Proposal for Beam Time and Research Program at IFJ PAN LINAC

1. General Information

Project Title: Investigation of Nuclear Two-Photon (2γ) Decay in Even-Even Nuclei via Proton Excitation of 0_2^+ States

Principal Investigator (PI): Michał Ciemała

Co-Investigators / Research Team:

2. Particle and Energy Selection

Please check the required particle and the target energy section:

Primary Particle:

[X] Proton (p+)

[ ] Deuteron (2H+ / d)

[ ] Alpha (4He2+)

[ ] Lithium-7 (7Li3+)

[ ] Other (e.g., 16O8+): _________

Acceleration Stage (Energy):

[ ] **Section 1:** 2.5 MeV/u

[ ] **Section 2:** 12.5 MeV/u

[ ] **Section 3:** 250 MeV/u (Future expansion / High energy)

[X] **Custom Energy:** needed variable energy within 2.5 – 12.5 MeV range, this is **non-negotiable requirement**

3. Abstract of Planned Research

This experiment aims to perform a high-precision, systematic study of double gamma (2γ) decay in $0^+ \to 0^+$ transitions. We target the first excited 0^+ states in ^{72}Ge and ^{98}Mo, alongside re-measurements of benchmark isotopes ^{16}O, ^{40}Ca, and ^{90}Zr.

The 2γ decay is a rare second-order electromagnetic process. By utilizing inelastic proton scattering (p,p′) with a highly stable beam to populate 0_2^+ states, we can measure the partial decay rates. This is vital for establishing a systematic understanding of 2γ in case when single γ emission is forbidden.

A critical motivation for this proposal is the recent breakthrough measurement for the decay rate of 0_2^+ state in fully ionized ^{72}Ge, which was published in Phys. Rev. Lett. 133, 022502 (2024). Observations of fully ionized ^{72}Ge ions in a storage ring determined the 2γ half-life of the 0_2^+ state to be 23.9(6) ms. This value strongly deviates from theoretical expectations and established systematics. Our proposed experiment will provide direct, by measurement of two gamma-rays, high-precision result for the ^{72}Ge 0_2^+ state decay by 2γ process. Comparing our results (direct 2γ decay) may allow to validate if the unexpected lifetime observed in bare ions points to the existence of previously unrecognized or even more exotic decay channels. A dedicated, background-less scintillator setup (e.g., $CeBr_3$) combined with precise proton beam definition ($\Delta E<10$ keV, minimal dark current) **is essential** for this systematic verification.

4. Technical Beam Requirements

Please specify the desired beam parameters to ensure the feasibility of the experiment:

Intensity / Current:

Required current on target: 10 pA – 500 nA (e.g., 10 pA – 10 nA)

High intensity requirements (if applicable): _________ mA

Time Structure:

Pulse repetition rate: [X] 100 ns | [X] 200 ns | [X] 400 ns | [X] Other: pulsation within range of 100 ns up to 1000 ns

Bunch width (Sigma/FWHM): < 0.5 ns

[X] Absolute suppression of dark current is mandatory to eliminate off-pulse background. **This is a non-negotiable requirement** (*sine qua non)* for the successful identification of rare 2γ events.

Beam Spot Geometry:

Desired spot size on target: 1 mm (e.g., < 0.5 mm)

[X] Requirement for no beam halo

Energy Resolution:

ΔE requirement: 10-20 keV (e.g., < 10 keV)

5. Application Category

[X] **Fundamental Nuclear Physics**

[ ] **Medical Applications**

[ ] **Electronics Irradiation**

[ ] **Material Science / Biophysics**

6. Additional Infrastructure Needs

a) Gamma-Ray Detectors

Dedicated array of background-less fast scintillators is required. $CeBr_3$ or equivalent (better/newer) is highly recommended over $LaBr_3$:Ce as it lacks the intrinsic background, which is critical for identifying rare 2γ events.

b) Particle detectors (proton, electron)

To measure Internal Conversion Electrons (ICE) and Internal Pair Creation (IPC), which are the dominant competing decay modes for $0^+ \rightarrow 0^+$, as well as for the detection of the scattered protons.