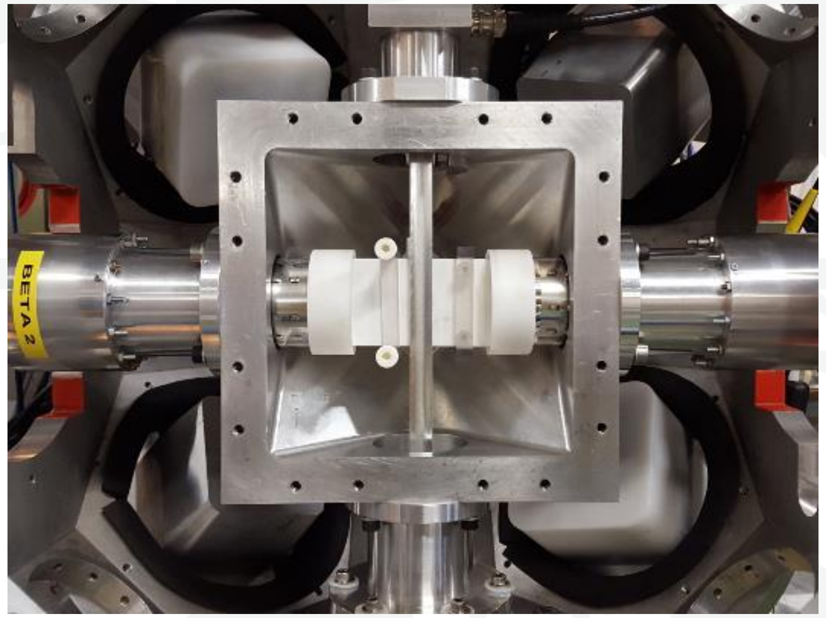
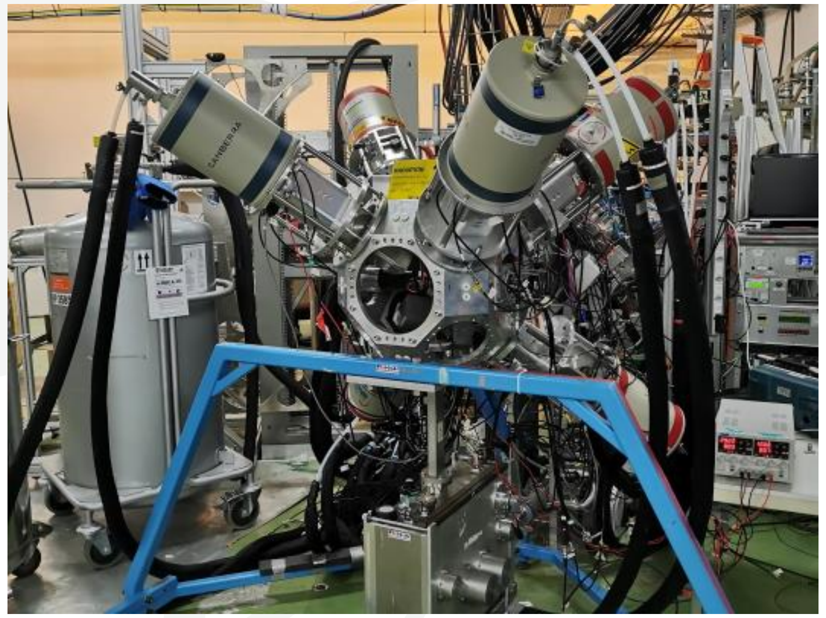
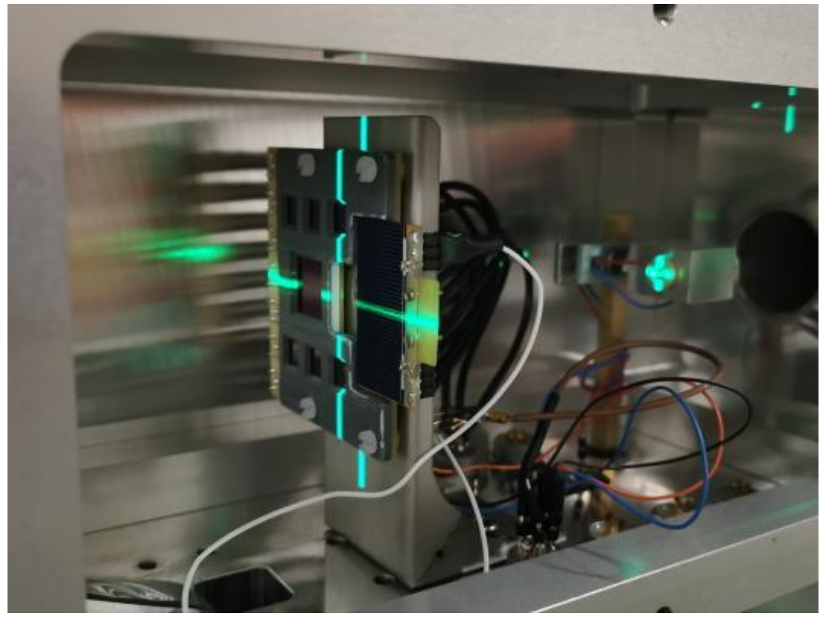
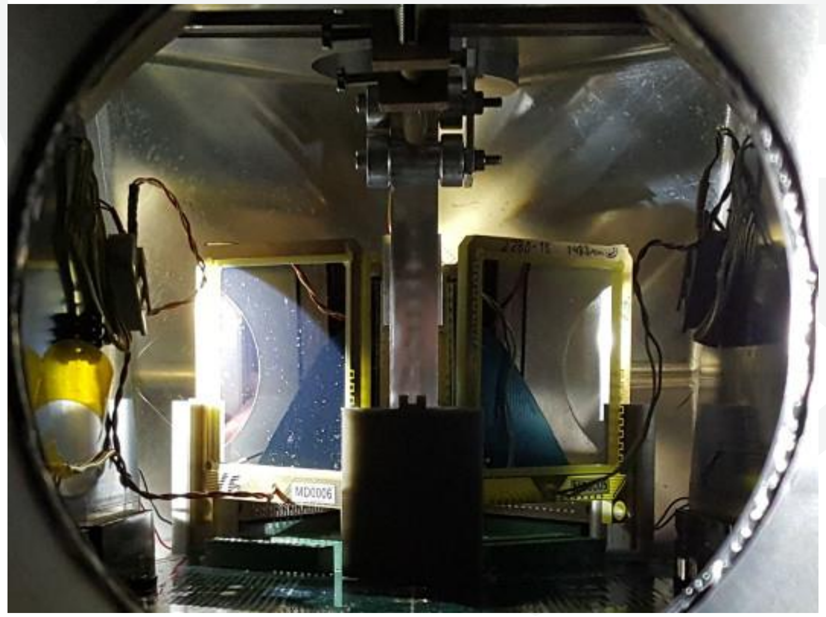
The ISOLDE Decay Station

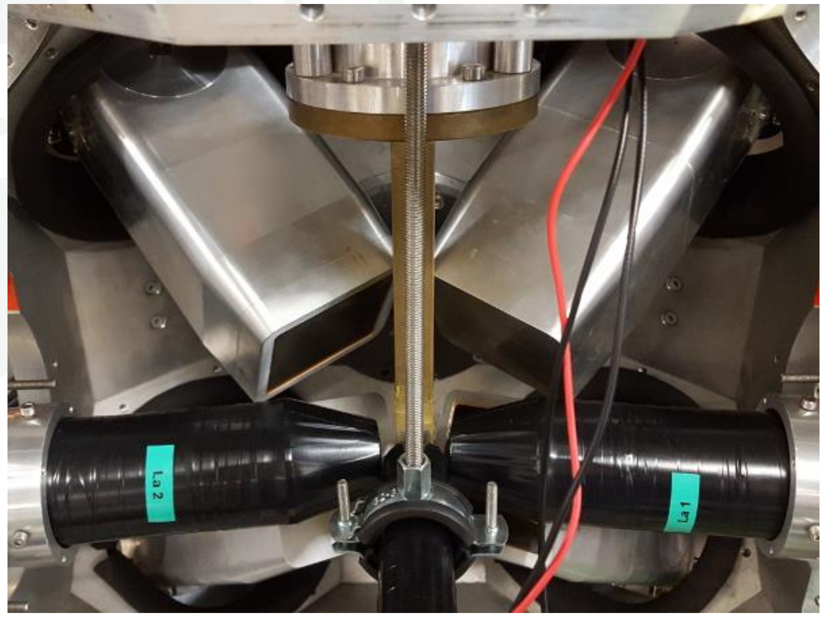
James Cubiss – University of York – james.cubiss@york.ac.uk
On behalf of the ISOLDE Decay Station collaboration, https://isolde-ids.web.cern.ch/

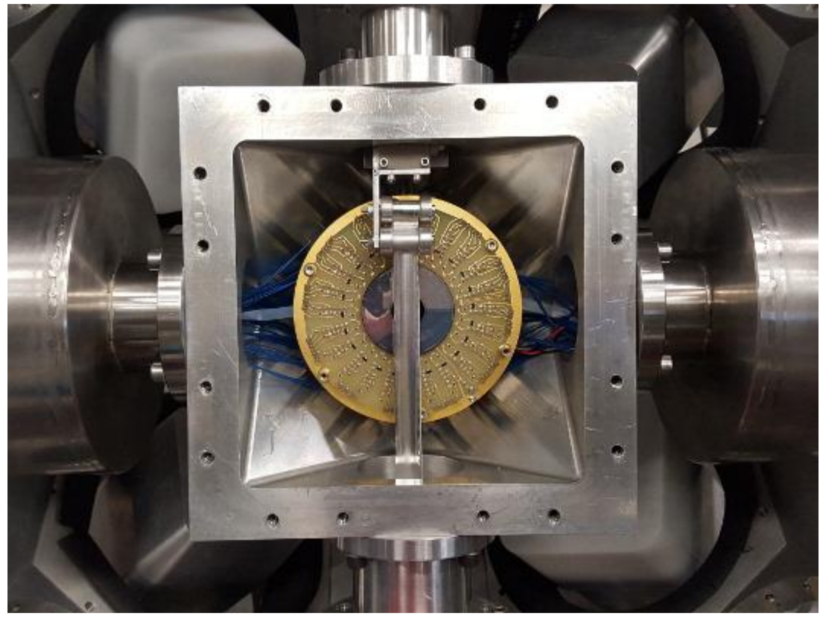








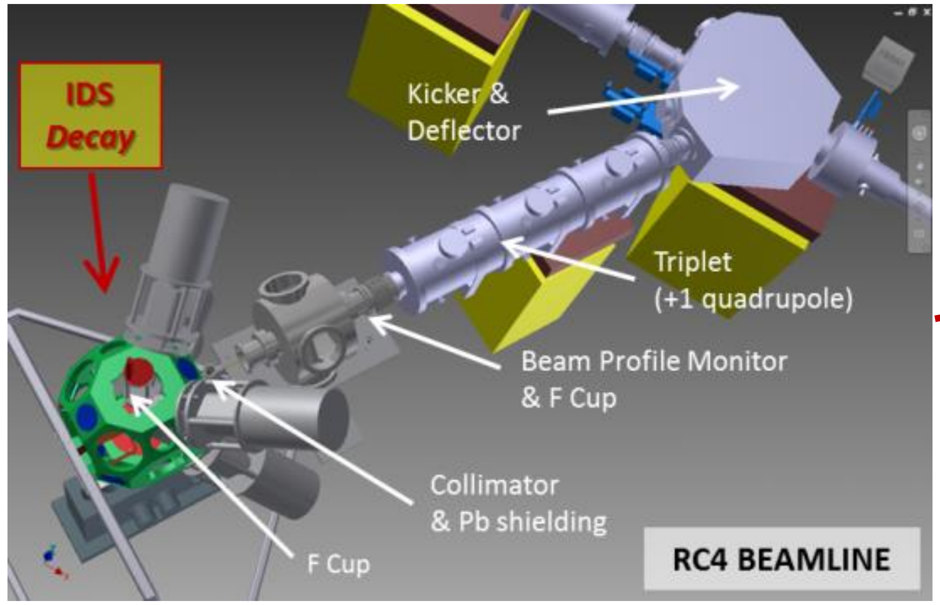


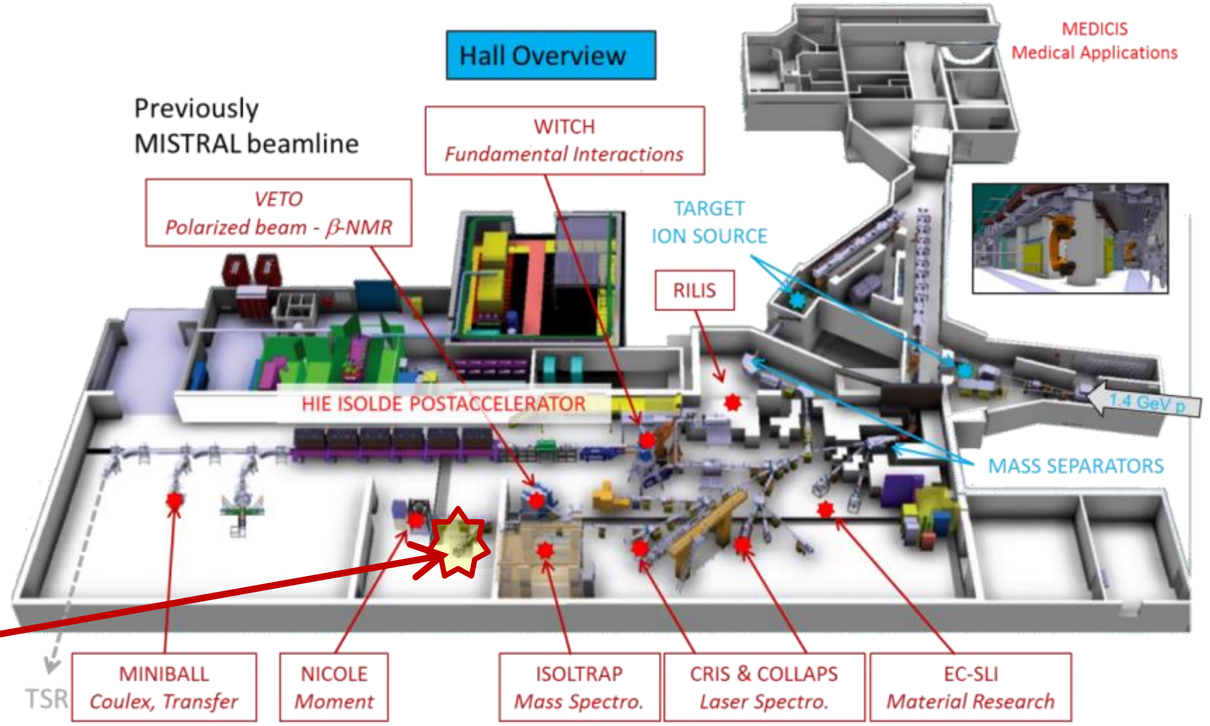


The ISOLDE Decay Station

- Permanent setup at the low-energy branch of ISOLDE

- **Physics programme**
  - Nuclear structure physics (80%)
  - Nuclear astrophysics (10%)
  - Nuclear industry and medicine (5%)
  - Solid state physics (5%)





Over 100 researchers from 19 institutions

- 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; University of the Western Cape)
- 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 19 institutes across the world, and used by many more globally.

Core IDS setup

Six HPGE clover detectors (+6 Aug. 2024)

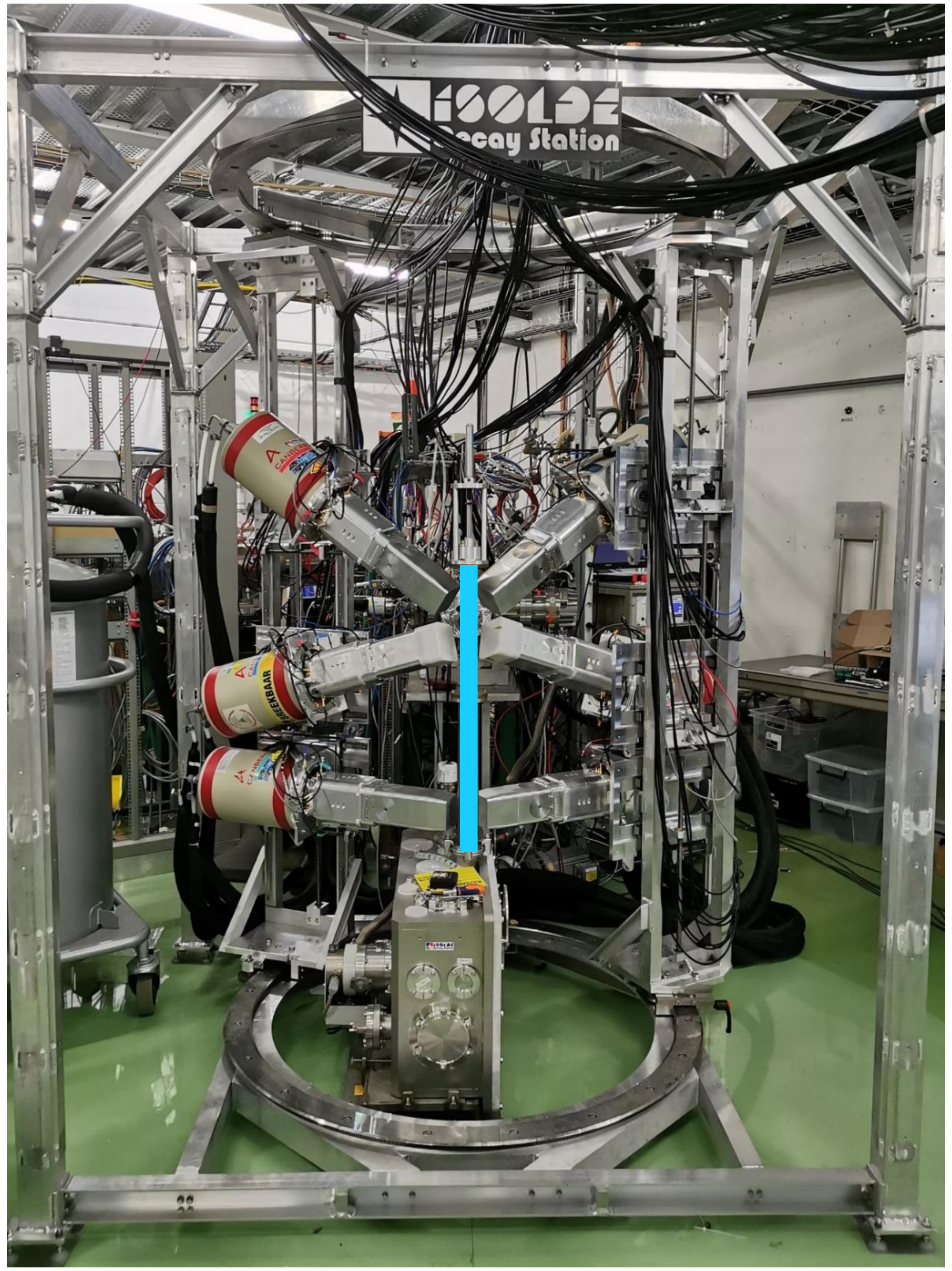
- 4 crystals / clover
- 20% relative eff. / crystal
- 2 thin-carbon window detectors for low-E (~10 keV)

Flexible + dynamic support structure (2023)

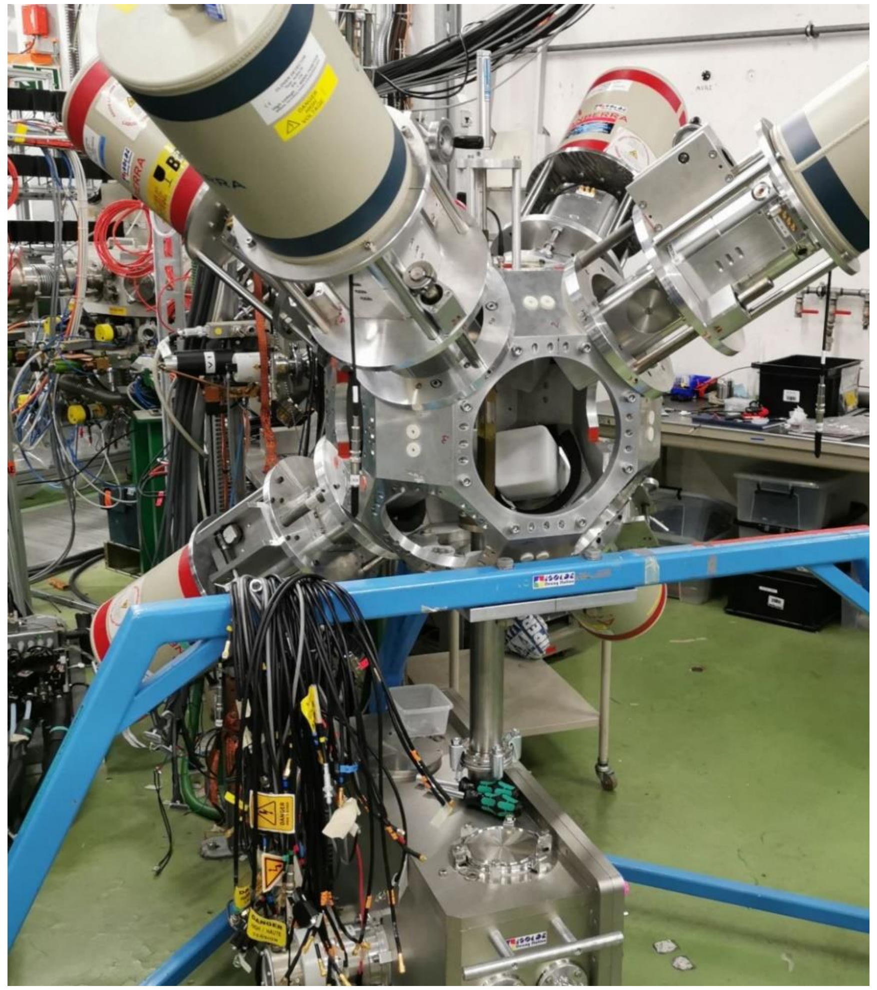
- Minimise material around implantation position
- Detectors mounted on vertical gantries, 3 clovers per gantry, gantries mounted on circular rails
- Can move detectors radially + vertically, tilt vertically, rotate on axes

Digital XIA pixie-16 acquisition system

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

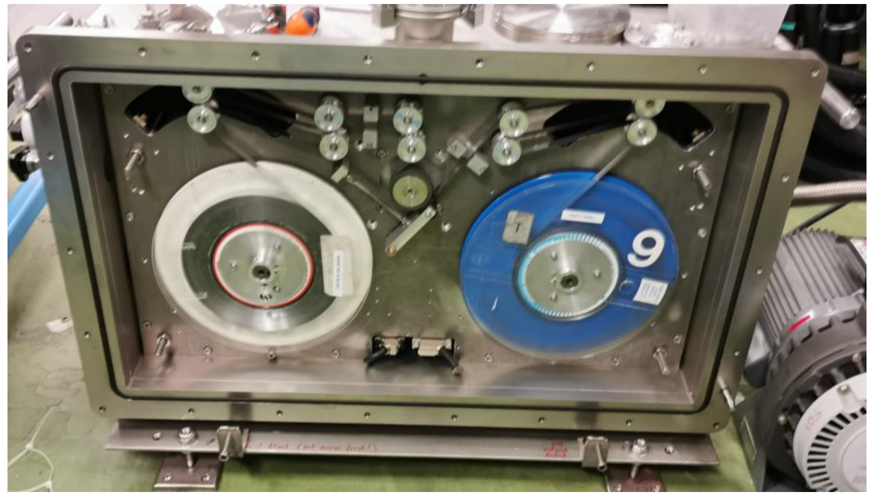


Old, pre-2023 system



Movable tape system

- Reel-to-reel aluminised mylar tape (~2.5 km)
- Fully automated system
- Integrated with ISOLDE beam logic, RILIS laser system, and our DAQ



