Isotopic Fragment Distribution of Minor Actinides produced in Transfer Reactions

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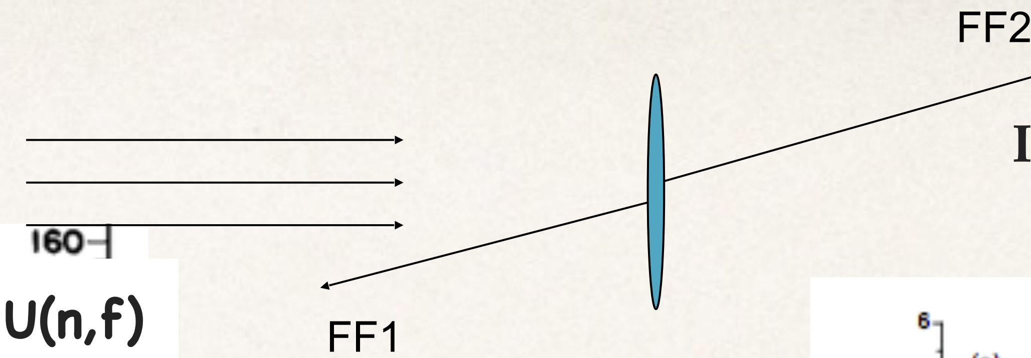
Tokai, Japan

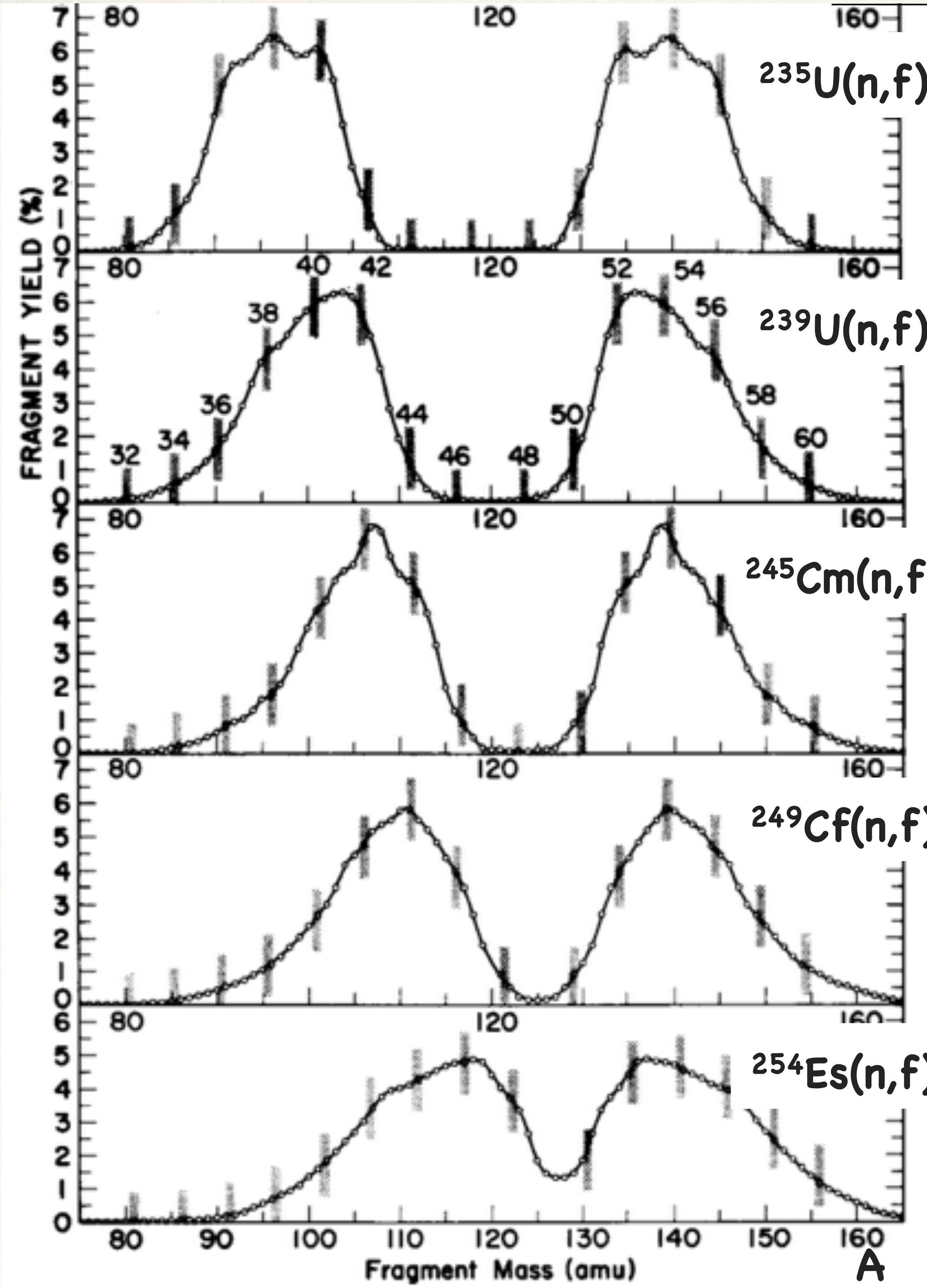
03/12/2014

Limitations of Direct Kinematics

Good measurement of **mass distribution**



Isotopic distribution by ɣ-spectroscopy



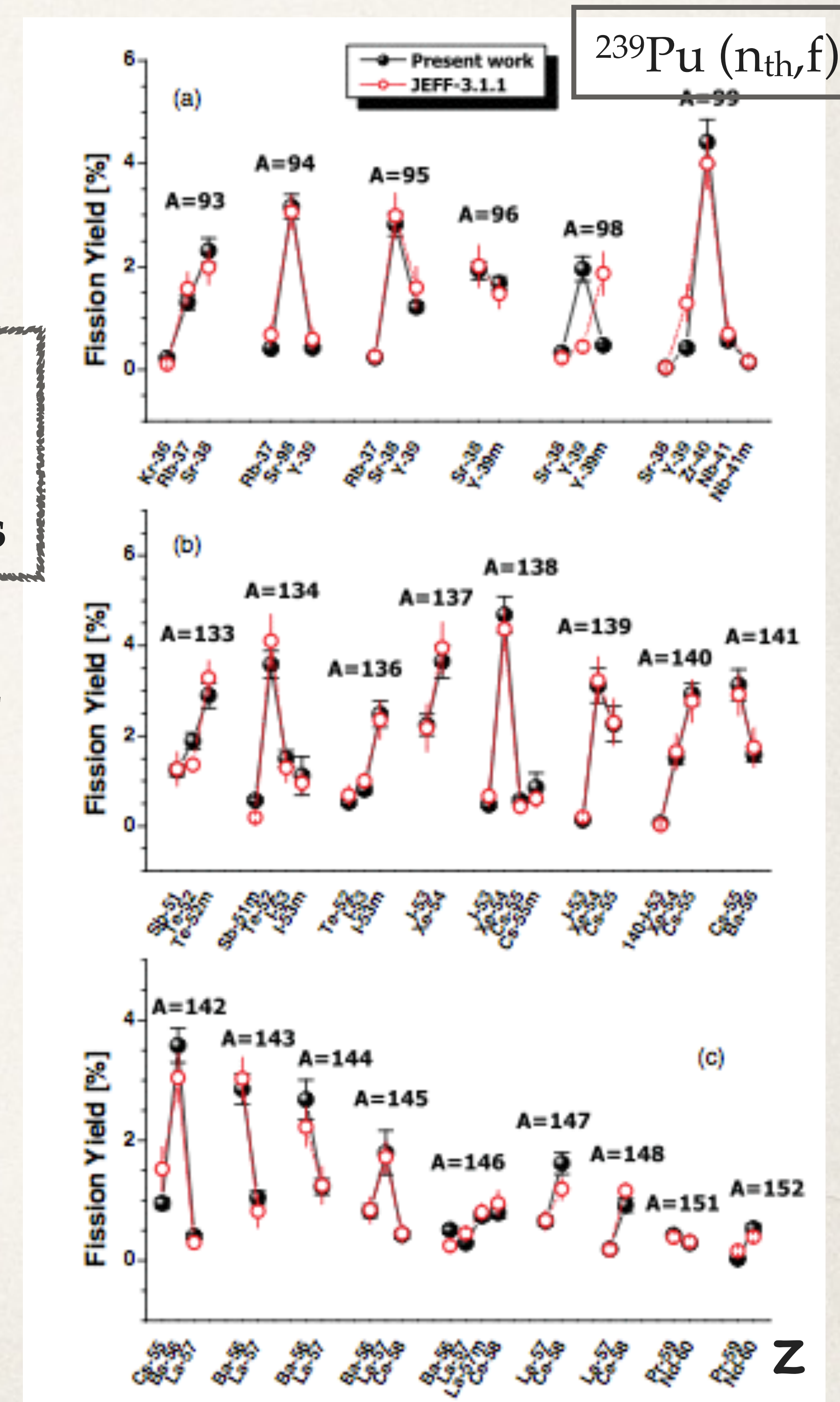
J.P. Unik, IAEA –SM-174/209

Incomplete Measurements of Isotopic distributions

limitations for heavy ff

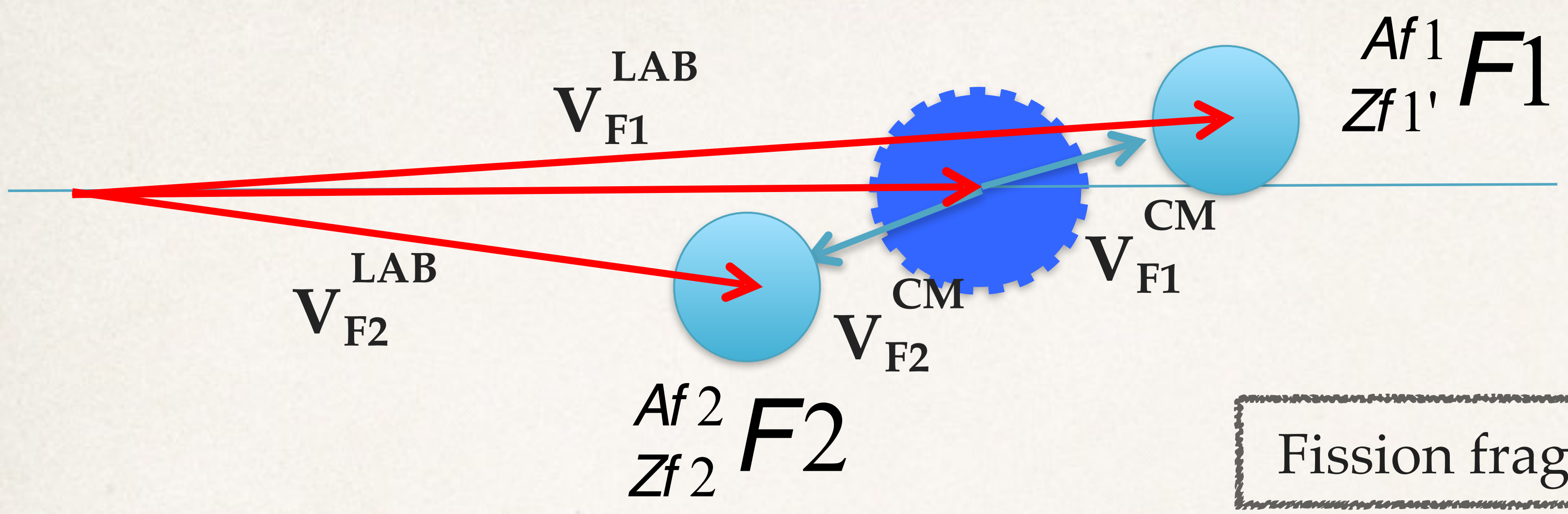
- lifetimes

-unknown level schemes



A. Bail PRC 84(2011)

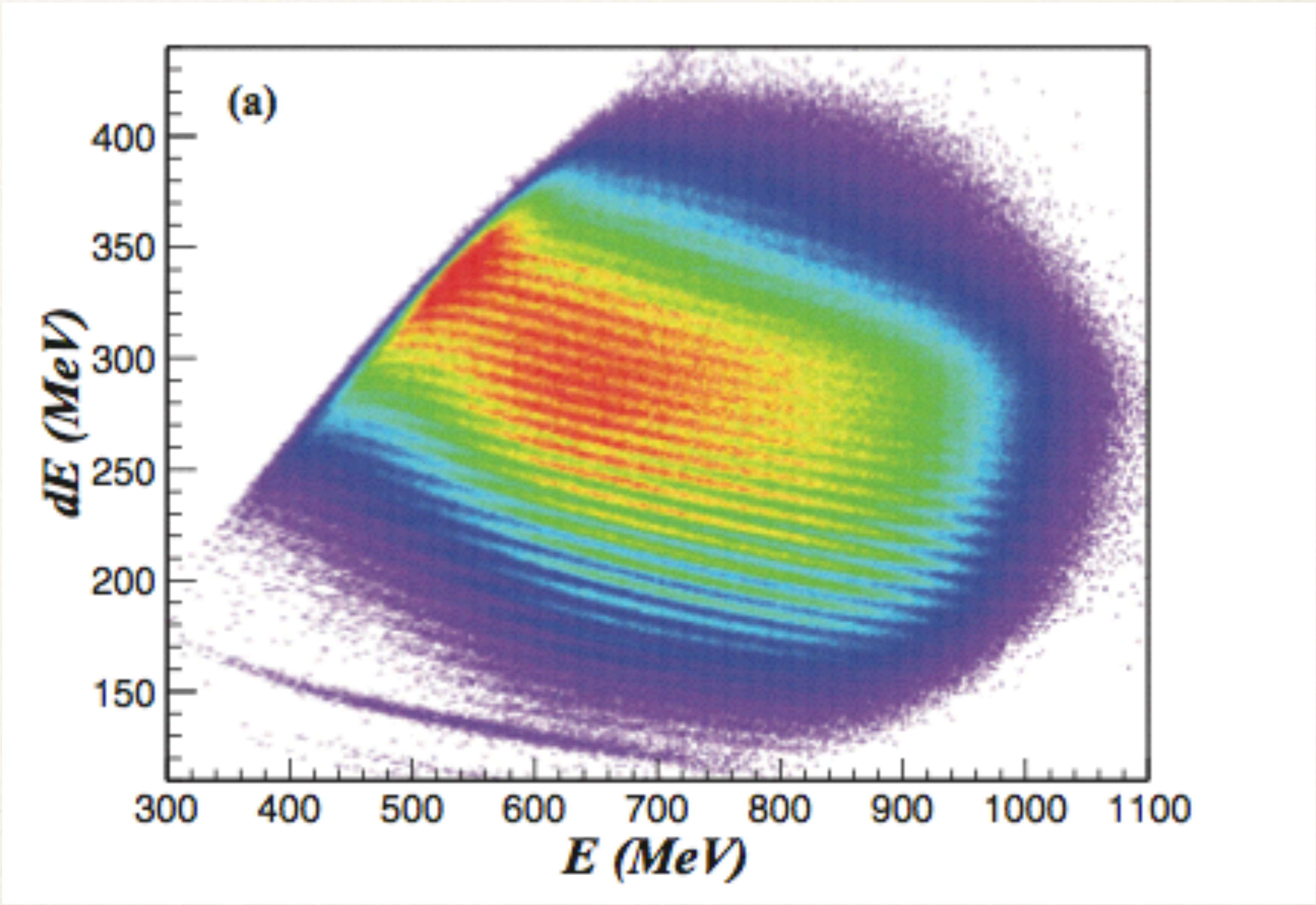
Goals of Inverse kinematics



Fission fragment Z matrix identification

Kinematical boost increases the kinetic energy of the fission fragments providing **the capability of a direct identification**

