Searching for Sub-GeV Dark Matter at Fixed Target Neutrino Experiments

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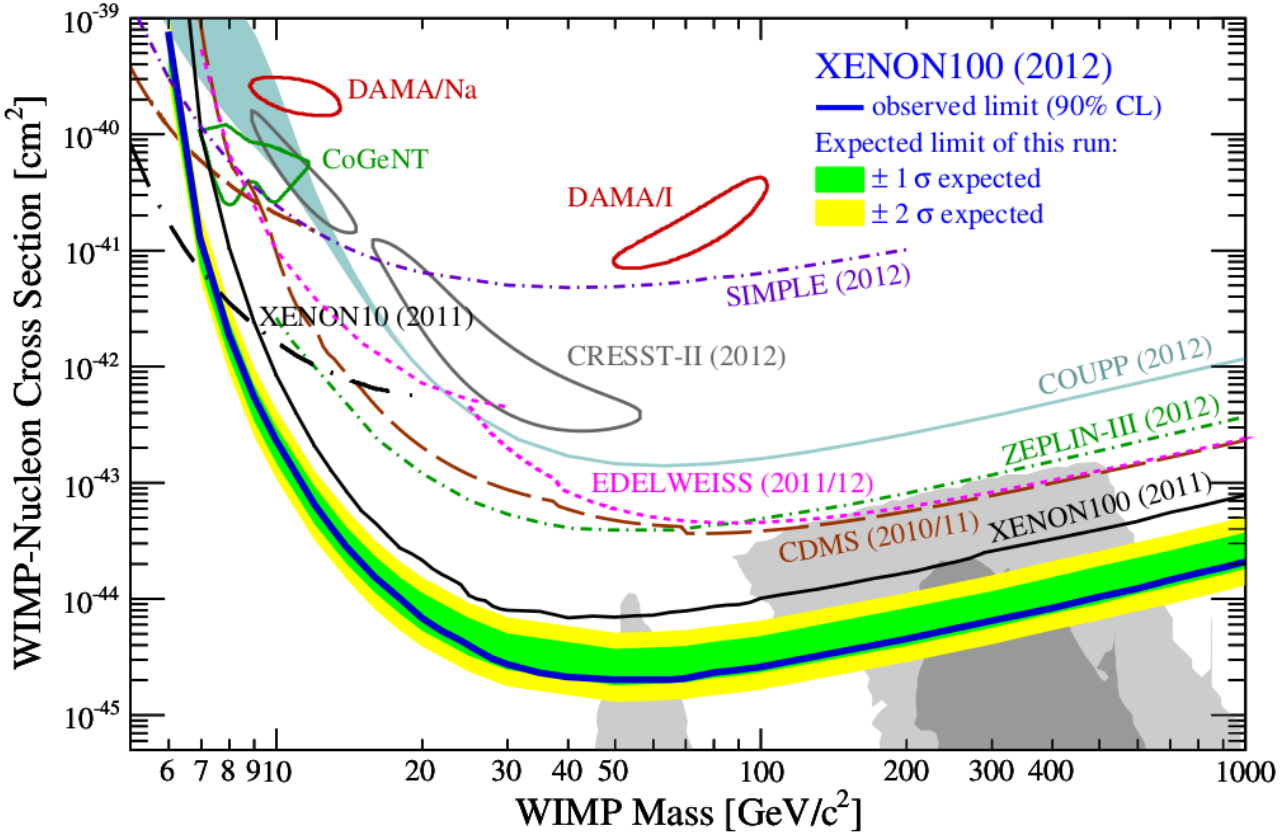
[P. dN, M. Pospelov & A. Ritz '11, arXiv: 1107.4580 [hep-ph]]
[P. dN, D. McKeen & A. Ritz '12, arXiv: 1205.3499 [hep-ph]]
[B. Batell, P. dN, D. McKeen, M. Pospelov, A. Ritz '14, to appear]

Motivation

Experimental limits for WIMP-Nucleon cross section



[XENON Collaboration 2012, arXiv:1207.5988 [astro-ph]]

A Low Mass Dark Matter Scenario

Dark sector containing scalar DM χ and vector mediator V, with $m_V > 2m_\chi$.

$$\mathcal{L} = |D_\mu \chi|^2 - m_\chi^2 |\chi|^2 - \frac{1}{4} V_{\mu\nu}^2 + \frac{1}{2} m_V^2 V_\mu^2 + g_B V_\mu J_B^\mu - \frac{\kappa}{2} V_{\mu\nu} F^{\mu\nu} + \ldots$$

