PROCEEDINGS OF SCIENCE

The Borexino & SOX experiments

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Building upon its highly successful **Phase I (2007-2010)** results –which demonstrated the unprecedented radiopurity and precision levels reached, through the measurement of all but two of the solar neutrino components– the **Borexino** neutrino observatory is producing new measurements with its **Phase II (2012-present day)** dataset, started after very successful calibration (2009-10) and scintillator purification (2010-11) campaigns. A new geo-neutrino flux measurement, and searches for electric charge conservation violation and GRB-correlated neutrino events lead the way in a path that will see a unified, wideband solar neutrino spectroscopy analysis with the more radiopure Phase II statistics and new data selection techniques. Furthermore, the recently-completed **Borexino Thermal Management and Monitoring System** (BTMMS) represents a critical detector hardware upgrade which, together with complementary numerical fluidodynamic simulations, enables us to keep watch and correct temperature excursions. At the extremely low levels of background concentration currently seen in the Fiducial Volume (FV), these may otherwise have yielded problematic fluid mixing from less radiopure, peripheral scintillator areas. Finally, a new detector-wide **calibration campaign** is in its final stages of preparation, just ahead of the transition to the **SOX program**, which will see the deployment of a $\sim$150 kCi ^{144}Ce-^{144}Pr source in a pit under the detector, with the aim of studying anomalous short-distance $\overline{\nu}_e$ oscillation effects starting in 2018.

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1. Introduction

Borexino has so far been able to fulfill its design requirement of a precision ∼5% measurement of the ^{7}Be solar neutrino flux. It also has observed most of the remaining solar neutrino fluxes with varying levels of ever-increasing precision, including the current best limit for CNO νs. The accumulation of high-quality statistics with improving background conditions is ongoing. In addition, the enhancement of analysis techniques and data selection for the whole statistics, enabling a complete spectroscopy of the solar neutrino spectrum, is also in the late stages of development as part of the ***NuSol*** project. The detector is virtually background-free for $\overline{\nu}$ detection through the Inverse Beta Decay (IBD) coincidence signal, which makes geo-ν spectroscopy possible too. The antineutrino signal will also be exploited extensively in the near future through the study of possible anomalous low-baseline oscillatory behaviors in an artificially-generated $\overline{\nu}$ signal coming from a high-activity ^{144}Ce-^{144}Pr source: the ***CeSOX*** project. If the achieved cerium results (and funding) warrant it, a ^{51}Cr ν source could also be used to generate a cleaner and easier-to-interpret signal.

2. Borexino Neutrino Observatory

Borexino is a neutrino detector based on the principles of ultra-radiopure liquid scintillator and graded shielding. The overburden of the mountains of the Gran Sasso d'Italia, under which the Laboratori Nazionali del Gran Sasso (LNGS) are located, provide ∼3600 meters of water-equivalent shielding against cosmic backgrounds. The detector itself is surrounded by a domed tank filled with ultra-pure water, which serves as a Čerenkov muon veto, with an efficiency >99.99%. Inside this water tank, an 18-meter-diameter Stainless Steel Sphere (SSS), filled with ∼1100 tons of pseudocumene (PC), has 2212 inward-facing photomultiplier tubes (PMTs) mounted on its walls (see Figure 1). This volume is separated by two ultra-low-radioactivity nylon spheres: the outer vessel (OV), used to prevent radon gas emanating from the SSS's hardware from reaching the center of the detector; and the inner vessel (IV), which separates the buffer region outside the IV, doped with dimethylphthalate (DMP, 2 g/L), used to quench light emission; from the interior of the IV, doped with 2,5-diphenyloxazol (PPO, 1.5 g/L), used to shift the UV scintillation light to a longer wavelength, closer to the maximum PMT efficiency. Finally, software cuts generate a ∼100-ton, most radiopure fiducial volume (FV) specially tailored for each particular data analysis[1].

