Pygmy Dipole Resonances

E. G. Lanza
INFN-Sezione di Catania, Italy

Experimental evidences for the PDR

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A.Tamii et al., PRL 107 (2011) 062502
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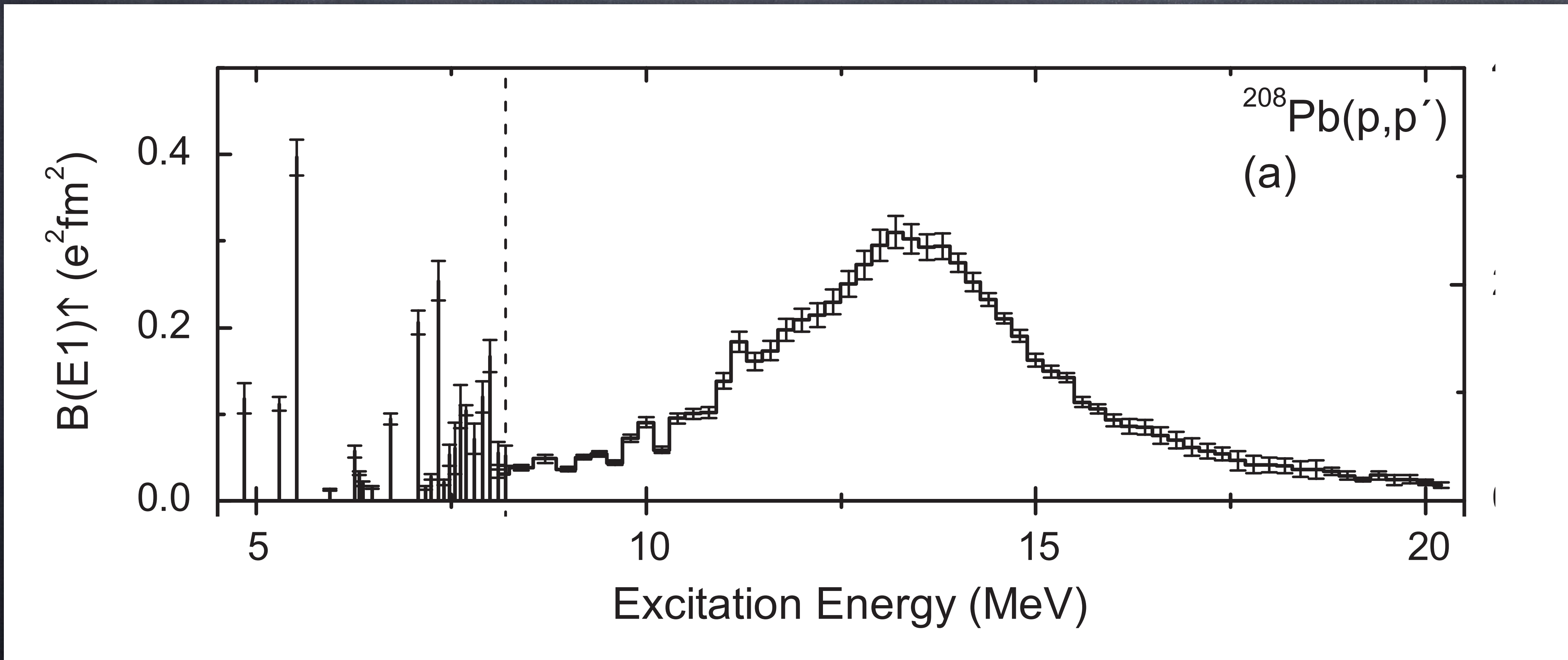
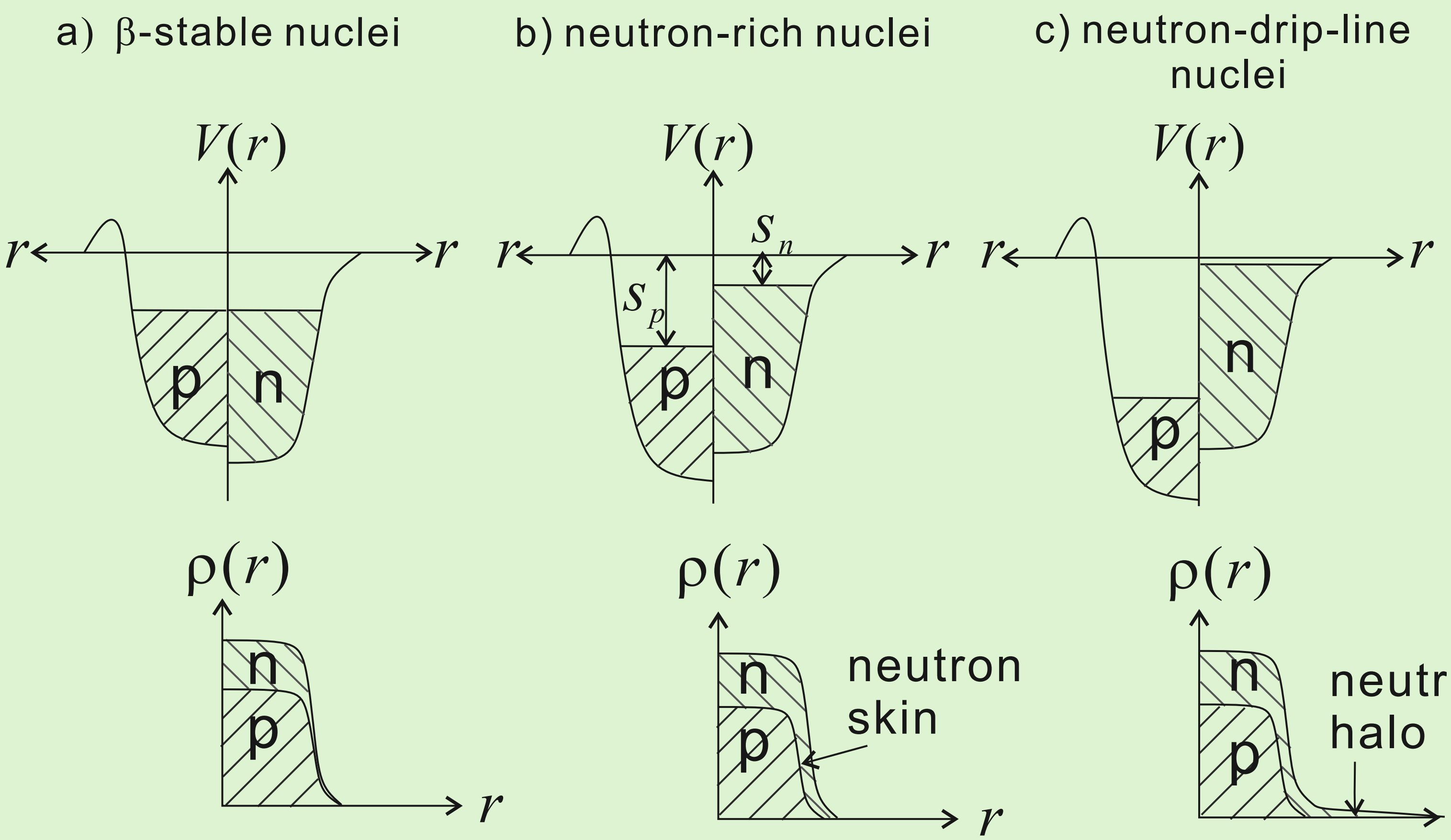


T.Aumann and T. Nakamura

Phys. Scr. **T152** (2013) 014012



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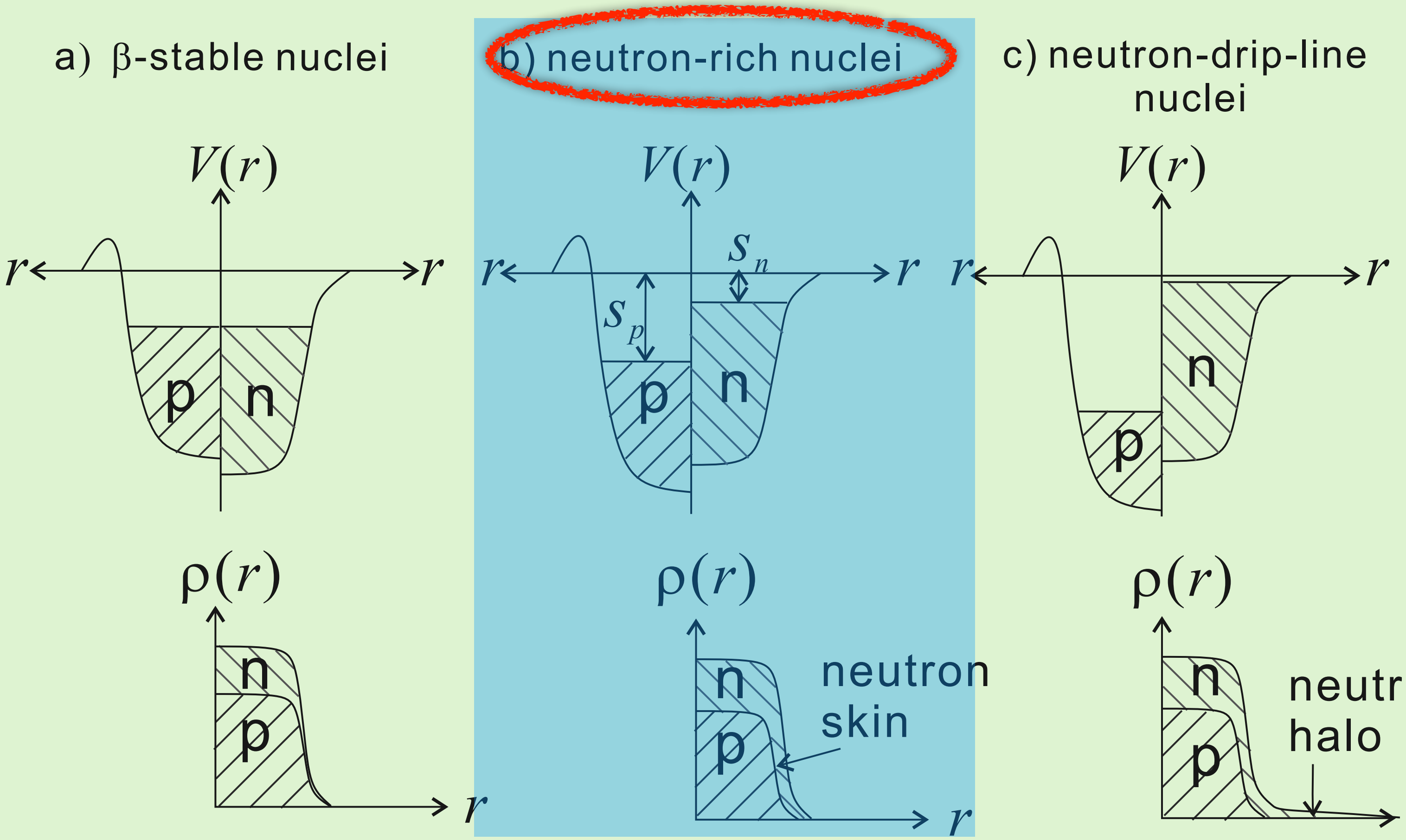

Review papers

- D. Savran, T. Aumann and A. Zilges, Prog. Part. Nucl. Phys. 70, 210 (2013).
- T. Aumann and T. Nakamura, Phys. Scr. T152, 014012 (2013).
- A. Bracco, F. C. L. Crespi and E. G. Lanza, Eur. Phys. J. A 51, 99 (2015).
- A. Bracco, E. G. Lanza and A. Tamii, Prog. Part. Nucl. Phys. 106 (2019) 360.

Review papers
Theory

- N. Paar, D. Vretenar, E. Khan and G. Colo`, Rep. Prog. Phys. 70, 691 (2007).
- E. G. Lanza, L. Pellegri, A. Vitturi and M. V. Andrés, Prog. Part. Nucl. Phys. 129 (2023) 104006
- E. G. Lanza and A. Vitturi, Theoretical Description of Pygmy (Dipole) Resonances, in Handbook of Nuclear Physics, Eds. I. Tanihata, H. Toki,T. Kajino

From the theoretical point of view they are studied with

Macroscopic model

- Incompressible three fluid model: Steinwedel-Jensen
- Inert core oscillating against a neutron skin: Goldhaber-Teller

Microscopic model

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coupling to more complex configurations

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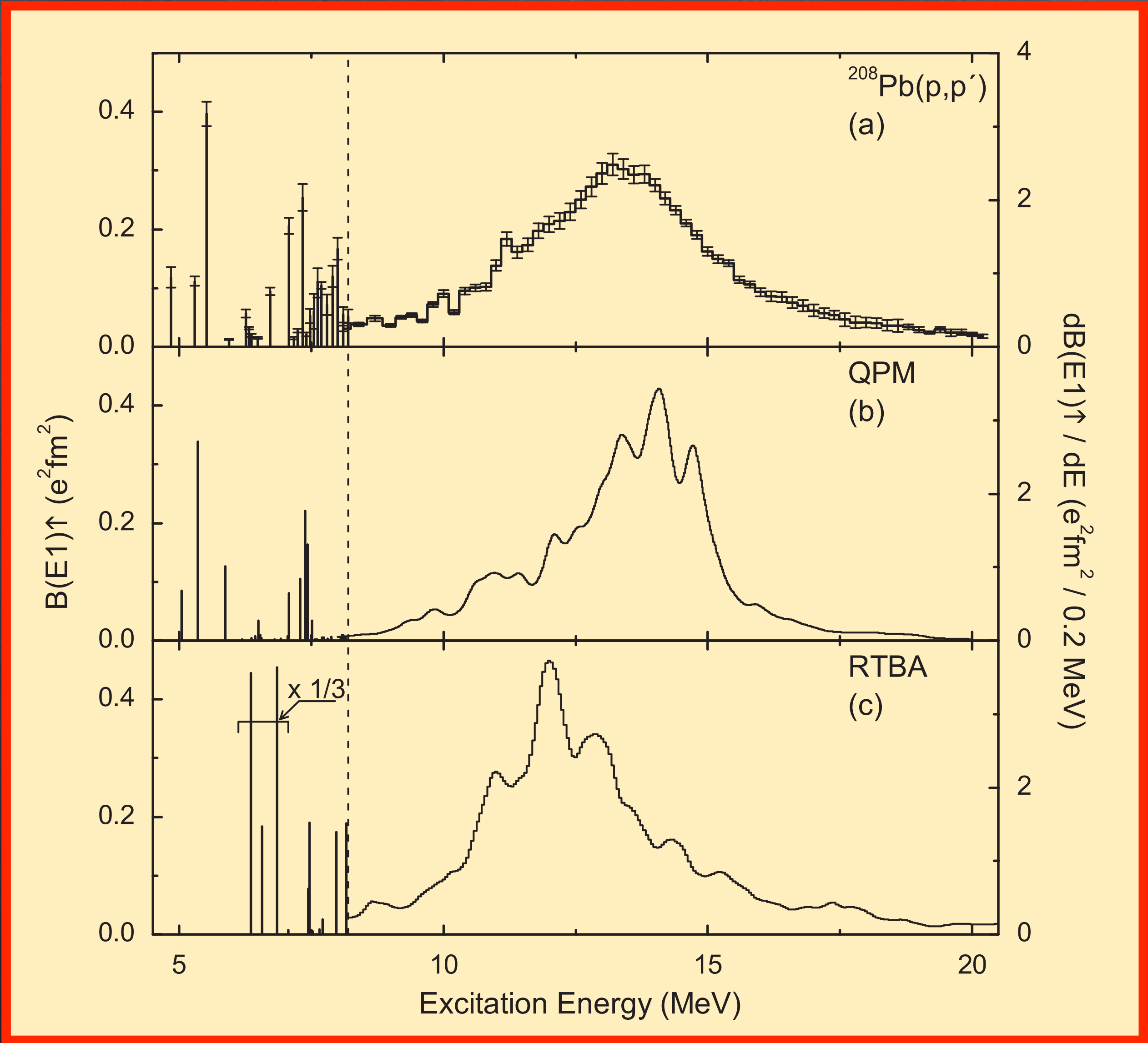

