International Conference on Simplicity, Symmetry and Beauty of Atomic Nuclei

25 – 29 September 2018

PAIRING IN EXCITED NUCLEI

Nguyen Dinh Dang

RIKEN

Good morning, ladies and gentlemen,

I'm thankful to the organizers, especially Prof. Yu-Min Zhao, for giving me this opportunity to be at this celebration of Prof. Akito Arima's 88th birthday.

Nguyen Dinh Dang
Oil Painting Techniques
Published: 13/08/2018, 436 pages
Book signing event: 25/08/2018, Hanoi

Nguyễn Đình Maya (16/05/2018)
阮廷真耶 (グェン・ディン　まや)

This year has been particularly happy for me because of four birthday events.

The first one was the birth of my granddaughter, Nguyen Dinh Maya, in May.

The second one was the publication of my book on oil painting techniques in August, the first of its kind in Vietnam.

The third one was that I was reborn, that is turning 60, on the third of this month.

And the climax is this celebration of Prof. Arima's 88th birthday.

米寿 おめでとう ございます。

Opening of “Opus 7” – solo show of NDD paintings at Fazioli Piano Showroom in Tokyo (3 April 2010)

The last time my wife and I met with Prof. Arima was at the solo show of my paintings “Opus 7” in October 2010.

In the picture, the man on the right of Prof. Arima is Alec Weyl, the director of the Fazioli Piano Showroom in Tokyo, who kindly offered me the hall for free to hold the exhibition. At the opening of this show, we were honored to welcome Prof. Arima.

So I am happy seeing Prof. Arima today healthy and well after these 8 years.

A decade (1995 – 2006) of collaboration with Prof. Akito Arima (35 papers)

Major achievements:

- Spreading of Gamow-Teller resonance (PRL 79, 1997)
- Phonon damping model (PDM) (PRL 80, 1998)
- Double giant dipole resonance (DGDR) (PRL 85, 2000)
- Pairing effect on GDR width at low temperature (PRC 68, 2003)

Topical conference on giant resonances, Varenna, May 1998

I had the honor to meet with Prof. Arima for the first time in March 1994 in Hanoi at the Vietnam's first international conference on nuclear physics, which I organized with Prof Da-Hsuan Feng. This was few months before my departure to Japan as a Nishina Memorial Fellow. So Prof. Arima said: "*Why don't you come visit RIKEN once you are in Tokyo?*" At lunch during our first meeting in RIKEN, Prof. Arima told me the problem of Gamow-Teller resonance's quenching and asked me if I could handle it. I replied that I got some experience working on damping of giant resonances with my former mentor, Prof. Vadim Soloviev, in Dubna so I can deal with it. This started our one-decade collaboration with Prof. Arima, which remains in my memory as one of happiest periods of my entire career as a physicist.

My major achievements in collaboration with Prof. Arima include these four subjects. Among them, I would like to emphasize the Phonon Damping Model (PDM), as it is closely related to what I am going to report today.

This model was proposed by us twenty years ago to describe the evolution of the GDR width as a function of temperature in hot nuclei. The PDM describes the increase and the saturation of the GDR width with temperature as the result of coupling the GDR to non-collective pp, and hh configurations, which appear at finite temperature due to the distortion of the Fermi surface.

