Systematic calculations of electric dipole responses with fully self-consistent Skyrme-RPA

Workshop on
Gamma Strength and Level Density
in Nuclear Physics and Nuclear Technology
Dresden-Rossendorf, Aug. 30 to Sep. 3, 2010

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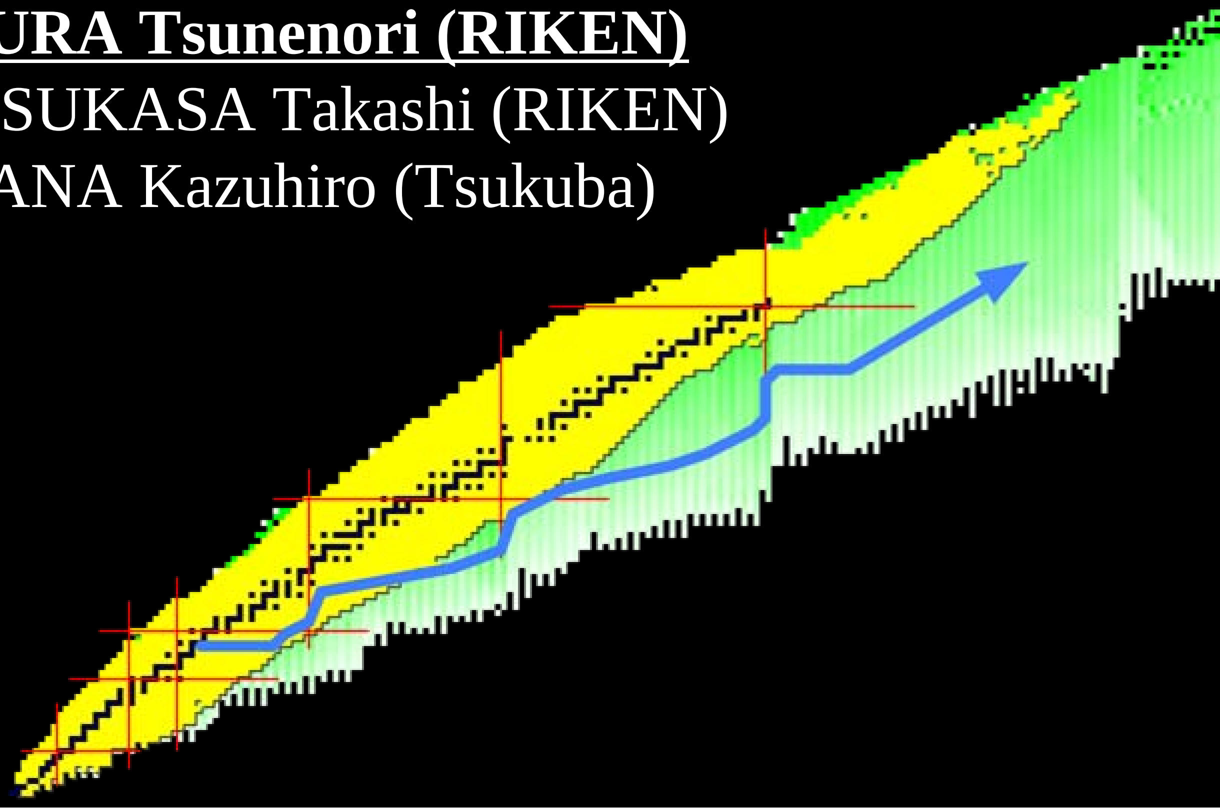
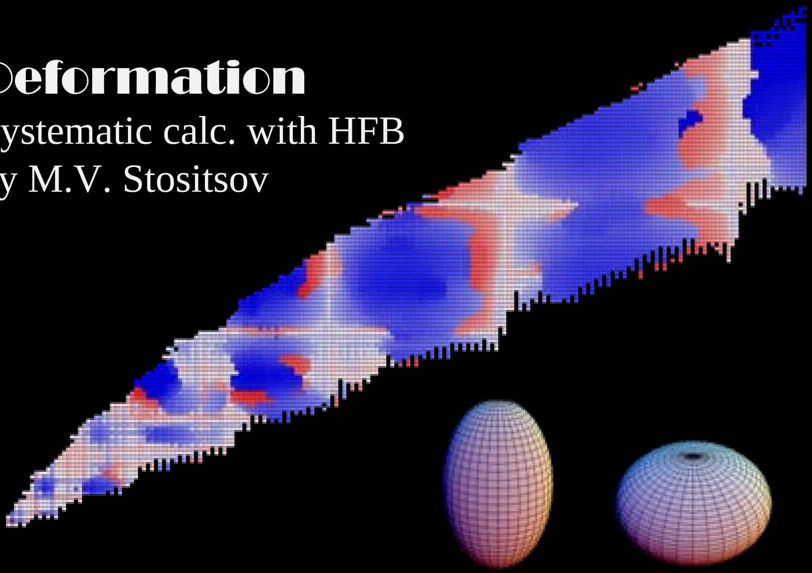


Electric dipole mode

- Simplest collective vibration mode.
- Abundant experiment data in stable nuclei.
- Pygmy dipole resonance (PDR).

Deformation
Systematic calc. with HFB
by M.V. Stositsov



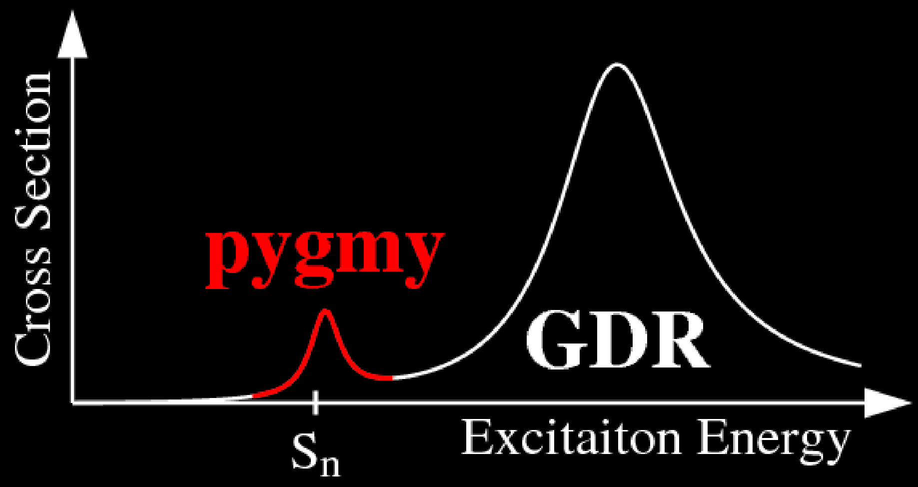
Preceding systematic calc.

- Spherical nuclei only.
- Use localized wave functions.
- Phenomenological treatment.

Systematic calculation of E1 mode

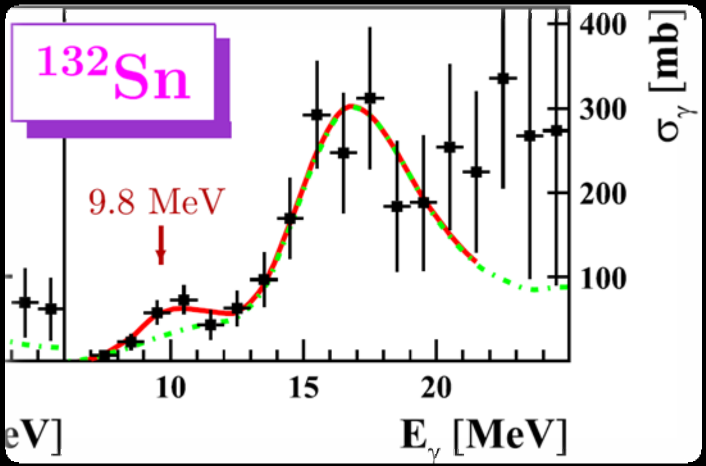
- Self-consistent calculation.
- Including deformed nuclei.
- Proper treatment of continuum states.

Pygmy Dipole Resonance (PDR)



Experiments

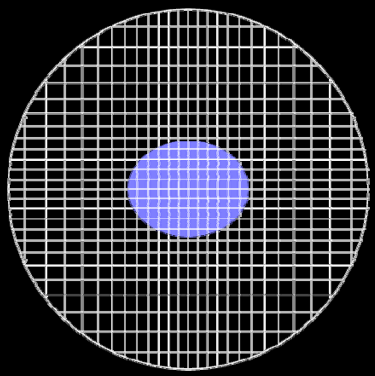
^{26}**Ne**: J. Gibelin et al., PRL101, 212503.
^{68}**Ni**: A. Bracco et al., Acta Phys. Pol. B38, 1229.
O. Wieland et al. PRL 102, 092502.
$^{130, 132}$**Sn**: P. Adrich et al., PRL 95, 132501.
^{140}**Ce**: R.-D. Herzberg et al., PLB390, 49.
^{138}**Ba**: R.-D. Herzberg et al., PRC60, 051307.
^{138}**Ba,** ^{140}**Ce,** ^{144}**Sm**: A. Zilges et al., PLB542, 43.
^{208}**Pb**: N. Ryezayeva et al., PRL 89, 272502.
$^{204, 206\text{-}208}$**Pb**: J. Enders et al., NPA724, 243.



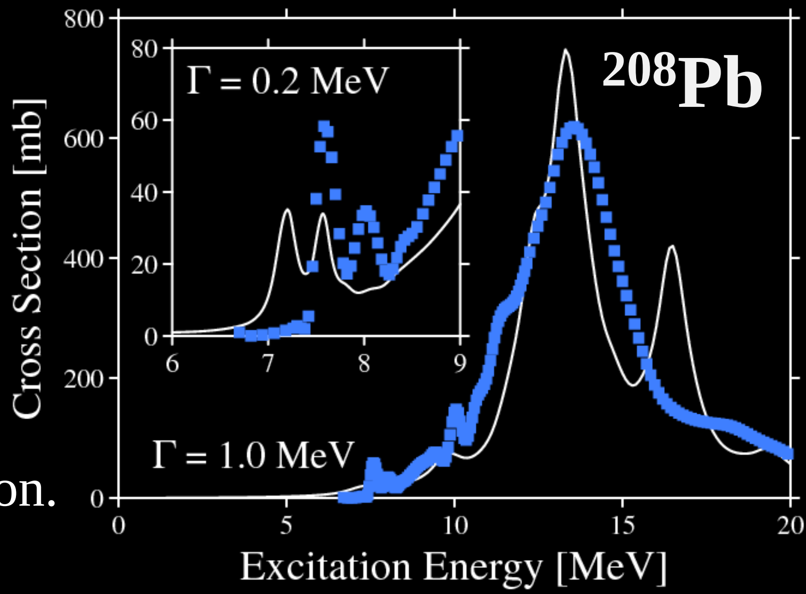
- **Appear around neutron threshold energy.**
- **Strong impact on r-process.**
- **Nature of PDR is not well-known.**
  - ➢ **collective or single-particle?**
  - ➢ **Condition for its emergence?**

Skyrme-RPA in 3D mesh

T. Inakura et al., PRC80, 044301.



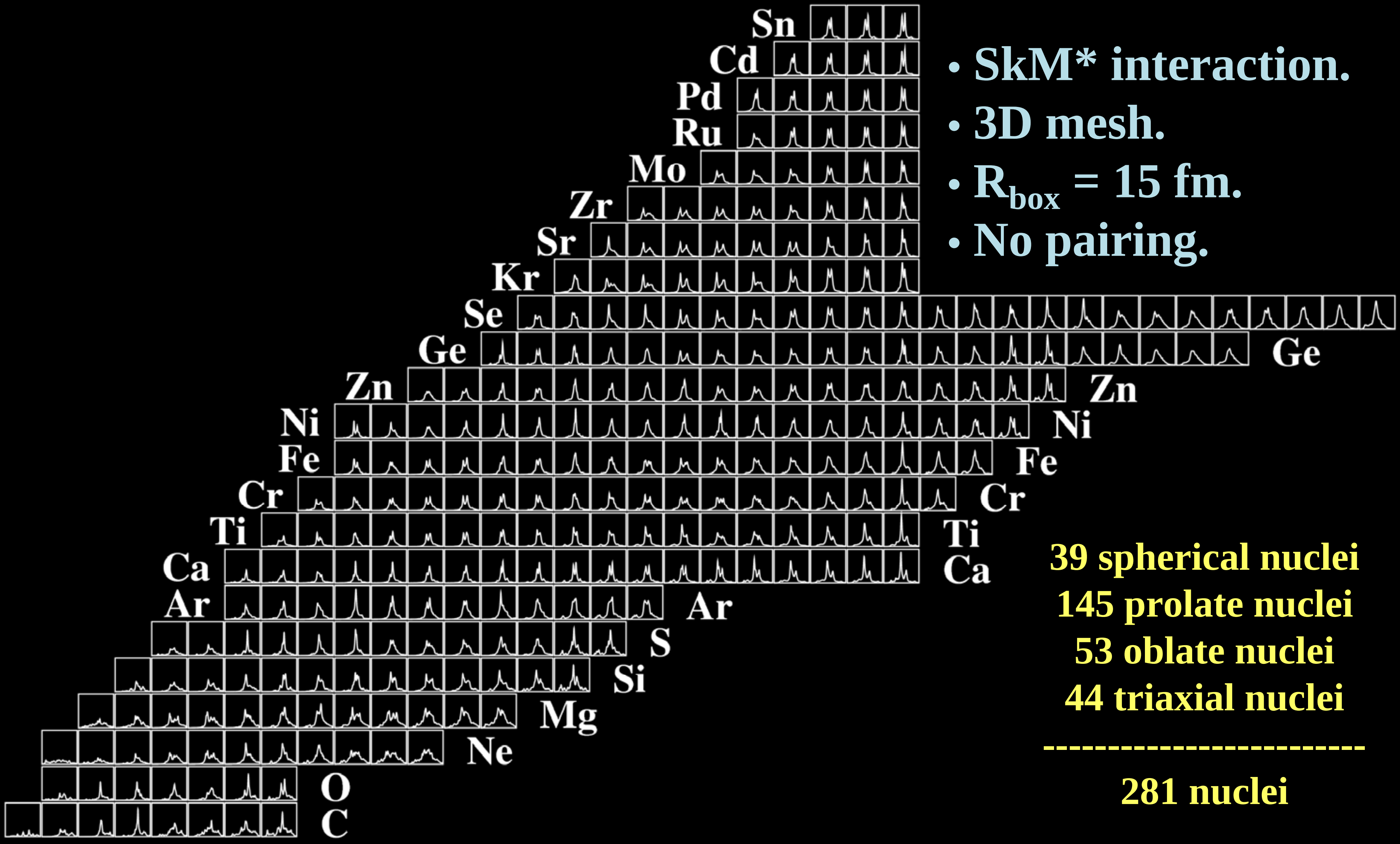
- **Fully self-consistent Skyrme-RPA**
  - Including time-odd, residual LS and Coulomb.
- **3D mesh representation**
  - suitable to describe unstable nuclei.
  - applicable for deformed nuclei.
  - treat particles escaping from nuclei in good approximation.
- **RPA matrix: Dimension O(10^6)**
- **No pairing correlation**



Technically…

- **Finite Amplitude Method**
  numerical estimation of residual interaction.
- **Response calculation**
  - at fixed complex energies.
  - suitable for the paralleled supercomputer.

Systematic calc. of E1 mode



- SkM* interaction.
- 3D mesh.
- R_{box} = 15 fm.
- No pairing.

