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Fission Studies with VAMOS and FALSTAFF Spectrometers

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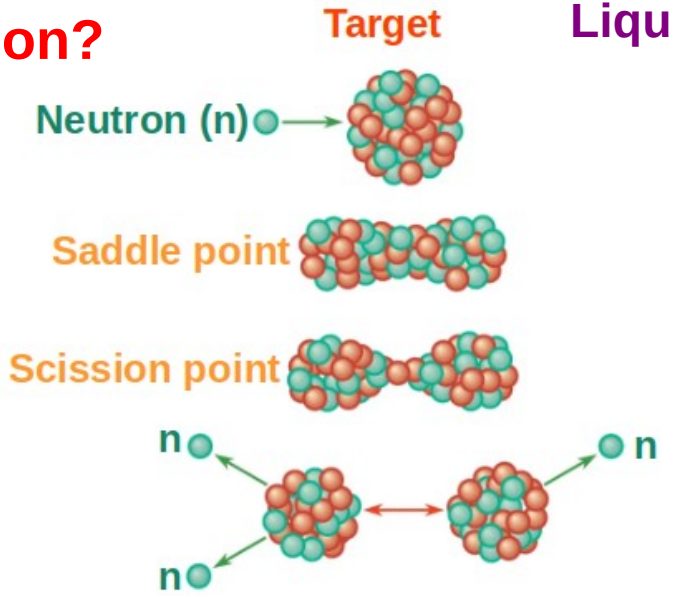
Outline

- Introduction
- Experimental Setup
- VAMOS Analysis
- FALSTAFF Analysis
- Conclusions

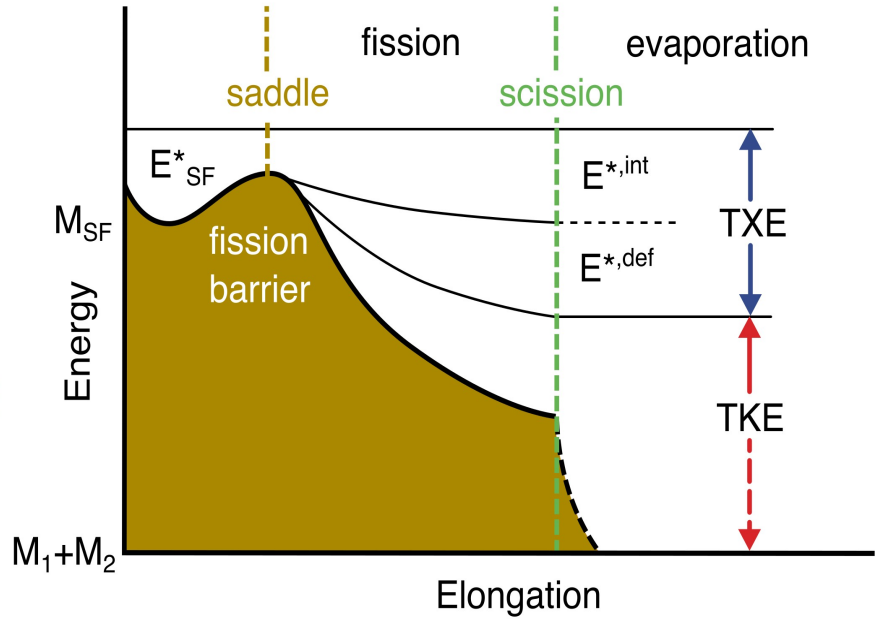
Introduction

What is nuclear fission?

Released kinetic energy (TKE) ~ 200 MeV



Liquid drop model potential energy curve



Theoretical approach

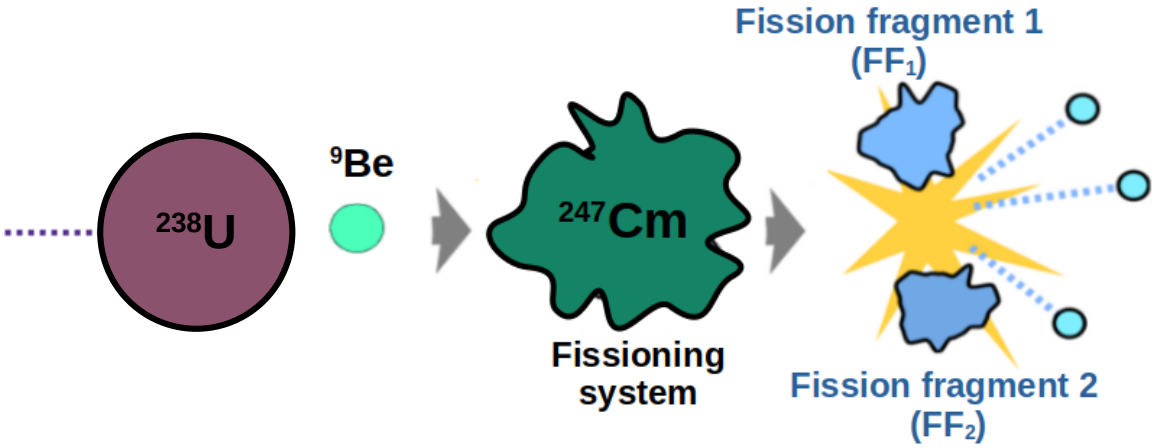
- Microscopic (dynamic)
- Scission point (statistical)

Experimental approach

- Entrance channels (fissioning system):
  Atomic number, mass number, excitation energy and angular momentum.
- Exit channels (fission fragments):
  Atomic number, mass number, isotopic yields, scission point configuration (total TKE and TXE), and neutron multiplicity.

Motivation

Inverse kinematics



Allows the direct measurement of nuclear charge.

^{238}U (5.88 MeV/A) + $^{27}Al \rightarrow {}^{265}Db$ (E* = 62 MeV)

^{238}U (5.88 MeV/A) + $^{9}Be \rightarrow {}^{247}Cm$ (E* = 43 MeV)

