EUROPEAN UNION

Structural Instruments 2014-2020

Extreme Light Infrastructure - Nuclear Physics (ELI-NP)

The electric dipole response of nuclei with Z<50

10th Workshop on Nuclear Level Densities and Gamma Strength – 19 May 2026

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eli nuclear physics

IFIN-HH

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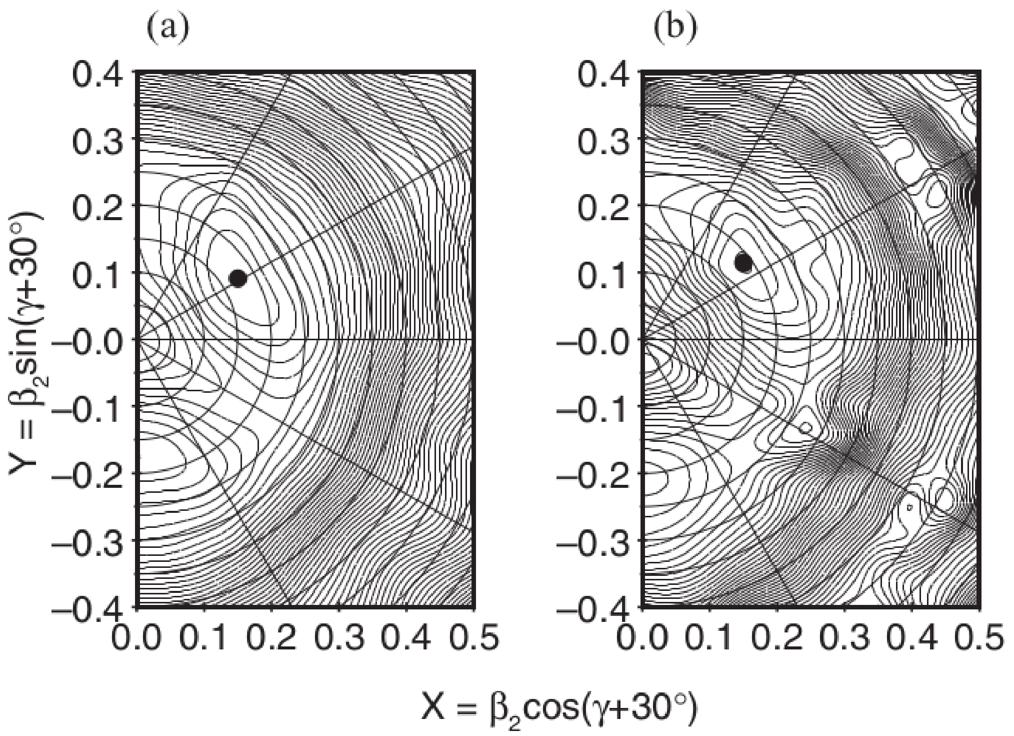
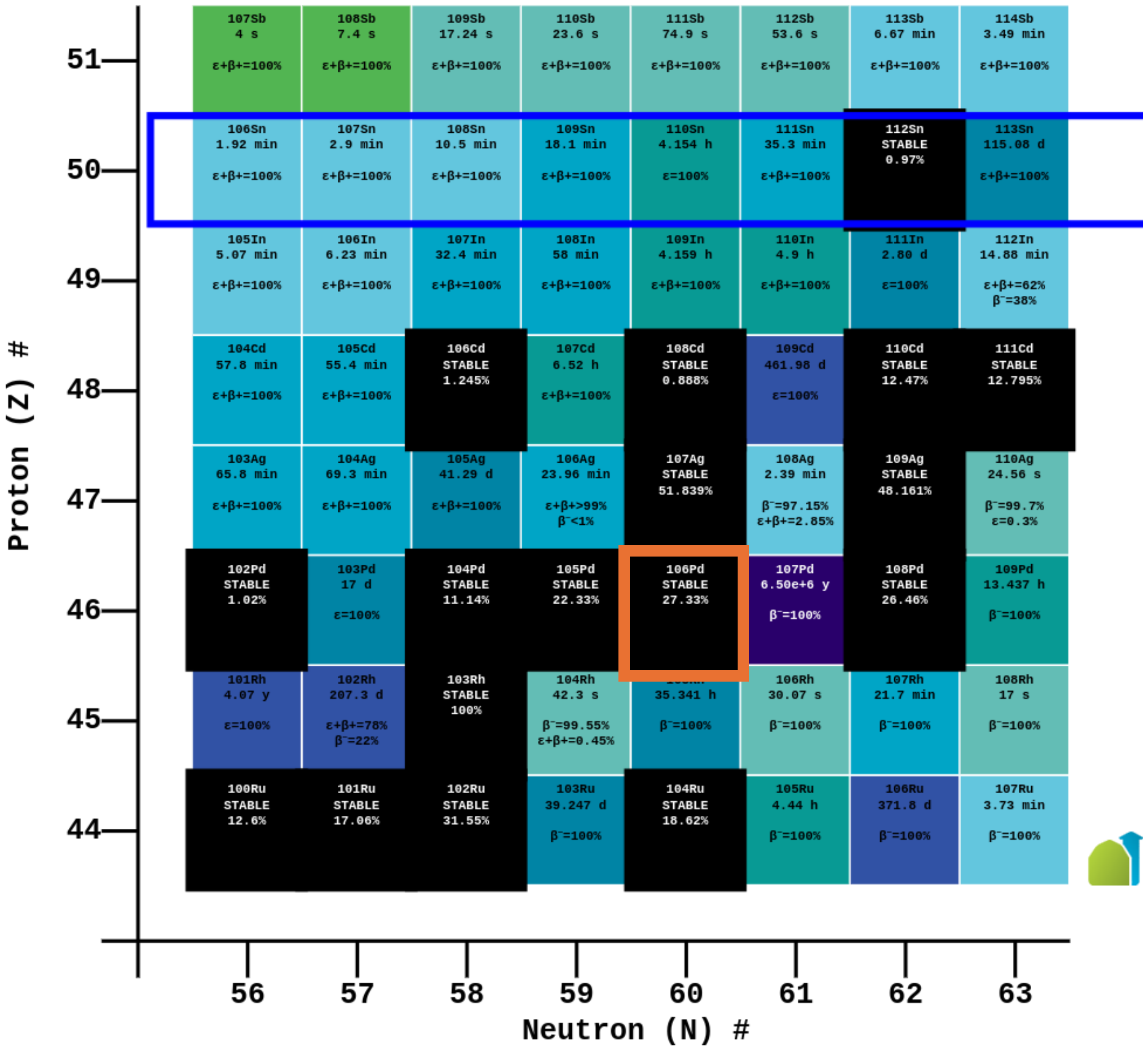
Objectives

- Determination of the E1 strength
- Determination of the dependence of the E1 strength in the transition region from vibrational to rotational nuclei
- The low-lying E1 states in the transitional Pd nuclei are expected to be weak and strongly fragmented

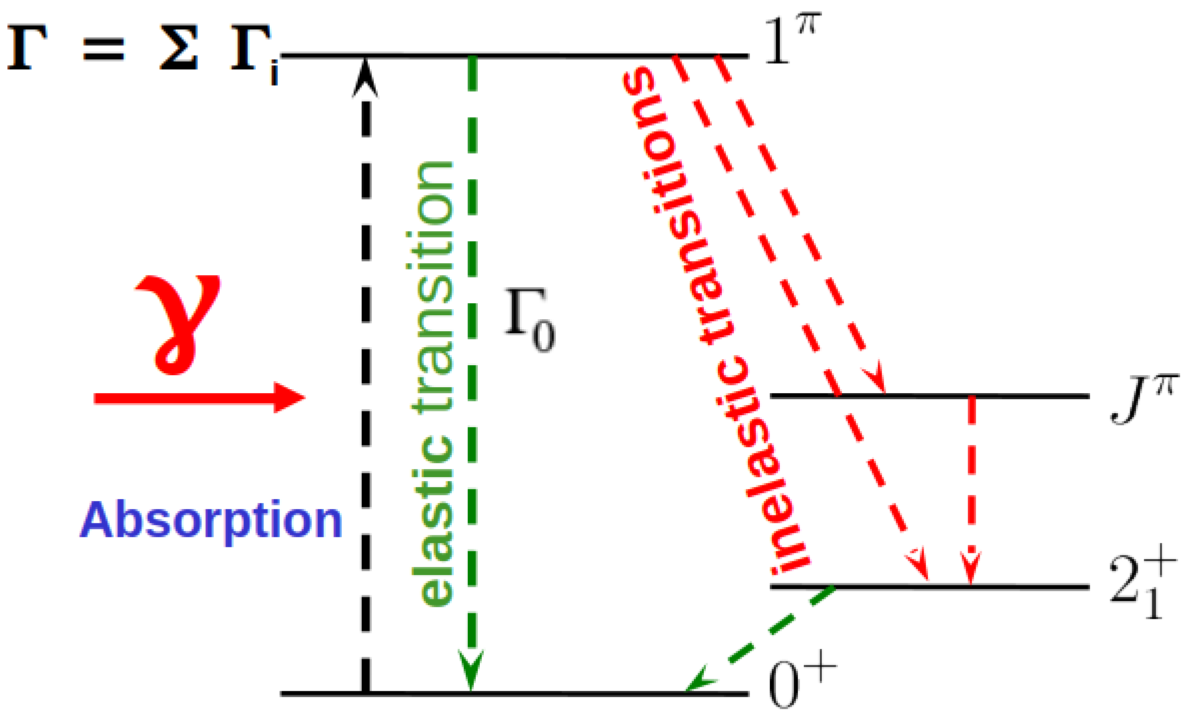


Potential energy surfaces of the lowest-lying band structures in ^{106}Pd calculated within the tilted-axis cranking model (C.E. He et al., Phys. Rev. C 86, 047302 (2012))



