Snowmass2021 - Letter of Interest

Reactor and Geo Neutrinos at SNO+

NF Topical Groups:

■ (NF1) Neutrino oscillations
□ (NF2) Sterile neutrinos
□ (NF3) Beyond the Standard Model
■ (NF4) Neutrinos from natural sources
□ (NF5) Neutrino properties
□ (NF6) Neutrino cross sections
■ (NF7) Applications
□ (TF11) Theory of neutrino physics
□ (NF9) Artificial neutrino sources
□ (NF10) Neutrino detectors

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Collaboration: SNO+

Abstract: SNO+ is a multipurpose neutrino experiment located 2 km underground in a Canadian mine. The detector will be filled with 780 tonnes of liquid scintillator and at present, contains 370 tonnes. With this amount of scintillator temporarily fixed, SNO+ has begun to measure antineutrinos from nuclear reactors and the local terrain. It is expected to measure the neutrino mass splitting Δm^2_{21} with a precision comparable to that of KamLAND, and make the first measurement of U/Th geo neutrino flux in the Western Hemisphere.

Detection at SNO+

SNO+ uses liquid scintillator to detect electron antineutrinos through the inverse beta decay (IBD) reaction: $\overline{\nu}_e$ + $p \rightarrow e^+$ + n [1]. The tight relationship between the kinetic energy of the detected positron and the incident antineutrino makes analysis of the measured energy spectrum relatively straightforward, and the delayed coincidence of the 2.2-MeV neutron capture γ provides powerful background rejection. Indeed, a few months of data with a nearly half-filled detector indicate that at present only ^{13}C$(\alpha, n)^{16}$O reactions are a relevant background to IBDs from reactor and geo neutrinos.

Reactor Neutinos

The KamLAND collaboration has studied neutrinos from reactors a few hundred km away using 1000 tonnes of liquid scintillator, producing the most precise measurement to date of $\Delta m^2_{21} = 7.53{\pm}0.18 \times 10^{-5}$ eV^2 [2]. Currently, this measurement is in mild tension with that made using solar neutrinos, which has a much larger uncertainty. The forthcoming JUNO experiment is expected to make subpercent measurements of both Δm^2_{21} and $\sin^2\theta_{12}$ [3], though SNO+ expects to be the next experiment to measure this mass splitting, ultimately at the percent level. Furthermore, the measurement samples different baselines, making use of distinct features in the measured energy spectrum.

Nearly 60% of the antineutrinos that SNO+ detects originate from three nuclear generating stations at two different baselines, which helps to preserve the spectral features due to neutrino oscillation, as illustrated in Fig. 1. The Bruce reactor complex is nearest to SNO+ at 240 km, and comprises the most powerful set of reactors currently active. The Pickering and Darlington complexes are 340 km and 350 km from SNO+, respectively. In contrast, KamLAND has an average baseline of 180 km and JUNO primarily samples two complexes, both at 53 km. As a result, SNO+ has more oscillation cycles accessible in the energy spectrum, which provides robustness against backgrounds and systematics.

When completely filled with scintillator, it is expected to detect about 110 IBDs per year, which is roughly four times lower than KamLAND when all reactors in Japan were operating, but the sensitivity to both Δm^2_{21} and $\sin^2\theta_{12}$ is compensated by the sharpness of the peak structures in the measured spectrum.

Geo Neutrinos

Antineutrinos are produced in the Earth during the beta-decay of ^{40}K and isotopes in the ^{238}U and ^{232}Th decay chains. The flux of these antineutrinos is of interest in geophysics because it conveys information about the radiogenic component of heat production in the Earth. At present, geophysical models have large uncertainties on the flux of the geo neutrinos; therefore, measurements made at locations with differing predicted fluxes can be analyzed together to better constrain the models.

The KamLAND collaboration was the first to detect geo neutrinos in 2005, in Japan [4], and since then has updated its measurement [2]. An independent measurement was made five years later by the Borexino collaboration in Italy [5], and has been updated recently [6].

Located in Sudbury, Ontario in Canada, SNO+ is well positioned for a third measurement of geo neutrino flux because the local geology in the region has been extensively characterized. The region is predicted to have a higher natural flux than that around either KamLAND or Borexino, making the SNO+ geo neutrino measurement an important addition to the global constraint of the mantle contribution to the total flux [7].

When completely filled with scintillator, it is expected to detect 20-30 IBDs per year from U/Th geo neutrinos. The measured energy spectrum spans from about 0.9 MeV to 2.6 MeV, which overlaps with the reactor neutrino spectrum as shown in Fig. 1. As such, these two types of neutrinos must be fit simultaneously in a single spectral analysis. At SNO+, reactor and geo neutrinos contribute approximately equally below 2.6 MeV and will be separated by their distinct spectra.

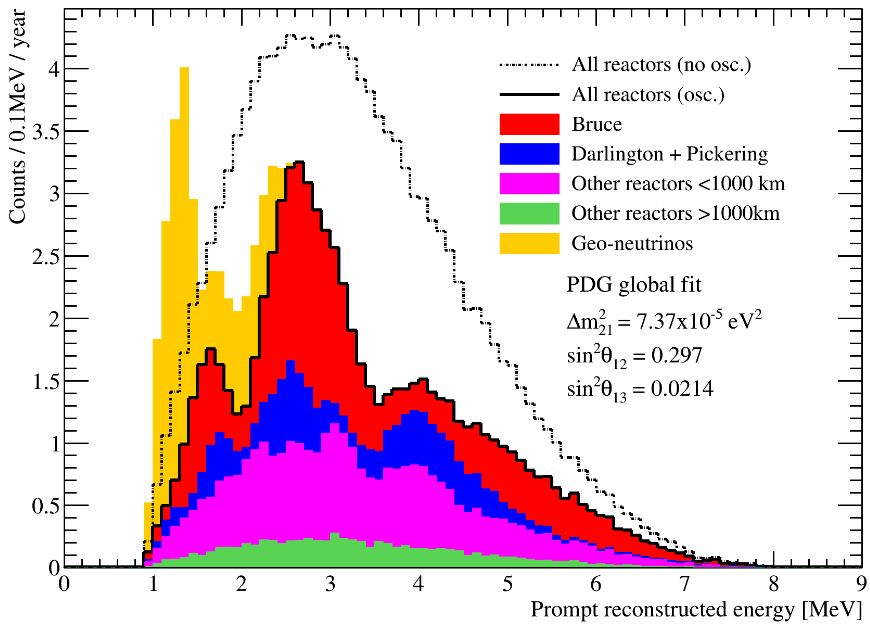

Figure 1: Predictions of measured energy distributions of prompt events from reactor and geo antineutrino IBDs in the SNO+ detector filled with scintillator. Various contributing components are stacked. The oscillation parameters used come from the global fit in the PDG 2016. The integral of the reactor histograms gives 110 IBDs per year within the acrylic vessel.

References

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