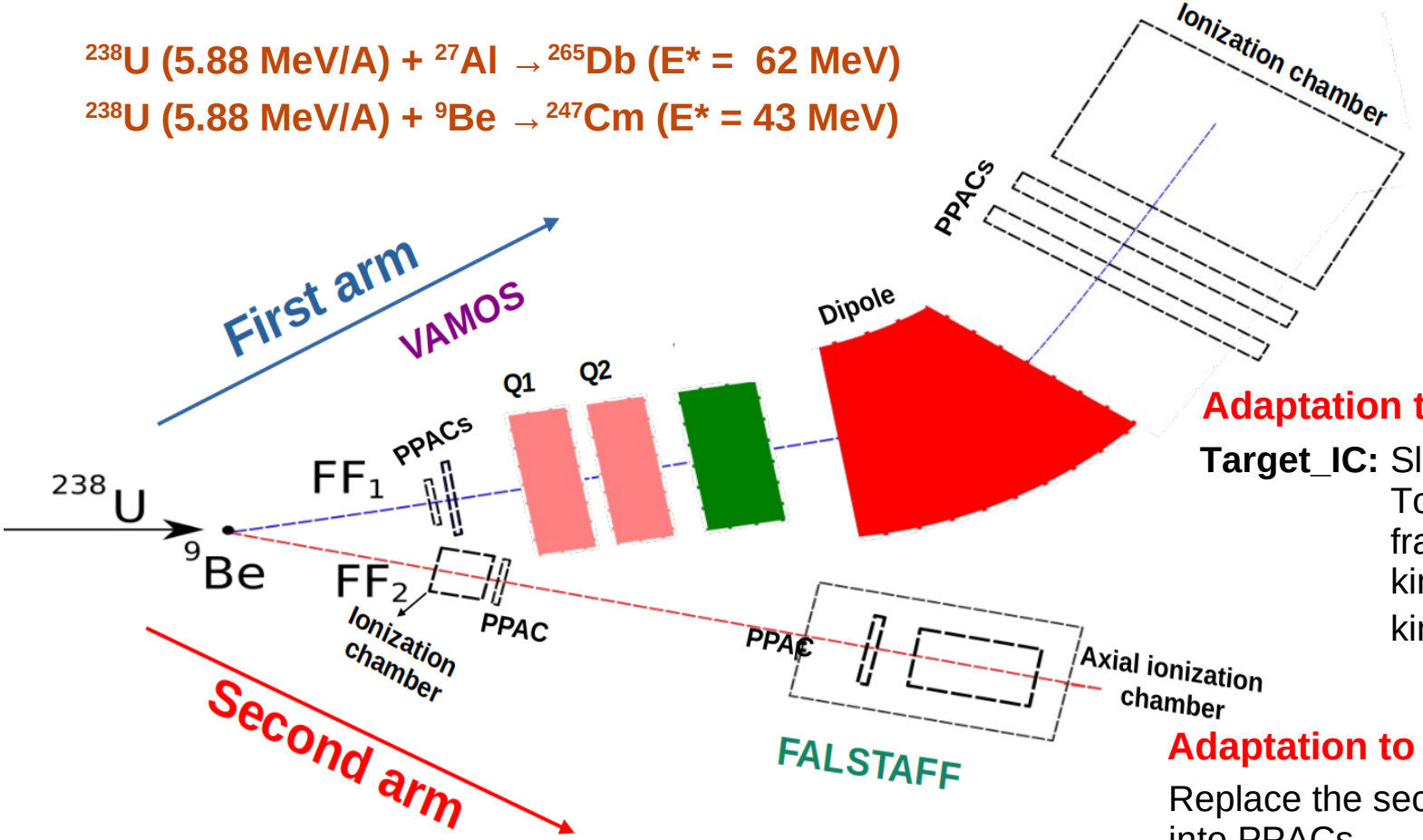
Study the fission dynamics of exotic minor actinides using both **VAMOS** and **FALSTAFF** spectrometers

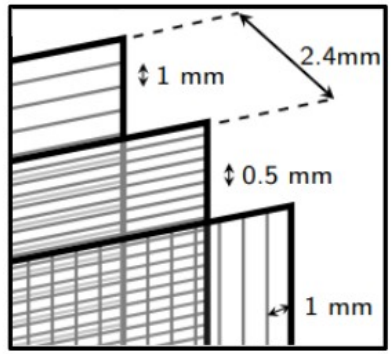
- Atomic number, mass number, isotopic yields, scission point configuration (TKE and TXE), and neutron multiplicity

Experimental Setup

^{238}U (5.88 MeV/A) + ^{27}Al → ^{265}Db (E* = 62 MeV)

^{238}U (5.88 MeV/A) + ^{9}Be → ^{247}Cm (E* = 43 MeV)





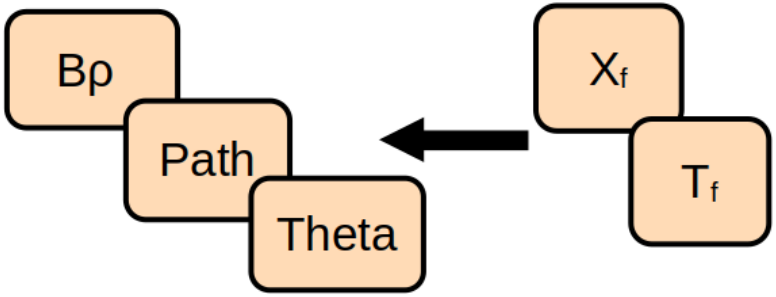
Adaptation to inverse kinematics

Target_IC: Slow down the fragments
To change the velocity of fragments from 5 cm/ns (inverse kinematics) to 1 cm/ns (direct kinematics).

