Submitted to the
25th International Conference on High Energy Physics
Singapore, August 2-8, 1990

GALLEX

THE STATUS OF GALLEX

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ABSTRACT. The present status of the Gallium Solar Neutrino Experiment performed by the GALLEX Collaboration in the Gran Sasso Underground Laboratory is described. The implementation phase of this experiment is now completed, the whole gallium is at hand and data taking starts now. After a short introduction and an outline of the basic experimental procedure, details will be given on different parts of the experiment and on some background.

1. Introduction

The long-term averaged solar neutrino production rate measured with the radiochemical Homestake Chlorine Detector is 2.33 ± 0.25 SNU[1] [Davis 89]. There is a persistent discrepancy (called the "solar neutrino problem") between this result and the prediction from the Standard Solar Model (SSM) [Bahcall 88], 7.9 SNU, which usually is attributed to a deficiency of solar ^8B neutrinos (E_ν < 15 MeV) ; another Solar Model [Turck-Chieze 88] predicts also more higher energy neutrinos (5.8±1.3 SNU) than observed. This conclusion has been confirmed by the Kamiokande-II water Cerenkov detector which observes only (39 ± 11) % of the ^8B neutrino flux expected from the Standard Solar Model [Hirata 89].

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[1] 1 SNU : Solar Neutrino Unit equals 10^{-36} capture per second and per target nuclei.

Both detectors have energy thresholds much above the maximum energy (0.42 MeV) of the pp neutrinos which are produced in the primary fusion reaction in the sun. It has long been recognized that an experiment capable to observe these pp neutrinos could provide :

- a test of the SSM in view of the solar neutrino problem;
- the experimental verification that hydrogen burning via the pp chain is indeed the principal energy source of the sun;
- information on neutrino oscillations with squared mass differences much smaller ($\geq 10^{-12}$ eV^2) than those accessible in terrestrial experiments and sensitive to a wide range of mixing angle if the MSW effect takes place [Mikheyev 89]. Due to the different sensitivity in energy, the future result combined with the already existing results could restrict severely the oscillation parameter in a nearly solar model independent way [Spiro 90].

The only experimental approach in this direction for which feasibility has been demonstrated is the radiochemical gallium detector. Two experiments using this technique are soon to yield data : a Soviet-American experiment [Gavrin 89] installed at the Baksan Underground Laboratory in the Caucasus (USSR) which in the final configuration will use 60 tons of Ga metal, and an experiment with 30 tons of Ga in form of gallium chloride solution performed by the GALLEX Collaboration [Hampel 89, Kirsten 90] in the Gran Sasso Underground Laboratory in Italy. Here the present status of GALLEX is reported.

2. Outline of the experiment

The gallium detector is based upon the reaction ^{71}Ga (ν_e,e$^-$)^{71}Ge. The energy threshold (233.2 ± 0.5 keV) is well below the maximum energy of the pp neutrinos (420 keV). ^{71}Ge decays back to to ^{71}Ga by electron capture with a half life of 11.43 ± 0.03 d. The total rate of 132 SNU predicted by the SSM for the gallium detector is dominated by 74 SNU from the pp and pep neutrinos resulting from the basic fusion reaction in the pp chain [Bahcall 88] and closely related to the solar luminosity.

The experimental procedure for the full scale experiment is as follows [Hampel 89, Kirsten 90]. 30 tons of gallium in form of a concentrated $GaCl_3$ -HCl solution are exposed to solar neutrinos during periods of 3 weeks. In this solution, the neutrino induced ^{71}Ge atoms (as well as the inactive Ge carrier atoms added to the solution at the beginning of a run) form the volatile compound $GeCl_4$, which at the end of an exposure is simply swept out of the solution by means of a gas stream (nitrogen). This gas stream is then passed through a gas scrubber where the $GeCl_4$ is absorbed in water. The $GeCl_4$ is finally converted to GeH_4 , which together with xenon (70%) is introduced into a proportional counter in order to determine the number of ^{71}Ge atoms by observing their characteristic radioactive decay.

3. Status of the experiment

Funding of the GALLEX detector was assured at the end of 1985. The implementation phase is now completed, and we have received the total amount of gallium. We are finishing the final outgassing and tests of the solution. In the following we shall describe the present status of the experiment in more details.

3.1 GALLIUM ACQUISITION

The target used in the experiment consists of 101 metric tons of an 8-normal gallium chloride solution (equivalent to 30.3 t Ga), produced by the Rhône-Poulenc Company in Salindres (France). The purity specifications required in order to keep background production of ^{71}Ge low enough (see section 3.5) is easily met by the total solution . The final delivery has been completed beginning of may 90. Prior to entering the underground laboratory an important outgassing is made to remove the abundant cosmogenically produced germanium atoms.

