Can octupole vibrations on the fine structure of the ISGMR in ^{208}Pb enrich its energy scales?



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https://www.wits.ac.za/physics/research-areas/nuclear-and-radiation-physics/

14th Joint workshop on Physics of Strong Interacting Systems, Nanjing, China.

NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

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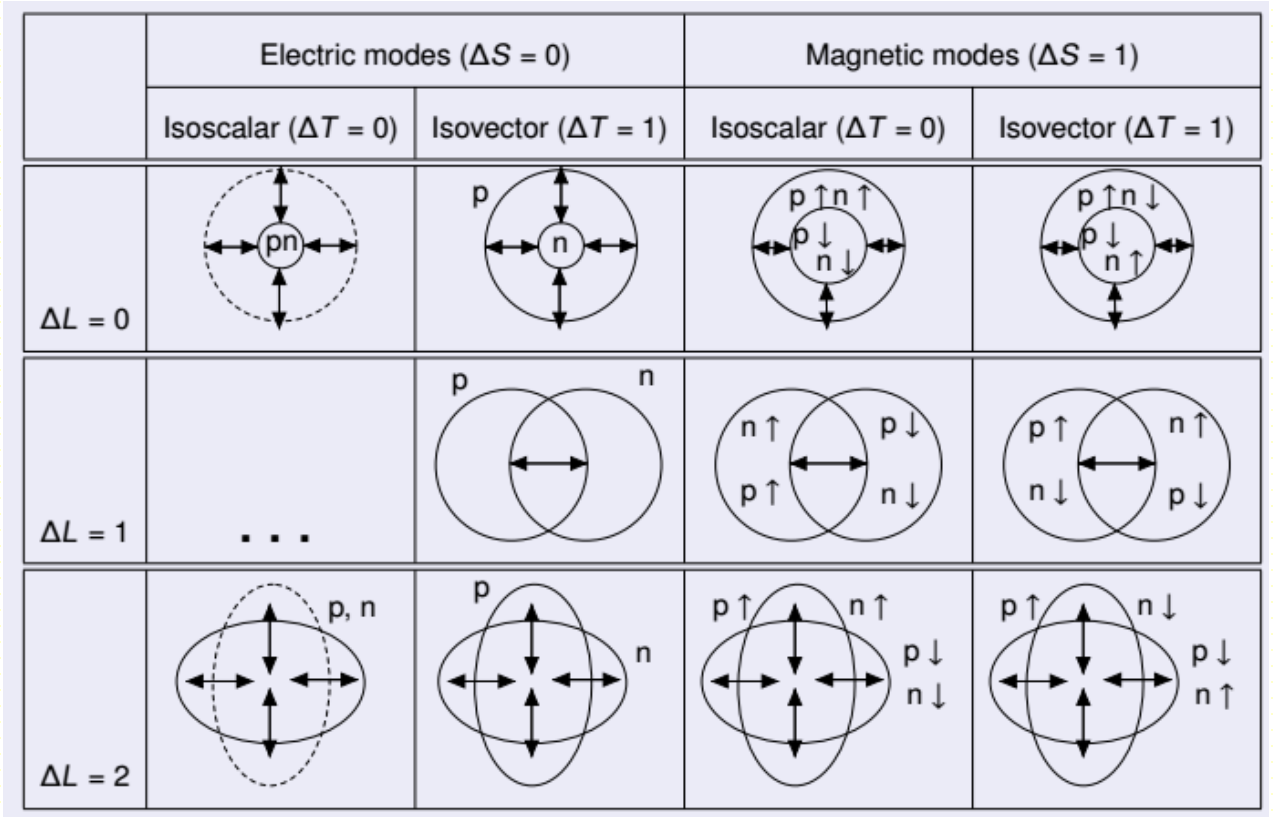
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Outline

