Excitation of Pygmy Dipole Modes via Nuclear and Coulomb fields

Andrea Vitturi

In collaboration with Edoardo Lanza, Maria Victoria Andrés, Francesco Catara and Danilo Gambacurta

Special interest has been devoted to the evolution of multipole response in neutron-rich nuclei and in particular to the possible existence of Pygmy Dipole modes

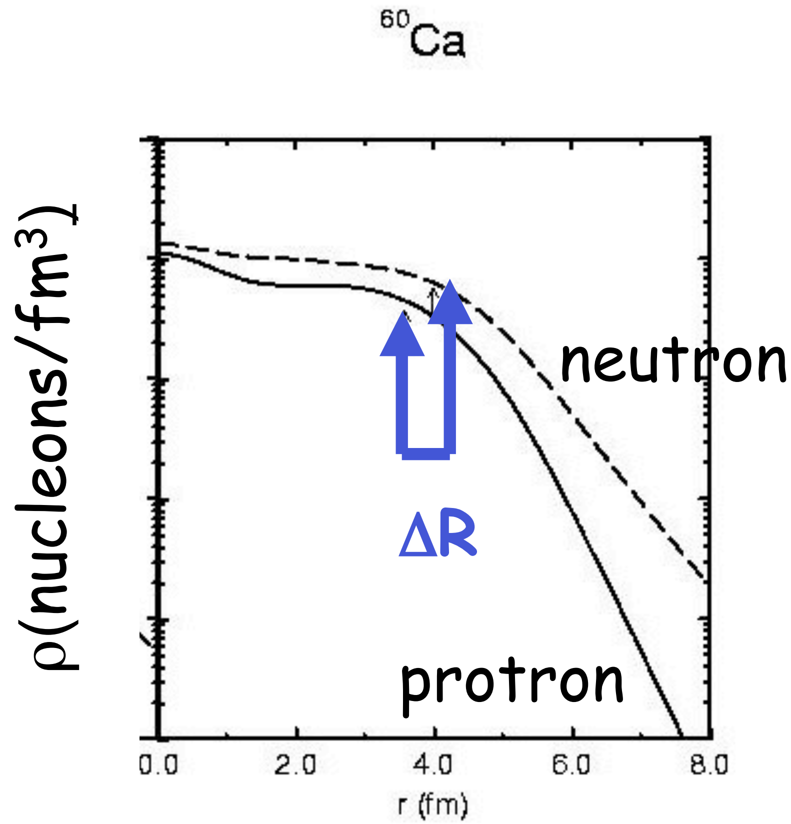
Data are still scarce. On the other side there are many predictions, mainly within mean-field + RPA (non-relativistic, relativistic, discrete, continuum, ………). For the low-lying dipole strength different models predict similar amounts but may differ in the nature of these states.

Let me start with the “standard” GDR (Giant Dipole Resonance) and follow its evolution as one moves from the stability line

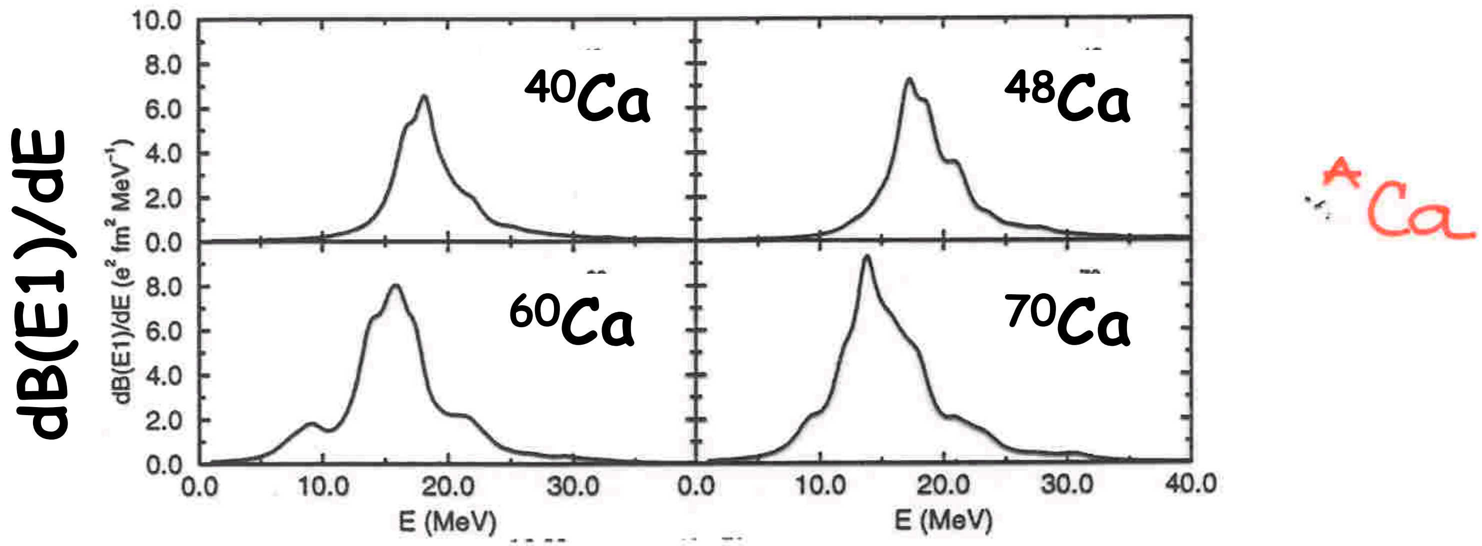
OBS Similar features for the Giant Quadrupole Resonance (GQR)

Examples: comparing the response in ^{40}Ca vs ^{60}Ca with HF (SGII) + discrete RPA

First step: HF densities: presence of skin

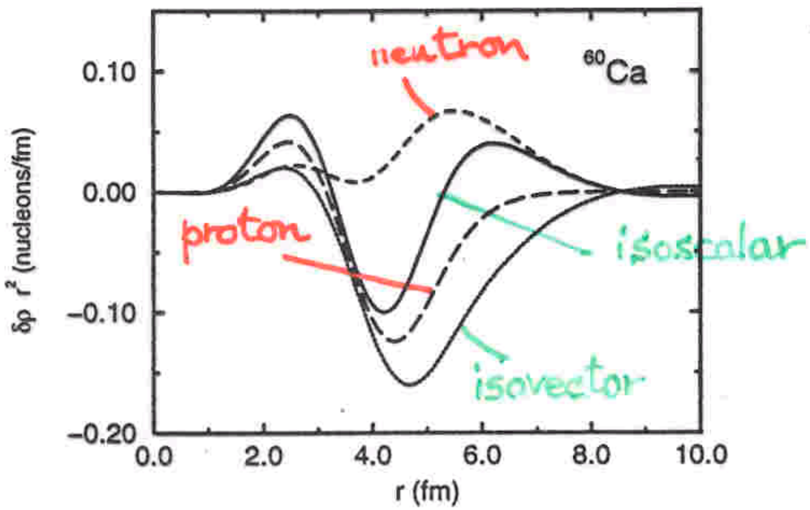


Dipole Response (HF+RPA SGII)
(Catara etal, 1996; cf also Hamamoto etal, 1996)



Response dominated by the Giant Dipole Resonance (GDR)

Transition densities to Giant Dipole Resonance (HF+ RPA)



Transition density with nonvanishing isoscalar component

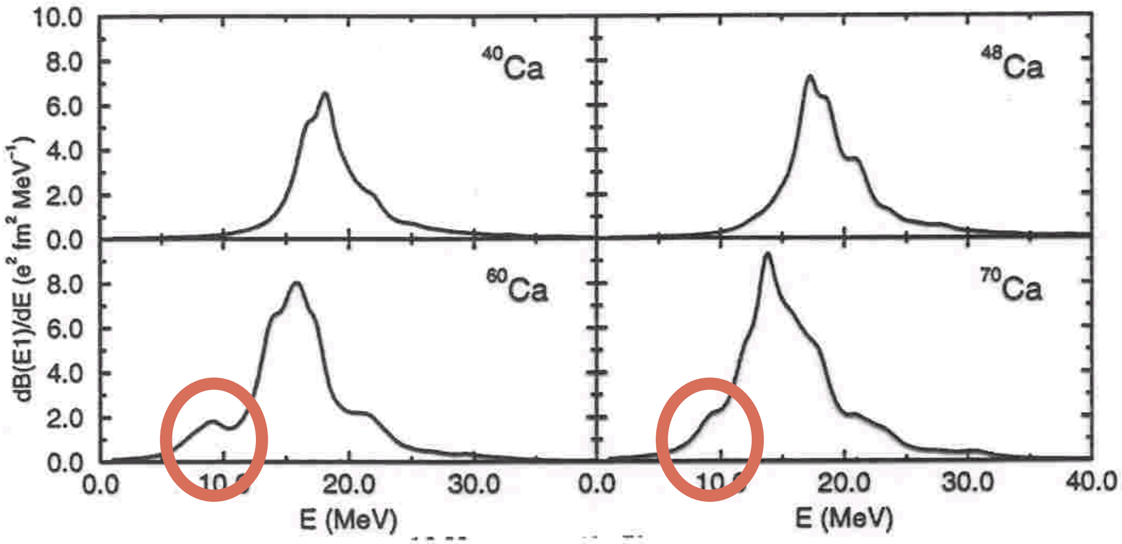
The isoscalar/isovector mixed character of the GDR opens the possibility of exciting the state by isoscalar nuclear field (as in (α,α') reactions). In fact the isoscalar transition density (and the consequent isoscalar nuclear formfactor) becomes, in leading order, directly proportional to the neutron skin Δr. So the excitation of the GDR via isoscalar fields may provide a tool to determine the neutron skin Δr.

So far for the usual Giant Dipole Resonance. But what about the low-lying region (7-10 MeV)?

