ASY-EOS 2015

Nuclear Symmetry Energy and Reaction Mechanism

Microscopic nuclear form factor for the Pygmy Dipole Resonance

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The description of inelastic cross section

- DWBA, first order theory
- Coupled Channel, high order effect important
- Semiclassical approximations

Example: the transition amplitude for the DWBA

$$T^{DWBA} = \int \chi^{(-)}(k_\beta, r) F(r) \chi^{(+)}(k_\alpha, r) dr$$

the radial form factor *F(r)* contains all the structure effects, they can be derived in macroscopic or microscopic approaches

$$F^C(r) \approx \frac{\sqrt{B(EL)}}{r^{L+1}}$$

$$F^N(r) \approx \beta_N \frac{dU^N(r)}{dr}$$

Double folding potential

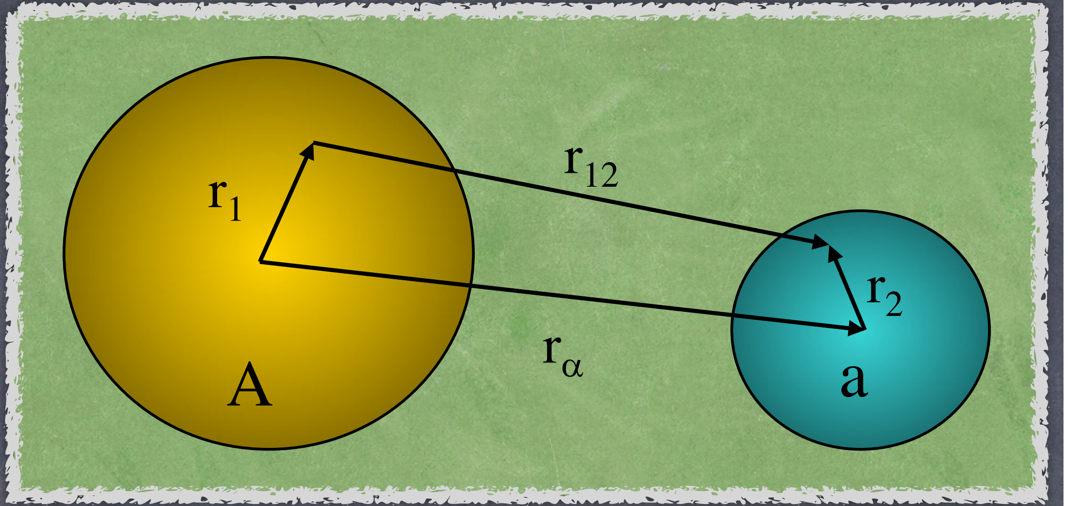
$$U_0(\vec{r}_\alpha) = \iint \rho_A(\vec{r}_1)\, v_0(r_{12})\, \rho_a(\vec{r}_2)\, d\vec{r}_1\, d\vec{r}_2$$

v_0 nucleon-nucleon potential

and

$$r_{12} = |\vec{r}_\alpha + \vec{r}_2 - \vec{r}_1|$$

Double Folding procedure



The nuclear form factors

$$F(r_\alpha) = \int\int [\delta\rho_{A_n}(r_1) + \delta\rho_{A_p}(r_1)] \times v_0(r_{12})[\rho_{a_n}(r_2) + \rho_{a_p}(r_2)] r_1^2 dr_1 r_2^2 dr_2$$

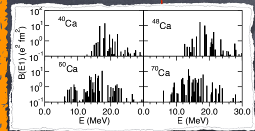
Why is the determination of the form factor so important for the Pygmy Dipole Resonances?

Low-lying dipole states aka Pygmy Dipole Resonance

Properties

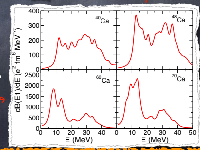
stronger if neutron excess

Isovector response



RPA calculations with Skyrme interaction were employed to study the multipole response in neutron rich nuclei. The spectral distributions of such nuclei are much more fragmented than those for well bound systems.

Isoscalar response



Additional strength below the normal giant resonance region
F. Catara, E.G. Lanza, M.A. Nagarajan, A. Vitturi,
NPA 614 (1997) 86; NPA 624 (1997) 449

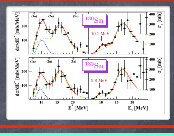
experimental data: present below and above neutron separation threshold

Experimentally they have been measured mainly by mean of Coulomb excitation by various groups

ABOVE NEUTRON SEPARATION THRESHOLD
exotic nuclei

- using the FRS-LAND setup at GSI
- using the RISING setup at GSI (for ^{68}Ni)

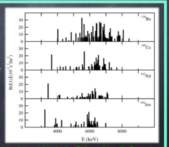
P.Adrich et al. PRL 95 (2005) 132501
O.Wieland et al. PRL 102 (2009) 092502



BELOW NEUTRON SEPARATION THRESHOLD
stable nuclei

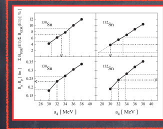
- with (γ,γ') studies (Darmstadt University)
- with ($\alpha,\alpha'\gamma$) at KVI.

D.Savran et al. PRL 100 (2008) 232501
J.Endres et al. PRC 80 (2009) 034302



symmetry energy

Although is controversial discussed, it seems there exist a strong relationship between the PDR strength and the neutron skin.
The neutron skin can be related to the energy symmetry parameter a_4.
Consequences on neutron stars and r-process

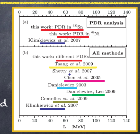


A. Klimkiewicz et al. (LAND Collaboration), PRC 76 (2007) 051603(R)

Relativistic Hartree-Bogoliubov (RHB) plus the quasi particle relativistic RPA (RQRPA) calculations

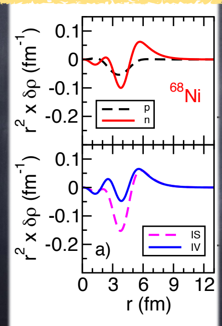
Carbone et al., PRC 81 (2010) 041301(R)

Hartree-Fock + RPA (RHB) and relativistic mean field RMF plus relativistic RPA (RQRPA) calculations using several Skyrme interactions and effective Lagrangians



To be compared with the values deduced from PREX and polarizability experiments.

Transition densities define the new mode

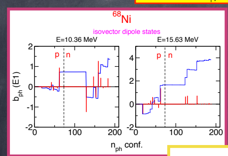


neutron and proton transition densities are in phase inside the nucleus; at the surface only the neutron part survive.

