^{235}U fission fragment study with Falstaff at NFS

Outline

- FALSTAFF: goals, methods and experimental setup, preliminary meas.
- Falstaff@NFS
- Perspectives

FALSTAFF: goals, methods and experimental setup

Physics of the fission process

Excitation energy sharing
The deformation at scission
The role of structure effects
…

Observables

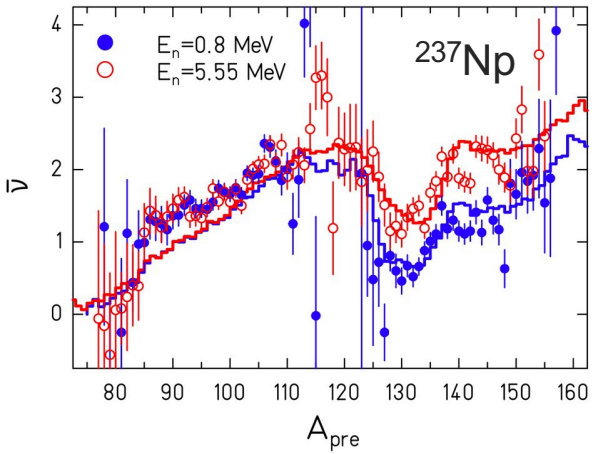
Coincident measurement of both fragments
Fragment mass, energy, charge
Gammas & neutrons multiplicities
Evolution with excitation energy
Evolution with fissionning nucleus
…

Observables

Nuclear application

Characterization of fission products of actinides

Few data available in the fast neutron energy domain



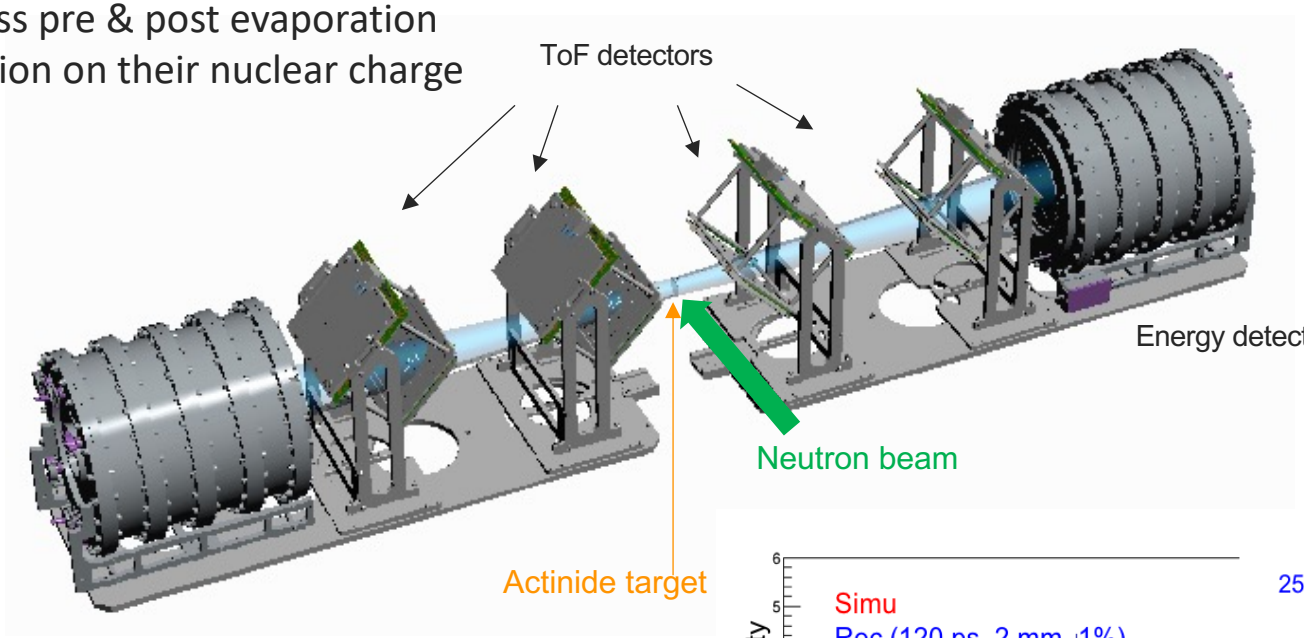
- A. A. Naqvi et al, PRC 34 (1986) 21
- Mueller et al., PRC 29 (1984) : ^{235}U 0.55 et 5.5 MeV
- Moore et al., Nucl. Data Sheets 184 (2022) : 235U 0.11-92.4 MeV

Falstaff

FALSTAFF: goals, methods and experimental setup

Study fission
- Direct kinematics (n-induced)
- Actinide targets

Experimental goals are to:
- detect both fragments in coincidence
- measure their kinetic energy
- identify their mass pre & post evaporation
- provide information on their nuclear charge



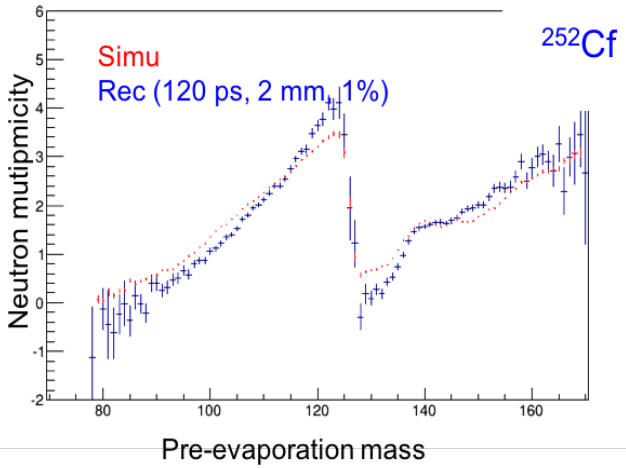
Geant4 simulations

TOF detectors : $\sigma(t)$ = 120 ps & σ (xy) = 2 mm

Axial IC: $\sigma(E)/E$ ~ 1 %

Pre-evap. fragment masses (2V): $\sigma(A)$ ~1 uma

Post-evap. fragment masses (EV): $\sigma(A)$ ~2 uma



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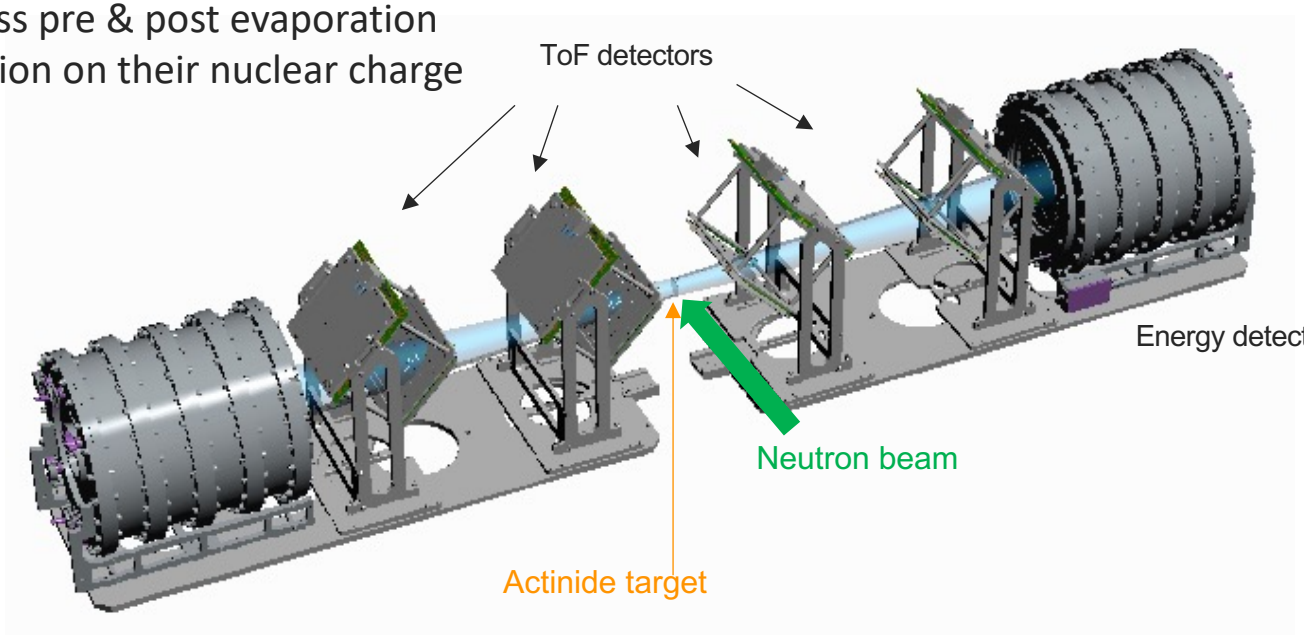