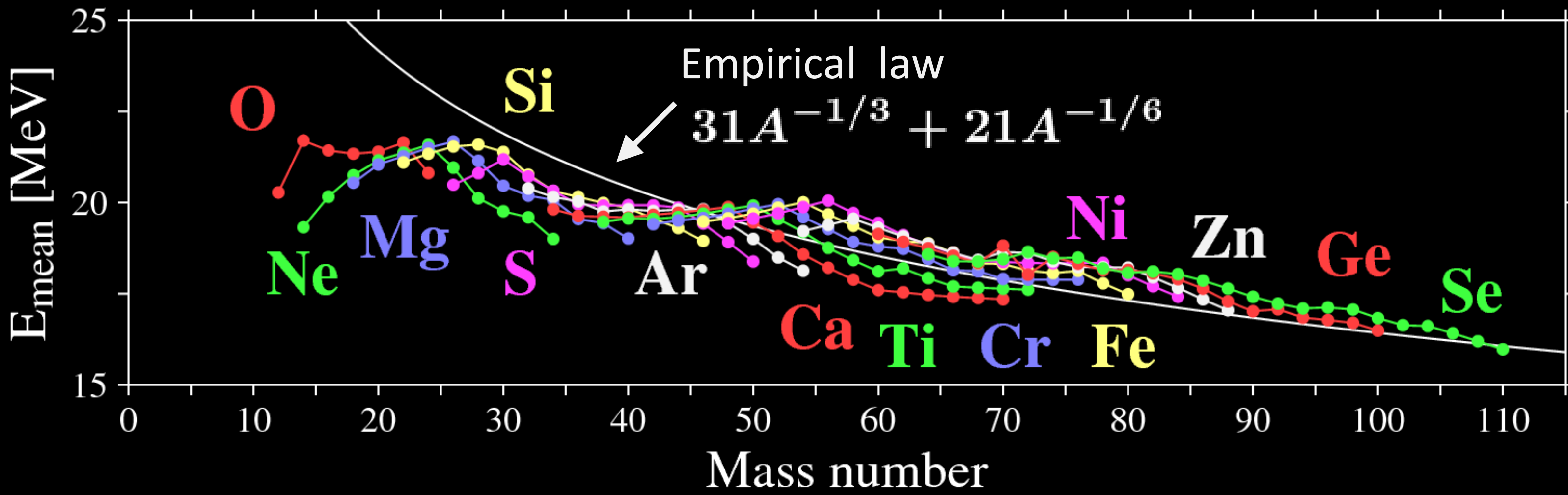
39 spherical nuclei
145 prolate nuclei
53 oblate nuclei
44 triaxial nuclei
----
281 nuclei

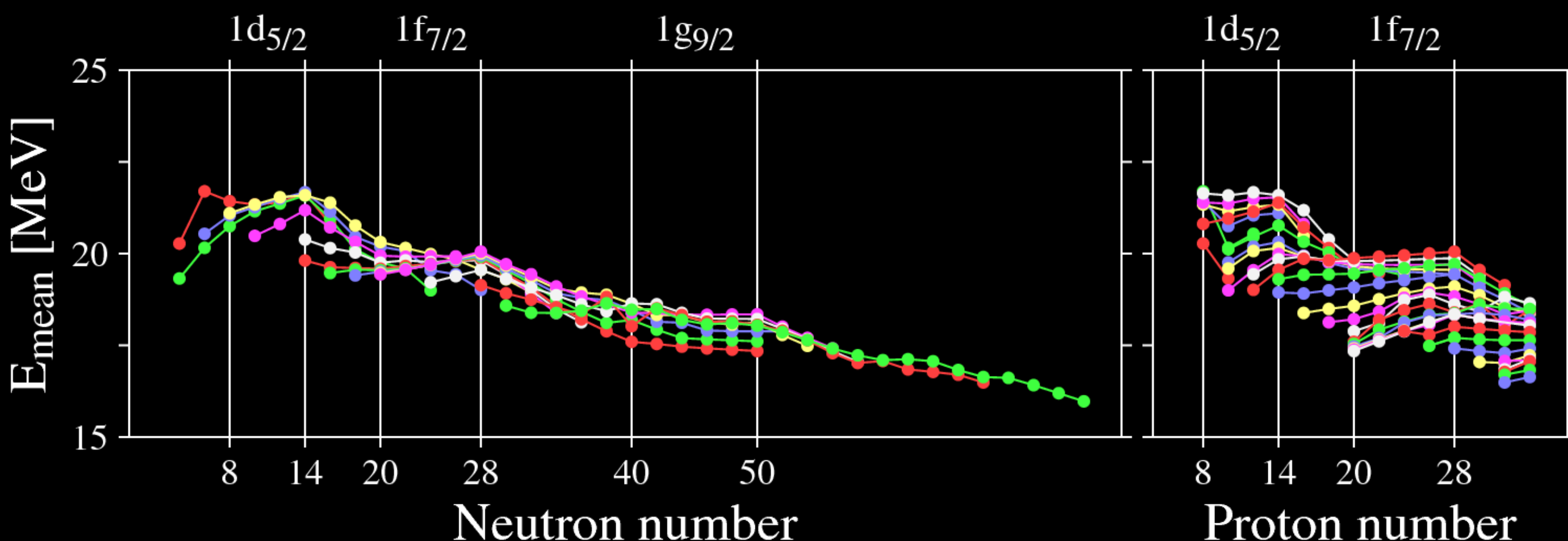
GDR peak ($E_{\rm mean}$)

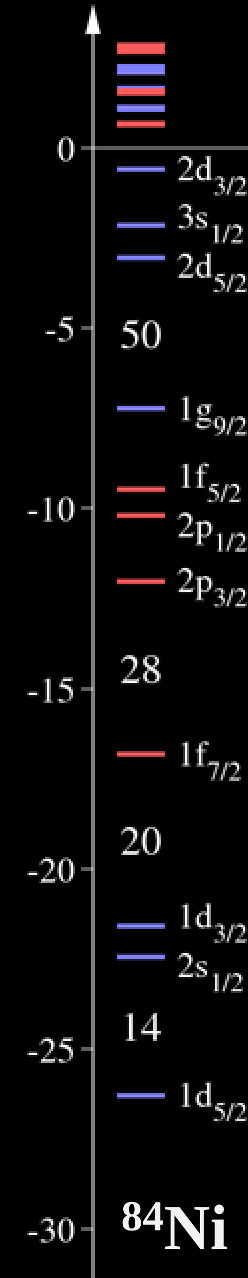
Mean Energy

$$E_{\rm mean} = m_1/m_0$$

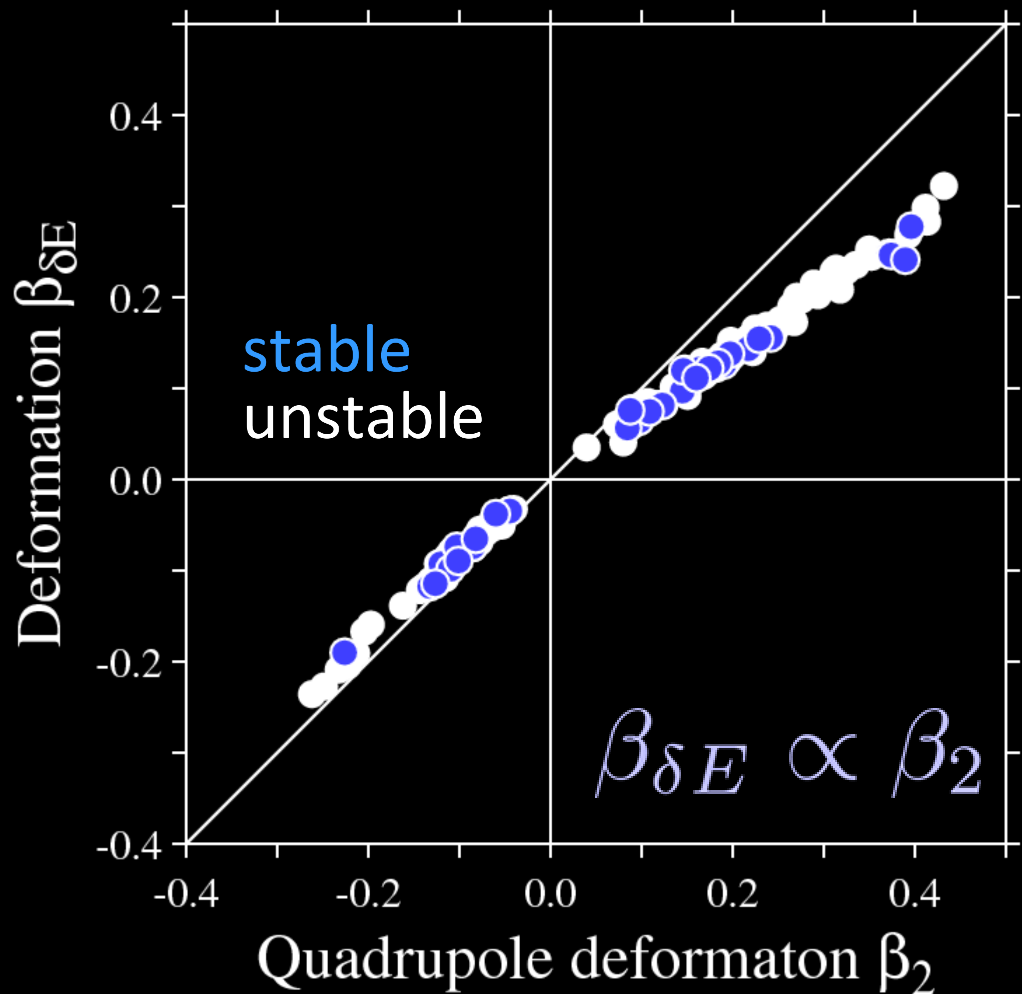
$$m_k \equiv \int dE\, E^k \sigma(E)$$



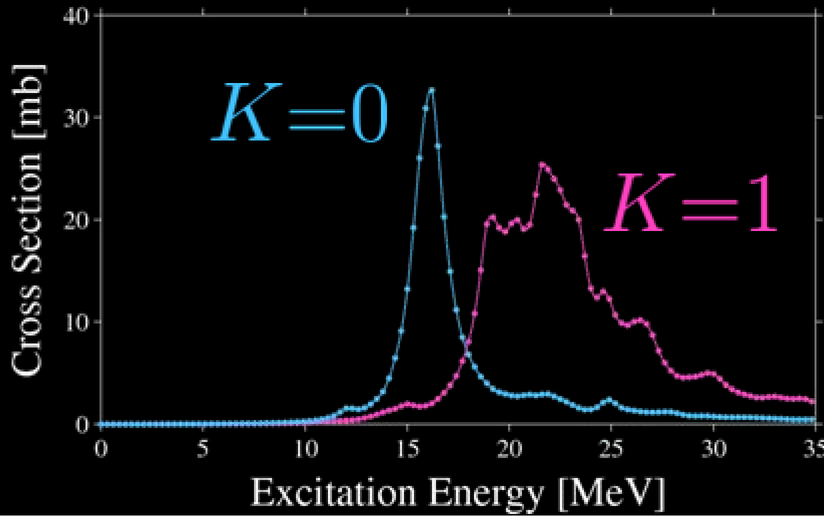




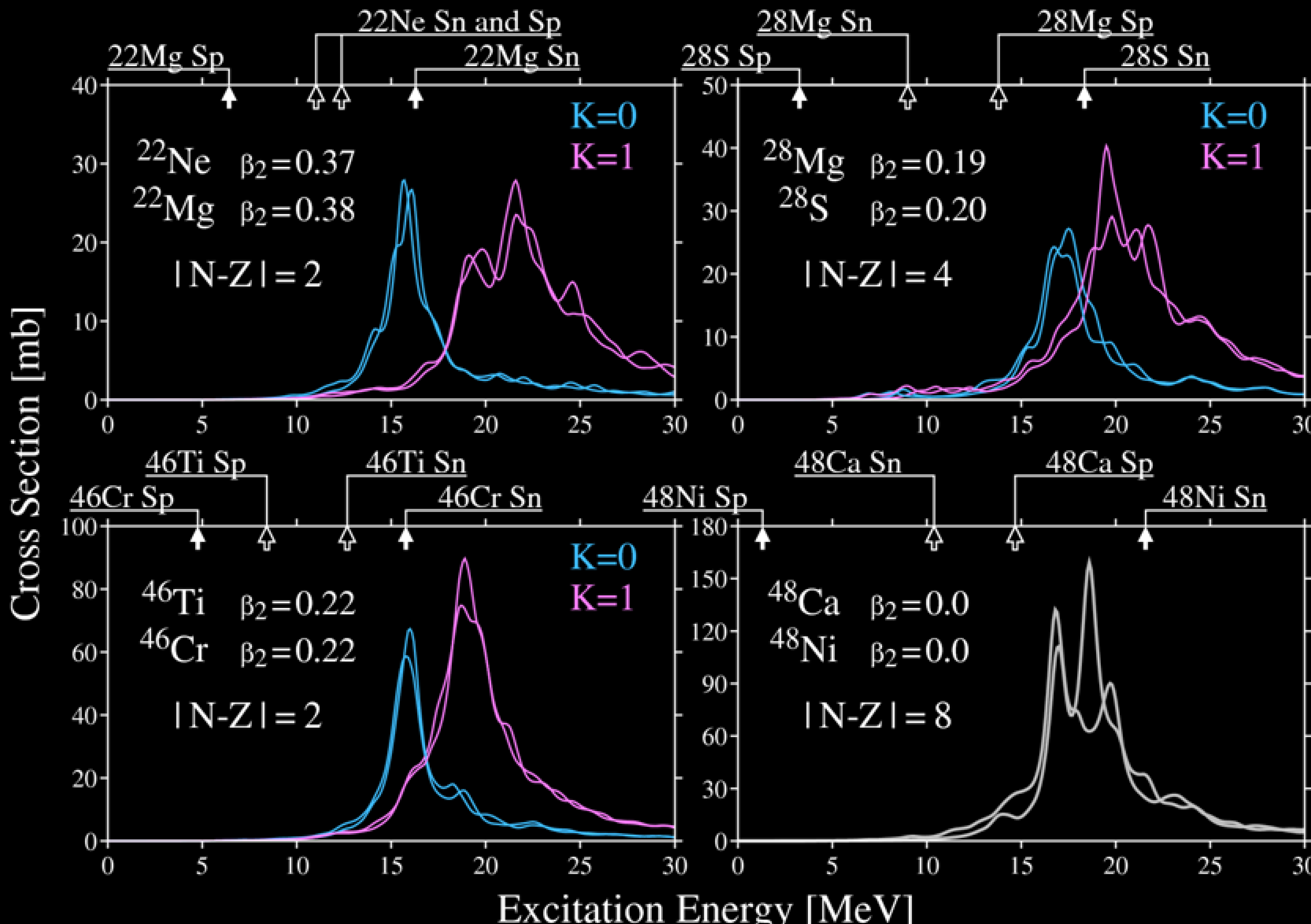
GDR peak splitting by deformation



$$\beta_{\delta E} \equiv \frac{E^{K=1}_{\text{mean}} - E^{K=0}_{\text{mean}}}{E^{\text{all}}_{\text{mean}}}$$