Position of the ^{106}Pd nucleus in the nuclear chart (https://www.nndc.bnl.gov/nudat3/)

Investigation method



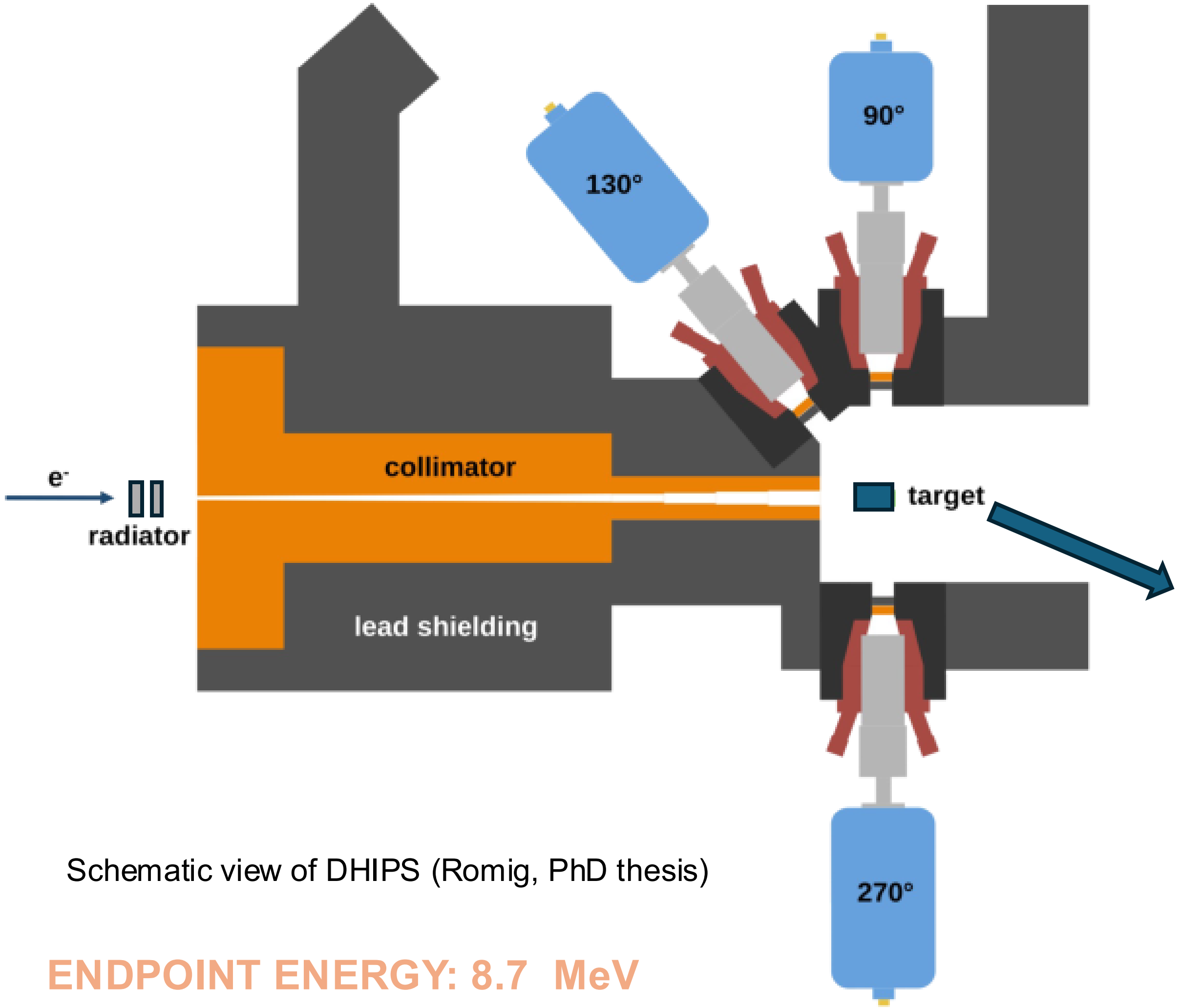
Spectroscopic quantities in NRF experiments:

- integrated photonuclear resonance cross sections $I_{s,f}$
- parity quantum numbers π of nuclear levels
- γ -ray transition energies E_{γ}
- total level widths Γ
- level lifetimes τ
- spin quantum numbers J of nuclear levels
- decay transition strengths $B(\Pi L; J_{\pi} \rightarrow J_{f f})$
- multipole-mixing ratios δ of γ -ray transitions

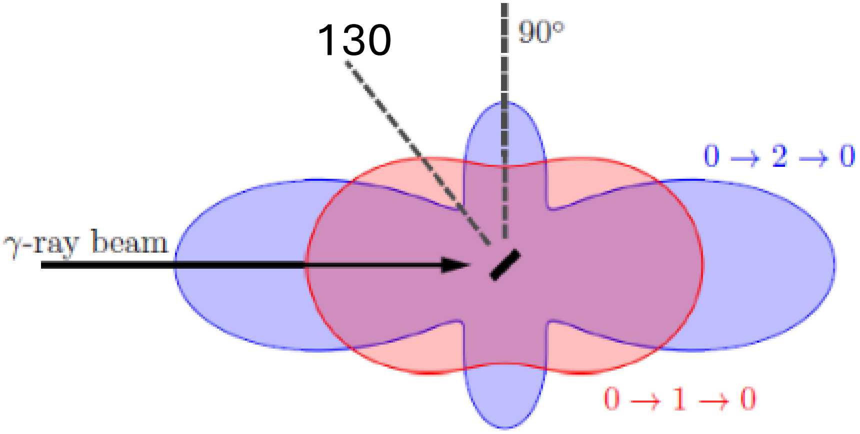
…

Experimental Setup

- The NRF experiment has taken place at TU Darmstadt, at **DHIPS** (**D**armstadt **H**igh **I**ntensity **P**hoton **S**etup)



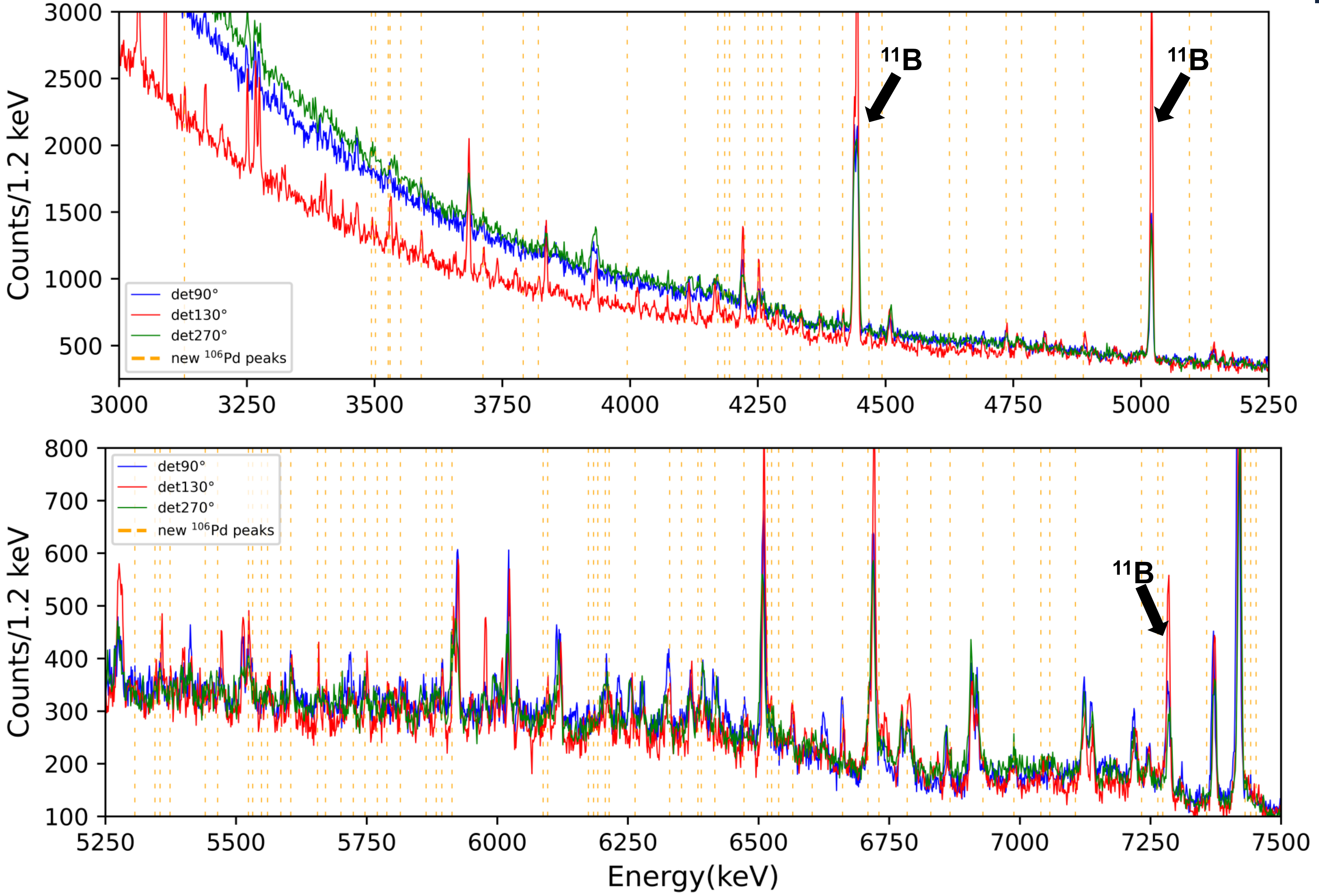
Schematic view of DHIPS (Romig, PhD thesis)



