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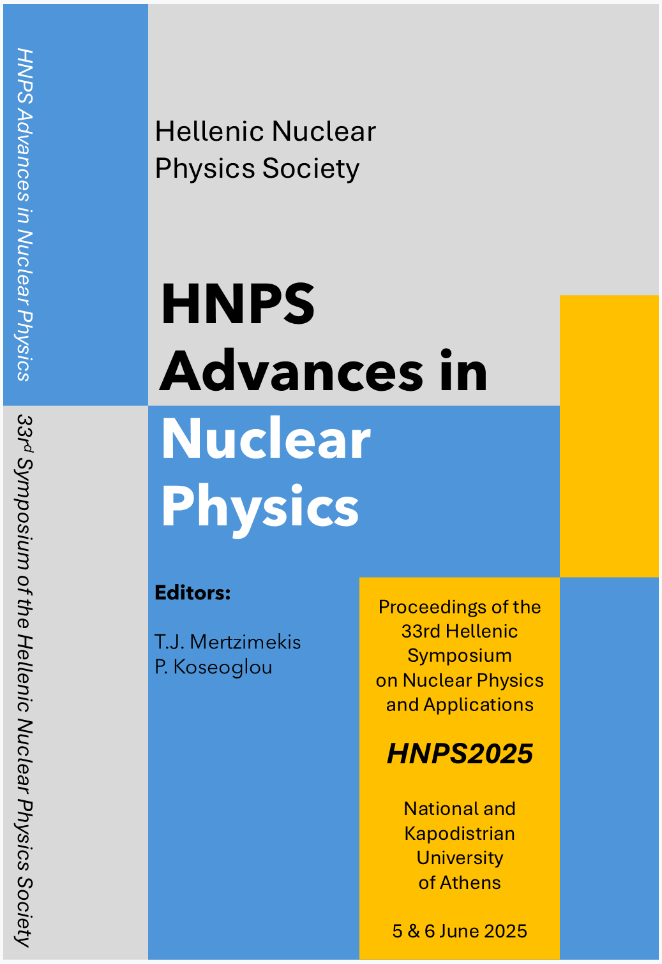

A novel methodology for the treatment of the ??-flash for fission experiments with Micromegas at EAR1 of n_TOF (CERN).

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ARTICLE

A novel methodology for the treatment of the γ-flash for fission experiments with Micromegas at EAR1 of n_TOF (CERN).

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Abstract
The study of neutron induced fission reactions in major and minor actinides is an ongoing effort, important both for the development of advanced nuclear systems, such as Generation IV reactors and accelerator driven systems and for basic research on the fission process. As part of this effort a new measurement of the ^{243}Am (n,f) reaction cross-section took place at the n_TOF facility (CERN) to provide data from thermal neutrons up to hundreds of MeV. In this work a novel method for the treatment of the γ-flash in EAR1 of the n_TOF facility has been developed in order to extend the upper limit of the measured neutron energies. This approach has been experimentally tested using the reference targets of the ^{243}Am measurement, ^{235}U and ^{238}U, to show the maximum neutron energy that can be measured with this setup. The results of this analysis are presented here.

Keywords: n_TOF facility; Micromegas; fission

1. Introduction

The study of neutron induced fission reactions in heavy nuclei plays an important role in both basic nuclear physics research to study the fission process and to cover the needs of the nuclear technology industry. For the development and operation of advanced nuclear reactor systems, such as accelerator driven systems and Generation IV nuclear reactors, there is a strong need for highly accurate nuclear data on both major and minor actinides on a wide range of neutron energies. One such minor actinide is ^{243}Am, which is among the longest lived actinides ($T_{1/2} = 7364$ y) in nuclear waste and contributes to the long term radiotoxicity, through production of ^{239}Pu ($T_{1/2} = 24110$ y). Due to the scarce experimental data available in literature, especially in the resonance and high-neutron energy regions, a new measurement of the ^{243}Am(n,f) reaction cross-section took place at the neutron time-of-flight facility (n_TOF) at CERN. The n_TOF facility [1] is one of the key facilities for neutron induced fission reaction cross-section measurements providing a pulsed white neutron beam on a wide energy range from thermal to GeV, with high instantaneous flux. The measurement was carried out in both experimental areas EAR1 and EAR2 to take advantage of their different characteristics. In this work, we extended the highest neutron energies that can be measured with this setup, using Micromegas detectors. Specifically, a new analysis methodology, based on previous works that were measuring fission cross-sections using Micromegas detectors [2–4], was developed for the treatment of the γ-flash at EAR1 at even higher energies in order to extend the neutron energy range to the highest energies achievable. The results of this analysis are presented here for the first time.

