Studying the microscopic structure of the low-energy electric dipole response in ^{120}Sn

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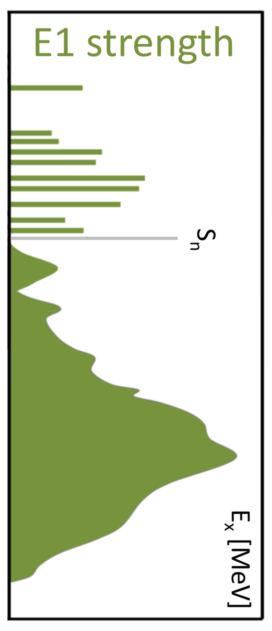
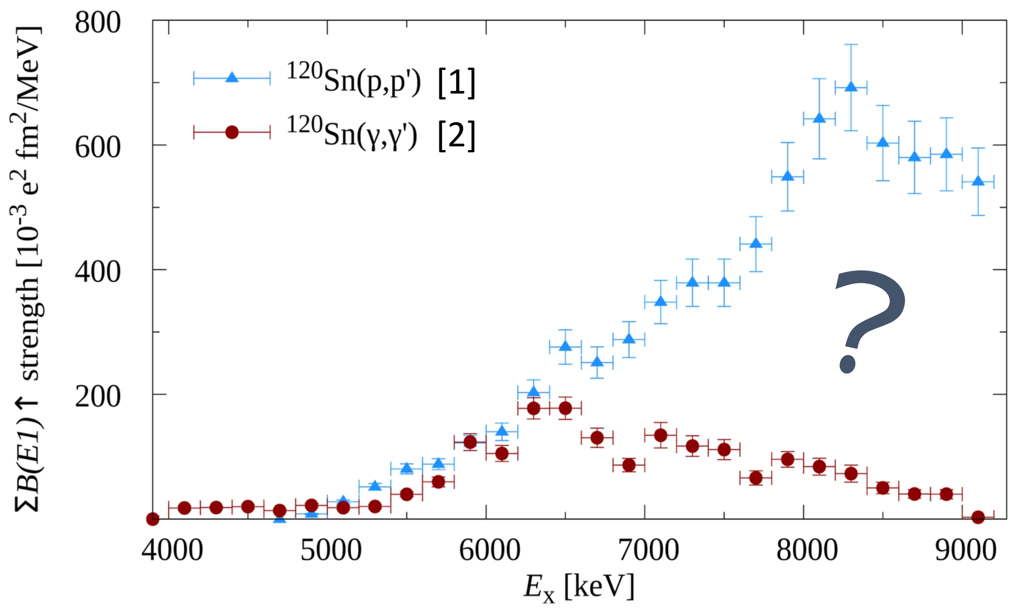
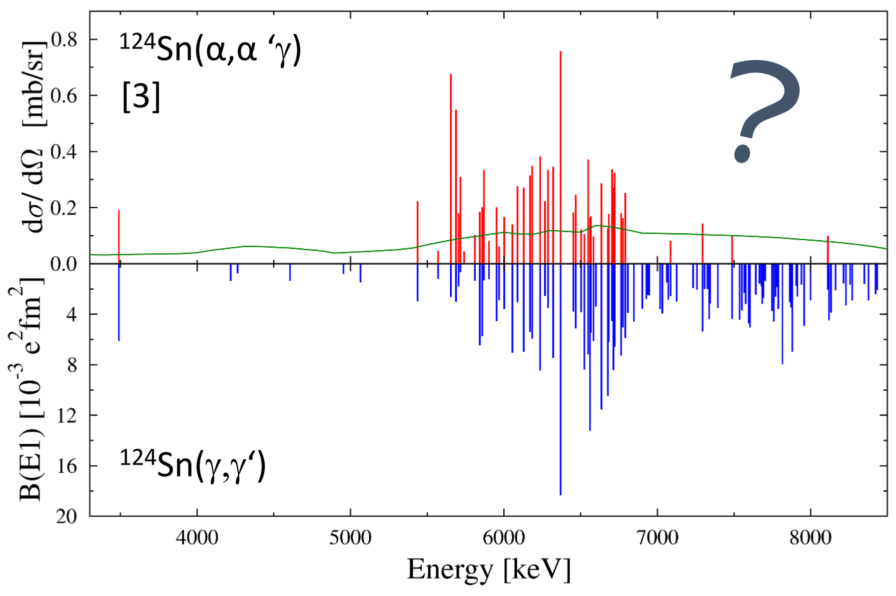




Prerequisites

The accumulation of low-energy electric dipole strength below S_n, often called Pygmy Dipole Resonance (PDR) , is a common feature of medium to heavy mass nuclei. The generating nuclear structure is still puzzling and results vary between probes (➡) and experiments (⬅). One of the missing pieces is the single-particle nature of the excited 1^- states, which has been studied using the (d,pγ) reaction and a novel theoretical approach that combines detailed nuclear structure input and reaction theory.



