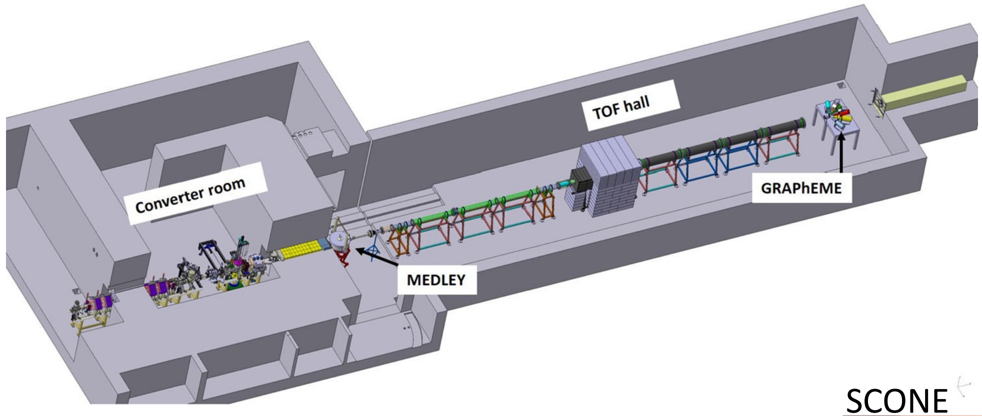
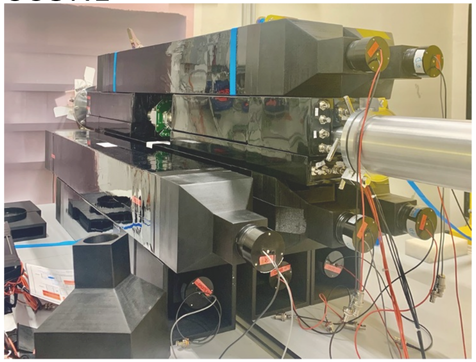
Fission studies at NFS

Why? What? How?



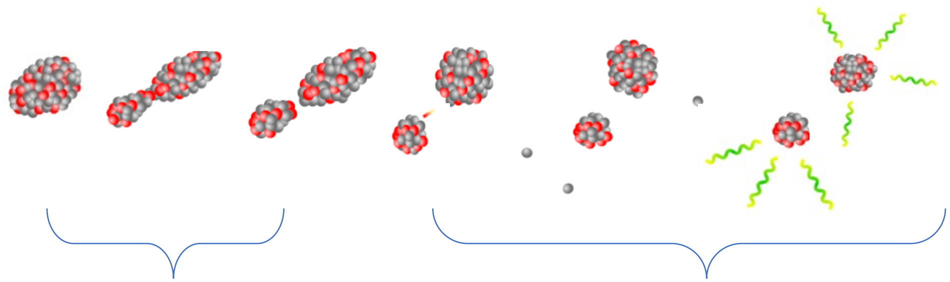
SCONE



MEDLEY

FALSTAFF

Simplified scheme



Fundamental physics
Mechanism study
Scission point

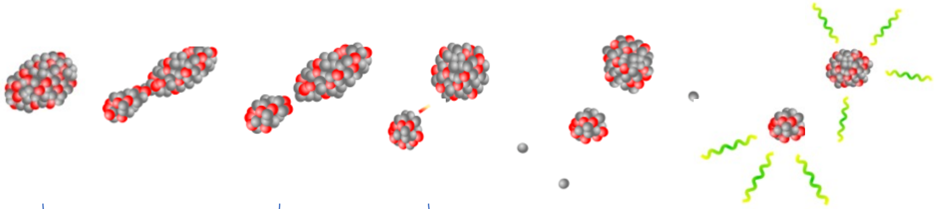
≈

Nuclear data (Energy)
Reproduction of fragments,
neutrons, gamma characteristics

Microscopic calculations

Macro-microscopic

Phenomenological calculations with microscopic ingredients



Fundamental physics
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≈

Nuclear data (Energy)
Reproduction of fragments, neutrons, gamma characteristics

Microscopic calculations

Macro-microscopic

Phenomenological calculations with microscopic ingredients

Excitation energy sharing
Deformation at scission
Angular momentum sharing
Role of structure, even-odd effects
Dominant role: Z or A
Pre-scission neutrons, ternary fission

Most of needed experimental observables are the same

Correlations between observables
Large excitation energy range
Large number of fissioning nuclei

Small uncertainties and propagation
« Limited » energy range
Actinides

Fission observables

Fragment	Neutron		Gamma	Ternary part.
Z, A, Ek, f(θ)	<u>Prompt</u> F(mult), $\overline{\nu}$ PFNS	<u>Delayed</u> ν Group charact. (a_i,$t_{1/2}$)	Mult., PFGS Total E f(θ)	Z, A, Ek, f(θ)

NFS : Direct kinematics: n+Nuclei

Difficulties

Low energy fragments (60-110 MeV after coulomb acceleration)

large slowing down in materials, difficult to identify the nuclear charge

Thin actinide targets (allow fragments to leave the target (150-200 μg/cm2)) *for fragment study*

although beam intensity is high (some 10^6 n/s/cm2)

and cross sections are large (~0.5-1 b), fission rate is limited (~2000 fiss/s)

Limited choice of actinide targets (and more and more difficult to find)

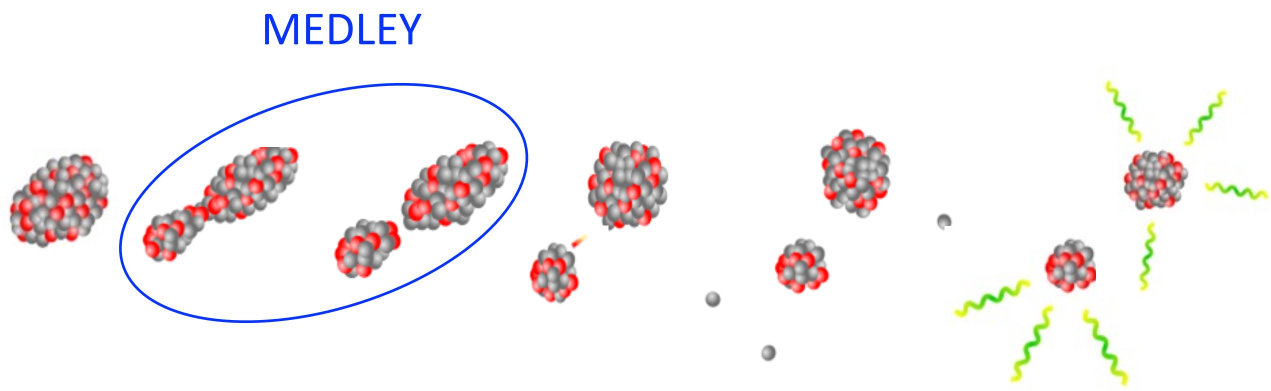
Advantages at NFS

Large incident neutron energy range (0.5 – 40 MeV)

Excitation energy known (incident neutron energy known)

Reaction rate allowing the use of « slow » detection technologies and standard acquisition system

Use of actinide targets possible



Fission cross sections
Fragment angular distributions

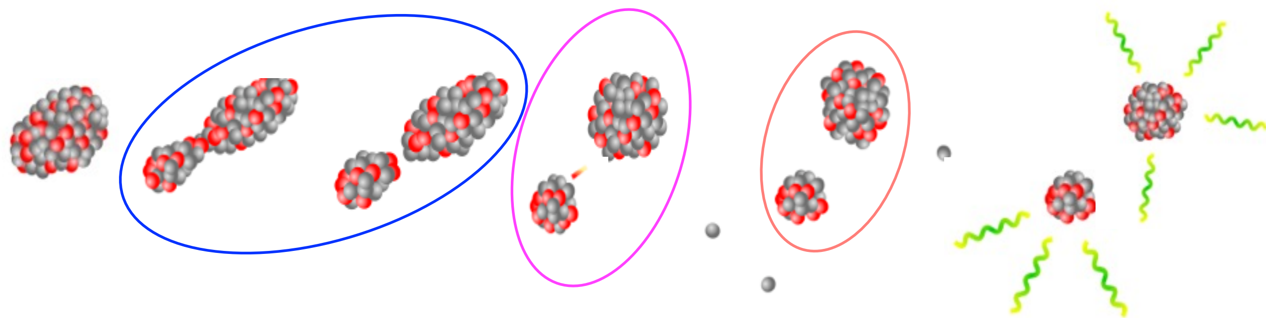
Fission barriers
Transition levels

Fragment characteristics
&
Correlation with neutron mult.