2. Experimental Details

The neutron time-of-flight facility (n_TOF) produces the neutron beam via the spallation mechanism. A 20 GeV pulsed proton beam impinges on a lead target producing neutrons that are subsequently moderated, creating a white neutron beam with energies that range from thermal up to GeV. Two different intensities for the proton beam were used during this experiment. The dedicated pulses, with approximately $8.5 \cdot 10^{12}$ protons per pulse and parasitic pulses with lower intensity of $3.5 \cdot 10^{12}$. The neutron beam then travels on two different paths to reach the two experimental areas. EAR1 lies at the end of a horizontal flight path approximately 185 m in length, while EAR2 lies perpendicular to the target with a flight path of approximately 19 m. The energies of the neutron that are detected are then estimated from their time-of-flight and the distance to the experimental setup. Due to their different flight paths and the orientations the two experimental areas exhibit different characteristics, with EAR2 having higher neutron flux and thus being ideal for measuring samples with low mass or low cross-section. EAR1 on the other hand has better energy resolution and, coupled with the preferential emission of high energy neutrons in the direction of the proton beam, is better suited for measuring at the highest end of the neutron energy range and is the focus of this work. In both cases the first signal that arrives at the experimental area and the detection system is the so called *γ-flash*. This is a very high amplitude signal that consists of γ rays and high energy relativistic particles that are created by the spallation process and is used as the start signal for the estimation of the time-of-flight of the neutrons. However, because of the large energy deposited in the detectors, a large oscillating baseline is recorded afterwards, negatively impacting the pulse recognition of pulses from high energy neutrons and increasing the background of the measurement.

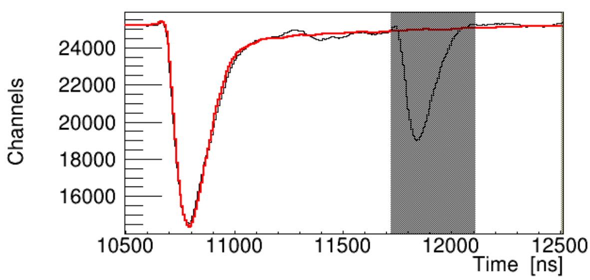


Figure 1. Raw data showing the γ-flash followed by a fission fragment pulse

The targets used in this measurement include high purity ^{243}Am samples as well as reference samples of ^{235}U, ^{238}U and ^{10}B, produced at the EC-JRC-Geel Target Preparation Laboratory (JRC.G.II.5) in Belgium. The analysis described in this work concerns two of the ^{235}U samples (74.53 $\mu m/cm^2$, 76.19 $\mu m/cm^2$) and the ^{238}U sample (227.2 $\mu m/cm^2$) that were optimized for measuring in EAR1. For the detection of the fission fragments, a setup based on the Micromegas detectors was used.

The Micromegas detectors [5] are gaseous detectors characterized by their two highly asymmetrical parts. The drift region between the drift electrode and the micromesh, where the particles deposit their energy, and the amplification region between the micromesh and the anode. The electrons created in the drift region from the energy deposited by the particles passing through the detectors are guided through the micromesh under a weak electric field to the amplification region. There, under a much stronger electrical field, the electrons are multiplied through the Townsend avalanche mechanism. The actinide sample itself serves as the drift electrode for the detector. The distance between the micromesh and the anode is 50 μm while the distance between the drift electrode and the micromesh can be adjusted and is usually of the order of 4-10 mm. In this work, in order to minimize the detector active gas volume, the drift region was taken to be 4.2 μm. Due to the small mass and size of the Micromegas detectors, they interact minimally with the neutron beam and have low γ sensitivity, which is ideal for reducing the background of the measurement and reducing the impact of the γ-flash at the highest neutron energies.

3. Methodology

As explained above, the main limiting factor for measuring at the highest neutron energies is the response of the detectors and electronics to the γ-flash and thus there is a need for the proper treatment of the γ-flash to extend the reconstruction of the fission fragment pulses to higher energies. The response of the Micromegas detector to the γ-flash has previously been shown to be remarkably consistent [2–4] and methodologies have been developed to properly subtract the oscillating baseline and reconstruct the true baseline following the γ-flash, based on the average shape, which are described in detail in Ref [6]. Based on this methodology, a more refined procedure was developed to allow the reconstruction of fission fragment pulses even closer to the γ-flash and to extend the fission cross-section measurements to neutron energies that have never before been reached at n_TOF using this setup.

