Experimental report

20/08/2024

Proposal: 3-01-723 **Council:** 4/2023

Title: Lifetime determination of the first excited 0+ state and non-yrast states in 104Mo

Research area: Nuclear and Particle Physics

This proposal is a new proposal

Main proposer: Martin VON TRESCKOW

Experimental team: Vasil KARAYONCHEV
Emily TADDEI
Senuri DANTANARAYANA
Leyla ATAR
Martin VON TRESCKOW
Andi MESSINGSCHLAGER
Thorsten KROELL
Corinna HENRICH
Maike BEUSCHLEIN
Arwin ESMAYLZADEH
Jean Marc REGIS
Luis Mario FRAILE

Local contacts: Ulli KOESTER
Jean Michel DAUGAS

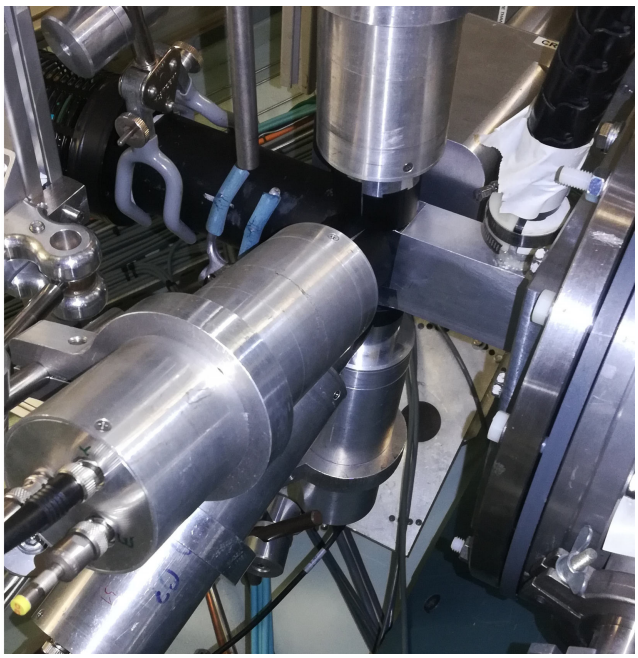
Samples:

Instrument	Requested days	Allocated days	From	To
PN1	13	10	22/08/2023	01/09/2023

Abstract:

We propose to repeat our lifetime measurement experiment for non-yrast states in 104Mo. Our previous experiment was done at LOHENGRIN in 2021 and we could measure some new lifetimes in this nucleus. The aim of this experiment is to investigate the shape coexistence in 104Mo. The lifetime of the first excited 0+ state and the B(E2; 0+_2 -> 2+_1) are of paramount importance for this investigation and could not measured with a good precision in our first experiment. Our proposed modified setup will consist of 3 LaBr3(Ce) detectors, 1 Clover Ge detector and 1 beta-detector with good time resolution to determine the lifetime of the first excited 0+ state via beta-gamma-gamma timing.

The aim of this experiment was to determine the lifetime of the first excited 0_2^+ state of ^{104}Mo which is of paramount importance for the investigation of shape coexistence in the Z = 40 and N = 60 region. The lifetimes in this experiment will be determined by the β-γ, β-γ-γ timing (ATD method [1]) and the mirror symmetric centroid difference method [2]. We performed this experiment in August 2023 at the Lohengrin mass separator and it is a repetition of the experiment 3-01-700 from 2021 where the lifetime determination was not possible mainly due to the worse β-γ time resolution of the used β-detector and the lower statistics and contamination in the only γ-γ coincidence populating and depopulating the 0_2^+ state. The ions of interest were produced by thermal-neutron induced fission of a ^{241}Pu target which was placed in the high-neutron-flux in the H9 beam tube. The fission fragments were then selected using the Lohengrin mass separator which was optimised for transmission of ^{104}Nb ions, the mother isotope of ^{104}Mo.
In our experiment, we optimised the setup compared to the previous experiment for β-γ timing. To increase the number of implanted ions, we changed the target chamber from a chamber with a 4 cm x 4 cm square focal plane to a chamber with a 6 cm x 3 cm rectangular focal plane and removed the upfront gas-filled ionisation chamber. The new chamber gave us more space to place the detectors so that we could place the same number of $LaBr_3$(Ce) detectors and HPGe Clover detector as in the previous experiment, plus a photomultiplier tube for the thin β-plastic detector to achieve a β-γ time resolution of about 200 ps. Two of the four $LaBr_3$(Ce) detectors were placed on a long side of the focal plane and one $LaBr_3$(Ce) detector was placed on each short side of the focal plane. The HPGe Clover detector was placed closer to the implantation area as in the previous experiment at the second long side of the focal plane and the β-plastic detector was placed as closed as possible in parallel to the implantation area. The setup is shown in Fig. 1 (left).



