Angela and the Electric Dipole Response – Giant and Pygmy, Hot and Cold

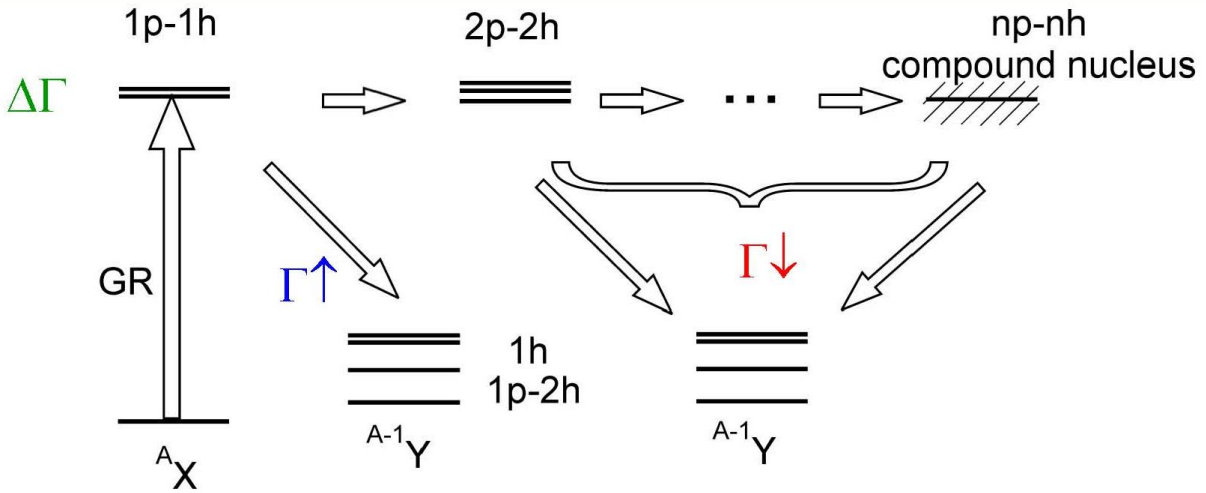
Peter von Neumann-Cosel
Institut für Kernphysik, Technische Universität Darmstadt

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SFB 1245

- Fine structure of giant resonances
- Brink-Axel hypothesis
- Nature of the PDR

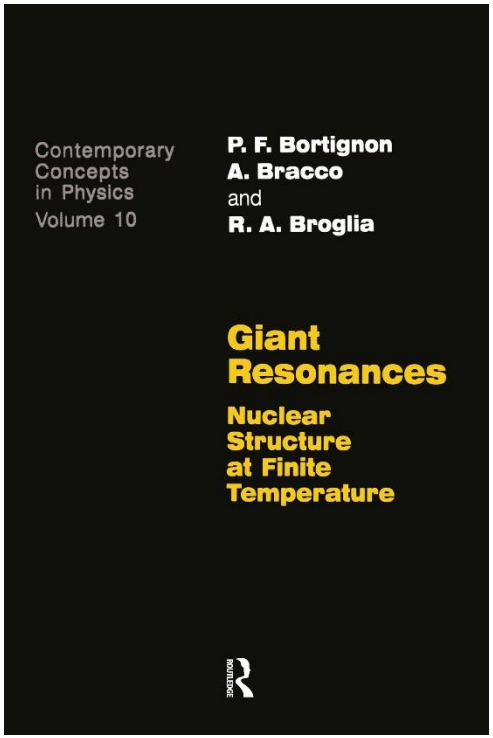
Damping of Giant Resonances



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

Resonance width | Landau damping | Escape width | Spreading width

Figure adapted from



High-Resolution Measurements

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QCLAM spectrometer
S-DALINAC
Darmstadt, Germany



(e,e‘)

K600 spectrometer
iThemba LABS
Cape Town, South Africa



(p,p‘) @ 200 MeV

Grand Raiden spectrometer
RCNP
Osaka, Japan



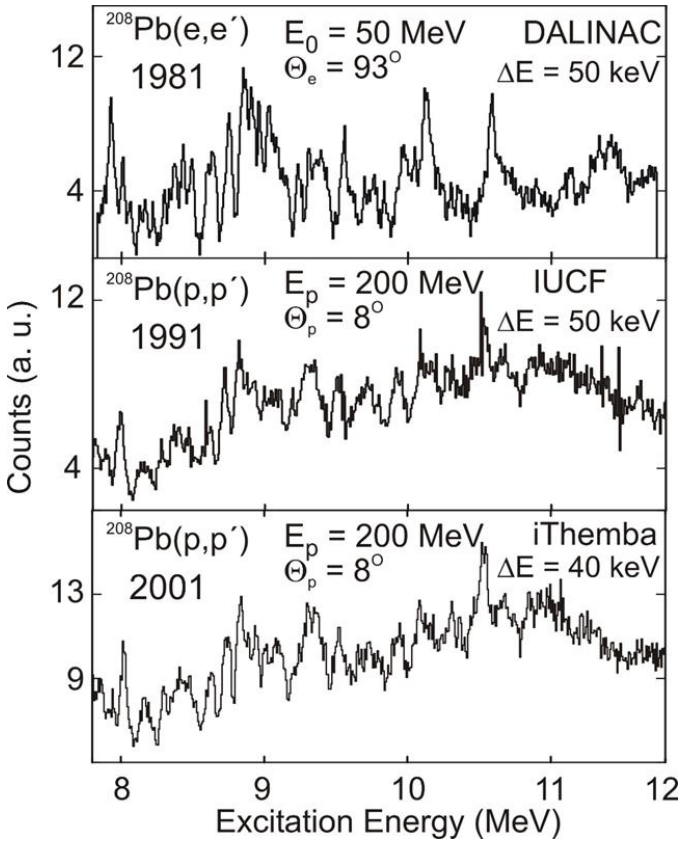
(p,p‘) @ 300 MeV
(^{3}He,t) @ 420 MeV

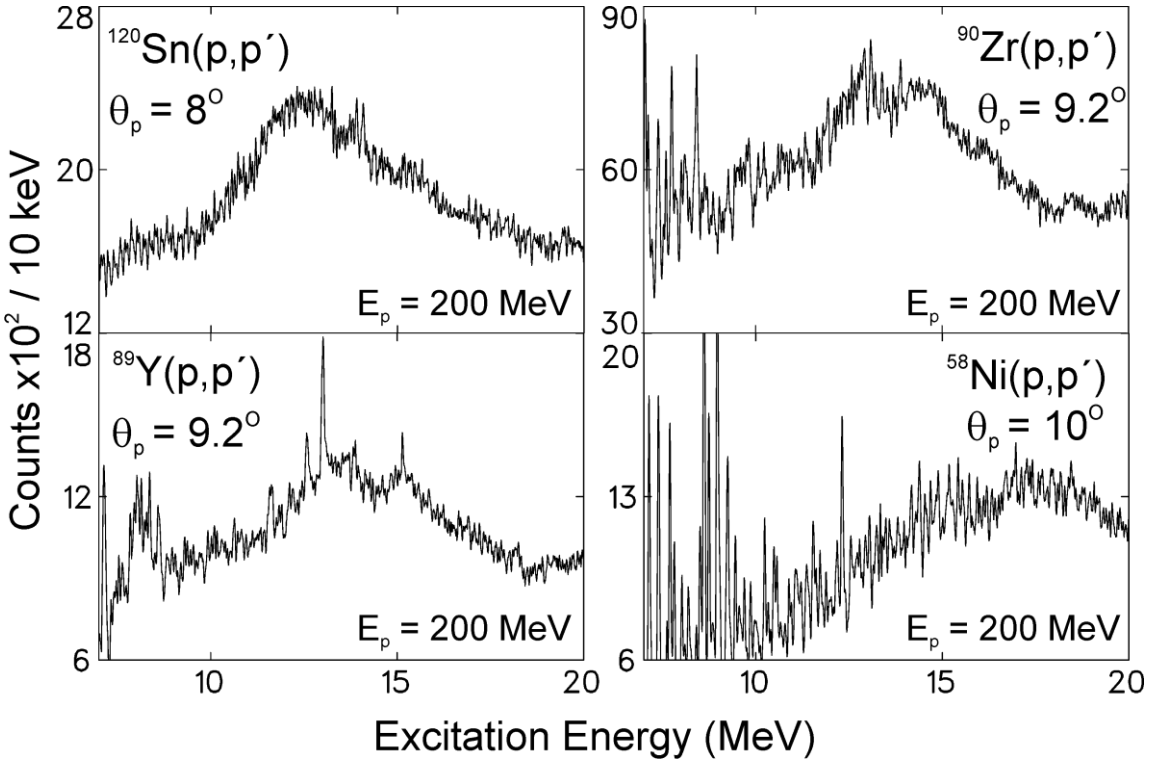
Dispersion matching techniques ➡ $\Delta E/E \approx 10^{-4}$ (FWHM)

Fine Structure of the ISGQR: A Systematic Phenomenon

TECHNISCHE UNIVERSITÄT DARMSTADT

A. Shevchenko et al., PRL 93, 122501 (2004); PRC 79, 044305 (2009)

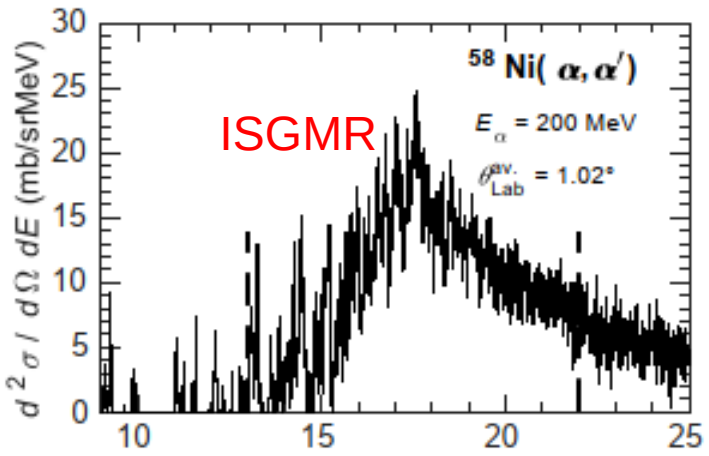




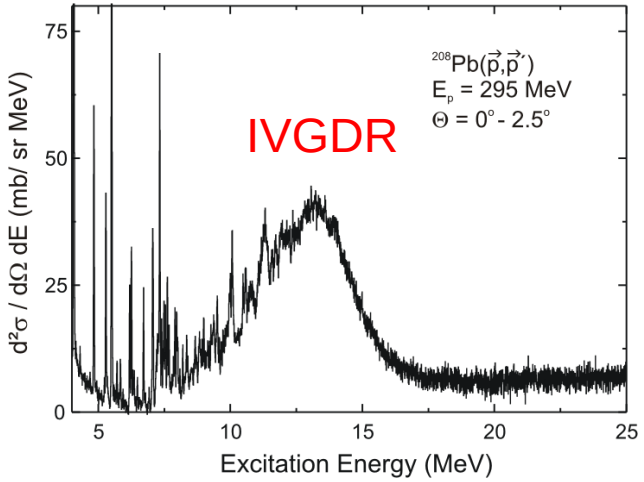
Fine Structure of GRs: A Global Phenomenon

