Towards γ-Spectroscopy of the odd - N Fission Isomer in ^{237f}Pu using MINIBALL ◇

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Based on our studies of even - even fission isomers [1] subsequent investigations aim, for the first - time, at the identification of single - particle states in the odd - N fission isomer in ^{237f}Pu ($t_{1/2} = 110$ ns). Two preparatory experiments were performed at the MINIBALL γ - ray spectrometer operating at the Tandem accelerator of the IKP, Cologne. The ^{235}U(α,2n) reaction ($E_\alpha = 24$ MeV) was used to populate the fission isomer in ^{237f}Pu. Due to the small production cross section an efficient trigger on delayed fission events is required, which is intended to be realised by a 4π array of silicon solar cell detectors [2] in combination with a thick, metallic ^{235}U target to allow for an emission of γ - rays from the stopped ^{237f}Pu recoil nuclei prior to delayed fission. The schematics of the experimental set up is shown below and discussed in [3].

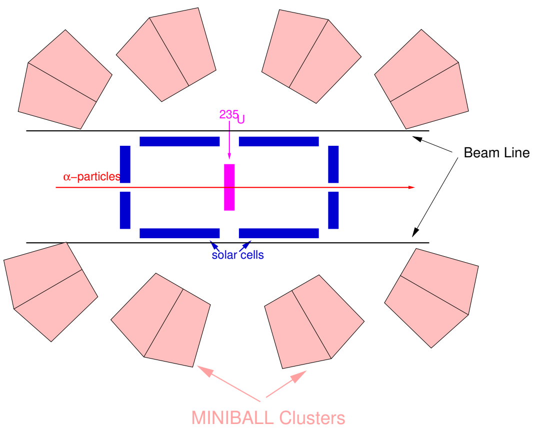

Fig. 1: schematic view of the 4π solar cell array set up [3] used in the first MINBALL test experiment.

The production of these rolled metallic ^{235}U targets represents a technical challenge, as the material is highly oxidising, therefore requiring an oxygen - free atmosphere from the production in the hot lab in Munich until the installation in the target chamber in Cologne. For the first experiment target material was available which turned out to be contaminated with oxidisation seeds, thus limiting the achievable target thickness to 5 - 6 mg/cm^2, which is the borderline where fission fragments produced in the first half of the target will not be able to leave the target any more. During this test, the performance of the detector set up and the quality of the beam pulse system ($\Delta t = 400$ ns, pulse width $= 2.5$ ns) was tested. Since the available target thickness was not sufficiently thin to guarantee a successful main experiment and new material was not readily available, for the second experiment an alternative experimental set up was chosen.

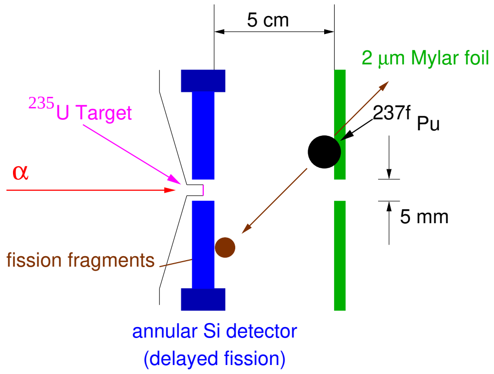

Fig. 2: Schematic display of the experimental set up used in the recoil shadow measurement of ^{237f}Pu.

A thin ($\sim 40\,\mu$g/cm^2) U_2O_3 target on a C - backing was used in a geometry as shown in Fig. 2. The target (diameter ~ 2.5 mm) was placed inside the 4 mm hole of an annular silicon detector, slightly retracted with respect to the active front surface. A recoil shadow technique was used to identify delayed fission events: prompt fission will occur in the shadow of the active detector surface, while the recoiling fission isomers ($t_{1/2} = 110$ ns) will be implanted into an annular Mylar foil (thickness $\sim 2\,\mu$m) placed 2.5 cm in front of the detector. Starting from there, delayed fission fragments were detected under backward angles in the Si detector ($d\Omega/4\pi = 9\,\%$). γ - rays were detected in the 8 surrounding MINIBALL triple Ge detectors (24 sixfold segmented crystals in a typical distance ~ 13.5 cm to the target, $d\Omega/4\pi = 34\,\%$) in coincidence with delayed fission events. Usi ng a beam current of ~ 2 nA, the Si detector registered ~ 180 /s, while each of the Ge detectors recorded about 15000 events/s. Figure 3 shows a picture of the Cologne target chamber used. One can see the actual detector set up with the recoil catcher foil implemented as well as a monitor detector placed in forward direction.