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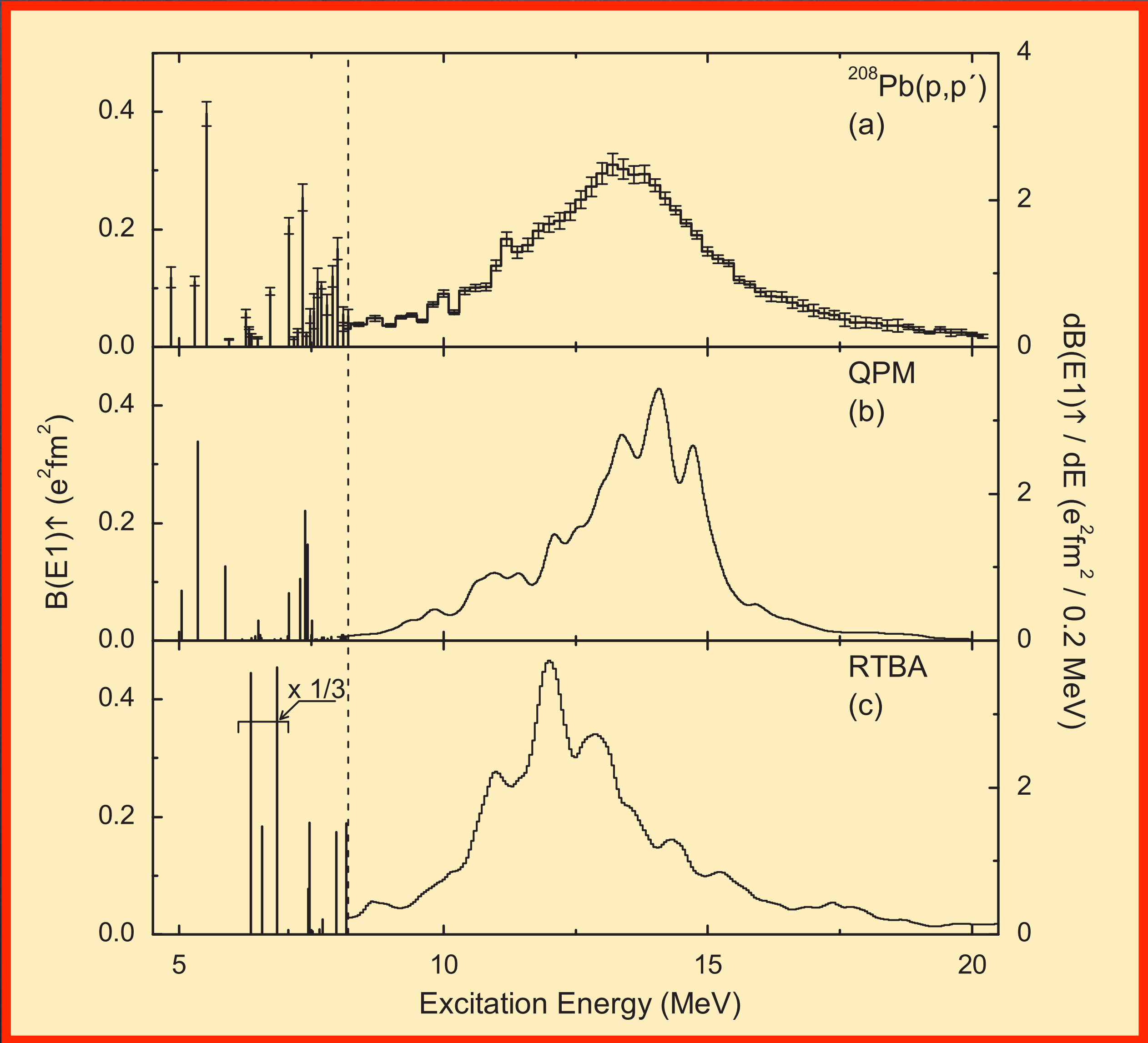

Quasiparticle-Phonon Model (QPM) calculations contain up to 3-phonon configurations at low energy

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A.Tamii et al., PRL 107 (2011) 062502

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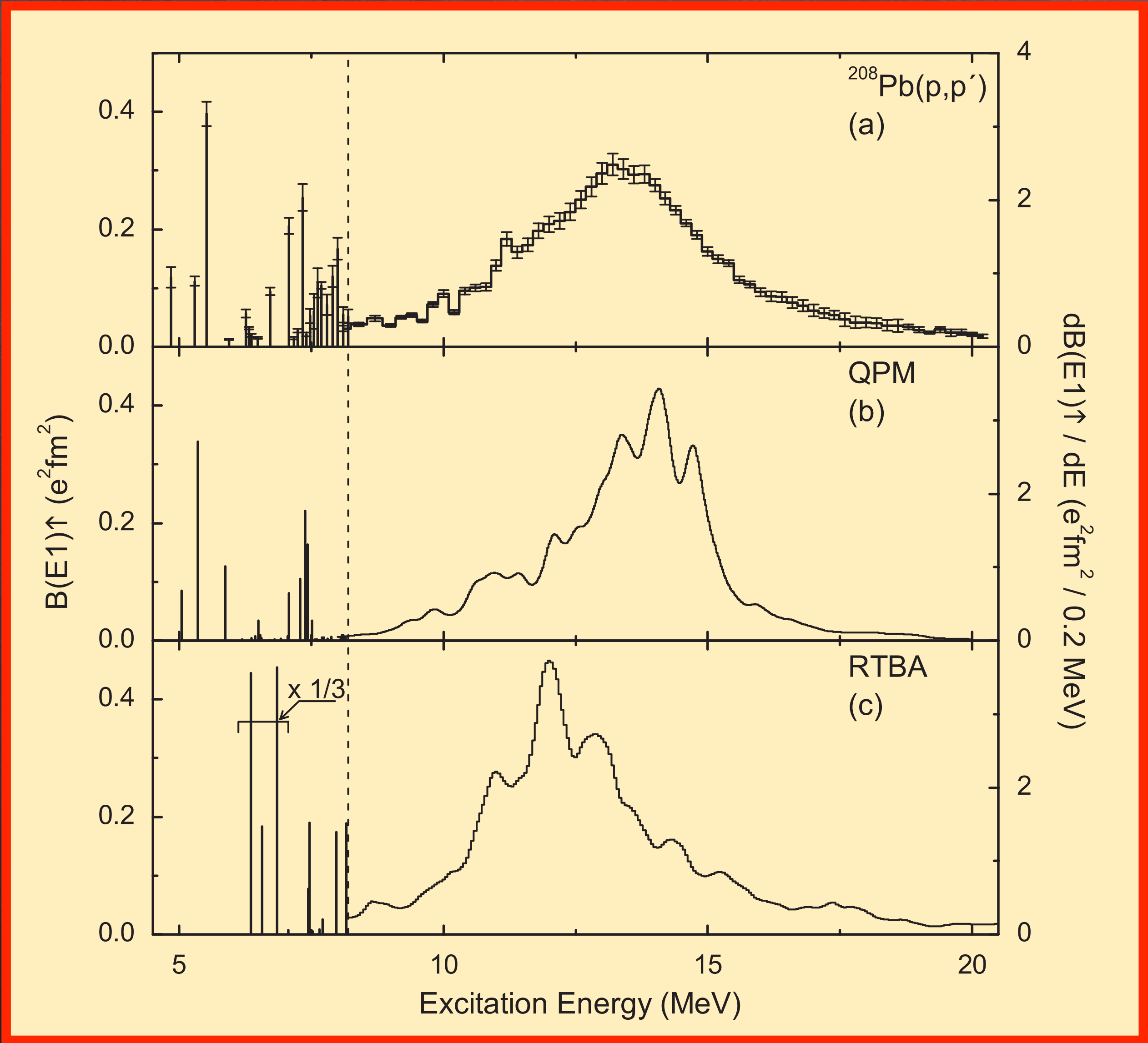

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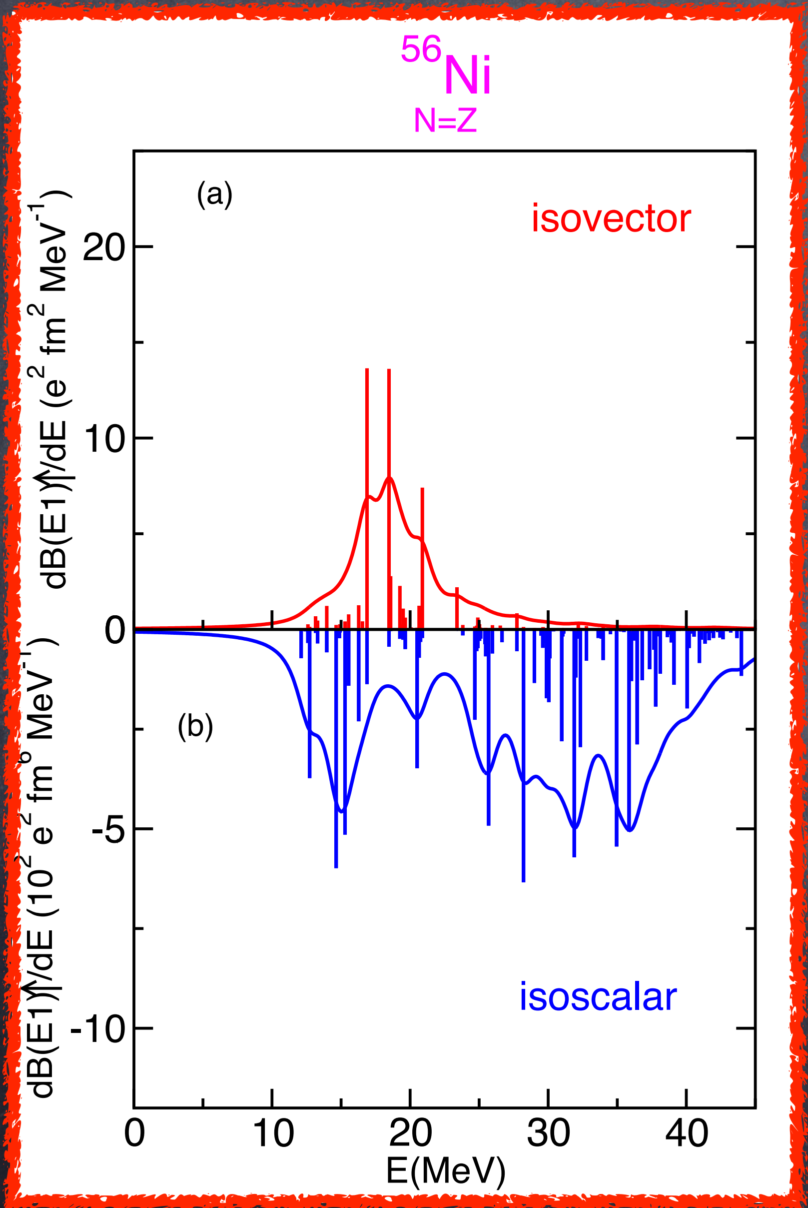
Relativistic Time-Blocking Approximation (RTBA) based on a particle-hole ⊗ phonon model space

(by E. Litvinova)

RPA calculations with SGII interaction

$$O_{1M}^{(IV)} = \frac{eN}{A}\sum_{p=1}^{Z} r_p Y_{1M}(\hat{r}_p) - \frac{eZ}{A}\sum_{n=1}^{N} r_n Y_{1M}(\hat{r}_n)$$

$$O_{1M}^{(IS)} = \sum_{i=1}^{A}(r_i^3 - \frac{5}{3} < r^2 > r_i) Y_{1M}(\hat{r}_i)$$



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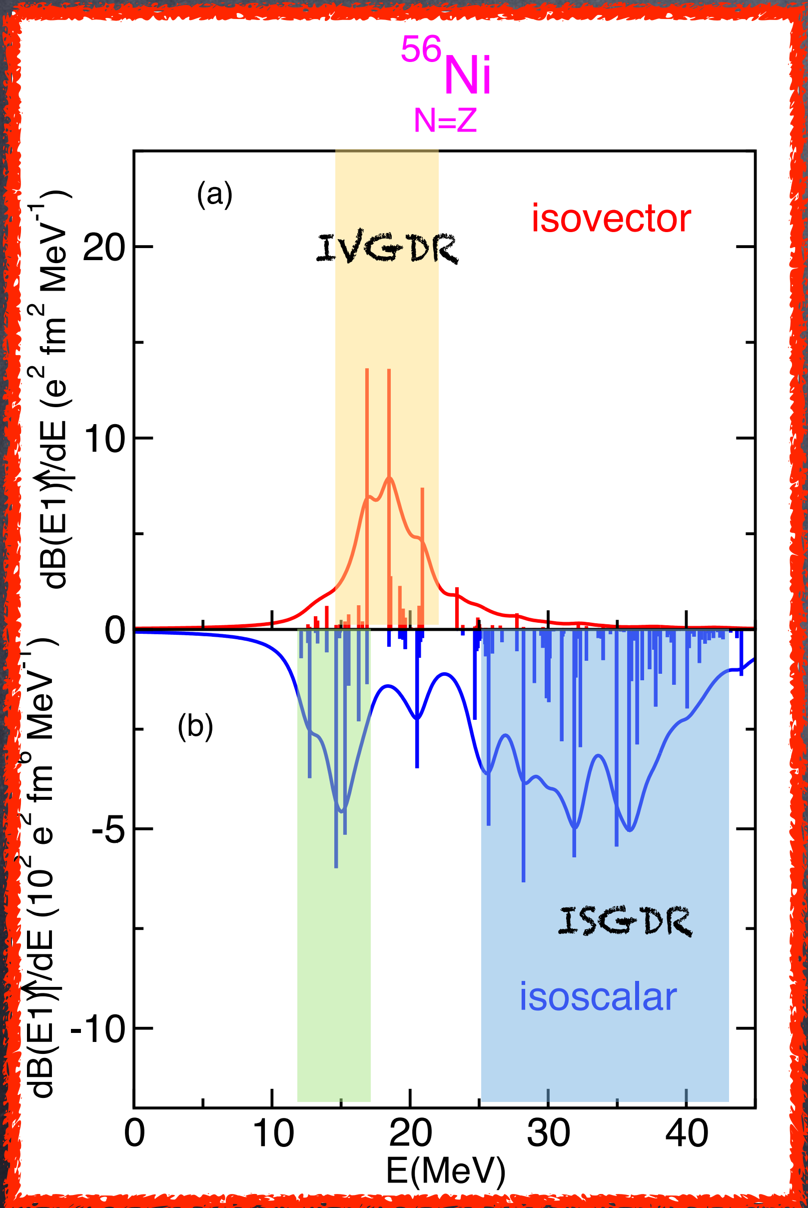