TECHNISCHE UNIVERSITÄT DARMSTADT

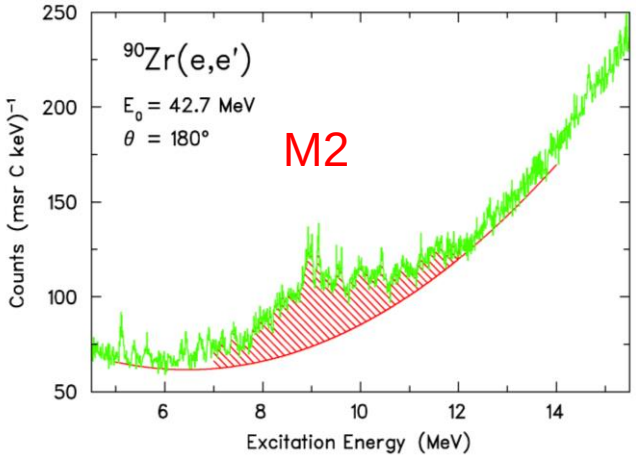
A. Bahini et al., PRC 109, 014325 (2024)



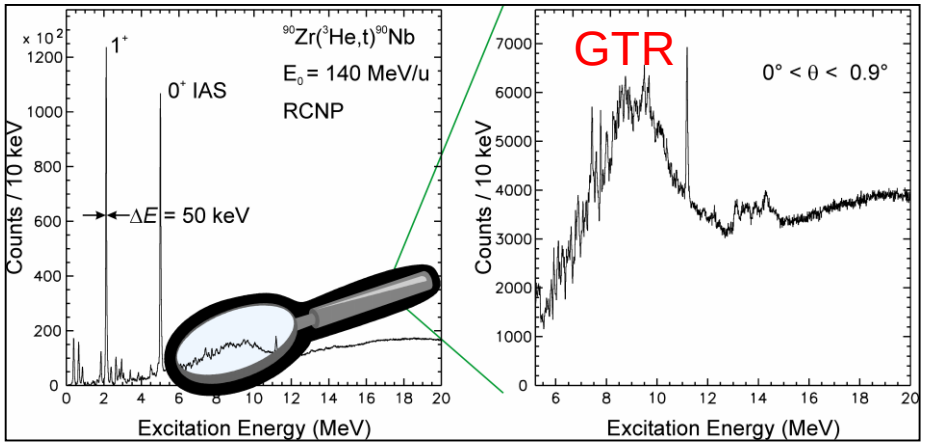
I. Poltoratska et al., PRC 89, 054322 (2014)



PvNC et al., PRL 82, 1105 (1999)

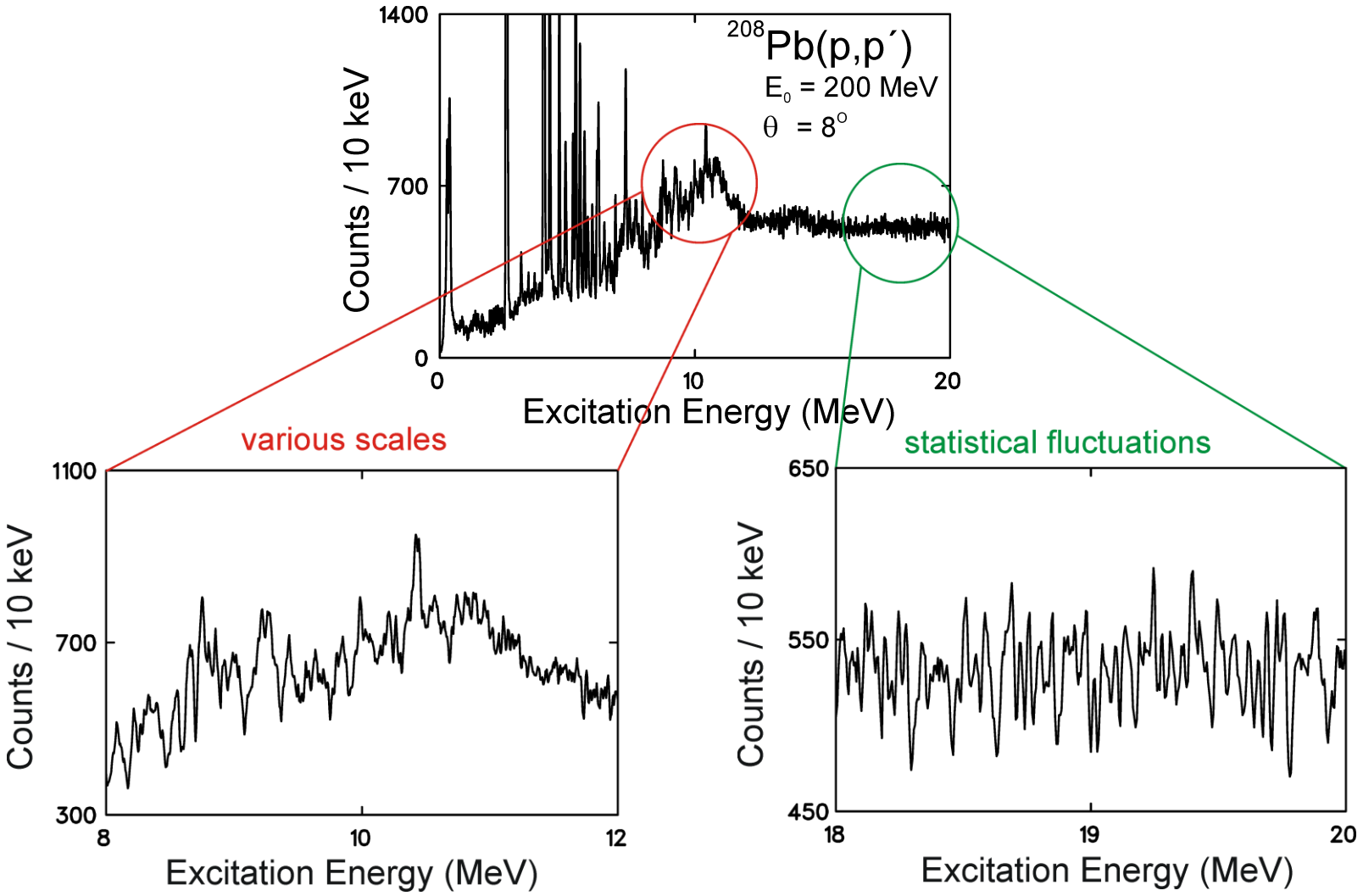


Y. Kalmykov et al., PRL 96, 012502 (2006)



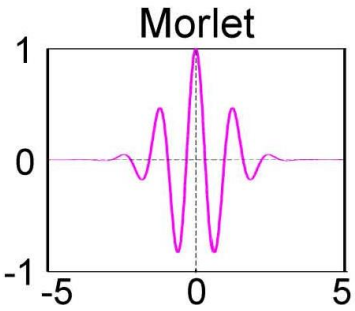
Fine Structure: Fluctuations and Scales

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Wavelet Analysis

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



$$\Psi(x) = \frac{1}{\sqrt{\pi f_b}} \exp(2\pi i f_c) \exp\left(-\frac{x^2}{f_b}\right)$$

Wavelet coefficients:

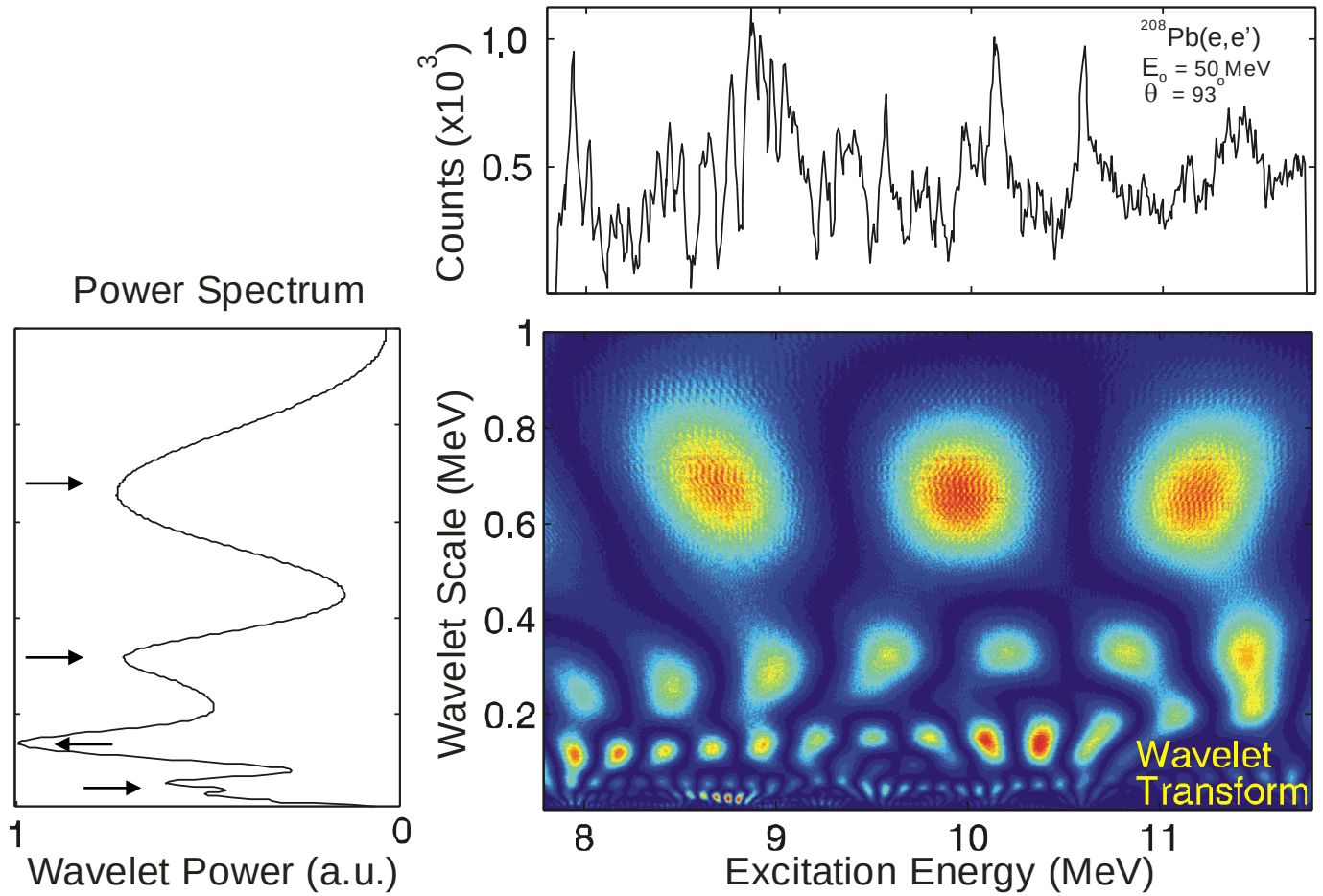
$$C(\delta E, E_x) = \frac{1}{\sqrt{\delta E}} \int \sigma(E)\ \Psi^*\left(\frac{E_x - E}{\delta E}\right) dE$$

