Pygmy dipole resonances in stable and unstable nuclei

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Motivation

Giant Resonances are collective excitations of atomic nuclei.

The measurement of such excitations has allowed us to constraint many properties of the nuclear equation of state,

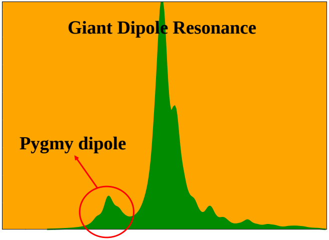
Giant Monopole Resonance $\to K_0$
Giant Dipole Resonance $\to c_{\rm sym}(\rho = 0.1\ \textbf{fm}^{-3})$
Giant Quadrupole Resonance $\to m^*$

Experiments on Giant Resonances constitute a basic tool for the study of fundamental properties of the nuclear strong interaction.

Motivation

What is the Pygmy Dipole Strength (PDS)?

Low-energy peak in the dipole response of neutron rich nuclei



We know that

- the PDS may influence the neutron-capture rates in the $r-$processes
- if collective, it may be correlated with the slope of the symmetry energy: a basic property of the nuclear EoS that impacts on a variety of physical systems: from the very big (neutron stars) to the very small (neutron skin)

But, why does the PDS seems to appear in certain models as a coherent excitation (resonance), and not in others (shell effect)?

Motivation: L versus Pygmy Dipole Strength

It is shown for a large set (26) of successful MF models that the EWSR exhausted by the PDS is correlated with the slope of the symmetry energy

RAPID COMMUNICATIONS

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

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

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Correlations between the behavior of the nuclear symmetry energy, the neutron skins, and the percentage of energy-weighted sum rule (EWSR) exhausted by the pygmy dipole resonance (PDR) in ^{68}Ni and ^{132}Sn are investigated by using different random phase approximation (RPA) models for the dipole response, based on a representative set of Skyrme effective forces plus meson-exchange effective Lagrangians. A comparison with the experimental data has allowed us to constrain the value of the derivative of the symmetry energy at saturation. The neutron skin radius is deduced under this constraint.

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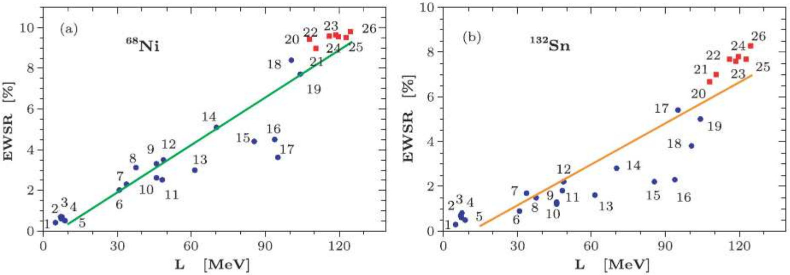
Motivation: L versus Pygmy Dipole Strength

L correlated with the PDS $L = 65 \pm 16$ MeV



PDS may be understood as a collective mode

Motivation: L versus Pygmy Dipole Strength

Correlation analysis of SV-min interaction

The curvature of the $\chi^2(p_i)$ around the minimum as a function of the model parameters $\rightarrow$ allows one to determine the correlation between parameters and predicted observables

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **81**, 051303(R) (2010)

Information content of a new observable: The case of the nuclear neutron skin

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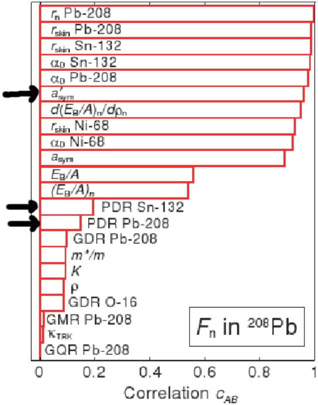
We address two questions pertaining to the uniqueness and usefulness of a new observable: (i) Considering the current theoretical knowledge, what novel information does new measurement bring in? (ii) How can new data reduce uncertainties of current theoretical models? We illustrate these points by studying the radius of the neutron distribution of a heavy nucleus, a quantity related to the equation of state for neutron matter that determines properties of nuclei and neutron stars. By systematically varying the parameters of two theoretical models and

Motivation

L UNcorrelated with PDS



PDS may be understood as a shell effect (depends on the nucleus under study)

Motivation

From the theoretical point of view, a better understanding of the PDS needs:

