Multi-cluster decays of heavy nuclei

D.V. Kamanin

for the FOBOS collaboration

Progress report on the JRP "Fission and Clustering"

Focal area "Heavy Ions"

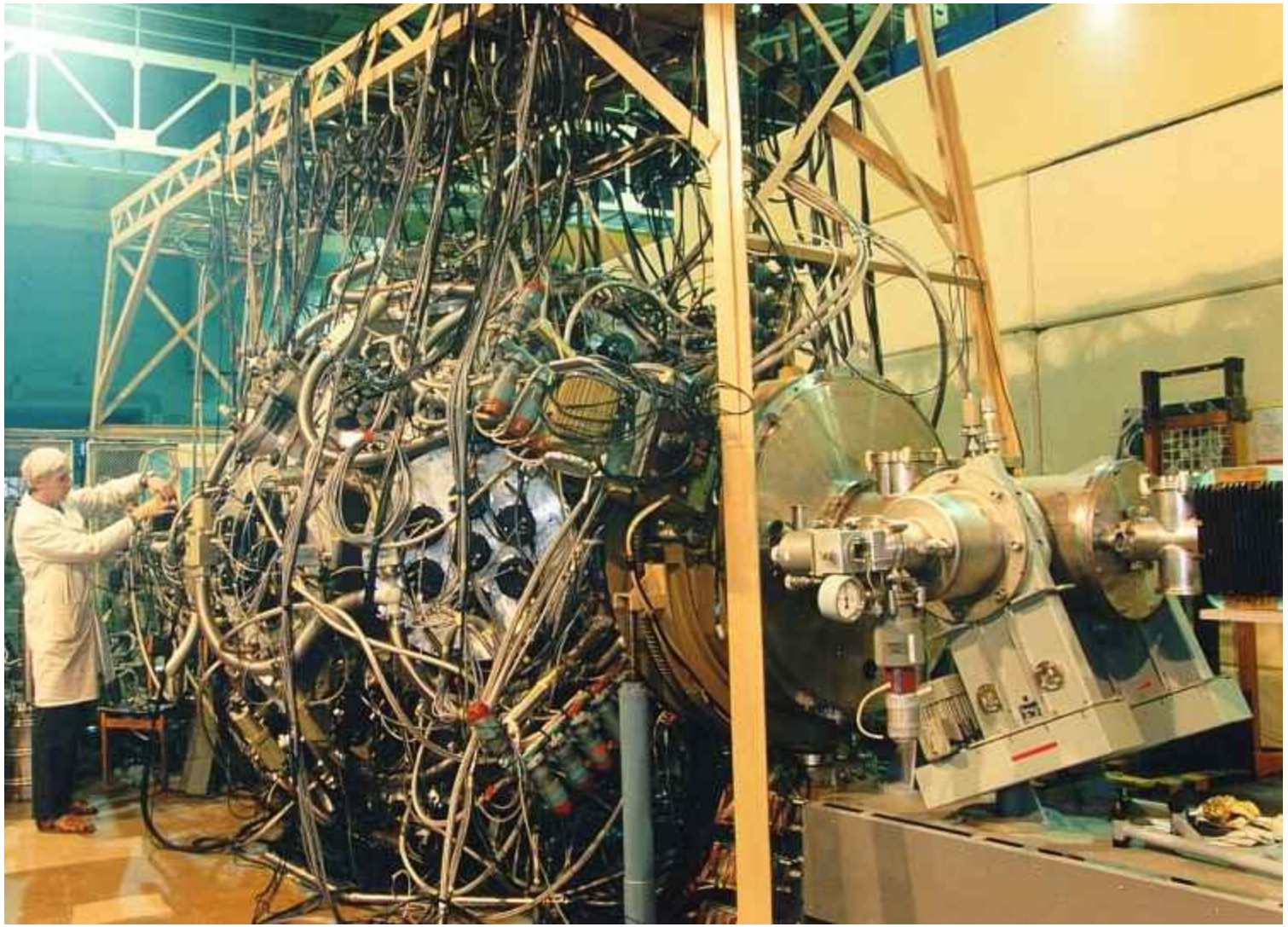
under JINR-SA Agreement

2 collaboration lines

2nd South Africa – JINR Symposium

Models and Methods in Few- and Many-Body Systems

FOBOS 4π-detector of charged particles, 1996



http://fobos.jinr.ru

Challenge
to the modern nuclear physics

Is it possible after 60 years of the study of nuclear fission to observe some new bright phenomena in the fission experiment?

With rather simple equipment and within low run time?

With a well studied “simple” system - ^{252}Cf(sf) or ^{235}U(n_{th},f) ?

If possible - would be excellent for young researchers!

Difficult, however, possible, but only with some new ideas!

Collaboration line 1:

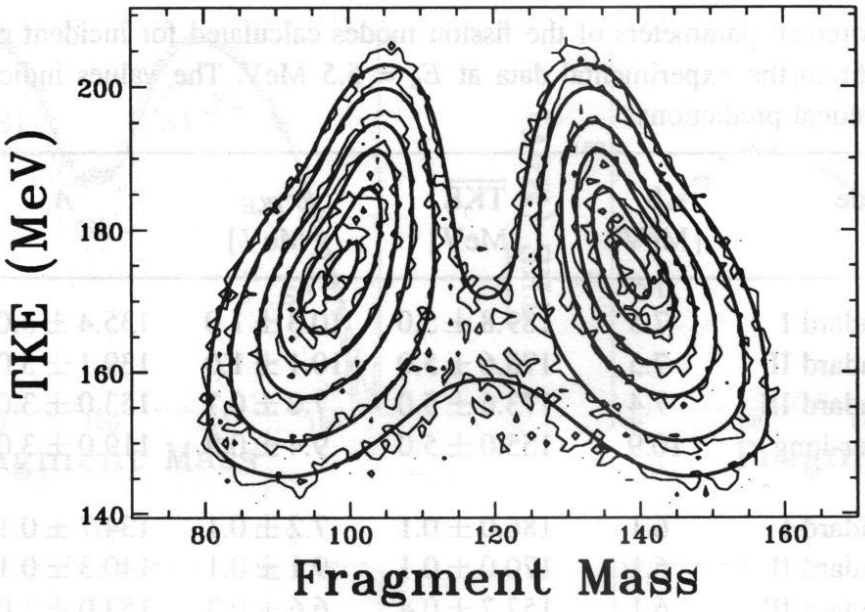
Analysis of hidden regularities in the known nuclear data

D. Kamanin[1], Yu. Pyatkov[1,2], W. Trzaska[3], Yu. Lavrova[2], O. Falomkina[4], B. Herbst[5]

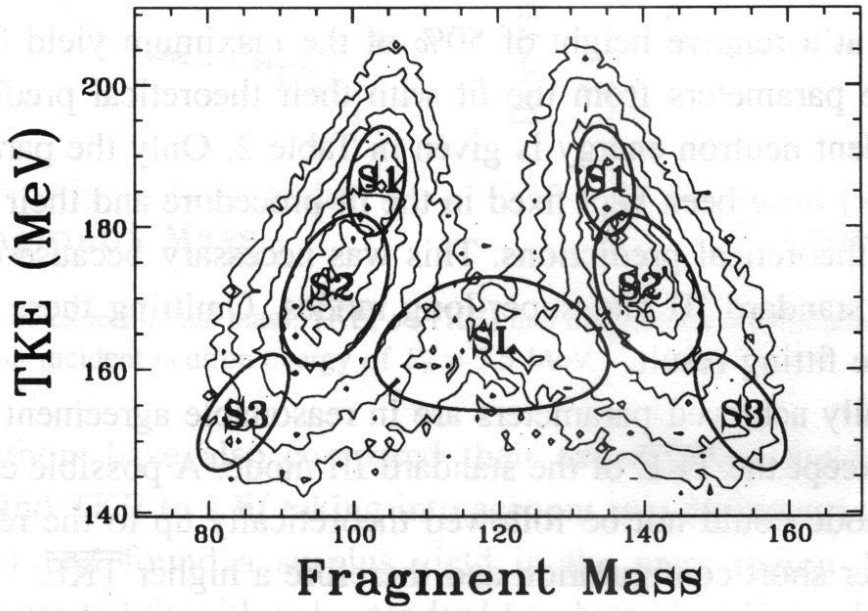


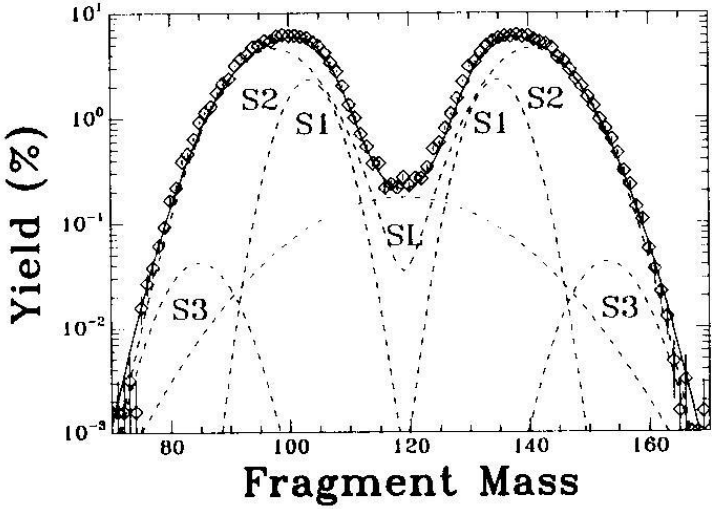
[1]Joint Institute for Nuclear Research, 141980 Dubna, Russia
[2]National Research Nuclear University “MEPHI”, 115409 Moscow, Russia
[3]Department of Physics of University of Jyväskylä, Finland
[4]Lomonosov Moscow State University, 119899,Russia
[5]Stellenbosch University, Matieland, 7602, South Africa

