Neutrino Floor in Isospin-Violating Dark Sector

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Outline

- Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)
- Neutrino Background/Spectrum : Solar and Atmospheric neutrinos are more effective
- Neutrino Event Rate and Neutrino Floor (SM)
- Isospin-Violating Dark Sector : a light Z'
- Neutrino Event Rate and Neutrino Floor : Our case
- Result and Conclusion

Background

- The known fundamental particles (SM particles) cannot be dark matter candidates.
- Some observational evidences: Galaxy rotation curves, Gravitational Lensing etc.
- No DM candidate is observed in different particle and astrophysical experiments up to now.
- BSM models suggest different DM candidates: WIMPs, SIMPs etc.
- Direct detection of DM: LZ, PandaX, Xenon1T experiments.
- Neutrino floor is a critical component in dark matter direct detection: It is the background to the possible DM signal.

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)

- Coherent Elastic Neutrino-Nucleus Scattering has been a powerful test of the Standard Model of particle physics, and a search tool for new physics (BSM).
- A neutrino and nucleus collide elastically in a coherent manner, A particular interaction of neutrinos with atomic nuclei.
- The Coherent Scattering Differential Cross-Section (SM),

$$\frac{d\sigma_{\nu N}^{SM}}{dE_R} = G_F^2 (Q_v^{SM})^2 \frac{m_N}{4\pi}\left(1 - \frac{E_R m_N}{2E_\nu^2}\right) F^2(E_R)$$

$$Q_v^{SM} = N - (1 - 4\sin^2\theta_w)Z$$

C. Boehm, et al, arXiv:1809.06385.

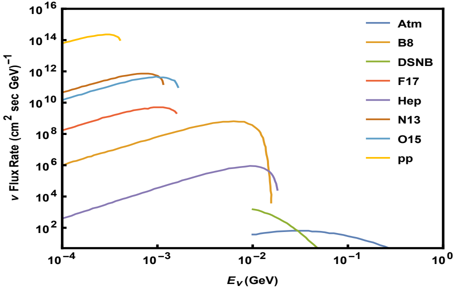
Neutrino Spectrum

- Neutrino event rate,

$$\frac{dN}{dE_R} = \frac{\epsilon}{m_N} \int_{E_\nu^{min}} dE_\nu \frac{d\sigma_{\nu N}^{SM}}{dE_R} \frac{d\phi_\nu}{dE_\nu}$$

Solar:
pp, B8, F17, O15, Hep, N13; Atm: Atmospheric; DSNB: Diffuse supernova neutrino background.

M.C. Gonzalez-Garcia, et al, JHEP, 07:019, 2018.



Neutrino Floor

- What is the neutrino floor?
  The neutrino floor is a theoretical lower limit on WIMP-like dark matter models that can be probed in direct detection experiments.

- The differential DM-nucleus scattering event rate is,

$$\frac{dN_{DM-N}}{dE_R} = \epsilon \frac{\sigma_0 A^2 \rho_{DM}}{2\mu^2 m_{DM}} F^2(E_R) \int_{v_{min}} \frac{f(v)}{v} d^3v$$

- DM-nucleon scattering cross-section,

$$\sigma_0 = \Bigg[\frac{2.3}{1} \int_{E_{th}}^{E_R^{max}} dE_R \left(\frac{1}{m_N} \int_{E_\nu^{min}} dE_\nu \frac{d\sigma_{\nu N}^{SM}}{dE_R} \frac{d\phi_\nu}{dE_\nu} \right) \times \left(\frac{\rho_{DM} A^2}{2 m_{DM} \mu^2} F^2(E_R) \int_{v_{min}} \frac{f(v)}{v} d^3v \right)^{-1} \Bigg]$$

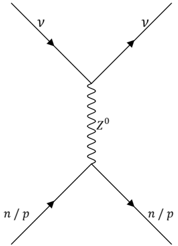
Soumya Sadhukhan,et al, arXiv:2006.05981v2.

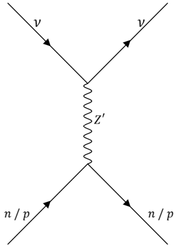
Isospin-Violating Dark Sector

Lagrangian

- The Lagrangian involving a Z' mediator with isospin violating interaction is given by,

$$L \supset Z'_\mu \sum_f \bar{f}\gamma^\mu (g_V^f - g_A^f \gamma_5) f + \frac{1}{2} m_{Z'}^2 Z'_\mu Z'^\mu$$





CEνNS in Our Model

- The Coherent Scattering Differential Cross-Section for Our Model,

$$\frac{d\sigma}{dE_R} = \xi_V \frac{d\sigma_{\nu N}^{SM}}{dE_R}$$

- $\xi_V = 1 + A + B$

A (Interference term) $=\frac{1}{\sqrt{2}}\frac{Q_V(g_V^\nu+g_A^\nu)}{G_F Q_V^{SM}(2m_N E_R+m_{Z'}^2)}$

B(Completely contributed by Z$'$) $= \frac{1}{4}\frac{Q_V^2[(g_V^\nu)^2+(g_A^\nu)^2]}{G_F^2(Q_V^{SM})^2(2m_N E_R+m_{Z'}^2)^2}$

$$Q_V = (2Z + N)g_V^u + (Z + 2N)g_V^d$$

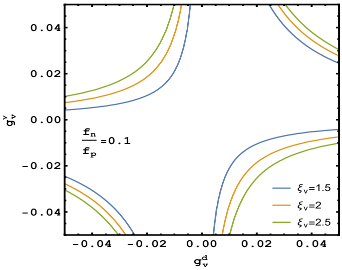
$$Q_v^{SM} = N - (1 - 4\sin^2\theta_w)Z$$

