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Report on preliminary measurements related to the pulse height weighting technique applied to the C6D6 detectors

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Introduction

In the initial phase of the n_TOF experiment the Pulse Height Weighting (PHW) technique applied to measurements with C6D6 detectors will be used to obtain capture cross sections of several isotopes of interest in the fields of astrophysics and transmutation.

The PHW technique is based on, a) the use of low efficiency detectors (the C6D6 liquid scintillator detectors), such that only one gamma-ray of the capture cascade is detected at a time, and b) the introduction of a counting weight, function of the energy deposited in the detector, which guarantees that the efficiency is proportional to the gamma-ray energy. In this way the cascade detection efficiency becomes proportional to the known cascade energy and independent on the cascade path. This Weighting Function (WF) is obtained from a set of detector response functions for different gamma-ray energies. The accuracy of the weighting function depends thus on the accuracy with which the gamma response functions could be determined.

In a preliminary study [1], we have shown that the detector response depends not only on the detector active volume, but is very sensitive to the surrounding passive materials and in particular to the investigated sample itself. In other words a sample dependent weighting function has to be determined. The only possibility to perform such a task is by means of accurate Monte Carlo simulations. The accuracy of the weighting function has to be verified from capture measurements on well known resonance peaks with different decay patterns (cascade energy and multiplicity) and using samples of various sizes. In this way the systematic effects of the WF on the extracted cross sections will be enhanced. In particular the 1.15 keV resonance in ^{56}Fe, the 5.2 eV resonance in ^{109}Ag and the 4.9 eV resonance in ^{197}Au are well suited for this purpose. These measurements are part of the nTOF2 proposal.

Experimental details

During the week of 4-11th of June a high intensity (4, even 5, bunches per PS supercycle) parasitic proton beam was available at the n_TOF spallation target. Although it was found that the background level in the present experimental conditions is very high, it was decided to use part of this time to make preliminary measurements on the weighting functions determination, with the aim also to perform a general check of the performance of the experimental set-up and the data reduction procedure.

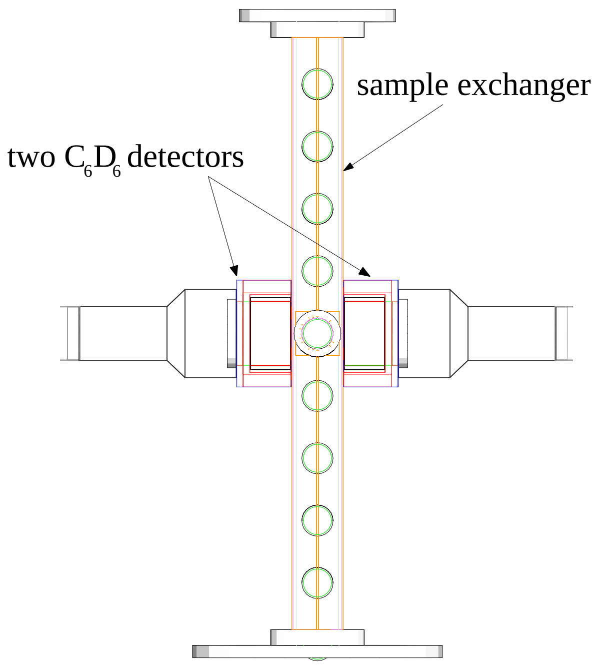

Figure 1. Schematic view of the experimental set-up with the two C6D6 detectors and the sample exchanger

Two C6D6 detectors manufactured by Bicron with an active volume of 612 ml were placed at 90° respect to the neutron beam direction very close to the carbon fibre chamber which contains the sample exchanger. The combined detection efficiency of both detectors was about 4%. Figure 1 shows a view of the experimental arrangement. Two sets of samples were measured. One set has a sample diameter of 20mm (smaller than the neutron beam size), and consisted in a 1.5 mm thick natural Fe sample and a 0.2 mm thick natural Ag sample. The other set has a sample diameter of 45mm (larger than the neutron beam size), and consisted in a 0.5 mm thick natural Fe sample and a 0.1 mm thick Au sample.

