Fine Structure of Giant Resonances – What Can Be Learned

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- Experimental evidence for fine structure
- Characteristic scales and decay modes of giant resonances
- K splitting of the ISGQR
- Level densities

High-Resolution Measurements

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QCLAM spectrometer S-DALINAC Darmstadt, Germany	K600 spectrometer iThemba LABS Cape Town, South Africa	Grand Raiden spectrometer RCNP Osaka, Japan
		
vNC	Smit, Usman	Frekers, H. Fujita, Y. Fujita, Matsubara, Tamii, …

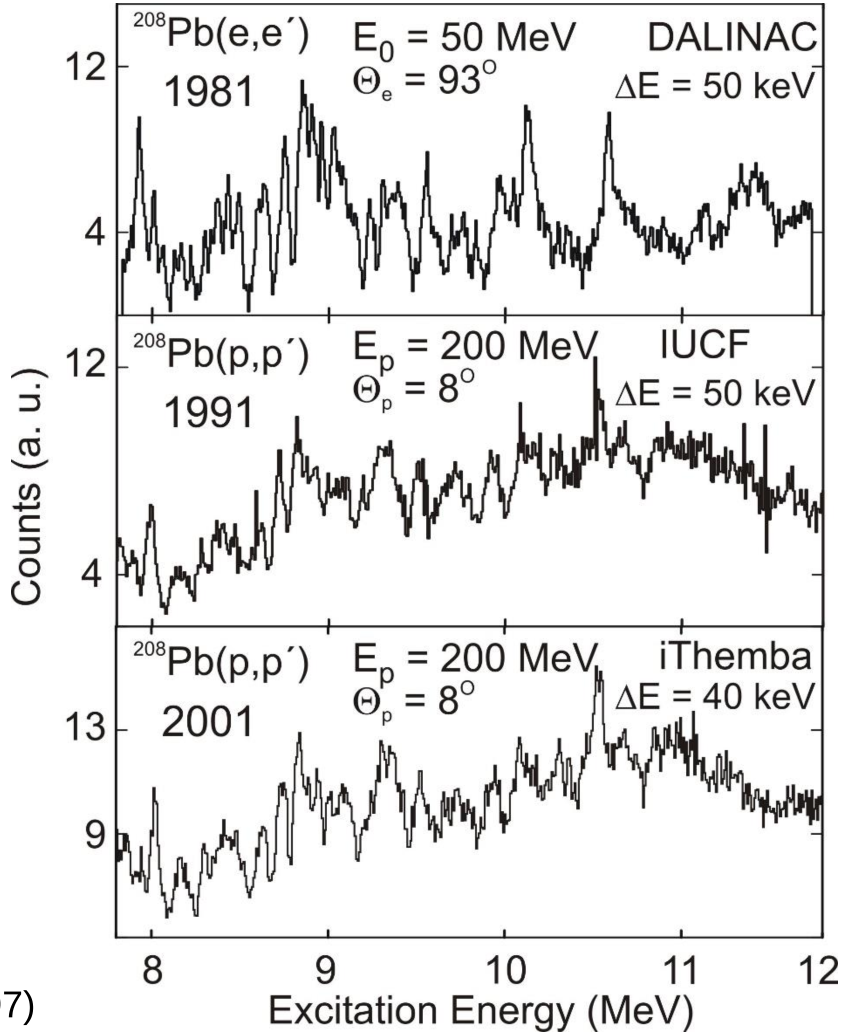
Techniques of high-resolution measurements ➡ talk by **Georg Berg**

Fine structure of giant resonances:

Experimental evidence

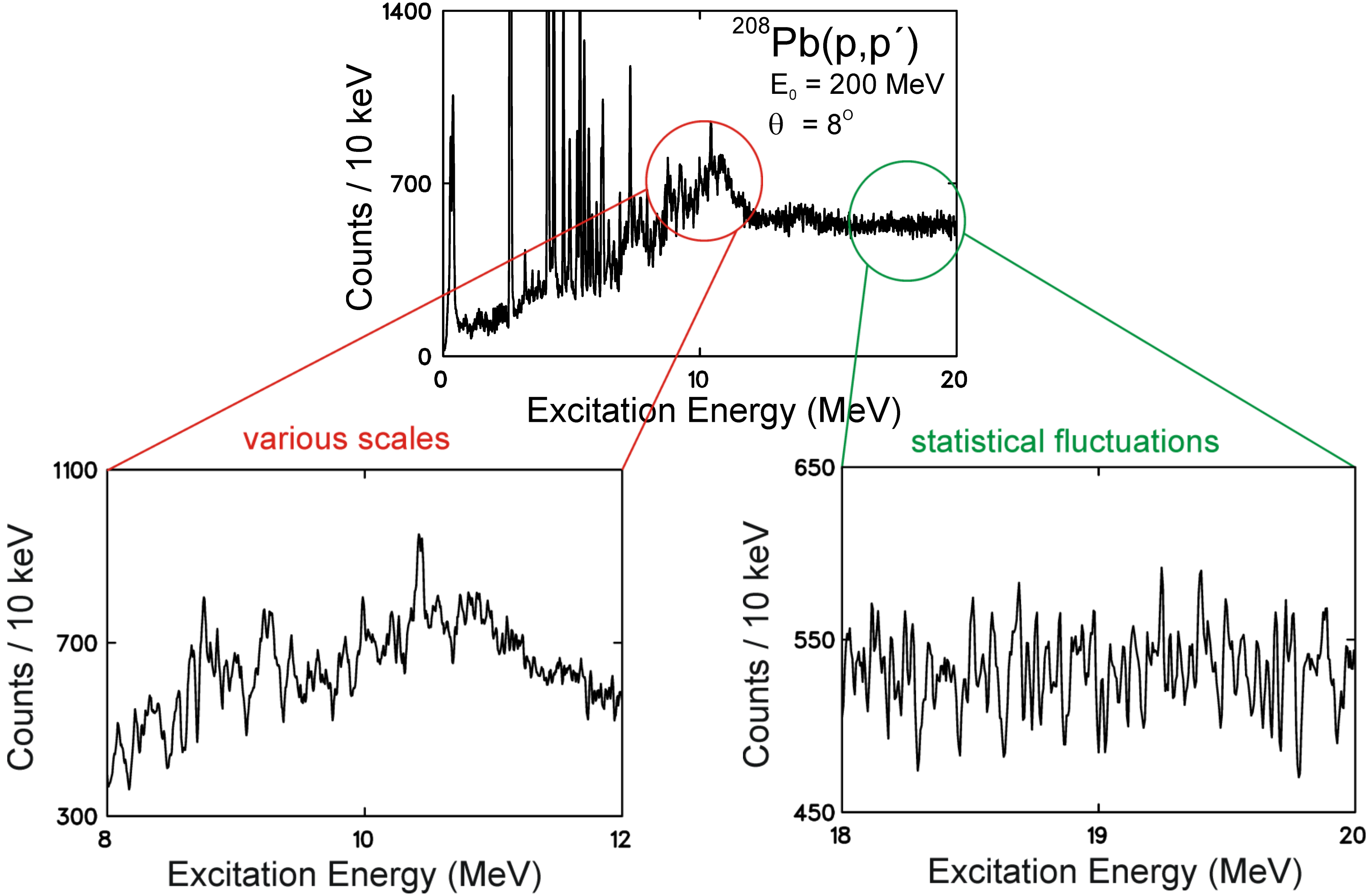
The Case of the ISGQR in ^{208}Pb

- Fine structure independent of exciting probe

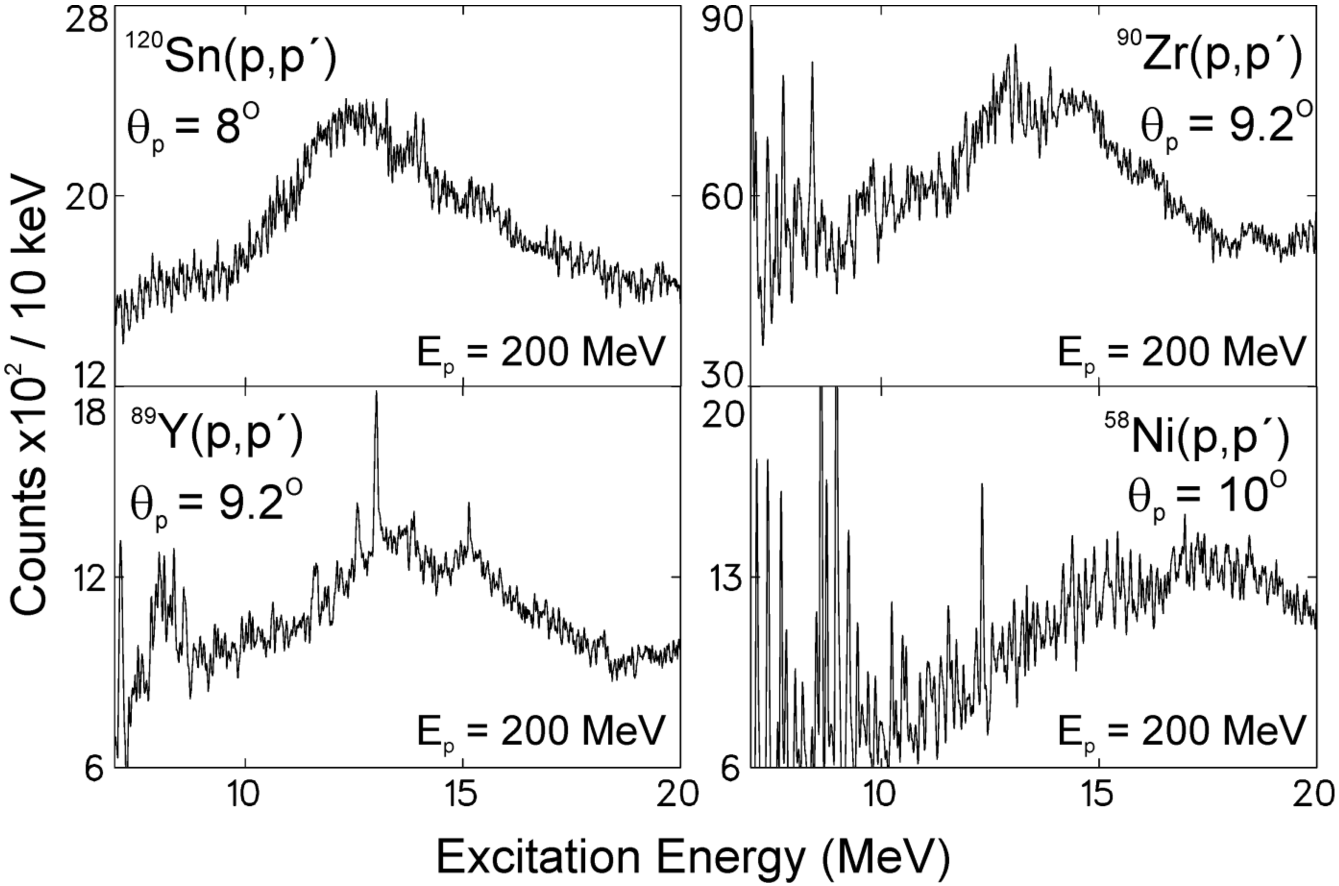


S. Kamerdzhiev et al., Phys. Rev. C 55, 2101 (1997)

Scales and Fluctuations

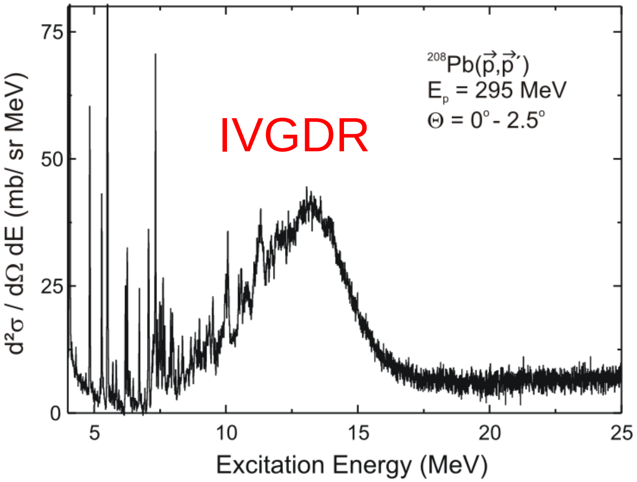


Fine Structure of the ISGQR – a Systematic Phenomenon

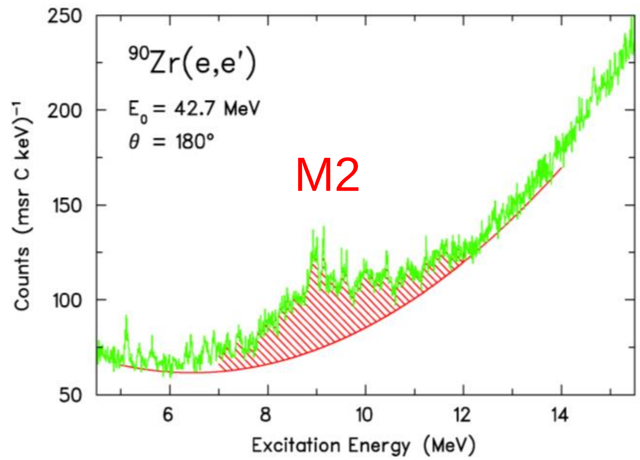


A. Shevchenko et al., Phys. Rev. C 79, 044305 (2009)

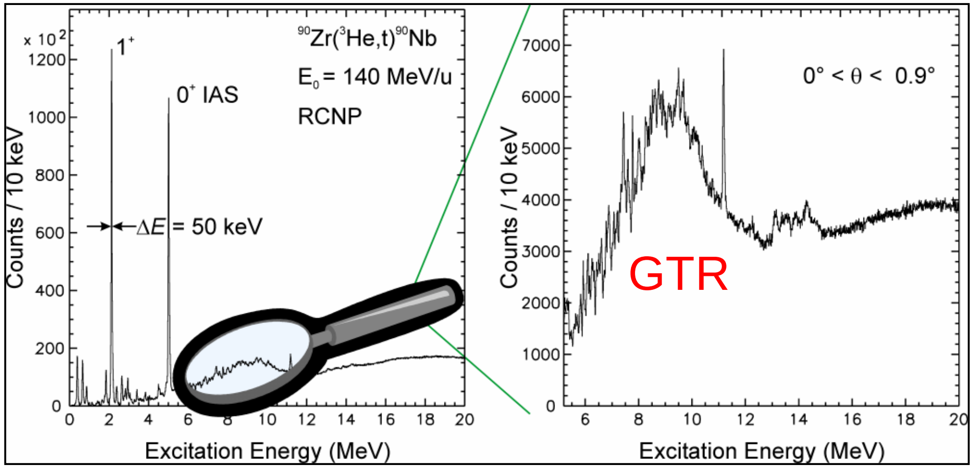
Fine Structure of GRs – a Global Phenomenon



I. Poltoratska et al., Phys. Rev. C 89, 054322 (2014)



PvNC et al., Phys. Rev. Lett. 82, 1105 (1999)



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

Characteristic scales:

A quantitative measure of fine structure

Excitation and Decay of Giant Resonances

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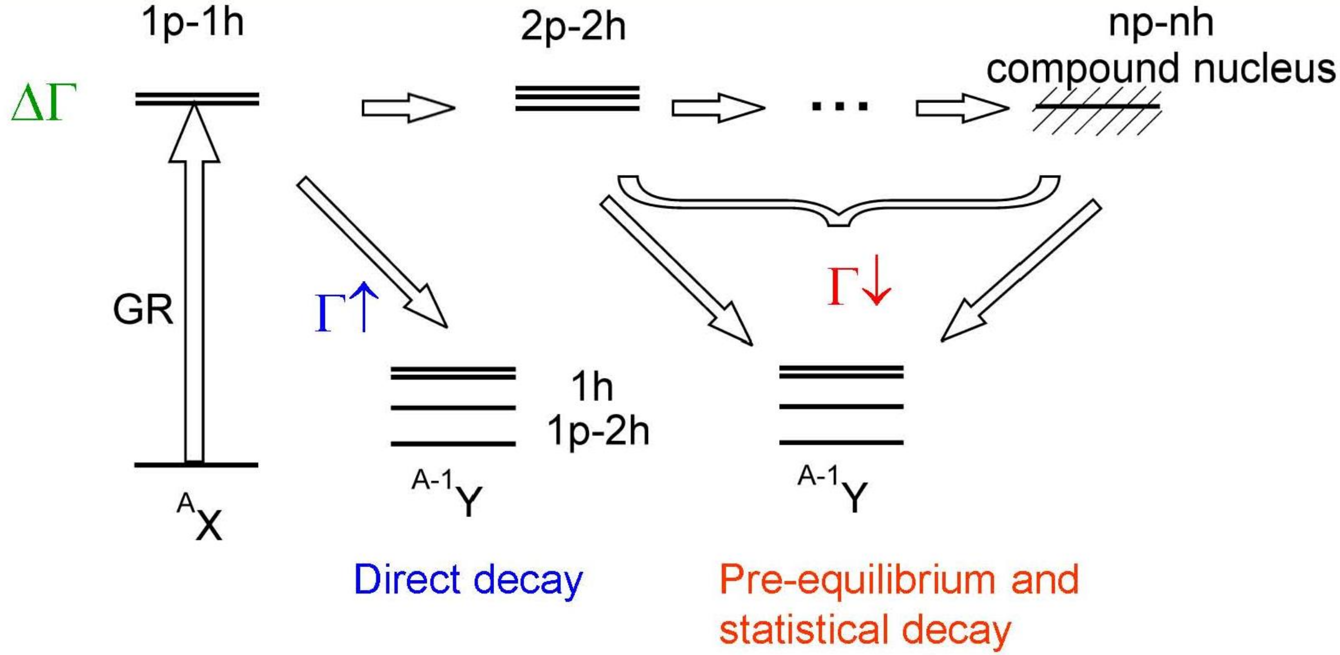
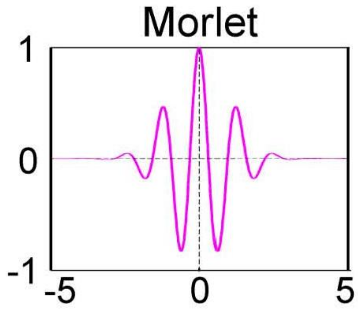


$$\Gamma = \Delta\Gamma + \Gamma\uparrow + \Gamma\downarrow$$

Resonance width = Landau damping + Escape width + Spreading width

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:

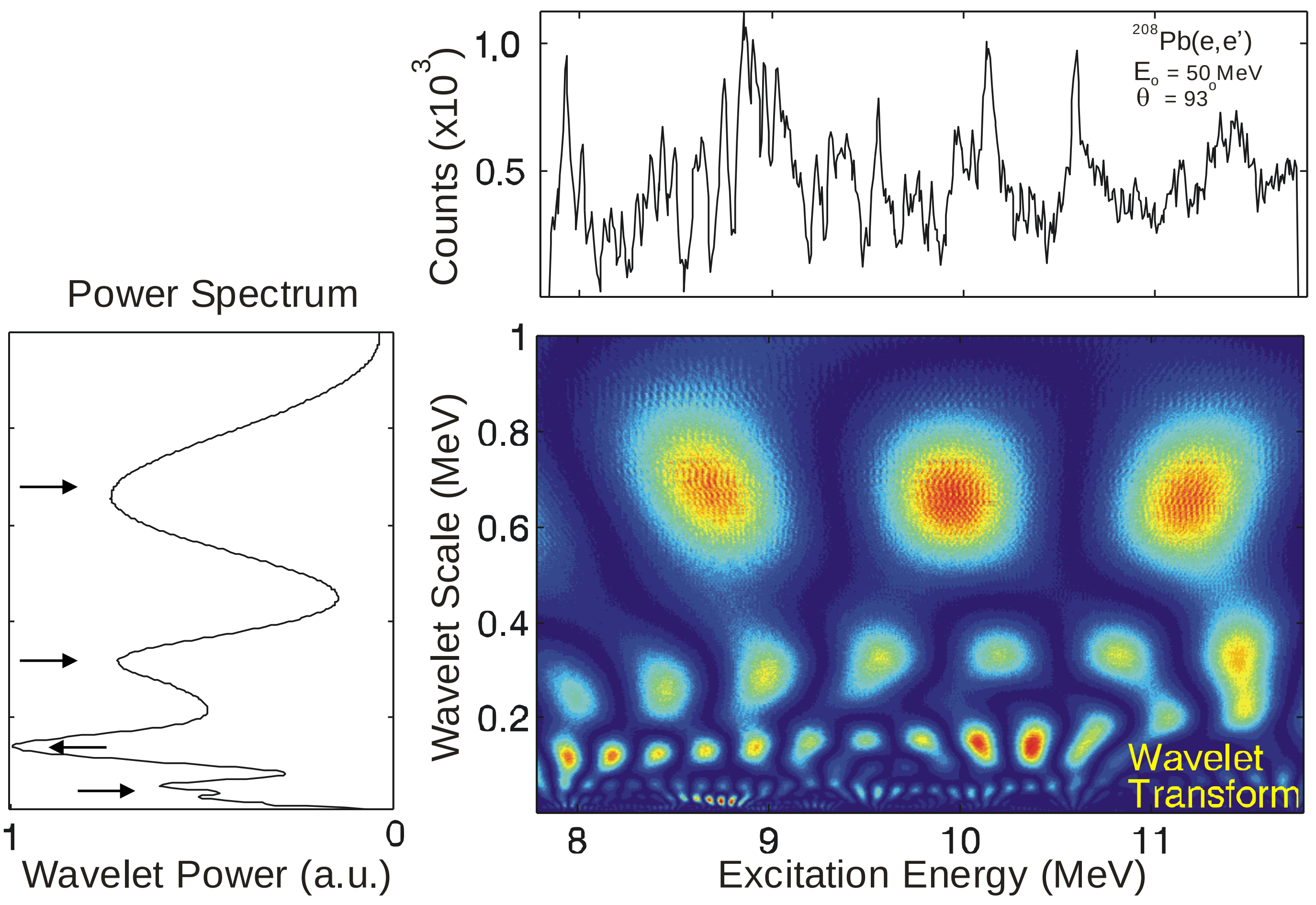
$$C(\delta E, E_x) = \frac{1}{\sqrt{\delta E}} \int \sigma(E)\, \Psi^*\left(\frac{E_x - E}{\delta E}\right) dE$$

scale (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

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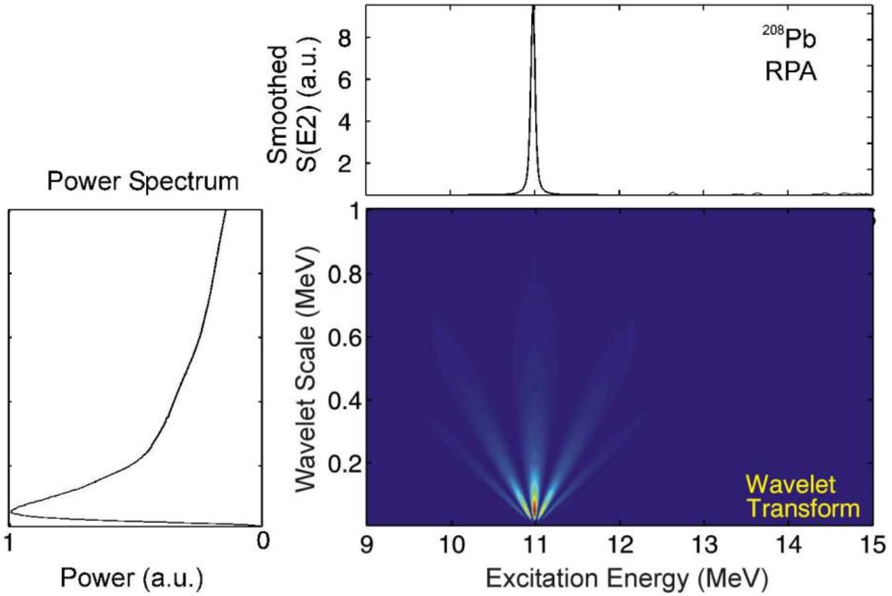
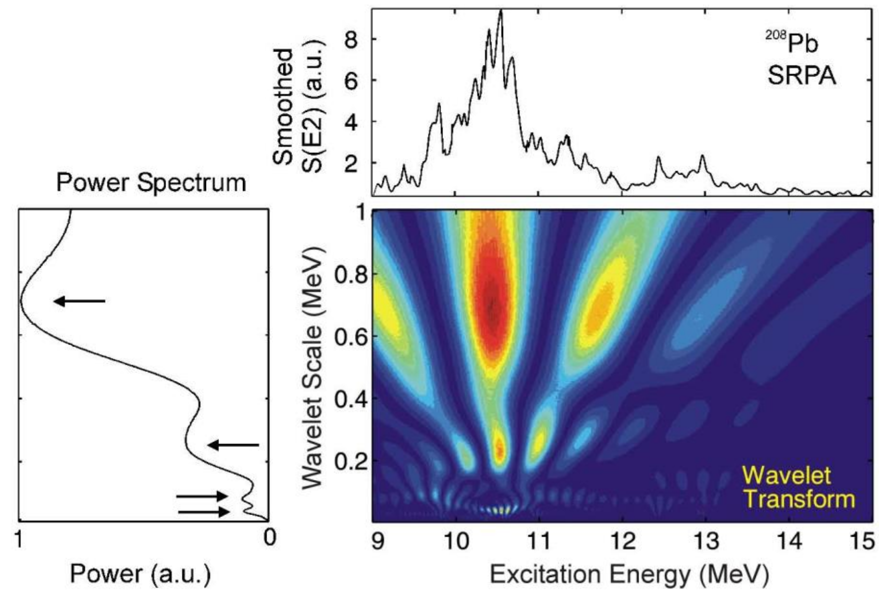


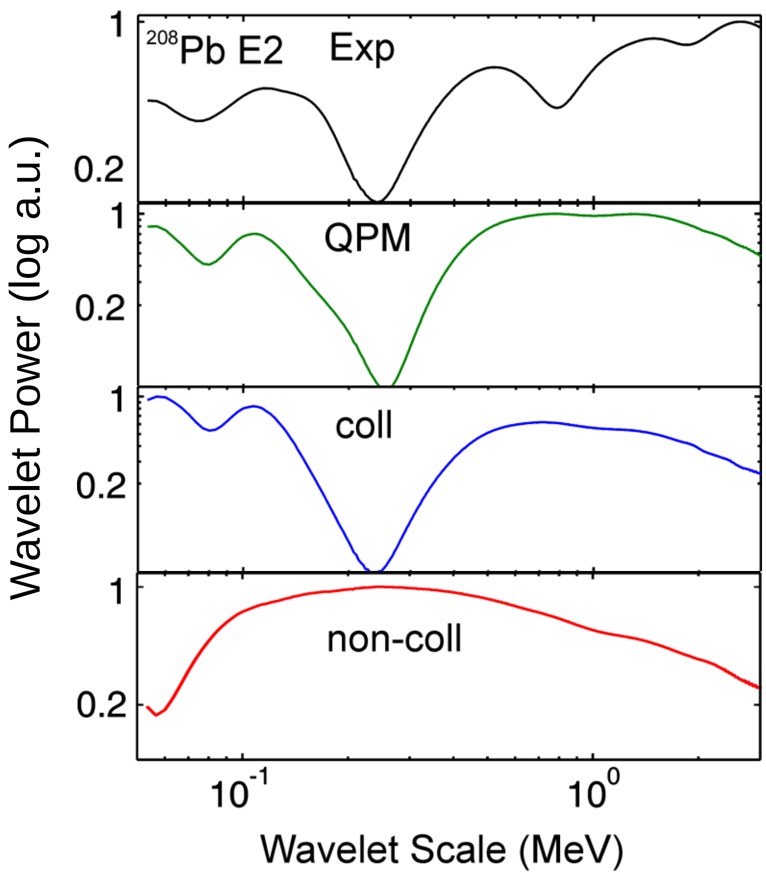


- No scales from 1p-1h states
- Coupling to 2p-2h generates fine structure and scales

