

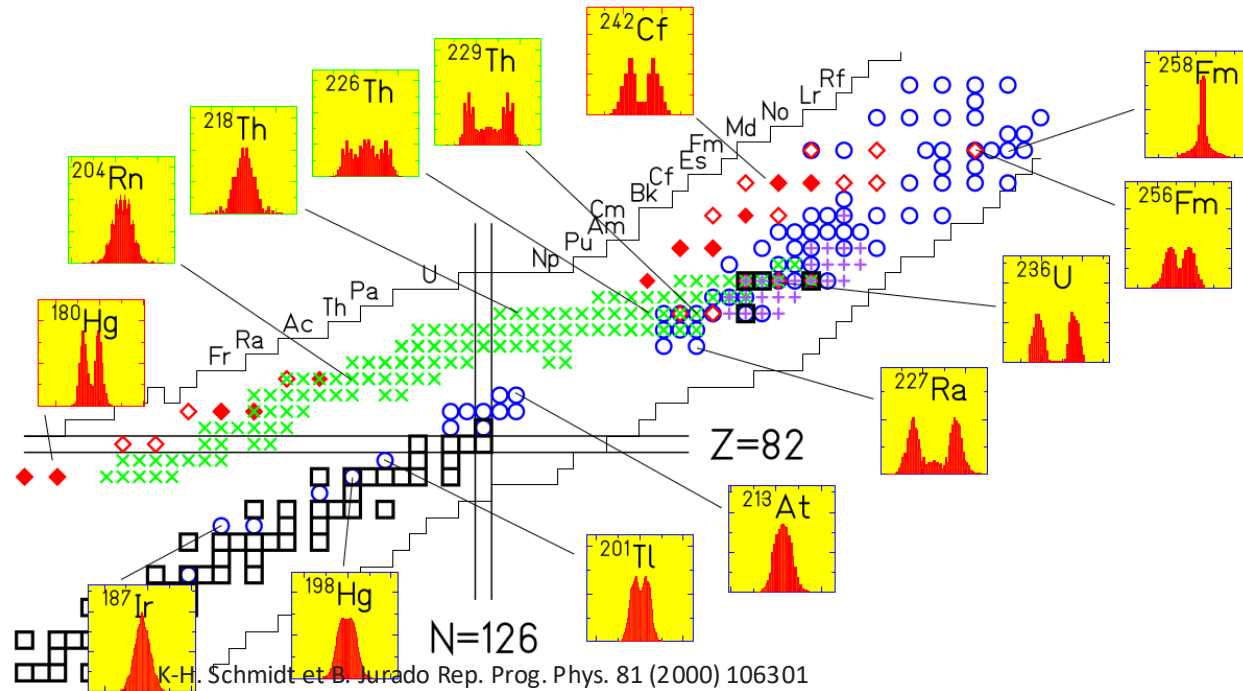


Experimental Fission Campaign at VAMOS++

Diego Ramos

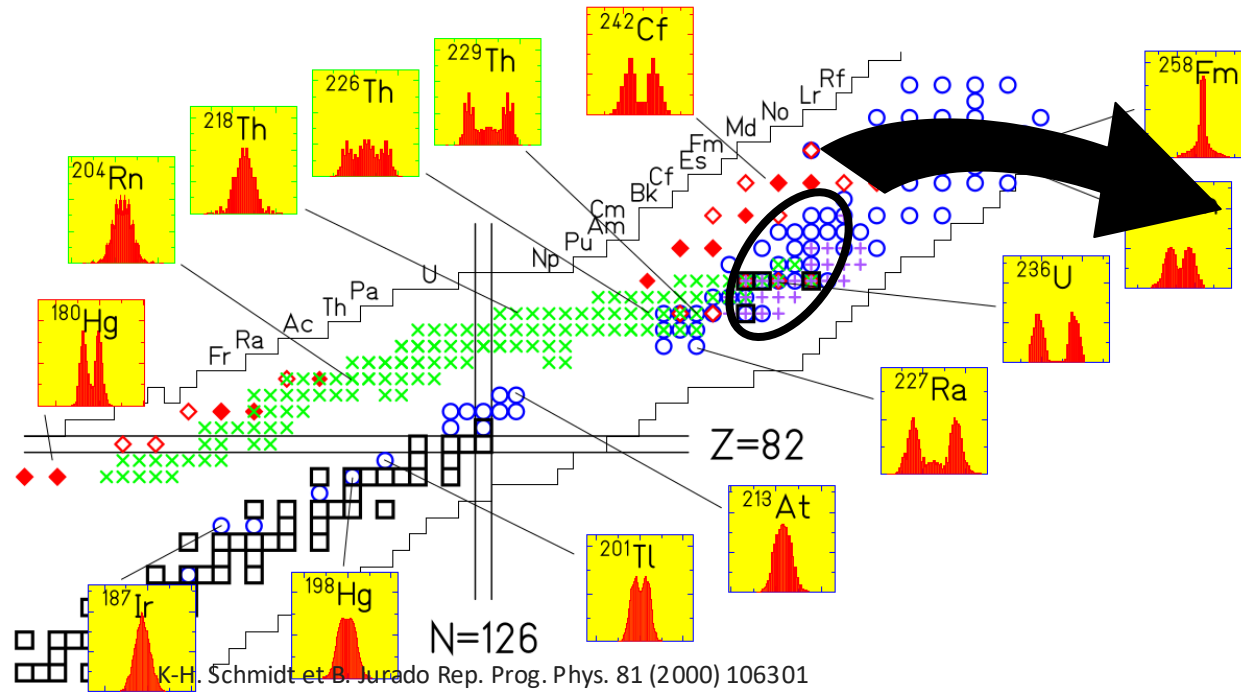
◆ FISSION@VAMOS

- Heavy ion Beams (Xe, Th, U, Pb)
- Inverse-Kinematics Surrogate-Induced Fission

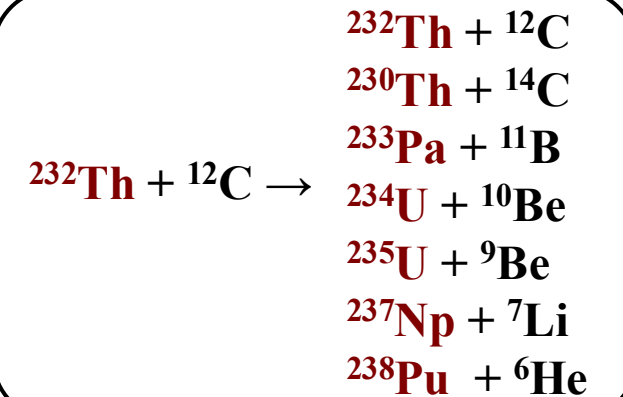
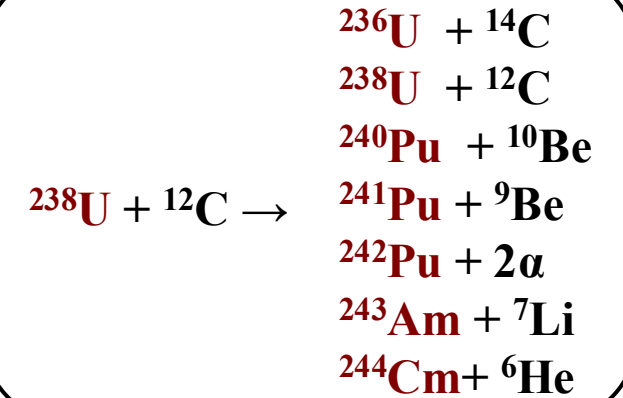


◆ FISSION@VAMOS

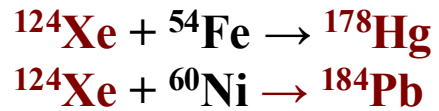
- Heavy ion Beams (Xe,Th,U, Pb)
- Inverse-Kinematics Surrogate-Induced Fission



• MultiNucleon Transfer Reactions



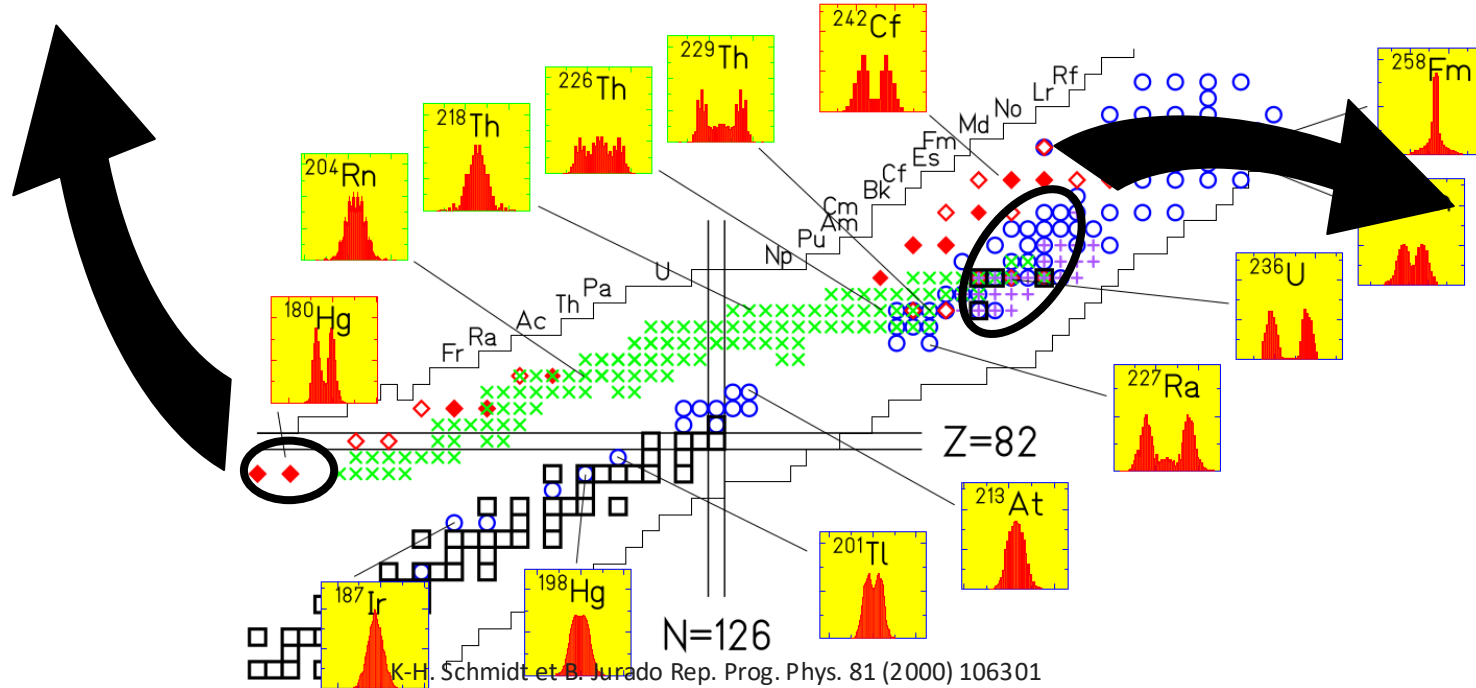
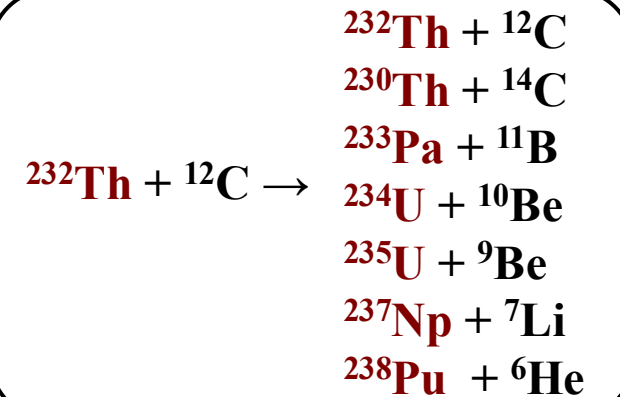
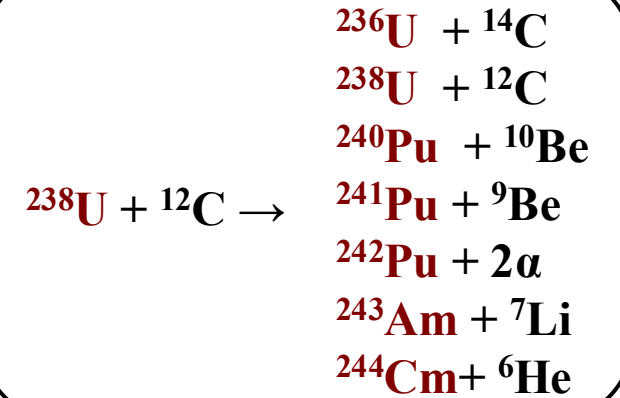
• Fusion Reactions