A total of more than 2.8×10^4 bunches with an average of 7.2×10^{12} protons were dedicated to measure the 1.5 mm Fe sample, and a total of nearly 4.4×10^4 bunches with an average of 6.8×10^{12} protons were dedicated to the 0.5 mm Fe sample measurement. This allowed to collect over 3×10^4 counts in the respective peaks corresponding to the 1.15 keV resonance. In the case of the Ag and Au samples about 1.6×10^3 proton bunches were enough to collect over 3×10^5 counts in the saturated peaks corresponding to the 5.2 eV and the 4.9 eV resonances respectively.

The PMT anode pulses were digitized every 2 ns with the Acqiris FADC cards. A acquisition lower threshold of about 80 keV was used during the measurement. The recorded wave forms for every proton bunch were stored at the CDR system for ulterior analysis. These files were then off-line processed to obtain the relevant parameters as Time Of Flight (TOF), pulse area, etc..., which are then stored in DST files. From these files convenient histograms, N-tuples, etc..., are created to allow easy data manipulation.

Analysis, Monte Carlo simulations and results

It was decided to try to perform a fast (but as complete as possible) preliminary analysis of the data in order to identify as early as possible, unknown problems (if any) of the experimental installation, which should be solved. The work which will be described bellow was performed in only 3 weeks time and should not be regarded as giving answer to the problem of the accuracy of the weighting functions.

The DST data reduction routine consisted essentially in a simple pulse start searching algorithm which gave the reference mark to integrate (in a fixed length interval) the signal before the pulse in order to determine the reference base line, which has to be subtracted from the integration of the pulse signal itself in order to obtain the true pulse area. Since no significant pileup is expected for the studied cases the procedure should be correct although it will be further investigated.

The application of the PHW technique requires and accurate calibration of the energy deposited in the detector. Also the width of the experimental detector resolution (assumed gaussian) has to be determined in order to convolute the simulated response distributions. Both tasks were accomplished by matching the GEANT4 simulated responses to the measured responses with ^{137}Cs and ^{60}Co calibration sources. Figure 2 shows the comparison for one of the detectors. An instrumental width of the form $\sigma = 3E$ seems to reproduce the data adequately. It was found during the analysis that the energy calibration determined in this way was not accurate enough at high energies, in particular for one of the detectors, but at the same time a procedure for improving the energy calibration was found. It is based on the presence of the ^{40}K background peak visible in weakly capturing samples and on the well defined edge corresponding to the low energy neutron capture in Au or Ag (at their corresponding neutron separation energies). This correction will be applied in subsequent more refined analysis.