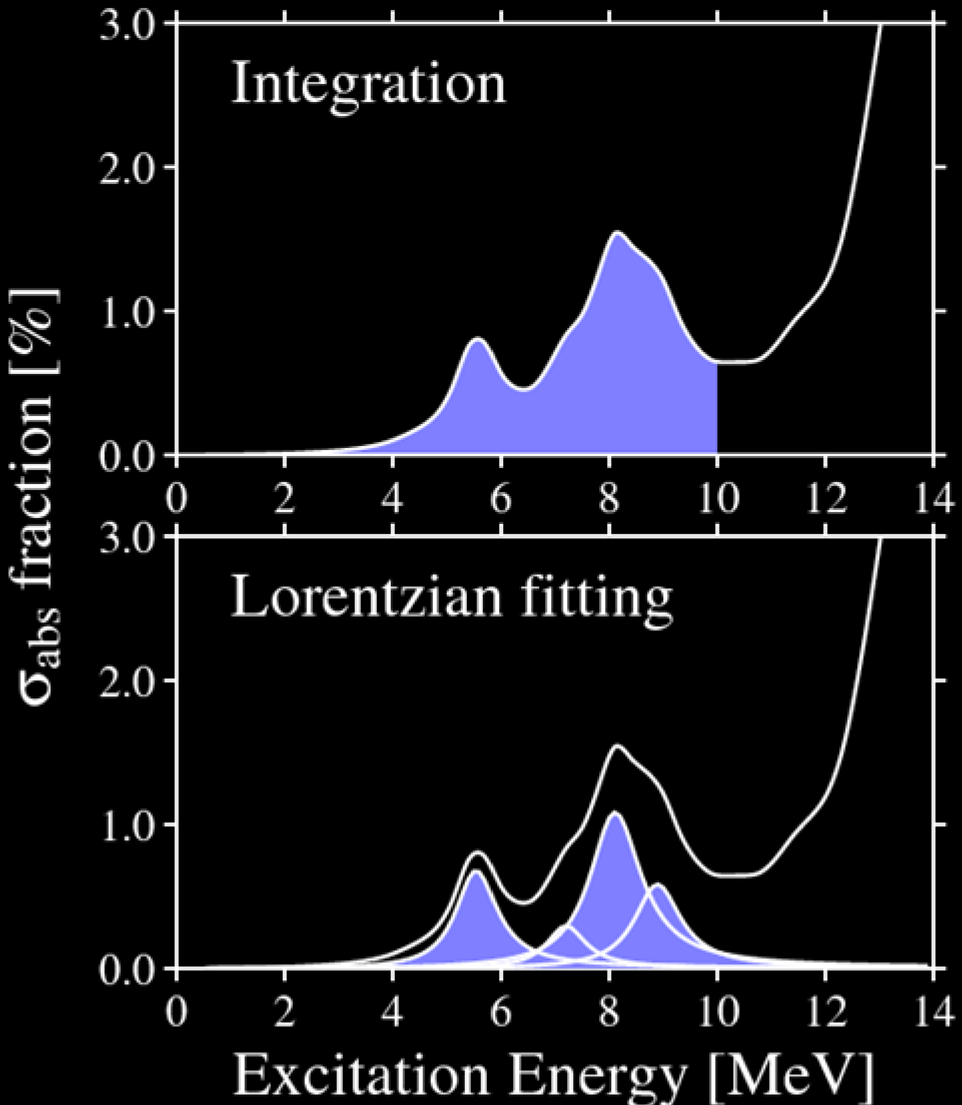
Mirror symmetry in GDR

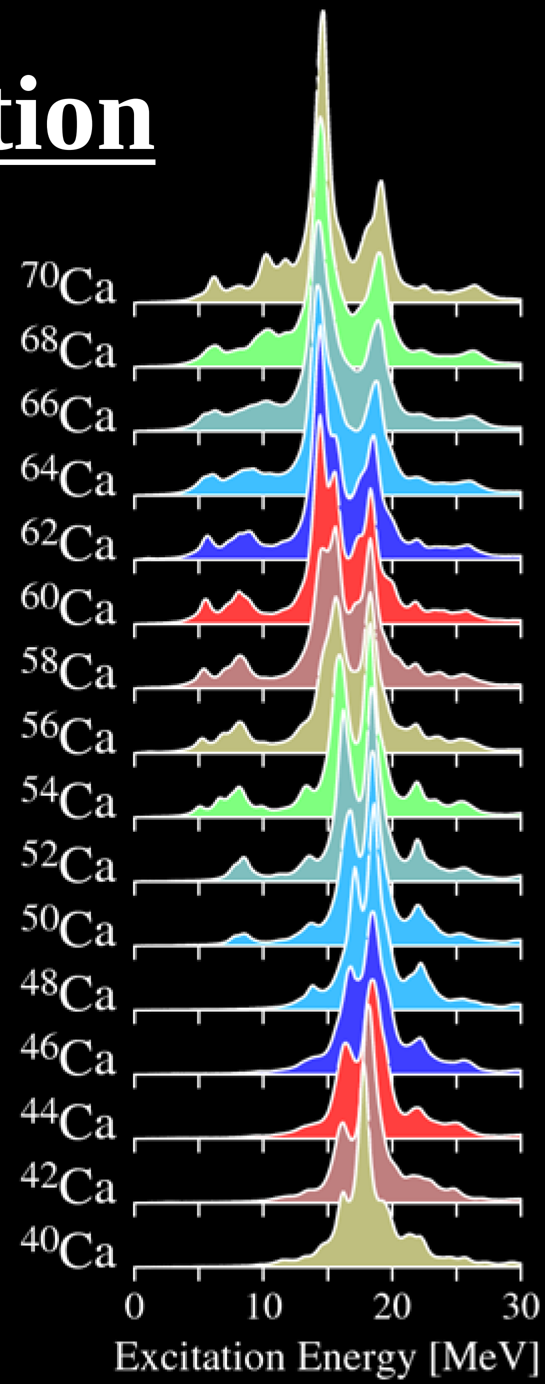


Pygmy dipole resonance (PDR)

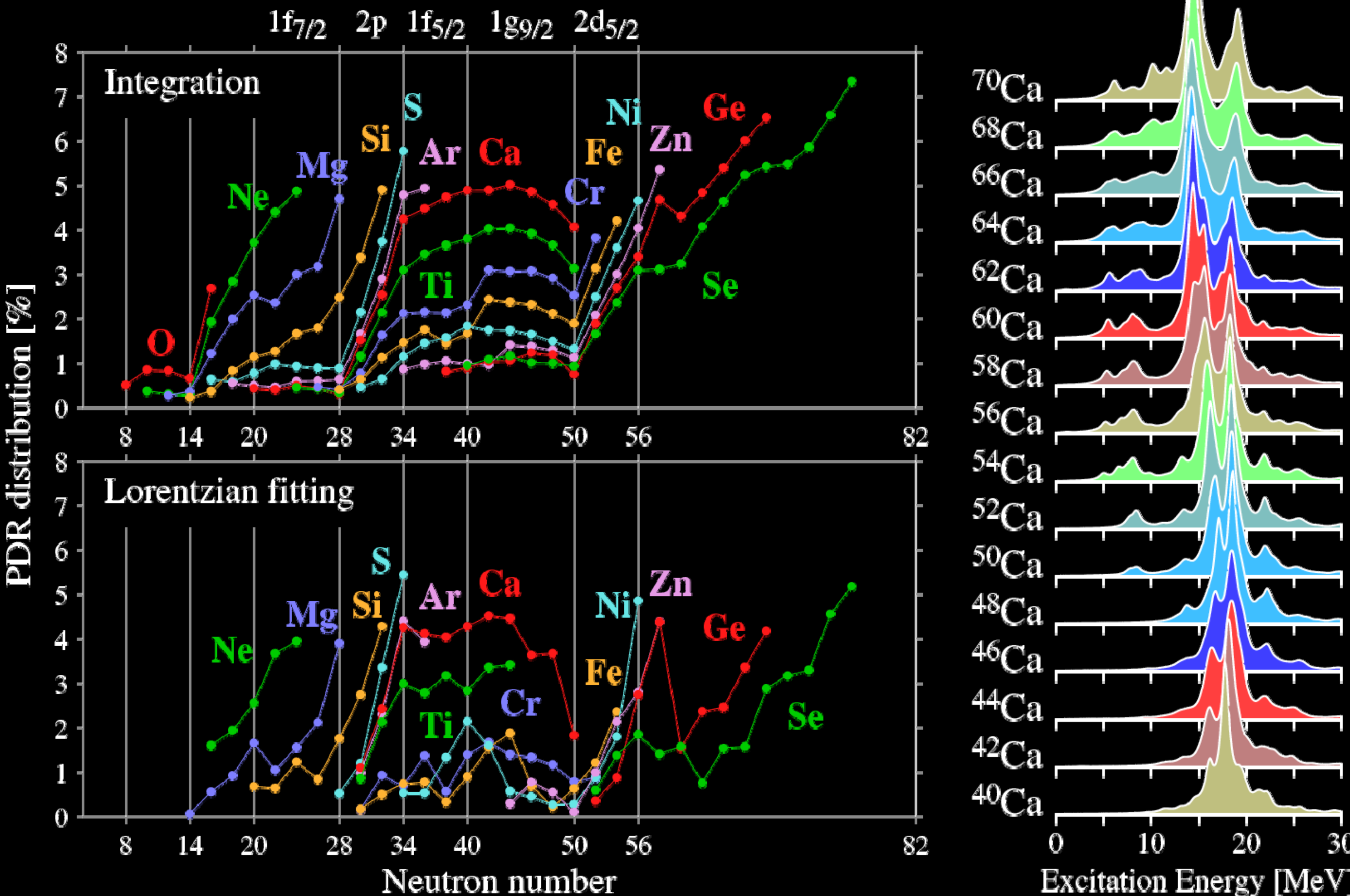
- Which nuclei have PDR?
- What is condition for its emergence?
- Is PDR collective?

