Searching for Light Dark Matter at Neutrino Factories

Brian Batell
The Enrico Fermi Institute
The University of Chicago

Dark Matter at the LHC
KICP, The University of Chicago

Based on:

BB, Pospelov Ritz; arXiv:0906.5614

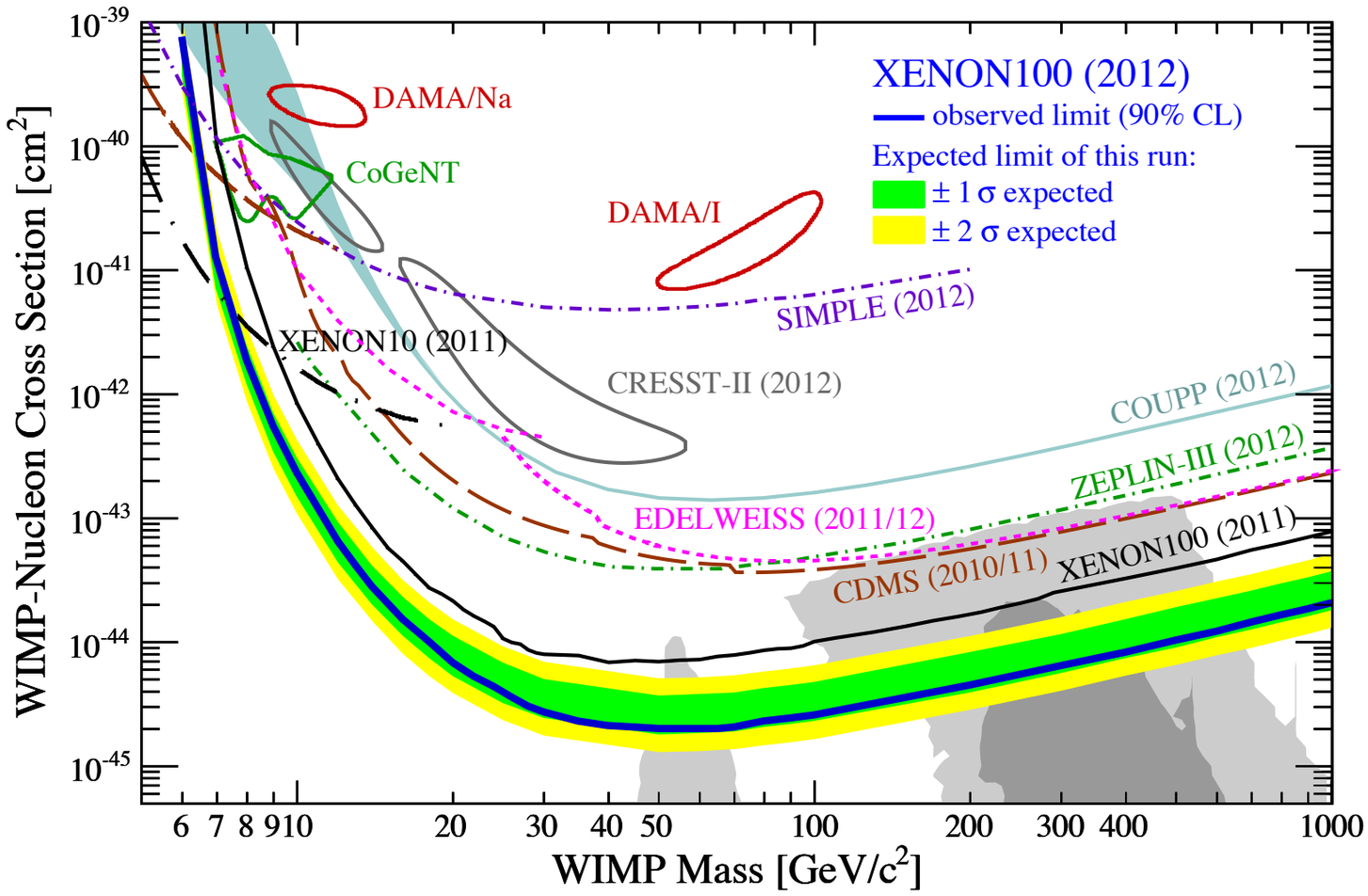
deNiverville, Pospelov, Ritz; arXiv:1107.4580

deNiverville, McKeen, Ritz; arXiv:12005.3499

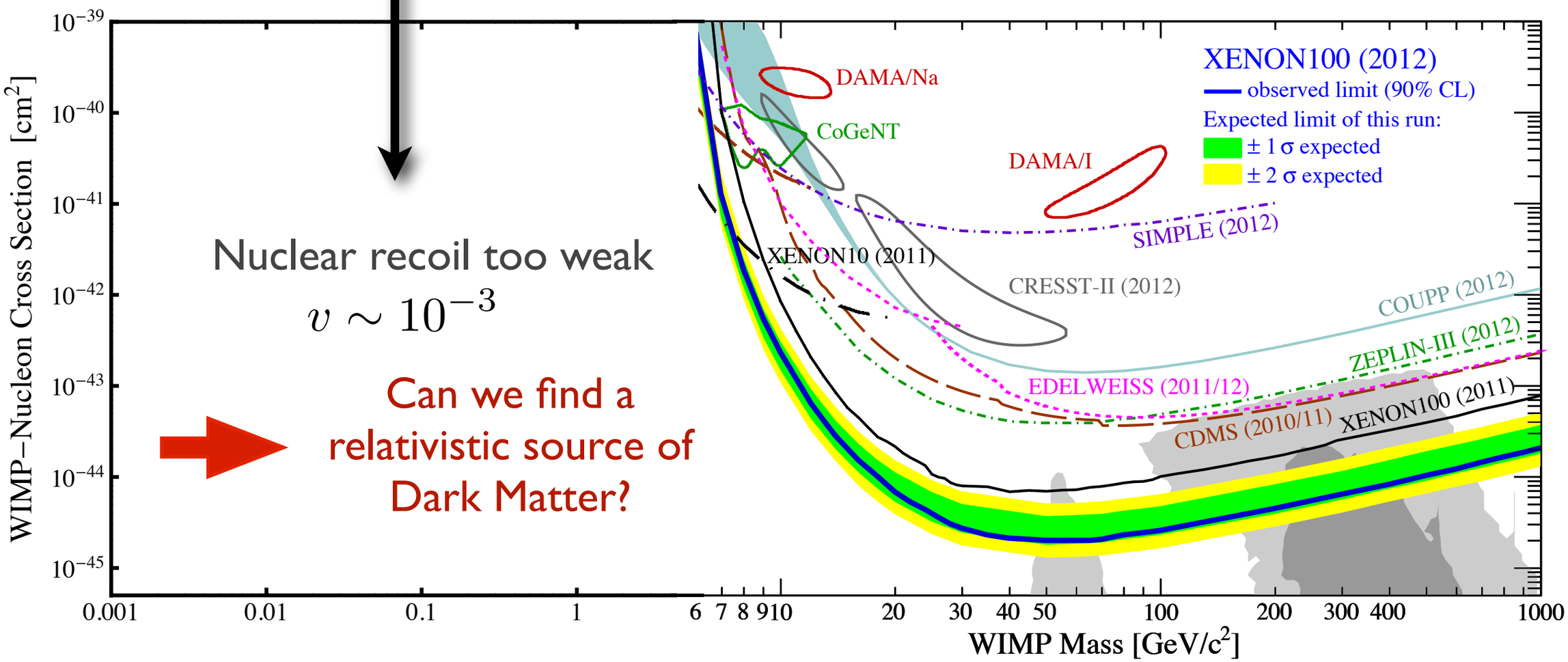
Proposal to search for light DM with MiniBooNE

