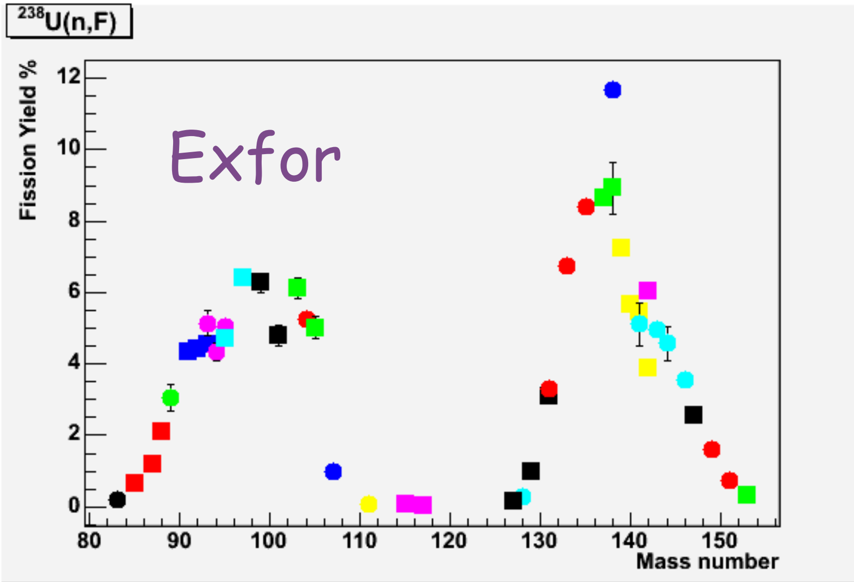
FUSTIPEN Topical Meeting
« Fission-fragments in low-energy fission: a gauge for macroscopic and microscopic influences »

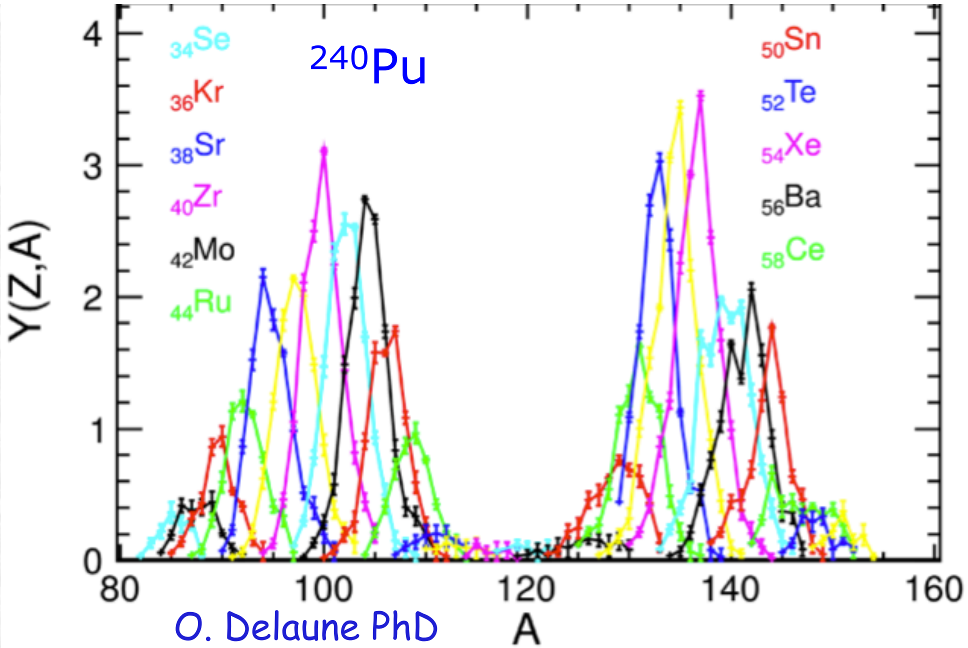
From fission yields to scission properties

Fanny Farget,
GANIL
October 22nd, 2015

The strength of inverse kinematics for fission

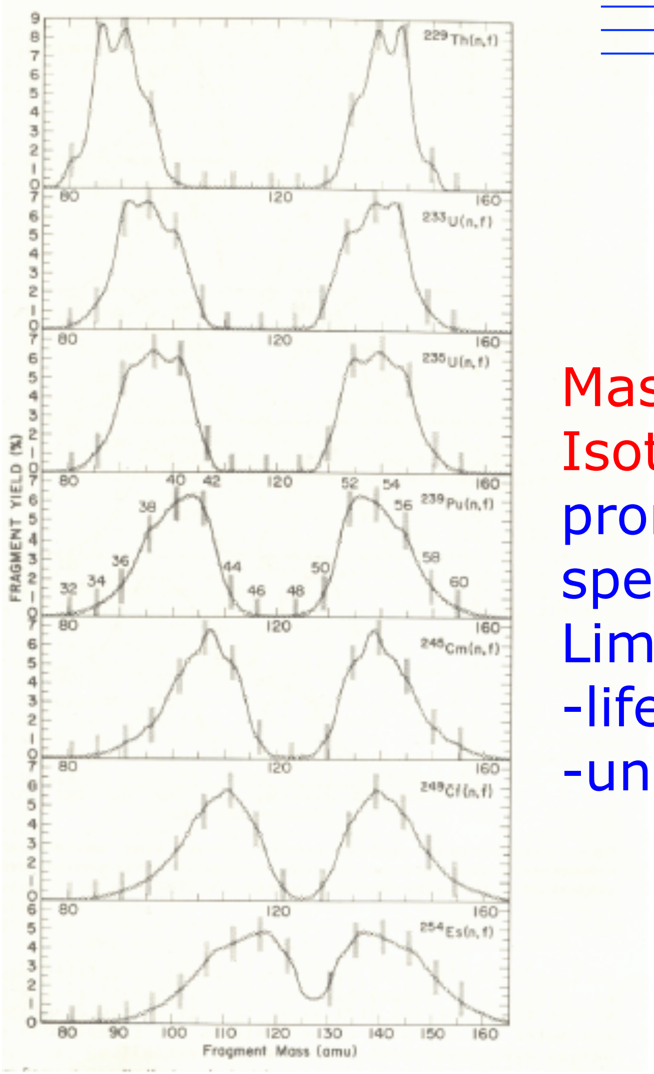
Isotopic fission yields

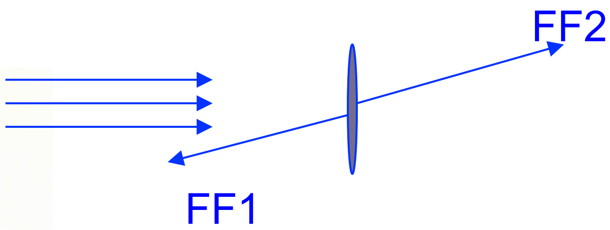




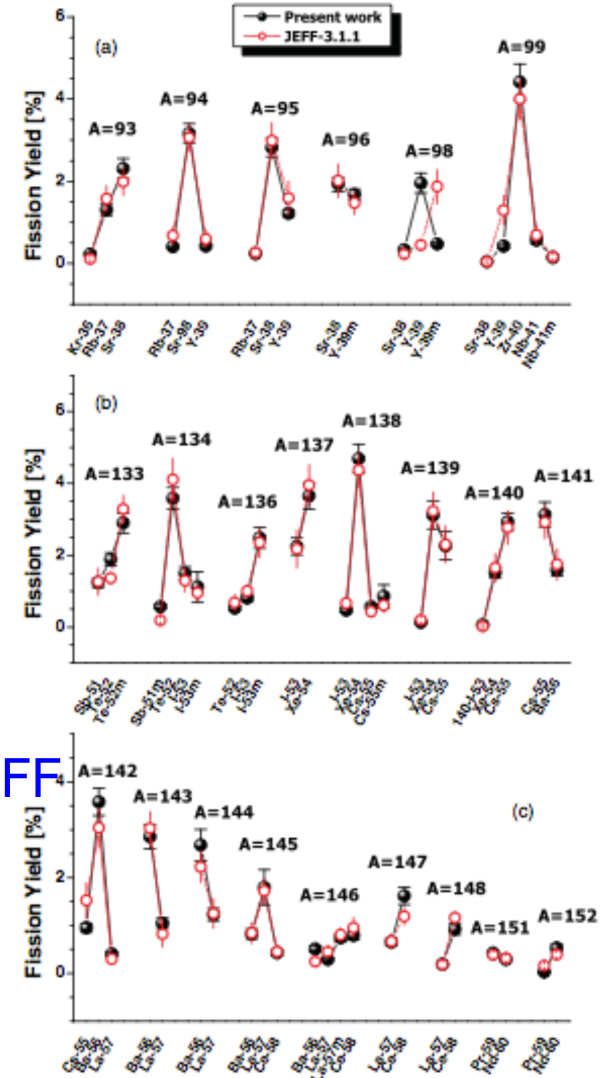
Fission yields in direct kinematics

J.P. Unik, IAEA –SM-174/209





A. Bail PRC 84(2011)



Mass distribution: OK

Isotopic distribution:

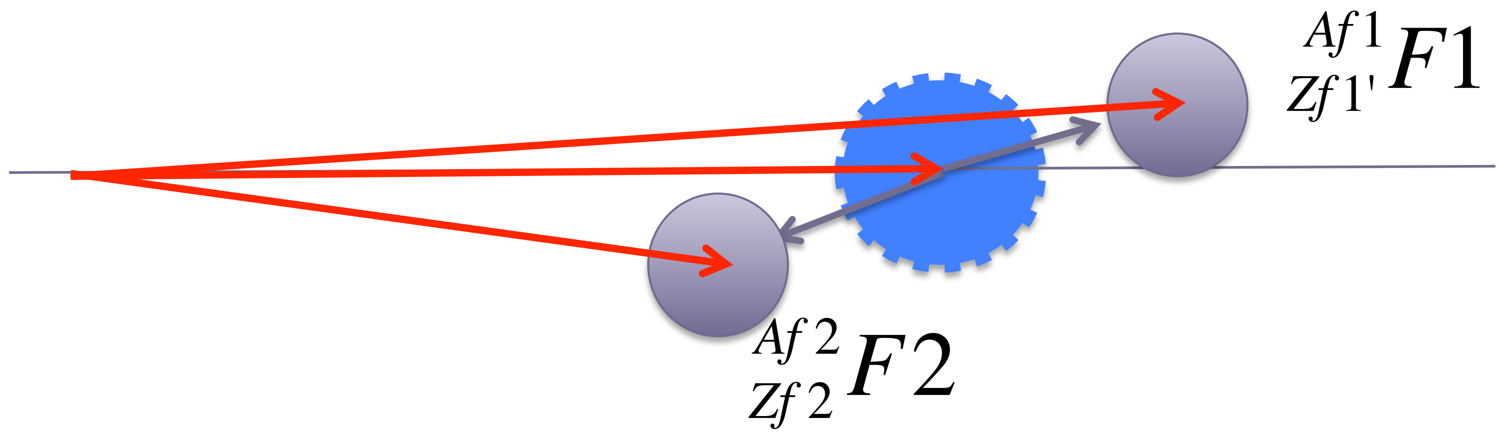
prompt or β-delayed spectroscopy

Limited by the

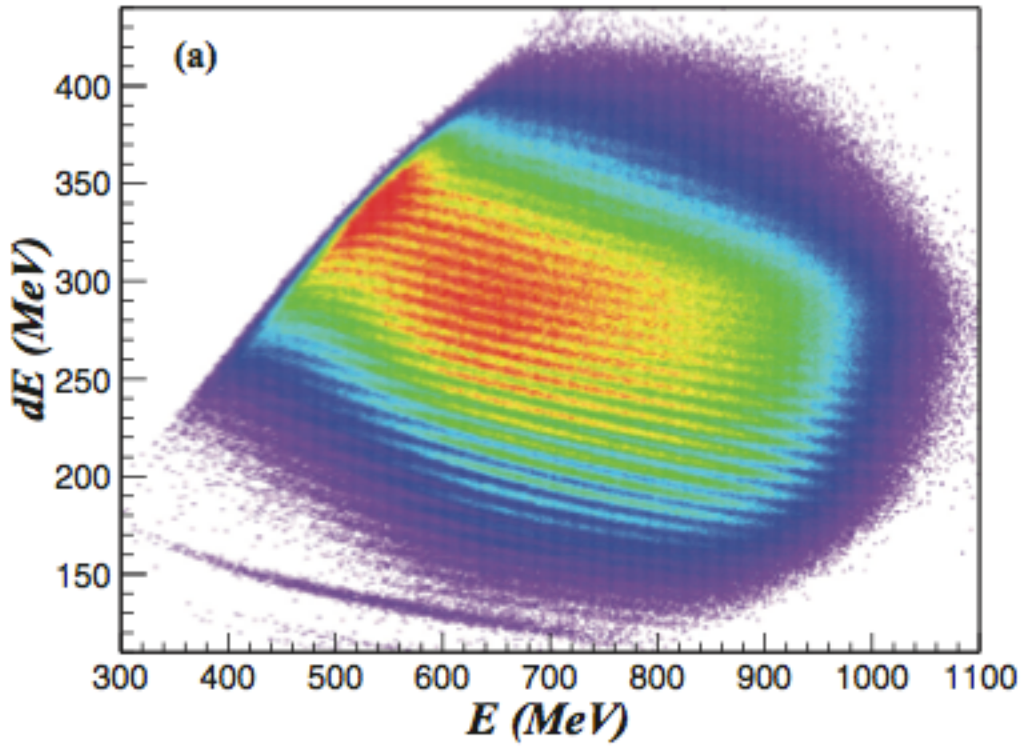
-lifetime of the FF

-unknown level scheme of FF

Fission in inverse kinematics: kinematical boost for a direct identification of the fission fragments

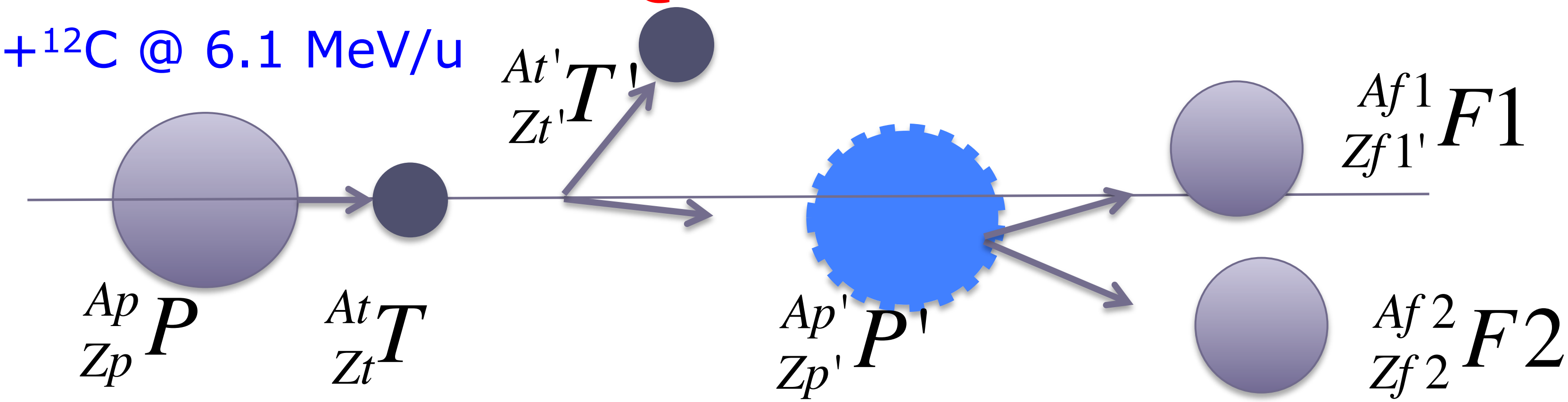


We will see in the following slides (and presentations)
That inverse kinematics brings more than isotopic distribution



Transfer-induced fission in inverse kinematics @ GANIL

$^{238}U + ^{12}C$ @ 6.1 MeV/u



242 Cf	243 Cf	244 Cf	245 Cf	246 Cf	247 Cf	248 Cf	249 Cf	250 Cf	251 Cf	252 Cf
241 Bk	242 Bk	243 Bk	244 Bk	245 Bk	246 Bk	247 Bk	248 Bk	249 Bk	250 Bk	251 Bk
240 Cm	241 Cm	242 Cm	243 Cm	244 Cm	245 Cm	246 Cm	247 Cm	248 Cm	249 Cm	250 Cm
239 Am	240 Am	241 Am	242 Am	243 Am	244 Am	245 Am	246 Am	247 Am	248 Am	249 Am
238 Pu	239 Pu	240 Pu	241 Pu	242 Pu	243 Pu	244 Pu	245 Pu	246 Pu	247 Pu	
237 Np	238 Np	239 Np	240 Np	241 Np	242 Np	243 Np	244 Np			
236 U	237 U	238 U	239 U	240 U	241 U	242 U				

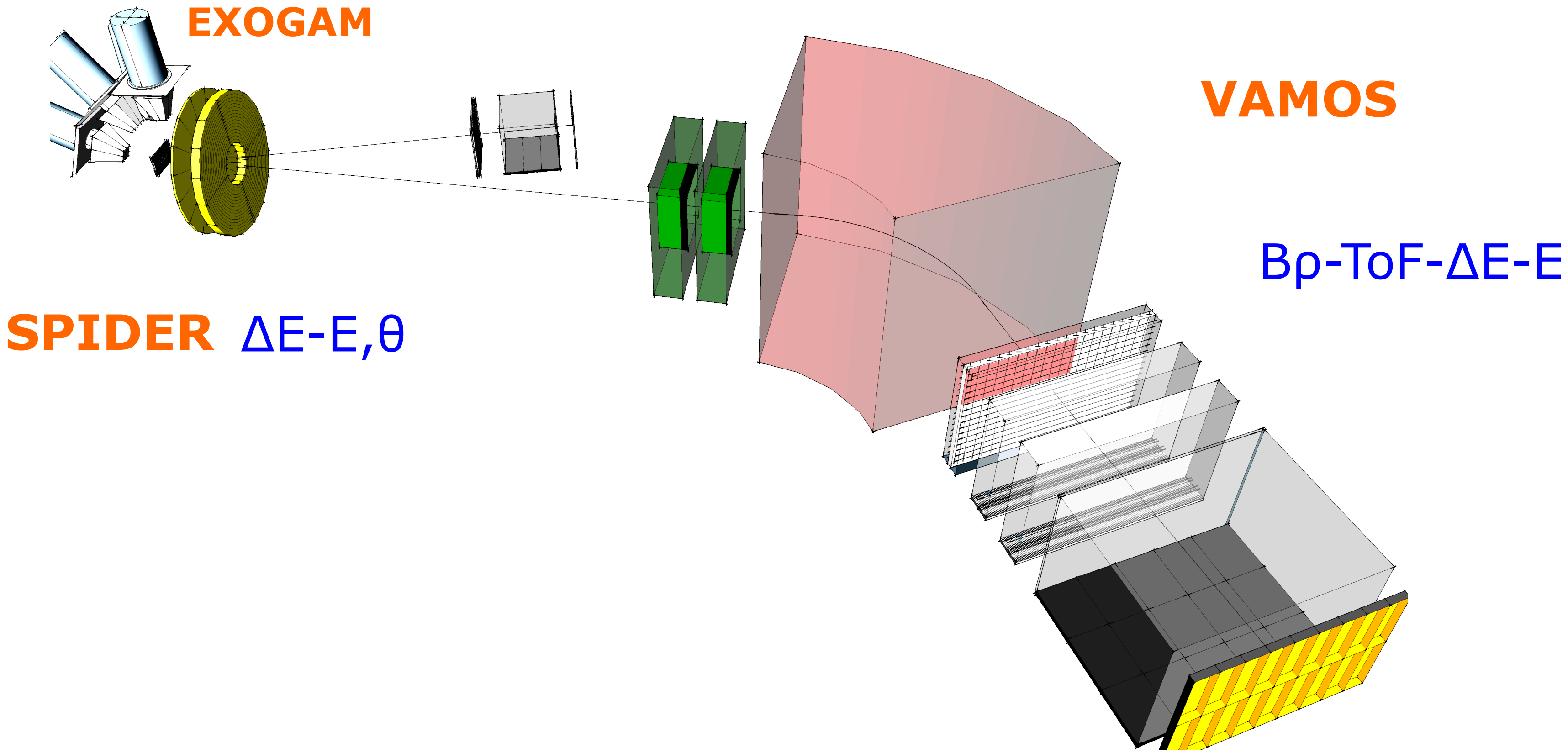
- 10 actinides produced
- E* distribution
- Full resolution in (Z,A) of fragments
- TKE
- Détermination of scission fragments

Can't choose your actinide

Can't choose your E*

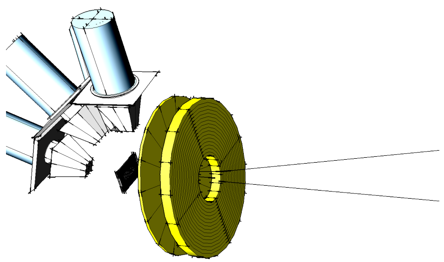
See talk of D. Ramos

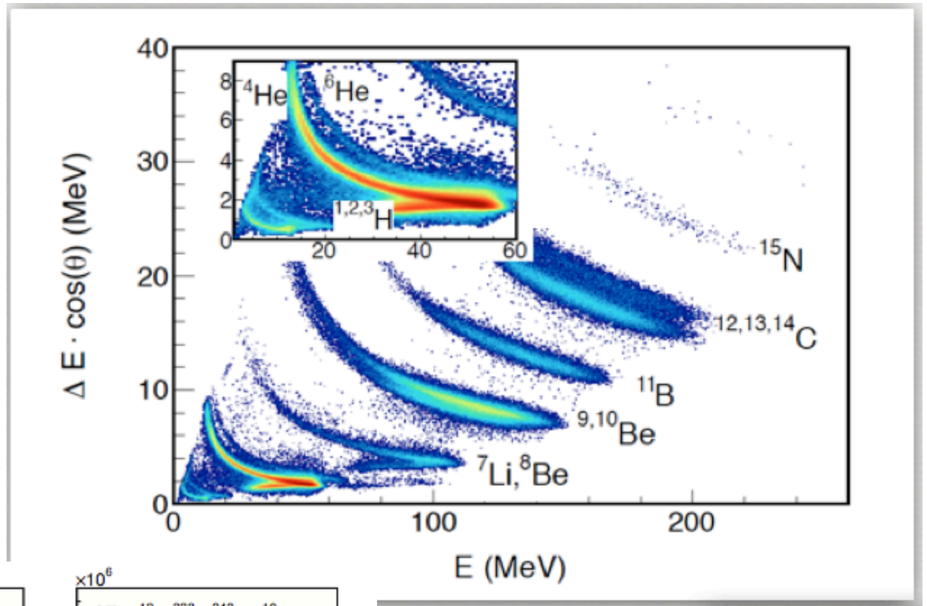
Transfer-induced fission in inverse kinematics