The average shape for the γ-flash and the following oscillating baseline is created by stacking multiple γ-flash events in 2D histograms, and applying cuts in the z axis to remove possible fission fragment pulses that would distort the shape of the baseline. A selected portion of the shape is then fitted on the leading edge of the γ-flash pulse of each event and the total shape is subsequently subtracted, allowing the recovery of the baseline. In this way, fission fragment pulses can be better reconstructed at lower time-of-flights, reaching the tail of the γ-flash pulse, extending the measurement to higher neutron energies. As the time-of-flight decreases, the residuals created by the subtraction of the average shape increase rapidly. This puts a limit on the high neutron energies that can be measured, typically <400 MeV for experiments using Micromegas detectors. In order to increase the neutron energy range in which fission fragments are properly recognised towards higher energies, i.e. on top of the γ-flash, a closer examination of the γ-flash pulse shape as well as a more detailed analysis of the subtraction of the γ-flash pulse in each event was performed.

After a careful examination of the γ-flash shape, it was discovered that, while the tail of the γ-flash is remarkably consistent event by event, the width of the γ-flash pulse itself varies enough, that an average γ-flash cannot describe it well enough for all events. As can be seen in Fig. 2 for a ^{235}U sample, the γ-flash pulse FWHM is in the range of 160-220 ns for most events. Using the average γ-flash FWHM of approximately 180 ns for the subtraction in an event that the actual γ-flash pulse differs significantly leads to increased residuals, as can be seen in Fig. 3a.

In order to properly treat the γ-flash at these higher energies, each γ-flash pulse was grouped according to its FWHM and a different average shape was created for each group. Afterwards, the γ-flash subtraction was performed for each of these shapes. In total, four such groups were used in this analysis for each detector. This analysis was performed only for the lower intensity parasitic

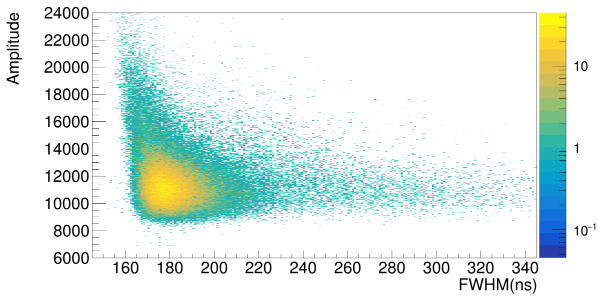
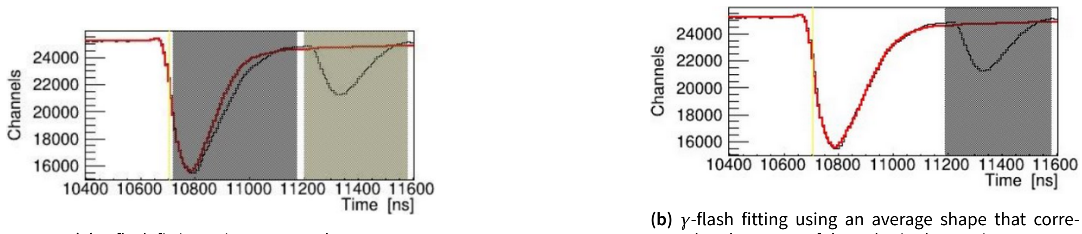


Figure 2. FWHM vs Amplitude distribution of the γ-flash pulse



(a) γ-flash fitting using average shape.

(b) γ-flash fitting using an average shape that correspond to the FWHM of the pulse in the movie

Figure 3. γ-flash fitting in raw movies. Gray area corresponds to recognized pulses

pulses ($3.5 \cdot 10^{12}$ protons per pulse), to take advantage of the lower γ-flash pulse. As can be seen in Fig. 3b, using the corresponding shape can significantly reduce the residuals created by the subtraction and thus eliminate false pulses recognized by the routine and reduce the background in the measurement.

The effect this procedure has on our data can be seen in the amplitude distribution spectra for each detector. In Fig. 4 the amplitude distribution for one of the ^{235}U samples for neutron energies 500-800 MeV is shown, corresponding to the time-of-flight region approximately 120-200 ns after the γ-flash (See Fig. 3), i.e the falling edge of the γ-flash. When using a single average shape, we observe a very high background, caused by the residuals of the γ-flash subtraction, that hinders the proper counting of the fission fragments at these energies. By following the procedure described above and using