"Theoretical definition" of the PDR

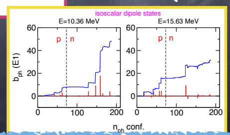
Are they collective or not collective?

$$B(E\lambda;0\rightarrow\nu)=\left|\sum_{ph}b_{ph}(E\lambda)\right|^2=\left|\sum_{ph}\left(X^{\nu}_{ph}-Y^{\nu}_{ph}\right)T^{\lambda}_{ph}\right|^2$$



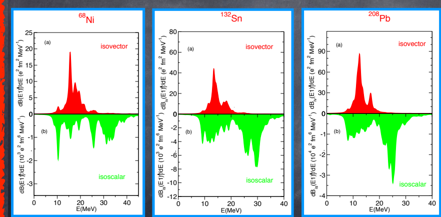
collective

non collective



theoretical studies

Calculations done with the Hartree-Fock plus RPA with SGII Skyrme effective interactions



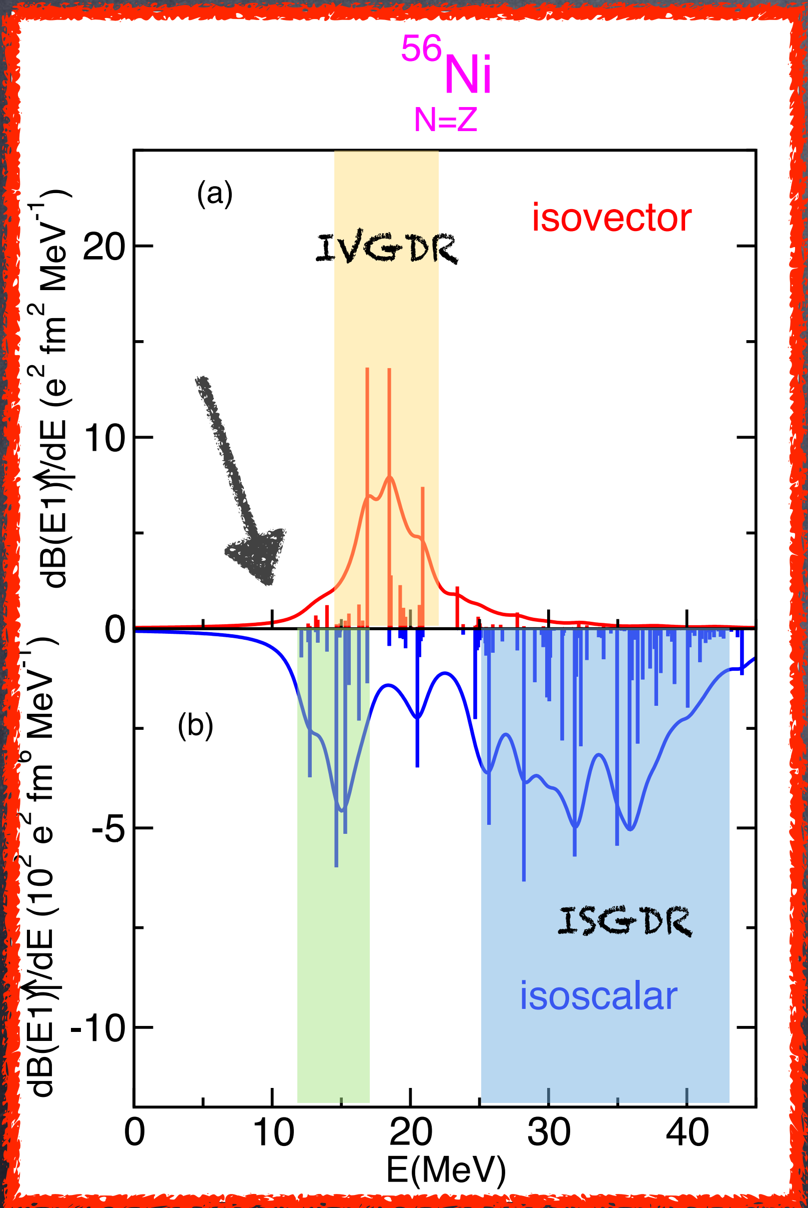
$$O^{(IV)}_{1M}=\sum_{i=1}^{A}r_1Y_{1M}(\hat{r}_1)\tau_z(i)$$