Exc. energy sharing
Vanishing structure effects
Deformation

FALSTAFF
2 arms 1 arm

MEDLEY



Fission cross sections
Fragment angular distributions

Fission barriers
Transition levels

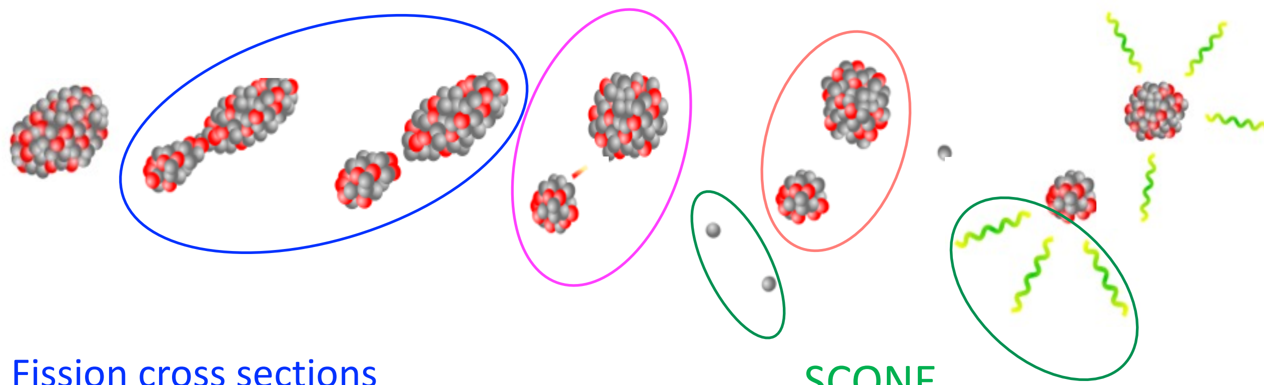
Accepted fission experiment at NFS : MEDLEY, SCONE, FALSTAFF

Fragment characteristics
&
Correlation with neutron mult.

Exc. energy sharing
Vanishing structure effects
Deformation

FALSTAFF
2 arms 1 arm

MEDLEY



Fission cross sections
Fragment angular distributions

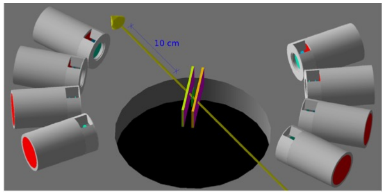
Fission barriers
Transition levels

SCONE

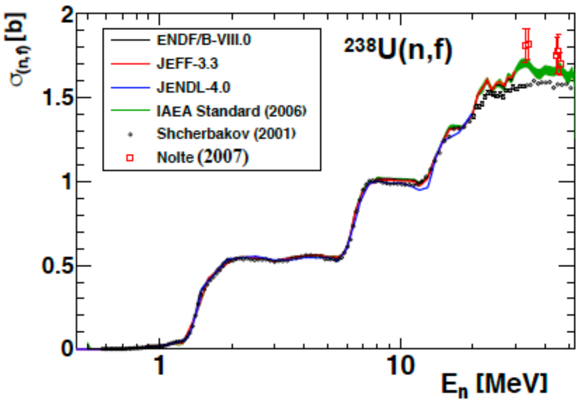
σ(n,xn)
Prompt Fission Neutron Spectrum (PFNS)
Total gamma energy

Excitation energy
Angular momentum

MEDLEY: Measurement of fission cross section standards relative to elastic n-p scattering at neutron energies from 1 to 40 MeV



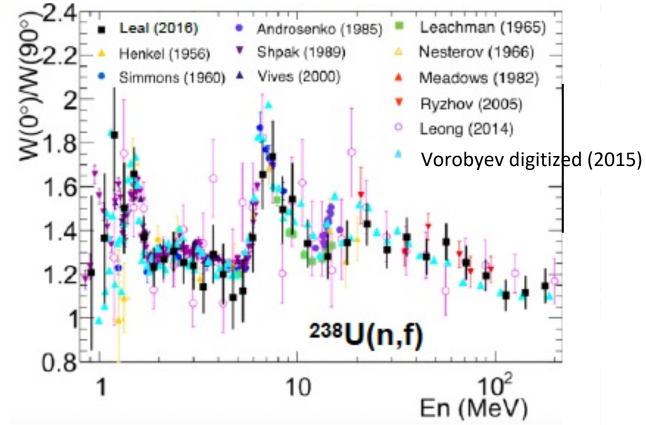
- Neutron-induced cross sections are measured relative to one of the standards (no flux meas. needed)
- H(n,n) cross-section is considered to be the most accurately known of the standards [1]



^{238}U and ^{235}U cross section data needed for fission barrier parametrizations

Angular distributions needed to evaluate the efficiency (not only)

E. Leal-Cidoncha et al. EPJ Web of Conf 111 (3016) 10002



1- A. Carlson et al., ND Sheets 148, Feb. 2018, Pages 143-188

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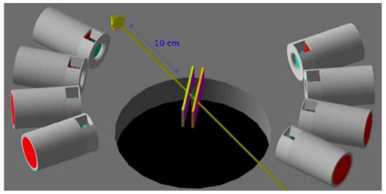

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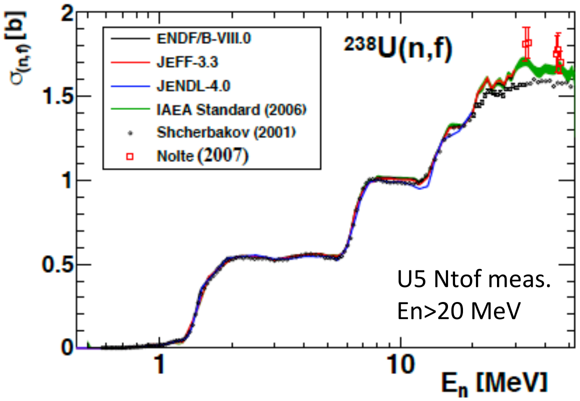
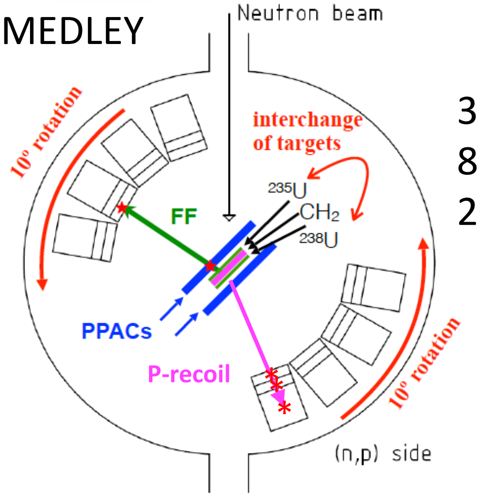


MEDLEY

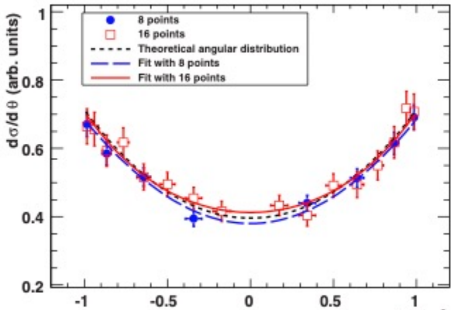


3 targets
8 telescopes
2 PPAC

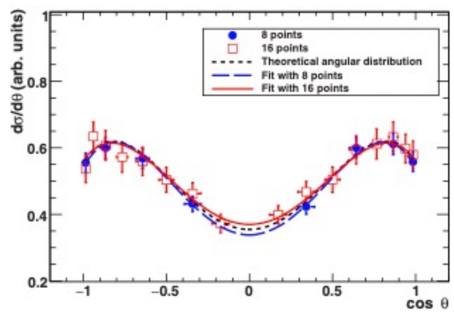
^{238}U and ^{235}U cross section data needed for fission barrier parametrizations

Angular distributions needed to evaluate the efficiency (not only)

Simulations[2]

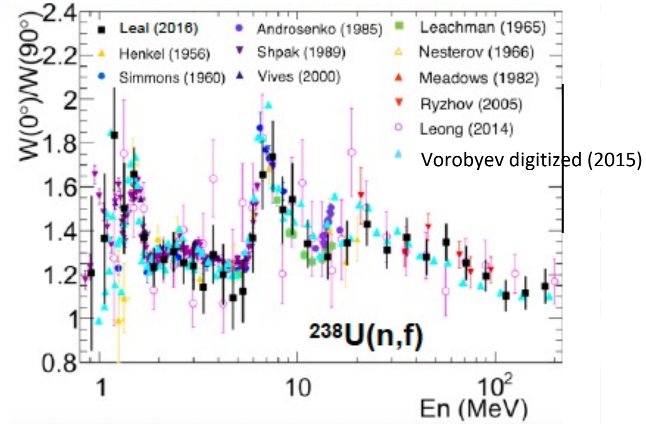


(a) Forward peaked distribution



(b) Side peaked distribution

E. Leal-Cidoncha et al. EPJ Web of Conf 111 (3016) 10002



Simulations

Total fission cross section a.u.)