Core IDS setup

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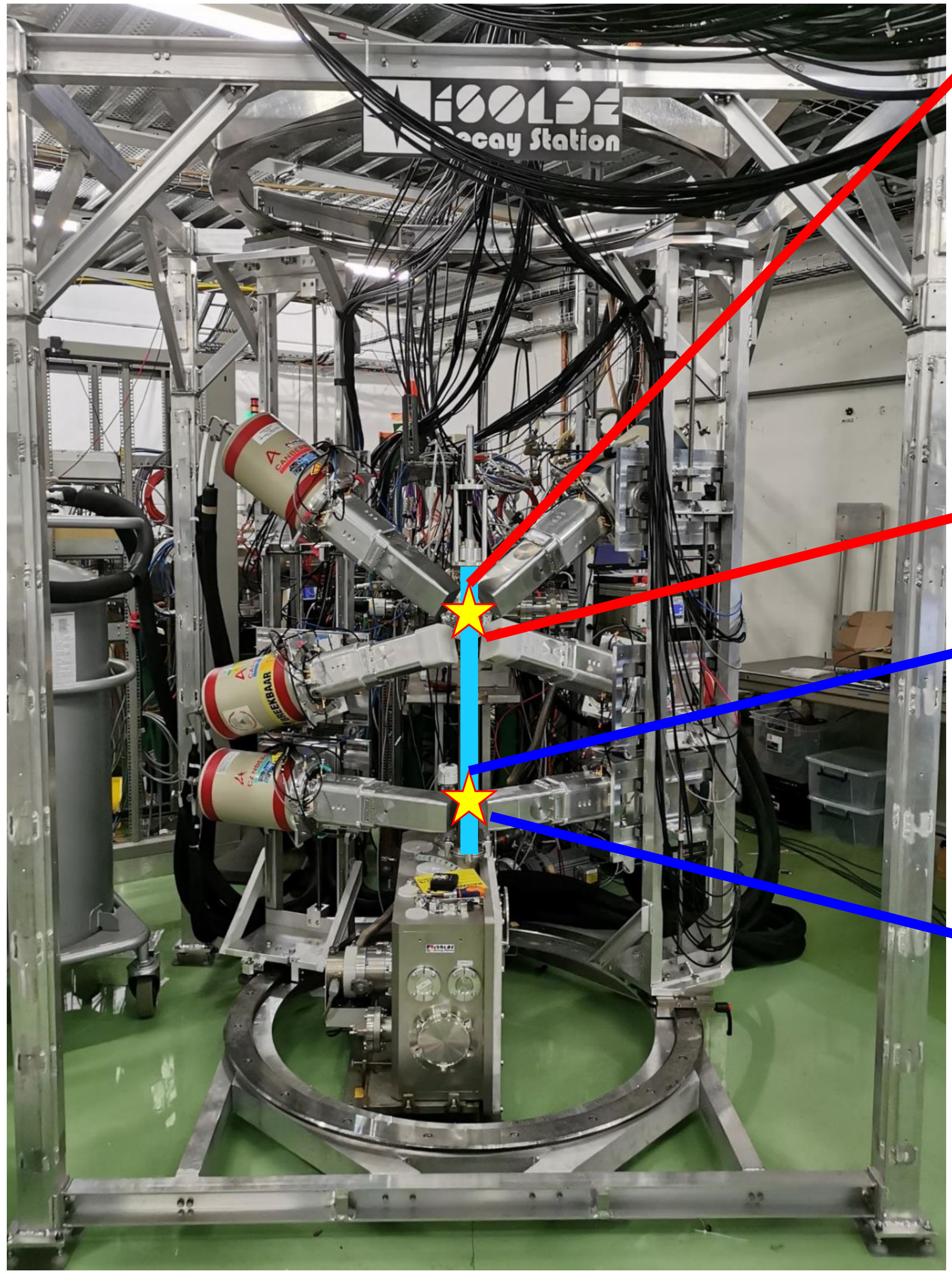
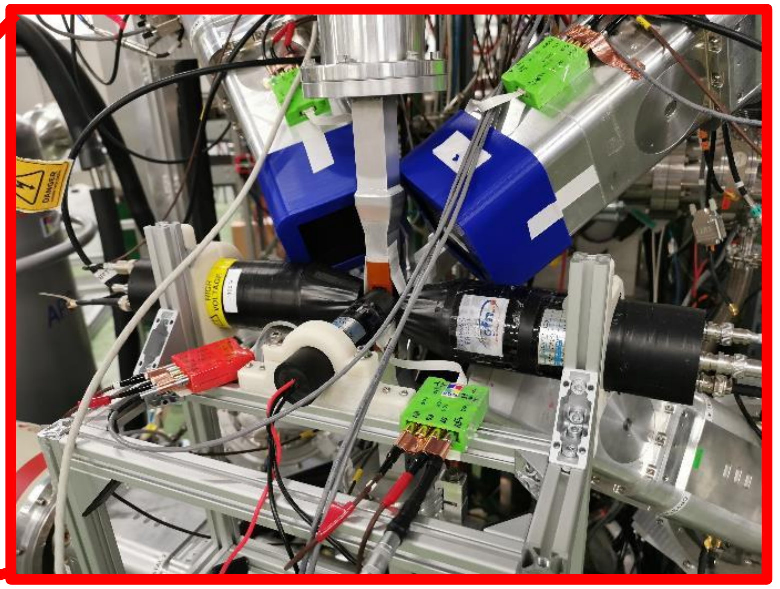
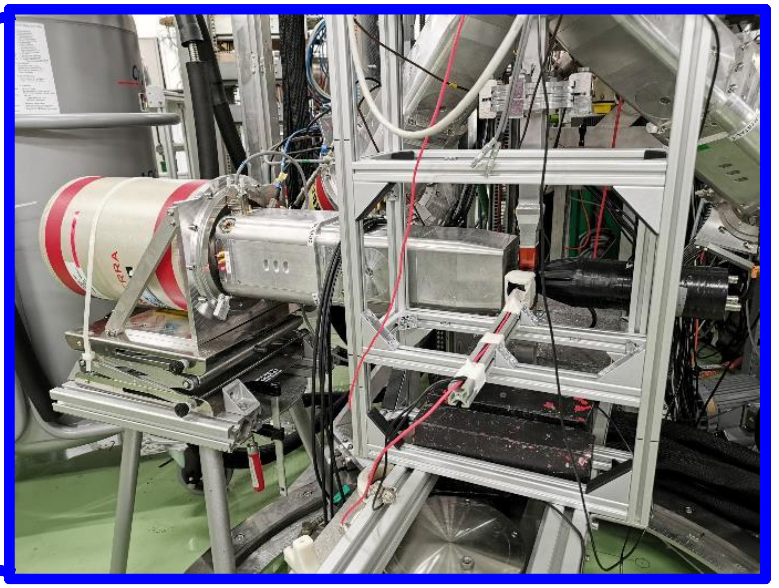
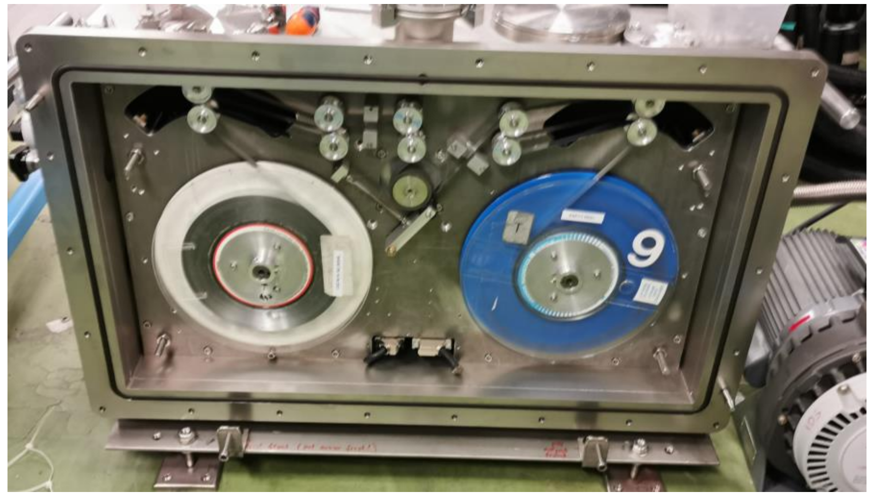






Movable tape system

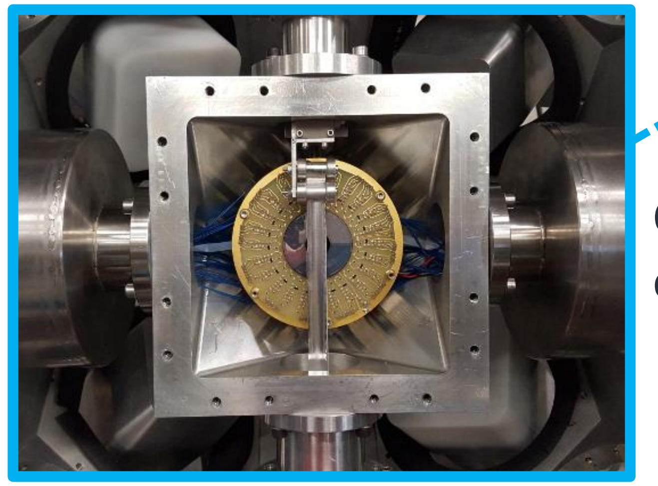
- Reel-to-reel aluminsed mylar tape (~2.5 km)
- Fully automated system
- Integrated with ISOLDE beam logic, RILIS laser system, and our DAQ
- **Primary "implantation" position**
  For main aims of experiments
- **Secondary "decay" position**
  Free "bonus" experiment, long-lived activity



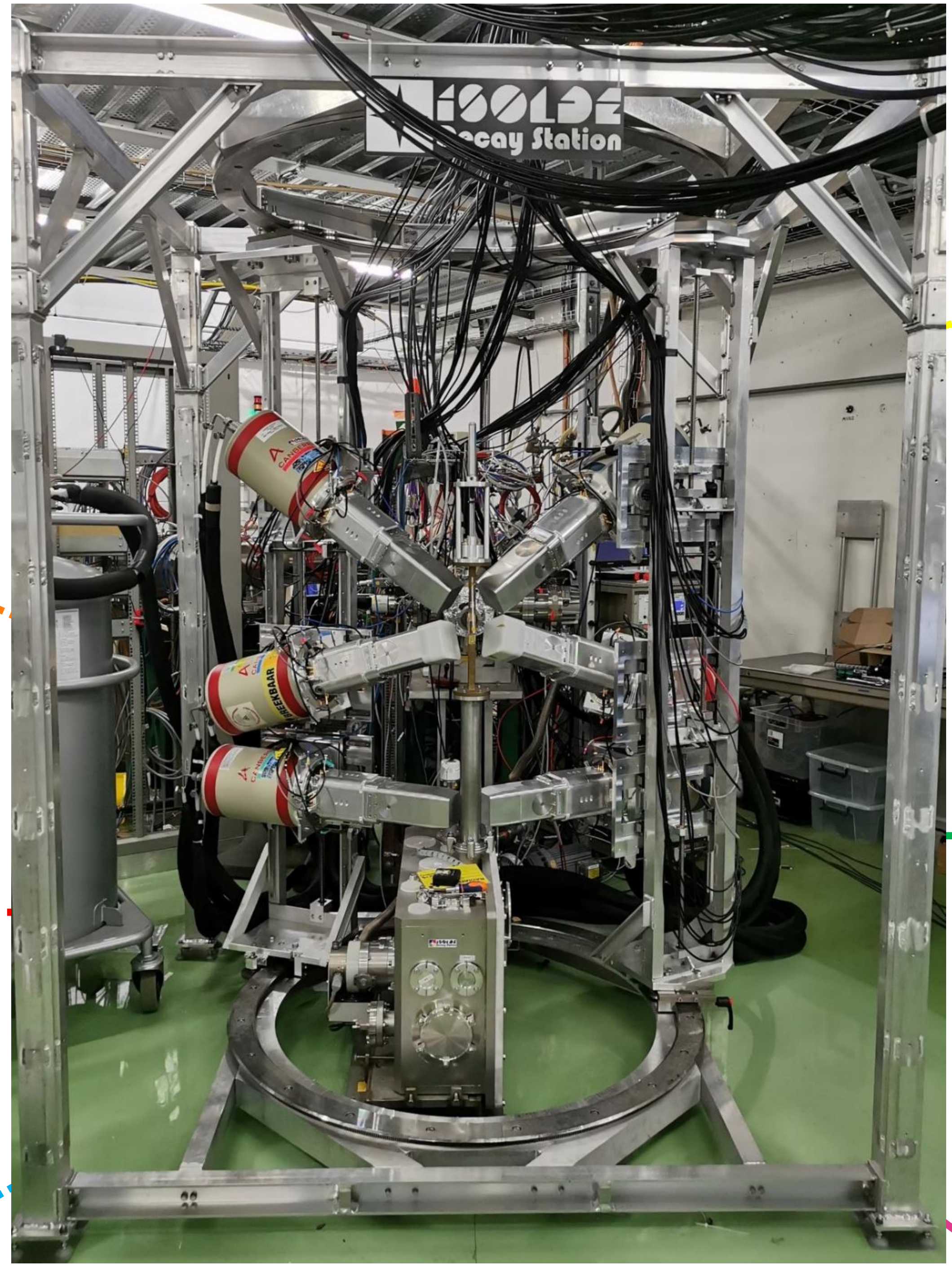
Ancillary systems

High β-γ efficiency

Fast-timing



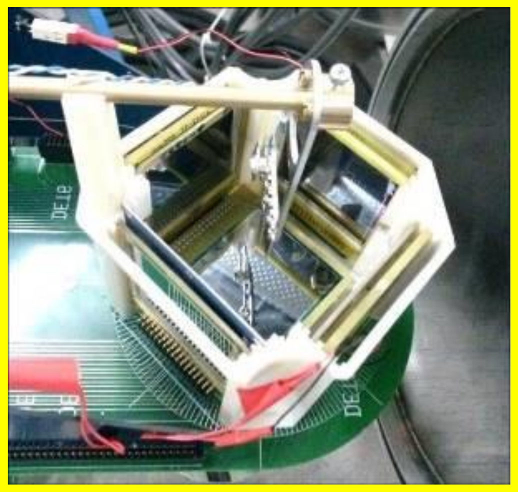
Conversion electrons



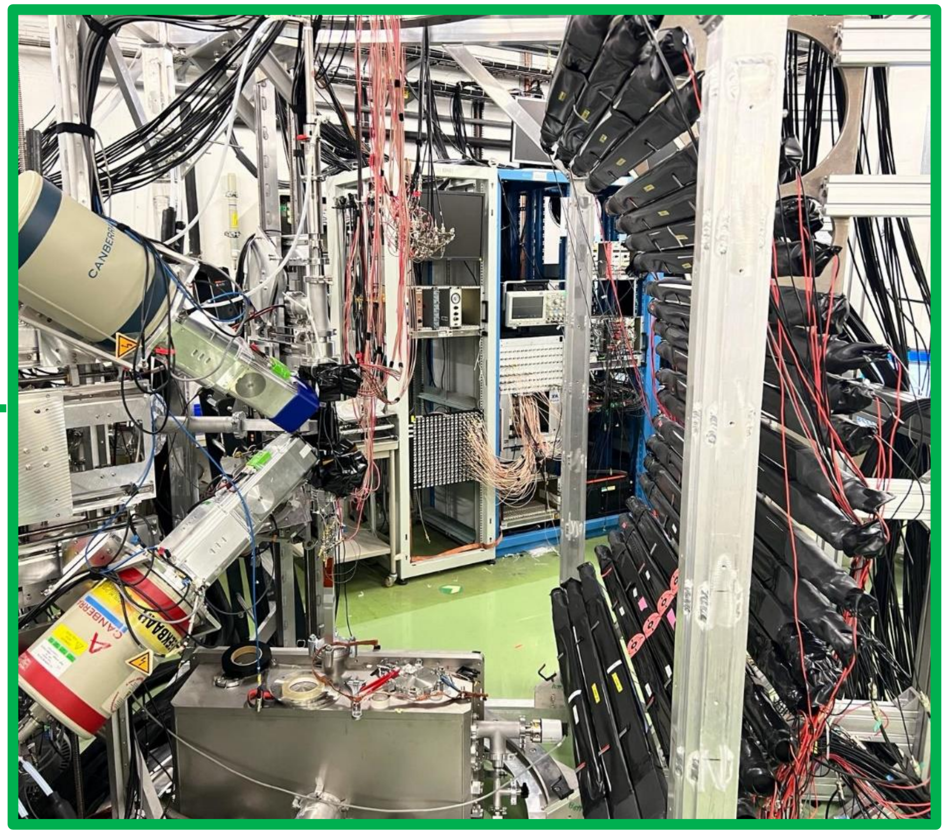
TD-PAC – Coming soon

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

Charged-particle Spectroscopy



Neutron Spectroscopy



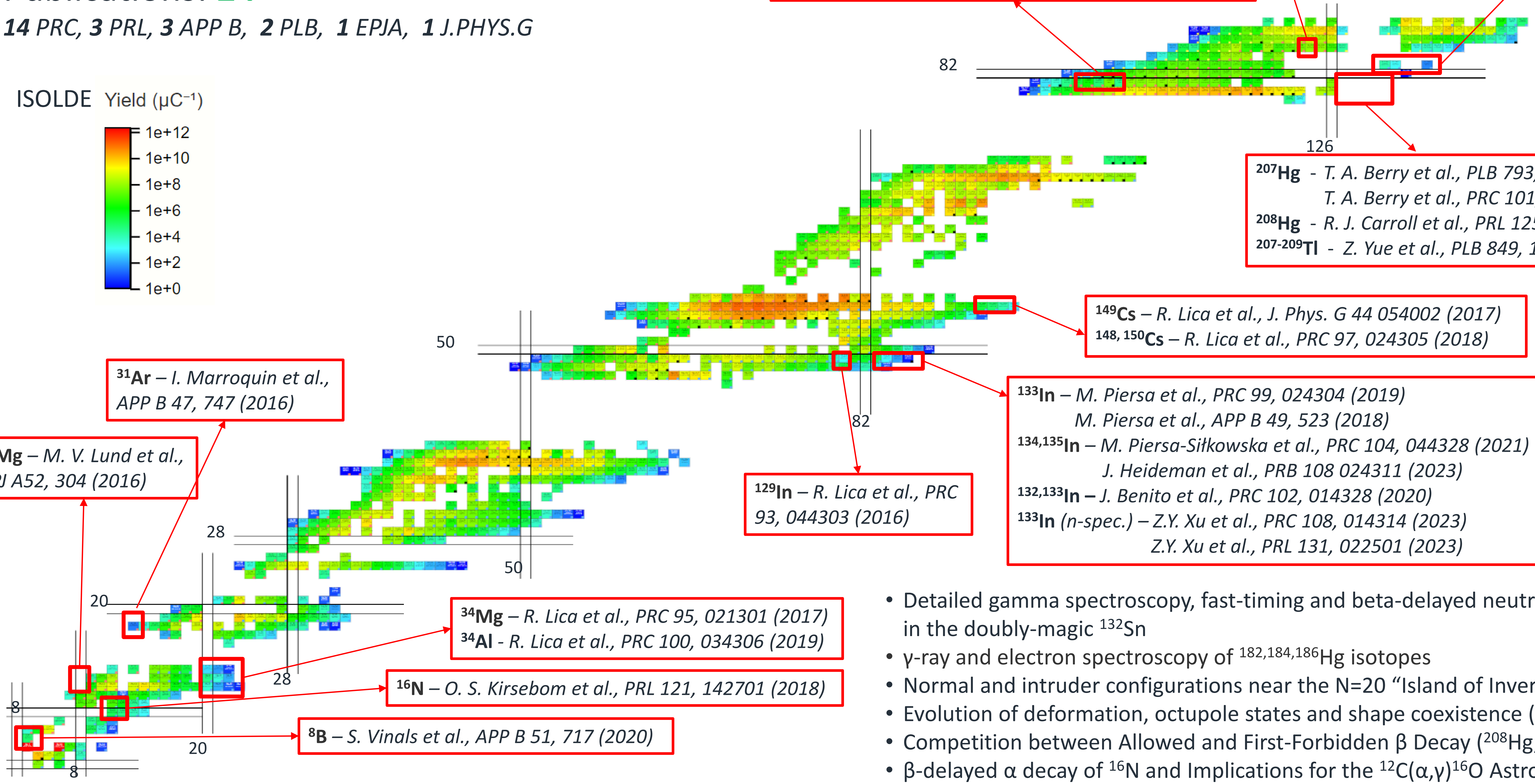
Plastic scints. (β tagging)

Some results from IDS

IDS publications

Publications: **24**

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



^{208}At - *M. Brunet et al., PRC 103, 054327 (2021)*

^{214}Bi - *B. Andel et al., PRC 104, 054301 (2021)*

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

^{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)*

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

^{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., PRB 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)

^{129}In – *R. Lica et al., PRC 93, 044303 (2016)*

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

^{20}Mg – *M. V. Lund et al., EPJ A52, 304 (2016)*

^{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)*

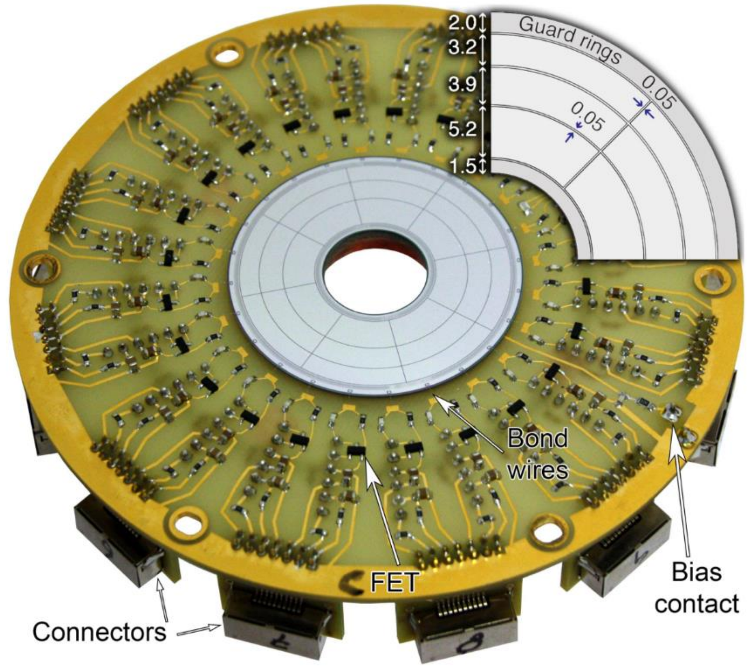
- Detailed gamma spectroscopy, fast-timing and beta-delayed neutron spectroscopy in the doubly-magic ^{132}Sn
- γ-ray and electron spectroscopy of ^{182,184,186}Hg isotopes
- Normal and intruder configurations near the N=20 "Island of Inversion" (^{34}Si)
- Evolution of deformation, octupole states and shape coexistence (^{207}Tl, $^{148-150}$Ba)
- Competition between Allowed and First-Forbidden β Decay (^{208}Hg, ^{208}At)
- β-delayed α decay of ^{16}N and Implications for the ^{12}C(α,γ)^{16}O Astrophysical Reaction Rate

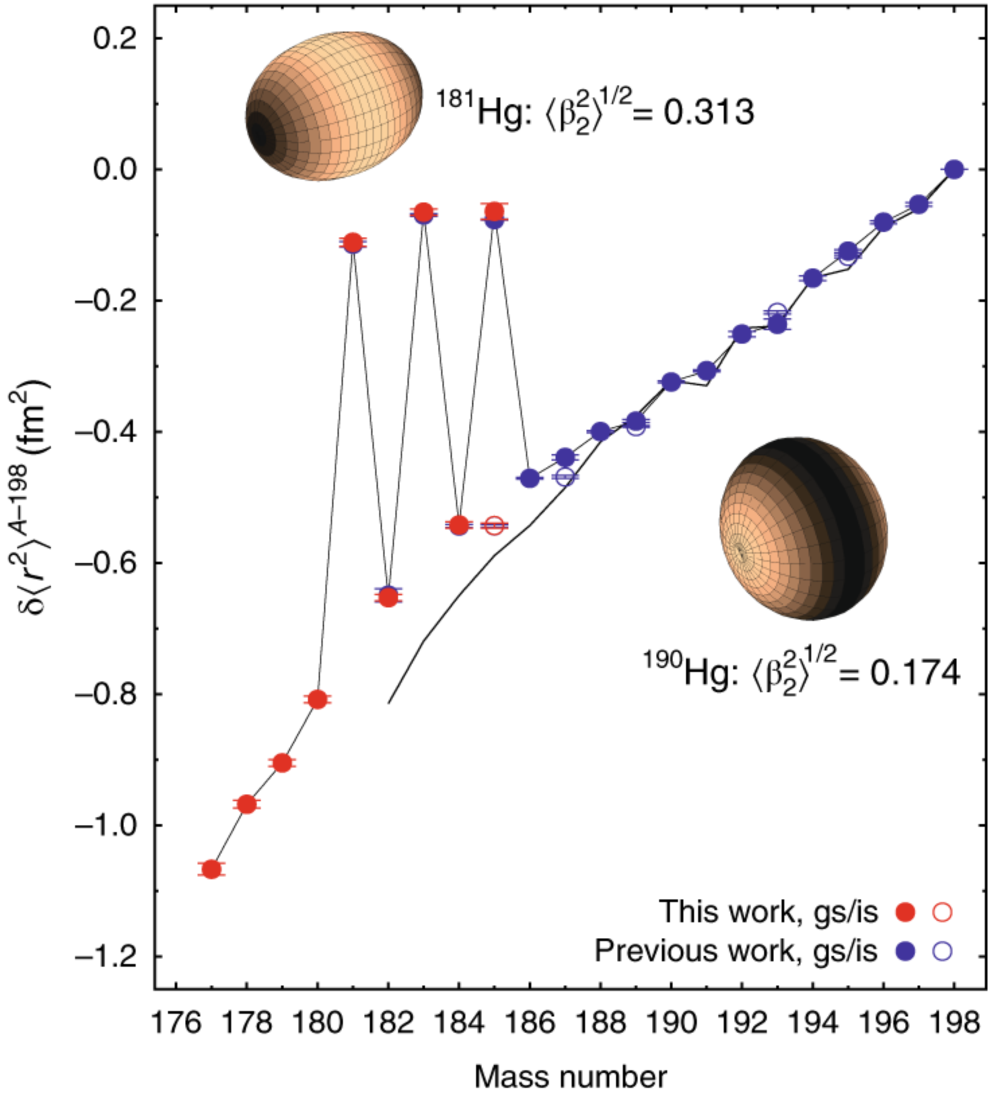
Chart source: https://isoyields2.web.cern.ch/IsoldeYieldChart.aspx

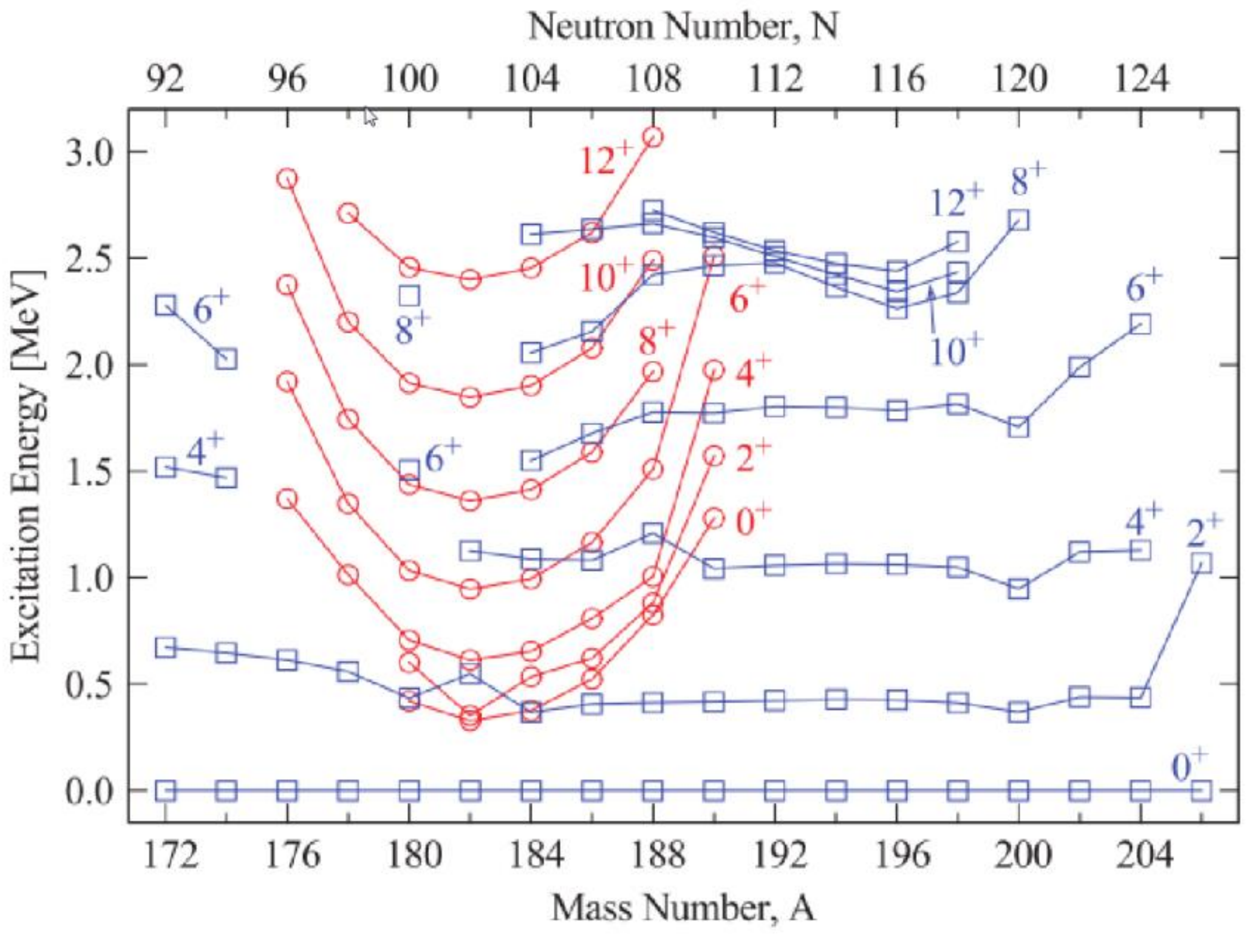
IS641: Conv. e^- spec. of ^{182,184,186}Hg