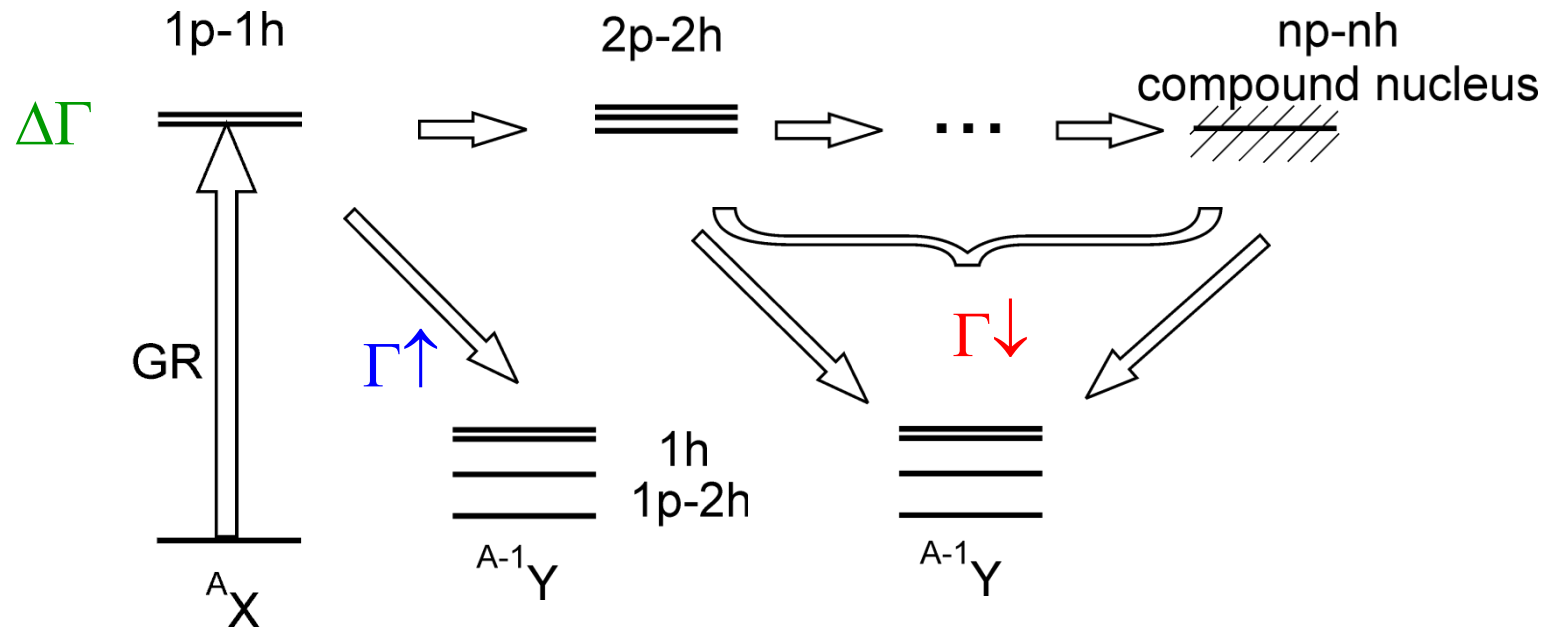
- **Introduction**
- **Methodology**
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  - Difference-of-Spectra Technique using DWBA Calculations
- **Characteristic Energy Scales Analysis**
  - Wavelet Analysis
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Introduction

- Giant resonances (GRs) are defined as collective, small amplitude excitation modes which occur at excitation energy of 10 MeV and above in nuclei across the periodic table.
- They are characterised by the three quantum numbers *L*, *S* and *T*.
- The study of the ISGMR is important since knowledge of its excitation energy provides information relevant to the nuclear matter incompressibility coefficient K_∞ which is crucial in the study of supernova collapse, neutron stars, etc.