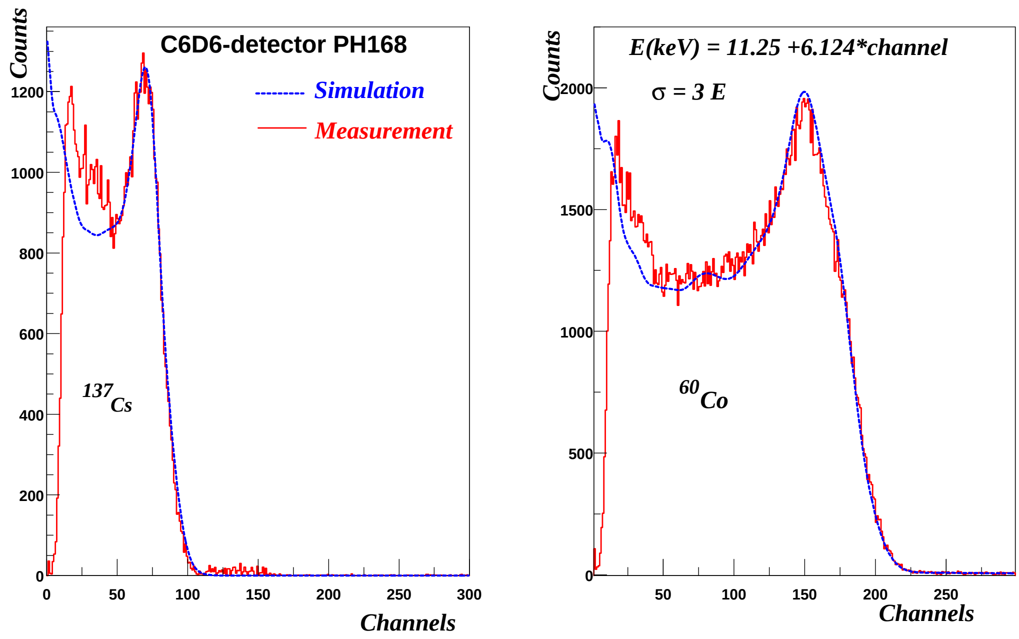

Figure 2. Energy and width calibration for one of the C6D6 detectors

In order to calculate the WF necessary to analyse the data a set of Monte Carlo simulations using the GEANT4 package were performed. The geometry and materials of the experimental set-up were carefully implemented (see Fig. 1). The largest uncertainty comes from the composition of the carbon fibre composite which is the material of the sample holder and chamber. Although expected to have a small influence it will be further investigated. Another simplification is the uniform distribution of the photon source points within the sample which will be replaced by the actual neutron beam profile distribution in future simulations. Because of the lack of time only eight photon energies between 1.26 MeV and 8.39 MeV were simulated for each of the four samples considered. From the simulated response distributions (see Figure 3) the weighting functions parameterised as a fourth degree polynomial are obtained by the least squares method. In Figure 3 the WF obtained for the small diameter Fe and Ag samples are also shown. Uncertainties are not shown since in a previous work [2] it was demonstrated by means of detailed Monte Carlo simulations of capture experiments that the precision of the WF can be made high enough to play no significant role.

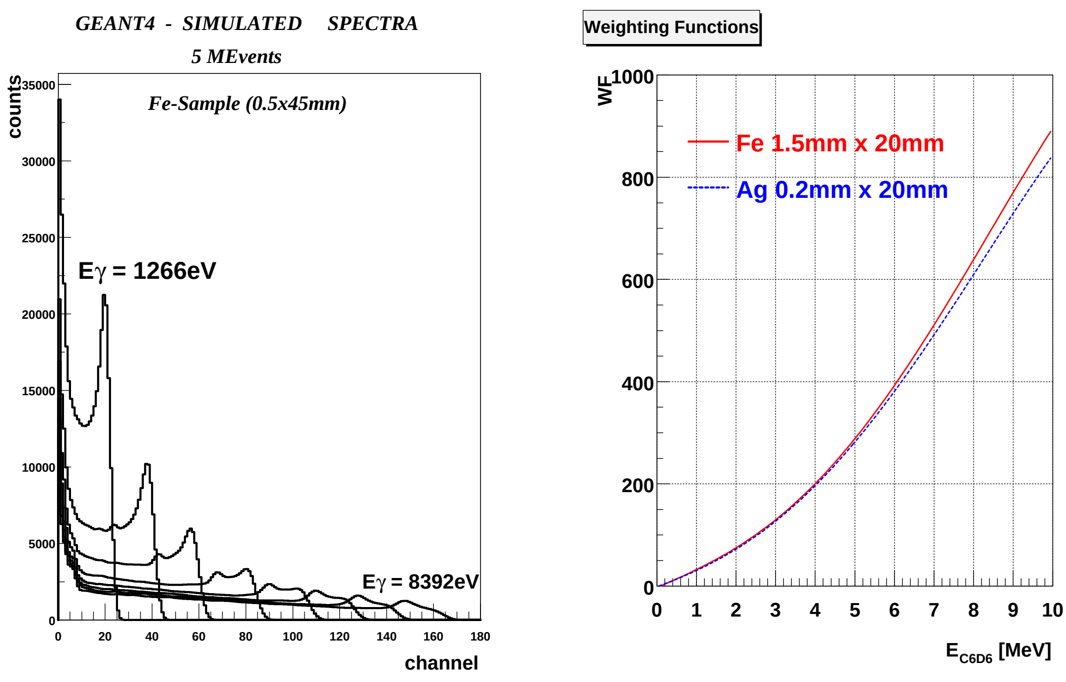

Figure 3. Example of the simulated gamma-ray response functions and of the deduced weighting functions

With the information on the C6D6 energy calibration and the weighting functions, the DST files can be processed to obtain the weighted TOF spectra. These spectra will be then analysed using one of the available resonance analysis codes as, for instance, SAMMY [3]. But in order to do such analysis, proper consideration has to be given to another important installation parameter which is the TOF resolution function .