The light yield is ∼500 photoelectrons/MeV, with a hardware threshold of ∼60 keV. Scintillation light in Borexino can be generated in many indistinguishable ways apart from the neutrinos elastic-scattering off electrons in the PC: thus the extreme radiopurity levels sought and mantained. In order to filter out these background events, specific scintillator purifications, software discrimination of events and calibrations are used, on top of cleanliness and hardware design.

Four major calibration campaigns have taken place since Borexino's activation in 2007, using different types of radiation sources (α, β, γ, neutrons) with energies ranging from the detector's lowest threshold to ∼10 MeV. Since most of these activities involved placing the calibration source *inside* the FV, special care was taken not to contaminate the pristine environment with long-lifetime radioactive substances: this was successfully achieved in all cases[2].

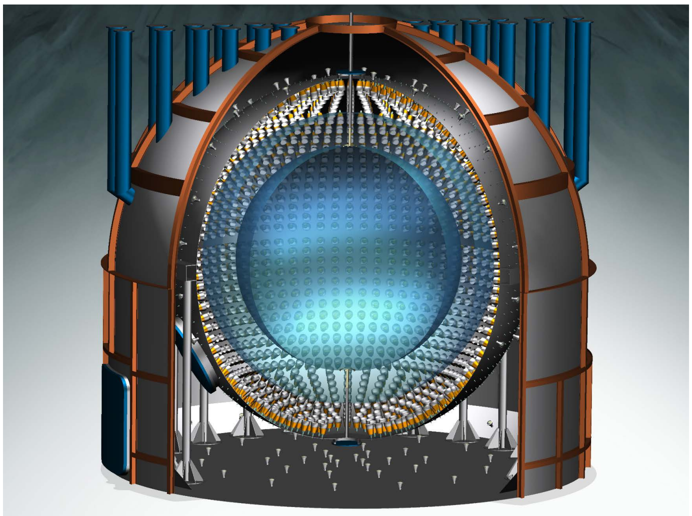

Figure 1: Artist's cut-out rendering of Borexino's main elements.

3. Solar, geoneutrino and other results

The main design goal for Borexino was the improvement of the precision (until then worse than $\sim>20\%$) in the determination of the ^{7}Be solar neutrino flux. Of course, other objectives in solar neutrino spectroscopy around the same *golden* energy window were also hoped for: all solar neutrino components visible to Borexino have been observed –and the precision for these measurements has, or is in the process of being, improved from the first observation– except for the CNO signal, for which the best current upper limit has nevertheless been determined. These measurements also contributed to the definitive backing of the MSW-LMA solution as the correct parameter space for the matter effect. The extremely feeble *hep* signal is almost out of Borexino's sensitivity, but recent analyses may provide a tight upper limit on its flux.

***pp* neutrinos** In 2014, the Collaboration disentangled the major component of the integrated solar neutrino flux from Borexino's scintillator irreducible and inherent ^{14}C background by measuring the *pp* ν flux with a $\sim$15% precision (9% statistical) as ϕ_{pp}=(6.37$\pm$0.46)$\cdot 10^{10}$ cm^{-2}s^{-1} (rate in Borexino: 144$\pm$13(stat)$\pm$10(sys) cpd/100 ton)[8][9].

***pep* neutrinos** In 2011, the first direct detection of *pep* neutrinos was achieved by the Collaboration with a $\sim$29% precision (20% statistical) as ϕ_{pep}=(1.6$\pm$0.3)$\cdot 10^8$ cm^{-2}s^{-1} (rate in Borexino: 3.1$\pm$0.6(stat)$\pm$0.3(sys) cpd/100 ton)[10]. In parallel, this measurement also set the strongest available limit on CNO neutrinos at $<7.7\cdot 10^8$ cm^{-2}s^{-1} at 95% c.l., since an integrated neutrino signal between 1.0 and 1.5 MeV was measured for this result.