Excitation and Decay of Giant Resonances

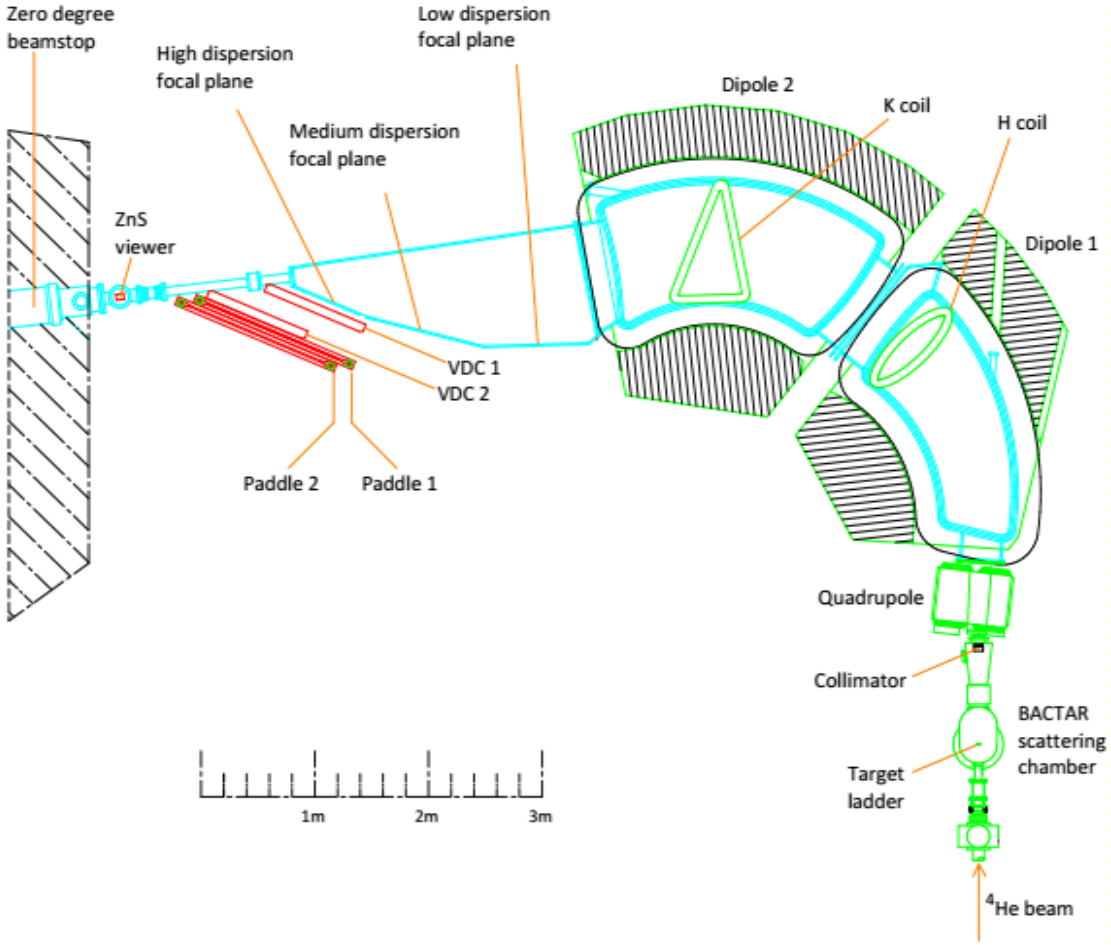


$$\Gamma = \Delta\Gamma + \Gamma\uparrow + \Gamma\downarrow$$

Resonance width	Landau damping	Escape width	Spreading width

Experiments: K600 Magnetic Spectrometer at iThemba LABS

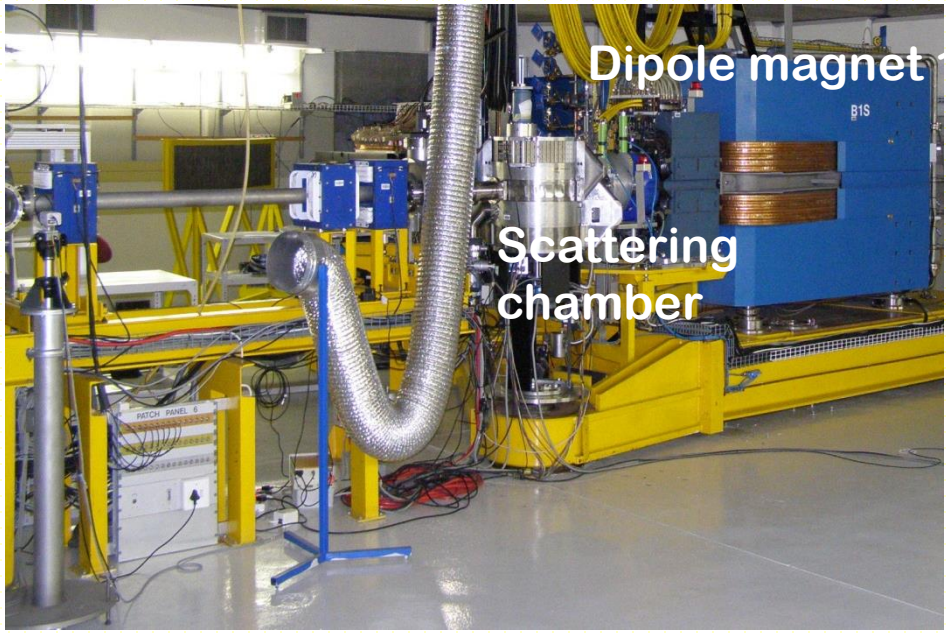
- (α, α') scattering using the K600 magnetic spectrometer positioned at zero and four degrees.
- Angular acceptance of ± 1.91°.
- 196 MeV α -particles beam interacts with ^{208}Pb (1.43 mg/cm^2) foil, using beam dispersion matching techniques, energy resolution of 70 keV (FWHM) was achieved.
- Reaction Kinematics where the ISGMR is enhanced close to zero-degrees scattering angle and at small scattering angle of 4°.
- "Background-free" and high energy-resolution inelastic alpha scattering spectra were obtained.

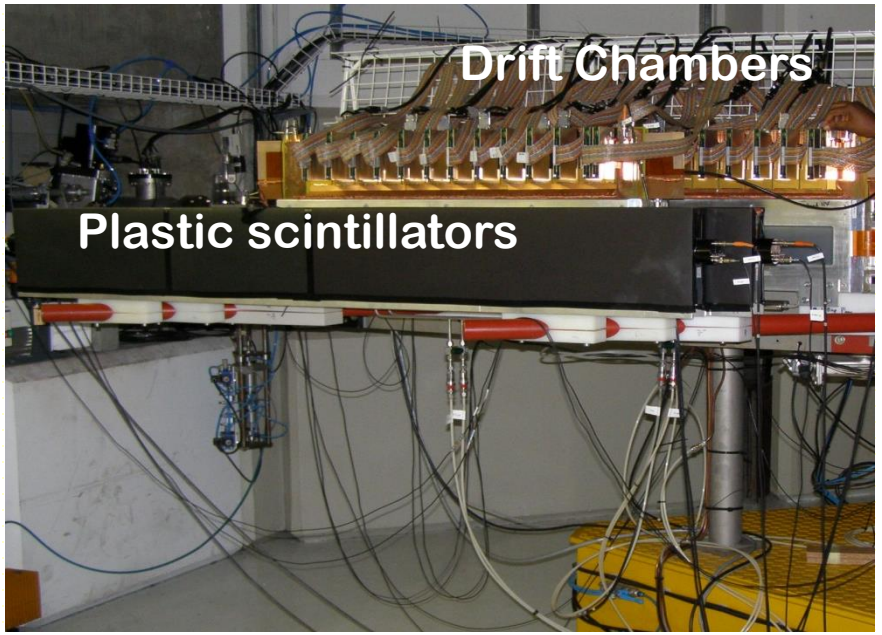


R. Neveling *et.al.*, Nucl. Instrum. Methods Phys. Res A 654, 29 (2011).

K600 Magnetic Spectrometer at iThemba LABS

Contact person: Dr. Retief Neveling (r.neveling@ilabs.nrf.ac.za)





