Weekly Update

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July 26, 2017

From last time: Reproducing the paper's sensitivity plots

- Went on to reproduce this plot (figure 7 of arXiv:1609.01770v3):

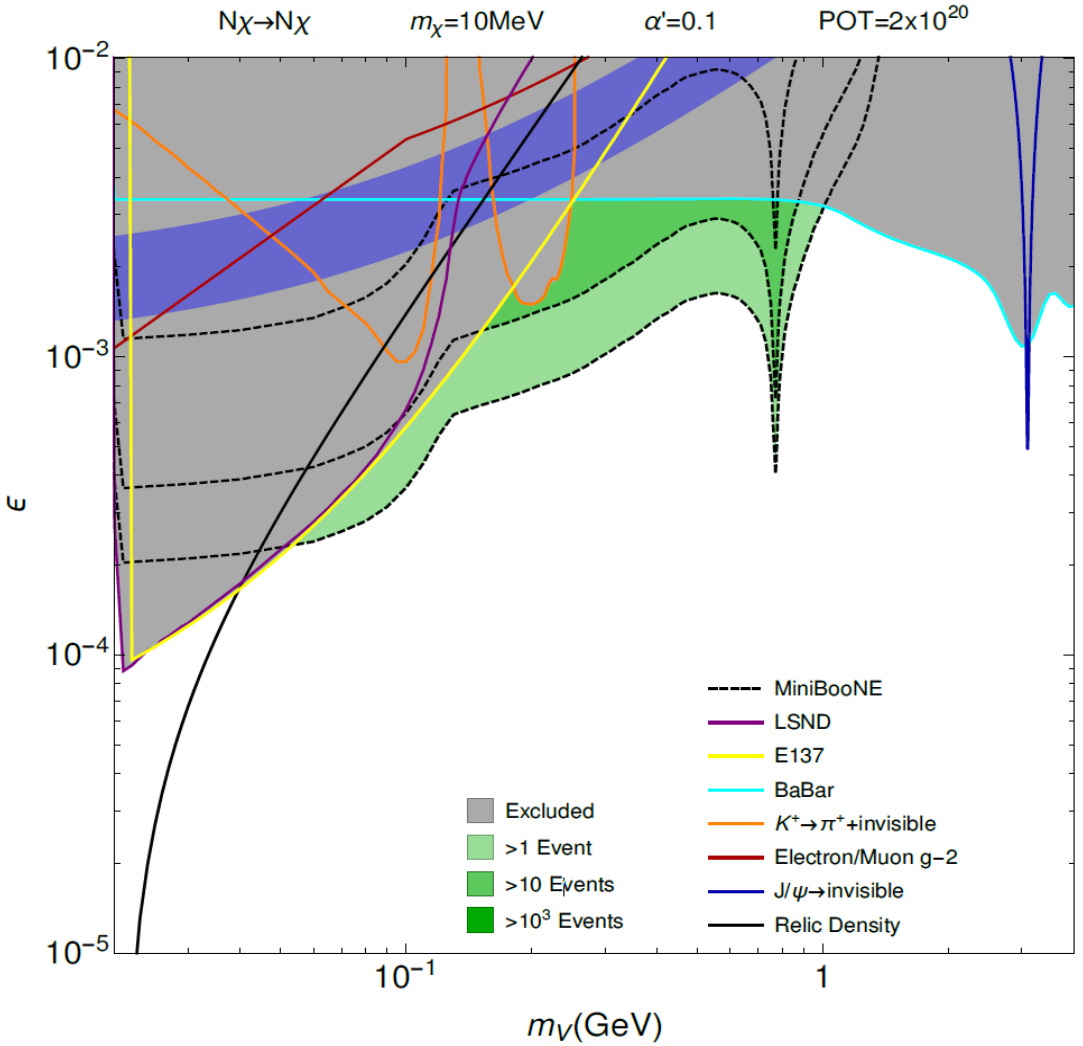


FIG. 7. Plots showing the MiniBooNE yield of light dark matter scattering events in nucleon elastic scattering. In this plot and the others to follow, the gray regions are excluded by existing constraints, while the green contours indicate 1, 10 and 1000 events.