(the main topic of this talk)

- a more exhaustive analysis of its microscopic properties employing different nuclei and a representative set of nuclear interactions [Phys. Rev. C 85 024601 and Nucl. Phys. A 877, 35 (2012)]

(work in progress)

- the extension of the correlation analysis made by P.-G. Reinhard and W. Nazarewicz to other interactions

Contents

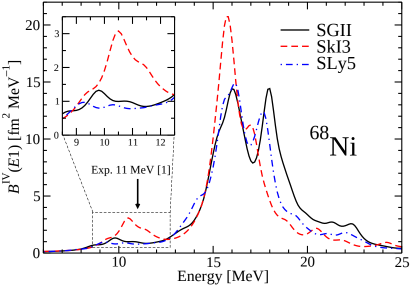
Microscopic analysis of the PDS: model dependence and sensitivity to the symmetry energy

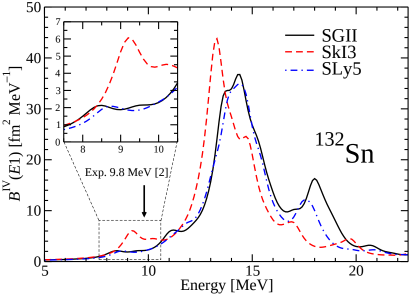
We study the PDS within the self-consistent HF+RPA approach in the measured ^{68}Ni, ^{132}Sn and ^{208}Pb nuclei. For that, we use three Skyrme interactions with very different isovector properties (L ranges from 40 MeV to 100 MeV). We focus on:

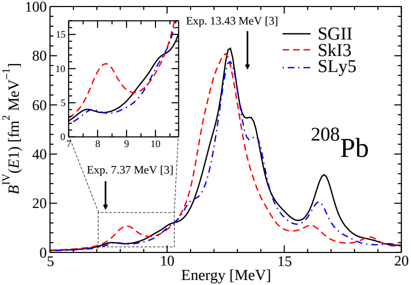
- RPA and unperturbed dipole strength.
- the isoscalar or isovector nature.
- the transition densities.
- the most relevant p-h contributions.

X. Roca-Maza, G. Pozzi, M.Brenna, K. Mizuyama and G. Colò, Phys. Rev. C 85 024601 (2012)

Dipole strength functions (IV)







larger L → larger PDS peak

A. Carbone *et. al.*, PRC81 (2010) 041301.

Isovector properties of the interactions:

SGII $L = 37.6$ MeV

SLy5 $L = 48.3$ MeV

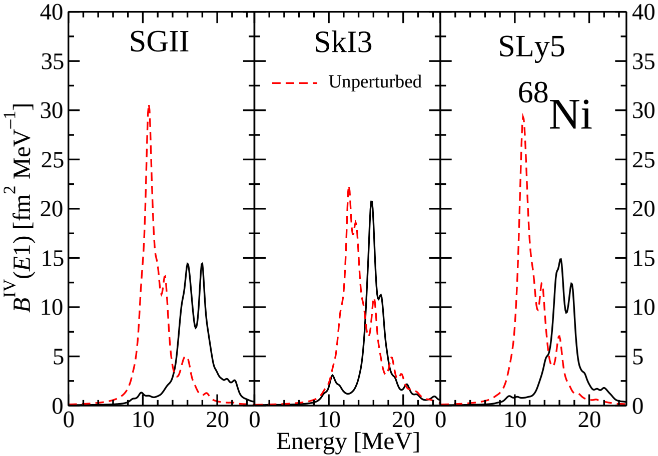
SkI3 $L = 100.5$ MeV

Experiment:

[1] O. Wieland *et. al.*, PRL **102** (2009) 092502.
[2] P. Adrich *et. al.*, PRL **95** (2005) 132501.
[3] N. Ryezayeva *et. al.*, PRL **89** (2002) 272502.

