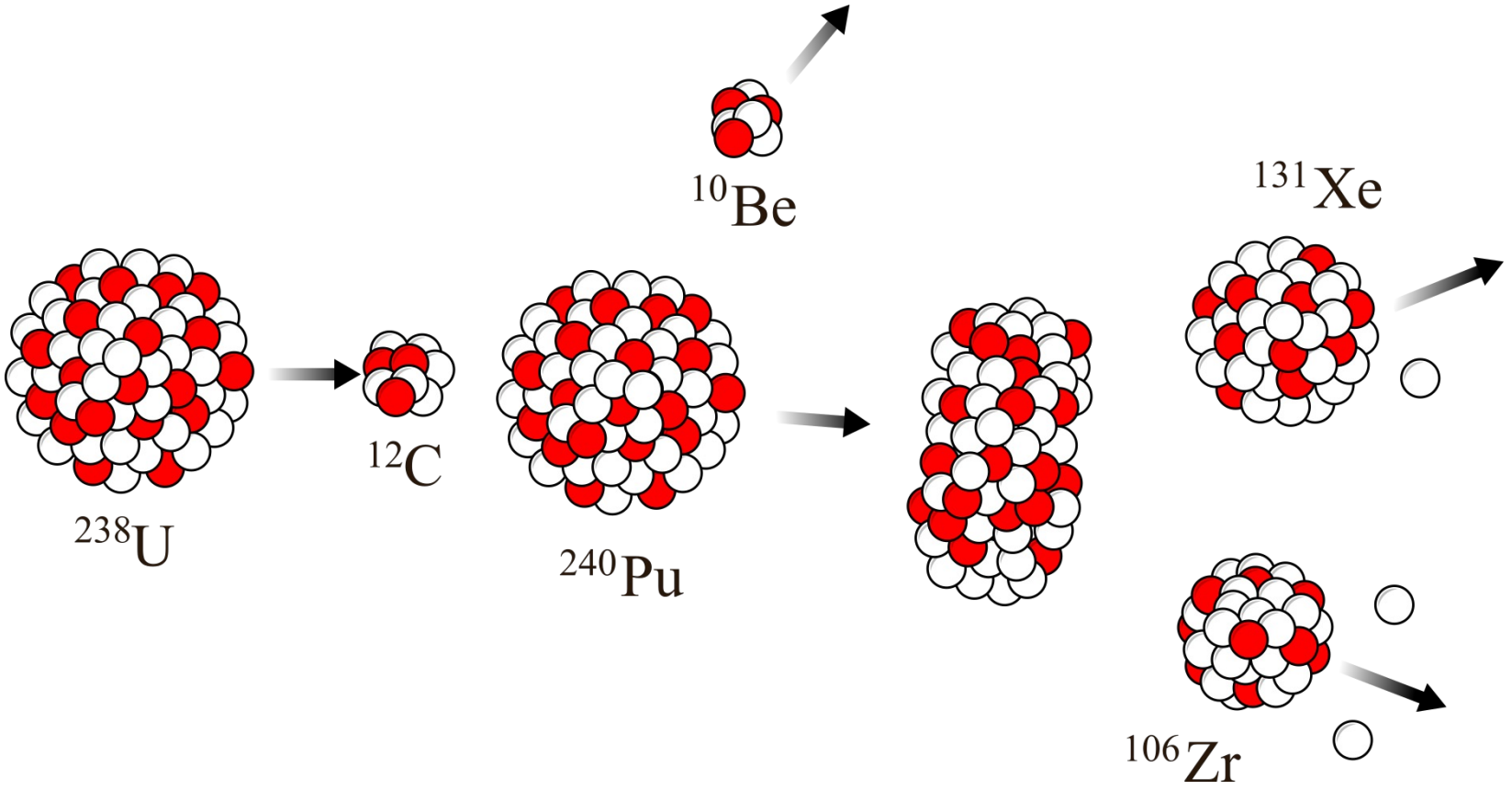
PISTA@VAMOS: Upgrade of the Fission Program in Inverse Kinematics at GANIL

Diego Ramos

Inverse-Kinematics Fission @ Coulomb-Barrier Energies



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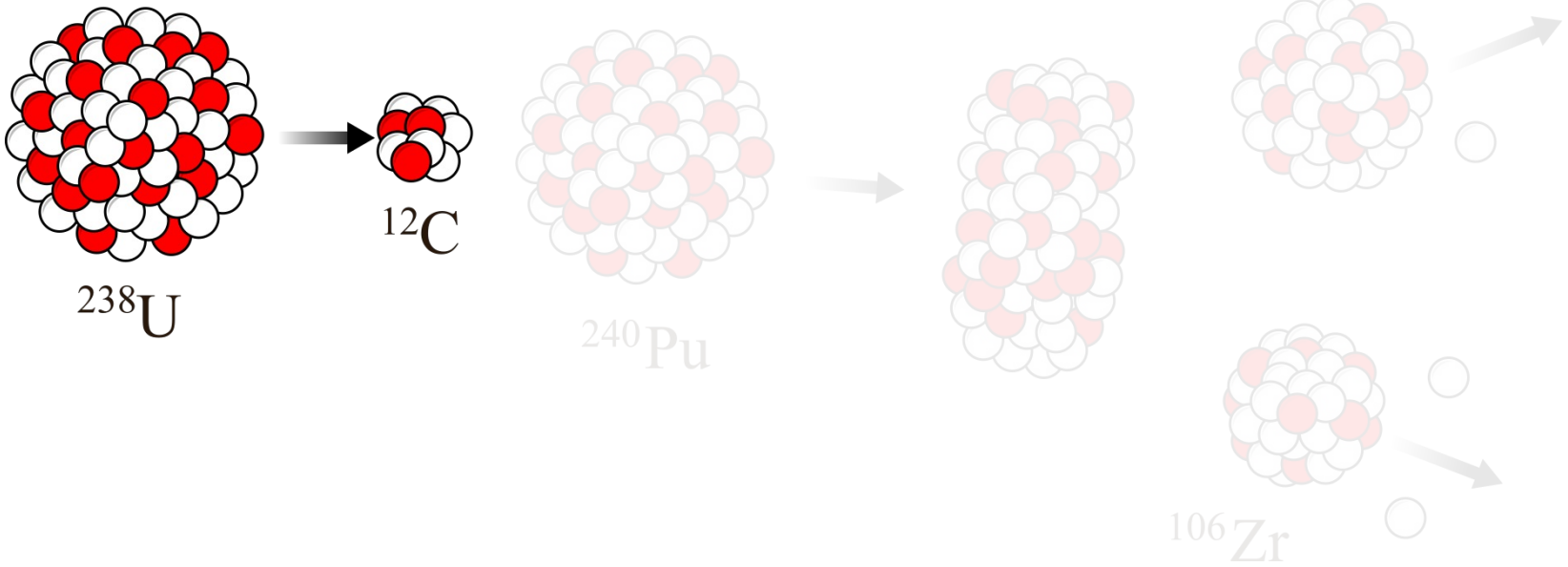
- **Heavy Ion Beam (^{238}U, ^{232}Th)**
  ~ 6 MeV/u
  ~ 10^{10} pps
- **Light Target (^{12}C, ^{9}Be, …)**
  ~ 100 ug/cm^2



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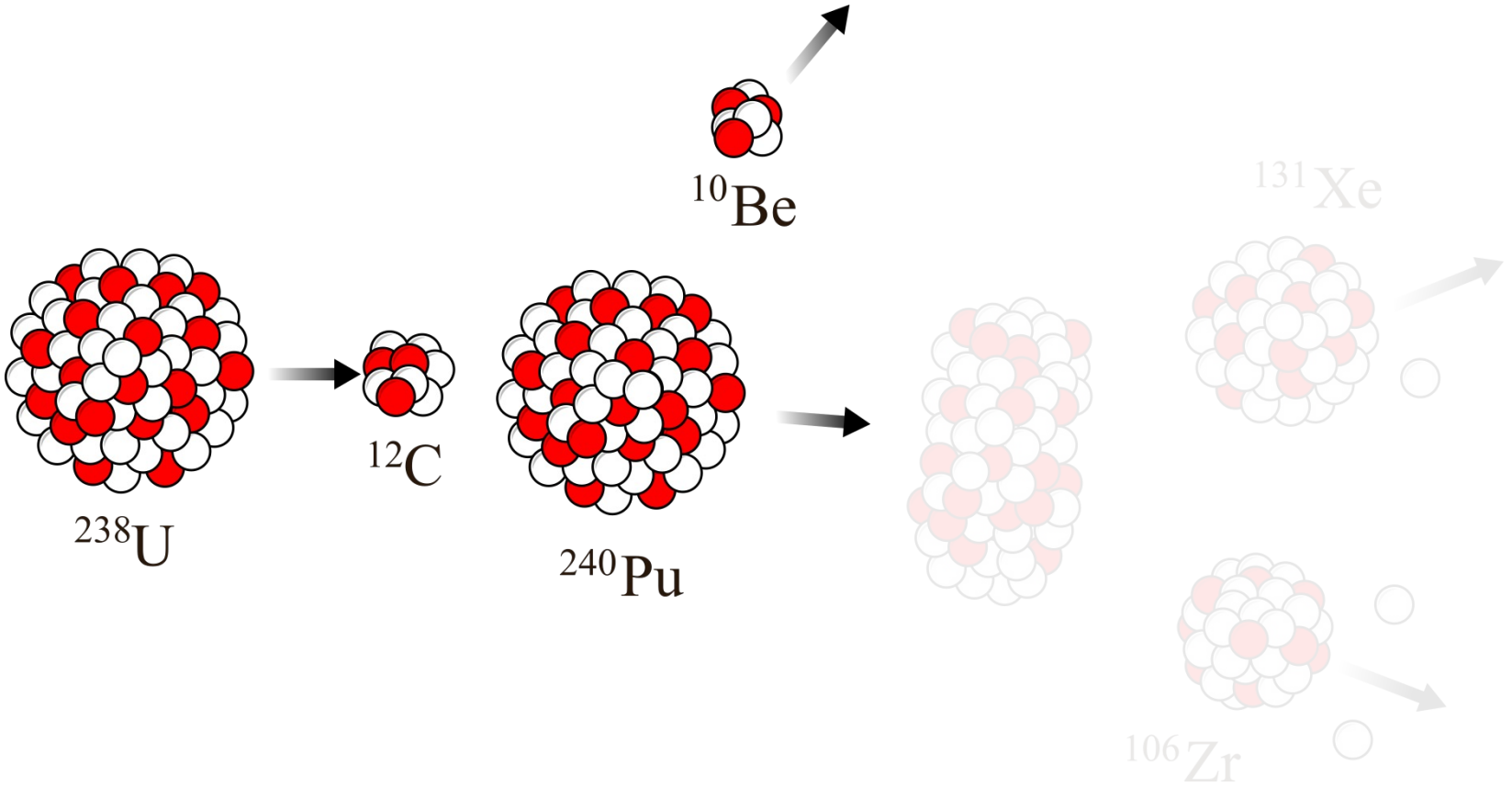

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- **MultiNucleon Transfer Reactions**
  ~ 10 mbarn
  - **Target-Like Recoil**
    E~ 10-200 MeV
    $\theta_{grazing}$ ~ 30 deg
  - **Actinide**
    Heavier than Beam
    Forward focussed
    E_x ~ B_f - 40 MeV

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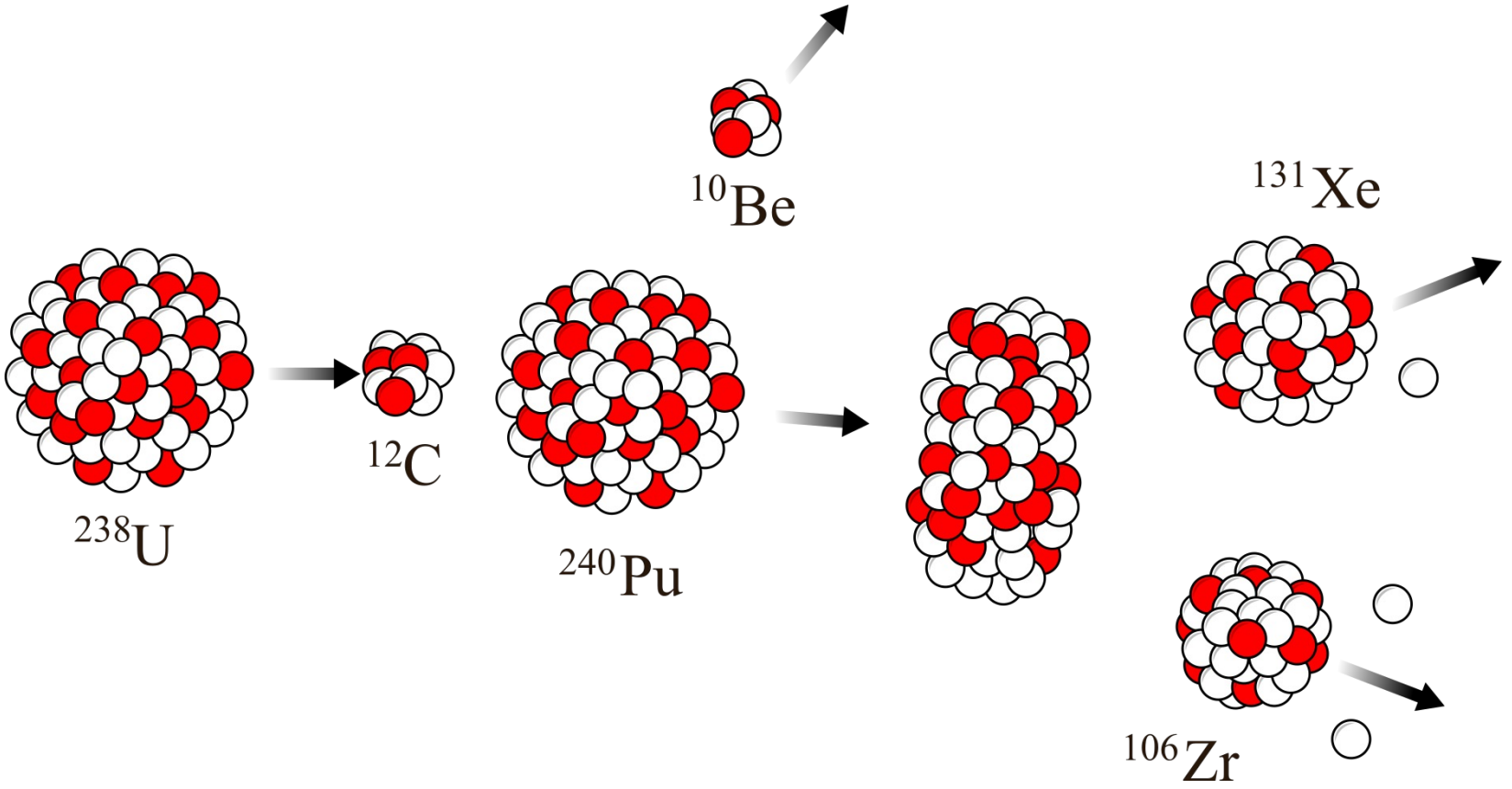