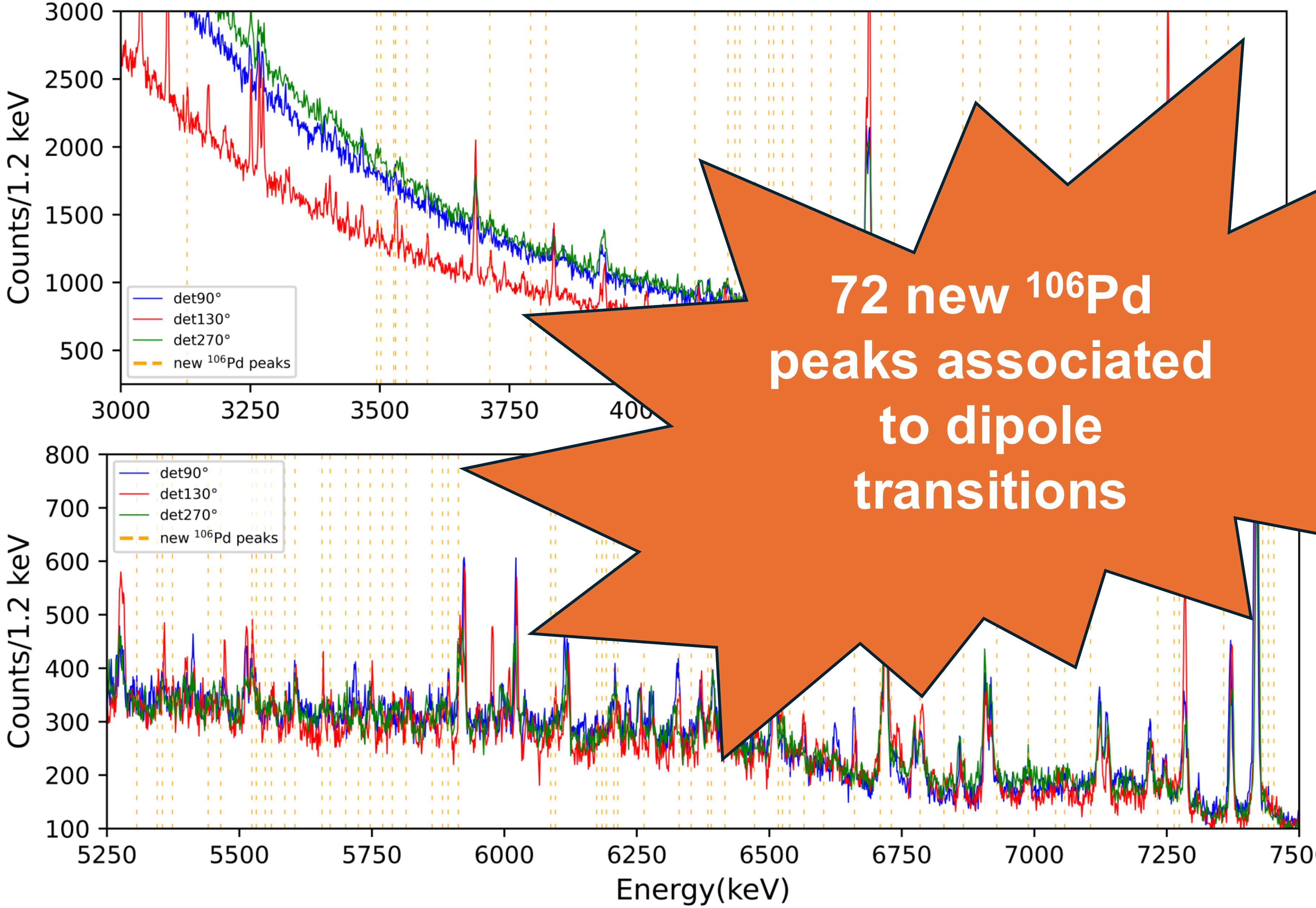
^{106}Pd target

ENDPOINT ENERGY: 8.7 MeV

^{106}Pd Spectra in the 3.5-7.5 MeV region



^{106}Pd Spectra in the 3.5-7.5 MeV region



72 new ^{106}Pd peaks associated to dipole transitions

NRF Reactions: Number of Target Nuclei

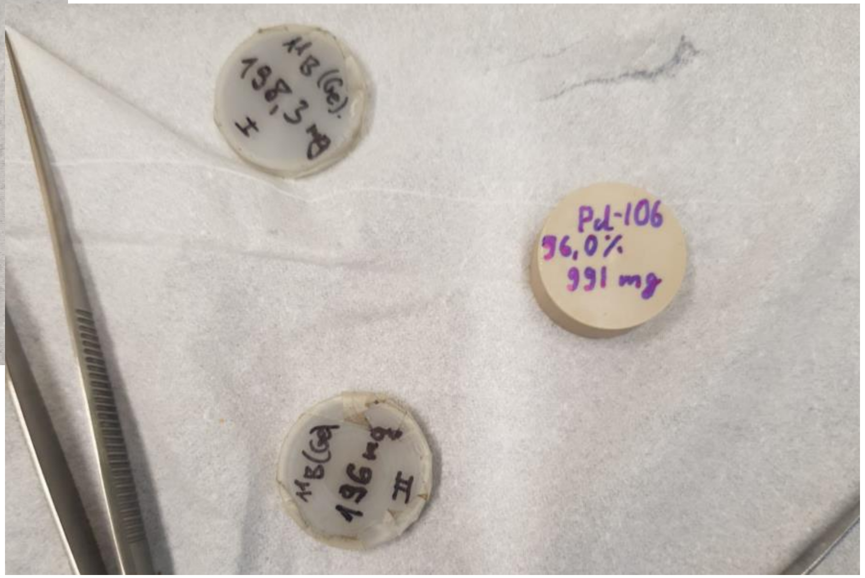
Final goal: calculating the integrated cross section

$$A_{j\to k} = N_T \cdot \varepsilon_{rel}\,(E_j - E_k) \cdot N_\gamma(E_j) \cdot I_{j\to k} \cdot W^{\mathrm{eff}}_{i\to j\to k}(\Theta, \Delta\Omega)$$

Number of counts

Fitting

^{106}**Pd mass: 0.991(1)g**

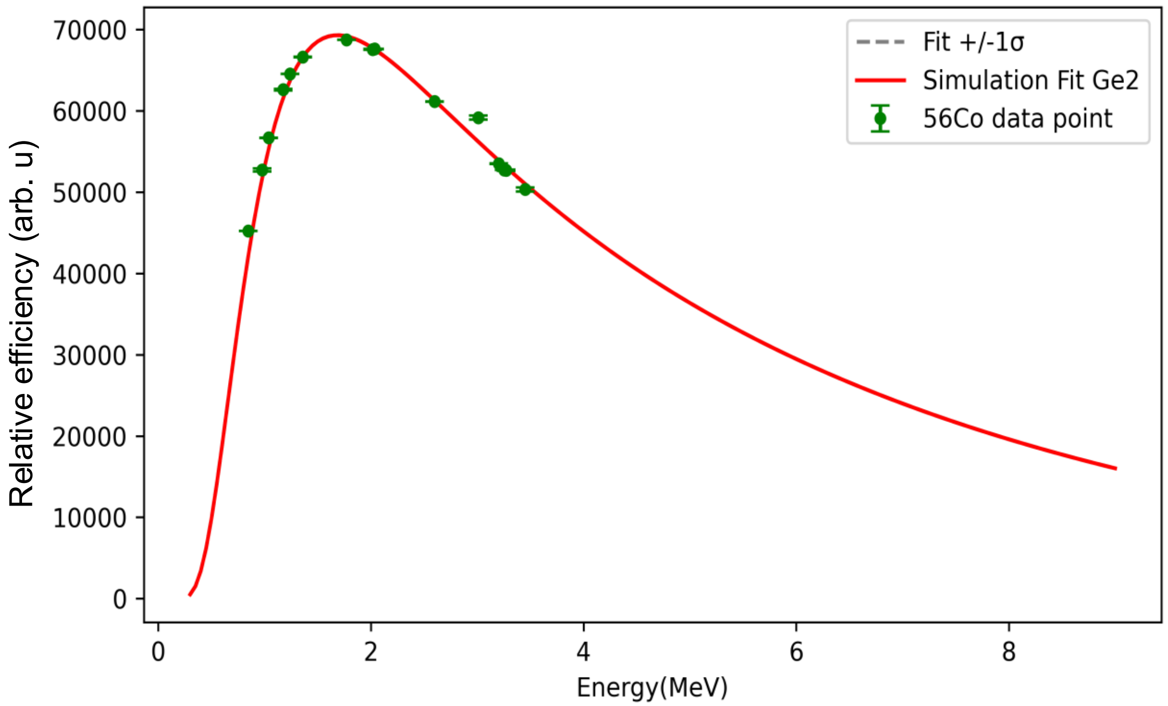


NRF Reactions: Efficiency calibrations

$$A_{j\to k} = N_T \cdot \varepsilon_{rel}\,(E_j - E_k) \cdot N_\gamma(E_j) \cdot I_{j\to k} \cdot W^{\mathrm{eff}}_{i\to j\to k}(\Theta, \Delta\Omega)$$

