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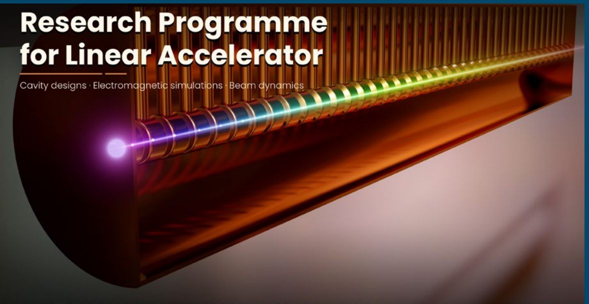
Discrete gamma-ray spectroscopy in light ion beam-induced reactions

M. Matejska-Minda, P. Bednarczyk, I. Dedes,
D. Duda (PhD student), et al.,



2nd Workshop on Research & Innovation in Poland
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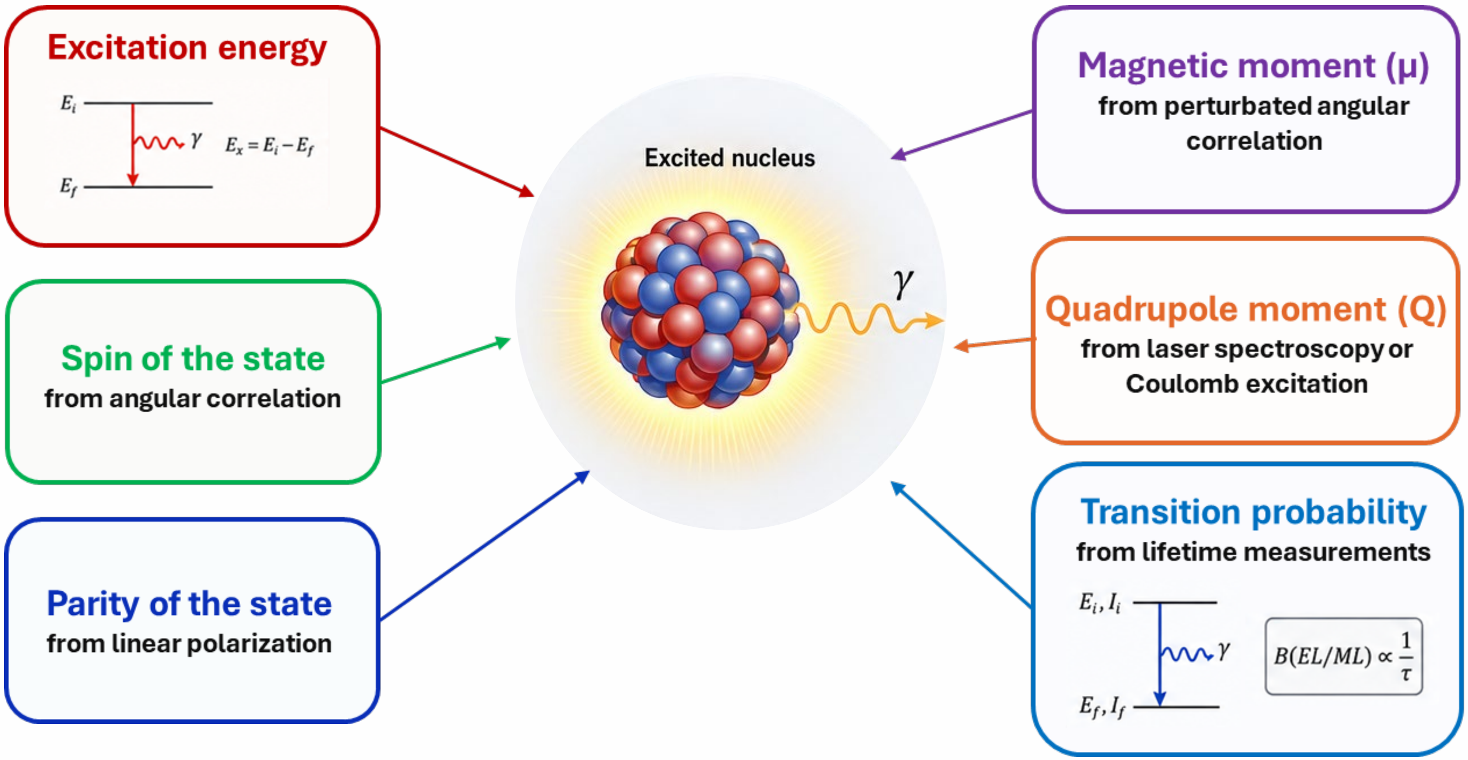
Discrete gamma-ray spectroscopy gives access to the most important observables of the excited nuclear states

