Giant Resonances - Some Challenges from Recent Experiments

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- Collective modes – real developments and open questions
- Fine structure and its relation to GR decay
- Pygmy dipole resonance in stable nuclei

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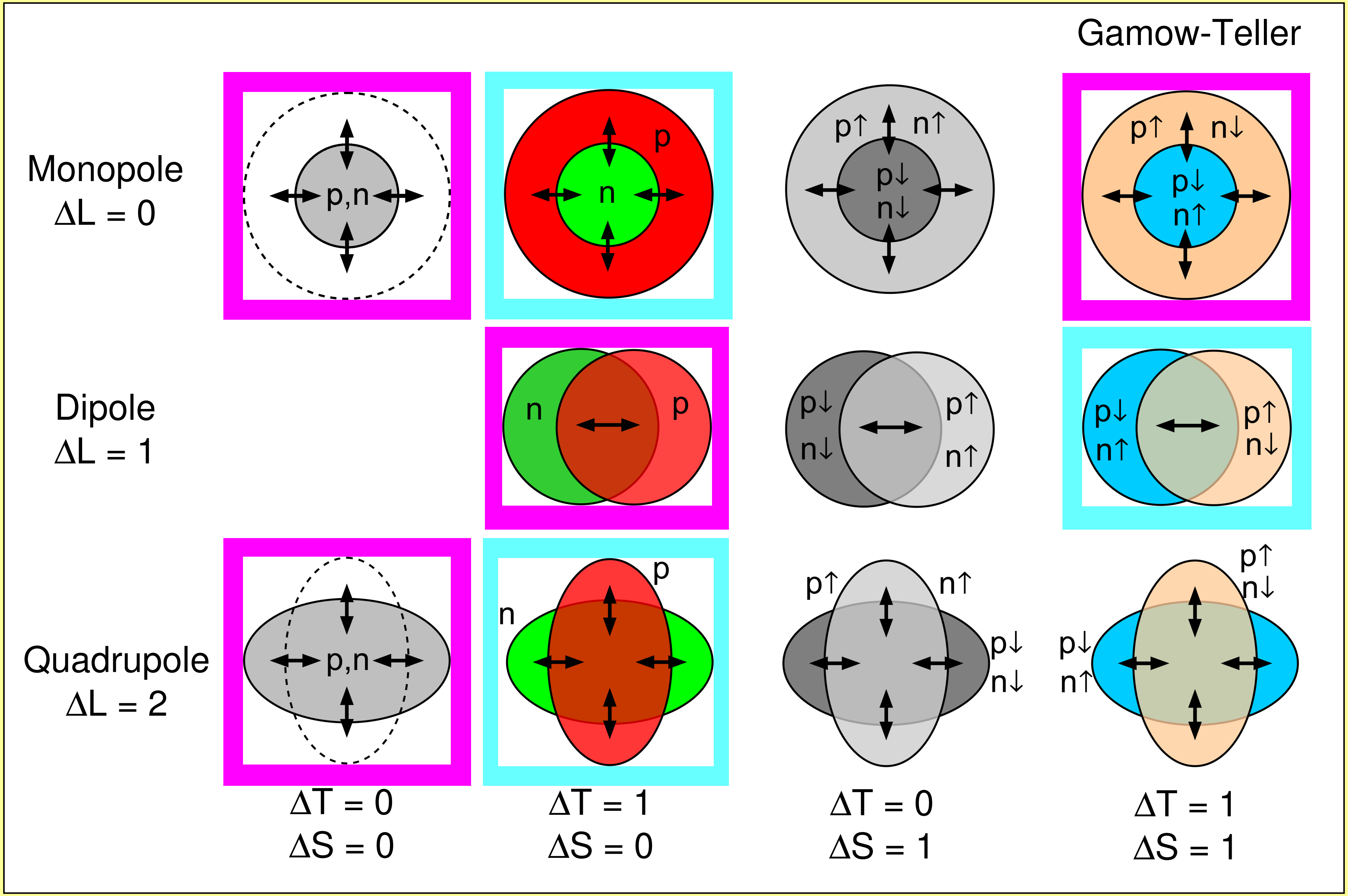
* Supported by DFG under contracts SFB 634, 446-JAP-113/0/2 and NE 679/2-2

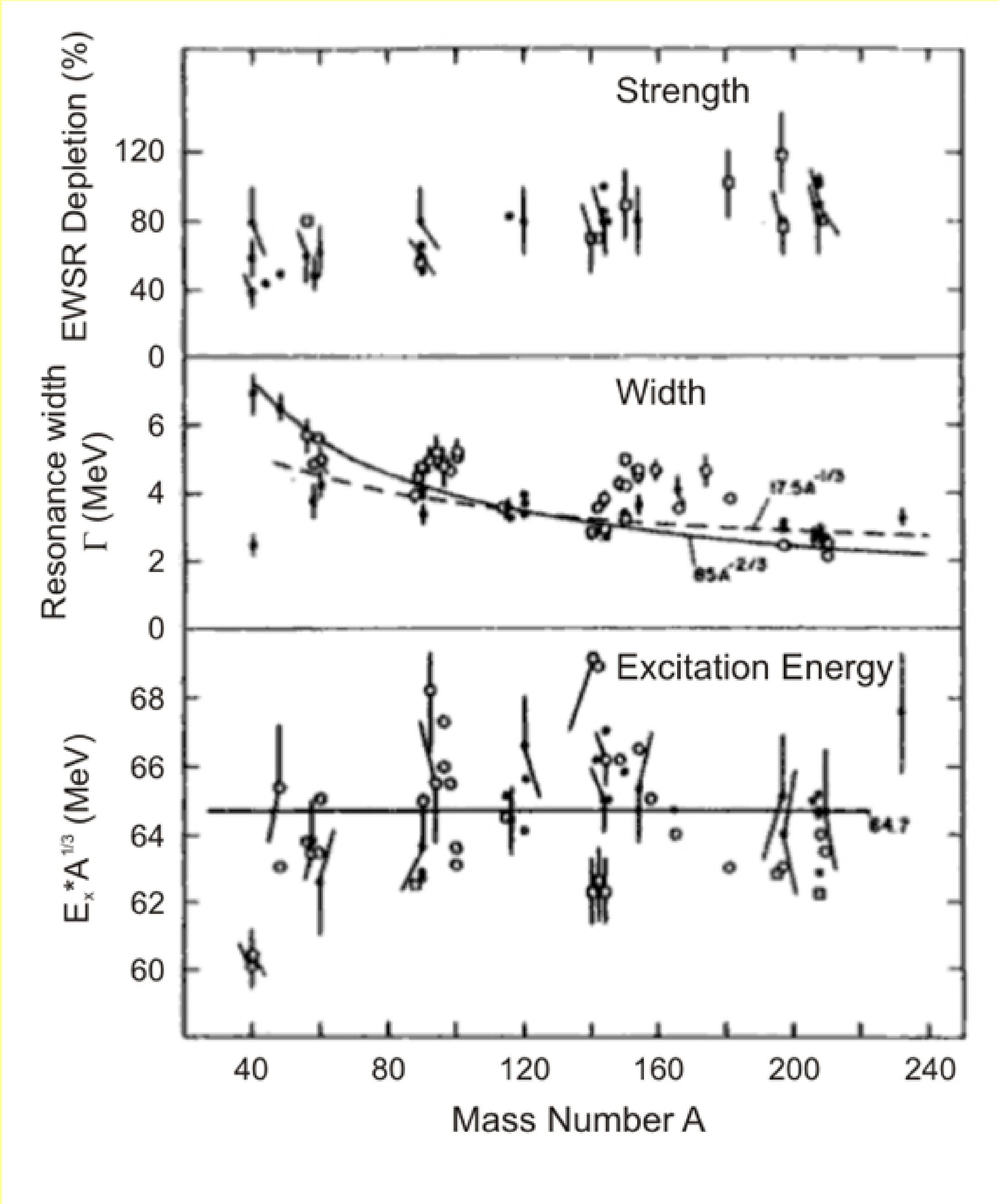
Giant Resonances



Electric Giant Resonances

- The centroids and EWSR exhaustions are reasonably understood, but the widths ?

Example: Systematics of the ISGQR



Electric Giant Resonances

- The centroids and EWSR exhaustions are reasonably understood, but the widths ?

- How can one learn about the main decay contributions ?

  - coincidence experiments → difficult, few data

  - fine structure → new approach

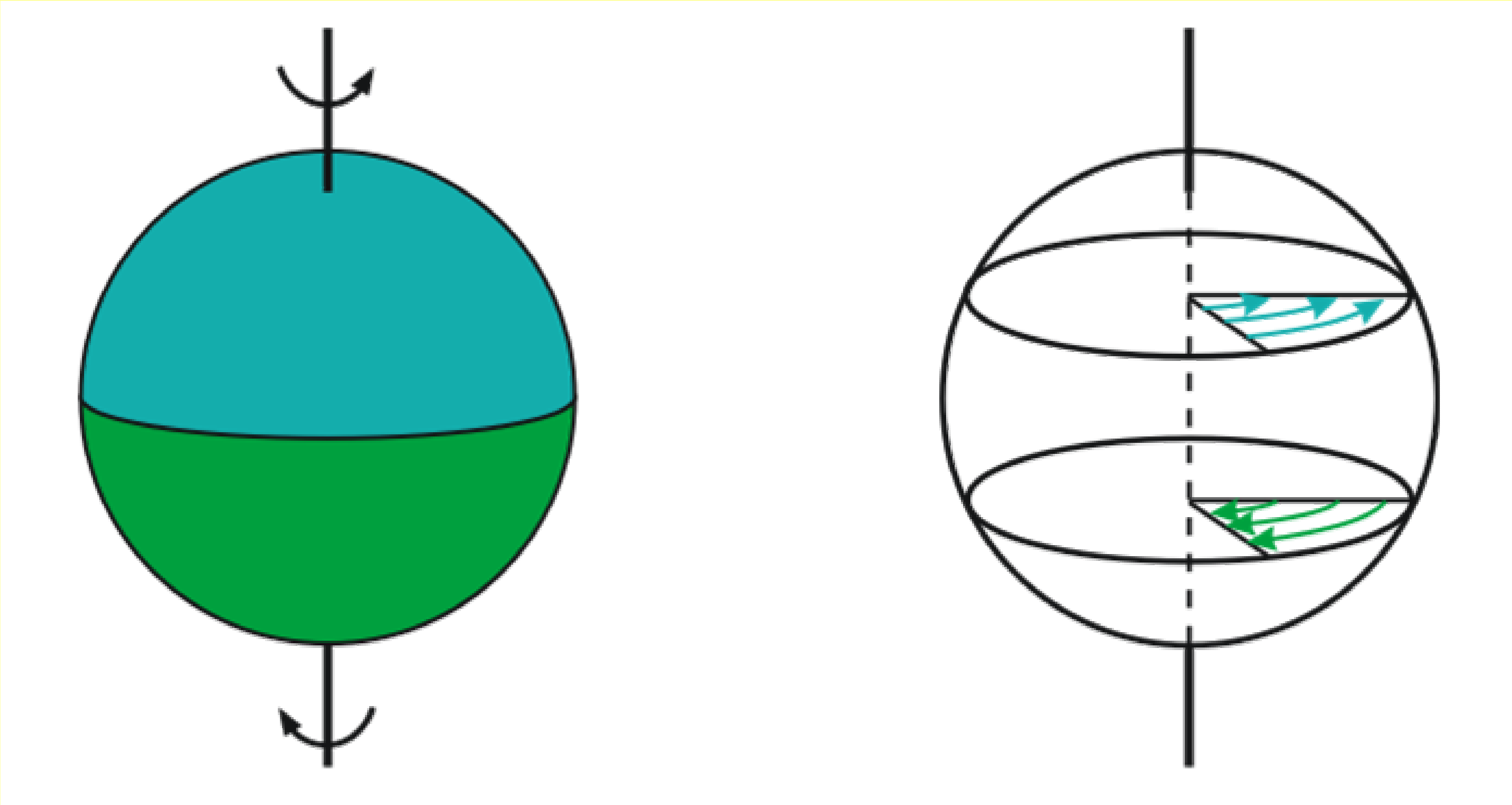
Magnetic / Spin – Isospinflip Modes

- Importance to astrophysics
  - predictive power?
  - a bulk of new high-resolution data → Yoshi Fujita's talk

Orbital Modes

- M1 scissors mode reasonably well understood
- Twist mode

Twist Mode



- Purely transverce
- Quantum phenomenon in finite Fermi systems

Magnetic / Spin – Isospinflip Modes

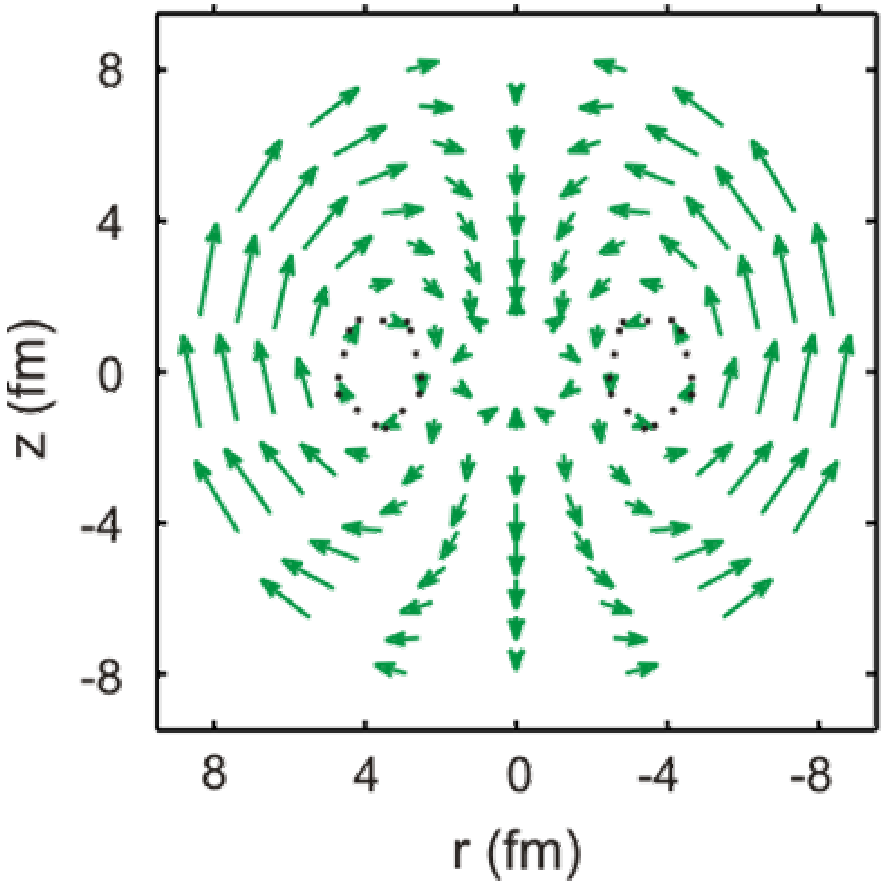
- Importance to astrophysics
  - predictive power?
  - a bulk of new high-resolution data → Yoshi Fujita's talk

Orbital Modes

- M1 scissors mode reasonably well understood
- Twist mode
- Toroidal mode

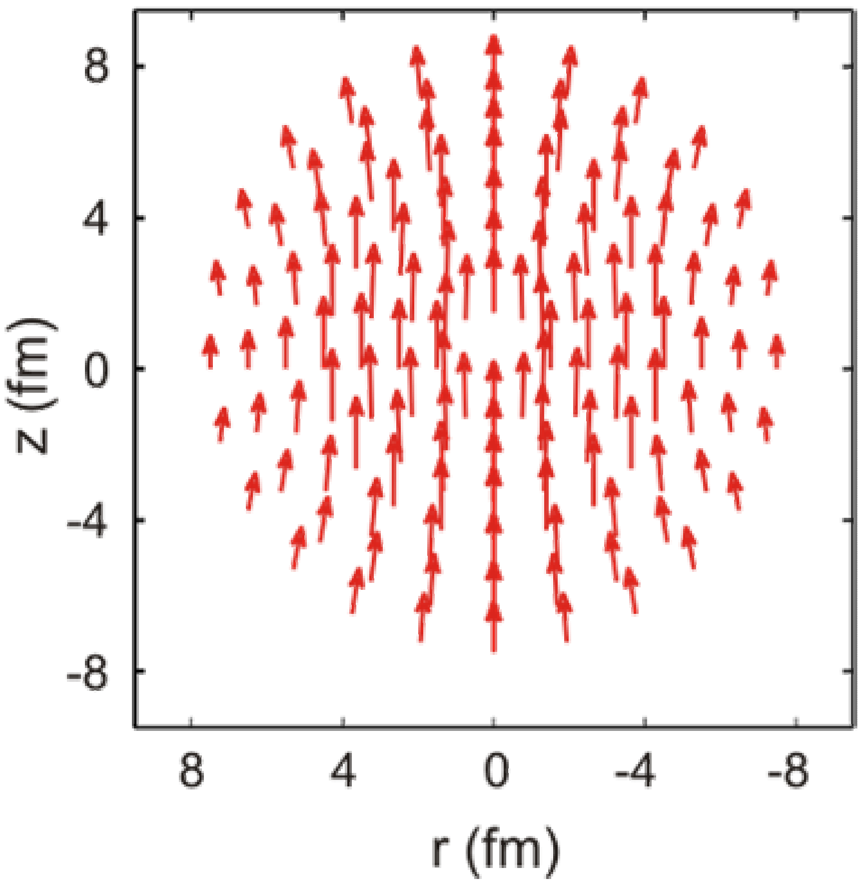
Velocity Distributions

Toroidal



$E_x = 6.5 – 10.5$ MeV

GDR



$E_x > 10.5$ MeV

Magnetic / Spin – Isospinflip Modes

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Orbital Modes

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} What are the signatures?

