Status of the BOREXINO Solar Neutrino Experiment ◇

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The motivation for the BOREXINO experiment comes from the long standing solar neutrino puzzle that originates from the discrepancy between the predicted solar neutrino flux according to the Standard Solar Model (SSM) and the experimental results. Data analysis of the existing solar neutrino experiments GALLEX [3] and GNO [4], SAGE [5], KAMIOKANDE [6] and SUPER-KAMIOKANDE [7] show an energy-dependent deficit of the solar neutrino flux whereas the combination of the results indicates a significant suppression of the ^{7}Be-neutrino branch. The latter fact is often called the 2nd solar neutrino problem or neutrino paradoxon. Taking into account the model independent constraint on the charged current ^{7}Be neutrino flux derived from the experimental results of SuperKamiokande and Gallex and the value of the solar luminosity, less then about 20% of the expected ^{7}Be neutrino flux is compatible with experimental results within 90% C.L. [9]. Modifications of the Standard Solar Model [1,2] as a possible solution to the solar neutrino problems are strongly disfavoured since helioseismology confirmes the SSM to an accuracy better than 0.5% [1]. Explanations based on a resonant change of the nuclear cross sections relevant for the neutrino production in the sun are also ruled out to a large extent by experiments like LUNA [8]. In addition, the overall performance of the radiochemical gallium experiments has been checked using artificial neutrino sources showing a perfect agreement with the expected values.

Taking all together, the solar neutrino problem reveals a strong hint for a particle physics solution beyond the standard model whereas vacuum- and matter enhanced neutrino flavour oscillations are the most favoured scenarios that can provide a solution to all existing solar neutrino experiments.

The main objective of BOREXINO [10] is the first determination of the monoenergetic ^{7}Be solar neutrino flux ($E_\nu = 862\,$keV) with an energy threshold of about $E_\nu \approx 450\,$keV. The detection reaction in the liquid scintillator target is the pure leptonic process of neutrino electron scattering $\nu_x + e^- \rightarrow \nu_x + e^-$ giving rise to a distinct compton-like electron recoil spectrum with its edge at 660 keV. Since the ν-e scattering process is sensitive to neutral current (NC) as well as charged current (CC) interactions, BOREXINO is able to detect ν_e as well as $\nu_{\mu,\tau}$, whereas the cross section for $\nu_{\mu,\tau}$ scattering is suppressed by a factor of $\sim$4 compared to ν_e scattering.

Borexino is being constructed in Hall C of the Gran Sasso underground laboratory in Italy at an rock overburden of about 3600 mwe. Liquid scintillator (total mass $\approx 300\,$t, fiducial volume $\approx 100\,$t) will be target and detector material at once, allowing a high statistics measurement of the ^{7}Be solar neutrino flux ($\approx$43/d according to the standard solar model, $\approx$9/d for full flavour conversion). A detailed description of the BOREXINO detector design is given in reference [10].

From beginning of 1995 until summer 1997 several tests with the "Counting Test Facility (CTF)" of Borexino have been performed. This includes test procedures to maintain and improve the purity and optical stability of the scintillator, respectively. Results on the measured intrinsic purity of the liquid scintillator are $^{14}C/^{12}C = 1.94 \cdot 10^{-18}$, $^{238}U = (3.5 \pm 1.3) \cdot 10^{-16}$ g/g and $^{232}Th = (4.4 \pm 1.5) \cdot 10^{-16}$ g/g, which meet the requirements for BOREXINO.

A complete discussion of the CTF results including experimental techniques for further background suppression are given in reference [11] and reference [12]. Details about the experimental setup of the CTF can be found in reference [13].

The responsibilities of the Munich group in Borexino are:

- Design and construction of the external steel tank.
- Purification of liquid scintillators with Si-Gel columns and water extraction [18].
- The Inner- and Outer Muon-Veto detector [14,15,16] (together with MIT and Princeton, USA).
- Design and construction of the light concentrators for the Photomultiplier Tubes (PMTs).
- Test of the PXE-scintillator, light concentrators, muon veto, and liquid handling for the up-graded 'Counting Test Facility' (CTF-II) at Gran Sasso [17].
- NAA and gamma spectroscopy in the new underground lab in Garching [19].
- Event reconstruction in Borexino and CTF-II (together with Univ. Milano, Genova, Italy).