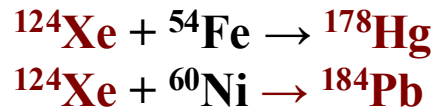
◆ FISSION@VAMOS

- Heavy ion Beams (Xe, Th, U, Pb)
- Inverse-Kinematics Surrogate-Induced Fission

• MultiNucleon Transfer Reactions



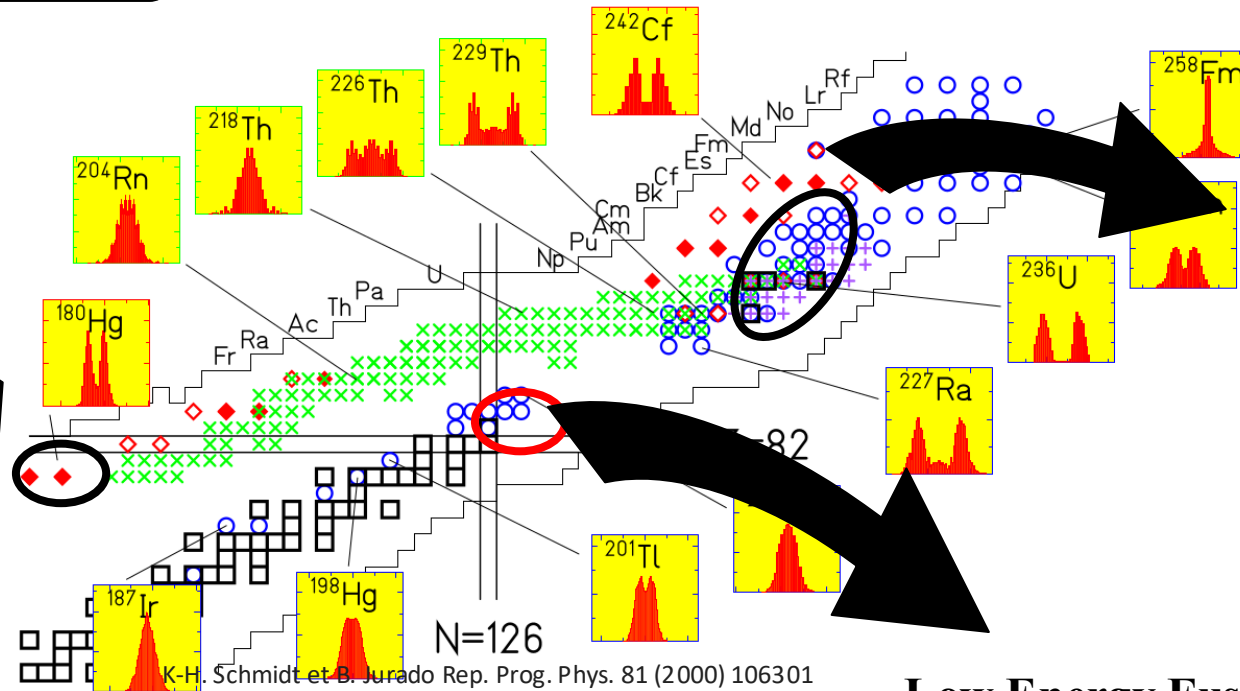
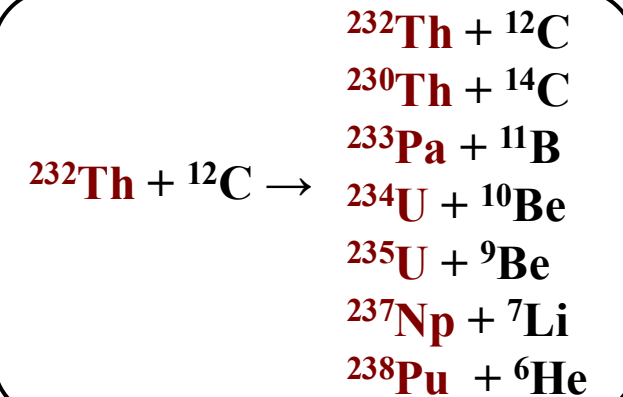
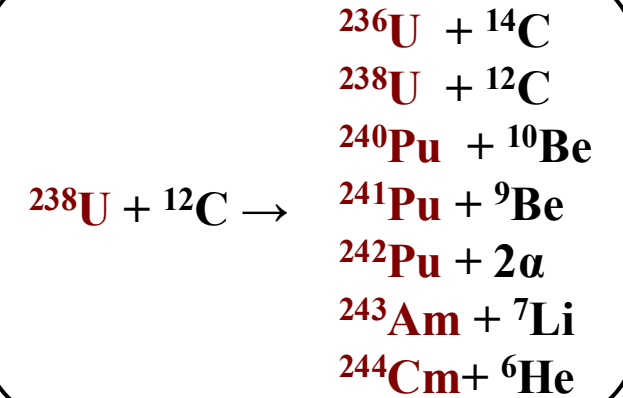
• Fusion Reactions



◆ FISSION@VAMOS

- Heavy ion Beams (Xe,Th,U, Pb)
- Inverse-Kinematics Surrogate-Induced Fission

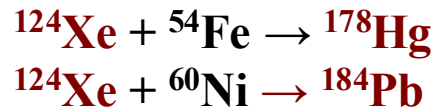
• MultiNucleon Transfer Reactions



• Low Energy Fusion



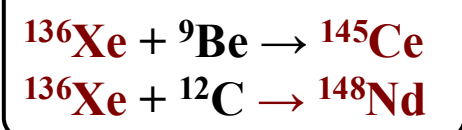
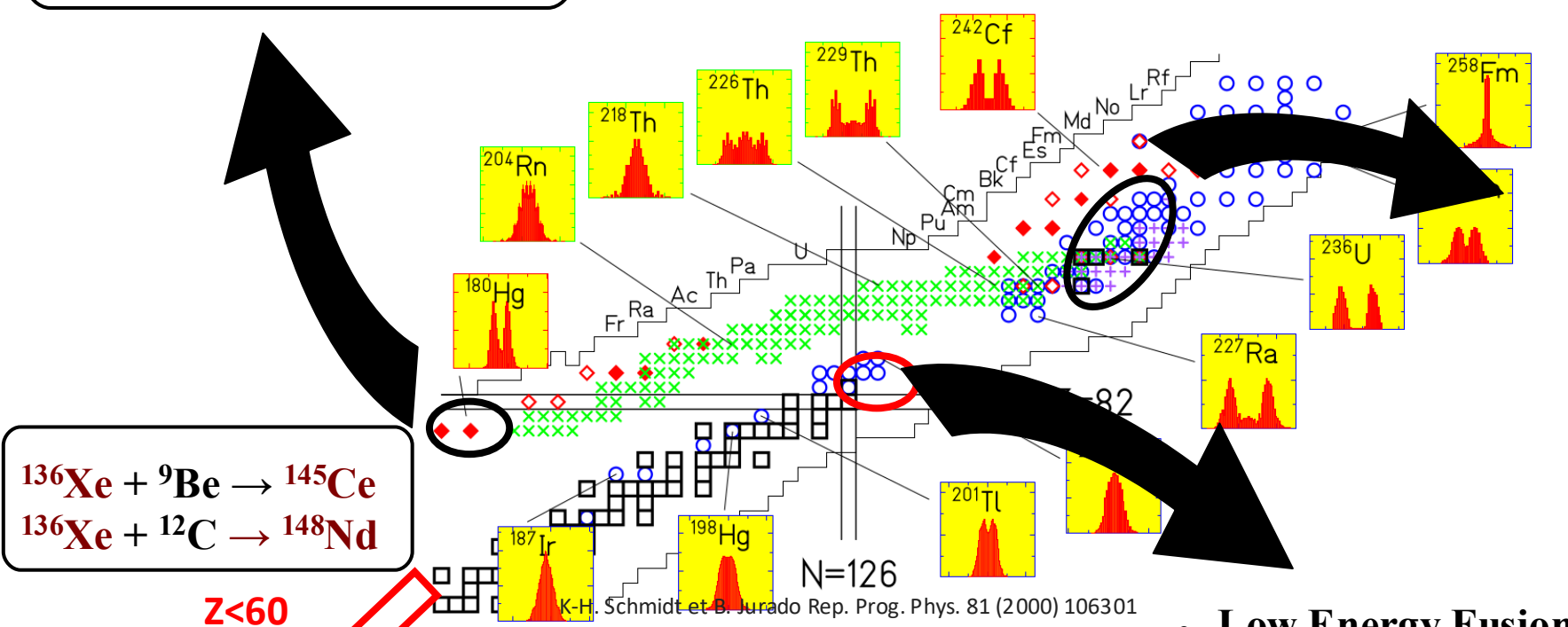
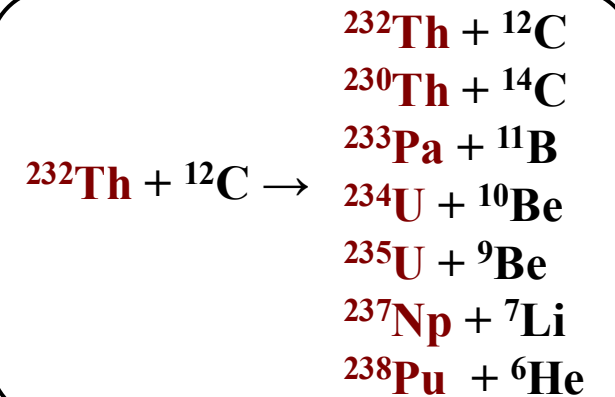
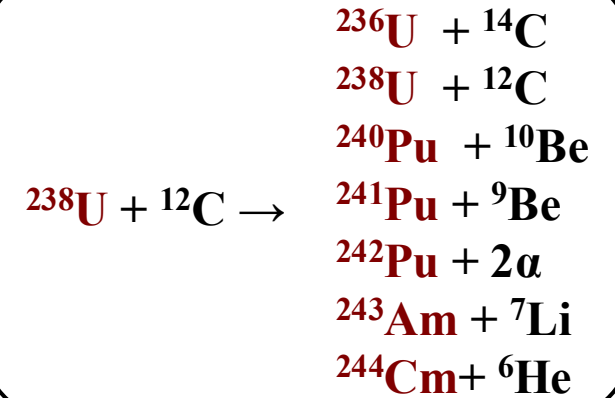
• Fusion Reactions