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

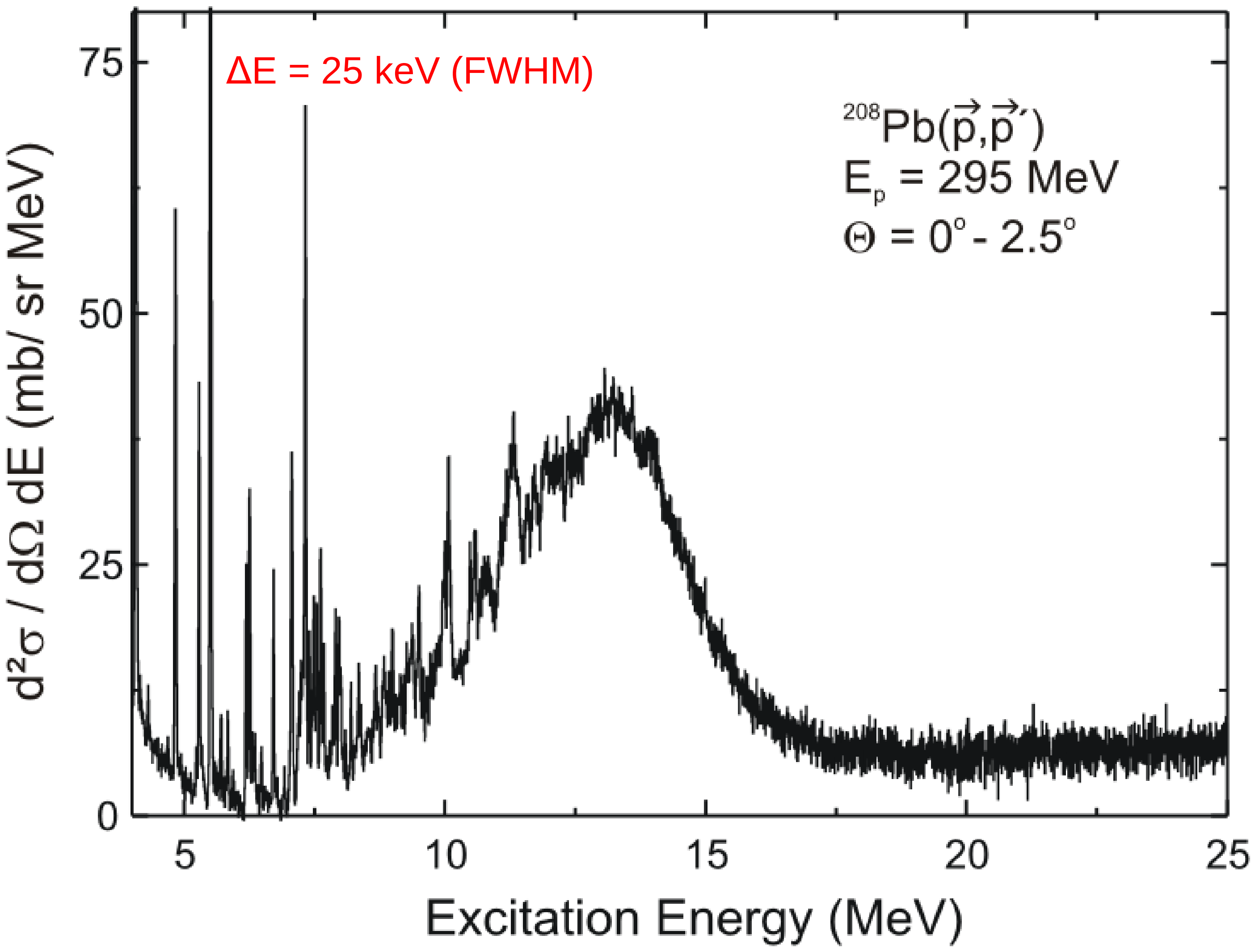
- Collective part: all scales
- Non-collective part: no prominent scales

  → Stochastic coupling



A. Shevchenko et al., Phys. Rev. Lett. 92, 122501 (2004)

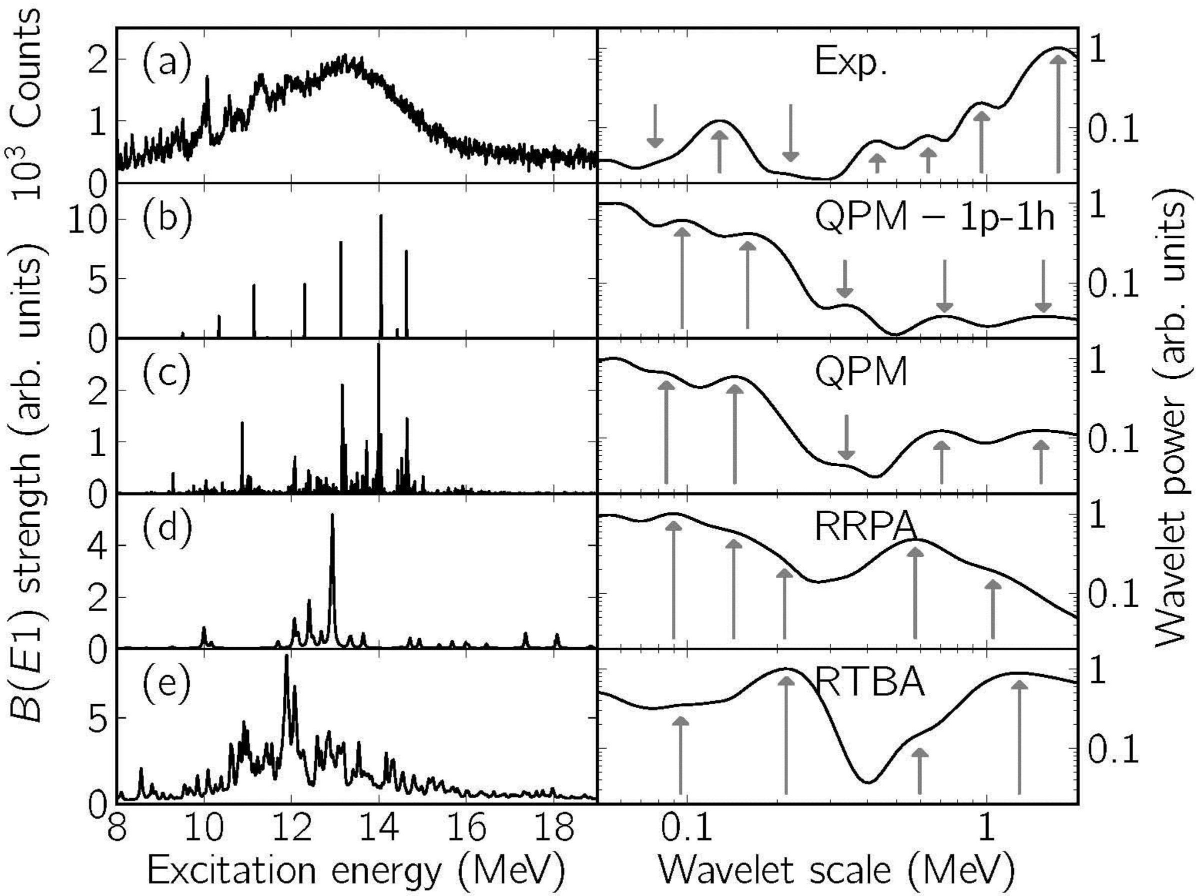
Scales of the IVGDR



Scales of the IVGDR

- Scales from1p-1h states
- Scales from1p-1h states

Landau damping

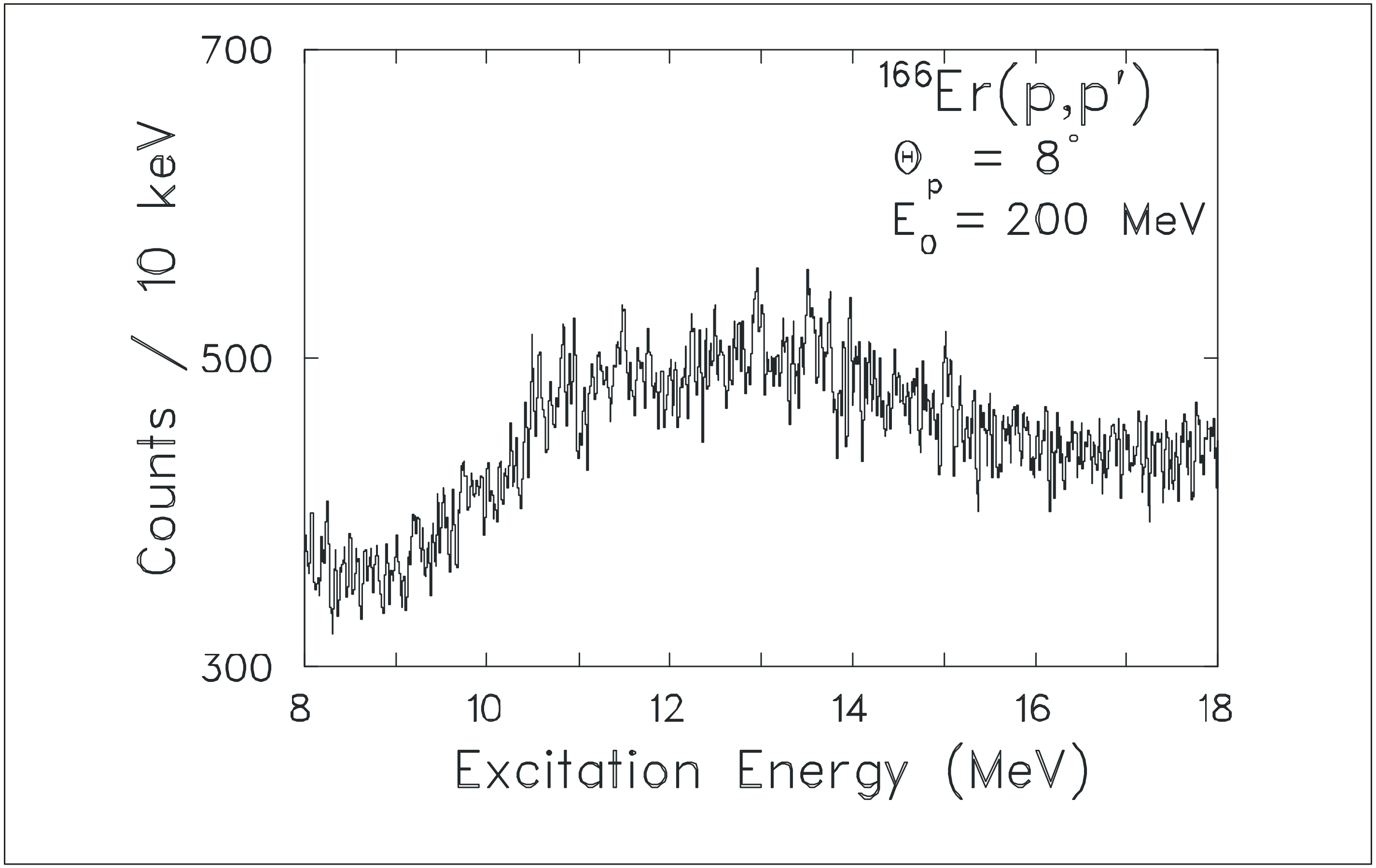


I. Poltoratska et al., Phys. Rev. C 89, 054322 (2014)

Fine structure in heavy deformed nuclei:

K splitting of the ISGQR

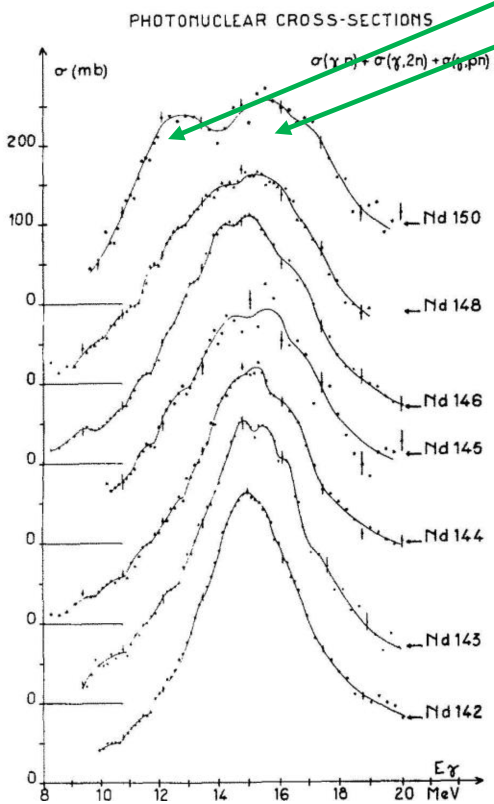
Fine Structure in Heavy Deformed Nuclei?



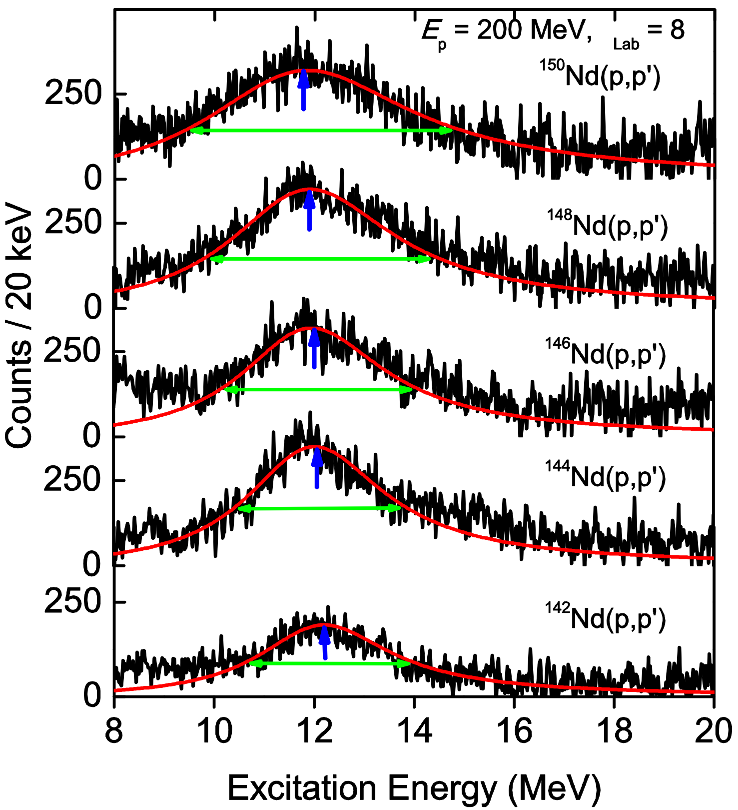
- Level density of 2^+ states in the ISGQR region 10^6 – 10^7 / MeV

IVGDR and ISGQR Resonances in the Nd Chain

IVGDR K splitting ISGQR

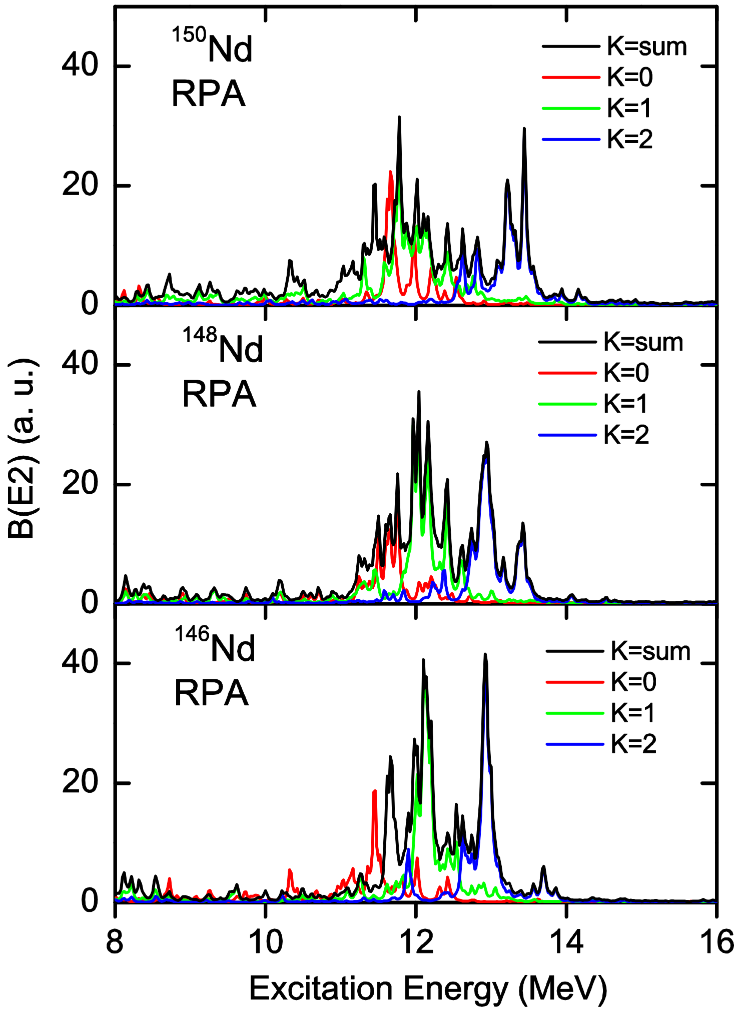


P. Carlos et al., Nucl. Phys. A 172, 437 (1971)



O. Kureba, PhD thesis, University of the Witwatersrand (2014); and to be published

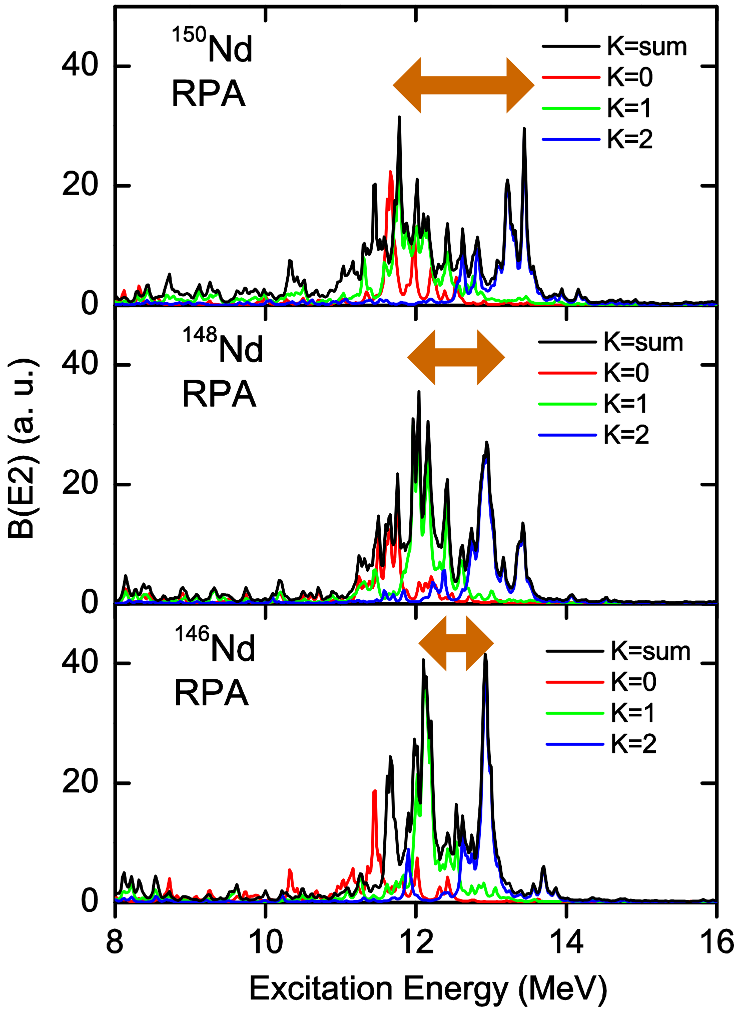
Predicted K splitting



V.O. Nesterenko et al., Phys. Rev. C 74, 064306 (2006)