Obs We are NOT discussing here the threshold strength arising from the possible halo nature of the system

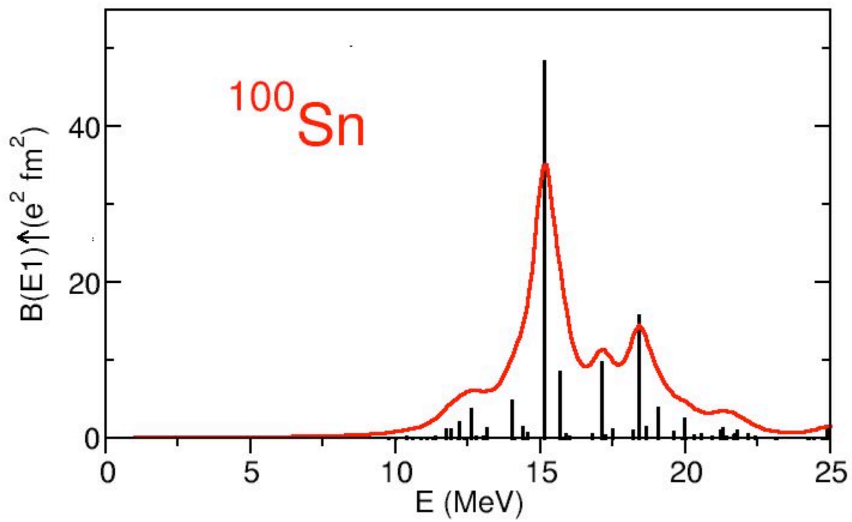
Low-lying dipole strength

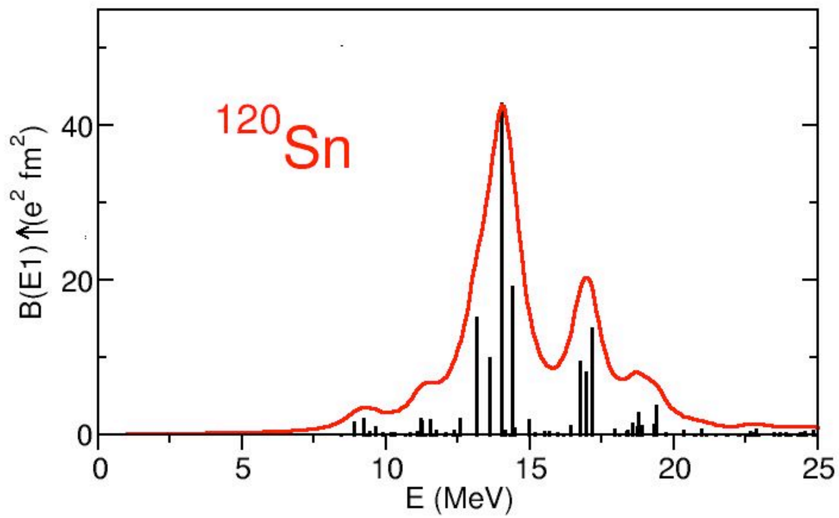
dB(E1)/dE

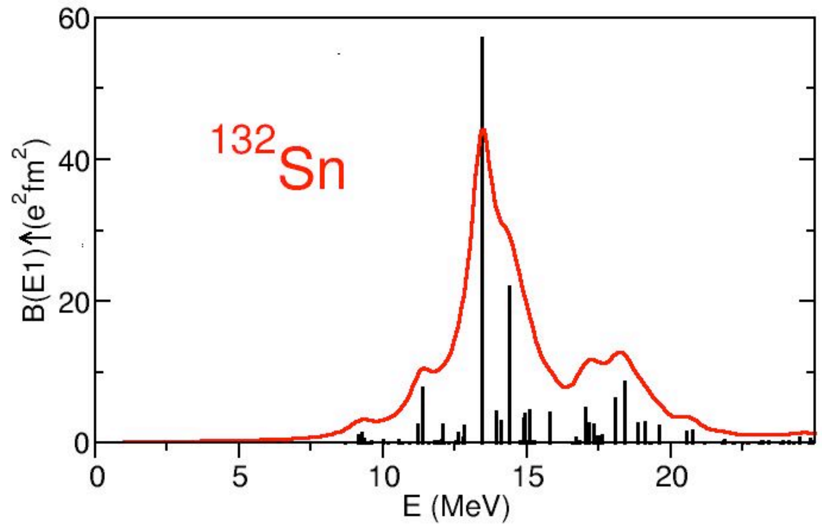


^{A}Ca

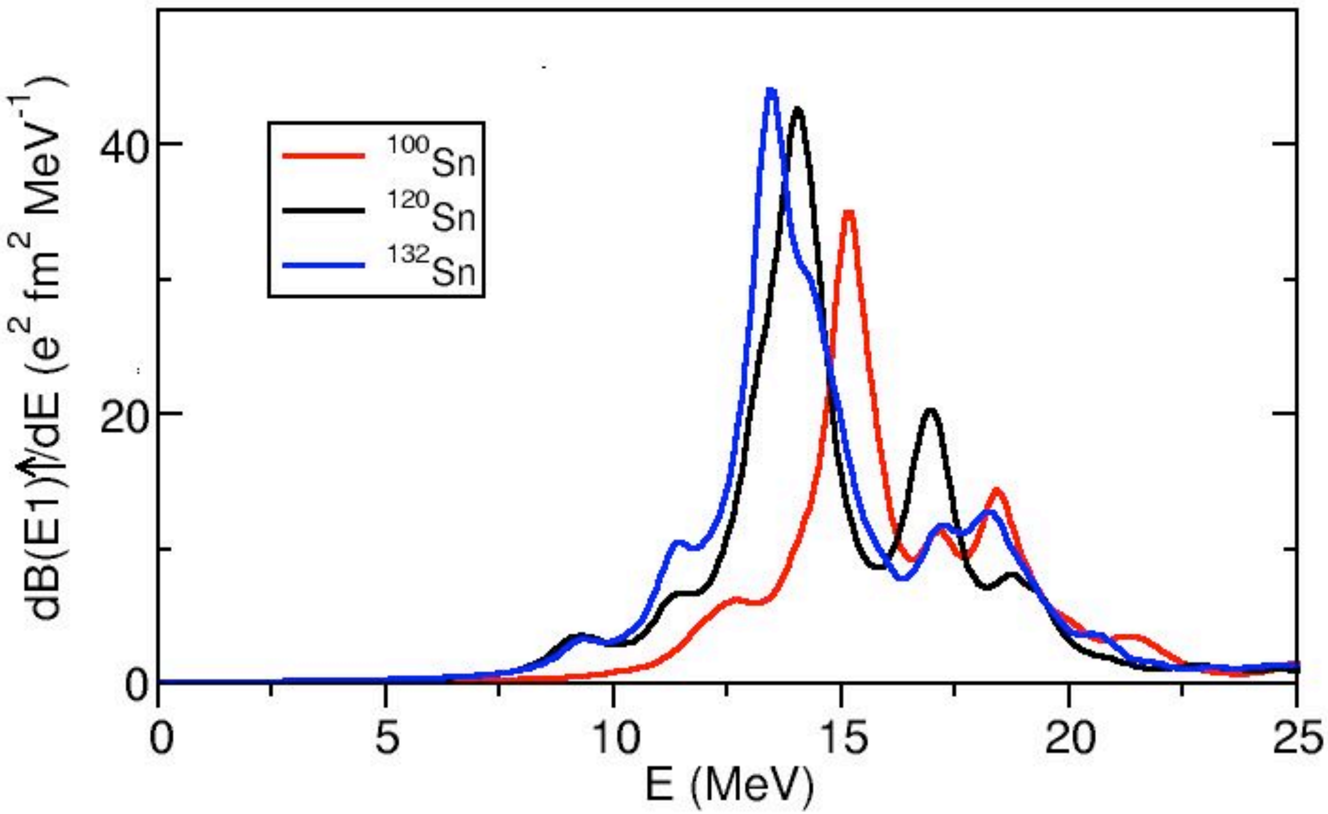
Other example:
Sn isotopes
(Lanza etal, 2009)





