Detection of Low Energy Protons

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We investigate the time reversal invariance in the angular correlation of the decay products of free, polarised neutrons, specifically in measuring the coefficient D.

$$\frac{W}{W_0} = 1 + D\vec{\sigma}_{\rm n}\frac{\vec{p}_{\rm e}\times\vec{p}_{\nu}}{E_{\rm e}E_{\nu}}$$

The D coefficient is related to the electron and antineutrino momentum. For neutrons at rest or negligible momentum the vector product $\vec{p}_{\rm e}\times\vec{p}_{\nu}$ equals $\vec{p}_{\rm e}\times\vec{p}_{\rm p}$.

The detection of the proton in the free neutron decay is technically difficult. With an energy release of 782 keV in the decay, the proton only obtains a kinetic energy of up to 751 eV. In practical experiments the protons are accelerated to 20 or 30 keV prior the detection. Even then the detection is not easy, when high efficiency and good separation from electronic noise is required.

1. Phosphor Screens

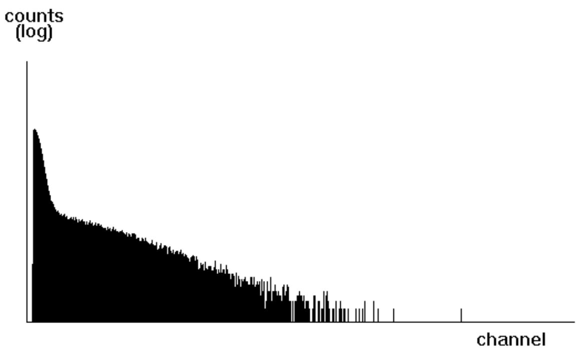

Fig. 1: Pulse height spectrum of the phosphorscreen with photomultiplier.

We have investigated thin layers of non hygroscopic phosphor screens coupled to photomultipliers. We used phosphor screens because their light output is comparable to the high light output of NaJ. We tested three types of commercially available phosphors: P11 (ZnS:Ag), P43 (GdOS:Tb), and P47 (YSiO:Ce). The phosphors are polycrystalline materials (large single crystalls can not be produced). Protons of an energy of 20 keV have a very short range of about 200 nm. Therefore we used the smallest available phosphor crystalls of 1 μm. The total thickness of the screen was 3 μm. This is the minimum thickness to cover the whole sensitive area of the screen completely with 1 μm crystalls.

In fig. 1 a pulse height spectrum (logarithmic scale on the ordinate) with 12 keV protons from the source is shown. The peak on the left side of the spectrum is the single electron peak due to thermal emission. To summarize, the phosphor screens allow the fabrication of large area detectors for protons. But in general this method has the disadvantage of a poor pulse height resolution, which makes a full discrimination from the noise practically impossible.

2. PIN-Diodes

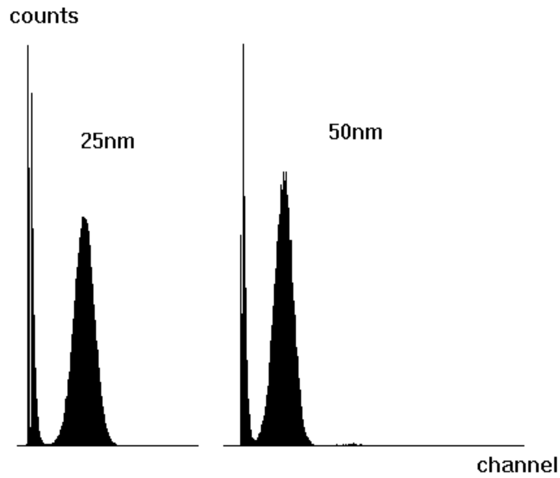

Fig. 2: Comparison of the two diodes with dead layer thickness of 25 nm and 50 nm, respectively.

With new types of ion implanted PIN diodes we achieved a complete discrimination of the proton signal against the noise of the electronics. We investigated diodes with extremely thin entrance windows of 25 nm and 50 nm, respectively. The range of a proton of 20 keV in silicon is about 200 nm [1]]. The energy loss in the entrance window of 50 nm thickness is about 4.2 keV and thus 15.8 keV are deposited in the depleted layer of the diode. To read out the signal of the diodes we used charge sensitive preamplifers of low noise (Canberra 2003 or a hybrid module of similar quality). The noise of the preamplifier was 2.4 keV FWHM without diode connected to its entrance. With the connected detector the noise rised to 4.1 keV at a bias voltage for maximum depletion of the diode (about 40-80 V). The main contributions to this noise are the Shot noise of the leakage current of the diode (5-10 nA) and the capacitance of the diode (35 pF). For more detailed noise analysis see for example [2].

In fig. 2 the pulse height spectra for a proton energy of 20 keV are shown as obtained with the diodes of 25 nm and 50 nm dead layer, respectively. In both cases the proton peak is well separated from the noise. The peak of the diode with the thinner entrance window is shifted towards higher channel numbers due to a smaller energy loss in the thinner dead layer. The peak width at half maximum is about 4.3 keV, which is only slightly more than the electronic noise.

References

[1] J. F. Ziegler. *The stopping power and ranges of ions in matter*, Vol. 3, Pergamon, London 1977.

[2] Ch. Weinheimer, M. Schrader, J. Bonn, T. Loeken, and H. Backe. Nucl. Instr. Meth. **A311** (1992) 273