Experimental and theoretical studies of exotic nuclei at ISOLDE (EXONTEX) 2025

Project Director: Razvan LICA, IFIN-HH

IFA CERN-RO ISAB Open Session, 28 November 2025

Project impact

The scientific focus of the project is well integrated in a more general context at European level, where the study of the structure of atomic nuclei is expected to get a boost from the major investment projects in the field like FAIR in Germany, SPIRAL2 in France or, more recent, ELI-NP in Romania.

In particular, the project aims to:

- Support the Romanian contribution to the ISOLDE Collaboration (CERN-MoU-2016-015)
- Provide equipment, manpower and expertise for the ISOLDE Decay Station - permanent decay spectroscopy setup of ISOLDE established in 2014 and other experiments and infrastructure present at ISOLDE (ISOLDE Tapestation, VITO, Gamma-MRI, WISArD, ISS, CRIS, etc.)
- Establish a state-of-the-art beyond-mean-field theoretical description of structure and dynamics of exotic medium mass nuclei manifesting shape coexistence and mixing

Complementary projects that support the local IFIN-HH group: NUCLEU, RO-FAIR, EUROLABS, …

Project description

PROJECT WORK PLAN (2024 - 2026)

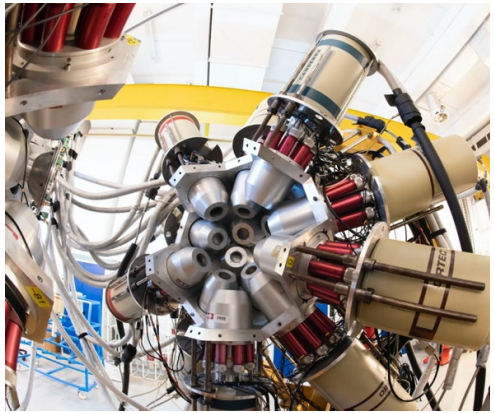
1. **Beta-decay spectroscopy of medical radioisotopes at the ISOLDE Decay Station and Shape coexistence and mixing in ^{98}Y**
    a. Experimental investigation of the decay signatures of ^{225}Ac at the ISOLDE Decay Station
    b. Shape coexistence effects on low-lying states in ^{98}Y

2. **<u>Upgrades of the WISArD beta particle detection setup and Coexistence phenomena in neutron-rich nuclei within the complex Excited Vampir beyond-mean-field model</u>**
    a. Development and installation of the WISArD beta detectors based on SiPM arrays readout
    b. Effective realistic interactions in large model spaces. Coexistence phenomena in neutron-rich medium mass nuclei

3. **Commissioning of the TDPAC setup of IDS and Investigation of shape coexistence effects on the structure and dynamics of exotic medium mass nuclei**
    a. Commissioning of the Time Dependent Perturbed Angular Correlations setup of IDS and first measurement of magnetic moments of isomeric states in neutron-rich Po isotopes
    b. Refined effective interactions in adequate large model spaces. Shape coexistence impact on the structure and dynamics of exotic medium mass nuclei

Complementary local infrastructure

- 9MV Tandem accelerator
- ROSPHERE gamma spectroscopy array
- HPGe detector laboratory
- Electronics laboratory
- Target laboratory
- Mechanical workshop



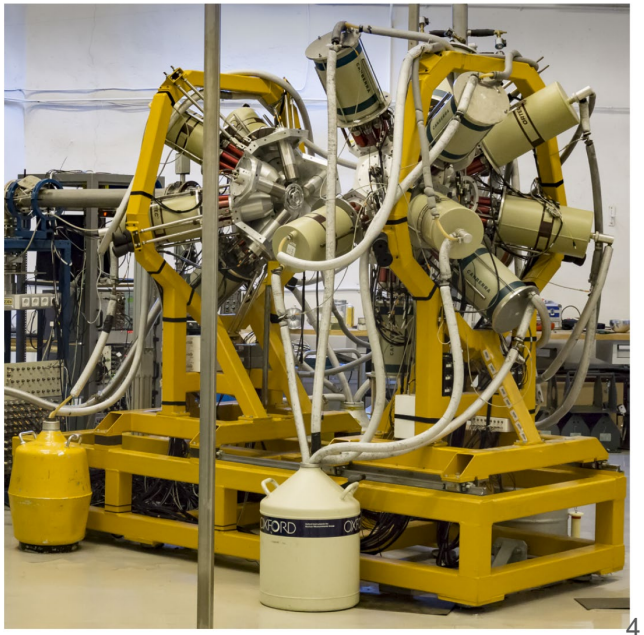
ELSEVIER

Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 837, 21 November 2016, Pages 1-10

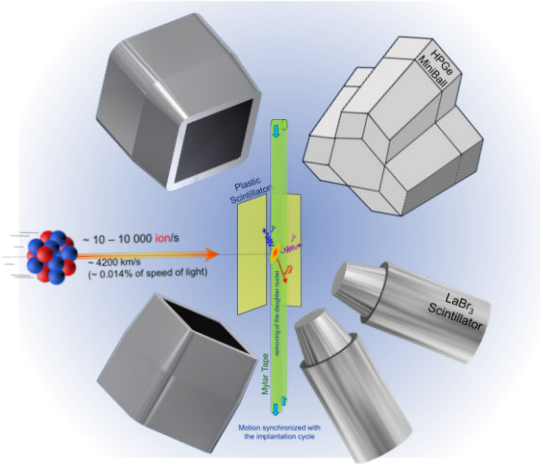
The ROSPHERE γ-ray spectroscopy array

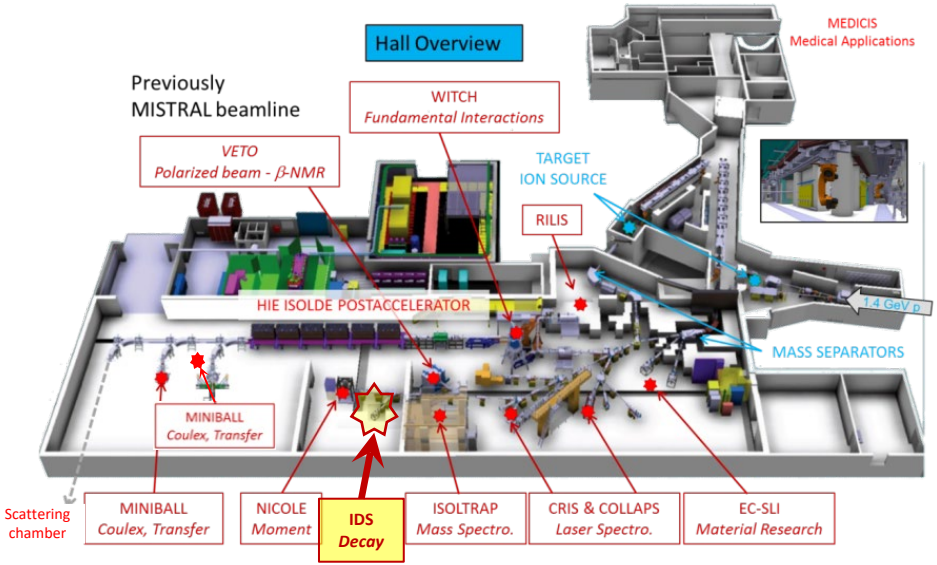
D. Bucurescu [a], I. Căta-Danil [a], G. Ciocan [a], C. Costache [a], D. Deleanu [a], R. Dima [a], D. Filipescu [a, c], N. Florea [a], D.G. Ghiță [a], T. Glodariu [a], M. Ivașcu [a], R. Lică [a], N. Mărginean [a], R. Mărginean [a], C. Mihai [a], A. Negret [a], C.R. Niță [a], A. Olăcel [a], S. Pascu [a], T. Sava [a], L. Stroe [a], A. Şerban [a, j], R. Şuvăilă [a], S. Toma [a], N.V. Zamfir [a, c], G. Căta-Danil [b], I. Gheorghe [c], I.O. Mitu [c], G. Suliman [c], C.A. Ur [c], T. Braunroth [d], A. Dewald [d], C. Fransen [d], A.M. Bruce [e], Zs. Podolyák [f], P.H. Regan [f, g], O.J. Roberts [h]

