isotopic yields of fission fragments in multi-nucleon transfer-induced fission in inverse kinematics

m. caamaño[1,2], f. rejmund[1], x. derkx[1], k.-h. schmidt[1],
l. audouin[3], c.-o. bacri[3], g. barreau[4], j. benlliure[2], e. casarejos[2],
b. fernández-domínguez[5], l. gaudefroy[6], c. golabek[1], b. jurado[4],
a. lemasson[1], a. navin[1], m. rejmund[1], t. roger[1], c. schmitt[7], j. taieb[6],
a. shrivastava[1]

1 ganil, france. 2 u. de santiago de compostela, spain. 3 ipn, france.
4 cenbg, france. 5 u. of liverpool, uk. 6 cea/dam, france. 7 ipnl, france.

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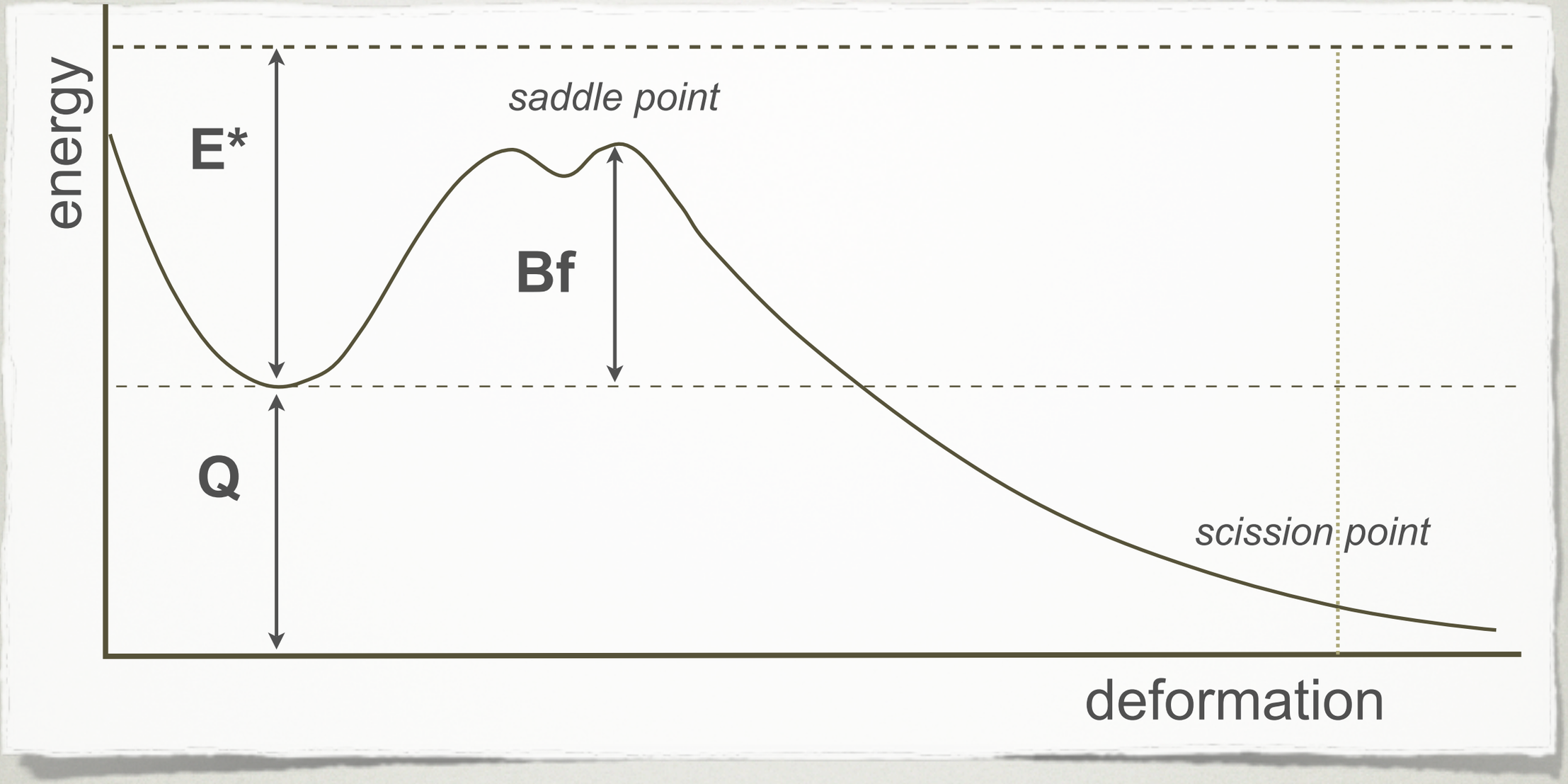
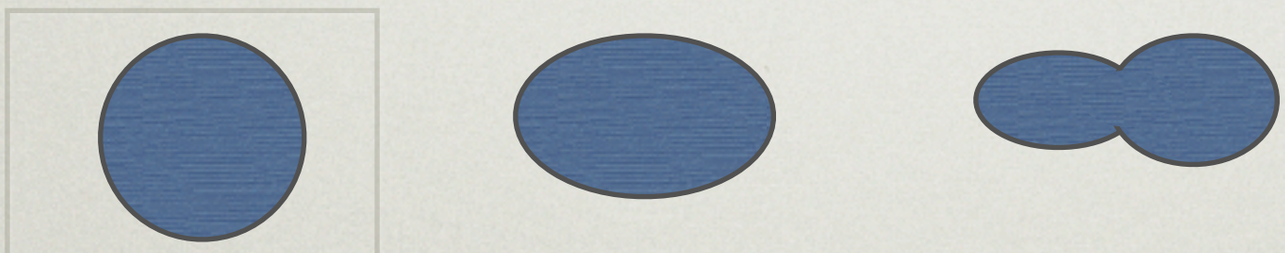
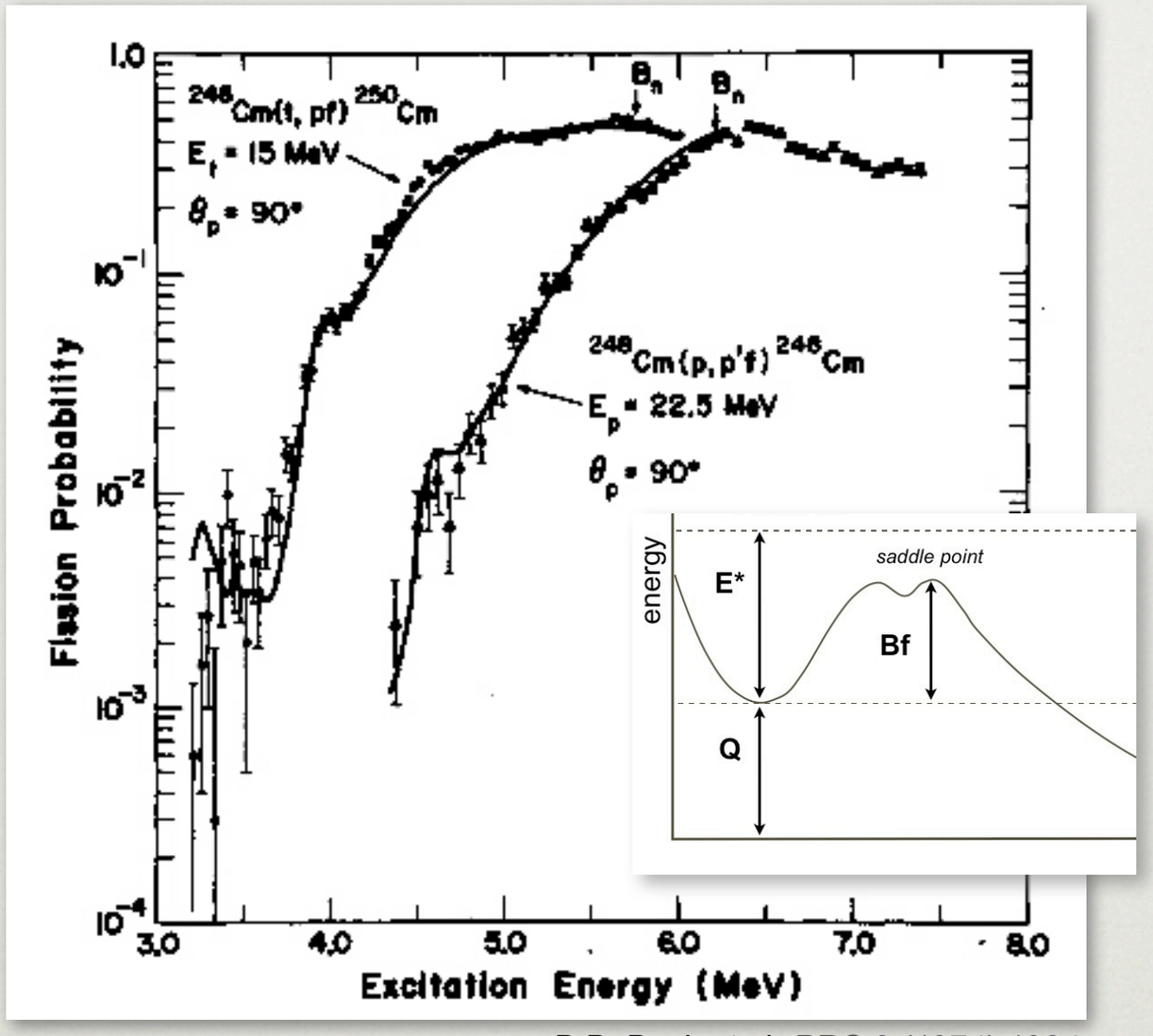
the fission process





observables: fission probability

transfer-induced fission



B.B. Back et al. *PRC 9 (1974) 1924*

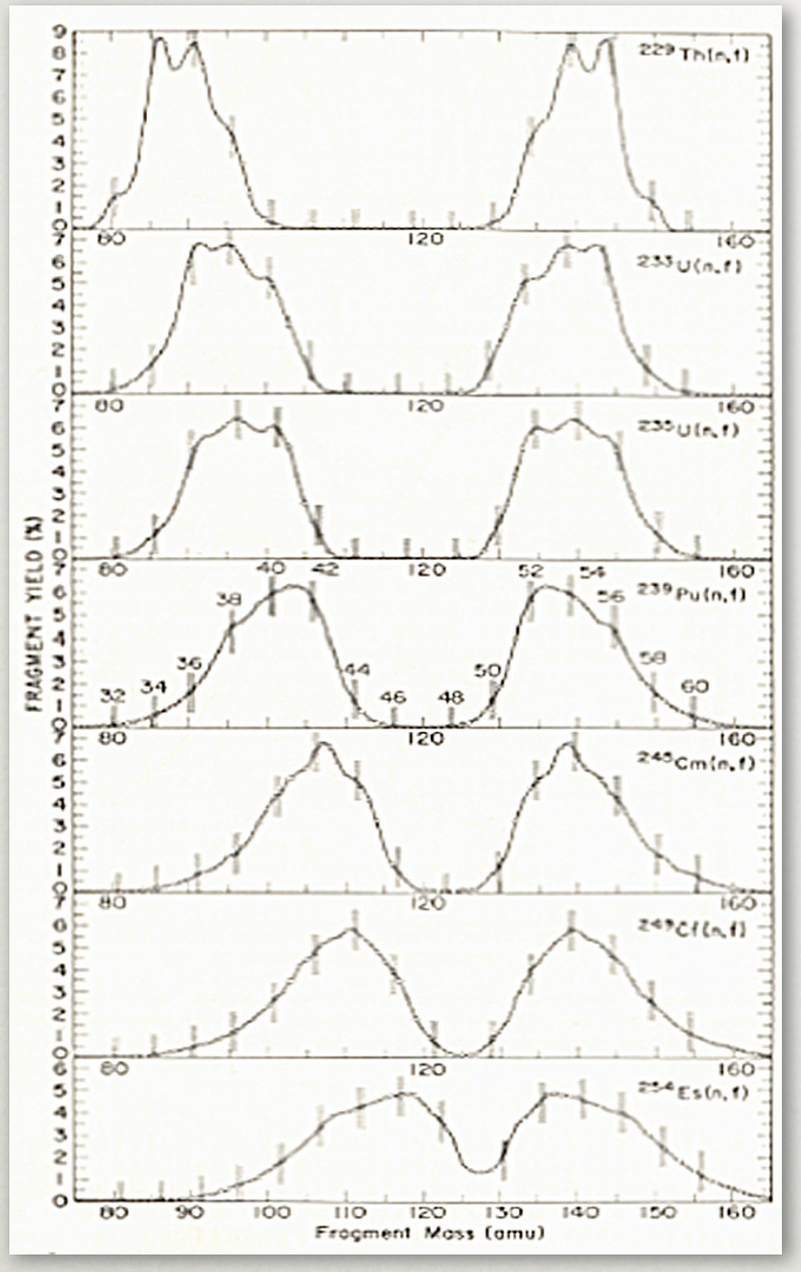
- production of **different fissioning systems**

