The dipole strength: microscopic properties and correlations with the symmetry energy and the neutron skin thickness

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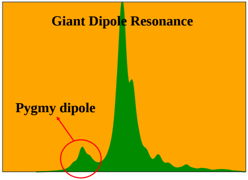
Motivation

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 $\rightarrow K_0$
Giant Dipole Resonance $\rightarrow c_{\mathrm{sym}}(\rho = 0.1\ \mathrm{fm}^{-3})$
Giant Quadrupole Resonance $\rightarrow m^*$

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

And the Pygmy Dipole Strength?



Why does the PDS appear in certain models as a coherent excitation, and not in others? Does the PDS corelate with the slope of the symmetry energy?

Motivation: L versus Pygmy Dipole Strength

It is shown for a large set 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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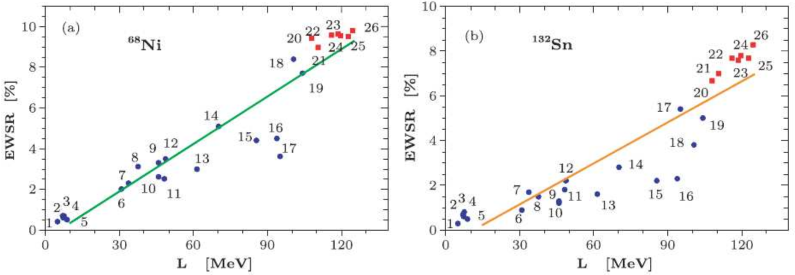
One of the interesting problems presently receiving particular attention is that of the size of the neutron root-mean-square (r.m.s.) radius in neutron-rich nuclei. In fact, this quantity is

PDR) [6], and of the charge-exchange spin-dipole strength [7] were suggested as constraints. In addition, by means of heavy-ion collisions the symmetry energy has also been probed

Motivation: L versus Pygmy Dipole Strength

L correlated with the PDS

$$L = 65 \pm 16 \text{ MeV}$$



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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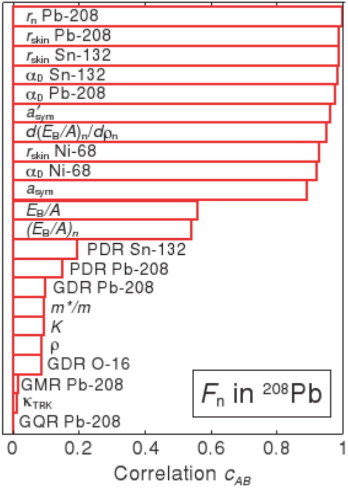
We address two questions pertaining to the uniqueness and usefulness of a new observable: (i) Considering the current theoretical knowledge, what novel information does new measurement bring in? (ii) How can new data reduce uncertainties of current theoretical models? We illustrate these points by studying 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 studying the resulting confidence ellipsoid, we quantify the relationships between the neutron skin and various properties of finite nuclei and infinite nuclear matter. Using the covariance analysis, we identify observables and pseudo-observables that correlate, and do not correlate, with the neutron skin. By adding the information on the neutron radius to the pool of observables determining the energy functional, we show how precise experimental

Motivation

L UNcorrelated with PDS



Motivation

For a better understanding of the PDS we need:

- a more exhaustive analysis of the microscopic properties of the PDS employing different nuclei and a representative set of nuclear interactions (the main topic of this seminar).
- extend the correlation analysis made by P.-G. Reinhard and W. Nazarewicz to other interactions (work in progress).

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.

Contents

Does there exist the possibility of a better and tighter determination of the slope of the symmetry energy by using a different experimental investigation?

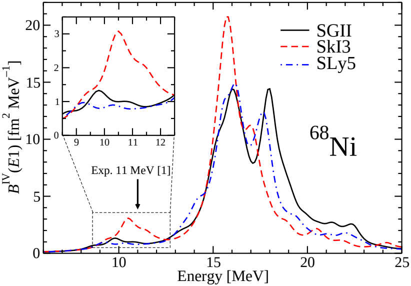
We will show (theoretically) that parity violating elastic electron scattering experiments constitute one of our best (if not the best) means of constraining the symmetry energy.

