ASTROCENT

CAMK PAN

Neutrinos in direct detection experiments: obstacle or aid to new physics?

IDM 2022

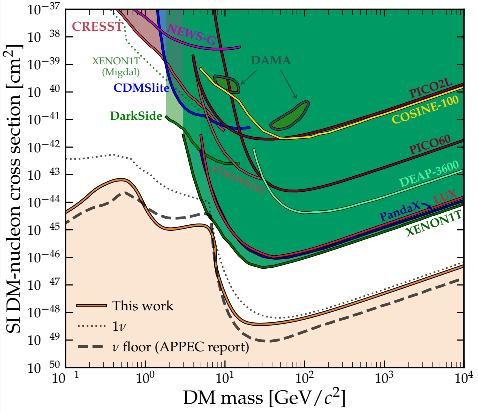
D. Amaral, D. G. Cerdeño, **Andrew Cheek**, P. Foldenauer

Based on: arXiv:2104.03297 (*Eur.Phys.J.C*) and arXiv:2209.xxxx

July 21, 2022

The Neutrino Floor and Direct Detection

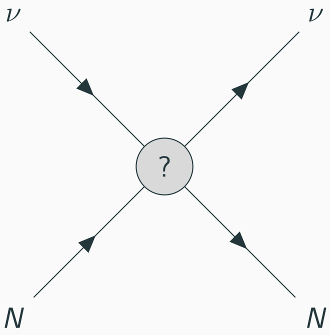
- As direct detection experiments get more sensitive, they will start to observe solar neutrinos.
- This signal is very similar to dark matter signal, makes up an irreducible background known as the neutrino floor or fog.
- Work on annual modulation and directional detection needed to move past this.



arXiv:2109.03116 + C. O'Hare's talk

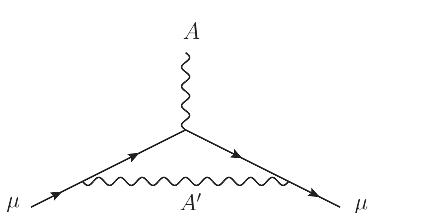
Direct detection as a neutrino detector

- For dark matter physics, ν signal is a pesky background.
- In our work, we try to determine what can be learnt about neutrino physics from direct dark matter detection experiments.
- In **arXiv:2104.03297** we do this in the context of a specific model.
- Currently finalising a more general study with Non-Standard neutrino Interactions (NSI's).



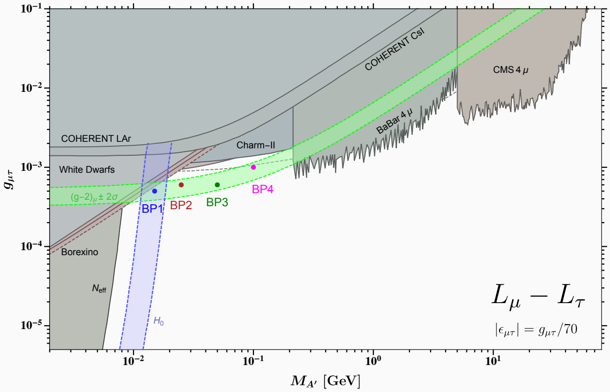
Direct detection testing a solution to $(g-2)_\mu$

- The measurement of the anomalous magnetic moment of the muon is in tension with the Standard Model theoretical expectaction.
- A simple solution is to invoke the existence of new light gauge boson, A'.
- We note that only the $\mu - A'$ interaction contributes.



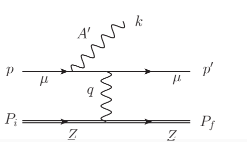
An anomaly free solution requires τ interactions

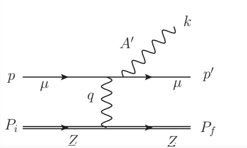
- In order to cancel anomalies in the gauge theory, one needs additional interactions to the $\mu - A'$.
- The $U(1)_{L_\mu - L_\tau}$ interaction is a viable solution and evades existing constraints.

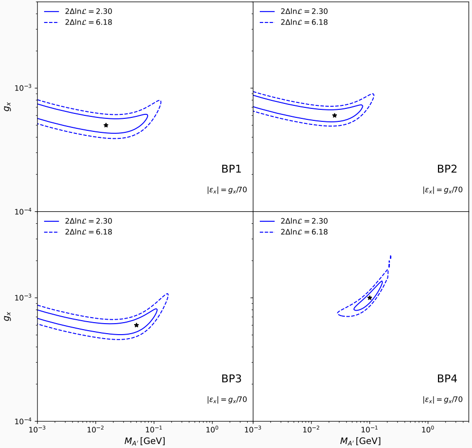


Muon fixed targets and $U(1)_{L_\mu - L_\tau}$

- Muon fixed target experiments like M^3 and NA64μ will be able to probe $U(1)_{L_\mu - L_\tau}$ by searching for invisible decays.
- Only a test of muon interaction.