$$O^{(IS)}_{1M}=\sum_{i=1}^{A}r_1^3Y_{1M}(\hat{r}_1)$$

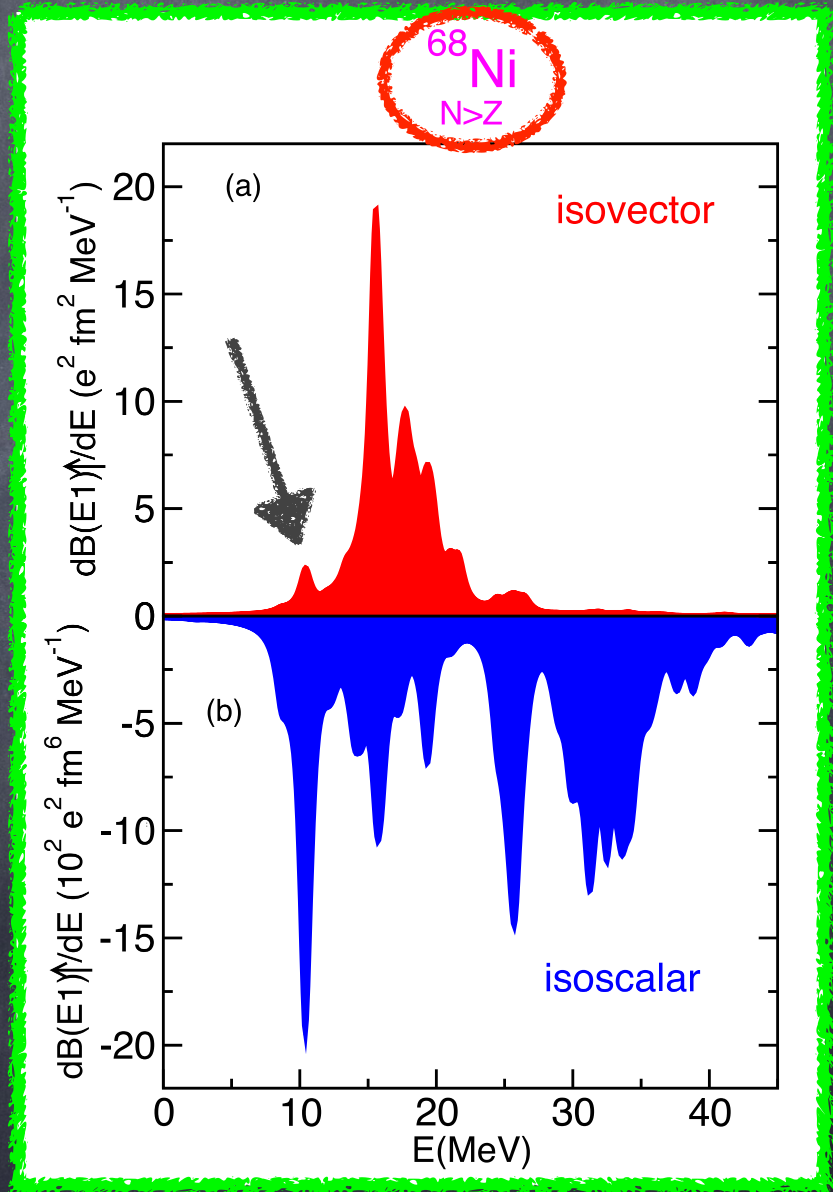
RPA calculations with SGII interaction

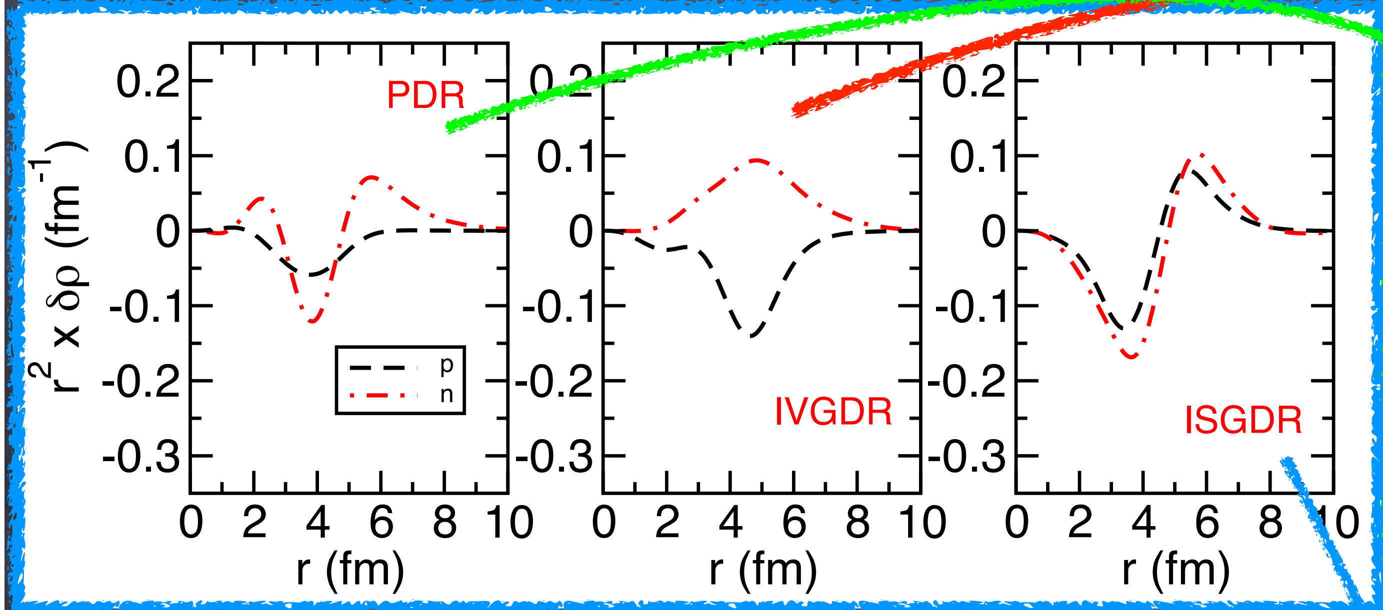
$$O_{1M}^{(IV)} = 2\frac{Z}{A}\sum_{n=1}^{N} r_n Y_{1M}(\hat{r}_n) - 2\frac{N}{A}\sum_{p=1}^{Z} r_p Y_{1M}(\hat{r}_p)$$

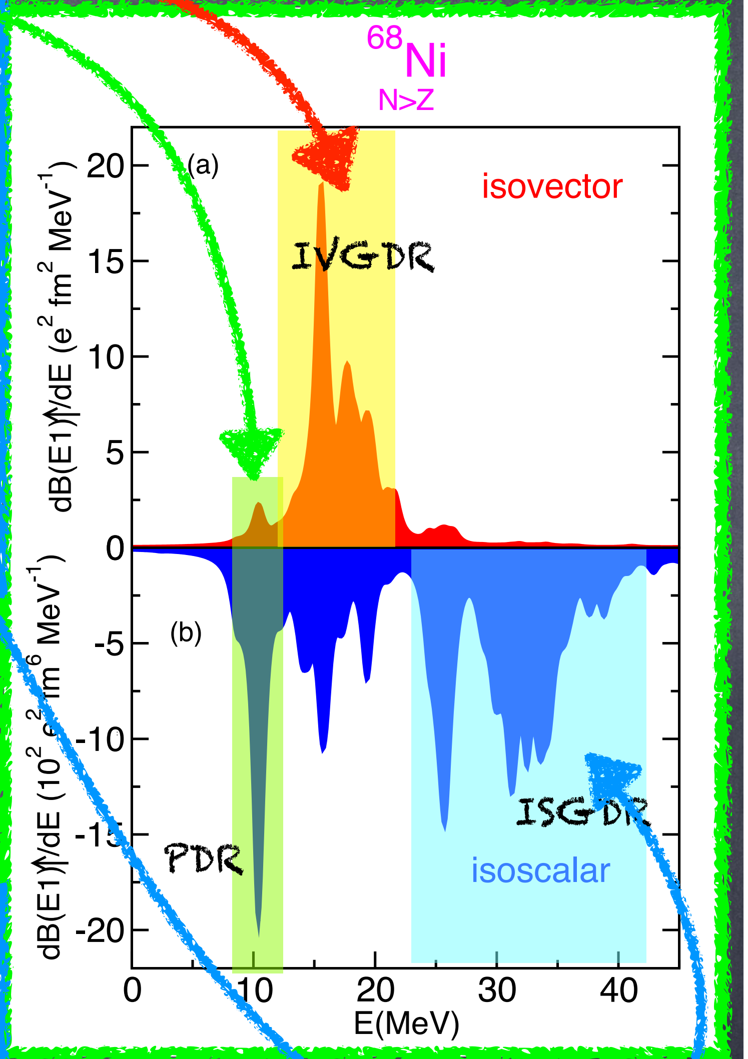
$$O_{1M}^{(IS)} = \sum_{i=1}^{A}(r_i^3 - \frac{5}{3} < r^2 > r_i)Y_{1M}(\hat{r}_i)$$



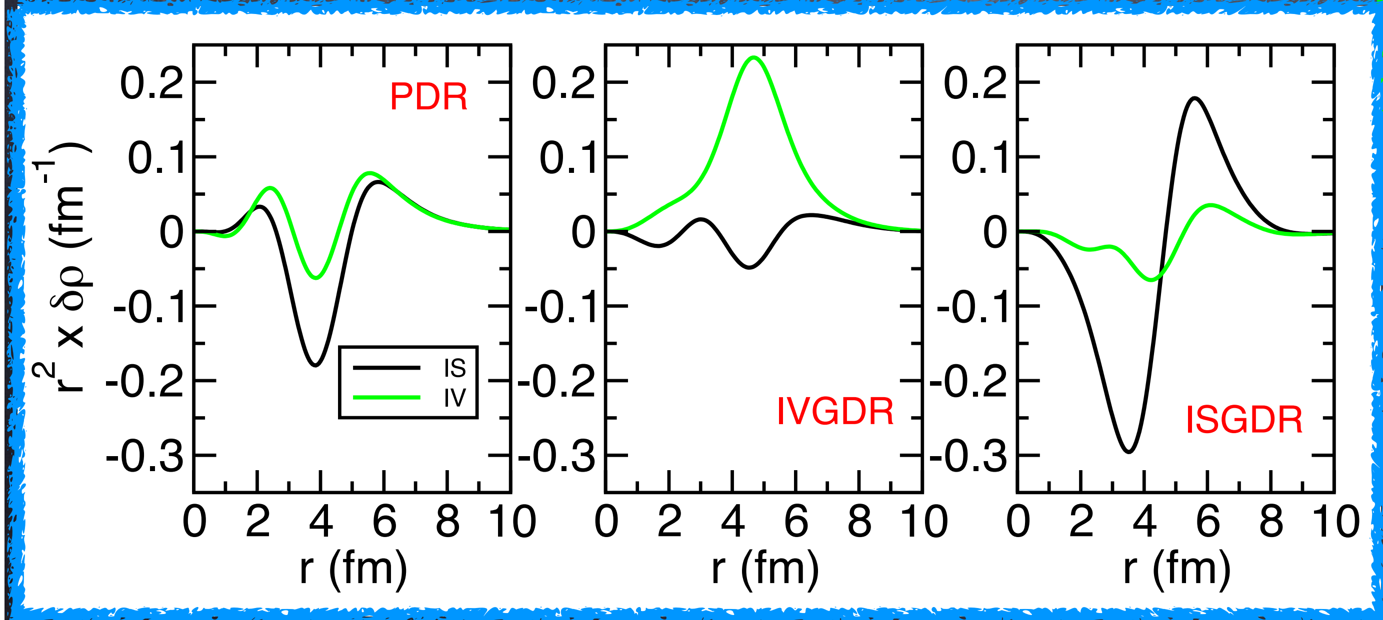
Dipole states







$$\delta\rho^{\nu} = \frac{1}{\sqrt{4\pi}} \sum_{ph} (-)^{j_p + l_p + \frac{1}{2}} \frac{\hat{j}_p \hat{j}_h}{\hat{\lambda}} < j_h \, \tfrac{1}{2} \, j_p \, -\tfrac{1}{2} \, | \, \lambda 0 > \delta(\lambda + l_p + l_h, even) \cdot \left[X^{\nu}_{ph} - Y^{\nu}_{ph} \right] R_{l_p j_p}(r) R_{l_h j_h}(r)$$



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.

