COFFEE
Cracow-Orsay Fission Fragment Exclusive Experiments)

24/10/2024, IFJ PAN – IJCLAB WORKSHOP, KRAKOW

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CCB

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

ALTO Accélérateur Linéaire et Tandem à Orsay

COFFEE (Cracow-Orsay Fission Fragment Exclusive Experiments)

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 (Cracow-Orsay Fission Fragment Exclusive Experiments)

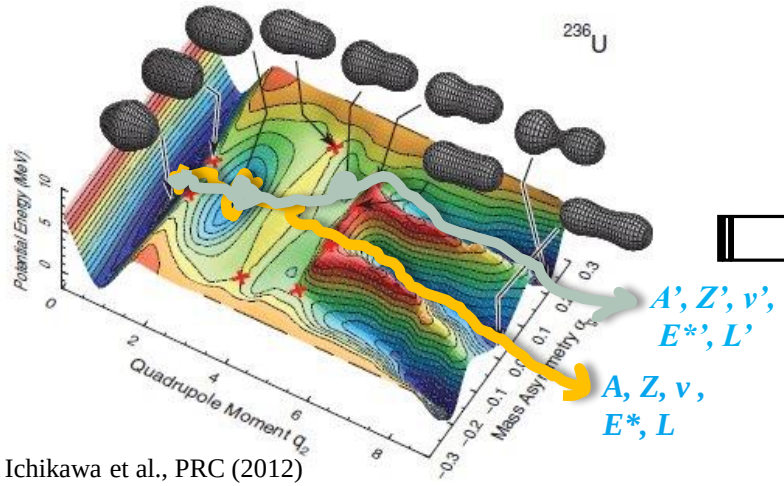
COFFEE PROJECT COMPLIMENTARITIES

• 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.

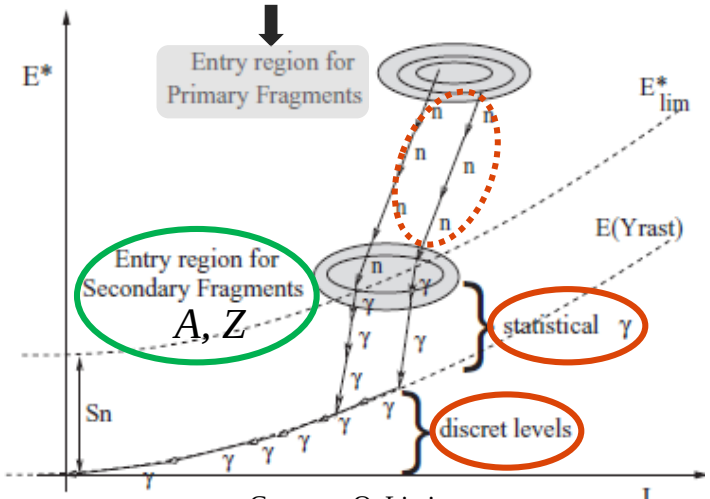
• Existing collaborative activities: Recent nu-Ball2 project at ALTO. The gamma decay from high-lying states and giant resonances excited in stable isotopes via (p, p') and (n,n') reactions. Evaluation of the nuclear theory virtual services Theo4Exp implemented at IFJ PAN. Development of the PARIS Array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

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

Fission - motivation



Ichikawa et al., PRC (2012)



Courtesy O. Litaize

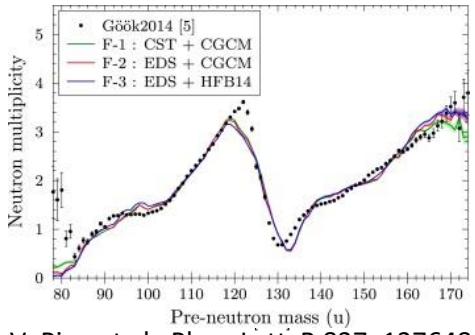
Outcome depends on:

- PES topography (system A and Z) and E^*_{ini}
- Dynamics
- Fragment entry point (E^*, L)
- Fundamental nuclear properties

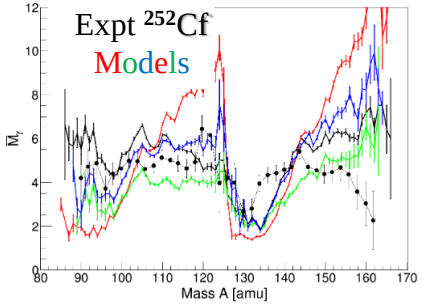
Possible observables in experiment:

- Fragments $A_{1,2}$, $Z_{1,2}$, $TKE=KE_1+KE_2$
- Neutrons M_n , E_n
- γ-rays M_γ, E_γ

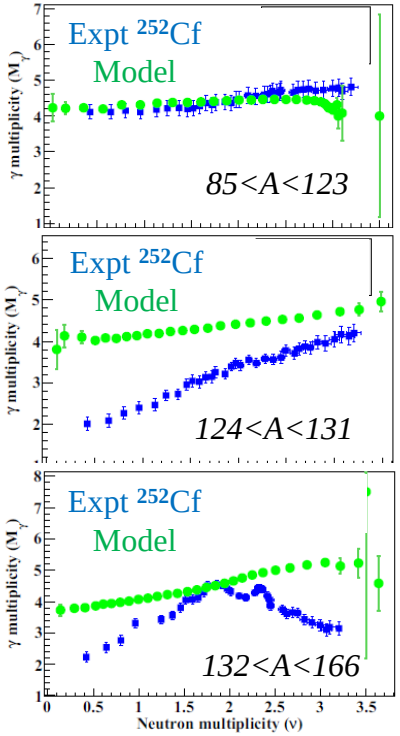
Fission - motivation



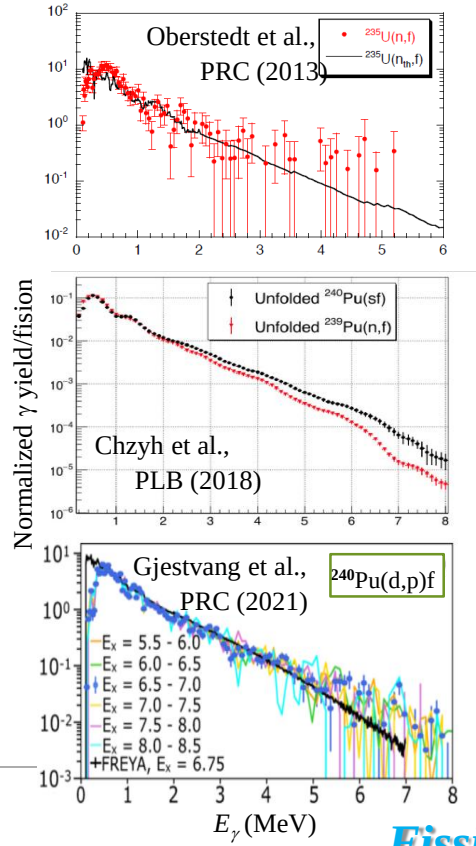
V. Piau et al., Phys. Lett. B 837, 137648 (2023)



Thulliez et al., EPJ Web Conf (2016)



Wang et al., PRC (2016)



Complex and possibly « perverse » interplay between the plenty of aspects affecting fission

Fission physics and general nuclear properties

Many open questions…

- ⇨ **Generation of *E** and *L***, and **sharing** between the fiss. Frag. at scission
- ⇨ Nuclear binding energy and **shell effects**
- ⇨ Nuclear **level density**
- ⇨ **γ-ray strength function**

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Scientific Program

Fission studies at ALTO

The open questions in fission that we would like to address at ALTO are centered 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

Scientific Program

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:

