Intrinsic States and Rotational Bands in $^{175}$Ta

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Abstract

Rotational bands built on one and three-quasiparticle states in $^{175}$Ta have been populated through the $^{170}$Er($^{10}$B,5n) reaction. The four previously known one-quasiproton bands based on intrinsic states arising from $g_{7/2}$, $d_{5/2}$, $h_{9/2}$ and $h_{11/2}$ parents were extended to higher spin. Two new three-quasiparticle states with $K^* = \frac{17}{2}^+$ and $\frac{31}{2}^+$ and their rotational bands were established, as was the rotational band associated with the previously known $K^* = \frac{31}{2}^-$ three-quasiparticle state at 1555.9 keV. $B(M1)/B(E2)$ and $g_K - g_r$ values extracted from the in-band branching ratios, have been utilized, together with the decay properties and alignments, to assign configurations. A multi-quasiparticle calculation based on the Lipkin-Nogami method, including approximately the orbital dependent residual nucleon-nucleon interactions, has been used to predict the multi-quasiparticle energies for comparison with experiment.
Keywords: NUCLEAR REACTIONS $^{170}\text{Er}(^{10}\text{B},5n)^{175}\text{Ta}$; $E=64$ MeV; measured $\gamma(\gamma(t), \gamma(\theta)$, pulsed beams. $^{175}\text{Ta}$ deduced levels, $J, \pi, T_\lambda$, quasiparticle states, isomers, rotational bands, $B(M1)/B(E2)$ ratios, $g_K - g_R$, alignments. Pairing and residual nucleon-nucleon interactions, Lipkin-Nogami method.
1 Introduction

A number of multi-quasiparticle states, formed by combining individual nucleon orbits close to the Fermi surface have recently been observed in $^{176}$Ta and $^{177}$Ta [1]. The investigation of such states and their rotational bands is adding to a comprehensive map of nuclear properties in the region near $A \approx 180$ and could illuminate aspects of nuclear structure, such as the competition between intrinsic and collective excitations, configuration-dependent pairing reduction, details of the nucleon-nucleon residual interactions and K-violation.

In the context of a systematic study of the odd-Z Ta isotopes, the present paper focuses on the high-spin spectroscopy of the odd-proton nucleus $^{175}$Ta for which we have obtained new results for both the intrinsic states and the associated rotational bands.

Previously, $^{175}$Ta was investigated by Foin et al. [2] using the $^{170}$Lu(α,4n) reaction. They identified four one-quasiproton states, $^{7/2}$[404] ($g_{7/2}$), $^{5/2}$[402] ($d_{5/2}$), $^{1/2}$[541] ($h_{9/2}$), and $^{9/2}$[514] ($h_{11/2}$), and rotational bands built on them. A three-quasiparticle isomer, with a tentative $I=\frac{21}{2}^+$ spin assignment was also reported, but its associated rotational band was not observed. Recently Shuxian et al. [3] extended the one-quasiparticle structures to higher spin using the $^{160}$Gd($^{19}$F,4n) reaction.

2 Experimental Procedure and Data Reduction

States in $^{175}$Ta were populated using the $^{170}$Er($^{10}$B,5n) reaction with 64 MeV $^{10}$B pulsed and chopped beams (1 ns wide, 1712 ns apart) from the ANU 14 UD Pelletron accelerator. An isotopically enriched $^{170}$Er metallic target with a thickness of ~4 mg cm$^{-2}$ was used. Gamma-rays emitted from the reaction products were detected with the CAESAR array [4], which comprised six Compton-suppressed (CS) HPGe detectors and an unsuppressed planar Ge detector (LEPS). Three experiments were performed: (i) γ-γ-time (ii) γ-time (iii) γ-ray angular anisotropy and singles.

2.1 γ-γ-time

In this experiment, two-fold coincidence γ-ray events between pairs of detectors within a ±856 ns range were registered. The fast timing signals produced by detected γ-rays
were required to satisfy the coincidence requirement, before being used to stop one of the seven time-to-digital converters (TDC), each of them associated with a Ge detector. These TDCs were started by a common signal, having a direct time relationship to the beam pulse, thus enabling the time of each individual γ-ray relative to the beam to be registered. Four-parameter (the two γ-ray energies and the corresponding times relative to the beam pulse) events were written on magnetic disk in event-by-event mode. In subsequent off-line analysis, two dimensional matrices taking either all combinations of CS detectors, or with any of the six CS detectors against the LEPS detector were created (4096x4096 channels, with a dispersion of 0.5 keV per channel for the CS detectors and 0.2 keV per channel for the LEPS detector). Various time-difference conditions were imposed in construction of the matrices: (i) narrow "prompt", where the two events occur within ±20 ns of each other (ii) wide "prompt", where the time difference is fixed to ±170 ns, in order to include low energy (E_γ ≤ 80 keV) γ-rays, which experience considerable time walk (iii) out-of-beam "prompt", where the two events occur within ±20 ns of each other, but with the additional condition that the events occur between beam pulses (iv) "early-delayed", in two time regimes 20-170 ns ("short") and 170-800 ns ("long"), where the events preceding or following an isomer are projected. For all matrices, background subtracted coincidence γ-ray spectra were generated for each individual line.

To isolate the lifetimes of individual states, a three dimensional matrix was created, with the two γ-ray energies on the y and z axes respectively, and the time difference between them on the z-axis. Time-difference spectra obtained by projecting onto the time axis with gates on the γ-rays which populate and depopulate the level of interest were constructed with appropriate background subtraction.

2.2 γ-time

This experiment was used for direct measurement of lifetimes and identification of contaminants and activities. A second LEPS detector was incorporated into the previously described configuration to give better efficiency in the 15 to 150 keV energy region. Time signals from all detectors were mixed to provide the common start input of a time-to-amplitude converter, which was stopped by a signal which had a direct time relationship to the beam pulse. In order to optimise the time resolution, slow-rise-time rejection was
used in the constant fraction discriminators, thus enabling the measurement of half-lives down to $\sim 0.5$ ns in favourable cases to be performed. In the off-line analysis, two-dimensional matrices of $\gamma$-ray energies against time were constructed, after matching of the individual times and energies of the six CS or two LEPS detectors. Background subtracted time spectra were constructed for each transition, and the time spectra were analysed in detail as will be discussed in sec. 3.3.

2.3 $\gamma$-ray anisotropies

Angular anisotropies were measured using the 6 CS detectors in singles mode, with the extra condition that only events occurring inside a 50 ns time-window centered on the beam pulse were collected. This time condition reduces attenuation of the $\gamma$-anisotropies due to side feeding from isomeric states. Because of the limited angles in the array ($\pm 49^\circ$, $\pm 97^\circ$ and $\pm 145^\circ$), only the $A_0$ and $A_2$ coefficients were extracted, with the $A_4$ term fixed at zero.

In-beam singles measurements without time restrictions were made and singles activity spectra collected at the end of various bombardments.

3 Results

3.1 Level Scheme

The $^{175}$Ta level scheme, constructed on the basis of the observed $\gamma$-ray coincidence relationships, is shown in two parts in fig. 1. We confirm the previously assigned one-quasiparticle structures [2,3], albeit with some differences, as discussed below. Many new transitions were assigned and all of those were found to be connected to existing bands.

3.2 Gamma-Ray Intensities, Spin and Parity Assignments

The relative $\gamma$-ray intensities for transitions assigned to $^{175}$Ta are given in table 1. Some were obtained from the singles measurements, however, due to the complexity of the spectra, others were extracted from prompt coincidence projections after appropriate
normalisation. In such cases, angular correlations could affect the measured intensities (at a level of 15%), but no corrections have been applied. Where the extraction is exclusively from prompt coincidence spectra, this is indicated in table 1.

Spin and parity assignments to the observed structures have been performed on the basis of the following methodology: (a) Only E1, M1 and E2 multipolarities were considered for γ-ray transitions, except where significant half-lives were involved, in which case M2 transitions were also considered. (b) Gamma-ray intensity balances were used to extract total electron-conversion coefficients, to distinguish between E1, M1 and E2 character for transitions with energy below about 200 keV for which the conversion coefficients are significantly different. (c) The more strongly populated rotational sequences were generally assumed to be closer to yrast. (d) A comparison of the measured angular anisotropy coefficients $A_2$ (corrected for partial alignment) with theoretical values [5] were used as supporting evidence. In such analyses, a Gaussian substate population distribution with a width $\sigma/I=0.40(8)$ (deduced from anisotropies of stretched prompt E2 transitions) has been used for the initial state.

The transition energies, angular anisotropy coefficients and placement of transitions assigned to $^{175}\text{Ta}$ are listed also in table 1.

### 3.3 Half-lives

The lifetimes of the intrinsic states assigned to the $^{175}\text{Ta}$ were obtained by use of the time spectra from both the γ-γ-time and γ-time experiments. For half-lives shorter than ~800 ns, the time difference spectra produced with gates on the transitions above and below the level of interest were preferred, because they remove the influence of sidefeeding and the contribution from multiple lifetimes and contaminants. In other cases the time spectra from the γ-time measurement were used. In both methods, the lifetimes were obtained directly by fitting the time spectra taking into account the prompt response function and incorporating combinations of exponential decays depending on the sequence of states involved.

Short half-lives (less than ~5 ns) were measured by fitting the time spectra with a Gaussian function of variable position, with the width fixed according to the parameterisation obtained from the analysis of the time spectra for transitions from in-band states.
which are known to have a very short half-life. The position of the Gaussian could then be compared with that obtained for short-lived states.

3.4 Band Assignments

3.4.1 $\frac{7}{2}^+ [404] (g_{7/2})$ band

Beta-decay data [6, 7] and the systematics of the experimental one-quasiproton band head energies in a number of Ta isotopes [8 -13], as well as theoretical calculations [14] suggest that the $\frac{7}{2}^+[404]$ configuration forms the ground state in $^{175}$Ta. The corresponding rotational band was known previously [2, 3] up to $I^* = \frac{41}{2}^+$ and in the present work it has been extended up to $I^* = (\frac{45}{2}^+)$. A narrow prompt coincidence spectrum with gates on the 129.6, 196.9 and 443.0 keV transitions in the band is shown in fig. 2a. Positive anisotropies for a number of $\Delta I = 1$ cascade and $\Delta I = 2$ crossover transitions (see table 1) consistent with mixed E2/M1 and stretched E2 character respectively, have been measured. New cascade transitions at 240.5, 250.1 and 258.8 keV were found to connect both signatures of the band below $I^* = \frac{25}{2}^+$.

3.4.2 $\frac{5}{2}^+ [402] (d_{5/2})$ band

This band was known previously [2, 3] up to $I^* = \frac{27}{2}^+$ and in the present work it has been extended to $I^* = (\frac{45}{2}^+)$. Its structure can be seen in fig. 2b, which shows a spectrum constructed from a narrow prompt coincidence gate on the 105.9 keV $\gamma$-ray, the first cascade transition in the band. Both signatures of this band are connected by $\Delta I = 1$ transitions up to $I^* = \frac{29}{2}^+$, whose measured anisotropies are consistent with a mixed E2/M1 character. The obtained anisotropies for crossover $\Delta I = 2$ transitions are consistent with stretched E2 character. Because it was neither possible to extract anisotropies for the transitions above $I^* = \frac{31}{2}^+$, nor were cascade transitions connecting both signatures above this level observed, the spin and parity assignments to the states are less certain, as indicated by parentheses in fig. 1a.

The excitation energy of the $\frac{5}{2}^+$ band head was given by Foin et al. [2] at 36.4 keV above the $\frac{7}{2}^+[404]$ ground state, the two being connected by a 36.4 keV M1 transition.\footnote{Unfortunately, the primary evidence for that transition is not available in the published literature.}
In the present study, a weak 36.4 keV γ-ray has been seen in a wide prompt coincidence with the strongest transitions of $\frac{3}{2}^+[402]$ band and the intensity balance at the 36.4 keV level gives a value of 14(6) for its total conversion coefficient. This compares to the theoretical values for E1($\alpha_T=1.1$), M1($\alpha_T=14.9$) and E2($\alpha_T=37.5$) transitions [15] and favours the M1 character, in agreement with ref. [2]. Unfortunately, the weakness of the decay branch, did not allow precise time information for the $I^*=\frac{5}{2}^+$ band head to be obtained. However, the prompt (±170 ns) coincidence relationships between the $\frac{3}{2}^+[402]$ in-band transitions and the 36.4 keV depopulating transition suggest that the half-life cannot be very long, possibly ≤100 ns.