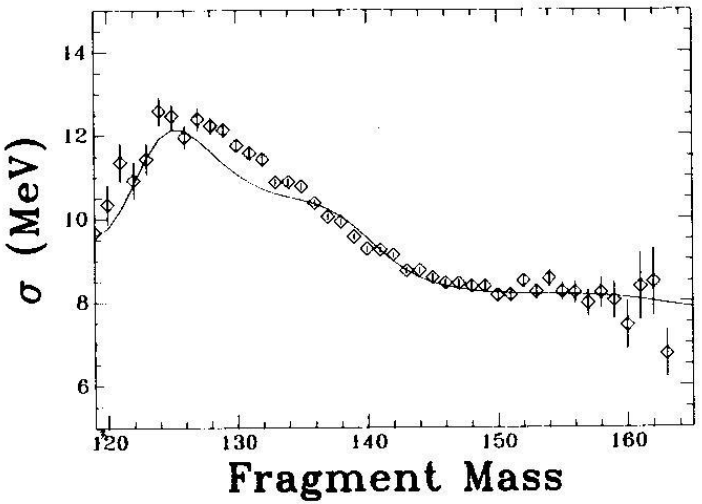
Conventional analysis



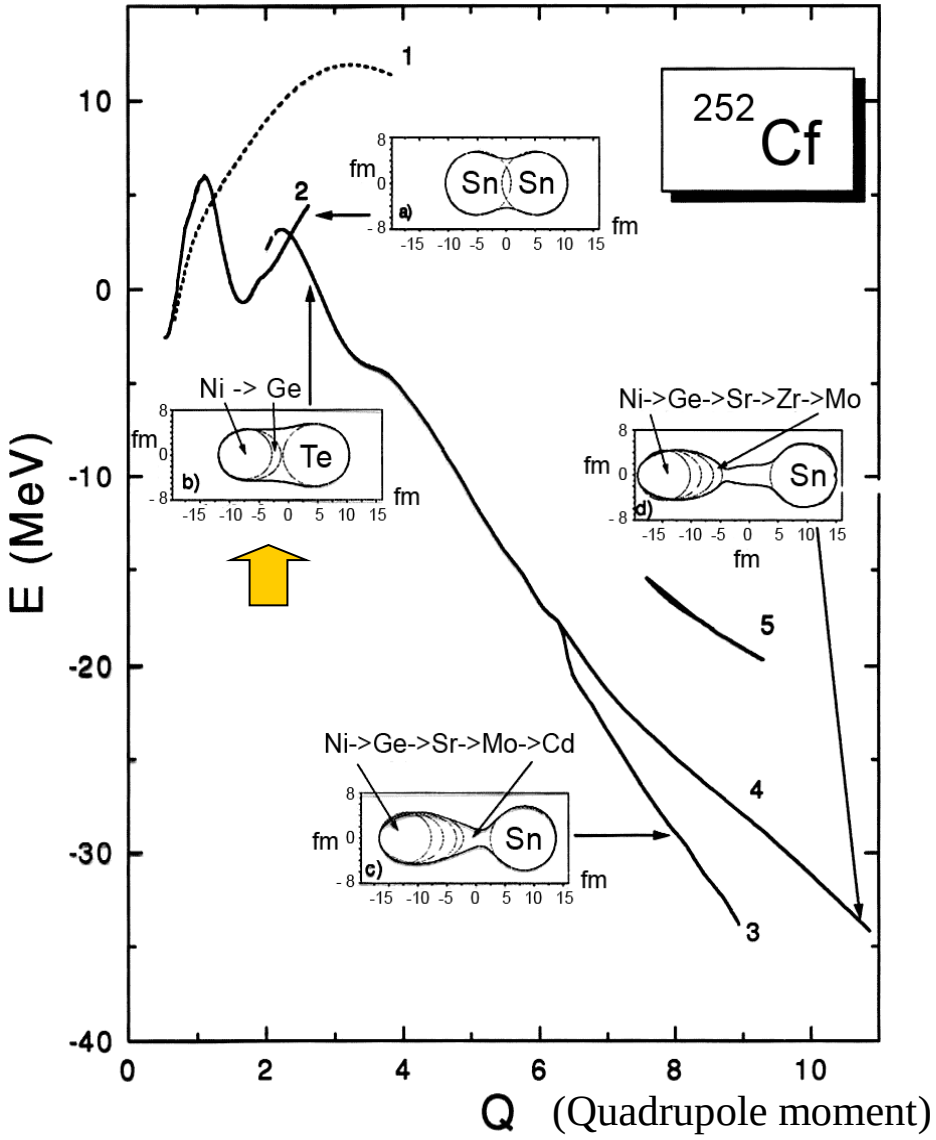
P.Siegler, F.-J. Hambsch, S. Oberstedt, J.P.Theobald
Nuclear Physics A 594 (1995) 45-56







Calculated Fission Valleys (^{252}Cf)



Fission valleys 2 – 5 are connected with different **di-cluster configurations.**

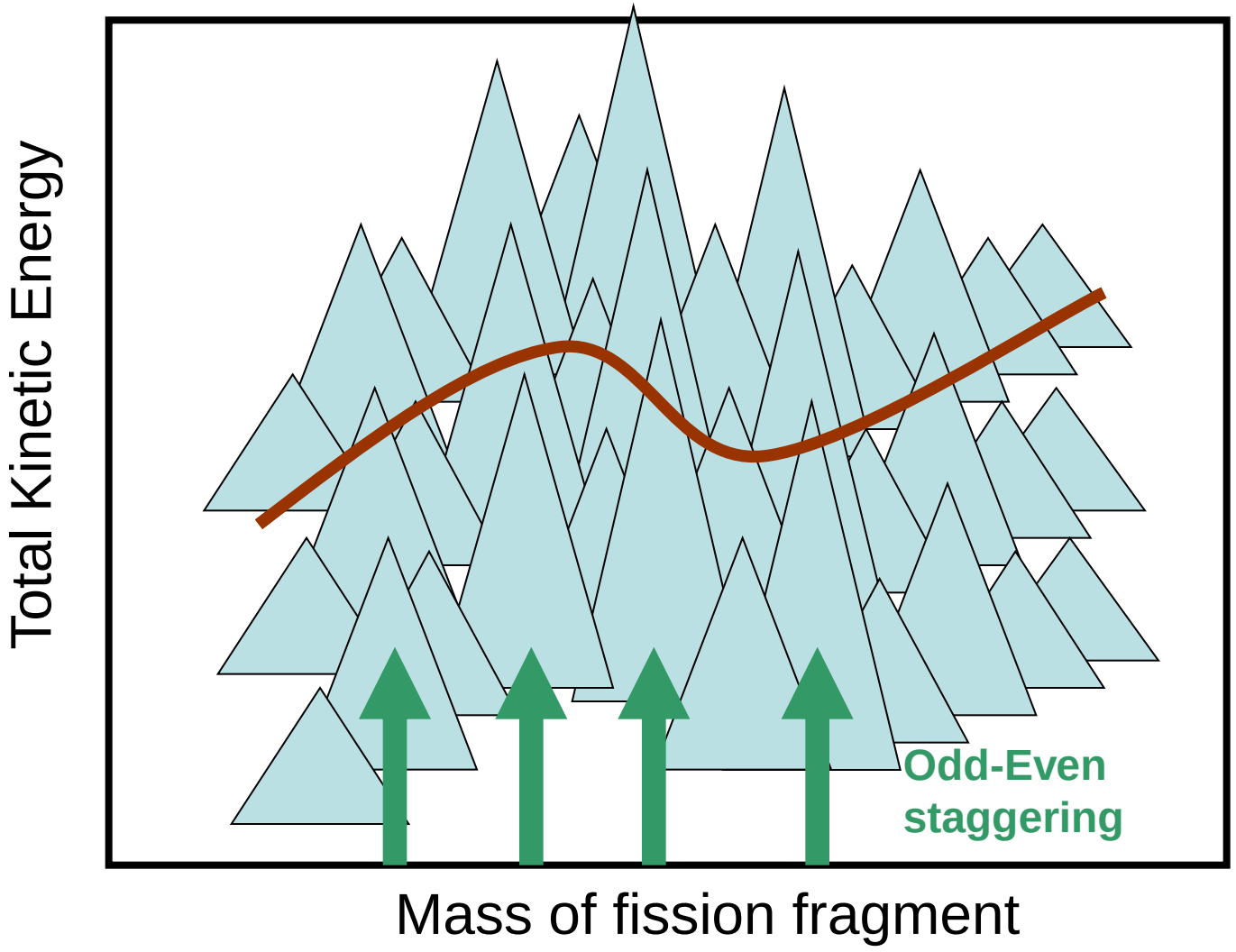
1. Cluster radioactivity.
2. Cold binary fission, for which no neck has yet developed.

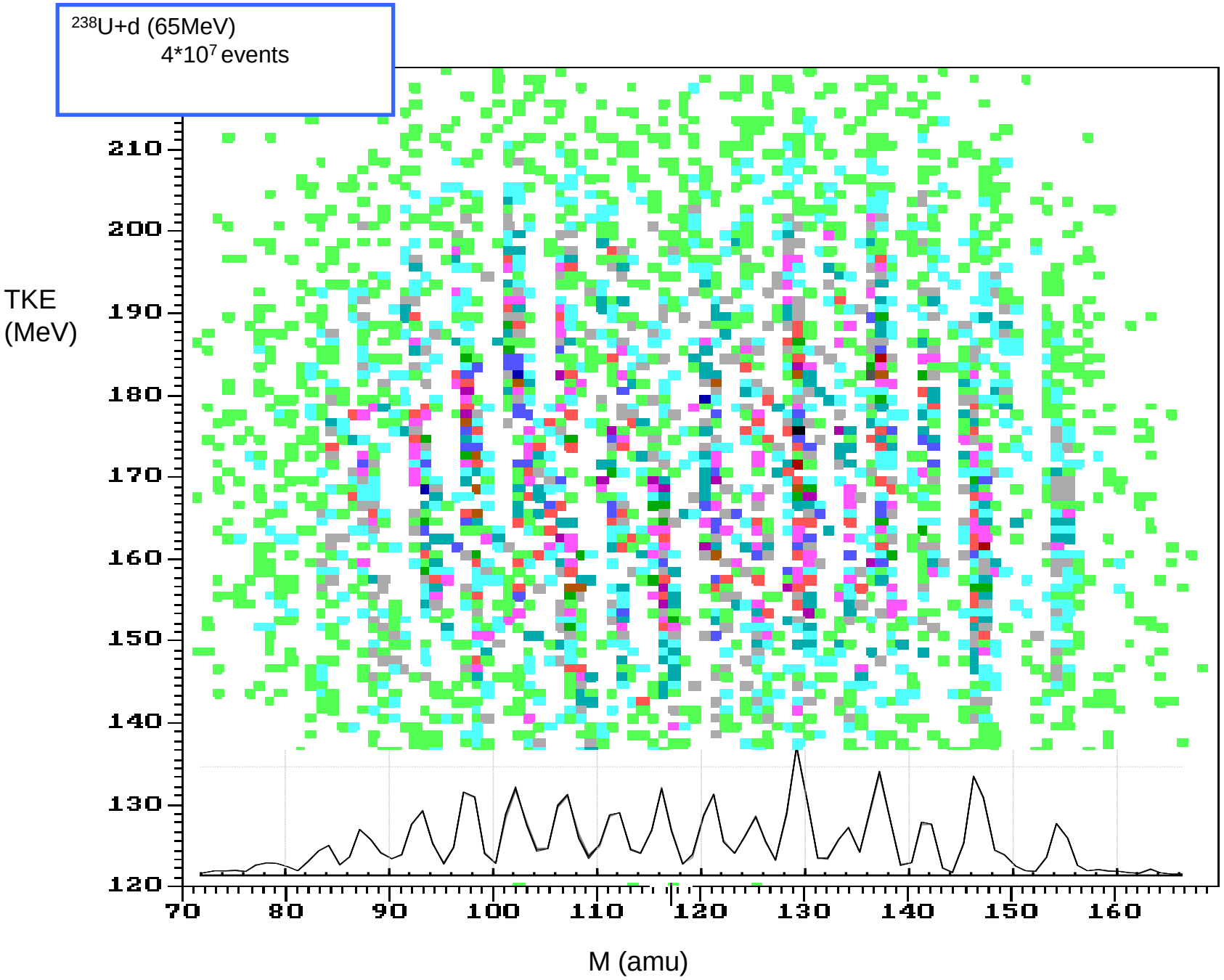
3& 4. Two different asymmetrical valleys (B, A).