^{7}Be neutrinos The flagship Borexino result, this was also the first direct detection of this particular solar neutrino spectral component. The most recent published result[11] has a $\sim$5% precision for an MSW-LMA flux of (3.10$\pm$0.15)$\cdot 10^9$ cm^{-2}s^{-1} (Borexino rate: 46.0$\pm$1.5(stat)$\pm$1.5(sys) cpd/100 ton). The 2009-10 calibration campaign was key in understanding the detector's response –especially with regard to the energy response– and enabling an accurate MonteCarlo fit of the background components.

^{8}B neutrinos Borexino's direct observation of the ^{8}B solar neutrino flux represents the lowest-threshold (3 MeV) measurement available for this spectral component, at a precision of ~20% in the Phase I-only latest published result ($\phi_{^8B}$=2.4±0.4(stat)±0.1(sys)·10^6 for a Borexino rate of 0.217±0.038(stat)±0.008(sys) cpd/100 ton[12]). This result also highlighted the downturn in rate due to the solar MSW effect in the transition region.

The ^{7}Be signal was also used for the seasonal modulation study[14] and the verification of the LMA prediction for the lack of diurnal/nocturnal asymmetry[13] in the solar neutrino flux reaching a detector on the surface of Earth (A_{d-n} = 0.001 ± 0.012(stat) ± 0.007(sys) cm^{-2}s^{-1}).

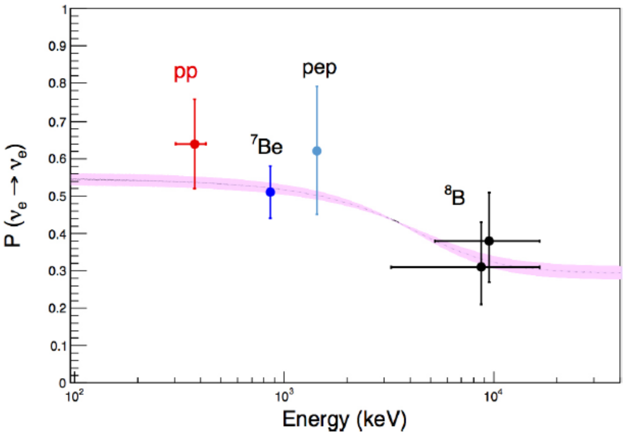

Figure 2: Survival probability according to the MSW effect (1σ band) and experimental measurements from Borexino for all observed solar neutrinos, from [8].

The Inverse Beta Decay (IBD) reaction $\overline{\nu_e} + p^+ \rightarrow n^0 + e^+$ is Borexino's main channel to detect antineutrino signals, of which reactor and **geo-neutrinos** are the most abundant example. IBD has a threshold of 1.806 MeV for the antineutrino energy, and therefore rules out very low energy measurements (mainly coming from ^{40}K). However, its coincidence signal in the detector's scintillator [1] is easily translatable to $\overline{\nu}$ energy ($E_{visible} = E_{\nu_e} - 0.784MeV$) and affected by very few backgrounds. This visible energy range for Borexino allows for a small part of the ^{238}U (6.3%) and ^{232}Th (3.8%) geo-antineutrinos to be detected, since they are the only geologically-abundant enough isotopes to yield a measurable fraction of $\overline{\nu}$ over the IBD threshold.

For the most recent analysis[3], data were selected from a livetime of 2055.9 days (before any selection cuts) since December 15th, 2007 to March 8th, 2015. The efficiency-corrected exposure after all cuts is 907±44 ton·year (or (5.5±0.3)·10^{31} p·y). Seventy-seven $\overline{\nu}$ candidate coincidences were found following this method, following three independent analysis tools, yielding a geoneutrino sample of $23.7^{+6.5}_{-5.7}$(stat)$^{+0.9}_{-0.6}$(sys) events (~27% precision), as shown in Figure 3.

