The Borexino Experiment- A Status Report

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The goal of the Borexino experiment is to measure the mono-energetic 0.86 MeV ^{7}Be solar neutrinos, a central feature in the on-going story of missing solar neutrinos. Borexino will accomplish this by detecting neutrino-electron scattering events in a low background liquid scintillator, well shielded from external radiation in the underground Gran Sasso Laboratory.

1. Introduction

Neutrino oscillations are widely believed to be the cause of the solar neutrino deficit. From various analyses of existing solar neutrino experiments one finds that the ^{7}Be neutrinos must be highly suppressed. The result is robust and not dependent on details of the solar model. Indeed, in a general analysis in which one assumes only the composition of neutrinos, namely that there are pp, ^{7}Be, and ^{8}B neutrinos with unknown fluxes, one finds that the best fit to the data yields a non-physical negative ^{7}Be flux, assuming no neutrino oscillations. But ^{7}Be nuclei must be present in the sun since we observe the neutrinos of the ^{8}B nucleus, produced through the reaction ^{7}Be(p,γ)^{8}B. This missing ^{7}Be neutrinos are thus a puzzle.

The missing neutrinos and evidence for neutrino oscillations based on current solar neutrino experiments can be explained by matter enhanced neutrino oscillations, the Mikheyev-Smirnov-Wolfenstein (MSW) effect [1]. The three MSW solutions that best fit the data are the small mixing angle (SMA), the large mixing angle (LMA), and low mass (LOW) solutions.

Borexino will detect neutrinos by elastic scattering off electrons. In the SMA solution the ^{7}Be neutrinos are fully converted during passage through the sun to another active neutrino, either the muon or tau neutrino. The ^{7}Be signal in Borexino in this case is due solely to neutral current scattering of the new neutrino on the electron, a process with a cross section smaller compared to ν_e-e scattering by as factor ~4. Thus the rate is reduced to 24% of the Standard Solar Model rate, and is due essentially to neutral current scattering of muon and tau neutrinos.

For the LMA solution the ^{7}Be electron neutrinos are not fully converted and the rate is reduced to 59% of the Standard Solar Model rate. For Borexino the only measurable difference between the SMA and LMA solutions is the rate. However, the difference is quite large compared to the estimated uncertainty in the measurement.

For the LOW solution there is also an incomplete conversion of ν_e in the sun, but in this case passage of the neutrino through the earth can produce regeneration, resulting in a distinctive day / night difference in rates. Fogli et. al., [2] have shown that in this solution there is an increase in the ^{7}Be nighttime rate of 10%-20%, compared to daytime. Such a signal will be easily detected in Borexino and will be a dramatic "smoking gun" detection of neutrino oscillations. The goodness of fit for this solution has improved recently (see Ref. [3]).

Vacuum oscillations will produce a large seasonal variation in the rate of the ^{7}Be neutrinos as the distance between the earth and sun changes, in addition to the change due to the purely geometrical effect, The effect is biggest for the ^{7}Be neutrinos owing to its monochromatic energy. For the "large mass" VAC$_L$ solution, Berezensky, et. al. show that the survival probability of the ^{7}Be neutrinos dips twice a year from a maximum of ~100 % to a minimum of ~14% [4]. In the small mass VAC$_S$ solution, the survival probability changes from ~55% to ~25%, again a large effect. In both cases the signal in Borexino will be large and unmistakable.

Conversion to sterile neutrinos [2] will result in a unique null signal in Borexino.

2. Overview of the Borexino Detector

The goal of the Borexino experiment is to measure the mono-energetic 0.86 MeV ^{7}Be solar neutrinos. Borexino will employ a large liquid scintillator to detect neutrinos in real time by observing the scintillation light produced by the recoil electrons from neutrino-electron elastic scattering.

The Borexino detector is located in Hall C of the Gran Sasso underground laboratory in Italy, the Laboratori Nazionale del Gran Sasso (LNGS).