Paper's plot:

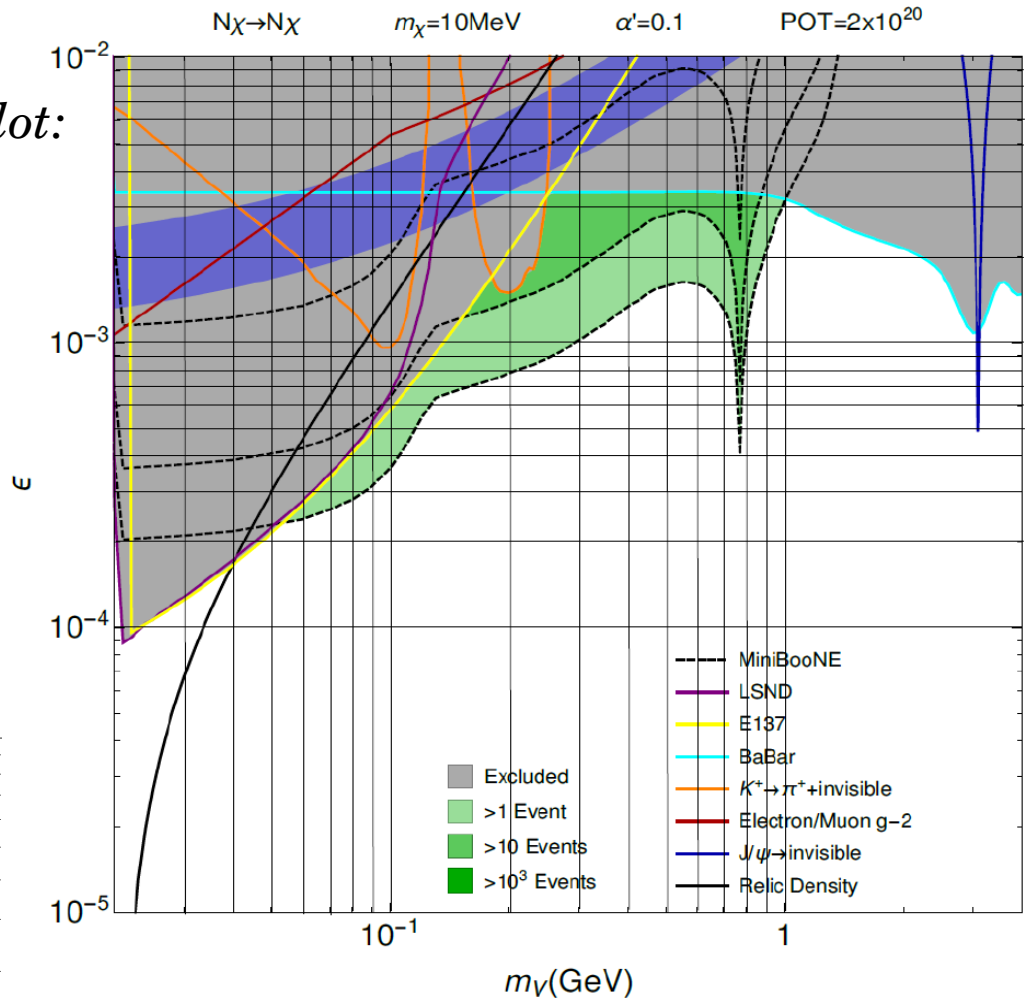
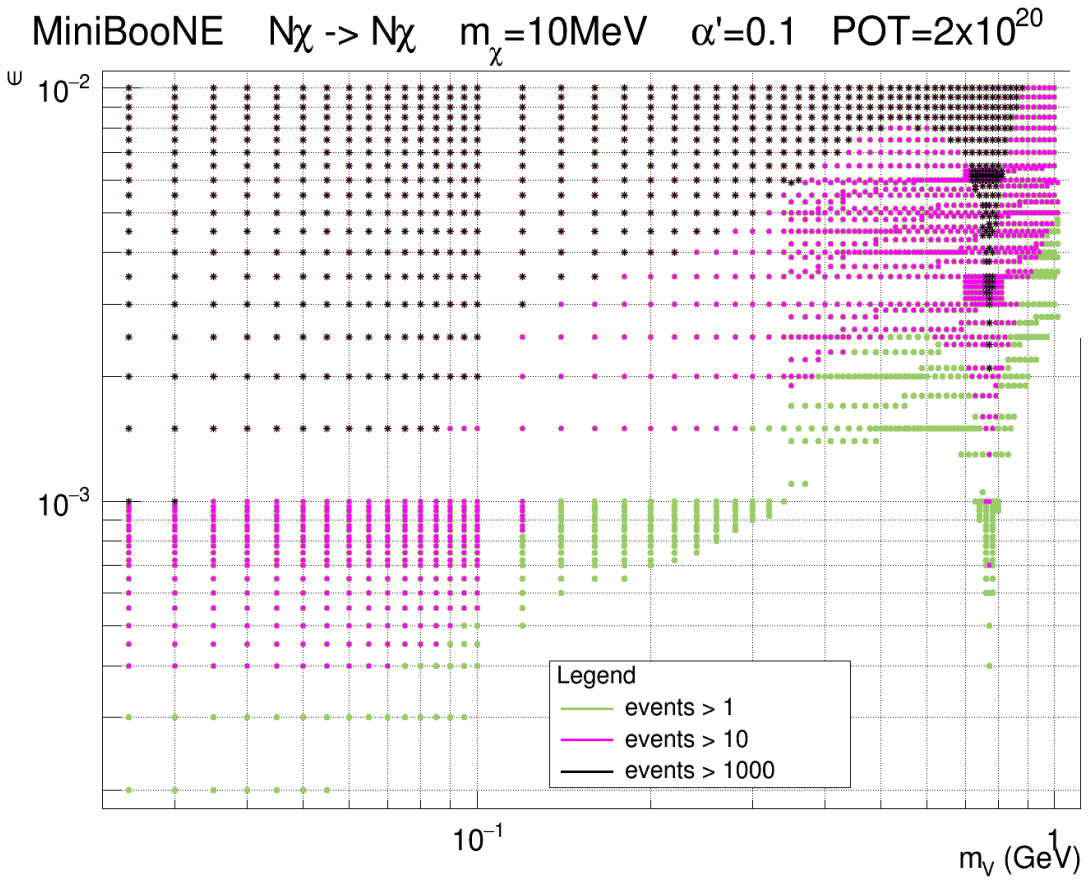