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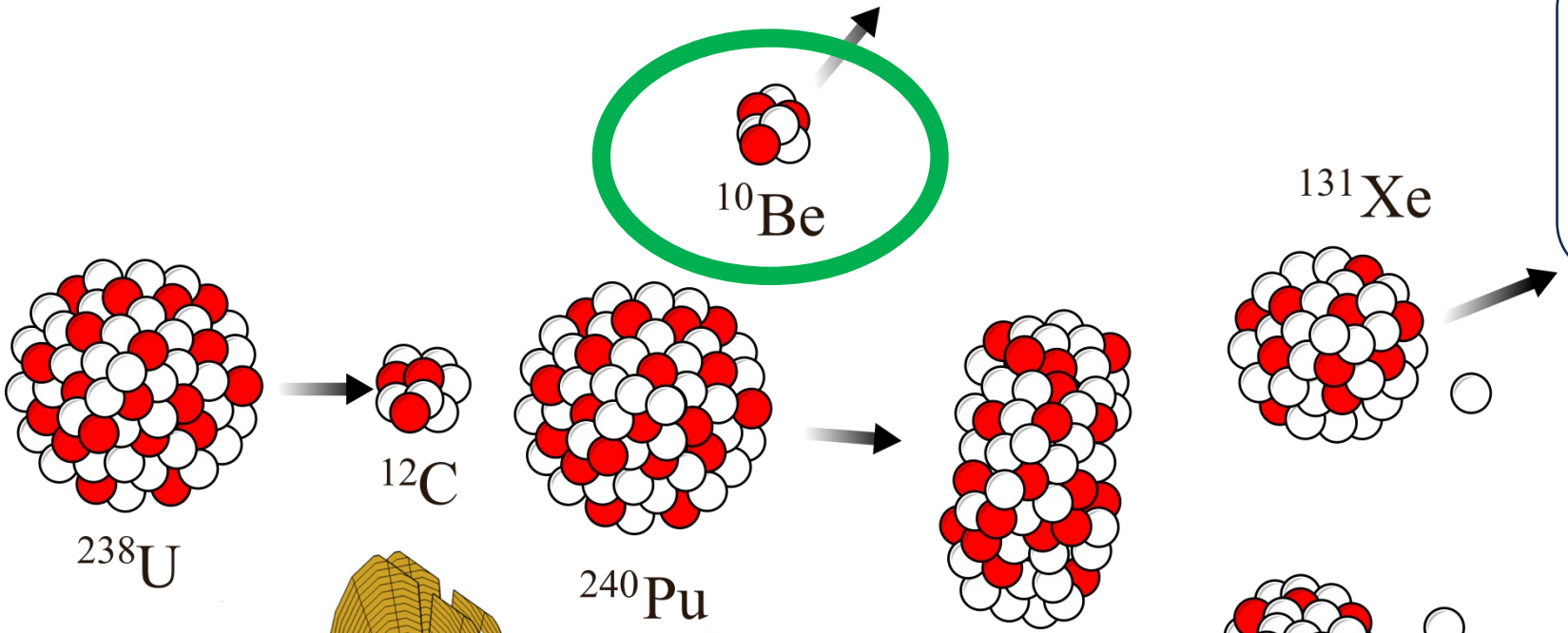
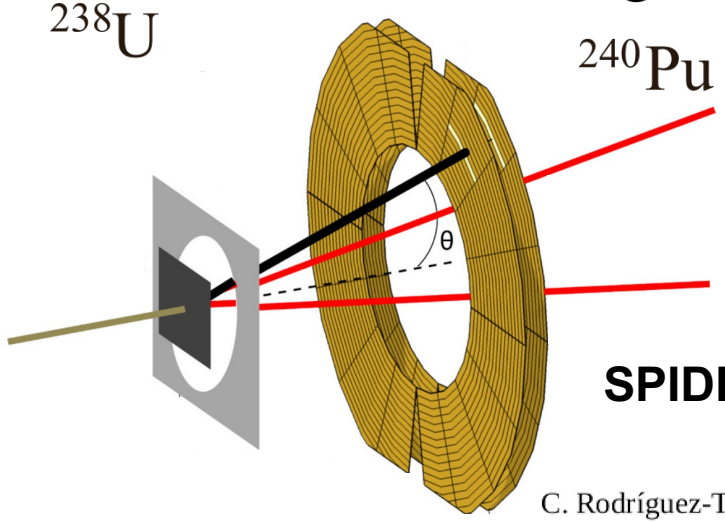
- **Fission In Flight**
  $\theta_{fragment}$ < 30 deg
  $E_{fragment}$ ~ 100 -1000 MeV

Fissioning System Identification and E_x

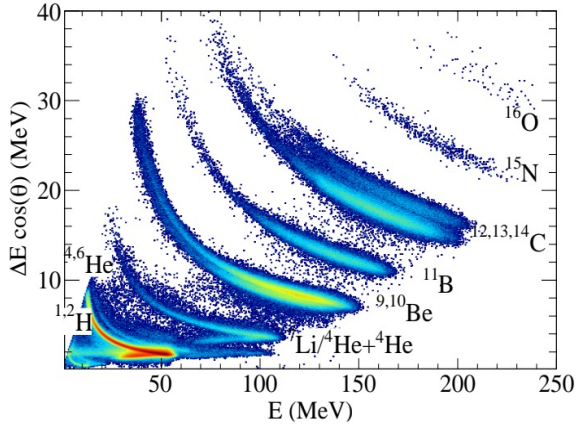
- **STRIP SILICON TELESCOPE**

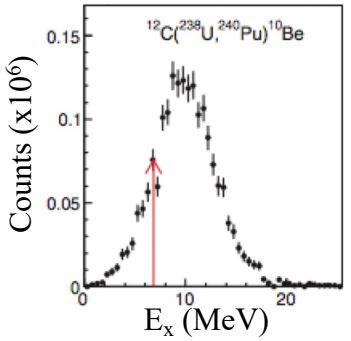
  - Identification of the fissioning system by detection of the target-like recoil
  - Measurement of the Excitation Energy by reconstruction the binary reaction
  - Measurement to fission probabilites by detection of fission fragments





SPIDER



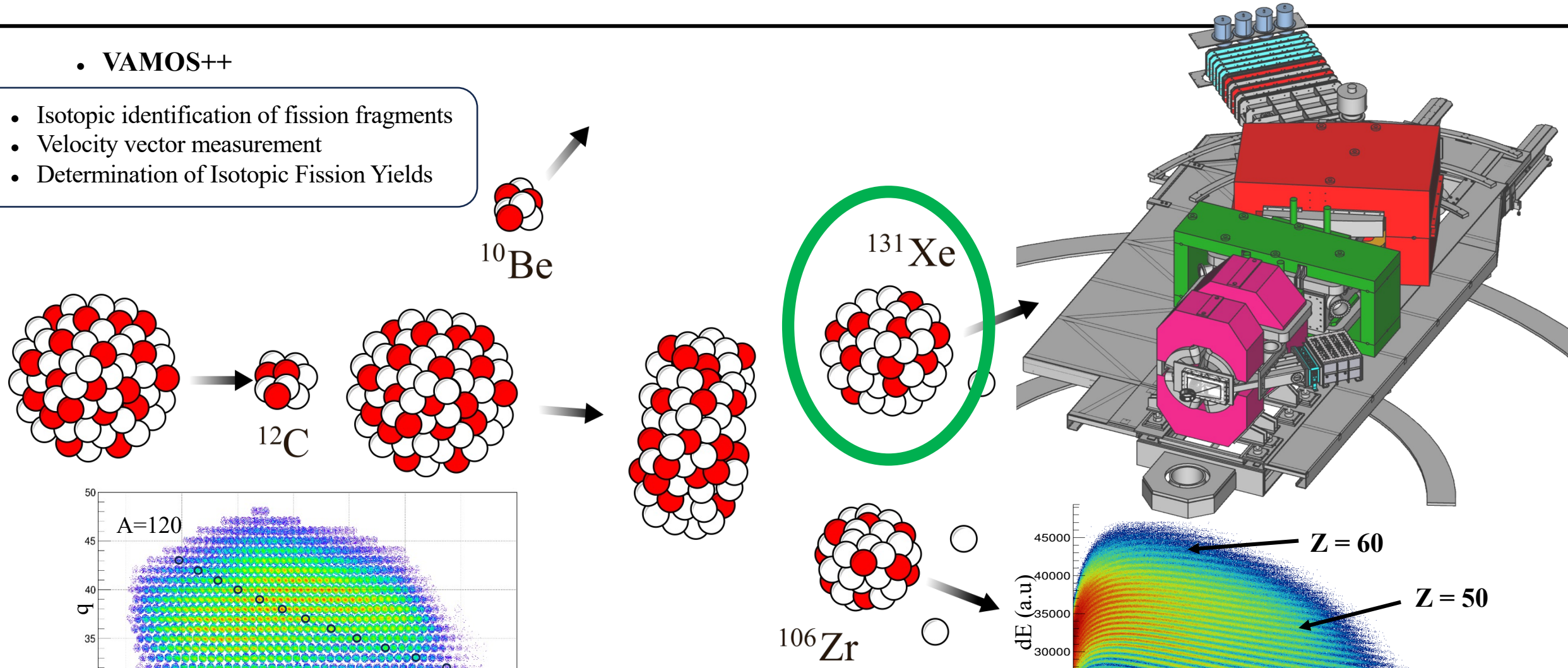


C. Rodríguez-Tajes et al., PRC 89, 024614 (2014)

Fission Fragment Identification

- **VAMOS++**

- Isotopic identification of fission fragments
- Velocity vector measurement
- Determination of Isotopic Fission Yields

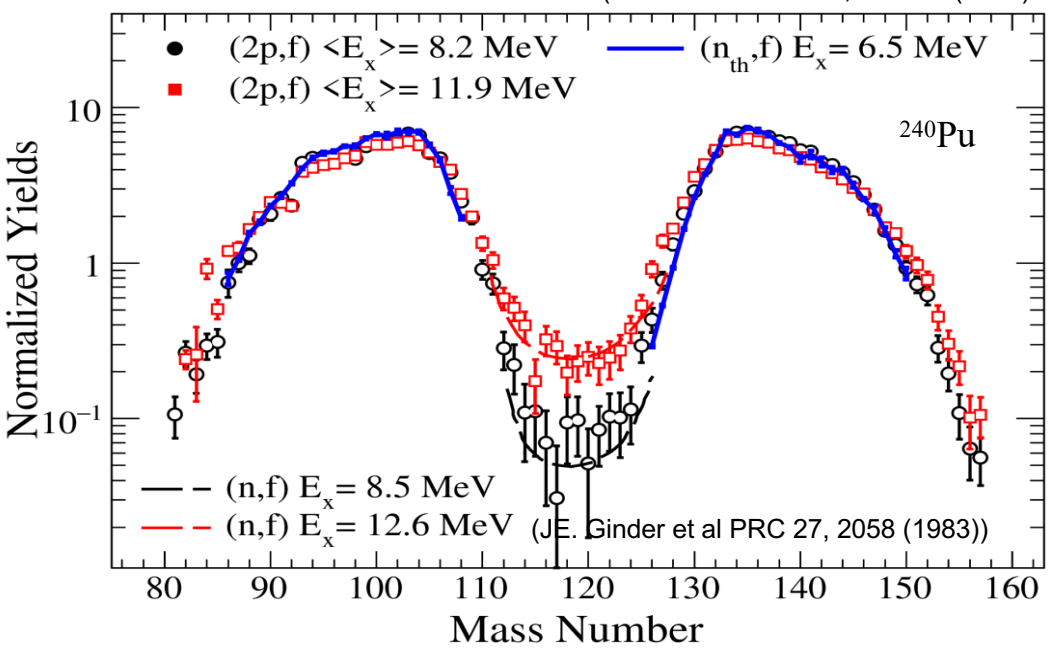


M. Rejmund et al. NIM A 646, 184 (2011)
A. Lemasson & M. Rejmund, NIM A 1054, 168407 (2023)
M. Rejmund & A. Lemasson, JINST 20 P08022 (2025)

VAMOS + SPIDER

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

(A.Bail et al. PRC 84, 034605 (2011)



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- Evidence of damping of Shell effects
- Very good agreement with n-induced fission

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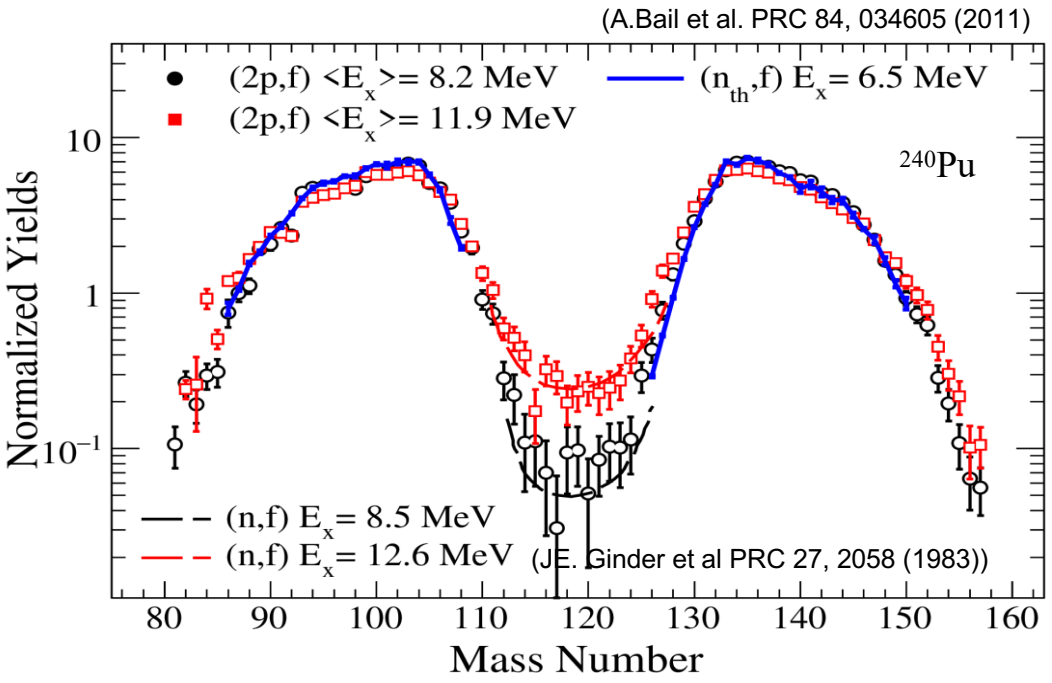

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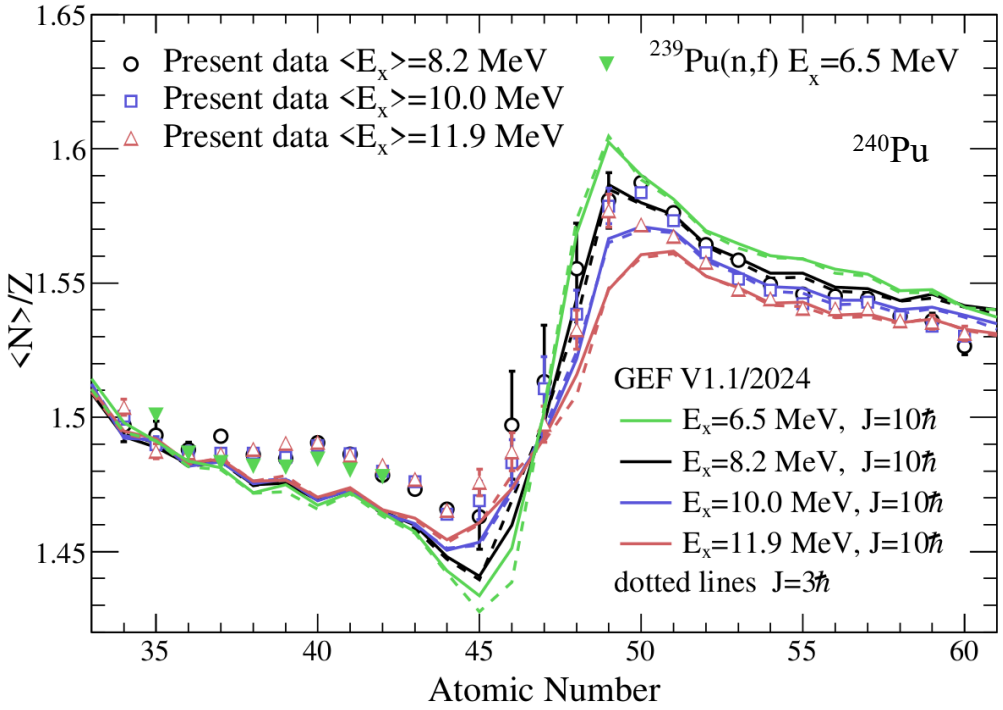
- **Fission fragment Neutron content**
- New Observable to constrain fission models.
- Evidences of neutron evaporation



