IL NUOVO CIMENTO Vol. 37 C, N. 1 Gennaio-Febbraio 2014
DOI 10.1393/ncc/i2014-11675-8

Colloquia: IFAE 2013

The Borexino experiment: Recent results and future plans

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ricevuto l'1 Ottobre 2013

Summary. — The Borexino experiment (located at Laboratori Nazionali del Gran Sasso) is the most radiopure liquid scintillator neutrino detector allover the world. Starting from 2007, the Borexino experiment provided a precision measurement of ^{7}Be solar neutrino flux (including also a detailed day/night modulation analysis), and gave the first detection of *pep* neutrinos, a detection of the ^{8}B neutrinos at low energy threshold (3 MeV) and an important contribution to the geo-neutrino physics. The forthcoming program includes an improvement of the solar neutrino and geo-neutrino detection and an important project focused on the sterile neutrino search (SOX).

PACS `14.60.St` – Non-standard-model neutrinos, right-handed neutrinos, etc..
PACS `26.65.+t` – Solar neutrinos.
PACS `95.55.Vj` – Neutrino, muon, pion, and other elementary particle detectors; cosmic ray detectors.
PACS `29.40.Mc` – Scintillation detectors.

1. – Solar physics scenario

Solar neutrinos are an important tool to study the physics at the core of the Sun and neutrino propagation in dense matter. Solar neutrinos are produced by two main reaction chains which turn hydrogen into helium according to the Solar Standard Model (SSM) [1, 2]. The most abundant source of neutrinos comes from the *pp* reaction. The flux of these *pp* neutrinos depends on a number of input parameters, *i.e.* the luminosity of the Sun, the age, the opacity, the heavy elements to hydrogen ratio abundance and the astrophysical factors related to the interaction cross-sections of the reaction considered in the model. The uncertainties on these input parameters affect the overall uncertainty on the predicted neutrino fluxes. Figure 1 shows the SSM electron neutrino fluxes, mostly in the sub-MeV energy region. Since 2005, the new opacity calculations and a revised determination of solar surface heavy-element abundances have been showing a relevant disagreement between the SSM and helio-seismology measurements [3, 4]. As a consequence, we distinguish two SSM outputs named high (SSM-GS98) [5] and low (SSM-AGSS09) [6] metallicity, respectively. After about 40 year of neutrino experiments we can explain all the measurements in the framework of matter-enhanced neutrino oscillations (MSW-LMA) [7-10]. Figure 2 shows the survival probability of solar electron neutrinos as predicted by the oscillation scenario and as determined by observations. The most interesting feature of the survival probability is the so-called upturn at 2–3 MeV. Future measurements of pep and ^{8}B solar neutrinos could improve our determination of this effect predicted by the matter to vacuum transition of neutrino oscillations inside the sun. The future measurements should also solve the metallicity problem by observing CNO neutrinos. The Borexino experiment is already pioneering this possibility also considering further improvements of the apparatus itself. Figure 3 shows the expected solar neutrino spectrum in Borexino phase II, with a lower background after a new purification of the liquid scintillator. This spectrum includes subtraction of ^{11}C cosmogenic background according to the method reported in [11].

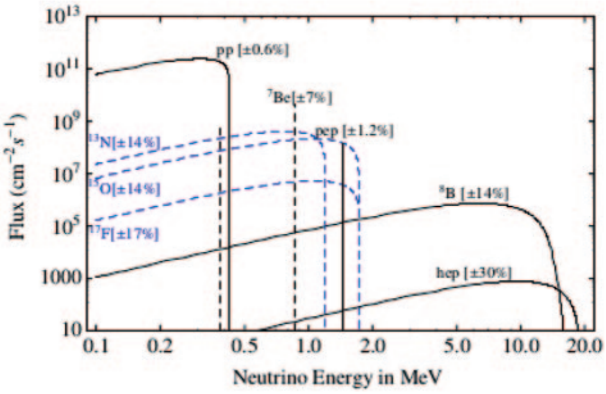

Fig. 1. – Solar neutrino spectrum [2].

2. – The Borexino experiment

The Borexino experiment is a liquid scintillator detector for sub-MeV solar neutrinos. They are detected by means of their elastic scattering on electrons. The very high radiopurity of the detector (the contamination is lower than 10^{-18} g/g for ^{238}U and lower than 3×10^{-18} g/g for ^{232}Th) allowed us to achieve a precise measurement of the rate induced by the monochromatic electron neutrinos (862 keV) produced by the ^{7}Be electron capture in the sun [12], a first detection of the *pep* solar neutrinos [11], a low energy threshold (3 MeV) detection of ^{8}B neutrinos [13] and a significant detection of the geo-neutrinos through the inverse beta reaction [14]. The future program of the phase II is focused also on the possibility of the *pp* and CNO solar neutrino detection.

The ^{7}Be neutrino flux is obtained by fitting the energy spectrum extracted by the scintillation light after an accurate data selection. Figure 4 shows the main features of this result. Our best measurement of the 862 keV ^{7}Be neutrino interaction rate is $46.0 \pm 1.5(\mathrm{stat})^{+1.5}_{-1.6}(\mathrm{sys})$ counts/day/100 tons.