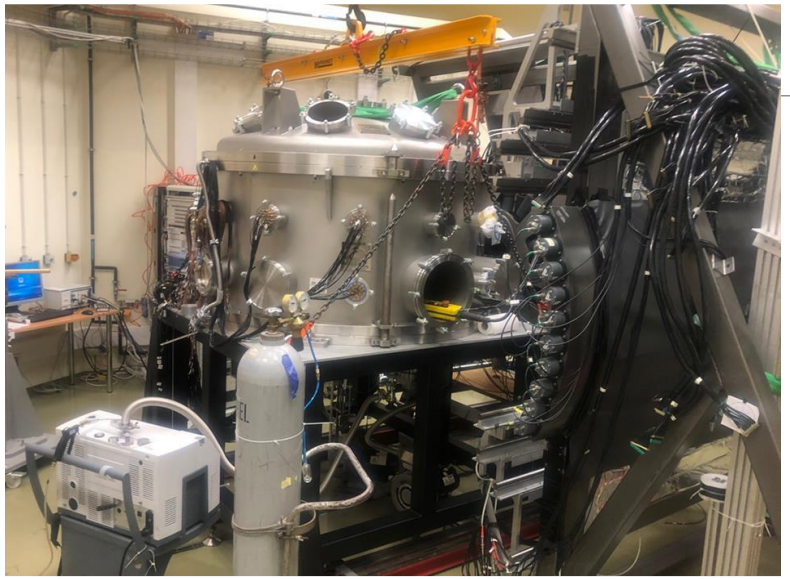
• Study of the transition from asymmetric to symmetric fission modes as a function of excitation energy, mass and charge for various systems.

• 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}Thas 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.

