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ScienceDirect
Nuclear Physics B (Proc. Suppl.) 168 (2007) 111–114
NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS
www.elsevierphysics.com

Borexino

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In the exciting field of the solar neutrino investigation a new player is expected to enter soon this challenging arena: Borexino. Such a massive, calorimetric, liquid scintillation detector, completely installed and ready for operations at the underground Gran Sasso Laboratory, is aimed towards one of the more demanding aspect of this research, i.e. the real time determination of the flux of the sub-MeV neutrinos produced in the ^7Be electron capture reaction in the Sun. As a prototype program for the large scale detector, the Counting Test Facility, operated for several years at Gran Sasso, gave the convincing demonstration that the crucial technological challenge of the experiment, the achievement in the scintillator of unprecedented radiopurity levels, can be reached successfully, thus providing the solid experimental foundation for the powerful detection technique with which Borexino will start to reveal solar neutrinos from the middle of 2007.

1. INTRODUCTION

A long saga of more than 30 years of measurements is at the basis of the solar neutrino research, which along its history evolved from a pure astrophysical puzzle to a crucial particle physics issue. The strong hints provided by the pioneer experiments of scenarios beyond the standard model, characterized by possible neutrino mass/mixing properties of massive neutrinos leading to oscillation effects among different neutrino flavours, have been finally confirmed by the epochal measurement of SNO [1] which proved unambiguously the presence of a non electron neutrino component in the solar flux.

In this framework, Borexino [2], will provide soon new important data through the precise determination of the ^7Be solar neutrinos, whose detection will shed further light to the neutrino mass/mixing properties, representing in particular a unique window to confirm in the low energy regime the operation of the MSW conversion mechanism.

2. THE BOREXINO DETECTOR

Borexino is based on 300 tons of liquid scintillator acting as detection medium, contained in a nylon transparent vessel of 8.5 m of diameter, observed by more than 2200 photomultiplier tubes located on a stainless steel sphere of 13.7 m of diameter. The whole detector, as sketched in figure 1, is enclosed in a cilindrical tank of 18 meter of diameter and 17 m of maximum height.

A three liquids design envisages scintillator in the inner vessel, pure solvent (Pseudocumene) in the buffer region between the inner vessel and the sphere, and water in the external tank.

The phototubes in the light detection system are partly (1800) devoted to the detection of the scintillation signals, while the remaining 400 will observe the pulses of cosmic muons passing either in the PC buffer or in the water in the external tank.

2.1. The liquid scintillator

The liquid scintillator is the key element for the success of the experiment. Its high luminosity and extremely high radiopurity are indeed the factors which make the experiment feasible. The scintillaton cocktail is realized with Pseudocumene as solvent, and PPO at the concentration of 1.5 g/l as solute.

A thorough series of laboratory tests have been performed over the entire period of research and development to asses the intrinsic optical properties of the scintillator, as well as its radiopurity.

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doi:10.1016/j.nuclphysbps.2007.02.064

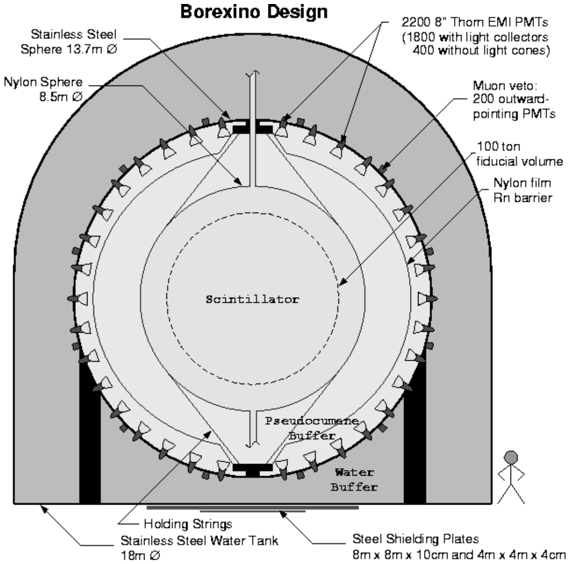

Figure 1. Sketch of the Borexino detector.