The Resolution Function (RF) describes the distribution of neutron TOF leading to capture at a given resonance energy. At low neutron energies the thermal (also called Doppler) broadening dominates, but in the keV region the spallation target dependent component becomes comparable to it. This component is characterised by a long tail extending to large TOF, reflecting the different production-moderation histories of neutrons of a given energy.

In order to obtain a target RF parameterisation suitable for use in SAMMY we have analysed the results obtained from a Monte Carlo simulation of the spallation process performed by the Bologna group [4]. The data available for neutrons of about 5 eV and 1.15 keV were fitted with the so called RPI resolution function [3]. Figure 4 shows the result of this fit.

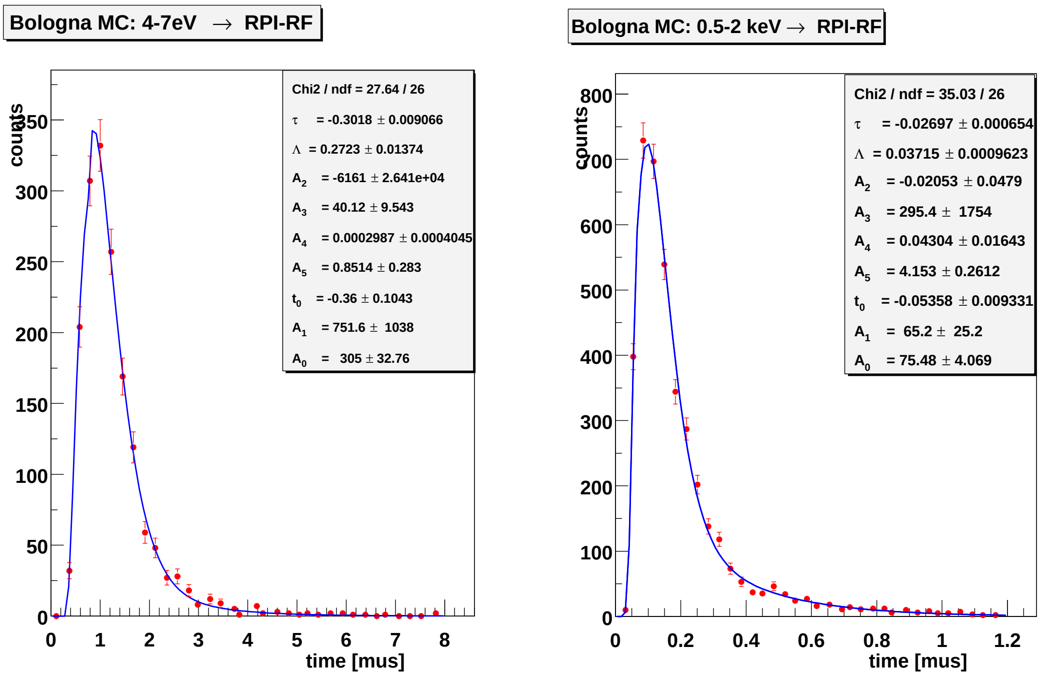

Figure 4. Result of the MC simulation for the target resolution function and the fit at two neutron energies

In Figure 5 it is shown the weighted TOF spectra in the region around the resonance peaks in ^{109}Ag and ^{56}Fe measured with the small diameter (20 mm) samples (the only ones analysed for the moment). Also shown is the fit obtained with SAMMY. In the fit the well known parameters of these resonances were kept fix, except for the resonance energy to allow for inaccuracies in the TOF calibration (which turned out to be very accurate). Fitted parameters were a global yield normalisation factor and a background function which at this stage was assumed to be constant. In the case of the 1.5 mm Fe sample the multiple scattering contribution to the spectrum is clearly visible to the right of the resonance peak. This corresponds essentially to neutrons of higher energy which suffer an elastic collision whereby they loose enough energy to match the resonance energy. This process is included in the SAMMY fit shown in the figure, and as can be observed a very good reproduction of that part of the spectrum is obtained. Also to be noticed is the rather good fit of the low energy tail of the resonance. This is only possible with the inclusion of the target RF discussed in the previous paragraph, given thus the very first information on this important parameter of the installation. A more detailed RF study extending to higher energies will be performed in the future.