Spokespersons: K. Rezynkina

- Explore shape coexistence in proton rich Hg isotopes
- Determine conv. coeffs. and γ-ray branching ratios for low-lying transitions
- Data essential for ongoing CoulEx campaign at Miniball/HIE-ISOLDE



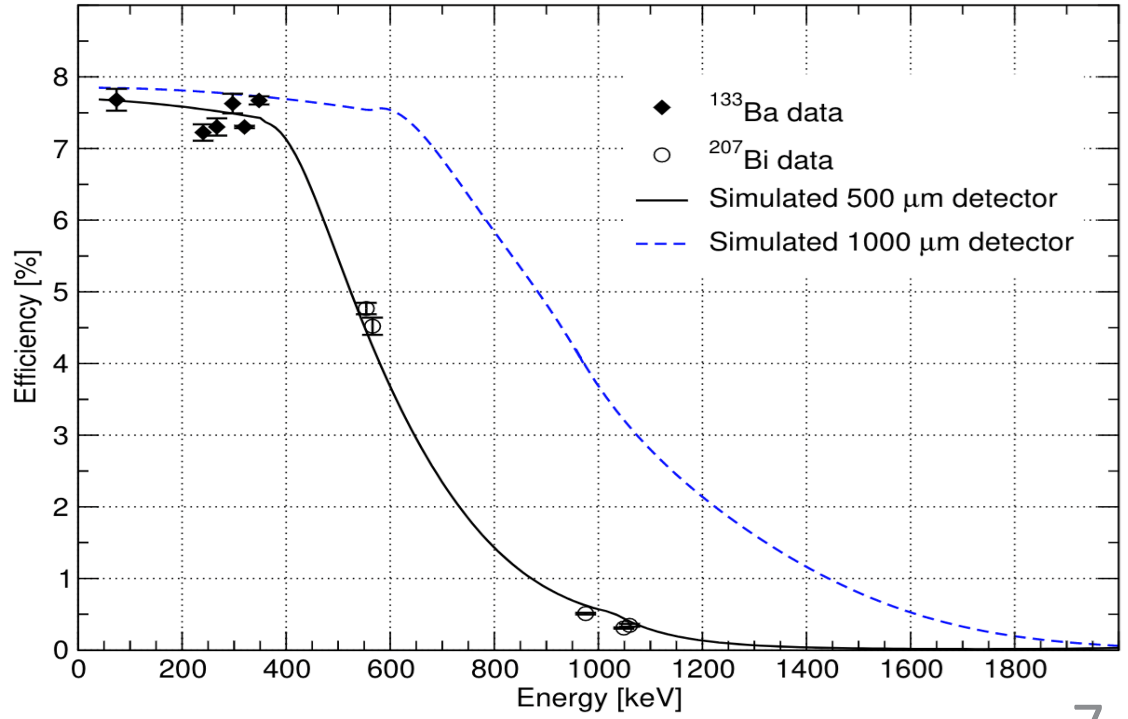




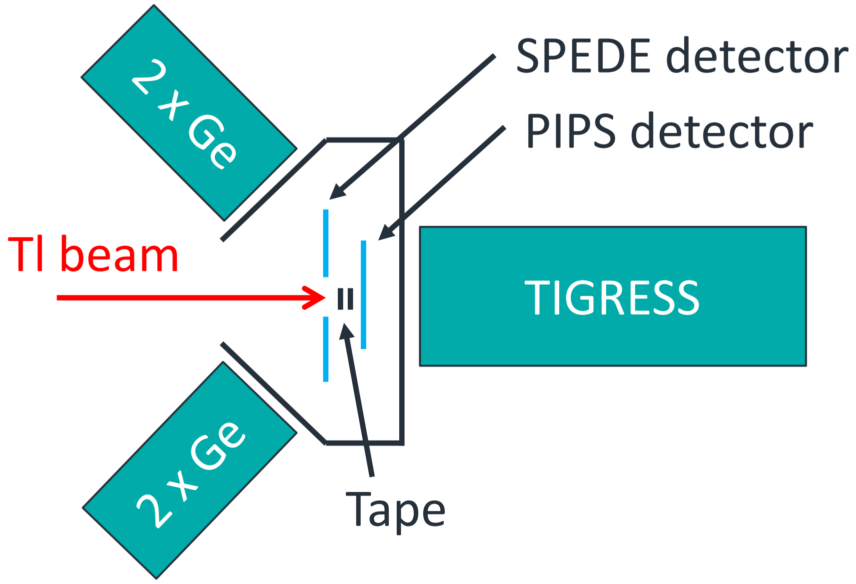
SPEDE

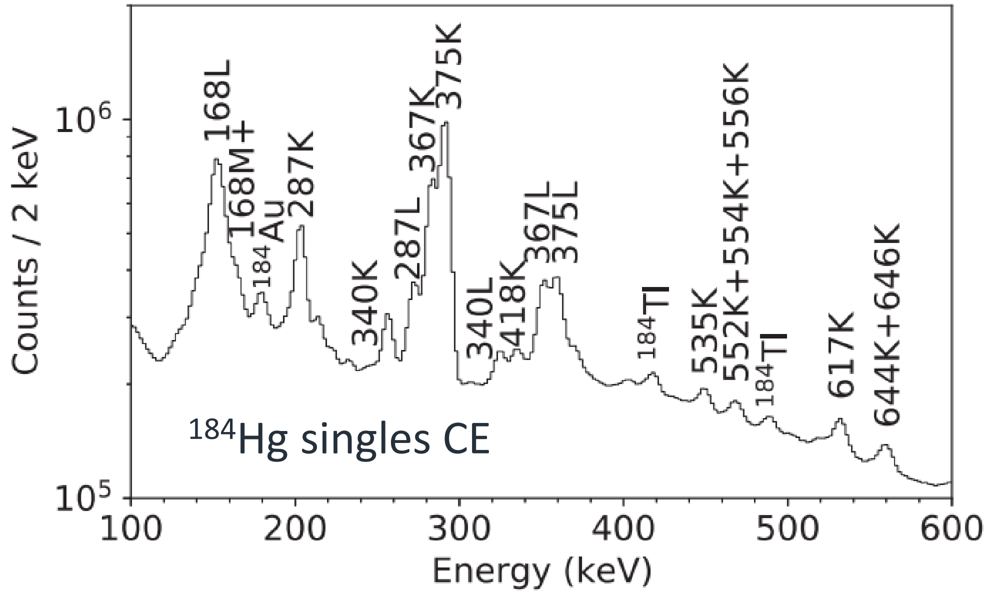
- Annular Si detector with 24 segments.
- Ethanol cooled to -20°C
- FWHM of 6-8 keV at 320 keV

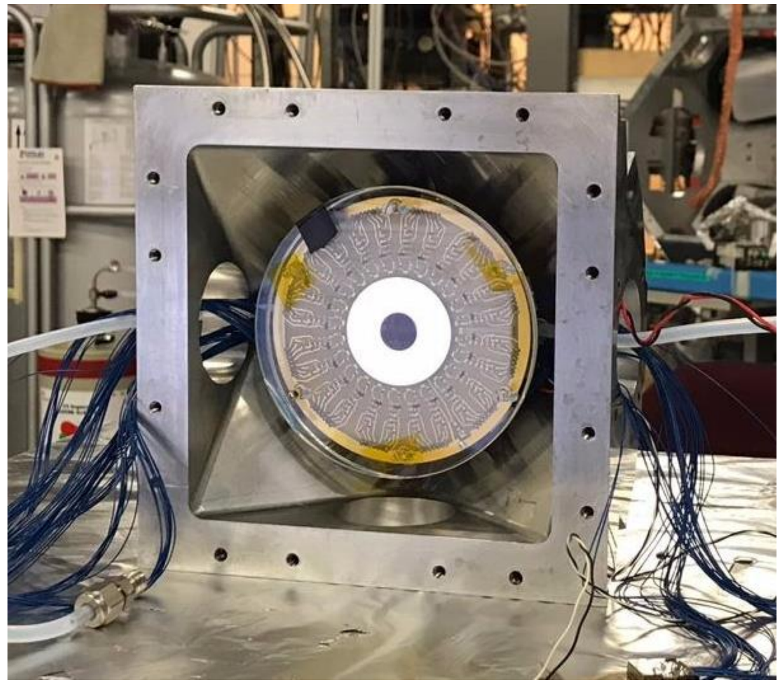
P. Papadakis et al., Eur. Phys. J. A. 54:42, 2018

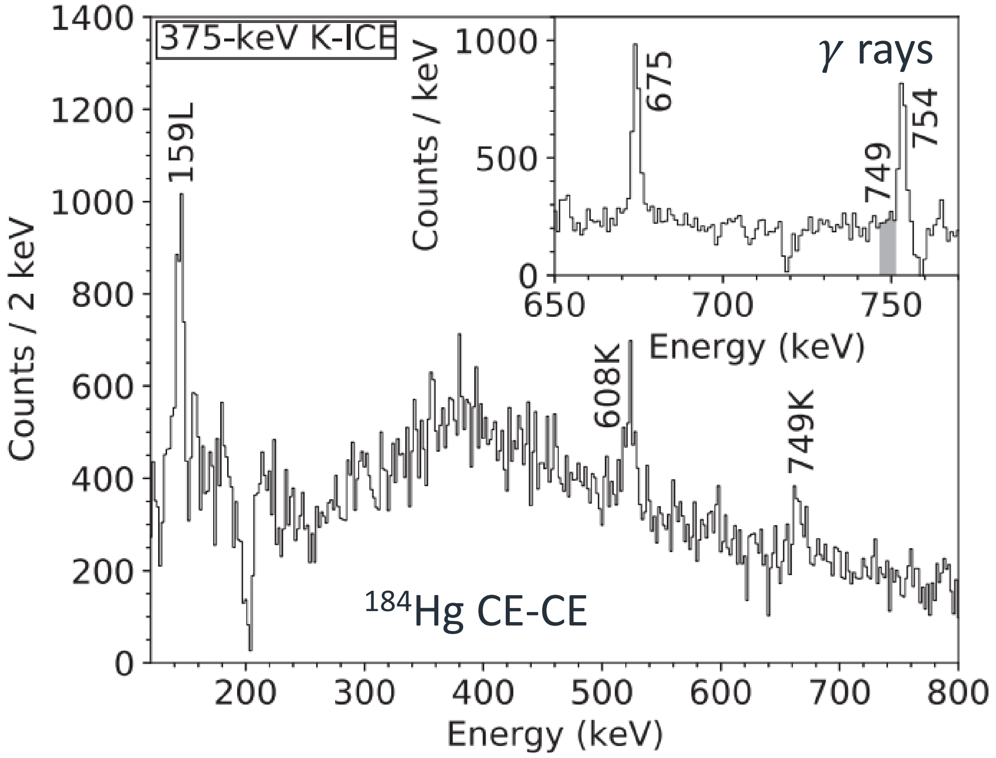


IS641: Conv. e$^-$ spec. of ^{182,184,186}Hg







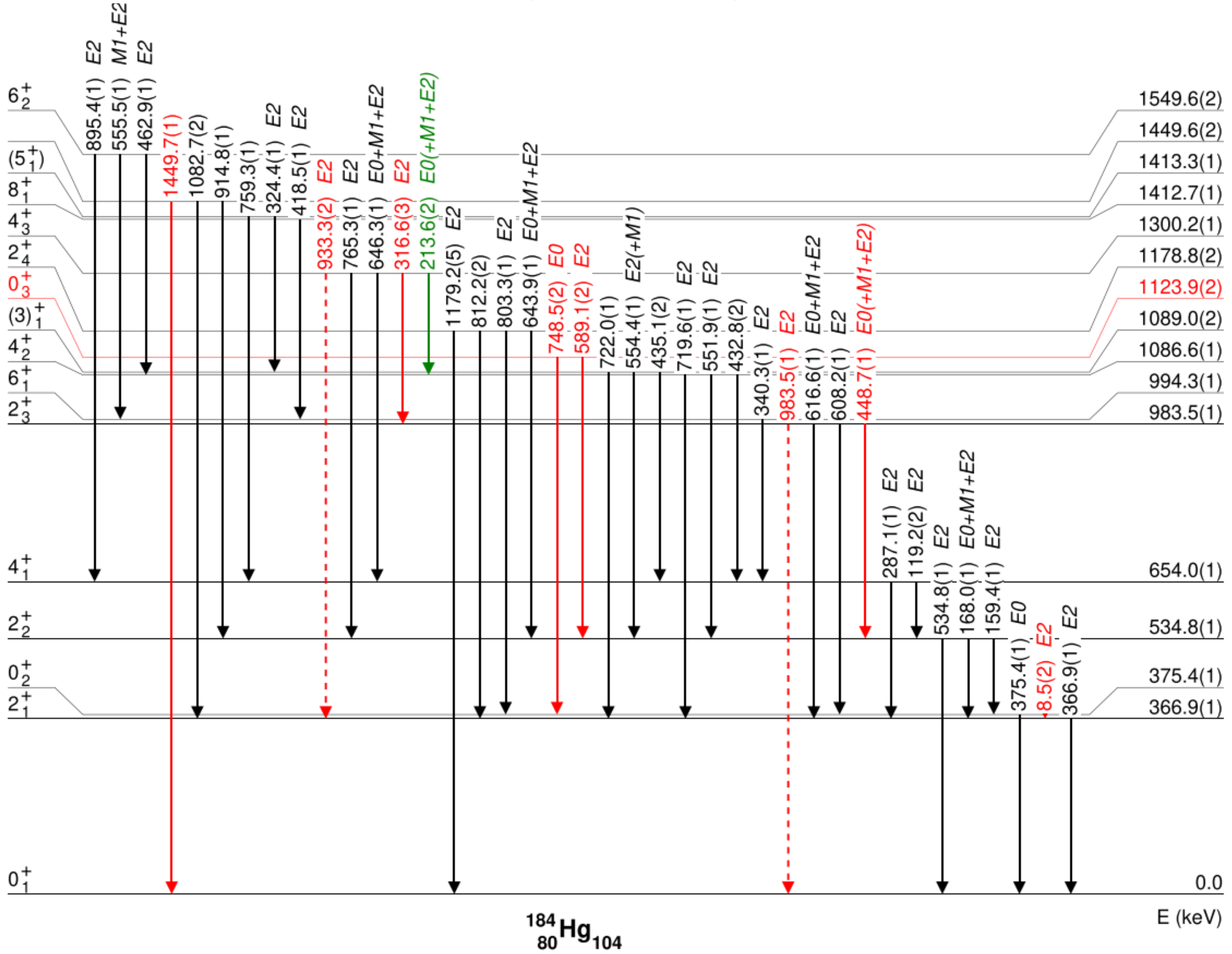


- **PhD of Marek Stryjczyk**
- 527 transitions observed, 392 new
- ICC for 23 transitions deduce, E0 component for 12
- $\rho^2(E0; 0_2^+ \rightarrow 0_1^+)$ and $B(E2; 0_2^+ \rightarrow 2_1^+)$ for ^{184}Hg
- New 0_3^+ state identified in ^{184}Hg through e$^-$-e$^-$ coincs.

PHYSICAL REVIEW C **108**, 014308 (2023)

Simultaneous γ-ray and electron spectroscopy of ^{182,184,186}Hg isotopes

M. Stryjczyk,[1,2,*] B. Andel,[1,3,†] J. G. Cubiss,[4,5,†] K. Rezynkina,[1,6,†] T. R. Rodríguez,[7,8] J. E. García-Ramos,[9,10] A. N. Andreyev,[5,11] J. Pakarinen,[2,12] P. Van Duppen,[1] S. Antalic,[3] T. Berry,[13] M. J. G. Borge,[14,4] C. Clisu,[15] D. M. Cox,[16] H. De Witte,[1] L. M. Fraile,[8] H. O. U. Fynbo,[17] L. P. Gaffney,[4,18] L. J. Harkness-Brennan,[18] M. Huyse,[1] A. Illana,[19,2,8] D. S. Judson,[18] J. Konki,[4] J. Kurcewicz,[4] I. Lazarus,[20] R. Lica,[15,4] M. Madurga,[4,21] N. Marginean,[15] R. Marginean,[15] C. Mihai,[15] P. Mosat,[3] E. Nacher,[22] A. Negret,[15] J. Ojala,[2,12] J. D. Ovejas,[14] R. D. Page,[18] P. Papadakis,[18,20] S. Pascu,[15] A. Perea,[14] Zs. Podolyák,[13] L. Próchniak,[23] V. Pucknell,[20] E. Rapisarda,[4] F. Rotaru,[15] C. Sotty,[15] O. Tengblad,[14] V. Vedia,[8] S. Viñals,[14] R. Wadsworth,[5] N. Warr,[24] and K. Wrzosek-Lipska[23]
(IDS Collaboration)

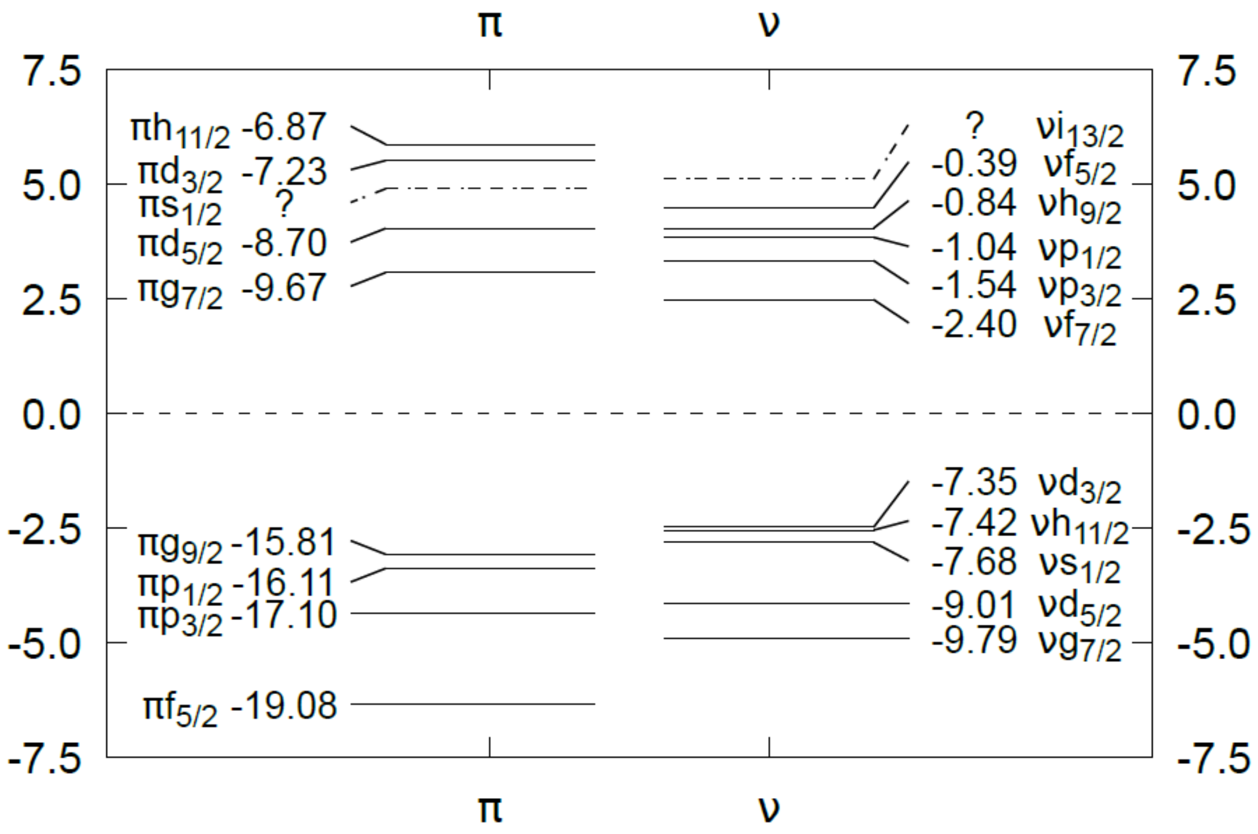


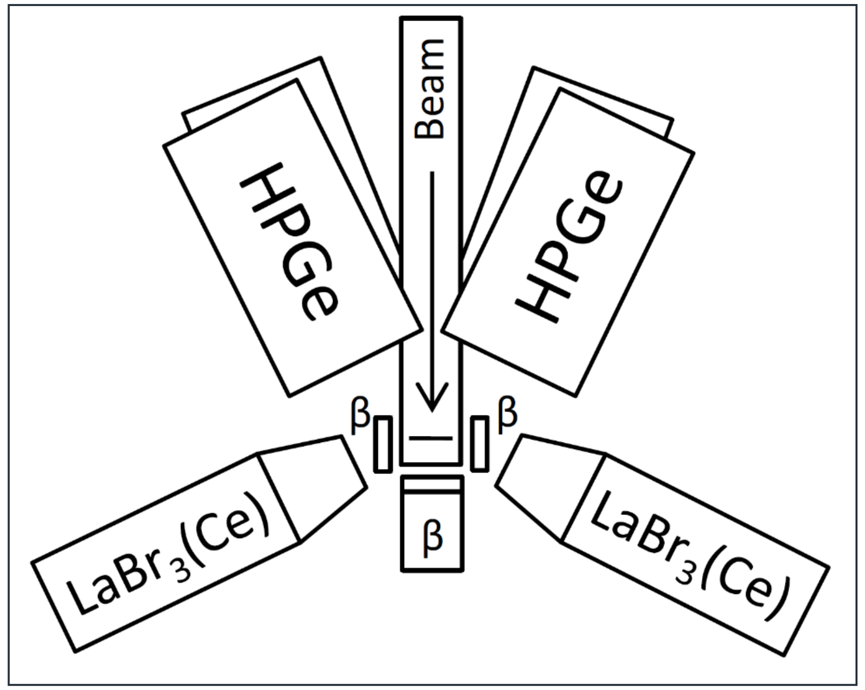
IS685: β-decay of neutron-rich Cd

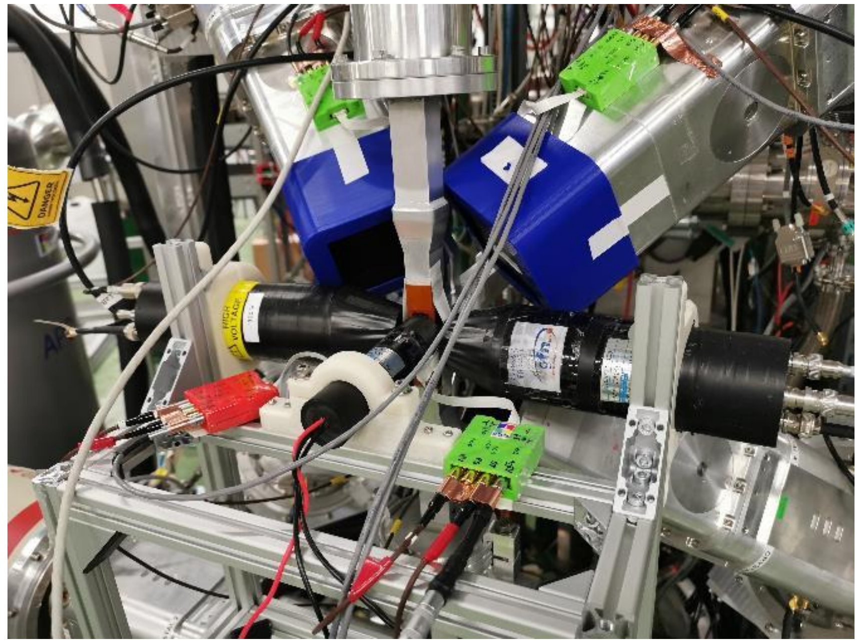
Spokespersons: L. M. Fraile, A. Korgul

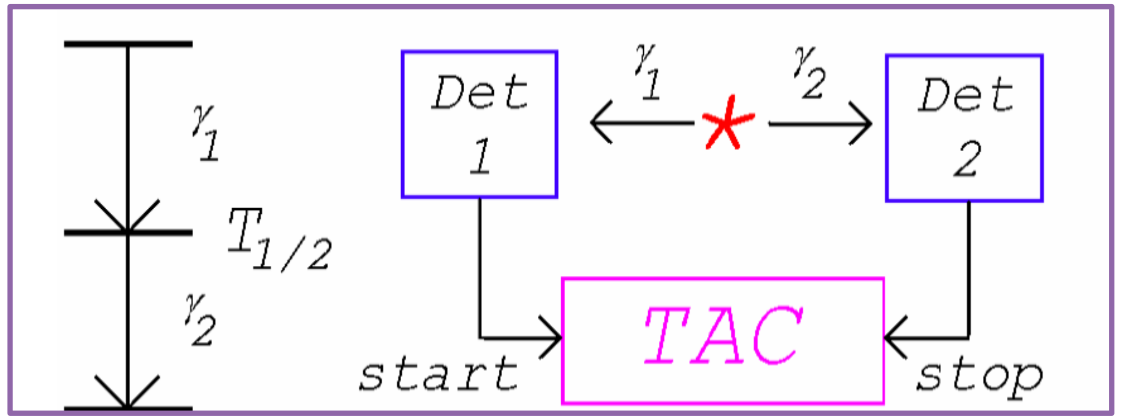
- Using high-res γ spec. and fast timing measurements to study decays of $^{130-133}$Cd
- Probe structure near ^{132}Sn
  - Single particle states
  - Configurations associated with core excitations
  - Proton-neutron couplings
  - EM transition properties

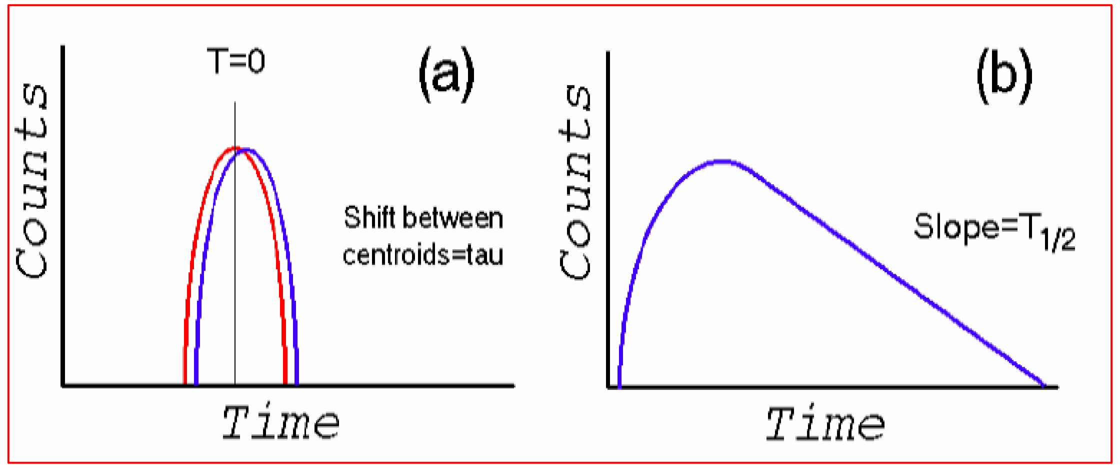
^{131}Sb 3.23 MeV	^{132}Sb 5.55 MeV	^{133}Sb 4.01 MeV	^{134}Sb 8.51 MeV	^{135}Sb 8.04 MeV
^{130}Sn 2.15 MeV	^{131}Sn 4.72 MeV	^{132}Sn 3.09 MeV	^{133}Sn 8.05 MeV	^{134}Sn 7.59 MeV
^{129}In 7.75 MeV	^{130}In 10.25 MeV	^{131}In 9.24 MeV	^{132}In 14.14 MeV	^{133}In 13.41 MeV
^{128}Cd 6.9 MeV	^{129}Cd 9.78 MeV	^{130}Cd 8.77 MeV	^{131}Cd 12.81 MeV	^{132}Cd 12.15 MeV