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Challenges

Experimental resolutions

Direct kinematics :
- Charge identification
- low energy fragments
  -> energy loss corrections

FALSTAFF: goals, methods and experimental setup …

Challenges

Experimental resolutions

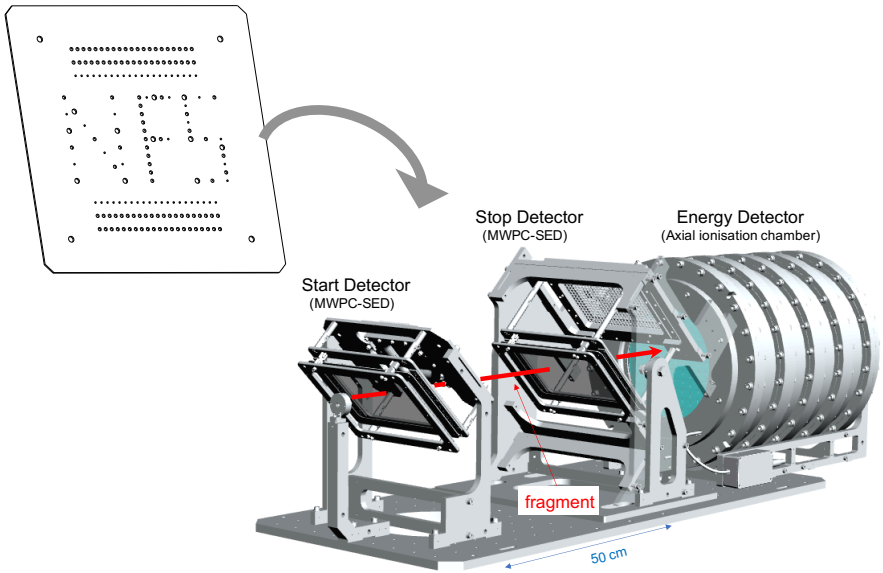
Direct kinematics :

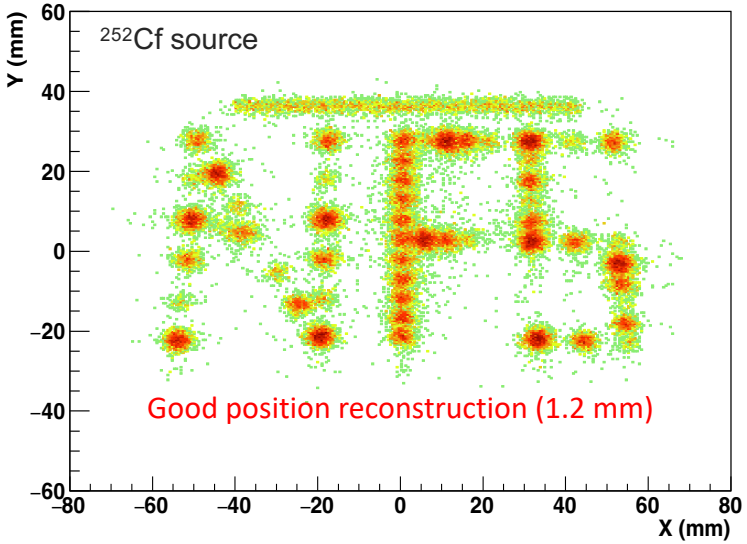
- Charge identification
- **Low energy fragments**
  -> energy loss corrections

Energy loss

- measurement at ILL: T. Materna et al., NIMB 505 (2021)
- thickness measurement of emissive foils
- thickness measurement of ChIo window to be done
  - Setup in development

Position resolution



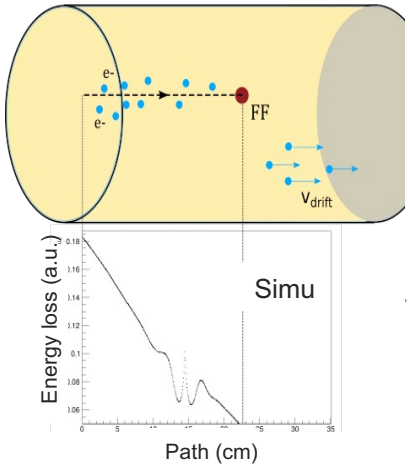


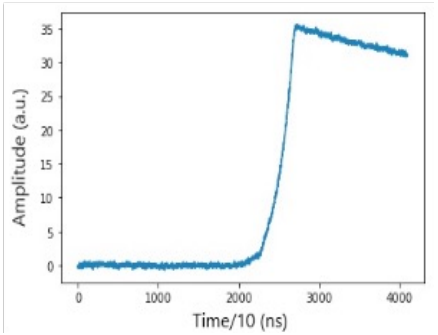
Charge identification through energy loss profile measurement

Possible to identify fragment nuclear charge using the energy loss profile and neural network

Need data with identified fragment to « settle » the neural network

→ *FALSTAFF@VAMOS experiment (D. Ramos)*

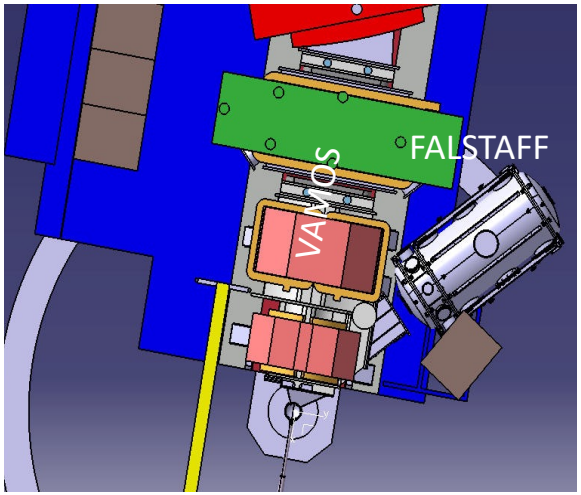




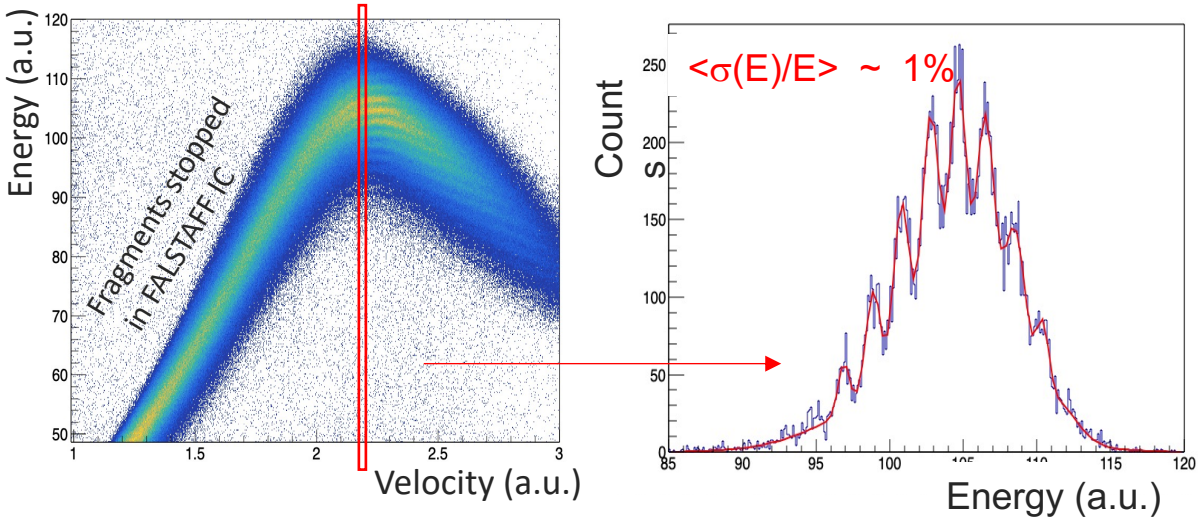
FALSTAFF @ VAMOS (test experiment, March 2022, PI D. Ramos)

