# Lifetime measurements of the negative-parity states in $^{103}$Pd

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**Abstract**

We propose to measure the half-lives of the negative-parity excited states in $^{103}$Pd produced in fusion/evaporation reaction. By using the delayed coincidence technique, the half-life ($T_{1/2}$ = 30 ps) of the $15/2^-$ state in $^{103}$Pd was estimated. Effective half-lives of the higher-lying states were evaluated by using the half-life of the $15/2^-$ state and the area ratios for the Doppler shifted and non-shifted peaks, observed in a $^{13}$C+$^{94}$Zr reaction. To test the limits of applicability of the fast-timing method we propose to re-measure $^{103}$Pd using the recoil distance method. In the focus of the experiment will be the negative-parity band, built on top of $11/2^-$ state and in particular the half-life of the $15/2^-$ state.

## 1 Motivation and Preceding experience

During our previous experiment, $^{103}$Pd was obtained as a bypass product in a $^{13}$C+$^{94}$Zr reaction. Using CASCADE calculations a maximum cross section of approximately 600 mb was obtained at a beam energy of 55 MeV. The target had a thickness of 1 mg/cm$^2$ deposited on 25 $\mu$m thick Pb backing. The gamma-rays, emitted in the reaction, were detected by the $\gamma$-ray array at Magurele, comprising 8 HPGe detectors working in coincidence with 11 $LaBr_3$:Ce detectors. The aim of the experiment was the measurements of short half-lives by using the in-beam delayed coincidence method. Half-lives of several excited states in $^{103}$Pd were measured by using the $LaBr_3$:Ce-$LaBr_3$:Ce delayed coincidences, and gated on HPGe detector as described in [2, 3]. Of particular interest is the half-life of the first excited state above the $11/2^-$ isomeric state (Fig. 1). The preliminary analysis of the $15/2^-$ time distribution shows a half-life of the order of $T_{1/2}$ =30 ps. Given the electronic binning is about 6 ps the half-life of $15/2^-$ state is almost on the edge of the timing range of the NIPNE Set Up. In fact this value is the shortest half-life measured there. Also, given that the the half-life is measured in-beam, the shortest half-lives which are of the order of few tens of picoseconds may be significantly perturbed by the background contribution. In addition, because of the higher in-beam counting rate, the prompt component of the time distribution may be different from the one which we traditionally correct with $^{60}$Co source. Therefore, to test the limits of applicability of the set up at NIPNE, we need an independent measurement using a different method.

A half-life of 30 ps is within the range of the Recoil Distance Method. Therefore, **we propose to re-measure $^{103}$Pd by using the NIPNE plunger**. In addition to the $15/2^-$ half-life, we will determine the half-lives of the excited negative parity states on top of the $11/2^-$ isomeric state. These data is directly related to the transitions matrix elements. Due to the Pauli blocking principle, the back bending in the negative-parity bands of the odd-Pd nuclei is delayed [4, 5], which gives us the possibility to study the transition strengths even at higher rotational frequencies than the ones in the even-even core.