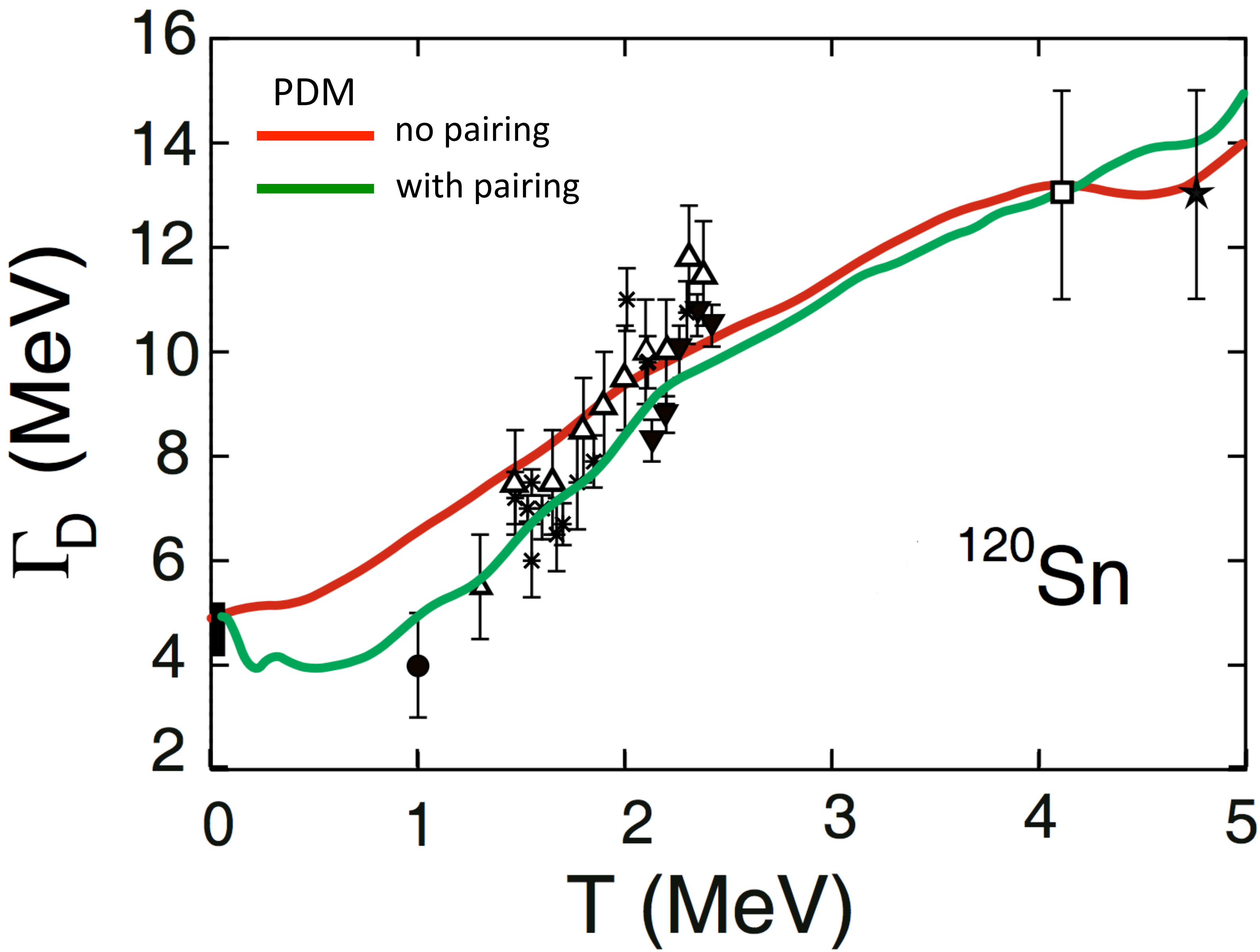
CONTENTS

- Pairing effect on giant dipole resonance's (GDR) width at low T
- Inclusion of pairing in Thermal Shape Fluctuation Model (TSFM)
- Evidence of pairing reentrance in hot rotating nuclei
- Role of exact pairing on the pygmy dipole resonance (PDR)
- Simultaneous microscopic description of nuclear level density (NLD) and radiative strength function (RSF)
- Bubble nuclei within the self-consistent Hartree-Fock (HF) mean field + pairing approach

Because time limitation, I choose to highlight here only some most important results we have obtained in this topic of pairing in excited nuclei.

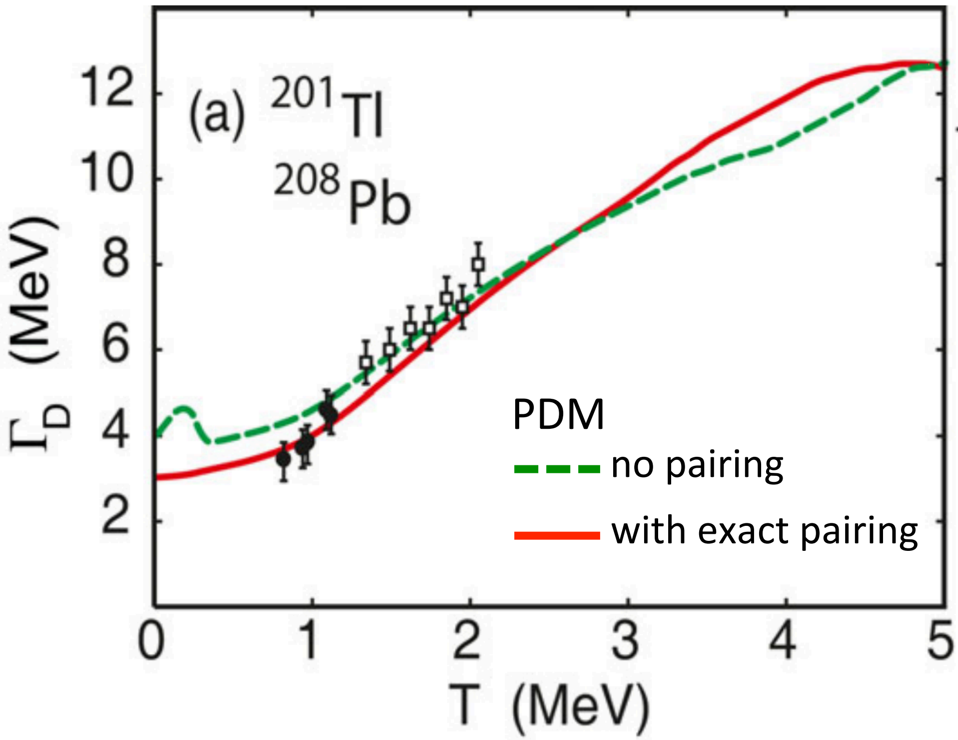
Pairing effect on GDR width at low T

NDD & Arima, PRC 68 (2003) 044304

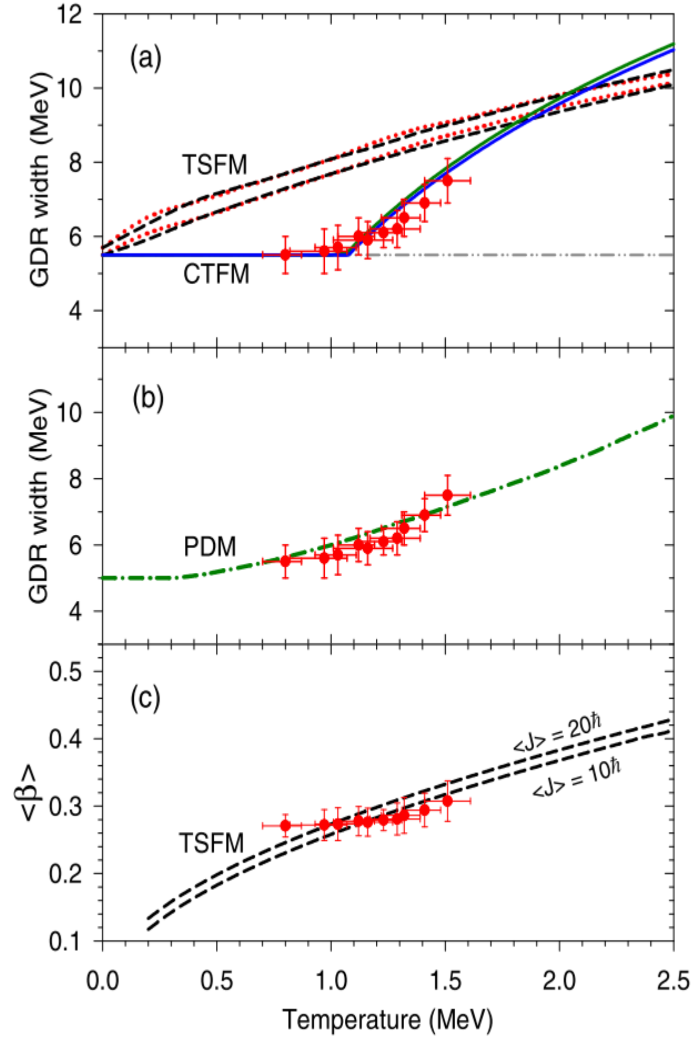


In this paper with Prof. Arima, we have shown for the first time how nuclear pairing, which does not vanish at a critical temperature of superfluid-normal phase transition, plays the crucial role to maintain a nearly temperature-independent width of the GDR in an open-shell nucleus, ^{120}Sn, at low temperature $T \leq 1$ MeV.