- **E*** determined by transfer kinematics

- measurement of the fission barrier

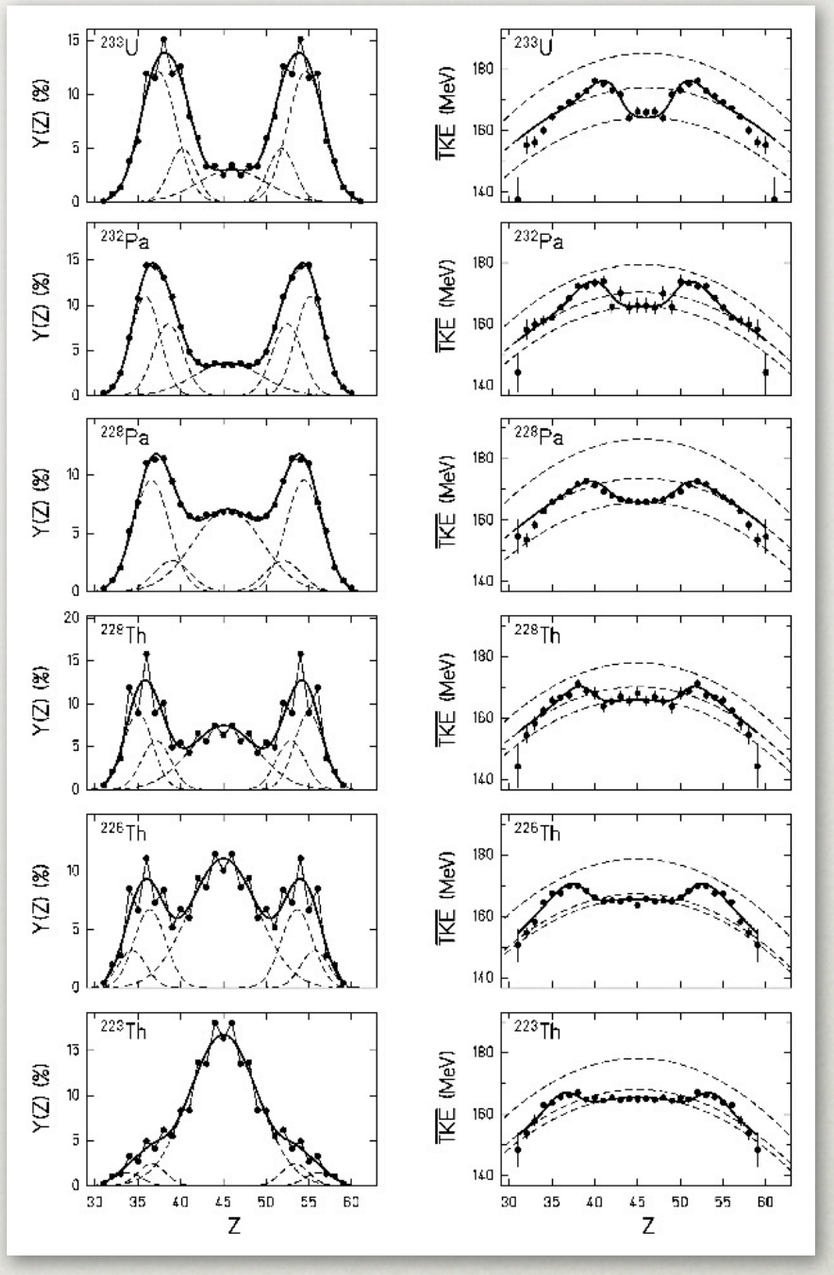
observables: **mass**, **Z** and **TKE** distributions

mass distribution



J.P. Unik et al. *Proc. Symp. on Physics and Chem. of Fission (1974), Vol. 2, 19*

Z distribution **TKE** distribution



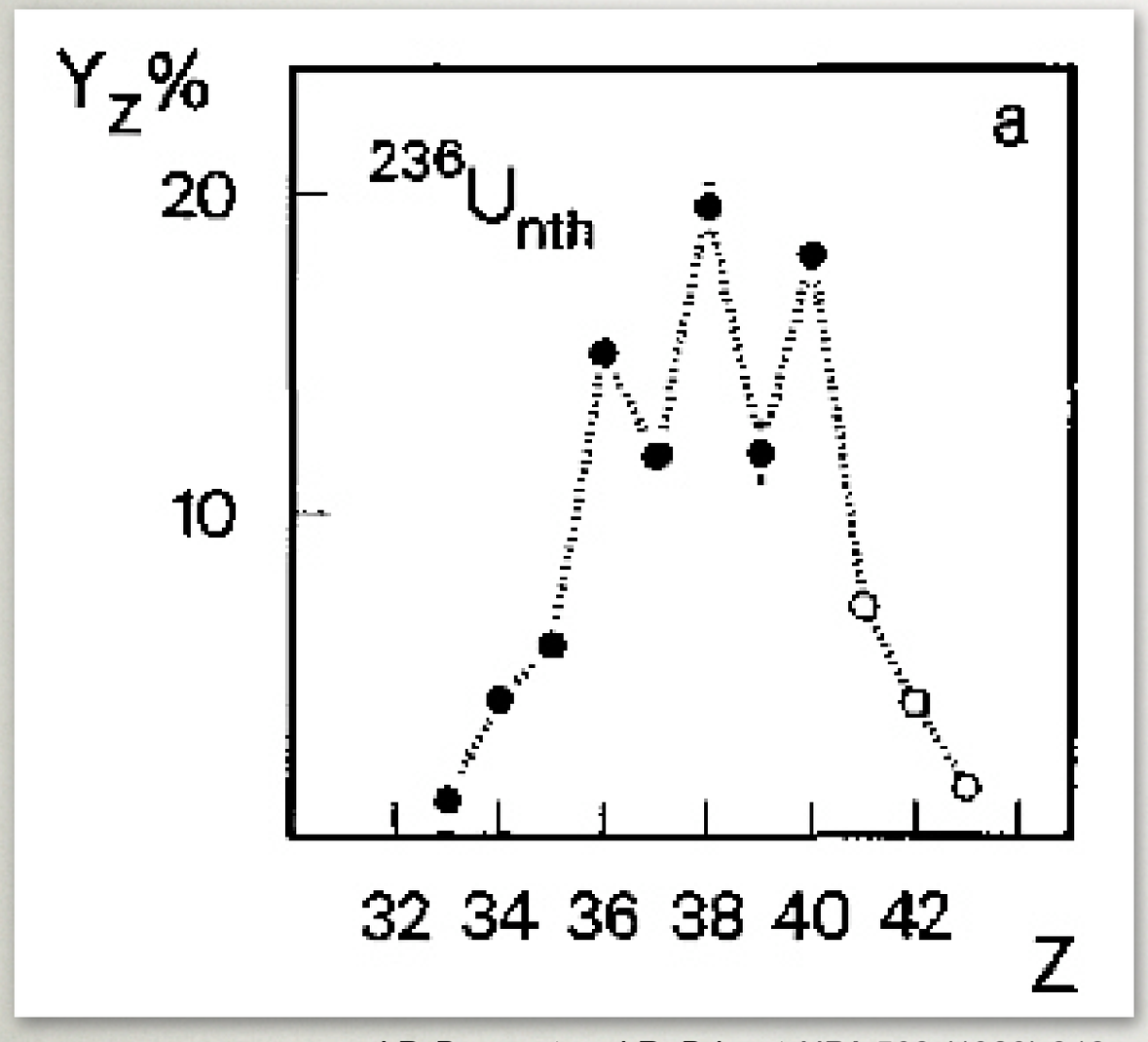
C. Böckstiegel et al. *NPA 802 (2008) 12*

thermal-neutron induced fission

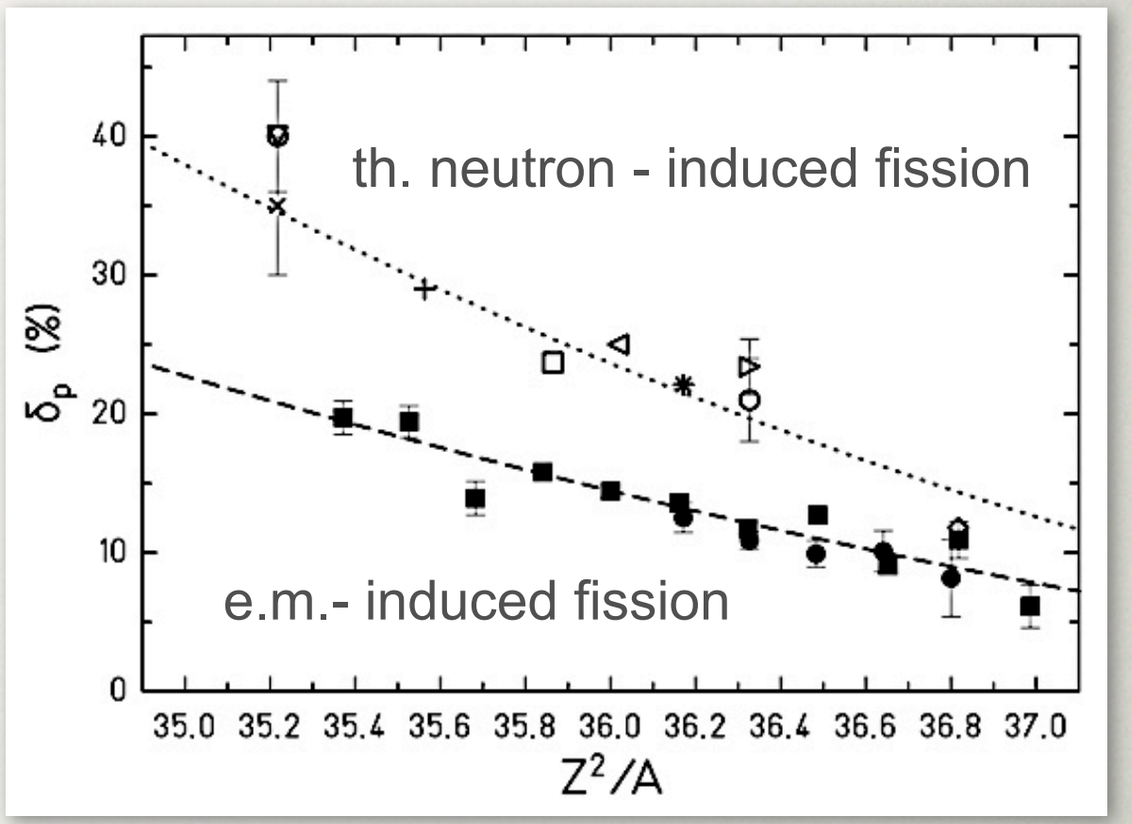
inverse kinematics

are neutrons or protons driving the fission?

observables: even-odd effect



J.P. Bocquet and R. Brissot *NPA 502 (1989) 213c*



S. Steinhäuser *PhD Thesis, 1997, Germany*

proton **even-odd** effect ↔ **dissipation**

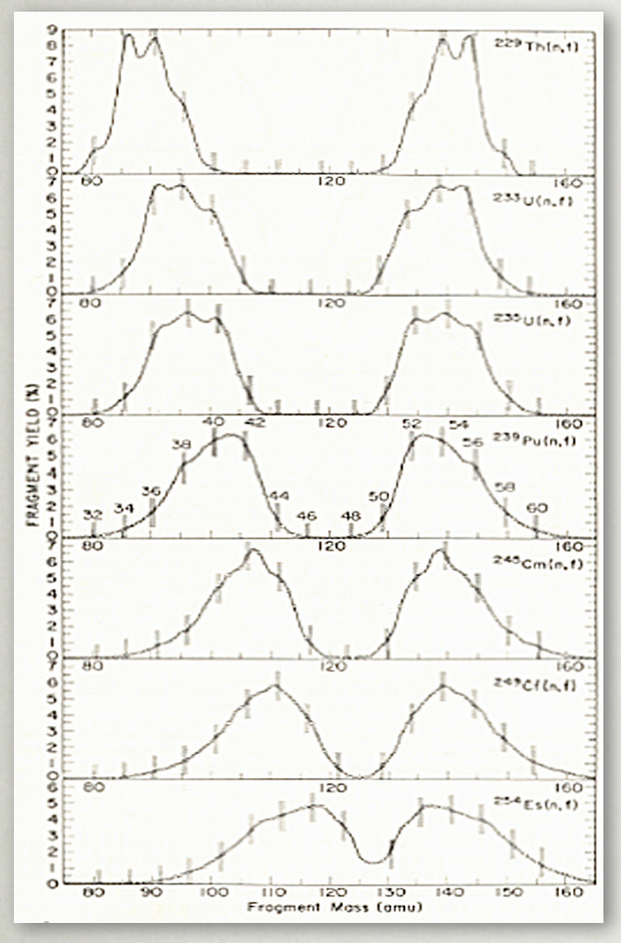
what is the dependence of δ_p on **excitation energy**?

...and on the fission mode?

