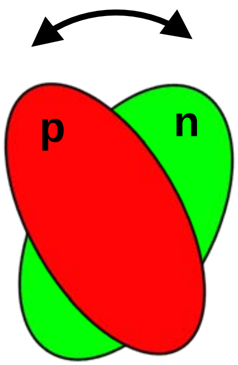
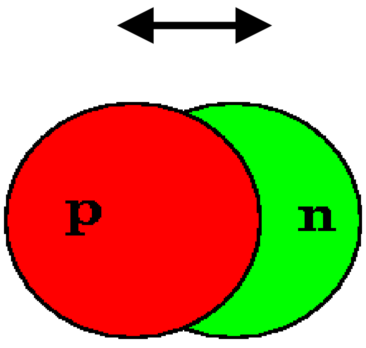
E1 excitations in atomic nuclei: From Giants, Pygmies and Octupoles

Andreas Zilges
Institut für Kernphysik
Universität zu Köln

MAGNETIC and ELECTRIC dipole excitations



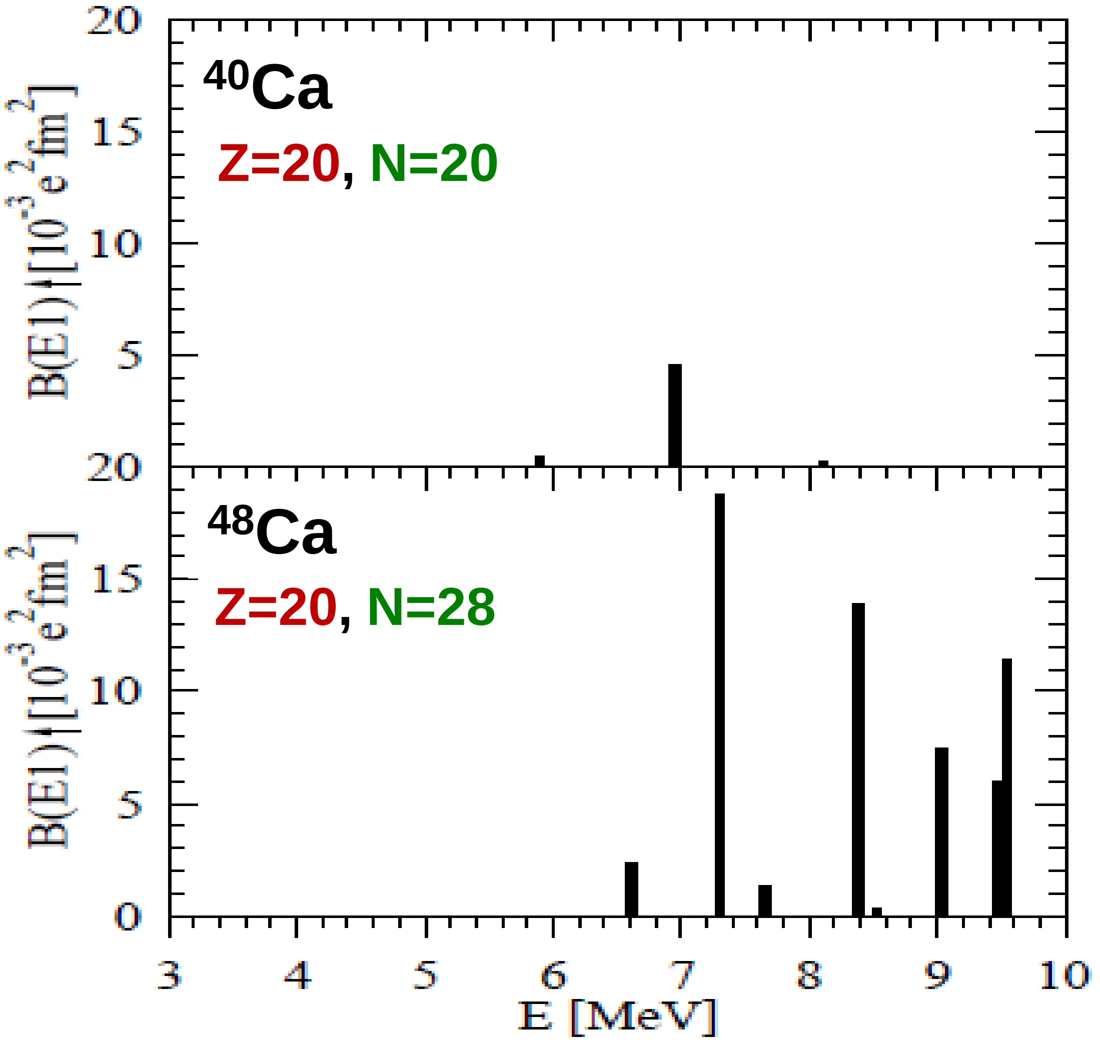


Isovector Magnetic
Scissors Mode
(A. Richter, 1984)

Isovector Electric
Giant Dipole Resonance
(W. Bothe and W. Gentner, 1937)

Proton-Neutron Symmetry Breaking

Electric dipole response in Ca isotopes



T. Hartmann et al., Phys. Rev. Lett. 85 (2000) 274

Half life: M1 vs. E1 at E_x = 3 MeV

Typical strengths for dipole excitations at 3 MeV:

$$B(M1)\uparrow \approx 1\mu_N^2 \approx 100\,\mathrm{meV} \approx 5\,\mathrm{fs\ half\text{-}life}$$

$$B(E1)\uparrow \approx 10^{-2} e^2\, fm^2 \approx 100\,\mathrm{meV} \approx 5\,\mathrm{fs\ half\text{-}life}$$

E1 excitations in atomic nuclei:
From Giants, Pygmies and Octupoles

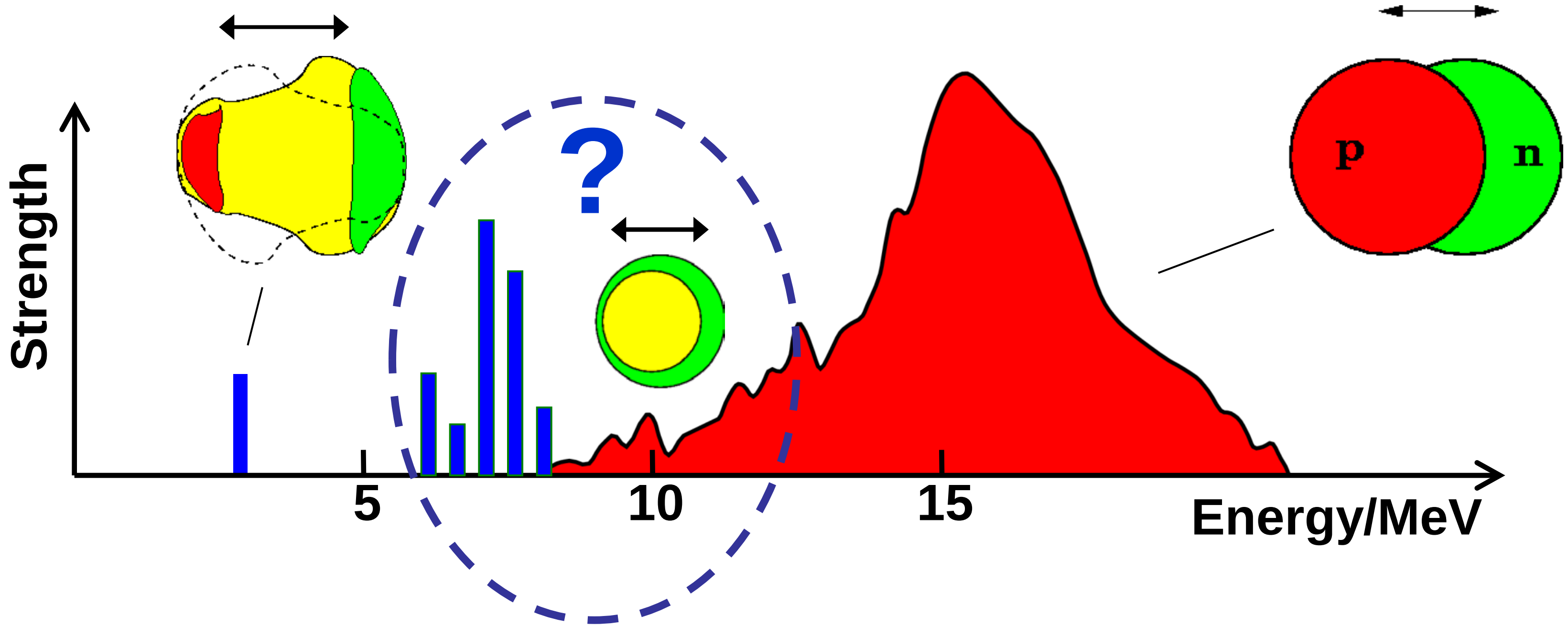
- **Overview**

- **Studies of the Pygmy Dipole Resonance**

  - completeness of (γ,γ') measurements
  - systematics
  - structure

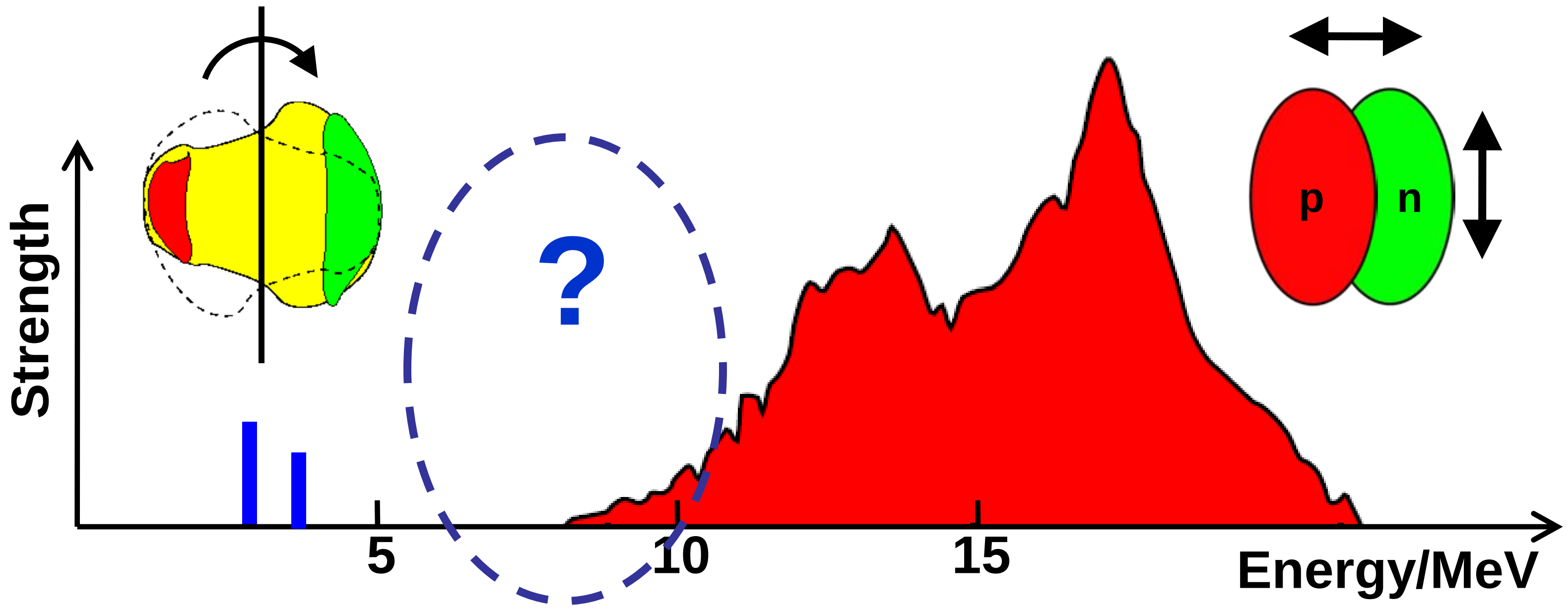
- **Octupole Modes**

The E1 response of spherical atomic nuclei



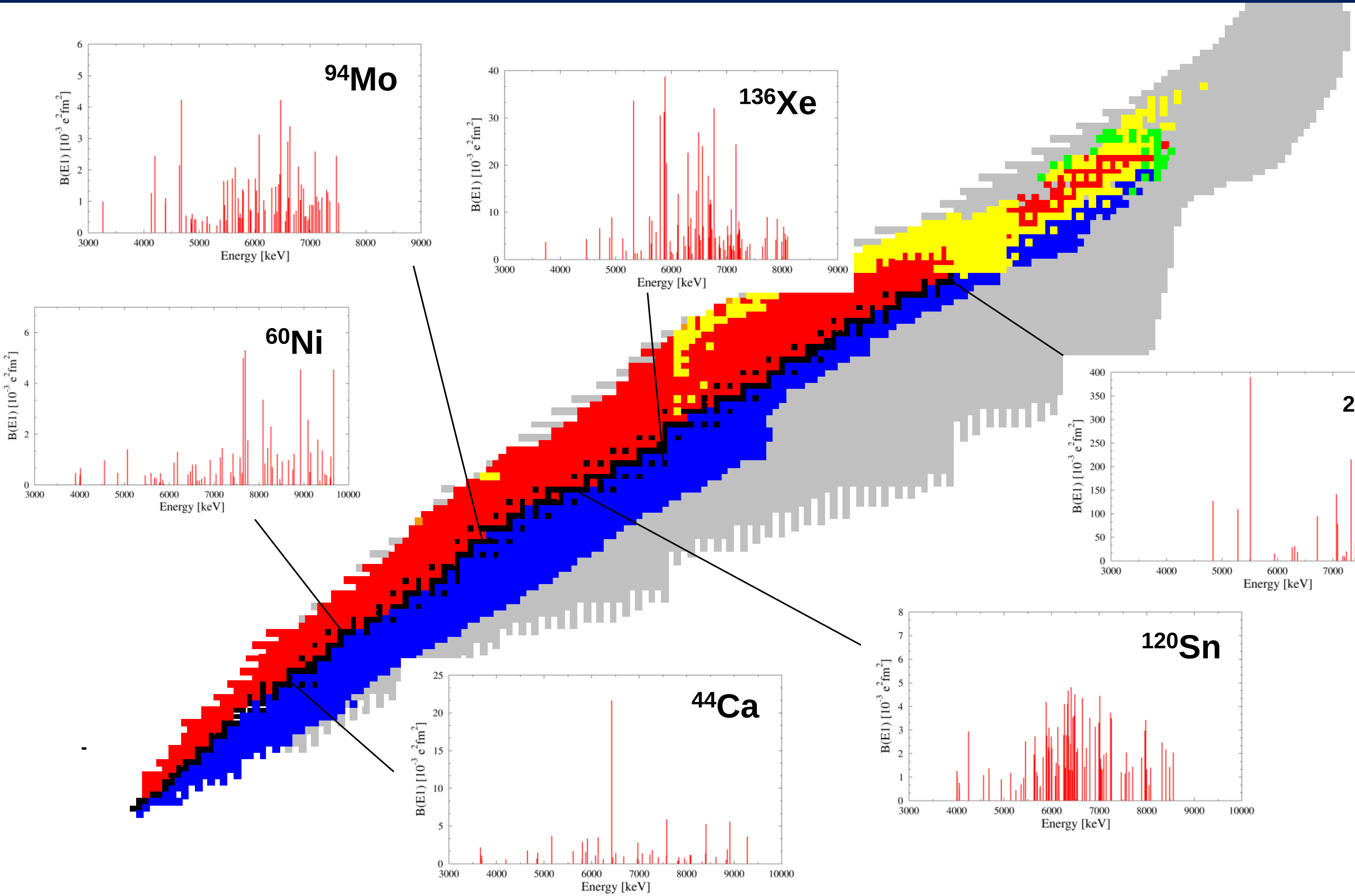
- **Two Phonon Excitation: E_x ~ 3 MeV, B(E1) ~ 10^{-2} W.u.**
- **Giant Dipole Resonance: E_x ~ 18 MeV, B(E1) ~ 10 W.u.**
- **Pygmy Dipole Resonance: E_x ~ 7 MeV, B(E1) ~ 10^{-1} W.u.**