Theory

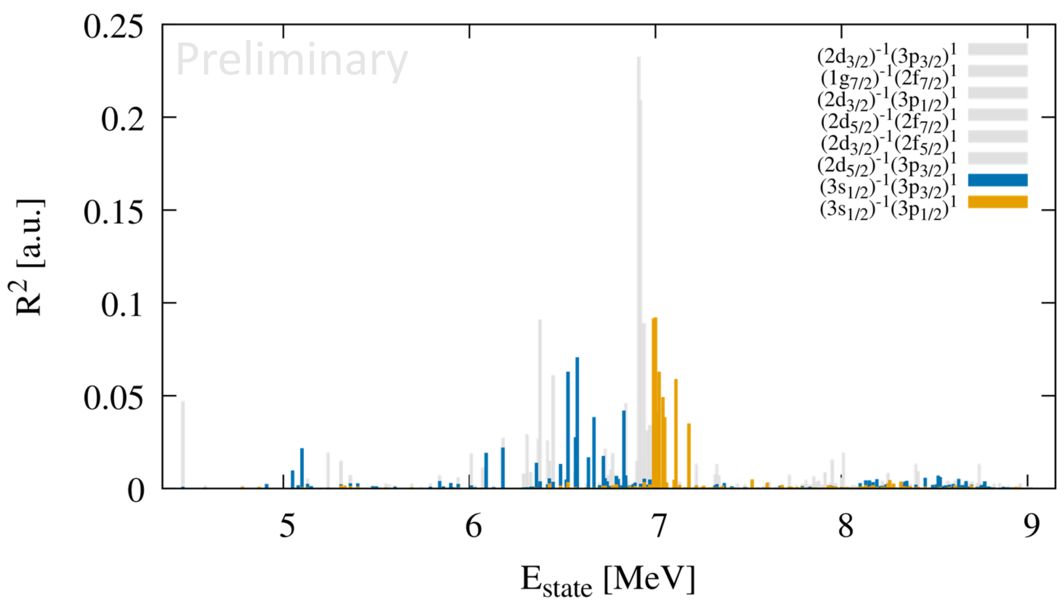
Nuclear structure information from energy-density functional (EDF) plus **quasiparticle-phonon model** (QPM) theory were **combined with reaction theory** (QPM+Reaction) to consistently predict (d,p) cross sections, γ-decay branching, (d,pγ) yields, and energy-integrated (γ,γ') cross sections for excited $J^\pi = 1^-$ states in ^{120}Sn.

Each QPM state is built from contributions that represent one phonon, two phonons, three phonons

$$\Psi_\nu = \Big\{ \sum_i R_i(\nu)\, Q^+_{1Mi} + \sum_{\substack{\lambda_1 i_1\\ \lambda_2 i_2}} P^{\lambda_q i_1}_{\lambda_2 i_2}(\nu) \left[Q^+_{\lambda_1\mu_1 i_1} \times Q^+_{\lambda_2\mu_2 i_2}\right]_{1M} + \sum_{\substack{\lambda_1 i_1 \lambda_2 i_2\\ \lambda_3 i_3 I}} T^{\lambda_1 i_1 \lambda_2 i_2 I}_{\lambda_3 i_3}(\nu) \left[\left[Q^+_{\lambda_1\mu_1 i_1} \times Q^+_{\lambda_2\mu_2 i_2}\right]_{IK} \times Q^+_{\lambda_3\mu_3 i_3}\right]_{1M} \Big\} \Psi_0$$

The (d,p) reaction selects only one-phonon contributions that are accessible from the ground state of ^{119}Sn!