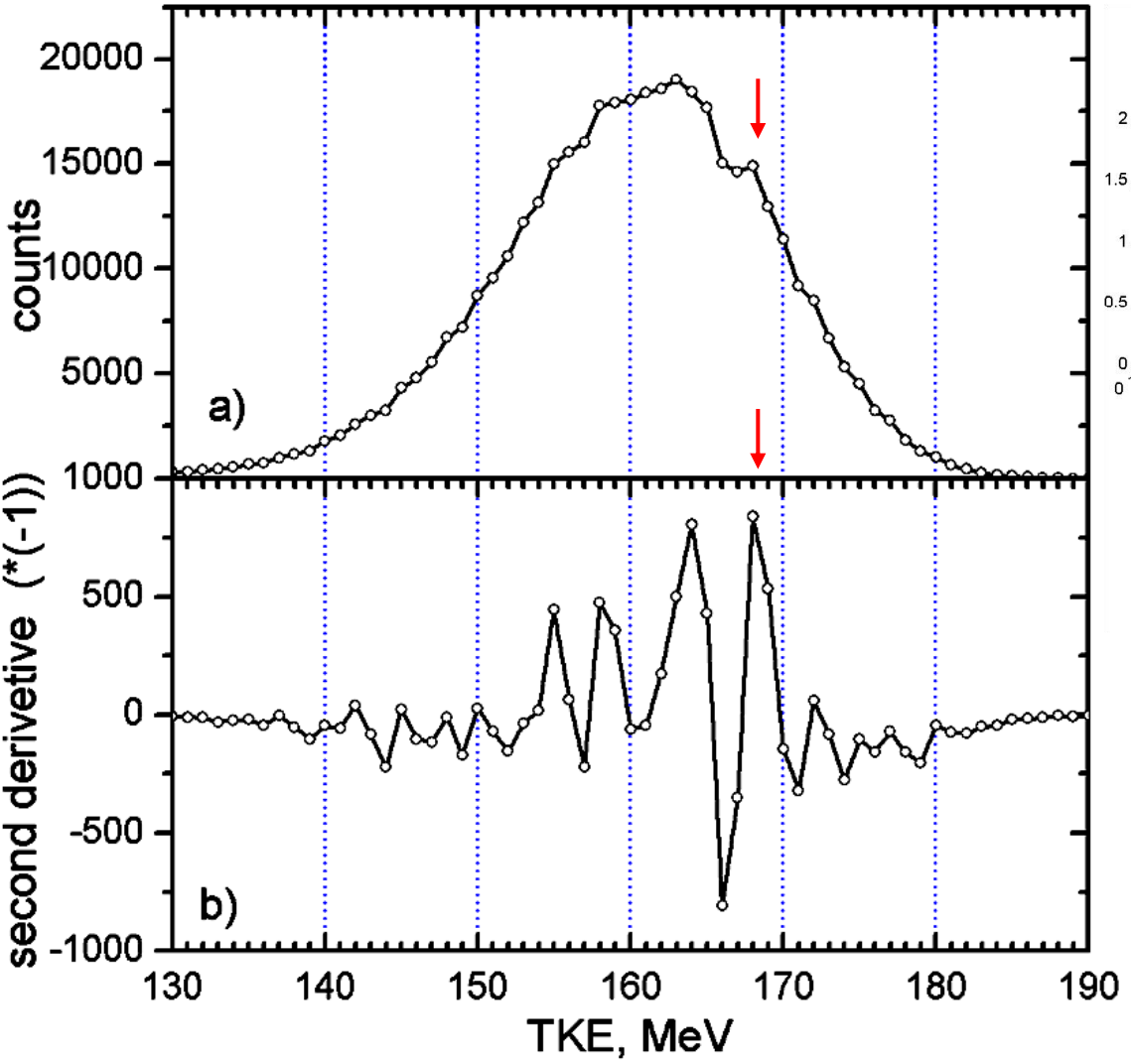
5. Symmetrical valley.

Yu.V.Pyatkov,V.V.Pashkevich et al.,
Nucl. Phys. A 624 (1997) 140

What and why is observed?




^{238}U+d (65MeV)
4*10^{7} events
TKE (MeV)
210
200
190
180
170
160
150
140
130
120
70
80
90
100
110
120
130
140
150
160
M (amu)



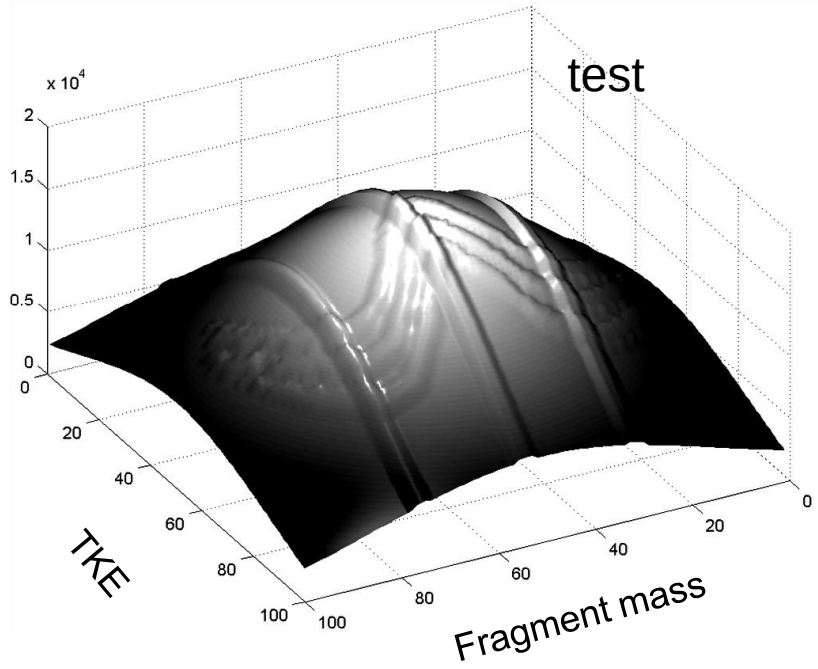


Fig. 1a Sructures (peaks) revealed by the second derivative method; (a) the section M=const of the initial TKE-M distribution; (b) the second derivative of the spectrum.

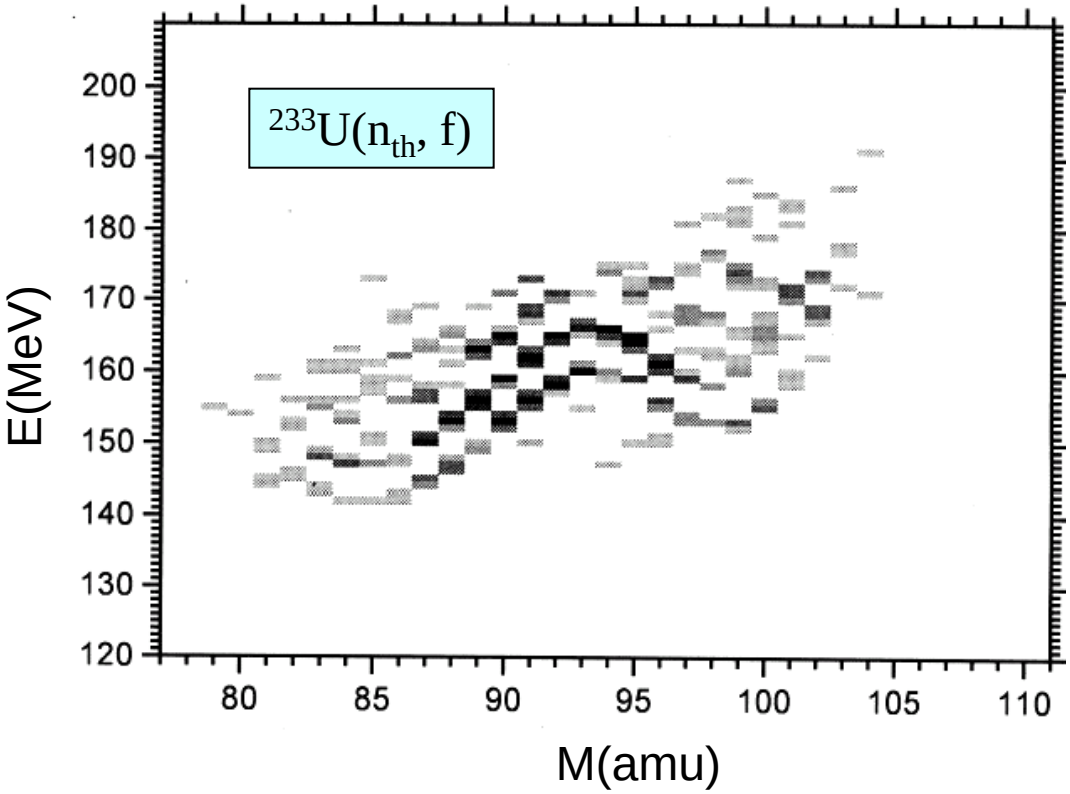
Thus we deal with a superposition of two types of structures, namely

