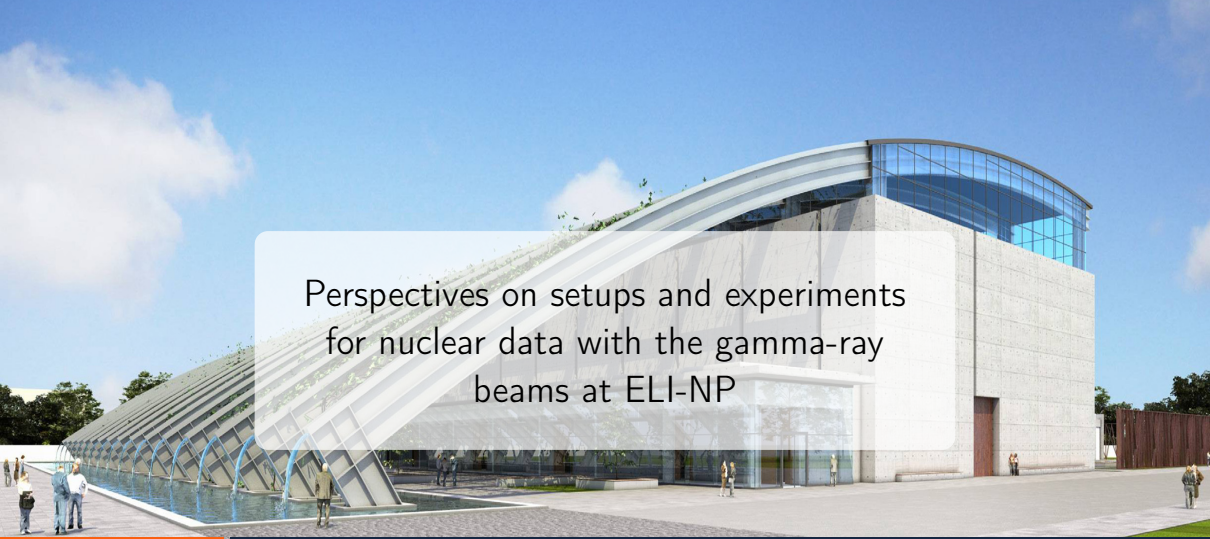
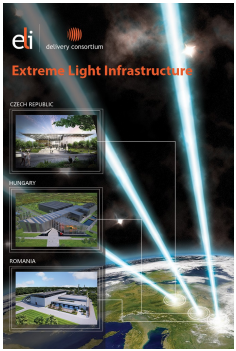


Perspectives on setups and experiments for nuclear data with the gamma-ray beams at ELI-NP

Pär-Anders Söderström
par.anders@eli-np.ro

P(ND)^2-3 Nuclear Data for the Next Decade

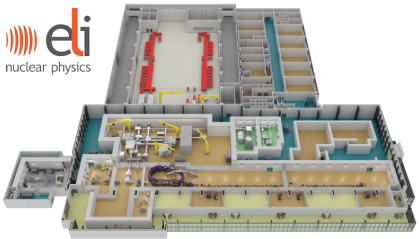
The Extreme Light Infrastructure



- ELI Beamlines, Prague
- ELI ALPS, Szeged
- ELI Nuclear Physics, Măgurele

- ELI-NP is based on two main components
- High-power lasers (HPLS) 100 TW, 1 PW, 10 PW, Thales Romania
- High-brilliance gamma-beam (ELI-GBS)

The ELI-NP GBS



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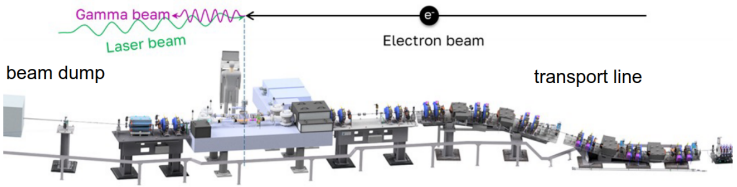
- High-brilliance gamma-beam (ELI-GBS)

`https://www.eli-np.ro/gsd_second.php`

Parameter	**Specification**
Maximum Photon Energy	19.5 MeV
Tunability of the Photon Energy	Steplessly variable
Linear Polarization of Gamma-Ray Beam	> 95 %
Average Relative Bandwidth of Gamma-Ray Beam (FWHM)	$\leq 5.0 \times 10^{-3}$
Total Photon Flux	$\geq 1.0 \times 10^{11}$ 1/s
Time-Average Spectral Density at Peak Energy	$\geq 5.0 \times 10^{3}$ 1/(s eV)

Gamma Production System – contract with RI for:

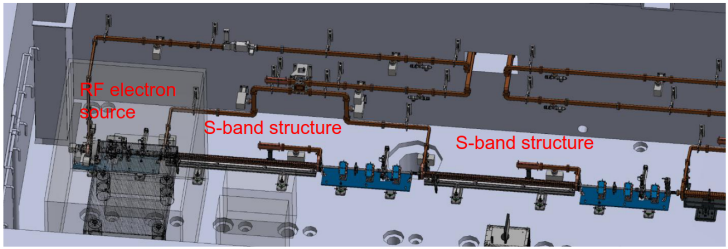
transport line + interaction chamber & optical cavity – finalized by 11/26



	Conservative	Technical limit
Flux (photons/sec)	**2.4×10^5**	**4.3×10^7**

C. Matei: private communication

Components for the Upgrade for existing ELI-NP LINAC – contract with RI for: multi-bunch electron source (50 Hz x 200 micro pulses) + x2 accelerator structures, more modulators + klystrons – to be delivered by 11/2026 (installation 2027+)



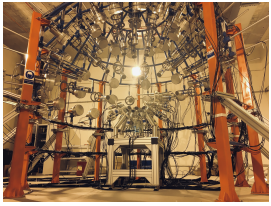
	Conservative	Technical limit	Development potential
Flux (photons/sec)	**2.5×10^{7}**	**1.8×10^{9}**	**4×10^{11}**

C. Matei: private communication

Physics with the gamma beam system

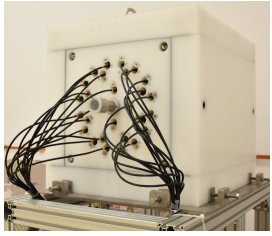
- Nuclear Resonance Fluourescence spectroscopy using (γ, γ') reactions and the HPGe array ELIADE
- Pygmy- and giant resonances, level population following neutron emission, and neutron resonances, using (γ, n) reactions in ELIGANT
- Photo-induced fission cross-sections, fragment distributions, and fission isomers with the ELI-BIC and ELITHGEM instruments
- Production of exotic isotopes using through a γ-induced ISOL facility
- Properties of key astrophysics (γ, p) and (γ, α) reactions using ELISSA Si array and ELI-eTPC time-projection chamber
- High-intensity positron beamline for material research and characterization
- Applications of Nuclear Resonance Fluourescence for non-proliferation, waste-management and cultural heritage with ELIADE

ELIGANT - ELI Gamma Above Neutron Threshold



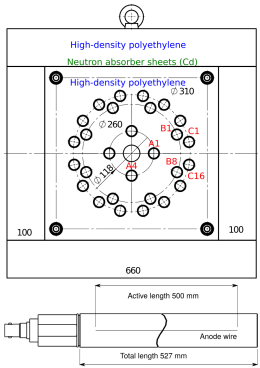
- An array of CeBr and LaBr for γ-rays, liquid scintillators and Li-glass detectors for neutrons
- Tested in-beam (2022-2025 campaigns at ROSPHERE, IFIN 9MV)

P.-A. Söderström, et al.: Nucl. Instrum. Methods Phys. Res. A 1027 (2022) 166171

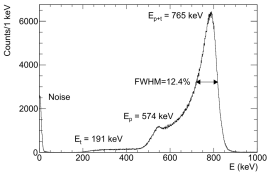


- ^{3}He tube array contained in a polyethylene moderator for neutron counting
- Detector is operational
- Tested in-beam

P.-A. Söderström, et al.: Nucl. Instrum. Meth. A 1084 (2026) 171229

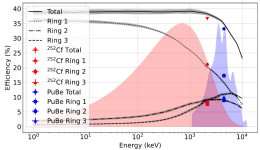


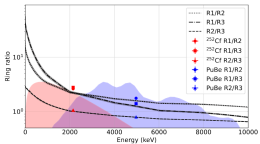
P.-A. Söderström, et al.: Nucl. Instrum. Meth. A 1084 (2026) 171229

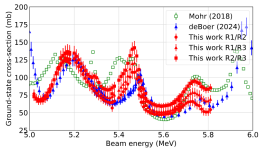


- Thermal neutron capture on ^{3}He gas
- Low γ-ray sensitivity
- Integrate total counts

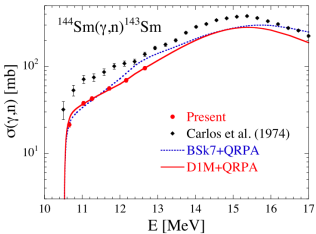
- 28 ^{3} He neutron counters
- 12 bar gas pressure
- Arranged in three rings for neutron energy sensitivity via ring ratio method
- Flat efficiency for minimizing systematic uncertainties