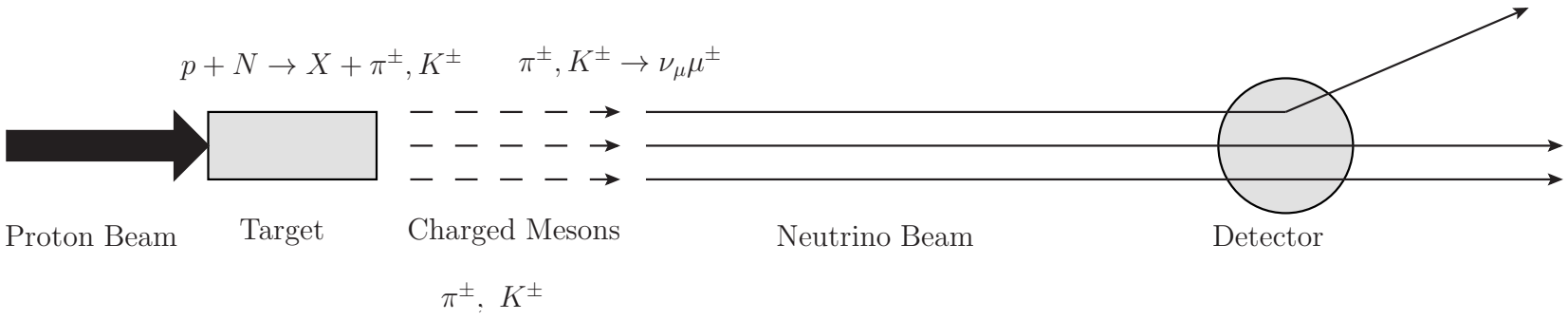
$$D_\mu = \partial_\mu - i g_B q_B V_\mu = \partial_\mu - i e' V_\mu$$

- Dark vector mediator interacts with SM through kinetic mixing with photon, coupling to baryonic current, or some combination of the two.

$$\mathcal{L} \supset V_\mu \left(g_B J_B^\mu - \kappa e J_{EM}^\mu \right)$$

- Five free parameters: m_χ, m_V, κ, g_B and e'.
  - ${e'}^2 = 4\pi\alpha'$ when we consider only kinetic mixing.
  - ${e'}^2 = 4\pi\alpha_B$ when we add coupling to baryons.

Fixed Target Neutrino Experiments

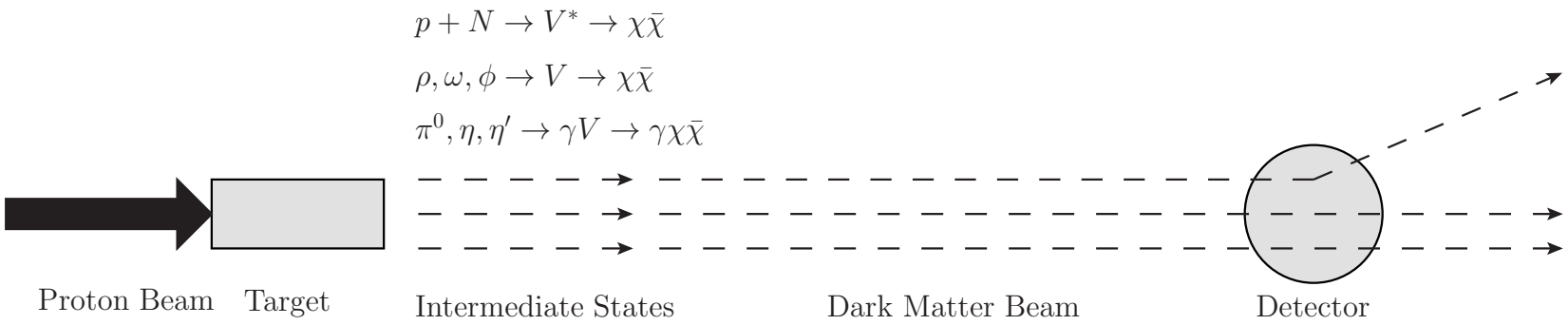


- Experiments involve impacting a target with $\sim 10^{20} - 10^{22}$ protons to produce a high intensity neutrino beam.
  - Neutrinos produced from decays of charged mesons.
  - Can select for neutrino or antineutrino beams through the use of magnetic focusing horns.
- Non-neutrinos are removed from the beam before it reaches the target to reduce background.
- Several fixed target neutrino experiments were investigated: LSND, MiniBooNE, T2K.

