Status of the BOREXINO Solar Neutrino Experiment

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Aim of BOREXINO is to measure in real time solar neutrinos with an energy threshold of about 250 keV via pure leptonic neutrino electron scattering $\nu + e \to \nu + e$. Special interest in BOREXINO is the first determination of the low energy ^7Be solar neutrino flux. In the MSW-scenario a strong depletion of this flux should be found. In case of vacuum oscillations a clear time fluctuation in the measured flux is to be expected. In addition the large mixing angle MSW solution can be probed independently by measuring the $\bar{\nu_e}$ flux of european power reactors in a long baseline oscillation experiment.

1. Introduction

The solar neutrino problem 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. Information from helioseismology confirms the solar standard model to an accuracy within <1%. In addition, results from the Luna experiment [2] at low energies disfavour explanations based on discrepancies in this nuclear cross section. At last, the overall performance of both gallium experiments has been tested by terrestial neutrino sources, and no discrepancy from the expected values has been found [3].

Data analysis of the existing experiments leads to the assumption of severe suppression of the charged current solar ^7Be-branch. Fig. 1 shows a model independent constraint on this flux [4]. The only inputs are the integral flux of the SuperKamiokande experiment, which is taken as the value for the $^8B-$neutrinos, and the known luminosity of the sun, whereas contributions from other branches of the pp-cycle and the CNO-cycle are even neglected. Within the 90% confidence limits a flux of only 20% of the expected charged current ^7Be neutrinos is consistent with the data, revealing a strong hint for physics beyond the standard model.

If neutrinos have non-zero masses and if they mix in analogy to the quark sector, neutrino oscillations arise. It can be shown that certain parameter on neutrino masses and mixing angles provide a solution to the result of all solar neutrino experiments. There exist three parameter areas: the MSW[1] small mixing angle solution with values typically for neutrino mass differences $\Delta m^2 \approx 10^{-6} \to 10^{-5}\ eV^2$ and mixing strength in the region $10^{-6} < sin^2 2\theta < 2 \cdot 10^{-5}$, the MSW large mixing angle solution for the same mass region but almost full mixing strength, and the vacuum oscillation solution with strong mixing at $\Delta m^2 \approx 10^{-10}$ eV^2.

Fig. 2 shows the deformation of the solar neutrino spectrum as expected in case of the MSW solution. The ^7Be neutrino line at 861 keV is almost fully suppressed in the small mixing angle solution as it is indicated by experimental data. The spectral shape of the high energy ^8B neutrino branch is deformed. The measurement of this shape is aim of SuperKamiokande and SNO, whereas BOREXINO will deliver direct information about the ^7Be neutrino flux.

2. 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 to measure in real

[1]Mikhejev, Smirnov, Wolfenstein effect: resonant flavour conversion inside the sun, e.g. ref [5].

