# Study of the K quantum number of pygmy states in $^{154}$Sm

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REPUBLIC OF SOUTH AFRICA

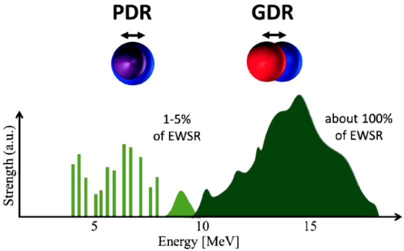
African Nuclear Physics Conference, iThemba LABS, Cape Town, South Africa

November 24, 2025

# Pygymy Dipole Resonance (PDR)

- Three-Fluid Hydrodynamical Model of Nulcei → Out of phase oscillation of a core with **Z protons and Z neutrons against a N–Z neutron skin**.
- A concentration of $J^{\pi} = 1^{-}$ states located around the neutron threshold.
- Lies well below the Giant Dipole Resonance (GDR).

A. Zilges, J. Phys.: Conf. Ser. 590 (2015) 012006



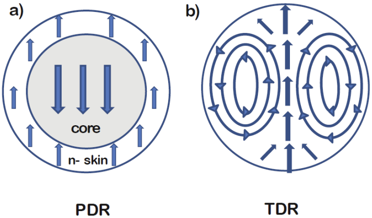

The splitting of the $E1$ strength into the PDR and the GDR.

# Objections and Open questions on the PDR

- Some studies show $E1$ strength in the PDR region in nuclei with little or no neutron skin. → Alternative excitation? e.g. Toroidal mode?

- The toroidal mode is associated with a current transition density distribution that has a vortex structure. (Predicated by Semenko *et.al*, 1981)

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



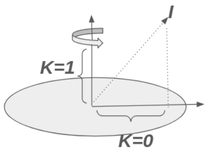

A demonstration of the current flow between the PDR and TDR.

- Is the simplistic collective picture of the PDR valid?
- What is the role of nuclear deformation on the PDR?
- The features of the PDR are currently debated and the landscape of low-lying $E1$ states remains open.

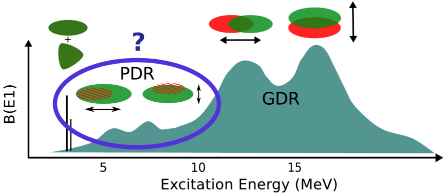
# Role of nuclei deformation on the PDR-Objectives of the study

- PDR defies interpretation → affecting mostly predictive power for exotic nuclei.
- Role that nuclear deformation plays is yet to be understood.
- The main objective of this study is to investigate the impact of ground-state deformation on the properties of PDR in $^{154}$**Sm**.
    1. Determine **Spins and Parities**, **Cross-Sections** and the **Branching Ratios** in $^{154}$Sm.
    2. **Compare results** of $^{154}$Sm with $^{150}$Nd ( *O. Papst, Ph.D. thesis, TU Darmstadt, 2024.*)

**Collective picture of the PDR →A possible double-hump structure in the PDR, resembling that observed in the GDR.**



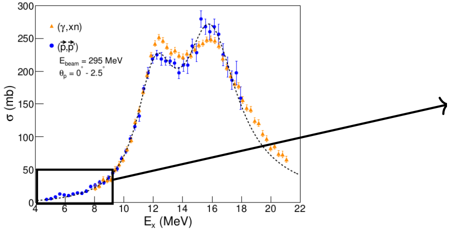

Angular K quantum numbers for a deformed nucleus.




Demostration of the B(E1) response in heavy deformed nuclei.

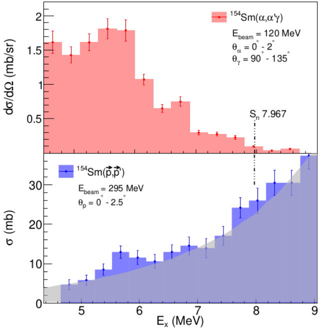
# Experimental signatures of the PDR in $^{154}$Sm

- PDR Single-hump structure observed in $^{154}$Sm through (p,p′) on the IVGDR dataset.




GDR study

L.Pellegri, H.Jivan, P von Neumann-Cosel, A. Tamii et al.