Distribution	8 values	16 values
Forward peaked	1.000 ± 0.021	1.000 ± 0.011
Side peaked	1.000 ± 0.022	1.000 ± 0.011

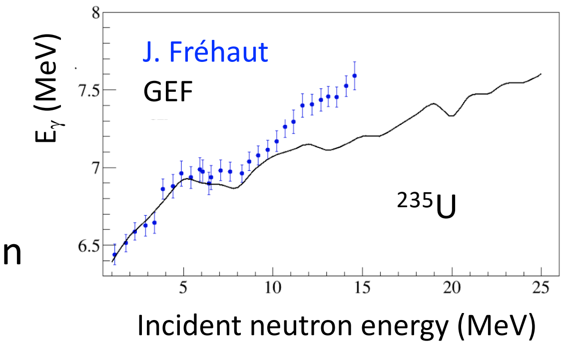
16 points with smaller statistics give a more precise result for total fission cross sectio

Experiments to be performed next year

1- A. Carlson et al., ND Sheets 148, Feb. 2018, Pages 143-188
2- D. Tarrio et al., EPJ Web of Conferences 146, 03026 (2017)

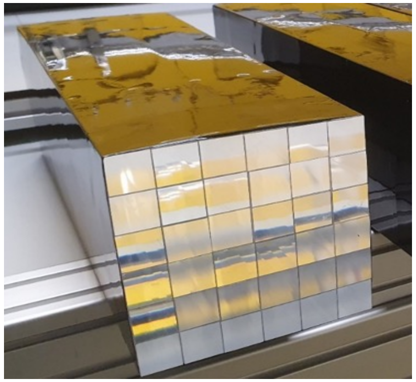
SCONE : Neutron and gamma measurement for fission study
Measurement of (n,xn) reaction cross sections

- *Need of complete neutron multiplicity distribution and total γ energy*

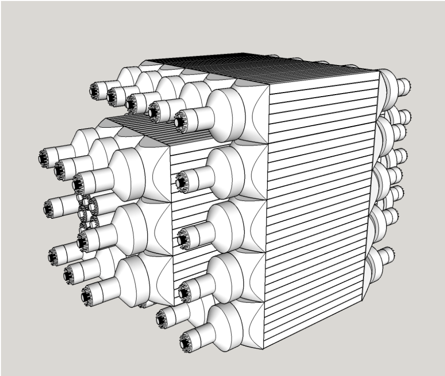


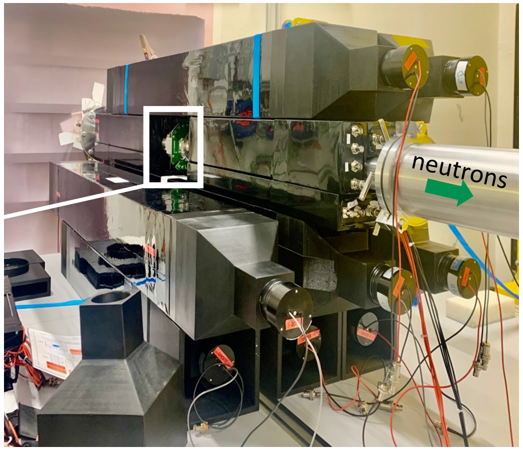
Fission chamber + Plastic scintillator (with Gd doped foils) for n & γ detection

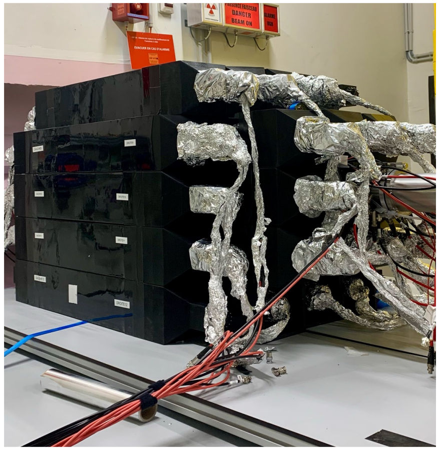
1 SCONE assembly

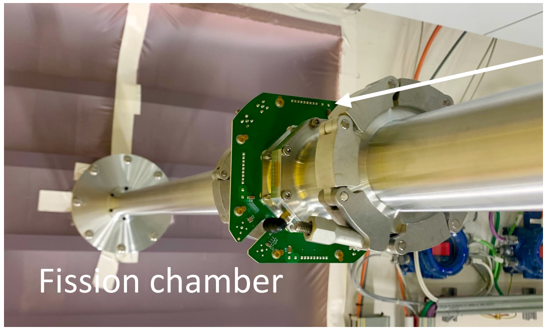


8 assemblies of 1 m
16 assemblies of 50 cm
8 central assemblies of 40 cm









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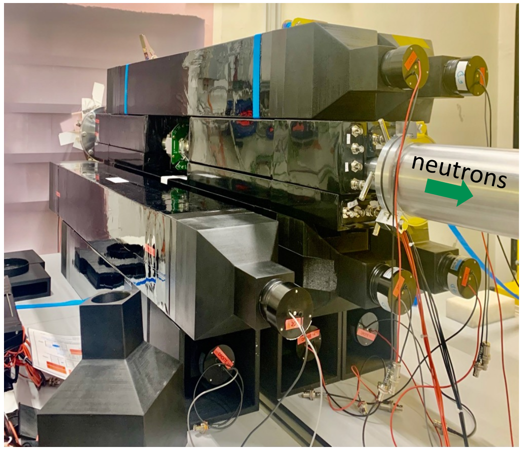
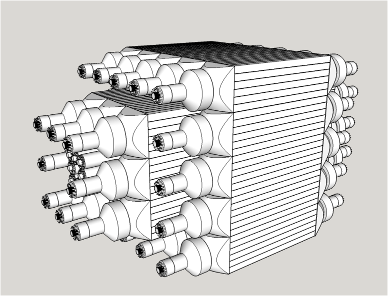
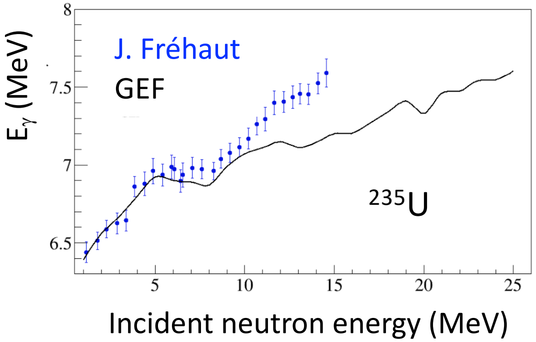
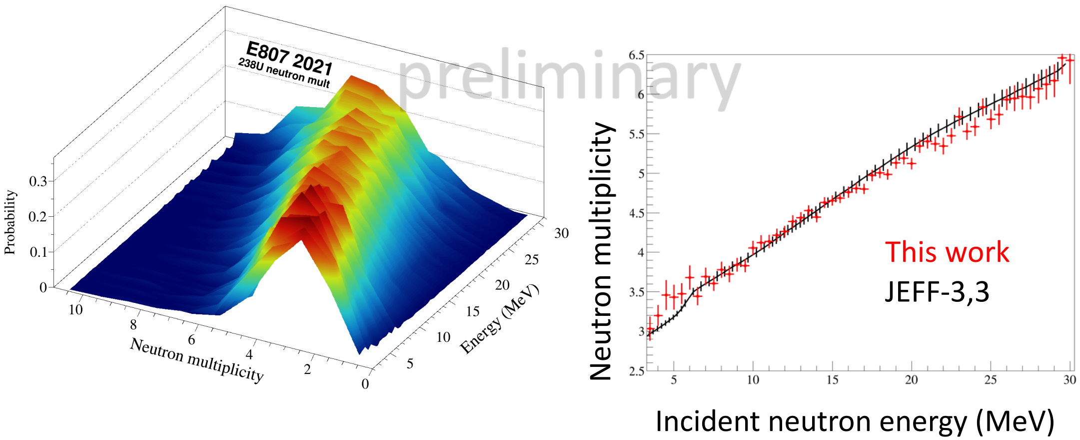




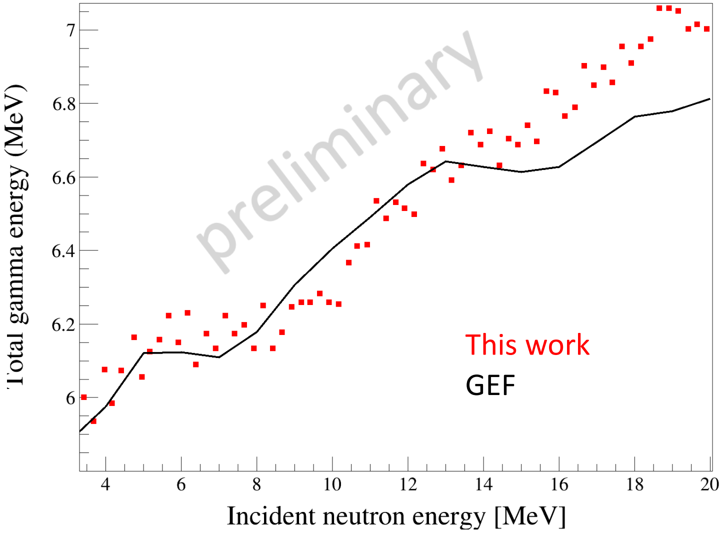
For n & γ detection:
896 Plastic scintillator bars
2316 Gd doped foils