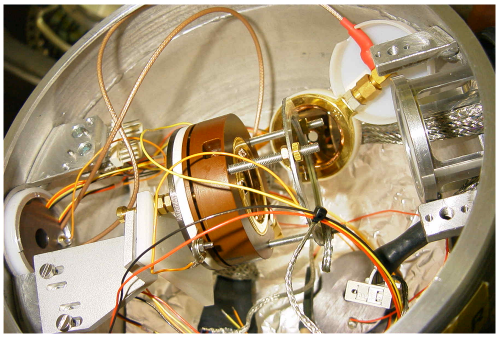

Fig. 3: shows a picture of the Cologne target chamber, with the installed detector set up and a monitor detector in the recoil shadow experiment (beam enters the chamber from the left).

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Fig. 4 shows the results from this experiment, where data taking had to stop after only eight hours due to accelerator problems. Nevertheless the key questions of the test could be answered. Fig. 4a) shows the typical energy spectrum from prompt fission measured with a monitor detector under forward angles, while parts b) and c) display the delayed fission data (containing 17 events) and the γ-ray spectrum in coincidence with delayed fission (containing 46 counts, corresponding to an average γ multiplicity of about 3), respectively. From the number of delayed fission events an estimate of the isomer population cross section in ^{237f}Pu can be derived, based on the known cross section of 10 μb for the population of the fission isomer in ^{240}Pu [4]. The comparison of the two reactions is shown in Table 1, resulting in an estimated cross section $\sigma_{del} \sim 2\,\mu$b for ^{237f}Pu.

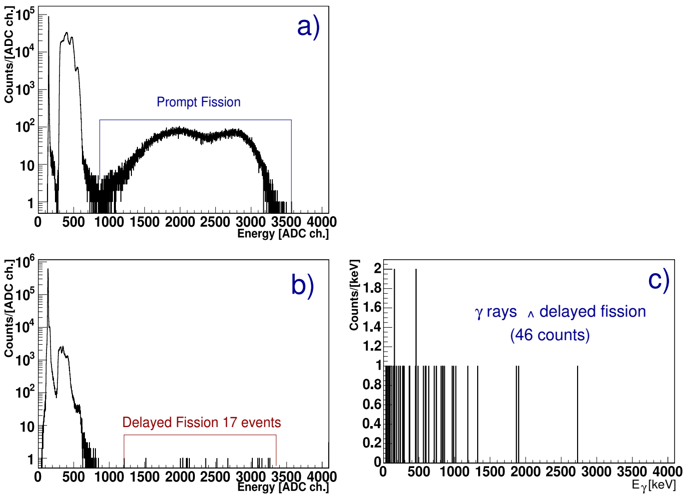

Fig. 4: a) shows the prompt fission spectrum. Part 4b) displays the delayed fission spectrum while part c.) shows the ^{237f}Pu γ-spectrum taken at the MINIBALL spectrometer in an eight hour shift.

	^{240f}Pu	^{237f}Pu
reaction	^{238}U(α,2n)^{240f}Pu	^{235}U(α,2n)^{237f}Pu
E_α [MeV]	24	24
I_α [nA]	500	2
target thickness	$\sim 30\,\mu g/cm^2$	$\sim 40\,\mu g/cm^2$
N_{del}^{fiss}	1200/hour	2/hour
$d\Omega/4\pi$ [%]	14	9
σ_{del}	10 μb	2 μb

Table 1. Comparison of reaction-specific parameters for ^{240f}Pu and ^{237f}Pu, respectively.