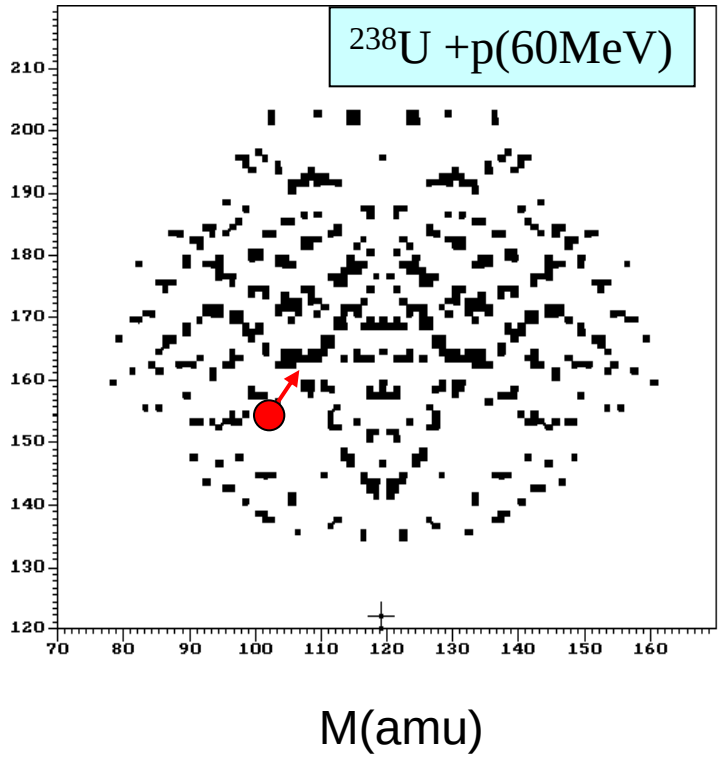
--“vertical” ridges

-- “snake-like” ridges

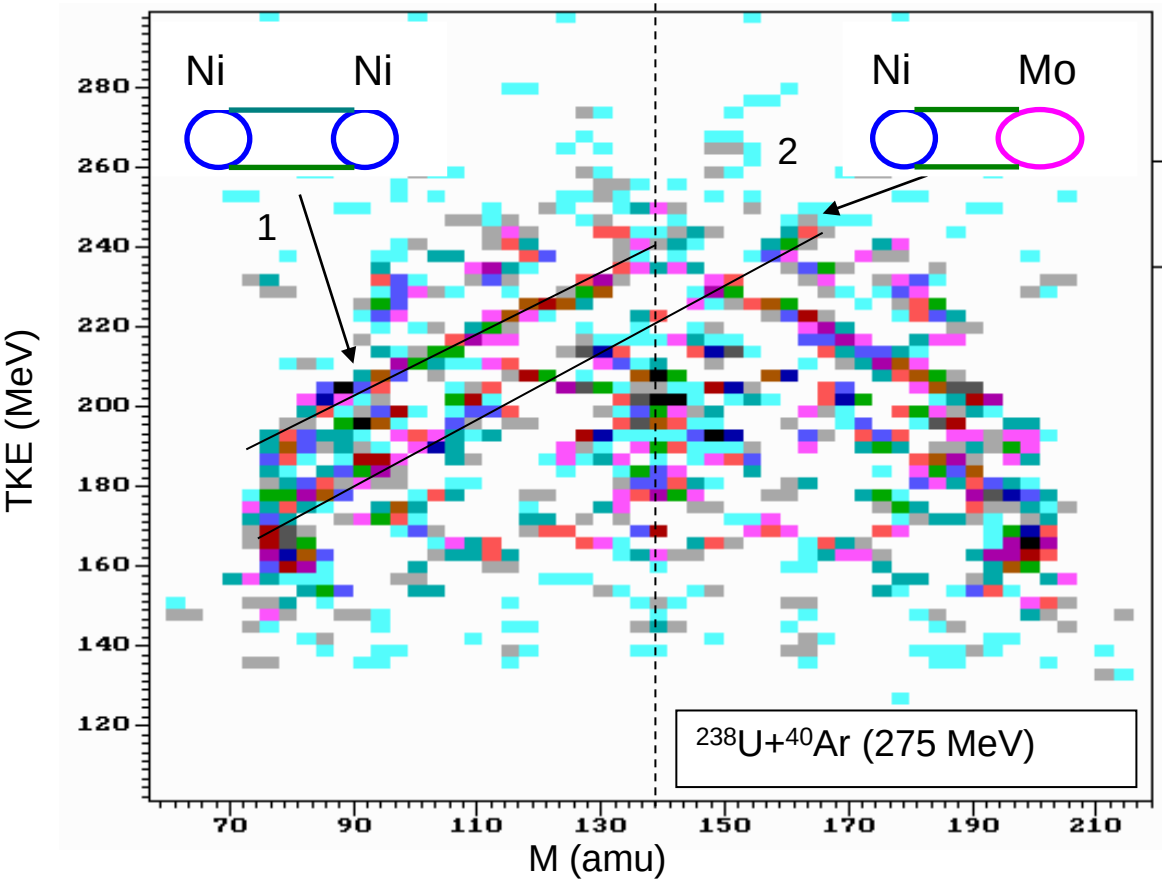
Fine structure of mass-energy distribution

UNIVERSITEIT STELLENBOSCH UNIVERSITY

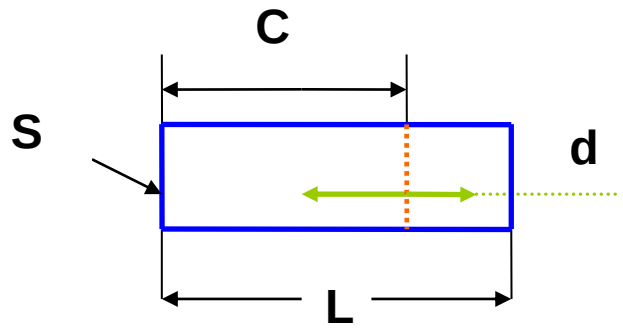




- Bifurcation point at M_L=108 amu (magic ^{108}Mo)



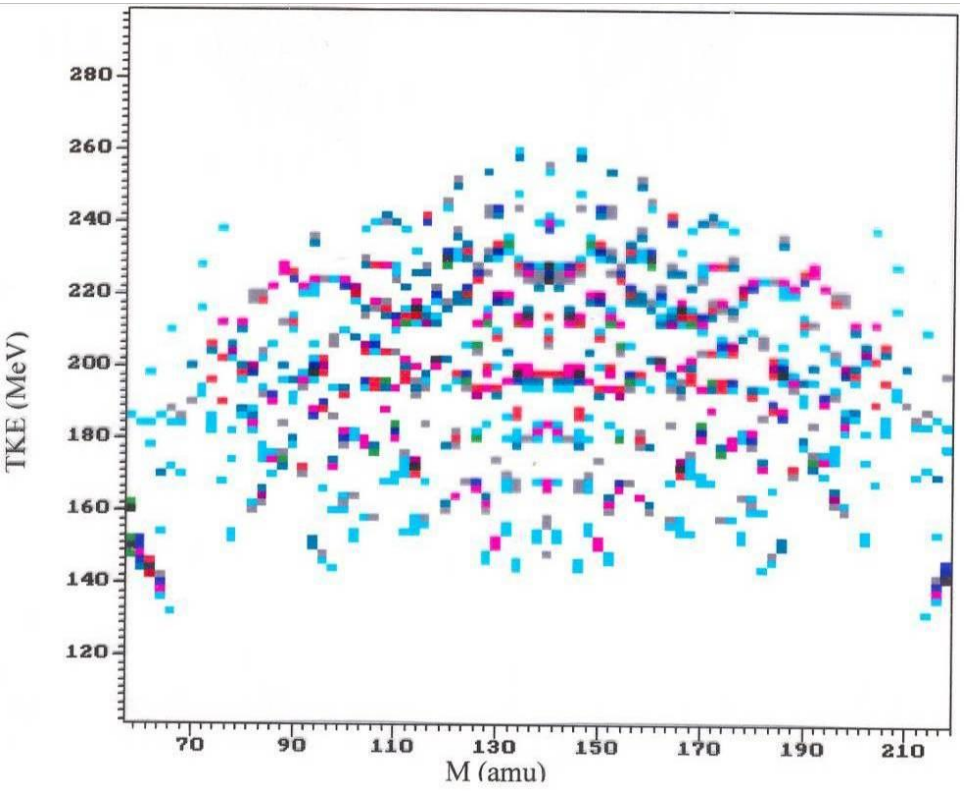
Fine structure in neutron gated TKE-M distribution of the fragments.

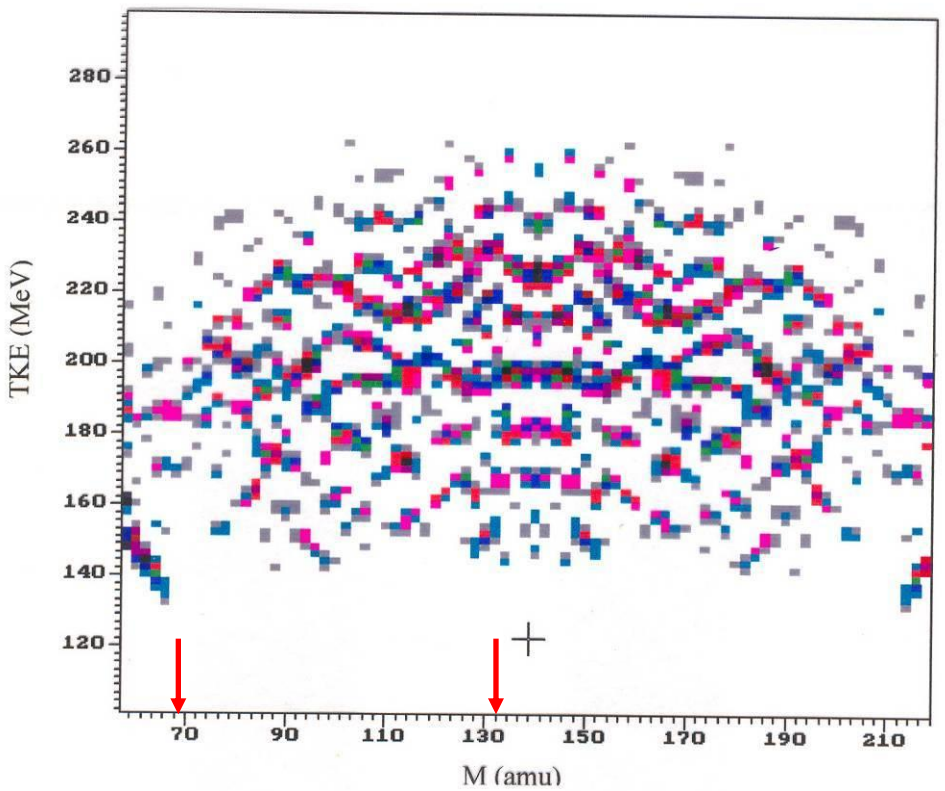


Experiment:
d~(Z1*Z2)/TKE;
m1~78amu
m2~134amu
d1≈d2

Model:
Z1=s*C;
Z2=s*(L-C);
d=C/2+(L-C)/2=L/2

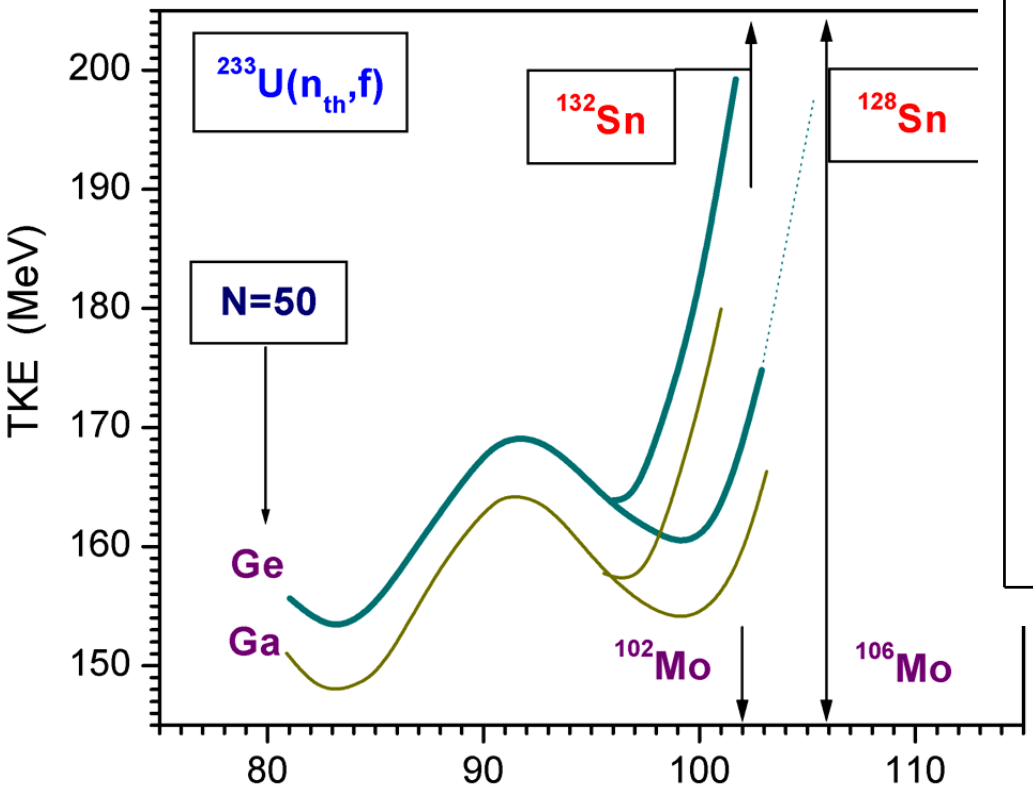
Snake - like FS from the reaction $^{238}U+^{40}Ar(275MeV) \longrightarrow {}^{278}110$