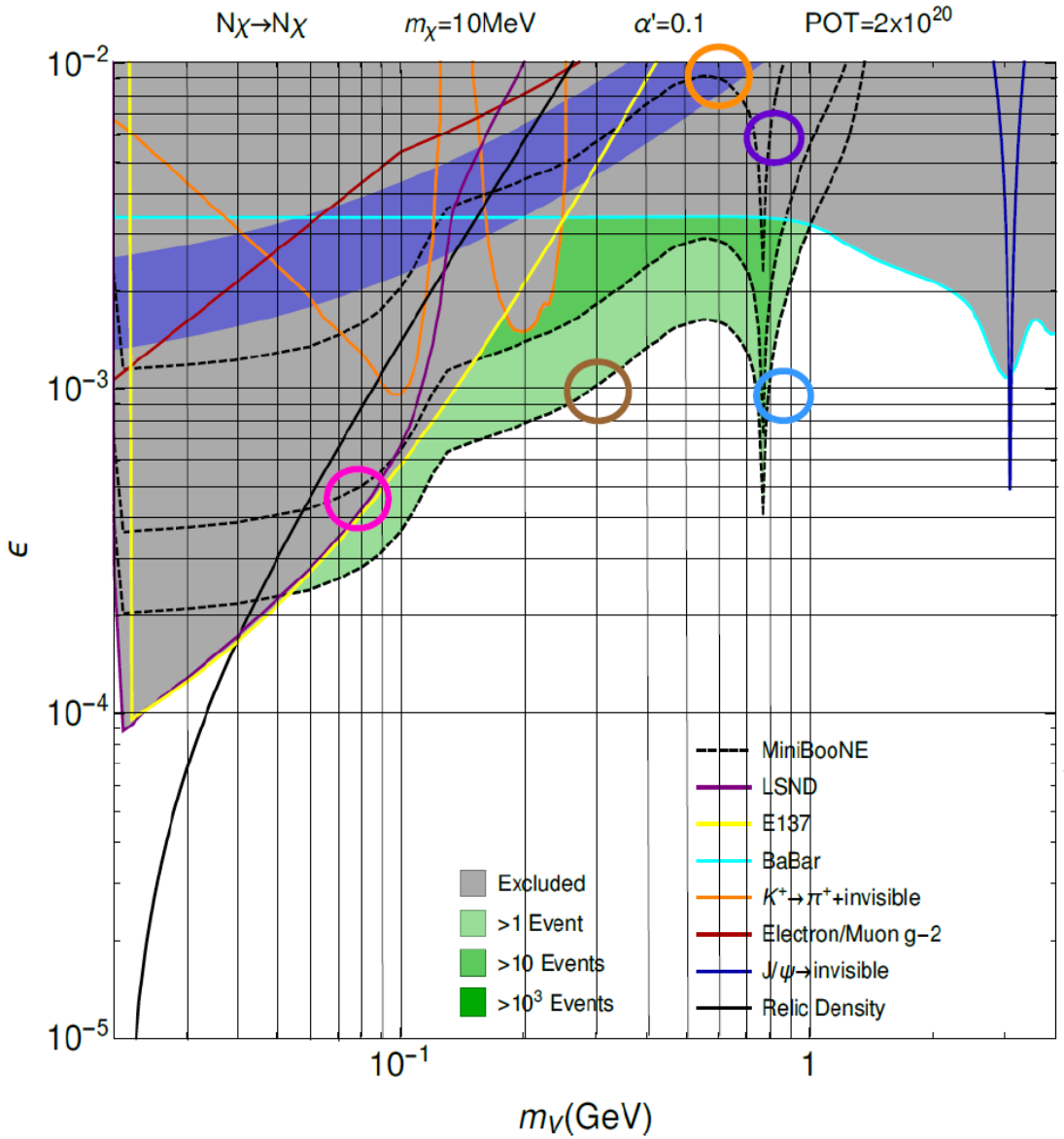
FIG. 7 of *arXiv:1609.01770v3:* **Plots showing the MiniBooNE yield of light dark matter scattering events in nucleon elastic scattering. In this plot and the others to follow, the gray regions are excluded by existing constraints, while the green contours indicate 1, 10 and 1000 events.**