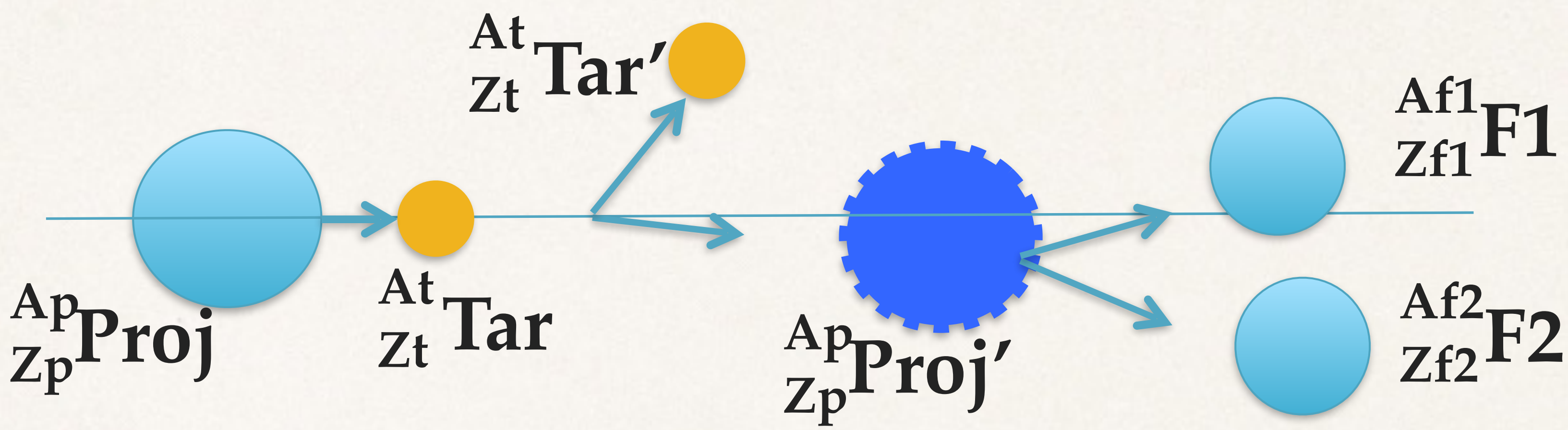
Kinematical boost allows to keep a wide angular coverage in the CM frame when the size of the detectors is limited



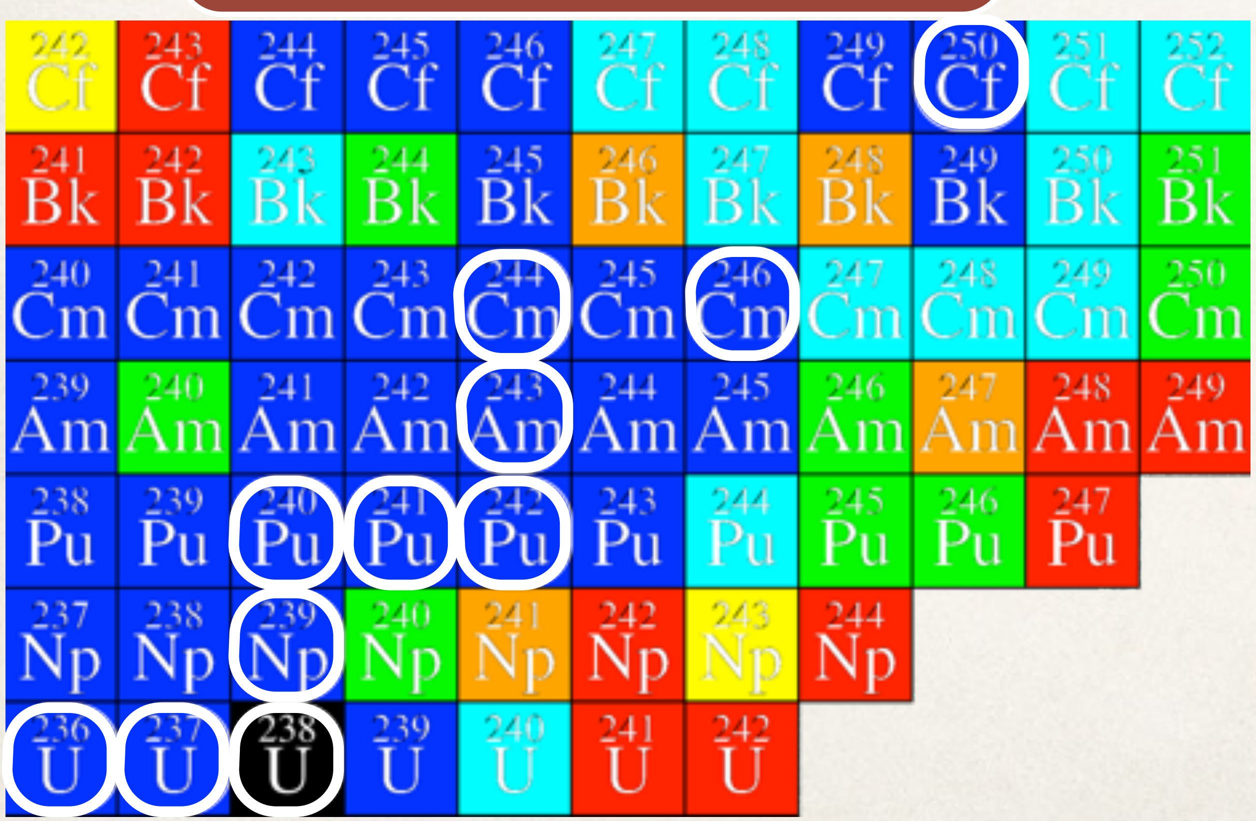
M. Caamaño et al. PRC 024605 (2013)

Reaction Mechanism

$^{238}U + ^{12}C$ @ 6.14 AMeV



Fissioning Systems



Fissioning systems not accessible from any other mechanism

10% above Coulomb barrier

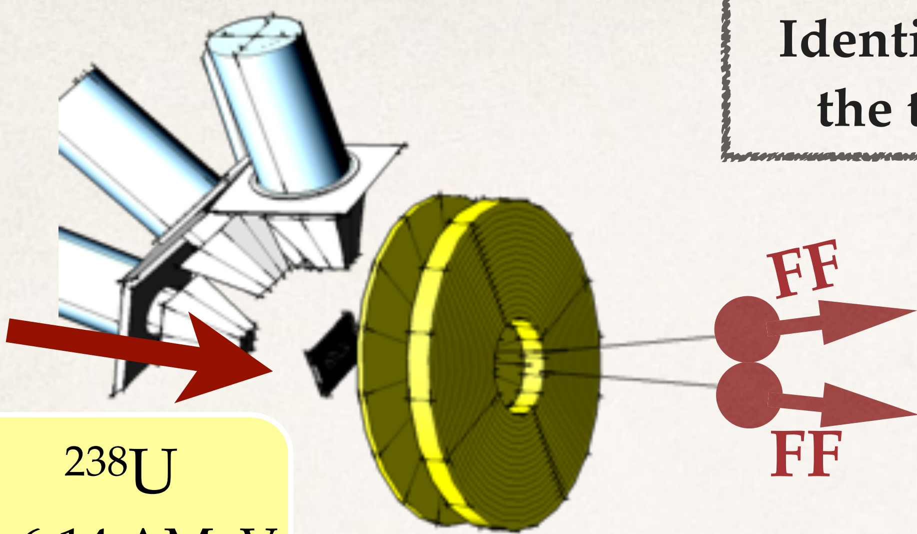
Transfer-Fission:

10 n-rich actinides produced with a distribution of E_X below 30 MeV

Fusion-Fission:

production of ^{250}Cf with $E_X = 45$ MeV 10 times more likely than any transfer channel

