SOLAR NEUTRINO PROBLEM

Experiments Begin to Shed Light

D.L. Wark of the Physics Department, Oxford University, UK, and J.S. Nicos and J.F. Wilkerson of Los Alamos National Laboratory, USA, compare the latest SAGE and GALLEX results.

It is unusual in particle physics for a significant discrepancy between theory and experiments to persist for more than twenty years. Yet that is the length of time that Ray Davis and his collaborators [1] have been measuring the solar neutrino flux by determining the amount of 8B neutrinos produced in the first step in the proton-proton chain which powers the sun. The flux of these neutrinos is well determined by the solar luminosity, and is insensitive to the details of solar structure. A significant suppression of this flux could not be explained by any plausible solar model and would be a very strong indication that some sort of neutrino mixing was taking place.

**Explanations for the Disagreement**

The reactions which generate the 8B are extremely sensitive to the core temperature of the sun (Tc), and only about a 10% reduction in Tc would be necessary to explain the rate seen in the Davis experiment. While no solar model which features such a reduction in Tc has gained general acceptance, sceptics point out that the sun may have a better idea of Tc than we do, and the possibility of such a reduction cannot be dismissed. Another possibility is that the electron-neutrinos are emitted in the predicted numbers, but that after their emission some fraction of them change into muon-neutrinos or tau-neutrinos, which cannot be detected by the existing experiments. This flavour mixing, which is analogous to the Cabibbo mixing between the weak and strong eigenstates of quarks, can occur if neutrinos are massive. Even a small amount of mixing could be amplified by the matter in the sun (the MSW effect [5]) to produce the observed suppression.

Supporters of this mechanism point out that it can neatly explain why the rate in the Davis experiment seems to be lower than that seen by Kamiokande, even though the Davis experiment is sensitive to lower energy neutrinos. This difference in the rates cannot be explained by a simple reduction in Tc. One way to decide between these two possibilities is to observe the far more numerous low-energy neutrinos coming from the first step in the proton-proton chain which powers the sun. The flux of these neutrinos is well determined by the solar luminosity, and is insensitive to the details of solar structure. A significant suppression of this flux could not be explained by any plausible solar model and would be a very strong indication that some sort of neutrino mixing was taking place.

**Comparison of SAGE and GALLEX solar neutrino data.** Flux in solar neutrino units (SNU) is plotted as a function of the date 71Ga was extracted. The SAGE data are for runs to late 1990 with 30 tonnes of Ga and for runs in 1991 with 57.5 tonnes. The Standard Solar Model (SSM) prediction is 132 SNU.

SAGE has now added results from measurements using 57.5 tons during 1991 of 71Ga with 35% (stat.) ± 20, for a combined result of 58 SNU ± 14 SNU. The GALLEX group has 30 tonnes of gallium; their initial results indicate a rate of 83 ± 19 (stat.) ± 8 (sys.) 71Ge. [8]. Given the above values, the initial results of both experiments show reasonable agreement. Yet that is the length of time that Ray Davis and his collaborators [1] have been measuring the solar neutrino flux by determining the amount of 8B neutrinos produced in the first step in the proton-proton chain which powers the sun. The flux of these neutrinos is well determined by the solar luminosity, and is insensitive to the details of solar structure. A significant suppression of this flux could not be explained by any plausible solar model and would be a very strong indication that some sort of neutrino mixing was taking place.

**Experimental Differences**

How do the two experiments differ? GALLEX had the considerable statistical advantage of lower backgrounds at low pulse heights, which permits them to use the data from L-captures (SAGE has used only the K-captures and thereby doubles GALLEX’s effective mass). In the K peak, the combination of larger target mass (for the 1991 data) and lower background gives SAGE a better ratio of signal-to-noise. To reduce background, the SAGE experiment uses metallic gallium as the target (30 t for the initial results in 1990, 57.5 t since early 1991), while GALLEX has 30 t of gallium which they keep in the form of an aqueous solution of GaCl4. This makes the initial stages of the chemical extraction simpler for GALLEX, but the absence of hydrogen in the SAGE target makes it less sensitive to some cosmic-ray induced backgrounds. One nagging worry about both experiments is that the solar-neutrino produced 71Ge may not be extracted with the same efficiency as the carrier germanium (although the different initial chemistry makes it unlikely that both experiments would be affected in the same manner). GALLEX was delayed in reporting their first results by residual 68Ge (which is made by muon spallation when the gallium is on the surface), the decay of which is hard to distinguish from 71Ge. (SAGE experienced the same difficulty, but it was an order of magnitude smaller). GALLEX’s background has now been reduced to an acceptable level.

**Further Work**

The lowest rate which would be consistent with nuclear fusion being the power source of the sun is ~ 80 SNU. This rela-
High-Mass Photon Pairs
Unconfirmed – So Far

Maurice Jacob of the Theory Division, CERN, discusses recent announcements that two of LEP's experimental collaborations have not confirmed peculiar events producing a photon pair with an invariant mass of around 60 GeV.

A computer visualisation of a high-mass photon event at CERN's L3 detector (the concentric details represent sub-detectors). An e+e- collision has produced a pair of photons with an invariant mass close to 60 GeV, and a pair of muons whose trajectories show that they passed into the outermost sub-detector.

The LEP collider at CERN was designed as the ideal instrument to test the Standard Model of particle physics. It has done this for three years to a precision which in some cases reaches one in a thousand. The model has held the line magnificently so physicists can look to it with pride. However, this is also frustrating since one hopes that some small failure could be the signal of hitherto unknown physics.

Each of the four LEP experiments has already recorded over one million Z particles so some highly improbable and unexpected features could show up. It is therefore hardly surprising that the announcement that the L3 experiment had observed four peculiar events resulted in a packed amphitheater when S.M. Ting presented them at a CERN seminar on 26 November.

The events appear to be of a very peculiar type and the need for more statistics is compelling. Two events had already been seen at L3 in 1991 and two more appeared more recently. It has also become known that the DELPHI experiment had also detected an event.

The quickest way to increase statistics at LEP is to use data from all the experiments. So collaborations other than L3 were extremely busy after the first announcement of the L3 results. What was special about the CERN seminar, besides an extensive presentation of the L3 events, was that DELPHI, ALEPH and OPAL also reported their findings.

Although DELPHI now has two-leptonic events with a two-photon invariant mass also around 60 GeV, the collaboration would not conclude at the present time from their whole set of data that there was something special. ALEPH sees such events but without evidence for mass clustering around the 60 GeV level.

The conclusions are that one must continue with the analysis of many more events at the Z energy as the number of collected events increases, and think more about possible sources of background. The situation is neatly summed up by the comment that "Ting has the event and others the background" – an event that according to a senior member of the L3 collaboration "is a good event – it has been attacked from all sides but it's still there".