Project COFFEE
(Cracow-Orsay Fission Fragment Exclusive Experiments)

Michal Ciemala, IFJ PAN Kraków
Jonathan Wilson, IJCLab Orsay

IFJ PAN-IJC Lab collaboration Workshop
7 December 2023, Orsay

INSTYTUT FIZYKI JĄDROWEJ
IM. HENRYKA NIEWODNICZAŃSKIEGO
POLSKIEJ AKADEMII NAUK

CCB

IJCLab
Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

ALTO
Accélérateur Linéaire et Tandem à Orsay

Proposed common project: COFFEE (Cracow-Orsay Fission Fragment Exclusive Experiments)

Summary

COFFEE PROJECT GOALS

- Spectroscopic study nuclear fission using complimentary techniques at CCB and ALTO
- CCB: high energy proton induced fission (control of compound nucleus excitation energy)
- ALTO: light charged particle, HI induced fission and spontaneous fission (FROZEN)
- To add value to existing setups/equipment/detectors and best exploit current common expertise

COFFEE PROJECT COMPLIMENTARITIES

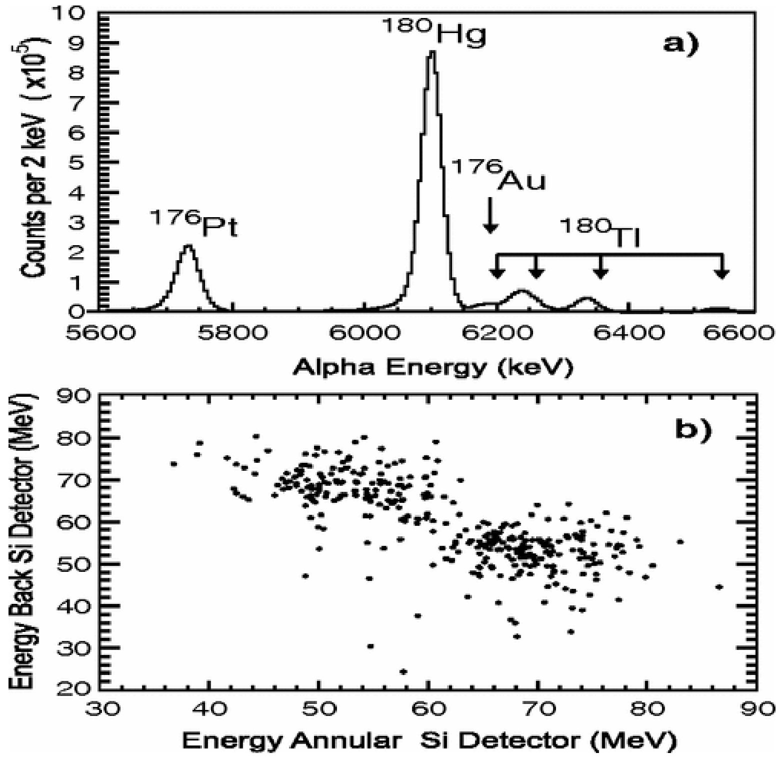
- ❑ Experience with development of hybrid spectroscopy systems At CCB, ALTO (and Warsaw) we developed detection systems which exploit synergies between different types of detectors (Scintillators, Ge, Semiconductor, etc.). Easy integration only recently possible due to fully digital electronics. Scope for technical improvements.

- ❑ Existing collaborative activities: Recent nu-Ball2 project at ALTO. The gamma decay from high-lying states and giant resonances excited in stable isotopes via (p, p') and (n,n') reactions. Evaluation of the nuclear theory virtual services Theo4Exp implemented at IFJ PAN. Development of the PARIS Array towards 4pi. 7

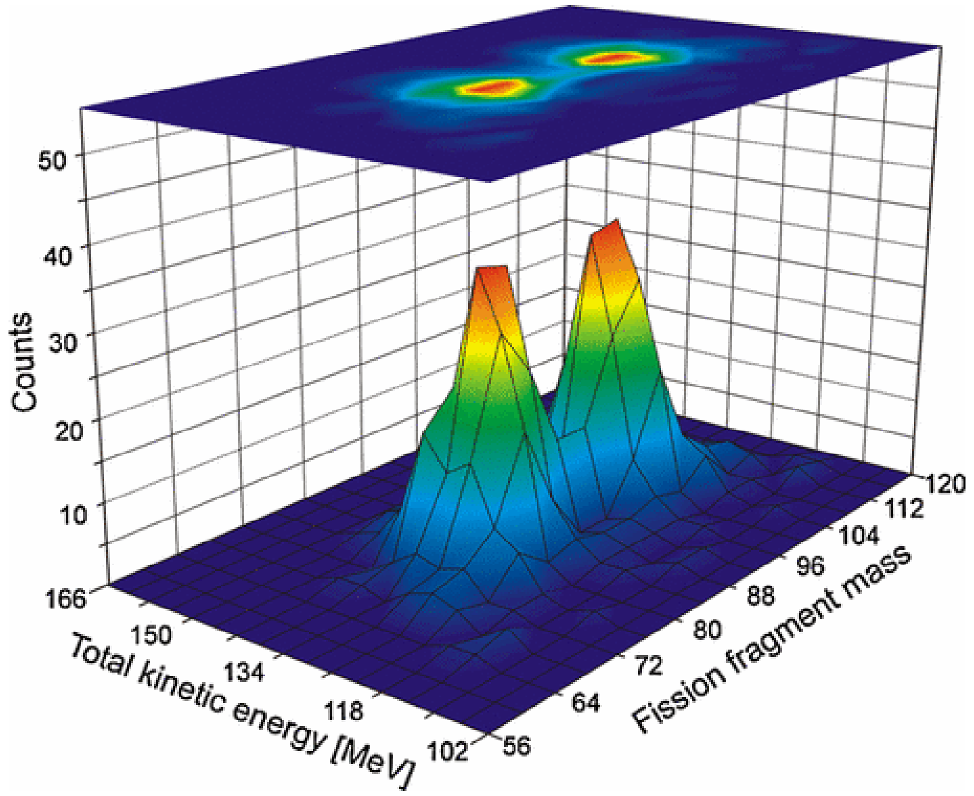
- ❑ Mutualizable equipment: Ge detectors, PARIS 2pi, DSSD (Warsaw), fission fragment detectors, etc.

Context: Renewed Interest in Fission

New fission regions



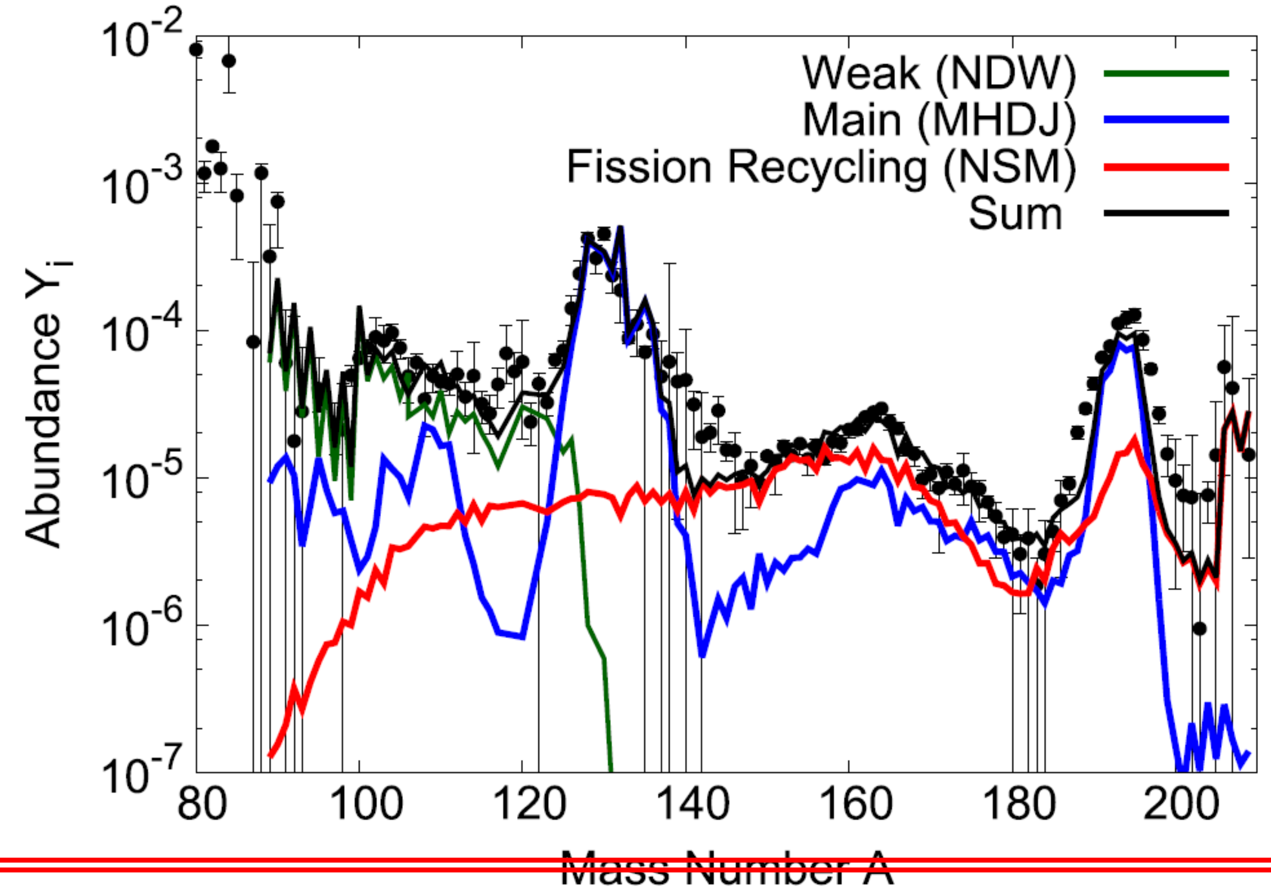
^{180}Hg



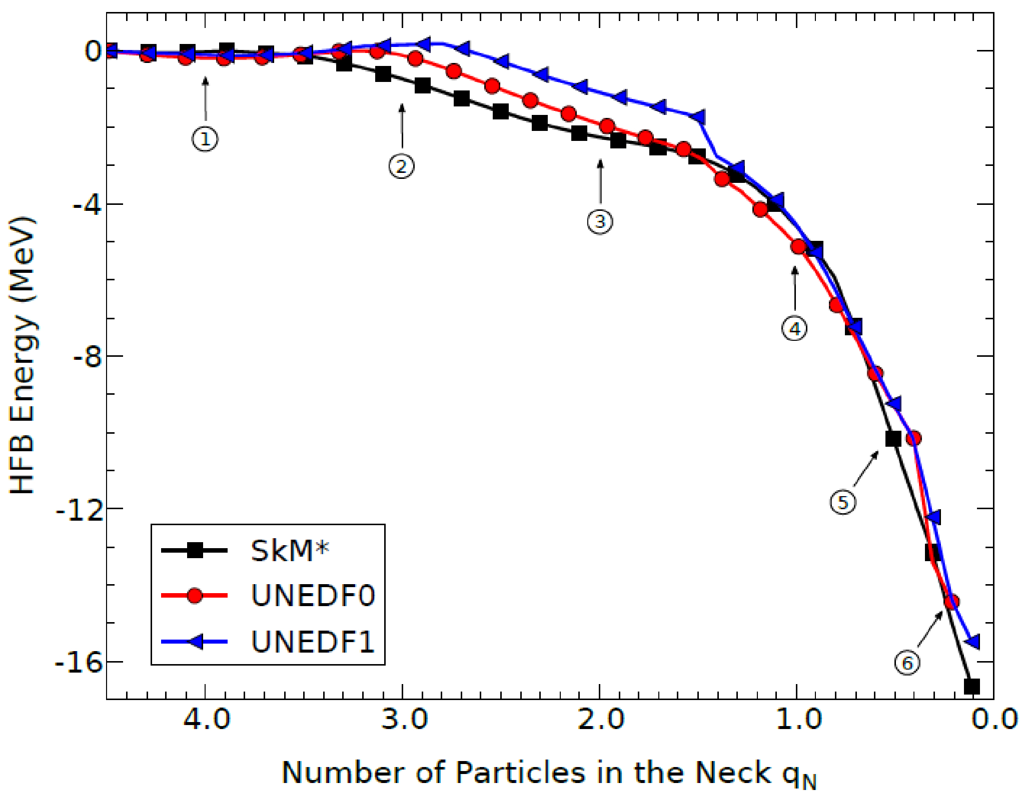
A. N. Andreyev et al. Phys. Rev. Lett. 105, 252502 (2010)