◆ FISSION@VAMOS

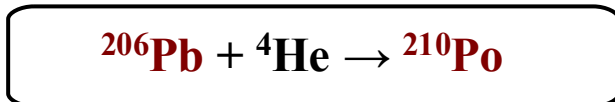
- Heavy ion Beams (Xe,Th,U, Pb)
- Inverse-Kinematics Surrogate-Induced Fission

• MultiNucleon Transfer Reactions

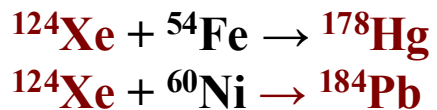


Z < 60

• Low Energy Fusion



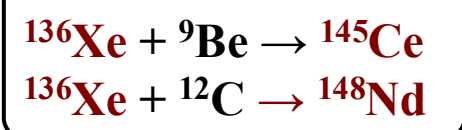
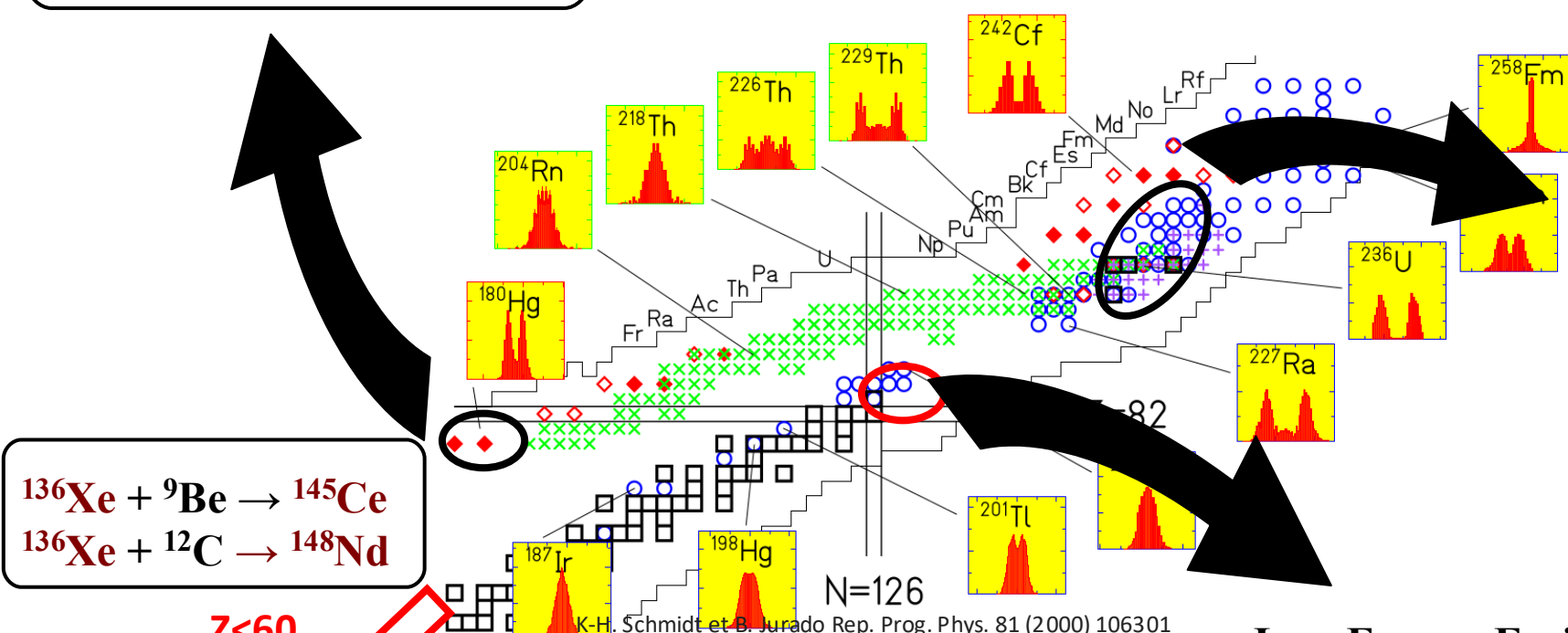
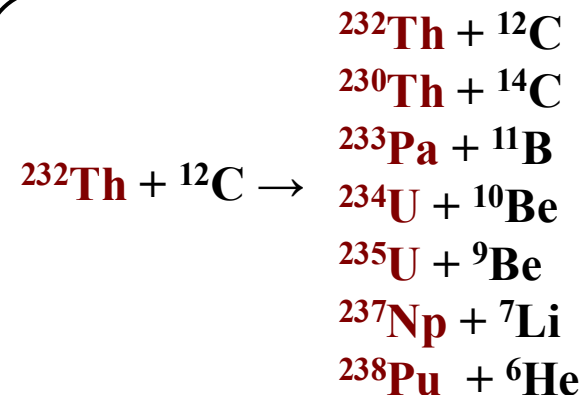
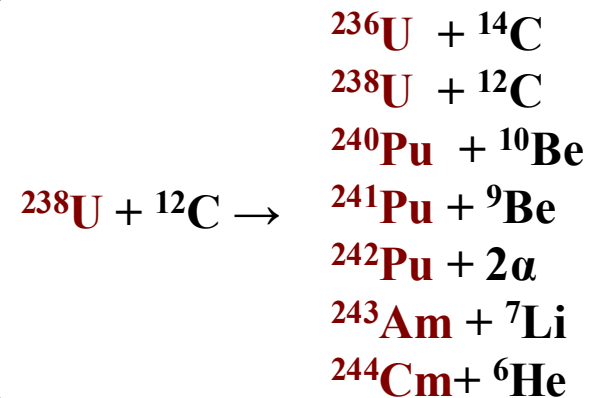
• Fusion Reactions



◆ FISSION@VAMOS

- Heavy ion Beams (Xe,Th,U, Pb)
- Inverse-Kinematics Surrogate-Induced Fission

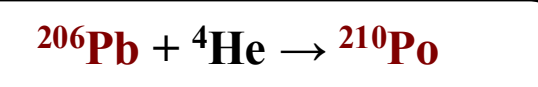
• MultiNucleon Transfer Reactions



Z < 60

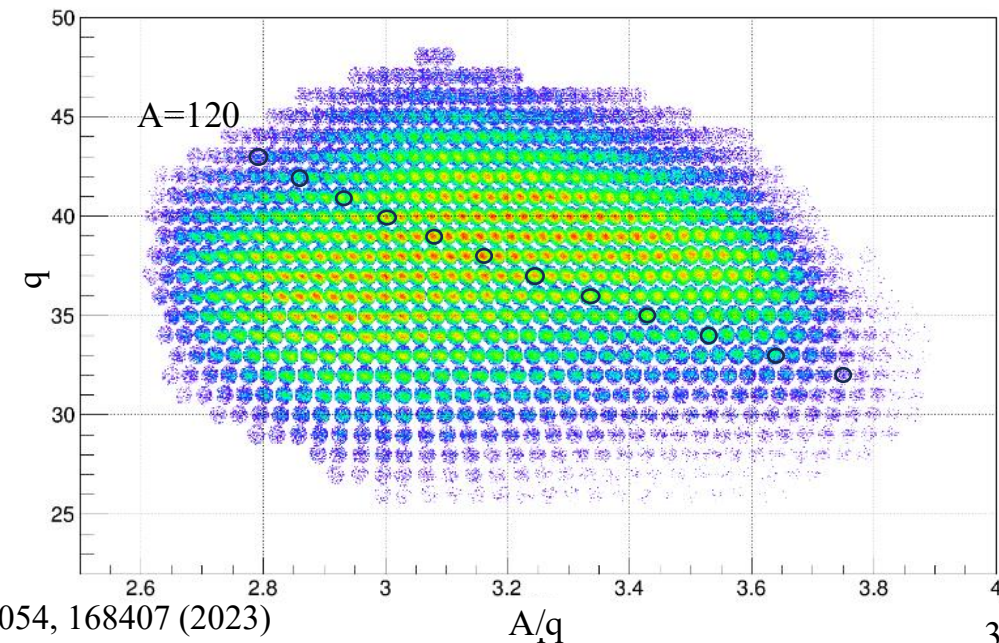
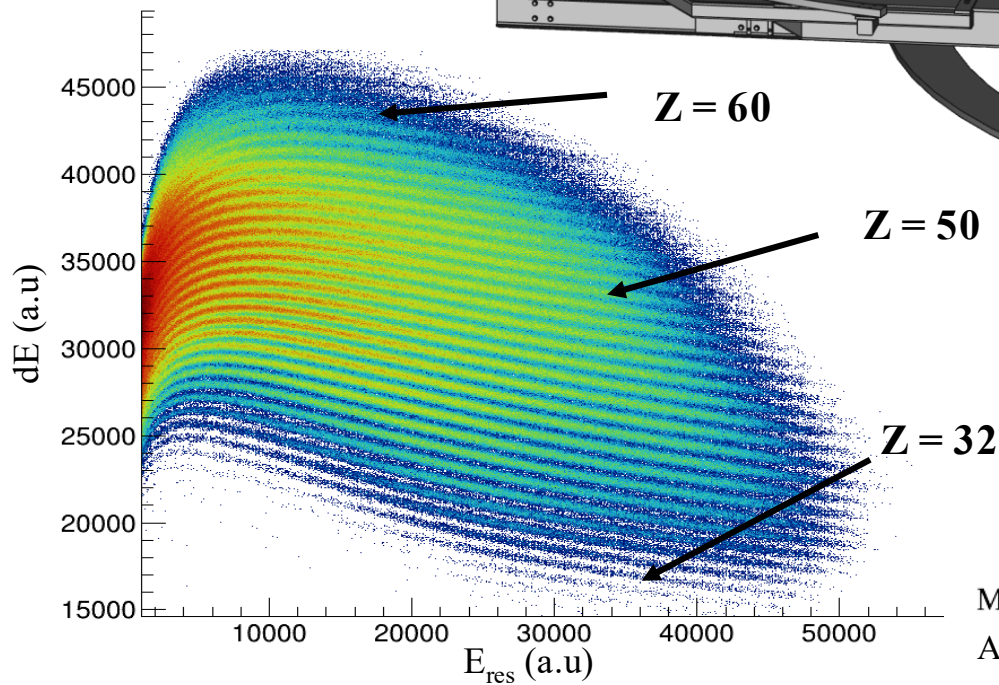
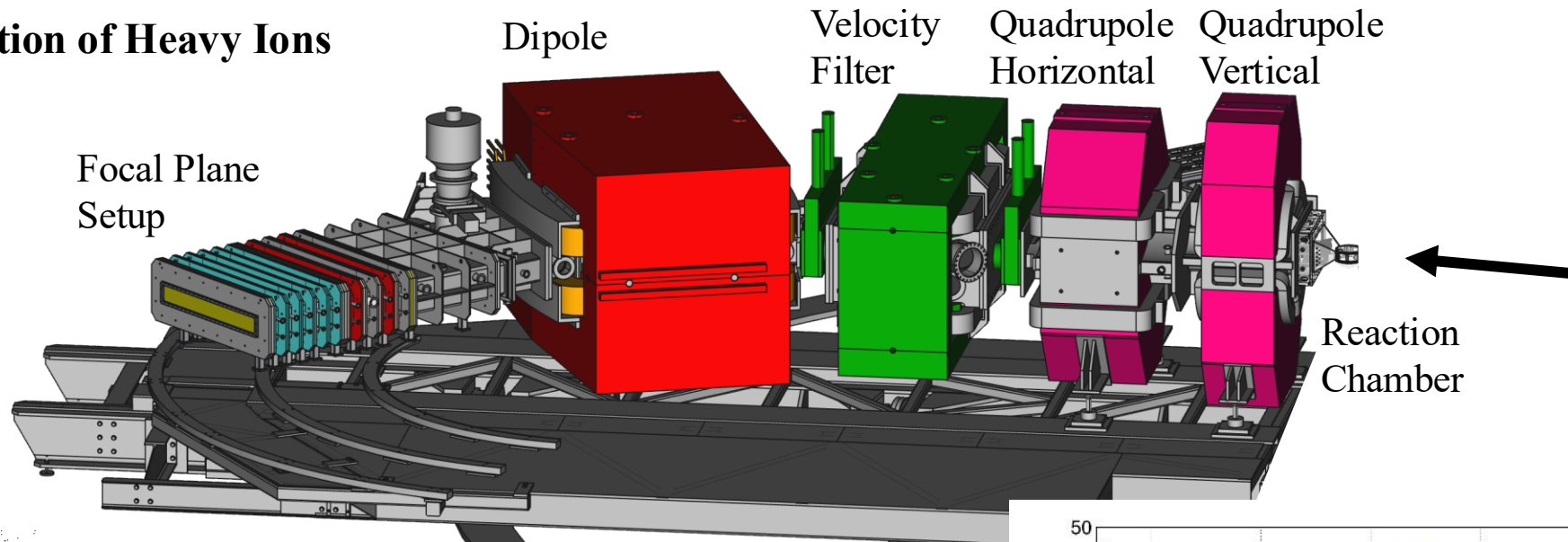
N = 126