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

These states have been studied also with reactions where the nuclear part of the interaction is involved.

In the experimental analysis, which form factors are commonly used?

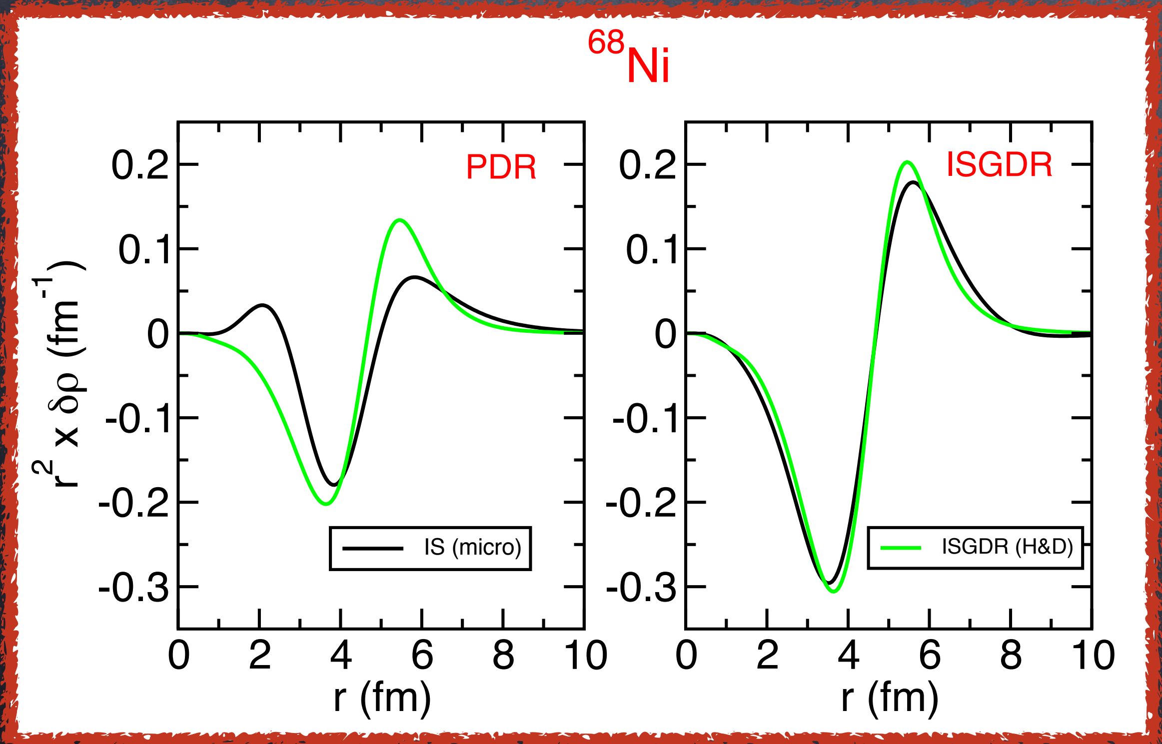
T. J. Deal, NPA 217 (1973) 210;
M. N. Harakeh and A. E. L. Dieperink PRC 23 (1981) 2329

Macroscopic transition density for the ISGDR

$$\rho^1(r) = -\frac{\beta_1}{R\sqrt{3}}\left[10r + (3r^2 - \frac{5}{3} < r^2 >)\frac{d}{dr})\right]\rho_0(r)$$

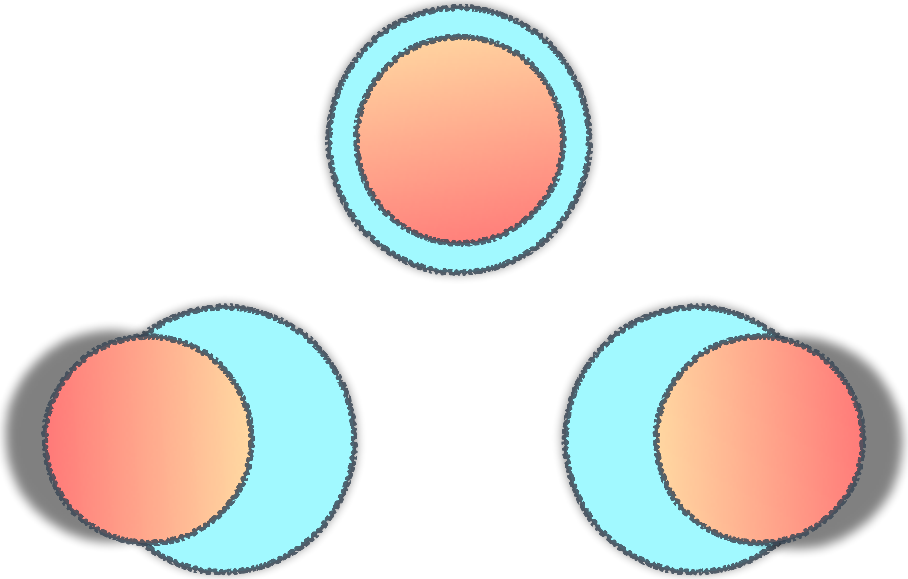
$$\beta_1^2 = -\left(\frac{6\pi\hbar^2}{mAE_x}\right)\frac{R^2}{11 < r^4 > -\frac{25}{3} < r^2 >^2)}$$

R is the half-density radius of the mass distribution.



For both states, the macroscopic transition density has been scaled according to the following condition

$$\int_0^\infty \rho^1_{RPA}(r)\, r^5\, dr = \int_0^\infty \rho^1_{macro}(r)\, r^5\, dr$$