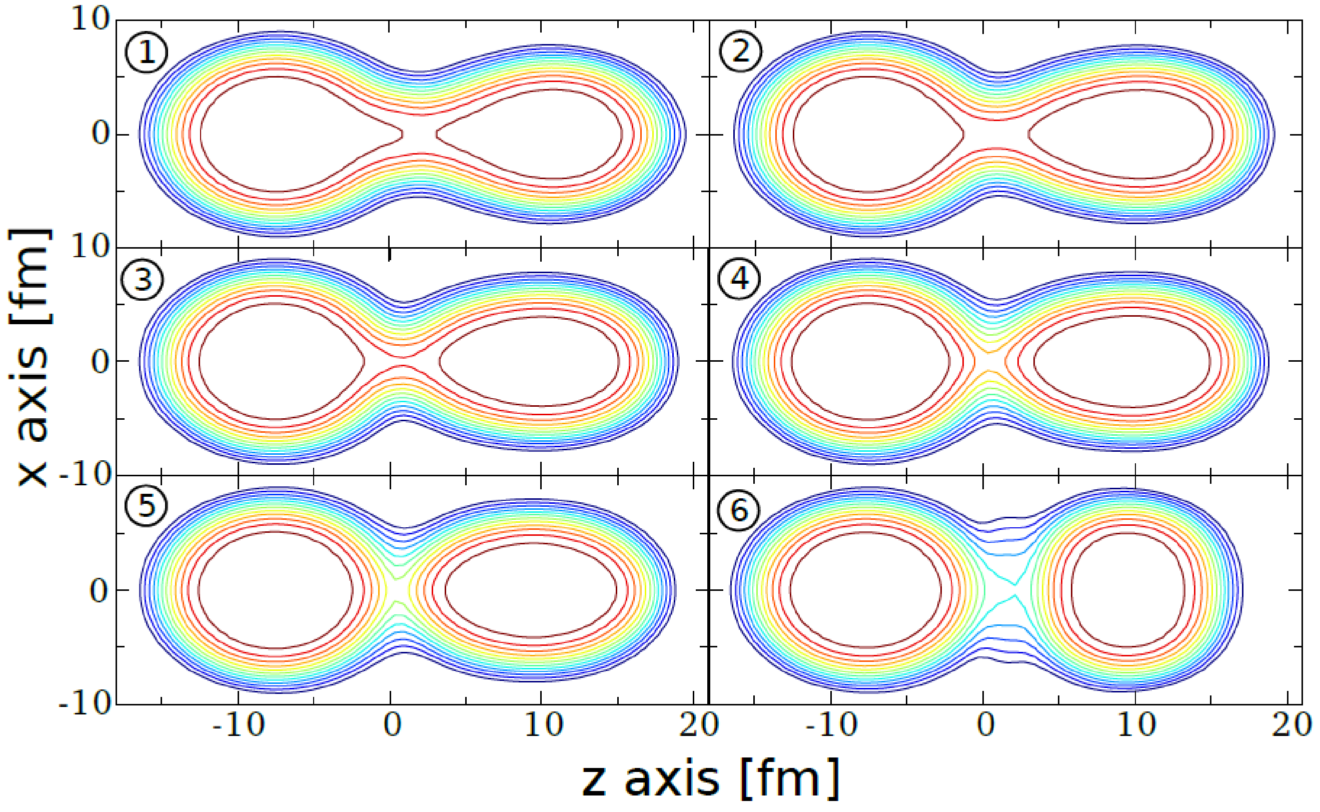
Fission recycling in r-process nucleosynthesis

S. Shibagaki et al. Astro. Journ, 816:79 (201



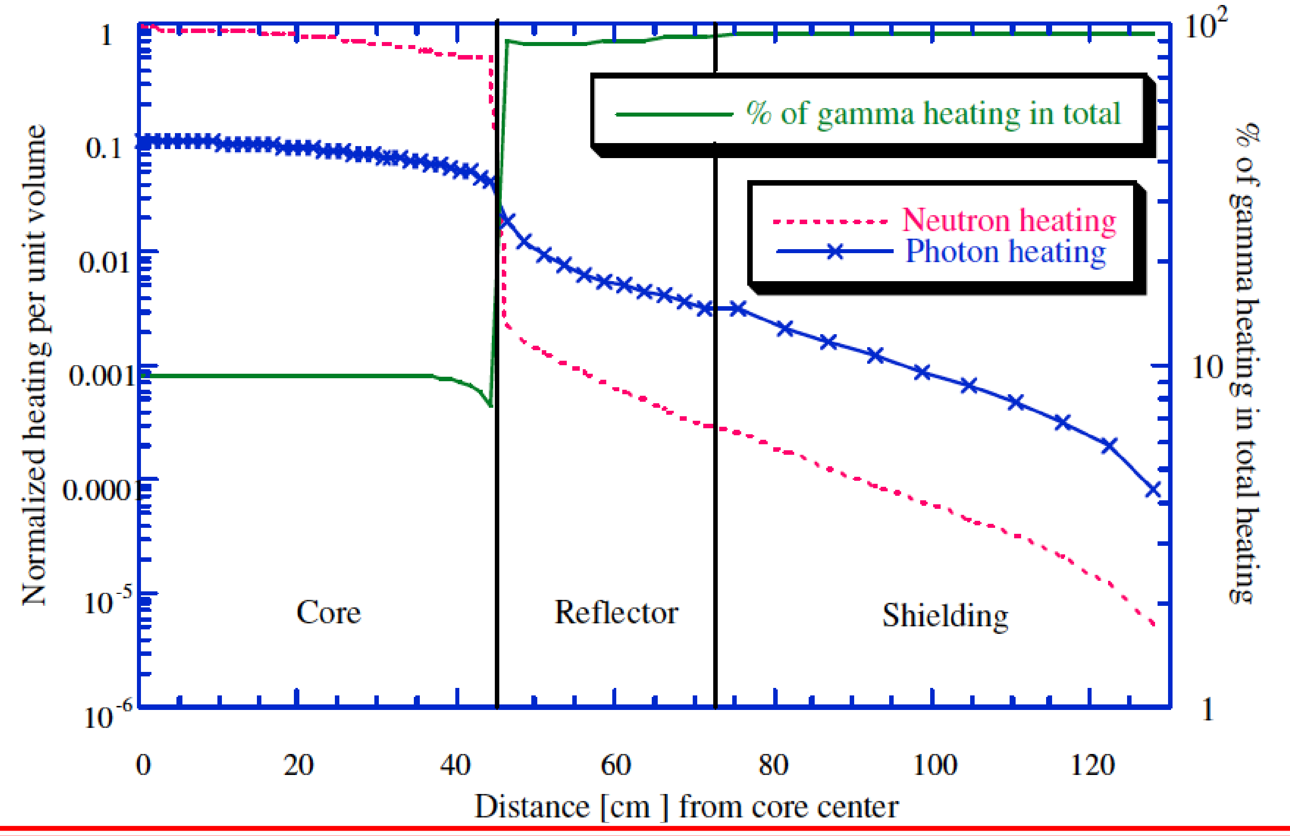
Microscopic theoretical approaches





N Schunck, L M Robledo, Prog. Nu.c Part. Phys. (2016)

Prompt gamma-ray emission in fission



G. Rimpault, Phys. Proc. 31, 3–12. (2012) *J.N. Wilson et al. Nature 590 566 (2021)*

Scientific Motivation/Program

Fission studies at ALTO

The open questions in fission that we would like to address at ALTO are centred around fission reactions induced by light charged particles (p, d, ^{3}He, ^{4}He, ^{7}Li, ^{11}B, ^{12}C) and spontaneous fission.

- Fission isomer spectroscopy in the light actinides
- Evolution of mass and charge yields with compound nuclear excitation up to 1st chance fission and tests of the energy sorting mechanism
- High energy gamma ray emission in fission and potential population of collective resonances (PDR, GDR, etc.) in some of the hot fragments
- Charged particle emission in fission and ternary fission
- Isomeric yield ratios and angular momentum effects

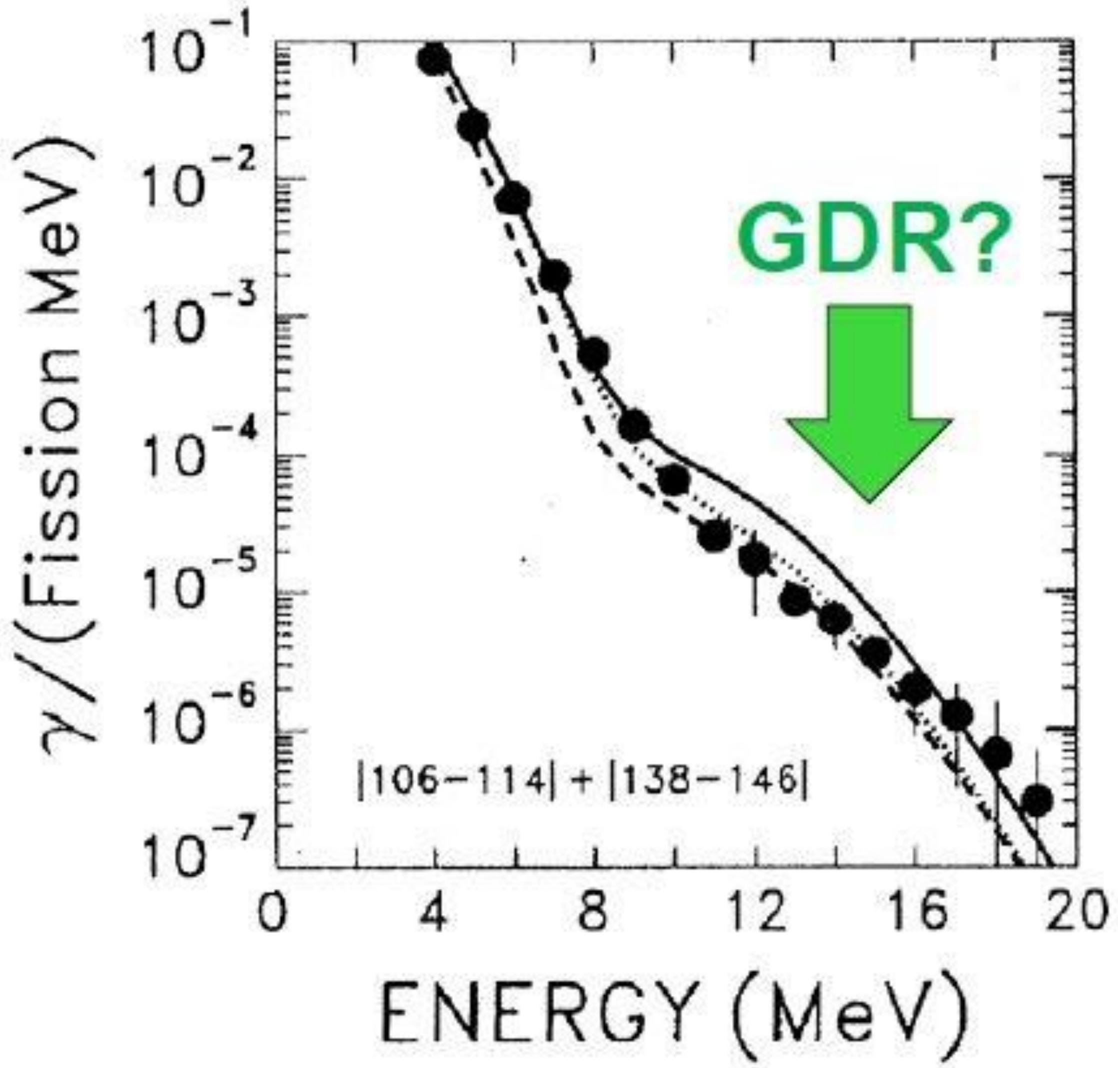
Fission studies at CCB

Use of (p,p') reactions at around 200 MeV to induce fission and detect outgoing protons in the KRATTA detectors. Control the excitation energy of the compound nuclear system up to several 10's of MeV. With the addition of plastic scintillators to detect fission fragments the following questions can be addressed:

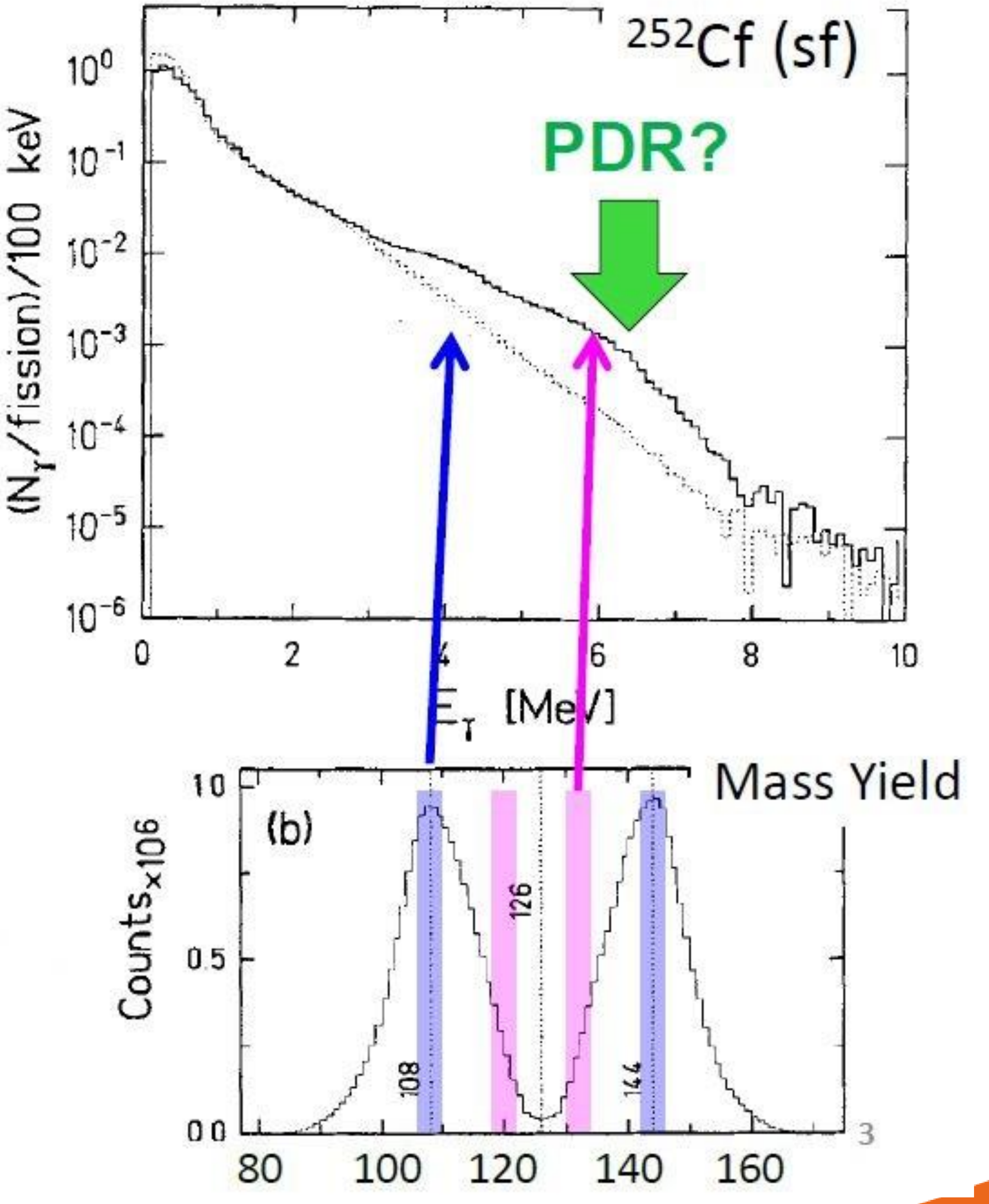
- Study of the transition from asymmetric to symmetric fission modes as a function of excitation energy, mass and charge for various systems
- Study of possible collective excitations (PDR, GDR) in fission fragments and understanding which fragments can be excited in this way in the process
- The study of high energy fission gamma rays as a ultra-fast "clock" to understand fission reaction timescales close to the scission point, and as an alternative method to de-excite fragments than prompt neutron emission
- The high excitation energies at CCB will allow study of the fission of ^{232}Th as well as of *sub-actinide* nuclei such as ^{208}Pb, ^{197}Au, ^{196}Pt, ^{186}W, etc. where fission barrier heights are around 25-30 MeV. Measure Prompt Fission Gamma-ray spectra as a function A and E* for each system

High Energy gamma-rays emitted in fission

H. van der Ploeg *et al.*,
Phys. Rev. C, **52**, 1915 (1995).

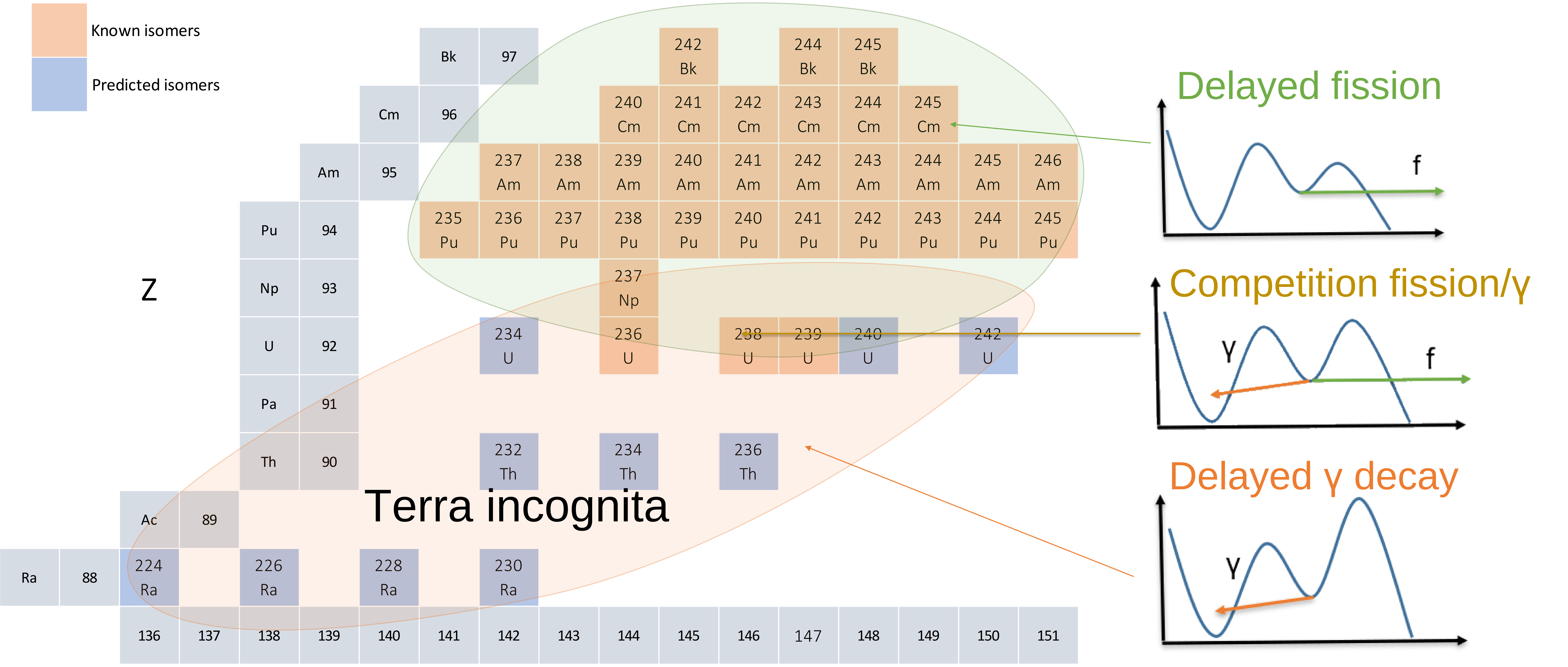


A. Hotzel et al., Z. Phys. A336 (1996) 299.



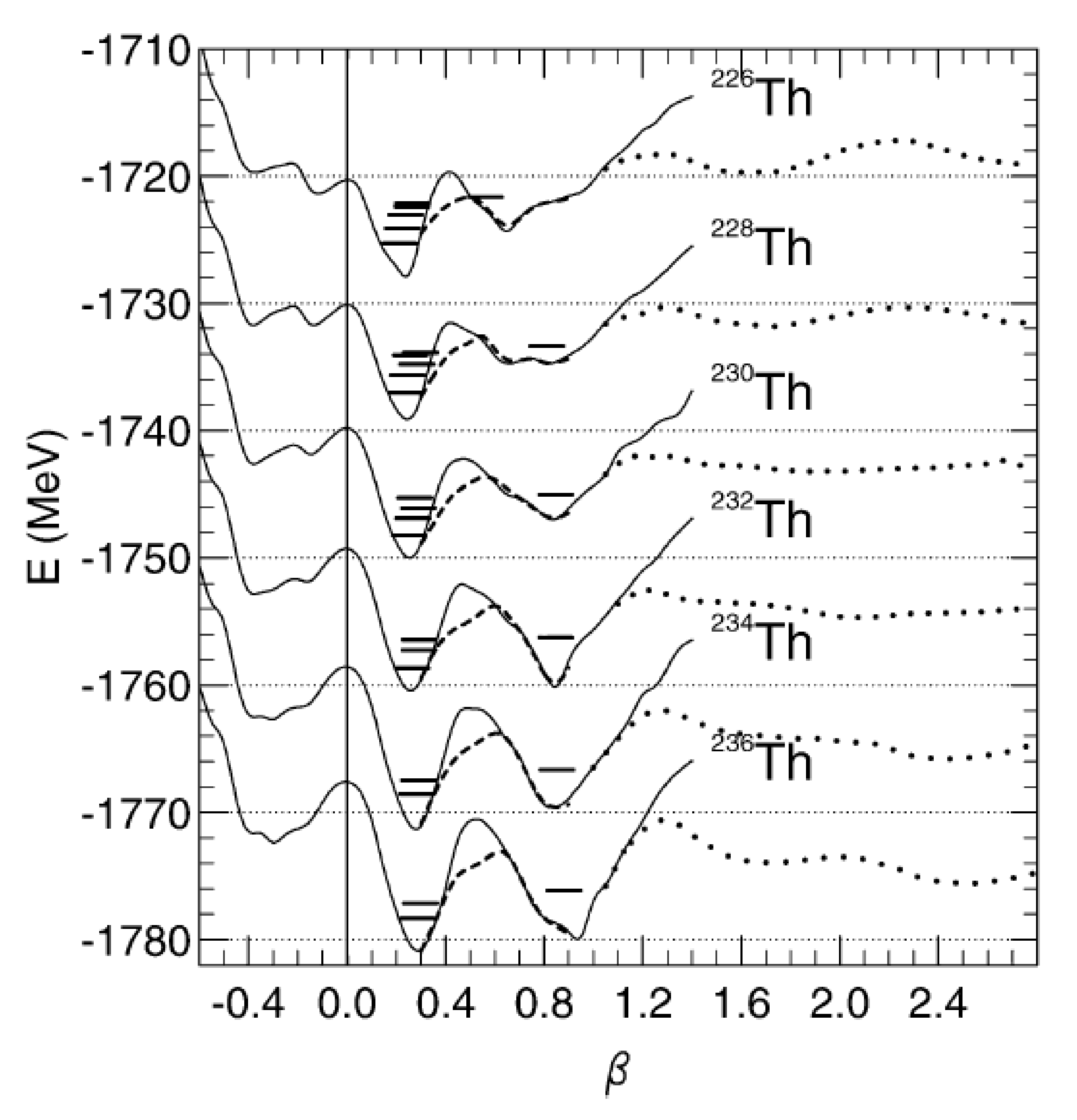
- Evidence for the population of collective resonances in fission fragments
- But very little information on the nature of such resonances and which fragments they originate from