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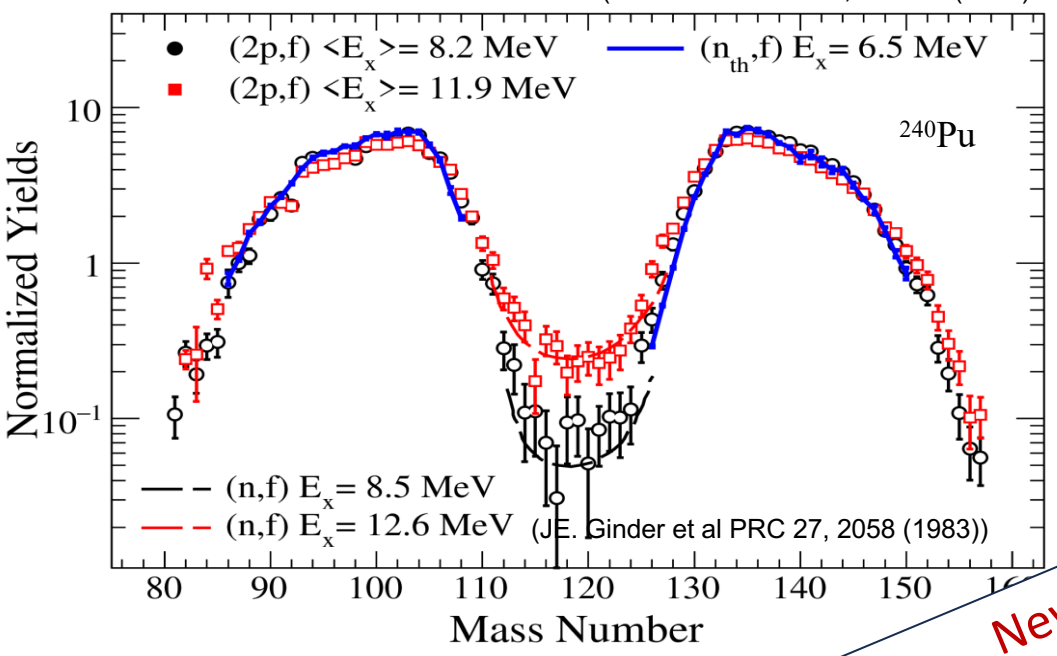

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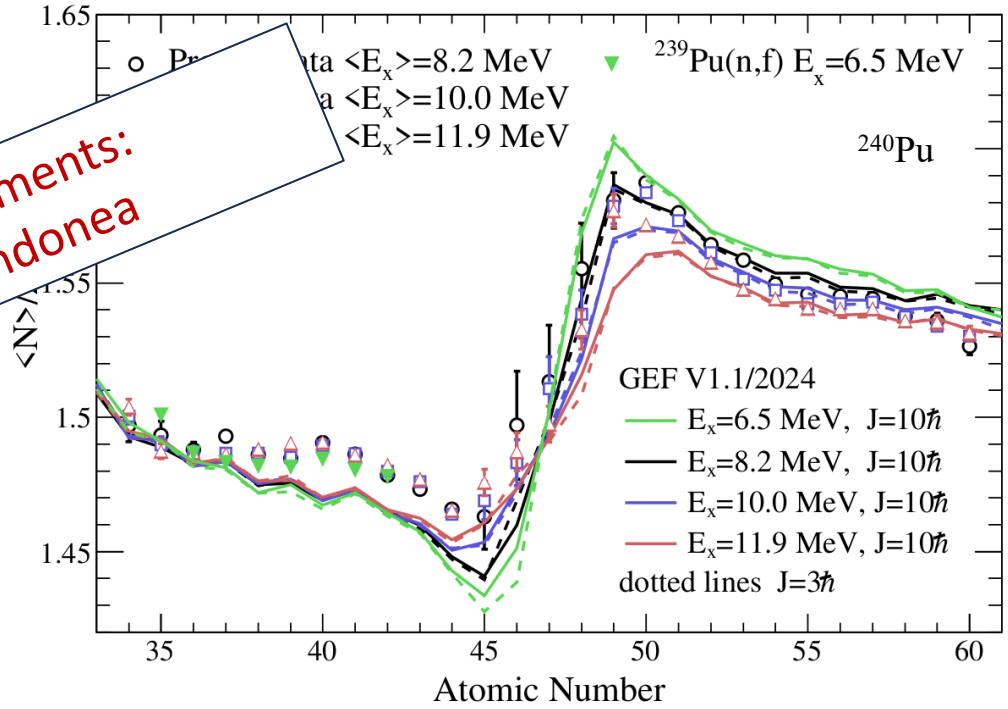
New Measurements:
Beatriz Errandonea



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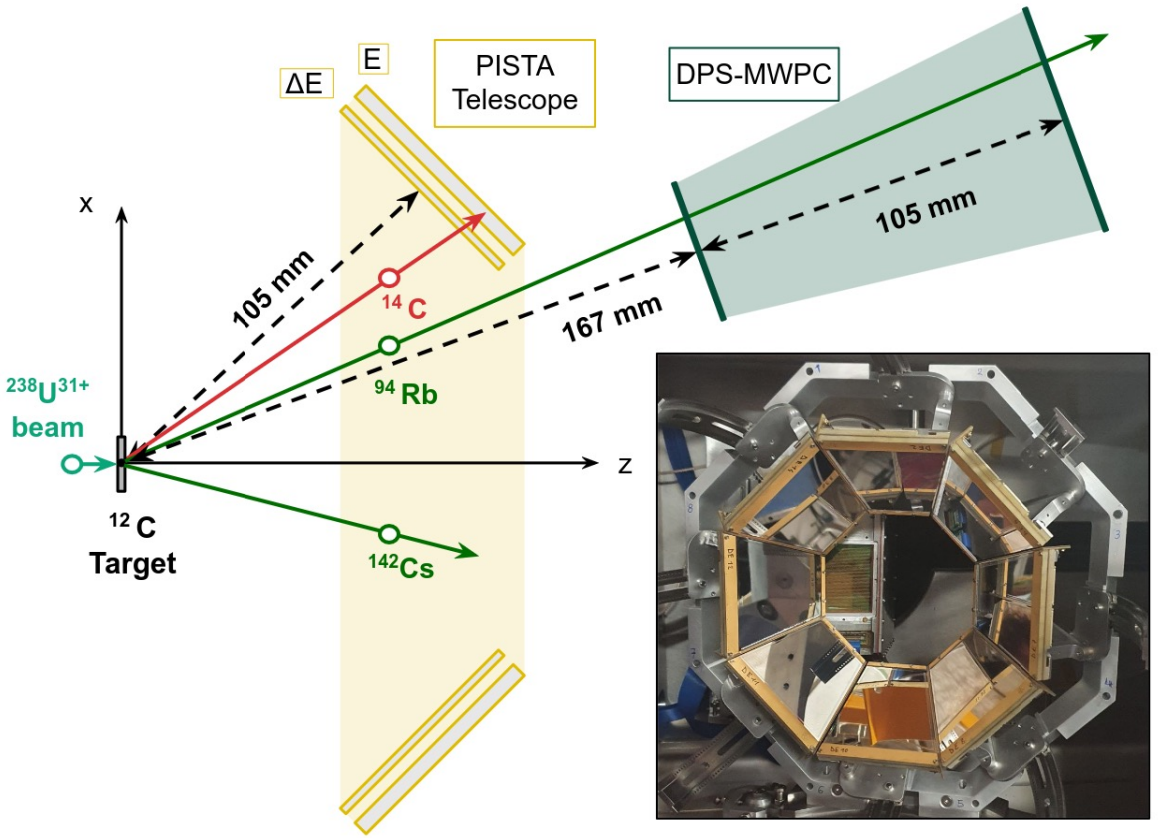
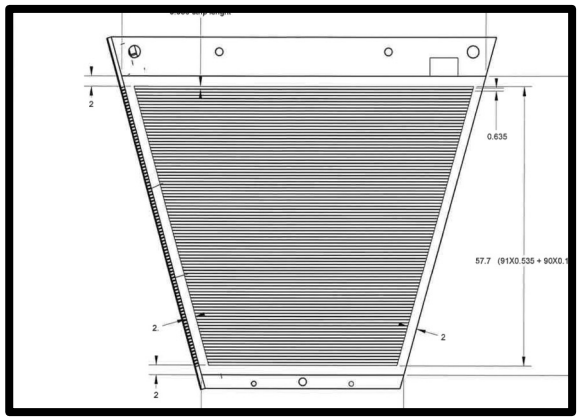
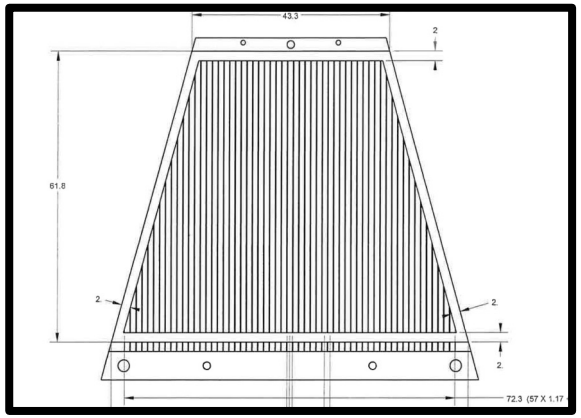
New Detection Generation
PISTA

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

PISTA Detector







DE – E Silicon Telescope

dE :

100 um 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 precission: < 5 mrad

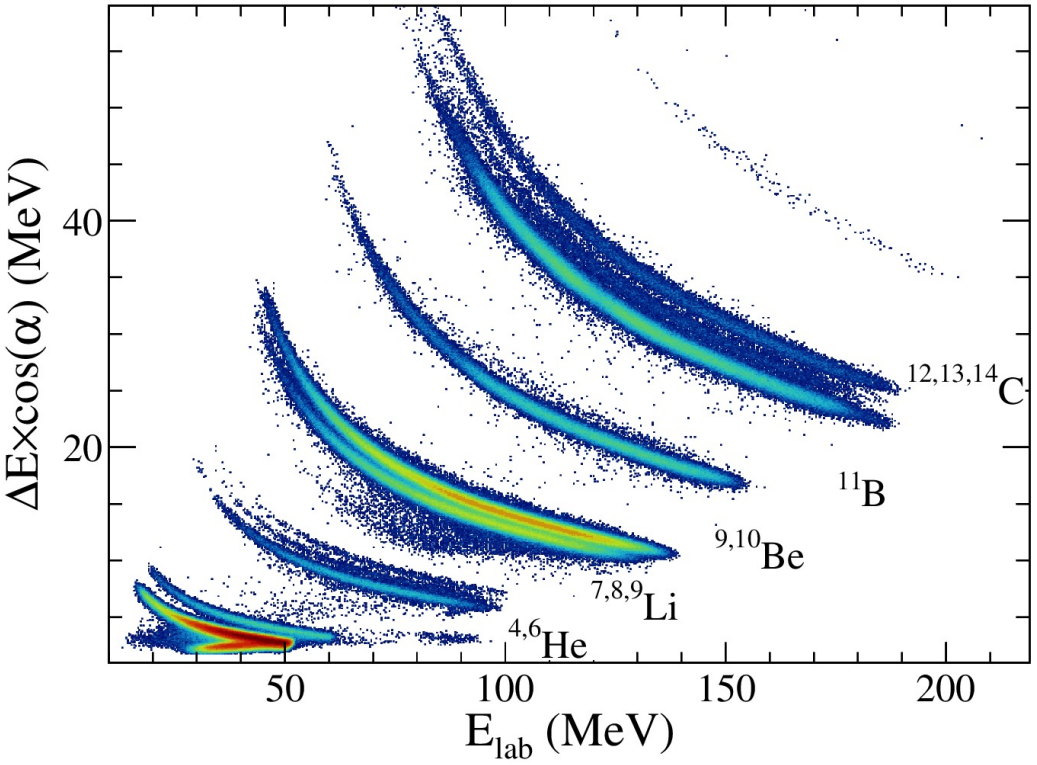
Goals:

Isotopic identification from He to C

E_x resolution < 1 MeV

Identification Capabilities

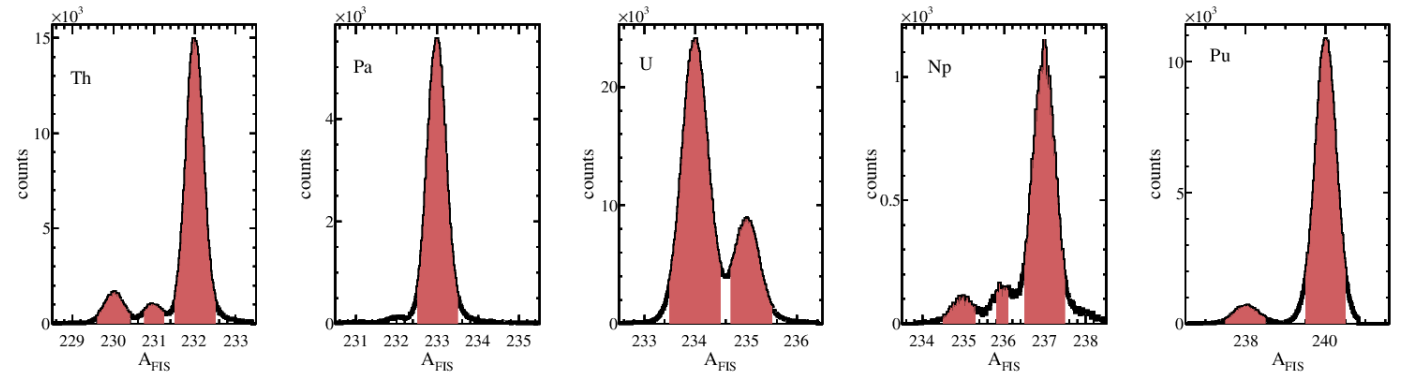
Target-like recoil Identification Matrix