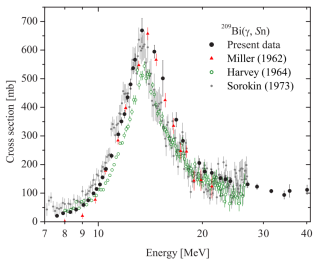






Preparatory GANT experiments at NewSUBARU





- 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

ELIGANT-TN (α, n) cross-sections for applications

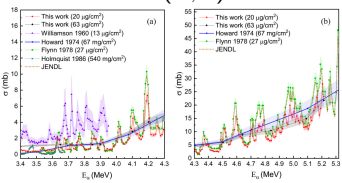
- ELI-NP; Nuclear Physics Department; Applied Nuclear Physics Department at IFIN-HH
- National Physical Laboratory (NPL), UK
- Indian institute of Technology Ropar, India
- UK Atomic Energy Authority (UKAEA), UK

- Complementary program to measure (α, n) cross-sections in the energy range of the α decay from actinides
- Mainly energy range of interest $3 - 6$ MeV, but other ranges for specific applications
- 3 MV and 9 MV Tandetron accelerators at IFIN-HH
- Example 1: ^{19}F (α, n) induced neutron background from ^{234}U in UF_6
- Example 2: ^{27}Al (α, n) induced neutron background in low-background experimental constructions

R. Roy: Ph.D. Thesis, Indian Institute of Technology Ropar (2025)

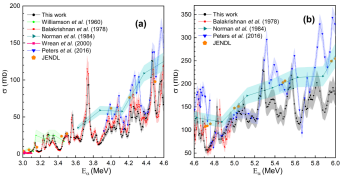
ELIGANT-TN (α, n) cross-sections for applications

^{27}Al(α, n)

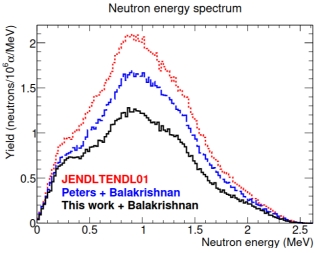


R. Roy, et al.: Phys. Rev. C, 112 (2025) 044613

^{19}F(α, n)



R. Roy, et al.: in manuscript



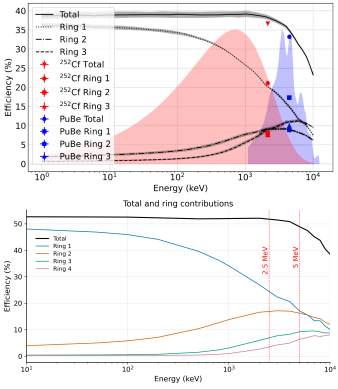
Example of the impact of the ^{19}F(α, n) cross-sections using three different data sets

- The cross-sections were included in the Geant4 based (α, n) source simulation code SaG4n

  E. Mendoza, et al.: Nucl. Instrum. Meth. Phy. Res. A 960, 163659 (2020)

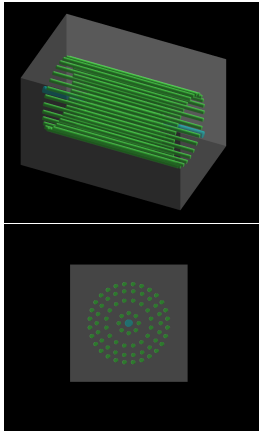
- ^{234}U α source isotropically distributed in a UF_6 cylinder of 76 cm diameter and 206 cm length

ELIGANT-TN-74



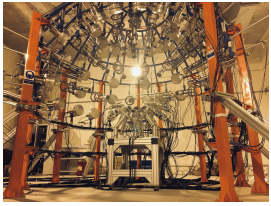
H.T. Aslani: private communication

- Next step: Upgraded version ELIGANT-TN-74
- Add 44 new detectors
- Four-ring concept for improved ring ratios
- Extend the flat-efficiency region
- Collaboration between ELI-NP/IFIN-HH and NCSR Demokritos



H.T. Aslani: private communication

ELIGANT - ELI Gamma Above Neutron Threshold



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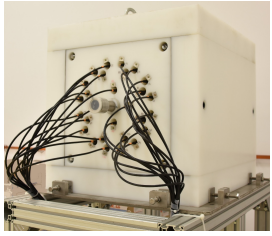
P.-A. Söderström, et al.: Nucl. Instrum. Methods Phys. Res. A 1027 (2022) 166171



