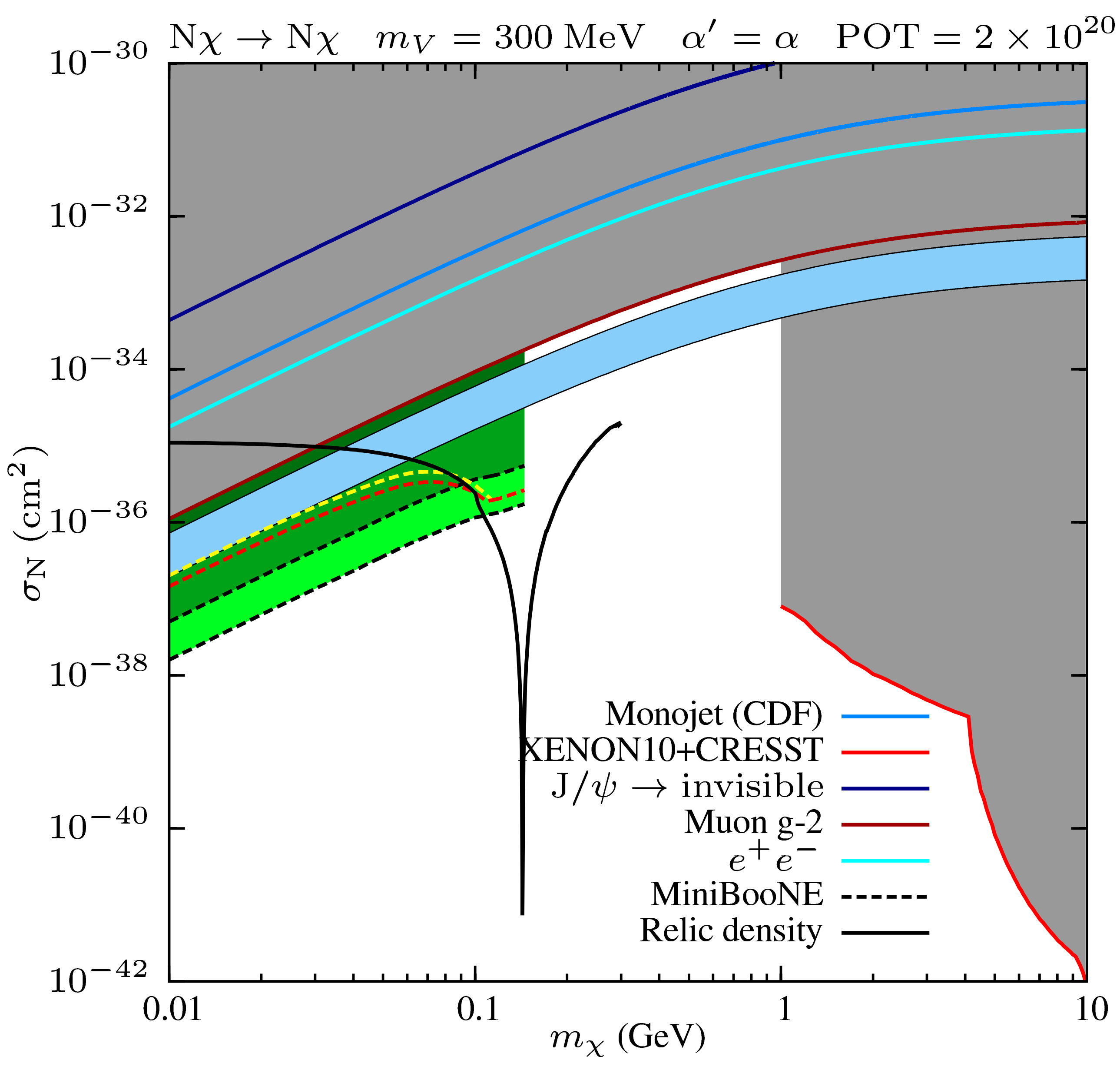
The signature of dark matter is a neutral current scattering event