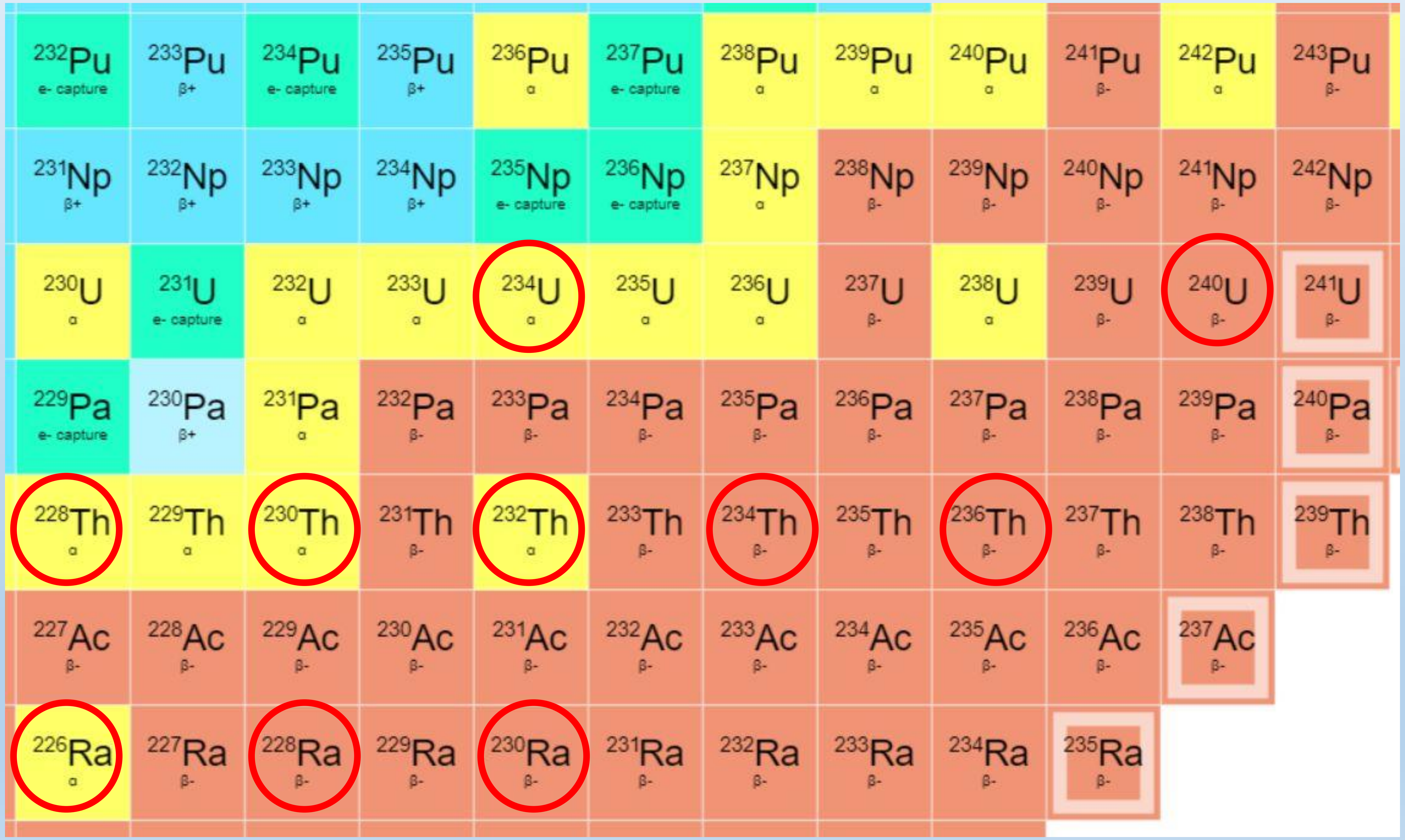
Searching for gamma back decays



Predicted fission shape isomers in the light actinides

S. J.-P. Delaroche, M. Girod, H. Goutte, J. Libert., Nuclear Physics A 771 103–168 (2006)
P. Jachimowicz, M. Kowal and J. Skalski, Phys. Rev. C 85, 034305 (2012)
B. Nerlo-Pomorska, K. Pomorski, J. Bartel, and C. Schmitt, Eur. Phys. J. A 53:67 (2017)





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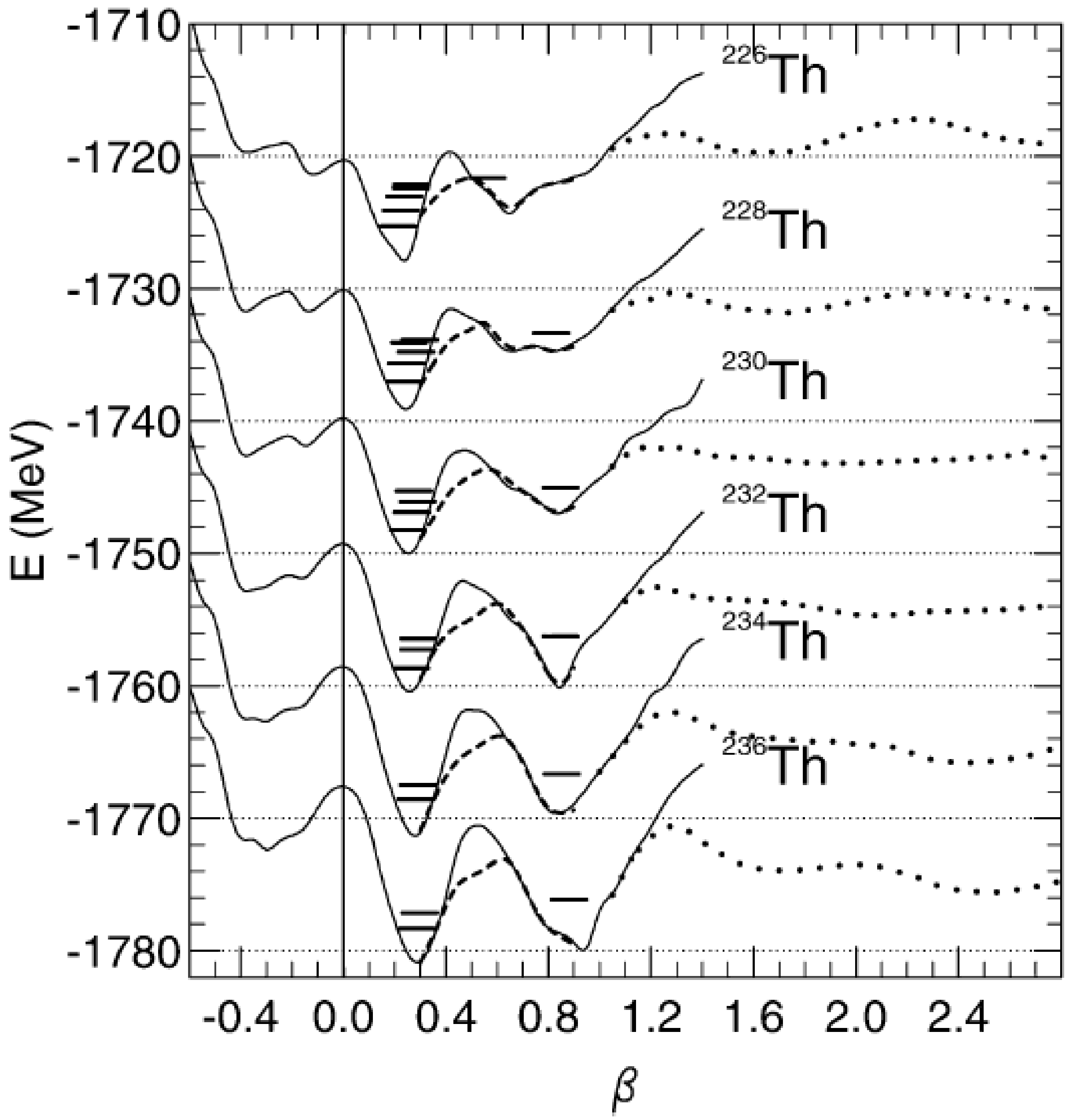
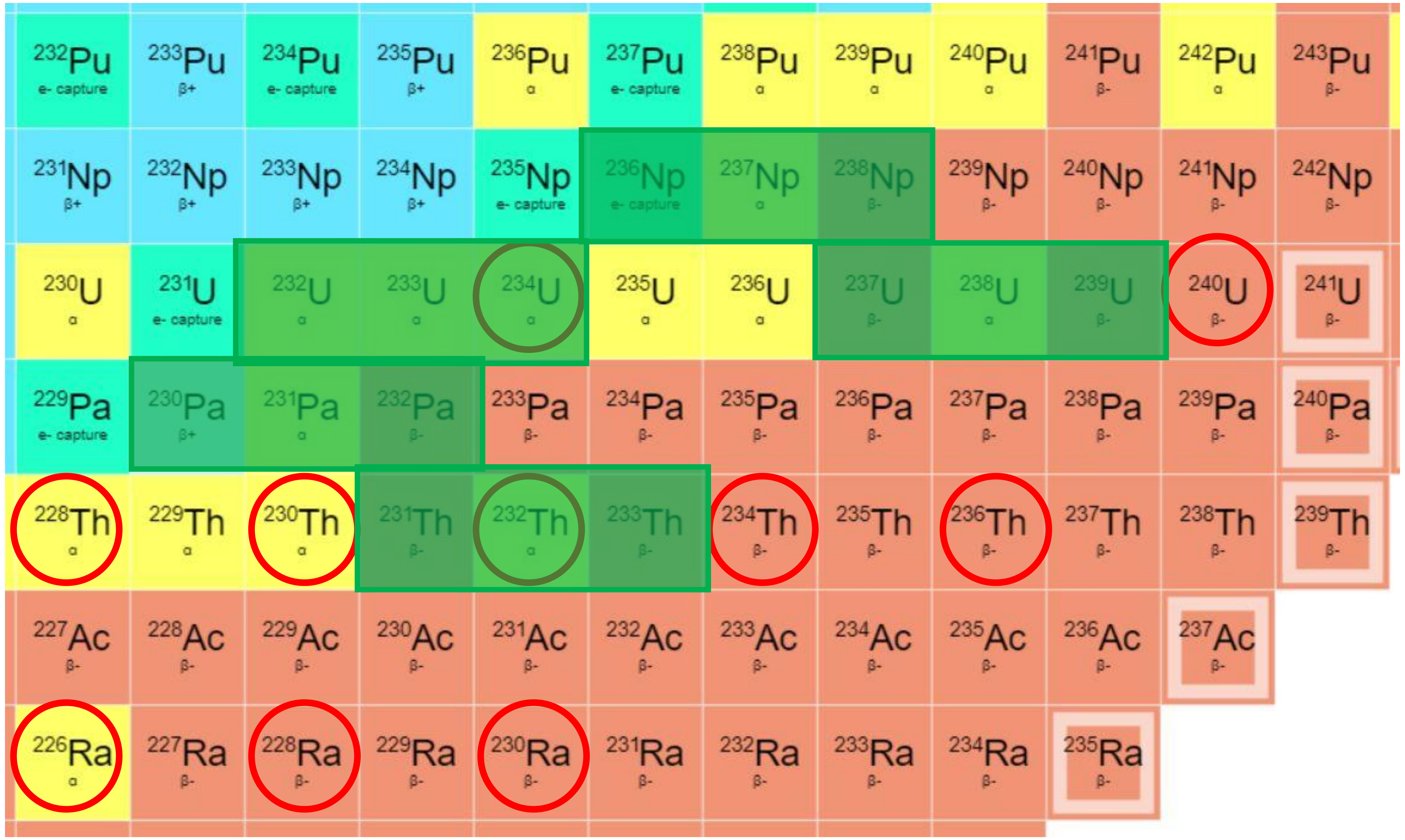
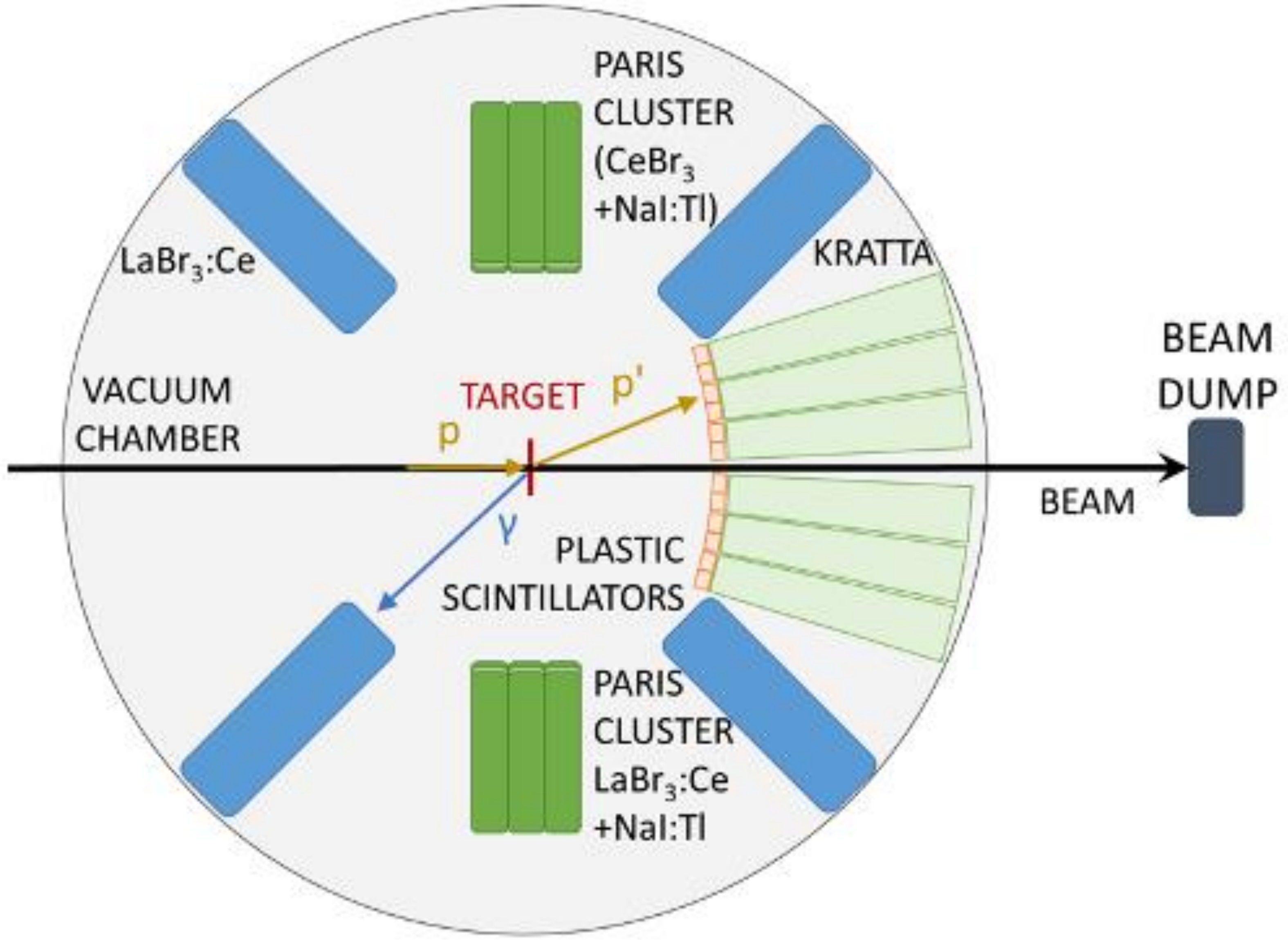
Unexplored area can be accessed at ALTO with ^{232}Th, ^{238}U, ^{231}Pa and ^{233}U targets

