Probing the structure of $^{95}$Mo


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1 Motivation

$^{94,95}$Mo nuclei have few neutrons outside the N=50 shell closure and are placed in a region where a transition from spherical to deformed shape is expected to occur. The low-spin states in $^{94}$Mo have been successfully described in the framework of the shell model as arising from the $\pi(p_{1/2}, g_{9/2})$ and $\nu(d_{5/2}, s_{1/2}, g_{7/2})$ single particle orbitals. The high-energy transitions, placed on top of the $J = 13\hbar$ state were interpreted as neutron excitations across the N=50 shell gap. The positive-parity states in $^{95}$Mo have been interpreted in the framework of the shell model as single-particle configurations coupled to the $^{94}$Mo core. In 1998, a negative parity band, consisting of stretched E2 transitions was observed on the top of the 1333-keV level [1]. It has been interpreted as arising from the $\nu h_{11/2}$ configuration. However, to make a more definitive assignment a need of lifetimes measurements has been emphasized [1]. Later, in [2], it has been suggested that the 11/2$^-$ level lies at 1938 keV and decays via a 386-keV transition to the 7/2+ state, which is non-yrast and decays via a branch of transitions to the yrast sequence. The appearance of 11/2$^-$ state at higher energies fits to the lower intensity of the band sequence, based on 11/2$^-$ state with respect to the yrast-sequence of states. And while the positive-parity part of the level scheme of $^{95}$Mo is successfully described in the framework of both shell model and vibarional model the negative-parity band remains not well studied. Therefore, with the present proposal we suggest to measure the half-life of the negative-parity band head in $^{95}$Mo. The lifetime of the level is directly related to the reduced transition probabilities and give the opportunity to test the nuclear wave function in a region deep bellow N=82, where $\nu h_{11/2}$ is expected to emerge.

2 Half-life estimation

The negative-parity band in $^{95}$Mo has a similar structure to the negative-parity band in $^{97}$Mo (Fig. 1). Both bands are observed to decay via stretched E2 transitions to the 11/2$^-$ state. The half-life of the 11/2$^-$ state in $^{97}$Mo has been measured to be 2.5 (3) ns [3]. It decays via 320-keV E1 transition to the 9/2$^+$ state and via 778-keV M2 transition to the 7/2+ state. Given that the branching ratio is $BR = I_{320}/(I_{320} + I_{778}) = 0.9$ we estimate the partial half-life $T_{1/2}$ on 2.3 ns. The Weisskopf estimates for a stretched E1 320-keV transition is $9.7 \times 10^{-15}$s., which leads to a hindrance factor of $F_w = T_{1/2}^{320\gamma}/T_{W.e.} = 2.3 \times 10^5$. 

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Figure 1: Partial level schemes of $^{95}$Mo [2] (left) and $^{97}$Mo [4] (right)

The half-life of the $11/2^-$ state in $^{95}$Mo can be estimated if the state has a similar to the $11/2^-$ state in $^{97}$Mo structure. Given that the $11/2^-$ level in $^{95}$Mo decays via a branch of transitions with 386-keV E1 transition being the strongest branch the half-life is estimated to be $T_{1/2}^{\text{exp}} = 1/BR \times F_W \times T_{1/2}^{W,e} = 1/0.544 \times 2 \times 10^5 \times 5.6 \times 10^{-15}$ s, i.e. $T_{1/2}^{\text{exp}} = 2 \times 10^{-9}$ s.

Upper limit of $T_{1/2}$ for $11/2^-$ state in $^{95}$Mo has also been estimated by NNDC [3] on 6.9 ns. Both values, the calculated in the present proposal and the NNDC value, are within the range of the fast-timing setup in Magurele. In addition to the $11/2^-$ state a number of excited single particle states with $J^\pi = 15/2^+$ to $19/2^+$, which decay by low-energy M1 transition, are estimated to have half-lives of order of few hundreds of picoseconds. The precise value of the half-life will give additional spectroscopic information and will allow a more definitive configuration assignment of the states below the Z=50 shell gap.

3 Experimental Set Up

Lifetimes in the sub-nanosecond range will be measured by using the specially designed system for in-beam fast-timing measurements at NIPNE. It comprises 8 HPGe detectors working in coincidence with 5 LaBr$_3$:Ce detectors [5]. The system is triggered by two LaBr$_3$:Ce fired in coincidence with one HpGe detector. The half-life of the level of interest will be measured by using the time interval between the feeding and de-exciting gamma-rays detected by two of the five LaBr$_3$:Ce detectors under the condition that the cascade is fed by a third transition detected by HpGe detector.

4 Preceding experience

In 2009 and 2010 a cycle of four experiments have been performed at the Tandem accelerator of NIPNE-Magurele, Romania. The aim of the experiments was to measure short-lived states in $^{103,105,107}$Cd [6]. The first experiment of the cycle was a test experiment and aimed on the first excited $7/2^+$ state in $^{107}$Cd, which has a half-life of 710 ps. In a following experiment, the half-life of the first $7/2^+$ states in the neighbouring $^{105}$Cd and $^{103}$Cd nuclei have been also
measured. Sample spectra, showing the measured half-times of the $7/2^+$ states are presented at Fig. 2. The $T_{1/2}$ for $^{105}$Cd taken from NNDC is 1.75 ns and it has been re-evaluated in our experiment, while the $T_{1/2}$ for the $7/2^+$ state in $^{103}$Cd has been measured for the first time.

The NNDC value for $T_{1/2}$ of $11/2^-$ in $^{107}$Cd is 71 ns. The half-life of the $11/2^-$ state in $^{105}$Cd has been measured for the first time at NIPNE and it has been found to be 142 ps. A sample spectrum is shown on Fig. 3. The half-life of $11/2^-$ in $^{103}$Cd has been found to be prompt in our last experiment.

**Figure 2:** Time spectra for the $7/2^+$ states in $^{103}$Cd and $^{105}$Cd [6]

5 Beam time estimation

5.1 $^{95}$Mo experiment

$^{95}$Mo will be studied via $^{18}$O+$^{82}$Se reaction which has a cross section of 400 mb at beam energies at 68 MeV, as calculated with the CASCADE code. Given that the energy loss of the 68 MeV $^{18}$O beam in $^{82}$Se target is approximately 3 MeV/(mg/cm$^2$) a target of 9 mg/cm$^2$ thickness will be used. In order to stop the beam in the target the target will be backed with 15 μm of Au.
Then for a current of 100 pnA and for population of 4% of the $11/2^-$ with respect to the first excited state, and given that the LaBr$_3$ detectors, with an intrinsic efficiency of 80% for low-energy $\gamma$-rays, are typically placed at 8 cm from the target, a total number of 800 de-exciting $\gamma$-rays per second in singles are expected, i.e. 4 counts in the $\gamma - \gamma$ matrix. Then the HpGe gated time spectrum will contain 124 counts per shift, i.e. 2604 counts in a week. Therefore, to obtain enough statistics to determine the half-life of the $11/2^-$ state in $^{95}$Mo one week of beam time is requested.

References

[5] N. Marginean et al., submitted