2021 experiment: ^{238}U

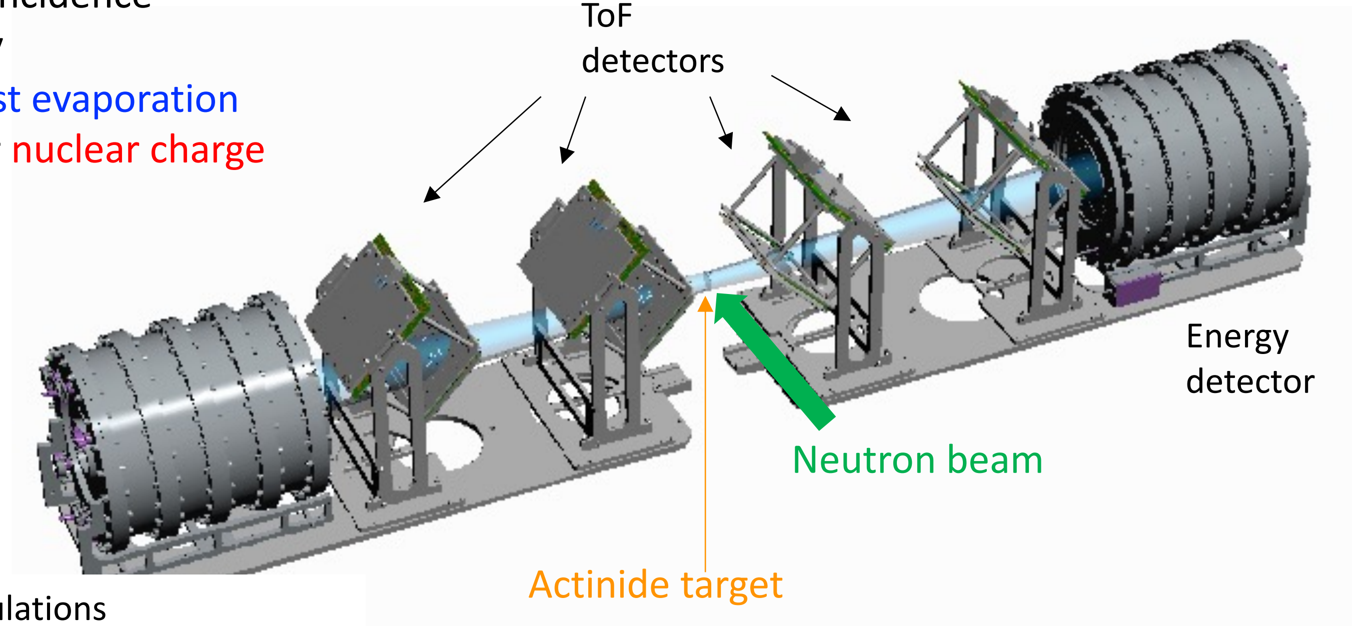


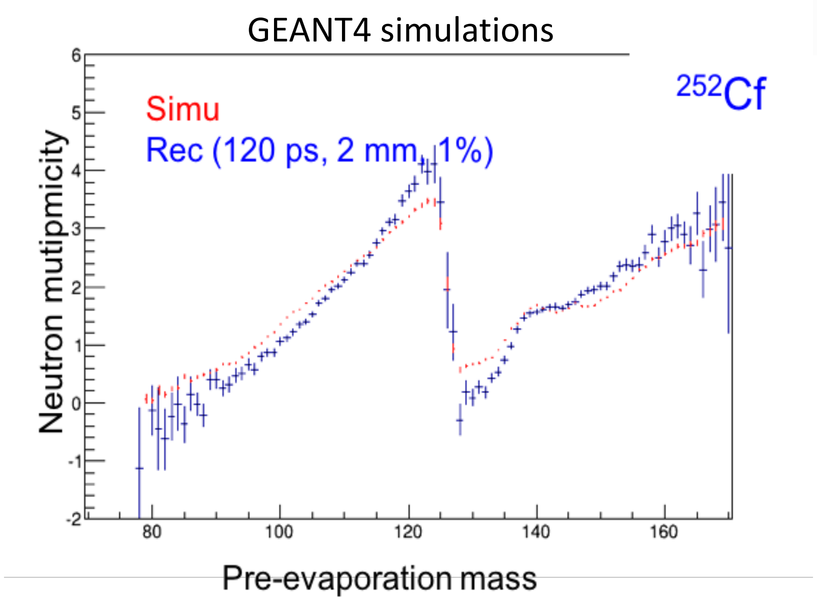
2021 experiment: ^{238}U



Very preliminary results
Analysis in progress

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

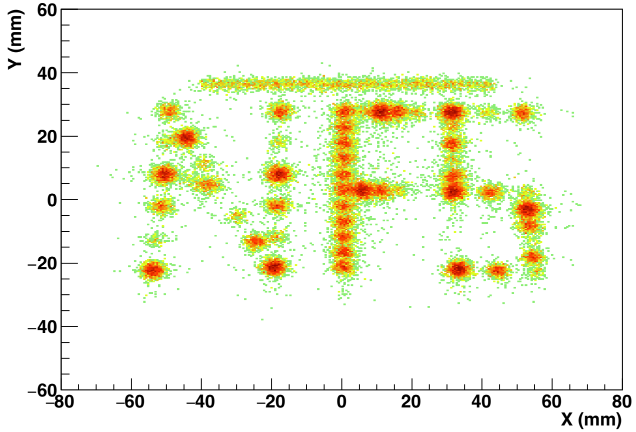




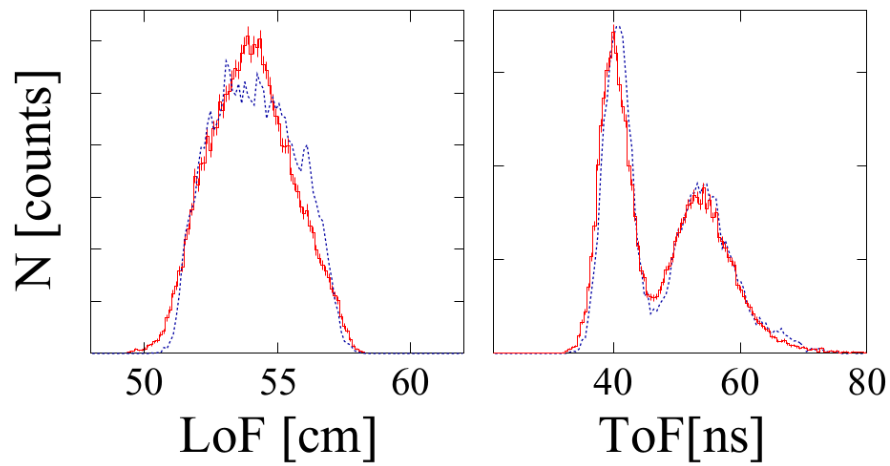
TOF detectors : σ(t) = 120 ps & σ(xy) = 2 mm
Axial IC: σ(E)/E ~1%
Pre-evap. fragment masses (2V): σ(A) ~1 uma
Post-evap. fragment masses (EV): σ(A) ~2 uma

FALSTAFF results with a Cf-252 source

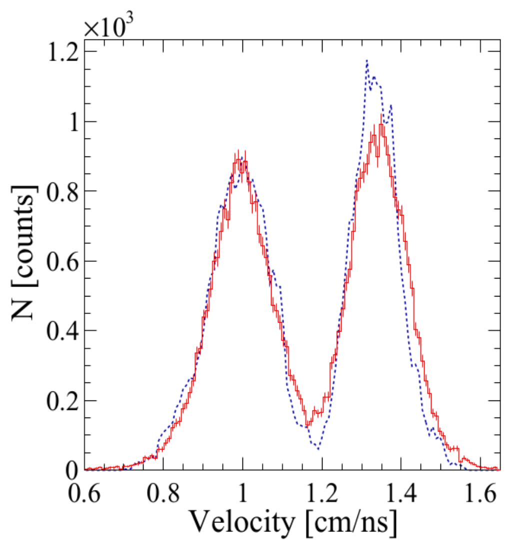
Good resolution (σ=1.2 mm) and good position reconstruction