My plot:



- It seems like at some points, I'm getting more events than the paper's plot, next slide →

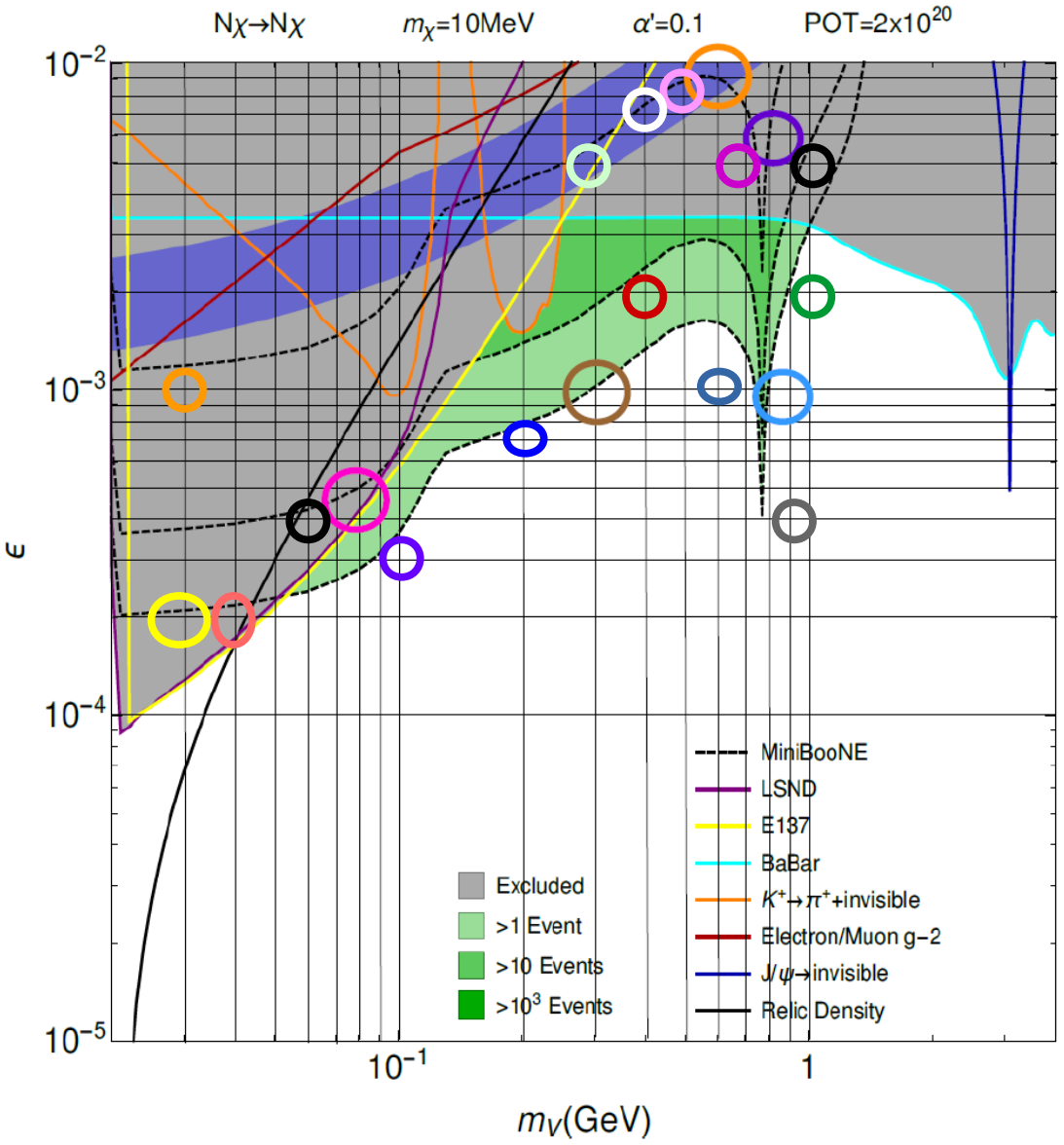
- Did what hiro suggested, ran BdNMC with POT=2×10^{25}, then divided #signal events by 10^5
  Did this for some points on the curves corresponding to events>1, events>10, events>1000