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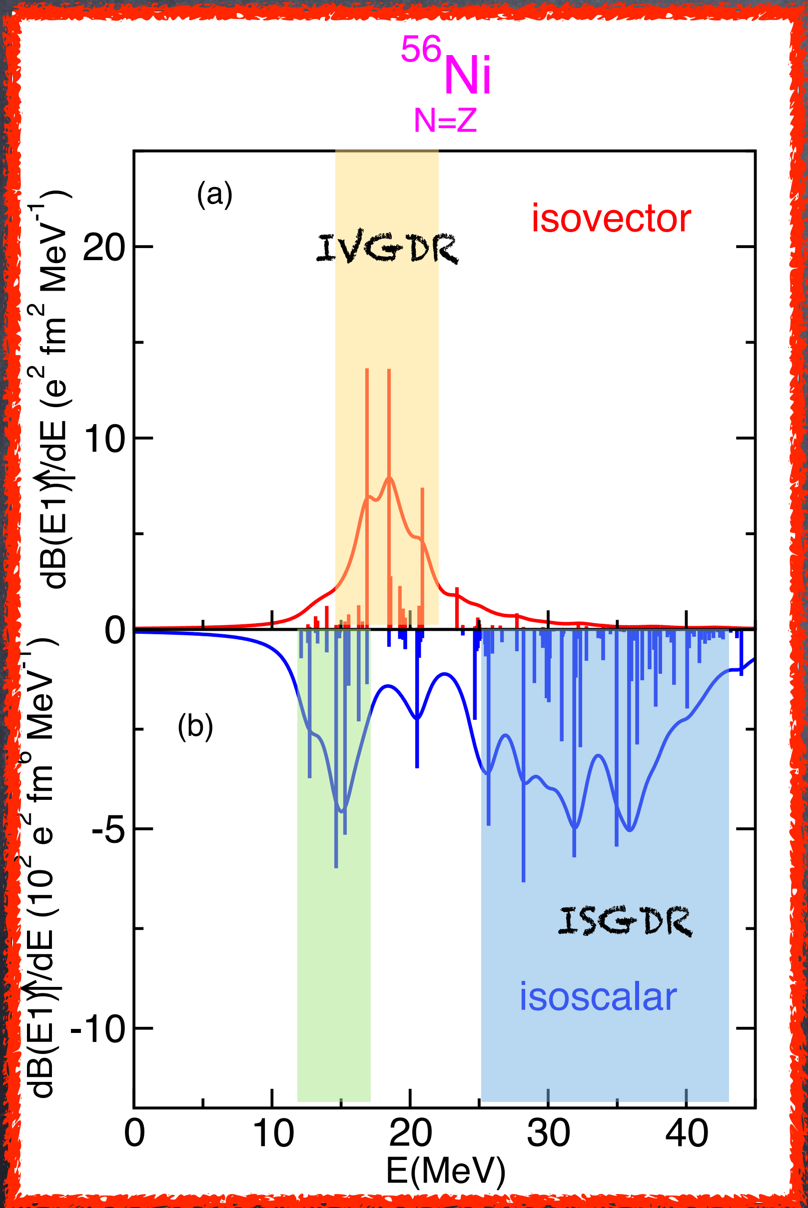

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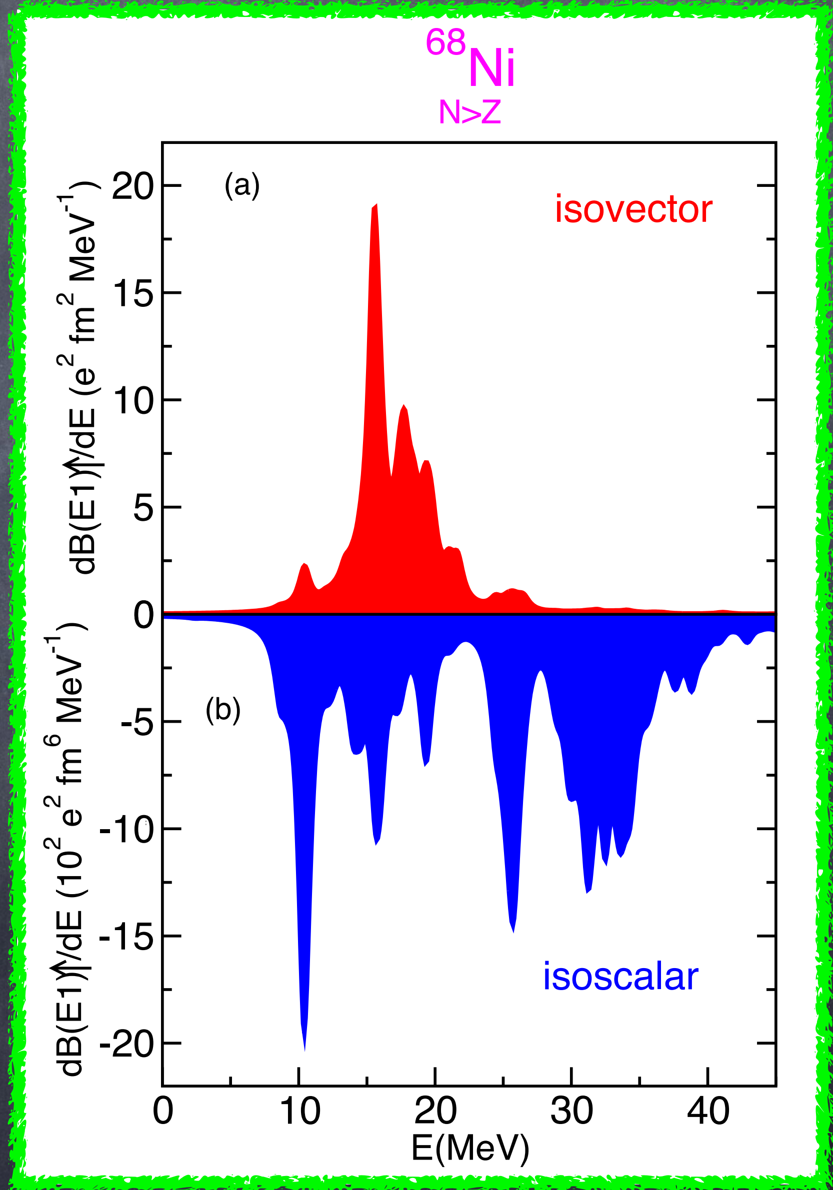

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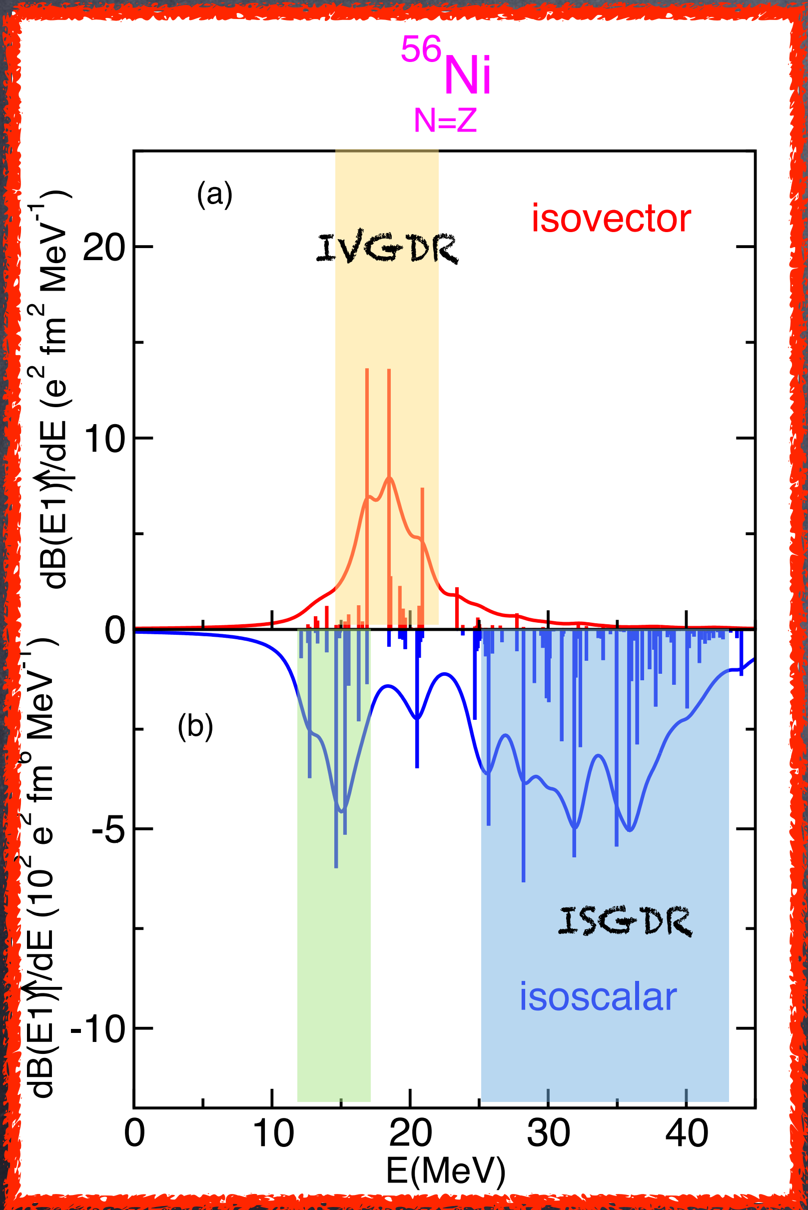

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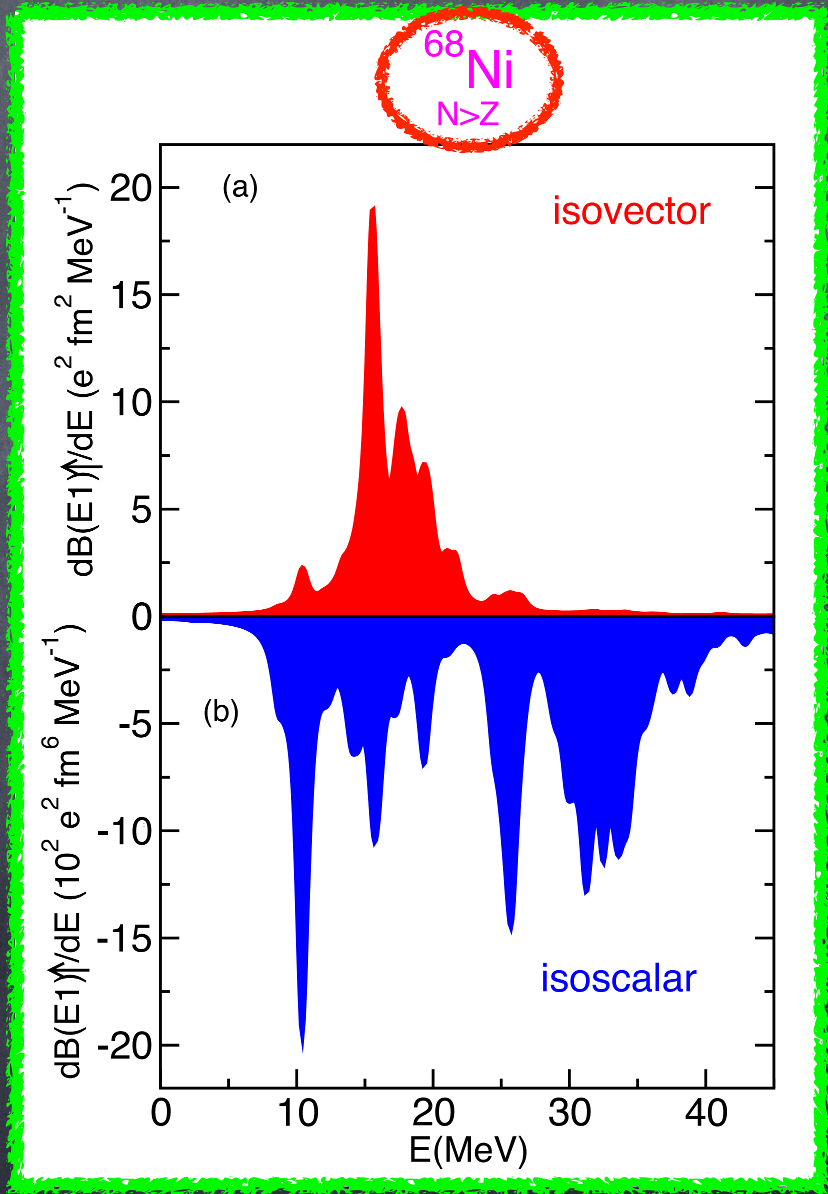

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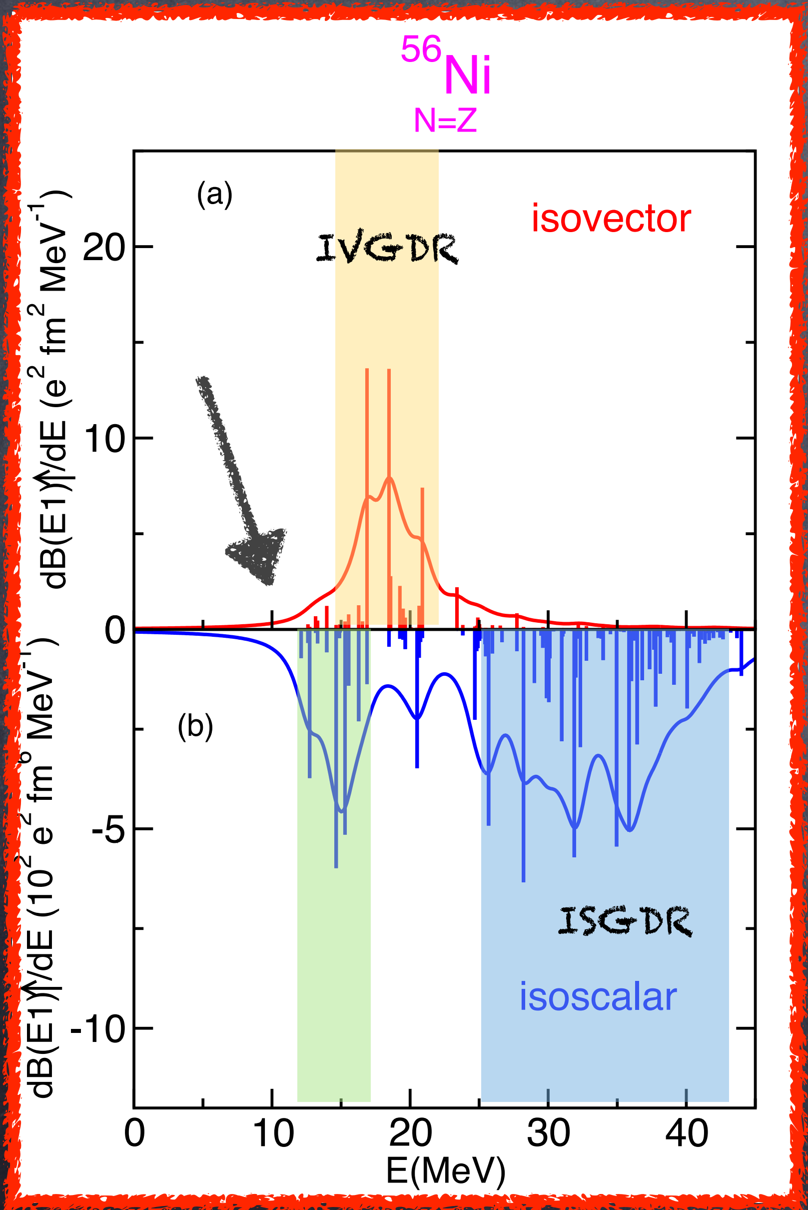