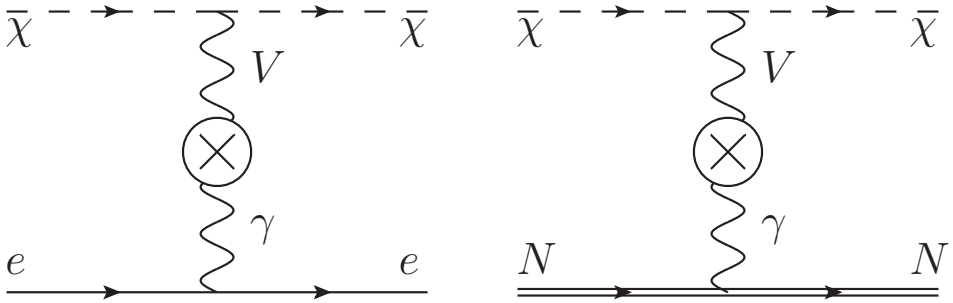
Dark Matter Beams

Production of a dark matter beam through:

- Radiative decays of pseudoscalar mesons: π^0, η, η'.
- Coupling to vector mesons: ρ, ω, ϕ.
- Direct parton-level production: $p + N \to V^* \to \chi\bar{\chi}$



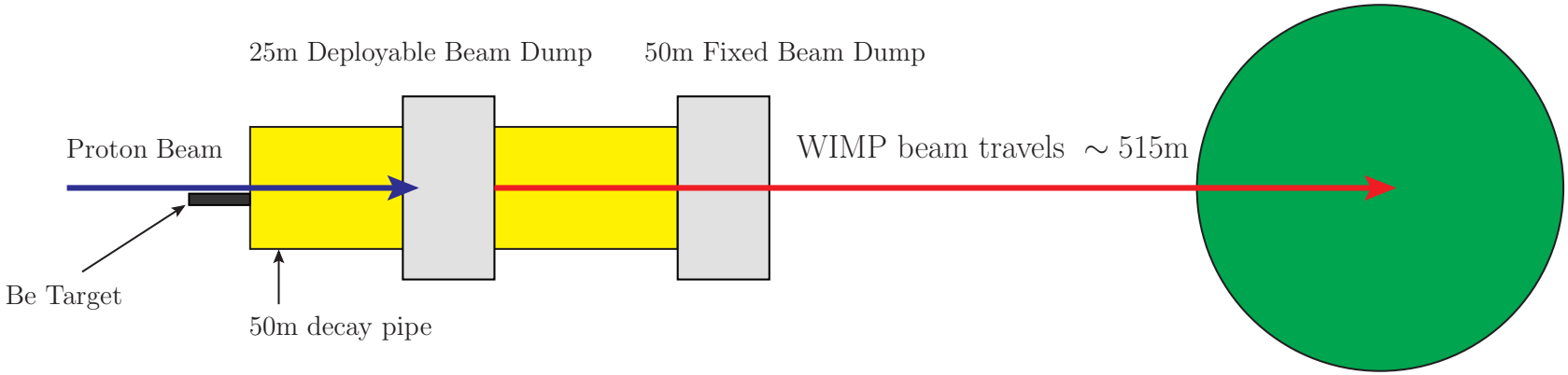
Detection through NCE scattering off electrons or nucleons. Very similar to neutrino NCE scattering.



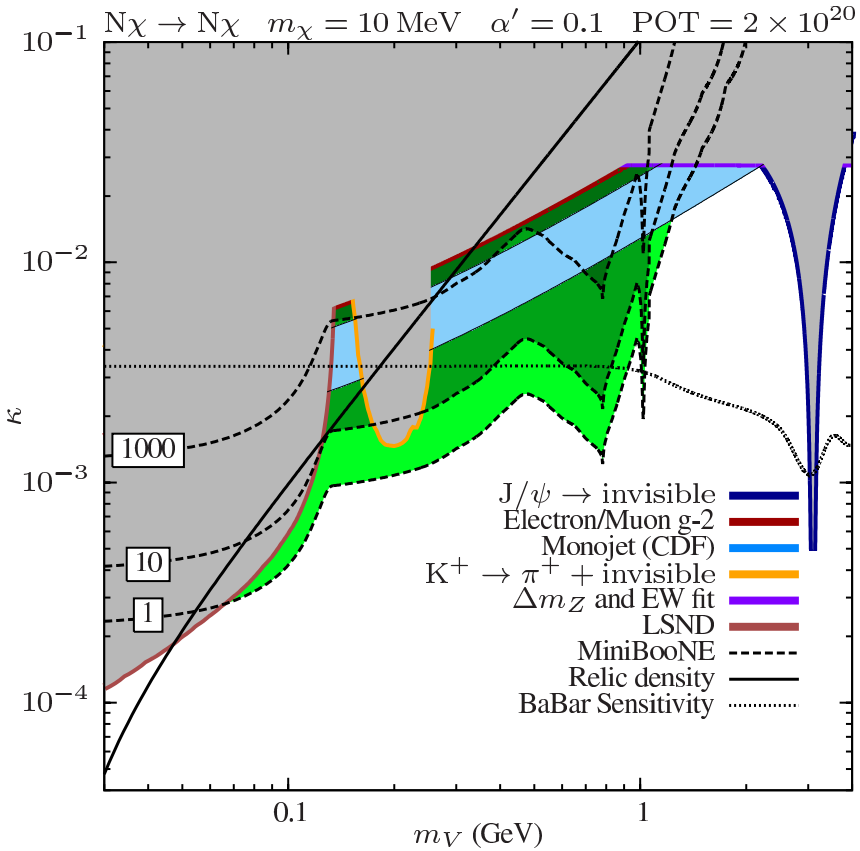
Reducing Backgrounds: The MiniBooNE Off-Target Run

