CNO Solar Neutrino Flux Sensitivity with Theia

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Main Aim

Estimate sensitivity to the CNO neutrino flux from the Sun using a proposed large-scale optical detector with a water-based liquid scintillator target, Theia [1-2]. This is important for two reasons:

1. Precision measurement of the CNO flux can help refine solar models
2. Demonstrating potential for new detector technologies to be employed in Theia

CNO Solar Neutrinos

- CNO cycle energy production mechanism in Sun produces neutrinos yet to be experimentally observed
- Observation would help resolve tension regarding solar metallicity, due to linear dependence on heavy element content (Z>2)

$$^{13}\mathrm{N} \rightarrow {}^{13}\mathrm{C} + e^{+} + \nu_e$$

$$^{15}\mathrm{O} \rightarrow {}^{15}\mathrm{N} + e^{+} + \nu_e$$

$$^{17}\mathrm{F} \rightarrow {}^{17}\mathrm{O} + e^{+} + \nu_e$$

Eqns. 1-3: Neutrino producing reactions of the CNO cycle

Water-based Liquid Scintillator (WbLS)

- Class of novel scintillating liquids combining benefits of directional Cherenkov light, exploited in experiments like Super-Kamiokande, and high yield scintillation light, used in experiments like Borexino.
- This work considers various mixtures of linear alkyl benzene loaded with 2,5-Diphenyloxazole (LABPPO) and water
- Assumed for simulation: light yield of 100 photons/MeV per % scintillator, LABPPO scintillation time profile, emission spectrum, separate refractive index, absorption, scattering lengths for water/LABPPO

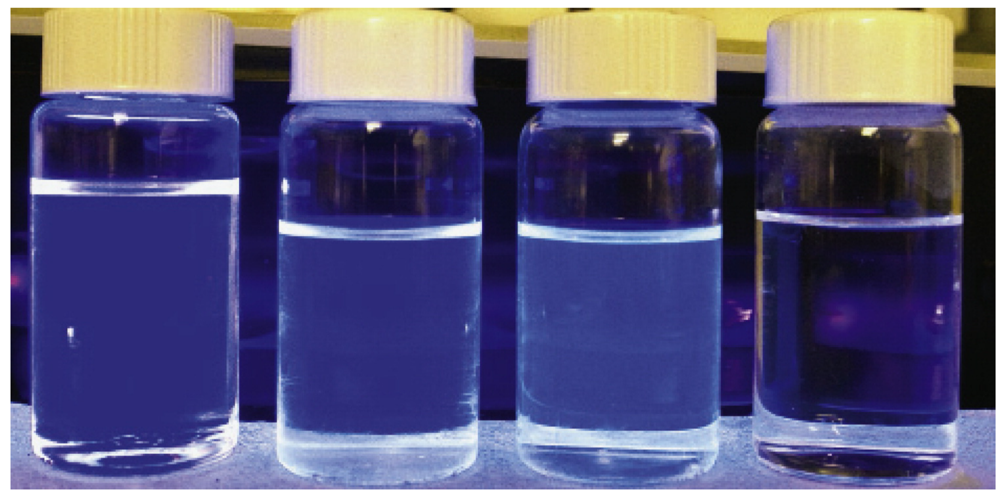

Fig. 1: Water-based liquid scintillator cocktails displaying scintillation [3]

Theia

- Multi-purpose, multi-kiloton, optical neutrino detector with WbLS target
- Two proposed scales, 25 kt and 100 kt, at depth of Sanford Underground Research Facility (SURF), 4300 mwe with 90% PMT coverage