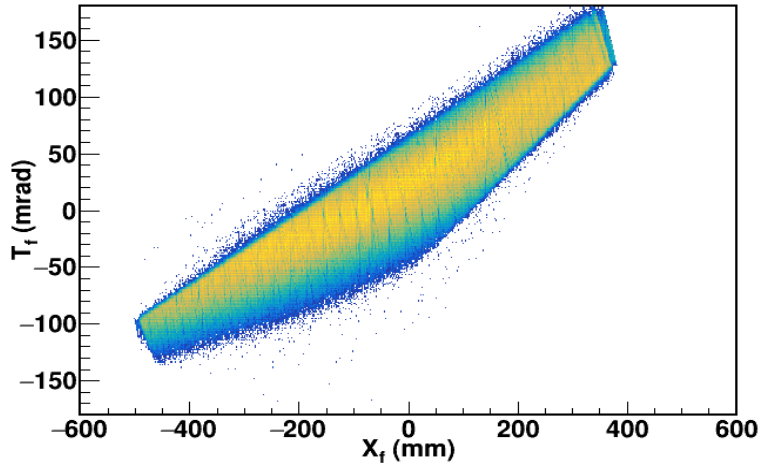
Adaptation to VAMOS magnetic field

Replace the secondary electron detectors into PPACs

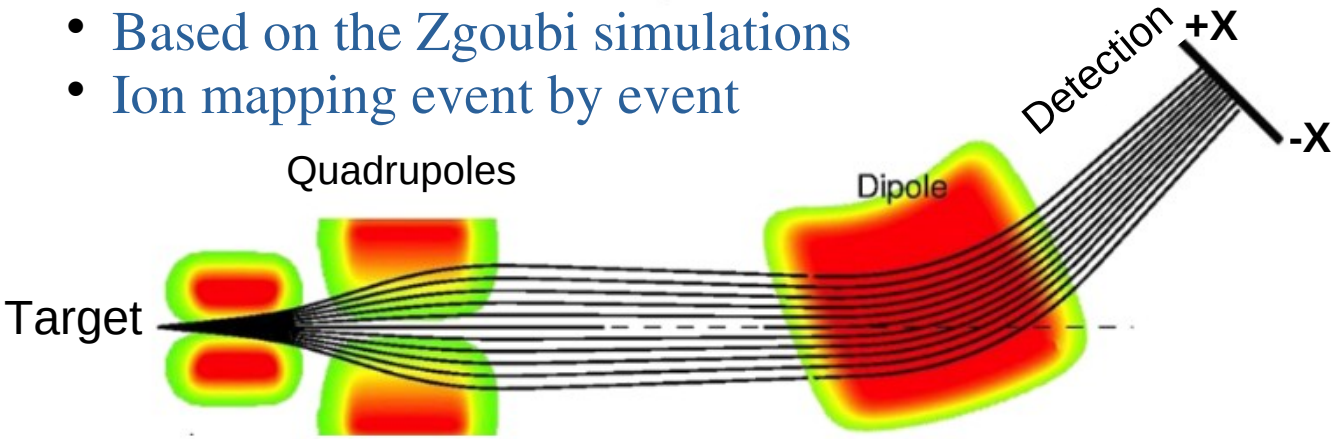
Reconstruction Method



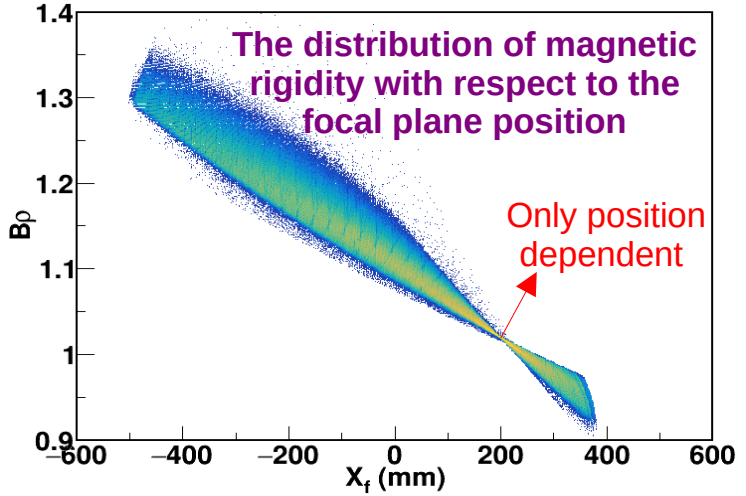
Focal plane



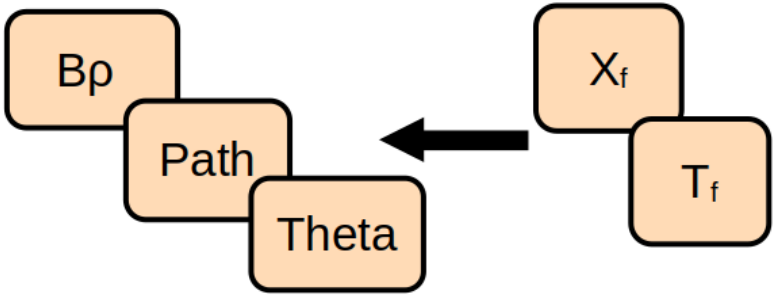
- Based on the Zgoubi simulations
- Ion mapping event by event



$$M/Q = \frac{B\rho}{3.105\,\beta\gamma} \qquad \beta = \frac{V}{c}, \gamma = \frac{1}{\sqrt{1-\beta^2}}$$



Reconstruction Method



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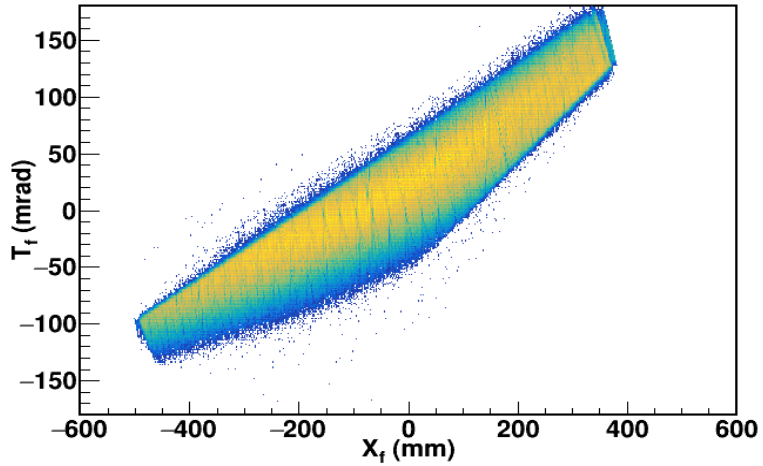

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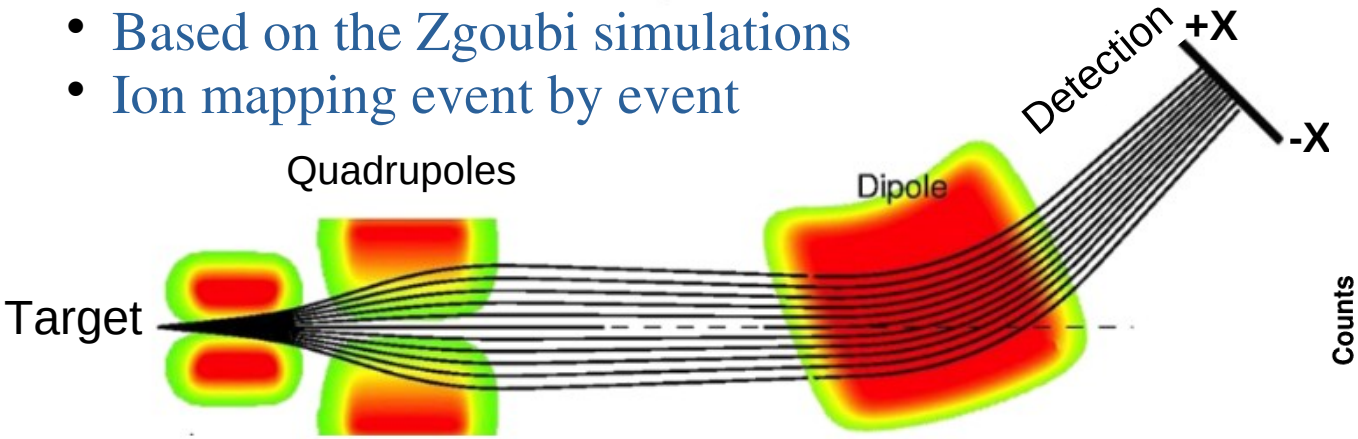
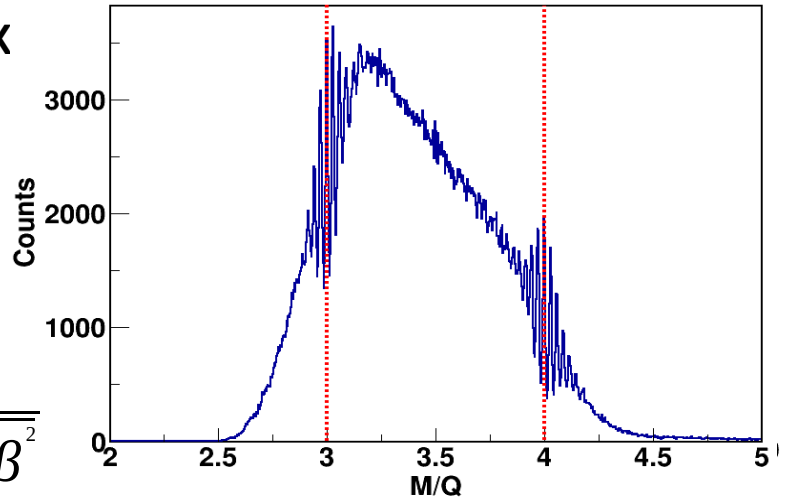
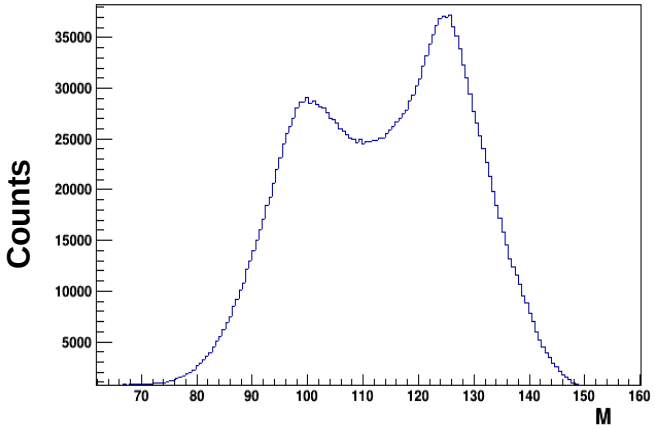