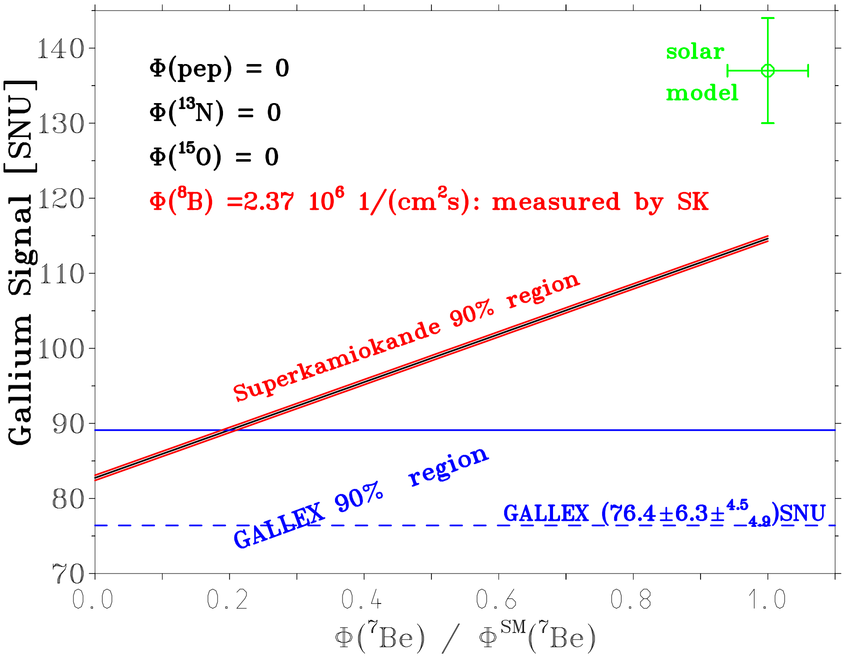

Figure 1. Model independent constraint on the charged current solar 7-Be neutrino flux derived by the experimental results from SuperKamiokande, Gallex, and the value of the solar luminosity. The signal strength (1 SNU = 1 capture in 10^{36} target atoms per second) of a gallium experiment is depicted as function of the 7-Be neutrino flux, resulting in the black line. The width of the line represents the experimental uncertainty of SuperKamiokande. Within 90% CL only about 20% of the expected 7-Be neutrino flux is compatible with experimental results.

time the solar neutrino flux at a low energy threshold with high statistics and energy resolving via pure leptonic neutrino electron scattering $\nu + e \rightarrow \nu + e$. Liquid scintillator (300t total mass) will be target and detector material. Monoenergetic ^7Be-neutrinos give rise to a compton like recoil spectrum in BOREXINO with a edge at 660 keV. Assuming validity of the standard model a counting rate for ^7Be-neutrinos, which would consist in this case purely as ν_e, of roughly 55/day in BOREXINO is expected. Here charged current as well as neutral current interaction in the neutrino electron scattering takes place.

In scenarios of total neutrino flavour conversion, i.e. for neutrino mass differences $\Delta m^2 \approx 10^{-6} \rightarrow 10^{-5}\ eV^2$, a reduced flux of approximately 12/day would be measured due to the lower cross section of $\nu_{\mu,\tau}$ scattering, which occurs only via neutral current interaction.

In case of vacuum oscillations, i.e. for neutrino mass differences $\Delta m^2 \approx 10^{-10}\ eV^2$, BOREXINO would see a distinct time dependent periodical neutrino signal due to the seasonal eccentricity of the earths orbit around the sun. In fig. 3 the counting rate of the 7-Be solar neutrino flux in BOREXINO is depicted in case of vacuum oscillations for parameters favoured by the recent SuperKamiokande results. A very distinct seasonal dependence should be observed. As a dashed line the oscillation probability is indicated with the

