Neutron correlations in the spontaneous fission of ^{252}Cf

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Introduction

Nuclear fission is a complicated large-scale collective motion, governed by the spectrum of transition states that exists at nuclear deformations corresponding to the fission saddle point, as predicted by Bohr [1]. A typical binary fission event produces two excited daughter nuclei that prompty de-excite by the emission of neutrons and photons. These promptly emitted neutrons and photons can be detected in coincidence with the product nuclei presenting a wide range of possible fission observables. The prompt neutrons are emitted on a shorter time scale than the γ-ray emission [2, 3] and are correlated with one another in their emission angle and energy. The measurement of these correlations are useful for understanding the distribution of the excitation energy between the fragments [4–6] as well as for gaining the insights into the primary mechanism behind the generation of nuclear angular momentum in the fission process [7]. The sensitivity of the various neutron observables on the sampling of the fission events for ^{252}Cf, were recently reported in Ref. [8] within the framework of FREYA fission simulations. Bowman et al. performed a comprehensive measurement and analysis of the spontaneous fission of ^{252}Cf and found discrepancies between the data and a model of isotropic neutron emission in the fission fragment CMs. It was suggested to be due to the existence of scission neutrons, and a possible anisotropy in the neutron emission due to the fragment spin [13]. These effects can be experimentally explored via neutron-neutron correlations with respect to neutron energies.

The current work aims at studying the two-neutron and three-neutron angular correlations as a function of neutron energy using the ELIGANT-GN array at ELI-NP, Romania, to understand the neutron emission and the generation of nuclear angular momentum in the fission process.

The ELIGANT-GN Array

The Extreme Light Infrastructure - Nuclear Physics (ELI-NP) facility [9] hosts an array of 34 γ-ray detectors (15 LaBr3, 19 CeBr3), and 61 neutron detectors (36 Liquid Scintillators and 25 Lithium Glass) forming the ELIGANT-GN (ELI Gamma Above Neutron Threshold: The Gamma-Neutron) array [10]. The combination of the two-types of neutron detectors make the array highly efficient in detecting neutrons with a wide energy range from few keV to more than 10 MeV. The array with detectors distributed in different angles making an almost 4π algular coverage, proofs to be an ideal set-up for the study the neutron-neutron and neutron-γ and γ-γ correlations mentioned above. The commissioning experiment for the ELIGANT-GN array was carried out using a the spontaneously fissioning ^{252}Cf source, the details of which of which were reported in Ref. [11].

Measurements and Results

Angular correlations of the neutrons emitted from the spontaneous fission of ^{252}Cf, were studied using the the ELIGANT-GN array and the first results for the two-neutron correlations were reported in Ref. [11]. Due to the absence of a dedicated fission-fragment detec-

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tor, the γ-ray detectors were used to distinguish the fission events from other types of decay and ambient room background. Since fission events have high multiplicity and high energy released, ELIGANT-GN was used as a γ-ray calorimeter, and distributions based on total energy and total multiplicity were produced for a clean selection of fission events [10].

The prompt fission γ-ray energy distribution has been analysed with the LaBr3:Ce and CeBr3 detectors. The general absolute distribution and the slope of the distribution agree well with the previously published data [12], providing confidence that the quality of the data collecting and sorting procedures is reasonable. After a proper cross-talk rejection between the neutron detectors, time alignment, and efficiency estimation, neutron neutron angular-correlations were obtained. Figure 1 shows the energy distribution of the fission neutrons, as seen by the liquid scintillators, efficient in detecting the high-energy neutrons. Two-neutron and three-neutron angular collerations were obtained as a function of neutron energies were then compared with FREYA calculations [14]. A second measurement in on-going at ELI-NP, combining a 16×16 Si strip detector with the ELIGANT-GN array for the measurement of angular correlations of the neutrons with the fission fragments along with the neutron-neutron and neutron-γ correlations, giving an insight into the origin of the neutrons in the fission process. The status and current results of these measurements will be presented.

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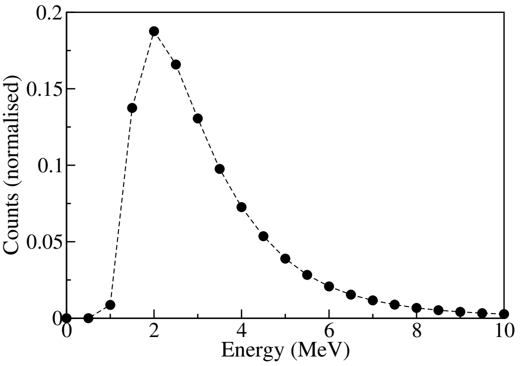

FIG. 1: Energy distribution of the fission neutrons detected by the liquid scintillators.

References

[1] A. Bohr, Proc. of the International Conf. on the Peaceful Uses of Atomic Energy, Geneea, Szoitsexland **2**, 151 (1955).

[2] J. Fraser, Phys. Rev. **88**, 536 (1952).

[3] K. Skarsvag, Nucl. Phys. A **153**, 82 (1970).

[4] H.R. Bowman *et al.*, Phys. Rev. **126**, 2120 (1962).

[5] S. Pozzi *et al.*, Nucl. Sci. Eng. 178, 250 (2014).

[6] P.F. Schuster *et al.*, Phys. Rev. C **100**, 014605 (2019).

[7] J.N. Wilson *et al.*, Nature **590**, 556 (2021).

[8] J. Randrup, P. Talou, and R. Vogt, Phys. Rev. C **99**, 054619 (2019).

[9] N.V. Zamfir, Phys. News **25:3**, 34 (2015).

[10] P.-A. Söderström *et al.*, Nucl. Instum. Meth. Phys. Res. A **1027**, 166171 (2022).

[11] P.-A. Söderström *et al.*, ELI-NP Annual Report Pg. 125 (2022).

[12] A. Oberstedt *et al.*, Phys. Rev. C 92, 014618 (2015).

[13] A. Chietera *et al.*, Eur. Phys. J. A 54, 98 (2018).

[14] J. Randrup, Private Comm.