The main background identified is reactor antineutrinos, which are nevertheless well-understood thanks to the International Atomic Energy Agency (IAEA)'s Power Reactor Information System (PRIS) that identifies the 435 known man-made reactor cores in operation. These are fitted away

[1] *prompt* signal from the two back-to-back 511 keV γs resulting from the positron annihilation with an electron typically nearby the interaction point; and *delayed* signal from the 2.2 MeV γ resulting from the neutron capture on one of the abundant hydrogen atoms after thermalization within a mean lifetime of 259.7±1.3(stat)±2.0(sys) μs

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according to the reported load factors to a ∼4% precision. The ^{8}Li-^{8}He cosmogenic background that decays via $\beta - n$ (wide visible energy spectrum with ∼5 MeV endpoint) was constrained to an estimated number of expected events in the golden $\overline{\nu_e}$ sample of 0.194. Correlated and accidental coincidences were estimated at 0.035±0.028(stat)$^{+0.006}_{-0.004}$(sys) and 0.221±0.004 events, respectively. The $(\alpha - n)$ background is determined independently by the ^{210}Po rate in the scintillator and included in the fit. All other backgrounds were absorbed in the systematics for energy scale.

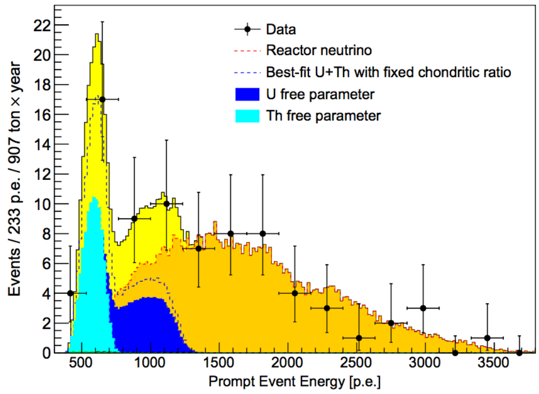

Figure 3: Observation (black points with error bars) of reactor and geoneutrinos at 5.9σ with 2056 days of data compared to a MonteCarlo-generated spectrum (color-filled histograms; blue hues = geoneutrinos and orange hues = reactor neutrinos). Two signal components (S_{geo} and S_{reac}) are left free and three background components (S_{LiHe}, $S_{\alpha n}$ and S_{acc}) are constrained to the reported values and 1σ deviations. The other components, owing to their small rate and uncertainty in energy spectrum, were left out as their uncertainty is absorbed in the systematics for the energy scale.

This corresponds to a uranium/thorium chain $\overline{\nu_e}$ fluxes at the detector of $\phi(^{238}U)$=(2.7±0.7)·10^{6} cm^{-2}s^{-1} and $\phi(^{232}Th)$=(2.3±0.6)·10^{6} cm^{-2}s^{-1}. The null hypothesis is disfavored with a probability of 3.6·10^{-9} (5.9σ) with this data. With a larger exposure, Borexino could disentangle the U/Th components and discriminate between different Earth models. The radiogenic heat production from Earth's uranium and thorium is then measured to be P_{rad}(U+Th)=28$^{+23}_{-17}$ TW, for a global measured terrestrial output power of P_{tot}=47±2 TW. Finally, a null mantle contribution to the signal is rejected at 98% c.l. and is estimated to be $S_{geo}(mantle) = 20.9^{+15.1}_{-10.3}$ TNU.

Other recent Borexino results include the study of electron decay[4] through $e \rightarrow \nu_e + \gamma$ (256 keV) and GRB-correlated neutrino bursts[5].