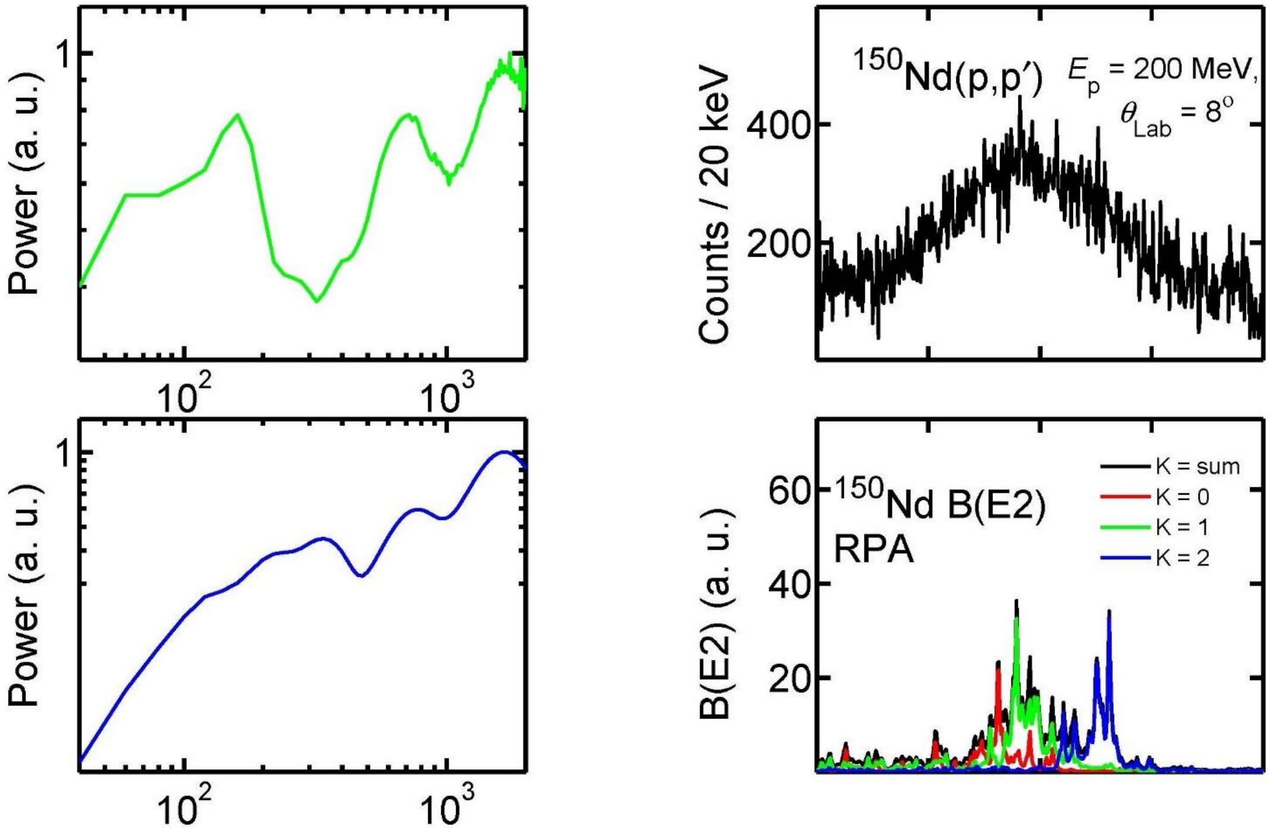
Predicted K splitting

- Signature splitting of K = 1 and K = 2 components
- K = 0 component weak



V.O. Nesterenko et al., Phys. Rev. C 74, 064306 (2006)

Fine Structure in the Deformed ^{150}Nd

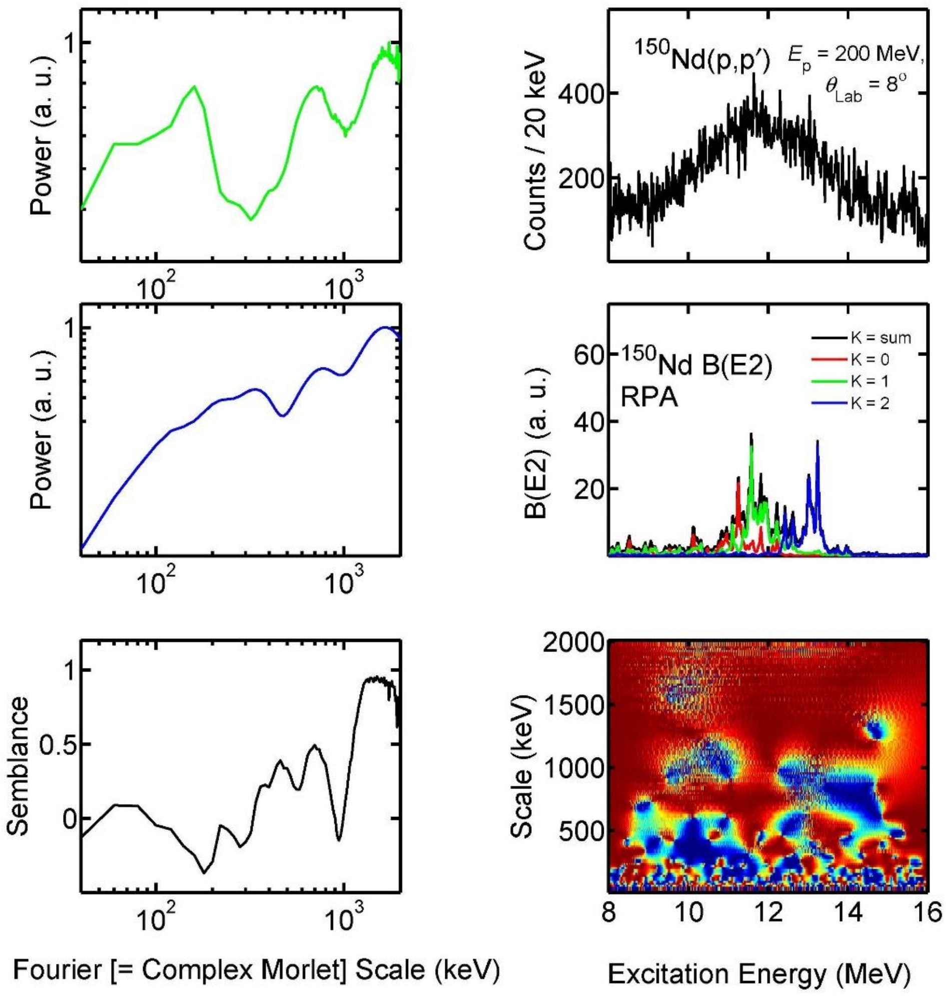


Semblance Analysis

Semblance

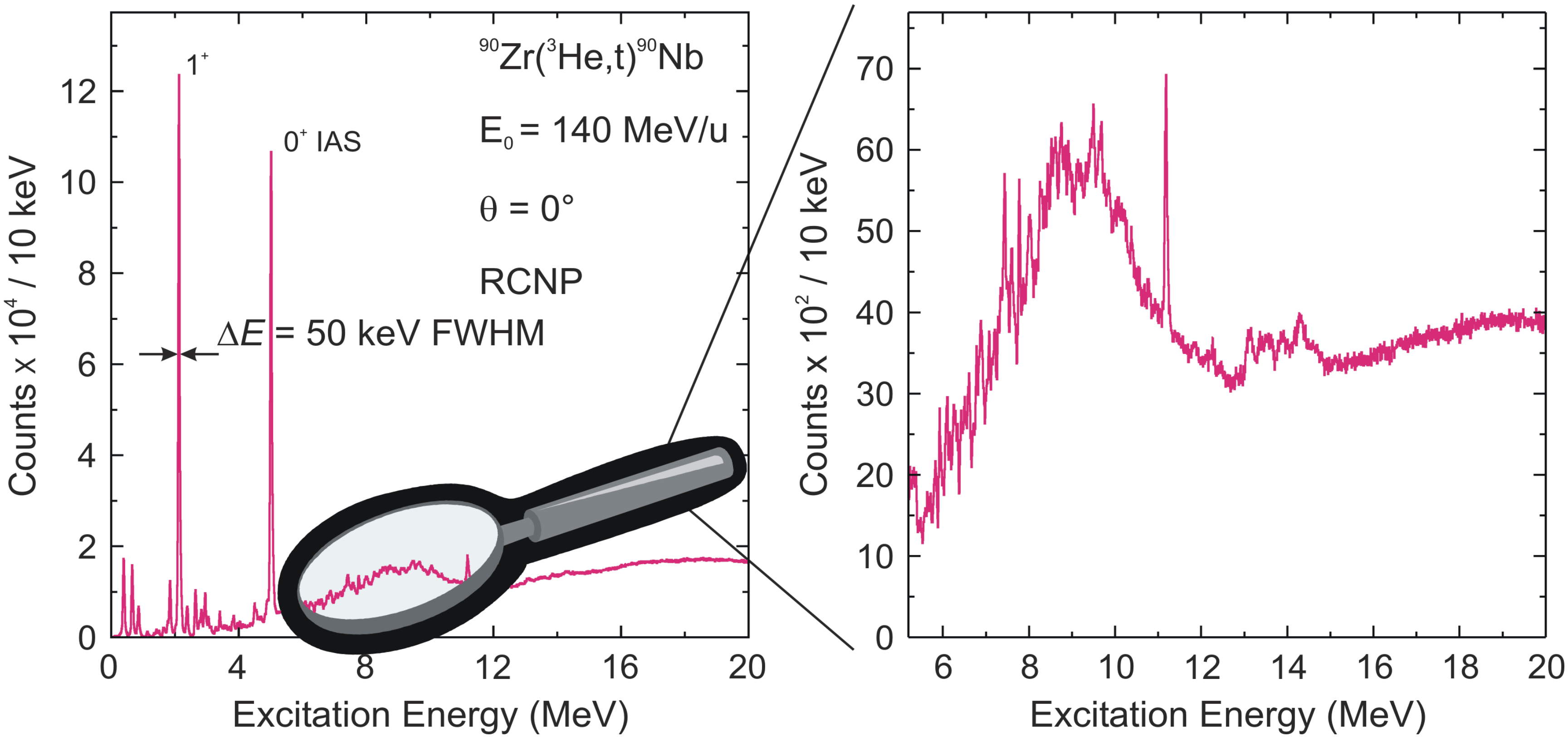
$$D = \cos^{n}(\theta) \mid C_1 \, C_2^* \mid$$

