Photonuclear spectroscopy with the ELIADE array at ELI-NP: Status and perspectives

Pär-Anders Söderström

Extreme Light Infrastructure – Nuclear Physics

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Outline

1. Extreme Light Infrastructure – Nuclear Physics
2. High-brilliance gamma beams
3. ELI Array of Detectors – ELIADE
4. Day one physics cases
5. Summary
ELI consist of three pillars: ELI Beamlines, Czech Republic, ELI Attosecond Light Pulse Source, Hungary, ELI Nuclear Physics, Romania

ELI-NP is based on two main components: High-power lasers, High-brilliance gamma-beam system
Properties of the gamma beam system

- Gamma beam created from inverse Compton scattering of a 515 nm Yb:YAG laser with 720 MeV electron beam
- Selection of energies based on angular distributions
- Almost monoenergetic $\gamma$-rays

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>0.2 – 19.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Density (ph/s-eV)</td>
<td>$&gt; 0.5 \cdot 10^4$</td>
</tr>
<tr>
<td>Bandwidth rms (%)</td>
<td>$\leq 0.5$</td>
</tr>
<tr>
<td>Linear polarization (%)</td>
<td>$&gt; 95$</td>
</tr>
<tr>
<td>Macro repetition rate (Hz)</td>
<td>100</td>
</tr>
<tr>
<td># pulses per macropulse</td>
<td>32</td>
</tr>
<tr>
<td>Pulse–to–pulse separation (nsec)</td>
<td>16</td>
</tr>
</tbody>
</table>
The gamma beam system will have three main experimental areas:

- The low-energy area (E2) with energies up to 3.5 MeV
- The high-energy area (E8) with energies up to 19.5 MeV
- The high-power laser and high-brilliance gamma-beam interaction area
ELIADE – ELI Array of Detectors

- Eight HPGe segmented Clover detectors
- Four detectors at angles around 90°
- Four detectors at 135°
- Retractable for optimization of geometry depending on experimental conditions
- 19 cm from the target when closest, up to 37 cm
Challenges for ELIADE

Environmental boundaries:

- Measure in a sea of $\gamma$-rays ($10^6 \gamma$/pulse), primarily 511 keV
- Anti-Compton not possible, reject everything
- Well defined beam structure

Solutions:

- Heavy shielding
- Segmented HPGe detectors
- Save front of traces

Superimposed waveforms from A. Kusoglu, G.V. Turturica, et al. experiment “Detector efficiency calibration and polarization sensitivity for high energy $\gamma$-rays”, IFIN-HH 3MV Tandem, Mar 2018
Solutions for the ELIADE detectors

Example: NRF of a 2 cm thick $^{238}$U target with and without 2 cm Pb shields

<table>
<thead>
<tr>
<th></th>
<th>$E_\gamma$ (MeV)</th>
<th>$\gamma$/s</th>
<th>$\gamma$/s (Pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRF</td>
<td>2.1</td>
<td>566</td>
<td>199</td>
</tr>
<tr>
<td>CS 98°</td>
<td>0.36</td>
<td>61966</td>
<td>1</td>
</tr>
<tr>
<td>CS 135°</td>
<td>0.26</td>
<td>43359</td>
<td>0</td>
</tr>
<tr>
<td>$e^+e^-$</td>
<td>0.511</td>
<td>59020</td>
<td>1521</td>
</tr>
</tbody>
</table>

- NRF yield reduced by 1/3
- Background strongly reduced
- Interested in high-energy $\gamma$-rays

- We need one $\gamma$ ray per macropulse = 100 Hz max
- Using segmented Clover detectors we can increase this to 16 $\gamma$ rays
- Most low-energy $\gamma$-rays interact in the front segments
Details of the ELIADE detectors

- 8 Canberra 4x60x90 Seg32 Clover detectors
- 32 v1725 CAEN 14 bit 250 MS/s 16 ch digitizers
- 32 v1730 CAEN 14 bit 500 MS/s 8 ch digitizers
- CAEN SY4527 High-Voltage supply
Signal transmission and readout

- Single-ended signals read out from the preamplifiers
- Differential cables for low-noise signal transmission
- Single-ended signals for digitization
- System developed by IKP Köln
- CAEN v1725 digitizer boards
- MIDAS DAQ software from Daresbury
Matrix elements for $0\nu\beta\beta$-decay

- Decay rate ($\lambda_{0\nu\beta\beta}$) depends on neutrino mass ($m_\nu$) and nuclear matrix element ($M^{(0\nu)}$)

$$\lambda_{0\nu\beta\beta} = G_0 \nu |M^{(0\nu)}|^2 \left( \frac{\langle m_\nu \rangle}{m_e} \right)^2$$

- Matrix element needs to be calculated from nuclear structure physics and depends strongly on pn coupling

- Scissors mode particularly sensitive to pn coupling

- Example: $^{150}$Sm with large $0\nu\beta\beta$ branching both to $0_1^+$ and $0_2^+$

- Ideal case to determine parities of $J = 1$ states and measure scissors branching to $0_2^+$ using NRF
Parity violation in $^{20}\text{Ne}$

- Parity a fundamental symmetry in both the electromagnetic and strong force, but not in weak force
- In the effective nuclear force this can introduce a small parity violating term $\beta \sim 10^{-4}$ as $\langle J^- \rangle = \alpha \langle \phi^- \rangle + \beta \langle \phi^+ \rangle$
- In $^{20}\text{Ne}$, a $1^\pm$ parity doublet with $\Delta E = 3-4$ keV at 11.2 MeV
- Cross section for $1^+ \sim 50$ times higher than $1^-$
- Thick $^{20}\text{Ne}$ absorber to remove all 11.259 MeV beam $\gamma$-rays
- At ELI-NP: 100% linear polarization
- Measure $\beta$ from angular distributions of 11.255 MeV $\gamma$-rays

$$\langle 0^+ | T(E1) + T(M1) | 1^- \rangle = \alpha \langle 0^+ | T(E1) | \phi^- \rangle + \beta \langle 0^+ | T(M1) | \phi^+ \rangle$$

Status of E8 installation as of Aug 2018

- Crane
- L.E. beam
- H.E. beam
- Storage area

Diagram showing the layout of the installation with labeled areas.
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The ELIADE collaboration

ELI-NP:
- Anukul Dhal
- Gabriel Suliman
- Pär-Anders Söderström
- Calin Alexandru Ur
- Luigi Capponi
- Aslı Kuşoğlu
- Violeta Iancu
- Gabriel Turturică
- Cristian Petcu
- Emil Udup

Collaborators:
- Jacob Beller, IKP, TU Darmstadt
- Vera Derya, IKP, University of Cologne
- Ivan Kojouharov, GSI Darmstadt
- Bastian Löher, IKP, TU Darmstadt
- Constantin Mihai, IFIN-HH Bucharest
- George Pascovici, IFIN-HH Bucharest
- Norbert Pietralla, IKP, TU Darmstadt
- Vic Pucknell, STFC, Daresbury
- Panu Rahkila, University of Jyväskylä
- Christopher Romig, IKP, TU Darmstadt
- Deniz Savran, EMMI, GSI Darmstadt
- Andreas Zilges, IKP, University of Cologne
- Volker Werner, IKP, TU Darmstadt
- Julius Wilhelmy, IKP, University of Cologne