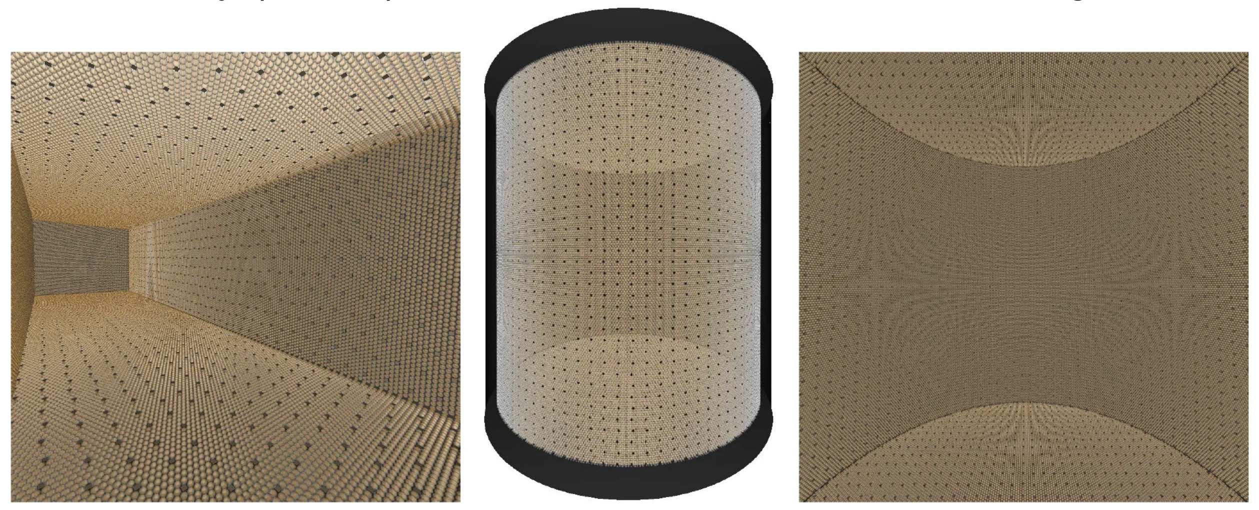

Fig. 2: Potential 25 kt (left) and 100 kt (center, right) detector configurations

Sensitivity Estimation Procedure

- 2D dimensional, binned, extended maximum likelihood fit in reconstructed energy, solar direction to estimate rate parameter sensitivity
- PDFs constructed for solar neutrino interactions, radioactive and cosmogenic backgrounds
- Lookup table-based energy reconstruction that estimates PMT hit count coming from Cherenkov, scintillation light and converts to energy
- Radioactive and cosmogenic backgrounds assumed isotropic in solar direction, while neutrino interactions follow neutrino-electron elastic scattering cross section smeared by characteristic resolution function, though achievable angular resolution currently unknown
- Conservative fiducial volume cut assumed to remove external backgrounds from PMTs and support structures.