The general plan for the Borexino detector is illustrated in Figure 1. The active detector consists 321 m^{3} (280 metric tons) of liquid scintillator contained in a thin nylon vessel of diameter 8.5 m. The scintillator consists of pseudocumene (PC) (1,2,4 trimethybenzene) with ~ 2 g/liter of PPO (3,5 diphenyloxazole) added as a wavelength shifter. The PPO absorbs the primary scintillation light of the PC (centered around 285 nm) and re-emits light at a longer wavelength, centered around 365 nm. The final scintillation light has a mean free path in the scintillator of about 7 m, dominated by Rayleigh scattering.

The scintillator is surrounded by a pseudocumene (PC) buffer fluid for shielding external radiation. The PC buffer fluid contains ~ 5 g/liter of DMP (dimethylphthlate) to quench the primary PC scintillation light. The buffer is subdivided into two zones by a second nylon vessel, diameter 10.5 m, that serves as a barrier to prevent radon and other impurities from reaching the scintillator vessel. The choice of a common fluid (PC) for the scintillator and buffer eliminates buoyancy effects and a mismatch of optical index of refraction, as would be the case with the use of a water buffer.

The buffer fluid is contained within a 13.7 m diameter stainless steel sphere (SSS) which also serves as a support structure of the phototmultiplier tubes (PMT). The scintillation light is detected by an array of 2200 8" diameter photomultiplier tubes (PMT) manufactured by ETL, mounted on the inside surface of the SSS. Light collection cones, optimized to view the 8.5 m scintillator vessel, are mounted on 1800 of the PMTs. The remaining 400 PMTs are bare to optimize their detection efficiency for muons that produce Cerenkov light in the buffer outside of the scintillator volume.

An external tank contains water as a final shield against gamma rays and neutrons from the rock. The thickness of the water shield is 2 m, except at the bottom of the sphere where it is only 1 m. Steel plates under the floor of the external tank provide the equivalent of 1 m of water shielding. The water also serves as a medium for detecting muons by means of the Cerenkov light they produce in passing through the water. The Cerenkov light produced in the water by the muons is detected by 210 PMTs located on the outside surface of the stainless steel sphere. Collection of the Cerenkov light is enhanced by reflecting sheets of Tyvek film that are mounted on the surfaces of the external tank and the sphere.

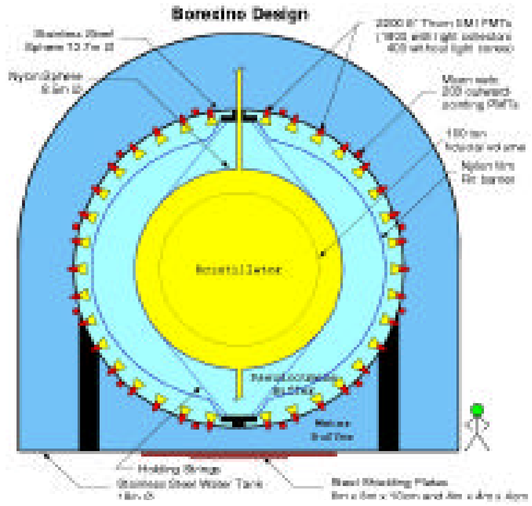

Figure 1. The Borexino Detector

3. Results from the Counting Test Facility

^{7}Be neutrinos are difficult to detect in live time, owing to their relatively low energy and the likelihood of backgrounds from natural radioactivity. The design of Borexino is based on several years of research and development with the Counting Test Facility (CTF), a 4 ton prototype of Borexino. We summarize here the main results of the CTF which was designed to study backgrounds due to internal sources in the scintillator. Details can be found in References [5], [6], [7], [8], and [9].

The ^{14}C/^{12}C ratio was determined to be (1.94 +/- 0.09) x 10^{-18}, the lowest abundance ever measured for ^{14}C. This is to 7 orders of magnitude lower than the ^{14}C in the atmosphere and is sufficiently low to permit the measurement of the ^{7}Be neutrino without interference.