Mass resolution of 1.1% in Carbon region

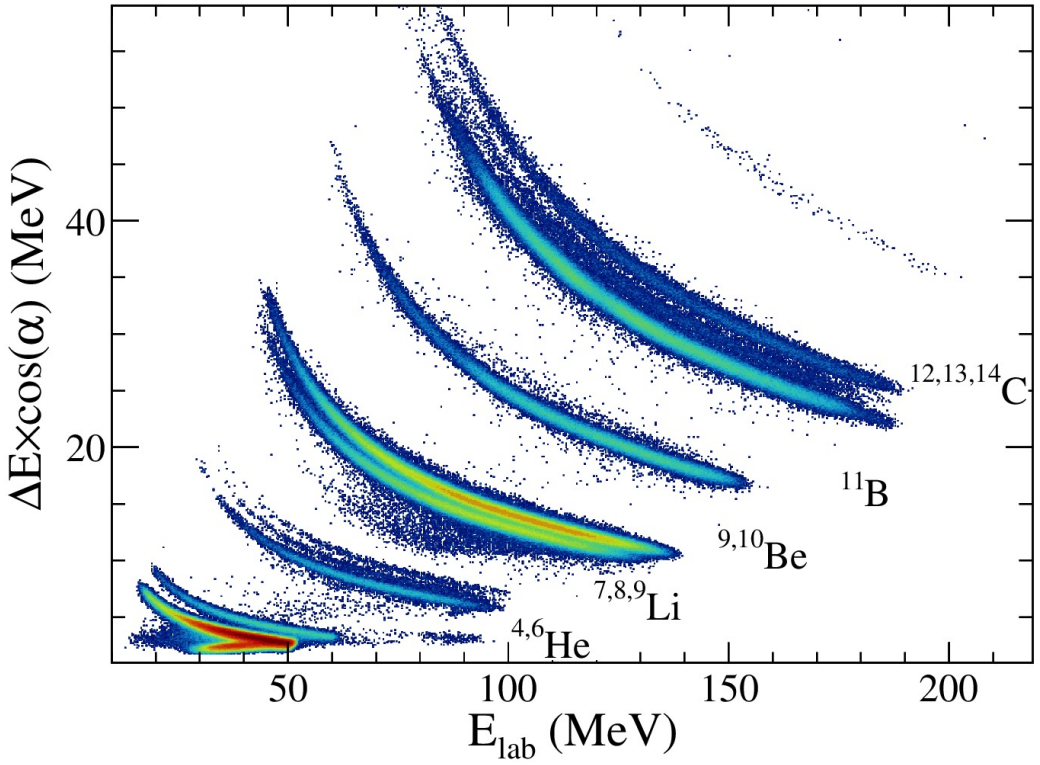
$^{232}Th + ^{12}C$ -> FF

Red Region: Less than 1% of contamination from overlap



Excitation Energy Resolution

Target-like recoil Identification Matrix



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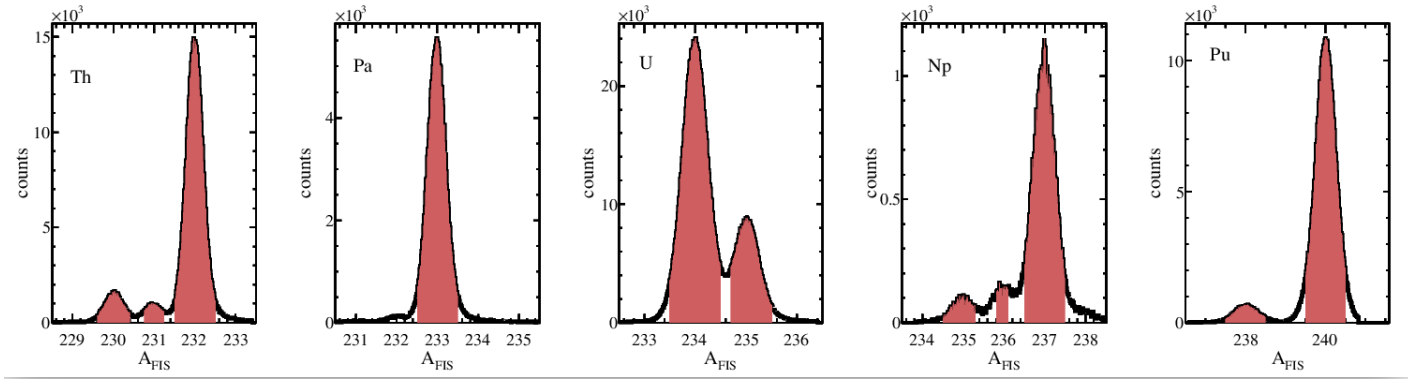
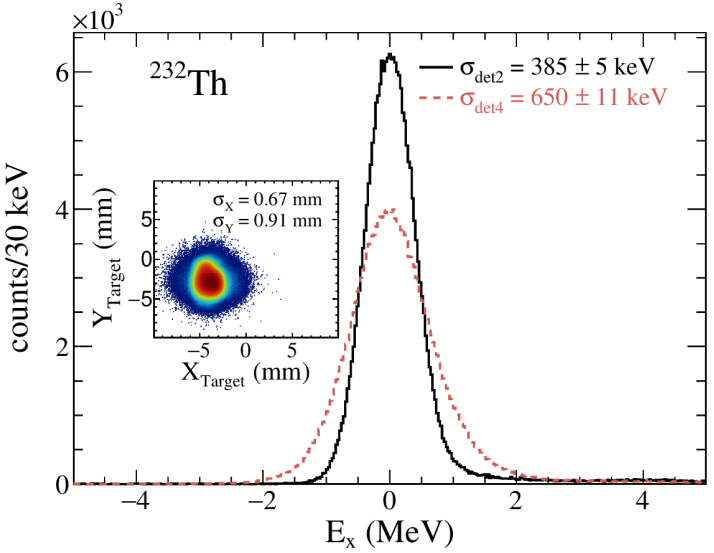


Excitation energy resolution measured in the elastic peak



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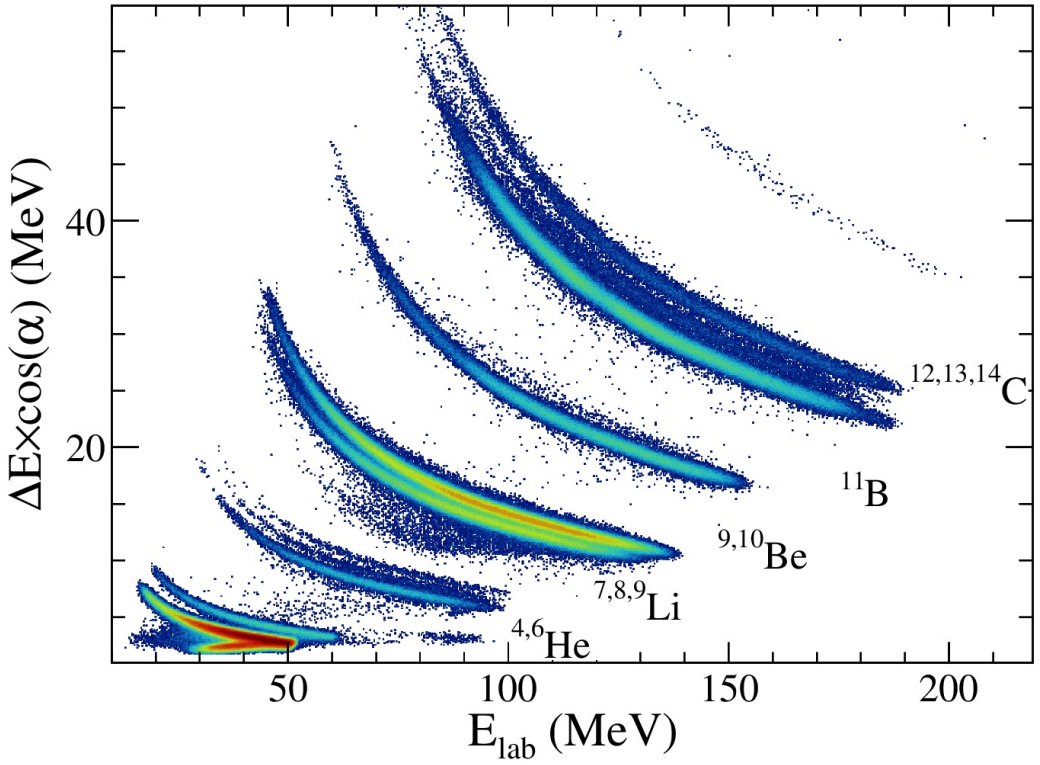

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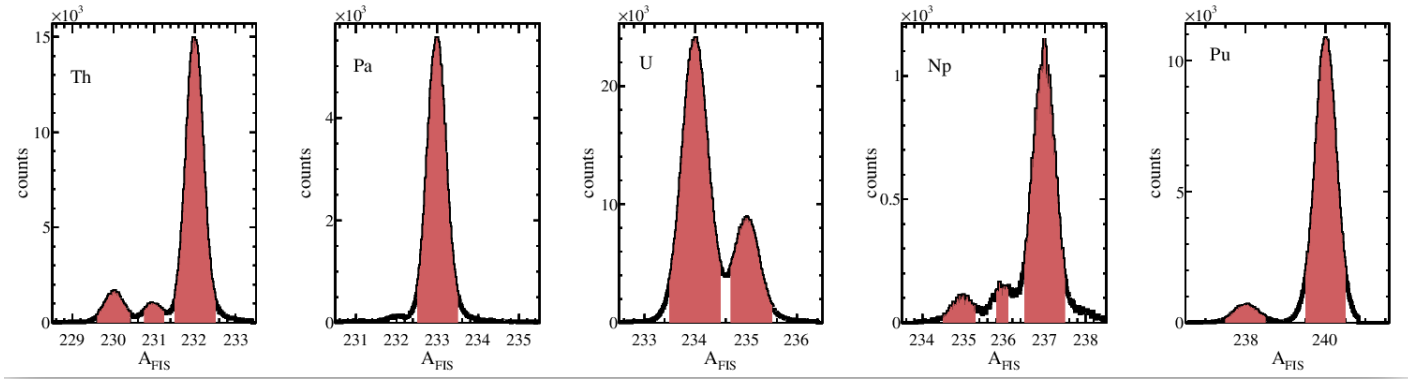

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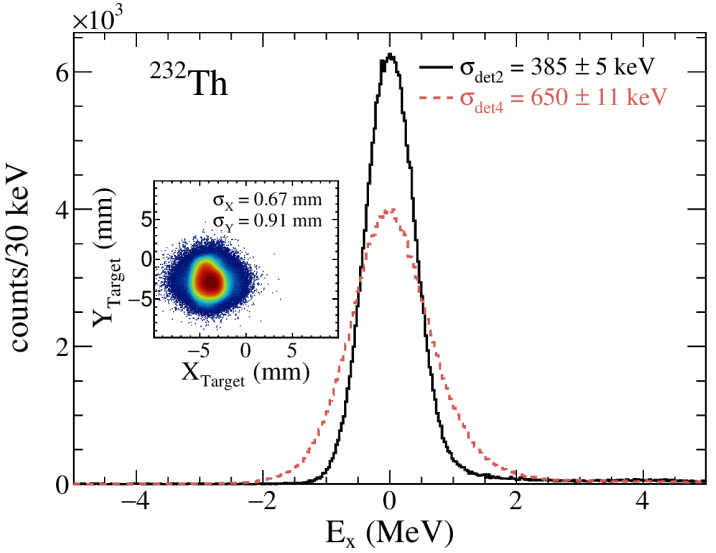

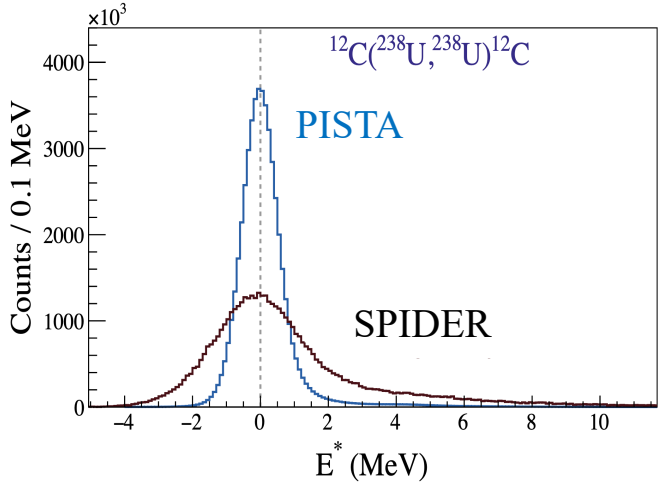

L. Bégué-Guillou, NIM A 1090 171671 (2026)

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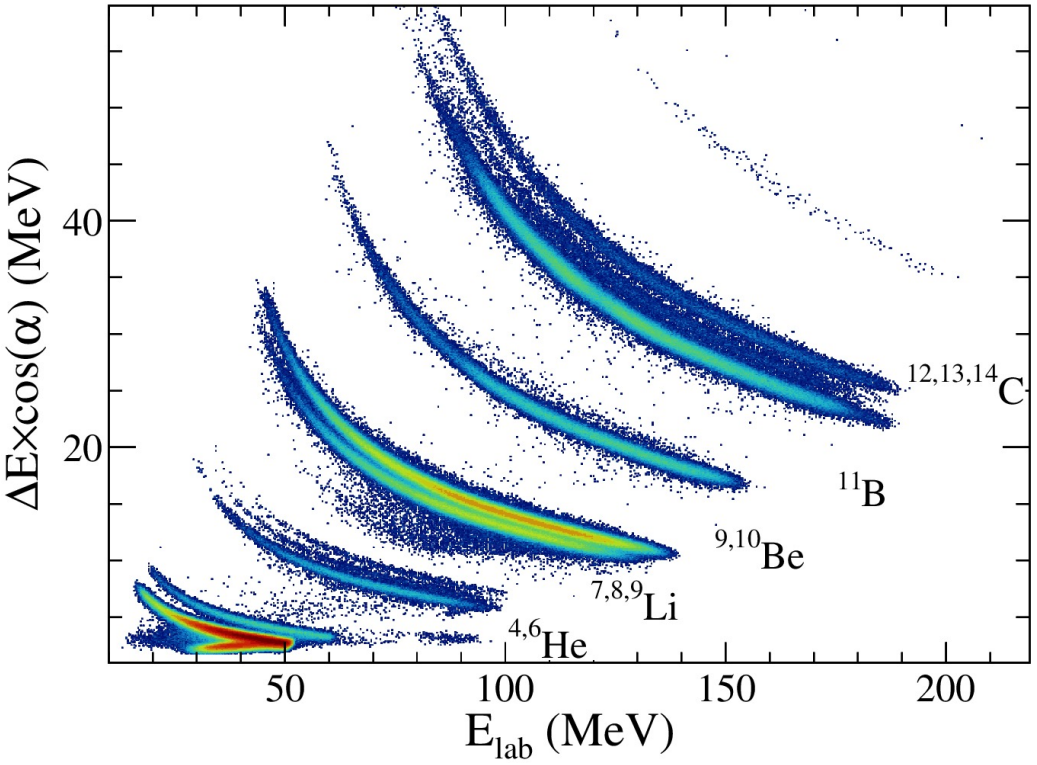

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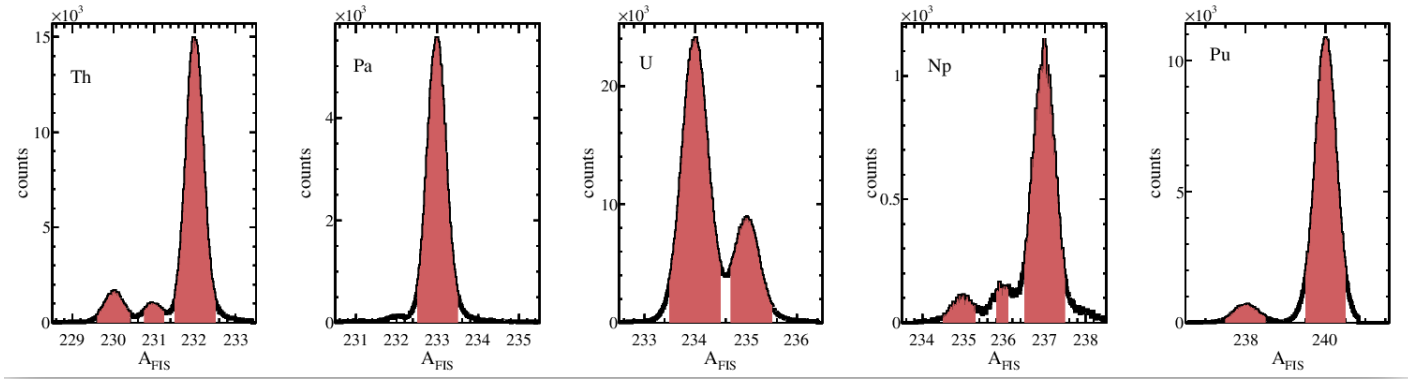

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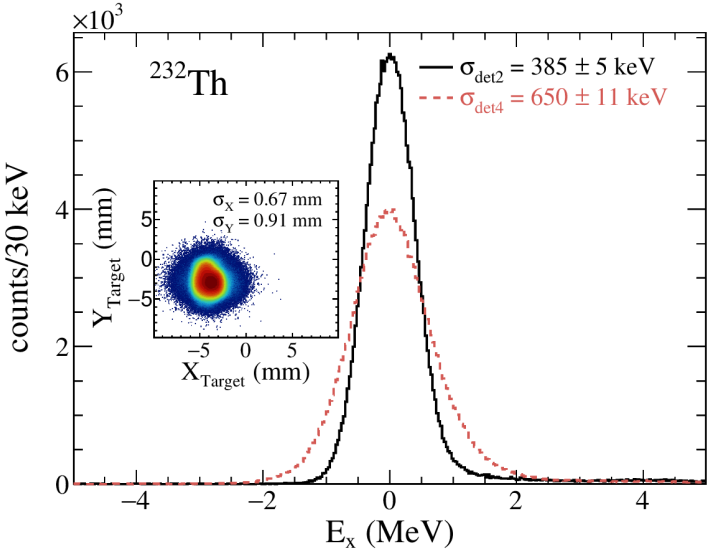
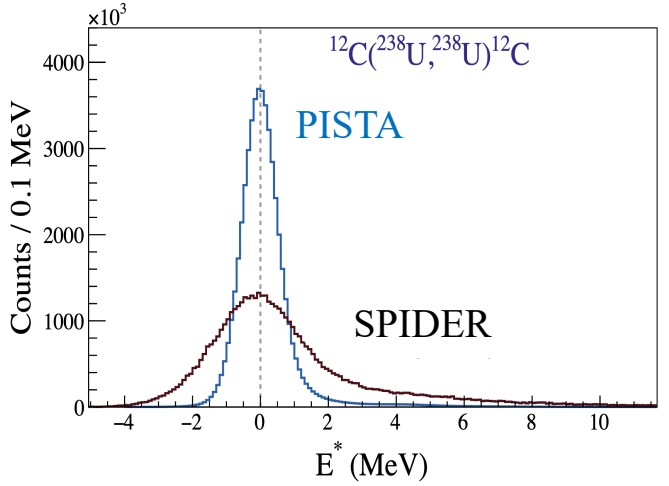


