Dipole response in even and odd nuclei: microscopic properties and correlation with the symmetry energy

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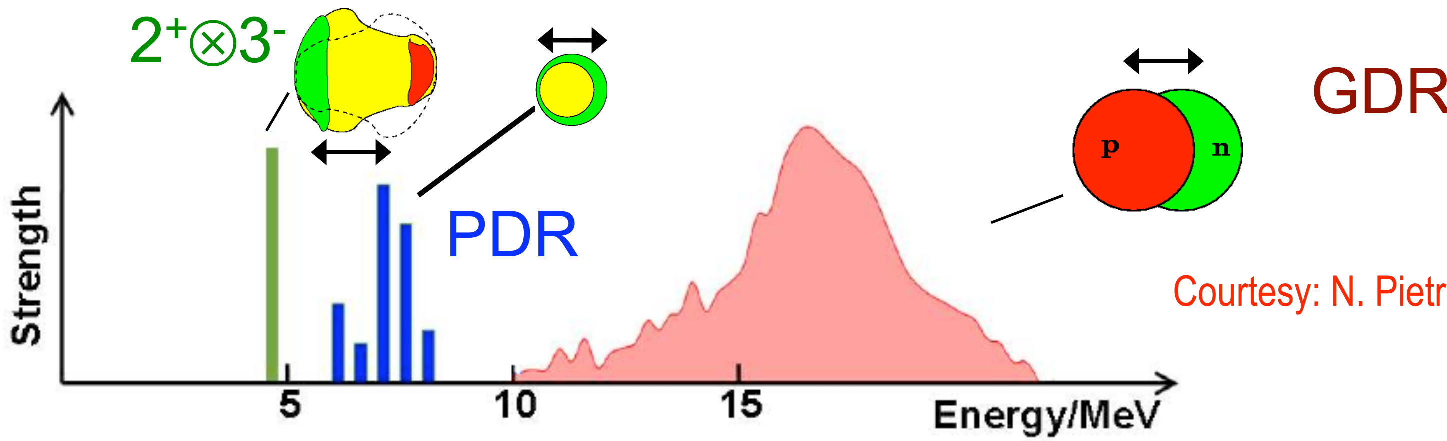
Thank you, Peter, for being very friendly, for stimulating discussions and for appropriate criticisms.

Sincere wishes for all the best in the future !

Outline

- Motivation: nuclear structure and nuclear EoS
- Method: fully self-consistent RPA with Skyrme forces
- The correlation of the GDR with the symmetry energy
- What about the low-lying strength or “PDR” ?
- The nature of the low-lying strength: isoscalar/isovector, surface/bulk, particle-hole structure
- The problem of odd systems

Motivation (I)



Courtesy: N. Pietralla

•In the case of well-bound nuclei the dipole spectrum can display states having quite different nature

•The existence itself of a “pygmy” dipole resonance is under debate

•In any event, it should be clearly distinguished from threshold effects in weakly-bound nuclei

IOP Publishing — Reports on Progress in Physics

Rep. Prog. Phys. 70 (2007) 691–793 — doi:10.1088/0034-4885/70/5/R02

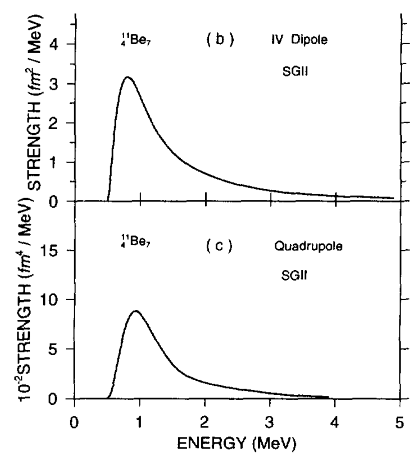
Exotic modes of excitation in atomic nuclei far from stability

Nils Paar[1,2], Dario Vretenar[2], Elias Khan[3] and Gianluca Colò[4]

^{11}Be

$S_n \approx 0.5$ MeV

I. Hamamoto, H. Sagawa, X.Z. Zhang, NPA 648, 243 (1999)



Motivation (II)

- We can expect correlations with the <u>symmetry energy</u>

Giant Dipole Resonance (GDR) – expected (!)

Pygmy Dipole Resonance (PDR) – debated (?)

Two-Phonon excitation ($2^+ \otimes 3^-$) – not expected

- The issue is of interest in keeping with the <u>nuclear EoS</u>

Nuclear matter EOS

Symmetric matter EOS

Symmetry energy S

$$\frac{E}{A}(\rho,\delta) = \frac{E}{A}(\rho,\delta=0) + S(\rho)\,\delta^2$$

where $\delta = (\rho_n - \rho_p)/\rho$.

Large uncertainty on:

$$\begin{aligned} S(\rho_0) &= J \\ S'(\rho_0) &= L/3\rho_0 \\ S''(\rho_0) &= K_{\rm sym}/9\rho_0^2 \end{aligned}$$

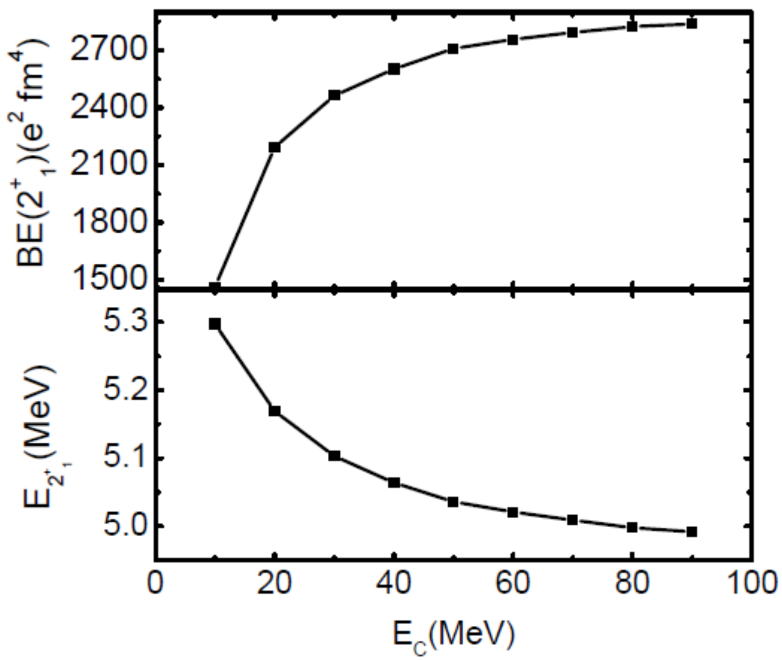
Method: fully self-consistent HF plus RPA