$$\Delta x_S = -x\frac{Z+N_C}{A} \quad ; \quad \Delta x_C = x\frac{N_S}{A}$$

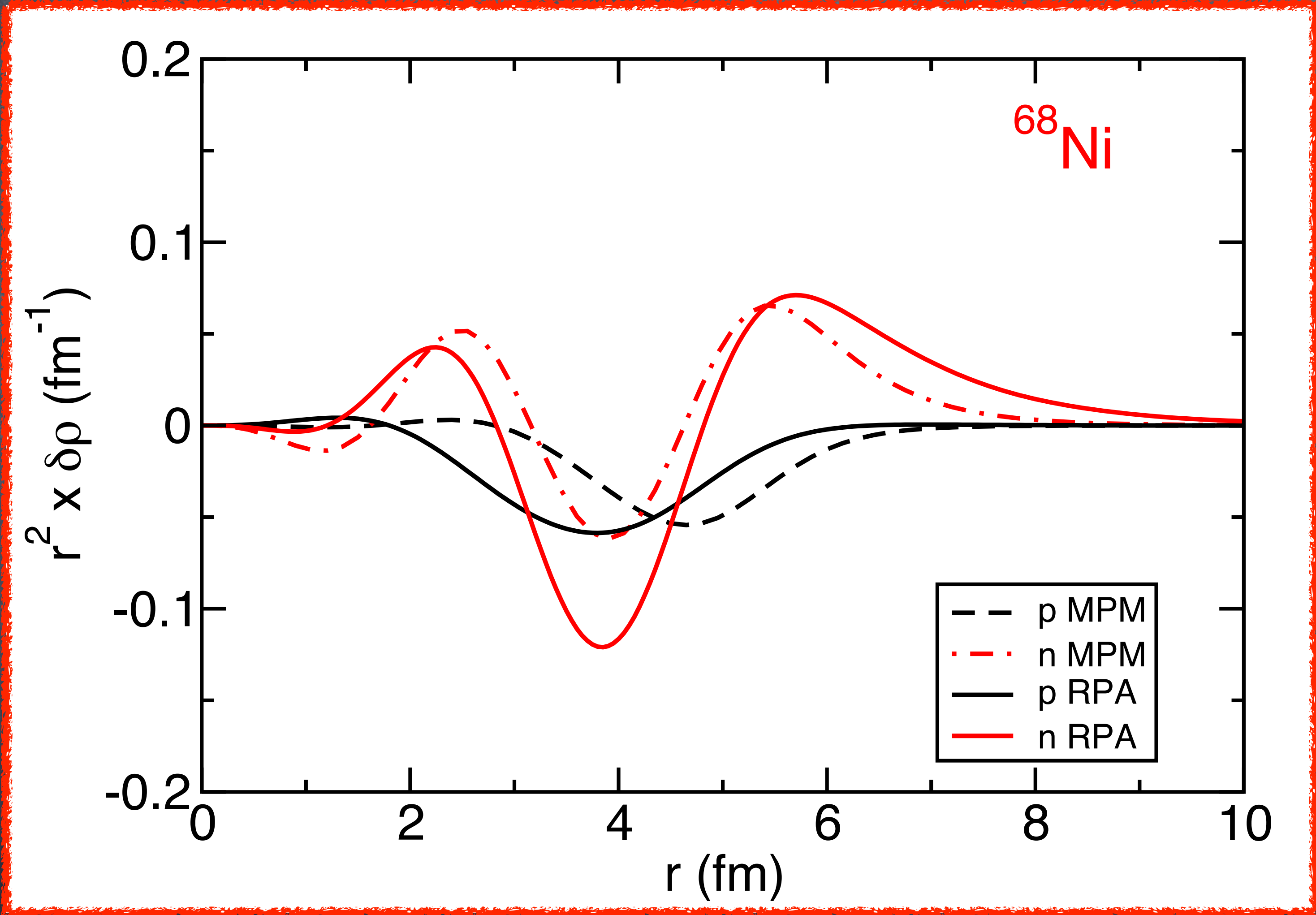
$$\rho(r) = \rho_p(r) + \rho_n^C(r) + \rho_n^S(r)$$

$$\delta\rho_n = \beta\left(\frac{N_S}{A}\frac{d}{dr}\rho_n^C - \frac{Z+N_C}{A}\frac{d}{dr}\rho_n^S\right)$$

$$\delta\rho_p = \beta\frac{N_S}{A}\frac{d}{dr}\rho_p$$

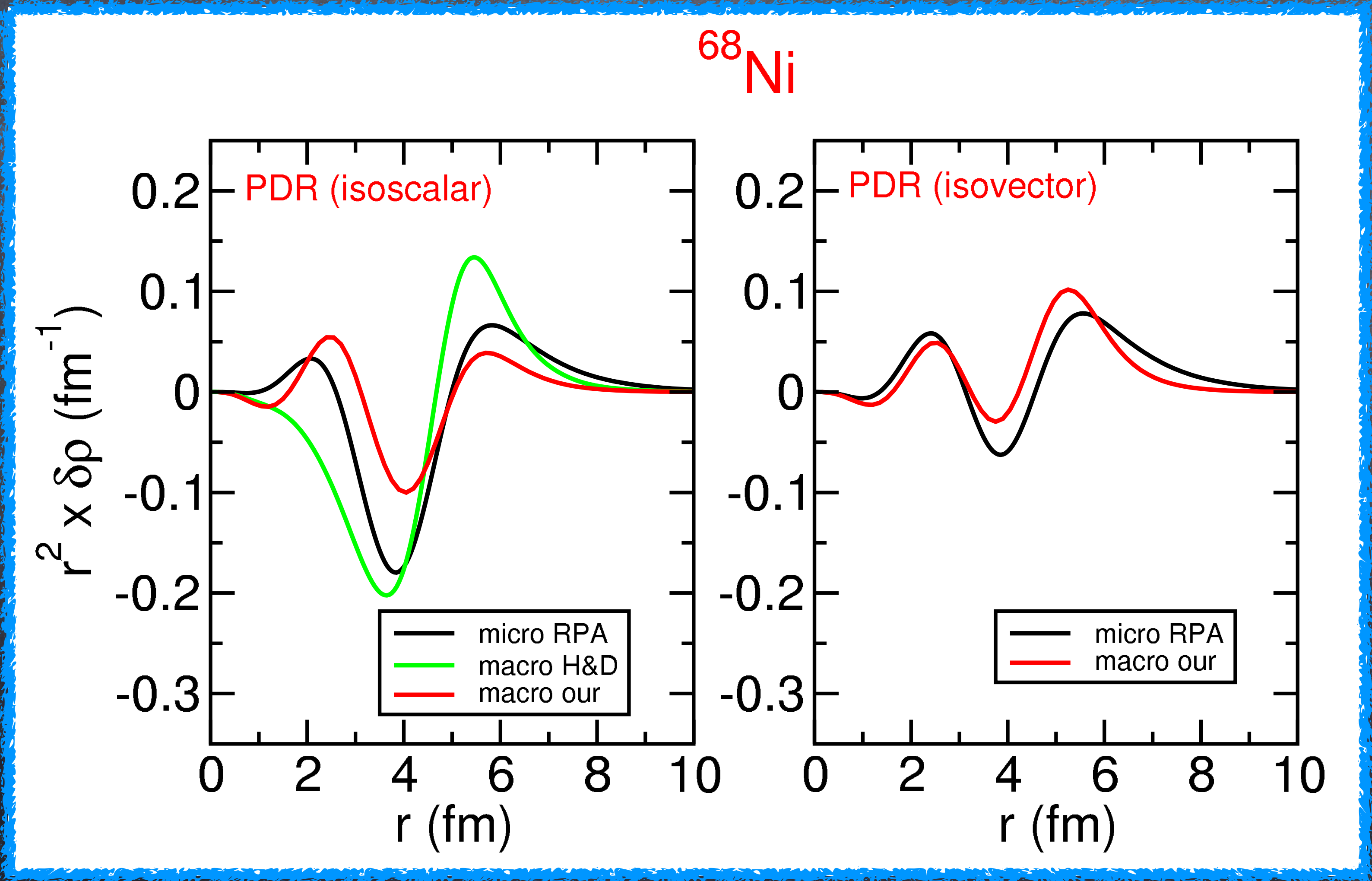
$$\delta\rho_{isosc} = \beta\left(\frac{N_S}{A}\frac{d}{dr}\left(\rho_n^C + \rho_p\right) - \frac{Z+N_C}{A}\frac{d}{dr}\rho_n^S\right)$$

