LA-UR 94-2995

Conf-940722--24

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

TITLE: RESULTS FROM SAGE II

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SUBMITTED TO: Proceedings from the 27th International Conference on High Energy Physics, Glasgow, SCOTLAND, July 20-27, 1994.

Results from SAGE II

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Abstract

The Russian-American Gallium solar neutrino Experiment (SAGE) began the second phase of operation (SAGE II) in September of 1992. Monthly measurements of the integral flux of solar neutrinos have been made with 55 tonnes of gallium. The K-peak results of the first nine runs of SAGE II give a capture rate of 66^{+14}_{-13} (stat) $^{+5}_{-7}$ (sys) SNU. Combined with the SAGE I result of 73^{+18}_{-16} (stat) $^{+5}_{-7}$ (sys) SNU, the capture rate is 69^{+11}_{-11} (stat) $^{+5}_{-7}$ (sys) SNU. This represents only 52%-56% of the capture rate predicted by different Standard Solar Models.

1. Introduction

At present, all four operating solar neutrino experiments have reported significant deficits of the flux of solar neutrinos relative to standard solar model (SSM) predictions. Numerous non-standard solar models [1,2] have been suggested, but none have been able to reproduce the observed ^{8}B flux without running into difficulties accounting for other observed features of the Sun. New particle physics [1,2], such as neutrino matter oscillations, have been invoked to provide an explanation of the "solar neutrino problem". Analyses [3,4] of the consistency of the chlorine and Kamiokande II results conclude that the results are inconsistent with any astrophysical explanations and are better described by Mikheyev-Smirnov-Wolfenstein (MSW) neutrino oscillations. However, given the uncertainties in the SSMs, it does not seem possible to rule out an astrophysical origin of the solar neutrino problem [5].

The ^{71}Ga (ν_e, e^-)^{71}Ge reaction [6] provides the only feasible means at present to measure low-energy solar neutrinos. The SSM calculations show that the dominant contribution to the capture rate in ^{71}Ga arises from the p-p neutrinos (71 $\pm$ 4 SNU where 1 Solar Neutrino Unit = 10^{-36} captures/target atom/s), while the total predicted rate in the SSMs is 122.5 − 131.5 SNU [7,8].

2. The Baksan Gallium Experiment

The detector is situated in a specially built underground laboratory at the Baksan Neutrino Observatory in the Northern Caucasus Mountains. The experimental layout and the chemical and counting procedures have been described previously [9] and are not discussed here. The SAGE II counting system underwent several upgrades in the summer of 1992. These upgrades included replacing several components of the detector with ultrapure materials, use of a 1 GHz transient digitizer, and implementation of extensive noise suppression techniques. Eighteen additional solar neutrino runs have been made since September 1992, most of which include 1 GHz transient digitization of the pulse waveform. As a result of the upgrades to the counting system, the signal to background in SAGE II improved substantially relative to SAGE I. The K-peak background rate ranged from an initial value of 0.116±0.019 to 0.064±0.010 cts/d at the end of SAGE I.

Exposure Date	Ga Mass (tonnes)	^{71}Ge Events	K Peak Events	Best Fit SNU	68% CL (SNU)	Nw^2	Probability (%)
Sept 92	55.600	1.9	3	43	12-83	0.134	27
Oct 92	55.482	2.2	4	39	12-71	0.060	62
Nov 92	55.377	5.0	5	102	56-150	0.077	69
Dec 92	55.263	4.9	10	83	40-132	0.061	51
Jan 93	55.136	7.4	9	125	65-172	0.126	30
Feb 93	55.026	3.0	3	56	14-80	0.203	69
Apr 93	48.220	2.3	5	46	15-85	0.053	22
May 93	48.171	2.5	5	57	19-104	0.022	99
Jun 93	54.656	2.3	4	45	8-83	0.089	41

Table 1. Statistical analysis of the first nine runs from SAGE II. The analysis of the SAGE I runs are found in Ref. [9].

By comparison, the first nine runs of SAGE II presented here have a background rate of 0.013 ± 0.003 cts/d. In the SAGE II data, we are able to measure both the ^{71}Ge K and L peaks. Analysis of the L peak is proceeding, and results will be forthcoming.

The proportional counter containing the extraction sample is typically calibrated at one month intervals using an external ^{55}Fe source. The ^{71}Ge K-peak acceptance window is then determined by extrapolation from the ^{55}Fe peak. The extrapolation procedure was verified by filling a PC with $^{71}GeH_4$ together with the standard counter gas. In SAGE II, we have also employed a Cd-Se fluorescence source which provides peaks at 11.2 keV (Se K-peak fluorescence), 6.9 keV (Xe escape peak), 6.4 keV (fluorescence from the Fe cathode), and 1.4 keV (Se L-peak fluorescence). We now also routinely measure the resolution integrated over the full counter volume using a Cd source in order to check the uniformity of the counter response.

A standard analysis procedure [9] for event selection was developed with two primary goals in mind: minimizing the efficiency uncertainty over the course of counting and keeping the background rate constant. Several cuts are made on the data. First, a cut is made to eliminate periods of noise bursts in the data. This results in the exclusion of a small fraction of a percent of the counting time. Second, cuts are made on energy and inverse rise time that accept 2 FWHM (98.15% acceptance) in energy centered symmetrically around the ^{55}Fe peak, and 95% of the inverse rise time distribution, with 1% being cut on fast rise time pulses (i.e., noise) and 4% cut on slow rise time pulses (i.e., background). Third, any event that has associated NaI activity is eliminated. Fourth, a cut was made to eliminate possible backgrounds from Rn daughters on the external surfaces of the PCs. Removing all data within 1.0 hour of a shield opening eliminates any observable excess of such events in the K-peak acceptance window.