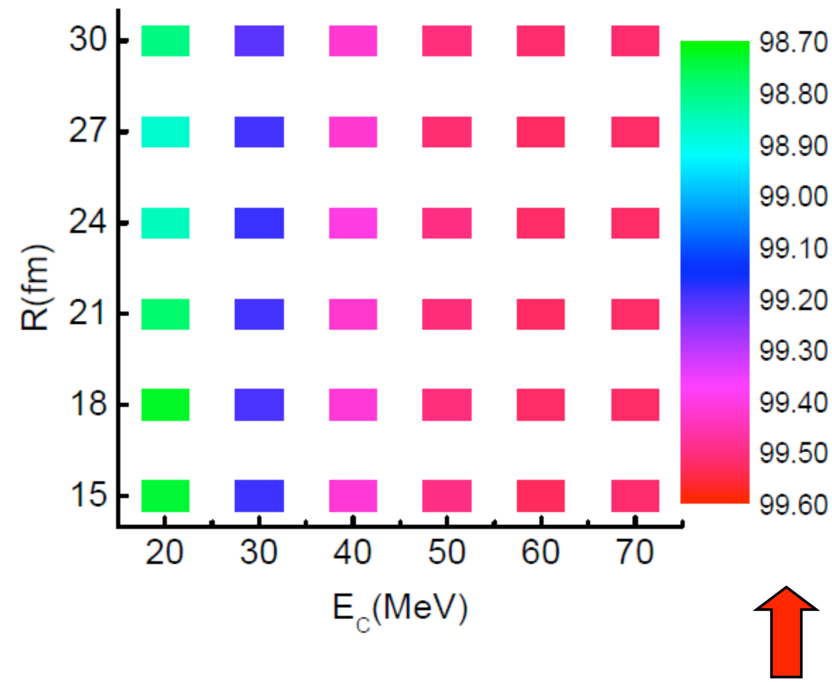
The continuum is discretized. The basis must be large due to the zero-range character of the force.

The energy-weighted sum rule should be equal to the double-commutator value: well fulfilled !

$$m_1(\hat{O}) = \sum_\nu E_\nu |\langle \nu|\hat{O}|\tilde{0}\rangle|^2 = \frac{1}{2}\langle 0|[\hat{O},[H,\hat{O}]]|0\rangle$$

^{208}Pb - SGII





Percentages m_1(RPA)/m_1(DC) [%]

What **precisely** is the GDR correlated with ?

In the case in which the GDR exhausts the whole sum rule, its energy can be deduced following the formulas given by E. Lipparini and S. Stringari [Phys. Rep. 175, 103 (1989)]. Employing a simplified, yet realistic functional they arrive at

$$E_{-1} \equiv \sqrt{\frac{m_1}{m_{-1}}} = \sqrt{\frac{3\hbar^2}{m\langle r^2\rangle}\frac{b_{\rm vol}}{\left[1+\frac{5}{3}\frac{b_{\rm surf}}{b_{\rm vol}}A^{-\frac{1}{3}}\right]}(1+\kappa)}.$$

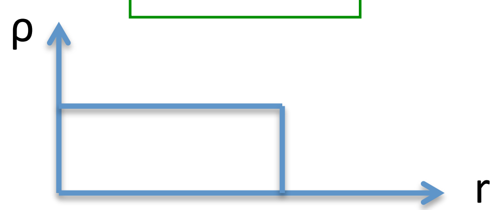
$$\mathrm{EWSR} = \frac{60NZ}{A}(1+\kappa)$$

Cf. also G.C., N. Van Giai, H. Sagawa, PLB 363 (1995) 5.

$$E = \int d^3r\ \mathcal{E}\left[\rho(\vec{r}), \beta(\vec{r})\right],$$

$$\beta = \frac{\rho_n - \rho_p}{\rho}$$

LDA



$$E \sim \int d^3r\ \rho S(\rho)\beta^2$$

$$\hbar\omega_{\rm GDR} \sim \sqrt{\frac{\delta^2 E}{\delta\beta^2}}$$

If there is only volume, the GDR energy should scale as $\sqrt{S(\rho_0)}$ which is $\sqrt{J}$ or $\sqrt{b_{vol}}$.

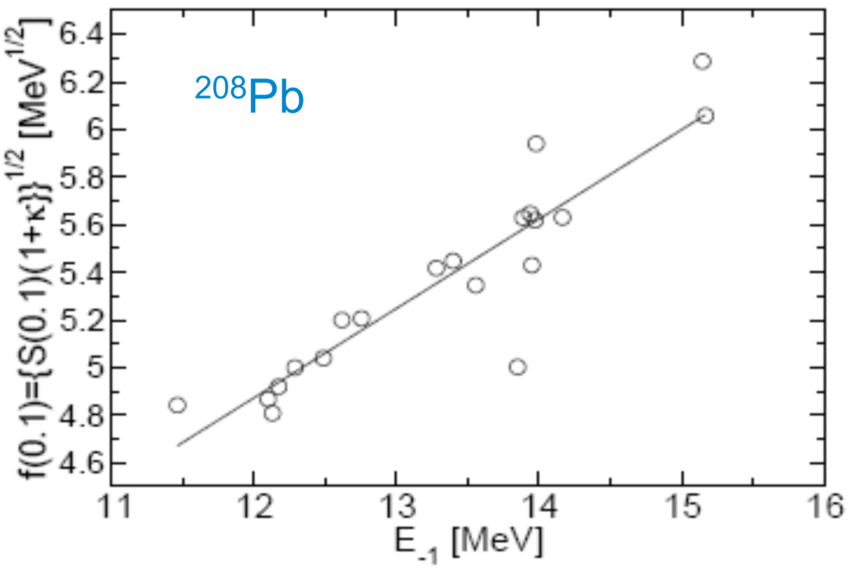
The surface correction may be slightly model-dependent but several results point to $b_{eff} = S(0.1\ \mathrm{fm}^{-3})$! Cf., e.g., talk by Mario Centelles in this workshop.

The Giant Dipole Resonance as a quantitative constraint on the symmetry energy

Luca Trippa, Gianluca Colò and Enrico Vigezzi

Phys. Rev. C77, 061304(R) (2008)

It is assumed that the GDR energy scales with the square root of S at "some" sub-saturation density. The best value comes from χ^2_{min}. It turns out to be 0.1 fm^{-3}.