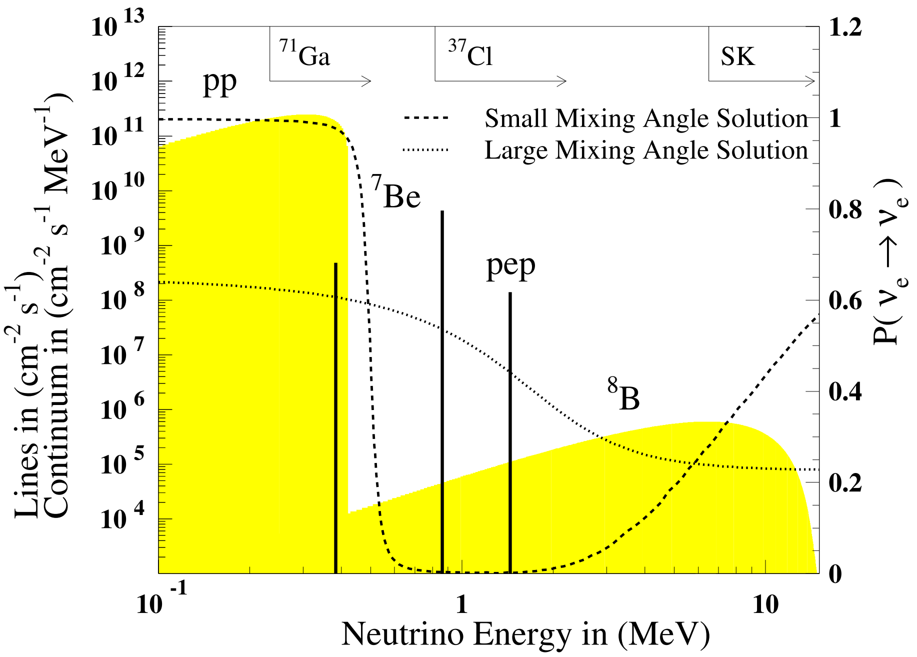

Figure 2. The solar neutrino spectrum as calculated in the standard model and the electron neutrino survival curve due to resonant neutrino flavour transversion. The 7-Be neutrino line at 861 keV is almost completely suppressed in the small mixing angle solution, as it is indicated by experimental data. The spectral shape of the high energy 8-B neutrino branch should be deformed. The measurement of this shape is aim of SuperKamiokande and SNO, BOREXINO will deliver information about the 7-Be neutrino flux.

scale on the right side. But also for other parameters in the range of $\Delta m^2 \approx 10^{-10}\ eV^2$ a very clear seasonal fluctuation should be expected.

For neutrino mass differences in the range of $\Delta m^2 \approx 10^{-7}\ eV^2$ and for large mixing BOREXINO should see a 'day/night' effect due to electron neutrino recovery during the path through the earth.

BOREXINO also can serve for additional projects in neutrino physics. Search for a magnetic moment can be performed by means of terrestial neutrino sources by investigating the electron recoil shape at low momentum transfer. Via the inverse beta-decay $\bar{\nu_e} + p \rightarrow e^+ + n$ BOREXINO can look for signals from geophysical neutrinos [6] as well as for neutrinos emitted by european nuclear power plants [7]. The latter would serve as a long baseline neutrino oscillation experiment probing the large mixing angle solution for the solar neutrino problem.

2.1. The BOREXINO Detector

BOREXINO is placed in hall C of the underground laboratory at Gran Sasso, Italy. An overburden of about 3500 m.w.e. suppresses the cosmic muon flux to 1.1 $/hm^2$. The detector is shielded successively from outer radioactivity.