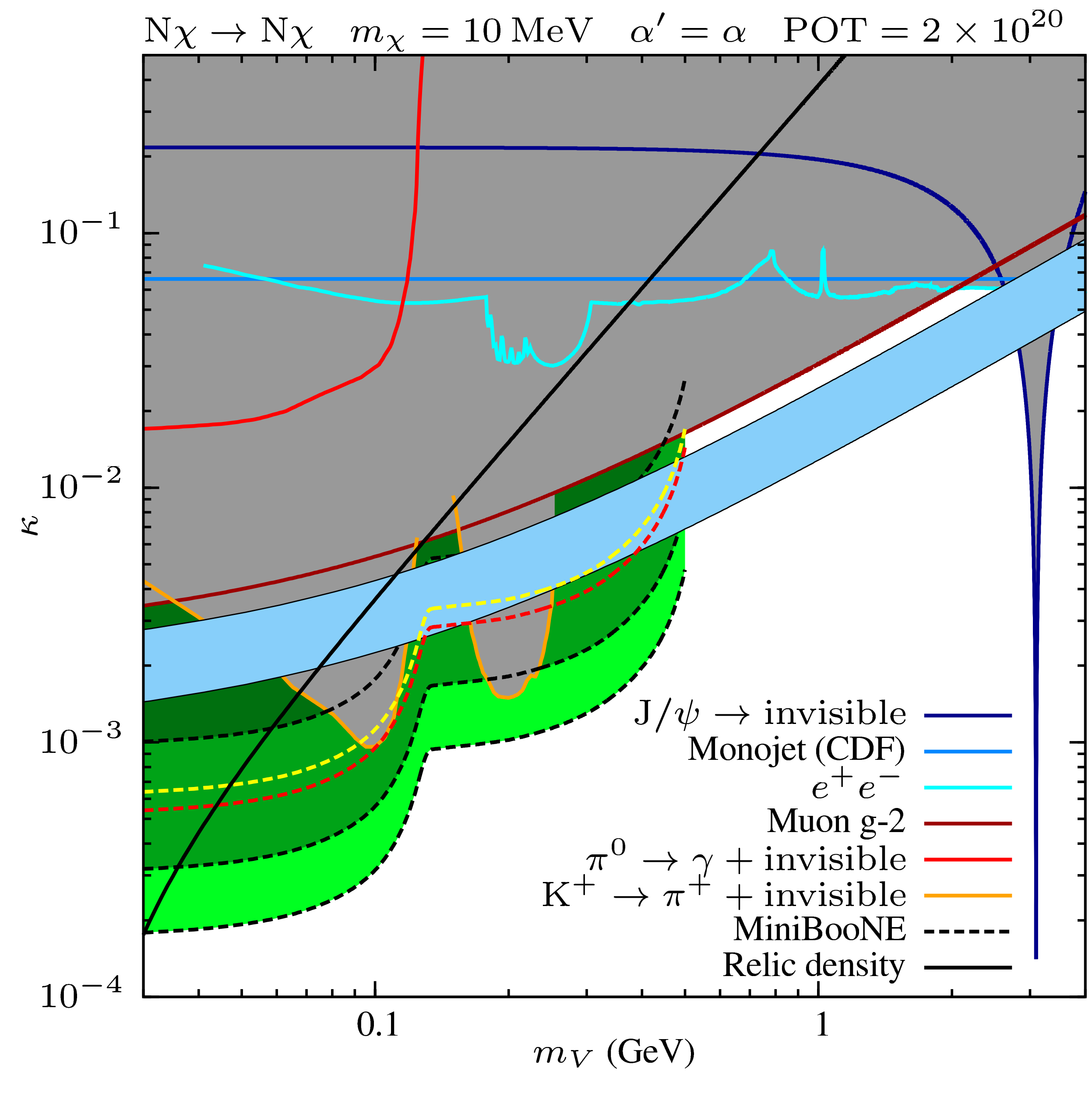
Very similar to neutrino induced neutral current event!

Focus beam onto an absorber!



Neutrino background reduced by up to 2 orders of magnitude!





See next talk by
R. Van de Water
for more details

Future searches

- How should NLWCP physics be probed with proton beams? Several levels:
  - A) Low-level: interpret existing searches from neutrino, muon, kaon, nuclear experiments.
  - B) Mid-level: suggest dedicated searches for hidden sector states/effects for neutrino, muon, kaon, nuclear experiments.
  - C) High-level: Carry out dedicated experiments to produce and detect hidden sector particles
    - Cost? Focus on beam-line? Target Detectors? Monitors? Can we make devices multi-purpose, e.g. muon & kaon facillities?

Where to gain in sensitivity?

$$\boxed{N_{\rm events} = N_{\rm prod} \times P_{\rm det}}$$

Production:

What is mass of Y?
Energy of beam?

Bigger target?

$$N_{\rm prod} = \sigma(pA \to Y\,X) \times (N_{\rm POT}\, n_T\, L_T)$$

Target type,
High Z?

Increase power?
decrease energy?

Where to gain in sensitivity?

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

Detection:

Bigger Detector?

Decay:

$$P_{\text{det}} \simeq \left[\gamma^2 \frac{\pi R_D^2}{d^2}\right] \frac{R_D}{\gamma c \tau}$$

Target type, High Z?

Closer detector?

Scattering:

$$P_{\text{det}} \simeq \sigma(YN \to YN) \times \left[\gamma^2 \frac{\pi R_D^2}{d^2}\right] \times n_D R_D$$

Project X: New high-intensity proton source

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