^{238}U + C (Be) → fusion-fission main channel

Indu Jangid thesis



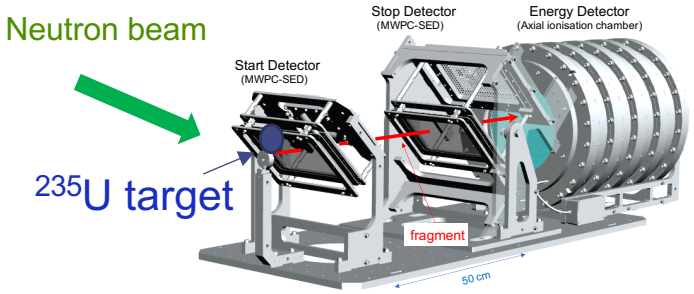
Additional information



Charge analysis still in progress, preliminary results are promising

E814 experiment: ^{235}U *Fission fragment study with FALSTAFF at NFS*

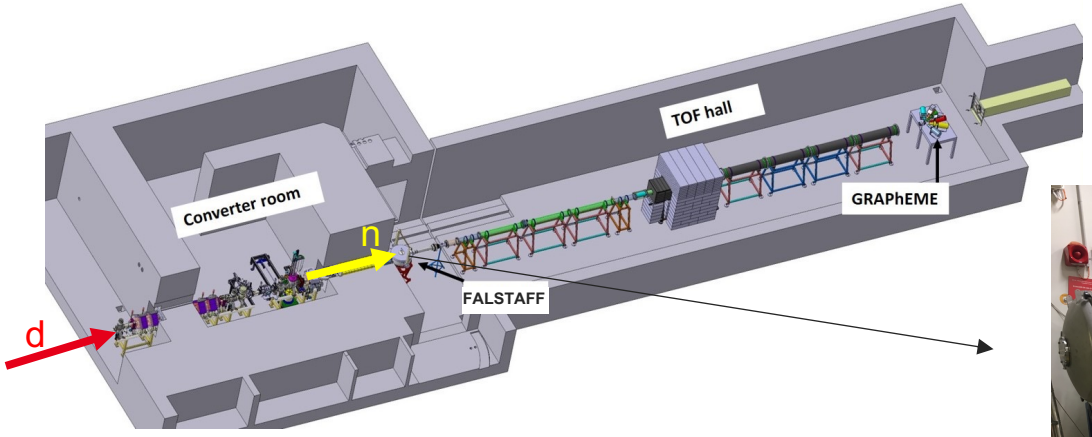
One arm experiment

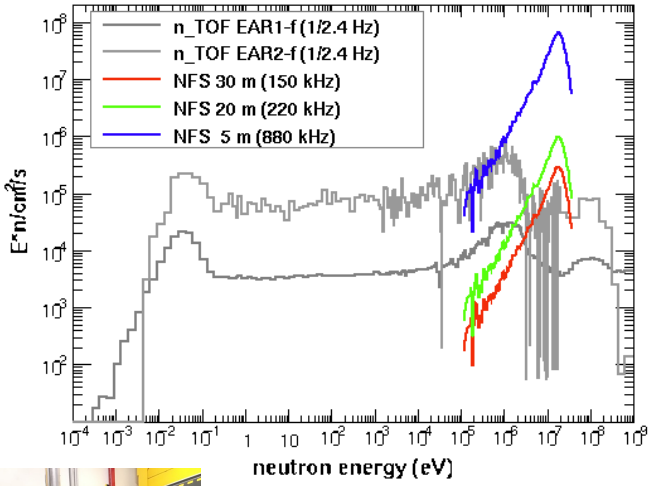


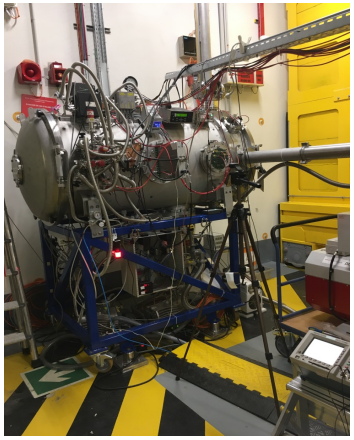
EV method
- Post-evaporation fragment mass

+2 LaBr3 detectors (Subatech, Nantes) close to the target

d+^{9}Be (thick)
I_{beam} = 8 μA (nominal 50 μA)
f = 1/200 * 88 MHz



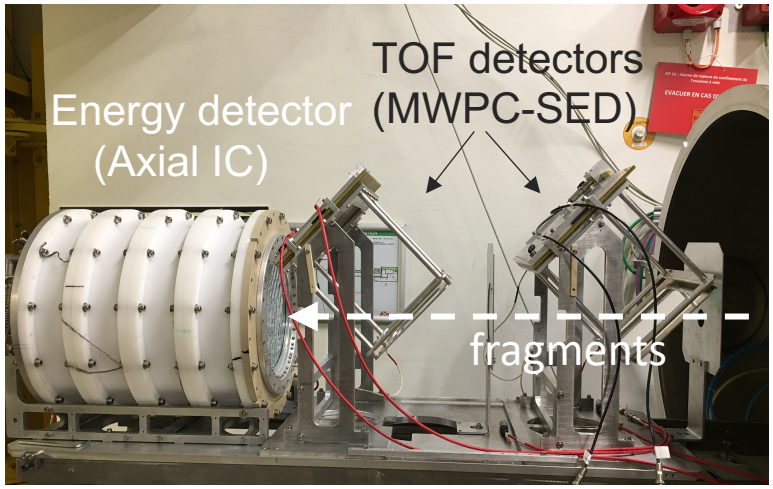


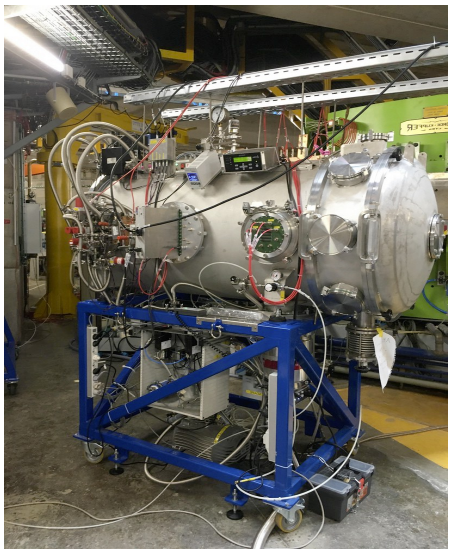


~1/5 of the expected neutron flux
< 1 detected fragment /s

E814 pictures

E814 : Falstaff@NFS : ^{235}U

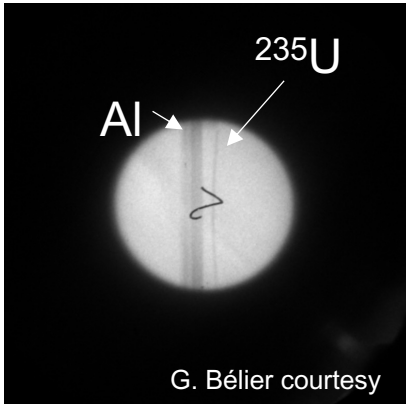




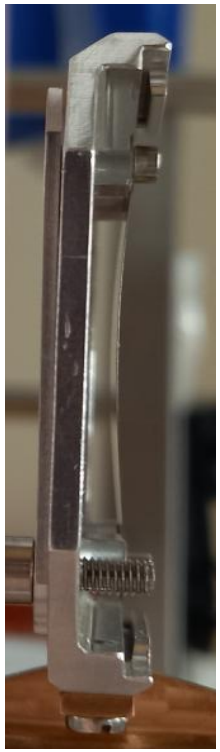
E814 target

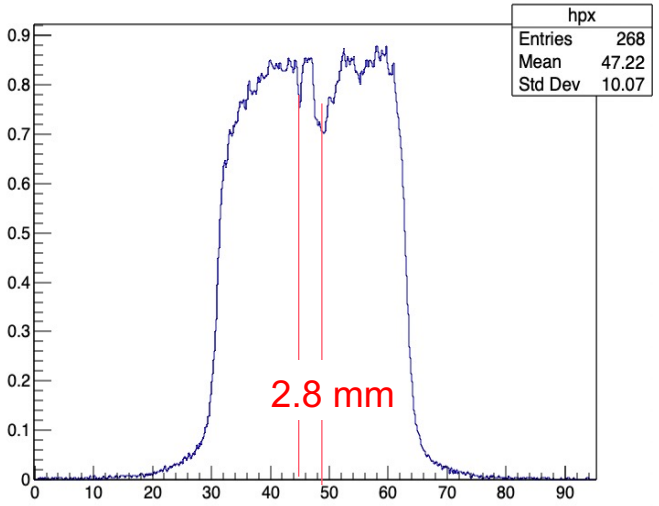
^{235}U target:

- JRC-Geel (99.94% ^{235}U)
- 195 μg/cm^2
- Φ 28 mm
- 1.2 mg
- Ta backing
- Al support



Photostimulable phosphor plate placed at the exit of the FALSTAFF chamber





Incident neutron energy spectrum

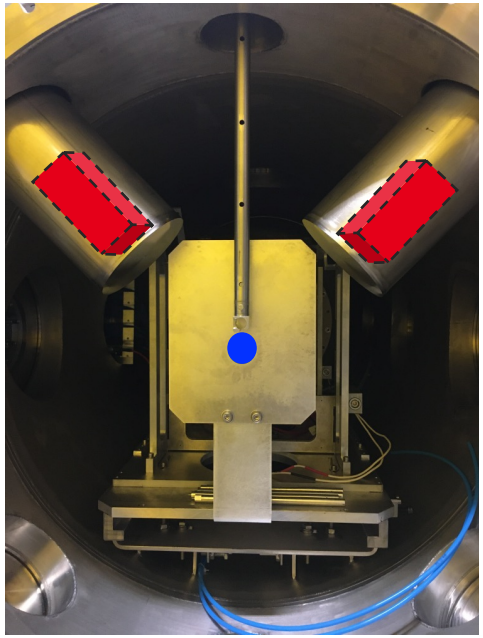
- Need of reference time

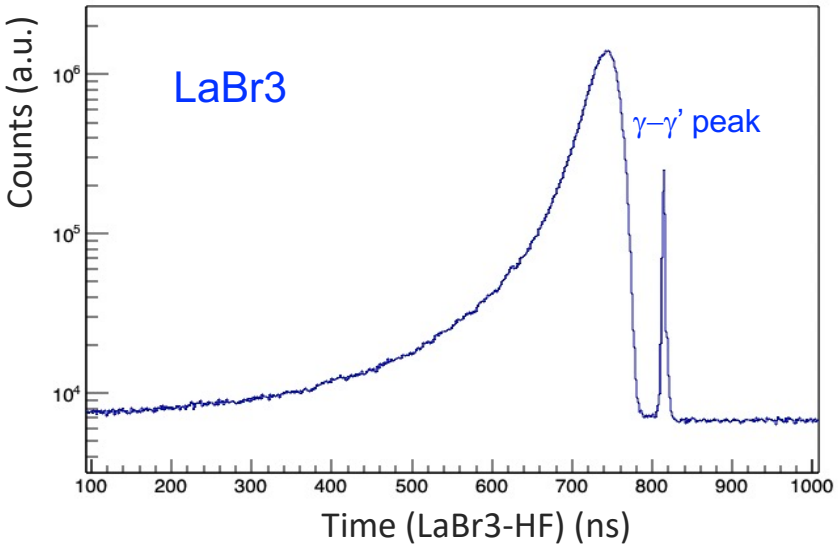
  Low energy gamma flash at NFS: no photo-fission

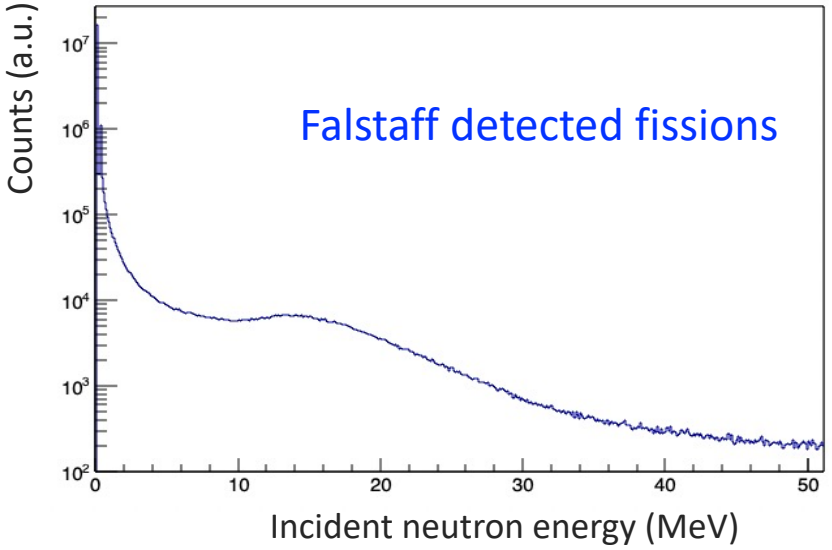
- 2 LaBr3 detectors from Subatech
  - 51x51x102 mm^3
  - 2 PM of 2''
  - 2% FWHM pour 1.33MeV
  - Internal bkg 730cps

- Neutron time spectra (producing detected fission in FALSTAFF) is obtained using:

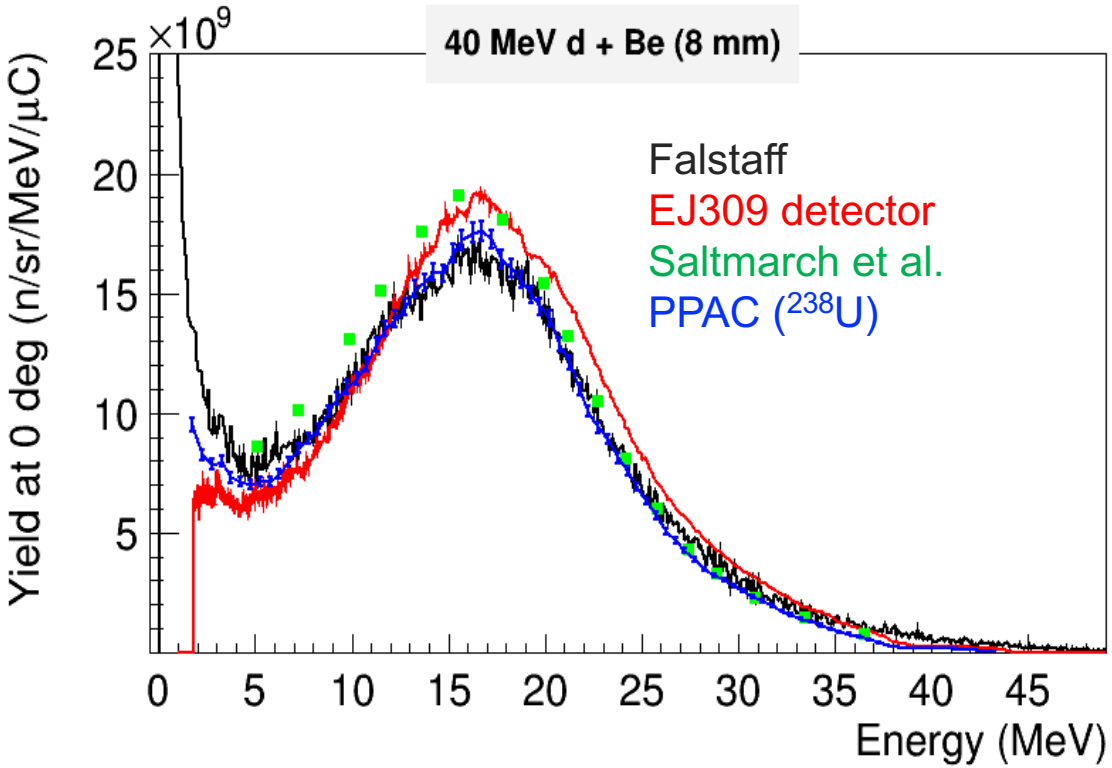
  Different dtime (HF, Falstaff, LaBr3)







