Development of a Cryogenic Detection Concept for the Solar Neutrino Experiment GNO ◇

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Experimental as well as theoretical research concerning neutrino properties have experienced a tremendous boost in the last few years leading eventually to a revision of the standard model of particle physics. Nowadays, whilst so many new experiments are present or underway, each designed to cover one of the many peculiarities of the neutrino, one ought to recall how it initiated. First, neutrinos were particles of interest to astrophysicists who believed they would serve them as probes to understand how the interior of a star functions, namely our Sun, to that time only predicted by standard solar model theory. The disagreement between theory and experiment was so obvious that it called for more experimental evidence to confirm or reject new particle or solar models. Gallium experiments seemed especially attractive since they could provide information on the low-energetic and predominant part of the solar neutrino spectrum, the pp-neutrinos. At the beginning of the 1990s two Gallium detectors operated each by an international collaboration, started solar neutrino data taking: SAGE, the Soviet American Gallium Experiment in Bhaksan, Russia, and GALLEX in Gran Sasso, Italy, later in 1998 to become GNO, the Gallium Neutrino Observatory. For more than 12 years these two detectors have been monitoring the solar core, confirming both the presence of pp-neutrinos and an important lack in the measured neutrino interaction rate on earth, as we know now, due to the oscillatory behaviour of neutrinos [1]. Unfortunately, end of 2004 GNO had to dismantle its target due to external non scientific reasons; leaving only the present low-level counting facility of the experiment in the underground laboratory at Gran Sasso.

In the past few years a considerable amount of work has been invested at our institute into the development of highly-efficient low-temperature detectors, designed to suppress statistical as well as systematic contributions to achieve an overall uncertainty of the experiment in the order of 5%. This sensitivity is not only required for a precise and continuous monitoring over time of the solar interior, but also if future solar neutrino detectors such as BOREXINO wish to separate the two energetically overlapping fluxes of pp- and ^{7}Be-neutrinos. In addition, the fact of analyzing the Sun's behaviour over a longer time interval could again, as it did for the pioneering neutrino experiments, point in research directions, up to now not yet considered. In any case, glancing at the evolution of the neutrino interaction rate on Gallium over 12 years, one realizes that it might be decreasing very slowly but steadily at a pace of 1.7 SNUs per year at a confidence level of 1.4σ, an occurrence also cross-confirmed by SAGE.

Solar ν_es are detected via the charged current reaction on Gallium

$$\nu_e +^{71} Ga \longrightarrow^{71} Ge + e^- \qquad (1)$$

GNO's target consists of 101 tons of acid $GaCl_3$ solution, corresponding to 30.3 tons of natural Gallium. The few neutrino-produced ^{71}Ge atoms are extracted in a monthly cycle called a 'solar run'. After chemical extraction and concentration of the Germanium present in the target, it is then synthesized into Germane gas, mixed with Xenon and introduced into miniaturized proportional counters to measure the EC-decay of ^{71}Ge to ^{71}Ga (with energy releases of X-rays and Auger-electrons between 160eV and 10.3keV) under ultra-low background conditions over a period of about 6 months.

In order to introduce low-temperature detectors in the experimental procedure a suitable interface to the experiment is needed. Using the dissociation process of Germane gas at temperatures higher than 280°C, it is possible to deposit the neutrino-produced Germanium within a metallic film onto a sapphire substrate (Al_2O_3). The deposition process itself must be highly efficient and known very accurately, e.g. by means of neutron-activation analysis. The feasibility and optimization of this process has been performed up to a level of $\geq 91\%$ thus meeting the requirements of the overall experiment. In order to achieve a high detection efficiency, i.e. close to 100%, the cryogenic detector has to exhibit a full absorption in 4π solid angle, a feature realized by using two individual detectors placed on top of each other. The efficiency of this detection geometry was tested in a Monte Carlo simulation showing that it lies in the region between 98% and 100%; also the agreement between measured and simulated spectra could be confirmed. Both detectors consist of a 10 x 20 x 1 mm^3 sapphire substrate with a 1 x 3 mm^2 Iridium-Gold bilayer serving as a superconducting phase transition thermometer (TES = transition edge sensor) the working point of which is in the region of 30mK. The TES is weakly coupled to a heat bath via a Gold bond wire, whereas two Aluminum bondwires connect it to the electronic read-out circuit. Unfortunately, the high temperatures necessary to deposit Germanium onto the sapphire substrate (500°C for 3-4h) cause destruction of the TES bilayer. To overcome this problem, Ge-deposition and the detection sensor (TES) had to be decoupled, which was realized by using a Silicon substrate bearing the TES that can later easily be glued onto the sapphire substrate. This procedure also proved to be extremely satisfactory (energy threshold: ∼100eV, energy resolution @ 6keV: ∼187eV FWHM) and applicable in other fields of cryogenic detection, too. In the past year an alternative to Iridium-Gold bilayers was also successfully tested in 4π geometry using Tungsten monolayers as transition-edge sensors.

In order to gain further knowledge on various possibilities to produce superconducting/non-superconducting bilayers for the above mentioned applications and to ensure the production of reproducible low-temperature detectors, a magnetron sputtering system has been set up. This new thin-film deposition system, presently equipped with Ir-, Au- and Al-targets is being characterized and optimized

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for maximum flexibility for future cryogenic-detector production.

With the aim to show the feasibility of 'cryoGNO' [2] a dilution refrigerator (Oxford: Kelvinox) was installed in the underground laboratory of the Maier-Leibnitz-Laboratorium (UGL). Eversince, the shielding of the cryostat has been improved progressively. It is presently completely surrounded by 15cm of lead equipped with a muon-veto that is operated in anticoincidence with the cryogenic detector and a new internal low-activity shielding at base temperature (∼10mK). The cryostat is equipped with 3 SQUID read-outs (2 Jena, 1 Hypres), of which Jena 1 and Jena 2 are used for the GNO detectors. The housing of the 4π detector is made of ultrapure copper, serving as a holder as well as a shielding (min. thickness 5mm). Special care has been given to the design of the holder, since the implementation in GNO requires maximum redundancy in order not to lose a solar run and at the same time to ensure easy and straightforward handling. In addition to that a further cylindrical shielding made of ultrapure copper and low activity lead, to be operated at a temperature of 100mK, was conceived and successfully realized to shield the 4π detector from the inner part of the cryostat itself. First background and long-term measurements have now been performed and are presently being analyzed, pointing towards a value of 5-10 cts/keV/d in the energy region between 7-10keV, which would be a satisfactory result considering the rather low overburden of 15mwe (= meter water equivalent) of the laboratory. As a last step, to show the feasibility of cryoGNO and thus the long-term stability of our cryogenic measuring system, a sample of artificially activated ^{71}Ge is presently being measured in the UGL, Garching.

References

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[2] J.-C. Lanfranchi *et al.*,Nucl.Instr.Meth. **A520** (2004) 135