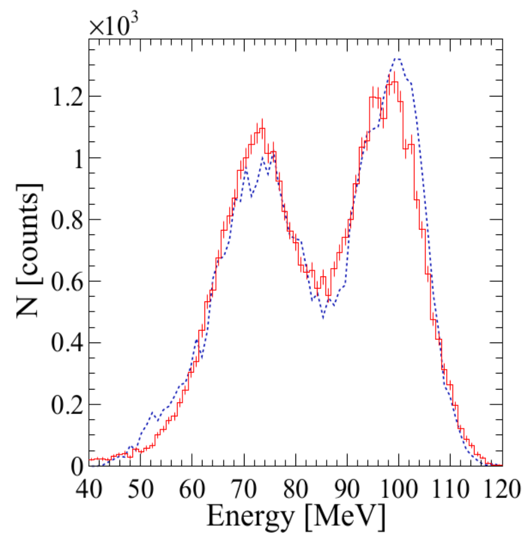


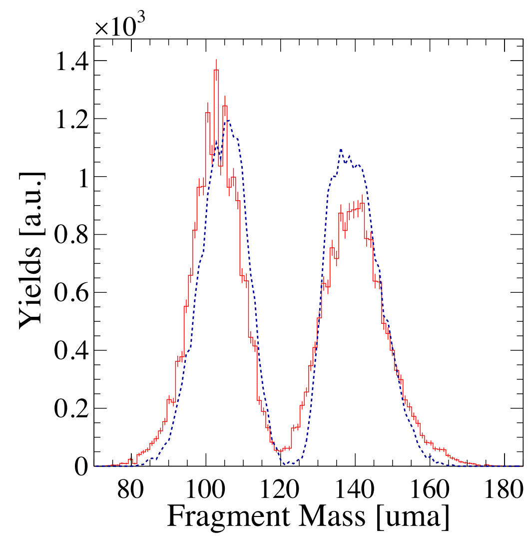
Data GEF



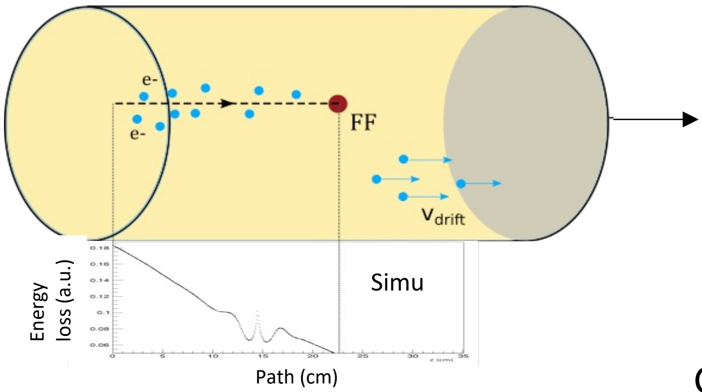
Data GEF

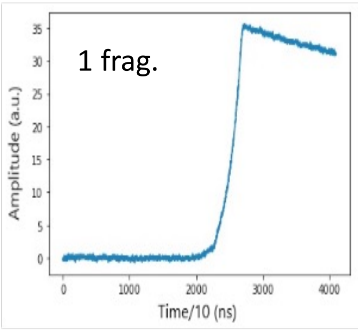


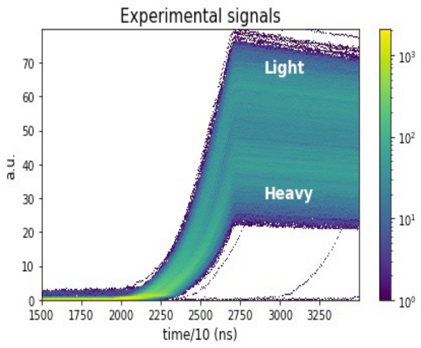




Energy loss profile in the axial ionization chamber

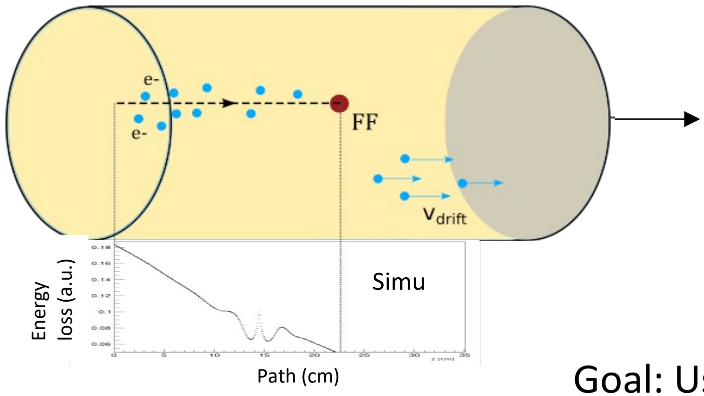


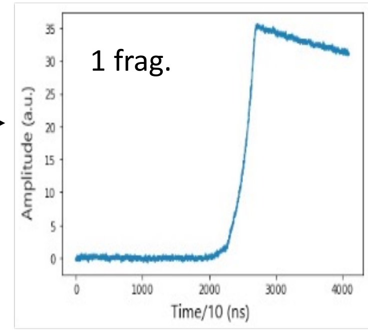


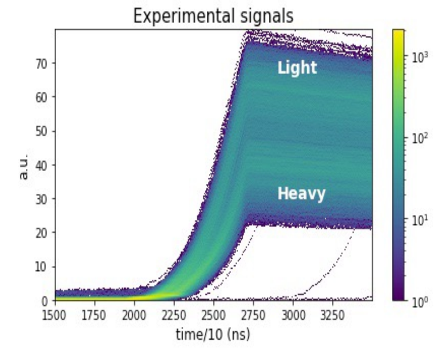


Goal: Use of neural networks to identify fragment nuclear charge using the energy loss profile

Energy loss profile in the axial ionization chamber

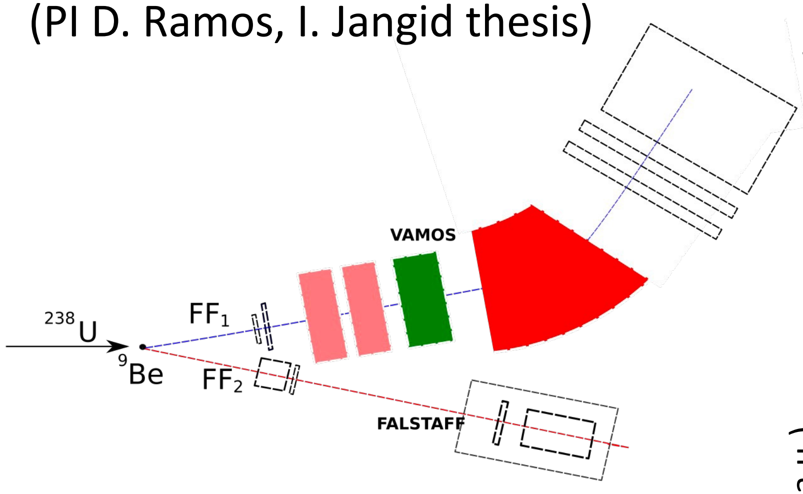




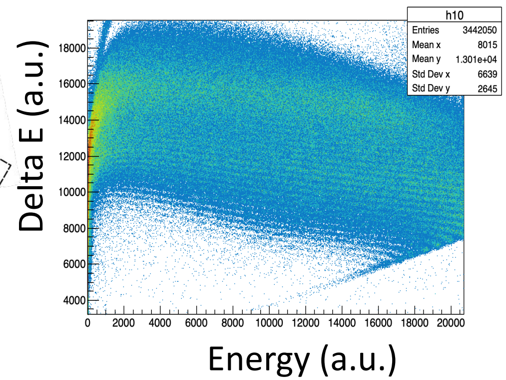


Goal: Use of convolutional neural networks to identify fragment nuclear charge using the energy loss profile

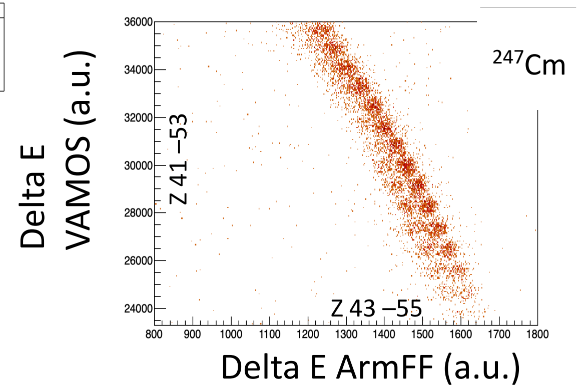
Experiment FALSTAFF@VAMOS (PI D. Ramos, I. Jangid thesis)