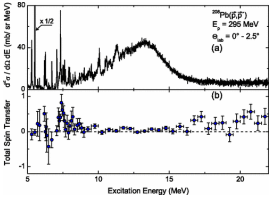
- ^{3}He tube array contained in a polyethylene moderator for neutron counting
- Detector is operational
- Tested in-beam

P.-A. Söderström, et al.: Nucl. Instrum. Meth. A 1084 (2026) 171229

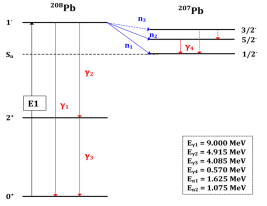
Typical ELIGANT-GN physics case

- Excitation cross section measured with polarized protons at RCNP – Good case for commissioning
- No information on the GDR decay to ground or high lying states through gamma or neutron emission – Good case for day-1
- Clean measurement of the absolute value of GDR ground state γ-decay
- Measure the energy dependence of the GDR $B(\mathrm{E1})$
- Simultaneous $\sigma(\gamma,\gamma)$ and $\sigma(\gamma,n)$ to exctract details of the wave function
- Finer structure from higher-order (3p-3h,...) coupling?
- What is the nature of the PDR?

F. Camera, et al., Rom. Rep. Phys. 68 (2016) S539 M. Krzysiek, et al., Nucl. Instrum. Meth. A916 (2019) 257 P.-A. Söderström, et al., Nucl. Instrum. Meth. A 1027 (2022) 166171



A. Tamii, et al.: Phys. Rev. C 107, 062502 (2011)

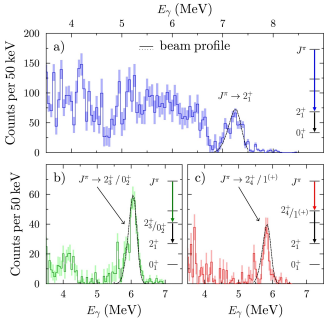


γ strength with gamma beams - Example from HIγS

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]

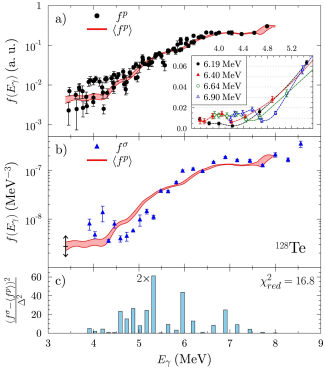
J. Isaak, et al.: Phys. Lett. B 788, 225 (2019)

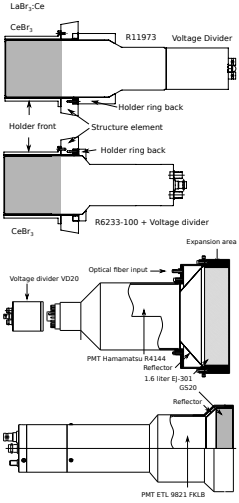


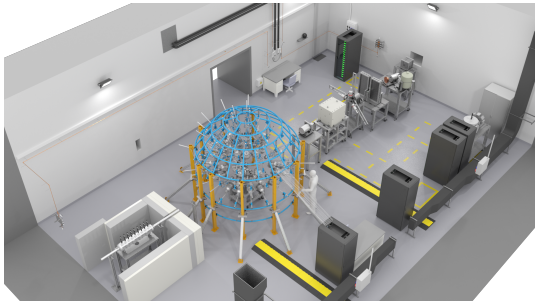
- γ-ray strength functions can be measured in a model independent way with γ beams
- Ratio method $(k, j \neq 0)$

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

- High-resolution beams can clearly separate different states!

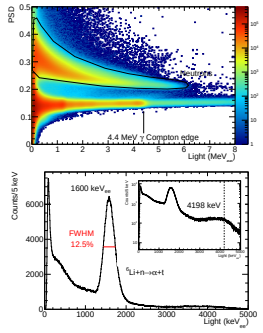




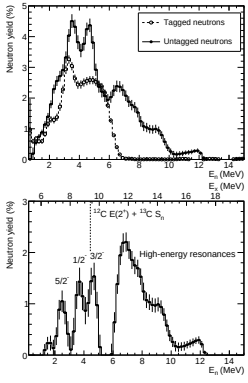


- 34 $LaBr_3$:Ce and $CeBr_3$ detectors
- 36 EJ-301 liquid scintillator detectors
- 25 GS-20 lithium glass detectors