4. Future Phase II perspectives with BTMMS and new calibrations

Since the end of the dedicated scintillator purification efforts in 2012, Borexino has entered its most stable, most radiopure data-taking period yet, known as Phase II –which also benefited from the completion of the internal and external calibration campaigns in 2009-10. Among the most spectacular intrinsic background reductions achieved, the scintillator purification campaign yielded unprecedentedly low equilibrium concentrations of ^{238}U and ^{232}Th: at present, <9·10^{-20} g(^{238}U)/g of scintillator, and <7·10^{-19} g(^{232}Th)/g of scintillator, respectively: 13-15 orders of magnitude under typical ambient concentrations in dust, and 7-8 orders of magnitude under concentrations in untreated scintillator. ^{85}Kr was another isotope where the reduction was very noticeable, now bringing it under levels where it had been problematic (from ~30±5 cpd/100tonnes to <7 cpd/100tonnes). A factor of 10 reduction was also achieved for ^{222}Rn. Out-of-equilibrium ^{210}Po was brought up because of the fluid movement operations inherent in the purification technique, but its natural decay rate ($\tau_{1/2}$=138.376 days) and the scintillator isolation from external sources of this radioisotope meant that its level fell to less than 1 cpd/tonne since mid-2013, with the exception of a brief ~2 cpd/tonne spike in mid-to-late 2014.

This long and high-quality data corpus offers great opportunities for renewed precision measurements of the solar neutrino components already detected. Moreover, it offers the opportunity for more daring initiatives such as a **wideband, precision fit of the full solar neutrino spectrum**, from the *pp* to the ^{8}B νs, employing a new neutral network-based Pulse Shape Discrimination (PSD) technique based on a Multi-Layer Perceptron (MLP) strategy, superseding the previously used Gatti parameter analysis.

High-efficiency, low deadtime rejection of cosmogenic ^{11}C is of paramount importance in the medium energy (~1-2 MeV) range of the spectrum, where *pep* and the lowest-energy ^{8}B neutrinos lie. The Three-Fold Coincidence (TFC) selection algorithm[16] is therefore considered another pivotal element, which continues to be improved and better characterized.

Moreover, the possibility may exist to improve the existing best limit on the contribution of CNO neutrinos to the solar spectrum. Ultimately, all reasonable measures are being taken to improve Borexino's sensitivity to this crucial spectral component, with the aim of exploring all avenues towards what is currently understood to be an extremely challenging direct detection –which would signify a major achievement in stellar physics, while shedding more light into the *Solar Metallicity Problem*[15].

To this end, **precise knowledge of the ^{210}Bi rate** during each period of Phase II is of utmost importance. It is intimately linked to that of ^{210}Po (bismuth being its progenitor isotope in the decay chain, "supports" the combined ^{210}Bi+Po secular equilibrium rate), which is reasonably well constrained thanks to PSD techniques. An ideally-behaving static concentration of ^{210}Po in the scintillator would decay away asymptotically to the *plateau*, or *supported*, equilibrium rate of ^{210}Bi –itself difficult to tag because of its β-like signature, indistinguishable from other signals in the same energy range. Hence, once "legacy" polonium from construction and wash-off decays away, it will leave a plateau corresponding to the Inner Volume's intrinsic, equilibrium levels. Uncooperatively though, the ^{210}Po rate has fluctuated unpredictably and non-homogeneously in Borexino's FV since the start of Phase II. Fortunately, a proximal cause was soon found for this behavior, with ambient temperature swings in the experimental Hall being the culprit understood to be causing scintillator fluid mixing from its ideally-stratified (cool bottom, warmer top) configuration. This brings polonium from more peripheral, less radiopure areas of the detector to its FV. Consequently, a detector wide, multi-phase effort to monitor and manage Borexino's internal temperatures was kicked-off in 2014: *Borexino's Thermal Monitoring and Management System* (BTMMS), that would expand the aging, coarse heritage temperature monitor system installed during construction. It features three major subsystems already in place:

Latitudinal Temperature Probes System (LTPS) The first component to be added, as a prototype, in the summer of 2014, was a set of 14 30m-long temperature monitoring probes, sheathed within teflon tubes to be inserted at the end of the *re-entrant tubes system* –originally designed to house externally-inserted calibration sources in the outer buffer for the external calibration campaigns. Unused for the rest of the experiment's lifetime, these ports provided an excellent location to finely measure fluid temperatures inside the SSS, 50 cm inside the Outer Buffer, on the Sphere's vertical "main meridian". This system was complemented by a second set of 14 more probes, housed in the same tubes 1 m behind the firstly installed, in the water surrounding the SSS: for redundancy as well as to study the thermal transport between both sides of the Sphere. This *Phase I* LTPS was soon complemented by 20 more probes on the outer skin of the WT and 4 in the so-called *Icarus/SOX pit* under the detector (*Phase II*), as well as 7 more on the top of the WT's "crown" and 4 external air probes (*Phase III*), all cross-calibrated among themselves to exceed factory specifications.