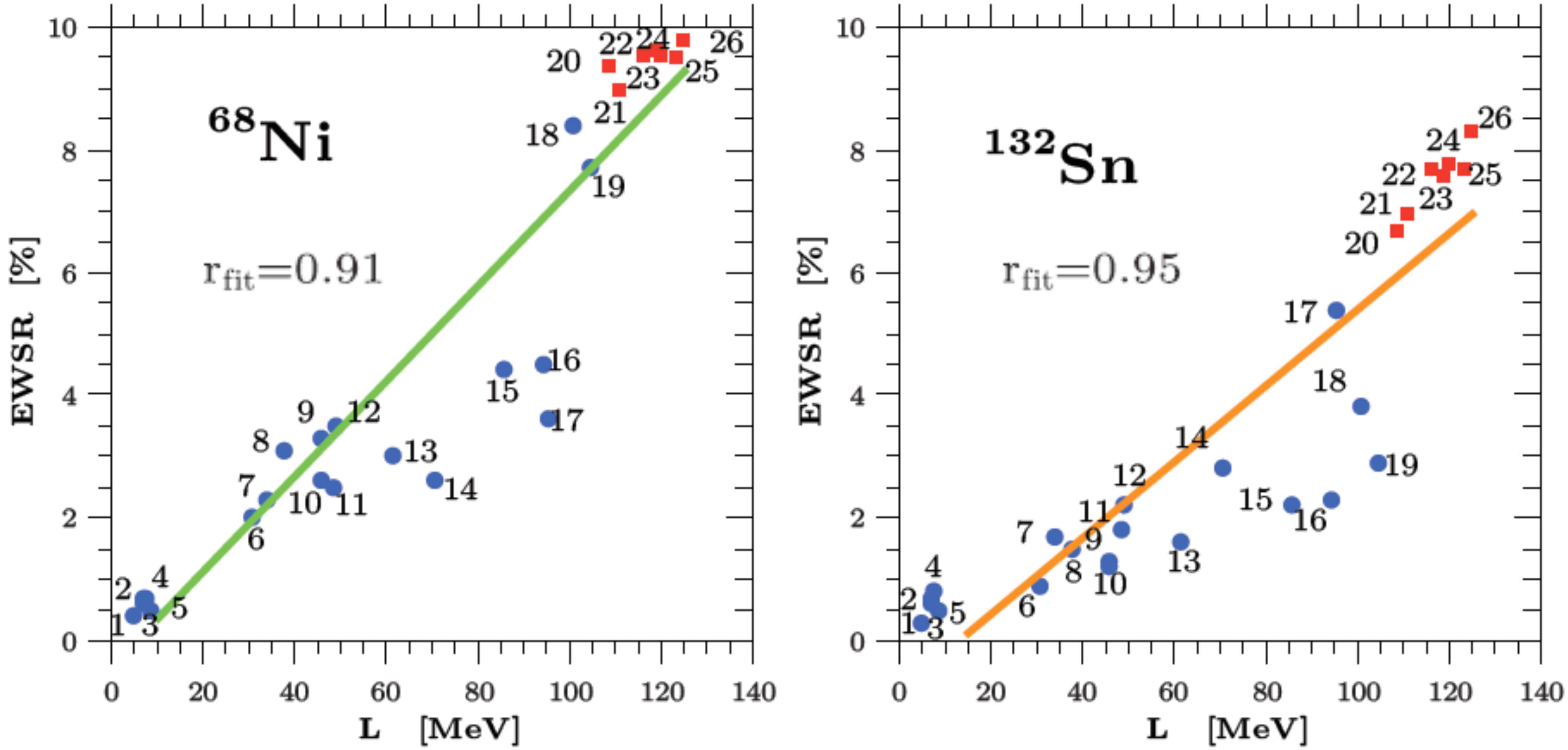


- x-axis: $E_{\rm GDR}$ from RPA;
- y-axis: $\left[S(\rho = 0.1 \text{ fm}^{-3})(1+\kappa)\right]^{1/2}$; κ is the enhancement factor.

23.3 < S(0.1) < 24.9 MeV

This result, namely 24.1 ± 0.8 MeV is based on an estimate of κ. Most of the error is coming from the uncertainty on this quantity.

Correlation between L and the PDR (I)



We have used different nuclei and different classes of energy functionals. Blue=Skyrme; red=RMF.

PHYSICAL REVIEW C **81**, 041301(R) (2010)

Constraints on the symmetry energy and neutron skins from pygmy resonances in ^{68}Ni and ^{132}Sn

Andrea Carbone,[1] Gianluca Colò,[1,2] Angela Bracco,[1,2] Li-Gang Cao,[1,2,3,4] Pier Francesco Bortignon,[1,2]
Franco Camera,[1,2] and Oliver Wieland[2]

Skyrme forces:

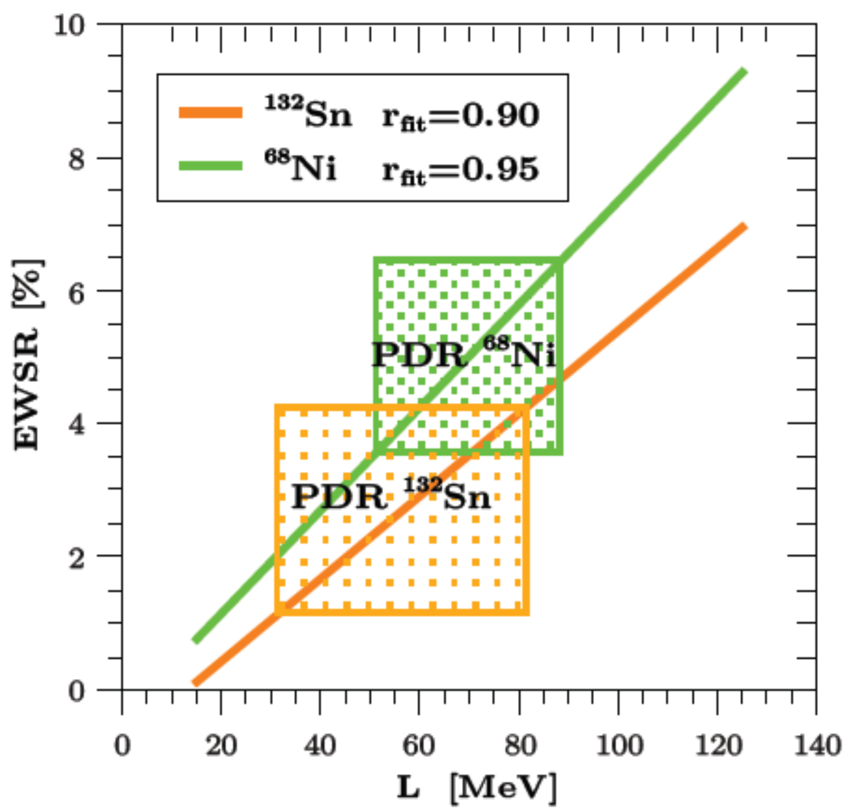
1=v0902, 2=MSk3, 3=BSk1, 4=v110, 5=v100, 6=Tond6, 7=Tond9, 8=SGII, 9=SkM*, 10=SLy4, 11=SLy5, 12=SLy230a, 13=LNS, 14=SkMP, 15=SkRs, 16=SkGs, 17=SK255, 18=SkI3, 19=SkI2