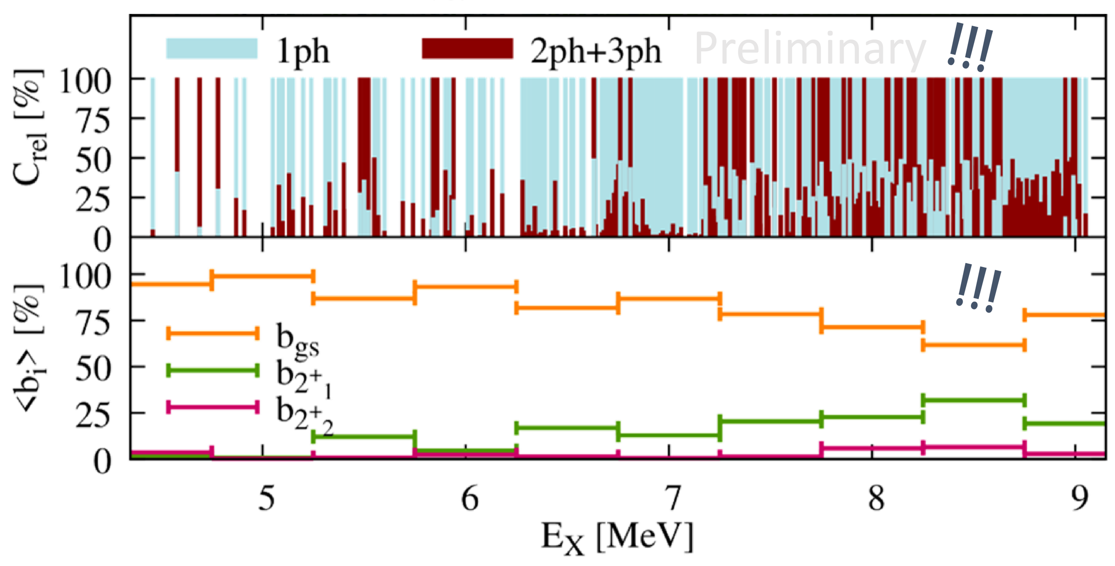
$$\frac{d\sigma_\nu}{d\Omega}(\theta) = \frac{\mu_i \mu_f}{(2\pi\hbar^2)^2}\frac{k_f}{k_i} \times \left| u_{3p_{1/2}} R_{3p_{1/2}}(\nu)\, \psi^{3\,p_{1/2}}_{\frac{1}{2}\frac{1}{2}}\, \mathcal{T}_{p_{1/2}}(\theta) + u_{3p_{3/2}} R_{3p_{3/2}}(\nu)\, \psi^{3\,p_{3/2}}_{\frac{1}{2}\frac{3}{2}}\, \mathcal{T}_{p_{3/2}}(\theta) \right|^2$$



The distribution of one-phonon contributions (R^2) to each final state is **concentrated between 6 and 7 MeV** for the two configurations relevant for the excitation of 1^- states in ^{119}Sn(d,p). Two- and three-phonon contributions (P^2 and T^2) are not shown.