scale: δE — position: E_x — spectrum: $\sigma(E)$ — wavelet: Ψ^*

Continuous: δE, E_x are varied continuously

A. Shevchenko et al., Phys. Rev. C77, 024302 (2008)

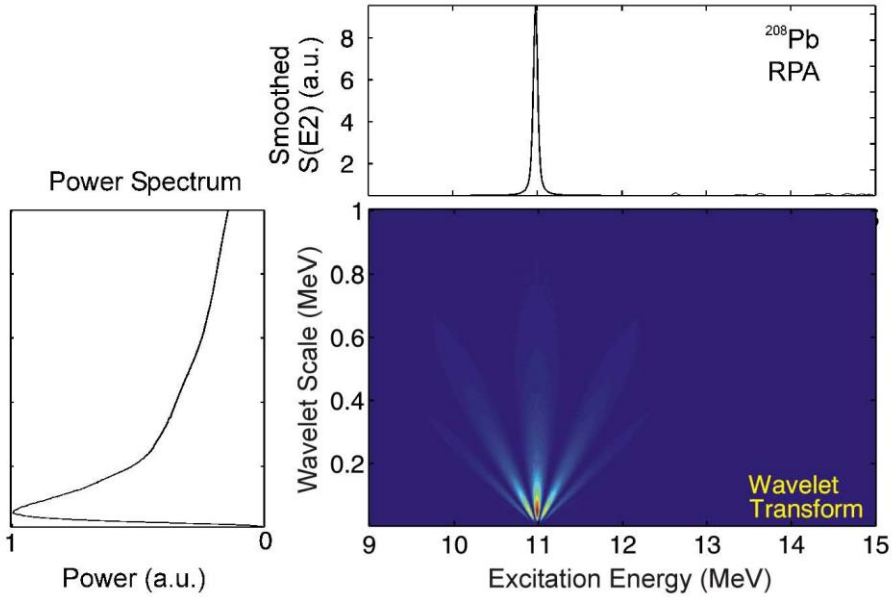
ISGQR in ^{208}Pb from (e,e‘)

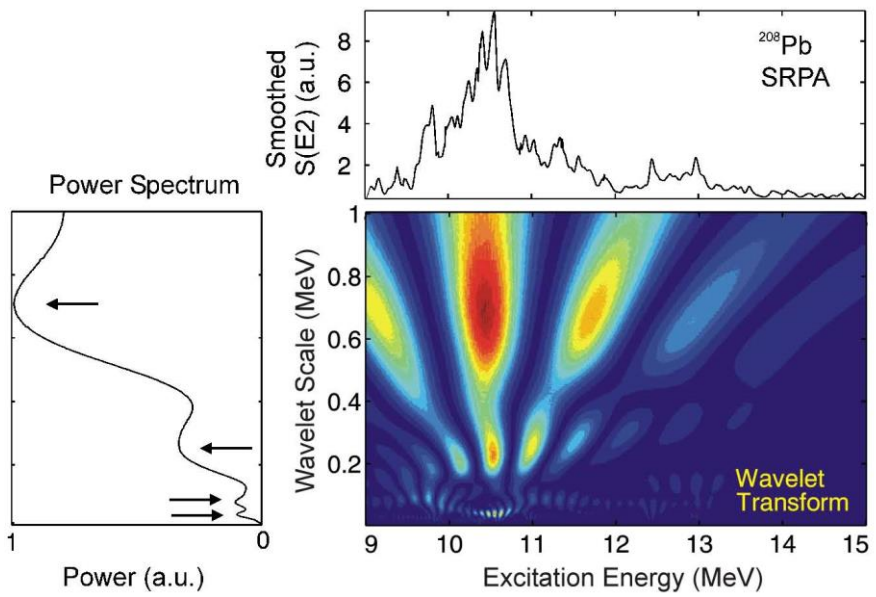


(S)RPA Model Calculations

TECHNISCHE UNIVERSITÄT DARMSTADT

A. Shevchenko et al., Phys. Rev. Lett. 92, 122501 (2004); Phys. Rev. C 79, 044305 (2009)





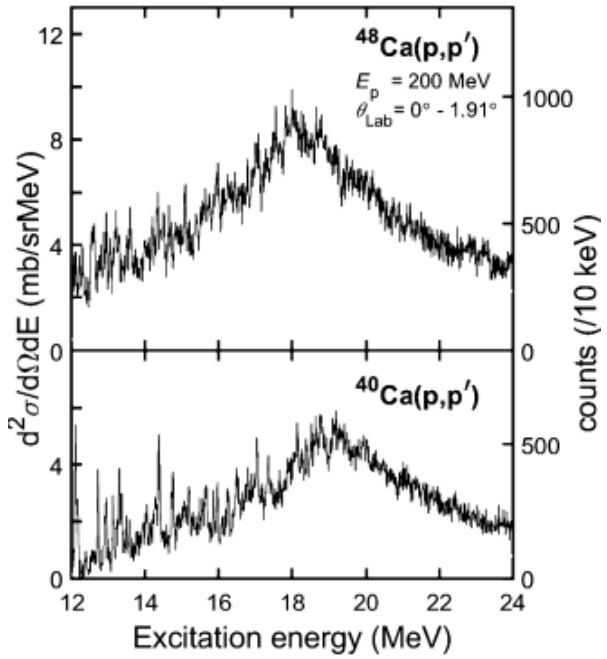
- No scales from 1p-1h states
- Coupling to 2p-2h generates fine structure and scales

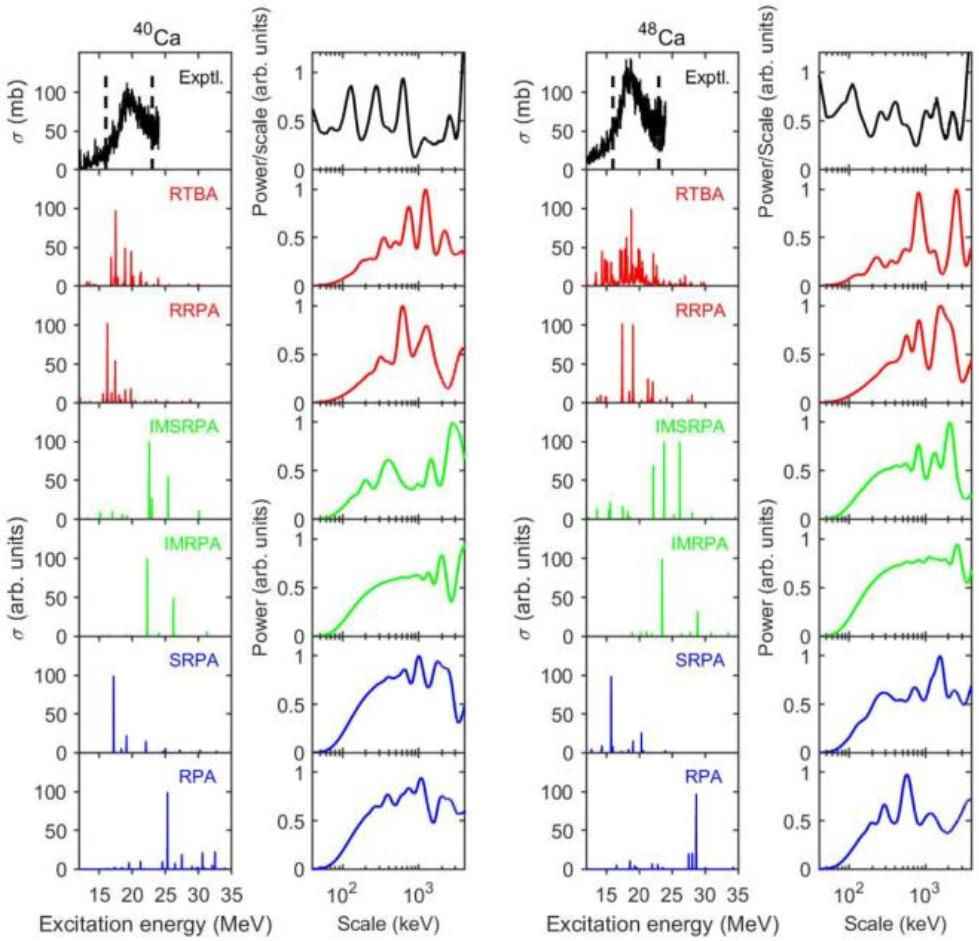
→ Spreading width

Scales of the IVGDR: ^{40}Ca and ^{48}Ca

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J. Carter et al., PLB 833, 137374 (2022)





Scales from
1p-1h states:
Landau damping

Electric Dipole Strength at Finite Temperature

TECHNISCHE UNIVERSITÄT DARMSTADT

VOLUME 62, NUMBER 18 PHYSICAL REVIEW LETTERS 1 MAY 1989

Saturation of the Width of the Giant Dipole Resonance at High Temperature

A. Bracco,[(1,2)] J. J. Gaardhøje,[(1)] A. M. Bruce,[(1),(a)] J. D. Garrett,[(1),(b)] B. Herskind,[(1)] M. Pignanelli,[(1,2)]
D. Barnéoud,[(3)] H. Nifenecke

VOLUME 74, NUMBER 19 PHYSICAL REVIEW LETTERS 8 MAY 1995

Increase in Width of the Giant Dipole Resonance in Hot Nuclei: Shape Change or Collisional Damping?