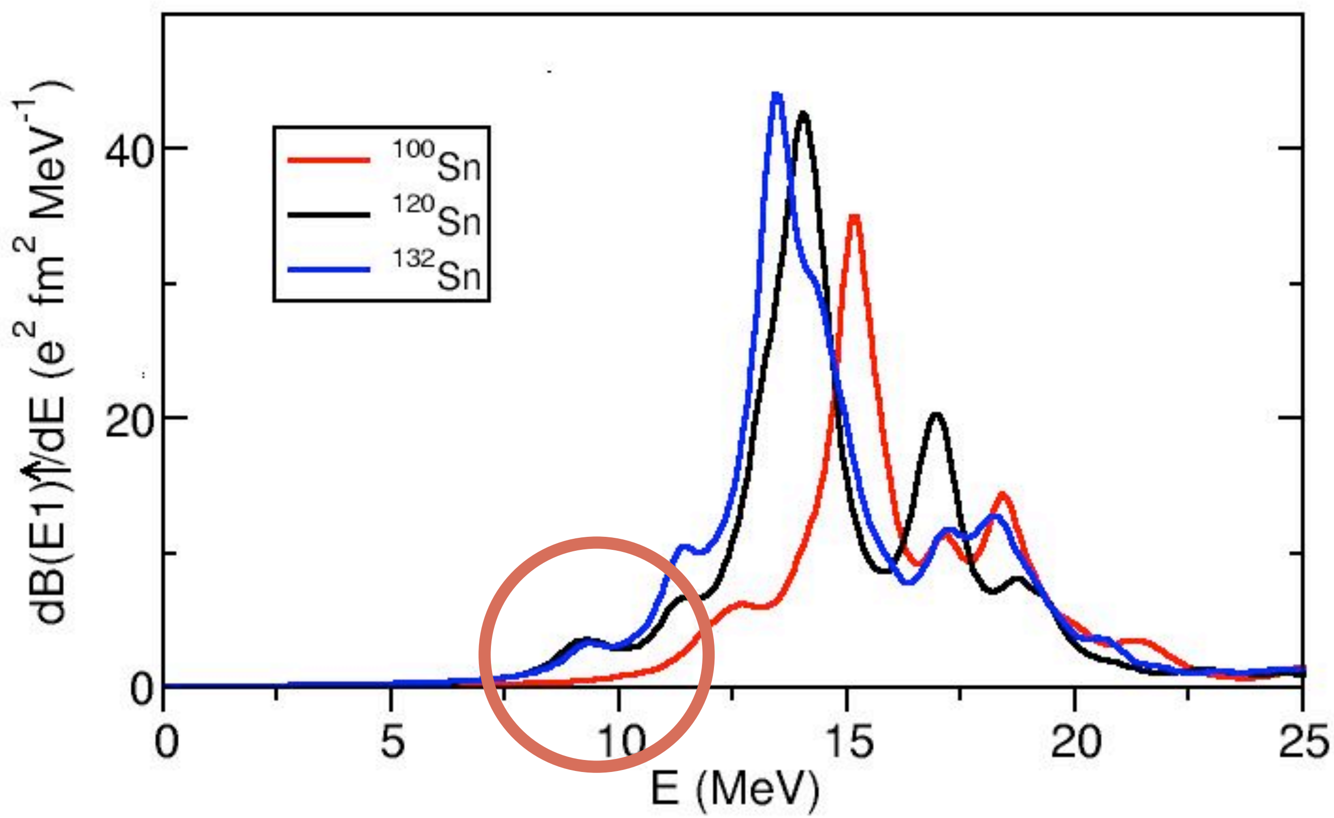


Dipole strength distribution in Tin isotopes

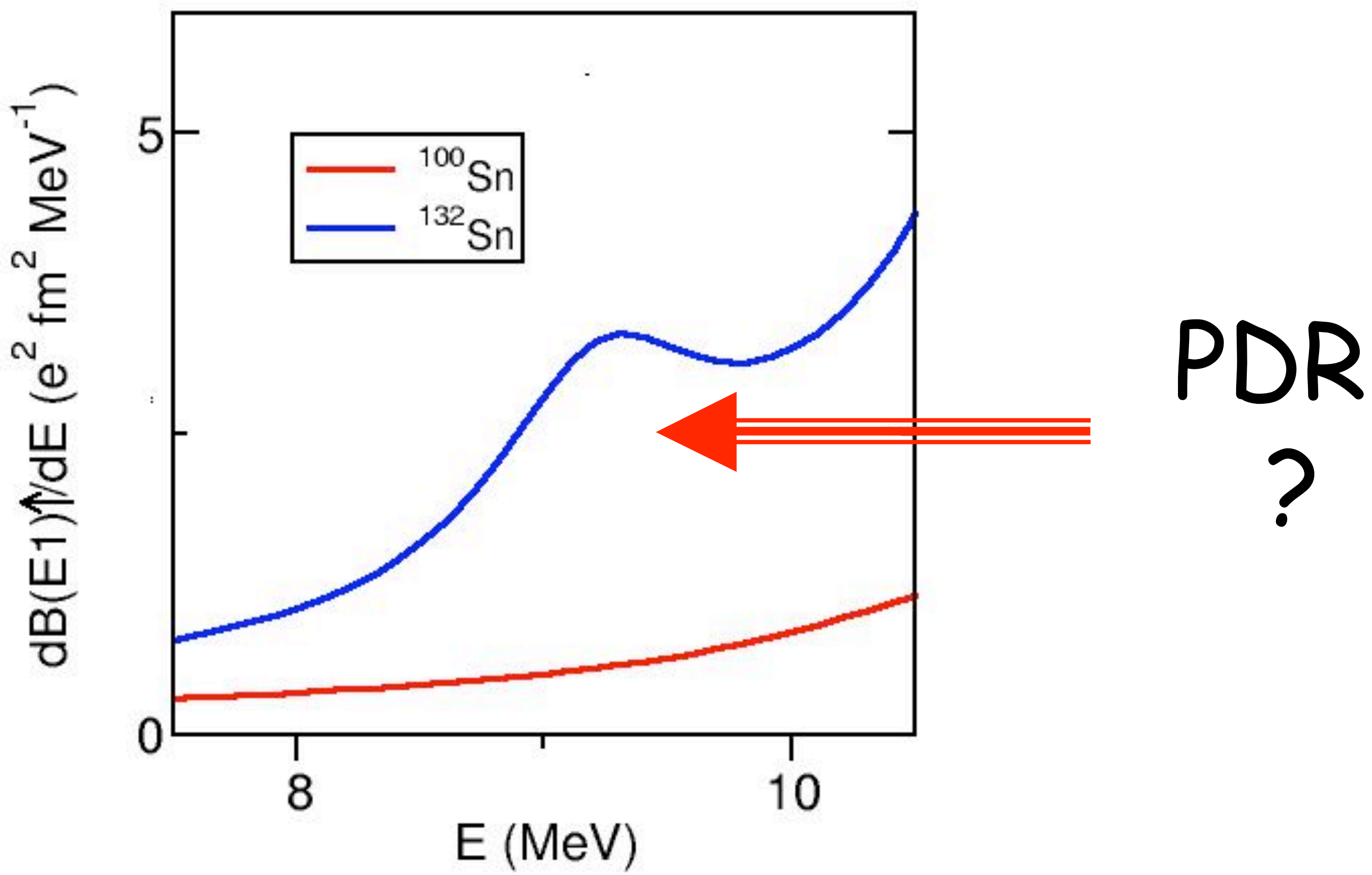


HF+RPA (SGII)

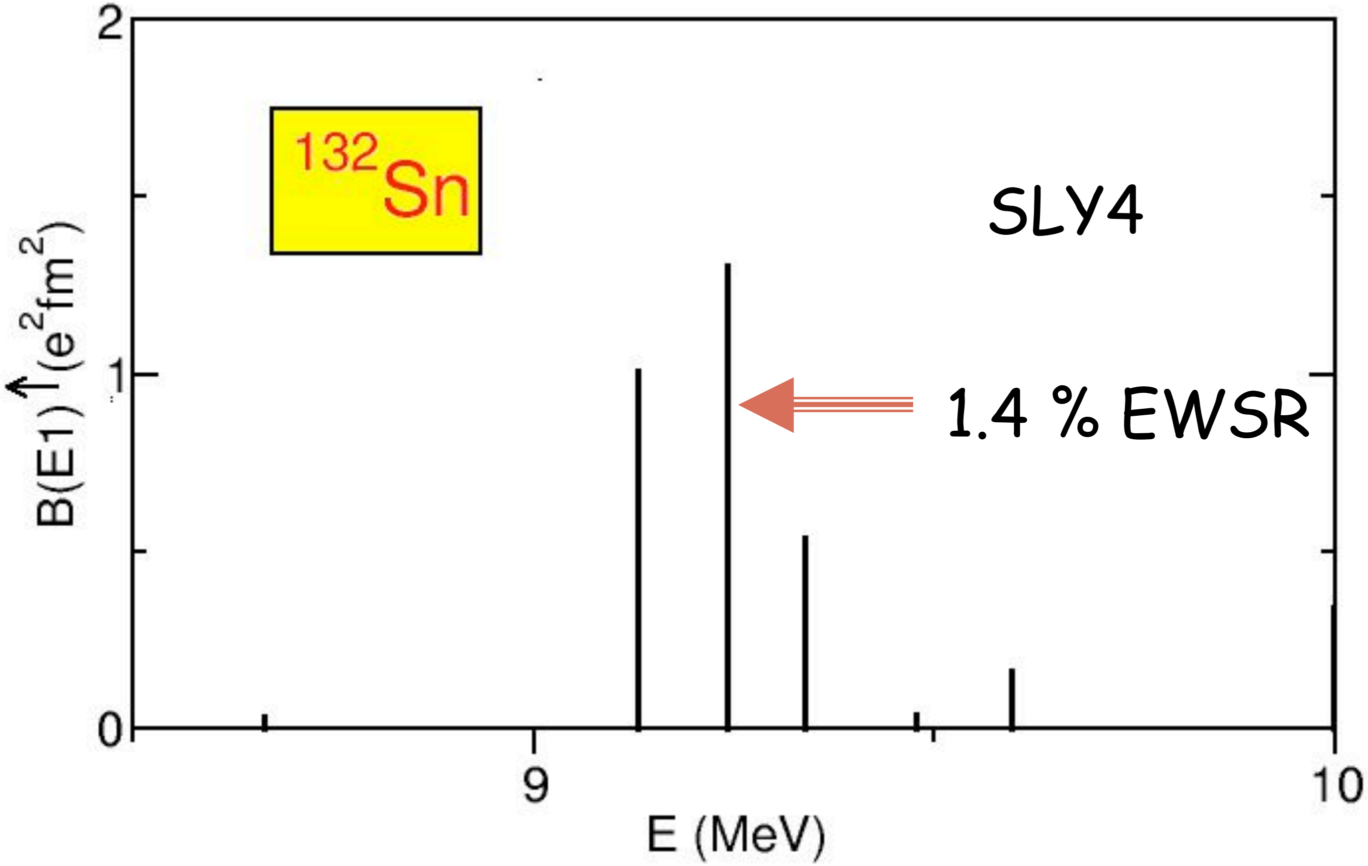
..... dipole strength in low-lying region .....



Low-lying dipole strength



Dipole response



The states in the low-energy region only collect few percent of the EWSR
How can we put them into better evidence?

