Gamma Above Neutron Threshold at ELI-NP: How we got here and where we are going (Measurements of γ-ray strength functions)

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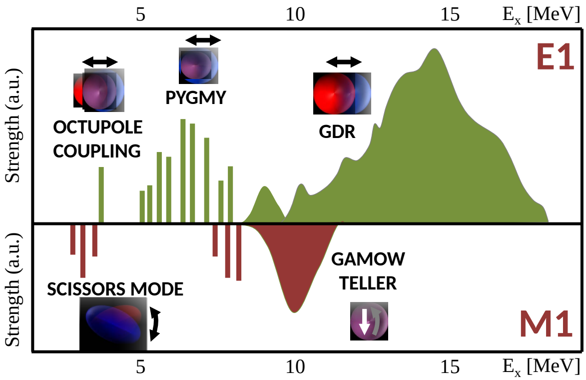
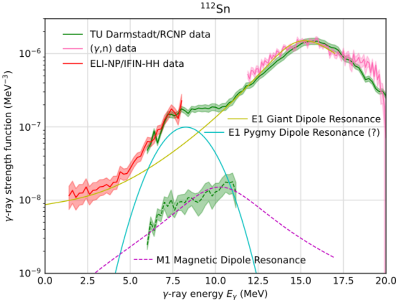
Extreme Light Infrastructure – Nuclear Physics

International Symposium on Nuclear Science
2024-09-10

ELIGANT physics scope

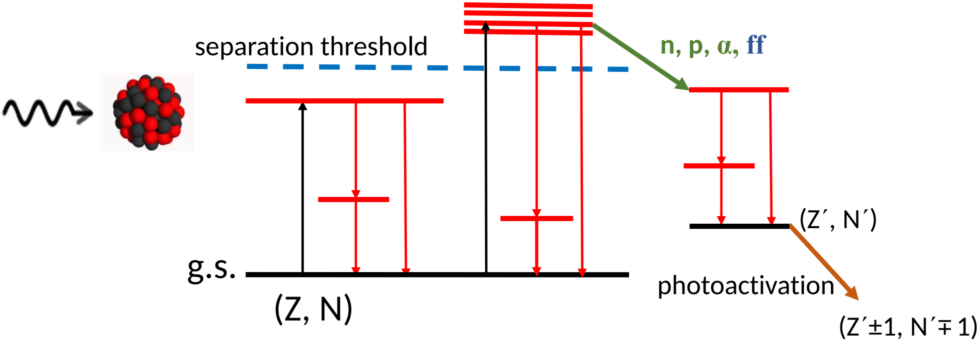


A. Zilges: Nuclear Photonics, June 24 - 28, 2018, Brasov, Romania



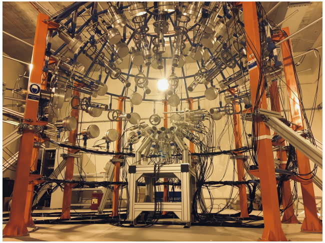
- Low energy $(p,p'\gamma)$, $(d,p\gamma)$ etc.
- Also low energy (γ,γ'), $(\gamma,\gamma'\gamma'')$
- High energy (p,p'), (γ,n)

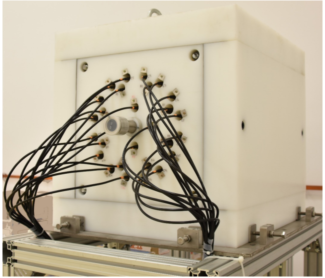
Photonuclear physics



- Incoming γ ray can select individual states to excite
- Above particle separation threshold, particle decay to neighbouring nucleus, fission, etc.
- ... or γ-decay. This type of branching probabilities will be one key topic for measurements