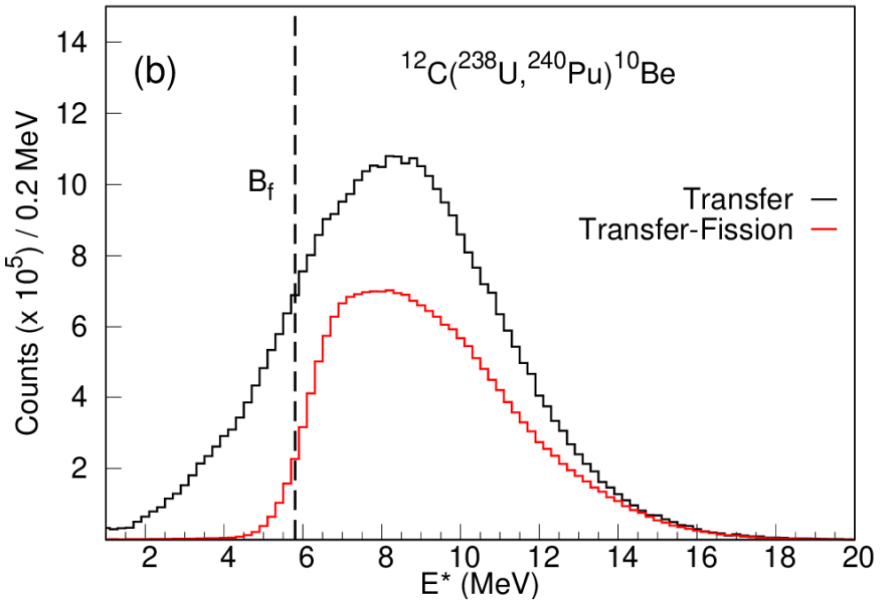


Expected E_x resolution : 340 keV
(with interaction point at target)

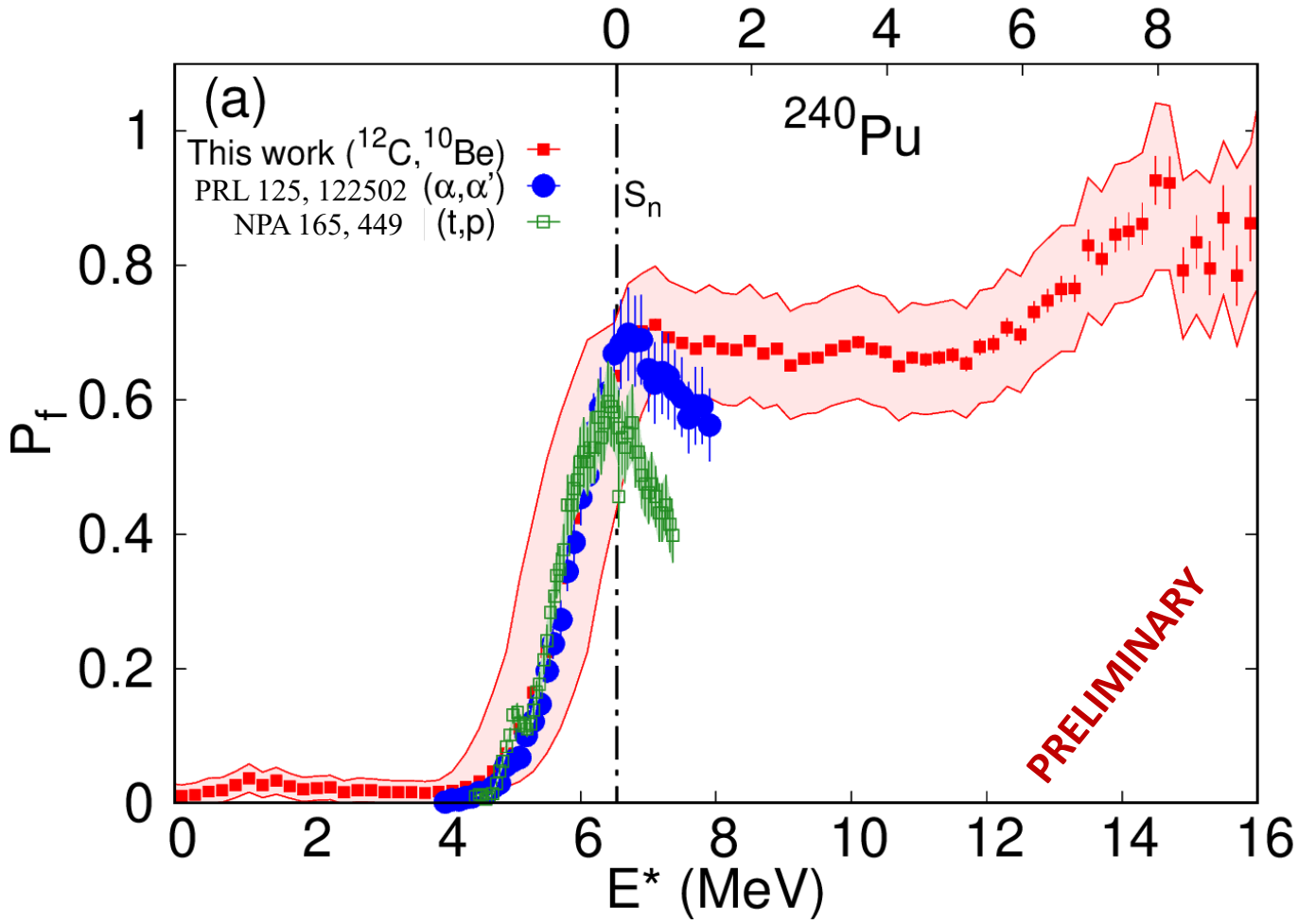
L. Bégué-Guillou, NIM A 1090 171671 (2026)

Fission Probability Measurement

$^{238}U + ^{12}C \rightarrow ^{240}\mathbf{Pu} + ^{10}Be$



- Sharp fission threshold:
  - E* resolution comparable to direct-kinematics measurements
- Evidence of different competition between neutron evaporation and fission



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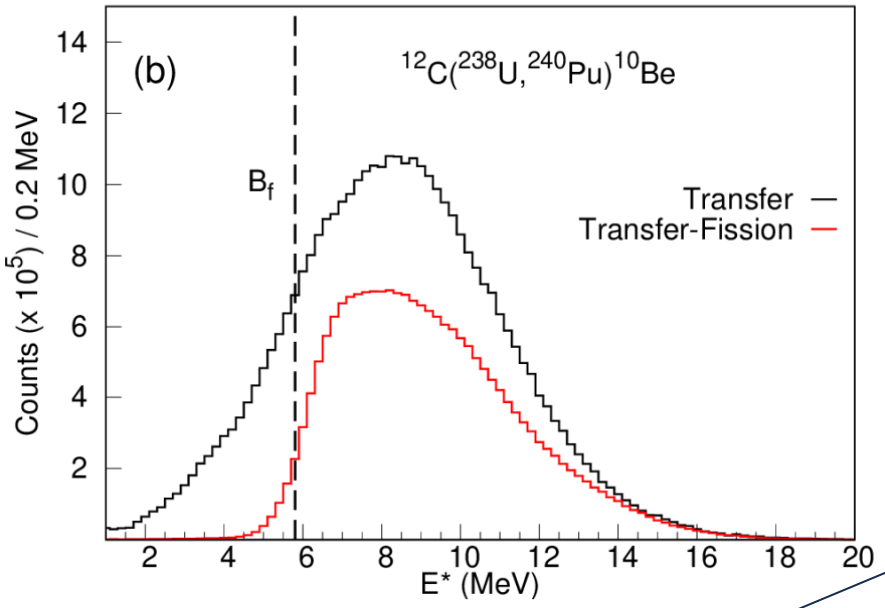

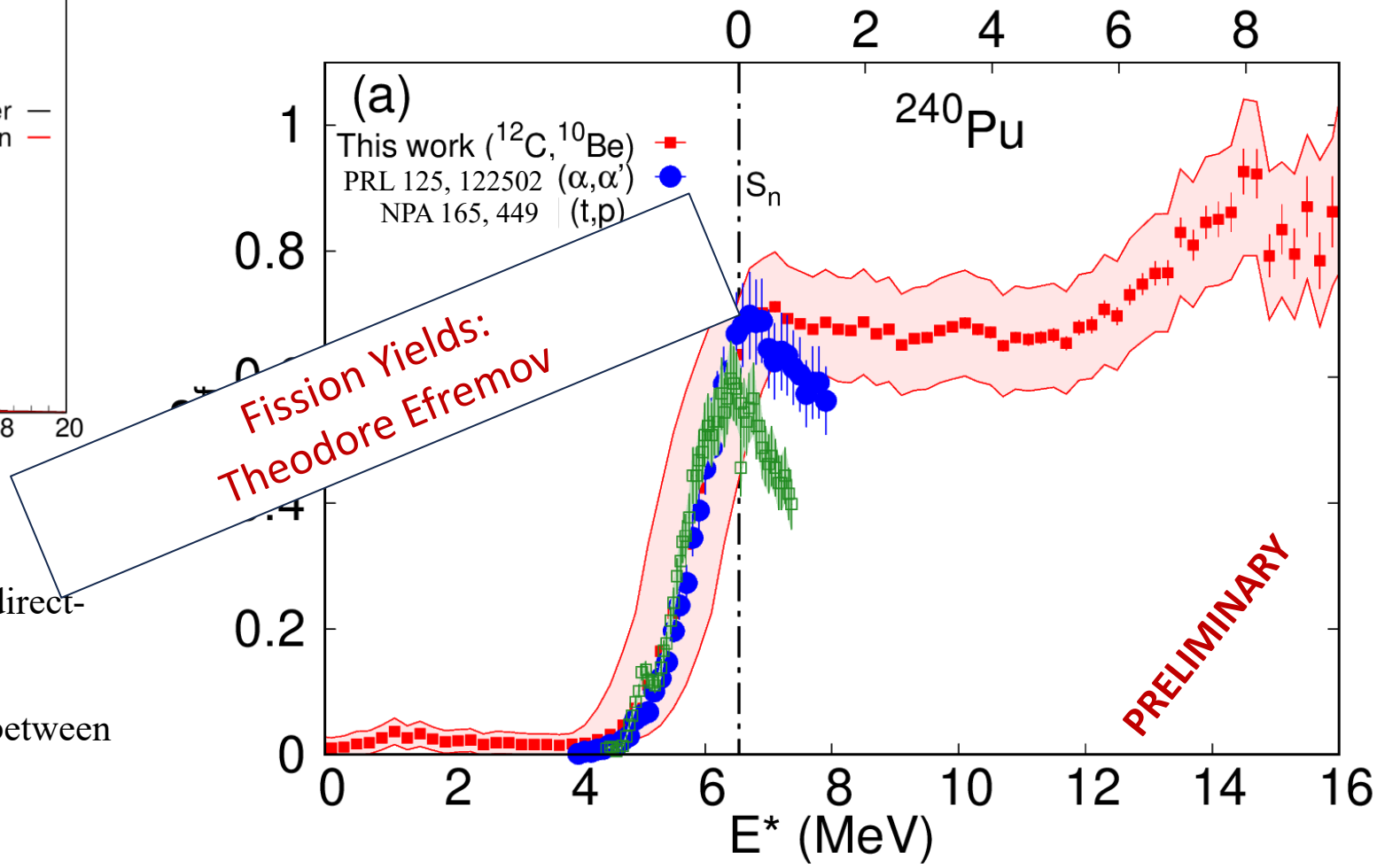

Fission Yields:
Theodore Efremov

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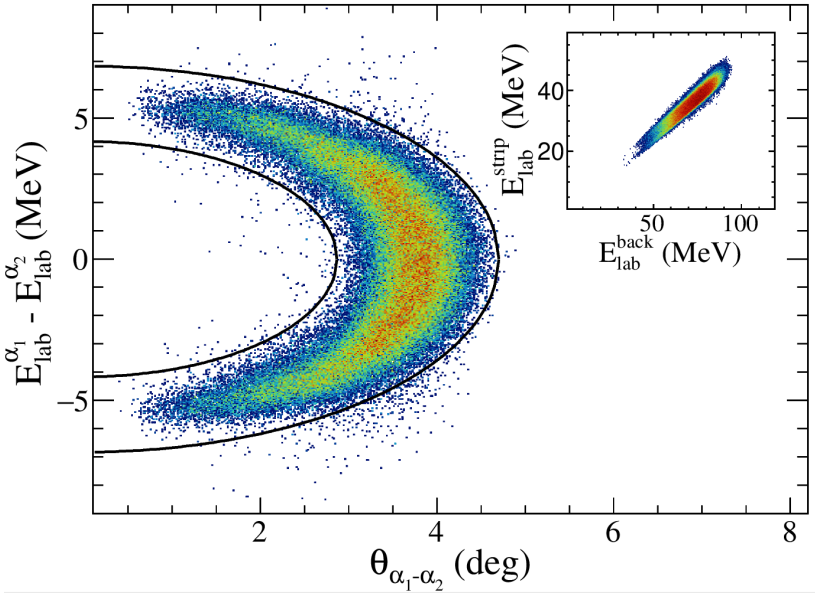
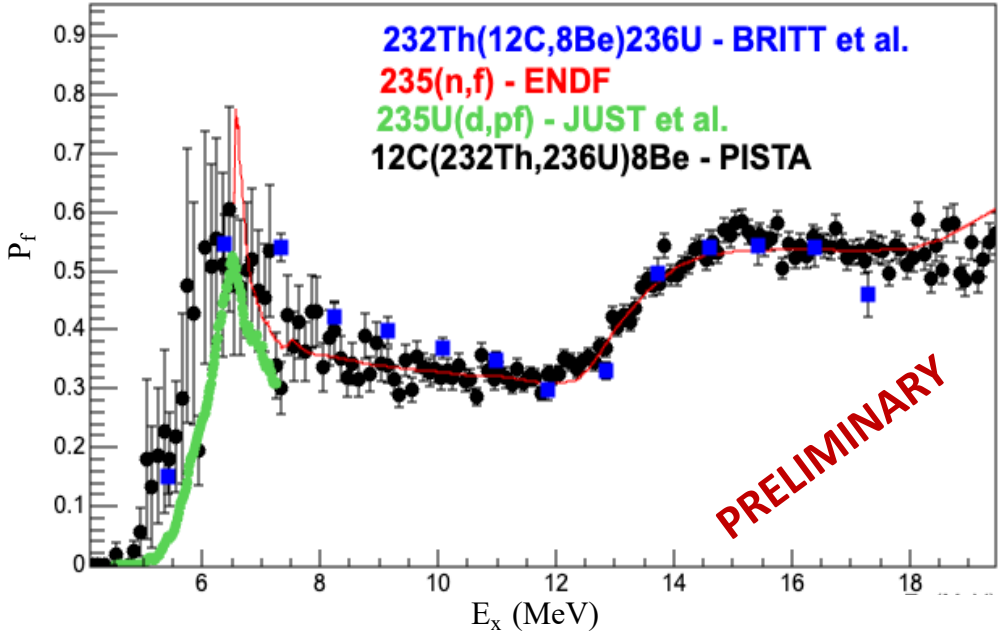
^{236}U from 1α transfer