mV	epsilon	#events from paper's plot	What I get for #events with samplesize=2000
0.08	0.0005	10	19.7047
0.3	0.001	1	1.7586
0.6	0.009	1000	1625.62
0.8	0.006	1000	1591.48
0.8	0.001	1	1.2306

- Values don't agree (my #signal events are higher), even when considering the statistical error of my # of signal events

- Did this for some more points
  I'm getting more events than the paper for points near the boundries of the regions



mV	epsilon	#events from paper's plot	What I get for #events with samplesize=1000
0.08	0.0005	10	19.6593
0.03	0.0002	events<1	1.53437
0.04	0.0002	Events < 1	1.46220
0.1	0.0003	events<1	0.866641
0.2	0.0007	events<1	1.14948
0.6	0.001	events<1	0.243613
0.9	0.0004	events<1	0.00206906
1.0	0.002	events<1	0.28754
0.06	0.0004	1<events<10	14.7441
0.4	0.002	1<events<10	8.69028
1	0.005	1<events<10	12.0527
0.03	0.001	10<events<1000	975.59
0.3	0.005	10<events<1000	1047.9
0.4	0.007	10<events<1000	1280.88
0.5	0.008	10<events<1000	1034.59
0.7	0.005	10<events<1000	341.881
0.08	0.0005	10	19.7047
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0.6	0.009	1000	1625.62
0.8	0.006	1000	1591.48
0.8	0.001	1	1.2306

Thoughts:
Not really a problem:
- the #signal events I get is very close to the paper's plot
- A discrepancy between my results and the paper's probably comes from the difference in the parameters given to BdNMC → not an issue since we'll put in accurate parameters for SK

mV	epsilon	#events from paper's plot	What I get for #events with samplesize=1000
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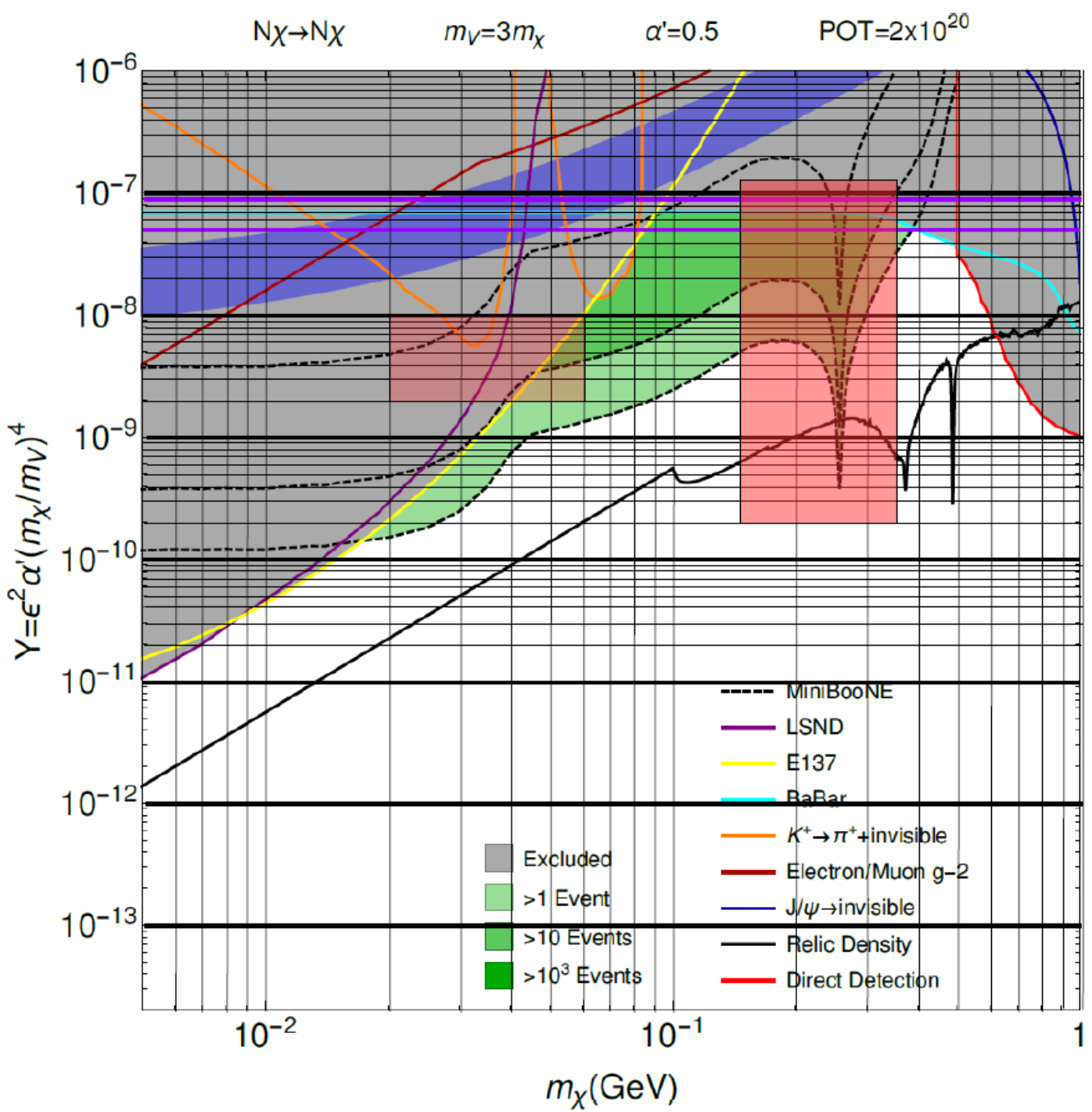