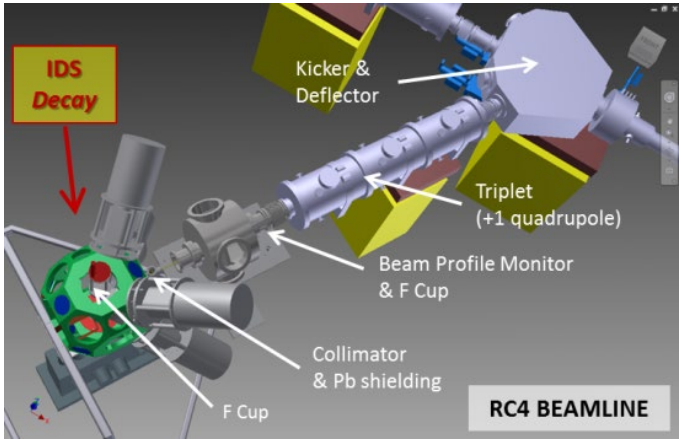


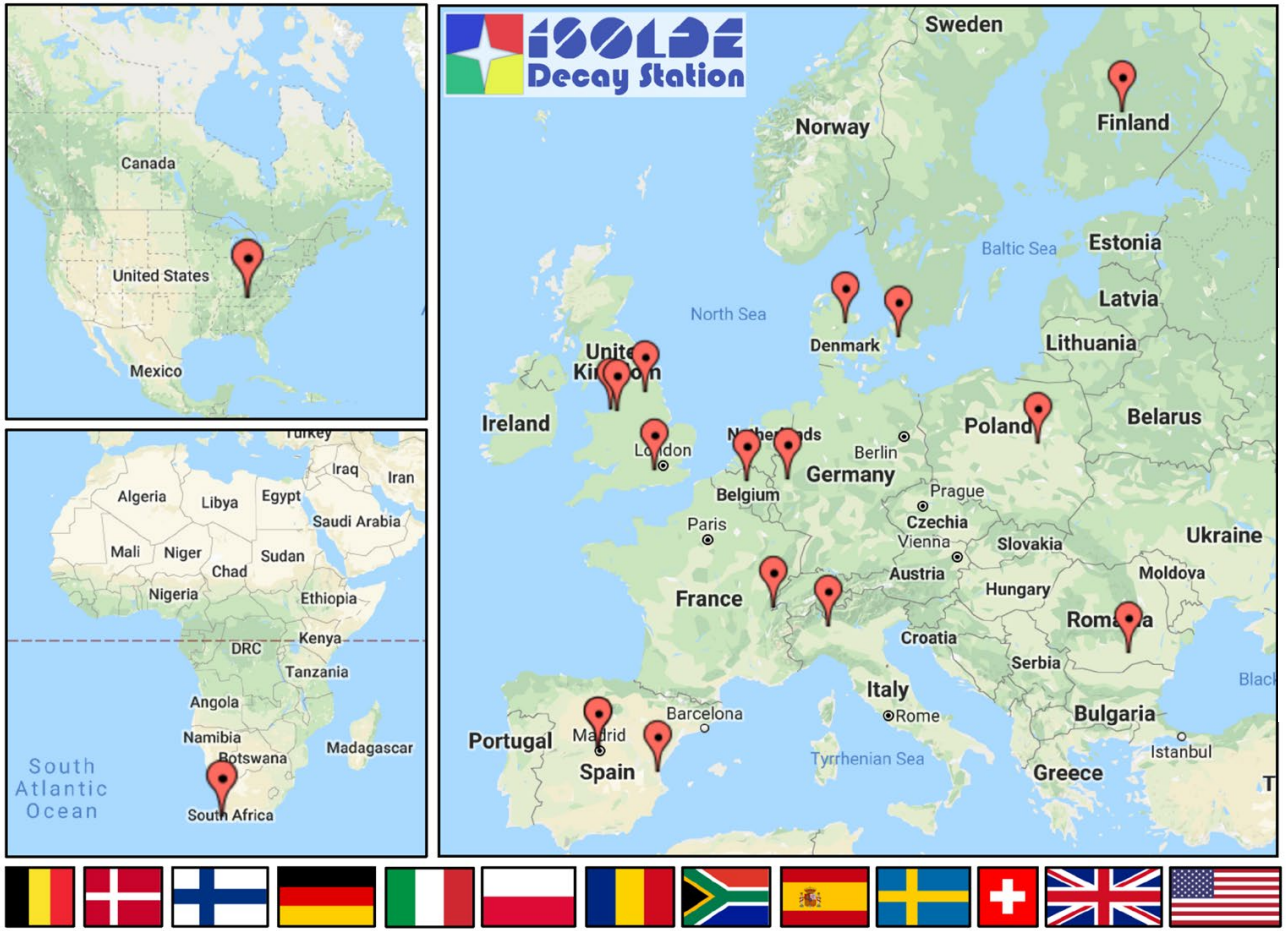
The ISOLDE Decay Station (IDS) project aims to provide:

- **Permanent Setup** for beta-decay studies using the beams from ISOLDE (since 2014)
- **Flexible approach** (for several decay types and studies)
  - **HPGe detectors** (4 permanent Clovers + extra)
  - **Ancillary detectors** ($LaBr_3$, plastic scintillator, silicon, neutron)
  - **Tape station**
  - **In-Source Laser Spectroscopy Studies using RILIS** (since 2017)
- **Collaboration** to support and perform decay studies at ISOLDE









Collaborating institutes

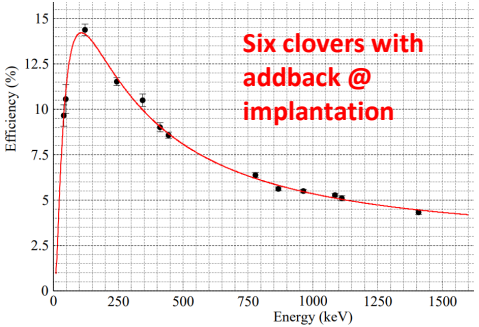
- Belgium (KU Leuven)
- Denmark (Aarhus University, Department of Physics and Astronomy)
- Finland (University of Jyväskylä)
- Germany (Institut für Kernphysik - Universität zu Köln)
- Italy (Università degli Studi e INFN Milano)
- Poland (Faculty of Physics, University of Warsaw)
- Romania (IFIN-HH Bucharest)
- South Africa (iThemba LABS)
- Spain (IEM-CSIC Madrid; IFIC-CSIC Valencia; UCM Madrid)
- Sweden (Lund University)
- Switzerland (CERN - ISOLDE)
- UK (STFC Daresbury Laboratory; University of Liverpool; University of York; University of Surrey)
- USA (University of Tennessee)

IDS is supported by 18 institutes across the world, and used by many more globally.

Core IDS setup

Six HPGE clover detectors (+6 Aug. 2024)

- 4 crystals / clover
- 20% relative eff. / crystal
- 2 thin-carbon window detectors for low-E (~10 keV)

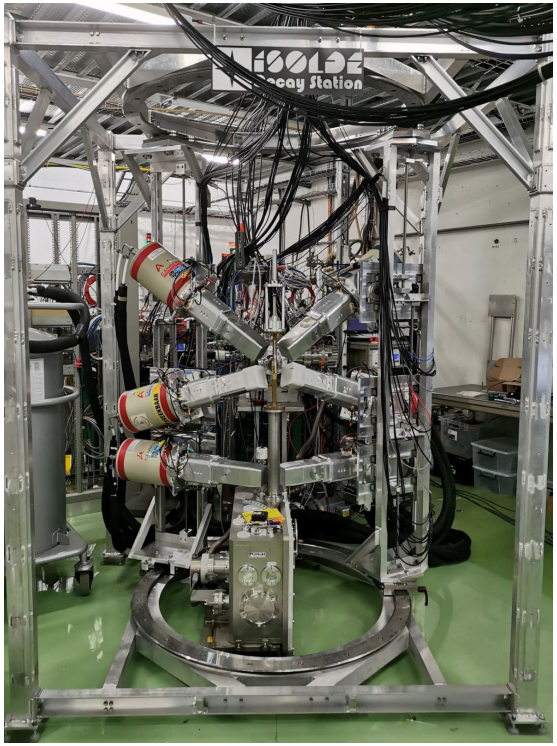


Flexible + dynamic support structure (2023)

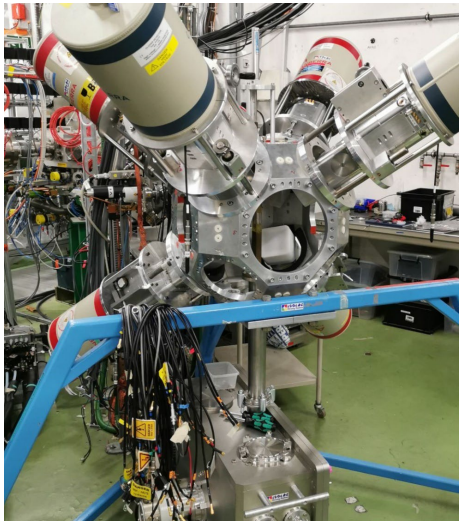
- Minimise material around implantation position
- Detectors mounted on vertical gantries, 3 clovers per gantry, gantries mounted on circular rails
- Can move detectors radially + vertically, tilt vertically, rotate on axes