Kinematic Correlation of 2α from ^{8}Be

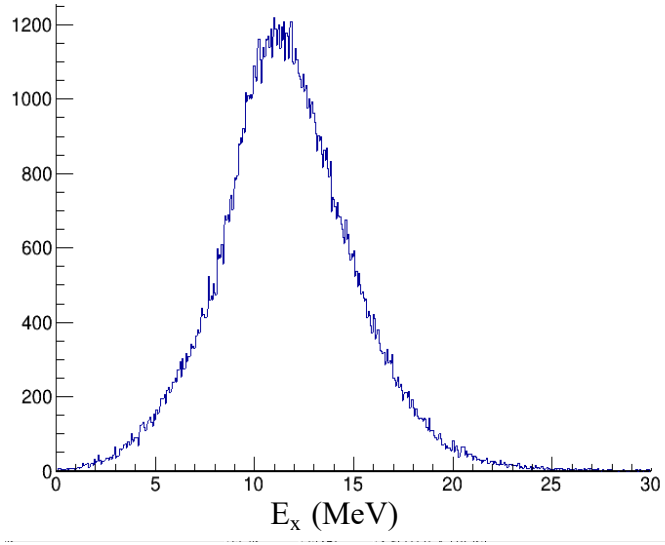


^{232}Th+ ^{12}C -> **^{236}U** + ^{8}Be

Fission probability of ^{236}U



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



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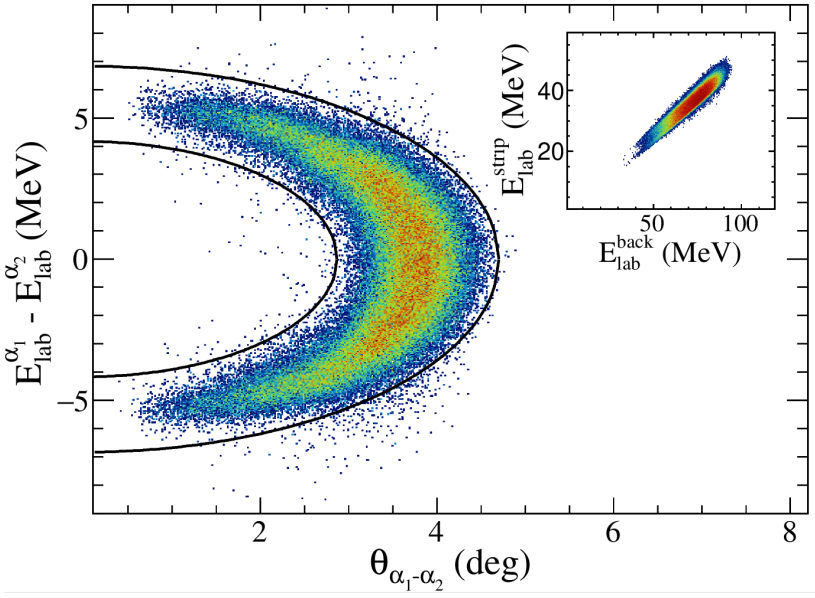

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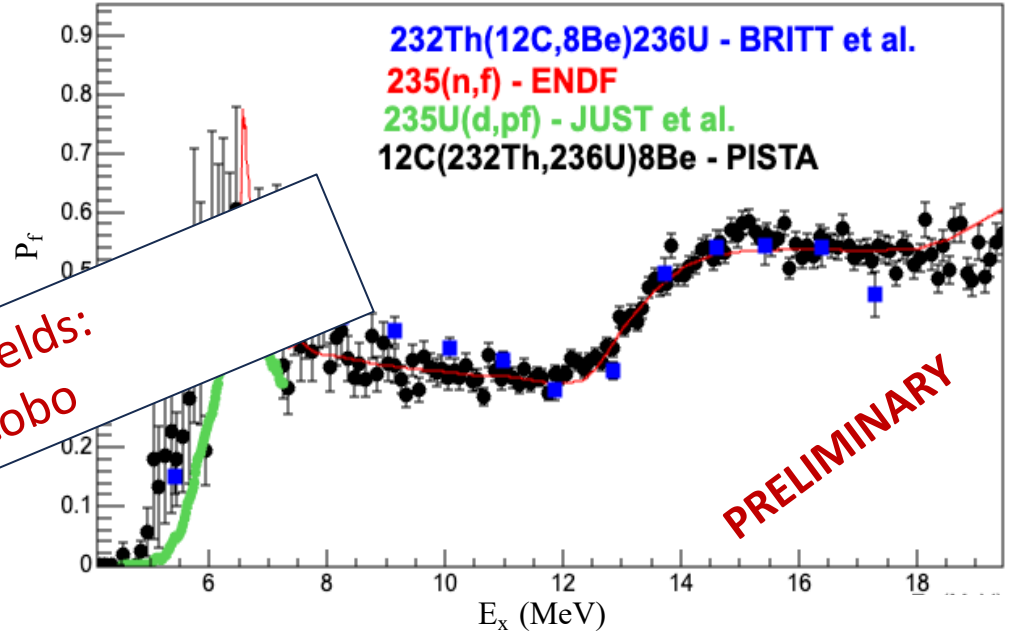

Fission Yields:
Alex Cobo

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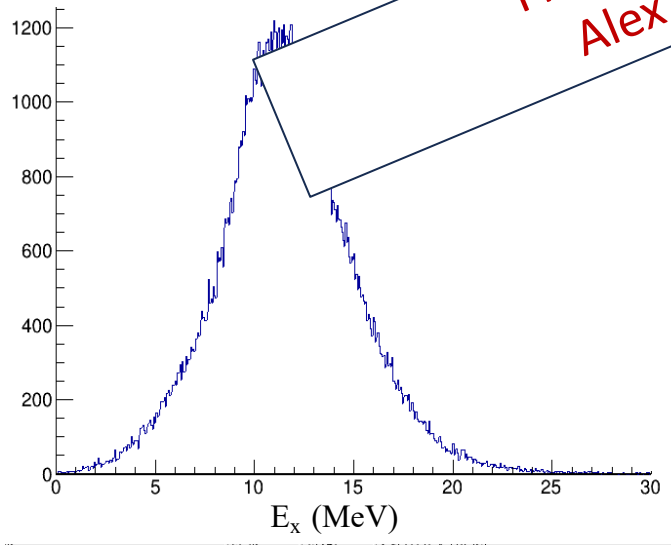

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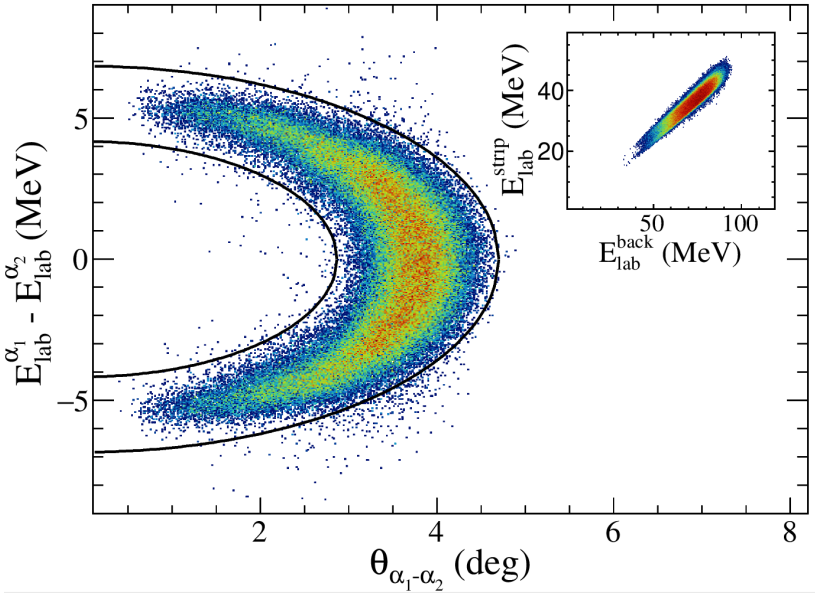

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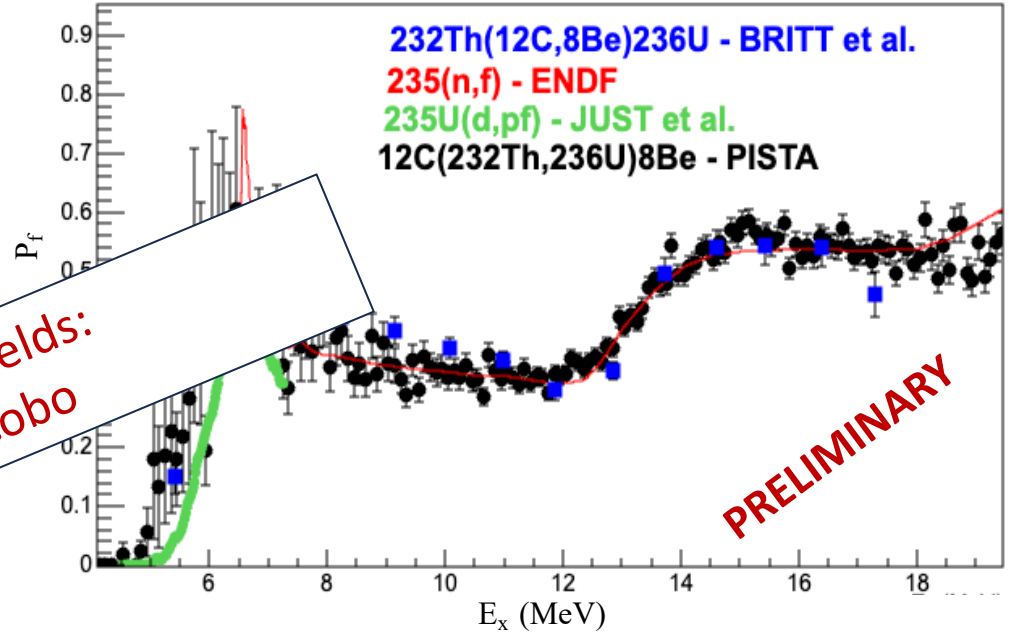

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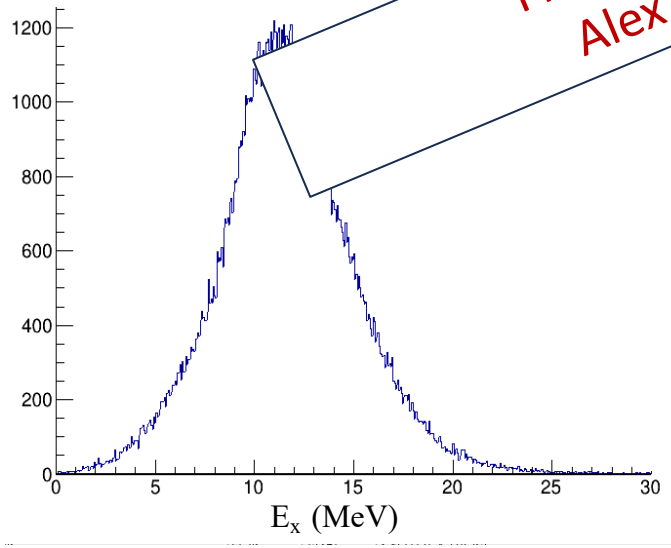
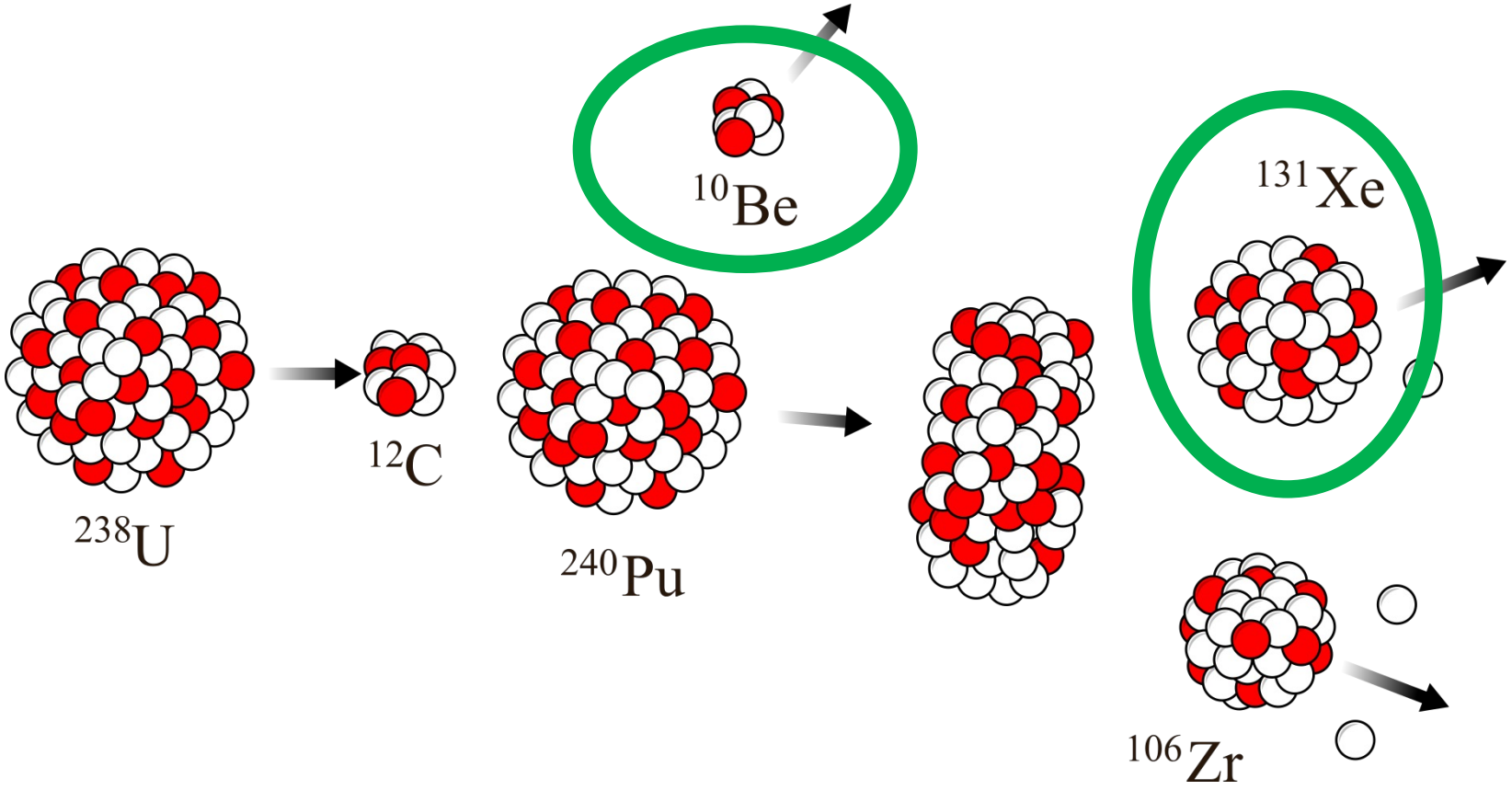


New measurement in 2026:

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

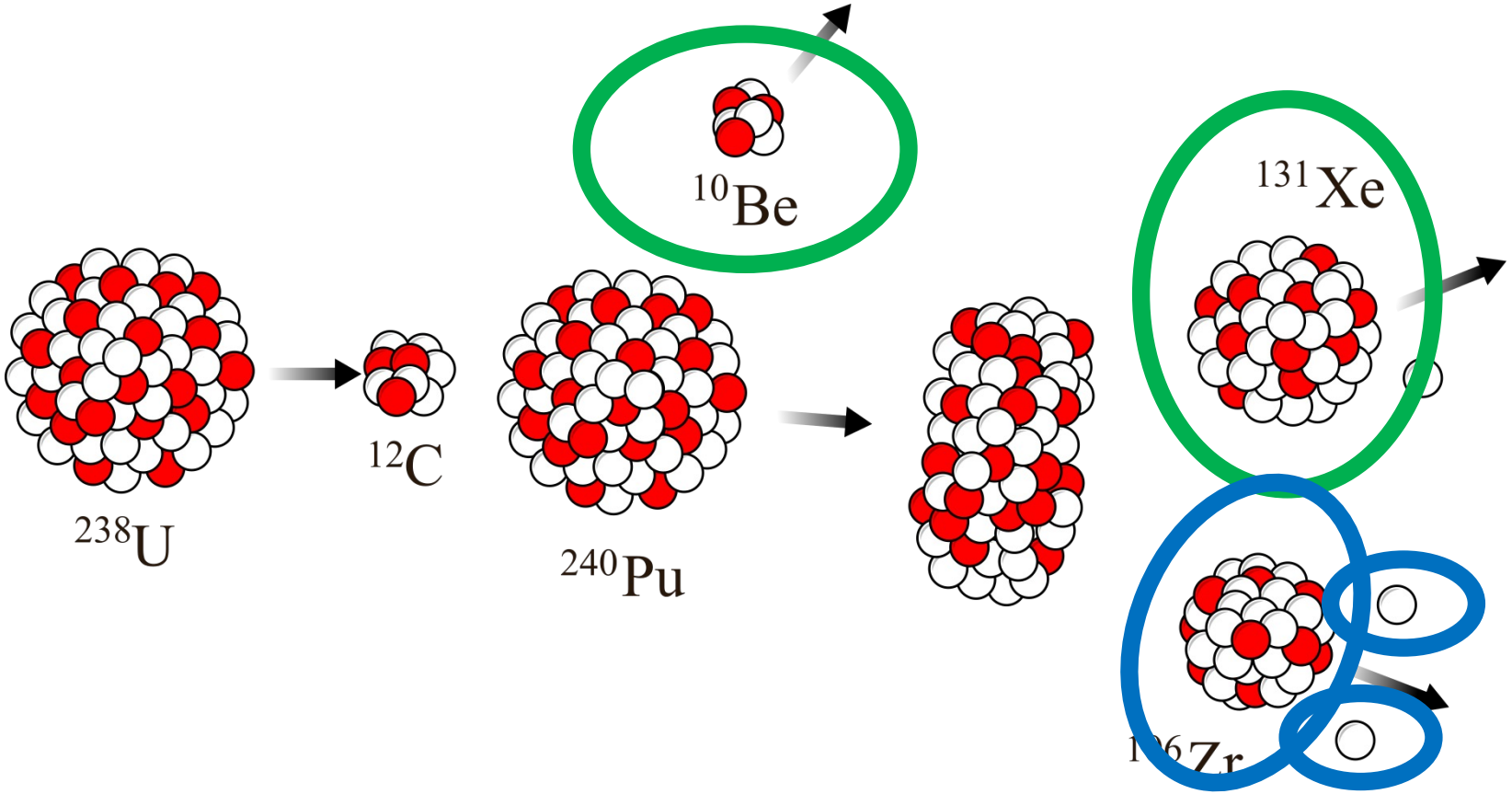
FUTURE of FISSION@VAMOS:
Towards a More Complete Measurement

Next Steps



- **INCOMING CHANNEL**
  - Identification
  - Excitation Energy
- **OUTGOING CHANNEL**
  - FF Z identification
  - FF Post-neutron evaporation masses

Next Steps



- **INCOMING CHANNEL**
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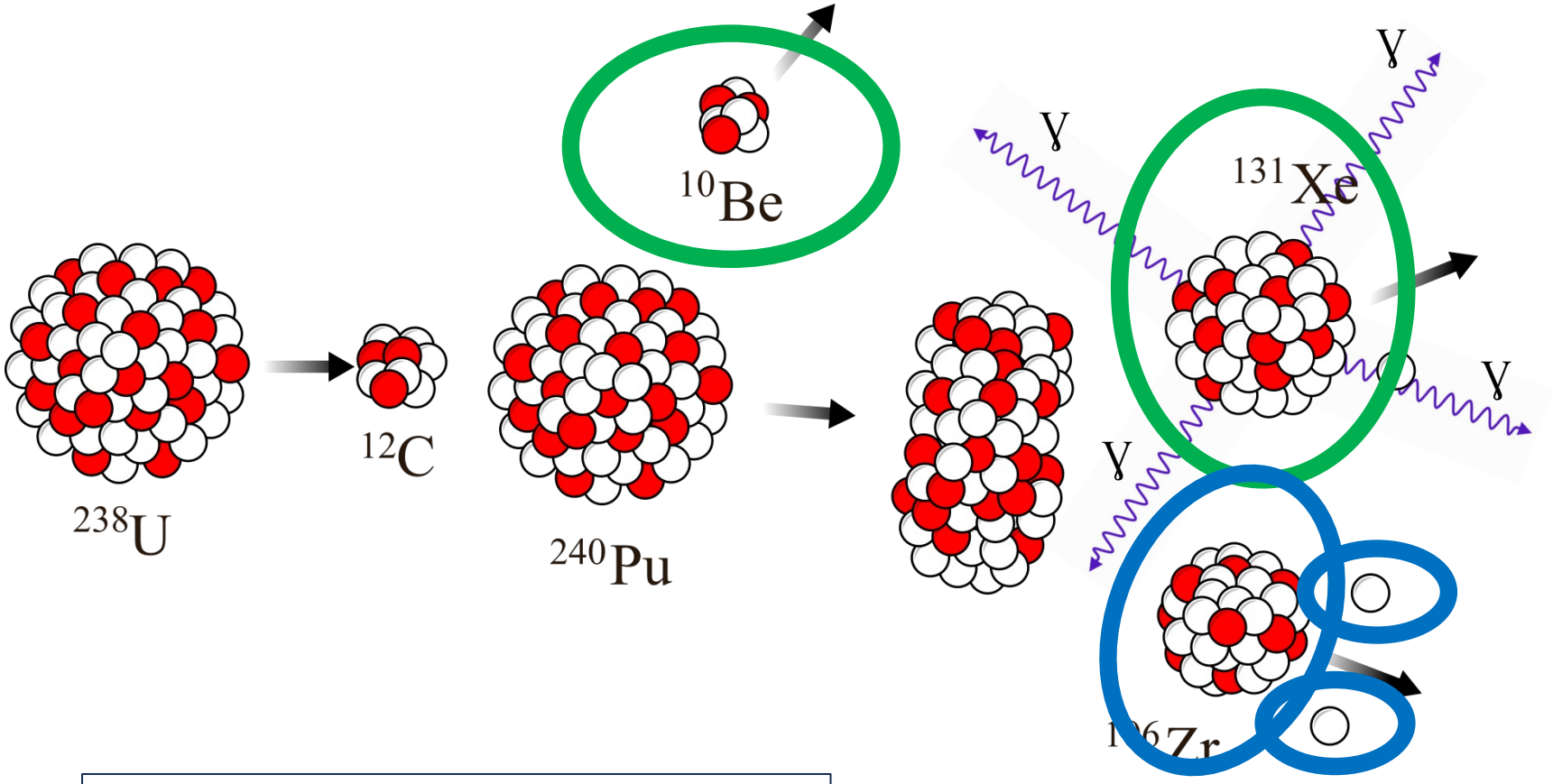
  - Excitation Energy
- **OUTGOING CHANNEL**
  - FF Z identification
  - FF Post-neutron evaporation masses
  - FF Pre-neutron evaporation masses
  - Total Kinetic Energy
  - Neutron Multiplicity
  - Total Excitation Energy

Precise measurement of 2 fission fragment angle & velocity

Measurement of the prompt neutrons

Next Steps



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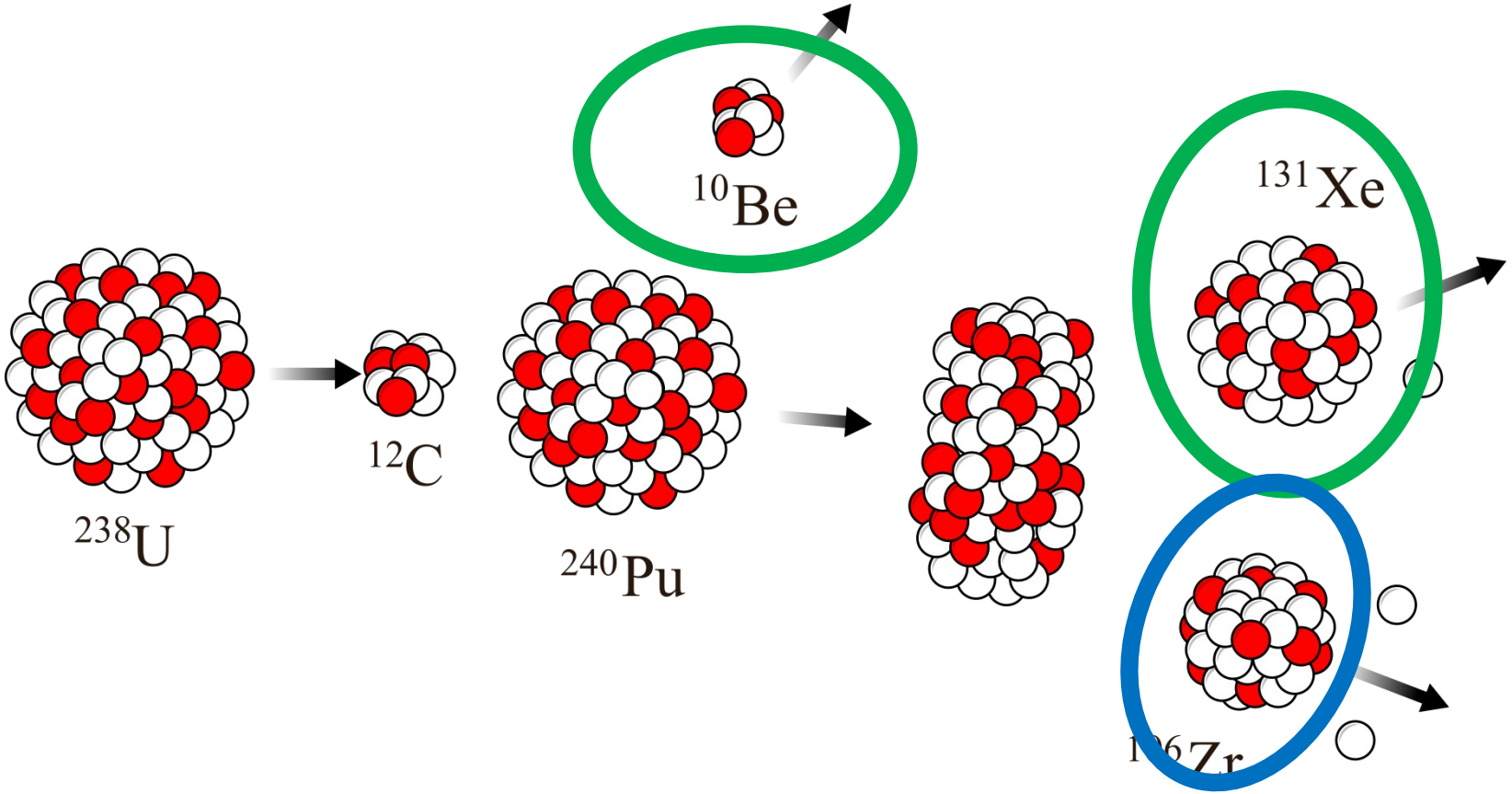
Precise measurement of 2 fission fragment angle & velocity

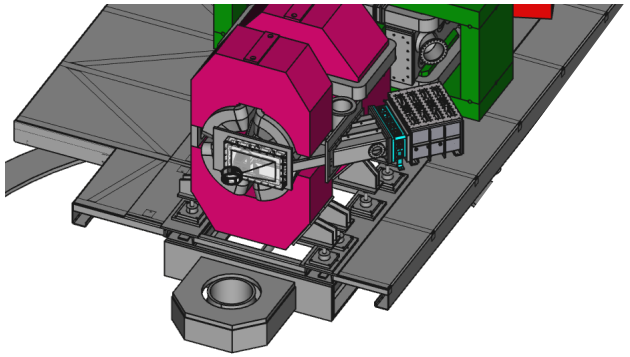
Measurement of the prompt neutrons

Fission Fragment Gamma Decay

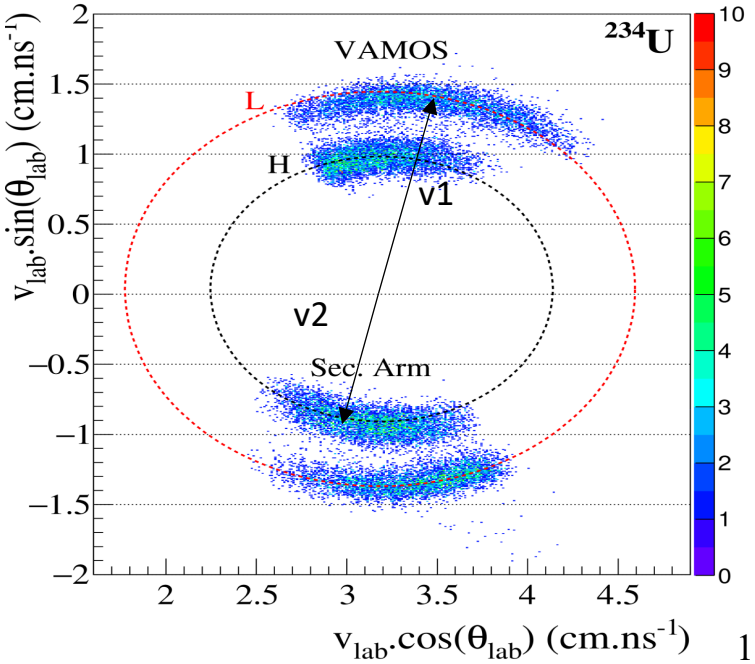
Fission Fragments Spin:
Jonathan Bequet

Fission Fragments in Second Arm





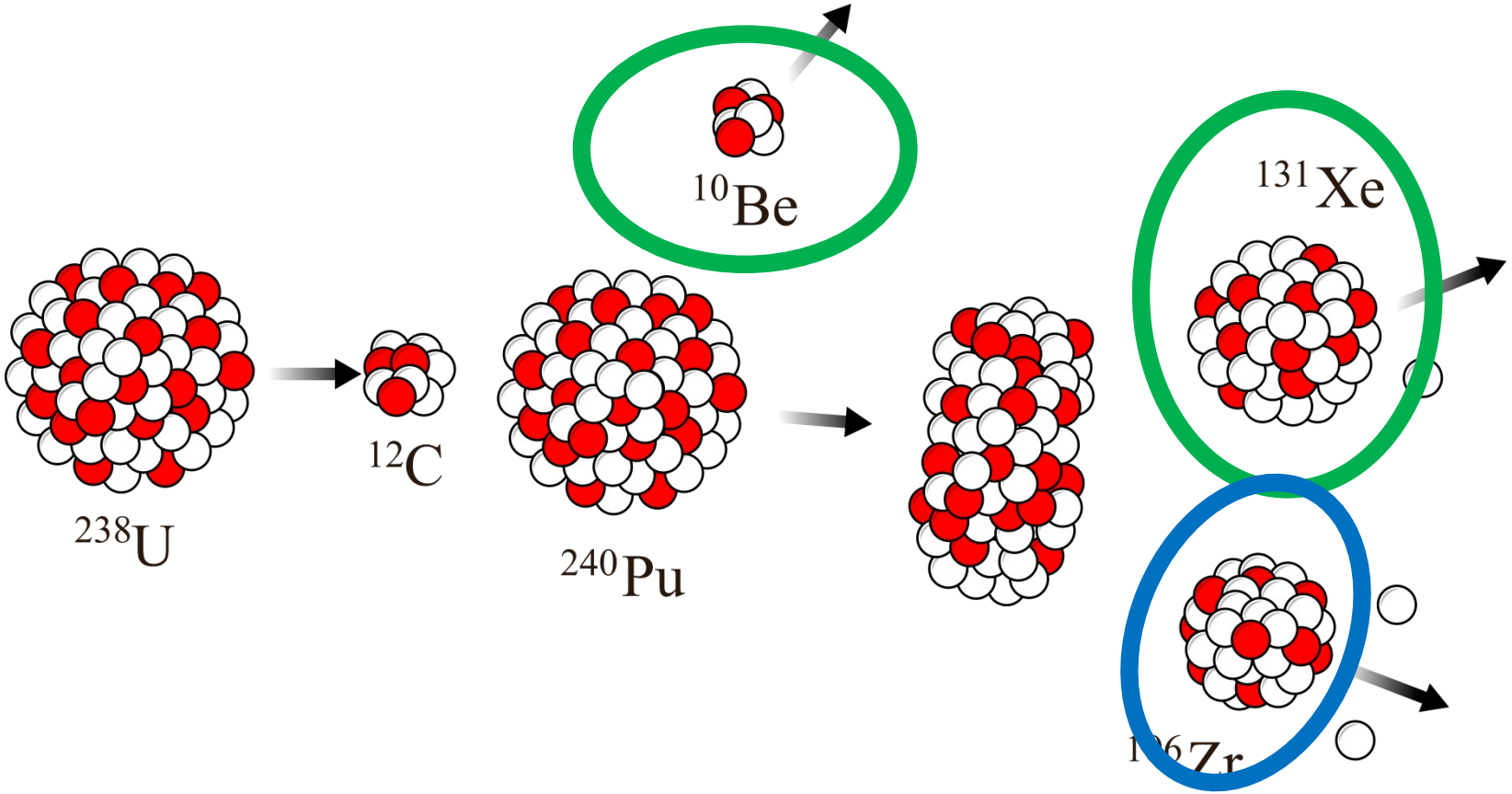
- First attempt to measure the second fission-fragment velocity in 2024