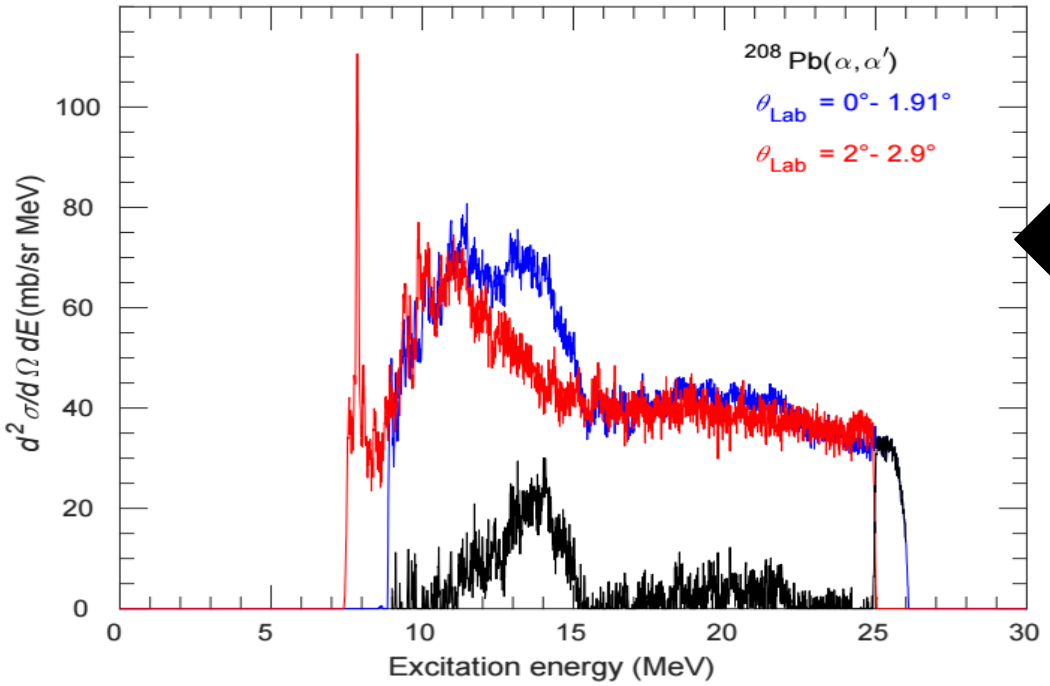
Best resolution = 25 keV @ 200 MeV on Au target
Best resolution = 9 keV @ 66 MeV on Pb target
Largest angle so far = 87°
Smallest angle = 21° with external beamstop
Smallest angle = 4° with internal beamstop

Including Zero-degree facility

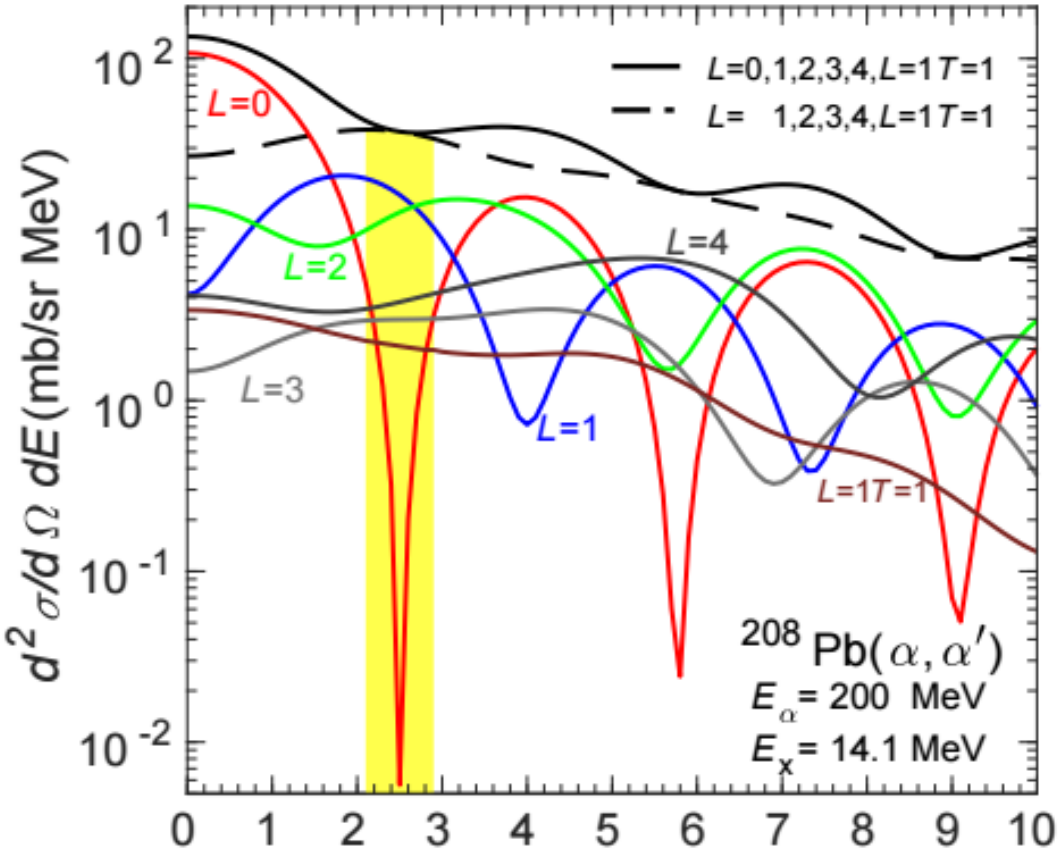
- 2 VDC: high accuracy horizontal position determination in focal plane
- 1 HDC: high accuracy vertical position determination
- 2 plastic scintillators (BC-408) acting as trigger detectors for particle identification

