COMEX6

6th International Conference on Collective Motion in Nuclei under Extreme Conditions

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Cape Town, South Africa

Pygmy Dipole Resonances in deformed nuclei

(Isoscalar and isovector probes
to investigate the
Pygmy Dipole Resonances)

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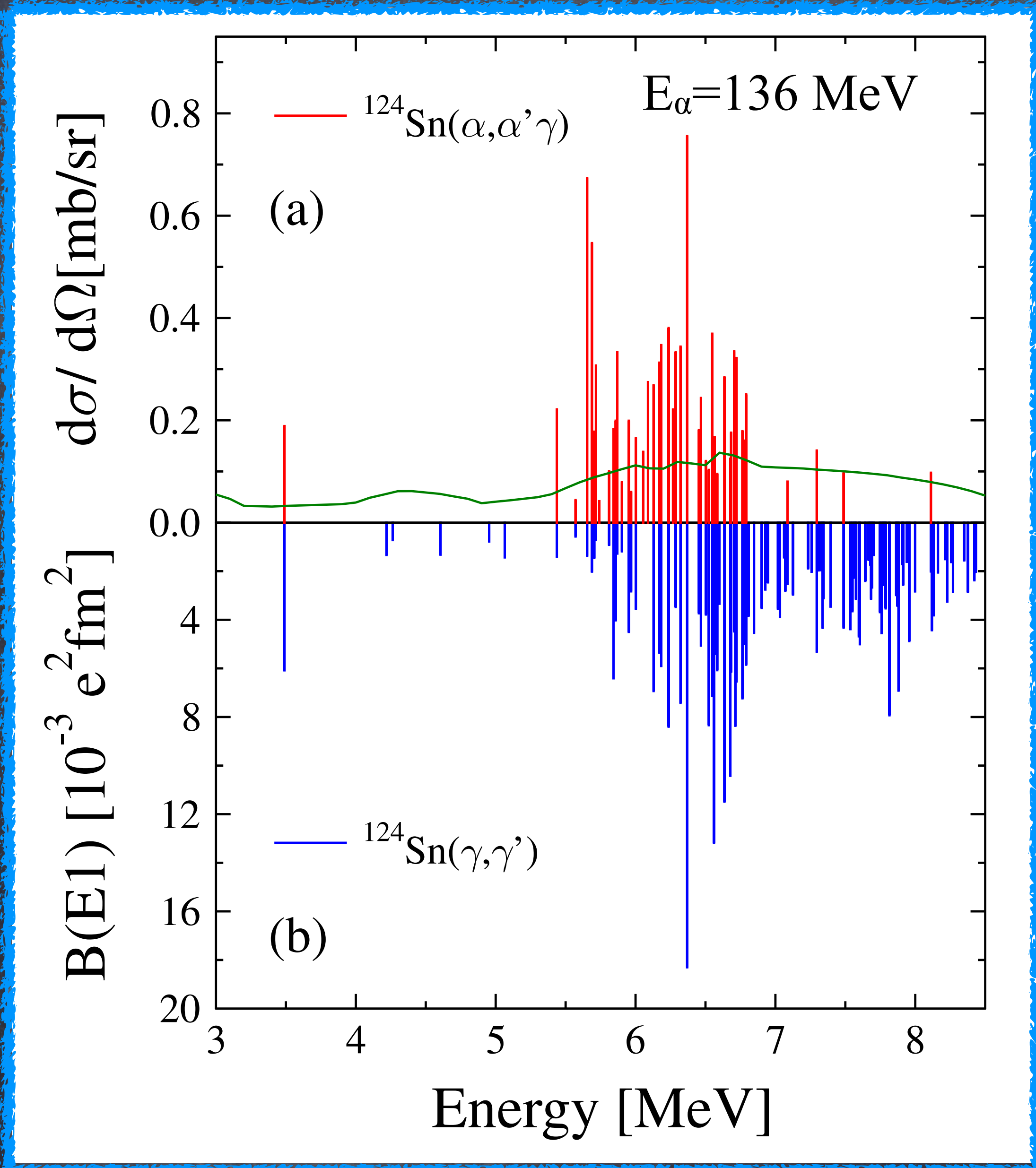
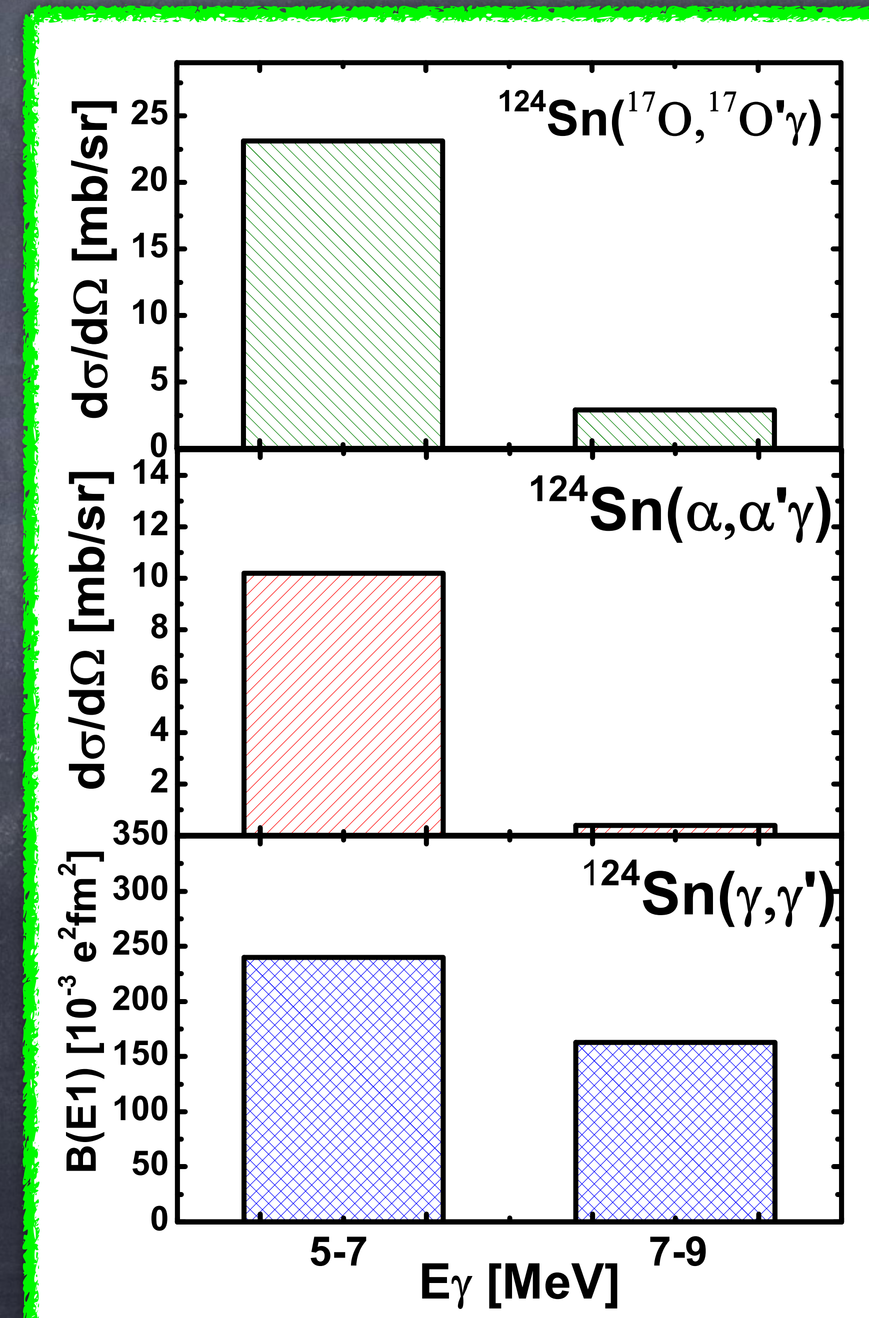


Experimental data isoscalar probe

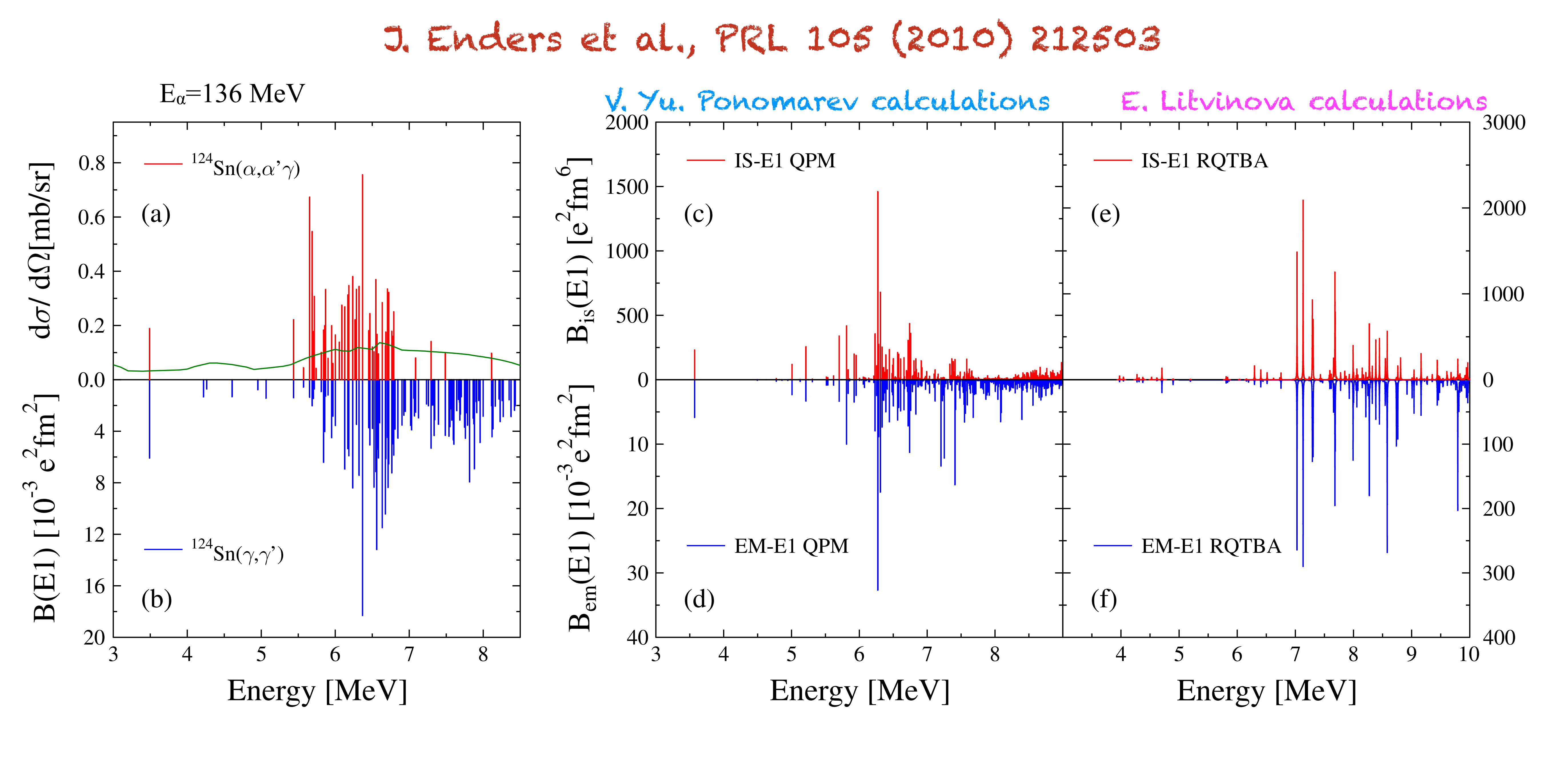
The use of isoscalar probes has brought to light a new feature of this new mode

The splitting of the PDR



D. Savran et al., PRL 97 (2006) 172502
J. Endres et al., PRL 80(2009) 034302
J. Endres et al., PRL 105 (2010) 212503
F.C.L. Crespi et al., PRL 113 (2014) 012501
L. Pellegri et al., PLB 738 (2014) 519
F.C.L. Crespi et al., PRC 91 (2015) 024323