The E1 response of deformed atomic nuclei



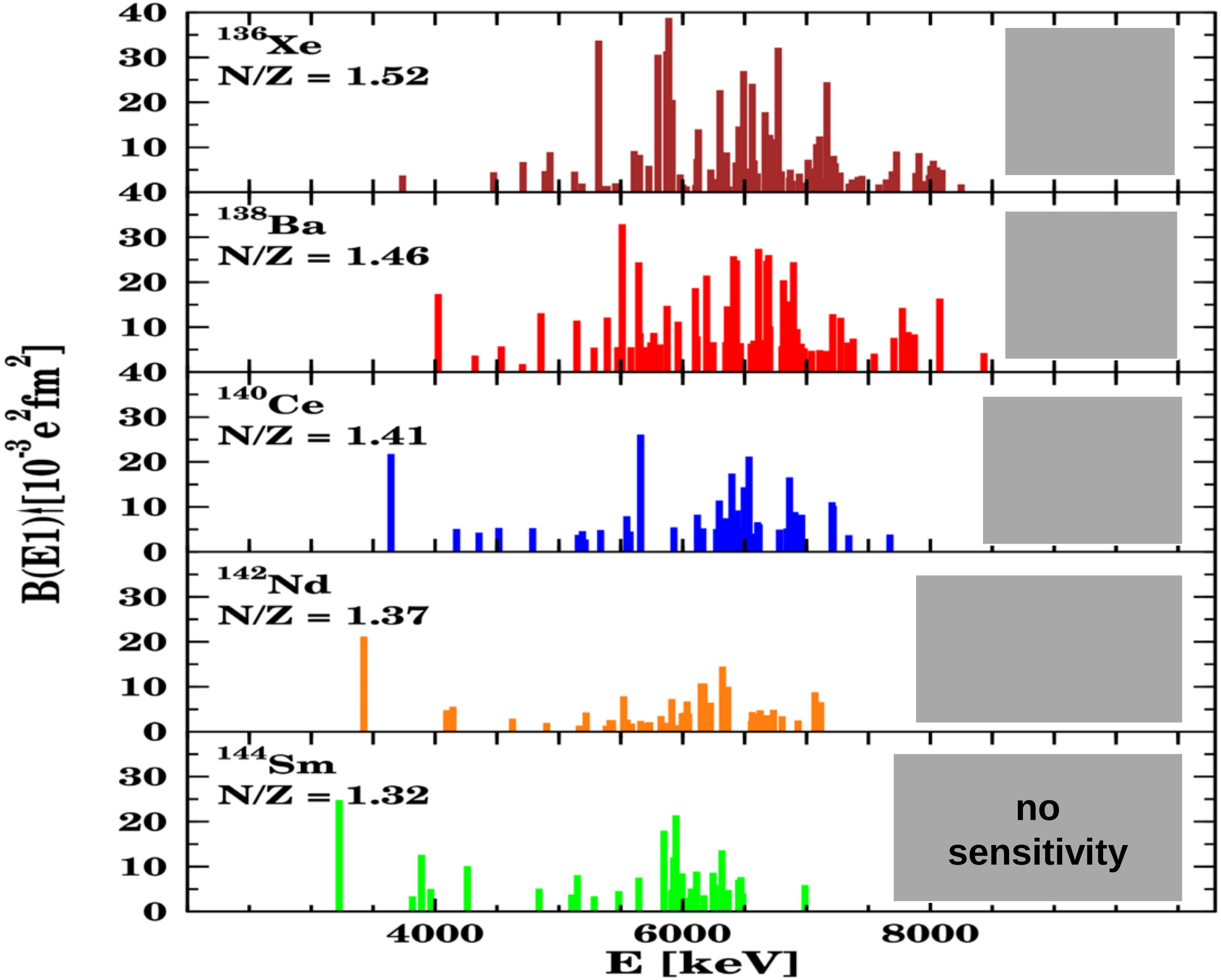
- **Octupole vibrational bandheads:**
  E_x ~ 2 MeV, B(E1) ~ 10^{-2} W.u.
- **Splitted Giant Dipole Resonance:**
  E_x ~ 13 MeV and 18 MeV, B(E1) ~ 10 W.u.

E1 response in spherical nuclei studied in photon scattering experiments



by courtesy of **D. Savran**

E1 distribution in the N=82 isotones from (γ,γ')

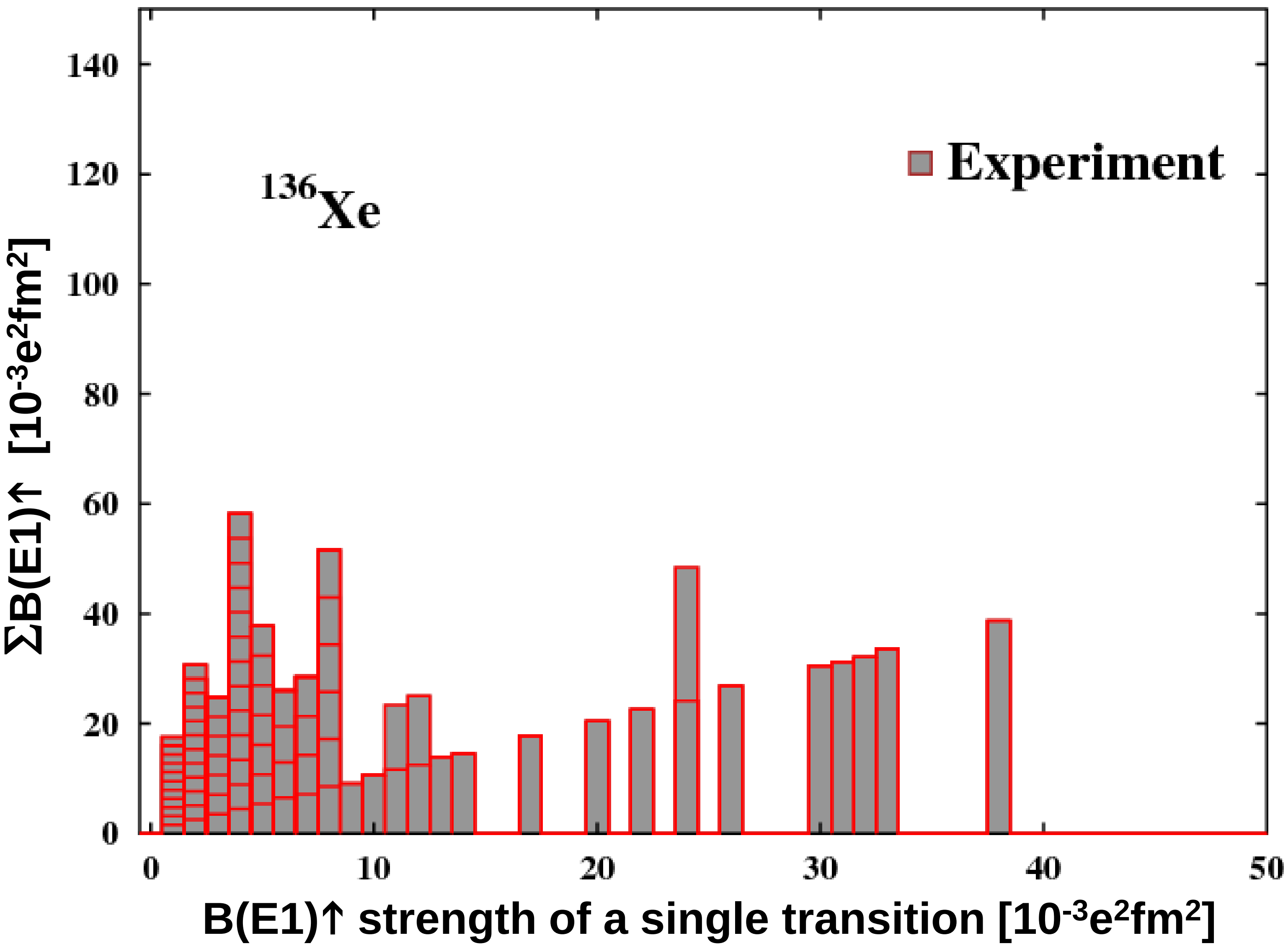


A. Zilges et al., PLB 542 (2002) 43
S. Volz et al., NPA 779 (2006) 1

Open questions on the Pygmy Dipole Resonance

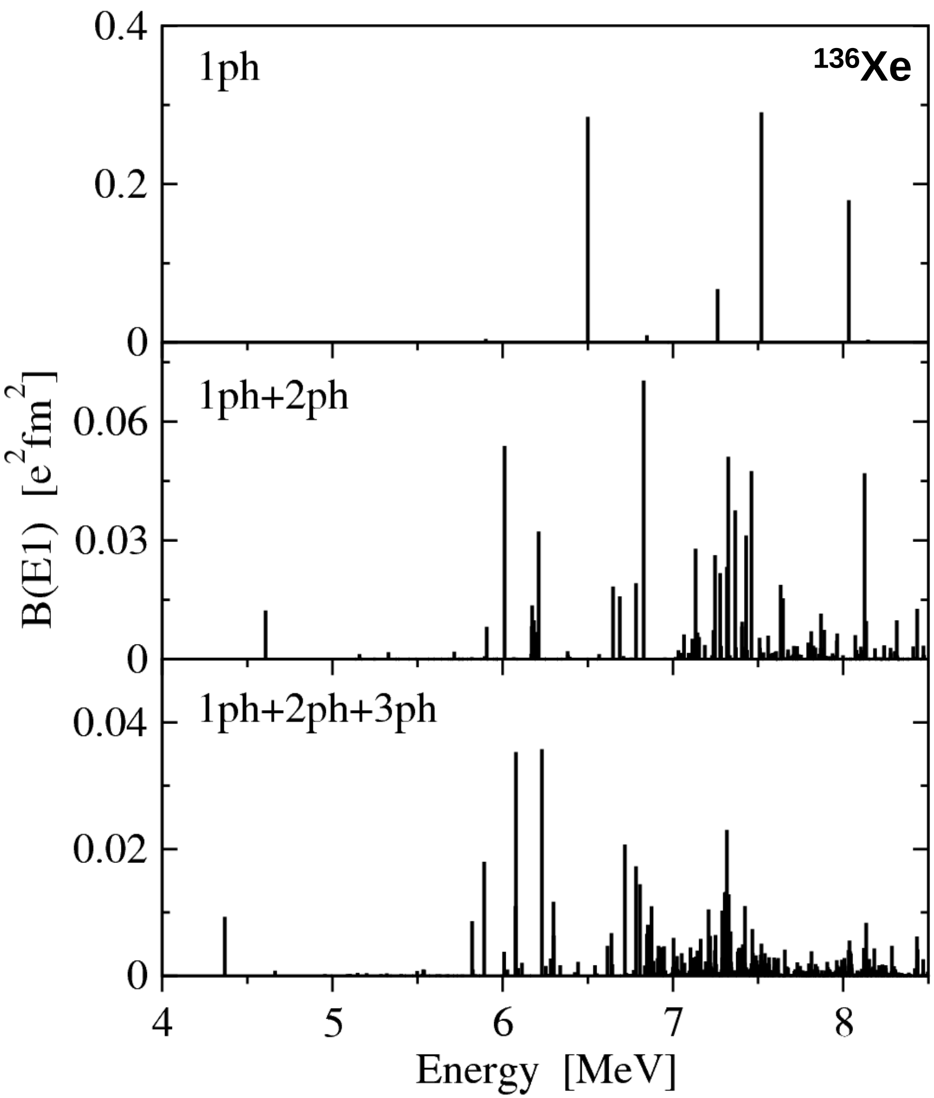
- **How complete are photon scattering experiments?**
- **Does the PDR show a N/Z dependence?**
- **What is the underlying excitation structure?**
- **What is the connection to the PDR in exotic nuclei?**

^{136}Xe: Experimental fragmentation



D. Savran et al., PRL 100 (2008) 232501

Fragmentation in the Quasiparticle Phonon Model

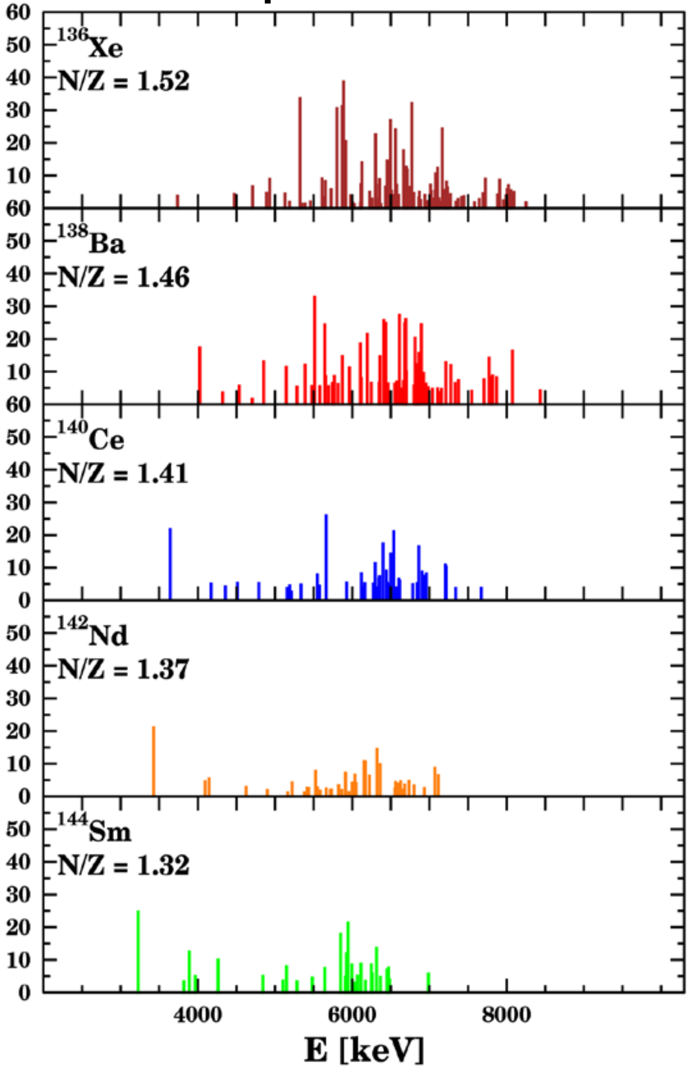


- B(E1) nearly completely carried by 1ph part
- Coupling to complex configuration produces fragmentation
- 1ph, 2ph, 3ph up to 8.5 MeV
  - ⇒ Model space nearly complete up to 8.5 MeV