3.4.3 $\frac{9}{2}^-[514] (h_{11/2})$ band

This band was known previously [2,3] up to $I^*=\frac{27}{2}^-$ and is now extended to $I^*=\frac{35}{2}^-$. The time correlated coincidence γ-ray spectrum, constructed from a delayed gate on the 131.4 keV transition, depopulating the band head, projecting γ-rays which precede this level (in a 20–170 ns time window) is presented in fig. 3a. It shows a characteristic pattern of $\Delta I=1$ cascade and less intense $\Delta I=2$ crossover transitions similar to that observed in the heavier tantalum isotopes [8,9]. The measured anisotropies for the strongest $\Delta I=1$ cascade and $\Delta I=2$ crossover transitions are consistent with mixed E2/M1 and stretched E2 character respectively.

In a previous study, Foin et al. [2] found that the $I^*=\frac{9}{2}^-$ state was an isomer, with a half-life $T_{1/2}≥100$ ns, decaying-by an 131.4 keV E1 γ-ray to the $\frac{7}{2}^+[404]$ ground state. Later, André et al. [16] gave a value of $T_{1/2}=135(25)$ ns. While the present study confirms the isomeric nature of the $I^*=\frac{9}{2}^-$ band head, a considerably longer half-life of $T_{1/2}=222(8)$ ns has been obtained. A sum of the time spectra from the γ-γ-time measurement, constructed from gates on the 144.6, 170.0 and 193.6 keV γ-rays which precede the isomer (start) and the depopulating 131.4 γ-ray (stop) is shown in fig. 4.

A time correlated γ-ray spectrum with gates on 144.6, 170.0, 193.6, 216.6 and 236.4 keV $\Delta I=1$ transitions in the $\frac{9}{2}^-[514]$ band, projecting all γ-rays in the LEPS detector, which follow the isomer in a 170–800 ns time window, is shown in fig. 5. Observation of the 71.9 keV $\frac{9}{2}^-→\frac{5}{2}^-$ transition in the $\frac{1}{2}^-[541]$ band suggests a connection between the $\frac{9}{2}^-[514]$ band head and the $\frac{9}{2}^-$ state in the $\frac{1}{2}^-[541]$ band. The depopulating transition was not identified, presumably because of its low energy ($E_\gamma≤30$ keV) and the large total
conversion coefficient such an M1 transition would have.

With the total (conversion-corrected) branching intensity of 83.6 % for the 131.4 keV transition and 16.4 % for the 71.9 keV transition, deduced from the spectrum shown in fig. 5, a B(E1) value of $6.2(7) \times 10^{-9}$ e²b was obtained for the 131.4 keV $\frac{3}{2}^{-} [514] \rightarrow \frac{7}{2}^{+} [404]$ transition, in agreement with systematics in the region [10].

An out-of-beam prompt spectrum with a gate on the 217.0 keV $\gamma$-ray is shown in fig. 3b. It shows that the transitions below the $I^* = \frac{21}{2}^-$ level are delayed, because of feeding from the isomeric state at 1565.9 keV (see also sec. 3.4.7).

3.4.4 $\frac{1}{2}^{-}[541]$ ($h_{9/2}$) band

The decoupled $\frac{1}{2}^{-}[541]$ band is easily identified through a sequence of quadrupole transitions. A summed spectrum with wide prompt gates on the 172.3 and 461.9 keV $\gamma$-rays is shown in fig. 6a. This is the most strongly populated band in $^{175}$Ta and it is yrast up to high spin. It has a high moment-of-inertia, characteristic of a Coriolis mixed band based on the $h_{9/2}$ proton configuration, when the Fermi level is close to the $\Omega = \frac{1}{2}$ orbital. The strong Coriolis interaction and large positive decoupling parameter lower the energies of the $I^* = \frac{3}{2}^-$ and $\frac{5}{2}^-$ levels with respect to the $I^* = \frac{1}{2}^-$ ($\alpha = +\frac{1}{2}$ signature) and $\frac{3}{2}^-$, $\frac{5}{2}^-$ ($\alpha = -\frac{1}{2}$ signature) making the $I^* = \frac{5}{2}^-$ state the band head.

In the recent work of Shuxian et al. [3] four E2 transitions, with energies 732.5, 751.1, 822.0 and 911.0 keV were placed above the $I^* = \frac{45}{2}^-$ level, which implied a sharp backbend in the moment-of-inertia. In fig. 6b a narrow prompt coincidence $\gamma$-ray spectrum constructed from gates on the 682.2 and 742.3 keV transitions is shown. As can be seen, the 792.7 keV $\frac{45}{2}^- \rightarrow \frac{41}{2}^-$ transition is clear but none of the proposed transitions stand out. Furthermore, from the spectrum shown, an 824.0 keV $\gamma$-ray is a candidate for the $\frac{49}{2}^- \rightarrow \frac{45}{2}^-$ in-band transition. Unfortunately the absence of experimental information in ref. [3] does not allow a detailed comparison between the two data sets to be made. However, it should be noted that a 911.5 keV transition is placed in the present work as feeding the $I^* = \frac{23}{2}^-$ member of the $\frac{1}{2}^-[541]$ band from a level at 2315.4 keV, and 732.5 and 822.0 keV $\gamma$-rays coincide closely with other observed inter-band transitions.

The excitation energy of the $I^* = \frac{5}{2}^-$ band head was given as 51.5 keV by Foin et al. [2], depopulating by means of 51.5 keV E1 and 15.1 keV M1 transitions to the $\frac{7}{2}^+[404]$ and $\frac{5}{2}^+[402]$ band heads, respectively. In the present study, we have not been able to see these
transitions either in prompt or delayed coincidence with the strongest $\frac{1}{2}^{-}[541]$ in-band transitions. A wide prompt spectrum projecting $\gamma$-rays in the LEPS detector with a gate on the 172.3 keV $\frac{13}{2}^{-}\rightarrow\frac{9}{2}^{-}$ transition in all six CS detectors is shown in fig. 7. If the $I^*=\frac{5}{2}^{-}$ state were depopulated solely by means of a 51.5 keV E1 transition its expected yield would be approximately 9 times that of the 71.9 keV $\frac{9}{2}^{-}\rightarrow\frac{5}{2}^{-}$ cascade transition, due to the significant difference in the total conversion coefficients for E1($\alpha_T=0.424$) and E2($\alpha_T=14.0$) $\gamma$-rays. However, this possibility is not supported by the spectrum shown. The deduced intensity limit for the transitions from the spectrum shown in fig. 7, suggests, that if 51.5 keV transition does exist, it must take less than 2 % from the total intensity that passes through the 51.5 keV level. Then, with a 98 % decay branch for the 15.1 keV $\gamma$-ray, the subsequent 36.4 keV transition would have one third of the observed yield of the 71.9 keV transition, which obviously it does not from the spectrum shown.

The possibility remains that the $I^*=\frac{5}{2}^{-}$ state could be long-lived, given the 2-fold forbidden nature of the 51.5 keV transition. The systematics [10] would suggest a Weisskopf hindrance factor of $1.9\times10^8$, implying a partial half-life of $\sim300$ $\mu$s, a possibility which could explain the unobserved decay transitions and the intensity balance anomaly. Unfortunately, we do not have sufficient information from the experiment of Foin et al. [2] to reconcile that possibility with their observation and we label the $\frac{5}{2}^{-}$ level with an energy of 51.5$+X$.

3.4.5 Sequence I

A decoupled sequence, shown on the left of fig. 1a, was found to feed the $I^*=\frac{17}{2}^{-}$, $\frac{21}{2}^{-}$, $\frac{25}{2}^{-}$ and $\frac{29}{2}^{-}$ members of the $\frac{1}{2}^{-}[541]$ band by means of 925.8, 881.9, 807.7 and 685.4 keV transitions respectively. The extracted large and positive anisotropy for the 881.9 keV transition is consistent with a dipole $\Delta J=0$ or alternatively quadrupole $\Delta J=2$ transition. However, the $J\rightarrow J-2$ transition is unlikely, since band I would be yrast at intermediate spin, inconsistent with its weak population and consequently, the spin of the 1824.5 keV level is restricted to ($\frac{21}{2}$). Because it was not possible to extract anisotropies for the other inter-band transitions, the spin assignments of states in the band are indicated by parentheses in fig. 1a.
3.4.6 Sequence II

Another decoupled sequence feeds the $I^*={11\over 2}^-$, $21\over 2^-$ and $31\over 2^-$ members of the $1\over 2^-[541]$ band by means of 997.3, 911.5 and 819.3 keV transitions. The states of this band are weakly populated and also only connected by weak cascade transitions within the band, because of the preference for out-of-band decays to the $1\over 2^-[541]$ band. The anisotropy was extracted only for the 911.5 keV $\gamma$-ray. Although it is contaminated in the singles data by the 912.1 keV $\gamma$-ray, depopulating a state at 1551.7 keV (see fig. 1b and sec. 3.4.9), the measured $A_3$ coefficient and comparable intensities suggest that both transitions have a $J\rightarrow J-1$ character. Therefore, the probable spin of the 2315.4 keV level is $I=(31^+_2)$. Again, the E2 character for the in-band transitions follows from the population arguments and the ordering within the band is based on their relative intensities.

3.4.7 Three-quasiparticle state at 1565.9 keV

In the previous work of Foin et al. [2], the state at 1565.9 keV was found to be isomeric with a half-life of $T_{1/2}=200(70)$ ns. It was assigned tentatively as having a spin of $I=(21^+)$, decaying to the $I^*={13\over 2}^-$ member of $31^-[514]$ band by means of a 473 keV transition.

The present work has confirmed the isomeric nature of this state and identified a rotational band build on it and two other decay branches; the 216.5 and 709.6 keV transitions to the $I^*={21\over 2}^-$ and $13^+_2$ members of the $31^-[514]$ band respectively. The presence of the new depopulating transitions is evident from the spectrum constructed from the out-of-beam prompt gate on the 217.0 keV $\gamma$-ray shown in fig. 3b, where the 709.6 keV and a second 217 keV $\gamma$-ray are seen in prompt coincidence.

A half-life of 1950(150) ns for the 1565.9 keV band head has been obtained from analysis of the $\gamma$-time data, about ten times higher than the value given by Foin et al. [2]. A summed time spectrum with gates on the 144.6, 170.0, 193.6, 217.0, 236.4 and 709.6 keV $\gamma$-rays is shown on fig. 8. (A prompt component is present because the in-band transitions are also fed directly.)

The $\gamma$-ray spectrum with gates on several transitions below the isomer, showing all $\gamma$-rays that precede it, is presented in fig. 9a. It shows a rotational band with 311.2, 325.2, 334.5 and 342.5 keV $\Delta I=1$ cascade transitions and less intense 635.9, 659.5 and 677.1 keV $\Delta I=2$ crossover transitions, built on the isomer. The other transitions are
from another three-quasiparticle band which will be discussed below.

Given the new decay branches, the spin of the 1565.9 keV state is restricted to $I^\pi=\frac{19}{2}$ or $\frac{21}{2}$. The $I^\pi=\frac{17}{2}$ possibility was rejected because the spin is inconsistent with the population relative to the other bands. An $I^\pi=\frac{19}{2}^{+}$ assignment is unlikely because of the branching ratios of the depopulating transitions. For example, if the 473.3 and 709.6 keV transitions were dipoles their branching ratio is expected to be $(473.3/709.6)^3=0.3$, while the experimental value is 2.3(6). The out-of-beam intensity balance at the 1349.5 keV level gives a value of $\alpha_T=0.3(2)$ for the total conversion coefficient of the 216.5 keV inter-band transition, which compared to the theoretical values for $E1 (\alpha_T=0.05)$ or $M1 (\alpha_T=0.51)$ favours $M1$ character. Therefore, an $I^\pi=\frac{21}{2}^{+}$ assignment for the 1565.9 keV state is favoured over $I^\pi=\frac{19}{2}^{+}$.

3.4.8 Three-quasiparticle state at 1729.3 keV

Another three-quasiparticle state and associated rotational band, feeding through a 163.4 keV transition to the $\frac{21}{2}^-$ three-quasiparticle state, are identified for the first time, extending up to $I^\pi=(\frac{45}{2}^+)$, as shown in fig. 1b. The transitions in this band are seen in the spectra shown in fig. 9a and 9b. The limit deduced for the total conversion coefficient of the 163.4 keV $\gamma$-ray of $\alpha_T\leq0.16$, when compared to the theoretical values for $E1 (\alpha_T=0.103)$, $M1 (\alpha_T=1.12)$, $E2 (\alpha_T=0.602)$ and $M2 (\alpha_T=6.75)$ multipolarities [15] establishes $E1$ character and hence $I^\pi=\frac{21}{2}^{+}$ or $\frac{23}{2}^{+}$ for the 1729.3 keV state. However, the measured positive anisotropy of $A_2=0.4(2)$ of the 163.4 keV $\gamma$-ray is consistent only with a dipole $J\rightarrow J$, and not with a dipole $J+1\rightarrow J$ transition, for which one would expect [5] $A_2\approx-0.3$, thus favouring $I^\pi=\frac{21}{2}^{+}$.

