

RESULTS OF ULTRA-LOW LEVEL ^{71}Ge COUNTING
FOR APPLICATION IN THE "GALLEX"-SOLAR NEUTRINO EXPERIMENT
AT THE GRAN SASSO UNDERGROUND PHYSICS LABORATORY

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ABSTRACT

It has been experimentally verified that the Ultra-Low-Level Counting System for the "Gallex"-solar neutrino experiment is capable to measure the expected solar ν -flux to $\pm 12\%$ during two years of operation.

1. Introduction. More than a decade after Davis implemented his Chlorine detector, experimental solar neutrino spectroscopy is still in a state of infancy and lacks behind existing technical possibilities. The only available experimental result, a deficit of solar ^8B -neutrinos as measured with the Cl-detector, has caused serious doubts on the appropriateness of our understanding of stellar structure and evolution. Urgently required is the detection of the pp-neutrinos from the principal fusion reaction $p+p \rightarrow d+e^++\nu_e$. Their flux is largely model independent and directly related to the solar luminosity. The extremely low energy of pp-neutrinos (maximum 420 keV) limits the choice of potential radiochemical detector materials. The Gallium detector, based on $^{71}\text{Ga}(\nu_e, e^-)^{71}\text{Ge}$ is by far the most promising pp-neutrino detector. The newly formed "Gallex-collaboration" (1) intends to perform a solar neutrino experiment based on this reaction at the Gran Sasso Underground Physics Laboratory (Italy) (2). The major goals of this experiment are:
 - to provide the first experimental proof that the sun is producing its energy by nuclear fusion.
 - to limit or identify neutrino mass differences through eventual ν_e -disappearance between sun and detector via neutrino oscillations.
 The parameter range accessible in this way is many orders of magni-

tude below that for other ν -oscillation experiments.

- to identify the cause of the "solar neutrino puzzle" posed by the Chlorine solar neutrino experiment (3).

2. Outline of experiment components

(1) Underground laboratory

Cosmic ray-induced (p,n) reactions produce ^{71}Ge from ^{71}Ga just as solar neutrino capture. The overburden required to suppress the cosmic ray-induced ^{71}Ge production rate to $\leq 2\%$ of the expected neutrino induced production rate is 3100 m.w.e. (corresponding to a muon flux of $I_{\mu} = 21 \text{ m}^{-2}\text{d}^{-1}$). The generous space available in the Gran Sasso underground laboratory is shielded by 3200-3500 m.w.e., hence sufficient for the experiment. Background reactions will also be monitored by ^{69}Ga (p,n) ^{69}Ge . This reaction has an even larger yield than ^{71}Ga (p,n) ^{71}Ge , whereas pp-neutrinos do not produce ^{69}Ge .

(2) Target

The high costs of Gallium force us to choose the smallest target size which is still sufficient to produce a $\pm 10\%$ result within 4 years of measurements (this assumes the standard solar model neutrino flux). Given the achieved conditions (see below), this corresponds to 30 t of Ga (converted into 8m GaCl_3 solution). The required radiochemical purity of this solution has been demonstrated to be achievable even in the multiton scale. Ga acquisition is pending.

(3) Ge extraction system

The quantitative and reproducible extraction of Ge (as volatile GeCl_4) from GaCl_3 solution and its conversion into GeH_4 (Germane) to be used as counting gas has been developed and tested in the earlier BNL MPI 1.3 t Ga pilot experiment (4).

(4) Counting system

^{71}Ge ($T_{1/2} = 11.43 \text{ d}$) decays by K (88%) L (10.3%), and M (1.7%) electron capture. Auger-electrons and stopped X-rays are counted in GeH_4/Xe gas mixtures in miniaturized proportional counters made of ultrapure materials. Up to 8 counters can be accommodated in the well of a well type NaI pair spectrometer. Apart from its anticoincidence mode, it serves in the coincidence mode to

identify ^{69}Ge decays ($T_{1/2}=1.6$ d; EC; EC+ γ ; and $e^+ \rightarrow e^- + 2\gamma$). The NaI crystal is surrounded by plastic scintillator anticoincidence shields and passive Fe/Pb shields. The data from all active components (proportional counters, NaI halves, plastic scintillators) are fed into the PDP/LSI computer both for on line evaluation and for storage on magnetic tape ("Mulia" system) (4).