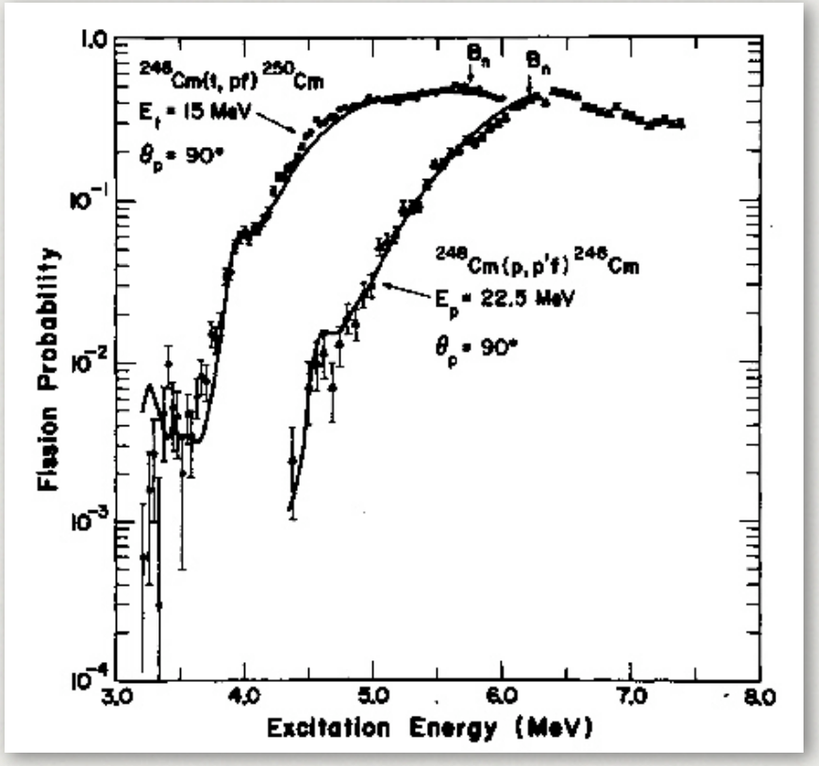
M. Caamaño and F. Rejmund *Proceedings of the 4th Int. Conf; on Fission and Prop. of Nucleon-Rich Nuclei, 2008 USA*

contribution by **f. rejmund** after coffee break

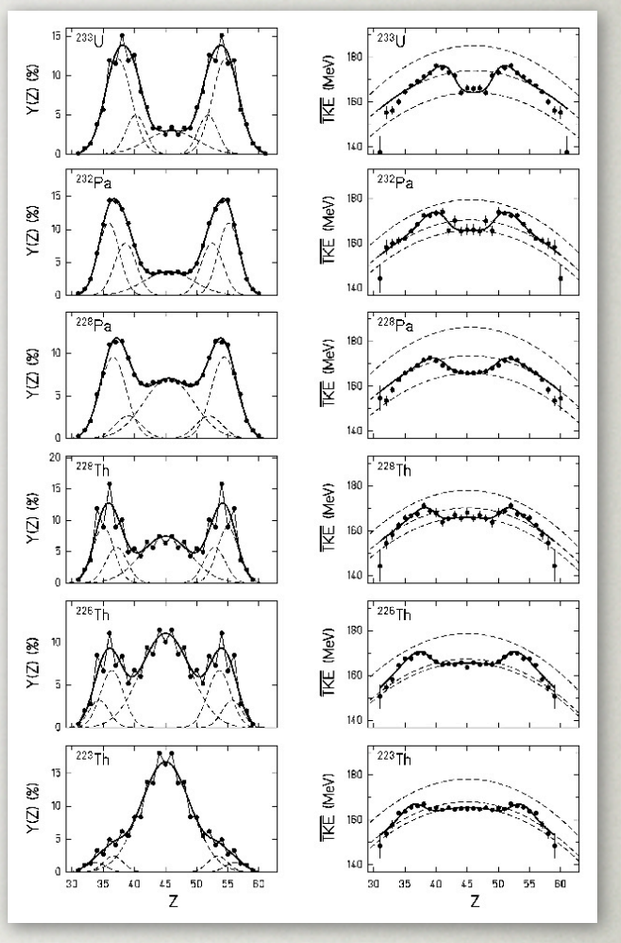
observables: a review



n-capture induced fission



transfer-induced fission



in-flight **inverse kinematics**

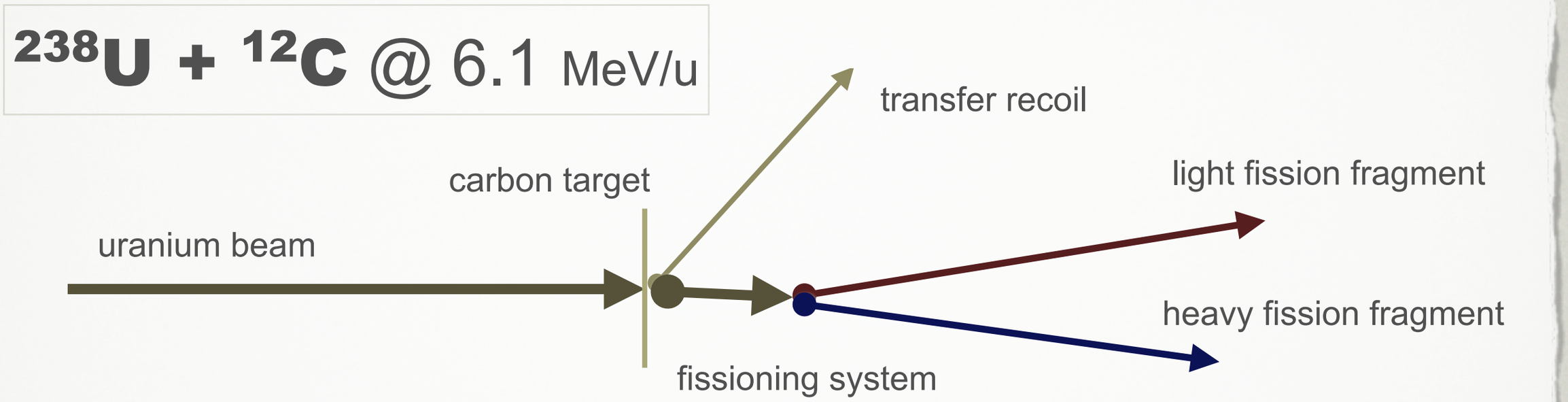
transfer:
different systems
access to **E***

&

inverse kinematics:
accurate information
on fragments

simultaneous measurement of **M**, **Z**, **E**

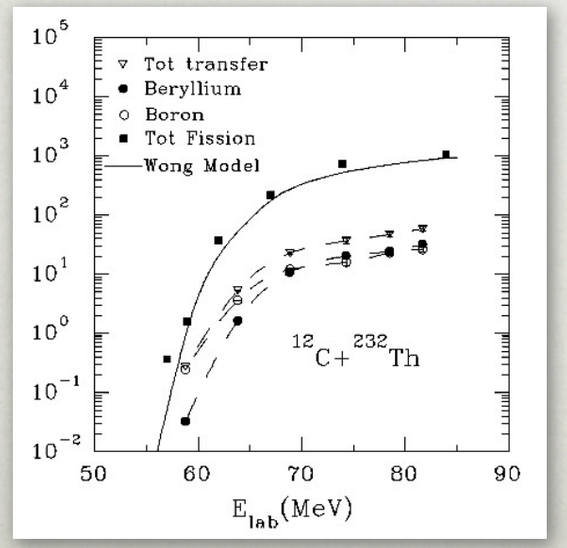
transfer-induced fission in inverse kinematics



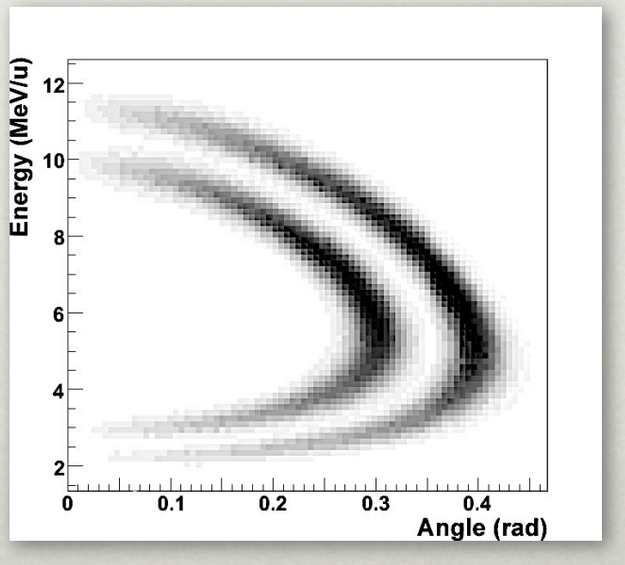
transfer
- U, Np, Pu, Am, Cm
- different **E***

fission
- **M**: 80 - 150
- **q**: 25 - 45
- **Z**: 30 - 60
- **E**: 2 - 10 MeV/u