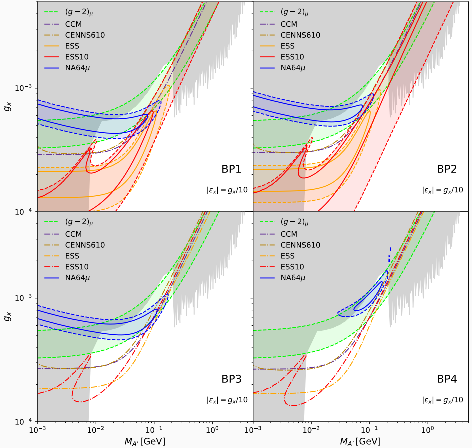


Spallation sources and $U(1)_{L_\mu - L_\tau}$

- Measuring coherent neutrino-nucleus scattering (CEνNS) at spallation sources allows one to measure the kinetic mixing parameter ϵ.

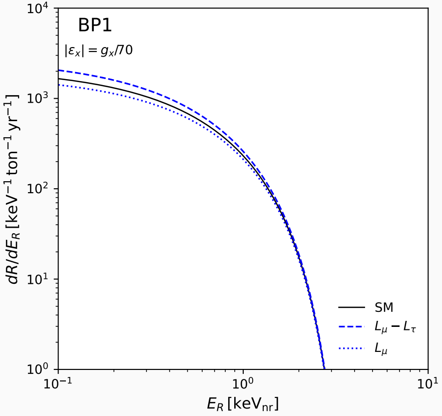
$$\epsilon_{\mu\tau} \approx \frac{e\, g_{\mu\tau}}{6\pi^2} \log\left(\frac{m_\mu}{m_\tau}\right) \approx -\frac{g_{\mu\tau}}{70}$$

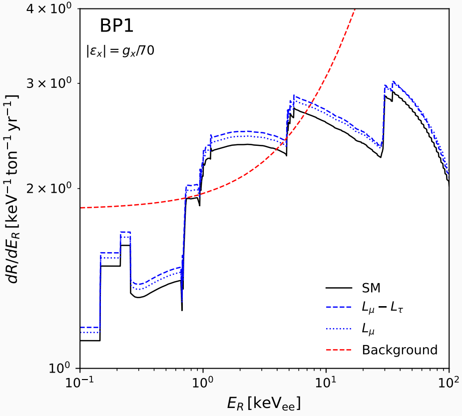
- Also makes neutrino and DM-coupled mediator models distinguishable.



Direct detection would measure the ν_τ interactions

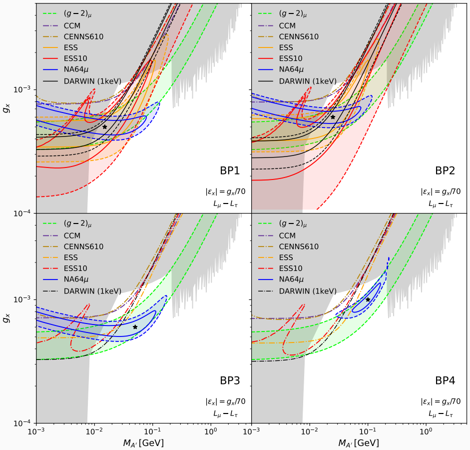
- The flux of ν_τ's from the sun will provide an important differentiator between direct detection and CEνNS.





Confirmation of the $U(1)_{L_\mu - L_\tau}$

- Direct detection could provide confirmation of the $U(1)_{L_\mu - L_\tau}$ solution to $(g-2)_\mu$.
- The lighter $m_{A'}$ solutions would be observed in DARWIN for example.
- There is a high degree of complementarity across the searches.



Non Standard Neutrino Interactions and Direct Detection

Direct Detection and General Non-Standard Neutrino Interactions

- A general way to parameterize neutrino interactions beyond the Standard Model is by using an effective description

$$\mathcal{L}_{\text{NSI}} = -2\sqrt{2}\, G_F \sum_{\substack{f=e,u,d \\ \alpha,\beta=e,\mu,\tau}} \varepsilon^{fP}_{\alpha\beta} \; [\bar{\nu}_\alpha \gamma_\rho P_L \nu_\beta] \; \left[\bar{f} \gamma^\rho P f\right]$$

- Consider only $f = e, u, d$ because we consider neutrino interactions with matter.