ELIGANT - ELI Gamma Above Neutron Threshold

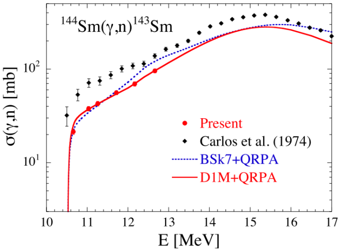


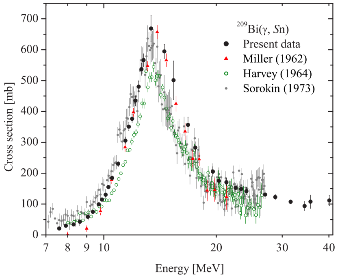


- An array of CeBr and LaBr for γ-rays, liquid scintillators and Li-glass detectors for neutrons
- All the ELIGANT-GN detectors installed at ELI-NP
- Tested in-beam (6 months campaign at ROSPHERE, IFIN 9MV)

- ^{3}He tube array contained in a paraffin moderator for neutron counting
- Detector is operational
- Tested in-beam

Preparatory GANT experiments at NewSUBARU





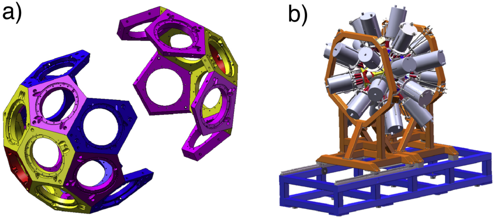
- First campaign of (γ, xn) experiments performed at NewSUBARU LCS beamline, D. M. Filipescu and I. Gheorghe
- Part of the *Coordinated Research Project on Photonuclear Data and Photon Strength Functions* (IAEA CRP F41032)
- Wealth of experimental data, continued measurements possible at ELI-NP
- *T. Kawano, et al., IAEA Photonuclear Data Library 2019, Nucl. Data Sheets, 163 (2020) 109*
- *S. Goriely, et al., Reference database for photon strength functions, Eur. Phys. J. A55 (2019) 172*

D. M. Filipescu, et al., Phys. Rev. C 90 (2014) 064616

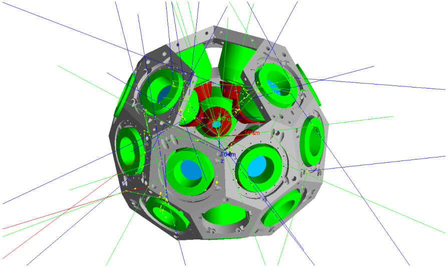
I. Gheorghe, et al., Phys. Rev. C 96 (2017) 044604

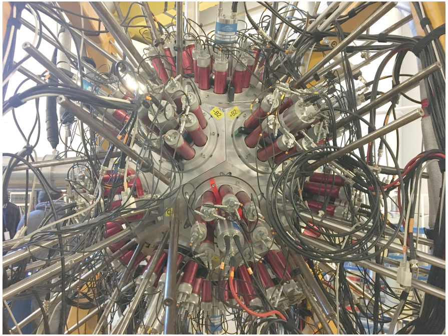
ELI-NP, IFIN-HH, and Tandem $\rightarrow$ ELIFANT

- Combining the large volume γ-ray detectors with the ROSPHERE anti-Compton shields
- In-beam experiments using the 9MV Tandem at IFIN-HH
- Collaboration between ELI-NP and Department of Nuclear Physics
- Clean measurements of high-energy γ-rays



D. Bucurescu, et al.: Nucl. Instrum. Methods Phys. Res. A 837, 1 (2016)





Approved experiments (so far...)

2022

- A. Oberstedt, A. Dragic et al. The ^{72}Ge(p,p'γ) reaction cross-section and $\gamma\gamma$ decay measurements (2021)
- B. Million, F. Camera, et al. Position-Sensitivity in large volume LaBr$_3$:Ce:Sr and performances of the ELIGANT-GN detectors using 15.1 MeV gamma-rays (2021)
- C. Borcea, et al. GDR excitations of fission fragments (2021)
- D. Nichita, P.-A. Söderström, et al. Study of dipole strength below particle separation energy in ^{56}Fe (2021)
- F. Camera, F. Crespi, et al. Study of the isospin symmetry in ^{72}Kr at low temperature (2021)
- O. Wieland, E. Gamba, et al. Search for pygmy dipole strength in ^{58,60}Ni at finite temperature (2021)
- P. Constantin, P.-A. Söderström, et al. Spectroscopy of the first excited 2^+ state of ^{10}B with inelastic proton scattering (2021)
- S. Pascu, et al. Detailed investigation of low-lying states of ^{144}Sm (2021)
- T. Kawabata, et al. Measurement of the Radiative-Decay Probability of the Hoyle State (2021)