A. Bracco, F. Camera, M. Mattiuzzi, B. Million, and M. Pignanelli

VOLUME 76, NUMBER 24 PHYSICAL REVIEW LETTERS 10 JUNE 1996

ia 16, 20133 Milano, Italy

Z. Żelazny,[§]
2100 Ø, Denmark

Microscopic Simulations of γ Cascades in Warm Rotating Nuclei

A. Bracco, P. Bosetti, S. Frattini, and E. Vigezzi
Dipartimento di Fisica, Universitá di Milano,

PRL 97, 012501 (2006) PHYSICAL REVIEW LETTERS week ending 7 JULY 2006

Eur. Phys. J. A (2019) **55**: 233
DOI 10.1140/epja/i2019-12887-x

Review

Giant Dipole Resonance in the Hot and Thermalized ^{132}Ce Nucleus: Damping of Collective Modes at Finite Temperature

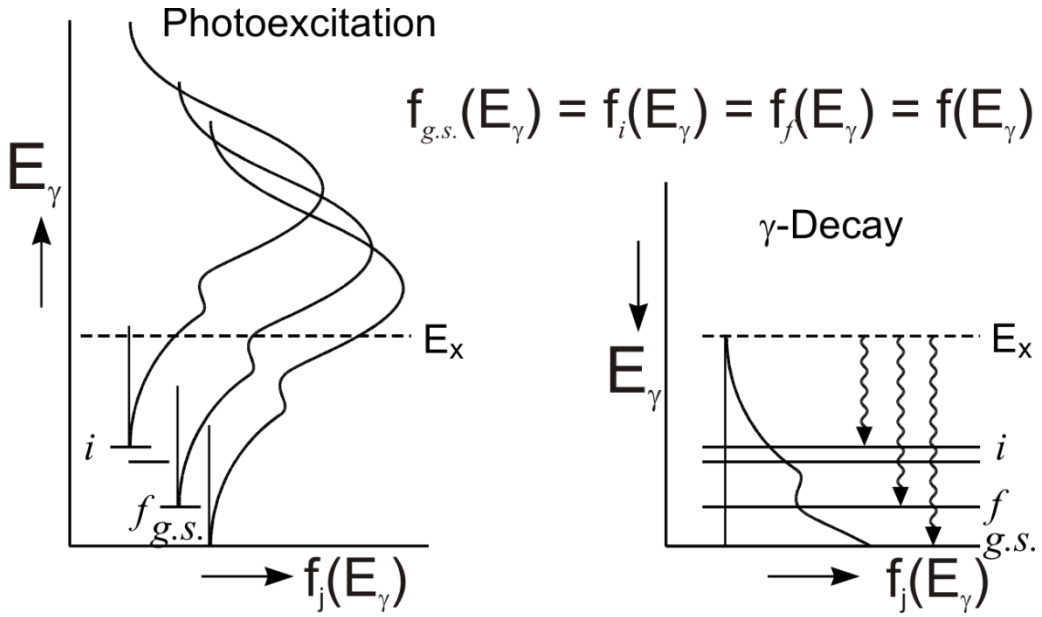
O. Wieland,[1] A. Bracco,[1] F. Camera,[1] G. Benzoni,[1] N. Blasi,[1] S. Brambilla,[1] F. Crespi,[1] A. Giussani,[1] S. Leoni,[1] P. Mason,[1]

Gamma-decay from dipole vibrations: Probe for nuclear properties*

A. Bracco[1,2], F. Camera[1,2,a], F.C.L. Crespi[1,2], B. Million[2], and O. Wieland[2]

[1] Dipartimento di Fisica dell'Università di Milano, Via Celoria 16, 20133 Milano, Italy
[2] Istituto Nazionale Fisica Nucleare, Sezione di Milano, Via Celoria 16, 20133 Milano, Italy

Brink-Axel (BA) Hypothesis

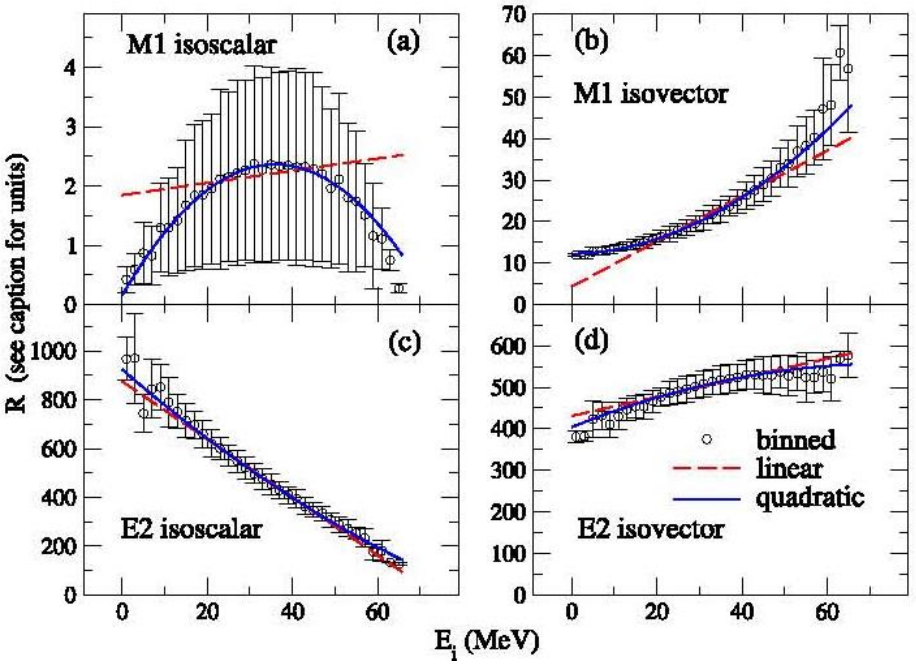


- Strength
  - depends only on E_γ
  - is independent of the initial and final state structure: E_x, J^π,…

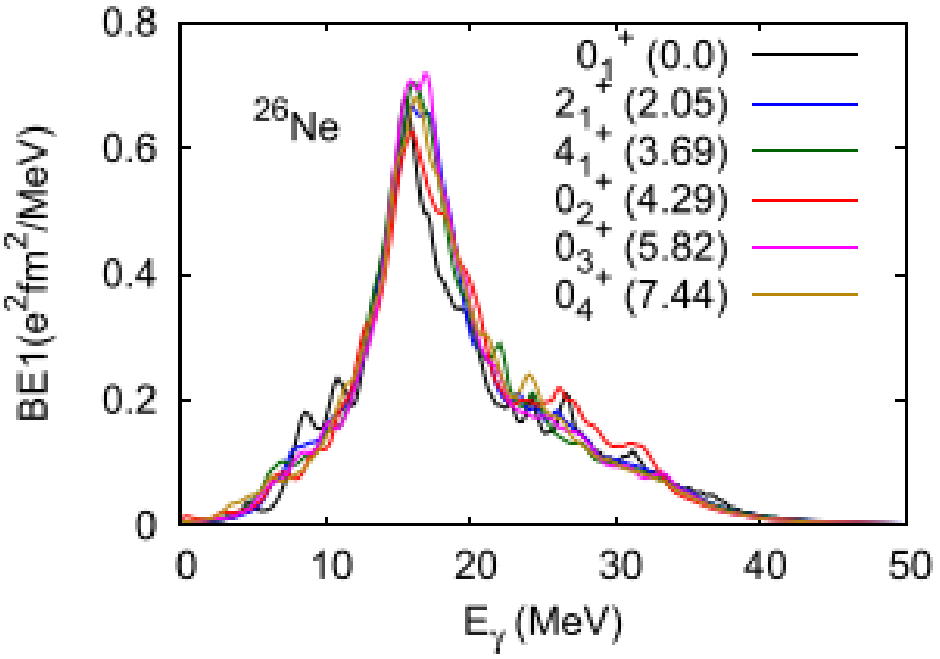
- Same GSF for γ absorption and emission

Shell-Model Studies of BA Hypothesis

C.W. Johnson, PLB 750, 72 (2015)



K. Sieja, EPJA 59, 147 (2023)



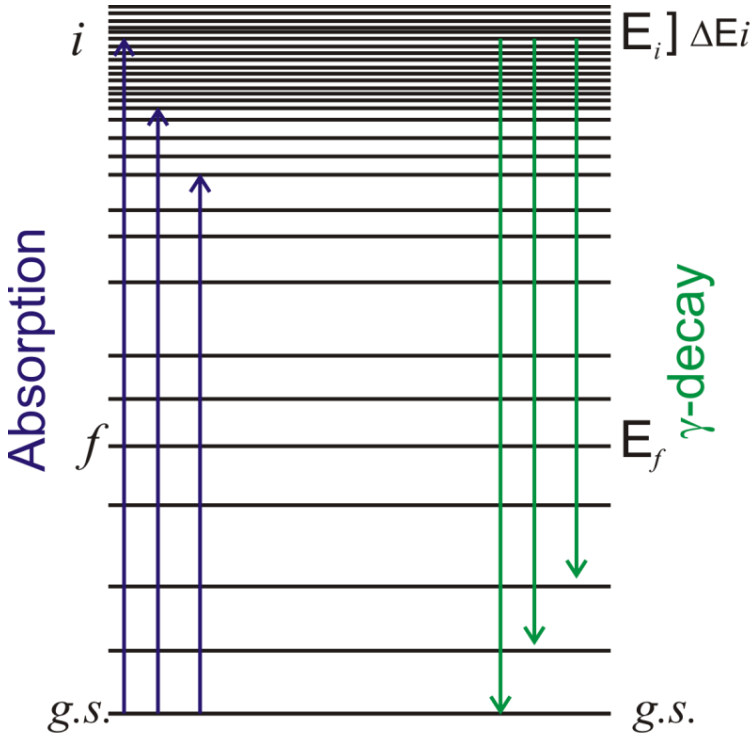
- Brink-Axel hypothesis does not hold in general for collective modes (and is not expected to)
- Holds approximately for the GDR in light nuclei

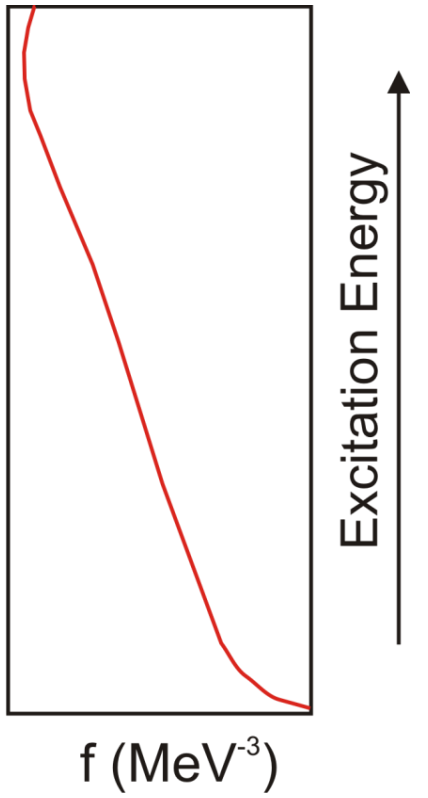
Gamma Strength Function (GSF)

$$\langle \Gamma(E_i) \rangle = \frac{1}{\rho(E_i)} \cdot \int_0^{E_i} E_\gamma^3 f^{E1}(E_\gamma) \rho(E_i - E_\gamma)\, dE_\gamma$$

$$\langle \Gamma_{i \to g.s.} \rangle = \frac{f^{E1}(E_\gamma) \cdot E_\gamma^3}{\rho(E_i)}$$

$$f^{E1}(E_\gamma) = \frac{\sigma_{abs}(E_i)}{3(\pi\hbar c)^2 \cdot E_\gamma}$$





E1 Strength from (p,p‘) Experiments

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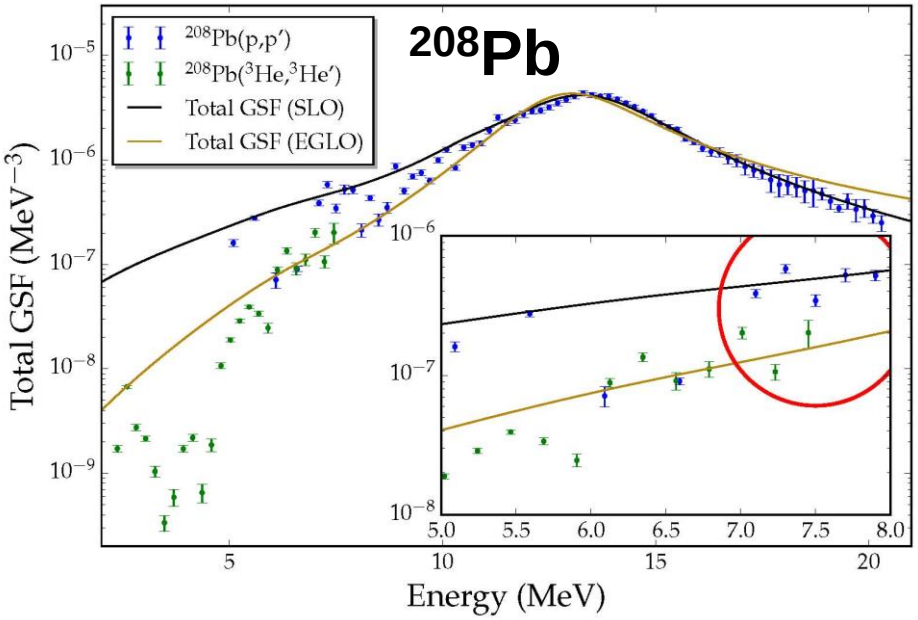
P. von Neumann-Cosel, A. Tamii, EPJA 55, 110 (2019)

