Study of decay properties for Ba to Nd nuclei (A∼160) relevant for the formation of the r-process rare-earth peak

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Introduction

Around half of the nuclei heavier than iron are created via the rapid neutron capture process (r-process). For nuclear masses A>100, there are two main peaks in the r-process elemental solar system abundances, located at A∼130 and A∼195, which are associated with the neutron shell closure during the $(n,\gamma) \leftrightarrow (\gamma,n)$ equilibrium. In contrast, the rare-earth peak (REP) is a small - but clear - peak around mass A=160, which originates from the freeze-out during the late phases after neutron exhaustion. The formation of the REP offers a unique probe for the study of the late-time conditions on the r-process site. According to theoretical models and sensitivity studies, half-lives ($T_{1/2}$) and beta-delayed neutron emission probabilities (P_n) of very neutron-rich nuclei for $55 \leq Z \leq 64$ are the most influential ones on the formation of the REP [1,2]. The BRIKEN project [3,4] has been in operation from 2016 to 2021 at the Radioactive Isotope Beam Factory (RIBF) in the RIKEN Nishina Center. BRIKEN has performed an ambitious measurement program of beta-decay properties of nuclei on the path of the r-process. The proposal for the REP region was approved in 2016, it included the neutron-rich nuclei from Ba to Gd. The full experiment was carried out in three experimental campaigns performed in 2017, 2018, and 2020. This work focuses on the data analysis for Ba to Nd species from the 2018 dataset. The results for Pm to Gd species, including their astrophysical impact, are being published in a separate report [5]. In this contribution we present the first experimental results of new $T_{1/2}$ and P_{1n}-values for nuclei in the neutron-rich region from Ba to Nd.

Experimental setup

The experiment was performed using a 60 pnA ^{238}U primary beam, with an energy of 345 MeV/nucleon, and bombarding a 5 mm thick ^{7}Be target. The experimental setup consisted of:

- **BigRips separator:** To select the desired isotopes produced by the fragmentation reaction, the standard ΔE-Bρ-ToF technique is used.
- **AIDA implantator:** Six-silicon double-sided strip detector, placed one in front of the other, separated by 10 mm. Each has a thickness of 1 mm, dimensions of 71.68 mm x 71.68 mm, and 128 strips. AIDA also has dual electronic chains. A low grain branch to allow high energy implant detection and a high gain branch for beta particle detection.
- **BRIKEN detector:** An array of 140 ^{3}He-filled proportional tubes embedded in a 90 cm x 90 cm x 75 cm polyethylene block to ensure neutron moderation. This block has a central hole of 11.6 cm x 11.6 cm where AIDA is inserted. It also has two HPGe detectors at the sides to offer neutron-gamma coincidences [6]. This array offers a nominal neutron efficiency of 68.6% [7].

To perform the analysis of the data from this setup, it is necessary to merge the information given by three independent DAQS (BigRips, AIDA, and BRIKEN). For this reason, a synchronization signal has been fed to each DAQ, creating an absolute time-stamp reference.