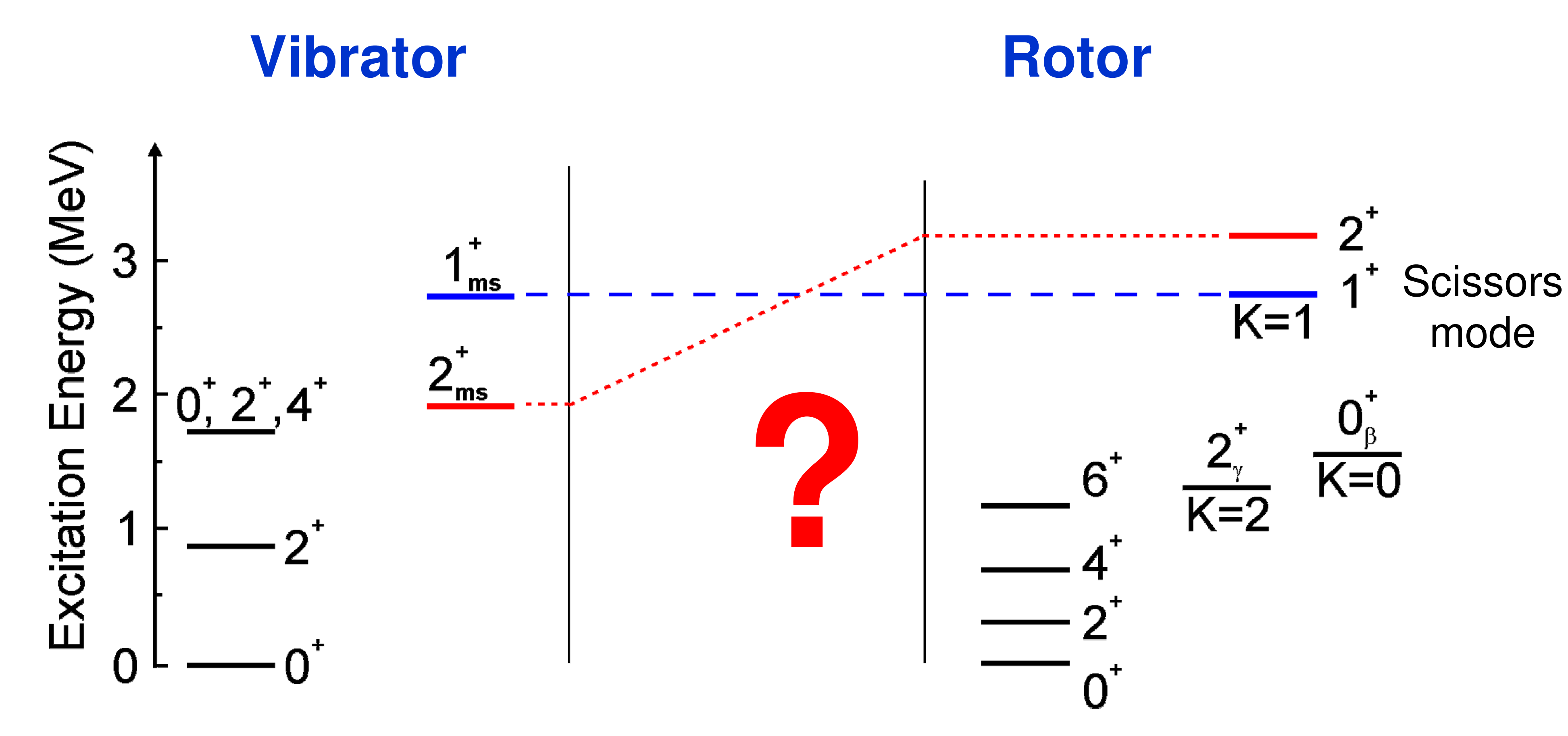
Soft Modes

- PDR in stable nuclei
  - relation to PDR in exotic systems
  - is it collective?
- Are there other modes?
  - L = 2, 3?
  - in stable nuclei?

Low – Energy Collective Modes

- Evolution as a function of deformation

Phase-Shape Transitions

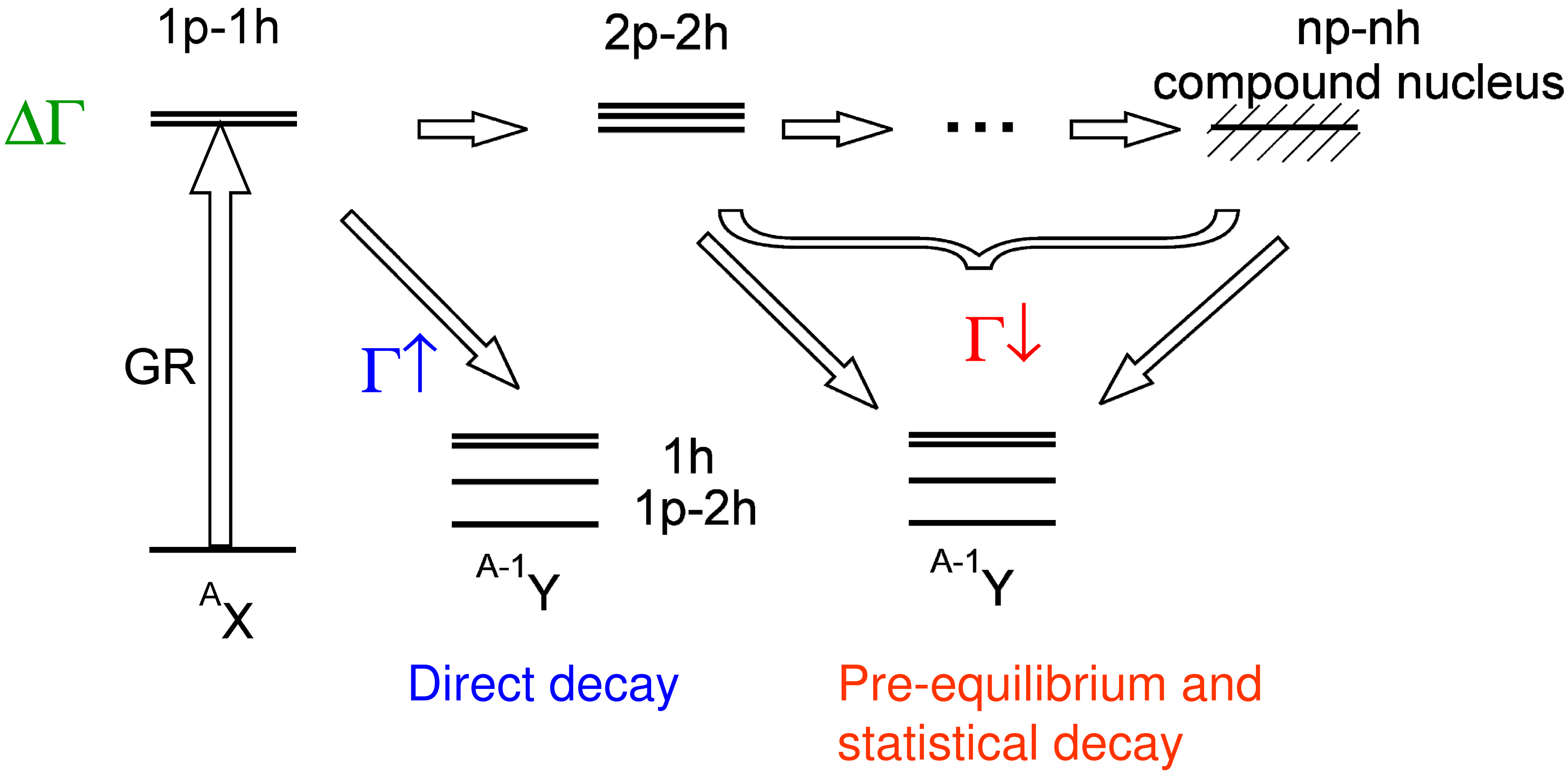


- **Proton-neutron degrees of freedom** in the evolution of nuclear structure
- **Phase transitions**

Relation of GR´s to Quantities of General Interest

- Compressibility
  - relativistic vs. non-relativistic RPA
- Neutron skin / symmetry energy
  - relation to PDR
  - relation to GT / spin-dipole resonance
- Pairing?

First Example: The Width



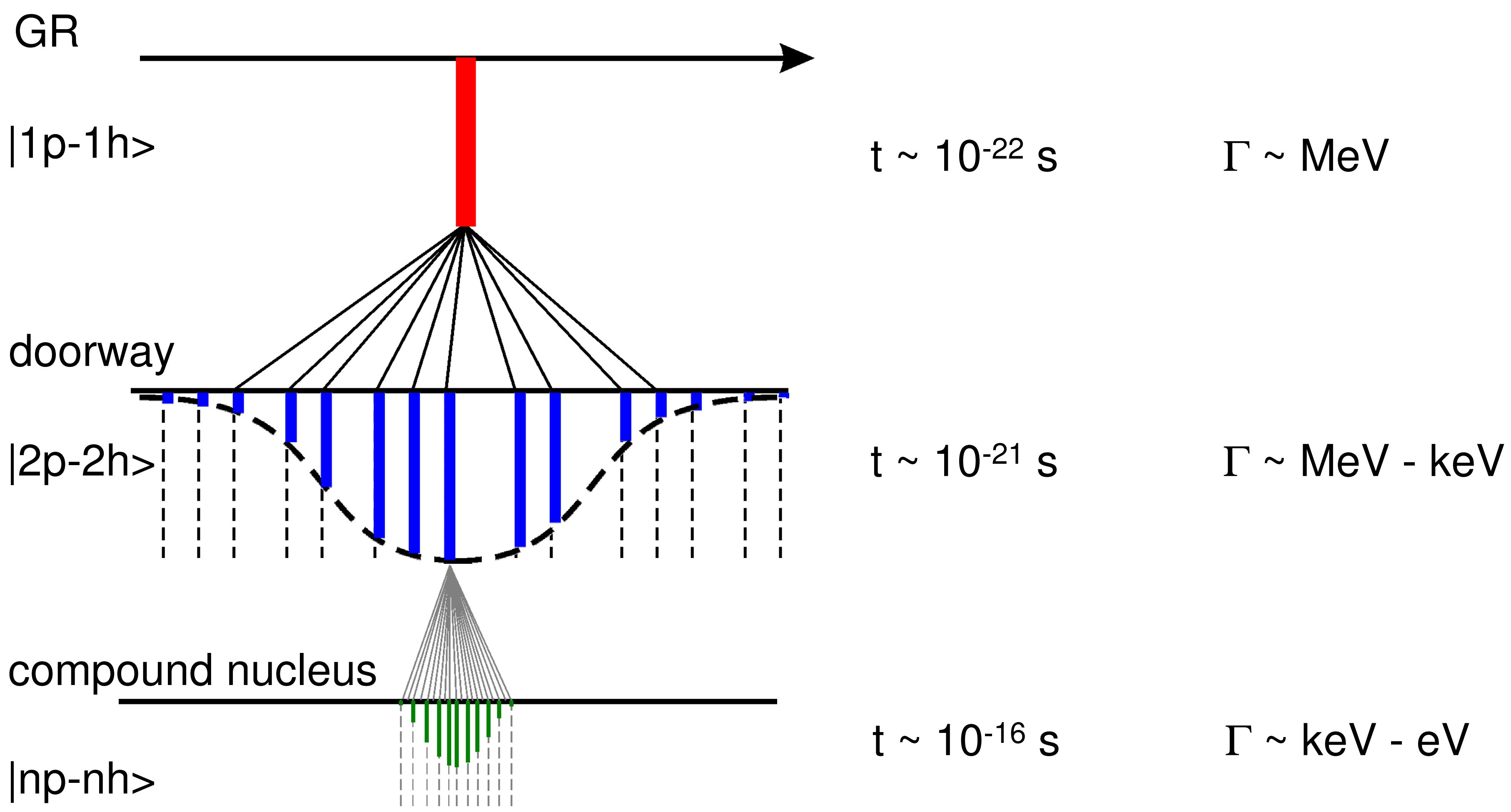
$$\Gamma = \Delta\Gamma + \Gamma\uparrow + \Gamma\downarrow$$

Resonance width | Landau damping | Escape width | Spreading width

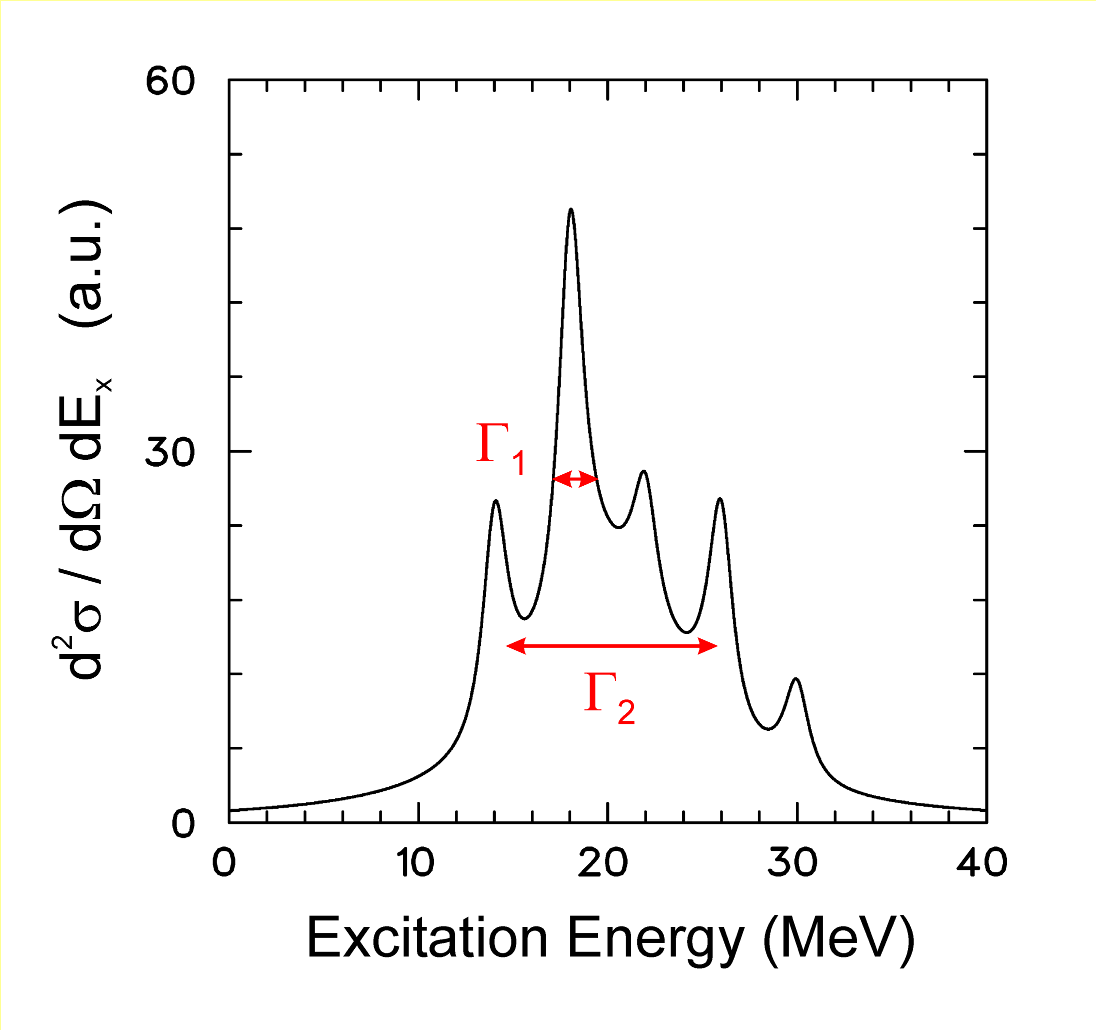
What do We Know

- Landau damping important for some resonances (e.g. IVGDR, but not ISGQR)
- Escape width contributes significantly in $A \lesssim 40$ nuclei
- Spreading width dominant in $A \gtrsim 60$ nuclei

