Experimental work on nuclear level densities and photon strength functions at ELI-NP/IFIN-HH

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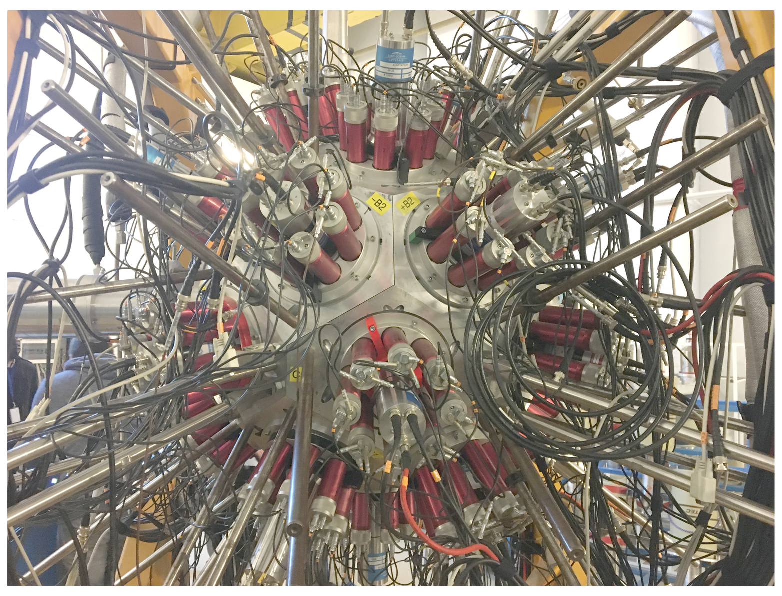
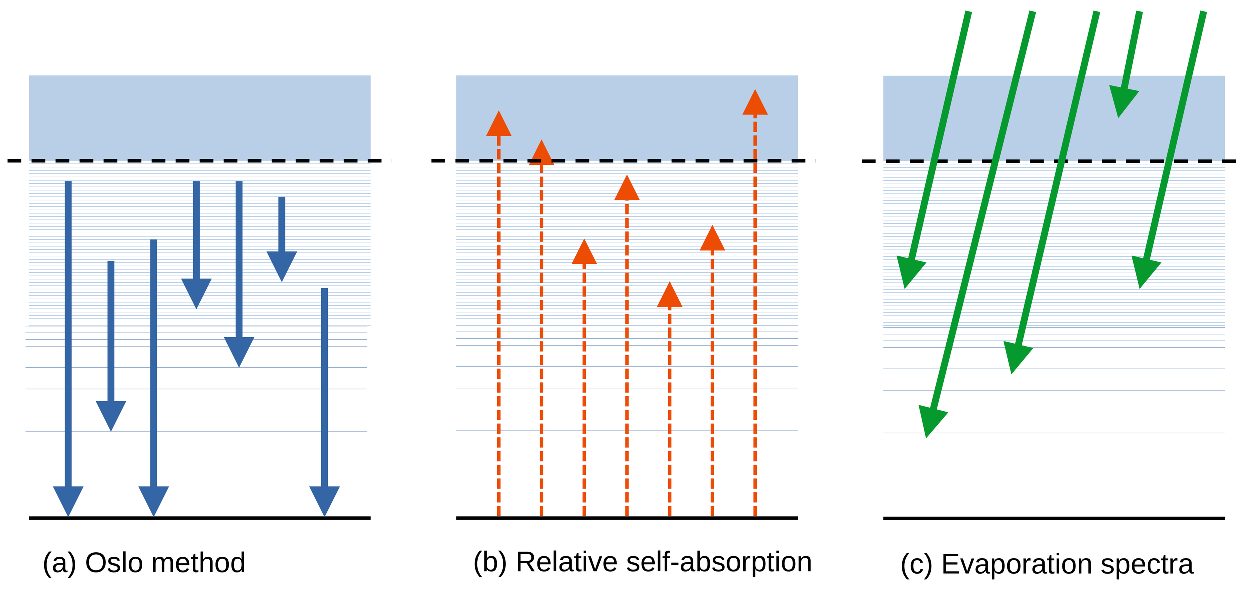
What made us start doing this?