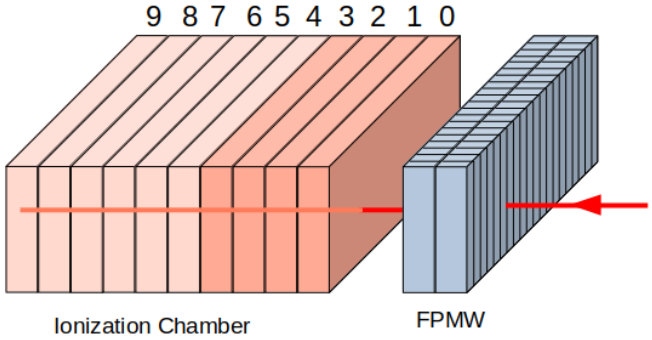


$$M/Q = \frac{B\rho}{3.105\,\beta\gamma}$$

$$\beta = \frac{V}{c}, \gamma = \frac{1}{\sqrt{1-\beta^2}}$$

Mass Identification



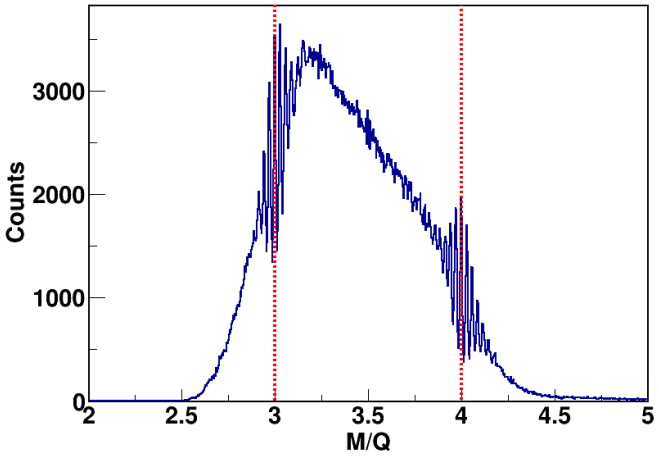


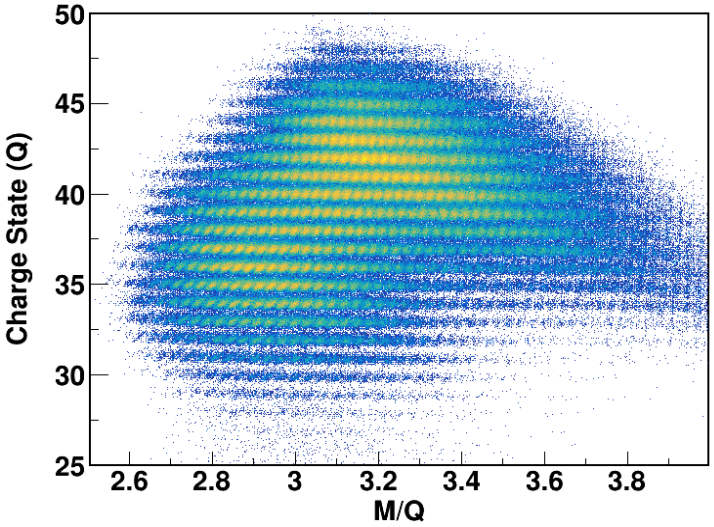
$$E = k_0 \sum_i \alpha_i E_{IC_i}$$

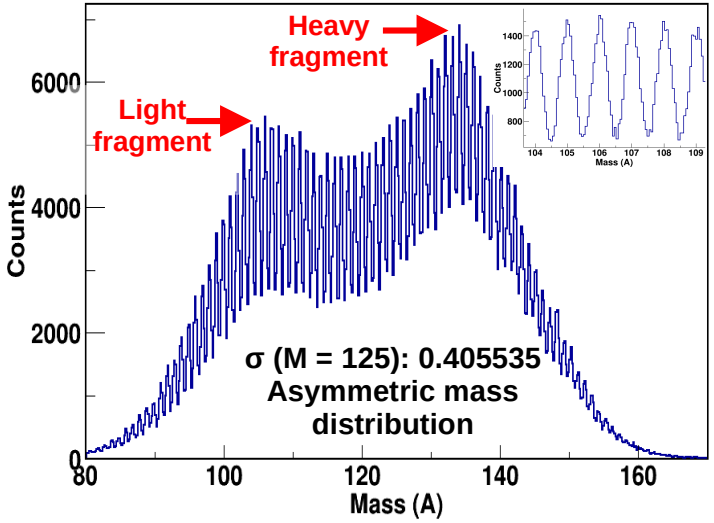
$$M_{IC} = \frac{E}{(\gamma - 1)931.5}$$

Charge state (Q) versus mass over charge state (M/Q)

Reconstructed mass (A)