- Polarized proton scattering at forward angles including 0^o
  - Experiments performed at RCNP
  - intermediate energy: 300 MeV optimal for spin-isospin excitations
  - Strong Coulomb excitation of E1 strength
  - high resolution: ΔE = 25 - 30 keV (FWHM)
  - angular distributions: E1 / M1 separation
  - polarization observables: spinflip / non-spinflip separation

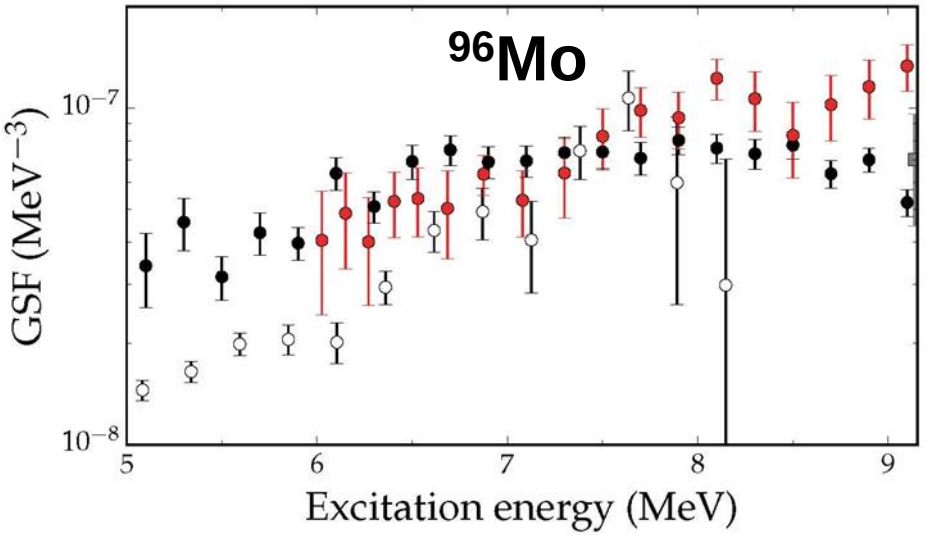
GSF in ^{208}Pb and ^{96}Mo: Comparison with Oslo Data

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S. Bassauer et al., PRC 94, 054313 (2016)



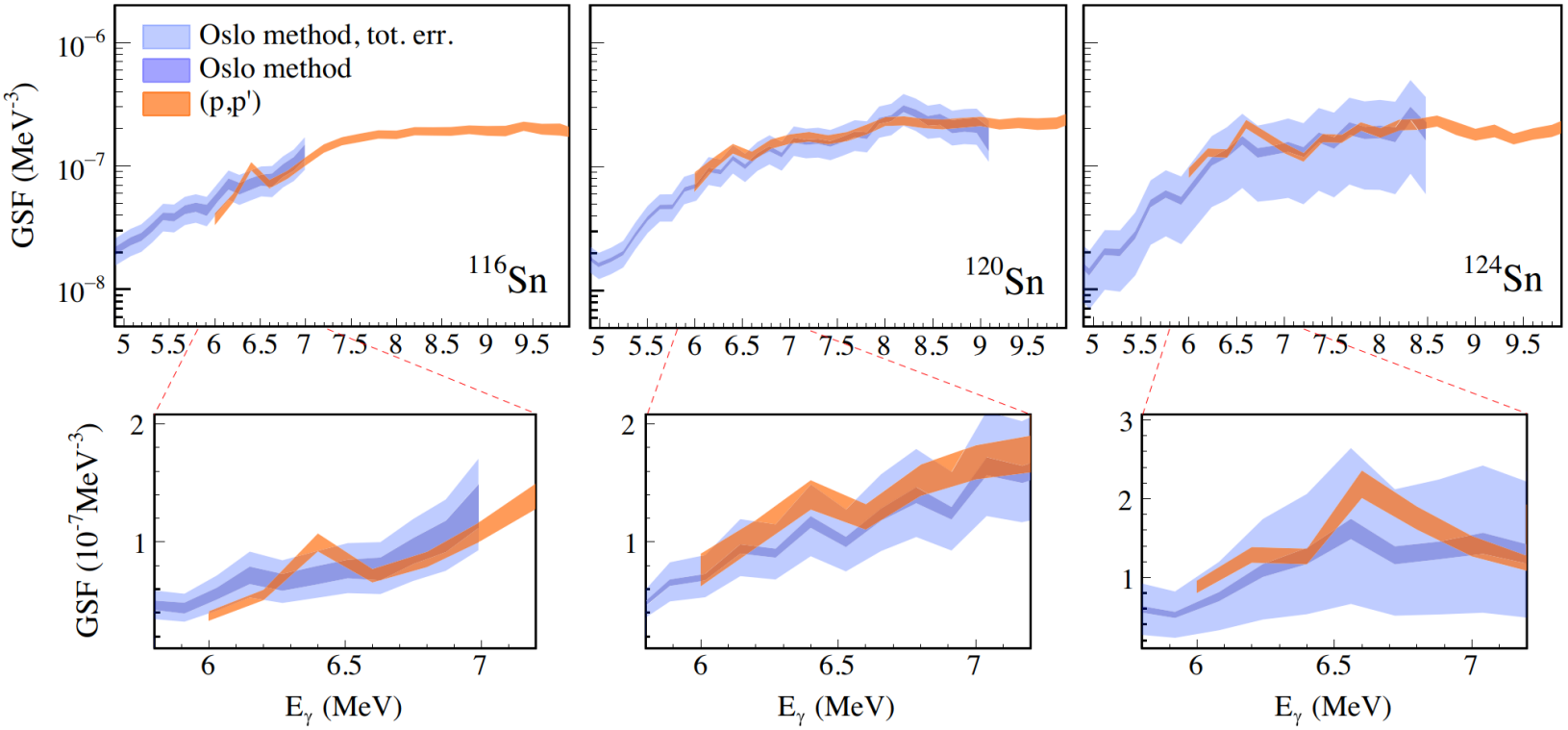
D. Martin et al., PRL 119, 182503 (2017)



- ^{208}Pb: strong Porter-Thomas fluctuations, level density too low
- ^{96}Mo: intermediate between Oslo method and (γ,γ‘)

GSF in ^{116,120,124}Sn: Comparison with Oslo Data

(p,p‘) S. Bassauer et al., PRC 102, 034327 (2020)
(p,p‘γ) M. Markova et al., PRL 127, 182501 (2021)

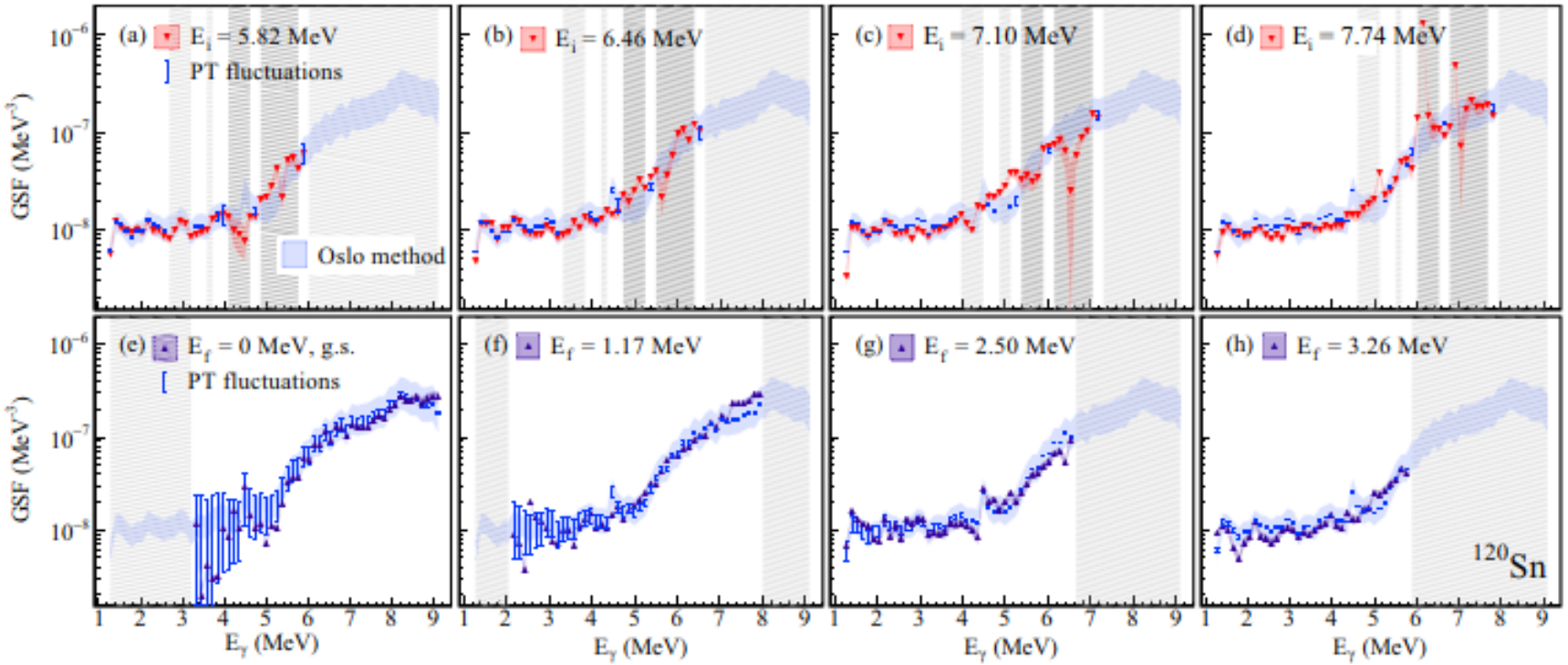


- Good agreement in the PDR region

Further Tests of BA Hypothesis in ^{120,124}Sn

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M. Markova et al., PRC 106, 034322 (2022)

