Searching for solar hep neutrino interactions with Borexino

Georgy Raikov on behalf of the Borexino collaboration

National Research Center "Kurchatov Institute"

Abstract

Hep neutrinos from the Sun produced in the reaction $^3He + p \rightarrow {}^4He + e^+ + \nu_e$. According to Standard Solar Model (SSM) these neutrinos have the highest possible energies ($E < 18.8MeV$) and the lowest flux ($\sim 10^3\ cm^{-2}s^{-1}$). In Borexino the study of hep neutrinos is possible through the neutrino-electron elastic scattering and by means of neutral current reaction with carbon $^{12}C(\nu,\nu')^{12}C^*$. An upper limit on the integral total flux of hep neutrinos of $1.8 \cdot 10^5\ cm^2s^{-1}$ has been derived at the $90\%\ C.L.$

Previous studies of hep neutrinos

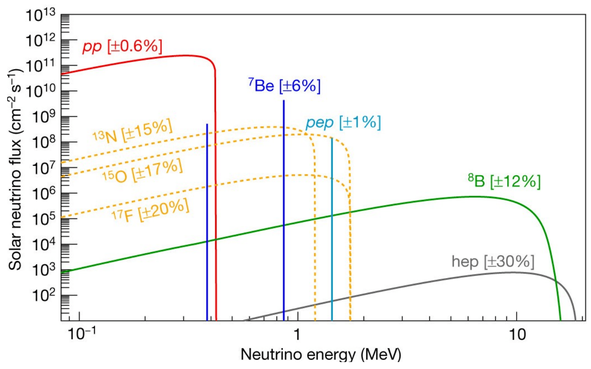

Figure 1: Solar neutrinos

According to Standard Solar Models hep neutrinos are produced in pp chain, having the total flux of $\sim 8 \cdot 10^3\ cm^{-2}s^{-1}$ and the endpoint 18.8 MeV.

Due to low flux the hep neutrinos are the only neutrinos produced in the solar pp-chain yet to be observed[1]. Previous experimental studies were performed by SNO and Super-Kamiokande detectors. Super-Kamiokande set an upper limit of $1.5 \cdot 10^5\ cm^{-2}s^{-1}$ $(90\%C.L.)$ on the integral total flux of hep neutrinos by neutrino-electron elastic scattering[2]. The most accurate upper limit has been obtained in the Sudbury Neutrino Observatory through the reactions in heavy water: $\Phi_{total} < 2.3 \cdot 10^4\ cm^{-2}s^{-1}$ $(90\%C.L.)$[3].

Possibilities of Borexino detector

Borexino detector

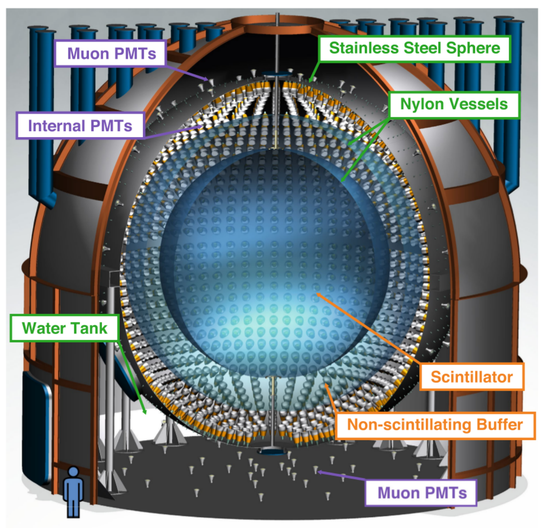

Figure 2: Borexino detector

- Located underground at 3800 mwe (in Italy, Gran Sasso)
- Target mass: 270 tons of liquid scintillator (C_9H_{12});
- Scintillation light is detected by 2212 (nominal) ETL 9351 8" photomultiplier tubes (PMTs) uniformly mounted on a 13.7 m-diameter stainless steel sphere (SSS)
- Two concentric spherical buffer shells separate the active scintillator from the PMTs and SSS (323 and 567 t, respectively) filled with pseudocumene solvent doped with dimethyl phthalate
- 208 8" PMTs as a Čerenkov detector (and veto) of cosmic muons
- Two semi-independent DAQ systems: the primary readout optimized for solar neutrino physics up to a few MeV, and a fast waveform digitizer system tuned for events above 1 MeV

Hep neutrinos in Borexino

The Borexino target mass is not optimized for a clear detection of neutrino fluxes at the level of $\sim 10^3\ cm^{-2}s^{-1}$, as predicted for hep neutrinos in the SSM. But due to liquid organic scintillator target it is possible to study hep neutrinos not only by neutrino-electron elastic scattering. In this work we search for hep neutrino interactions both with electrons and with carbon nuclei. In neutrino-electron elastic scattering the recoil electron is detected. And in reaction $^{12}C(\nu,\nu')^{12}C^*$ the exchange of Z-bozon is occurred and exited carbon nuclei emits photon with energy 15.11 MeV which is registered.The cross-section of this reaction strongly rising with the increasing of neutrino energy[4].

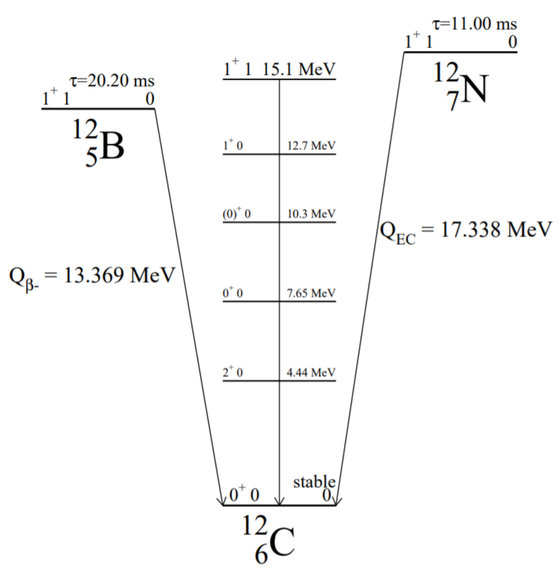

Figure 3: Level diagram for the $^{12}C, ^{12}N, ^{12}B$ triad.