Aguilar-Arevalo et al.; arXiv:1211.2258

Direct Detection

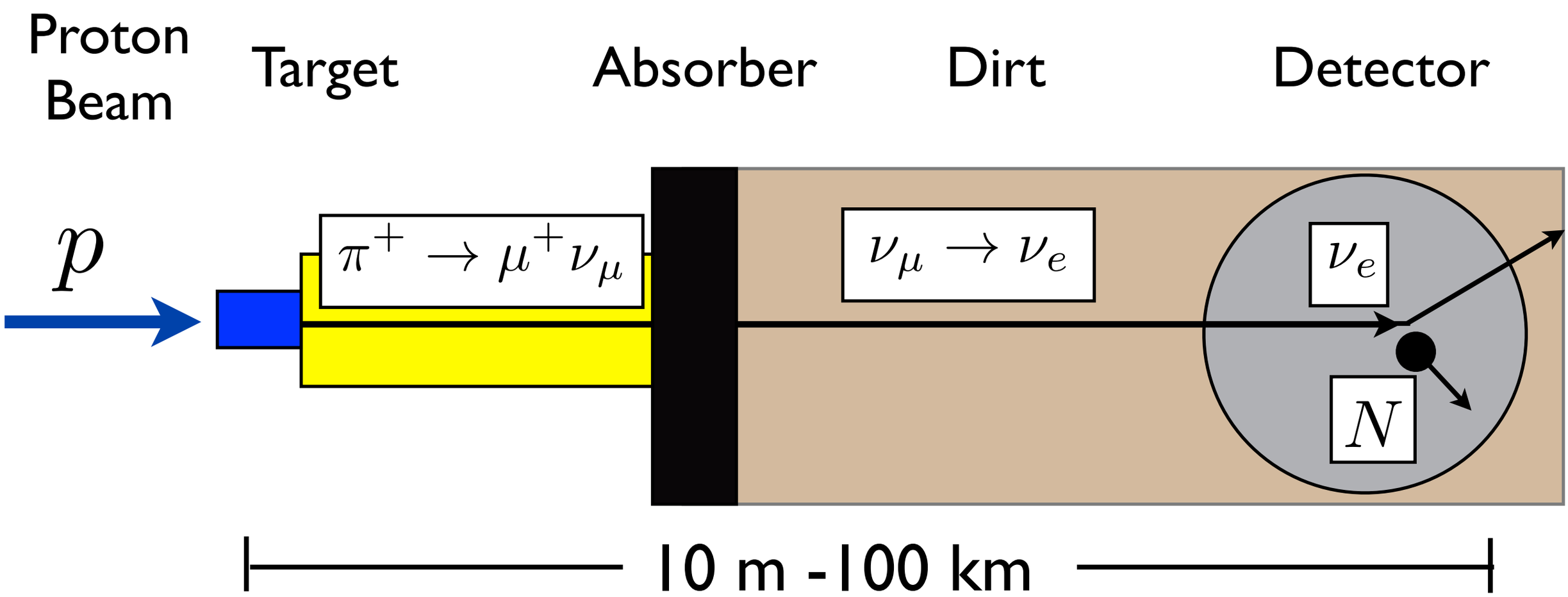


What about here?

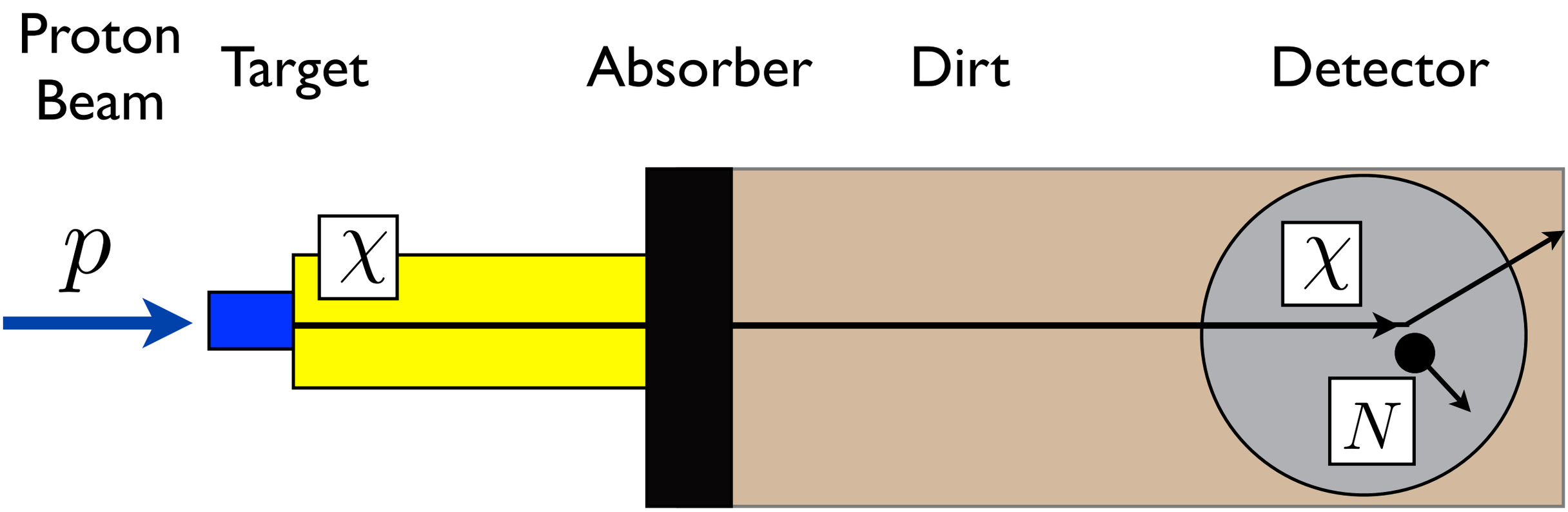


Neutrino Factories

MiniBooNE, MINOS, MicroBooNE, NOvA, T2K, LBNE, Project X, ...