Transfer Reaction and Excitation Energy

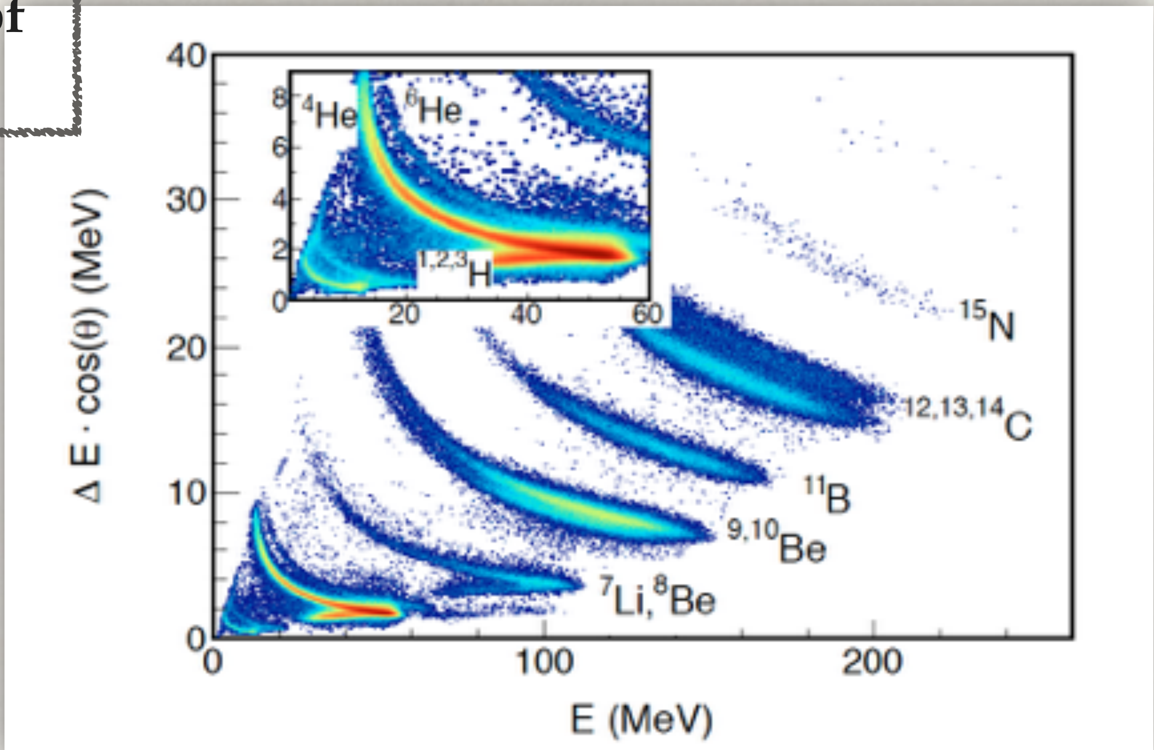


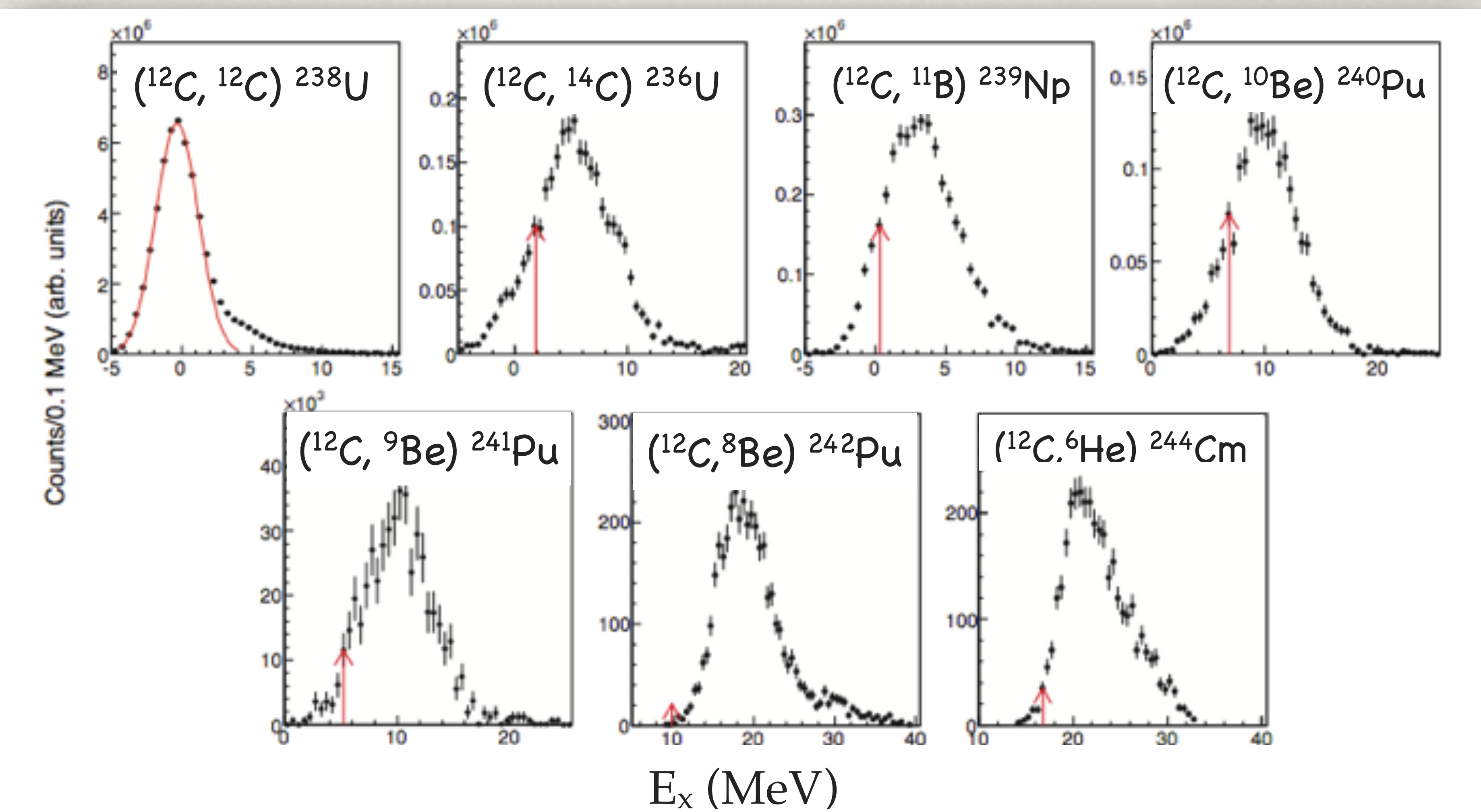
^{238}U @ 6.14 AMeV

E-ΔE and θ,φ of the recoil

reconstruction of the transfer reaction & E*

Identification Matrix of the target-like recoil





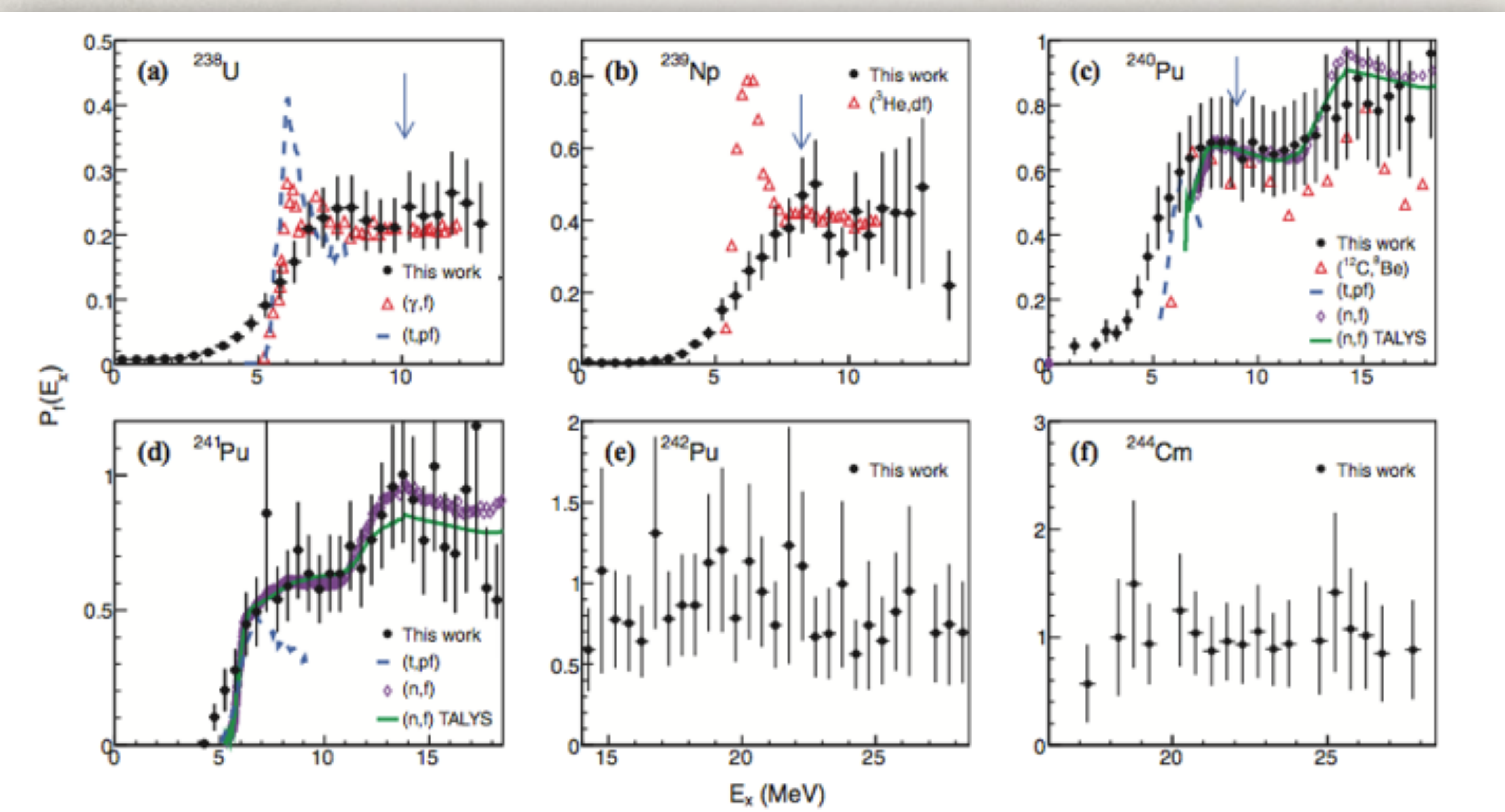
Distribution of E_x for the different fissioning systems from reconstruction of the binary reaction

Higher E_x for higher number of transferred nucleons

E_x ~ 8 MeV is comparable with fast-neutron fission

C. Rodriguez-Tajes et *al.*, PRC (2014) 024614

Fission Probabilities & Excitation of Target-like Recoil

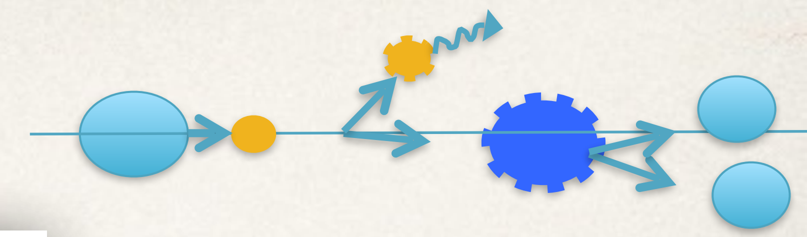


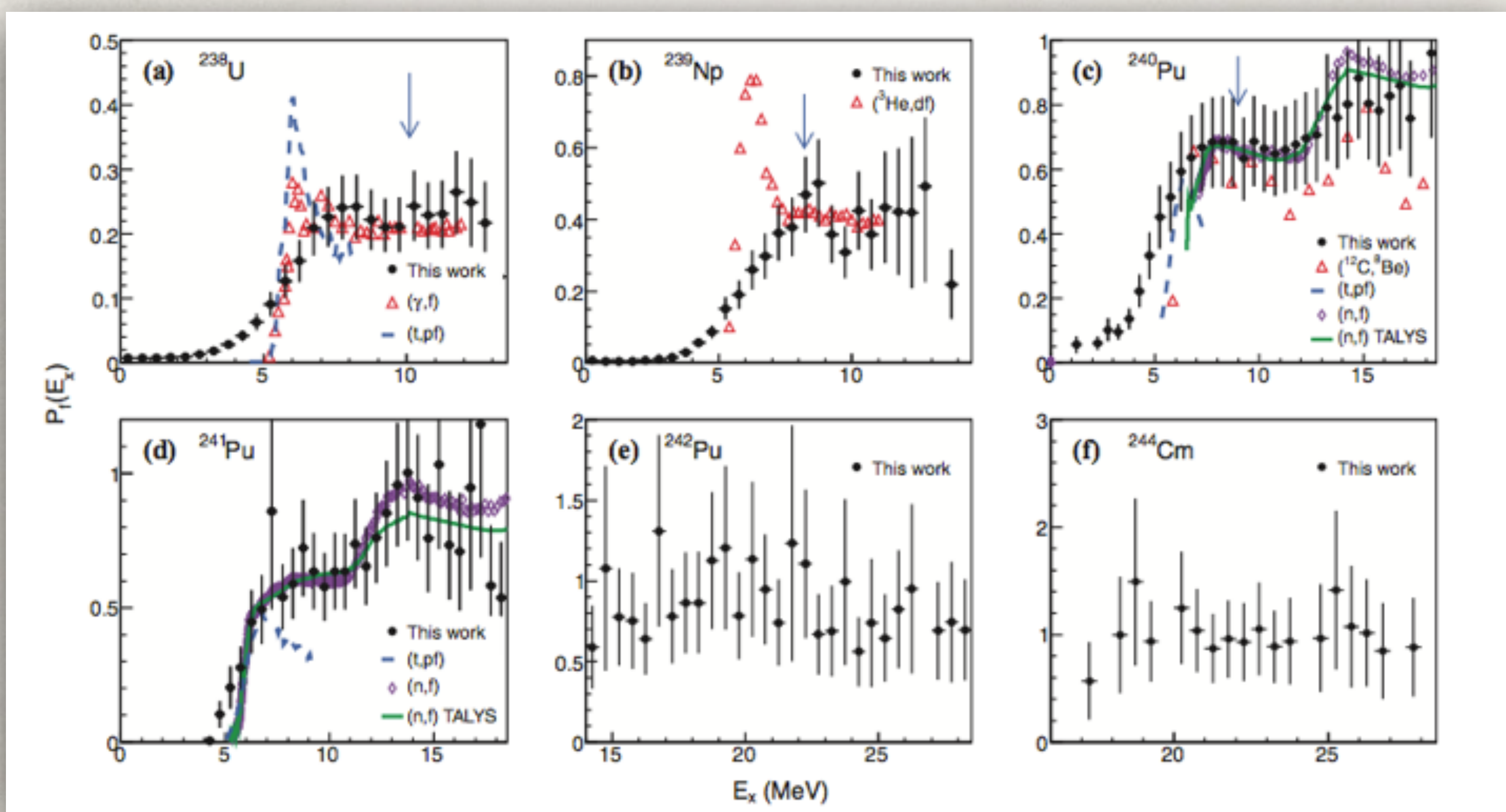
We observe a general agreement with previous data
with small discrepancies

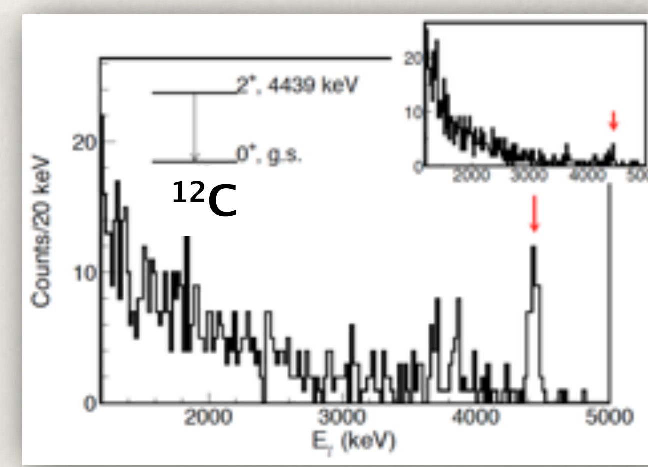
this experiment provides data never measured before for ^{242}Pu and ^{244}Cm

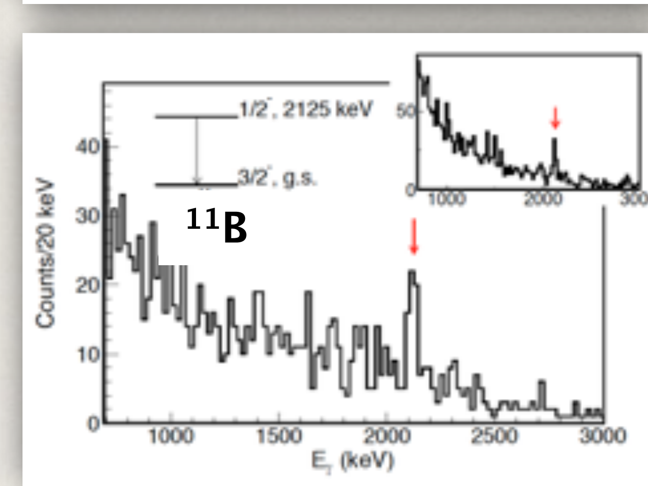
C. Rodriguez-Tajes et *al.*, PRC (2014) 024614

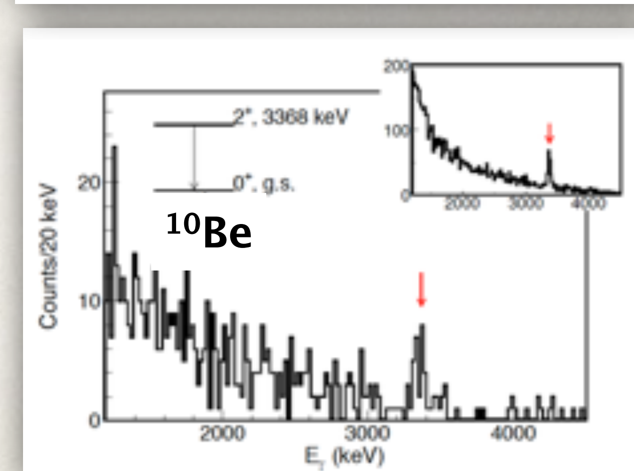
Fission Probabilities & Excitation of Target-like Recoil