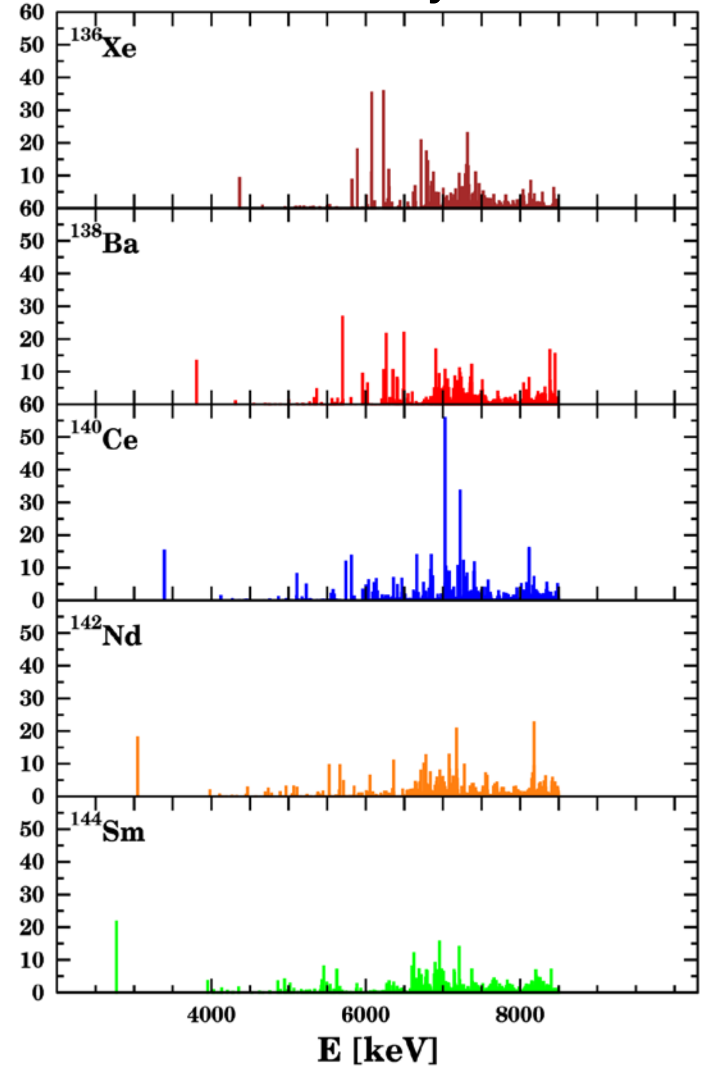
V. Yu. Ponomarev

N=82 isotones: Experiment vs. QPM

Experiment



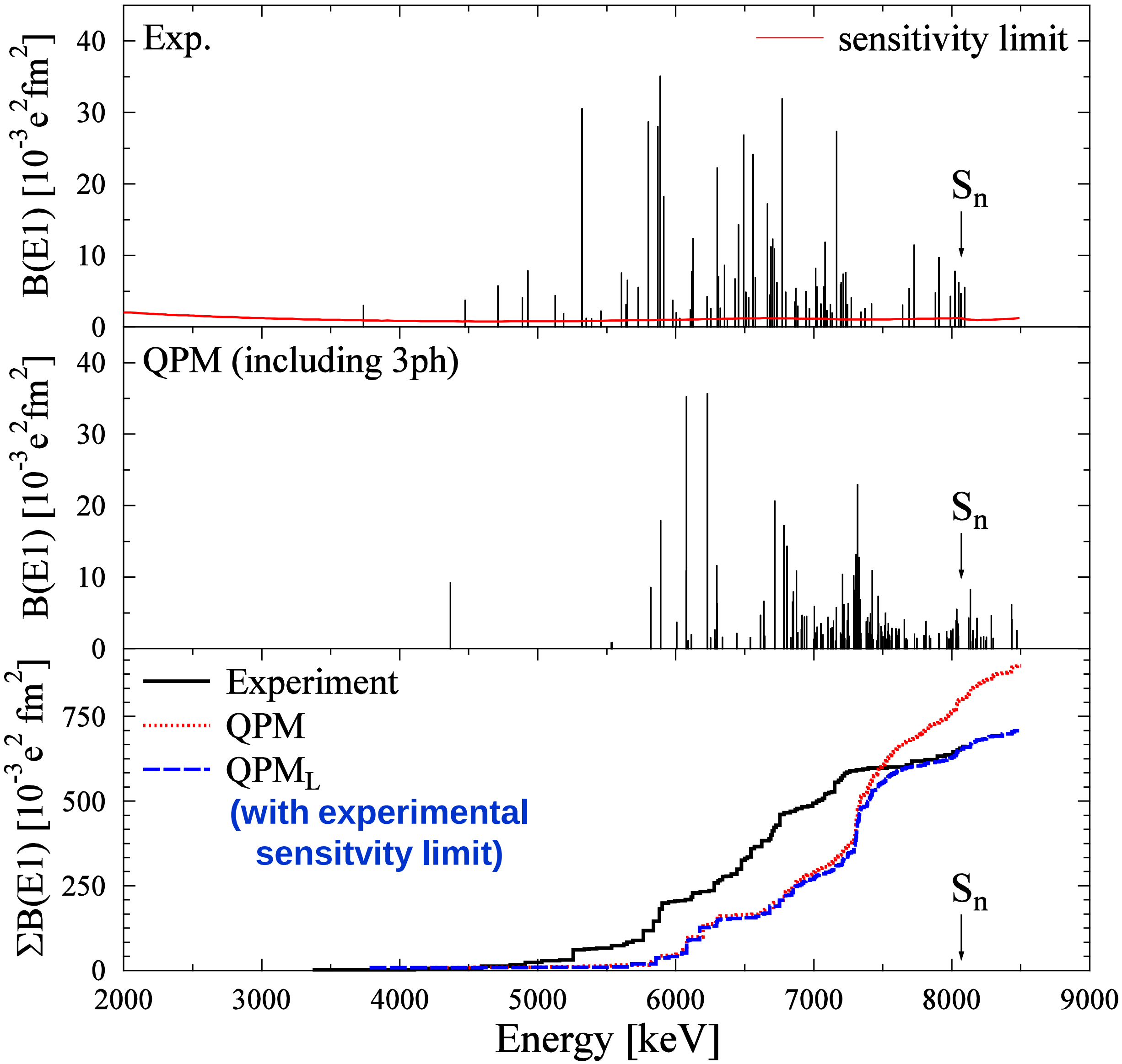
Theory



S. Volz et al., Nucl. Phys. A779 (2006) 1

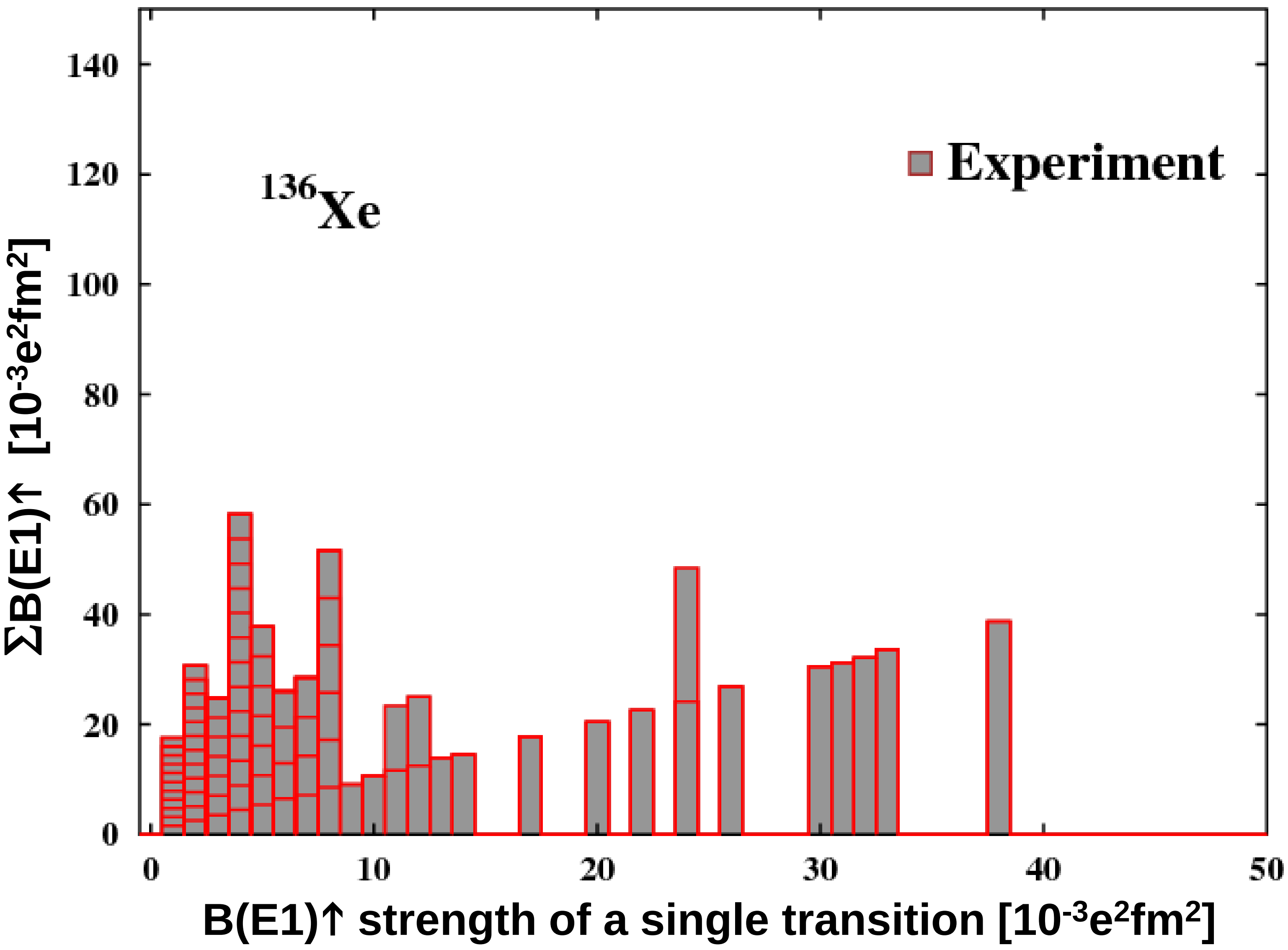
V. Yu. Ponomarev

^{136}Xe: Experiment vs. QPM

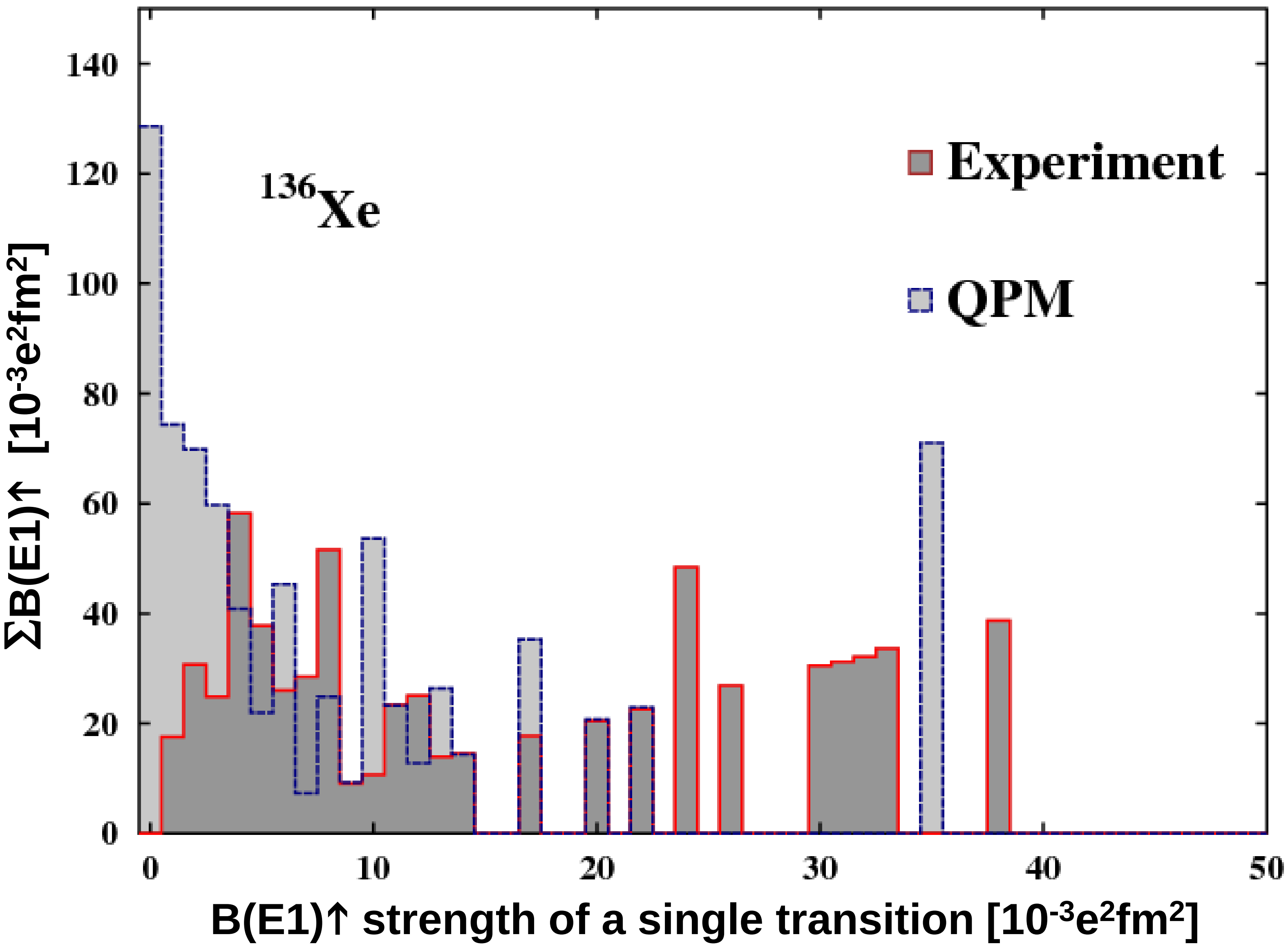


D. Savran et al., PRL 100 (2008) 232501

^{136}Xe: Experimental fragmentation

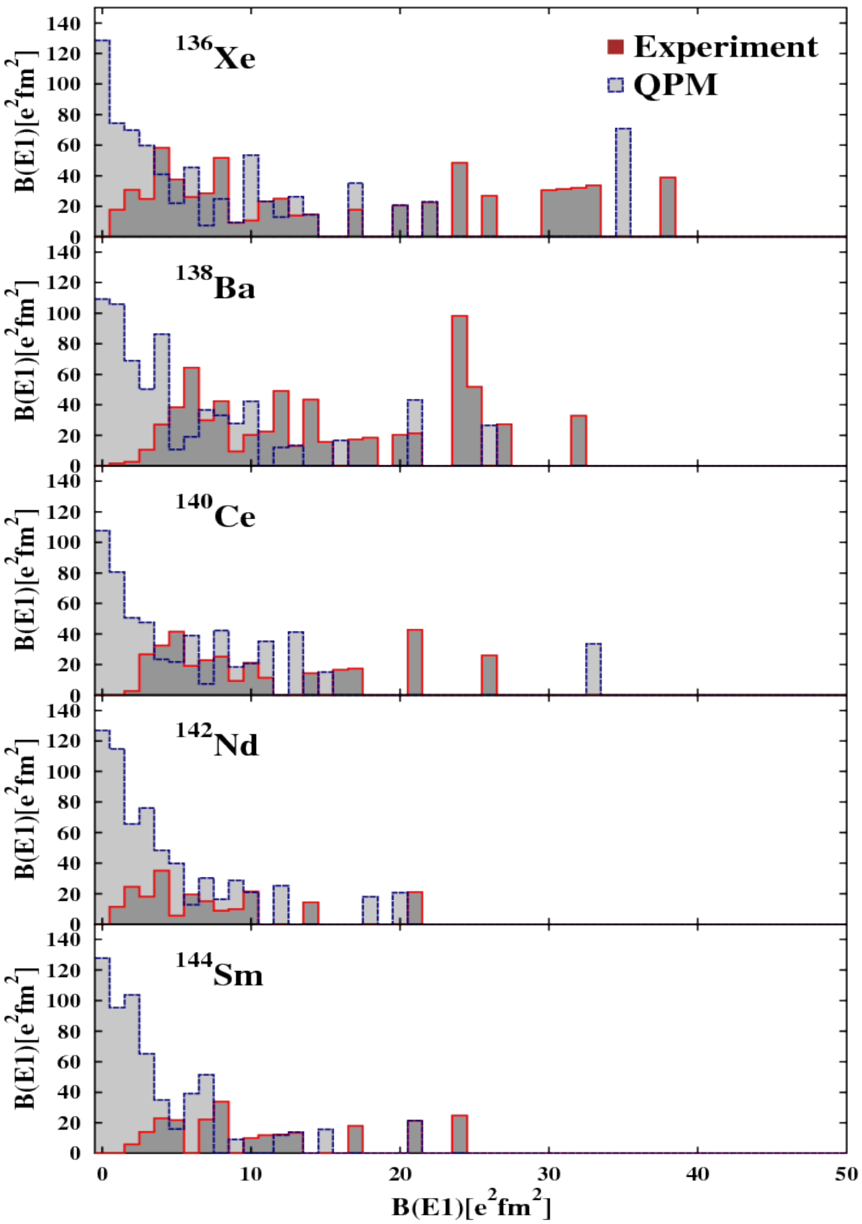


^{136}Xe: Experiment vs. QPM



D. Savran et al., PRL 100 (2008) 232501

How complete are photon scattering experiments ?



