The Proton Detector for the Neutron Lifetime Experiment PENeLOPE $\diamond$

A.R. Müller, H. Angerer, W. Carli, F.J. Hartmann, S. Paul, R. Picker, and W. Schott

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 from the world average established by the Particle Data Group (PDG) by $6\,\sigma$. Our goal is to measure the neutron lifetime, using a magnetic storage bottle, with an accuracy of $0.1\,\mathrm{s}$ [2]. A very important prerequisite to reach such a small experimental error is to count the decay protons on-line during neutron storage. Protons, which are generated with energies below $730\,\mathrm{eV}$, 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 and $300\,\mathrm{mm}$, respectively, to cover a large area. The scintillation efficiency of CsI was measured using the 122-keV γ-ray line from a ^{57}Co source. We used the existing equipment from the PAFF accelerator. A crystal of $5 \cdot 5 \cdot 5\,\mathrm{mm}^3$ volume, mounted on a cold head, looked at the source. Employing a heater, the temperature could be adjusted to values between $8\,\mathrm{K}$ and $300\,\mathrm{K}$. An attached quartz, plastic or wavelength-shifting rod of $5\cdot5\cdot50\,\mathrm{mm}^3$ guided the light to a low-noise photomultiplier (Hamamatsu R2801). The temperature dependence of the efficiency of pure CsI and CsI(Tl) is shown in Fig. 1. The temperature dependence of the light-guide material was measured without crystal employing a pulsed LED. No significant effect was detected. From our experiments we learned that the working temperature of the detector to be used in the lifetime experiment has to be higher than $10\,\mathrm{K}$.
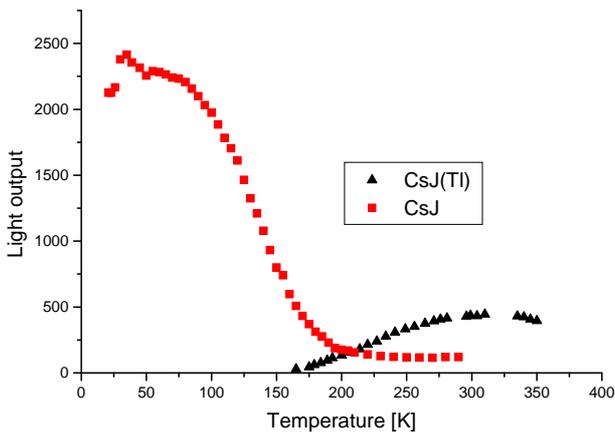

Fig. 1: Temperature dependence of the light output from CsI and CsI(Tl).

In order to avoid large light losses, we want to put the photon counting unit as close as possible to the scintillator. Instead of photomultipliers with their problems in the expected environment ($B \approx 2\,\mathrm{T}$, $T \approx 15\,\mathrm{K}$) we plan to employ semiconductor devices. To achieve highest sensitivity we want to use high-gain large-area avalanche photodiodes (LAAPDs). These detectors had not yet been *extensively* tested at temperatures below 200 K. The diode character-

istics were first measured as a function of temperature for a standard LAAPD (Hamamatsu S8664-10x10). From the current-voltage curves (cf. Fig. 2) one gets a maximum working voltage close to the breakdown voltage. The gain was measured for different temperatures as a function of the detector voltage, using a ^{55}Fe x-ray source. The results are shown in Fig. 3. Cooling the detector decreases the dark current from $100\,\mathrm{nA}$ at $300\,\mathrm{K}$ to well below $1\,\mathrm{nA}$ at $240\,\mathrm{K}$. The temperature behavior of a special LAAPD from RMD was reported down to $4\,\mathrm{K}$ [3]. A dark current below $1\,\mathrm{pA}$ and a maximum gain of 10^4 was reported for a temperature of $12\,\mathrm{K}$. In the near future the performance of LAAPDs from different companies at temperatures down to $4\,\mathrm{K}$ will be tested. Furthermore the efficiency of light guides coated with μm thick CsI layers for γ rays, protons and electrons shall be measured.
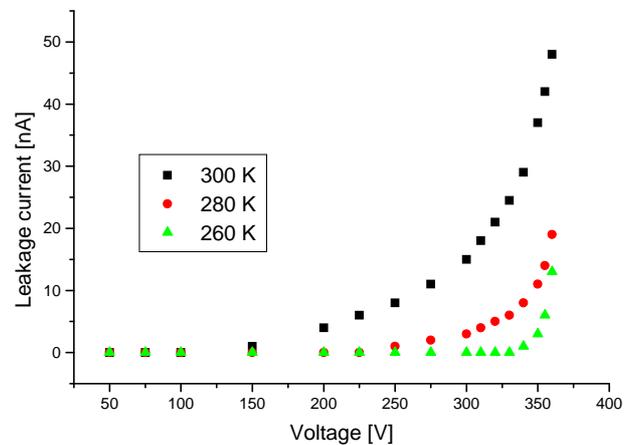

Fig. 2: Current-voltage characteristics of the Hamamatsu LAAPD, at different temperatures.
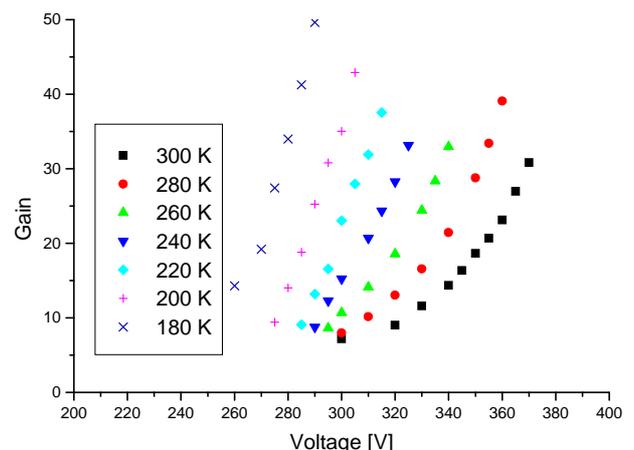

Fig. 3: The gain of the LAAPD as a function of the detector voltage for different temperatures.

References

[1] A.Serebrov *et al.*, Phys.Lett. **B605** (2005) 72

[2] R. Picker *et al.*, J. Res. Natl. Inst. Stand. Technol. **110** (2005) 257

[3] L.Yang *et al.*, Nucl. Instr. and Meth. **A 508** (2003) 388