S. Pullanhiotan et al., NIM 593 (2008) 343
M. Rejmund et al., NIMA 646 (2011) 184

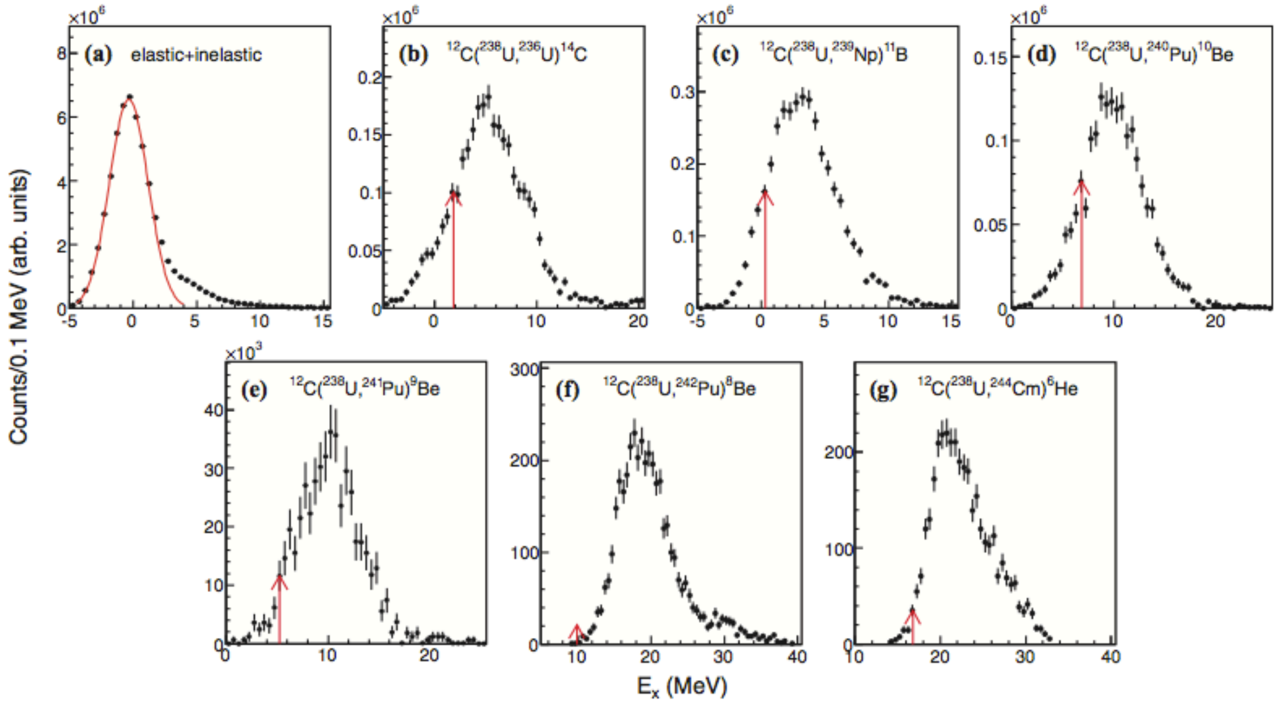
Transfer-induced fission in inverse kinematics



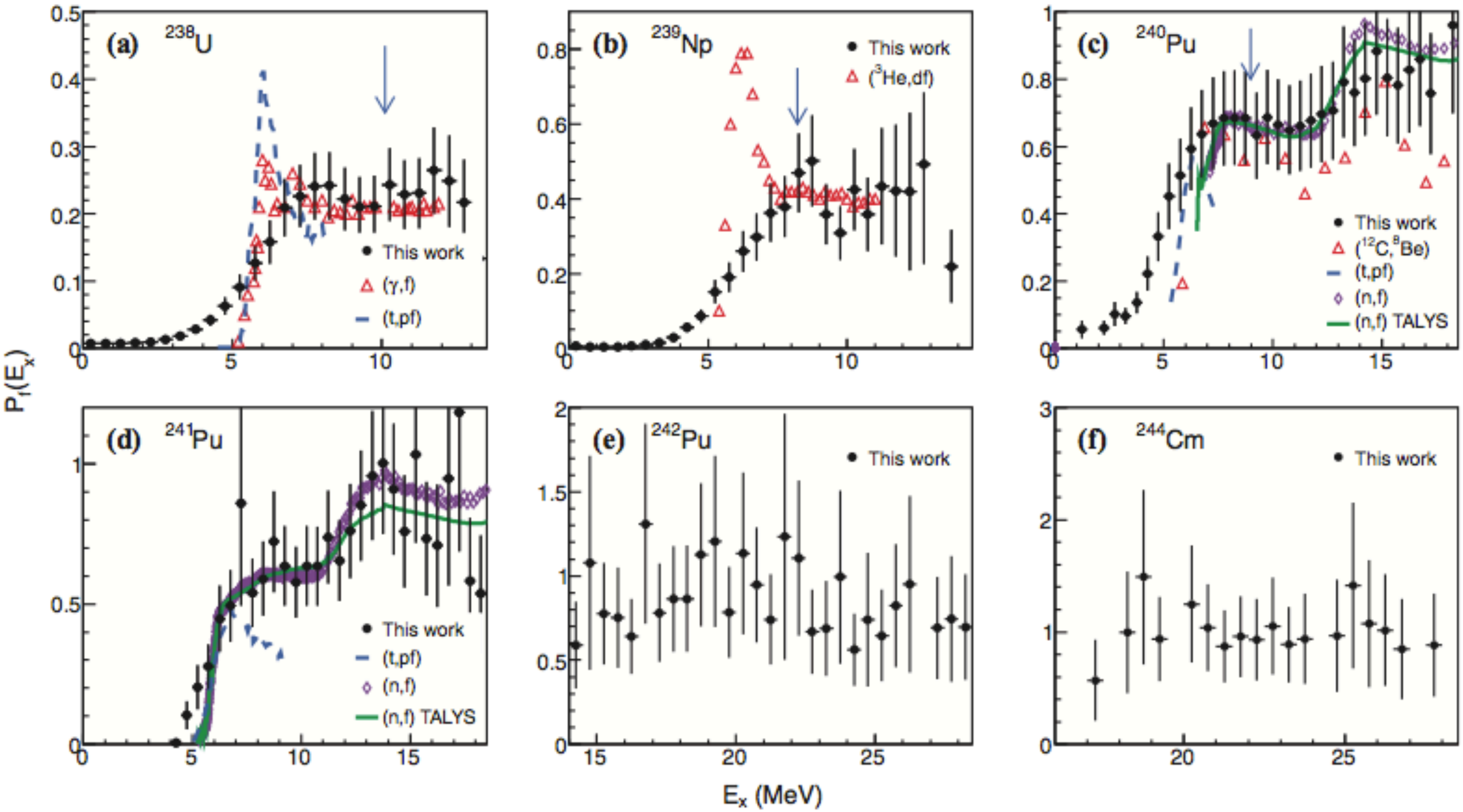


SPIDER ΔE-E,θ

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



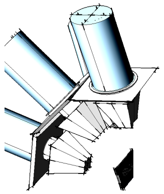
Fission probabilities

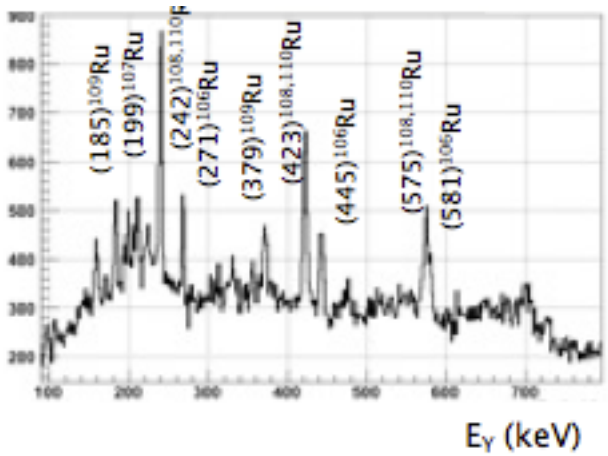


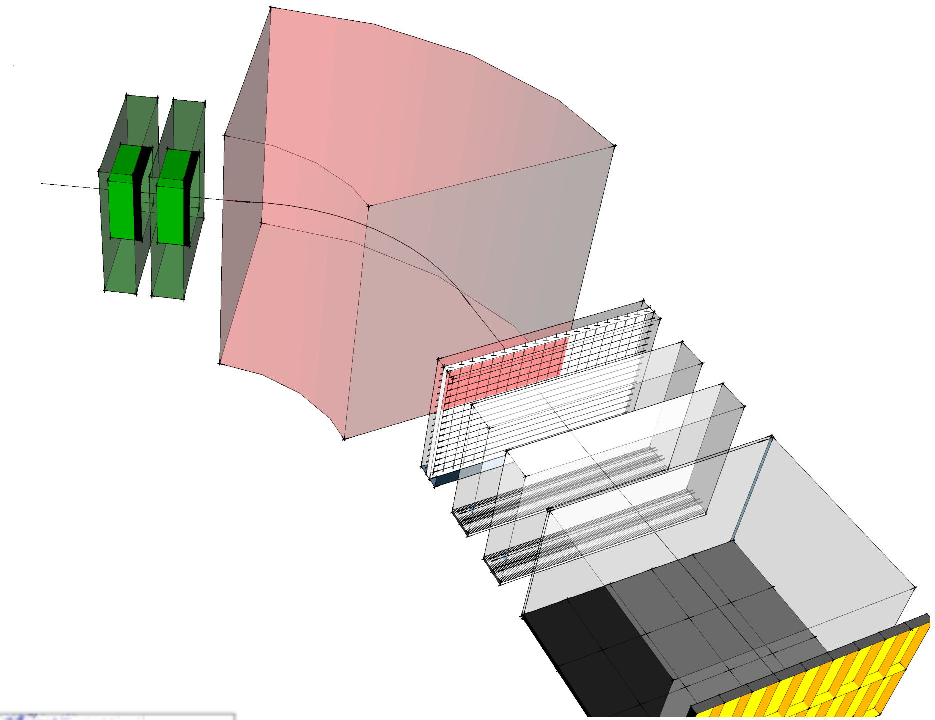
Limitations : excitation energy resolution
angular momentum effects