DWBA calculations for the application of the Difference-of-Spectra (DoS) technique

- The method consists of subtracting a spectrum obtained from an angle cut of the 4° data where the angular distributions for the other multipolarities except L = 0 are nearly flat, and that of GMR is at a minimum, from the spectrum obtained with data taken at 0°.



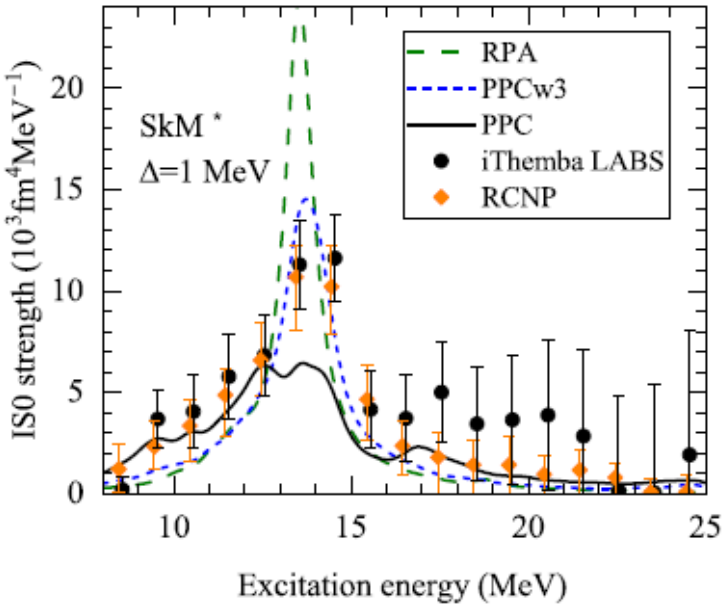
DoS result for ^{208}Pb

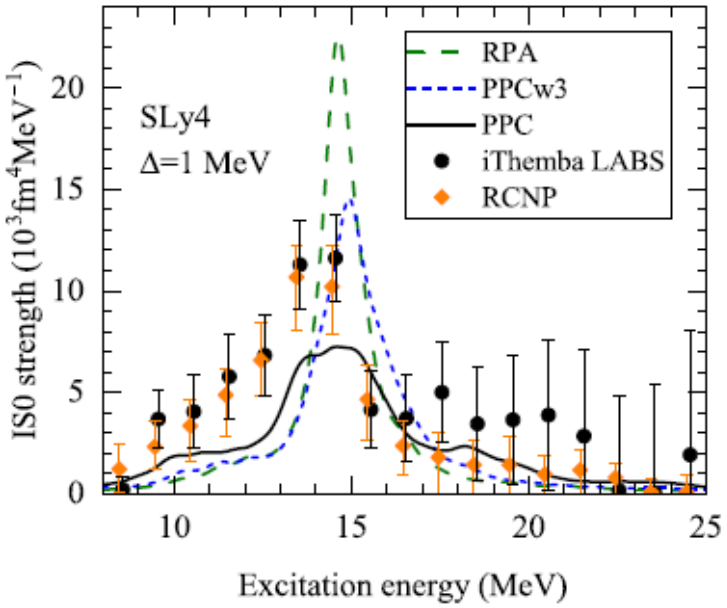


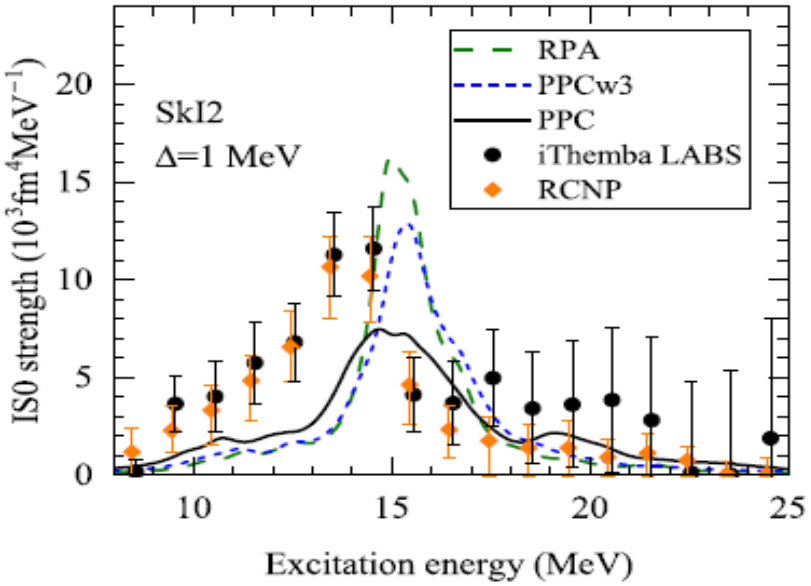
Angular distributions for ^{208}Pb

Theoretical Model Calculations

- Impact of Octupole vibrations on the ISGMR width in ^{208}Pb calculations using SkM*, SLy4 and SkI2 EDFs.