To initiate the ELI-NP scientific program already during the implementation phase a set of campaigns with the large volume $LaBr_3$:Ce and $CeBr_3$ detectors [1] for large efficiency of high-energy γ rays, together with four HPGe detectors for spectroscopy, have been performed at the 9MV Tandem accelerator facilities at IFIN-HH. These experimental campaigns from 2022-2025 have already proved very successful with several publications on multiple topics related to, among many other, light nuclei, statistical properties, collective motion and astrophysics.

ELI-NP

Part of the scientific cases at ELI-NP will be the measurement of electromagnetic dipole response and strength distribution. These are among the key inputs for reaction rate calculations in astrophysics.





Proton scattering

Making a note here: Huge success!

First goal: We needed to reproduce the results from the Oslo group to convince ourselves of the analysis methods.

This was done in a first $(p, p'\gamma)$ experiment on ^{112,114}Sn [2] in 2023.

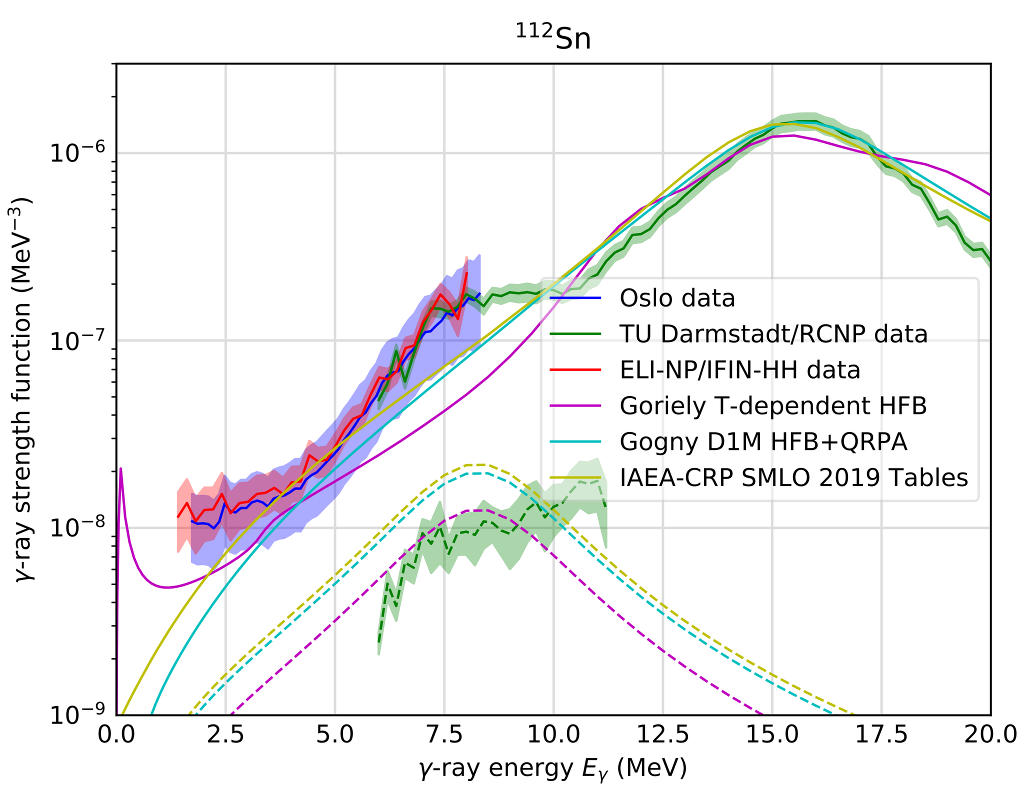


Figure 1. Experimental γ-ray strength function of ^{112}Sn obtained from ELI-NP/IFIN-HH, Oslo data, and RCNP data compared with three typical parametrisations implemented in the code. [2]