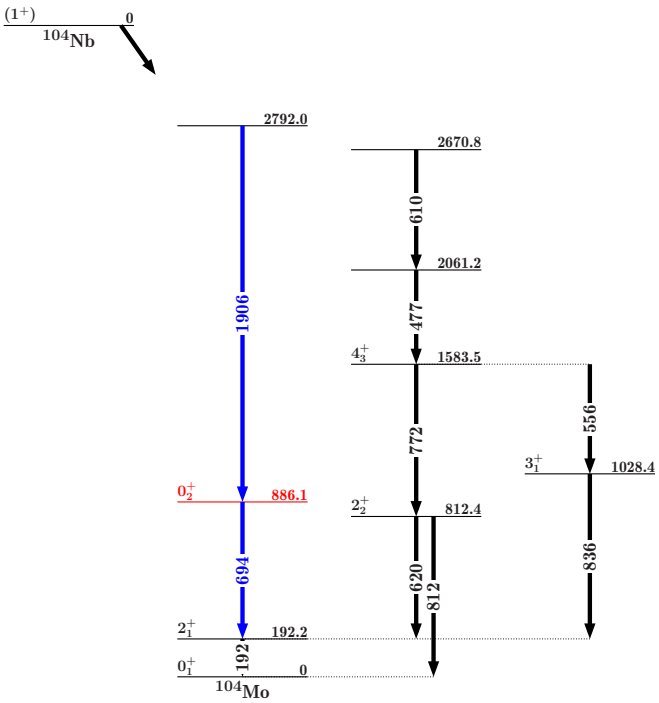


Figure 1: (left) The detector setup used in this experiment. (right) Partial β-decay scheme of ^{104}Nb showing the $\gamma-$ray transitions observed in the experiment. Highlighted in red is the first excited state 0^+ state whose lifetime can be determined via β-γ timing and β-γ-γ timing using the blue coloured transitions.

Calibration measurements were performed using the standard sources ^{60}Co, ^{133}Ba, ^{152}Eu, ^{207}Bi as well as sources specially produced by neutron irradiation at the reactor: ^{24}Na, ^{185}Os, ^{187}W, and ^{198}Au. In addition, during the uranium fission target run in one of the following experiments of the Lohengrin campaign (experiment 3-01-721), we changed to the mass A = 97, optimising the transmission of ^{97}Sr ions, in order to use ^{97}Y in beam data to calibrate the time-walk behaviour of our detectors. These measurements allow us to calibrate the time-walk of our setup from 40 keV up to 2754 keV.

In the ^{104}Mo run itself, we had a total net measurement time of about 8 days. The effect of the larger target chamber can be seen in Fig. 2, which shows the γ-ray single spectra recorded during the first 6 hours of the previous experiment 3-01-700 (2021) and of this experiment. It can easily be seen that the statistics increases for all dominant γ-rays from the A = 104 isotopes of our β-decay chain compared to the previous experiment.

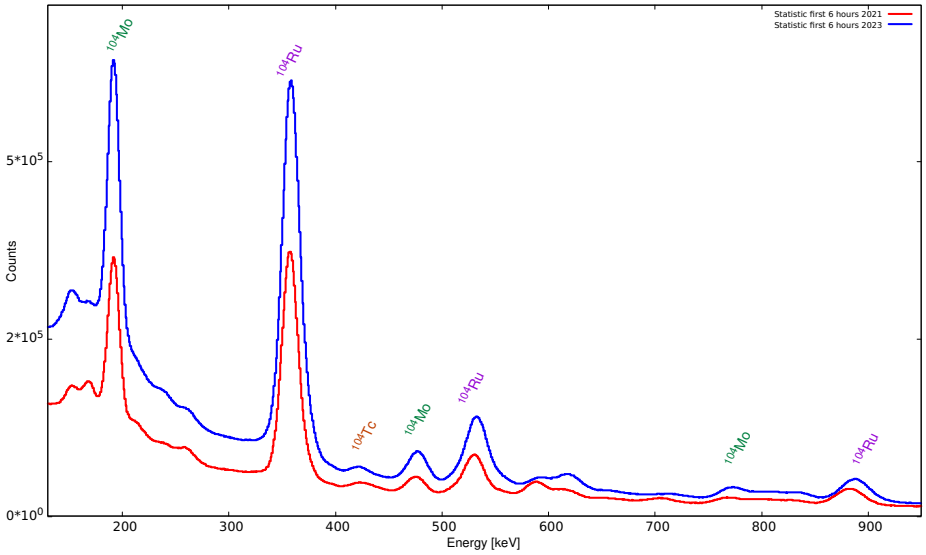


Figure 2: The $LaBr_3$(Ce) $\gamma-$ray single spectra recorded during the first 6 hours of the measurement. In red is the spectrum from experiment 3-01-700 (2021) and in blue is the spectrum from this experiment.

To verify our β-γ timing setup and to get an idea of our β-γ time resolution, we analysed the half-life of the 2_1^+ state in ^{104}Mo. In the previous experiment, we obtained a preliminary half-life of $T_{1/2} \approx 800$ ps using γ-γ timing. The β-γ time-difference spectrum of this experiment is shown in Fig. 3. A $LaBr_3$(Ce) gate was placed on the $2_1^+ \rightarrow 0_1^+$ transition in ^{104}Mo (192 keV) and a Ge cleaning gate on the 477 keV transition. The slope, coming from the lifetime of the 2_1^+ state in ^{104}Mo, is well visible and the resulting preliminary half-life of $T_{1/2} \approx 750$ ps using β-γ timing agrees with the result of the previous experiment.