Thermal Insulation System (TIS) In conjunction with the *Phase II.a* (WT exterior surface probes) LTPS deployment, a large-scale campaign to insulate the detector's exterior surface from the environment was started in May 2015. Two layers of 20cm-thick rock wool fireproof material (the second of which hosting a reflective aluminized mesh layer) were adhered to all exposed WT structural surfaces. The Phase II.a LTPS sensors would be housed underneath these layers, to provide an accurate picture of the water temperature on the same vertical section of Borexino as the *Phase I* sensors. After a $\sim$3 month technical stop with $\sim$70% of Borexino already insulated, the TIS was finished in December 2015. Temperature stabilization results were seen detector-wide since the first stages of the installation (see Figure 5) thanks to the new LTPS, and no adverse effects were noted – hence the rapid pace with which it was completed. It should be noted that this stabilization effect was a combination of the TIS influence as well as the shut-down of a water loop that kept the lower half of the WT in circulation, an hence mostly mixed.

Figure 4: External Borexino appearance after TIS installation in early 2016.

Active Gradient Stabilization System (AGSS) With an ideal TIS, the detector would see a global cooling due to the unavoidable thermal heat sink of its bottom resting on the mountain's rock (at an approximately constant 7-8°C). In reality, even though sudden changes will be smoothed out, some heat will inevitably seep through the TIS, leading to a more stable stratification. A global cooling of the detector that could homogenize the internal temperature to a low value and also shrink the top-bottom temperature gradient is practically ruled out for this reason, as well as by the detector's long calculated relaxation constant. However, possible temperature inversions at the top that could induce strong currents or equally worrisome reductions in the gradient that would weaken the natural tendency toward stable, static fluid stratification, would remain a danger. It was then decided that, before finishing the installation of the upper TIS layers, a dedicated active heating system would be put in place, in thermal contact with the uppermost areas of the WT, consisting of two independent water loops ("serpentines") that would transfer heat from their top to their bottom thanks to a recirculation pump and a 3 kW heater. Its influence would be kept localized by its good thermal contact with the WT and its location under the insulation.

Numerical simulations of the combined behavior of all BTMMS subsystems with seasonal or induced air temperature changes and the bottom's thermal sink are in progress, with the aim of fully understanding the IV's fluidodynamical influence in ^{210}Po shifts and precisely manage its future behavior.