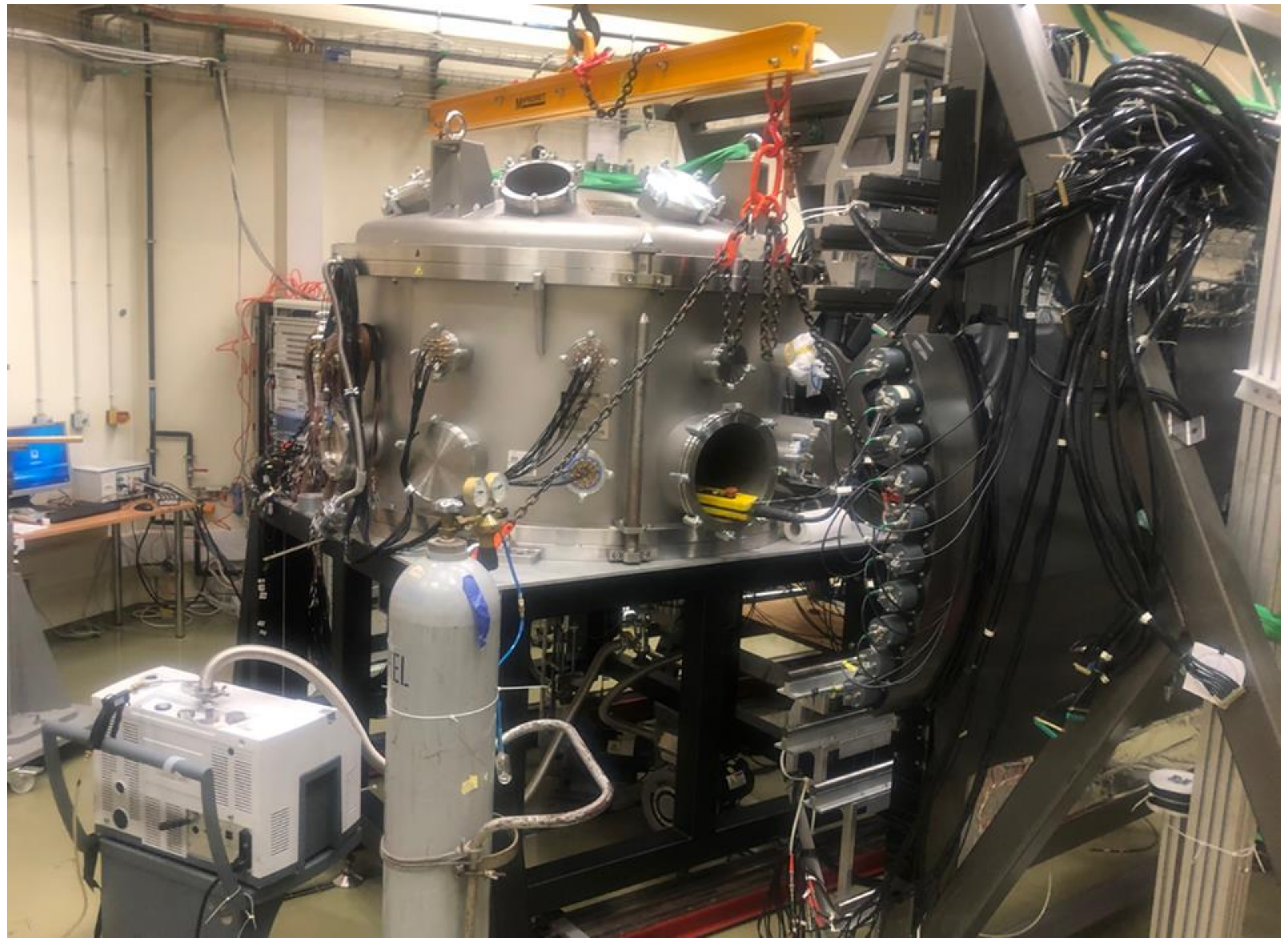


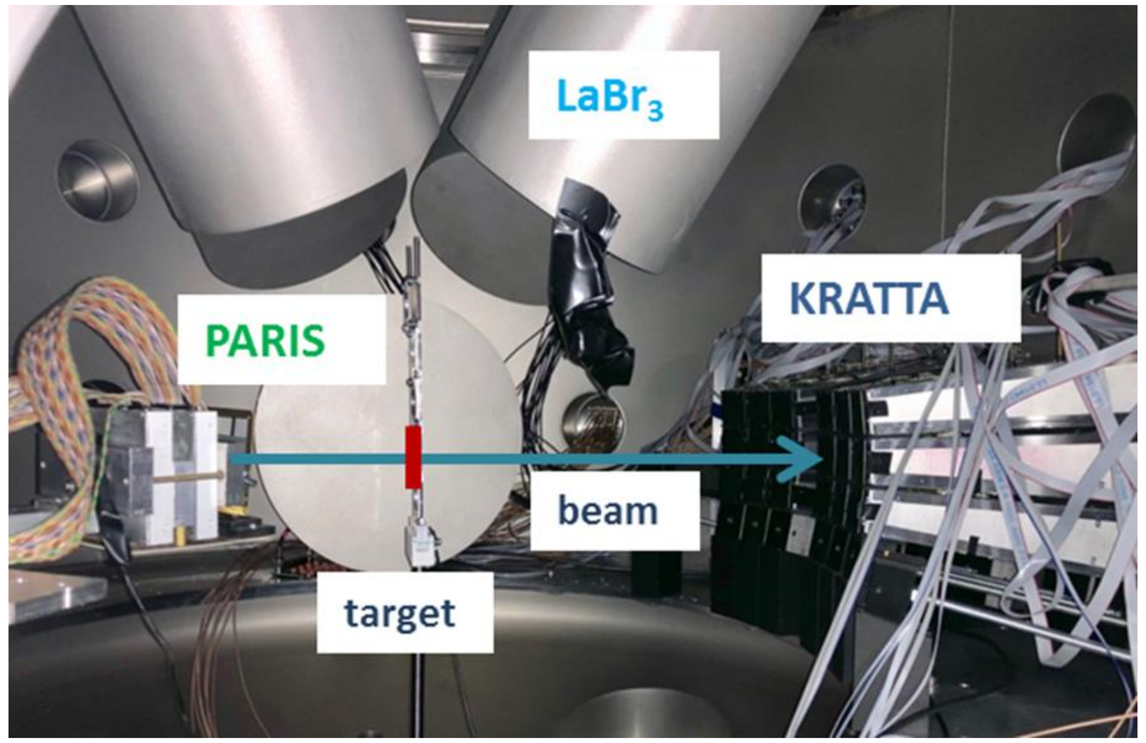


IFJ/CCB setup

(p,p'f) of 180 MeV proton beam on targets of ^{232}Th, ^{208}Pb, ^{197}Au, ^{196}Pt, ^{186}W, etc.







Coincident measurement of scattered protons gamma rays and fission fragments

Experimental setup: standard setup at CCB Krakow: large scattering vacuum chamber
detectors:

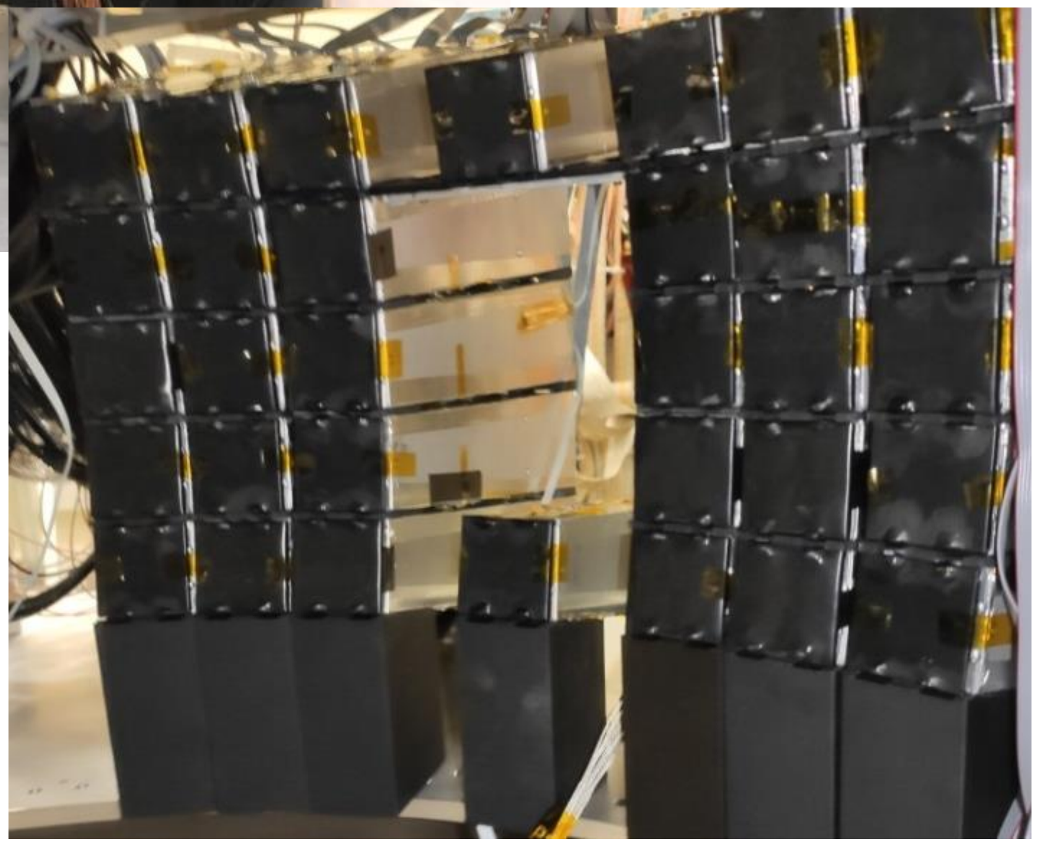
- 32 **KRATTA** triple telescopes
  measurement of the angle and energy of scattered protons
- 4 large volume **$LaBr_3$** detectors (3.5"x8") at top
- 2 **PARIS** clusters + 8 phoswiches (26 phoswiches)
  measurement of the energy of γ rays
- **Modification of Plastic Scintillators for FF detection**
- **Addition of 1 (or more) Ge detectors for diagnostics**

KRATTA detectors

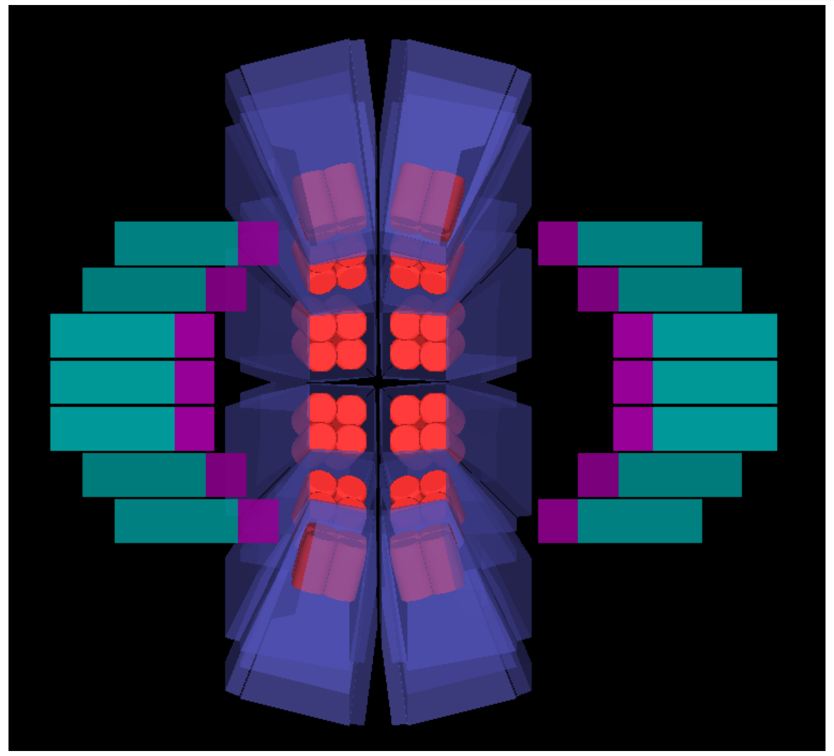
32 triple telescopes (Si + CsI + CsI)