Splitting of the low-lying dipole strength



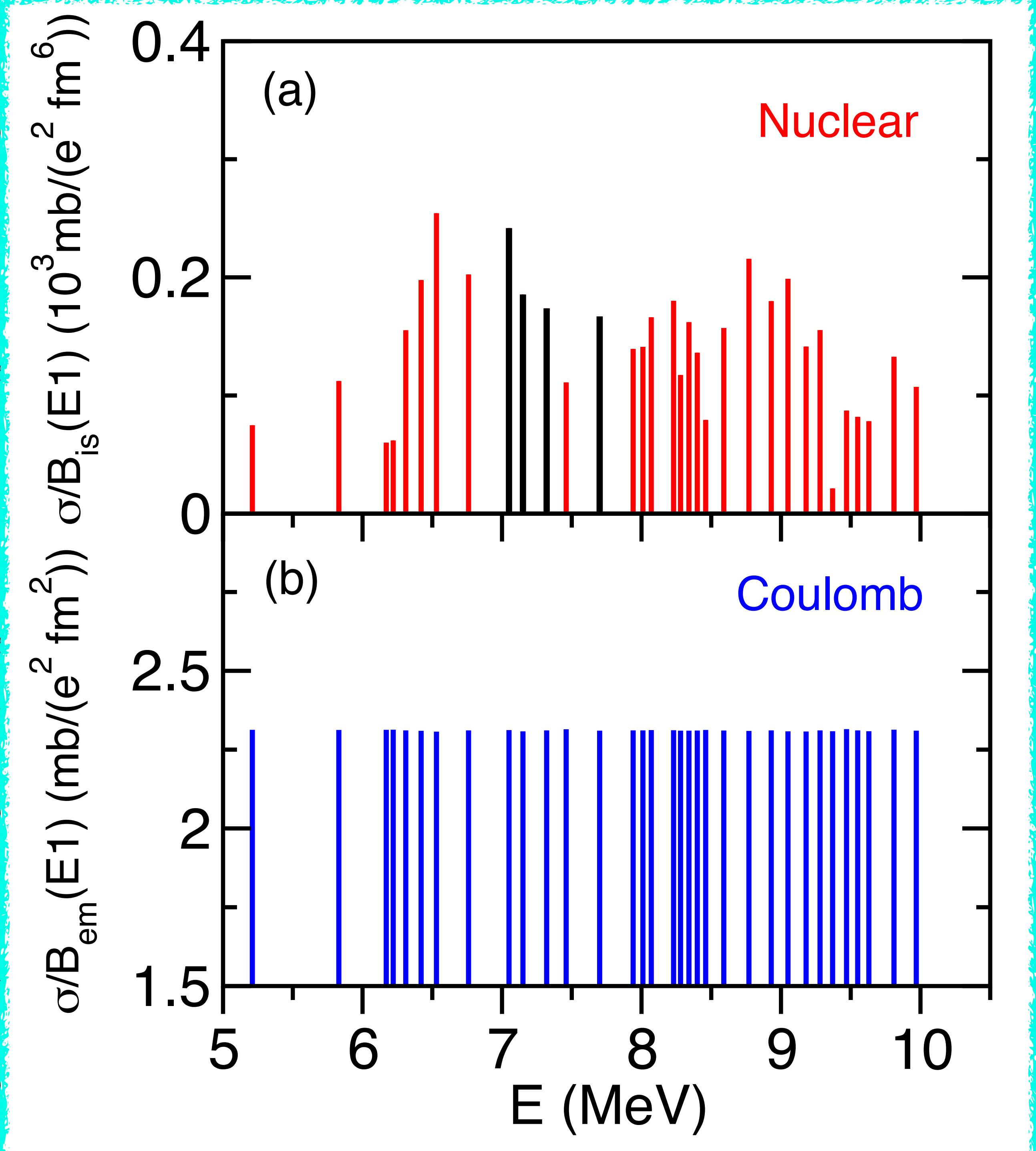
The lower lying group of states is excited by both isoscalar and isovector probes while the states at higher energy are excited by photons only.

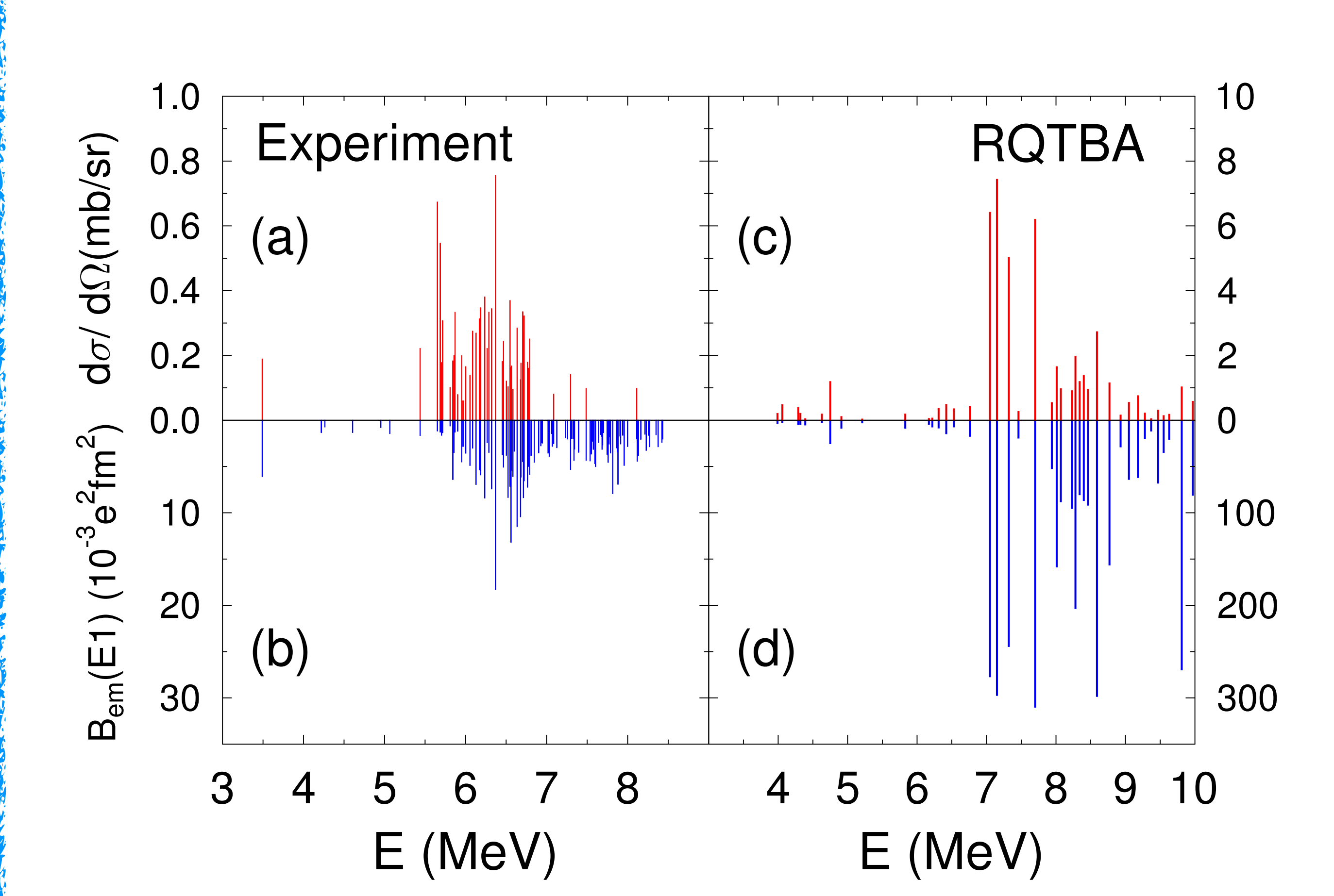
For the isoscalar case they are comparing cross section with $B_{is}(E1)$

Calculations done using the transition densities of the RQTBA (E. Litvinova) and by putting by hand the energies of all the states to zero in order to eliminate the contributions due to the dynamic of the reaction, such as the Q-value effect.

The relation between the isoscalar response and the inelastic excitation cross section due to an isoscalar probe it is not so evident.

For pure Coulomb excitation the relation between the inelastic cross section and the $B_{em}(E1)$ is clear: they are proportional.

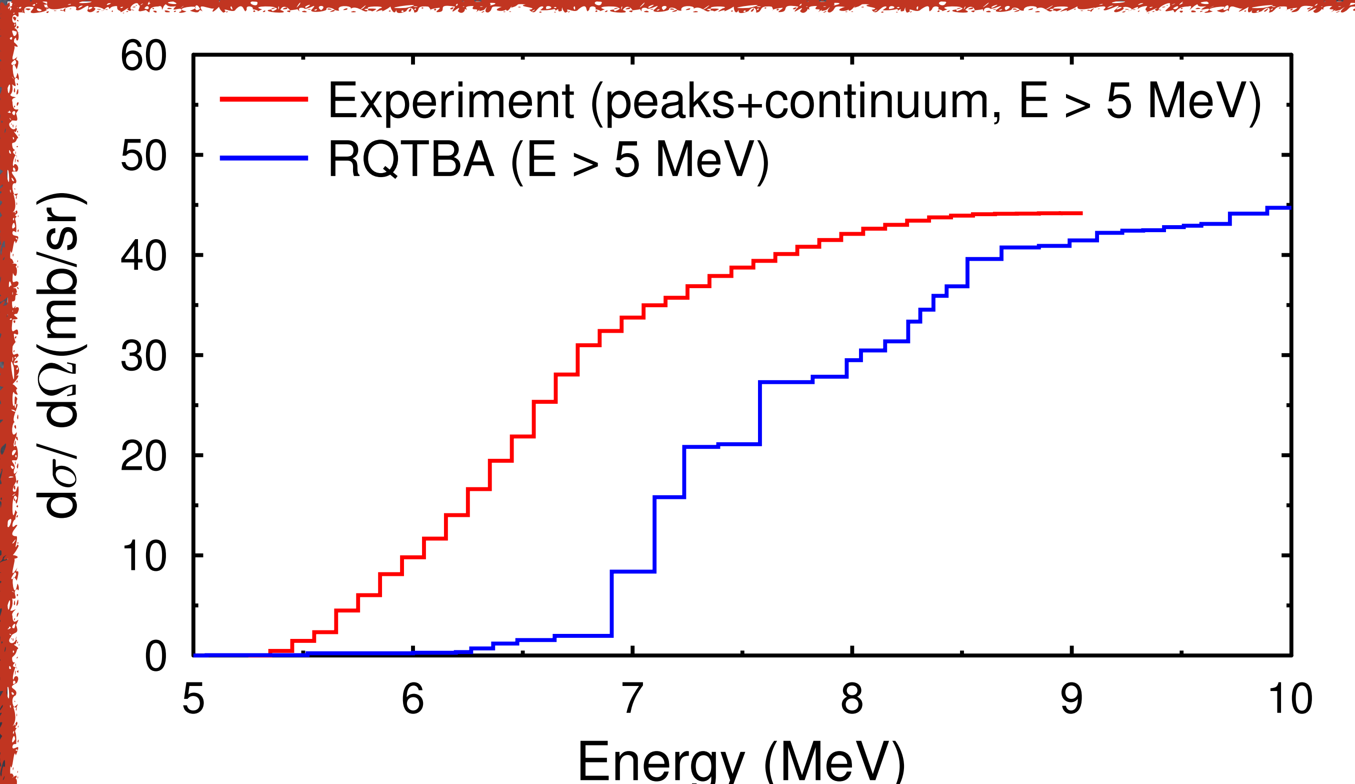




E.G.Lanza, A.Vitturi, E.Litvinova, D.Savran
PRC89 (2014) 041601(R)

Comparison between semiclassical cross section calculations (with the transition densities of RQTBA) and the experimental data.

This calculation provides the missing link to directly compare the results from the microscopic RQTBA calculations to experimental data measured via the (α, α′ γ) reaction, confirming the structural splitting of the low-lying E1 strength.



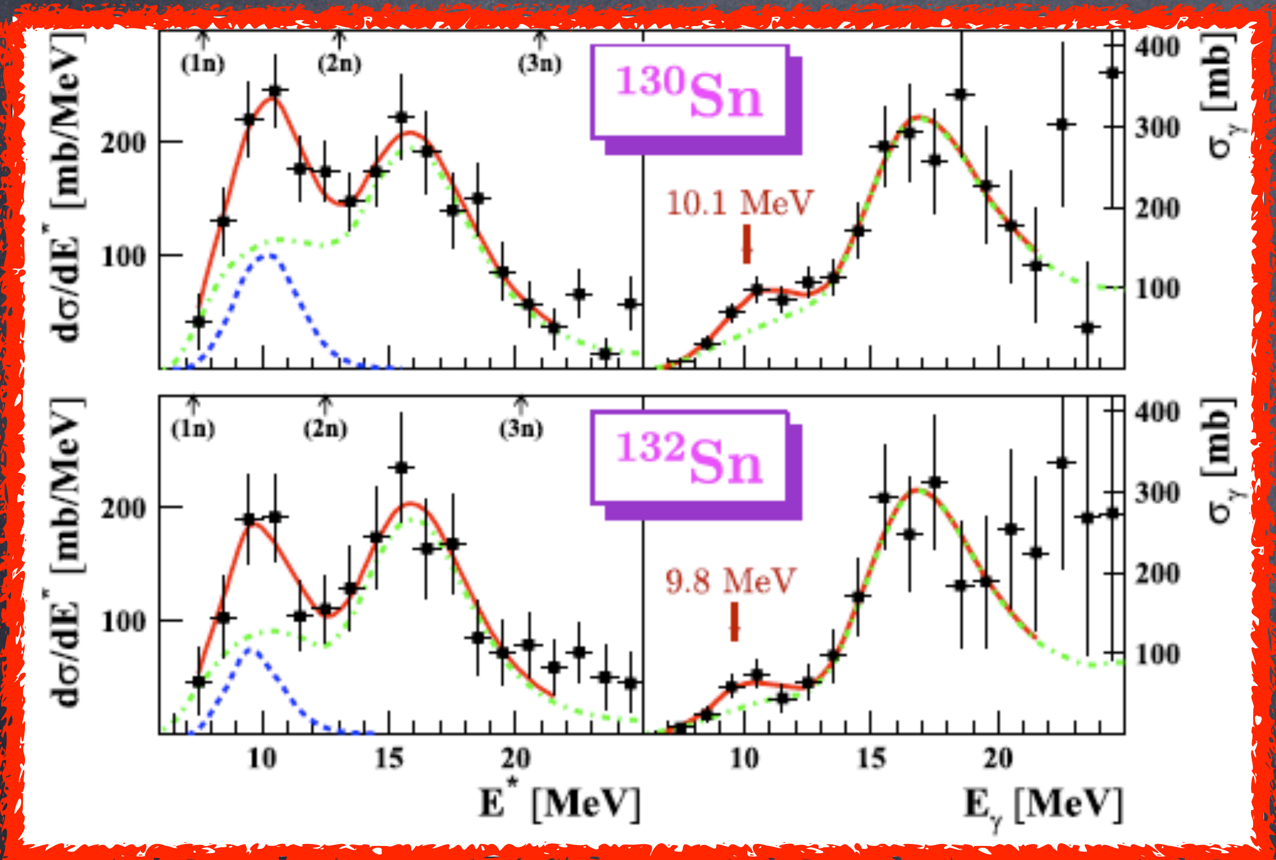
Comparison in terms of the cross section cumulative sum.

