W HY DO SOLAR NEUTRINO EXPERIMENTS BELOW 1 M EV ?^a

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I discuss why we need solar neutrino experim ents below 1 M eV. I also express my prejudices about the desired num ber and types of such experim ents, em phasizing the importance of p-p solar neutrino experim ents.

The great challenge of solar neutrino research is to make accurate measurements of neutrinos with energies less than $1 \text{ MeV} \cdot \text{W}$ enced to develop experiments that will measure the the total ux, the avor content, and the time dependence of the ⁷Be neutrinos (energy of 0.86 MeV), and the total ux,

avor content, energy spectrum , and time dependence of the fundam ental p-p neutrinos (< 0.43 M eV).

M one than 98% of the calculated standard model solar neutrino ux lies below 1 M eV. The rare ⁸B neutrino ux is the only solar neutrino source for which m easurem ents of the energy have been made, but ⁸B neutrinos constitute a fraction of less than 10⁴ of the total solar neutrino ux.

The p-p neutrinos are overwhelm ingly the most abundant source of solar neutrinos, carrying about 91% of the total ux according to the standard solar model. The ⁷Be neutrinos constitute about 7% of the total standard model ux.

I want to express rst m y own views about what we should and should not emphasize in developing new experiments and then say a little bit about speci c experiments.

Each of the measurable quantities for low energy solar neutrinos is in portant and can be used to constrain models of the neutrino and of the sun. In my view, too much emphasis has been placed in the past on trying to devise experiments that can do everything. I think we should be happy if a low energy solar neutrino experiment can measure any of the desired physical quantities accurately. For example, an experiment that is sensitive to time dependences need not necessarily measure a ux accurately. If an experiment measures a charged current rate, it does not need to provide detailed spectral information. We have to learn how to craw lbefore we try to run.

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We should aim at ultimately developing experiments with high statistical signi cance in order to re ne the tests of solarm odels and neutrino oscillations. But, the rst experiments do not have to have high counting rates, especially if they are modular and can demonstrate proof-of-principle.

The interaction cross sections must be known accurately, to a 1 accuracy of 5% or better, if we are to have a measurement that is good to 10%. I think a 1 measurement of the total rate, for ⁷Be and for p-p neutrinos, that is at least as accurate as 10% is necessary in order to make real progress. There is no reason to believe that we can rely on (p,n) measurements or nuclearm odel calculations to provide a determination of the absolute cross section to this accuracy. Instead, we must either make use of the related beta-decay process when available or carry out precise measurements with intense radioactive sources.

Solar neutrino experiments are alldicult and alltake a very long time to carry out. It is tempting to say that a given part of parameter space is covered by a particular experiment and so we must design an experiment that tests an entirely different part of parameter space. I think this type of reasoning is dangerous, because the history of science shows that experimental results are misinterpreted or are misleading much more offen than one would expect from the quoted errors. Moreover, the claim that two different experimental techniques measure the same quantity offen rests upon a theoretical assumption, a theoretical model that itself requires testing.

W e m ust have redundancy. W e m ust have di erent ways of m easuring the sam e quantities. The implications of the experimental results, for physics and for astronom y, are too important to depend upon single experiments.

A number of promising possibilities were discussed at the LowNu2 workshop. These include the BOREXINO observatory, which can detect e scattering and is so far the only approved solar neutrino experiment that is both being built at full scale and that can measure neutrino energies less than $1 \text{ MeV} \cdot 0$ ther very promising experiments that were described at this workshop include CLEAN, GENIUS, HERON, KamLAND, LENS, MOON, and XMASS. After the workshop, Raju Raghavan¹ succeeded in demonstrating that one can build a stable In liquid scintillator that could potentially be used for a very low threshold p p solar neutrino detector (if one can overcome by coincidence and modular techniques the unfavorable raw signal to noise ratio of 10^{-11}).

W e want to test and to understand neutrino oscillations with high precision using solar neutrino sources.

M agic things can be done with neutrino lines², like the 0.86 M eV 7 Be line. To make the magic work, one has to measure the neutrino-electron scattering rate (as will be done for the ⁷Be line with the BOREX INO experiment), and also the CC (neutrino-absorption) rate with the same line (no approved experiment). A sum ing there are no sterile neutrinos, one can then use the two m easurements to determ ine uniquely the survival probability at a particular energy and the total neutrino ux. One can test for the existence of sterile neutrinos by m easuring² the neutrino-electron scattering rate and the CC rate for both the 0.86 M eV and the 0.34 M eV ⁷Be neutrino lines, but this is a tough jbb.