Extraction of PDR distribution

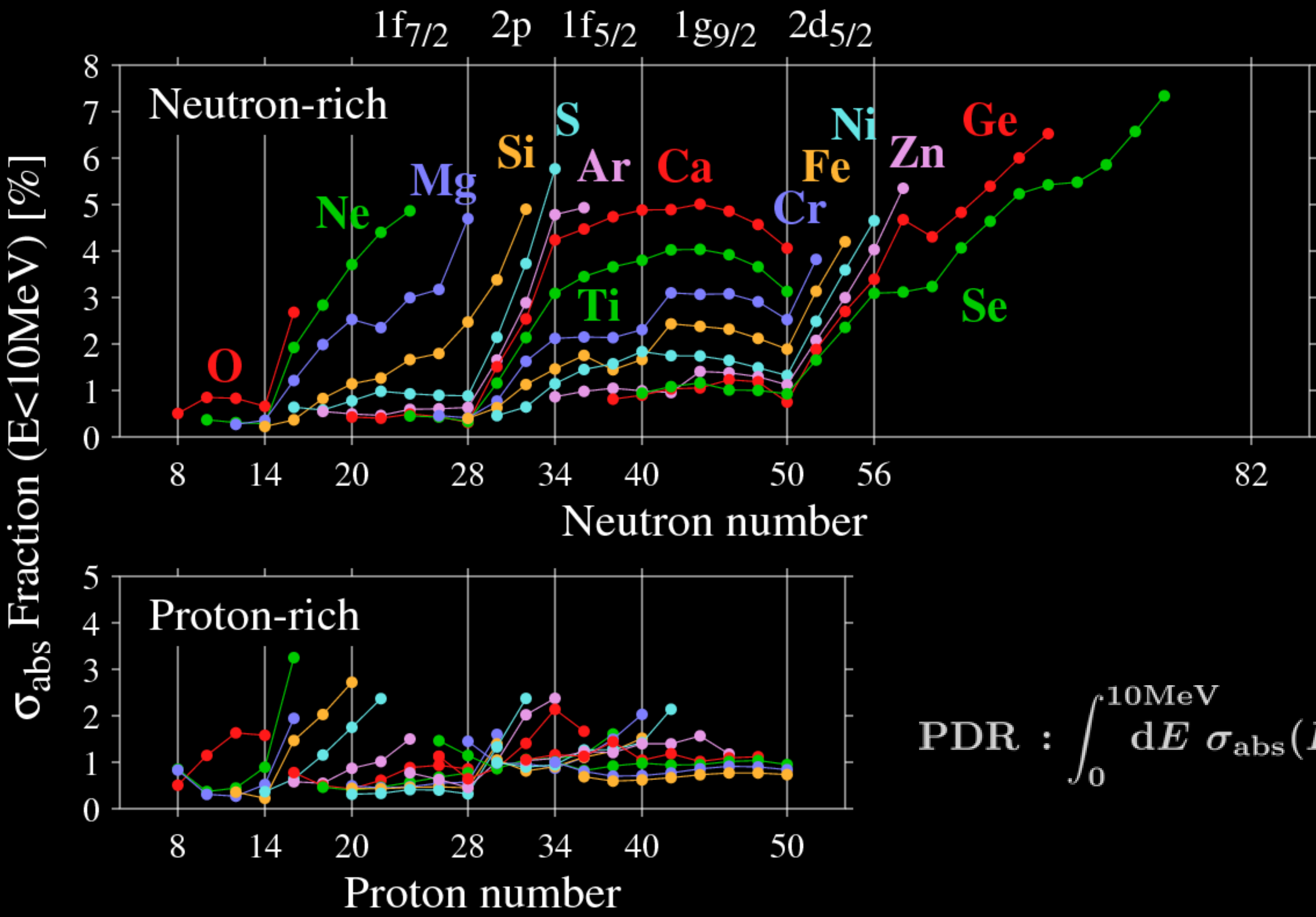




PDR distribution

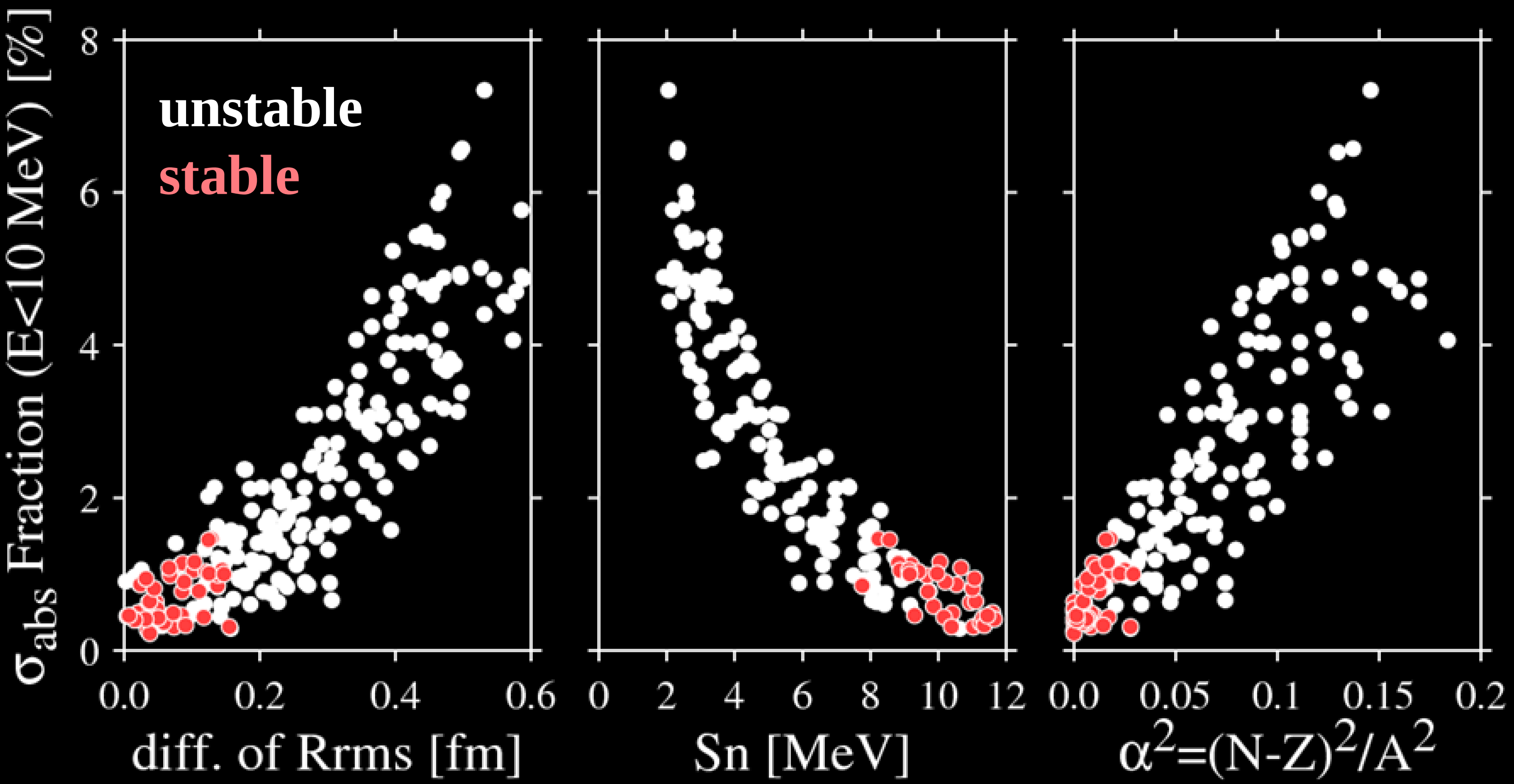


Nucleon excess dependence

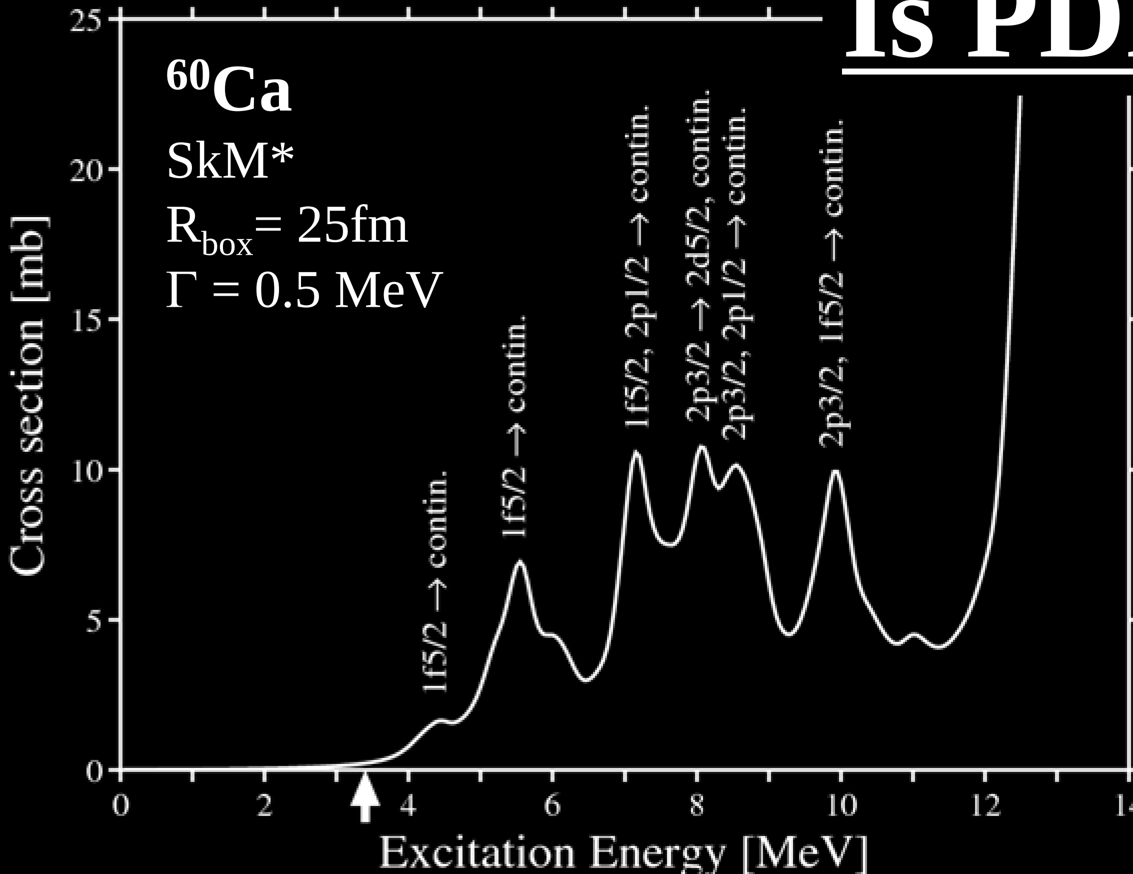


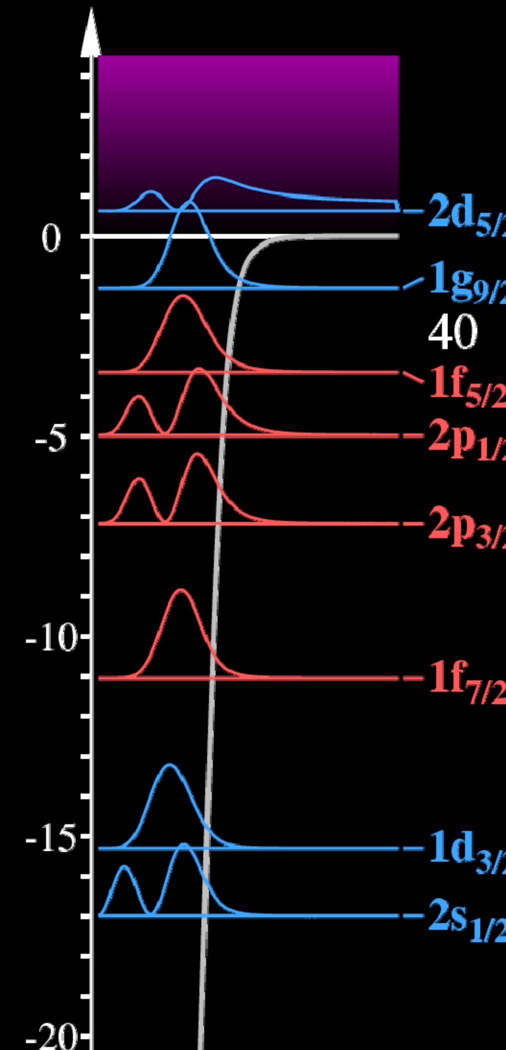
$$\mathrm{PDR}\ :\ \int_0^{10\mathrm{MeV}} \mathrm{d}E\ \sigma_{\mathrm{abs}}(E)$$

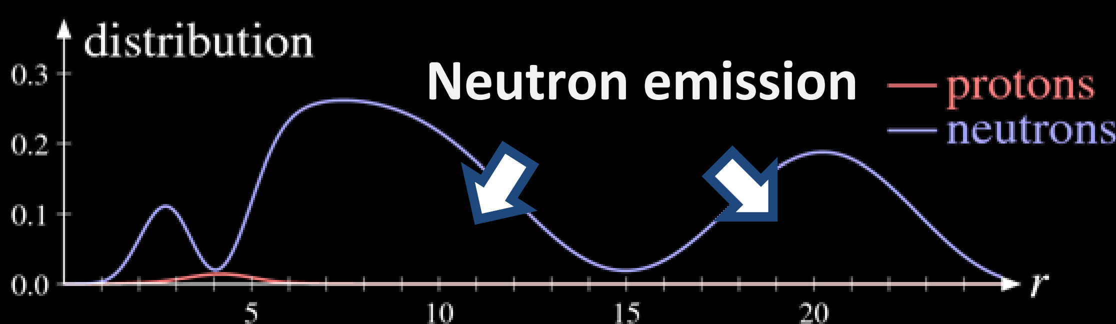
PDR :correlate with other observables?



Is PDR collective?