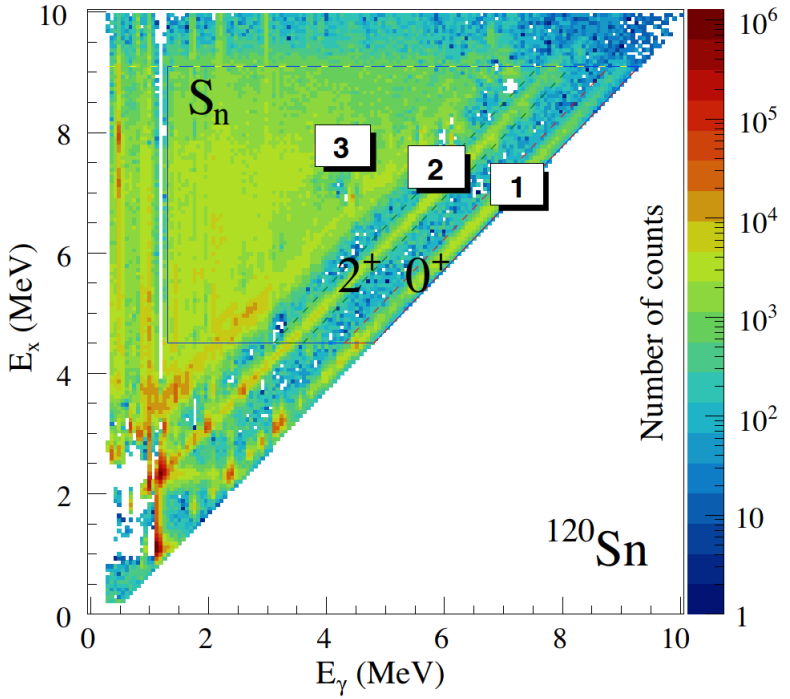


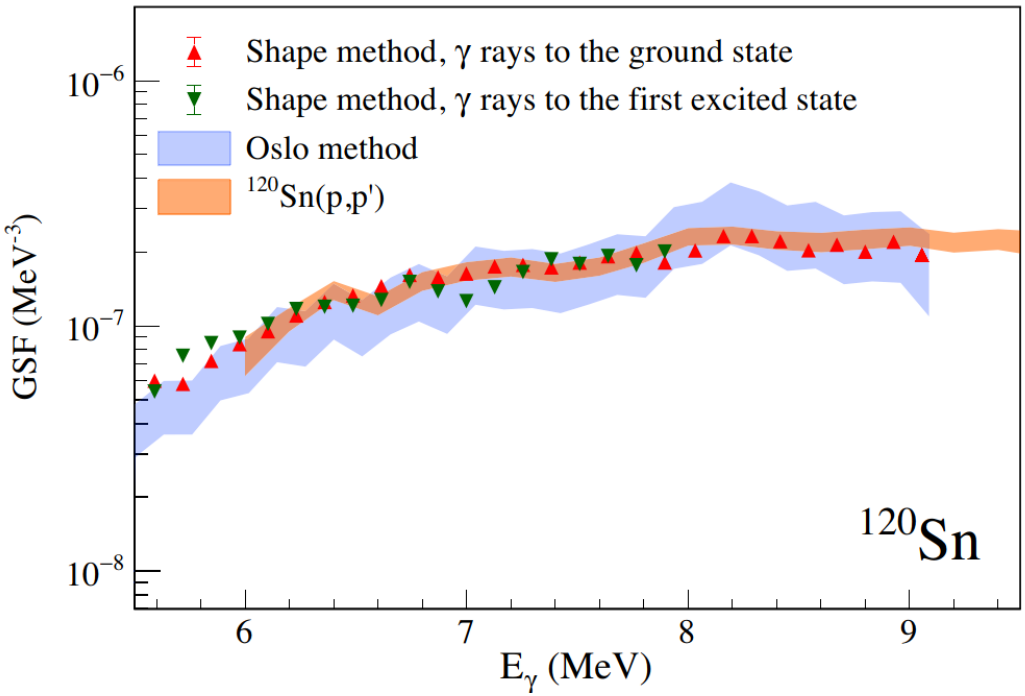
- Independence of initial and final states

Further Tests of BA Hypothesis in ^{120,124}Sn

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M. Markova et al., PRL 127, 182501 (2021)





- GSFs from shape method agree

Nature of the Pygmy Dipole Resonance

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Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

Review

Isoscalar and isovector dipole excitations: Nuclear properties from low-lying states and from the isovector giant dipole resonance

A. Bracco [a,b,*], E.G. Lanza [c], A. Tamii [d]

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

The structure of low-lying 1^- states in ^{90,94}Zr from $(\alpha, \alpha'\gamma)$ and $(p, p'\gamma)$ reactions

F.C.L. Crespi [a,b], A. Bracco [a,b,*], E.G. Lanza [c], A. Tamii [d], N. Blasi [b], F. Camera [a,b], O. Wieland [b],

PRL 102, 092502 (2009) PHYSICAL REVIEW LETTERS week ending 6 MARCH 2009

Search for the Pygmy Dipole Resonance in ^{68}Ni at 600 MeV/nucleon

O. Wieland,[1] A. Bracco,[1,2] F. Camera,[1,2] G. Benzoni,[1] N. Blasi,[1] S. Brambilla,[1] F. C. L. Crespi,[1,2] S. Leoni,[1,2] B. Million,[1]

PRL 113, 012501 (2014) PHYSICAL REVIEW LETTERS week ending 4 JULY 2014

Isospin Character of Low-Lying Pygmy Dipole States in ^{208}Pb via Inelastic Scattering of ^{17}O Ions

F. C. L. Crespi,[1,2] A. Bracco,[1,2,*] R. Nicolini,[1,2] D. Mengoni,[3,4] L. Pellegri,[1,2] E. G. Lanza,[5] S. Leoni,[1,2] A. Maj,[6]

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Pygmy dipole resonance in ^{124}Sn populated by inelastic scattering of ^{17}O

L. Pellegri [a,b], A. Bracco [a,b,*], F.C.L. Crespi [a,b], S. Leoni [a,b], F. Camera [a,b], E.G. Lanza [c],

PHYSICAL REVIEW C 81, 041301(R) (2010)

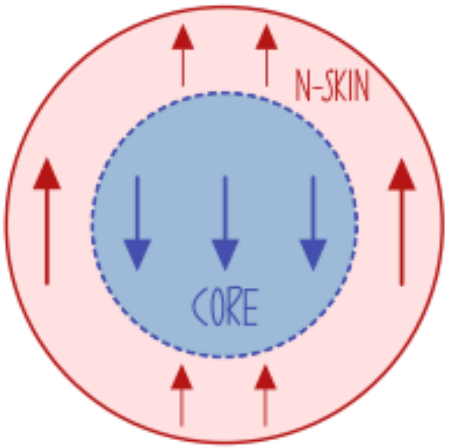
Constraints on the symmetry energy and neutron skins from pygmy resonances in ^{68}Ni and ^{132}Sn

Andrea Carbone,[1] Gianluca Colò,[1,2] Angela Bracco,[1,2] Li-Gang Cao,[1,2,3,4] Pier Francesco Bortignon,[1,2] Franco Camera,[1,2] and Oliver Wieland[2]

Theoretical Explanations of the PDR

E. Lanza, L. Pellegri, A. Vitturi, M.V. Andrés, PPNP 129, 104006 (2023)

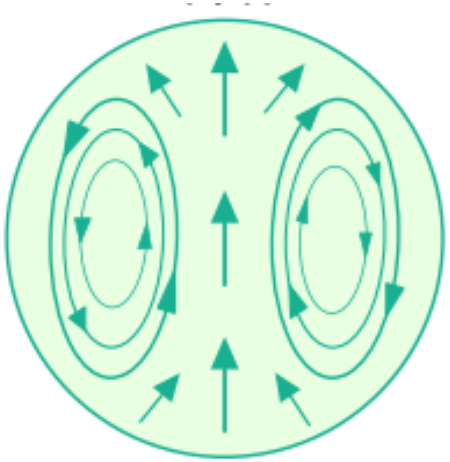
Neutron Skin Ocillations



Compression Mode



Toroidal Mode

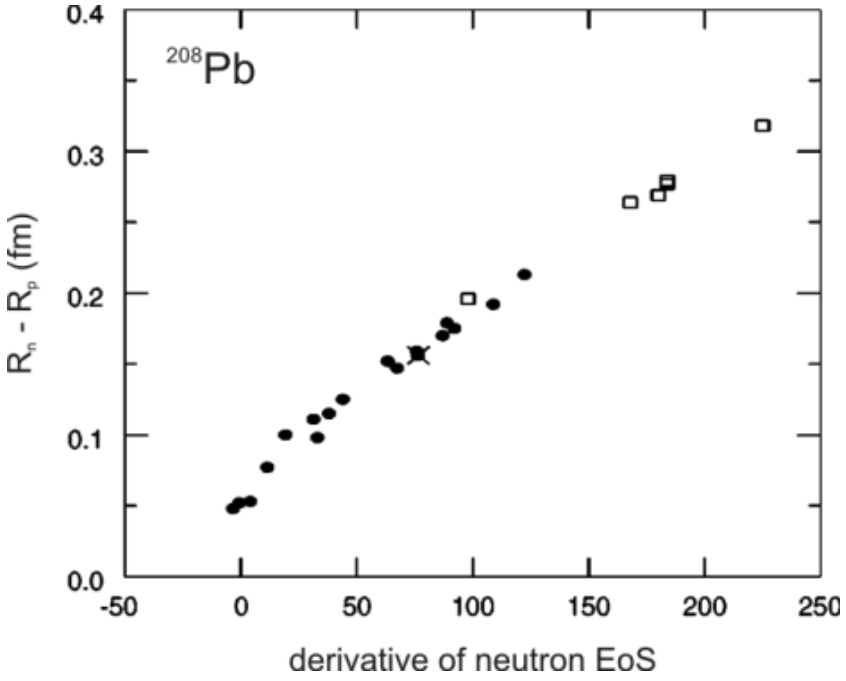


- Excluded by compressibility

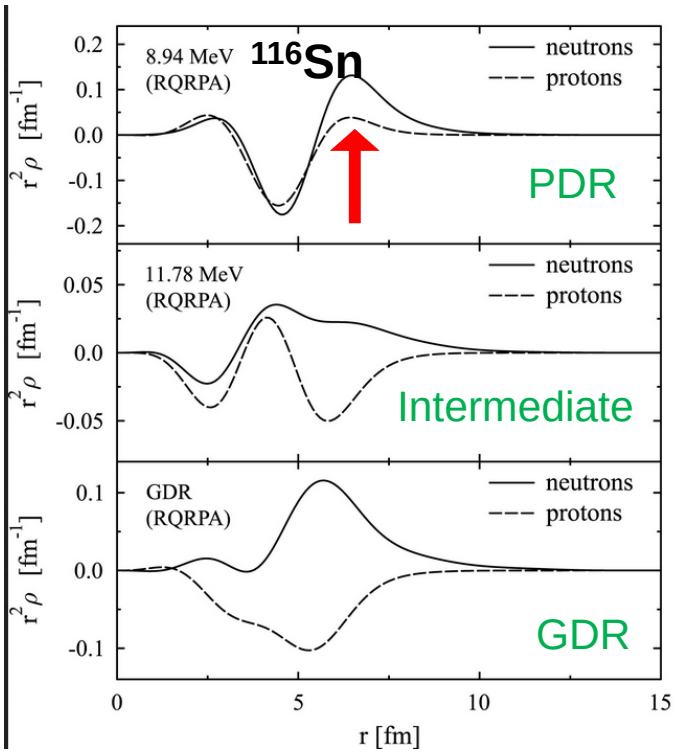
Neutron Skin Oscillations and Symmetry Energy

