Development of Cryogenic Detectors for the Gallium Neutrino Observatory (GNO) ◇

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Since spring 1998 the Gallium Neutrino Observatory GNO [2], an upgrade of the extremely successful GALLEX solar neutrino experiment at Gran Sasso Laboratories, is taking data. In phase-I GNO utilizes the GALLEX target of 30 tons of natural gallium in the form of an aqueous solution of 101 tons of $GaCl_3$, acidified in HCl. The GALLEX results by themselves pointing towards neutrino oscillations, thus massive neutrinos and lepton flavour mixing, it is of obvious importance to confirm them in an improved, high-statistics experiment. In addition, it recently has been shown [5] that the time-structure of the GALLEX single run results can be excellently fitted assuming two-flavour neutrino vacuum oscillations with a mass-squared difference $\Delta m^2 = |m_1^2 - m_2^2| = 4.7 \times 10^{-10}\,\mathrm{eV}^2$ and a mixing angle $\sin^2 2\theta = 0.83$. To further pinpoint oscillation parameters which, in this range, cause short-term periodic variations of the integral neutrino flux, a statistical significance of single-exposure data points exceeding that of GALLEX is required. GNO in its second phase will exploit a factor-of-two increase in target mass and improvements in counting of the ^{71}Ge back decay $^{71}\mathrm{Ge} + \mathrm{e}^- \rightarrow {}^{71}\mathrm{Ga} + \nu_e$, which is expected to lead to substantial improvements of both, the statistical and systematic uncertainty. Low temperature calorimetric detectors are among the most promising techniques to exhibit the required specifications [4].

For application in GNO it is essential that the 1.3 keV, 10.4 keV and possibly also the 0.16 keV X-rays and Auger electrons associated with the ^{71}Ge EC-decay are detected with high efficiency and low systematic uncertainty. As typical activities to be measured are in the order of $5 - 10$ decaying ^{71}Ge nuclei, the detector has to exhibit extreme intrinsic radiopurity and must operate stable and largely background-free for a counting period of several months.

Low temperature cryogenic detectors are – at least in principle – due to their excellent energy resolution in the soft X-ray energy region, their low detection threshold, near to 100% efficiency for radiation detection, and their small size and intrinsic radiopurity of construction materials well suited for such a measurement. Our ongoing R&D project at TUM focusses on meeting the technical requirements for implementation of this new detector concept into the large-scale experiment at Gran Sasso [1].

We have developed cryogenic calorimetric detectors which use a superconducting phase transition thermometer evaporated directly onto a dielectric crystal. The energy deposited in the crystal by particle interaction or radiation absorption is measured via the resulting temperature rise in the thermometer. The device is operated in the transition region of the superconducting to the normal conducting state of the thermometer, where a small temperature rise ΔT of the thermometer leads to a large increase ΔR of its resistance. The readout is done with a Squid-based DAQ-system.

First results obtained with test detectors did already serve to demonstrate an improvement by more than a factor of five in energy resolution [3], compared to the miniaturized low background proportional counters which are used in GNO phase-I. In these measurements the energy threshold was at about 500 eV, limited by noise from the laboratory environment; thus, with a new dilution refrigerator in the Garching low background laboratory becoming available in fall 1999 we expect to be able to detect also the energy release of 0.16 keV from ^{71}Ge M-capture. This is not possible with the GNO proportional counters and would constitute an additional 2% gain in total efficiency.

In 1998 we did demonstrate the feasibility of a compound detector structure consisting of two thermally separated sapphire absorber crystals, each of them equipped with a superconducting Ir/Au-proximity effect phase transition thermometer, and a germanium film containing ^{71}Ge deposited in between. This setup with the two detectors operated in OR-mode ensures an essentially 100% detection efficiency, with the sum energy of both devices resembling the entire energy release of the ^{71}Ge decay, independent from the de-excitation mode of the ^{71}Ge daughter atom. The next steps now are improvements in the Ge-deposition technique, tests of absorber materials other than sapphire, and a several weeks prototype run.

References

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