$$\theta = \tan^{-1}[Im(C_1 C_2^*) / Re(C_1 C_2^*)]$$



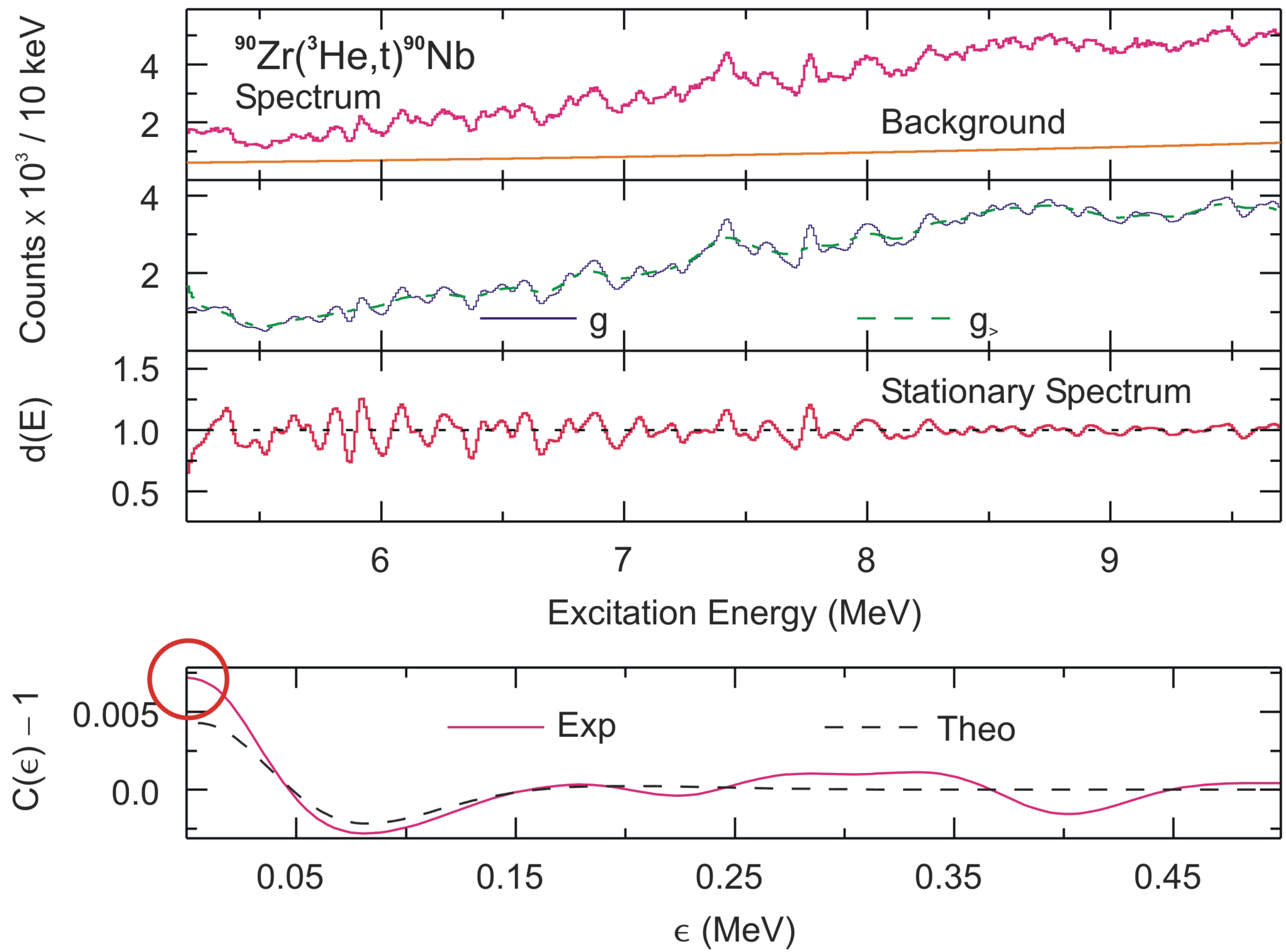
Level densities

Fine Structure of the spin-flip GTR: A = 90



- Selective excitation of 1$^+$ states

Fluctuation Analysis

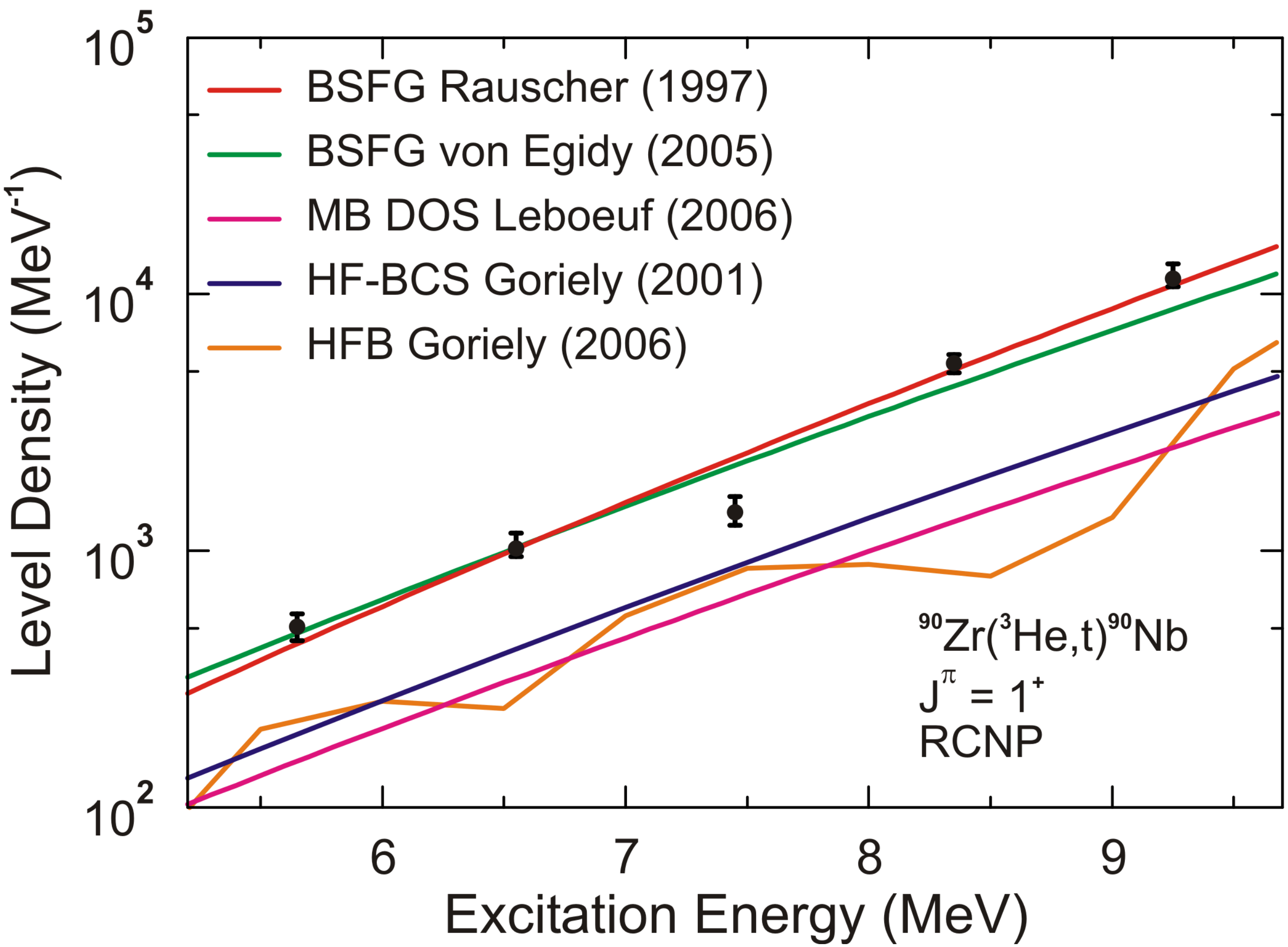


- Background
  - From discrete wavelet analysis
- Statistics, local features
- Local fluctuations
- Autocorrelation function