transfer - fission
~ 100 mbarn
fusion - fission
~ 1000 mbarn



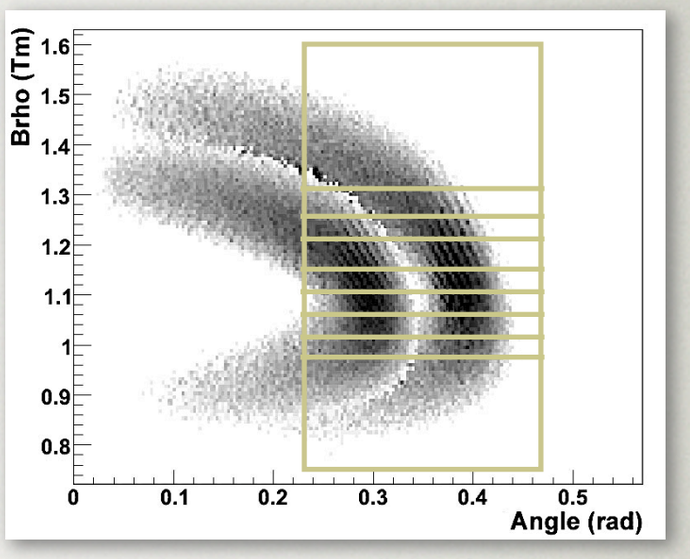
D.C. Biswas et al. *PRC 56 (1997) 1926*



inverse kinematics
- restricted angular distribution

experimental set-up at VAMOS

acceptance: • 14 deg Θ
• ~ 3 deg Φ
• 10 % Bρ



at 20 deg

ionization chamber

21 Si detectors

drift chamber

SeD

drift chamber

E_{res}

dE

X,Y

ToF

X,Y

reconstruction

• Path • Bρ • Θ_{lab}, Φ_{lab}

M. Rejmund

• β, γ

•KE •Z •M •M/q

20 deg

Aside

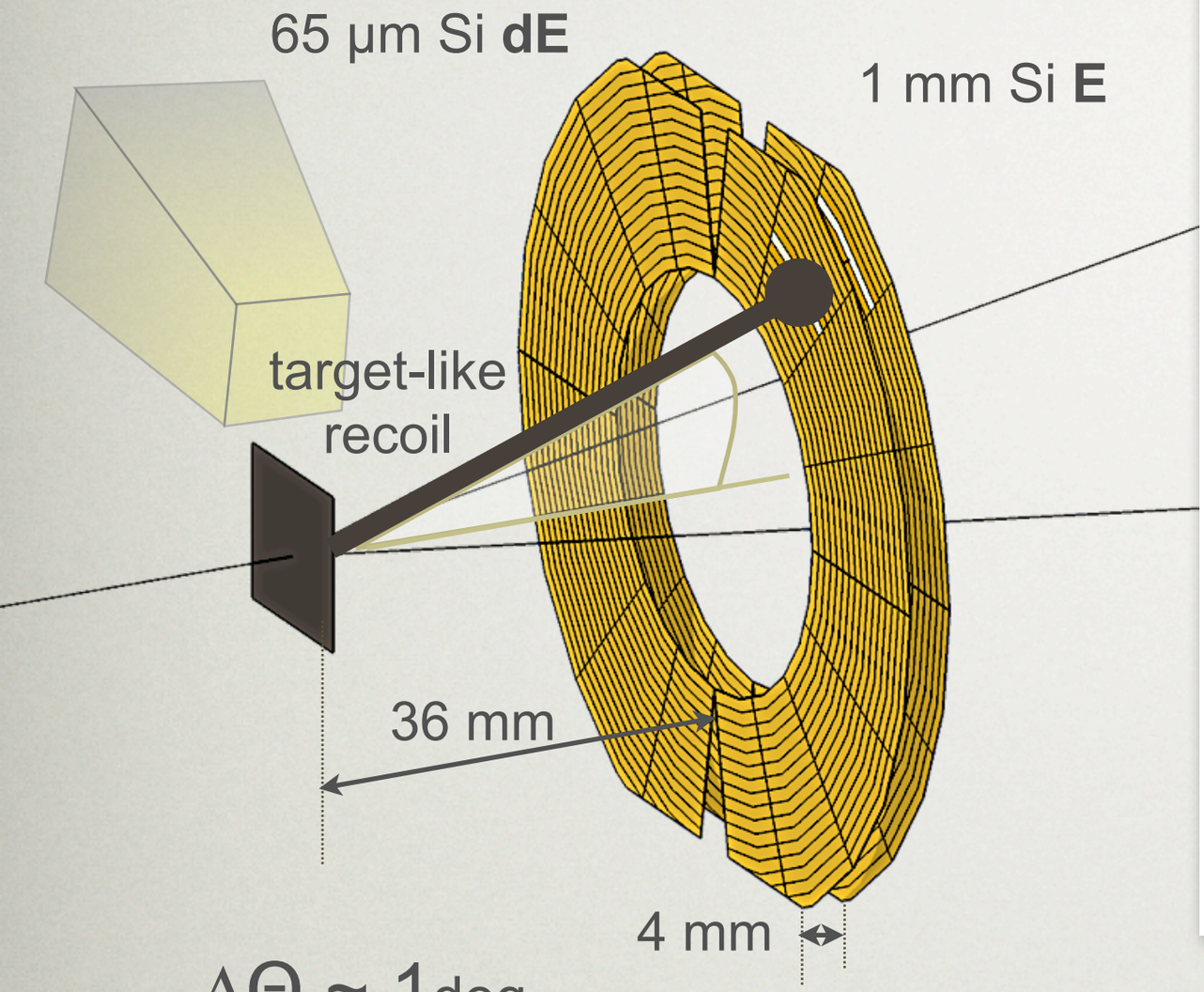
E, dE, recoil angle

SPIDER

EXOGAM

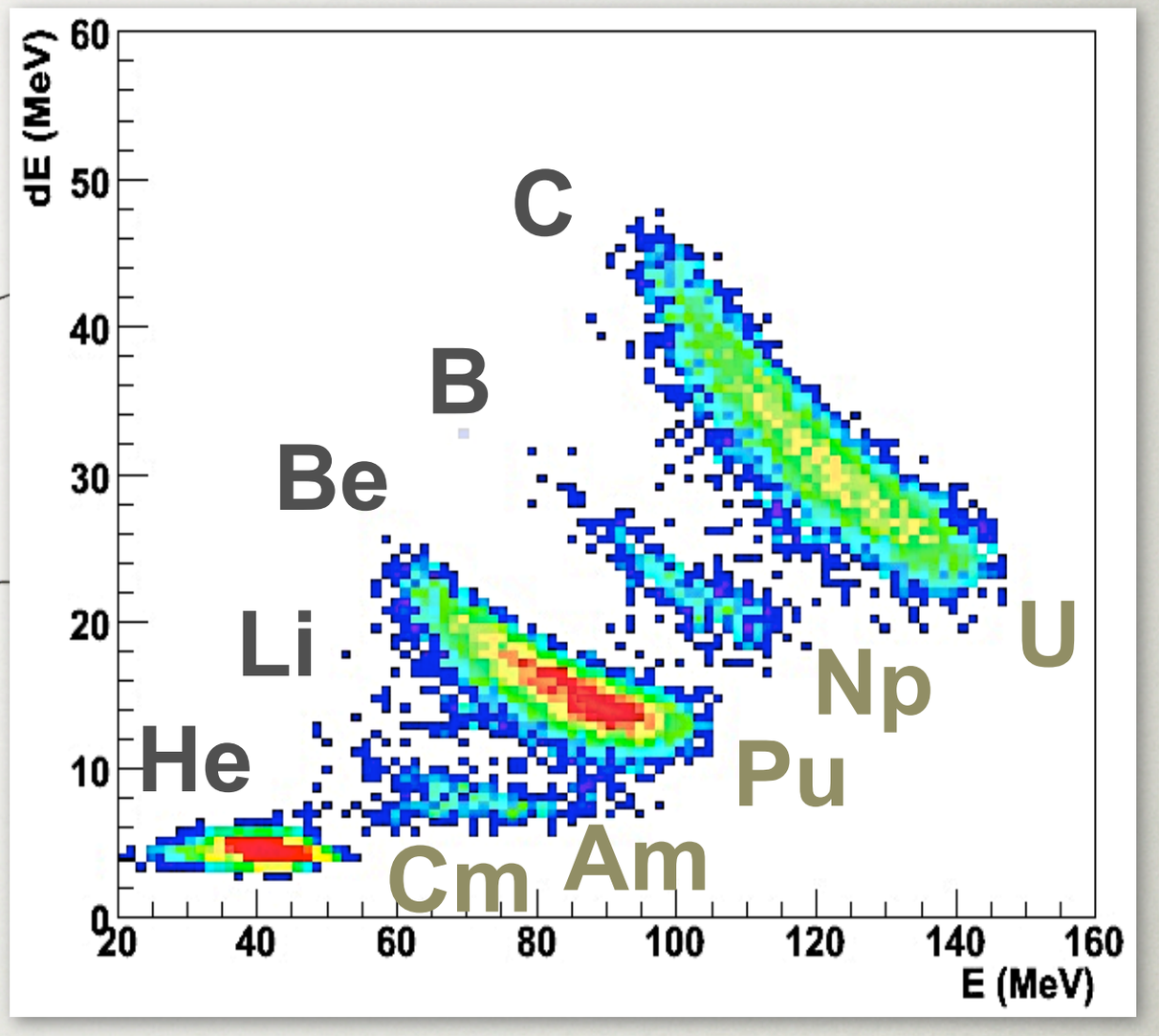
^{238}U beam

transfer kinematics with SPIDER



$\Delta\Theta \sim 1^{deg}$

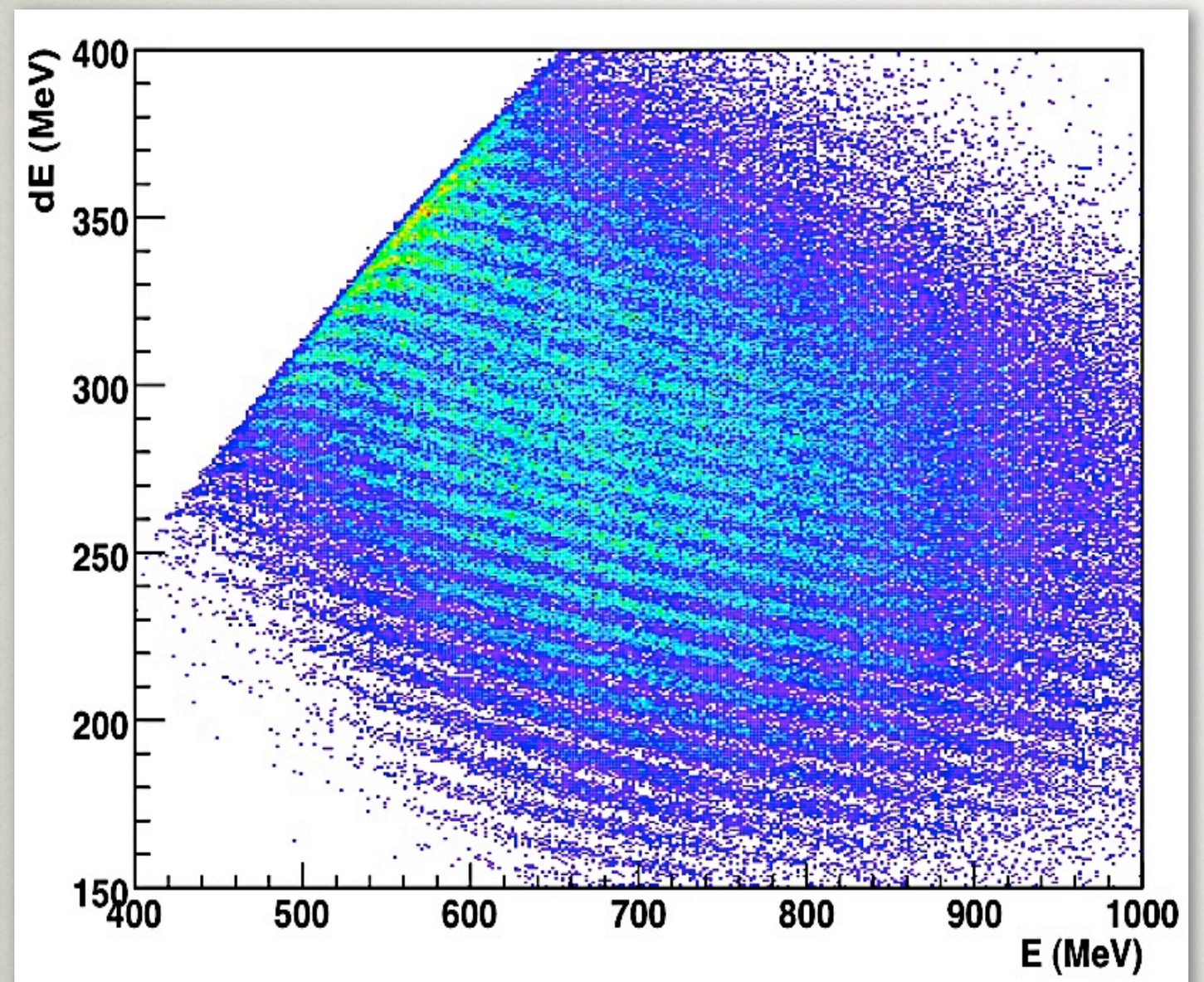
$\Delta E^* \sim 2$ MeV



identification of the **fissioning system**

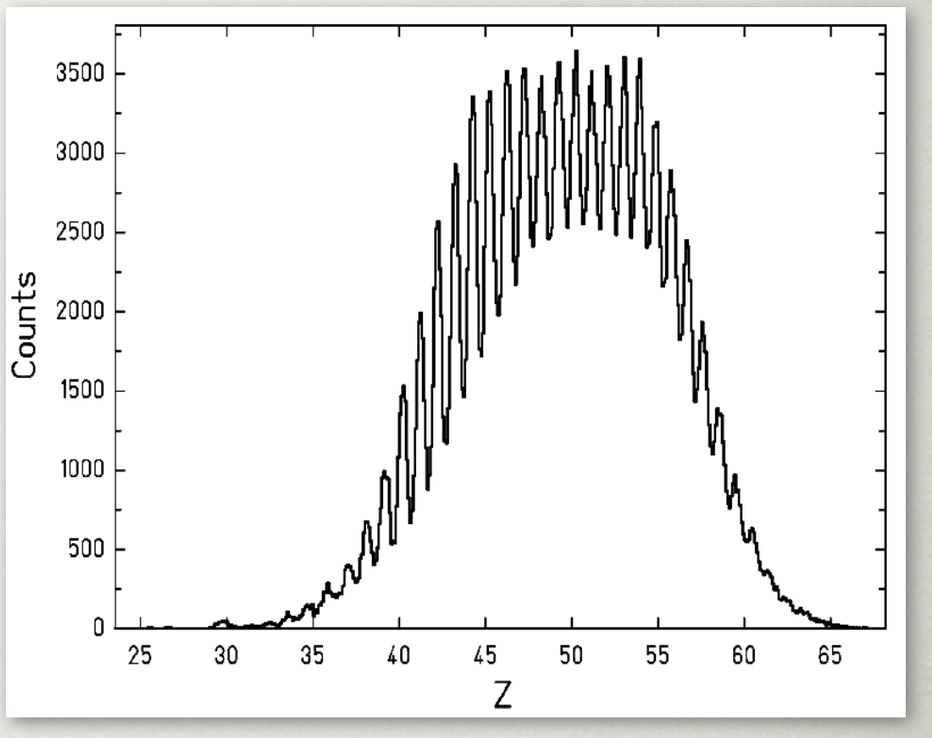
reconstruction of transfer kinematics: **determination of E***

fission fragment isotopic identification with VAMOS



$$dE \propto (q_{eff})^2/\beta^2 f(\beta)$$

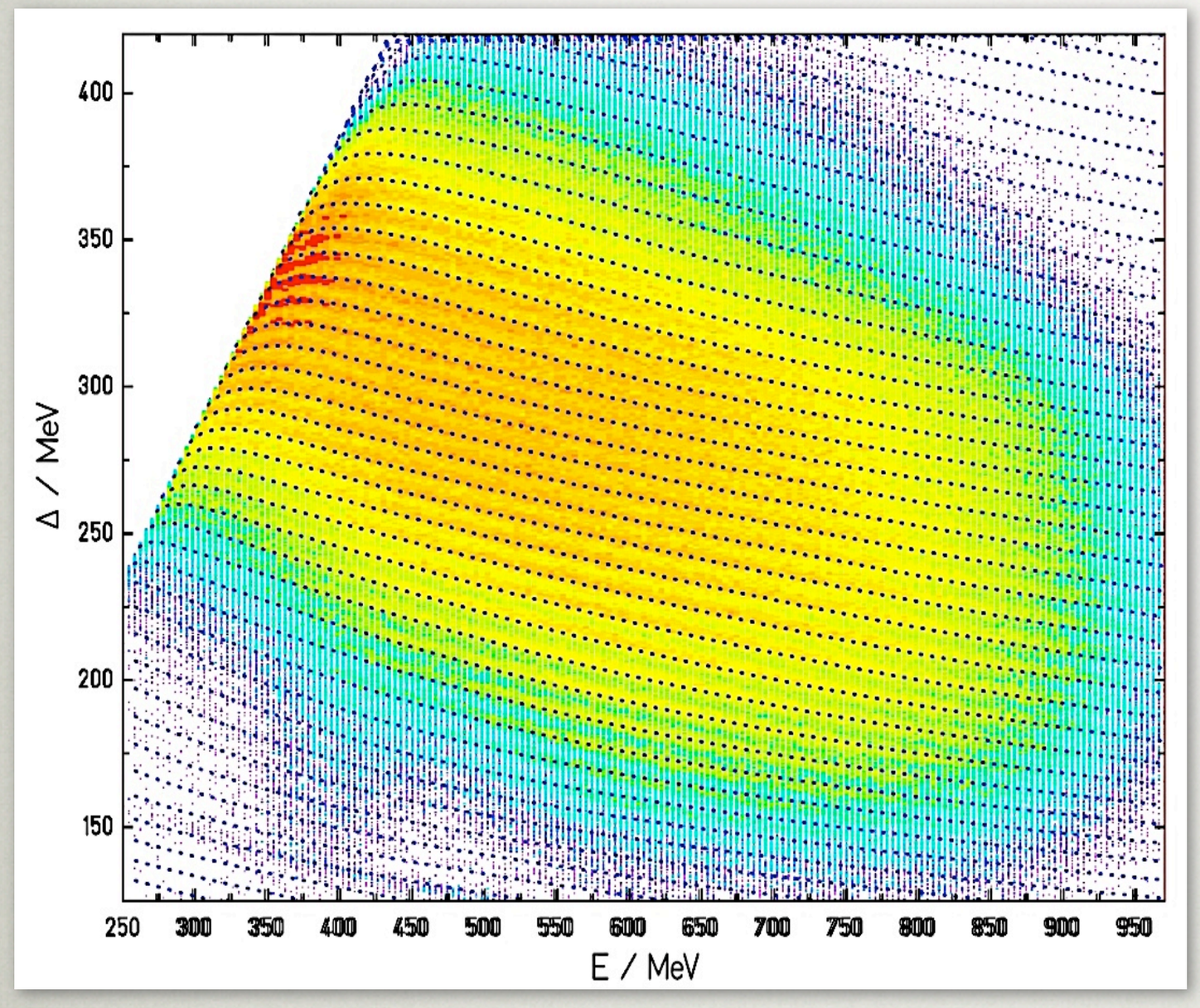
$$q_{eff} \propto \beta Z^{\wedge 1/3} + q_{shift}$$