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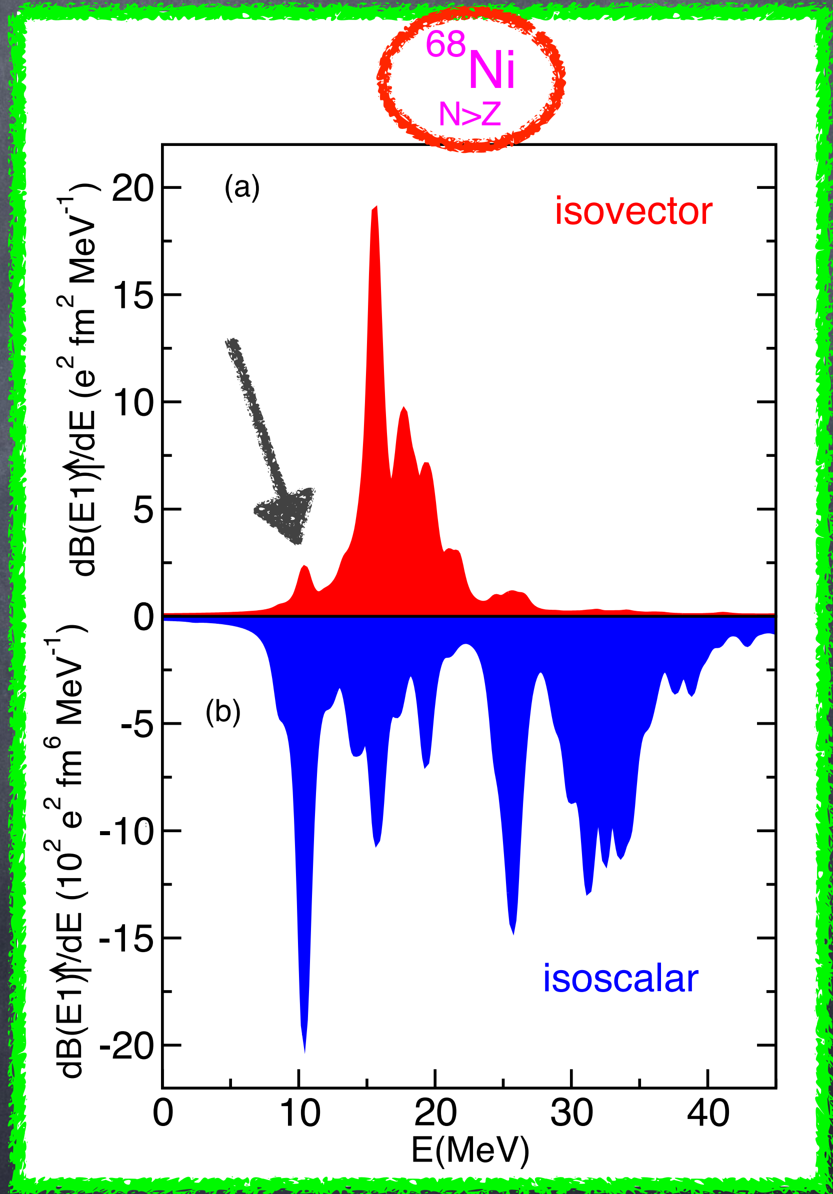
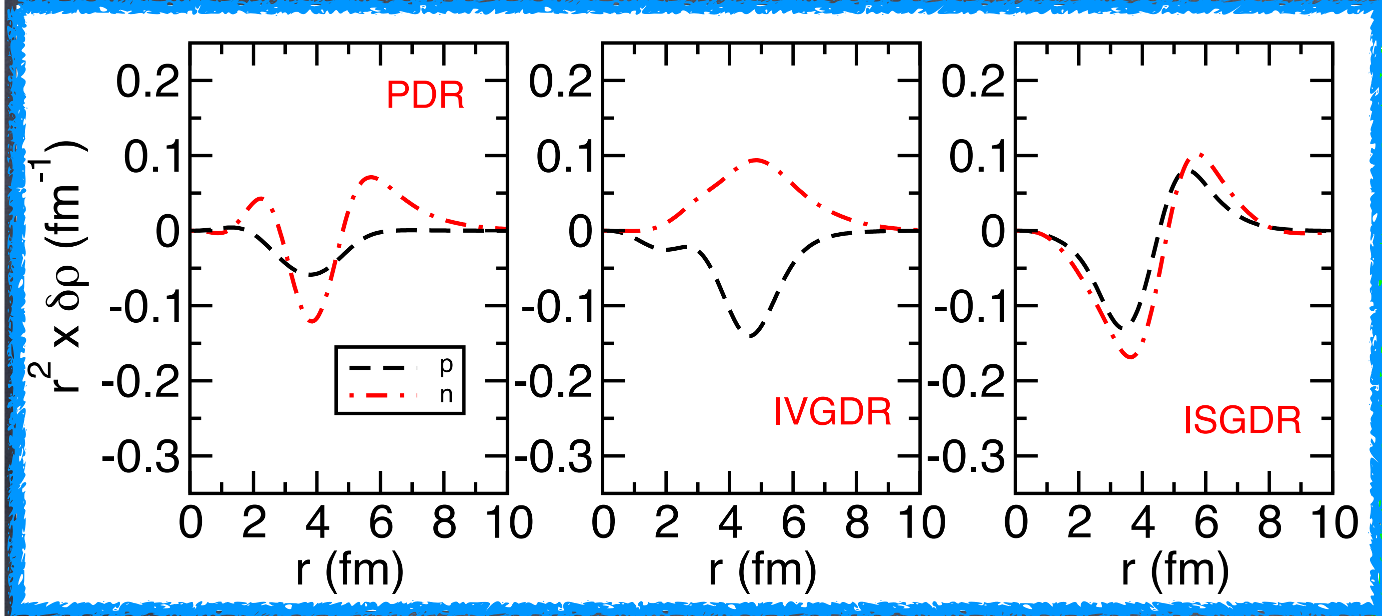
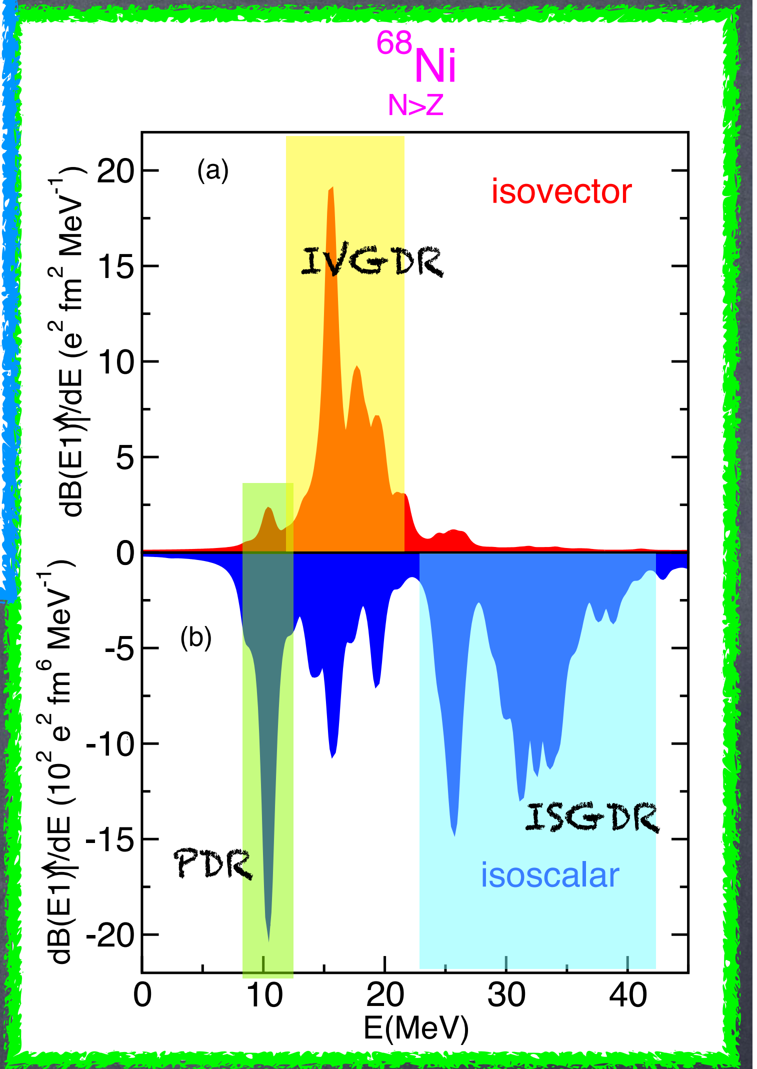
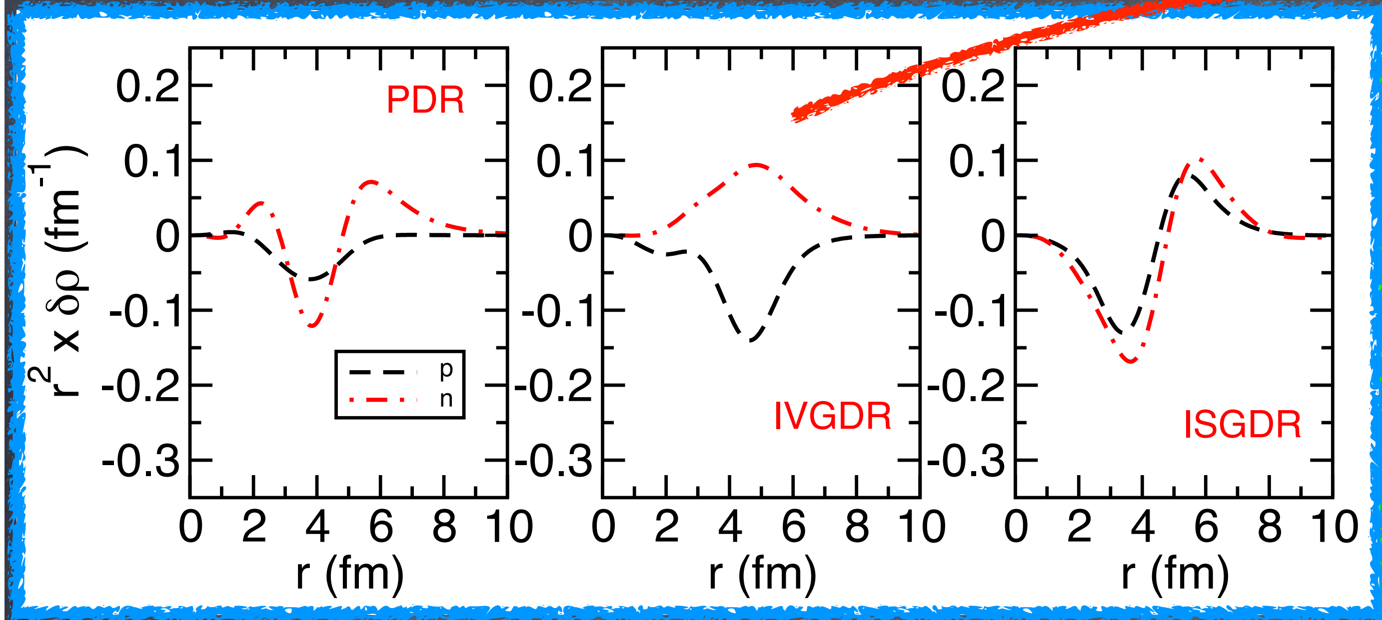


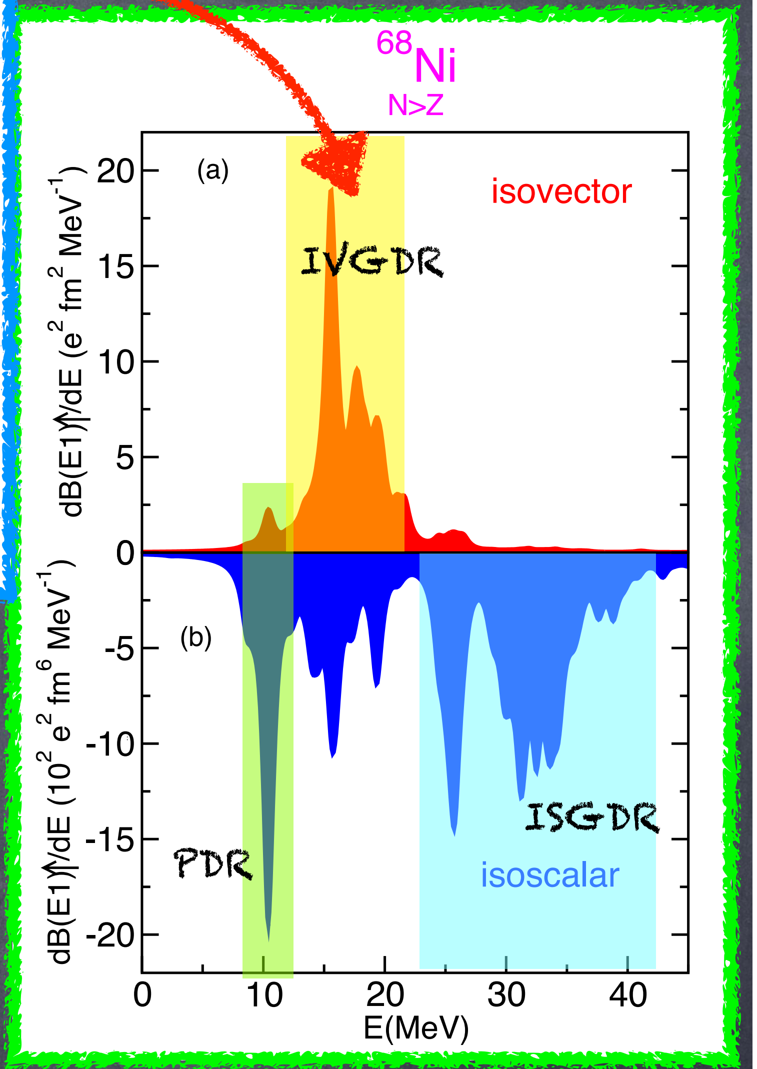


$$\delta\rho^{\nu} = \frac{1}{\sqrt{4\pi}} \sum_{ph} (-)^{j_p + l_p + \frac{1}{2}} \frac{\hat{j}_p \hat{j}_h}{\hat{\lambda}} \langle j_h \tfrac{1}{2}\, j_p\, -\tfrac{1}{2} \,|\, \lambda 0 \rangle \delta(\lambda + l_p + l_h, even)$$

$$\cdot \left[X^{\nu}_{ph} - Y^{\nu}_{ph} \right] R_{l_p j_p}(r) R_{l_h j_h}(r)$$