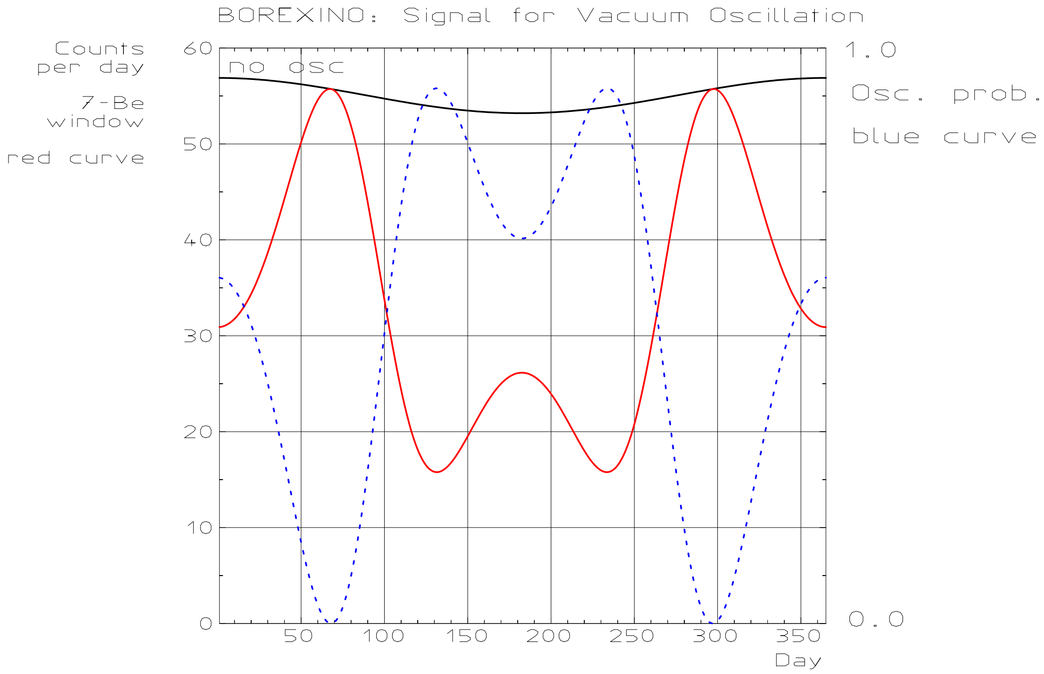

Figure 3. Counting rate of the 7-Be solar neutrino flux in BOREXINO in case of vacuum oscillations for parameters favoured by the recent SuperKamiokande results. A very distinct seasonal dependence should be observed. As a dashed line the oscillation probability is indicated with the scale on the right side.

The adjacent inner layer serves as shielding and has to provide an increased purity in terms of internal radioactivity. Fig. 4 shows the experimental setup.

Inside the 'external' tank a stainless steel sphere will support about 2200 phototubes on the inside and 200 tubes at the outside. Latter provide the muon veto Cherenkov system. Tubes inside the sphere will be equipped with light guides in order to increase the geometrical coverage and hence the energy resolution.

The steel sphere will be filled with a transparent, high purity buffer liquid which itself holds a nylon sphere, filled with organic scintillator. Between the steel sphere and the scintillator region an additional nylon shroud hinders radon convection from the outer area towards the critical region. The active scintillator mass will be around 300t. As our first option serves pseudocumol (PC) with a wavelengthshifter at concentrations of about 0.15%.

Time information in each channel provides reconstruction of the event position. A fiducial volume of about 100t for solar neutrino interaction will be defined, establishing a counting rate of 55 neutrinos per day according to the standard solar model. The outer part of the scintillator sphere serves as an active additional shielding against external background.

3. Results of CTF and NAA

The demands on purity in terms of radioactivity in BOREXINO, especially for the scintil-

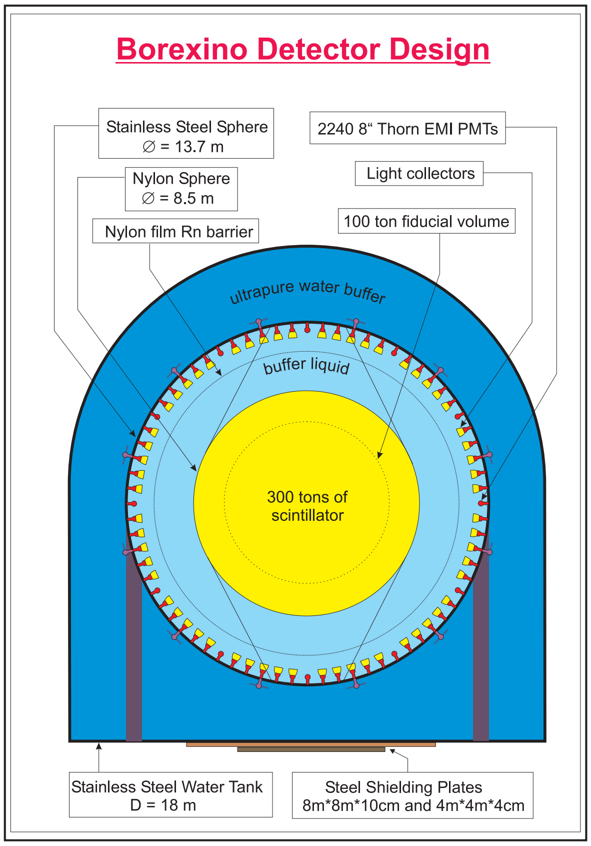

Figure 4. Schematic view of BOREXINO. The ultrapure scintillator (300t) inside a nylon vessel is shielded differentially by means of a liquid buffer (1040t), a steel sphere on which the tubes are mounted, and the outer water buffer which is contained in an external steel tank with dimensions of about 18m. A transparent nylon shroud hinders radon convection in the liquid buffer region. Additional tubes mounted on the outer surface of the steel sphere allow detection of penetrating muons via the Cherenkov effect.