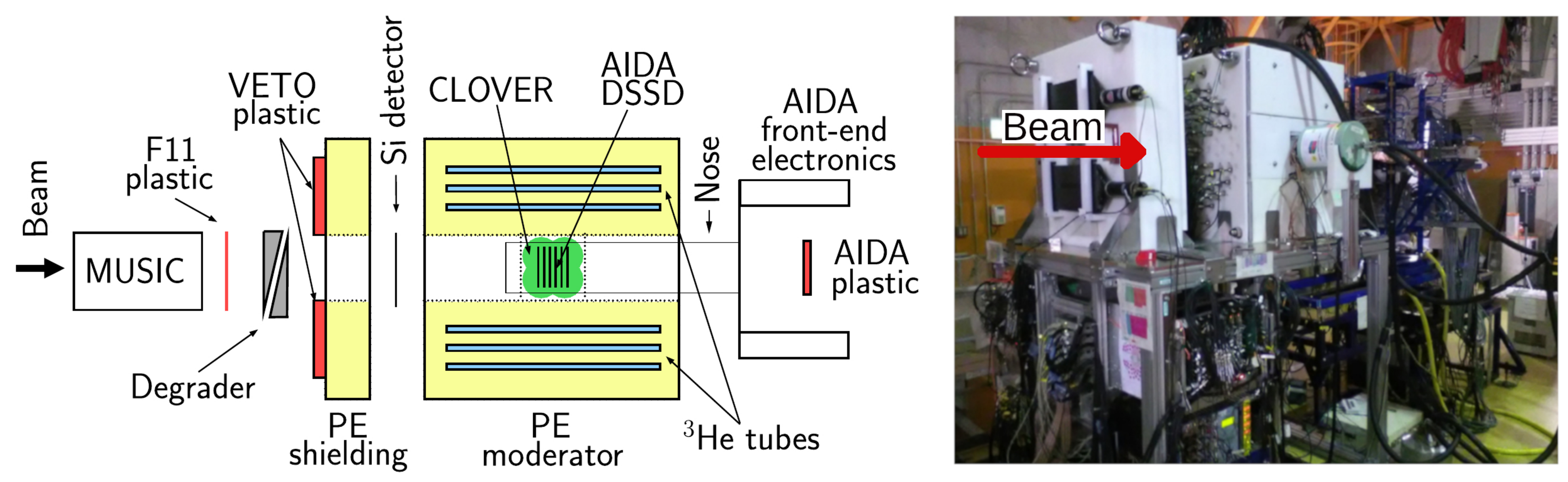

Fig. 1: Scheme and picture of the BRIKEN setup.

Preliminary results

The preliminary results from the analysis of the 2018 dataset can be summarized as follows:

- $\mathbf{T_{1/2}}$: We report **4 new** $T_{1/2}$ (^{157}La, ^{159}Ce, ^{161}Pr, and ^{163}Nd). The final value of these $T_{1/2}$ is expected to be improved by the reduction of the contribution of charged states. In addition, 38 $T_{1/2}$ have been remeasured, with most cases showing good agreement with previous measurements.
- $\mathbf{P_{1n}}$: We report **20 new** P_{1n} values ($^{151-152}$Ba, $^{151-155}$La, $^{154-157}$Ce, $^{155-160}$Pr, and $^{160-161}$Nd). In addition, two P_{1n} values (^{149}La and ^{150}La) have been remeasured with improved precision.