• Low Energy Fusion



Complete Isotopic-distribution of fission-fragments Yields

Isotopic Identification of Heavy Ions

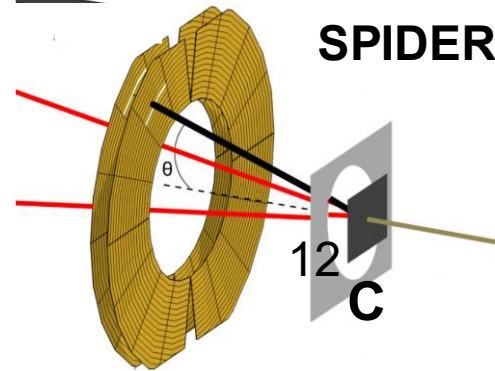
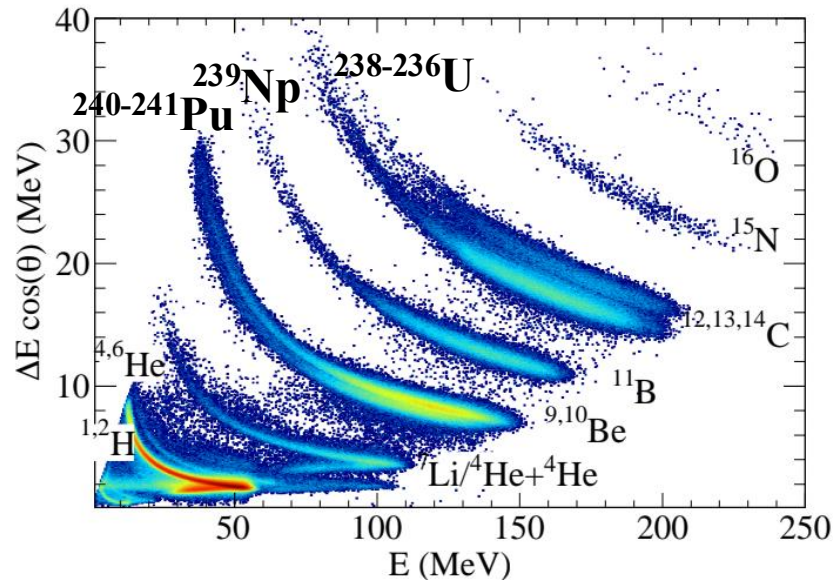
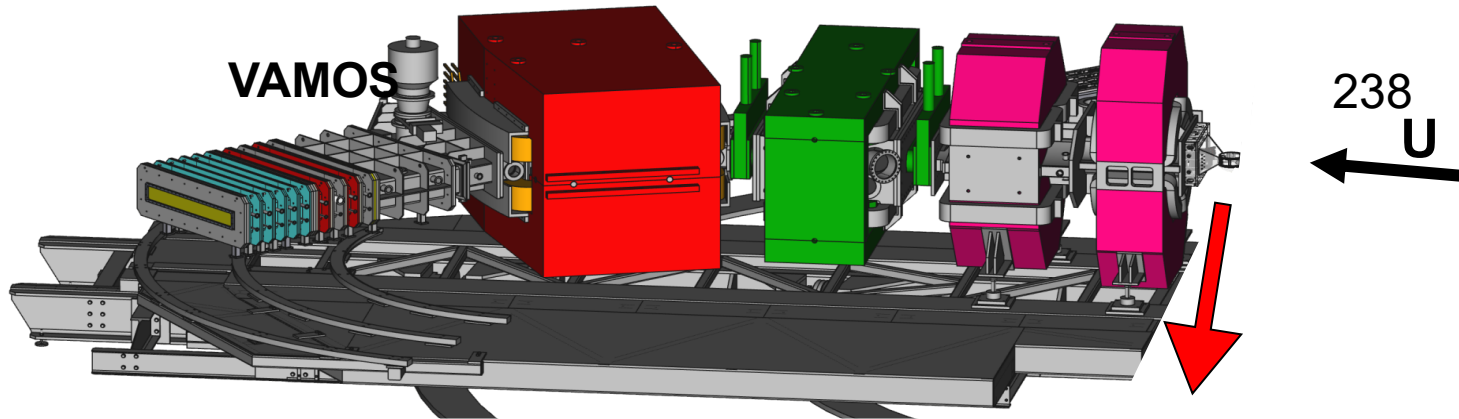


M. Rejmund et al., NIM A 646 (2011) 184

A. Lemasson & M. Rejmund, NIM A 1054, 168407 (2023)

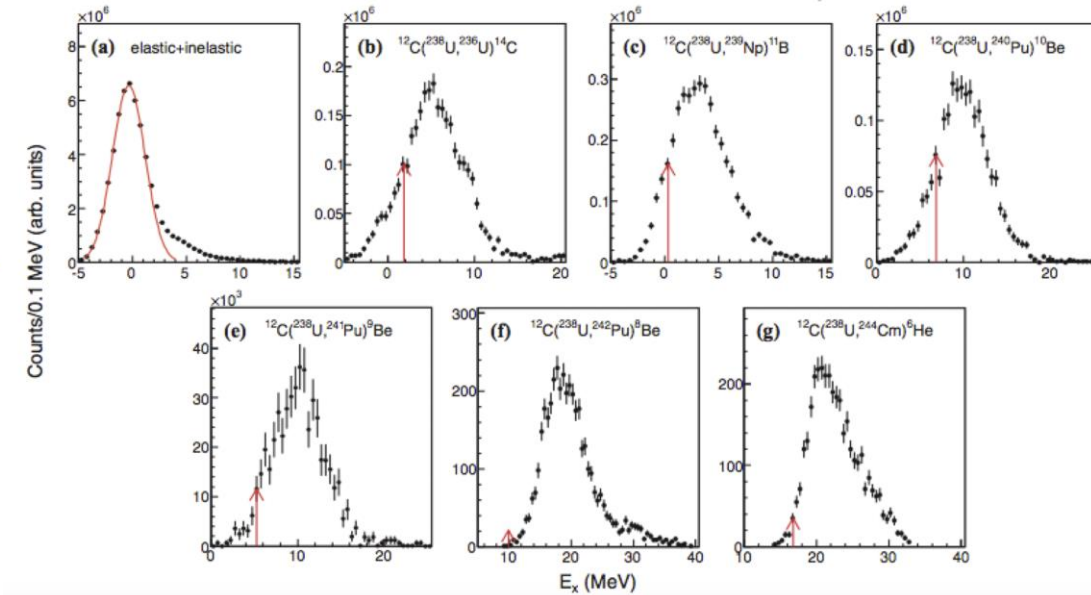
Multi-nucleon Transfer Reactions
Access to Actinides

- ^{238}U beam at ~ 6 MeV/u (Coulomb energies)

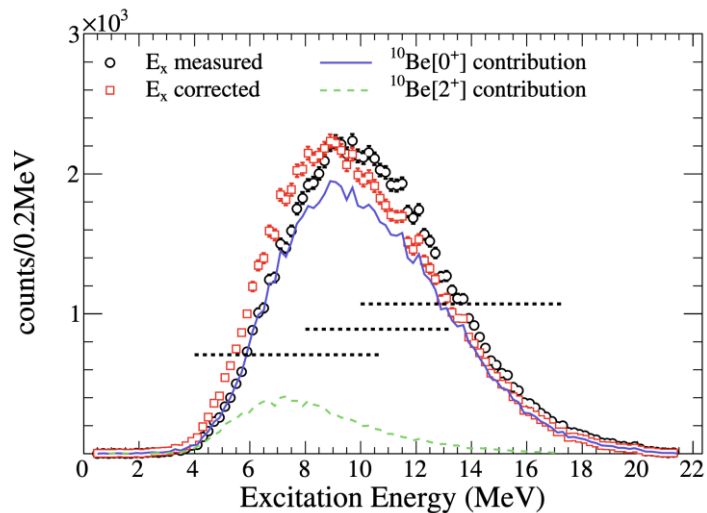
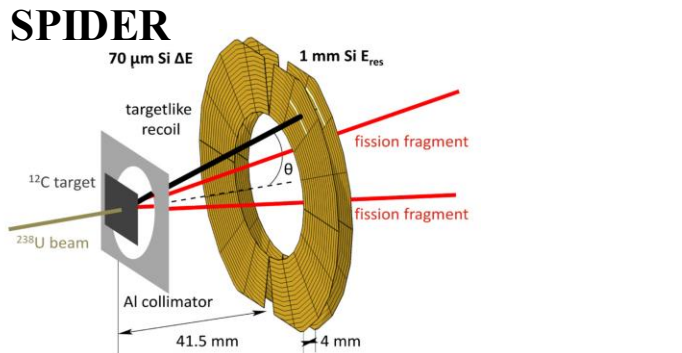


• STRIP SILICON TELESCOPE

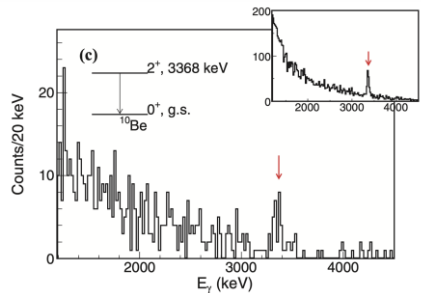
- Identification of the fissioning system by detection of the target-like recoil
- Measurement of the Excitation Energy by reconstruction the binary reaction
- Measurement to fission probabilities by detection of fission fragments