(with segmented plastic scintillator in front for better time and angle resolution) mounted in 6 columns, each with 5 detectors, at the forward angles (from ~7° to ~23°)

(~2 MeV energy resolution and 0.8° angular resolution)



Proposed COFFEE setup at ALTO

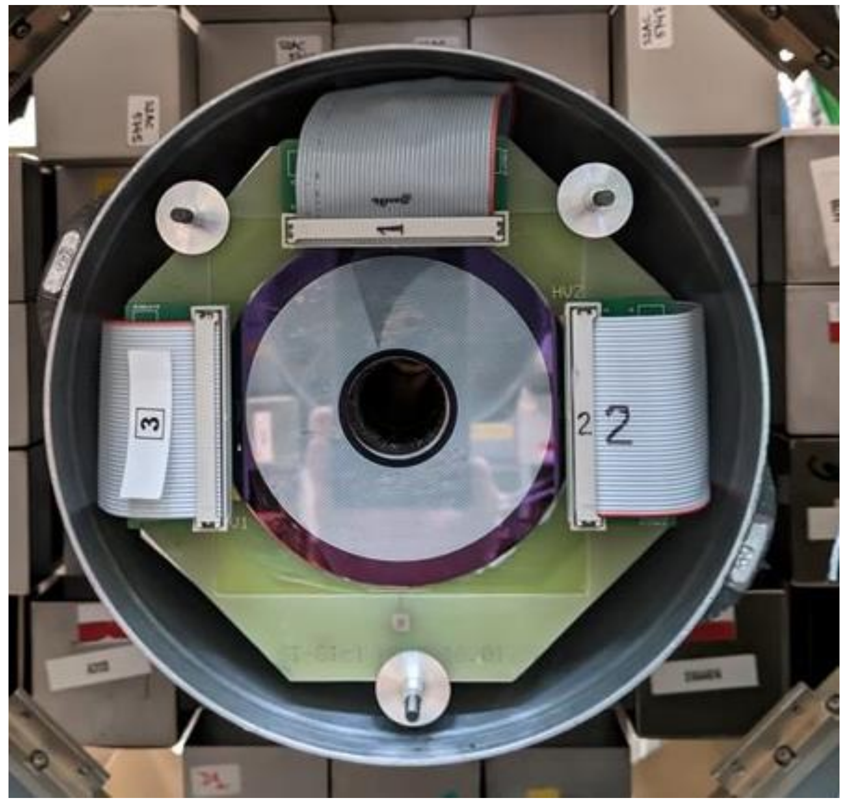


Existing at ALTO

- 20 Loan Pool Co-axial Germaniums
- (2 rings of 10 at 90 degrees)
- Mechanics for 2pi PARIS
- Mechanics for DSSD
- 200 digital DAQ channels

To be added (borrowed)

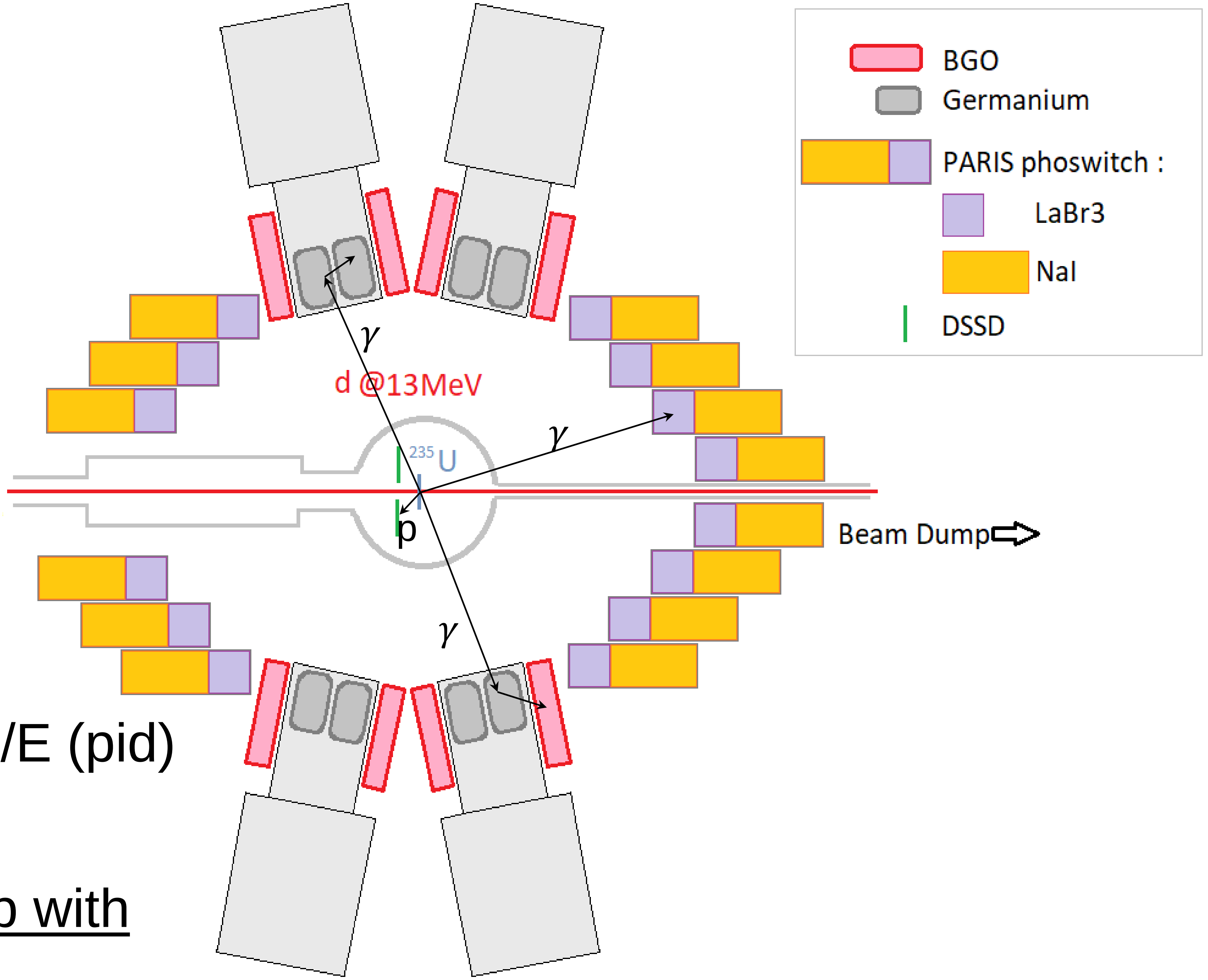
- 2pi PARIS (PARIS collaboration)
- DSSD (Warsaw or Copy)



DSSD

To be bought

DSSD 2nd Silicon disc for ΔE/E (pid)



<u>Unique and competitive setup with high selectivity</u>

Ge's at ALTO/IJC Lab

Current inventory of high efficiency Co-axial Ge's at IJC Lab (Replacement cost 3 M euros)

Loan Pool

10 working

5 poor signals and currently unusable

5 no signals

Gammapool

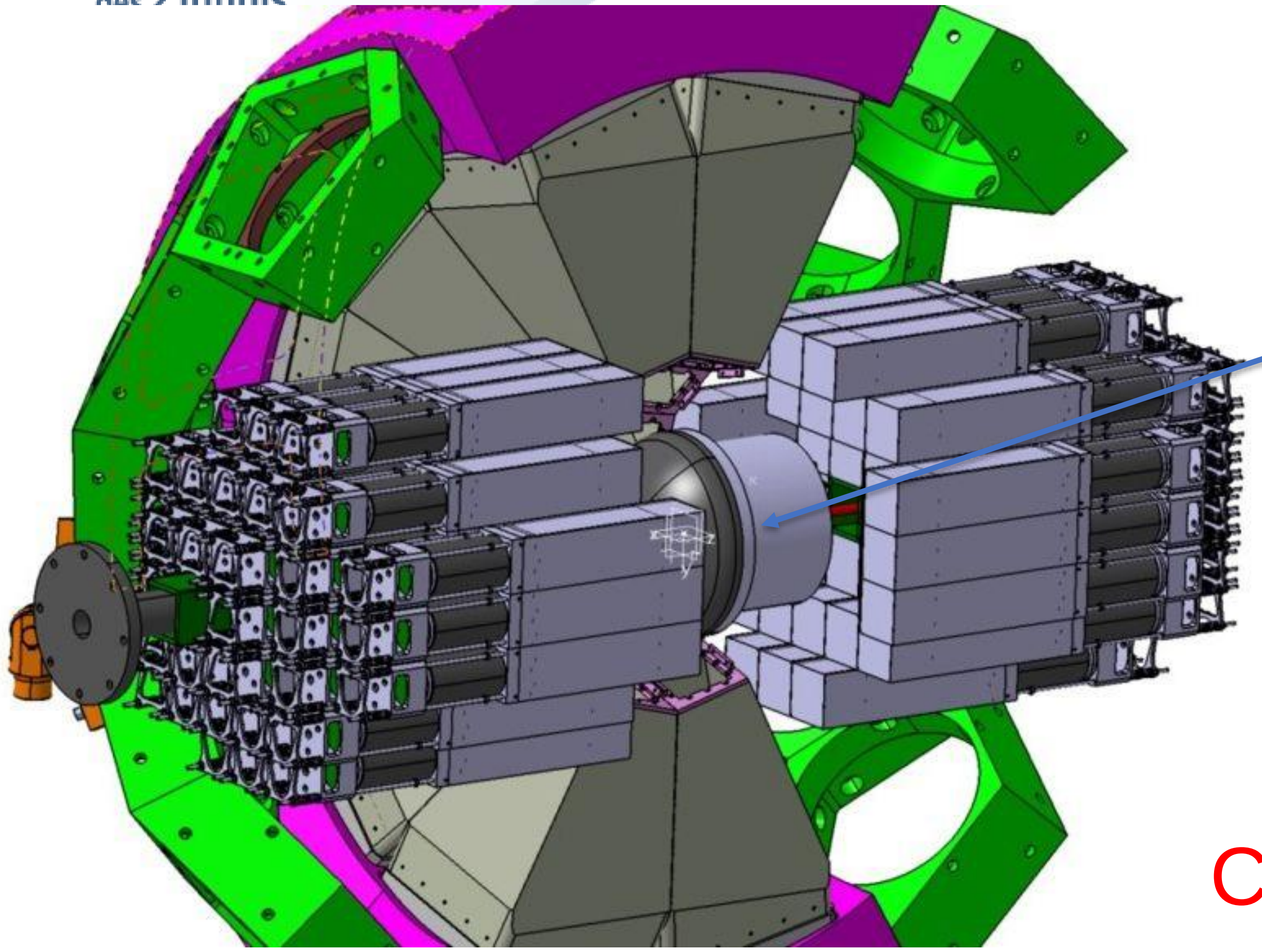
3 detectors requiring factory repair

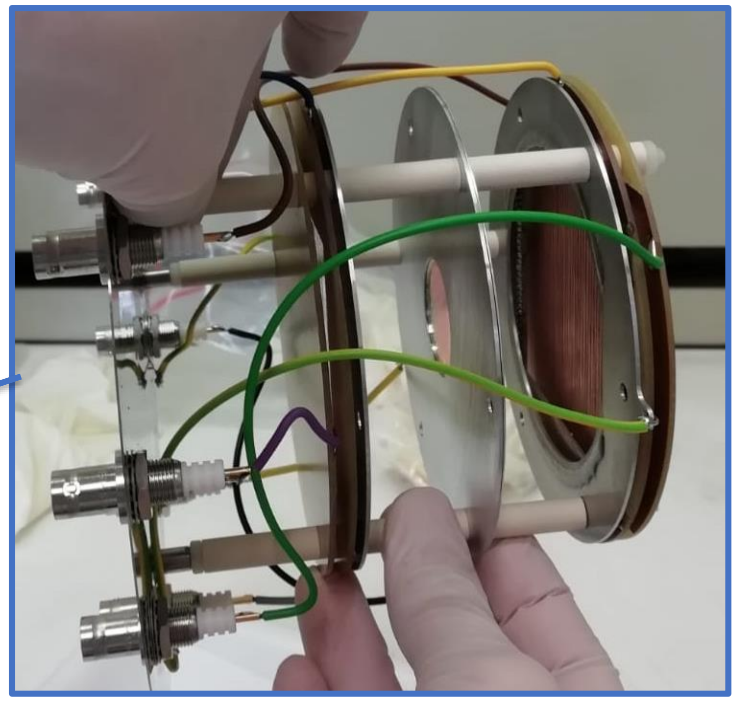
20 working Ge's required for the COFFEE project setup

