

Quadrupole vs. single-particle excitations in $^{99,101,103}\text{Ru}$ isotopes, produced in $(\alpha, n\gamma)$ reactions

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Abstract

We propose to measure half-lives of excited states in $^{99,101,103}\text{Ru}$ isotopes, produced in fusion-evaporation reactions. The states of interest will be populated via $(\alpha, n\gamma)$ reactions with a beam of α -particles at 14-15 MeV. The sub-nanosecond half-lives will be measured by the delayed coincidence technique, applied with a mixed detector array of $\text{LaBr}_3:\text{Ce}$ and HPGe detectors.

1 Motivation

A large variety of nuclear structure phenomena are presented in the $A \sim 100$ region, where different shapes, as prolate, oblate and spherical, exist. In several nuclei triaxiality arises. Also, given the proximity of the $\Delta l = \Delta j = 3$ orbitals, enhanced octupole collectivity is expected at around $N=56$. Among the most neutron-rich stable Zr and Mo isotopes shape co-existence occurs. In fact, the collective behaviour of the nuclei in this mass region arises with the number of the valence particles, soon after filling the $N=50$ shell closure. The shape change in the Zr and Mo isotopic chains is abrupt, while the shape change in Ru isotopic chain is more modest (Fig. 1) [1]. Ruthenium isotopic chain is placed between the rotational neutron-rich Zr and Mo nuclei and the vibrational Cd and transitional Pd nuclei. In particular, $^{96,98}\text{Ru}$ have vibrational behaviour, while the mid-shell Ru isotopes are triaxially deformed. Thus, $^{99,101,103}\text{Ru}_{55,57,59}$ isotopes are placed in the region where the onset of deformation is expected to occur [1, 2]. The low-lying parts of their spectra have similar structure (Fig. 2) [3]. The $5/2^+$, $7/2^+$, $3/2^+$, $1/2^+$, $11/2^-$ states, appearing at low energies, suggest that the $2d_{5/2}$, $1g_{7/2}$, $2d_{3/2}$, $3s_{1/2}$ and $1h_{11/2}$ single-particle orbitals dominate. On the other side, states can arise from collective excitations from the coupling of a triaxial rotor to an unpaired particle. Thus, in order to track the evolution of collectivity in the medium-mass Ru isotopes, we propose to measure the half-lives of the lowest-lying states in these nuclei. The half-lives are related to the matrix elements and hence will allow a systematical study of the evolution of collectivity in the mass region.

Besides the low-lying states, also half-lives of higher-spin states in $^{99,101,103}\text{Ru}$ can be studied by using the fast-timing technique. In the odd- A nuclei, from the $A \sim 110$ mass region, intense $\Delta I=2$ transitions built on top of the $11/2^-$ states arise. These quasi-rotational bands often have $15/2^-$ states with half-lives within the RoSphere time range. Thus, for example, the half-life of the $15/2^-$ state in ^{107}Cd is $T_{1/2}=21(8)$ ps [3] and the half-life of the $15/2^-$ state in ^{105}Pd was

recently measured $T_{1/2}=28(4)$ ps [4]. Now, by measuring the $T_{1/2}$ of the $15/2^-$ state in ^{103}Ru , we will track the evolution of the quasi-rotational bands, built on top of $11/2^-$ in the $N=59$ isotonic chain. Similarly, we would like to measure the half-lives of the $15/2^-$ states in $^{99,101}\text{Ru}$, in order to complete the systematics.

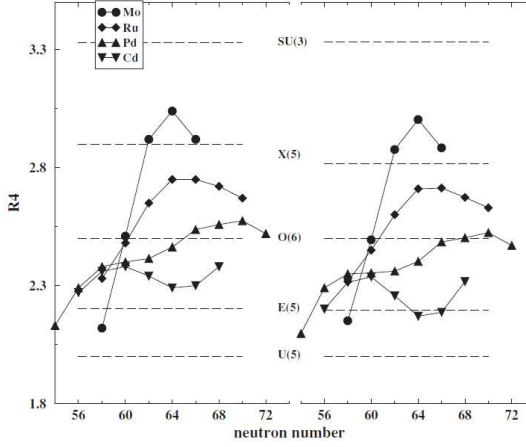


Figure 1: The excitation energy ratios R_4 and R_6 in neutron-rich Mo, Ru, Pd and Cd isotopes, plotted as a function of the neutron number [1]