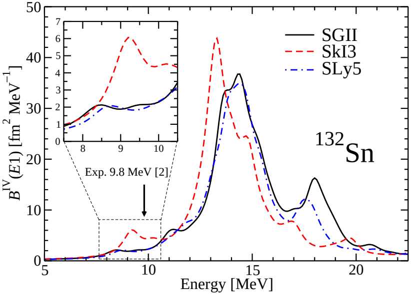
L estimates:

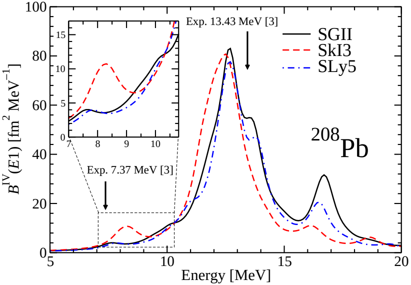
Are the different estimates of the L parameter compatible?

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

Dipole strength functions







larger $L \rightarrow$ 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

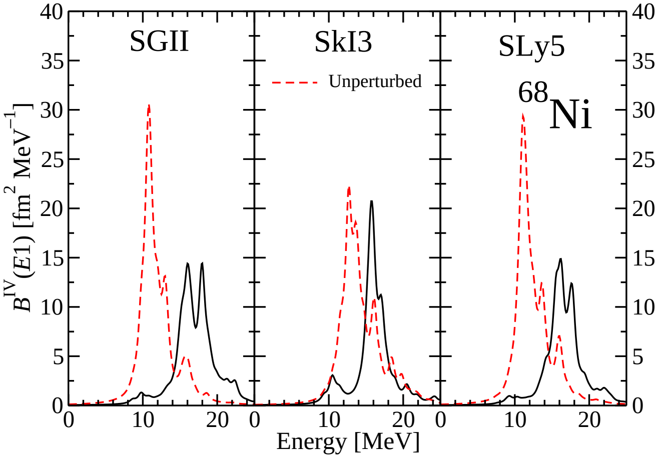
SkI3 $L = 100.5$ MeV

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

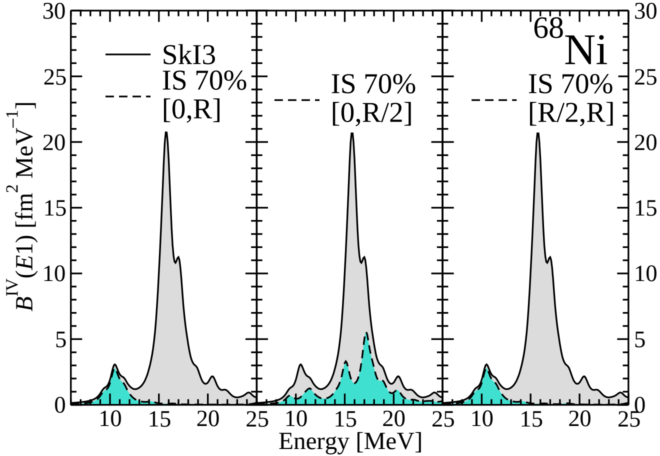
RPA versus unperturbed strength



No low energy peak in the unperturbed response. The low energy peak and the GDR peak of the RPA response does not coincide in energy with the unperturbed peak (SkI3): indications that the PDS may show some coherency depending on the model.

Microscopic analysis of the PDS

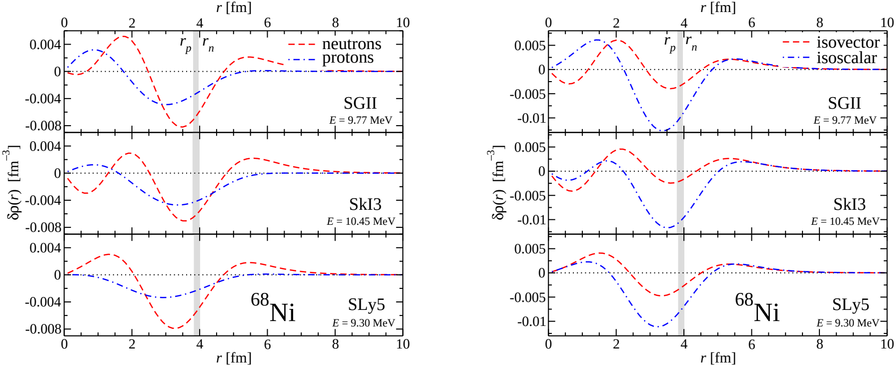
Isoscalar or isovector? $B_{\mathrm{IV}}(E1) = \sum_\nu \left(\frac{Z}{A} \int drr^3 \delta\rho^n_\nu(r) - \frac{N}{A} \int drr^3 \delta\rho^p_\nu(r) \right)$