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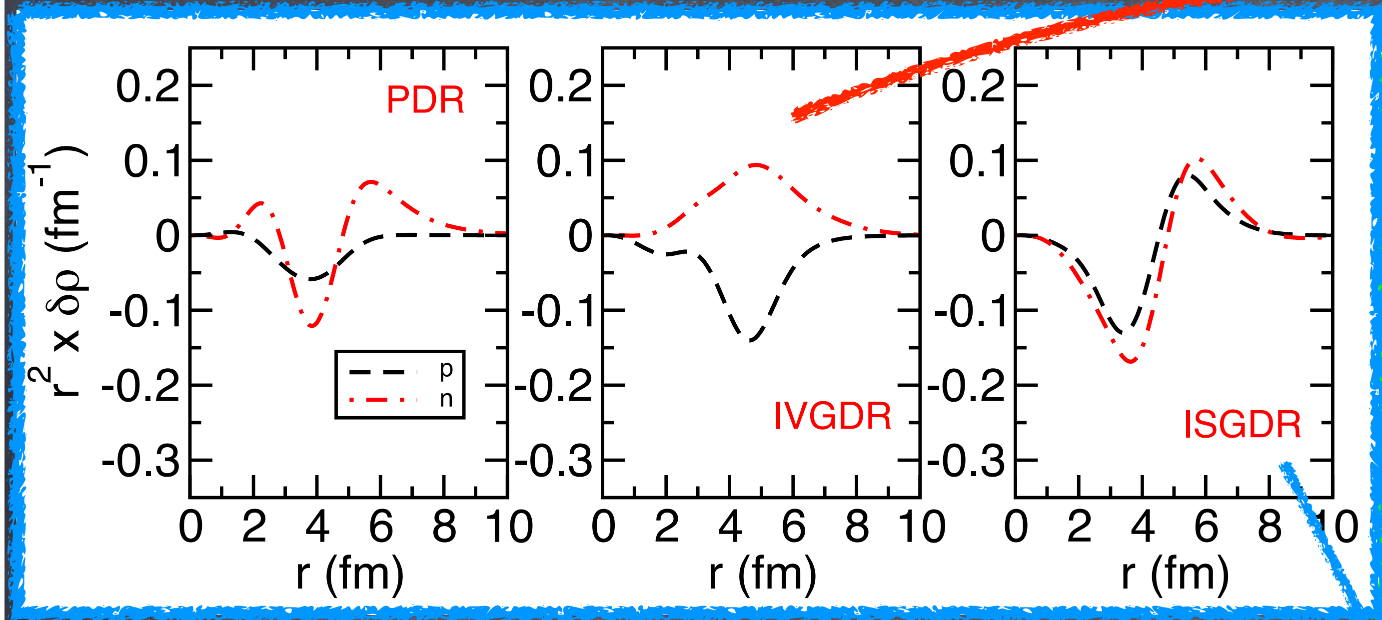

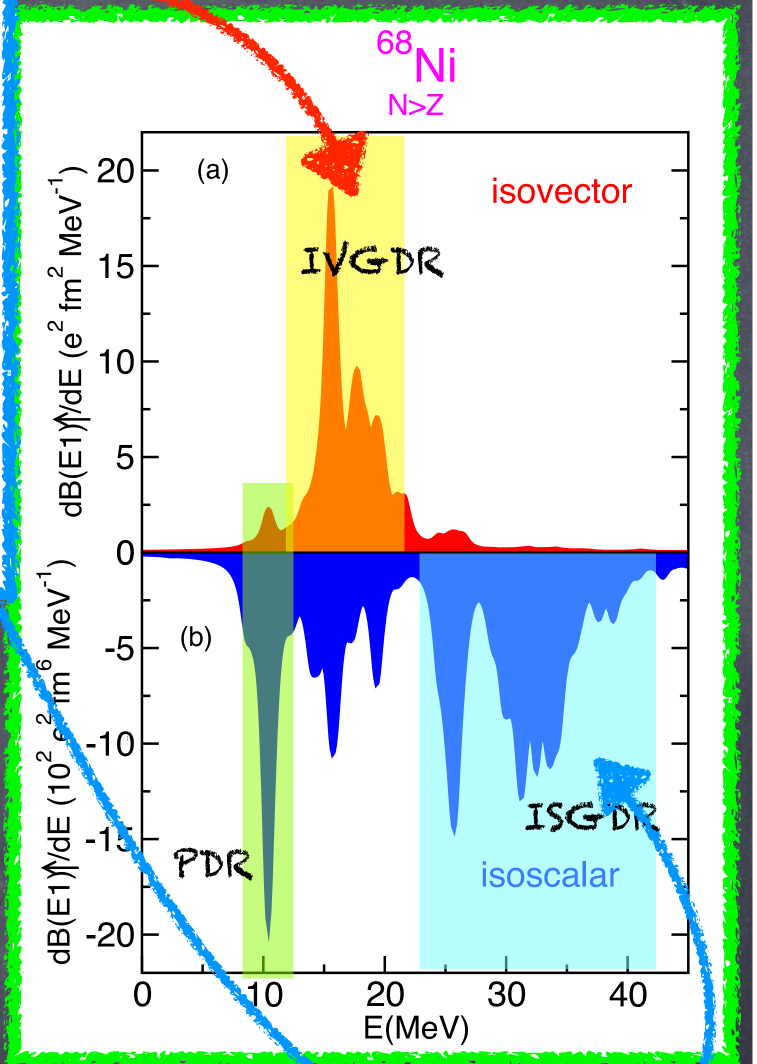

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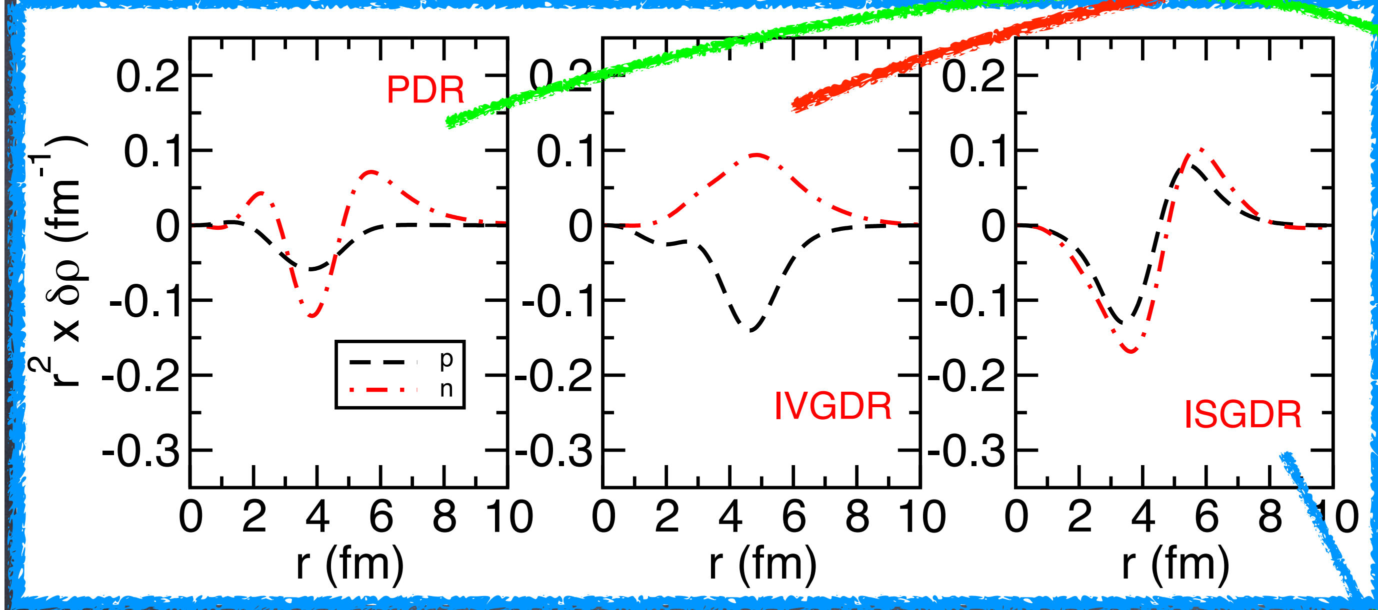
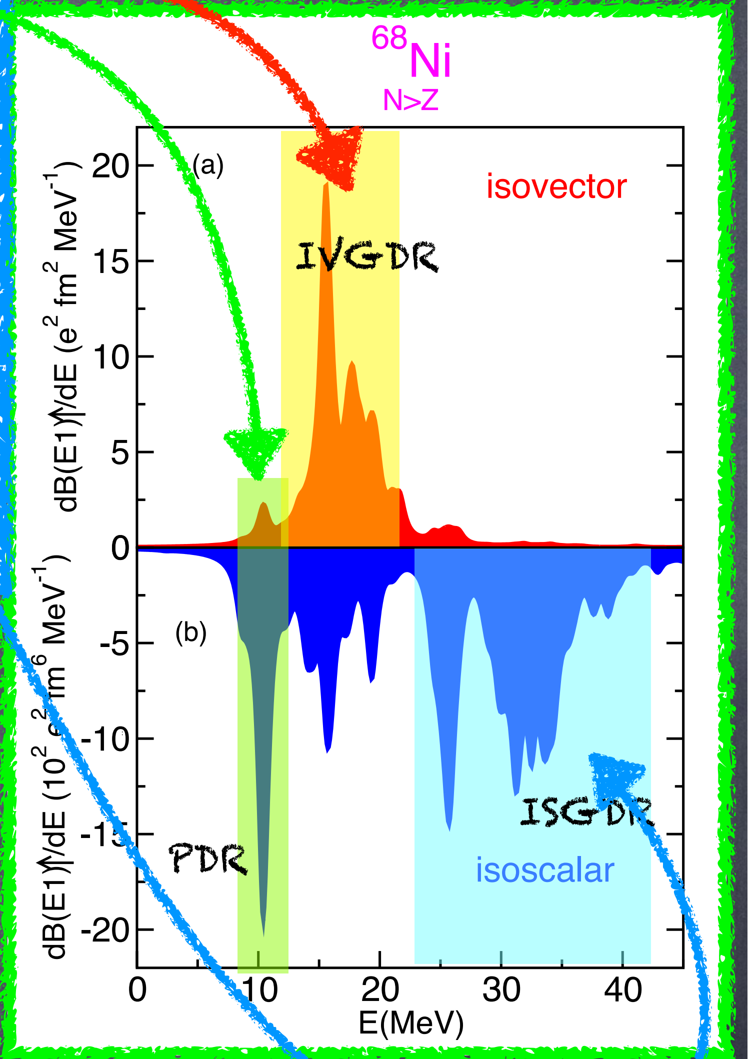
This is a $3\hbar\omega$ nuclear transitions generated by the second order $\Delta L=1$ transition operator and it can be seen as a compressional mode.





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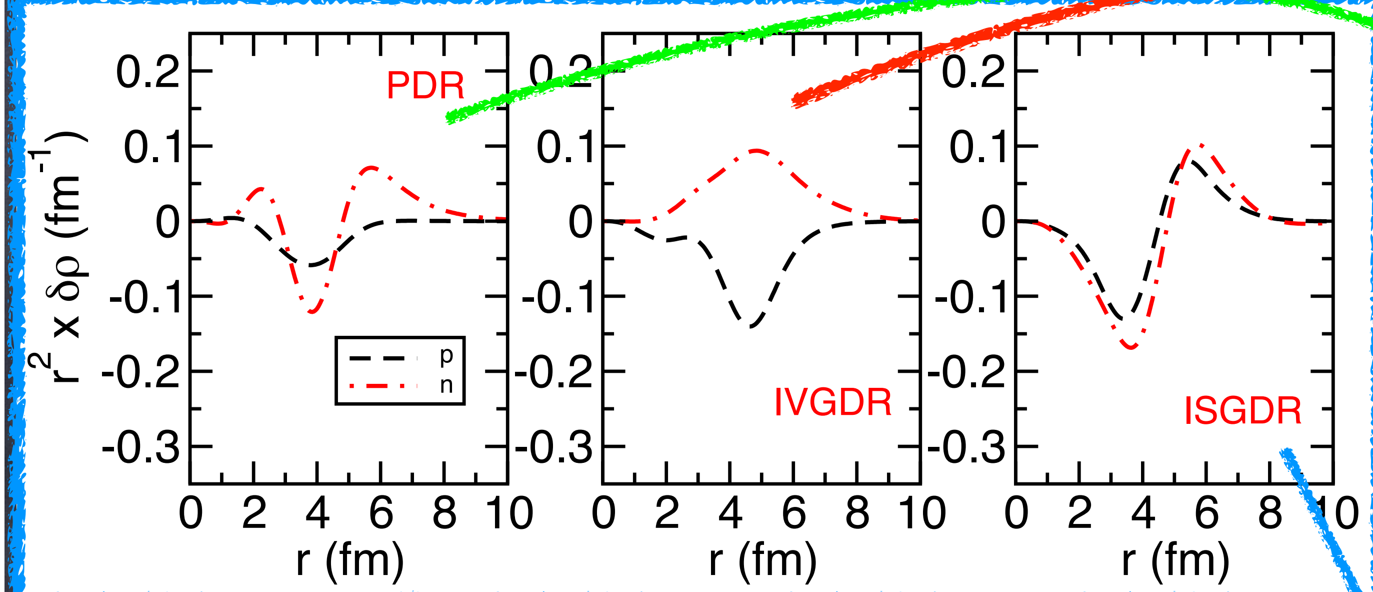