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S. Typel , B.A. Brown, PRC 64, 027302 (2001)

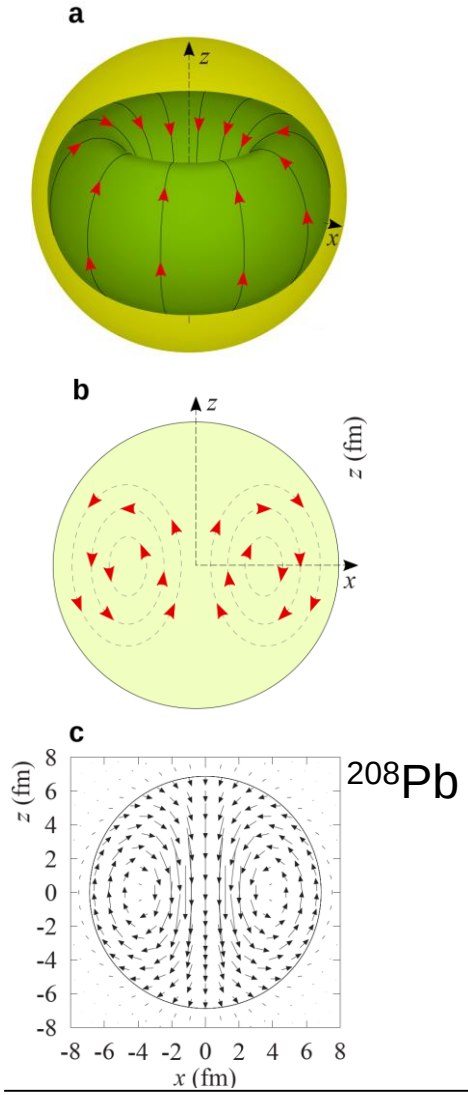


E. Litvinova et al, PRC 79, 054312 (2009)



- Relation between neutron skin thickness and symmetry energy
- PDR transition density indicates collective neutron skin oscillation

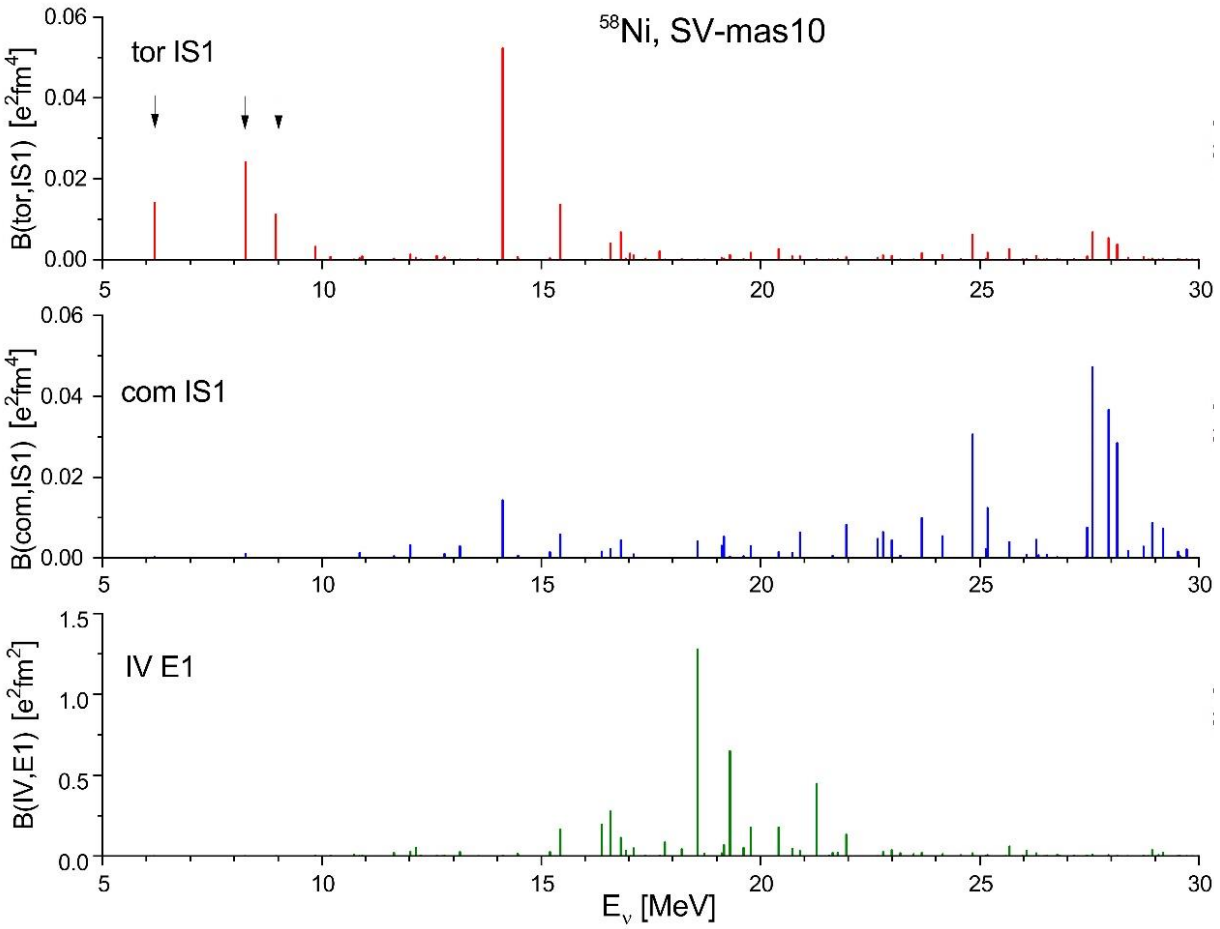
Nuclear Toroidal Modes



^{208}Pb

- Quantum phenomenon, mean-field origin
- Predicted more than 50 years ago in hydro/fluid-dynamical models, QPM, relativistic and nonrelativistic QRPA
- Simplest mode has E1 multipolarity
- Similar to Hill‘s spherical vortex ring, but corresponds to oscillations along the streamlines
- Dominantly IS at low excitation energies

E1 Modes in ^{58}Ni



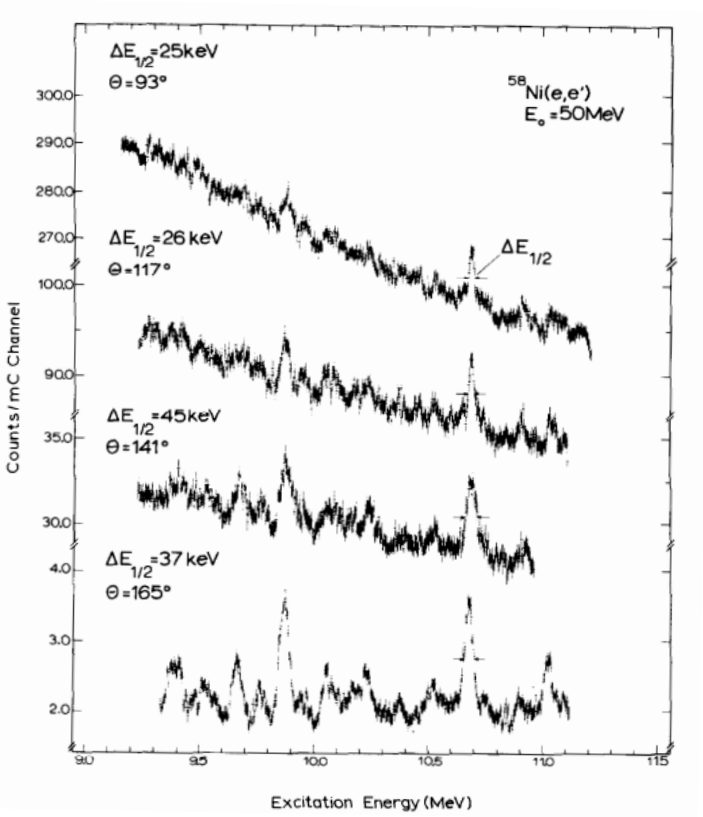
- Toroidal strength very fragmented but dominates at low energies

^{58}Ni(e,e‘) Data

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$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} f_{rec} \left[|F_L(q)|^2 + \left(\frac{1}{2} + \tan^2\left(\frac{\theta}{2}\right)\right)|F_T(q)|^2\right]$$

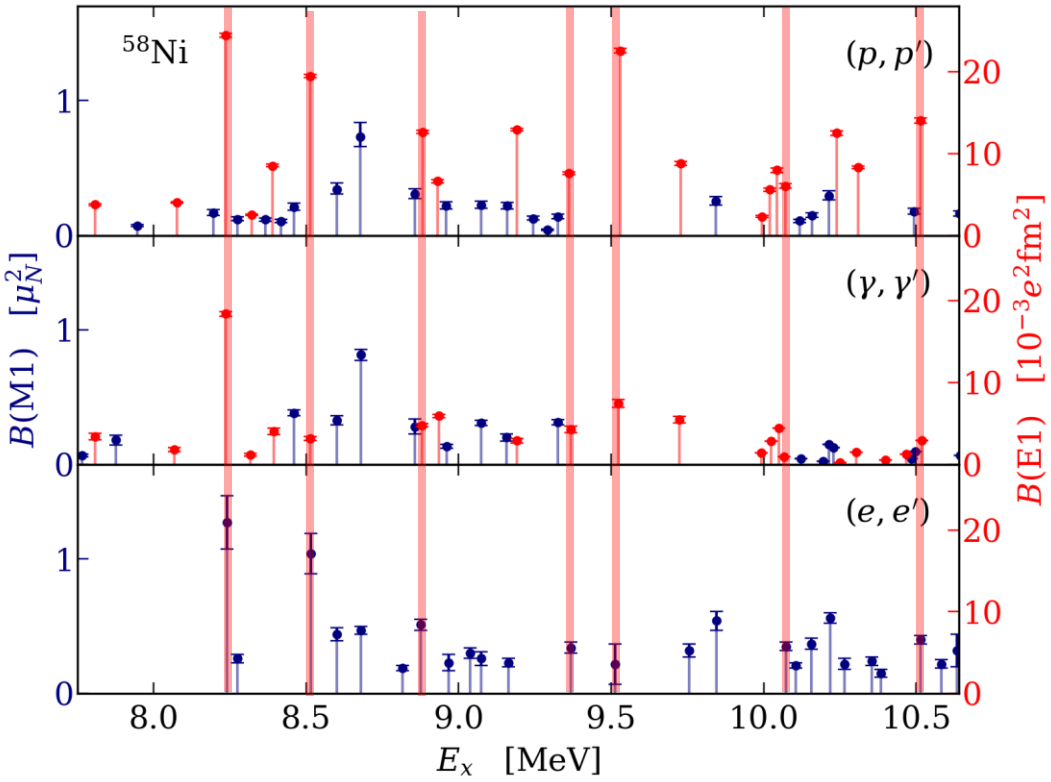
- Most data at $E_0 \approx 50$ MeV
- $\Delta E \approx 25$ - 35 keV (FWHM)
- Variation of momentum transfer by changing the scattering angle
  → change of *L/T* ratio
- Increase of σ/σ_{Mott} with angle was taken as signature for magnetic transitions