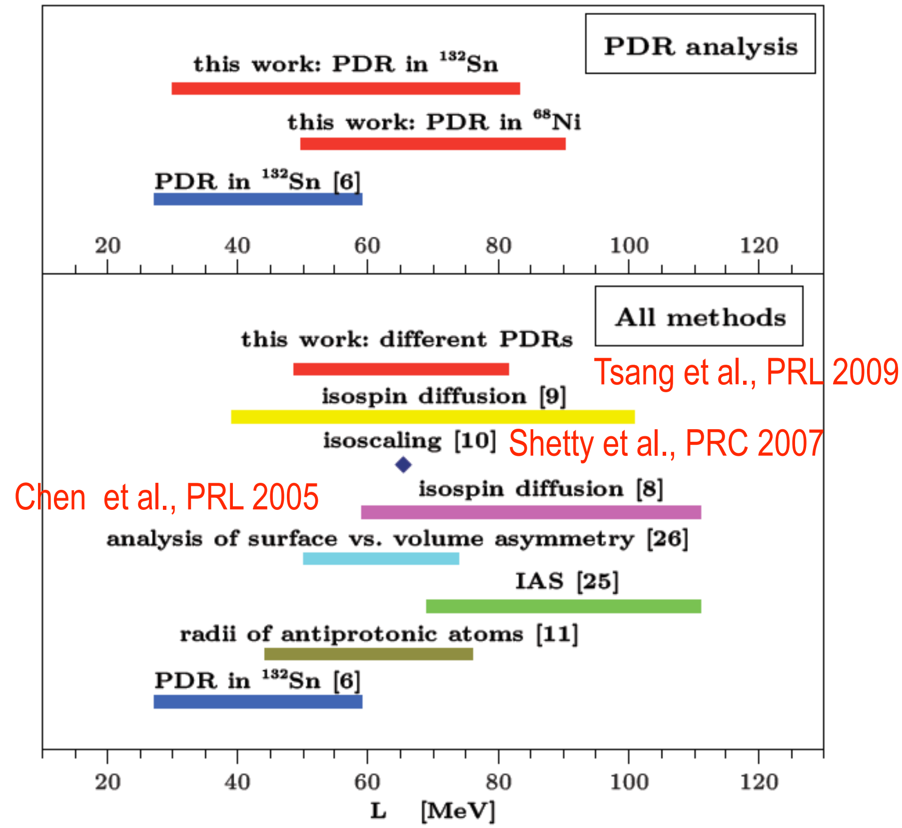
RMF (meson exchange) Lagrangians:

20=NLC, 21=TM1, 22=PK1, 23=NL3, 24=NLBA 25=NL3+ 26=NLE

Correlation between L and the PDR (II)

Exp. values from: O. Wieland *et al.*, PRL 102, 092502 (2009); A. Klimkiewicz *et al.*, PRC 76, 051603(R) (2007).





We deduce the <u>weighted average</u>

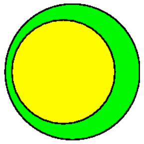
L = 65.1 ± 15.5 MeV

Our extraction of L from the PDR leads to values which are compatible with those extracted from analysis of HI collisions

How do we understand this correlation ?

- There exist macroscopic models that describe the PDR as an oscillation of the “neutron excess” fluid with respect to core – in analogy with the macroscopic models (GT or SJ) for the GDR

Y. Suzuki, K. Ikeda, H. Sato, Prog. Theor. Phys. 83, 180 (1990)



- Then the EWSR of the PDR is proportional to the number of the excess neutrons

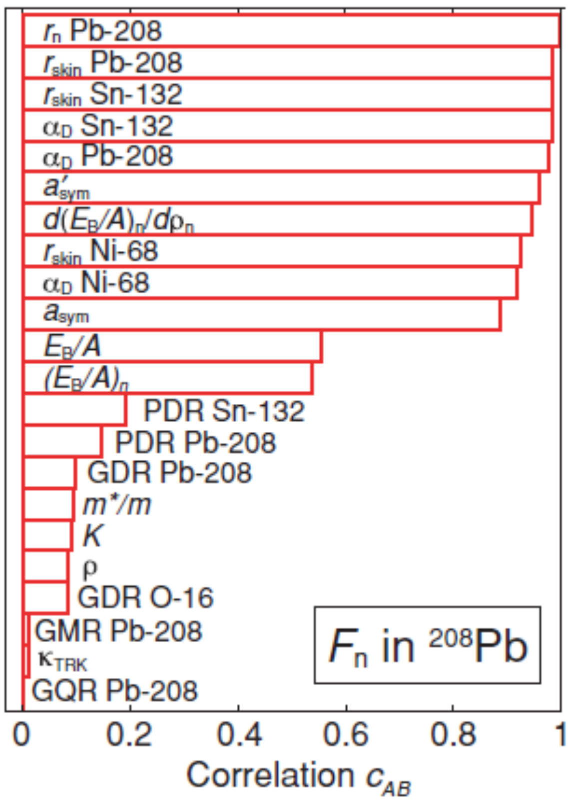
The dipole strength of the PDR is given by [3),5)]

$$=0.857\times\frac{Z(N-N_c)}{N(Z+N_c)}SR\ ,$$

- This may explain the correlation with L (it defines P, the amount of neutron excess or the neutron skin)

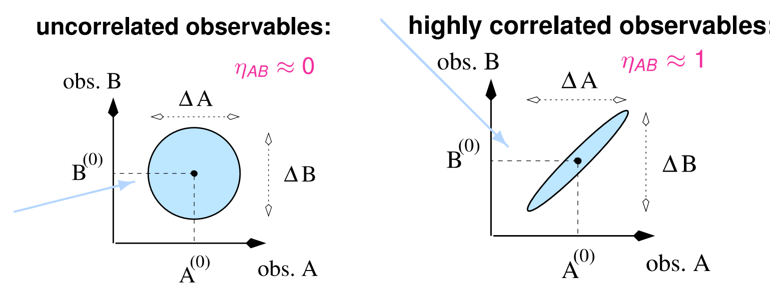
- Are these models realistic enough ?

Claim that the PDR is uncorrelated with the symmetry energy has been made in W. Nazarewicz and P.-G. Reinhard, PRC 81, 051303(R) (2010).