The time dependences, seasonal and day-night, of the observed event rates of the ${}^{7}\text{B}$ e neutrino lines will be valuable diagnostic tests of neutrino oscillation scenarios.

I believe that we have calculated the ux of p-p neutrinos produced in the sun to an accuracy of 1%. This belief should be tested experimentally. Unfortunately, we do not yet have a direct measurement of this ux. The gallium experiments, which have played an enormously important role in understanding what is happening to solar neutrinos, nevertheless only tell us the rate of capture of all neutrinos with energies above 0.23 MeV.

The most urgent need for solar neutrino research is to develop practical experiments to measure directly the p-p neutrino ux, hopefully both charged current and neutrino-electron scattering, the energy spectrum, and the time dependences. An experiment, or a combination of di erent experiments, that measures the total ux of p-p neutrinos can be used to test the precise and fundamental standard solar model prediction of the p-p neutrino ux.

Figure 1 shows the calculated neutrino survival probability as a function of energy for three global best- tM SW oscillation solutions. You can see directly from this gure why we need accurate measurements for the p-p and ⁷Be neutrinos. The currently favored solutions exhibit theirm ost characteristic and strongly energy dependent features below 1 M eV. N aturally, all of the solutions give sim ilar predictions in the energy region, 7 M eV, where the K am iokande, Super-K am iokande, and SNO data are best. The survival probability shows a strong change with energy below 1 M eV for all the solutions, whereas in the region above 5 M eV (accessible to Super-K am iokande and to SNO) the energy dependence of the survival probability is at best modest.

M easurem ents of both the CC and the neutrino-electron scattering rate of either the ${}^{7}\text{Be}$ or the p-p neutrinos will be extrem ely im portant. W hen com - bined, they can determ ine the total neutrino ux and therefore allow a direct com parison with solarm odel predictions. The same thing could be achieved by a neutral current m easurem ent, although that m ay be m ore di cult to obtain in practice.

In the m ore distant future, we will want to measure the average energy and

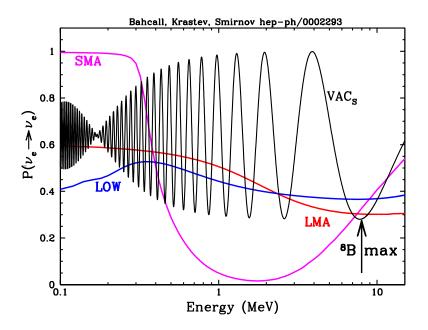


Figure 1: Survival probabilities for M SW solutions. The gure presents the yearly-averaged survival probabilities for an electron neutrino that is created in the sun to rem ain an electron neutrino upon arrival at the Super-K am iokande detector.

shape of the ⁷Be neutrino line with a precision better than 0.3 keV in order to obtain a direct determ ination of the central temperature of the sun. The standard solar model predicts that the average energy of the ⁷Be neutrinos emitted from the sun exceeds by 1.3 keV the laboratory energy of the (higher energy) ⁷Be line. This energy shift is due to the high temperature of the plasm a in the region in which the ⁷Be line is produced.

The p-p neutrinos are the gold ring of solar neutrino physics and astronom y. Their m easurem ent will constitute a simultaneous and critical test of stellar evolution theory and of neutrino oscillation solutions.

No matter what we learn from experiments at higher neutrino energies, from the wonderful experiments of SNO and SuperK am iokande, we will still desperately want to measure the p-p neutrinos. The p-p neutrinos are a fundamental product of the solar energy generation process who ux is precisely predicted but not yet measured separately. The p-p neutrinos represent the dominant mode of neutrino emission from the sun, with a ux that is 10° times larger than the ux of the rare⁸B neutrinos measured by SNO and Su-

perK am iokande. Therefore, m easurem ents of the p-p neutrinos will severely test theoretical ideas regarding both the interior of the sun and the nature of neturinos that are inferred from m easurem ents of the less abundant, higher energy neutrinos.

A cknow ledgm ents

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