3.2 GRAN SASSO UNDERGROUND LABORATORY

In order to escape the muon induced background (see section 3.5) the experiment is performed in an underground position. The GALLEX experiment is installed in hall A of the Gran Sasso Underground Laboratory (Laboratorio Nazionale del Gran Sasso). This underground facility, shielded by about 3400 meters of water equivalent, has been built by the Italian INFN (Istituto Nazionale di Fisica Nucleare) in the middle of a highway tunnel through the Abruzzese mountains, about 150 km east of Rome, at the latitude of 42° 27' N [Bellotti 88].

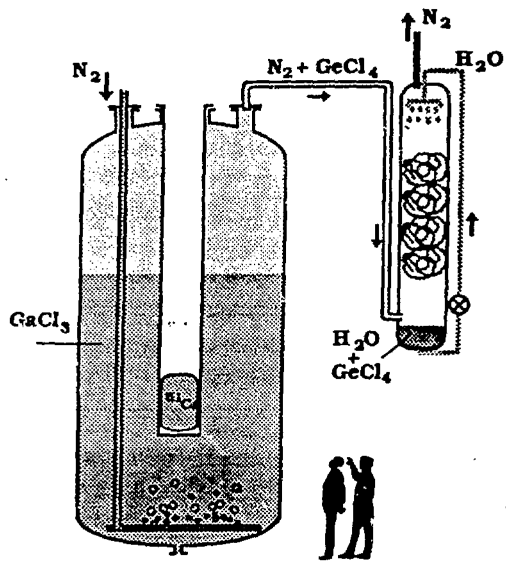

Fig.1:The 70 m³ tank is filled by the 54 m³ of $GaCl_3$ -HCl solution. The reintreant tube will be used to introduce an artificial neutrino source which will allow an overall test and a calibration of the experiment, without modification of the apparatus. At the end of a run, the extraction consist in sweeping 3000 m³ of gaseous nitrogen which carry out the $GeCl_4$ originating from the carrier and from the solar neutrinos. The columns with water concentrate the germanium in a much smaller volume.

Within hall A, GALLEX is accommodated in two buildings. The process tank (which will contain the $GaCl_3$ solution), a spare tank (70 m³ each) and the equipment for the Ge extraction are installed in the main building (12x10x9 m³) (see Fig.1). This building also houses the germane synthesis line, the counter filling station and the facilities for the calcium nitrate neutron monitor (see section 3.5). The counting equipment for ^{71}Ge detection (counter shield and the analog part of the electronics) is set up in a Faraday cage which has been erected in the ground floor of the Low-Level counting building (10x10x6 m³). The first floor laboratory of this building houses the digital part of the counting system (connected to the ground floor Faraday cage via an optical fibre link), two μVax computers and a second auxiliary counting station for counter testing. The evaporator which produces the gaseous nitrogen used in the extraction is located in a gallery closed to hall A.

3.3 GERMANIUM EXTRACTION AND CONVERSION

The basic chemical procedures for Ge extraction out of large quantities of $GaCl_3$ solution have been developed in the pilot experiment [Hampel 85], and optimized by the help of pilot facility (scale 1:9) which has been set up at the KfK Karlsruhe [Kirsten 90]. The two gallium tanks (see section 3.2) used in the experiment are plastic tanks reinforced with glass fibre backing and equipped with an inner PVDF liner. The process tank is equipped with a reintrant tube in order to hold a ^{51}Cr neutrino source [Cribier 88]. The spare tank is needed for safety reasons in the event of a tank leak, and is used for the final outgassing of the solution.

The germanium extraction (fig. 1) is performed by passing 3000 m^3 of nitrogen through the process tank and the absorption columns (duration 16 to 20 hours). Germanium chloride ($GeCl_4$), which is very volatile in the presence of HCl, is removed from the solution and then absorbed in the pure water of the absorption columns. A series of columns serves to concentrate the germanium into smaller and smaller volumes. For ^{71}Ge counting, the germanium is finally converted into the gas germane (GeH_4), which is purified from remaining impurities (air, radon, ...) by gas chromatography.

3.4 ^{71}GE COUNTING

The ^{71}Ge decay rates expected in a full scale gallium experiment are below 1 per day. The measurement of such low decay rates is an extreme low-level counting task and can only be achieved with miniaturised proportional counters (volume ≈ 1 cm^3) constructed from ultrapure materials (fig. 2). In such counters, the electron capture decay of ^{71}Ge results in a spectrum with two peaks: an L peak at 1.2 keV and a K peak at 10.4 keV. In order to reach sufficiently low background count rates in the L and K peak energy regions, pulse shape analysis of the proportional counter pulses has to be applied to discriminate between fast pulses originating from point-like ^{71}Ge decay and background from Compton scattering with an extended track. Thus, the CAMAC-based counting system for the experiment is equipped with a fast transient digitizer (sampling every .5 ns) to record the whole shape of each preamplifier output pulse.