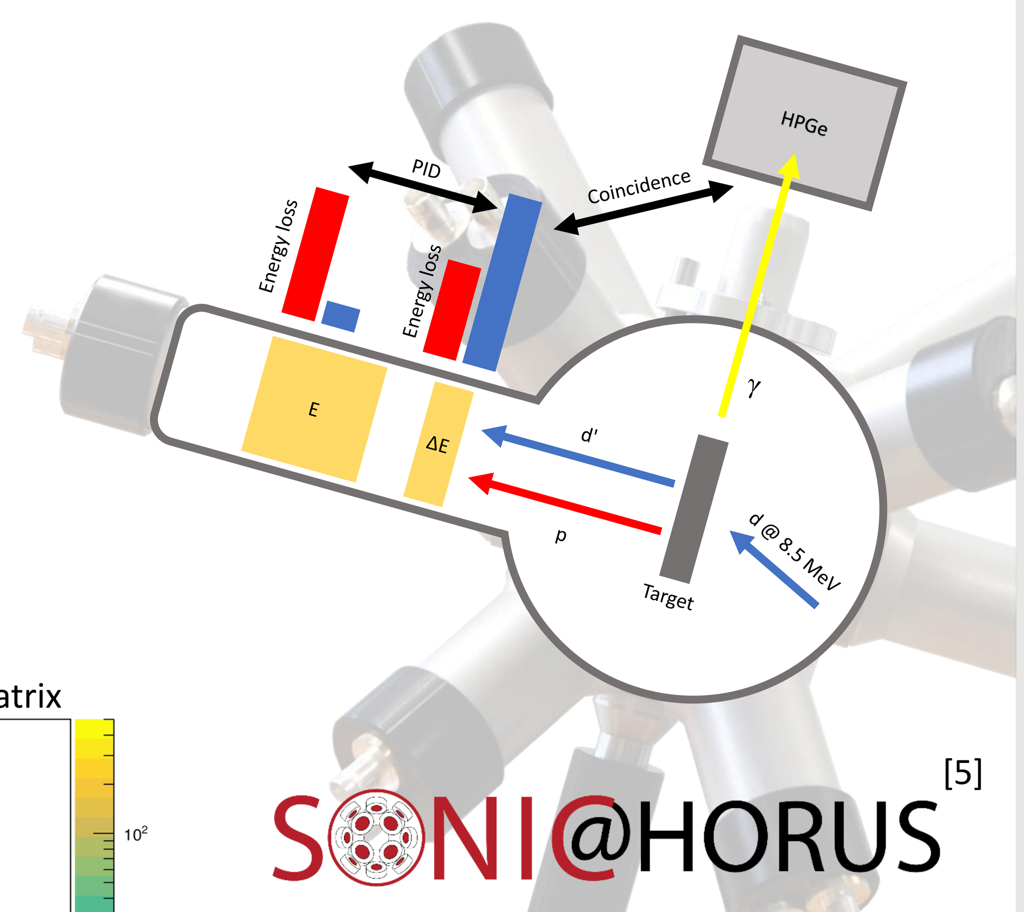
$$C^{1ph}_{rel} = \sum R^2 / \sum(R^2 + P^2 + T^2)$$
$$C^{2ph+3ph}_{rel} = \sum(P^2 + T^2) / \sum(R^2 + P^2 + T^2)$$

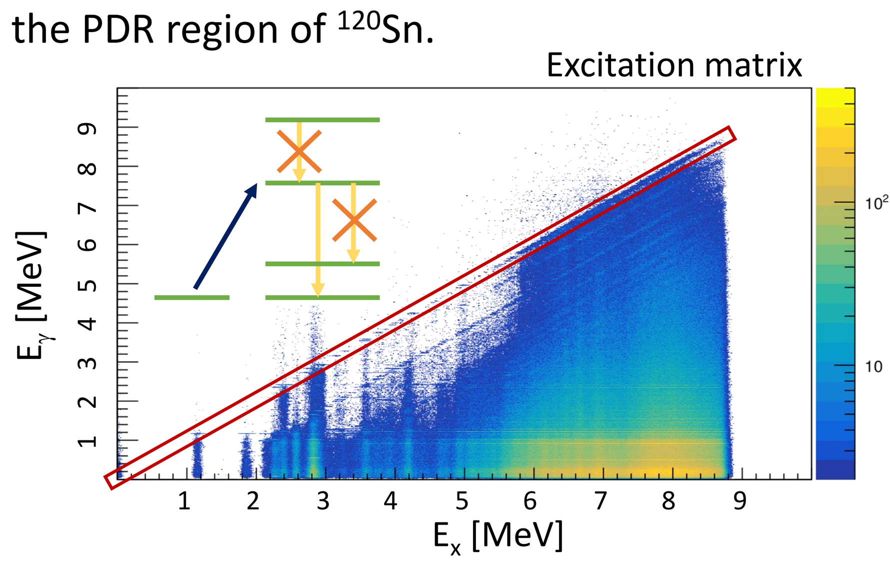
The QPM gives access to intricate details of each state's wave function. **Dominant one-phonon character** is predicted below 7 MeV, while higher lying states show increased complexity and decreased γ-decay branching to the ground state. Possible cause for the discrepancy between (γ,γ') and (p,p')!