Digital XIA pixie-16 acquisition system

- 16 channels per module
- 12-16 bit ADC
- 100, 250 and 500 MHz modules
- 208 channels/crate



Old, pre-2023 system



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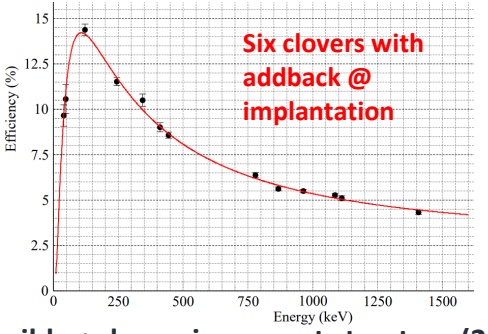

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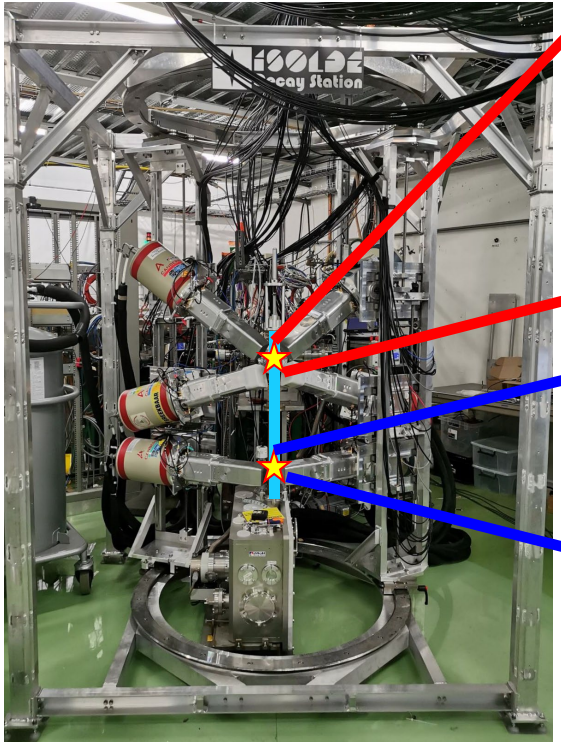
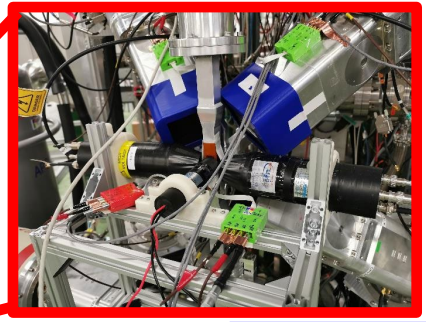
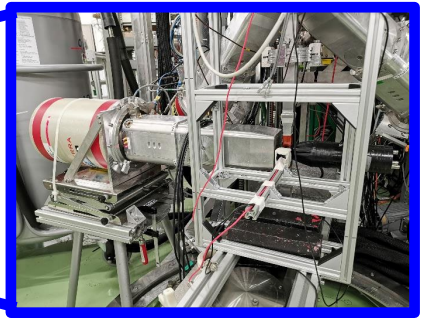
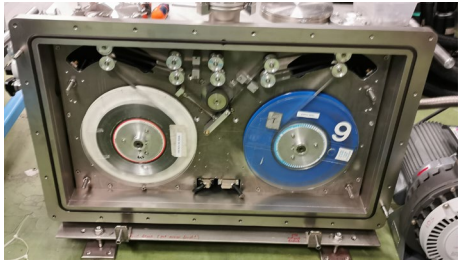








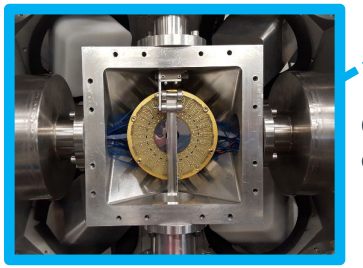
Movable tape system

- Reel-to-reel aluminsed mylar tape (~2.5 km)
- Fully automated system
- Integrated with ISOLDE beam logic, RILIS laser system, and our DAQ
- **Primary "implantation" position**
  For main aims of experiments
- **Secondary "decay" position**
  Free "bonus" experiment, long-lived activity

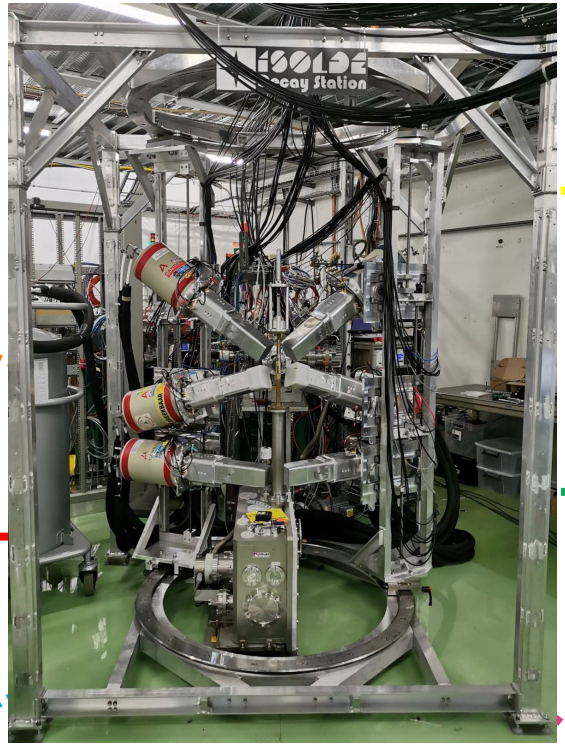
Ancillary systems

High β-γ efficiency

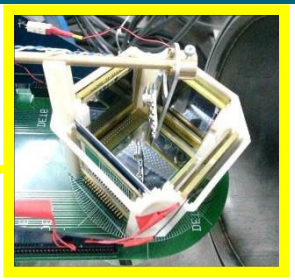
Fast-timing



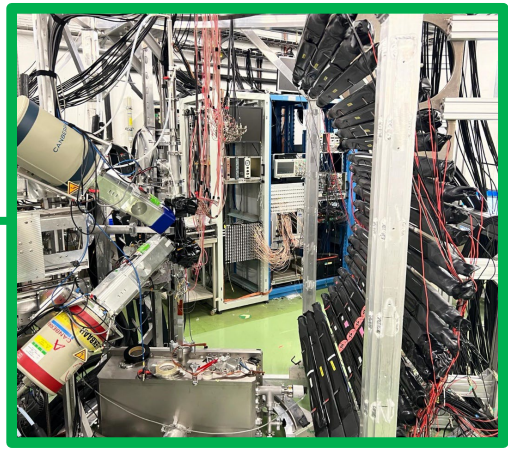
Conversion electrons



Charged-particle Spectroscopy



Neutron Spectroscopy



Plastic scints. (β tagging)

TD-PAC – Coming soon

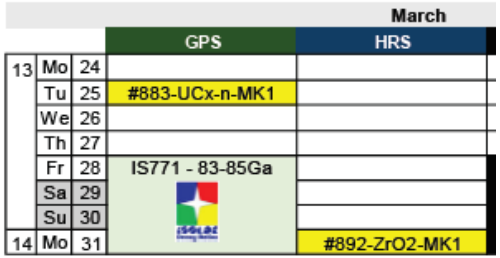
- System “specialized” to needs of particular experiment
- Easily interchangeable, and compatible with each other

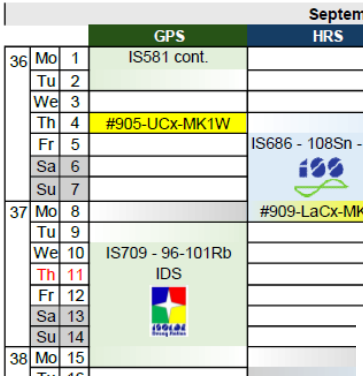
Experimental highlights 2025

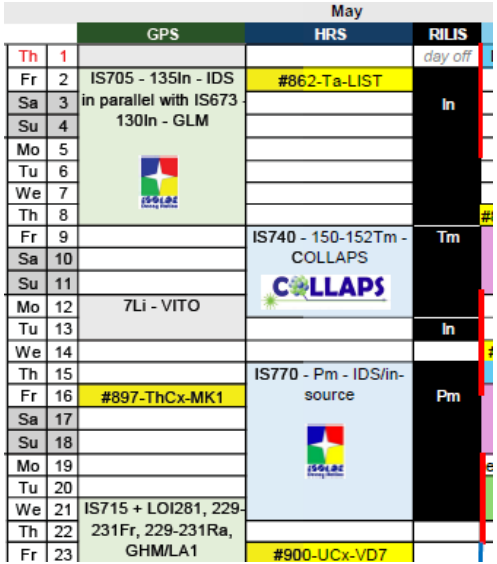
Romanian contribution to the ISOLDE Decay Station