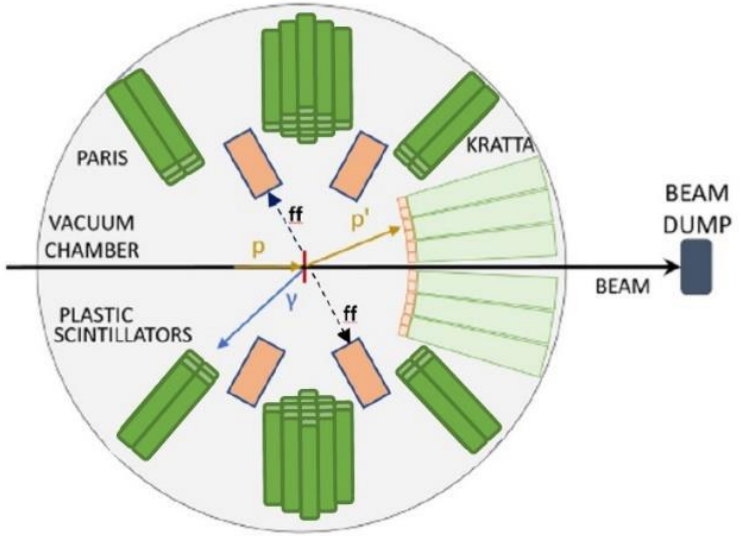
COFFEE setup at CCB

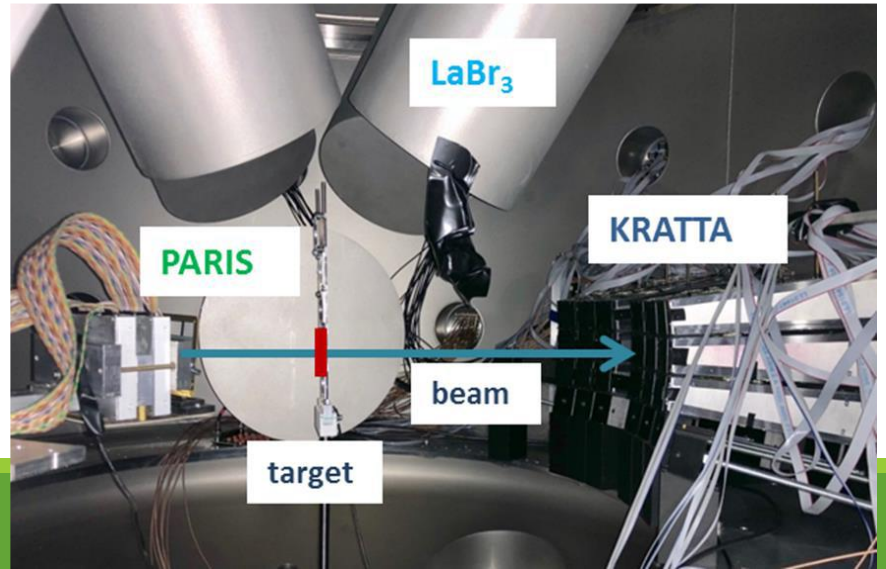


Coincident measurement of scattered protons gamma rays and fission fragments.

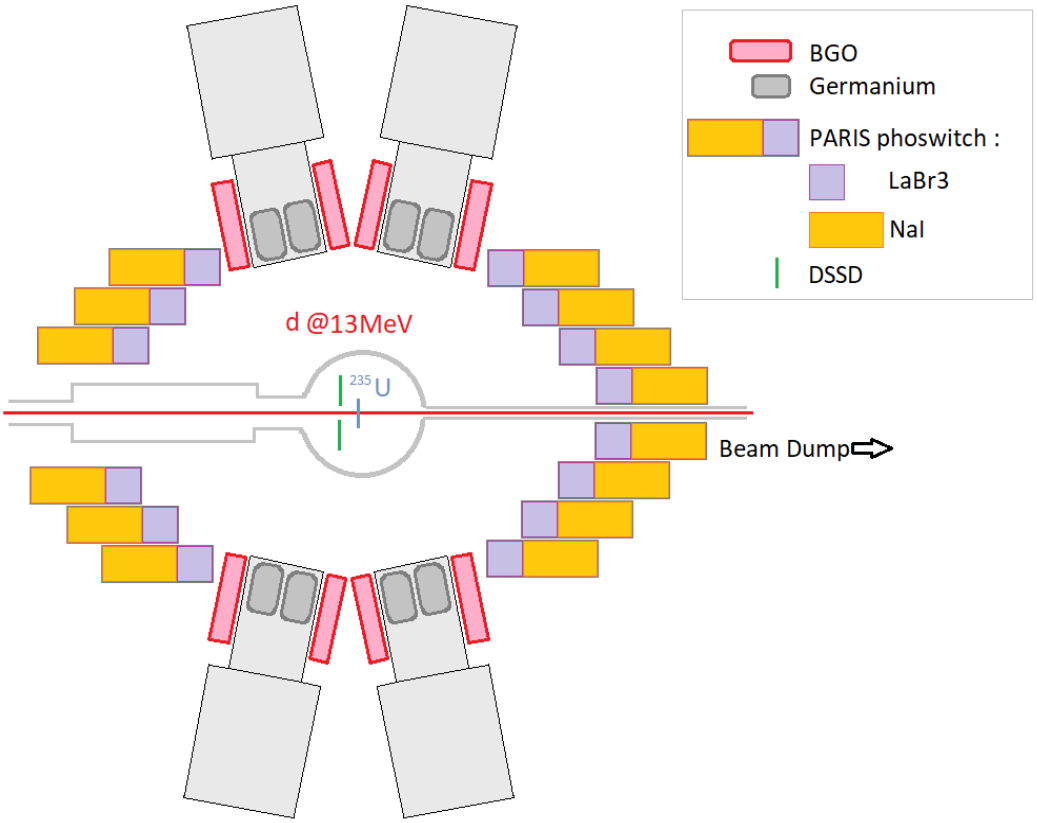
Experimental setup equipped with detectors:

- 32 **KRATTA** telescopes **measurement of the angle and energy of scattered protons,**
- 4 large volume **LaBr3** detectors(3.5”x8”) and at least 2 **PARIS**clusters+ 8 phoswiches (26 phoswiches),
- fission fragment detection system (to be added)