Isoscalar nature of the PDS is due to outermost neutrons. The nuetron excess is sensitive to the symmetry energy as it is well known from studies on the Δr_{np}. (see also N. Paar *et. al.*, PRL103 (2009) 032502)

Microscopic analysis of the PDS

the transition densities



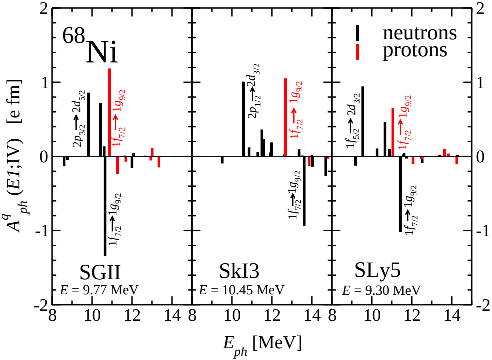
Around the nuclear surface: all models clearly isoscalar.

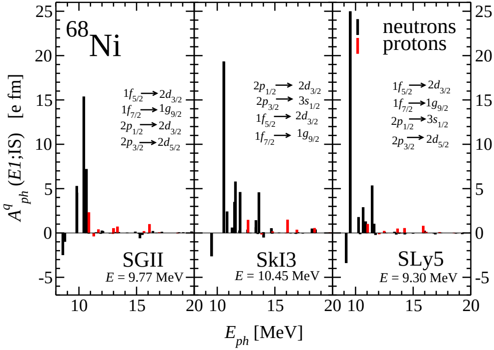
In the interior: neither clear nor definite trends for the studied models.

Microscopic analysis of the PDS

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

$B^{\mathrm{IS/IV}}(E1) \equiv \mid \sum_{ph,q} A^{q}_{ph}(E1;\mathrm{IS/IV}) \mid^2$





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 larger the value of L, the larger in strength we find the IV peak in the PDS region.
2. The isoscalar character of the PDS is qualitatively supported by all models and it is basically due to the outermost neutrons.
3. The IV dipole response in neutron rich nuclei DOES NOT display a clear collectivity in all studied models.
4. The IS dipole response in neutron rich nuclei display a clear collectivity in all studied models. If systematically confirmed, it would provide a reasonable explanation to the correlation of the PDS with the neutron excess, hence, with the neutron skin thickness and, therefore, with the slope of the symmetry energy.

Does there exist the possibility of a better and tighter determination of the slope of the symmetry energy by using a different experimental investigation?

Yes, there exists:
PREX-like experiments are essentially model independent!
They may allow us to further constrain models and substantially improve our understanding of the PDS and other observables

PREX data analysis: Next talk for a more detailed explanation

Parity violating electron elastic scattering is a model indepedent probe of neutrons in nuclei:

1. Electrons interact by exchanging a γ or a Z_0 boson.
2. While protons couple basically to γ, neutrons do it with Z_0.
3. Ultra-relativistic electrons, depending on their helicity, interact with the nucleons $V_\pm = V_{\rm Coulomb} \pm V_{\rm Weak}$.
4. PREX measures the parity violating asymmetry,

$$A_{pv} = \left(\frac{d\sigma_+}{d\Omega} - \frac{d\sigma_-}{d\Omega}\right) \Big/ \left(\frac{d\sigma_+}{d\Omega} + \frac{d\sigma_-}{d\Omega}\right)$$

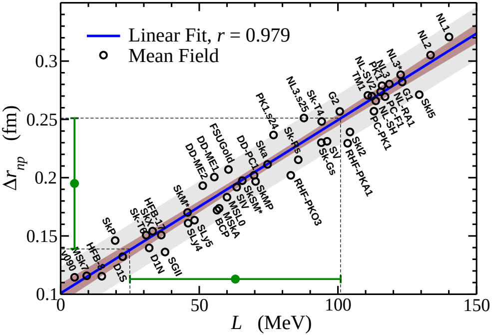
   at a single angle.