Microscopic analysis of the PDS

RPA versus unperturbed strength

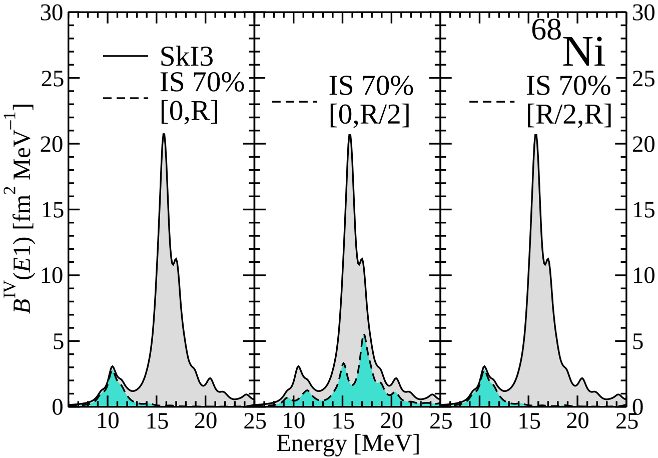


- **No low energy peak in the unperturbed response.**
- **Indications that the PDS may show some coherency depending on the model.** (RPA peaks do not coincide in energy with the unperturbed peak)

Microscopic analysis of the PDS

Isoscalar or isovector?

$B_{\mathrm{IV}}(E1) = \sum_\nu \left(\frac{Z}{A} \int drr^3 \delta\rho^n_\nu(r) - \frac{N}{A} \int drr^3 \delta\rho^p_\nu(r) \right)$

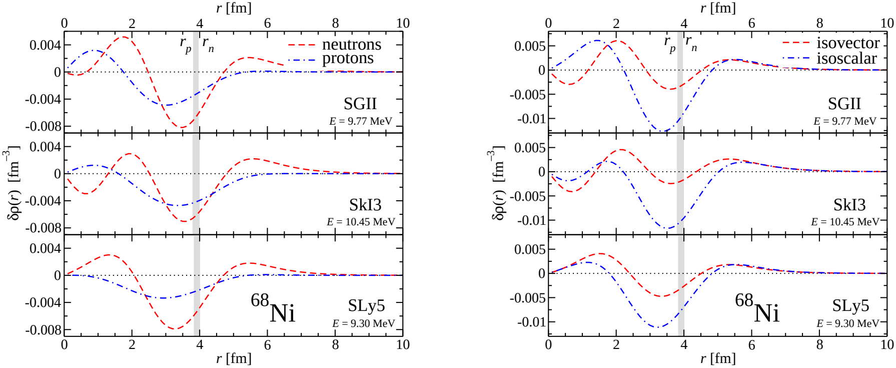


[N. Paar *et. al.*, PRL103 (2009) 032502]

IS nature of the PDS due to outermost nucleons (neutrons in a neutron-rich nucleus). The Δr_{np} is correlated with I and L.

Microscopic analysis of the PDS

the transition densities (∼ amplitude of neutron and proton transition probabilities as a function of r-coordinate)



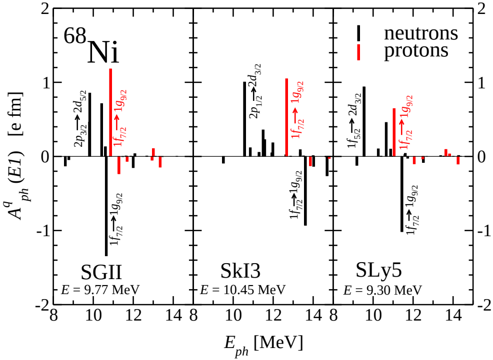
Around the nuclear surface: all models clearly isoscalar.

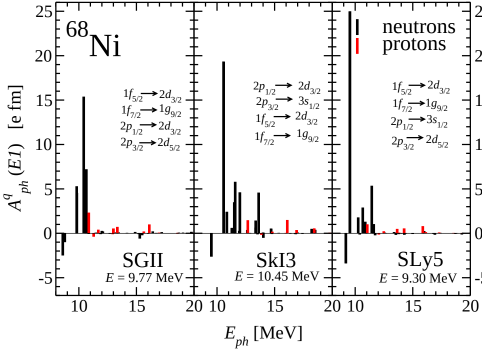
In the interior: not clear nor definite trends in the studied models.

Microscopic analysis of the PDS

The most relevant p-h excitations in the IS and IV dipole response

$B(E1) \equiv \left| \sum_{ph,q} A^{q}_{ph}(E1) \right|^2$





The largest neutron p-h contributions (around 8 with $B_{\mathrm{IS}} > 1$) are coherent and all of them (except one) correspond to transitions of the outermost neutrons $\rightarrow$ **indicates that the ISPDS is a collective mode that may be correlated with** $N - Z$.