That the 163.4 keV $\gamma$-ray is contaminated in singles with an 163.5 keV $E2 \gamma$-ray, depopulating an $I^\pi=7^{+}$ member of the $K^*=1^{+}$ band in $^{174}$Ta [17] was taken into account as follows: Anisotropies of $A_2=0.37(18)$ and 0.29(27) for the 339.3 keV $11^{+}\rightarrow 9^{+}$ and 423.0 keV $13^{+}\rightarrow 11^{+}$ in-band $E2$ transitions were obtained in the current work and therefore a similar anisotropy ($A_2\sim0.30$) is expected for the 163.5 keV $7^{+}\rightarrow 5^{+}$ transition in $^{174}$Ta. The deduced total (conversion-corrected) intensities from the spectrum constructed from a narrow prompt gate on the 163.5 keV $\gamma$-ray and shown in fig. 9b, suggest that 63% of the total intensity of this peak arises from the $K^*=\frac{21}{2}^{+}$ band in $^{175}$Ta and 37% arises from the $K^*=1^{+}$ band in $^{174}$Ta. To reproduce the measured anisotropy of the combined 163
keV γ-ray of 0.37(13), a positive value of $A_2 \sim 0.4(2)$ is required for the $^{172}$Ta transition.

The lower population relative to the $K^* = \frac{31}{2}^-$ band also supports the $I^* = \frac{31}{2}^+$ assignment for the 1729.3 keV state.

The half-life of 0.9(3) ns for the 1729.3 keV band head was obtained using the analysis of the time difference spectra constructed with gates on the 191.0 keV (as start) and either the 165.7 and 163.4 keV γ-rays (as stop). The $\{191.0,165.7\}$ combination gives the time spectrum for the intermediate in-band level and the $\{191.0,163.4\}$ combination gives the spectrum for the desired band head. The positions of the Gaussian fitted to both spectra are shown in fig. 10. Because of the close energies of the 163.4 and 165.7 keV γ-rays, the systematic error due to the time walk is minimal in such a procedure.

The $B(E1)$ value of $1.0(4) \times 10^{-6} \text{ e}^2\text{b}$ for the 163.4 keV transition obtained from the half-life of 0.9(3) ns and $\alpha_T = 0.103$, is in agreement with the systematics for $\Delta K=0$ E1 transitions [18]. The preferred decay path via the $\Delta I=0$ 163.4 keV transition rather than via, say, a 637.0 keV E1 transition to the $I^* = \frac{13}{2}^-$ member of the $\frac{9}{2}^-[514]$ band is attributable to the relatively fast $\Delta K=0$ nature of the low energy transition, compared to the K–forbidden nature of the high energy transition. The latter is 5-fold K–forbidden ($\nu = \Delta K - \lambda = 5$) which would imply a Weisskopf hindrance factor of $\sim 10^{11}$ [18]. Its expected branching ratio would then be $\leq 1.1 \times 10^{-3}$ % of the $\Delta K=0$ transition, well below the present detection limit.

3.4.9 Three-quasiparticle state at 1551.7 keV

The $K^* = \frac{15}{2}^+$ state and associated band are identified for the first time in the present work. The spin assignment is based on the multiple branches to the $\frac{9}{2}^-[514]$, $\frac{7}{2}^+[404]$ and $\frac{5}{2}^+[402]$ band members, and also from consideration of the relatively weak direct population of the band. The observation of the 1090.6 and 932.4 keV transitions to the $I^* = \frac{13}{2}^+$ levels of the $\frac{7}{2}^+[404]$ and $\frac{5}{2}^+[402]$ bands respectively and the absence of the transition to the $I^* = \frac{13}{2}^-$ member of the $K^* = \frac{9}{2}^-[514]$ band, suggest positive parity for the 1551.7 state. In addition, the measured branching ratios for the depopulating transitions, as well as the measured $A_2$ coefficient of the 912.1 keV transition, connecting the $I^* = \frac{13}{2}^+$ band head with the $I^* = \frac{15}{2}^-$ state of the $\frac{9}{2}^-[514]$ band also support the proposed spin and parity assignment.

The half-life of 5.5(8) ns for the 1551.7 keV band head has been obtained from the
time spectrum from the $\gamma$-time experiment constructed with a gate on the 912.1 keV transition and shown in fig. 11. It shows a prompt component because of contamination from the 911.5 keV transition, depopulating the 2315.4 keV level (see fig. 1a). The underlying long-lived component in the spectrum is from the 911.3 keV activity line. Independently, a value of 4.4(11) ns was obtained from an analysis of two time difference spectra (see fig. 10). The first was constructed with gates on the 175.5 keV $\gamma$-ray, above the $K^* = 1^+$ band head and the $\frac{9}{2}^-[514]$ in-band 144.6 keV $\gamma$-ray, the second with gates on the $\frac{9}{2}^-[514]$ in-band 170.0 keV and 144.6 keV cascade transitions. An average value of 5.1(6) ns for the 1551.7 keV band head half-life was adopted.

3.4.10 Five-quasiparticle states

The states at 3215.7, 3526.1 and 3761.8 keV, shown feeding into the top of the $K^* = \frac{31}{2}^-$ band, have $I^*=(\frac{31}{2}^-), (\frac{33}{2}^-)$ and $(\frac{35}{2}^-, \frac{37}{2}^-)$ assignments respectively. Considering the available Nilsson orbitals close to the Fermi surface they are probably five-quasiparticle states, although there remains some ambiguity as to which are intrinsic states, and which are band members.

The 3526.1 keV state decays via a 646.8 keV transition to $I^* = \frac{39}{2}^-$ member of $K^* = \frac{31}{2}^-$ band. In fig. 12 the centroid time positions for selected $\gamma$-rays in all CS detectors against their energies, from the $\gamma$-time experiment, are shown. The lack of a significant shift in the time centroid of the 646.8 keV $\gamma$-ray leads to a $<0.5$ ns limit on the level half-life, which excludes $M2$ multipolarity for the depopulating transition. The relative population of this state is sufficiently high that the 646.8 keV transition must be $\Delta J=2$ rather than $\Delta J=1$, leading to spin and parity of $I^*=(\frac{33}{2}^-)$.

A 336.4 keV $\gamma$-ray shows prompt coincidences with the 311.2, 325.2, 334.5 and 342.5 keV $K^* = \frac{31}{2}^-$ in-band $\Delta I=1$ transitions, but not with a 646.8 keV $\gamma$-ray and therefore it was assigned to depopulate a state at 3215.7 keV. There is evidence for feeding from the 3526.1 keV state by means of a 310.4 keV transition, as the prompt gates on 235.7, 279.1 and 288.0 keV transitions, above the 3526.1 keV level, show a 336.4 keV $\gamma$-ray in prompt coincidence. However, the overlap with the stronger 311.2 keV $\gamma$-ray (the first $\Delta I=1$ cascade transition in the $K^* = \frac{31}{2}^-$ band), as well as the weakness of the decay branch did not allow direct confirmation of the 310.4 keV transition. The anisotropy information is uncertain for the 336.4 keV $\gamma$-ray, but the observation of the 678.8 keV transition to the
\( I^*_{\frac{7}{2}^-} \) member of the \( K^*_{\frac{21}{2}^-} \) band, as well as their branching ratio suggest that the probable spin would be \( I^*=(\frac{31}{2}^-) \).

The state at 3761.8 keV has a spin of \( I=(\frac{35}{2}, \frac{37}{2}) \), depopulating by the 235.7 keV transition to the 3526.1 keV state. The assignment is tentative, because the intensity balance at the 3761.8 keV level does not give a definitive value for the total conversion coefficient of the depopulating transition, and because anisotropy information is absent. A limit of \( \leq 2 \) ns (see fig. 10) for the level half-life has been obtained, comparing time difference spectra constructed with gates on the 279.1 keV (above the 3761.8 keV level) and the 235.7 keV \( \gamma \)-rays (see fig. 1b) on the one hand, and the 271.1 keV and 236.6 keV 2\( ^{1/2} \)-[514] in-band \( \gamma \)-rays on the other.

The 279.1, 288.0 and 305.8 keV \( \gamma \)-rays are placed above the 3761.8 keV level and the ordering is based on their relative intensities.

### 3.4.11 Other states

A number of weak transitions feed the \( \frac{1}{2}^-[541] \) band as indicated in fig. 1a. Their ordering is based on the coincidence relationships and the relative \( \gamma \)-ray intensities. The 730.6 keV \( \gamma \)-ray has a large and negative \( A_2 \) coefficient, consistent with a mixed E2/M1 character, leading to a spin of \( I=\frac{13}{2}^- \) or \( \frac{15}{2}^- \) for the 1300.8 keV level. The \( I=\frac{15}{2}^- \) assignment is preferred because of the low population of this state. The 1548.1 keV level decays via a 977.9 keV transition to the \( I^*=\frac{17}{2}^- \) member of the \( \frac{1}{2}^-[541] \) band. Its measured anisotropy is consistent with a mixed E2/M1 transition and considering the relative population, an \( I^*=\frac{15}{2}^- \) assignment for this level is suggested.

No anisotropy information was obtained for the 1119.4 keV transition, but its relative intensity suggests that the 1689.6 keV level has a probable spin of \( \frac{15}{2}^- \).

A weakly populated state at 1279.3 keV was found to decay to the \( I^*=\frac{13}{2}^- \) member of \( \frac{9}{2}^-[514] \) band via an 833.4 keV transition. The absence of apparent centroid shift for this transition leads to \( \leq 1 \) ns limit for the half-life of the level. Because of the low population of this state a tentative \( I=(\frac{15}{2}) \) assignment is suggested.
4 Discussion

4.1 Band properties

4.1.1 In-band decay properties

The determination of the crossover-to-cascade branching ratios and the analysis of the anisotropy data allows the deduction of the $B(M1)/B(E2)$ ratios and the $\epsilon_K - \epsilon_R$ values for strongly coupled bands through the rotational formulae:

$$\frac{B(M1)}{B(E2)} = 0.697 \frac{E_\gamma^5(I \rightarrow I - 2)}{E_\gamma^3(I \rightarrow I - 1)} \frac{1}{\lambda(1 + \delta^2)} \frac{\mu_N^2}{\epsilon^2 b^2} \tag{1}$$

$$g_K - g_R = 0.93Q_0 \frac{E_\gamma(I \rightarrow I - 1)}{(\sqrt{I^2 - 1}) \delta} \tag{2}$$

where, the $\gamma$-ray energies $E_\gamma$ are in MeV, the intrinsic quadrupole moment is taken as $Q_0 = 7.8(7) \text{ eb}$ [19] and $\lambda$ is the ratio of $\gamma$-ray intensities defined by:

$$\lambda = \frac{I_\gamma(I \rightarrow I - 2)}{I_\gamma(I \rightarrow I - 1)} \tag{3}$$

Since the mixing ratio $\delta$ obtained from the anisotropy data generally has a large error, it was preferable to extract its magnitude from the crossover-to-cascade branching ratio using the rotational model, assuming pure $K$:

$$\frac{1}{\delta^2} = \frac{1}{\lambda} \left( \frac{E_\gamma(I \rightarrow I - 2)}{E_\gamma(I \rightarrow I - 1)} \right)^5 < IK20|I - 2K|^2 - 1 \tag{4}$$

The sign of $\delta$ obeys the relation $\text{sign}(\delta) = \text{sign}((g_K - g_R)/Q_0)$, and can be deduced from the comparison between the measured anisotropies (corrected for partial alignment) and the theoretical values [5].

The values obtained for $\lambda$, $\delta$, $B(M1)/B(E2)$ and $g_K - g_R$ are given in table 2. A positive sign of $\delta$ was determined for all bands and the magnitudes from the branching ratios and rotational model are in agreement with the measured values from anisotropy data.

The $g_K - g_R$ values for one- and three-quasiparticle bands are discussed in sec. 4.2.1 and 4.3.1.
4.1.2 Aligned angular momenta

The aligned angular momentum \(i(\omega)\) is defined as the difference between the projection of total angular momentum on the axis perpendicular to the nuclear symmetry axis and that from collective rotation:

\[
i(\omega) = I_z(\omega) - I_z^{rot}(\omega)
\]

where,

\[
I_z(\omega) \approx \sqrt{(I(\omega) + 1/2)^2 - K^2} \quad \text{and} \quad I_z^{rot}(\omega) = \Theta^{rot}\omega
\]

The moment-of-inertia parameters \(\Theta_0 = 32 \text{ MeV}^{-1}\hbar^2\) and \(\Theta_1 = 85 \text{ MeV}^{-3}\hbar^4\) for the core moment-of-inertia \(\Theta^{rot} = \Theta_0 + \Theta_1\omega^2\) have been used, chosen to give a reasonably flat alignment for the \(\frac{3}{2}^-[541]\) band.