Fig 8.0 of arXiv:1609.01770v3: Further plots showing the MiniBooNE yield of light dark matter scattering events in various channels, now using mV = 3mX with alpha' = 0.5, and using the variable Y for the vertical scale. In these plots and below the black dotted line shows the parameters required to achieve the dark matter relic density, so smaller values of Y are excluded due to over-production of dark matter.

- Next: replicated some points (in red) in this plot
. Checked the number of signal events for each point: same 'issue' as figure 7: # signal events agree, but I get (a few) more signal for some points

Note about BdNMC

.Need m_DM < m_pi0/2 and m_DM < m_eta/2 for energy conservation

- BdNMC produces a seg fault if m_DM>m_pi0/2 (doesn't crash if m_DM>m_eta/2, ignores the eta production channel
  - Have to comment out this production channel for this region for m_DM

Resonant Vector Meson Mixing

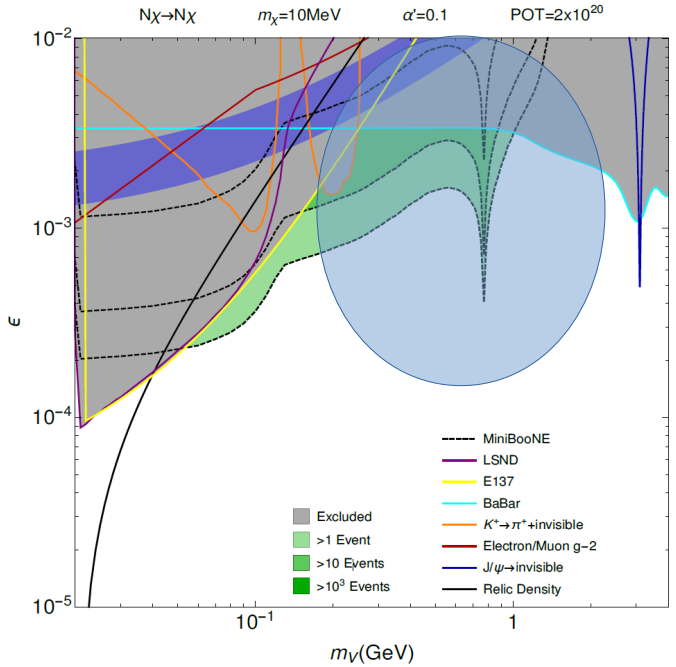

FIG. 7. Plots showing the MiniBooNE yield of light dark matter scattering events in nucleon elastic scattering. In this plot and the others to follow, the gray regions are excluded by existing constraints, while the green