E_x Resolution = 2.7 MeV (FWHM)

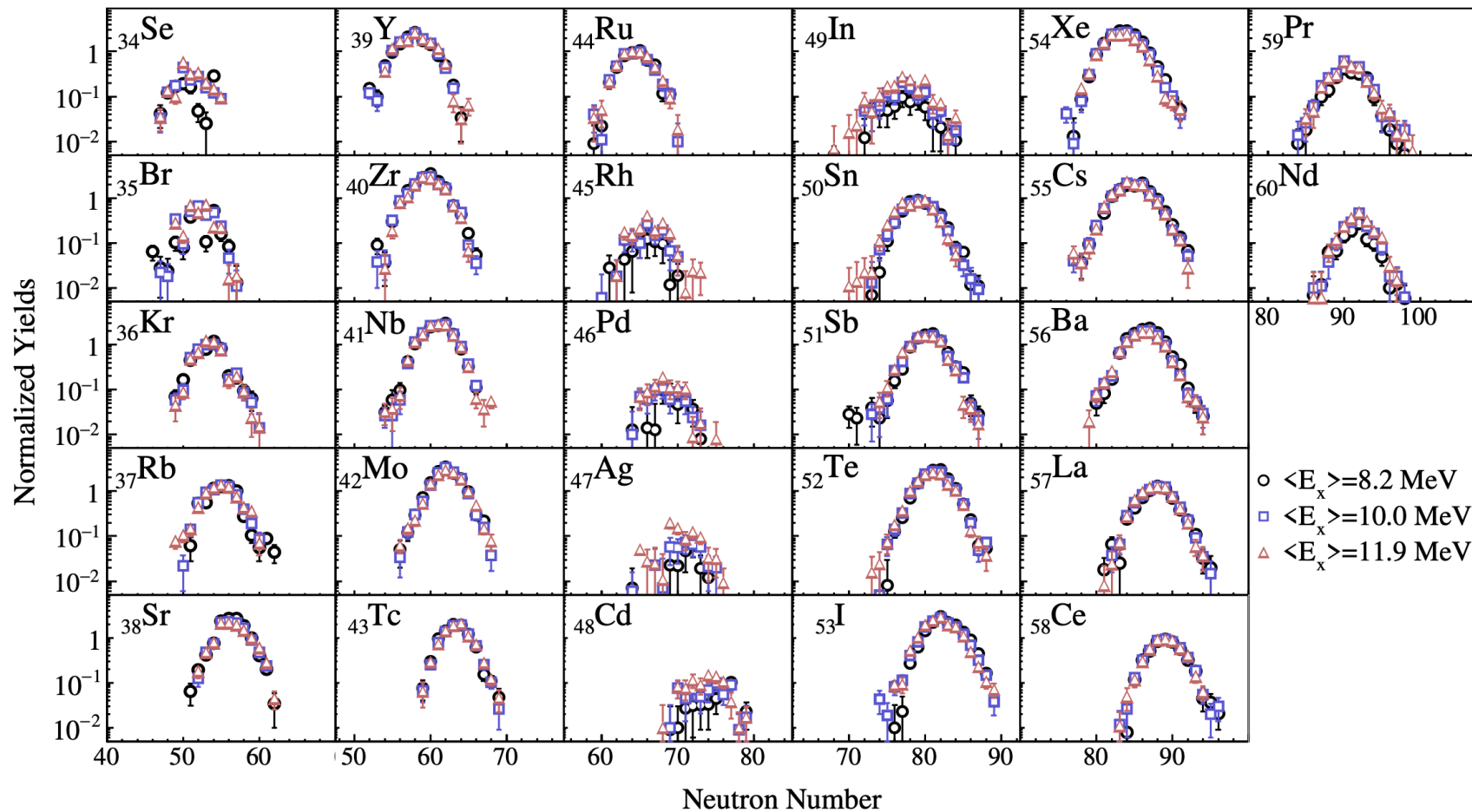


EXOGRAM



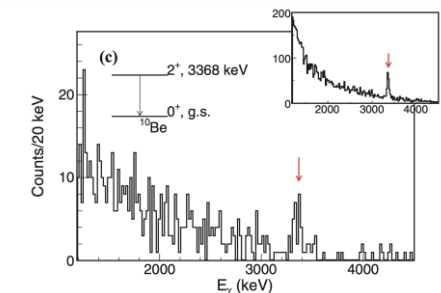
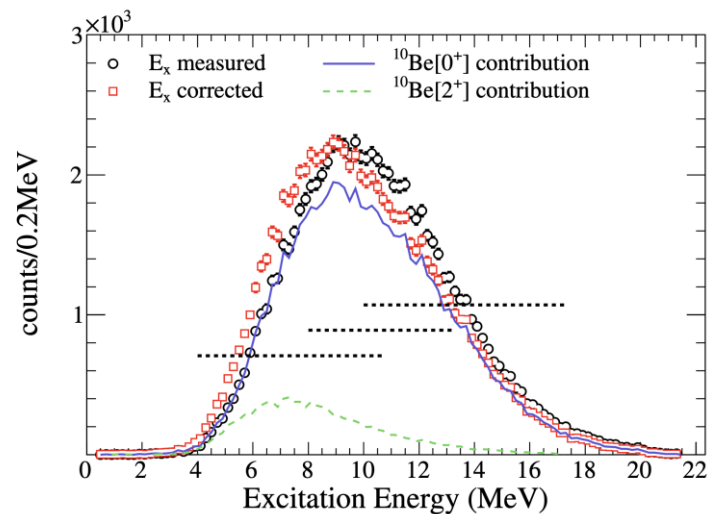
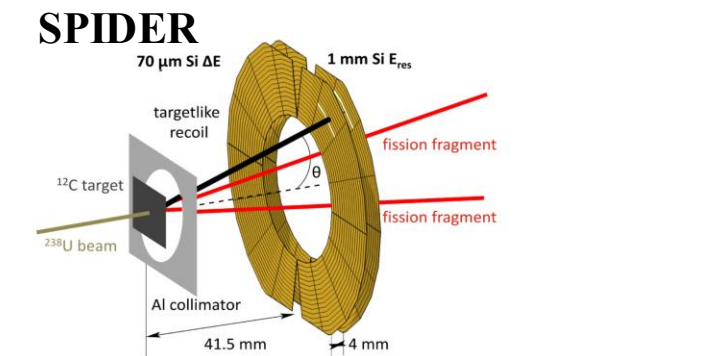
$$P(^{10}\text{Be}[2^+]) = 0.14 \pm 0.04$$

VAMOS



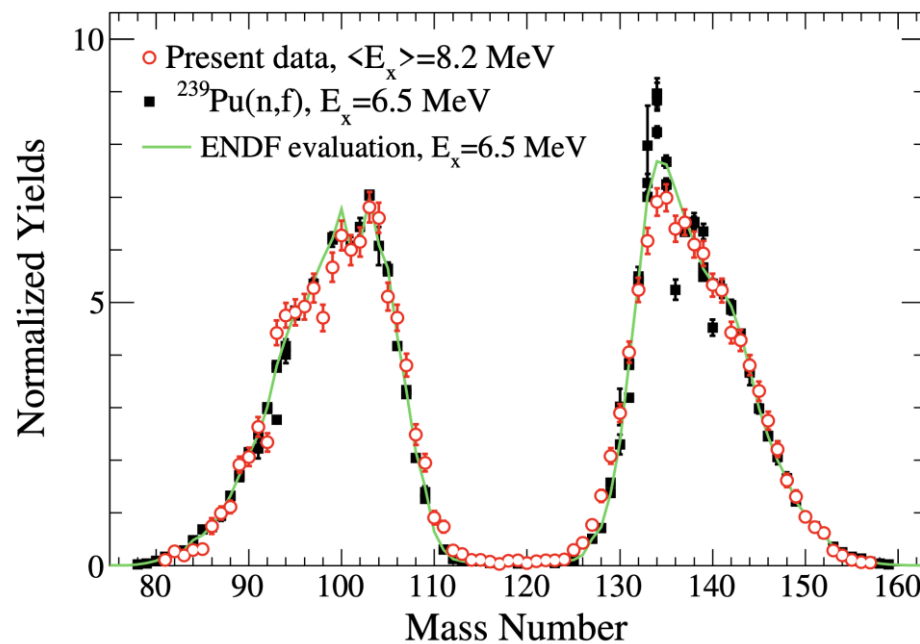
Full distribution of post-neutron evaporation
Isotopic Fission Yields as a function of E_x