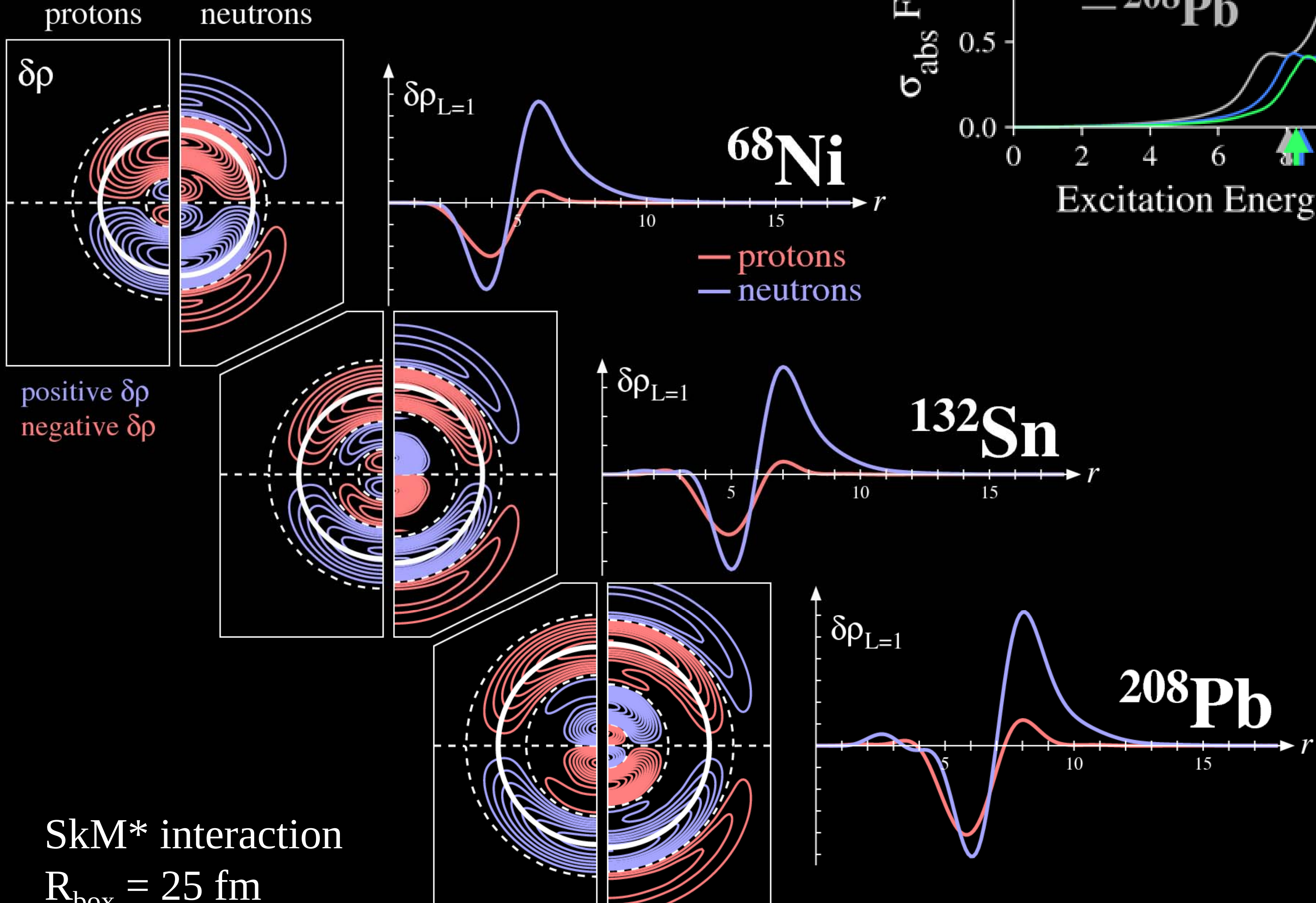


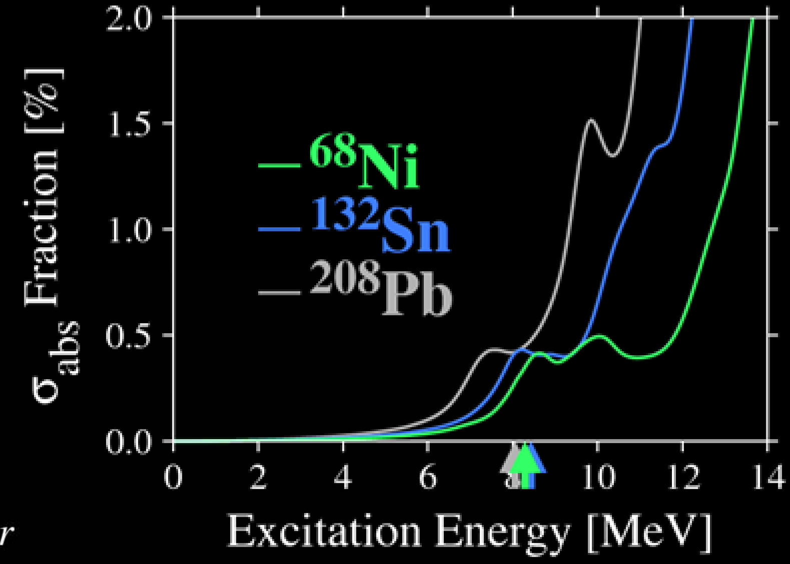




Spatial distribution of particle state

Collective PDR



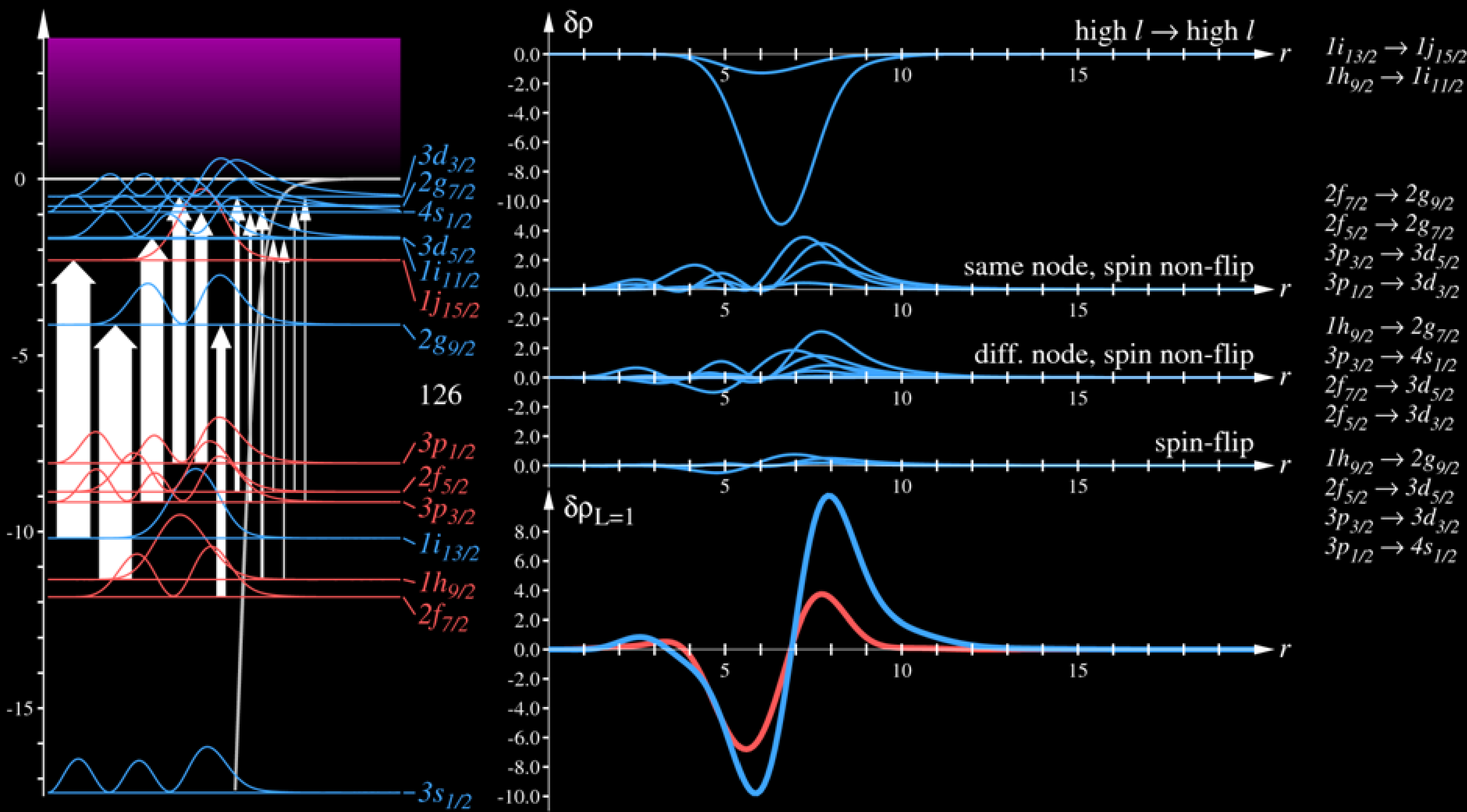


SkM* interaction

R_{box} = 25 fm

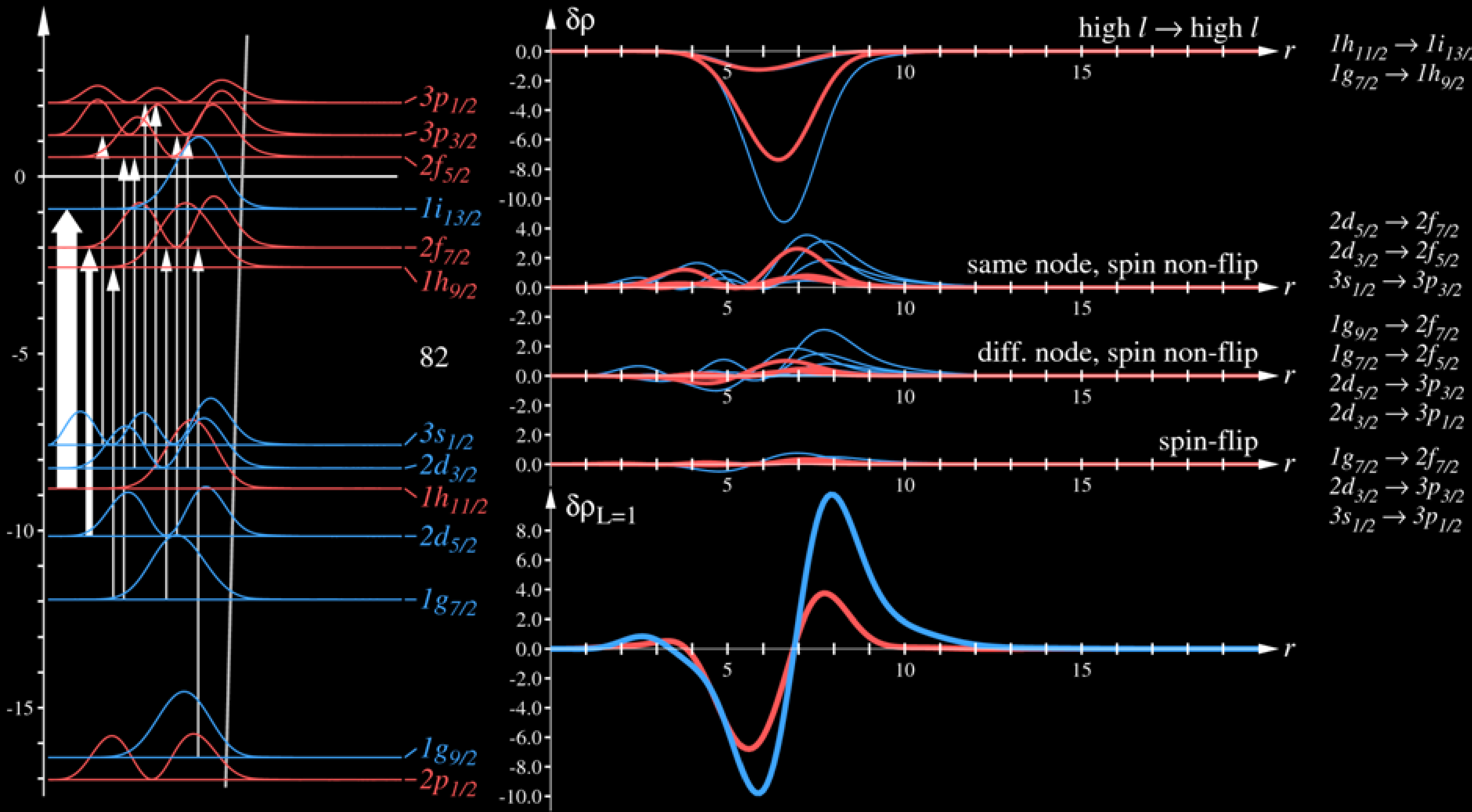
Neutron $\delta\rho$ in ^{208}Pb PDR

$E = 7.20 + 0.1\,i$ MeV
$R_{box} = 25$ fm
SkM* interaction
$S_n = 8.1$ MeV
Rrms = 5.6 fm



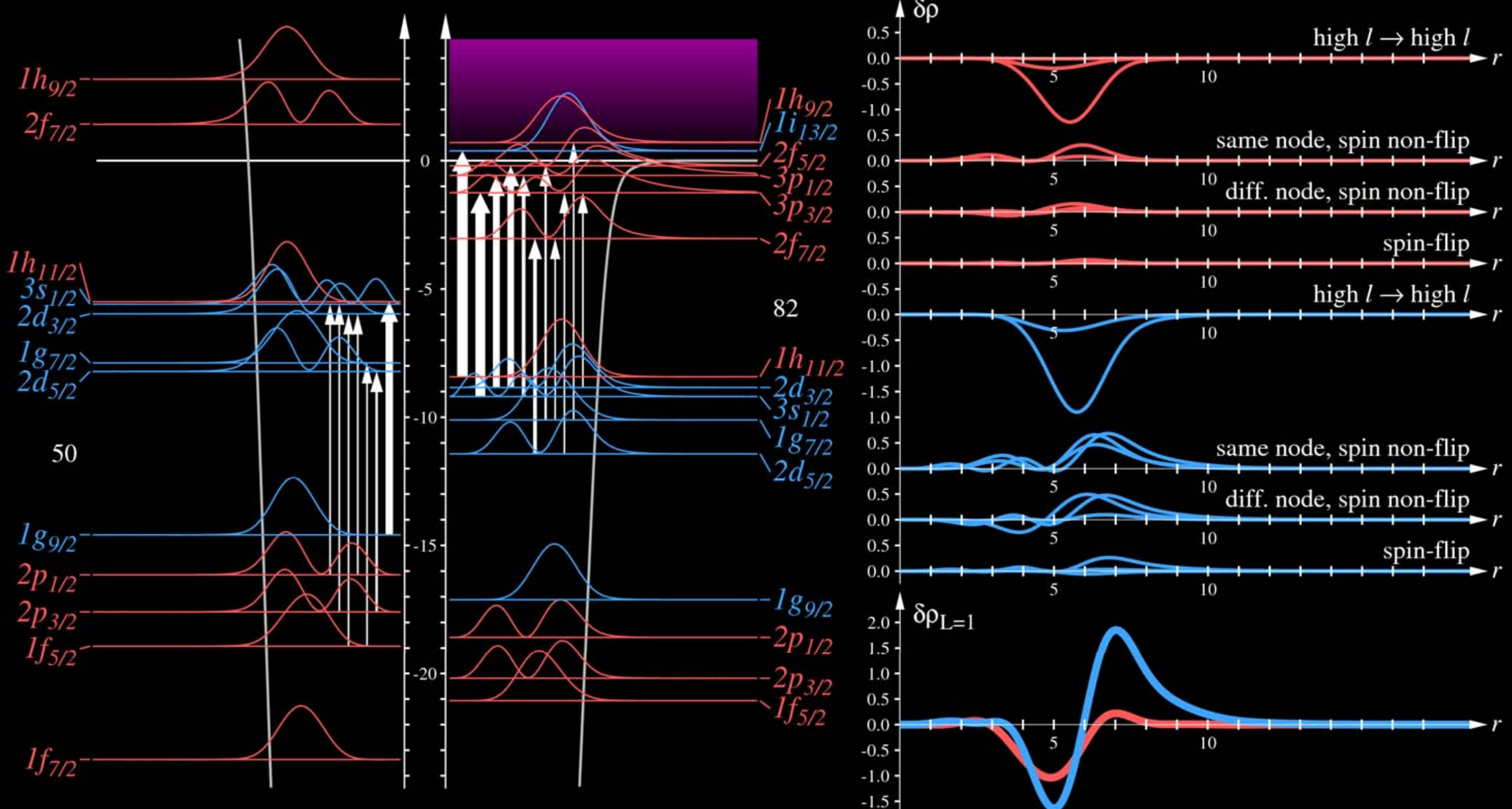
Proton δρ in ^{208}Pb PDR

E = 7.20 + 0.1 *i* MeV
R_{box} = 25 fm
SkM* interaction
S_n = 8.1 MeV
Rrms = 5.6 fm



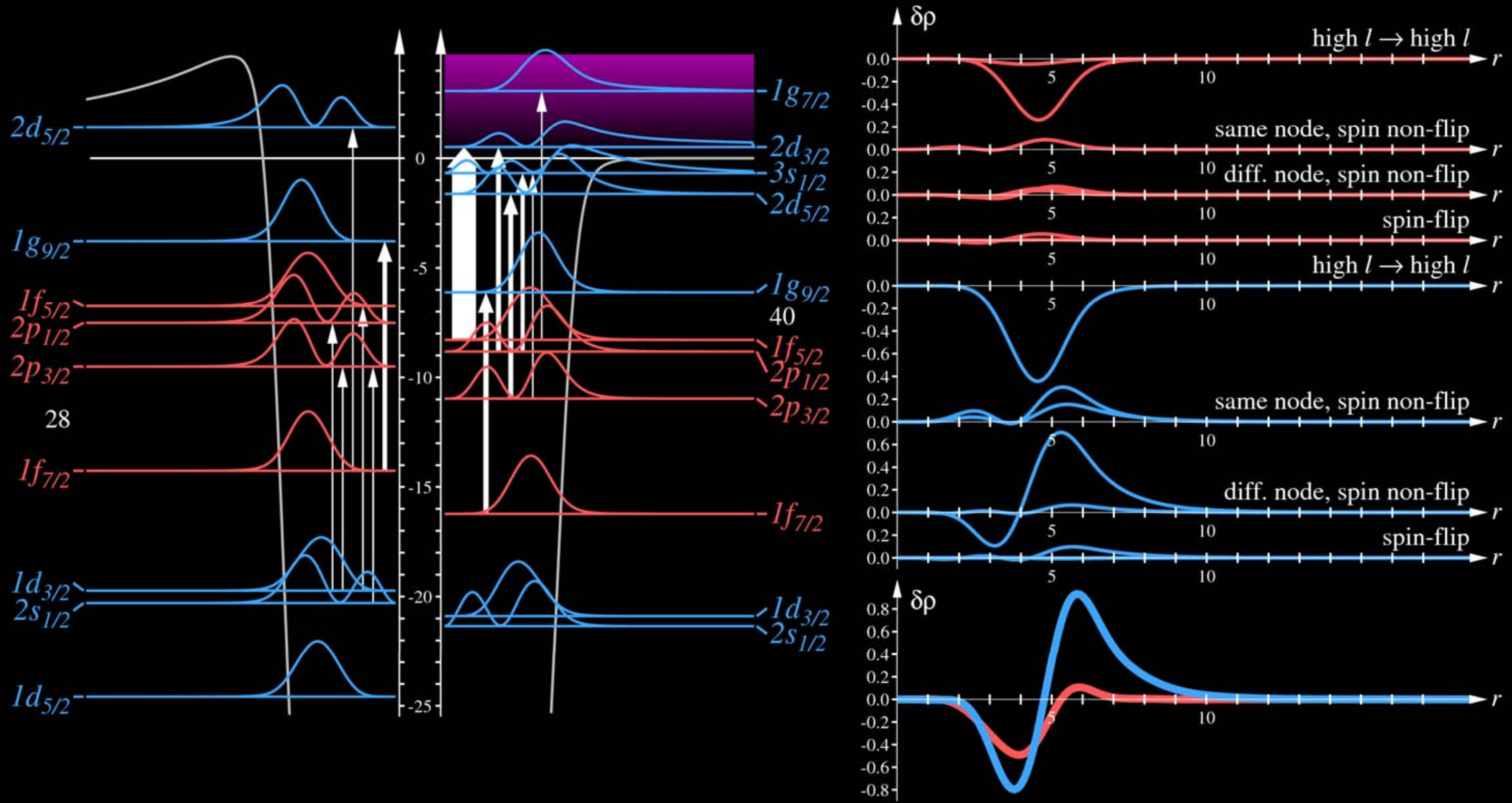
PDR in ^{132}Sn

E = 8.2 + 0.5 *i* MeV
R_{box} = 25 fm
SkM* interaction
S_n = 8.4 MeV
Rrms = 4.9 fm



PDR in ^{68}Ni

$E = 8.6 + 0.5\,i$ MeV
R_{box} = 25 fm
SkM* interaction
S_n = 8.3 MeV
Rrms = 4.0 fm



Summary

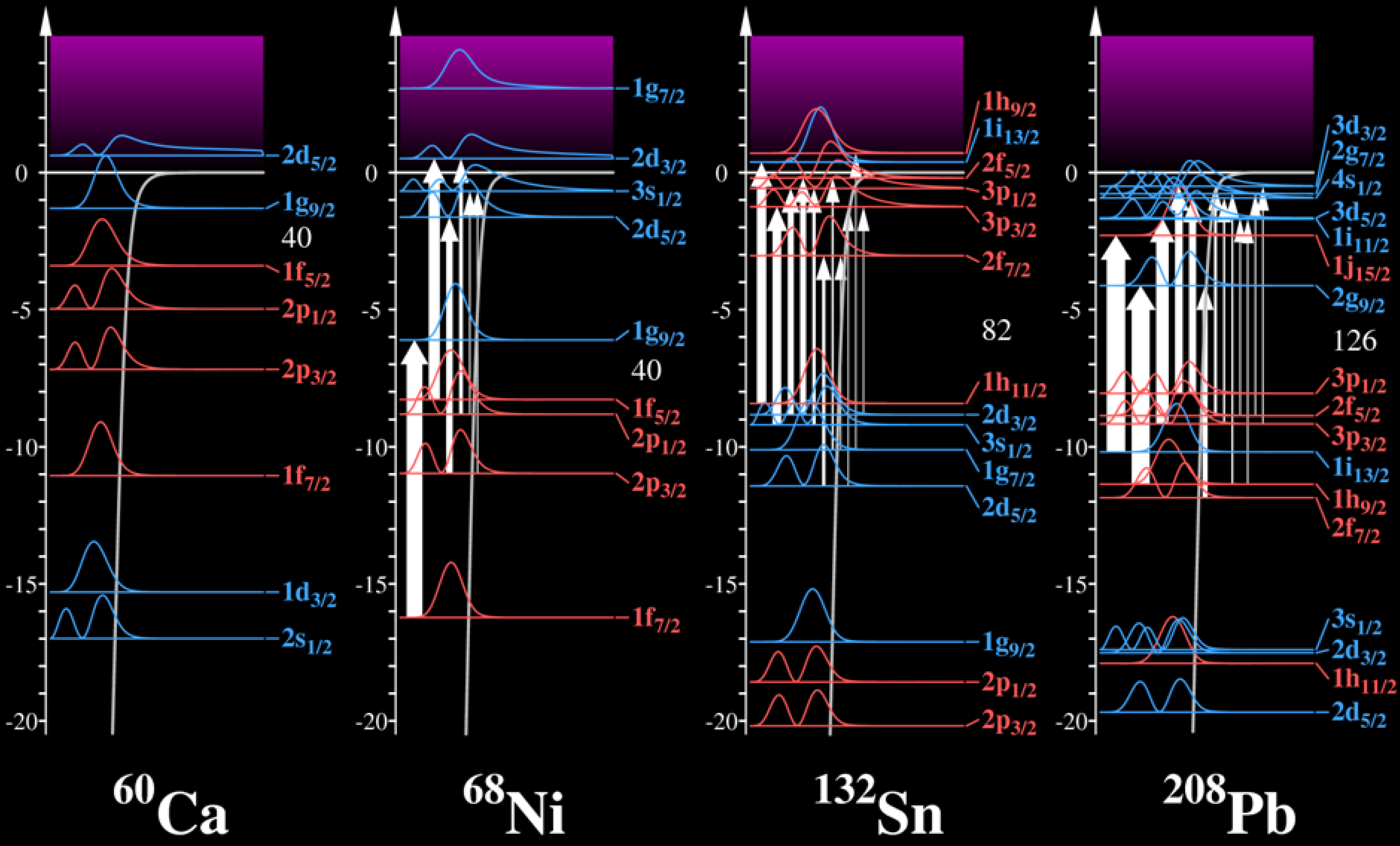
- GDR mean energy follows the empirical law.
- Neutron shell structure have strong affection on GDR mean energy.
- GDR peak splitting is proportional to static quadrupole deformation.
- Good mirror symmetry in GDR is seen.

- PDR in light neutron-rich nuclei is mainly neutron emission mode from loosely-bound low-*l* orbit.
- Correlations with Rn-Rp, Sn, N-Z asymmetry are present, but not strong.

- PDR in ^{68}Ni, ^{132}Sn and ^{208}Pb have collectivity.
    - Expressed by a superposition of excitations to loosely-bound states.
    - Loosely-bound states are essential for spatial expanding of neutrons.
    - Coherence of neutron $\delta\rho$ outside of nucleus.
    - Coulomb barrier prevents protons from spatial spreading.

