IL NUOVO CIMENTO Vol. 33 C, N. 6 Novembre-Dicembre 2010
DOI 10.1393/ncc/i2011-10780-6

Colloquia: IFAE 2010

Geo-neutrinos signal with Borexino

A. C. Re(*) on behalf of the Borexino Collaboration

Dipartimento di Fisica, Università di Milano and INFN, Sezione di Milano - 20133 Milano, Italy

(ricevuto l' 8 Ottobre 2010; pubblicato online l'8 Febbraio 2011)

Summary. — Geo-neutrinos are electron antineutrinos produced in β-decays of long-lived radioactive isotopes naturally present in the Earth (^{238}U, ^{232}Th and ^{40}K). By measuring their fluxes it is possible to have a unique direct probe of our planet's interior, to reveal the terrestrial distribution of uranium and thorium and to assess the radiogenic contribution to the total heat balance of the Earth. The Borexino experiment is one of the few which can perform a geo-neutrino analysis: we present the evidence of geo-neutrinos' signal with 252.6 ton·y Borexino data.

PACS `14.60.Pq` – Neutrino mass and mixing.
PACS `91.35.-x` – Earth's interior structure and properties.

1. – Introduction

In this paper, we present the evidence of geo-neutrinos' signal obtained by Borexino. Antineutrinos on Earth are geo-neutrinos and reactor-$\overline{\nu}_e$. Geo-neutrinos (geo-$\overline{\nu}_e$) are electron antineutrinos produced in β decays of ^{40}K and of several nuclides in the chains of long-lived radioactive isotopes ^{238}U and ^{232}Th. Geo-$\overline{\nu}_e$ are direct messengers of the abundances and distribution of radioactive elements within our planet. By measuring their flux and spectrum it is possible to reveal the distribution of long-lived radioactivity in the Earth and to the radiogenic contribution to the total heat balance of the Earth. The unprecedently low intrinsic radioactivity achieved in Borexino ($\sim 10^{-17}$ g/g for ^{238}U and ^{232}Th), the high photon yield and the large number of free target protons offer a unique opportunity for a sensitive search for $\overline{\nu}_e$'s in the MeV energy range. Borexino [1] is a real-time experiment for low-energy neutrino spectroscopy, operating since May 2007 at the underground Laboratori Nazionali del Gran Sasso. In Borexino, solar neutrinos are detected by means of their elastic scattering on electrons in a liquid scintillator target, 278 tons of pseudocumene (PC) doped with 1.5 g/l of diphenyloxazole (PPO), a fluorescent dye. The scintillator is confined within a thin nylon vessel (4.25 m radius) and is shielded from external radiation by 890 tons of liquid buffer, a solution of PC and 5.0 g/l

(*) E-mail: `alessandra.re@mi.infn.it`

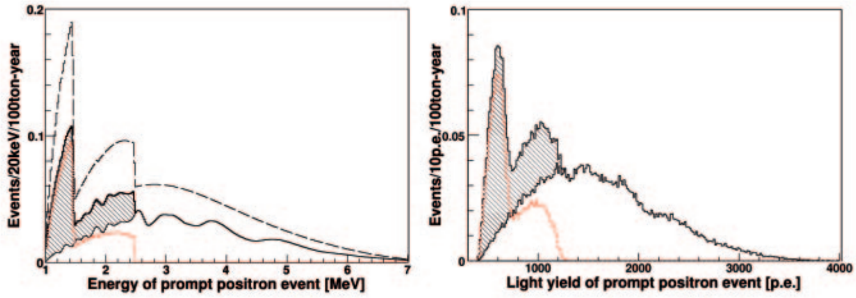

Fig. 1. – (Colour on-line) On the left, the expected spectrum for $\overline{\nu}_e$ in Borexino (prompt event). Dashed line: total geo-$\overline{\nu}_e$ + reactor-$\overline{\nu}_e$ without oscillations; solid thick lines: geo-$\overline{\nu}_e$ and reactor-$\overline{\nu}_e$ with oscillations; dotted red line: geo-$\overline{\nu}_e$ with the high (low) energy peak due to decays in the ^{238}U + ^{232}Th chains; solid thin line: reactor-$\overline{\nu}_e$. On the right, the expected prompt positron event spectrum as obtained from the MC code, using the plot on the left as input and the selections cuts described in [2].

of dimethylphthalate (DMP), a light quencher. A second nylon vessel (5.75 m radius) protects the active target from the radon emanating from the periphery of the detector. 2212 8″ PMTs, mounted on a stainless steel sphere (SSS), detect the scintillation light. Finally, the SSS is installed inside a 9 m radius, 16.0 m height water tank (WT) which provides the necessary shielding against rock-induced external backgrounds. Čerenkov light radiated by muons passing throught the WT is measured by 208 8″ external PMTs. Borexino detects anti-neutrinos via the inverse neutron β-decay ($\overline{\nu}_e + p \rightarrow e^+ + n$) with a threshold of 1.806 MeV. Some $\overline{\nu}_e$ from the ^{238}U and ^{232}Th series are above threshold while those from ^{40}K decays are below threshold. The inverse β reaction turns out one prompt and one delayed event whose time and spatial coincidence offers a clean and unmistakable signature of $\overline{\nu}_e$ detection.

