Development of Neutron-Time-of-Flight Detectors for the Investigation of Astrophysically Relevant (γ,n) Reactions

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In (γ,n) reactions of importance for the formation of the chemical elements in the universe, neutron energies in a range from a few tens of keV to several MeV, i.e., fast neutrons, play a decisive role. For these energies there are very few established types of neutron detectors. Three different types, normally used for much lower or higher energies, were tested in this energy range: Li-glass, plastic and ZnS scintillators [1]. The neutron-energy determination was done by time-of-flight technique.

Every scintillator is read out by high-gain Hamamatsu R2059-01 photomultiplier tubes. The detector signals, having rise and fall times of a few ns, are processed by very fast CFDs developed at our institute. The dead time of these CFDs is about 30 ns and the threshold can be set to a minimum of 10 mV with little walk. For signals of 1 ns rise and fall times, the walk from 1 V to 10 mV amplitude was about 400 ps.

The time measurement was done by means of a state-of-the-art multichannel multihit TDC CAEN V1190A. At the same time the charge of the detector signal was measured using a multichannel QDC CAEN V792. With the whole electronics setup one can determine the correlated energy and time signals of up to ten detectors simultaneously, what can easyly be extended. The measured values are read out via VME Bus using a RIO3 Power PC running the GSI software MBS. The data taking is triggered by the logical OR of the CFD signals of all detectors used. To ensure the correlation of the time and energy signal, this logical OR is vetoed by the trigger signal itself, delayed by some ns, by the busy signal of the QDC, and by the dead time of the read-out electronics. This results in a total dead time per event of about 72 μs, corresponding to a maximum average detection rate of $13 \cdot 10^3$ events per second. The data reduction was done by means of the GSI software LEA, executing an individual analysis program for every detector type. These programs can be executed online with the experiment or afterwards using the list-mode data created by MBS.

To investigate the properties of the different detectors, i.e., time resolution and efficiency, a ^{252}Cf neutron source was used. The well known neutron-energy spectrum of ^{252}Cf [2] is normalized by means of the activity of the source, the number of emitted neutrons per fission, the branching ratio, the solid angle of the detector and the efficiency of a BaF$_2$ detector, used to determine the moment of fission giving the start of the time-of-flight measurement.

The Li-glass scintillators, containing 70 mg/cm^3 ^{6}Li, are cylindric discs with a diameter of 46 mm and thicknesses of 10 or 25 mm. To detect neutrons with these detectors the reaction $^6\mathrm{Li} + \mathrm{n} \rightarrow \alpha + {}^3\mathrm{H} + 4.78\,\mathrm{MeV}$ is applied. The positive Q-value can be used to reduce the background of low-energy photons and of events produced by afterpulses by setting a threshold just below the corresponding peak in the QDC spectrum. From the difference of this Q-value peak for a free-running neutron detector compared to a measurement in coincidence with the BaF$_2$ detector one gets the efficiency of the BaF$_2$ detector. The efficiency of the neutron detector is determined by the comparison of the measured time-of-flight spectrum and the normalized spectrum of the ^{252}Cf source and is found to be in the order of 5 %.

The ZnS scintillators are cylindrical discs of 46 mm diameter and with a thickness of 6 mm. They contain 9 mg/cm^3 ^{6}Li. The advantage over the Li-glass detectors is the capability of pulse shape discrimination. By this technique one can reduce the photon background by several orders of magnitude, whereas the neutron events stay unaffected. The disadvantage of this type of detectors is the very low detection efficiency of less than 1 % for fast neutrons.

The plastic scintillators where stripes with a rectangular cross section of 11 x 42 mm^2 and lengths of 125, 250 or 1000 mm, respectively. Each strip was directly coupled to two photomultiplier tubes, one at each end, to get a position information by means of the time difference between both signals. These tubes were operated at the highest gain, so that one is able to put the CFD threshold just below the single-electron peak. By doing this one can adjust a stable and reproducible detection threshold and on the other hand can use these proton recoil detectors to detect neutrons of energies down to a few tens of keV [3]. The efficiency was found to be almost 90 % at neutron energies of 50 keV. The position resolution was determined by means of a collimated ^{90}Sr electron source to be about 5 cm (FWHM). The time resolution of about 0.6 ns (FWHM) is the same as for the Li-glass detectors and twice as good as for the ZnS scintillators.

In summary, for the measurements of cross sections of astrophysically relevant (γ,n) reactions the plastic scintillator is the best choice of the three tested types because of its good timing characteristics and high efficiency.

[1] R. Beyer, Diplomarbeit (2005), to be published
[2] W. Mannhart, IAEA-TECDOC 410 (1987) 158
[3] N.W. Hill, J.A. Harvey et al., IEEE Trans. Nucl. Sci. NS-32 (1985) 367

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