3. Results of Ultra-Low Level Background Reduction

In the proposed configuration of the Gallex experiment one expects per run an average of 7 ^{71}Ge decays during the first month after extraction according to the standard solar model. From this it follows that background rates of order $\lesssim 1$ c/10 days must be achieved. Apart from the measures described above, this goal is in particular approached by a complete pulse shape analysis using a transient digitizer to reject background, mainly from Compton electrons and from electronic noise.

The energy deposition from Auger electrons and X-rays emitted in the ^{71}Ge electron capture decay results in a spectrum with 2 peaks: the L peak at ~ 1.2 keV and the K peak at ~ 10.4 keV. Counting efficiencies ϵ are determined using active ^{71}Ge in prototype counters. Thus, the acceptance fields of 95% are defined in an energy-pulse form parameter plot for K- and L peak (Fig.1). The pulse form is most efficiently parameterized as $G \cdot I = S(T)/S(t_{\max}) \cdot \frac{1}{T} \int_0^T S(t) dt / S(t_{\max})$ where $S(t)$ is the pulse height at time t after pulse onset, t_{\max} is the time at which $S(t)$ is maximal, and T is an empirically selected parameter, here $T=160$ nanoseconds. In this way, background pulses simulated by Compton electrons from a ^{60}Co source are rejected with an efficiency of 96.3% (L peak) and 99.9% (K peak).

The values previously achieved with many counters ($\epsilon_L=25\%$, $b=0.2$ cpd; $\epsilon_K=38\%$, $b=0.08$ cpd) would allow to determine a solar neutrino rate of 90 SNU with a standard error of 14% in a two year experiment (50 extractions). 90 SNU is the rate compatible with the Cl detector result interpreted in terms of astrophysical causes ("consistent" model). Meanwhile, improvements have been made and background rates measured with some counters are about a factor of two lower than the values listed above. Fig.2 displays the results of a 51.5 day background measurement obtained with one of the best counters. Here $b_K=0.04$ cpd, $b_L=0.08$ cpd. This would allow to measure 90 SNU with a 30 t Ga detector during two years of operation

to $\pm 12\%$, as compared to $\pm 10\%$ if the background were zero. Additional advances have been recently made with an improved counter design. Its dead volume is reduced to 5% by directly evaporating the Al-cathode onto the quartz tube and directly sealing the tungsten anode wire into the quartz ends. With this counter type we obtain an overall efficiency of 74% ($\epsilon_K=46\%$, $\epsilon_L=28\%$).

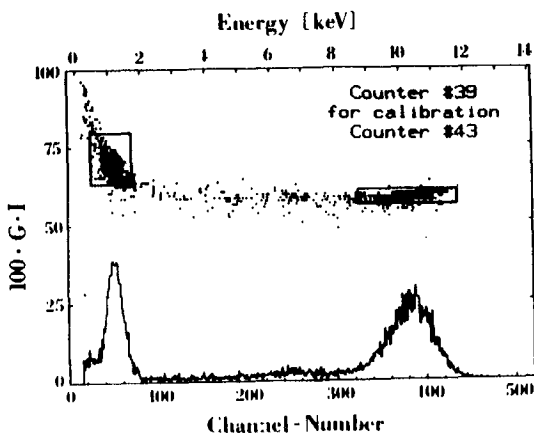


Fig. 1: ^{71}Ge spectrum and 95% acceptance fields for genuine ^{71}Ge decays. The pulse shape parameter $G \cdot I$ is defined in the text.

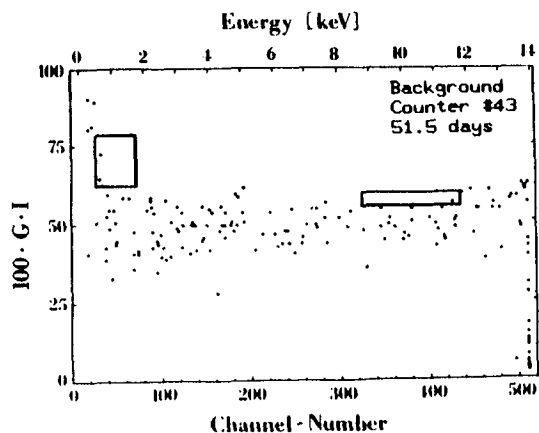


Fig. 2: Result of 51.5 days of background counting of counter #43 applying pulse shape analysis with the MULIA system. Acceptance windows for K and L peak are indicated.

References

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