D. Ramos et al., Phys. Rev. C 113, 054611 (2026)



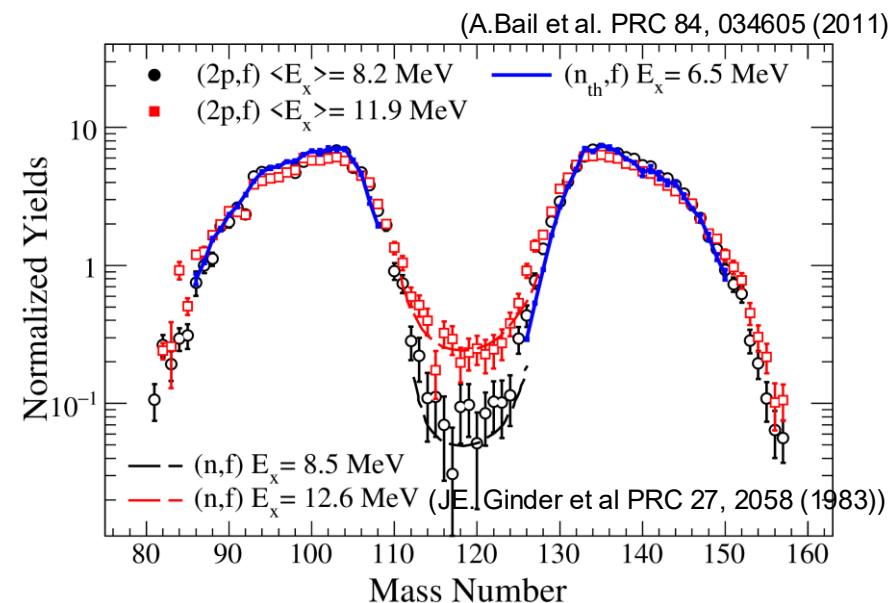
EXOGAM

$$P(^{10}\text{Be}[2^+]) = 0.14 \pm 0.04$$



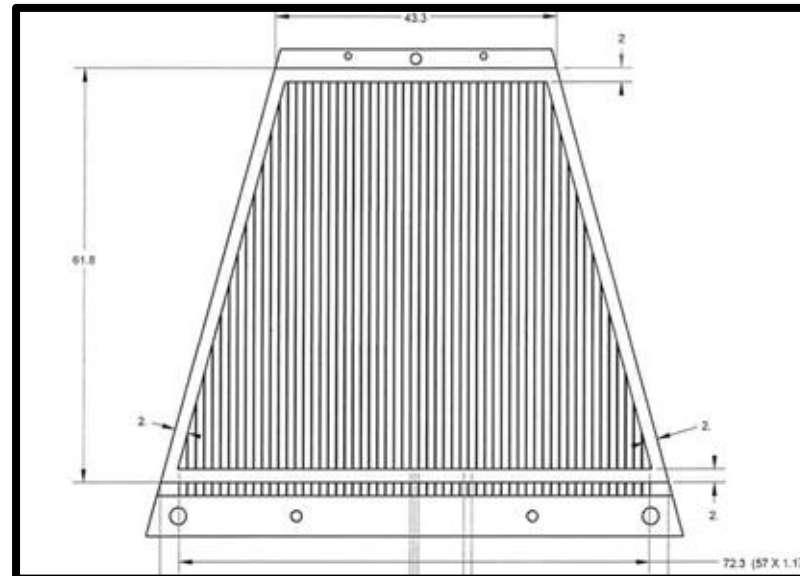
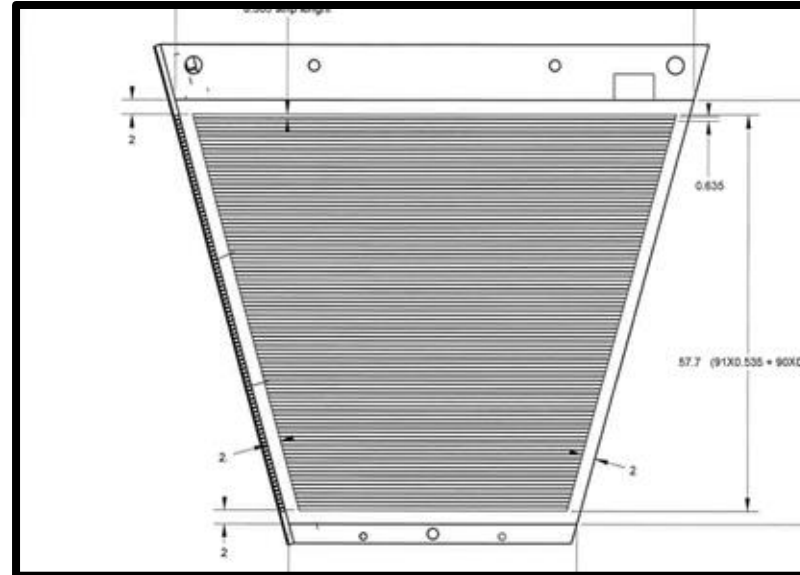
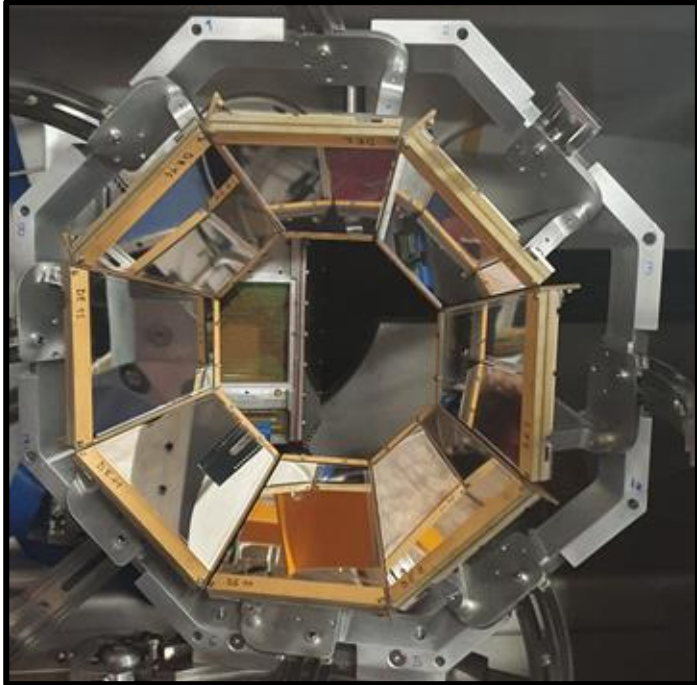
- Same feeding of the symmetric valley with increasing E_x

- **Post-neutron evaporation mass yields.**
- Very good agreement with n-induced fission (H. Naik et al. NSE 196, 824 (2022)) and data bases (ENDF)
- Evidence of E_x effect in $A \sim 132$



New Detection Generation **PISTA**

NEW COLLABORATION: GANIL – CEA-DAM BRUYERES-LE-CHÂTEL



DE – E Silicon Telescope

dE :

100 μ m thick

0.53 mm horizontal strips

E :

1 mm thick

1.17 mm vertical strips

10 cm from the target:

Angular coverage: 30 – 60 deg

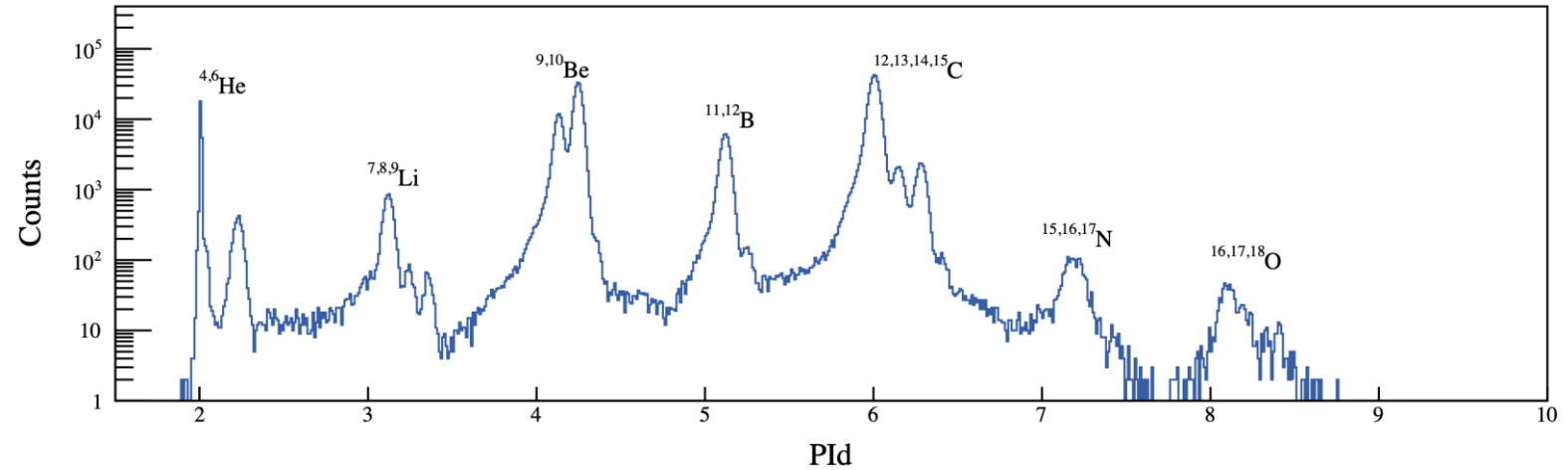
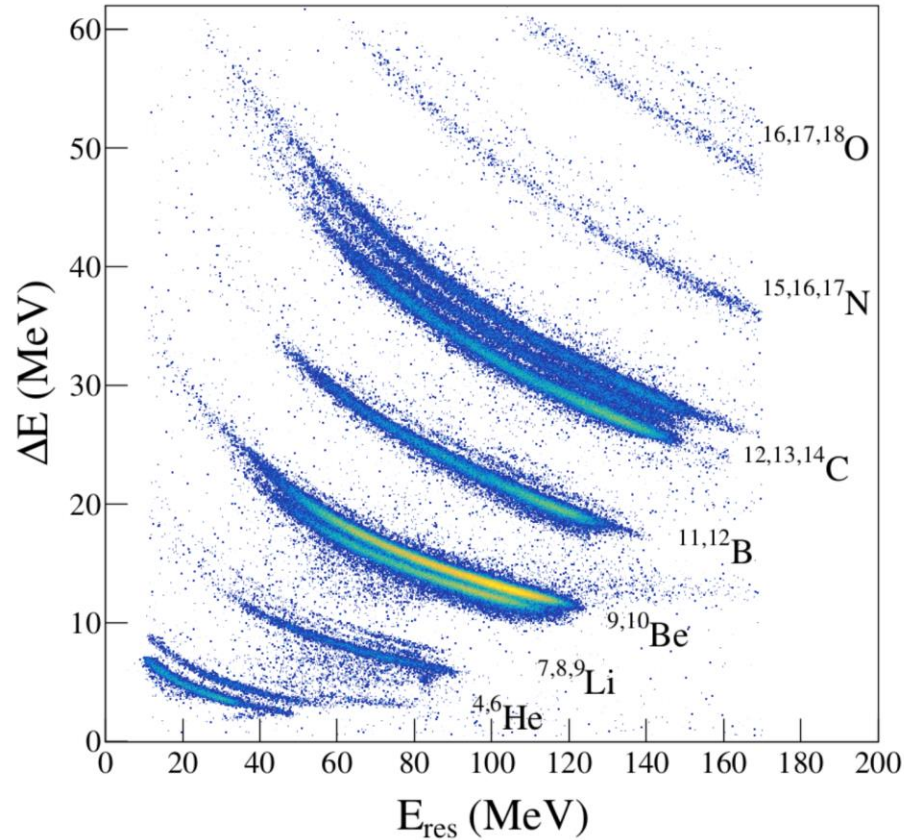
Angular precision: < 5 mrad

Goals:

Isotopic identification from He to C

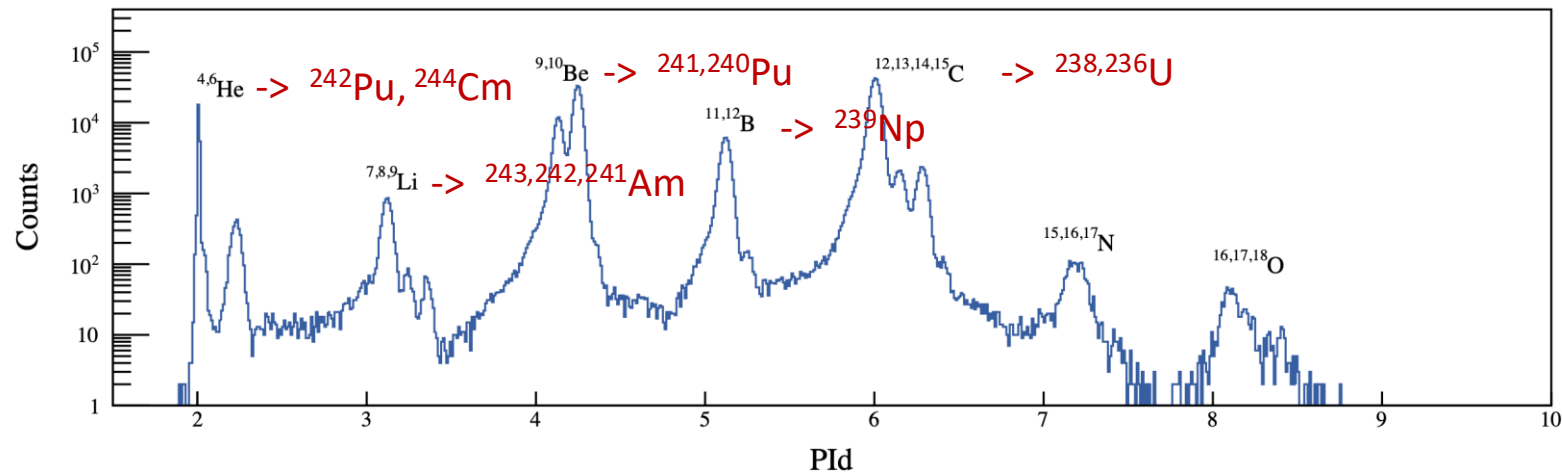
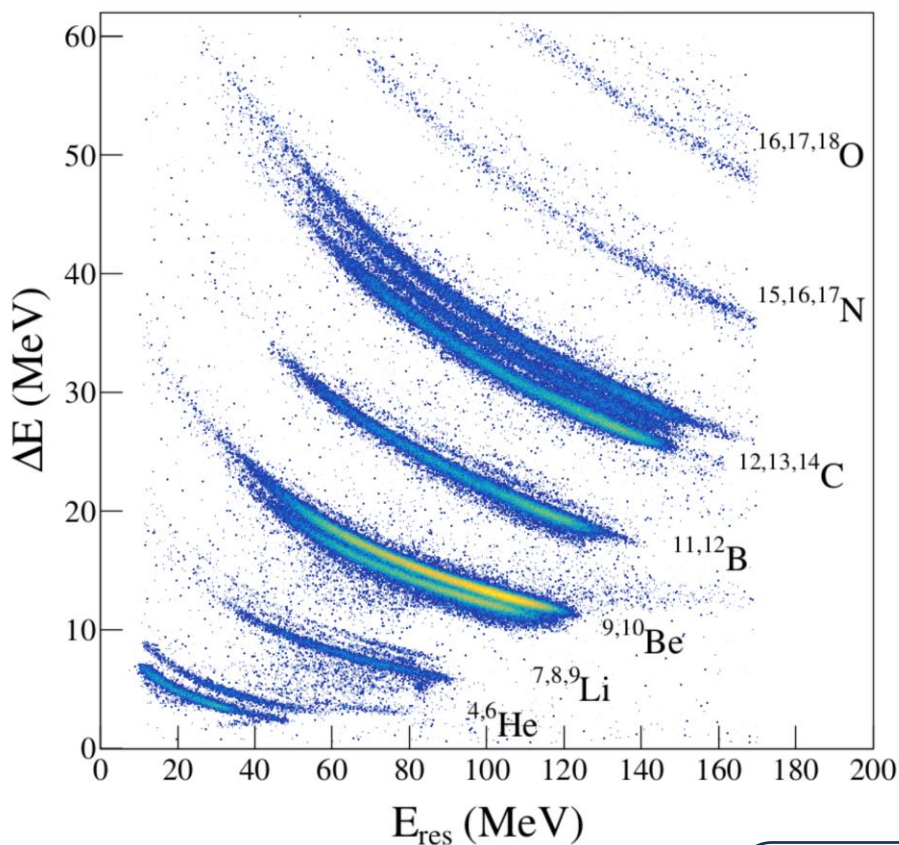
E_x resolution < 1 MeV

Target-like recoil Identification Matrix

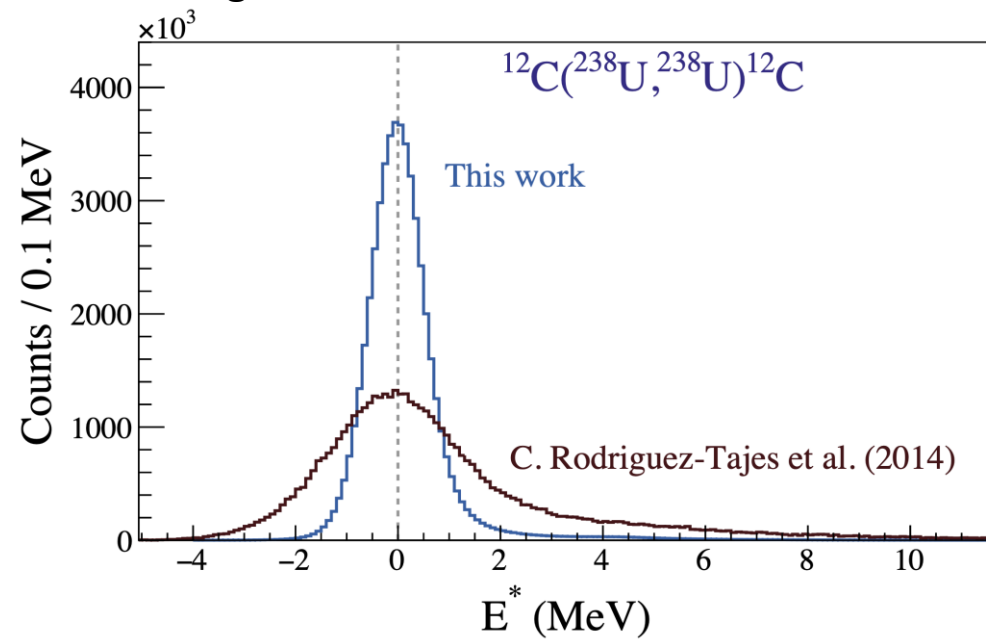


Mass resolution of 1.1% in Carbon region

Target-like recoil Identification Matrix



Mass resolution of 1.1% in Carbon region



Lucas Begue PhD (GANIL – CEA DAM)
Submitted to NIMA (2026)

E_x resolution = 511 keV (elastic)
Expected E_x resolution : 370 keV
(with interaction point at target)

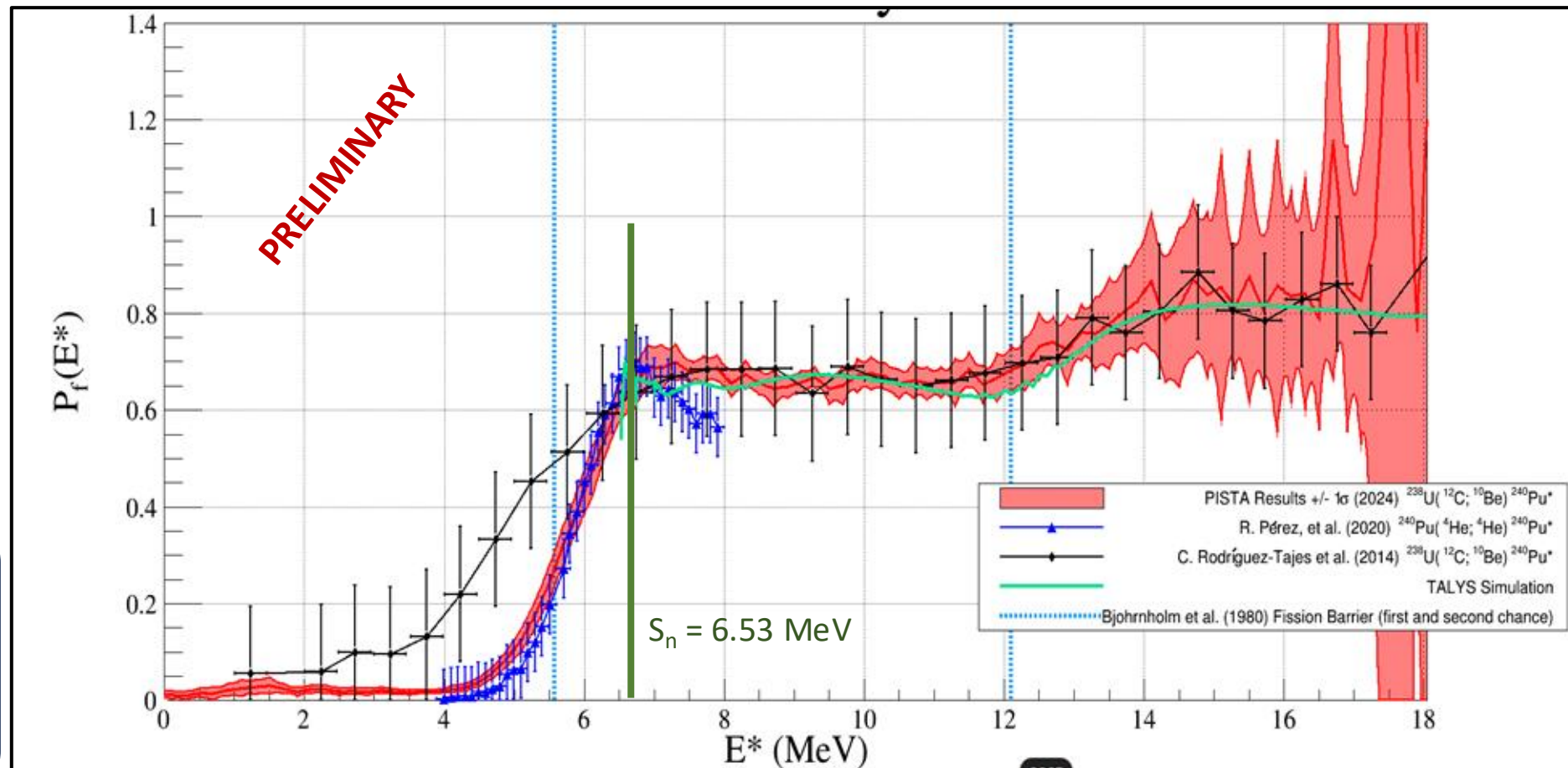


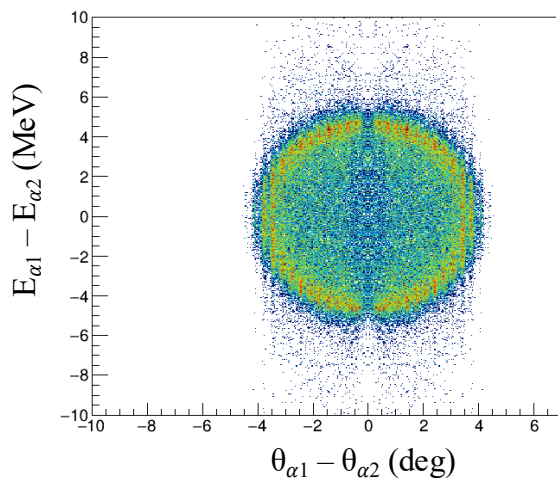
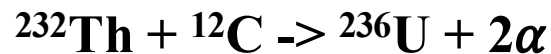
PISTA Measurement:

Significant improvement with respect to SPIDER

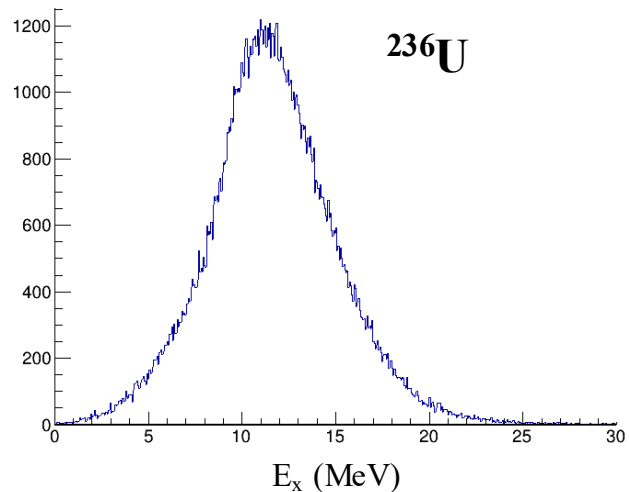
Clear difference with respect to Coulomb excitation in $E_x > S_n$:

The competition between fission and neutron evaporation seems to be different in both type of reactions