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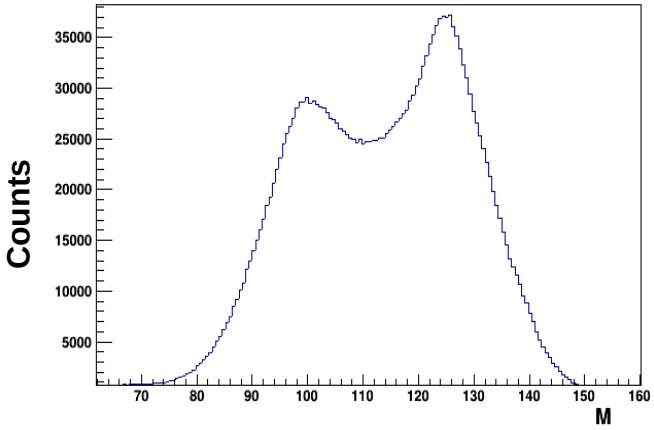
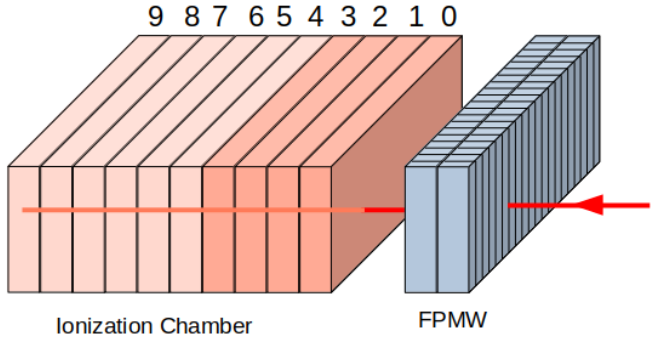
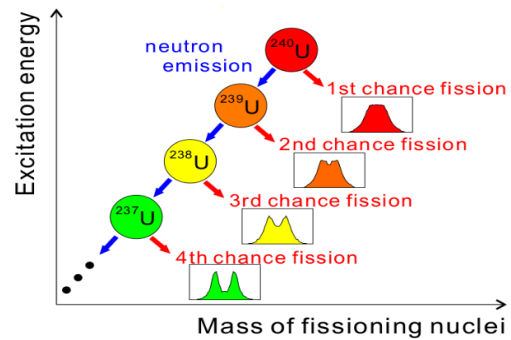


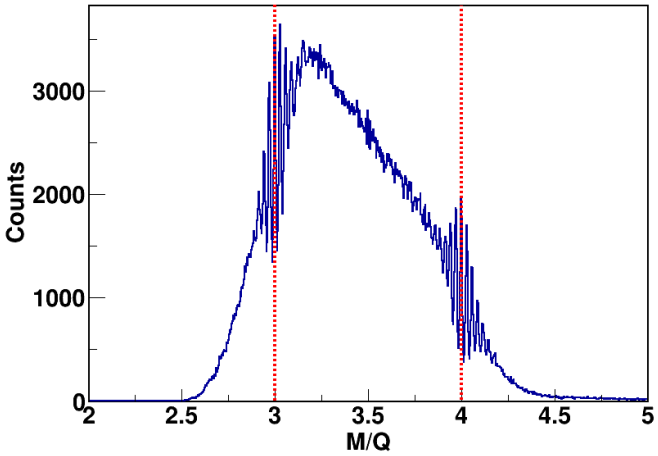


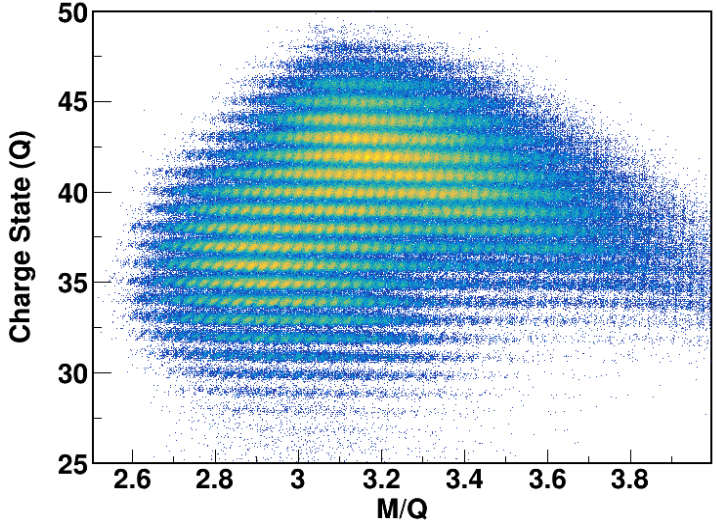
Charge state (Q) versus mass over charge state (M/Q)

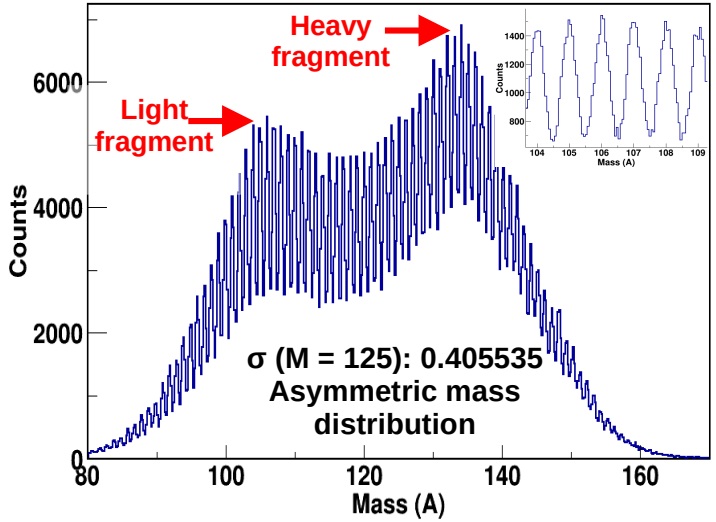
Multichance fission ?



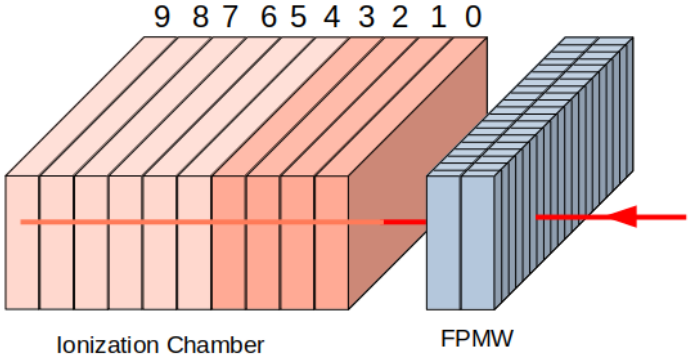
Reconstructed mass (A)