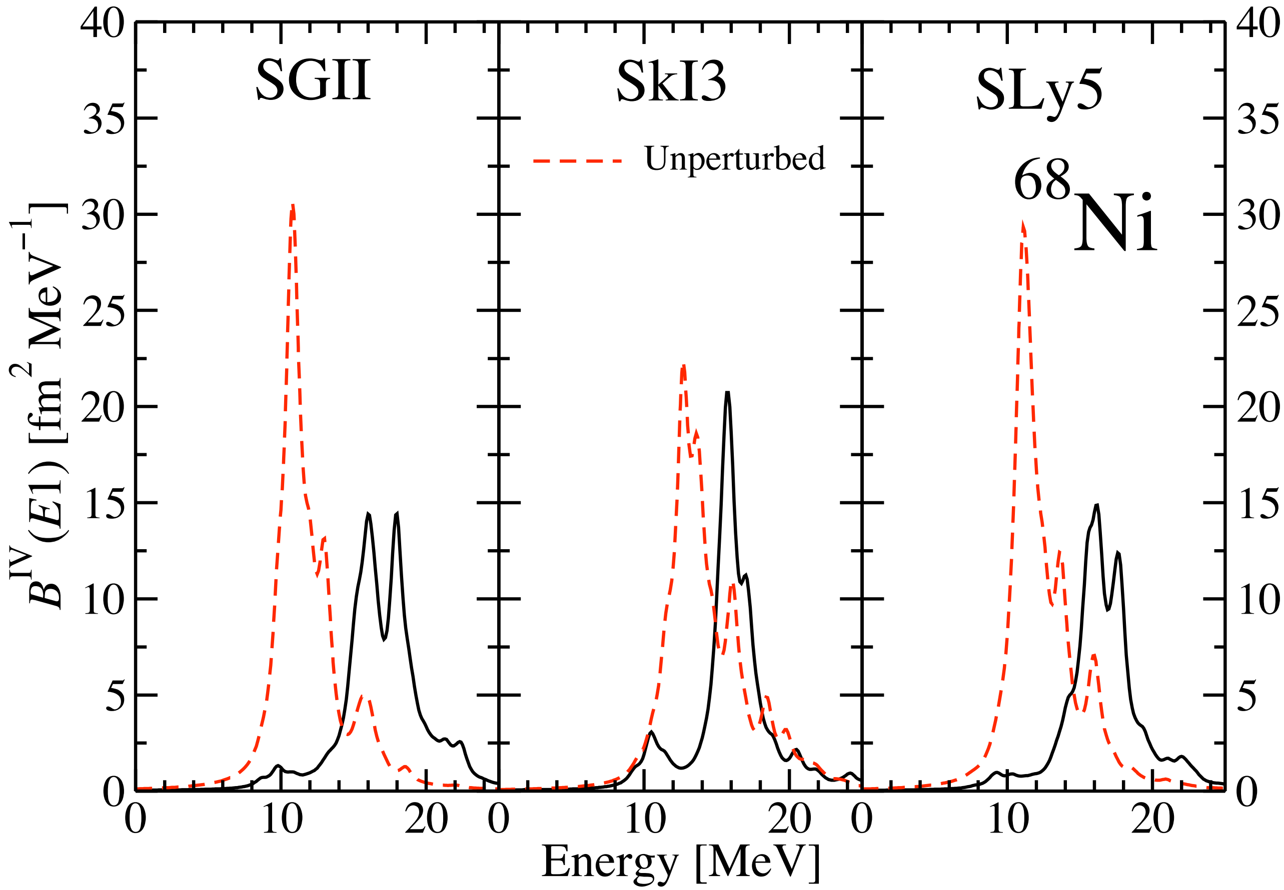
However:

•these are correlations within a single model, not between models



- the specific model (SV-bas) shows low-E RPA strength that is basically equal to the unperturbed p-h

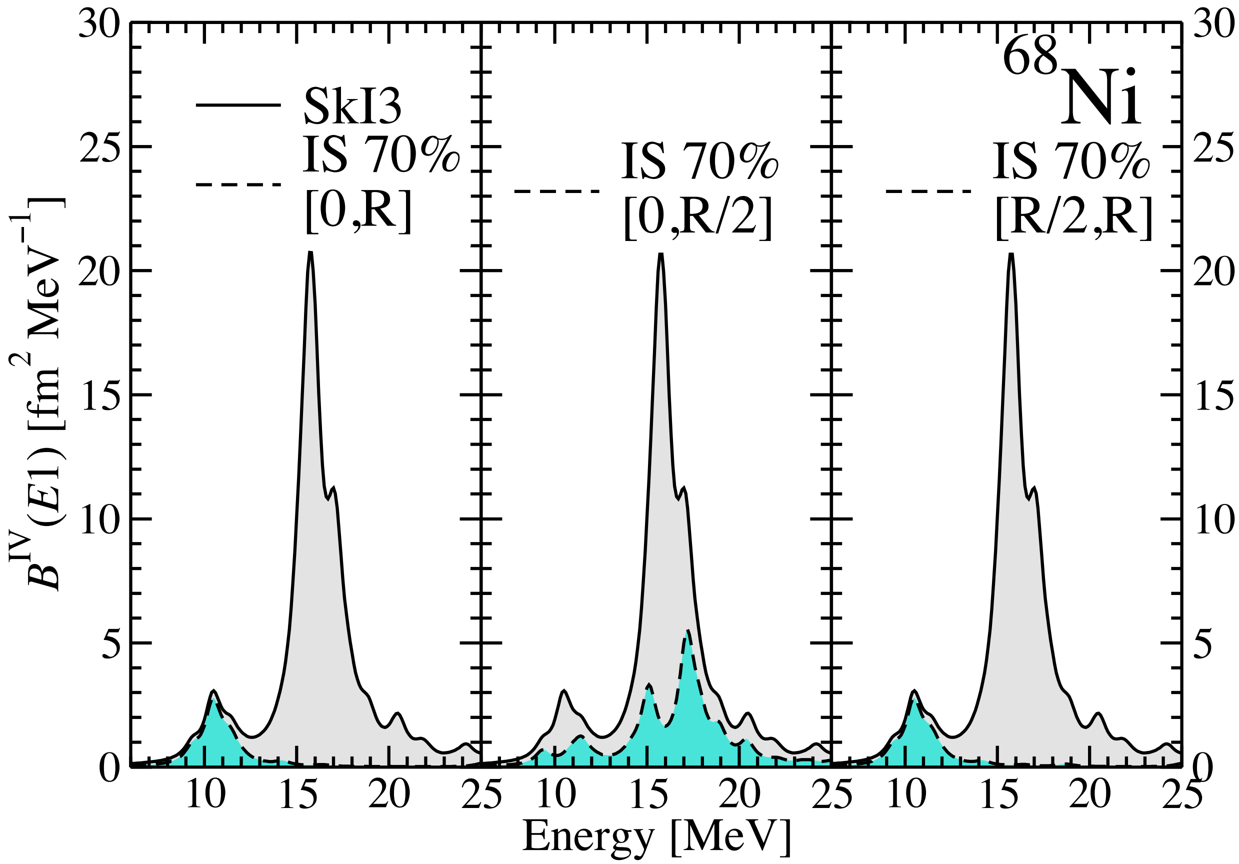
Model dependence of the results for the PDR