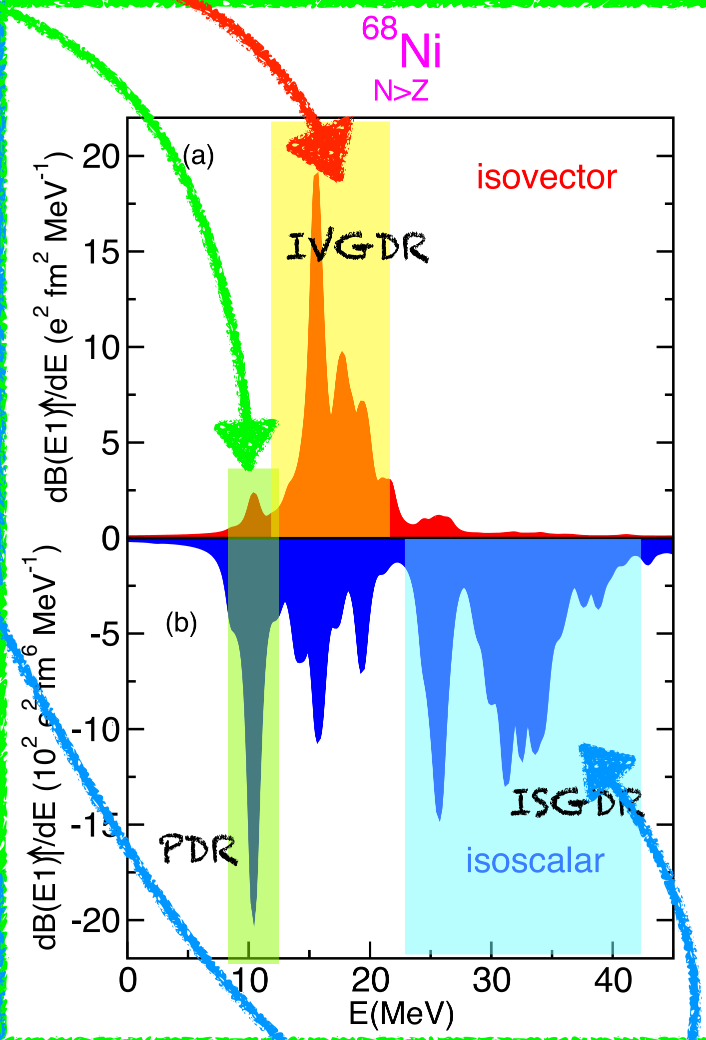

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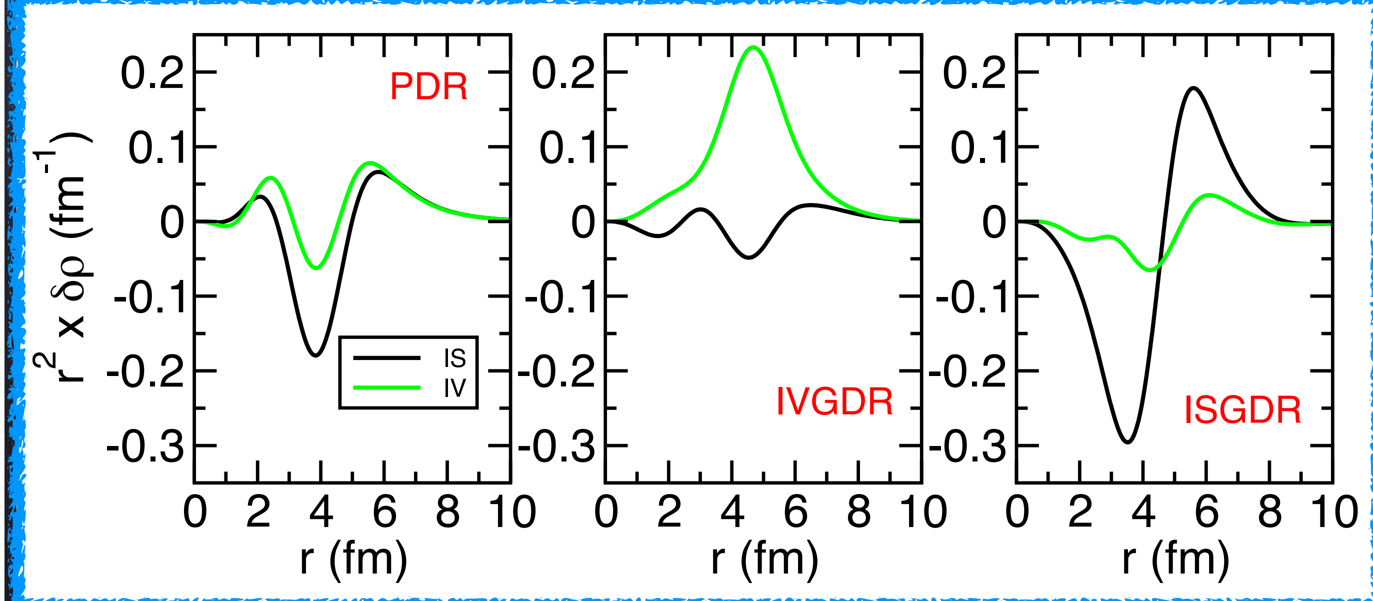

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Therefore they can be studied by both isoscalar and isovector probes

The low-lying dipole states can be a good laboratory to study the interplay between isoscalar and isovector modes

Experimentally they are studied with

Isovector probes

- Relativistic Coulomb excitation at GSI
- Nuclear resonance fluorescence (NRF) technique: (γ, γ') at Darmstadt
- Coulomb excitation by proton scattering: (p, p') in Osaka and iThemba LABS

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- $(\alpha, \alpha' \gamma)$ At KVI
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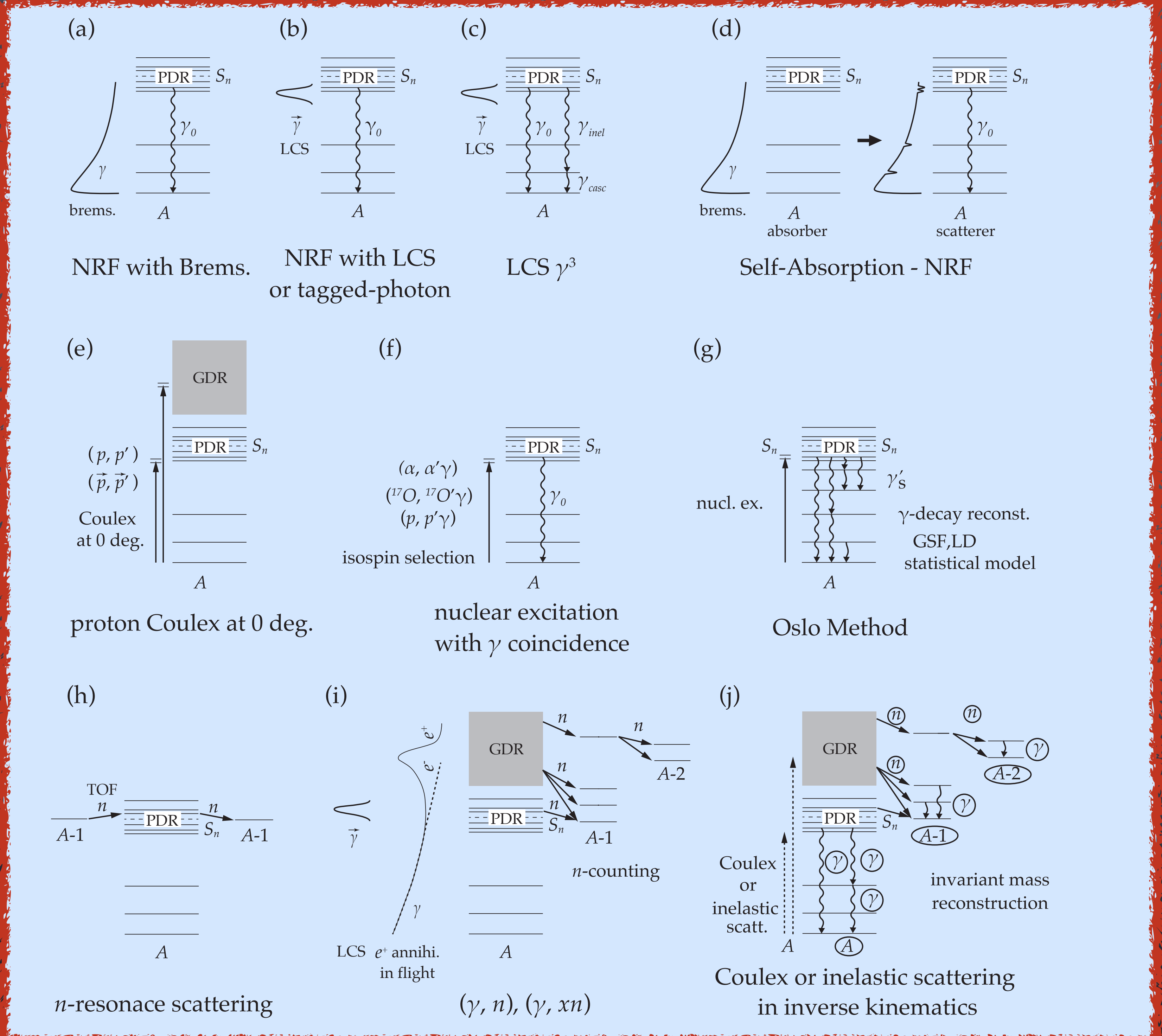
For the Isoscalar probes, inelastic cross sections are also measured

A. Bracco, E.G. Lanza, A. Tamii, Prog. Part. Nucl. Phys. 106 (2019) 360.



Few experimental data for the PDR

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Data using isovector probes

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Data using isovector probes { Stable nuclei

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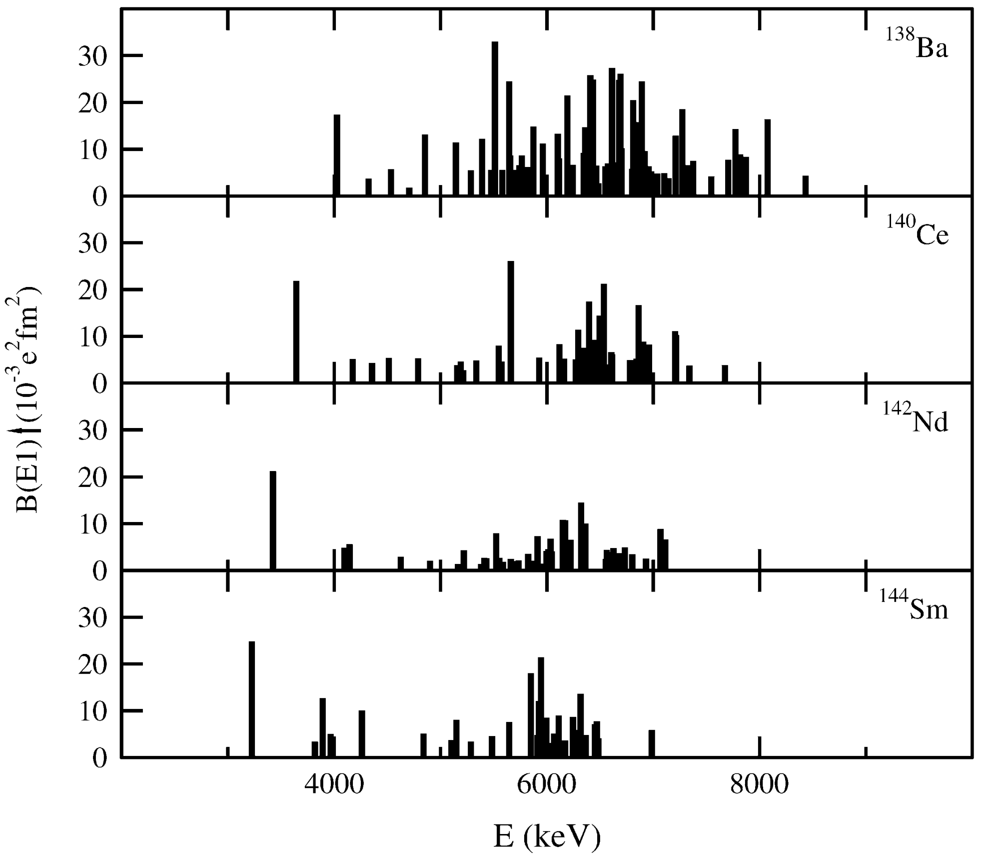
Experimental data: isovector probe

stable nuclei

Photon scattering

BELOW NEUTRON SEPARATION THRESHOLD



S. Volz et al.
NPA 779 (2006) 1

Photon scattering or
Nuclear Resonance Fluorescence
at S-DALINAC (TU Darmstadt)

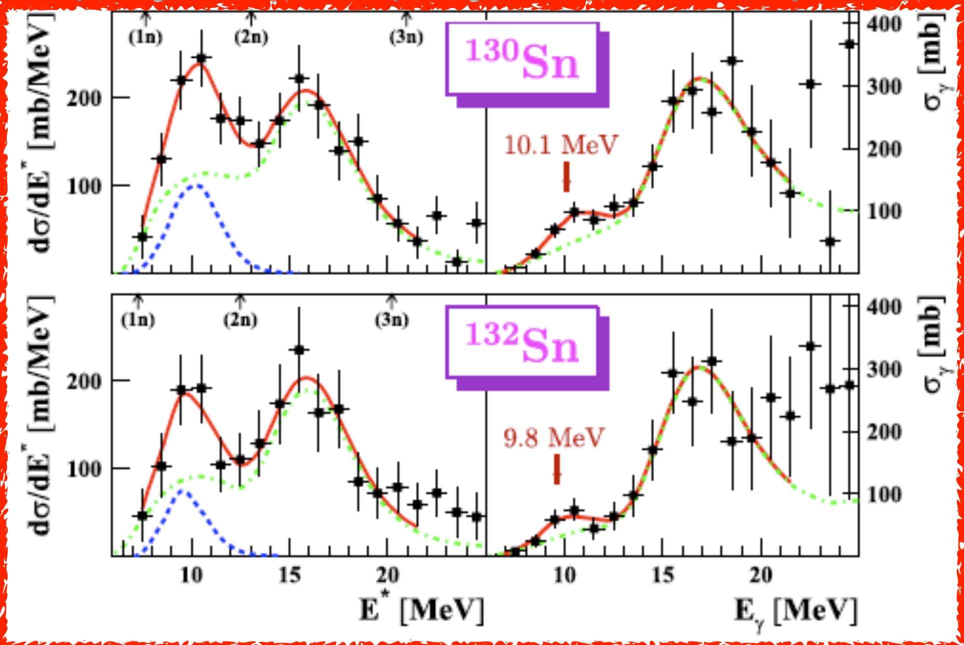
Experimental data: isovector probe

exotic nuclei

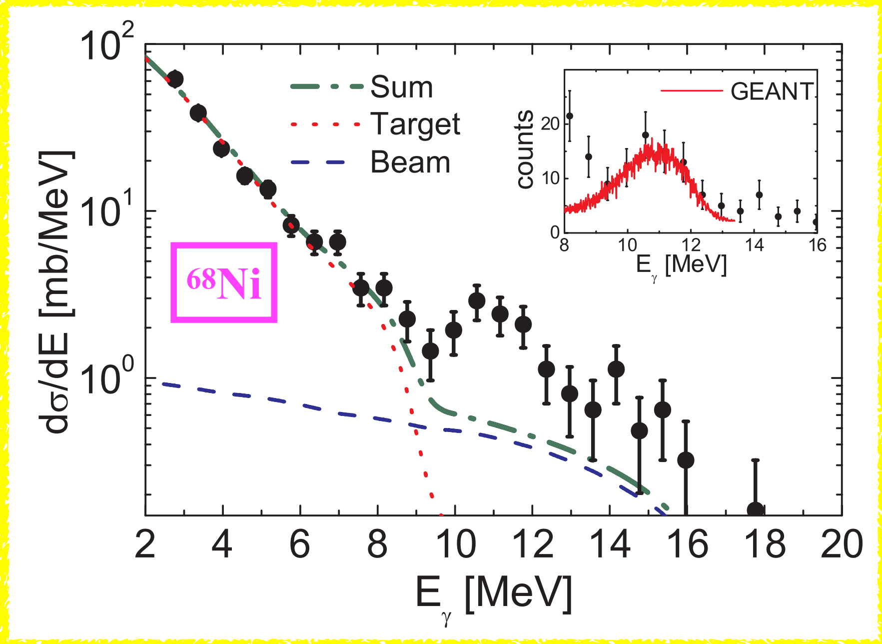
Relativistic Coulomb Excitation

ABOVE NEUTRON SEPARATION THRESHOLD

^{132}Sn + ^{208}Pb @ 500 A•MeV



^{68}Ni + ^{197}Au @ 600 A•MeV



using the FRS-LAND setup at GSI
P. Adrich et al. PRL 95 (2005) 132501

using the RISING setup at GSI (for ^{68}Ni)
O. Wieland et al. PRL 102 (2009) 092502