$A_{j\to k}$: Number of counts ← Fitting

N_T: Number of target nuclei ← Weighting

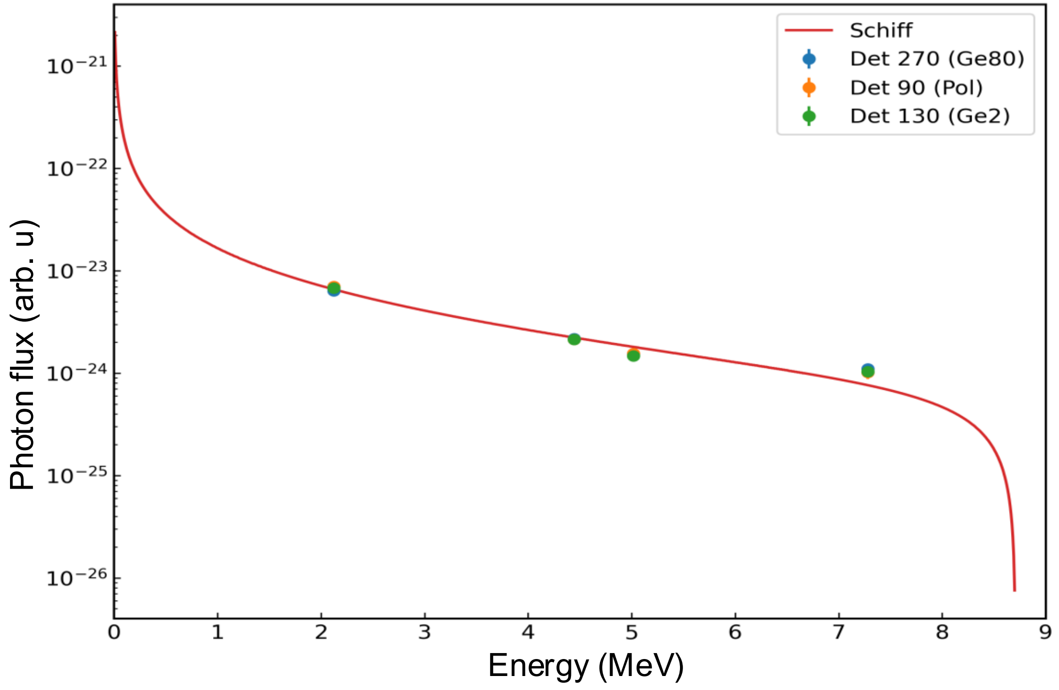


- A ^{56}**Co** source was used for calibrations
- GEANT4 simulations were used to determine the efficiency for the rest of the spectra

NRF Reactions: Photonflux calibrations

$$A_{j\to k} = N_T \cdot \varepsilon_{rel}\,(E_j - E_k) \cdot N_\gamma(E_j) \cdot I_{j\to k} \cdot W^{\mathrm{eff}}_{i\to j\to k}(\Theta, \Delta\Omega)$$

- $A_{j\to k}$: Number of counts ← Fitting
- N_T: Number of target nuclei ← Weighting
- $\varepsilon_{rel}(E_j - E_k)$: Relative efficiency ← GEANT4 Simulations
- $N_\gamma(E_j)$:

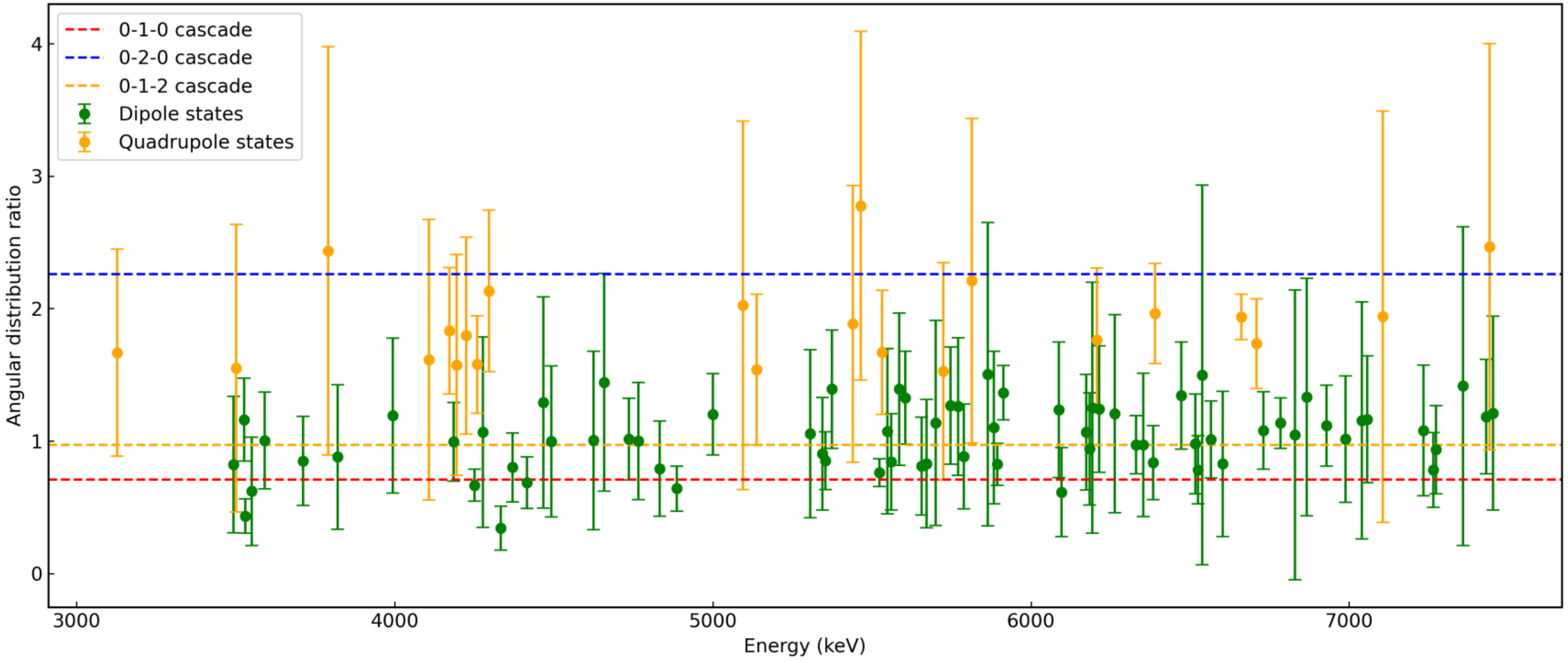


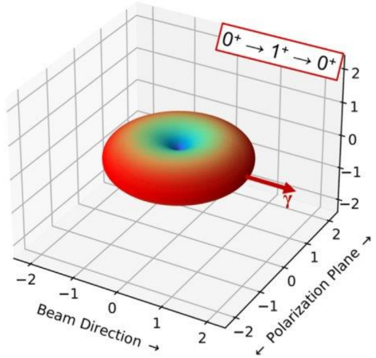
Obtained from Schiff's formula

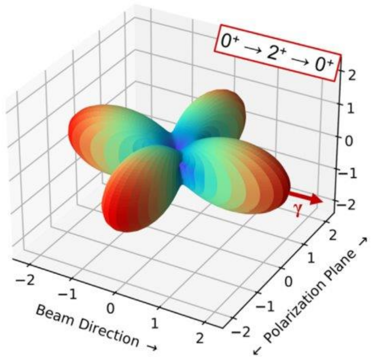
NRF Reactions: Angular distribution

$$A_{j\to k} = N_T \cdot \varepsilon_{rel}\,(E_j - E_k) \cdot N_\gamma(E_j) \cdot I_{j\to k} \cdot W^{\mathrm{eff}}_{i\to j\to k}(\Theta, \Delta\Omega)$$

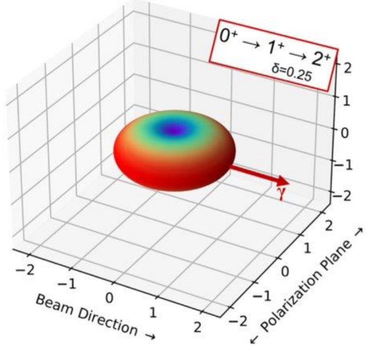
- Depends on the spins of the states involved in the cascade
- Can be calculated from the theory of electromagnetism and yield for an unpolarized photon beam







3-D plots of the angular distribution of ($\vec{\gamma}$, γ′) NRF intensity about a fully linearly polarized photon beam (Pγ = 1) entering from the left (A. Zilges, , D.L. Balabanski, J. Isaak, N. Pietralla, Progress in Particle and Nuclear Physics **122** (2022)))