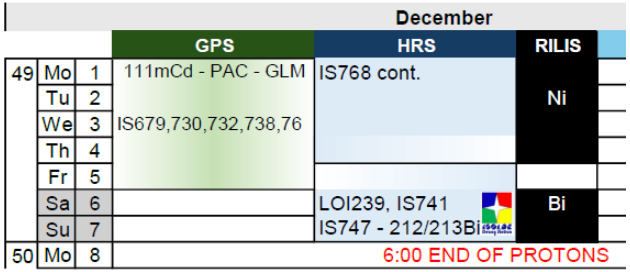
2025 Campaign at IDS

- **IS771**: Shell evolution in Ge isotopes with N<=50 investigated via fast-timing methods
- **IS705**: Beta-delayed neutron emission of ^{135}In using IDS neutron and gamma detectors and the new high-resolution neutron detector NEXT.
- **IS770**: First online laser spectroscopy study of promethium isotopes
- **IS709**: Locate excited 0+ state(s) in ^{100}Sr in order to unravel the nuclear structure responsible for the sudden change in deformation characteristic of the region.
- **IS747**: In-source laser and decay spectroscopy studies of high-spin states in ^{212,213}Bi
- **IS741**: unique decay signatures of ^{225}Ac, ^{221}Fr, ^{213}Bi and ^{209}Tl
- **LOI239**: ion source test of Bi production using an UCx target at IDS to test the applicability of the TDPAC technique









https://isolde.web.cern.ch/isolde-schedule-2025

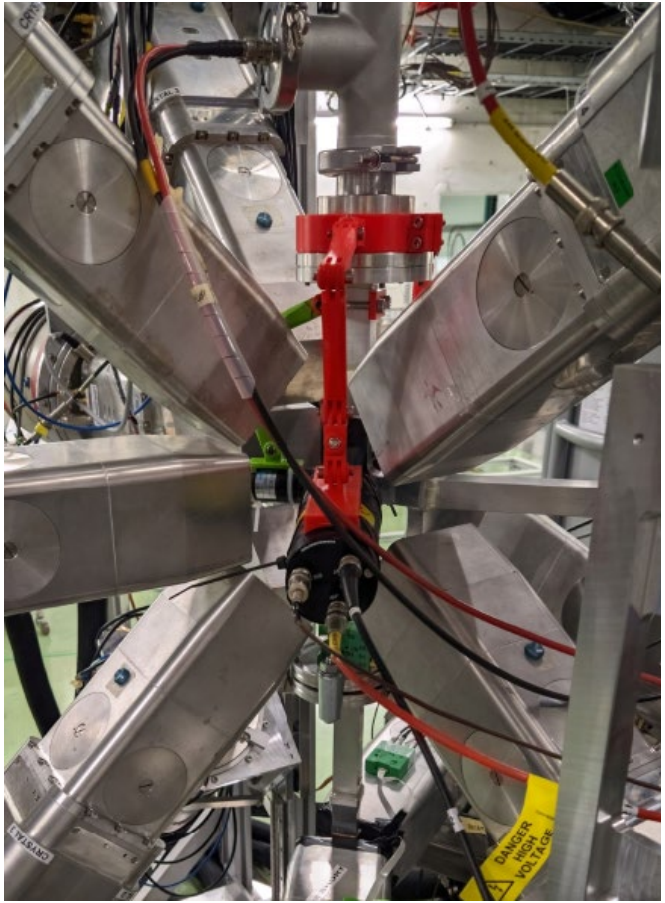
Experimental highlights 2025

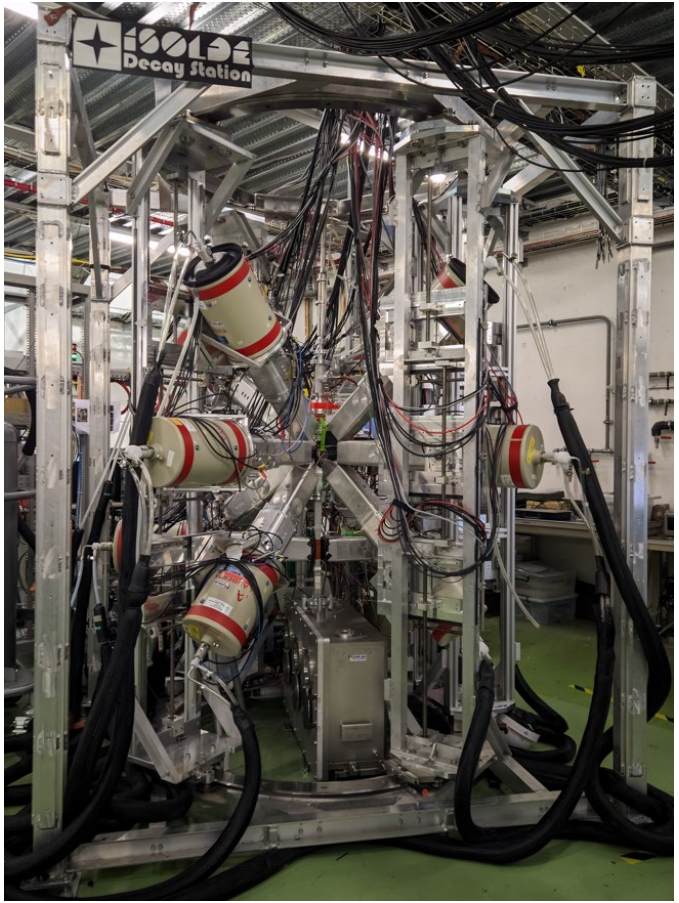
Romanian contribution to the ISOLDE Decay Station

2025 Campaign at IDS

- 12 HPGe clover detectors were used at IDS between Dec 2024 – Dec 2025. (8 contributed by our group)

- In the future, we plan to include up to 11 HPGe Clover detectors at IDS as part of the permanent experimental setup, allowing the new structure to reach the maximum number of 15 detectors (together with the detectors contributed by KU Leuven)