Experimental data: isoscalar probe

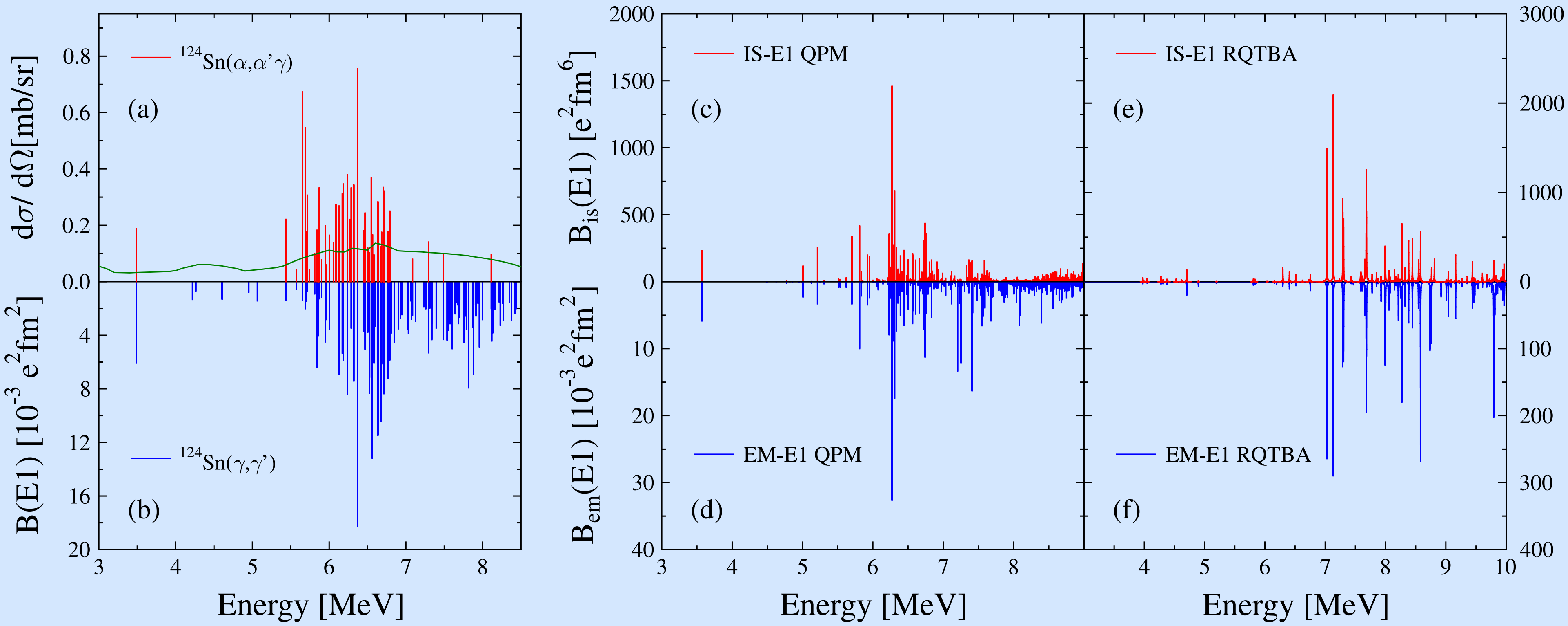
stable nuclei

Nuclear Excitation

BELOW NEUTRON SEPARATION THRESHOLD

J. Enders et al., PRL 105 (2010) 212503

V. Yu. Ponomarev calculations   E. Litvinova calculations



The Splitting of the PDR

Experimental data: isoscalar probe

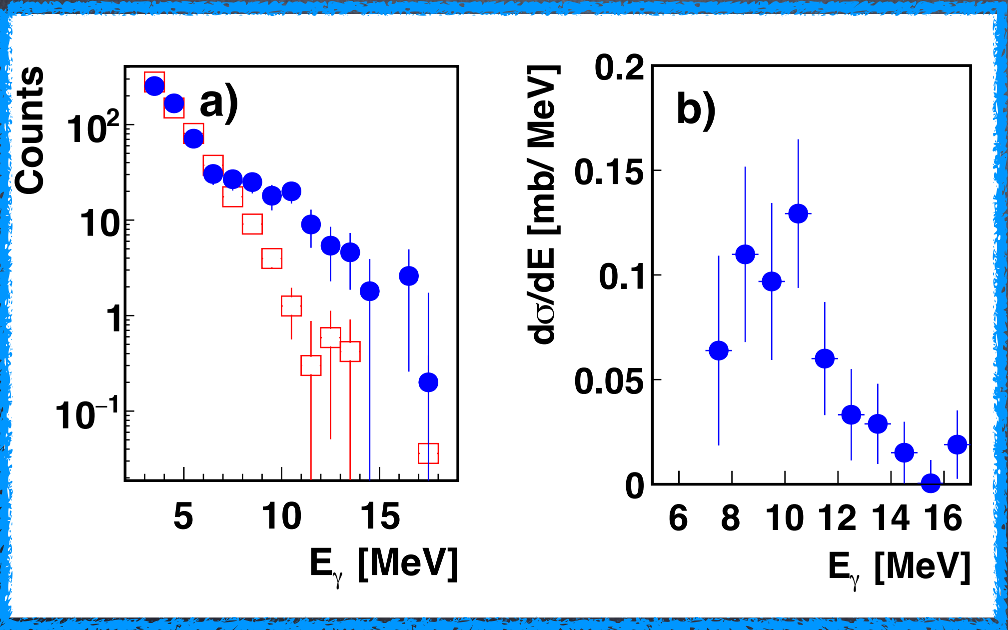
exotic nuclei

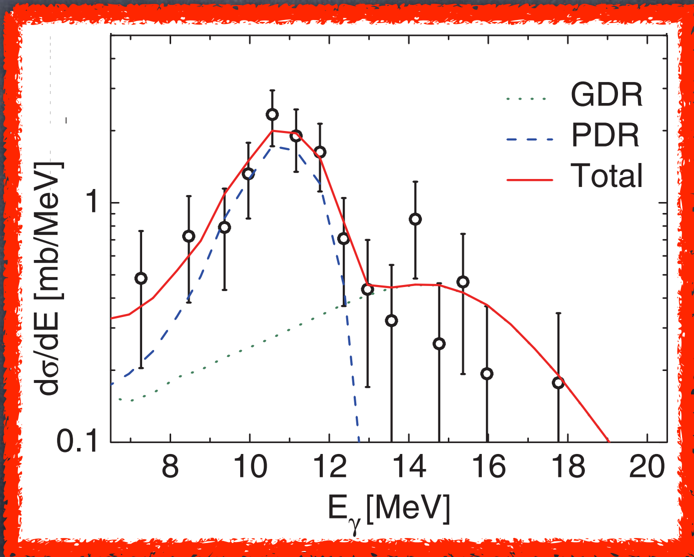
Nuclear Excitation

ABOVE NEUTRON SEPARATION THRESHOLD

N. S. Martorana et al., PLB 782 (2018) 112

^{68}Ni + ^{12}C @ 28 A·MeV at LNS with CHIMERA + FARCOS





^{68}Ni + ^{197}Au @ 600 A·MeV

Apparently no Splitting of the PDR above the threshold

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2. What is the interplay between isovector and isoscalar contributions?

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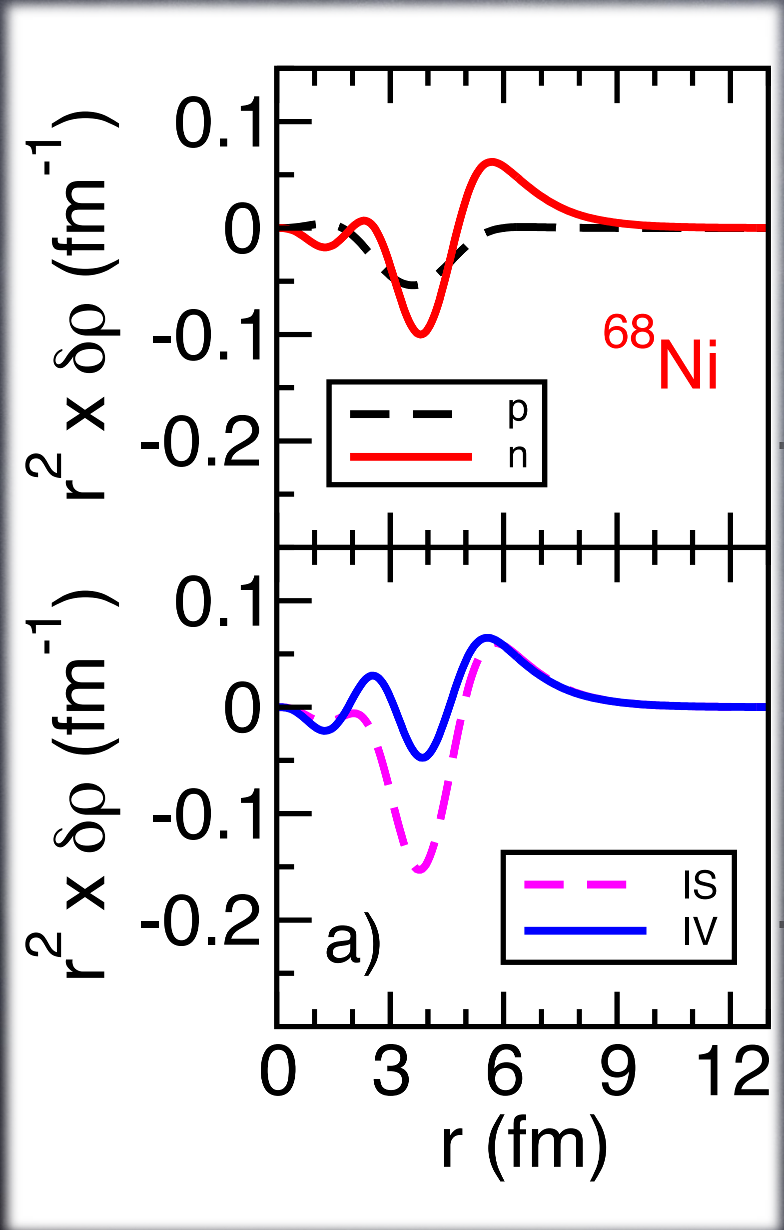
4. Questioning the existence of the PDR above the neutron emission threshold

All the microscopic models find that the states in the energy region of the PDR show a strong isospin mixing at the nuclear surface region.

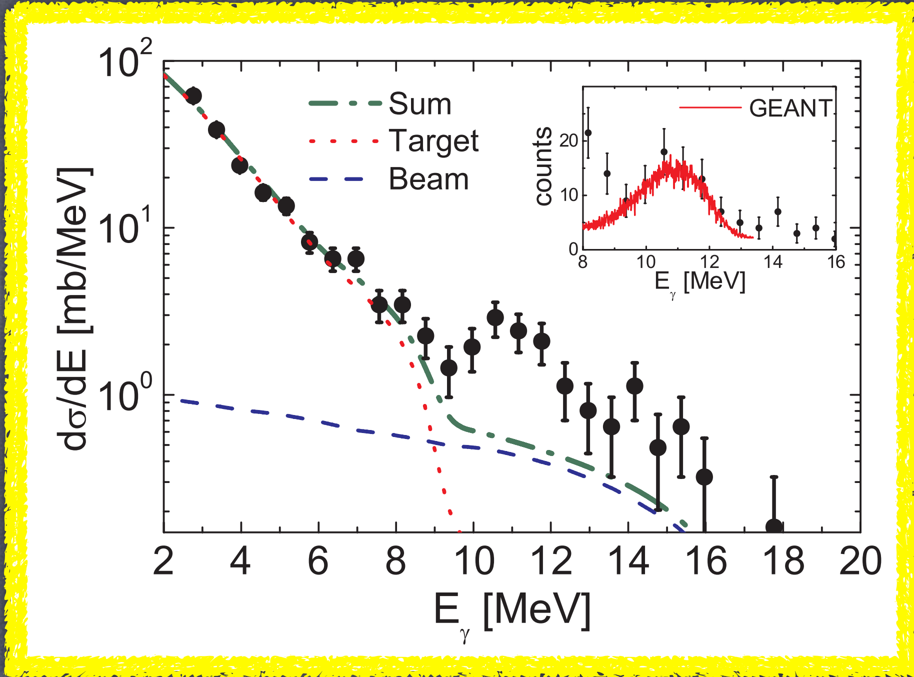


neutron and proton transition densities are in phase inside the nucleus; at the surface only the neutron part survive.

"Theoretical definition" of the PDR

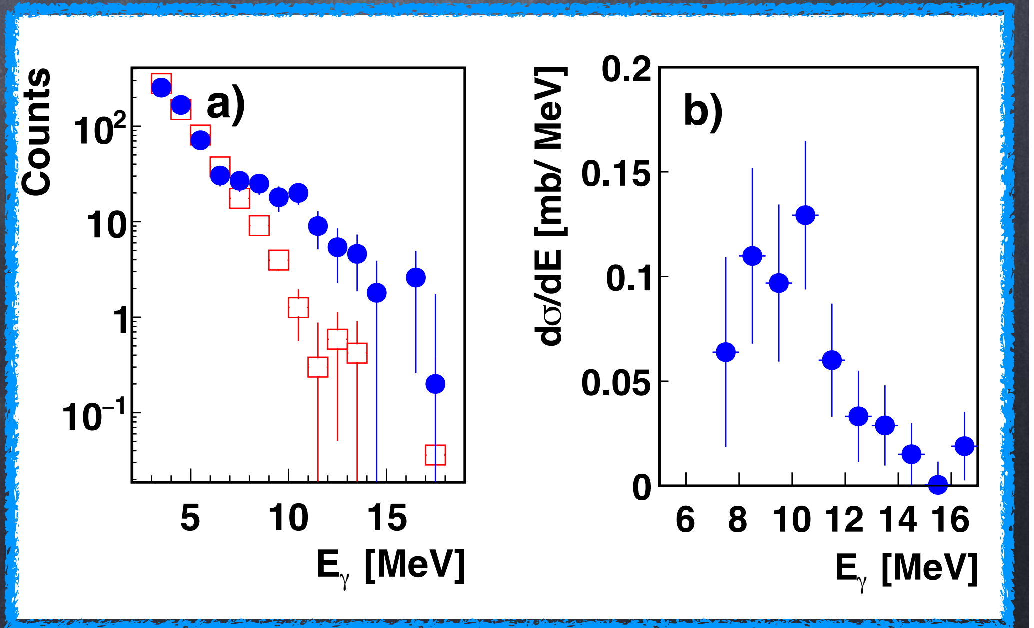
It has been shown that the PDR of the ^{68}Ni excited by the isovector relativistic Coulomb probe at GSI by the Angela Bracco group

^{68}Ni + ^{197}Au @ 600 A•MeV



can also be excited by an isoscalar probe like ^{12}C at LNS with CHIMERA +FARCO

^{68}Ni + ^{12}C @ 28 A•MeV



The comparison should be done by paying attention to the different experimental systems and different parameters of the reactions .

It is of paramount importance to have data taken with the same experimental apparatus and same conditions. Such experiment with two different probes, like alpha or ^{12}C target for the isoscalar one, and ^{197}Au or ^{208}Pb for the isovector probe at higher energies, should clarify this aspect of the PDR.