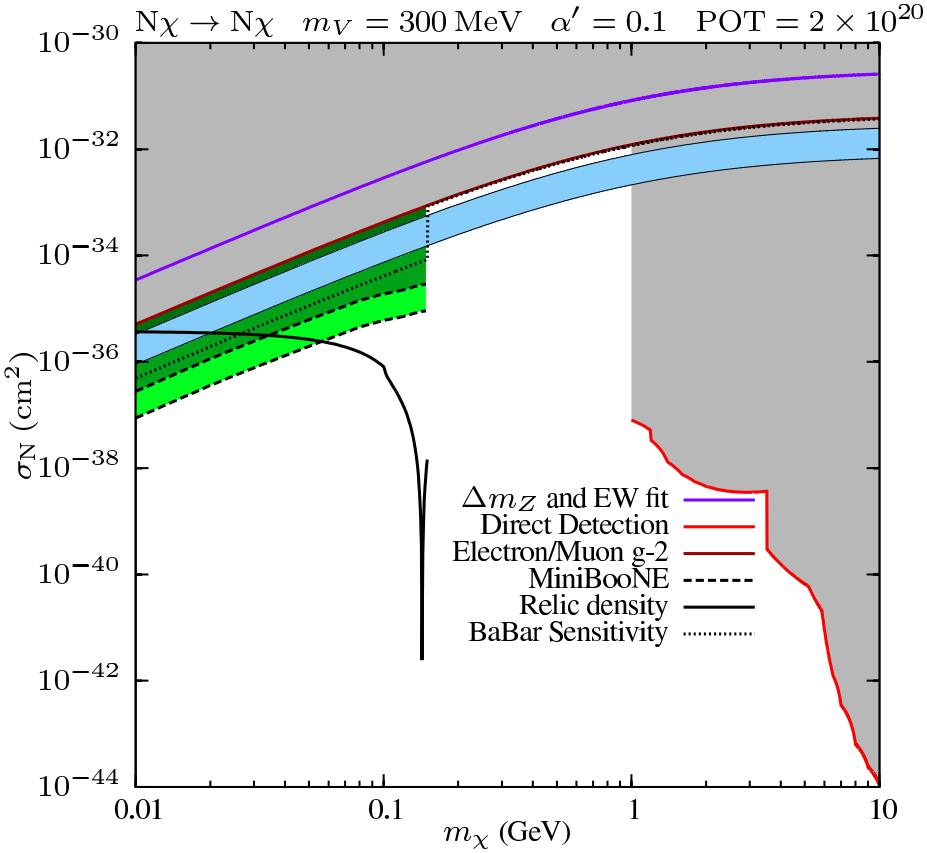
Neutrinos provide the primary background in these searches.

- Can discriminate between neutrinos and dark matter by differences in their timing, energy, and angular distributions.
- Neutrino production can be dramatically reduced by performing an off-target or beam dump run.
  - Unfortunately not compatible with neutrino running.
- The MiniBooNE experiment is currently conducting such a run, expects to collect 1-2$\times 10^{20}$ POT (PAC proposal [arXiv:1211.2258v1, with R. Van de Water]).