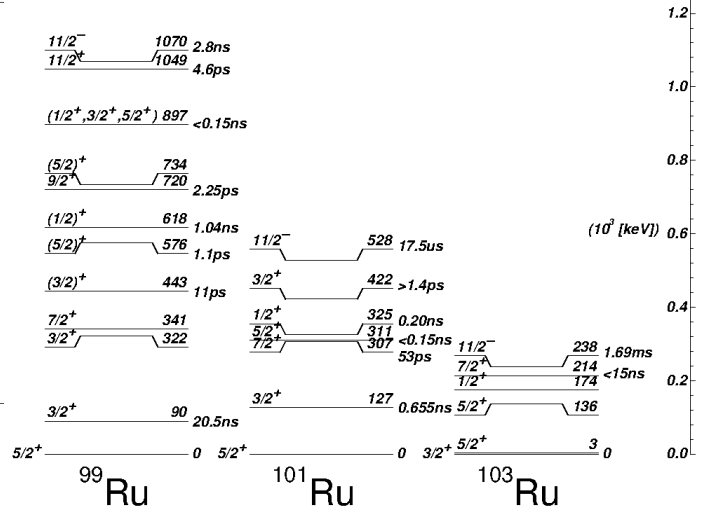


Figure 2: Low-lying excited states in $^{99,101,103}\text{Ru}$ isotopes [3]

2 Half-lives estimation

The half-lives estimations were made on the basis of the known half-lives of the $7/2_1^+$ state in ^{101}Ru and the $15/2^-$ states in $^{101,103,105}\text{Pd}$. Assuming that the structure of the $7/2_1^+$ states does not change abruptly in the neighbouring ^{99}Ru , ^{101}Ru and ^{103}Ru nuclei, estimations of the unknown half-lives of the $7/2_1^+$ states in ^{99}Ru and ^{103}Ru were performed. The same mixing ratio as in ^{101}Ru ($\delta=-0.10$) was accepted for the M1+E2 transitions, de-exciting $7/2_1^+$ in ^{99}Ru and ^{103}Ru . Under such assumption $T_{1/2}=32$ ps and $T_{1/2}=325$ ps for the half-lives of the $7/2_1^+$ states in ^{99}Ru and ^{103}Ru respectively, were obtained. The two values are within the RoSphere timing range.

Assuming a similar structure of the quasi-rotational bands in the region we estimate the half-lives of the $15/2^-$ states in $^{99,101,103}\text{Ru}$. The calculations are based on the transition probabilities, previously measured for the analogous states in $^{101,103,105}\text{Pd}$. Evaluated values for the $15/2^-$ states in ^{99}Ru , ^{101}Ru , ^{103}Ru are $T_{1/2}=14$ ps, 70 ps and 60 ps respectively.

3 Experimental set up and preceding experience

The half-lives in the sub-nanosecond region will be measured with a specially designed system for fast-timing measurements at NIPNE. It comprises 14 HPGe detectors, working in coincidence with 11 $\text{LaBr}_3:\text{Ce}$ detectors. The system is triggered by at least two $\text{LaBr}_3:\text{Ce}$ detectors, fired in coincidence with a HPGe detector. The half-lives of the levels of interest will be measured by using the time interval between the feeding and de-exciting γ rays detected by any two of the $\text{LaBr}_3:\text{Ce}$ detectors, under the condition that the cascade is fed by a third transition with a γ ray detected in a HPGe detector. In the last three years we have already used the experimental

Table 1: Estimated half-lives for the $7/2^+$ and $15/2^-$ excited states in $^{99,101,103}\text{Ru}$.

Isotope	J^{π^\dagger}	E_{level}^\dagger [keV]	E_γ^\dagger [keV]	$T_{1/2}$ [ps]
^{99}Ru	$7/2^+$	341	341	32
^{101}Ru	$7/2^+$	307	307	53^\dagger
^{103}Ru	$7/2^+$	214	211	325
^{99}Ru	$15/2^-$	1572	502	14
^{101}Ru	$15/2^-$	958	431	70
^{103}Ru	$15/2^-$	654	416	60

† data from NNDC [3]

set up for several fast-timing experiments [4, 5, 6, 7]. The $^7\text{Li}+^{107}\text{Ag}$ reaction was used to populate ^{111}Sn . The structure of low-lying excited states in $^{103,105,107}\text{Cd}$ was studied. In-beam experiments were carried out in order to measure half-lives of high-spin states in $^{95,96}\text{Mo}$. In January 2012 a fast-timing experiment was performed on $^{102-106}\text{Pd}$. Sample timing spectra from this experiment are presented on Fig. 3. The present experiment is focused on the odd-mass Ru isotopes, which will allow to make a systematical study in the region and to track the evolution of collectivity for specific states. This will shed light on the influence of particular single-particle orbits onto the collective motion.