A Dark Matter Beam!



[BB, Pospelov, Ritz '09]
[deNiverville, Pospelov, Ritz '11]
[deNiverville, McKeen, Ritz '12]

Experiment	proton beam energy ($\sqrt{s}$)	Near detector distance	POT
Booster/ MiniBooNE	8.9 GeV (4.2 GeV)	540 m	1.8×10^{21}
NuMi/MINOS	120 GeV (15.5 GeV)	970 m	1.6×10^{21}
J-PARC Main Ring/T2K	30 GeV (7.7 GeV)	280 m	3.0×10^{20}
CNGS/OPERA, ICARUS	400 GeV (28 GeV)	No near detector	1.7×10^{20}

Can probe DM (in principle!) up to masses O(10 GeV)

What about LHC and monojet searches?

1. Contact/Heavy Mediator

$$\frac{1}{\Lambda^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$$

$$N_\chi \sim \frac{E^2}{M^4}\mathcal{L}$$

High energy colliders,
e.g. monojet, etc.

2. Light Mediator

$$g_\chi V_\mu\bar{\chi}\gamma^\mu\chi + g_q V_\mu\bar{q}\gamma^\mu q$$

$$N_\chi \sim \frac{1}{E^2}\mathcal{L}$$

Low energy, high luminosity
Fixed Target/Beam Dumps

Cross sections and luminosity are much larger
in fixed target experiments than LHC

Why Light Dark Matter?

Dark Matter provides one of the few *empirical* hints for new dynamics

But, absolutely no empirical suggestion for the mass of the DM

A great deal of attention has been given to the WIMP

"WIMP miracle" - particle with weak scale mass, weak interactions yields the observed dark matter relic abundance

In tandem with the hierarchy problem, WIMP is a compelling picture for DM

Huge experimental effort to discover WIMP DM (e.g. Direct, Indirect, Collider...)

But so far, no new physics at LHC - perhaps DM is not at the weak scale

We must search everywhere we can for Dark Matter,
both high mass and low mass!

Why Light Mediators?

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

(Assumes DM annihilates via Standard Model interactions)

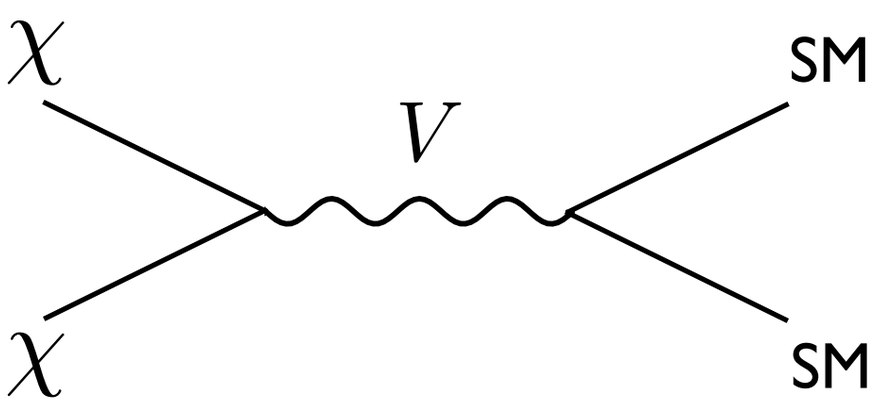
New forces ⇒ viable light thermal relic dark matter!

[Boehm, Fayet '03]

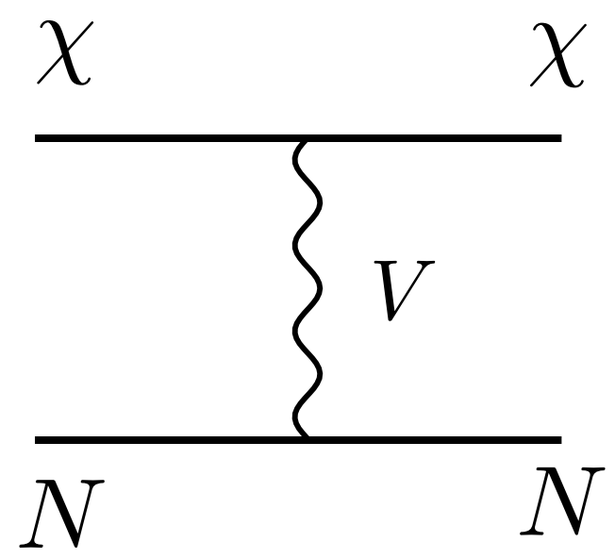
Force carriers serve dual purpose:

1. Open new annihilation channels

2. Mediate interactions with the SM

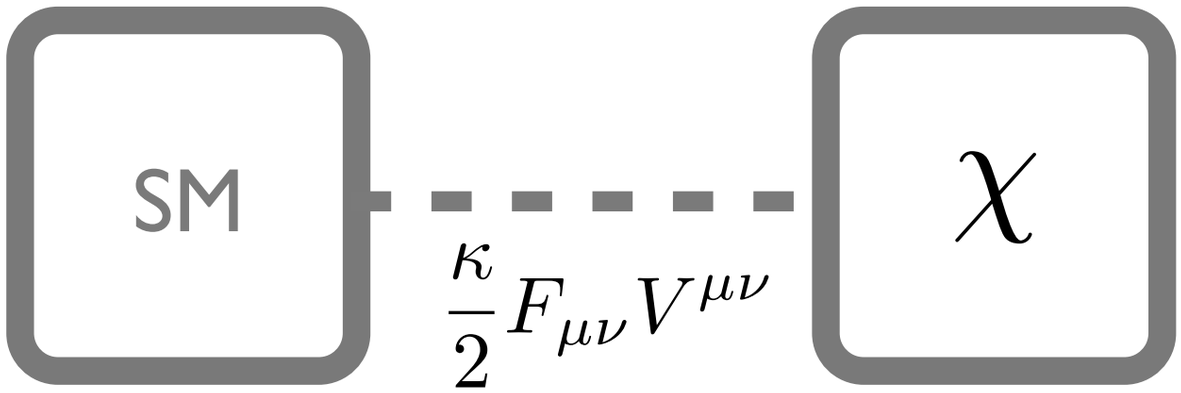


Annihilation



Scattering

A minimal vector portal model

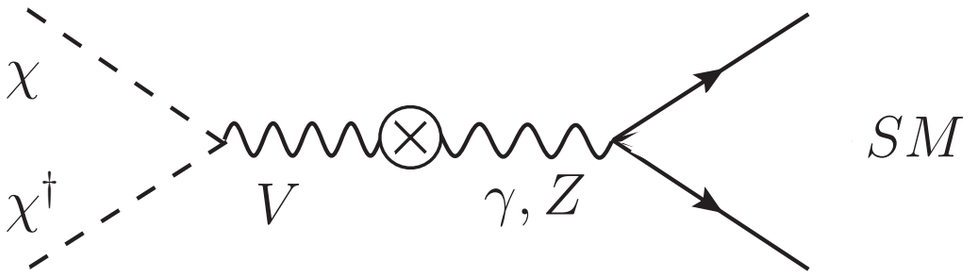


[Holdom]
[Pospelov, Ritz, Voloshin]
[deNiverville, Pospelov, Ritz]