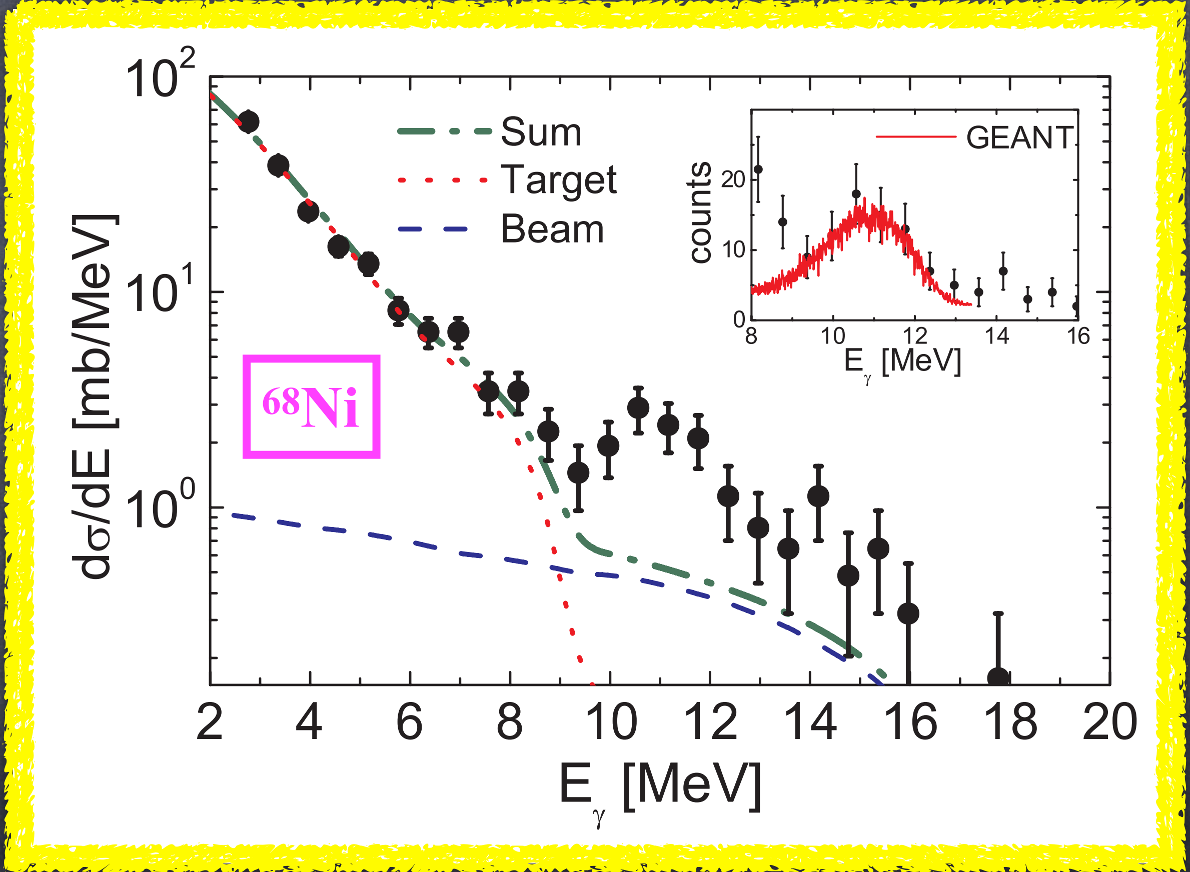
Experimental data: isovector probe

exotic nuclei

Relativistic Coulomb Excitation

ABOVE NEUTRON SEPARATION THRESHOLD





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

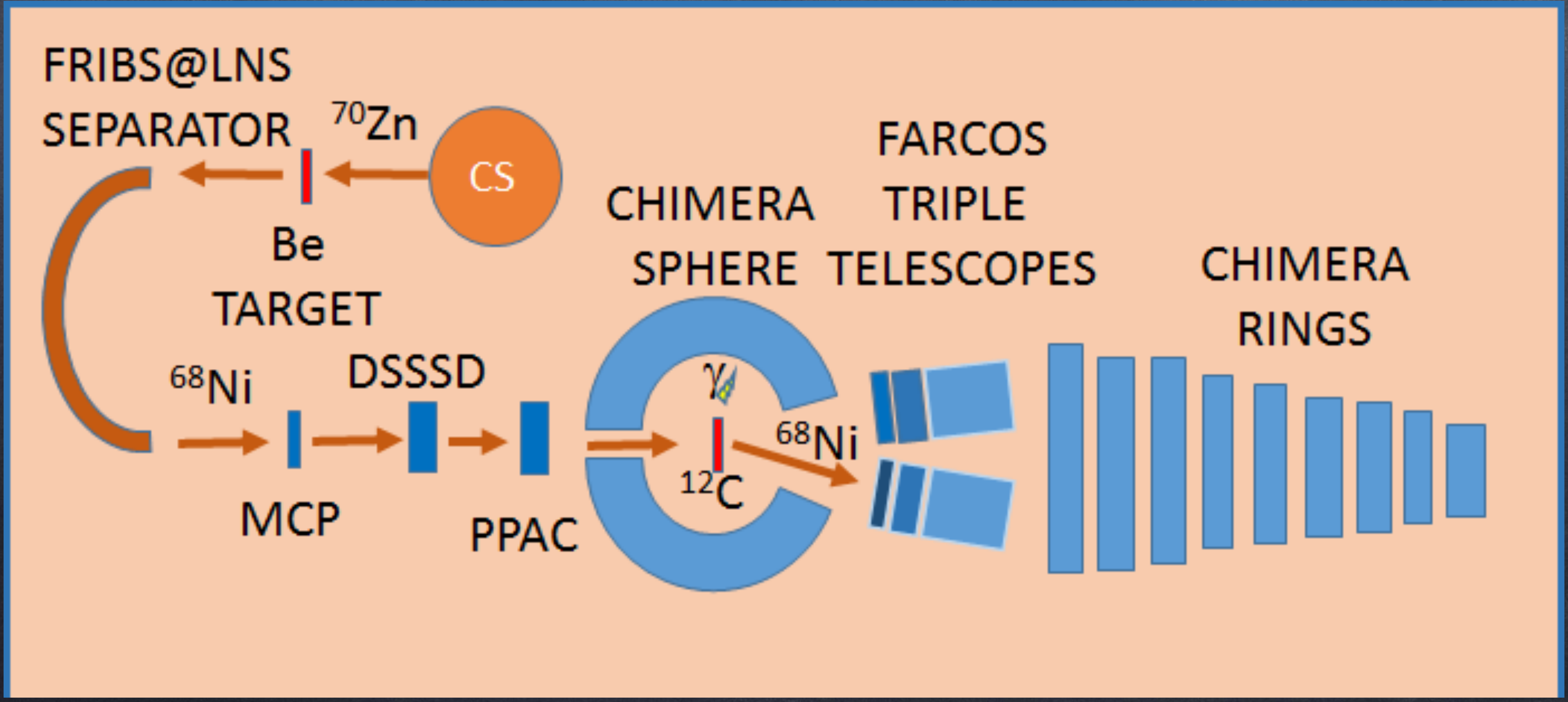
using the RISING setup at GSI (for ^{68}Ni)
O. Wieland et al. PRL 102 (2009) 092502

Measurement of PDR in unstable nucleus (^{68}Ni) via isoscalar probe at LNS Catania

^{68}Ni + ^{12}C @ 28 A•MeV

A primary ^{70}Zn beam of 40 MeV/A on a ^{9}Be target was employed to produce a secondary ^{68}Ni beam at 28 A•MeV which was sent on a ^{12}C target. The residues of the reaction are measured with FARCOS and the γ with the CsI of CHIMERA

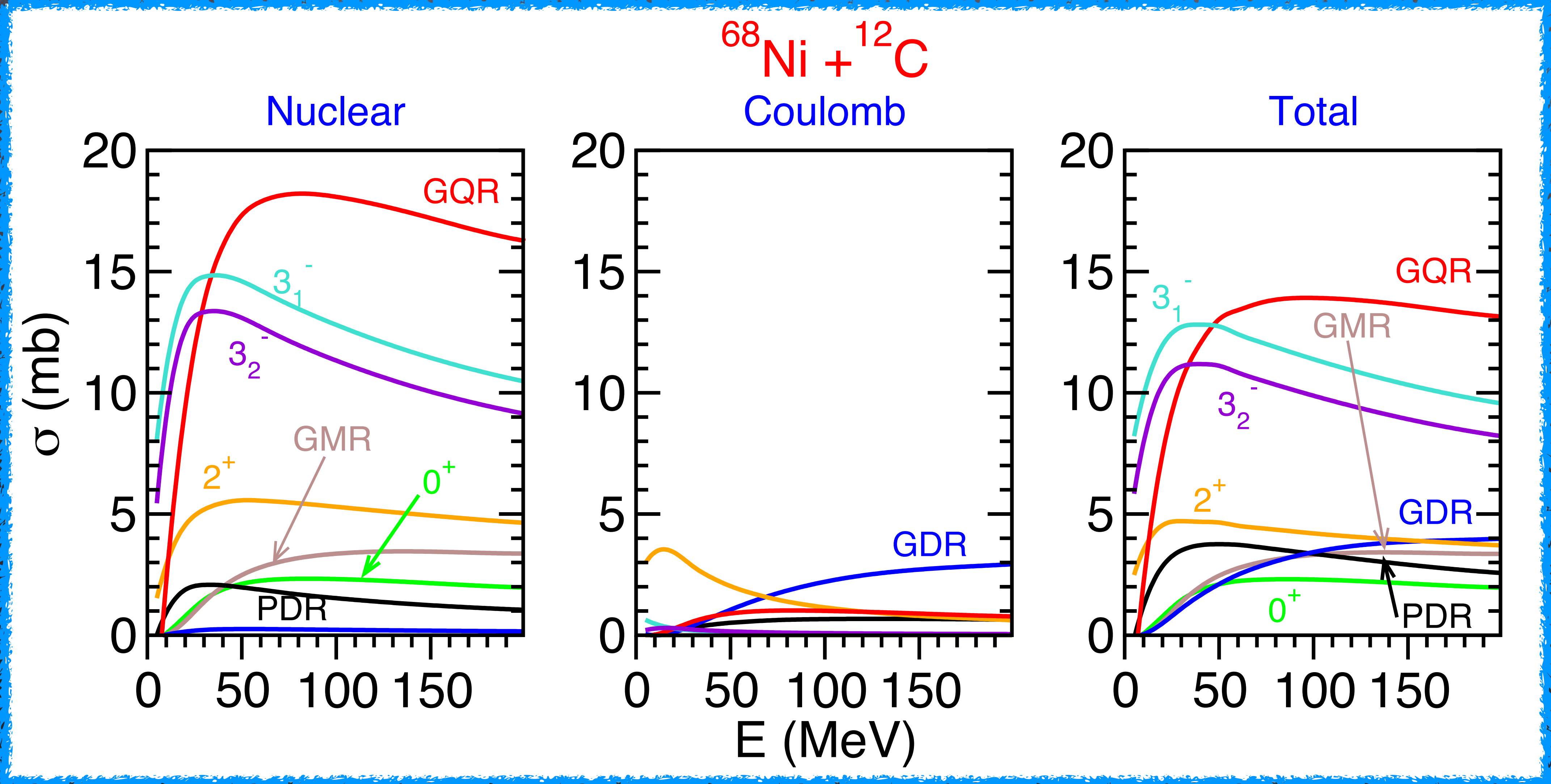
N. S. Martorana et al., PLB 782 (2018) 112