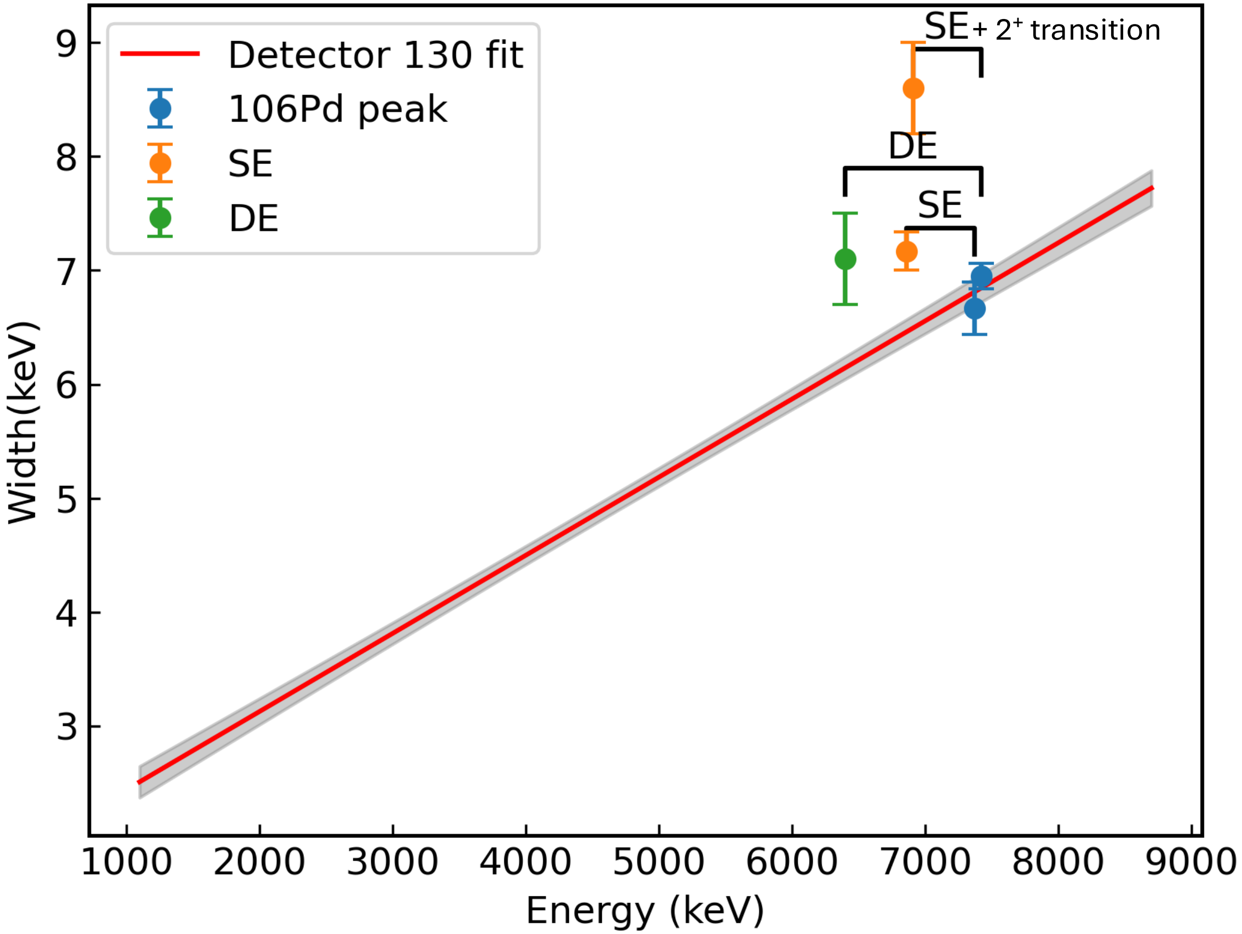


Single-Escape calibrations

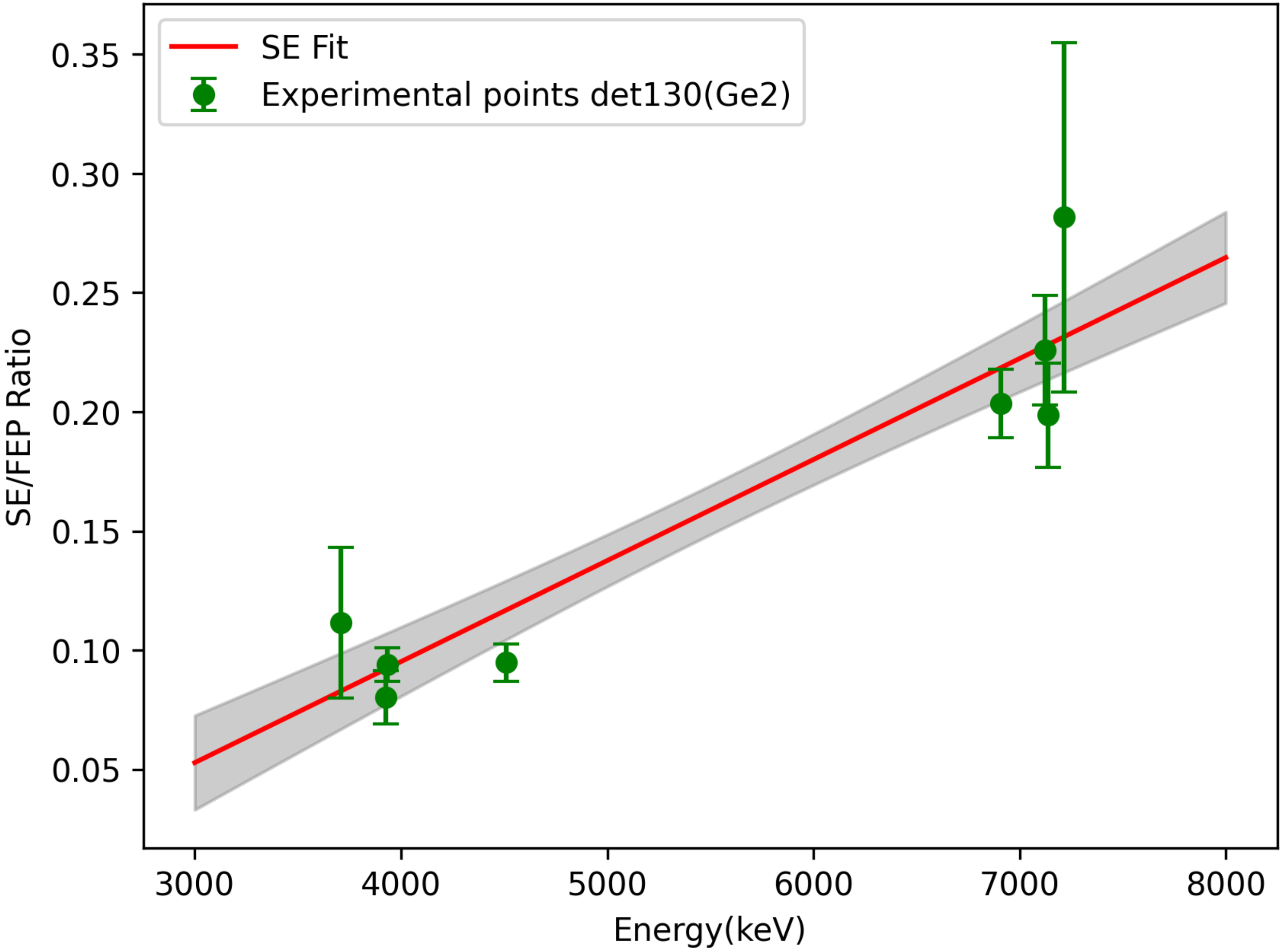
Main issue: the first 2+ level is situated at 511.82 keV

→ Makes it difficult to differentiate between a SE and a transition to the first 2+

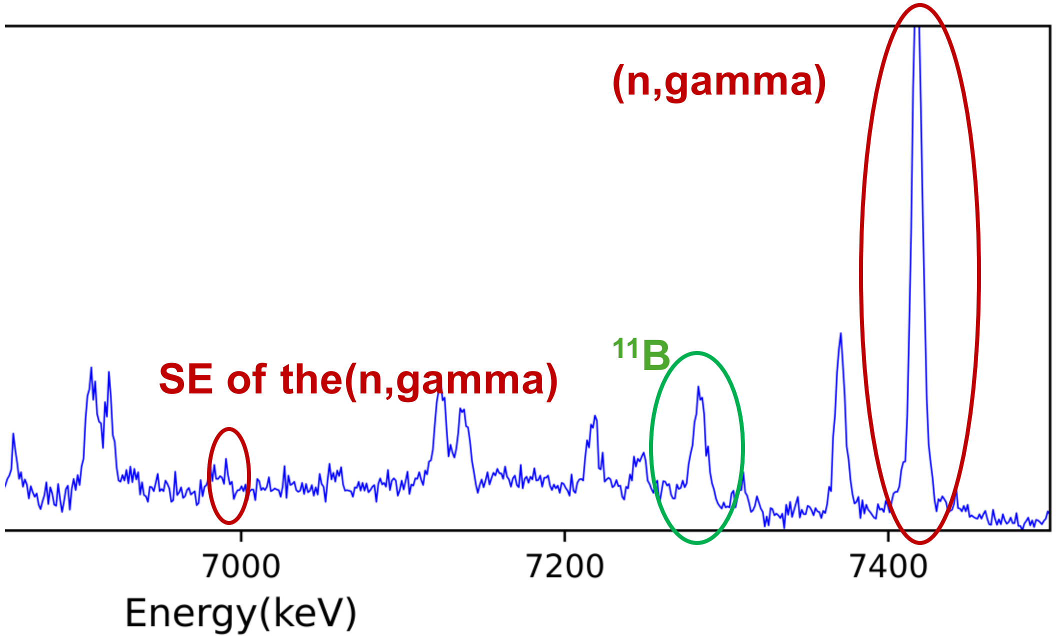
Example of width interpretation in case of a 2+ transition and a SE in a peak