Experimental alignments for the observed bands in \(^{175}\text{Ta}\) are shown in fig. 13. They are discussed in sec. 4.2.2 and 4.3.2.

4.2 One-Quasiparticle States

4.2.1 \(g_K - g_R\) values

The collective value \(g_R = 0.34(3)\) was obtained from the measured magnetic moment of the \(\frac{3}{2}^+[404]\) ground state in \(^{175}\text{Ta}\) using the formula,

\[
\mu = g_R I + (g_K - g_R) \frac{K^2}{I + 1},
\]

a value [20] of the magnetic moment of \(\mu = 2.27(5)\, \mu_N\) and \(g_K - g_R = 0.40(4)\), as deduced from the in-band branching ratios (see table 2). If the same value of \(g_R\) is assumed for all other bands, experimental \(g_K\) values of 1.72(15), 0.74(7) and 1.24(11) are obtained for the \(\frac{5}{2}^+[402]\), \(\frac{7}{2}^+[404]\) and \(\frac{9}{2}^-[514]\) bands respectively. They agree well with the predictions of 1.56, 0.62 and 1.26, calculated using Nilsson model wave functions, with parameters taken from ref. [21] and \(g_* = 0.7g^{free}_*\), deformations \(\epsilon_2 = 0.249\) and \(\epsilon_4 = 0.037\), the mean values from the neighbouring \(^{174}\text{Hf}\) and \(^{176}\text{W}\) isotopes [22].
4.2.2 Alignments and band crossing

Experimental alignments for one-quasiparticle bands in $^{178}$Ta are shown in fig. 13a. For comparison the alignment for the yrast band in the even-even core $^{174}$Hf [23,24] is also shown. The crossing frequencies, together with predicted deformations [14] and single-quasiparticle quadrupole moments are given in table 3.

The positive signature of the $\frac{1}{2}^+ [541]$ band has an alignment $i \sim 3.5 \hbar$ and it begins to upbend at considerably higher frequency than the ground state band of the even-even core, as well as the other one-quasiparticle bands in $^{175}$Ta. Such a delayed backbend was found in a number of Lu, Ta, Re and Ir isotopes (see for example refs. [12,25,26] and references therein) and has been the subject of many discussions usually based on the assumption of a large deformation for the $h_{9/2}$ proton orbital, although the magnitude of the delay is larger than that expected from predicted deformation differences. For details the reader is referred to refs. [25,26].

The experimental alignments and the crossing properties of the bands based on the $\frac{5}{2}^+ [402]$ and $\frac{9}{2}^- [514]$ quasiproton configurations are analogous to these of other odd-even Ta isotopes. They all upbend at approximately the same frequency as the yrast bands of the even-even neighbours, suggesting similar deformations (if no other effects are responsible). In contrast to the bands based on the same configurations in the Re and Ir isotopes [25-27], they do not show a complex alignment gain.

Although the $\frac{7}{2}^+ [404]$ band shows a simple alignment curve (fig. 13a), the crossing occurs at $\hbar \omega \approx 0.25$ MeV, considerably earlier than in the other bands. If the gain in the $\frac{7}{2}^+ [404]$ band corresponds to the alignment of a pair of $i_{13/2}$ quasineutrons, the earlier crossing frequency could imply lower deformation for the $\frac{7}{2}^+ [404]$ band compared to that of the other strongly coupled one-quasiparticle bands in $^{175}$Ta, or the ground state bands in the even-even neighbours [28]. However, the measured quadrupole moment of the $\frac{7}{2}^+ [404]$ state [19], corresponds to a relatively high value for its deformation $\beta_2 \approx 0.284$. In addition, the predicted deformations in ref. [14] and in the recent calculations of Möller et al. [29] do not show significant differences between the $\frac{7}{2}^+ [404]$, $\frac{5}{2}^+ [402]$ and $\frac{9}{2}^- [514]$ states in $^{175}$Ta, or between the $\frac{7}{2}^+ [404]$ ground state in $^{175}$Ta and the same configuration in the heavier Ta isotopes, where the anomaly (the difference in crossing frequencies) is not observed.
Alternatively, the upbend of the $\frac{7}{2}^+[404]$ band could be attributed to the crossing with a more deformed band in which a pair of protons is excited into the $h_{9/2}$ orbital [27,30,31]. This possibility was recently discussed for the related configuration in $^{173}$Ta [13].

Band I ($\alpha=+1/2$) shows a rapid alignment gain at low frequency, similar to that seen in the $\frac{3}{2}^+[660]$ quasiproton bands, observed in some Re and Ir isotopes [25–27]. Because of the position of the proton Fermi level, the $\frac{5}{2}^+[660]$ ($i_{13/2}$) quasiproton orbital is expected to be located at higher excitation energy in Ta than in the Re and Ir isotopes. From that point of view the relatively high excitation energy of the $I=(\frac{21}{2})$ state in comparison to the $I^+=\frac{21}{2}^+$ member of the $\frac{5}{2}^+[660]$ band in $^{177}$Re [32], $^{177}$Ir and $^{181}$Ir [30,31] isotopes would be consistent with a $\frac{5}{2}^+[660]$ assignment for band I, although no decay branches to either $\frac{5}{2}^+[402]$ or $\frac{7}{2}^+[404]$ bands, also expected from the systematics, were found.

Further, Bark et al [35] have shown recently that the $\frac{1}{2}^+[660]$ assignment in $^{177}$Re is incorrect, and their analysis of the energy systematics suggests that such bands do not compete with certain aligned 3-quasiparticle bands for $N \geq 100$ in the Re isotopes and $N \geq 104$ in the Ir isotopes. By implication they will be even less competitive in the Ta isotopes, presumably explaining why the $\frac{1}{2}^+[660]$ band was not observed in $^{173}$Ta. In that nucleus a band with similar behaviour to band I was instead interpreted [13] as a vibrational mode coupled to the $\frac{1}{2}^-[541]$ quasiproton.

Band II ($\alpha=-1/2$) also has a moderately large, but almost constant alignment ($i \approx 7.0\hbar$). Considering the available Nilsson orbitals close to the proton Fermi surface, this fact rules out a one-quasiparticle assignment. The band could possibly arise from aligned $\nu^2i_{13/2}$ quasineutrons coupled to the $\frac{1}{2}^+[411]$ quasiproton, for which the negative signature is favoured.

Firmer experimental information is required to clarify the structure of both bands I and II.

### 4.3 Multi-Quasiparticle Configurations

The configuration of the multi-quasiparticle states discussed above can be constrained by considering the band head spin and parity, the in-band decay properties and alignments, as well as the systematics of the observed multi-quasiparticle structures in the
neighbouring isotopes.

4.3.1 \( g_K-g_R \) values

In general, the experimental \( g_K \) value for given configuration obtained using eqn. (2) can be compared with the prediction from the Nilsson model and use of the formula:

\[
K g_K = \sum_{i=1}^{n} g_{n_i} \Omega_i \quad \text{and} \quad K = \Omega_1 + \Omega_2 + \Omega_3 + \ldots + \Omega_n
\]

(8)

where \( n \) is the number of the excited quasiparticles, \( \Omega_i \) is the projection of the intrinsic angular momentum on the symmetry axis and the \( g_{n_i} \) is the intrinsic \( g_K \)-factor for each quasiparticle. In some cases, several factors could make the results of such analysis inaccurate, namely: (i) mixing between multi-quasiparticle rotational bands with different intrinsic configurations (ii) deformation changes, reflected in a change in the \( Q_0 \) values (eqn. (2)) (iii) change in the \( g_R \) values, due to the reduction of the pairing (iv) coriolis mixing between configurations involving the \( i_{13/2} \) quasineutron or \( h_{9/2} \) quasiproton

Generally, the \( g_R \)-factor, expressed by the inertias associated with the orbital motions of the protons and neutrons as \( g_R = \Sigma_p/\Sigma_n + \Sigma_p \) [33], is expected to be reduced in the high-seniority configurations due to the blocking of the pairing correlations. Therefore, the \( g_R \) value for a given multi-quasiparticle rotational band would be expected to increase or decrease, in comparison with those of the one-quasiparticle states of the same nucleus, depending on whether the added particles break the pair of protons or neutrons.

According to the geometrical model of Donau [34], the presence of an aligned \( i_{13/2} \) or \( h_{9/2} \) quasiparticle in a given multi-quasiparticle state, could increase or decrease the \( g_K \) value, compared to the value given using eqn. (8). In the light of this formalism, eqn. (8) can be rewritten as [35]:

\[
K g_K = \sum_{i=1}^{n} g_{n_i} \Omega_i - \frac{K}{\sqrt{I^2 - K^2}} \sum_{j=1}^{n} (g_{n_i} - g_R) i_j
\]

(9)

where \( i_j \) is the alignment of the \( j^{th} \) nucleon.

The Nilsson model calculations give \( g_{n_{i13/2}} \approx -0.26 \) and \( +0.73 \) for configurations arising from the \( i_{13/2} \) neutron and the \( h_{9/2} \) proton shells respectively. Therefore, the \( g_K \) value of a multi-quasiparticle state involving an \( i_{13/2} \) quasineutron would be expected to in-
crease, while those for configurations with a $h_{9/2}$ quasiproton component would decrease compared to the strong coupling estimates (eqn. (8)).

The experimental $g_K$ values, obtained for the three-quasiparticle bands in $^{175}$Ta, assuming $Q_0=7.8(7)$ $e$ $b$ [19] and $g_R=0.34(3)$ are given in table 4. The predictions using the Nilsson model and additivity, as well as values computed using eqn. (9) are also given. In the latter case the values are state dependent, but for convenience the values averaged over the observed spin range are given. In addition, the values predicted for alternative three-quasiparticle configurations expected are also presented.

As can be seen from table 4, the experimental value for the $K^*=\frac{31}{2}^-$ band is consistent only with the predicted three-quasiproton configuration.

The value of $g_K=0.56(6)$ obtained for the $K^*=\frac{21}{2}^+$ band is somewhat larger than the prediction of $g_K=0.37$ from the Nilsson model for the $\pi^1[\frac{9}{2}^-]$$\otimes\nu^2[\frac{7}{2}^+,\frac{5}{2}^-]$ configuration, but is in good agreement with the value when alignment is taken into account.

Of the two alternatives for a $K^*=\frac{17}{2}^+$ state, the experimental value of $0.72(7)$ when compared to the Nilsson estimates (penultimate column, table 4) falls between the $\pi^1[\frac{9}{2}^-]$$\otimes\nu^2[\frac{7}{2}^+,\frac{1}{2}^-]$ and $\pi^3[\frac{7}{2}^+,\frac{9}{2}^-,\frac{1}{2}^-]$ configurations, slightly favouring the former. When alignment is approximately included (last column, table 4), the calculated values are essentially the same. However, the possibility of pairing differences also has to be considered, in particular for the three-quasiproton configuration in which the three quasiparticles are of the same type. Due to the blocking of three quasiproton orbitals close to the Fermi surface, the proton pairing in the that state could be reduced by $\sim30$ % compared to the $\frac{7}{2}^+[404]$ ground state, leading indirectly to an increase in $g_R$. An experimental estimate of that effect can be obtained from the results for the $K^*=\frac{21}{2}^-$ band, where the proton pairing should be reduced to approximately the same level. Equating the theoretical Nilsson model value of $g_K=1.12$ for the $K^*=\frac{21}{2}^-$ band, with the experimental weighted average $g_K-g_R$ value of $0.68(10)$, leads to $g_R=0.44(10)$. If $g_R=0.44(10)$ is assumed, a value of $g_K=0.82(14)$ for the $K^*=\frac{17}{2}^+$ band is obtained, in good agreement with the value for either of the alignment-corrected values for the $\pi^1$$\otimes\nu^2$ and $\pi^3$ configurations, so that no distinction is possible.

