Study of the K quantum number of pygmy states in ^{154}Sm
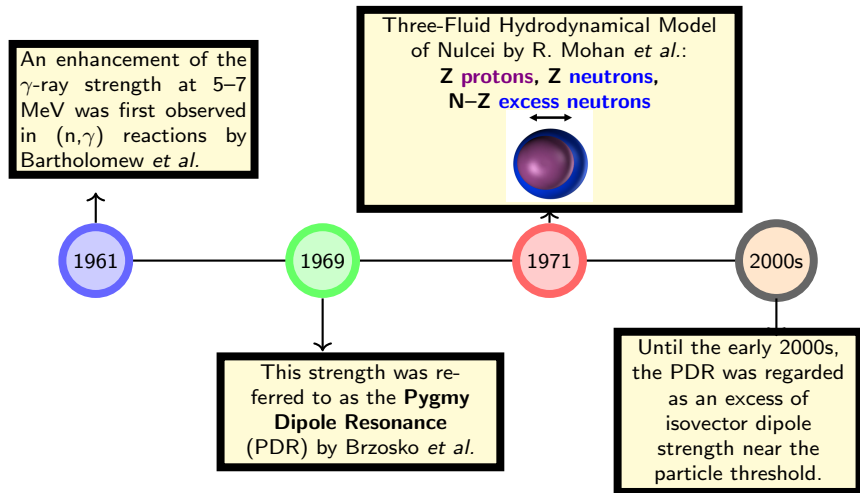
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Back story: Pygymy Dipole Resonance (PDR)

An enhancement of the γ-ray strength at 5–7 MeV was first observed in (n,γ) reactions by Bartholomew *et al.*

Three-Fluid Hydrodynamical Model of Nulcei by R. Mohan *et al.*:
Z protons, Z neutrons,
N–Z excess neutrons

1961

1969

1971

2000s

This strength was re-referred to as the **Pygmy Dipole Resonance** (PDR) by Brzosko *et al.*

Until the early 2000s, the PDR was regarded as an excess of isovector dipole strength near the particle threshold.
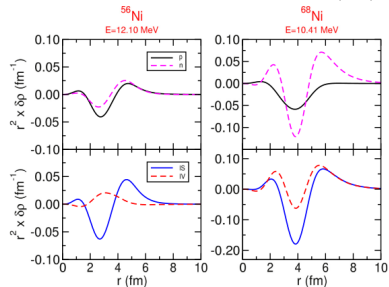
Pygymy Dipole Resonance (PDR)

▶ 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

A. Bracco et al., Prog. Part. Nucl. Phys. 106 (2019) 360-433
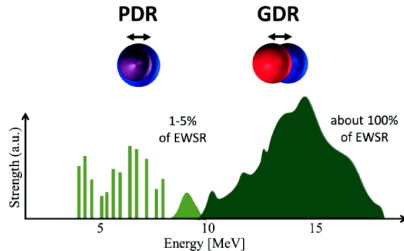

The splitting of the $E1$ strength into the PDR and the GDR.

Transition densities of the low-lying $E1$ state for ^{56}Ni and ^{68}Ni.

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?

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

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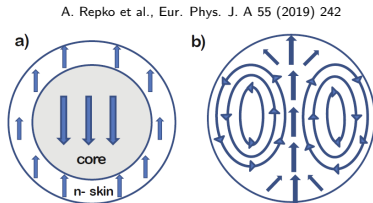

A demonstration of the current flow between the PDR and TDR.

▶ 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

- ▶ Nature and behaviour of the PDR defies interpretation.

- ▶ The most affected are the predictive power for exotic nuclei.

- ▶ Most studies of the PDR are on spherical nuclei; the role that nuclear deformation plays on the PDR 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. Measure the cross-sections of the individual states contributing to the PDR .

    2. Extract the branching ratios and associated K quantum numbers in ^{154}Sm.

    3. Compare results of ^{154}Sm with ^{150}Nd (*Talk by Johann Isaak on Tuesday!*)
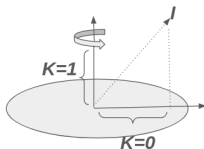
Angular K quantum numbers for a deformed nucleus.

Role of nuclei deformation on the PDR

- ▶ Collective picture;
    - ●A possible double-hump structure in the PDR, resembling that observed in the GDR could be expected.

- ▶ Potential interpretation:
    - ●Deformed proton-neutron saturated core, oscillating against a neutron skin along two different axes.
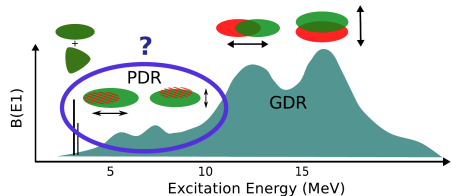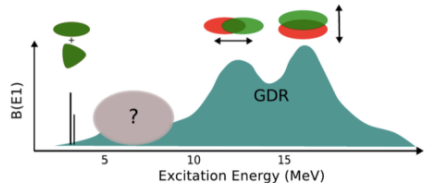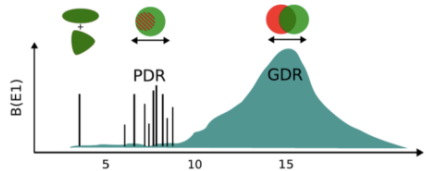
Demostration of the B(E1) response in heavy deformed nuclei.

