Some Future Solar Neutrino Experiments

Hervé de KERRET [a]

[a]PCC Collège de France, 11, place Marcelin Berthelot, 75005 Paris, France

We briefly review some future solar neutrino projects. All of them aim to a better determination of the low energy (< 1 MeV) solar neutrino spectrum.

1. Introduction

The running experiments SuperKamiokande [1] and SNO [2] will achieve the measurements of the high energy ^{8}B part of the solar neutrino energy spectrum, with its flavour content. A precise measurement of the annual and day-night variation will also be performed.

A complete knowledge of the solar neutrino spectrum require the same experimental effort for the low energy ^{7}Be line and pp spectrum.

Part of the information is already there, since the GALLEX and SAGE results provided a sum rule for the charge current reaction of the neutrinos electrons ν_e coming from the Sun. The next experiment, Borexino [3], will measure from end of 2001 the ^{7}Be contribution using the elastic scattering reaction ν_e e $\rightarrow$ ν_e e (with a high statistics).

So we are left with 2 informations missing, one for the charge current interactions, one for the elastic reaction for pp neutrinos.

2. Elastic reaction

The elastic scattering reaction ν_e e $\rightarrow$ ν_e e is very well know, and its cross section can be computed very precisely.

The only signature is the recoil electron. So a major effort on the background reduction and the radiopurity of the materials used must be undertaken. The door to this sub-MeV neutrino physics has been opened successfully by Borexino [3], whose prototype CTF has demonstrated the feasibility of the required very low activity.

Most of the projects use noble gas (helium, neon, xenon) except krypton and argon (which are known to be radioactive). CF_4 can also be purified at the required level and people of the MUNU collaboration are thinking to a solar neutrino detector.

An important parameter for these detectors is the Z of the active material in the target. High Z means good self shielding against external background, but potential problems with cosmogenics activation. If this can be solved (and going deeper underground is a direct solution), high Z detectors such as xenon ones [4] could be the more direct way to a future detector.

This cosmogenic problem is much less severe for most of the low Z materials. the absence of self-shielding is a severe draw back, which leads to very clever detectors, using the interesting properties of some of these low Z materials. Since there is much to learn from these projects, and since they are old and mature R&D, we will focus here on the helium projects.

2.1. HERON

The target is superfluid ^{4}He [5]. The signal is about 2 events/day/ton, of which half is pp neutrinos. This is an ultra-pure material: superfluidity guarantees that other atoms are pushed towards the walls or fall to the bottom. Helium has no long lived isotopes. So all the background is due the gammas coming from outside of the target. The helium target is surrounded by a moderator (which could be frozen nitrogen) to reduce this flux.

The recoil electrons create both rotons and 16 eV photons. which are detected by sensors located a few mm above the liquid surface. The photons arrive first, and provide an energy measurement and localisation. They are followed by the rotons, which evaporate atoms at the surface: the atoms are then detected by the sensors and used to increase the energy resolution and cross check the localization.

A highly original solution has been suggested for the event position reconstruction. It consists to use a coded mask, which is a standard method in astronomy. Here the sensors themselves are disposed on 2 planes. The sensor of the first plane (near the surface) form the mask, and the second plane sensors receives the 16 eV photons through the holes between them. This localization has been simulated, and a spatial resolution better than 10 cm seems achievable. A rejection agains the multiple Compton exists (neutrino interaction is a point vertex, which gives a better likelihood).

After reconstruction, the spatial localization is used to define a fiducial volume. The radial dependance of the background is measured outside the fiducial volume, and then extrapolated in the fiducial volume.

Two main developments have still to be made to achieve this R&D:

- Sensors have been developped and 13 eV resolution achieved [6]. A progress by about an order of magnitude is still needed, but seems within of the possibility of the current progress in this field.

- The reconstruction must be fully studied. The control of the tails of badly reconstructed events is of course a critical point.

This should be achieved in 2002 and the question of creating a collaboration will rise soon.

2.2. HELLAZ

The HELLAZ project [7] consists in a TPC filled with pressurized helium (20 bars in 2000 m^3). Such a detector would give a neutrino yield of 4 ^{7}Be and 7 pp neutrinos/day above a threshold of 200 keV neutrino energy (corresponding to a recoil electron above 100 keV).