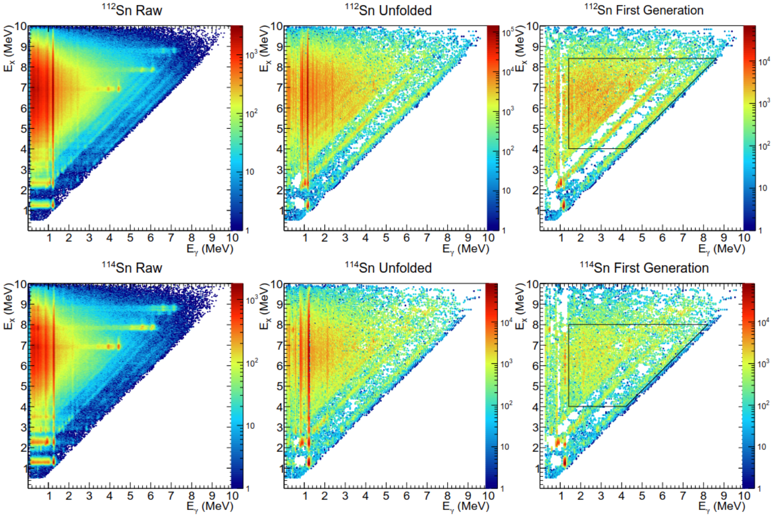
2023

- A. Kusoglu, M. Weinert, et al. Investigating the single-particle content of the sub-threshold electric dipole response of ^{88}Sr (2022)
- D. Nichita, P.-A. Söderström, et al. Study of dipole strength below particle separation energy in ^{56}Fe (2021)
- P.-A. Söderström, M. Markova, et al. Gamma strength function measurements in ^{112,114}Sn (2022)

2024

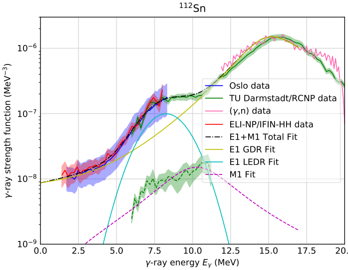
- A. Kusoglu, et al. Access to the Single-Particle Structure of the Low-Lying Electric Dipole Response of ^{62}Ni via One-Neutron (d, pγ) Transfer (2023)
- P.-A. Söderström, J. Isaak, et al. Study of gamma strength functions in ^{128}Te with complementary probes and methods (2023)
- T. Furuno, et al. Measurement of ^{14}N(^{3}He,t)^{14}O(1^-_1) Cross Section for Stellar ^{13}N(p,γ) Reaction Rate (2023)
- O. Wieland, A. Giaz, et al. Search for HOT PDR in neutron rich ^{66}Ni at finite temperature (2023)

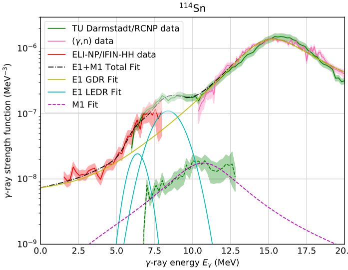
First photon strength experiment at IFIN-HH



- First experiment performed with the Oslo method at IFIN-HH in 2023
- Target nuclei: ^{112}Sn and ^{114}Sn

Fits of the strength functions

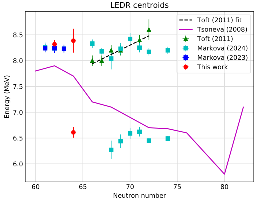




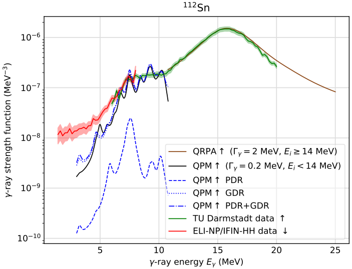
	$E_{\rm GDR}$	$\Gamma_{\rm GDR}$	$\sigma_{\rm GDR}$	$T_{\rm f}$
^{112}Sn∗	16.14(9)	5.46(31)	265.9(95)	0.70(5)
^{112}Sn	16.18(12)	5.30(12)	279(12)	0.718(20)
^{114}Sn	15.980(29)	5.78(12)	251.9(29)	0.614(21)