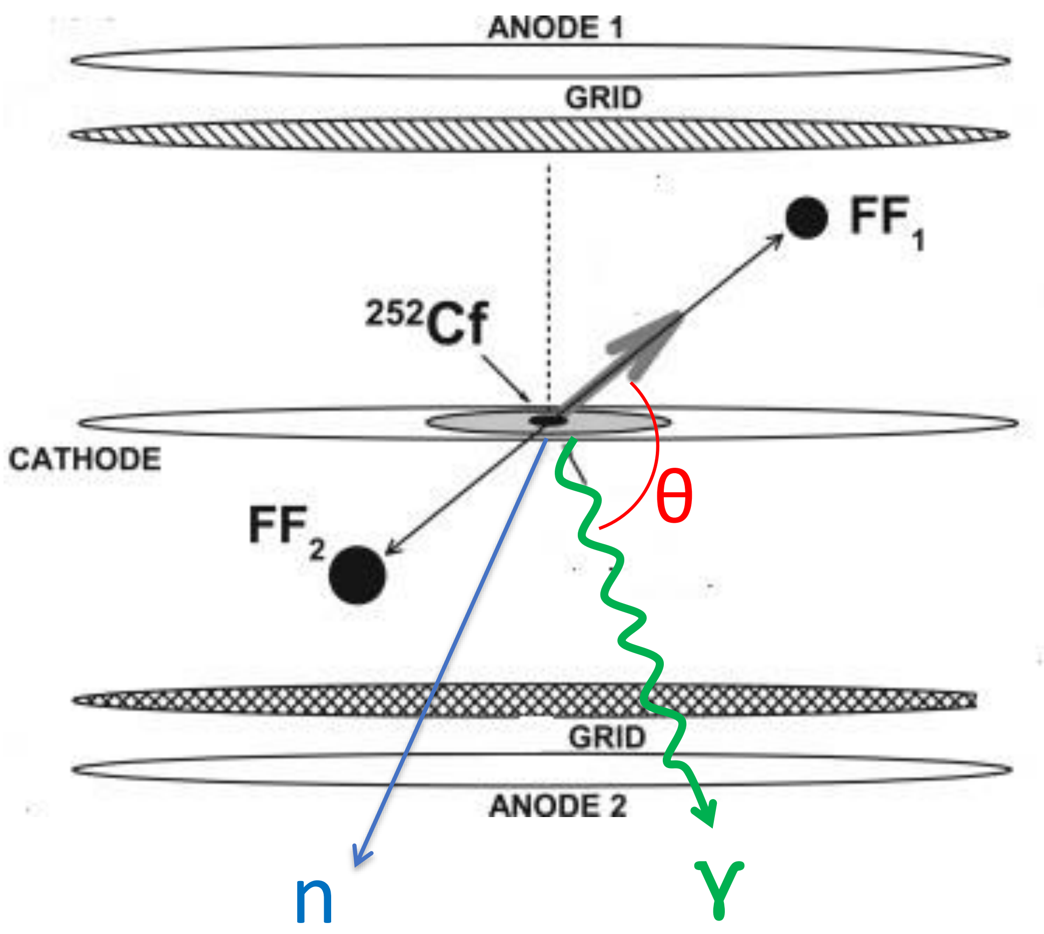
→ Refurbishment needed

Refurbishment cost estimated between 40 and 100 k euros

Long term loan of one (or more) detectors to IFJ







COFFEE array + 4π ^{252}Cf source + Segmented Ionisation chamber

Simultaneous event-by-event measurement of:

- Prompt/delayed fission gamma rays and neutron(s) (via TOF)
- Fragment Kinetic Energies, Fragment A/Z and partner A/Z
- Fission axis direction and all directional correlations
- Prompt/Delayed gamma sum energy and multiplicity

Measurment of correlations between multiple fission observables are key to obtaining interesting new results (in our opinion)

→ Analysis + Development is ongoing
Thesis: Malia Mehdi (IJC Lab)

Budget

Total (4 years)

<u>Option 1 (optimal)</u>

IFJ PAN: 255   kPLN (60 kEuro)

- Equipment cost: 135 kPLN
- New engineer position (1/4 time): 120 kPLN

IJCLAB: (95 kEuro)

- Refurbishment Ge Loan Pool detectors
- Segmented silicon CD detector
- Consumables

<u>Option 2 (minimum)</u>

IFJ PAN: 115 kPLN (25 kEuro)

- Equipment cost: 115 kPLN

IJCLab:

Request for 2024

IFJ PAN

Personnel: 1/4 time employment for DAQ/electronic technician/specialist for maintain changes in the DAQ

Equipment:

a) special flanges (2 pieces) for the HPGe mounting in reaction chamber – 3300 EUR

b) addition electronic equipment (HV for one HPGe) – 3300 EUR

c) firmware upgrade for V1730/B1724 digitized to be used for HPGe readout – 1000 EUR

small liquid nitrogen filling system – 4400 EUR

Total 18600

IJC Lab

40 k euros – Ge refurbishment

The IFJ-PAN and IJC Lab teams

	Function	Role	% participation
Michał Ciemała	Researcher	Coordination, fission detectors, KRATTA, DAQ	15%
Adam Maj	Researcher	Co-coordination, Giant and Pygmy resonances	10%
Maria Kmiecik	Researcher	scintillator detectors	10%
Piotr Bednarczyk	Researcher	Germanium detectors	10%
Bogdan Sowicki	Technician	mechanics	20%
Mirosław Ziębliński	Technician	electronics	20%

	Function	Role	% participation
Jonathan Wilson	DR	Coordination	15%
Iolanda Matea	MdC	Mechanics, PARIS	15%
Mathieu Lebois	MdC	Integration FROZEN	15%
Giorgia Pasqualato	Pdoc	Ge detectors	5%
Corentin Hiver	PhD	Electronics/DAQ	5%
Malia Mehdi	PhD	IC FROZEN	20%

IJC Lab/ALTO Timeline/work plan

(2024) Refurbishment of the 20 loan pool detectors
The COFFEE project requires simultaneous used of all 20 of the loan pool detectors currently at ALTO. The full refurbishment and repair of the loan pool is a necessary first step for the COFFEE project at ALTO. The replacement cost of this equipment is around 2.6 M euros. However, we estimate that the entire parc could be brought into good working order for between 40 and 80 k euros [diagnostics are required by a dedicated technician to get a more precise figure].
Transfer and setup of one loan pool Ge on long-term loan to the CCB facility for use in the KRATTA/HECTOR/PARIS setup as a diagnostic tool to help characterise experimental conditions.

(2025-2026)
Development of Silicon E/DE system either by installation of a second silicon disk for inclusion in the HIL Warsaw setup if such an agreement can be negotiated, or purchase of two disks plus construction of a copy of the HIL chamber. This will allow a significant increase in selectivity of the hybrid system at ALTO allowing light charged particle identification and the of stopping protons and deuterons with energies up to 15 MeV allowing high resolution energy measurements.
Source and in-beam test and commissioning experiments at ALTO to quantify performance and make improvements.
Installation of the FROZEN Ionization Chamber at ALTO (Thesis of Malia Mehdi).

(2027) Dedicated experimental campaign at ALTO with 2π PARIS + Loanpool Ge's + enhanced DSSD hybrid calorimeter system + FROZEN IC.

IFJ PAN/CCB Timeline/work plan

(2024-2025)
Preparation of the updated experimental setup at CCB which includes manufacture of the dedicated flanches for the vacuum chamber to mount Ge detector(s). Installation of the liquid nitrogen filling system which will be necessary to use of HPGe detector in the experimental hall of the CCB. Acquisition of high-resolution gamma spectra using Ge detectors will require the purchase of digital electronics with signal processing capabilities (equipped with a dedicated firmware) and its integration with the existing DAQ. Choose of the best suited fission fragment detector and integration of it into data acquisition with DAQ upgrade. Especially in this stage additional technician/expert of the DAQ may be needed to properly configure newly created experimental setup. Test experiments of this new setup should be performed using proton induced fission of 232Th.

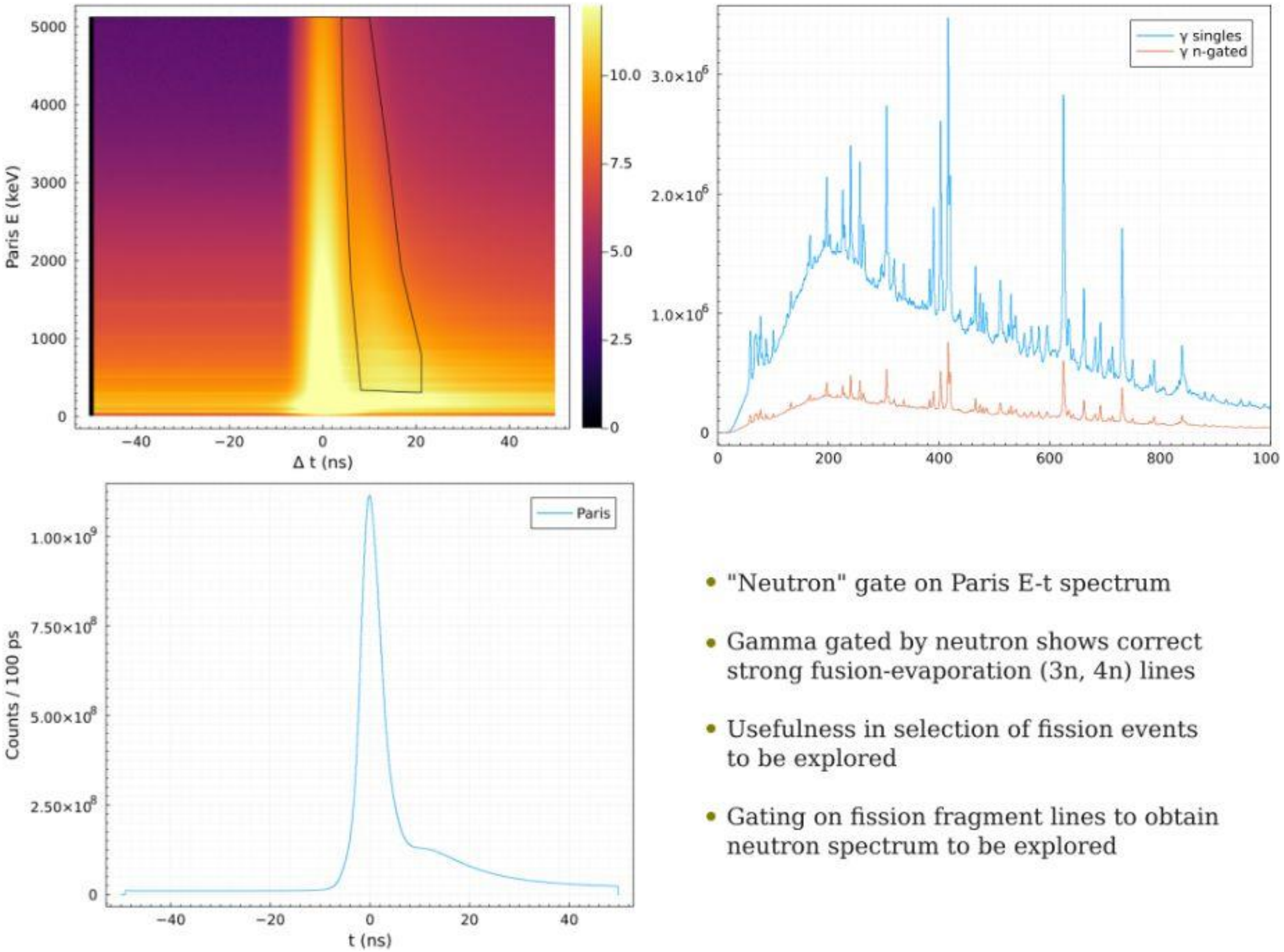
(2026-2027)
Dedicated experiments aiming at the proton induced fission studies, with use of 232Th with next step with use of 208Pb, 197Au, 196Pt, 186W nuclei.