P.-A. Söderström, et al.: Nucl. Instrum. Meth. A 1027 (2022) 166171



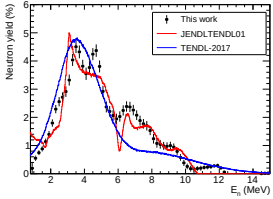
Historical Pu-Be sources

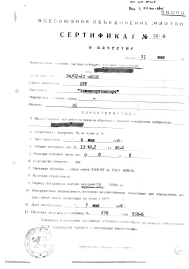


P.-A. Söderström, et al.: Appl. Radiat. Isot., 167 (2021) 109441

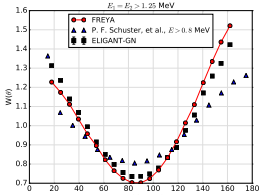
- ELIGANT instrumentation to investigate "legacy sources"
- Subtracting tagged from untagged gives direct n transition from excited states in ^{13}C to the ^{12}C ground state
- Peak like structures originate from known resonances in ^{13}C
- Compare the results with source simulation software using latest cross-section libraries

  E. Mendoza, et al.: Nucl. Instrum. Methods Phys. Res A. 960, 163659 (2020)
- Underestimate the low-energy resonances and overestimate high-energy branching to first excited state in ^{12}C

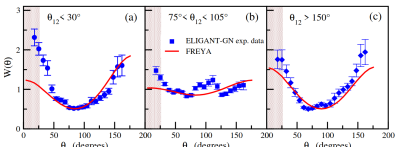




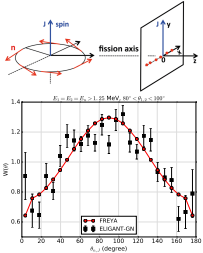
ELIGANT-GN ^{252}Cf array performance



- Simple angular correlations works well
- Low-energy (250 keV) - high-energy (>1.25 MeV) neutron angular correlations from Li-glass detectors
- Can obtain the three-neutron angular correlations
- Assume neutrons emitted in a plane $\perp$ to the spin axis J:
- Angular distribution of third neutron relative to J



A. Chietera, et al.: Eur. Phys. J. A 54, 98 (2018)

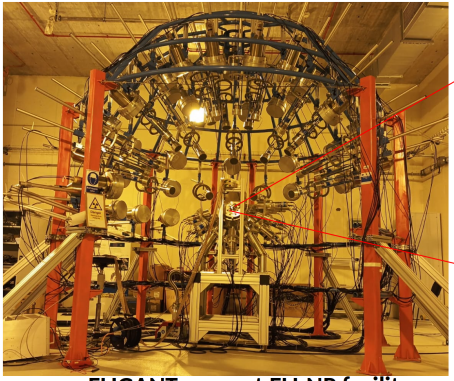


D. Choudhury, et al.: in manuscript

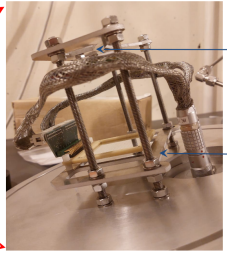
Three-neutron angular correlations; $\theta_{2,3}$ given $\theta_{1,2}$

ELIGANT-GN ^{252}Cf array performance

- Experimental setup to measure the prompt fission neutrons and **γ**-rays in coincidence with fission fragment



ELIGANT array at ELI-NP facility



Holder for ^{252}Cf source mounting

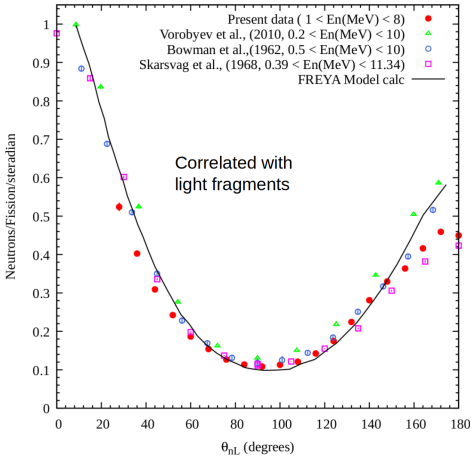
Double sided silicon strip detector (DSSSD) for fission fragment detection