Doorway State Model

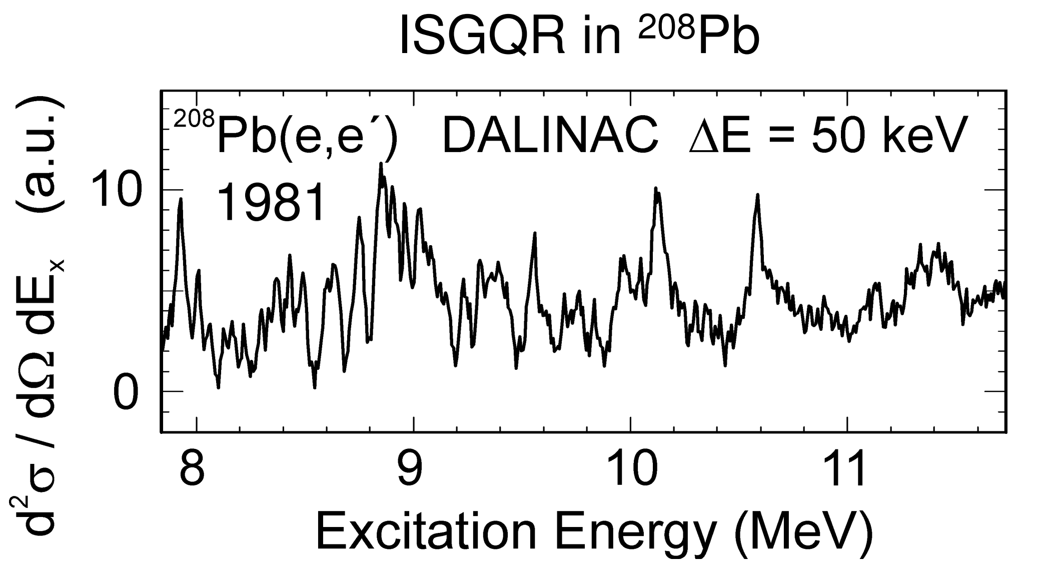


Fine Structure of Giant Resonances

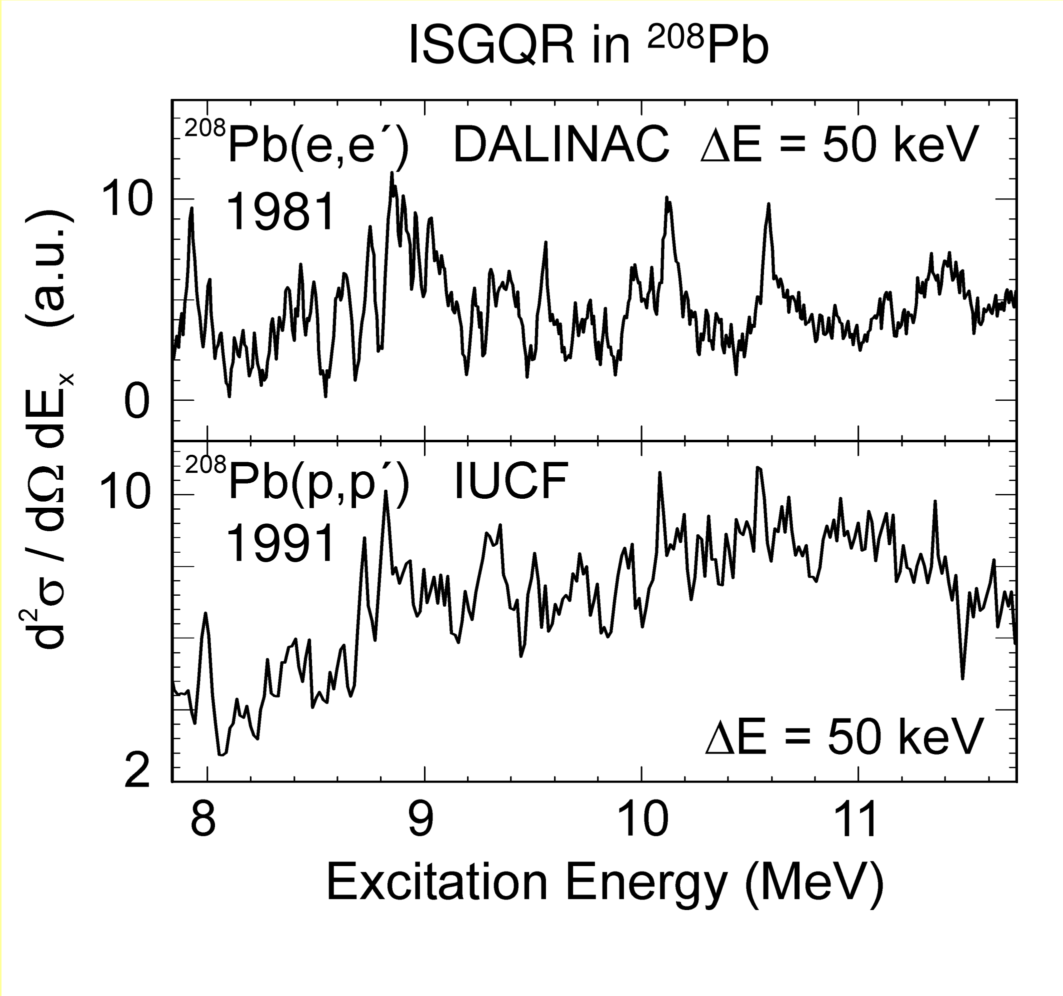


- High resolution is crucial
- Possible probes: electrons and hadrons

Fine Structure of Giant Resonances



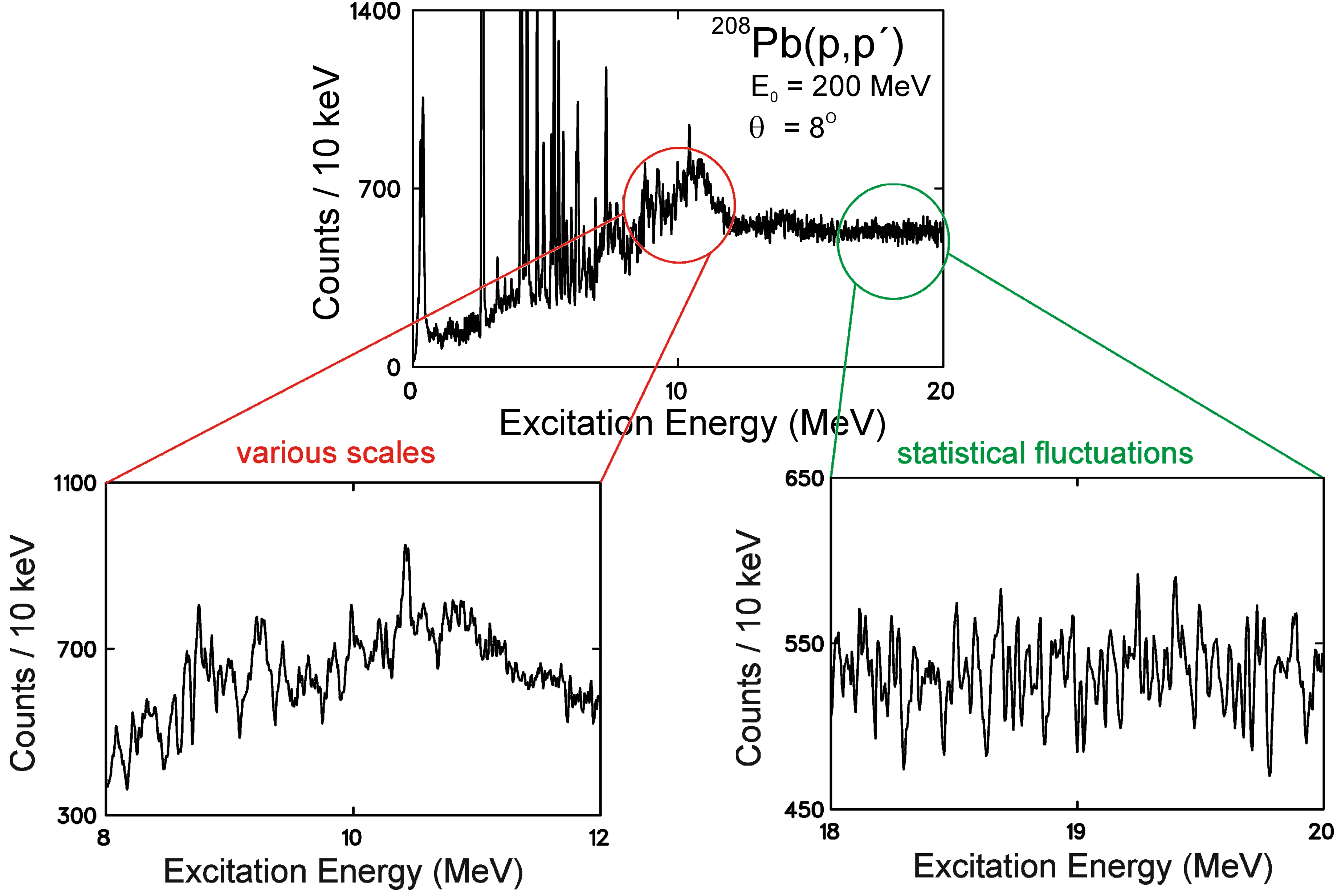
Fine Structure of Giant Resonances



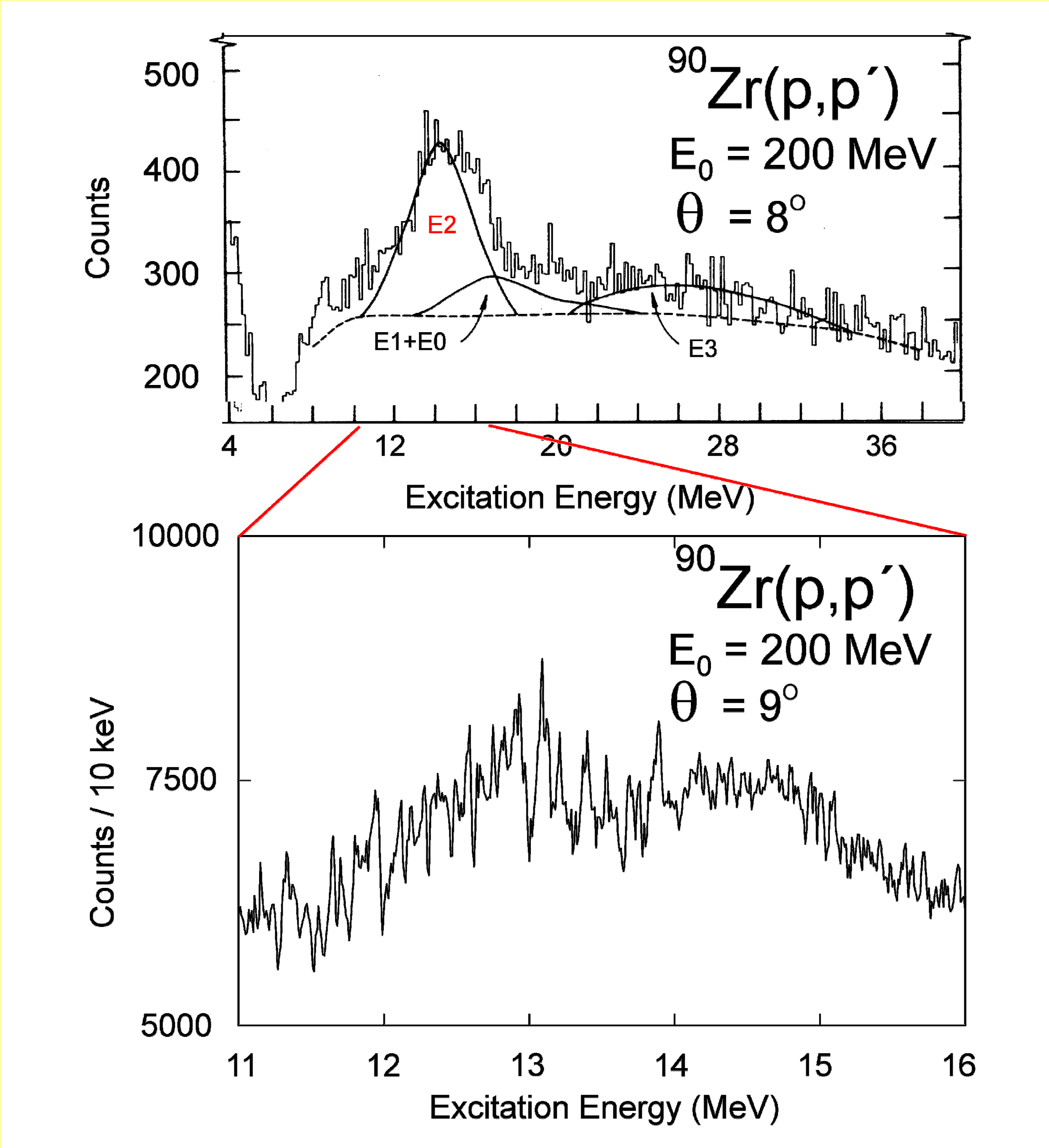
- Different probes but similar structures

→ physical information content is the same

Scales and Fluctuations



Fine Structure of the ISGQR

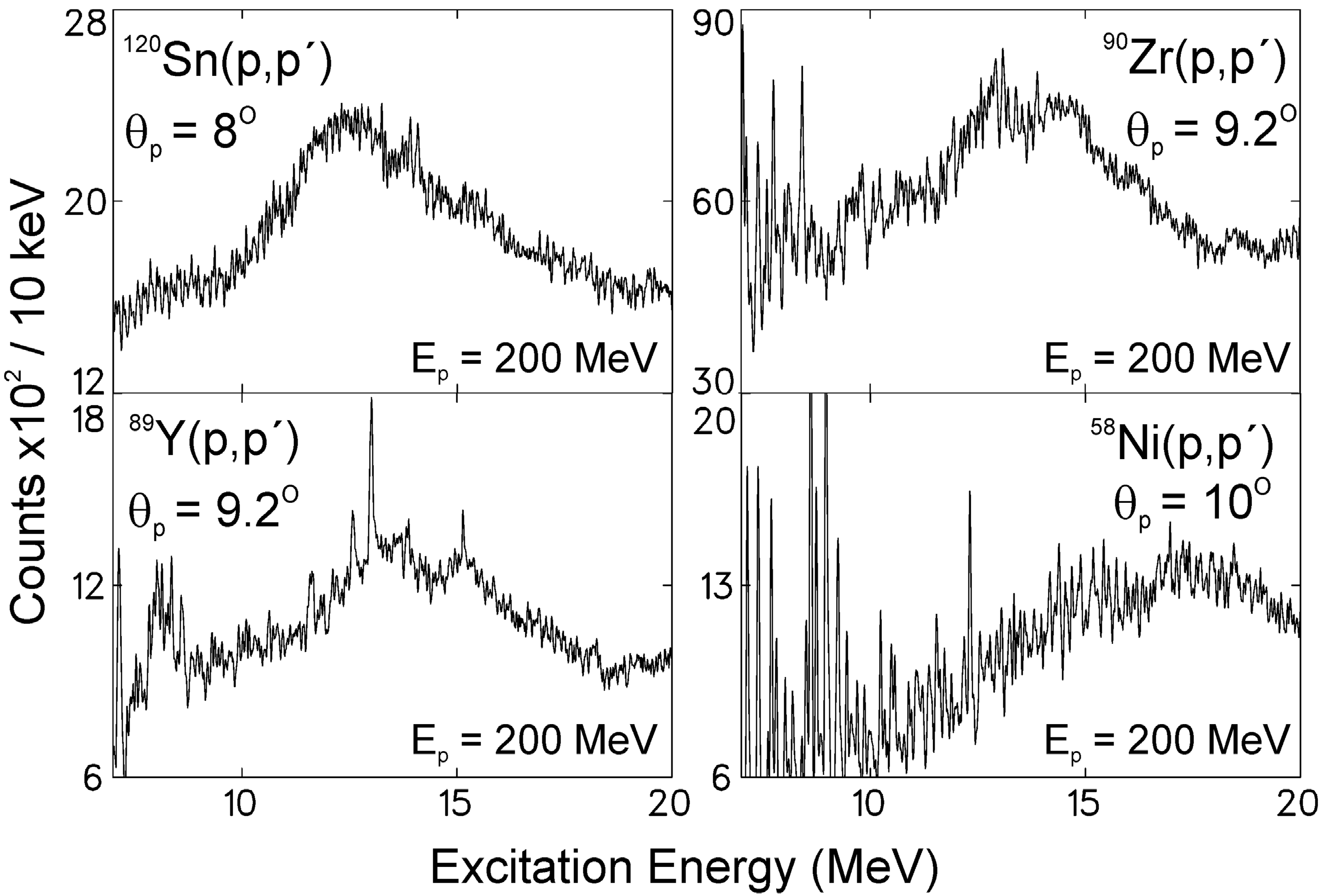


$\Delta E \approx 1$ MeV
TRIUMF (1981)

$\Delta E \approx 40$ keV
iTHEMBA (2001)

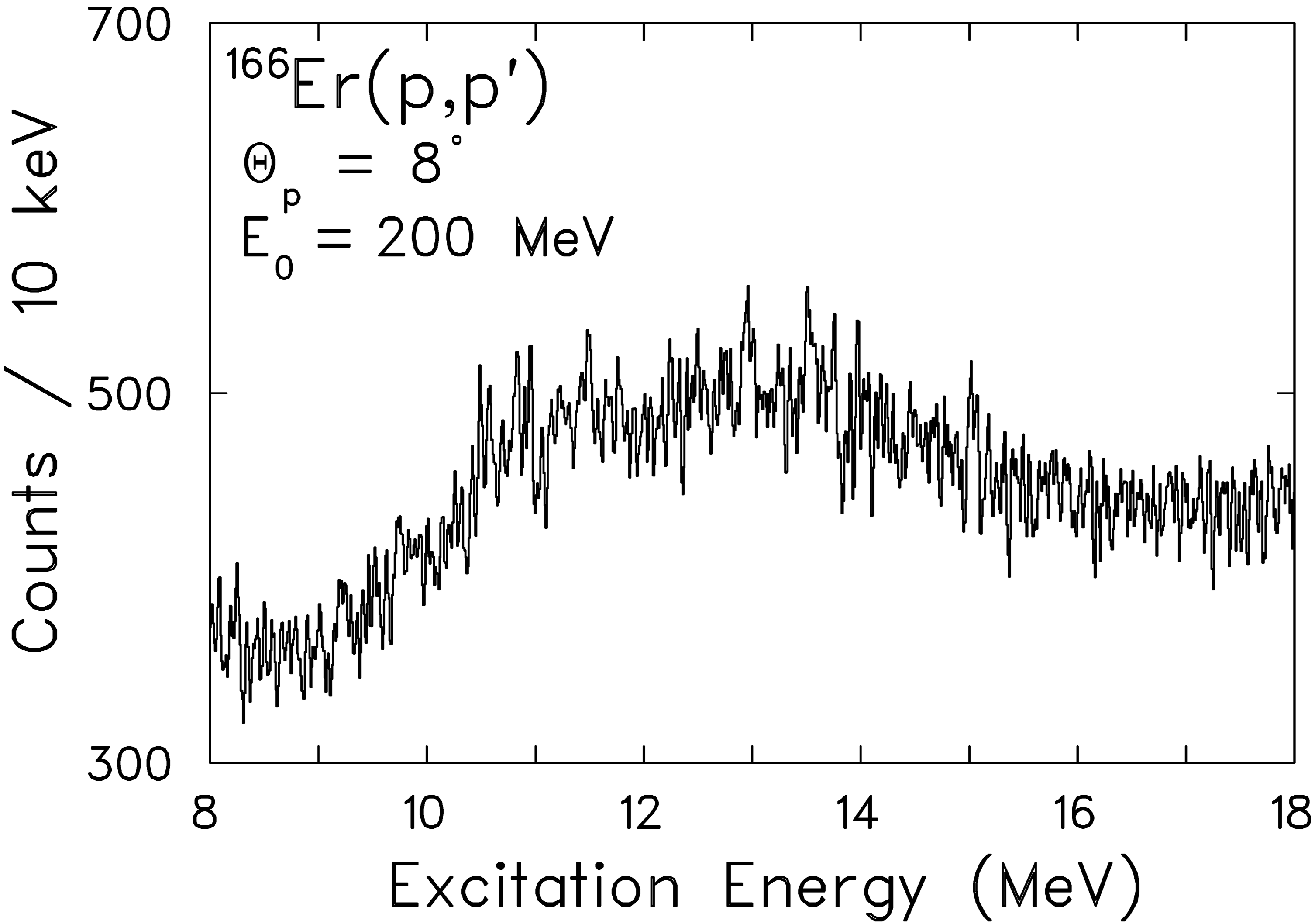
- Fluctuations of different strengths and scales
- Not a Lorentzian