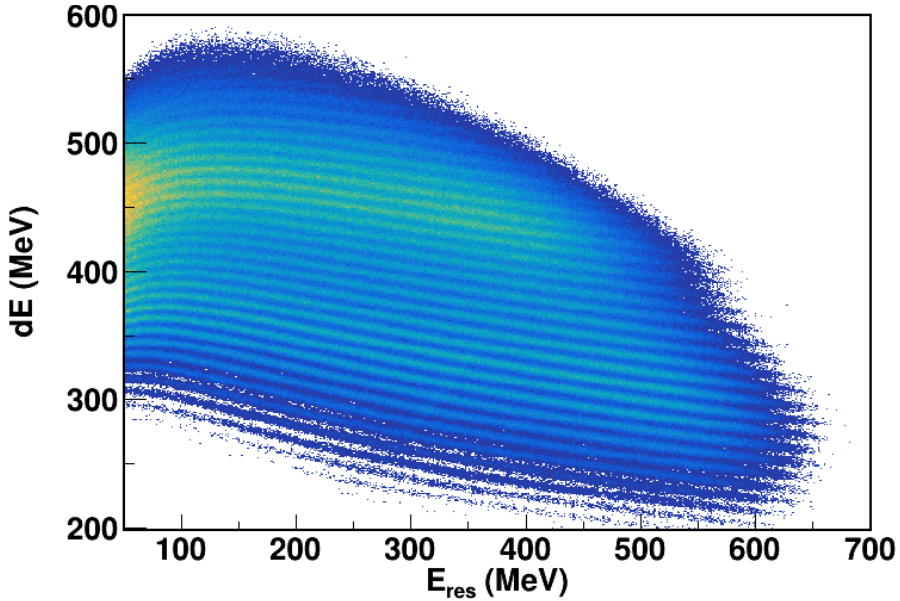




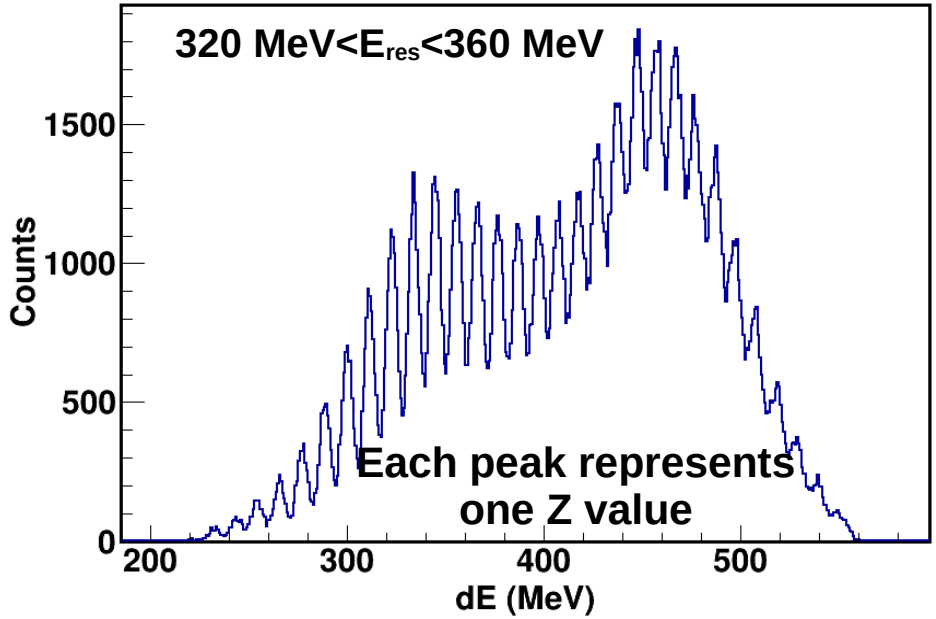
Charge Identification



- ✔ **dE:** Energy loss in first 5 sections of ionization chamber.
- ✔ **E_{res}:** Energy loss in other sections of ionization chamber (residual energy).



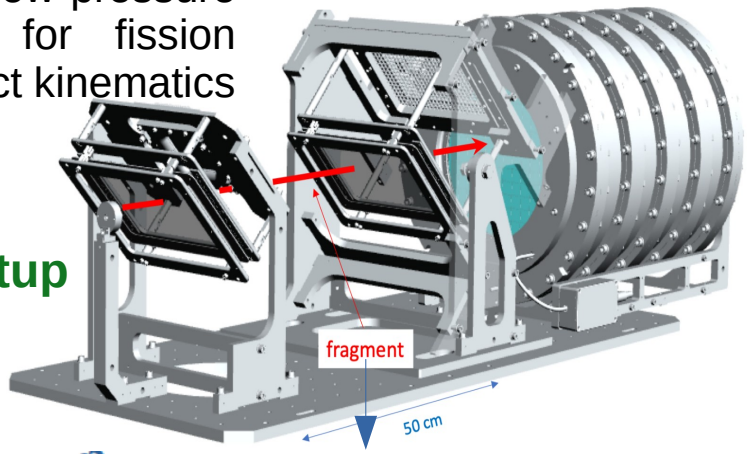
Atomic number (Z) distribution from the projection of dE-E matrix

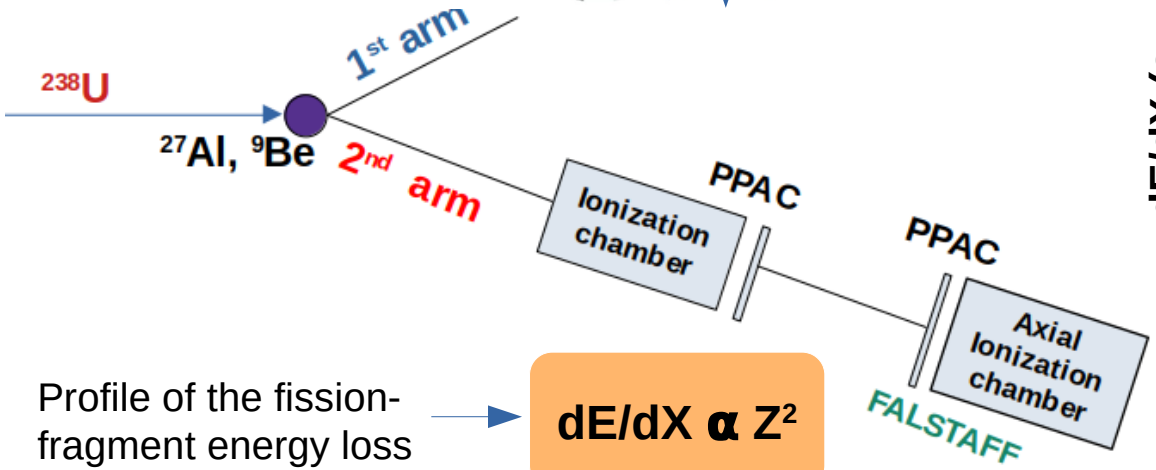


FALSTAFF

FALSTAFF is a low pressure gaseous setup for fission fragments in direct kinematics