In addition the absolute photopeak efficiency of the MINIBALL spectrometer was measured using a ^{152}Eu source (190 kBq). Exploiting the coincident γ cascades of the 121 keV/1408 keV and 344 keV/778 keV transitions, respectively, which are shown in Fig. 5 together with their respective coincidence ratios, by gating on one of the γ transitions in a single Ge crystal the photopeak efficiency for the corresponding coincident transition could be determined simply by counting the number of registered photopeak events in the rest of the MINIBALL array. This resulted in the efficiency curve as shown in Fig. 6, with a value of $\varepsilon_{ph} \sim 4.5\,\%$ at 1.3 MeV γ energy, which is in good agreement with earlier measurements [5].

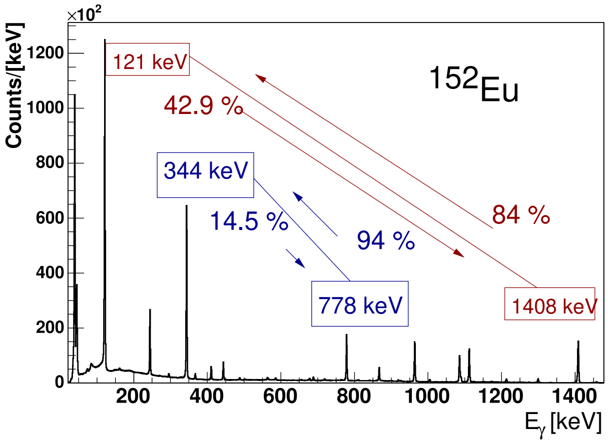

Fig. 5: γ-ray spectrum from a ^{152}Eu source taken at the MINIBALL spectrometer with 8 triple detectors in $\sim$13.5 cm distance between the target and the 24 Ge crystals. The relative coincidence ratios are indicated for the 121, 344, 778 and 1408 keV lines, respectively.

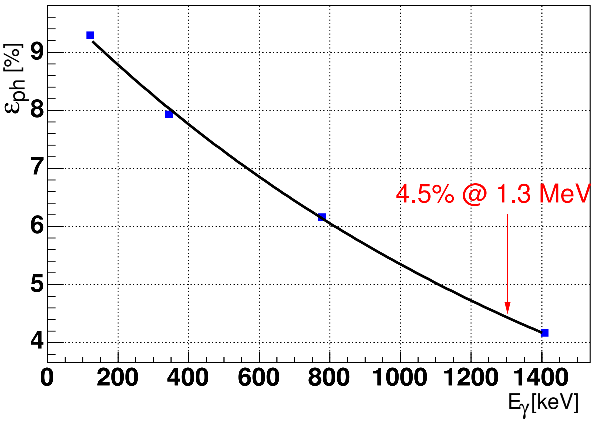

Fig. 6: Photopeak efficiency curve measured with 8 triple MINIBALL clusters at a distance of $\sim$13.5 cm between target and Ge crystal.

Given the cross section estimate as quoted in Tab. 1, for a two week experiment about 4×10^3 ($\sim$20 events/hour)delayed fission events from the ^{237f}Pu can be expected, resulting in about 1×10^4 γ-rays detected in the MINIBALL. This estimate is based on the use of new thick metallic ^{235}U targets ($\sim 3\,mg/cm^2$), which are presently under development at the Munich radioactive target laboratory. It should be noted that while the comparison of the two isomeric production yields for ^{240f}Pu and ^{237f}Pu as listed in Tab. 1 may raise doubts on the feasibility of the ^{237f}Pu experiment, an additional gain factor of about 10 in favour of ^{237f}Pu arises from the different isomeric half-lives. Due to the short half-life ^{240f}Pu ($t_{1/2} = 3.8$ ns) three half-lives had to be sacrificed for the time condition to identify delayed fission events [6], while the longer half-life of 110 ns in the case of the ^{237f}Pu will avoid these losses. Thus the expected yield difference between the two reactions narrows to a factor of 6, making the experiment on ^{237f}Pu feasible.

References

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