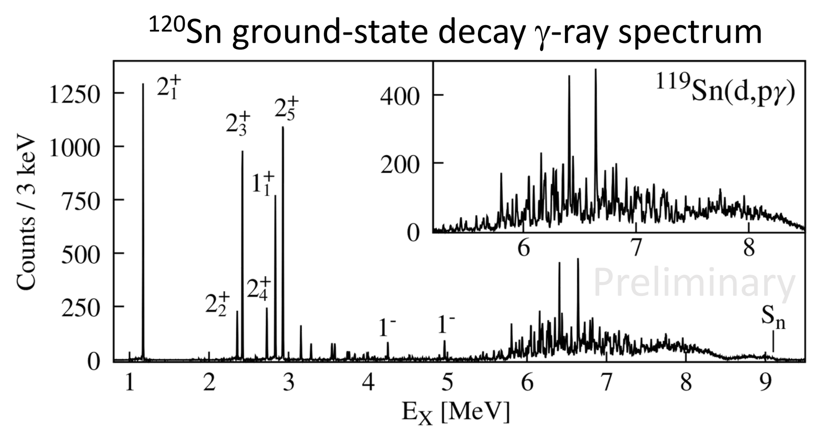
Experiment

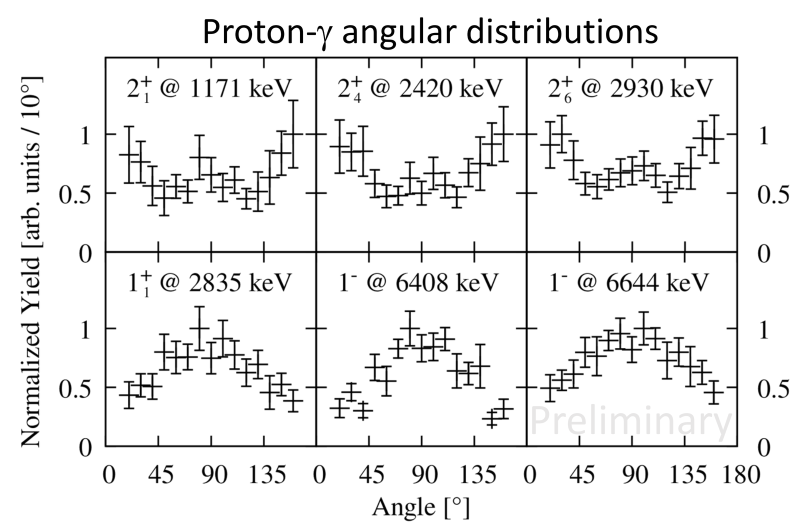
A ^{119}Sn(d,pγ)^{120}Sn experiment at an energy of E_d = 8.5 MeV was performed at the 10 MV FN-Tandem accelerator laboratory at the University of Cologne. The combined particle and γ-ray spectrometer **SONIC@HORUS** allowed the identification and detailed investigation of excited $J^\pi = 1^-$ states in the PDR region of ^{120}Sn.