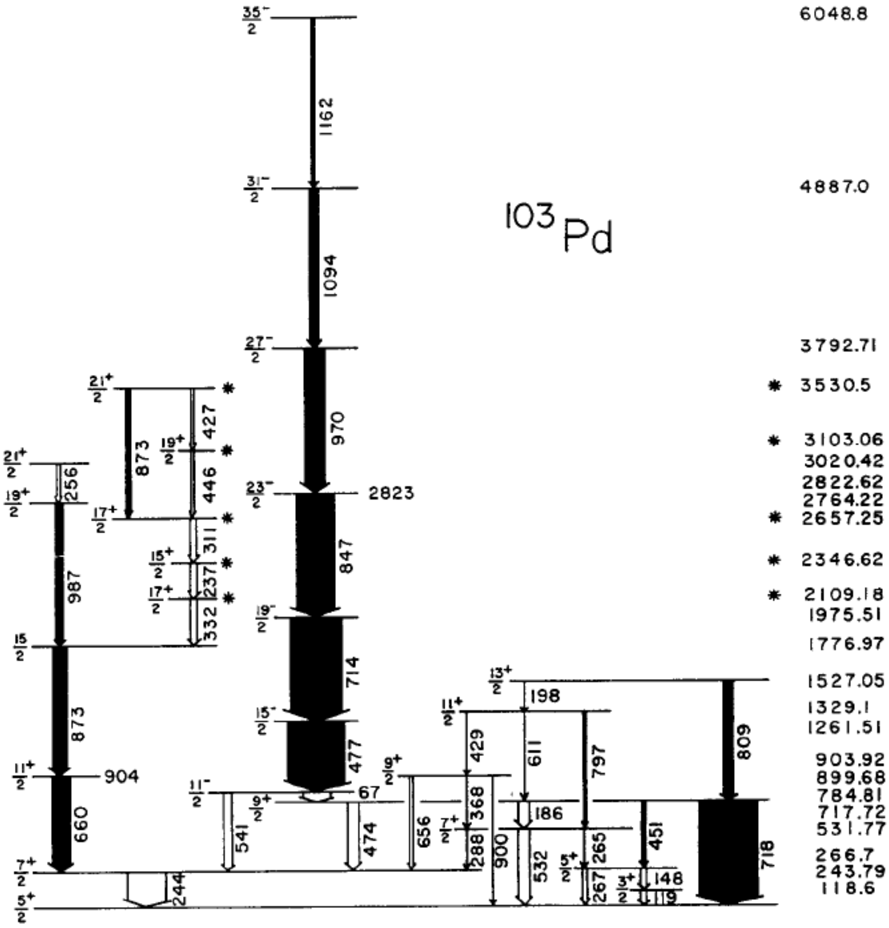



Figure 1: Partial level schemes of $^{103}$Pd from [1].

## 2 Half-life estimations

During our last experiment [6] performed in January 2012, when high beam current was introduced on target, the target and the backing were put up apart because of the low melting point of the Pb backing. As a result, the energy spectra observed with the HPGe detectors contained Doppler shifted peaks (Fig. 2). The speed of $^{103}$Pd ions was calculated to be 1.5% of the speed of light, using data obtained with one of the HPGe detectors placed at 35° with respect to the beam axis. Then the "effective" half-lives, listed in Table 1, were obtained from the ratio $\ln \frac{I_0}{I_0+I_f}$. Here, $I_0$ and $I_f$ are the intensities of the non-shifted and shifted components. The distance dependence was eliminated as we know the half-life of the $15/2^-$ state. In these calculations we suppose that the $^{94}$Zr target and the Pb stopper were parallel. Also, after the initial damage caused by the beam, no change in the distance between the target and the stopper was observed.

Table 1: Negative-parity levels in $^{103}$Pd. Half-lives are estimated from the first excited state and the ln $\frac{I_0}{I_o+I_f}$ ratios

| $J^\pi$ | $E_{level}$ (keV) | $T_{1/2}$ (ps) | $E_\gamma$ (keV) | $^{103}$Pd M.E.(E2) | $J_i - J_f$ | $^{104}$Pd M.E.(E2) |
|---|---|---|---|---|---|---|
| $11/2^-$ | 785 | 25 000 | 67, 541 | | | |
| $15/2^-$ | 1262 | 30 | 477 | 20.6 | $2^+ - 0+$ | 13.6 |
| $19/2^-$ | 1976 | 5.6 | 714 | 19.5 | $4^+ - 2^+$ | 21.3 |
| $23/2^-$ | 2823 | 3.9 | 847 | 16.7 | $6^+ - 4^+$ | |
| $27/2^-$ | 3792 | 3.1 | 970 | 14.4 | $8^+ - 6^+$ | |
| $31/2^-$ | 4887 | 2.2 | 1094 | 13.5 | $10^+ - 8^+$ | |
| $35/2^-$ | 6049 | 2.1 | 1162 | 12.4 | $12^+ - 10^+$ | |

The half-lives, obtained for the negative-parity yrast states in $^{103}$Pd, are of the order of few picoseconds, which is within the range for plunger measurements [7]. The matrix elements for the $E2$ transitions, calculated from the estimated half-lives for the negative-parity states in $^{103}$Pd, coincide with the $E2$ matrix elements, calculated for the ground state band in $^{104}$Pd (Table 1), which is consistent with the interpretation of the band as a decoupled rotational-aligned band.

