First direct evidence of the CNO fusion cycle in the Sun with Borexino

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Solar neutrinos are neutrinos produced in the nuclear fusion processes in the Sun's core and can provide direct information about the information. The main fusion process in the Sun is the *pp* fusion chain that produces about 99% of the energy. The CNO-cycle was first hypothesised as a main energy production mechanism in stars heavier than the Sun in 1938-39 by C.F. Weisäcker and H. Bethe independently. If present in the Sun, it is a sub-dominant and rare process. One of the open questions in solar physics is the so-called *metallicity*, i.e. the fraction of elements heavier than ^{4}He present in the Sun. Measurement of CNO-cycle neutrinos can help solve this puzzle as there is a 28% difference in its prediction by the Low Metallicity (LZ) and High Metallicity (HZ) models.

The Borexino detector is a liquid scintillator detector located at the Laboratori Nazionali del Gran Sasso (LNGS), Italy. The main goal of the experiment is the measurement of solar neutrinos. Solar neutrinos are detected via their elastic scattering off electrons in the liquid scintillator. Borexino has already performed a complete spectroscopy of the *pp*-chain solar neutrinos and recently in 2020, provided the first direct experimental evidence of the CNO-cycle in the Sun. The extreme radiopurity of the scintillator and the successful thermal stabilisation of the detector have proven to be valuable assets in the quest for CNO neutrinos.

The low abundance of CNO neutrinos and the similarity of its spectral shape to that of *pep* solar neutrinos and the intrinsic ^{210}Bi background, make CNO neutrino detection challenging. Therefore, it is necessary to constrain these backgrounds independently. While the *pep* solar neutrinos can be constrained with 1.4% precision using *pp/pep* ratio from theory, solar luminosity constraints, and experimental data of other solar neutrino experiments, the estimation of the ^{210}Bi background is fully dependent on the background levels in the experiment. Since the β-decays of ^{210}Bi cannot be distinguished from solar neutrino interactions, it can be measured through its daughter ^{210}Po (α-decays) which can be distinguished through an event-by-event basis via pulse shape discrimination, assuming that ^{210}Bi and ^{210}Po are in secular equilibrium. However, this required reducing the convective motions in the scintillator that brought additional ^{210}Po from peripheral sources. This was made possible through the thermal insulation and stabilization campaign performed between 2015 and 2016. A minimum ^{210}Po rate can be obtained from the cleanest region of the detector called the Low Polonium Field, leading to a ^{210}Bi upper limit. This gives a lower limit on the CNO-cycle solar neutrinos, and not a measurement. The energy and radial distribution of the events can then be exploited to perform a multivariate fit to obtain the CNO neutrino rate, using the above-mentioned *pep* and ^{210}Bi constraints. This also requires a careful evaluation of the systematic uncertainty associated with the Monte-Carlo spectral shapes used. A simple counting analysis was also performed, complementary to the multivariate fit, which confirmed the presence of CNO signal at $3.5\,\sigma$ significance level.

Borexino has successfully rejected the null hypothesis of CNO-cycle neutrinos in the Sun at greater than 5.0σ significance with 99% C.L., through a frequentist hypothesis test. The result is of utmost significance for Astrophysics, in order to understand the main energy production mechanism in the Universe and its stars. The Borexino experiment has already disfavoured Low Metallicity (LZ) in the Sun at 96.6% C.L. using its measurement of ^{7}Be and ^{8}B solar neutrinos. Future CNO measurements can be helpful in solving the metallicity puzzle.

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