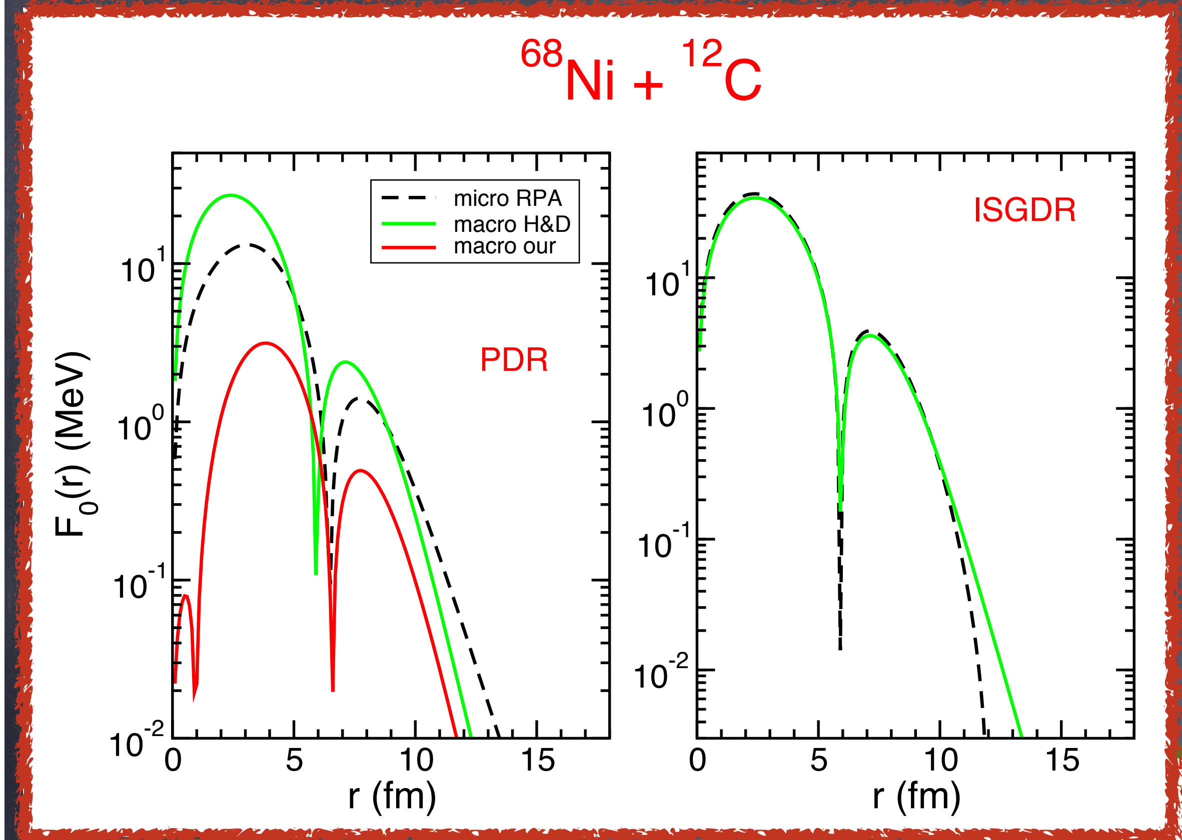
$$\delta\rho_{isov} = \beta\left(\frac{N_S}{A}\frac{d}{dr}\left(\rho_n^C - \rho_p\right) - \frac{Z+N_C}{A}\frac{d}{dr}\rho_n^S\right)$$



0.2
0.1
0
-0.1
-0.2
0
2
4
6
8
10
r^2 x δρ (fm^{-1})
r (fm)
^{68}Ni
p MPM
n MPM
p RPA
n RPA

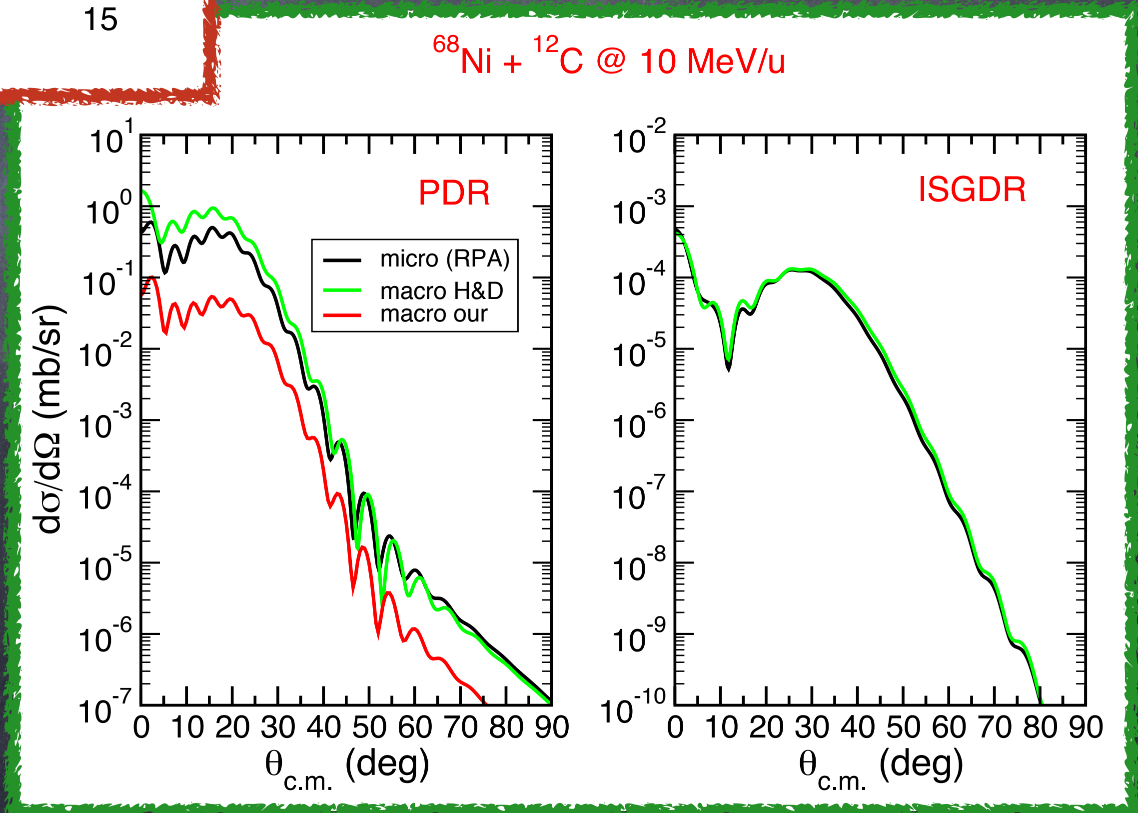
We compare the RPA isoscalar transition densities with the two macroscopic model.

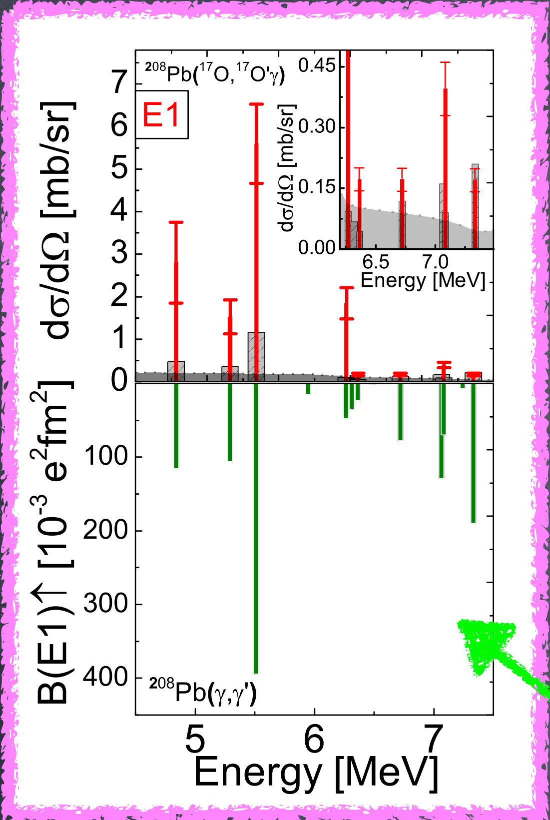




The form factors have been obtained with the double folding procedure with the M3Y nucleon-nucleon potential and with the micro (RPA) and macro transition densities