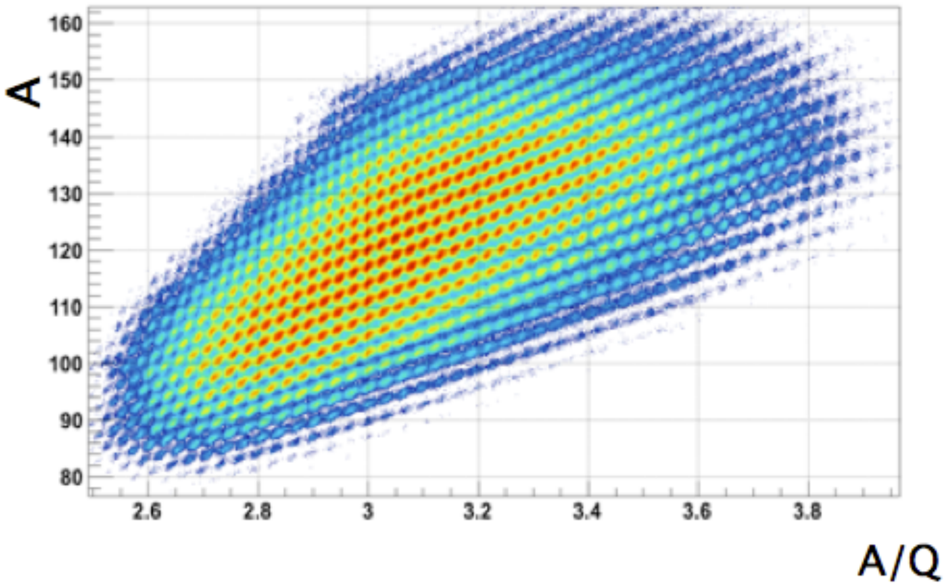
C. Rodriguez-Tajes et al., PRC89 (2014) 024614

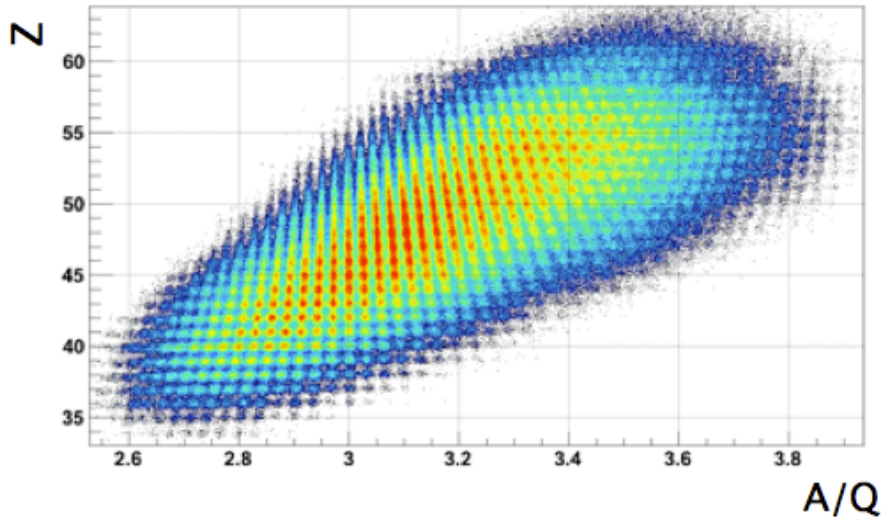
Fission fragment identification







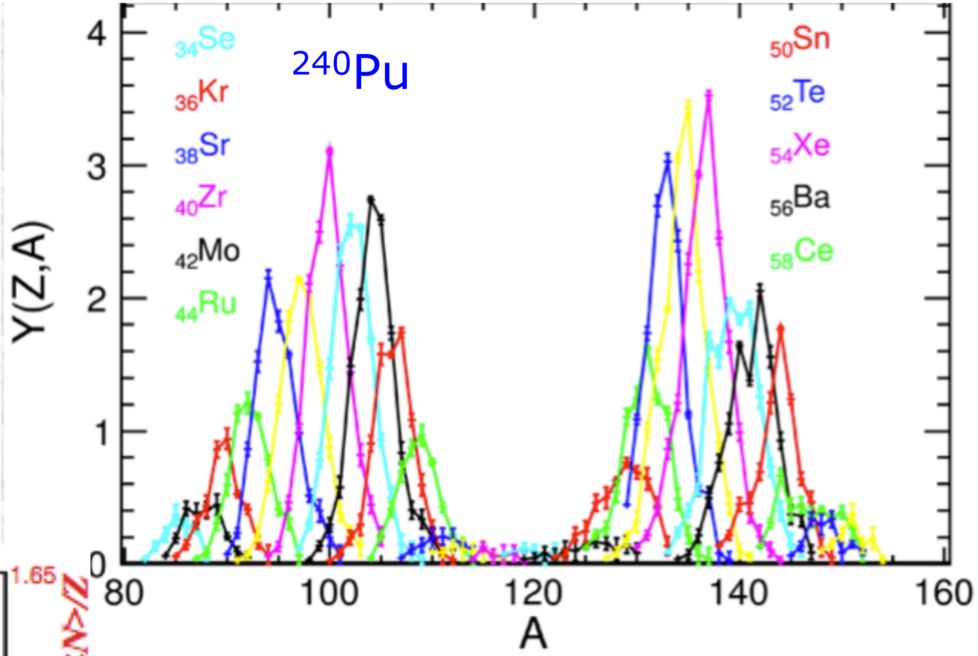


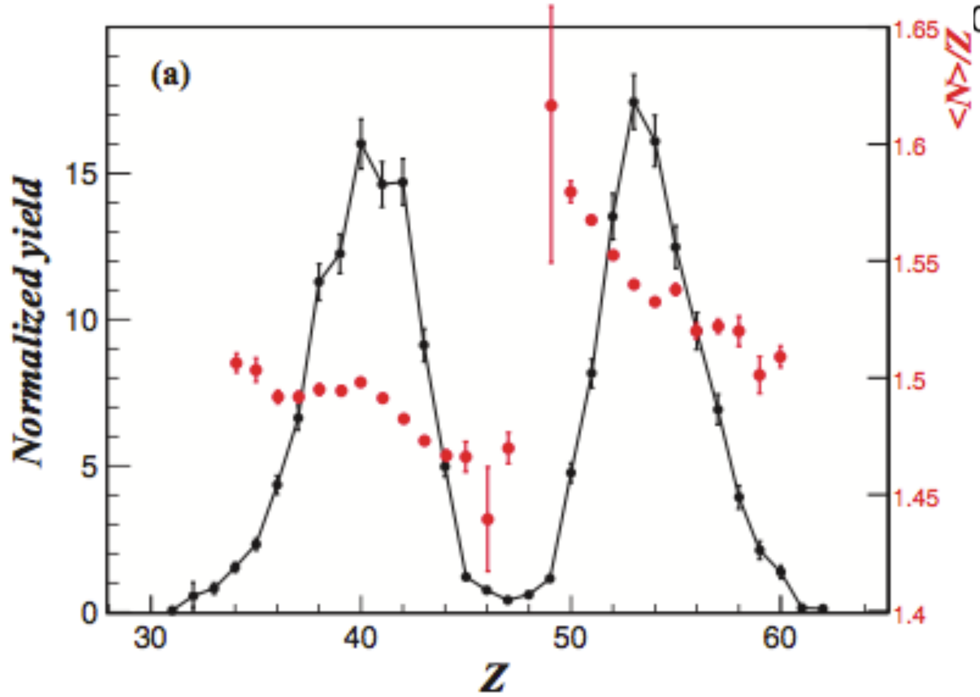


Isotopic distributions of fission fragments induced in 2 proton transfer

$^{238}U(^{12}C,^{10}Be)^{240}Pu$ E*~9 MeV

M. Caamaño et al., PRC 88 (2013) 024605

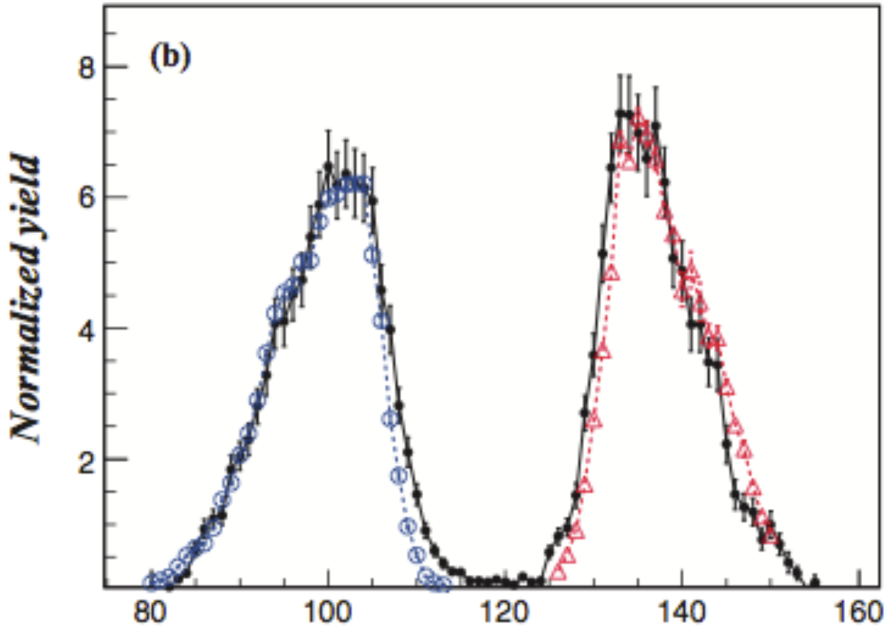




Neutron excess

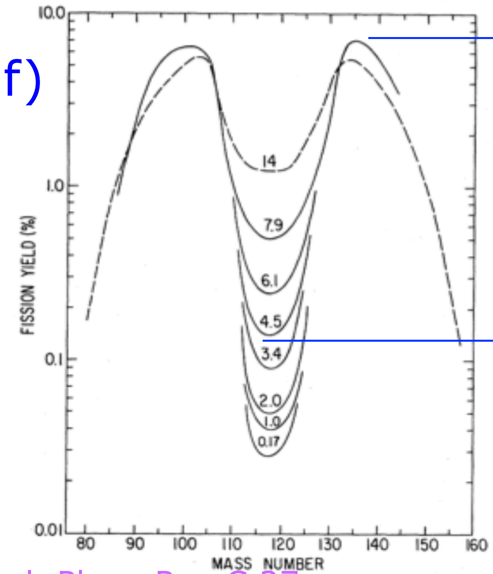
$$\langle N\rangle(Z) = \frac{\sum_A A\, Y(Z,A)}{\sum_A Y(Z,A)} - Z.$$

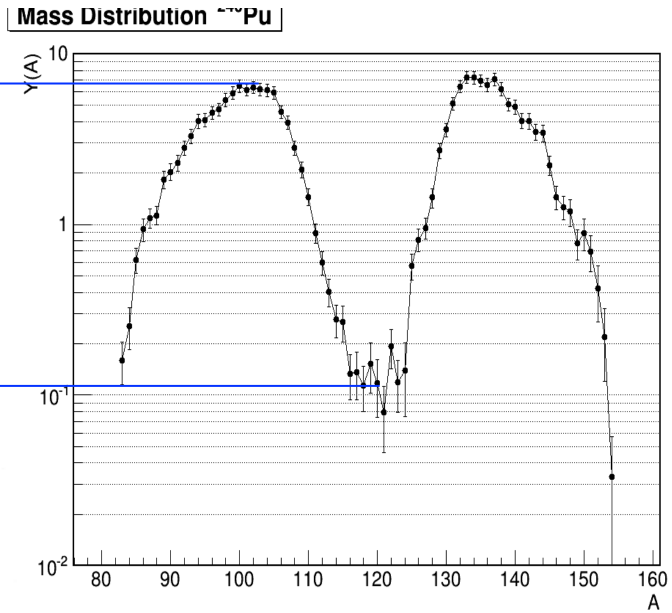
Mass distribution for ^{240}Pu E*~9 MeV



C. Schmitt et al, NPA430 (1984) A. Bail, PRC84 (2011)

^{239}Pu(n,f)