5. What is the effect of the temperature on the excitation of the dipole states?

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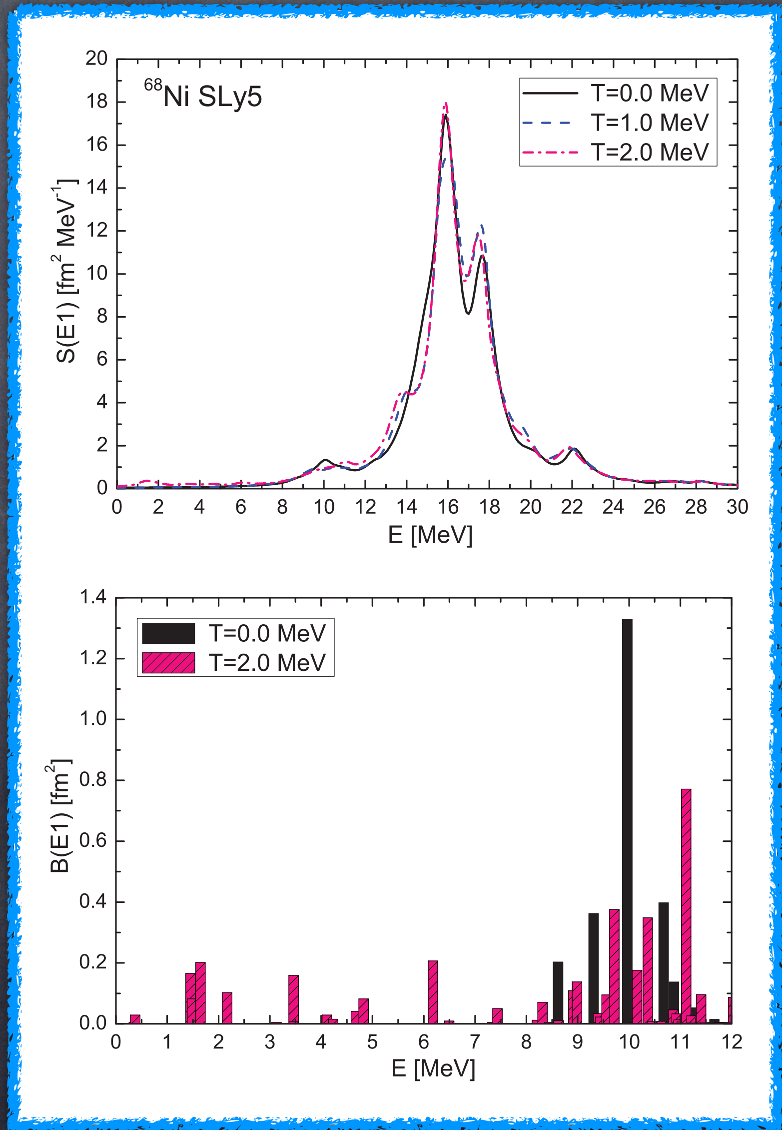
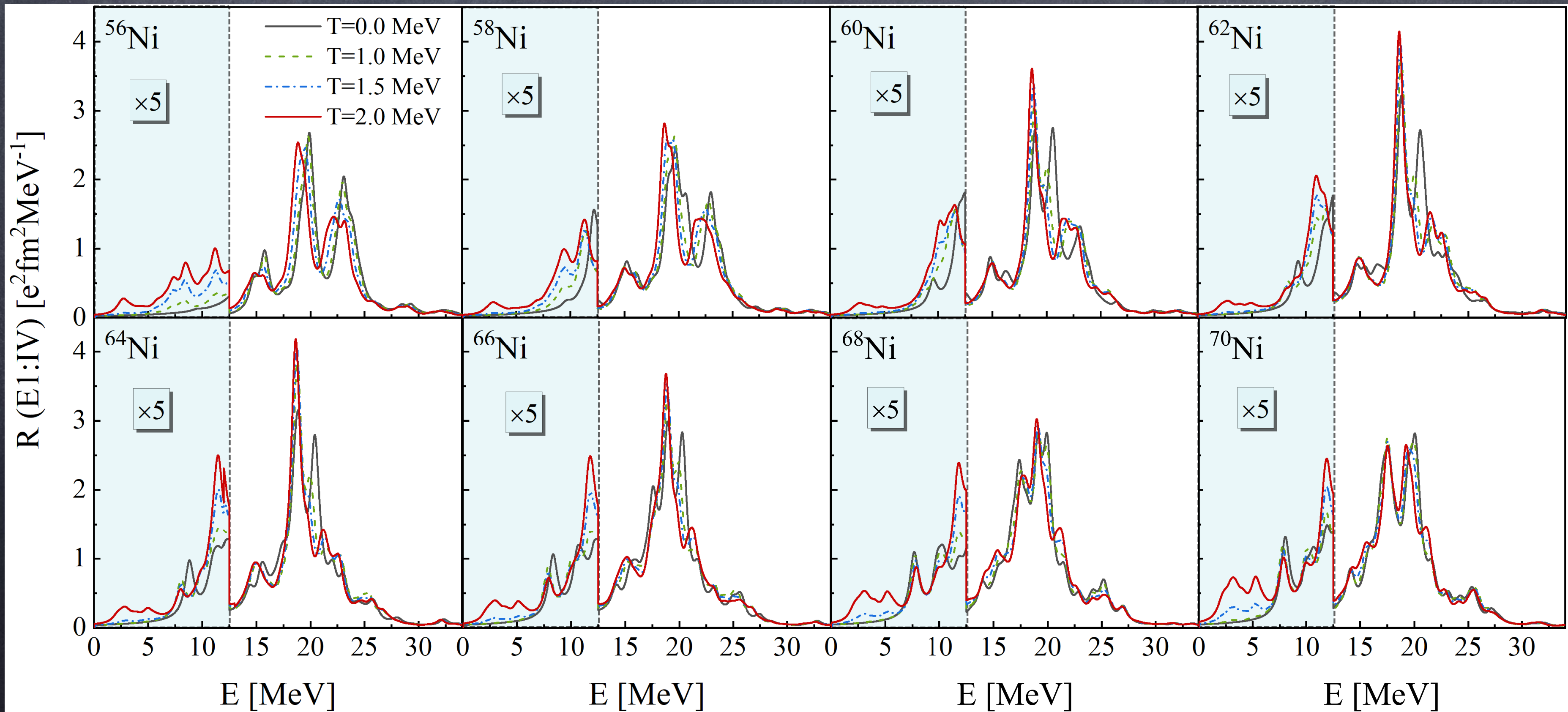


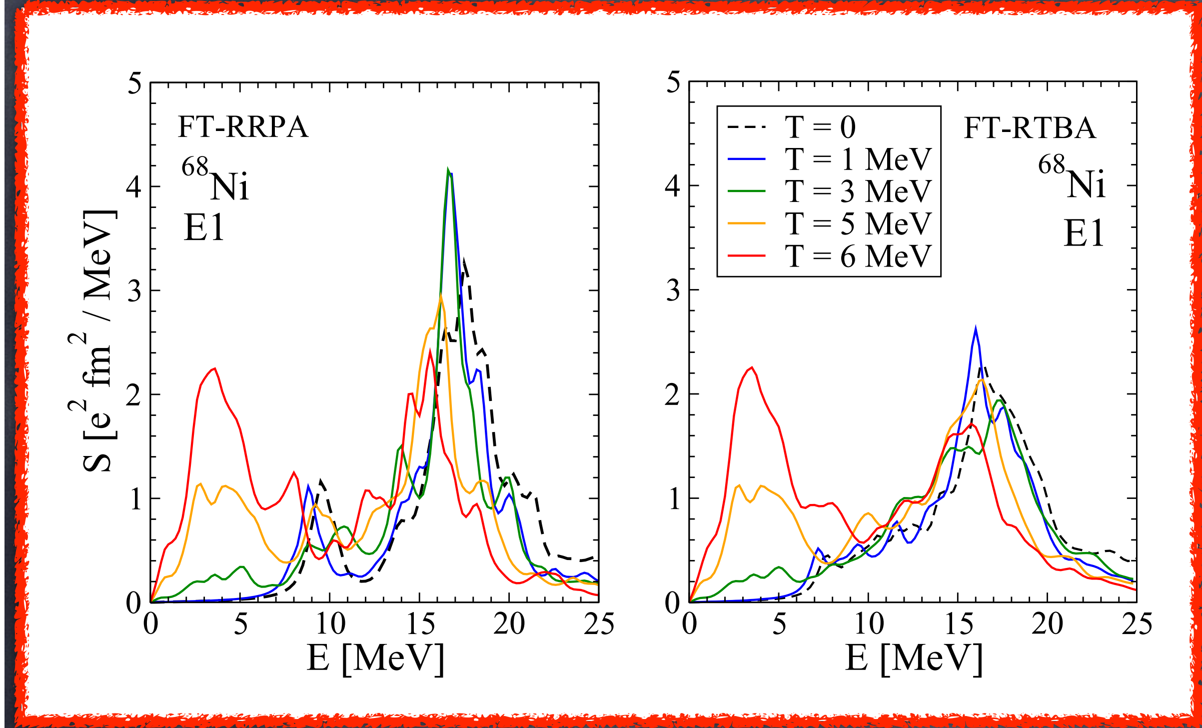
Amandeep Kaur, E. Yüksel, and Nils Paar,
https://arxiv.org/abs/2506.13354v16

Finite-Temperature Relativistic Quasiparticle Random Phase approximation (FT-RQRPA) based on the relativistic energy density functional (REDF)

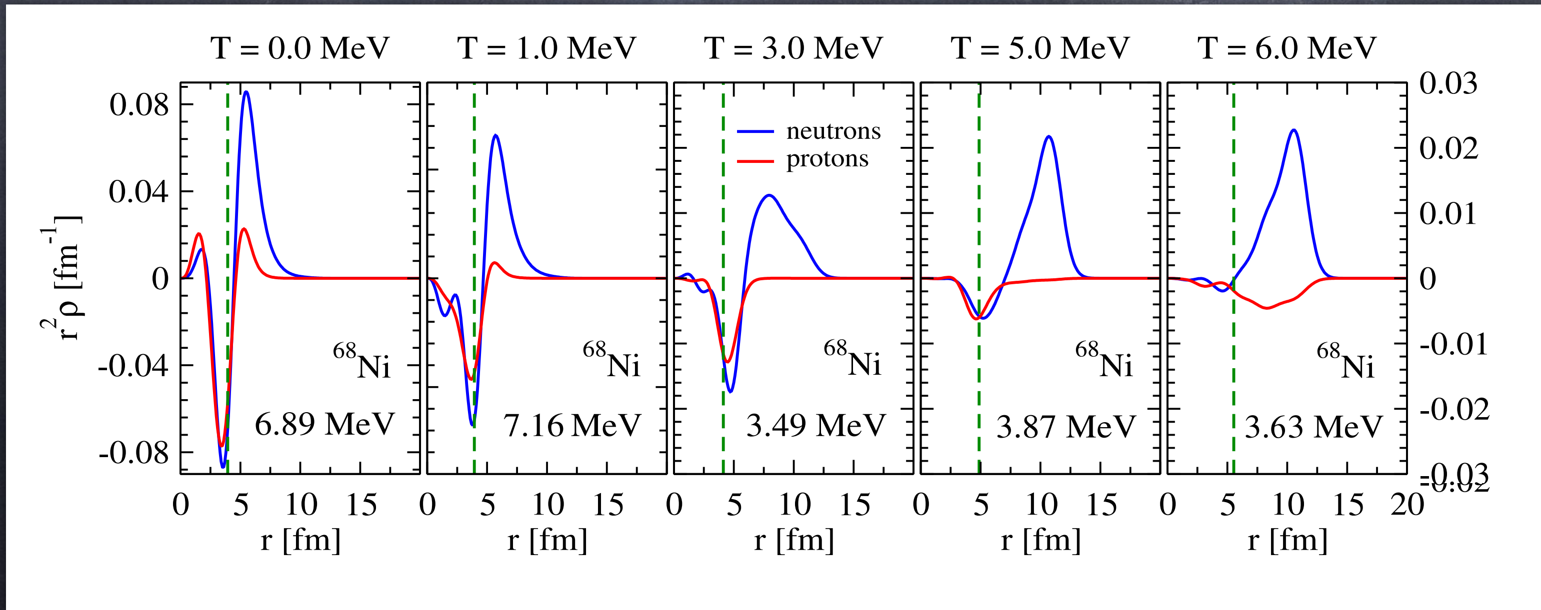


Herlik Wibowo and Elena Litvinova

PRC 100, 024307 (2019)



Calculations performed with Finite-Temperature Relativistic Random Phase Approximation (FT-RRPA) and Finite-Temperature Relativistic Time-Blocking Approximation (FT-RTBA)



O. Wieland, A. Bracco et al.,
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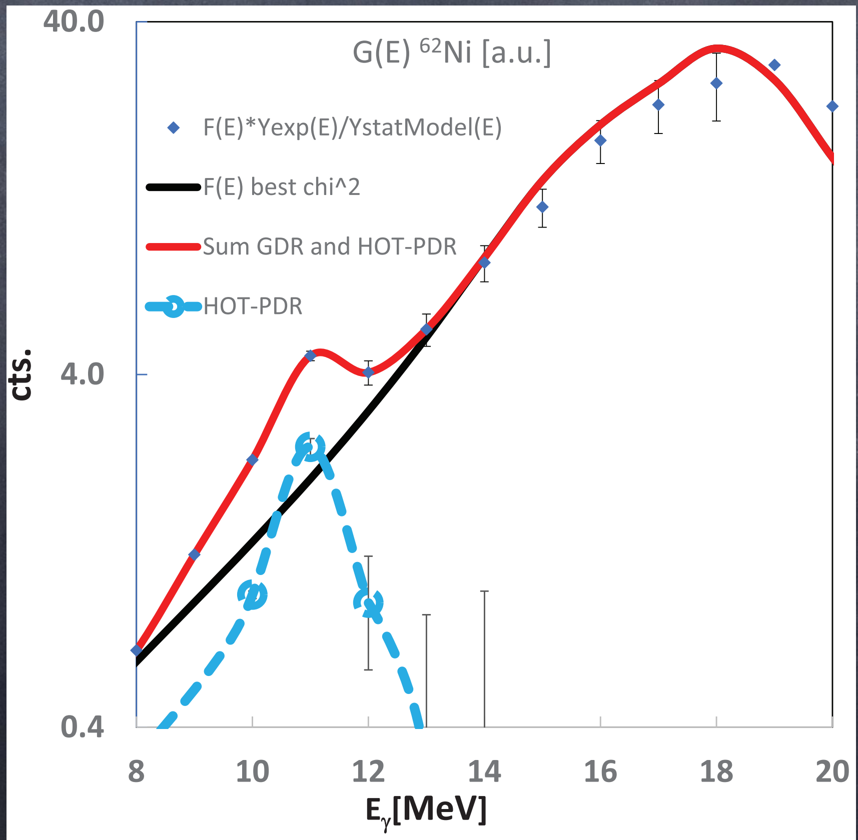
The high-energy γ-rays from the GDR decay of ^{56,60,62}Ni nuclei at finite temperature were measured and analyzed with statistical model using a Monte Carlo approach. It is found that the present analysis gives some evidence on the presence of an extra yield on the tail of the Giant Dipole Resonance which may be attributed to a Pygmy Dipole Resonance in an excited nucleus.



Thank you
for your attention