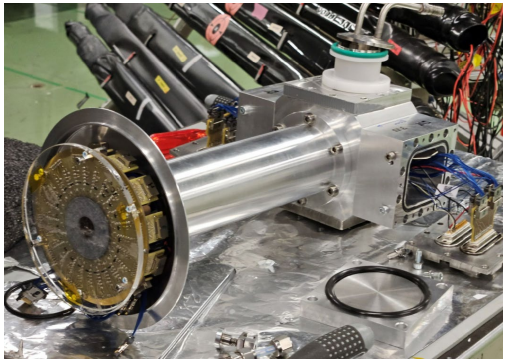


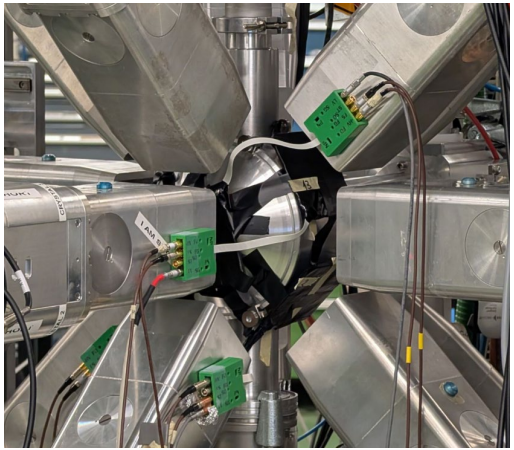


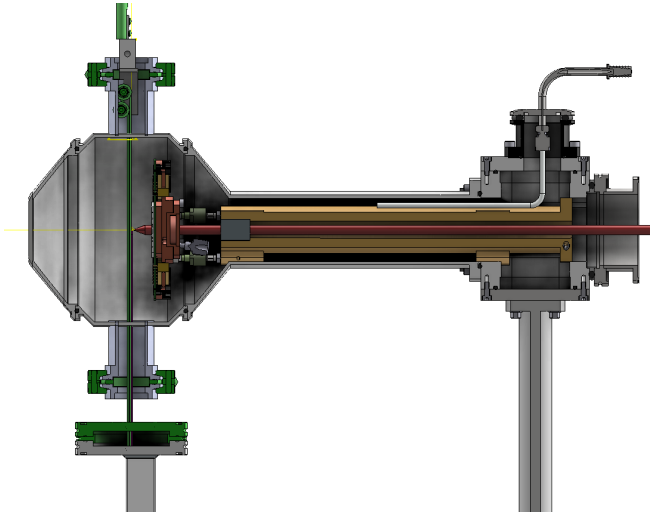
Experimental highlights 2025

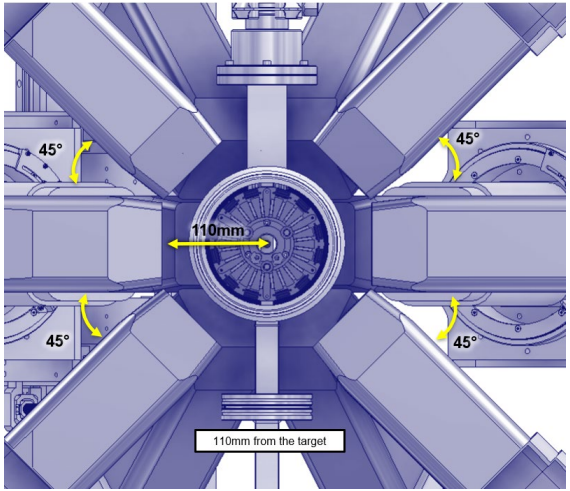
Romanian contribution to the ISOLDE Decay Station

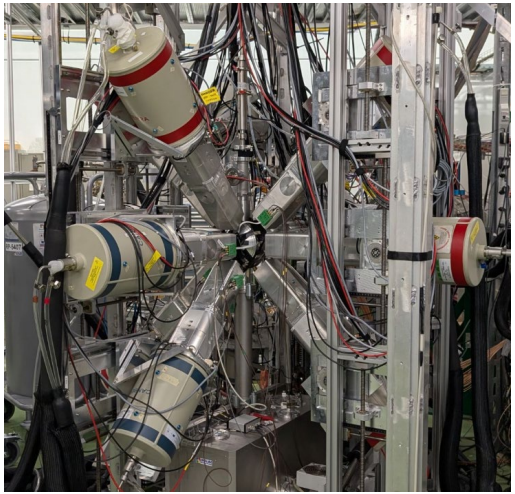
- The IDS Collaboration developed a new implantation chamber dedicated to conversion electron spectroscopy using the SPEDE detector, upgrading the old one from 2018.
- First use during experiment **IS709** “Exploring shape coexistence across N=60 in ^{100}Sr using IDS” **(Sep 2025)**









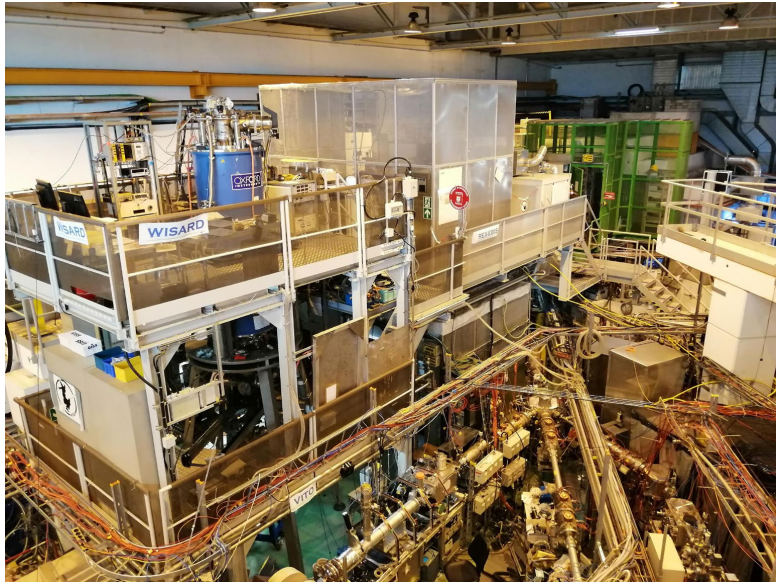


Experimental highlights 2025

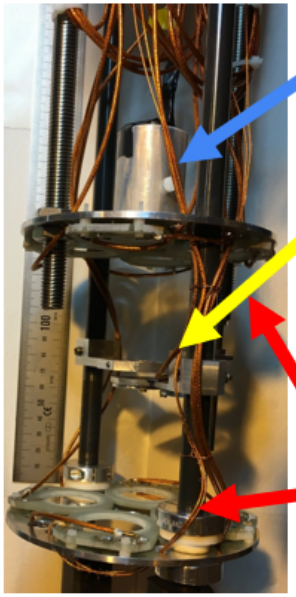
Romanian contribution to complementary projects

Search for physics beyond the Standard Model with radioactive probes

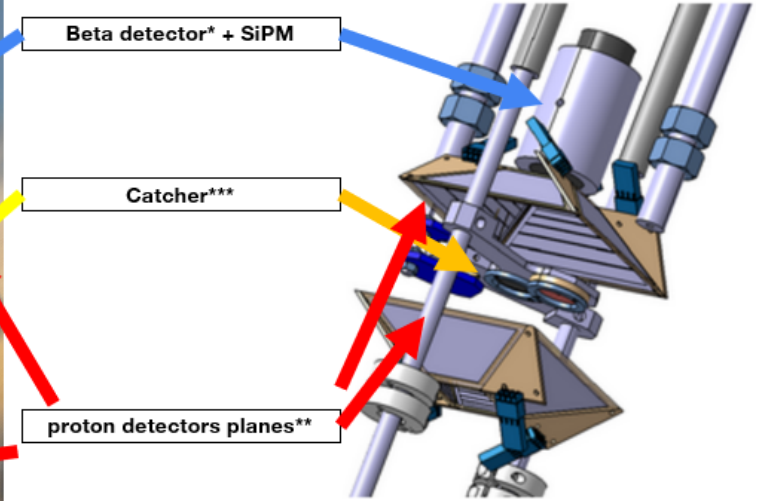
WISArD: The Weak Interaction Studies with 32Ar Decay



2018



2021



* Plastic scintillator;
** Silicon surface-barrier (thickness = 300 μm);
*** Aluminized Mylar (thickness = 6.7 μm)

* Plastic scintillator – EJ200;
** MICRON single-sided silicon-strip (thickness = 300 μm);
*** Aluminized Mylar (thickness = 0.5 μm)

Aim: improved description of the weak interaction via beta-delayed proton emission. The 30-keV $^{32}Ar^{+}$ ions are implanted in the catcher foil at the center of the setup. The positrons emitted upwards are guided by the field of a superconducting magnet and detected by a plastic scintillator. Silicon detectors surrounding the catcher foil measure the kinematic shift of the beta-delayed protons.

Experimental highlights 2025

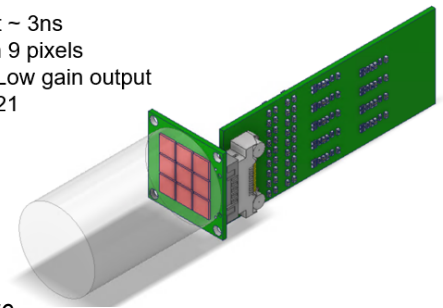
Romanian contribution to complementary projects

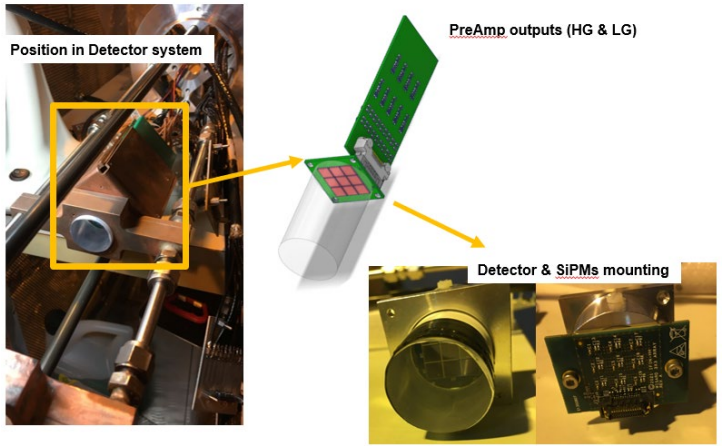
Search for physics beyond the Standard Model with radioactive probes