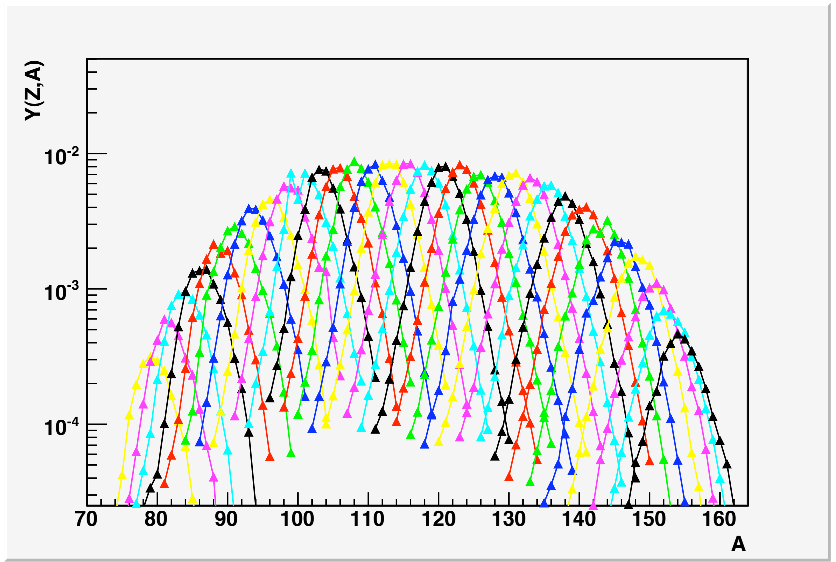


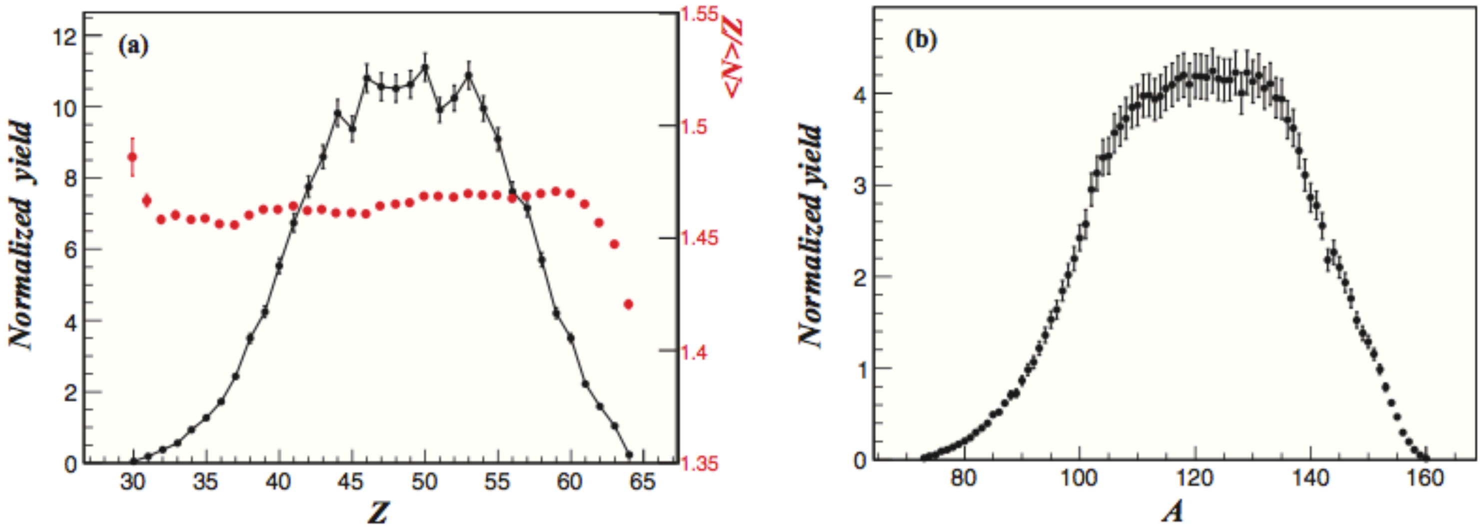
E*~ 9 MeV
Sn = 5.6MeV
En ~ 4 MeV

J.E. Gindler et al. Phys. Rev C 27

Isotopic distributions of fission fragments induced in fusion

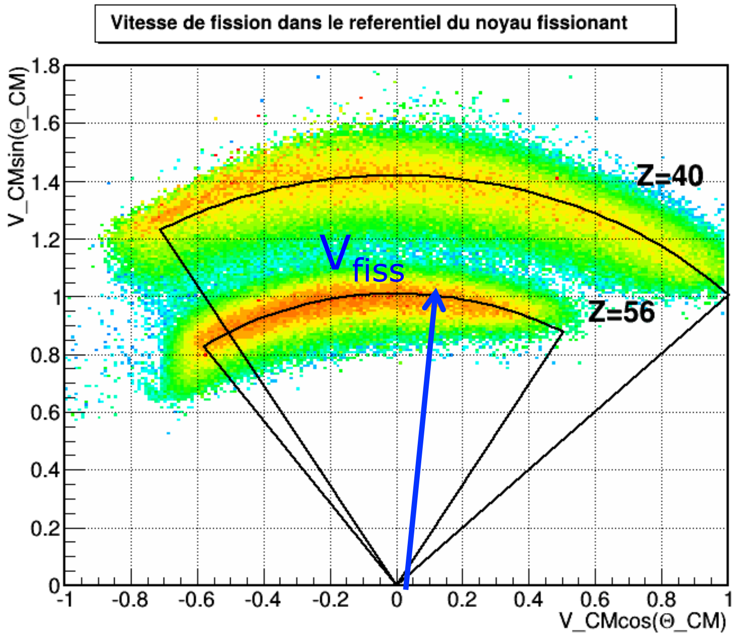
$^{238}U+^{12}C \rightarrow ^{250}Cf$ E*~45 MeV