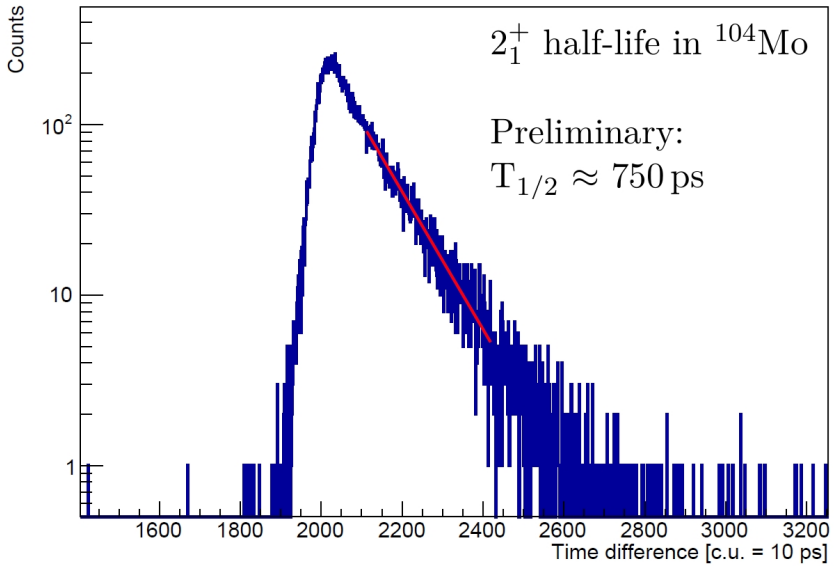


Figure 3: Preliminary lifetime analysis of the 2_1^+ state in ^{104}Mo using the β-γ delayed time difference spectrum. A $LaBr_3$(Ce) gate was placed on the $2_1^+ \rightarrow 0_1^+$ transition in ^{104}Mo (192 keV) and a Ge cleaning gate on the 477 keV transition.

The β-γ-γ statistics for the main goal of this experiment (lifetime determination of the first excited 0_2^+ state in ^{104}Mo) are on a reasonable scale. We have about 400 relatively clean events for the determination, which can be seen in Fig. 4. This gives us a statistical uncertainty of about 10 ps, taken into account a β-γ time resolution of 200 ps, which is acceptable in most of the expected lifetime range of between 6 ps and 90 ps.

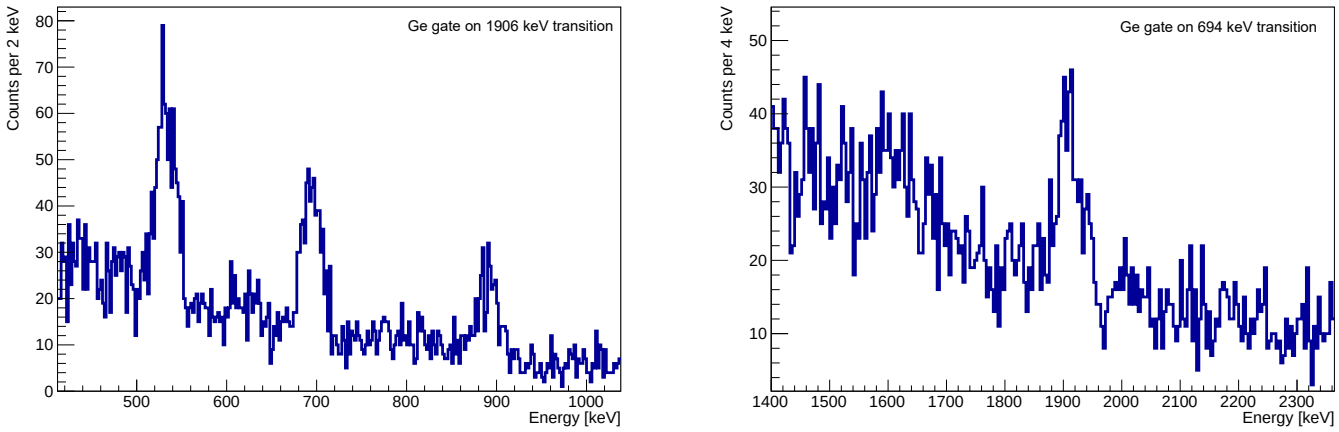


Figure 4: $LaBr_3$(Ce) γ-ray spectra with a Ge gate on the 1906 keV feeder transition (left) and 694 keV decay transition (right) of the first excited 0_2^+ state in ^{104}Mo.

References

[1] H. Mach et al. *Nuclear Physics A*, 523(2):197–227, 1991.

[2] J.-M. Régis et al. *NIM A*, 622:83, 2010.