Highly Efficient Cryogenic Detectors for the Solar Neutrino Experiment GNO

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For more than a decade GALLEX/GNO has been measuring solar neutrinos, thus contributing in many a way to present neutrino physics and to our understanding of how the sun is working. After the spectacular results of SNO (=Sudbury Neutrino Observatory) and KamLAND that both confirmed flavour oscillations, GNO's role in astroparticle physics is going towards that of a longterm solar neutrino monitor and will therefore be a powerful tool for astrophysics in the future.

GNO (=Gallium Neutrino Observatory) is located at Laboratori Nazionali del Gran Sasso (Italy) and is the successor experiment of GALLEX (GALLEX 1991-1997, GNO 1998-present). Neutrinos are measured radiochemically via the reaction ^{71}Ga(ν,e)^{71}Ge. The energy threshold of the experiment being the lowest (233keV) of all neutrino detectors along with SAGE (=Soviet American Gallium Experiment), GNO is mainly sensitive to the pp-neutrinos that constitute about 53% of the overall signal theoretically predicted for Gallium experiments. Further contributions are: ^{7}Be neutrinos (27%), ^{8}B neutrinos (12%) and CNO neutrinos (8%).

The GNO target consists of 101 tons of acid $GaCl_3$ solution, containing 30.3 tons of natural Gallium. The neutrino-produced ^{71}Ge-atoms are extracted in a monthly cycle from the Gallium tank and introduced into low-background proportional counters after a synthesis process as Germane gas (GeH_4). When combining the published data of GALLEX and GNO, the observed neutrino flux is:

$$\Phi_{\nu_e} = (70.8 \pm 4.5(\mathrm{stat}) \pm 3.8(\mathrm{syst}))\ \mathrm{SNU}$$

The statistical error within GNO is presently of ± 6.4 SNU, the systematic error of ± 3.0 SNU. If refined at a 5% accuracy level in the measurement, GNO could give, by monitoring one whole solar cycle (11 years), upper limits on the neutrino's magnetic moment and would be able together with BOREXINO to distinguish, i.e. separate the pp-neutrino flux from the ^{7}Be-neutrino flux.

In order to reach these goals a further reduction of statistical and systematic errors is inevitable. Apart from a calibration of GNO using a strong ^{51}Cr source with an activity of ~2.5 MCi to determine very precisely the neutrino-capture cross section on ^{71}Ga, special care has to be given to the detection mode. Up to now the decay of ^{71}Ge to ^{71}Ga is being measured by miniaturized proportional counters. A favourable way to drastically increase the detection efficiency would be the use of high-resolution cryogenic detectors which provide several features making them a highly interesting alternative to the proportional counters. The development of such a cryogenic detection setup for GNO has been performed at E15/MLL in Garching over the past few years and is now reaching an essential phase potentially leading towards a prototype run on the location at the Laboratori Nazionali del Gran Sasso.

An important prerequisite, when implementing cryogenic detectors, is that the established and highly efficient chemical extraction procedure, in which a few atoms of ^{71}Ge are 'filtered out' of 101 tons of $GaCl_3$, must not be altered under any circumstances.

As a first step to realize a cryogenic detection concept for GNO, a highly efficient (98%) 4π-detector was developed and tested successfully, as well in our laboratory as with Monte Carlo simulations. Due to the short half-life of ^{71}Ge ($T_{1/2}$ = 11.43d), the time window between extraction and measurement is very small. Therefore, a detection set-up was realized in which the fabrication and testing of the transition edge sensor of the cryodetector can be performed independently from the chemical deposition of ^{71}Ge via CVD (= chemical vapour deposition) onto the detector's substrate. After the CVD the transition edge sensor and the substrate are coupled to each other with a special cryo-resin. Later the two glued parts are integrated into the existing 4π geometry. This concept has proved to be very reliable and is presently becoming a technique that might also be applicable to the detection of intrinsic radioactive impurities, for instance in lead. The energy spectrum resulting from an ^{55}Fe source demonstrates that the glueing process does in no way negatively affect the energy resolution (187eV @ 6keV). Furthermore, the energy threshold of this detector lying in the region of ~100eV is low enough not only to detect the electron capture from the K- and L-shells but also opens the detection range down to the energy deposition of the M-capture with 160eV.

To prepare a cryogenic prototype experiment at the Gran Sasso Underground Laboratory (3600 mwe), a new dilution cryostat was set up and serves now as a test facility for GNO and is located in the Underground Laboratory of the 'Maier-Leibnitz Laboratorium' (15 mwe) in Garching. In the past year the shielding of the cryostat was altered. The lead which only covered half of the cryostat was replaced by especially designed broad rings (by Fa. JL Goslar) allowing to efficiently shield the entire cryostat with an overall weight of 11 tons of lead. In addition to the external shieding an ultra low activity internal shielding is under preparation, too. Furthermore the cryostat is shielded by a muon-veto consisting of several panels of plastic scintillator, which has been adapted to the new lead geometry. Since the installation of the cryostat many temperature cycles between room temperature and ~20mK were successfully performed. The cryostat is presently equipped with three SQUIDs and their electronic read-out systems two of which are planned for the operation of the 4π-detector. Present activity is concentrating on the optimization of the electronics, low level analysis of the components used both in the cryostat and in the detector fabrication. Ongoing longterm runs will lead to a solid understanding of the whole detection apparatus. The main aim is a longterm measurement with artifically activated ^{71}Ge thus proving the feasibility of Cryo-GNO.