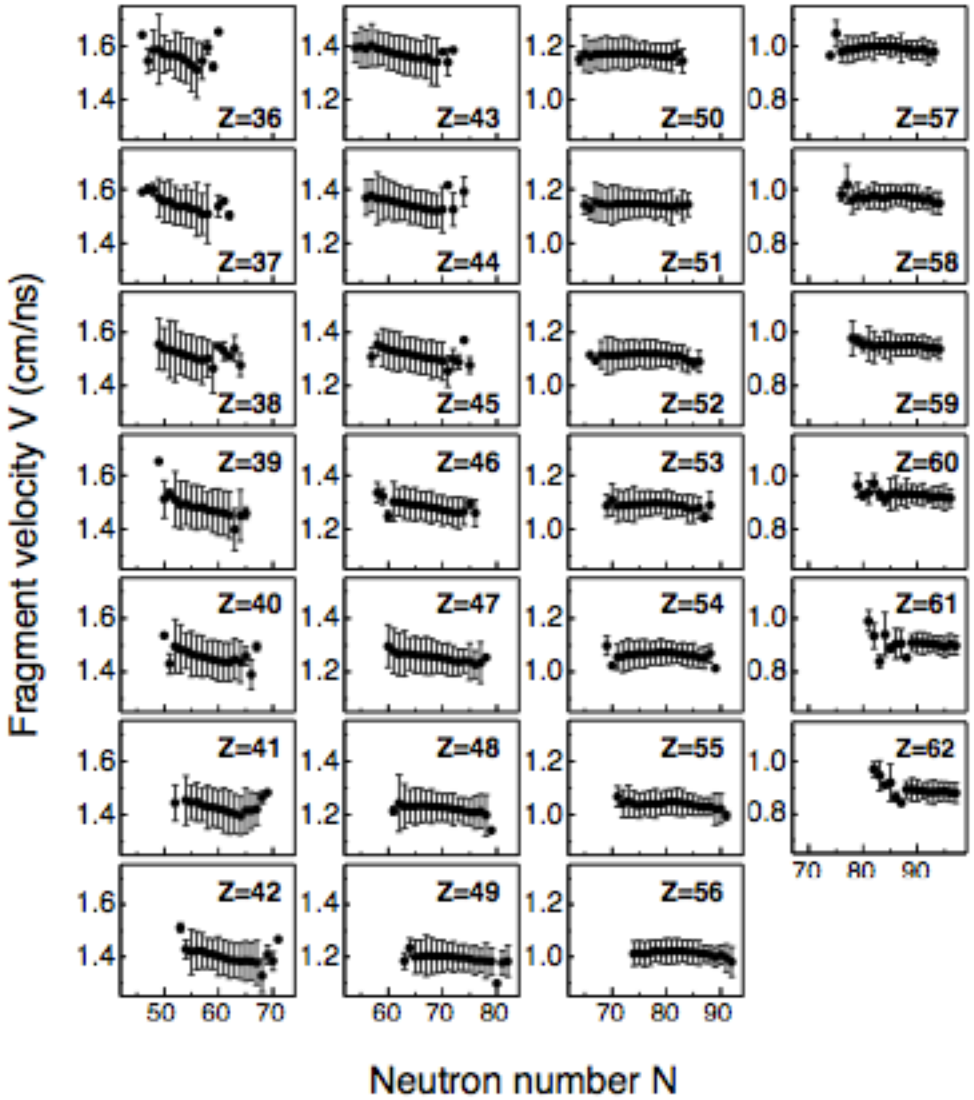




M. Caamaño et al., PRC 88 (2013) 024605

Assets of the experimental set-up:
Reconstruction of kinematical properties

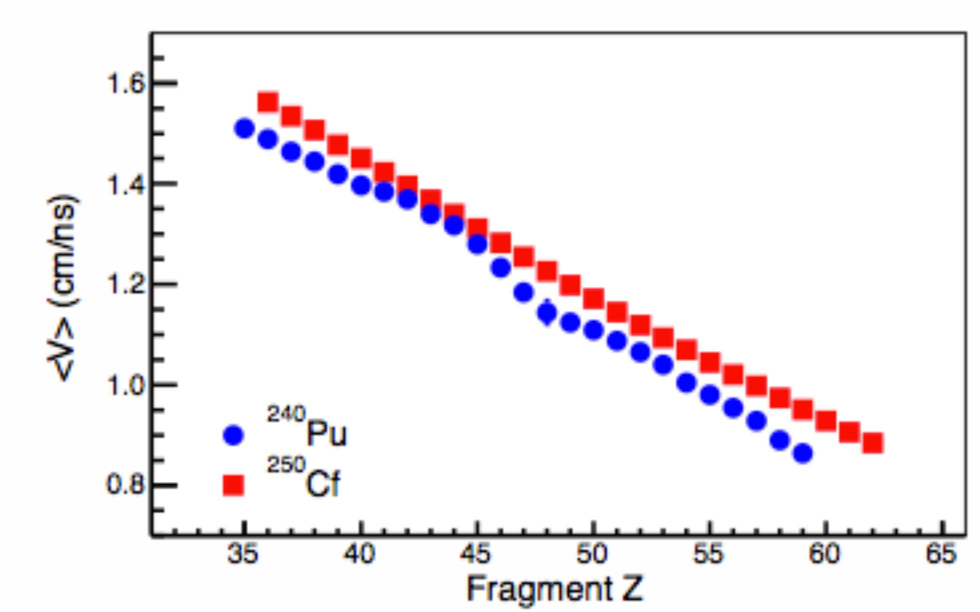




M. Caamaño, F. Farget et al. **PRC 92, 034606 (2015)**

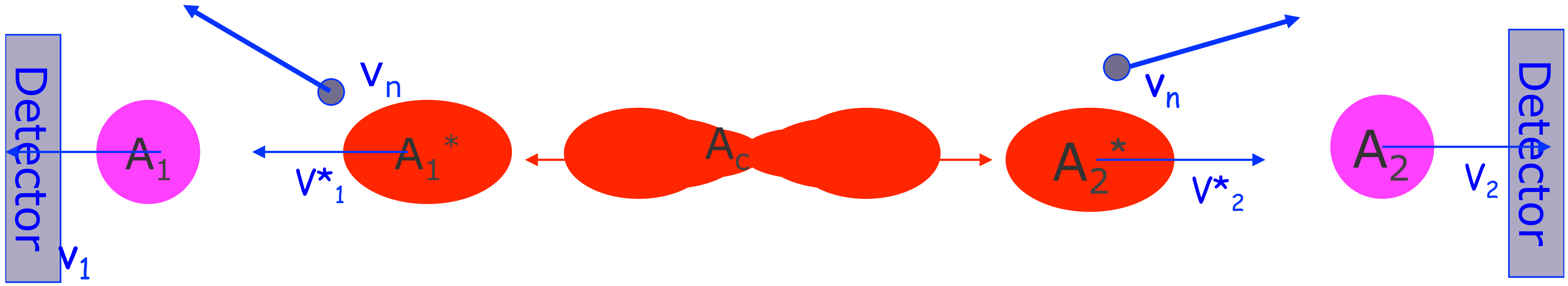
Average velocity of fission fragments

$$< V > (Z) = \frac{\sum_A Y(A,Z)V(Z,A)}{\sum_A Y(A,Z)}$$



M. Caamaño, F. Farget et al**. PRC 92, 034606 (2015)**

Recovering scission masses from fragment velocities



$A^*_1\, v^*_1 = A^*_2\, v^*_2$	Momentum conservation
$A^*_1 + A^*_2 = A_c$	Mass conservation
$\langle v^*_{1,2} \rangle = \langle v_{1,2} \rangle$	Isotropic evaporation
$\langle v_1 \rangle / \langle v_2 \rangle = A^*_2 / A^*_1$	$A^*_1 = A_c\,(v_1/(v_1 + v_2))$
	$A^*_2 = A_c - A^*_1$

$$A^*_1 = A_c\,(v_1/(v_1 + v_2))$$
$$A^*_2 = A_c - A^*_1$$

Reconstruction of the scission fragment masses A*

$$\frac{V_1}{V_2} = \frac{A_2^*}{A_1^*}$$

Momentum conservation

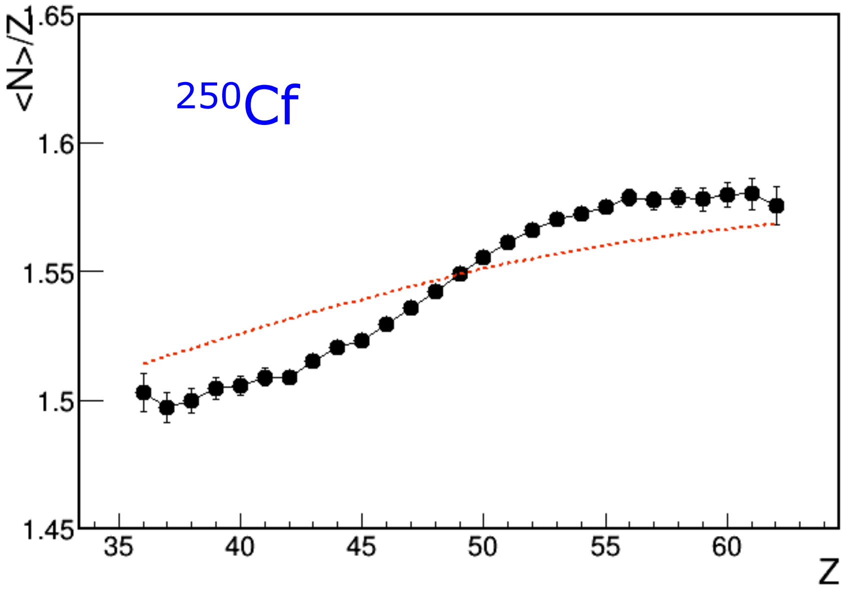
$$< A^* >_1 = A_{FS} \frac{< V_2 >}{< V_1 >}$$

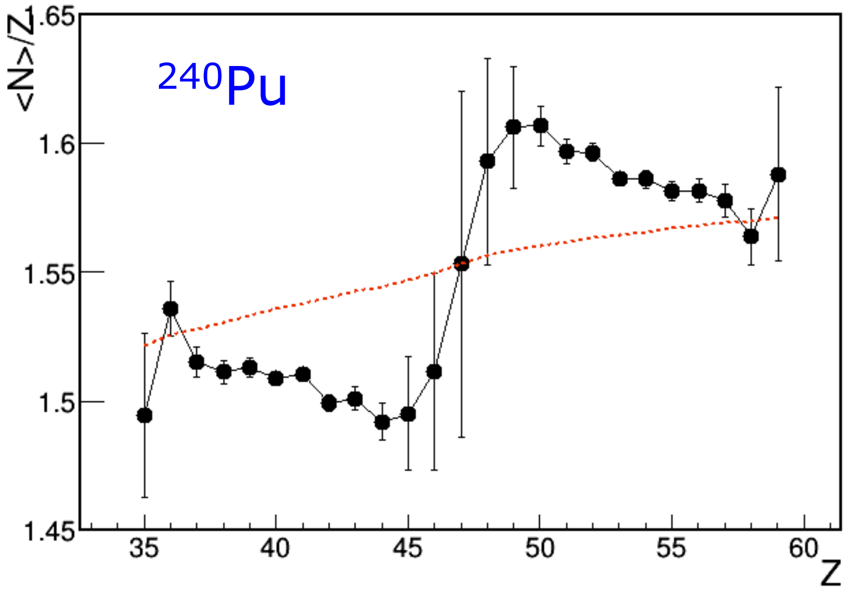
$$< A^* >_2 = A_{FS} - < A^* >_1$$

$$Z_2 = Z_{FS} - Z_1$$

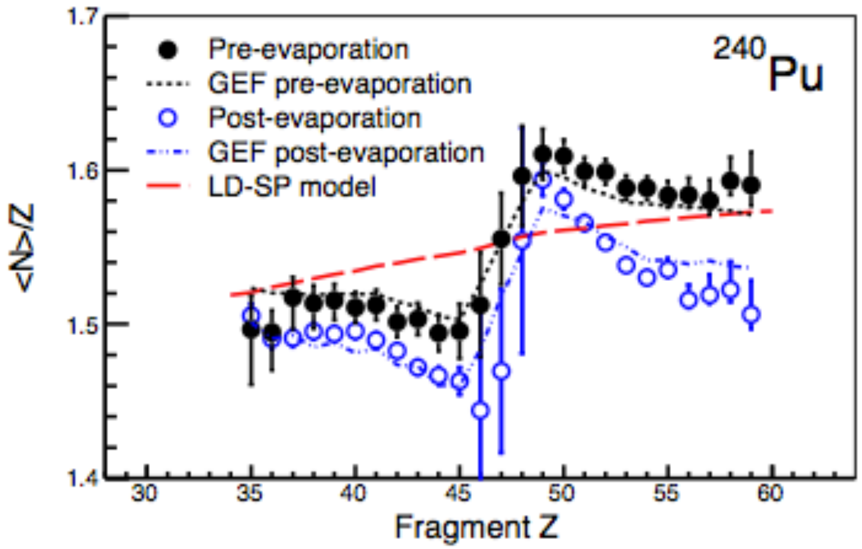
Charge conservation

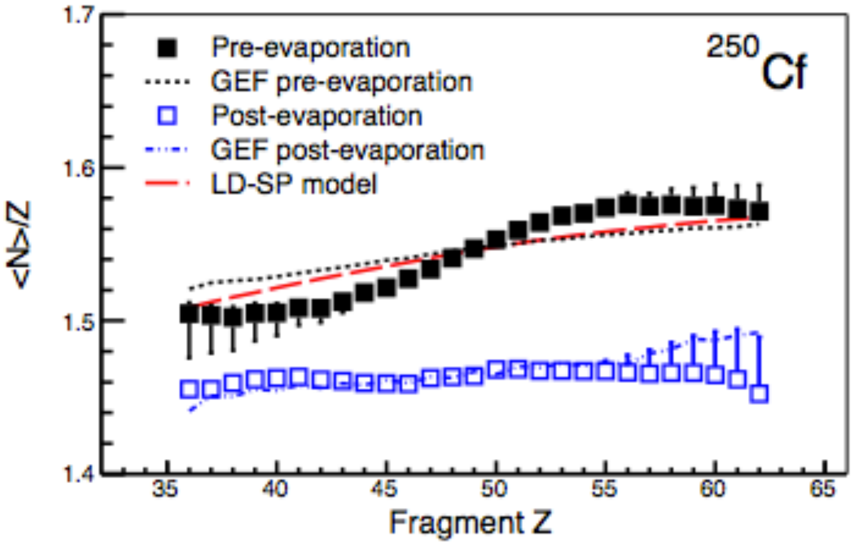
Neutron excess of the fragments at scission