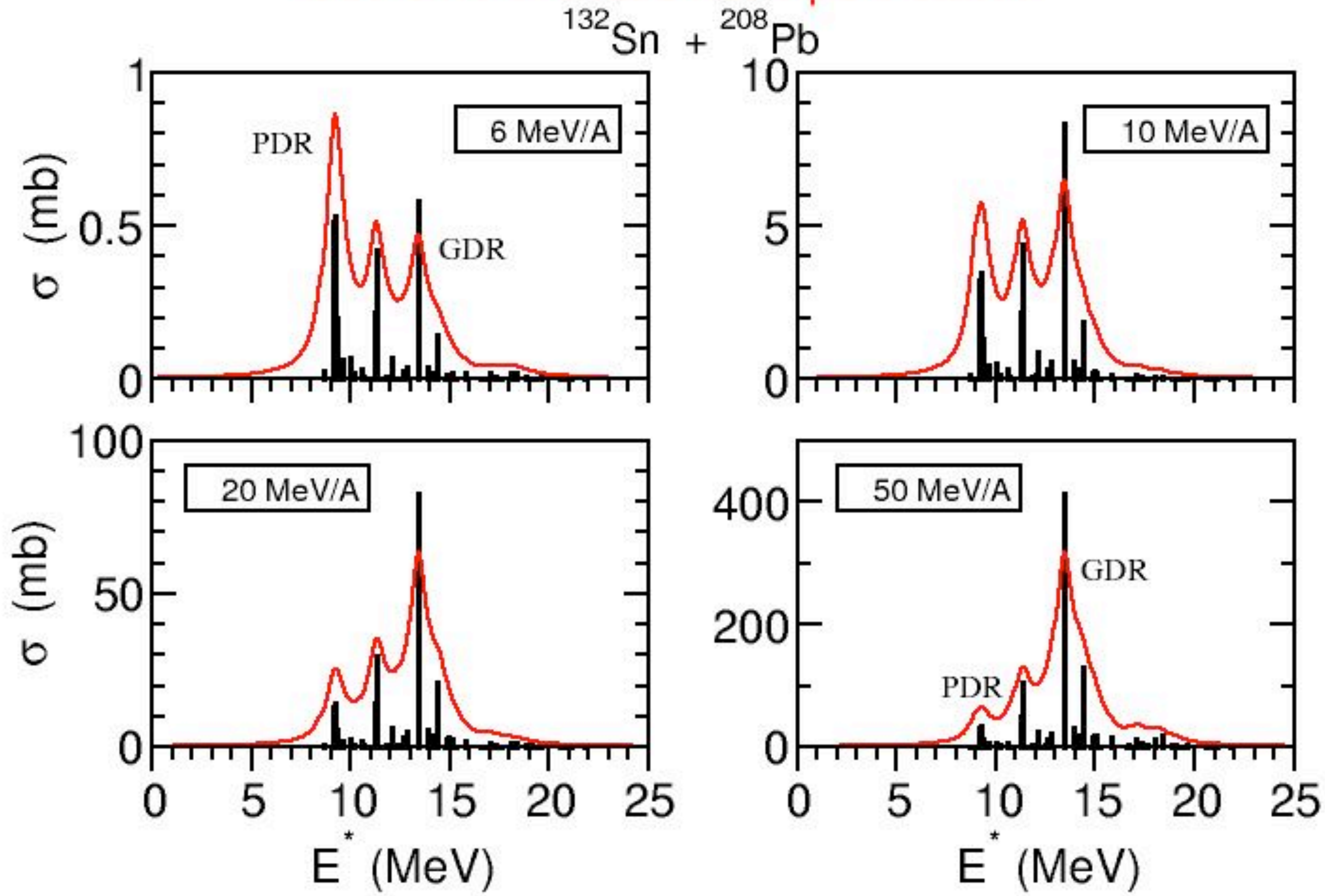
One possibility: Coulomb excitation

- At high energy the cross sections just follow B(E1) strength distribution

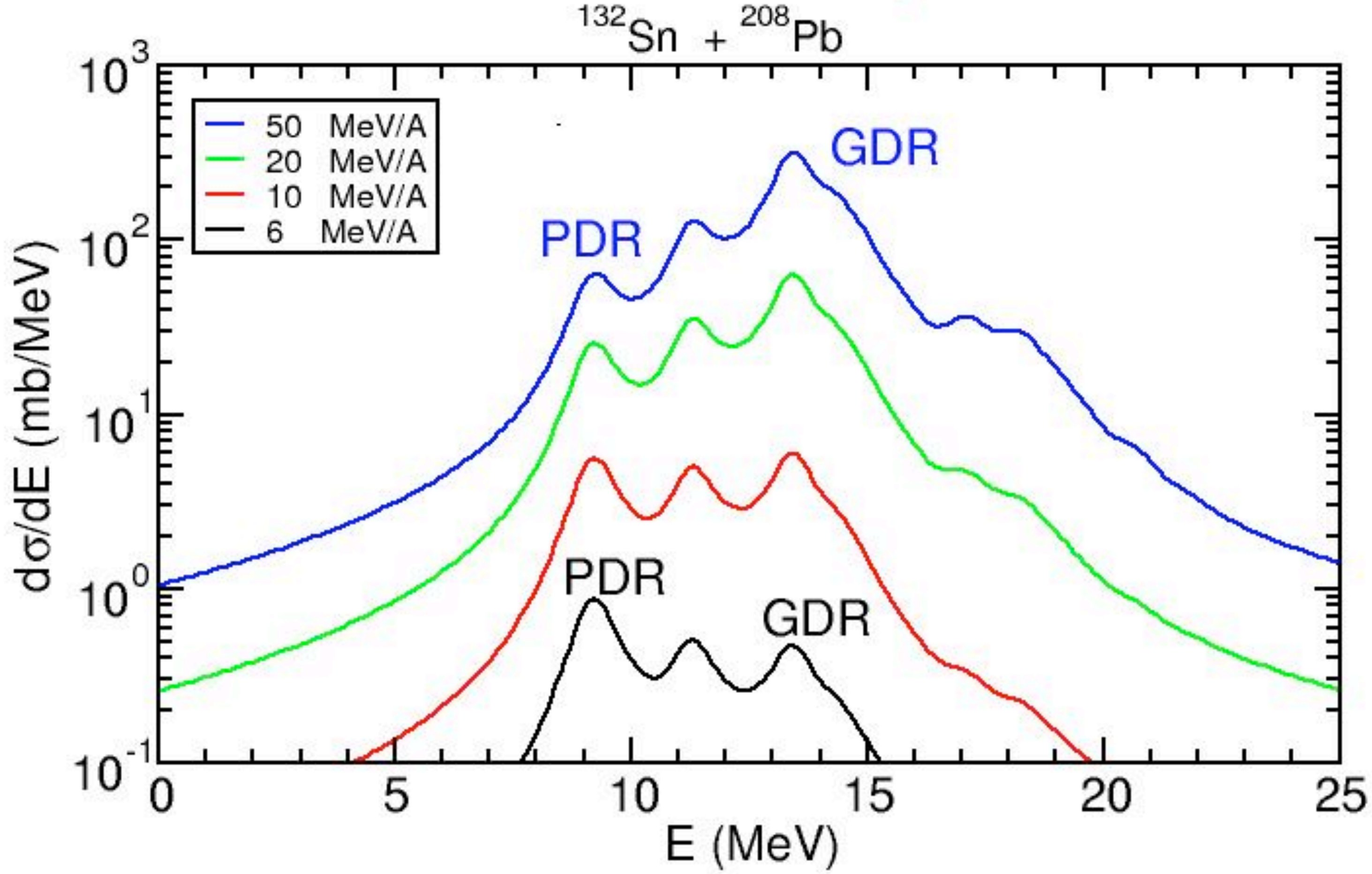
but

- at lower energy the kinematical cut-off will enhance the role of the states with lower energies

Coulomb excitation of dipole states

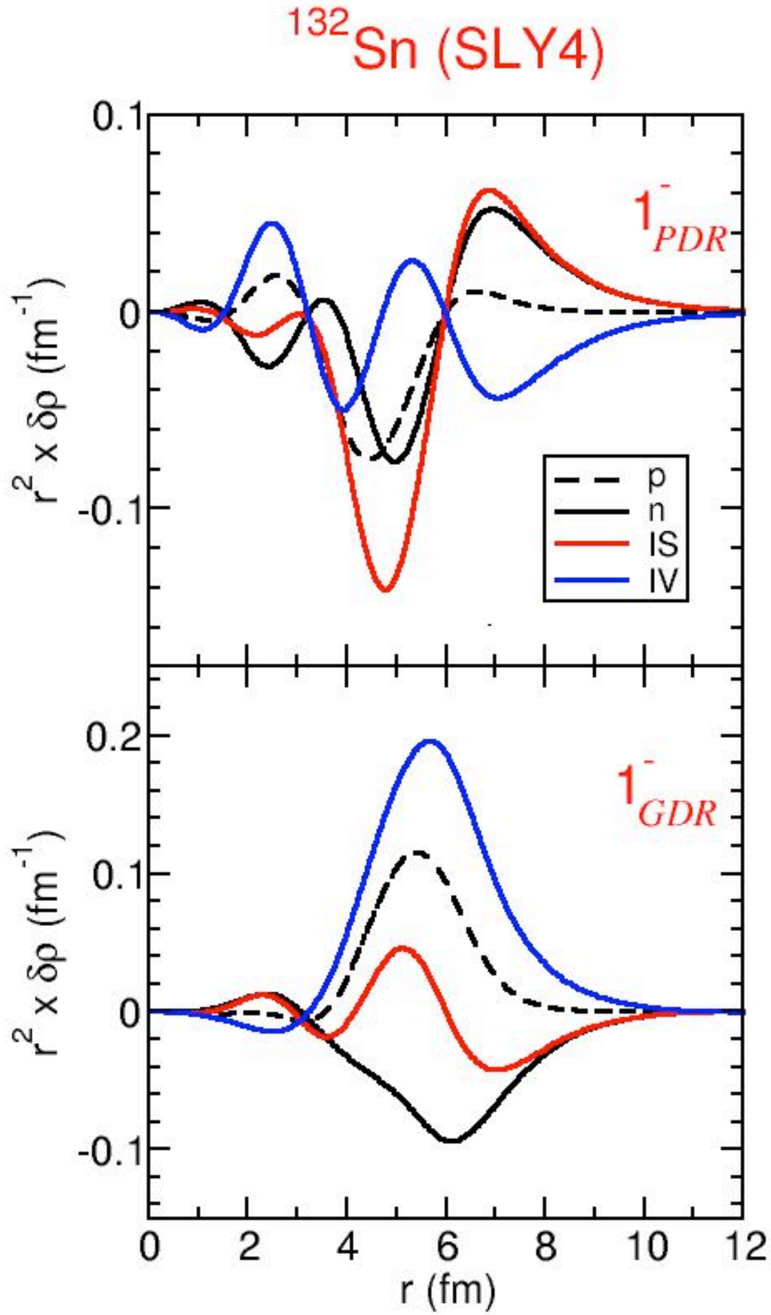


Coulomb excitation of dipole states



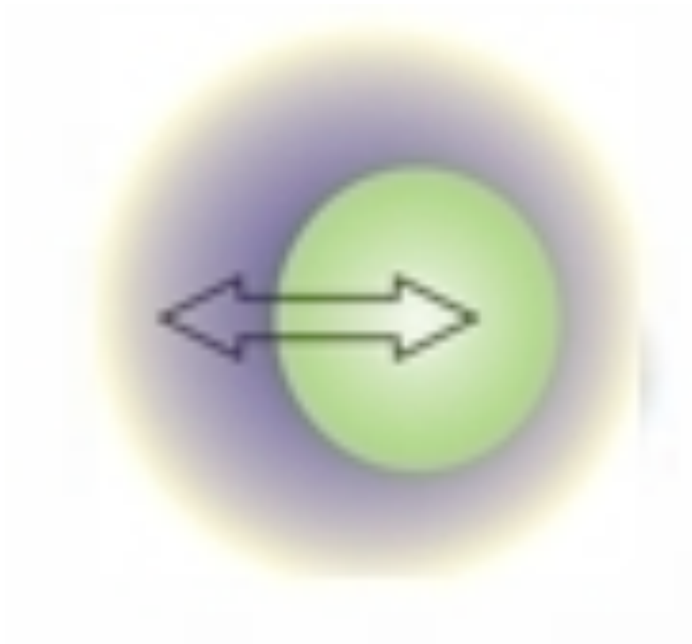
What is the nature of these low-lying states?