enabling comparison with nuclear structure models

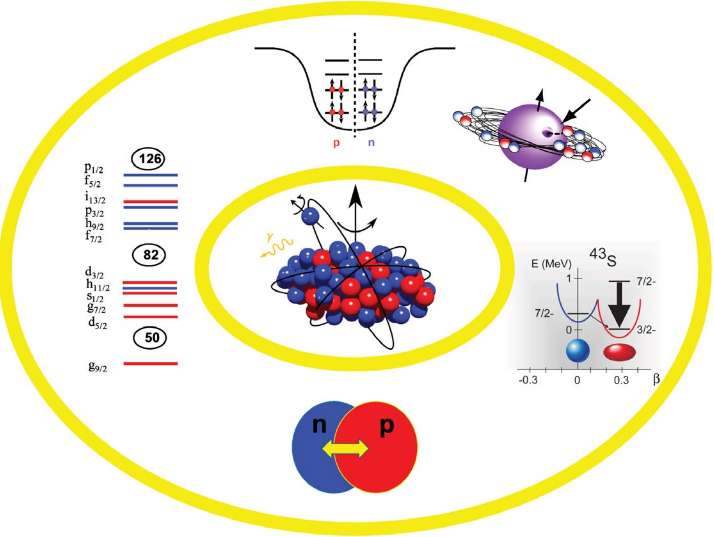


Key properties of the nuclear structure that can be studied using high-resolution γ -ray spectroscopy

Level filling with nucleons and the impact of their interactions

Complex configurations and isomerism

Shell structure and single-particle properties



Nuclear shapes and shape coexistence

Collective vibrations of nuclei

A. Bracco, G. Duchêne, Zs. Podolyák, P. Reiter - Progress in Particle and Nuclear Physics, 121 (2021) 103887

High-resolution measurement of discrete transitions a tool to study the structure of the atomic nucleus

A HIGH RESOLUTION LITHIUM-DRIFT GERMANIUM GAMMA-RAY SPECTROMETER

A. J. TAVENDALE* and G. T. EWAN

Chalk River Nuclear Laboratories, Atomic Energy of Canada Limited

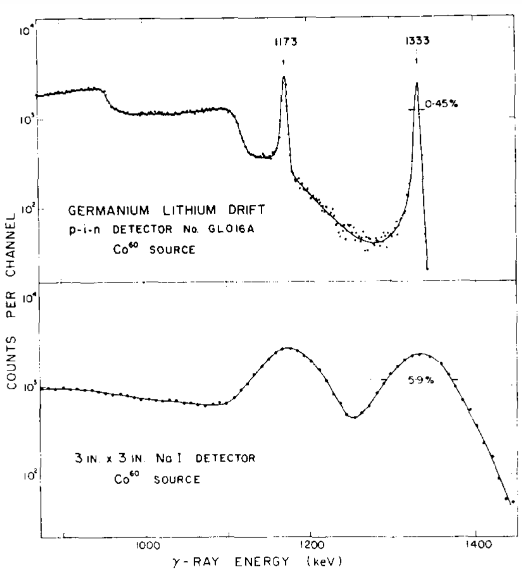
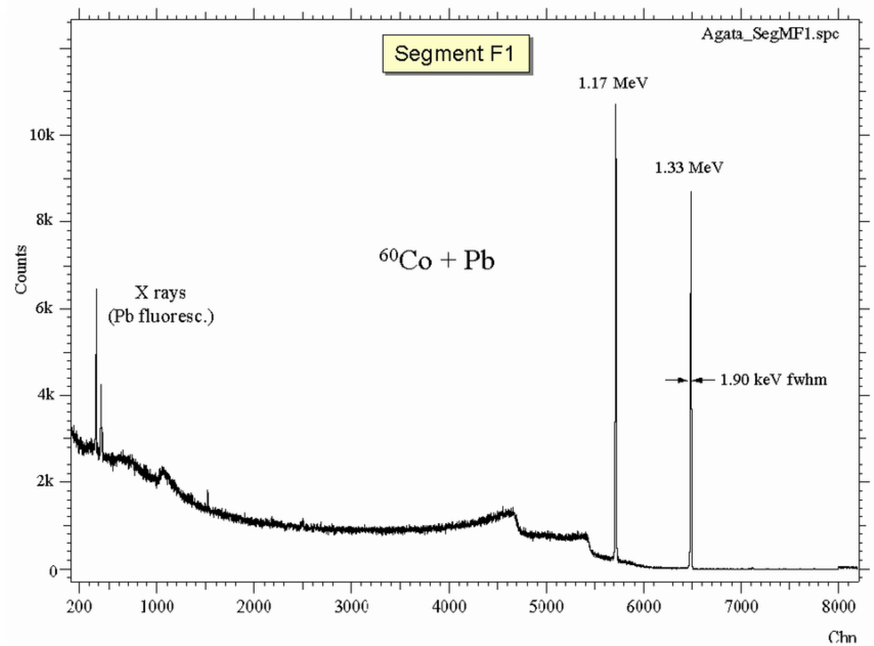