Fine Structure of the ISGQR in Other Nuclei

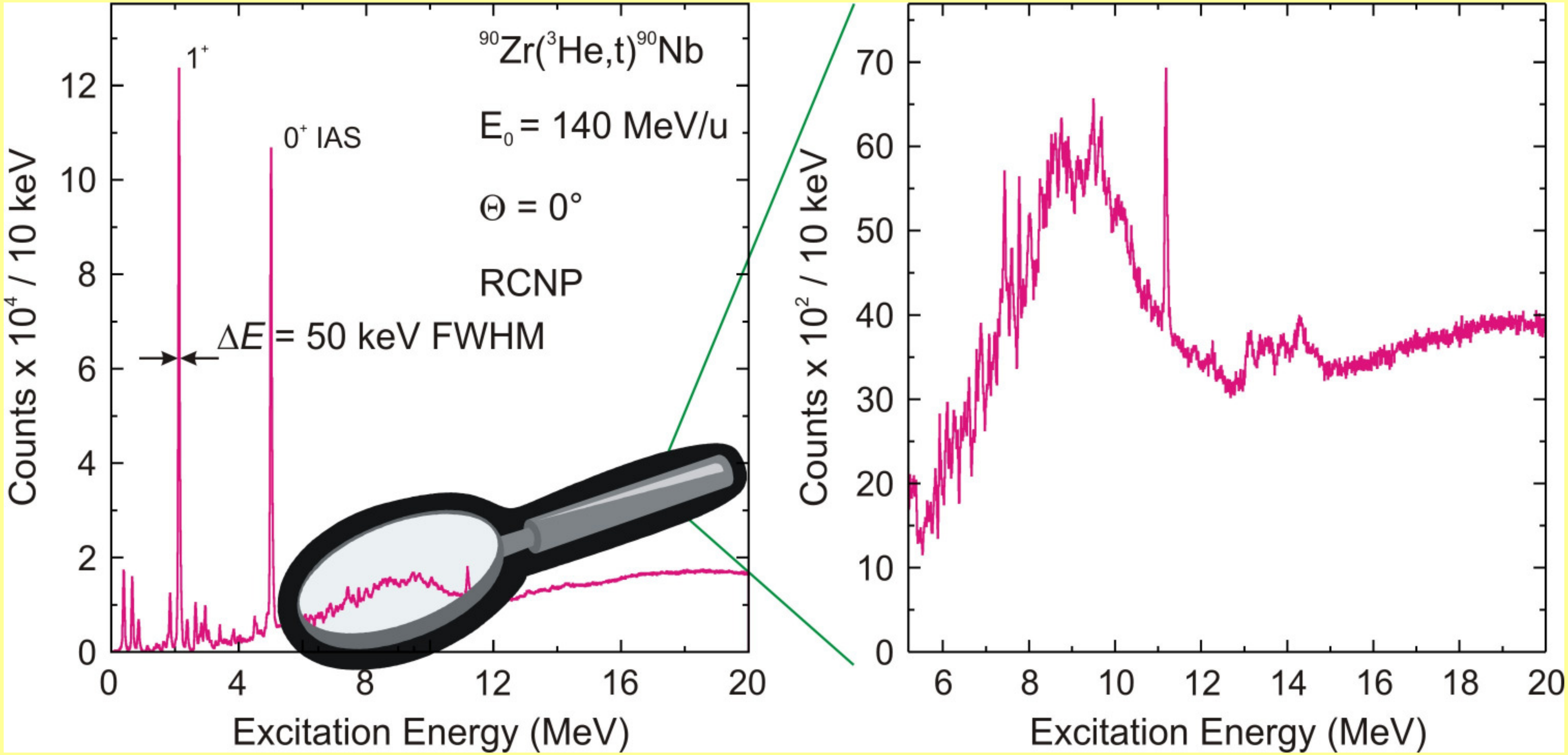


- Fine structure of the ISGQR is a global phenomenon

Fine Structure in Deformed Nuclei?



Fine Structure of the Spinflip Gamow-Teller Resonance

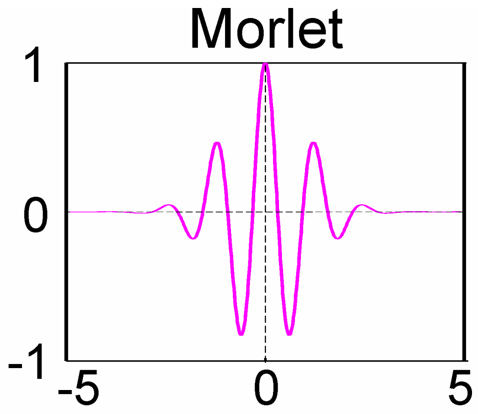


- Fine structure of giant resonances is a global phenomenon, e.g. observed also in the GT resonance (a spin-isospin flip mode)

Y. Kalmykov et al., Phys. Rev. Lett. 96, 012502 (2006)

Wavelet Analysis

$$\int_{-\infty}^{\infty} \Psi^*(x)\, dx = 0 \quad \text{and} \quad \int_{-\infty}^{\infty} \left|\Psi^*(x)\right|^2 dx < \infty$$



$$\Psi(x) = \cos(2\pi\omega x)\, e^{-x^2/2}$$

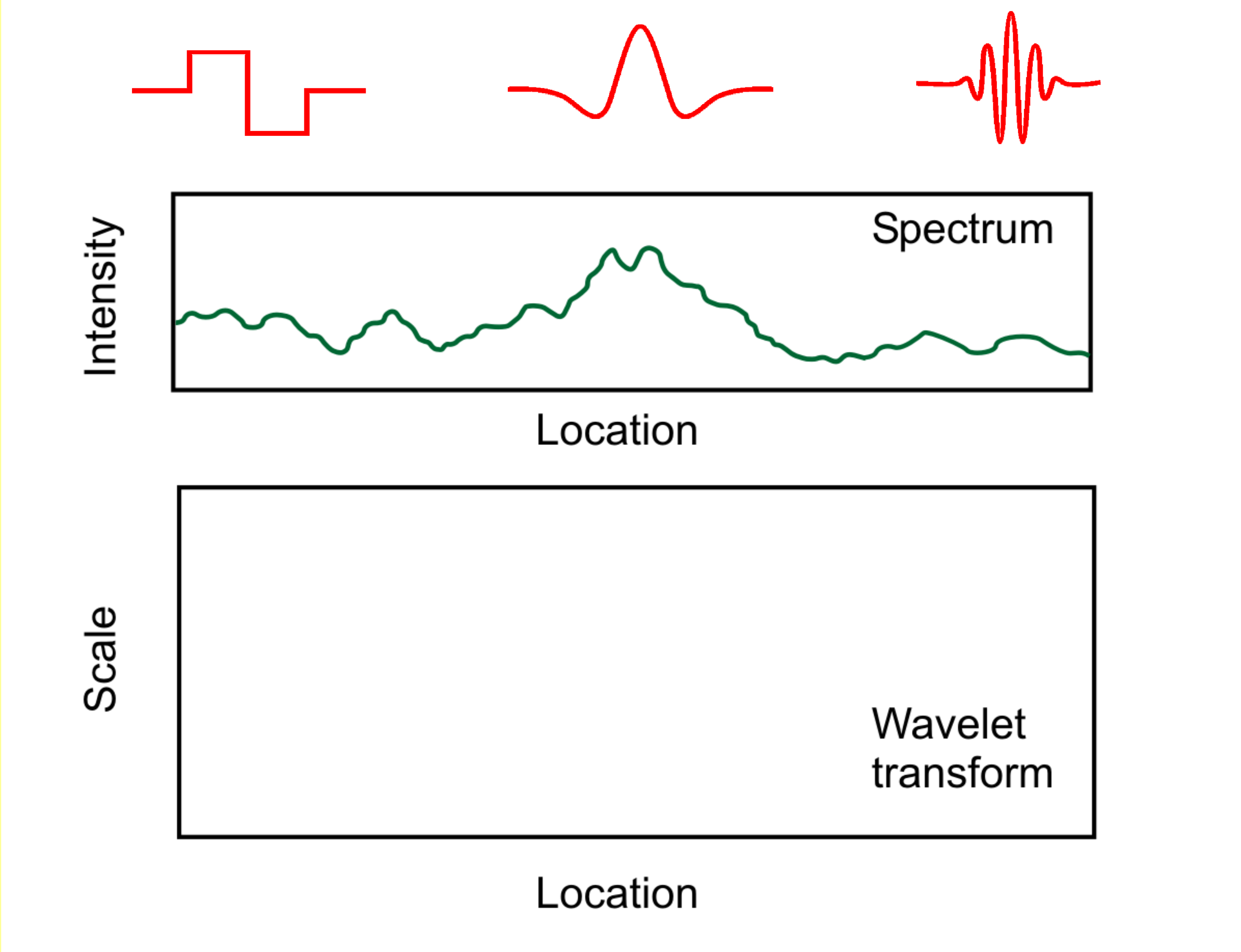
Wavelet coefficients:

$$C(\delta E, E_x) = \frac{1}{\sqrt{\delta E}} \int \sigma(E)\, \Psi^*\left(\frac{E_x - E}{\delta E}\right) dE$$