Figure 2: Energy spectrum obtained with one HPGe placed on 35° with respect to the beam axis

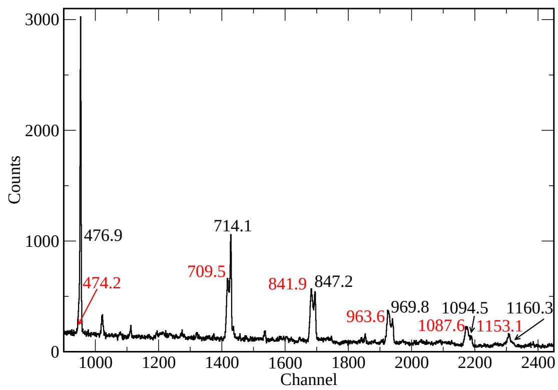
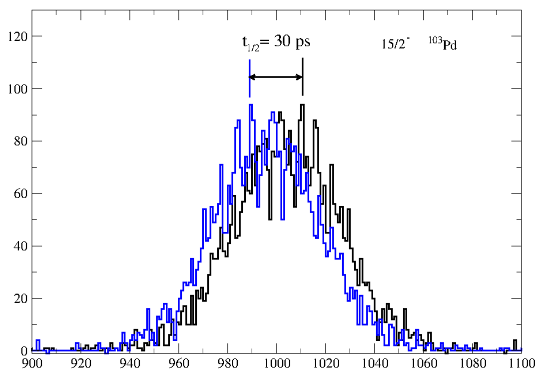



Figure 3: Half-life of the $15/2^-$ state, gated on 477-keV and 714-keV transitions with $LaBr_3$:Ce detectors and on the delayed transitions below the $11/2^-$ isomer with HPGe detectors




## 3 Experimental set up

To test the shortest half-lives we have measured so far by means of fast-timing technique developed at Magurele, we propose to re-measure them using the NIPNE Plunger device. To obtain enough statistics, 20 distances from 1 $\mu$m to 700 $\mu$m will be used. Emitted gamma-rays will be detected by the gamma-ray array, comprising 8 HPGe detectors, placed at 143° and 35° with respect to the beam axis working in coincidences with 11 $LaBr_3$:Ce detectors.

## 4 Beam time estimation

The $^{103}$Pd ions will be produced in $^{13}$C+$^{94}$Zr reaction, used in our previous experiment [6]. The target thickness will be 0.5 mg/cm$^2$. The stopper will be 15 $\mu$m of gold in order to stop the recoils. $^{13}$C$^{6+}$ at 55 MeV and $I_c = 2$ pnA will be used. The reaction cross-section ($\sigma \approx 600$ mb at 55 MeV) was estimated by using CASCADE code. At these conditions in our previous experiment, for two shifts we have obtained enough statistics in triple coincidences to evaluate the half-lives of the negative parity states for one fixed distance between the target and the stopper. Given that the half-lives evaluated cover a wide range of half-lives between few picoseconds up to few tens of picoseconds, **we request 12 days of beam-time which will be used for 20 plunger distances**.

## 5 Conclusion

We propose to re-measure the half-lives of the negative-parity band states in $^{103}$Pd by means of the Recoil Distance method. The re-measurement of the half-lives of the negative-parity band states and the $15/2^-$ half-life in particular will give an independent approach which will be used to test the shortest half-lives obtained so far at Magurele. The $E2$ matrix elements in the negative-parity band will be analyzed in the framework of the even-even core rotations. Because of the Pauli blocking principle, we expect to observe highly excited rotational modes in the odd-A nucleus. And at last, but not least, the experiment will allow us to test the time range to which a hybrid array of HPGe and $LaBr_3$:Ce detectors is sensitive. By using the excellent timing properties of the $LaBr_3$:Ce and the high energy resolution of the HPGe detectors it may appear that nuclear half-lives down to few picoseconds can be measured at a fixed plunger distance. This would significantly reduce the time needed for plunger measurements in the rotational bands, where the band head half-life can be measured with the $LaBr_3$:Ce detectors.

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