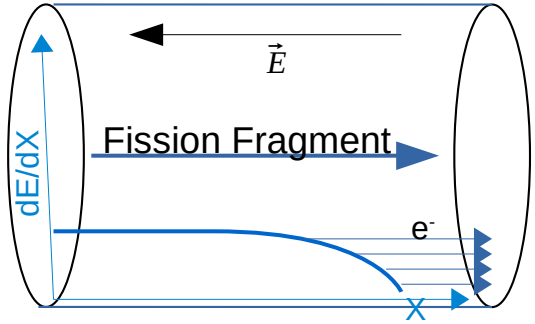
FALSTAFF setup

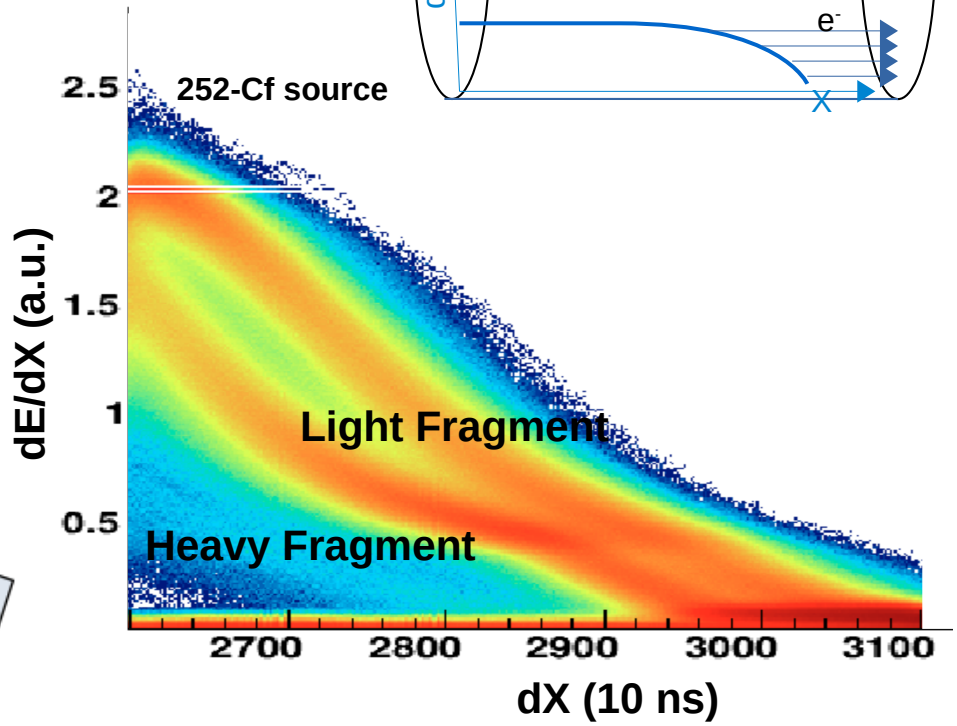




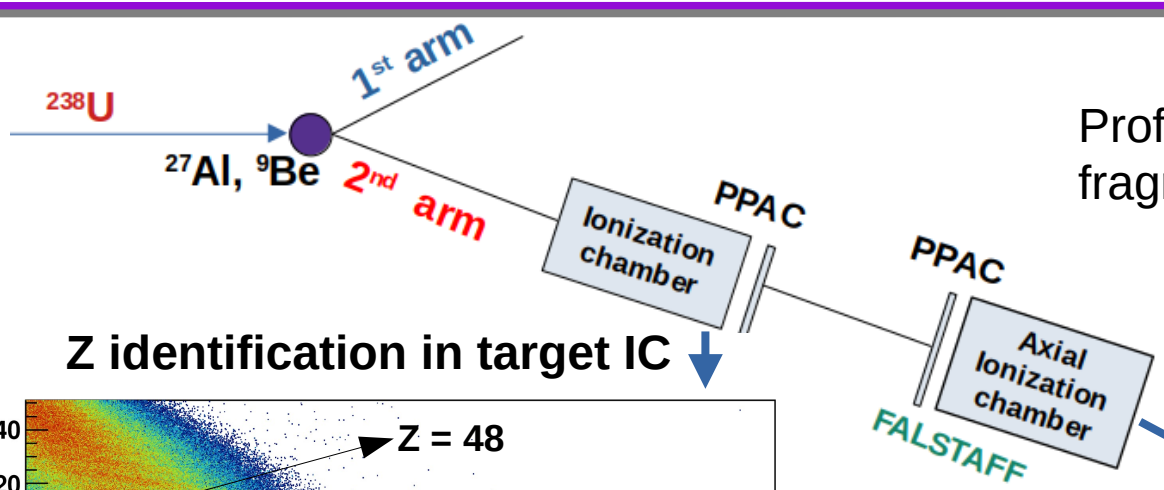
Profile of the fission-fragment energy loss → **dE/dX α Z²**

Electrons **drift to the anode at different times**



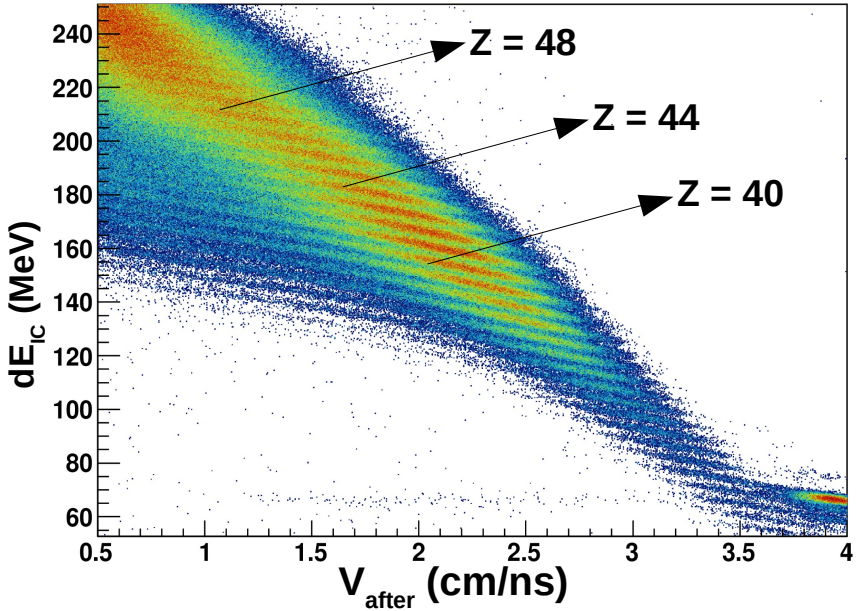


FALSTAFF Analysis



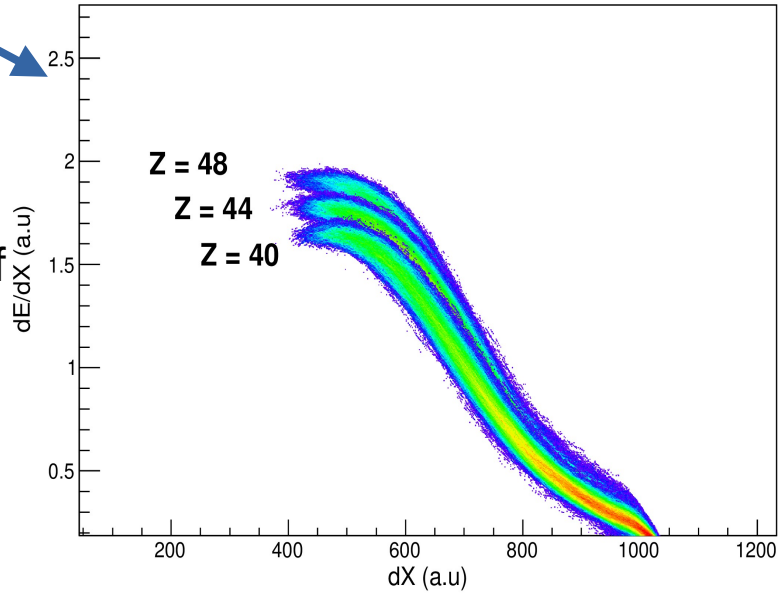
Profile of the fission-fragment energy loss → **dE/dX α Z^2**