Its light yield resulted equal to about 11,000 photons/MeV, the attenuation length at 420 nm 30 m, the scattering length at the same wavelength 7 m, the fast component of the decay time 3.5 ns. The mixture resulted also characterized by a good α/β discrimination.

2.2. Phototubes, light concentrators and electronics

The phototubes that will be used in the detector are the 8" 9351 manufactured by Electron Tubes Limited (former Thorn Emi ETL). They feature a limited transit time dispersion (1 ns), a pronounced peak to valley ratio (2.5), a reduced dark noise rate (1 kHz), a low afterpulsing probability (<3%). Special low radioactivity glass and internal parts have been used for their construction.

The light cones have been designed following the prescription for non imaging devices intended to enhance light collection. Specifically, they are truncated string cones with a maximum length of 24 cm, realized with anodized aluminium, a material which features good reflectivity in the 400 nm region as well as good capability to withstand Pseudocumene.

The DAQ electronics for each triggered event measures the pulse height and the photoelectron arrival times of the photomultipliers signals. The former information is used to infer the original event energy, while the latter is exploited in order to estimate the event position.

In addition, the absolute time of the event is measured and stored, for the cross check of possible astronomical events, like supernova neutrino bursts, recorded by other detectors.

2.3. Calibrations

A variety of calibration and monitoring systems are planned to assure a careful understanding of the detector operational conditions during the data taking.

A fiber system laser-based will provide the time and gain calibration of the pmts + electronic channels.

External thorium sources, located just inside the stainless steel sphere, at the level of the light concentrators entries, will be used to check the stability in time of the detector, while the position reconstruction capability will be checked via internal sources deployed in the core of the detector.

A continuous check of the stability of the optical properties of the buffer and of the scintillator will be carried out by exploiting lasers with different wavelengths.

Finally, it has to be underlined that the collaboration is actively pursuing an overall detector test via a ^{51}Cr neutrino source, whose purpose will be to demonstrate unambiguously that the detector is really able to detect neutrinos.

2.4. Plants

An important role in the Borexino operation is that of the numerous plants located near the detector.

The purification systems are targeted to reaching and maintaining the challenging radipurity requirements of the experiment. They can perform distillation, water extraction, nitrogen stripping and silica gel column extraction of the scintillator.

Other two plants are the water purification system and the liquid handling. The former is targeted to the purification of the outside water, while the latter is the ensemble of connections, pumps and storage tanks for the preparation of the scintillator solution and its transfer into the vessel.

The ensemble of the plants is completed by four storage vessels and by a system to deliver Nitrogen gases at extremely high level of purity.

3. NEUTRINO DETECTION IN BOREXINO

In Borexino neutrino detection will occur through the scattering off the electrons of the scintillator $\nu + e^- \to \nu + e^-$ signalled by the light produced by the scattered electron.

The threshold will be as low as 250 keV, allowing the detection of the monoenergetic ^7Be neutrinos (in particular its component at 0.862 MeV), producing in the detector a continuum recoil spectrum (maximum energy of 0.66 MeV).

According to the current MSW solution, the expected event rate should be of about 35 ev/day, for a fiducial volume of 100 tons. On the other hand, the background for the target purities of $10^{-16} g/g$ of U and Th and $10^{-14} g/g$ of natural K, is of the order of 15 ev/day.

In figure 2 the expected spectrum of the scattered electrons is reported, together with the prediction for the dominant, internal background.

4. PHYSICS GOALS

The measurement of the ^7Be component from the Sun maintains intact its validity and importance: not only it will provide the first accessible window to the low energy region where the majority of the solar neutrino production occurs, but it will give the opportunity to check the operation of the MSW mechanism in the sub-MeV regime, by the direct detection of the so-called matter-vacuum transition.

Furthermore, Borexino will represent the first opportunity for a clue towards the investigation of the CNO and pep neutrinos, by exploiting the cosmogenic rejection technique illustrated in [3].