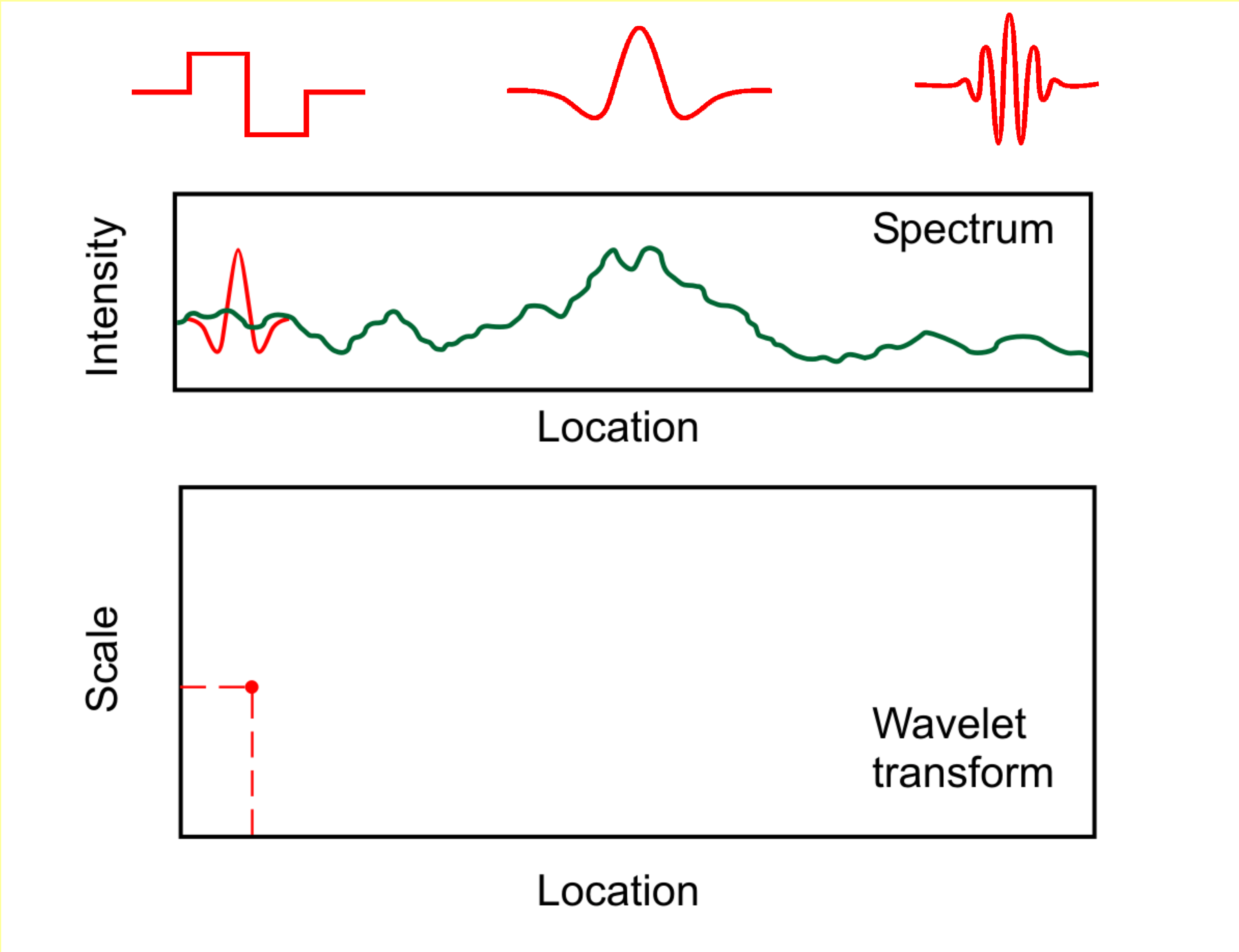
scale — position — spectrum — wavelet

Continuous: δE, E_x are varied continuously

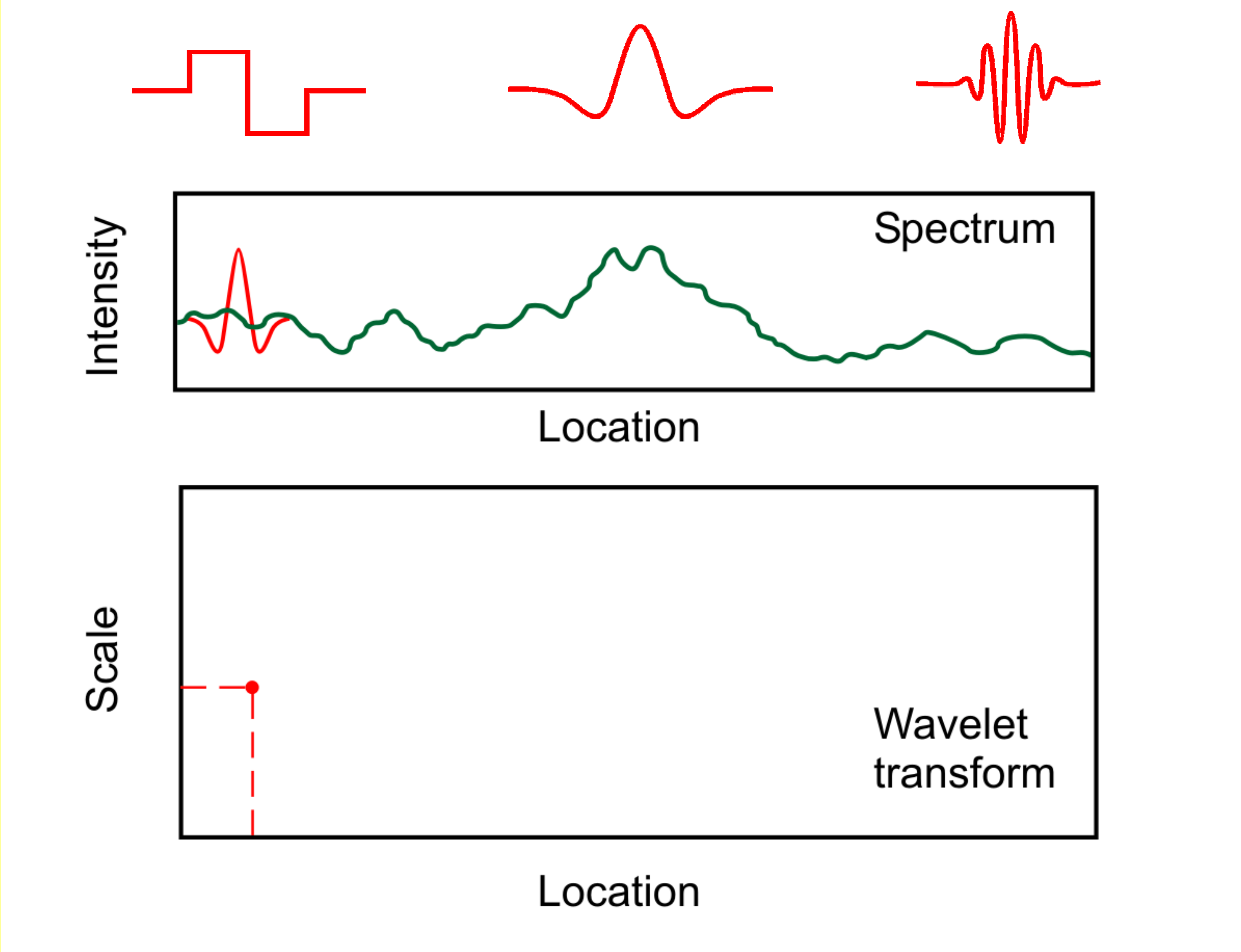
Wavelet Analysis



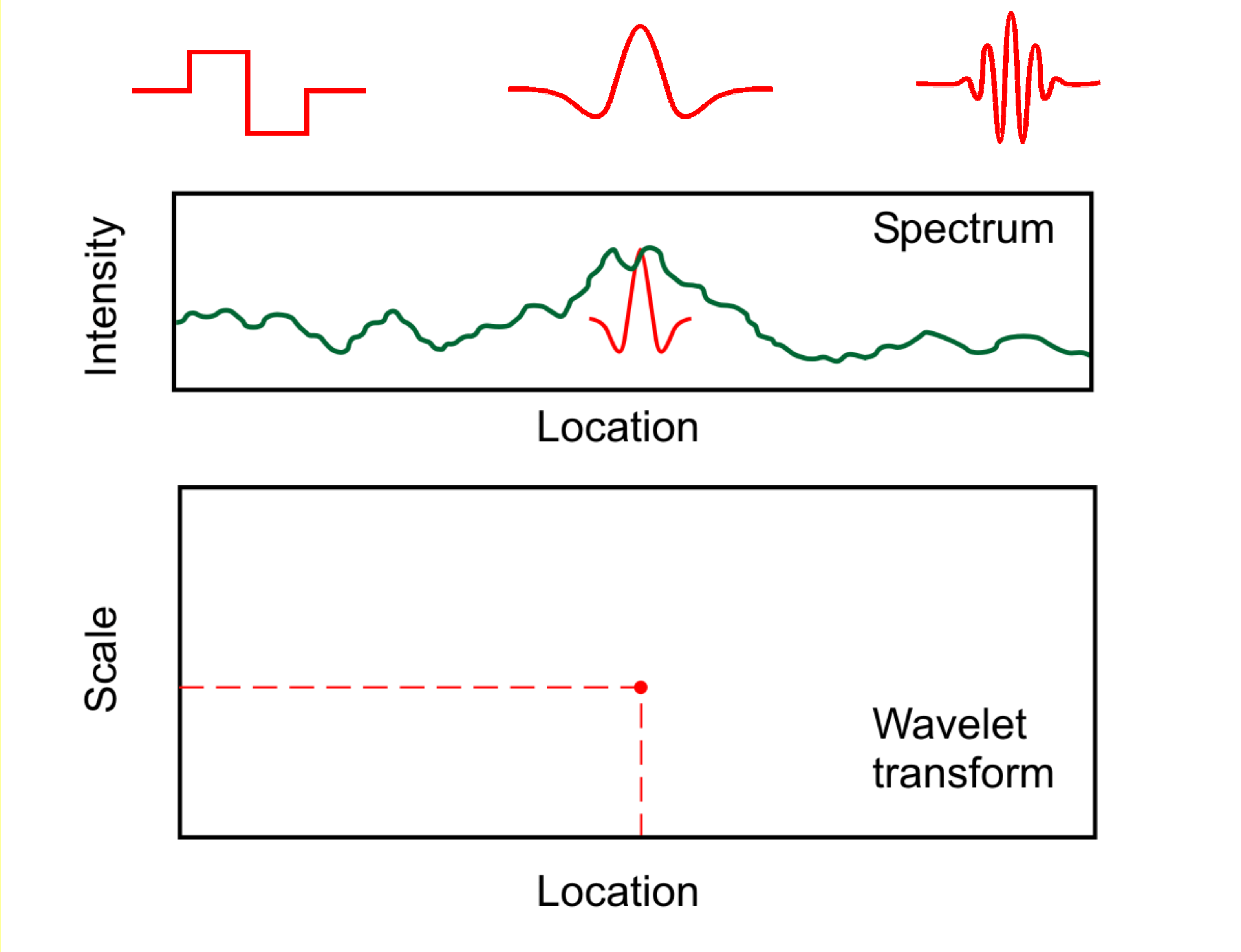
Wavelet Analysis



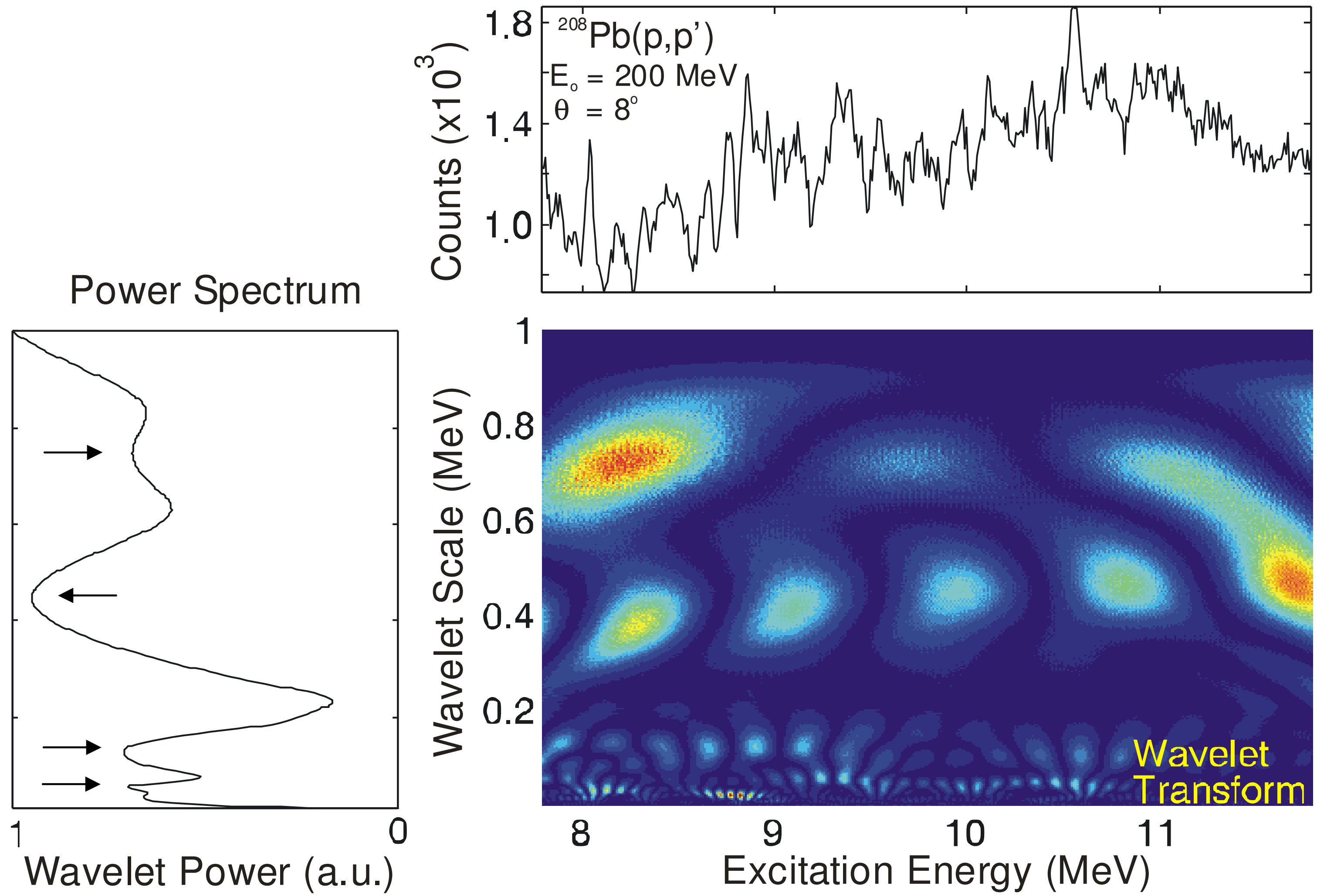
Wavelet Analysis



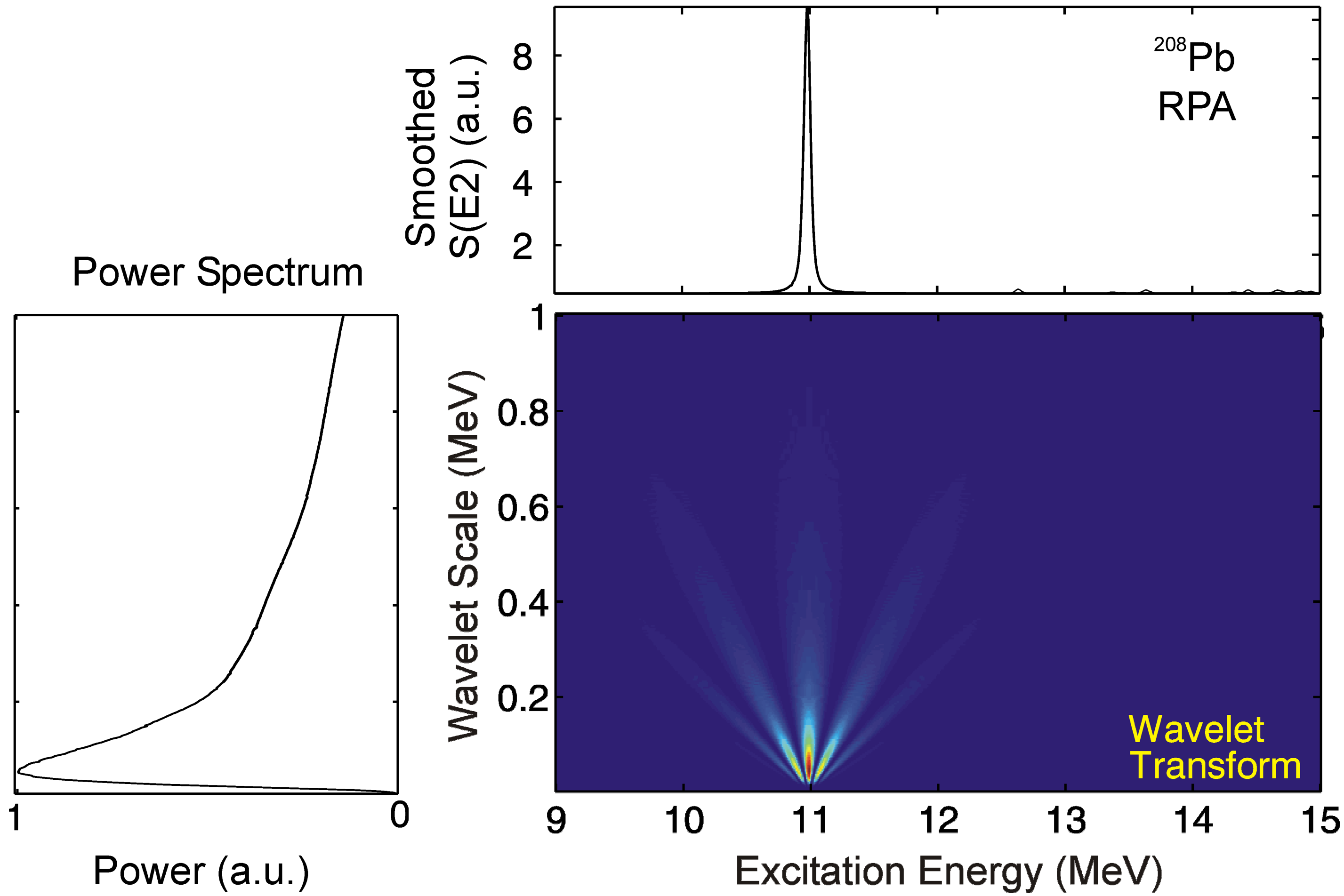
Wavelet Analysis



^{208}Pb(p,p´) at iThemba LABS

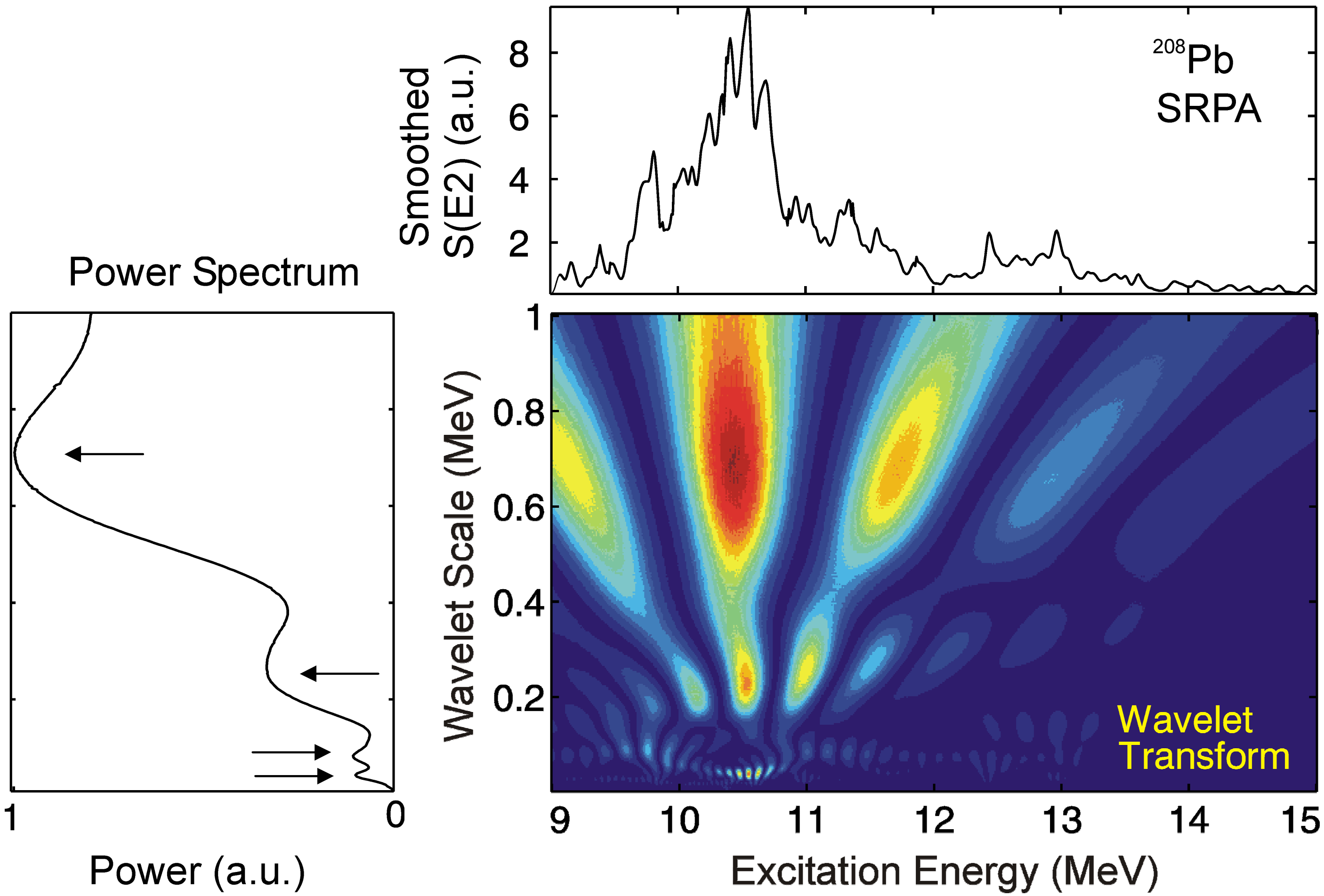


^{208}Pb RPA



- No scales from 1p-1h states

^{208}Pb SRPA

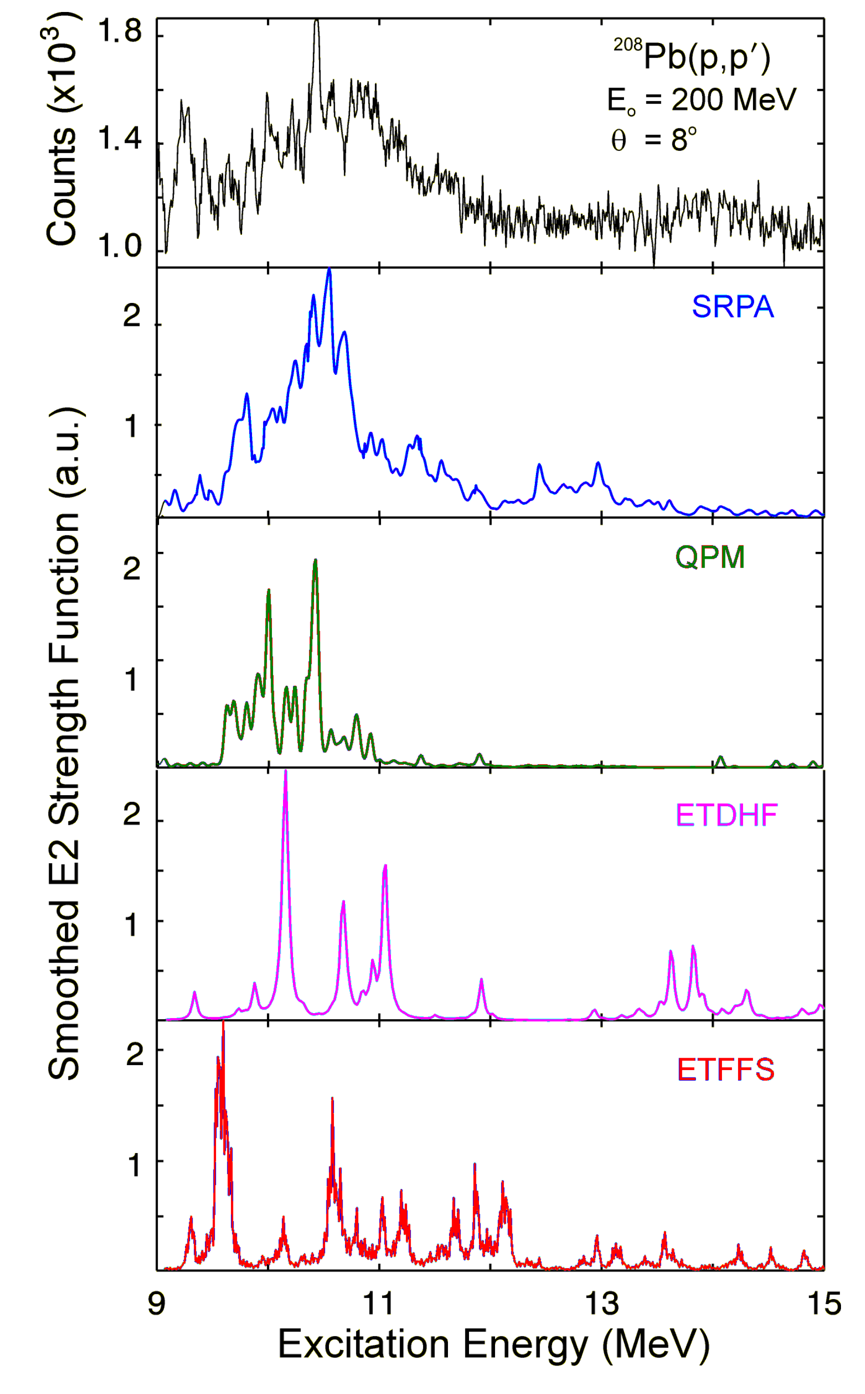


- Coupling to 2p-2h generates fine structure and scales

Interpretation of the Scales in ^{208}Pb - Models

RPA	Wambach et al.	(2000)
SRPA	Wambach et al.	(2000)
QPM	Ponomarev	(2003)
ETDHF	Lacroix et al.	(2003)
$1p-1h \otimes$ phonon ETFFS	Kamerdziev et al.	(1997)