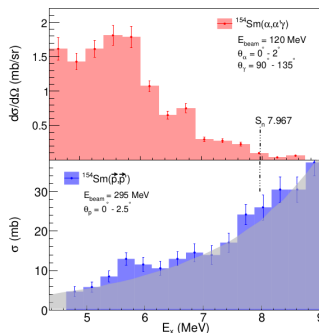# Experimental signatures of the PDR in ^{154}Sm

- ▶ PDR Single-hump structure observed in ^{154}Sm through (p,p') on the IVGDR dataset.
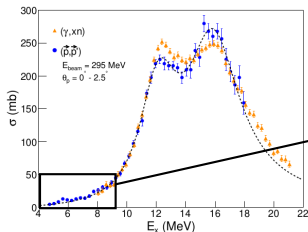
GDR study

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

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

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

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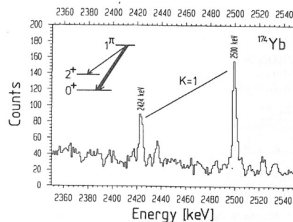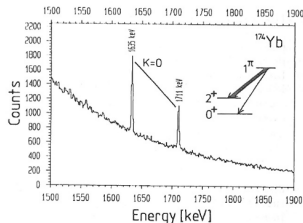
The K components - Alaga Rules

A. Zilges et al. PRC 42 (1990) 1945

- ▶ The branching ratio between decay to the 0_1^+ and 2_1^+, according to the Alaga rules

$$R = \frac{B(1^- \to 2^+)}{B(1^- \to 0^+)} \quad (1)$$

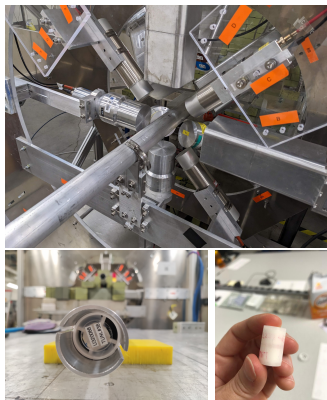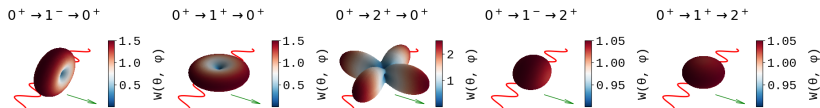is 0.5 for K=1 and 2 for K=0.

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

Experimental Setup at the High Intensity γ-ray Source (HIγS).

$0^+ \rightarrow 1^- \rightarrow 0^+$ $0^+ \rightarrow 1^+ \rightarrow 0^+$ $0^+ \rightarrow 2^+ \rightarrow 0^+$ $0^+ \rightarrow 1^- \rightarrow 2^+$ $0^+ \rightarrow 1^+ \rightarrow 2^+$


γ-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(γ,γ') 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° for beam profiling measurements.

Beam Energy Profile

- ▶ 25 different beam energies.
- ▶ Good overlap-continuous scan of the excitation energy.
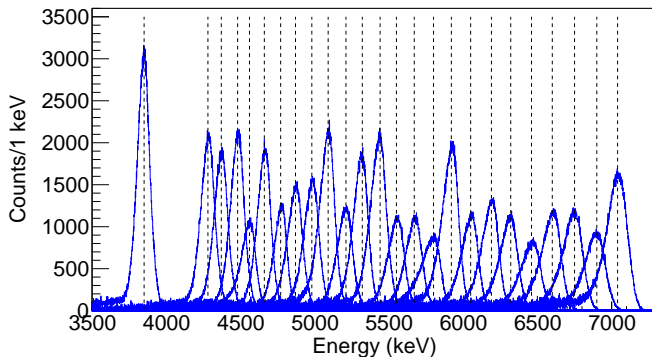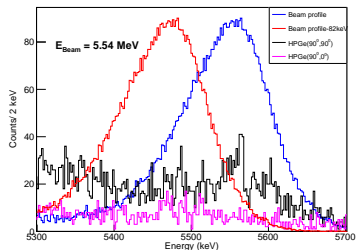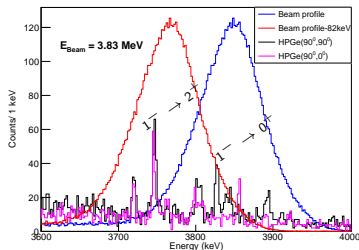
- ▶ **Mono-energetic LCS** → Selectivity of the excitation energy.
- ▶ Measurements by the asymmetry method in the two perpendicular detectors for J^{π} assignments.