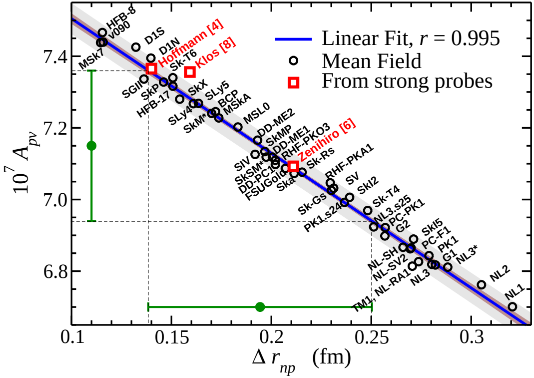
5. For solving the problem of an ultra-relativistic e^- moving under the effect of $V_\pm$, we solve the Dirac equation via the exact phase-shift analysis (DWBA). Input: ρ_n and ρ_p

PREX data analysis:

How we can extract from PREX the value of L?

Figures from arXiv:1103.1762 accepted for publication in PRL.





Almost perfect linear correlation in MF models

Different experiments also in agreement

$$A_{pv}^{\mathrm{BA}} = \frac{G_F q^2}{4\pi\alpha\sqrt{2}}\left[4\sin^2\theta_{\mathrm{W}} + \frac{F_n(q) - F_p(q)}{F_p(q)}\right]$$

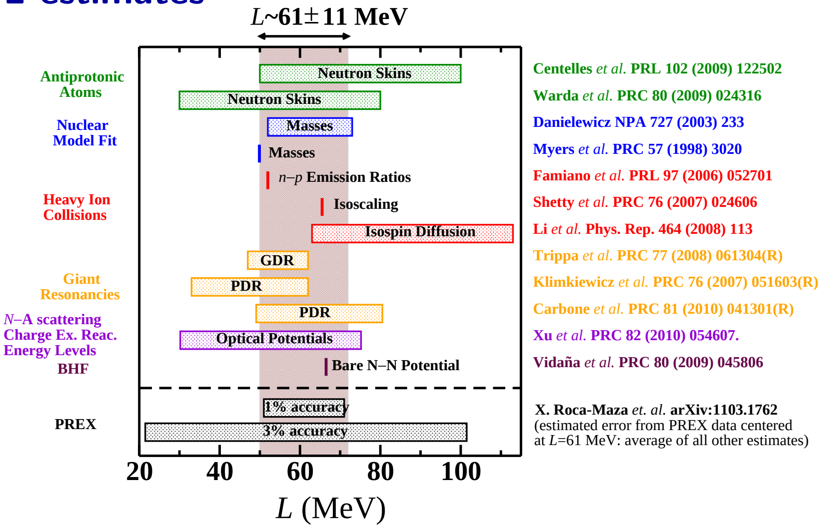
Conclusions:

Δr_{np} of ^{208}Pb and L from PREX:

- Careful and exhaustive analysis of mean field predictions.
- Analysis free from model dependent assumptions on the nucleon distributions.
- We demonstrate a close linear correlation between the parity violating asymmetry and the neutron skin thickness within the same framework in which the latter is correlated with L.
- Other experiments fairly agree with the shown correlations.
- The quality of the correlation supports the commissioning of an improved PREX run to measure the parity violating asymmetry more accurately.

Which is the constrain PREX can set on the density slope of the nuclear symmetry energy? And, how does it compares with other estimates?

L estimates



L~61±11 MeV
Antiprotonic Atoms
Nuclear Model Fit
Heavy Ion Collisions
Giant Resonancies
N–A scattering
Charge Ex. Reac.
Energy Levels
BHF
PREX
Neutron Skins
Neutron Skins
Masses
Masses
n–p Emission Ratios
Isoscaling
Isospin Diffusion
GDR
PDR
PDR
Optical Potentials
Bare N–N Potential
1% accuracy
3% accuracy
20
40
60
80
100
L (MeV)
Centelles et al. PRL 102 (2009) 122502
Warda et al. PRC 80 (2009) 024316
Danielewicz NPA 727 (2003) 233
Myers et al. PRC 57 (1998) 3020
Famiano et al. PRL 97 (2006) 052701
Shetty et al. PRC 76 (2007) 024606
Li et al. Phys. Rep. 464 (2008) 113
Trippa et al. PRC 77 (2008) 061304(R)
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. arXiv:1103.1762
(estimated error from PREX data centered
at L=61 MeV: average of all other estimates)

Thank you for your attention!