Dark photon mediates interaction between DM and SM

4 new parameters: $m_\chi, m_V, \kappa, \alpha'$

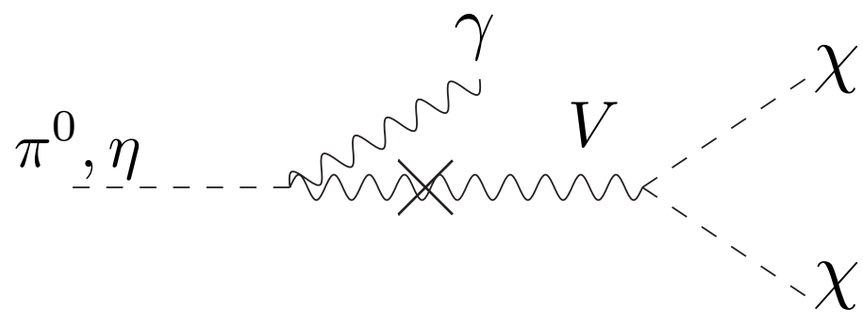
Can obtain correct relic abundance



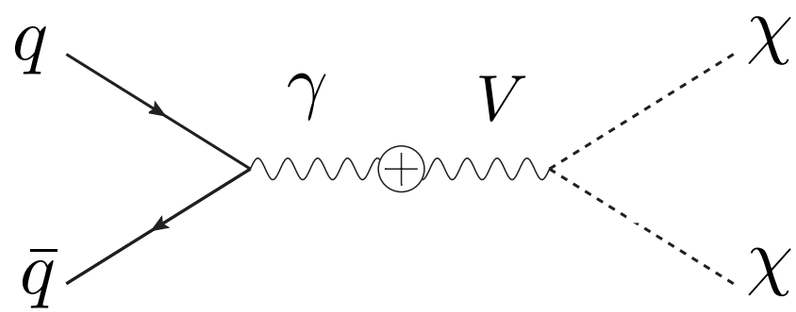
Scalar DM: p-wave annihilation, CMB ok

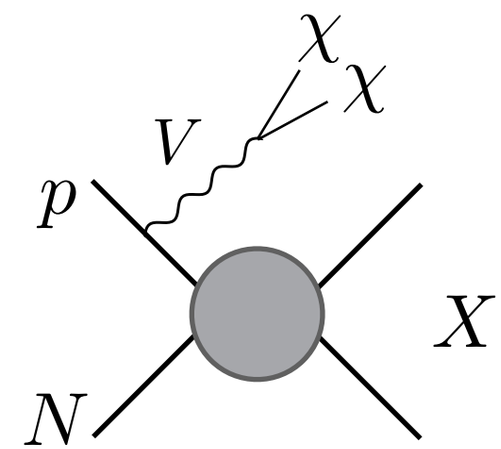
Production of the Dark Matter beam

Decays of mesons:

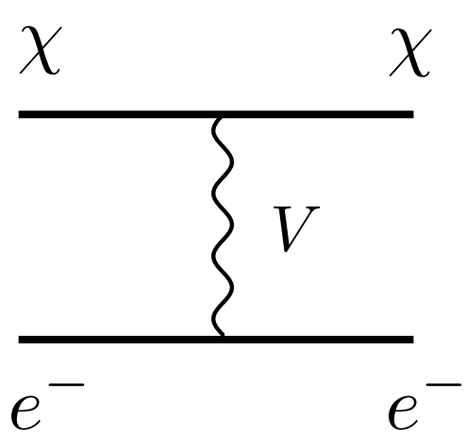


Direct production

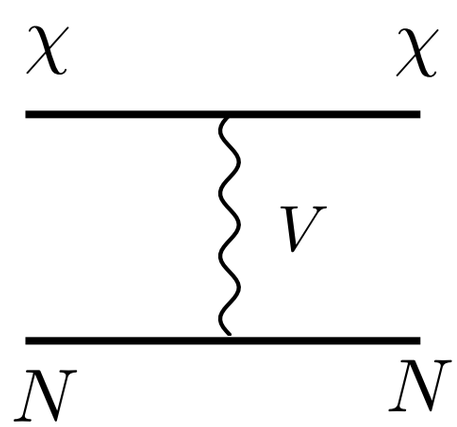




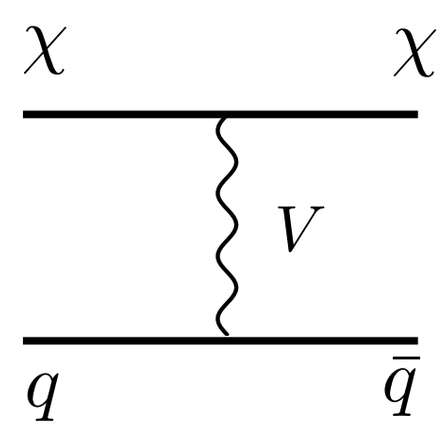
Detection via scattering



$\chi - e^-$ elastic



$\chi -$ nucleon elastic



deep inelastic

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

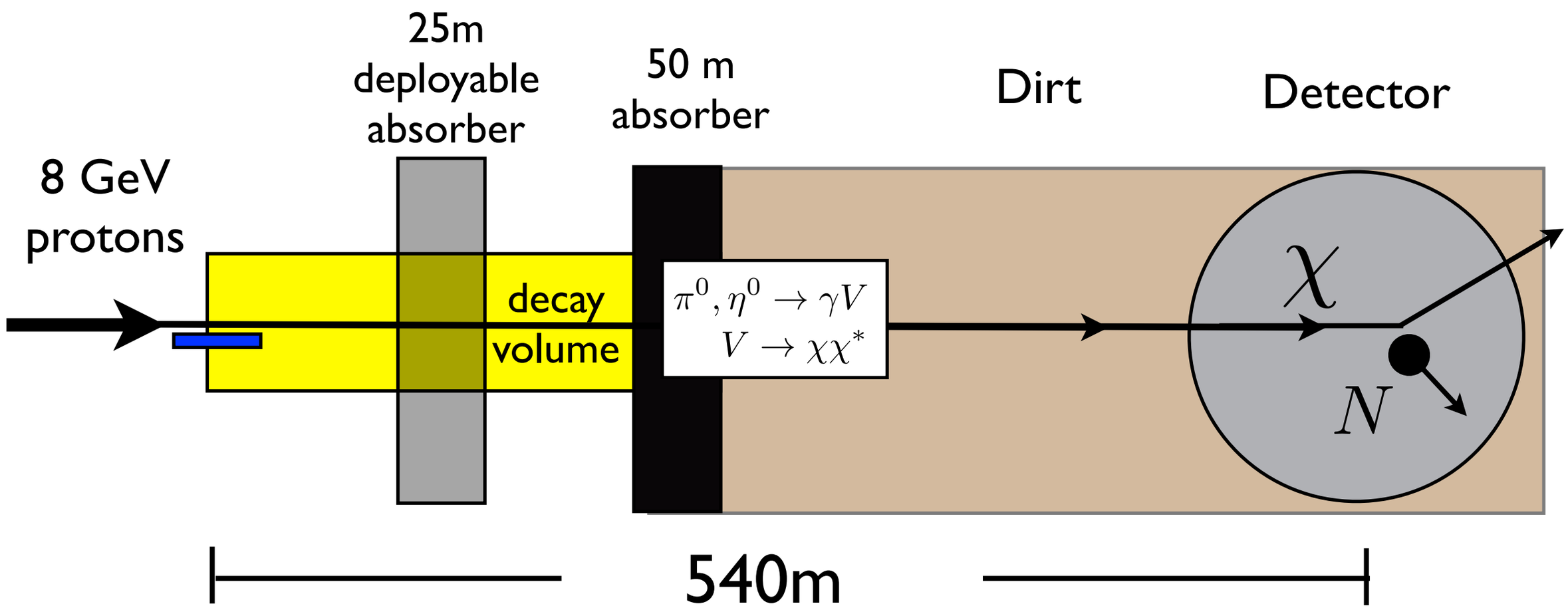
P. deNiverville , D. McKeen, M. Pospelov, & A. Ritz
University of Victoria, Victoria, BC, V8P 5C2

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!

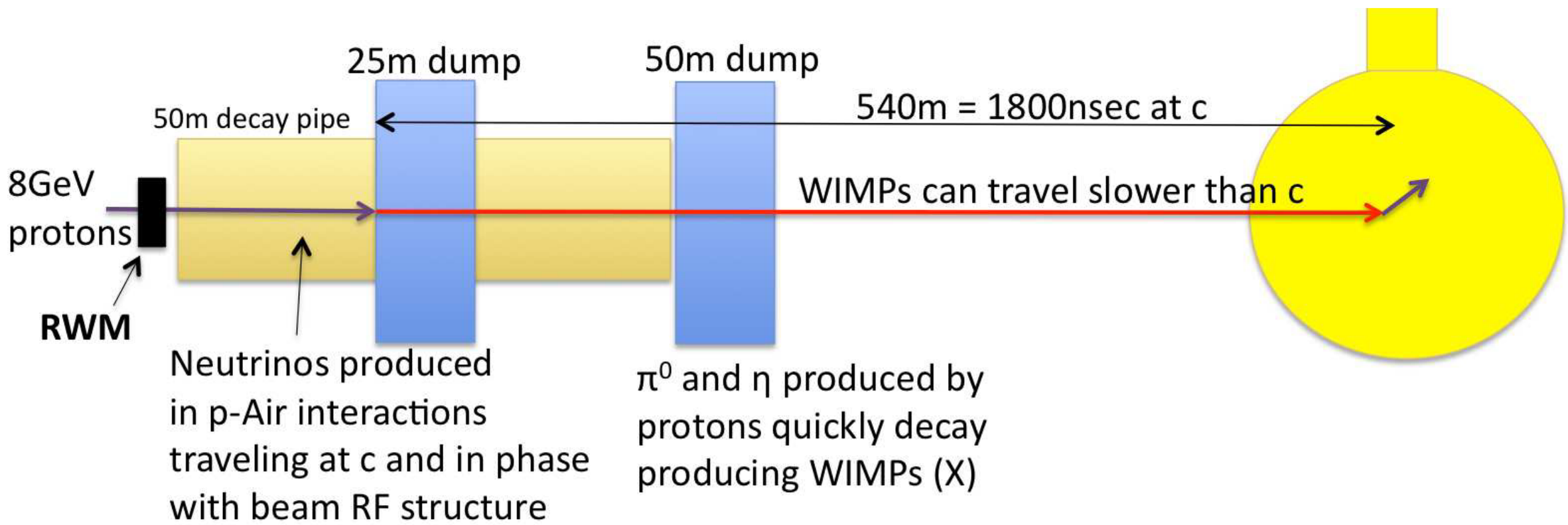


Neutrino background reduced by up to 2 orders of magnitude!