Astrophysics impact

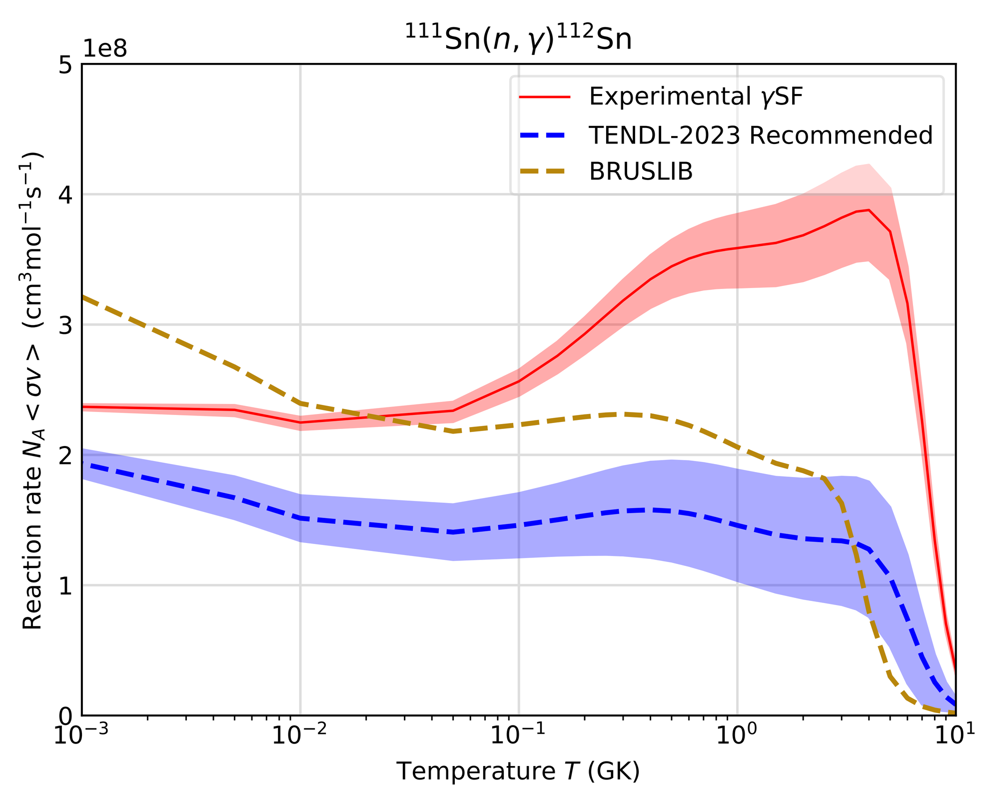


Figure 2. Reaction rates for the radiative neutron capture calculated from the experimental data, compared to BRUSLIB, and 10 models in the TENDL-2023 library. [2]

Including these data into the statistical model gives an updated reaction rate for p-process type (n, γ) reactions, performed by Yi Xu. This is an example for ^{112}Sn.

Photons vs. protons

One of the goals was to compare photonuclear methods like (γ, n), (γ, γ') and $(\vec{\gamma}, \gamma'\gamma'')$, to $(p, p'\gamma)$. We did this for ^{128}Te [3]. The results are very promising, showing agreement within error bars.