- Experimental data are taken from iThemba LABS (A. Bahini et al., Phys. Rev. C 107 (2023) 034312.) and RCNP (D. C. Patel et al., Phys. Lett. B 726 (2013) 178).
- A smoothing parameter of 1 MeV is applied to the strength distribution described by the Lorentzian function.







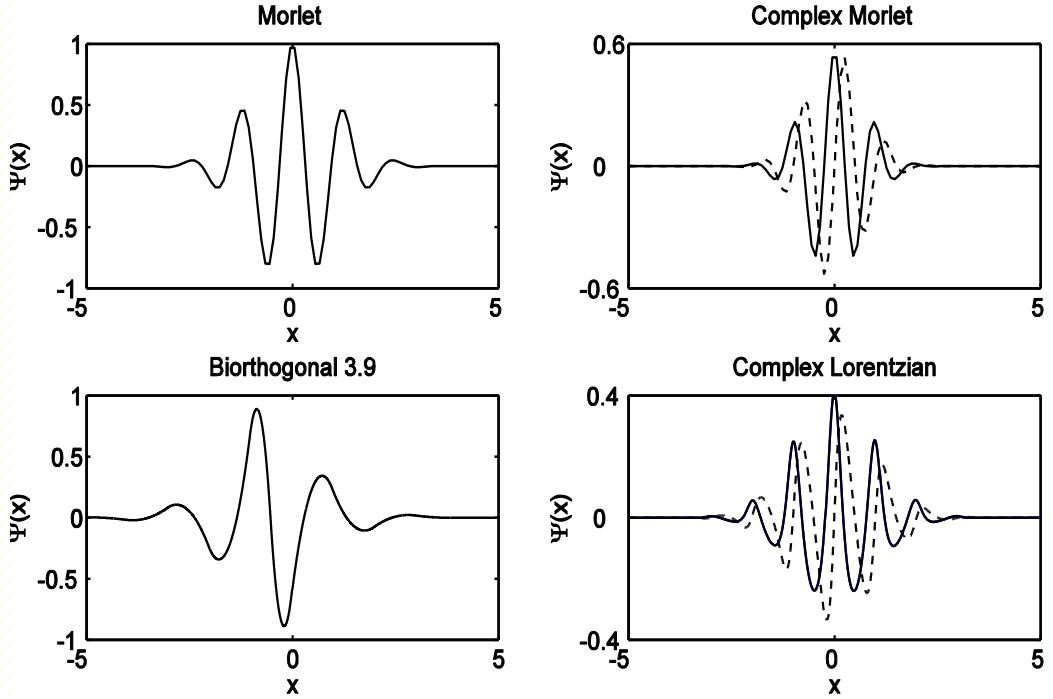
SkM* SLy4 SkI2

(N.N.Arsenyev and A. P. Severyukhin BLTP JINR)

Wavelet Analysis

$$\int_{-\infty}^{\infty} \Psi^*(x)dx$$

$$\int_{-\infty}^{\infty} |\Psi^2(x)|dx < \infty$$



Continous Wavelet Transform

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

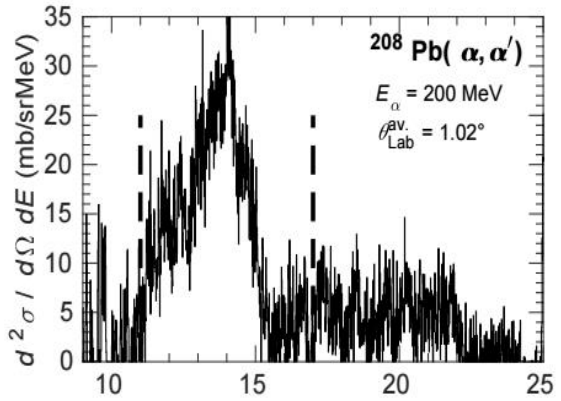
position scale spectrum wavelet

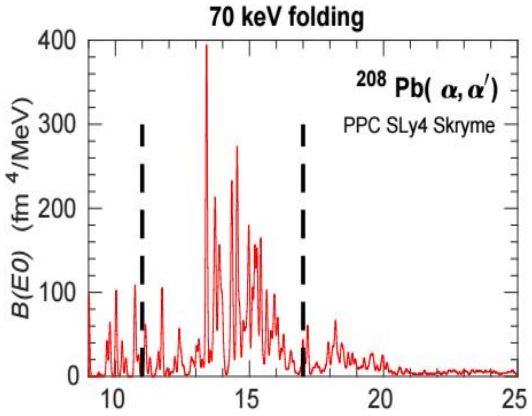
Morlet: $$\Psi(x) = \frac{1}{\pi^{1/4}} \cos(ikx) \exp\left(-\frac{x^2}{2}\right)$$