Fig. 1. High energy region of gamma-ray spectrum of Co^{60}

NUCLEAR INSTRUMENTS AND METHODS 25 (1963) 185–187

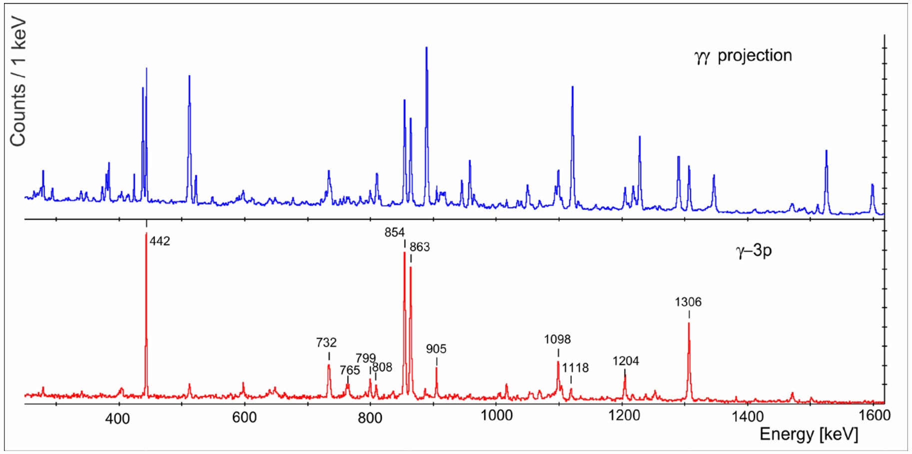
Modern gamma-ray spectrometer



High-resolution measurement of discrete transitions a tool to study the structure of the atomic nucleus

EAGLE+NEDA+DIAMANT

^{32}S(86 MeV) + ^{40}Ca



D. Duda (PhD thesis, Acta Phys. Pol. B Proc. Suppl. 19, 1-A20 (2026))

Main experimental tools

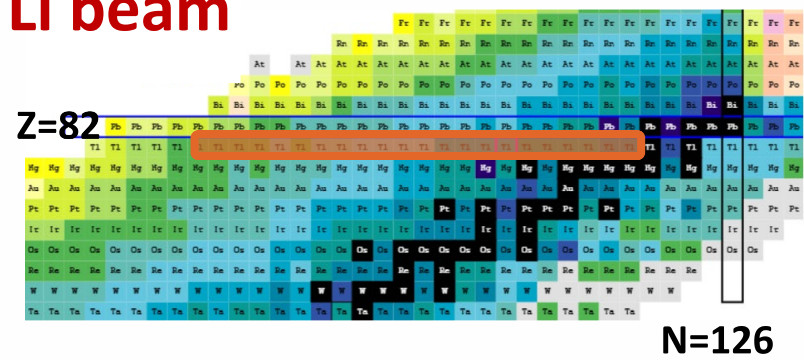
- HPGe detectors
- Particle-gamma coincidence measurements