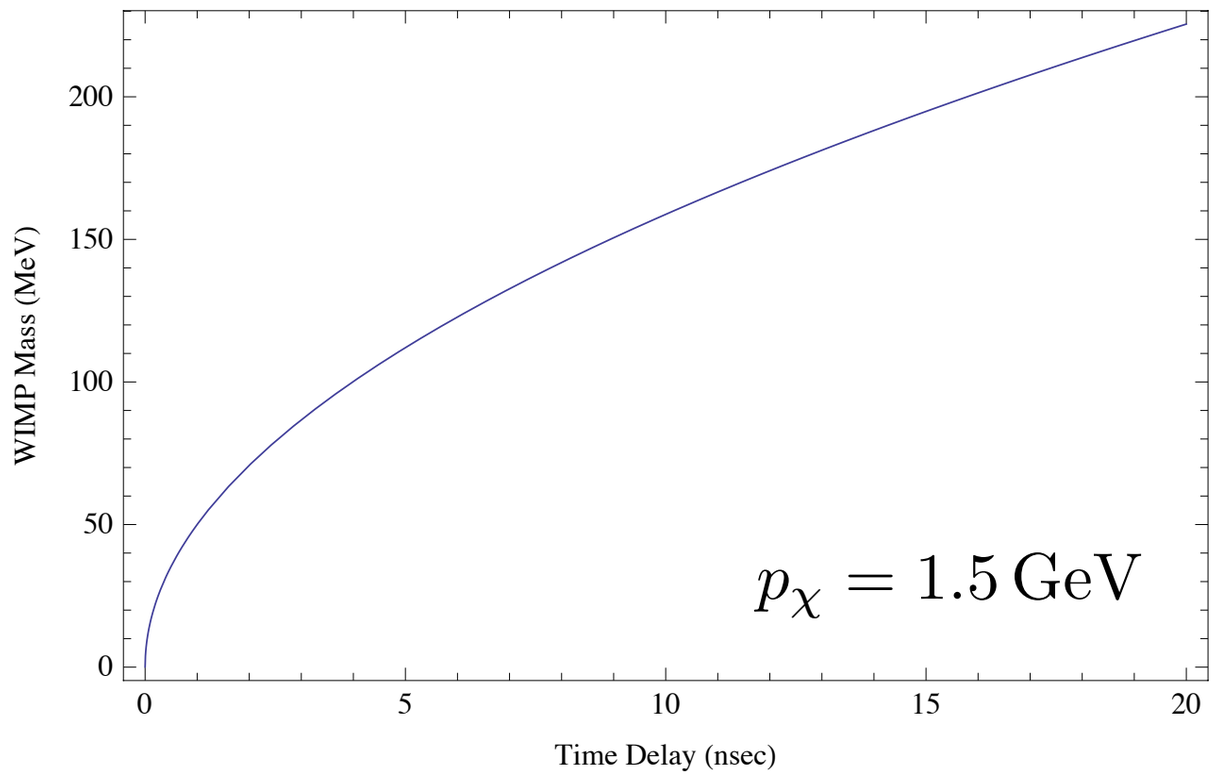
Timing

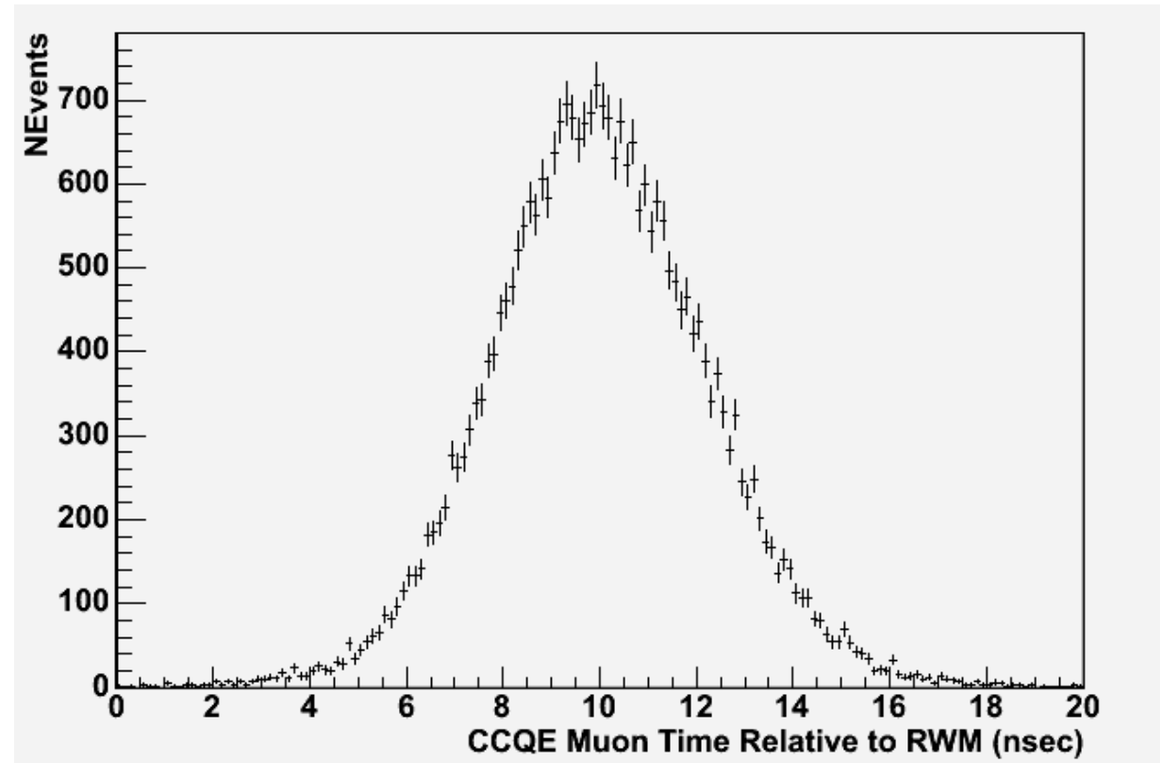
Dark matter is heavier than neutrinos - arrives at the detector later!