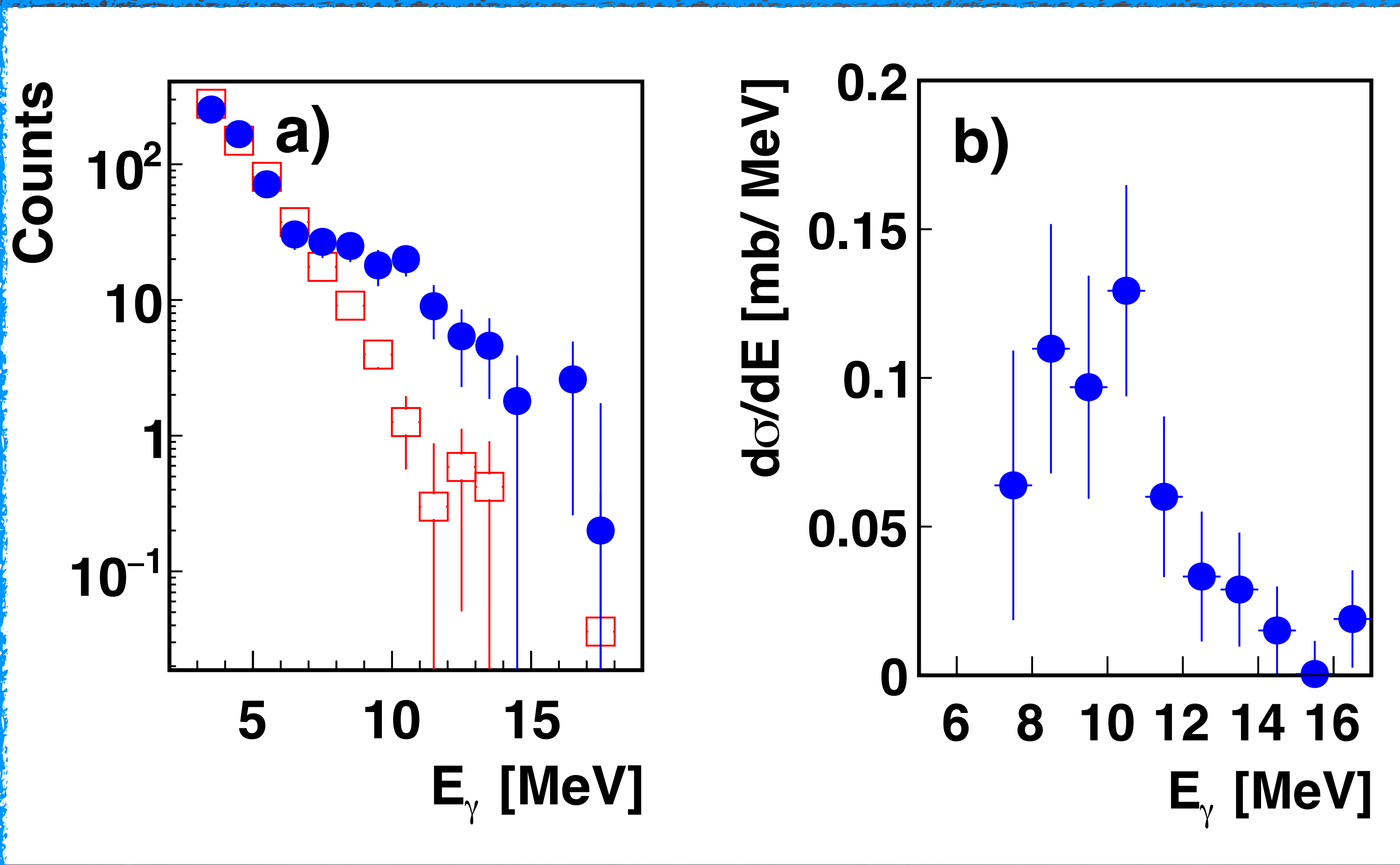
Measurement of PDR in unstable nucleus (^{68}Ni) via isoscalar probe at LNS Catania

$^{68}Ni + {}^{12}C$ @ 28 A·MeV

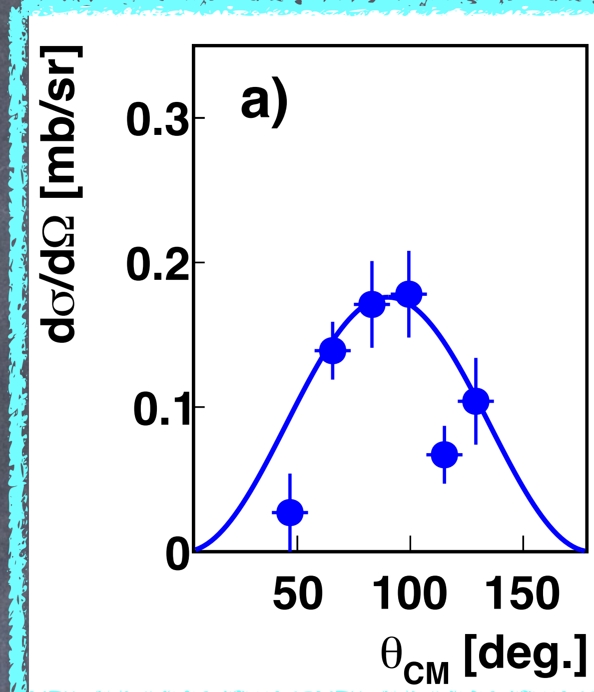
Semiclassical calculations: RPA transition densities, form factors build up with the double folding procedure



The γ-decay of the pygmy resonance, in coincidence with the ^{68}Ni isotope, has been measured using the CsI of the CHIMERA detector.



γ-ray angular distribution for E1

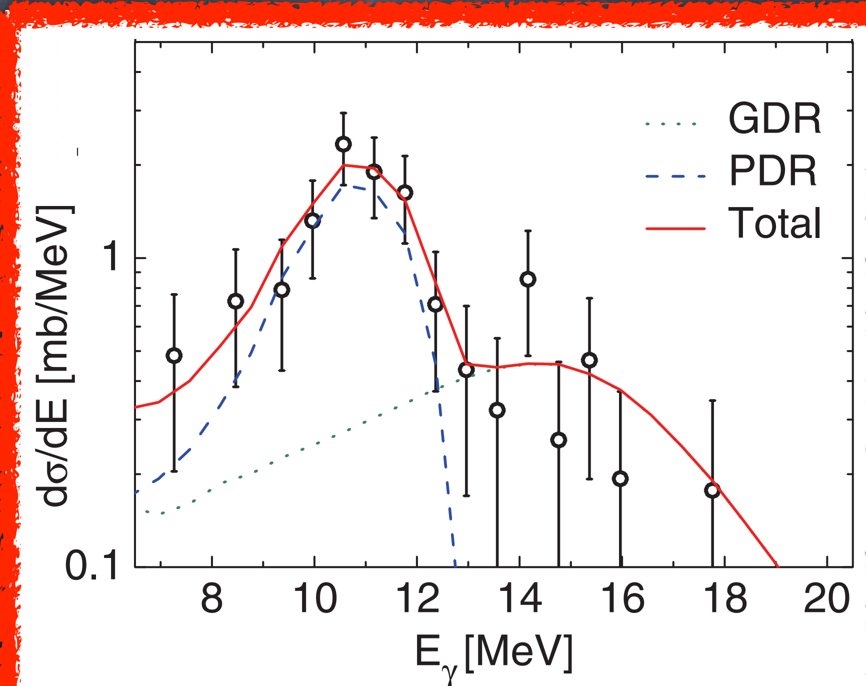


Apparently there is no splitting for the PDR above the neutron threshold emission. Due to the small statistic and relative scarce energy resolution, this is not a definite conclusion.

^{68}Ni + Au @ 600 A MeV

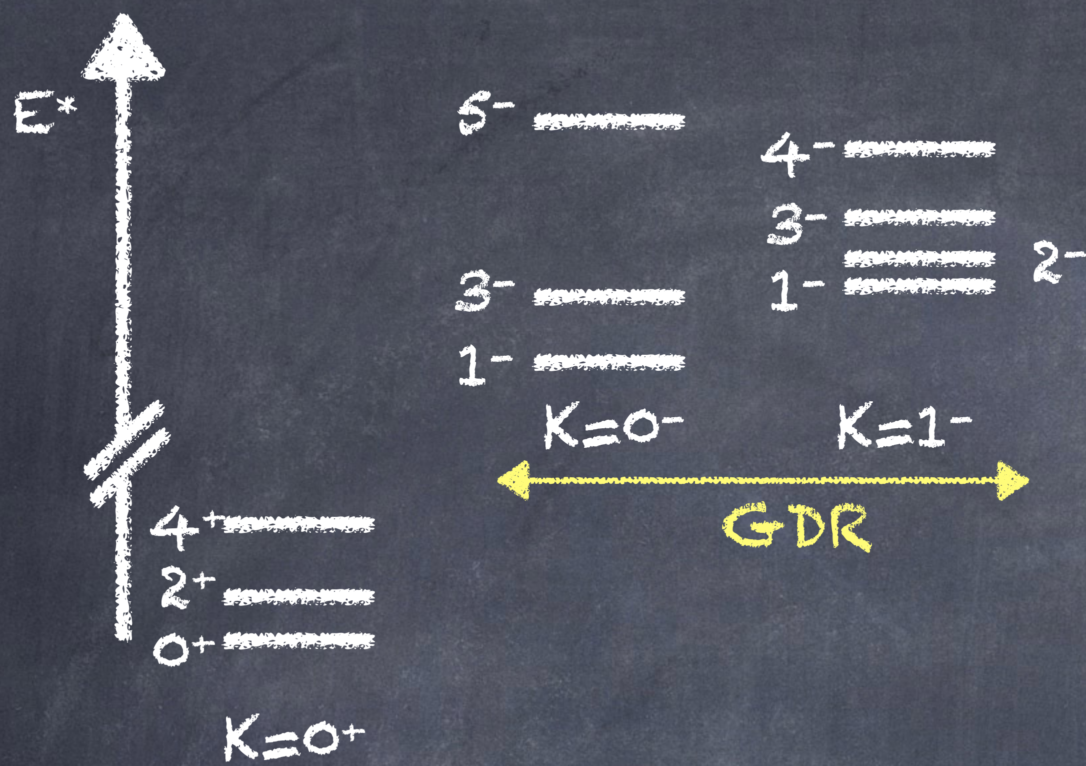
O. Wieland et al.

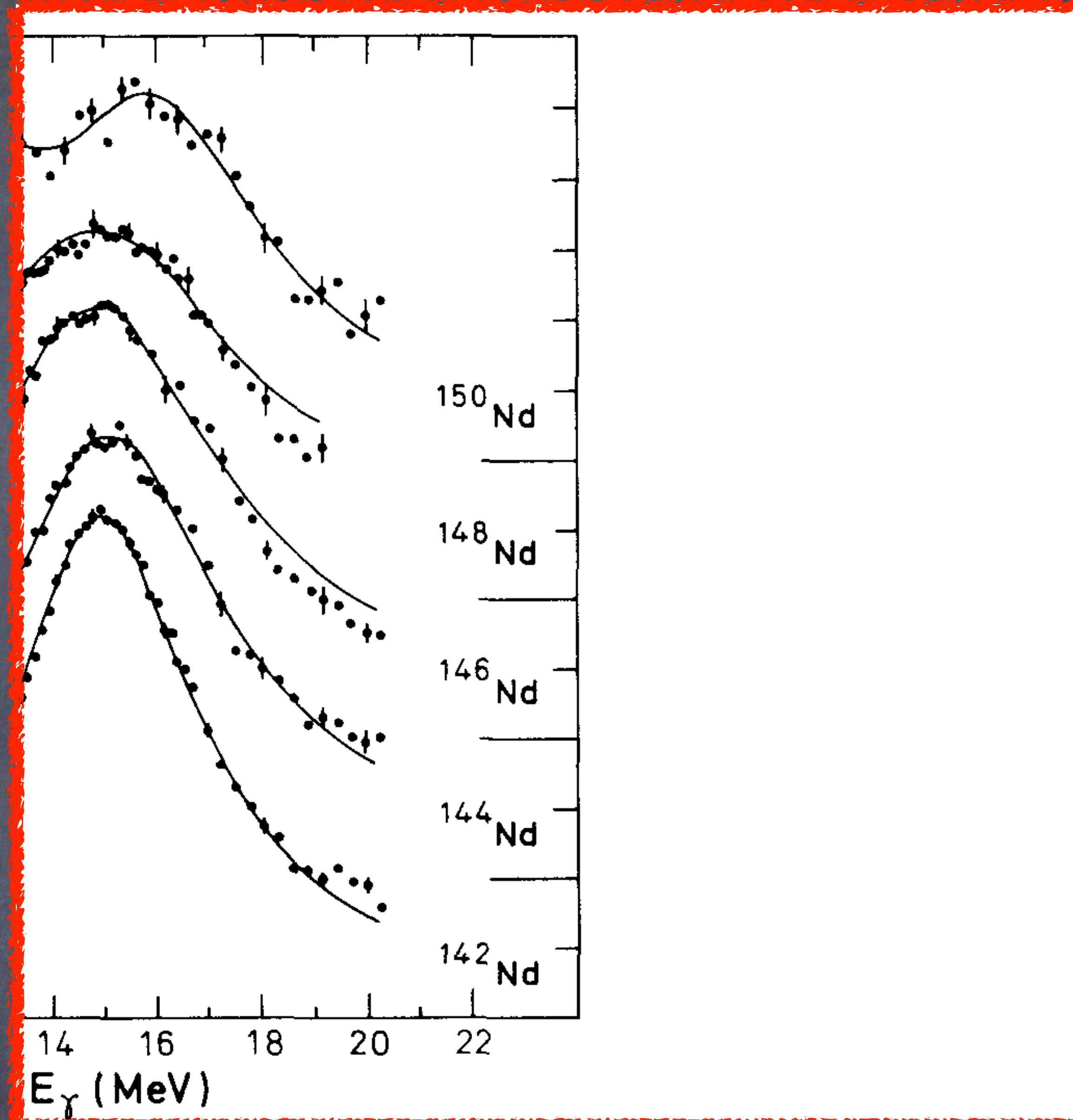
PRL 102 (2009) 092502



The use of an isoscalar probe for studying the Pygmy Dipole Resonance has brought to light novel aspects of this mode.

The different response to isoscalar and isovector probes is important also in the study of the pygmy in the deformed nuclei.