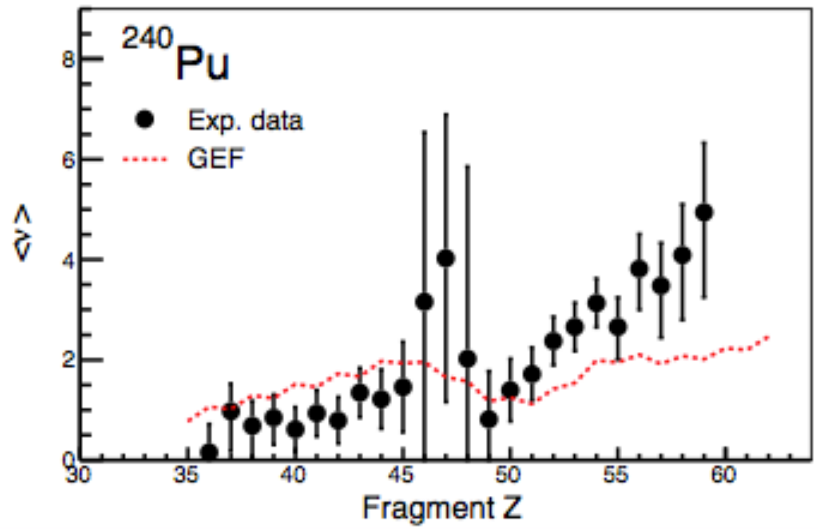


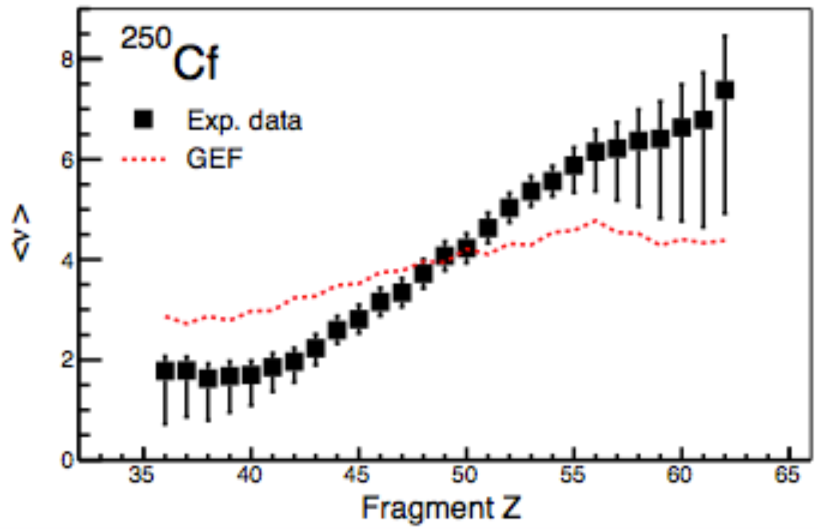
Average neutron excess @ scission





Average neutron multiplicities @ scission



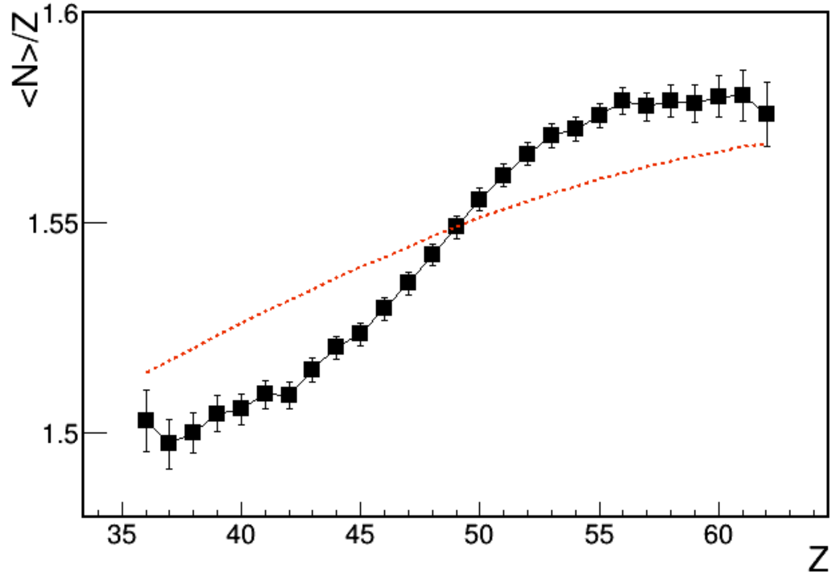


Scission point model:
minimization of the total potential energy

$$V(N_1, Z_1, \beta_1, N_2, Z_2, \beta_2, \tau, d) = V_{LD_1}(N_1, Z_1, \beta_1) + V_{LD_2}(N_2, Z_2, \beta_2)$$
$$+ S_1(N_1, \beta_1, \tau) + S_1(Z_1, \beta_1, \tau) + S_2(N_2, \beta_2, \tau) + S_2(Z_2, \beta_2, \tau)$$
$$+ P_1(N_1, \beta_1, \tau) + P_1(Z_1, \beta_1, \tau) + P_2(N_2, \beta_2, \tau) + P_2(Z_2, \beta_2, \tau)$$
$$+ V_C(N_1, Z_1, \beta_1, N_2, Z_2, \beta_2, d) + V_n(N_1, Z_1, \beta_1, N_2, Z_2, \beta_2, d),$$

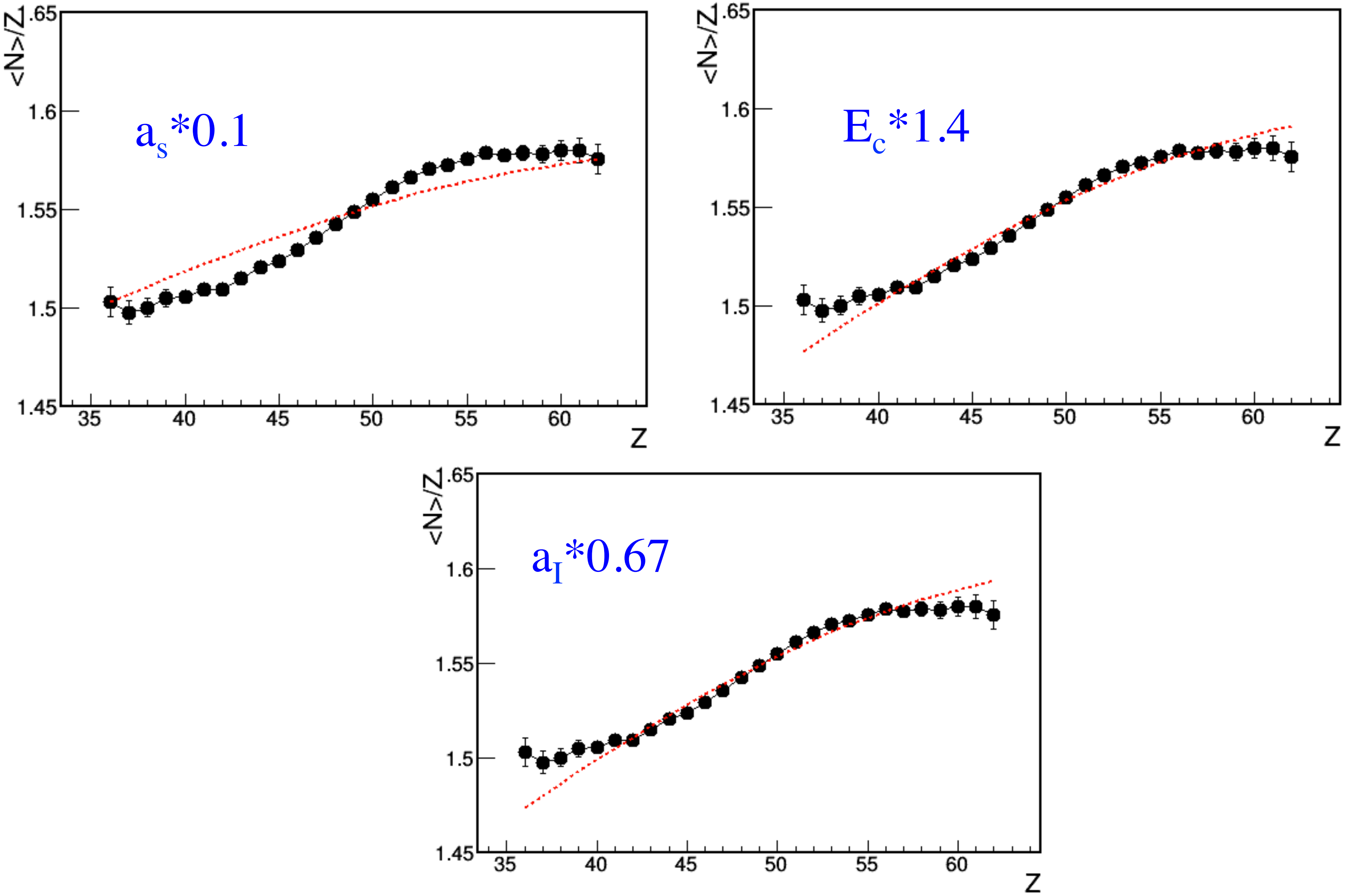
^{250}Cf E*=45 MeV :
only liquid-drop terms play a role (shell effects disapeared)

$$V_{LD}(Z, N, \beta) = a_a A - a_s A^{2/3}(1 + 0.4\,\alpha^2)$$
$$- 1.78\, I^2(a_a A - a_s A^{2/3}(1 + 0.4\,\alpha^2))$$
$$+ Z^2((0.705/A^{1/3})(1 - 0.2\,\alpha^2) - 1.15/A)$$

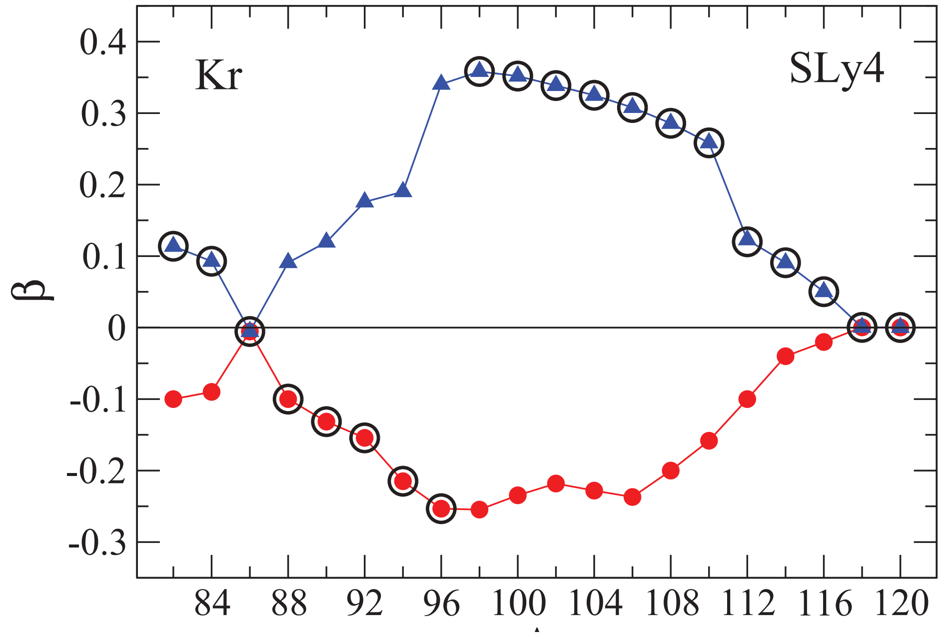


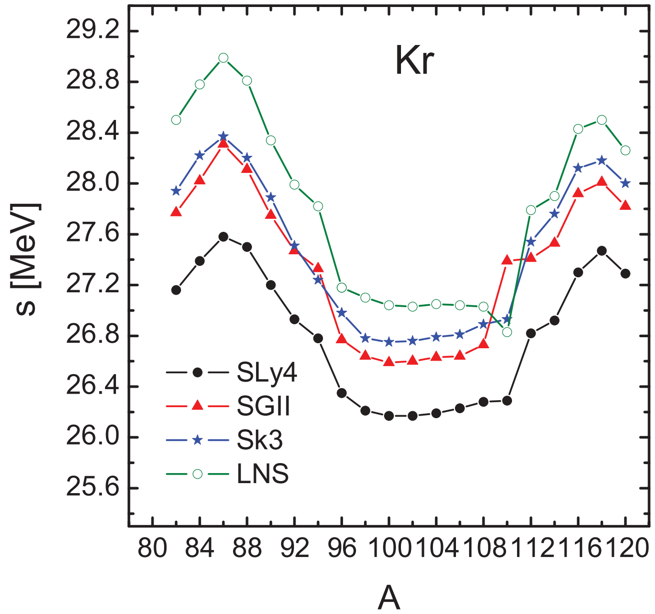
W.D. Myers, and W.J. Swiatecki, Ark. Fys., 36, 343, (1967)

Scission point model: influence of different mass terms



Diminution of symmetry energy with deformation ?