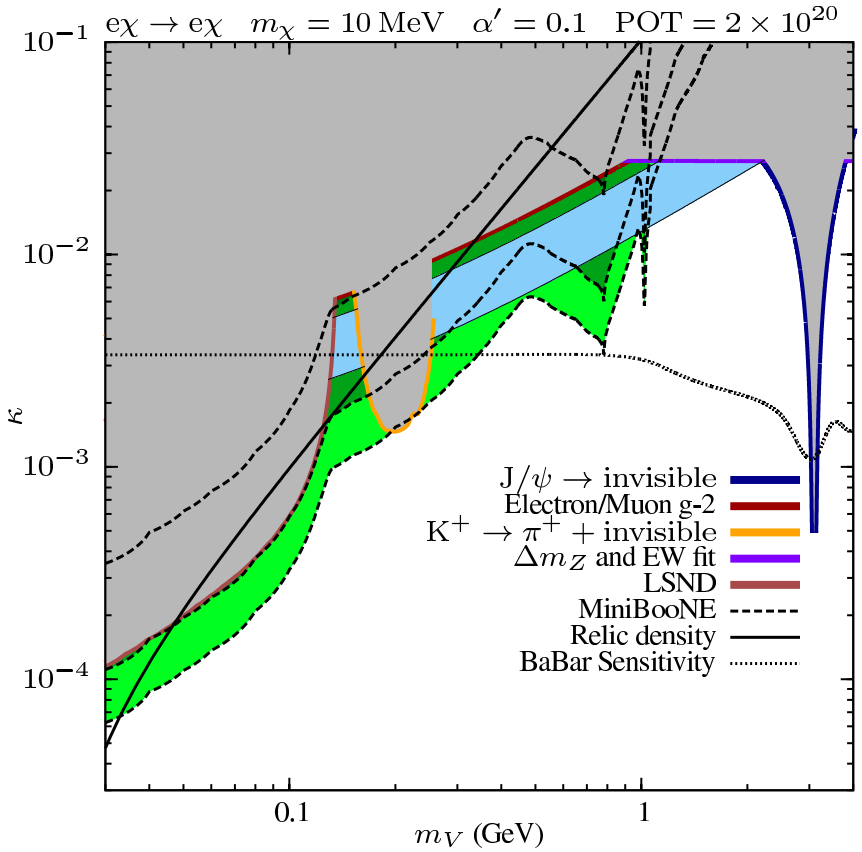
MiniBooNE Kinetic Mixing - $\chi N \to \chi N$