- **Increasing fragmentation from ^{136}Xe to ^{144}Sm in experiment and QPM**
- **Impact of experimental sensitivity limit more important with increasing proton number**
- **Missing strengths can vary from a few percent to a factor of three**

D. Savran et al., PRL 100 (2008) 232501

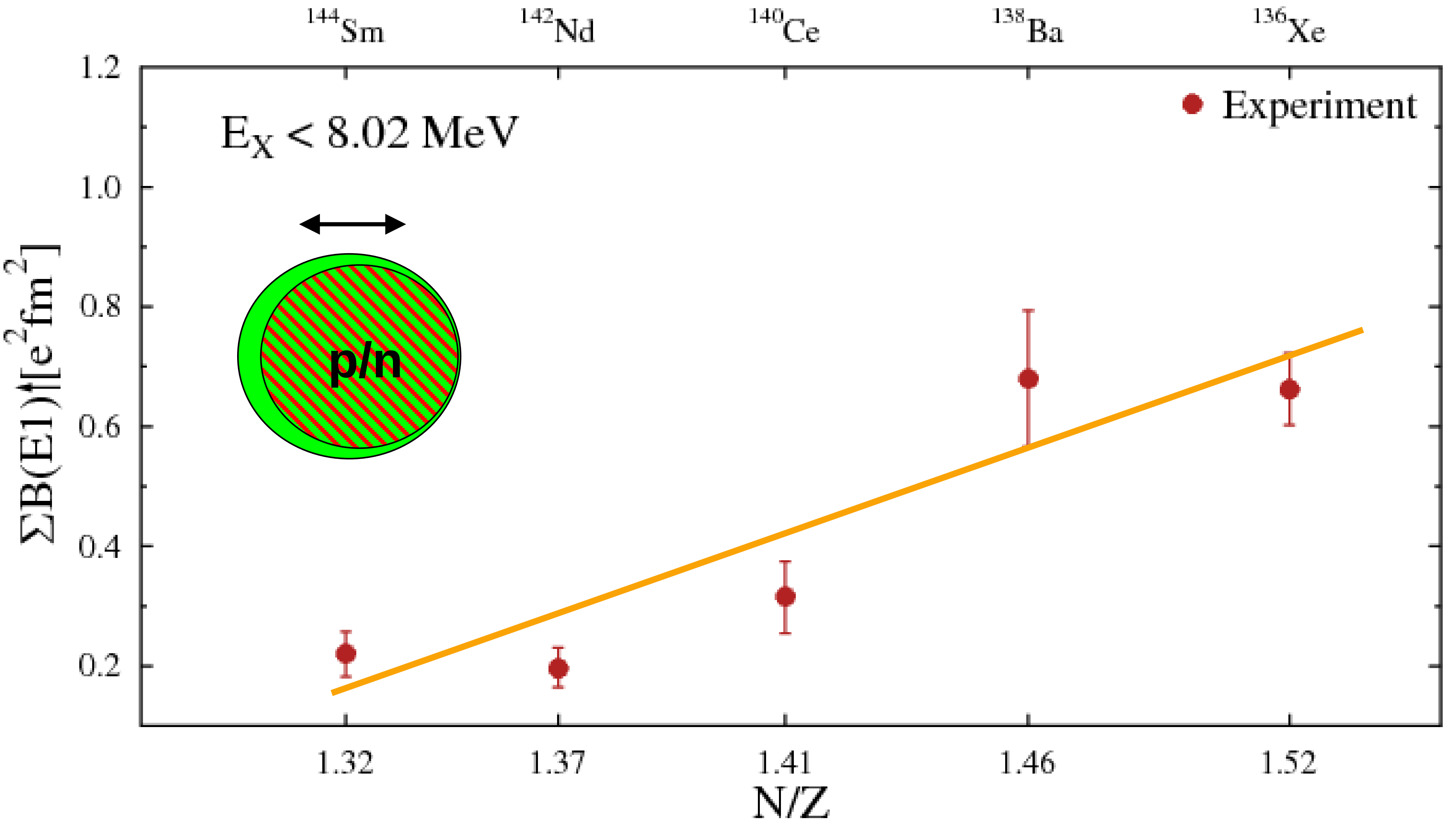
Open questions concerning the PDR

- How complete are photon scattering experiments?

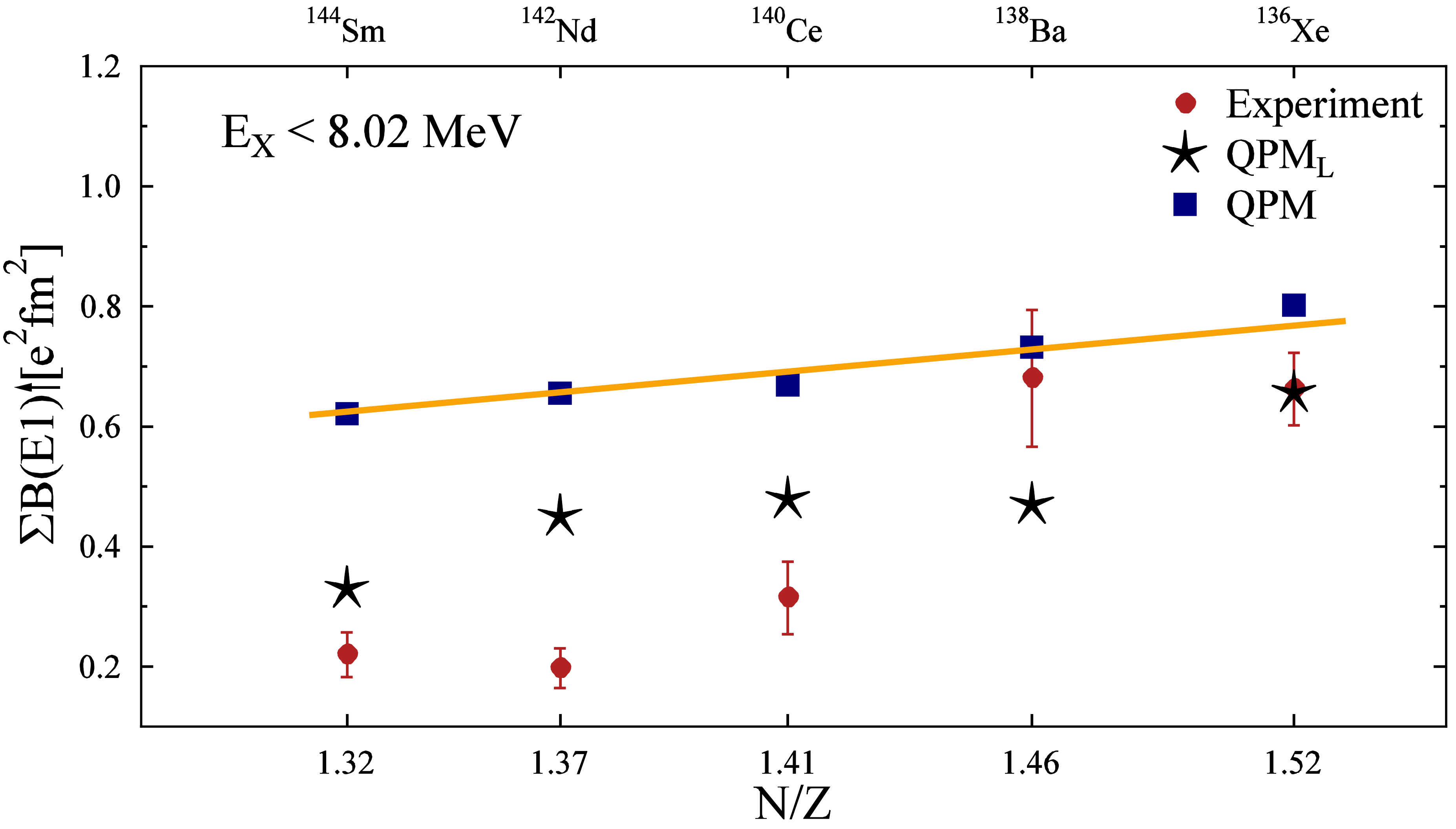
  → Depending on the nucleus 10% to 300% of the total strength are missing.

- Does the PDR show a N/Z dependence?

Summed E1 strength vs. N/Z ratio



Summed E1 strength vs. N/Z ratio



Open questions concerning the PDR

- How complete are photon scattering experiments?

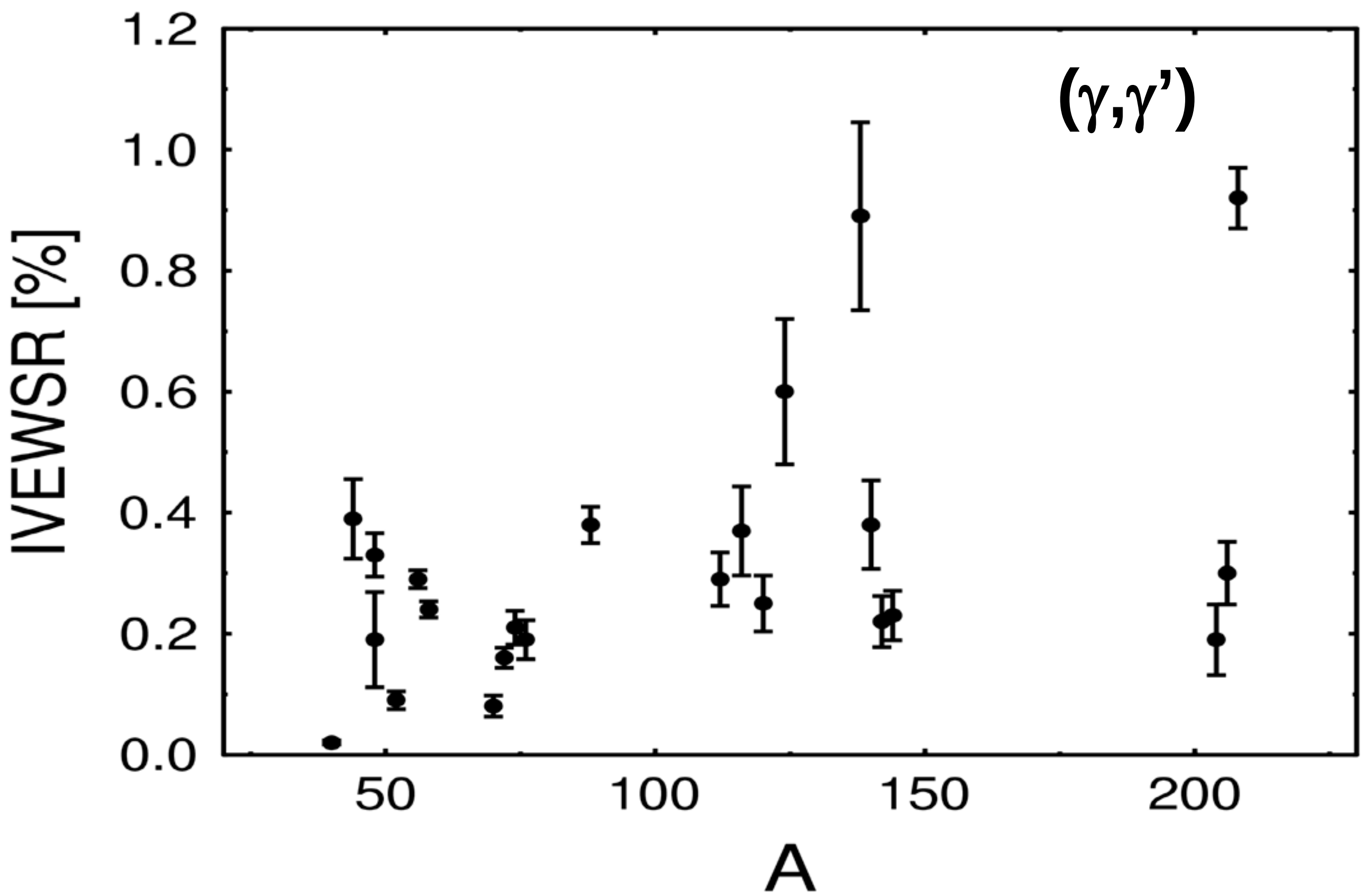
  → Depending on the nucleus 10% to 250% of the total strength are missing.

- Does the PDR show a N/Z dependence?

  → No direct evidence.

- What is the underlying excitation structure?

Exhaustion of isovector E1 sum rule



K. Govaert et al., Phys. Rev. C 57 (1998) 2229
N. Ryezayeva et al., Phys. Rev. Lett. 89 (2002) 272502
A. Zilges et al., Phys. Lett. B 542 (2002) 43
P. Adrich et al., Phys. Rev. Lett 95 (2005) 132501
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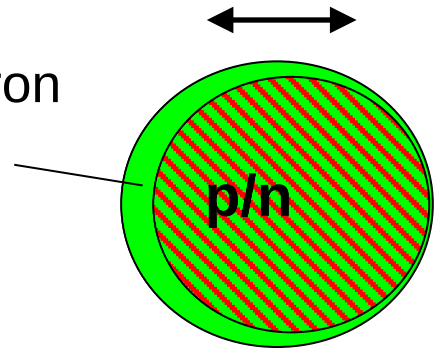
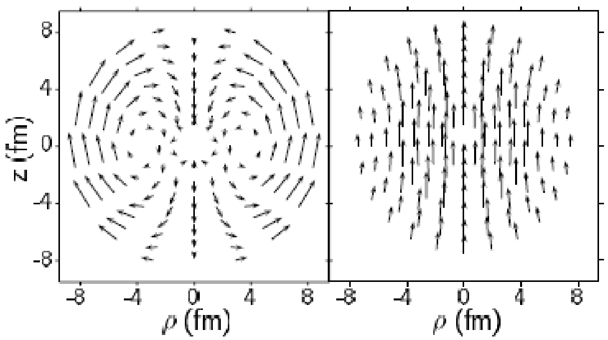
O. Wieland et al., Phys. Rev. Lett. 102 (2009) 092502

What is the underlying excitation structure?

