Status of the BOREXINO Solar Neutrino Experiment

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Abstract. Aim of BOREXINO is to measure in real time low energetic solar neutrinos via neutrino electron scattering. Special interest in BOREXINO is the measurement of the counting rate of the 861 keV ^{7}Be solar neutrinos in order to separate between scenarios beyond the standard model which are favored by the results of running solar neutrino experiments.

THE SOLAR NEUTRINO PUZZLE - MISSING ^{7}BE-NEUTRINOS

The solar neutrino puzzle originates from the discrepancy between the ν_e expectations of the solar neutrino flux, as calculated by the Solar Standard Model (see e.g. [1]), and the experimental results. On the other side helioseismology confirms the solar standard model very accurately, also for those inner regions where solar neutrino production occurs. Uncertainties in thermo-nuclear cross sections may have an impact on the knowledge of solar neutrino production, but there is no experimental evidence for large deviations in the most important reactions as shown in the Luna experiment [2]. The data of existing solar neutrino experiments leads to the astonishing result, that most of the monoenergetic (861 keV) ^{7}Be-neutrinos are missing. It can be shown in a 'model independent' analysis (see e.g. [3]) where only the well-known solar luminosity and the indubitable Superkamiokande result on the ^{8}B-flux is taken into account, that existing data constrain the flux of ^{7}Be-ν_e to about 20% of the expected one at 90% cl. This suppression is significantly higher as that of the high energetic solar ^{8}B-neutrinos, which is around 50%. However, the ^{8}B-flux is much more sensitive on alternations in the solar model (e.g. decreasing the central temperature by alternations of the opacities) and therefore it seems impossible to explain why the ^{7}Be-neutrinos are suppressed so severe and why the suppression is even larger as for ^{8}B-neutrinos.

Strong conversion of the solar ^{7}Be ν_e-neutrinos into another flavor during their flight from the sun to earth would explain the experimental findings. This can be invoked by neutrino oscillations which occur when neutrinos have non-zero masses and if they mix in analogy to the quark sector. There exist four parameter spaces in the Δm^2 (i.e. the mass difference squared) - $\sin^2\theta$ (the oscillation amplitude) plane, which can account for the experimental results.

PHYSICS WITH BOREXINO

BOREXINO is going to be build up in the underground laboratory at Gran Sasso, Italy. The collaboration consists of several european and american institutes and is listed at the end of this article.

The aim of BOREXINO is the measurement of the counting rate of the 861 keV solar ^{7}Be-neutrinos via neutrino electron scattering $\nu + e \rightarrow \nu + e$. A liquid scintillator with a total mass of about 300t and a fiducial mass of about 100t will be the target. The monoenergetic ^{7}Be-neutrinos give rise to a compton like electron recoil spectrum in BOREXINO with an edge at 660 keV. According to the Standard Solar Model a counting rate of about 45/day would be expected. The high light yield of the scintillator and the large geometrical coverage of $\sim$2200 photomultiplier allow to recognize these low energetic events. For a description of the BOREXINO detector see [12].

The counting rates in BOREXINO depend on the favored values in Δm^2 and $\sin^2\theta$, which are listed below, as follows:

- neutrino mass differences $\Delta m^2 \sim 10^{-6} \rightarrow 10^{-5}\ eV^2$ and mixing strength in the region $10^{-6} <\sin^2 2\theta < 2 \cdot 10^{-5}$ (SMA, 'small mixing angle' solution) lead to a counting rate of ~12/day.
- neutrino mass differences $\Delta m^2 \sim 10^{-5} \rightarrow 10^{-4}\ eV^2$ and mixing strength in the region $0.6 <\sin^2 2\theta < 1.0$ (LMA, 'large mixing angle' solution) lead to a counting rate of ~24/day.
- neutrino mass differences $\Delta m^2 \sim 10^{-7}\ eV^2$ and mixing strength in the region $0.7 <\sin^2 2\theta < 1.0$ (LOW, 'low value' solution) lead to a counting rate of ~23/day.
- neutrino mass differences $\Delta m^2 \sim 10^{-11} \rightarrow 10^{-9}\ eV^2$ and mixing strength in the region $0.7 <\sin^2 2\theta < 1.0$ ('vacuum oscillations') lead to seasonal fluctuations in the counting rate between ~10/day and ~45/day.

The rates given above are calculated for the best fit parameters of each solution region. For areas around the best fit parameter with lower significance (but still within the 95% c.l.) the counting rates of the individual regions may overlap. However, there exist additional means to separate the different regions! For the 'low'-solution a part of the converted neutrinos will recover to the ν_e-state as they intersect the earth during night. This would lead to an increased counting rate during night with respect to what is measured during the day and this repeating effect can well be used to separate this parameter area from others. On the other hand, vacuum oscillations will be seen as seasonal variations in the counting rate due to the alteration of the distance of the earth to the sun during one year. These modifications differ significantly in amplitude and/or phase from the ordinary r^2-dependence which leads to a 7%-difference in the measured rate between winter and summer. The LMA-solution will be additionally probed by a long baseline experiment using reactor neutrinos, i.e. $\bar{\nu}_e$. This will be accomplished by the japanese KAMLAND experiment with high statistics and also by BOREXINO, here however with a small annual rate of $\simeq$ 30 counts [4]. In both cases the inverse beta decay reaction will be used for reactor neutrino detection. Both, LMA and SMA will lead to a constant (besides the trivial winter/summer difference) counting rate.