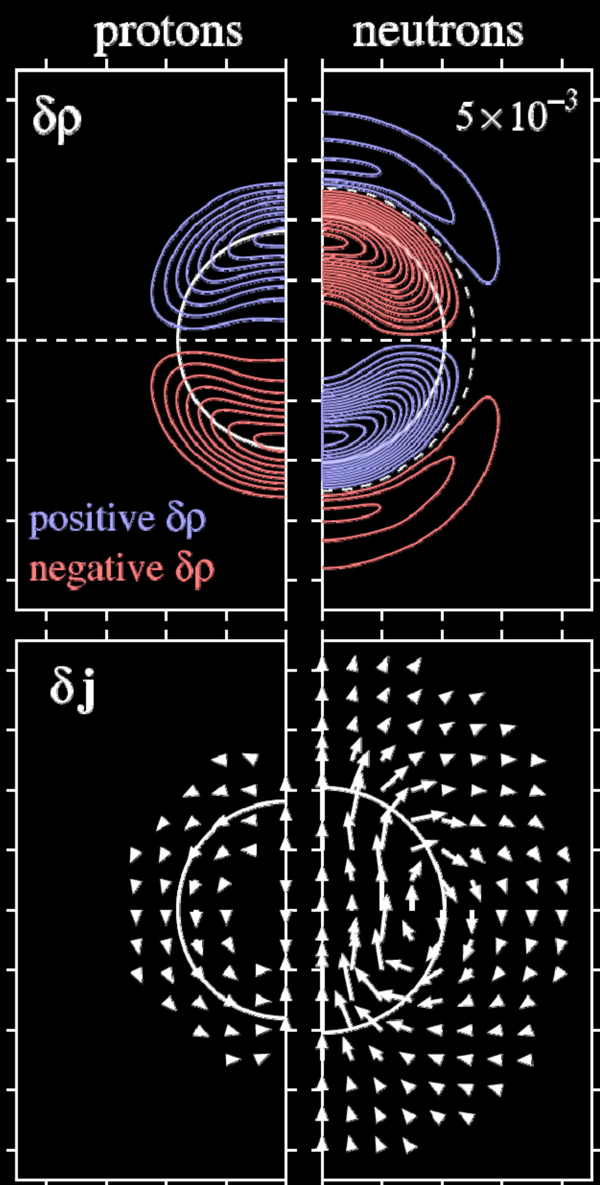
backup

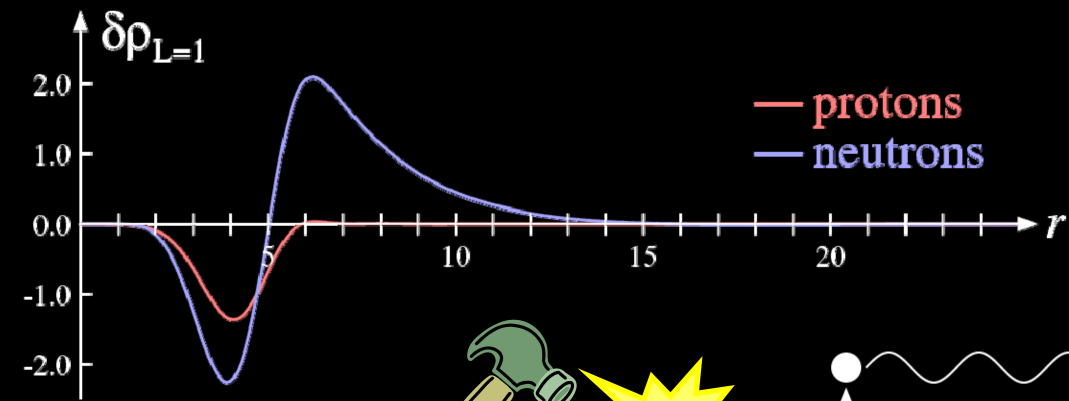
Neutron single-particle levels

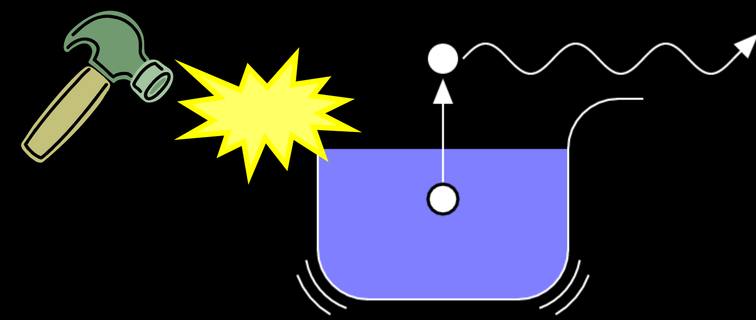


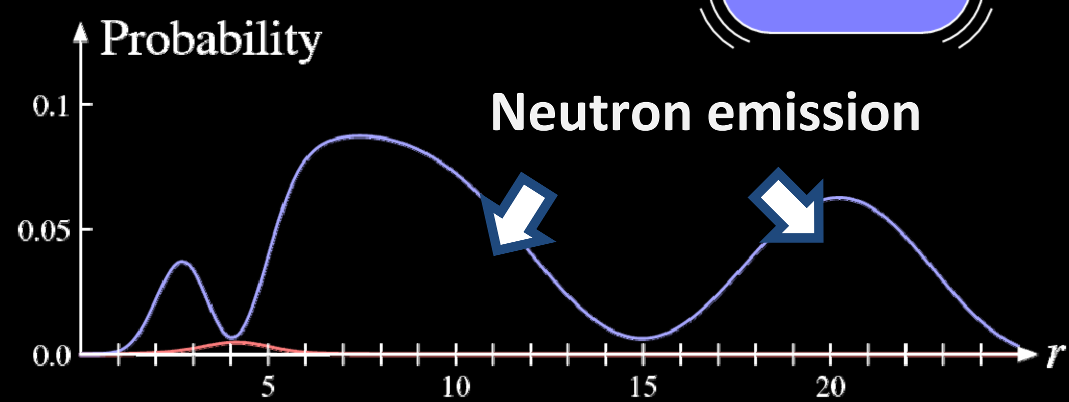
PDR in ^{60}Ca

$E = 5.54 + 0.1\,i$ MeV
$R_{box} = 25$ fm
SkM* interaction
$S_n = 3.4$ MeV
Rrms = 3.9 fm