We observe a general agreement with previous data
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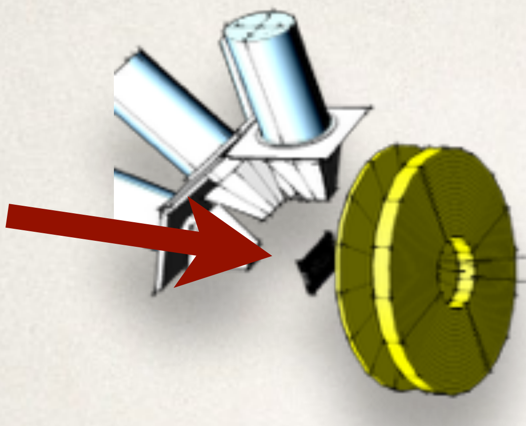
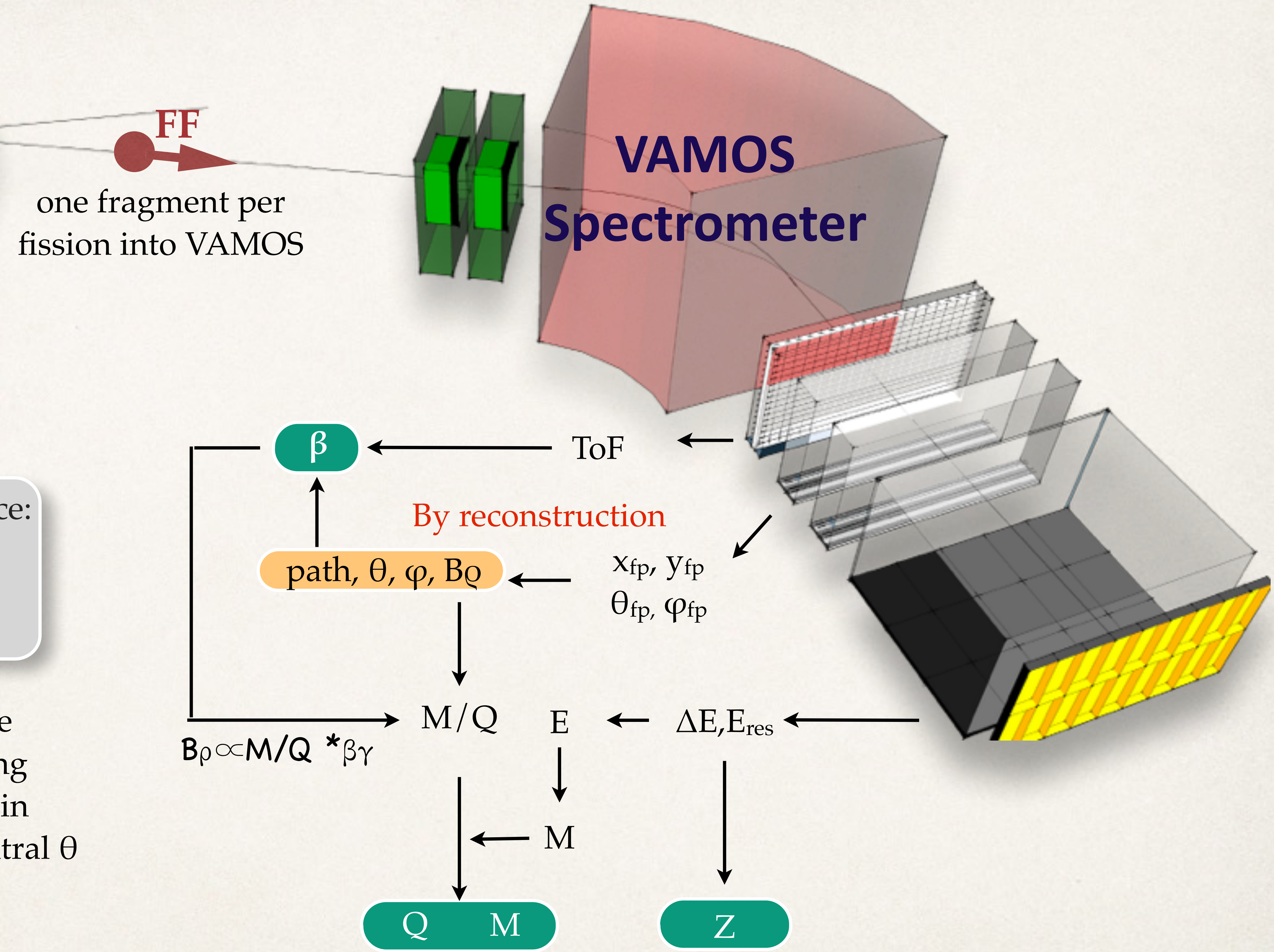
γ-rays measurements show excited states in ^{12}C, ^{11}B and ^{10}Be **in coincidence with fission with P_γ = 0.12-0.14**

C. Rodriguez-Tajes et *al.*, PRC (2014) 024614

Fission Fragments Detection





VAMOS Acceptance:
$\Delta\theta \sim 13$ deg
$\Delta\phi \sim 30$ deg
$\Delta B\rho \sim 10$ %

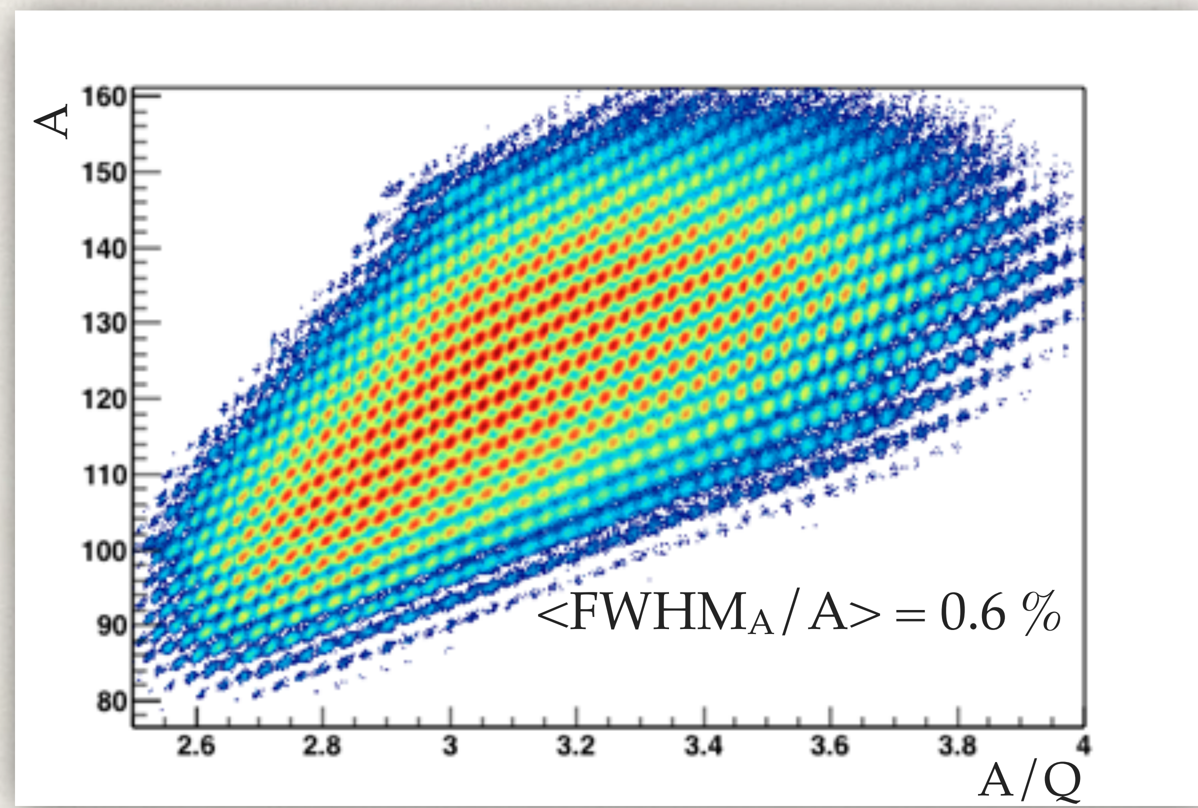
Large acceptance increased by using different settings in central Bρ and in central θ

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

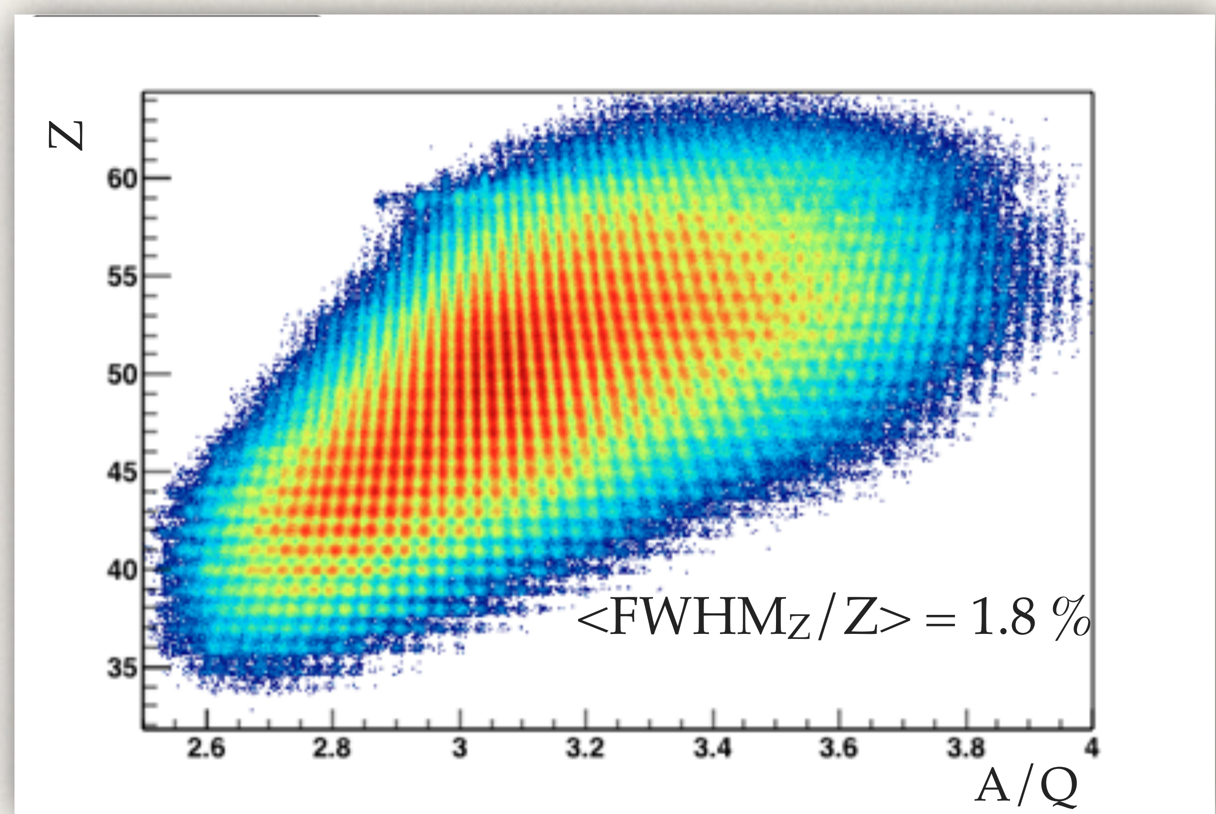
S. Pullanhiotan et al., NIM A 593 (2008) 343

Fission Fragments Identification

Mass Identification



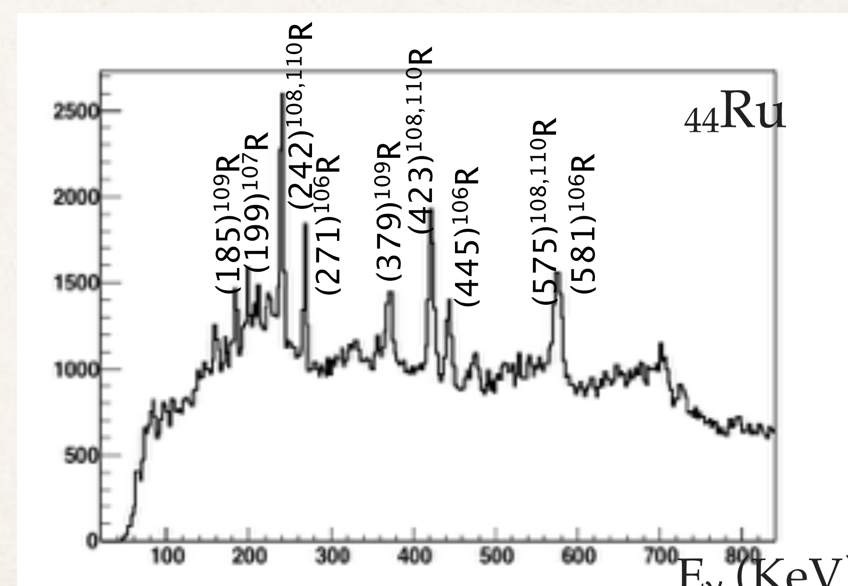
Proton Number Identification



A/Q provides the Q separation and contributes to a better A resolution

More than 300 isotopes identified

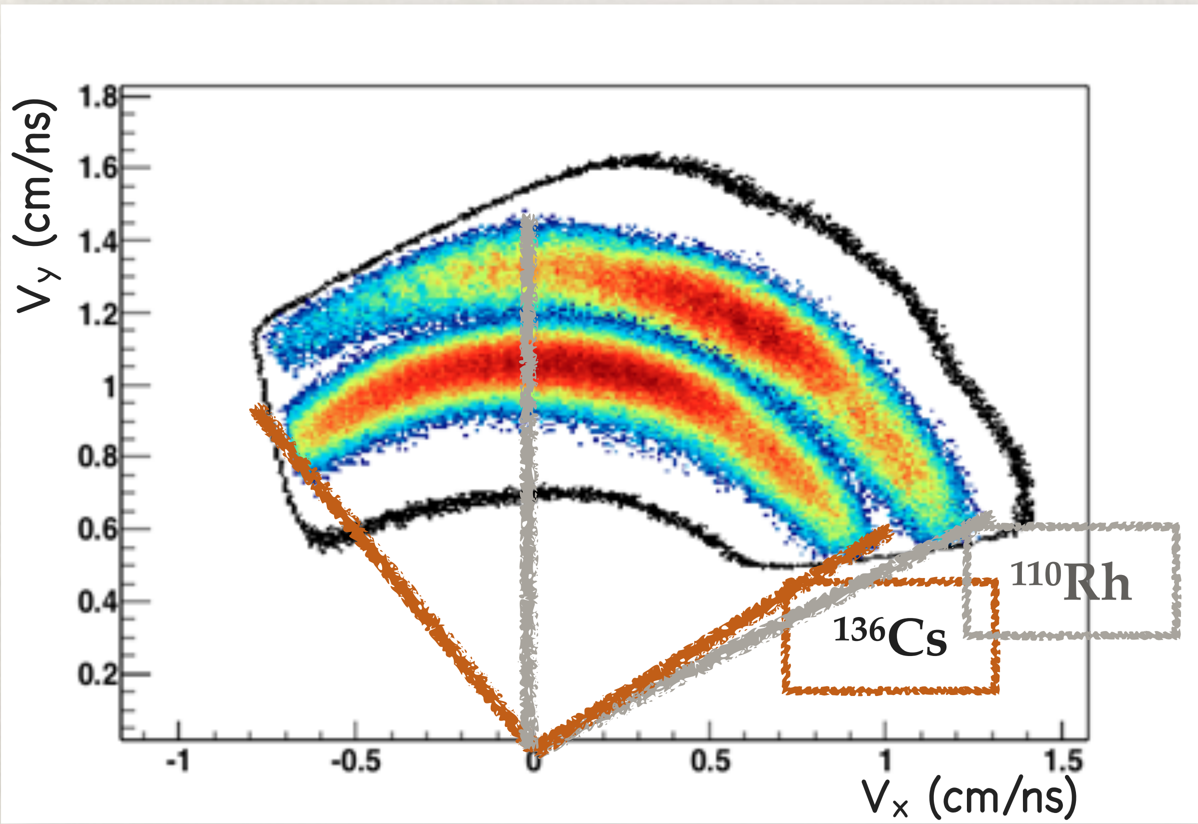
γ-rays in coincidence with fission fragments provide a cross check for the Z and A identification