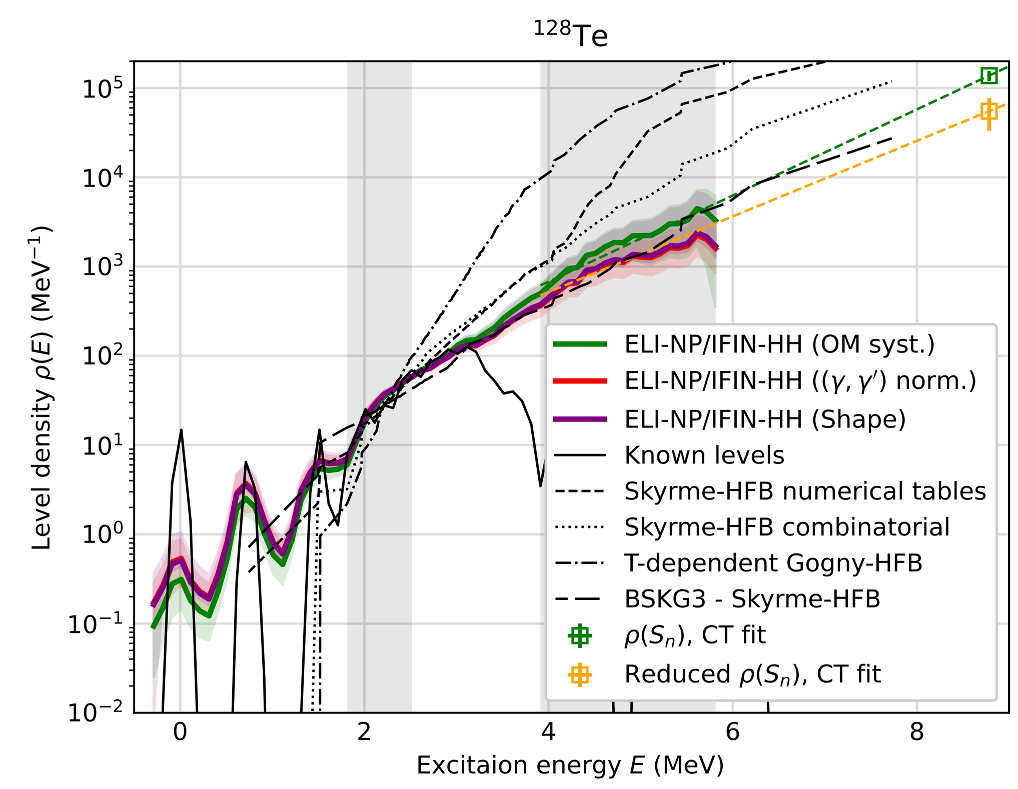


Figure 3. Intrinsic NLD with an RMI spin distribution using Oslo method systematics and (γ, γ') data, $\rho(S_n)$ from neutron resonance systematics and constant-temperature extrapolation with a reduced NLD to account for the populated spin distribution being narrower than the intrinsic. Also shown is four typical NLDs as implemented in TALYS. Manuscript under review.

Since we have HPGe detectors in the array we can estimate the spin distribution.

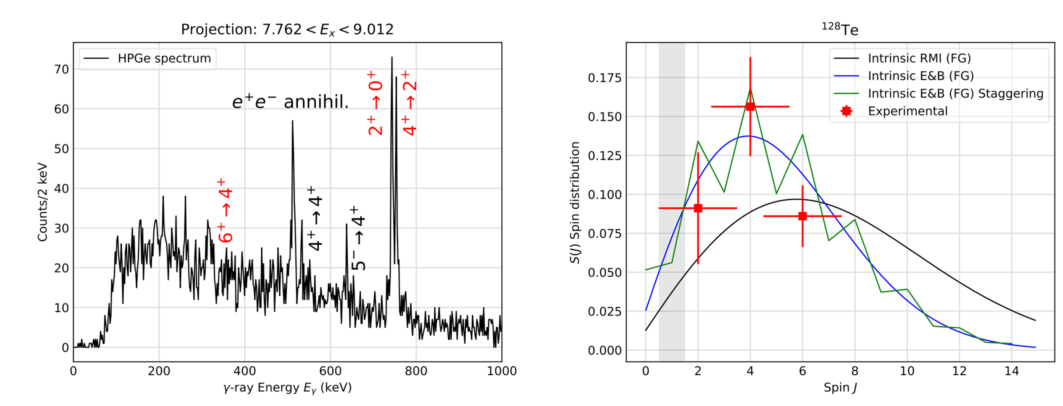


Figure 4. (Left) HPGe spectrum with an excitation energy gate around the neutron separation threshold. (Right) Intrinsic spin distribution at the neutron threshold from three models and data. [3]

Each reaction have their own unique spin distribution. Understandiing the experimental spin distribution is critical interpret and to translate the data to other reaction systems. With γ-ray beams the populated spin distribution is completely $J^P = 1^-$.