Let us look at the transition densities



Rather different behaviour between low-lying (PDR) and high-lying (GDR) dipole states

Possible interpretation as Pygmy Dipole Resonance: oscillations of the valence neutrons against the proton+neutron core



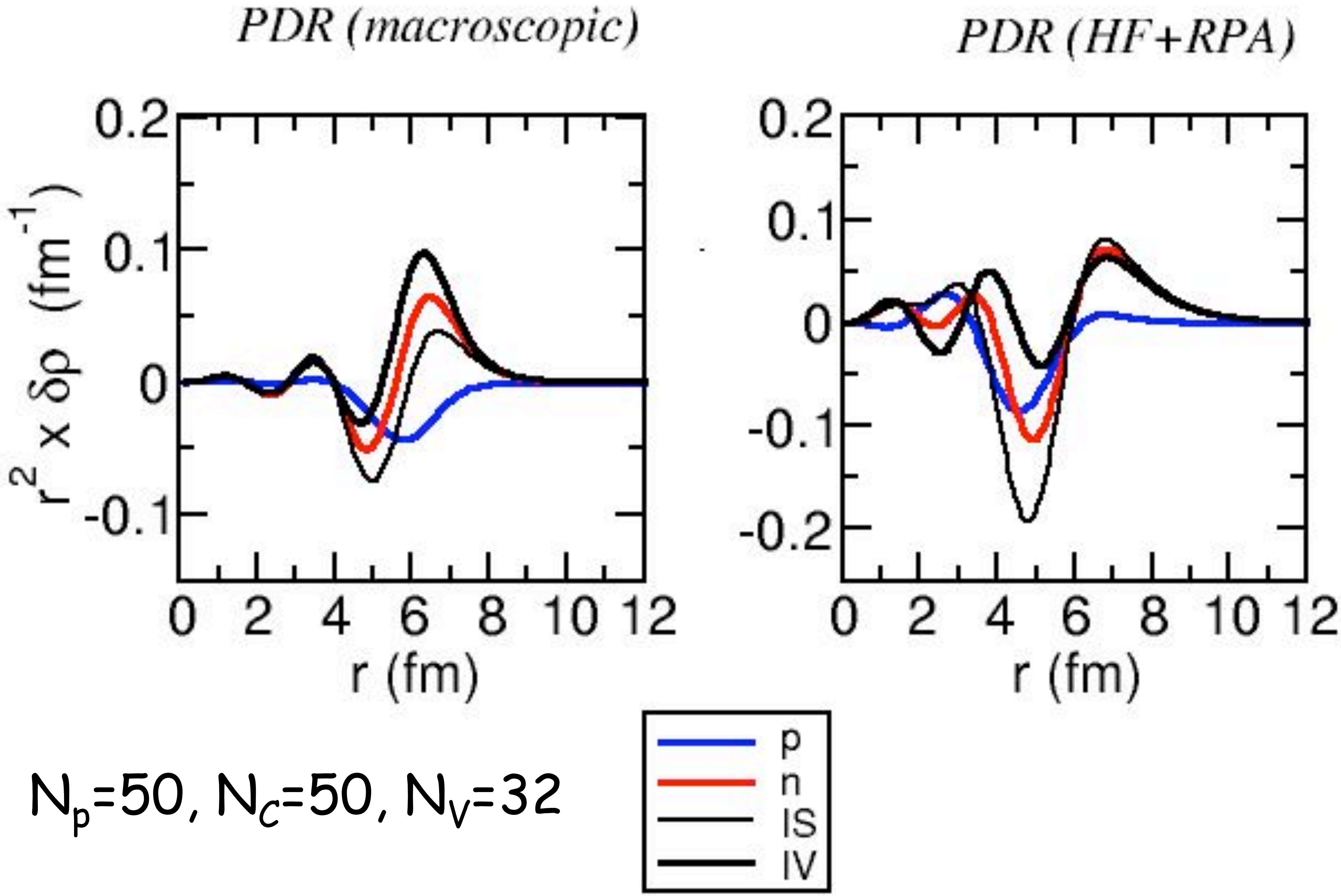
Macroscopic picture:

assuming a separation of the neutron density into a core part ρ_N^c with N_c neutrons and a valence part ρ_N^V with N_V neutrons ($N=N_c+N_V$) and defining the proton density ρ_P with Z protons, one obtains for this macroscopic collective mode the following form for neutron and proton transition densities

$$\delta\rho_N(r) = \beta\,[N_V/A\; d\rho_N^c(r)/dr - (N_c+Z)/A\; d\rho_N^V(r)/dr]$$

and

$$\delta\rho_P(r) = \beta\,[N_V/A\; d\rho_P(r)/dr]$$



N_p=50, N_C=50, N_V=32

Coulomb excitation processes provide information only on B(Eλ) matrix elements (i.e. on the integrated transition densities). More precise information on the transition densities can be obtained from nuclear excitation processes via the corresponding nuclear formfactors

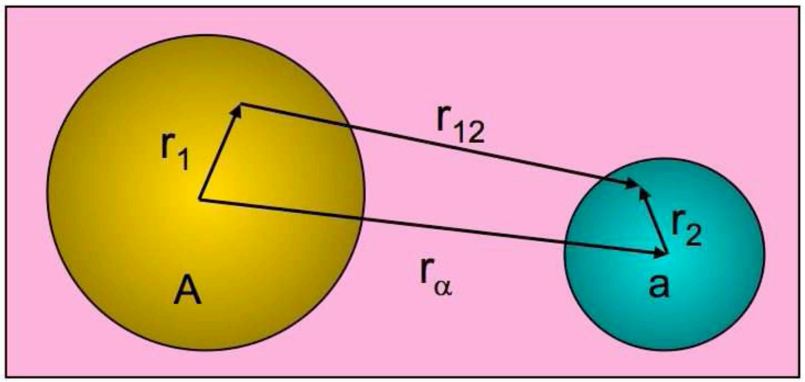
Nuclear inelastic formfactor obtained by doublefolding the transition density with the projectile density and the NN interaction (here taken to be M3Y)

$$F = \int\int \delta\rho_A(r_1)\rho_a(r_2)v_{12}r_1^2dr_1r_2^2dr_2$$

$$v_{12} = v_0(r_{12}) + v_1(r_{12})\boldsymbol{\tau_1}\cdot\boldsymbol{\tau_2}$$

so including both isoscalar and isovector components

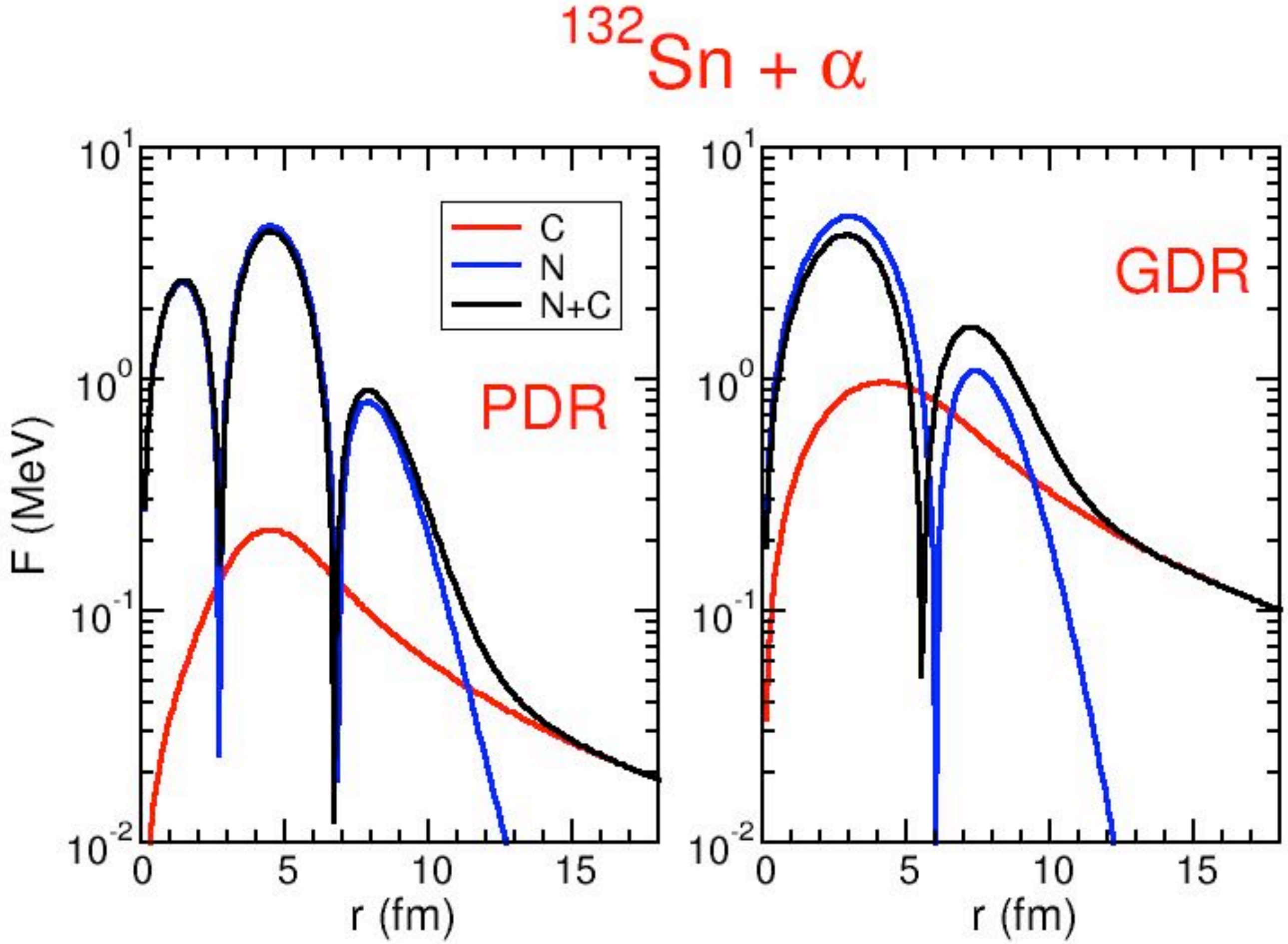
$F = F_{isoscalar} + F_{isovector}$



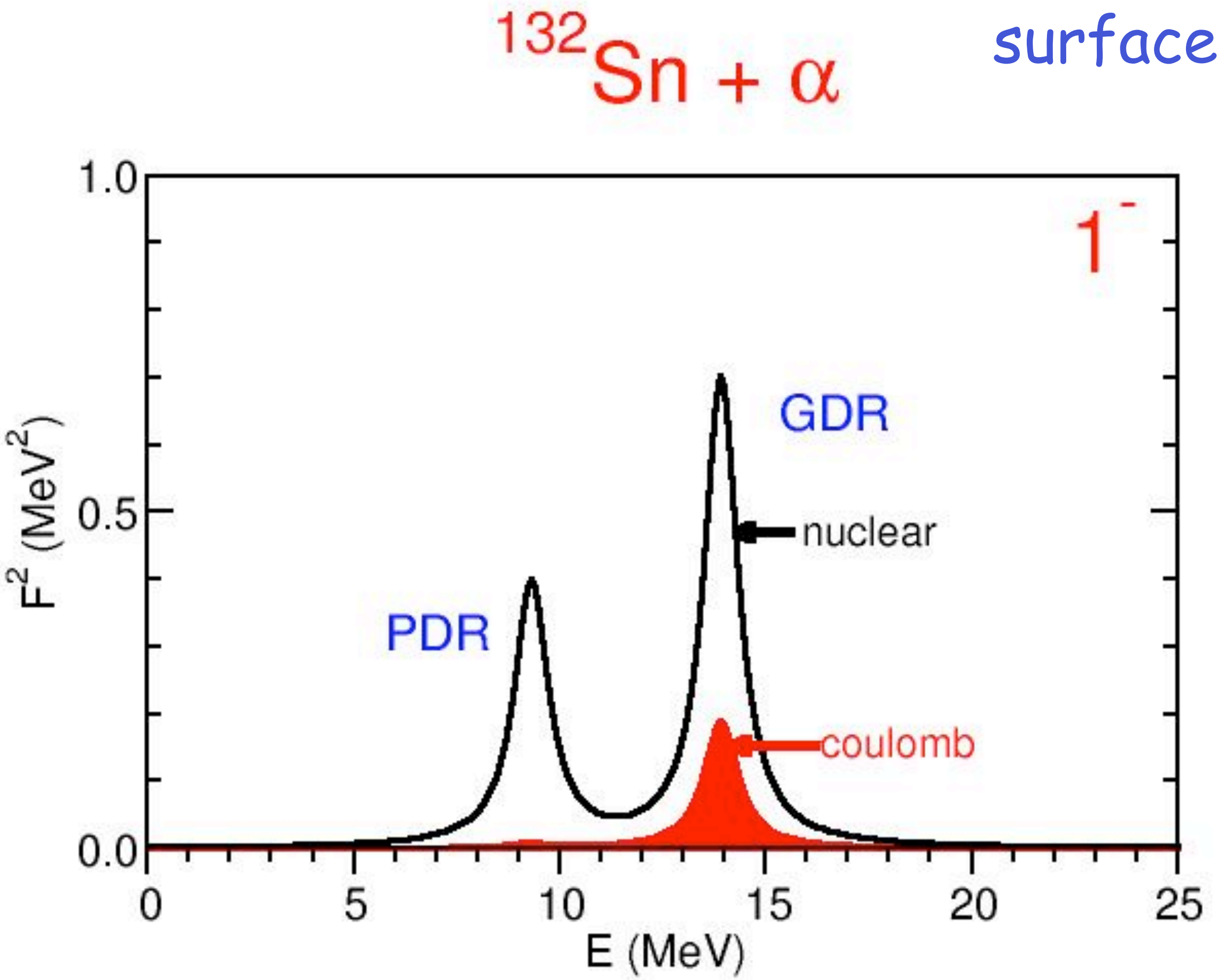
We consider the excitation of the Pygmy and Giant dipole states in ^{132}Sn by different projectiles: α, ^{40}Ca and ^{48}Ca