Both the energy and the recoil angle of the electron are measured, which allows to fully reconstruct the kinematics, and obtain the neutrino energy and direction. So the ^{7}Be line is seen as a peak, not as a Compton-like front (as in Borexino or HERON), which improves the background rejection. Using the direction information, it is possible to subtract the noise measured in other directions. (the movement of the Earth around the Sun makes this bias free).

HELLAZ pushes the TPC idea at its extreme possibility. The slow drift speed (1.4 mm/sec) of helium allows a detection electron by electron, which provides the maximal information on the electron track in the gas. The diffusion is low, so the precision on the 3D reconstructed direction is maximized.

From the simulation, and thanks to this good direction measurement, till 10 000 external gammas per day can be substracted effficiently. So the requested level of radioactivity is about 10^{-12} g/g of uranium and thorium for the cage of the TPC and the detector.

An important R&D program has tested detectors fast enough to separate electrons. The Micromegas detector has been proven to be able to do it. Successive electrons have been detected separately at 10 ns intervals, which reachs the goal of the project.

The main effort is now to tune the quenchers at 20 bars, to assure a high enough gain in operational conditions.

3. Charged currents projects

The reaction is ν_e + (A,Z) $\rightarrow$ (A,Z+1) + e^-. Since the Z of the hit atom is changed, these reactions allow more interesting signatures. A subsequent decay of this atom can provide with a delayed signature. The occurence of 2 particules at the same place and time is a strong signature, highly reducing the accidental background. Some exemples of such targets are Indium [8] and more recently Molybdenum [9].

This field is now dominated by an important collaboration, LENS [10], from an idea of R.Raghavan [11]. This leads to new candidates as target for solar neutrinos, of which an ytterbium isotope, ^{176}Yb, has been chosen. 20 tons are requested to observe about 400 solar neutrino interactions per year. The primary signal gives the neutrino energy over a threshold of 301 keV, and the signature is a gamma of 72 keV, delayed by 50 ns [12].

The choice has been made to develop a loaded liquid scintillator, with 5 to 10 % Yb loading. An important R&D is in progress, mostly at Bell labs and Moscow, with the help of the Rhodia company to study the industrialisation of the process. Small samples of stable liquids, whose properties are close to the requested parameters in light yield and transmission length, have been produced.

Accidental backgrounds are efficiently suppressed by the a space time correlation between these 2 signals. The amount of ^{14}C in liquid scintillators (at the level measured by the counting test facility CTF in Borexino) requires a spatial resolution of a few hundred liters, which leads to some segmentation inside the detector.

The R&D has to face several correlated backgrounds. The most severe is the ^{231}Th in the ^{235}U chain (a β from 0 to 305 keV is followed by a 84 keV gamma 65 ns later). This is very close of the signature, and leads to ^{235}U purity of 10^{-15} g/g. Such low level has been achieved by Borexino for simple and non-polar liquids, and could be more difficult for complicated loaded ones. A solution under investigation is to use isotopic dilution, decreasing artificially the ratio ^{235}U / ^{238}U by adding depleted uranium.

Another important noise is due to the self-correlation inside the pulse : a fluctuation in the late charge can mimic the signature. Imposing a minimum delay between the main pulse and the secondary one (the 72 keV γ) will reduce this, at the cost of a fast decrease of the efficiency of the detector (a delay of 40 ns divides it by 2).

The rather poor knowledge of the cross section makes a neutrino source measurement necessary to calibrate the detector. Due to the existence of 2 levels in the ^{176}Yb nucleus, both ^{51}Cr (751 keV) and ^{75}Se (463 keV) will be necessary.

A high light amount is needed, to achieve a good definition of the 72 keV photon. This improves also the self correlation problem : the statistical fluctuation in the late charge are reduced.

Another interesting direction is crystals of the YAG type, where yttrium is replaced by ytterbium. The measurements of the UV scintillation and time constants seem promising. The purity of crystals is limited, but a solution could be to localize very severely inside the crystal itself.

A low activity shielding is to be built in 2001 at Gran Sasso, to house the future prototype of the detector. The R&D phase is intended to be finished at the end of the year.

4. Conclusion

After the present running (or running soon like Borexino) experiments, new types of solar neutrino detectors have to be built to measure the low energy spectrum (mainly via charged current reactions) and to contribute to disentangle the different oscillation scenarios of the solar neutrino problem. R&D is in progress and is promising, but a proposal is not expected before end of 2001.

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