Force	L [MeV]
SGII	37.6
SLy5	48.3
SkI3	100.5

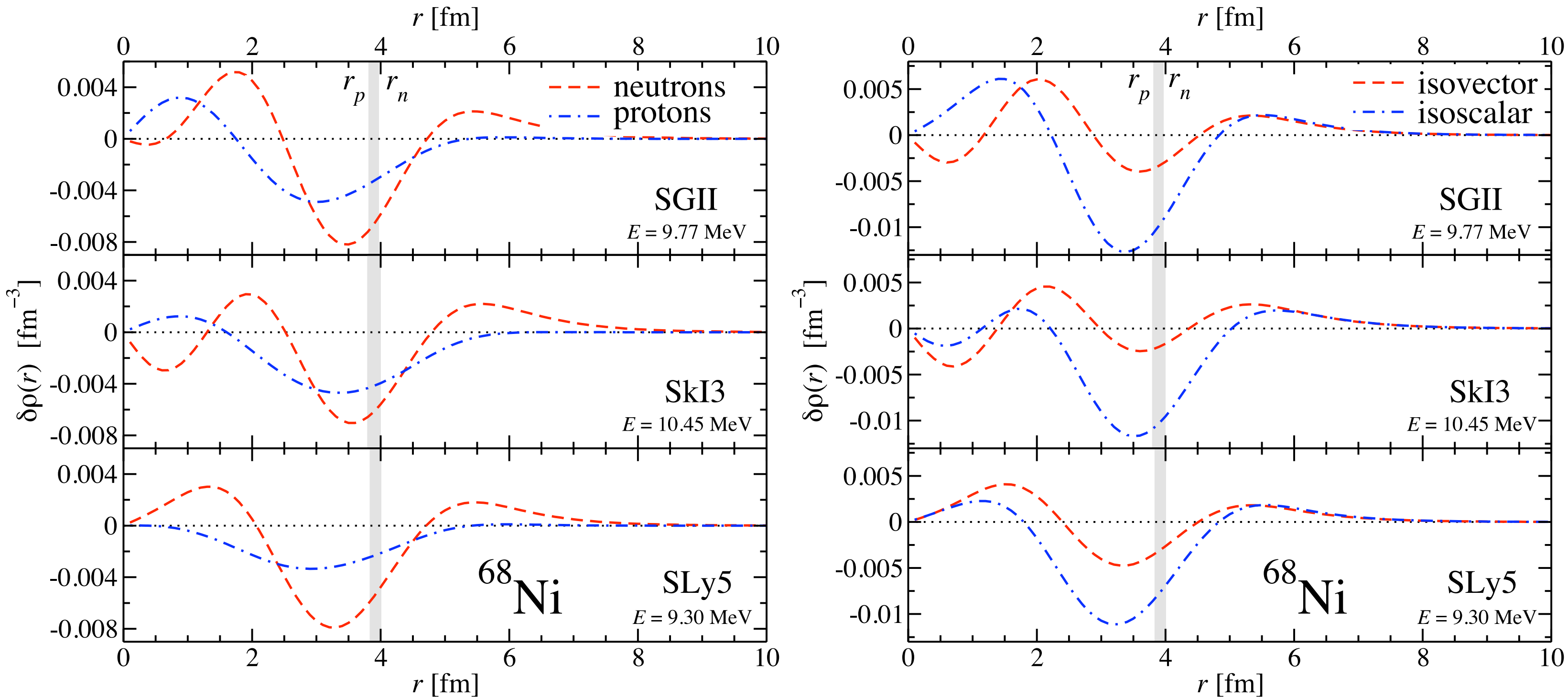
Care should be taken before making general statements. The PDR nature is model-dependent. DD-ME2 calculations show even more collective low-E peak (cf. N. Paar).

IS/IV nature

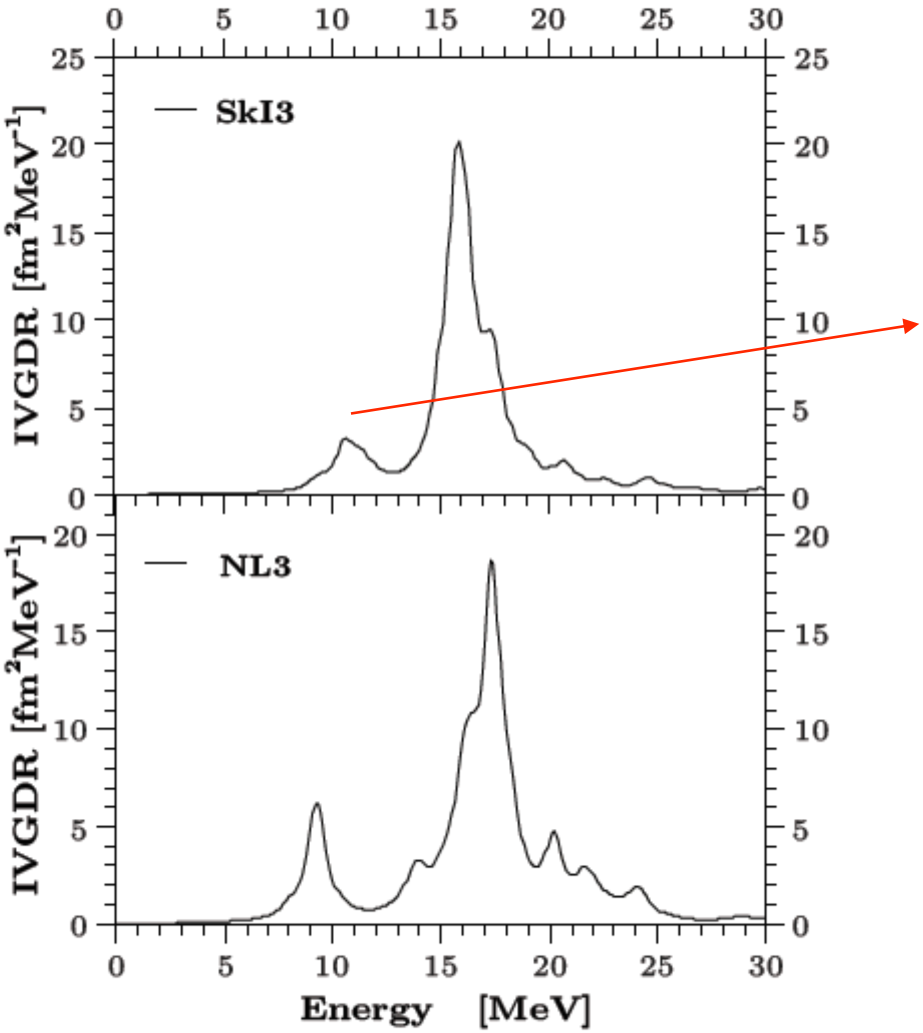


The PDR is a state dominated by neutrons. It appears in the IV response but it is half IS and half IV: the IS character is apparent on the surface.