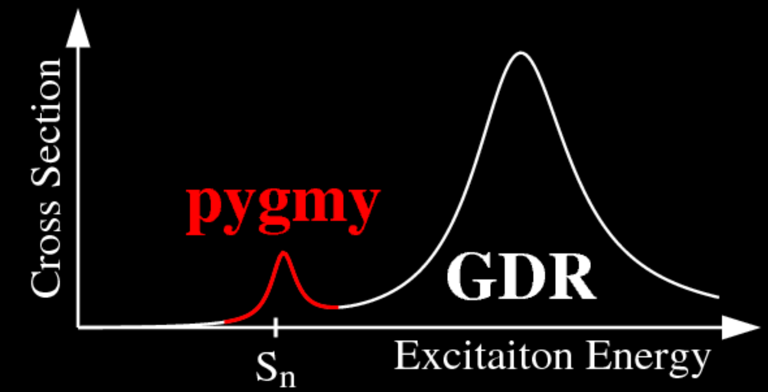


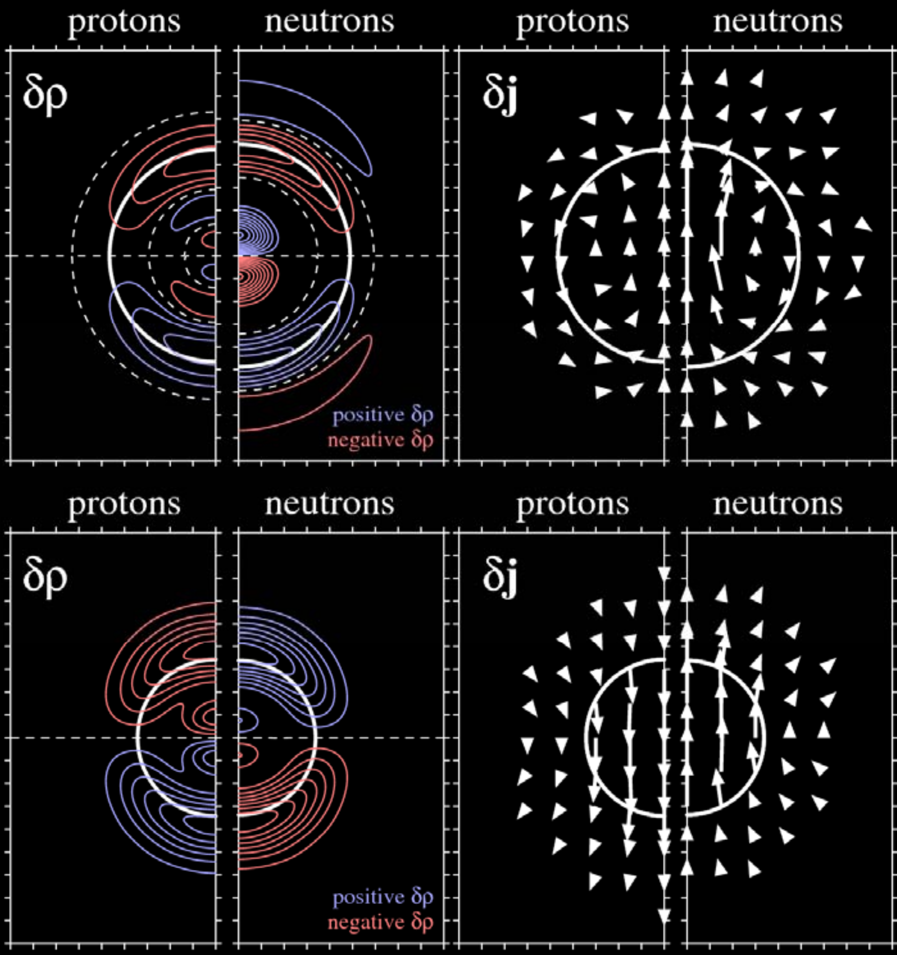


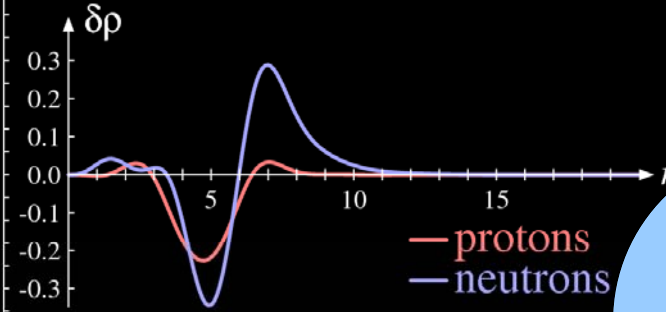


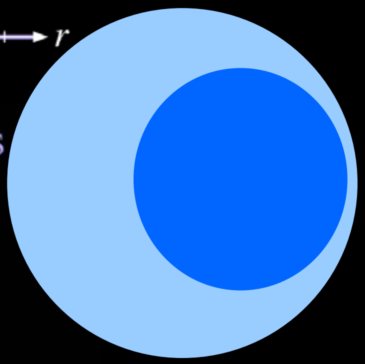
Spatial distribution of particle sates

<u>Soft dipole & GDR</u>



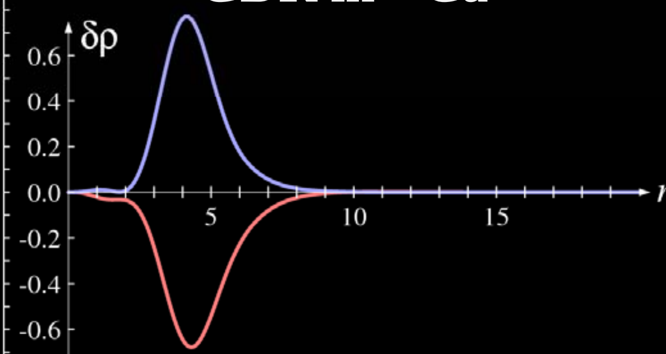


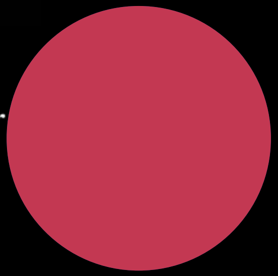




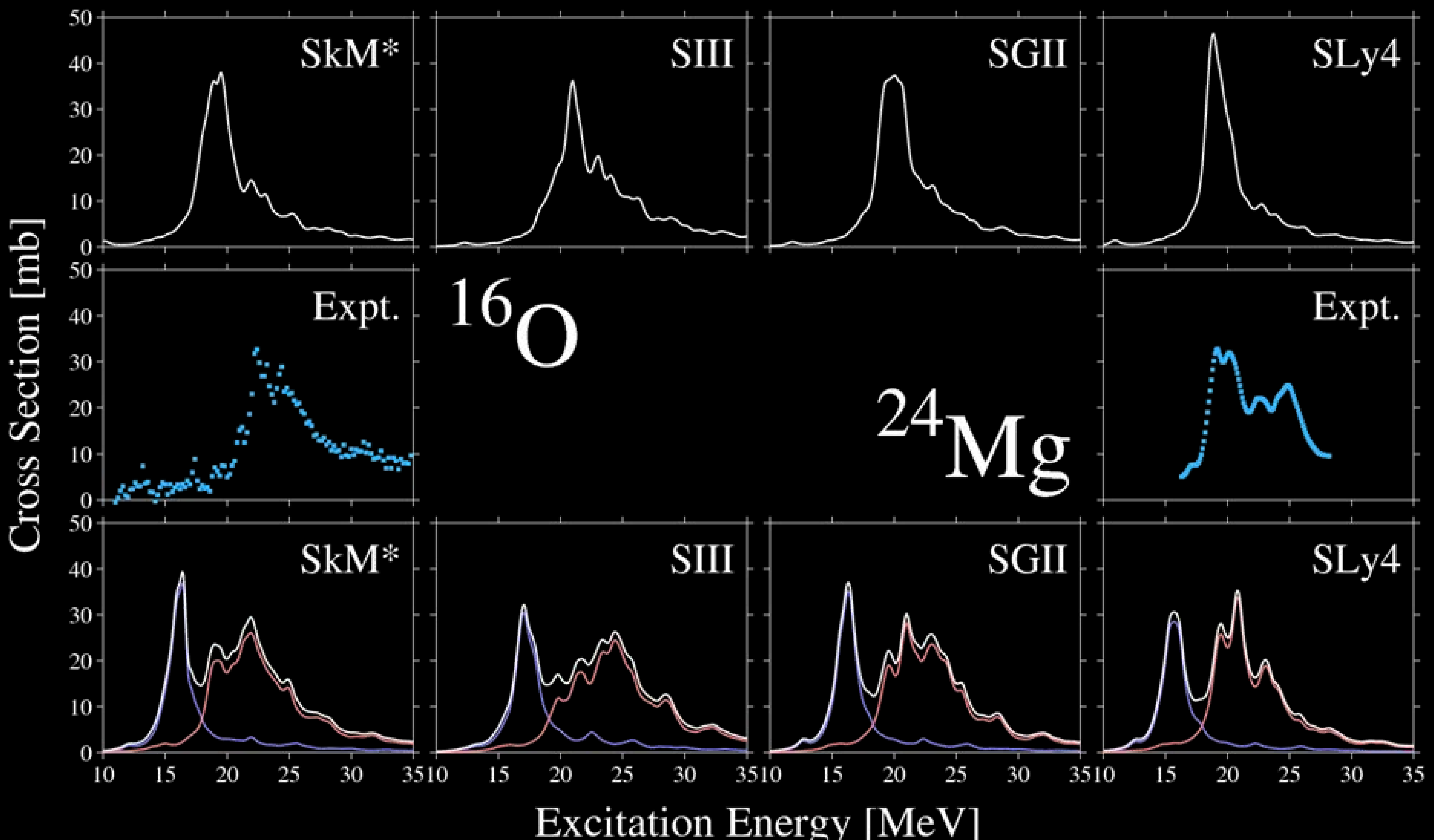
Soft dipole in ^{132}Sn

GDR in ^{40}Ca

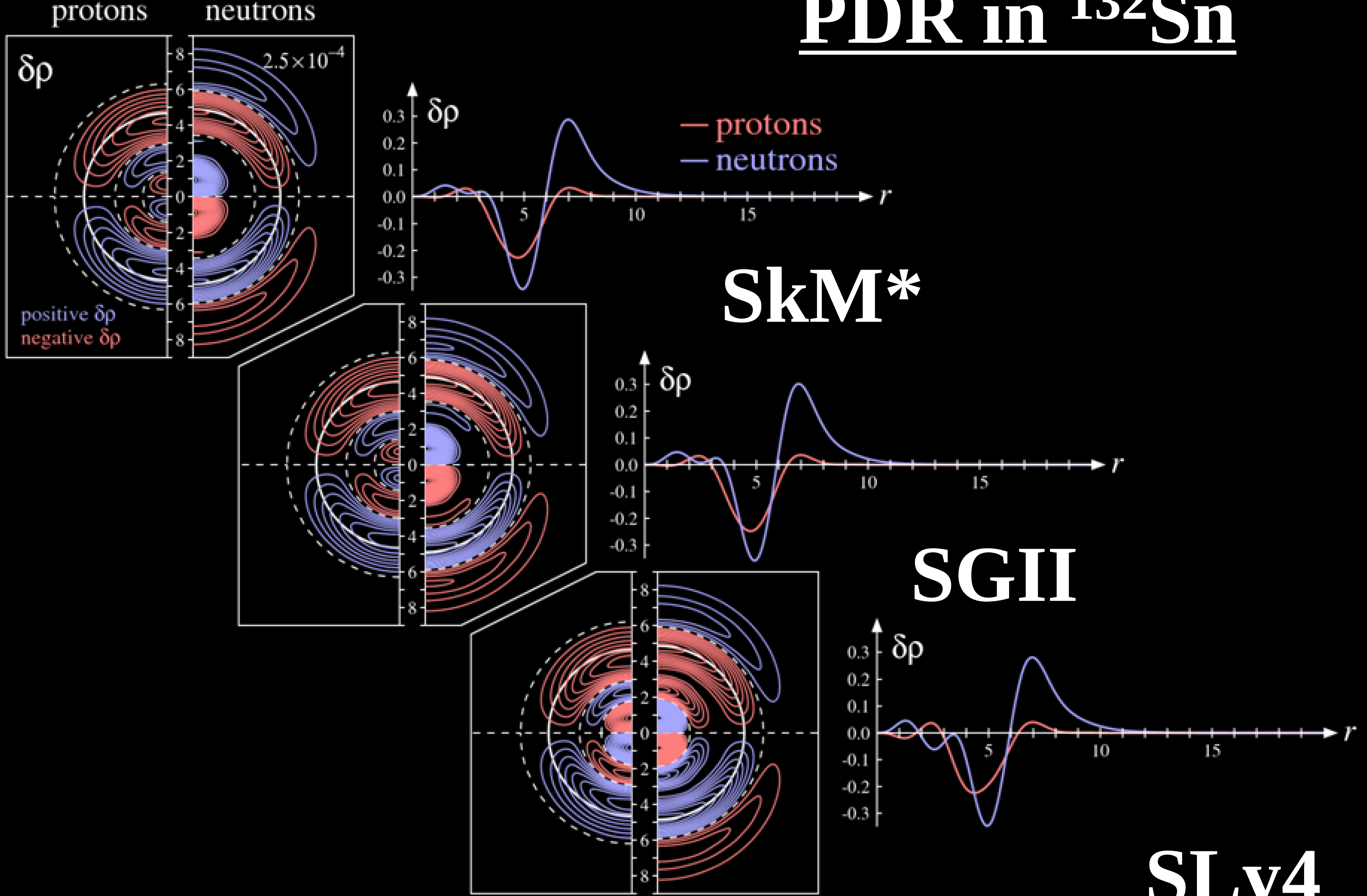




Interaction Dependence



PDR in ^{132}Sn

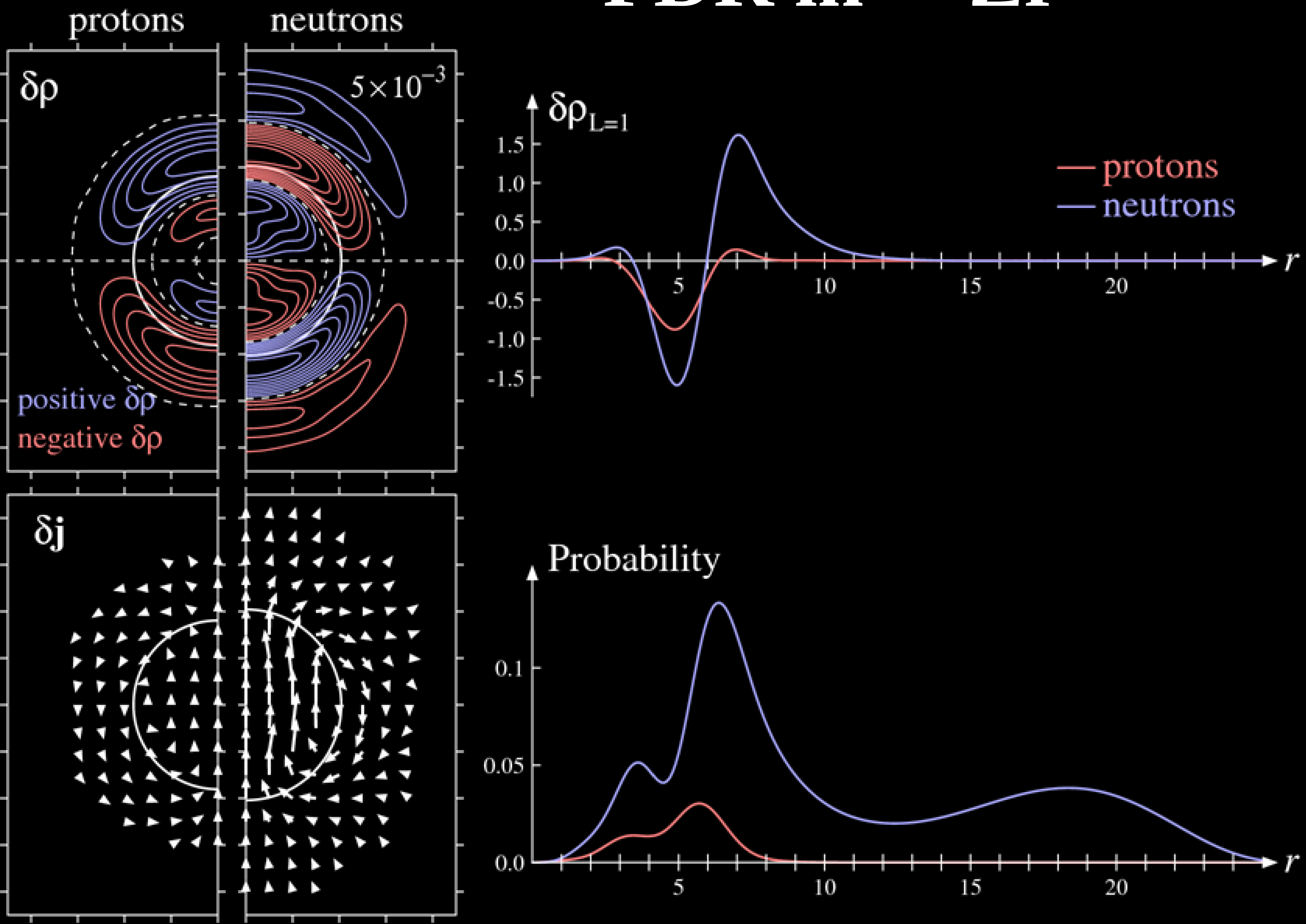


SkM*

SGII

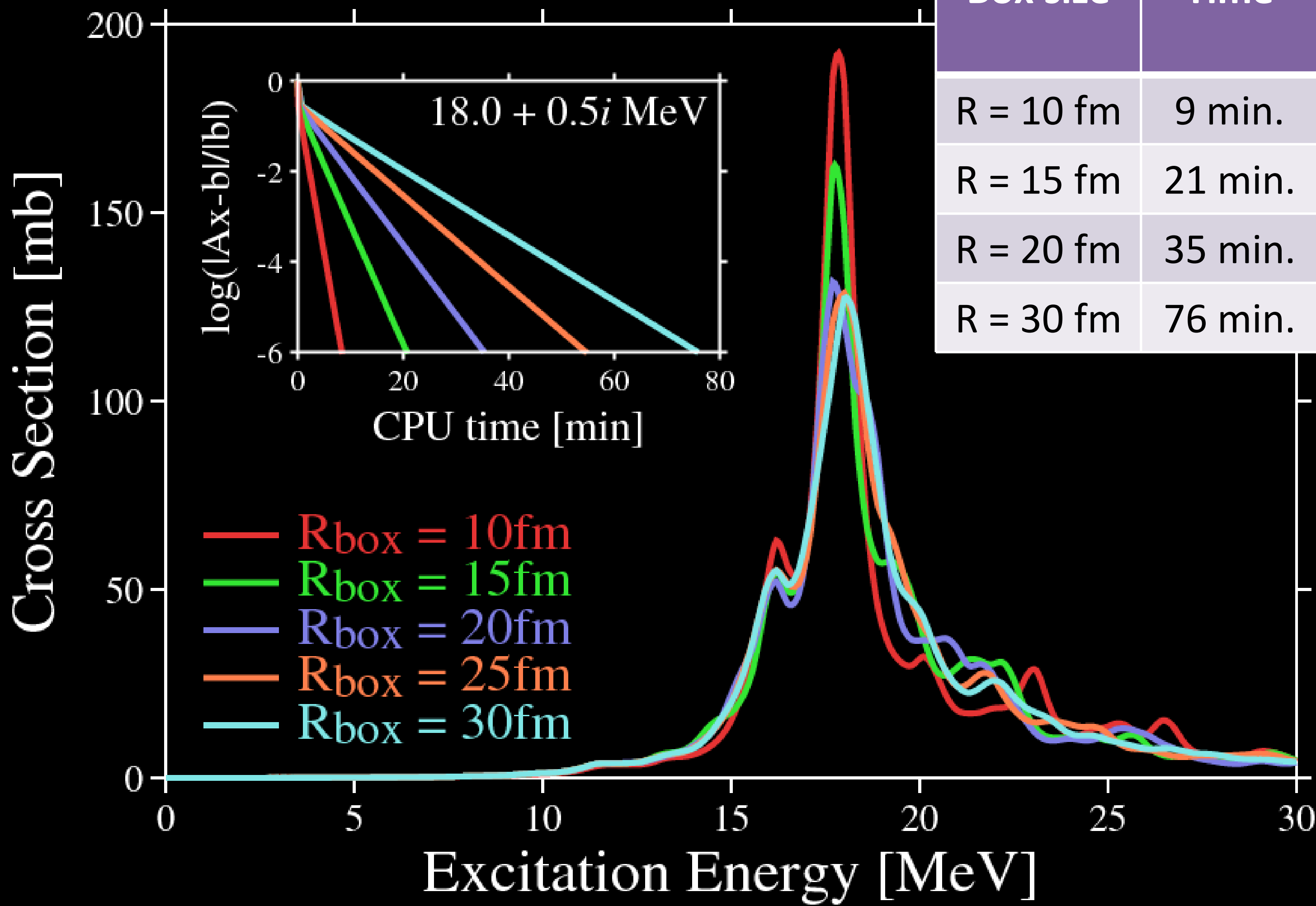
SLy4

PDR in ^{122}Zr



protons
neutrons
δρ
5×10⁻³
positive δρ
negative δρ
δj
δρ_L=1
protons
neutrons
Probability
r

Box size dependence



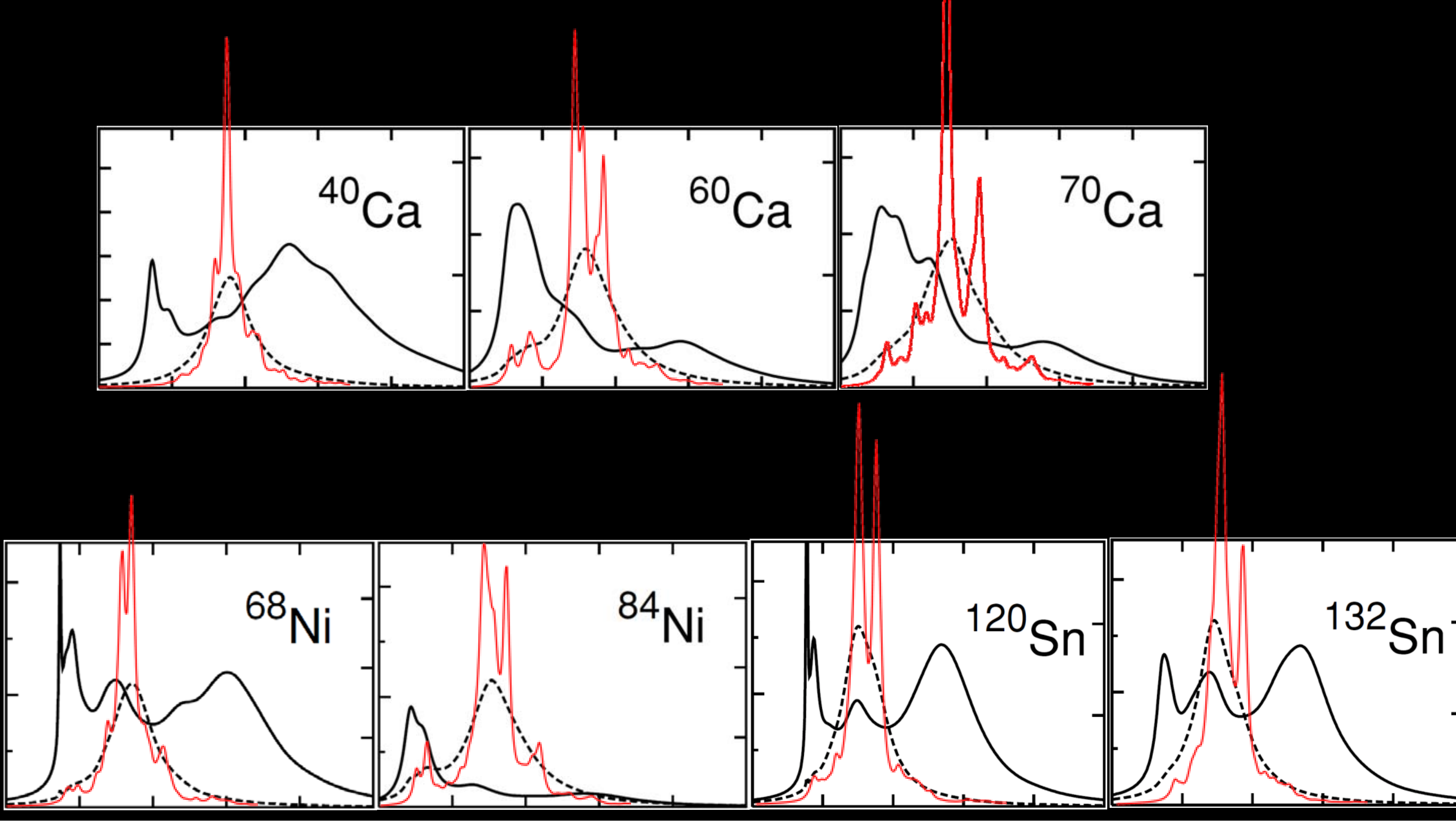
Box size	Time	Epeak [MeV]	Width [MeV]
R = 10 fm	9 min.	17.77	1.55
R = 15 fm	21 min.	17.80	2.49
R = 20 fm	35 min.	17.90	2.89
R = 30 fm	76 min.	17.96	3.01