How about neutrons

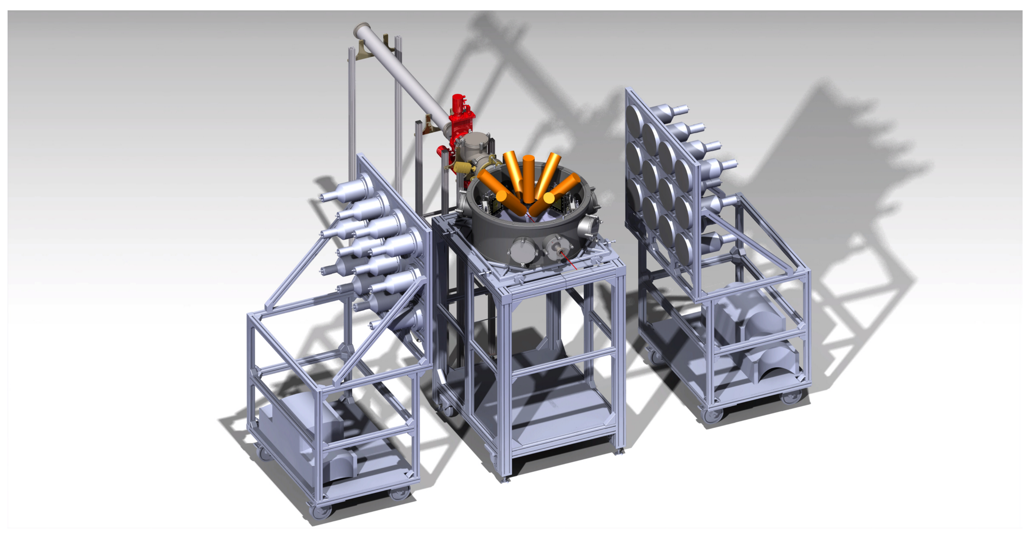


Figure 5. Prepared and designed by Alexandru State.

Given that we already have data on ^{140}Ce from a Oslo-type experiment in 2025, we are already planning our next step to measure the nuclear level densities at the final states from neutron evaporation spectra. A proposal to do this with a $\sim$ 25 MeV ^{6}Li beam for the ^{139}La$(^6\text{Li}, \alpha n)^{140}$Ce is already approved and scheduled.

Summary

We have started systematic measurements of nuclear level densities and photon strength functions at ELI-NP/IFIN-HH. Our first experiment on ^{112,114}Sn in 2023 was to follow the Oslo method to lay the foundation [2]. Our second experiment in 2024 was to connect these to photonuclear methods via ^{128}Te [3]. In 2025 a third experiment on ^{140}Ce was done to connect to neutron evaporation, scheduled for 2026. The long term goal is to establish a research program with the γ-ray beams at ELI-NP, complemented by experiments with charged particle beams at the 9MV Tandem facilities.

References

[1] S. Aogaki, et al. A setup for high-energy γ-ray spectroscopy with the ELI-NP large-volume $LaBr_3$:Ce and $CeBr_3$ detectors at the 9 MV Tandem accelerator at IFIN-HH. Nucl. Instrum. Methods Phys. Res. A, 1056:168628, 2023.

[2] P.-A. Söderström, et al. Statistical properties and photon strength functions of the ^{112,114}Sn isotopes below the neutron separation threshold. Phys. Rev. C, 112:024327, 2025.

[3] P.-A. Söderström, et al. Nuclear level density of ^{128}Te from $(p, p'\gamma)$ scattering and complementary photonuclear data. Phys. Scr., 100:075301, 2025.