2. – Anti-neutrinos candidates selection

This analysis relies on data collected between December 2007 and December 2009, corresponding to a lifetime of 537.2 days. The fiducial exposure after cuts is 252.6 ton·y. The expected prompt spectrum in figs. 1 was obtained taking into account for what concerns geo-$\overline{\nu}_e$, the known energy spectra of β-decays, the chondritic Th/U mass ratio of 3.9, and the geo-$\overline{\nu}_e$ fluxes derived from the Bulk Silicate Earth (BSE) geochemical model [3]; for what concerns the expected signal from reactor-$\overline{\nu}_e$, we collected the detailed information on the time profiles of power and nuclear fuel composition for nearby reactors. As reported in detail in [2], the software strategy adopted to reduce the background includes muon veto and time window acceptance, correlated distance, energy and radial cuts on the coincidence events. The background is mainly due to cosmogenic nuclides (*i.e.* ^{9}Li and ^{8}He) crossing the scintillator, to accidental coincidences and to (α, n) reactions occuring because of the ^{210}Po content in the scintillator and in the buffer. The expected number of background events in the fiducial exposure (252.6 ton·y) results 0.40 ± 0.05 events: the signal-to-background ratio in the $\overline{\nu}_e$'s Borexino search is an unprecedented $\sim 50{:}1$.

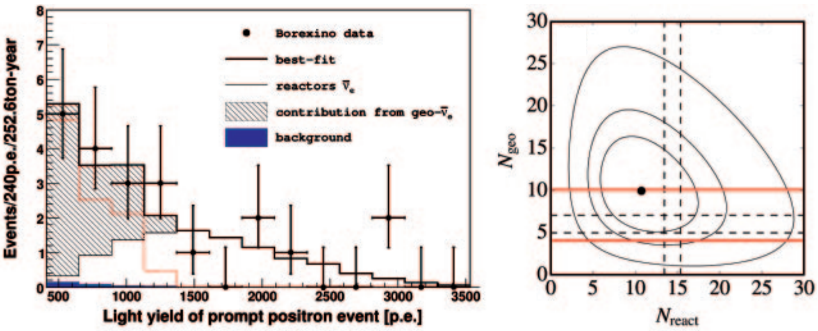

Fig. 2. – (Colour on-line) On the left, the light yield spectrum for the positron prompt events of the 21 $\overline{\nu}_e$ candidates and the best fit obtained with the unbinned likelihood analysis; the conversion factor is approximately 500 p.e/MeV. On the right, the allowed regions for N_{geo} and N_{react} at 68%, 90% and 99.73% CL. Vertical dashed lines: 1σ range about the expected N_{react} (with oscillations); horizontal dashed lines: range for N_{geo} prediction based on [4]; horizontal red lines: prediction of the Maximal and Minimal Radiogenic Earth models.

3. – Results

A total of 21 $\overline{\nu}_e$ candidates pass all the selection cuts described above. From fig. 2 (left) it can be seen that fifteen candidates are in the geo-$\overline{\nu}_e$ energy window and six candidates have a light yield exceeding 1300 p.e. The 50:1 signal-to-background ratio and the clear separation of the two $\overline{\nu}_e$ sources permit a clear identification of the number of events belonging to each source, and allow to establish observation of the geo-neutrinos. Our best estimates are $N_{geo} = 9.9^{+4.1}_{-3.4}(^{+14.6}_{-8.2})$ and $N_{react} = 10.7^{+4.3}_{-3.4}(^{+15.8}_{-8.0})$ at 68.3% CL (99.73% CL). Scaling the best estimate of N_{geo} with the fiducial exposure, we obtain as our best measurement for the geo-neutrinos rate $3.9^{+1.6}_{-1.3}(^{+5.8}_{-3.2})$events/(100 ton $\cdot$ y). By studying the profile of the log-likelihood (see fig. 2 right) with respect to N_{geo}, we calculated that the null hypothesis for geo-$\overline{\nu}_e$ can be rejected at 99.997% CL that means that we establish observation of geo-neutrinos at 4.2σ. In fig. 2 (right) we also report as terms of comparison upper and lower bounds on the BSE model [4], considering the spread of U and Th abundances and their distributions according to this model; the expectation under the Minimal Radiogenic Earth scenario which considers U and Th from only those Earth layers whose composition can be studied on direct rock samples; the expectation under the Maximal Radiogenic Earth scenario which assumes that all terrestrial heat is produced exclusively by radiogenic elements.

REFERENCES

[1] Alimonti G. *et al.* (Borexino Collaboration), *Nucl. Instrum. Methods A*, **600** (2009) 568.
[2] Bellini G. *et al.* (Borexino Collaboration), *Phys. Lett. B*, **687** (2010) 299.
[3] Mantovani F. *et al.*, *Phys. Rev. D*, **69** (2004) 013001.
[4] Fiorentini G. *et al.*, *Phys. Rep.*, **453** (2007) 117.