^{70}Ni ^{132}Sn

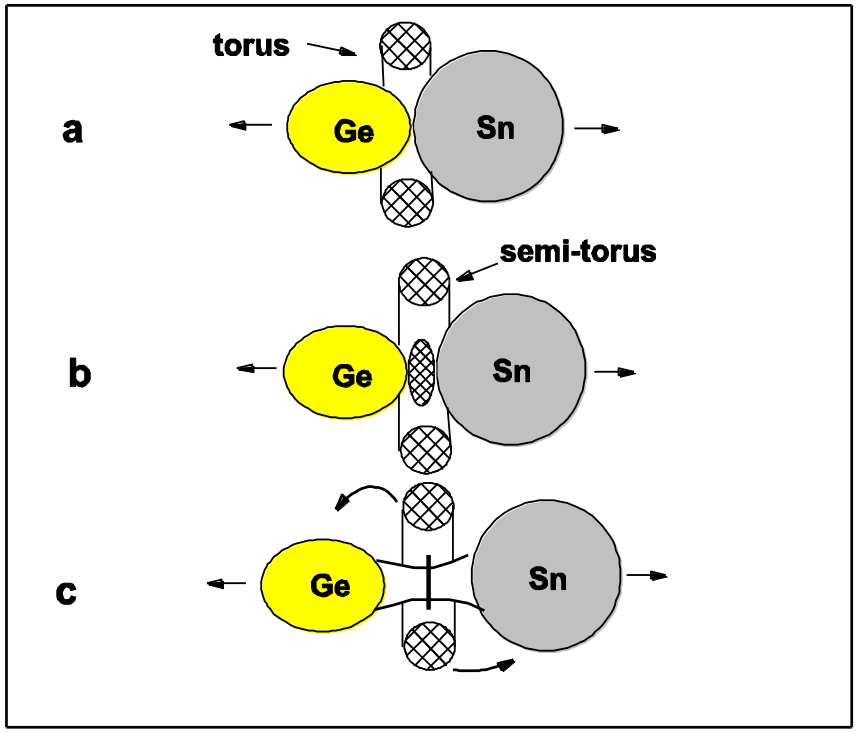
The most intensive FS



The most complete "snakeology" for this reaction

Yu.V. Pyatkov et al.,

NIM A 488 (2002) 381



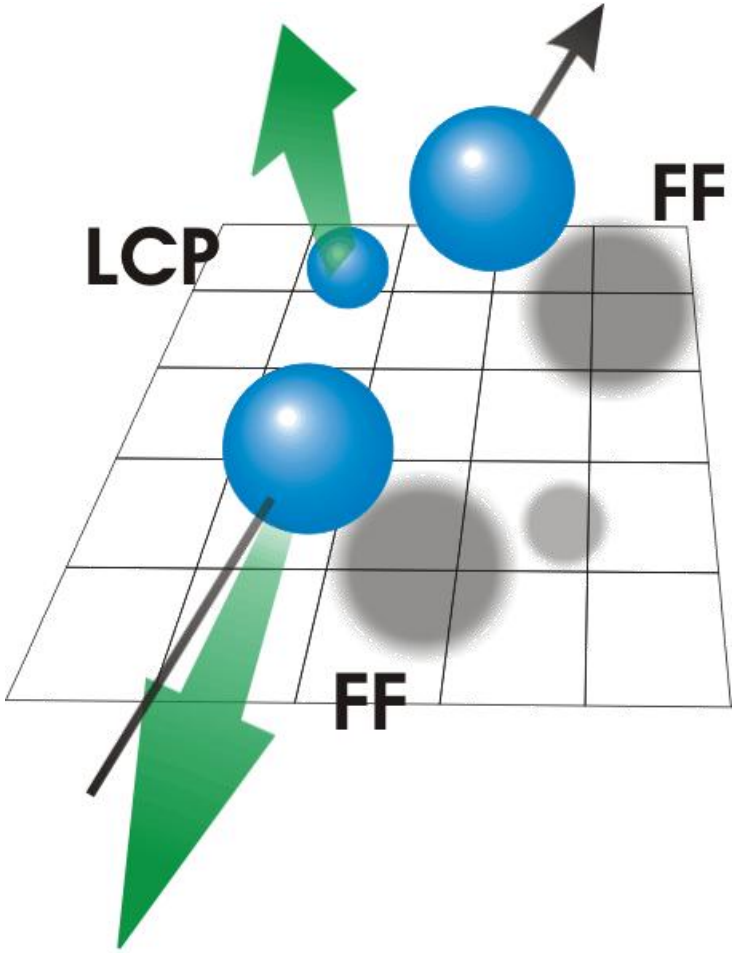
Presumable shapes of the fissioning system in the framework of Ge-Sn fission mode for:

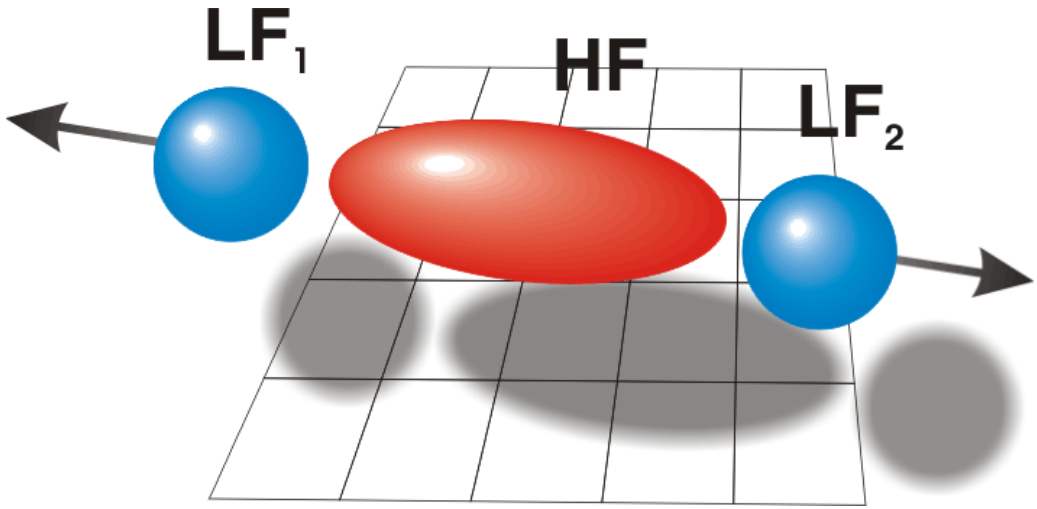
The most compact configuration (a), some grater elongation (b), prescission phase (c).

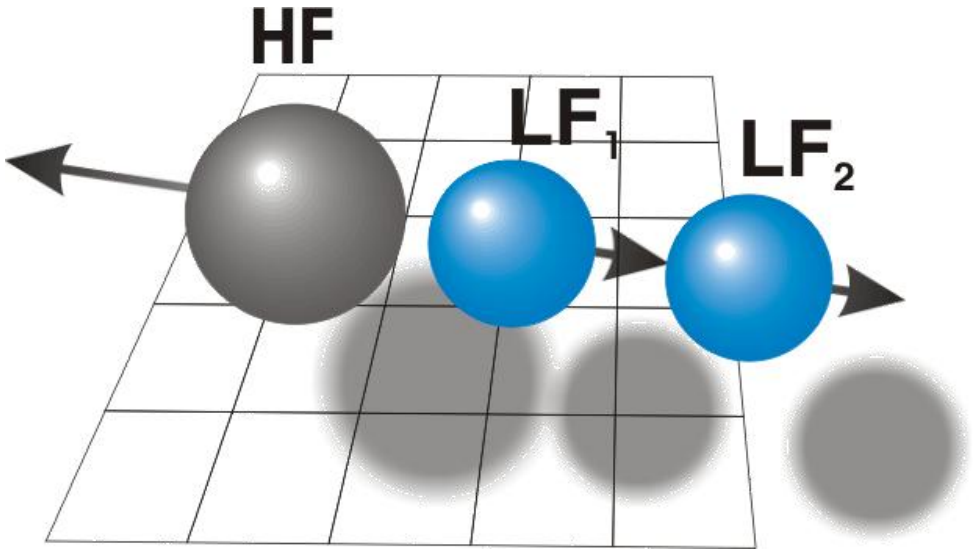
Yu. V. Pyatkov, V.V.Pashkevich, W. H. Trzaska et al., *Physics of Atomic Nuclei, V. 67(2004) 1726*

Collinear Cluster Tripartition

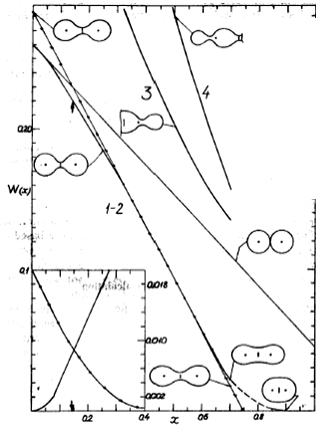
Conventional ternary fission







Positive theory background

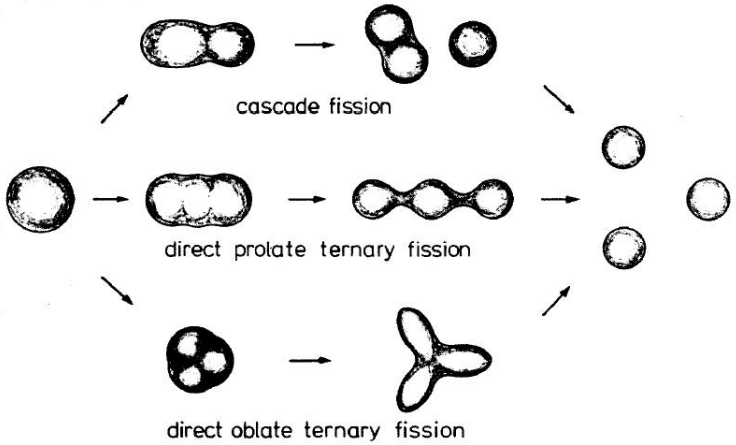


SYMMETRICAL SHAPES OF EQUILIBRIUM FOR A LIQUID DROP MODEL

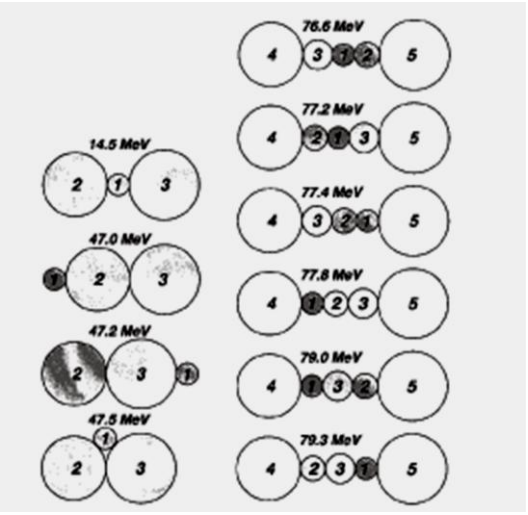
V.M. STRUTINSKY, N.Ya. LYASHCHENKO and N.A. POPOV