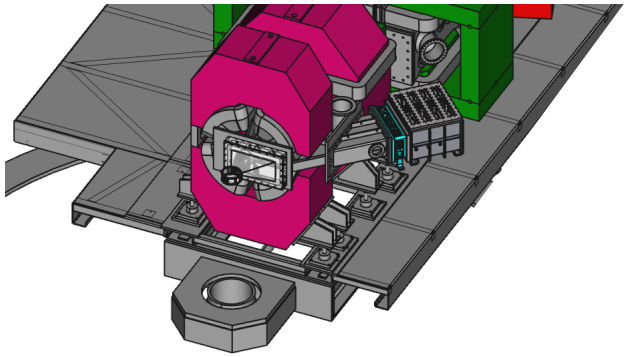


Access to fission masses before neutron evaporation

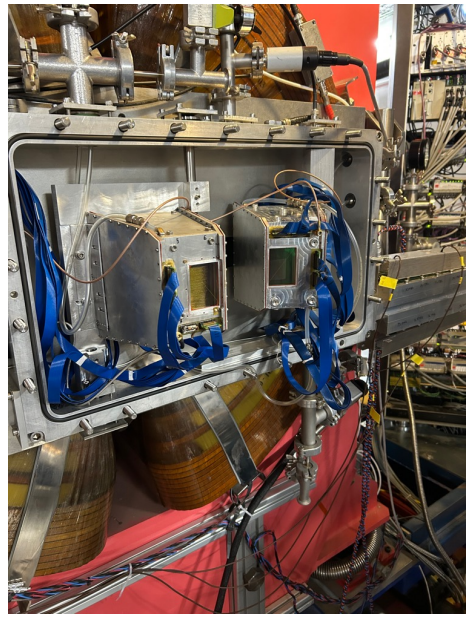
$$\frac{M_1^*}{M_2^*} = \frac{\gamma_{c.m.2}\, v_{c.m.2}}{\gamma_{c.m.1}\, v_{c.m.1}}$$

Fission Fragments in Second Arm





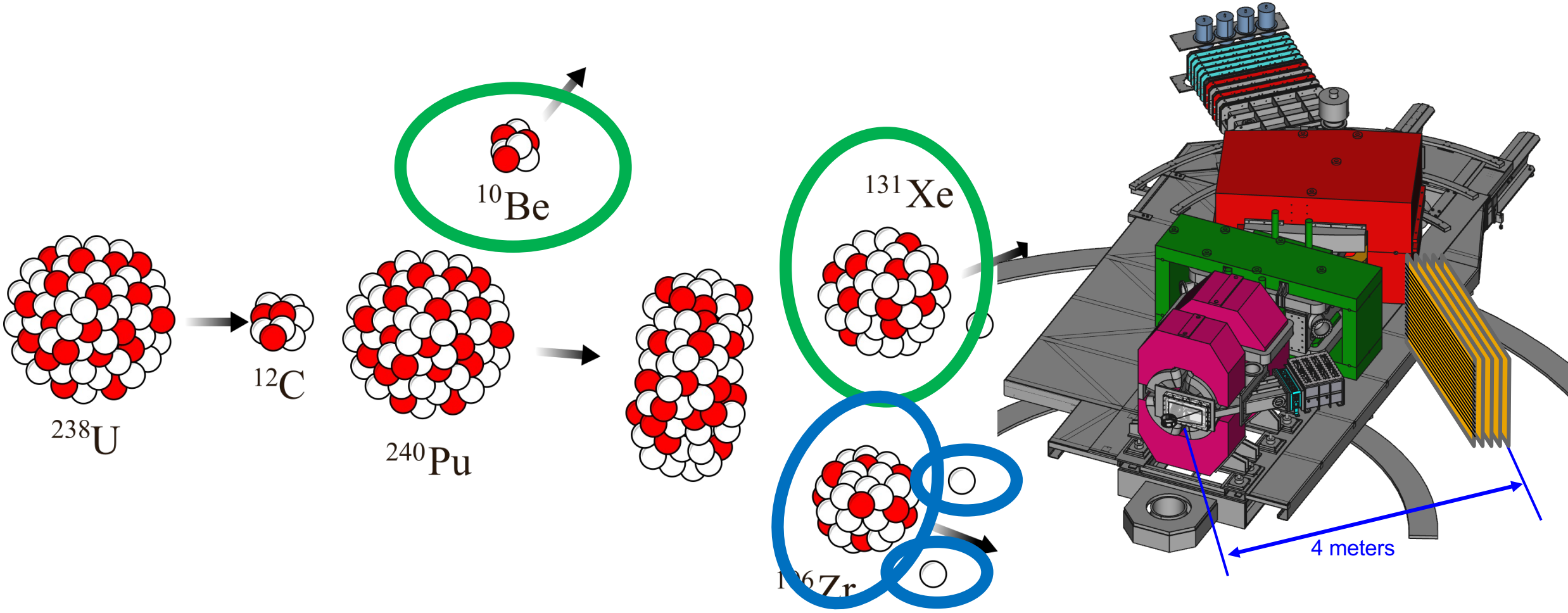
- Complete setup with 2 telescopes in 2027



Access to fission masses before neutron evaporation

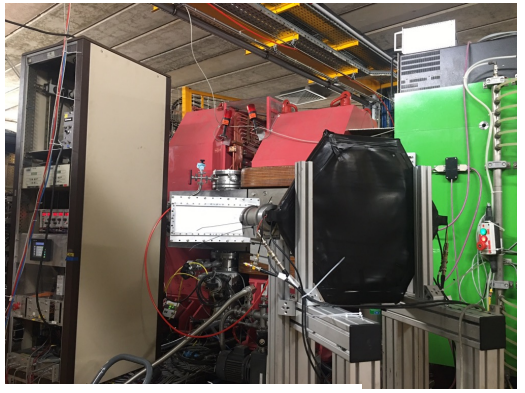
$$\frac{M_1^*}{M_2^*} = \frac{\gamma_{\mathrm{c.m.}_2} v_{\mathrm{c.m.}_2}}{\gamma_{\mathrm{c.m.}_1} v_{\mathrm{c.m.}_1}}$$

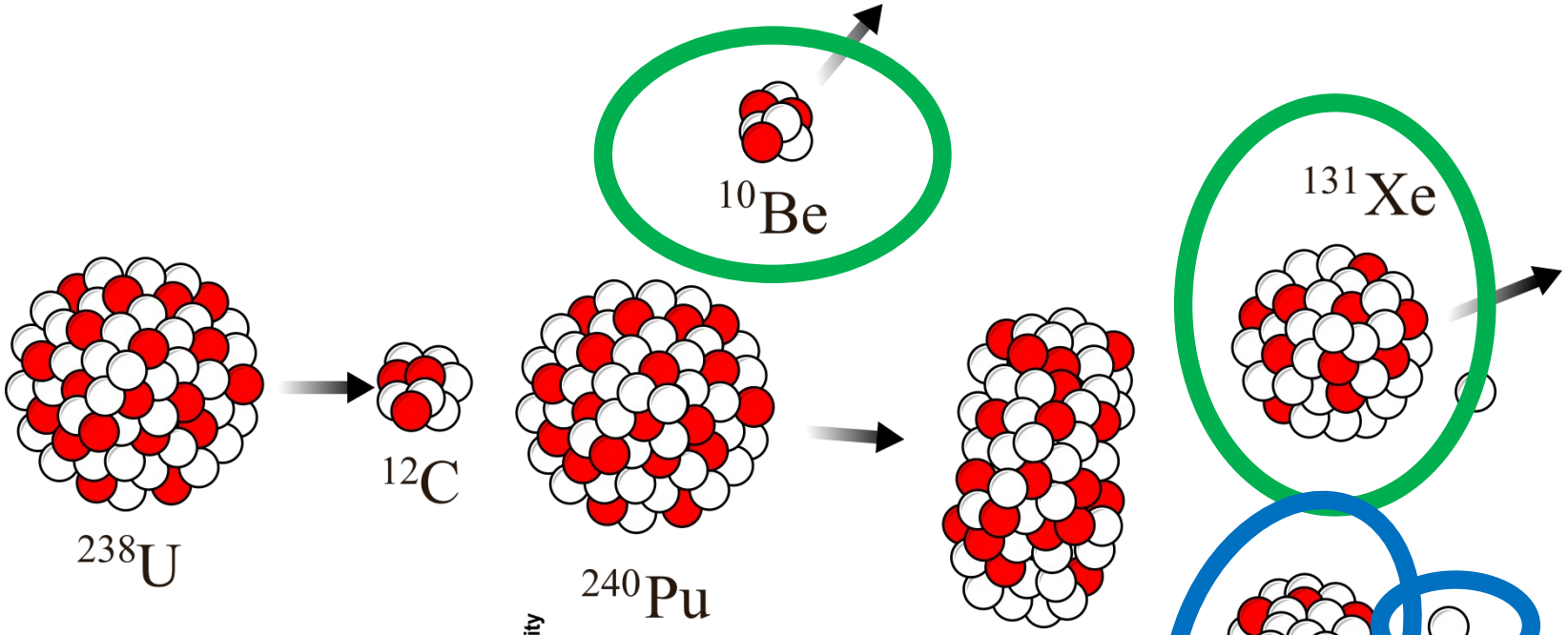
Neutron Detection @ VAMOS++

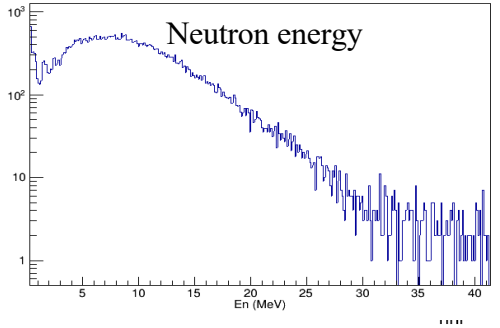


Neutron Detection @ VAMOS++

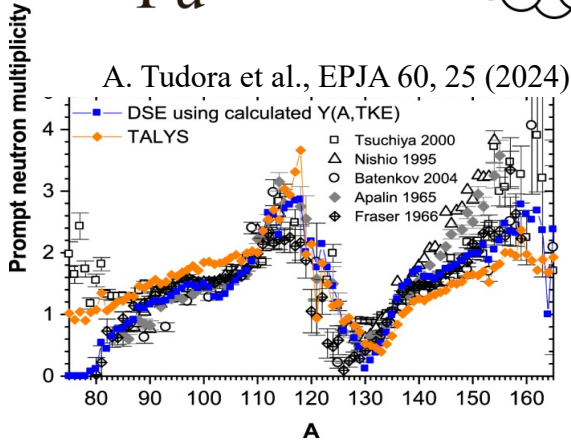
- First attempt in 2024

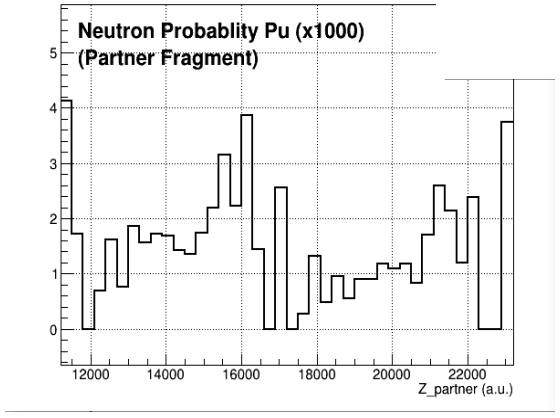






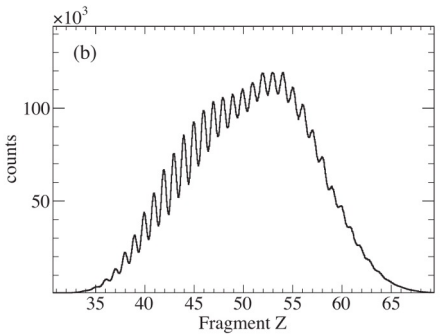
A. Tudora et al., EPJA 60, 25 (2024)

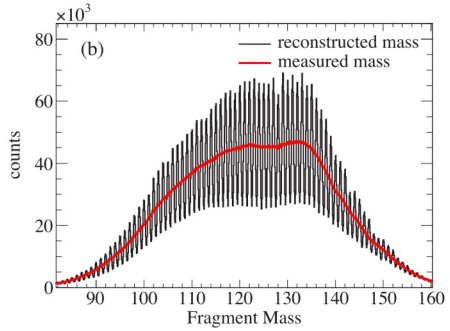




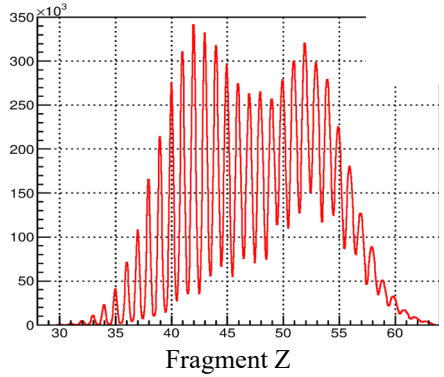
Fission@VAMOS

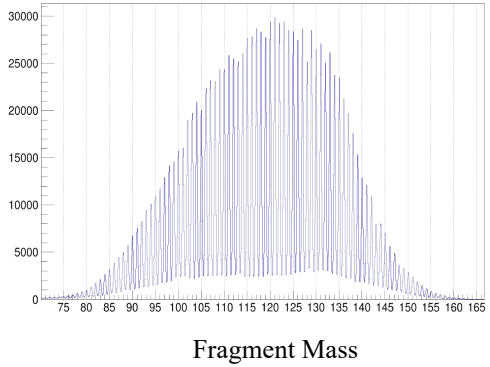
VAMOS



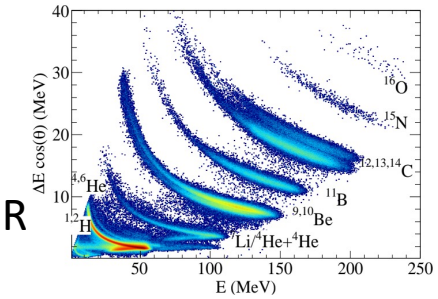


VAMOS++

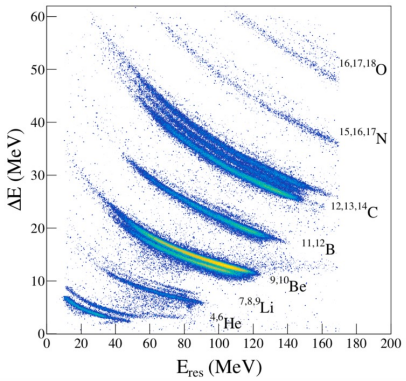




SPIDER



PISTA



- The fission program at VAMOS/GANIL is a rich, very competitive, and a well stablished program.
- The combination of inverse kinematics at Coulomb-barrier 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.