Single-Escape calibrations

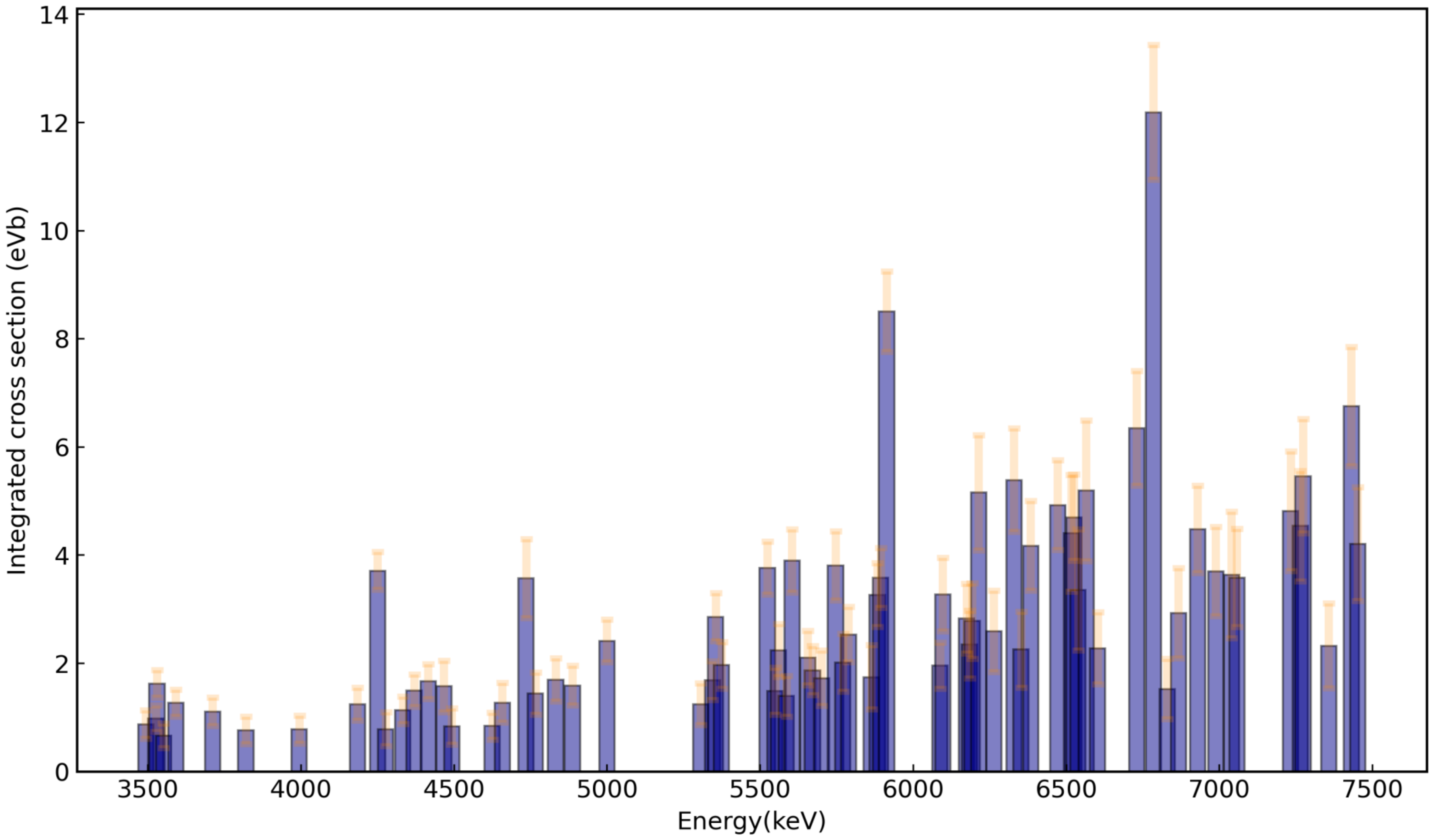


SE calibration for the detector at 130 degrees



Integrated cross sections

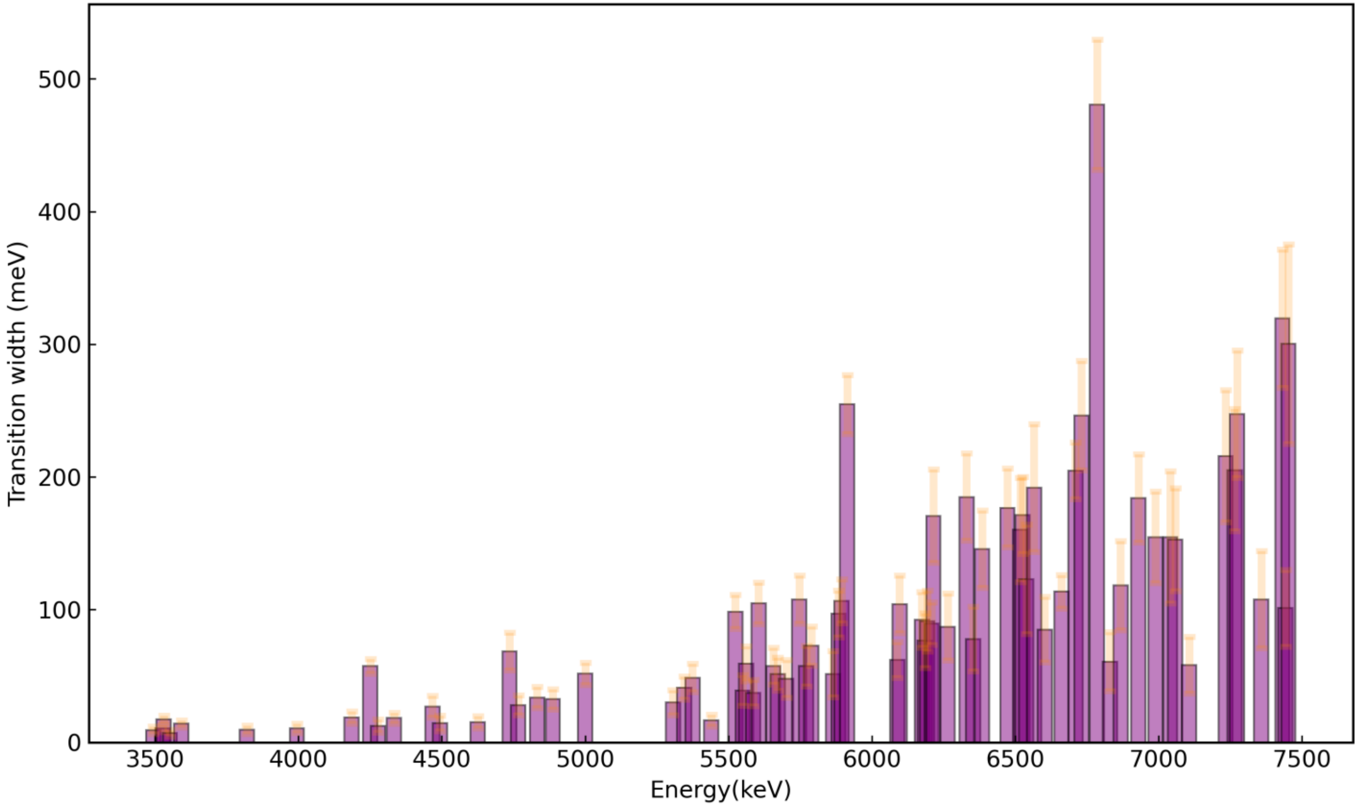
- The integrated cross section for the excited state – g.s transitions has been calculated, revealing the shape of the PDR.



$$I_{i\to f} = g\pi^2\left(\frac{\hbar c}{E_i}\right)^2\frac{\Gamma_0\Gamma_f}{\Gamma}$$

Branching ratios can be obtained from:

$$\frac{\Gamma_f}{\Gamma_0} = \frac{I_{i\to f}}{I_{i\to 0}} = \frac{A_{i\to f}\,\epsilon_{\mathrm{rel}}(E'_{\gamma,i\to 0})\,W_{0\to i\to 0}(\theta)}{A_{i\to 0}\,\epsilon_{\mathrm{rel}}(E'_{\gamma,i\to f})\,W_{0\to i\to f}(\theta)}.$$



Conditions for a peak to be obtained from a branching transition instead of a ground-state transition:

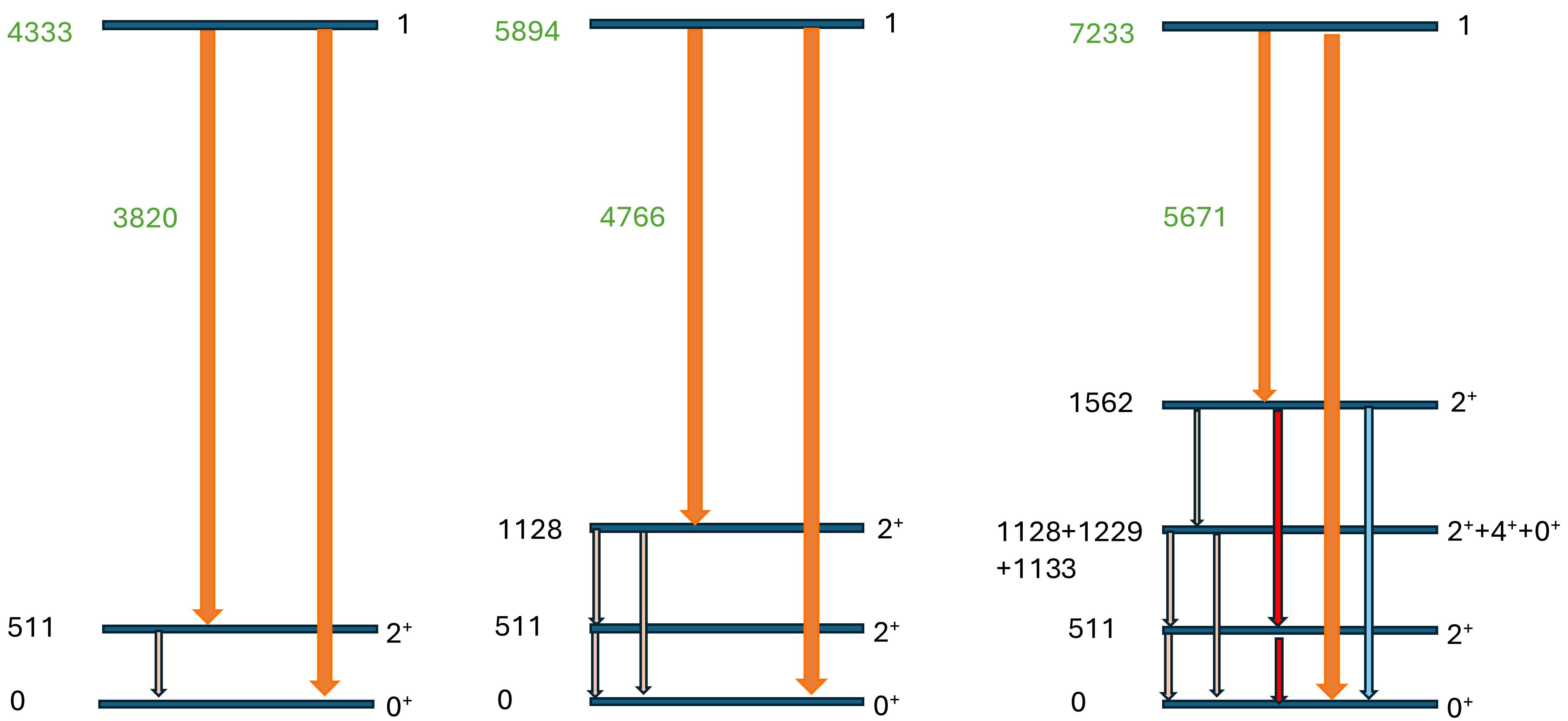
1. The photon emitted after such a branching transitions has the energy $E_{\gamma'} \approx E_i - E_f$

2. After looking into the angular distribution, checking if the transition is among the favoured ones

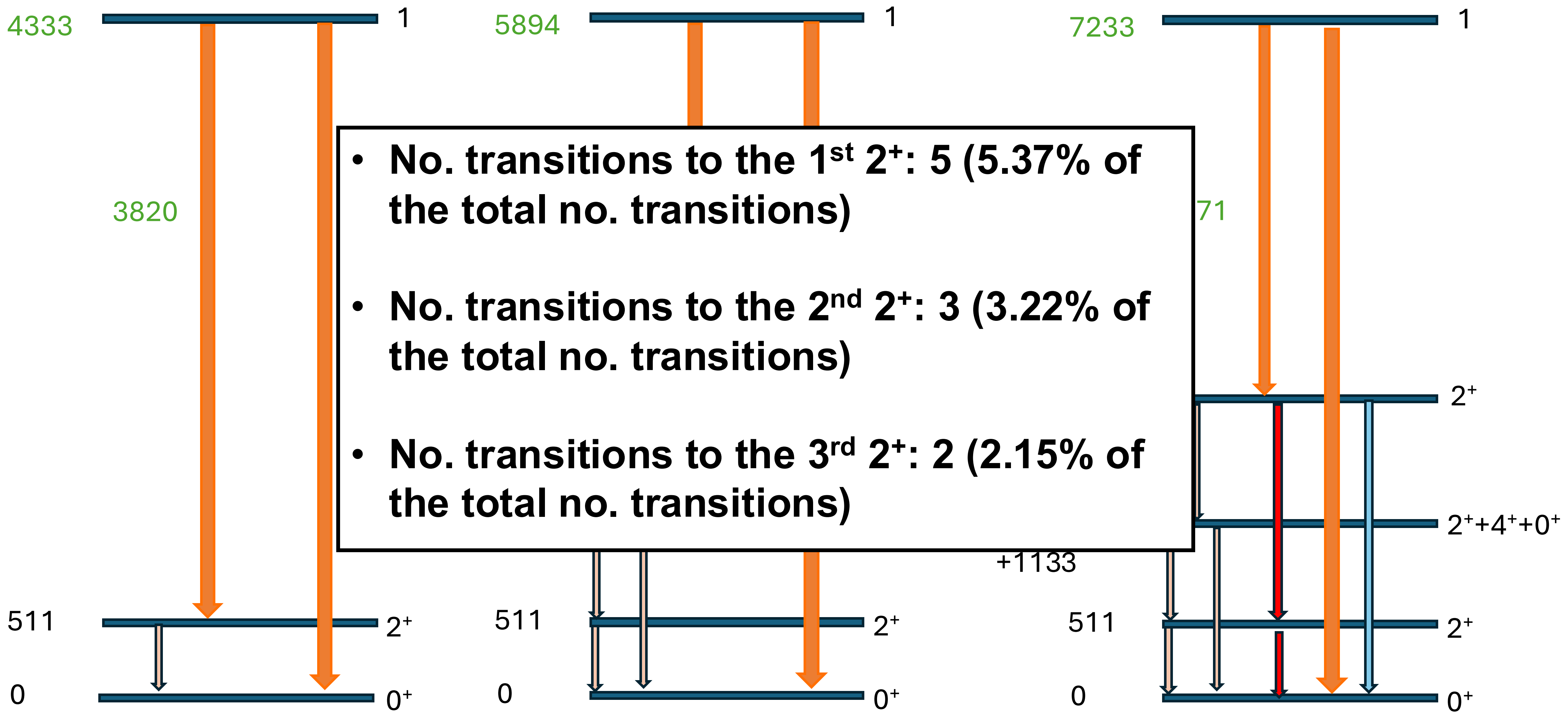
$$|J - J_f| \le L \le J + J_f$$

$$(-1)^L \pi\pi_f = \begin{cases} +1 & \text{for } \Pi = E \\ -1 & \text{for } \Pi = M \end{cases}$$

Branching to other 2$^+$ states - examples



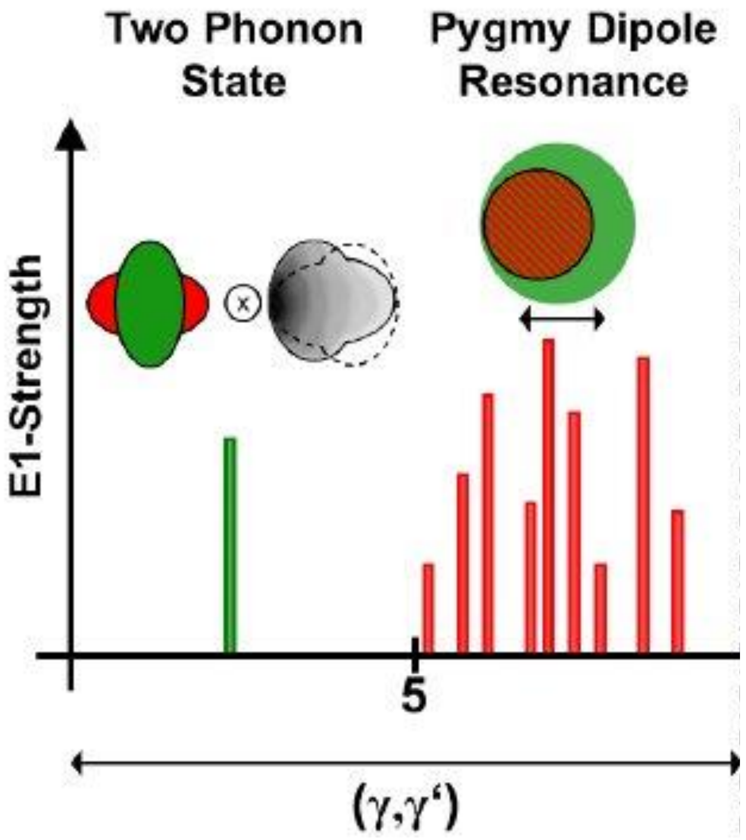
Branching to other 2^+ states - examples