e.g. at MiniBooNE



Timing

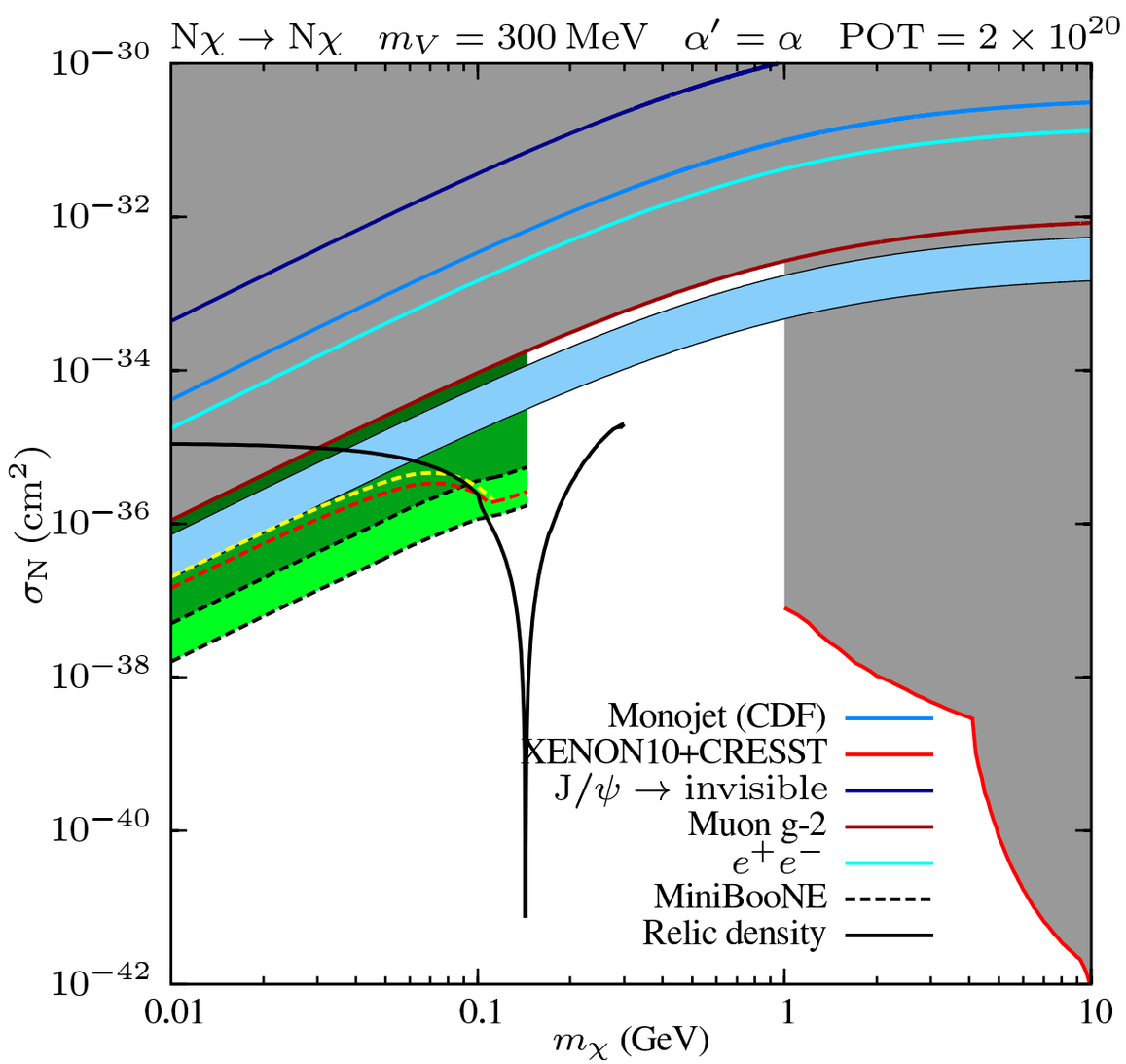


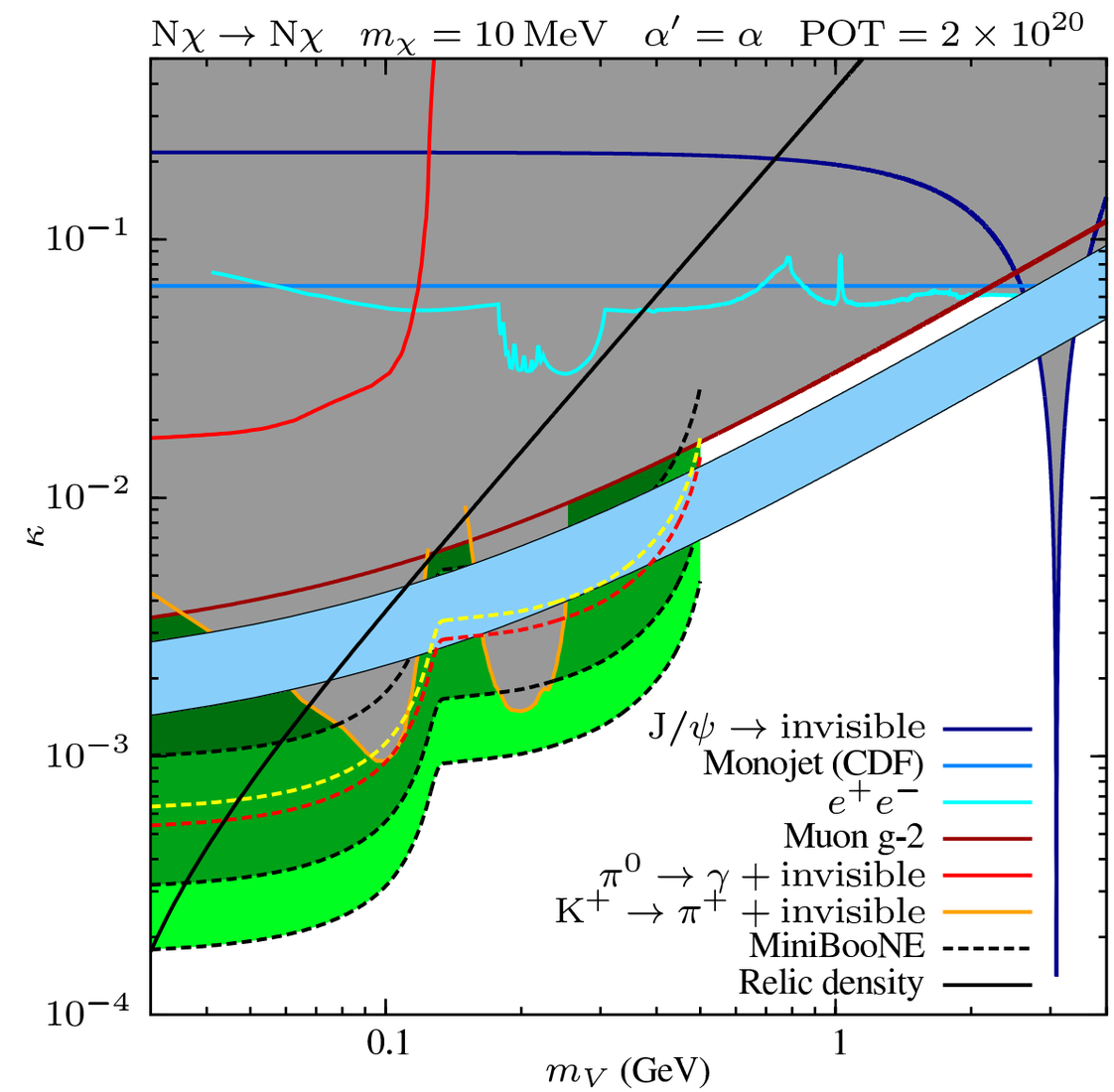


Timing cut (nsec)	Background Reduction (%)	WIMP Velocity β	WIMP Mass (MeV)
3.0	90	0.9984	85
4.6	99	0.9974	108
5.9	99.9	0.9967	122

MiniBooNE Sensitivity

[Aguilar-Arevalo et al., arXiv:1211.2258]