Microscopic Models: Case of ^{208}Pb



- Large differences between model predictions
- No a priori judgement possible which model should be preferred
- Use wavelet analysis for a quantitative measure in comparison with the experimental observations

Experiment vs. Model Predictions

	Scales (keV)		
	I	II	III
Exp / keV	110	550	1500 2600
Models / keV			
SRPA	80	250 800	2100
QPM	110	770	1400
ETDHF	120	230	1000
ETFFS	130	310 570	2500

- Three classes of scales as in the experiment on a qualitative level
- But strong variations of class II and class III scales
- Take QPM for semi-quantitative analysis of damping mechanisms

Semi-Quantitative Attempt of Interpretation: ^{208}Pb as Example

Two types of dissipation mechanisms:

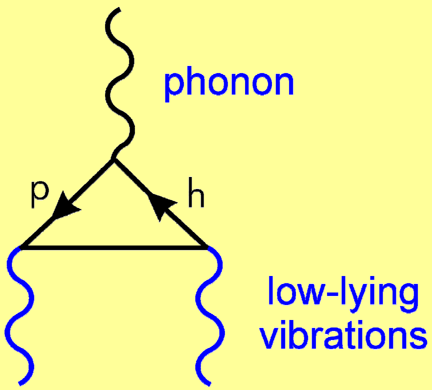
collective damping

⬇

low-lying surface vibrations

⬇

1p – 1h ⊗ phonon



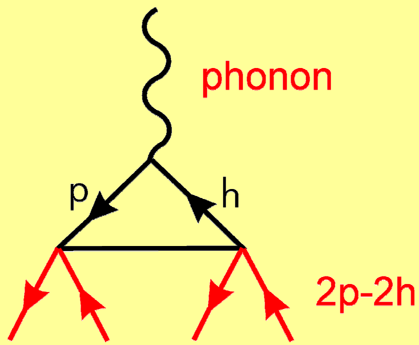
non-collective damping

⬇

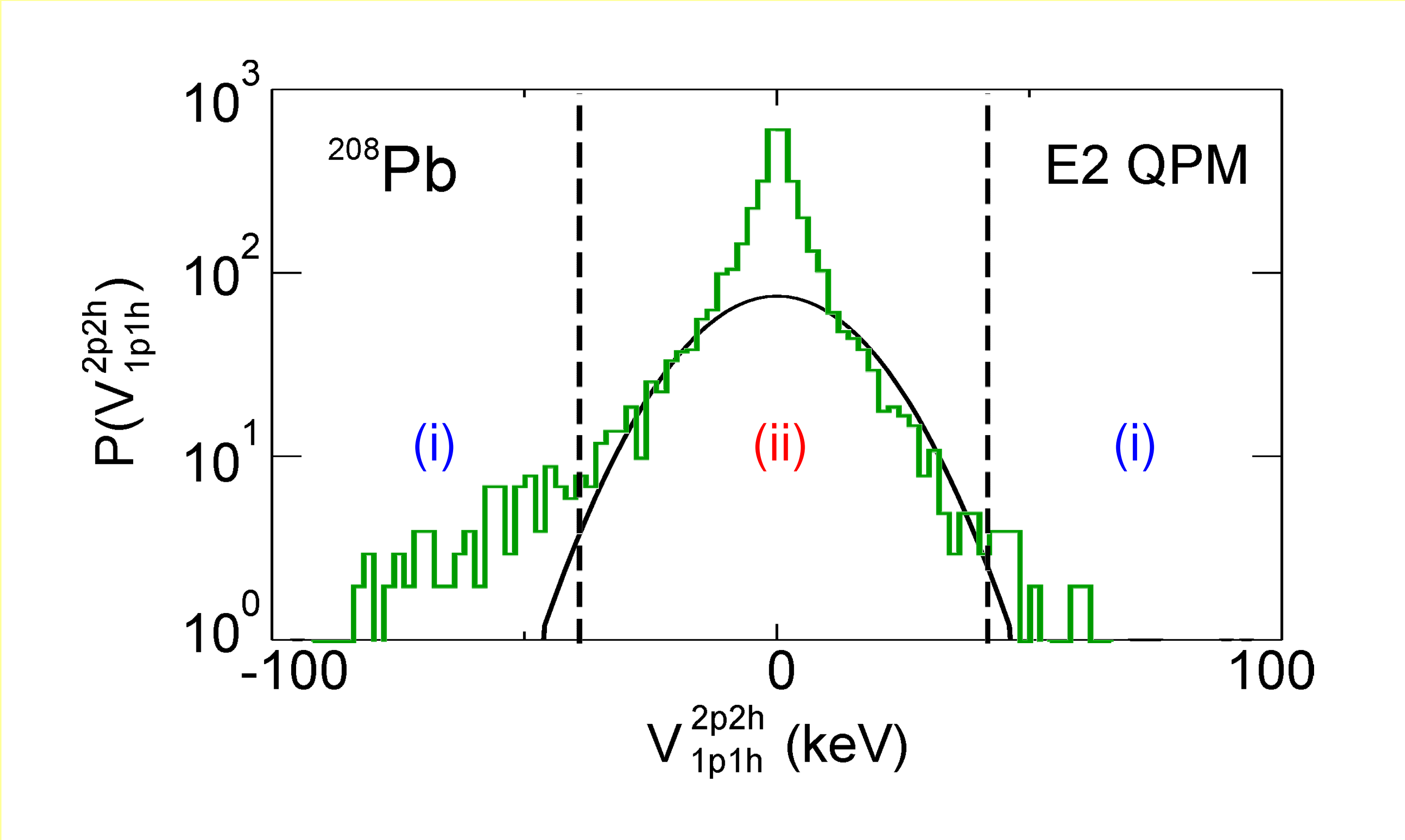
background states

⬇

coupling to 2p – 2h states

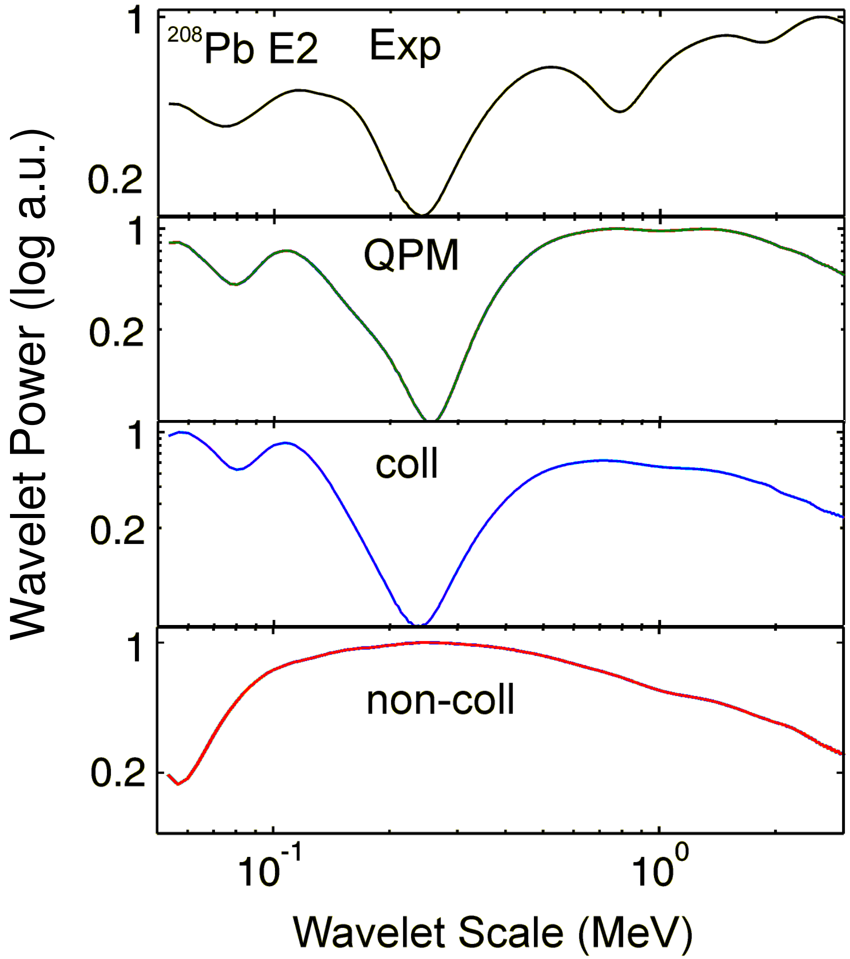


How Can the Two Mechanisms Be Separated: Distribution of the Coupling Matrix Elements



- QPM: distribution for $\langle 1p1h \mid V^{2p2h}_{1p1h} \mid 2p2h \rangle$
- RMT: deviations at large and at small m.e.
- Large m.e. define the collective damping mechanism
- Small m.e. are responsible for the non-collective damping

Collective vs. Non-Collective Damping in ^{208}Pb

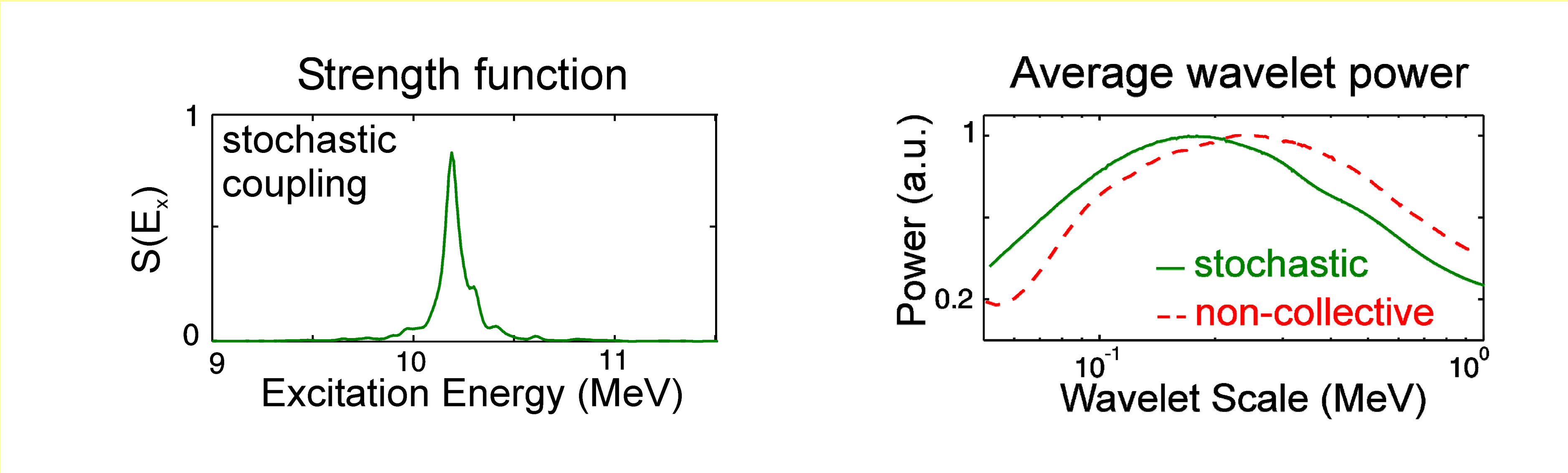


- Collective part: all scales
- Non-collective part: no prominent scales

⮡ Stochastic coupling

Stochastic Coupling Model

- Gaussian distribution for coupling matrix elements (RMT)
- Level spacing distribution according to GOE
- Average over statistical ensemble



- Similar results as those from the non-collective damping mechanism
- Non-collective scales are generic in all nuclei

Summary First Example

- Fine structure established as a global phenomenon in GR´s

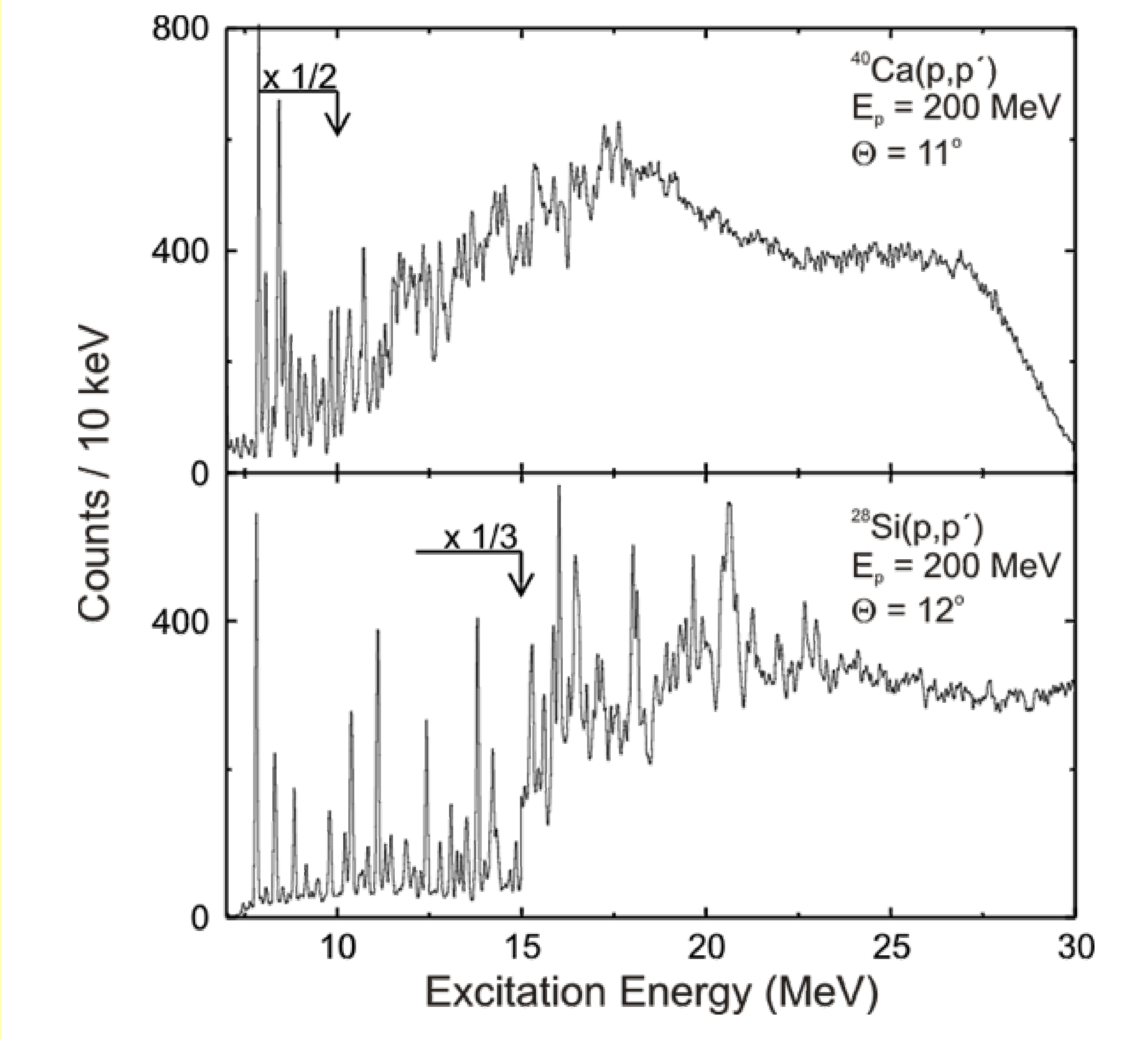
- Quantitative analysis with wavelets

  - nature of scales: coupling between 1p-1h and 2p-2h states
  - role of coupling to low-lying phonons
  - importance of different scales
  - spin- and parity-resolved leveldensities → parity dependence ?

- Large differences between the models

  - role of continuum ?
  - model space ?
  - interections ?