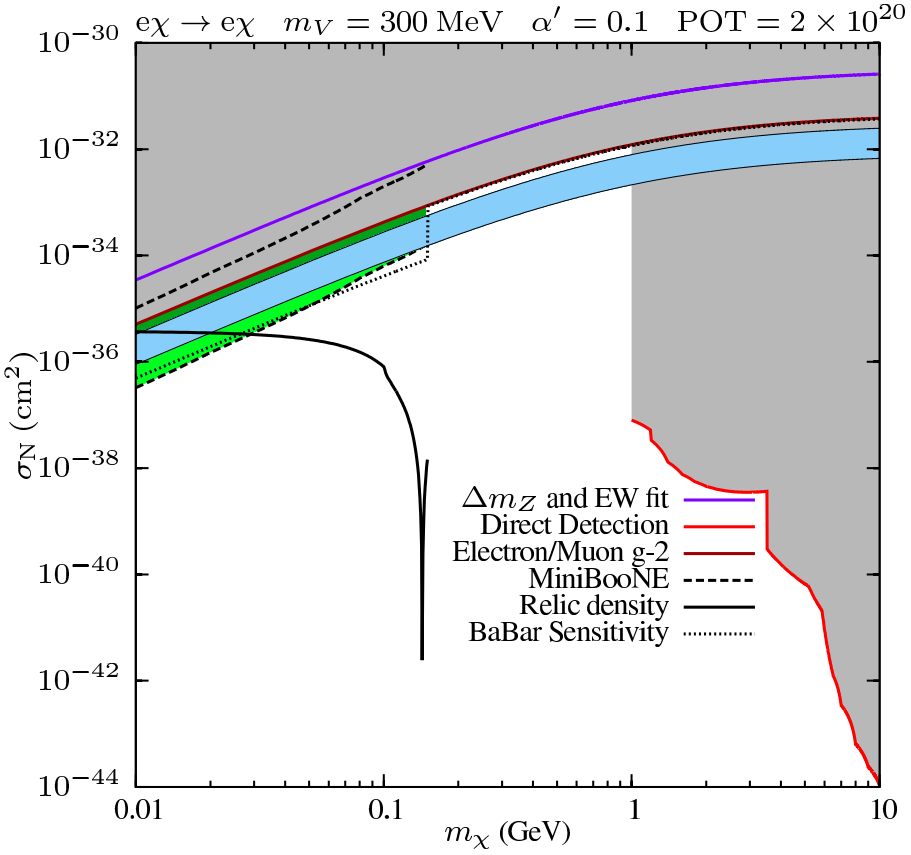




PRELIMINARY

MiniBooNE Kinetic Mixing - $\chi e \to \chi e$





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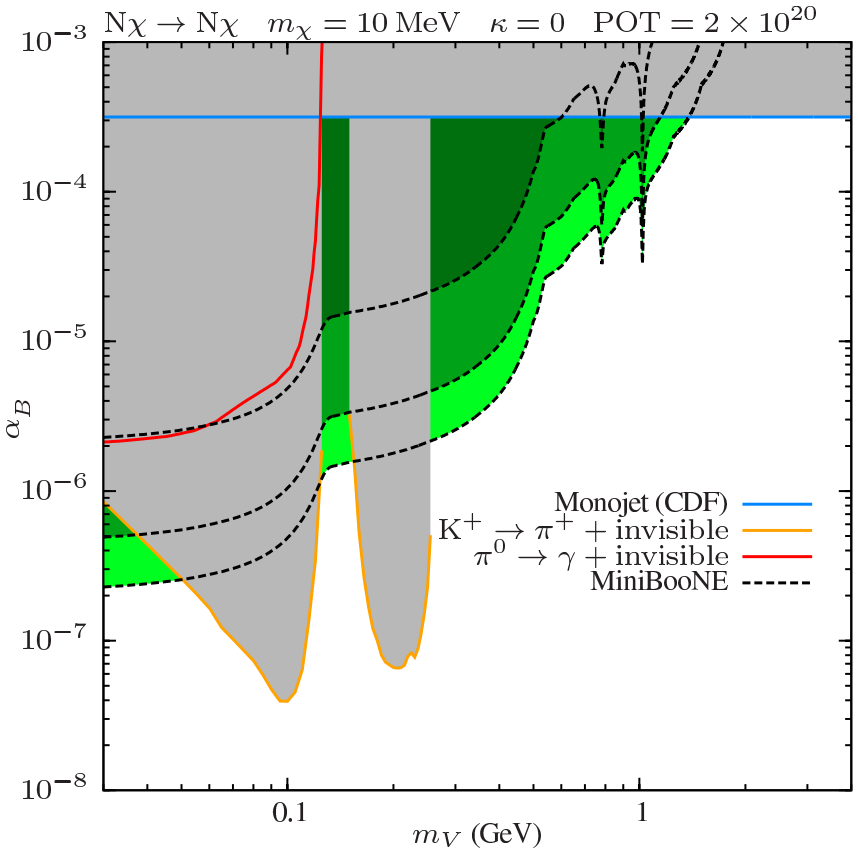
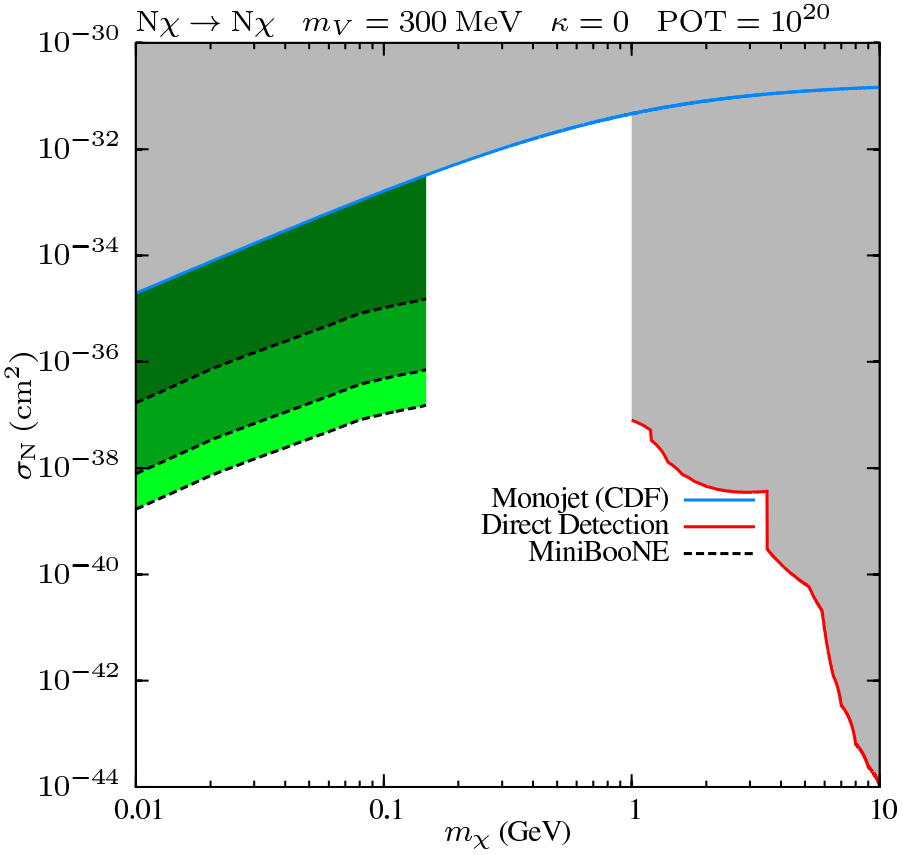
MiniBooNE Baryonic Vector