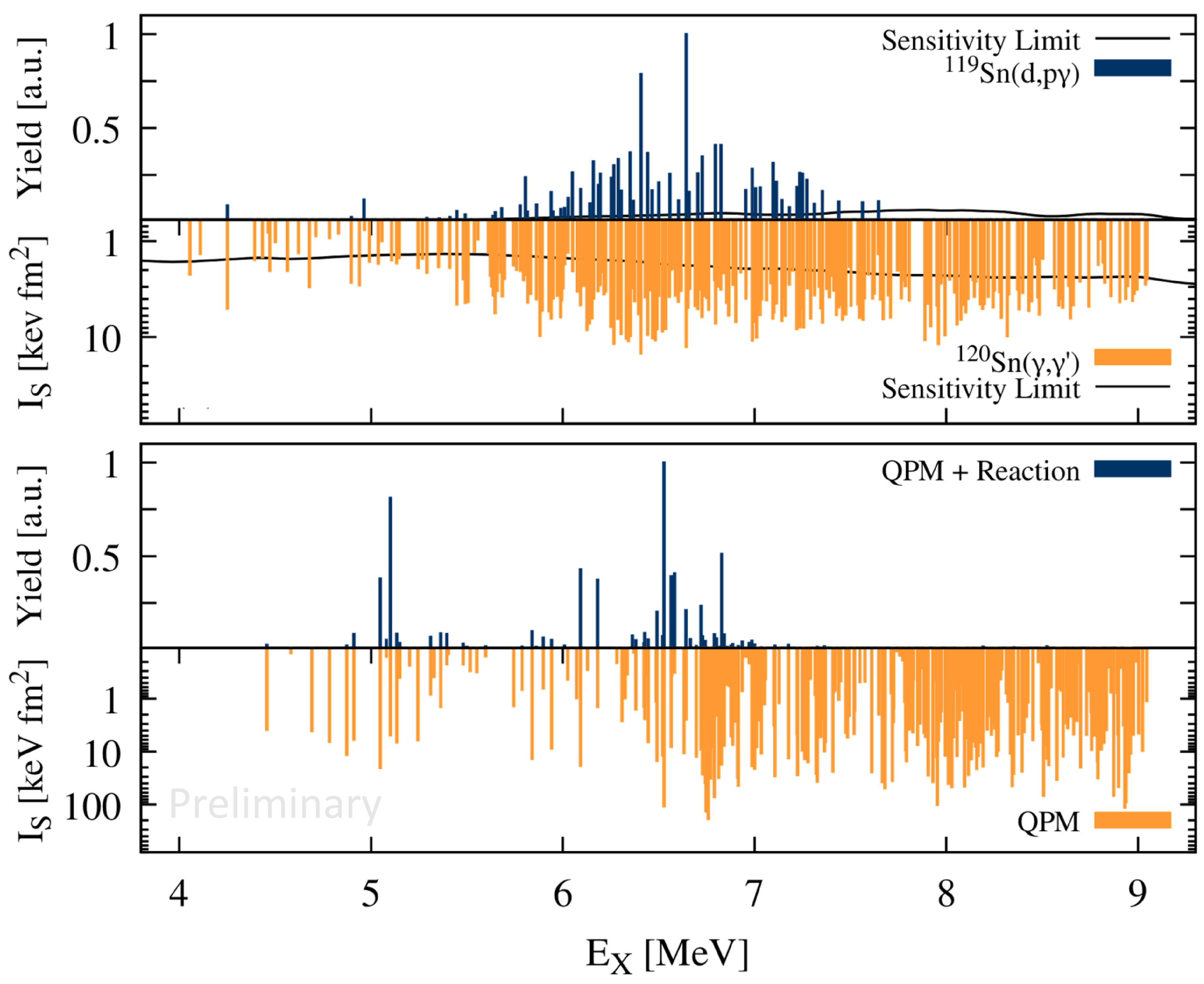




The selection of ground-state γ-decays enhances the **sensitivity to 1^- states** and yields a γ-ray spectrum free from any contamination. The Doppler-corrected γ-ray spectrum shows a strong response in the PDR region of ^{120}Sn. Of the **80 discretely observed lines**, 64 were also observed in a (γ,γ') experiment on ^{120}Sn [2]. Proton-γ angular distributions allow to identify dominant J=1 character between 5 and 7.5 MeV, while an M1 contribution in the energy range can be neglected [4]. In conclusion, **all observed γ-decays stem from $J^\pi = 1^-$ states in ^{120}Sn.**

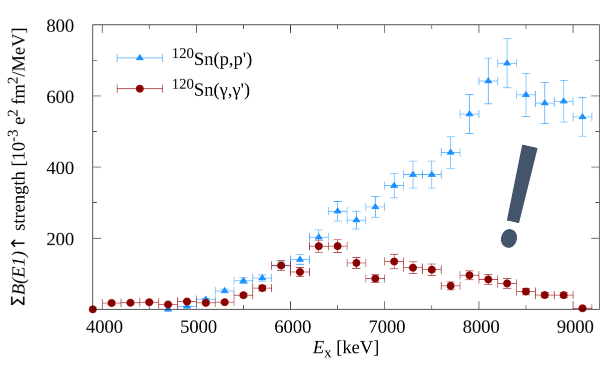






The EDF+QPM approach **correctly predicts relevant single-particle energies** not just for the doubly-magic ^{208}Pb [6], but also for the tin isotopes. Especially the prediction of the here observed **$3p_{1/2}$** and **$3p_{3/2}$** strength in neutron-rich tin isotopes has been demanded recently in the literature [7].

Careful analysis of the QPM wave functions allows to investigate nuclear structure in the PDR region. The QPM **reproduces the suggested decrease** of ground-state γ-decay branching towards higher excitation energies due to more complex configurations [4].



$$\sum I^{NRF}_S = 337(21)\,\text{keV fm}^2$$
$$\sum I^{QPM}_S = 243 - 360\,\text{keV fm}^2$$
(d,pγ) > 1 % – 0.5 %

The (d,pγ) yields and energy-integrated (γ,γ') cross sections predicted by the QPM+Reaction approach show **excellent agreement with experimental data**. The (d,pγ) strength is fragmented to the lower-energy part of the PDR region, reproducing the (d,pγ) centroid energy of 6.49 MeV. Summed (γ,γ') cross sections for states excited with both probes also show excellent agreement, taking into account the (d,pγ) experimental sensitivity limit of approx. 1 %.

If the observed **splitting** can be found in additional and even more neutron rich isotopes, this might have a significant impact on the *r* process?

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