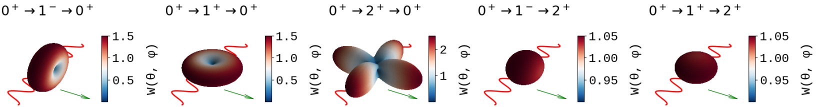


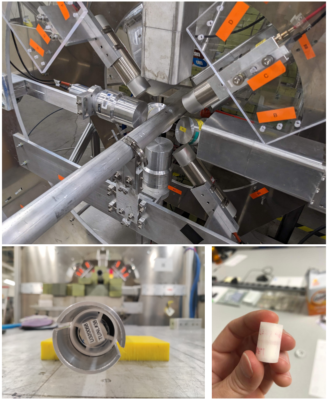

Comparisons of $^{154}$Sm$(\alpha, \alpha'\gamma)$ and $^{154}$Sm(p,p′).

- PDR Single-hump structure observed through $^{154}$Sm$(\alpha, \alpha'\gamma)$.
  - **IS probe**

- The current study is expected to give **complementary information** on the role of deformation in the PDR region.

# Experimental Setup at the High Intensity $\gamma$-ray Source (HI$\gamma$S).



$\gamma$-ray detectors around the target position, target holder inside the pipe and the target.

- 2.5g of $^{154}$Sm in oxide form, enriched to >90% for the isotope of interest
- $^{154}$Sm($\gamma$,$\gamma$') with Laser Compton Scattered (LCS) beam energy ranging from 3.83 to 7.05 MeV.
- 3 hours of beam time for every beam energy.
- 5 HPGe detectors, 4 $LaBr_3$:Ce and 3 $CeBr_3$ detectors.
- 1 HPGe at 0$^o$ for beam profiling measurements.

# Beam Energy Profile: Photon flux

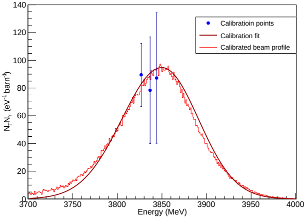
- 25 different beam energies.
- Good overlap-continuous scan of the excitation energy.
- Photon flux calibration points from *Ziegler et.al, 1993*

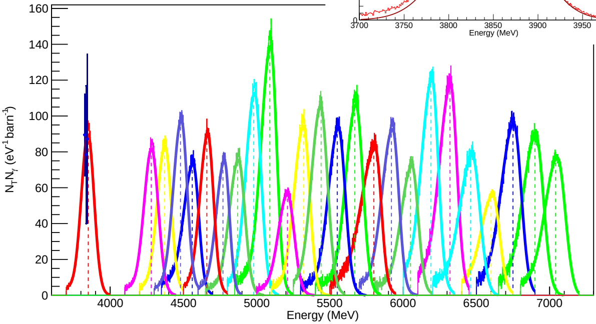
Nuclear Physics A564 (1993) 366–382
North-Holland

NUCLEAR PHYSICS A

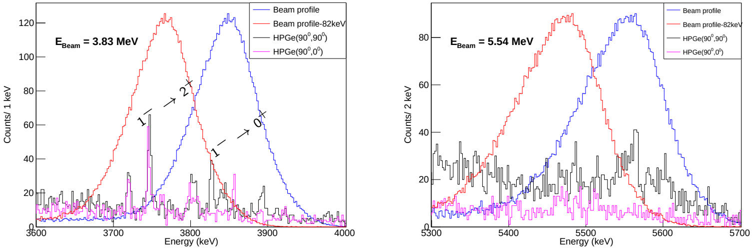
Low-energy dipole-strength distributions in $^{148,150,152,154}Sm$ *

W. Ziegler [1], N. Huxel, P. von Neumann-Cosel, C. Rangacharyulu [2], A. Richter, C. Spieler
*Institut für Kernphysik, Technische Hochschule Darmstadt, D-64289 Darmstadt, Germany*



# HPGe clover detectors $\gamma$-decay spectra




- **Mono-energetic LCS** $\rightarrow$ Selectivity of the excitation energy.
- Measurements by the asymmetry method in the two perpendicular detectors for $J^{\pi}$ assignments.