Nucl. Phys. **46** (1963) 639

two-neck and three-neck shapes



H. Diehl & W. Greiner,
Nuclear Physics A229 (1974)



Aligned and compact configurations for α-accompanied and α+^{6}He+^{10}Be accompanied cold fission of ^{252}Cf

D.N. Poenaru et al., Phys. Rev. C 59 (1999) 3457

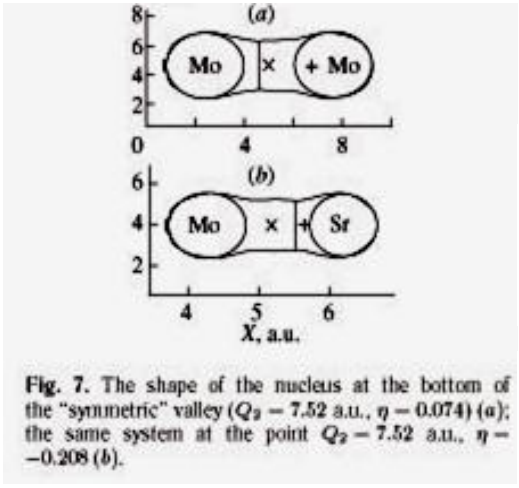


Fig. 7. The shape of the nucleus at the bottom of the "symmetric" valley ($Q_3 = 7.52$ a.u., $\eta = 0.074$) (*a*); the same system at the point $Q_2 = 7.52$ a.u., $\eta = -0.208$ (*b*).

Yu.V. Pyatkov, V.V. Pashkevich, A.V. Unzhakova et al., Physics of Atomic Nuclei 66 (2003) 1631

PHYSICAL REVIEW C **81**, 044608 (2010)

True ternary fission of superheavy nuclei

V. I. Zagrebaev,[1] A. V. Karpov,[1] and Walter Greiner[2]

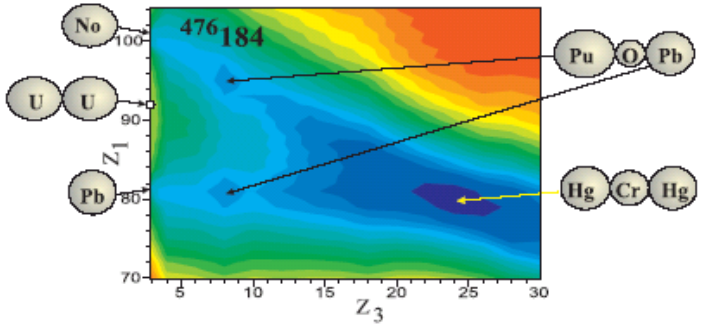
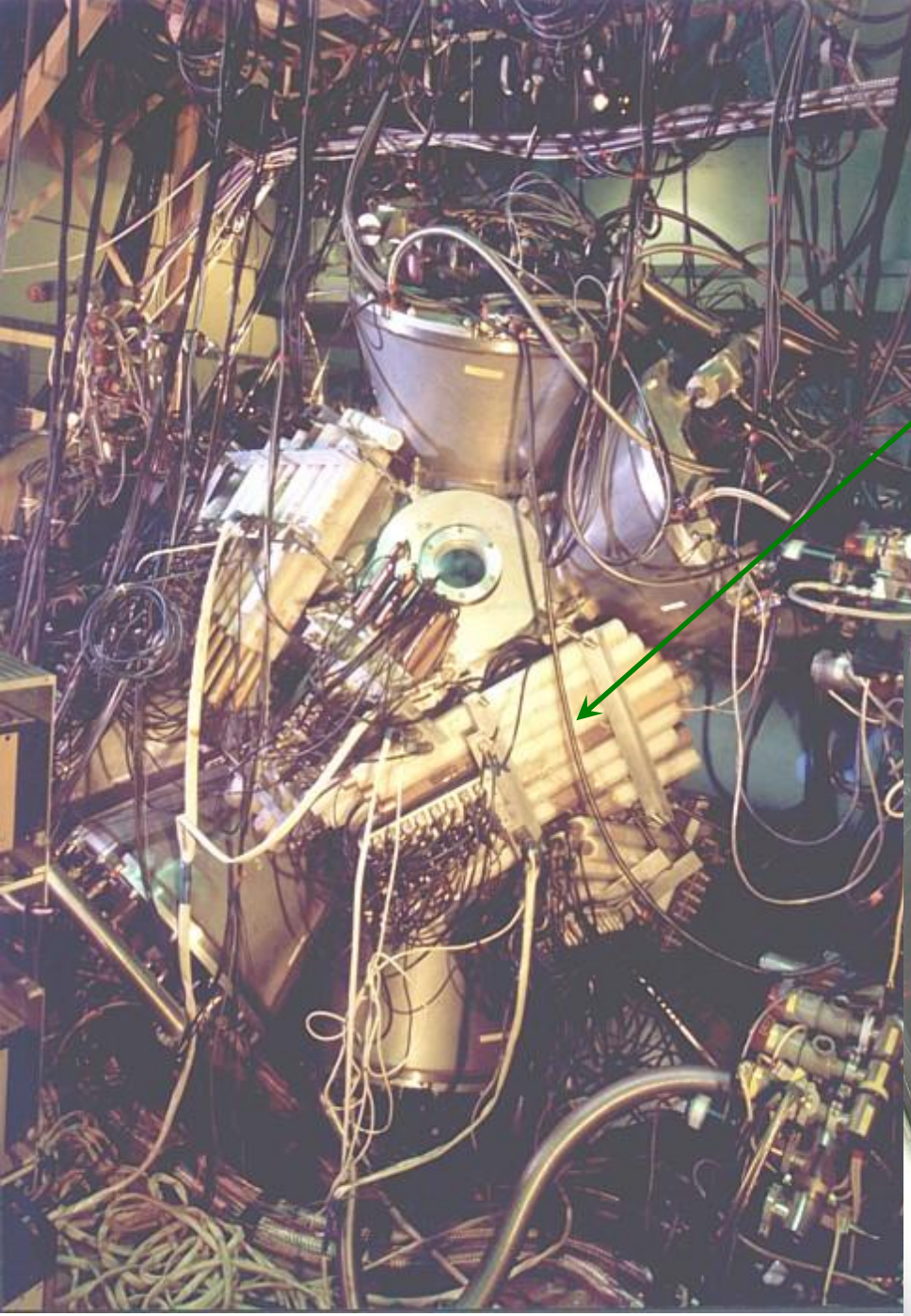


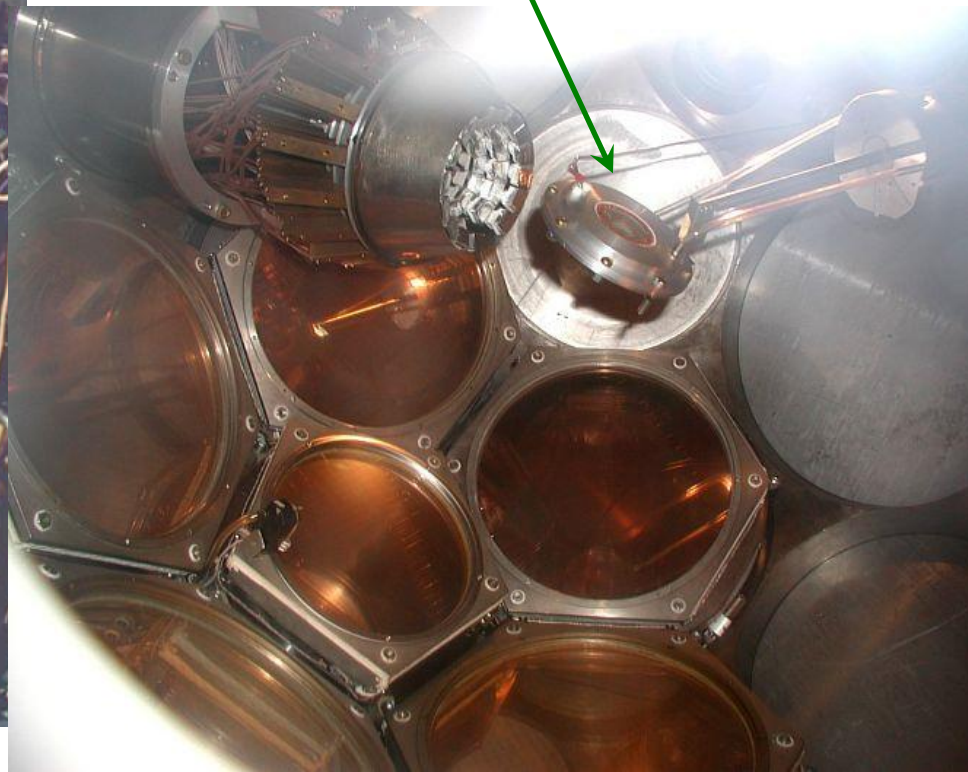
FIG. 6. (Color online) Landscape of potential energy of three-body configurations formed in collision of ^{238}U + ^{238}U.