In the first two cases ($N_a=Z_a$) only the isoscalar part is active, in the last ($N_a \neq Z_a$) both isoscalar and isovector

Nuclear and Coulomb formfactors

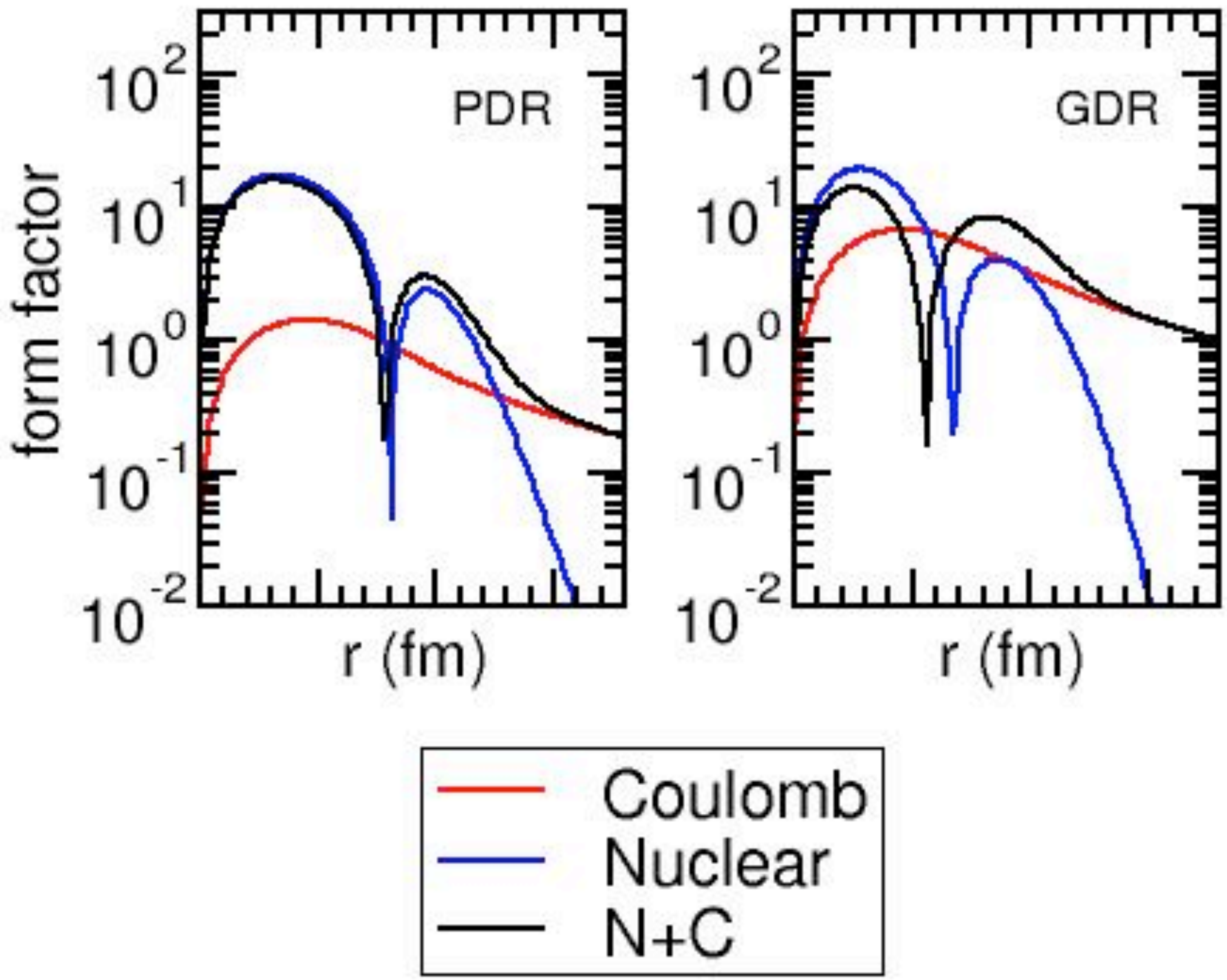


Nuclear and Coulomb formfactors (calculated at the surface)