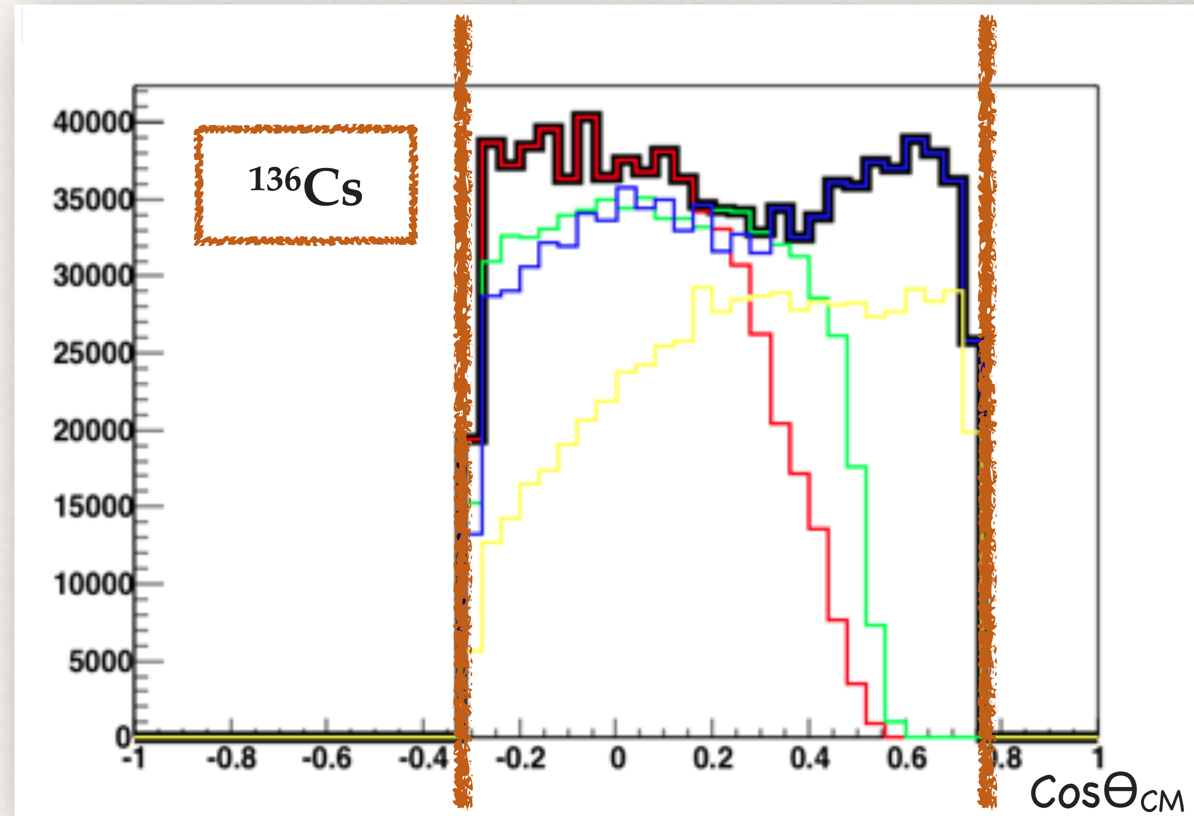


A. Shrivastava et al. PRC 80 (2009) 051305

Transmission through VAMOS

The detection is limited by the transmission





The transmission is different for different isotopes

$$Y(Z,A) = I(Z,A)\frac{2}{Range(Z,A)}$$

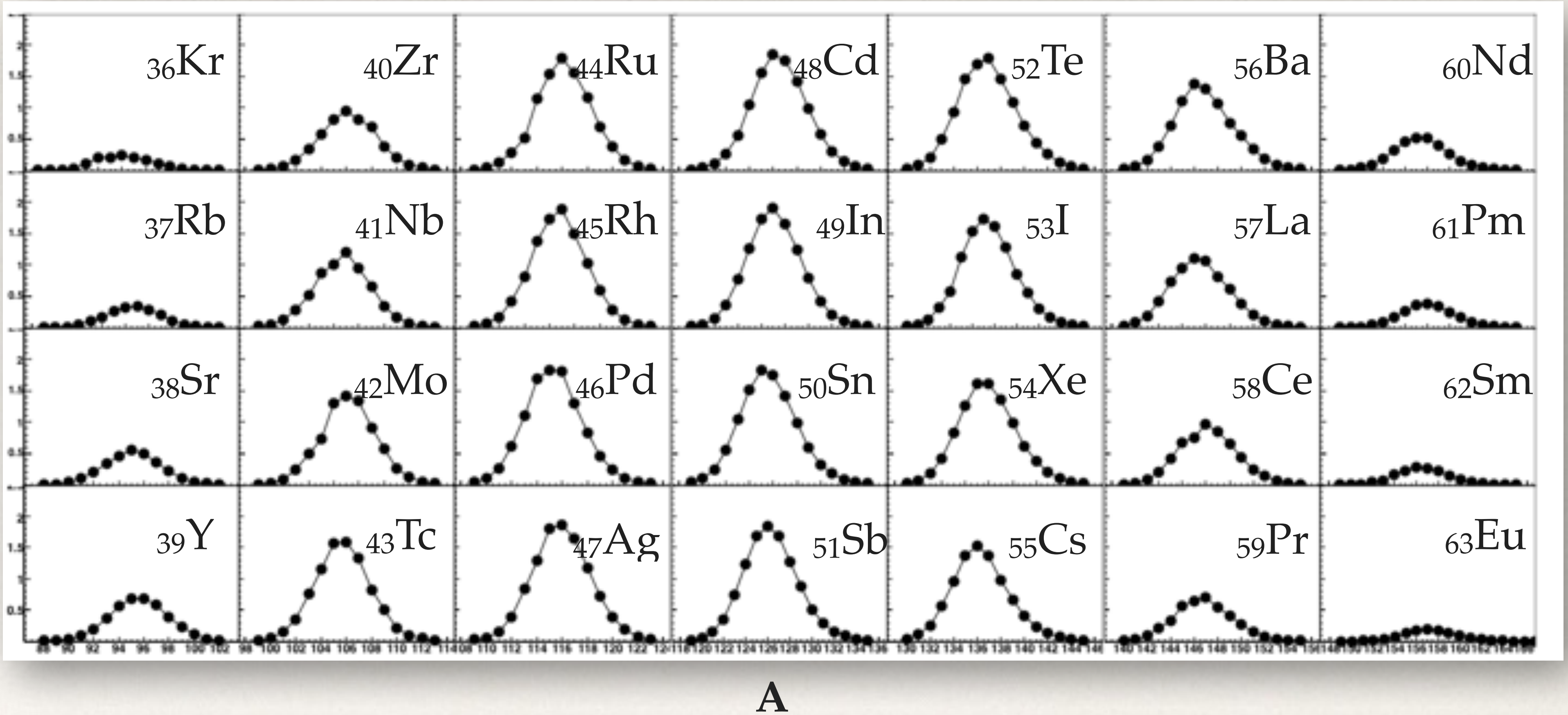
We need to recover all the charge states per isotope and compensate the acceptance in the azimuthal and polar angles