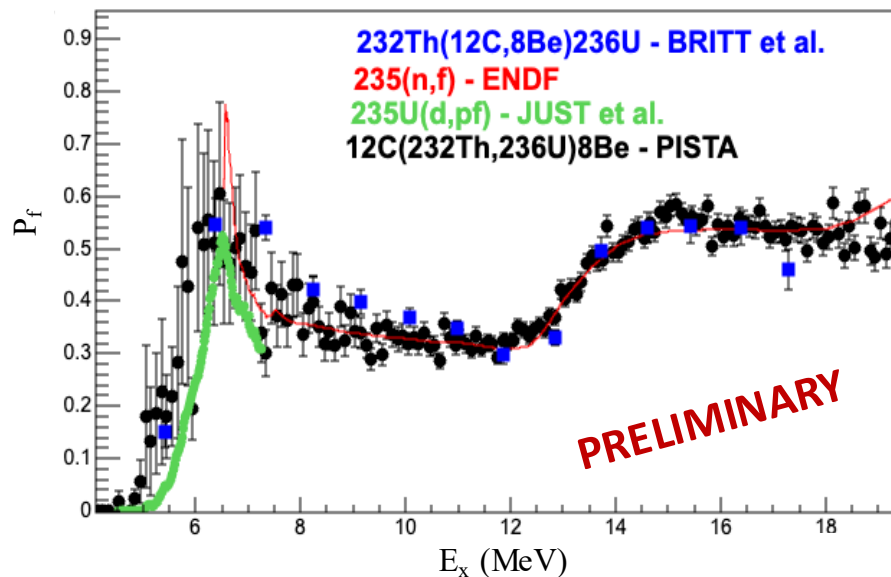


Kinematic Correlation
of 2α from ^8Be



Excitation energy
distribution of ^{236}U
without fission
condition

Fission probability of ^{236}U from 1α transfer



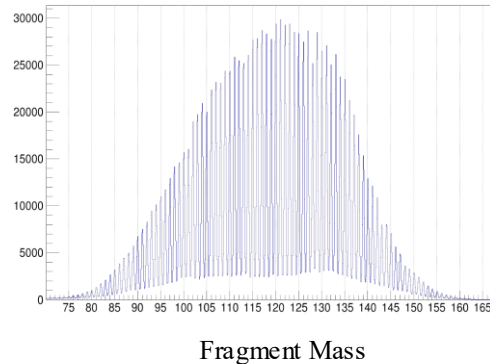
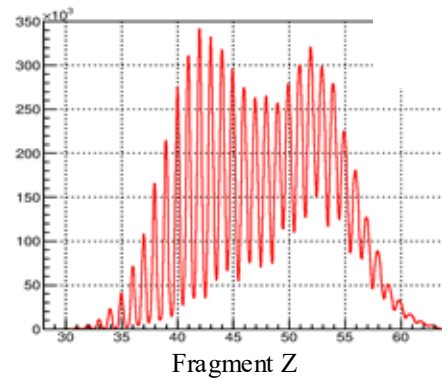
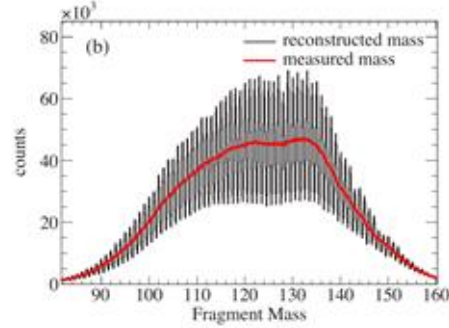
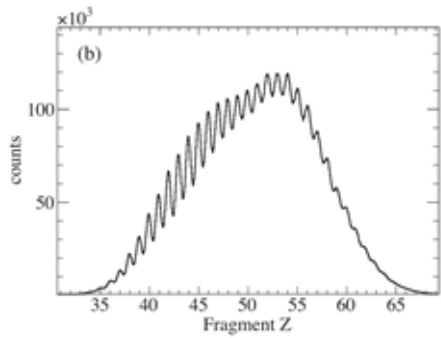
New measurement is foreseen this year:

- PISTA2 :
 - Improved setup for 2α measurement
 - Access to low E_x of ^{236}U

VAMOS



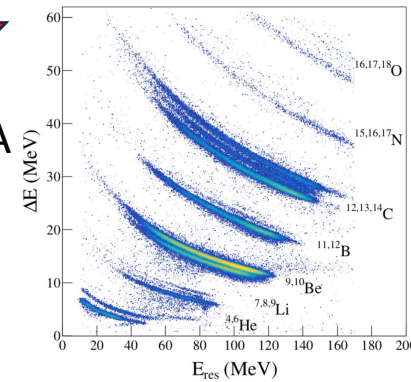
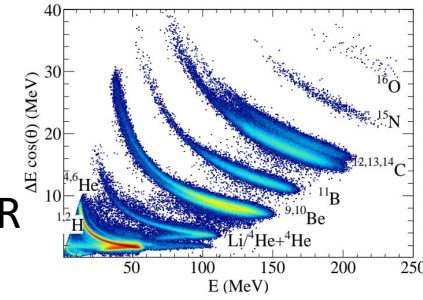
VAMOS++



SPIDER



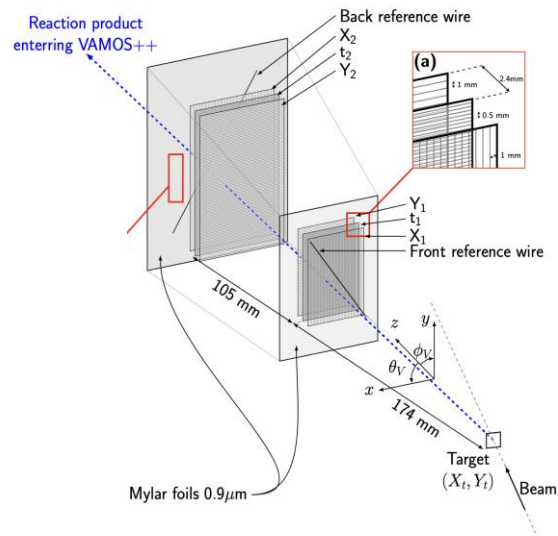
PISTA



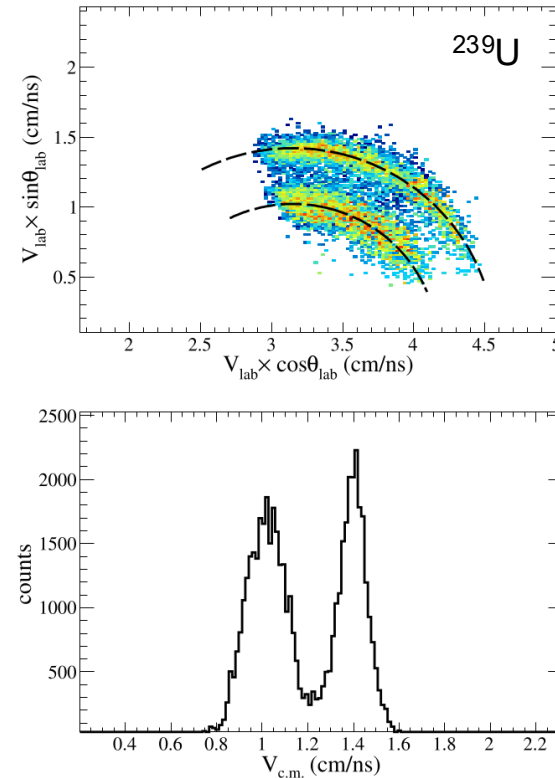
- The fission program at VAMOS/GANIL is a rich, very competitive, and a well established program providing experiment fission data for more than 10 years.
- The combination of inverse kinematics at Coulomb energies, a magnetic spectrometer, and complementary setups allows to study fission with a wide set of observables in a common setup.
- New and accurate observables and their correlations are now experimentally available.

$$\langle A_1^* \rangle = A_{FS} \frac{\langle V_2 \gamma_2 \rangle}{\langle V_1 \gamma_1 \rangle + \langle V_2 \gamma_2 \rangle}$$

Dual Position-Sensitive MultiWire at Target

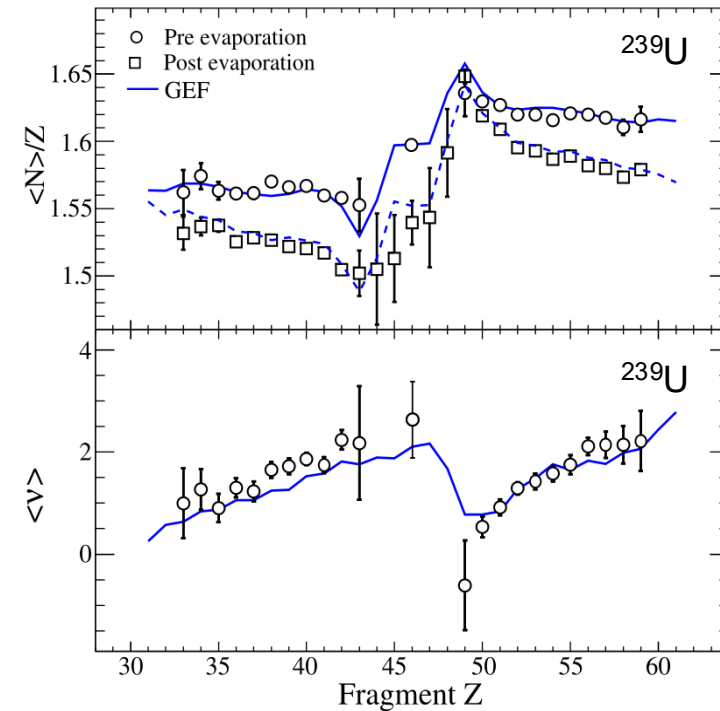


- Low kinetical boost allows to recover the fission-fragment velocities in center-of-mass frame



- 2V-method with one fragment detected by fission reaction:
 - Average mass numbers as a function of Z

$$\langle A_1^* \rangle(Z_1) + \langle A_2^* \rangle(Z_2) = A^{FIS}, Z_1 + Z_2 = Z^{FIS}$$



- Momentum conservation allows to determine the mass of fission fragments before neutron evaporation

$$\frac{M_1^*}{M_2^*} = \frac{\gamma_{c.m.2} v_{c.m.2}}{\gamma_{c.m.1} v_{c.m.1}}$$

- New fission Observable: Fragments neutron excess
 - Structural effect observed in Z~50, maximum of neutron content.
- Neutron multiplicity show the sawtooth shape with a minimum in Z~50

M. Vandebrouck et al, NIMA 812, 112 (2016)

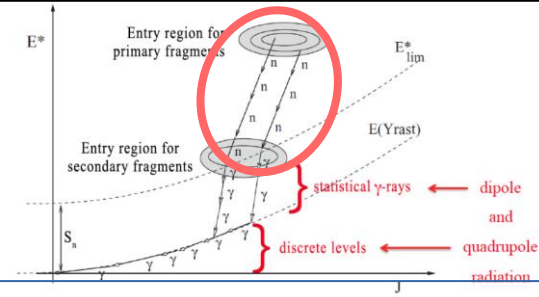
D. Ramos et al., Phys. Rev. C 101, 034609 (2020)

• NEUTRON WALL @ VAMOS

Requirements :

- High Time resolution (~ 200 ps)
- High Granularity (~ 2 cm)

Energy resolution
 ~ 200 keV



• First Test in 2023 ($^{238}\text{U} + ^{12}\text{C}$)