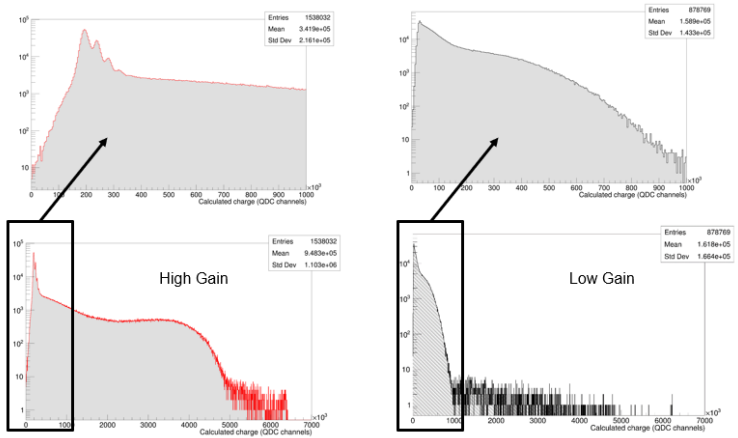
WISArD: The Weak Interaction Studies with 32Ar Decay

- Experiments performed in 2021 and 2023 using the prototype beta detector designed by IFIN-HH.
- Paper describing the experimental setup published in 2023
- New experiment **IS678** in April 2025
- Improved detector re-designed at IFIN-HH (to be continued)

- EJ 200 scintillator (S_{face}= 707mm^2)
  - 10^4 photons/MeV
  - Light output duration t ~ 3ns
- SiPM array equipped with 9 pixels
- Each pixel has High and Low gain output
- Prototype ready in Jul 2021







D. Atanasov et al., NIM, A 1050 (2023) 168159

Experimental highlights 2025

Romanian contribution to complementary projects

CRIS: Collinear Resonance Ionization Spectroscopy

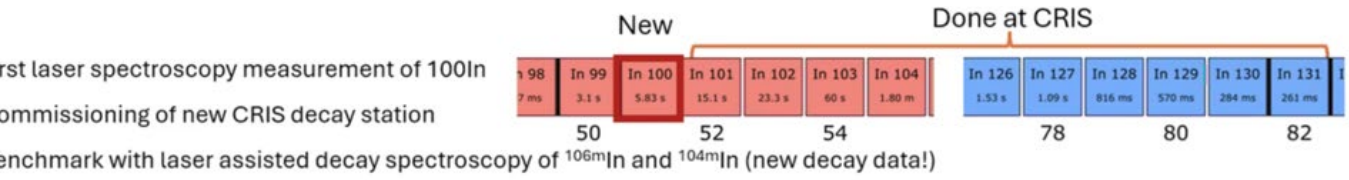
- We contributed to the **IS772** experiment “Collinear resonance ionization of neutron-deficient indium: closing up on N = 50” (Sep 2025).
- First use of the decay spectroscopy station with 3 HPGe detectors and the beta plastic developed at IFIN-HH.

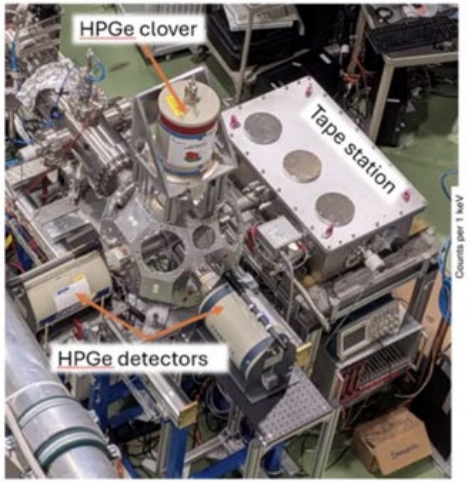
IS772 – Collinear resonance ionization of neutron-deficient indium

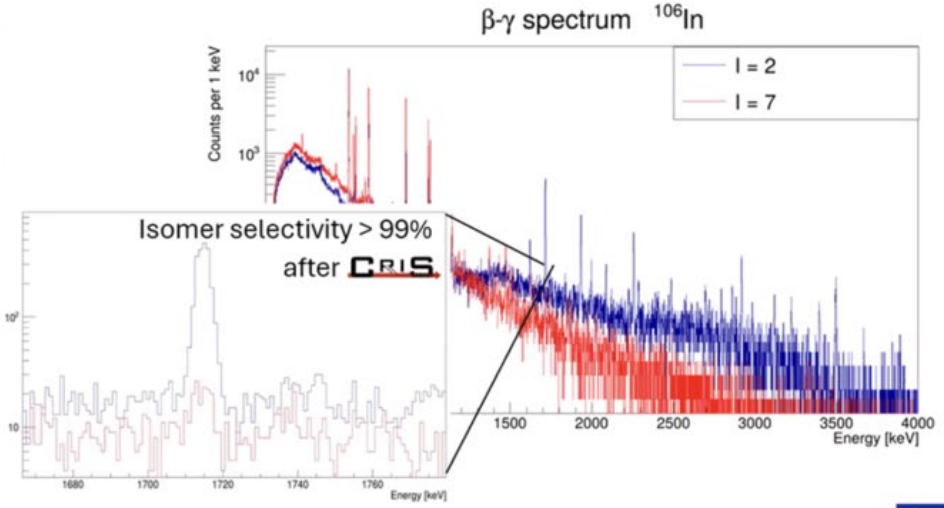
First laser spectroscopy measurement of 100In

Commissioning of new CRIS decay station

Benchmark with laser assisted decay spectroscopy of ^{106m}In and ^{104m}In (new decay data!)





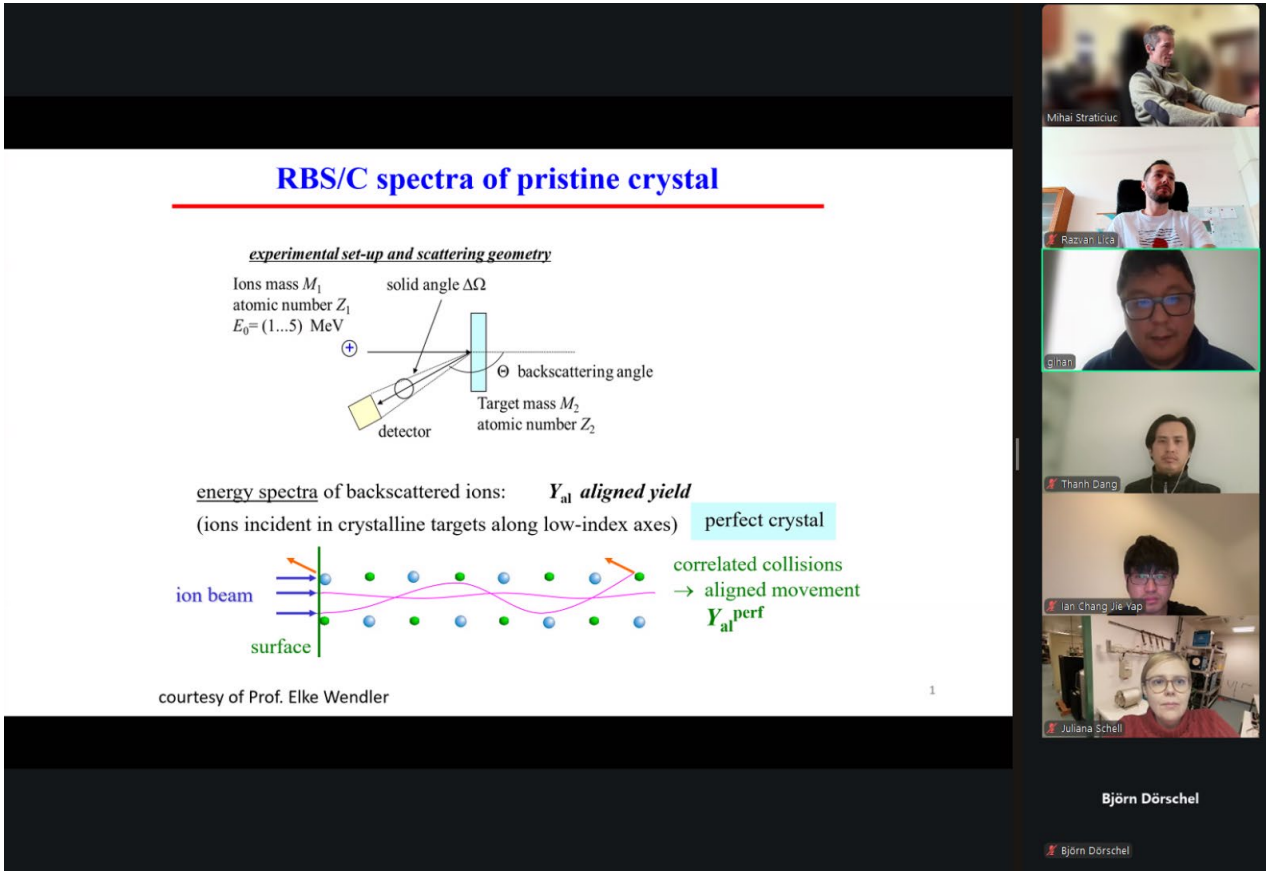


J. Warbinek et al.

Experimental highlights 2025

Romanian contribution to complementary projects

Discussions initiated regarding applied research opportunities with the Solid-State Physics (**SSP**) group of ISOLDE for a test implantation at the end of 2025 to characterize a sample irradiated at IFIN-HH, in preparation for a full proposal after CERN Long Shutdown 3 (LS3) to study the origin of the β-γ phase transition, the intrinsic mechanism to accommodate lattice disorder without amorphization, in Ga_2O_3, one of the most promising materials for next-generation high-power and high-efficiency electronics.