$$\Delta Z/Z \approx 1.5 \cdot 10^{-2}$$

fragments identified from **Z ≈ 30** to **Z ≈ 60**
in 600 MeV range

fission fragment isotopic identification with VAMOS



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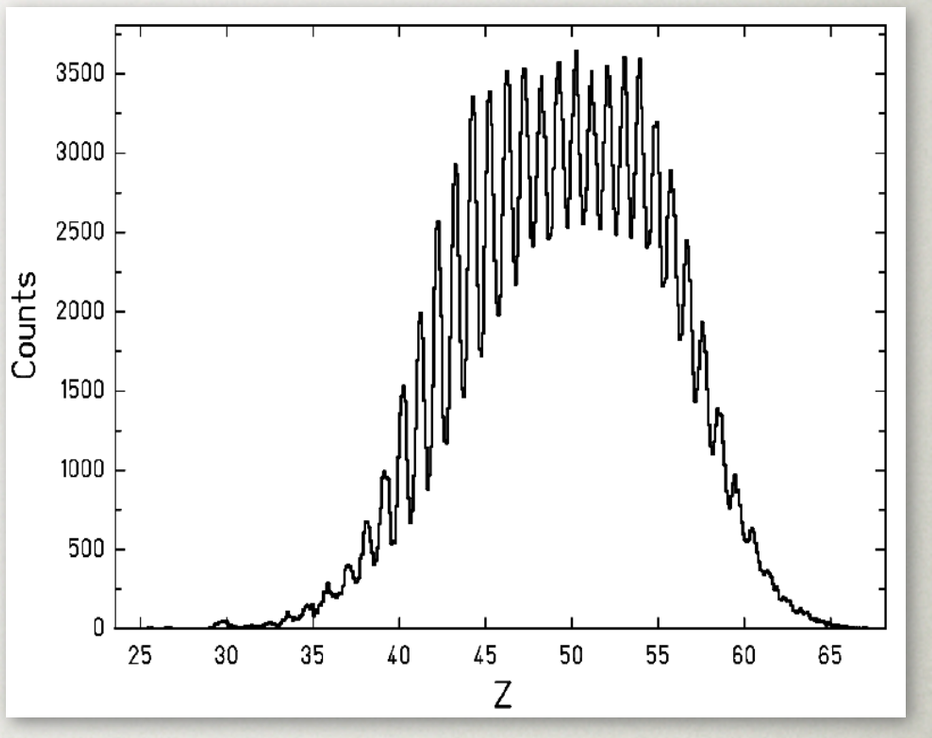
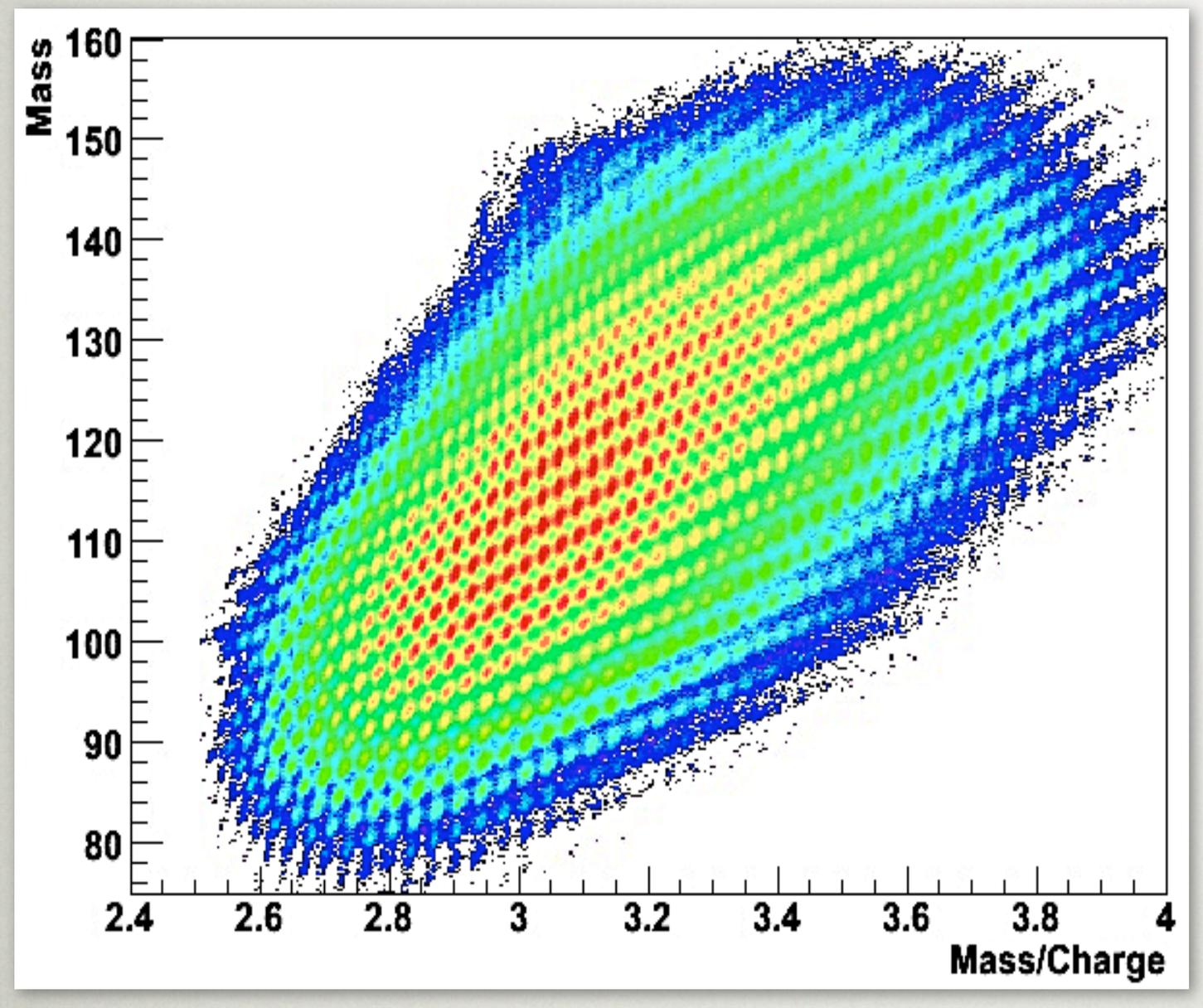


$\Delta Z/Z \approx 1.5 \cdot 10^{-2}$

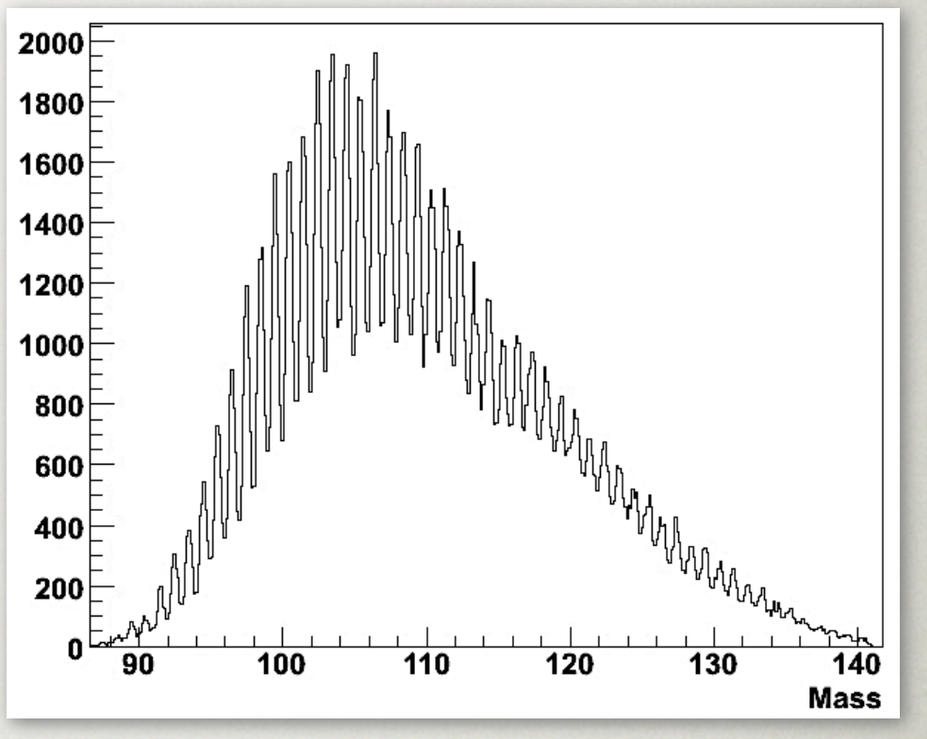
fragments identified from **Z ≈ 30** to **Z ≈ 60**
in 600 MeV range

fission fragment mass identification with VAMOS



$$\mathbf{M} = E/(\gamma-1)$$

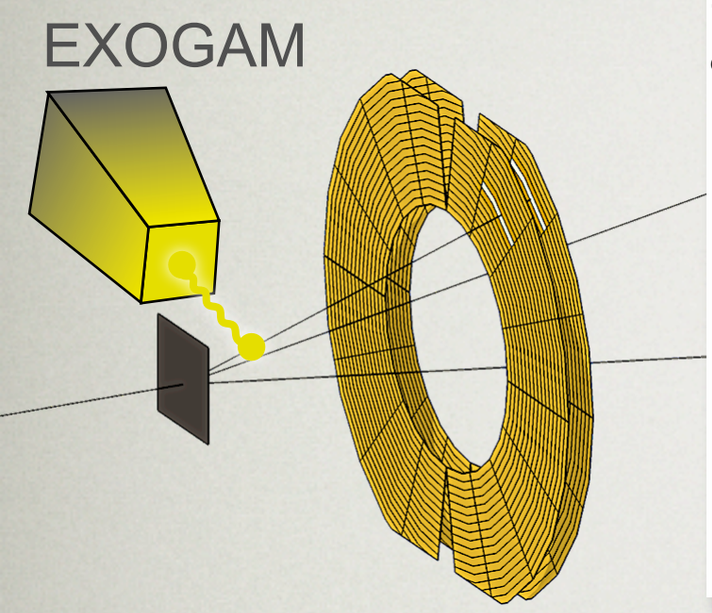
$$\mathbf{M/q} = B\rho/(\beta\gamma)$$

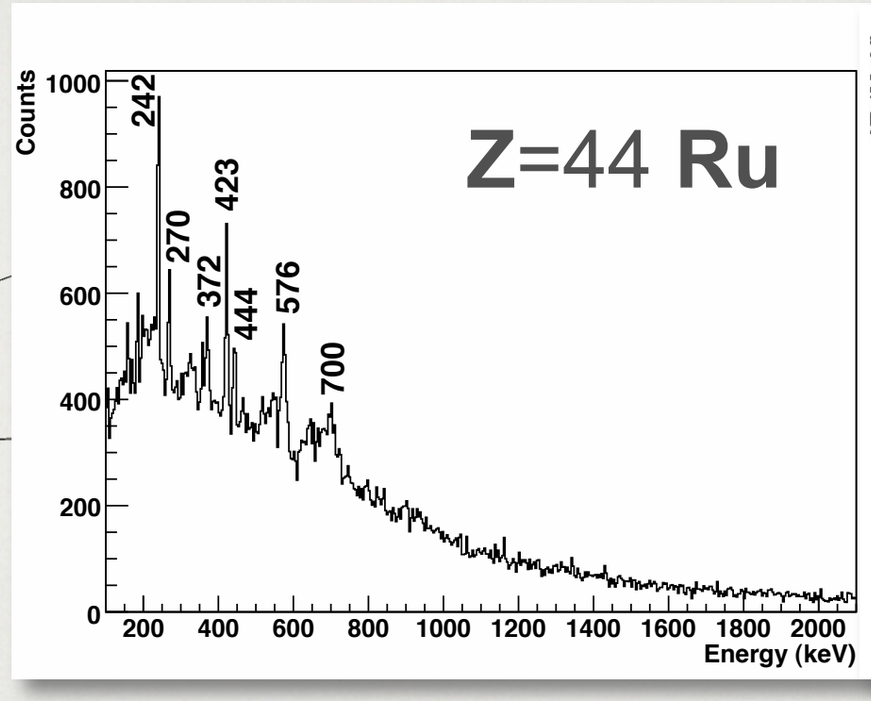


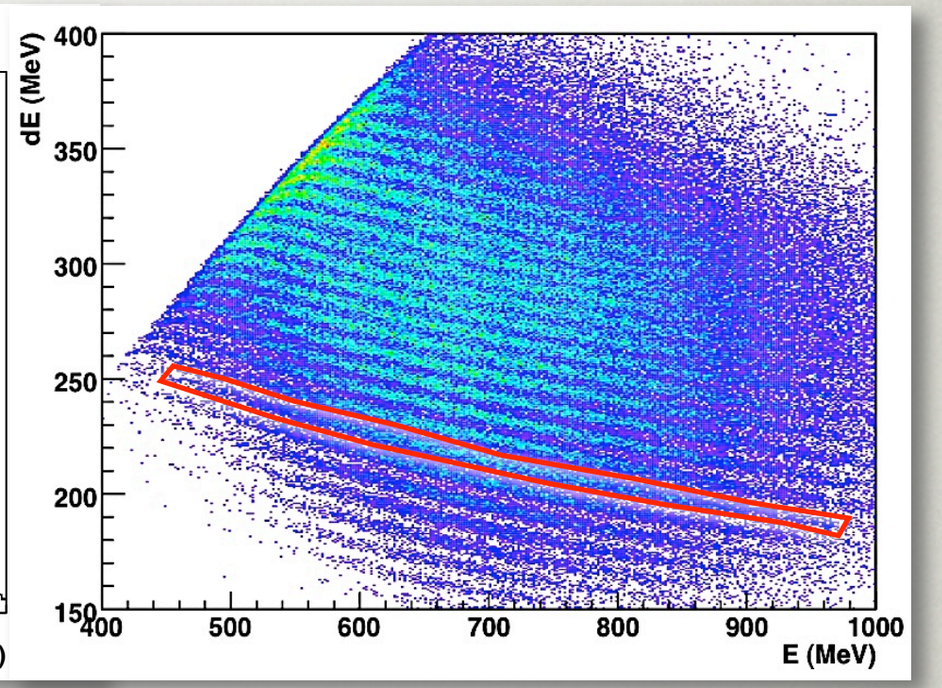
$$\Delta\mathbf{M/M} \approx 0.6 \cdot 10^{-2}$$