B.L. Berman and S.C. Fultz, Rev. Mod. Phys. 47 (1975) 713

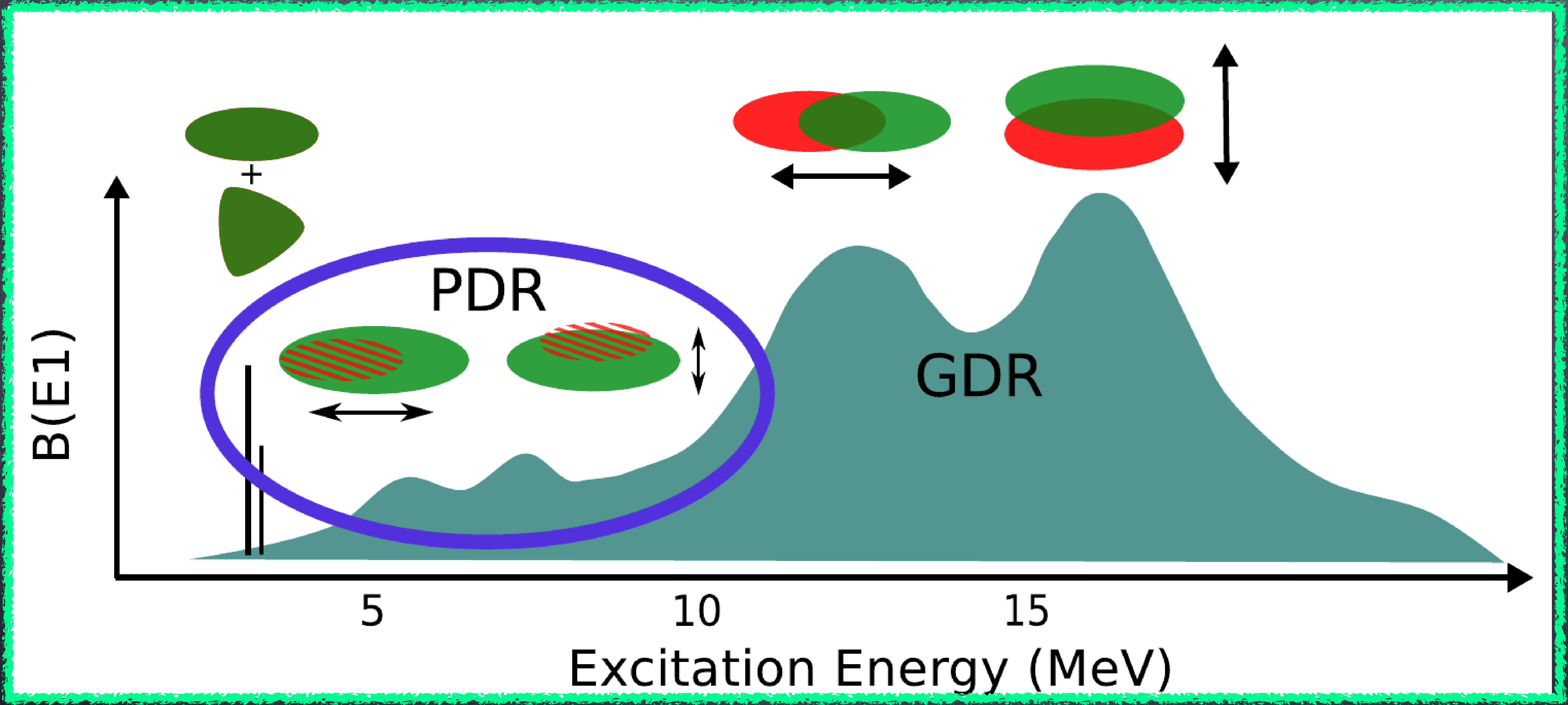
Splitting of the GDR

$$\frac{E_1^{\perp} - E_1^{\parallel}}{E_1} = \frac{R^{\parallel} - R^{\perp}}{R_0} = 0.95\,\beta$$

Bohr and Mottelson book

M. Danos, Nucl. Phys. A 5 (1958) 23
K. Okamoto, Phys. Rev. 111 (1958) 143

Furthermore one may wonder whether we can see a separation of the pygmy peak as it occurs in the case of the GDR one.



A. Krugmann, Thesis (2014), TU-Darmstadt,

Microscopic description of deformed nuclei

Self-consistent HFB-QRPA to describe simultaneously the effects of nuclear deformation and pairing correlations:

* S. Péru and H. Goutte, Phys. Rev. C 77, 044313 (2008) with the D1S Gogny effective force

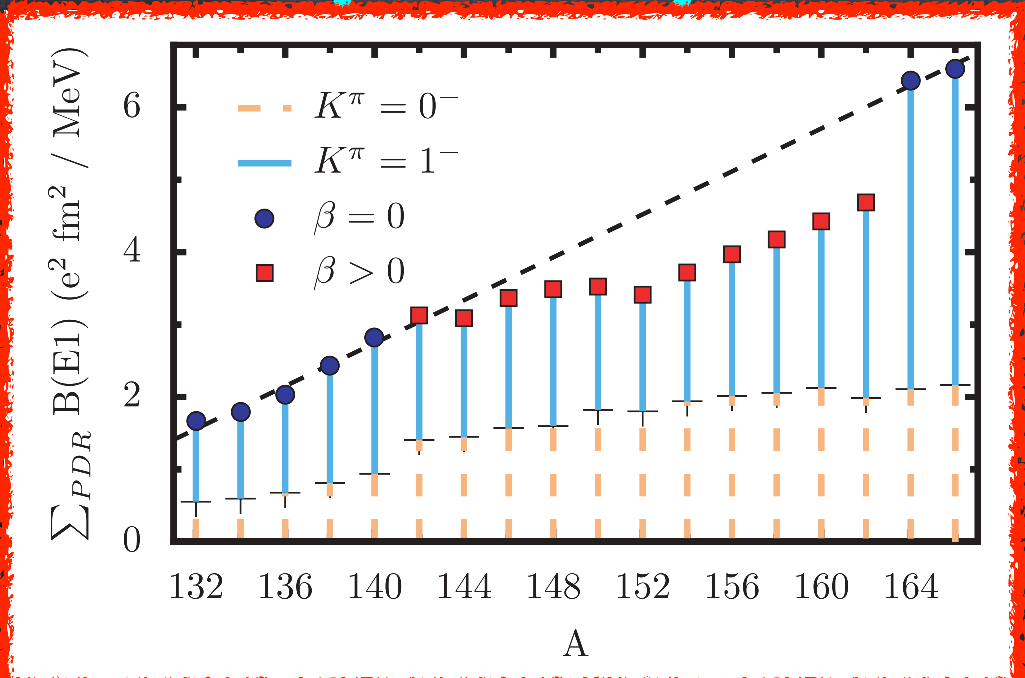
* K. Yoshida and N. Van Giai, Phys. Rev. C 78, 064316 (2008) with Skyrme interaction

Microscopic description of PDR in deformed nuclei

* D. Peña Arteaga, E. Khan and P. Ring, PRC 79, 034311 (2009).

Systematic study of the PDR for several tin isotopes within a relativistic Hartree-Bogoliubov (RHB) mean field plus a relativistic QRPA microscopic calculations.

They conclude that the deformation quenches the isovector dipole response in the low-lying energy region.



Neutron rich deformed nuclei may not be good candidates for the study of PDR states

* K. Yoshida and T. Nakatsukasa, PRC 83, 021304(R) (2011).

On the contrary, calculations performed within an HFB plus QRPA with Skyrme interactions for Nd and Sm isotopes, show an enhancement of the summed low lying dipole strength of about five times larger than those corresponding to spherical nuclei.

The two calculations use:

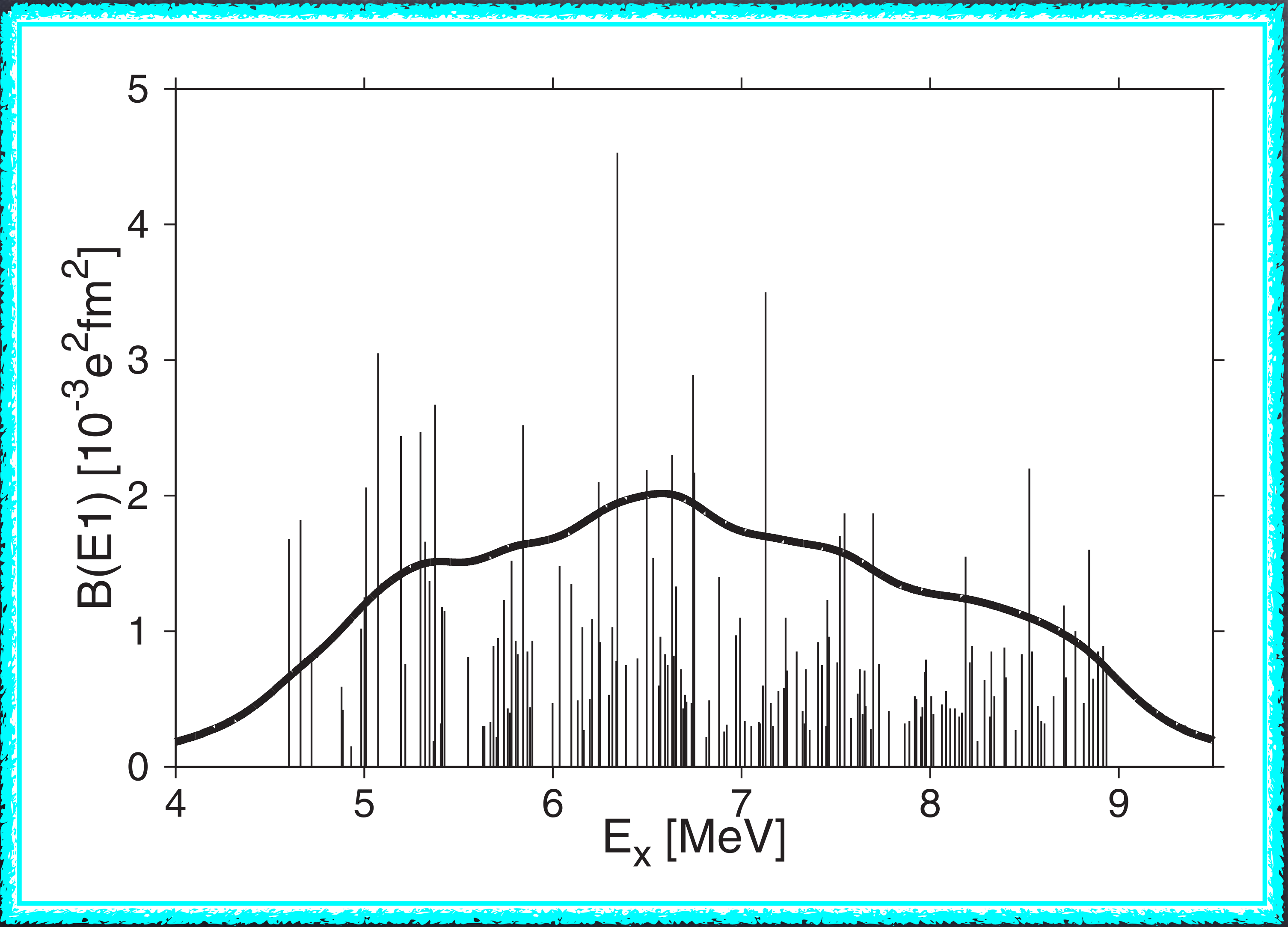
- different treatments for the pairing.
- Different use of the treatment of continuum and weakly bound orbitals.
- The calculations of Peña et al. are fully self-consistent, and they do not have the contamination of the spurious center-of-mass motion.

experimental work for pygmy dipole resonances in deformed nuclei

* P. M. Goddard et al., PRC 88, 064308 (2013).

Polarised $(\vec{\gamma}, \gamma')$ on ^{76}Se (relatively small neutron excess)

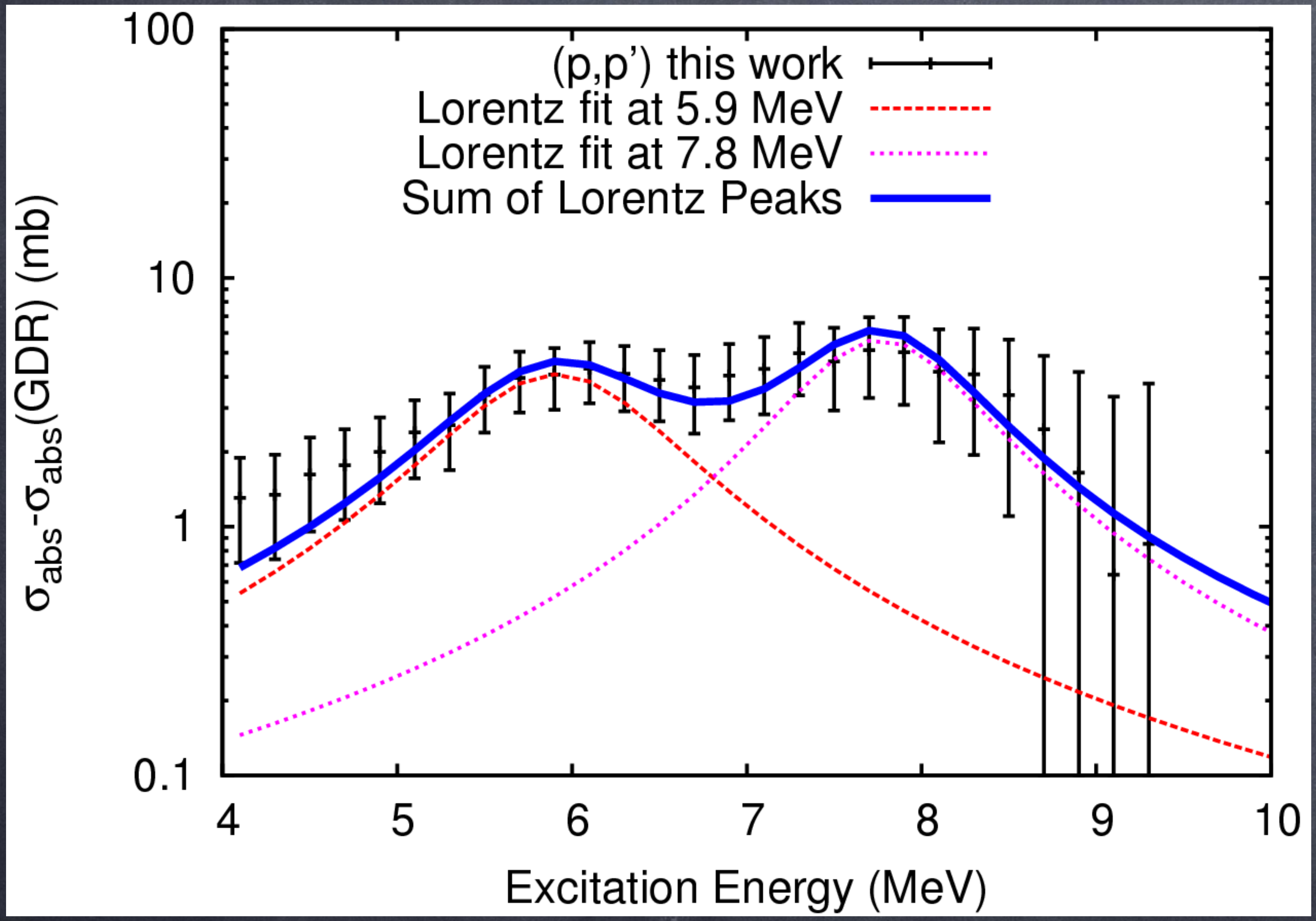
It is known that the GDR is split into two peaks



Observed many 1^- states between 4 and 9 MeV.