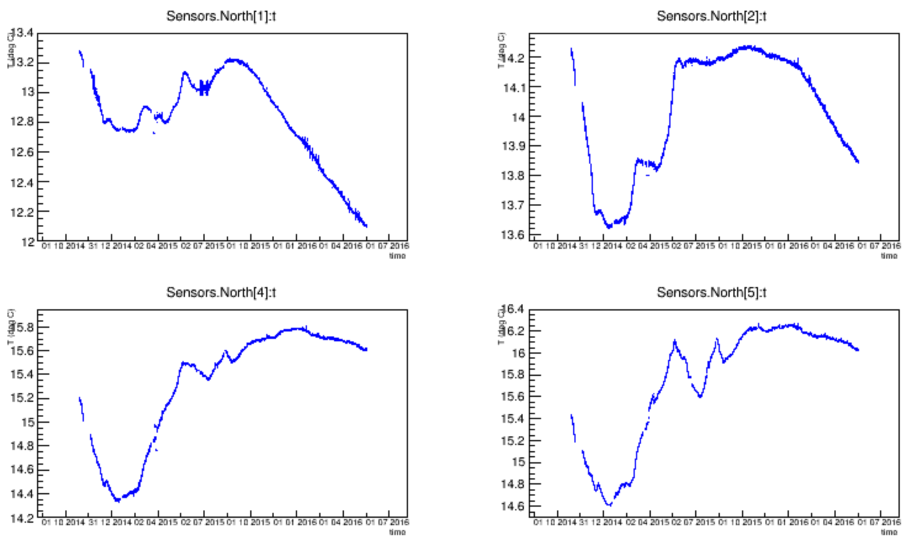

Figure 5: Temperature evolution in the North side of the Outer Buffer as measured by the Phase I.a LTPS sensors, from the bottom position at -67° latitude on the SSS (upper left) to +67° (lower center), highlighting the drastic, stable change in temperatures since the TIS installation and water loop shut-down.

A **new calibration campaign** is also foreseen in the near future, to ensure Phase II data is exploited to its maximum potential: new calibration isotopes and techniques not previously employed in the 2009-10 campaign are expected to be employed. The heritage system has been refurbished in preparation for its use, to again ensure that negligible levels of external contamination are introduced in the pristine scintillator. The tweaking and validation of the newly-developed `g4bx2` MonteCarlo simulation package will be one of the main focus items for the calibrations, as well as the mapping of possible changes in detector response, or a more precise definition of the scale (both spatial and energetic) where the last calibration did not reach. Finally, it provides a necessary check of the inhomogeneous response in the bottom half of the detector, where the SOX source experiment (described in the next section) will have its strongest signal, but also where most of the PMTs that have failed over time lie.

With these aims in mind, a new optical source positioning system was devised: instead of the simple diffuser located at the end of the mechanical insertion arm, close to the source, intended for red (650 nm) light fed through a fragile optical fiber[2], the new system employs 7 high-intensity infrared-emitting devices (IREDs) inside a custom-designed enlarged quartz vial. These IREDs (SFH4716S: 860 nm peak wavelength, 850 nm median) have a large (75° half-intensity) visibility angle and are specifically arranged in a "tower" design –at 60° mutual angles plus one in the vial's tip– to increase emission isotropy. Their operating wavelength is practically invisible to the PMTs, as opposed to the red visible light that noticeably increased their dark noise rates, allowing to keep their high voltage on during source positioning operations, thereby reducing on-off cycles in the HV supply. Furthermore, the CCD cameras used to triangulate the source position inside the IV[2] offer better panspectral sensitivity to IR than to red light, while the absorption for this longer wavelength in the scintillator/buffer mixtures is just marginally larger. The deployment system is similar to the heritage one, but the use of optical fiber is discontinued, being replaced by high-conductivity, low-background self-shielded electrical cable.

Additionally, the creation of unquenched, "high-intensity" ($\sim$70 Bq) ^{222}Rn sources dissolved in PC has been demonstrated in a new setup in Italy, in the Federico II University in Naples. Furthermore, a new 50 n^0/s, 850 kBq ($\pm$10%) ^{241}Am source (wrapped in beryllium for neutron emission: AmBe) was procured, to be used in conjunction with a moderating teflon/nylon + lead holder for neutron calibrations. Additionally, this holder can be outfitted with high-purity nickel foils to produce high-energy γs for high-energy calibration. In conjunction with this, a lower-activity 2 n^0/s ^{241}Am^{13}C source wrapped in gold foil will also be employed as a lower-noise alternative to neutron calibration. These sources, together with similarly high-intensity water-solved gamma- and positron-emitting isotopes, provide a full range of regimes representative of Borexino operations, as well as reduced data-taking time.

5. CeSOX

The existing hints toward the existence of roughly consistent anomalies in short-baseline neutrino oscillations (see [17] for a recent review) that may constitute pervasive evidence toward a 3+1 sterile neutrino scheme ($\Delta m^2_{14} \sim$1 eV^2), even more complex 3+N models or some other anomalous behavior in neutrino oscillations, instill urgency into peering deeper into the matter, to discover the nature of the anomaly or reject it with confidence.