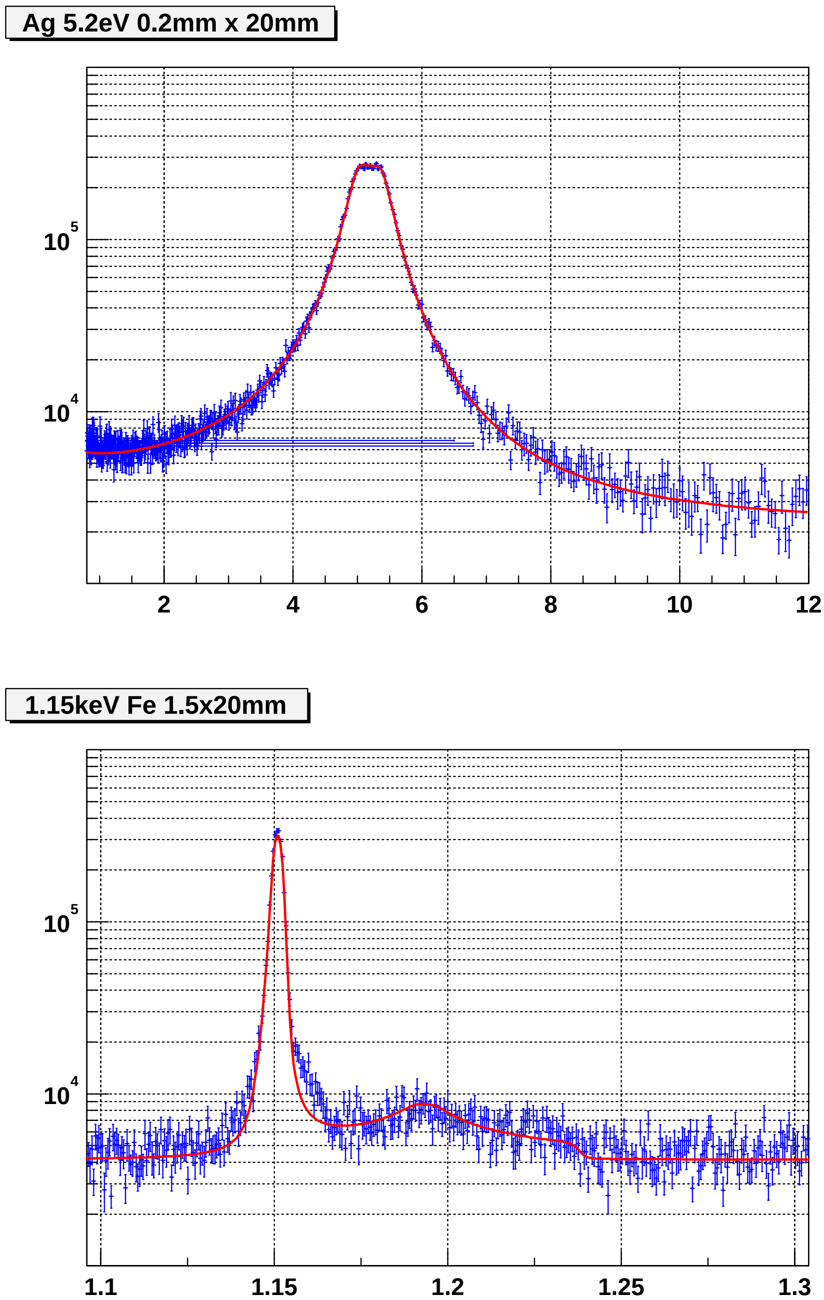

Figure 5. Weighted spectra and SAMMY fit for the Ag and the Fe resonance peaks

In general a very good fit is achieved for both resonance peaks. The only remarkable discrepancy appears at the right tail of the Fe peak. At present we do not have any explanation for such feature of the measured spectrum. The accuracy of the weighting functions will have to be deduced from the consistency of the normalisation factors for both resonance peaks. As can be deduced from the several comments made before, one should not attempt such a comparison at this stage, and it was also not the purpose of this preliminary analysis. On the other hand, from the uncertainties and correlations of the fitted parameters (normalisation and background), it can be concluded that enough precision will be attained if at least a similar statistics is acquired.

References

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