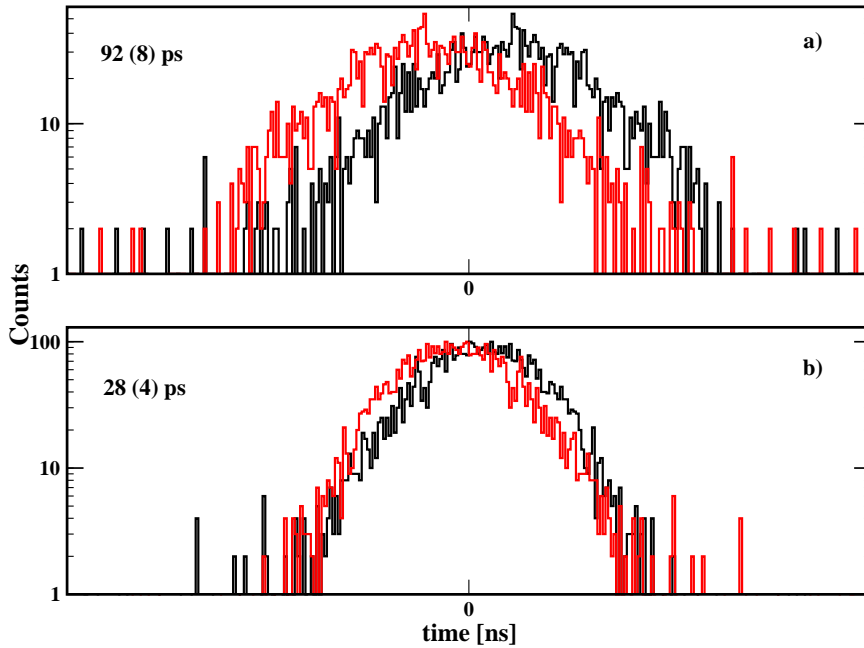


Figure 3: Time spectra, obtained for the decay of the $7/2_1^+$ state in ^{105}Pd (a) and for the $15/2^-$ state in ^{105}Pd [4]

4 Beam time estimation

Excited states in $^{99,101,103}\text{Ru}$ will be populated in $(\alpha, n\gamma)$ reactions. Targets of ^{96}Mo , ^{98}Mo and ^{100}Mo will be used. The cross section for a beam energy of 15 MeV is estimated by using the

CASCADE code to ≈ 500 mb and ≈ 400 mb for $^{96}\text{Mo}(\alpha, n\gamma)^{99}\text{Ru}$ and $^{98}\text{Mo}(\alpha, n\gamma)^{101}\text{Ru}$ reactions respectively. ^{103}Ru will be populated in $^{100}\text{Mo}(\alpha, n\gamma)^{103}\text{Ru}$ reaction with beam energy of 14 MeV and $\sigma \approx 100$ mb. ^{100}Ru and ^{102}Ru will be populated as side channels in the reactions. The energy loss (dE/dx) of the α -particles in the three reactions is ≈ 0.19 MeV/(mg/cm²). Hence, $^{96,98,100}\text{Mo}$ targets with thickness of 10 mg/cm² will be used. The typical currents for α -particles at NIPNE are of order of 20 nA. Thus, the expected yield for ^{103}Ru in triple coincidences in an 8-hour shift is 402 counts. Therefore, **6 days of beam-time are requested** to measure the half-lives of the lower-lying positive-parity states and half-lives in the negative-parity quasi-rotational bands in $^{99,101,103}\text{Ru}$.

5 Conclusion

We propose to measure half-lives of excited states in $^{99,101,103}\text{Ru}$ by using the in-beam delayed coincidence method. The measurements will give important information about the degree of collectivity in the odd-nuclei from the $A \sim 100$ mass region. The values, estimated for the half-life of the $15/2^-$ states in ^{101}Ru and ^{103}Ru , are in the range of RoSphere. A number of low-lying positive-parity states also have half-lives well within the range of RoSphere. The experimental data will be used for S. Kisyov PhD thesis, which is expected to start in the beginning of year 2013.

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