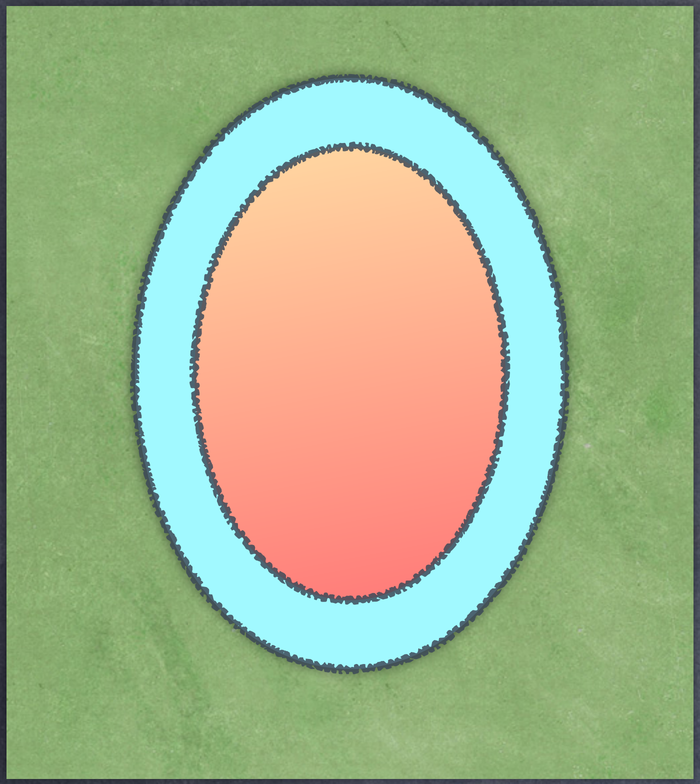
A pronounced splitting, as seen in the GDR ,is not evident

A. Krugmann, Thesis (2014), TU-Darmstadt



Experiment done at RNCP, Osaka, with polarized proton on a deformed nucleus ^{154}Sm at very forward angles

Pygmy for deformed nuclei



Fermi distribution with axially symmetric deformed surface with different geometries

$$\rho_p(r,\theta) = \frac{\rho_{0p}}{1+exp\{[r-R_{0p}(1+\beta_p Y_{20}(\theta)]/a_p\}}$$

$$\rho_n(r,\theta) = \frac{\rho_{0n}}{1+exp\{[r-R_{0n}(1+\beta_n Y_{20}(\theta)]/a_n\}}$$

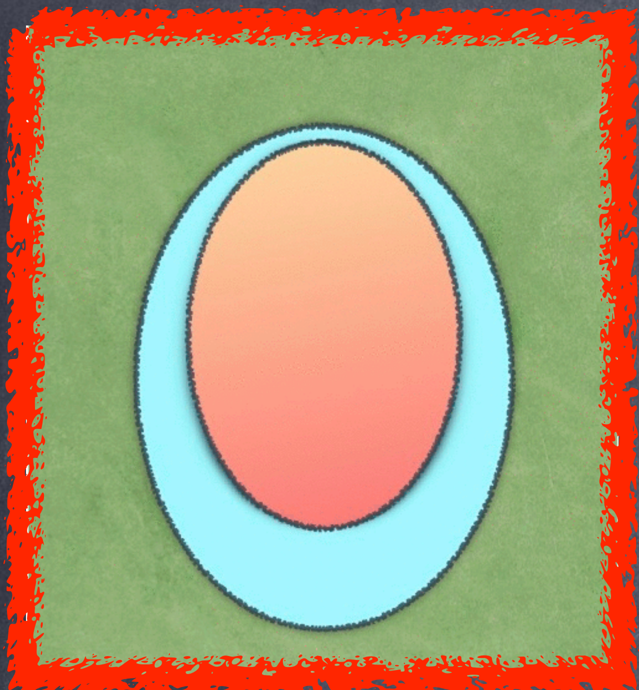
Assume $N=N^c+N^v$

$$\rho(r,\theta) = \rho_p(r,\theta) + \rho_n^c(r,\theta) + \rho_n^v(r,\theta)$$

Assume $N^c=Z$ then $\rho_n^c(r,\theta) = \rho_p(r,\theta)$

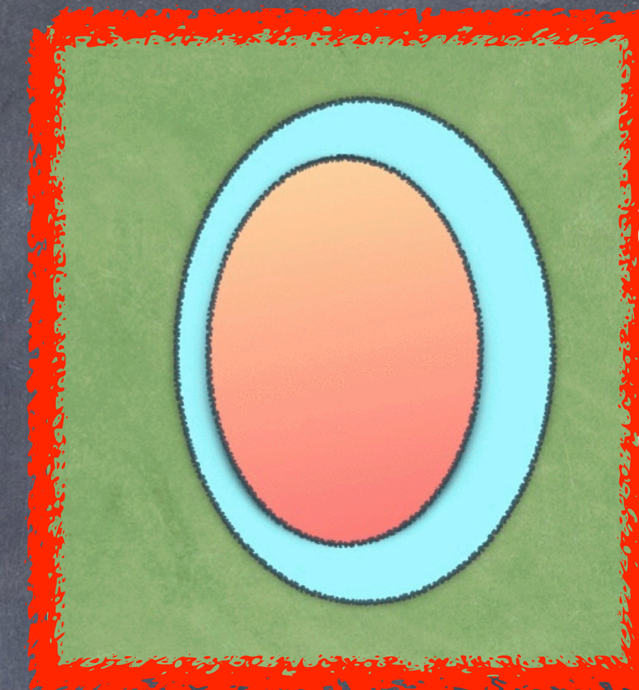
Pygmy for deformed nuclei

$K^{\pi}=0^{-}$



The "intrinsic" isovector transition densities to the intrinsic $K^{\pi}=0^{-}$ and $K^{\pi}=1^{-}$ states will be given within the Goldhaber-Teller model

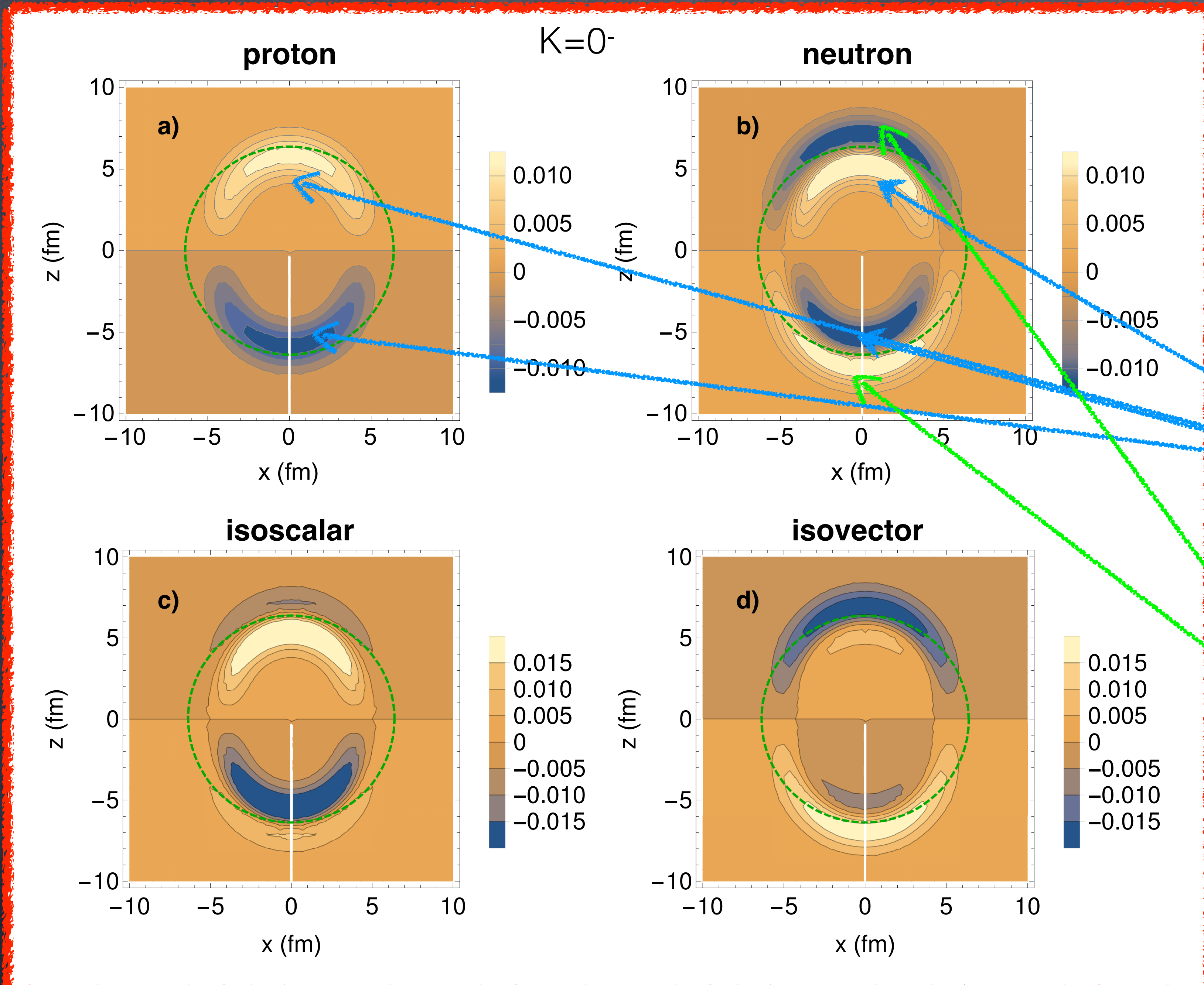
$K^{\pi}=1^{-}$



$$\delta\rho_p^{K^\pi}(r,\theta,\phi) = \delta_1\big[-\frac{2N^v}{A}\frac{d}{dr}\rho_p(r,\theta,\phi)\big]Y_{1,K}(\theta,\phi)$$

$$\delta\rho_n^{K^\pi}(r,\theta,\phi) = \delta_1\big[-\frac{2N^v}{A}\frac{d}{dr}\rho_n^c(r,\theta,\phi) + \frac{2(Z+N^c)}{A}\frac{d}{dr}\rho_n^v(r,\theta,\phi)\big]Y_{1,K}(\theta,\phi)$$