neutron skin



torroidal modes



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J. Liang, L. Cao, Z. Ma, Phys. Rev. C 75 (2007) 054320
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N. Paar, D. Vretenar, E. Khan, G. Colò, Rep. Prog. Phys. 70 (2007) 691
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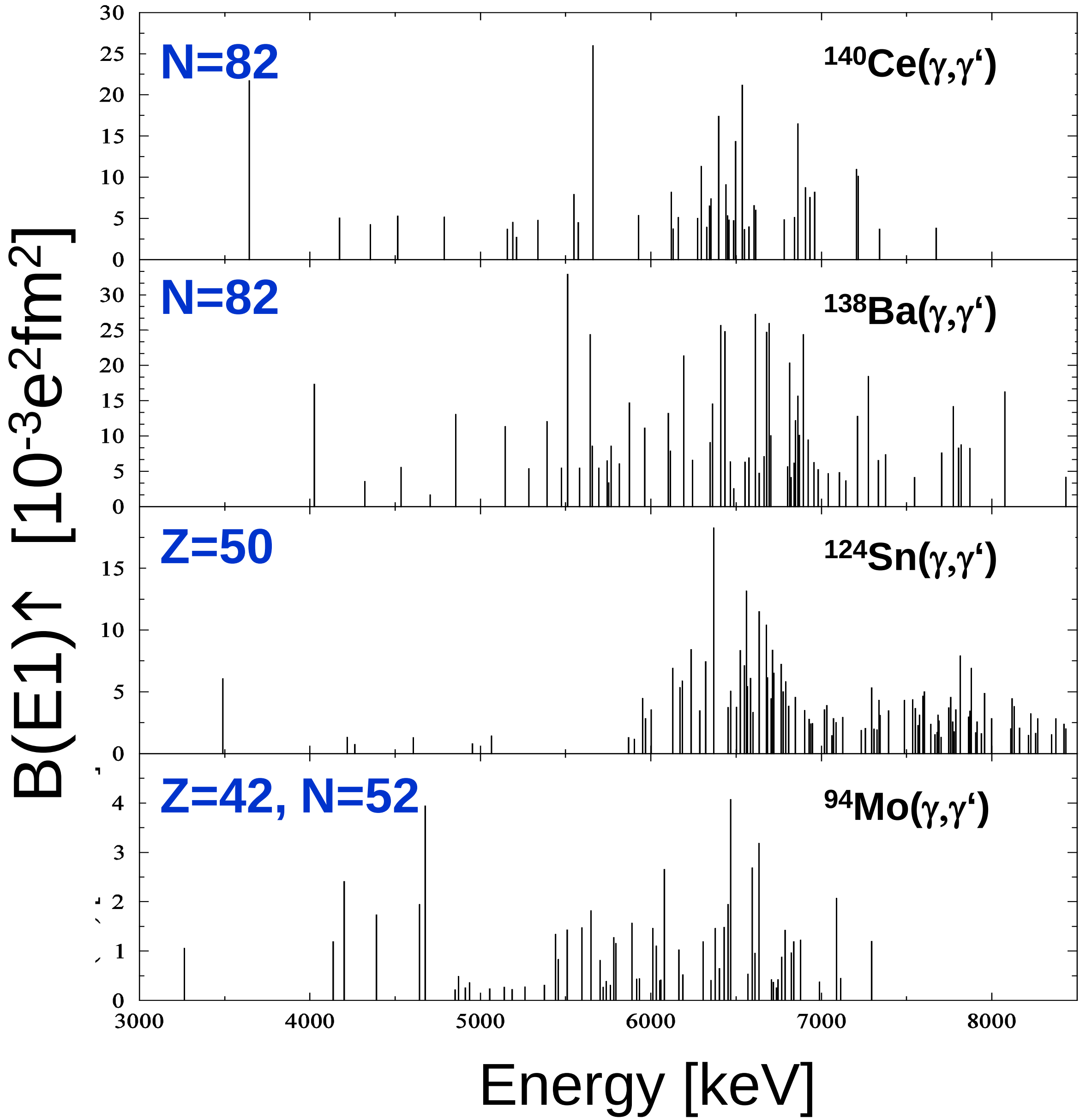
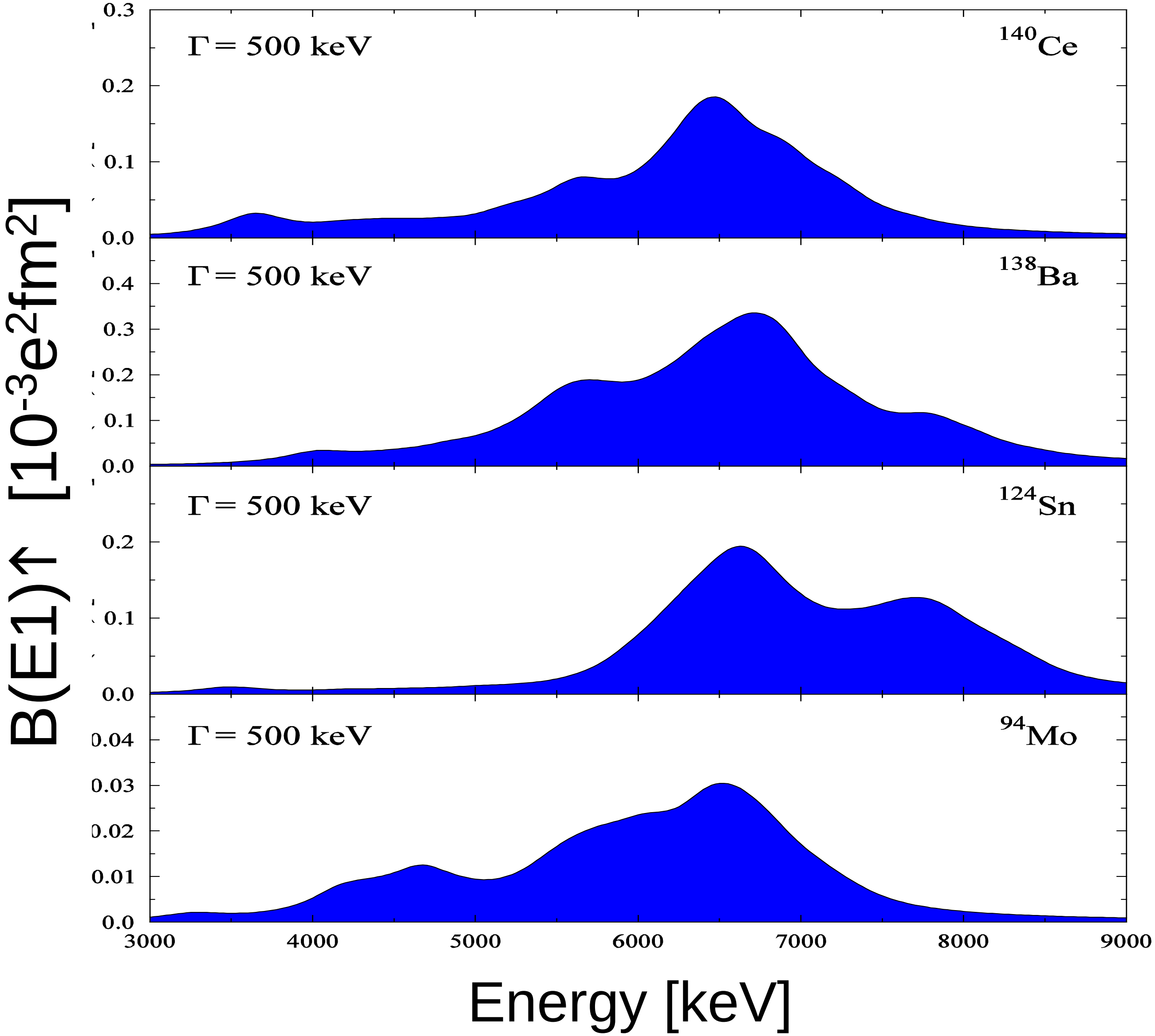
N. Paar, Y.F. Niu, D. Vretenar, and J. Meng, PRL 103 (2009) 032502

B(E1) strength distribution



J. Endres, to be published

A splitting of the PDR ?



F. Iachello, priv. comm.

A complementary probe: α scattering

- Isoscalar probe
  → Complementary structure information
- Problem:
  - 30-100 keV energy resolution

  → Single excitations not resolved

- Excitation of higher multipolarities

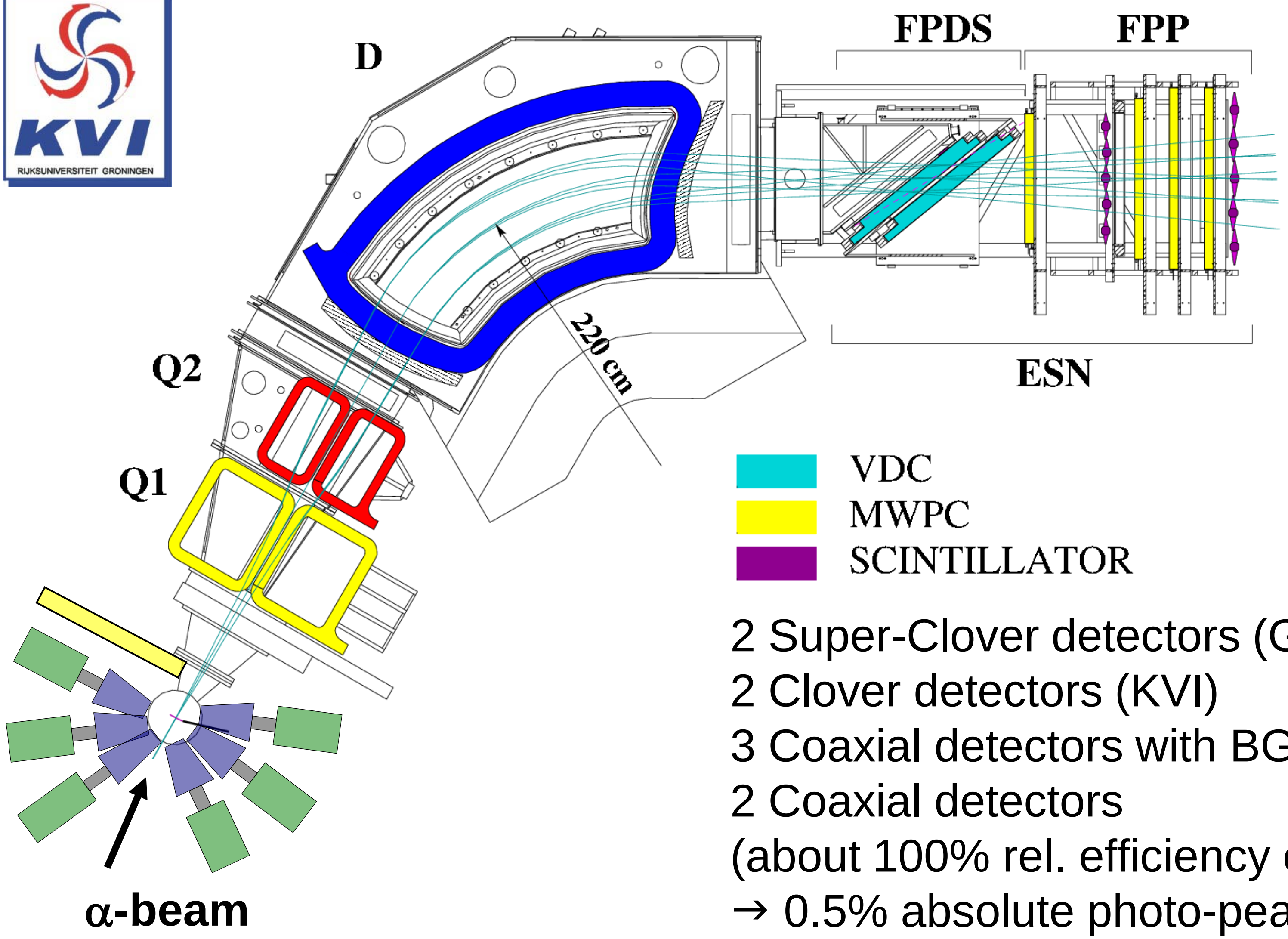
  → Difficult separation from other excitations

⇨ **No detailed spectroscopy of PDR possible with (α,α‘)**

The solution: $(\alpha,\alpha'\gamma)$ experiments

- Coincident measurement of γ-decay
  ⇨ $(\alpha,\alpha'\gamma)$
- Selection of decays to the ground state
  ⇨ Selectivity to E1 decays
  T.D. Poelhekken et al., Phys. Lett. B ***278*** *(1992) 423*
- Use of HPGe detectors
  ⇨ High energy resolution
  D. Savran et al., Nucl. Instr. and Meth. A ***564*** *(2006) 267*
- Experimental parameters:
  ⇨ E_α = 136 MeV and forward angle

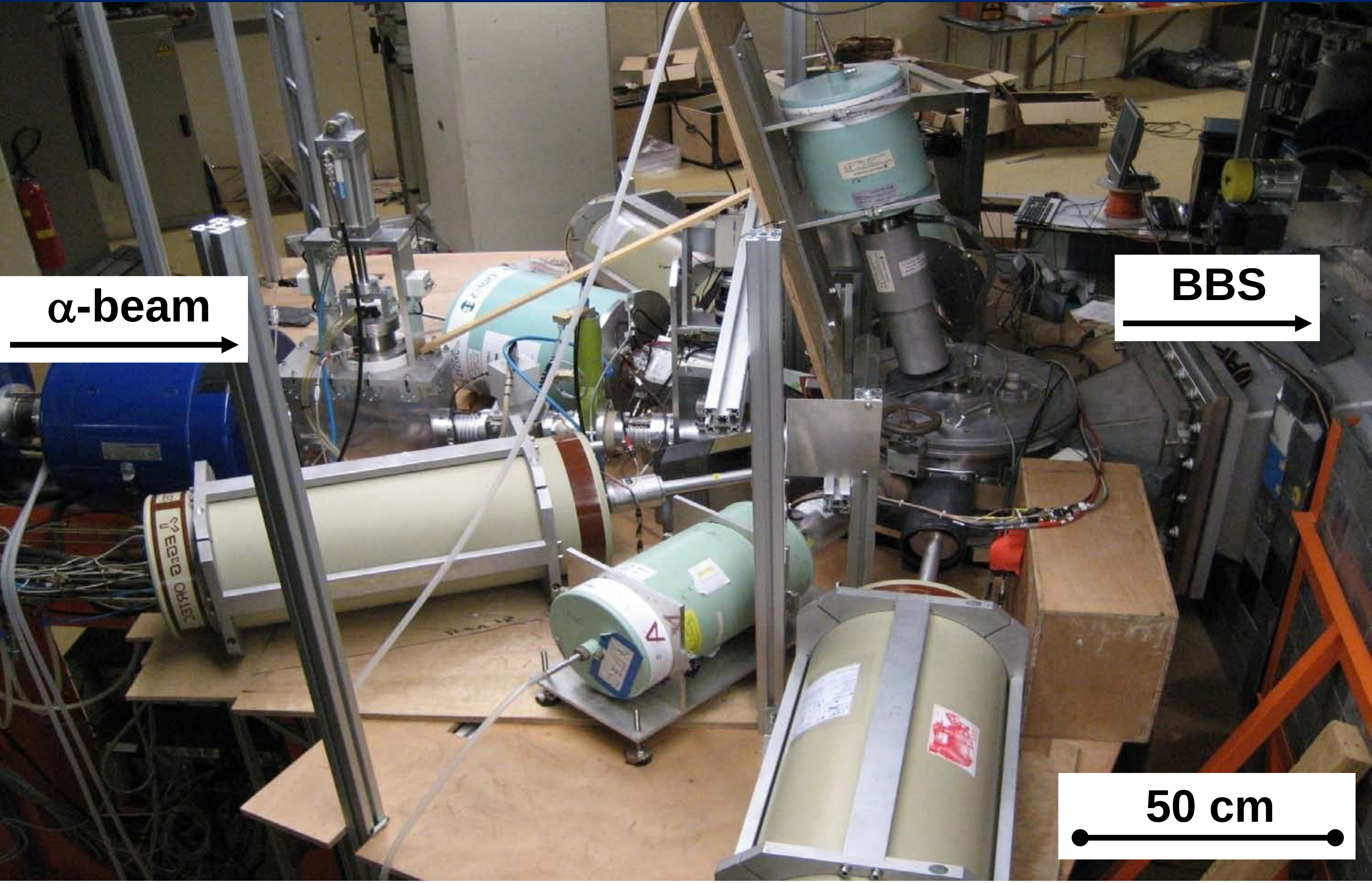
Realization at the BBS/EUROSUPERNOVA setup



2 Super-Clover detectors (GSI)
2 Clover detectors (KVI)
3 Coaxial detectors with BGO
2 Coaxial detectors
(about 100% rel. efficiency each)
→ 0.5% absolute photo-peak efficiency

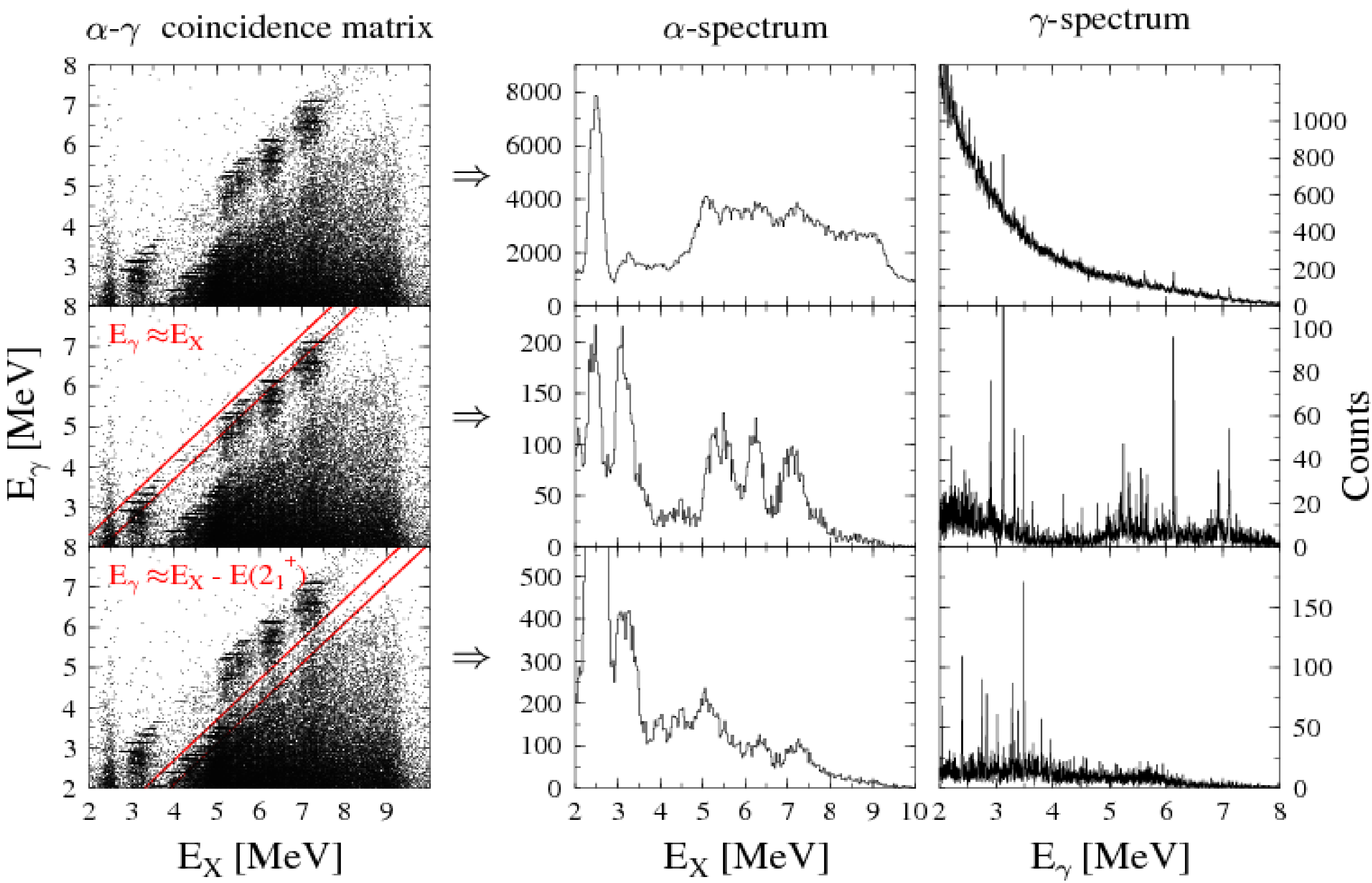
D. Savran et al., Nucl. Inst. and Meth. Phys. Res. A 564 (2006) 267