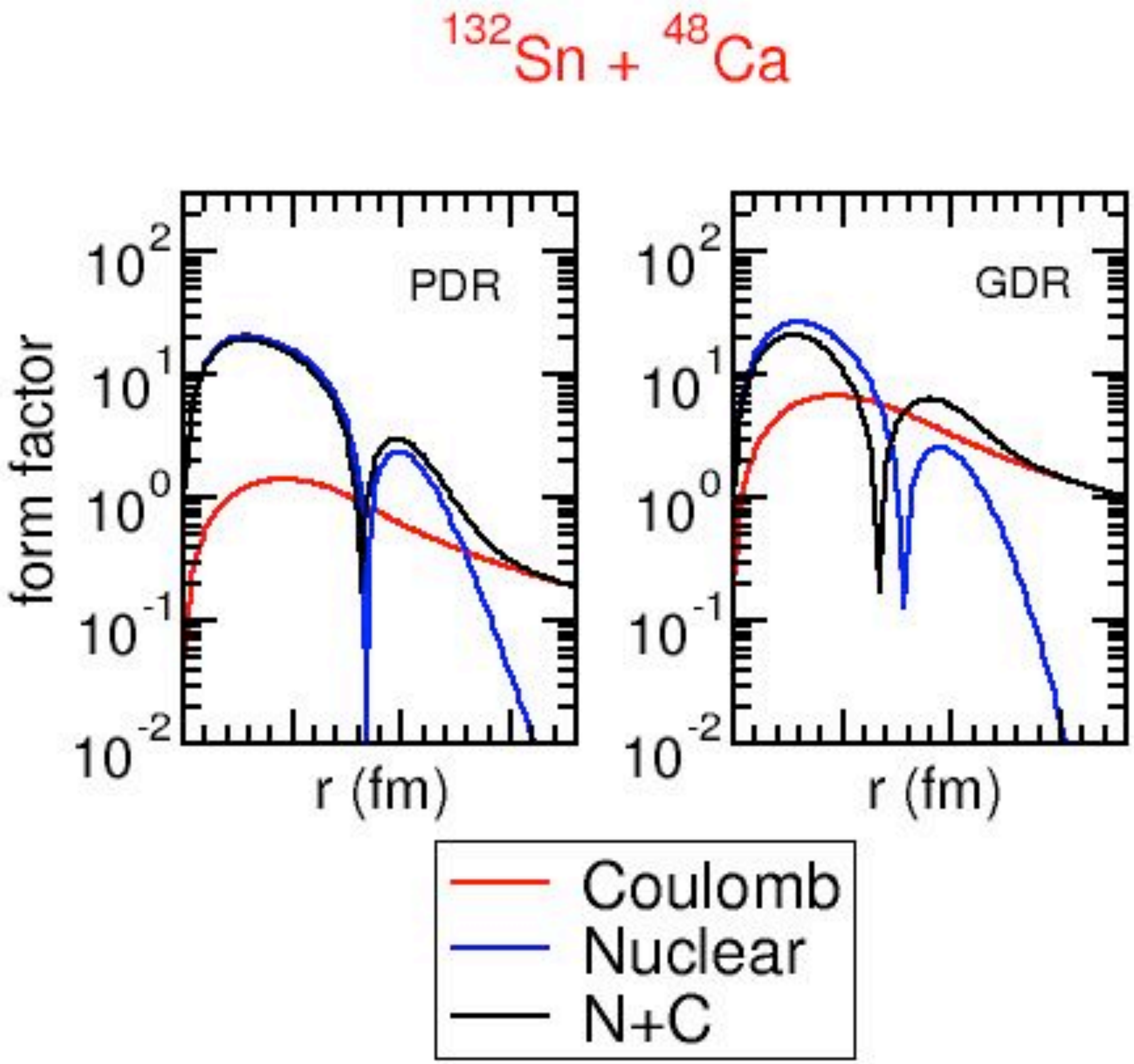
$^{132}Sn + ^{40}Ca$

Nuclear and Coulomb formfactors

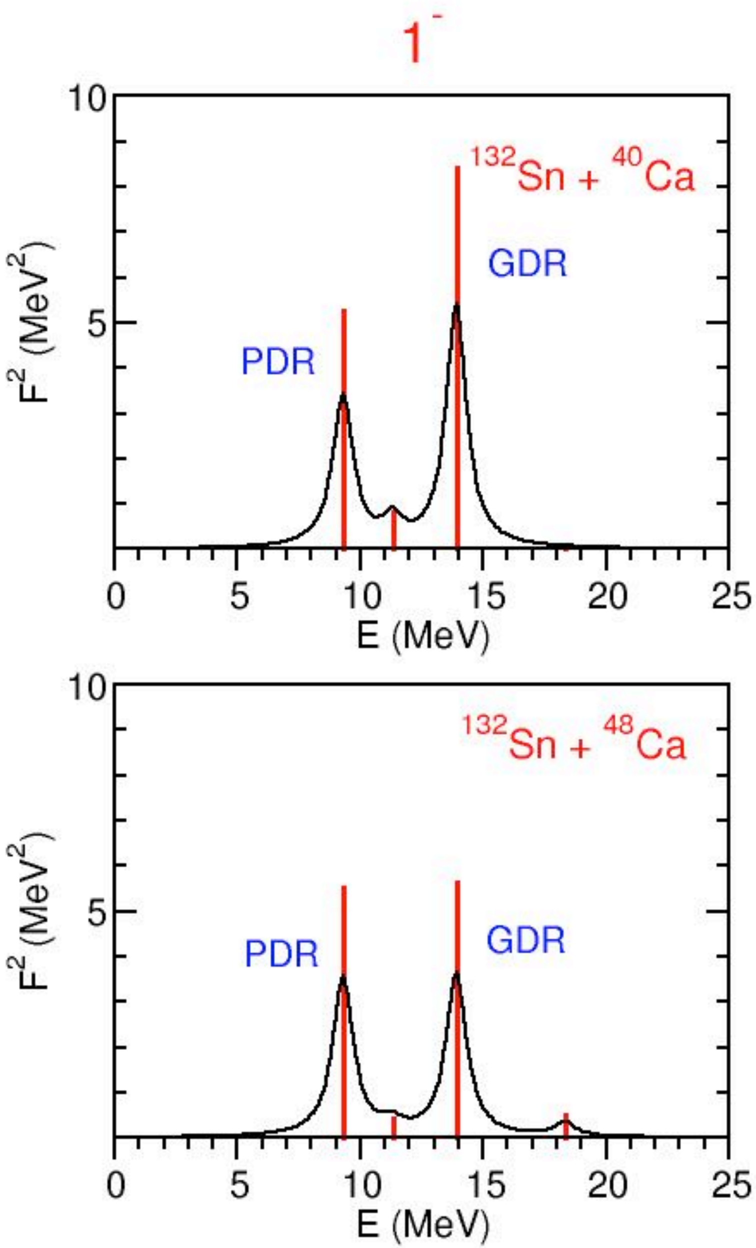


Active only the isoscalar field

Nuclear and Coulomb formfactors



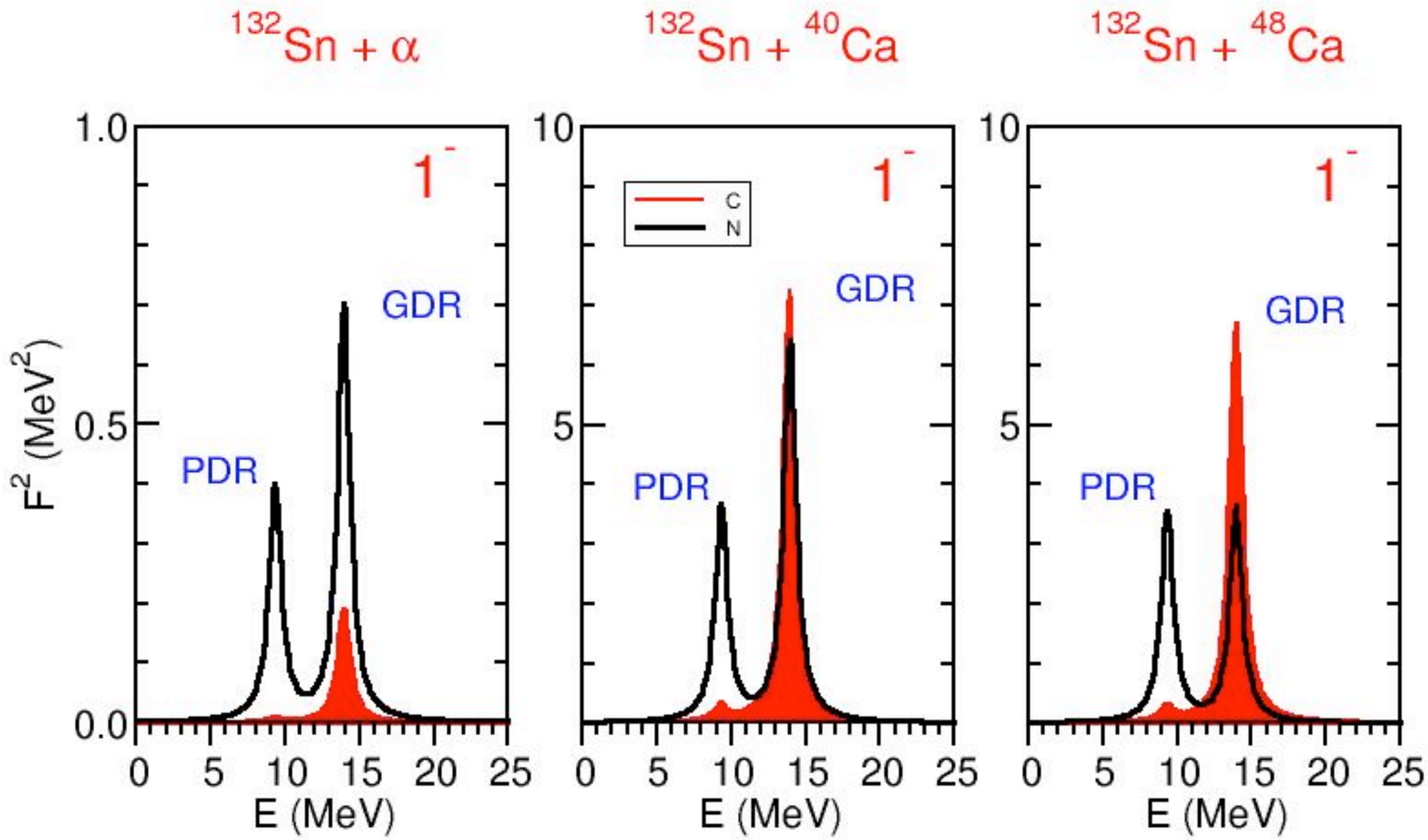
Active both isoscalar and isovector fields



Nuclear formfactors (calculated at the surface)

Different relative weights in the two cases, due to different interplay of isoscalar and isovector contributions

Nuclear and Coulomb formfactors (calculated at the surface)

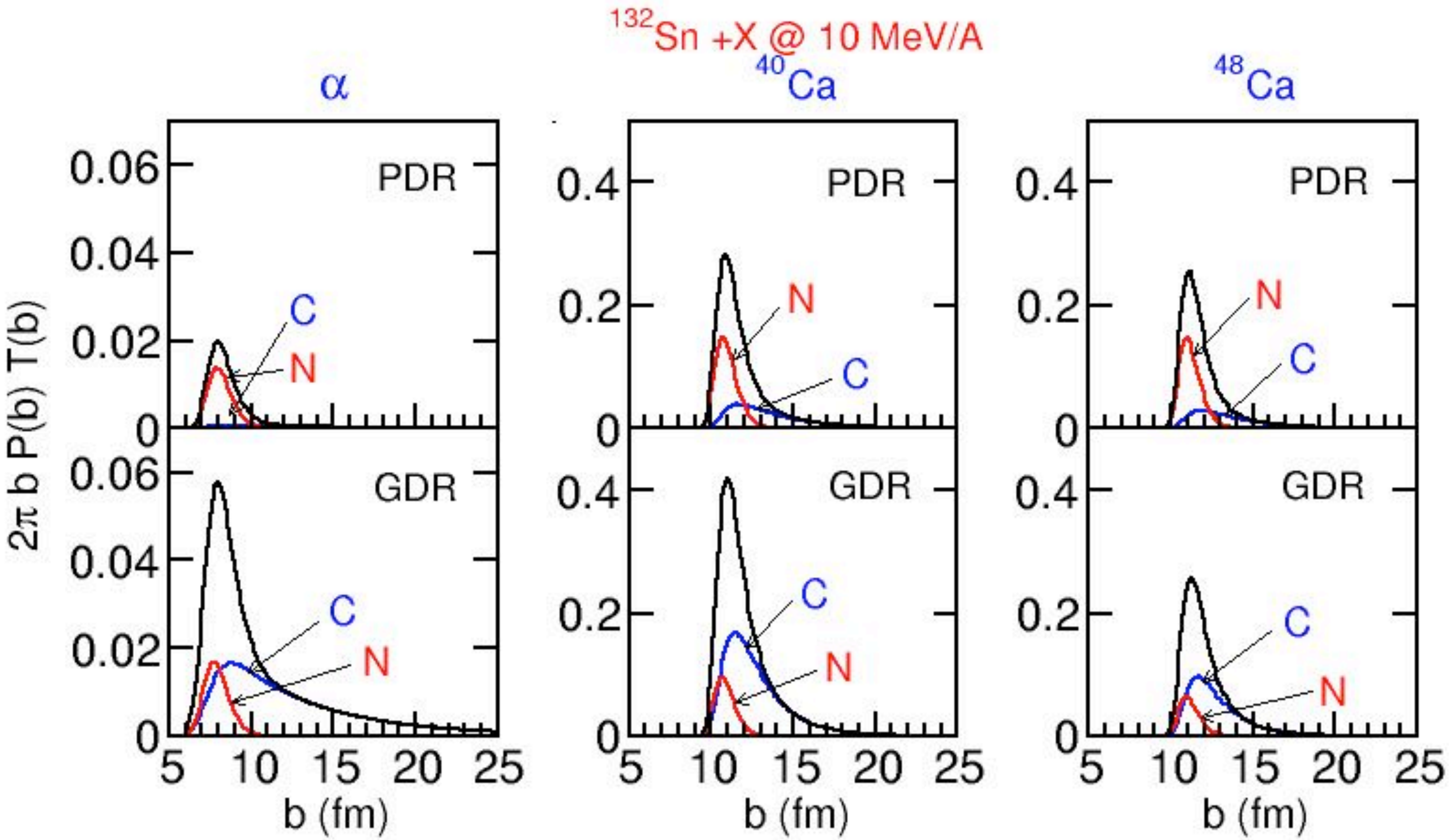


With ion-ion potential and formfactors we can now calculate cross sections (for example within the semiclassical approach)

OBS Careful elastic scattering measurements are needed to provide proper optical potentials