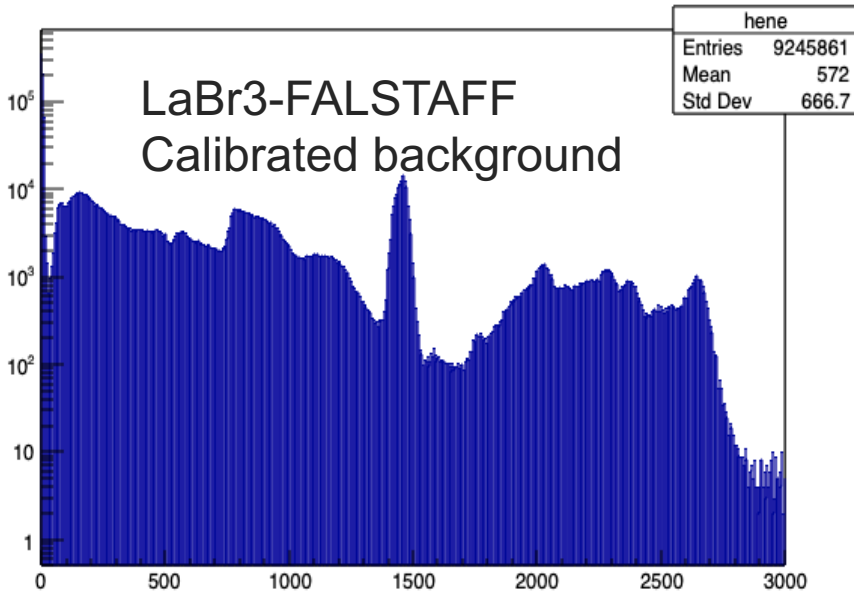
Neutron energy spectra & Statistics

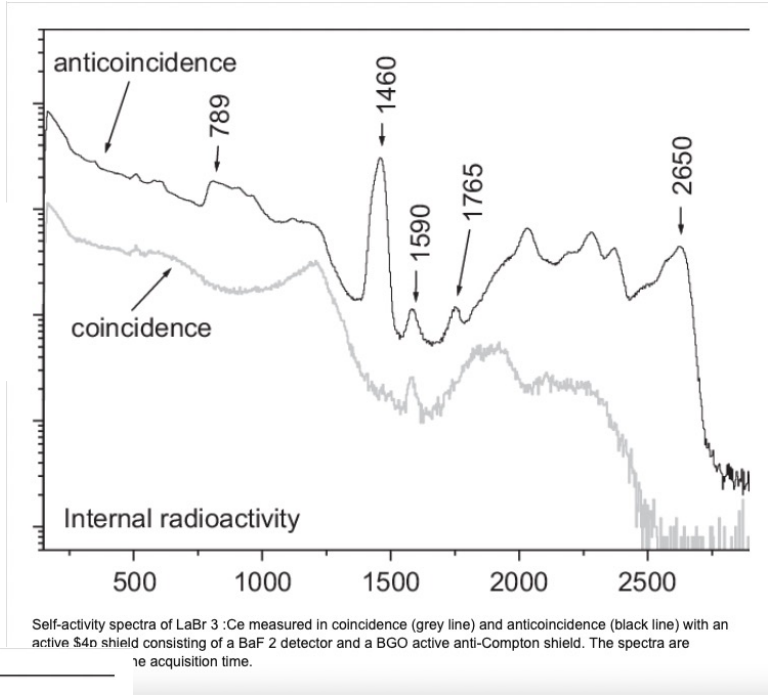


- Same trends
- Some discrepancies between measurements
  - not important for Falstaff since no absolute cross section measurement