Current NSI parameterisation

- When using oscillation experiments to constrain the $\varepsilon_{\alpha\beta}^{fP}$ one often assumes $\varepsilon_{\alpha\beta}^{eP} = 0$.
- This is because oscillations through neutral matter are effected by the sum of charged interactions

$$(\varepsilon_{\alpha\beta}^{e} + \varepsilon_{\alpha\beta}^{p}) + Y_n(x)\,\varepsilon_{\alpha\beta}^{n}$$

- where $\varepsilon_{\alpha\beta}^{p} = 2\,\varepsilon_{\alpha\beta}^{u} + \varepsilon_{\alpha\beta}^{d}$ and $\varepsilon_{\alpha\beta}^{n} = \varepsilon_{\alpha\beta}^{u} + 2\,\varepsilon_{\alpha\beta}^{d}$.
- This has the benefit of leaving the $\sigma_{\nu e}$ unchanged.
- Can reparameterise $\varepsilon_{\alpha\beta}^{fP} = \varepsilon_{\alpha\beta}^{\eta,\varphi}\,\xi^{fP}$ with

$$\xi^{p} = \sqrt{5}\cos\eta\,,$$

$$\xi^{n} = \sqrt{5}\sin\eta$$

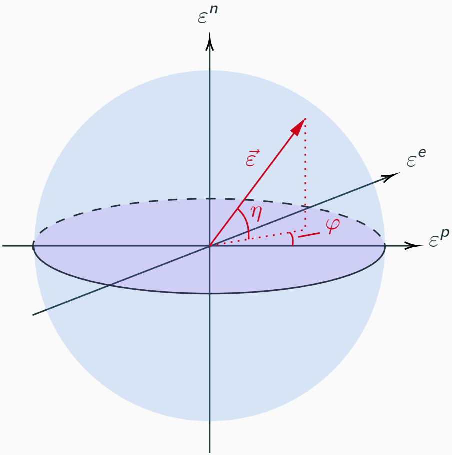
Extended NSI Parameterisation

- Because direct detection experiments will simultaneously be able to probe nuclear and recoil scatterings, we propose an extension of the NSI parameterisation.

$$\xi^e = \sqrt{5}\cos\eta\,\sin\varphi\,,$$

$$\xi^p = \sqrt{5}\cos\eta\,\cos\varphi\,,$$

$$\xi^n = \sqrt{5}\sin\eta\,.$$



Calculating the recoil rate from solar neutrinos

A modification is required in the rate calculation

- For flavour diagonal neutrino interactions

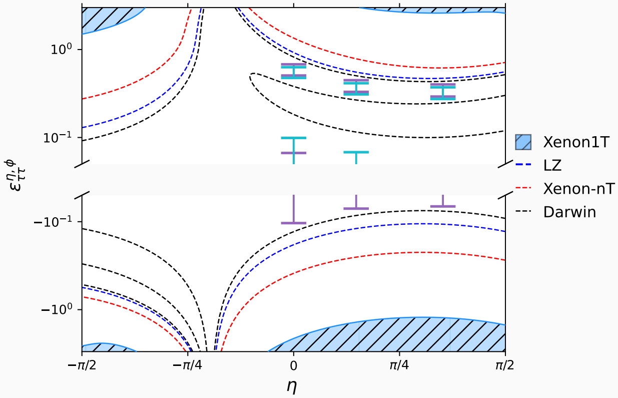
$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = n_T \sum_{\nu_\alpha} \int_{E_\nu^{\min}} \frac{\mathrm{d}\phi_{\nu_e}}{\mathrm{d}E_\nu} P(\nu_e \to \nu_\alpha) \frac{\mathrm{d}\sigma}{\mathrm{d}E_R} \, \mathrm{d}E_\nu \, ,$$

- In general, ($\varepsilon_{\alpha\beta} \neq 0$ when $\alpha \neq \beta$)

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = n_T \int_{E_\nu^{\min}} \frac{\mathrm{d}\phi_\nu}{\mathrm{d}E_\nu} \, \mathrm{Tr}\left[\boldsymbol{\rho} \frac{\mathrm{d}\boldsymbol{\sigma}}{\mathrm{d}E_R} \right] \mathrm{d}E_\nu$$

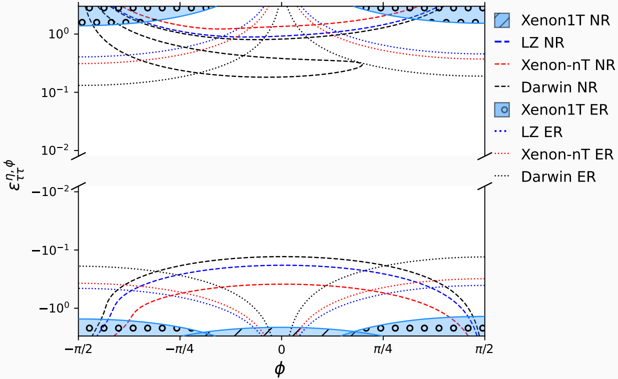
Projections for Nuclear recoils

- Here we show $\phi = 0$, i.e. completely in the proton-neutron plane.



Direct Detection will have Electronic and Nuclear Recoils

- When $\phi \neq 0$ electronic and nuclear recoils will be observable at direct detection experiments.



Conclusions

- Direct detection experiments will soon be probing the solar neutrino background.
- There are interesting new physics studies that can be done with this signal.
- We show that for the $U(1)_{L_\mu - L_\tau}$ solution to $(g-2)_\mu$, direct detection will provide important information.
- Current work is ongoing for calculating the projections for direct detection with non-standard neutrino interactions.
- Keep an eye on the arXiv!

Dark Wave

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952480