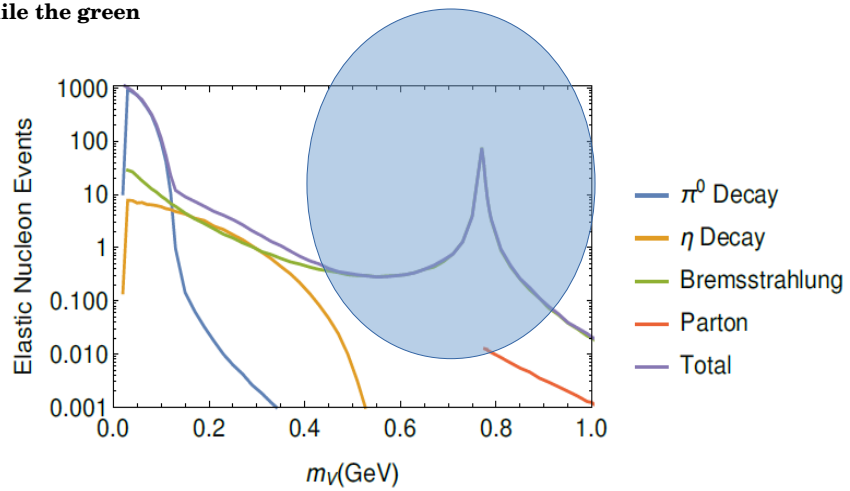

FIG. 1. A plot illustrating the distinct contributions to DM production (coupled through the vector portal), as discussed in the text, using the 9 GeV proton beam at MiniBooNE as an example. The rate of elastic scattering events on nucleons is plotted versus the vector mediator mass. From smaller to larger values of m_V, the dominant channels are π^0 decays, η decay, bremsstrahlung, which becomes resonant near the ρ/ω mass region, and finally direct parton-level production. The plot uses $m_\chi = 0.01$ GeV, $\epsilon = 10^{-3}$ and $\alpha' = 0.1$.

- In the paper 'leptophobic dark matter at neutrino factories' (2014), they have the production channels secondary meson decay, direct QCD production, and vector meson mixing ('for mV close to the mass of a vector meson rho, omega, phi, resonant production via mixing can be important …').

- Still learning; I think in the 2017 paper they included the vector meson mixing in the form factor that they use in the proton bremsstruhlung

(ii) *Vector meson mixing*: For m_V close to the mass of a vector meson $X = \rho, \omega, \phi$, resonant production via mixing can be important [31]. In principle, this requires an off-shell treatment of both X and V_B, to account for the full spectral shape. However, there is little (e.g. Drell-Yan) data available for the relevant kinematic range, and we will focus on one tractable contribution that corresponds to taking $\sigma(pp(n) \to V_B^* + \cdots) \sim \sigma(pp(n) \to X + \cdots) \times \mathrm{Br}(X \to V_B^* \to \chi\chi^\dagger)$. This relation can be derived in the narrow-width approximation for the vector meson resonance, and one can compute the branching ratio

$$\frac{\mathrm{Br}(X \to \chi\bar{\chi})}{\mathrm{Br}(X \to e\bar{e})} = r_\chi \left(c_X \frac{g_B}{e} - \kappa \right)^2 \left(\frac{g_B q_B}{e} \right)^2 \times \frac{m_X^4}{(m_X^2 - m_V^2)^2 + m_V^2 \Gamma_V^2} \times \left(1 + a_\chi \frac{m_\chi^2}{m_X^2} \right) \left(1 - \frac{4m_\chi^2}{m_X^2} \right)^{1/2}, \quad (9)$$

where $c_X = \{0, 2, -1\}$ for $X = \{\rho, \omega, \phi\}$, while $r_\chi = 1$, $a_\chi = 2$ (Dirac fermion χ), or $r_\chi = 1/4$, $a_\chi = -4$ (scalar χ). In practice, the X width is usually much larger than the V_B width, so to better approximate the spectral shape we will broaden the effective resonance width, $\Gamma_V \to \Gamma_{\mathrm{eff}} \sim \Gamma_X$. (In the case of ρ, we also modify the spectral shape as a Breit-Wigner distribution does not provide a good fit to higher energy Drell-Yan data.) Further calculational details are presented in Appendix A 2. Estimated production rates for the vector mesons are again summarized in Table I.

$P+P(N) \to X \to V^*_B \to DM + DM_{dagger}$

Where X is the rho, omega, or phi meson.

I'd like to confirm this is what they mean by vector meson mixing.