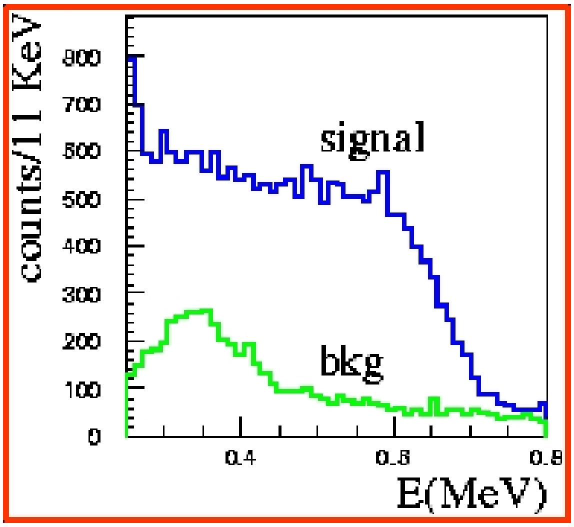

Figure 2. Monte-Carlo simulation of the ν signal and background rate in the $^7Be_\nu$ events observation window.

Besides the main focus of ^7Be neutrinos detection, a broad program of antineutrino science is made it possible via the reaction $\overline{\nu} + p \to n + e^+$ characterized by a threshold of 1.8 MeV, followed, with a time constant of 200 μs, by the reaction $n + p \to^2_1 H + \gamma$ signalled by the precise gamma energy of 2.2 MeV.

Due to this capability, in Borexino it will be possible to search for solar antineutrinos, for geophysical $\overline{\nu}_e$ from the Earth, for $\overline{\nu}_e$ of supernova origin.

It should be pointed out, finally, that the expected detection of the 7% annual modulation of the flux due to the variation along the year of the Earth-Sun distance will represent a powerful tag to demonstrate the solar origin of the detected signals.

5. RADIOPURITY OF THE SCINTILLATOR AND CTF

The demonstration of the capability to reach the unprecedented radiopurity levels demanded by Borexino required the design and construction of the Counting Test Facility [4], a pilot detector aimed at the direct measurement of the scintilla-

tor contaminations at the ton scale level, targeted to a sensitivity of at least $5 \cdot 10^{-16} g/g$.
Designed and constructed following concepts very similar to that of Borexino, with 100 phototubes surrounding an inner vessel of 1 m of diameter, all immersed in shielding water, the Counting Test Facility has represented the fundamental step in the evolution of the entire Borexino program.
Specifically the radiopurity levels evaluated in CTF are [5]:
$^{238}U \leq (3.5 \pm 1.3) \cdot 10^{-16} g/g$
$^{232}Th \leq (4.4 \pm 1.5) \cdot 10^{-16} g/g$
$^{14}C/^{12}C = (1.94 \pm 0.09) \cdot 10^{-18}$
These never attained before purity levels not only have opened the perspective of the construction of the detector, but also represented a major, fundamental, breakthrough in the broad field of low activity science.
Furthermore, CTF proved that the issue represented by other contaminants of relevance for the low energy investigation, as Radon, Polonium 210 and Krypton 85 can be successfully coped with a suitable combination of the planned purification methods described above.

6. STATUS OF THE EXPERIMENT AND NEAR FUTURE PERSPECTIVES

As for September of 2006 Borexino, after few years of difficulties due to the environmental problems of the Gran Sasso Laboratory, is fully installed, both the detector and the plants. The Collaboration is now undertaking the fill phase of the apparatus, with the goal to start data taking in the final configuration from the middle of 2007.
The fill phase is divided in two stages: a first preliminary water fill to perform an overall mechanical check of the detector integrity and of the proper operation of the plants, followed later on by the smooth replace of the water with the scintillator. Water fill started in August 2006 and requires 3 months for its completion. From the middle of December the Collaboration plans to begin the crucial scintillator fill, bringing fresh Pseudocumene from the production plant in Sardinia, with the perspective to complete by April 2007.
When also the water tank will have been filled, presumably in May-June 2007 the detector will be ready for the new exciting chapter of this adventure, i.e. the start-up of the detection of the neutrinos from the Sun.

7. CONCLUSION

After the impressive results of CTF, which demonstrated unprecedented radiopurity levels of the liquid scintillator, the construction of Borexino has progressed also throughout the difficult times which followed the August 2002 event. Being now the detector fully installed, the fill phase commenced in August 2006, with the promising perspective to start the neutrino measurement campaign already in the middle of 2007.

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