Thank you

Merci

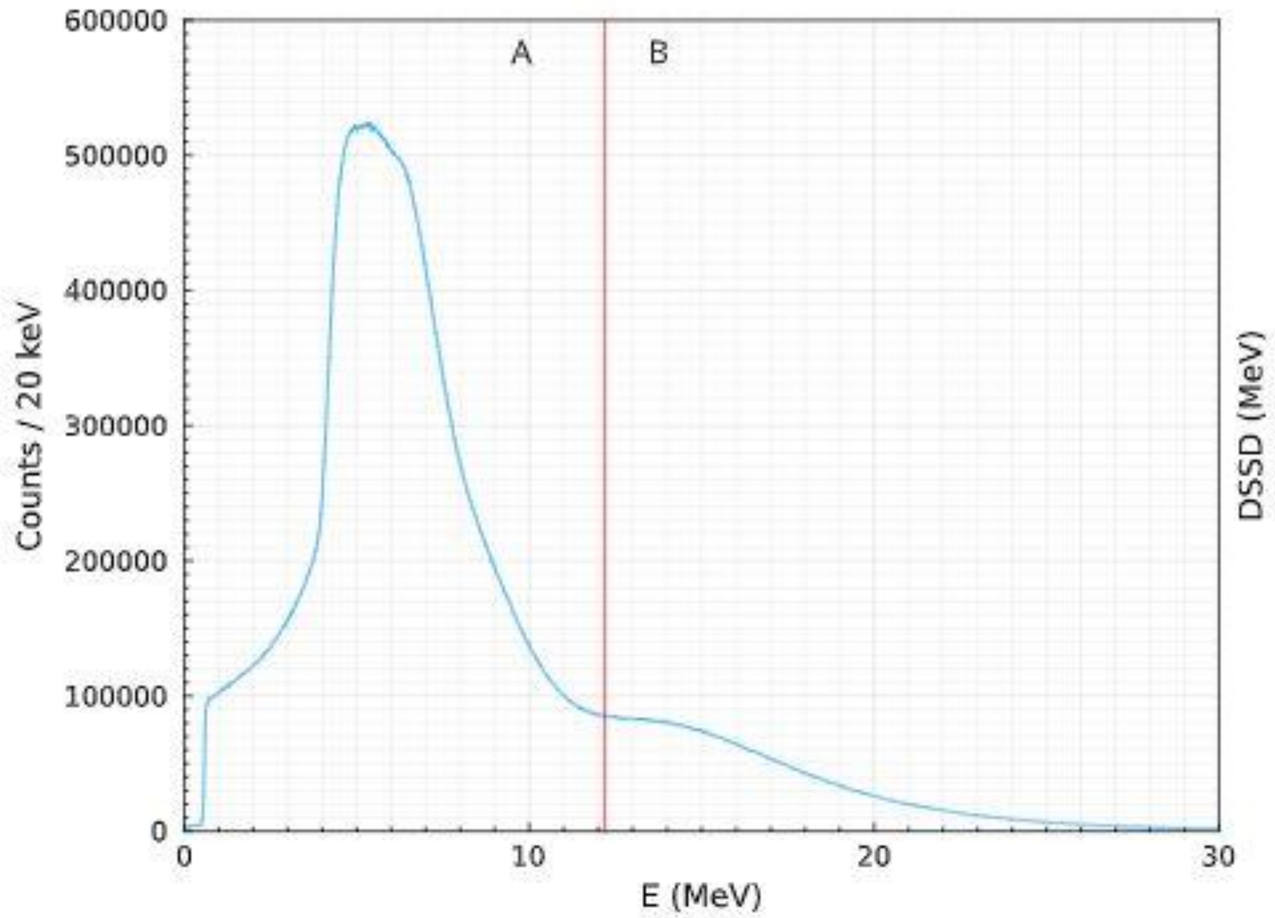
Dziękuję

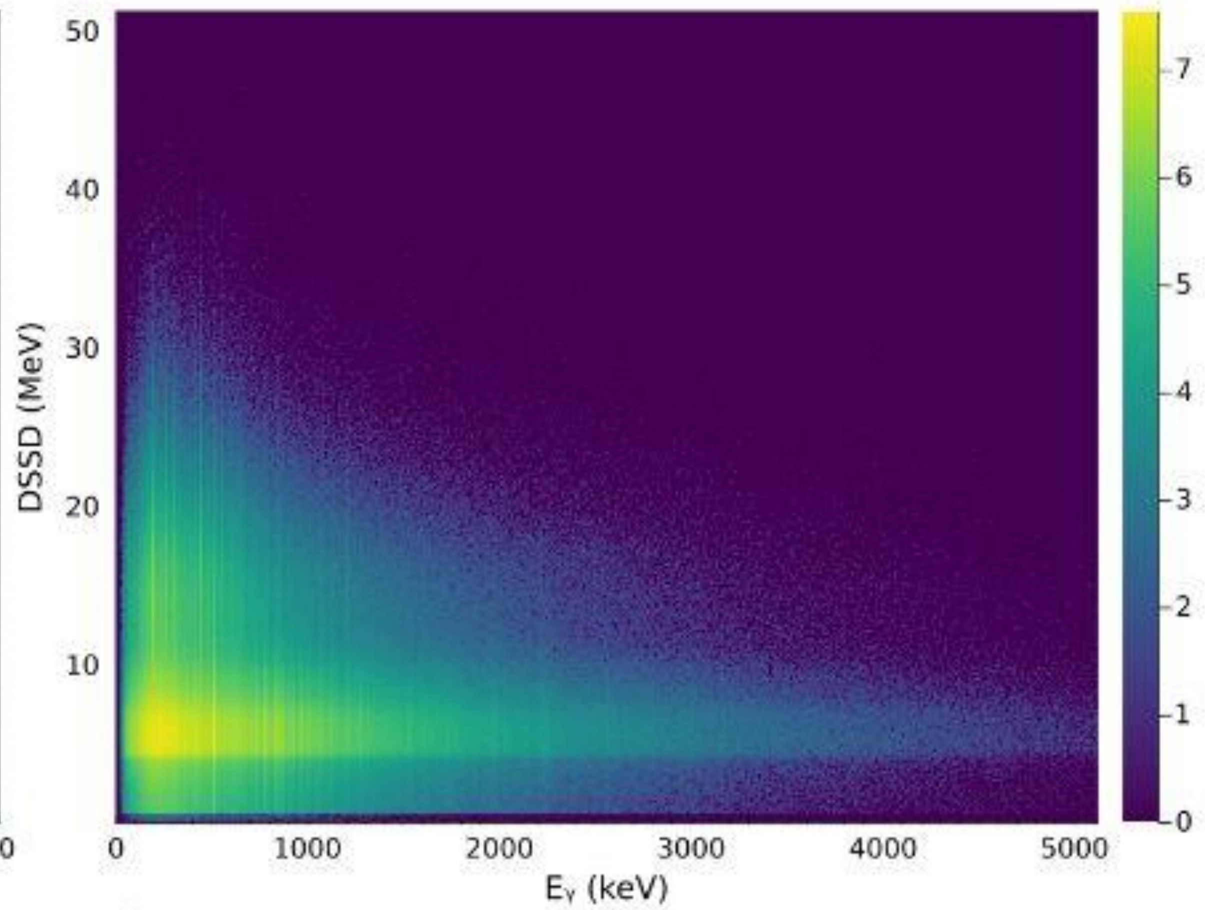
PARIS – neutron gate



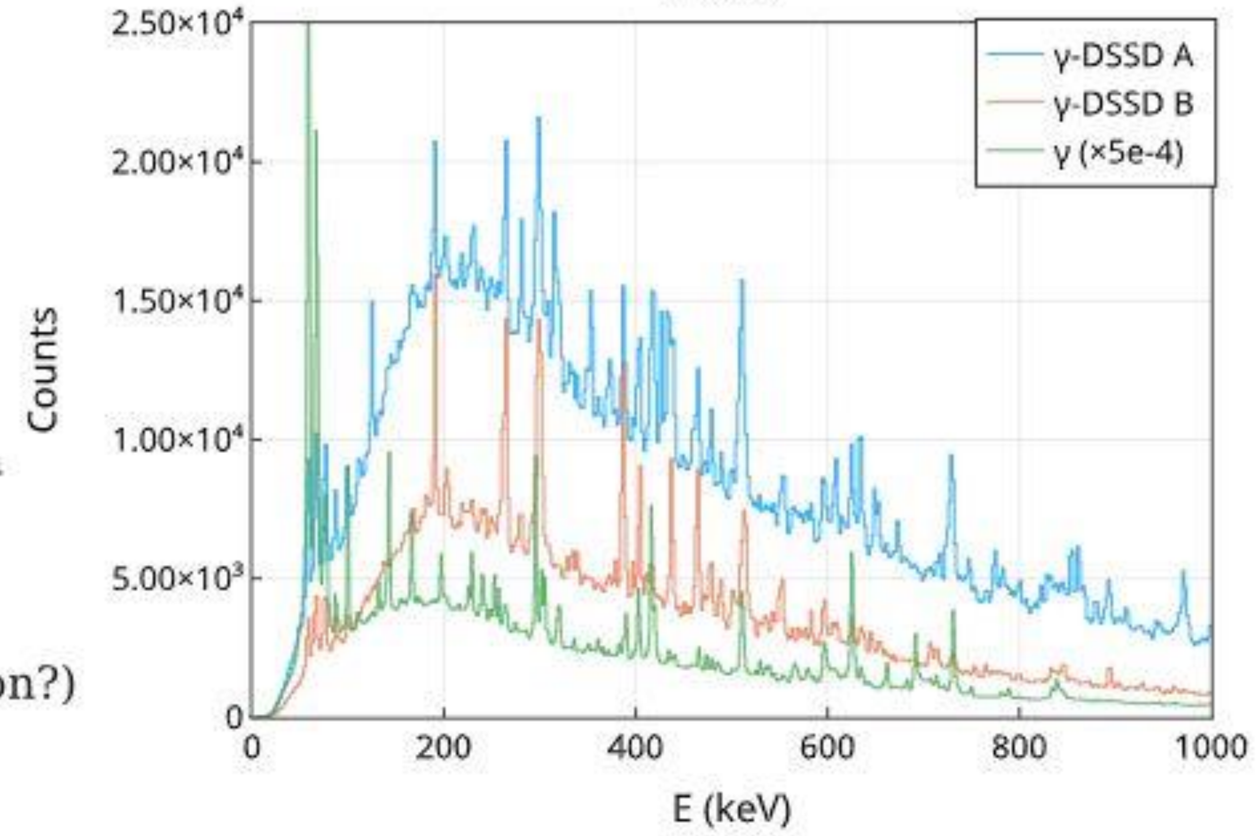
- "Neutron" gate on Paris E-t spectrum
- Gamma gated by neutron shows correct strong fusion-evaporation (3n, 4n) lines
- Usefulness in selection of fission events to be explored
- Gating on fission fragment lines to obtain neutron spectrum to be explored

DSSD gates

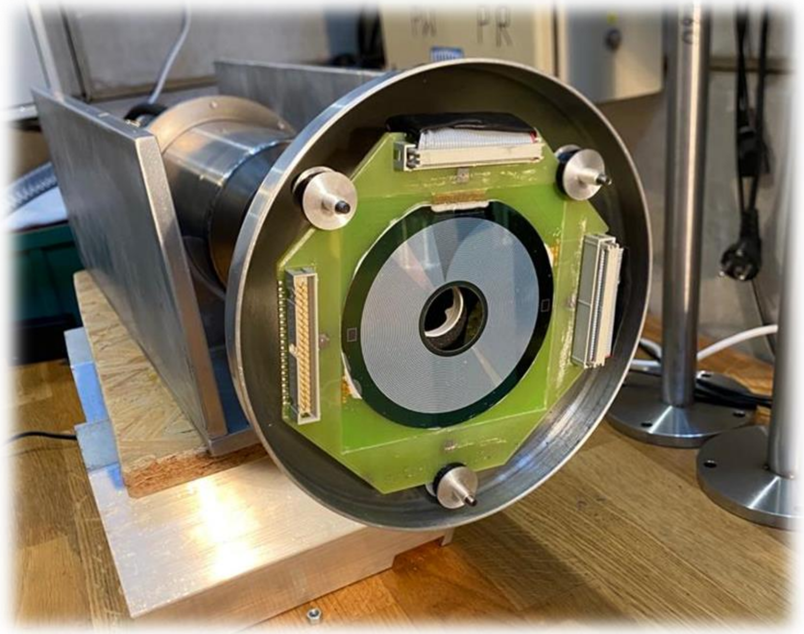




- Two groups of events in DSSD spectrum
- Gamma spectrum gated by range A or B show different lines
- Gamma singles show yet different pattern
- Group B → incomplete fusion (α2n, α4n) ^{186,188}Pt
- Group A → to be identified (p/d evaporation?)



Warsaw DSSD



Mechanical and electronics integration at ALTO: work completed 2022-2023 (420 beamline)