Additional physics goals in BOREXINO are: use of a strong terrestial neutrino source and search for a neutrino magnetic moment, and the measurement of neutrinos emitted in the earth's crust via beta decays and determination of the global radioactive release [5]. Under discussion are $0\nu - \beta\beta$-experiments using the excellent shielding capability of BOREXINO [6].

LOW LEVEL BACKGROUND TECHNOLOGY

The demands on purity in terms of radioactivity in BOREXINO, especially for the scintillator itself, are challenging. In order to be able to extract a clear signal above background events also in case of total flavor conversion, an intrinsic concentration in Uranium and Thorium of about $10^{-16}\,g/g$ should not be exceeded significantly. The amount of $^{14}C/^{12}C$ must not be higher than $\sim 10^{-18}$ in order to reach the desired ~250 keV threshold. However, even at this extremely low level ^{14}C would hinder the detection of the low energetic solar pp-neutrinos. In addition care has to be taken for six other primordial long-living radioactive nuclei (i.e. Cd, In, K, Lu, La, Rb), which could be present as trace elements in the liquid scintillator and which create signals falling into the energy window where BOREXINO is searching for neutrino events.

In order to test scintillating materials a Counting Test Facility (CTF) has been built up in hall C of the underground laboratory at Gran Sasso, which resembles a small prototype (ca. 4.2t of scintillator) of BOREXINO. In addition high sensitive neutron activation analysis (NAA) has been developed at the Technical University Munich in Garching, Germany. From beginning of 1995 until summer 1997 several CTF-tests about the feasibility of BOREXINO have been performed with pseudocumene (PC) as solvent with 1.5% PPO as wavelengthshifter. After water extraction of a 'master solution' whith the whole amount of PPO these encouraging results have been obtained: $^{14}C/^{12}C = 1.94 \cdot 10^{-18}$, $^{238}U = (3.5 \pm 1.3) \cdot 10^{-16}\ g/g$, $^{232}Th = (4.4 \pm 1.5) \cdot 10^{-16}\ g/g$. Purification in terms of radon daughters could be observed after water extaction and distillation of the whole scintillator. No effect was observed on the concentrations of U and Th. A complete discussion of the CTF results including experimental techniques for further background suppression are given in ref. [7] and ref. [8]. Details about the experimental setup of the CTF can be found in ref. [9].

High sensitive neutron activation analysis (NAA) of scintillation samples provides an independent test on the radiopurity in terms of U and Th, and allows to probe the secular equilibrium of the decay chains. With NAA an upper limit for uranium in PC/PPO of $^{238}U < 2 \cdot 10^{-16}\ g/g$ (90% c.l.) has been obtained. In addition concentration limits have been measured by this method for the six other relevant trace elements (for details, see ref. [10]). Besides potassium all limits are compatible with the requirements of BOREXINO. From measurements testing purification methods the depletion factors for potassium have been determined. Assuming these numbers apply also at lower concentration values possible trace elements of potassium should be removed from the scintillator very efficiently. After improvements in the performance of low-level gamma-spectroscopy better limits for Thorium and Uranium in liquid scintillators ($1 \cdot 10^{-16}$ and $1 \cdot 10^{-17}$, respectively) could be set. These limits have been reached at 90% c.l. for phenylxylylethane (PXE) with TP as wavelengthshifter after a multi-step purification using a silica-gel column combined with water extraction [11].

All detector materials have been investigated for low level background. The demands are clearly the highest for the scintillator itself. However, also the requirements for the outer parts are challenging. Important examples are the nylon vessel [13] which holds the liquid scintillator, the buffer liquid, extreme radon-pure nitrogen used for degasing purposes [14], and the photomultipliers [15] with light concentrators. All these detector materials have been selected via low-level gamma-spectroscopy at several laboratories (e.g. Gran Sasso, Heidelberg, IRMM), NAA, and/or via mass spectrometry (e.g. at ISPRA in Italy and at TAMCO in Japan for nylon samples).

CONCLUSIONS

BOREXINO is aiming for the measurement of solar ^{7}Be-neutrinos. The counting rate as well as possible time fluctuations of this quantity can be used to separate different neutrino parameter regions which have been proposed to solve the solar neutrino puzzle. The demands on radiopurity, especially in the scintillating target, are very high. However, results from the CTF and NAA show very encouraging results on the radiopurity of liquid scintillators.

In hall C of the underground laboratory at Gran Sasso the external tank and the inner steel sphere of BOREXINO has been finished. Installation of photomultipliers will start in fall of 2000. Start of the filling procedure of BOREXINO is expected at the end of 2001.

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