Z identification in target IC

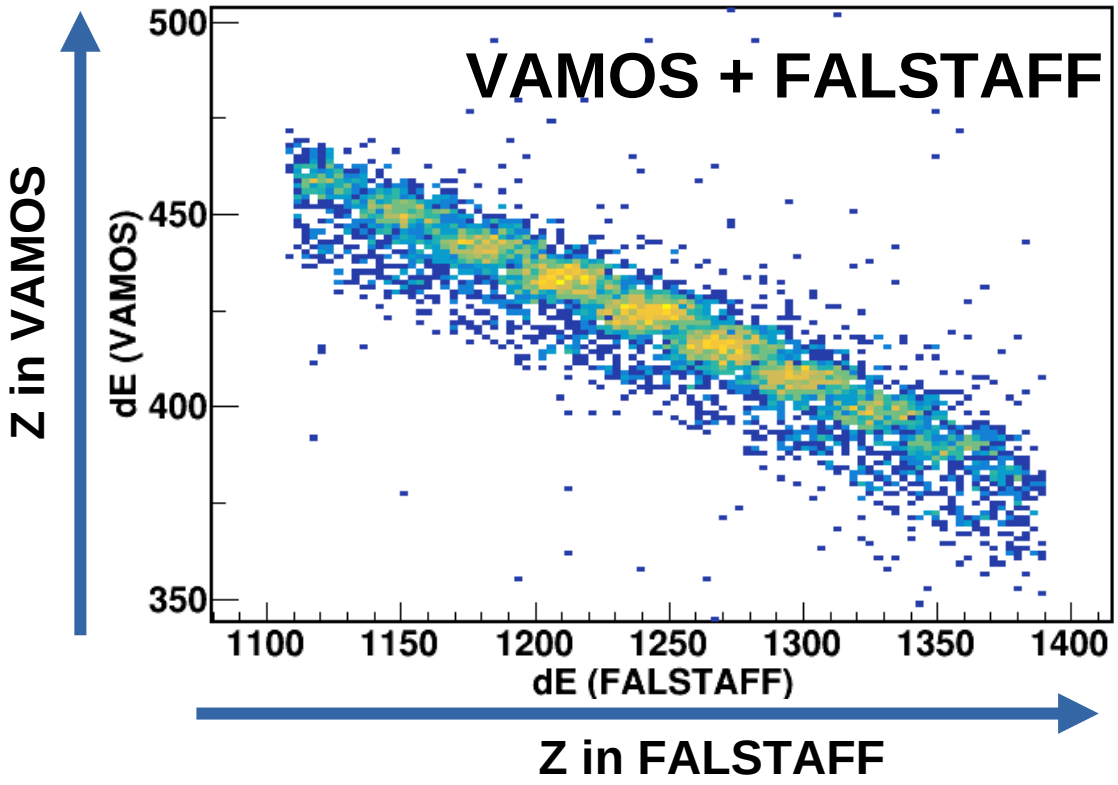


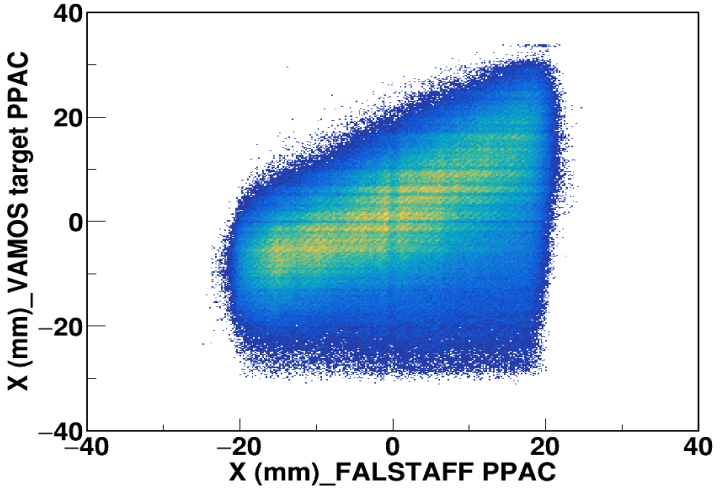
dE_{IC}: Energy loss of the fragment in target ionization chamber.

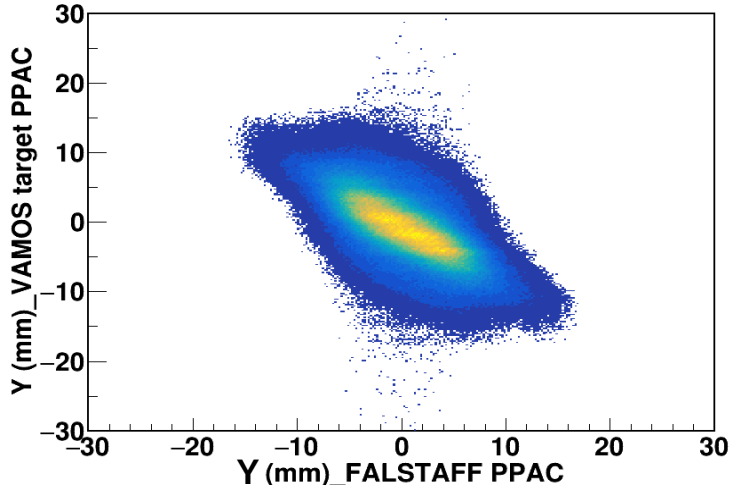
Profile of energy loss in axial ionization chamber for each Z



Correlations







Charge identification in nuclear fusion fission reaction using VAMOS and FALSTAFF spectrometer.

Conclusions and perspectives

- Two fission fragments can be measured simultaneously at one time (VAMOS + FALSTAFF).
- Full identification of fragments have been done in VAMOS, in terms of charge, mass number, charge states, and velocity vector .
- The mass distribution shows asymmetric fission, suggesting the multichance fission.
- This measurement demonstrates the Energy loss profile of the axial ionization chamber will be useful to identify the different nuclear charges in direct kinematics in the future.
- Further analysis is going on, where the mass of the second fragment (FALSTAFF), as well as neutron evaporation will be determined, and this will provide the excitation energy of fission fragments.

Acknowledgments

D. Ramos,[1] J-E. Ducret,[1] D.Dore,[2] A. Lemasson,[1] M. Rejmund[1] , VAMOS and FALSTAFF collobration

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[2] CEA, Centre de Saclay, Irfu/Service de Physique Nucléaire, 91191 Gif-sur-Yvette, France

Thank you