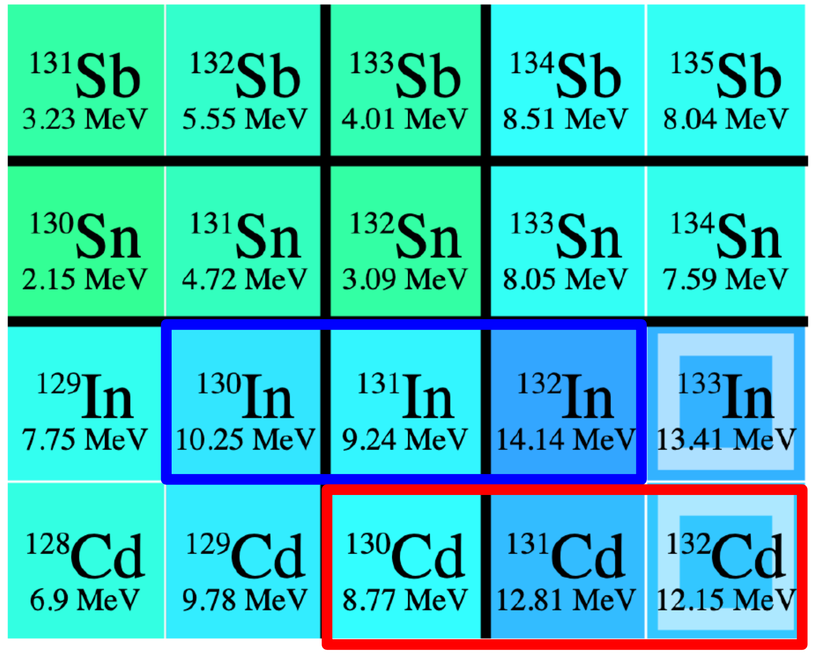




Ranges:
Centroid shift method: - **10 ps - 100 ps**
Slope method - **50 ps - 50 ns** (or longer)
[H. Mach et al. NIM A 280, 49 (1989)]

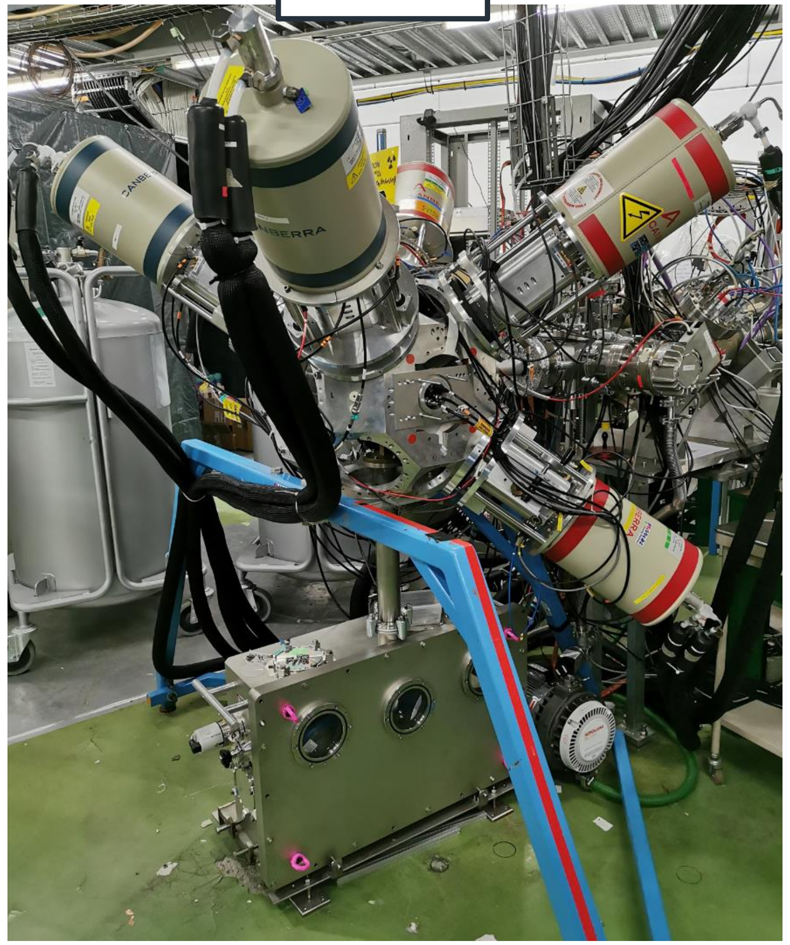
IS685: β-decay of neutron-rich Cd

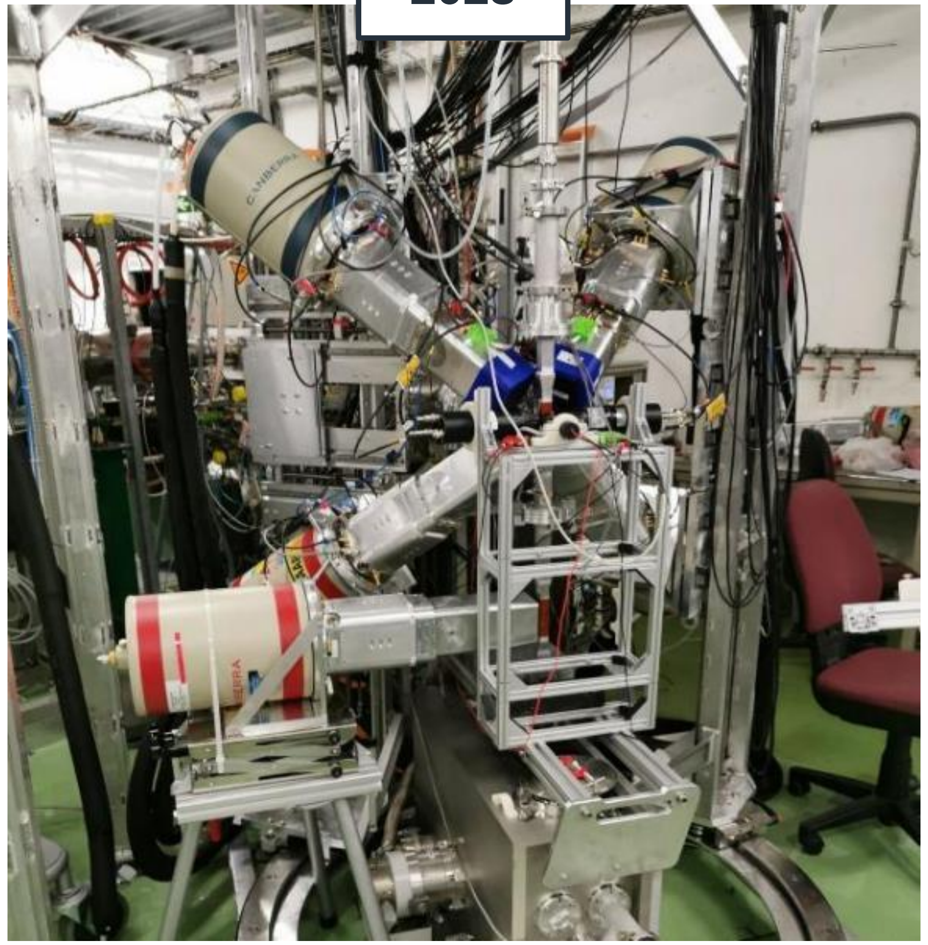
- **PhD Marcos Llanos Exposito**
- Huge statistics collected: ~3000 ions/uC ^{130}Cd, ~30 ions/uC ^{131}Cd, few ions/uC ^{132,133}Cd
- First observation of strong β-n branch observed in ^{132}Cd decay
- Analysis ongoing – plenty of data to sift through

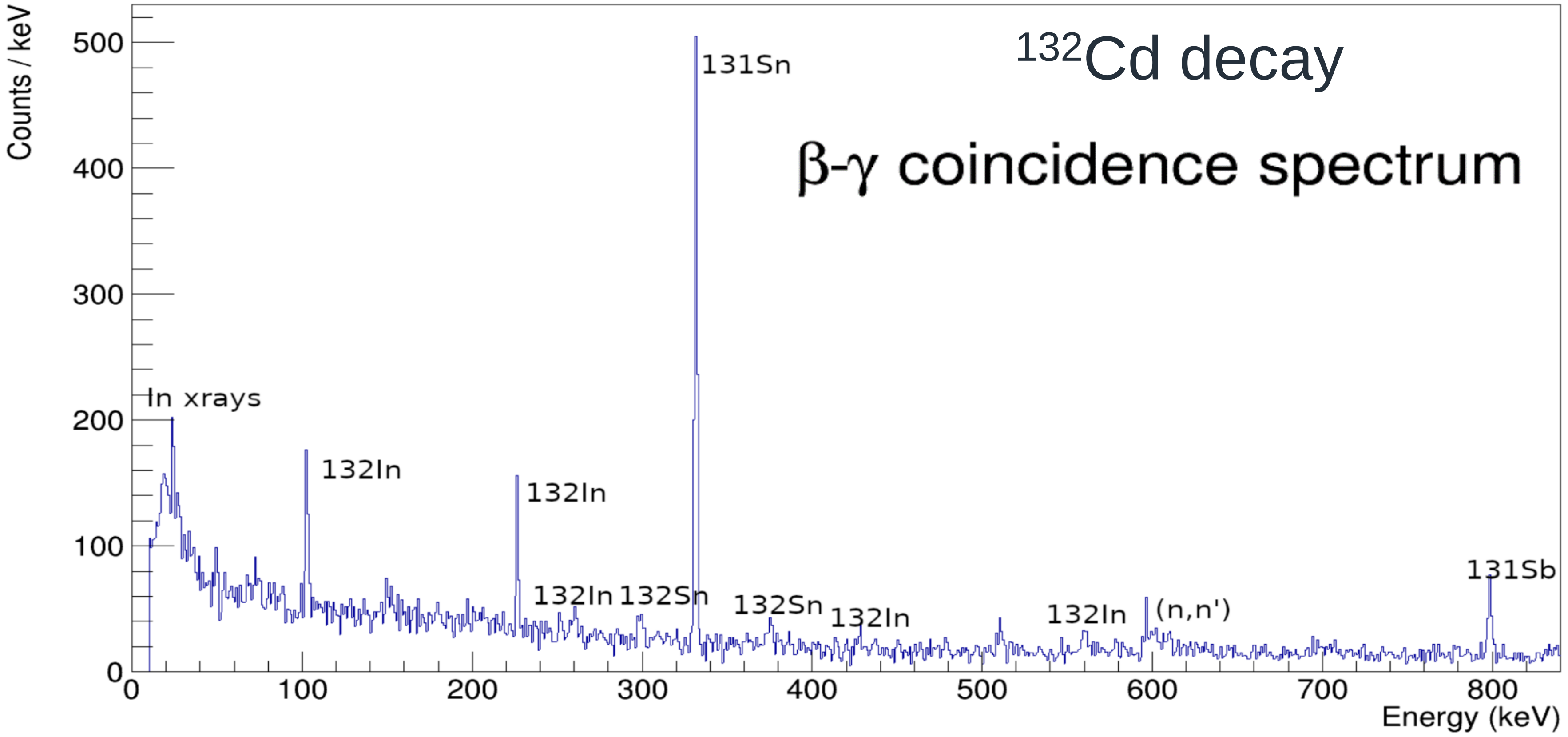


2022

2023





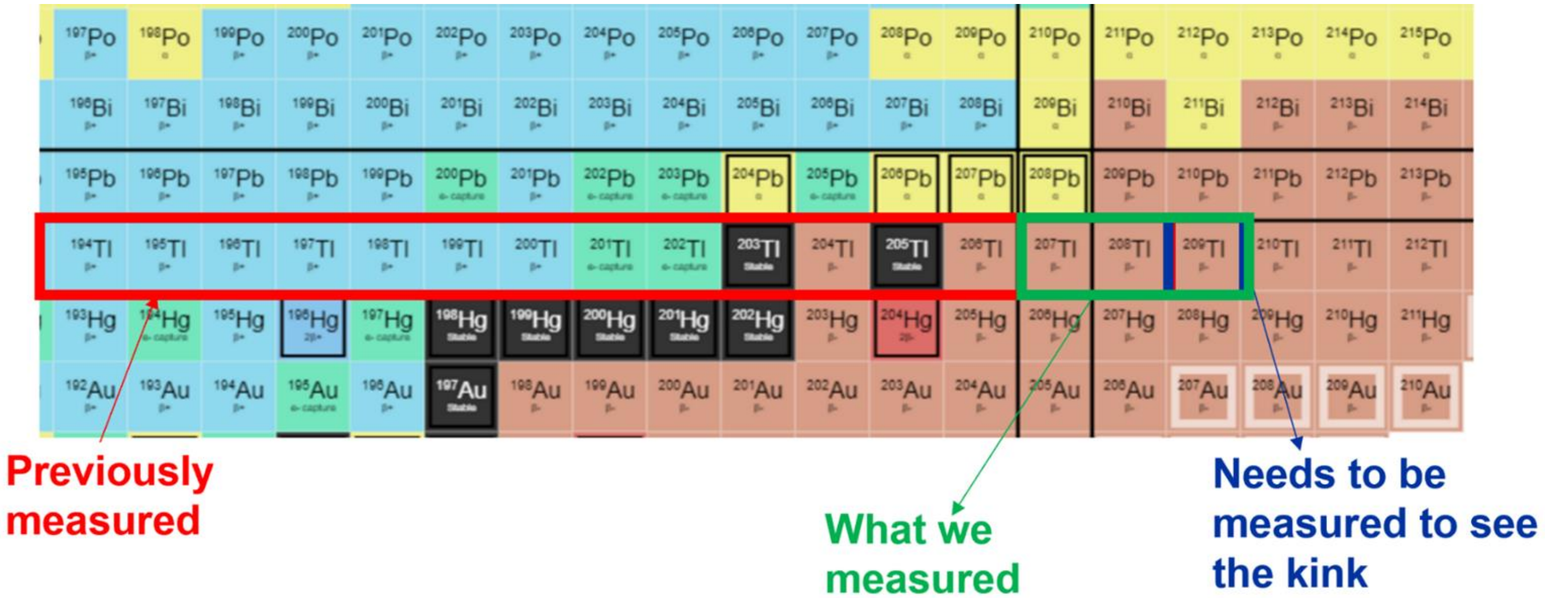


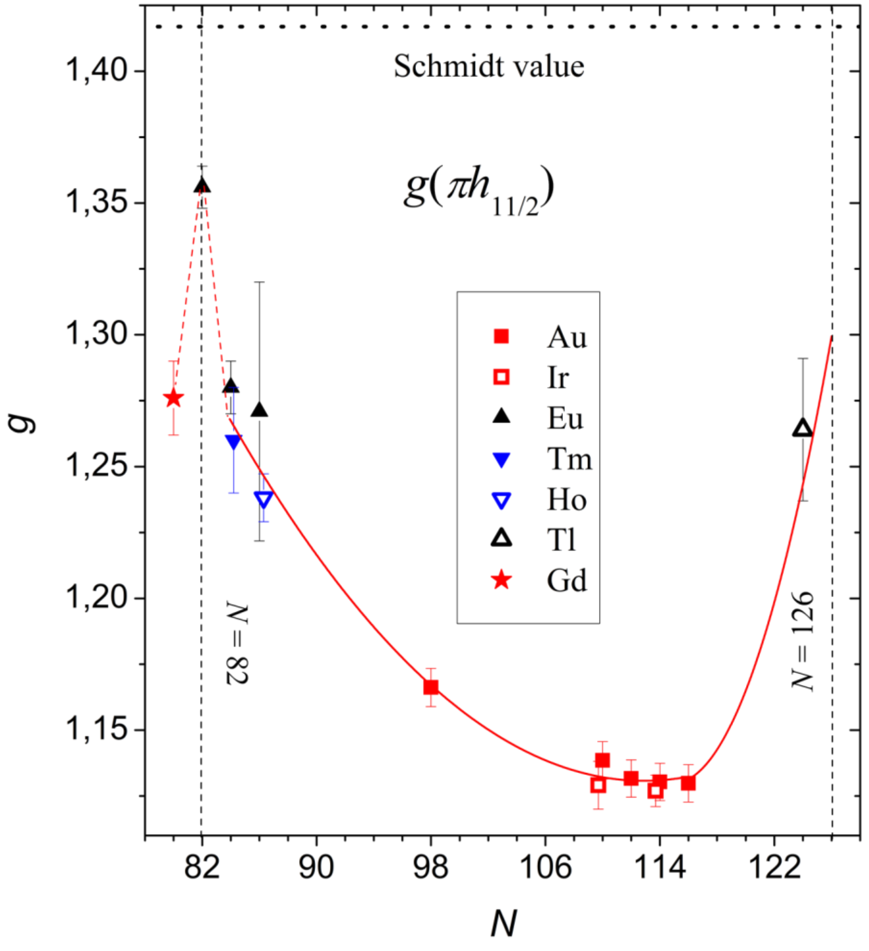
Courtesy of Luis Fraile, Marcos Llanos Exposito (Uni. Complutense Madrid)

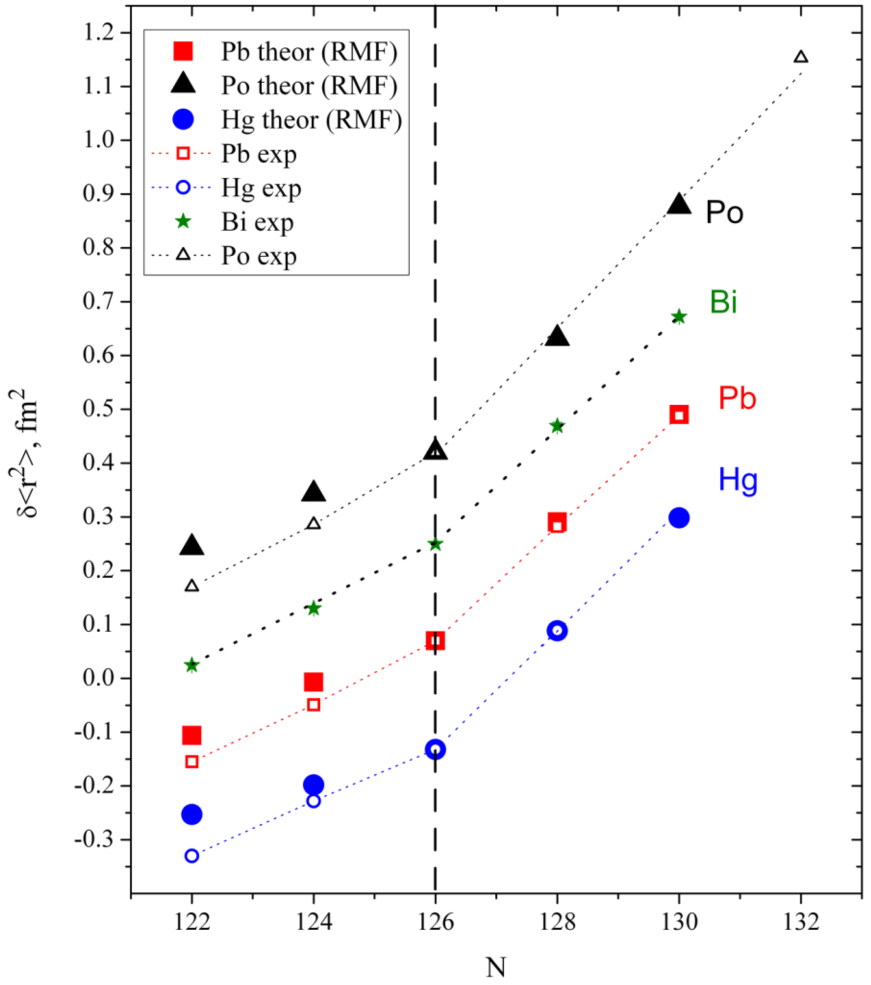
LoI219: In-source laser spec. of neutron-rich Tl

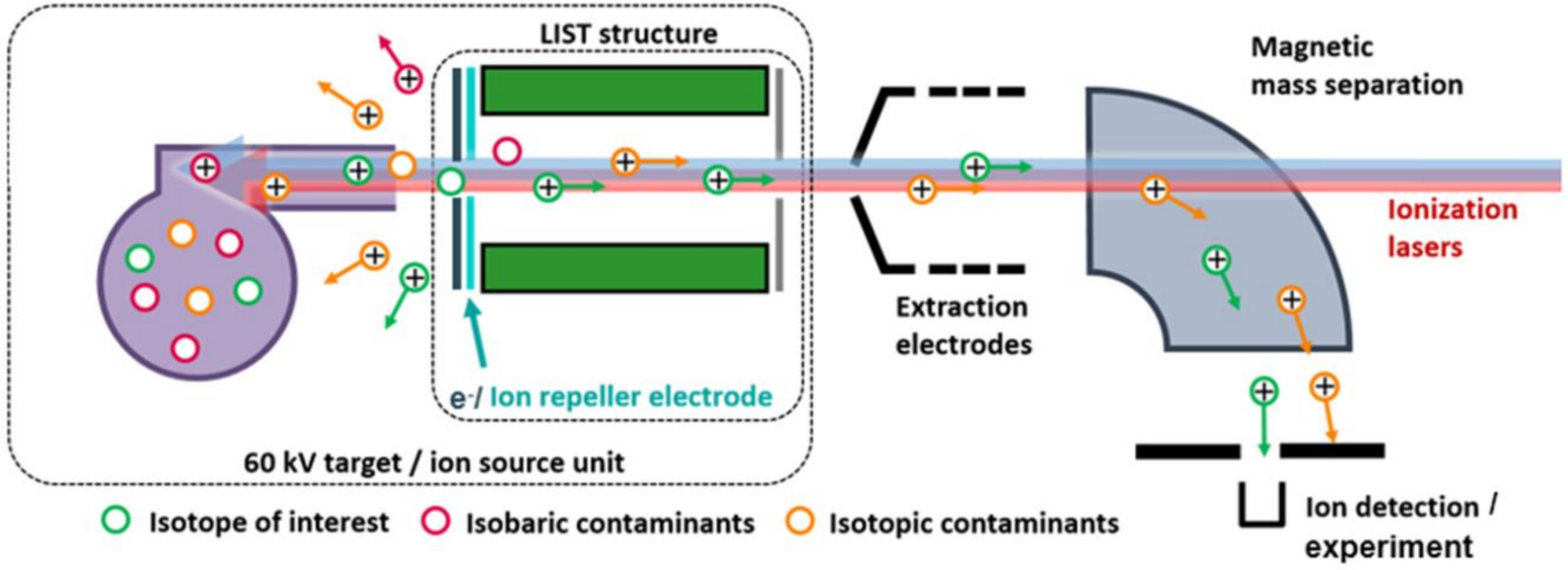
Spokesperson: A. N. Andreyev

- Test production of neutron-rich Tl isotopes
- Probe influence of Z=82, N=126 on ground + isomeric state properties
- Use Laser Ion Source and Trap (LIST) to suppress Fr contamination
- Open up poorly explored region of nuclear chart