In this sense, the SOX project (**Short-distance Oscillations with BoreXino**) will employ the unique capabilities of Borexino to unambiguously sweep the remaining allowed (Δm^2_{14}-θ_{14}) phase space. Right beneath the Borexino detector, there is a cubical pit (side 105 cm) accessible through a small squared tunnel (side 95 cm) that was built at the time of construction with the purpose of housing possible neutrino sources; for this reason, one such source can be deployed with no changes to the Borexino layout: this is referred to as the SOX-A phase. SOX-B and C (for now, conceptual phases) would insert the source in the Water Tank or in the center of the SSS, respectively. The center of the pit is at 8.5 m from the detector center, requiring a relatively high source activity: $\sim$150 kCi for a 1.5 year campaign. The first campaign in the SOX program (CeSOX) will be a

^{144}Ce source, which β-decays to ^{144}Pr ($t_{1/2}$=296 days). This daughter rapidly ($t_{1/2}$=17 min) β-decays again to ^{144}Nd, emitting a spectrum of $\overline{\nu}_e$, part of which falls above the IBD threshold (the endpoint of the ^{144}Pr decay is $\sim$3 MeV). The source can be created by isolating and extracting ^{144}Ce from spent nuclear fuel (SNF), yielding a few kilograms of CeO_2 –which would contain a few tens of grams of ^{144}Ce. The source also emits γ-rays that need to be shielded for both biological protection purposes and to avoid external source-induced background. Consequently, a cylindrical W-alloy shielding ($\rho >$18 g/cm^3) surrounds the source, whose design was driven by the 2.185 MeV γ-ray emitted with 0.7% b.r. to provide a $>10^{12}$ γ-ray attenuation factor along any direction.

Once the CeSOX is inserted, through a rail system, at the end of the tunnel under the detector, Borexino will observe both the rate at which the $\overline{\nu}_e$ are emitted from the source, as well as perform oscillometry to attempt to detect "non-standard" short-baseline oscillations with $\sim$m-scale wavelength, that deviate from the established 3 active ν paradigm. These *ripples* in the source-produced $\overline{\nu}_e$ flux would fit within the detector's dimensions while being large enough to be visible with Borexino's resolution. It is clear though, that for this to be possible, an extremely precise independent benchmark of the source's activity must be obtained, so that an accurate representation of the source's nominal $\overline{\nu}_e$ output can be known. Two custom-designed and -built water-loop calorimeters, developed by CEA in France and INFN/TUM in Italy/Germany, will ensure a $<$1% calorimetric measurement of SOX's source activity. An improved determination of the detector's response in the Inner Volume's bottom pole, both in efficiency, energy and position reconstruction, will be carried out through a dedicated, focused deployment of the ^{241}Am sources (see previous section) in the inner periphery of the vessel during the next calibration campaign, to maximize data collection and minimize systematic uncertainties in the volume with the largest expected event density.

6. Summary

The recent upgrade of Borexino's thermal management system featured by the installation of the multi-component BTMMS, coupled with the settling in of the unique and unprecedented levels of scintillator radiopurity in Borexino's Inner Volume after the 2011-12 purification campaigns, are allowing the build-up of an ever-improving, low-threshold, long-livetime dataset: Phase II. A continued striving towards data quality enhancement though the aforementioned BTMMS and an upcoming new calibration campaign, as well as the use of novel analysis techniques, are instrumental in yielding important refinements (10-3% precision) in the unique set of results obtained during Phase I. This is being complemented by the unification of the main components of the solar neutrino spectrum under a single measurement, including lowering the upper limit of CNO neutrinos. Furthermore, the external CeSOX source program, aimed at testing possible anomalies in short-baseline neutrino oscillations with a high-activity 150 kCi ^{144}Ce-^{144}Pr source, accurately characterized by high-precision calorimetry, will be directly benefited from these latest upgrades, upon its foreseen deployment in late 2017.

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