Uranium and Thorium concentrations were measured by detection of Bi-Po beta-alpha delayed coincidences in both decay chains. Assuming equilibirum in the radioactive decay sequences, the corresponding concentrations were found to be (3.5 +/- 1.3)x 10^{-16} and (4.4 +1.5/-1.2)x 10^{-16}, for U and Th, respectively. A high level of ^{222}Rn was found in the external water shield. The result for U is an upper limit for the scintillator background owing to diffusion of ^{222}Rn from the water into the scintillator.

The pseudocumene was not prepurified but was used as received from the producer, Enichem. The PPO, highly contaminated in potassium, as received, was prepurified by water extraction. The U and Th concentrations in the scintillator were low from the start of running and were not noticeably changed by on-line purification. On-line purification, consisting of water extraction, nitrogen stripping, and distillation [8], did prove to be successful in removing singles backgrounds. Background from internal activity was reduced from 470 +/- 90 counts/day to 21 +/- 47 counts/day. A peak in the internal background at ~ 400 keV was tentatively identified as the quenched alpha line of ^{210}Po, a daughter of 22 year ^{210}Pb. The ^{210}Po background was reduced from ~250 c/d to ~0 c/d. ^{85}Kr was also identified as a background and was successfully removed by nitrogen stripping.

A yield of 300 photoelectrons/MeV was measured, corresponding to an intitial light yield of ~ 10,000 photons/MeV of energy deposition. Energy resolution was 9% at 751 keV, the observed energy of the ^{214}Po alpha peak, suppressed due to the alpha quenching effect. Position resolution (one sigma) is 12 cm at this same alpha line. The difference in pulse shapes between alphas and betas provided a discrimination between them with an efficiency of 97% for the ^{214}Po alpha identification at an associated beta leakage of ~ 2.5%.

In summary, the CTF demonstrated low background techniques and procedures required for Borexino. In addition, the optical properties of large scale scintillators were studied and found to be acceptable.

4. Status of Borexino

The construction of Borexino is well underway. Among major hardware components, the external water tank, the stainless steel sphere are the scintillator storage vessels are now installed in the Gran Sasso Laboratory. The CTF is being rebuilt for further background studies and is nearly complete. New scintillator purification systems, which now include a silica gel column [10], are in an advanced state of construction, as are the electronics and phototube subsystems. The estimated time for start up the Borexino detector is late 2001.

5. The Borexino collaboration.

The Borexino collaboration is an international group consisting of members from Germany, Italy, the United States, Belgium, France, Hungary, Poland, and Russia,.

References:

[1] L. Wolfenstein, Phys. Rev. D **17**, 2369 (1978); A. Yu. Smirnov, Yad. Fiz. **42**, 1441 (1985) [Sov. J. Nucl. Phys. **42**, 913 (1985)]; Nuovo Cimento C **9**, 17 (1986).

[2] G. L. Fogli, E. Lisi, D. Montanino, and P. Palazzo, preprint, BARI-TH/364-99

[3] J.N. Bahcall, P.I. Kratsev, and A. Yu. Smirnov, preprint hep-ph/9911248, submitted to Phys. Letts. B.

[4] V. Berezinsky, G. Fiorentini, and M. Lissia, preprint, hep-ph/9904225

[5] *A Large Scale, Low Background Liquid Scintillation Detector: The Counting Test Facility at Gran Sasso*, Borexino-CTF Collaboration NIM **A406**, 411 (1998).

[6] *Ultra-Low Background Measurements in a Large-Volume Underground Detector*, Borexino-CTF Collaboration, Astroparticle Physics, **8** , 14 (1998).

[7] *Measurement of Carbon-14 Abundance in a Low Background Liquid Scintillator*, Borexino-CTF Collaboration, Physics Letters, **B422**, 349 (1998).

[8] J.B. Benziger, Michael Johnson, F.P. Calaprice, M. Chen, N.Darnton, F. Loeser, and R.B. Vogelaar, NIM **A417**, 278 (1998).

[9] R.B. Vogelaar, J. Benziger, F.P. Calaprice, and N. Darnton, NIM **A372**, 59 (1996).

[10] R.V. Hentig, et. al., Czech. J. Phys., **49** Suppl. S1, 277 (1999).