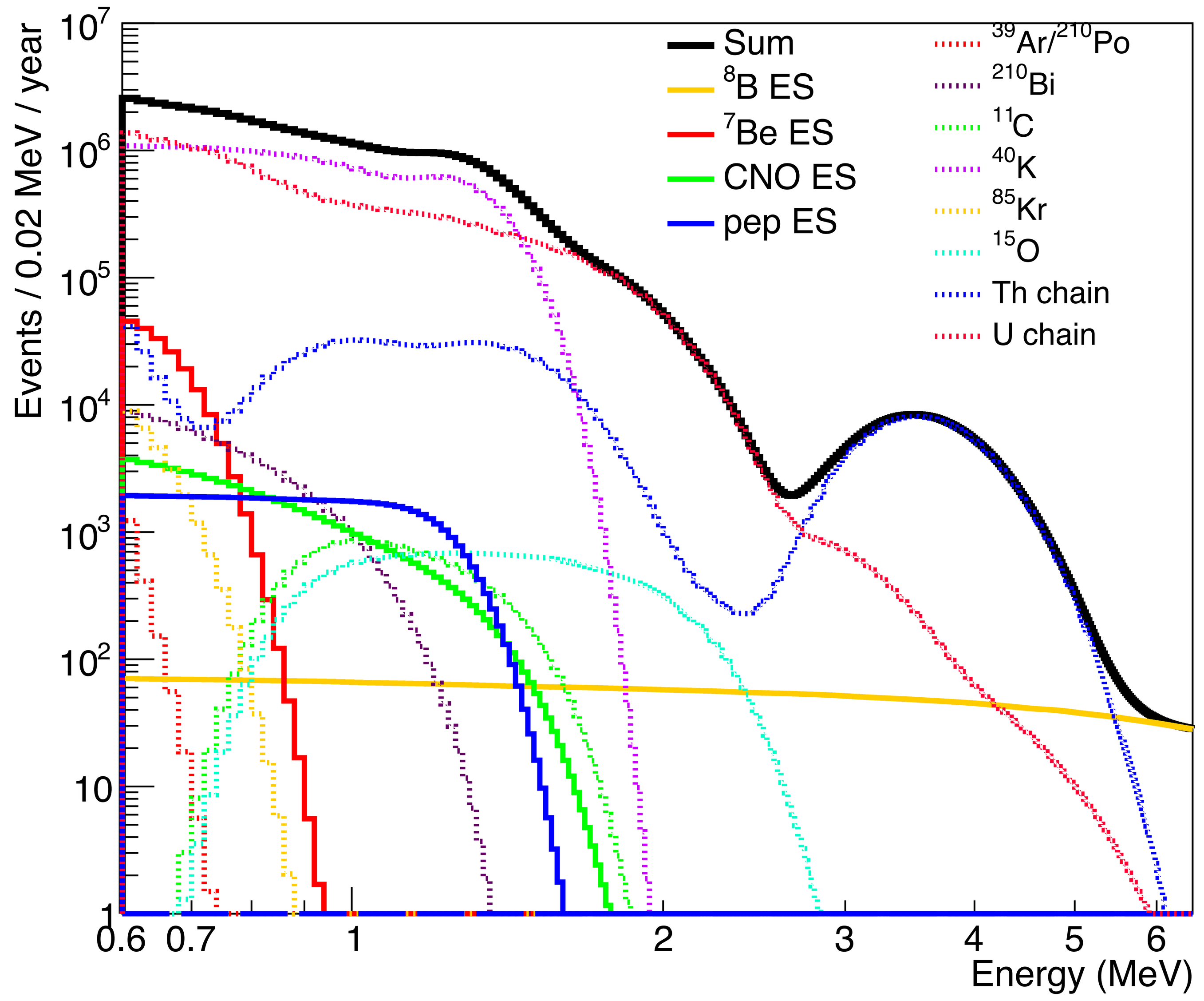

Fig. 3: Energy spectrum of expected signals for 25 kiloton, 5% WbLS loaded detector

Results

- 5 years data taking assumed, each configuration average of 100 fits
- Consider WbLS scintillator percentages, background levels, coincidence and alpha rejections, energy threshold, angular resolution

Target mass	WbLS	25°	45°	60°
100 kt	0.5%	4.7%	8.6%	12.1%
100 kt	1%	4.5%	8.0%	11.5%
100 kt	3%	3.7%	6.9%	9.8%
100 kt	5%	3.4%	6.3%	8.7%
25 kt	0.5%	11.1%	20.6%	28.4%
25 kt	1%	10.0%	18.1%	25.8%
25 kt	3%	8.0%	14.9%	21.5%
25 kt	5%	7.2%	12.9%	18.0%

Table 1: Relative uncertainty on fitted CNO normalization for detector configurations

Conclusions

- Sub 10%-level uncertainty to CNO flux achievable in Theia (no systematics, under assumptions here)
- Minor dependence on background level, rejection, WbLS scintillator fraction
- Increasing threshold from 0.6 MeV to 1.0 MeV degrades by factor of 5
- Angular resolution also significantly impacts sensitivity
- Improvement on current generation experiment with Theia requires WbLS cocktail and reconstruction with low energy threshold, fine angular resolution