Mixing between the two configurations is also possible (if the states were close in energy), although from the above arguments, such mixing would not be apparent from the $g_K$ values.
In fig. 14 the excitation energies of the $\pi^1-\nu^2$ and $\pi^3$ configurations in a number of Ta isotopes predicted using blocked Lipkin-Nogami calculations with inclusion of the residual nucleon-nucleon interaction are shown. These calculations should be indicative of the trend, if not the absolute values. Indeed in $^{175}$Ta the two $K^*=\frac{17}{2}^+$ states are predicted to be within $\sim 10$ keV of each other, but $\sim 300$ keV apart in $^{177}$Ta, with the $\pi^3$ configuration favoured. Recently Dasgupta et al. [8] observed a $K^*=\frac{13}{2}^+$ state and its corresponding band in $^{177}$Ta. Comparison between the two nuclei gives almost identical experimental $(g_K-g_R)/Q_0$ values as a function of the spin (for example at $I^*=\frac{23}{2}^+$ the values are 0.041(8) and 0.036(9) for $^{175}$Ta and $^{177}$Ta respectively; at $I^*=\frac{25}{2}^+$, 0.044(9) and 0.045(11), and at $I^*=\frac{27}{2}^+$, 0.056(9) and 0.056(12) respectively). As well the bandhead has very similar decay branches to the $\frac{5}{2}^+[402]$, $\frac{7}{2}^+[404]$ and $\frac{9}{2}^-[514]$ band members in both $^{175}$Ta and $^{177}$Ta which would also support the view that the configuration is the same in both nuclei.

The excitation energy calculations suggest that while the the bands might be close and therefore mix in $^{175}$Ta, the $\pi^3$ configuration is clearly favoured in $^{177}$Ta. Notwithstanding the conclusion above that the $g_K-g_R$ values would not distinguish between the configurations, the similarity in other properties suggests the same configuration in both, and therefore by default, the $\pi^3$ configuration.

4.3.2 Alignments

The experimental alignments of the observed three-quasiparticle bands can be used as supporting evidence for the configuration assignment. Although strict additivity, in which the alignment in the multi-quasiparticle band is equal to the sum of the constituent one-quasiparticle components, is unlikely when pairing changes are expected, and there are concomitant uncertainties when common reference parameters are used for all rotational bands, it is possible at least to distinguish the number (or absence) of $i_{13/2}$ neutrons or $h_{9/2}$ protons in a given multi-quasiparticle configuration. (This approach was successful in interpreting the behaviour of multi-quasiparticle bands in a recent study of $^{179}$W [36]). To reduce the uncertainties, it is more appropriate to compare the alignments of the three-quasiparticle bands in the even-odd $^{175}$Ta nucleus with those for multi-quasiparticle configurations in the even-even neighbours where the same pair of protons or neutrons is broken, since the pairing is already partly reduced.
The experimental alignments as a function of rotational frequency for the three-quasiparticle bands in $^{175}$Ta and selected two- and four-quasiparticle bands in the even-even core nucleus $^{174}$Hf [23, 24] are shown in fig. 13b.

$K^* = \frac{21}{2}^-$ band

The absence of aligned $\nu_{13/2}$ or $\pi h_{9/2}$ components in the $K^* = \frac{21}{2}^-$ state configuration is confirmed by its low alignment. Furthermore, the alignment for the band built on the $\pi^2[\frac{3}{2}^+, \frac{5}{2}^-]_8^-$ state in $^{174}$Hf [23, 24] is identical over a wide frequency region consistent with the neutral role of the $\frac{5}{2}^+ [402]$ quasiproton when added to the $8^-$ core. Similar alignments have been observed for the bands build on the $\pi^3[\frac{5}{2}^+, \frac{7}{2}^+, \frac{9}{2}^-]$ configuration in $^{177}$Ta [8] and $^{179}$Ta [9].

$K^* = \frac{11}{2}^+$ and $\frac{13}{2}^+$ bands

The large alignments for the $K^* = \frac{11}{2}^+$ and $\frac{21}{2}^+$ bands suggest the presence of the $\nu_{13/2}$ quasineutron or alternatively the $\pi h_{9/2}$ quasiproton. On the one hand, the $\frac{7}{2}^+ [633]$ quasineutron is the closest $i_{13/2}$ orbital to the neutron Fermi surface at $N \approx 102$ and it is a component of the $\nu^2[\frac{3}{2}^+, \frac{1}{2}^-]_4^-$, $\nu^2[\frac{5}{2}^+, \frac{5}{2}^-]_6^-$ and $[\pi^2[\frac{3}{2}^+, \frac{5}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{5}{2}^-]]_{14^+}$ state configurations, upon which bands are observed in the $^{174}$Hf [23, 24]. On the other hand, the proton Fermi surface lies in the beginning of the $h_{9/2}$ shell and the $\frac{1}{2}^-[541]$ quasiproton is the closest $h_{9/2}$ orbital to the proton Fermi surface. However, no bands with its involvement were observed in the neighbouring even-even isotopes.

The frequency dependence of the alignments in the $K^* = \frac{21}{2}^+$, $6^-$ and $14^+$ bands are almost the same. While the magnitudes in the $K^* = \frac{21}{2}^+$ and $14^+$ bands are identical, the constant difference between the $K^* = \frac{21}{2}^+$ and $6^-$ bands can be attributed to the contribution of $1.0h$ arising from the addition of the $\frac{9}{2}^- [514]$ quasiproton (see fig. 13a). Consequently, this comparison supports the presence of the $\nu^2[\frac{7}{2}^+, \frac{5}{2}^-]_6^-$ component in the $K^* = \frac{21}{2}^+$ state configuration and confirms the $\pi^1[\frac{9}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{5}{2}^-]_6^-$ configuration assignment for the state at 1729.3 keV.

As discussed earlier (sec. 4.3.1), there are two possible $K^* = \frac{17}{2}^+$ configurations, $\pi^1[\frac{9}{2}^-] \otimes \nu^2[\frac{3}{2}^+, \frac{1}{2}^-]_4^-$ and $\pi^3[\frac{3}{2}^+, \frac{5}{2}^-, \frac{1}{2}^-]_8^-$ the latter of which was somewhat favoured in the previous discussion. The former contains an $i_{13/2}$ quasineutron, the latter an $h_{9/2}$ quasiproton. On the one hand, the alignment (slope and magnitude) of the $K^* = \frac{17}{2}^+$ band can be well reproduced by adding the alignments of the $4^-$ band in $^{174}$Hf [24] and the $\frac{9}{2}^- [514]$ quasiproton band, thus supporting an $\pi^1[\frac{9}{2}^-] \otimes \nu^2[\frac{3}{2}^+, \frac{1}{2}^-]_4^-$ assignment.
Unfortunately we cannot make a direct test of the other alternative because the $^{17,22}_{T^2} \ell_4$ band is not observed in the core. However, the fact that the alignment of the $K^*={21}_2^+$ band has weaker frequency dependence than the $K^*={31}_2^+$ band, already assigned to have one $i_{13/2}$ quasineutron in its configuration, could indicate that the $K^*={17}_2^+$ band contains the $h_{9/2}$ proton. A similar difference is seen in multi-quasiparticle bands in $^{179}$W [36], where as a rule, the bands with $h_{9/2}$ quasiproton in their configuration stay almost constant compared to those with an $i_{13/2}$ quasineutron, whose alignment rises with frequency. (The difference in slope of the alignments is attributable to the different position of the neutron and proton Fermi levels in $i_{13/2}$ and $h_{9/2}$ shells respectively, the latter being close to the $\Omega=\frac{1}{2}$ orbital).

These considerations also favour the a $π^3[\frac{7}{2}^+, \frac{9}{2}^-, \frac{1}{2}^-]$ configuration.

### 4.4 K-Forbidden Transition Rates

The lifetime of the $K^*=\frac{31}{2}^-$ bandhead results from the K-forbiddenness of the transitions de-exciting it. For a transition of multipole order $\lambda$ the K-hindrance factor $f_\nu$ per degree of K-forbiddenness $\nu=\Delta K-\lambda$ is defined as:

$$ f_\nu = \left( \frac{T_W^\lambda}{T_W^\frac{1}{2}} \right)^{\frac{1}{\nu}} $$

where $T_W^\lambda$ is the Weisskopf single particle estimate [18]. The K-hindrance factors per degree of K-forbiddenness obtained for transitions depopulating the $K^*={31}_2^-$ and $K^*={17}_2^+$ isomers are given in table 5 and table 6. The values for the 709.6 keV ($\nu=4$) and 1090.6 (\nu=3) E2 transitions are about a factor of three larger than systematics suggest in this mass region [37]. A similarly large value was recently reported for the E2 transition depopulating the three-quasineutron, $K^*={21}_{12}^+$, isomer in $^{179}$W [36]. Recalling that in these cases, the three excited quasiparticles are all of the same type ($\pi^3$ and $\nu^3$), pairing reduction may play a role, a possibility which may require theoretical examination.
5 Multi-quasiparticle calculations and residual nucleon-nucleon interactions

In this section the excitation energies of the observed multi-quasiparticle states are compared with the calculations, including blocking of the pairing correlations. The approach follows the formalism of Lipkin-Nogami [38-40] and is similar to those used by Nazarewicz et al. [14] and Möller et al. [41], but extended to the multi-quasiparticle case. The calculations were done in a model space including all 64 states in the N=4, 5 and 6 oscillator shells. The proton and neutron systems were treated independently without considering an interaction between them. The single-particle energies were calculated using the Nilsson model potential, with parameters as discussed in sec. 4.2.1. Since this potential cannot reproduce the experimental band head energies precisely, a fine adjustment in the single-particle energies around the proton and neutron Fermi surface was made in such way that experimentally known one-quasiproton states in $^{175}\text{Ta}$ and the average values of one-quasineutron states in $^{175}\text{W}$ [42], $^{177}\text{W}$ [43], $^{173}\text{Hf}$ [44] and $^{175}\text{Hf}$ [45] were reproduced. Values of 0.12 and 0.11 MeV for the proton ($\pi$) and neutron ($\nu$) pairing strength $G$ have been used, giving pairing energy values of $\Delta_\pi=959$ keV for the proton $\frac{7}{2}^+$ [404] ground state and $\Delta_\nu=831$ keV for the neutron zero-quasiparticle ground state.

The orbital dependent residual nucleon-nucleon interactions between quasiparticles were taken into account approximately using a model given in ref. [46], which requires the Gallagher-Moszkowski splitting energies ($E^{(GM)}_{q_iq_j}$) [47] and Newby shifts $E^{(N)}_{q_iq_j}$ [48] between two-quasiparticle states ($q_iq_j$) in the neighbouring even-even and odd-odd nuclei. The residual interactions can be calculated using:

$$E_{res} = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \left[ \alpha_{q_iq_j} \left| E^{(GM)}_{q_iq_j} \left( \begin{array}{cc} \frac{3}{2} - \delta_{q_iq_j,0} \end{array} \right) - \delta_{q_iq_j,0} E^{(N)}_{q_iq_j} \right| \Pi_{q_iq_j} \right]$$

where $\alpha_{q_iq_j}=+1$ for like particles ($\nu-\nu$ or $\pi-\pi$) and -1 for unlike particles ($\nu-\pi$), $\Sigma_{q_iq_j}$ is the intrinsic spin projection on the symmetry axis, and $\Pi_{q_iq_j}$ is the parity, all defined for a given two-quasiparticle ($\nu-\nu$, $\pi-\pi$ or $\nu-\pi$) configuration.

In the present work the values for $E^{(GM)}_{q_iq_j}$ and $E^{(N)}_{q_iq_j}$ given in ref. [46], some of which are determined from experiment, others only estimates, were used. The calculated multi-
quasiparticle excitation energies, relative to the $\frac{7}{2}^+[404]$ ground state, are compared with the experimental values in table 7. (Note that in the present calculations, there is no explicit inclusion of the rotational energy $\hbar^2/2\Omega K$ in either the adjustment to the 1-quasiparticle energies described above, or to the calculation of the multi-quasiparticle energies.)

The influence of the blocking of orbitals close to the Fermi surface on the excitation energies can be seen from the comparison between the predictions given by our blocked Lipkin-Nogami calculations with those of the simple expectation without blocking:

$$E \approx 2\Delta + \sum_{i=1}^{n} E_{i}^{QP}$$  (12)

where the $E_{i}^{QP}$ are the experimentally observed one-quasiparticle excitation energies and $\Delta$ is the pairing-correlation energy of the ground state. If the blocking is not taking into account, in all cases, the excitation energies of the predicted multi-quasiparticle states are higher. For example eqn. (12) gives 2100, 2195 and 2163 keV, for the three-quasiproton states with $K^* = \frac{13}{2}^-$, $\frac{17}{2}^+$ and $\frac{21}{2}^-$ respectively, about $\sim 450$ keV higher than the values given using Lipkin-Nogami blocking calculation (see table 7).