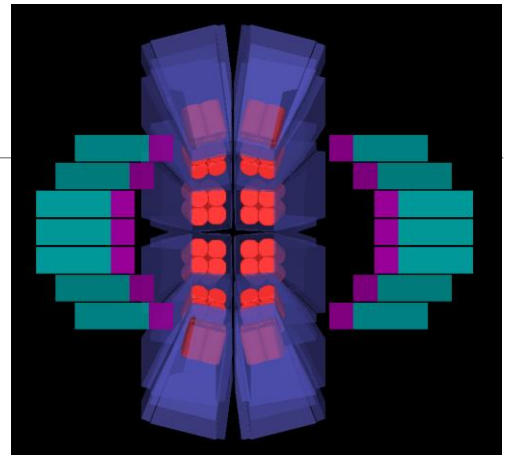


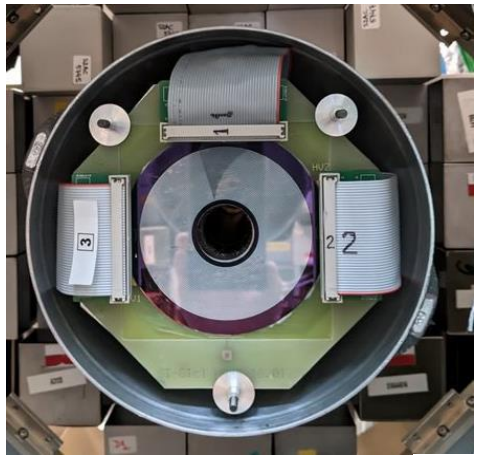
Proposed COFFEE setup at ALTO



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)

To be bought

- DSSD Silicon disc for ΔE/E (pid)

Unique and competitive setup with high selectivity

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HPGe at ALTO/IJC Lab

Loan Pool

10 working

5 poor signals and currently unusable

5 no signals

Gammapool

3 detectors requiring factory repair

Refurbishment needed

COFFEE project at IJCLab require 20 working HPGe detectors

ent cost estimated between 40 and 100 k euros.

Timeline/work plan (2024-2025)

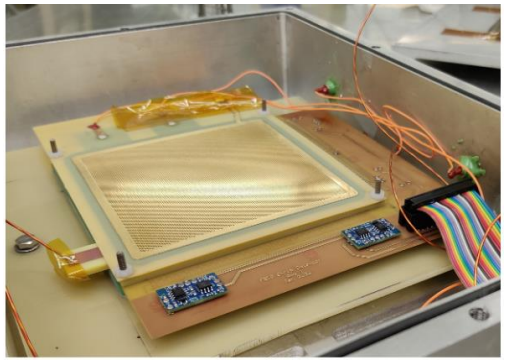
- Test experiments with new setup should be performed using proton induced fission of ^{232}Th

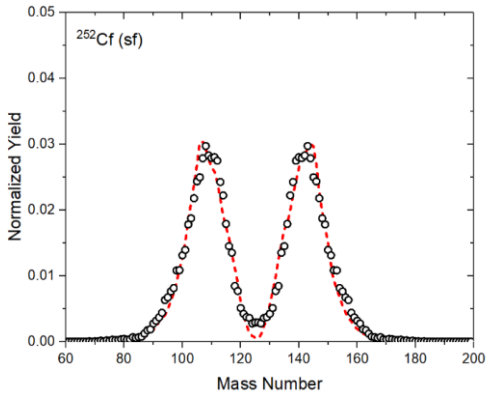
Proposal submitted and accepted by CCB IAC September 2024, Ch. Schmitt, M. Ciemała, J. Wilson, et al. „**Evolution of prompt fission γ-ray emission with excitation energy and the Thorium anomalies”**

- Choose of the best suited fission fragment detector and integration of it into data acquisition with DAQ upgrade.