Beam normalization for different settings is required as well

Isotopic Fission Yields

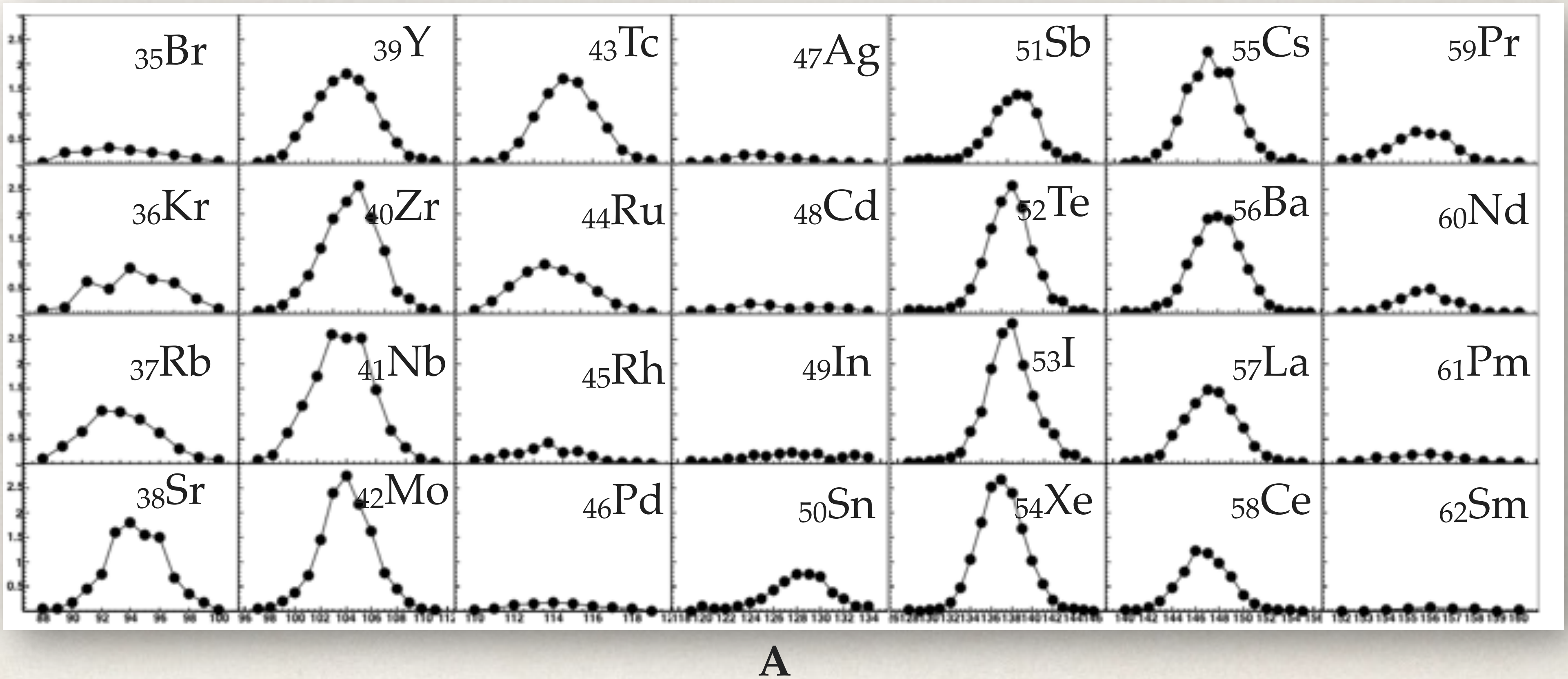
^{250}Cf

Isotopic Yields in **3 orders of magnitud**



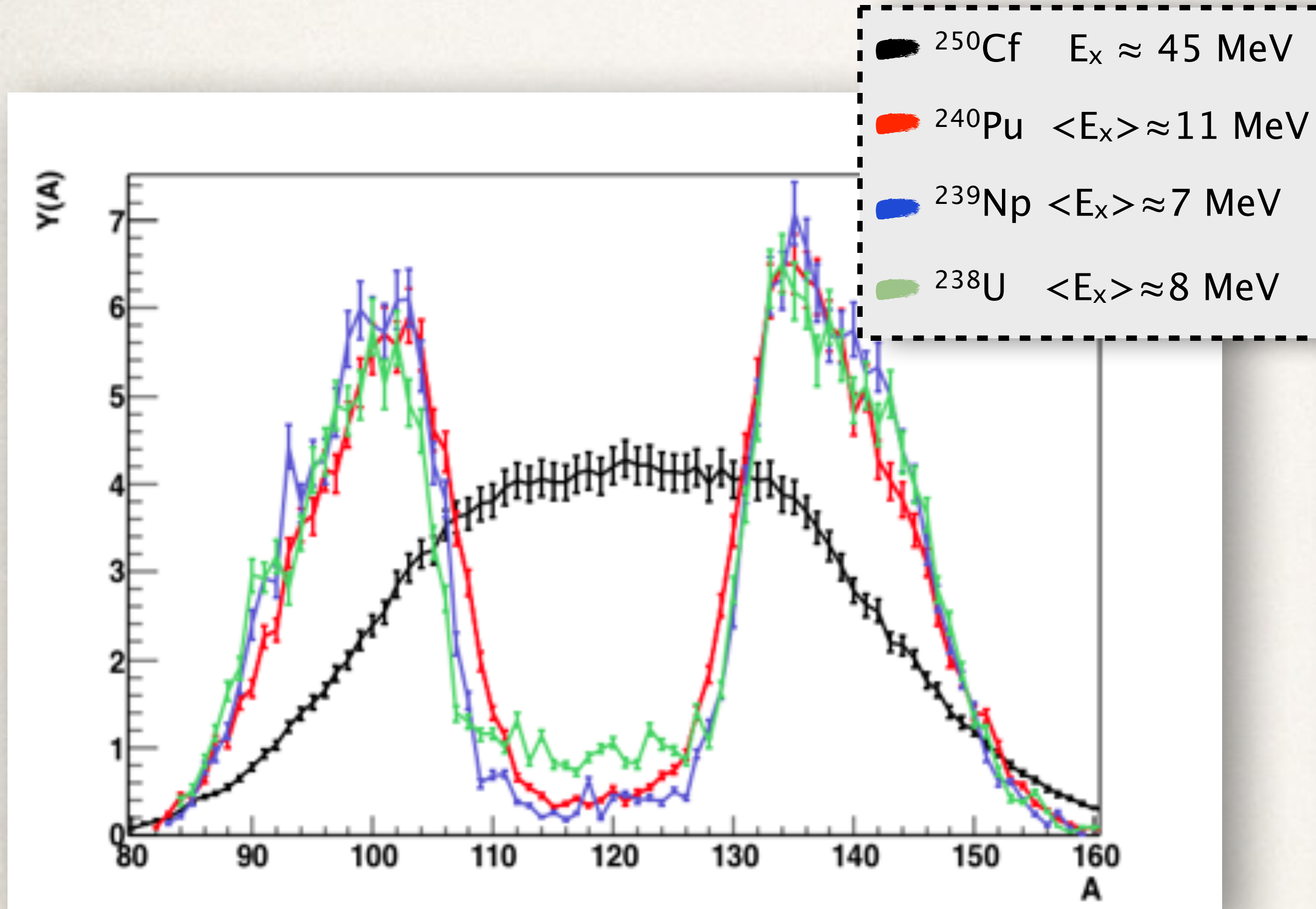
^{240}Pu

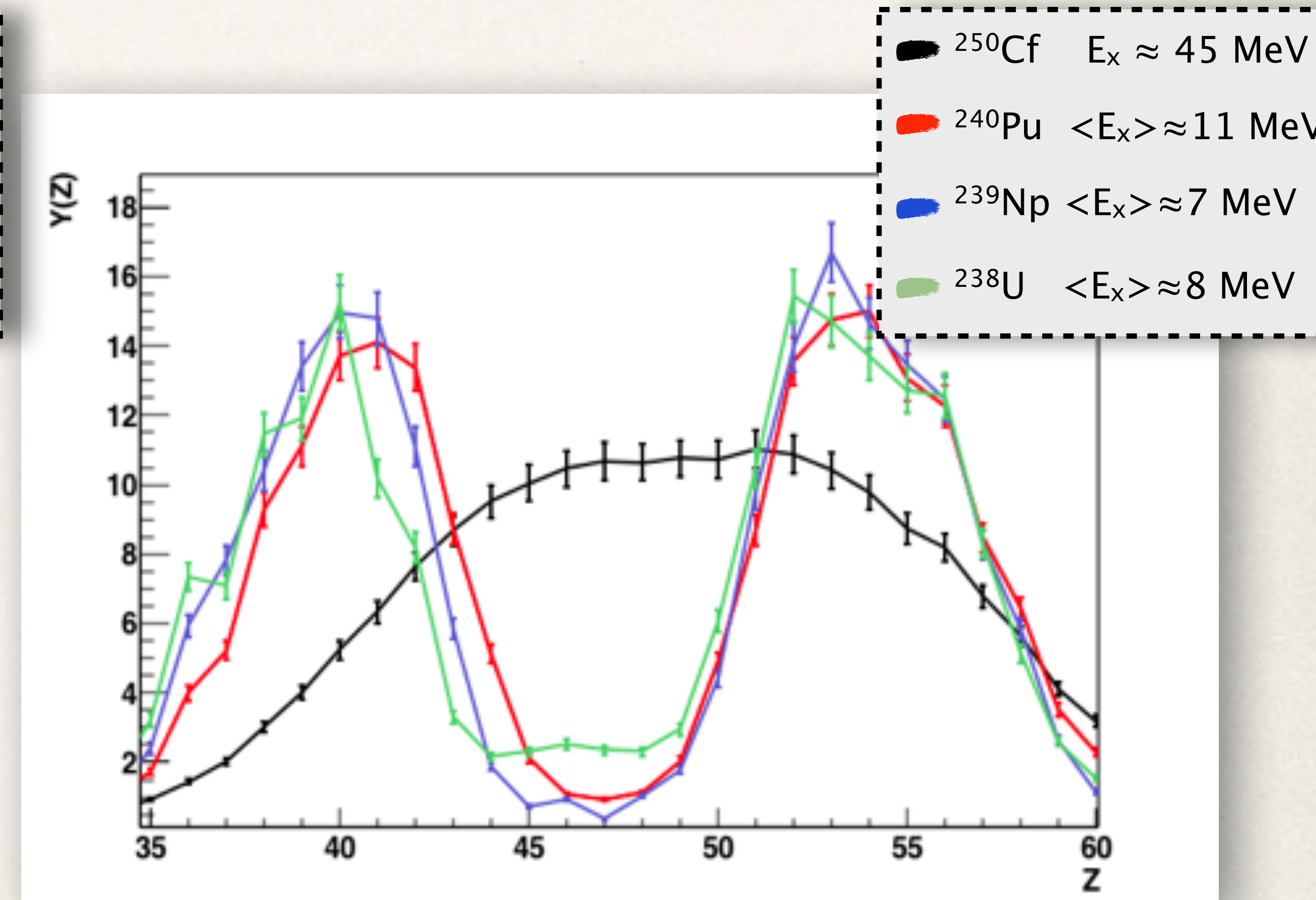
Isotopic Yields in **2 orders of magnitud**



Fission Yields

Isotopic yields distribution of 4 different fissioning systems, most of them exotic nuclei





New complete measurements, difficult to produce by n-capture

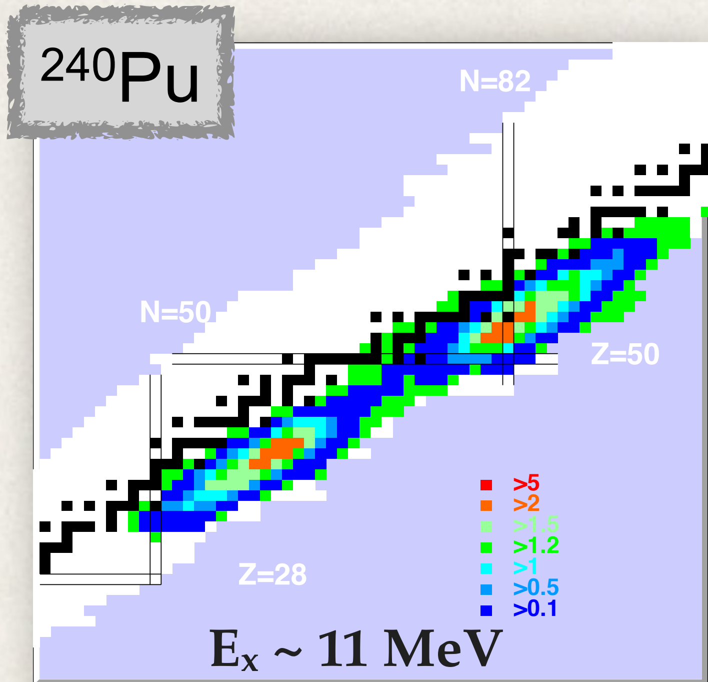
Measurements of fission fragment distributions of ^{239}Np is scarce

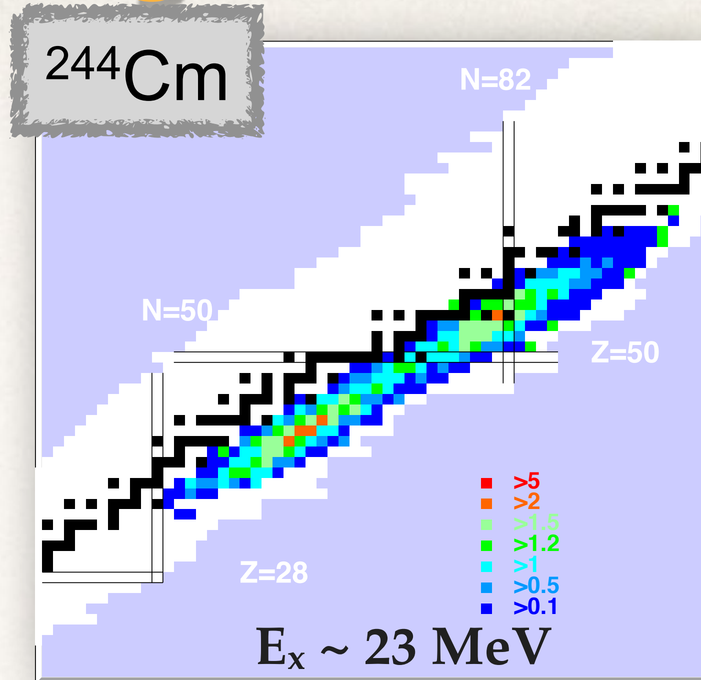
$T_{1/2}$ (^{238}Np) = 2.1 d

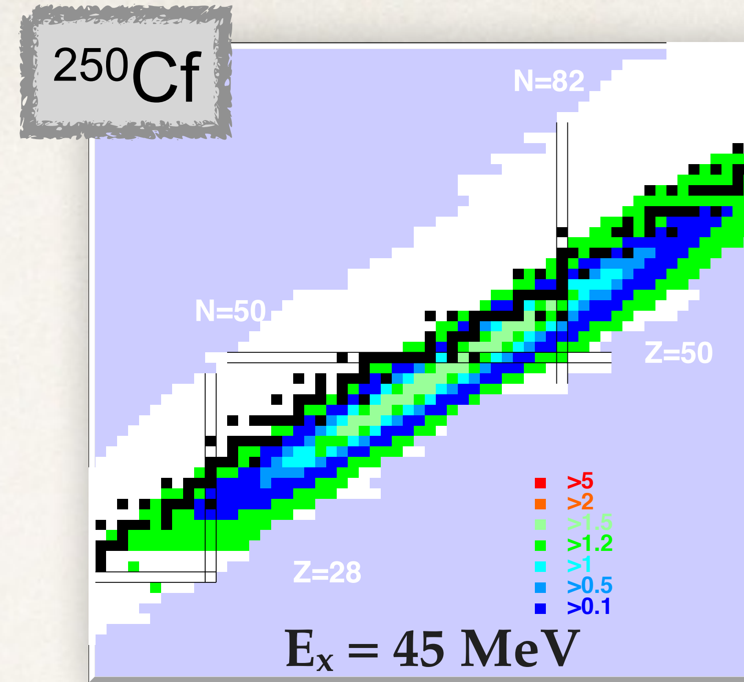
The contribution of the symmetric mode disappears for the systems at low excitation energy

The shift in Z of the light fragments reflects the atomic number of the fissioning system

Charge Polarization



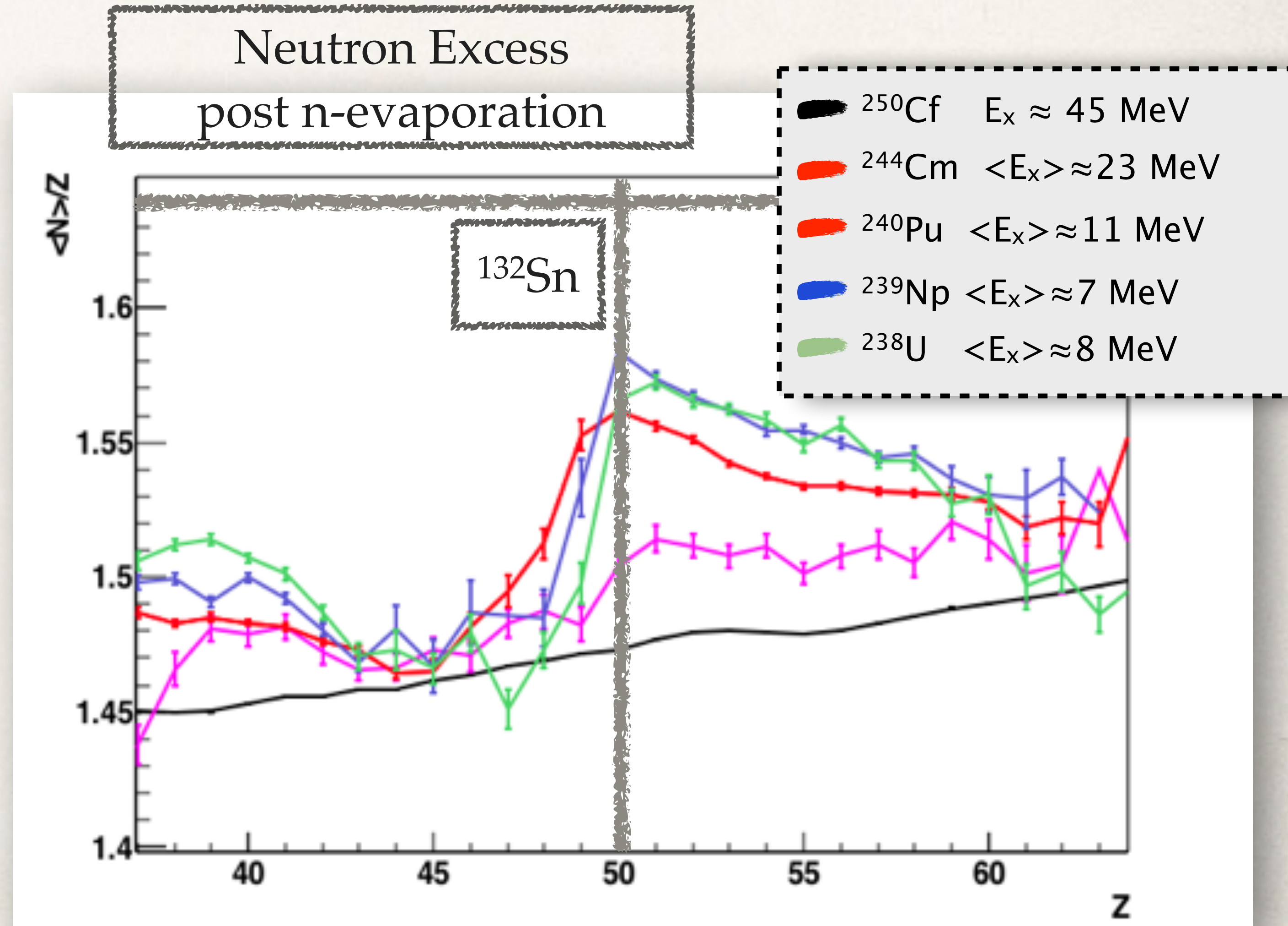




Evolution of the polarization with the E_x and the **fissioning system**

Clear accumulation of N driven by the double magic nucleus ^{132}Sn

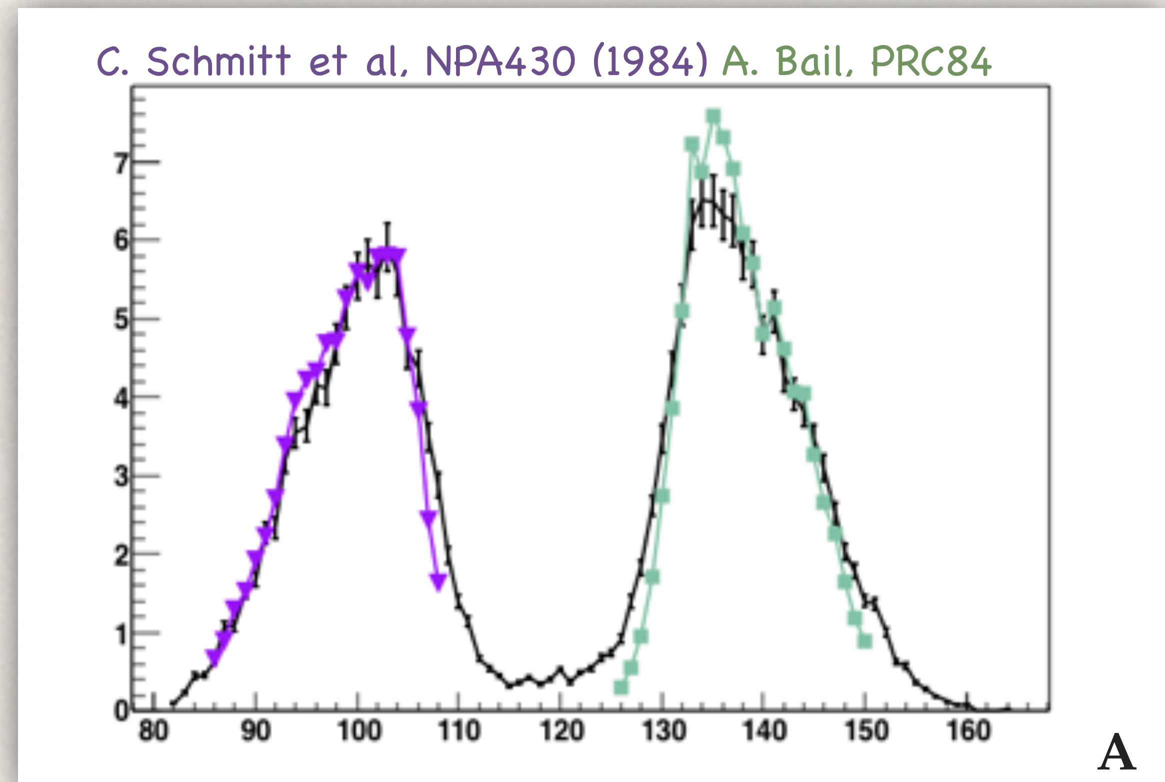
Charge Polarization present in all the systems

