Solar Neutrinos in Cryogenic Detectors

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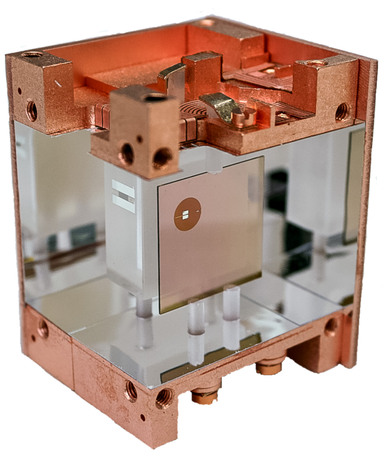
Introduction

A precise measurement of coherent elastic neutrino-nucleus scatterings (CEνNS) of solar neutrinos is an opportunity to study certain aspects of the solar model, such as the solar metallicity and allow for solar model independent tests of the Mikheyev-Smirnov-Wolfenstein (MSW) effect. We investigate the sensitivity to the flux of pp and ^{7}Be neutrinos, as well as CNO neutrinos. Furthermore, we investigate the sensitivity to dark matter (DM) signals in the presence of a solar neutrino background.

Detectors

We consider $CaWO_4$ or Al_2O_3 target crystals, equipped with transition edge sensors (TES), reaching energy thresholds of $\mathcal{O}$(eV) for nuclear recoils [1].

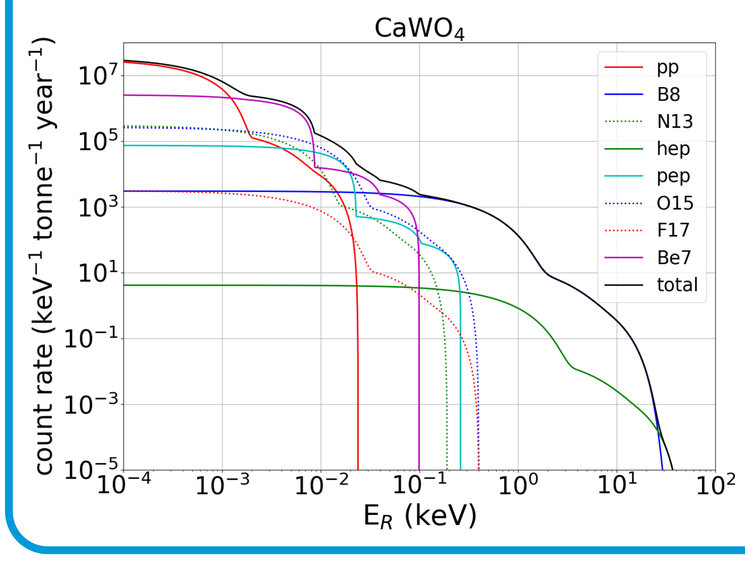


Nuclear recoils caused by CEνNS and DM lead to the same signal in the detector. They can only be distinguished by the shape of their respective recoil spectra.

Recoil spectrum

$$\frac{\mathrm{d}R_\nu}{\mathrm{d}E_\mathrm{R}} \propto \int_{E_{\nu,\min}}^{\infty} dE_\nu \Phi_\nu(E_\nu) \frac{\mathrm{d}\sigma(E_\mathrm{R}, E_\nu)}{\mathrm{d}E_\mathrm{R}}$$

- Φ_ν: solar neutrino flux, model BP04(Garching) [2]
- $\frac{\mathrm{d}\sigma}{\mathrm{d}E_\mathrm{R}}$: CE$\nu$NS cross section [3]



Binned Likelihood

$$\mathcal{L} = \prod_{i=0}^{m} e^{-N_e f_i} \cdot \frac{(N_e f_i)^{k_i}}{k_i!} \cdot \prod_{j=1}^{8} \mathcal{L}_{\nu,j}(\Phi_{\nu,j})$$

- m bins
- k_i: observed number of events
- f_i: binned pdf (sig + bck)
- N_e: total expected number of events
- $\mathcal{L}_{\nu,j}$: gaussian constrains to the flux parameters of a chosen subset of neutrino fluxes

Method

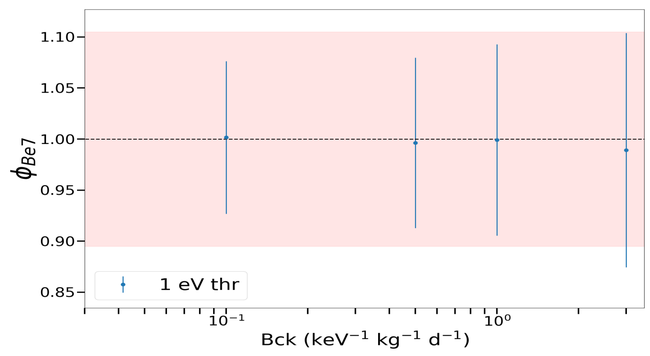
$\mathcal{O}$(1000) Monte Carlo simulations for each combination of:

- Target material ($CaWO_4$, Al_2O_3)
- Exposure (tonne years)
- Flat background rate (1/keV kg d)

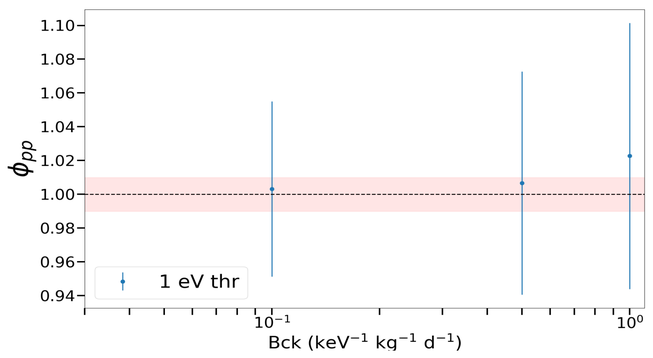
$\rightarrow$ reconstruct neutrino flux parameters.