Realization at the BBS/EUROSUPERNOVA setup



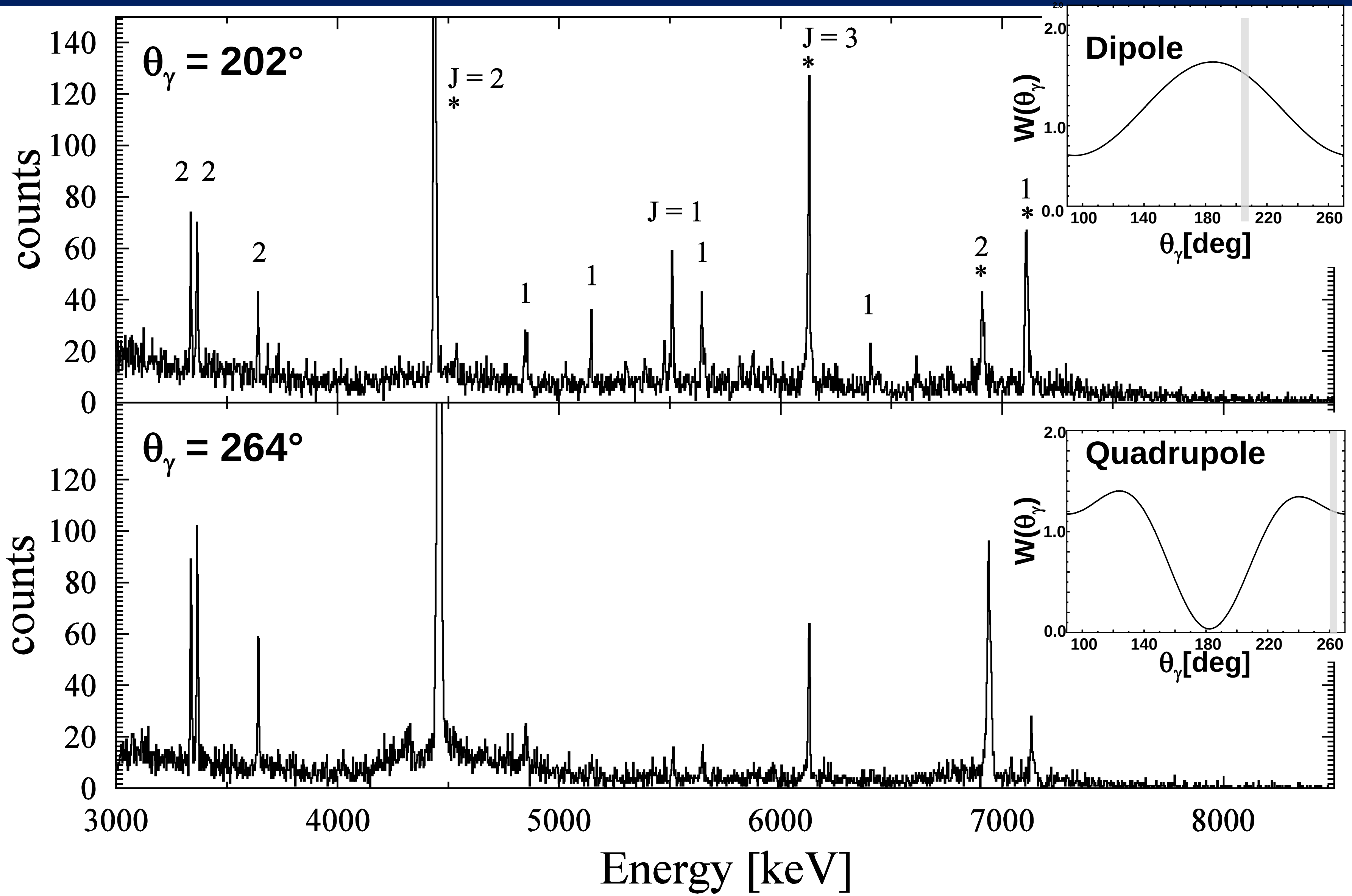
Realization at the BBS/EUROSUPERNOVA setup

The α–γ coincidence matrix for ^{140}Ce



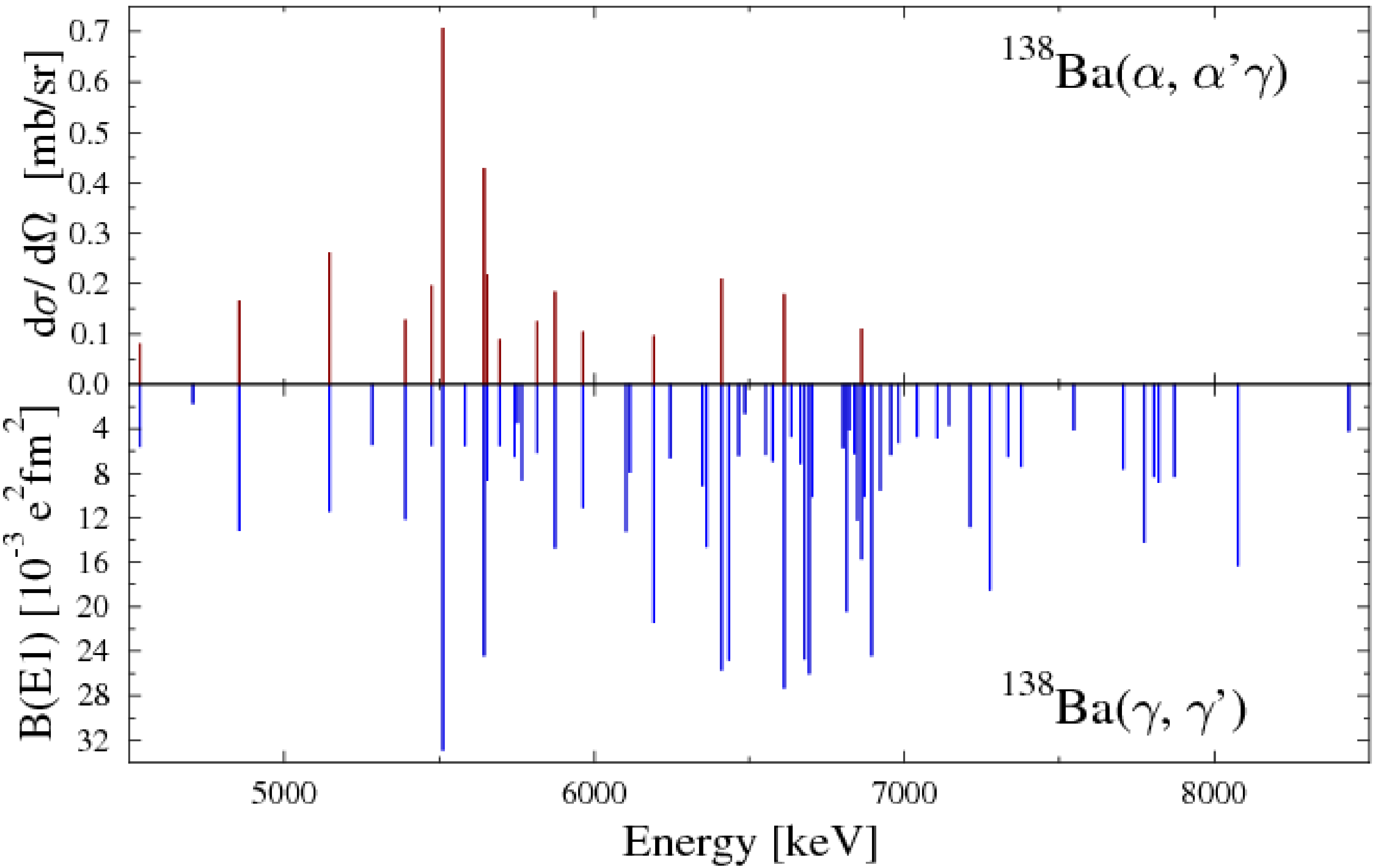
D. Savran et al., Phys. Rev. Lett. 97 (2006) 172502
J. Endres et al., Phys. Rev. C 80 (2009) 034302

Angular distribution



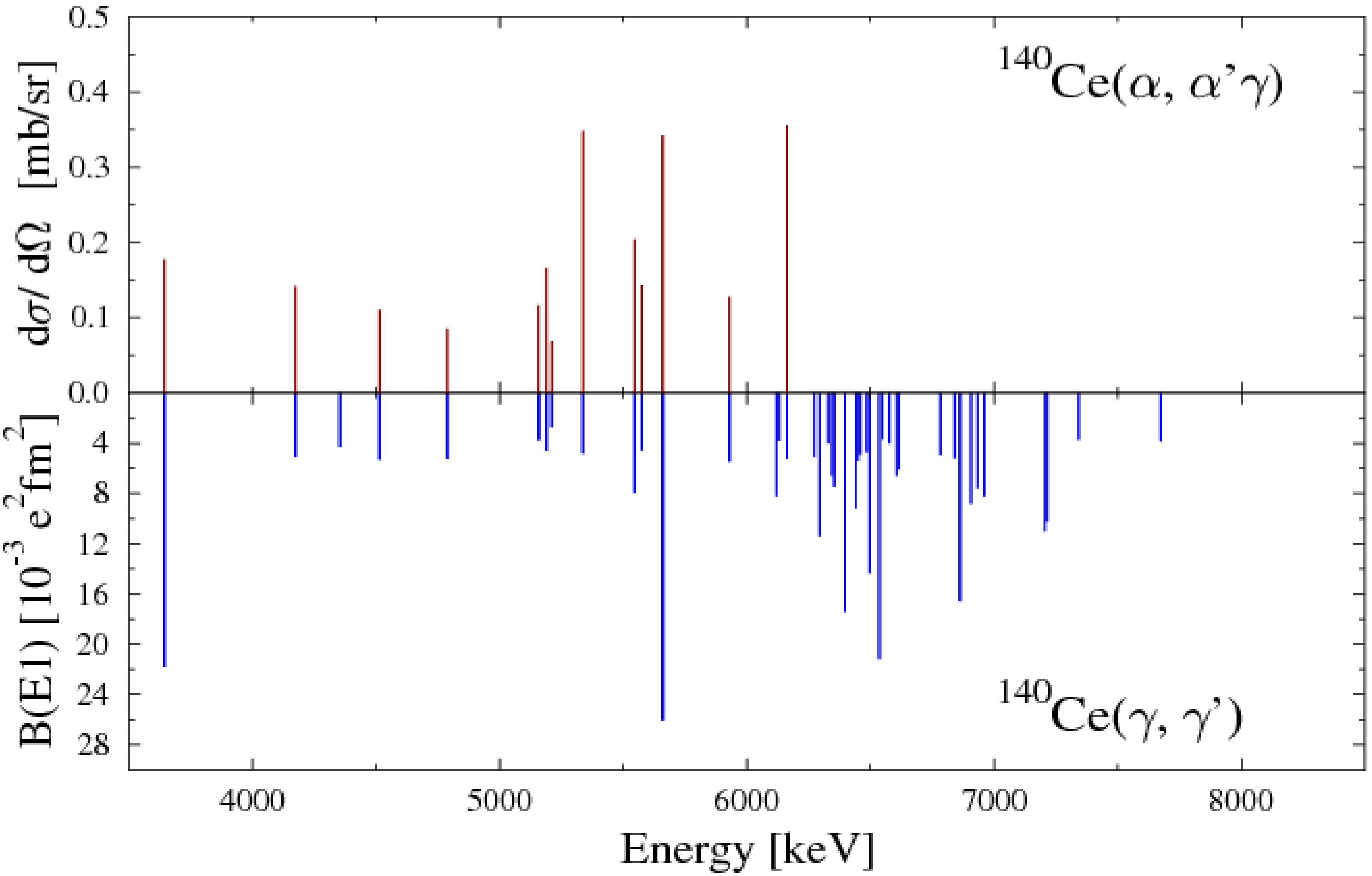
J. Endres et al., Phys. Rev. C 80 (2009) 034302

Comparison: ($\alpha,\alpha'\gamma$) and (γ,γ')



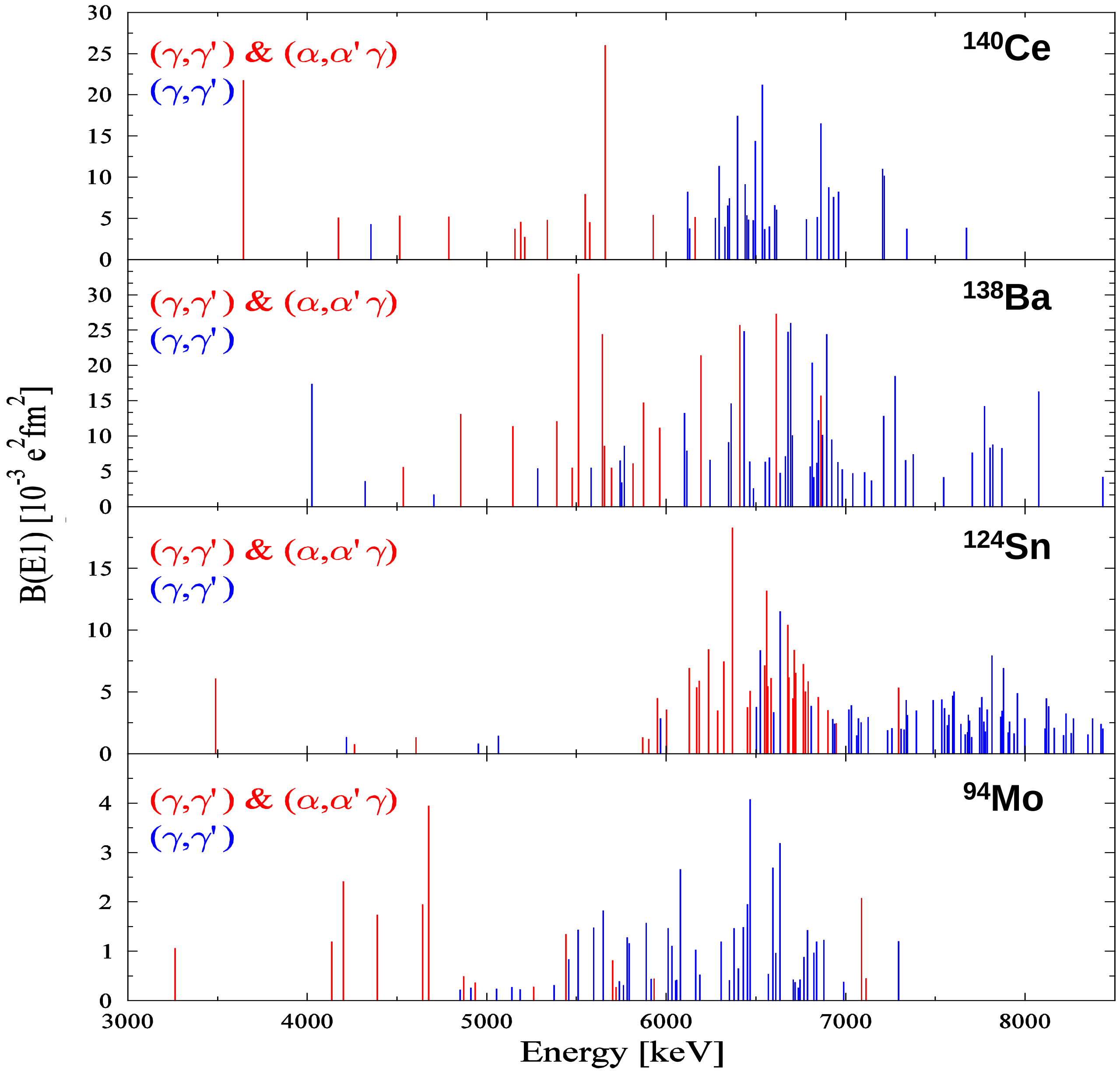
J. Endres et al., Phys. Rev. C 80 (2009) 034302