Previous Theoretical highlights
2022-2024

Shape coexistence and E0 transitions in the Z=N+2 ^{70}Kr nucleus and investigation of the β decay of the ground state of ^{70}Kr and 9^{+} isomer in ^{70}Br (2022-2023)

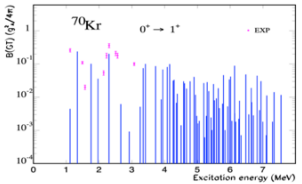
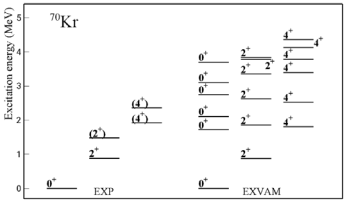


Fig.1. GT strength distribution for the decay of the 0^{+} state of ^{70}Kr to 1^{+} states in ^{70}Br [1].



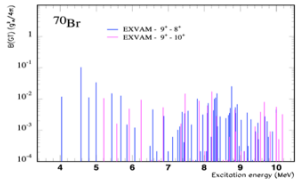


Fig.2. GT distribution for the decay of the 9^{+} isomer in ^{70}Br to 8^{+} and 10^{+} states in ^{70}Se.

Multifaceted impact of shape coexistence in proton-rich nuclei within a beyond-mean-field model - β decay study of ^{94}Ag → ^{94}Pd (2023)

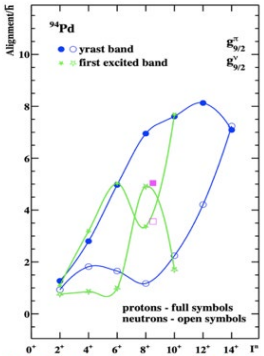
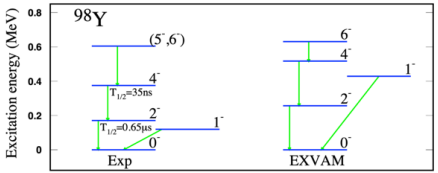
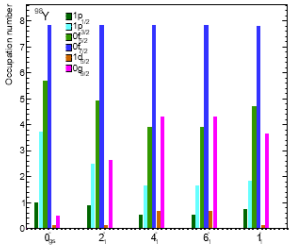


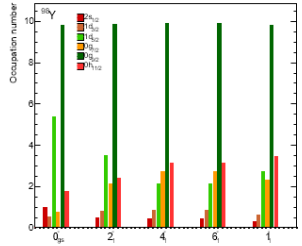
Fig.3. The alignment plot for the yrast and the first excited band as well as for the third 8^{+} state (in red) in ^{94}Pd.

Beyond-mean-field approach to low-lying isomeric states in ^{98}Y (2024)



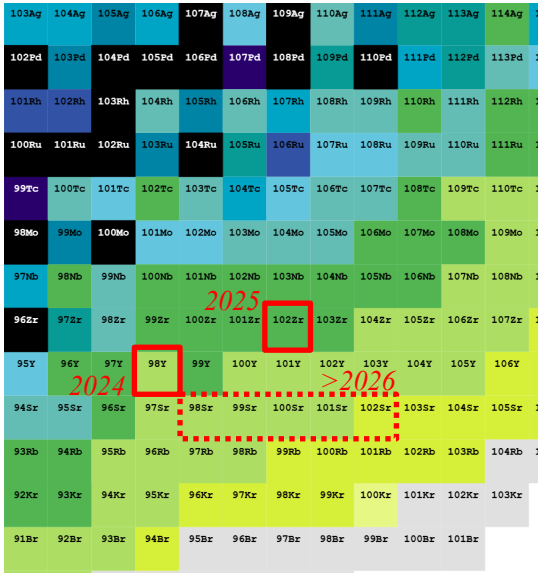


Proton occupation of valence spherical orbitals



Neutron occupation of valence spherical orbitals

(2025) Beyond-mean-field approach to shape coexistence in ^{102}Zr



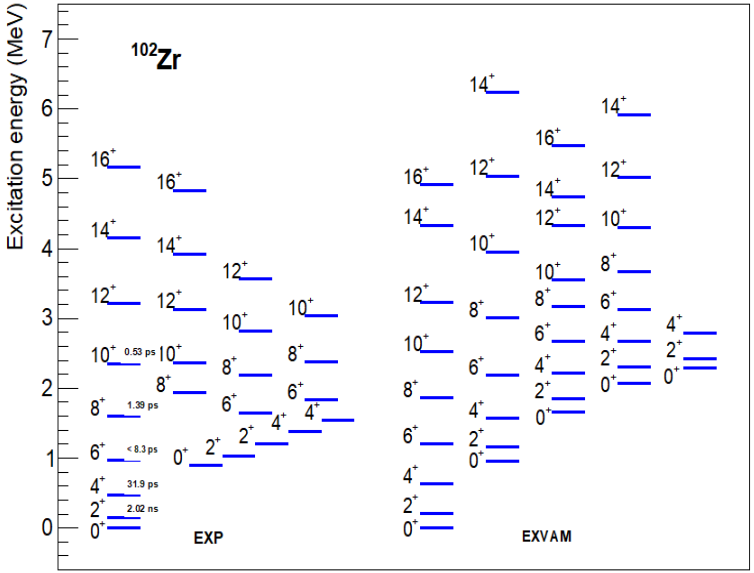


TABLE II. $B(E2;\Delta I = 2)$ values (in e^2fm^4) in ^{102}Zr compared to experimental results.

Transition	EXVAM	EXP
$B(E2;2_1^+ \to 0_1^+)$	2503	2802 *(96)*
$B(E2;4_1^+ \to 2_1^+)$	3558	4788 *(729)*
$B(E2;6_1^+ \to 4_1^+)$	3820	> 2504
$B(E2;8_1^+ \to 6_1^+)$	3872	4104 *(621)*
$B(E2;10_1^+ \to 8_1^+)$	3850	4312 *(814)*

TABLE I. The amount of mixing of the lowest *complex* Excited Vampir positive-parity states of ^{102}Zr. The contributions (of at least 1%) of prolate and oblate deformed EXVAM configurations are indicated in decreasing order.

$I[\hbar]$	prolate content	oblate content
0_1^+	96(2)%	1%
0_2^+	1(1)%	82(14)(1)%
0_3^+	93(1)(1)%	2(2)(1)%
0_4^+	68(5)(2)(2)(1)%	10(6)(5%
0_5^+	14(2)(1)%	70(10)(2)%
2_1^+	97(2)%	
2_2^+		86(13)(1%
2_3^+	97(1)%	1%
2_4^+	79(5)(2)%	9(2)(2)%
2_5^+	11(1)%	75(11)%
4_1^+	96(2)(1)%	
4_2^+		88(11)(1)%
4_3^+	96(1)(1)(1)%	
4_4^+	89(4)(3)%	2(1)%
4_5^+	2%	84(11)(1)(1)%
6_1^+	96(2)(1)%	
6_2^+		90(9)%
6_3^+	96(1)(1)%	1%
6_4^+	91(3)(3)(1)%	1%
8_1^+	94(3)(2)%	
8_2^+		92(7)%
8_3^+	93(4)(1)(1)%	
8_4^+	93(3)(2)(1)%	
10_1^+	88(8)(3)(1)%	
10_2^+	79(20)(1)%	
10_3^+		95(4)%
10_4^+	94(3)(1)(1)%	
12_1^+	80(14)(3)(2)(1)%	
12_2^+	94(3)(2)%	
12_3^+	94(3)(1)(1)%	
12_4^+		98(2)%
14_1^+	84(9)(4)(2)%	
14_2^+	88(10)(1)%	
14_3^+	93(5)(1)(1)%	
14_4^+		98(2)%
16_1^+	68(28)(2)(2)%	
16_2^+	71(27)(2)%	

Effects of shape coexistence in the structure and dynamics of low-spin states and high-spin bands: beyond-mean-field understanding within the complex Excited Vampir model involving an effective interaction starting from the charge-dependent Bonn CD potential and a large model space built out of the $1p_{1/2}$, $1p_{3/2}$, $0f_{5/2}$, $0f_{7/2}$, $2s_{1/2}$, $1d_{3/2}$, $1d_{5/2}$, $0g_{7/2}$, $0g_{9/2}$, $0h_{11/2}$ spherical orbitals for both protons and neutrons.