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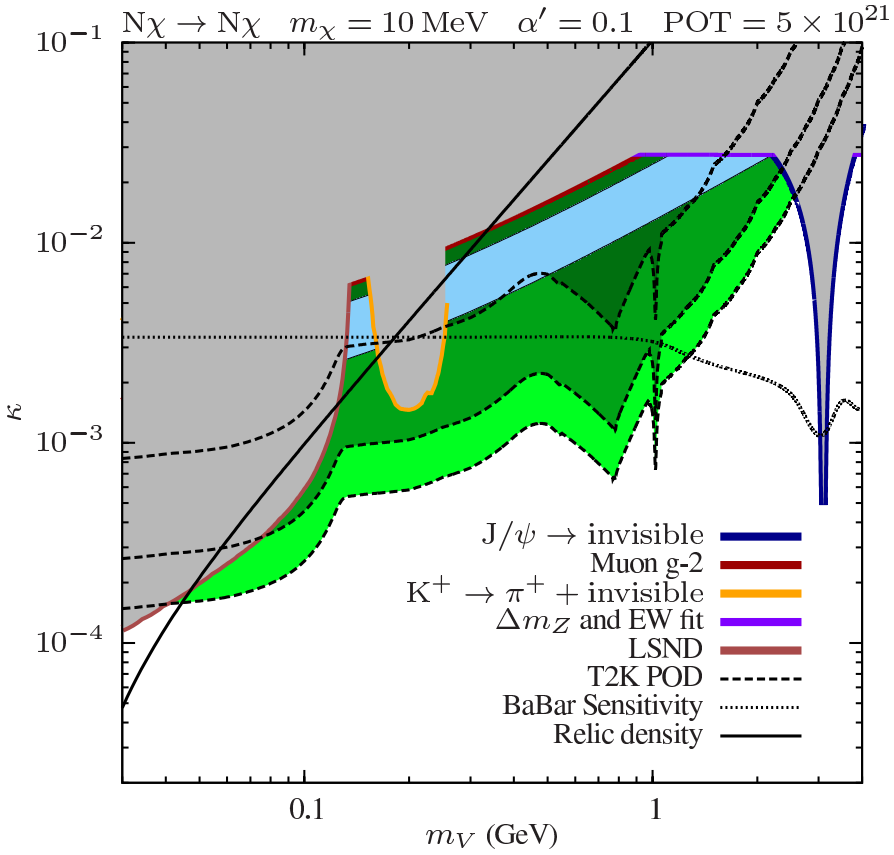
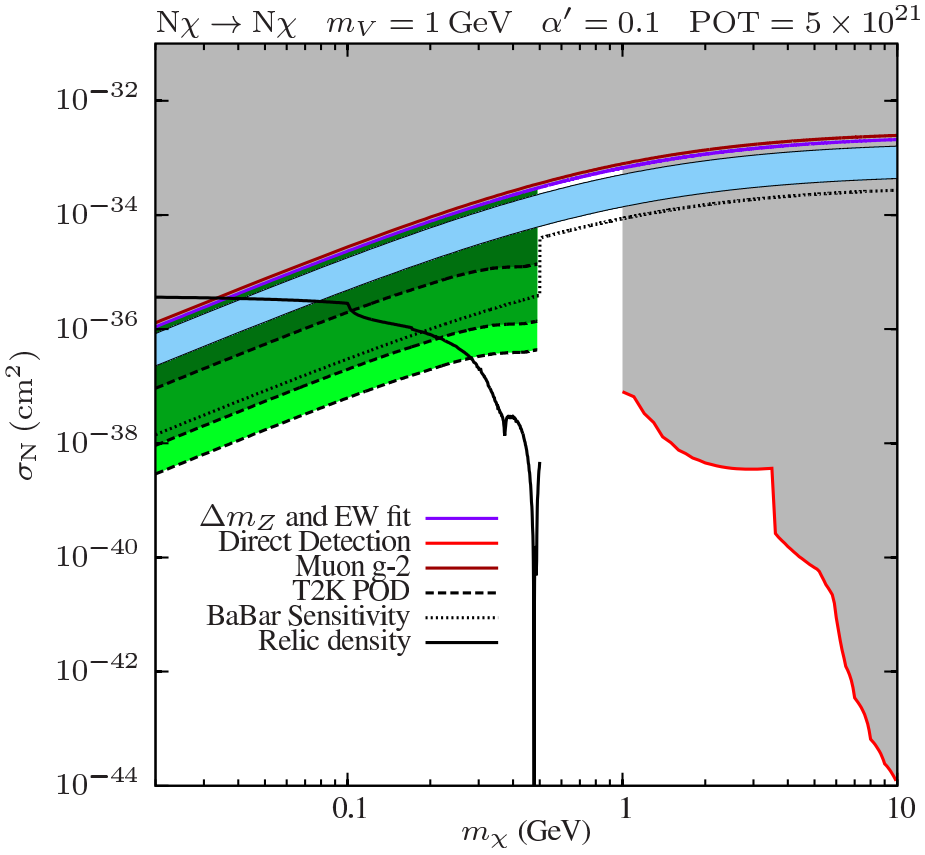
T2K P0D Kinetic Mixing





PRELIMINARY

Summary

- Thermal relic WIMP with a sub-GeV mass and interactions mediated by a light $U(1)'$ vector boson provides a viable dark matter candidate.
- This candidate escapes many of the best limits imposed by stand direct, indirect and collider searches.
  - While new limits are being placed on the parameter space, a great deal of viable parameter space remains unconstrained. Electron fixed target experiments could reduce this further.