The red curve is the result of PDM without pairing;
The green curve shows the result including thermal pairing obtained within the modified BCS theory, which has been proposed by Zelevinsky, Arima, and myself in 2001.



NDD & Quang Hung, PRC 86 (2012) 044333.



B. Dey et al., PLB 731 (2014) 92.

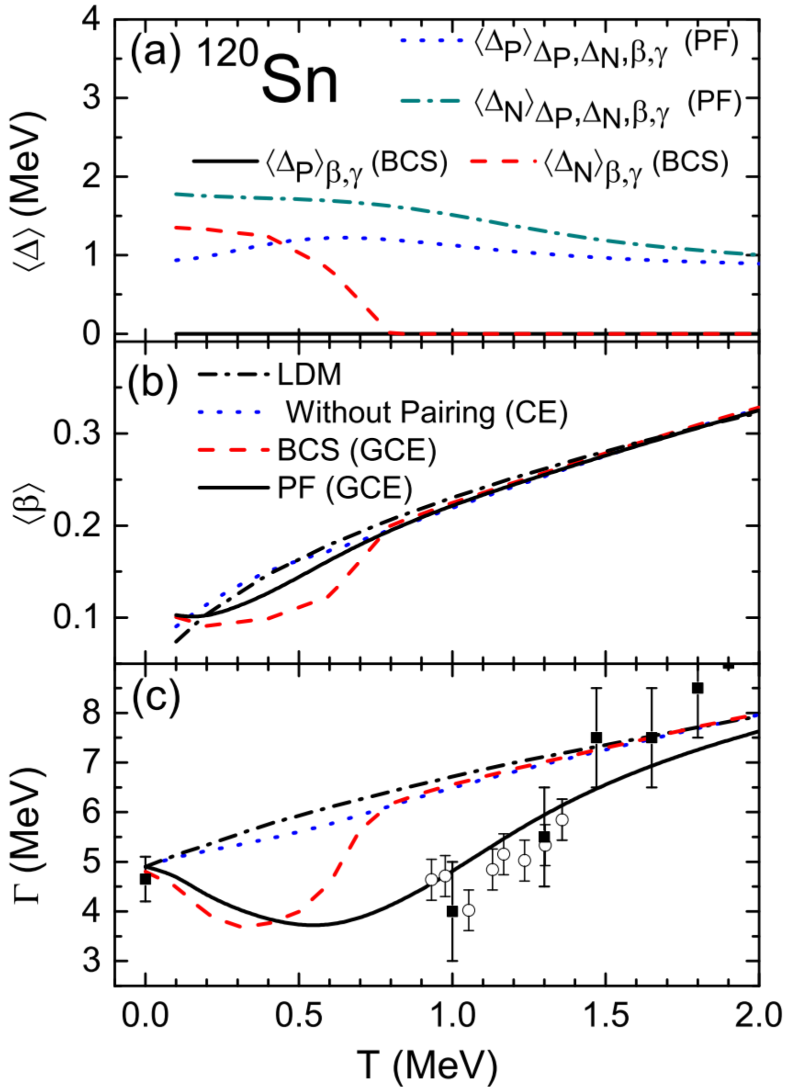
Fig. 5. (a) GDR width as a function of temperature. Experimental data (symbols) have been compared with the TSFM calculations with shell effect (dotted lines) and without shell effect (dashed lines) are shown for $\bar{J} = 0\hbar$ (lower) and $\bar{J} = 30\hbar$ (upper). The CTFM predictions for $\bar{J} = 10\hbar$ (lower) and $\bar{J} = 20\hbar$ (upper) are shown with continuous lines. The double dot-dashed line represents the ground state value of the GDR width. (b) The PDM prediction is shown by the dotted–dashed. (c) The empirical deformations (symbols) extracted from the experimental GDR widths compared with the TSFM predictions (dashed lines) at two angular momenta.

Later, in collaboration with Dr. Nguyen Quang Hung, my former PhD student, who is now professor of physics and director of the Institute of Fundamental and Applied sciences at Duy Tan University in Vietnam, by including exact pairing in the PDM, we showed that this effect is indeed robust.

Since then the PDM has been often used by the experimentalists from Krakow (Adam Maj's group) and Kolkata (at VECC) as the theoretical support for their experimental data as its description is much better than that given by the TSFM. In the life figure are some recent results of how the PDM describes the GDR width in ^{97}Tc, which was formed as the compound nucleus in the alpha particle fused with ^{93}Nb at 42 MeV incident energy.

Inclusion of pairing fluctuations in TSFM

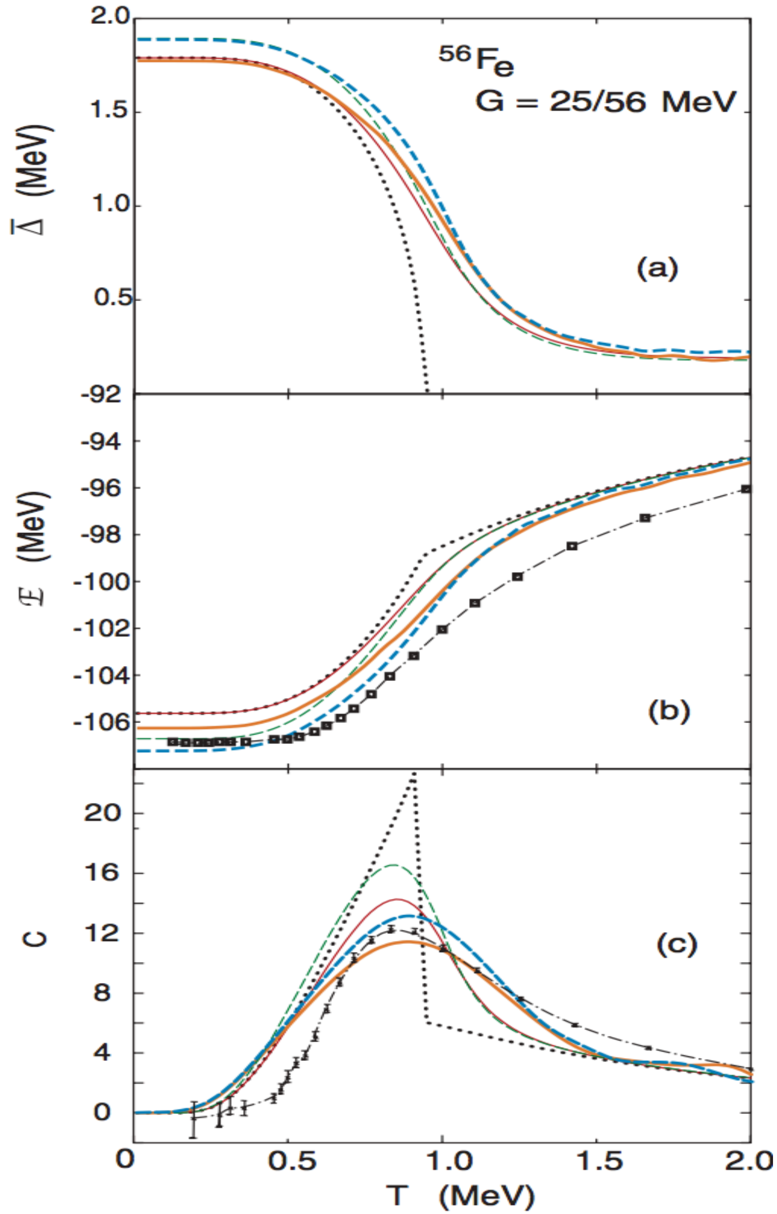
Kumar, Arumugam, NDD, PRC 91 (2015) 044305



In collaboration with Indian theorists at the Indian Institute of Technology Roorkee, we have also included thermal pairing in the TSFM, and in this way, greatly improved the description of the GDR width by this model as well.

BCS + quasiparticle number fluctution

NDD & Nguyen Quang Hung, PRC 77 (2008) 064315



Level weighted pairing gaps, total energies, and heat capacities for 10 neutrons in the $1f_{7/2}$, $2p_{3/2}$, $2p_{1/2}$, $1f_{5/2}$ shell of ^{56}Fe as functions of T.

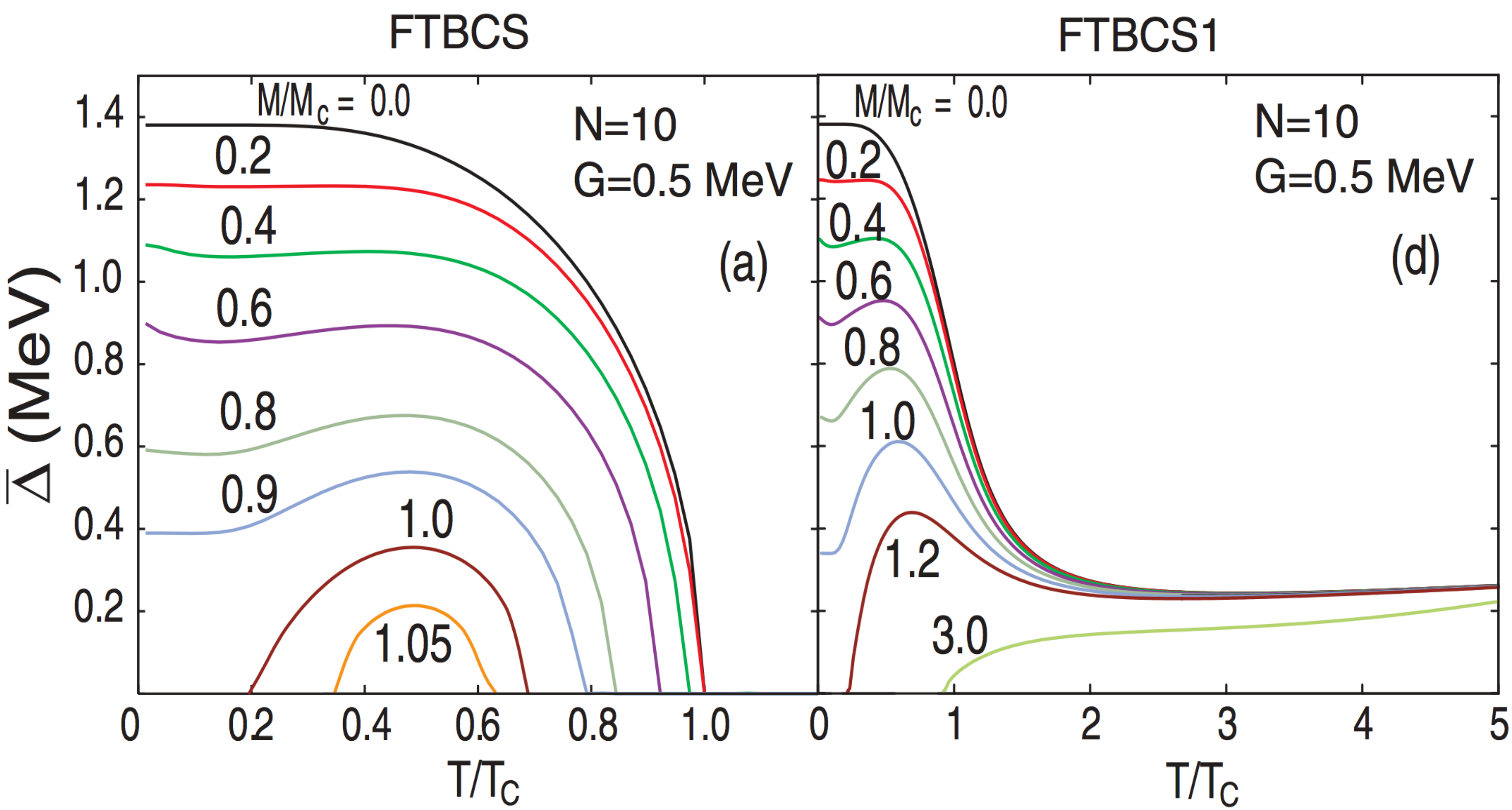
The dotted, thin solid, and thick solid lines show the FTBCS, FTBCS1, and FTBCS1+SCQRPA results, respectively. The predictions by the FTLN1 and FTLN1+SCQRPA are presented by the thin and thick dashed lines, respectively.

The predictions by the finite-temperature quantum Monte Carlo method are shown as boxes and crosses with error bars connected by dash-dotted lines.

Ten years ago, we proposed an improvement of the BCS theory, which includes quasiparticle-number fluctuations. As the result, the gap does not collapse at the critical temperature of the superfluid-normal phase transition, but remains finite at higher temperatures. So the phase transition is smoothed out. This approach, which we call FTBCS1, is qualitatively similar to the modified BCS, which Zelevinsky, Professor Arima and I proposed in 2001, but it does not use the secondary Bogoliubov transformation of the MBCS.

Pairing reentrance in hot rotating nuclei

Nguyen Quang Hung & NDD, PRC 78 (2008) 064315, 84 (2011) 054324

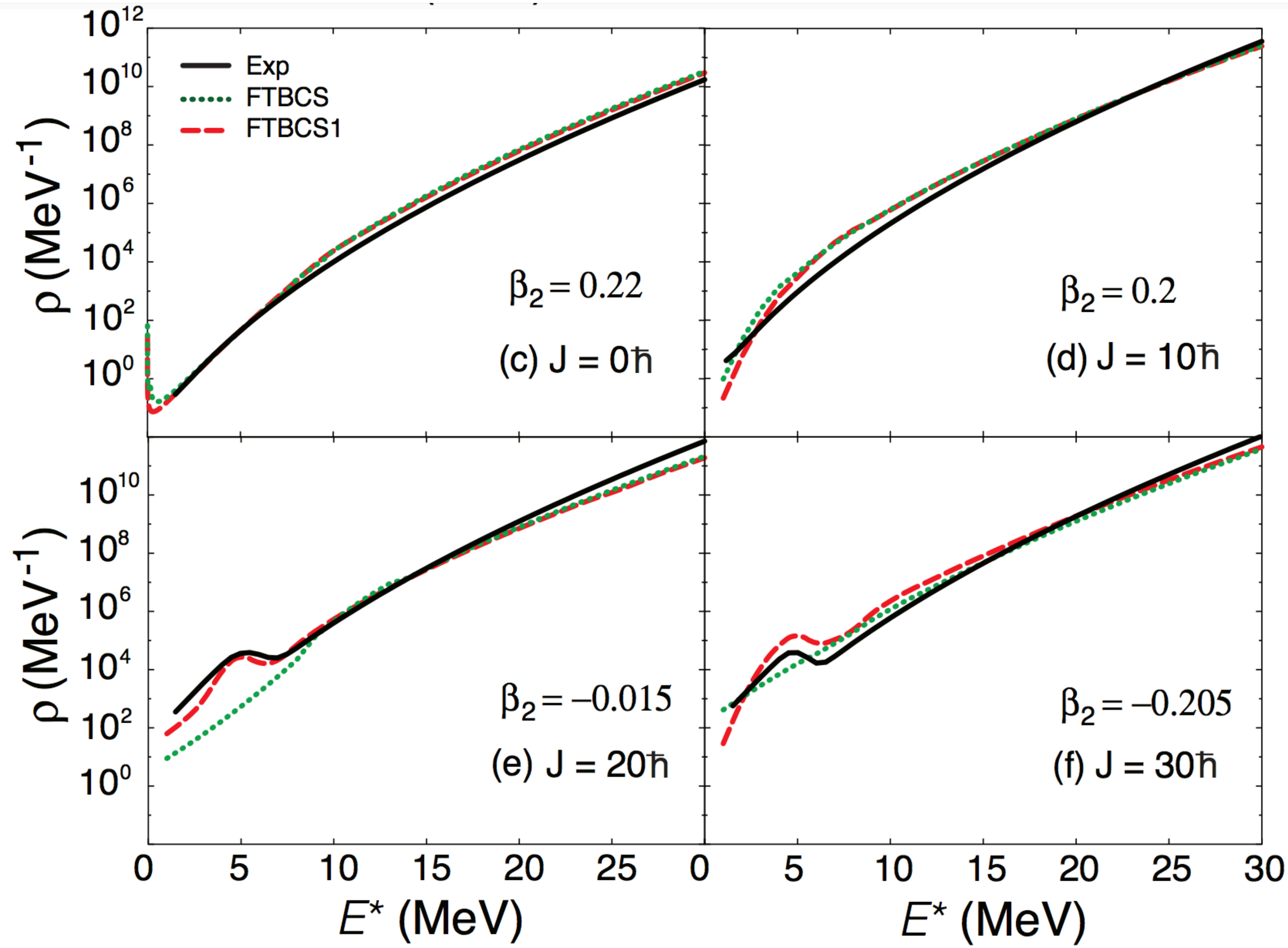


We also extended the FTBCS1 to include angular momentum (in terms of non-collective rotation), and obtained the pairing reentrance effect in finite nuclei, that is, with increasing the angular momentum, pairing reappears at a certain temperature.

As compared with the BCS for infinite systems, the pairing reentrance does not disappears at high T due to quasiparticle-number fluctuations.

Experimental evedience of pairing reentrance in hot rotating ^{104}Pd

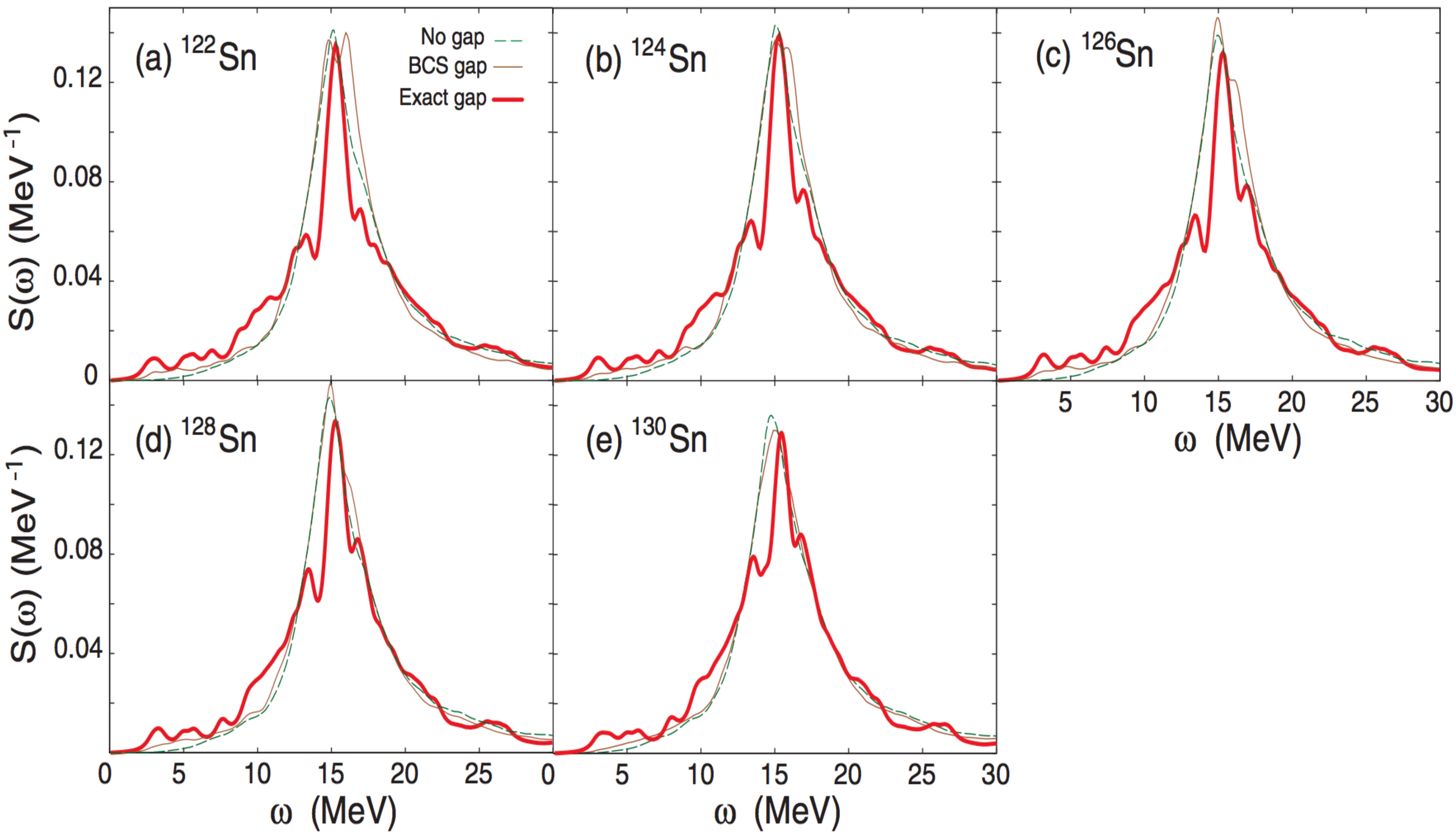
Nguyen Quang Hung, NDD, Agrawal, Datar, Mitra, Chakrabarty,
Acta Physica Polonica Proc. Supl. 8 (2015) 551



The first experimental evidence of pairing reentrance was seen in the experimentally extracted nuclear level density in ^{104}Pd in the reaction ^{12}C + ^{93}Nb $\rightarrow$ ^{105}Ag* $\rightarrow$ ^{104}Pd* + p at incident energy of 40 – 45 MeV by the VECC experimentalists.

Role of exact pairing on the PDR

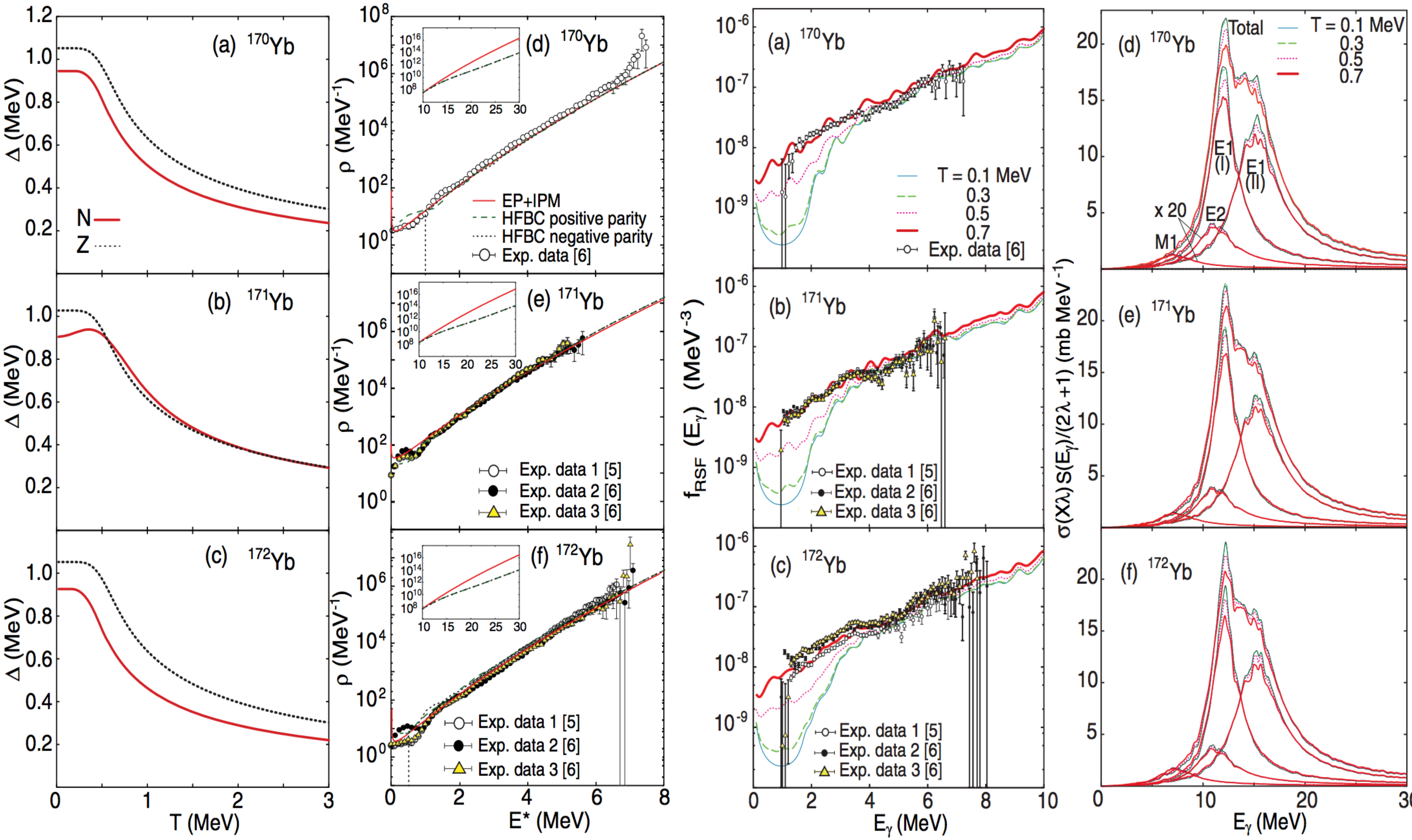
NDD & N. Quang Hung, JPG 40 (2013) 105103



With Prof. Nguyen Quang Hung, we have also shown the importance of exact pairing on the pygmy dipole resonance. The calculations showed that PDR becomes more pronounced by using exact pairing.

Simultaneous microscopic description of NLD and RSF

Quang Hung, NDD, Quynh Huong, PRL 118 (2017)



Last year, in collaboration with Nguyen Quang Hung and his PhD student Le Thi Quynh Huong, we proposed a microscopic approach, which is able to simultaneously describe bot the nuclear level density and gamma-radiative strength funtion. This work was published in PRL in January 2017 and was reported in the RIKEN Press Release at the same time.

The good agreement between the results of calculations and experimental data extracted by the Oslo group for Yb isotopes shows the importance of exact thermal pairing in the description of NLD at low and intermediate excitation energies. It also invalidates the assumption based on the Brink-Axel hypothesis in the description of the RSF.

N. Quang Hung, RIKEN APA (2006 – 2009), PhD (2009), Nishina Fellow (2009 – 2010), Assoc. Prof. (2014)
L.T. Quynh Huong, PhD student of N. Quang Hung

This is the picture of the co-authors of this paper. You see here the representatives of three generations of nuclear theorists of Vietnam.

News on Vietnam National TV 22 Feb. 2017

As our paper is the first one in nuclear physics with all authors being Vietnamese ever published in PRL, it got a big news coverage in Vietnam, including the national TV. This is the video footage taken from the Vietnam national TV broadcast in February of last year.

Bubble nuclei within the SC-HF mean field + pairing approach

Tan Phuc, Quang Hung, NDD, PRC 97 (2018) 024331

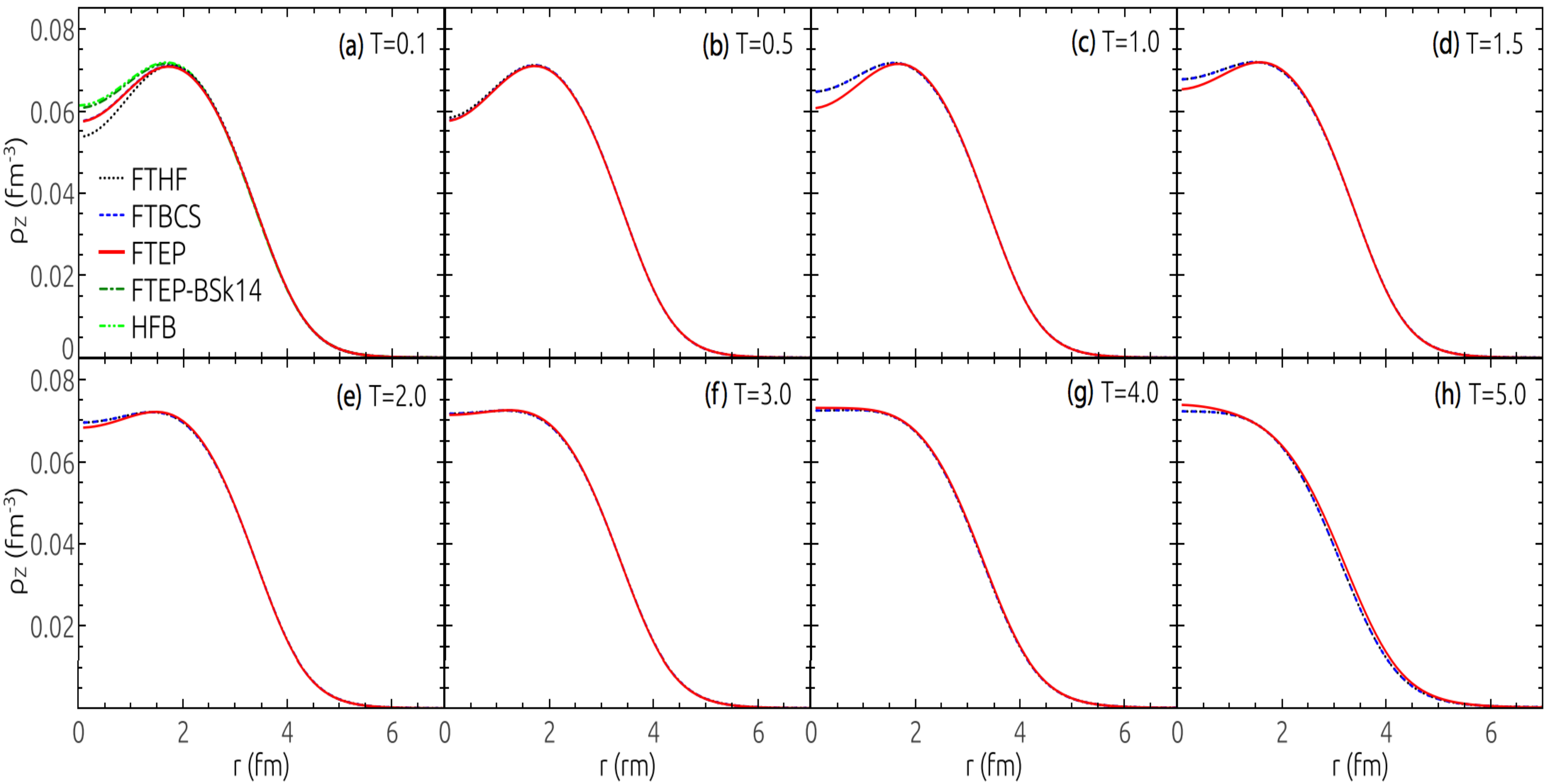


FIG. 7. Proton density $\rho_Z(r)$ in ^{34}Si obtained within the FTHF, FTBCS, and FTEP at several temperatures.

One of the most recent works in this series was our study of bubble nuclei including exact pairing.

Here, with Nguyen Tan Phuc, another PhD student of my former PhD student Nguyen Quang Hung, we calculated the depletion of the nuclear density at its center, called the nuclear bubble, within the Skyrme Hartree-Fock mean field consistently incorporating exact pairing for ^{22}O and ^{34}Si nuclei. Their bubble structures, caused by a very low occupancy of the $2s_{1/2}$ level, were previously predicted at T = 0.

As compared to the approaches employing the same BSk14 interaction, our approach with exact pairing predicts a pairing effect which is stronger in ^{22}O and weaker in ^{34}Si. The increase in temperature depletes the bubble structure and completely washes it out when the temperature reaches a critical value.

Bubble nuclei within the SC-HF mean field + pairing approach

Tan Phuc, Quang Hung, NDD, PRC 97 (2018) 024331

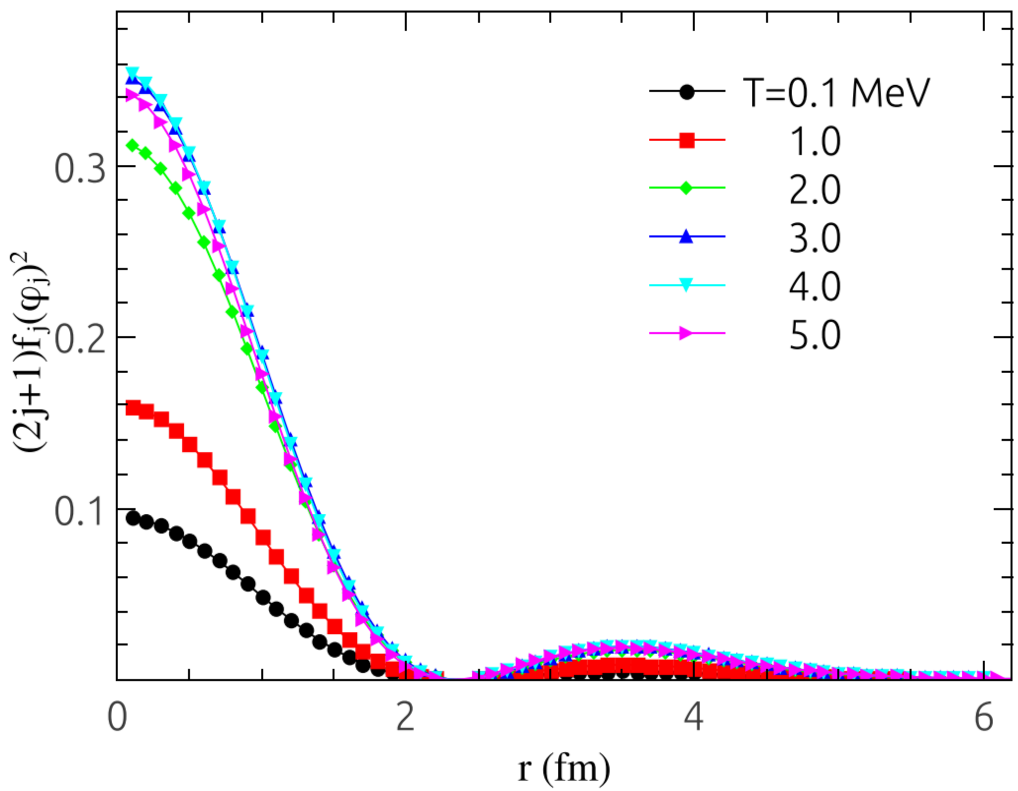


FIG. 10. Wave function of the proton $2s_{1/2}$ level in ^{34}Si obtained within the FTEP at several temperatures.

Pairing in highly-excited nuclei

N. Quang Hung, N. Dinh Dang, and L.G. Moretto

Invited review in Reports on Progress in Physics

All these results are included in our invited review on pairing in excited nuclei to be published in Reports on Progress in Physics. I am very happy that Luciano Moretto is one of our co-authors. He is a pioneer in the study of thermal pairing in nuclei, whose seminal works in the 70s have inspired me to pursuit this subject for more than three decades.

“It is, indeed, only in old age that intellectual men attain their sublime expression, whilst portraits of them in their youth show only the first traces of it.”

Arthur Schopenhauer

Nguyen Dinh Dang
Mother (2018)
oil on canvas, 91 x 72.7 cm

Coming back to the main reason, which made us get together here, I promised Prof. Arima yesterday to show him and you my latest paintings. You see here one of them, which was shown at the 54th exhibition of the Shyutai Bijyutsu Kyoukai (主体美術教会 = Association of Individual artists) in Tokyo Metropolitan Art Museum in the first half of this month. I am a member of this association. This is the portrait of my mother, who is 94 this year.

This portrait recalled the words by the renown German philosopher Arthur Schopenhauer, which I would like to recite as the conclusion of this talk: "*It is, indeed, only in old age that intellectual men (and women) attain their sublime expression, whilst portraits of them in their youth show only the first traces of it*."

I would like to wish Professor Akito Arima an excellent health for many many more years to come, so that he could continue to enjoy doing physics and writing haiku poems.

Thank you very much.