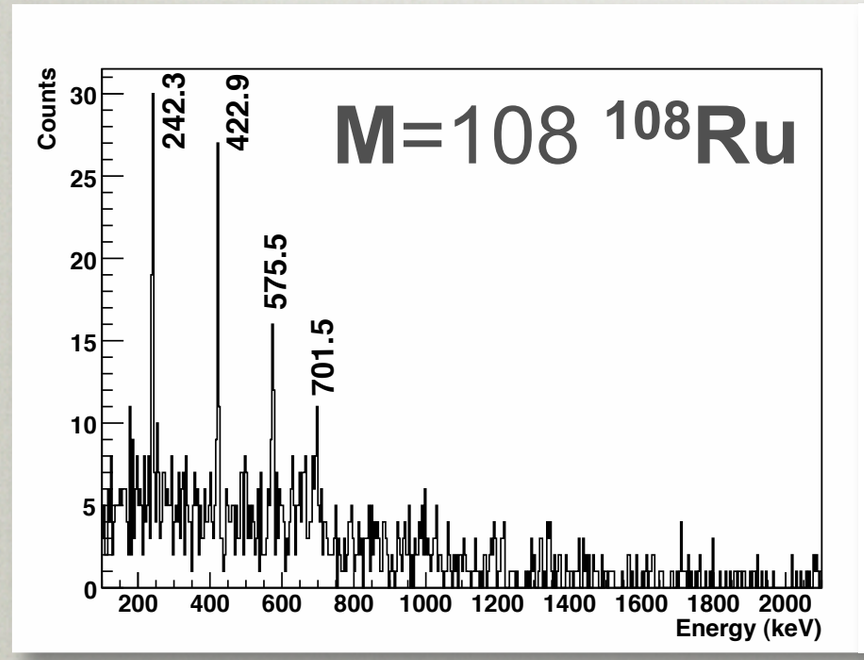
fragments identified from **M ≈ 80** to **M ≈ 150**

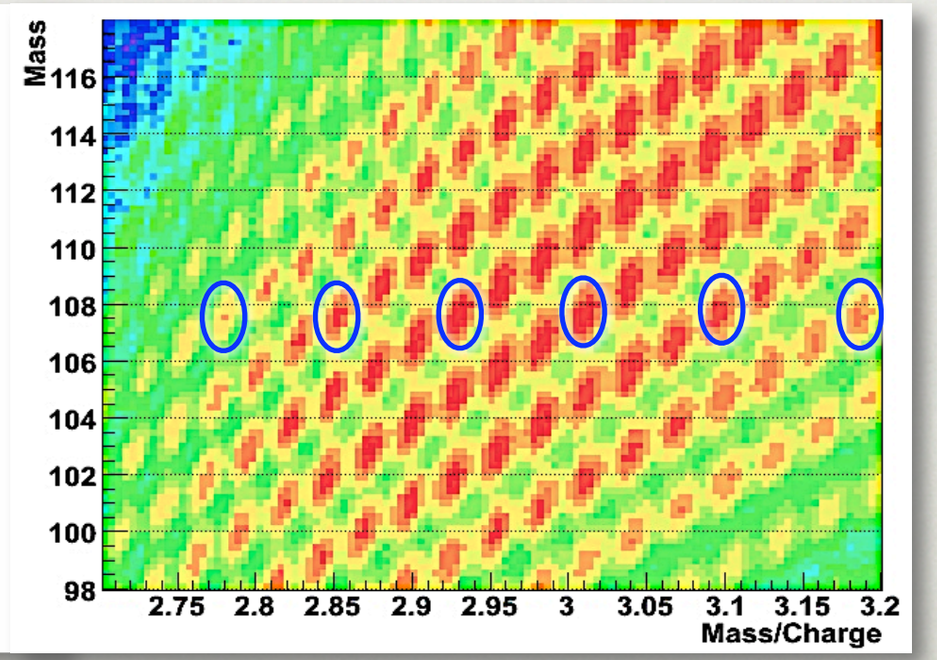
fission fragment identification with EXOGAM







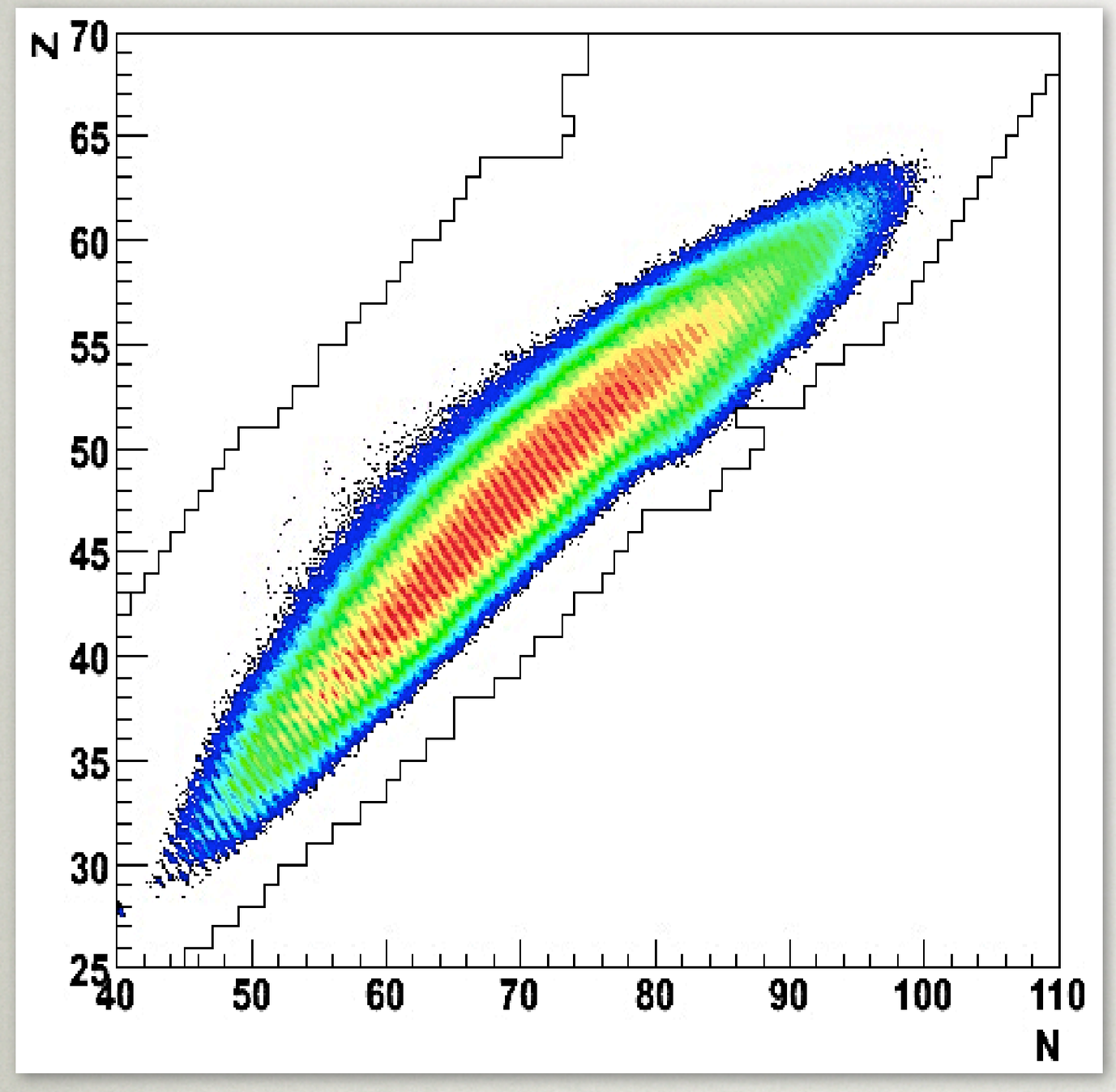


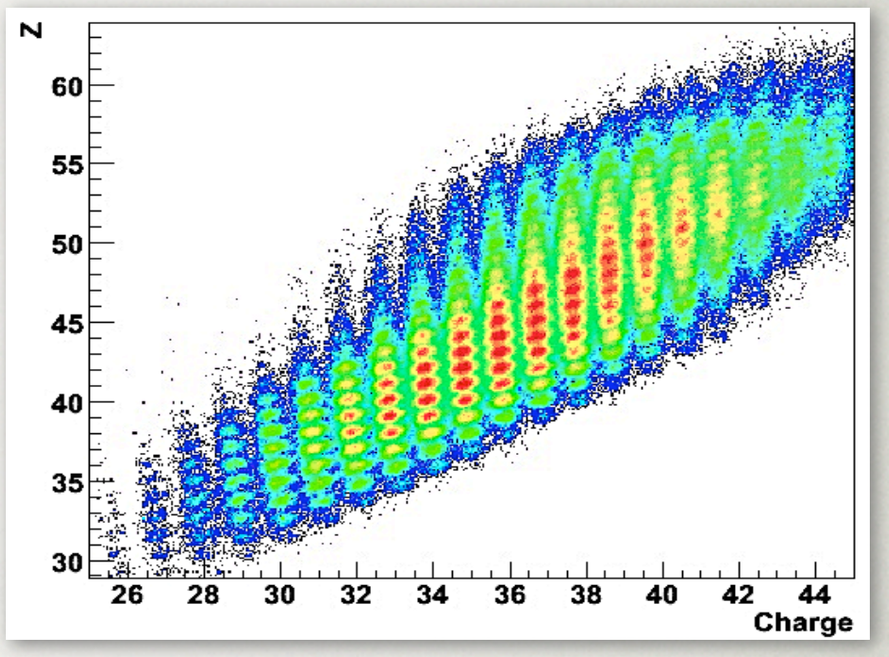


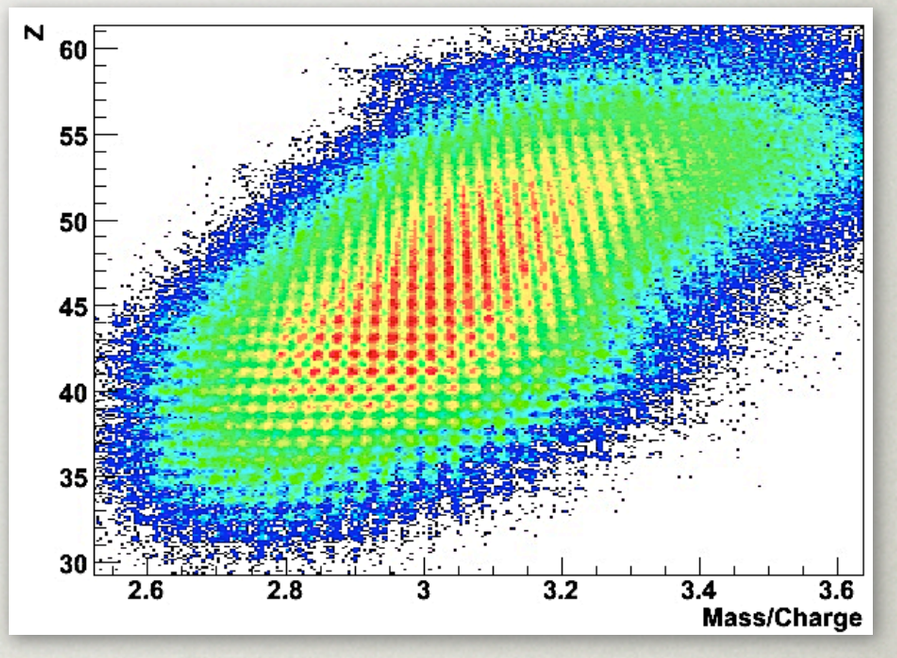
contribution by
a. shrivastava
tomorrow after lunch