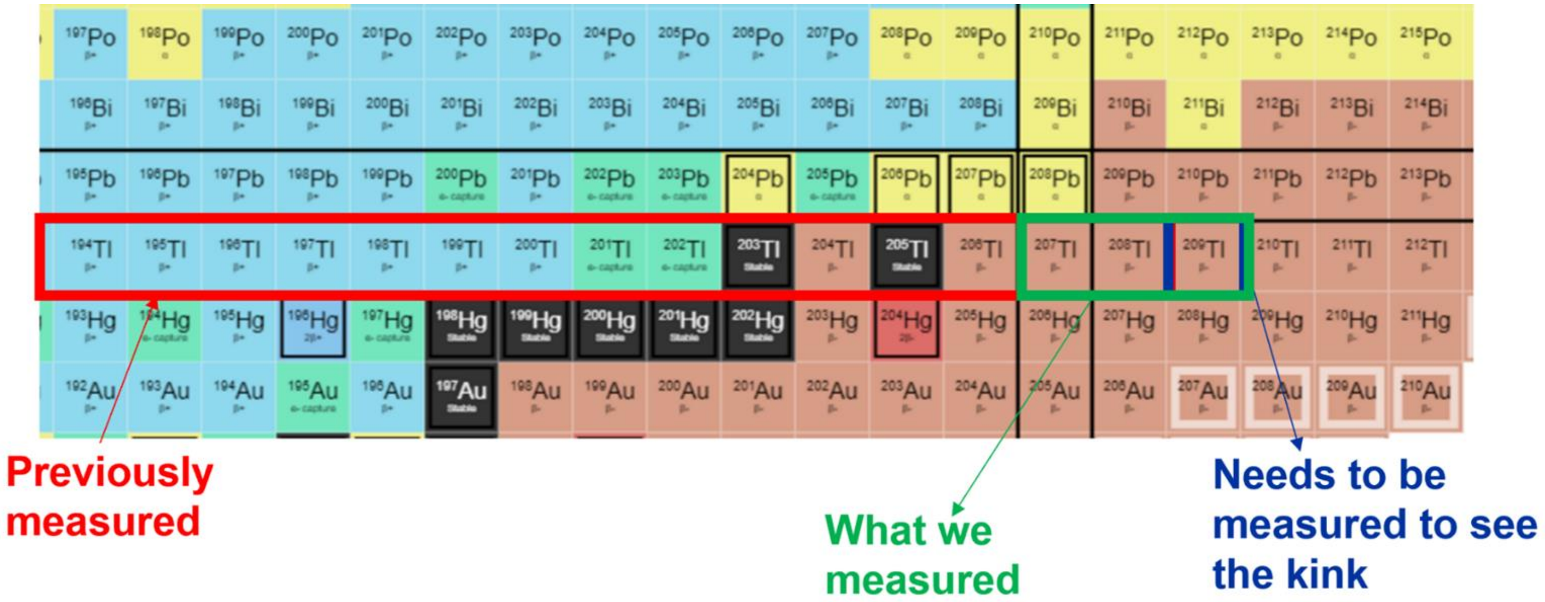


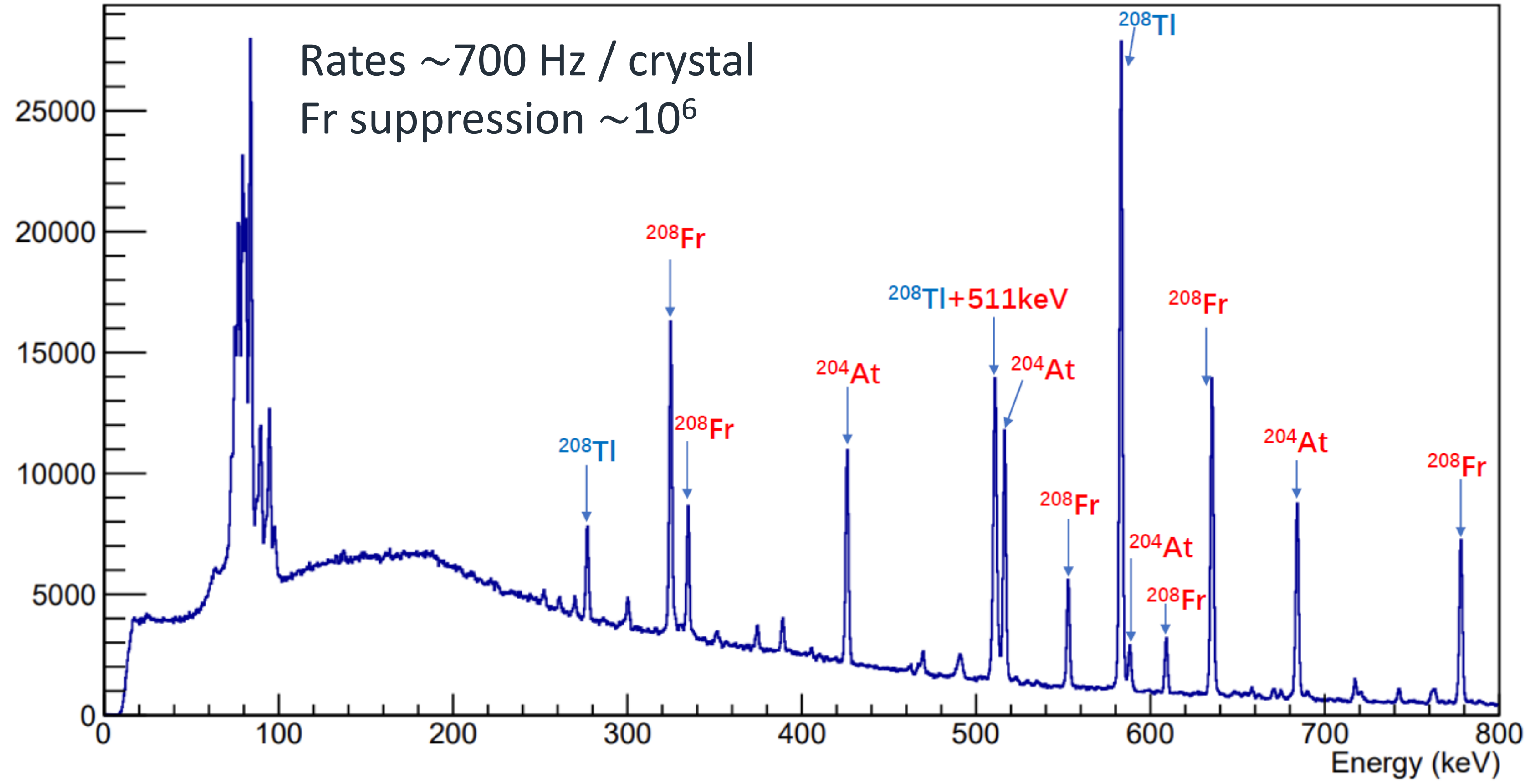


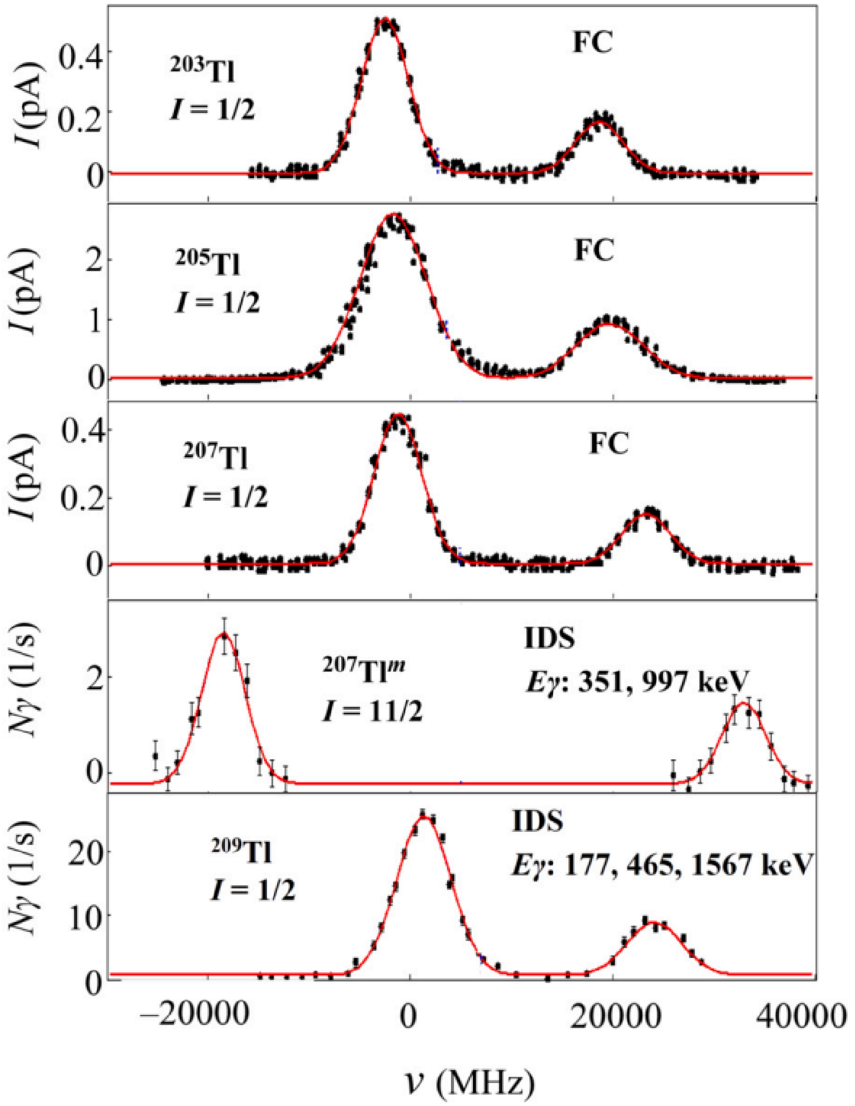


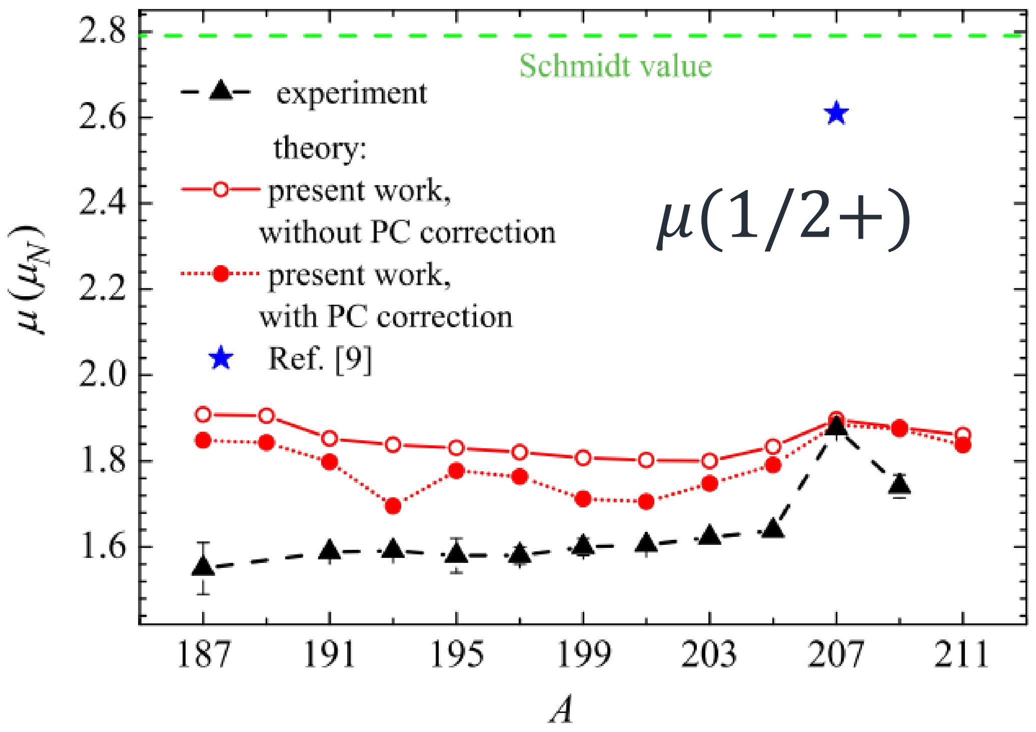
LoI219: In-source laser spec. of neutron-rich Tl

- **PhD Zixuan Yue**
- LIST performed excellently:
  Fr suppression factor: $\sim 10^4$
  Tl suppression factor: ~ 10
- Rates so good made hyperfine structure and isotope shifts measured for ^{207,209}Tl
- Shell effects on magnetic dipole moments probed with DF+CQRPA calcs. (I. Borzov), related to particle-vibrations coupling







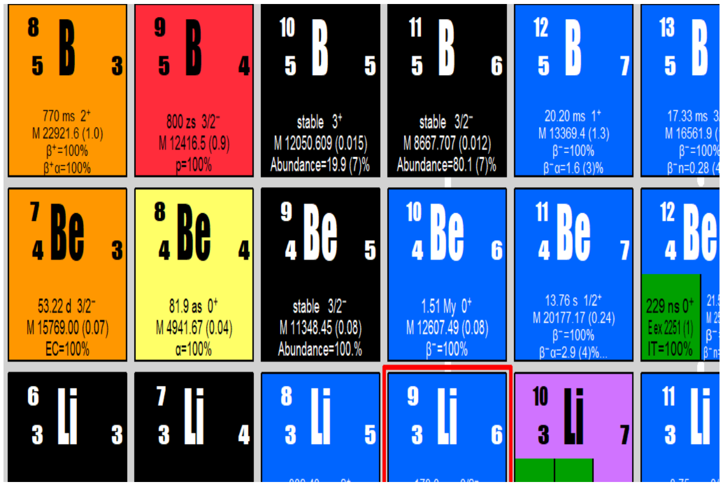


Z. Yue *et al.*, Phys. Lett. B **849**, 138452 (2024)

IS659: β decay of ^{9}Li, ^{8}He

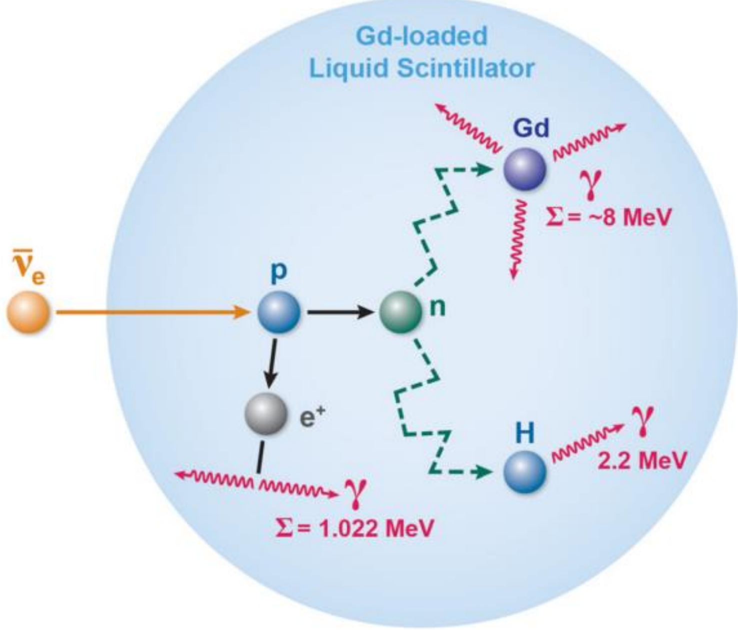
Spokesperson: H. O. U. Fynbo

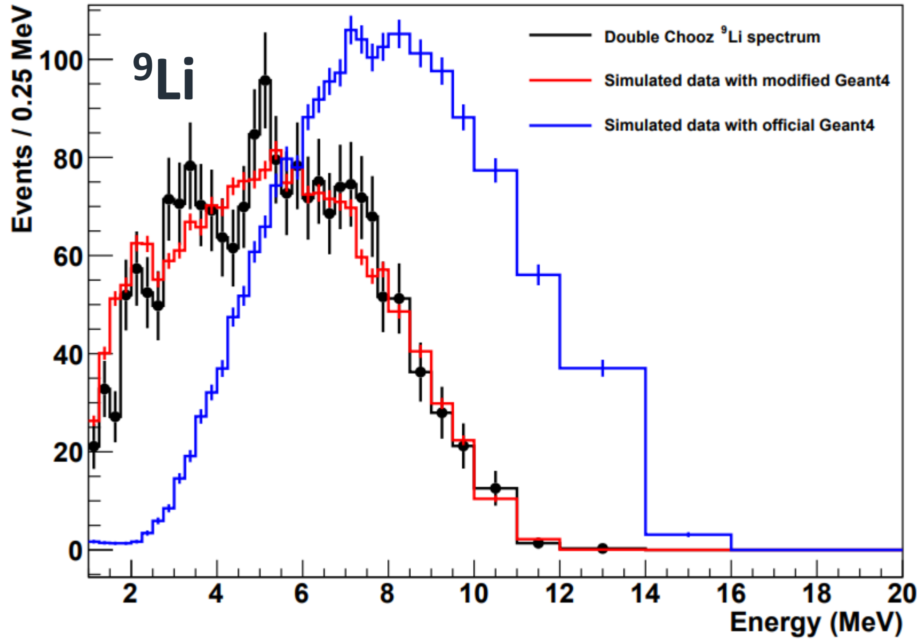
- Precise measurements of β decays for reactor neutrino experiments
- Some of largest cosmogenic background
- Need precise E level and branching ratios for ^{9}Li, ^{8}He and daughter

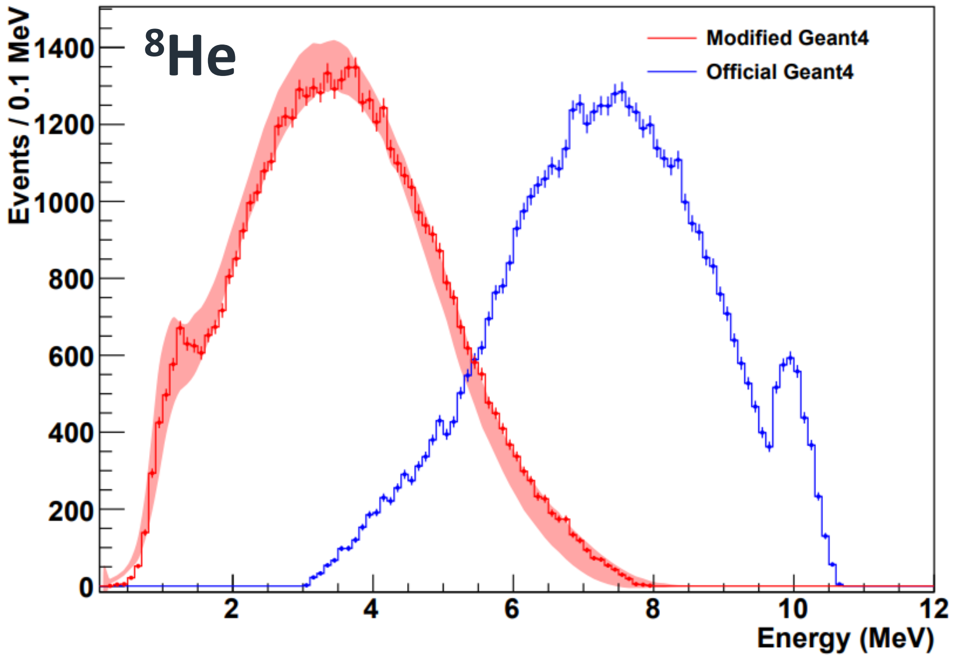


Reactor neutrino, inverse β decay:

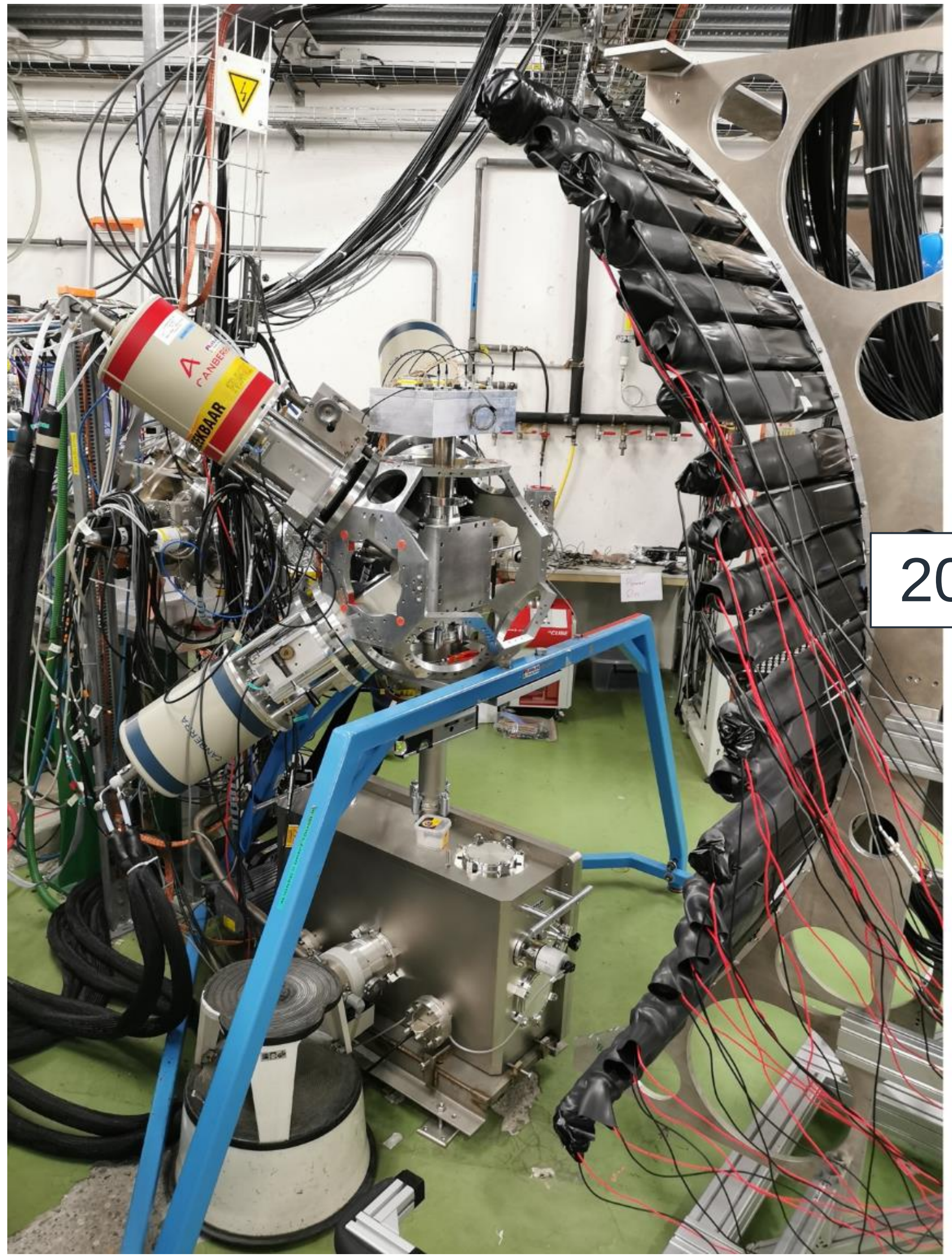
$$\overline{\nu_e} + p \rightarrow e^{+} + n$$



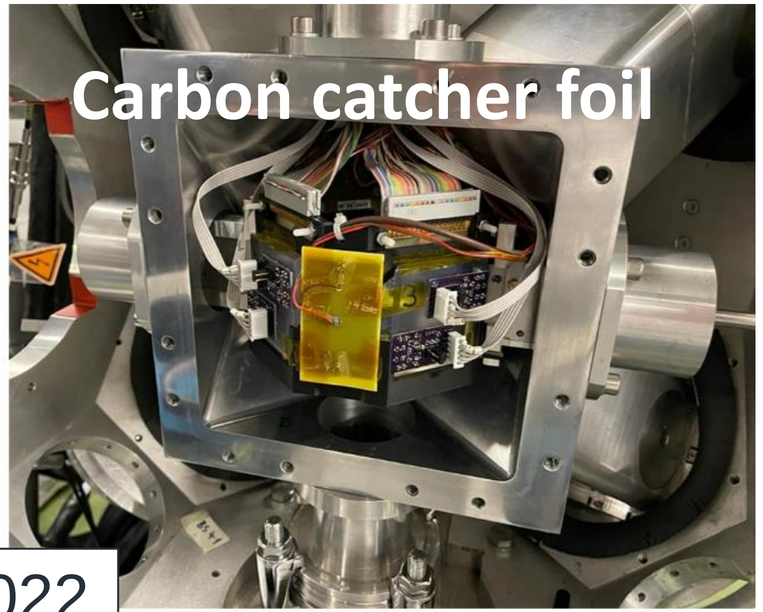


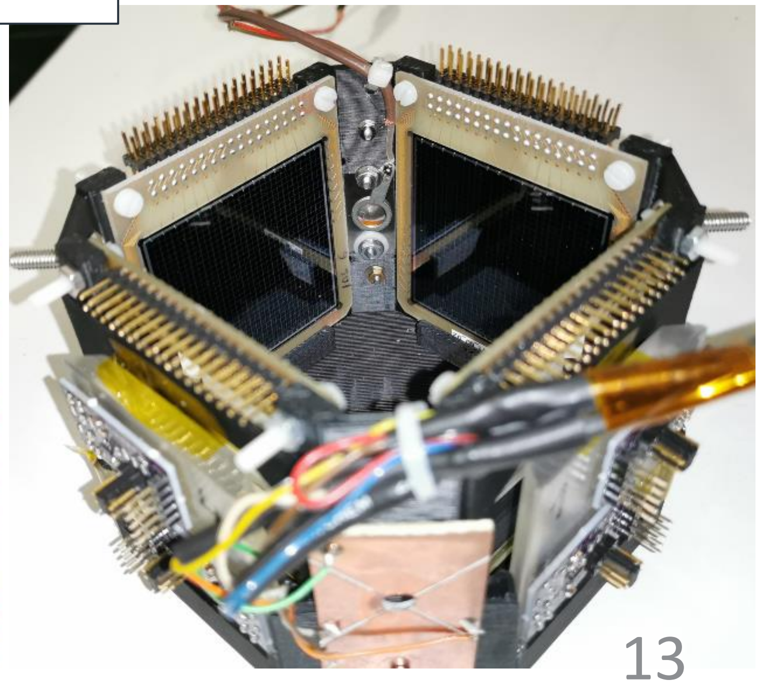


C. Jollet and A. Meregaglia, arXiv:1910.01060 (2019)



2022

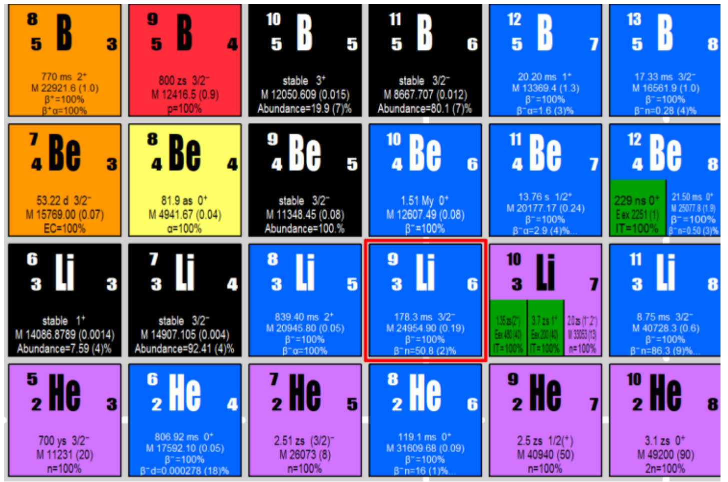


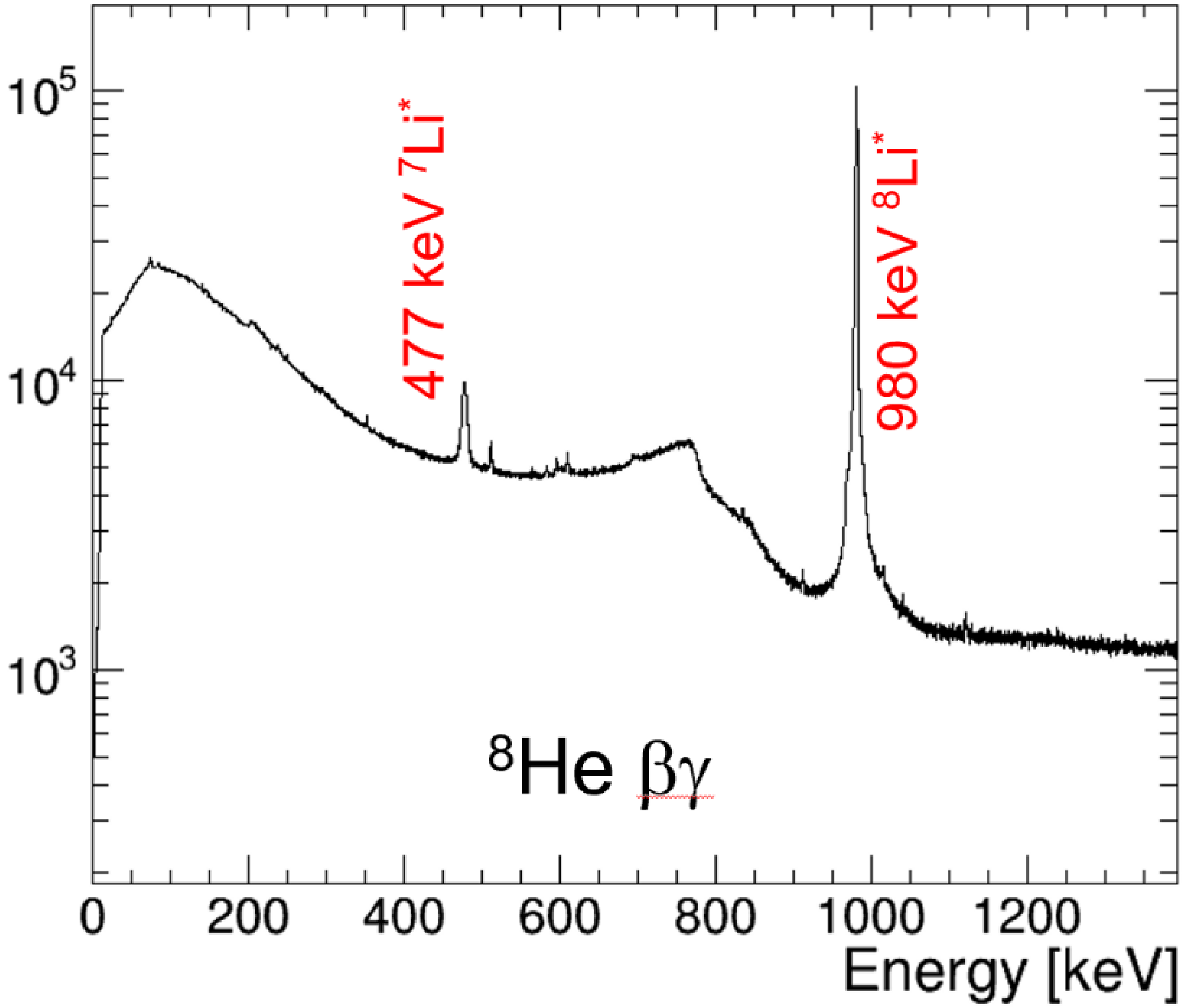


IS659: β decay of ^{9}Li, ^{8}He

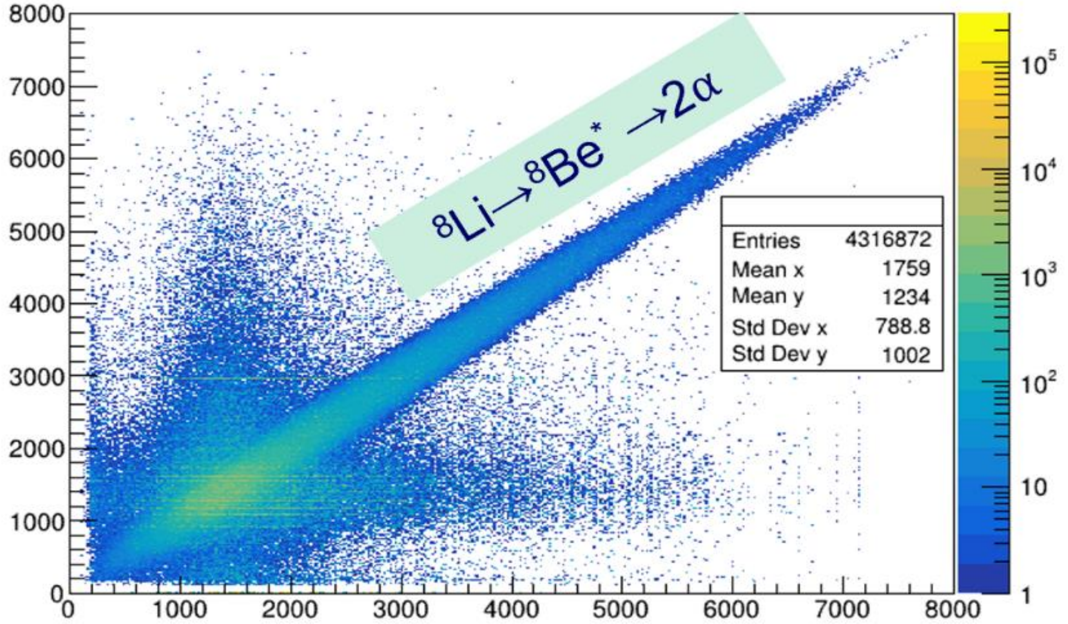
PhD Erik Jensen and Jeppe Schultz Nielsen