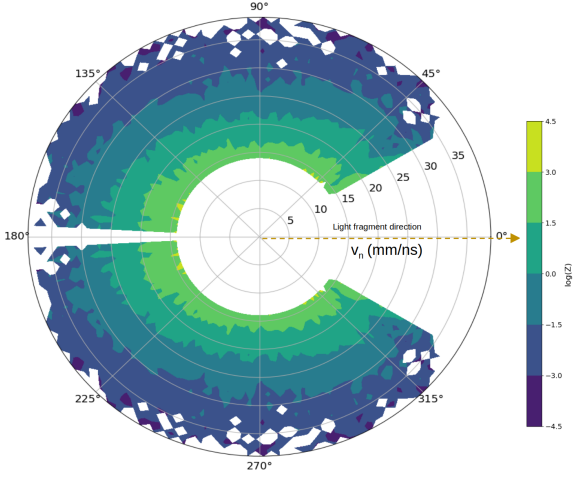
Inside view of the vacuum chamber

Data taking duration : 6 months

S. Dhuri, et al.: private communication

ELIGANT-GN ^{252}Cf array performance

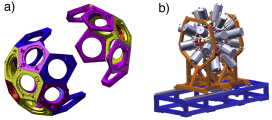




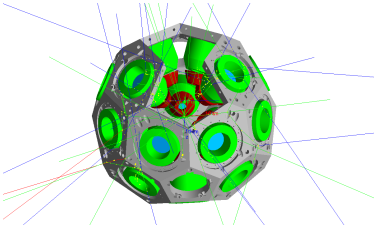
S. Dhuri, et al.: private communication

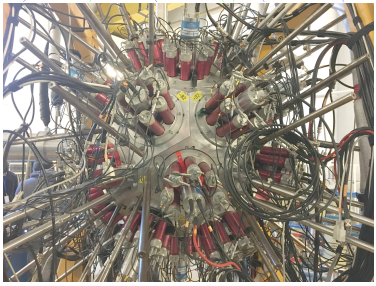
ELI-NP, IFIN-HH, and Tandem → ELIFANT

- 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

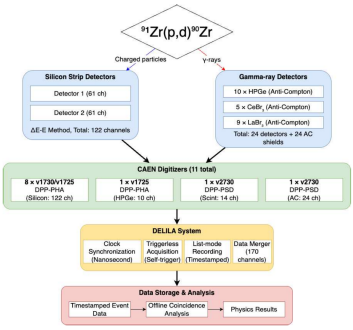


S. Aogaki, et al.: Nucl. Instrum. Methods Phys. Res. A 1056 (2023) 168628

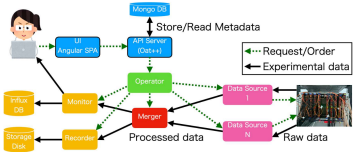


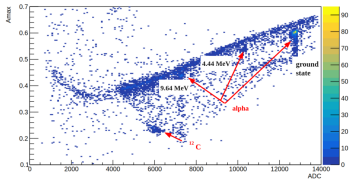


DAQ and hardware developments



S. Aogaki, et al.: IEEE Trans. Nucl. Sci., 72 (2025) 3652





K. Sakanashi, et al.: Phys. Lett. B, 870 (2025) 139893, *S-R. Ban, et al.: UPB Sci. Bull. A, 87(3) (2025) 165*

- Going towards fully digital, self-triggering, DAQ
- Increase counting rate a factor of 50 for Tandem experiments
- Implement complex pulse-shape discrimination procedures directly on the FPGA

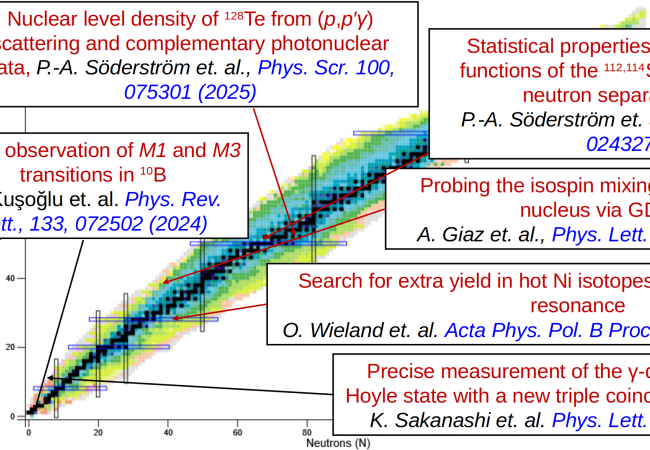
First Results with the ELIFANT Array

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

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

Direct observation of *M1* and *M3* transitions in ^{10}B
A. Kuşoğlu et. al. *Phys. Rev. Lett., 133, 072502 (2024)*

Probing the isospin mixing in the ^{72}Kr compound nucleus via GDR γ decay
A. Giaz et. al., *Phys. Lett. B, 868, 139653 (2025)*

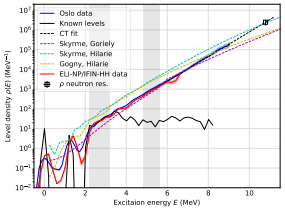


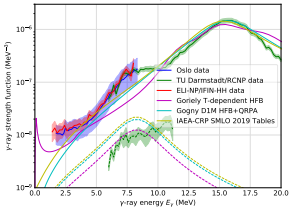
Search for extra yield in hot Ni isotopes below the giant dipole resonance
O. Wieland et. al. Acta Phys. Pol. B Proc. Suppl, 18, 2-A33 (2025)