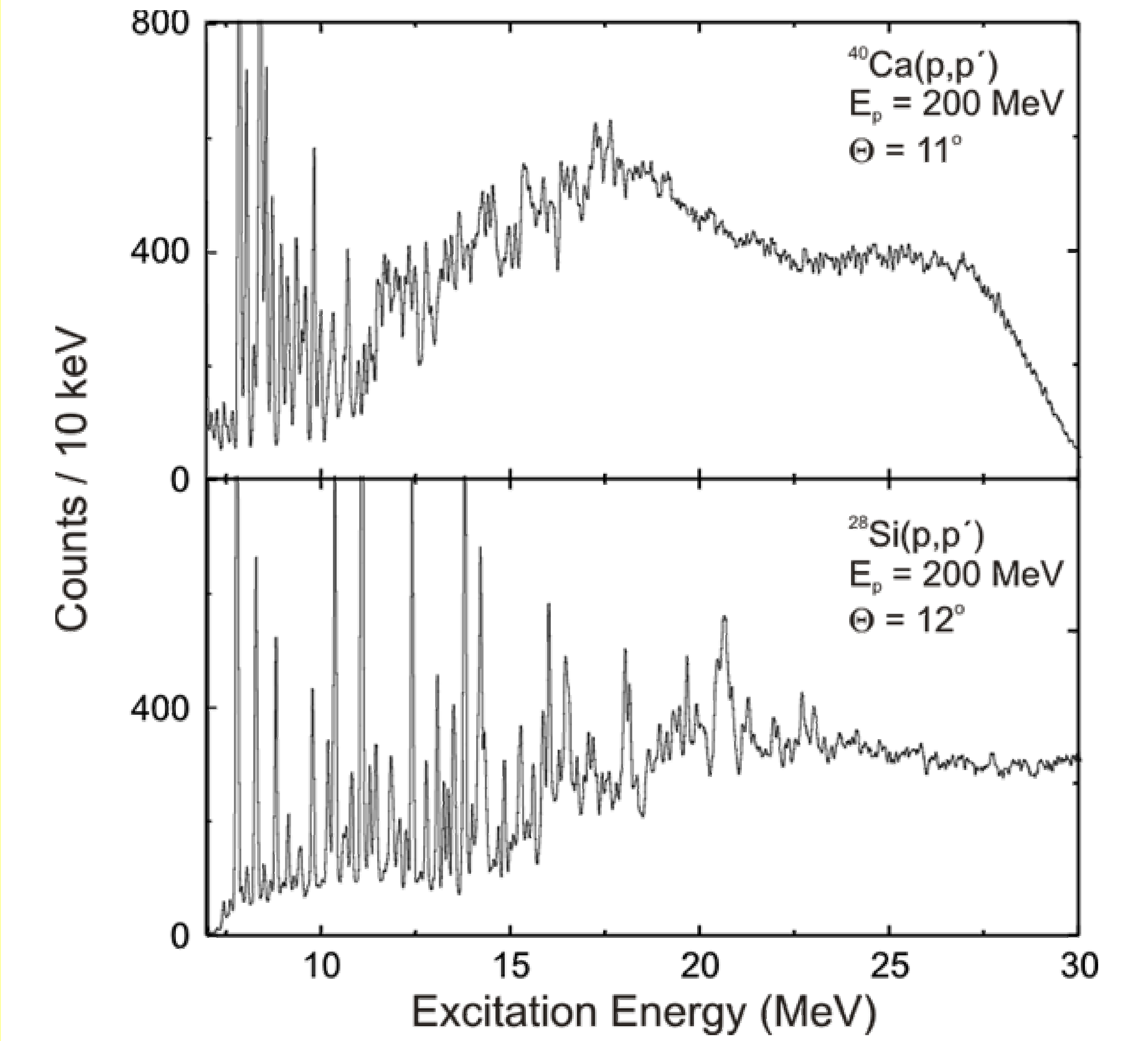
Escape Width



- Fine structure also found in lighter nuclei

  ⇨ importance of escape width can be tested

Escape Width



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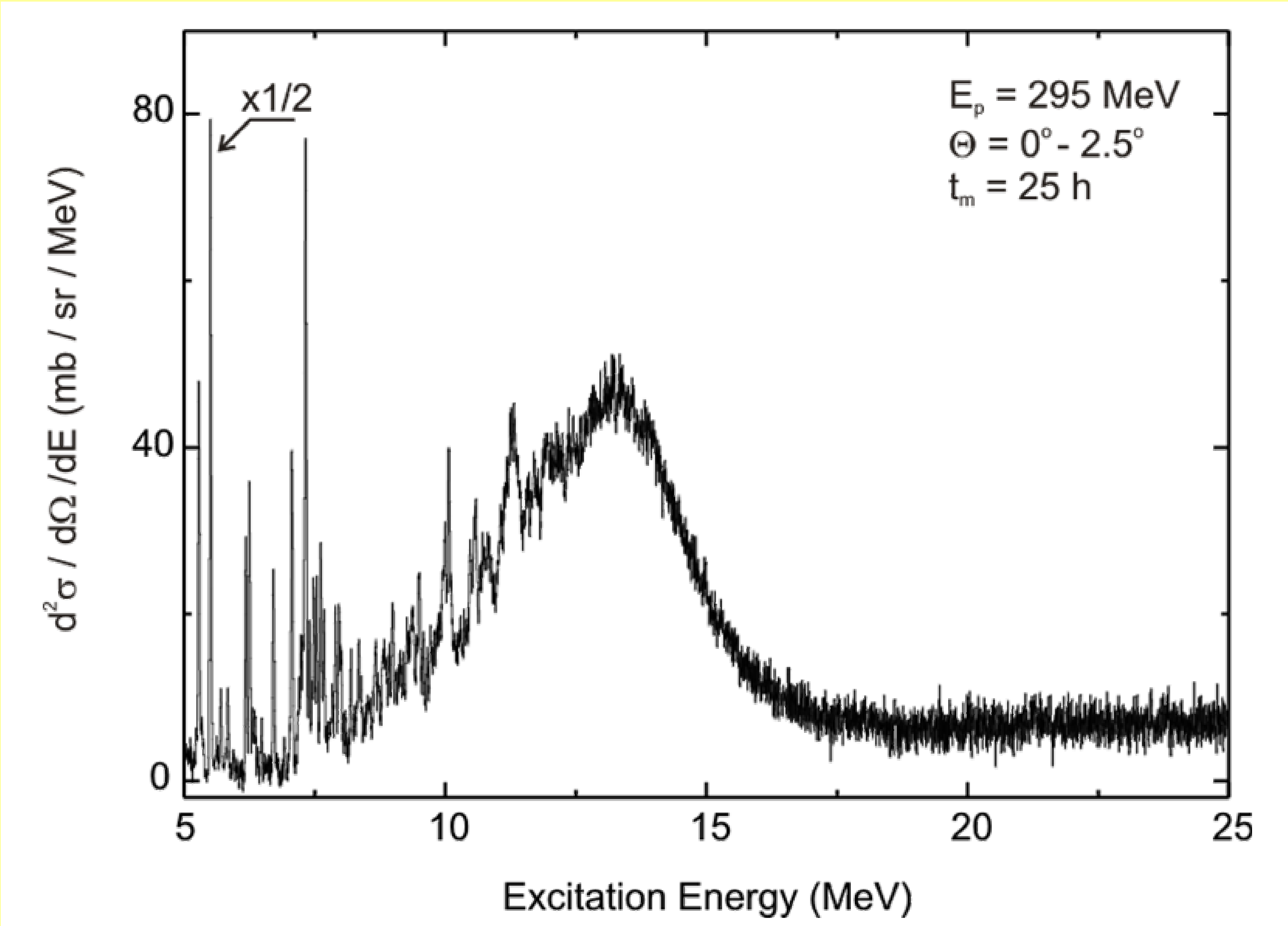
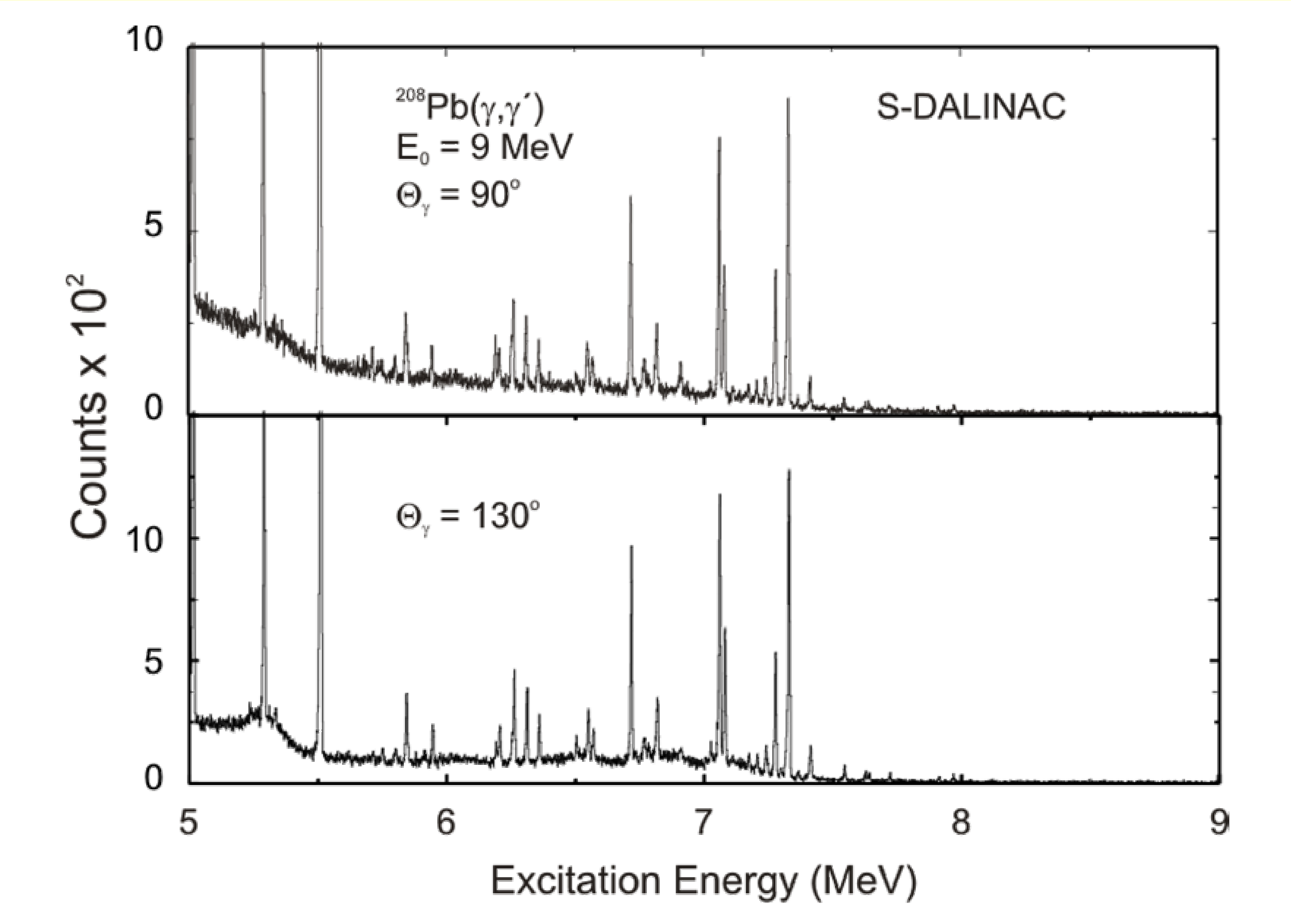
Landau Damping



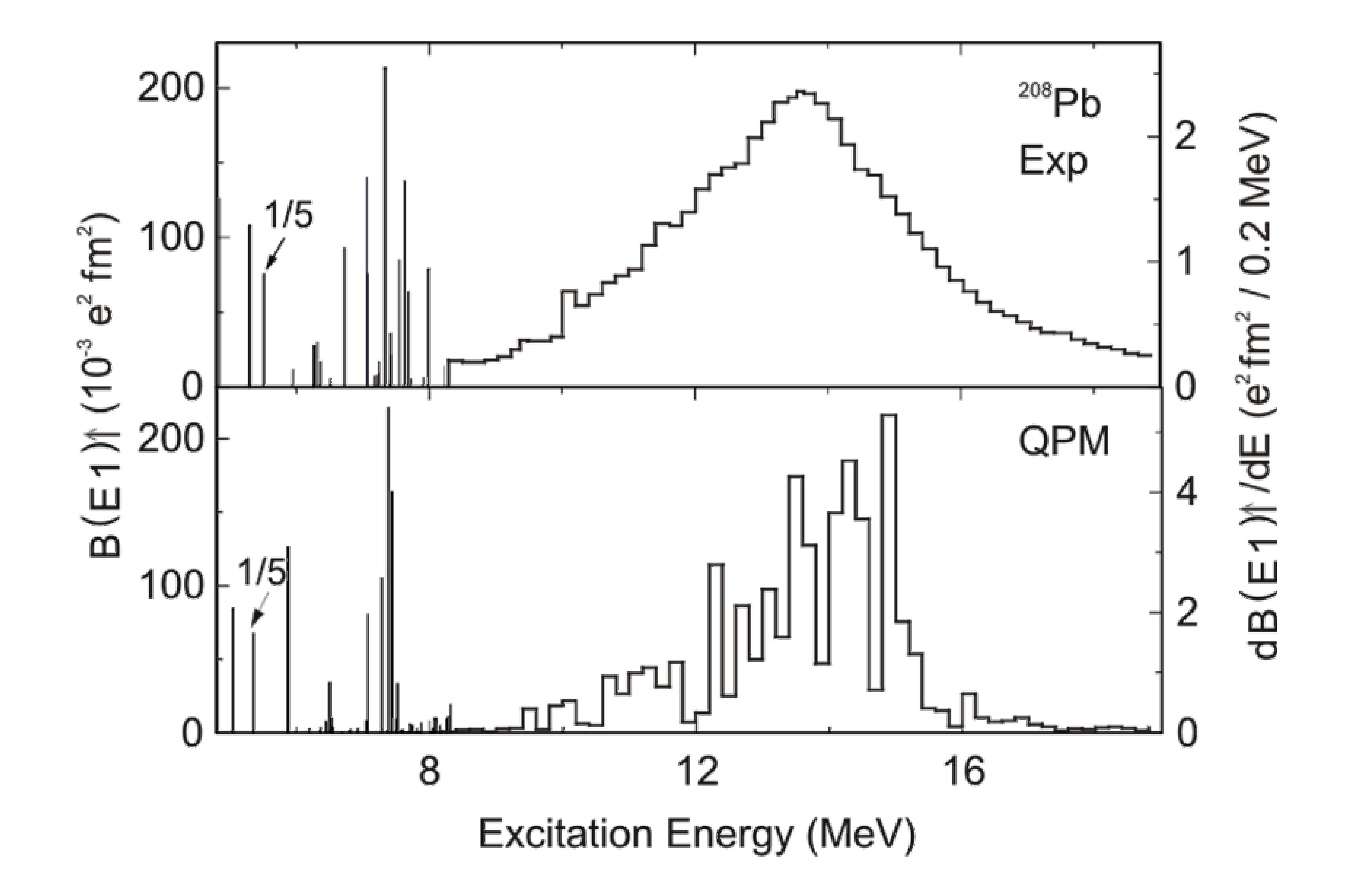
- Fine structure of the IVGDR from high-resolution (p,p´) scattering at 0° degrees

Second Example: The Pygmy Dipole Resonance in Stable Nuclei



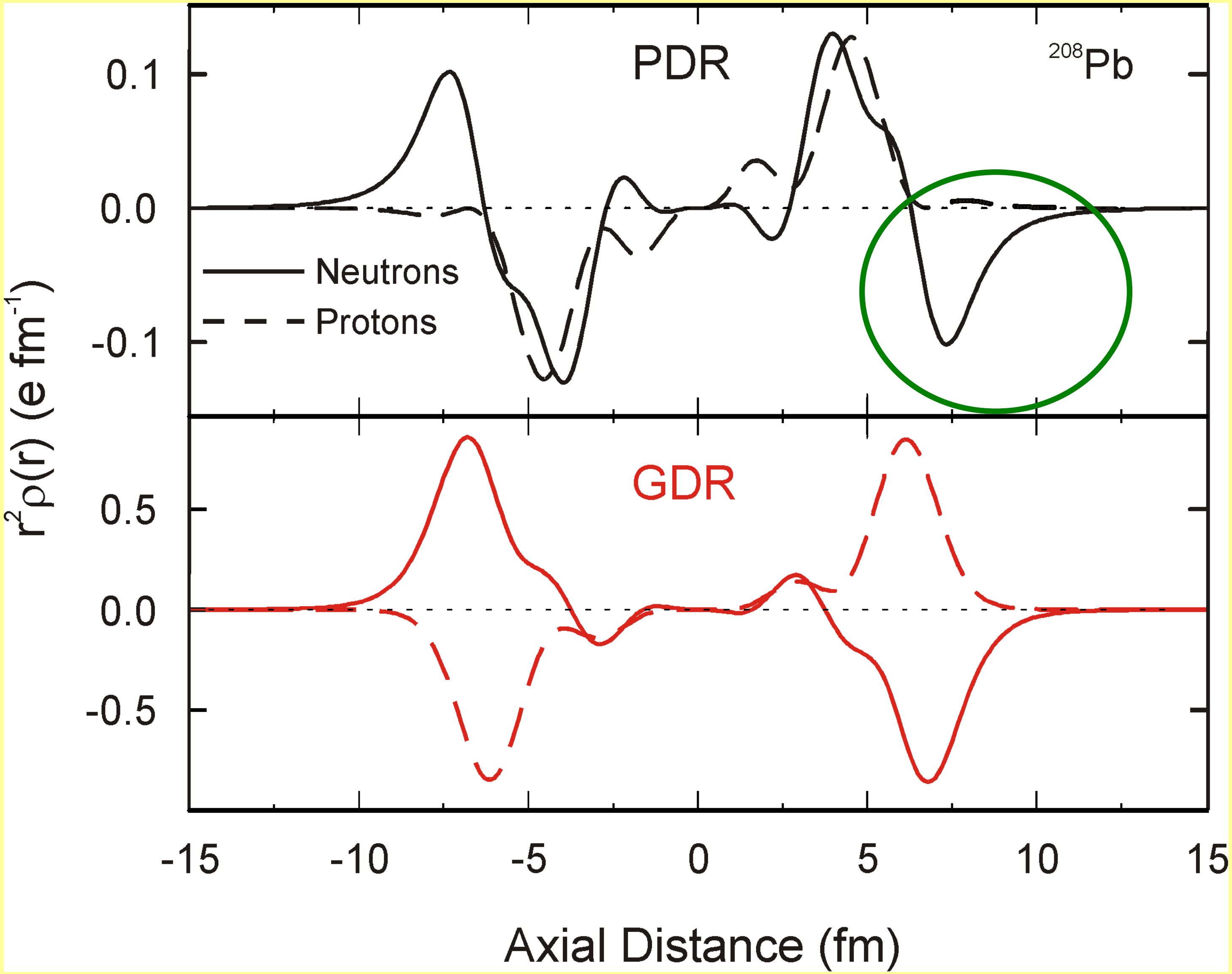
N. Ryezayeva et al., PRL 89 (2002) 272502