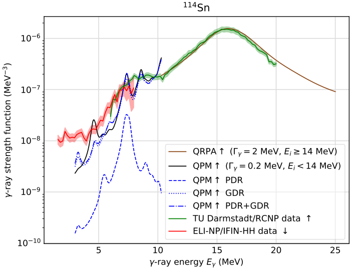
	$E_{\rm M1}$	$\Gamma_{\rm M1}$	$\sigma_{\rm M1}$
^{112}Sn∗	10.45(43)	4.77(53)	1.77(21)
^{112}Sn	10.44(11)	4.76(17)	1.77(8)
^{114}Sn	10.95(31)	4.5(6)	2.18(18)

	$E_{\rm LEDR}$	$W_{\rm LEDR}$	$\sigma_{\rm LEDR}$	% TRK
^{112}Sn∗	8.24(9)	1.22(8)	3.17(24)	1.81(15)
^{112}Sn	8.32(8)	1.39(6)	4.2(4)	2.08(25)
^{114}Sn	6.37(29) 8.4(5)	0.55(17) 0.95(22)	0.39(16) 3.0(15)	1.6(7)



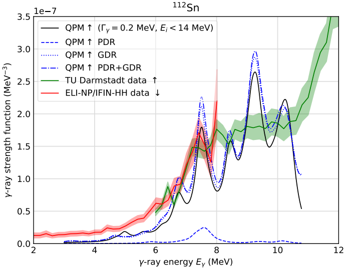
QPM calculations

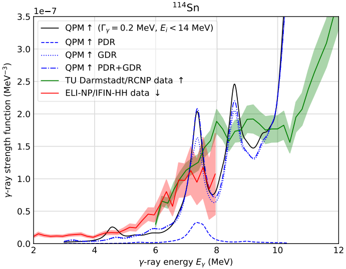




- QPM calculations performed by N. Tsoneva
- Model configuration space of QRPA states with $J^\pi = 1^\pm, 2^\pm, 3^\pm, 4^\pm, 5^\pm$
- One-phonon 1^- states up to $E^* = 30$ MeV
- Multi-phonon constituents up to $E^* \sim 11$ MeV
- Focus on E1 strength between $E^* \sim 6$-8 MeV, which resembles PDR structure

QPM calculations





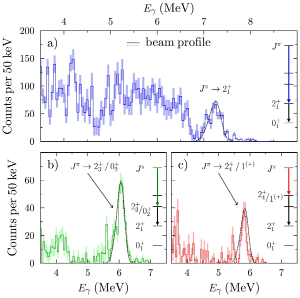
- 1^- states at $E^* \sim$7-8 MeV in ^{112,114}Sn have a predominantly neutron structure
- Associated with one or two major single-particle configurations, can be associated with PDR modes
- Coupling of the low-energy tail of GDR, and low-energy 1^- excited states can have a strong impact to the dipole strength below the neutron threshold
- The effect becomes increasingly important in nuclei where the neutron threshold is higher

Gamma strength with gamma beams - Example from HIγS

The concept of nuclear photon strength functions:
A model-independent approach via $(\vec{\gamma}, \gamma'\gamma'')$ reactions

J. Isaak [a,b,c,*], D. Savran [b], B. Löher [a,b], T. Beck [a], M. Bhike [d], U. Gayer [a], Krishichayan [d], N. Pietralla [a], M. Scheck [e], W. Tornow [d], V. Werner [a], A. Zilges [f], M. Zweidinger [a]

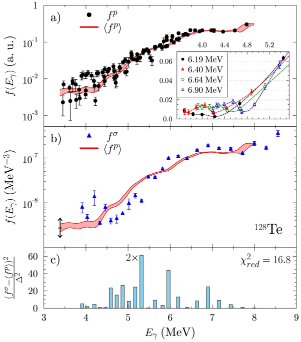
J. Isaak, et al.: Phys. Lett. B 788, 225 (2019)