lator itself, are challenging. In order to be able to extract a clear signal from background events also in case of total flavour conversion, an intrinsic concentration in Uranium and Thorium of about 10^{-16} should not be exceeded significantly. The amount of $^{14}C/^{12}C$ must not be higher than $\approx 10^{-18}$. In order to test scintillating materials a large Counting Test Facility (CTF) has been built up in hall C of the underground laboratory at Gran Sasso, which resembles a small prototype (ca. 5t of scintillator) of BOREXINO. In addition high sensitive neutron activation analysis (NAA) has been developped at the Technical University Munich in Garching.

3.1. CTF results

From beginning of 1995 until summer 1997 several CTF-tests about the feasibility of BOREXINO have been performed. This includes procedures to maintain or to improve the purity of the scintillator and encouraging results have been obtained: $^{14}C/^{12}C = 1.94 \cdot 10^{-18}$, $^{238}U = (3.5 \pm 1.3) \cdot 10^{-16}\ g/g$, $^{232}Th = (4.4 \pm 1.5) \cdot 10^{-16}\ g/g$. A complete discussion of the CTF results including experimental techniques for further background suppression are given in ref. [8] and ref. [9]. Details about the experimental setup of the CTF can be found in ref. [10].

Due to the three-dimensional array of phototubes the position of events in CTF could be reconstructed. Careful data analysis including source tests demonstrated, that the observed single rate was dominated by external background, mainly by radon present in the water shielding.

Several purification tests on the scintillator compounds have been performed, including N_2-bubbling, water extraction, distillation as well as column separation. Removal of radioactive gases present in the environment like Krypton and improvements in the concentration levels of ^{210}Pb-daughters could be demonstrated [8]. Column separation has been tested with an alternative scintillator and very promising results have been obtained.

The CTF response on intersecting cosmic muons has been studied and the necessity of an outer veto system in BOREXINO became clear. According to the requirements of the experiment a design for the outer detector has been finished. Measurements done at the high energy muon beam at SPS in CERN allowed for the careful study of cross sections of the generation of cosmogenic radionucleides in the scintillator. Data analysis is on-going and results can be expected in summer 1998.

Experience with the CTF helped to understand technical problems. Some of them concern deterioration of detector materials, the sealing of the tubes, radon diffusion through wet nylon, and radon tightness of liquid handling systems.

3.2. NAA results

Highly developped neutron activation analysis (NAA) of scintillation samples performed in Garching provides an independent test on the radiopurity and allows important tests on 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% CL) has been obtained. In addition concentration values or limits have been measured by this method for various isotopes, including man-made nuclei for different detector materials. For details, see ref. [11].

In Garching a new low background laboratory with shielding against the cosmic hadronic and soft electromagnetic component has been built up and completed in 1998. First measurements with neutron activation at the research reactor FRM-I in Garching, chemical extraction in a radiochemical laboratory, and final data taking in the low background laboratory show, that sensitivities in Uranium and Thorium far below the 10^{-16} limit can be reached now.

4. Conclusion

BOREXINO is dedicated to detect in real time low energy solar neutrinos. The demands on the purity of detector materials are challanging. However, results from the CTF and NAA show very encouraging results on the radiopurity of liquid scintillators. The CTF will be reinstalled and finds further use for testing purposes. NAA in Garching has been developped to concentration levels far below the 10^{-16} range. In hall C of the underground laboratory at Gran Sasso the external tank of BOREXINO has been finished. Start of the filling procedure of BOREXINO is expected in 2000.

5. Collaboration list

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