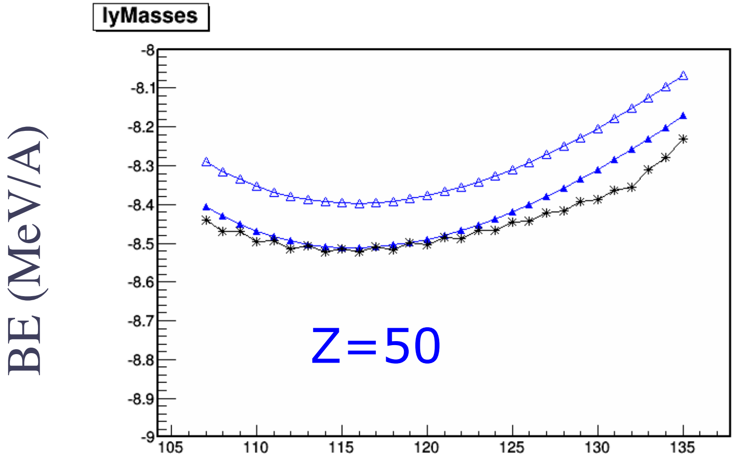
Gaidarov et al., PRC 85 (2012) 064319

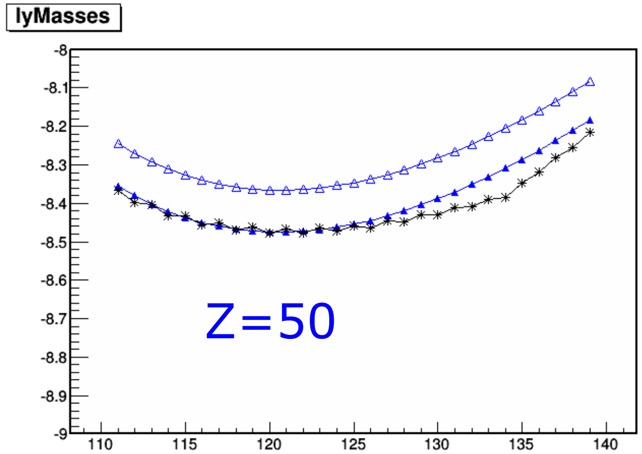
A diminution of 10% is predicted when deformation increases
From 0 to 0.4

⇒ What happens at scission deformation ??

⇒ Effect of density ??

Other explanation: Remaining of shell effects in BE

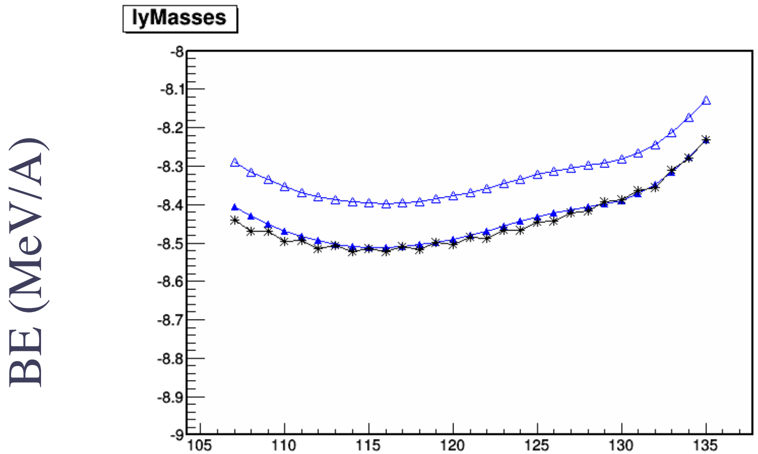


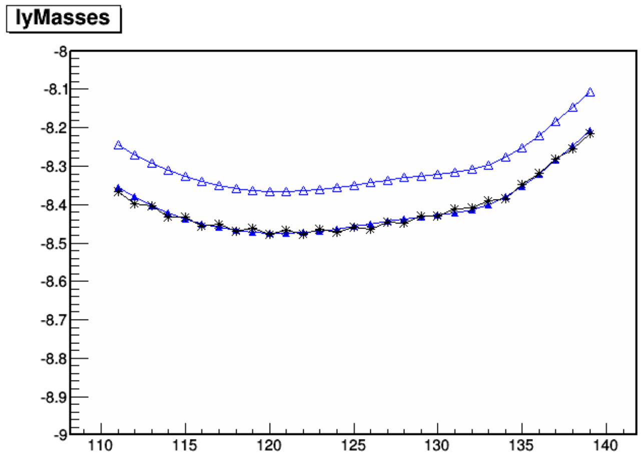


$$BE = BE + SE + SE_{def}$$

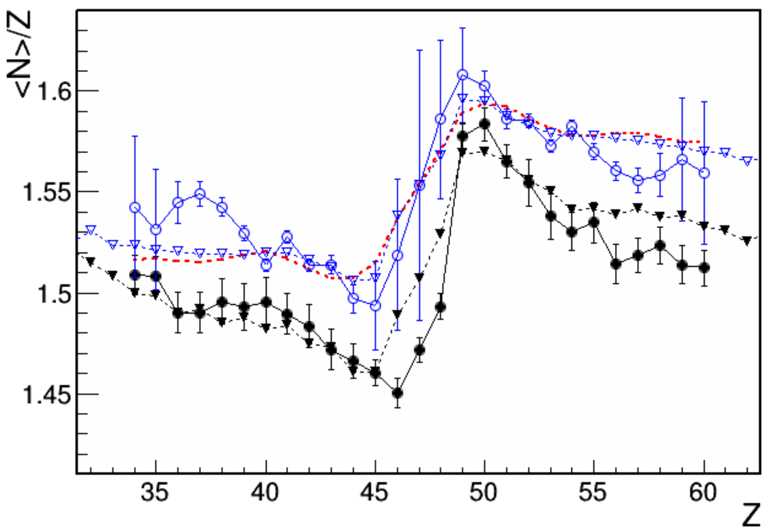
$$SE = 3*\exp(-(Z-50)^2/(2*3^2))*4*\exp(-(N-82)^2/(2*3.5^2))$$

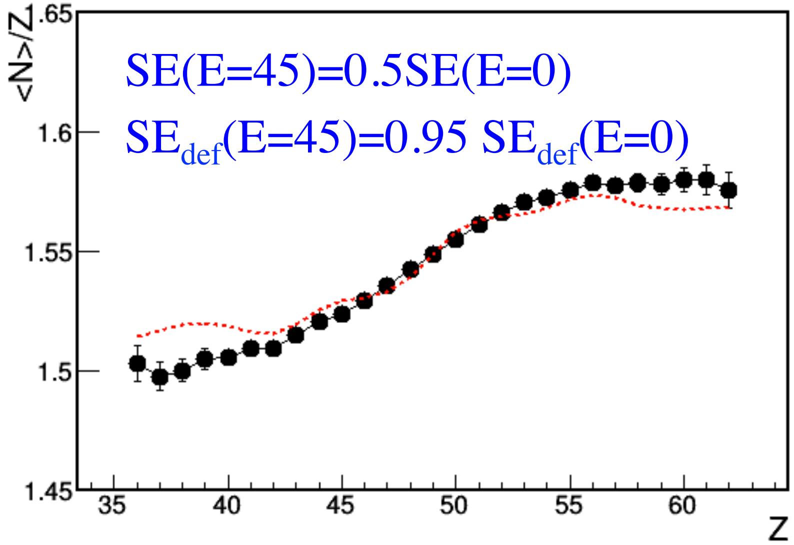
$$SE_{def} = 3*\exp(-(Z-54)^2/(2*3^2))*4*\exp(-(N-90)^2/(2*3.5^2))$$



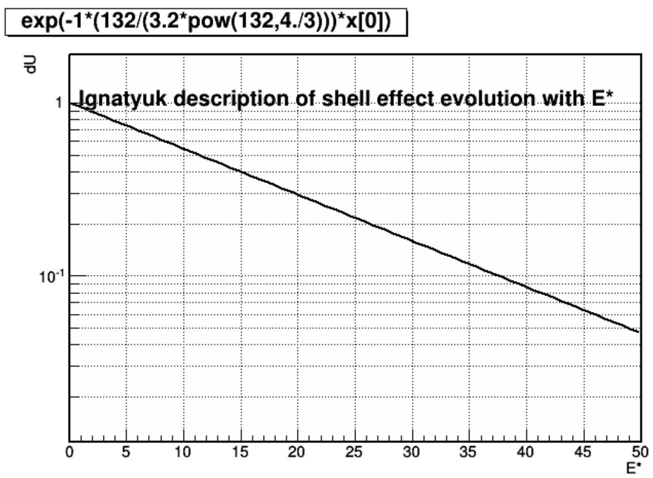


Scission-point model with shell effects





Shell effects remain quite strong, even at E*=45 MeV ??



CONCLUSIONS

- Inverse kinematics is a powerful method
  - Broad range of actinides produced
  - Isotopic distribution
  - Kinematical properties
  - Access to the scission point !!
    - Neutron evaporation multiplicity
    - Neutron and proton sharing

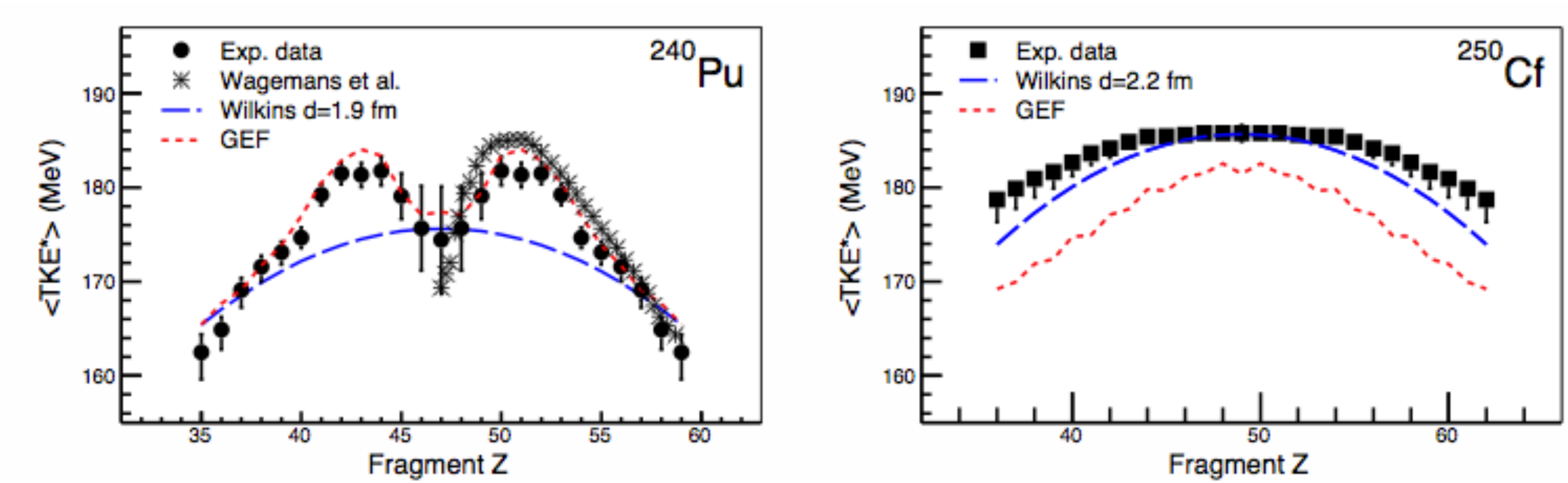
Talks of
L. Audouin,
D. Ramos

  - Evidence for charge polarisation, even at moderate (high) excitation energy
  - Possibility of investigate the influence of excitation energy

Talk of
D. Ramos

Total kinetic energies

$$TKE(Z) = \frac{1}{2} < A_1^* >< V_1 >^2 + \frac{1}{2} < A_2^* >< V_2 >^2$$



$$TKE = 1.44 \frac{Z_h Z_l}{r_0(A_h^{1/3}(1+\frac{2}{3}\beta_h) + A_l^{1/3}(1+\frac{2}{3}\beta_l)) + d}.$$

Deformation at scission !!

Talk of
M. Caamaño