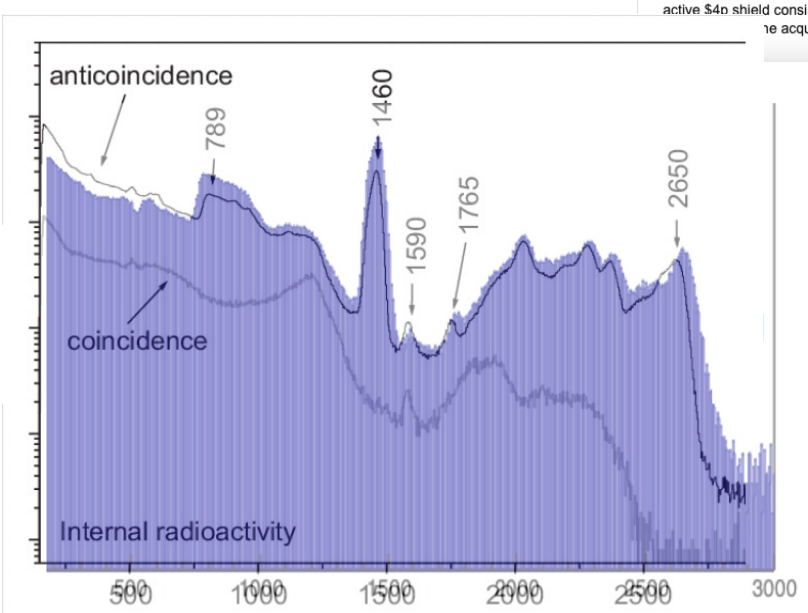
LaBr3

- Energy calibration with sources, some problems … but OK



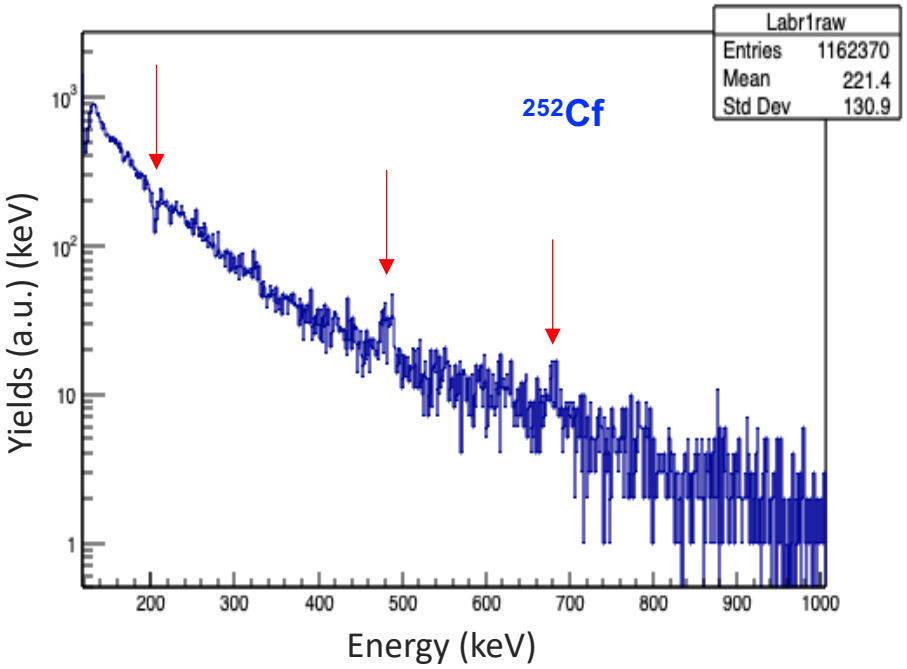


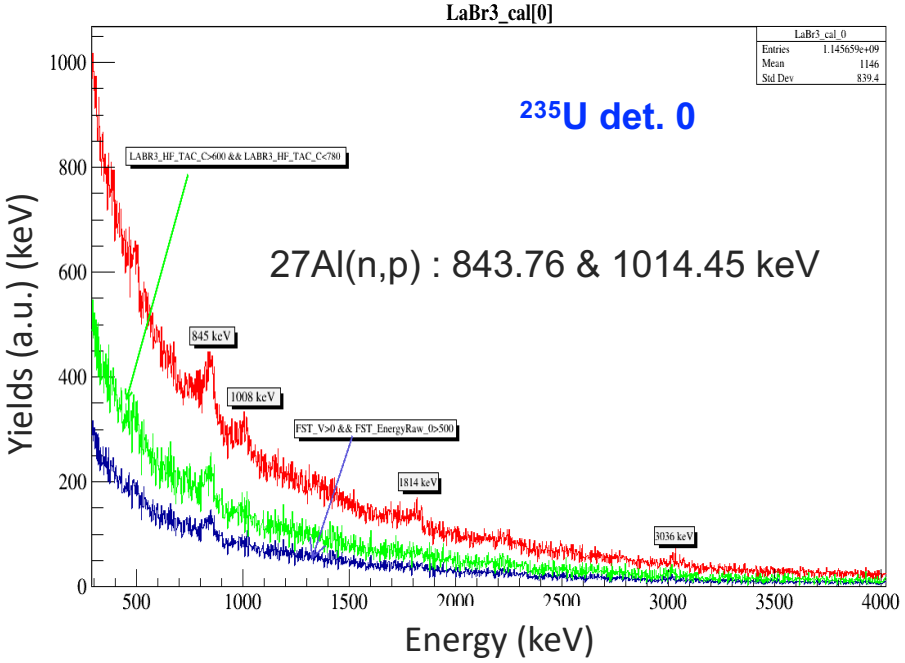
Self-activity spectra of LaBr 3 :Ce measured in coincidence (grey line) and anticoincidence (black line) with an active $4π shield consisting of a BaF 2 detector and a BGO active anti-Compton shield. The spectra are
…e acquisition time.



LaBr3 …

- Few peaks in distributions for ^{252}Cf and ^{235}U





- Test with a different electronics to be done soon

- In addition:

  HpGe will be put close to the ^{252}Cf source

  → to see fission gamma
  → to try to identify some fragments and check FALSTAFF reconstruction

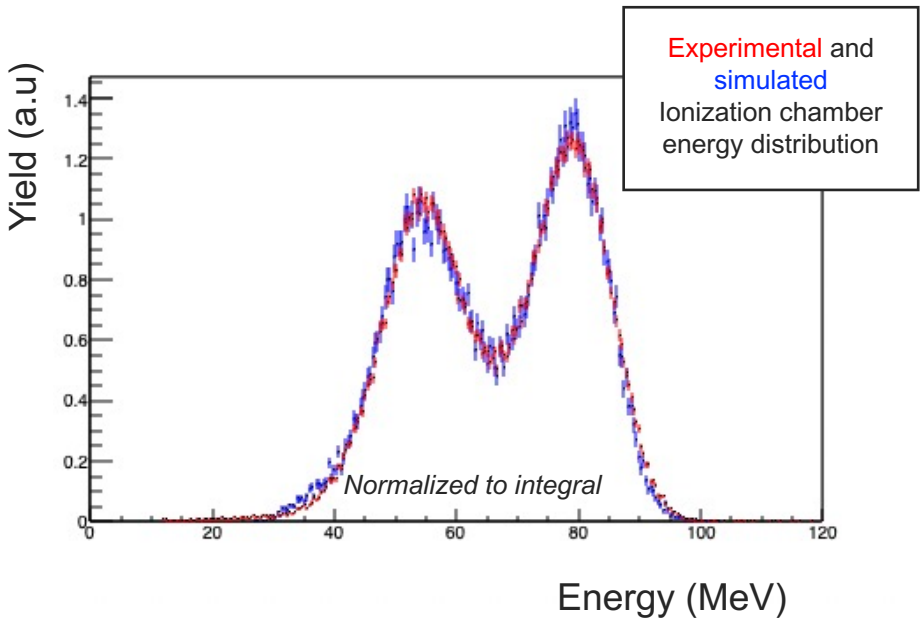
Calibration

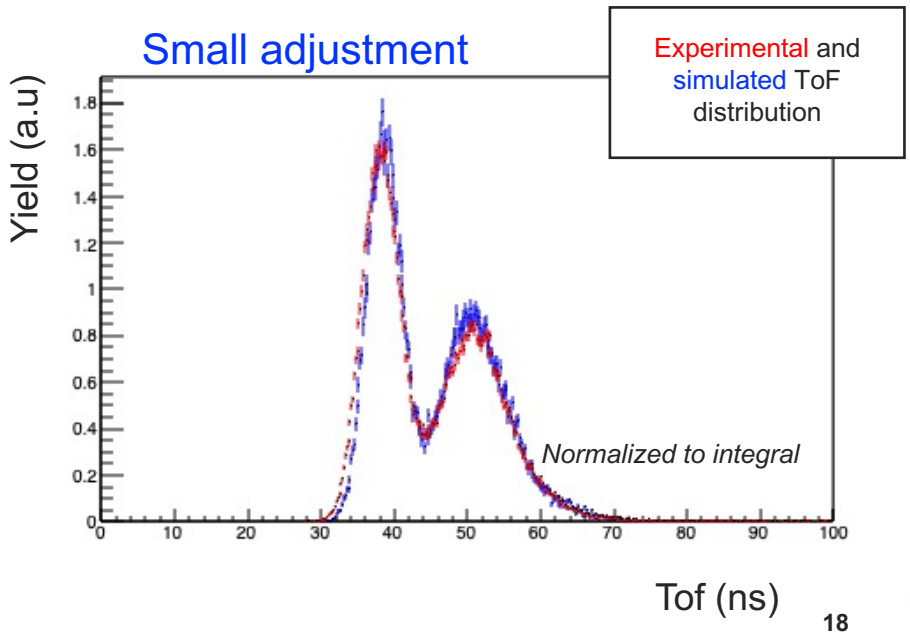
- Based on simulations : ^{252}Cf

Simulations with GEF code *K.H. Schmidt et al., Technical report, JEFF Report 24, 2014.*
- well known code in the nuclear data community
- parameters "adjusted" on available experimental data but …
  few data in the fast energy domain

FIFRELIN (DES/IRESNE). *O. Litaize et al., Phys. Rev. C, 82 (2010) 054616.*
Not used here because **FIFRELIN** results for U5
at different energies are not yet available (no pre-neutron data available)