DWBA calculations done with the DWUCK4 code



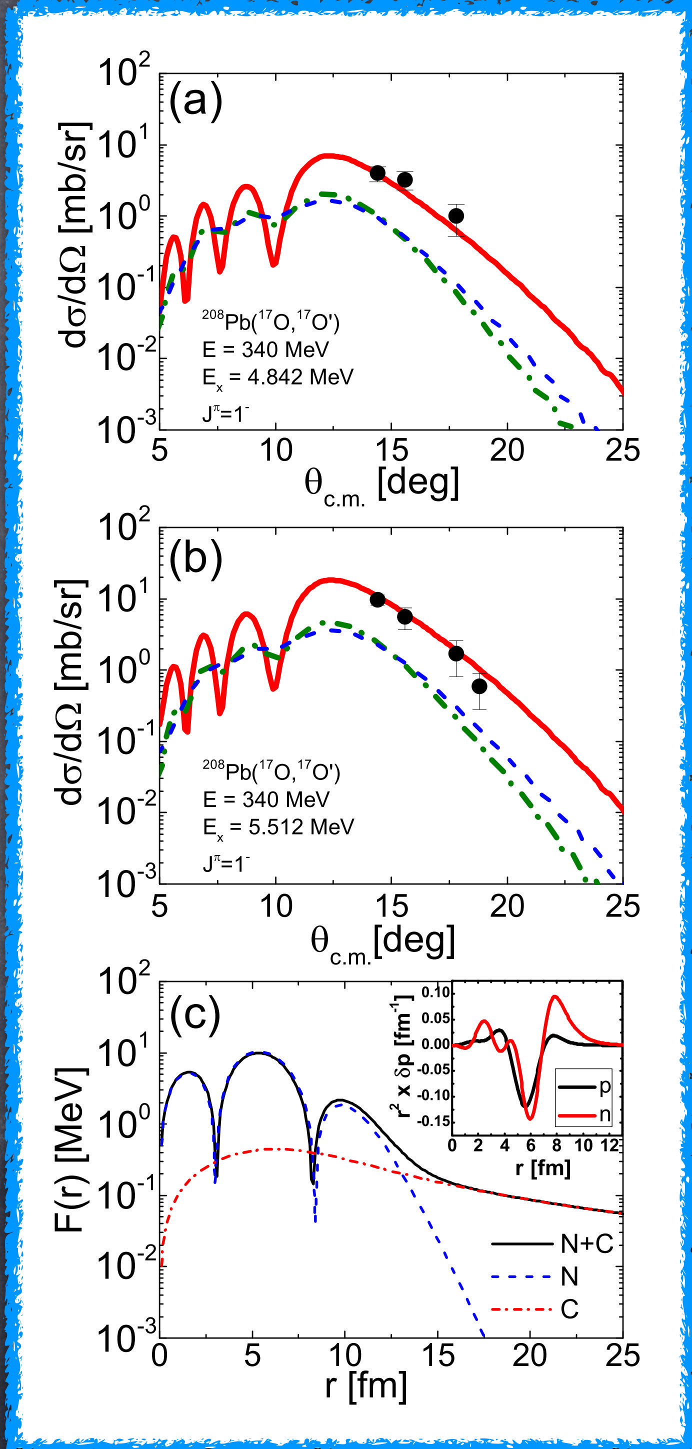


F.C.L. Crespi et al.,
PRL 113 (2014) 012501

^{208}Pb(^{17}O,^{17}Oγ)^{208}Pb
at 340 MeV

Using TRACE prototype and AGATA Demonstrator system

T. Shizuma et al.,
PRC 78 (2008) 061303

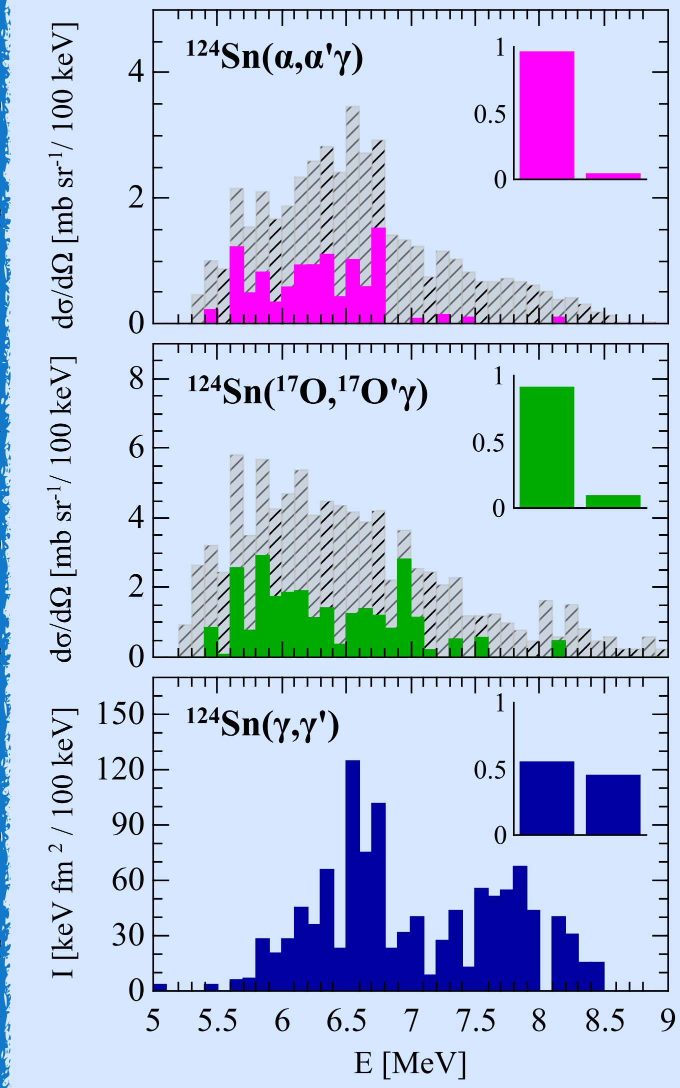


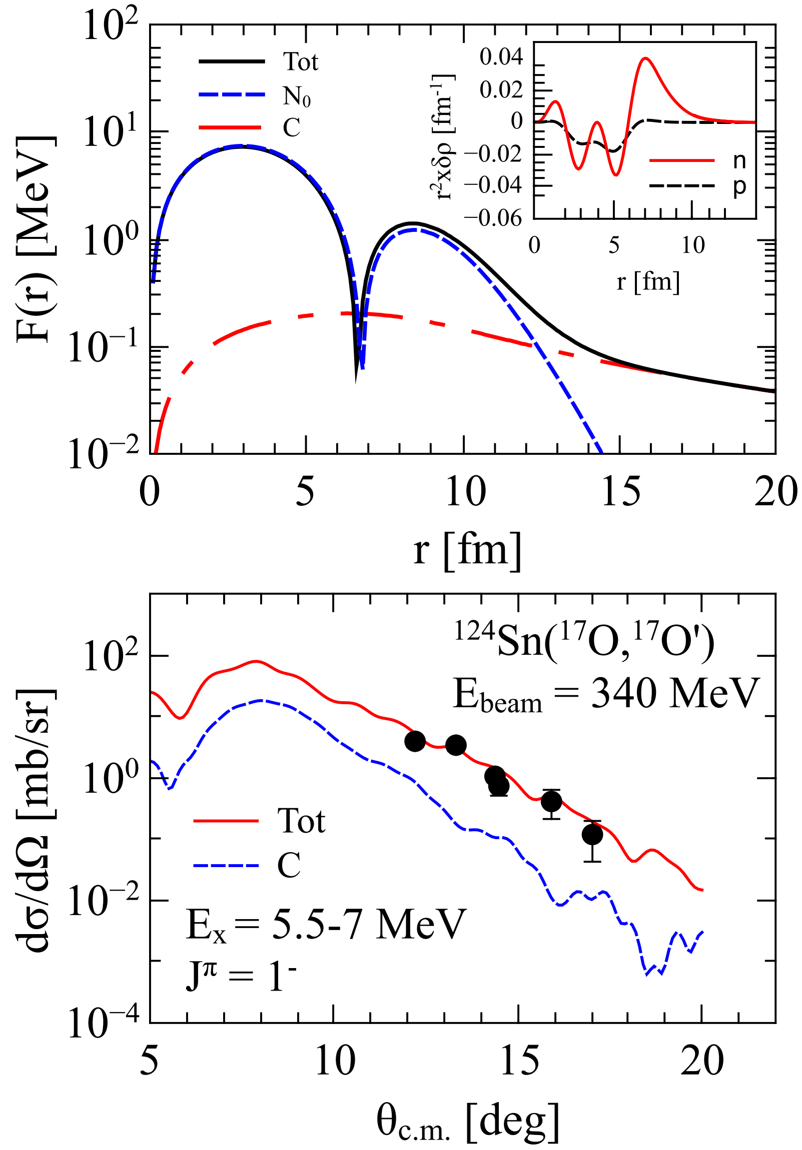
Use of standard phenomenological macroscopic form factor fails (blue dashed line).

Only our microscopic form factors are able to reproduce the experimental data.

L. Pellegri et al.,
PLB 738 (2014) 519

$^{124}Sn(^{17}O,^{17}O\gamma)^{124}Sn$
at 340 MeV





Using TRACE prototype and
AGATA Demonstrator system

Summary

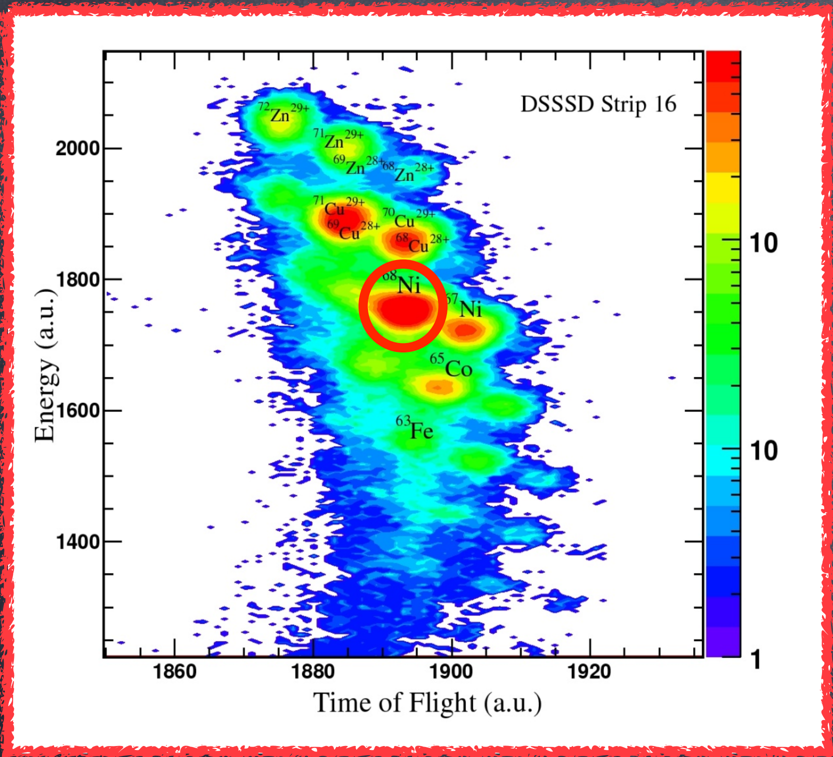
For the study of the Pygmy Dipole Resonance (PDR), form factors calculated within a microscopic model are compared with those provided by different macroscopic collective models.