- Clear observation of different decay modes
- Preliminary decay scheme established
- Analysis ongoing

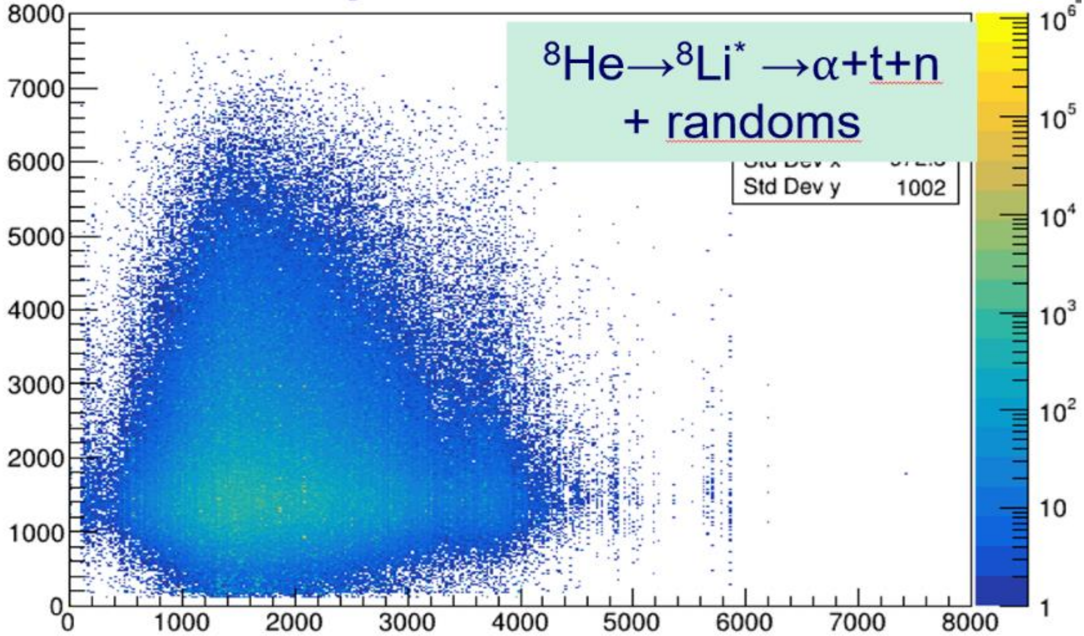




Opposing detectors

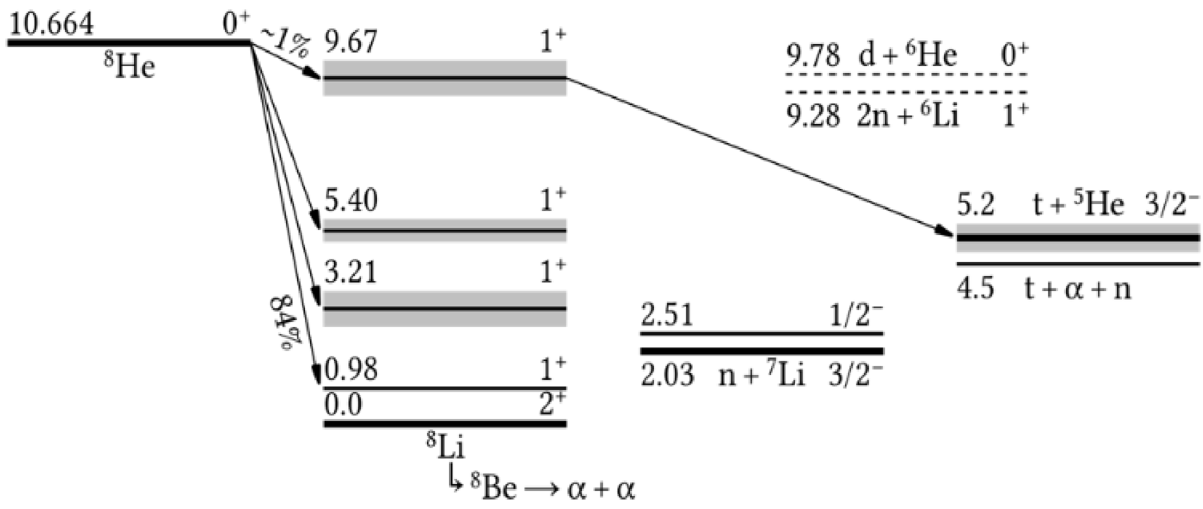


Adjacent detectors



Measured spectra

Preliminary data analysis

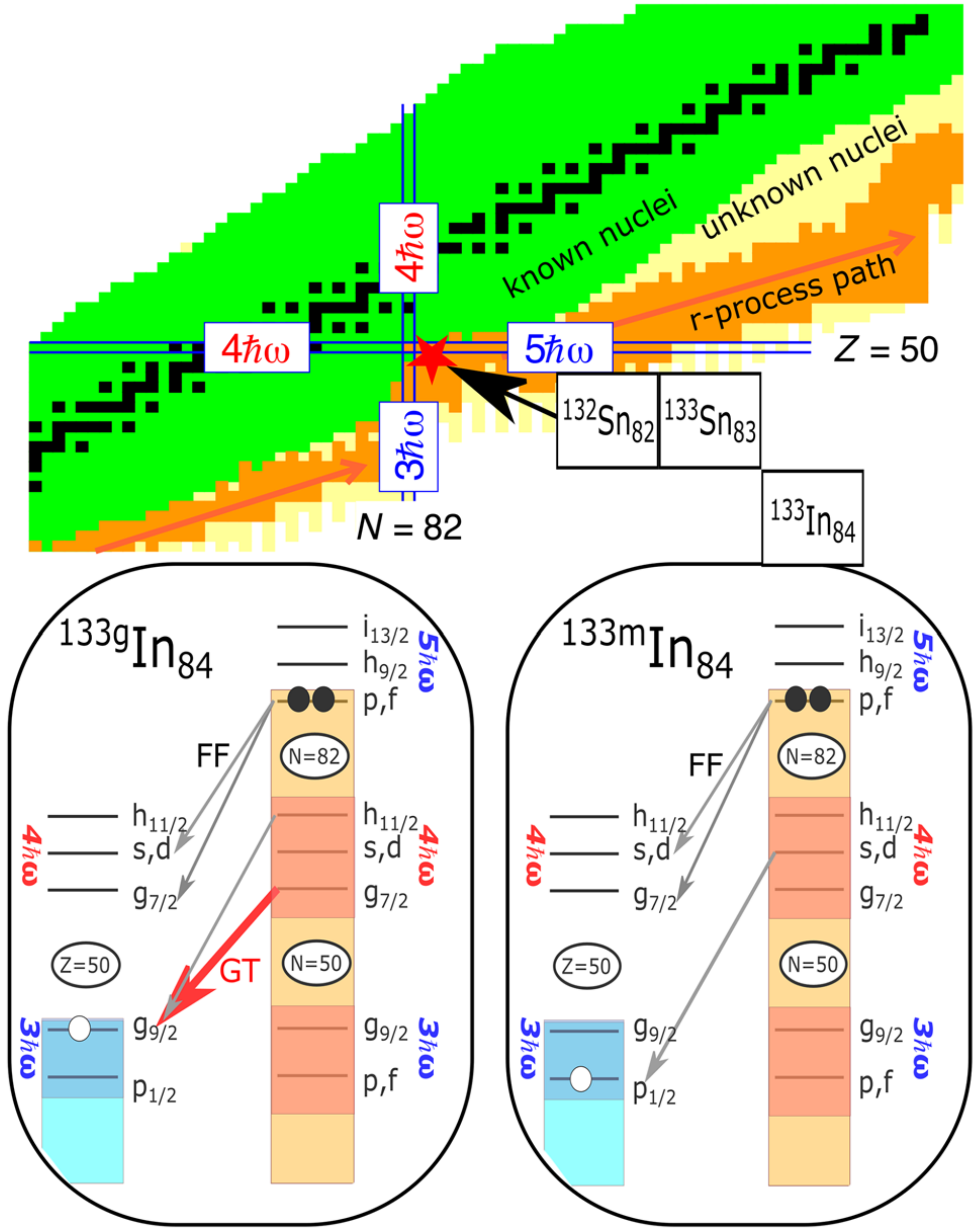


Courtesy of Erik Jensen, Hans Fynbo (Uni. Aarhus)

IS632: β-delayed neutrons of ^{133}In

Spokespersons: M. Madurga Flores, R Grzywacz

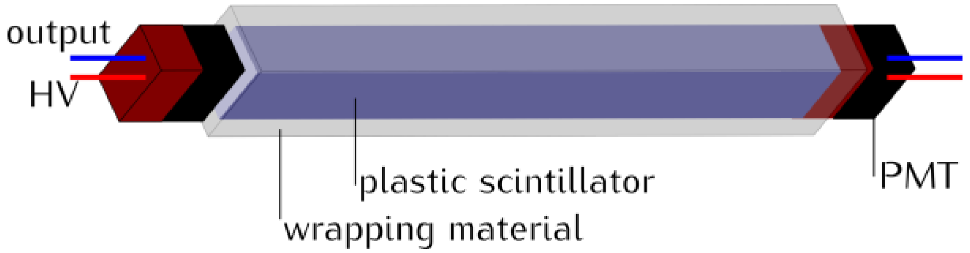
- Study β-delayed γ and neutron decays of I=1/2$^-$ ground and I=9/2$^+$ isomeric state
- Expect competition between allowed GT ($\Delta L = 0$) and first-forbidden ($\Delta L = 1$) decays – impact decay properties and *r*-process path
- Data place multiple constraints on β-decay theories ($T_{1/2},\ P_n,\ \log ft,\ S_\beta$)

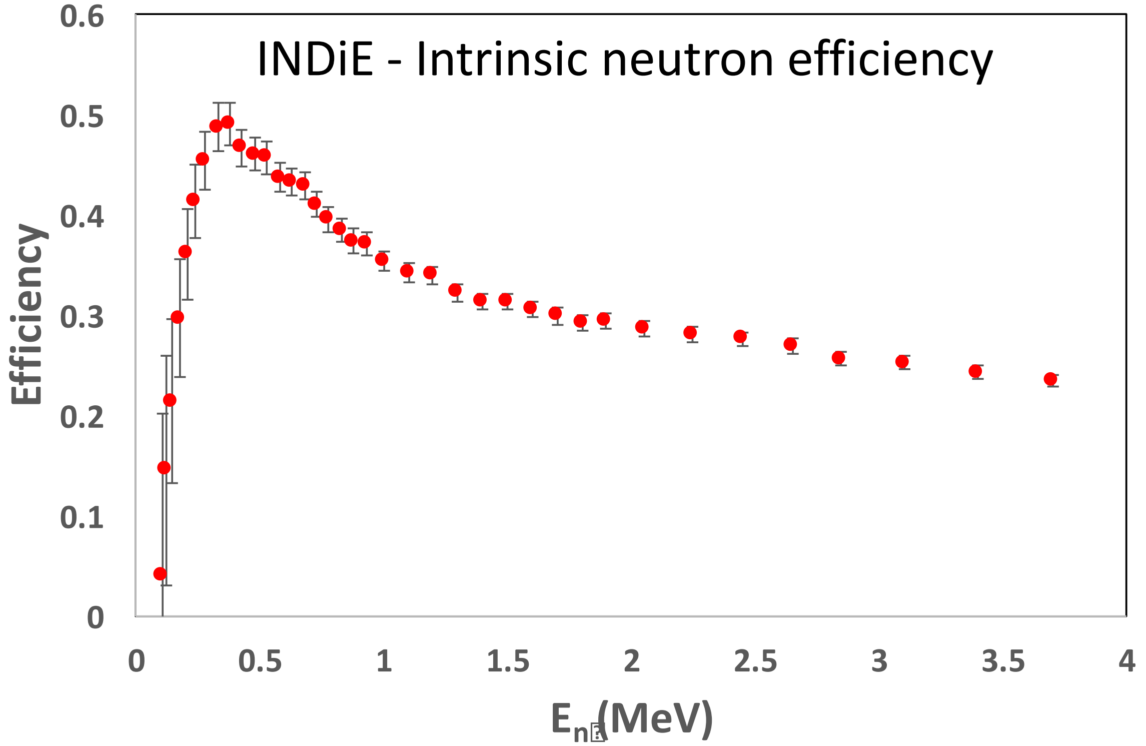


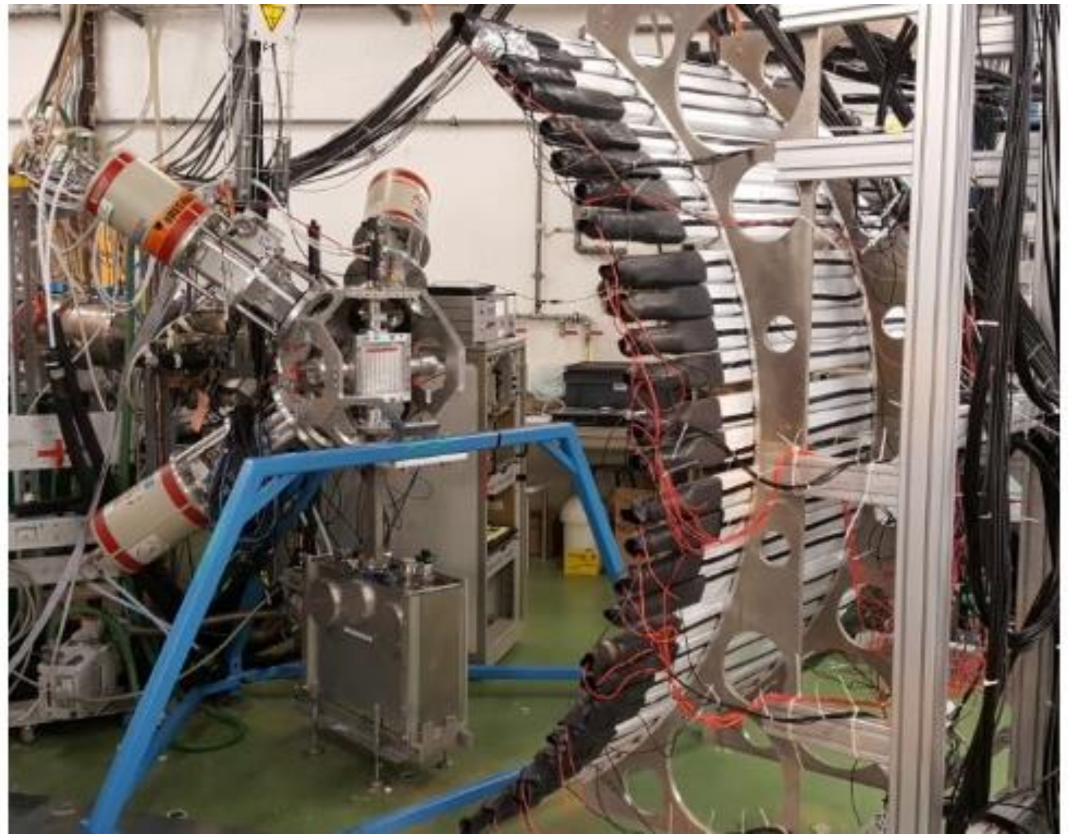
Z. Y. Xu *et al.*, Phys. Rev. Lett. **131**, 022501 (2023)

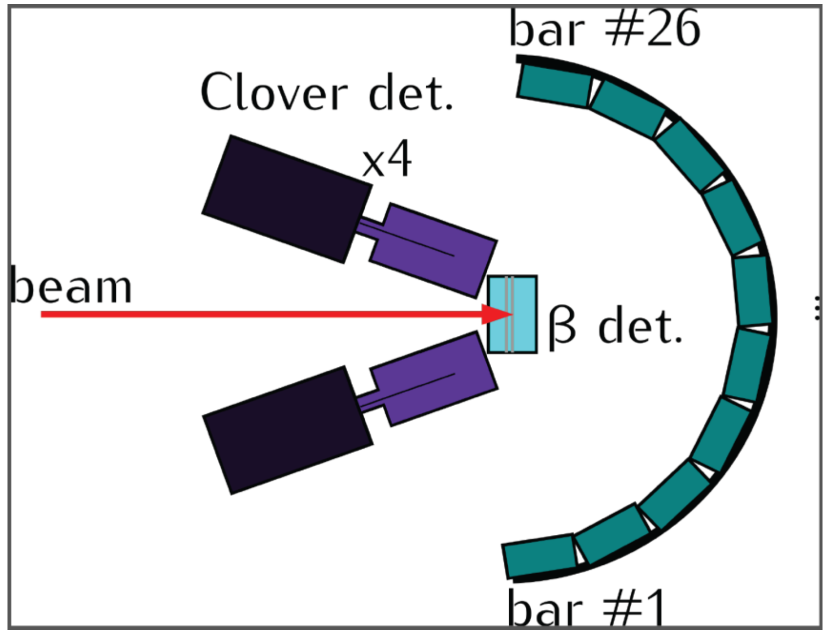
INDiE (IDS Neutron Detector)

- 26, 3x6x120 cm^3 bars
- Ω=14.9% of 4π
- Intrinsic neutron efficiency 25%-50%



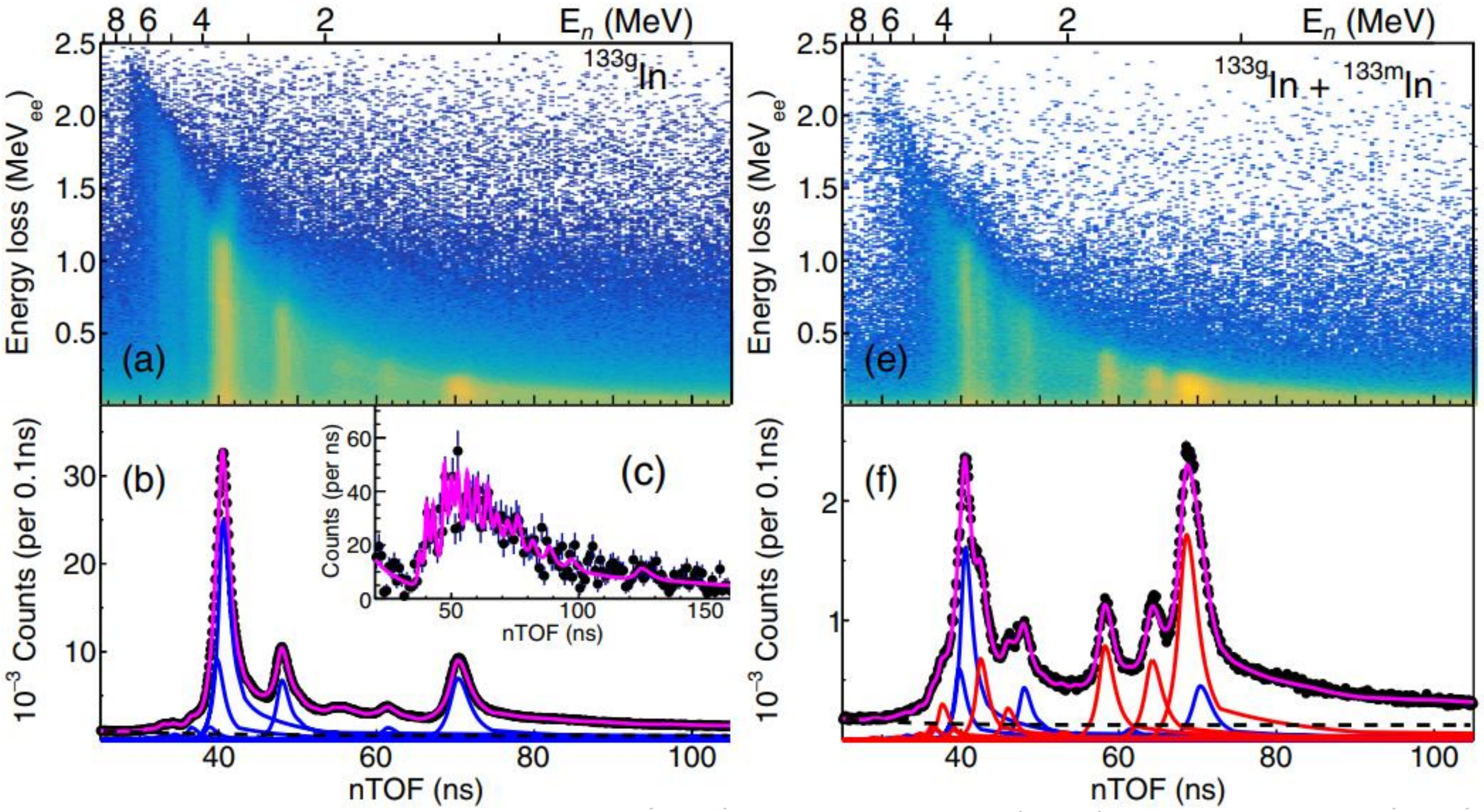




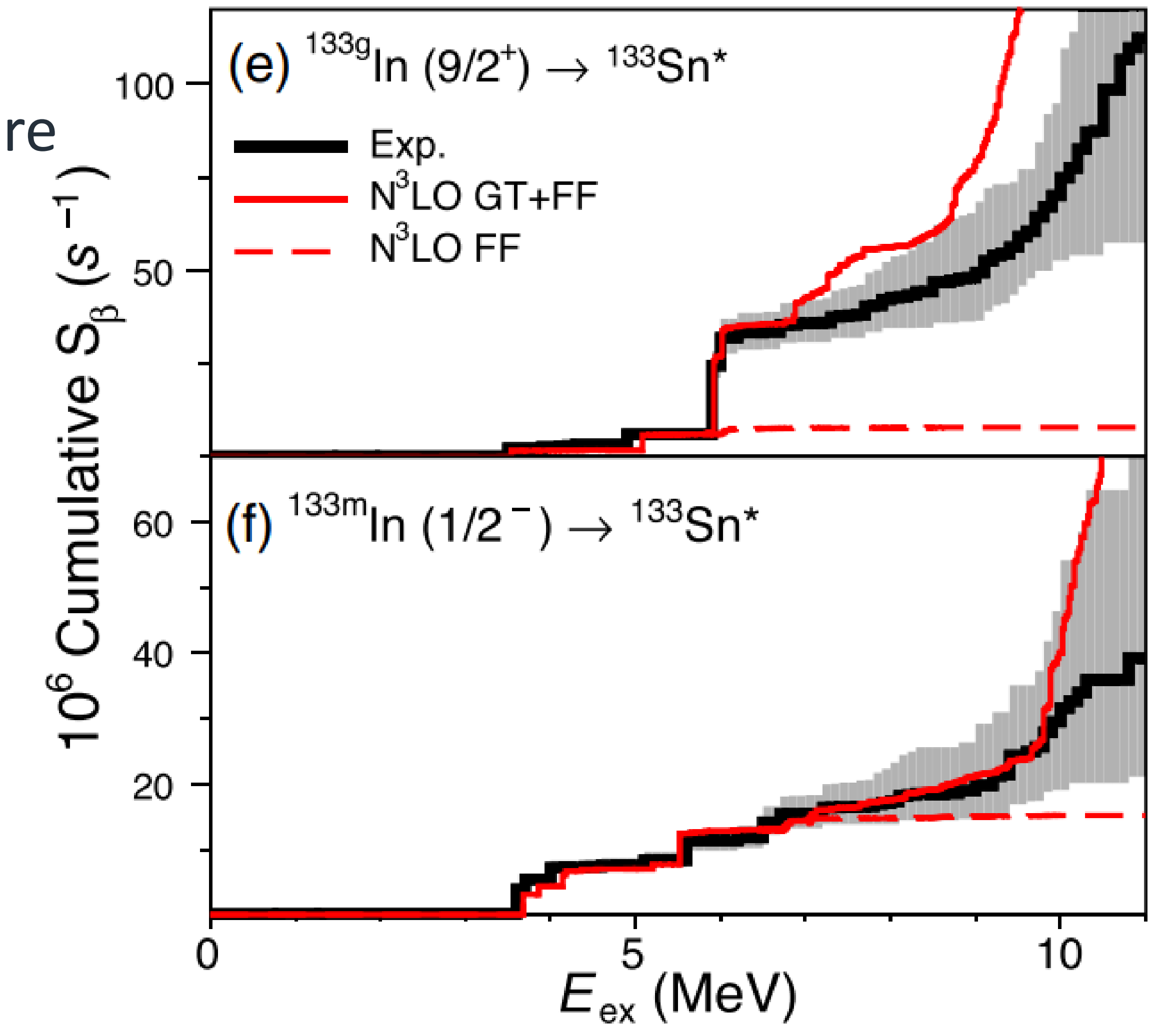


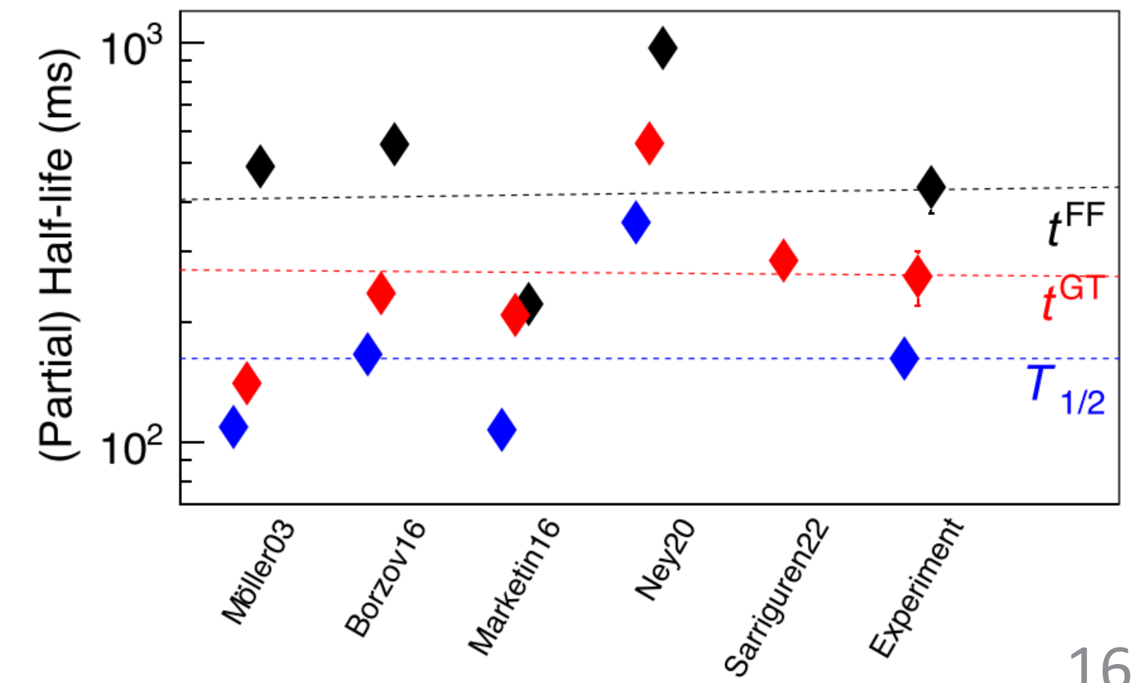
IS632: β-delayed neutron of ^{133}In

- **Analysed by Zhengyu Xu**
- **RILIS provided isomerically pure ground state** due to difference in hyperfine structure
- Large scale shell model (LSSM) - clear difference in GT and FF contribution to S_β, highlights need for precise description for *r*-process calcs.
- Data used to test predictions from "global" β-decay models (LSSM impractical for calculations across chart)