Gamma-ray spectroscopy on LINIAC beams at IFJ PAN

^{7}Li beam The weakly bound cluster structure of ^{7}Li makes it an ideal probe for transfer and fusion studies:

- ***Transfer reactions***
  - ***(^{7}Li, alpha), (^{7}Li, tritium), (^{7}Li, ^{6}Li), …***
  - ***Cluster structures in light nuclei***
- ***Fusion reactions*** *(^{7}Li beam can be utilized with a wide variety of targets, including heavy radioactive materials)*
  - ***Fusion-evaporation*** *as a standard approach*
  - ***Incomplete fusion - ICF*** *(possible reduction of fission cross section for heavy nuclei?)*

Spectroscopy of A~190 nuclei using ^{7}Li beam



- Neutron-deficient thallium (Z = 81) isotopes serve as a microscopic laboratory for nuclear physicists. They have just one proton less than the magic number for lead (Z = 82).

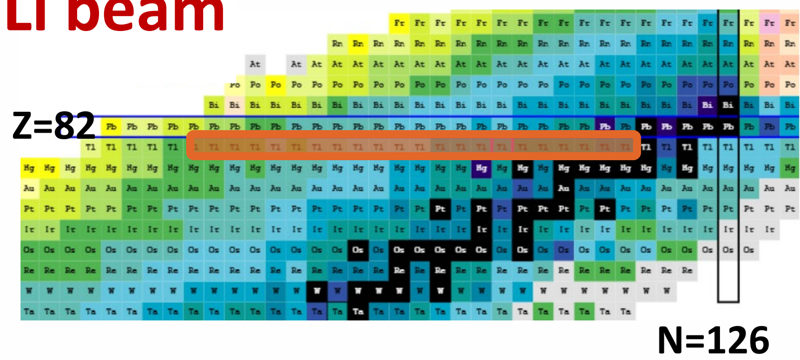
- A prolate-to-oblate shape transition is predicted to appear when moving towards the N = 126 shell closure, where the spherical shape should be restored.

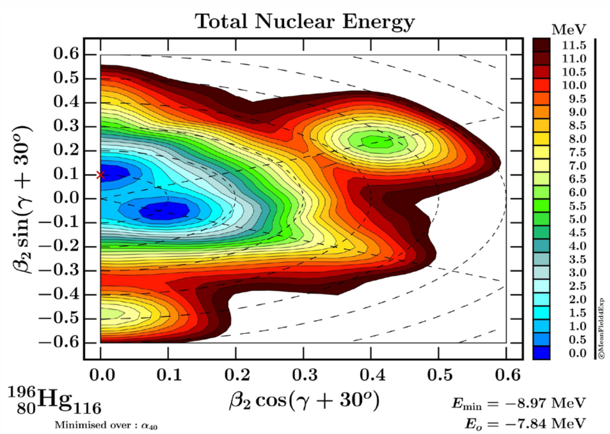
- Question of why prolate shapes dominate all over the chart of nuclei?

- Subtle interplay between single-particle and collective degrees of freedom - related to the underlying NN interaction and its role in the microscopic origin of deformation.

Spectroscopy of A~190 nuclei using ^{7}Li beam

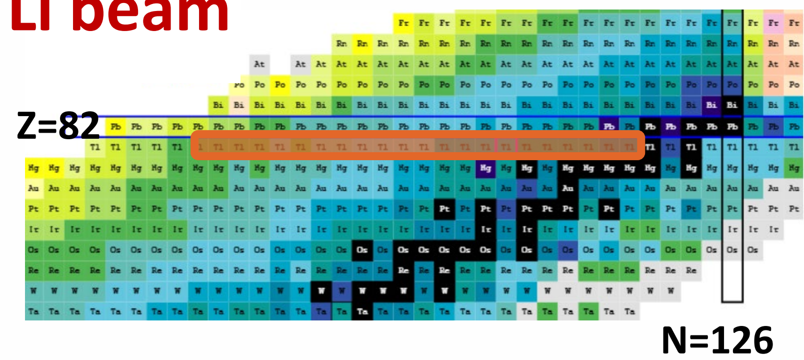
- At low spin, the 1-quasiparticle configurations in ^{195,196}Tl prefer an oblate shape
- As the nucleus is excited and neutrons align in the $i_{13/2}$ orbital, calculations show that the system shifts toward triaxiality





Potential energy surface as a function of the standard (beta, gamma) deformation, for ^{196}Hg, even-even neighbor of ^{196}Tl. In mean-field theory, it is a practical solution to refer to the even-even nucleus, since one expects similar results for the odd system concerned.