A maximum likelihood analysis [10] is carried out on the remaining events by fitting the time distribution to a ^{71}Ge exponential decay (11.43 day half life) plus a constant rate background. The results of the maximum likelihood analysis for the first nine runs of SAGE II are given in Table 1. We note that the number of ^{71}Ge events obtained by summing the individual runs (76.8 events) differs slightly from that (71.4 events) obtained by an analysis of the combined data. This is due to the constraint in the combined fit that all runs yield a common value of the capture rate. The good agreement is an indication of the consistency of the individual runs with the final result.

Figure 1 shows the individual run results along with the combined result. The 20 solar neutrino runs are consistent with the predicted statistical distribution of signals from 1000 Monte Carlo simulations of each extraction using the combined fit parameters and the constants of each data set. In addition, both the half-life for the decay measured from the combined data sets and the energy spectrum are in good agreement with the known properties of ^{71}Ge decay. The contributions to the systematic error are summarized in Table 2.

An experiment using a neutrino source is planned in order to test the overall extraction efficiency in situ. A suitable neutrino calibration source can be made using ^{51}Cr , which decays by electron capture, emitting monoenergetic neutrinos of 751 keV and 426 keV. Preparations are underway to carry out a full-scale experiment with a 1-MCi ^{51}Cr source in 1994.

3. Results and Conclusions

The best fit value for the capture rate and the uncertainties for the combined 1990-93 solar neutrino data are

$$^{71}\text{Ga Rate} = 69^{+11}_{-11} \text{ (stat) } ^{+5}_{-7} \text{ (syst) SNU.}$$

This assumes that the extraction efficiency for ^{71}Ge atoms produced by solar neutrinos is the same as that measured using natural Ge carrier. The result

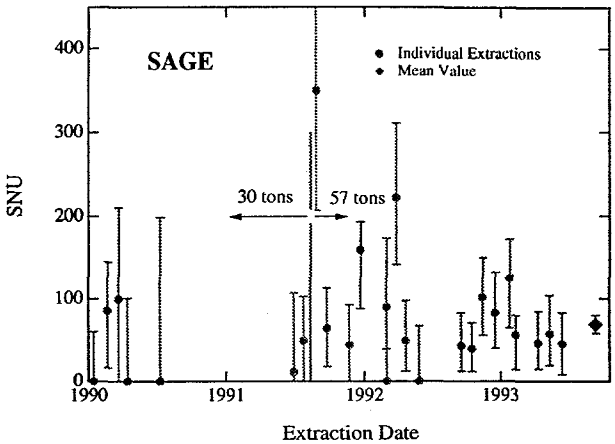

Figure 1. Results from SAGE for measurements from 1990 - 1993. Also shown is the current SAGE mean value from all runs reported. *The error is derived by adding the quoted statistical* and systematic uncertainties in quadrature.

corresponds to 71.4 counts assigned to ^{71}Ge decay, compared to the Bahcall-Pinsonneault and Turck-Chieze and Lopes SSM prediction of 136.1 and 126.8 counts, respectively

The measurements made by SAGE from January 1990 through June 1993 have observed fewer ^{71}Ge atoms than predicted by the SSMs. From the 1990-93 data, SAGE observes only 52% and 56% of the predicted Bahcall-Pinsonneault and Turck-Chieze rates, respectively. Taken alone, the SAGE result appears to favor a non-astrophysical solution of the solar neutrino problem, but cannot rule out an astrophysical solution. The solar neutrino experiments are consistent with two possible MSW solutions. The "non-adiabatic" solution ($\Delta m^2 \approx 6 \times 10^{-6} eV^2$ and $sin^2 2\theta \approx 7 \times 10^{-3}$) is the favored solution and represents a strong suppression of ^{7}Be neutrinos, a significant suppression of ^{8}B neutrinos, and essentially no suppression for the p-p neutrinos. Alternately, for the large-mixing angle solution ($\Delta m^2 \approx 10^{-5} eV^2$ and $sin^2 2\theta \approx 0.8$), it may be that all solar neutrinos are suppressed approximately the same, roughly independent of energy. With the improved precision from the combined 1990-93 SAGE data, SAGE is seeing approximately the rate predicted for the p-p neutrinos alone. With the ability to count both the K and L peaks with 55 tonnes of gallium, SAGE expects to reach a precision within the next two years that should provide a strong test for astrophysical solutions to the "solar neutrino problem".

The SAGE collaboration wishes to thank A.E. Chudakov, G.T. Garvey, M.A. Markov, V.A. Matveev, J.M. Moss, S.P. Rosen, V.A. Rubakov, and A.N. Tavkhelidze for their continued interest in our work and for stimulating discussions. We are also grateful to J.N. Bahcall, R.G.H. Robertson, A. Yu. Smirnov, and many members of the GALLEX collaboration for useful discussions. We acknowledge the support of the Russian Academy of Sciences, the Institute for Nuclear Research of the Russian Academy of Sciences, the Russian Ministry of Science and Technology, the Russian Foundation of Fundamental Research, the Division of Nuclear Physics of the Department of Energy, the National Science Foundation, Los Alamos National Laboratory, and the University of Pennsylvania.

Systematic	Contribution (SNU)
Chemical Extraction Efficiency	± 2.5
Counting Efficiency	$+2.9/-2.1$
K-Peak Acceptance	$+3.5/-0.7$
Backgrounds	-3.5
Radon	-5.9
Total	$+5.2/-6.9$

Table 2. Systematic uncertainties (1-σ) for the combined 1990-93 data sets.

4. References

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