β-DECAY HALF-LIVES MEASUREMENTS IN $A \sim 225$ Po–Fr NUCLEI[*] [**]

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The study presented in this work aims at increasing the experimental knowledge on the hard-to-reach $220 < A < 230$ n-rich region. In particular, a systematic study of the β-decay properties of the mentioned nuclei will help to probe the predictions of global nuclear models beyond $N = 126$, an important input to the r-process nucleosynthesis description. Moreover, the $A \sim 222$ region is the area of the nuclear chart where the strongest octupole deformations are expected to manifest. Preliminary results are reported from an experiment performed at GSI-FAIR (Darmstadt, Germany) in April 2021 within the HISPEC-DESPEC Collaboration experimental campaign, with the aim to study $220 < A < 230$ Po–Fr nuclei via β-decay measurements.

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1. Introduction

The main focus of this work is the study of the structure of $220 < A < 230$ Po–Fr nuclei, with the aim of extending the systematics of the lowest-lying states and provide a confirmation of the β-decay half-lives of nuclei in this region. A systematic study of the β-decay properties of the mentioned nuclei will help to probe the predictions of global nuclear models in exotic nuclei with $N > 126$, of relevance to understand the formation of the heaviest chemical elements through the r-process of explosive nucleosynthesis [1]. Developing a global model applicable over the entire neutron-rich side of the chart of nuclides is very challenging. In order to have an exact description of the β-decay process, the knowledge of ground-state properties for both the parent and daughter nuclei is required. However, owing to the limited experimental inputs and the limitations in shell model calculations, these quantities cannot be provided for medium-to-heavy systems. A different approach is given by models which aim at a global description throughout a large portion of the nuclide chart, such as Refs. [2–5].

The β-decay properties relevant to the r-process description are β-decay lifetimes and β-delayed neutron emission probabilities, which are known only for a small number of nuclei involved in the process, even if the number is increasing steeply in recent years. The nuclei studied within this work are also expected to show static octupole deformation [6], which is of importance for nuclear structure theory [7, 8], and also in searches for physics beyond the Standard Model since any measurable static electric-dipole moment (EDM) [9], violating parity, is expected to be amplified in these nuclei. Experimental signatures of the location of the first low-lying states are crucial inputs for such models.

2. The FRS+DESPEC setup at GSI-FAIR

In order to access the region of heavy nuclei ranging from Po to Fr, we performed an experiment exploiting a fragmentation reaction of a ^{238}U beam at 1 GeV/u of an energy and intensity of 10^9 particles per spill on a ^{9}Be target in April 2021, using the GSI accelerator complex. The fragments produced were selected and identified in the FRS [10] (FRagment Separator) using the $B\rho$–ΔE–$B\rho$ and TOF–$B\rho$–ΔE methods [11]. The ions of interest were then implanted in the DESPEC (DEcay SPECtroscopy) station [12], where they were let decay in an active detector (AIDA, Advanced Implantation Detector Array), a stack of three DSSD (Double-sided Silicon Strip Detectors). Additional detection layers were provided by two plastic scintillators, sandwiching the AIDA system, the β plastic detector. γ rays emitted after the decay were measured using an array of HPGe from the

EUROBALL array and $LaBr_3$(Ce) detectors, which form the FATIMA (FAst TIMing Array). The study of the internal structure of the daughter nuclei is performed using ion–β–γ correlation and fast timing techniques.

3. First results on β-decay half-lives

The half-life of a β-decay process was calculated by fitting the spectrum obtained as the difference between the time of a β and an ion event. We started considering a decay whose half-life has been previously reported, which was populated in our dataset with enough statistics, such as the decay of ^{227}Rn, reported in literature to be $T_{1/2} = 20.2 \pm 0.4$ s [13].

In order to better account for the background we decided to extend the ion–β correlations to long times.

The decay spectrum is fitted using a convolution of the parent decay function and an exponential background, which takes into account both the decay of the daughter nucleus and uncorrelated background

$$f_1(t) = A_1\, \mathrm{e}^{-\frac{t}{T_{1/2}(\mathrm{Parent})}\cdot \ln 2} + A_2\, \mathrm{e}^{\frac{t}{B}}\,, \tag{1}$$

where A_1, A_2, and B are fitted parameters, $T_{1/2}$ in Eq. (1) is the β-decay half-life of the ion that we want to determine.

The contributions of the two functions are shown in the plot in Fig. 1.

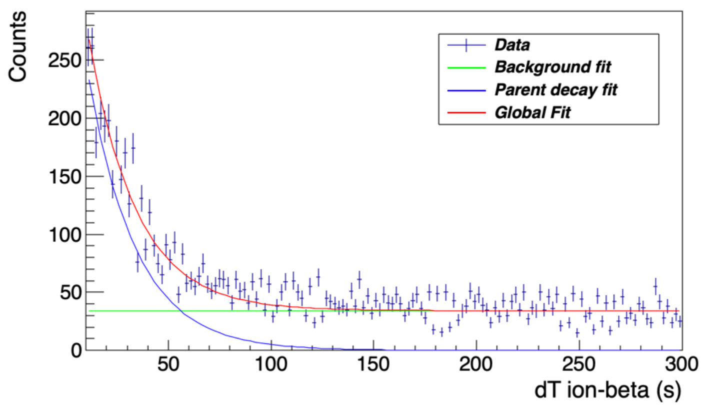

Fig. 1. (Color online) Fit of the ^{227}Rn decay spectrum: the parent decay function contribution is given by the blue/black line, the background by the green horizontal line, while the total fit function is given by the red/gray line. The errors on the data points correspond to statistical uncertainties.

The reduced chi square of the fit was $\chi^2 = 3.5$. The fitted value for the β-decay half-life is $T_{1/2}(^{227}\mathrm{Rn}) = 16.1 \pm 0.3$ s. In order to prove the consistency of the fits, several tests were performed by varying the binning and lower limit of the range of the fit function (Fig. 2).

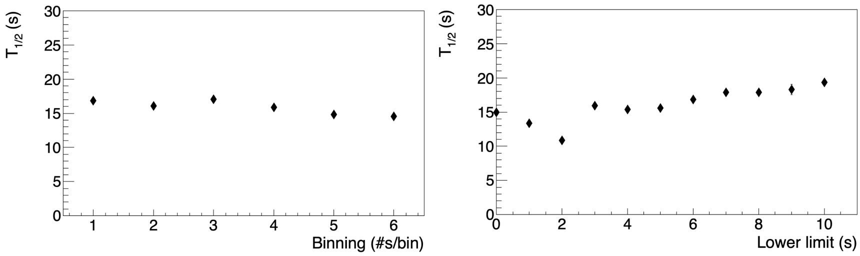

Fig. 2. Value of the fitted β-decay half-life of ^{227}Rn as a function of the number of seconds per bin (left panel) and of the lower limit of the fitting function (right panel), ranging from 0 to 10 seconds.

The final value for ^{227}Rn β-decay half-life is given by the average of all the values and the error as the standard deviation of the same values, and corresponds to $T_{1/2}(^{227}\mathrm{Rn}) = 16.7 \pm 1.4$ s, which is compatible within 3σ with the literature value of 20.2 ± 0.4 s [13]. The β-decay half-life for ^{229}Rn was also measured with the same method, obtaining the result of $T_{1/2}(^{229}\mathrm{Rn}) = 11.8 \pm 1.1$ s, which is in agreement with the literature value of $12^{+1.2}_{-1.3}$ s [14] within 1σ. Having confirmed the correlation technique and the fitting procedure, we can now proceed with the extraction of unknown β-decay half-lives for nuclei in our dataset.

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