Spectroscopy of A~190 nuclei using ^{7}Li beam



Previous studies - Tl nuclei were investigated using beams:

- ^{13}C, 75 MeV, Physics Letters B 782 (2018) 768–772
- ^{18}O ^{15}N, ~90 MeV, Z. Phys. A-Hadrons and Nuclei 338,471-472 (1991)
- ^{42}Ca, 195 and 200 MeV - Phys. Rev. C 70, 064308 (2004)

Example of proposed research using the future LINIAC at IFJ PAN:

- ^{7}Li beam of E~6-10 MeV/n
- Fusion-evaporation reactions
- i.e., investigation of high-spin states in $^{193\text{-}196}$Tl
- Measurement of the excited states’ lifetimes
- Set-up: HPGe array + particle detectors

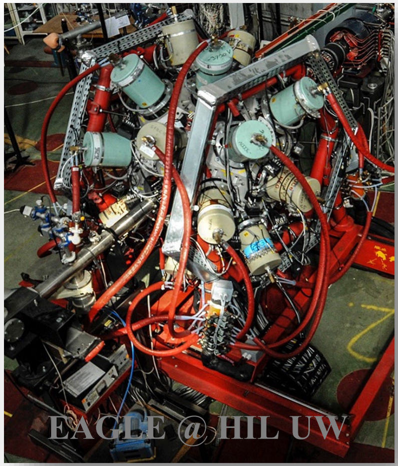
Which Section *(1, 2 or 3)*
Required beam: particle, energy and properties

Section 2

- **^{7}Li beam** with variable energy in the range of **2.5–12.5 MeV**, with absolute suppression of dark current (off-pulse background) by a factor of at least 10^6
- **Pulse structure** required: 100 ns and its multiples
- Beam **current on target** should reach up to ~500 nA
- Beam **energy resolution** of approximately 10–20 keV is desirable

Required Infrastructure

- **For HPGe Detector Operation**
  - Nitrogen cooling installation
  - Detector Service Laboratory



> ➢ **During the design phase, ensure that the experimental hall is adapted to the nitrogen cooling system.**
> ➢ **Allocate dedicated space for a detector servicing laboratory.**

- **Particle detectors**
  - Particle detectors are available both in IFJ and among collaborations (light charge particles, neutrons, recoils)

SWOT analysis for the project

- **S (Strengths)** *Potential for internationally competitive measurements. Access to an intense ^{7}Li beam (ensuring suitability for nuclear physics experiments), access to modern gamma-ray spectroscopy technologies, and availability of shared advanced detector systems for gamma spectroscopy.*
- **W (Weakness)** *Very limited range of available ion beams and lack of existing infrastructure for high-resolution gamma-ray spectroscopy experiments.*
- **O (Opportunities)** *Complementary nuclear structure studies using light-ion beams; development of technical and nuclear research competences at IFJ PAN and construction of a complete experimental setup. Opportunity to become an active member of the international community studying the structure of heavy and very heavy nuclei, and to establish IFJ PAN as an experimental site in this field.*
- **T (Threats**) *Long timescale, which may lead to partial obsolescence of the research program. Insufficient funding for the experimental setup and the high cost of advanced gamma-ray spectrometers.*

Conclusions

- Gamma-ray spectroscopy is a powerful tool in nuclear structure investigations
- Light-ion beams from the future LINAC accelerator at IFJ PAN will provide new opportunities to study nuclear structure and shape evolution, offering valuable insight into the underlying microscopic interactions
- This requires the availability of an HPGe germanium array @ IFJ PAN
- The future LINAC facility at IFJ PAN could establish a competitive program in nuclear spectroscopy