# Assignments of Spin-Parity: Measurements by the asymmetry method

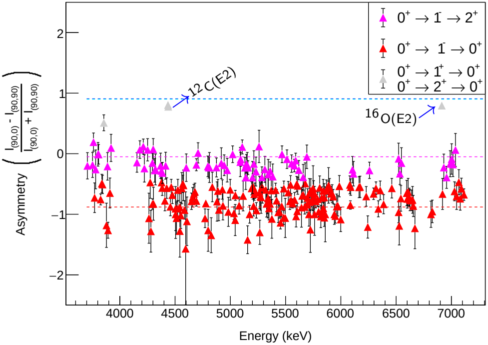
For extraction of the asymmetry values

$$\epsilon = \frac{A_{\parallel} - A_{\perp}}{A_{\parallel} + A_{\perp}} = p\Sigma \qquad (1)$$

The analysing power

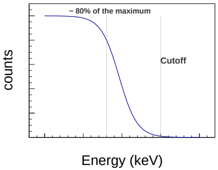
$$\Sigma = \frac{W_{\parallel} - W_{\perp}}{W_{\parallel} + W_{\perp}} \qquad (2)$$

measures the sensitivity to the parity quantum number of a $\gamma$-ray transition while $p$ accounts for detector effects.



# Average Branching Ratios: Spectral Convolution

- Measurements of average properties: **Convolution fitting procedure to extract and separate the different contributions from NRF reactions**: In our case $0^+ \rightarrow 1^- \rightarrow 0^+$ and $0^+ \rightarrow 1^- \rightarrow 2^+$.
- Required: Detector response from GEANT4 simulations: $R_{0_1^+}$, $R_{2_1^+}$, $R_{BG}$
- Each decay branch resembles the shape of the photon beam: **Asymmetric Gaussian**
- Beam-induced background: **Sigmoid function**

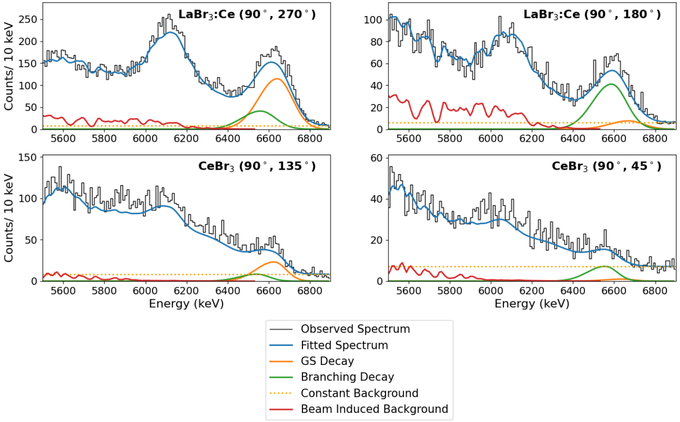



- Constant-background model: **Single scaling parameter**

Simultaneous Bayesian fit of all detectors.!!

**Fit code courtesy of Dr. Jörn Kleemann.**

# Simultaneous Spectral convolution @ 6.6 MeV



# Preliminary - Average Branching ratio and the associated K quantum numbers

- The ratio of the areas of corresponding peaks allows a simple identification of K=0 and K=1 transitions.

$$R = \frac{B(1^- \rightarrow 2_1^+)}{B(1^- \rightarrow 0_{\mathrm{g.s.}}^+)} = \frac{I_\gamma(1^- \rightarrow 2_1^+)}{I_\gamma(1^- \rightarrow 0_{\mathrm{g.s.}}^+)} \left( \frac{E_\gamma(1^- \rightarrow 2_1^+)}{E_\gamma(1^- \rightarrow 0_{\mathrm{g.s.}}^+)} \right)^{-3} \quad (3)$$

is **0.5** for **K=1** and **2** for **K=0**.