$Z=N^c=50$, $N=100$, $R_{0p}=4.89$ fm, $R_{0n}=5.52$ fm, $a_{0p}=a_{0n}=0.6$ fm,



$K^{\pi}=0^{-}$

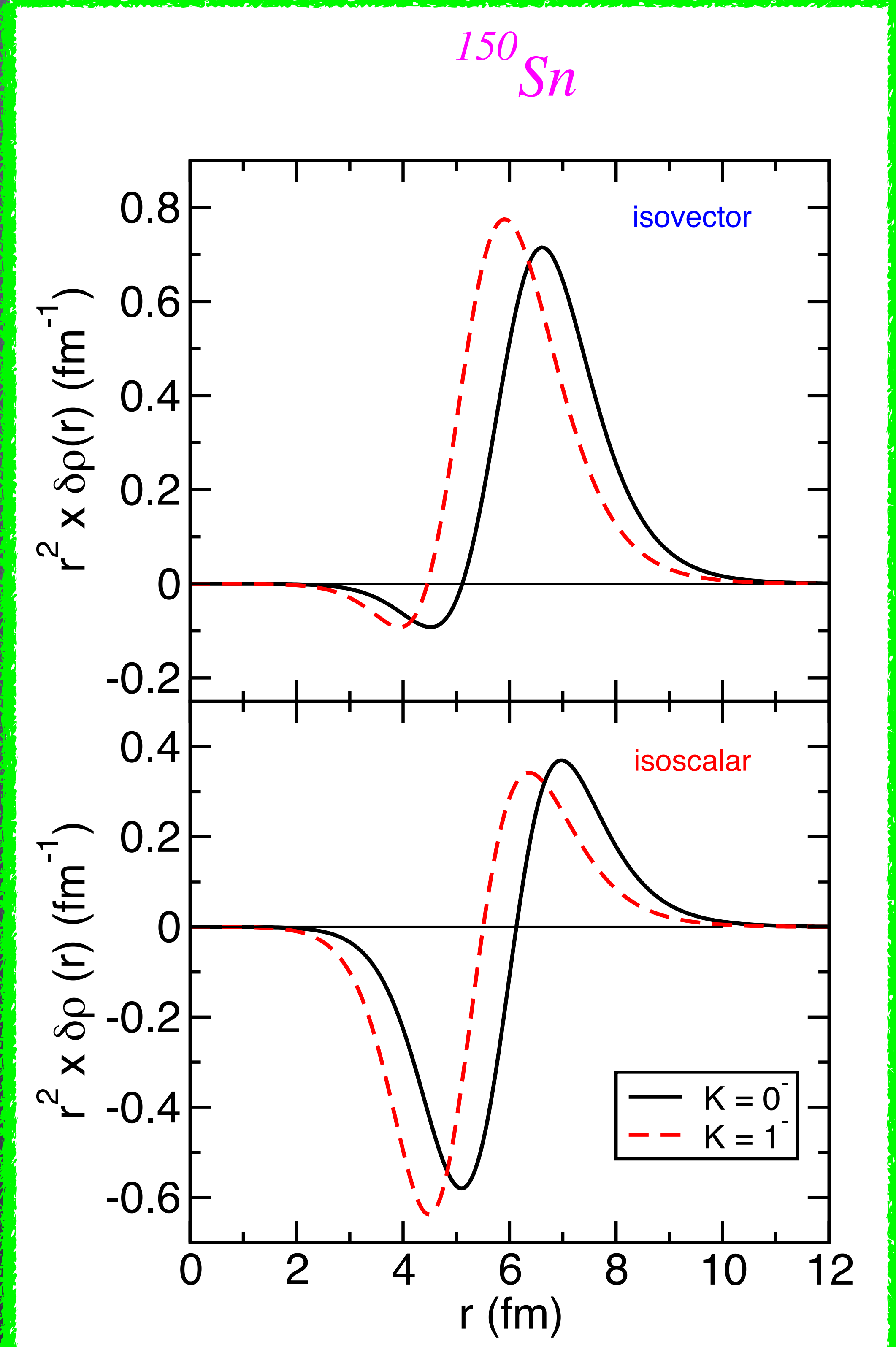
$\beta_p=\beta_n=0.31$

In the interior of the nucleus, protons and neutrons are in phase (same color)

At the surface only the neutrons give a contribution

The radial transition densities are obtained by expanding the intrinsic transition densities in spherical harmonics

Like in the spherical case, for the PDR there is a strong contribution of the isoscalar transition density at the nuclear surface



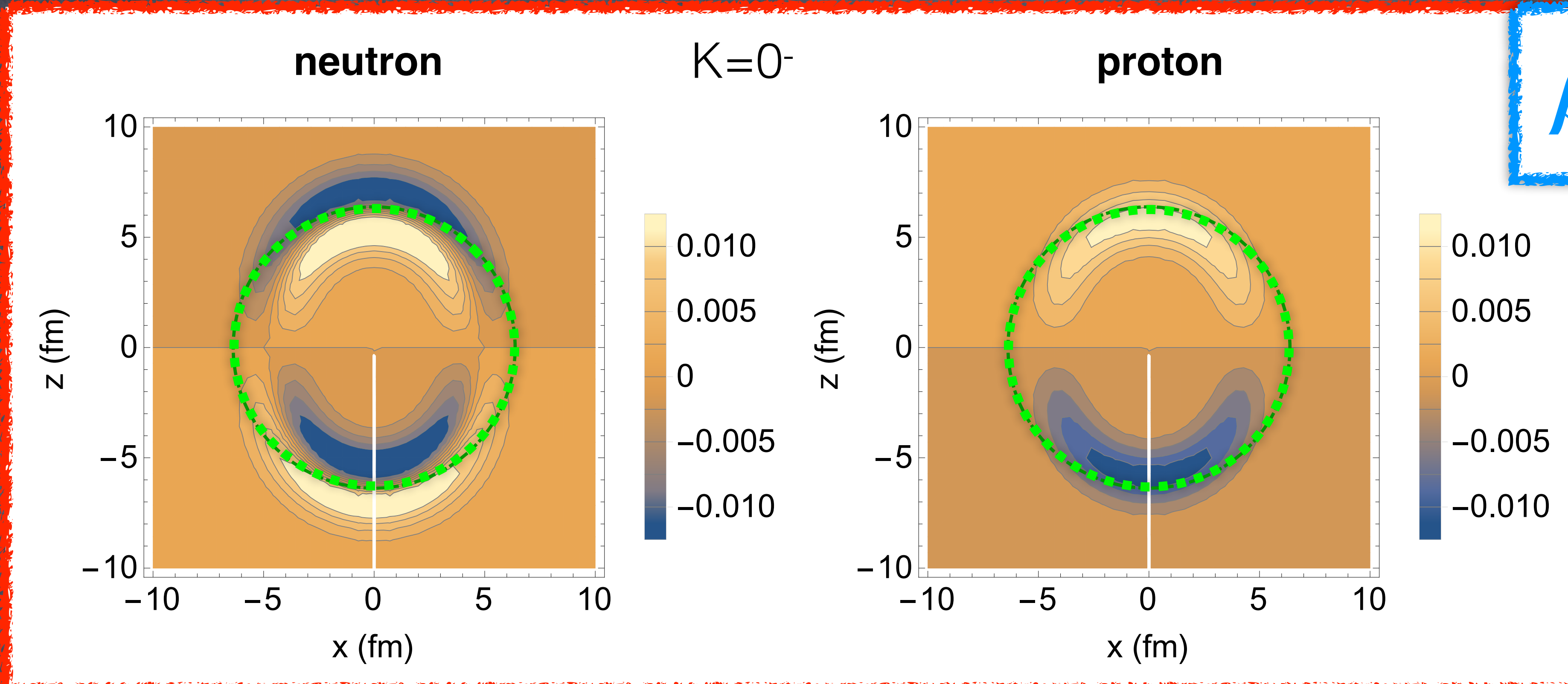
Isoscalar and isovector reduced dipole transition probabilities

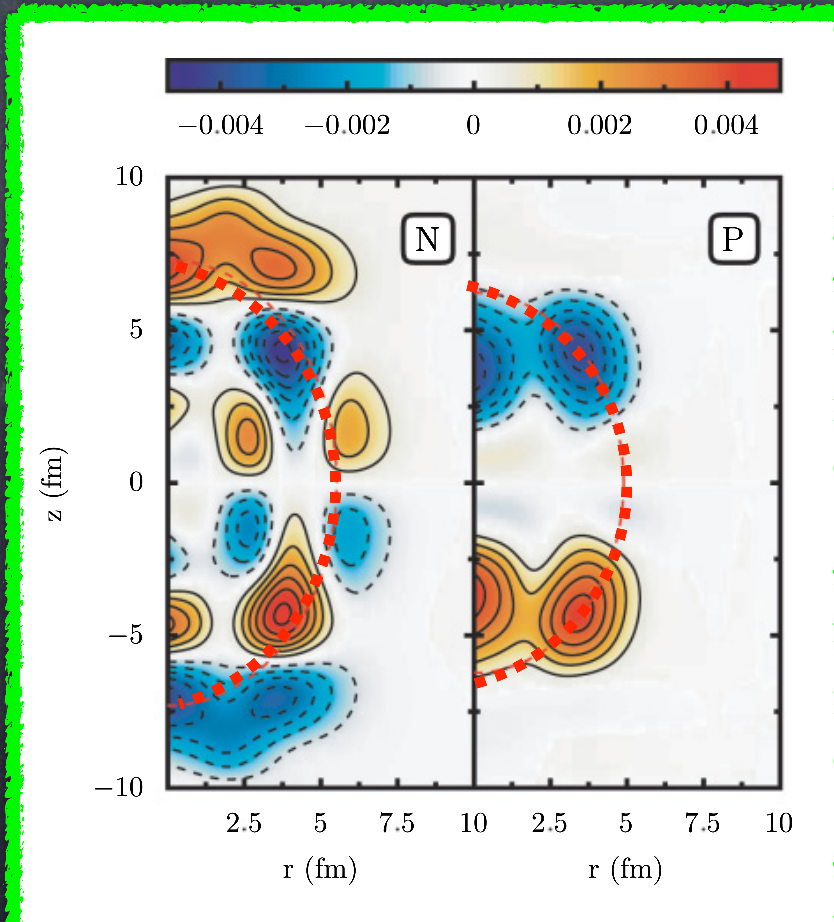
$$B_K^{IS}(E1) \propto \left| \int_0^\infty \delta\rho_{IS}^K(r)\, r^5\, dr \right|^2$$

$$B_K^{IV}(E1) \propto \left| \int_0^\infty \delta\rho_{IV}^K(r)\, r^3\, dr \right|^2$$

$Z=N^c=50$, $N=100$, $R_{0p}=4.89$ fm, $R_{0n}=5.52$ fm, $a_{0p}=a_{0n}=0.6$ fm,

$\beta_p=\beta_n=0.31$





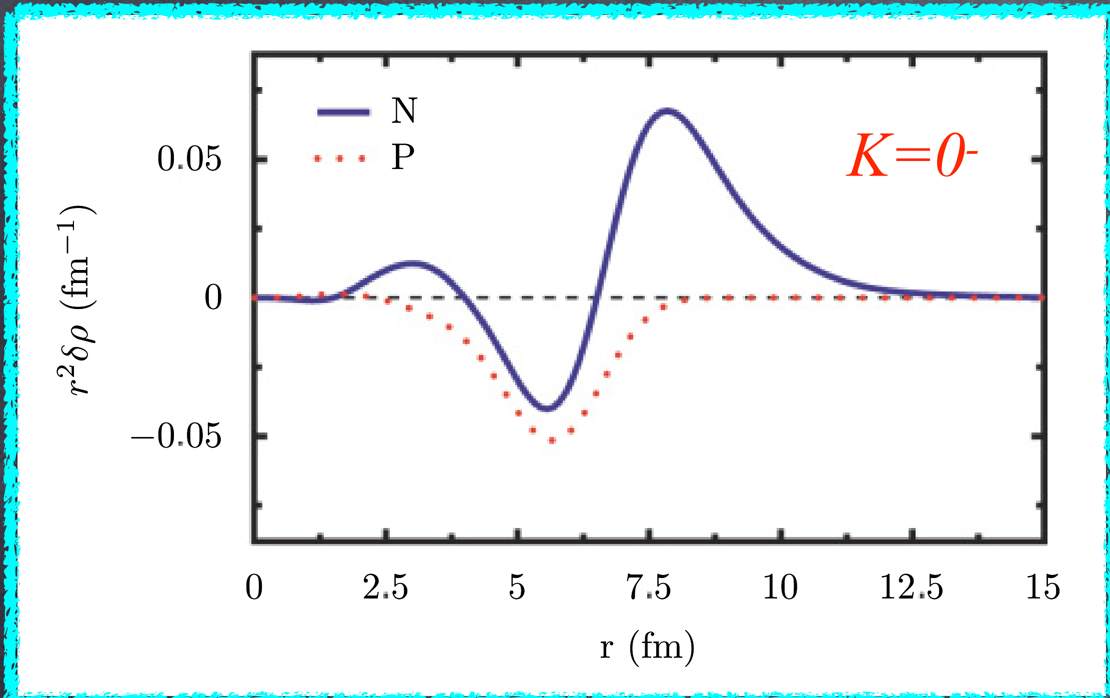
Calculation done within the relativistic QRPA based on a relativistic HFB basis.