Z. Y. Xu *et al.*, Phys. Rev. C **108**, 014314 (2023)



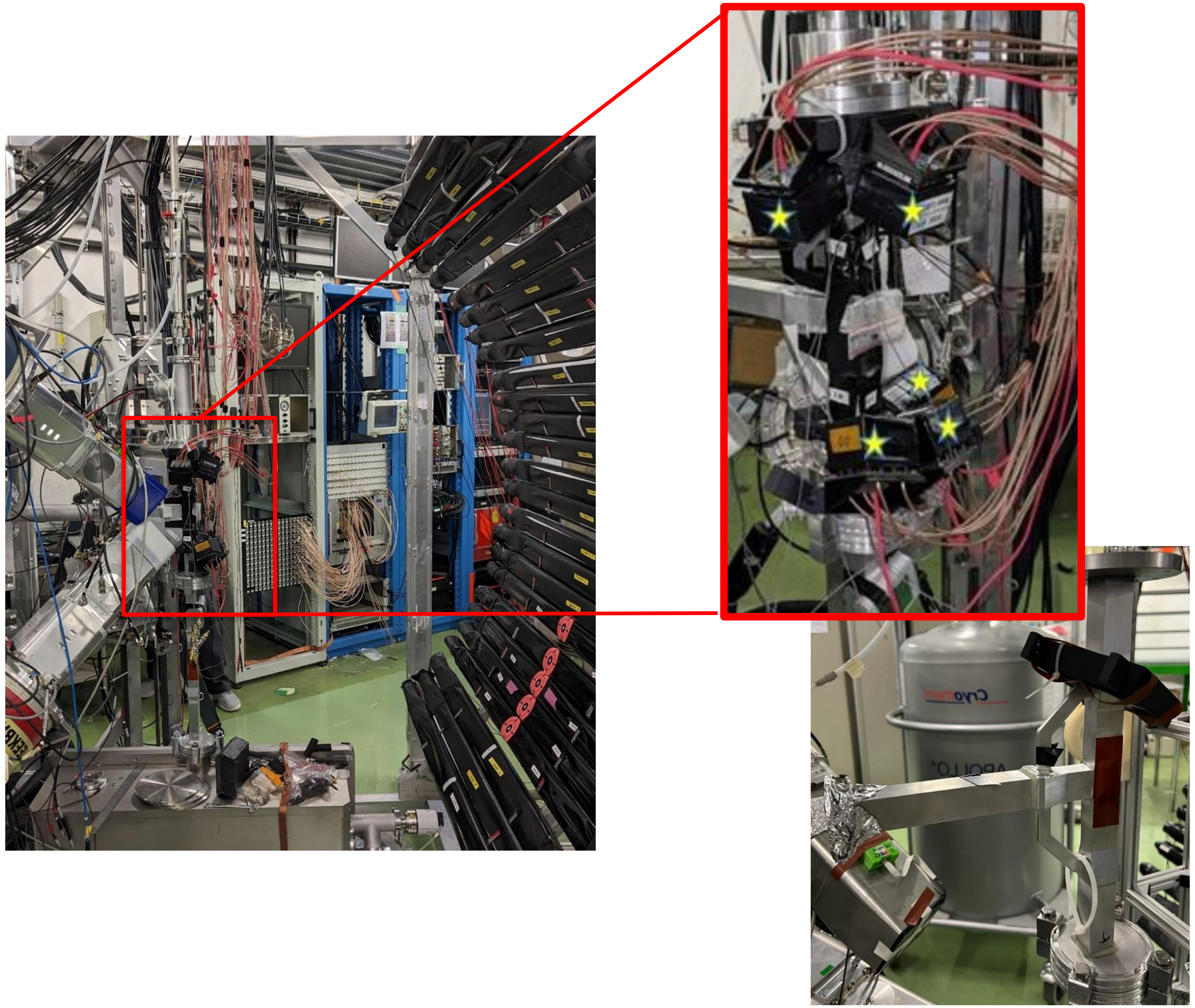


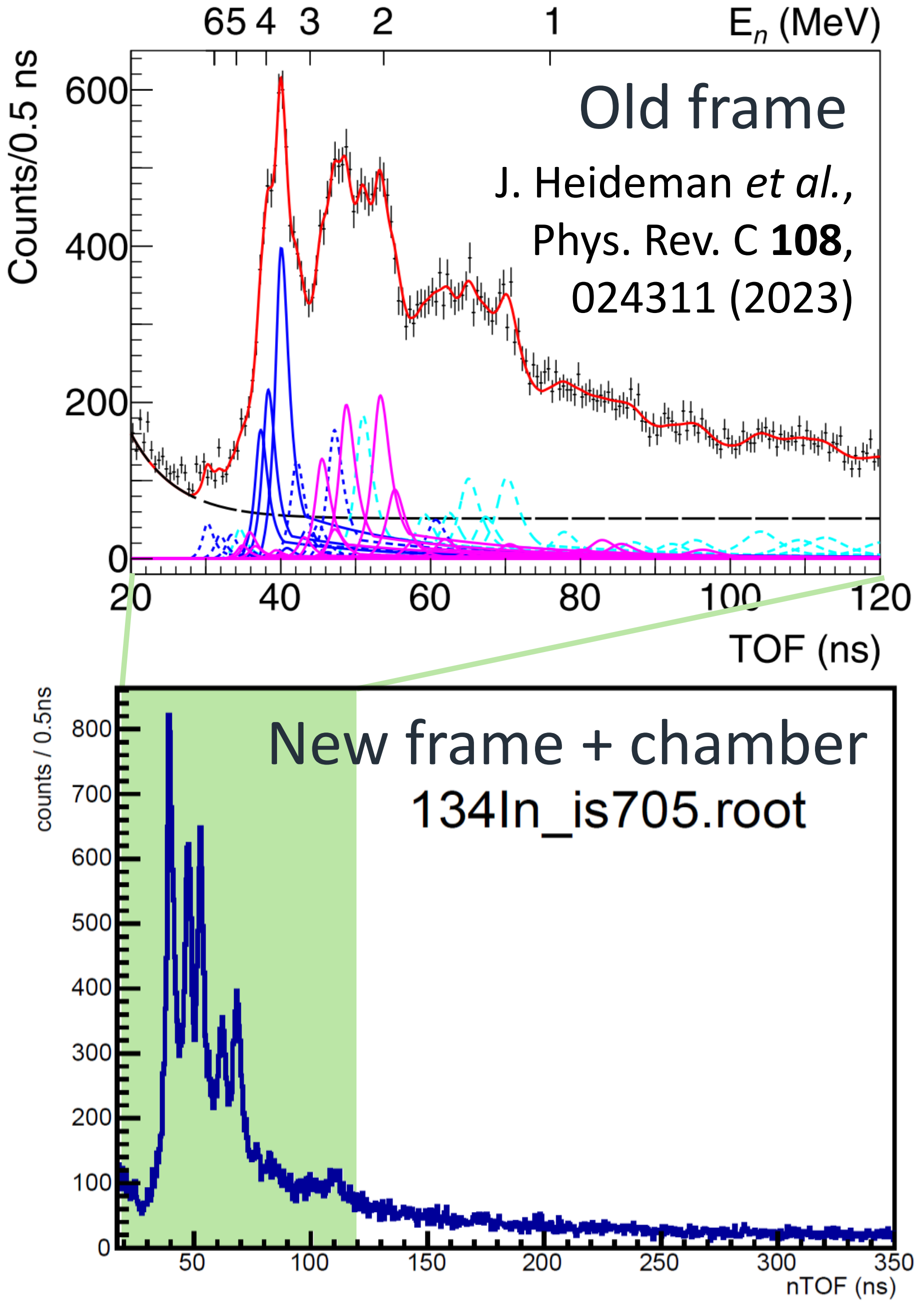
Z. Y. Xu *et al.*, Phys. Rev. Lett. **131**, 022501 (2023)

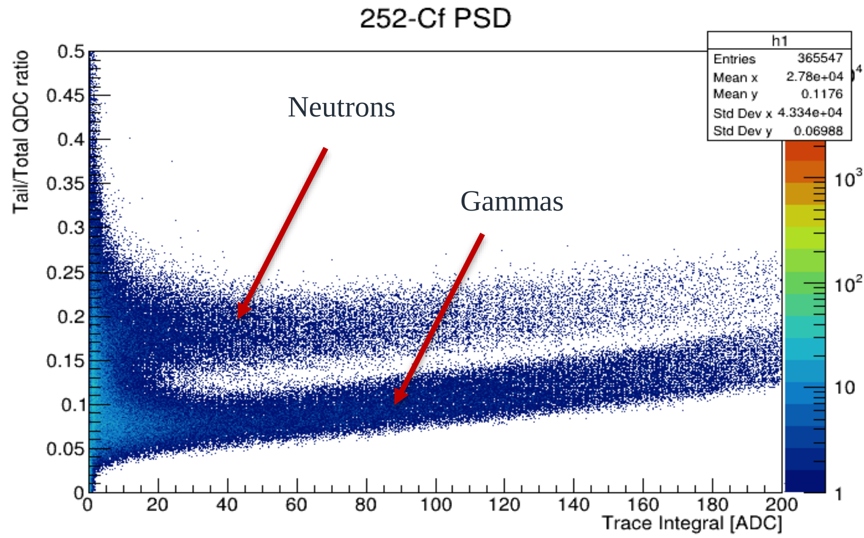
IS662/705: β-delayed neutron of ^{134,135}In

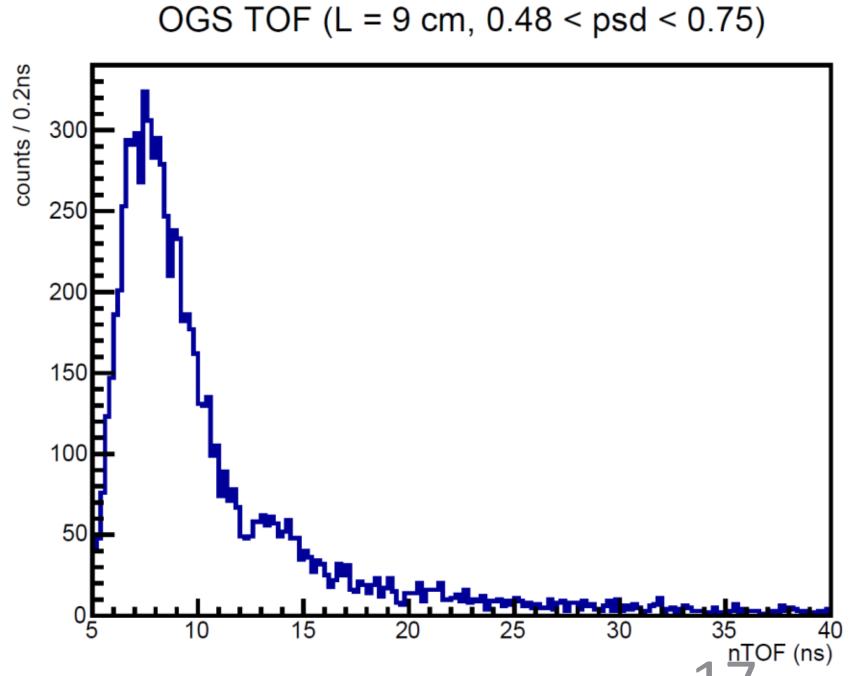
Spokespersons: R. Grzywacz, A. Korgul, M. Madurga, L. Fraile, **PhD Peter Dyszel**

- Initial tests of new detection system performed in autumn 2023 – OGS “nest” and INDiE
- Much improved resolution – new frame and “fast-timing” chamber → less scattering
- Working OGS “nest” for low-E neutrons, eff. ~80% for 50 keV neutrons, excellent PSD for γ vs. neutron







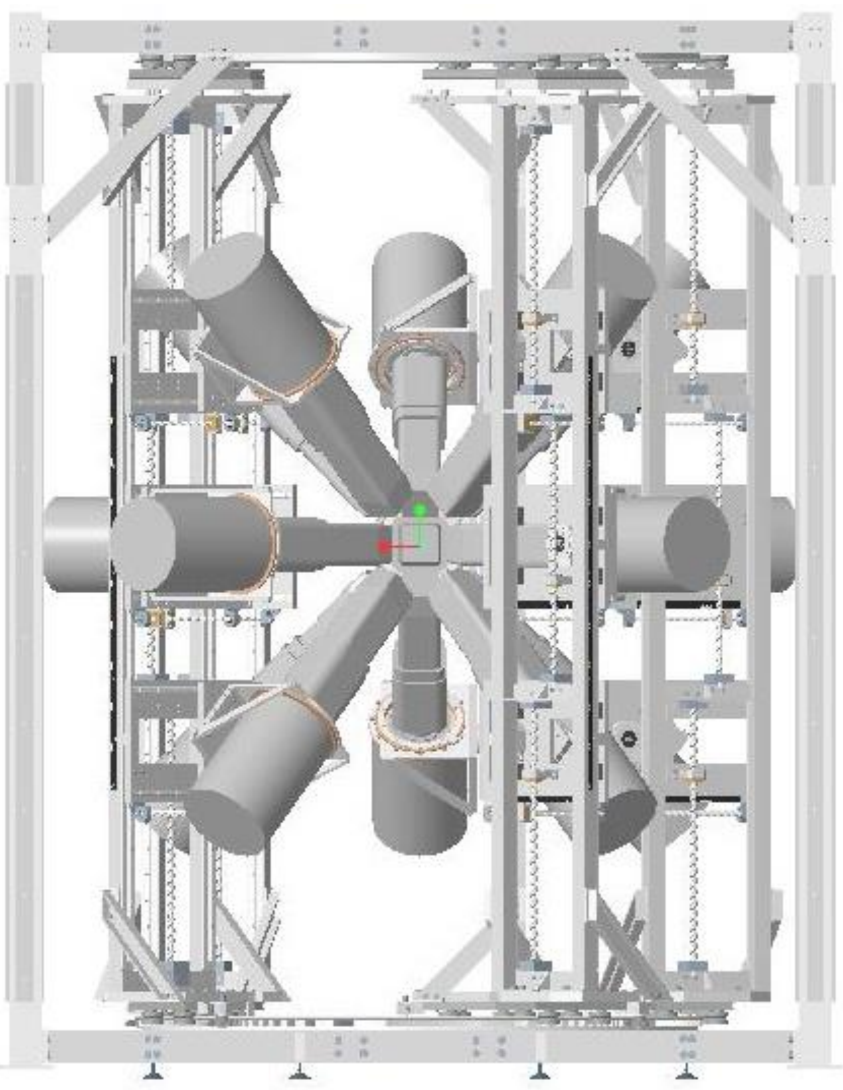


Courtesy of P. Dyszel, R. Grzywacz (U. Tenn. Knox.)

Plans for the future

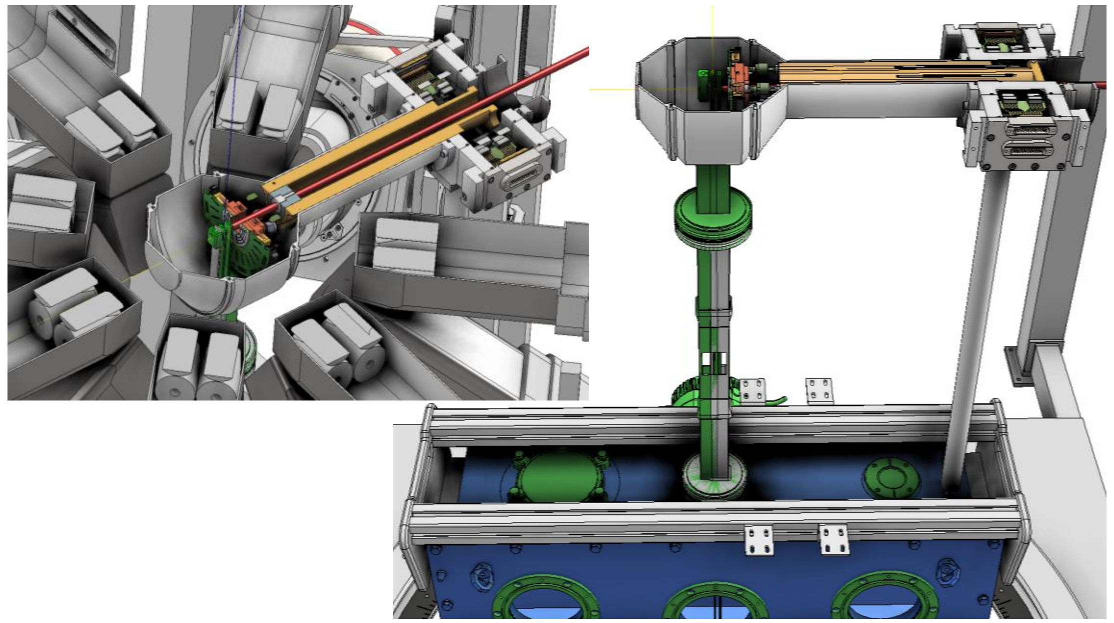
IDS of the future

Future – “more” IDS

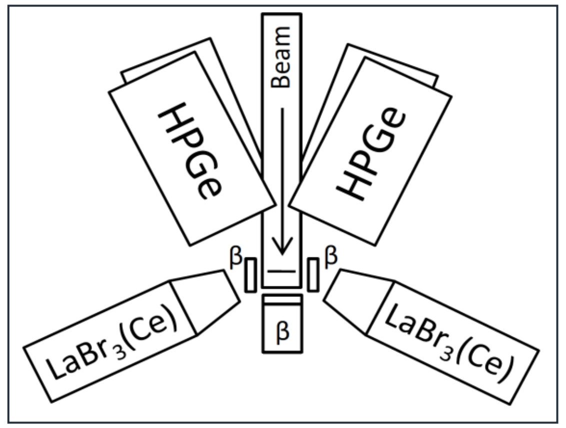


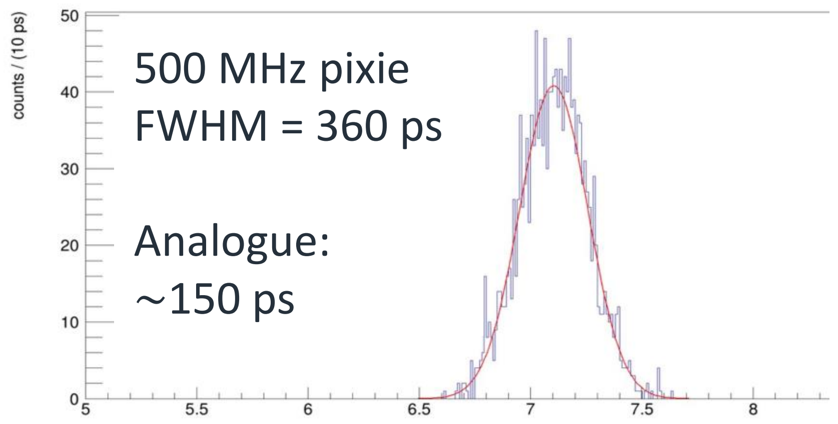
- 12 clovers by Aug. 2024 +3 more in “near” future (up 60 crystals)
- Even more plastic… (ε up to 70%)

New SPEDE setup

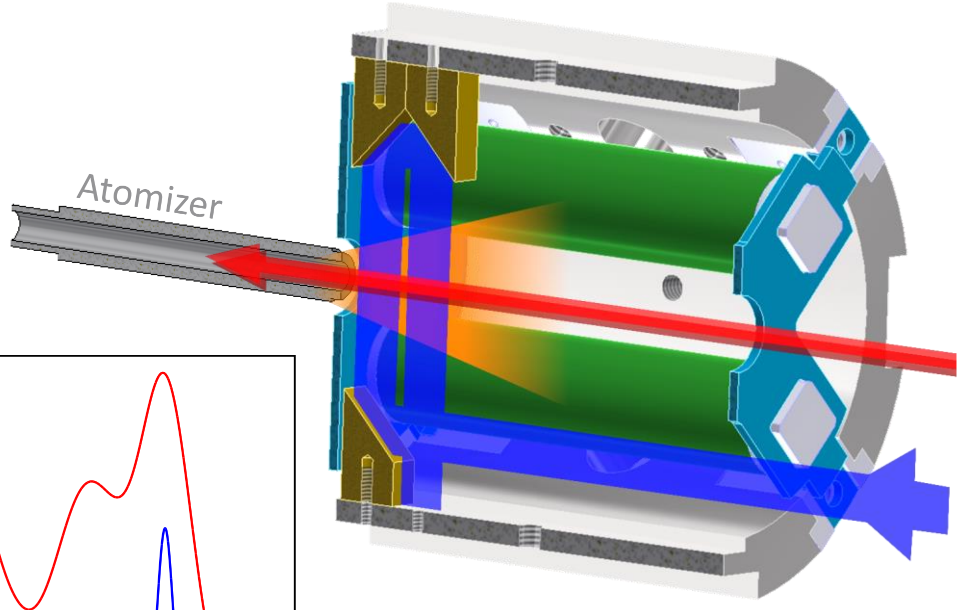


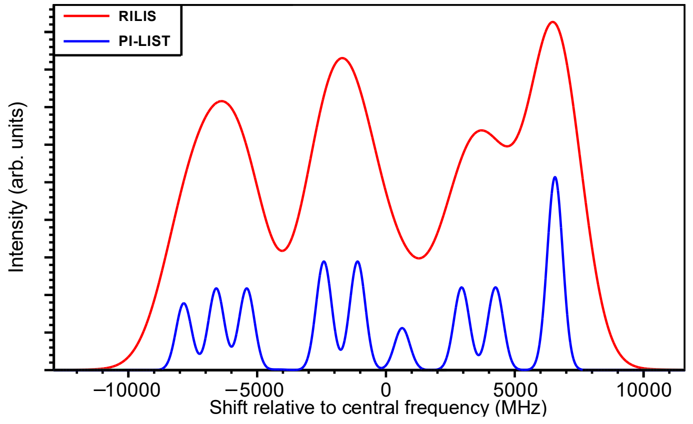
Fully digital fast-timing setup – increase #detectors





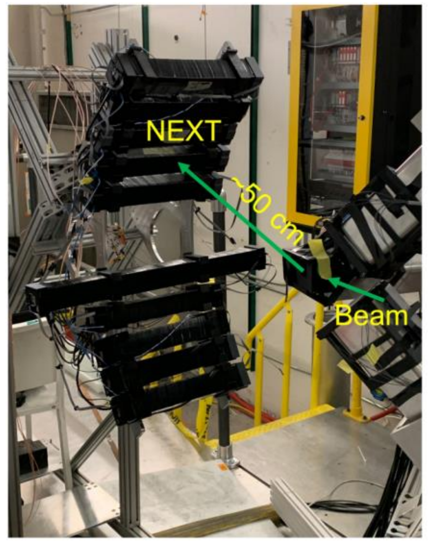
Collaborate with ion-source and laser teams