Comparison: (α,α‘γ) and (γ,γ‘)

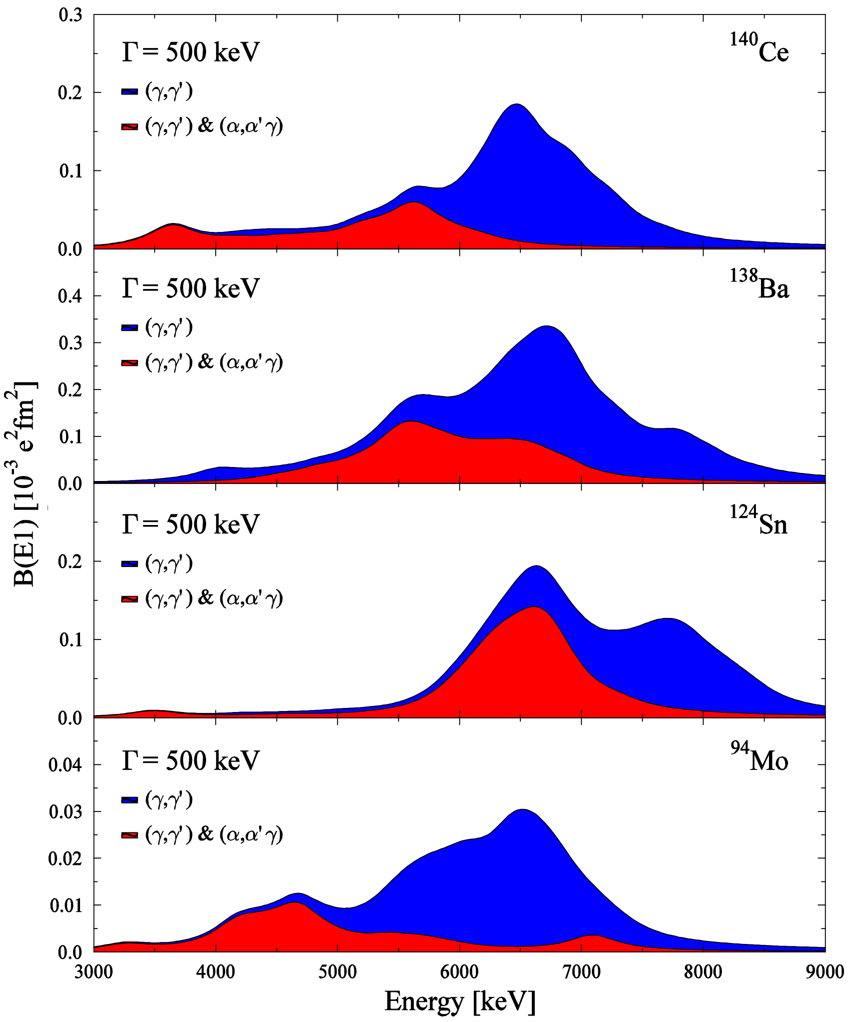


J. Endres et al., Phys. Rev. C 80 (2009) 034302

A splitting of the PDR ?



A splitting of the PDR !

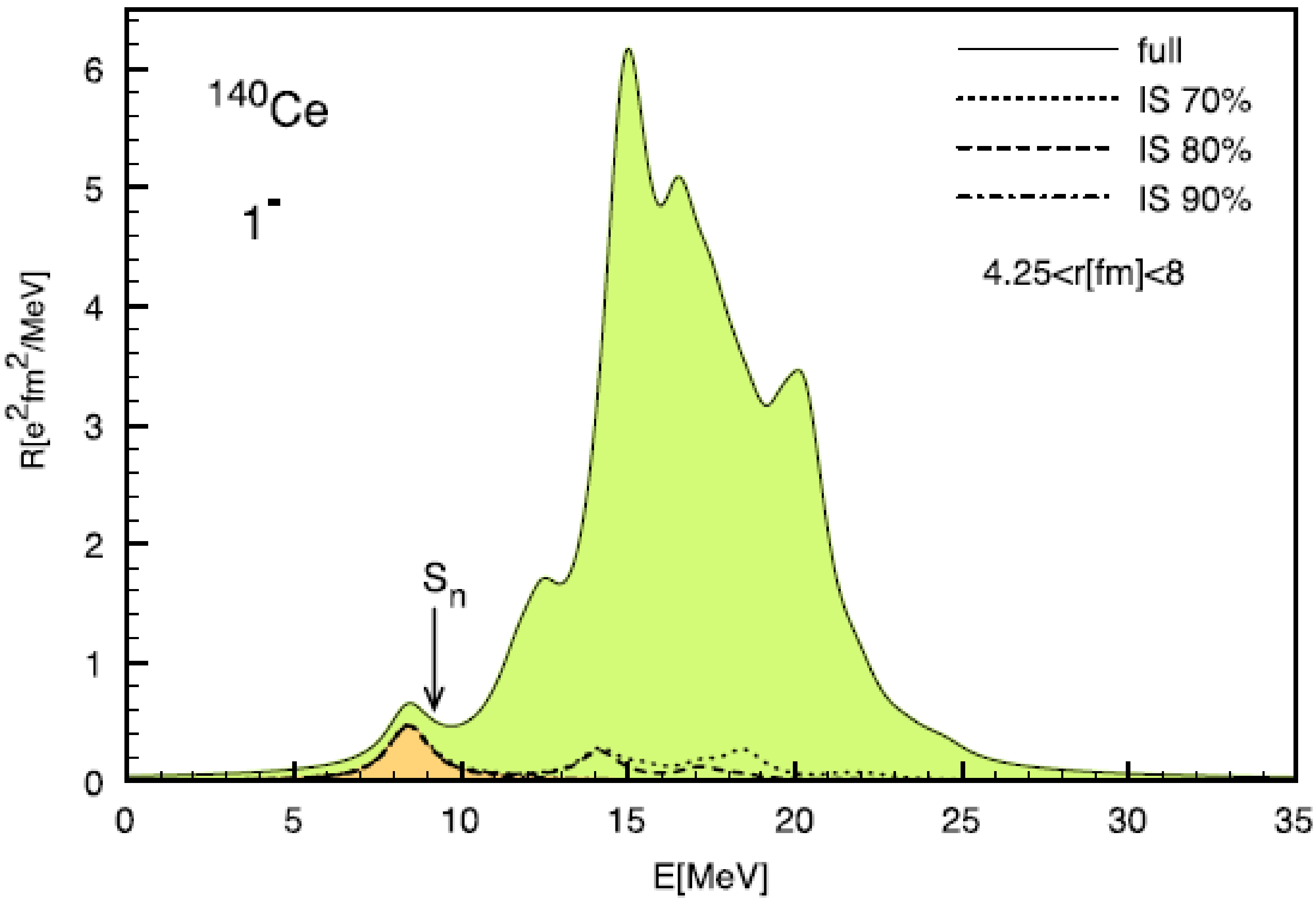


- **Splitting of the PDR:**
  - Two groups of states with different structure

- **Two different probes:**
  - Isospin character
  - Interaction with nucleus

J. Endres et al., to be published

E1 strength in the relativistic QRPA



N. Paar, Y.F. Niu, D. Vretenar, and J. Meng, PRL 103 (2009) 032502

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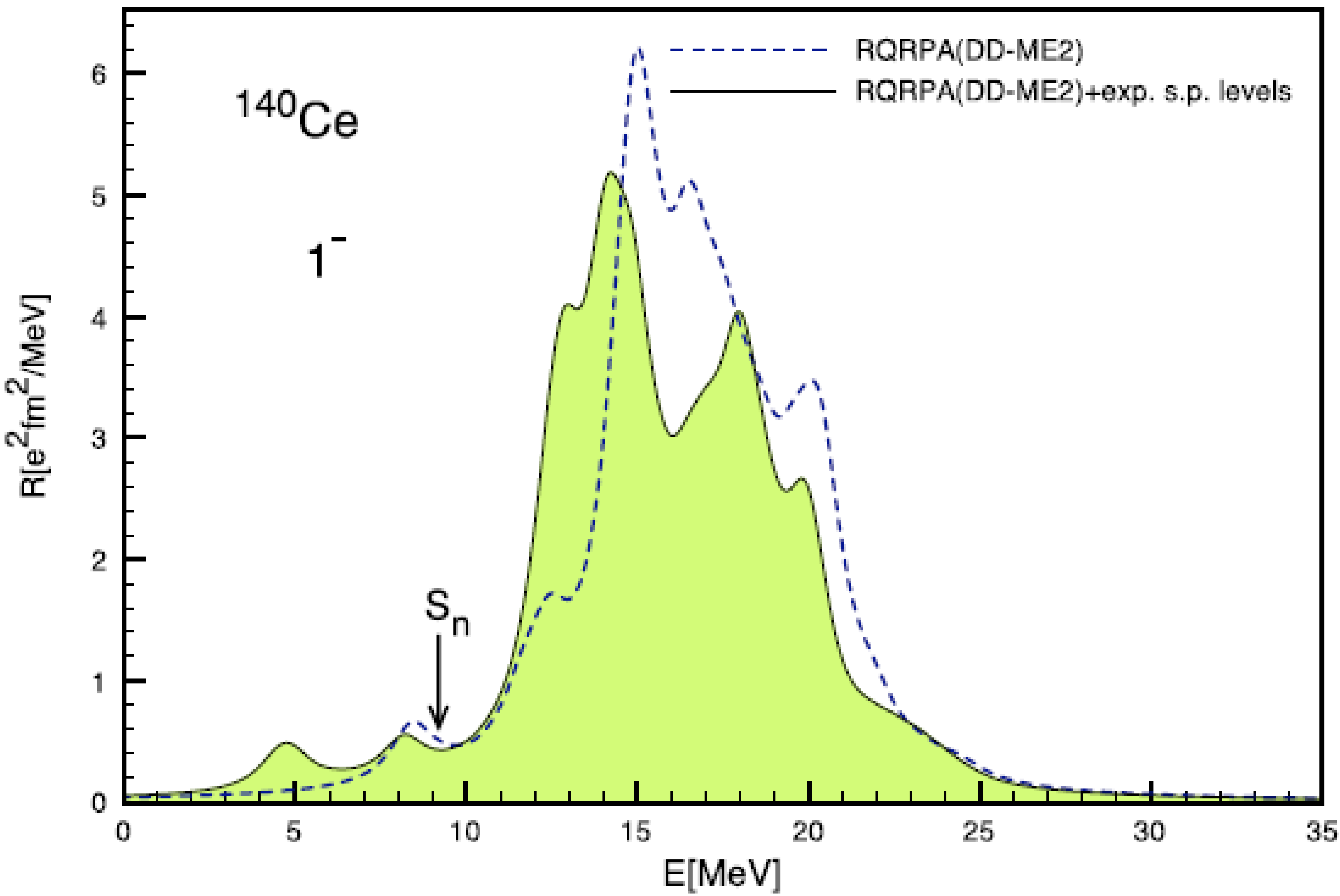


N. Paar, Y.F. Niu, D. Vretenar, and J. Meng, PRL 103 (2009) 032502

Open questions concerning the PDR

- How complete are photon scattering experiments?

  → Depending on the nucleus 10% to 300% of the total strength are missing.

- Does the PDR show a strong N/Z dependence?

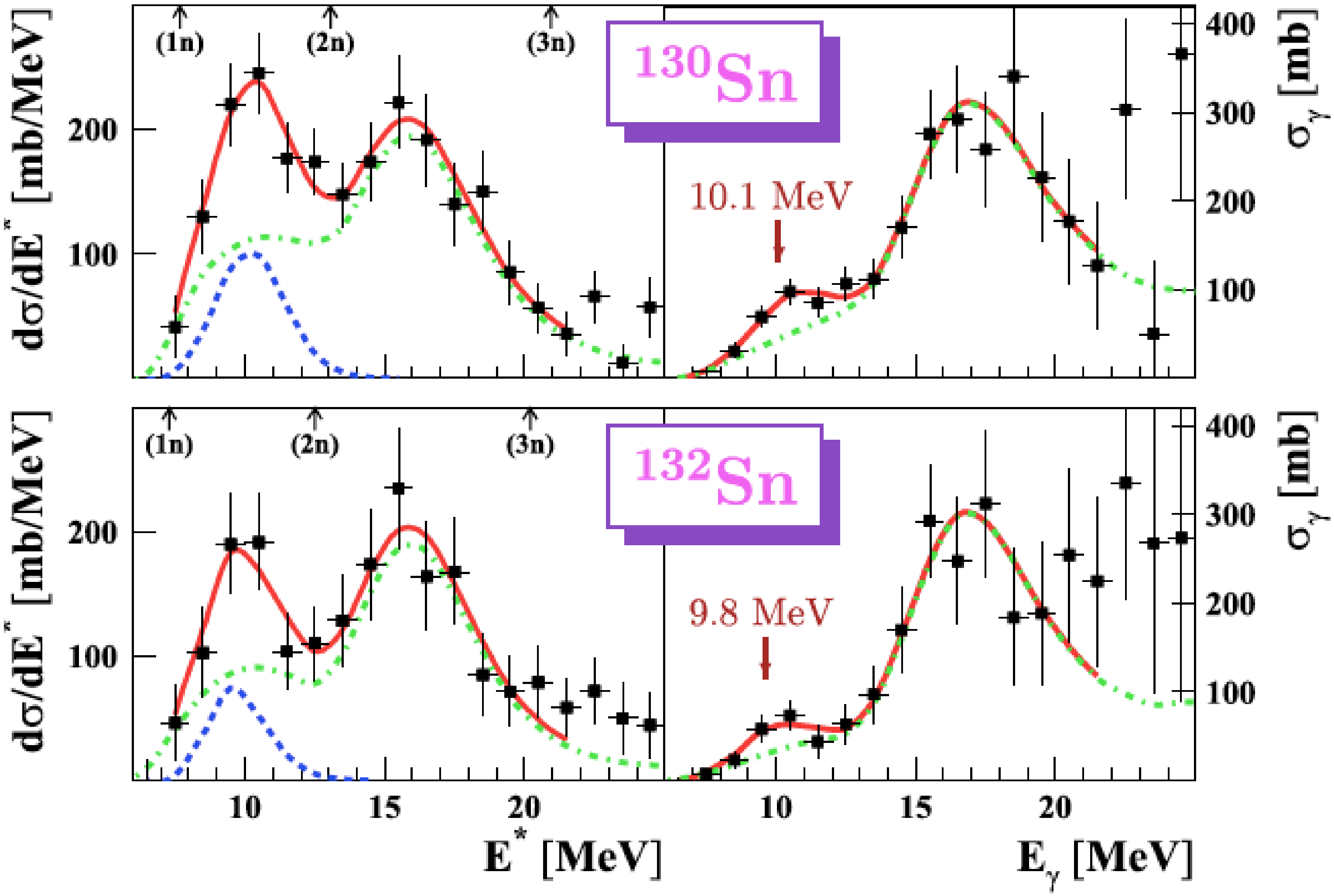
  → No direct evidence.

- What is the underlying excitation structure?

  → An isoscalar surface excitation at low energies plus an isovector part at higher energies.