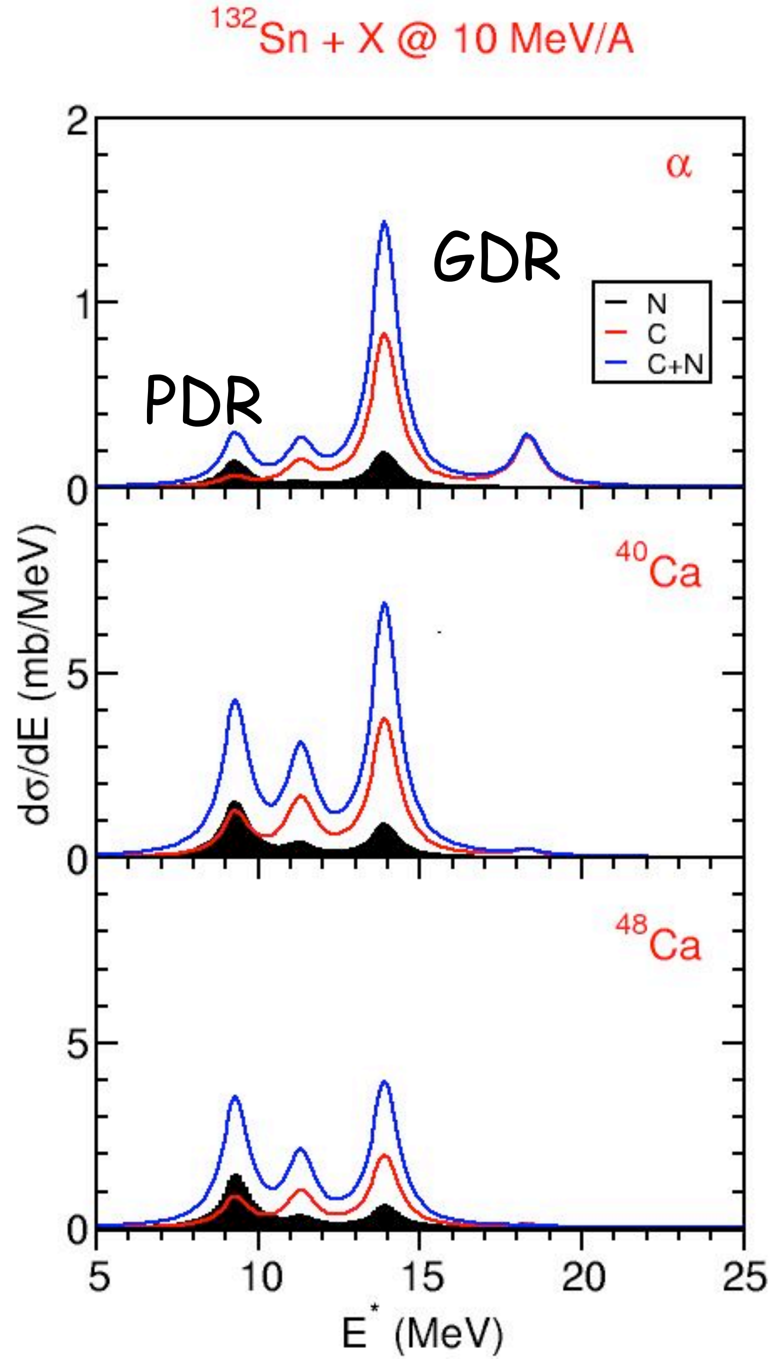
Different colliding systems

Partial wave cross sections



b : impact parameter

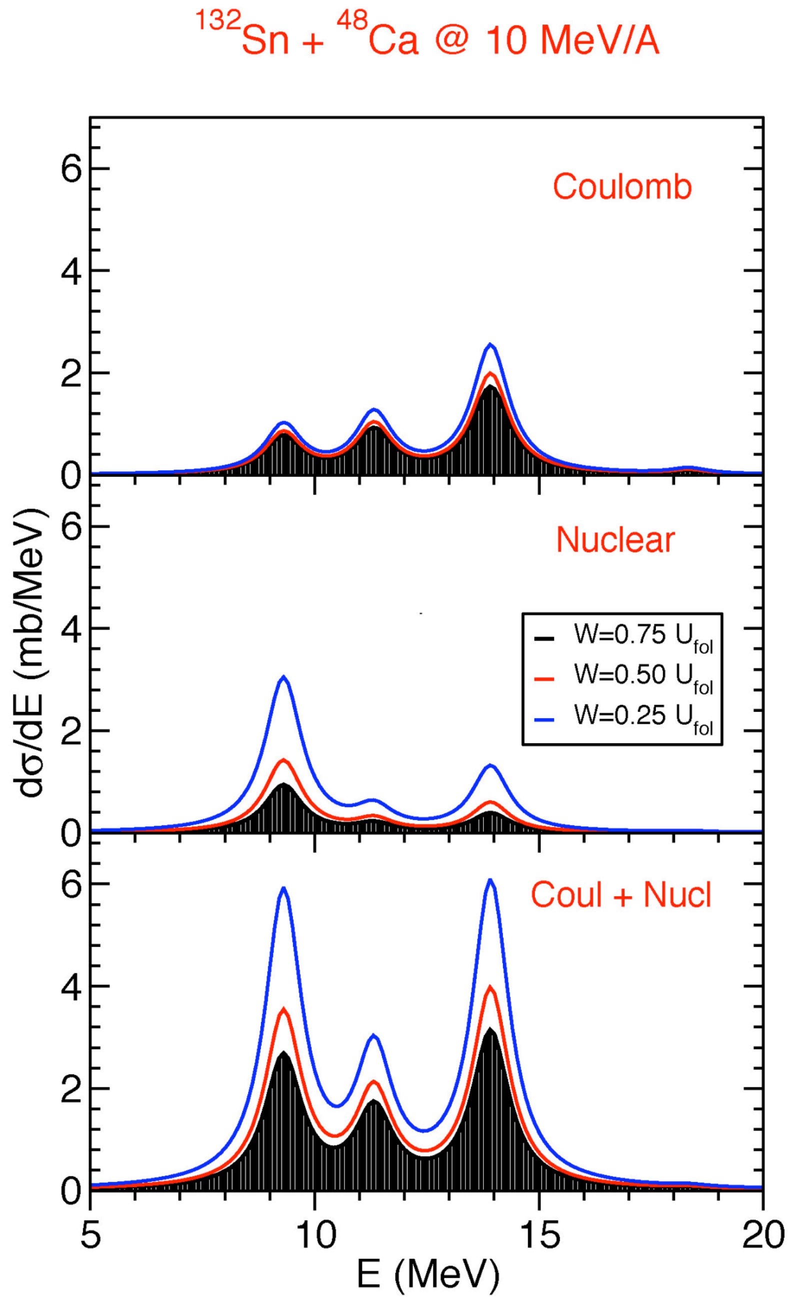
Total cross sections



Sensitivity to
the absorption

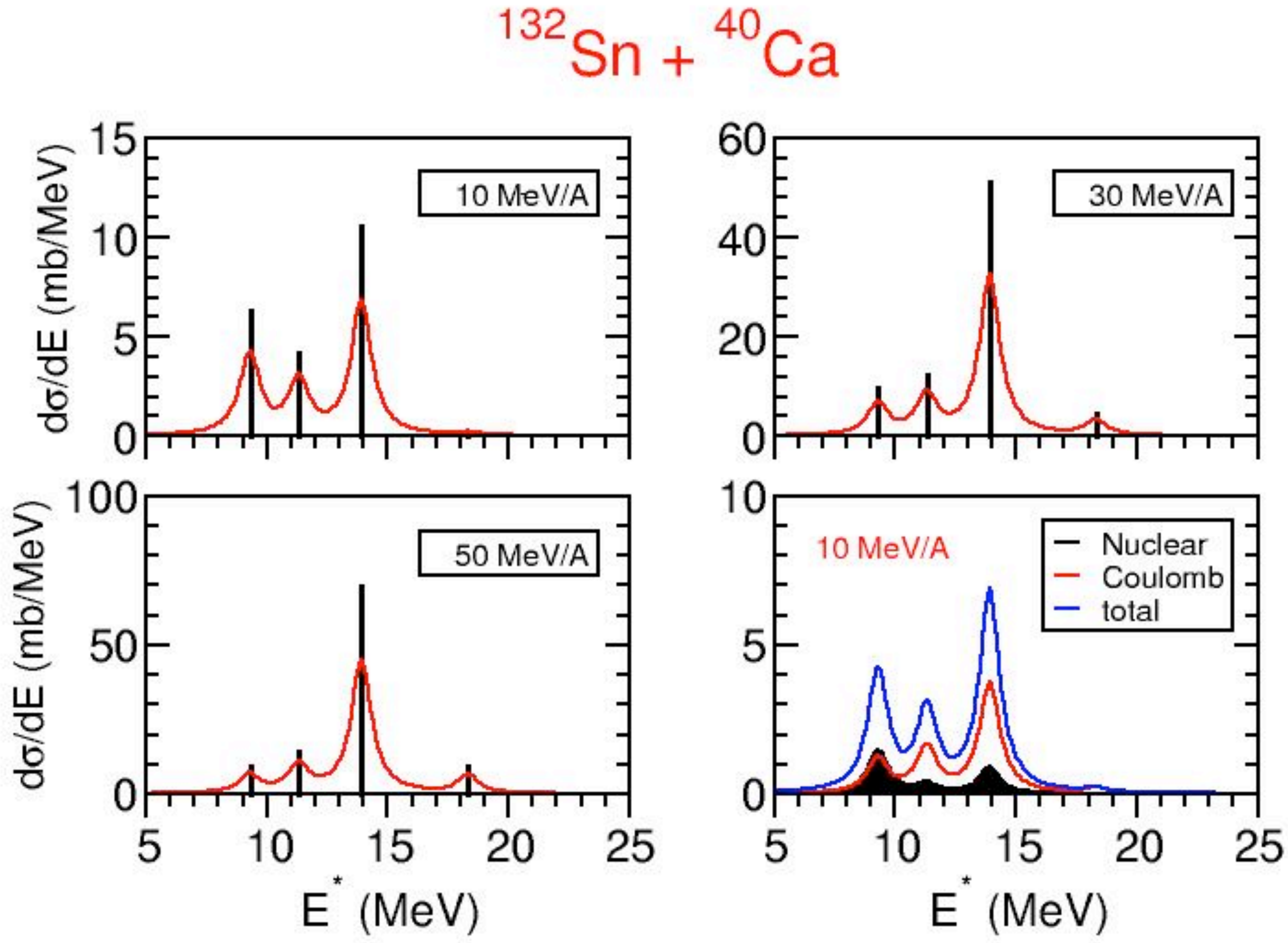
3 cases:
W=0.25V,0.5V,0.75 V

With weak absorption
the relative weight of
the nuclear contribution
increases



The nuclear contribution can naturally be enhanced by considering the differential cross sections and selecting scattering angles corresponding to grazing conditions.
An alternative possibility is to look at the total cross sections but to play with the bombarding energy, which alters the relative role of Coulomb and nuclear contributions

Different bombarding energies: different relative weights of PDR and GDR



Conclusions

The interpretation of the low-lying dipole strength as a "pygmy" dipole state of collective nature needs to be carefully checked.
Valuable information on the nature of these states can be obtained by excitation processes involving the nuclear part of the interaction, which can probe the shape of the transition densities.
The use of different bombarding energies, of different combinations of colliding nuclei involving different mixture of isoscalar/isovector components, together with the mandatory use of microscopically constructed formfactors, can provide the clue towards the solution of the problem.