Undergoing – possible use of MM-THGEM detectors

I.M. Harca, et al 2024, JINST 19 P05023





- Regeneration of the HPGe at IJCLab: No progress.

The technician hired to be trained to do this quit after 3 months.

- IJC Lab can make the ^{232}Th targets (already have made of 4 mg/cm^2). We need 0.4 mg/cm^2 for CCB experiment (it may cause some some difficulty getting below 1 mg/cm^2 with the rolling technique)

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Accepted experiment at CCB:
Evolution of prompt fission γ-ray emission with excitation energy and the Thorium anomalies

IFJ PAN Krakow (Poland): **C. Schmitt**, **M. Ciemała**, M. Kmiecik, A. Maj, B. Fornal, P. Bednarczyk, N. Cieplicka-Orynczak, M. Matejska-Minda, L. Iskra, M. Ziębliński, J. Łukasik, P. Pawłowski, J. Grębosz, K. Mazurek, I. Dedes, A. Gaamouci, et al.

IJCLab Orsay (France): **J.N. Wilson**, M. Lebois, I. Matea, et al.

IPHC Strasbourg (France): **C. Schmitt,** D. Curien, F. Didierjean, O. Dorvaux, G. Duchêne, J. Dudek, N. Kumar, M. Moukaddam, L. Stuttgé

GANIL Caen (France) : M. Lewitowicz, A. Lemasson, D. Ramos

USC (Spain) : M. Caamano

INFN and U. Milano (Italy): A. Bracco, G. Benzoni, F. Camera, A. Giaz, S. Leoni, O. Wieland

CEA Cadarache (France): O. Litaize

TIFR Mumbai (India): V. Nanal, I. Mazumdar

NIPNE Bucharest (Romania): M. Stanoui, F. Rotaru, C. Petrone, S. Calinescu, S. Ise.

University of York (UK): D. Jenkins, R. Wu

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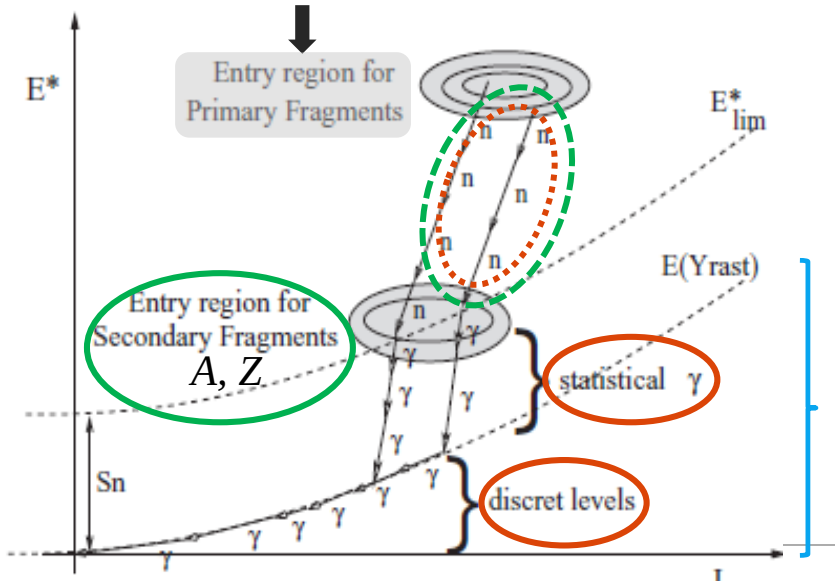
The idea

Find new signatures of the third minimum
Idea: Fragment de-excitation = f(E, L) which depends on the dynamical evolution prior scission. Possible influence of the third barrier on PFGS (and PFNS)*

Fission detectors
⇨ *A, TKE*



Courtesy O. Litaize

PARIS ⇨ M_n , E_n^{sum}

PARIS ⇨ *PFGS*, M_γ , E_γ^{sum}

PARIS ⊗ fission detectors
➥ *PFGS* over [0-30] MeV and estimate of M_n as a function of mass and *TKE* splits