- In the 2017 paper, they have “Bremsstruhlung and resonant vector meson mixing”
- Differential V production rate: $$\frac{d^2N_V}{dzdp_\perp^2} = \frac{\sigma_{pA}(s')}{\sigma_{pA}(s)} F_{1,N}^2(q^2) w_{ba}(z, p_\perp^2),$$

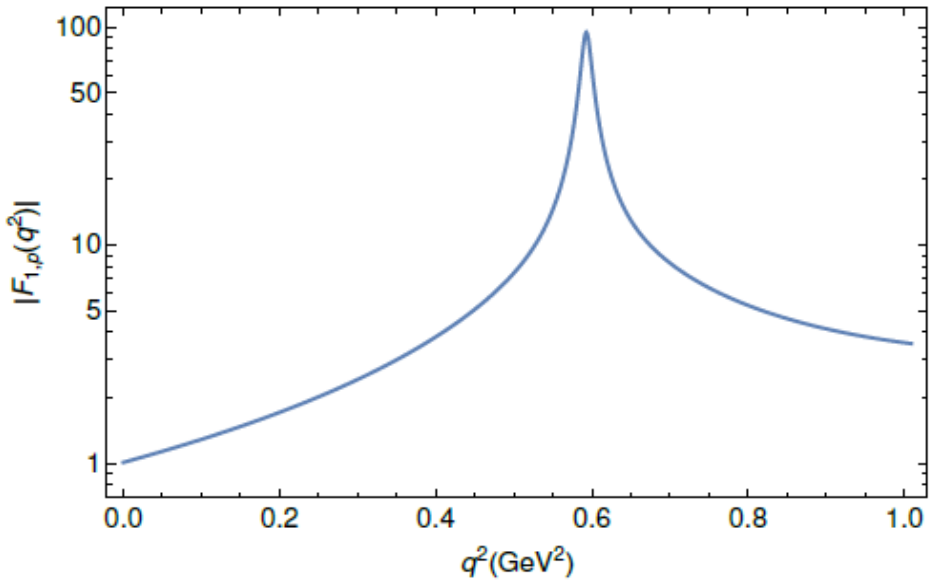

FIG. 3. The timelike form factor $F_{1,p}(q^2)$ from [56]. The resonant enhancement around the ρ/ω region is not fully resolved in the fit.

Direct partonic production at SK

Backup

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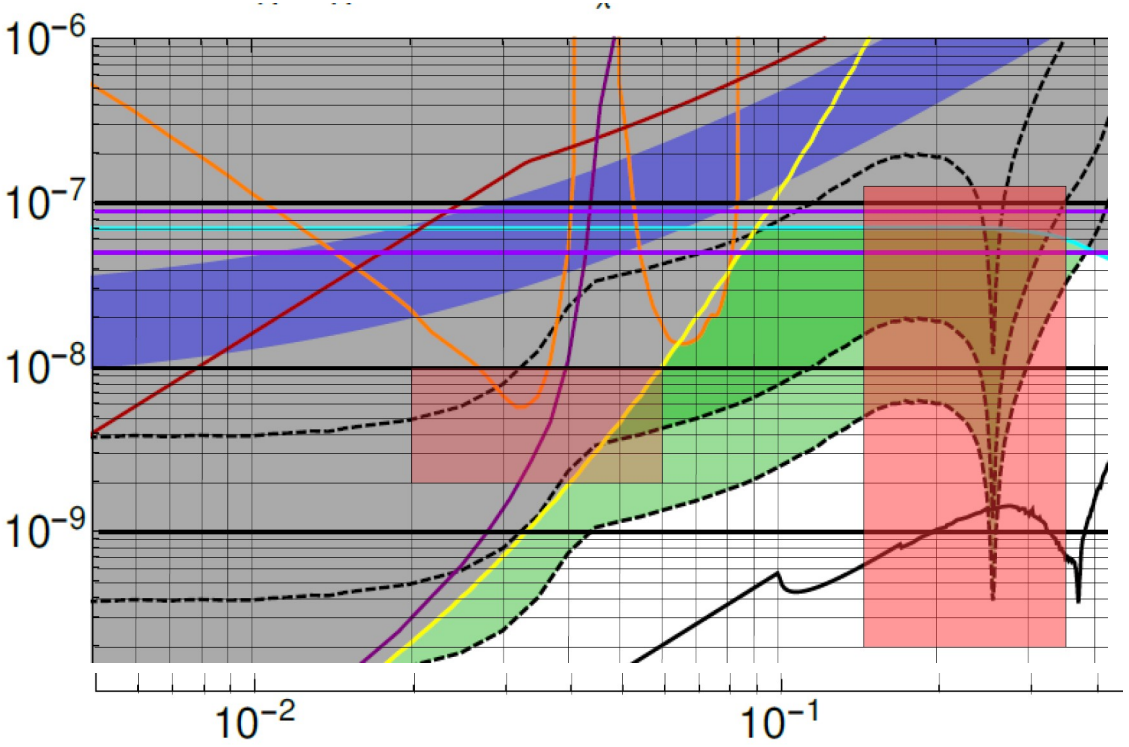
Zoomed in section of figure 8 from last slide



My plot: