Nuclear Theory Group

DUY TÂN UNIVERSITY

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Institute of Research and Development

Danang, Mar. 8-11, 2017

Content

- Group members
- Research Topics
  - Past
  - Present
  - Future
- Conclusion

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Assoc. Prof.

L. Tan Phuc
PhD Stud.

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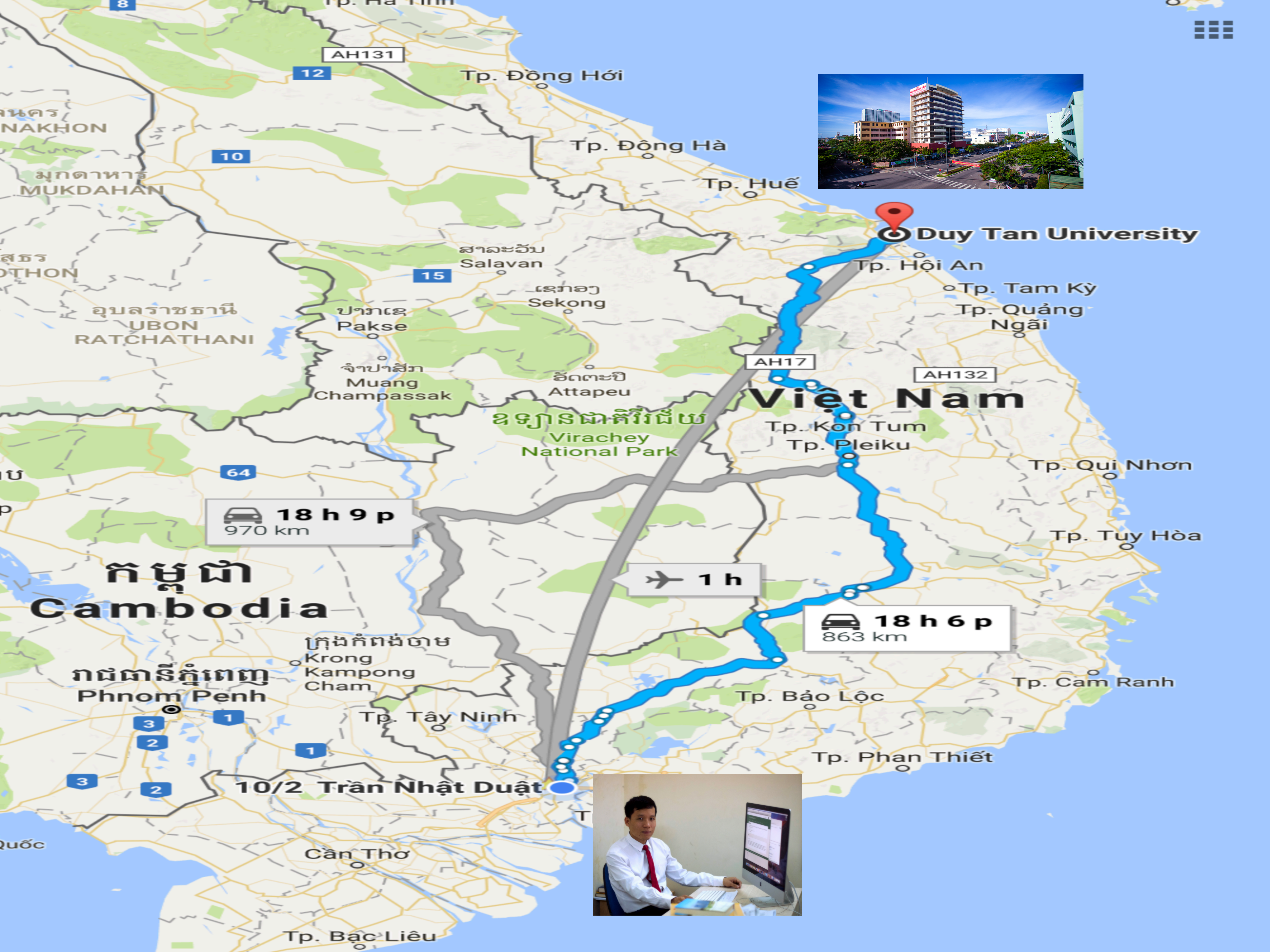

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Tp. Huế
Duy Tan University
Tp. Hội An
Tp. Tam Kỳ
Tp. Quảng Ngãi
Salavan
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Sekong
Pakse
UBON RATCHATHANI
AH17
AH132
Muang Champassak
Attapeu
Việt Nam
Virachey National Park
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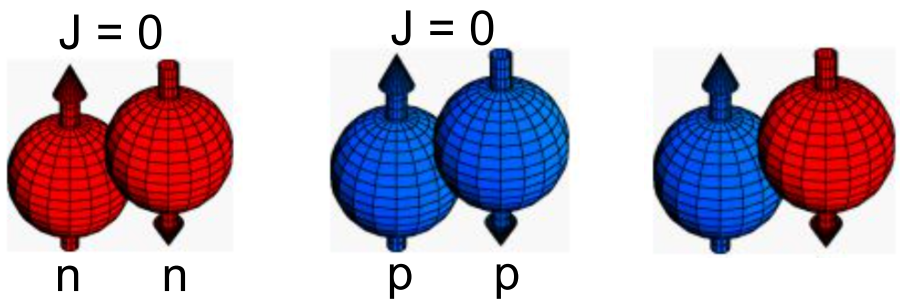
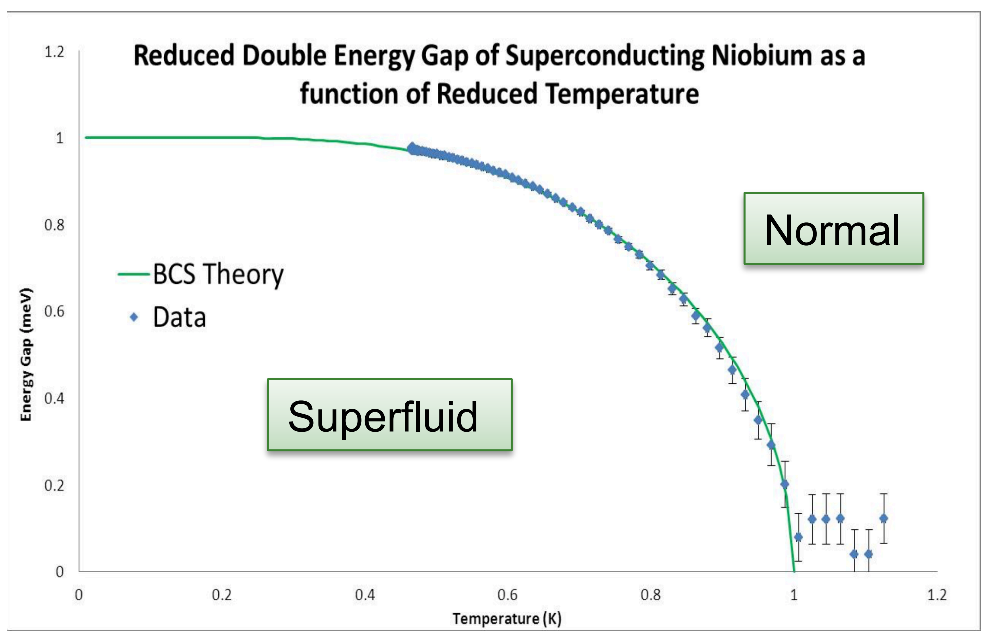
Cambodia
18 h 6 p
863 km
Krong Kampong Cham
Phnom Penh
Tp. Bảo Lộc
Tp. Cam Ranh
Tp. Tây Ninh
Tp. Phan Thiết
10/2 Trần Nhật Duật
Cần Thơ
Tp. Bạc Liêu

Research Topics

- Past Research Topics:
  - ✧ *Pairing Properties in Hot Rotating Nuclei*

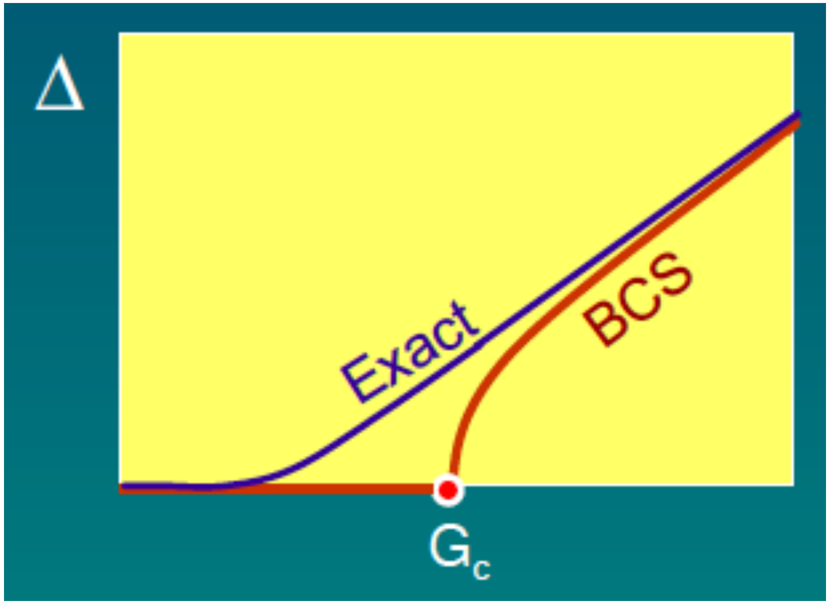


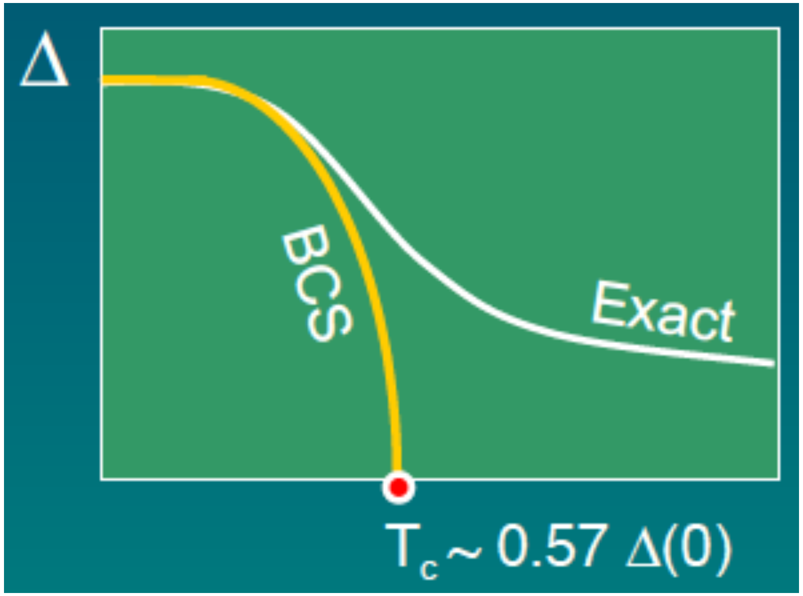
J. Bardeen, L. Cooper, and J. Schrieffer, Phys. Rev. ***108****, 1175 (1957)*



Shortcomings of the BCS

T = 0	T ≠ 0
➢ *Particle-number violation*	➢ *No thermal fluctuations*
➢ *Collapse at $G \leq G_C$*	➢ *Collapse at $T \geq T_C$*





Past Research Topics

Pairing in Hot Nuclei

Macroscopic Landau theory

*L. G. Moretto, Phys. Lett. B **40**, 1 (1972)*

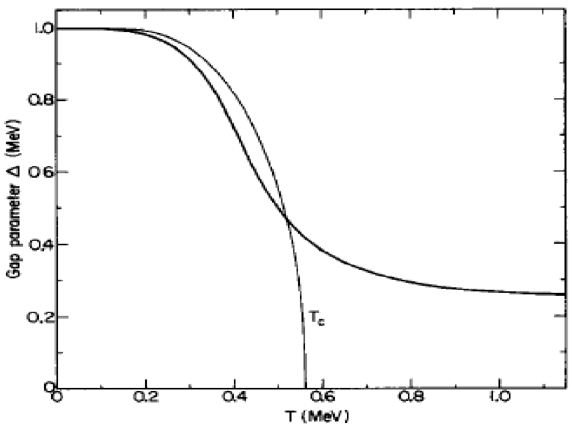


Fig. 2. The average gap parameter (thick line) and th most probable gap parameter is a function of temper ature.

HFB at finite temperature

*A. Goodman, Phys. Rev. C **29**, 1887 (1984)*

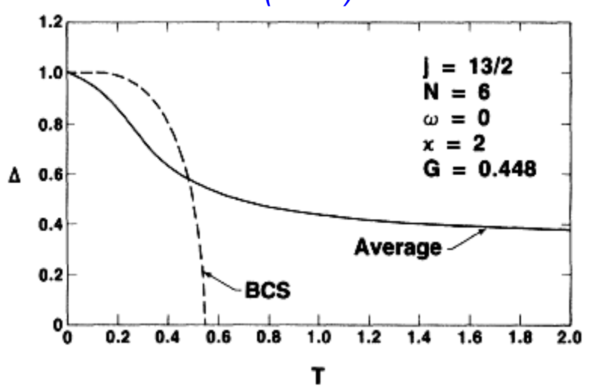
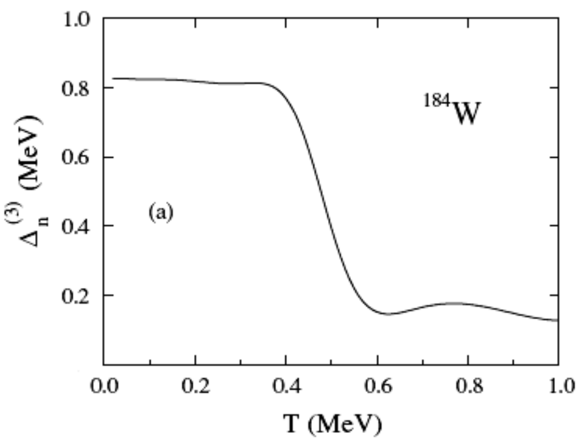


FIG. 15. The pair gap Δ versus the temperature T for $\omega=0$. The dashed curve is the BCS or most probable Δ, and the solid curve is the average Δ.

From experimentally extracted gap

*K. Kaneko and M. Hasegawa, Phys. Rev. C **72**, 024307 (2005)*

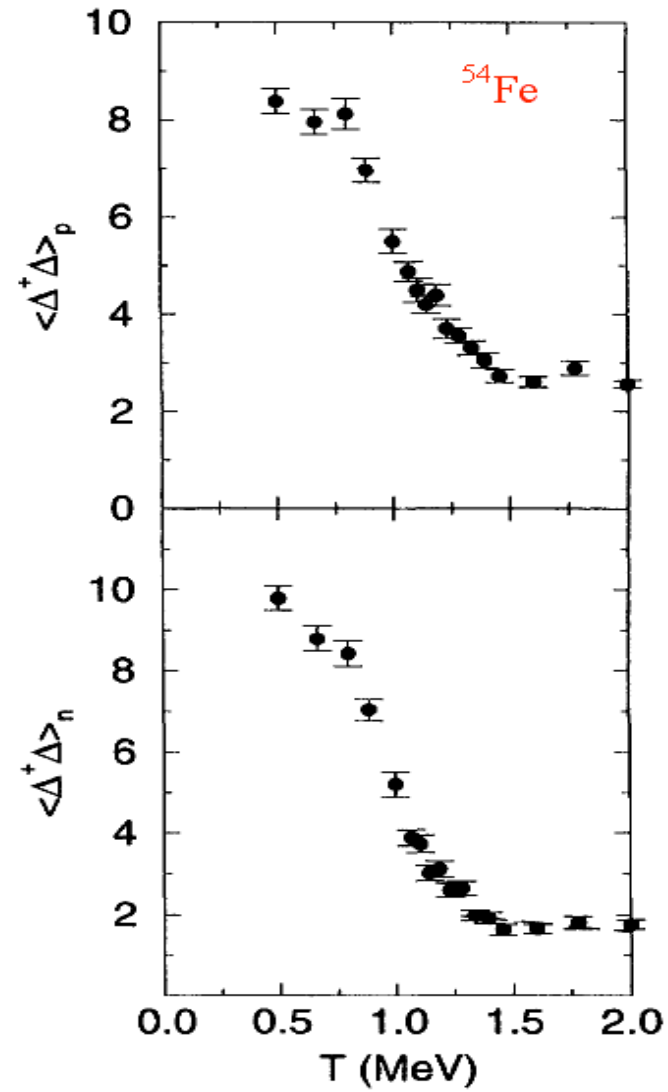


In finite nuclei, thermal fluctuations smooth out the sharp superfluid-normal (SN) phase transition

Thermal fluctuations ?

Shell-model Monte-Carlo

*Dean et. al, Phys. Rev. Lett. **74**, 2909 (1995)*



Past Research Topics

Pairing in Hot Nuclei

Modified BCS (MBCS):

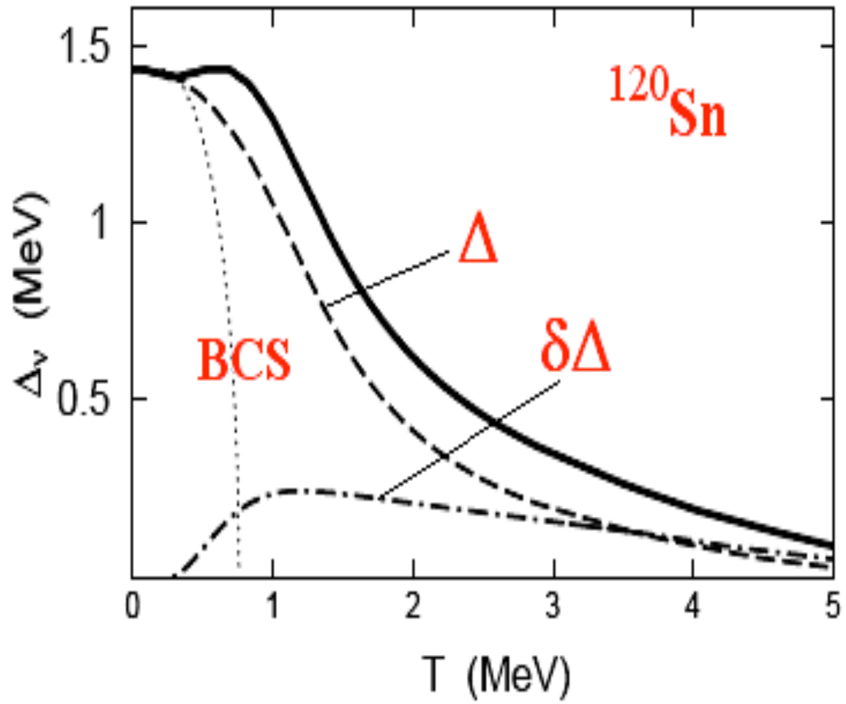
N. Dinh Dang and V. Zelevinsky, Phys. Rev. C ***64****, 064319 (2001);*

N. Dinh Dang and A. Arima, Phys. Rev. C ***67****, 014304 (2003).*

$$\overline{\Delta} = \Delta_{quantal} + \delta\Delta_{thermal} = G\sum_j u_j v_j (1-2n_j) + G(1-2v_j^2)\delta N_j$$

$$\delta N_j = \sqrt{n_j(1-n_j)}\ ;\ n_j = \left[1+e^{E_j/T}\right]^{-1}$$

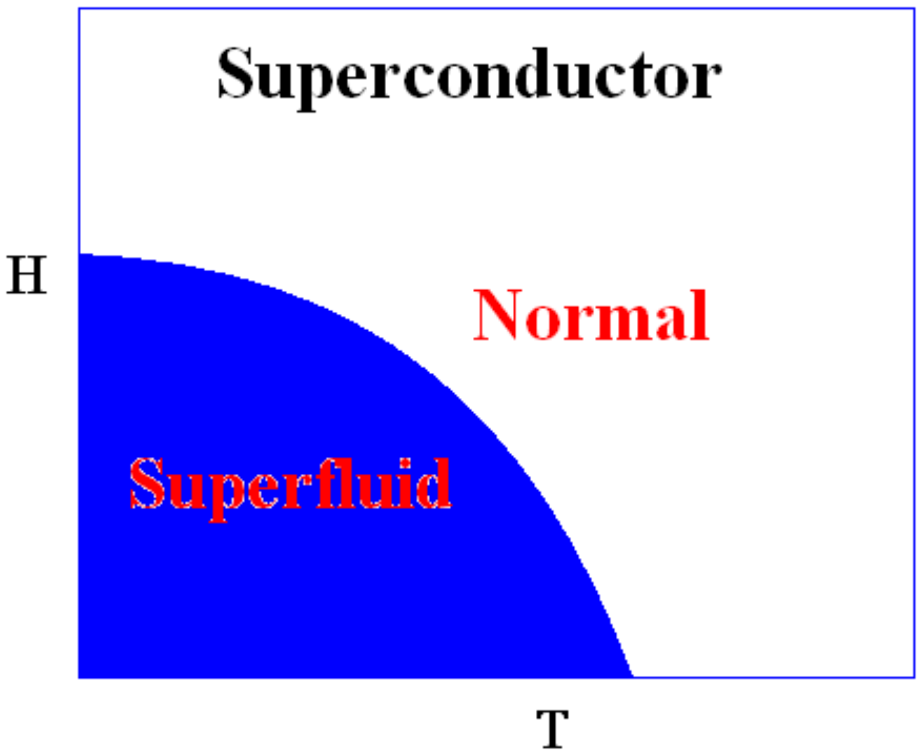
Quasiparticle-number fluctuations (QNF)



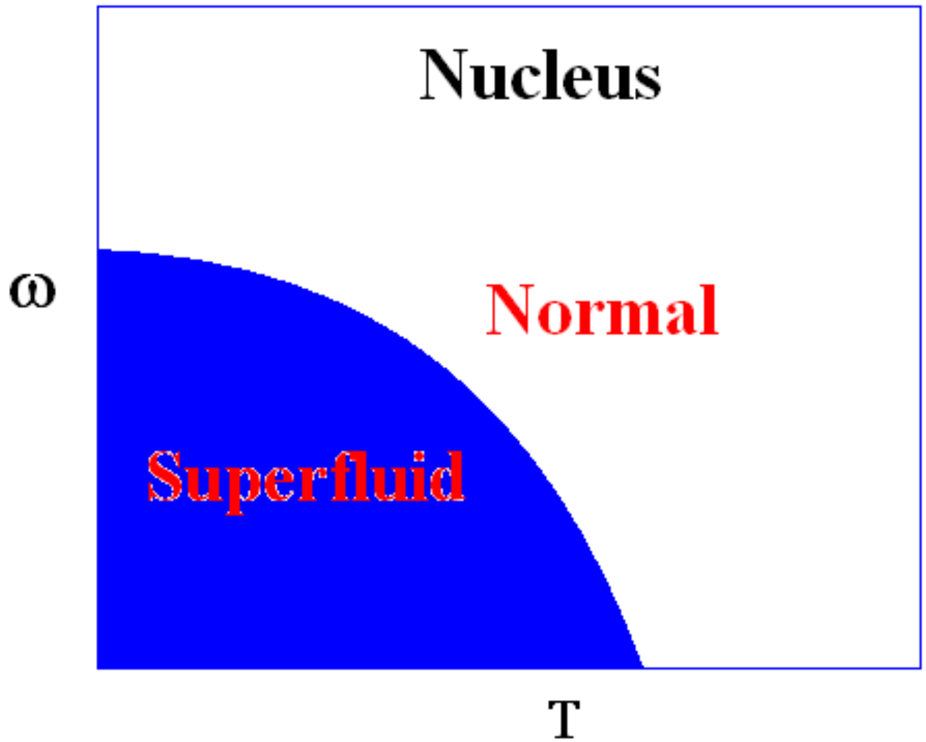
Past Research Topics

Pairing in Hot Rotating Nuclei

Magnetic field H



Angular momentum (velocity)



*A. Goodman, Nucl. Phys. A **369**, 365 (1981)*

Past Research Topics

Pairing Reentrance

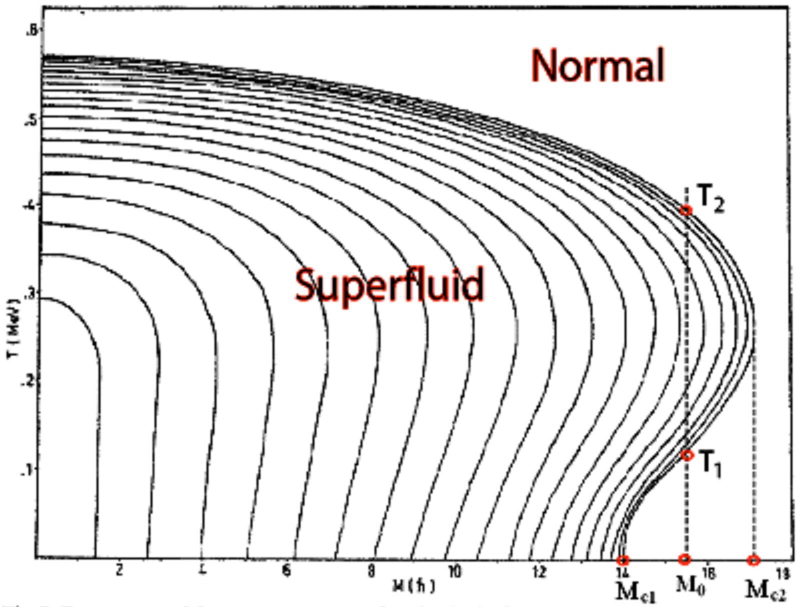
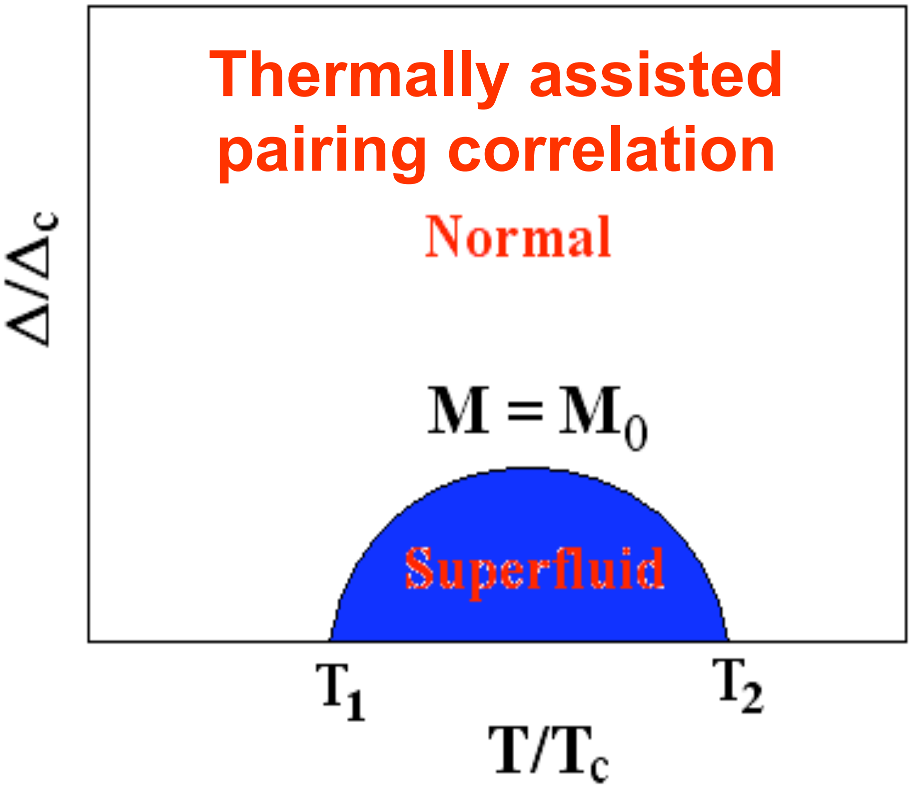
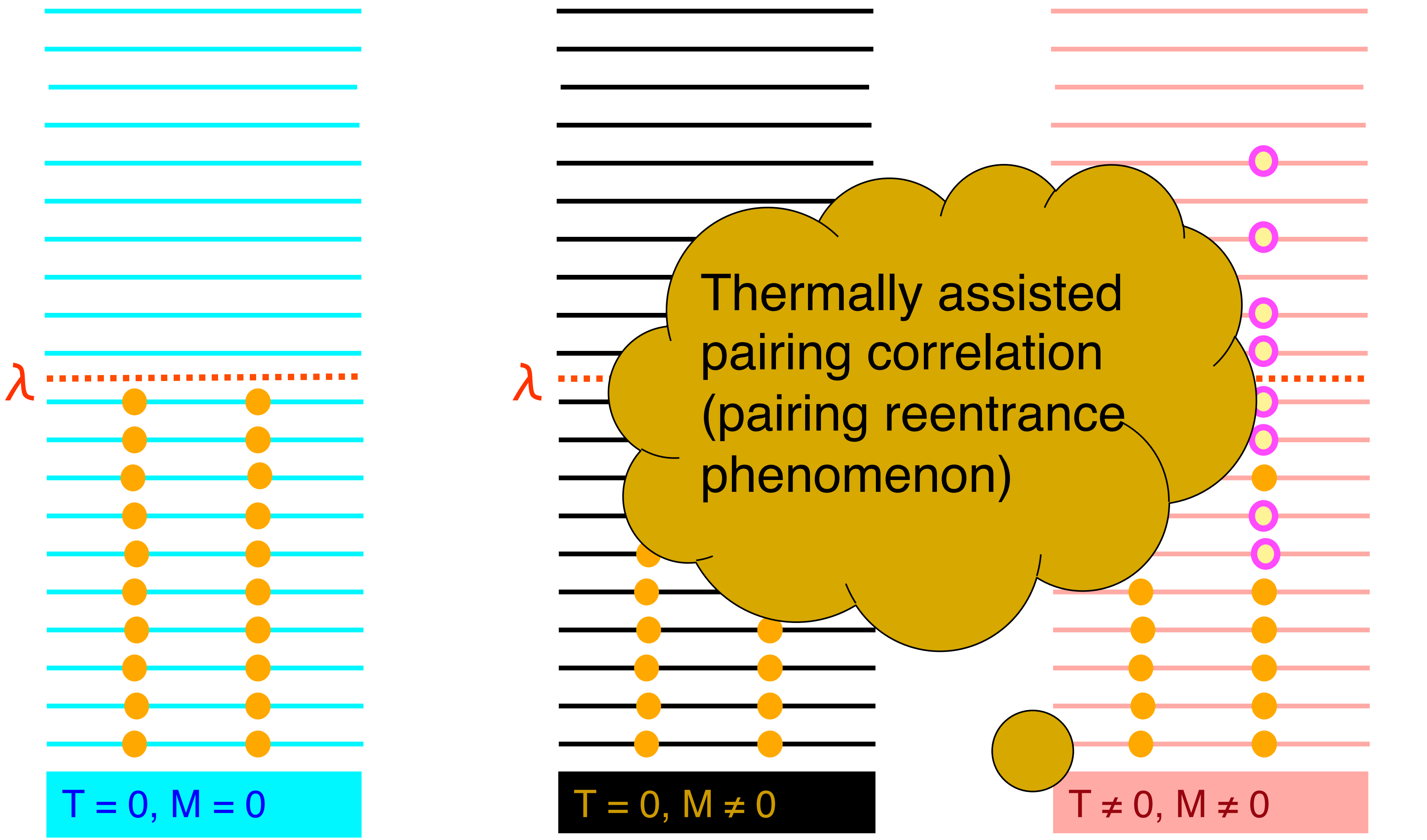


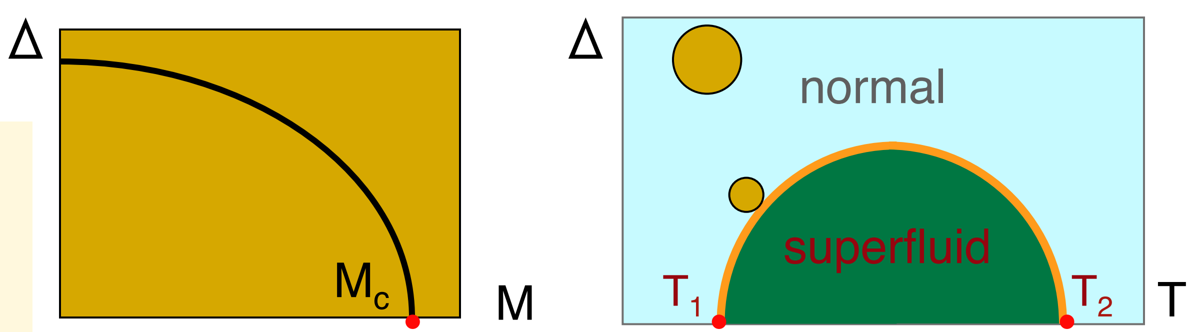
Fig. 7. Contour map of the gap parameter as a function both of temperature and angular momentum. The spacing in Δ between two successive lines is 0.05 MeV from $\Delta = 1.0$ MeV to $\Delta = 0.1$ MeV. The outer line corresponds to $\Delta = 0$ MeV.

Non-collective Rotation



L. G. Moretto, Phys. Lett. B ***35****, 379 (1971);*
Nucl. Phys. A ***185****, 145 (1972); Nucl. Phys. A* ***216****, 1 (1973)*



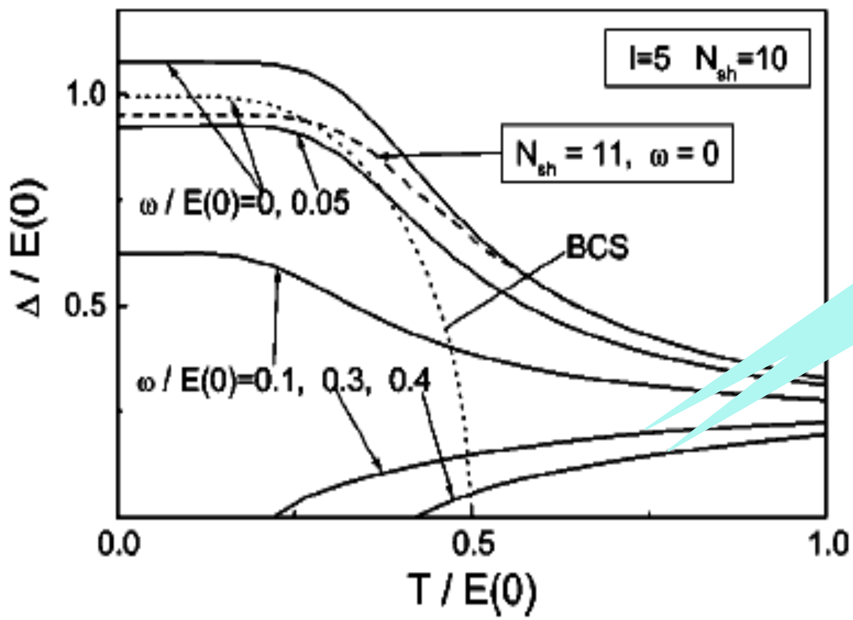


*L. G. Moretto, Nucl. Phys. A **185**, 145 (1972);*
*R. Balian, H. Flocard, M. Vénéroni, Phys. Rep. **317**, 251 (1999)*

Past Research Topics

Pairing Reentrance

Exact solution of degenerate model, canonical ensemble for cluster and nuclei



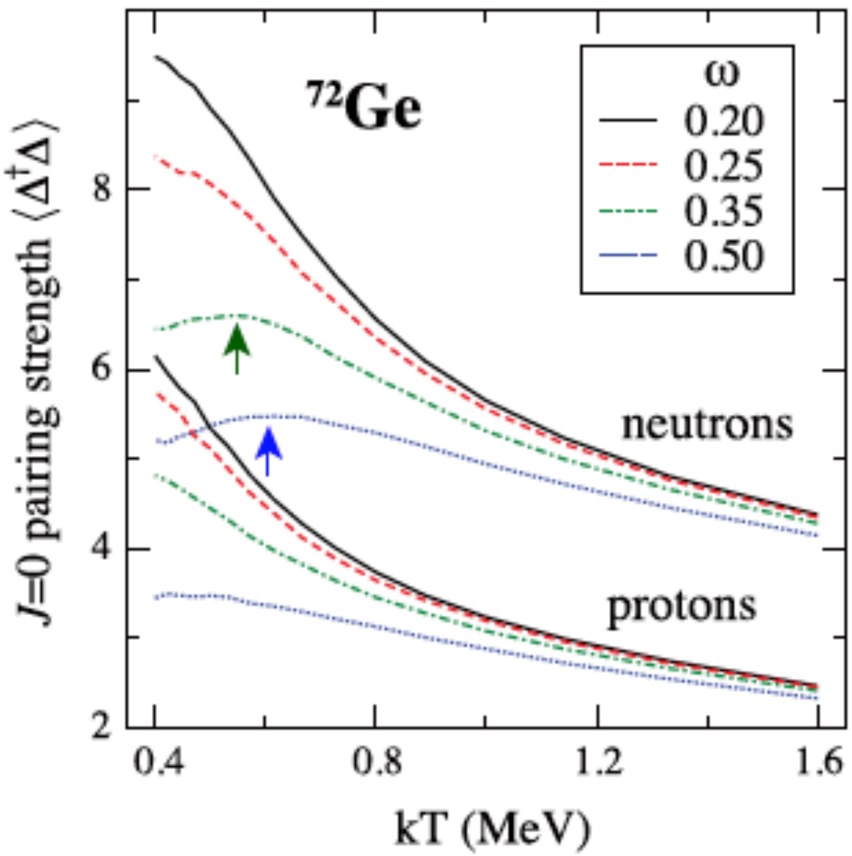
Temperature induced pair correlation

FIG. 2. Canonical gap $\Delta_{can}(T,\omega)$ for even (full lines) and odd (the dashed line) particle numbers, and the mean-field gap $\Delta_{mf}(T,\omega)$ (dotted line -BCS) vs the temperature T for a spherical shell.

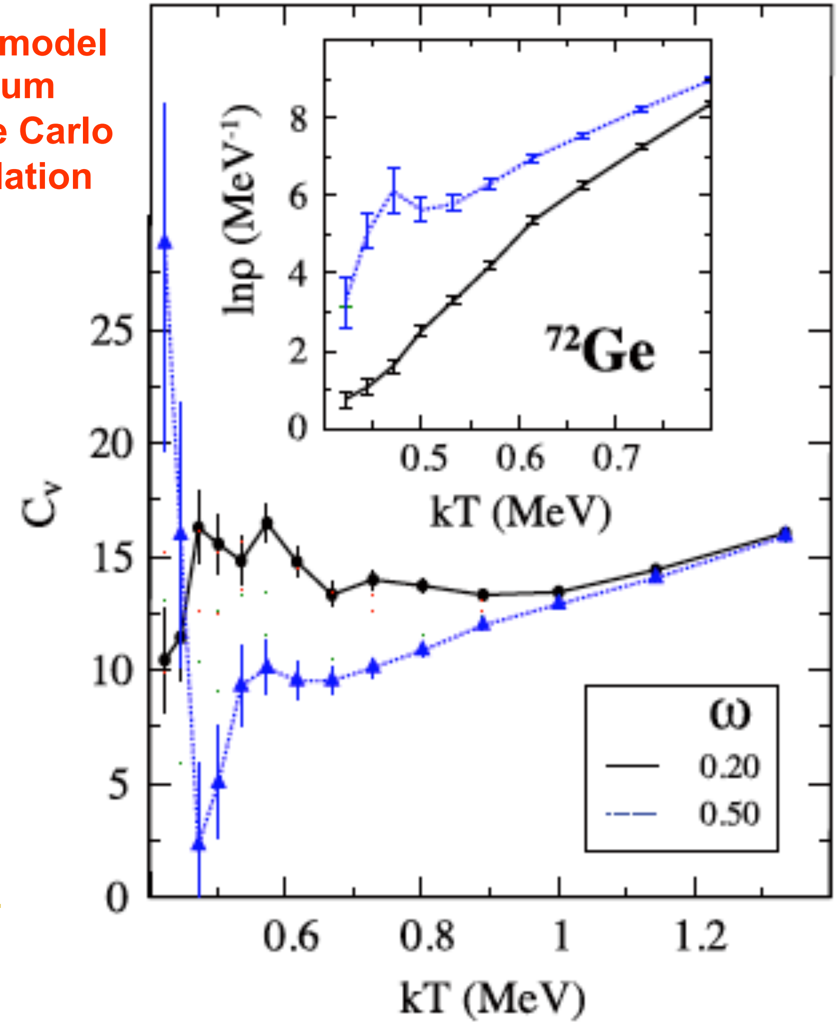
S. Frauendoft et al., Phys. Rev. B ***68****, 024518 (2003)*

Past Research Topics

Pairing Reentrance



Shell model quantum Monte Carlo calculation



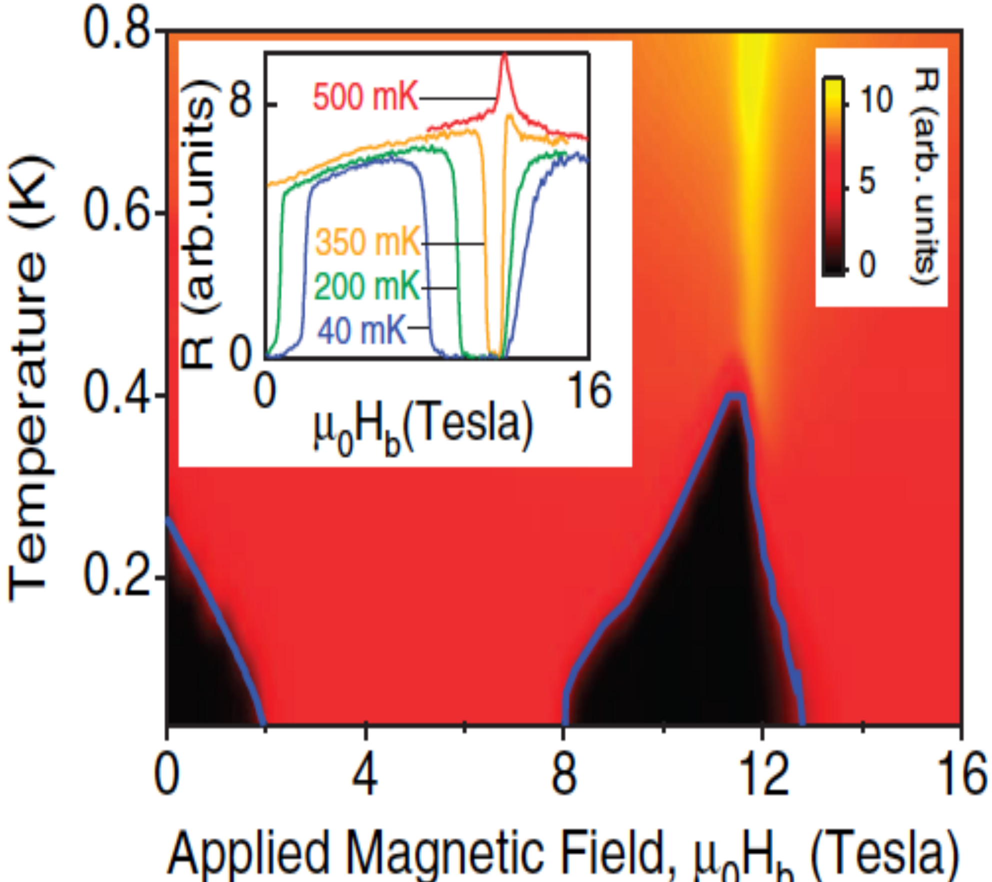
D.J. Dean, K. Langanke, H. Nam, and W. Nazarewicz, Phys. Rev. Lett. **105**, 212504 (2010)

Magnetic Field-Induced Superconductivity in the Ferromagnet URhGe

F. Lévy *et al.*
Science **309**, 1343 (2005);
DOI: 10.1126/science.1115498

- **T < T_c** (290 mK) and **H ~ 2T**: *superconductivity* (R = 0)
- **2T < H < 8T** *no superconductivity*
- **T ~ 400 mK** and **8T < H < 13T**: *superconductivity reappeared*

R: Resistivity



FTBCS1 at T≠0 & M≠0

Pairing Hamiltonian including z-projection of total angular momentum:

$$H' = H - \lambda\hat{N} - \gamma\hat{M},$$

$$H = \sum_{k,\sigma=\pm1} \varepsilon_k a^+_{k\sigma} a_{k\sigma} - G\sum_{kk'} a^+_{k+} a^+_{k-} a_{k'-} a_{k'+} ,$$

$$N = \sum_k (a^+_{k+} a_{k+} + a^+_{k-} a_{k-}) ,$$

$$M = \sum_k m_k (a^+_{k+} a_{k+} - a^+_{k-} a_{k-}) .$$

Bogoliubov transformation + variational procedure:

$$\Delta_k = \Delta + \delta\Delta_k ,$$

$$\Delta = G\sum_k u_k v_k \langle D_k \rangle , \quad \langle D_k \rangle = 1 - n_k^+ - n_k^- ,$$

$$\delta\Delta_k = G u_k v_k \frac{\delta N_k^2}{\langle D_k \rangle} ,$$

$$N = 2\sum_k \left[v_k^2 + \frac{1}{2}(1 - 2v_k^2)(n_k^+ + n_k^-) \right]$$

$$M = \sum_k m_k (n_k^+ - n_k^-)$$

$$u_k^2 = \frac{1}{2}\left(1 + \frac{\varepsilon'_k - \lambda}{E_k}\right), v_k^2 = \frac{1}{2}\left(1 - \frac{\varepsilon'_k - \lambda}{E_k}\right)$$

$$E_k = \sqrt{(\varepsilon'_k - \lambda - Gv_k^2)^2 + \Delta_k^2}$$

Quasiparticle-number fluctuation:

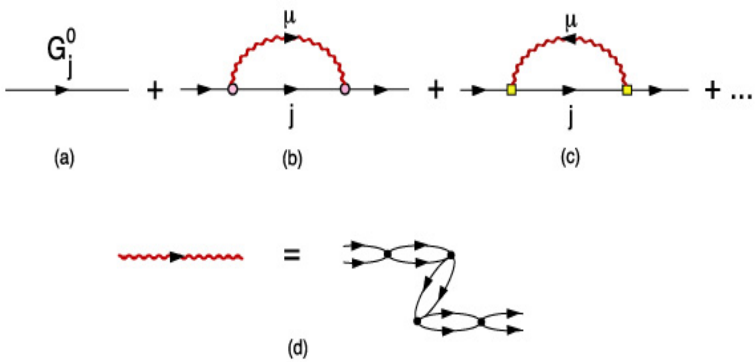
$$\delta N_k^2 = n_k^+ (1 - n_k^+) + n_k^- (1 - n_k^-)$$

$$\varepsilon'_k = \varepsilon_k + \frac{G}{\langle D_k \rangle} \sum_{k'} (u_{k'}^2 - v_{k'}^2)(\langle A_k^+ A_{k'}^+ \rangle + \langle A_k^+ A_{k'} \rangle) ,$$

$$A_k^+ = \alpha_{k+}^+ \alpha_{k-} .$$

FTBCS1: $$n_k^\pm = \frac{1}{1 + \exp[\beta(E_k \mp \gamma m_k)]} , \quad \langle A_k^+ A_{k'}^+ \rangle = \langle A_k^+ A_{k'} \rangle = 0 .$$

FTBCS1+SCQRPA at T≠0 & M≠0



$$G_k^{\pm}(E) = \frac{1}{2\pi}\frac{1}{E - \tilde{E}_k \mp \gamma m_k - M_k^{\pm}(E)} ,$$

$$\tilde{E}_k = b'_k + q_{kk} ,$$

$$b'_k = (\varepsilon_k - \lambda)\left(u_k^2 - v_k^2\right) + 2Gu_k v_k \sum_{k'} u_{k'} v_{k'} + G v_k^4 ,$$

$$q_{kk} = -G u_k^2 v_k^2 , \quad g_k(k') = G u_k v_k \left(u_{k'}^2 - v_{k'}^2\right) ,$$

$$M_k^{\pm}(E) = \sum_{\mu} \left(V_k^{\mu}\right)^2 \left[\frac{1 - n_k^{\pm} + \nu_{\mu}}{E - \tilde{E}_k \mp \gamma m_k - \omega_{\mu}} + \frac{n_k^{\pm} + \nu_{\mu}}{E - \tilde{E}_k \mp \gamma m_k + \omega_{\mu}}\right] ,$$

$$V_k^{\mu} = \sum_{k'} g_k(k') \sqrt{\langle D_{k'} \rangle} \left(X_{k'}^{\mu} + Y_{k'}^{\mu}\right) , \quad \gamma_k^{\pm}(\omega) = -\Im m\left[M_k^{\pm}(\omega \pm i\varepsilon)\right] .$$

$$n_k^{\pm} = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{\gamma_k(\omega)\left(e^{\beta\omega} + 1\right)^{-1}}{\left[\omega - \tilde{E}_k \mp \gamma m_k - M_k(\omega)\right]^2 + \gamma_k^2(\omega)} d\omega$$

Past Research Topics

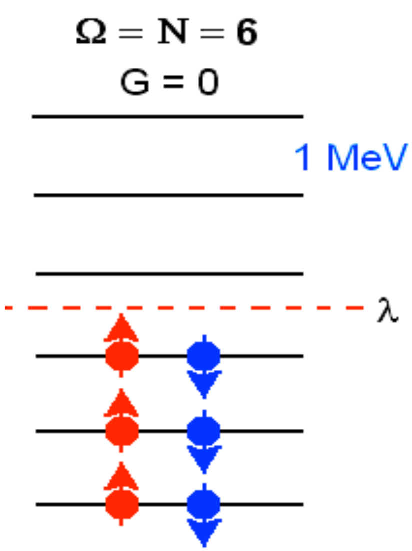
Our methods:

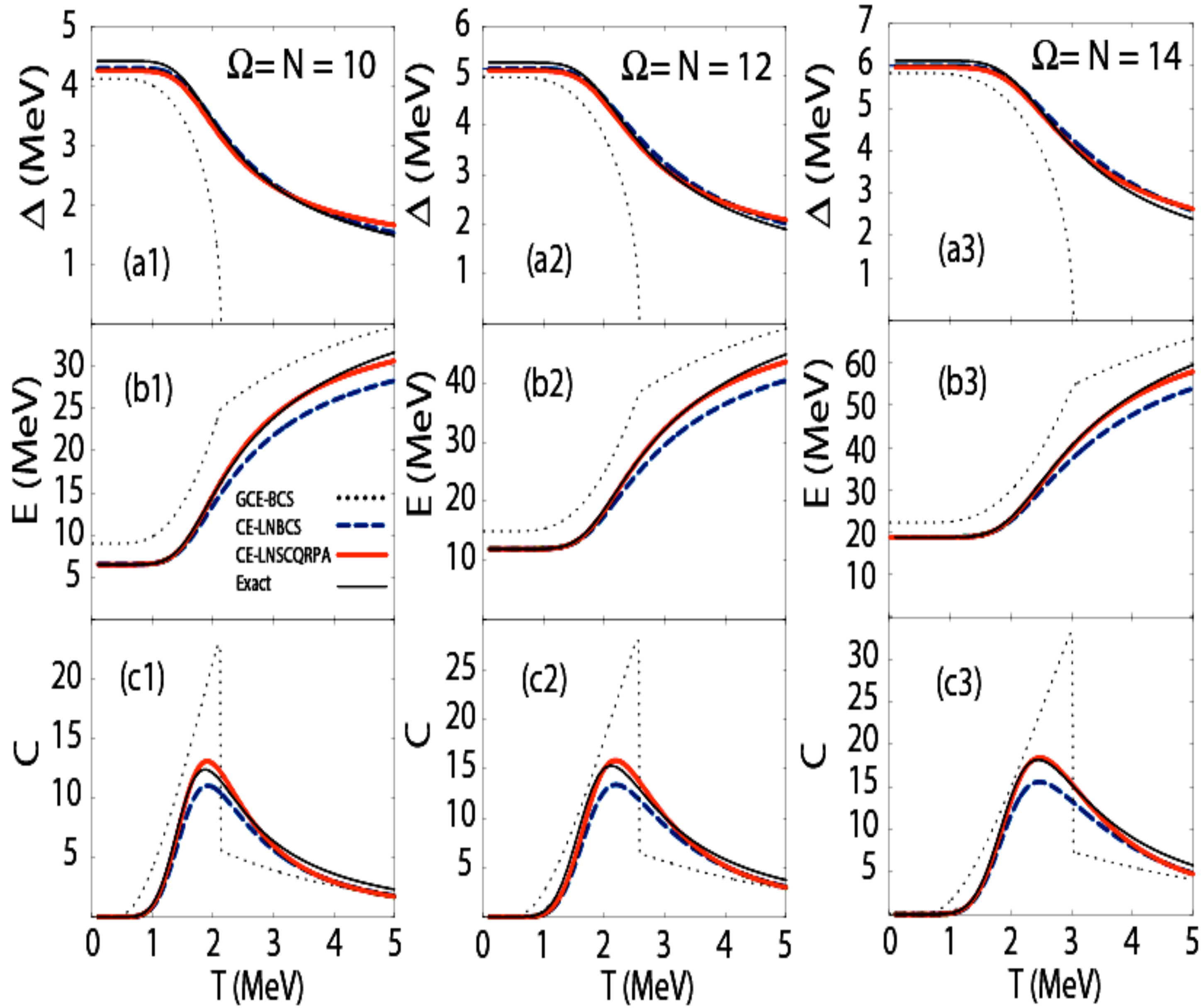
- **FTBCS1**: FTBCS + Quasiparticle-number fluctuations (QNF)
- **FTLN1**: FTBCS1 + Lipkin-Nogami (approximate) particle-number projection
- **FTBCS1 + SCQRPA**: FTBCS1 self-consistently coupled to quasiparticle ramdom-phase approximation (QRPA) vibrations
- **FTLN1 + SCQRPA**: FTLN1 self-consistently coupled to QRPA vibrations
- **CE(MCE)-LNBCS**: embed solutions of LNBCS equation at T=0 into the CE and MCE
- **CE(MCE)-LNSCQRPA**: embed solutions of LNSCQRPA equation at T=0 into the CE and MCE

*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **76**, 054302 (2007).*
*N. Dinh Dang and N. Quang Hung, Phys. Rev. C **77**, 064315 (2008).*
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **78**, 064315 (2008).*
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **79**, 054328 (2009).*
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **81**, 044301 (2010).*
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **81**, 057302 (2010).*
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **82**, 044316 (2010).*

Hot Nuclei

Doubly-fold equidistant multilevel pairing model





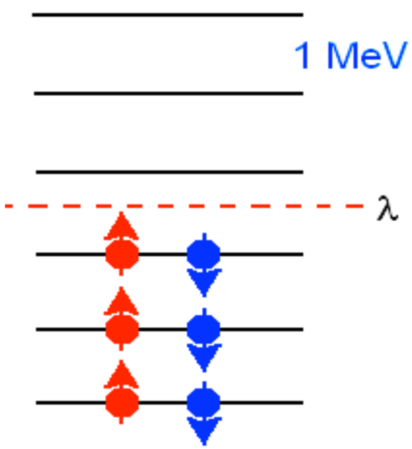
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **81**, 057302 (2010).*
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **82**, 044316 (2010).*

Hot Nuclei

Doubly-fold equidistant multilevel pairing model

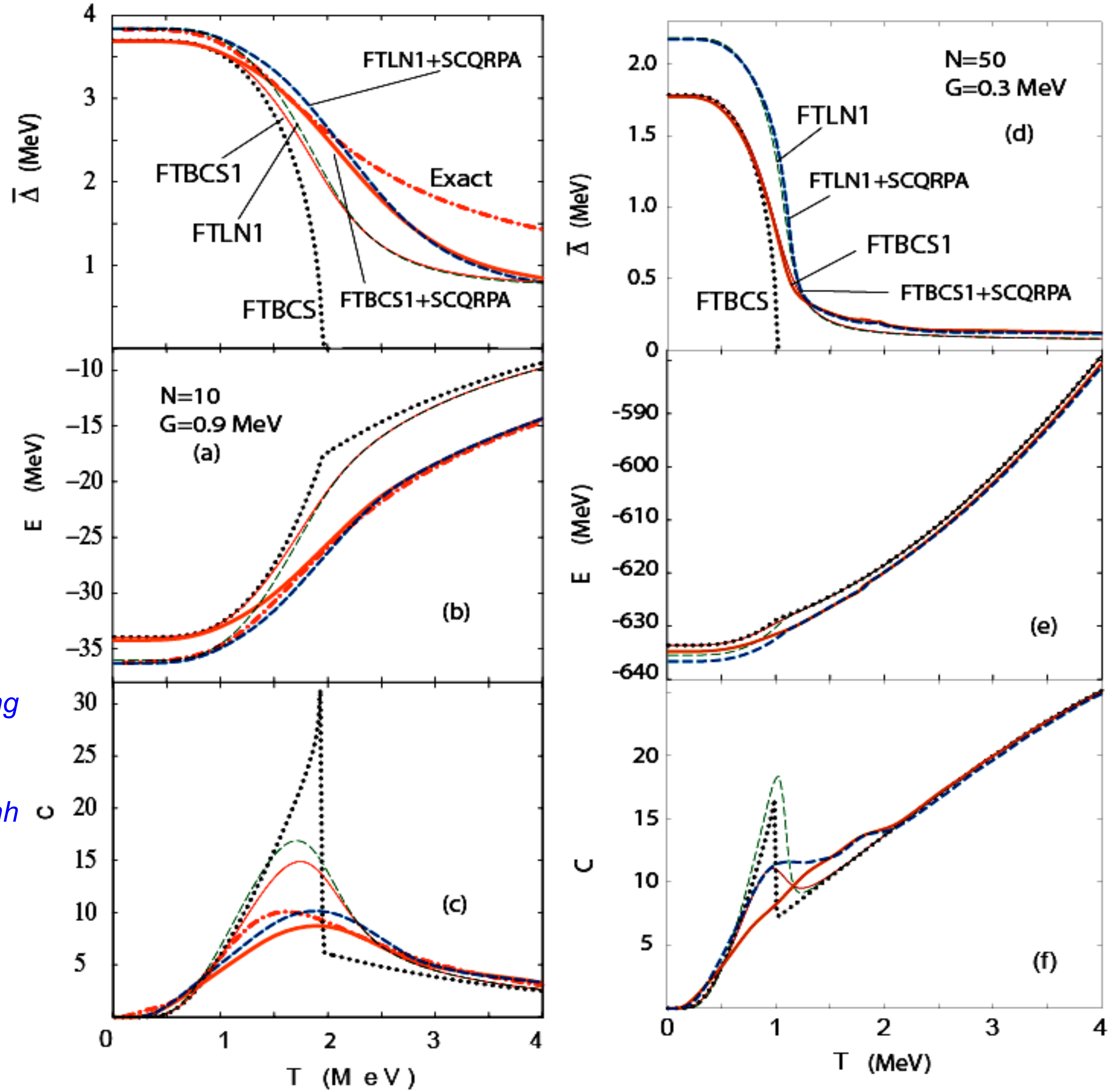
$\Omega = N = 6$

G = 0



*N. Dinh Dang and N. Quang Hung, Phys. Rev. C **77**, 064315 (2008).*

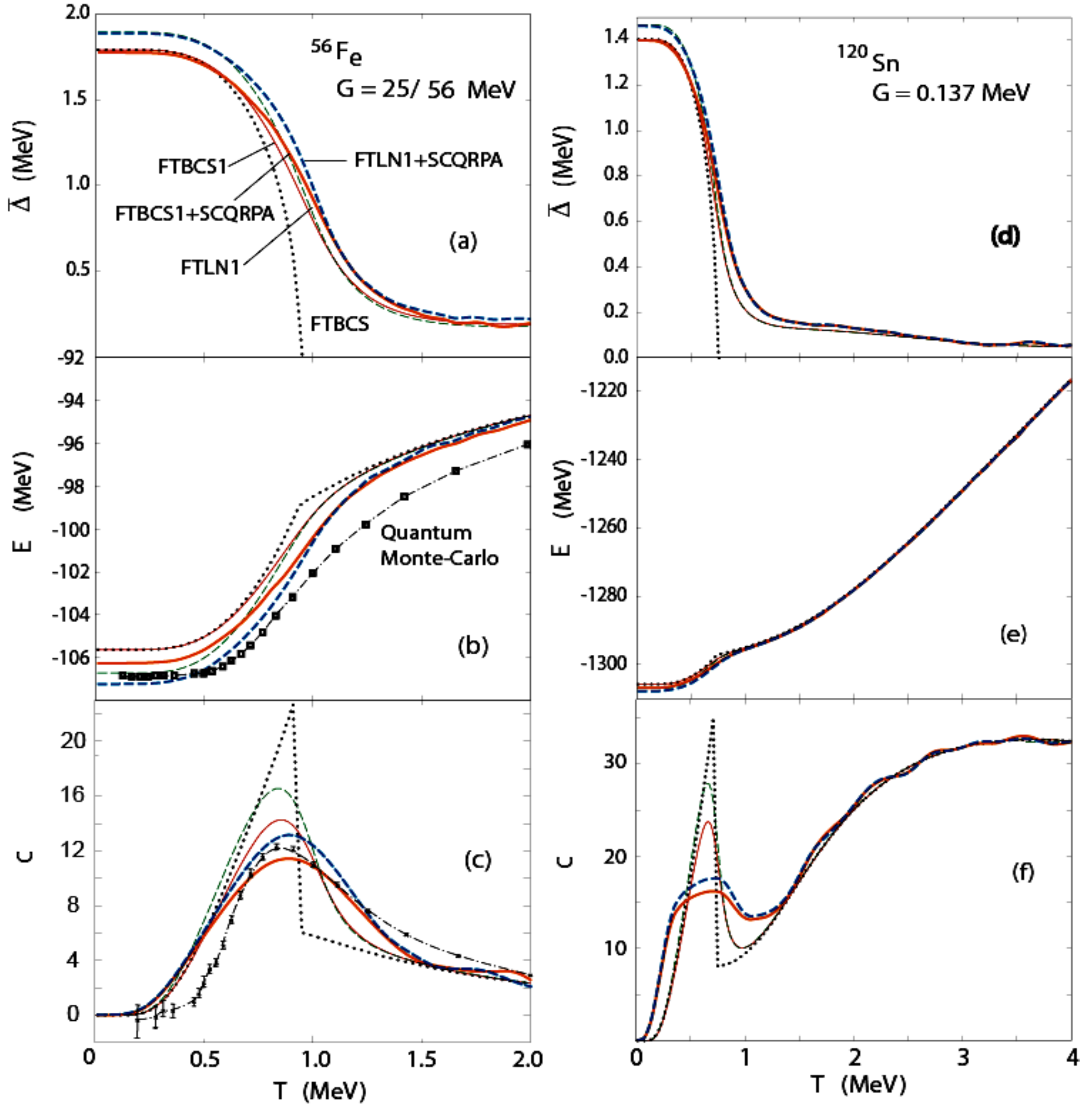
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **79**, 054328 (2009).*



Hot Nuclei

*N. Dinh Dang and N. Quang Hung, Phys. Rev. C **77**, 064315 (2008).*

*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **79**, 054328 (2009).*



CE-LNBCS(LNSCQRPA)

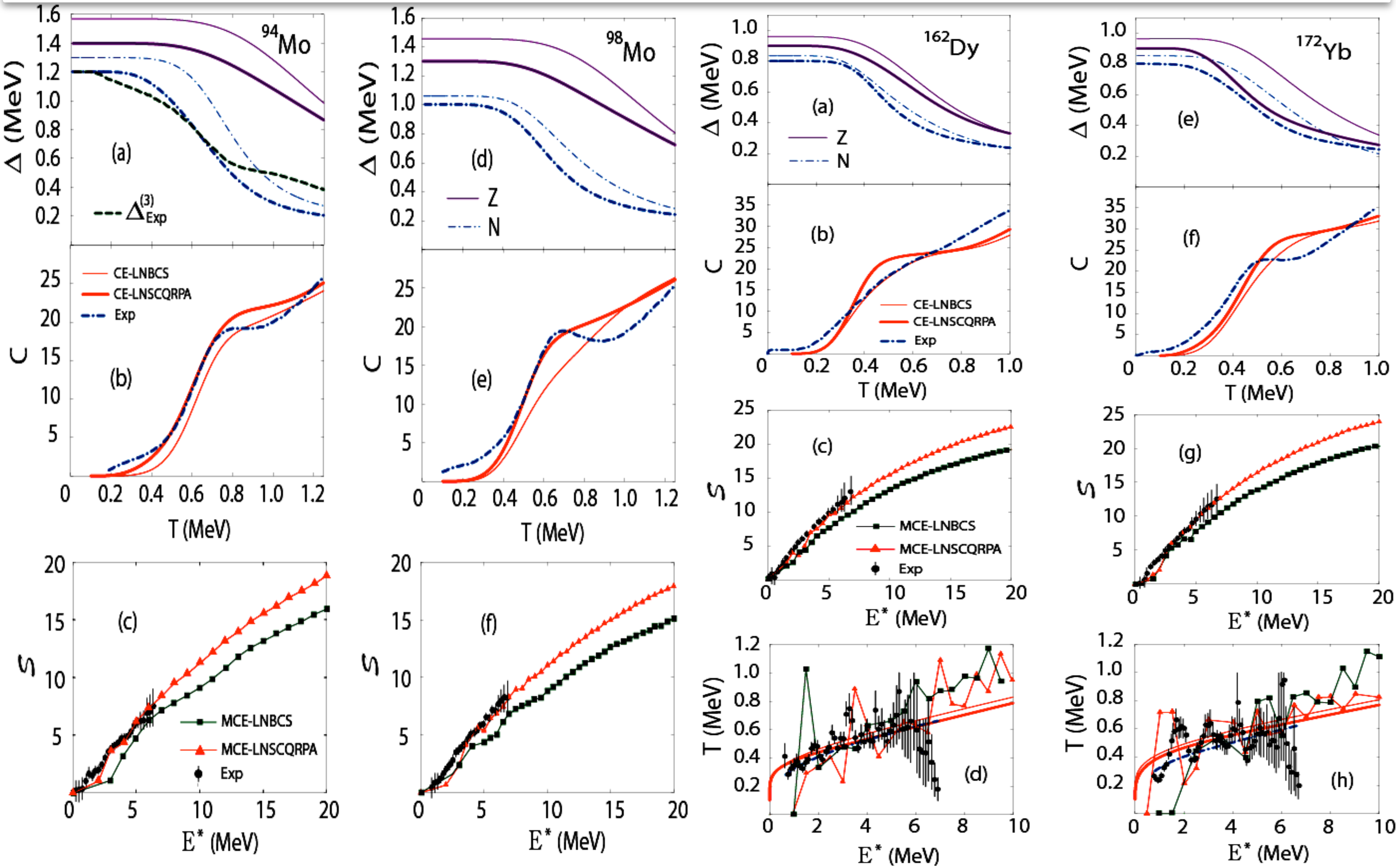
TABLE I. Number of eigenstates and computation time for the exact, CE-LNBCS and CE-LNSCQRPA calculations within the doubly-folded equidistant multilevel pairing model at several values of $N = \Omega$. The computation time is estimated based on a shared large memory computer Altix 450 with 512GB memory of RIKEN Integrated Cluster of Clusters (RICC) system.

	Number of eigenstates			Computation time		
N	Exact	LNBCS	LNSCQRPA	Exact	LNBCS	LNSCQRPA
10	8953	512	2560	1 hr	1 sec.	10 sec.
12	73789	2048	12288	10 hrs	10 sec.	1 min.
14	616227	8192	57344	24 hrs	1 min.	10 min.
16	5196627	32768	262144	-	10 min.	1 hr
18	44152809	131072	1179648	-	1 hr	3 hrs
20	377379369	524288	5242880	-	3 hrs	10 hrs

*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **81**, 057302 (2010).*

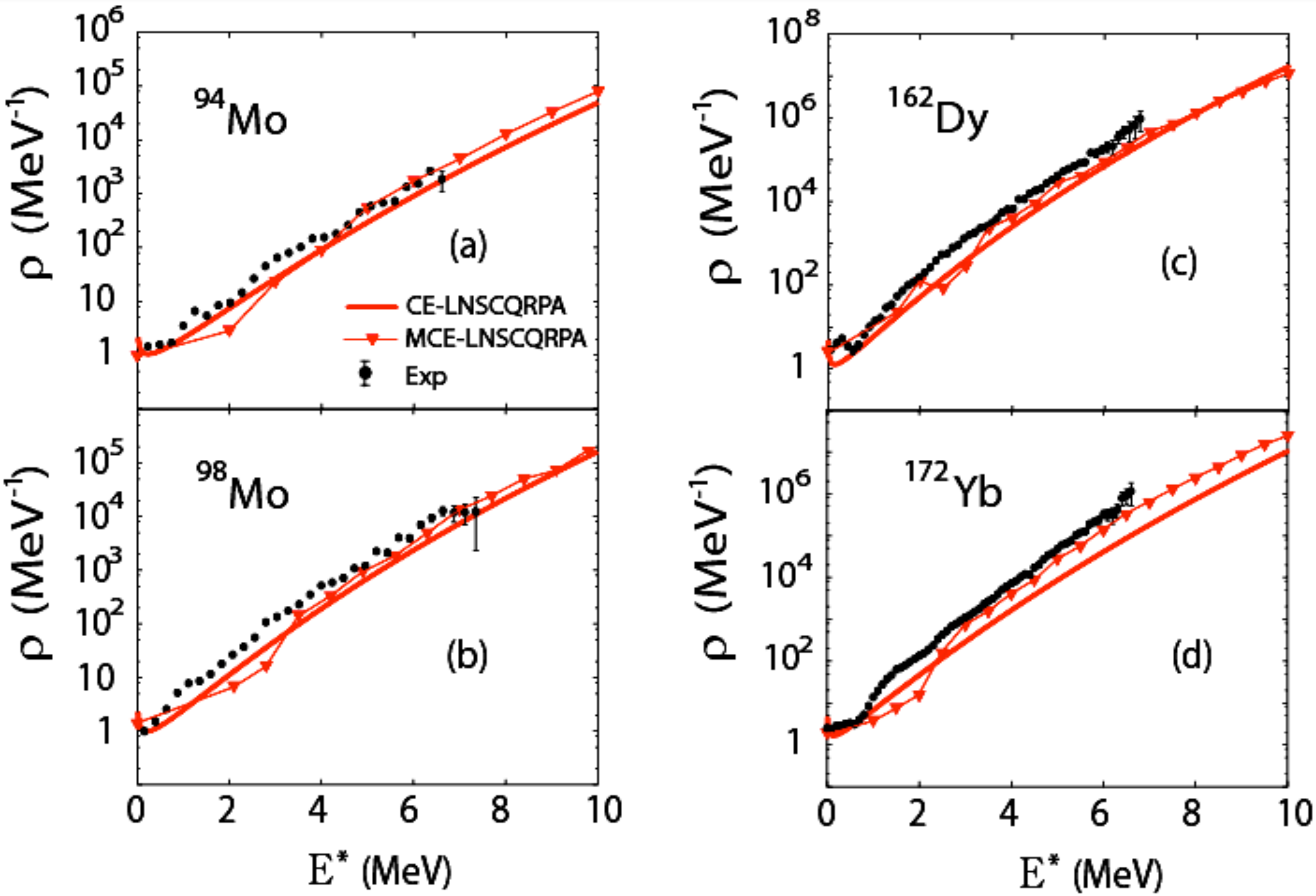
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **82**, 044316 (2010).*

Hot Nuclei



*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **81**, 057302 (2010).*
*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **82**, 044316 (2010).*

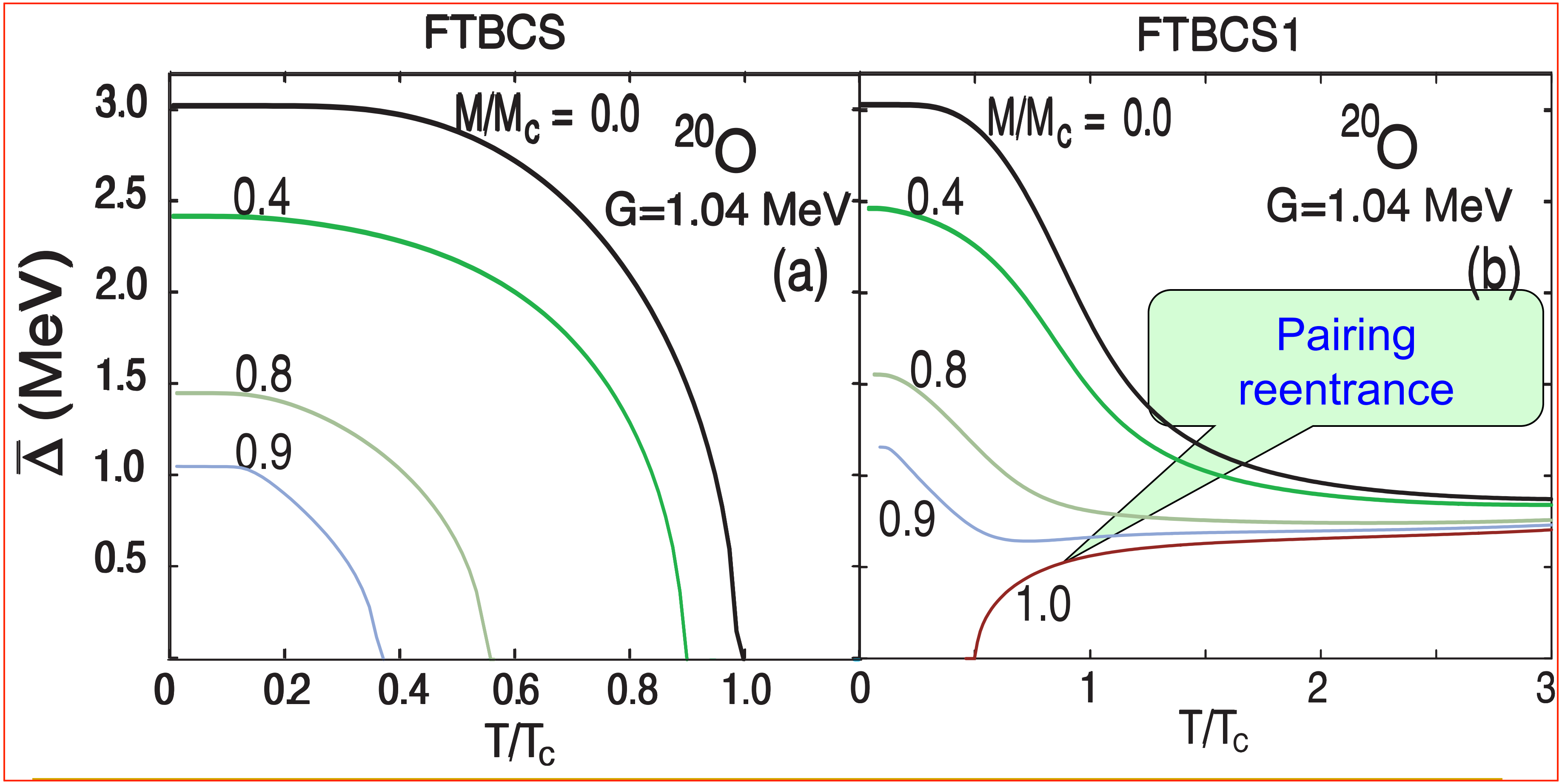
Hot Nuclei



N. Quang Hung and N. Dinh Dang, Phys. Rev. C **81**, 057302 (2010).
N. Quang Hung and N. Dinh Dang, Phys. Rev. C **82**, 044316 (2010).

Hot Rotating Nuclei

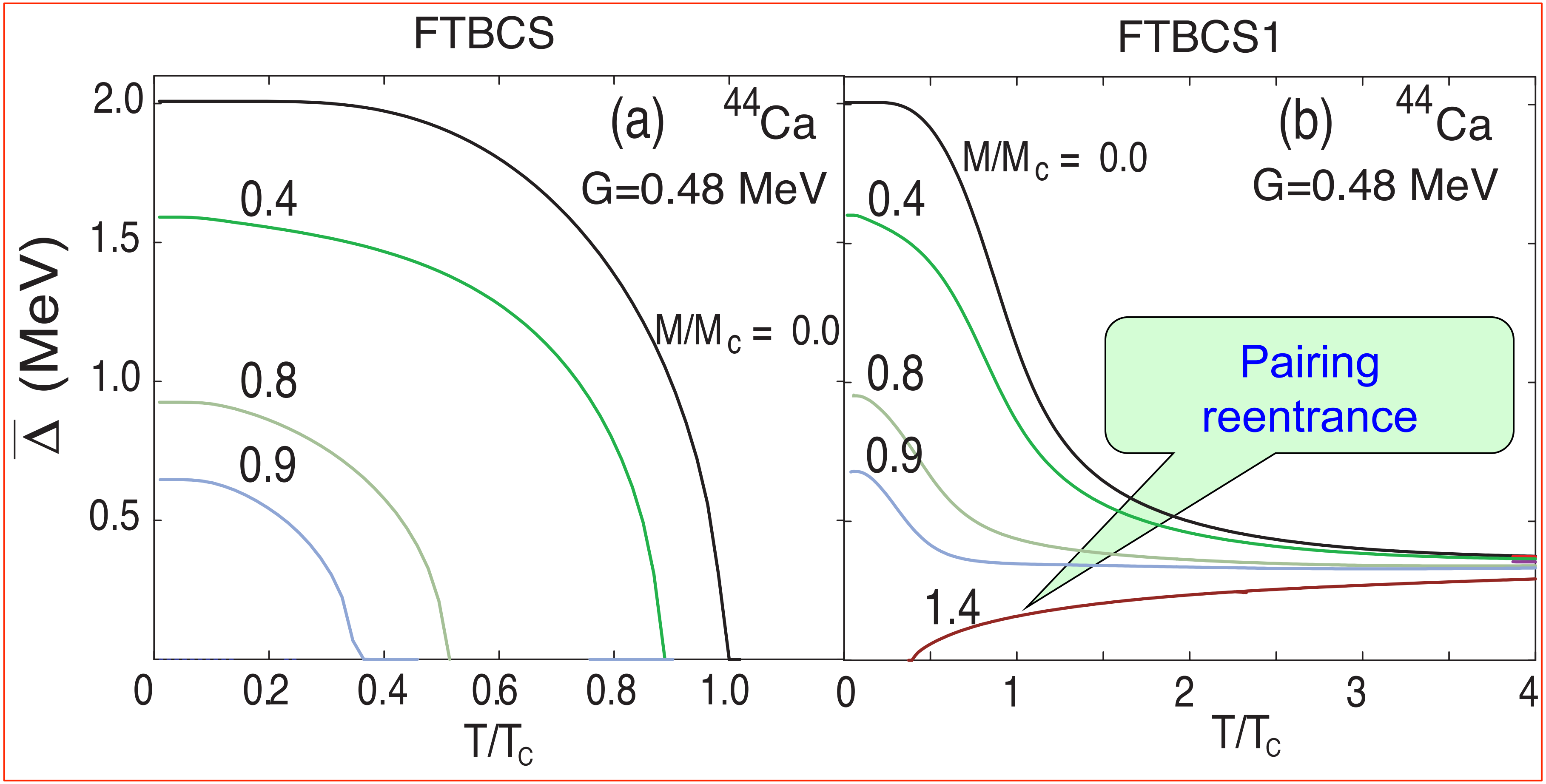
^{22}O



*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **78**, 064315 (2008)*

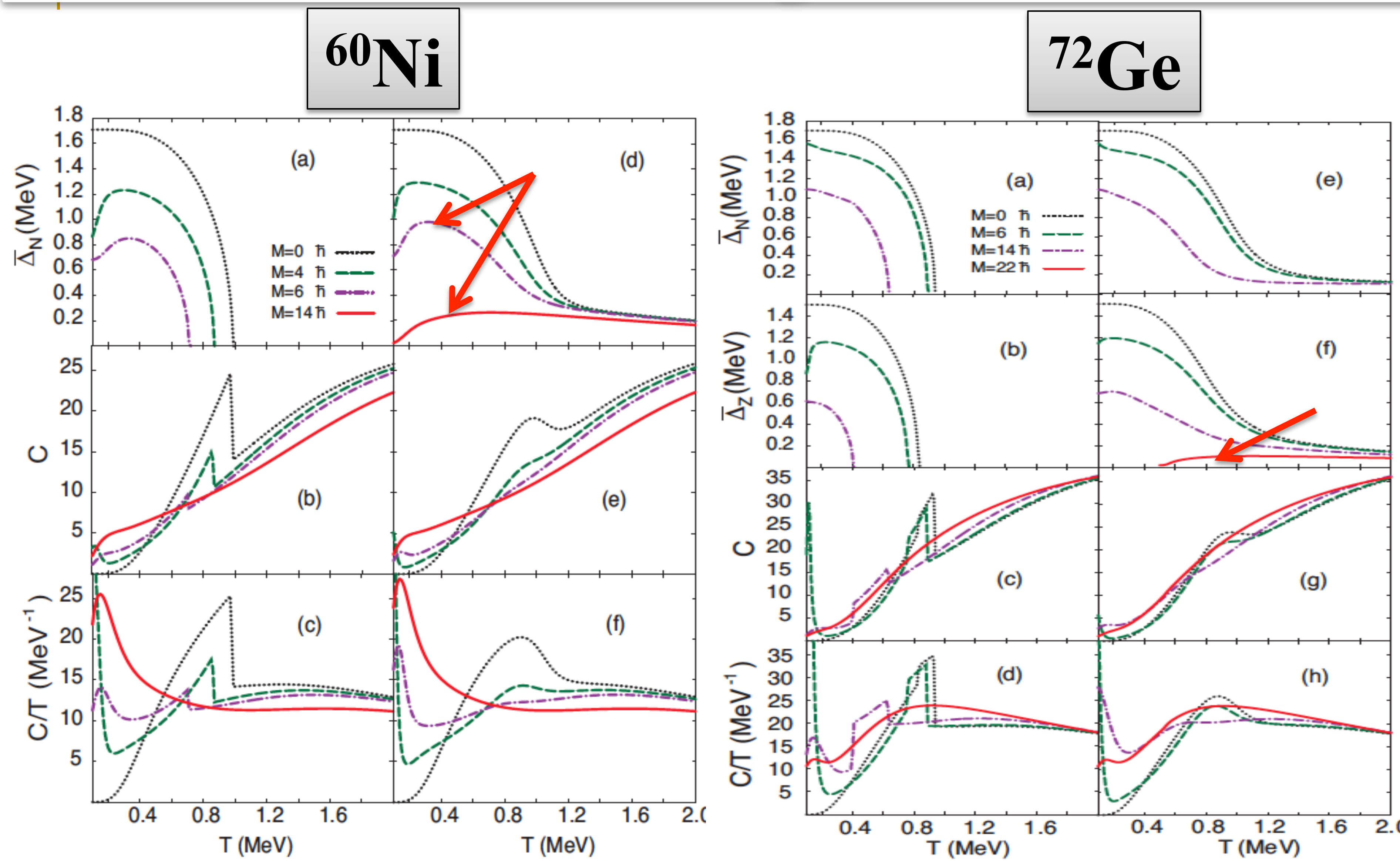
Hot Rotating Nuclei

^{44}Ca



*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **78**, 064315 (2008)*

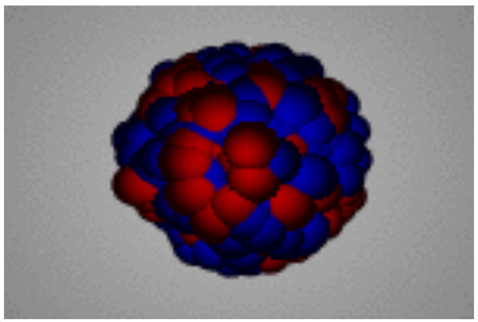
Hot Rotating Nuclei



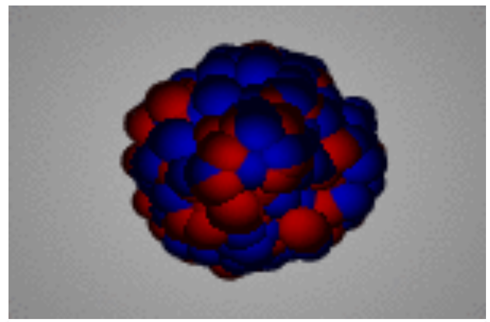
N. Quang Hung and N. Dinh Dang, Phys. Rev. C ***84****, 054324 (2011)*

Research Topics

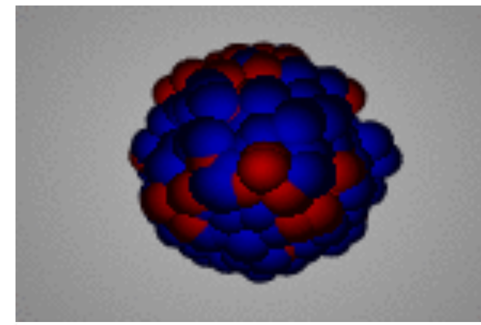
- Past Research Topics:
  - ✧ *Pairing Properties in Hot Rotating Nuclei*
  - ✧ *Nuclear Giant/Pigmy Dipole Resonances*



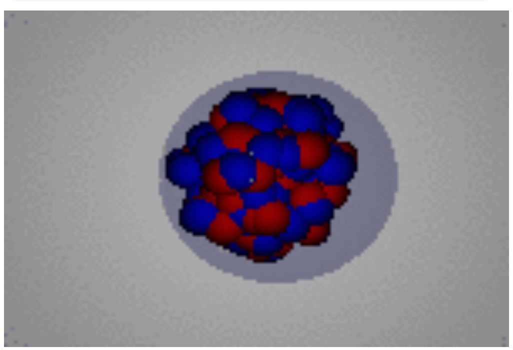
GMR



GDR



GQR



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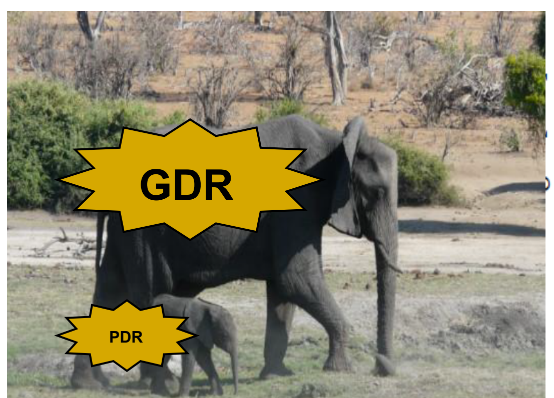
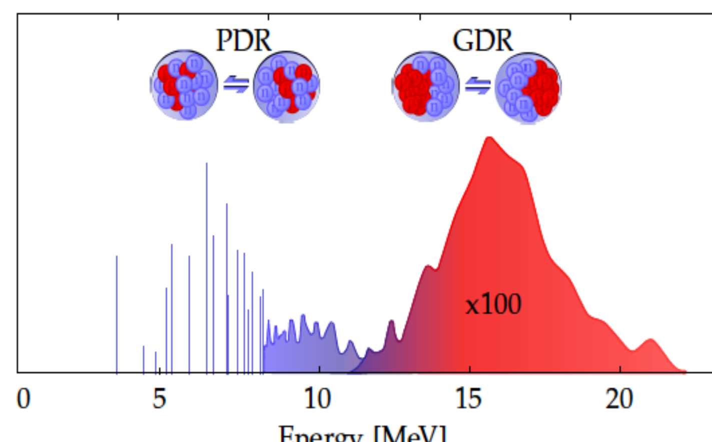
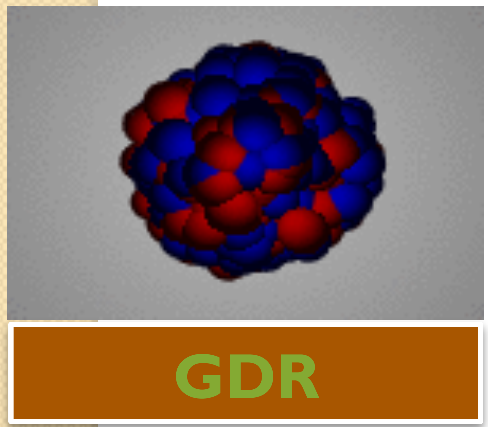
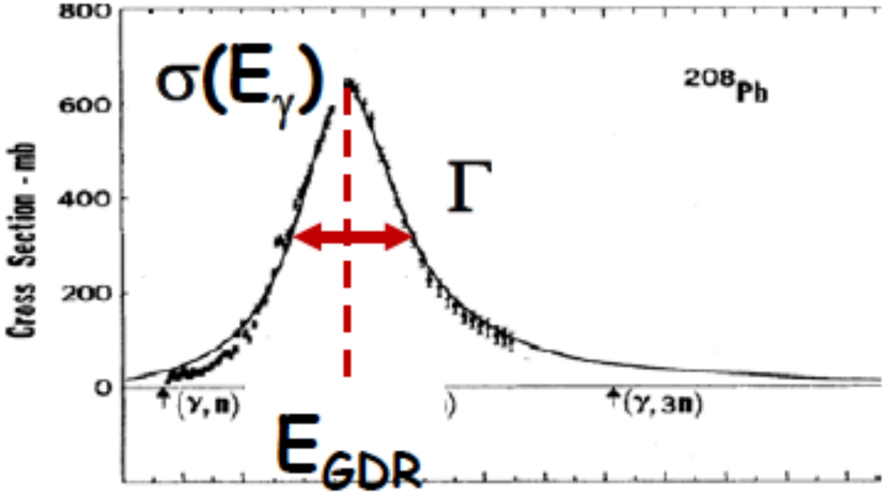




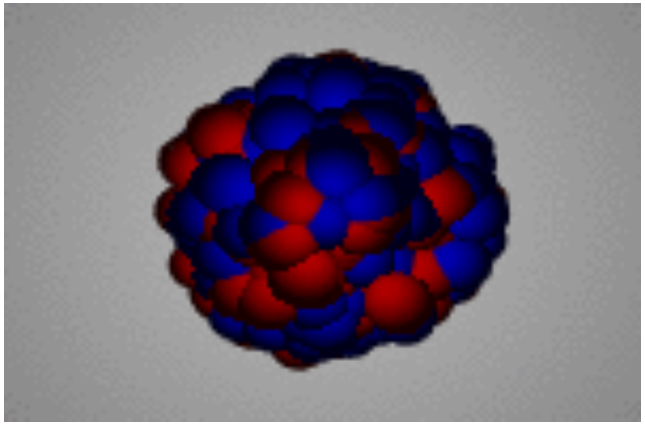
GDR



described with Lorentzian:

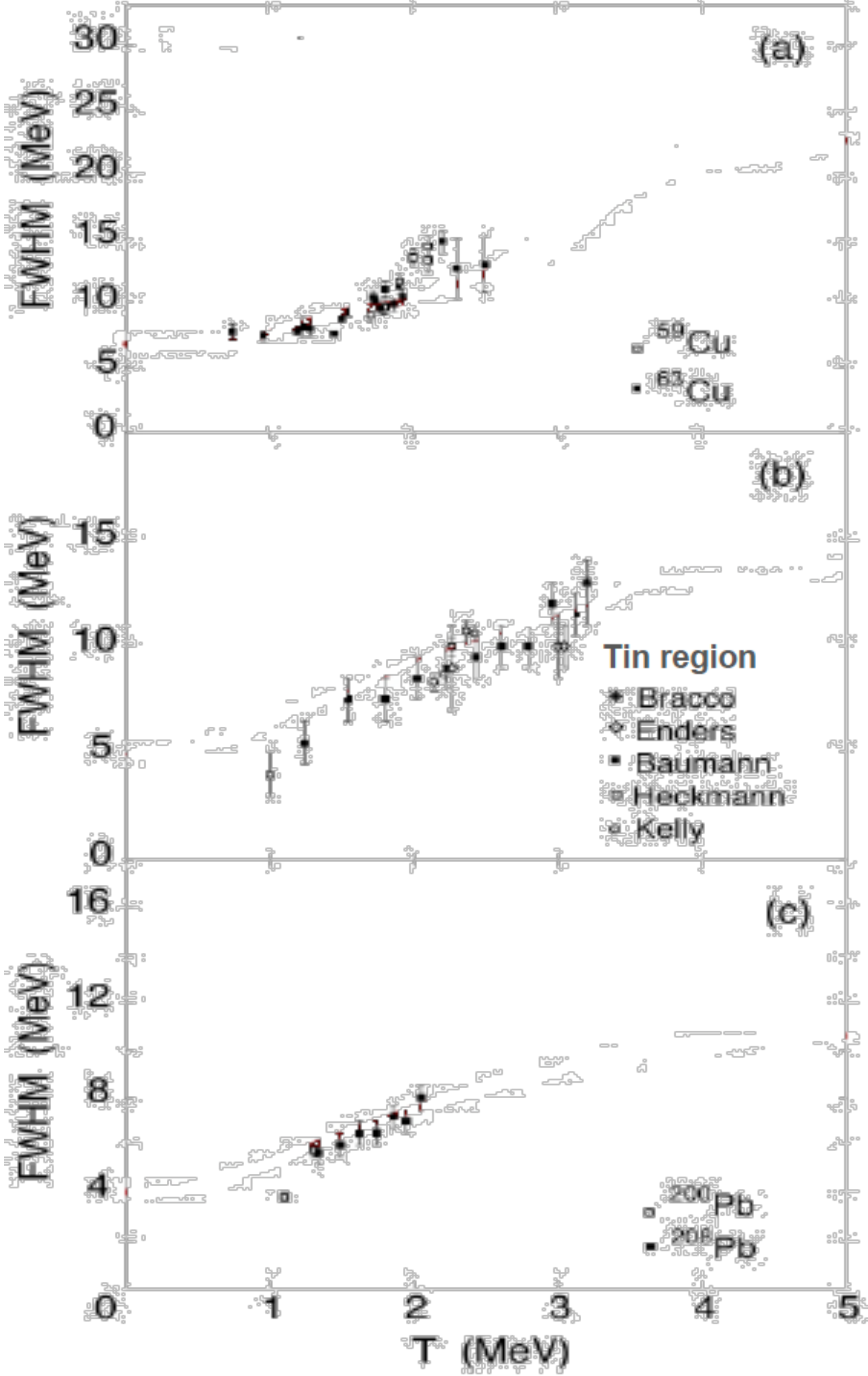


$$\sigma(E_\gamma) = \frac{\sigma_0 \Gamma_{GDR}^2 E_\gamma^2}{\left(E_\gamma^2 - E_{GDR}^2\right)^2 + \Gamma_{GDR}^2 E_\gamma^2}$$



GDR in Hot Nuclei

- Saturation of GDR width at high *T* ?
- Slight increase of GDR width at low *T* ?



Phonon Damping Model (PDM)

$$H = \sum_s E_s a_s^\dagger a_s + \sum_q \omega_q Q_q^\dagger Q_q + \sum_{ss'q} F_{ss'}^{(q)} a_s^\dagger a_{s'} (Q_q^\dagger + Q_q)$$

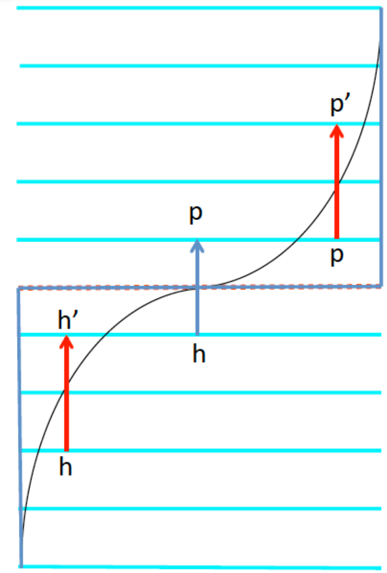
Topical conference on giant resonances, Varenna, May 1998

N. Dinh Dang and A. Arima,
Phys. Rev. Lett. ***80****, 4145 (1998)*

$$G_q(E) = \frac{1}{2\pi}[E - \omega_q - P_q(E)]^{-1}$$

$$P_q(E) = \sum_{ss'} F_s^{(q)} F_{s'}^{(q)} \frac{f_s - f_{s'}}{E - E_{s'} + E_s} ,$$

$$\gamma_q(\omega) = \Im m P_q(\omega \pm i\varepsilon) .$$



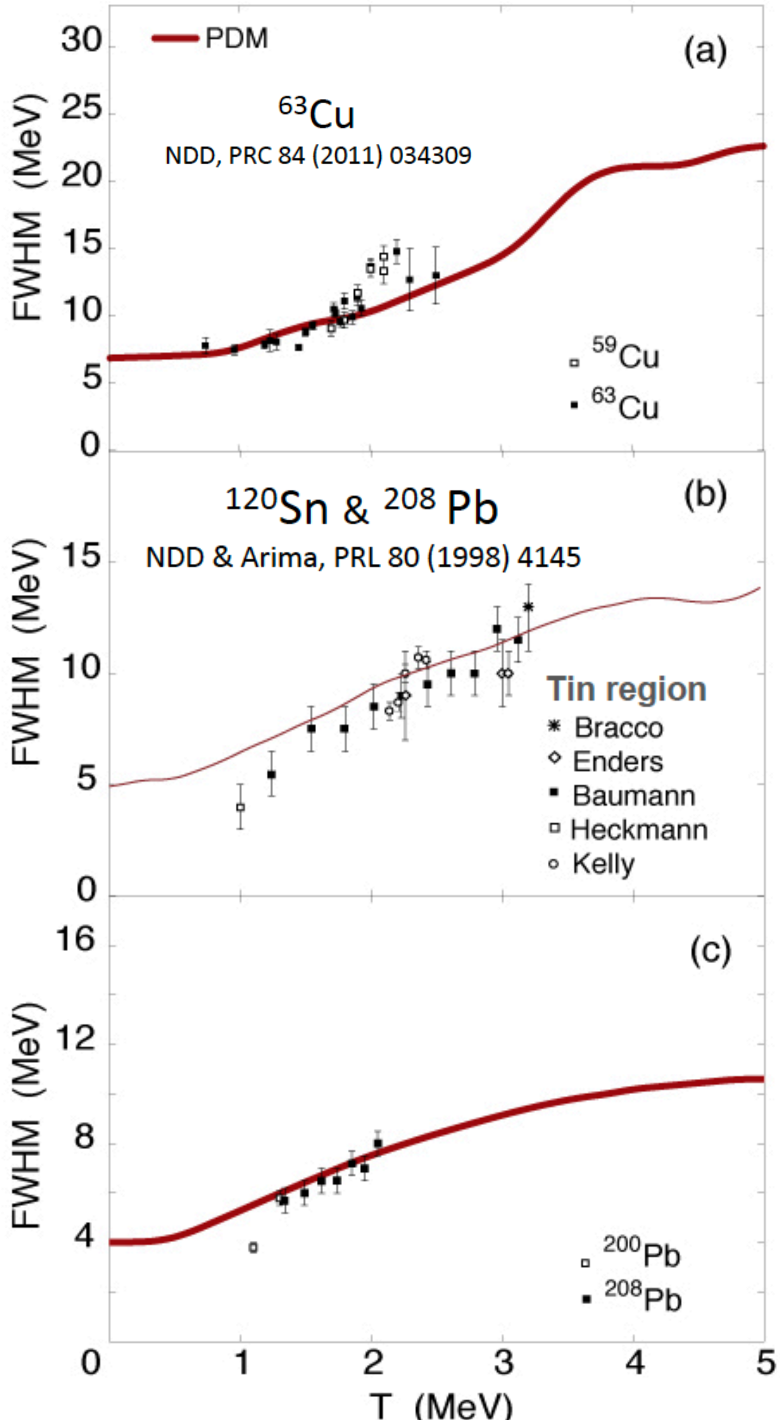
Quantal: $ss' = ph$
Thermal: $ss' = pp'$, hh'

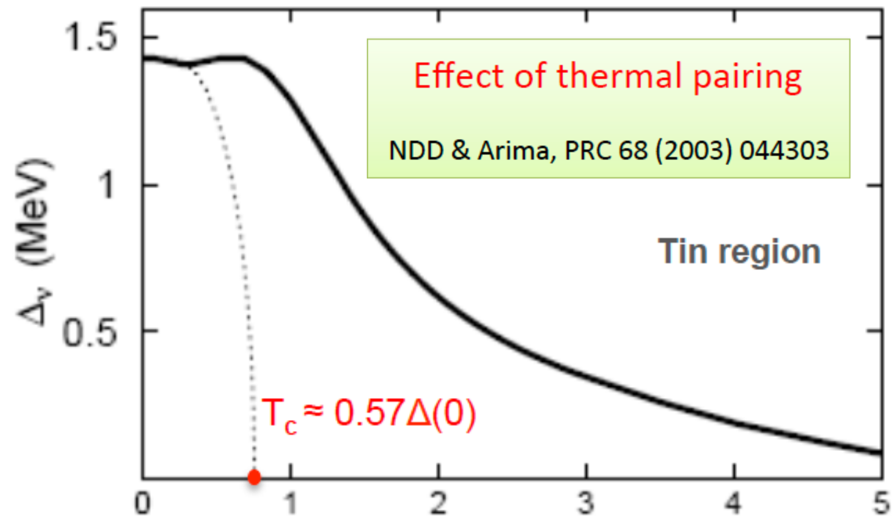
$$\Gamma = \Gamma_Q + \Gamma_T = 2\gamma_q(E_{GDR})$$

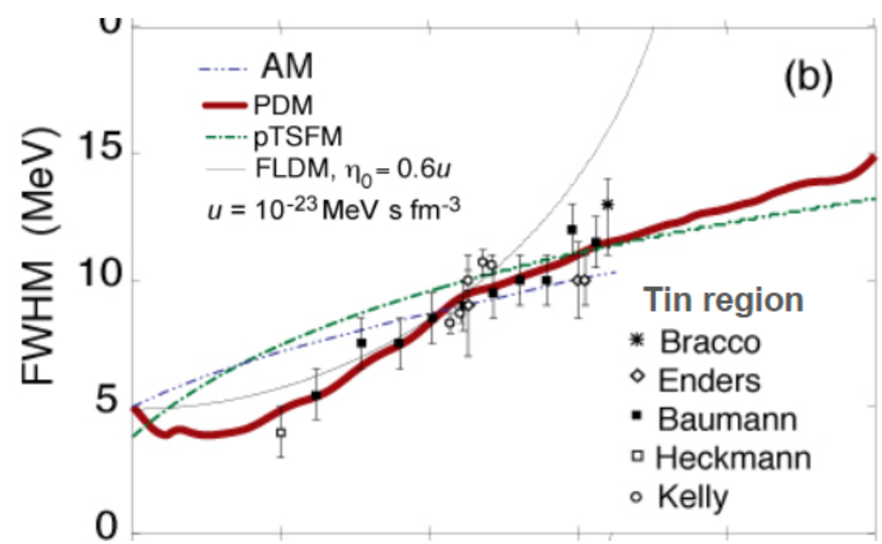
$$E_{GDR} - \omega_q - P_q(E_{GDR}) = 0 , \quad f_s = \{\exp[(\varepsilon_s - \lambda)/T] + 1\}^{-1}$$

GDR strenght function:

$$S_q(\omega) = \frac{1}{\pi} \frac{\gamma_q(\omega)}{[\omega - E_{GDR}]^2 + \gamma_q^2(\omega)} .$$







FLDM: Fermi-liquid-drop model

V. M. Kolomietz and S. Shlomo, Phys. Rep. ***390****, 133 (2004)*

pTSFM: Phenomenological thermal shape fluctuation model

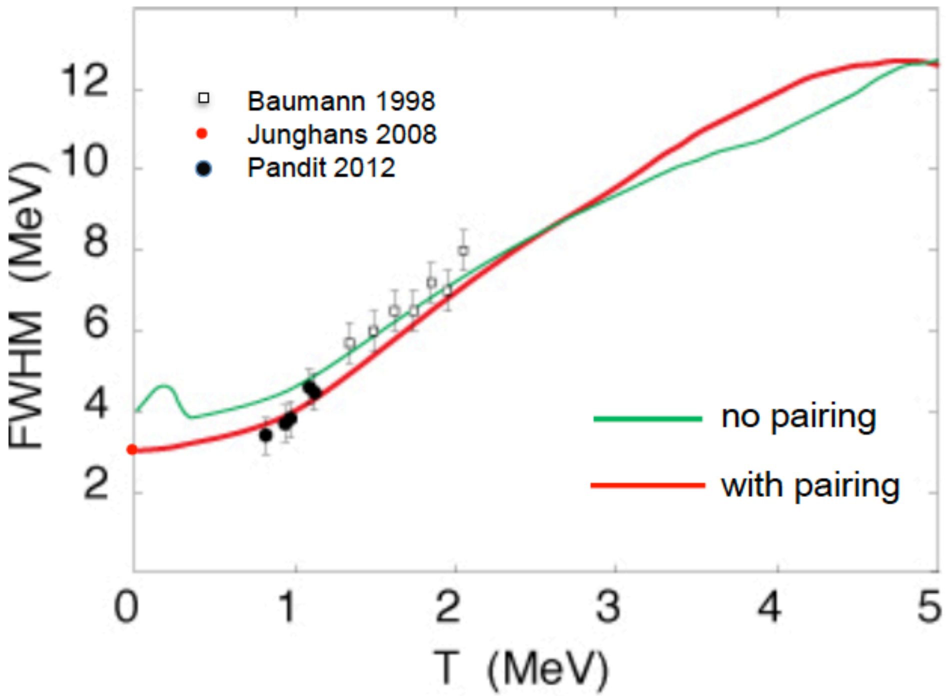
D. Kusnezov, Y. Alhassid, and K. A. Snover, Phys. Rev. Lett. ***81****, 532 (1998)*

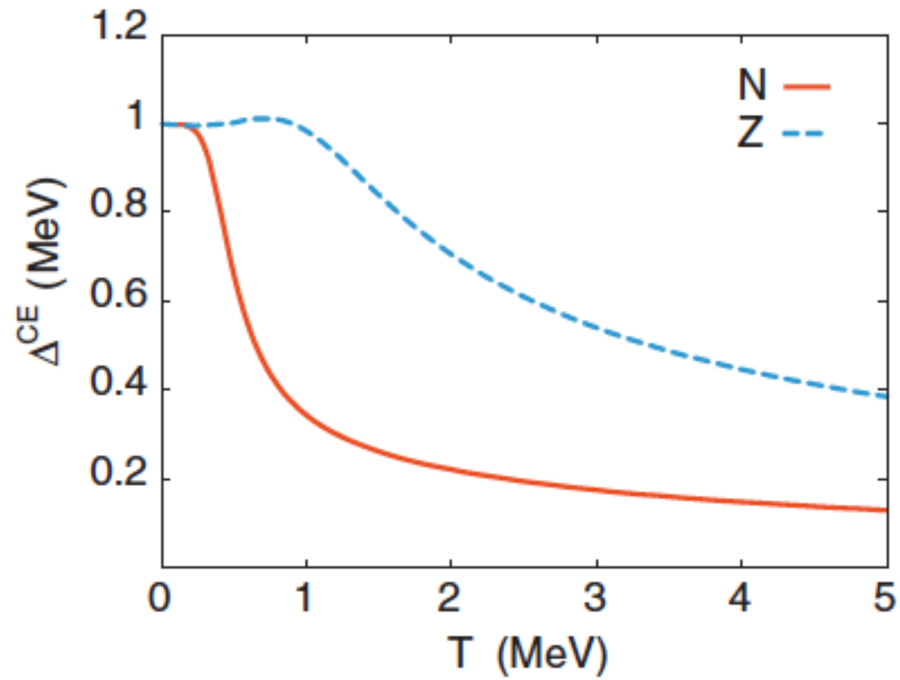
GDR: PDM + Exact Pairing at T≠0

^{201}Tl

New data at low T

D. Pandit et al., Phys. Lett. B ***713****, 434 (2012)*

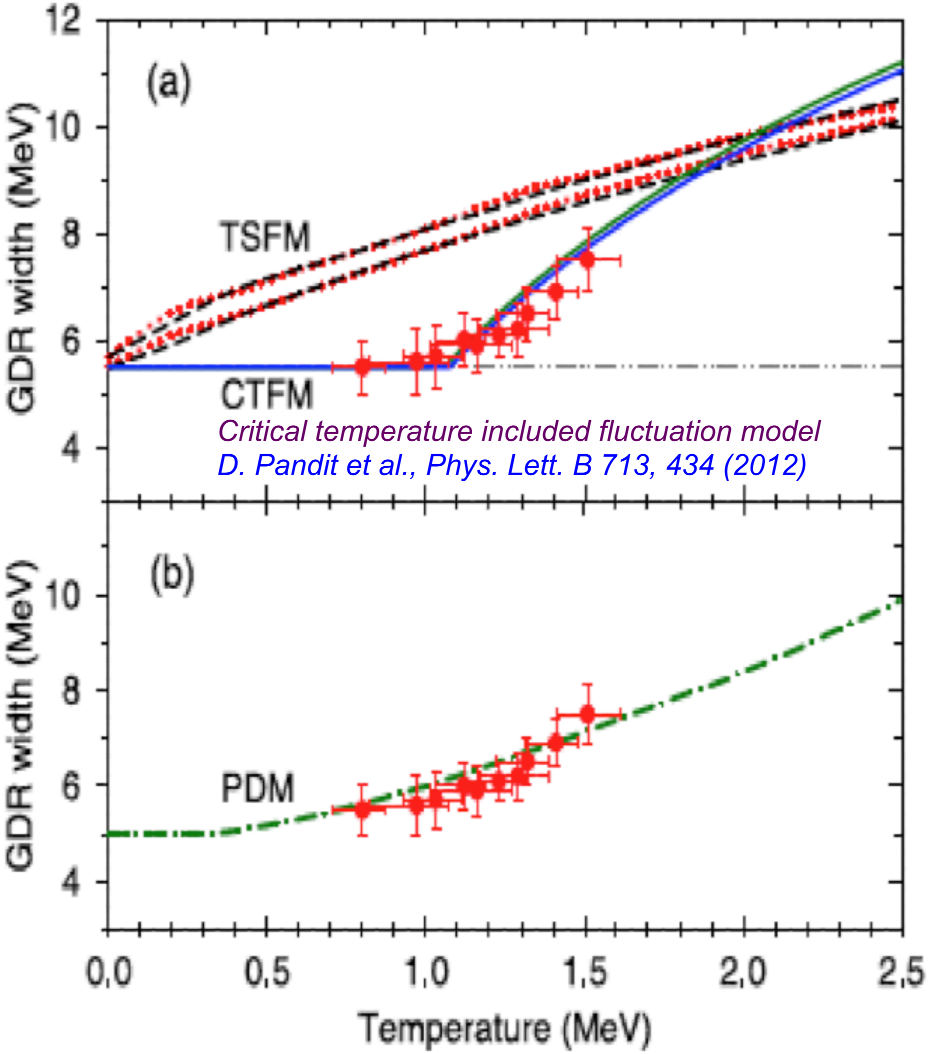


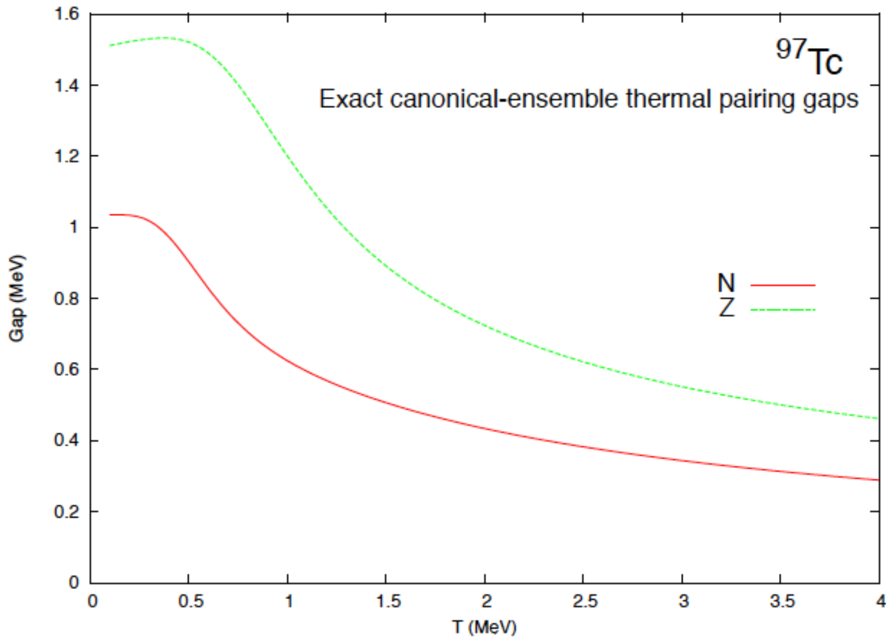


N. Dinh Dang and N. Quang Hung, Phys. Rev. C ***86****, 044333 (2012)*

GDR: PDM + Exact Pairing at T≠0

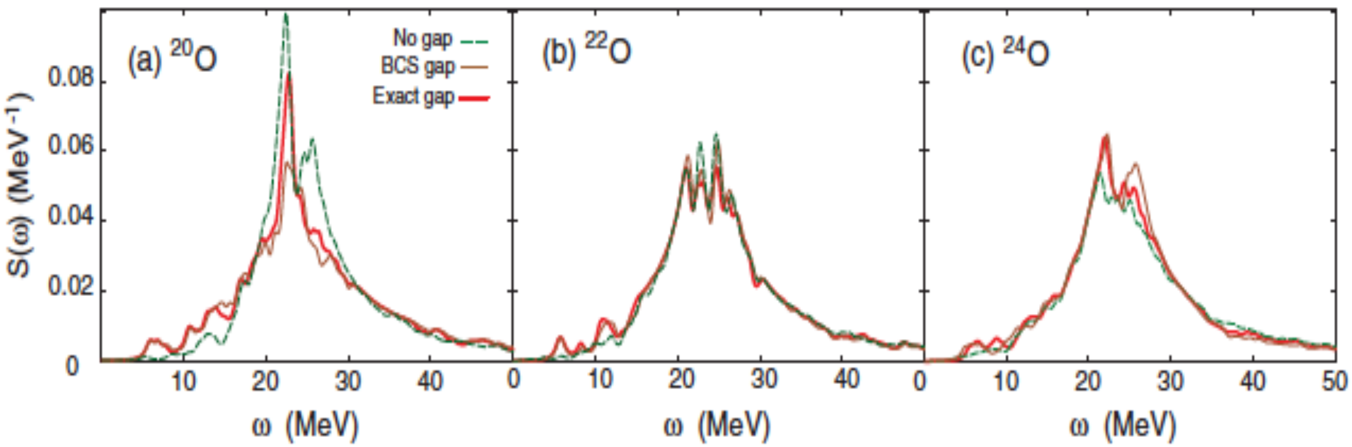
^{97}Tc

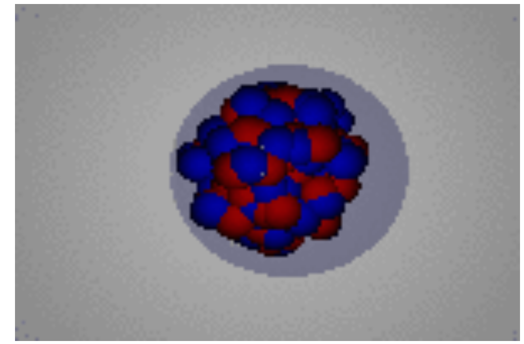


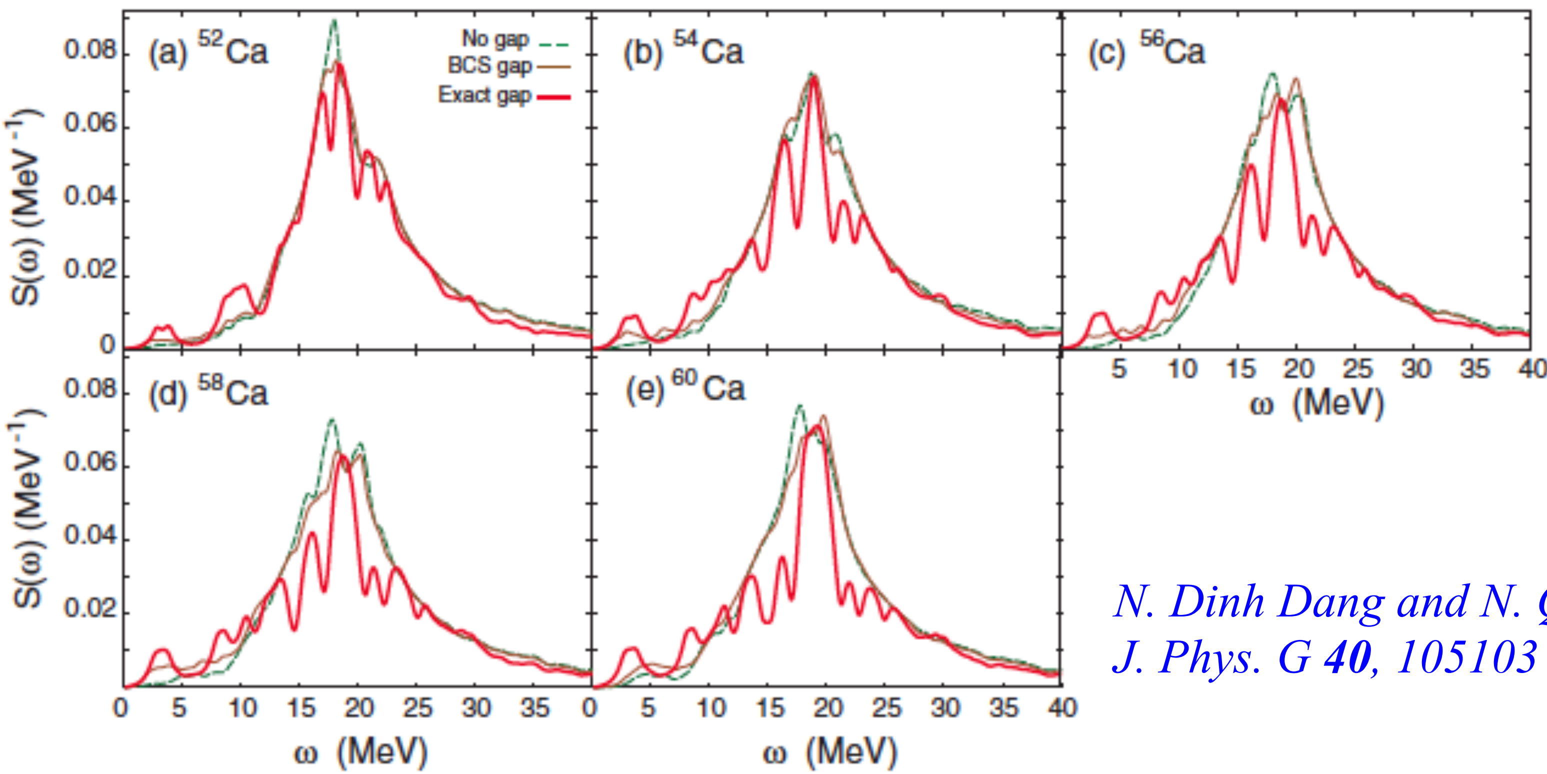


B. Dey, D. Mondal, D. Pandit, S. Mukhopadhyay, S. Pal, S. Bhattacharya, A. De, K. Banerjee, N. Dinh Dang, N. Quang Hung, and S. R. Banerjee, Phys. Lett. B ***731****, 92 (2014)*

PDR: PDM + Exact Pairing at T=0

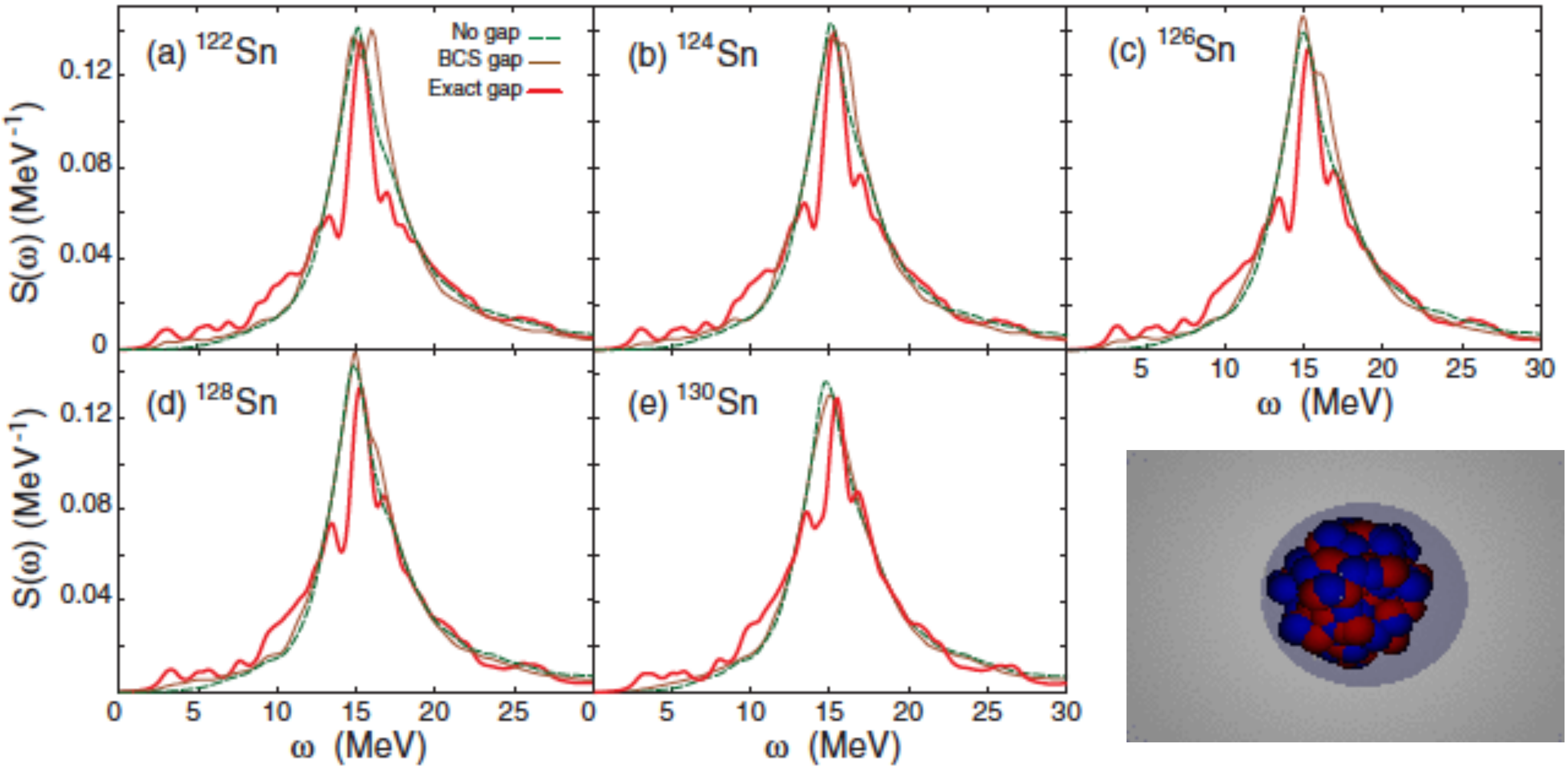






*N. Dinh Dang and N. Quang Hung, J. Phys. G **40**, 105103 (2013)*

PDR: PDM + Exact Pairing at T=0



N. Dinh Dang and N. Quang Hung, J. Phys. G ***40*** *(2013) 105103*

Research Topics

- Past Research Topics:
  - *Pairing Properties in Hot Rotating Nuclei*
  - *Nuclear Giant/Pigmy Dipole Resonances*
  - *Viscosity in Hot Rotating Nuclei*

$$\frac{\eta}{s} = \frac{\hbar}{4\pi k_B}, \quad s = \frac{\rho}{A} S$$

KSS conjecture: Universal lower bound for all fluids

η/s in Finite Nucleus

"Nuclear giant resonances can be described as vibrations of proton and neutron fluids. The isoscalar vibrations consist of proton and neutron fluids collectively vibrating in phase, while the isovector ones are described as vibrations of the proton liquid out of phase, with the neutron fluid".

N. Auerbach & S. Shlomo, *PRL 103 (2009) 172501*

N. Auerbach

Direct calculations using Hydrodynamical (Fermi Liquid-Drop) Model:

η/s = (4 - 19) KSS for heavy, (2.5 - 12.5) KSS for light nuclei

S. Shlomo

<u>Shortcomings:</u>

1) The GDR width does not agree with experimental systematic at high T
2) The entropy $S = 2aT$ with constant level density parameter a
3) Large uncertainties.

η/s in Hot Nuclei

PHYSICAL REVIEW C **84**, 034309 (2011)

Shear-viscosity to entropy-density ratio from giant dipole resonances in hot nuclei

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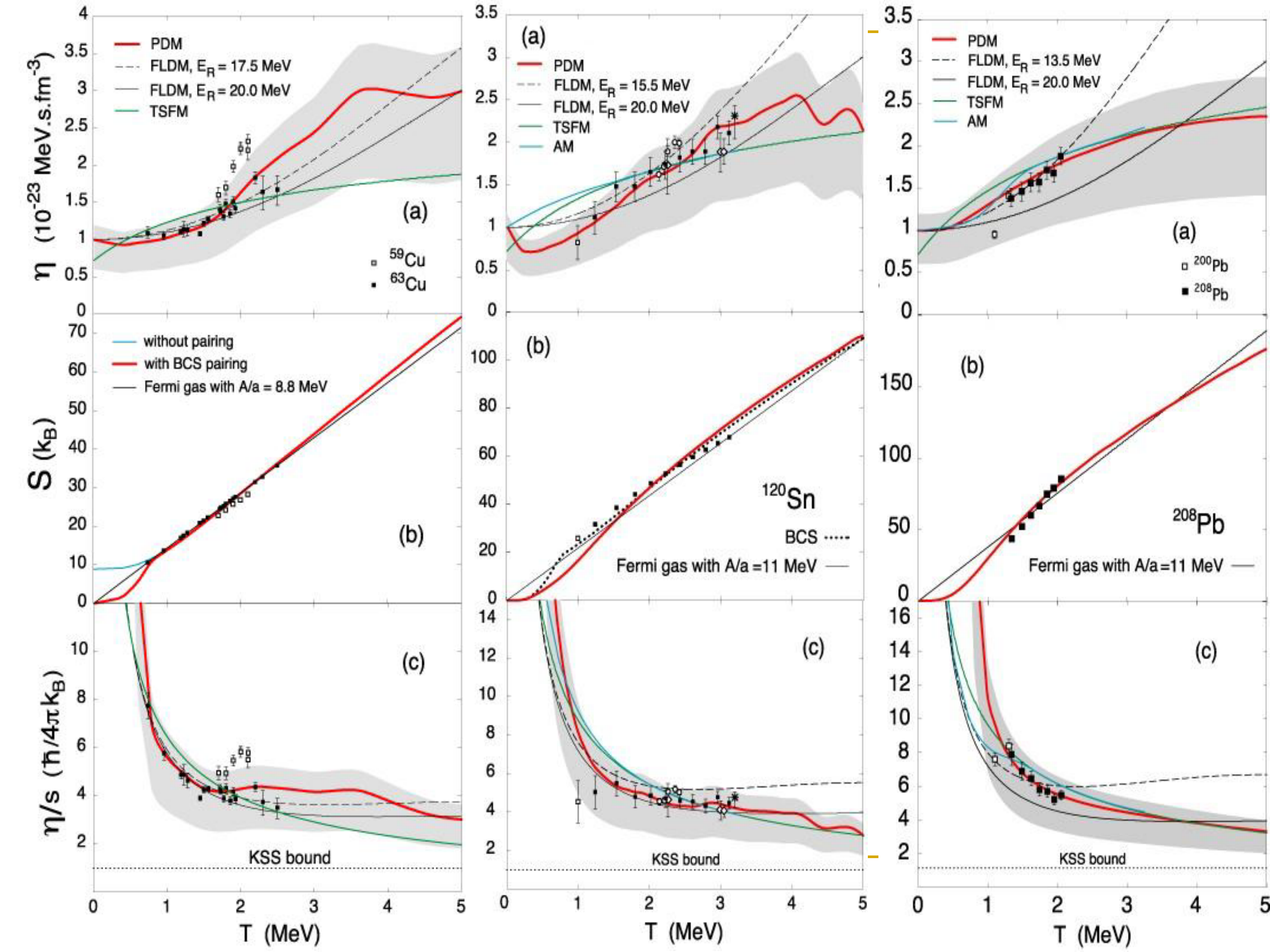
(Received 20 December 2010; revised manuscript received 17 June 2011; published 7 September 2011)

The Green-Kubo relation and fluctuation-dissipation theorem are employed to calculate the shear viscosity η of a finite hot nucleus directly from the width and energy of the giant dipole resonance (GDR) of this nucleus. The ratio η/s of shear viscosity η to entropy density s is extracted from the experimental systematics of the GDR in copper, tin, and lead isotopes at finite temperature T. These empirical results are then compared with the predictions by several independent models as well as with almost model-independent estimations. Based on these results, it is concluded that the ratio η/s in medium and heavy nuclei decreases with increasing temperature T to reach (1.3–4) $\times \hbar/(4\pi k_B)$ at $T = 5$ MeV.


PDM
FLDM, E_R = 17.5 MeV
FLDM, E_R = 20.0 MeV
TSFM
(a)
59Cu
63Cu
η (10^-23 MeV.s.fm^-3)
(a)
PDM
FLDM, E_R = 15.5 MeV
FLDM, E_R = 20.0 MeV
TSFM
AM
PDM
FLDM, E_R = 13.5 MeV
FLDM, E_R = 20.0 MeV
TSFM
AM
(a)
200Pb
208Pb
without pairing
with BCS pairing
Fermi gas with A/a = 8.8 MeV
S (k_B)
(b)
(b)
120Sn
BCS
Fermi gas with A/a =11 MeV
(b)
208Pb
Fermi gas with A/a =11 MeV
η/s (ħ/4πk_B)
(c)
KSS bound
(c)
KSS bound
(c)
KSS bound
T (MeV)
T (MeV)
T (MeV)

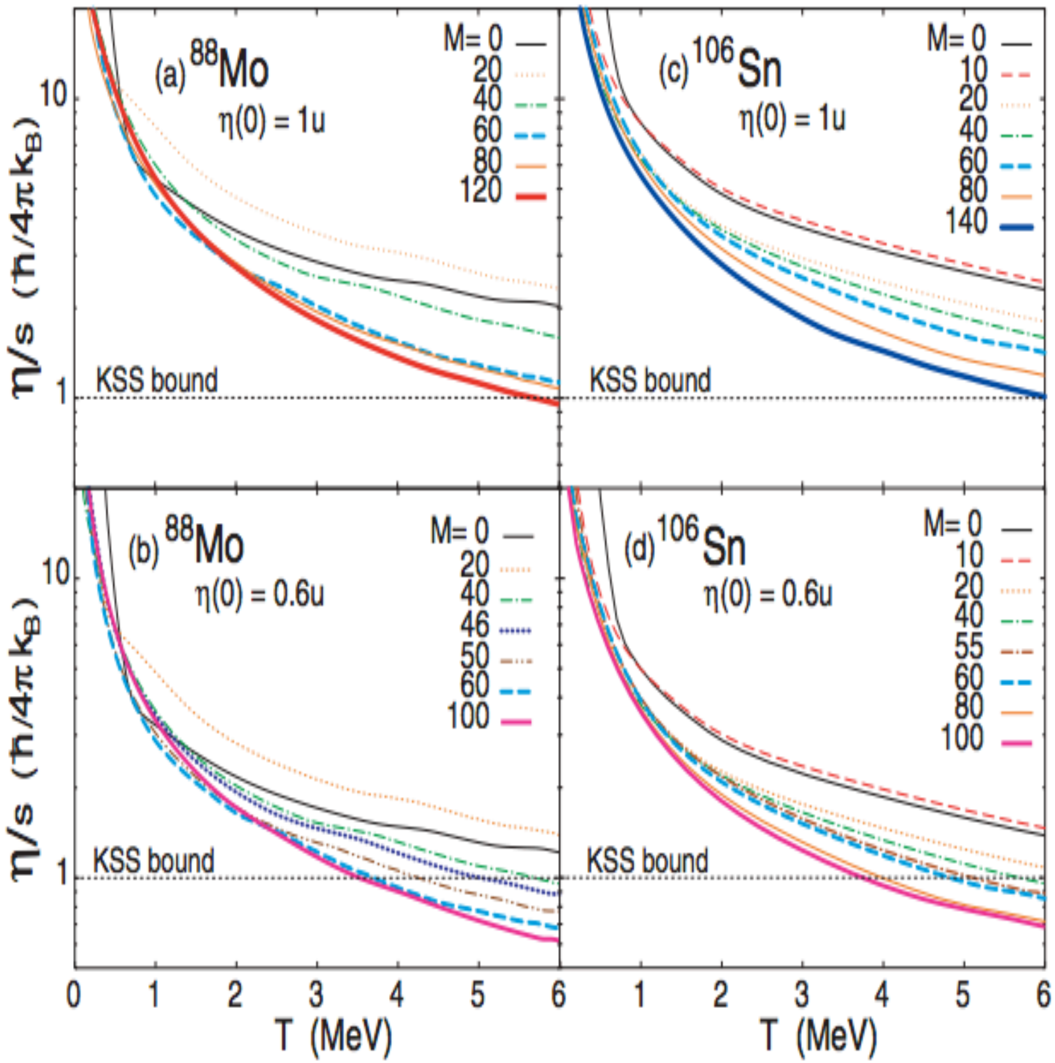
η/s in Hot Nuclei

1) The shear viscosity η increases with T up to T ~ 3 - 3.5 MeV, and saturates at higher T; η $(T = 5\ MeV)$ ~ (1.3 – 3.5) u ($u = 10^{-23}$ *MeV s fm*$^{-3}$).

2) η/s decreases with increasing T, to reach (1.3 ~ 4.0) KSS at T= 5 MeV. These values are lower and of less uncertainty than the prediction by the FLDM (4 ~ 19 KSS).

Nucleons inside a hot nucleus at T ~ 5 MeV has nearly the same viscosity as that of QGP (2 – 3 KSS units) at T > 175 MeV.

- ❖ The GDR width increases with *M* at a given value of *T* for $T \leq 3$ MeV. At higher T, the GDR width approaches a saturation at $M \geq 60\hbar$ for ^{88}Mo and $M \geq 80\hbar$ for ^{106}Sn
- ❖ The region of $M \geq 60$ goes beyond the maximum value of *M* up to which the specific shear viscosity η/s has values not smaller than the KSS lower-bound conjecture for this quantity. This maximum value of *M* is found to be equal to $46\hbar$ and $55\hbar$ for ^{88}Mo and ^{106}Sn, respectively, if the value $\eta(0) = 0.6u$ ($u=10^{-23}$ MeV s fm^{-3}) for the shear viscosity at $T = 0$ is used



N. Dinh Dang, Phys. Rev. C ***85****, 064323 (2012)*

η/s in Hot Rotating Nuclei

PHYSICAL REVIEW C **86**, 024302 (2012)

Specific shear viscosity in hot rotating systems of paired fermions

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[1]*School of Engineering, TanTao University, TanTao University Avenue, TanDuc Ecity, Duc Hoa, Long An Province, Vietnam*

[2]*Theoretical Nuclear Physics Laboratory, RIKEN Nishina Center for Accelerator-Based Science, 2-1 Hirosawa, Wako City, 351-0198 Saitama, Japan*

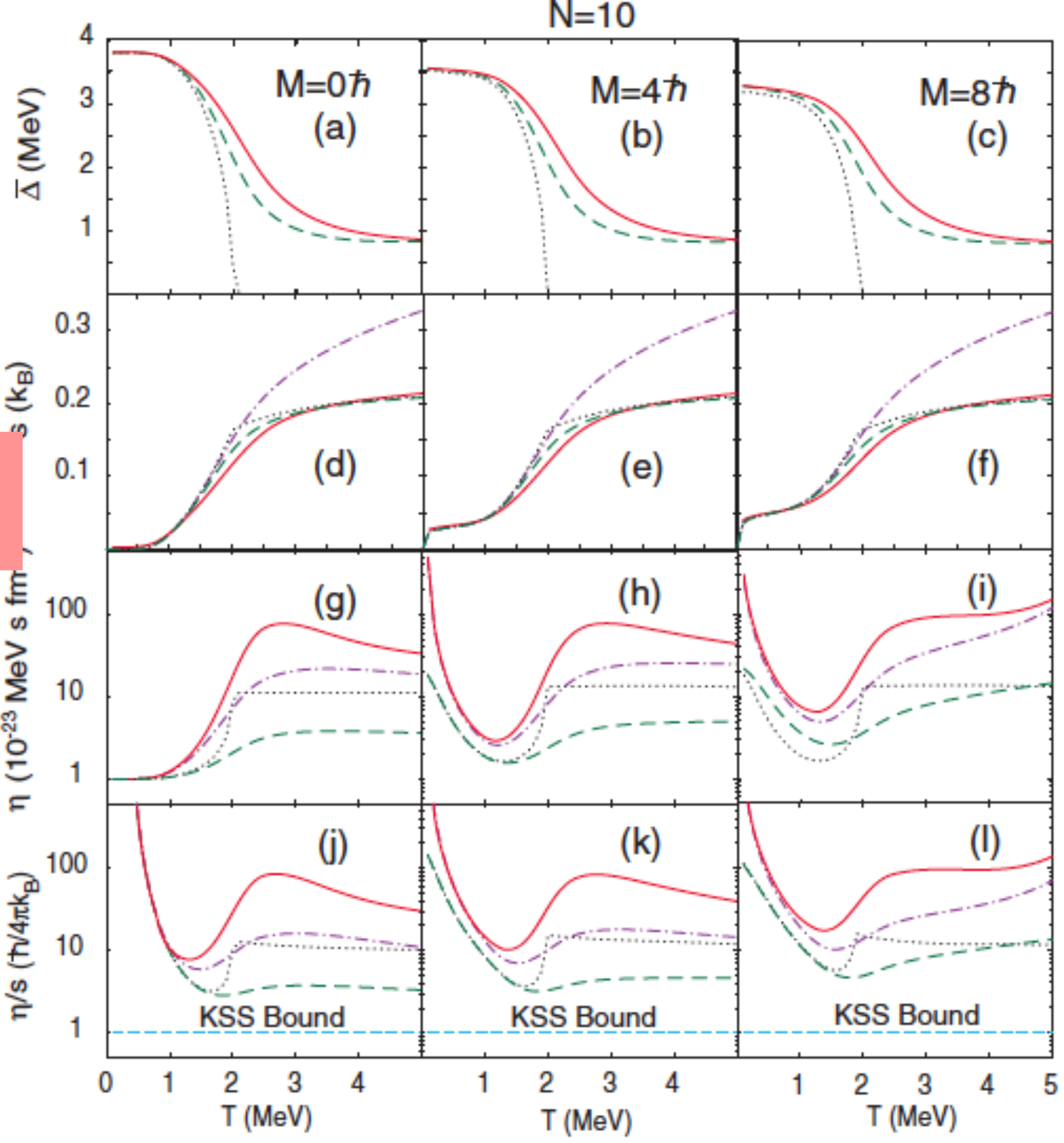
[3]*Institute for Nuclear Science and Technique, Hanoi, Vietnam*

(Received 26 June 2012; revised manuscript received 18 July 2012; published 3 August 2012)

The specific shear viscosity $\overline{\eta}$ of a classically rotating system of nucleons that interact via a monopole pairing force is calculated including the effects of thermal fluctuations and coupling to pair vibrations within the self-consistent quasiparticle random-phase approximation. It is found that $\overline{\eta}$ increases with angular momentum M at a given temperature T. In medium and heavy systems, $\overline{\eta}$ decreases with increasing T at $T \geqslant 2$ MeV and this feature is not affected much by angular momentum. However, in lighter systems (with the mass number $A \leqslant 20$), $\overline{\eta}$ increases with T at a value of M close to the maximal value $M_{\rm max}$, which is defined as the limiting angular momentum for each system. The values of $\overline{\eta}$ obtained within the schematic model as well as for systems with realistic single-particle energies are always larger than the universal lower-bound conjecture $\hbar/(4\pi k_B)$ up to $T = 5$ MeV.

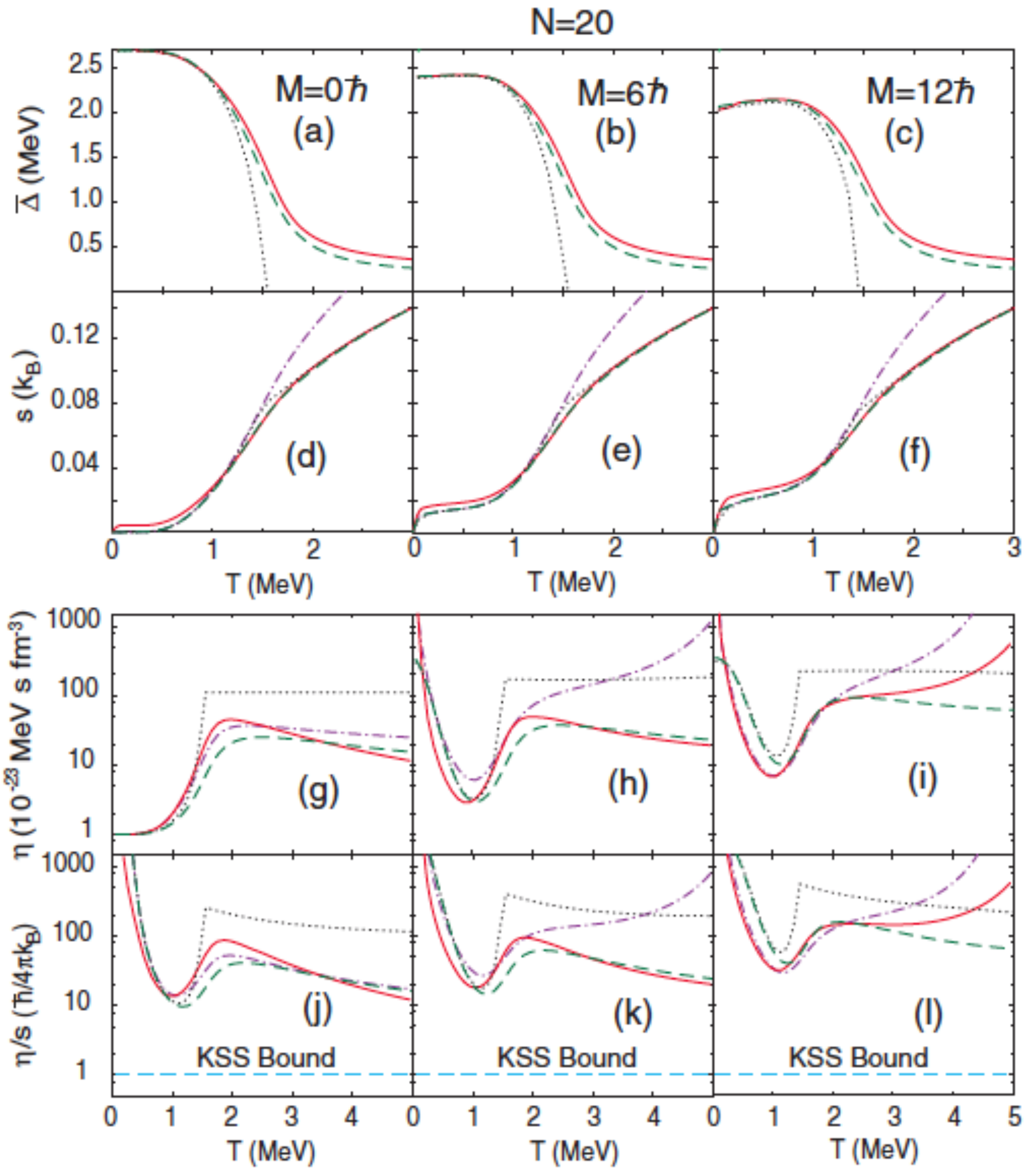
Schematic model N = 10

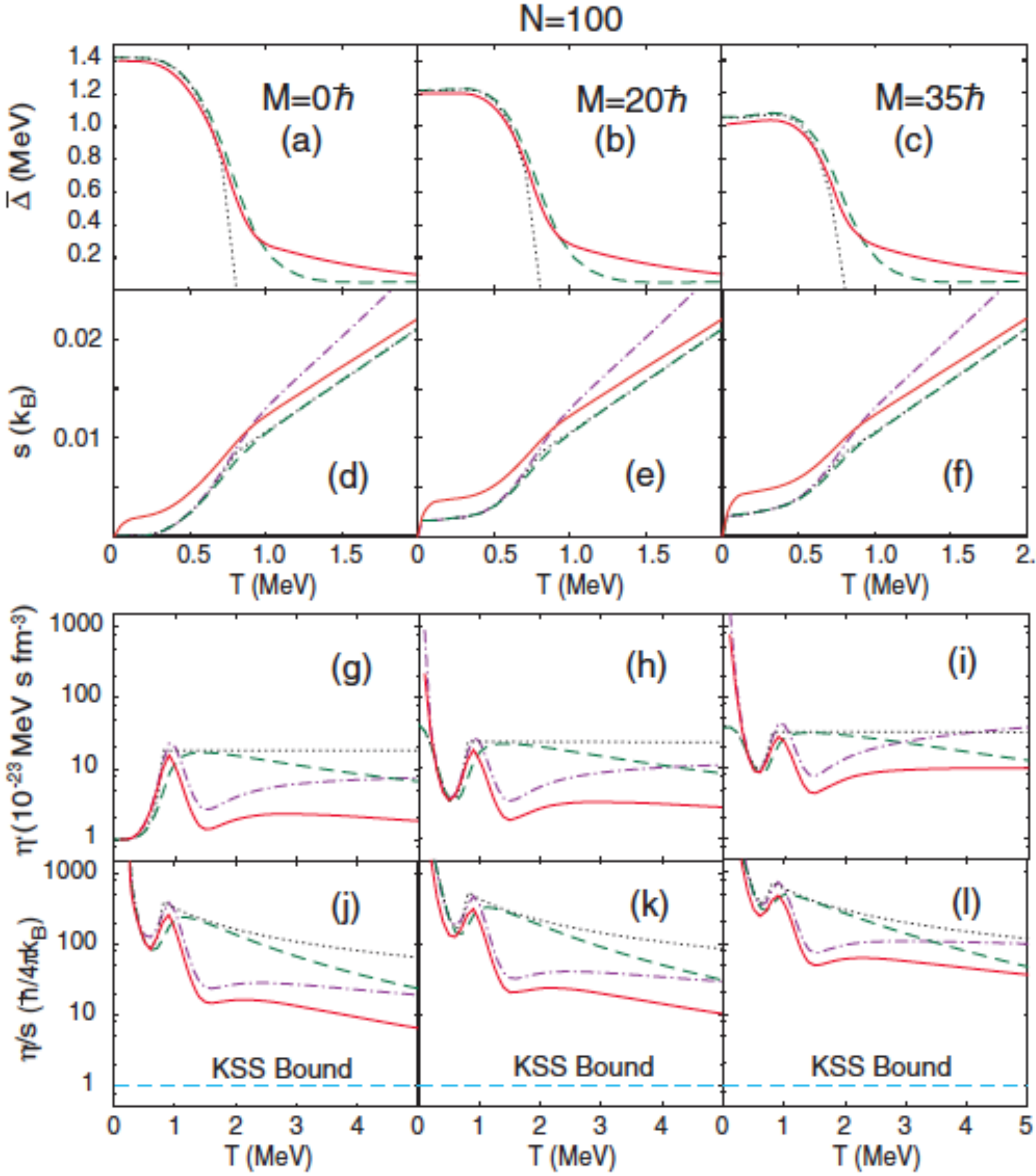
N. Quang Hung and N. Dinh Dang, Phys. Rev. C ***86****, 024302 (2012)*



Schematic model N = 20

*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **86**, 024302 (2012)*



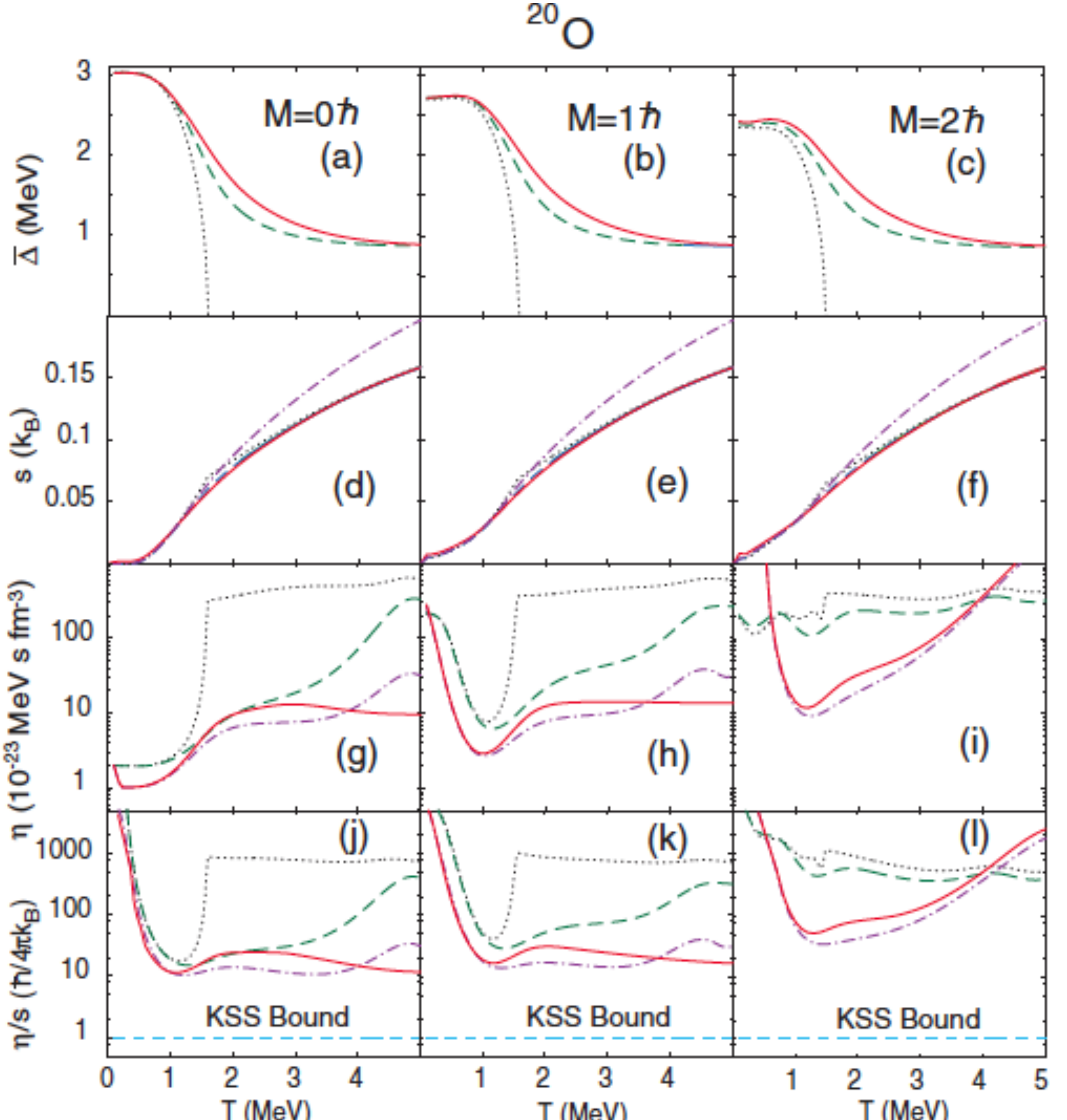


Schematic model
N = 100

N. Quang Hung and N. Dinh Dang, Phys. Rev. C ***86****, 024302 (2012)*

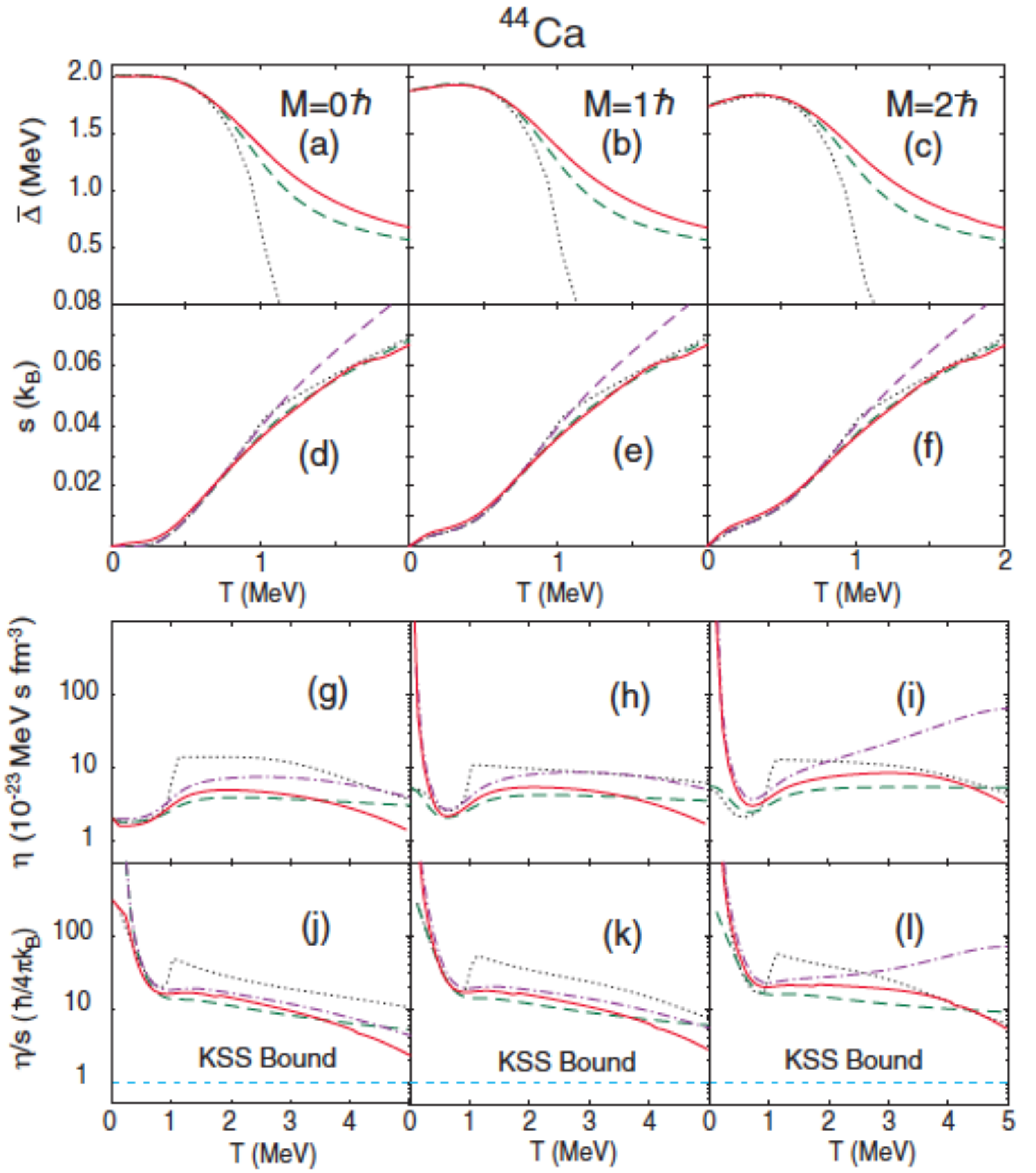
^{20}O

*N. Quang Hung and N. Dinh Dang, Phys. Rev. C **86**, 024302 (2012)*



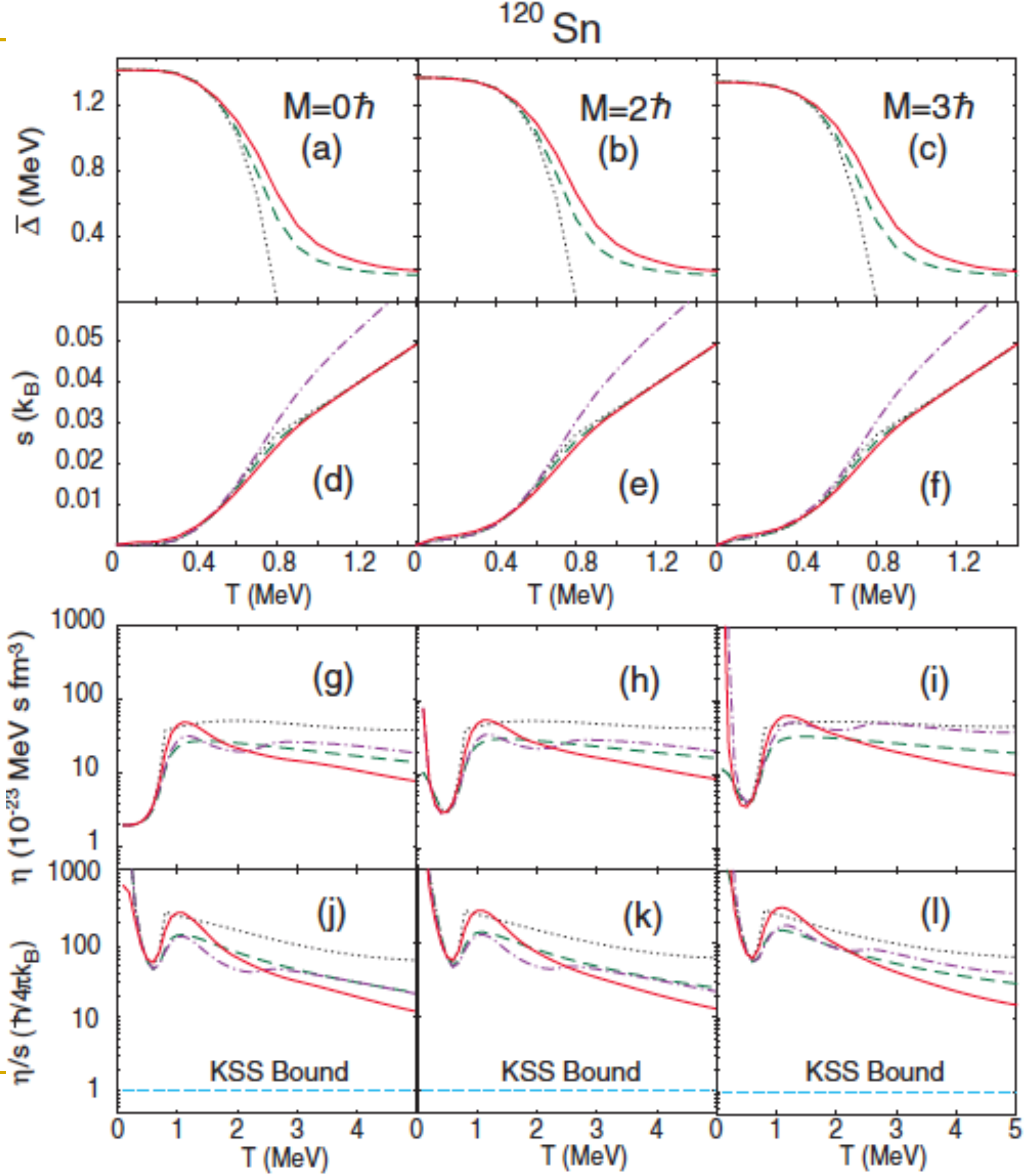
^{44}Ca

N. Quang Hung and N. Dinh Dang, Phys. Rev. C ***86****, 024302 (2012)*



^{120}Sn

N. Quang Hung and N. Dinh Dang, Phys. Rev. C ***86****, 024302 (2012)*



η/s in Hot Rotating Nuclei

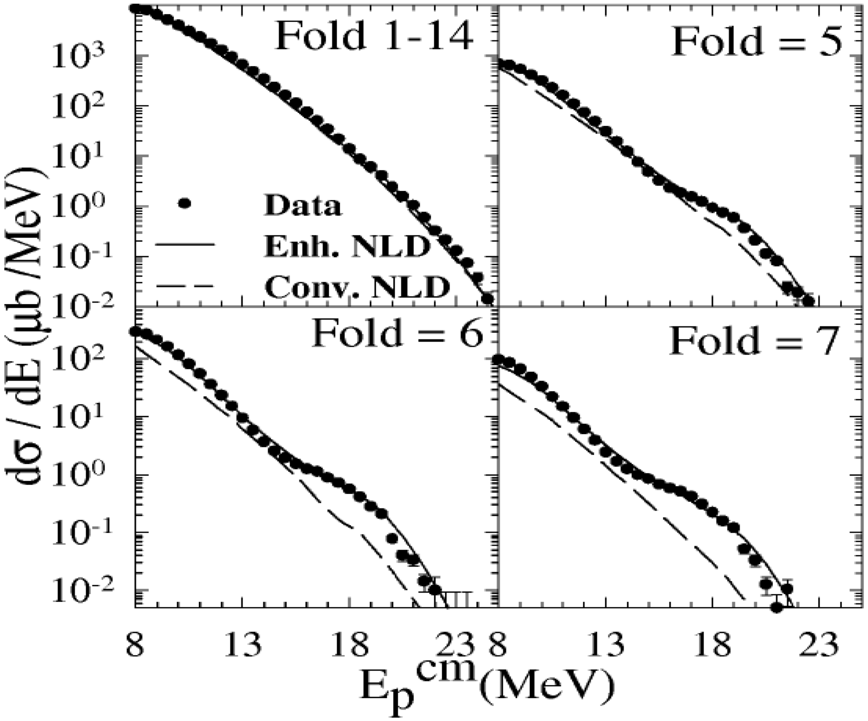
- In medium and heavy systems, η/s decreases with increasing T at T ≥ 2 MeV and this feature is not affected much by angular momentum, whereas it increases with T in light systems (with mass number A ≤ 20)

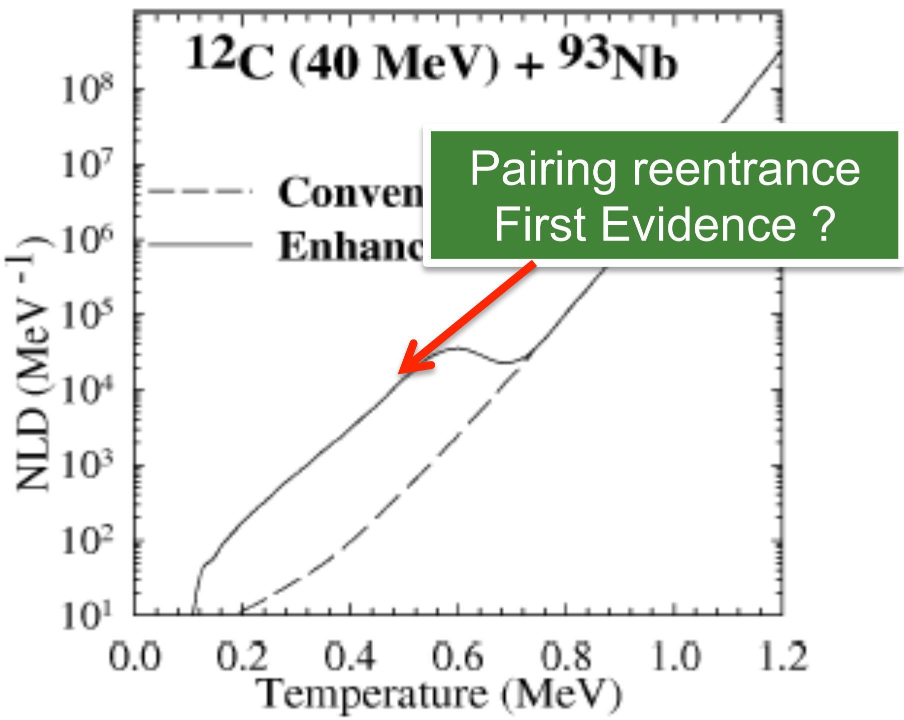
- The values of η/s obtained within the schematic model as well as for systems with realistic single-particle energies are always larger than the universal lower-bound conjecture $\hbar/(4\pi k_B)$ up to T = 5 MeV.

Research Topics

- Present Research Topics:
  - ✧ *Pairing Reentrance Phenomenon*

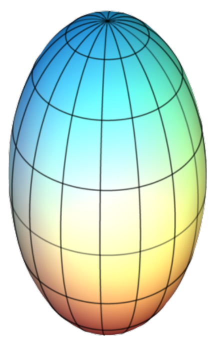
^{12}C + ^{93}Nb at $E(^{12}C)$ = 40 – 45 MeV

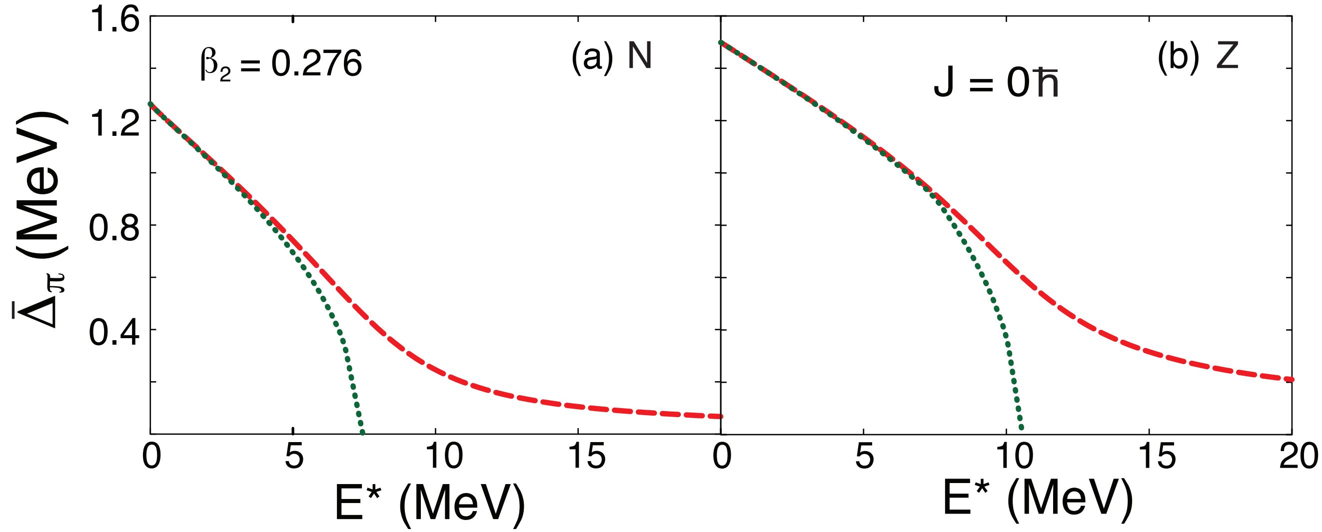




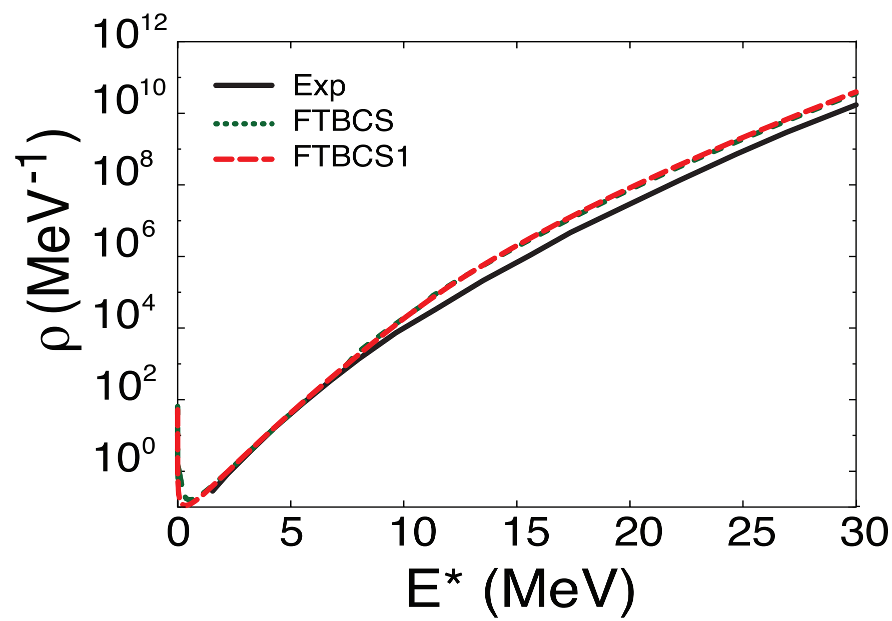
A. Mitra et al., J. Phys. G ***36****, 095103 (2009); A. Mitra et al., EPJ Web of Conf.* ***2****, 04004 (2010)*

FTBCS1 vs Exp



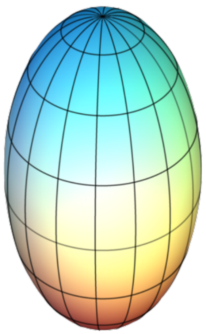


^{104}Pd

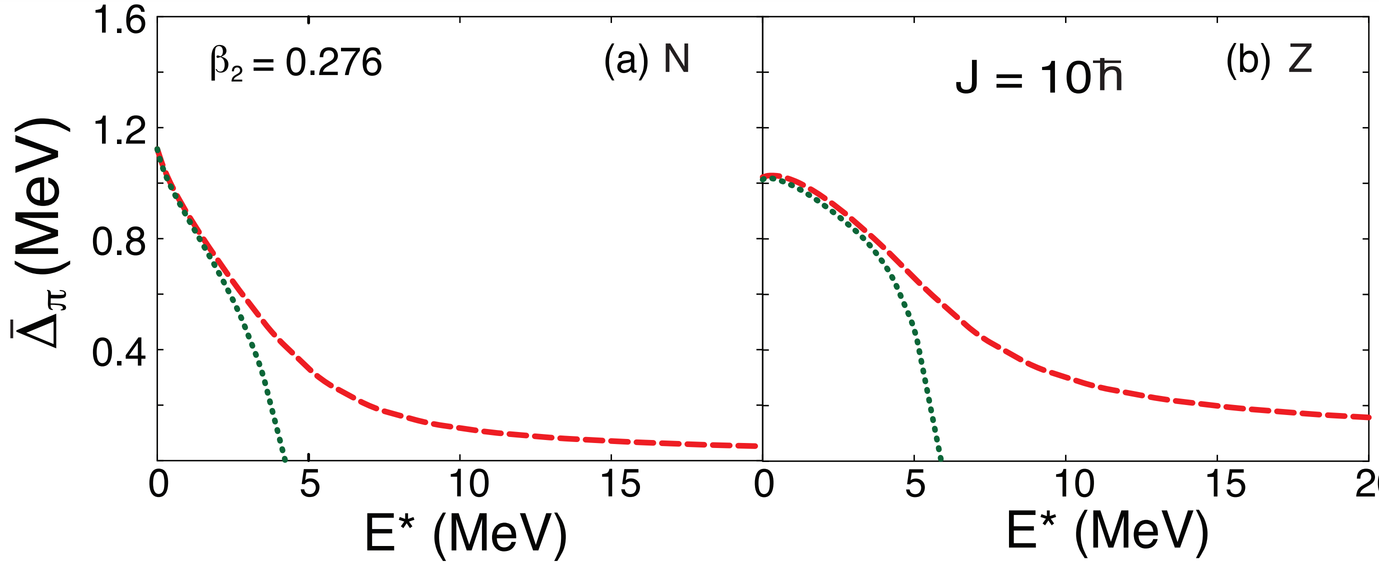


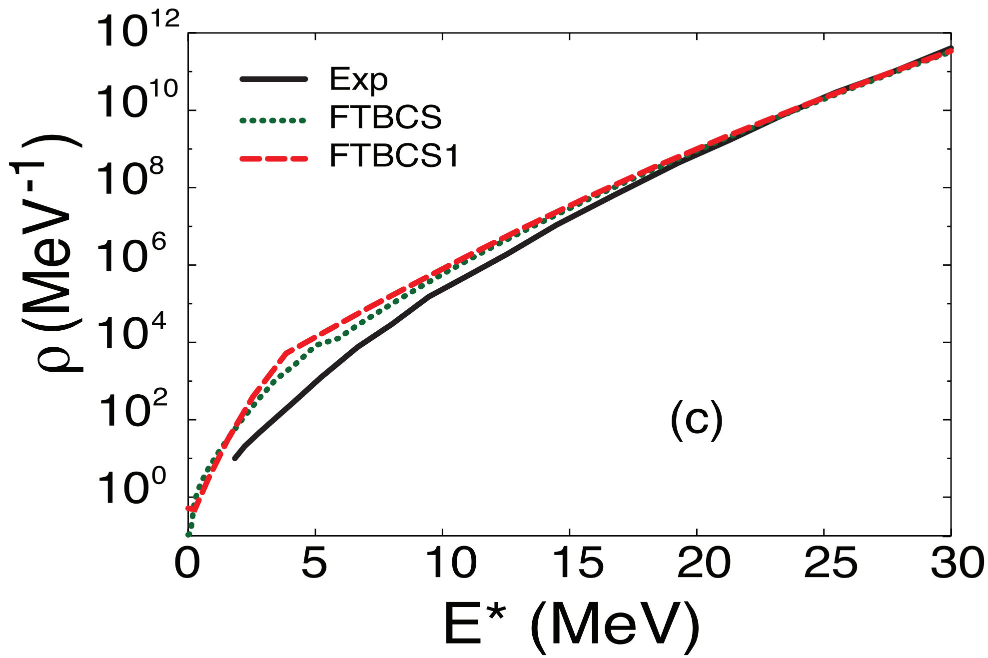
*N. Quang Hung, N. Dinh Dang, B. K. Agrawal, V. M. Data, A. Mitra, and D. R. Chakrabarty, Act. Phys. Pol. B **8**, 551 (2015)*

FTBCS1 vs Exp



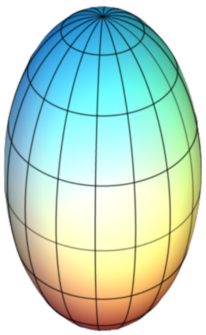
^{104}Pd

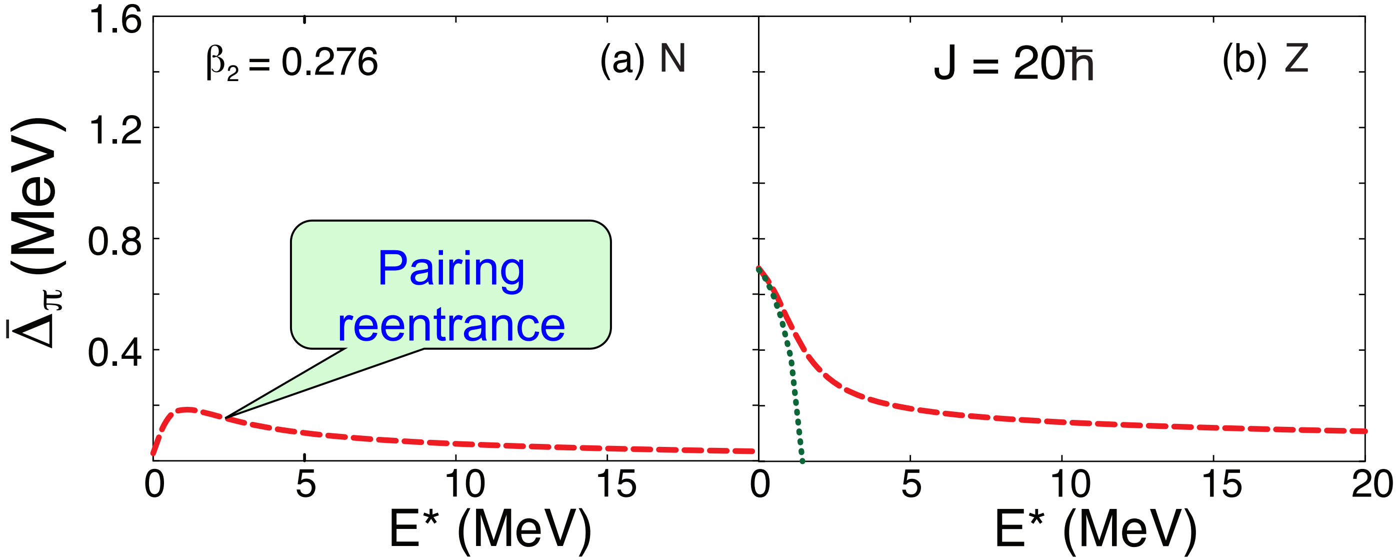




*N. Quang Hung, N. Dinh Dang, B. K. Agrawal, V. M. Data, A. Mitra, and D. R. Chakrabarty, Act. Phys. Pol. B **8**, 551 (2015)*

FTBCS1 vs Exp





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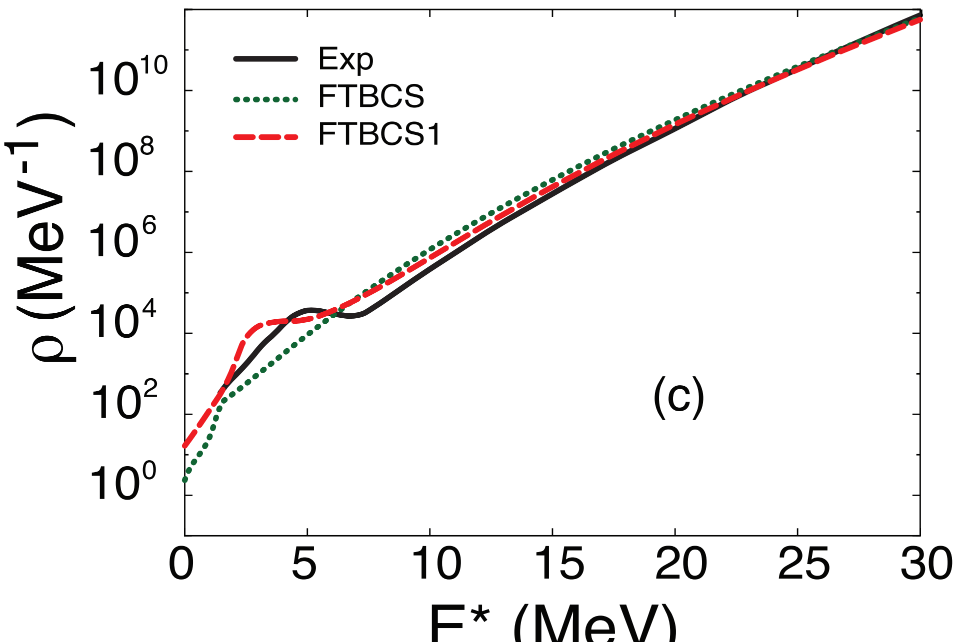
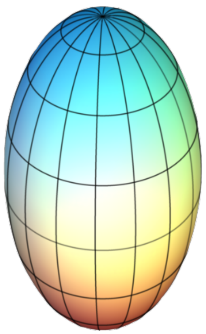


N. Quang Hung, N. Dinh Dang, B. K. Agrawal, V. M. Data, A. Mitra, and D. R. Chakrabarty, Act. Phys. Pol. B ***8****, 551 (2015)*

FTBCS1 vs Exp



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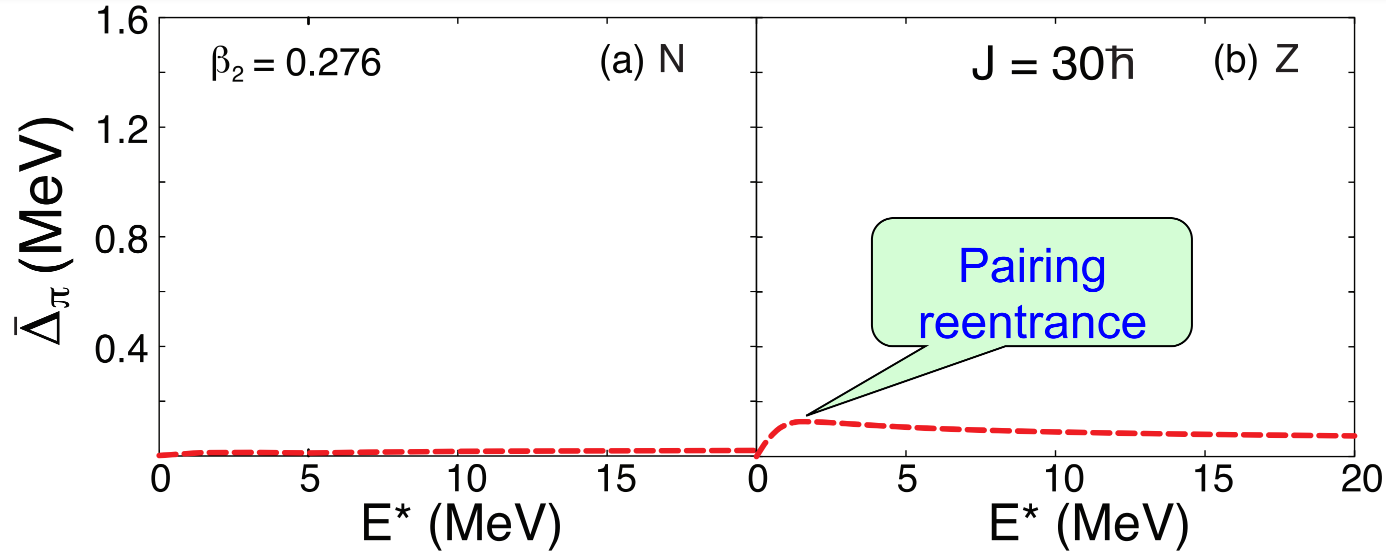
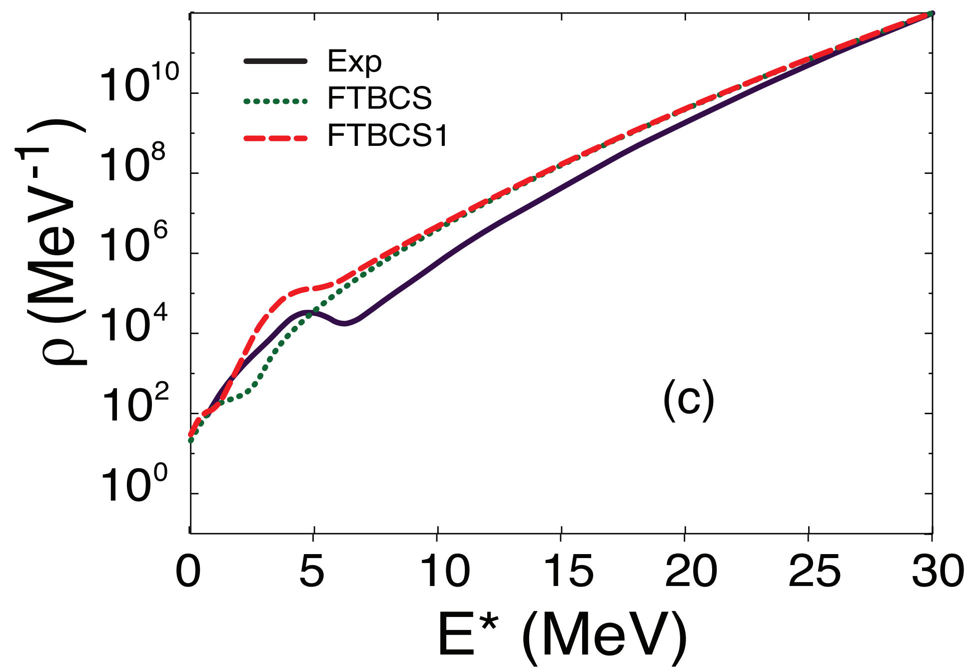
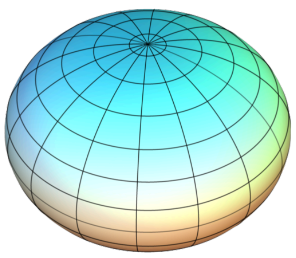


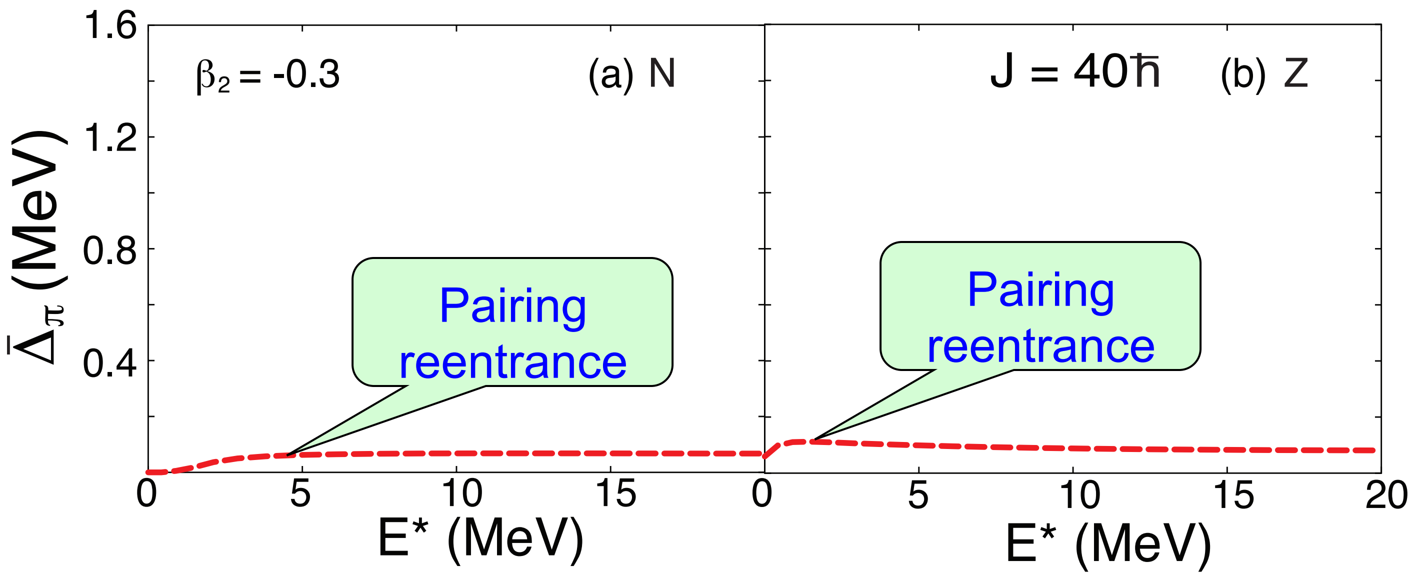


N. Quang Hung, N. Dinh Dang, B. K. Agrawal, V. M. Data, A. Mitra, and D. R. Chakrabarty, Act. Phys. Pol. B ***8****, 551 (2015)*

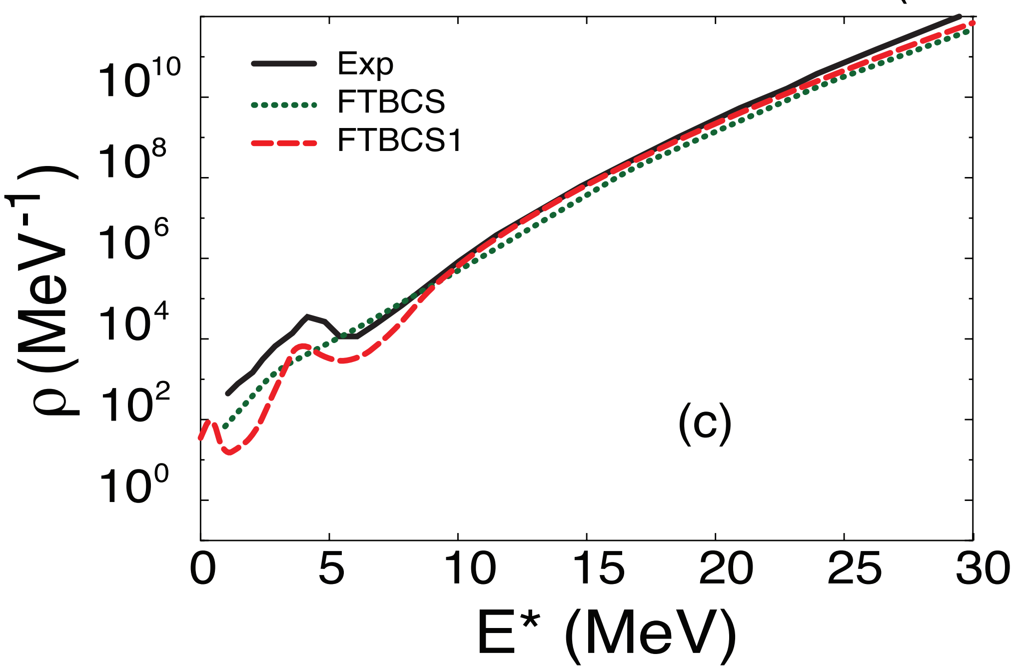
FTBCS1 vs Exp



^{104}Pd



N. Quang Hung, N. Dinh Dang, B. K. Agrawal, V. M. Data, A. Mitra, and D. R. Chakrabarty, Act. Phys. Pol. B ***8****, 551 (2015)*



Research Topics

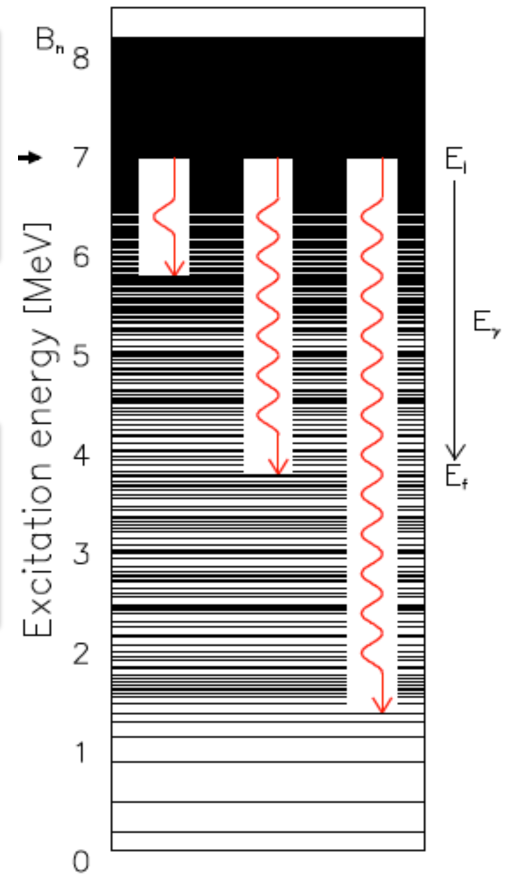
- Present Research Topics:
  - ✧ *Pairing Reentrance Phenomenon*
  - ✧ *Nuclear Level Density and Radiative Strength Function*

❖ NLD = number of excited levels per unit of excitation energy

*H. A. Bethe, Phys. Rev. C **50**, 332 (1936)*

❖ RSF = average transition probability per γ-ray energy

J. M. Blatt and V. F. Weisskopf, Theoretical Nuclear Physics (Wiley, New York, 1952).



Level densities and gamma-ray strength functions

http://www.mn.uio.no/fysikk/english/research/about/infrastructure/OCL/nuclear-physics-research/compilation/

The data are extracted according to the Oslo-method (A. Schiller et al., Nucl. Instrum. Methods A 447 (2000) 498). For the present data set, both the (^{3}He,^{3}He) and (^{3}He,^{4}He) reactions have been used. A comparison between the two reactions is performed in Ref.: A. Schiller et al., Phys. Rev. C61, 044324 (2000).

Some papers show, together with new data, also previously published data. These may be identical, however, in some cases small adjustments have been made from more recent information, e.g. new (n,g) neutron resonance spacing data. Therefore, the data from the most recent paper should be adopted.

You may download these data and pdf figures. If you publish them, please give references to the method and the journal where the data were published (see below).

If you have comments or questions, please contact magne.guttormsen[]fys.uio.no

Level densities

You may download pdf figures for some of these data here:
SmDyErYb, Dy, Yb, Mo, Fe, V, new 96Mo, Sc, new 56,57Fe, 116,117Sn

Gamma-ray strength functions (radiative strength functions RSF)

You may download pdf figures for some of these data here:
SmDyErYb, Dy, Yb, Mo, Fe, 50V, 51V, new 96Mo, Sc, new 56,57Fe

A. Voinov et al., Phys. Rev. C63, 044313 (2001): (^{3}He,^{4}He)^{161}Dy
A. Voinov et al., Phys. Rev. C63, 044313 (2001): (^{3}He,^{4}He)^{162}Dy

E. Melby et al., Phys. Rev. C63, 044309 (2001): (^{3}He,^{4}He)^{166}Er
E. Melby et al., Phys. Rev. C63, 044309 (2001): (^{3}He,^{3}He)^{167}Er

A. Voinov e

Bink-Axel hypothesis

A. Voinov et al., Phys. Rev. C63, 044313 (2001): (^{3}He,^{4}He)^{172}Yb

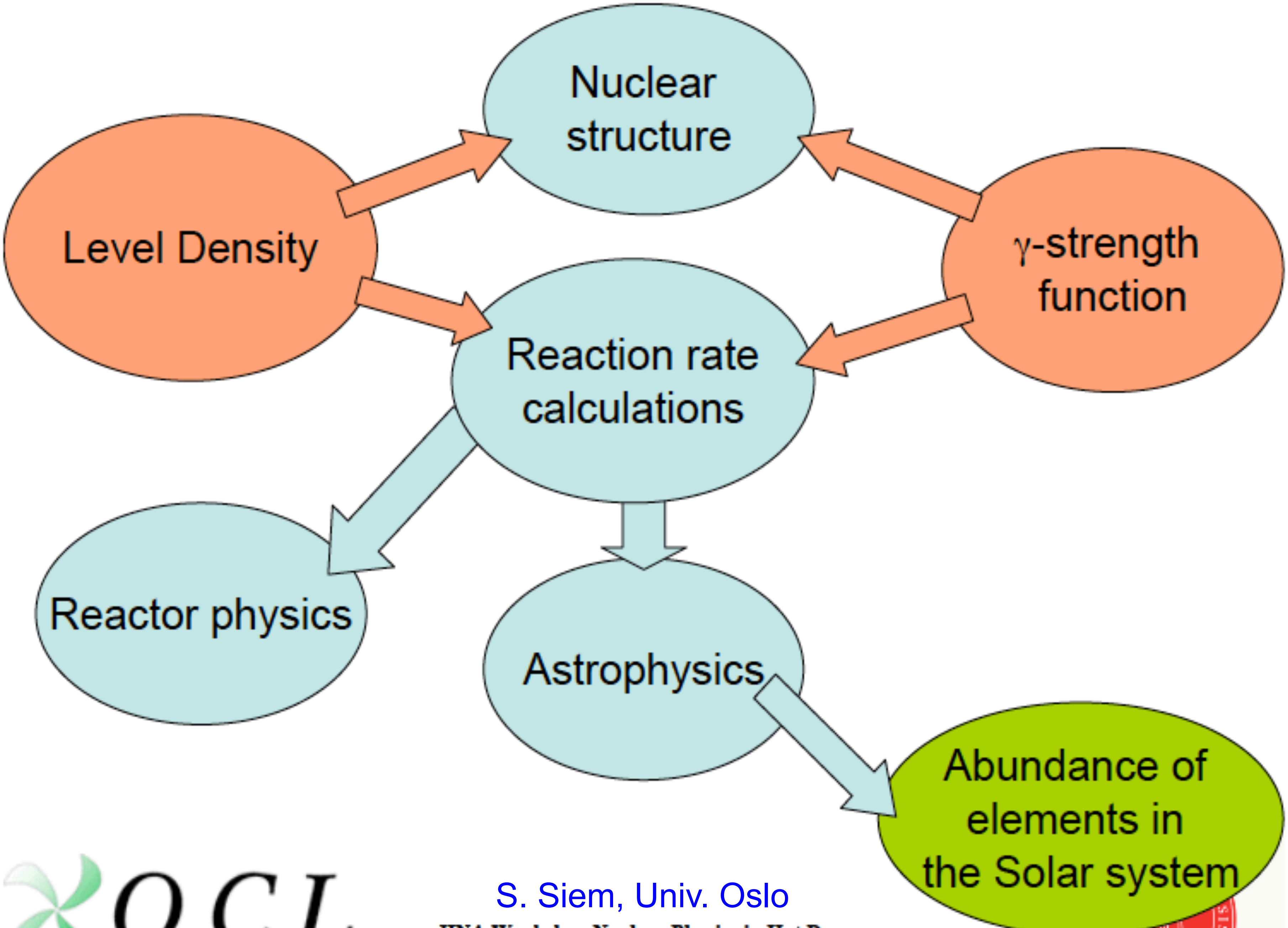
$$P(E_i,E_\gamma) \propto \rho(E_f)\cdot \mathcal{T}(E_\gamma)$$

M. Guttormsen et al., Phys. Rev. C68, 064306 (2003): (^{3}He,^{4}He)^{160}Dy
M. Guttormsen et al., Phys. Rev. C68, 064306 (2003): (^{3}He,^{3}He)^{161}Dy
M. Guttormsen et al., Phys. Rev. C68, 064306 (2003): (^{3}He,^{4}He)^{161}Dy
M. Guttormsen et al., Phys. Rev. C68, 064306 (2003): (^{3}He,^{3}He)^{162}Dy
M. Guttormsen et al., Phys. Rev. C68, 064306 (2003): (^{3}He,^{4}He)^{162}Dy

U. Agvaanluvsan et al., Phys. Rev. C70, 054611 (2004): (^{3}He,^{4}He)^{170}Yb
U. Agvaanluvsan et al., Phys. Rev. C70, 054611 (2004): (^{3}He,^{3}He)^{171}Yb
U. Agvaanluvsan et al., Phys. Rev. C70, 054611 (2004): (^{3}He,^{4}He)^{171}Yb
U. Agvaanluvsan et al., Phys. Rev. C70, 054611 (2004): (^{3}He,^{3}He)^{172}Yb
U. Agvaanluvsan et al., Phys. Rev. C70, 054611 (2004): (^{3}He,^{4}He)^{172}Yb

A. Voinov et al., Phys. Rev. Lett. 93, 142504 (2004): (^{3}He,^{4}He)^{56}Fe
A. Voinov et al., Phys. Rev. Lett. 93, 142504 (2004): (^{3}He,^{3}He)^{57}Fe

M. Guttormsen et al., Phys. Rev. C71, 044307 (2005): (^{3}He,^{4}He)^{93}Mo
M. Guttormsen et al., Phys. Rev. C71, 044307 (2005): (^{3}He,^{3}He)^{94}Mo
M. Guttormsen et al., Phys. Rev. C71, 044307 (2005): (^{3}He,^{4}He)^{95}Mo



OCL
Oslo Cyclotron Laboratory

S. Siem, Univ. Oslo

JINA Workshop Nuclear Physics in Hot Dense Dynamic Plasma, London, 13-14 March 2011

PHYSICAL REVIEW C VOLUME 56, NUMBER 3 SEPTEMBER 1997

Nuclear level density and the determination of thermonuclear rates for astrophysics

Thomas Rauscher
Institut für Physik, Universität Basel, Basel, Switzerland

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Karl-Ludwig Kratz
Institut für Kernchemie, Universität Mainz, Germany

Hauser-Feshbach Theory

$$d\sigma(E) \sim T(E)\rho(E^*)dE$$

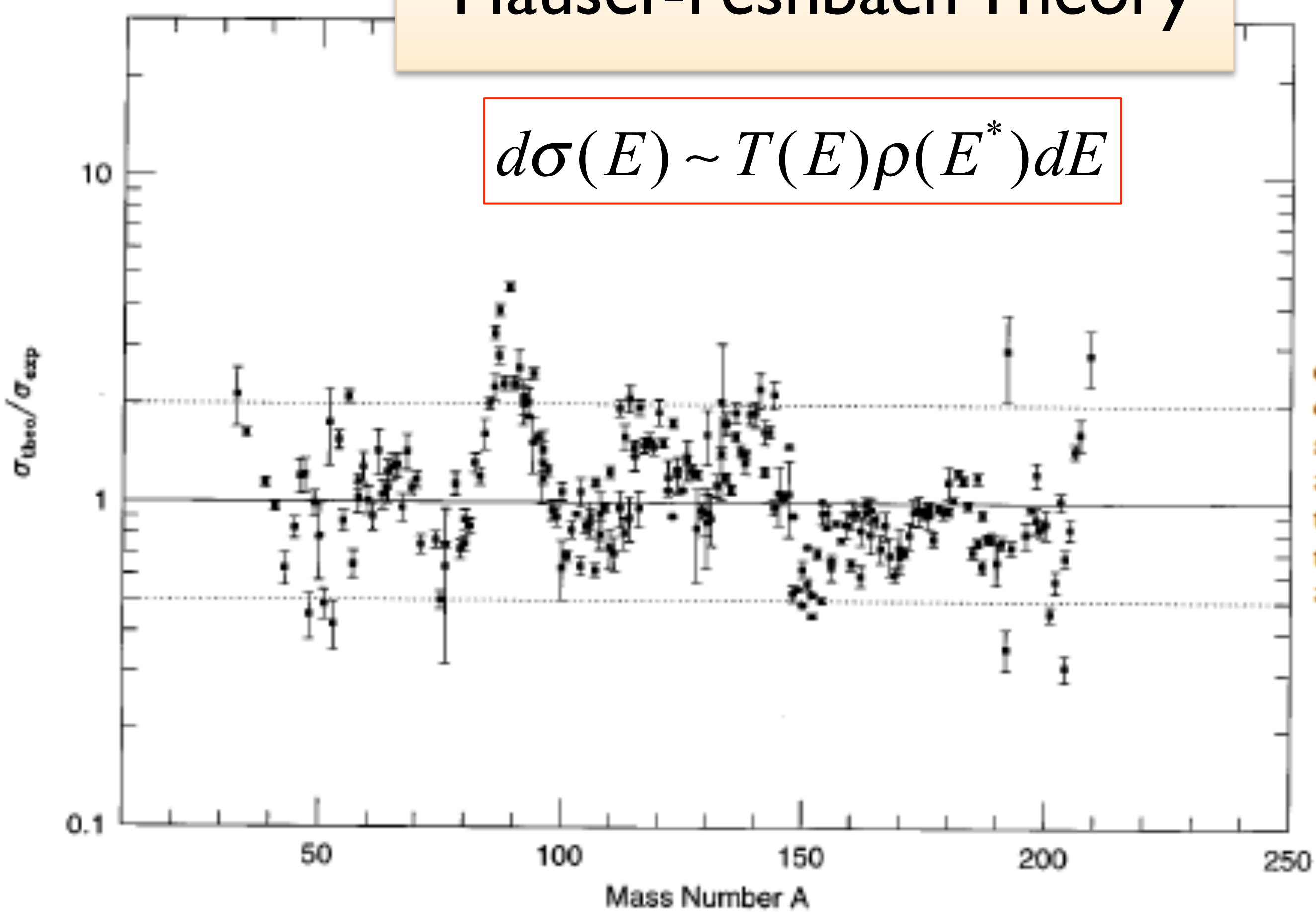


FIG. 5. Ratio of theoretical to experimental [50] neutron capture cross sections at 30 keV. Cross sections for light nuclei ($A<30$) are not plotted because the statistical model cannot be applied in that region for neutron-capture reactions (compare Fig. 7).

Present Research Topics

Phenomenological Models for NLD

Back-Shifted Fermi-gas model

Non-interacting Fermi particles moving in a potential

$$\rho(U) = \frac{1}{12\sqrt{2}\sigma} \frac{\exp(2\sqrt{aU})}{a^{1/4}U^{5/4}}$$

$$\sigma^2 = \frac{I_{\text{rigid}}}{\hbar^2}\sqrt{\frac{U}{a}}, \quad I_{\text{rigid}} = \frac{2}{5} m_u A R^2, \quad U = E - \delta$$

$$a(U,Z,N) = \tilde{a}(A)\left[1 + C(Z,N)\frac{f(U)}{U}\right]$$

$$\tilde{a} = \alpha A + \beta A^{2/3}, \qquad f(U) = 1 - e^{-\gamma U}$$

Constant temperature model

Classical ideal gas (used for low excitation-energy region)

$$\rho(U) = \frac{1}{T}\exp\left(\frac{U - E_0}{T}\right)$$

A. Gilbert and A. G. W. Cameron, Can. J. Phys. ***43****, 1446 (1965)*

H. A. Bethe, Phys. Rev. ***50****, 332 (1936)*

Present Research Topics

Microscopic Models for NLD

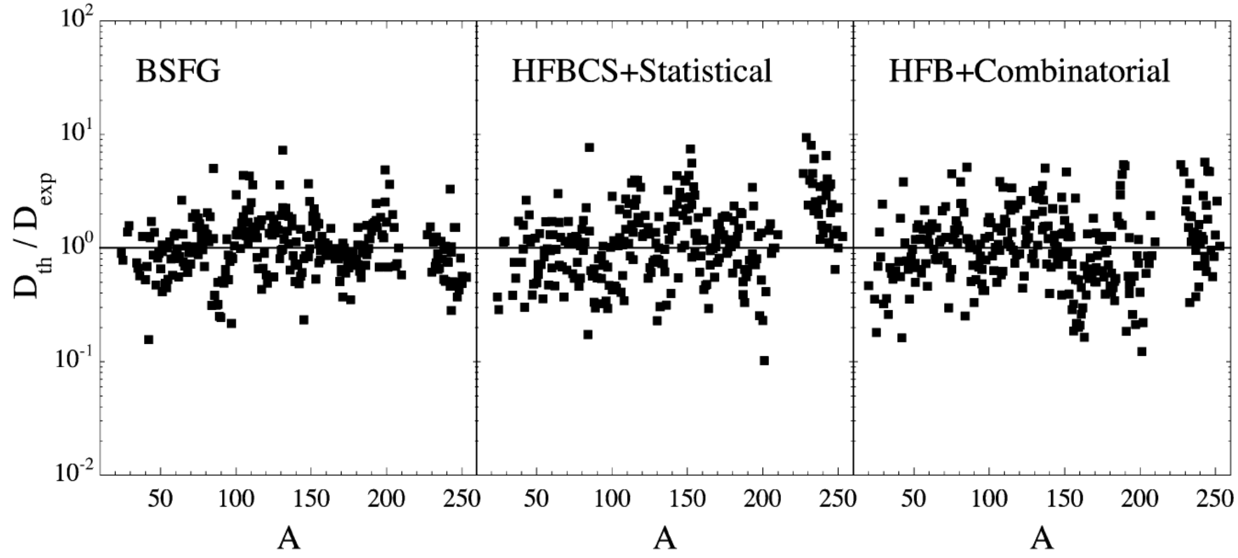
- Hartree-Fock-Bogoliubov plus Combinatorial Method (**HFBC**)

- Shell Model Monte Carlo (**SMMC**)

HFBC

- Single-particle levels: Hartree Fock Bogoliubov with Skyrme NN effective interactions (BSk14)
- Combinatorial Method:
  - Construct incoherent particle-hole (ph) state densities as function of E^*, M, and π.
  - Incoherent ph states plus vibrational enhancement treated by using the boson partition function including quadrupole, octupole, and hexadecapole vibrational modes are then used to compute the total state densities and NLD.

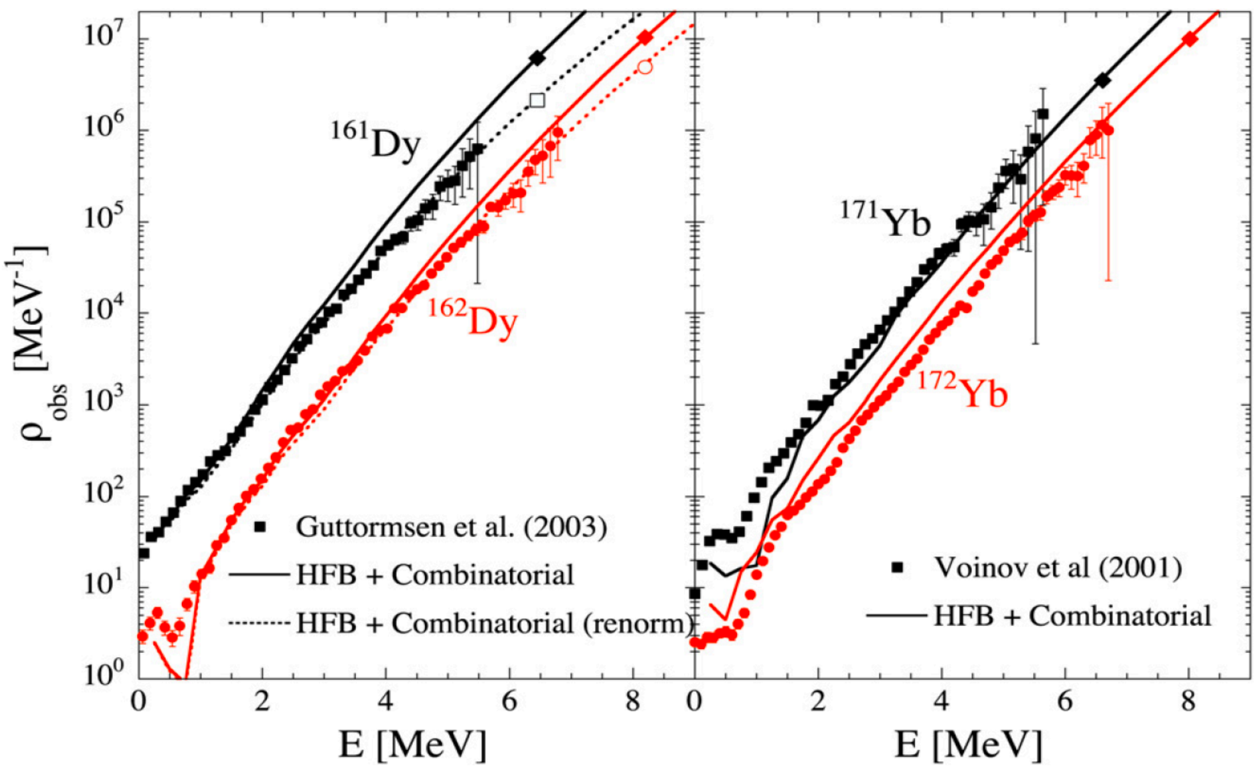
S. Hilaire and S. Goriely, Nucl. Phys. A ***779****, 63 (2006)*
S. Goriely et al., Phys. Rev. C ***75****, 064312 (2007)*
S. Goriely et al., Phys. Rev. C ***78****, 064307 (2008)*



[S. Hilaire and S. Goriely, Nucl. Phys. A 779, 63 (2006)]

$$D_0 = \frac{1}{\rho(S_n, J_0+1/2, P_0) + \rho(S_n, J_0-1/2, P_0)} \quad \text{for } J_0 > 0,$$
$$= \frac{1}{\rho(S_n, 1/2, P_0)} \quad \text{for } J_0 = 0.$$

Fig. 3. Ratio of theoretical (D_{th}) BSFG [21] (left), HFBCS plus statistical [19] (center) or the present HFB plus combinatorial (right) to experimental (D_{exp}) s-wave neutron resonance spacings for the 295 nuclei compiled in [20].



The most microscopic approach to NLD up to date !

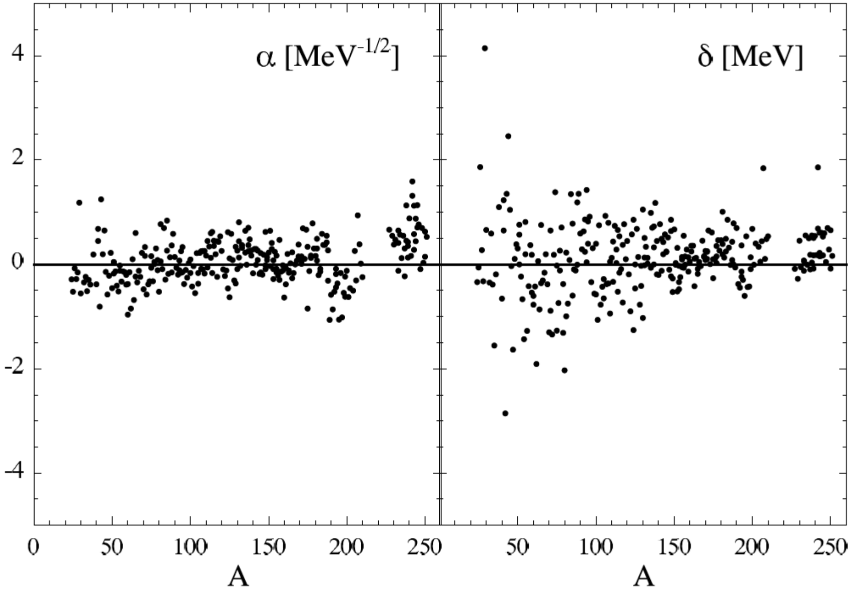
https://www-nds.iaea.org/RIPL-3/

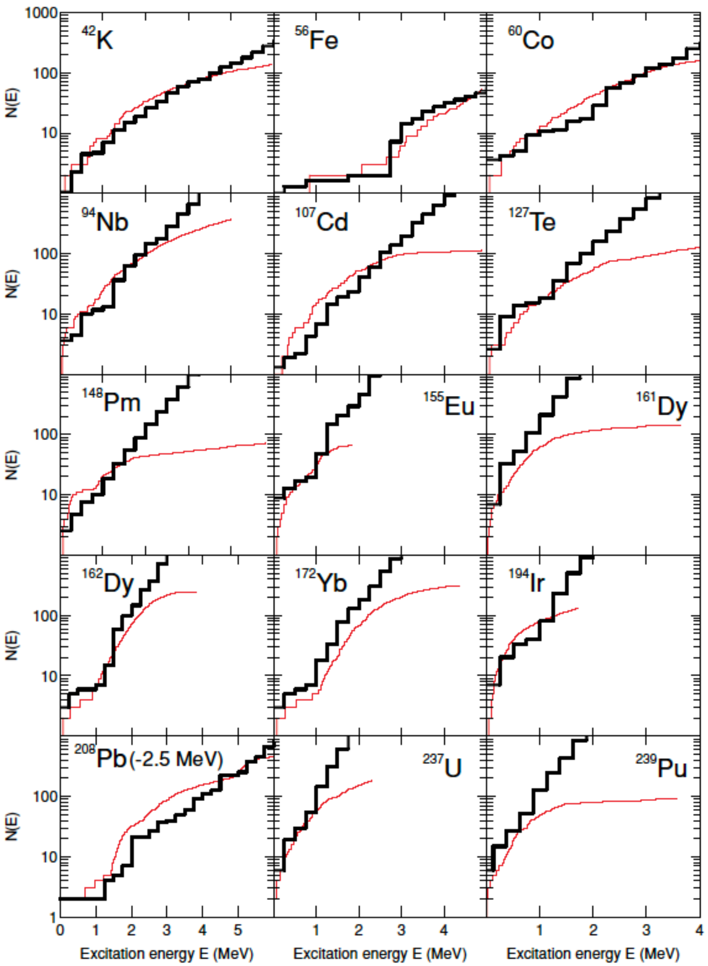
HFBC

$$\rho(U, J, P)_{\text{renorm}} = e^{\alpha\sqrt{(U-\delta)}} \times \rho(U-\delta, J, P),$$

δ: adjusted to fit the experimental cumulative levels at low U

α: adjusted to fit the experimental NLD at neutron separating energy B_n





[S. Goriely, S. Hilaire, and A. J. Koning, Phys. Rev. C 78, 064307 (2008)]

Reference Input Parameter Library (RIPL-3)

R. Capote, M. Herman, P. Oblozinsky, P.G. Young, S. Goriely, T. Belgya, A.V. Ignatyuk, A.J. Koning, S. Hilaire, V.A. Plujko, M. Avrigeanu, O. Bersillon, M.B. Chadwick, T. Fukahori, Zhigang Ge, Yinlu Han, S. Kailas, J. Kopecky, V.M. Maslov, G. Reffo, M. Sin, E.Sh. Soukhovitskii and P. Talou

Nuclear Data Sheets - Volume 110, Issue 12, December 2009, Pages 3107-3214

RIPL discrete levels database updated in August 2015 - it contains the correction for +X,.. levels

Level Densities Segment

Total Level Densities

https://www-nds.iaea.org/RIPL-3/

Back-Shifted Fermi Gas Model (BSFG)

Level density parameters for the BSFG model obtained by fitting the Fermi-gas model formula to the recommended spacings of s-wave neutron resonances and to the cumulative number of low-lying levels.

Data File (34.3kB)   README File (2.2kB)

Gilbert-Cameron Model

Level density parameters for the Gilbert-Cameron model obtained by fitting the Fermi-gas model formula to the recommended spacings of s-wave neutron resonances and by matching the corresponding level density to discrete levels.

Data File (42.8kB)   README File (2.4kB)

Enhanced Generalized Superfluid Model (EGSM)

Level density parameters for the Enhanced Generalized Superfluid Model (EGSM), which takes into account collective enhancement of the nuclear level density in addition to shell and superfluid effects. The parameters were obtained by fitting the corresponding model formulas to the recommended spacings of s-wave neutron resonances and by matching level densities to discrete levels.

Data File (26.1kB)   README File (2.4kB)

Z Systematics:
Data File (1.3kB)   README File (1.3kB)

Retrieval of Total Level Density Parameters

Atomic number (Z)
Mass number (A)
(blank for all mass numbers)
retrieve   reset

Plot of Total Level Density Parameters (a-parameters)

Select one of below and input no.:
Atomic number (Z)
Mass number (A)
Neutron number (N)

X-axis: A
plot   reset

Plot of Total Level Densities

Atomic number (Z)
Mass number (A)
plot   reset

HFB Total Level Densities

The data files (*.dat) contains the HFB plus combinatorial nuclear level densities at ground state deformations[1]. The nuclear level density is coherently obtained on the basis of the single-particle level scheme and pairing energy derived at the ground state deformation based on the BSk14 Skyrme force[2].

Retrieval of HFB

SMMC

The Gibbs ensemble $e^{-\beta H}$ describing a nucleus with Hamiltonian H at inverse temperature β, can be decomposed as a superposition of ensembles U_σ of non-interacting nucleons in external auxiliary fields $\sigma(\tau)$ that depend on imaginary time τ $(0 \leq \tau \leq \beta)$

$$e^{-\beta H} = \int D[\sigma] G_\sigma U_\sigma$$

Hubbard-Stratonovich transformation

G_σ is a Gaussian weight.

$$\langle O \rangle = \frac{\mathrm{Tr}\,(O e^{-\beta H})}{\mathrm{Tr}\,(e^{-\beta H})} = \frac{\int D[\sigma] W_\sigma \Phi_\sigma \langle O \rangle_\sigma}{\int D[\sigma] W_\sigma \Phi_\sigma}$$

$$W_\sigma = G_\sigma |\mathrm{Tr}\, U_\sigma|$$

$$\langle O \rangle_\sigma = \mathrm{Tr}\,(O U_\sigma) / \mathrm{Tr}\, U_\sigma$$

$\Phi_\sigma = \mathrm{Tr}\, U_\sigma / |\mathrm{Tr}\, U_\sigma|$ is the Monte Carlo sign

$$E(\beta) = \langle H \rangle \qquad Z(\beta) \equiv \mathrm{Tr} e^{-\beta H}$$

$$\rho(E) \approx \left(-2\pi \frac{dE}{d\beta}\right)^{-1/2} e^{S(E)}$$

SMMC

$$\rho_J(E_x) = \rho(E_x)\frac{(2J+1)}{2\sqrt{2\pi}\sigma_c^3}e^{-\frac{J(J+1)}{2\sigma_c^2}},$$

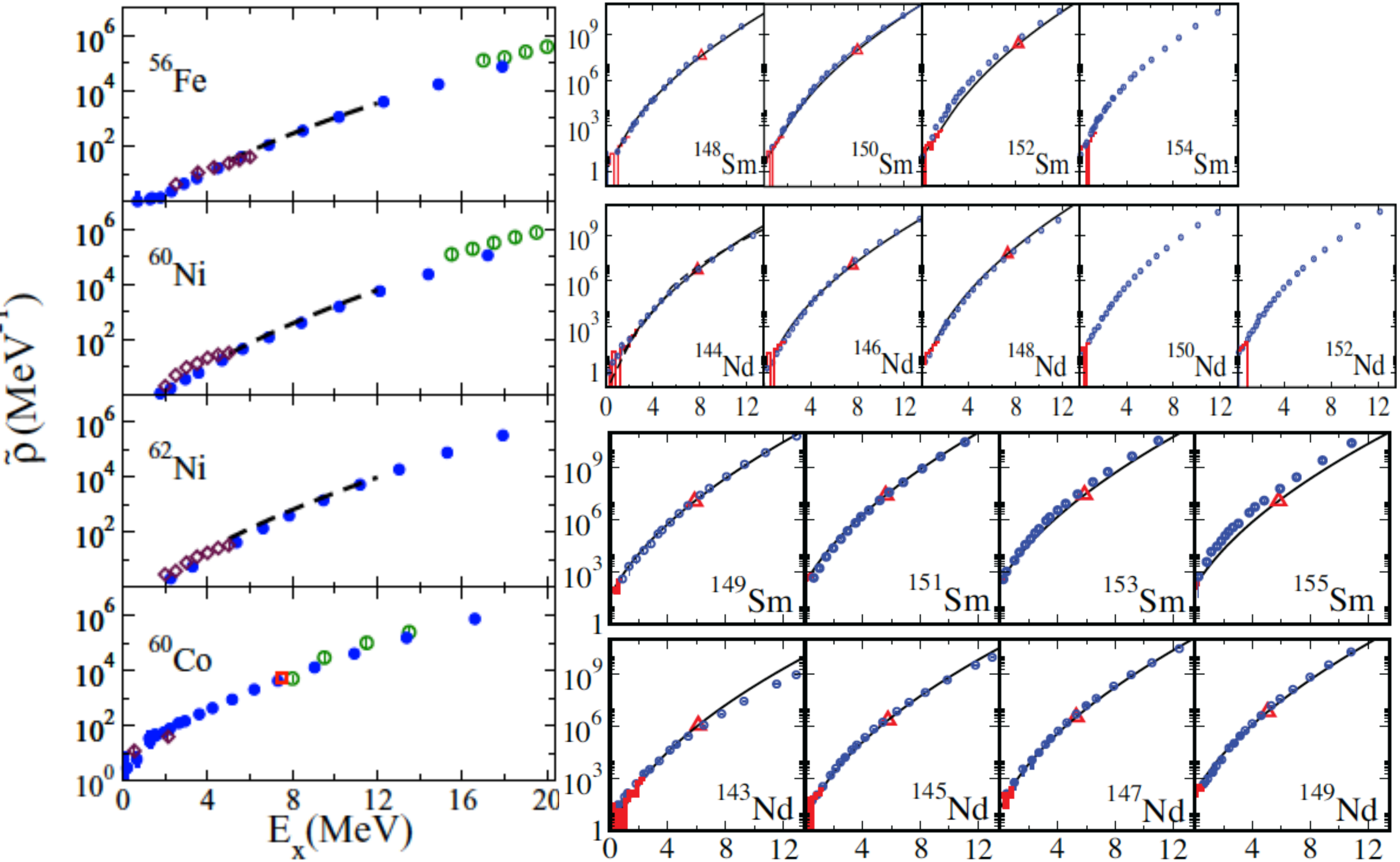
$$\tilde{\rho}(E_x) = \sum_J \rho_J(E_x) \approx \frac{1}{\sqrt{2\pi}\sigma_c}\rho(E_x),$$

$$\sigma_c(E_x) = (2\pi)^{-1/2}\rho(E_x)/\tilde{\rho}(E_x).$$

σ_c: obtained by fitting the theoretical NLD with exp

H. Nakada and Y. Alhassid, Phys. Rev. Lett. **79**, 2939 (1997).
Y. Alhassid, S. Liu, and H. Nakada, Phys. Rev. Lett. **83**, 4265 (1999).
S. Liu and Y. Alhassid, Phys. Rev. Lett. **87**, 022501 (2001).
Y. Alhassid, S. Liu, and H. Nakada, Phys. Rev. Lett. **99**, 162504 (2007).
Y. Alhassid, L. Fang, and H. Nakada, Phys. Rev. Lett. **101**, 082501 (2008).
C. Ozen, Y. Alhassid, and H. Nakada, Phys. Rev. Lett. **110**, 042502 (2013).

SMMC



^{56}Fe
^{60}Ni
^{62}Ni
^{60}Co
$\tilde{\rho}$ (MeV^{-1})
E_x(MeV)
^{148}Sm
^{150}Sm
^{152}Sm
^{154}Sm
^{144}Nd
^{146}Nd
^{148}Nd
^{150}Nd
^{152}Nd
^{149}Sm
^{151}Sm
^{153}Sm
^{155}Sm
^{143}Nd
^{145}Nd
^{147}Nd
^{149}Nd

Models for RSF

- **Phenomenological**
  - *Kadmenski-Markushev-Furman (**KMF**)*
  - *Standard Lorentzian (**SLO**)*
  - *Generalized Lorentzian (**GLO**)*
  - *Enhanced Generalized Lorentzian (**EGLO**)*
  - *Generalized Fermi Liquid (**GFL**)*

- **Microscopic**
  - *Hartree-Fock-BCS + Quasiparticle Random-Phase Approximation (**HFBCS + QRPA**)*

KMF Model

http://www.talys.eu/

$$f(E_\gamma) = \kappa[f_{E1}(E_\gamma) + f_{M1}(E_\gamma)] + E_\gamma^2 f_{E2}(E_\gamma) + f_{pygmy}(E_\gamma)$$

$$f_{E1}(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2}\frac{0.7\sigma_{E1}\Gamma_{E1}^2(E_\gamma^2+4\pi^2T^2)}{E_{E1}(E_\gamma^2-E_{E1}^2)^2}, \quad \Gamma_{E1}(E_\gamma,T) = \frac{\Gamma_{E1}}{E_{E1}^2}(E_\gamma^2+4\pi^2T^2)$$

$$f_{E2}(E_\gamma) = \frac{1}{5\pi^2\hbar^2c^2E_\gamma^2}\frac{\sigma_{E2}E_\gamma\Gamma_{E2}^2}{(E_\gamma^2-E_{E2}^2)^2+E_\gamma^2\Gamma_{E2}^2}$$

$$f_{M1}(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2}\frac{\sigma_{M1}E_\gamma\Gamma_{M1}^2}{(E_\gamma^2-E_{M1}^2)^2+E_\gamma^2\Gamma_{M1}^2}$$

$$f_{py}(E_\gamma) = \frac{1}{3\pi^2\hbar^2c^2}\frac{\sigma_{py}E_\gamma\Gamma_{py}^2}{(E_\gamma^2-E_{py}^2)^2+E_\gamma^2\Gamma_{py}^2}$$

S. G. Kadmenskij, V. P. Markushev, and V. I. Furman, Yad. Fiz. ***37****, 277 (1983)*

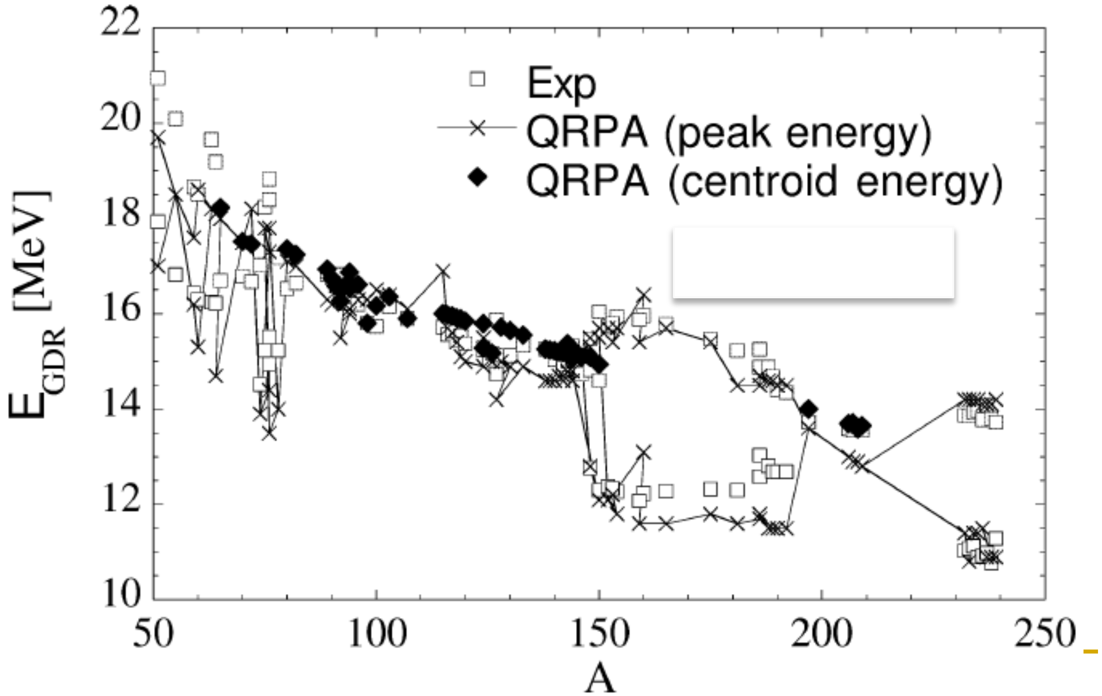
J. Kopecky and R. E. Chrien, Nucl. Phys. A ***468****, 285 (1987).*

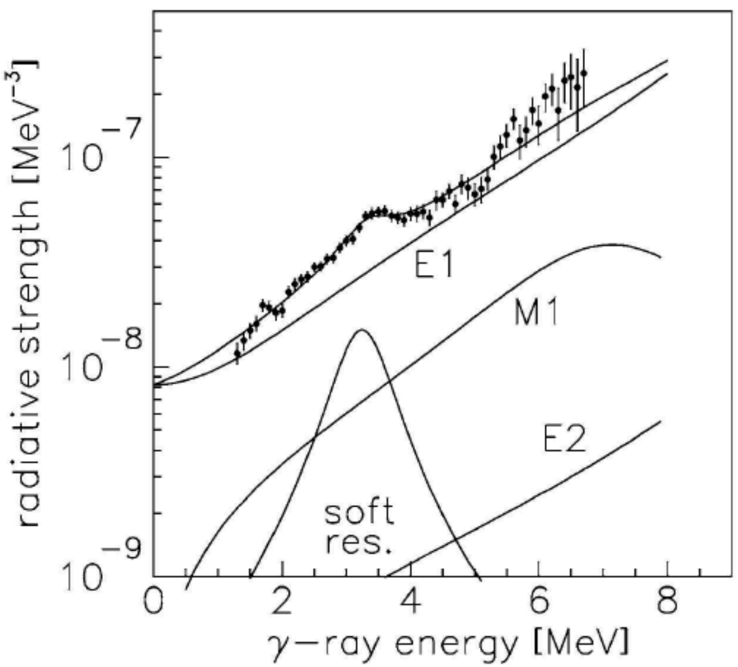
HFBCS + QRPA

https://www-nds.iaea.org/RIPL-3/

*S. Goriely and E. Khan, Nucl. Phys. A **706**, 217 (2002)*

$$f_L(E, E_i, \gamma_i) = \frac{2}{\pi} \frac{\gamma_i E^2}{(E^2 - E_i^2)^2 + \gamma_i^2 E^2}. \quad \gamma_i = \Gamma_{\mathrm{GDR}}/2$$





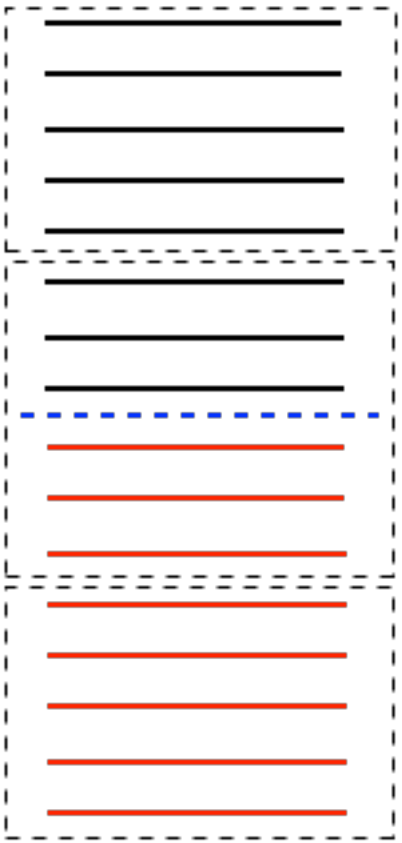
Microscopic Approach to NDL and RSF

N. Quang Hung, N. Dinh Dang, and L.T. Quynh Huong., Phys. Rev. Lett. **118**, 022502 (2017)

❑ For NLD

- *Exact pairing (EP): solve the pairing problem exactly by diagonalizing directly* $\mathbf{H = H_0 + H_{pair}}$ *within the truncated space → exactly conserve the particle number*
  A.Volya et al., Phys. Lett. B **509**, 37 (2001)

- *Independent Particle Model (IPM) (particles move independently when nucleus is excited): used to treat particles outside the truncated spaces.*
  Y.Allassid et al., Phys. Rec. C **68**, 044322 (2003)



$$\ln Z_{tol} = \ln Z_{EP} + \ln Z_{IPM}$$

Total state density: $$\omega(E) = \left(\frac{1}{2\pi i}\right)^2 \int_{-i\infty}^{+i\infty} e^{\beta E + \ln Z} d\beta$$

Total NLD: $$\rho(E^*) = k_{rot} k_{vib} \frac{\omega(E^*)}{\sigma\sqrt{2\pi}}$$

Microscopic Approach to NDL and RSF

N. Quang Hung, N. Dinh Dang, and L.T. Quynh Huong., Phys. Rev. Lett. **118**, 022502 (2017)

❑ For RSF

*N. Dinh Dang, A. Arima, Phys. Rev. Lett. **80**, 4145 (1998)*
*N. Dinh Dang, A. Arima, Phys. Rev. C **68**, 044303 (2003)*

➢ *Phonon Damping Model (PDM):*

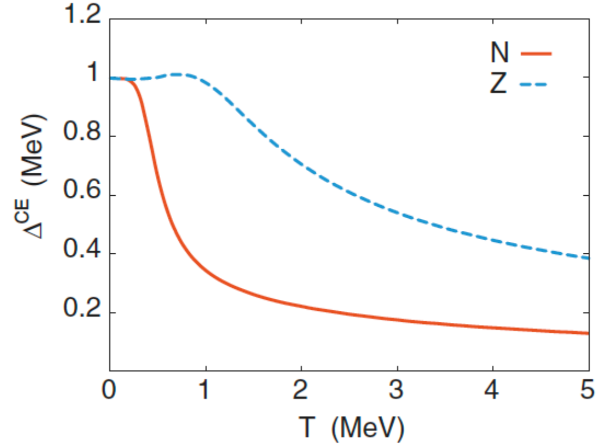
$$f_{XL}(E_\gamma) = \frac{1}{(2\lambda+1)\pi\hbar^2c^2}\frac{\Gamma(E_\gamma)\sigma(X\lambda)S_{X\lambda}(E_\gamma)}{E_\gamma}$$

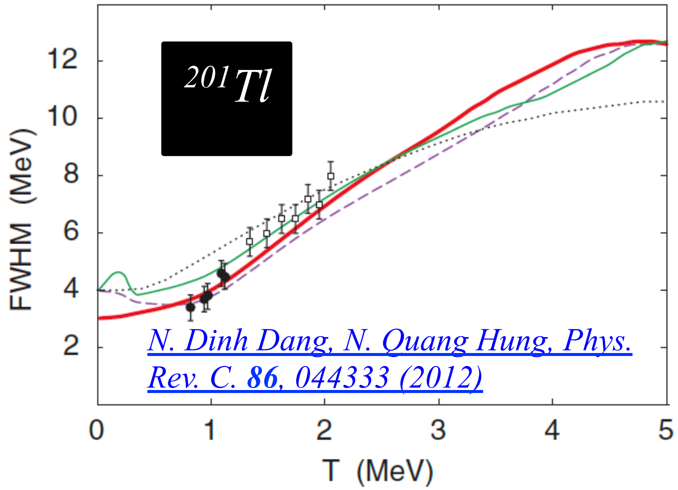
X: E (electric), M (magnetic); λ: multipolarity

$$S_{X\lambda}(E_\gamma) = \frac{1}{\pi}\frac{\gamma(E_\gamma)}{(E_\gamma - E_{X\lambda})^2 + \gamma(E_\gamma)^2}$$

$$\Gamma_{X\lambda}(T) = 2\gamma[E_{X\lambda}(T)]$$

$$\gamma(E) = \pi\left\{F_1^2\sum_{ph} u_{ph}^2(1-n_p-n_h)\delta(E-E_p-E_h) + F_2^2\sum_{ss'} v_{ss'}^2(n_{s'}-n_s)\delta(E-E_s-E_{s'})\right\}$$





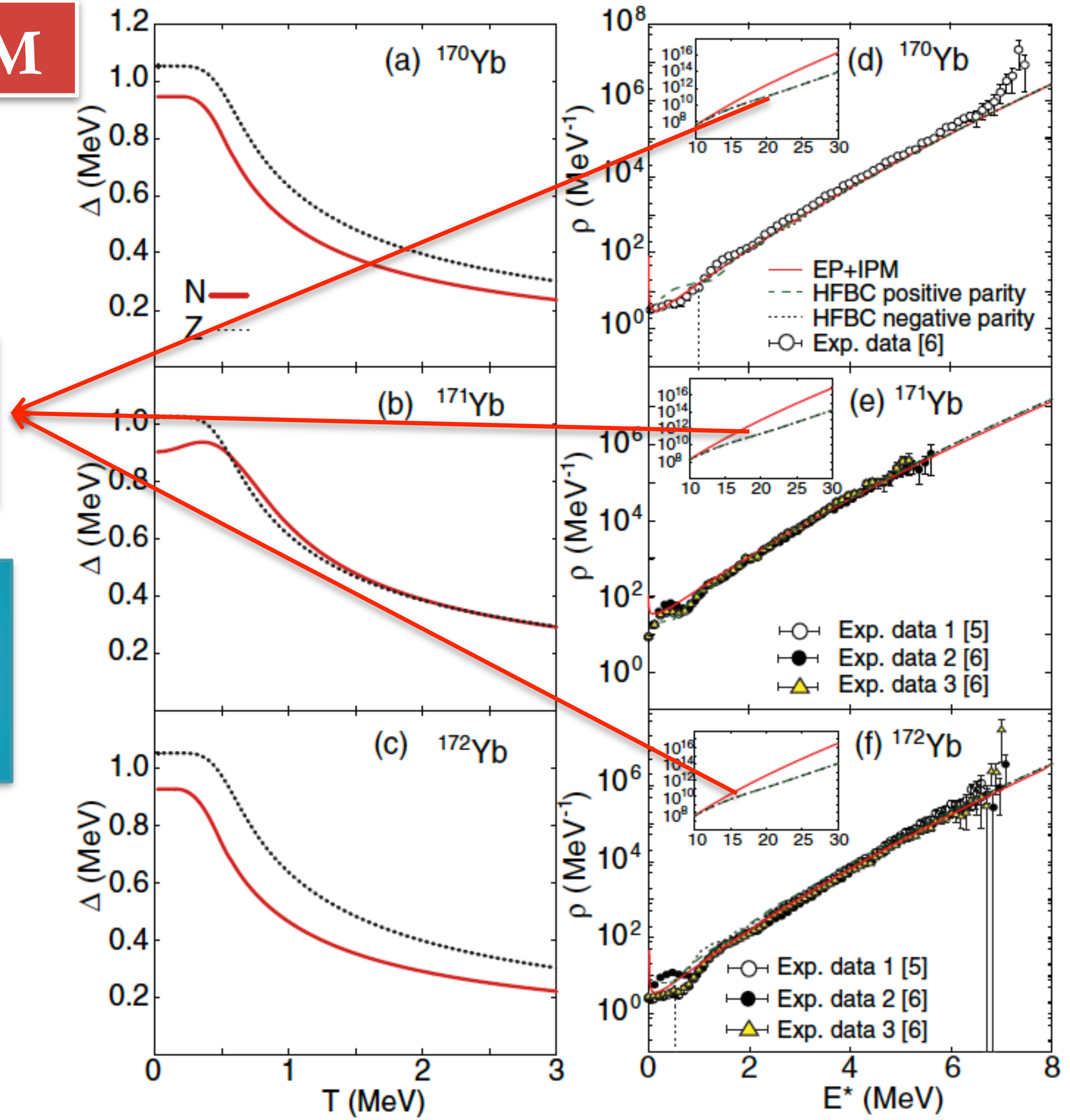
*N. Dinh Dang, N. Quang Hung, Phys. Rev. C. **86**, 044333 (2012)*

NLD: EP+IPM

The HFBC NLDs are always lower than our NLDs at $E^* > B_n$

The HFBC NLDs are not reliable at high E^* due to their fitting to NLD data at B_n

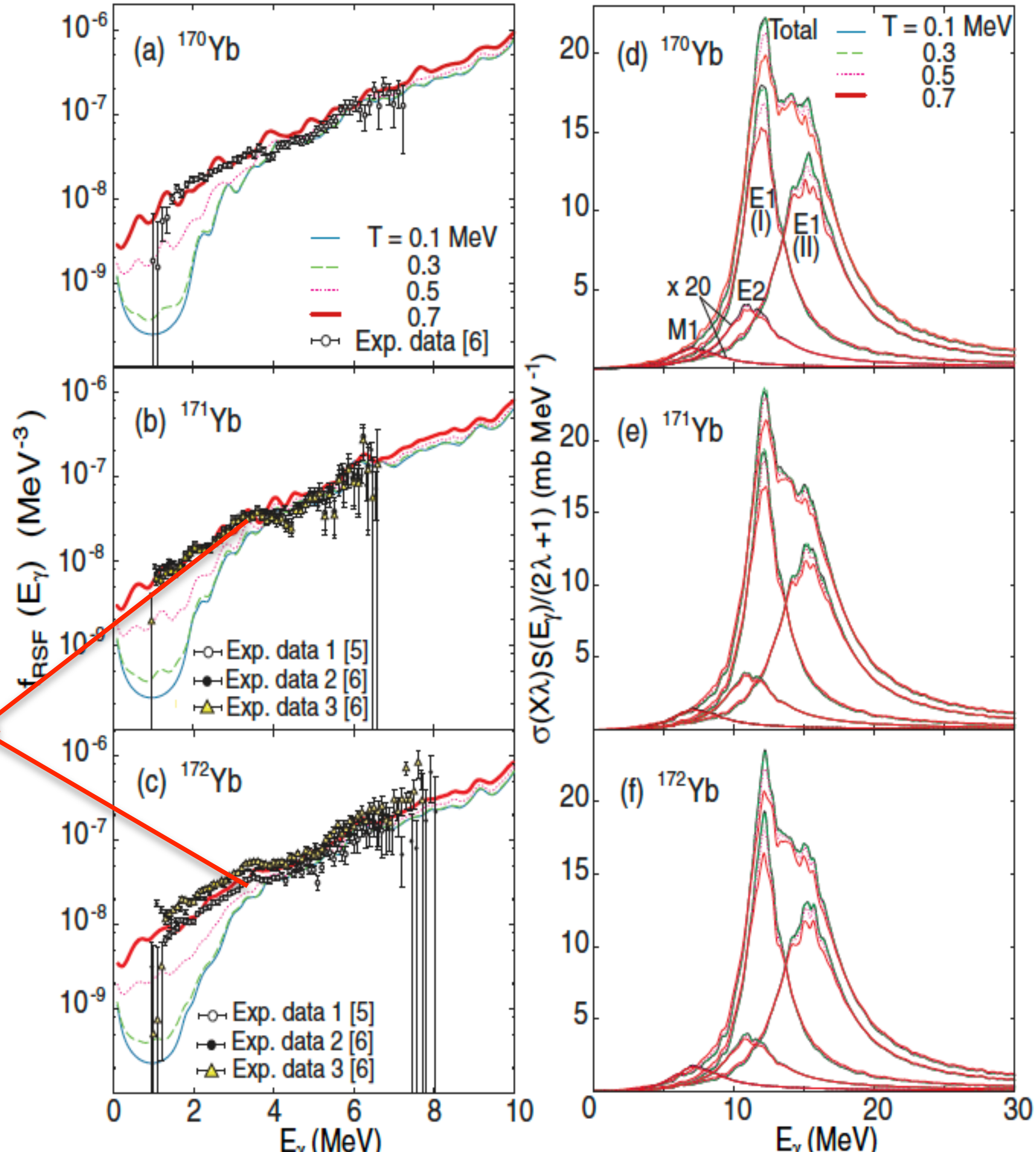
[N. Quang Hung, N. Dinh Dang, and L.T. Quynh Huong., Phys. Rev. Lett. **118**, 022502 (2017)]



RSF EP+IPM+PDM

Temperature dependent RSF → invalidate the Brink Axel hypothesis

Enhancement of RSFs at low E is well reproduced without introducing PDR → effect of EP



N. Quang Hung, N. Dinh Dang, and L.T. Quynh Huong., Phys. Rev. Lett. **118**, 022502 (2017)

Research Topics

- ❑ Present Research Topics (**Extended**)
  - ✧ *Pairing Reentrance Phenomenon*
  - ✧ *Nuclear Level Density and Radiative Strength Function*
  - ✧ *Nuclear Level Scheme from (n_{th}, γ) reactions*

Da Lat nuclear reactor began operating on 3.3.1963 with a capacity of 250KW, using US technology, and stopped working in 1968.

On 20/3/1984 it resumed operations, doubling its capacity.

Updated level scheme of ^{172}Yb from ^{171}Yb(n_{th}, γ) reaction studied via gamma-gamma coincidence spectrometer

Nguyen Ngoc Anh[a,c,*], Nguyen Xuan Hai[a], Pham Dinh Khang[b], Nguyen Quang Hung[c], Ho Huu Thang[a]

[a]*Nuclear Research Institute, Vietnam Atomic Energy Institute, 1 Nguyen Tu Luc, Dalat City, Vietnam*
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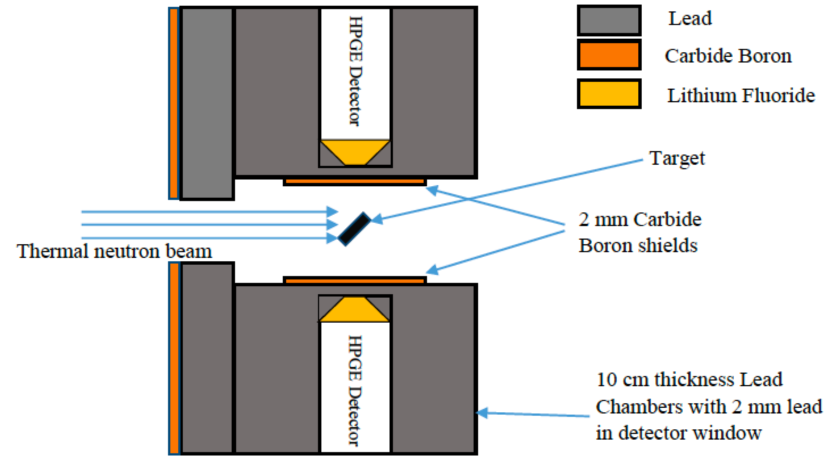
[c]*Institute of Research and Development, Duy Tan University, K7/25 Quang Trung, Danang city, Vietnam*

Submitted to Nucl. Phys. A (Feb. 2017)

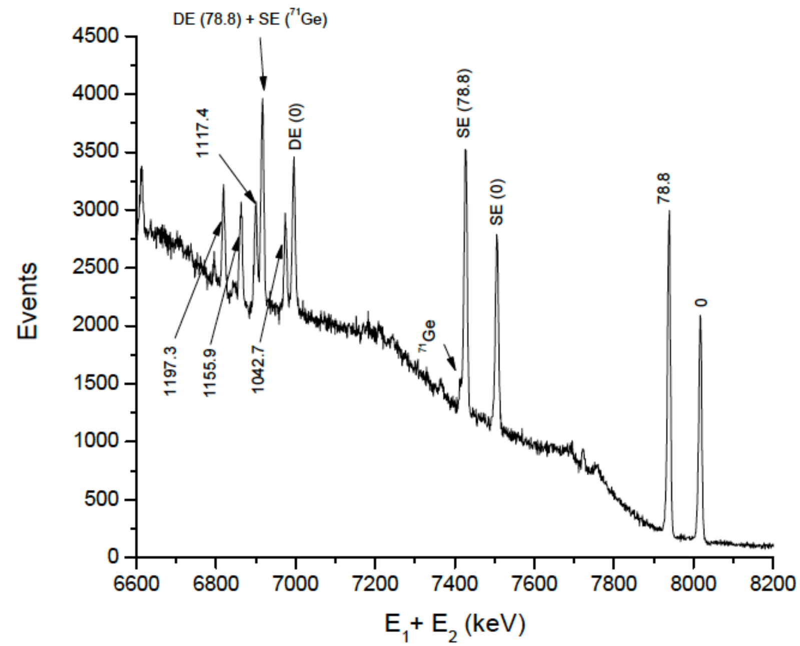
Abstract

This paper provides the updated information on the level scheme of ^{172}Yb nucleus studied via ^{171}Yb(n_{th}, γ) reaction using the gamma-gamma coincidence spectrometer at Dalat Nuclear Research Institute (Vietnam). The latter is used because of its advantages in achieving the low Compton background as well as in identifying the correlated gamma transitions. We have detected in total the energies and intensities of 128 two-step gamma cascades corresponding to 79 primary transitions. By comparing the measured data with those extracted from the ENSDF library, 61 primary gamma transitions and corresponding energy levels together with 19 secondary gamma transitions are found to be the same as the ENSDF data. Beside that, 18 additional primary gamma transitions and corresponding energy levels plus 109 secondary ones are not found to currently exist in this library and they are therefore considered as the new data.

Keywords: Level scheme, ^{171}Yb(n,γ) reaction, $\gamma-\gamma$ coincidence spectrometer.



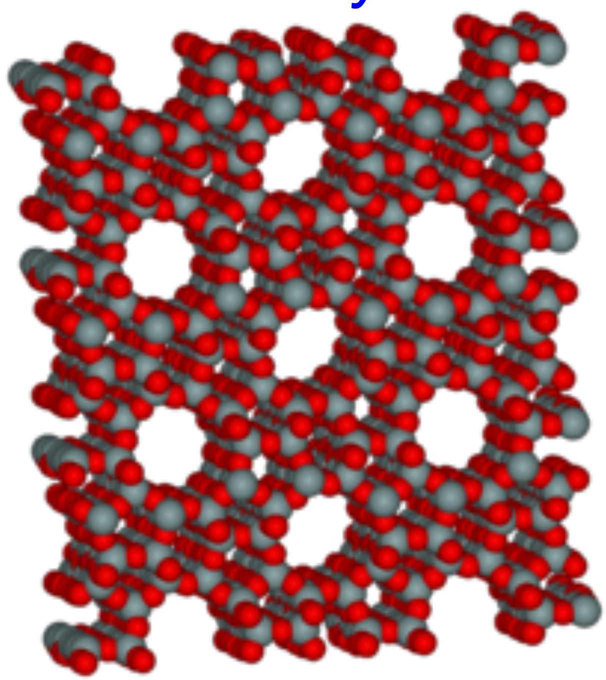
Experimental setup for measuring the gamma-gamma coincidences.



Research Topics

- Present Research Topics (**Extended**)
  - *Pairing Reentrance Phenomenon*
  - *Nuclear Level Density and Radiative Strength Function*
  - *Nuclear Level Scheme from (n_{th}, γ) reactions*
  - *Positron Annihilation Lifetime (PALS) and X-ray Diffraction Spectroscopies (XRD) Studies of Synthetic Nanosized Zeolite Materials*

ZSM-5



JOURNAL OF APPLIED PHYSICS **121**, 084303 (2017)

Simultaneous existence of defects and mesopores in nanosized ZSM-5 zeolite studied by positron annihilation and X-ray diffraction spectroscopies

L. Anh Tuyen,[1,2,a)] N. Quang Hung,[3,b)] L. Chi Cuong,[4] D. Duy Khiem,[1] P. Trong Phuc,[1] L. Ly Nguyen,[1] N. T. Ngoc Hue,[1,2] P. Thi Hue,[1] and D. Van Phuc[5]
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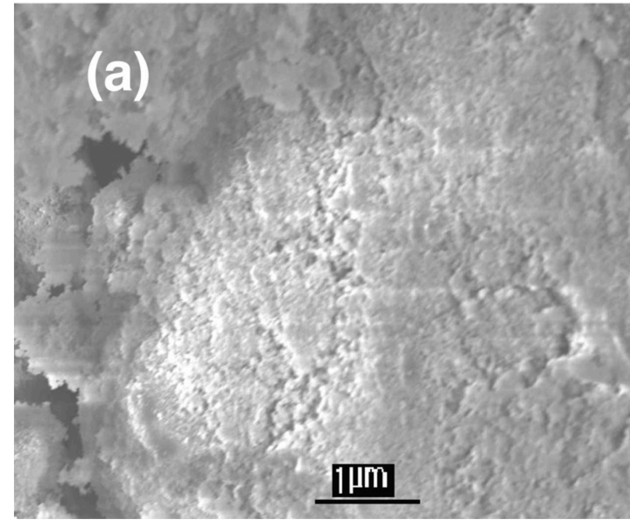
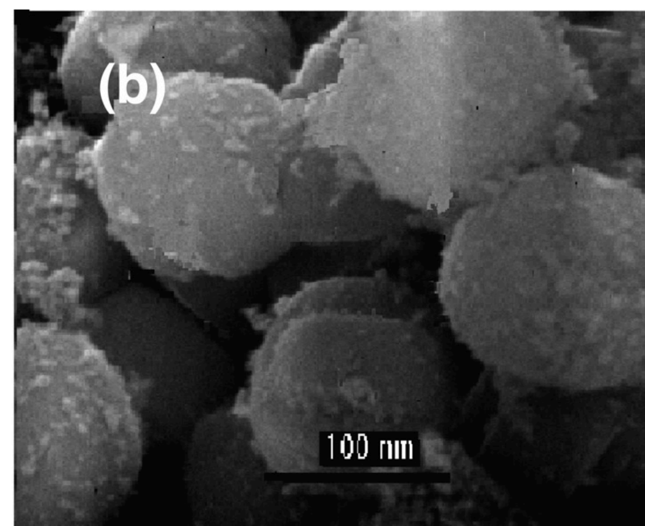
Crystallization, formation, and accumulation of defects and mesopores in the ZSM-5 zeolite samples, which are synthesized from the gel composition of 1.2Na_2O 0.1Al_2O_3 0.8 tetra-propylammonium hydroxide (TPAOH) 6SiO_2 400H_2O at a temperature of 140 degree Celsius (°C) in 10, 15, and 18 h, are studied by using the Positron annihilation lifetime (PALS) and X-ray diffraction (XRD) spectroscopies. The XRD is used for investigating the crystalline concentration and nano-crystal size of ZSM-5 during the crystallizing process, whereas the PALS is performed in order to determine the presence of templates, defects, and mesopores in the zeolite samples. The latter are calcined in air during 1, 2, and 3 h at a temperature of 600 °C before being measured. The results obtained indicate that there exist clusters of small crystals in the early crystalline stages of the samples. The size of these crystals increases with time and reaches approximately 100 nm after 18 h of reaction. In addition, the template (TPAOH) is found to exist not only in the channels inside the framework but also in the mesopores outside it. Finally, by analyzing the Positron lifetime spectra, we have found for the first time the simultaneous existence of defects and mesopores, which are formatted and accumulated during the crystallization of ZSM-5. Those important results contribute significantly to our understanding of the internal structure of the synthetic zeolite ZSM-5 as well as the synthetic processes for producing zeolites with special features. *Published by AIP Publishing*. [http://dx.doi.org/10.1063/1.4977013]

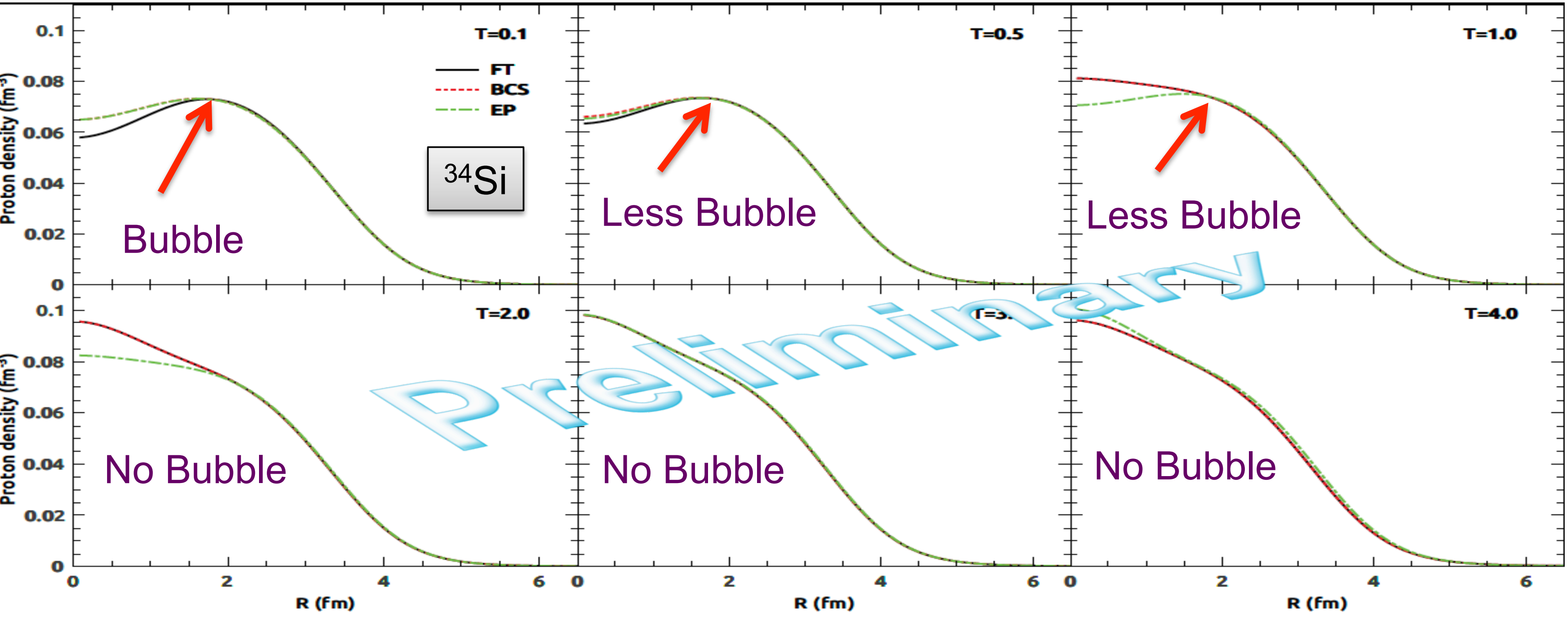


SEM images of the Z-10 (a) and Z-18 (b) zeolite samples.



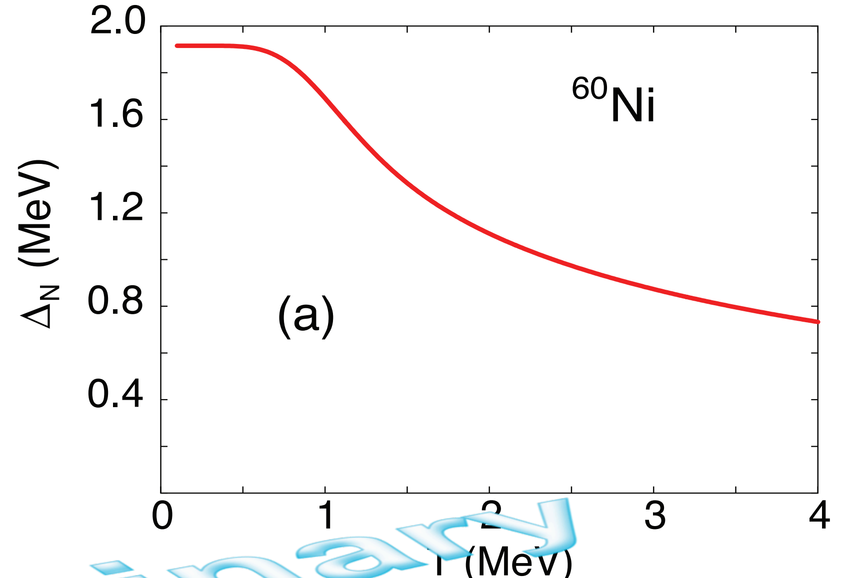
Research Topics

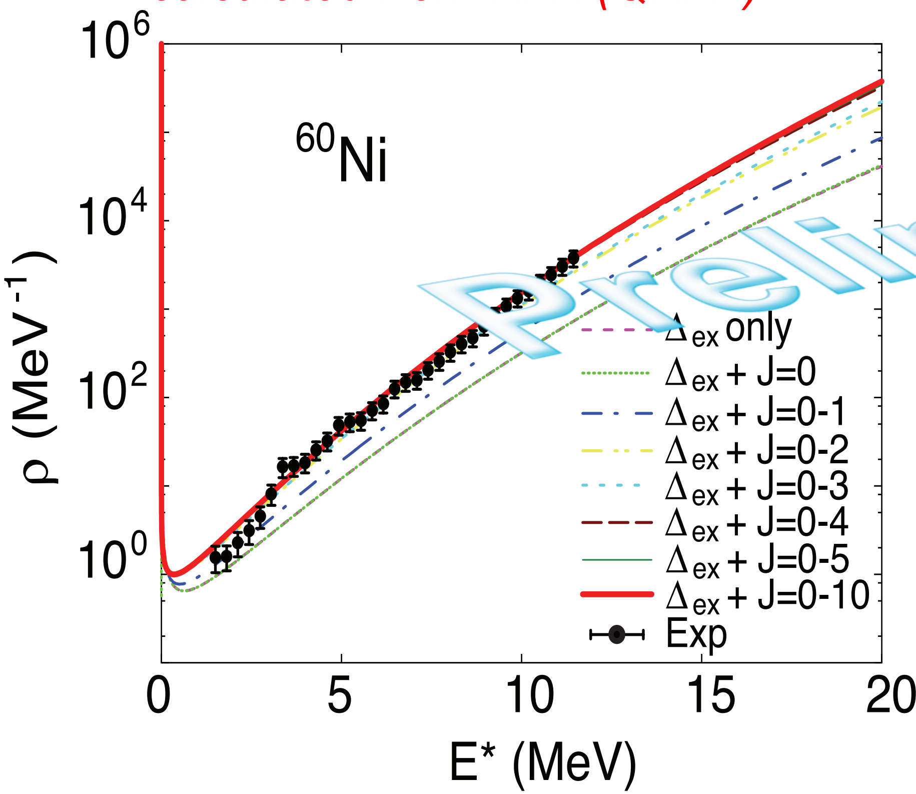
- Future perspectives
  - *Pairing Reentrance Phenomenon*
    More experimental data are needed
  - *PDR and GDR within the RRPA at T=0 and T≠0*
    - *Exact pairing (EP) should be included into the HF calculations*
    - *RRPA (+ EP) with fully selfconsistent treatment of pp and hh excitations*

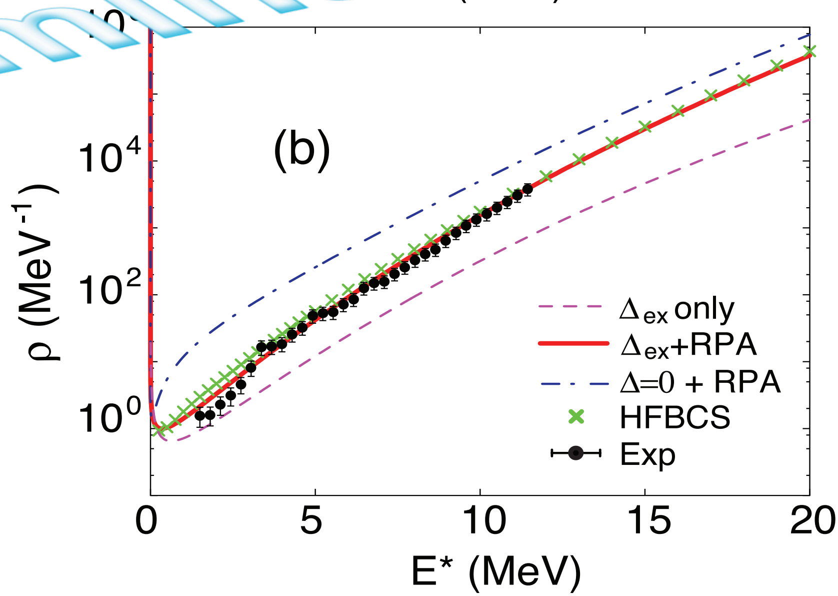


Research Topics

- Future perspectives
  - *NLD and RSF*
    - *Theory: EP+IPM with collective and rotational enhancement factors calculated from RPA (QRPA)*



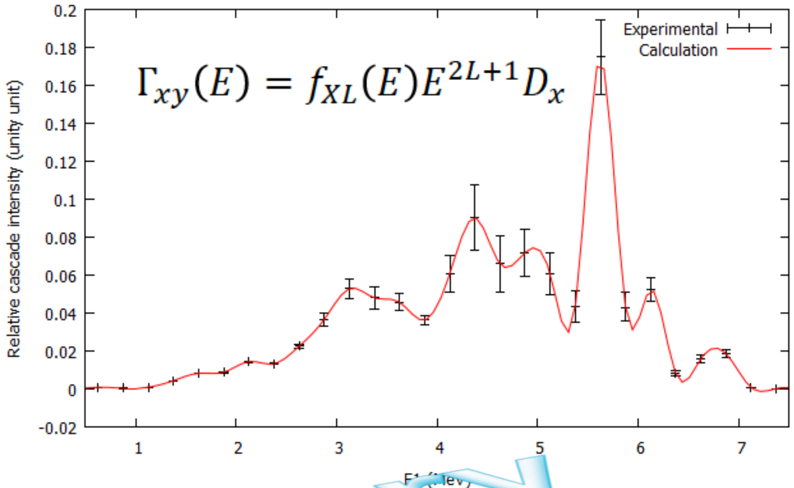




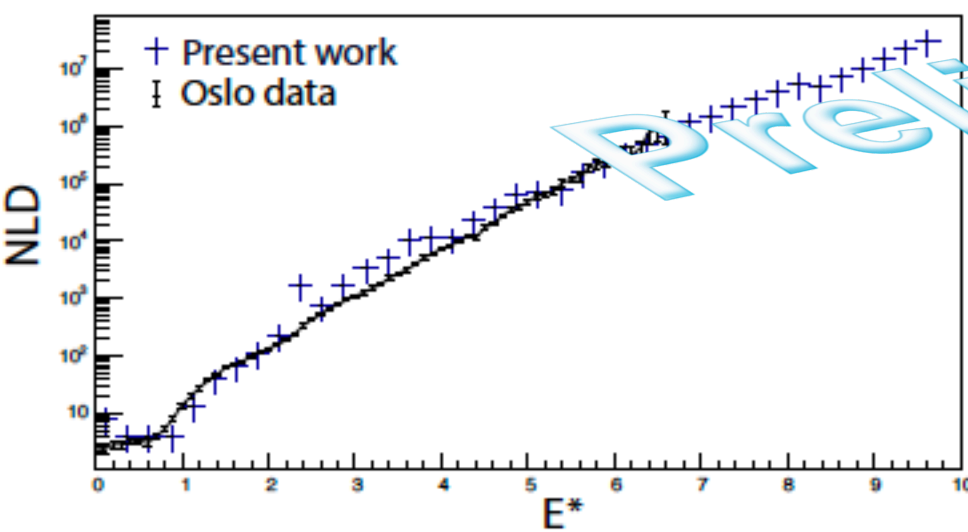
Research Topics

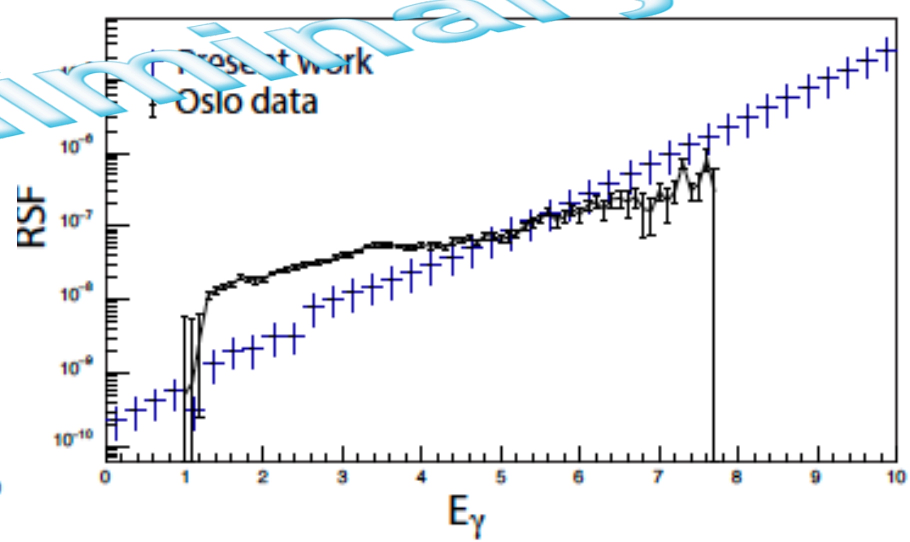
- Future perspectives
  - ✧ *NLD and RSF*
    - *Theory: extend EP+IPM with collective and rotational enhancement factors calculated from RPA (QRPA)*
    - *Experiment: extract NLD and RSF from gamma spectra of (n_{th}, γ) reactions*

$$I_{gg}(E1,E2) = \sum_{XL,J,\Pi} \frac{\Gamma_{im}(E1)}{\Gamma_i} \rho_m(B_n - E1, J, \Pi) \frac{\Gamma_{mf}(E2)}{\Gamma_m}$$



Preliminary





Research Topics

- Future perspectives
  - *NLD and RSF*
    - *Experiment: extract NLD and RSF from gamma spectra of compound reactions or evaporation spectra*

Reactions to be used

- Cyclotron: (^{3}*He, α*); (^{3}*He,* ^{3}*He'*); beam energy 10 – 30 MeV
- Pelletron: (*d, n*); (*p*, *α*); (*p, n*); (^{12}C, *p*); beam energy 5 – 40 MeV

Tandem Pelletron 5SDH-2

30MeV Cyclotron

Conclusion

Nuclear Theory Group at DTU

- Group members: 3
- Collaborators: from Japan, Indian, USA,…
- Research Topics
  - Past: pairing in hot rotating nuclei; nuclear giant (GDR) and pygmy (PDR) dipole resonances; viscoscity in hot rotating nuclei.
  - Present: pairing reentrance; NLD and RSF; nuclear level scheme from (n_{th}, γ) reactions; ZSM-5 materials using PALS and XRD.
  - Future: pairing reentrance; fully microscopic approach to NLD and RSF; NLD and RSF from (n_{th}, γ) reactions; zeolite materials synthesized from Kaolin source in Vietnam and studied using the PALS and XRD.

Thank you !