Their differences, shown in the shape and magnitude, are reflected on the calculated cross section and therefore jeopardize the extracted physical quantities.

For the PDR states, it is of paramount importance the use of a microscopic radial form factor

Experiment with CHIMERA at LNS (Catania) this year

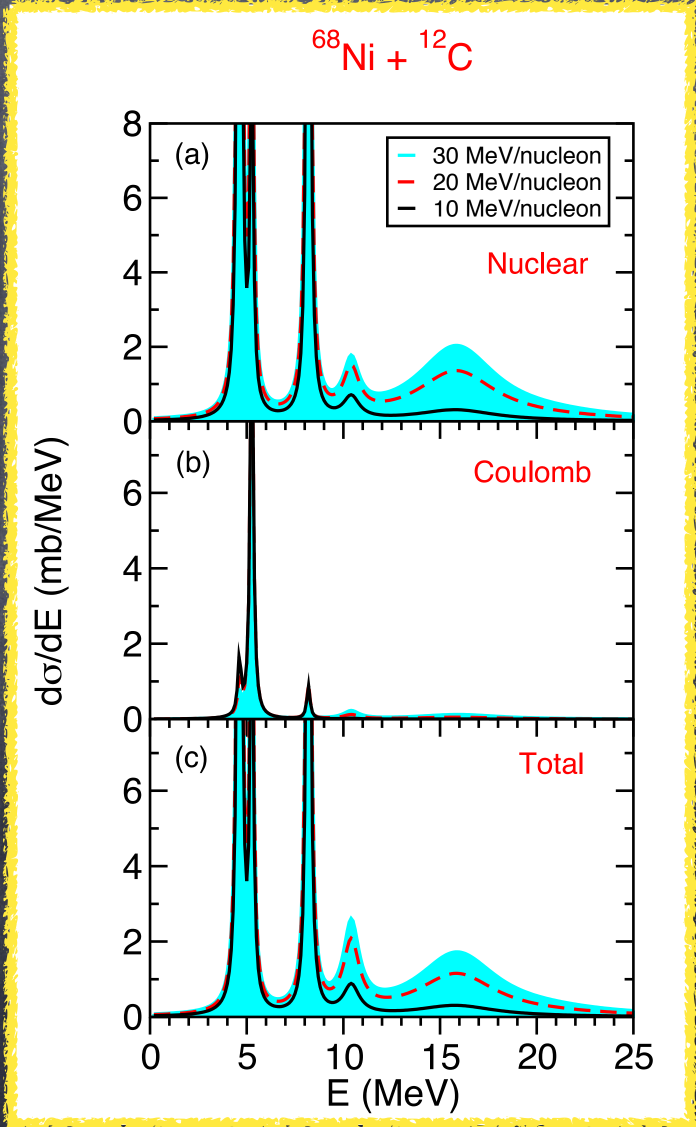
At LNS a primary ^{70}Zn beam of 40 MeV/A on a ^{9}Be target produce a secondary ^{68}Ni beam in the CHIMERA hall. A yield of 20kHz was measured for this beam.



^{68}Ni + ^{12}C

@

30 A•MeV



We propose to use this beam at energy around 30 A•MeV on a thick ^{12}C target to excite the pigmy resonance. The γ-decay of the resonance can be measured using the CsI of the CHIMERA detector.