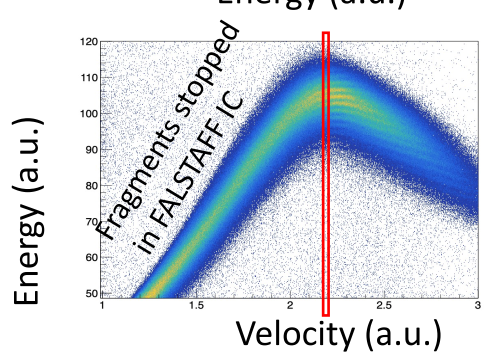


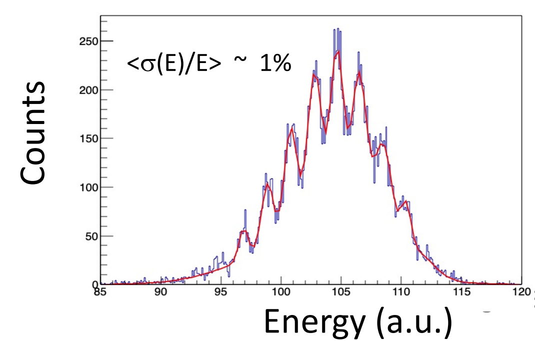
VAMOS charge identification



Correlations VAMOS – $ArmFF_2$

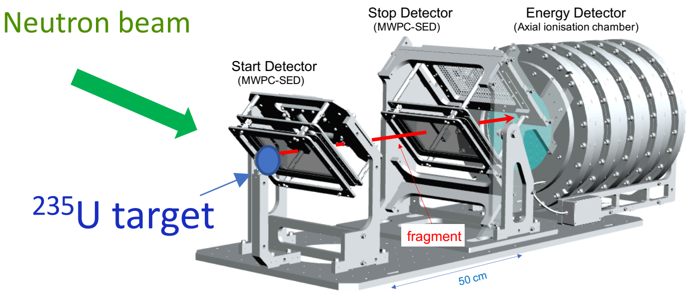


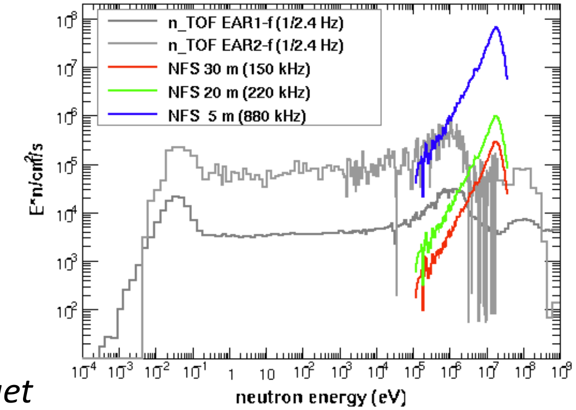




D. Doré et al., GCM, October 2022

^{235}U Fission fragment study with FALSTAFF at NFS



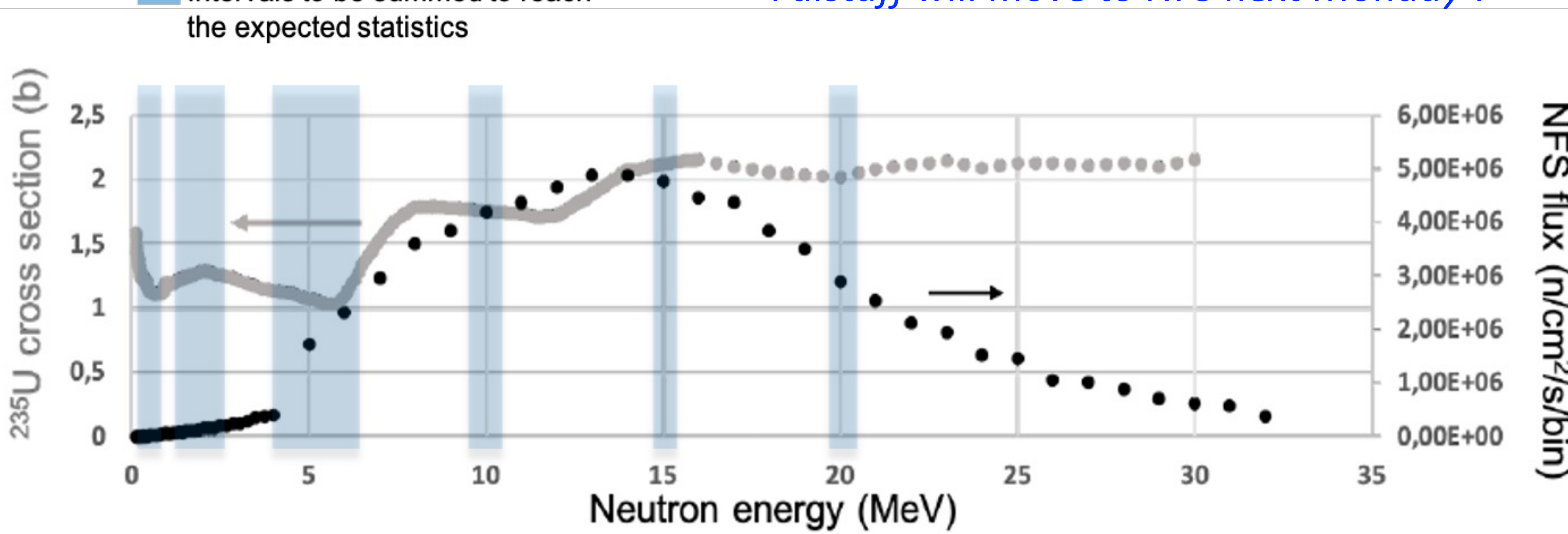


+2 LaBr3 (Subatech, Nantes) detectors close to the target

In 2020 (proposal), there were no similar data over a large incident energy range.

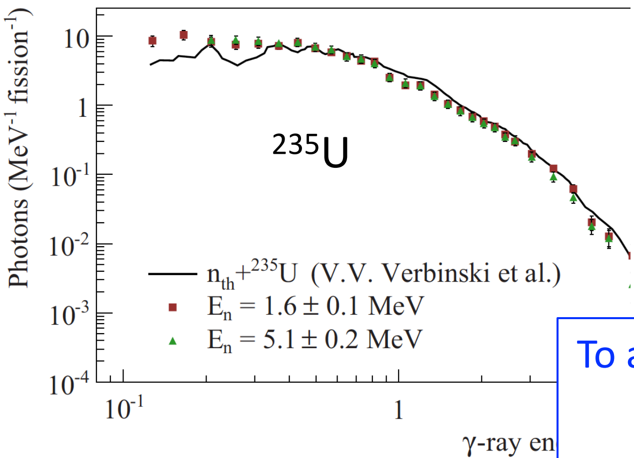
Target is at GANIL

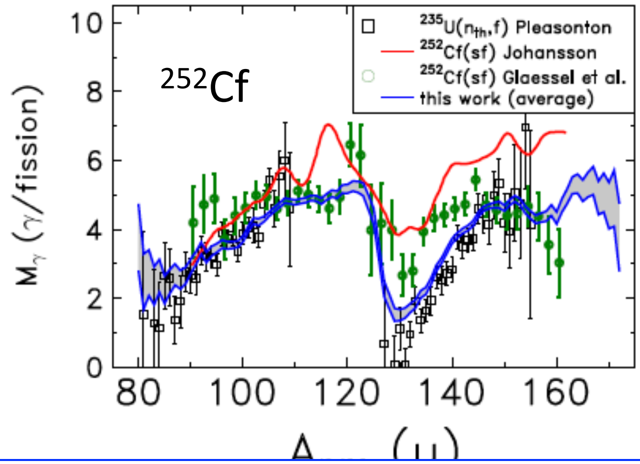
Falstaff will move to NFS next Monday !

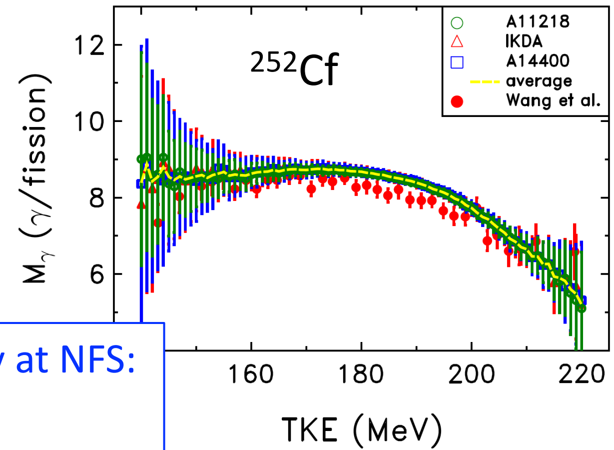


Other possible experiments at NFS

See S. Oberstedt presnetation at NFS Workshop April 2022 (references therein) and others…







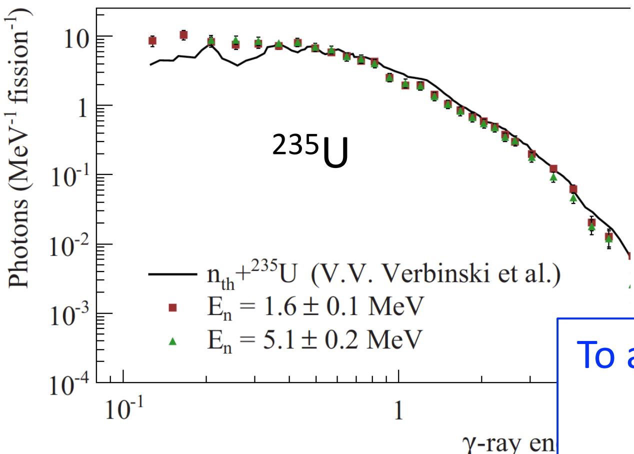
To add information, one could also study at NFS:

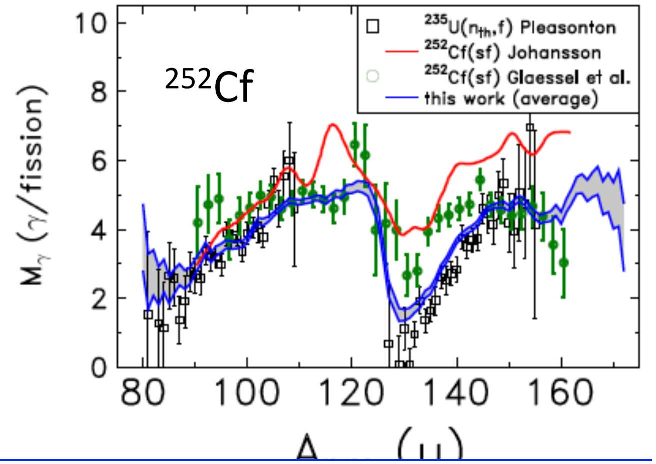
- Gamma energy spectrum
- Gamma mult. vs
  A_{frag}, TKE_{frag}, angle, E_n
- Angular gamma distribution
- Isomeric yield ratio
- ternary fission (angular distribution)

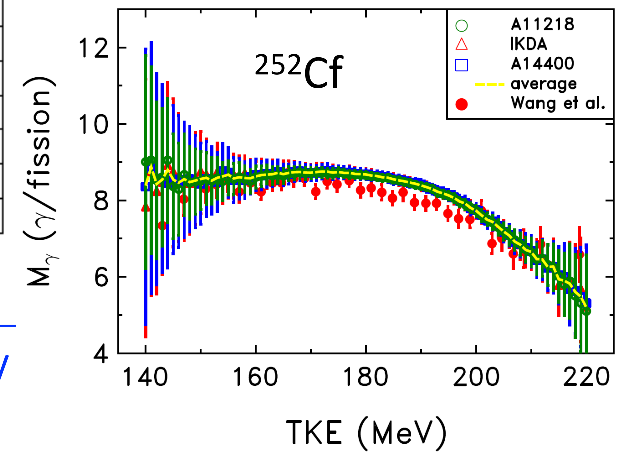
…

Other possible experiments at NFS

See S. Oberstedt contribution at NFS Workshop April 2022 (references therein) and others…







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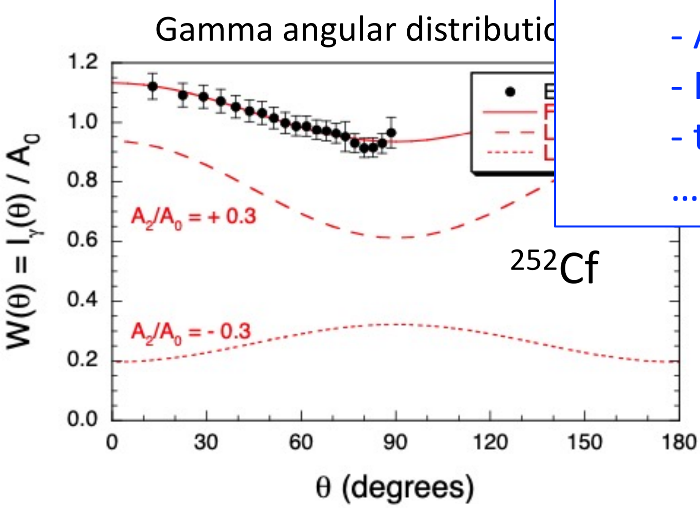
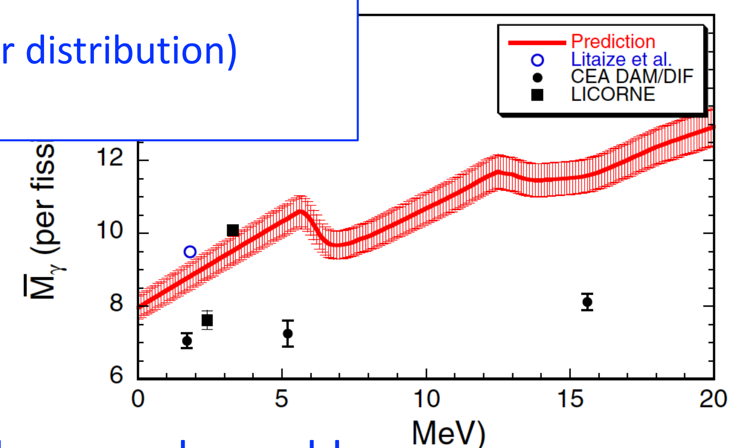


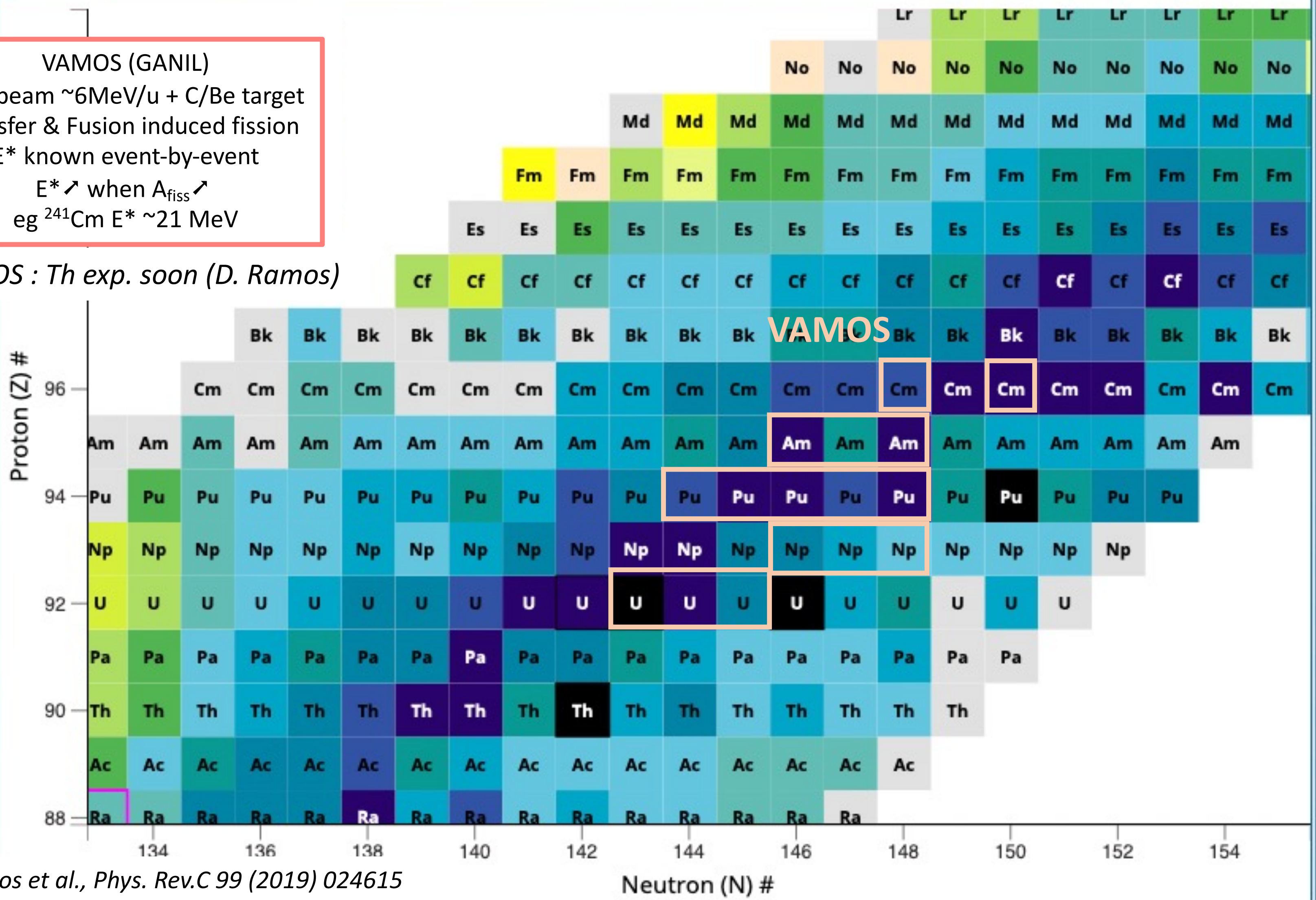


→ Different exp. setups to study same observables

Comparisons with two other fission experiments

VAMOS (GANIL)
^{238}U beam ~6MeV/u + C/Be target
Transfer & Fusion induced fission
E* known event-by-event
E*↗ when A_{fiss}↗
eg ^{241}Cm E* ~21 MeV

VAMOS : Th exp. soon (D. Ramos)