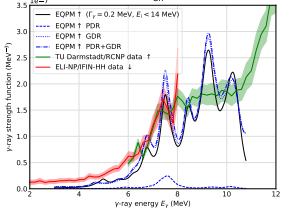
Precise measurement of the γ-decay probability of the Hoyle state with a new triple coincidence detection method
K. Sakanashi et. al. Phys. Lett. B, 870, 139893 (2025)

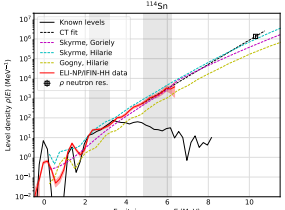
A. Kuşoğlu.: Private communication

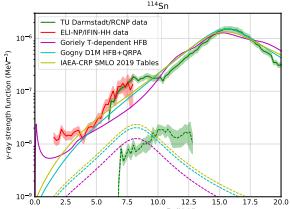
First experiment: results from the Sn nuclei

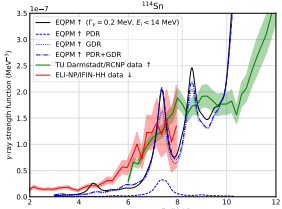










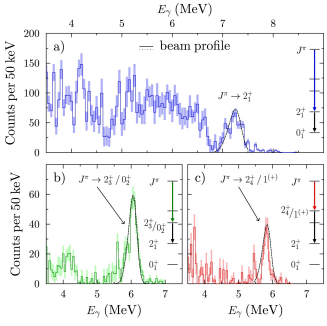


P.-A. Söderström, et al.: Phys. Rev. C 112 (2025) 024327, Calculations: N. Tsoneva

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]

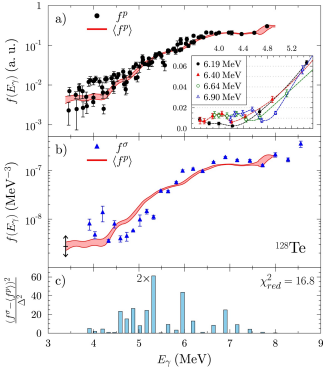
J. Isaak, et al.: Phys. Lett. B 788, 225 (2019)



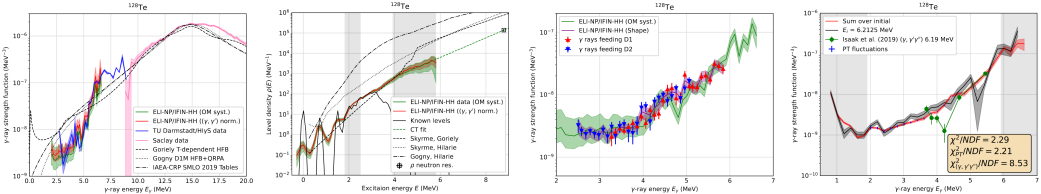
- γ-ray strength functions can be measured in a model independent way with γ beams
- Ratio method $(k, j \neq 0)$

$$\frac{\sigma_{ik}}{\sigma_{ij}} = \frac{f(\Delta E_{ik})}{f(\Delta E_{ij})} \frac{\Delta E_{ij}^3}{\Delta E_{ik}^3} \qquad (2)$$

- High-resolution beams can clearly separate different states!



^{128}Te experiment at IFIN-HH



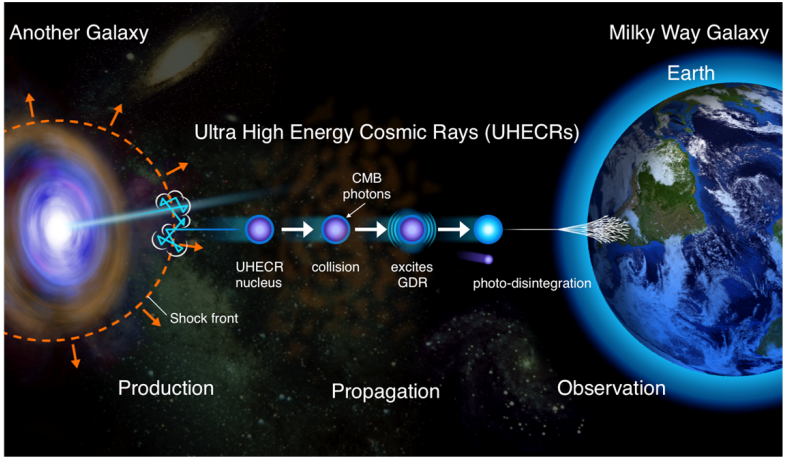
- Normalize γSF on the (γ, γ') data from HIγS
- Use the normalization to fix the NLD slope

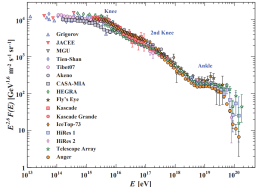
P.-A. Söderström, et al.: Phys. Scr. 100, 075301 (2025)

- All normalisation methods give consistent results
- No (or very small) violation of the Brink-Axel hypothesis observed!
- Several different complementary experimental methods and approaches available in the same campus!