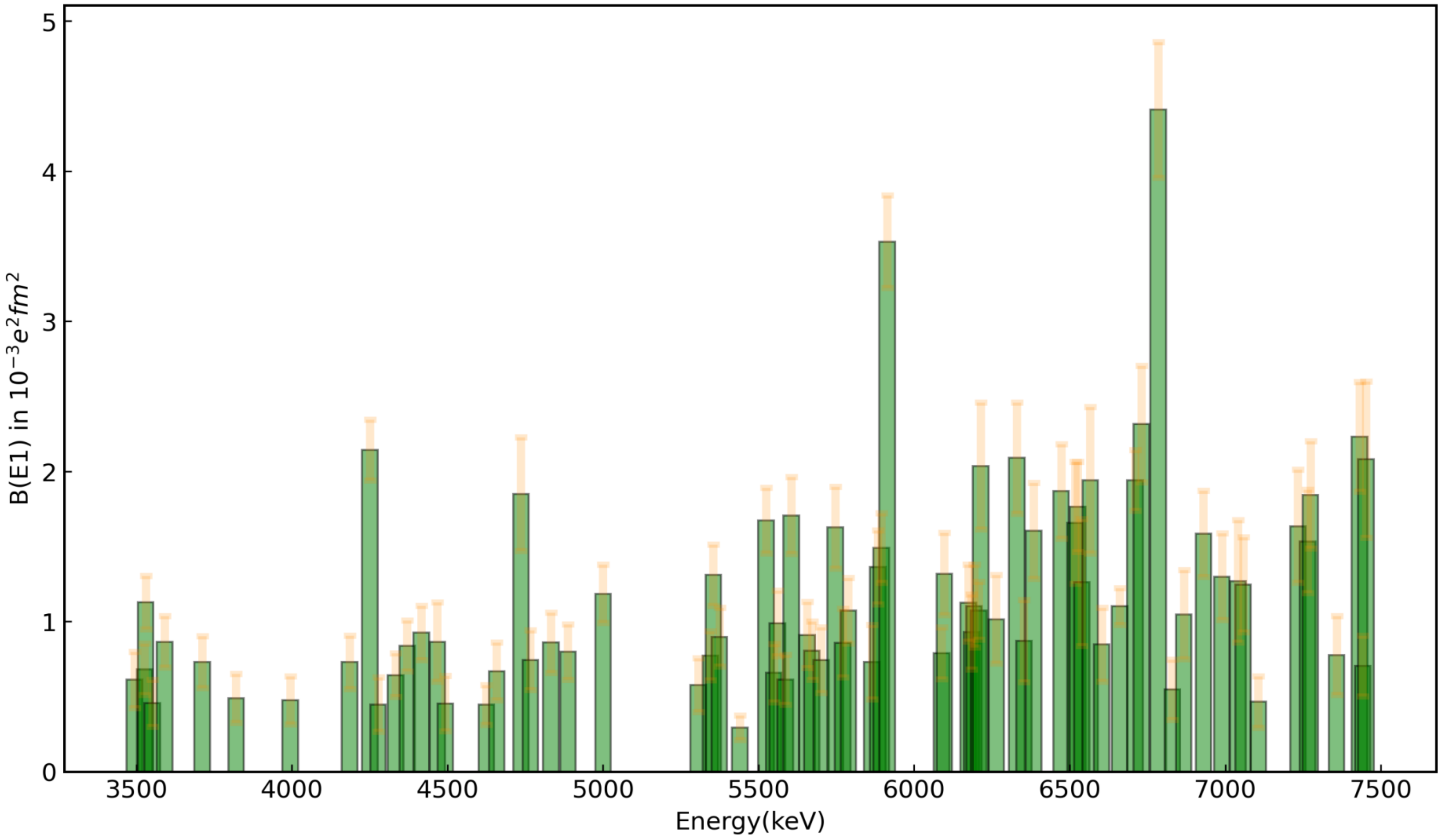


- **No. transitions to the 1st 2^+: 5 (5.37% of the total no. transitions)**
- **No. transitions to the 2nd 2^+: 3 (3.22% of the total no. transitions)**
- **No. transitions to the 3rd 2^+: 2 (2.15% of the total no. transitions)**

B(E1)

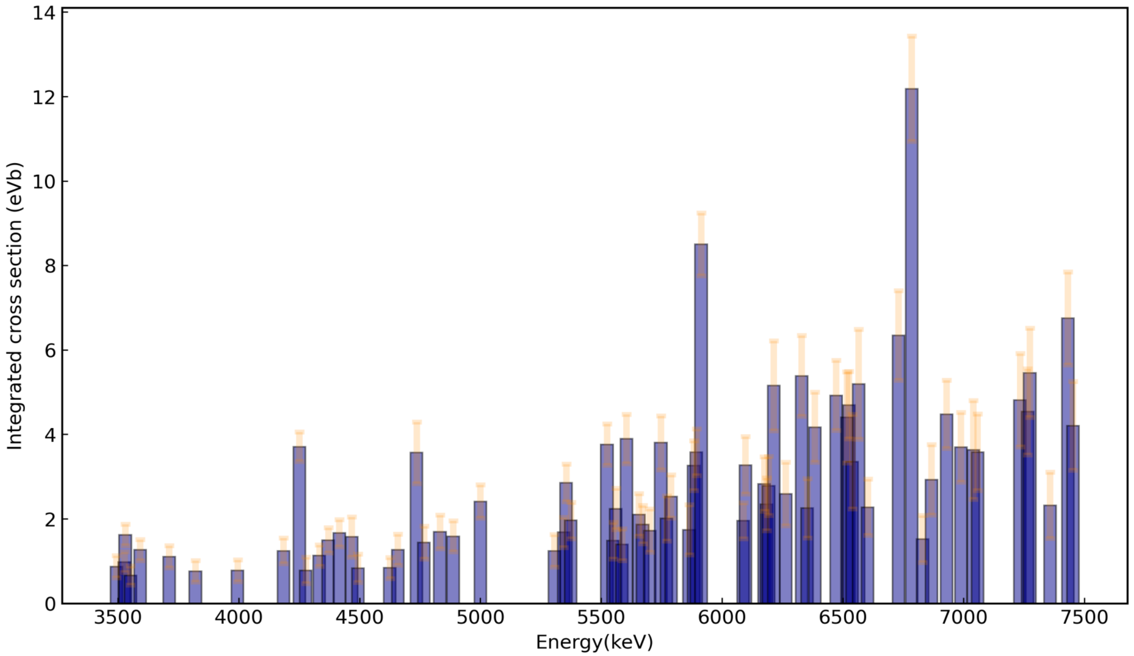
The PDR shape can be observed after the final calculations of the reduced dipole transition strength.

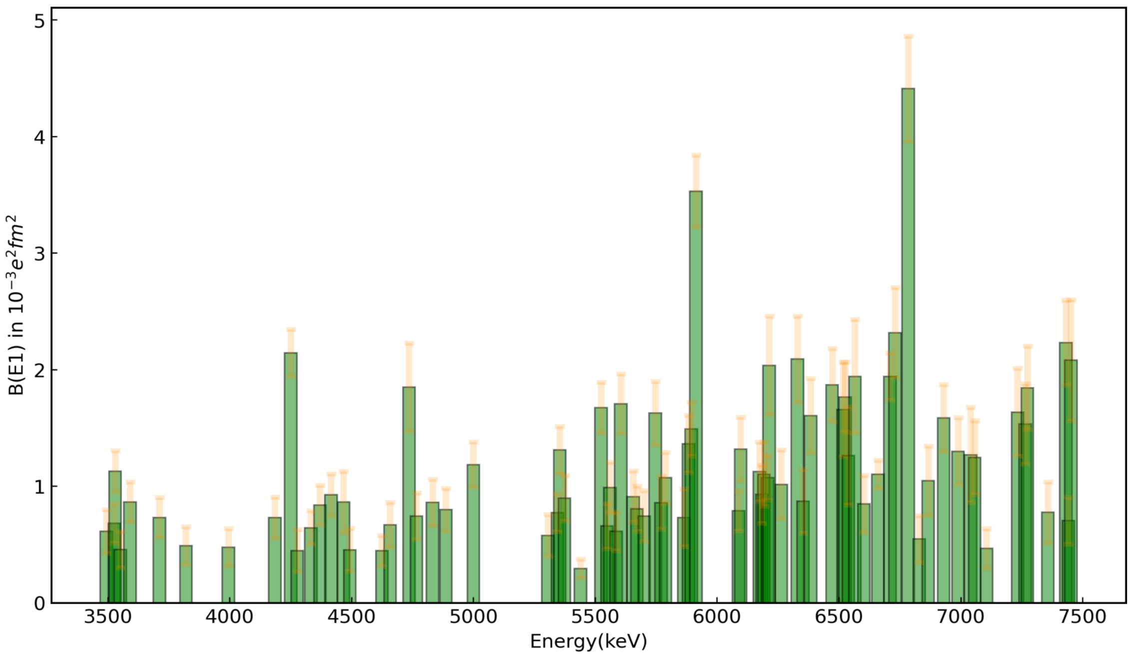




Conclusions and Outlook

- 72 new ^{106}Pd dipole transitions have been uncovered
- Preliminary results for the integrated cross section and the reduced transition strength have been calculated
- Another experiment at TU Darmstadt will take place this year, at a lower energy, reducing the effects from feeding
- In order to determine the parities, another experiment at TUNL Labs is necessary





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Thank you for your attention!

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NRF Reactions: Checkpoint in ^{11}B

- The angular distributions for the ^{11}B calibration points were calculated and compared to literature values
- The results seem to agree