Comparison with **(Q)RPA** by Terasaki

J. Terasaki and J. Engel, PRC74, 044301.

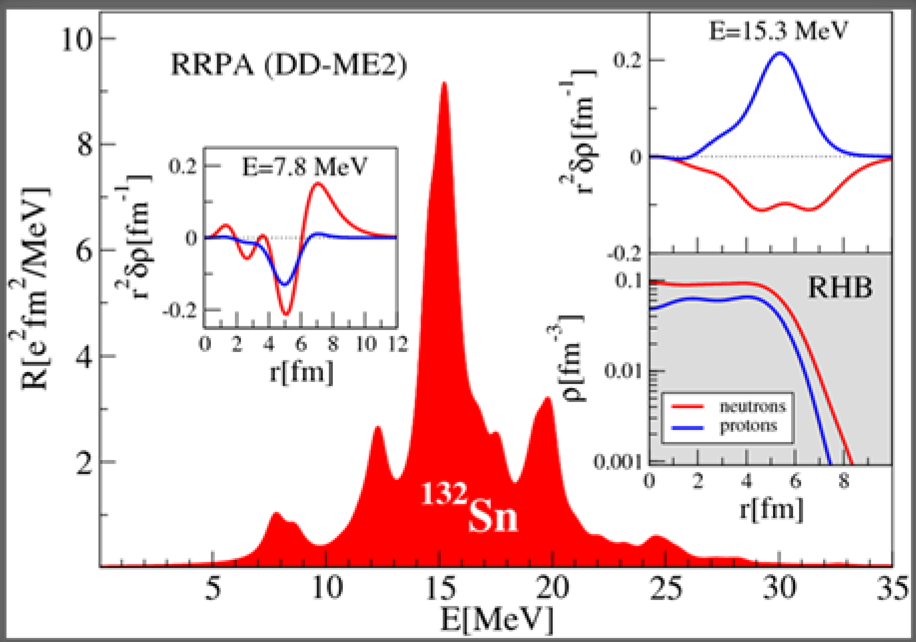
$$\Gamma = \frac{\pi}{R}\sqrt{\frac{\hbar^2}{2m}(E+\lambda_n)} \sim 3\mathrm{MeV@GDR}$$

$$\Gamma = 1.0\ \mathrm{MeV}$$

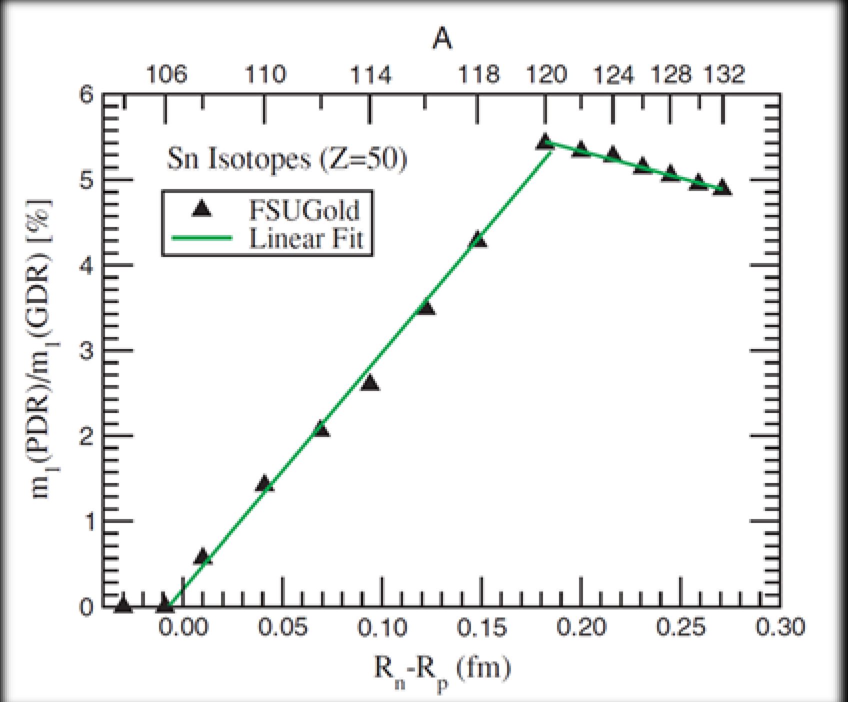


Preceding studies

- ✓ Calculate mainly spherical Sn isotope.
- ✓ No detailed discussion on the nature of PDR.
- ✓ Use H.O. basis, not suitable for describing unstable nuclei.
- ✓ Violates self-consistency.

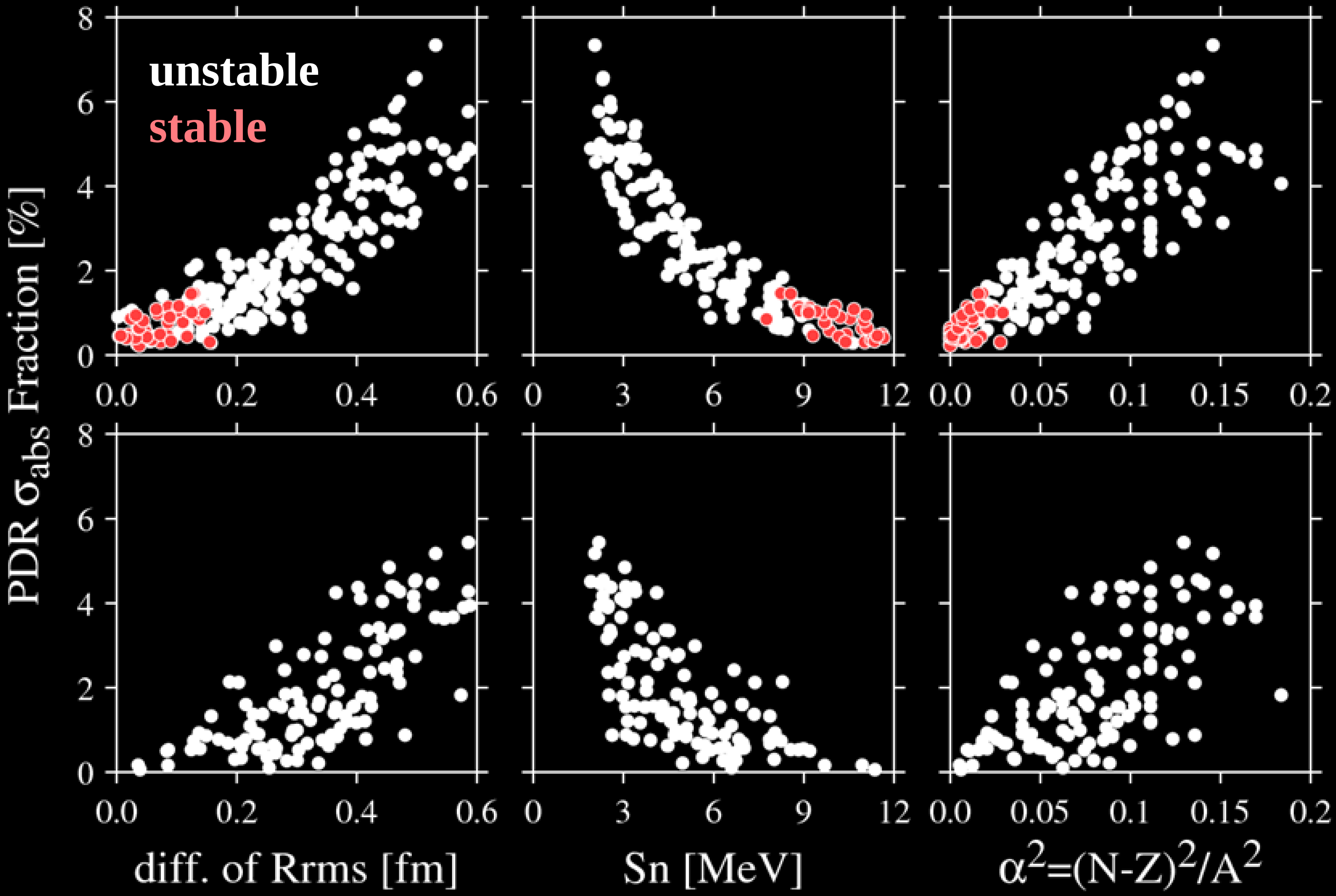


Relativistic (Q)RPA calc.
by Paar, Vretenar et al.

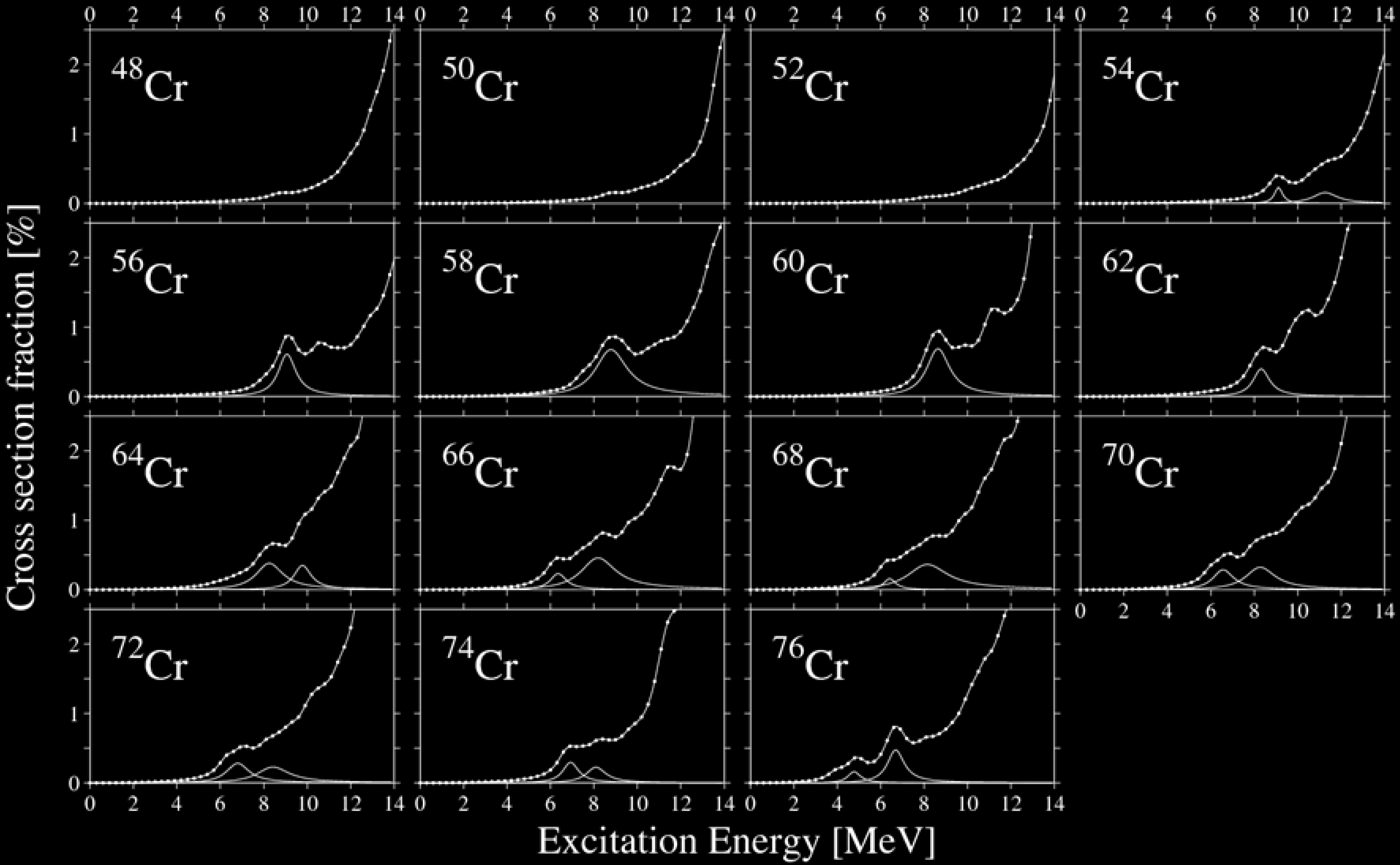


Rela. QRPA calc.
J. Piekarewicz, PRC73, 044325 (2006)

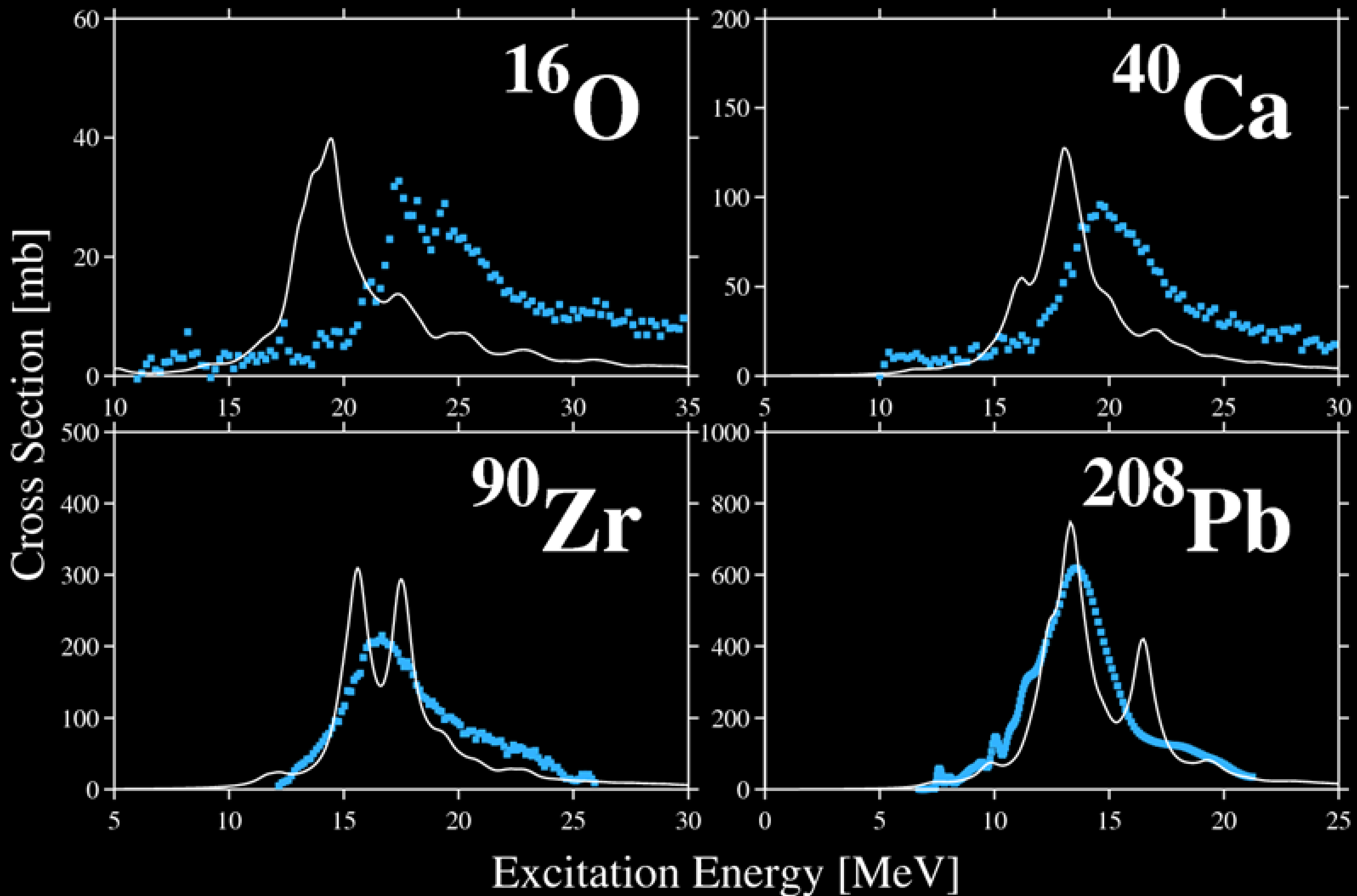
PDR distributions



Extraction of PDR distribution by Lorentzian fitting



Comparison with Expt. data



Expt. data **: http://cdfe.sinp.msu.ru/**