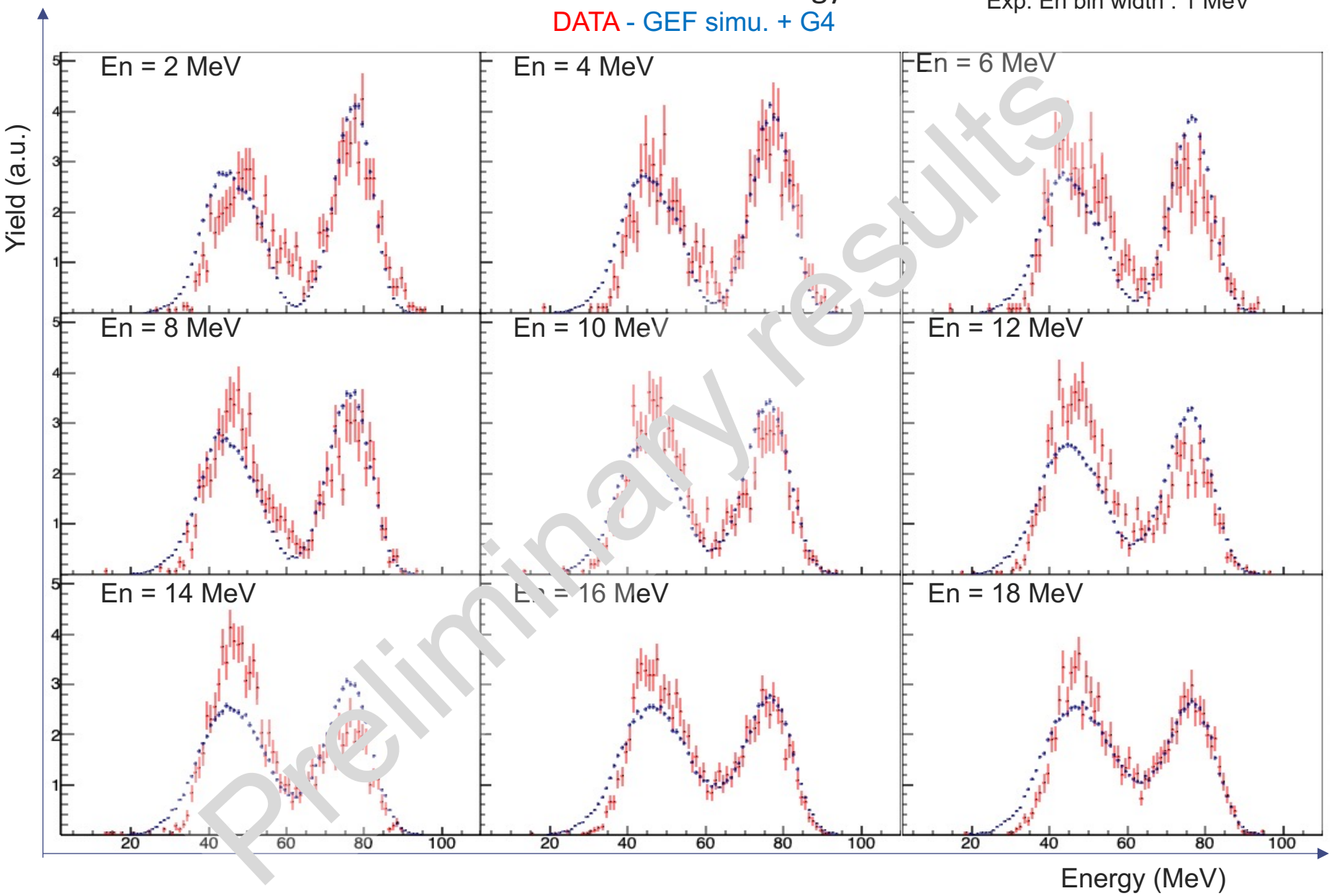
But, with FALSTAFF data, in the NACRE framework,
FIFRELIN developers and FALSTAFF coll. will work together





^{235}U preliminary results

Spectra normalized to integral
Exp. En bin width : 1 MeV



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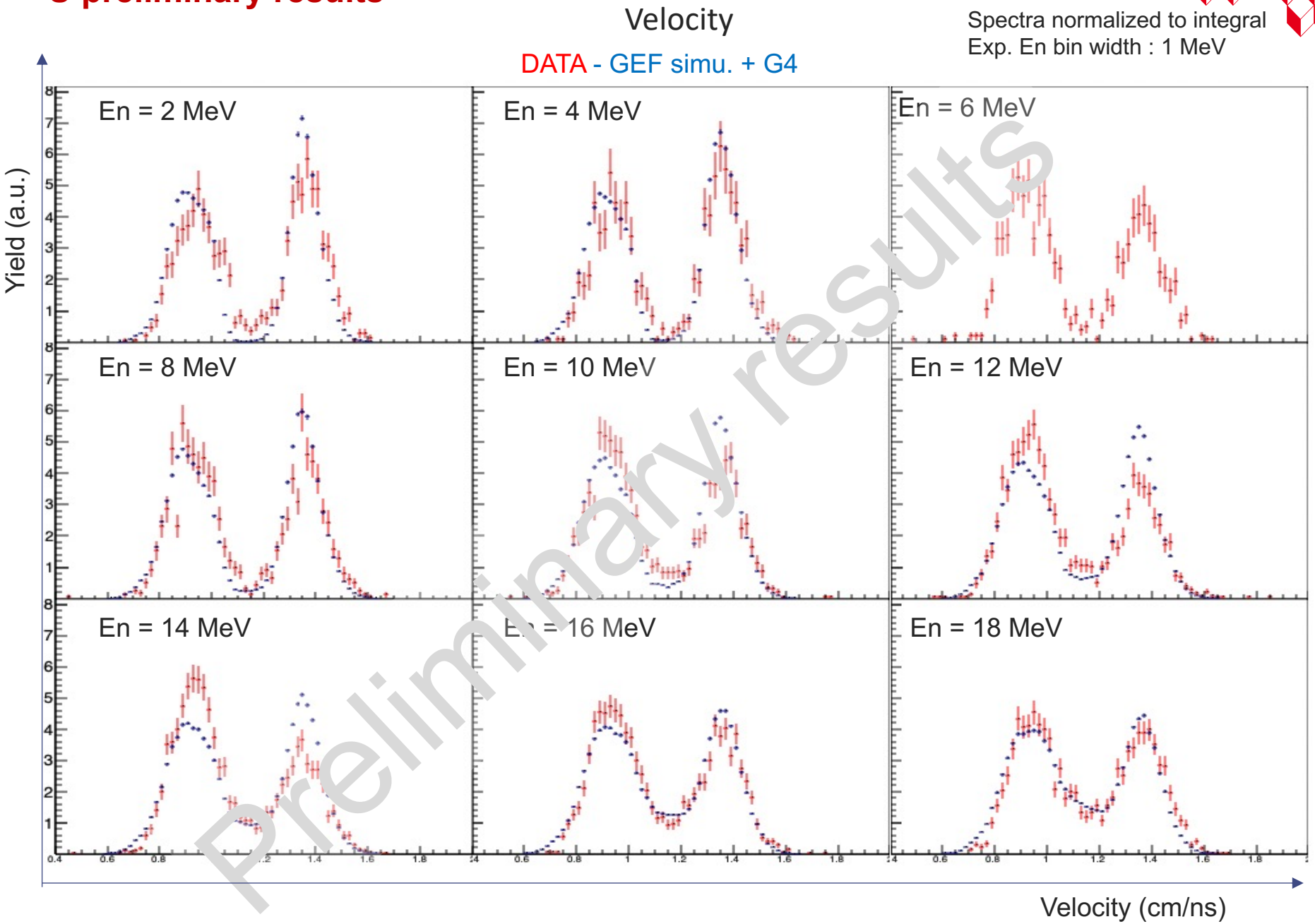