Transition densities



The transition densities confirm that the IS/IV character depend on **r**. Therefore, the probability to excite the state depends on the external probe (cf. the talk by E. Lanza).



(In the case of the SkI3 force) we display the p-h configurations from excess neutrons which contributes more than 3% to the PDR:

$2p_{1/2} \rightarrow 2d_{3/2}$

$1f_{5/2} \rightarrow 2d_{5/2}$

$2p_{3/2} \rightarrow 3s_{1/2}$

$1f_{5/2} \rightarrow 2d_{3/2}$

$2p_{3/2} \rightarrow 2d_{5/2}$

Conclusions

- The dipole response displays modes having quite different character (cf. also V. Nesterenko, P. Papakostantinou).

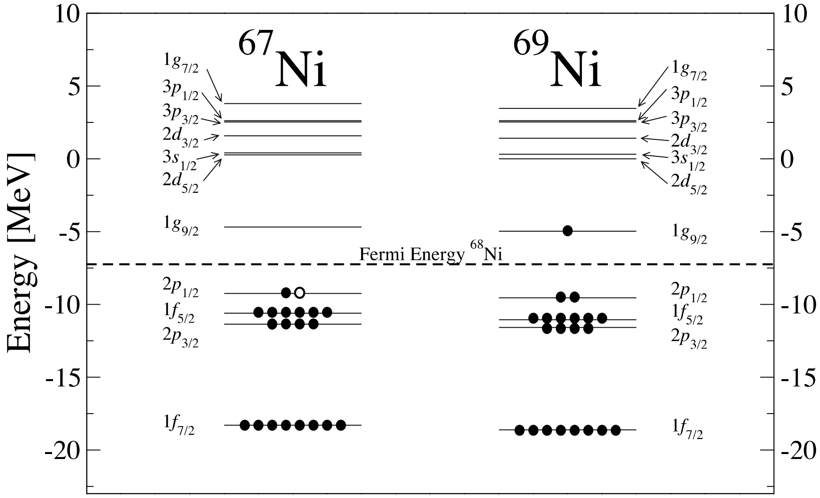
- It is desirable to understand both their microscopic structure and the possibility to extract information about the symmetry energy.

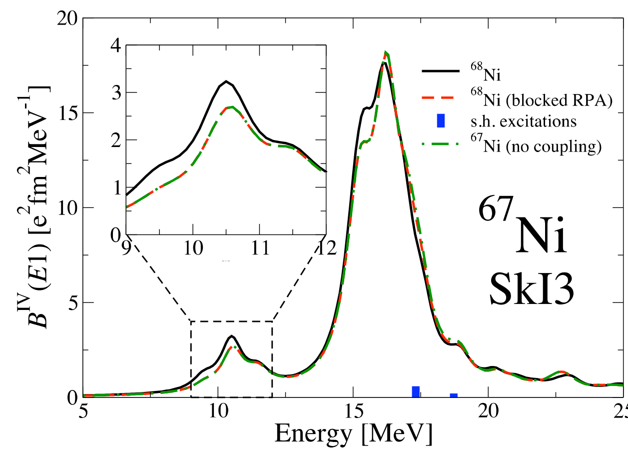
- From the IVGDR we constrain the symmetry energy at 0.1 fm^{-3}.

- The collectivity of the PDR seems to be model-dependent. It may lead to a constraint on L although this has been questioned.

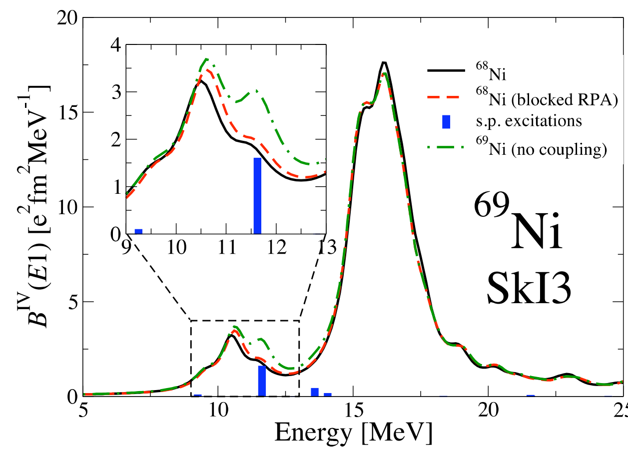
A model for odd nuclei

- In experiments, the dipole response of odd nuclei can also be measured. First approximation: even core and odd particle are decoupled.





(b)