The effect of the residual interactions is evident from the final column of table 7, where the interaction energies are shown. As a rule, the energies of the states involving $\nu^{2}[\frac{7}{2}^+,\frac{5}{2}^-]$ quasineutrons are pushed up, compared to the unperturbed energies given from the blocked Lipkin-Nogami calculations. This is because of the strong repulsive interaction between these particular orbitals (the intrinsic spins are oriented in the same direction), which affect even the predicted excitation energies of the five-quasiparticle states. On the contrary, the interactions in the $\nu^{2}[\frac{7}{2}^+,\frac{1}{2}^-], \pi^{3}[\frac{7}{2}^+,\frac{9}{2}^+,\frac{1}{2}^-]$ and $\pi^{3}[\frac{5}{2}^+,\frac{7}{2}^+,\frac{9}{2}^-]$ configurations are attractive, and their excitation energies are predicted to be lowered.

The effect of these interactions for determining the yrast state can be seen through an example. There are three calculated $K=\frac{17}{2}^-$ states with configurations:

(i) $\pi^{3}[\frac{7}{2}^+,\frac{9}{2}^-,\frac{1}{2}^-] \ K^* = \frac{17}{2}^+$

(ii) $\pi^{1}[\frac{5}{2}^+] \otimes \nu^{2}[\frac{7}{2}^+,\frac{1}{2}^-] \ K^* = \frac{17}{2}^+$

(iii)$\pi^{1}[\frac{5}{2}^+] \otimes \nu^{2}[\frac{7}{2}^+,\frac{5}{2}^-] \ K^* = \frac{17}{2}^-$

The unperturbed energies (relative to the ground states) from the blocked Lipkin-Nogami
calculations are 1791, 1775 and 1636 keV respectively. With the inclusion of the residual interaction, the two $K^*$=$\frac{17}{2}^+$ states are lowered by 119 and 107 keV respectively, while the $K^*$=$\frac{17}{2}^-$ state is pushed up 42 keV and the positive parity states become favoured.

Our calculations also predict that although two $K=\frac{21}{2}^+$ states, one with positive parity and a $\pi^1\nu^2$ configuration, the other with negative parity and a $\pi^3$ configuration, will have similar excitation energies, the residual interaction results in a separation of ~200 keV. As can be seen from table 7, this reproduces quite well the experimentally observed $K^*$=$\frac{21}{2}^+$ and $K^*$=$\frac{21}{2}^-$ states.

There was insufficient experimental information available to assign spins and parities unambiguously for the five-quasiparticle states, but candidates for five- and seven-quasiparticle states are summarised in table 7.

6 Summary and Conclusion

The structure of the $^{175}$Ta has been studied using the $^{170}$Er($^{10}$B,5n) reaction. The rotational bands built on the previously known one-quasiparticle $\frac{7}{2}^+$[404], $\frac{5}{2}^+$[402], $\frac{9}{2}^-$[514] and $\frac{1}{2}^-$[541] states have been extended to higher spin. Two new three-quasiparticle states, with $K^*$=$\frac{17}{2}^+$ and $K^*$=$\frac{21}{2}^+$ and their associated rotational bands have been observed. The band built on the previously known isomeric state at 1565.9 keV has been established, and the isomer itself has been assigned $K^*$=$\frac{21}{2}^-$. The $g_K$ values extracted from the in-band branching ratios, in comparison with predictions obtained using Nilsson model wave functions, have been used to assign configurations. The $K^*$=$\frac{21}{2}^+$ state was assigned as a two-quasineutron $\nu^2[\frac{3}{2}^-,\frac{7}{2}^+]$ state of the core, coupled to the $\frac{9}{2}^-$[514] quasiproton. The $K^*$=$\frac{21}{2}^-$ and $K^*$=$\frac{17}{2}^+$ states were assigned with the three-quasiproton $\pi^3[\frac{3}{2}^+,\frac{7}{2}^+,\frac{9}{2}^-]$, and $\pi^3[\frac{9}{2}^-,\frac{7}{2}^+,\frac{1}{2}^-]$ configurations respectively, although the $\pi^1\nu^2$ configuration cannot be rigorously excluded for the latter. These assignments were supported also by the comparison of the aligned angular momenta of the three-quasiparticle bands observed in $^{175}$Ta with these for related two- and four-quasiparticle configurations in the even-even neighbour, $^{174}$Hf.

The spectrum of observed multi-quasiparticle states can be reproduced using blocking calculations based on the Lipkin-Nogami method, taking into account empirically the orbital dependent residual nucleon-nucleon interactions, which have significant effects on
which states will be yrast. All three-quasiparticle states which could be expected to be populated have been observed. Predictions have been made as to the lowest-lying five-quasiparticle and seven quasiparticle states expected, but experimental information on such states is uncertain at present.

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\(a\) The energies are accurate to within 0.1–0.2 keV for the strong, well resolved transitions. For other transitions the uncertainty may rise to 0.6 keV.

\(b\) Relative intensities extracted from singles and coincidence spectra.

\(c\) Relative intensity extracted from prompt coincidence projection.

\(d\) K value code:

\(\frac{1}{2}: \frac{1}{2}^-[541] (h_{9/2}); \frac{5}{2}^+: \frac{5}{2}^+[402] (d_{5/2}); \frac{7}{2}^+: \frac{7}{2}^+[404] (g_{7/2}); \frac{9}{2}^-: \frac{9}{2}^-[514] (h_{11/2}); \frac{21}{2}^-: K^*=\frac{21}{2}^-; \frac{21}{2}^+: K^*=\frac{21}{2}^+; \frac{17}{2}^+: K^*=\frac{17}{2}^+; (34)^+: \) State at 3215.7 keV; (33)^+: \ State at 3526.1 keV; (32)^+: \ State at 3761.8 keV; (I): band I; (II): band II; (?) unknown assignment.
Table 2: Branching and mixing ratios, $B(M1)/B(E2)$ and $g_K - g_R$ values

| $I^+$ | $E_I(\Delta I=1)$ | $E_I(\Delta I=2)$ | $\lambda^a$ | $B(M1)/B(E2)$ | $|g_K - g_R|^b$ | $\delta^c$ | rotot $^c$ | expt. $^d$ |
|-------|-------------------|-------------------|-------------|---------------|----------------|-------------|-----------|-----------|
|       | (keV)             | (keV)             |             | ($\mu_N^2/\hbar^2$) |               |             |           |           |
| $7/2^+$ [404] |
| $11/2^+$ | 154.3             | 284.3             | 0.88(17)    | 0.32(7)       | 0.42(5)       | 0.49(6)     | 0.25(10)  |           |
| $13/2^+$ | 176.9             | 331.6             | 2.37(37)    | 0.16(2)       | 0.37(3)       | 0.54(5)     | 0.44(13)  |           |
| $15/2^+$ | 196.9             | 373.9             | 3.78(52)    | 0.14(2)       | 0.38(3)       | 0.51(4)     | 0.49(17)  |           |
| $17/2^+$ | 214.4             | 411.3             | 5.28(74)    | 0.13(2)       | 0.38(3)       | 0.48(4)     |           |           |
| $19/2^+$ | 228.8             | 443.0             | 5.31(116)   | 0.16(4)       | 0.44(6)       | 0.40(5)     |           |           |
| $21/2^+$ | 240.5             | 469.3             | 7.48(73)    | 0.13(2)       | 0.41(2)       | 0.41(7)     | 0.32(9)   |           |
| $23/2^+$ | 250.1             | 490.6             | 9.35(290)   | 0.12(3)       | 0.39(6)       | 0.41(7)     |           |           |
| $25/2^+$ | 258.8             | 509.0             | 8.30(201)   | 0.15(3)       | 0.45(5)       | 0.34(4)     |           |           |
| $5/2^+$ [402] |
| $9/2^-$ | 133.5             | 239.6             | 0.19(4)     | 1.16(24)      | 1.22(14)      | 0.18(2)     | 0.15(6)   |           |
| $11/2^-$ | 159.6             | 293.2             | 0.24(4)     | 1.54(26)      | 1.70(16)      | 0.13(1)     |           |           |
| $13/2^-$ | 183.5             | 343.3             | 0.83(7)     | 0.62(5)       | 1.17(5)       | 0.18(1)     | 0.21(14)  |           |
| $15/2^-$ | 206.4             | 390.2             | 0.79(14)    | 0.88(14)      | 1.45(12)      | 0.14(1)     |           |           |
| $17/2^-$ | 225.8             | 432.3             | 0.88(7)     | 1.02(7)       | 1.60(6)       | 0.12(1)     | 0.11(11)  | +15(16)   |
| $19/2^-$ | 245.4             | 471.1             | 1.75(30)    | 0.61(10)      | 1.27(11)      | 0.15(1)     | 0.21(10)  | +20(27)   |
| $21/2^-$ | 259.5             | 504.8             | 1.79(45)    | 0.71(18)      | 1.38(18)      | 0.13(2)     |           |           |
| $23/2^-$ | 275.1             | 534.6             | 1.89(39)    | 0.76(14)      | 1.44(13)      | 0.12(1)     |           |           |
| $25/2^-$ | 282.5             | 557.7             | 1.15(28)    | 1.43(35)      | 1.99(25)      | 0.08(1)     |           |           |
| $27/2^-$ | 292.4             | 575.1             | 2.17(49)    | 0.79(18)      | 1.49(17)      | 0.11(1)     |           |           |
| $29/2^-$ | 297.5             | 589.2             | 1.67(53)    | 1.13(36)      | 1.78(31)      | 0.08(1)     |           |           |
| $9/2^-$ [514] |
| $13/2^-$ | 170.0             | 314.5             | 0.14(3)     | 2.90(50)      | 0.91(9)       | 0.21(2)     | 0.12(9)   | +10(1)    |
| $15/2^-$ | 193.6             | 363.9             | 0.31(3)     | 1.86(24)      | 0.92(6)       | 0.21(1)     | 0.14(5)   |           |
| $17/2^-$ | 216.6             | 410.4             | 0.53(4)     | 1.45(11)      | 0.90(4)       | 0.21(1)     |           |           |
| $19/2^-$ | 236.4             | 453.1             | 0.65(6)     | 1.50(12)      | 0.97(4)       | 0.19(1)     | 0.09(8)   | +5(6)     |
| $21/2^-$ | 256.9             | 493.4             | 0.89(9)     | 1.30(13)      | 0.95(5)       | 0.19(1)     | 0.14(12)  | +17(14)   |
| $23/2^-$ | 271.1             | 528.3             | 1.93(45)    | 0.70(15)      | 0.71(8)       | 0.24(3)     |           |           |
| $25/2^-$ | 288.7             | 559.9             | 1.64(31)    | 0.94(18)      | 0.84(8)       | 0.20(2)     |           |           |
| $27/2^-$ | 295.7             | 584.6             | 1.31(27)    | 1.36(27)      | 1.03(11)      | 0.15(2)     |           |           |
| $29/2^-$ | 309.6             | 605.3             | 1.01(28)    | 1.85(52)      | 1.22(19)      | 0.13(2)     |           |           |
| $31/2^-$ | 310.4             | 619.0             | 1.13(30)    | 1.87(50)      | 1.23(17)      | 0.12(2)     |           |           |
| $33/2^- | 318.3             | 627.9             | 2.06(99)    | 1.00(46)      | 0.91(21)      | 0.15(4)     |           |           |

