# Pairing Reentrance in warm rotating $^{104}$Pd nucleus†

N. Quang Hung,*1,*2 N. Dinh Dang,*2 B.K. Agrawal,*3 V.M. Datar,*4 A. Mitra,*4 and D.R. Chakrabarty*4

The recent series of experiments conducted at the Bhabha Atomic Research Center (BARC) for the reaction $^{12}C + ^{93}Nb \rightarrow ^{105}Ag^* \rightarrow ^{104}Pd^* + p$ at the incident energy of 40 - 45 MeV has observed an anomalous enhancement of the nuclear level density (NLD) of $^{104}$Pd nucleus at low excitation energy $E^*$ and high angular momentum $J$[1]. This enhancement is similar to that previously predicted by the shell-model Monte Carlo (SMMC)[2] and FTBCS1 calculations[3] for a warm rotating $^{72}$Ge nucleus. Both the SMMC and FTBCS1 have pointed out that the local enhancement of NLD at low $T$ and high $J$ is associated with the pairing reentrance effect. The latter occurs when the angular momentum of the system is sufficiently high so that the pairing correlation, which is zero at low $T < T_1$, reappears at $T > T_1$. The goal of this work is to apply the FTBCS1 theory including finite angular momentum to study if the enhanced NLD observed in $^{104}$Pd can be interpreted as the first evidence of pairing reentrance in a warm rotating finite nucleus.

The FTBCS1 theory at finite temperature and angular momentum is obtained based on the conventional finite-temperature Bardeen-Cooper-Schrieffer (FTBCS) theory that takes into account the effect of quasiparticle-number fluctuations (QNF) on the pairing field[3]. The numerical calculations are carried out for $^{104}$Pd nucleus, whose single-particle spectra are taken from the axially deformed Woods-Saxon potential including the spin-orbit and Coulomb interactions. The quadrupole deformation parameter $\beta_2$ potential is adjusted so that the NLD obtained at different values of $J$ fit best the experimental data, especially in the region where the enhancement of NLD is observed. The variation of $\beta_2$ with $J$ is plotted in Fig. 1 (a). This figure clearly shows that $^{104}$Pd nucleus undergoes a shape transition from the prolate shape ($\beta_2 > 0$) to the oblate one ($\beta_2 < 0$) at around $J = 20\ \hbar$, which is reasonable in this mass region because of an alignment of protons in $g_{9/2}$ and neutrons in $h_{11/2}$ orbits. Figs. 1 (d) - (e) depict the NLD as a function of excitation energy $E^*$ obtained within the FTBCS1 and the conventional FTBCS theories.

It is found that due to the QNF, the FTBCS1 gaps at different $J$ values decrease monotonically with increasing $E^*$ and do not collapse at the critical value $E^* = E^*_c$ as in the case of the FTBCS. As a result, the pairing reentrance takes place only in the pairing gaps obtained within the FTBCS1 (*e.g.*, for protons at $J = 20\hbar$ and neutrons and at $J = 30\hbar$), whereas this effect does not appear in the FTBCS gaps. This leads to the local enhancements of the NLD obtained within the FTBCS1 at low $E^*$ ($2 < E^* < 5$ MeV) and high $J$, in agreement with the experimental data. This agreement indicates that the observed enhancement of the NLD might be the first experimental detection of the pairing reentrance in a finite nucleus.

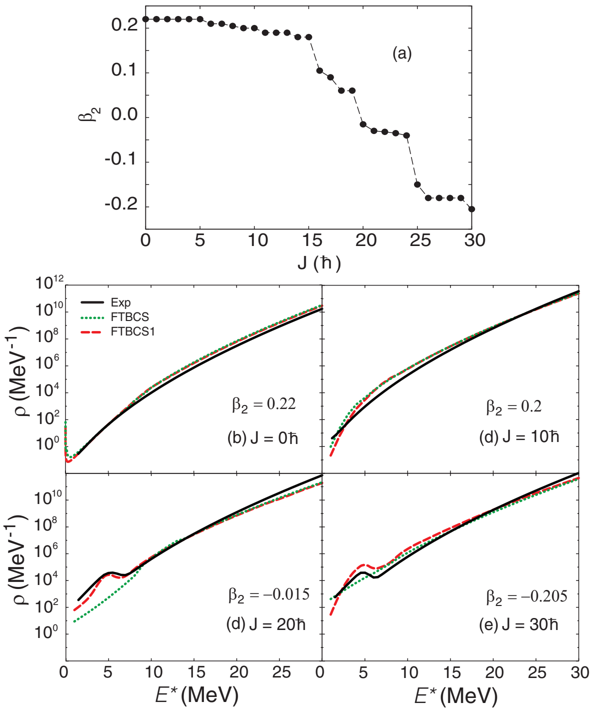


Fig. 1. (Color online) (a) - Quadrupole deformation parameter $\beta_2$ as functions of the total angular momentum $J$ obtained within the FTBCS1 theory. [(b) - (e)] - Total NLD as function of excitation energy $E^*$ obtained within the FTBCS (dotted lines) and FTBCS1 (dashed lines) at different values of $J$ and $\beta_2$. The solid lines are the experimental data.

References
1) A. Mitra *et al.*, J. Phys. G **36**, 095103 (2009); A. Mitra *et al.*, EPJ Web of Conf. **2**, 04004 (2010); V.M. Datar, A. Mitra, D.R. Chakrabarty, Proceedings of the DAE Sym. on Nucl. Phys., University of Delhi, Dec 37, 2012, Vol. 57, p. 184 (2012).
2) D.J. Dean, K. Langanke, H.A. Nam, W. Nazarewicz, Phys. Rev. Lett. **105**, 212504 (2010).
3) N.Q. Hung and N.D. Dang, Phys. Rev. C **78**, 064315 (2008), Phys. Rev. C **84**, 054324 (2011).

† Condensed from the article in Act. Phys. Pol. B **8**, 551 (2015)
*1 Institute of Research and Development, Duy Tan University
*2 RIKEN Nishina Center
*3 Theory Division, Saha Institute of Nuclear Physics
*4 Nuclear Physics Division, Bhabha Atomic Research Center