A "Munich" design for the encapsulation of the PMTs of the Outer Muon Veto detector has been realized [17]. These 210 tubes have been assembled, encapsulated and tested during the last year and will be installed at Gran Sasso during March 2001. Therefore, a pressure test chamber has been installed in Hall 2 of the *Beschleunigerlaboratorium* in which 21 tubes can be tested at once in terms of water tightness and functionality.

The design of the light concentrators which will be immersed in the liquid scintillator buffer (PC, pseudocumene) is completed. The fabrication of the first 1000 concentrators has been completed end of 2000 and they were shipped to the Gran Sasso underground labs recently. The residual 800 concentrators will be fabricated during the next months and will be installed together with the PMTs on the inside of the stainless steel sphere until September 2001.

The upgraded prototype test detector CTF-II has been set up in 1999 and first measurements with a PXE based

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scintillator have been performed from May until September 2000. The results on the optical properties of PXE have been very promising. Especially, as far as the $\alpha-\beta-$discrimination is concerned - an important tool for background suppression of events due to radioactive decays in the scintillator - the measurements showed encouraging results.

The liquid handling system module-0 at Gran Sasso has been completed in May 2000 and was already used for the filling and unloading of 5 tons PXE based scintillator in CTF-II. The interconnection to the storage tanks which will contain the 300 tons of liquid scintillator and to the BOREXINO detector itself will be assembled during the next months.

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High Resolution X-Ray Detectors with Superconducting Tunnel Junctions

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At the Technical University of Munich aluminum superconducting tunnel junctions (Al-STJs) are developed as a device for high resolution X-ray spectroscopy. Al-STJs consist of two superconducting aluminum layers that are separated by a thin dielectric tunneling barrier. Cooper pairs are broken up by the absorption of energy, giving rise to detectable currents across the tunneling barrier. The absorption of energy in both the top and the bottom layer can be detected. Al-STJs can either be used as a detector themselves or as a read out device for superconducting absorber films.

An energy resolution of 12 eV (FWHM) was obtained by Al-STJs at an X-ray energy of 5.9 keV, what is the best result obtained with STJs at this X-ray energy so far. The improvement in resolution is attributed to the introduction of a metallic buffer layer underneath the junction. The buffer layer is separated from the STJ by a thin polymeric insulation layer with low X-ray absorption efficiency. Energy of X-ray absorption in the buffer layer and phonons of X-ray absorption in the substrate thermalize very fast in the buffer layer. Thus, the emitted phonons reaching the STJ have mainly been converted into energies below $2\Delta_{Al}$, where Δ_{Al} is the energy gap of aluminum. As a consequence, the number of phonons able to break up Cooper pairs in the STJ's aluminum electrodes is reduced dramatically, leading to a reduced signal background.

The linearity of the Al-STJs was checked in the energy range between 1.74 keV and 6.49 keV. Only small deviations from linearity have been observed, giving recombination rates that are by far not sufficient to explain the energy resolution's deviation from the theoretical limit. From pulse shape analysis it can be deduced if the energy was deposited in the top or bottom electrode of the tunnel junction, or if it was shared between the two electrodes. The range of low energy photoelectrons in aluminum layers could be determined by the distribution of these events with shared energy deposition.

Major drawbacks of Al-STJs as X-ray detectors are the low absorption efficiency in the electrodes of the junction, the non-linearity between energy deposition and resulting pulse height and the fact that absorption in different electrodes causes different signal heights. These three disadvantages could recently be overcome by introducing an electrically insulated lead absorber onto the tunnel junction.

The lead film typically has a thickness of about 1.3 μm and is isolated from the tunnel junction by a naturally grown Al_xO_y layer on the surface of the aluminum junction. The absorption efficiency is about 50% at X-ray energies around 6 keV and higher than 99.9% below 1 keV. The electrical insulation is necessary to avoid changes in the gap structure of the superconducting aluminum, what could result in a reduction of the signal currents. Thus, the energy couples into the junction only via phonons. By fabricating the detector on a 300 nm thin Si_3N_4-membrane, signal degeneration caused by phonon losses into the substrate could be avoided. For the same reason, the nonlinearity of the tunnel junction is reduced significantly to a number consistent with zero.

Reading out a lead absorber with an Al-STJ on a membrane, again the high energy resolution of 12 eV FWHM at an X-ray energy of 5.9 keV was achieved.

The drawback of the lead absorbers is their degeneration during thermal cycling. This degeneration can be avoided by the deposition of a SiO layer onto the absorber, which, however, leads to a reduced energy resolution of about 20 eV (FWHM) at 6 keV.

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