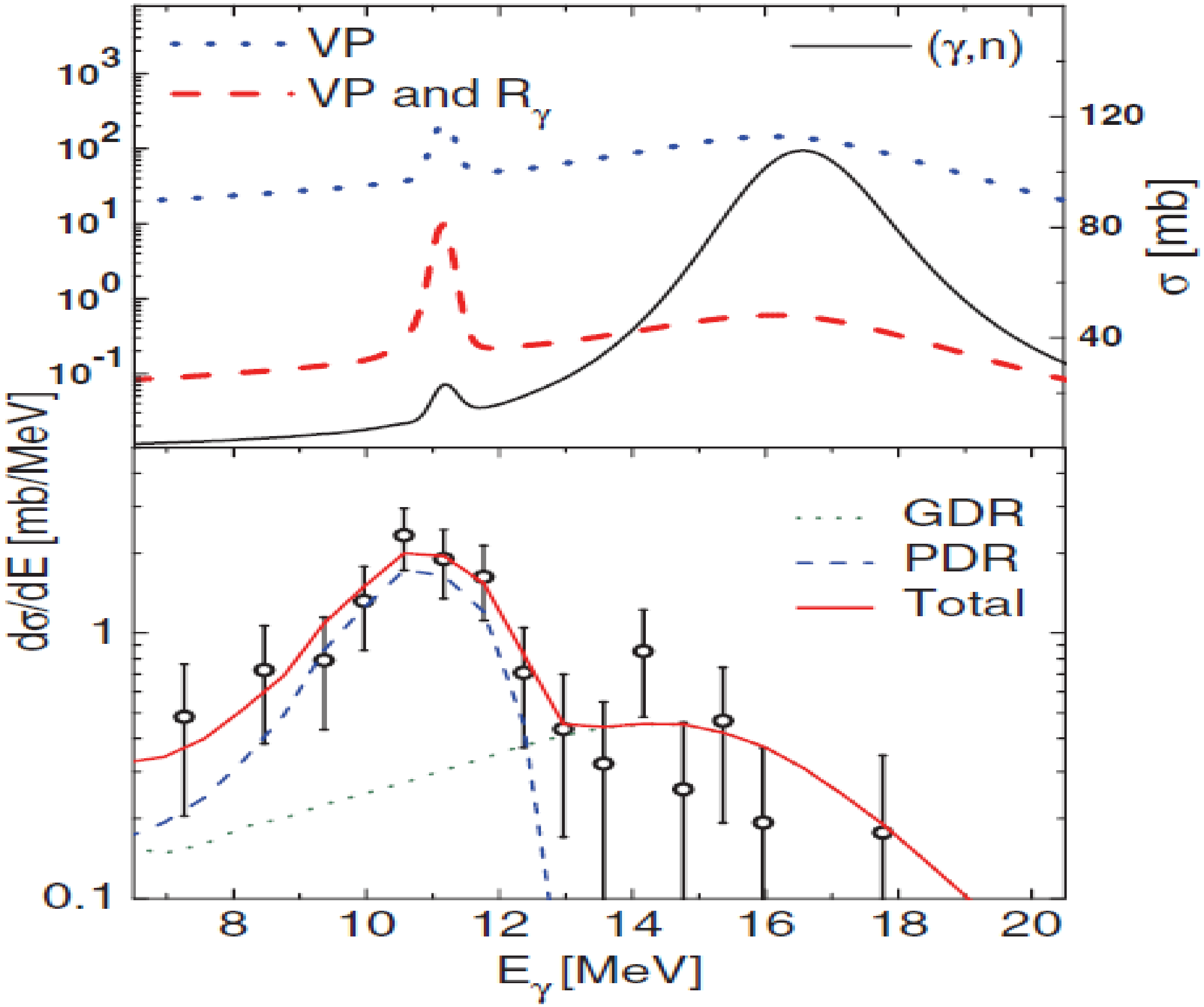
- What is the connection to the PDR in exotic nuclei?

PDR in neutron rich Sn isotopes observed in (γ,n)



P. Adrich et al., Phys. Rev. Lett. 95 (2005) 132501

PDR in neutron rich ^{68}Ni observed in γ decay



O. Wieland et al., Phys. Rev. Lett. 102 (2009) 092502

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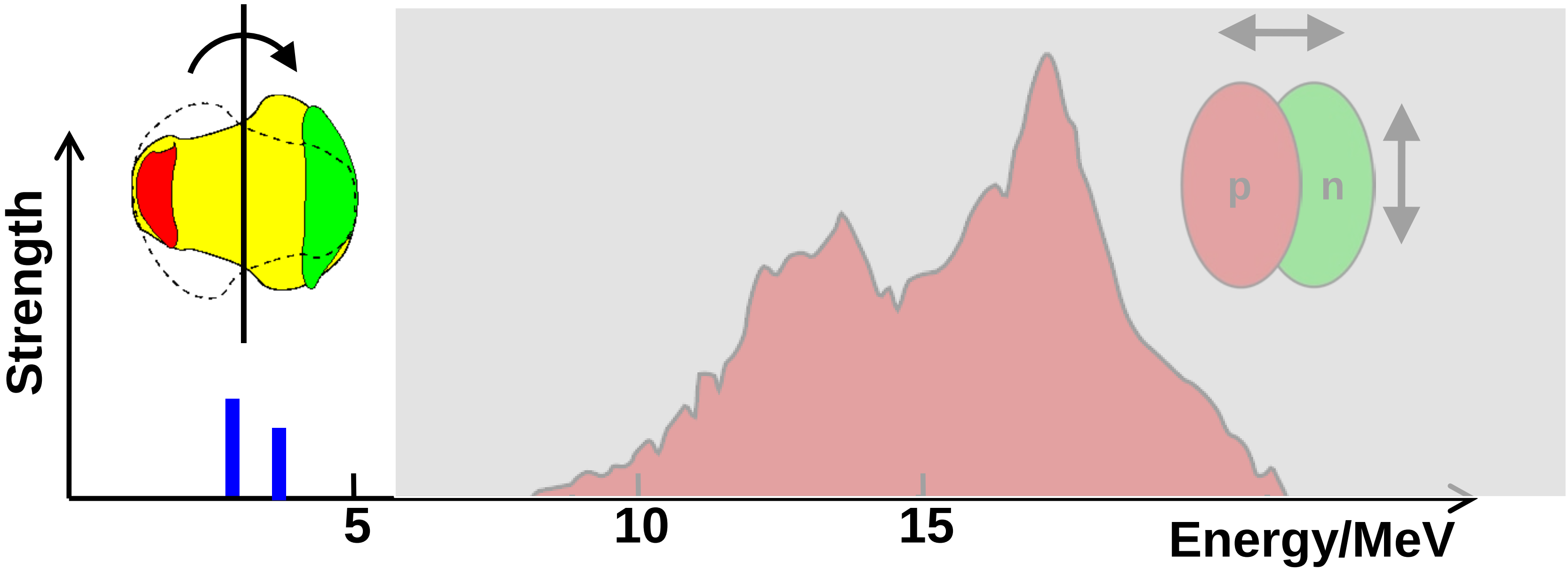
The E1 response of deformed atomic nuclei



Do we understand the octupole structures ?

Open questions concerning octupole structures

- What is the systematics of octupole excitations concerning energies, strengths, branching ratios?
- What is the influence of the K quantum number?
- How do the excitations evolve in a shape transition from spherical to well deformed?
- Are octupole excitations enhanced in exotic nuclei?

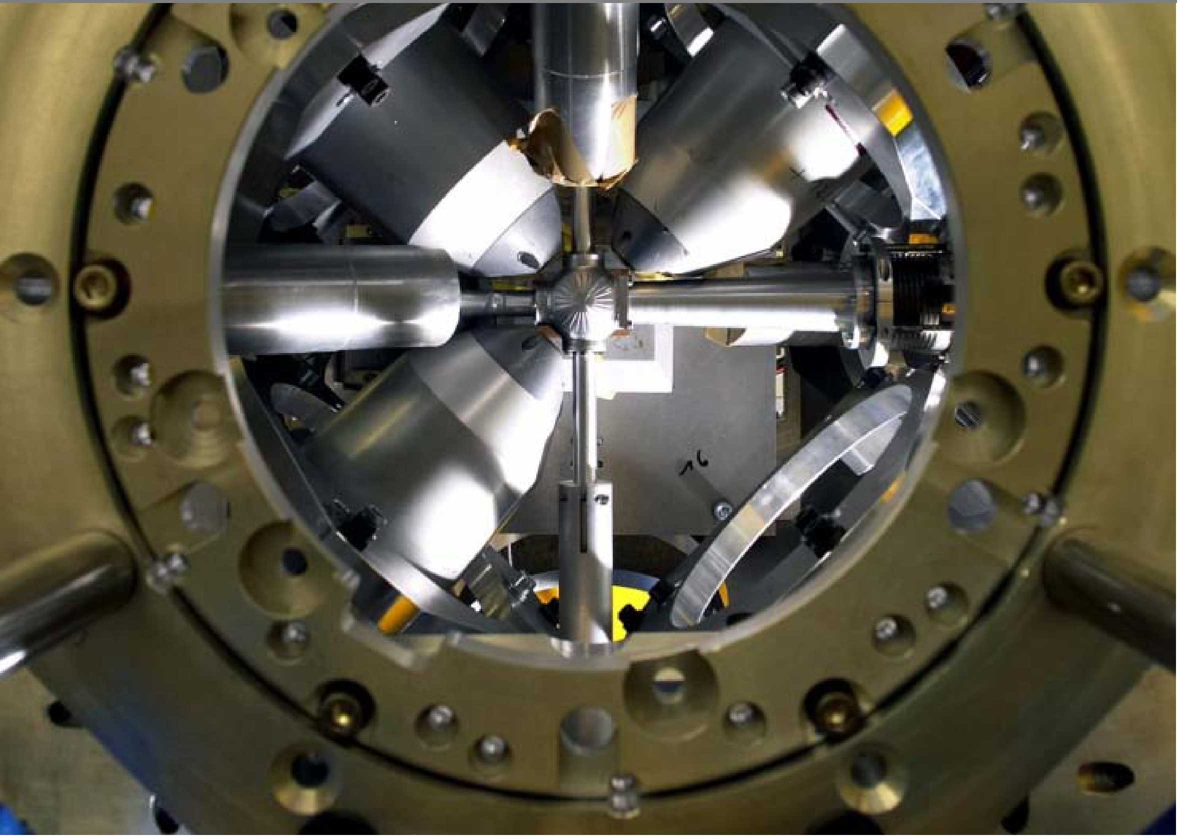
One needs <u>selective</u> and <u>sensitive</u> experiments yielding as much observables as possible!

An ideal setup for such experiments

HORUS array at University of Cologne:

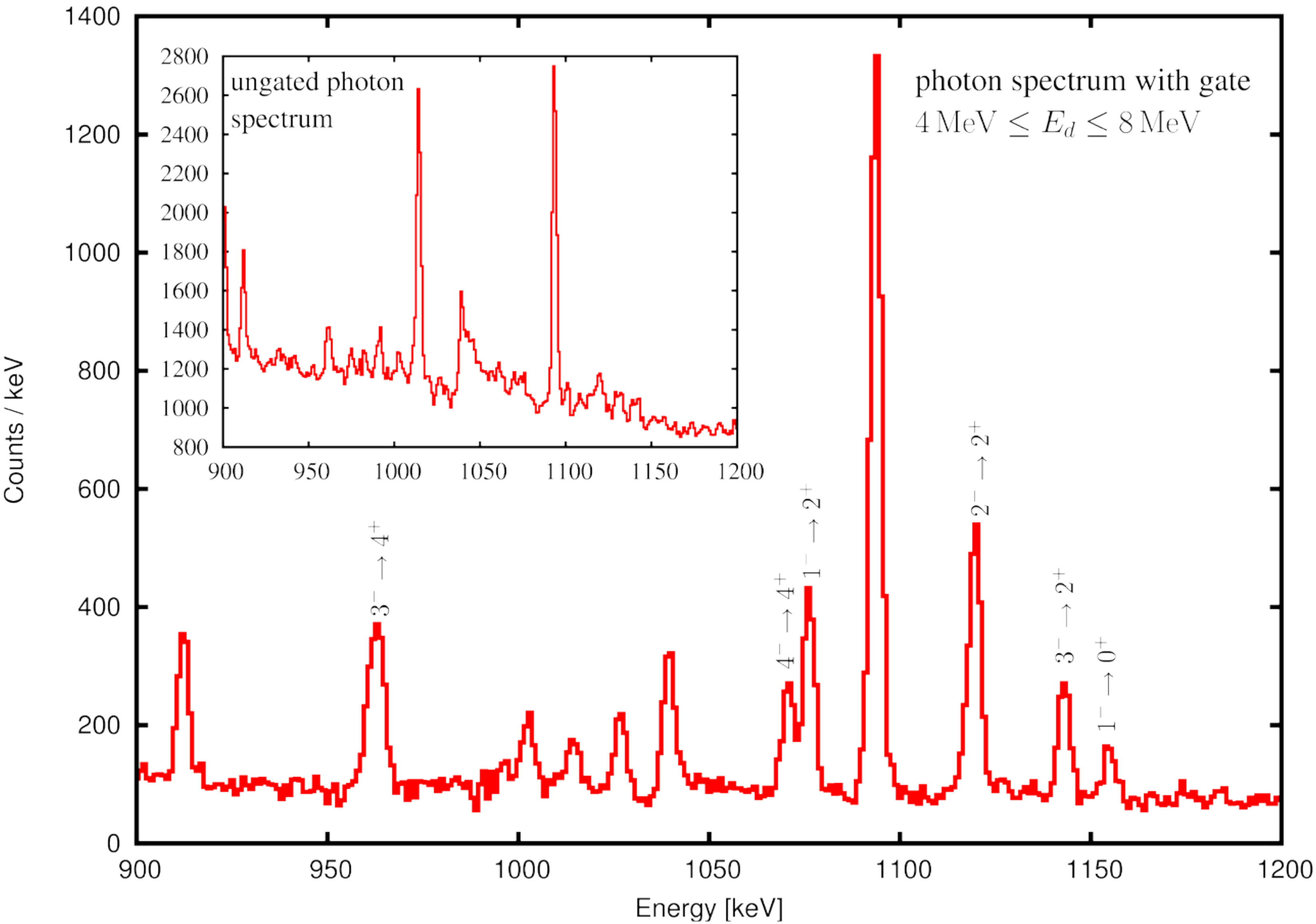
• 14 HPGe detectors (in close geometry)

• Photopeak efficiency at 1332 keV: up to 2%



• adequate efficiency
• high energy resolution
• angular resolution
• auxillary particle detectors
• coincidence techniques
• robust ion beam

(d,d'γ) experiments on ^{172}Yb



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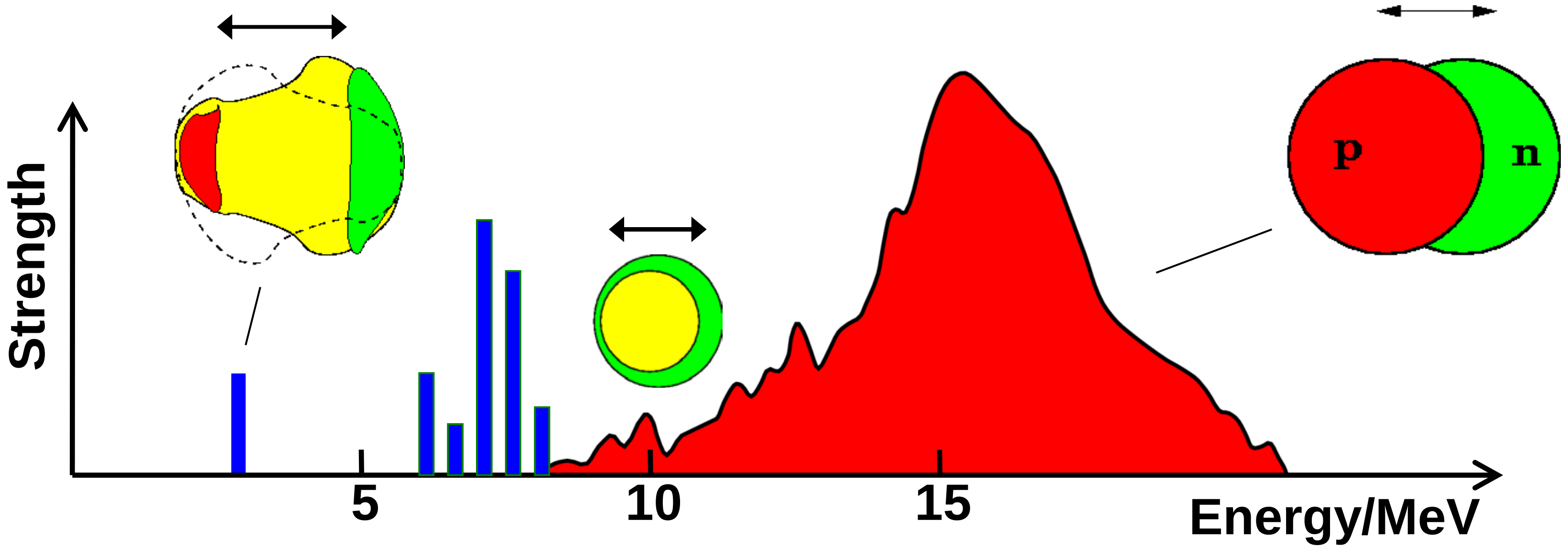

Not only spin-isospin excitations are interesting…

E1 excitations in atomic nuclei: From Giants, Pygmies and Octupoles

P. Butler, M. Elvers, J. Endres, M.N. Harakeh, S. Harissopoulos, J. Hasper, R.-D. Herzberg, R. Krücken, A. Lagoyannis, N. Pietralla, V. Yu. Ponomarev, D. Savran, M. Scheck, K. Sonnabend, H.J. Wörtche, and A. Z.

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