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<table>
<thead>
<tr>
<th>I*</th>
<th>E_r(ΔI=1)</th>
<th>E_r(ΔI=2)</th>
<th>λ</th>
<th>B(M1)/B(E2)</th>
<th></th>
<th>g_K − g_R</th>
<th>δ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(keV)</td>
<td>(keV)</td>
<td></td>
<td>(μ^2 / e^2 b^2)</td>
<td>rotor</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/2^-</td>
<td>235.2</td>
<td>635.9</td>
<td>0.10(3)</td>
<td>19.9(58)</td>
<td>0.74$-^{12}$</td>
<td>0.26(4)</td>
<td>0.24$+^{18}$</td>
</tr>
<tr>
<td>23/2^-</td>
<td>334.5</td>
<td>659.5</td>
<td>0.24(9)</td>
<td>9.0(38)</td>
<td>0.66$+^{16}$</td>
<td>0.27(5)</td>
<td>0.23$+^{16}$</td>
</tr>
<tr>
<td>25/2^-</td>
<td>342.5</td>
<td>677.2</td>
<td>0.40(13)</td>
<td>5.9(21)</td>
<td>0.62$+^{12}$</td>
<td>0.28(5)</td>
<td></td>
</tr>
<tr>
<td>21/2'^+</td>
<td>191.0</td>
<td>357.1</td>
<td>0.25(5)</td>
<td>1.90(49)</td>
<td>0.23(3)</td>
<td>0.49(6)</td>
<td>0.47$+^{12}$</td>
</tr>
<tr>
<td>23/2'^+</td>
<td>212.4</td>
<td>403.7</td>
<td>0.74(16)</td>
<td>0.78(22)</td>
<td>0.20(3)</td>
<td>0.59(9)</td>
<td>0.46$+^{33}$</td>
</tr>
<tr>
<td>25/2'^+</td>
<td>232.3</td>
<td>444.4</td>
<td>1.11(49)</td>
<td>0.67(40)</td>
<td>0.21$+^{7}$</td>
<td>0.56(16)</td>
<td>0.41$+^{24}$</td>
</tr>
<tr>
<td>21/2'^+</td>
<td>251.3</td>
<td>483.3</td>
<td>1.41(58)</td>
<td>0.65(32)</td>
<td>0.23$+^{6}$</td>
<td>0.52(12)</td>
<td></td>
</tr>
<tr>
<td>23/2'^+</td>
<td>269.5</td>
<td>520.4</td>
<td>1.87(60)</td>
<td>0.57(23)</td>
<td>0.23$+^{5}$</td>
<td>0.52(11)</td>
<td></td>
</tr>
<tr>
<td>25/2'^+</td>
<td>286.6</td>
<td>555.9</td>
<td>1.91(82)</td>
<td>0.68(37)</td>
<td>0.26$+^{8}$</td>
<td>0.46(12)</td>
<td></td>
</tr>
<tr>
<td>27/2'^+</td>
<td>302.1</td>
<td>588.8</td>
<td>2.14(108)</td>
<td>0.70(42)</td>
<td>0.27(8)</td>
<td>0.43(14)</td>
<td></td>
</tr>
<tr>
<td>29/2'^+</td>
<td>316.3</td>
<td>618.7</td>
<td>2.57(158)</td>
<td>0.65(52)</td>
<td>0.27$+^{12}$</td>
<td>0.44(18)</td>
<td></td>
</tr>
<tr>
<td>17/2'^+</td>
<td>175.5</td>
<td>318.6</td>
<td>0.32(11)</td>
<td>1.19(48)</td>
<td>0.32(6)</td>
<td>0.35(7)</td>
<td>0.22$+^{22}$</td>
</tr>
<tr>
<td>23/2'^+</td>
<td>204.1</td>
<td>379.8</td>
<td>0.57(21)</td>
<td>1.02(42)</td>
<td>0.34(7)</td>
<td>0.35(7)</td>
<td>0.31$+^{2}$</td>
</tr>
<tr>
<td>25/2'^+</td>
<td>229.4</td>
<td>433.7</td>
<td>0.58(19)</td>
<td>1.42(42)</td>
<td>0.44$-^{7}$</td>
<td>0.28(4)</td>
<td></td>
</tr>
<tr>
<td>27/2'^+</td>
<td>253.6</td>
<td>482.9</td>
<td>1.09(33)</td>
<td>0.92(32)</td>
<td>0.37$+^{7}$</td>
<td>0.34(6)</td>
<td></td>
</tr>
<tr>
<td>31/2'^+</td>
<td>275.1</td>
<td>528.2</td>
<td>1.13(43)</td>
<td>1.12(47)</td>
<td>0.43$+^{8}$</td>
<td>0.30(6)</td>
<td></td>
</tr>
<tr>
<td>33/2'^+</td>
<td>293.7</td>
<td>569.1</td>
<td>1.14(62)</td>
<td>1.34(86)</td>
<td>0.49(16)</td>
<td>0.27(9)</td>
<td></td>
</tr>
</tbody>
</table>

N) Branching ratios λ=\frac{I_{2}(I-1)}{I_{2}(I-1)} deduced from coincidence data as well as singles.

b) Experimental values using eqn. (2). Pure K and Q₀=7.8 eb [19] are assumed. The error quoted in this column does not include the error in Q₀ (which is approximately 10%)

c) Experimental values using eqn. (4).

d) Extracted values from anisotropy data.
Table 3: Summary of the observed crossing frequencies and predicted deformation parameters for one-quasiparticle bands in $^{175}$Ta and the yrast bands in the neighbouring even-even isotopes

<table>
<thead>
<tr>
<th>Band</th>
<th>Nucleus</th>
<th>$\hbar \omega$, (MeV)</th>
<th>$\beta_2$ a)</th>
<th>$\beta_4$ a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>yrast</td>
<td>$^{174}$Hf</td>
<td>0.30(1)</td>
<td>0.269</td>
<td>-0.021</td>
</tr>
<tr>
<td></td>
<td>$^{176}$W</td>
<td>0.28(1)</td>
<td>0.253</td>
<td>-0.017</td>
</tr>
<tr>
<td>$\frac{5}{2}^+ [402]$</td>
<td>$^{175}$Ta</td>
<td>0.29(2)</td>
<td>0.248</td>
<td>-0.024</td>
</tr>
<tr>
<td>$\frac{7}{2}^+ [404]$</td>
<td>$^{175}$Ta</td>
<td>0.25(1)</td>
<td>0.255</td>
<td>-0.024</td>
</tr>
<tr>
<td>$\frac{9}{2}^- [514]$</td>
<td>$^{175}$Ta</td>
<td>0.30(2)</td>
<td>0.256</td>
<td>-0.026</td>
</tr>
<tr>
<td>$\frac{11}{2}^- [541]$</td>
<td>$^{175}$Ta</td>
<td>$\geq 0.40$</td>
<td>0.281</td>
<td>-0.017</td>
</tr>
</tbody>
</table>

a) Ref. [14].
Table 4: Experimental, calculated and empirical $g_K$-factors for three-quasiparticle configurations in $^{175}$Ta

<table>
<thead>
<tr>
<th>$K^*$</th>
<th>Main configurations $^a$</th>
<th>$g_K$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>expt.$^b$</td>
<td>calc.$^c$</td>
</tr>
<tr>
<td>$^{15-}$</td>
<td>$\pi^1[\frac{9}{2}^-] \otimes \nu^2[\frac{1}{2}^-, \frac{5}{2}^-]$</td>
<td>0.68</td>
</tr>
<tr>
<td>$^{17+}$</td>
<td>$\pi^1[\frac{9}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{5}{2}^-]$</td>
<td>0.72(7)$^e$</td>
</tr>
<tr>
<td>$^{17+}$</td>
<td>$\pi^3[\frac{7}{2}^+, \frac{9}{2}^-, \frac{1}{2}^-]$</td>
<td>0.60</td>
</tr>
<tr>
<td>$^{17^-}$</td>
<td>$\pi^1[\frac{5}{2}^+] \otimes \nu^2[\frac{7}{2}^+, \frac{5}{2}^-]$</td>
<td>0.24</td>
</tr>
<tr>
<td>$^{19-}$</td>
<td>$\pi^1[\frac{5}{2}^+] \otimes \nu^2[\frac{7}{2}^+, \frac{5}{2}^-]$</td>
<td>0.04</td>
</tr>
<tr>
<td>$^{19+}$</td>
<td>$\pi^1[\frac{7}{2}^+] \otimes \nu^2[\frac{5}{2}^-, \frac{7}{2}^-]$</td>
<td>0.23</td>
</tr>
<tr>
<td>$^{21-}$</td>
<td>$\pi^3[\frac{5}{2}^+, \frac{7}{2}^+, \frac{9}{2}^-]$</td>
<td>1.02(15)</td>
</tr>
<tr>
<td>$^{21-}$</td>
<td>$\pi^1[\frac{5}{2}^+] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>0.22</td>
</tr>
<tr>
<td>$^{21-}$</td>
<td>$\pi^1[\frac{5}{2}^+] \otimes \nu^2[\frac{3}{2}^+, \frac{5}{2}^-]$</td>
<td>0.55</td>
</tr>
<tr>
<td>$^{21+}$</td>
<td>$\pi^1[\frac{5}{2}^+] \otimes \nu^2[\frac{7}{2}^+, \frac{5}{2}^-]$</td>
<td>0.56(6)</td>
</tr>
</tbody>
</table>

$^a$ Configurations:

- neutrons ($\nu$): $\frac{1}{2}^-, \frac{1}{2}^- [521]; \frac{7}{2}^+, \frac{7}{2}^+ [633]; \frac{5}{2}^-, \frac{5}{2}^- [512]; \frac{7}{2}^-, \frac{7}{2}^- [514]$.
- protons ($\pi$): $\frac{9}{2}^-, \frac{9}{2}^- [514]; \frac{7}{2}^+, \frac{7}{2}^+ [404]; \frac{5}{2}^+, \frac{5}{2}^+ [402]; \frac{3}{2}^-, \frac{3}{2}^- [541]$.

$^b$ Experimental weighted average values obtained using eqn. (2). Pure K, $Q_0=7.8(7)$ eV [19] and $g_R=0.34(3)$ are assumed.

$^c$ Calculated values using Nilsson model wave functions, with parameters as described in the text. K-mixing has not been taken into account.

$^d$ Calculated values using eqn. (9). Corrected approximately for the observed alignment ($i(\nu_{13/2})=2.5\hbar$ and $i(\pi h_{9/2})=3.5\hbar$) and averaged over the same spin interval as in experiment.

$^e$ Experimental value for $K^*=\frac{15}{2}^+$ band obtained with $g_R=0.34(3)$.

$^f$ Experimental value for $K^*=\frac{17}{2}^+$ band obtained with $g_R=0.44(10)$. 

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Table 5: $K^*_{\frac{21}{2}^-}$ isomer decays

<table>
<thead>
<tr>
<th>$E_\gamma$ (keV)</th>
<th>Mult.</th>
<th>$I_\gamma$ (rel.)</th>
<th>$\alpha_T$</th>
<th>$T_{1/2}^{77}$ (s)</th>
<th>$T_{1/2}^{W}$ (s)</th>
<th>$\nu$</th>
<th>$f_\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>216.5</td>
<td>M1</td>
<td>75(15)</td>
<td>0.512</td>
<td>9.4x10^{-6}</td>
<td>2.2x10^{-12}</td>
<td>5</td>
<td>21.2</td>
</tr>
<tr>
<td>473.3</td>
<td>M1</td>
<td>165(18)</td>
<td>0.063</td>
<td>4.3x10^{-6}</td>
<td>2.1x10^{-13}</td>
<td>5</td>
<td>29.0</td>
</tr>
<tr>
<td>709.6</td>
<td>E2</td>
<td>71(9)</td>
<td>0.009</td>
<td>9.9x10^{-6}</td>
<td>5.4x10^{-11}</td>
<td>4</td>
<td>20.7</td>
</tr>
</tbody>
</table>

a) $T_{1/2} = T_{1/2}^{exp} \sum_i I_\gamma(1 + \alpha_i)/ I_\gamma$, where $T_{1/2}^{exp} = 1950$ ns.

Table 6: $K^*_{\frac{12}{2}^+}$ isomer decays

<table>
<thead>
<tr>
<th>$E_\gamma$ (keV)</th>
<th>Mult.</th>
<th>$I_\gamma$ (rel.)</th>
<th>$\alpha_T$</th>
<th>$T_{1/2}^{77}$ (s)</th>
<th>$T_{1/2}^{W}$ (s)</th>
<th>$\nu$</th>
<th>$f_\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>458.9</td>
<td>E1</td>
<td>15(3)</td>
<td>0.008</td>
<td>3.3x10^{-8}</td>
<td>2.2x10^{-15}</td>
<td>3</td>
<td>245.7</td>
</tr>
<tr>
<td>695.7</td>
<td>E1</td>
<td>18(4)</td>
<td>0.003</td>
<td>2.8x10^{-8}</td>
<td>6.4x10^{-16}</td>
<td>3</td>
<td>350.5</td>
</tr>
<tr>
<td>912.1</td>
<td>E1</td>
<td>34(8)</td>
<td>0.002</td>
<td>1.5x10^{-8}</td>
<td>2.8x10^{-16}</td>
<td>3</td>
<td>371.8</td>
</tr>
<tr>
<td>680.3</td>
<td>M1</td>
<td>6(2)</td>
<td>0.025</td>
<td>8.3x10^{-8}</td>
<td>7.0x10^{-14}</td>
<td>4</td>
<td>33.0</td>
</tr>
<tr>
<td>894.2</td>
<td>M1</td>
<td>8(3)</td>
<td>0.012</td>
<td>6.2x10^{-8}</td>
<td>3.1x10^{-14}</td>
<td>4</td>
<td>37.7</td>
</tr>
<tr>
<td>1090.6</td>
<td>E2</td>
<td>5(2)</td>
<td>0.004</td>
<td>1.0x10^{-7}</td>
<td>6.3x10^{-12}</td>
<td>3</td>
<td>25.1</td>
</tr>
<tr>
<td>932.4</td>
<td>E2</td>
<td>11(3)</td>
<td>0.005</td>
<td>4.5x10^{-8}</td>
<td>1.4x10^{-11}</td>
<td>4</td>
<td>7.6</td>
</tr>
</tbody>
</table>

a) $T_{1/2} = T_{1/2}^{exp} \sum_i I_\gamma(1 + \alpha_i)/ I_\gamma$, where $T_{1/2}^{exp} = 5.1$ ns.
Table 7: Calculated and experimental excitation energies for multi-quasiparticle states in $^{175}$Ta