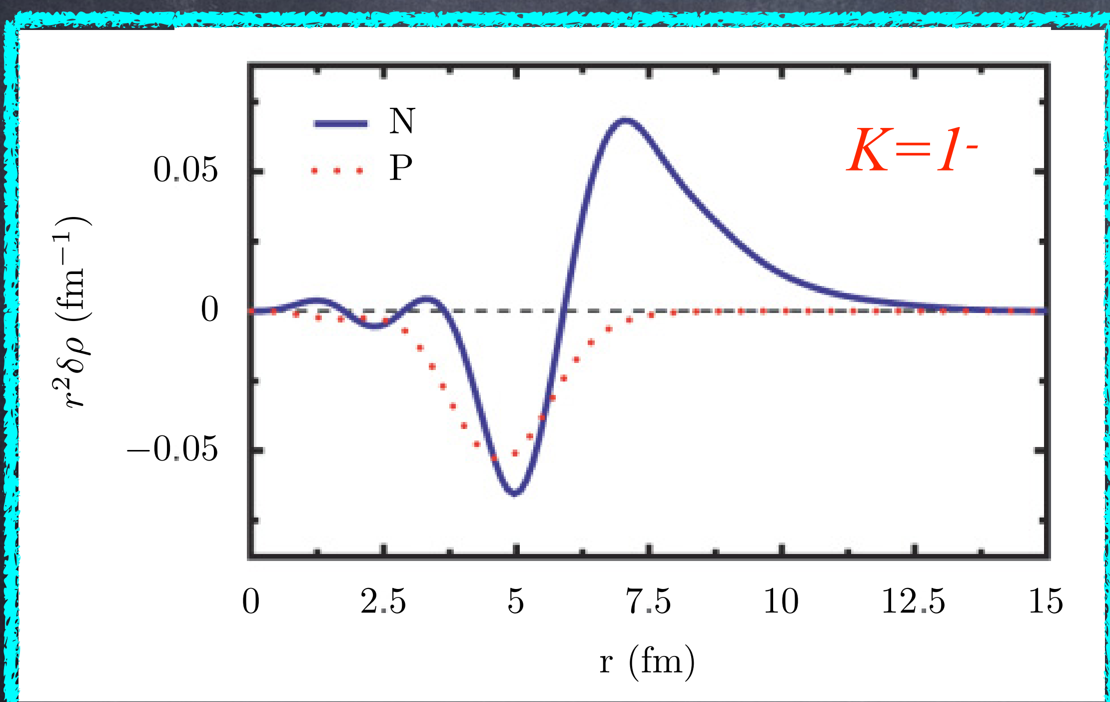
^{150}Sn

$K^{\pi}=0^-$

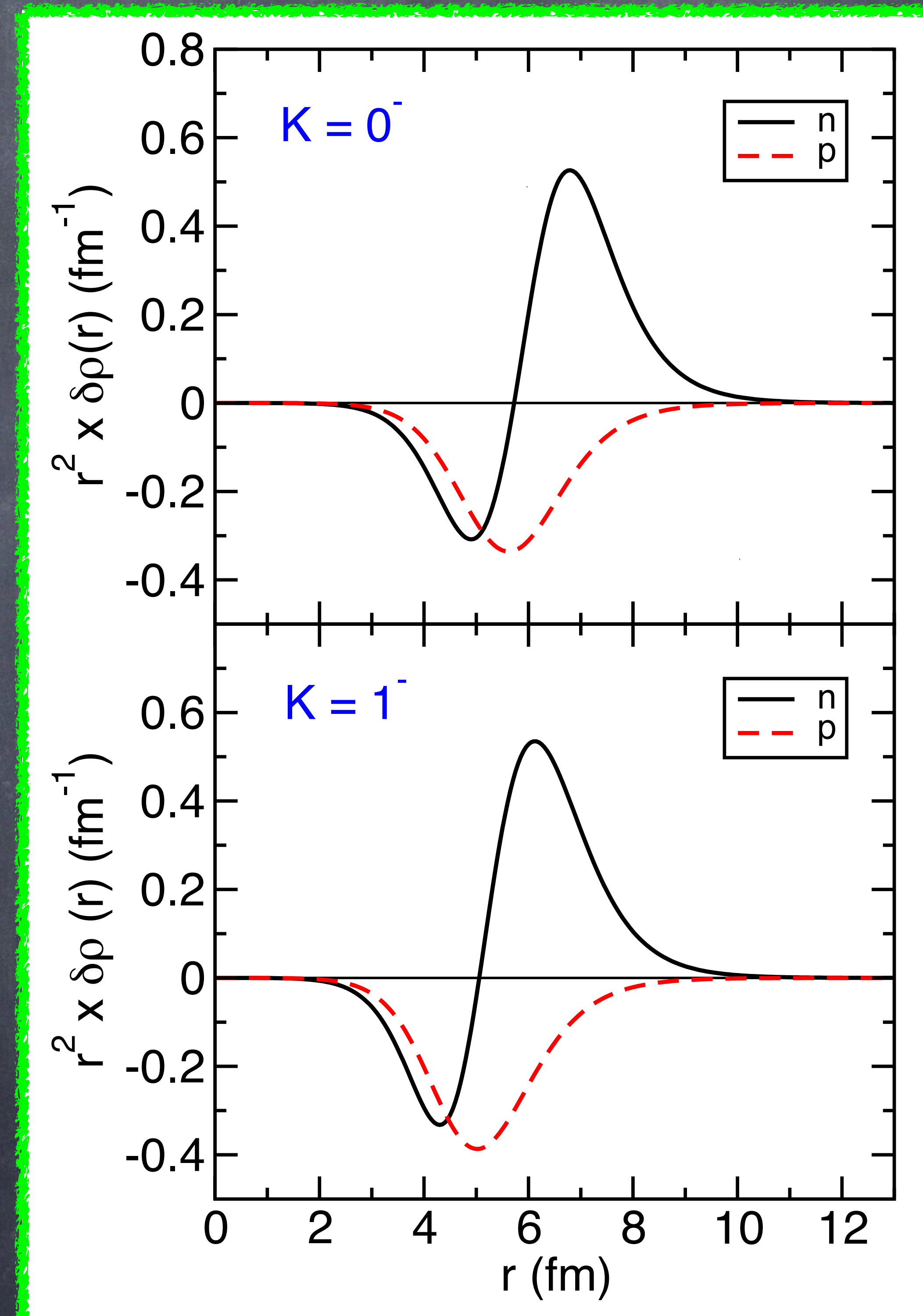
D.Peña Arteaga, E.Khan, P.Ring, PRC 79 (2009) 034311

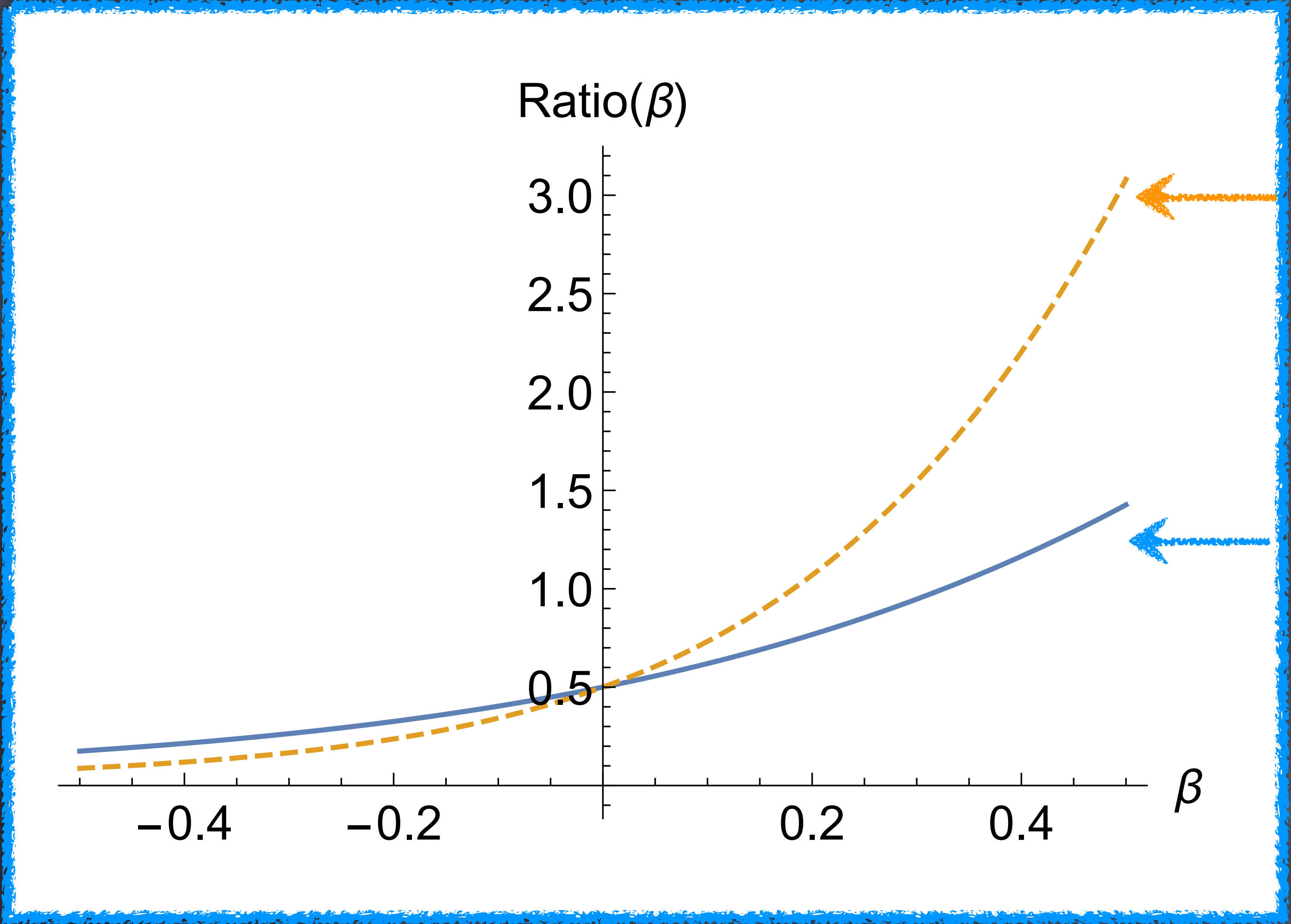
D.Peña Arteaga, E.Khan, P.Ring,
PRC 79 (2009) 034311





^{150}Sn



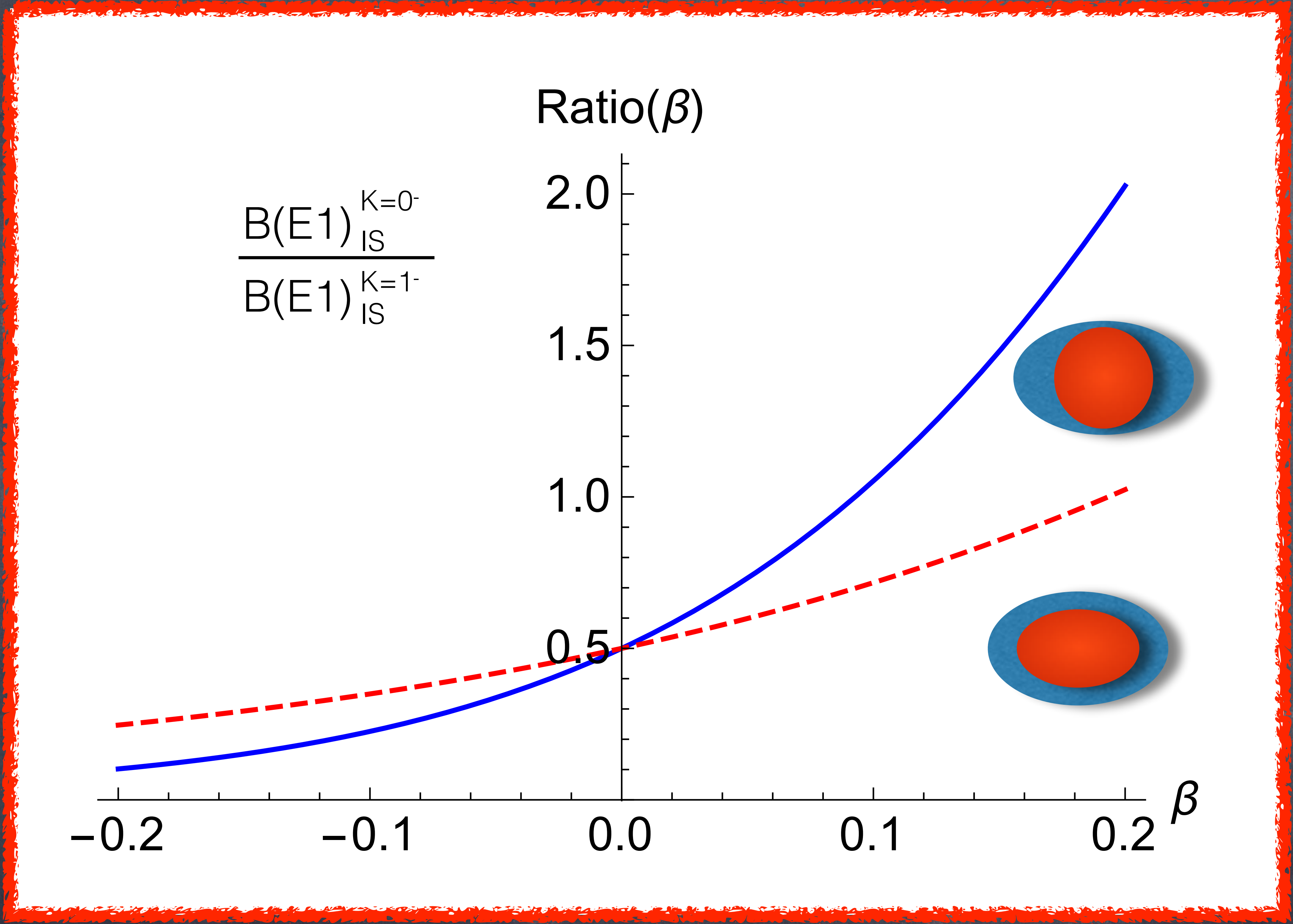


$$D = \frac{B(E1)^{is}_{K=0^-}}{B(E1)^{is}_{K=1^-} + B(E1)^{is}_{K=-1^-}}$$

$$C = \frac{B(E1)^{iv}_{K=0^-}}{B(E1)^{iv}_{K=1^-} + B(E1)^{iv}_{K=-1^-}}$$

As far as the deformation increases the sharing between the two component is more favourable to the oscillation along the longer axis

The variation of the ratio for the isoscalar case is stronger



For the isoscalar response and for prolate nuclei the isoscalar strength distribution reinforces the K = 0 response with respect to the K = 1. This dominance is further enhanced as the core approaches sphericity.

An experiment to measure the PDR in deformed nucleus with isoscalar probes has been performed here at the iThemba LABS

Project PR251, Research Proposal to the PAC of iThemba LABS, South Africa.

Spokeperson: Luna Pellegri

Study of the low-lying 1^- states in the deformed ^{154}Sm nucleus via inelastic scattering of α particles at 120 MeV.

Summary

It is well established that the low-lying dipole states (the Pygmy Dipole Resonance) have a strong isoscalar component.

The use of an isoscalar probe is important for both spherical and deformed nuclei.

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

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Review papers

* N. Paar, D. Vretenar, E. Khan and G. Colo`, Rep. Prog. Phys. 70, 691 (2007).
* T. Aumann and T. Nakamura, Phys. Scr. T152, 014012 (2013)
* D. Savran, T. Aumann and A. Zilges, Prog. Part. Nucl. Phys. 70, 210 (2013).
* A. Bracco, F.C.L. Crespi and E.G. Lanza, Eur. Phys. J. A 51, 99 (2015).