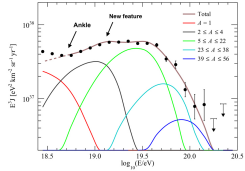
P.-A. Söderström, et al.: In manuscript

Nuclear data for Ultra High-Energy Cosmic Rays

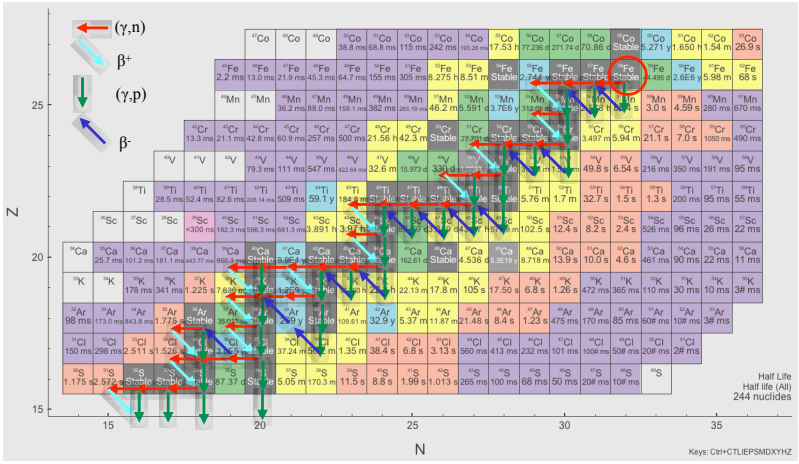


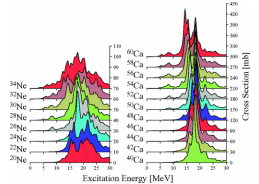


A Aab et al. (The Pierre Auger Collaboration), Phys. Rev. Lett. 125, 121106 (2020)

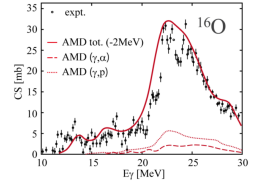


Nuclear data for Ultra High-Energy Cosmic Rays





T. Inakura, et al.: Phys. Rev. C 84, 021302(R) (2011)



M. Kimura, Y. Taniguchi: Private communication

Nuclear data for Ultra High-Energy Cosmic Rays

Japan

Romania

South Africa

Astroparticle physics

Nuclear physics

Theory

- Propagation Calculations
- Galactic magnetic field
- Acceleration mechanisms

Experiment

- Pierre Auger
- Telescope Array
- Source direction
- Composition

Theory

- Reaction theory
- Structure theory
- Shell model, mean-field models, ab-initio models...

Experiment

- $(p, p'x)$
  - RCNP, Japan
  - iThemba LABS, South Africa
- $(\gamma, \gamma'x)$, ELI-NP

- Oct 2023, RCNP: ^{10}B, ^{11}B, ^{12}C, ^{13}C, ^{27}Al
- Oct 2025, RCNP: ^{12}C, ^{27}Al, ^{24}Mg, ^{56}Fe
- High-priority to-do: ^{6}Li, ^{7}Li, ^{9}Be (Lightest IVGDR), ^{24}Mg, ^{28}Si, ^{32}S, ^{40}Ca (α-clustering), ^{26}Mg, ^{48}Ca ($N > Z$), ^{14}N, ^{51}V (odd-even and odd-odd effects)

A. Tamii, et al.: Eur. Phys. J. A, 59 (2023) 208

Conclusions

- ELI-NP instruments ready for nuclear data on electric dipole strengths; cross sections for astrophysics, astroparticle physics, energy applications; fission data; and much more
- Broad collaborations with scientists in related fields in Europe and worldwide
- Complementary measurements with charged particle accelerators provides a broad range of probes - photons, electrons, hadrons - in the same campus

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- PhD students: Sara Rebeca BAN, Emanuela BOICU, Andrei COVALI, Andreea GHITIU, Ioana KUNCSER, Cosmina NEDELCU, Teodora SEBE,
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