Autocorrelation Function and Mean Level Spacing

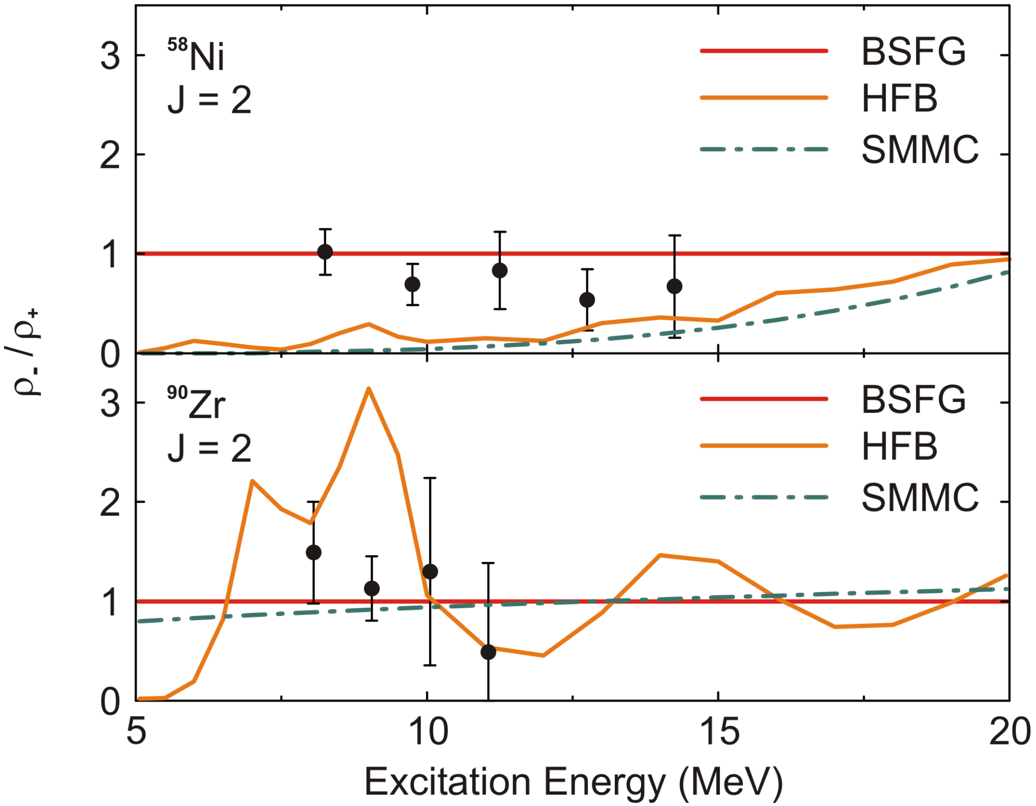
- $$C(\varepsilon) = \frac{\langle d(E_x) \cdot d(E_x + \varepsilon) \rangle}{\langle d(E_x) \rangle \cdot \langle d(E_x + \varepsilon) \rangle}$$ autocorrelation function
- $$C(\varepsilon = 0) - 1 = \frac{\langle d^2(E_x) \rangle - \langle d(E_x) \rangle^2}{\langle d(E_x) \rangle^2}$$ variance
- $$C(\varepsilon = 0) - 1 = \frac{\alpha \langle D \rangle}{2\sigma\sqrt{\pi}}$$ level spacing ⟨D⟩
- $\alpha = \alpha_{PT} + \alpha_W$ statistical properties
- σ resolution

Results and Model Predictions



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

Parity Dependence of Level Densities



- Experiments: no parity dependence
- HFB and SMMC: ^{58}Ni strong parity dependence: $\rho_- \ll \rho_+$

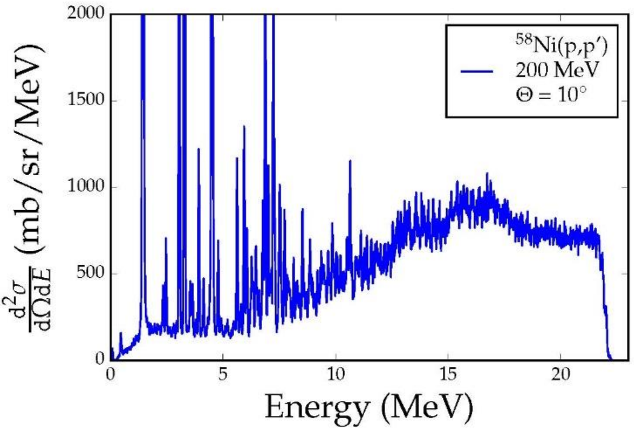
Y. Kalmykov et al., Phys. Rev. Lett. 99, 202502 (2007)

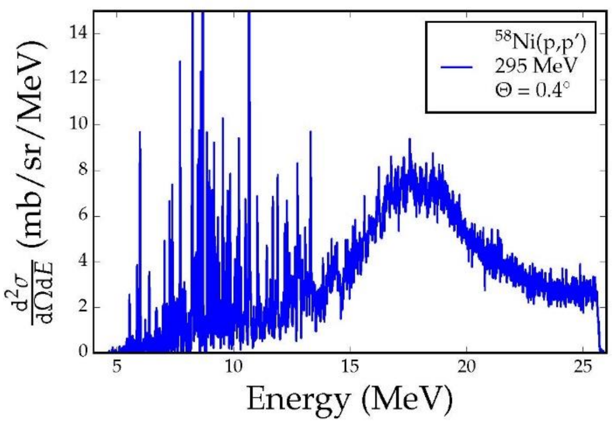
Spin Dependence of Level Densities

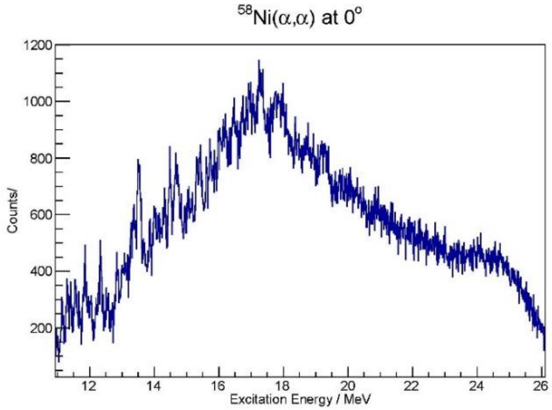
ISGQR
@iThemba

IVGDR(+ M1)
@RCNP

ISGMR
@iThemba







J = 0,1,2 level densities in the same nucleus → test of spin dependence

Fine structure:

A powerful tool for the study of nuclear structure in the continuum

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Discrete wavelet transform

- $$C(\delta E, E_X) = \frac{1}{\sqrt{\delta E}} \int_{-\infty}^{+\infty} \sigma(E) \Psi^* \left(\frac{E_X - E}{\delta E} \right) dE$$ wavelet coefficients

- Discrete wavelet transform *

  $\delta E = 2^j$ and $E_X = k \cdot \delta E$ with j, k = 1, 2, 3, …

  exact reconstruction is possible

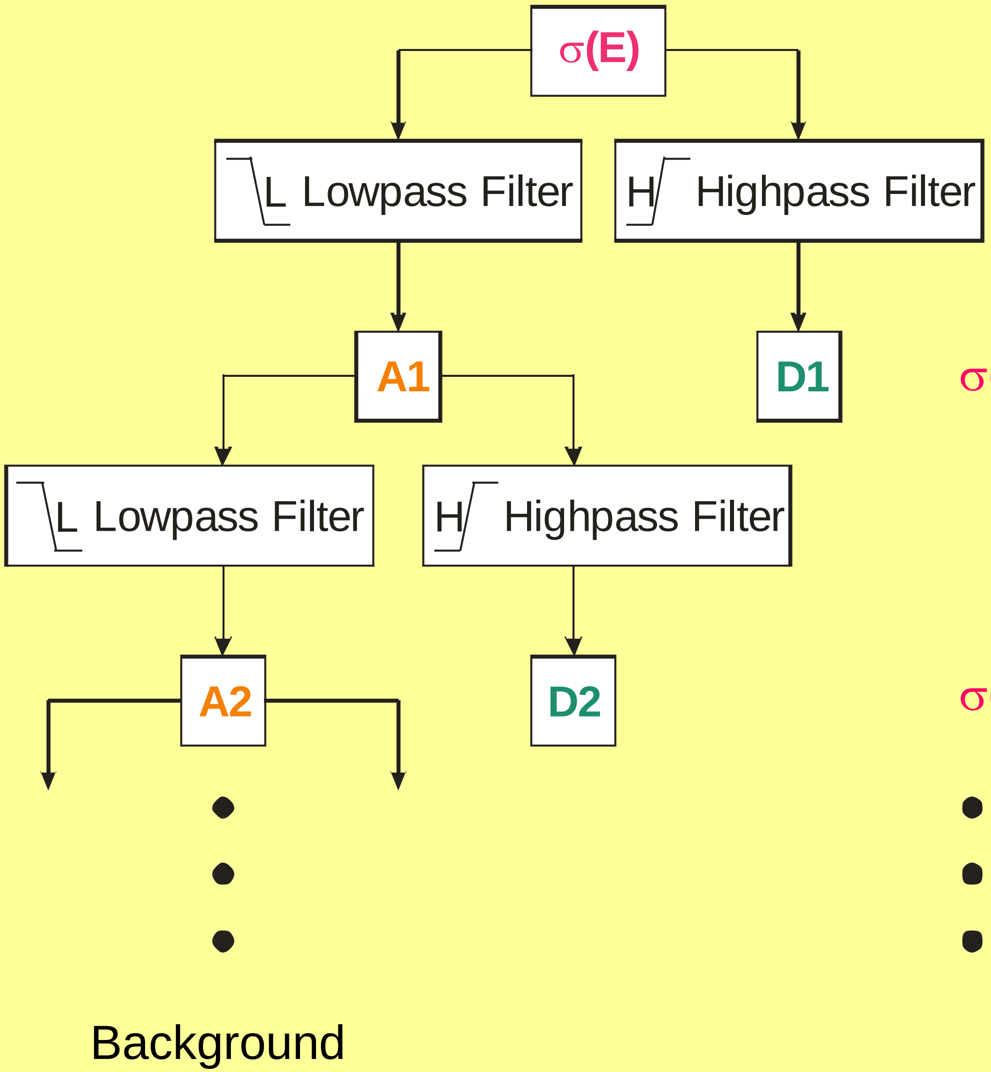
  is fast

- $$\int_{-\infty}^{+\infty} E^n \Psi^* \left(\frac{E_X - E}{\delta E} \right) dE = 0, \quad n = 0,1 \ldots m-1$$ vanishing moments

  this defines the shape and magnitude of the background

* http://www.mathworks.com/products/wavelet/

Decomposition of spectra



$\sigma(E) = A1 + D1$

$\sigma(E) = A2 + D2 + D1$

$\vdots$

Decomposition of $^{90}Zr(^{3}He,t)^{90}Nb$ spectrum