Double arm spectrometer
6+6 modules

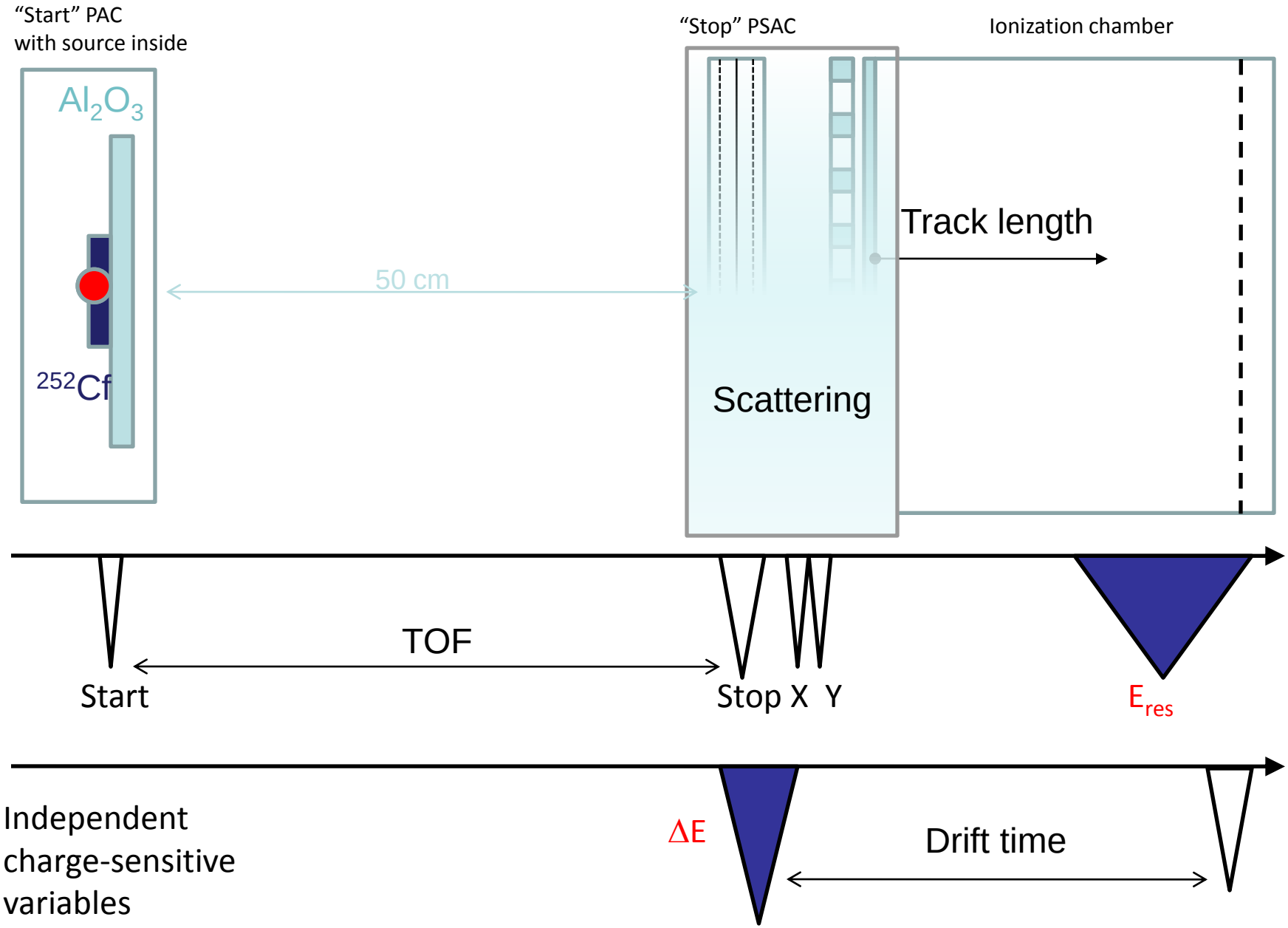
Neutron belt of FOBOS
140 ^{3}He (7 bar) conuters
In PE-moderator

Start PAC
with internal ^{252}Cf source



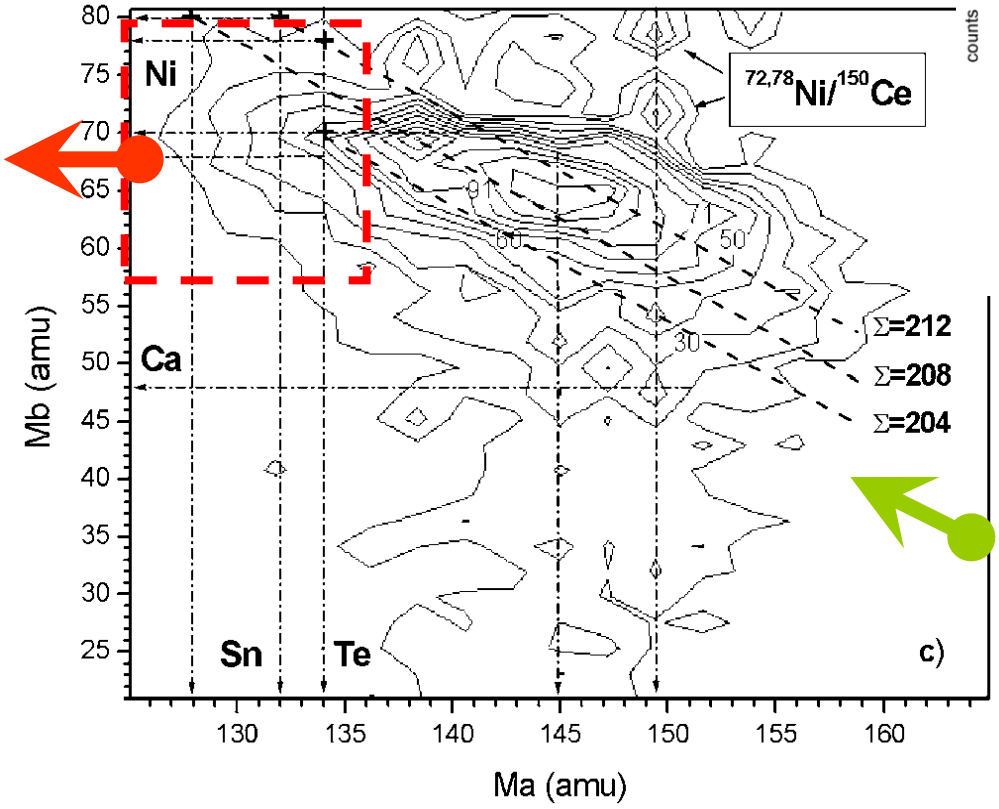


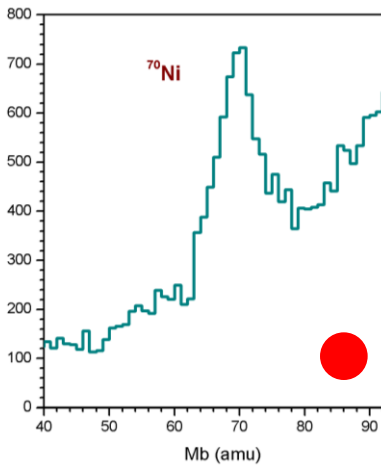
What is measured with mini-FOBOS

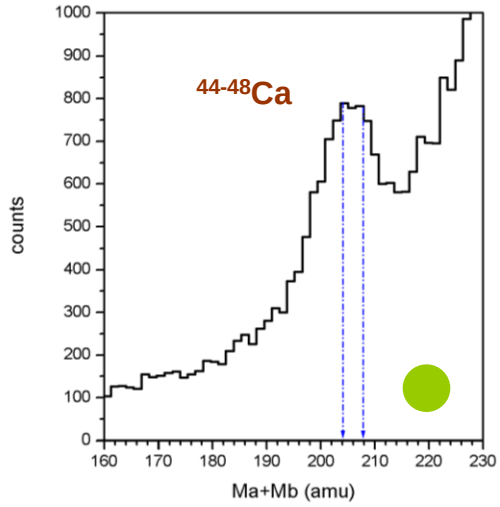


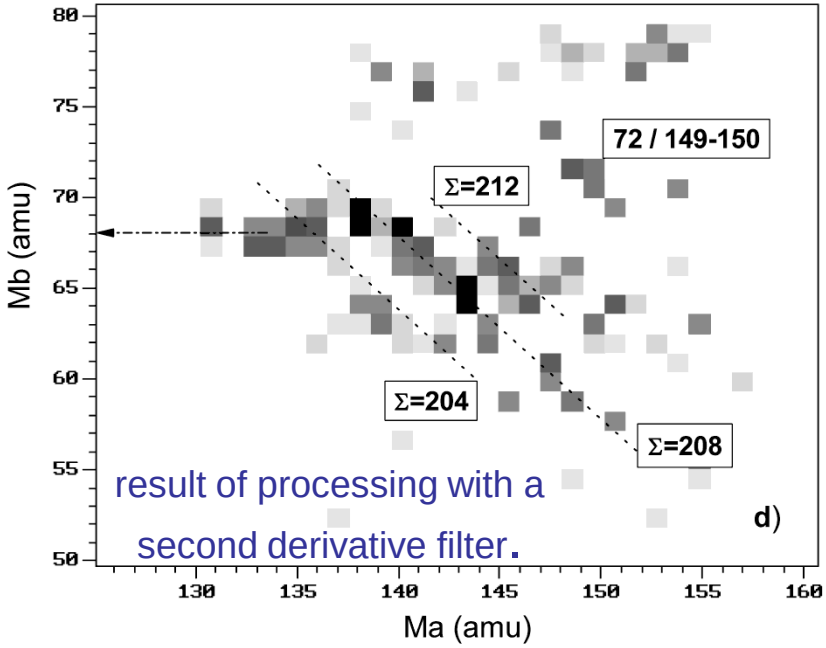
Missing mass study

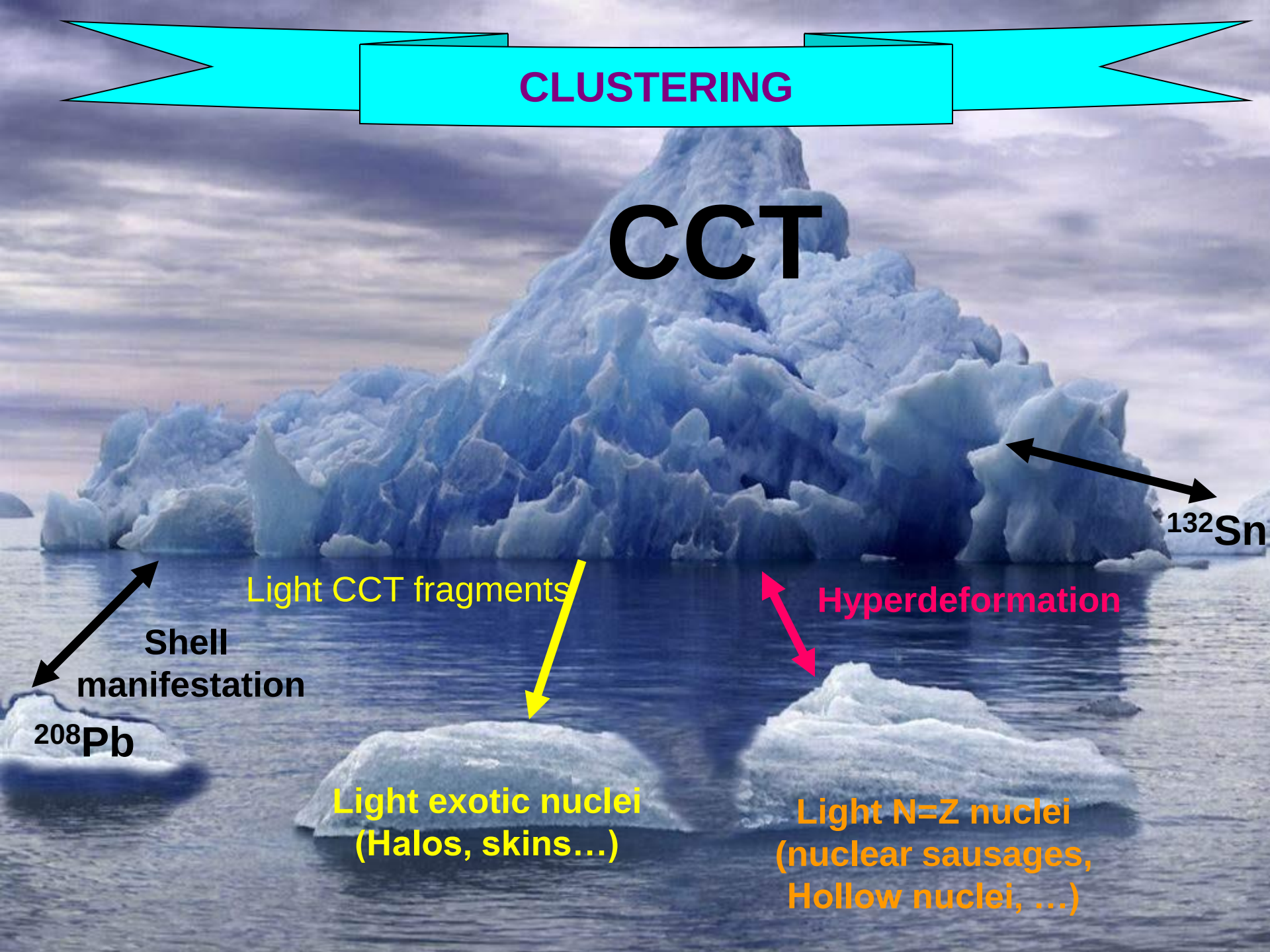
relative bump magnitude 0.003










CLUSTERING
CCT
^{132}Sn
Light CCT fragments
Hyperdeformation
Shell
manifestation
^{208}Pb
Light exotic nuclei
(Halos, skins…)
Light N=Z nuclei
(nuclear sausages,
Hollow nuclei, …)