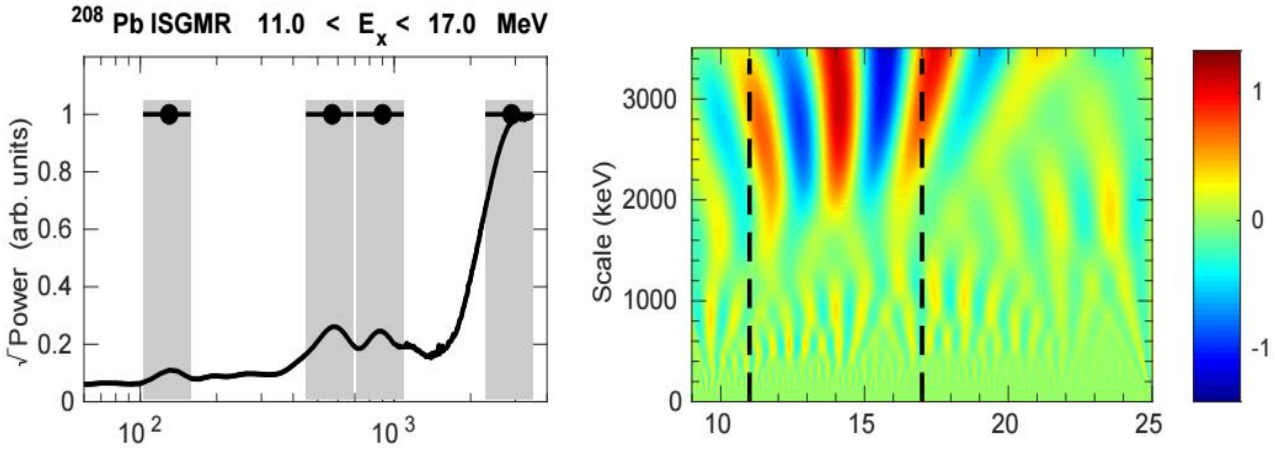
Complex Morlet: $$\Psi(x) = \frac{1}{\sqrt{\pi f_b}} \exp(2\pi i f_c) \exp\left(-\frac{x^2}{f_b}\right)$$

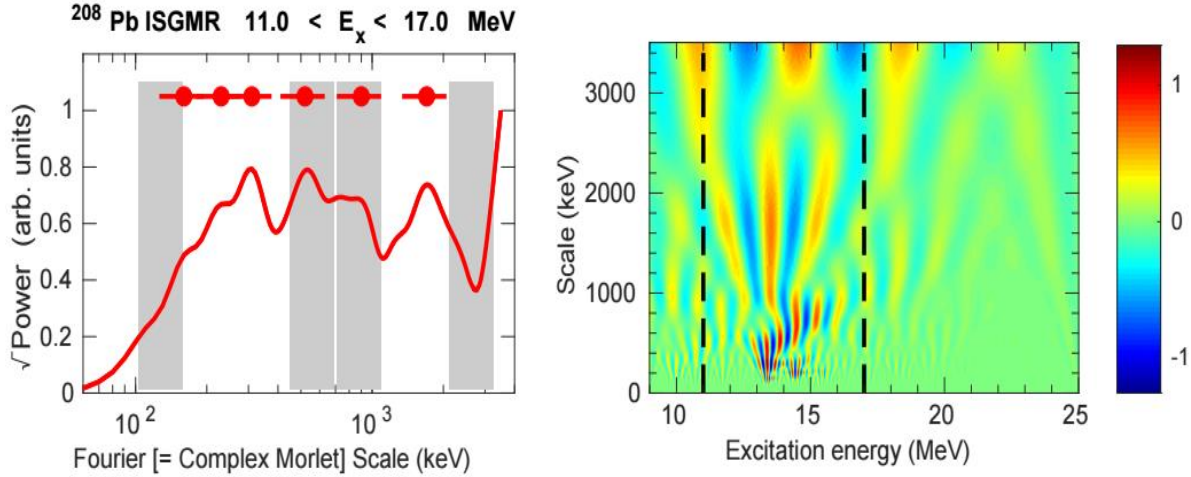
Wavelet Power: $$P_w(\delta E) = \frac{1}{N} \sum_i |C_i(\delta E) C_i^*(\delta E)|$$