unambiguous identification in **M**, **Q** and **Z**

fission fragment identification

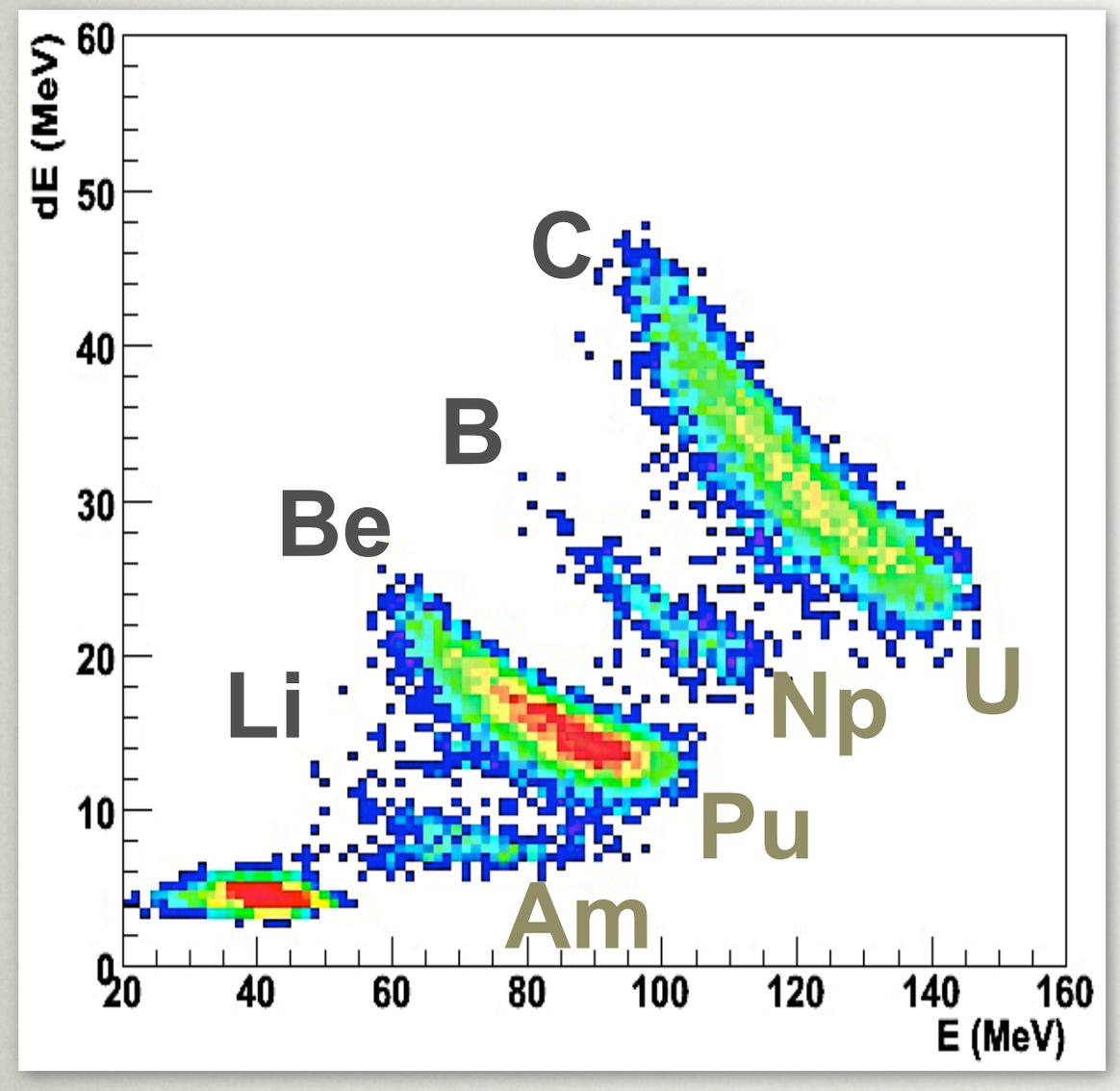


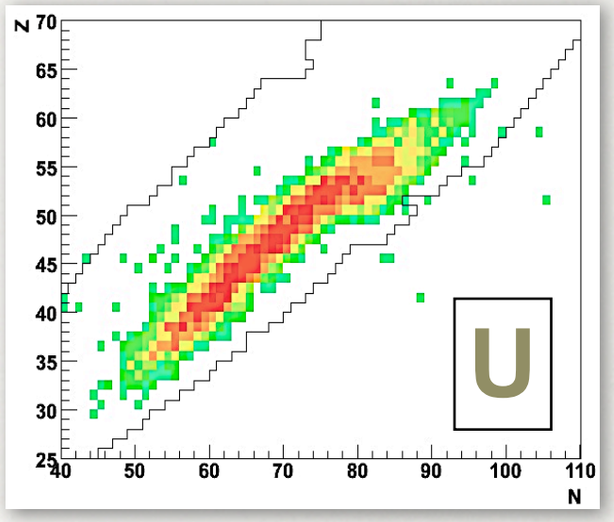


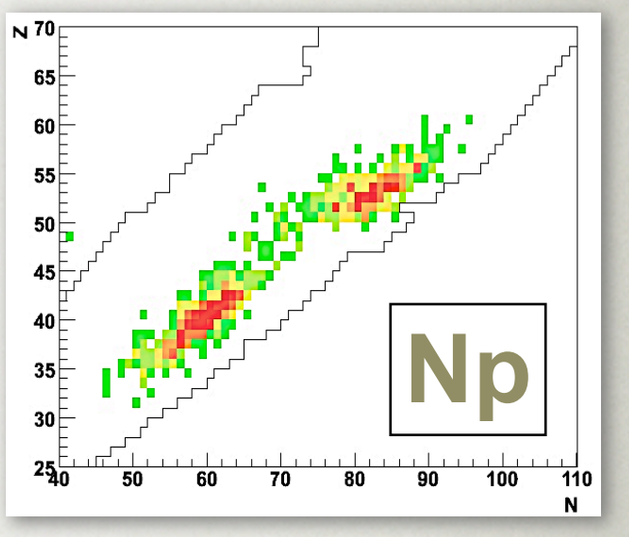


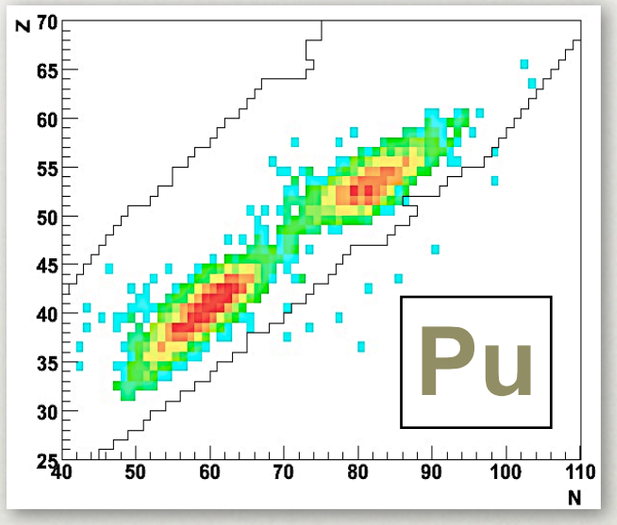
>300 fragments identified in **mass**, **Z** and **Q**

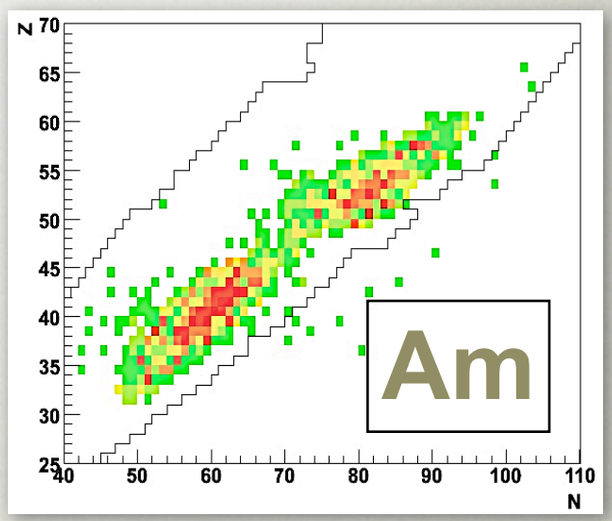
fissioning system and fragment distributions











systematic fragment distributions for different fissioning systems

$^{238}U+^{12}C$ transfer-induced fission

perspectives

- systematic fission cross-sections of systems from Pa to Cm

- mass, charge and energy distributions of fission fragments as a function of E*

isotopic identification (**mass** and **charge**) and **energy** measurement on the **whole fragment production** is done **for the first time**.

m. caamaño[1,2], f. rejmund[1], x. derkx[1], k.-h. schmidt[1],
l. audouin[3], c.-o. bacri[3], g. barreau[4], j. benlliure[2], e. casarejos[2],
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1 ganil, france. 2 u. de santiago de compostela, spain. 3 ipn, france.
4 cenbg, france. 5 u. of liverpool, uk. 6 cea/dam, france. 7 ipnl, france.

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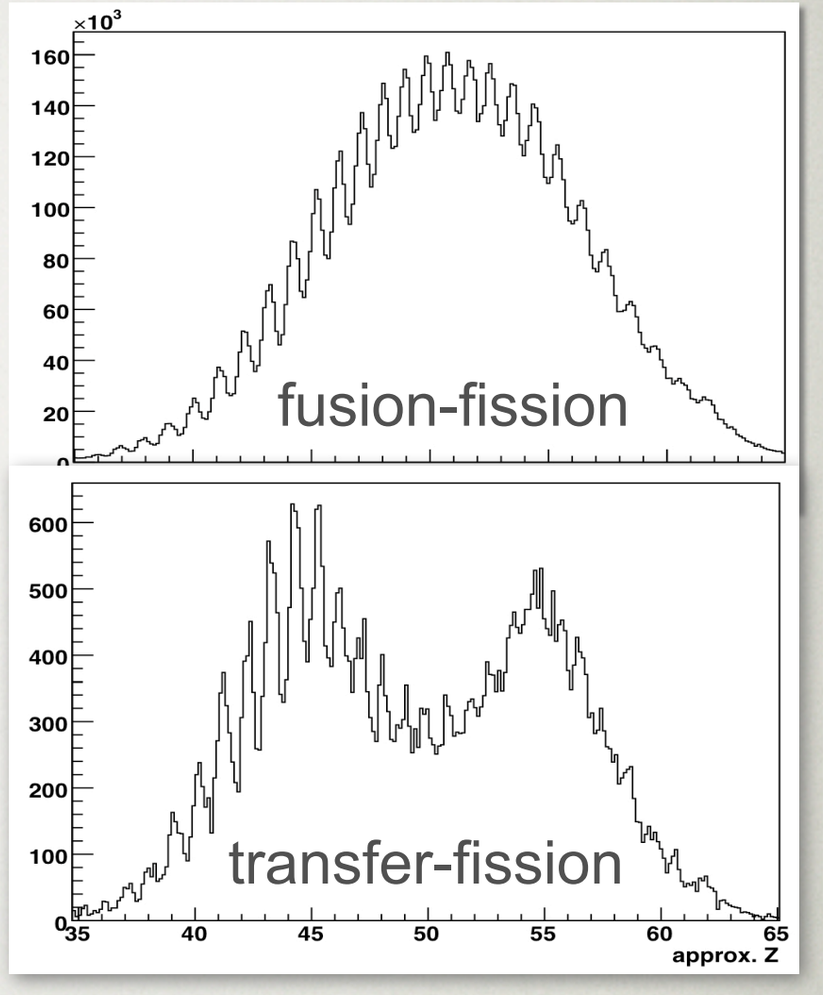