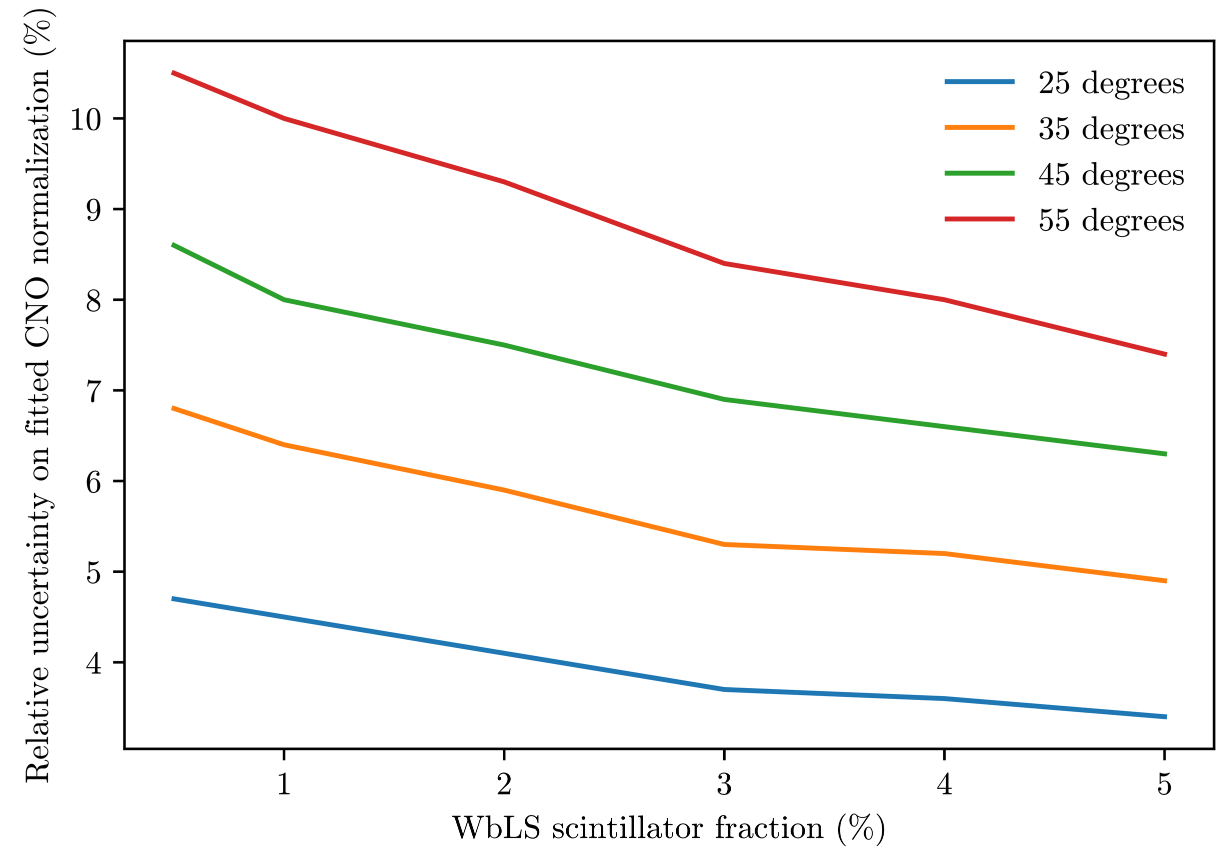

Fig. 4: Relative uncertainty on fitted CNO normalization as function of angular resolution and WbLS scintillator fraction, in 100kt

Future Work

- Potential for loading favorable isotopes, such as ^{7}Li, which has neutrino-nucleus charged current interaction cross section that highly correlates incoming neutrino and outgoing electron energy.
- Further detection channels may improve sensitivity to CNO flux, as well as other solar neutrino fluxes such as ^{8}B

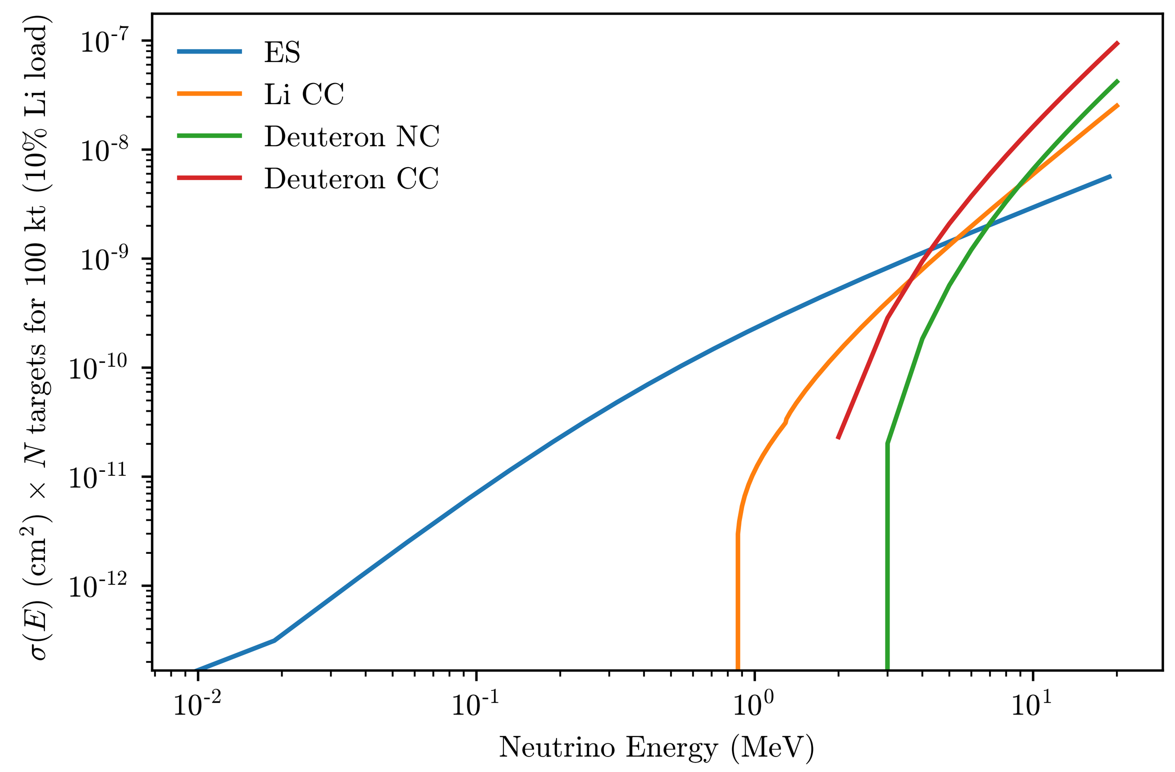

Fig. 5: Interaction cross sections weighted by available targets in 100 kt

References and Acknowledgements

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