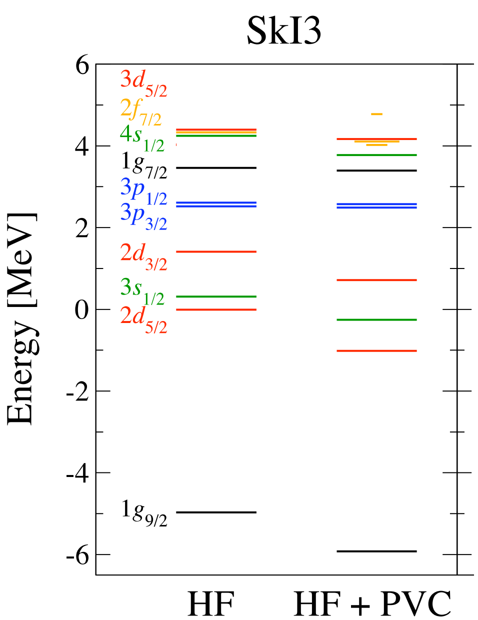


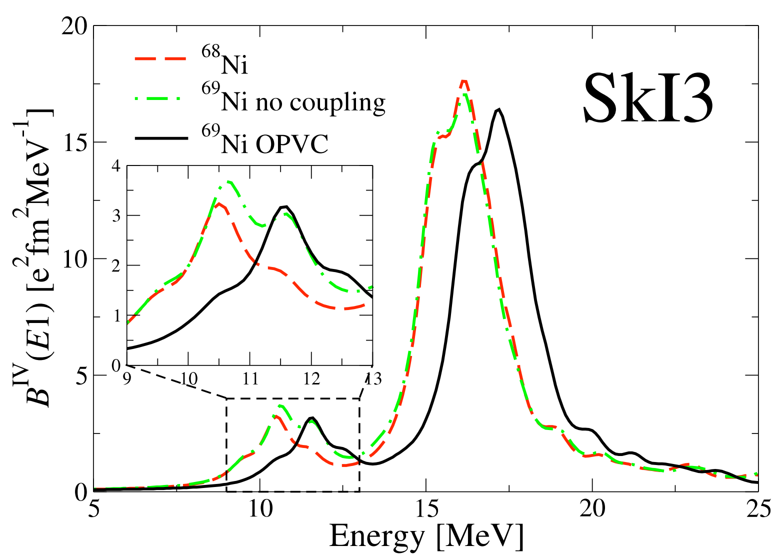
(Odd)PVC model

- We diagonalize the PVC Hamiltonian for the odd system.

$$H = H_{\mathrm{s.p.}} + H_{\mathrm{phonon}} + V$$

- We let the dipole operator act between the lowest state and the excited states.





Backup slides

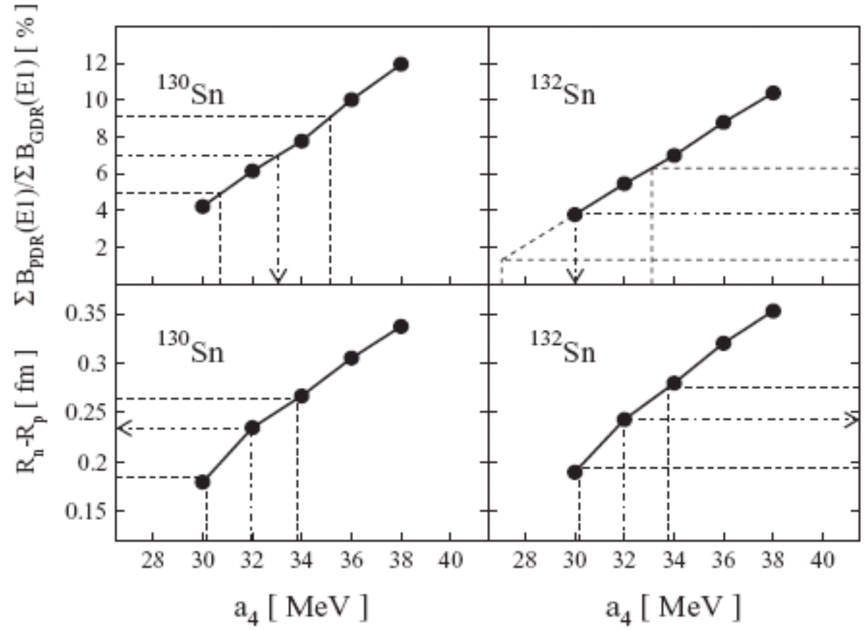
PHYSICAL REVIEW C **76**, 051603(R) (2007)

Nuclear symmetry energy and neutron skins derived from pygmy dipole resonances

A. Klimkiewicz,[1,2] N. Paar,[3] P. Adrich,[1,2] M. Fallot,[1] K. Boretzky,[1] T. Aumann,[1] D. Cortina-Gil,[4] U. Datta Pramanik,[1] Th. W. Elze,[5] H. Emling,[1] H. Geissel,[1] M. Hellström,[1] K. L. Jones,[1] J. V. Kratz,[6] R. Kulessa,[2] C. Nociforo,[6] R. Palit,[5] H. Simon,[1] G. Surówka,[2] K. Sümmerer,[1] D. Vretenar,[3] and W. Waluś[2]
(LAND Collaboration)

- Few interactions (all belonging to the same "class") have been used to check correlations.

- Pairing in ^{130}Sn ?



These kind of correlations should be shown using the same model for finite nuclei and infinite matter.

If pairing is inserted, it should be in both cases

Pairing affects the symmetry energy (but at most 10% around saturation).

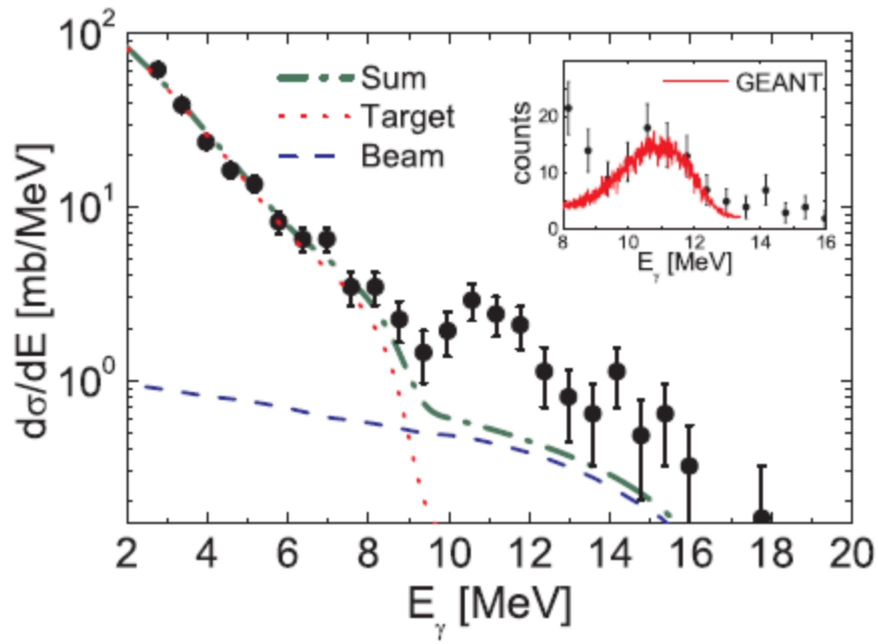
Effect of pairing correlations on incompressibility and symmetry energy in nuclear matter and finite nuclei

E. Khan,[1] J. Margueron,[1] G. Colò,[2] K. Hagino,[3] and H. Sagawa[4]

Recently, a Coulomb excitation measurement has been carried out by the experimental group of Milano U.: ^{68}Ni at 600 MeV/A on a Au target. Low-lying (or "pygmy") dipole strength has been found around 11 MeV. O.Wieland *et al.*, PRL 102, 092502 (2009)

RISING

The Gamma ray spectrum shows an excess with respect to statistical emission



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