Result

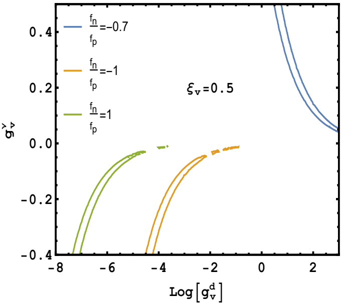
Parameter Set

- Target material is Xenon: $N = 77$; $Z = 54$; $m_{Z'} = 10$ GeV;

Parameter Space

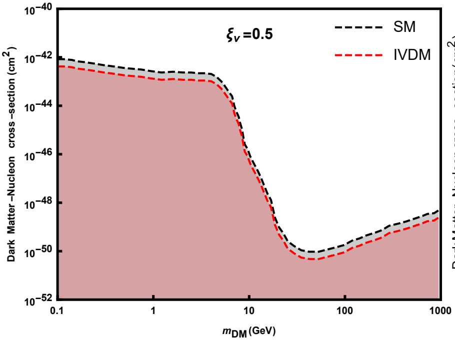


(a) Contour plot of ξ_V as a function of g_v^ν and g_v^d for $\frac{f_n}{fp} = 0.1$.

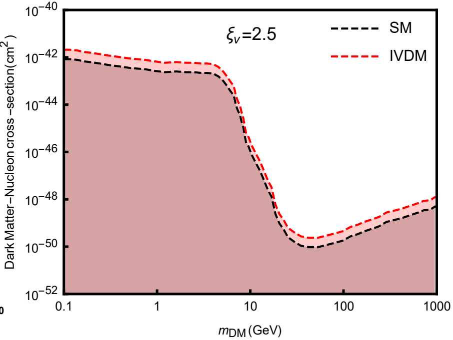


(b) Contour plot of $\frac{f_n}{fp}$ as a function of g_v^ν and g_v^d for $\xi_V = 0.5$.

Modification of Neutrino Floor



(a) The SM neutrino floor (dashed, black) is compared with the minimum level reached in our (dashed, red) model.



(b) The SM neutrino floor (dashed, black) is compared with the maximum level reached in our (dashed, red) model.

- New parameter space that can be probed in the direct detection experiments has further either opened up or been reduced due to presence of isospin violating interactions.

Modification in LZ Result

- The dark matter-nucleus spin-dependent cross section,

$$\sigma_N^Z = \sigma_p \frac{\sum_i \eta_i \mu_{A_i}^2 [Z + (A_i - Z) f_n/f_p]^2}{\sum_i \eta_i \mu_{A_i}^2 A_i^2}$$

Where η_i is the natural abundance of the isotope A_i,

$$\sigma_p = 4\mu_p^2 f_p^2/\pi$$

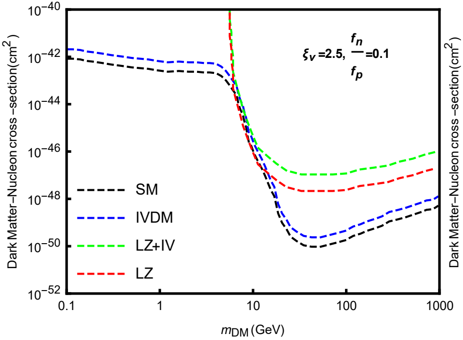
- If with out isospin violation in the dark matter sector then, $f_n = f_p$
- Degradation factor,

$$D_Z \equiv \frac{\sigma_N^Z}{\sigma_p} = \frac{\sum_i \eta_i \mu_{A_i}^2 [Z + (A_i - Z) f_n/f_p]^2}{\sum_i \eta_i \mu_{A_i}^2 A_i^2}$$

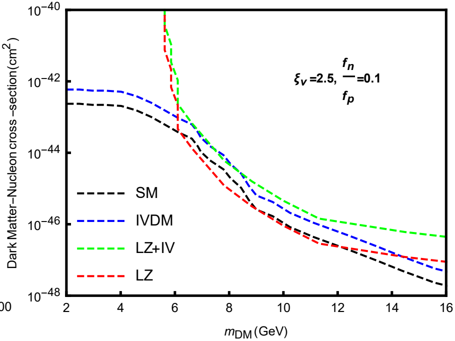
- The amount of isospin violation as the ratio between the neutron and proton interaction is given by,

$$f_n/f_p = (2g_V^d + g_V^u)/(2g_V^u + g_V^d)$$

Interpretation of Experimental Result



(a) A comparison between direct detection and LZ bound on the dark matter- nucleon cross section for $\frac{f_n}{f_p} = 0.1$, $\xi_V = 2.5$.



(b) We have focused on between 2 to 16 GeV mass scale.

Conclusion

- In our model, the neutrino floor can be both up and down from the SM, so we find new parameter space to be searched in DM direct direction experiment.
- Exploration of cross sections below neutrino floor is possible.
- If the next generation of dark matter detectors (such as LZ) fail to find the dark matter then future detectors would need to investigate parameter space populated by neutrinos.

Thank You