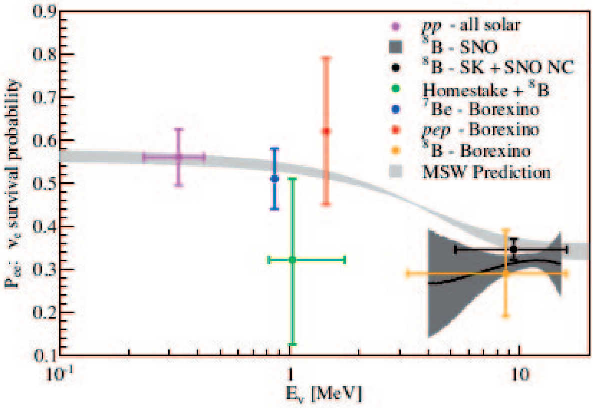

Fig. 2. – Solar neutrino survival probability as predicted by the MSW-LMA scenario and as determined by present observations.

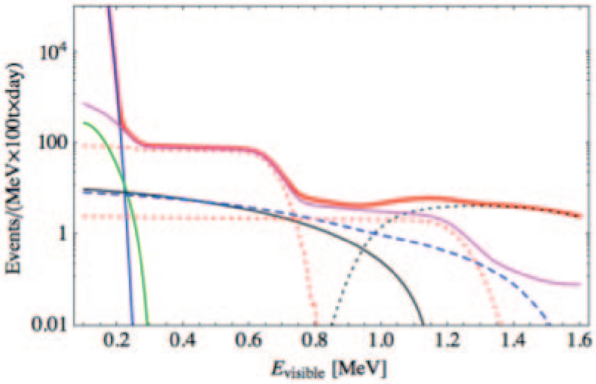

Fig. 3. – Solar neutrino spectrum in Borexino phase II. The solid black line shows the ^{210}Bi background at the level of 5 cpd/100 tons. The dashed line which goes up to 5 MeV shows the CNO neutrino contribution.

The Borexino experiment showed a clear lack of day/night asymmetry for the ^{7}Be solar neutrino flux. This result is useful to probe the MSW-LMA prediction and is potentially sensitive to new physics affecting low energy electron neutrino interactions [15]. Thanks to its unpredicted performances, Borexino determined the rate of pep solar neutrino interactions, equal to $3.1 \pm 0.6(\text{stat}) \pm 0.3(\text{syst})$ counts/day/100 tons. Assuming the pep neutrino flux predicted by the SSM, we also got a constraint of < 7.9 counts/day/100 tons (95% C.L.) for the CNO neutrino interaction rate [11]. This result was obtained after a rejection of cosmogenic ^{11}C, the dominant background in the 1–2 MeV region, tagged through the three-fold coincidence of the events generated by muons, the capture of the spallation neutron and the decay of ^{11}C. The future improvement of the measurements discussed above and the possible first detection of the pp component will strongly probe the MWS-LMA model. Also, a stronger upper limit or a real detection of the CNO component could solve the metallicity problem.

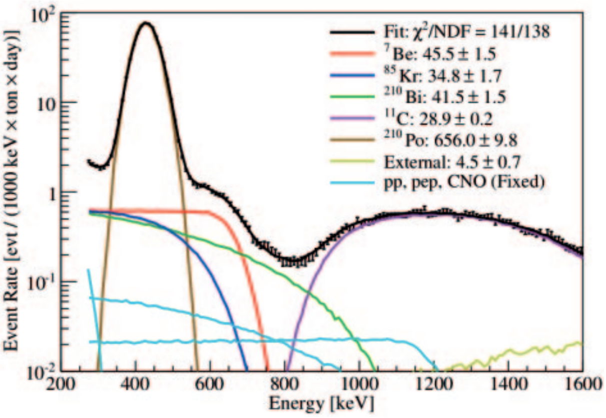

Fig. 4. – Borexino spectrum. The solid red curve shows the ^{7}Be contribution to the Borexino energy spectrum.

3. – Neutrino source in Borexino (SOX project)

The SOX project is aimed to study the possibility of searching for sterile neutrinos by means of neutrino and anti-neutrino artificial sources located near or inside the detector [16]. The main idea is to set up a ^{51}Cr neutrino source similar to the one used by the Gallex experiment. This source will be activated in a nuclear reactor (estimated activity of 10 MCi) and will provide a huge flux of sub-MeV neutrinos at short distance ($< 10\,\mathrm{m}$). This experiment can probe the gallium anomaly region, and cover almost completely the reactor anomaly region at 3σ level. Another possibility consists of using a ^{144}Ce internal anti-neutrino source placed at the center of the detector. This other set-up would cover at 3 level the whole reactor anomaly region and can drive a possible discovery of the sterile neutrino in the $\Delta m^2 \simeq 1\,\mathrm{eV}^2$ and $\sin^2(2\theta) > 0.02$ region. This configuration could allow us to detect neutrino waves with a clear signature, useful to solve the sterile neutrino puzzle.

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N. Rossi would like to thank the organizers of IFAE2013 Conference in Cagliari. The Borexino experiment is supported by INFN (in particular LNGS - Italy), NSF (USA), BMBF, DFG, and MPG (Germany), NRC Kurchatov Institute (Russia), and MNiSW (Poland).

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