- Located underground at 3800 mwe (in Italy, Gran Sasso)

Analysis details

Data selection

For this analysis we used data from November 2009 until October 2017, that corresponds to 4.766 live yerars anf 745 t · y exposure. For searching hep neutrino interactions following selection criteria were applied:

- event is present in both DAQ systems
- only point-like events are considered
- all muon and noise events are dropped
- 6.5 s veto is applied after each muon crossing the detector and after each start of the new run (to remove fast cosmogenic activity from muons)
- energy of candidate events falls in the [11, 20] MeV energy range (this energy range corresponds to best signal-background ratio)
- event vertex position is 25 cm away from the nylon vessel, corresponding to a fiducial target mass of 216 tons

Finally were observed ten candidate events which sutisfy all selection criteria.

Background sources

The background sources in the hep energy range are ^8B solar neutrinos, atmospheric neutrinos, untagged muons, and long-lived cosmogenic isotopes

- ^8B solar neutrinos: spectrum of ^8B solar neutrinos is well measuared by Borexino. And number of expected events from this background source is 7.61±0.54
- untagged muons: to calculate number of muon events we used data from outer detector (208 PMTs) and additional electronics algorithms. Number of expected events in energy range [11,20 MeV] is 2.2±1.5
- number of events from cosmogenic ^{8}B and ^{8}Li above 11 MeV is 0.55±0.20
- The number of background events induced by atmospheric neutrino interactions via charged and neutral currents with protons and carbon nuclei in the scintillator is estimated with the GENIE Monte Carlo. The number of events induced by atmospheric neutrinos in the hep range and exposure after data selection cuts is 2.4±1.6

In summary, the total number of expected events from backgrounds is 12.8±2.3, to be compared with the observed ten events.

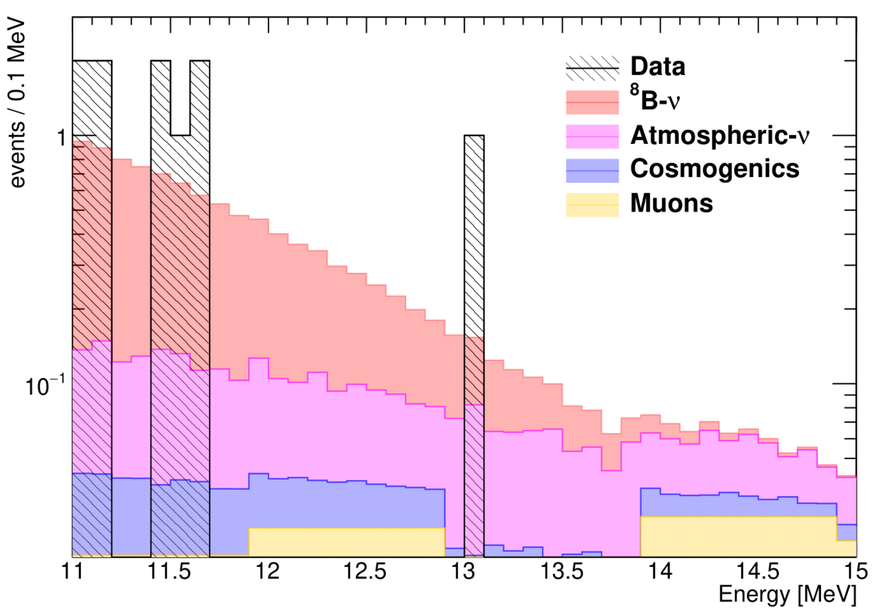

Figure 4: Energy spectrum of selected events above 11 MeV, compared with the expected background spectrum

Results

For obtaining limit on total hep neutrino flux we used two methods: Feldman-Cousins approach and profile likelihood approach. The result are consistent: $< 2.2 \cdot 10^5\ cm^{-2}s^{-1}$[5] and $< 1.8 \cdot 10^5\ cm^{-2}s^{-1}$[6] respectively. The PL limit is ~ 1.2 times stronger due to the inclusion of the additional background from atmospheric neutrinos.

[1] Agostini, M., et al. "Simultaneous precision spectroscopy of pp, Be 7, and pep solar neutrinos with Borexino Phase-II." Physical Review D 100.8 (2019): 082004;

[2] Hosaka, J., et al. "Solar neutrino measurements in Super-Kamiokande-I." Physical Review D 73.11 (2006): 112001;

[3] Aharmim, B., et al. "A search for neutrinos from the solar hep reaction and the diffuse supernova neutrino background with the sudbury neutrino observatory." The Astrophysical Journal 653.2 (2006): 1545;

[4] Cadonati, L., F. P. Calaprice, and M. C. Chen. "Supernova neutrino detection in Borexino." Astroparticle Physics 16.4 (2002): 361-372;

[5] Agostini, M., et al. "Comprehensive measurement of pp-chain solar neutrinos." Nature 562.7728 (2018): 505-510;

[6] Agostini, M., et al. "Improved measurement of B 8 solar neutrinos with 1.5 kt · y of Borexino exposure." Physical Review D 101.6 (2020): 062001.