Results

(Dec 2024 - Nov 2025)

Published final results from the IS608 (^{213,232}Fr beam) and IS650 (^{214,216,218}Bi beam) experiments.

- **Papers:**

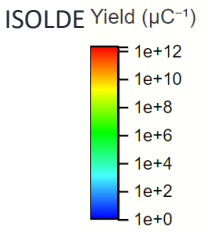
1. Multifaceted impact of shape coexistence in proton-rich nuclei within a beyond-mean-field model, A. Petrovici, O. Andrei, EPJ Web of Conferences 329, 02009 (2025)
2. Observation of the J≤7/2 low-spin states in 213Fr populated in the electron capture of the 1/2− ground state of 213Ra, C. Clisu, A. N. Andreyev, C. R. Nita*, R. Lica, et al., Phys. Rev. C 110, 064315 (Dec 2024) (Not reported in the 2024 Annual Summary)
3. Revealing the Nature of yrast States in Neutron-Rich Polonium Isotopes, R. Lica et al., Phys. Rev. Lett. 134, 052502 (2025)
4. New upper limits for β-delayed fission probabilities of 230,232Fr and 230,232,234Ac, S. Bara et al., Phys. Rev. C 111, 065803 (2025)
5. Structure of 128Sn selectively populated in the β decay of the 128In ground state, M. Llanos-Exposito et al., Phys. Rev. C 111, 064310 (2025)
6. The 76Cu conundrum remains unsolved, B. Olaizola et al., Phys Lett B 866, 1395519 (2025)
7. β- and α-decay spectroscopy of 182Au, J. Mist et al., Phys. Rev. C 112, (2025)
8. Charge radii and electromagnetic moments of 214−218Bi: Exploring the “southern” border of the Z>82 octupole-deformation region, A. Barzakh et al., Phys. Rev. C 112, 034304 (2025)
9. First β-Delayed Two-Neutron Spectroscopy of the r-Process Nucleus 134In and Observation of the i13/2 Single-Particle Neutron State in 133Sn, P. Dyszel et al., Phys. Rev. Lett. 135, 152501 (2025)

- **Talks of group members:**

1. Multifaceted impact of shape coexistence in neutron-rich nuclei within a beyond-mean-field approach, A. Petrovici, invited talk at Carpathian Summer School of Physics 2025, Sinaia, Romania, 22 June-03 July 2025
2. Shape coexistence effects in medium mass nuclei within a beyond-mean-field approach, A. Petrovici, invited talk at the Workshop on Nuclear Moments (WNM 25), Orsay, France, 12-14 May 2025
3. Revealing the nature of yrast states in neutron-rich polonium isotopes, R. Lica et al., invited talk at the 29th International Nuclear Physics Conference (INPC 2025), Daejeon, South Korea, 25–30 May 2025.

IDS publications

(Nov 2025)



^{214}Bi - *B. Andel et al., PRC 104, 054301 (2021)*
^{216}Bi - *B. Andel et al., PRC 109, 064321 (2024)*
$^{214-218}$Bi – *R. Lica et al., PRL 134, 052502 (2025)*
$^{214-218}$Bi – *A. Barzakh et al., PRC 112, 034304 (2025)*

^{208}At - *M. Brunet et al., PRC 103, 054327 (2021)*
^{213}Ra - *C. Clisu et al., PRC 110, 064315 (2024)*

^{230,234}Ac,Fr – *S. Bara et al., PRC 111, 065803 (2025)*

^{186}Tl - *M. Stryjczyk et al., PRC 102, 024322 (2020)*
^{182,184,186}Tl - *M. Stryjczyk et al., PRC 108, 014308 (2023)*
^{182}Au - *J. Mist et al., PRC 112, (2025)*

^{207}Hg - *T. A. Berry et al., PLB 793, 271-275 (2019); T. A. Berry et al., PRC 101, 054311 (2020)*
^{208}Hg - *R. J. Carroll et al., PRL 125, 192501 (2020)*
$^{207-209}$Tl - *Z. Yue et al., PLB 849, 138452 (2024)*

^{76}Cu – *B. Olaizola et al., PLB 866, 1395519 (2025)*

^{149}Cs – *R. Lica et al., J. Phys. G 44 054002 (2017)*
$^{148, 150}$Cs – *R. Lica et al., PRC 97, 024305 (2018)*

^{31}Ar – *I. Marroquin et al., APP B 47, 747 (2016)*

^{131}In – *J. Benito et al., PRC 110, 014328 (2024)*
^{133}In – *M. Piersa et al., PRC 99, 024304 (2019)*
M. Piersa et al., APP B 49, 523 (2018)
^{134,135}In – *M. Piersa-Siłkowska et al., PRC 104, 044328 (2021)*
J. Heideman et al., PRC 108 024311 (2023)
^{132,133}In – *J. Benito et al., PRC 102, 014328 (2020)*
^{133}In *(n-spec.)* – *Z.Y. Xu et al., PRC 108, 014314 (2023)*
Z.Y. Xu et al., PRL 131, 022501 (2023)
^{134}In *(n-spec.)* – *P. Dyszel et al., PRL 135, 152501 (2025)*

^{20}Mg – *M. V. Lund et al., EPJ A52, 304 (2016)*
^{21}Mg – *E.A.M Jensen et al., EPJ A60, 153 (2024)*

^{128}In - *M. Llanos-Exposito et al., PRC 111, 064310 (2025)*
^{129}In – *R. Lica et al., PRC 93, 044303 (2016)*

$^{51-53}$K - *Z. Y. Xu et al., PRL 133, 042501 (2024)*

^{34}Mg – *R. Lica et al., PRC 95, 021301 (2017)*
^{34}Al - *R. Lica et al., PRC 100, 034306 (2019)*

^{16}N – *O. S. Kirsebom et al., PRL 121, 142701 (2018)*

^{8}B – *S. Vinals et al., APP B 51, 717 (2020)*

Publications: 36

21 *PRC,* ***6*** *PRL,* ***3*** *APP B,* ***3*** *PLB,* ***2*** *EPJA,* ***1*** *J.PHYS.G*

Chart source: https://isoyields2.web.cern.ch/IsoldeYieldChart.aspx

Outreach

- The DUROCERN permanent exposition, where students and researchers involved in this project interact with the public and present our activities at ISOLDE together with the importance of studying radioactive isotopes.
- In 2025, the joint ISOLDE and nTOF stand was visited by approximately **400** students from schools and high schools in Romania.
- 2 new MSc students joined our project and are involved as guides.

Expected developments

The future upgrades for IDS where IFIN-HH will contribute during the next years are:

- Install the new permanent HPGe detectors from IFIN-HH at IDS and upgrade the automatic liquid nitrogen filling system.
- Develop the LaBr3(Ce) detection array of IDS dedicated to fast-timing measurements using digital processing.
- Explore new particle and fission fragment detectors at IDS such as Timepix and (THick Gaseous Electron Multiplier) THGEM, recently employed at IFIN-HH.

Other scientific activities planned for the future, for which our group is directly responsible, are:

- Finalize the data analysis following the measurements of neutron and proton-rich Tl during the IS622 and LOI219 experiments from 2021 and 2022.

- Finalize the IS741 experiment proposed as co-spokespersons aiming to measure the unique decay signatures of 225Ac, 221Fr, 213Bi and 209Tl through precise gamma-ray spectroscopy measurements (T. E. Cocolios, P. Reagan, S. Collins, R. Lica et al, CERN-INTC-2023-063; INTC-P-676).

- Continue and expand the on-going collaboration with WISArD, VITO and CRIS.

- Open a new research avenue dedicated Solid State Physics through Perturbed Angular Correlation (PAC) studies of phase transitions in complex materials driven by ion irradiation, together with the team at the 3MV Tandem Accelerator lead by G. Velisa.

Theoretical investigations will be focused on providing a comprehensive theoretical understanding of coexistence phenomena in neutron-rich Sr and Zr nuclei, in connection with the IS709 experiment successfully performed at IDS in September 2025 and dedicated to search for excited 0^+ states and E0 transitions in $^{96\text{-}102}$Sr, populated in the β decay of $^{96\text{-}102}$Rb.