A Low-Temperature Proton Detector for a Neutron Lifetime Experiment

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The lifetime of the free neutron is an important quantity for weak-interaction physics and for cosmology, in this case the synthesis of the light elements after the Big Bang. The latest experimental value [1], extracted in the usual way from a material-storage experiment, differs by 6σ from the world average established by the Particle Data Group (PDG). Our goal is to measure the neutron lifetime, using a magnetic-storage bottle, with an accuracy of 0.1 s [2]. A very important prerequisite to reach such a small experimental error is to count the decay protons on-line. Protons, which are generated with energies below 730 eV, will be accelerated to 30 keV and guided by a magnetic field to the detector assembly.

We want to use a thin ring-shaped CsI scintillator with inner and outer diameters of 90 mm and 300 mm, respectively, to cover an as large as possible area. The scheme of a feasible detector arrangement is shown in Fig. 1. In order to reduce the amount of photon counting units (LAAPD s= large-area avalanche photo diodes) necessary, we intend to read out the rectangular, 3 mm thick light guide from a side perpendicular to the CsI layer. As the detector will be near to the superconducting coils of the neutron storage vessel it has to run at cryogenic temperatures.

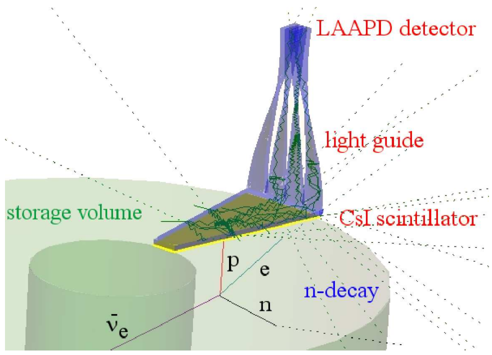

Fig. 1: A possible layout of the large area proton detector

Besides the temperature behaviour of the CsI scintillator presented already in [3], we measured the performance of LAAPDs from 300 K down to 15 K in $\Delta T = 20$ K steps (cf. Fig. 2). The dark current at these temperatures is below 1 pA. We started by investigating the temperature dependence of Hamamatsu LAAPDs (S8864-1010, area $10{\cdot}10\,\mathrm{mm}^2$). These reach-through detectors have the advantage of a very low operating voltage (200 V at $T_{\mathrm{LAAPD}} = 77$ K), which makes the use of a preamplifier near the detector at 50 K easier than for other LAAPD types. We measured the LAAPD gain as a function of the bias voltage U_{bias} down to $T = 15$ K.

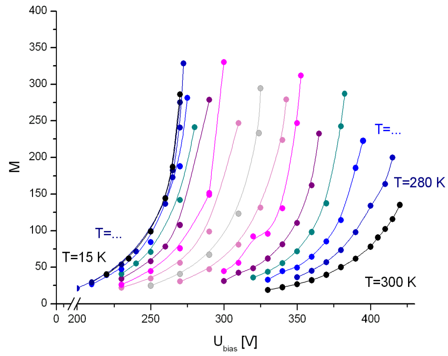

Fig. 2: LAAPD gain as function of temperature and applied voltage U_{bias}

As may be seen from Fig. 2, the LAAPDs can be used down to the expected operating temperature of $T = 50$ K where the maximum of CsI scintillation efficiency has been reported in [3]. A spectrum of 30-keV protons from the proton accelerator [4] is shown in Fig. 3. The detector was made of a 1μm thick CsI layer on a quartz light guide (dimensions $5 \cdot 5 \cdot 15\,\mathrm{mm}^3$). Together with the LAAPD photon counting units the detector was held at $T = 50$ K. The result proves the feasibility of the detection principle.

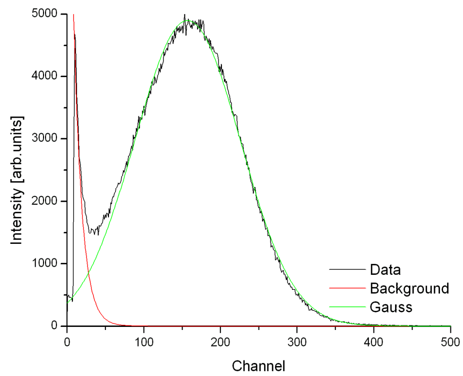

Fig. 3: Energy spectrum of 30-keV protons. The data together with an exponential background plus Gaussian fit are shown.

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References

[1] A. Serebrov *et al.*, Phys. Lett. **B605** (2005) 72
[2] R. Piker *et al.*, J. Res. Natl.Inst. Stand. Technol. **110** (2005) 257
[3] A.R. Müller *et al.*, Annual report 2006, p. 75
[4] H. Angerer *et al.*, Annual report 2005, p. 90