Experimental Techniques for Low Energy Neutrino Experiments

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During the past years it has become always more and more important to study solar neutrinos at low energies (below 1 MeV) in order to solve the solar neutrino problem.
Measuring low energy solar neutrinos is not an easy task because of the rapidly increasing background in the sub-MeV region. Thus new experimental methods have been developed to accomplish the challenging aim.

1. PROBLEMS

Observing solar neutrinos in the energy range below 1 MeV is one of the major objectives for the new generation of solar neutrino experiments. Unfortunately, using common techniques in the construction of the experimental apparatus, the number of events observed which are created by solar neutrinos would be completely overwhelmed by the number of events created by the common background sources, natural radioactivity and induced background.

An example of how challenging the requirements for the new generation of sub-MeV solar neutrino experiments are is shown in Table 1. It shows the concentration in Bq/kg of ^{238}U and ^{232}Th in the continental crust in comparison with the requirements for the detector material used in the solar neutrino experiment GNO (former GALLEX experiment, a first generation experiment) and in BOREXINO, one of the second generation solar neutrino experiments that aims to measure the neutrinos from the ^{7}Be-reaction in the pp-cycle inside the sun.

1.1. Natural radioactivity

The natural radioactivity consists mainly in the primordial radionuclides present everywhere in the natural environment (e.g. ^{40}K, radioactive chains of ^{238}U and ^{232}Th), the radioactive gas Radon (coming from the primordial radioactive Uranium and Thorium chains) and the cosmic rays. The primordial radionuclides can be reduced by material selection, Radon can be cast away flushing inert high purity gases through the empty spaces inside the experimental apparatus, whereas the cosmic rays can be shielded quite efficiently going underground (e.g. Kamioka mine, Homestake mine, Gran Sasso National Laboratories) [1].

1.2. Induced background

Induced background is a secondary product of the natural radioactivity. Cosmic rays produce so-called cosmogenic radionuclides with a large variety concerning their half life, ranging from days to several hundred years. Some of the most important cosmogenic radionuclides are ^{3}He, ^{7}Be, ^{10}Be, ^{36}Cl, ^{14}C and ^{42}Ar, [2]. Moreover there is the γ-induced background (e.g. Compton-scattering) neutron induced events (inelastic scattering and radiative capture) and muon induced background events (activation, neutron production and direct electromagnetic interaction) which may create neutrino-like events. This type of background can be reduced by selecting thoroughly the environment (low natural radioactivity) and putting additional shielding around the detector (anti-coincidence counters, passive shielding).

Table 1
Maximum tollerable radioactive contamination in ^{238}U and ^{232}Th of the detector material in the solar neutrino experiments GNO and BOREXINO in comparison with average radioactivity in the continental crust [1].

Material	Bq/kg of $^{238}U_{eq}$	Bq/kg of $^{232}Th_{eq}$
continental crust	36	44
$GaCl_3$-solution (GNO)	< 0.3	$< 8 \times 10^{-3}$
liquid scintillator (BOREXINO)	$< 10^{-9}$	$< 0.5 \times 10^{-9}$

2. POSSIBLE SOLUTIONS

Of course it is impossible to reduce the contribution of the background to zero. But with some effort it is feasable to reduce the background to levels which allow to detect the low rates of neutrino events predicted by theory.
The best reduction is obtained approaching the problems in multiple steps of refinement reducing in each step the possible contribution of disturbing background down to the minimum reachable level.

2.1. Material selection

The first step is to select very carefully the materials which will be used while building the detector. The nearer the material is located to the innermost part of the detector the lower has to be its radioactive contamination with natural radioactivity. Moreover the location of the experiment has to be selected due to the amount of radioactivity in the surrounding environment to reduce as much as possible the external background contributions.

Possible methods of material selection are first of all non destructive selections by means of low level Germanium detectors (e.g. HADES/Belgium, LNGS/Italy, [3–5], sensitivity: 0.5 mBq/kg), emanation chambers (Radon emanation measurements, sensitivity: 0.05 mBq, [6]) and gaschromatographic methods (filtering out radioactive gases, sensitivity: 1 μBq/m^3 of ^{222}Rn in nitrogen with a low temperature adsorber, [7]). Then there are also the destructive methods e.g. by means of neutron activation analysis (NAA) (e.g. TU Munich, sensitivity: 10^{-17} g/g in ^{238}U and ^{232}Th for liquid scintillators, [8]) and ICP mass spectrometry (e.g. Ispra/Italy, sensitivity: 10^{-15} g/g in ^{238}U and ^{232}Th).

Moreover it is sometimes necessary to treat the surface of the used materials in order to avoid the background contribution from surface contaminants. This can be done for example by means of etching the surface with acids, [1].

2.2. Shielding

Once the best possible materials for the detector and the environment are selected, the remaining radioactive contribution to the background has to be reduced again.

This can happen in two ways, either with a passive shielding with very low intrinsic radioactive contamination which absorbes most of the incoming external radiation without creating by itself secondary radiation, or with an active shielding. The latter method discriminates actively "real" events from background events or removes actively potential background candidates (nitrogen flushing of passive shieldings to avoid Radon isotopes). Usually it is convenient to combine both shielding methods for optimization.

Passive shieldings consist in several layers of materials, each of them sensitive to a certain kind of background radiation. Materials with large Z (lead, steel) absorb efficiently high energetic photons, whereas "medium" Z materials (copper) absorb better low energetic photons. Materials containing an high amount of hydrogen and/or are loaded with boron are very efficient in absorbing neutrons.

Of course all these shieldings must have undergone the first step of selection in order to be efficient in suppressing the external background and at the same moment be intrinsically clean to minimize their own contribution to the background.

Active shieldings make use of decay sequences, of signal patterns or of multiple detector mechanisms. Moreover, there are anticoincidence counters, tracking emulsions and many more experimental setups to reject background.

2.3. Purification of detector material

The most important step is the final treatment of the detector material itself. Even with the best shielding it is useless to start the experiment if the detector material is dirty from the beginning or deteriorates rapidly or by accident during the running of the experiment.

It is therefore mandatory to treat the detector material separately in order to guarantee the best performance of the detector. In case of organic liquids it is possible to do a distillation on site (removal of organic impurities, [9]) and to do a water extraction or a filtering with low radioactive silicagel (both for removing anorganic impurities, [10]). Liquids in general can be sparged with high purity nitrogen to remove radioactive gases inside the detector ([7]).
In case of the presence of radioactive isotopes the detector material has to undergo an isotopic separation during its production.

3. CONCLUSION

For the new generation of solar neutrino experiments which aims mostly at the measurement of low energy neutrinos (below 1 MeV) it is mandatory to reduce the background contribution by several orders of magnitudes with respect to the experiments observing neutrinos up to now. At low energies the background rises very rapidly and would cover the low rates of solar neutrinos expected. Therefore new methods for background reduction have been developed which guarantee a good performance of the solar neutrino detectors even at low energies. In this article was presented a small selection of these methods with the bibliography for a deeper study of the possibilities of today and for the future.

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