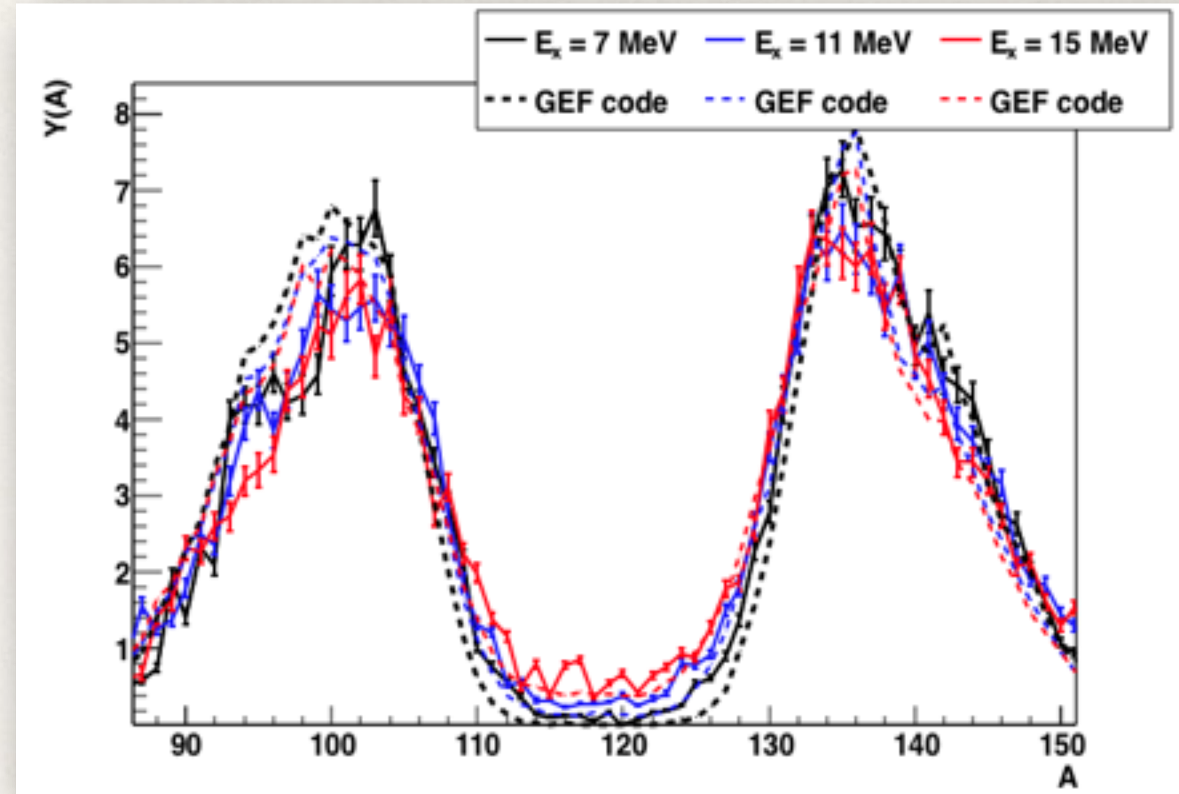


Evolution with Excitation Energy

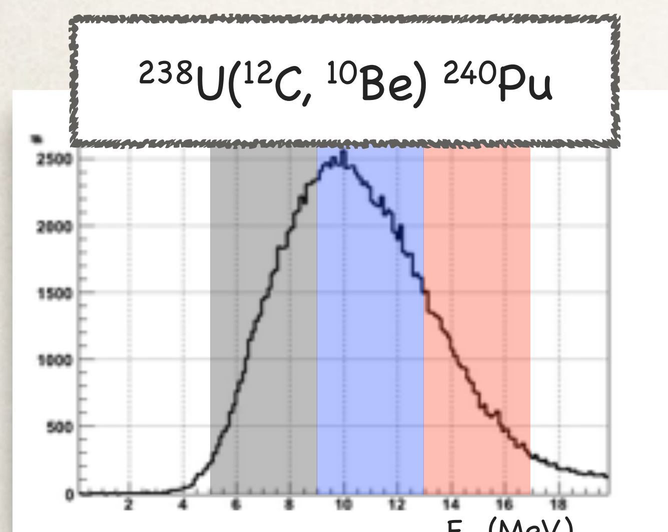
^{240}Pu

Comparison with previous data

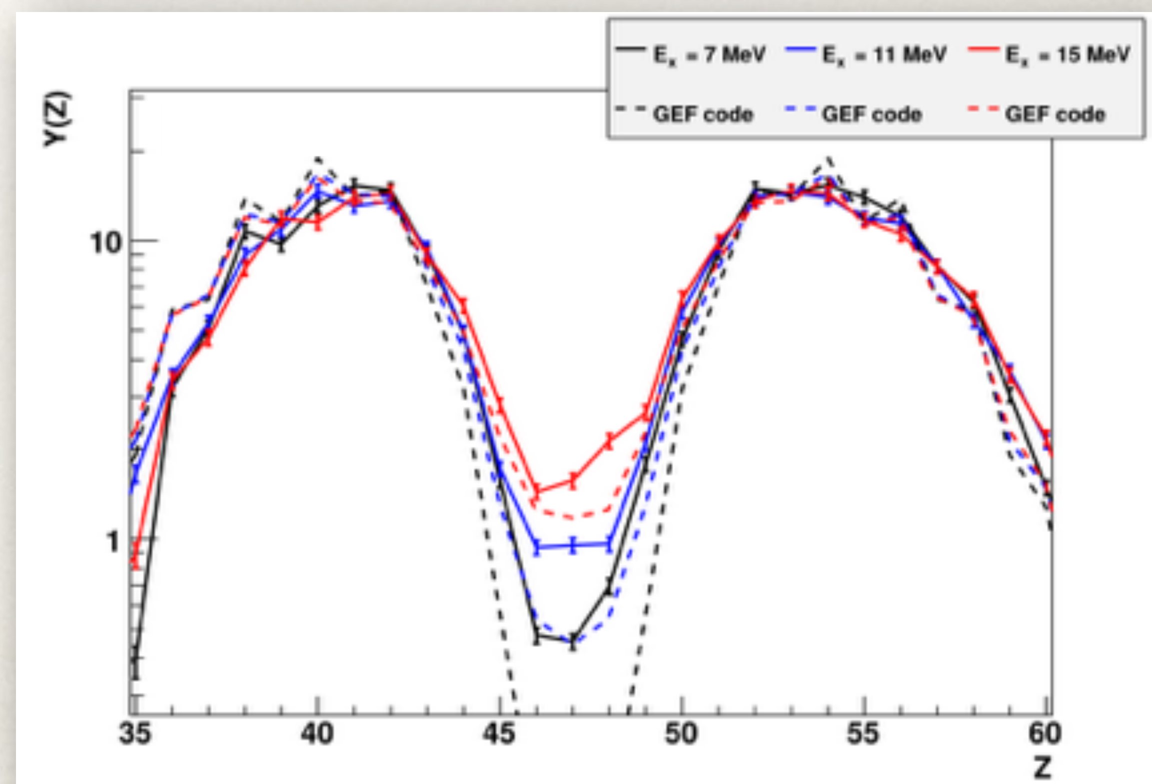




Evolution form asymmetric to symmetric fission by the effect of the excitation energy

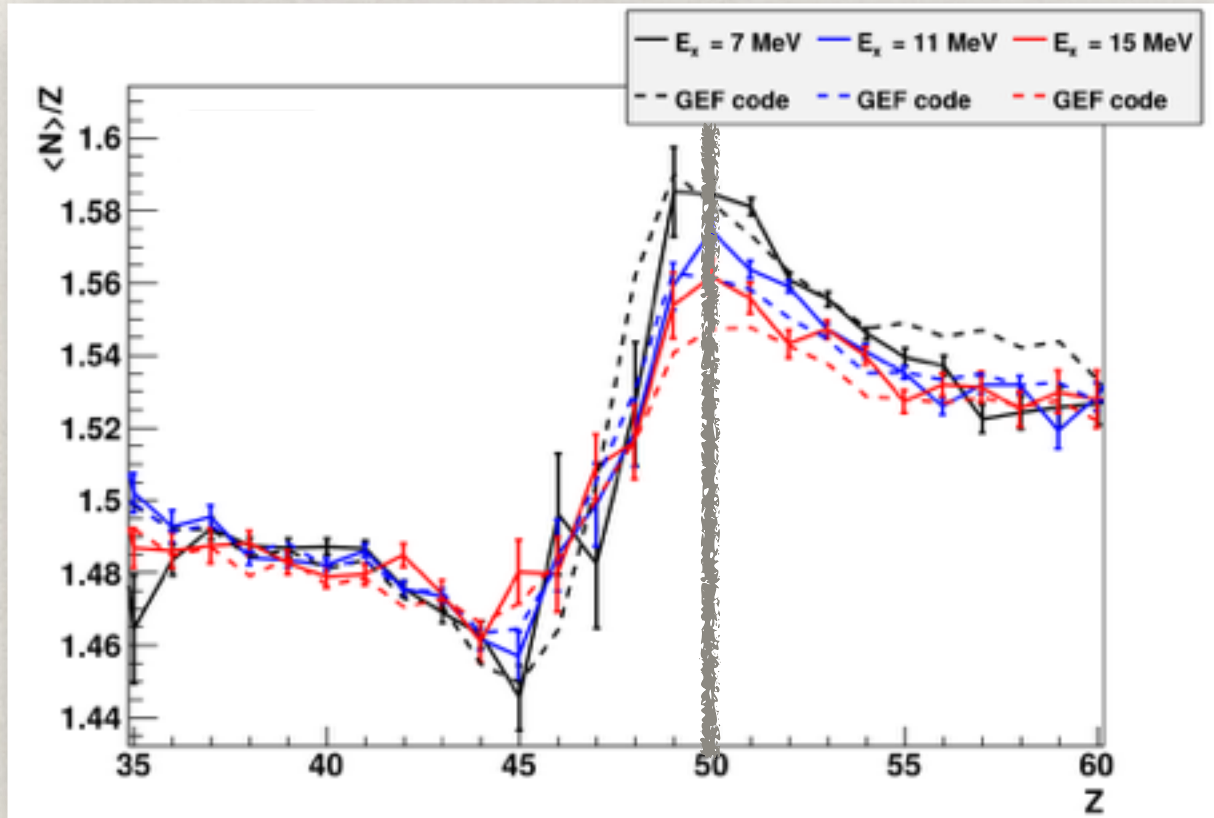


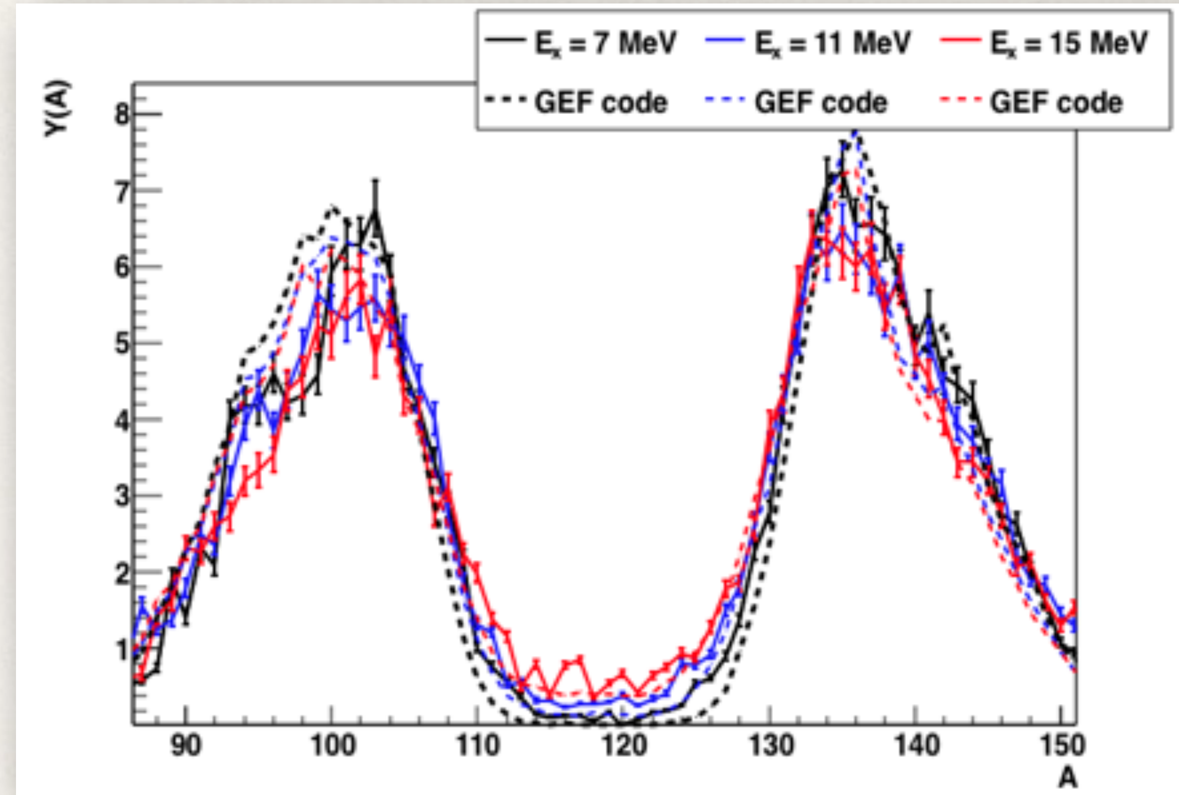
3 different regions of E_x were selected through the transfer reaction reconstruction