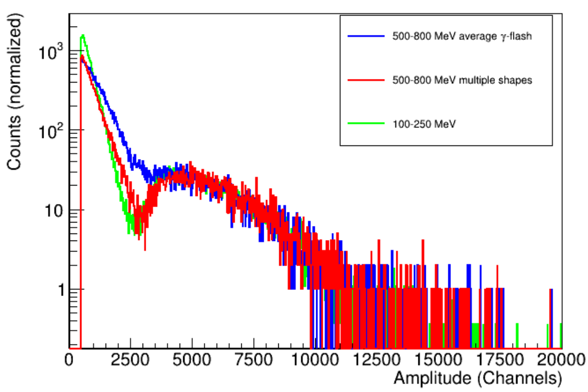


Figure 4. Amplitude spectra using a single average γ-flash shape (blue) and multiple shapes (red) at 500-800 MeV neutron energy. In addition a spectra at 100-250 MeV can be seen for comparison, where the two approaches give the same result

multiple shapes instead, we observe that the background from the residuals is drastically reduced, allowing the application of a clean amplitude cut to separate background from the fission fragments. To ensure that the distribution of the fission fragments remains consistent at these energies, the amplitude spectrum at lower energies, where the two methods give the same results, is also displayed. The shape of the fission fragment distribution is thus shown to be remarkably consistent, meaning that the fission fragments are still properly recognized

To test the validity of the results produced by this new method and ensure the reliability for the measurement of the ^{243}Am cross-section at the highest neutron energies, the reference targets of the measurement for EAR1, namely two ^{235}U samples and one ^{238}U, were used. The first step is to show that the two ^{235}U have similar fission fragment counts. In Fig. 5 the corrected counting spectra for the 2 different ^{235}U targets are shown. We observe that the two spectra are in good agreement over the whole energy range, up to approximately 700 MeV, where the two start deviating.

The final step for the validation of this method is to test if we can experimentally replicate the ^{238}U (n,f) cross-section. The results are shown in Fig. 6. By using the previous method for the γ-flash subtraction, there is a good agreement between the experimental results and the libraries (ENDF-VIII.1 + IAEA high energy reference) up to approximately 500 MeV. By using this novel method for the analysis there is a better agreement above 500 MeV, within $< 4\%$ for most of the energy range up to 800 MeV. By combining these results we can conclude that with this analysis we can extend the measurement to neutron energies up to at least 700 MeV.

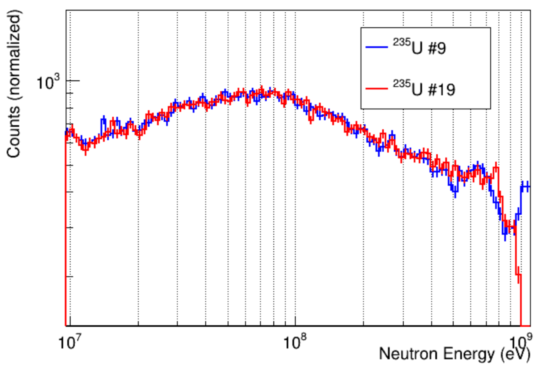


Figure 5. Counting Spectra of the two ^{235}U reference samples.

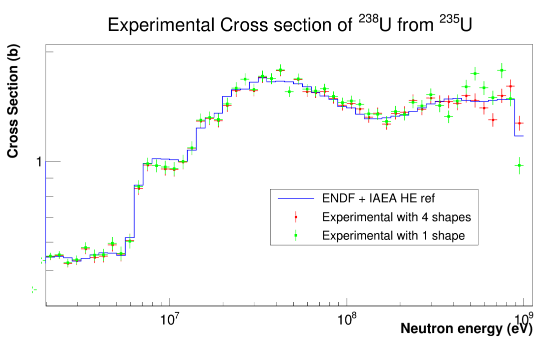


Figure 6. Experimental cross-section of ^{238}U using ^{235}U as reference using an average γ-flash shape (green) and using multiple shapes (red).

4. Conclusion

In this work a new analysis methodology was developed for the treatment of the γ-flash in the experimental EAR1 of the n_TOF facility at CERN for fission cross-section measurements with Micromegas detectors. This was tested with the setup for the measurement of ^{243}Am (n,f) reaction cross-section, using the reference targets of that measurement. It was found that by using multiple γ-flash shapes based on the FWHM of the γ-flash pulse for each movie the residuals for very low time-of-flight were significantly reduced allowing to extend the range of the neutron energies that can be measured. The spectra of the two ^{235}U samples were compared and found to be consistent until 700 MeV. Finally, a preliminary cross-section for ^{238}U using a ^{235}U target as reference, was extracted and was in good agreement with the reference cross-section at high energies up to 800 MeV. This methodology will be applied for the analysis of the ^{243}Am samples to extend the measured cross-section to the maximum possible energy.

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