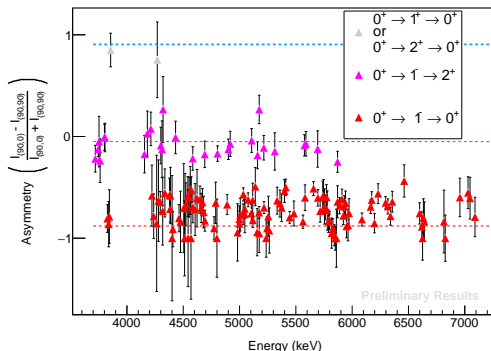## Assignments of Spin-Parity: Measurements by the asymmetry method

For extraction of the asymmetry values

$$\epsilon = \frac{A_\parallel - A_\perp}{A_\parallel + A_\perp} = p\Sigma \qquad (2)$$

The analysing power

$$\Sigma = \frac{W_\parallel - W_\perp}{W_\parallel + W_\perp} \qquad (3)$$

measures the sensitivity to the parity quantum number of a γ-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 $0^+ \to 1^- \to 0^+$ and $0^+ \to 1^- \to 2^+$.

▶ 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**
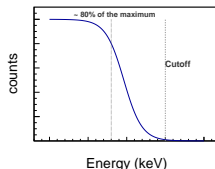
▶ Constant-background model: **Single scaling parameter**
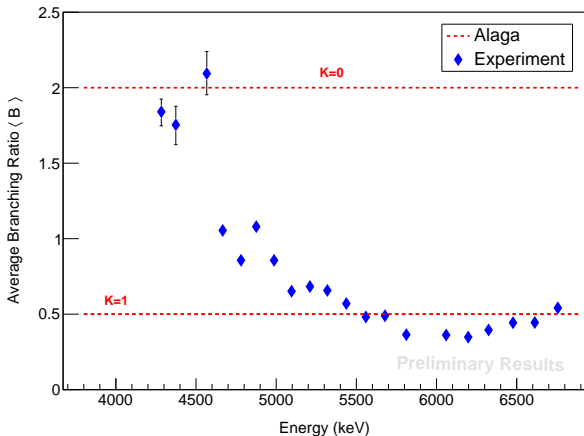
Simultaneous Bayesian fit of all detectors.!!

Fit code courtesy of Dr. Jörn Kleemann.

Spectral convolution @ 6.6 MeV
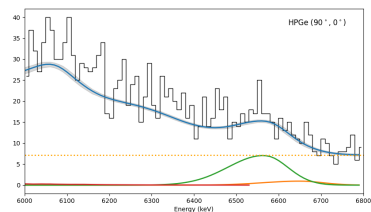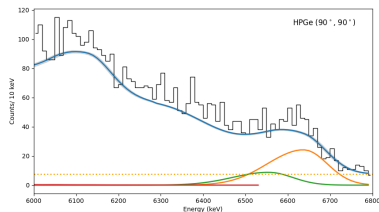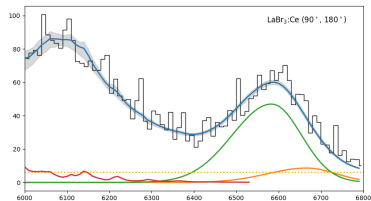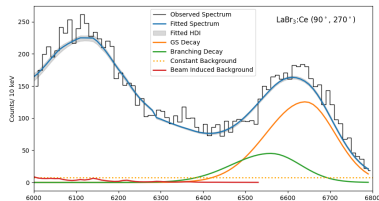
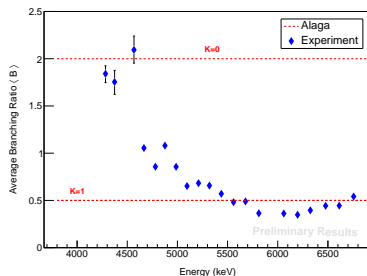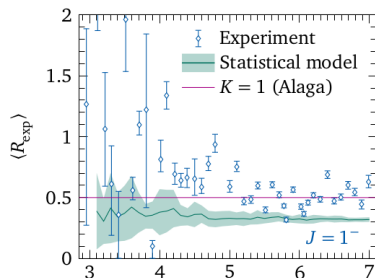# Pre-liminary - Average Branching ratio and the associated K quantum numbers

$$R = \frac{B(1^- \to 2_1^+)}{B(1^- \to 0_{\text{g.s.}}^+)} = \frac{I_\gamma(1^- \to 2_1^+)}{I_\gamma(1^- \to 0_{\text{g.s.}}^+)} \left(\frac{E_\gamma(1^- \to 2_1^+)}{E_\gamma(1^- \to 0_{\text{g.s.}}^+)} \right)^{-3} \tag{4}$$

^{154}Sm Preliminary - Comparison of the average branching ratios

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)

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 (γ,γ') technique to investigate dipole states in the PDR region.

- **Experimental Setup**: Employ the γ^3 setup at the HIγS facility.

- **Identification**: Determine the K quantum number of averaged 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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Thank you!!