Conclusions:

PDS in ^{68}Ni, ^{132}Sn, ^{208}Pb:

1. The IV (and IS) dipole response show a **low-energy peak** in the strength function **for all studied nuclei and models**.
2. Such an IV **peak** (and also IS) **increases** in magnitude with increasing values of L [in agreement with PRC 81, 041301(R) (2010)].
3. The **collectivity** associated with the RPA states giving rise to the PDS **show up depending on** the nature of the **probe** used for exciting the nucleus: **there is systematically more collectivity in the IS than in the IV transitions**.

Conclusions:

PDS in ^{68}Ni, ^{132}Sn, ^{208}Pb:

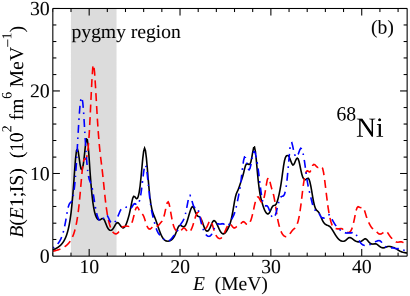
4. The low-energy **IS** response is basically due to the **outermost neutrons**.
5. The **isoscalarity** displayed by the RPA states giving rise to the PDS **may probe isoscalar properties**.

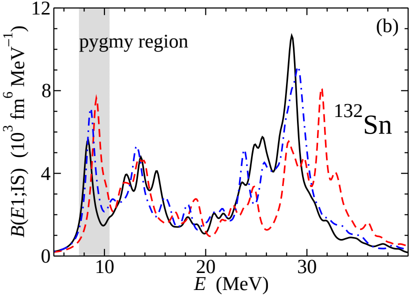
Therefore,

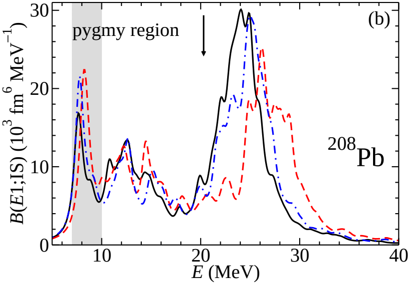
- **IS probes** seems to be more **suitable** for the study of the **low-energy dipole response** in nuclei far from the stability valley.
- **The EWSR exhausted by the PDS may display a more involved correlation with the parameters of the nuclear EoS than the linear dependence with L** (this would solve the discrepancy of the results presented in the motivation)

Extra material:

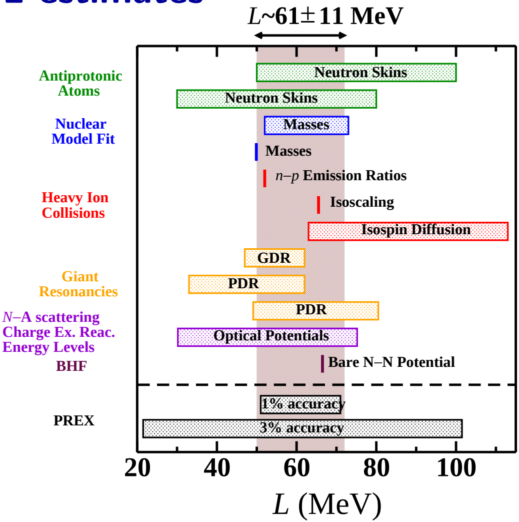
Dipole strength functions (IS)







L estimates



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Famiano *et al.* PRL 97 (2006) 052701
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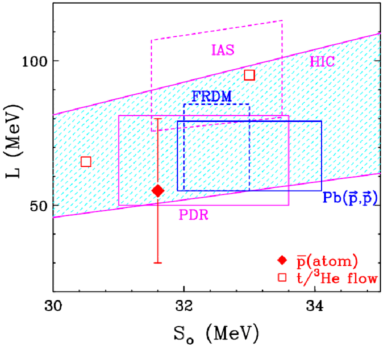
Klimkiewicz *et al.* PRC 76 (2007) 051603(R)
Carbone *et al.* PRC 81 (2010) 041301(R)
Xu *et al.* PRC 82 (2010) 054607.
Vidaña *et al.* PRC 80 (2009) 045806

X. Roca-Maza *et. al.* PRL 106 (2011) 252501
(estimated error from PREX data centered
at L=61 MeV: average of all other estimates)

J-L correlation: NuSYM collaboration

Current Status

Experimental Measurements



Results from models