Characteristic Energy Scales for ^{208}Pb





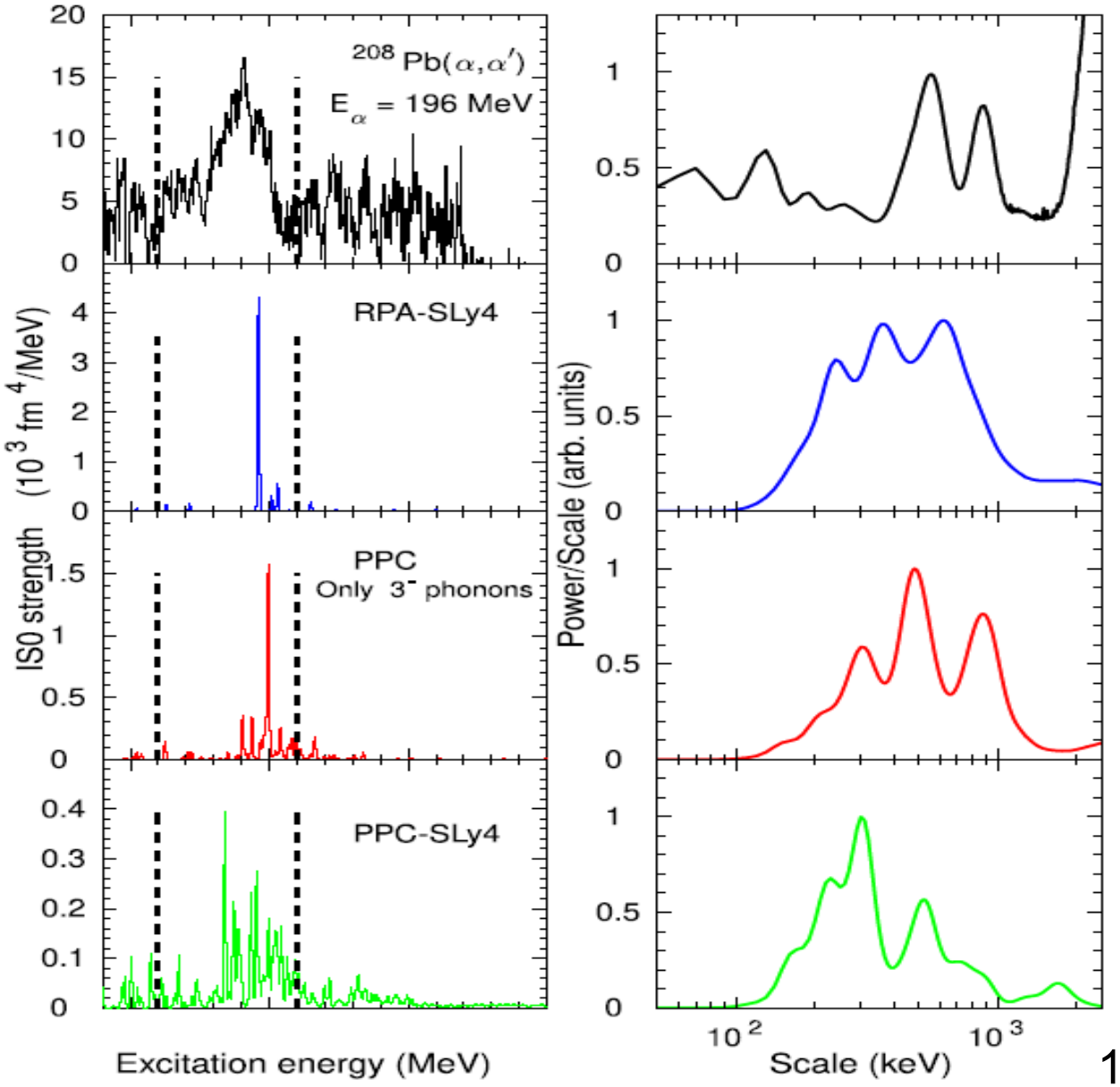




A. Bahini *et.al.*, PRC 109, 014325 (2024).

Comparison with Theoretical calculations: ^{208}Pb

- Left column: Experimental IS0 strength in ^{208}Pb (top row) in comparison with model predictions (rows 2–4) folded with the experimental energy resolution.
- Skyrme force SLy4 EDF calculations for RPA (Blue); PPCw3 with only octupole phonons (Red); and Full PPC (Green).
- The vertical dashed lines indicate the summation region of the wavelet coefficients (11–16 MeV) to determine the power spectra.
- Right column: Corresponding power spectra using complex Morlet wavelet analysis.



Comparison of extracted energy scales: ^{208}Pb

- The inclusion of interactions with octupole vibrations introduces additional scales that are not present in the analysis of the spectrum obtained in the RPA.
- The emergence of additional scales when only octupole vibrations are considered serves as a clear illustration of this enhancement.
- Therefore, considering octupole vibrations greatly enhances the power spectra and extracted scales.

Scales		< 300 (keV)	300−1000 (keV)
Expt.		130, 190, 260	570, 870
SLy4	RPA	240	360, 620
	PPCw3	150, 220	300, 480, 870
	PPC	160, 220	300, 520, 870

N. N. Arsenyev *et.al.*, International Journal of Modern Physics E, 2641012 (2026).

Conclusions and Outlook

- High energy-resolution experiments on nuclei presents a unique way to extract information about the dominant processes of the decay.
- The Wavelet analysis allows extraction of the characteristic energy scales associated with the fine structure of the ISGMR.
- For the special case of the ISGMR in ^{208}Pb, observed additional scales originated from calculations including complex configurations can be associated with the spreading width which makes the largest contribution in heavy nuclei.
- Combined with the significant broadening of the ISGMR width in ^{208}Pb, it can be found that octupole vibrations play a crucial role in the fine structure of ISGMR.
- Extension of this study to the case of the experimental data in ISGQR in heavy nuclei is ongoing.

South Africa-JINR Collaborators

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Thank You for Listening







And Plenty of WINES in South Africa!!!