    [see arXiv:1307.6554 [hep-ph] and arXiv:1403.6826 [hep-ph]]
  - Variants on this model, such as a baryonically coupled $U(1)_B$ vector boson, can escape many of these new constraints.
- Fixed Target Neutrino Facilities possess good sensitivity to these hidden-sector scenarios.
  - Capable of probing regions of the hidden-sector parameter space currently inaccessible to other techniques while using a straightforward counting approach.
- Running a Fixed Target Neutrino Experiment in an off target mode could provide new sensitivity, while requiring far fewer POT.
  - A test of this approach is being conducted by the MiniBooNE experiment

Acknowledgements

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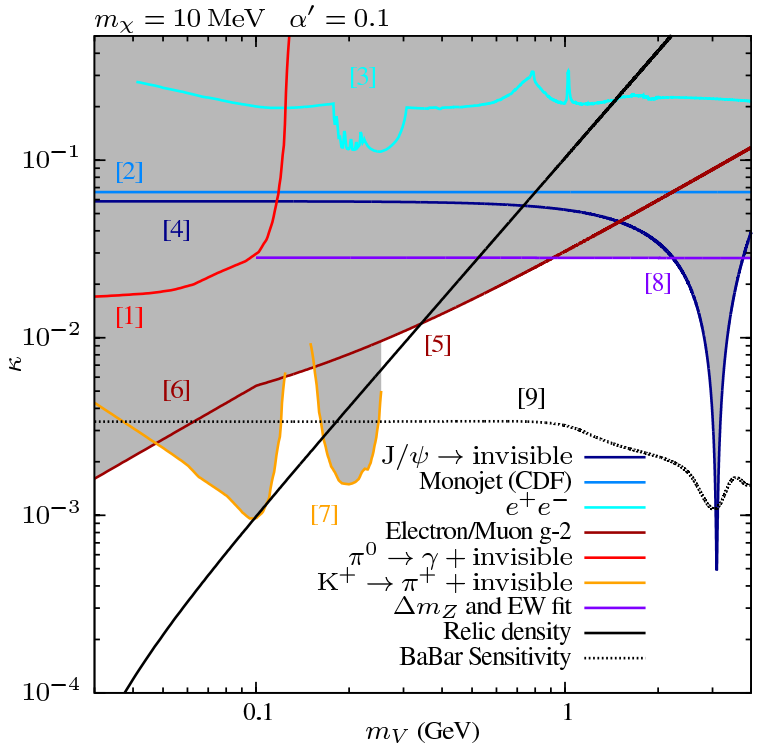
Kinetic Mixing Constraints



[1] E787. Atiya'92
[2] CDF. Shoemaker'12 [arXiv:1112.5457 [hep-ph]]
[3] KLOE, APEX, MAMI, BaBar. Hewett'12 [arXiv:1205.2671 [hep-ex]]
[4] BES. Ablikim'08 [arXiv:0710.0039 [hep-ex]]
[5] E821. Pospelov'08, [arXiv:0811.1030 [hep-ph]]
[6] Bouchendira'10, [arXiv 1012.3627 [physics.atom-ph]], Gabrielsi'10, [arXiv:1009.4831 [physics.atom-ph]], Aoyama'12, [arXiv:1205.5368 [hep-ph]], Endo'12, [arXiv:1209.2558 [hep-ph]].
[7] E949. Artamov'08, [arXiv:0808.2459 [hep-ex]]
[8] LEP. Hook'10 [arXiv:1006.0973 [hep-ph]]
[9] BaBar. Aubert'08 [arXiv:0808.0017 [hep-ex]], Izaguire'13 [arXiv:1307.6554 [hep-ph]], Essig'13 [arXiv:1309.5084[hep-ph]]

Choosing a Portal

For $m_V > 2m_\chi$

- **U(1)′ Mediator - Vector Portal**
  - **Fermionic DM** - s-wave annihilation and an increased dark matter number density due to the low dark matter mass results in a visible distortion of the CMB. Also leads to a more visible signal from galactic center. [Padmanabhan & Finkbeiner et al '05; Slatyer et al '08]
  - **Scalar DM** - p-wave annihilation allows this scenario to be viable for small κ, as the annihilation rate is suppressed by an additional factor of v. A small v heavily suppresses the dark matter annihilation rate.
- **Scalar Mediator - Higgs Portal**
  - **Scalar DM** - s-wave annihilation excludes this scenario for the reasons given previously.
  - **Fermionic DM** - p-wave annihilation renders this model viable. However, fermionic DM requires a large mixing, which could affect B decays. [Bird, Kowalewski & Pospelov 2006]