D. Ramos et al., Phys. Rev.C 99 (2019) 024615

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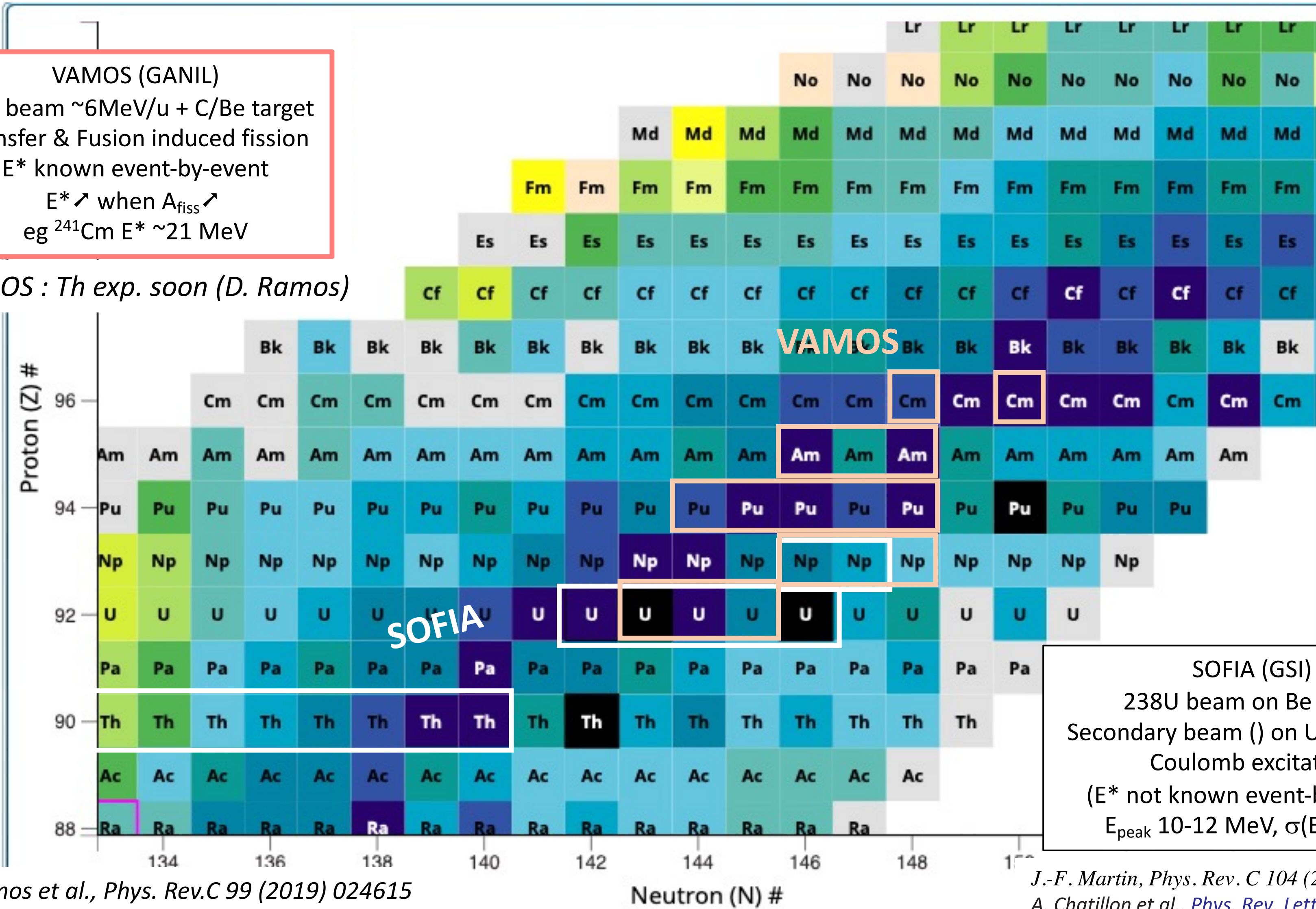
VAMOS : Th exp. soon (D. Ramos)



D. Ramos et al., Phys. Rev.C 99 (2019) 024615

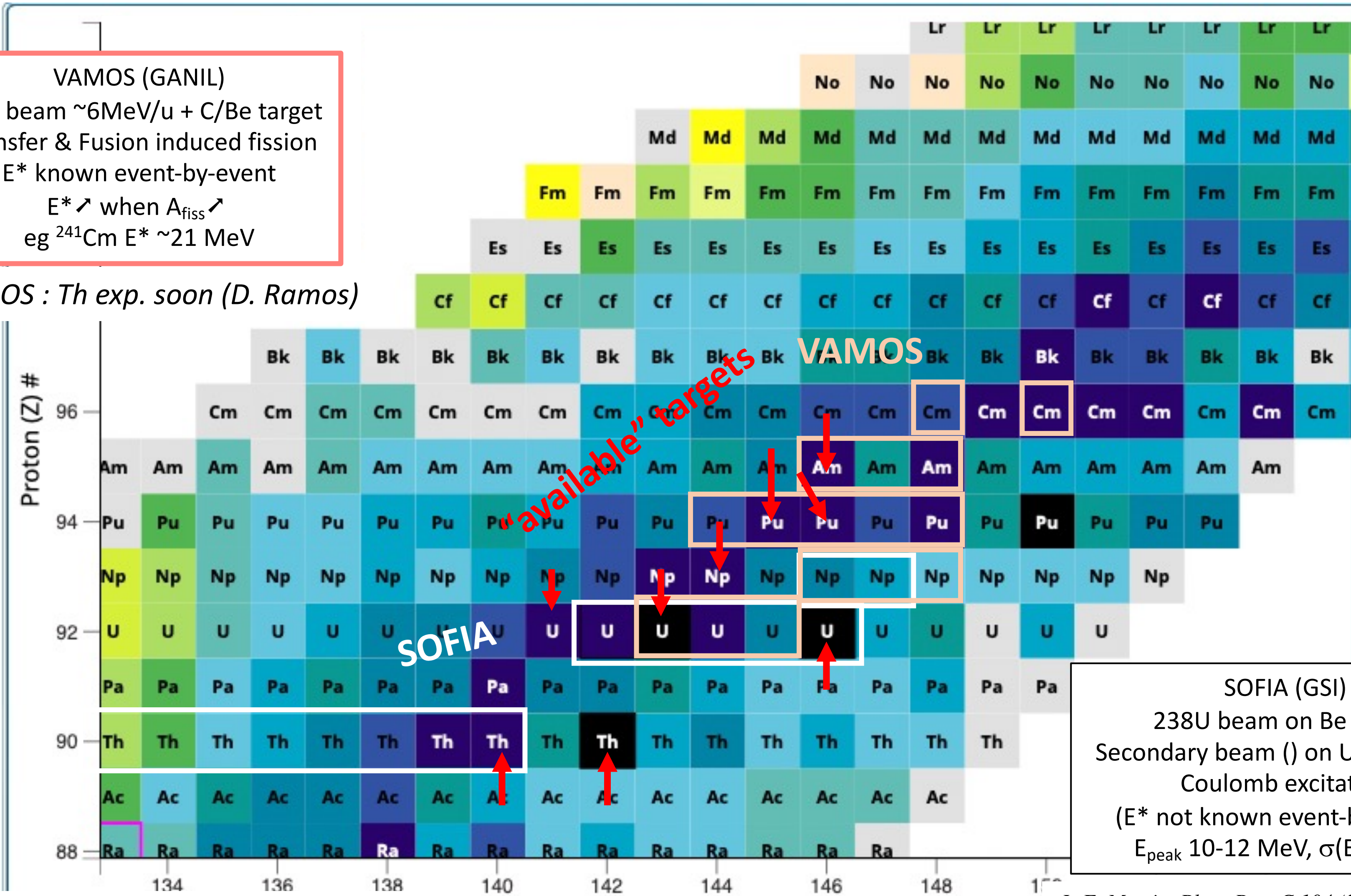
SOFIA (GSI)
238U beam on Be target
Secondary beam () on U/Pb targets
Coulomb excitation
(E* not known event-by -event)
E_{peak} 10-12 MeV, σ(E*) large

J.-F. Martin, Phys. Rev. C 104 (2021) 044602
A. Chatillon et al., Phys. Rev. Lett. 124, 202502 (2020) and references therein

Comparisons with two other fission experiments

VAMOS (GANIL)
^{238}U beam ~6MeV/u + C/Be target
Transfer & Fusion induced fission
E* known event-by-event
E*↗ when A_{fiss}↗
eg ^{241}Cm E* ~21 MeV

VAMOS : Th exp. soon (D. Ramos)



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Collaborations for fission accepted experiments at NFS

MEDLEY

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3 GANIL (Caen, France)
4 LPC Caen (ENSICAEN/CNRS-IN2P3/UCN)
5 Chiang Mai University (Thailand)
6 Kyushu University (Japan)

SCONE

G. Bélier[1], A. Francheteau[1], L. Gaudefroy[1], B. Fraisse[1], V. Méot[1], O. Roig[1], E. Berthoumieux[2], E. Dupont[2], F. Gunsing[2] X. Ledoux[3],D. Denis-Petit, B. Laurent, L. Lopez

1 CEA/DIF/DPTA, UPS/LMCE
2 CEA/IRFU/DPhN
3 GANIL
4 CEA/DIF/DCRE

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2) GANIL, Caen, France
3) European Commission, DG Joint Research Centre
4) CEA/DEN/DER/SPRC, Cadarache

Beginning of fission studies at NFS

SCONE has taken data, Falstaff is going to run next month and MEDLEY-fission will run next year.

But ,

Lot of different experiments could be performed:

to improve our understanding of fission process providing high quality nuclear data

Same goal, different approaches

Warning : High quality actinide targets needed !