The counters are placed into a copper box which is inserted either into a passive Cu shield or into the well of a NaI(Tl) detector. The NaI detector is used either as an anticoincidence device or in coincidence mode to distinguish ^{69}Ge decays from ^{71}Ge decays. Both the Cu shield and the NaI detector are installed inside a steel vessel filled with low activity lead. This vessel is constructed as an air-tight glove box to prevent radon from the outside air to penetrate into the inner part of the shield.

In the last few years it has been tried to optimise the counter performance (mainly with respect to the two most important counter properties, namely counting efficiency and background). The main advantage of the resulting counter type (named HDII-Fe) is a reduced dead volume (≈ 7 %, as compared to ≈ 15 % for the previously used counter type). With a simplified pulse shape analysis (ADP), the background values achieved so far is 1 count per day for energy above 0.5 keV, and much smaller (< 0.1 c/d) in the K-peak region. It allow to measure a solar neutrino production rate of 90 SNU with a 1 σ statistical uncertainty of 8 % in 4 years.

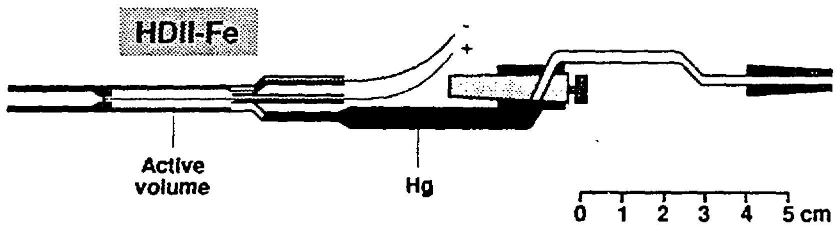

Fig.2:The counter used in the experiment (HDII-Fe), are made from ultrapure quartz, with an iron cathode (counters with a silicon cathode are also prepared); the active volume is 1 cm³. The mercury is used to fill it with the gas mixture (30 % GeH_4, 70 % Xe) at 800 torr.

3.5 SIDE REACTIONS

The most important side reaction for ^{71}Ge production in $GaCl_3$ solution by sources other than solar neutrinos is the $^{71}Ga(p,n)^{71}Ge$ reaction (threshold energy 1.02 MeV), the protons being generated in the $GaCl_3$ solution as secondaries from cosmic ray muon interactions and from (α,p) and (n,p) reactions. The cross section for ^{71}Ge production in the solution by muons has been measured at the CERN muon beam [Cribier 90]. When combined with a recent measurement of the cosmic ray muon flux at the Gran Sasso site (hall B) by the MACRO collaboration [Macro 90], a rate corresponding to 1.5 ± 0.4 SNU results.

A radiochemical experiment with 470 l $Ca(NO_3)_2$ solution based on the $^{40}Ca\ (n,\alpha)^{37}Ar$ reaction has been set up in order to measure the fast neutron flux (> 2.5 MeV) at the GALLEX detector site. Preliminary data from this experiment yield a ^{71}Ge production rate equivalent to (1.0 ± 0.8) SNU. The estimated ^{71}Ge production in the $GaCl_3$ solution by internal α emitters is very low (≈ 0.2 SNU). The actual concentrations in the solution are more than one order of magnitude below the limits which have been specified for uranium (< 25 ng/g), thorium (<2 ng/g) and radium ($2\ 10^{-5}$ Bq/g).

Summing up the various contributions to the ^{71}Ge background production rate in the $GaCl_3$ solution yields ≈ 3 SNU or 2 % of the solar neutrino production rate predicted by the Standard Solar Model.

4. Calibration

A radioactive ^{51}Cr neutrino source of 37 PBq, emitting neutrinos of similar energy than solar neutrinos, will be used to calibrate the experiment after two years of measurement [Cribier 88]. It is made by irradiating in a reactor 40 kg of chromium enriched in ^{50}Cr. Two sources of this kind will allow a calibration with an accuracy similar to the measurement of the solar neutrinos. The source will be placed in the centre of the Ga solution, and apart from shorter exposure time, all the procedures will be the same ; thus it will serve also as an overall check of the whole experiment.

5. Conclusion

The GALLEX experiment is now ready to start measuring the pp solar neutrinos after a final degassing in the spare tank and the counting of the extracted germanium ; it assure that no long life radioactive atoms are present in the solution. Backgrounds producing ^{71}Ge are at a few percent level. Counter background will allow a precision in the measurement after 4 years of data taking of around 8 % for a production rate corresponding to 90 SNU.

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