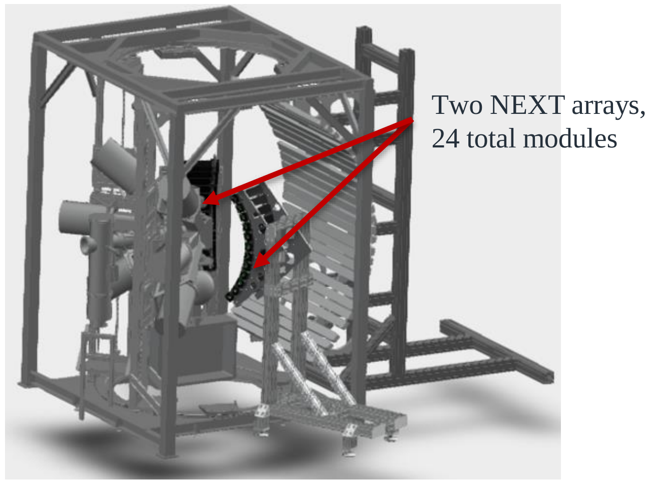


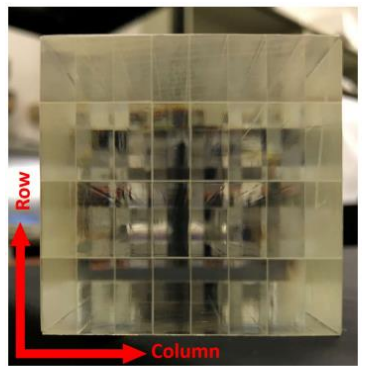


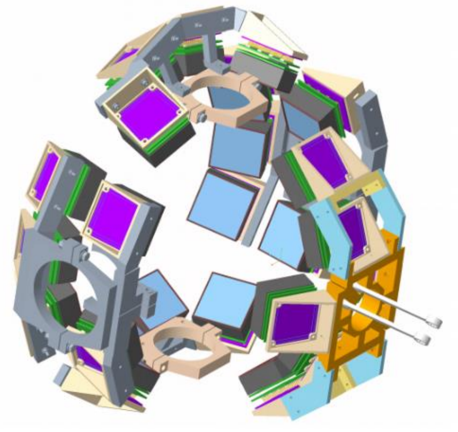
R. Heinke *et al.*, *Hyperfine Interactions* **238**, 6 (2017)

Full neutron setup: INDiE + NEXT + OGS



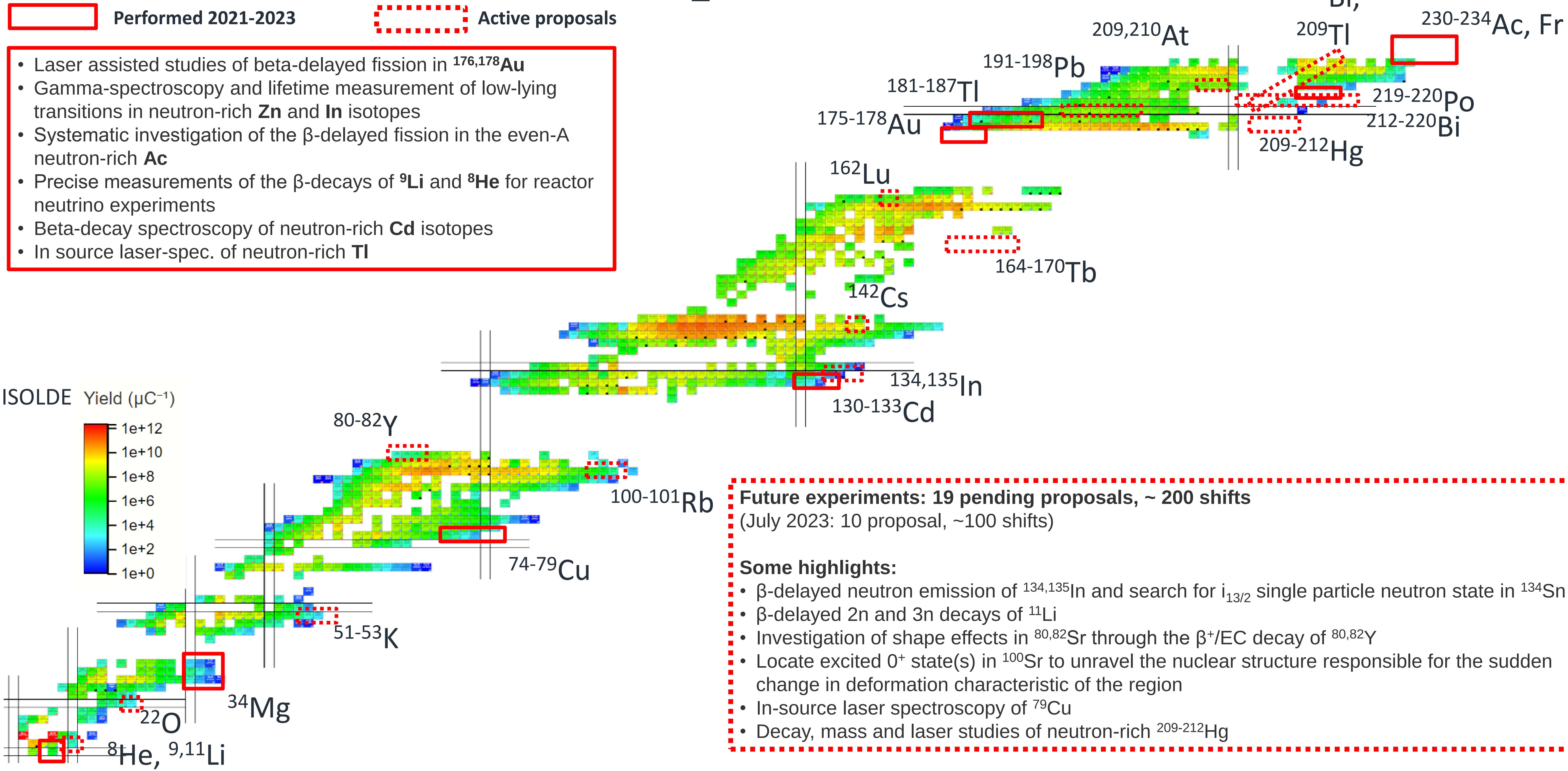






Recent and future experiments at IDS

- Laser assisted studies of beta-delayed fission in ^{176,178}**Au**
- Gamma-spectroscopy and lifetime measurement of low-lying transitions in neutron-rich **Zn** and **In** isotopes
- Systematic investigation of the β-delayed fission in the even-A neutron-rich **Ac**
- Precise measurements of the β-decays of ^{9}**Li** and ^{8}**He** for reactor neutrino experiments
- Beta-decay spectroscopy of neutron-rich **Cd** isotopes
- In source laser-spec. of neutron-rich **Tl**



Future experiments: 19 pending proposals, ~ 200 shifts
(July 2023: 10 proposal, ~100 shifts)

Some highlights:

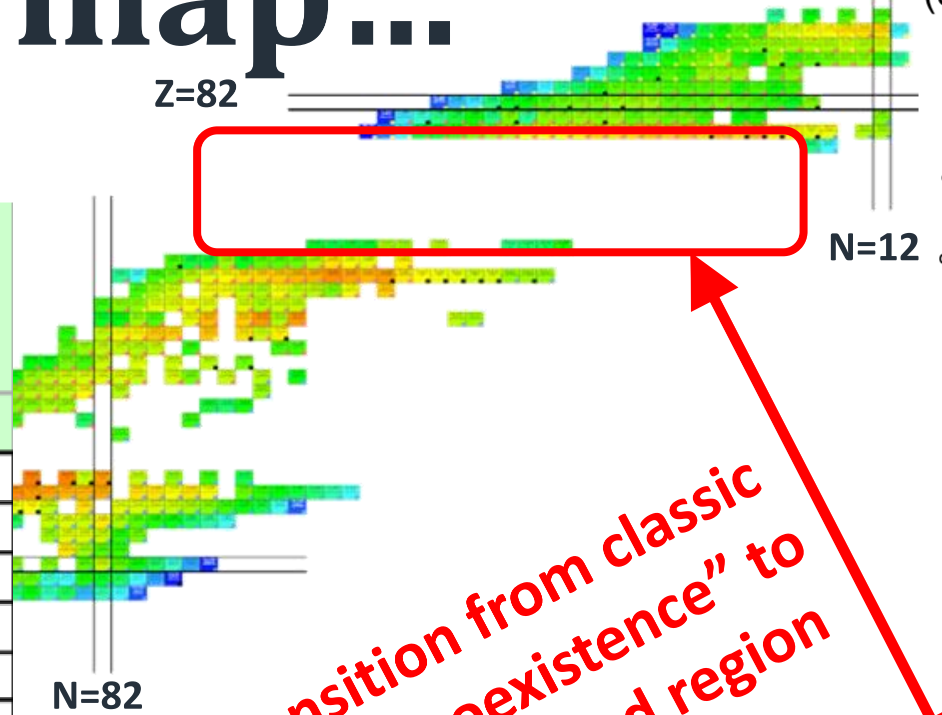
- β-delayed neutron emission of ^{134,135}In and search for $i_{13/2}$ single particle neutron state in ^{134}Sn
- β-delayed 2n and 3n decays of ^{11}Li
- Investigation of shape effects in ^{80,82}Sr through the $β^+$/EC decay of ^{80,82}Y
- Locate excited 0^+ state(s) in ^{100}Sr to unravel the nuclear structure responsible for the sudden change in deformation characteristic of the region
- In-source laser spectroscopy of ^{79}Cu
- Decay, mass and laser studies of neutron-rich $^{209\text{-}212}$Hg

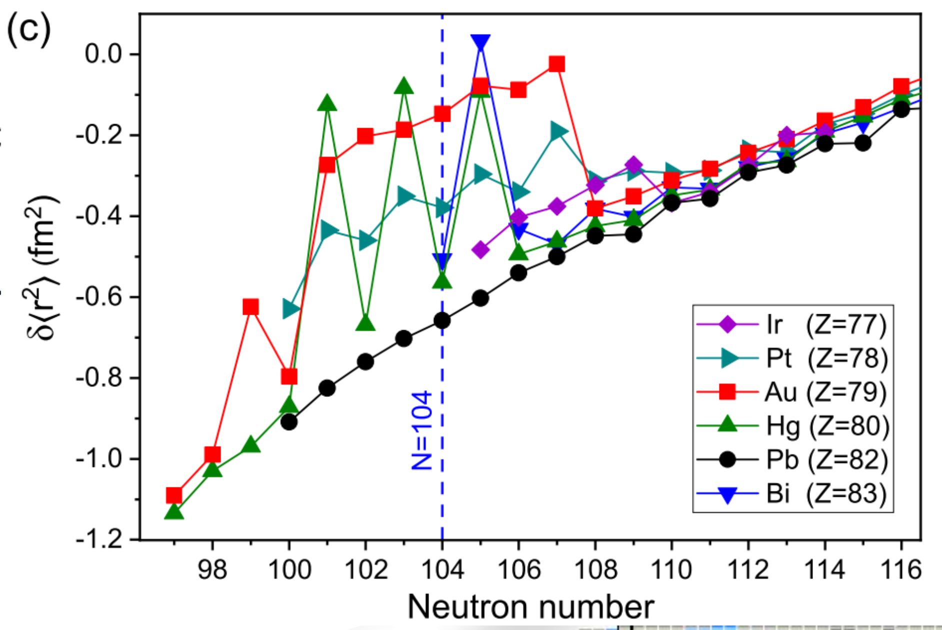
Chart source: https://isoyields2.web.cern.ch/IsoldeYieldChart.aspx

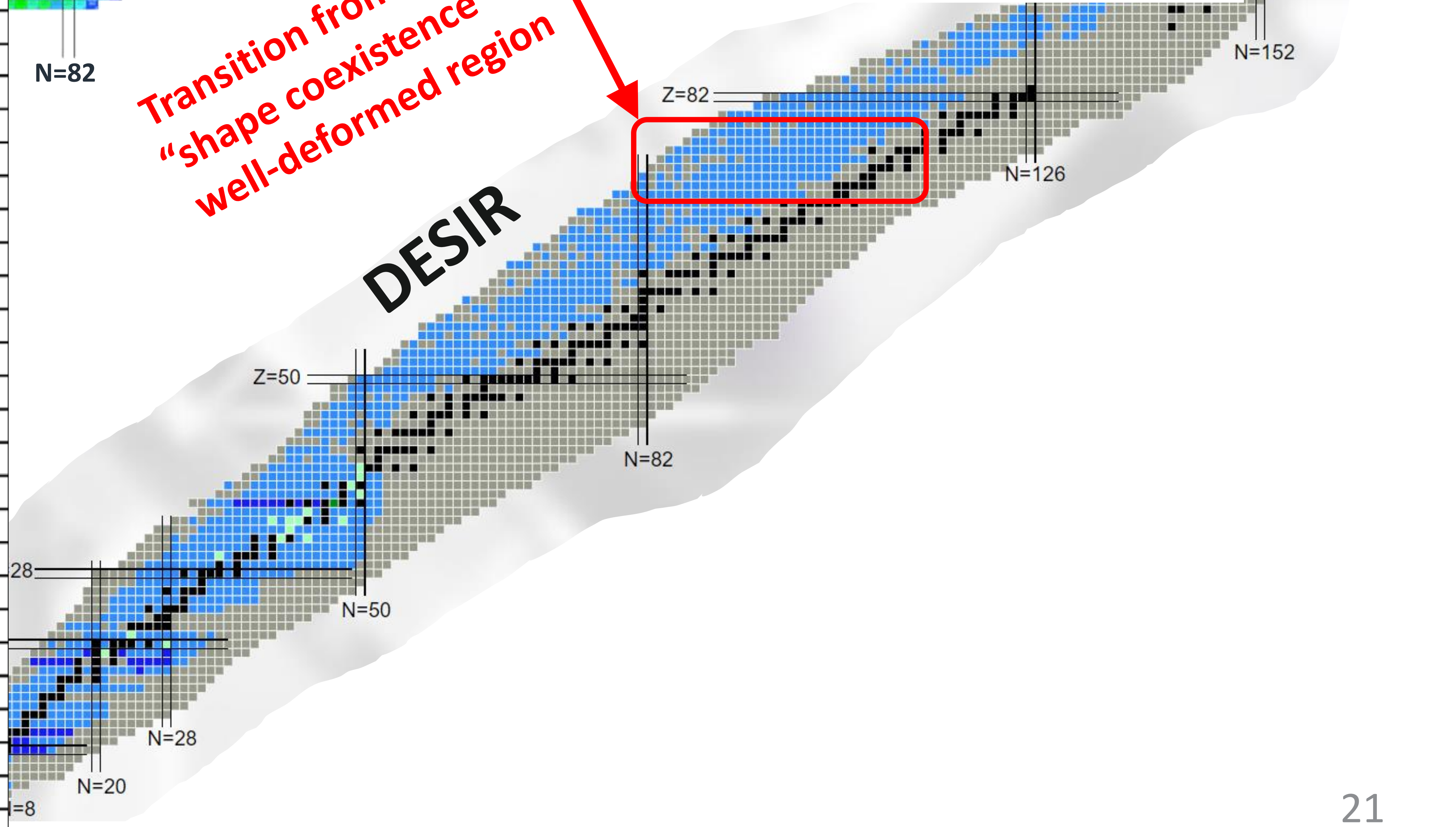
Gaping holes in the map…

Cubiss *et al.*, Phys. Rev. Lett. **131**, 202501 (2023)

Radioactive Beam	halflife	unit	Charge State	Intensity* (pps)		
				I_{ave} **	I_{min} ***	I_{max} ****
165Ir	0,01	s	1+	2,10E-07	3,40E-08	1,80E-06
165Ir	0,01	s	---	3,80E+01	6,20E+00	3,20E+02
166Ir	10,5	ms	1+	1,00E-06	3,90E-07	6,50E-06
166Ir	10,5	ms	---	1,90E+02	7,10E+01	1,20E+03
167Ir	35,2	ms	1+	1,50E+00	3,80E-01	4,30E+00
167Ir	35,2	ms	---	2,50E+03	6,50E+02	7,50E+03
169Ir	0,353	s	1+	5,70E+02	2,10E+01	3,80E+03
169Ir	0,353	s	---	8,90E+03	3,30E+02	6,00E+04
170Ir	0,87	s	1+	6,20E+02	1,80E+02	2,60E+03
170Ir	0,87	s	---	9,30E+03	2,70E+03	4,00E+04
171Ir	3,2	s	1+	2,40E+03	1,40E+03	4,40E+03
171Ir	3,2	s	---	3,20E+04	1,80E+04	5,70E+04
172Ir	4,4	s	1+	6,20E+01	6,20E+01	6,20E+01
172Ir	4,4	s	---	8,10E+02	8,10E+02	8,10E+02
173Ir	9	s	1+	3,40E-01	3,40E-01	3,40E-01
173Ir	9	s	---	4,30E+00	4,30E+00	4,30E+00
175Ir	9	s	1+	1,10E+05	8,00E+04	1,40E+05
175Ir	9	s	---	1,40E+06	1,00E+06	1,80E+06
176Ir	8,7	s	1+	5,80E+04	3,10E+04	1,70E+05
176Ir	8,7	s	---	7,40E+05	4,00E+05	2,20E+06
177Ir	30	s	1+	1,10E+05	4,90E+04	2,40E+05
177Ir	30	s	---	1,40E+06	6,20E+05	3,00E+06
178Ir	12	s	1+	1,60E+05	5,60E+04	3,70E+05
178Ir	12	s	---	2,00E+06	7,00E+05	4,60E+06
179Ir	79	s	1+	2,20E+05	7,80E+04	4,20E+05
179Ir	79	s	---	2,80E+06	9,70E+05	5,30E+06
180Ir	1,5	m	1+	3,80E+05	3,00E+05	4,70E+05
180Ir	1,5	m	---	4,70E+06	3,70E+06	5,90E+06







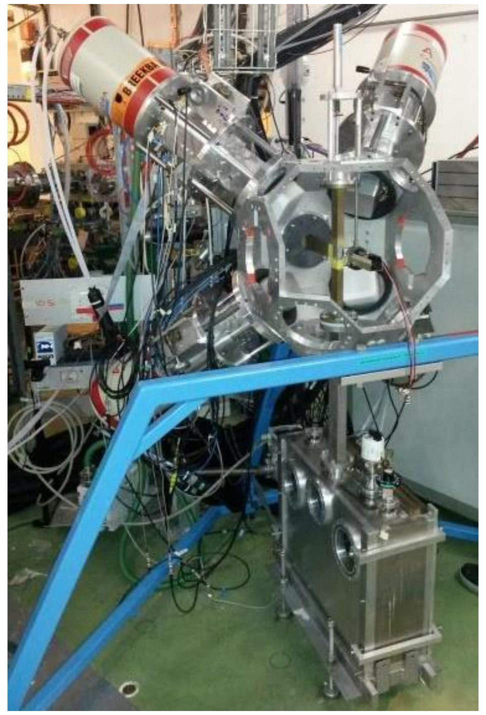
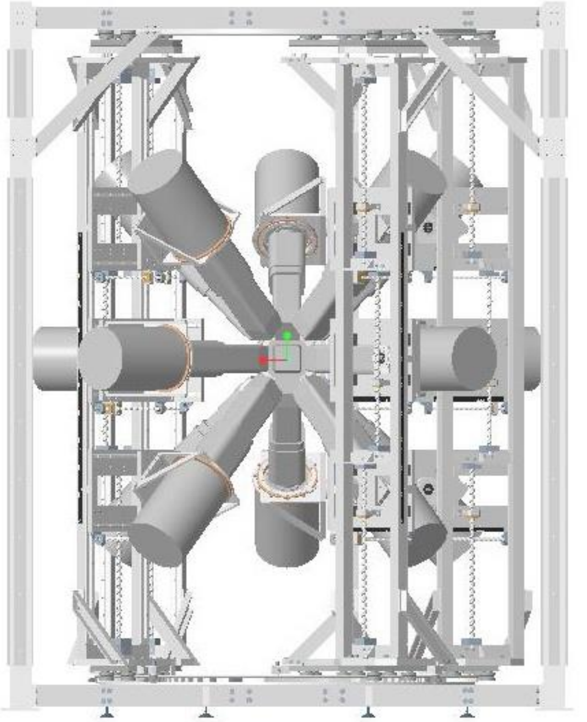
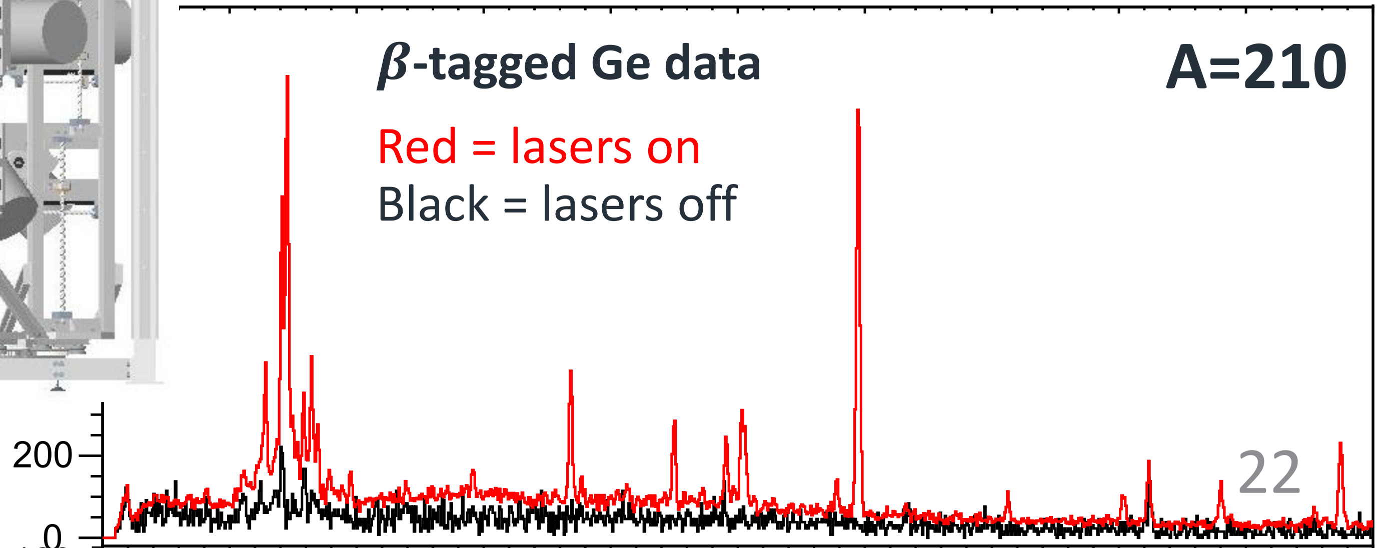
Summary and conclusions

- **Clear and growing demand for decay setup**
  - July 2023: 10 approved beamtimes with 100 shifts
  - Feb. 2024: 19 approved beamtimes with 200 shifts

- **Flexible approach has been great success for us**
  - Dedicated systems, how best to implement + combine
  - Coupling to (RILIS) and working with (MR-ToF) other systems and teams
  - Lots of fun been had, and still to have!

- **Increasing sensitivity and new methods key for future**
  - Improved $\gamma - \gamma$ efficiency, angular correlations
  - New setups → new physics cases
  - Isotope and isomer selectivity powerful – laser ionisation a must!



Thank you for listening

ISOLDE Decay Station

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

IFIN-HH

RESPICE PROSPICE
UNIVERSITY of the WESTERN CAPE

CERN

ISOLDE

KU LEUVEN

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Science & Technology Facilities Council

AARHUS UNIVERSITET

UNIVERSITY OF SURREY

NRF National Research Foundation

iThemba LABS Laboratory for Accelerator Based Sciences

UNIVERSITY of York

EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

UNIVERSITY OF LIVERPOOL

Universität zu Köln

IFIC INSTITUT DE FÍSICA CORPUSCULAR

LUND UNIVERSITY

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

INFN Istituto Nazionale di Fisica Nucleare

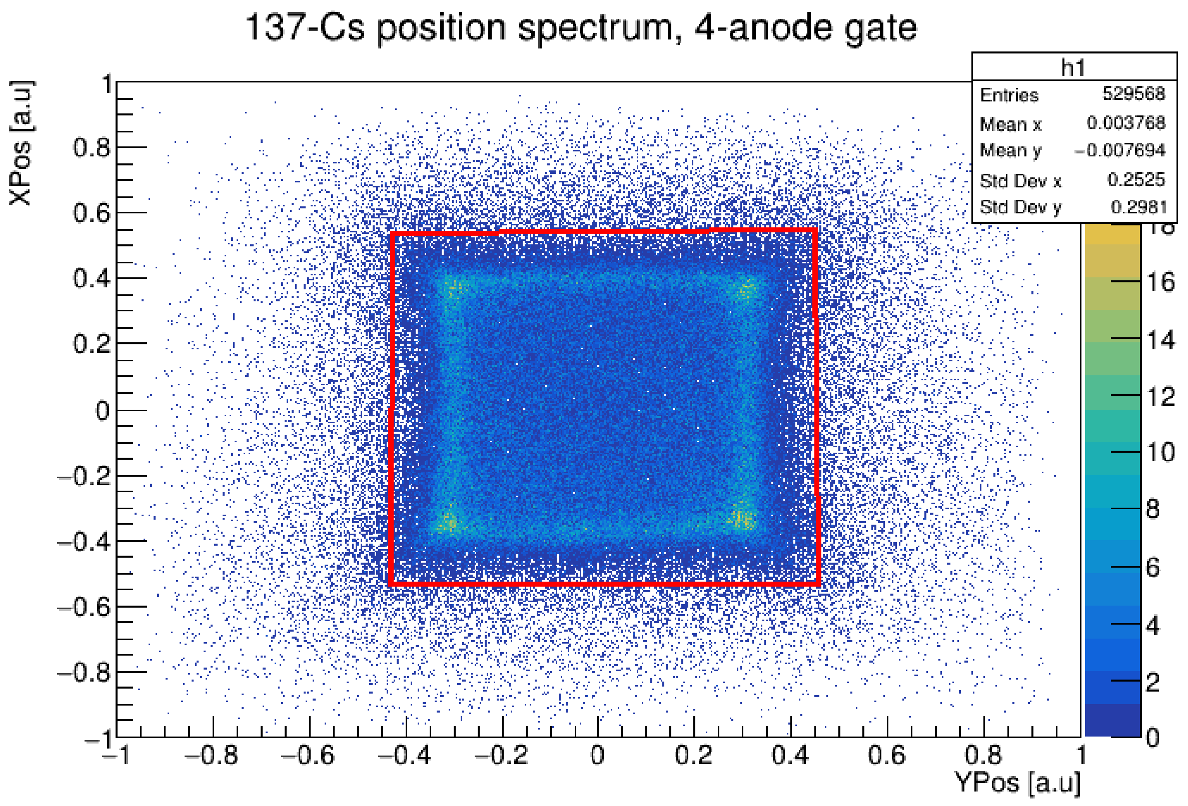
UNIVERSIDAD COMPLUTENSE MADRID

UNIVERSITY OF WARSAW

Additional slides

What is OGS

- Compact (approx. 50x50x6 cm^3) OGS (organic glass scintillator) developed for detection and measurement of low energy neutrons.
- Very bright with excellent PSD and efficiency (~0.8 for 50 keV neutrons)
- Coupled to Hamamatsu H12700 PMT
- Anger-logic readout ➔ Position readout
- Demonstrate neutron – γ discrimination



BLUESHIFT OPTICS