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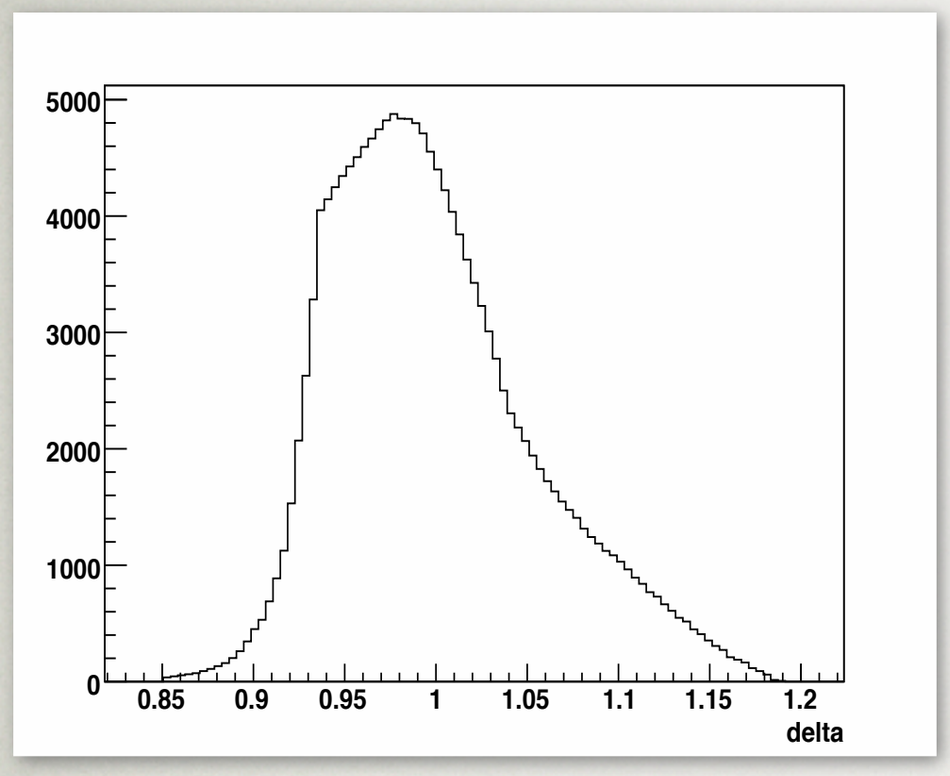
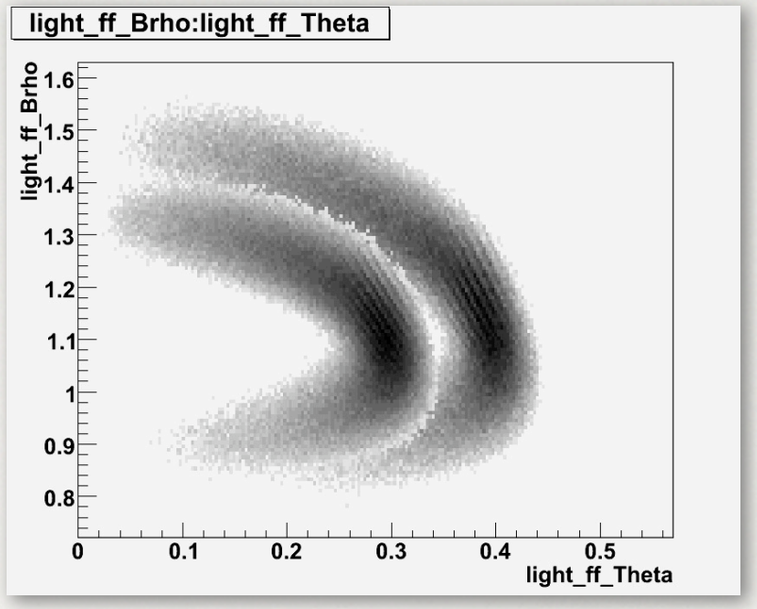
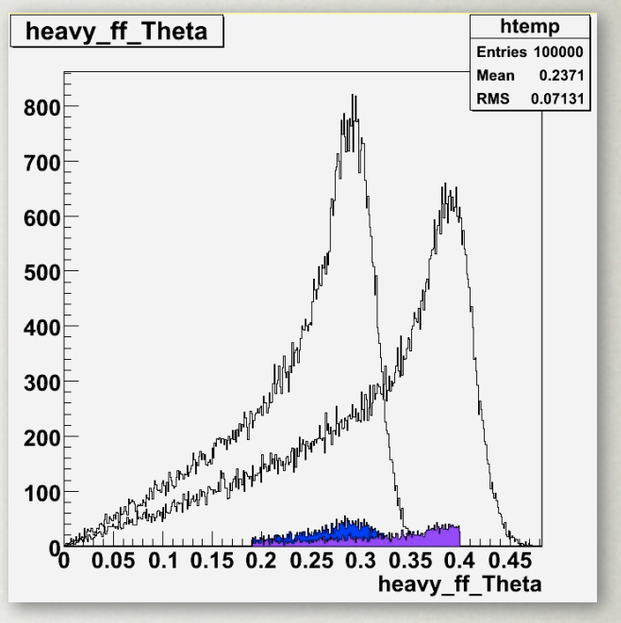
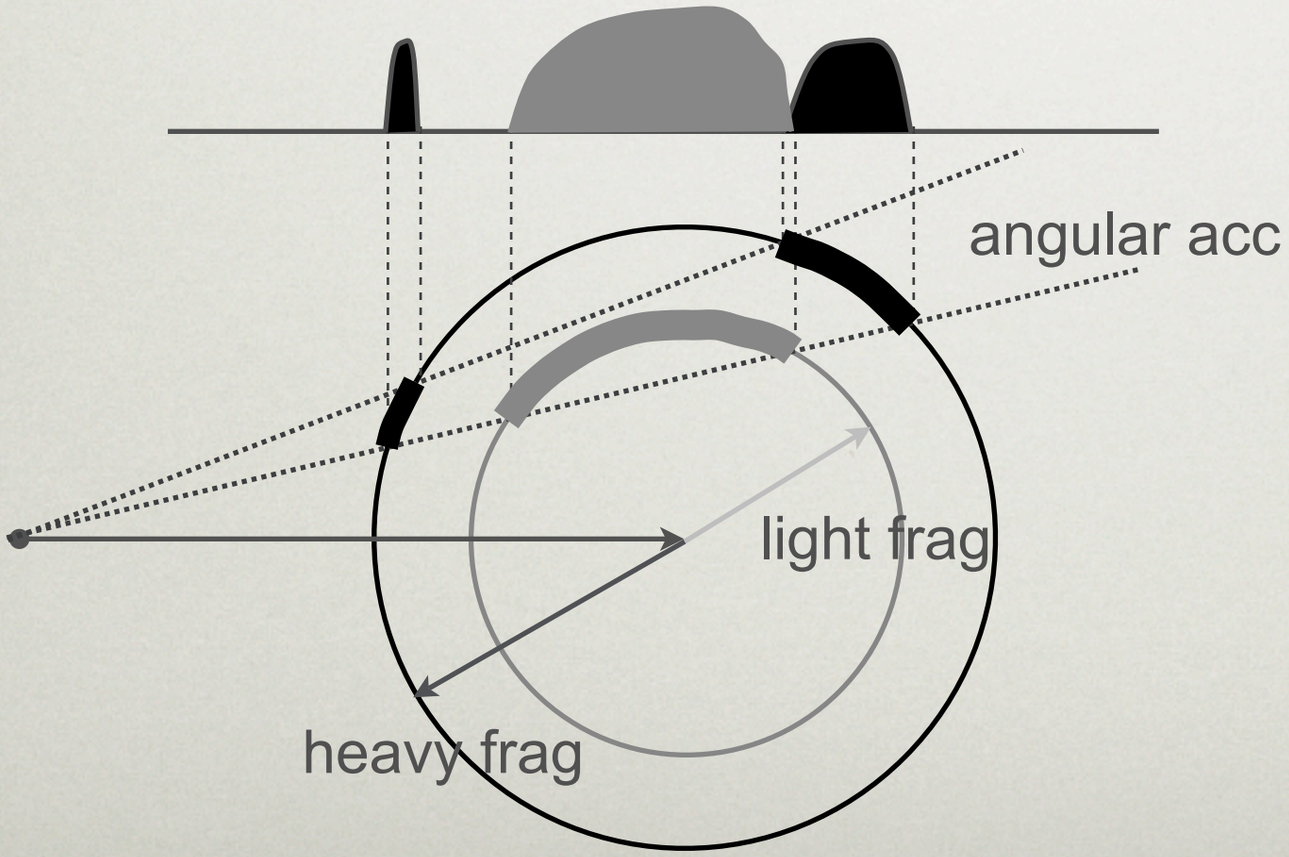
VAMOS acceptance

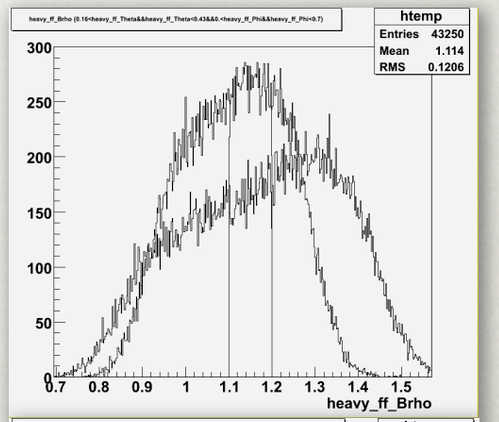


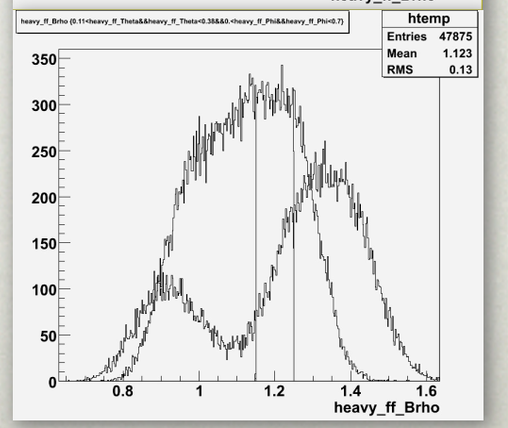




~ 1.5 % of acceptance





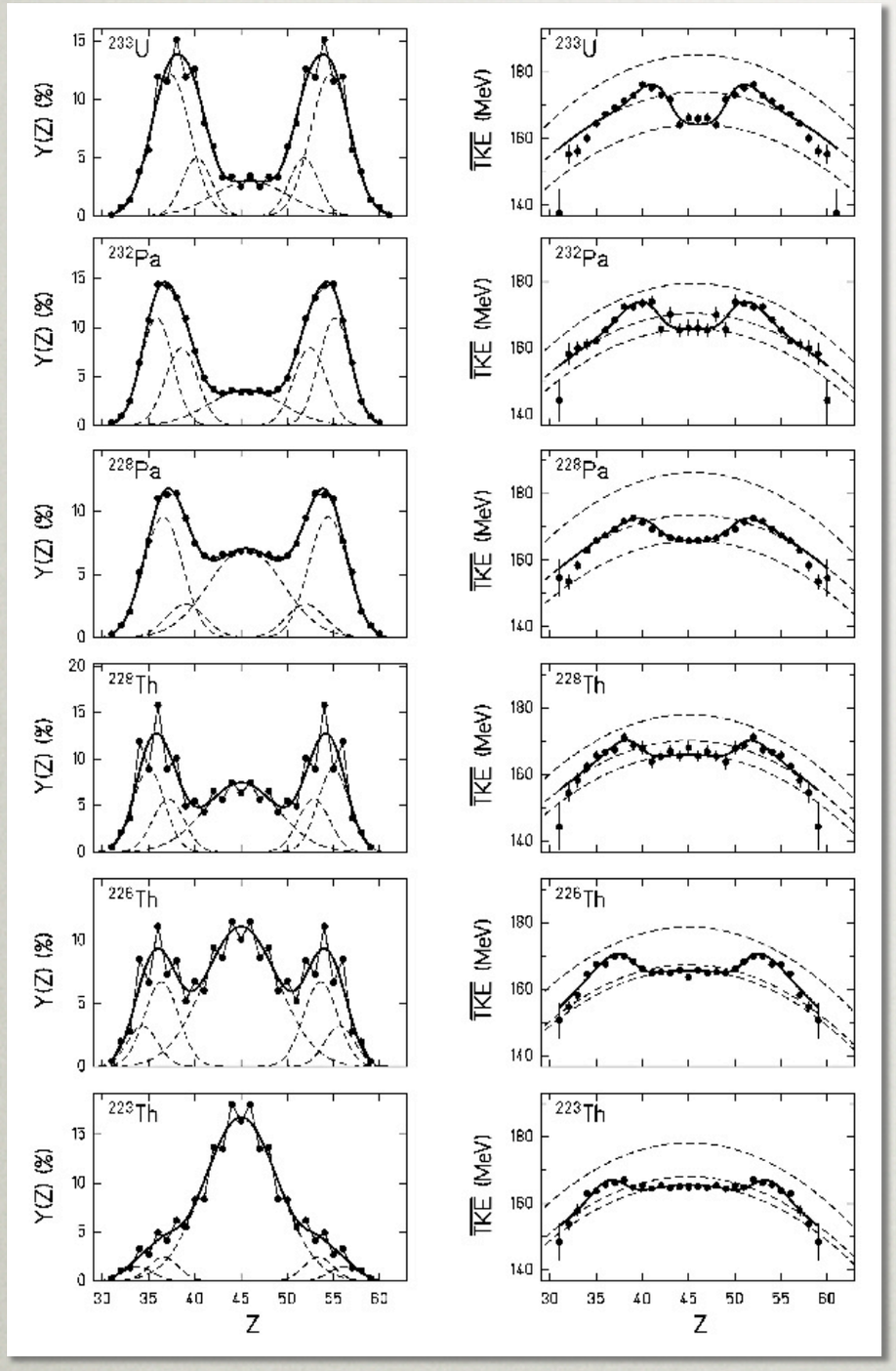


- ***Influence of Nuclear Structure on the Fission Process:***

Standard I : ^{132}Sn *Standard II :* N=86.
Super-Long : symmetry

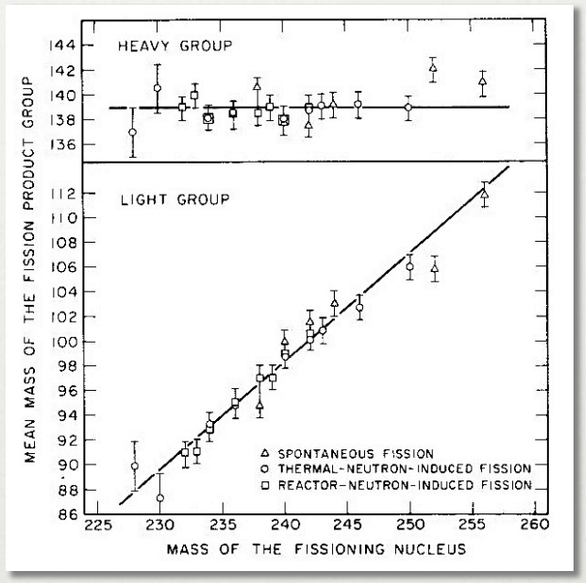
Brosa et al. *PR 197 (1990) 167* Wilkins et al. *PRC 14 (1976) 1832*

Z distribution TKE *distribution*



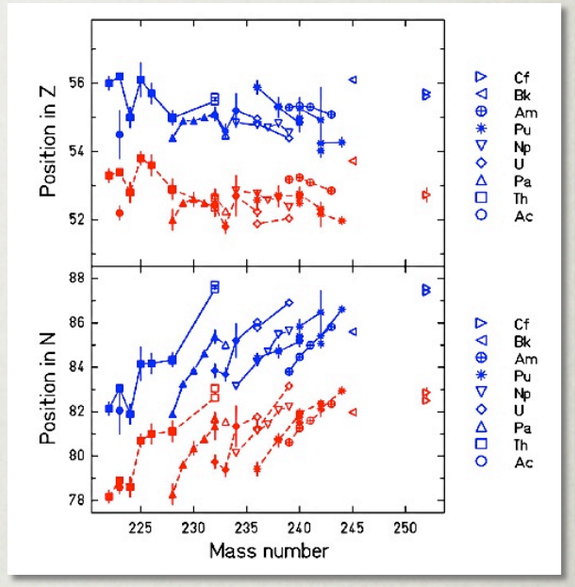
C. Böckstiegel et al. *NPA 802 (2008) 12*

A *distribution*



K.F. Flynn et al. *PRC 5 (1972) 1725*

Z, N *distributions*



C. Böckstiegel et al. *NPA 802 (2008) 12*

Standard I,II : A ~ 139

Standard I : Z ~ 52.5
Standard II : Z ~ 55

Need of systematic Z, A, TKE measurements of different systems