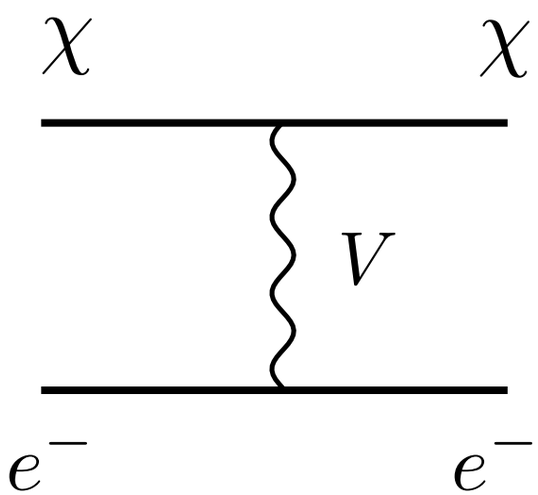


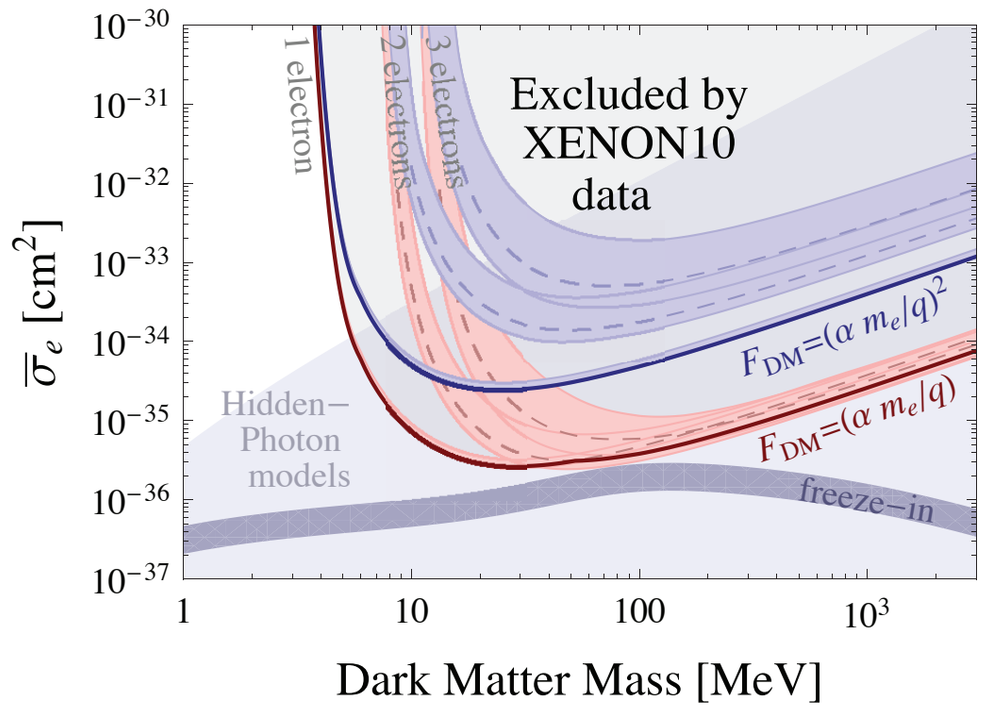


Analysis of existing dataset is underway

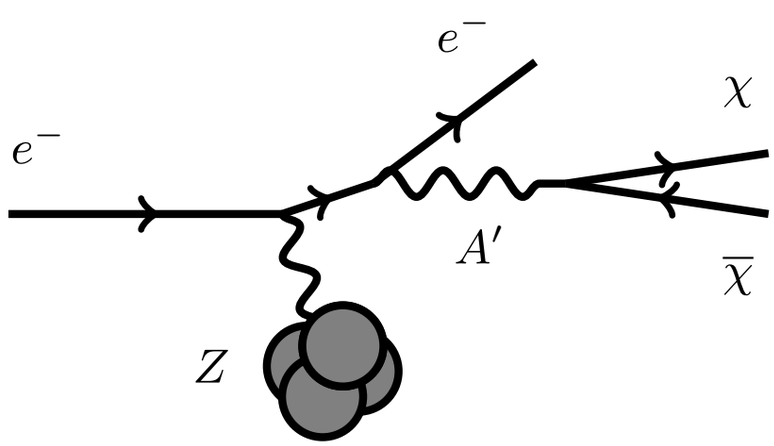
Dedicated run will start this fall!

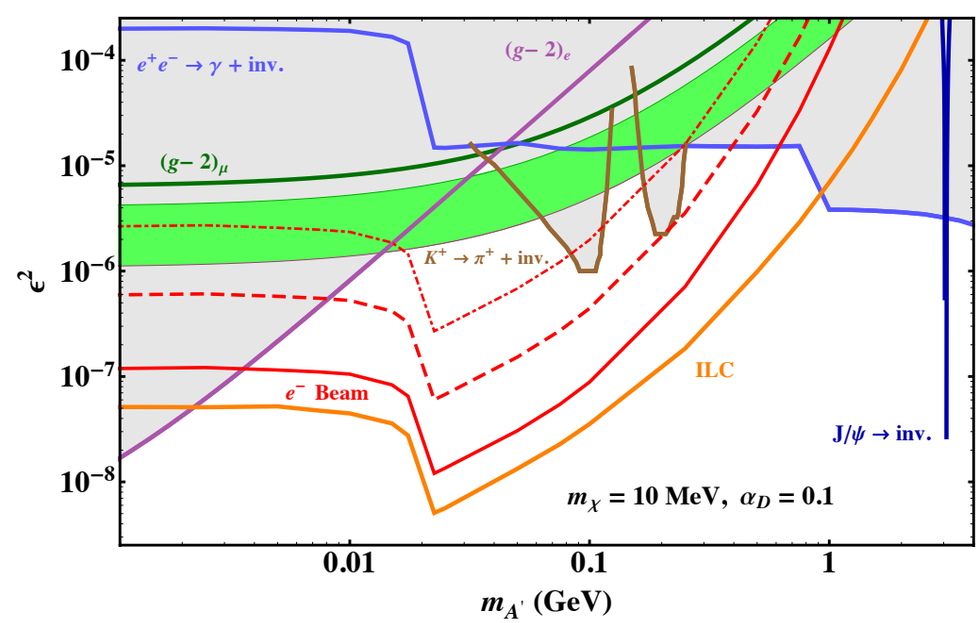
Direct Detection [Essig, Manalaysay, Mardon, Sorensen, Volansky `12]





Electron Beam Dumps [Izaguirre, Krnjaic, Schuster, Toro '13]





U.S. HEP domestic experimental program is based on intense proton beams/neutrino factories

Now: MiniBooNE, MINOS, MicroBooNE, NOvA
Future: LBNE, Project X

Search for dark matter gives another important motivation to these experiments!

Outlook

- Proton fixed target/beam dump experiments (e.g. neutrino factories) offer a new way to search for dark matter
- Complementary to traditional probes (e.g. direct detection,collider)
- First analysis is underway at MiniBooNE!
- Main obstacle is neutrino neutral current background
  - Dump, Timing, ... new ideas needed!
- Early days! Studies needed for both theory and experiment

Dark matter provides an important new motivation for these experiments! We must take advantage of this opportunity!