W. Mettner et al., NPA 473, 160 (1987)

Identification of Toroidal Candidates

I. Brandherm et al, PRC 110, 034319 (2024)

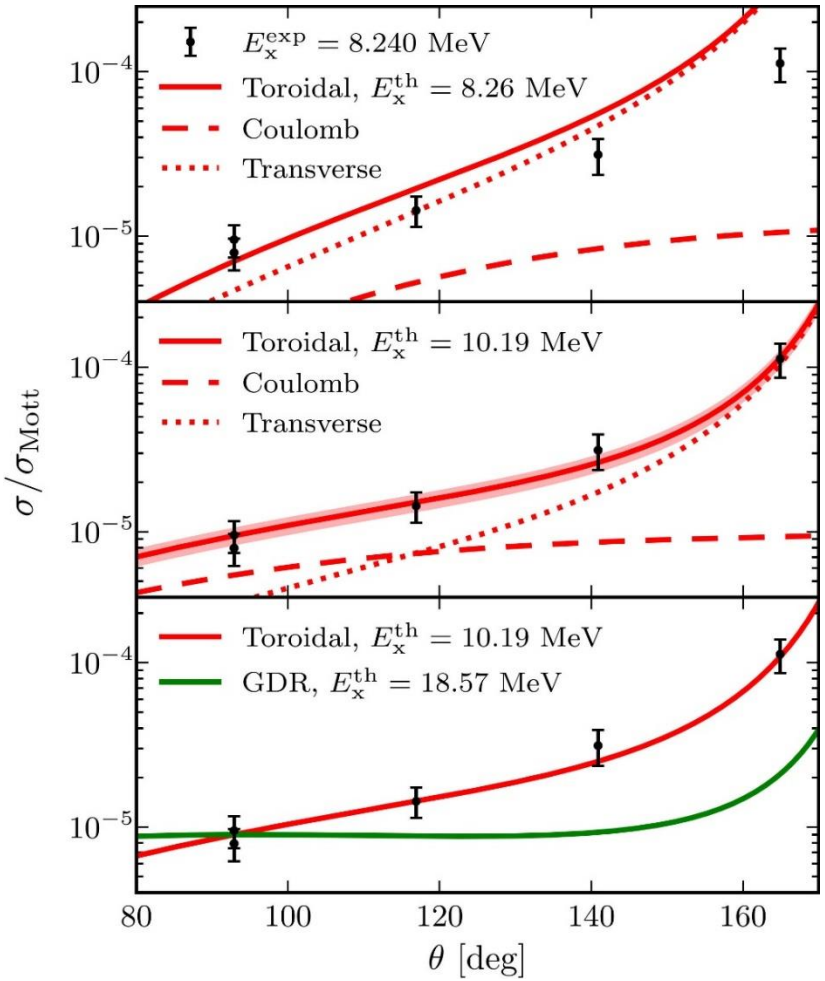


- Assumed to be M1 in (e,e‘) but uniquely assigned E1 in (p,p‘) + (γ,γ‘)

→ E1 transitions with large transverse cross sections

Evidence of Toroidal Nature from (e,e‘) Data

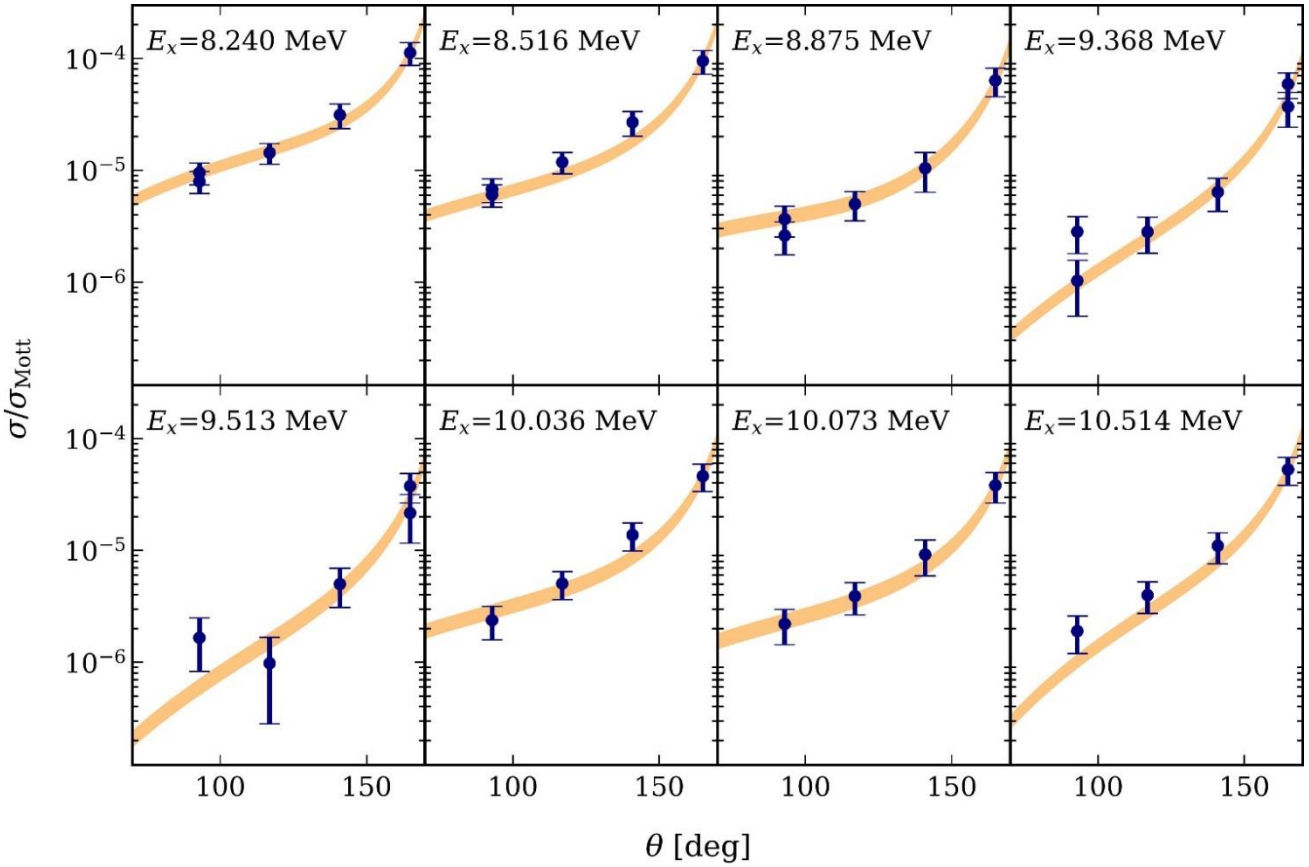
P. von Neumann-Cosel et al., PRL 133, 232502 (2024)



- Very small transverse form factors of IV and IS compressional E1 excitations

Evidence of Toroidal Nature from (e,e‘) Data

P. von Neumann-Cosel et al., PRL 133, 232502 (2024)

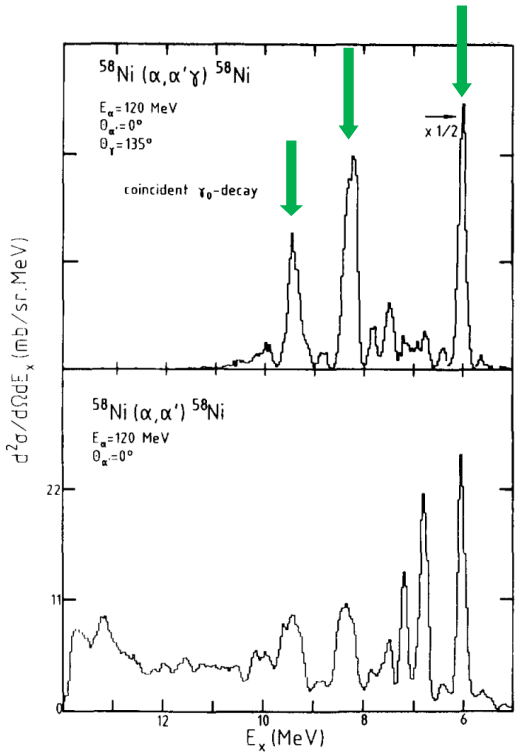


- Very good description of **all** toroidal candidates

Implications of the ^{58}Ni results for the PDR

- IS response: Strong peaks correspond to lowest toroidal candidates

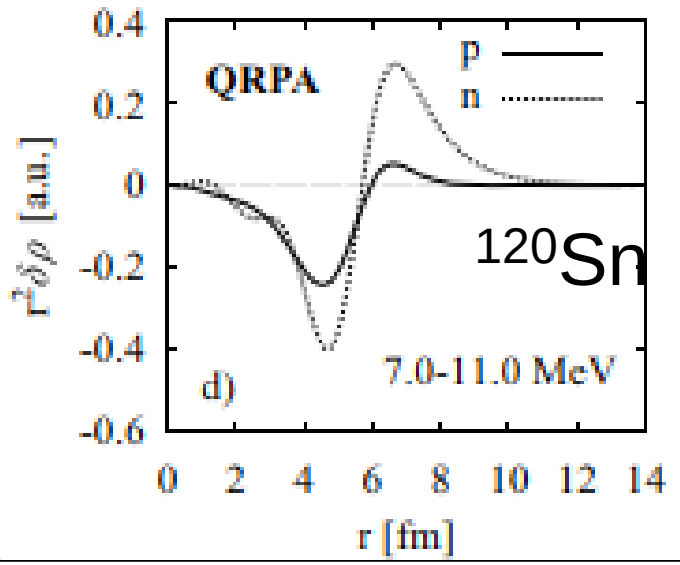
T.D. Poelhekken et al., PLB 278, 423 (1992)



- QRPA models successfully describing the toroidal mode in ^{58}Ni predict a toroidal character of the PDR

- They also reproduce the specific form of the PDR transition density

A. Repko et al., Eur. Phys. J. A 55, 242 (2019)



Implications of the ^{58}Ni results for the PDR

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Experimental features of the toroidal mode

- large g.s. branching ratios (observation in (γ,γ‘) experiments)

- strong IV response (on the scale of low-energy E1 transitions)

- strong IS response (from (α,α‘γ) experiment)

→ **same experimental signatures as PDR!**

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