PARIS ⊗ fission detectors ⊗ KRATTA for inelastic scattering
➥ Evolution with initial excitation energy E^*_{ini}

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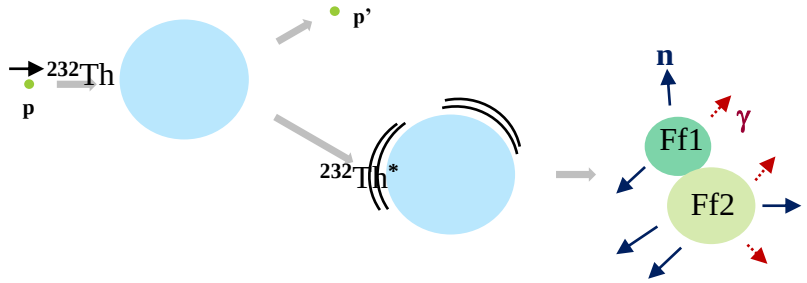
Experimental Set Up

Inelastic scattering

p + **^{232}Th** → **p'** + **^{232}Th*** (E^* up to ~ 30MeV)

(160Mev) (400µg/cm2)



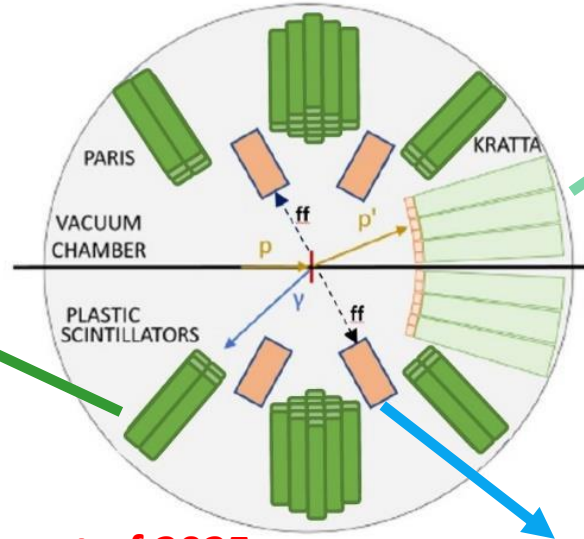
Event-by-event

- ✓ E^* - tagged fission of ^{232}Th
- ✓ Ff's (A, TKE)
- ✓ PFGS and PFNS

KRATTA

32 triple telescopes
40cm from target
from 6° to 18°

$E_{p'}$, $\vartheta_{p'}$



PARIS

42 phoswiches
27cm from target
@ ±45, 90, 135°

$PFGS$, E_γ^{sum}, M_γ, $PFNS$, M_n

Fission detectors

20cm from target
@ ±30° and ±150°

A_{ff}^{pre}, $\vec{v}_{ff}$, TKE_{ff}

Possible beam time: second part of 2025.

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Requests for 2025

For 2025 at IFJ CCB:

- electronic modules to connect fission detectors into the existing setup, estimated 20 k EUR,
- flanches, cables and small components, estimated 2 k EUR.

For 2025 at IJCLab:

- factory regeneration of one HPGe, estimated 12 k EUR,
- Th targets for CCB experiment, estimated 500-1000 EUR.

Conclusions

• Ongoing preparation for accepted by CCB IAC first COFFEE experiment in Krakow: **Evolution of prompt fission γ-ray emission with excitation energy and the Thorium anomalies,**

– fission detectors – proces ongoing,

– ^{232}Th targets – to be manufactured at IJCLab,

– use of Th in the experimentall hall at CCB permission from PAA – done.

Experiment to be performed in 2025.

• To proceed with the COFFEE at IJCLab/ALTO COFFEE project needs 20 working HPGe detectors, no progress as technician hired to be trained to do HPGe regeneration quit after 3 months -> needs to hire of the new technican and his/her training to speed up COFFEE project at IJCLab.

Thank you for your attention!