<table>
<thead>
<tr>
<th>$K^+$</th>
<th>Configuration a)</th>
<th>$E_{\text{expt}}$ keV</th>
<th>$E_{\text{calc}}$b) keV</th>
<th>$E_{\text{res}}$ keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{7}{2}^+$</td>
<td>$\pi^1[\frac{7}{2}^+]$</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$\frac{5}{2}^+$</td>
<td>$\pi^1[\frac{5}{2}^+]$</td>
<td>36</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>$\frac{3}{2}^-$</td>
<td>$\pi^1[\frac{3}{2}^-]$</td>
<td>68c)</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>$\frac{3}{2}^-$</td>
<td>$\pi^1[\frac{3}{2}^-]$</td>
<td>131</td>
<td>135</td>
<td>135</td>
</tr>
<tr>
<td>$\frac{1}{2}^-$</td>
<td>$\pi^1[\frac{1}{2}^-]$</td>
<td>1402</td>
<td>-211</td>
<td>-211</td>
</tr>
<tr>
<td>$\frac{5}{2}^-$</td>
<td>$\pi^3[\frac{5}{2}^-, \frac{7}{2}^+, \frac{1}{2}^-]$</td>
<td>(1280)</td>
<td>1466</td>
<td>-141</td>
</tr>
<tr>
<td>$\frac{5}{2}^-$</td>
<td>$\pi^1[\frac{3}{2}^+] \otimes \nu^2[\frac{5}{2}^-, \frac{7}{2}^-]$</td>
<td>1517</td>
<td>-123</td>
<td>-123</td>
</tr>
<tr>
<td>$\frac{5}{2}^-$</td>
<td>$\pi^1[\frac{3}{2}^+] \otimes \nu^2[\frac{5}{2}^-]$</td>
<td>1668</td>
<td>-107</td>
<td>-107</td>
</tr>
<tr>
<td>$\frac{5}{2}^-$</td>
<td>$\pi^3[\frac{5}{2}^-, \frac{7}{2}^+, \frac{1}{2}^-]$</td>
<td>1552</td>
<td>1672</td>
<td>-119</td>
</tr>
<tr>
<td>$\frac{5}{2}^-$</td>
<td>$\pi^1[\frac{3}{2}^+] \otimes \nu^2[\frac{5}{2}^+, \frac{7}{2}^-]$</td>
<td>1566</td>
<td>1678</td>
<td>+42</td>
</tr>
<tr>
<td>$\frac{7}{2}^-$</td>
<td>$\pi^1[\frac{7}{2}^+] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>2136</td>
<td>-128</td>
<td>-128</td>
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<tr>
<td>$\frac{7}{2}^-$</td>
<td>$\pi^3[\frac{5}{2}^-, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>2300</td>
<td>-99</td>
<td>-99</td>
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<tr>
<td>$\frac{7}{2}^-$</td>
<td>$\pi^1[\frac{3}{2}^+] \otimes \nu^2[\frac{5}{2}^+, \frac{7}{2}^-]$</td>
<td>1729</td>
<td>1738</td>
<td>+28</td>
</tr>
<tr>
<td>$\frac{7}{2}^-$</td>
<td>$\pi^1[\frac{3}{2}^+] \otimes \nu^2[\frac{5}{2}^+, \frac{7}{2}^-]$</td>
<td>2341</td>
<td>-99</td>
<td>-99</td>
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<tr>
<td>$\frac{5}{2}^+$</td>
<td>$\pi^3[\frac{5}{2}^+, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>3355</td>
<td>+139</td>
<td>+139</td>
</tr>
<tr>
<td>$\frac{5}{2}^+$</td>
<td>$\pi^3[\frac{5}{2}^+, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>2896</td>
<td>-266</td>
<td>-266</td>
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<tr>
<td>$\frac{3}{2}^+$</td>
<td>$\pi^3[\frac{3}{2}^+, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>3081</td>
<td>-249</td>
<td>-249</td>
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<tr>
<td>$\frac{3}{2}^-</td>
<td>\pi^3[\frac{3}{2}^+, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>3610</td>
<td>216</td>
<td>216</td>
</tr>
<tr>
<td>$\frac{3}{2}^-</td>
<td>\pi^3[\frac{3}{2}^+, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>3834</td>
<td>-262</td>
<td>-262</td>
</tr>
<tr>
<td>$\frac{3}{2}^-</td>
<td>\pi^3[\frac{3}{2}^+, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>3166</td>
<td>-128</td>
<td>-128</td>
</tr>
<tr>
<td>$\frac{3}{2}^-</td>
<td>\pi^3[\frac{3}{2}^+, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>(3526)</td>
<td>3649</td>
<td>-305</td>
</tr>
<tr>
<td>$\frac{3}{2}^-</td>
<td>\pi^3[\frac{3}{2}^+, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>(3762)</td>
<td>3674</td>
<td>-322</td>
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<tr>
<td>$\frac{1}{2}^-</td>
<td>\pi^3[\frac{1}{2}^-, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>5095</td>
<td>-237</td>
<td>-237</td>
</tr>
<tr>
<td>$\frac{1}{2}^-</td>
<td>\pi^3[\frac{1}{2}^-, \frac{7}{2}^+, \frac{1}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{7}{2}^-]$</td>
<td>4902</td>
<td>-330</td>
<td>-330</td>
</tr>
</tbody>
</table>

a) Configurations:

- neutrons ($\nu$): $\frac{1}{2}^-; \frac{3}{2}^-; \frac{5}{2}^-; \frac{7}{2}^+$ [521]; $\frac{7}{2}^-; \frac{9}{2}^+$ [633]; $\frac{5}{2}^+; \frac{7}{2}^+$ [642]; $\frac{3}{2}^+; \frac{5}{2}^+$ [512]; $\frac{3}{2}^-; \frac{5}{2}^- [514]$
- protons ($\pi$): $\frac{1}{2}^-; \frac{3}{2}^-; \frac{5}{2}^-; \frac{7}{2}^+$ [404]; $\frac{5}{2}^+; \frac{7}{2}^+$ [402]; $\frac{3}{2}^-; \frac{5}{2}^-; \frac{7}{2}^- [541]$

b) Does not include rotational terms explicitly (see text).

c) Band head according to ref. [2].
Figure Captions

Figure 1a: Partial level scheme of $^{175}$Ta. The transition widths are proportional to the $\gamma$-ray intensities. Band level half-lives are given where appropriate. Note that the band head positions for the $\frac{7}{2}^{-}[541]$ and $\frac{7}{2}^{+}[404]$ and the 619 keV level of the $\frac{5}{2}^{+}[402]$ bands are reproduced on figures 1a and 1b.

Figure 1b: Level scheme of $^{175}$Ta, continued.

Figure 2: Time correlated coincidence $\gamma$-ray spectra: a) sum of narrow prompt gates on the 129.6, 196.9 and 443.0 keV transitions in the $\frac{7}{2}^{+}[404]$ band; b) narrow prompt gate on the 105.9 keV transition in the $\frac{5}{2}^{+}[402]$ band.

Figure 3: Time correlated coincidence $\gamma$-ray spectra: a) delayed gate on the 131.4 keV transition depopulating the $\frac{9}{2}^{-}[514]$ band head, projecting all $\gamma$-rays preceding this level in a 20–170 ns time window; b) out-of-beam prompt gate on 217.0 keV $\gamma$-ray.

Figure 4: Time spectrum from the $\gamma$-$\gamma$-time experiment constructed from summed gates on 144.6, 170.0 and 193.6 keV $\gamma$-rays, which precede the isomer (on the $y$ axes) and the depopulating 131.4 keV $\gamma$-ray (on the $z$ axes). The solid line shows a fit, yielding a half-life of 222±8 ns.

Figure 5: Sum of earliest gates on 144.6, 170.0, 193.6, 216.6 and 236.4 keV $\Delta I=1$ transitions in the $\frac{9}{2}^{-}[514]$ band in all CS detectors, projecting the $\gamma$-rays in the LEPS detector which follow in a 170–800 ns time window.

Figure 6: Coincidence $\gamma$-ray spectra with gates on transitions in the $\frac{1}{2}^{-}[541]$ band: a) sum of wide prompt gates on the 172.3 and 461.9 keV $\gamma$-rays; b) sum of narrow prompt
gates on the 682.2 and 742.3 keV γ-rays.

Figure 7: Coincidence γ-ray spectrum constructed from a wide prompt gate on the 172.3 keV γ-ray in all CS detectors, projecting the γ-rays in the LEPS detector.

Figure 8: Time spectrum from the γ-time experiment with summed gates on the 144.6, 170.0, 193.6, 217.0, 236.4 and 709.6 keV γ-rays. The solid curve shows a fit, yielding a half-life of 1950(150) ns.

Figure 9: a) Coincidence γ-ray spectrum constructed from summed delayed gates on the 144.6, 170.0, 193.6, 216.6, 236.4, 314.5, 363.9, 410.4, 453.1 and 473.3 keV γ-rays in the $^2\!_2^+$[514] band, projecting all γ-rays in 170–800 ns time window, which precede the $K^* = \frac{1}{2}^+$ isomer; b) Coincidence γ-ray spectrum constructed from a narrow prompt gate on the 163.4 keV γ-ray.

Figure 10: Observed Gaussian positions fitted to time difference spectra as a function of the energy for transitions which precede the level of interest. The circles are for the 170.0 and 175.5 keV transitions as start and 144.6 keV transition as stop, the squares are for 191.0 keV transition as start and either 165.7 or 163.4 keV transitions as stop, the triangles are for 271.1 and 279.1 keV transitions as start and either 236.4 or 235.7 keV transitions as stop. The filled symbols correspond to the centroid position for levels that are prompt.

Figure 11: Time spectrum from the γ-time experiment with a gate on the 912.1 keV γ-ray. The solid curve shows a fit, yielding a half-life of 5.5±0.8 ns. The dashed line shows a prompt response curve and constant activity component.

Figure 12: Observed Gaussian positions fitted to the time spectra from the γ-time experiment, produced with gates on the γ-rays in the CS detectors as a function of their
energies. The filled symbols give the position of the prompt $\gamma$-rays.

Figure 13: Apparent aligned angular momentum as a function of rotational frequency: a) for the one-quasiparticle bands in $^{175}$Ta and the yrast band in $^{174}$Hf. K values of $1/2$ for band I and II have been used; b) for the three-quasiparticle bands in $^{175}$Ta (filled symbols) and selected two- and four-quasiparticle bands (open symbols) in $^{174}$Hf. Reference parameters $\mathcal{G}_0=32$ MeV$^{-1}$ and $\mathcal{G}_1=85$ MeV$^{-3}$ have been used for all bands.

Figure 14: Excitation energies of the $^\pi^1[\frac{9}{2}^-] \otimes \nu^2[\frac{7}{2}^+, \frac{1}{2}^-]$ (open symbols) and $^\pi^3[\frac{7}{2}^+, \frac{9}{2}^-, \frac{1}{2}^-]$ (filled symbols) states, predicted using Lipkin-Nogami blocking calculations with inclusion of the residual nucleon-nucleon interaction, in some Ta isotopes.
a) gates on 130, 197 and 443 keV $7/2^+ [^04]$
- contaminants
* gates

b) gate on 106 keV $5/2^+ [^402]
- contaminants

Fig. 2
Fig. 4

start: 145, 170 and 194 keV
stop: 131 keV

$T_{1/2} = 222(8)$ ns
gates on 145, 170, 194, 217 and 236 keV

- contaminants

energy [keV]

Ta X

counts

50  70  90  110  130

50  70  90  110  130

0  200  400  600  800

131.4
Ta X

a) gates on 172 and 462 keV
* gates

b) gates on 682 and 742 keV
* gates

energy [keV]
Fig. 7
gates on 145, 170, 194, 217, 239 and 710 keV

$T_{1/2} = 1950(150)$ ns
Fig. 9
Gate on 912 keV

$T_{1/2} = 5.5(8) \text{ ns}$
$E^* [keV]$ vs $N$ for $A = 173, 175, 177, 179$

- $\pi^3$
- $\pi^{12}$

$K\pi = 17/2^+$ states

Figure 14