Evolution with Excitation Energy

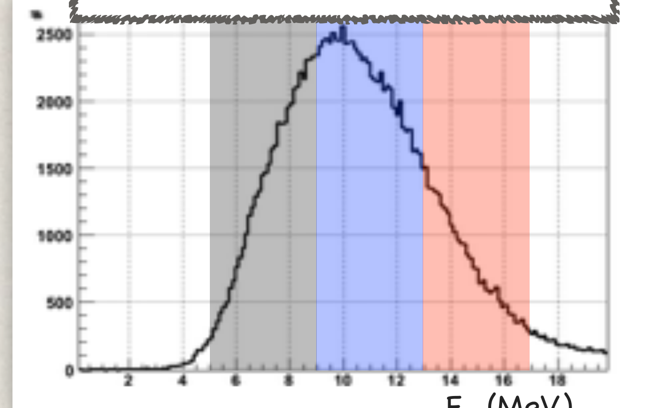
^{240}Pu





The <N>/Z ratio gets reduced around Z ≈ 50 by increasing E_x, signature of a closed shell which effect is smaller for higher E_x.

$^{238}U(^{12}C, ^{10}Be)\,^{240}Pu$



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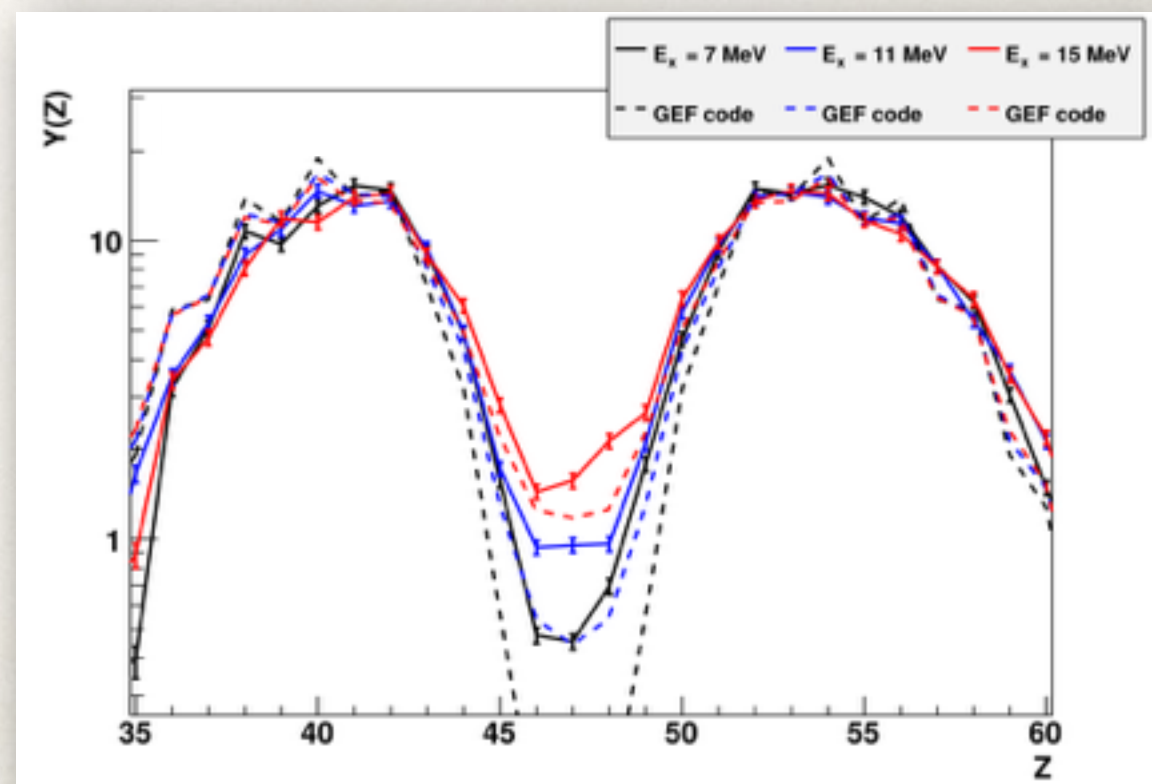
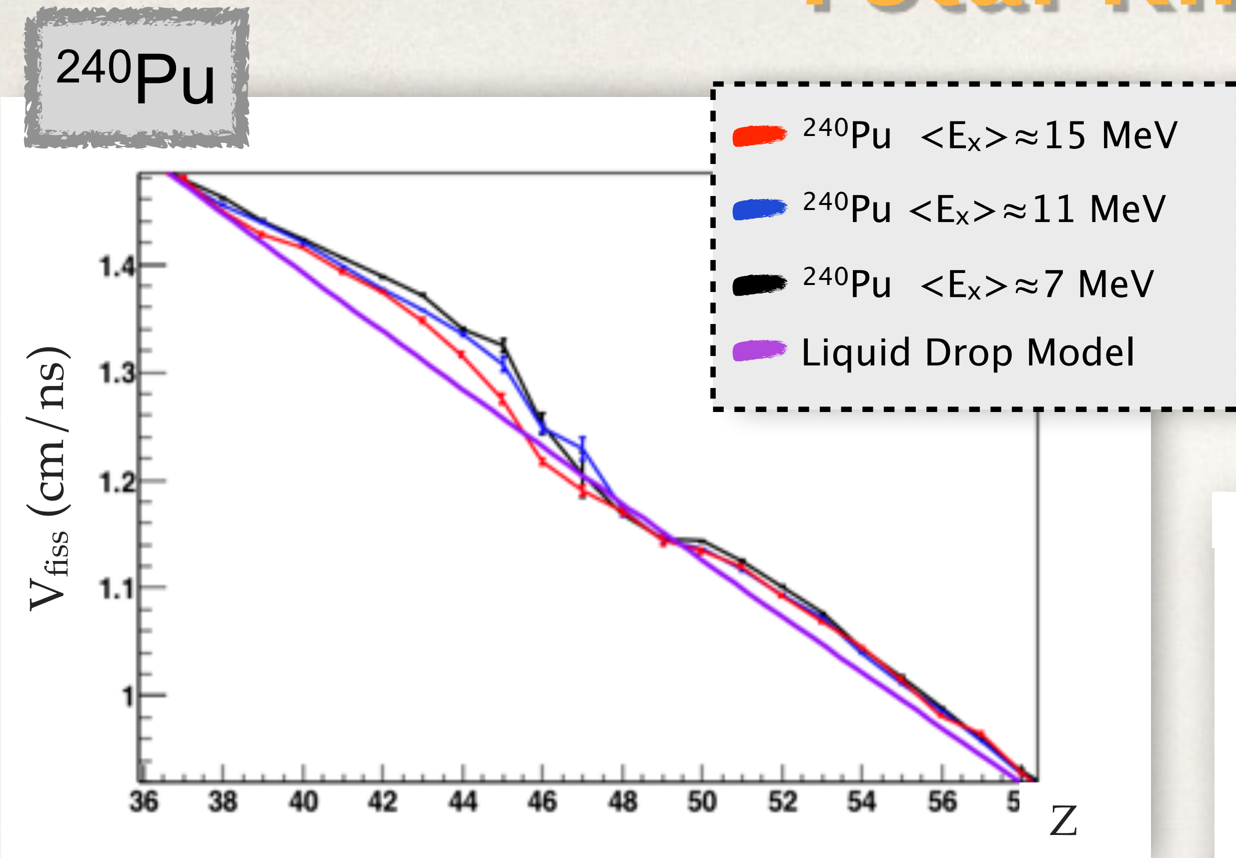


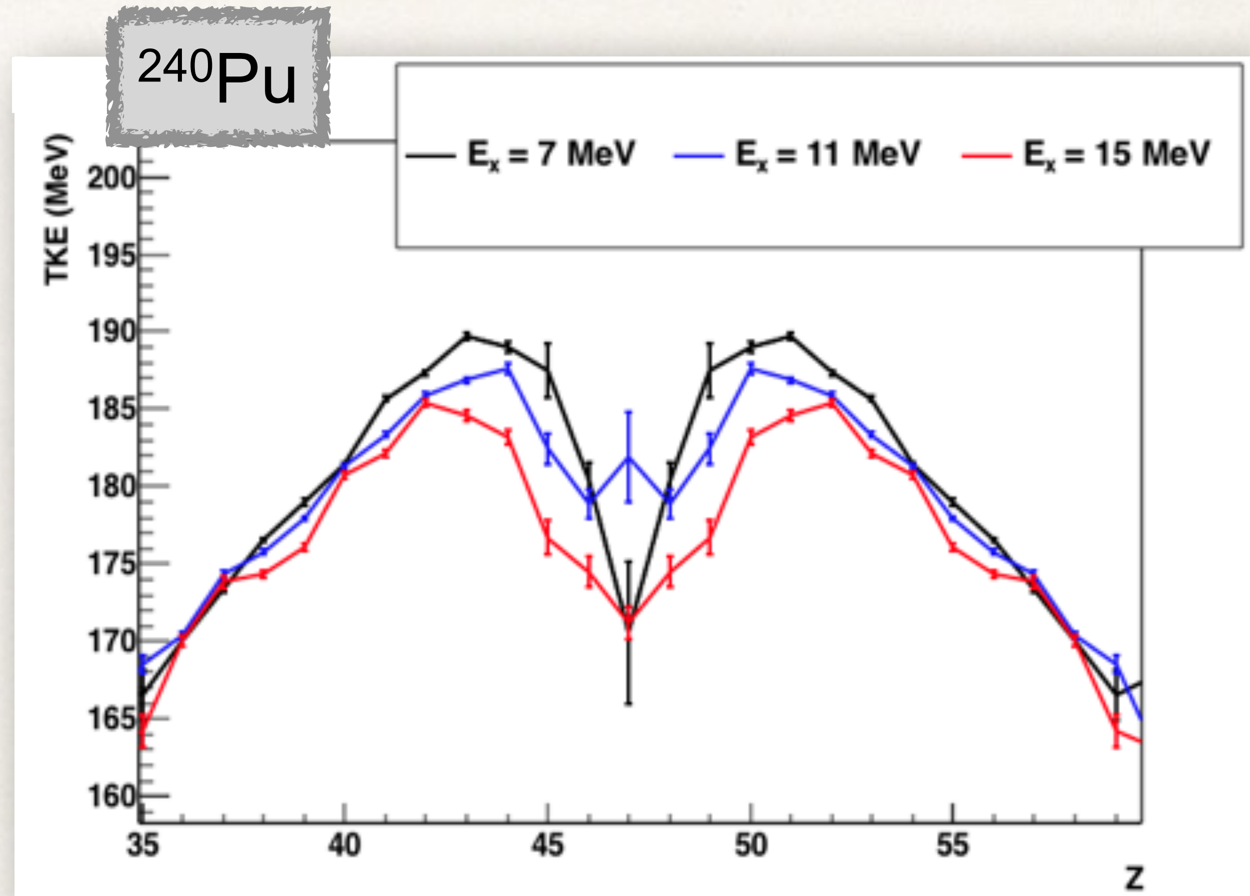
Total Kinetic Energy

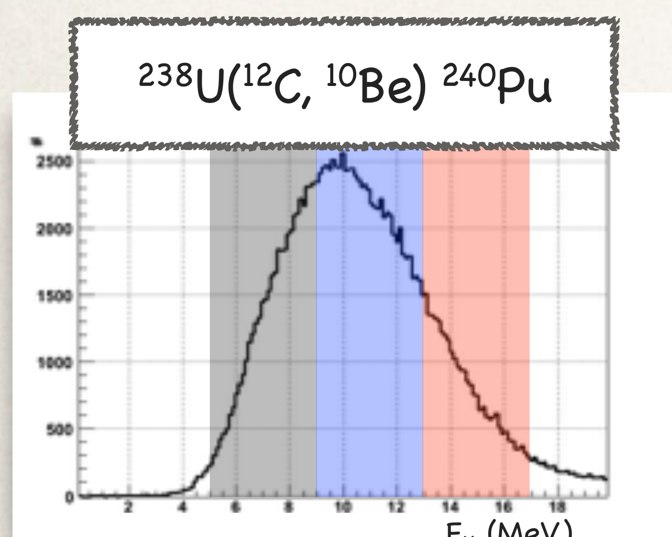


Mean value of the velocity of ff as a function of Z

In the asymmetric region, the light fragment is emitted with a higher velocity compared with the LD

$$TKE = u \cdot <A>_Z \cdot (<\gamma>_Z - 1) + u \cdot <A>_{Z_{Act}-Z} \cdot (<\gamma>_{Z_{Act}-Z} - 1)$$





TKE values decrease with higher E_x
The distance between both fragments at the scission point is larger with higher E_x

TKE distribution becomes more smooth at higher E_x

Conclusions

Transfer-induced fission in inverse kinematics coupled to the VAMOS spectrometer allowed us to:

Measure the fission of different fissioning systems, most of them exotic nuclei.

Identify the fissioning systems through the reconstruction of transfer reaction channels.

Measure the excitation energy distribution and fission probabilities of each system.

Obtain full isotopic identification of fission fragments using the VAMOS spectrometer.

The effect of closed shells was observed and can be study as a function of the excitation energy in <N>/Z, TKE, A and Z distributions.

An evolution of the fission fragments from asymmetric to symmetric distributions is observed to follow the excitation energy.

The <N>/Z ratio in Z ≈ 50 is observed to decrease by increasing the excitation energy.