Sensitivity to ^{7}Be and pp neutrinos

$CaWO_4$ with 0.05 tonne years exposure:



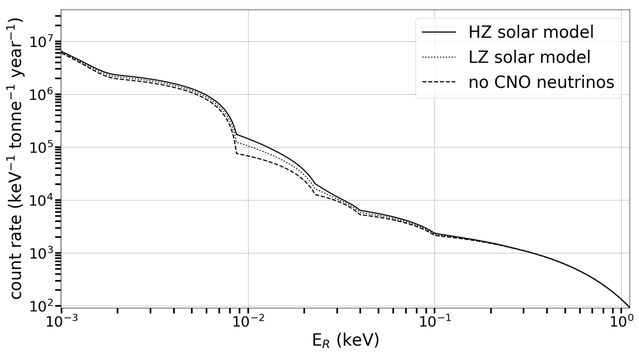
Al_2O_3 with 0.5 tonne years exposure:



Red band: theoretical uncertainty. Datapoints: mean and standard deviation of the reconstructed neutrino flux as a function of the background rate for a threshold of 1 eV.

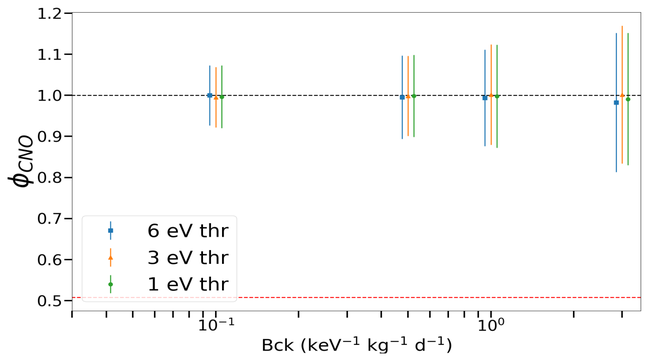
Sensitivity to CNO neutrinos

HZ and LZ solar models



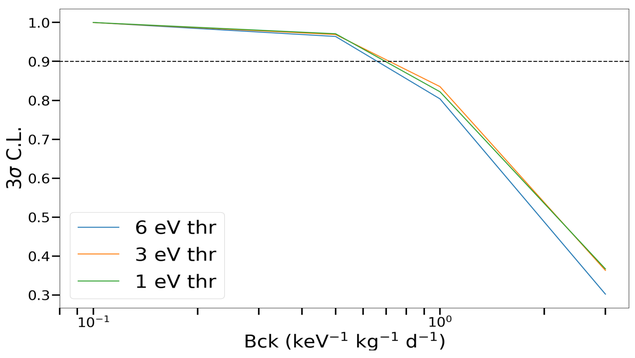
Difference between high-metallicity (HZ) and low-metallicity (LZ) BS05(OP) [2] models

Reconstructed summed CNO flux



$CaWO_4$ with 1 tonne year exposure black dashed: HZ, red dashed: LZ

Probability of rejecting LZ model



Probability of rejecting the LZ model with a significance of 3σ

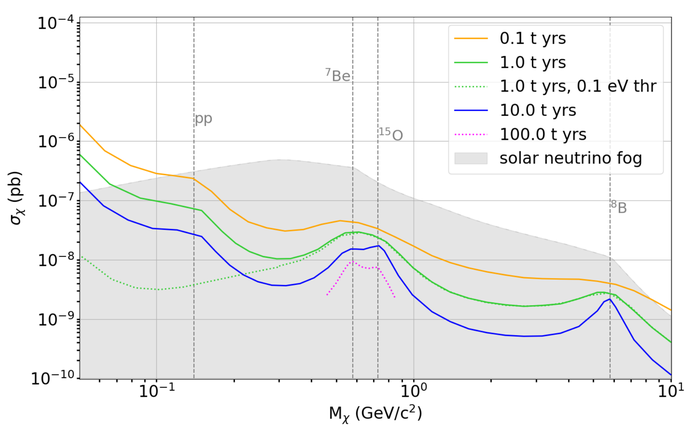
Conclusions

We explore the sensitivities of cryogenic solid state detectors to a flavor independent measurement of the fluxes of solar neutrinos. An experiment using $CaWO_4$ or Al_2O_3 detectors with an energy threshold of $\mathcal{O}$(1 eV) needs an exposure of $\mathcal{O}$(1 tonne years) and a background rate below $\mathcal{O}$(1/(keV kg d)) to be able to reconstruct the fluxes of ^{7}Be, pp and CNO neutrinos with an uncertainty of less than 10 %.

Furthermore, we show that a dark matter discovery is possible even below the classic definition of the neutrino floor.

Sensitivity to DM

Include DM signal, neutrinos are treated only as background.



3σ discovery potentials at 90% C.L. in $CaWO_4$ with 1 eV threshold at different exposures.

References

[1] G. Angloher *et al.*, (2024) [arXiv:2405.06527].

[2] J. N. Bahcall *et al.*, The Astrophysical Journal **621** (2005), doi:10.1086/428929.

[3] D. Papoulias *et al.*, Frontiers in Physics **7** (2019), doi:10.3389/fphy.2019.00191

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