E1 Response in ^{208}Pb



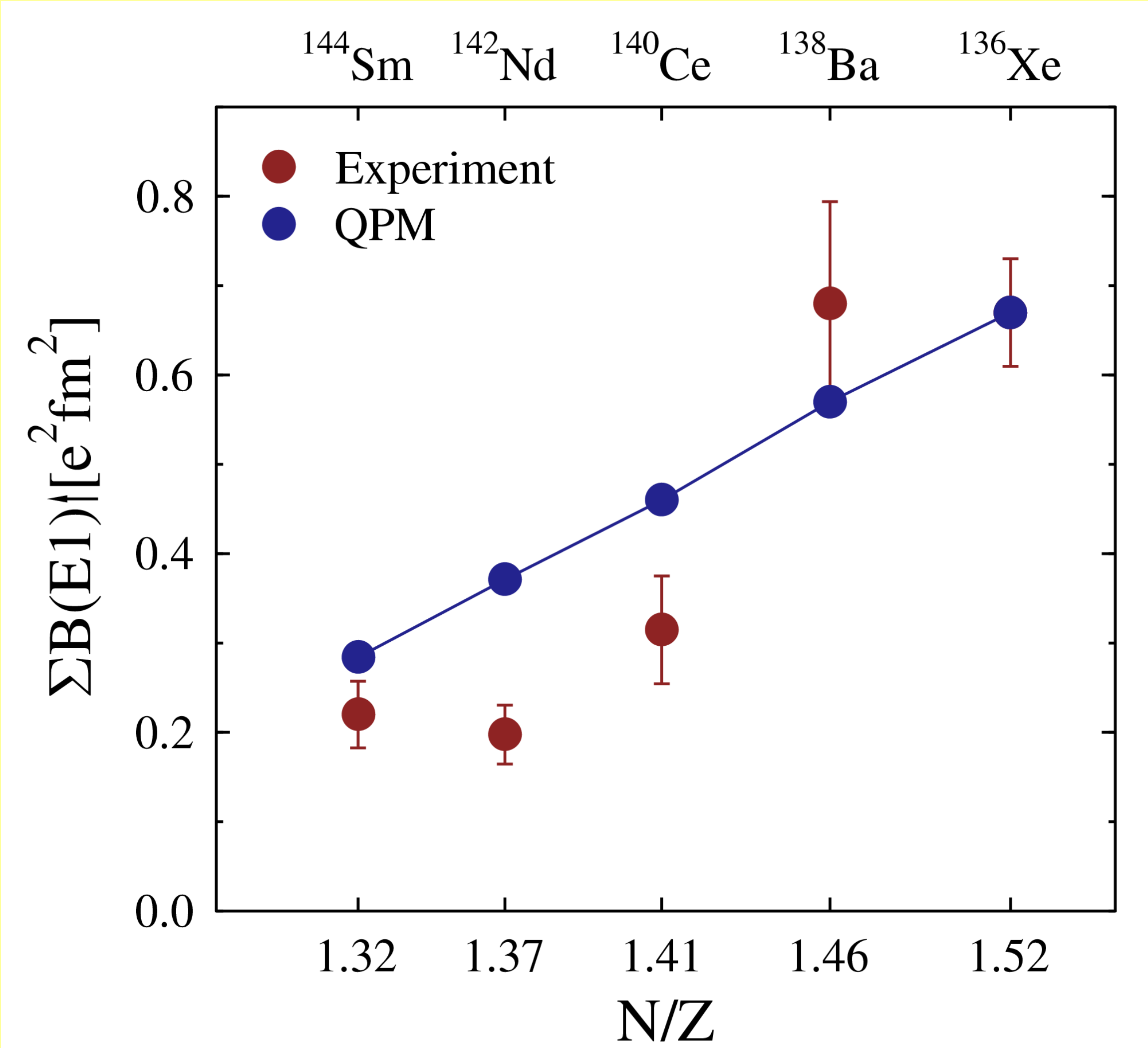
- Excellent agreement of QPM with experiment

Transition Densities



- Oscillation of neutrons against isospin-saturated core

Systematics of the PDR at N = 82

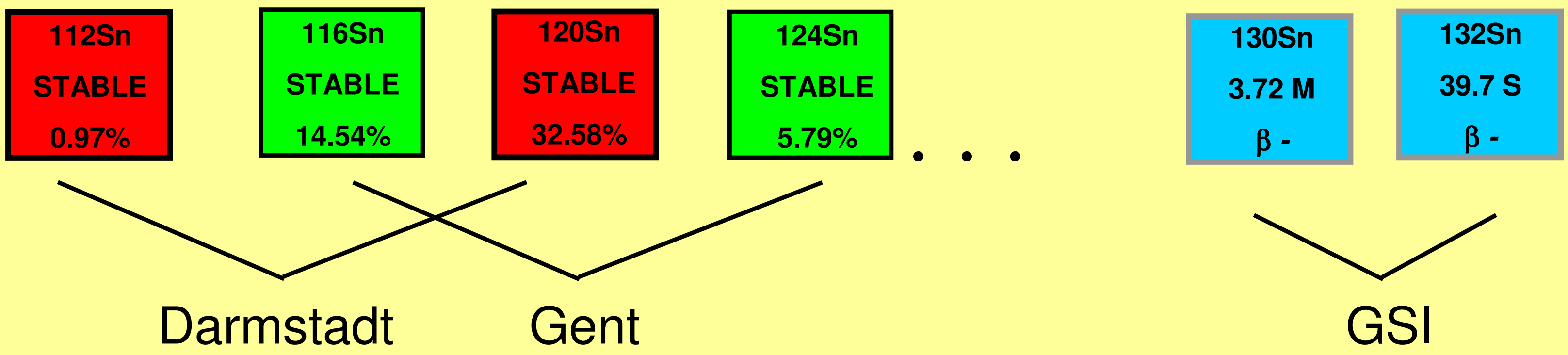


Systematics of the PDR in the Sn Isotope Chain

- Test case for theory, many calculations

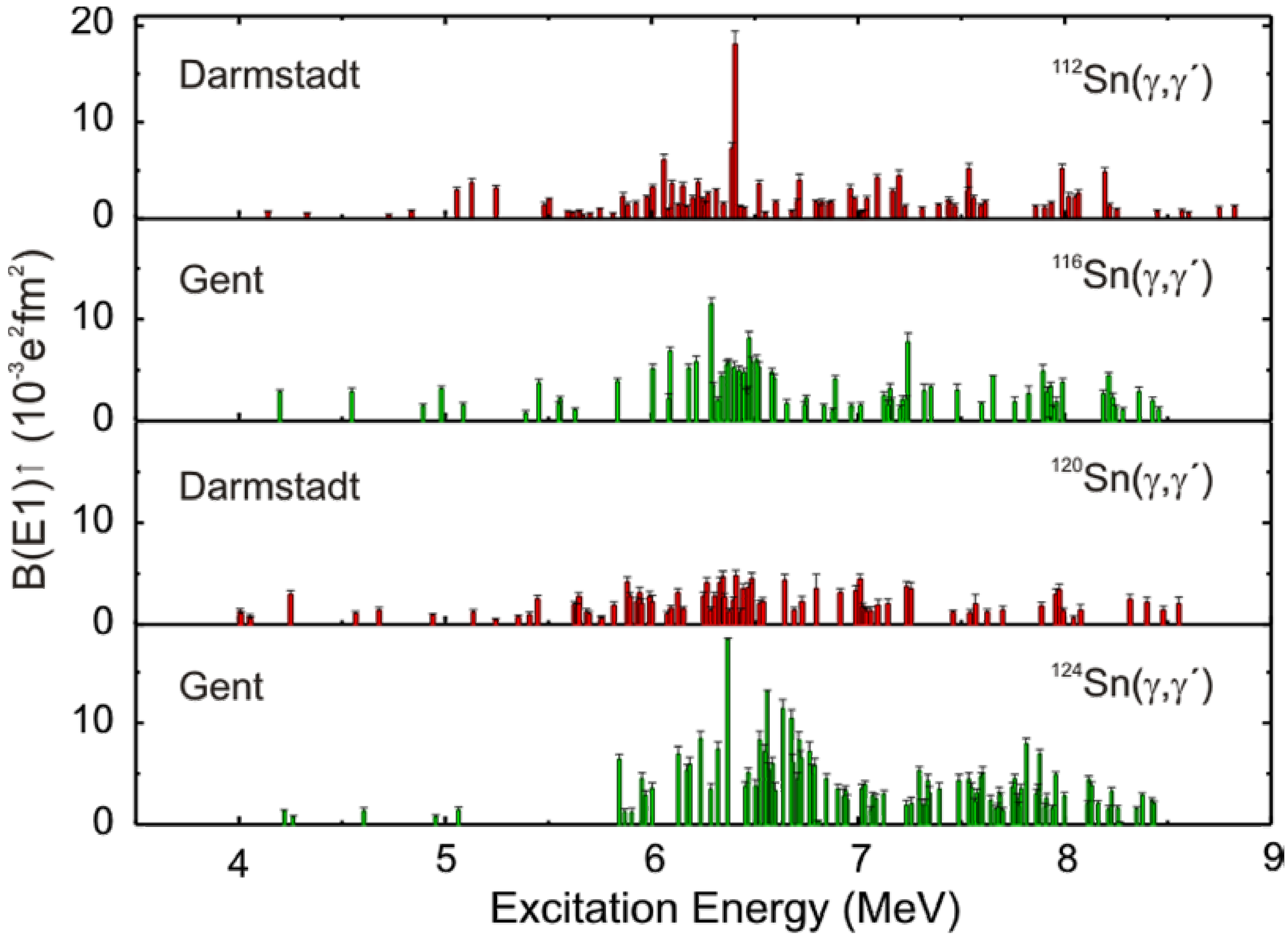
  N. Tsoneva et al. , NPA 731 (2004) 273
  D. Sarchi et al. , PLB 601 (2004) 27
  N. Paar et al., PLB 606 (2005) 288
  J. Piekarewicz, PRC 73 (2006) 044325
  S. Kamerdizhiev, S.F. Kovaloo, PAN 65 (2006) 418
  J. Terasaki, J. Engel, PRC 74 (2006) 044325
  E. Litvinova et al., PLB 647 (2007) 111

- Experimental data in stable and unstable Sn isotopes available

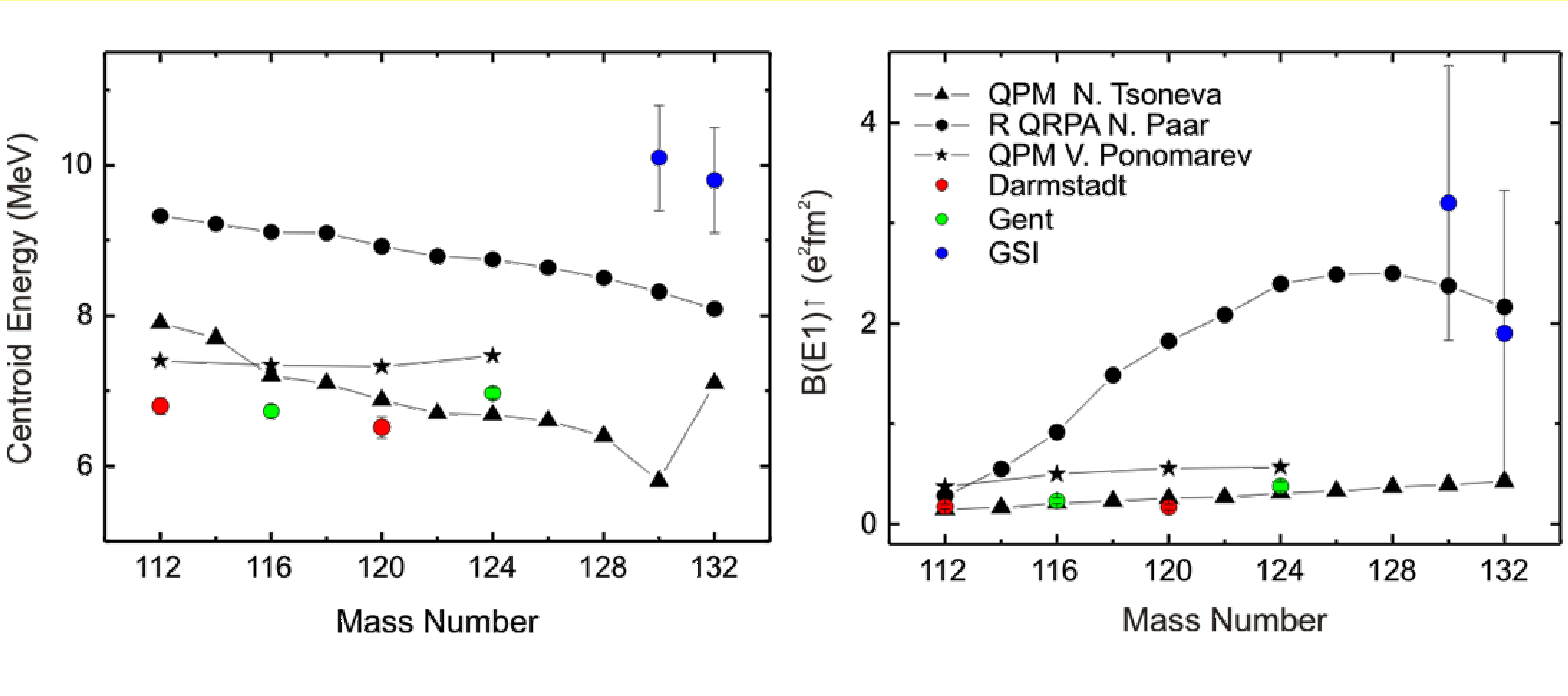


Nuclear Resonance Fluorescence **Coulomb Dissociation**

E1 Strength Distributions in Stable Sn Isotopes



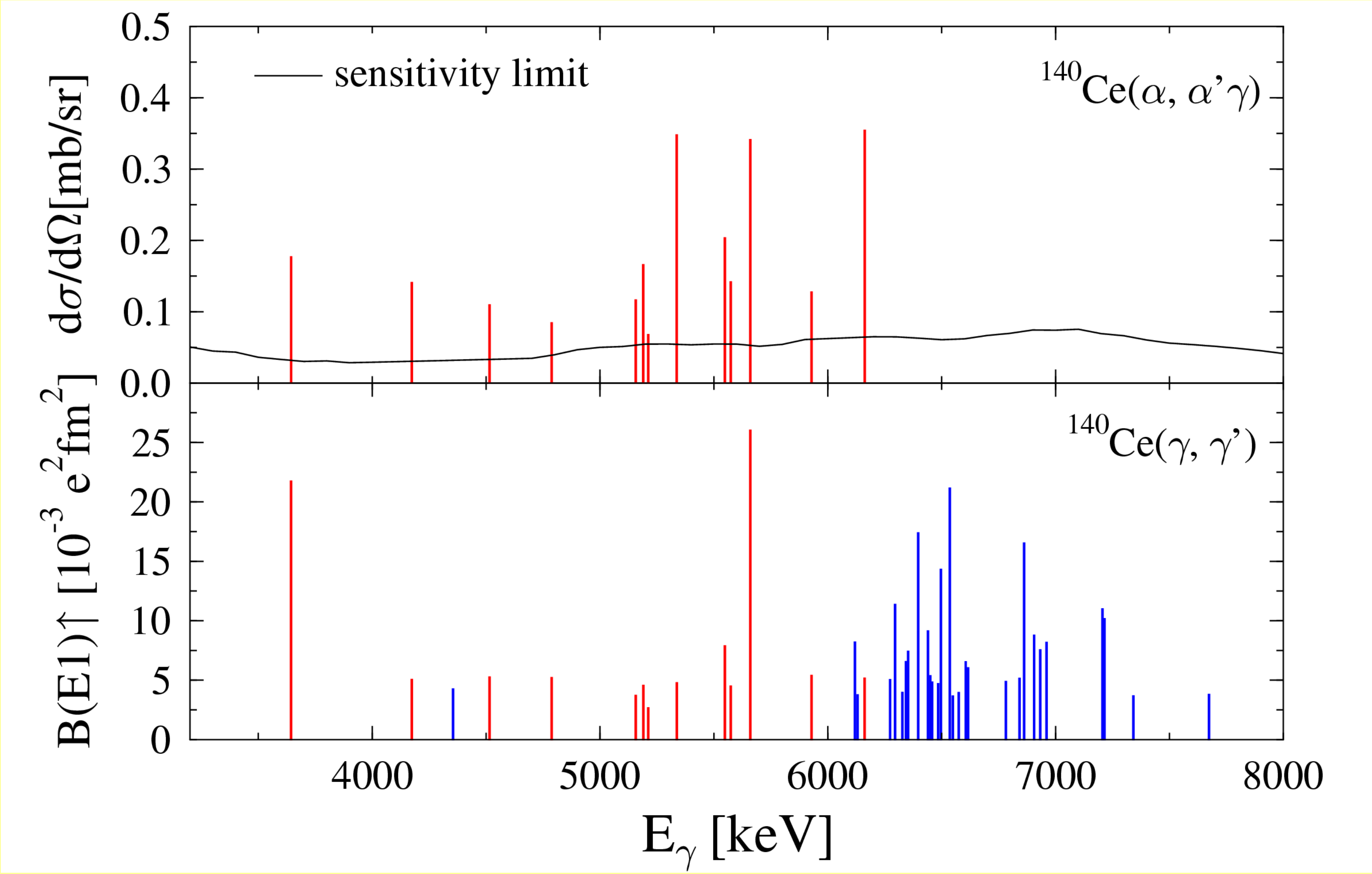
Comparison with Theory: Centroid and Cumulative Strength



Note: (γ,γ´) measures strength <u>below</u> threshold only

Coulomb dissociation measures strength <u>above</u> threshold only

(α,α´γ) vs. (γ,γ´)



- Are there two modes ?

Summary: The PDR in Stable Nuclei

- PDR experimentally esteblished in (semi)magic nuclei
- No simple scaling of strength with neutron excess
- Collectivity ?
- Difference between (g,g´) and (a,a´g): reaction mechanism ?
  Two modes?
- Sn isotope chain: properties of the PDR in stable and exotic nuclei cannot be described simultaneously but
  - we need consistent data below and above threshold