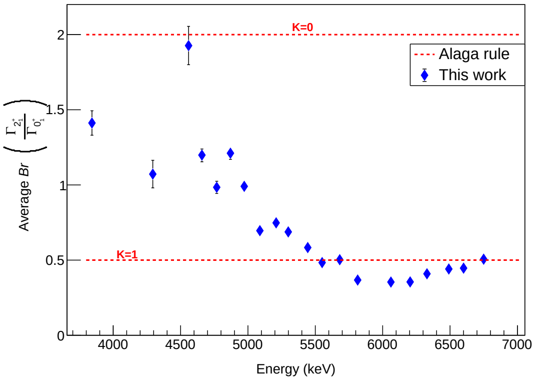
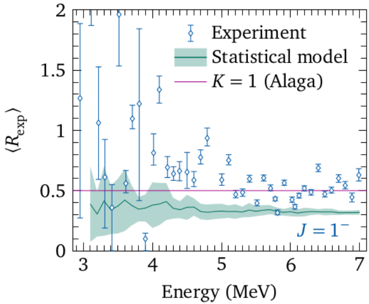
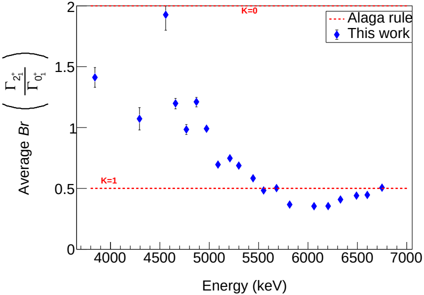


Figure adapted from: O. Papst, *Exploration of Nuclear-Structure Effects on Averaged Decay Quantities in the Quasicontinuum*, Ph.D. thesis, TU Darmstadt, 2024.



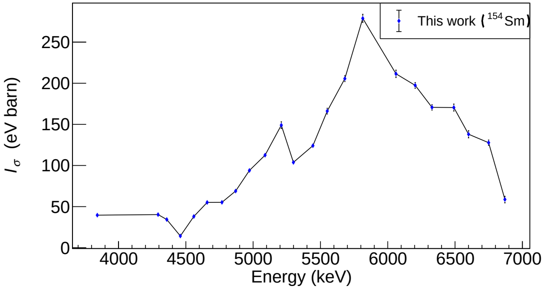




Comparison of the branching ratios obtained for $^{150}$Nd (left) and $^{154}$Sm (right)

# Pre-liminary - Average Integrated Cross-Sections

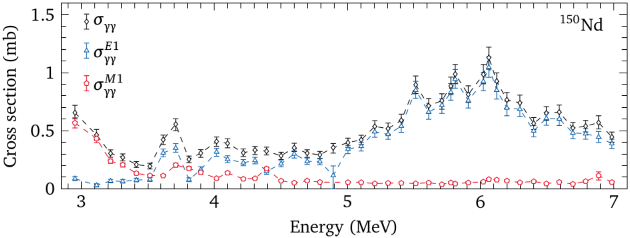
- Average cross-sections were determined using the the standard NRF Breit-Wigner integrated cross-section formula:

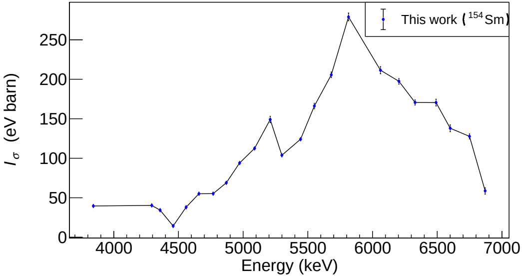
$$I_\sigma \equiv \int \sigma(E)\, dE = \frac{2J+1}{2J_0+1}\left(\frac{\pi\hbar c}{E_\gamma}\right)^2 \frac{\Gamma_0^2}{\Gamma} \tag{4}$$



# Preliminary - Comparison of the Average Integrated Cross-Sections with $^{150}$Nd

Figure adapted from: O. Papst, *Exploration of Nuclear-Structure Effects on Averaged Decay Quantities in the Quasicontinuum*, Ph.D. thesis, TU Darmstadt, 2024.




Comparison of the cross sections obtained for $^{150}$Nd (top) and $^{154}$Sm (bottom)

# Summary and outlook

- **Challenge**: Previous efforts have not provided a clear interpretation of PDR concerning deformation effects in nuclei.
- **Objective**: Understand the Pygmy dipole resonance (PDR) in the deformed $^{154}$Sm nucleus.
- **Methodology**: Utilize the ($\gamma$,$\gamma$') technique to investigate dipole states in the PDR region.
- **Experimental Setup**: Employ the $\gamma^3$ setup at the HI$\gamma$S facility.
- **Identification**: Determine the spins and parities, K quantum number and cross sections of excited states in the PDR region.
- **Comparative Analysis**: Comparison of results with data from other experiments is an effective way to fully understand PDR in deformed neutron-rich nuclei.

# Collaborators

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**This work is based on the research supported in part by the National Research Foundation of South Africa and the US Department of Energy.**

Thank you!!