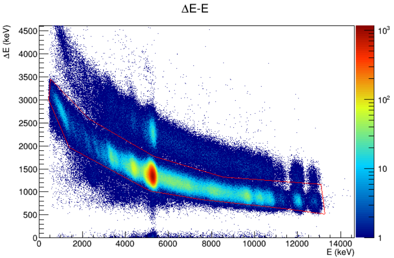
- γ-ray strength functions can be measured in a model independent way with γ beams
- Ratio method $(k, j \neq 0)$

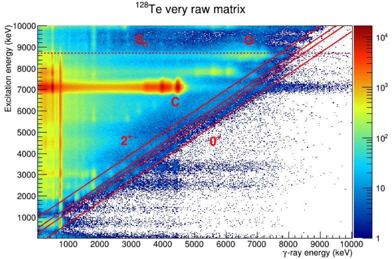
$$\frac{\sigma_{ik}}{\sigma_{ij}} = \frac{f(\Delta E_{ik})}{f(\Delta E_{ij})} \frac{\Delta E_{ij}^3}{\Delta E_{ik}^3} \qquad (1)$$

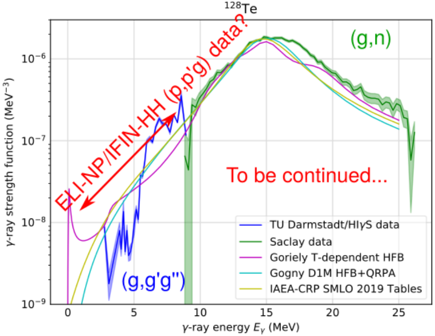
- High-resolution beams can clearly separate different states!



Outlook - ^{128}Te







- Next goal is ^{128}Te for comparing photon beams and charged particle method
- Carbon-backed target, challenging experiment

ELIGANT

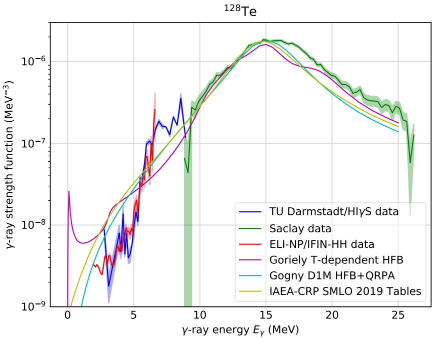
P.-A. Söderström

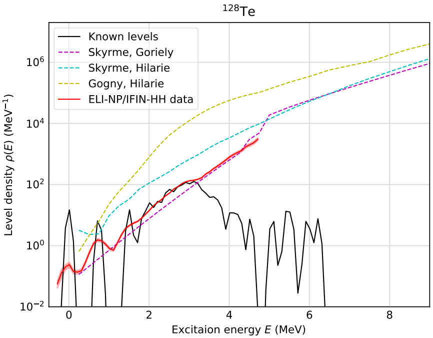
ELI-NP

ROSPHERE measurements

Acknowledgements

Outlook - ^{128}Te





- Very first attempt, very preliminary
- Cut data below the contamination
- Normalize strength function to Isaak data
- Retrieve level density without constant temperature/fermi gas model dependency
- To do: In-depth evaluation of analysis methods, subtraction of contaminants

Collaboration

ELIGANT-GN:

- Pär-Anders Söderström
- A. Kuşoğlu

ELI-NP core team:

- Soichiro Aogaki
- Dimiter Balabanski
- Mihai Cuciuc
- Asli Kusoglu
- Alfio Pappalardo
- Dmitry Testov

IFIN-HH core team:

- Ruxandra Borcea
- Cristian Costache
- Constantin Mihai
- Radu Mihai
- Lucian Stan
- Andrei Turturica

Spokespersons: A.Oberstedt, A.Dragic, B.Million, F.Camera, C.Borcea, D.Nichita, P.-A.Söderström, F.Crespi, O.Wieland, E.Gamba, P.Constantin, S.Pascu, T.Kawabata, A.Tamii, A. Kuşoğlu, M. Weinert, M. Markova, J. Isaak, A. Giaz, T. Furuno

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