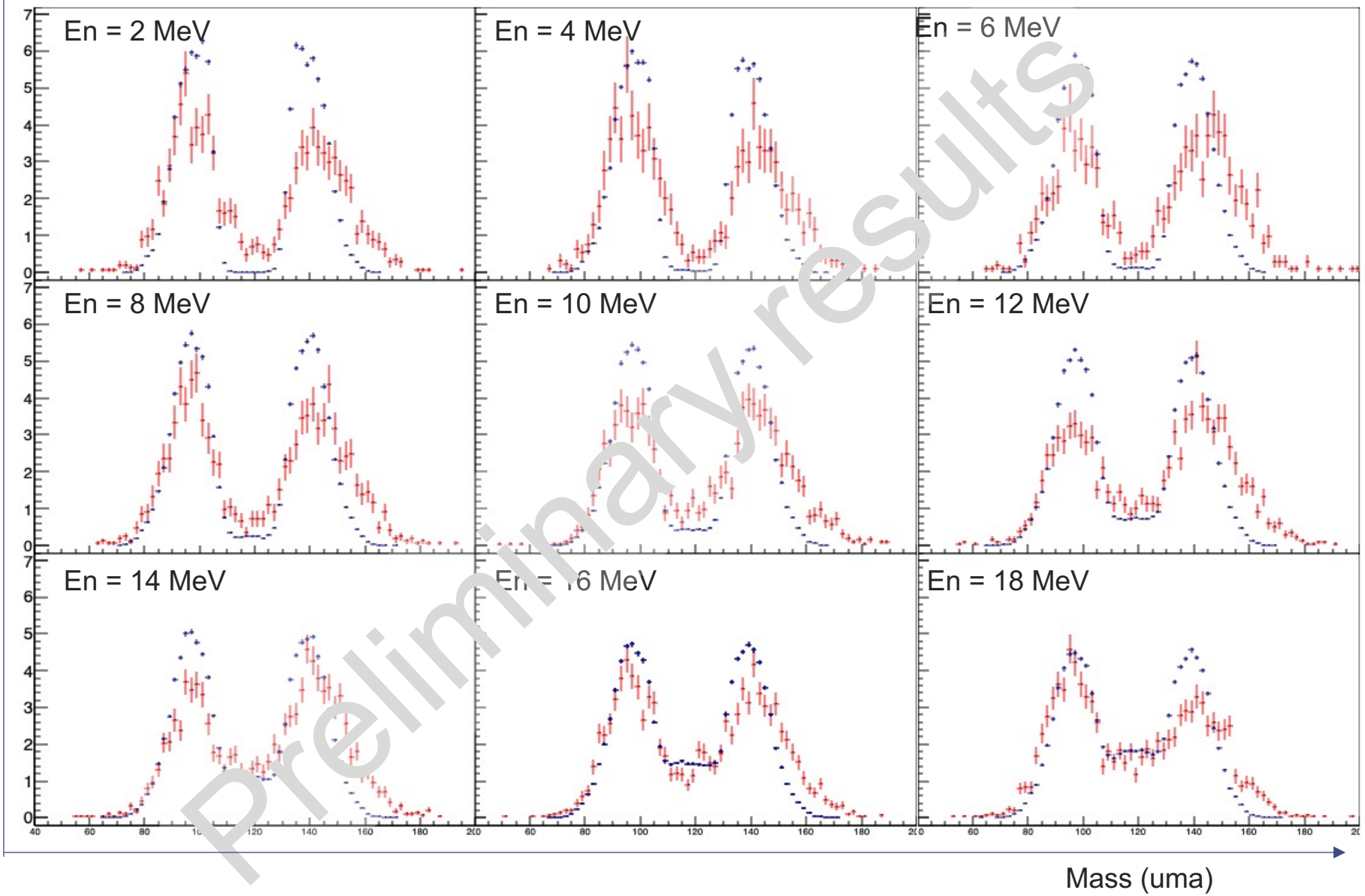
^{235}U preliminary results

- Iterative process to correct the energy loss in the IC window and the Stop emissive foil
  - Charge not known, UCD used

Spectra normalized to integral
Exp. En bin width : 1 MeV

Mass

DATA - GEF simu. + G4



NACRE (WP2)

Collaboration : DPhN/Irfu/CEA, GANIL, SPRC/DER/DEN/CEA, Subatech/IN2P3, JRC/Geel

Action 2023:
Analyse et mise en forme des résultats (fragments post-évaporation) pour une utilisation dans le code FIFRELIN en 2024 en collaboration avec le SPRC.

→ Réunion reportée de décembre 2023 à début 2024

En parallèle le second bras sera construit et une expérience est envisagée en 2024 sur NFS.

→ Expérience avec 2 bras reportée → Expérience ^{237}Np (1-arm) acceptée (J.E. Ducret)

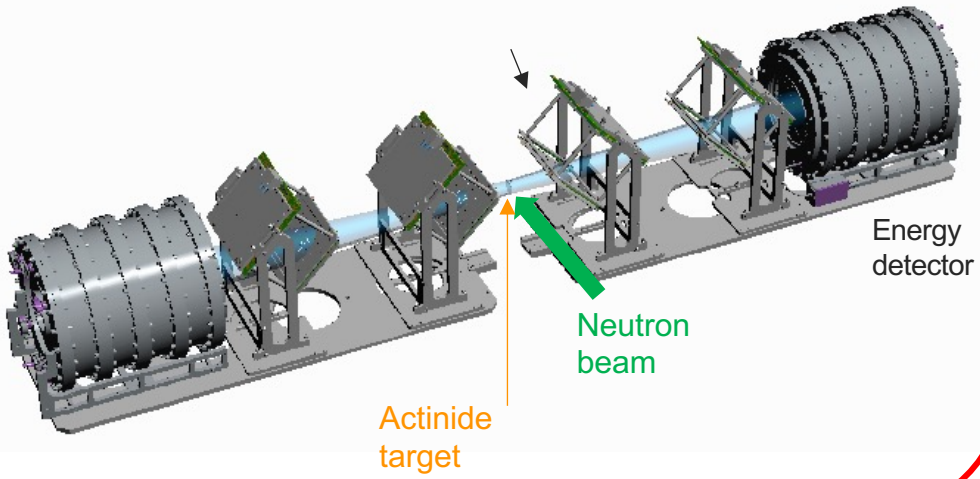
Good news

➢ Second arm of FALSTAFF in development (Région Normandie, Irfu/GANIL, Irfu/DPhN)

- Proposition to be submitted this Fall
- Experiment expected in 2025

- Reaction chamber to be delivered in April
- Ionization chamber to be delivered in May
- Seds for Summer

❖ ANR proposal for manpower and +
❖ APRENDE proposal



In summary

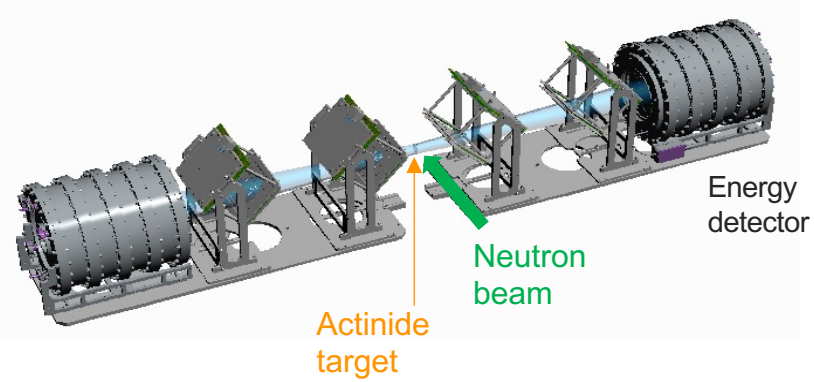
- Analysis of ^{235}U (n,f) exp. at NFS is still ongoing
  - Other calibrations for ionisation chamber needed
  - LaBr3 tests to perform
  - Cf meas. with HPGe in coincidence foreseen to check the mass reconstruction method
  - Analysis of FALSTAFF@ VAMOS exp. is in progress:
    - results needed to extract nuclear charge information FALSTAFF
- ^{237}Np experiment (1-arm) accepted to be performed Fall 2024
- Second arm of FALSTAFF in development

Thin actinide targets needed …. !

Support C. Stodel initiative and JRC-Geel target laboratory

→ One slide after questions

Falstaff



Participants to the E814 experiment

DPhN: *Diane Doré, Eric Berthoumieux, Alain Letourneau, Thomas Materna, LoïcThulliez, Marine Vandebrouck, Mattéo Ballu, Pierre Herran, Gurpreet Kaur, Périne Miriot, Borana Mom*
GANIL: *Jean-Eric Ducret, Diego Ramos , Xavier Ledoux, Anne-Marie Frelin, Indu Jangid, Priya Sharma*
JRC/Geel: *Stephan Oberstedt*
Subatech: *Eric Bonnet, Magali Estienne, Muriel Fallot, Amanda Porta, Julien Pépin*
LP2I: *Paola Marini, Ludovic Matthieu, Teresa Kurtukian Nieto*

+ Technical staff at GANIL and Irfu/Saclay

+ support from CEA/DES/Iresne (Abdel Chebboubi, Olivier Litaize, Olivier Serot)

Merci

C. Stodel, Ganil

PALAIS (Plateforme Cibles pour GANIL/SPIRAL2) project

→ IN2P3 support for an actinide target laboratory @GANIL

- For stable isotopes (including ^{238}U material):

  Upgrade of the existing target laboratory for stable material (2023-2025):

  - ✓ from 3*25 m² to ~ 100 m²
  - ✓ 3 new evaporators + 1 magnetron sputtering
    + X-ray fluorescence for chemical composition
  - → Large quantity of high quality stable targets for S3 in 2025-2026

- For actinide targets:

  - ✓ Post-doc for knowledge transfer of molecular plating technique, trained @ JRC Geel, JGU Mainz, IJC Lab
  - ✓ Preliminary studies on requirements for the laboratory building and its equipment, processes of fabrication according to French regulations
    - → Safety licences requests, specification on the laboratories, required skills….
    - → Identifying synergies & complementarity with JRC Geel & JGU Mainz
  - ✓ Realization of PALAIS ++