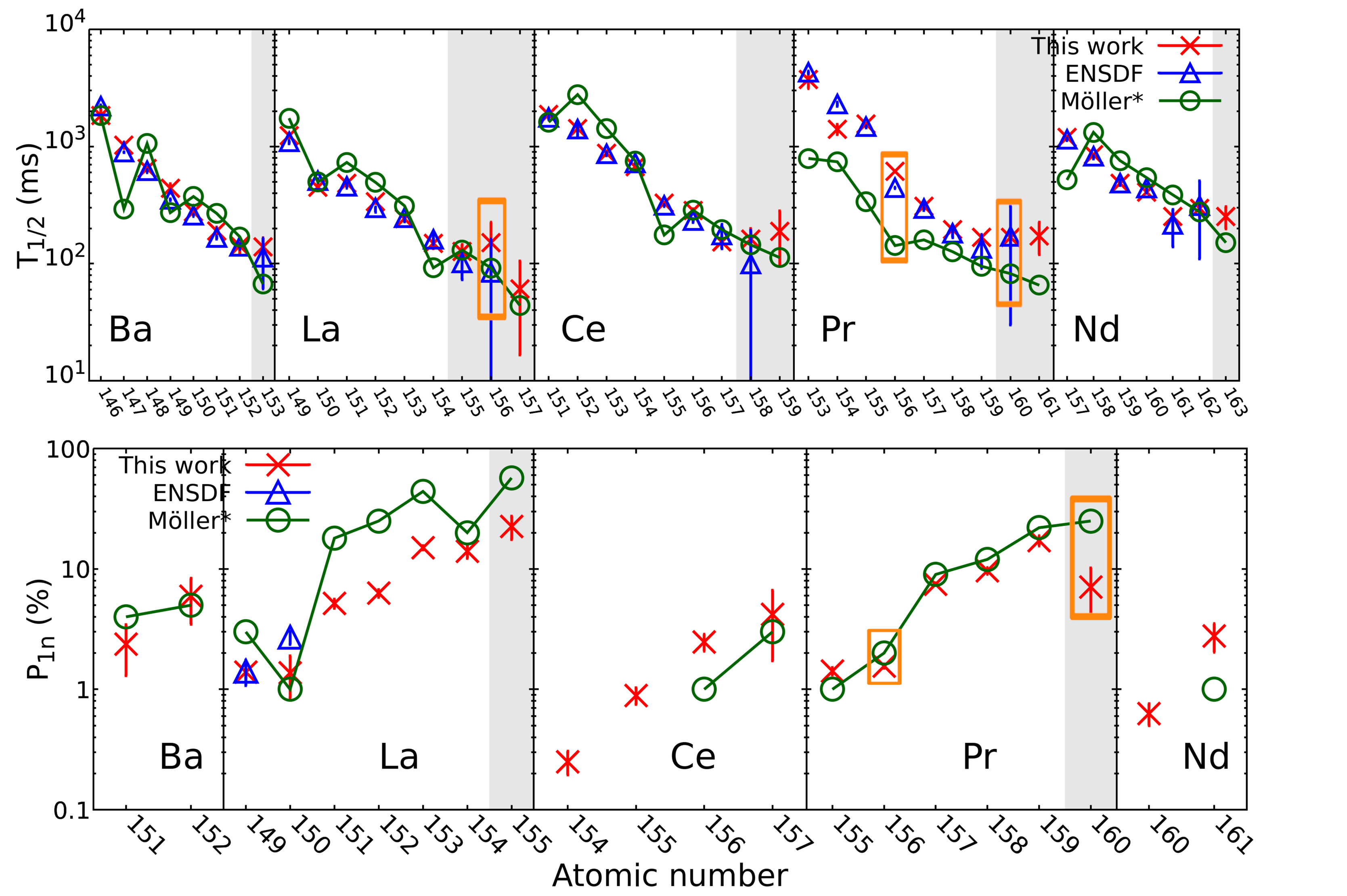

Fig. 3: Preliminary results for $T_{1/2}$ and P_{1n} from this work (in red), previous measurements (in blue), and Möller's theoretical predictions (in green) [8]. The grey region highlights results expected to be improved. Orange boxes indicate potential isomer candidates.

Remarks and future work

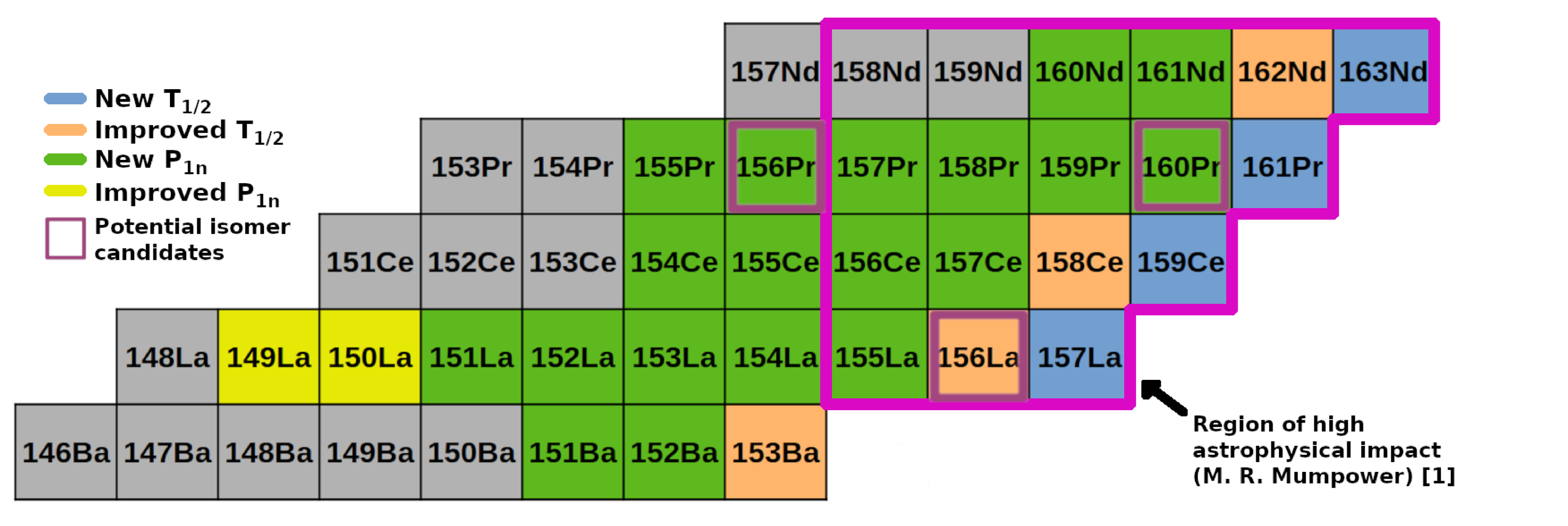

Fig. 2: Summary of the isotopes output. We present **4** $T_{1/2}$ and **20** P_{1n} new experimental values.

In this work, the measurements of exotic isotopes in the REP region are presented. **4** new $T_{1/2}$ and **20** new P_{1n} are reported. The preliminary findings of this study are summarized in figure 2. It also depicts the overlap between the region of high astrophysical impact as predicted by sensitivity studies [1] and our results. The future goals of this study are:

- Reduce contamination caused by charge states (mostly in the blue region).
- Discuss potential isomer candidates.
- Evaluate the astrophysical impact of the new nuclear data on the description of the r-process in the REP region.

Reference

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