Collaboration line 2:

(Direct) study of multi-cluster decays of heavy nuclei

JINR, Dubna

MEPhI, Moscow

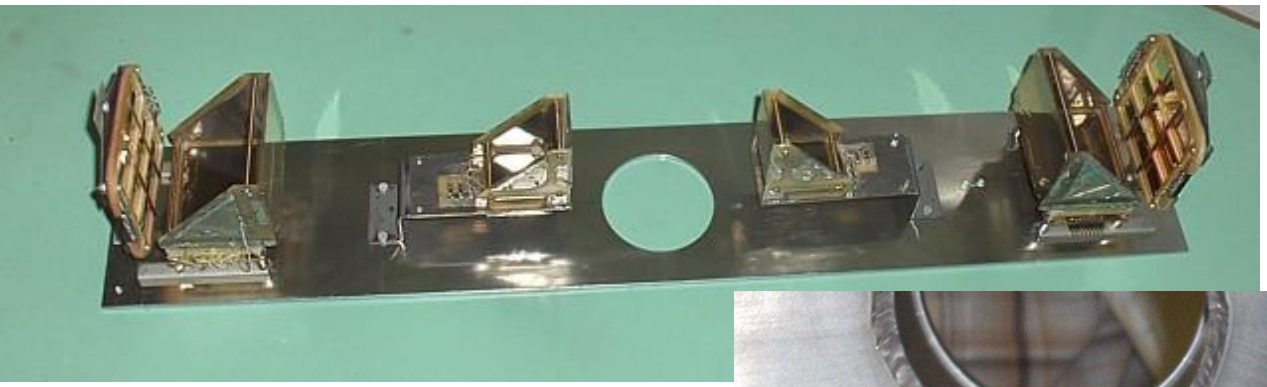
ATOMKI, Debrecen

iThemba LABS (S.Mullins)

SUN (N. Jacobs, V.Malaza)

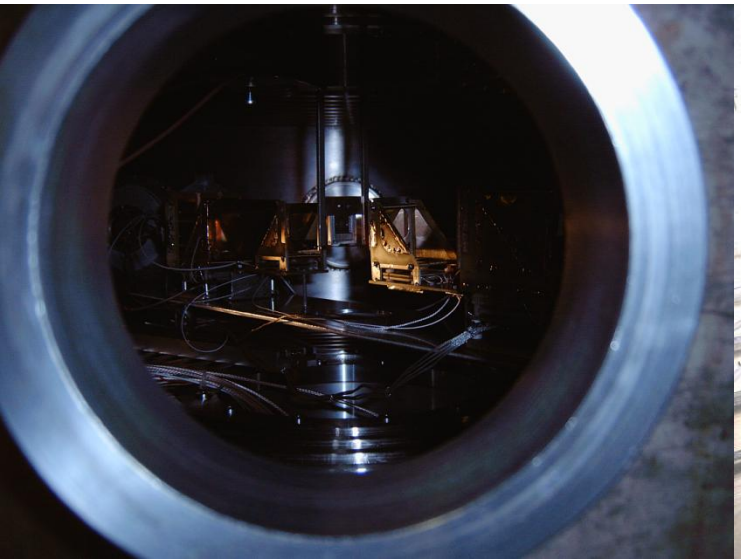
This work is supported in part by the grant of the Federal Ministry of Education and Research of Germany

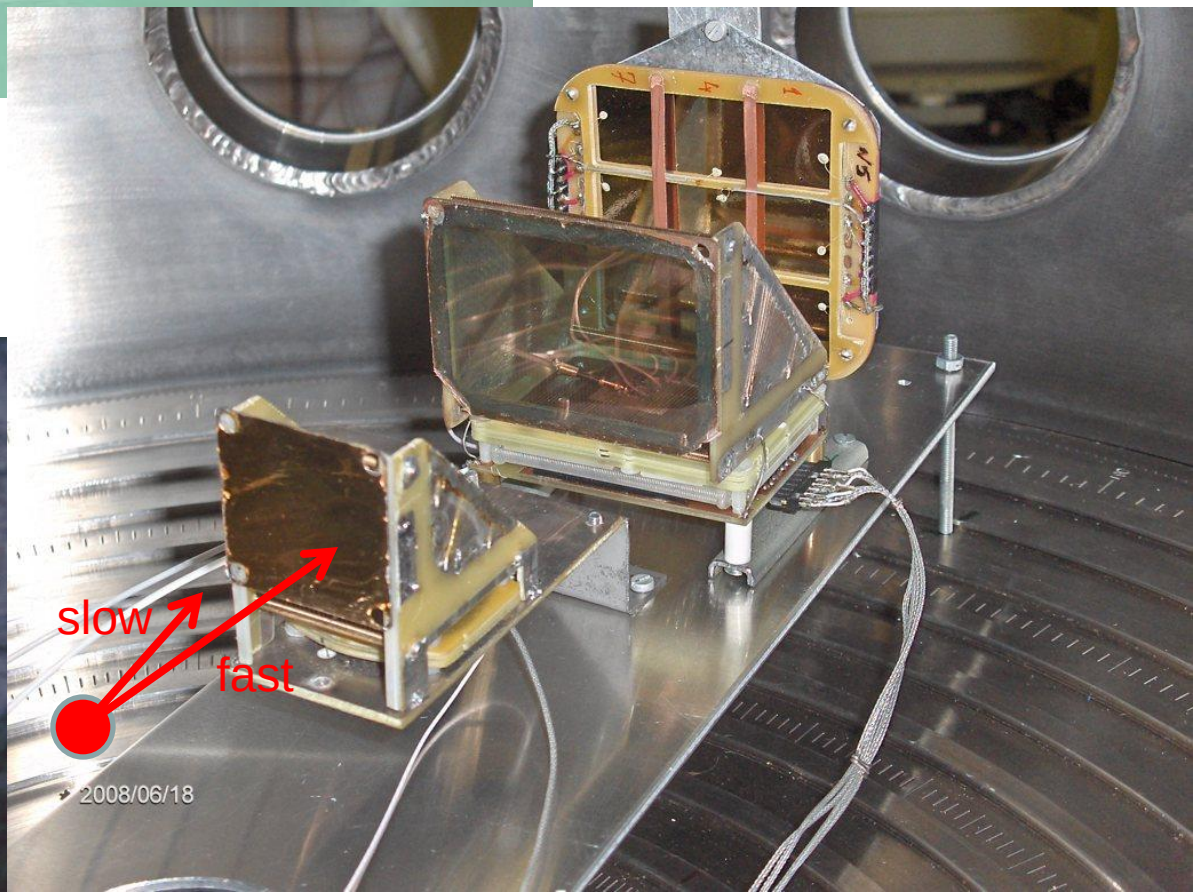
Experimental setup



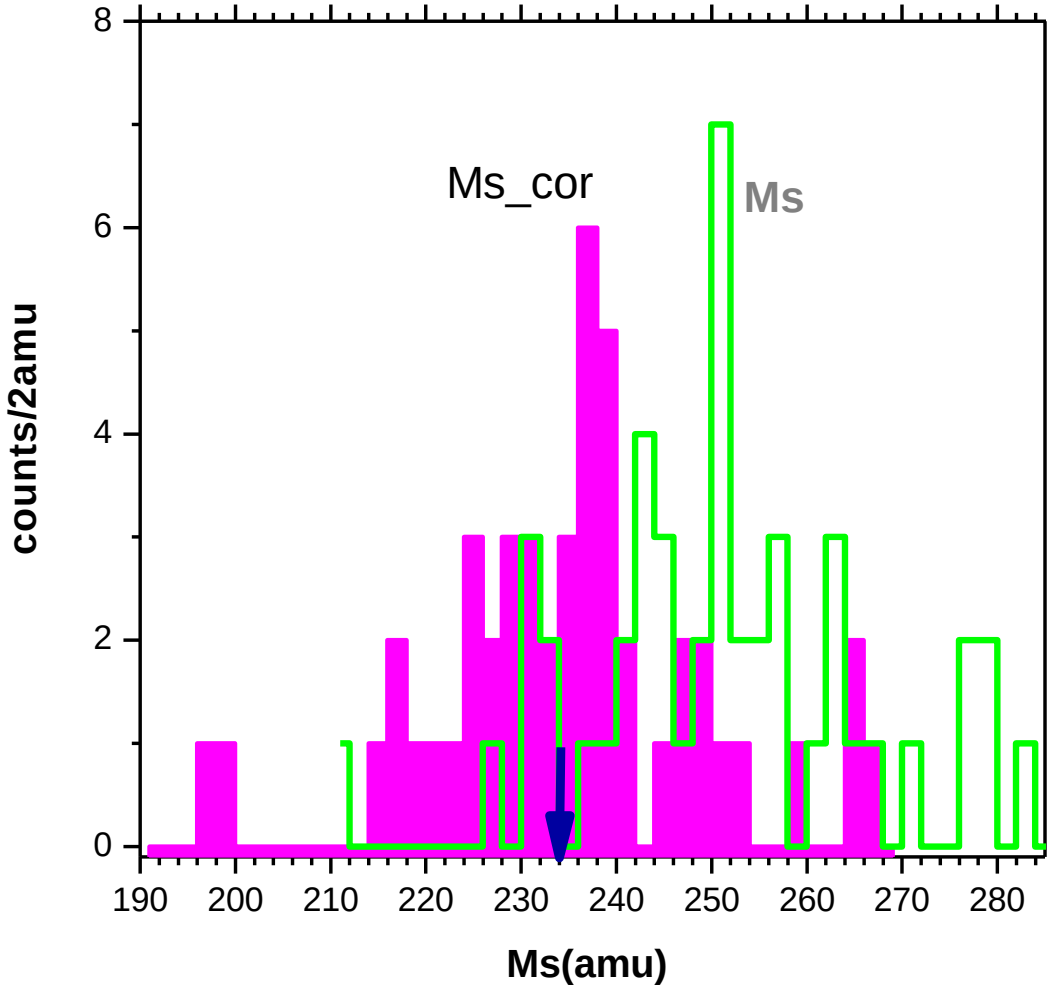
Data array $5.5*10^6$

ATOMKI, June 2008

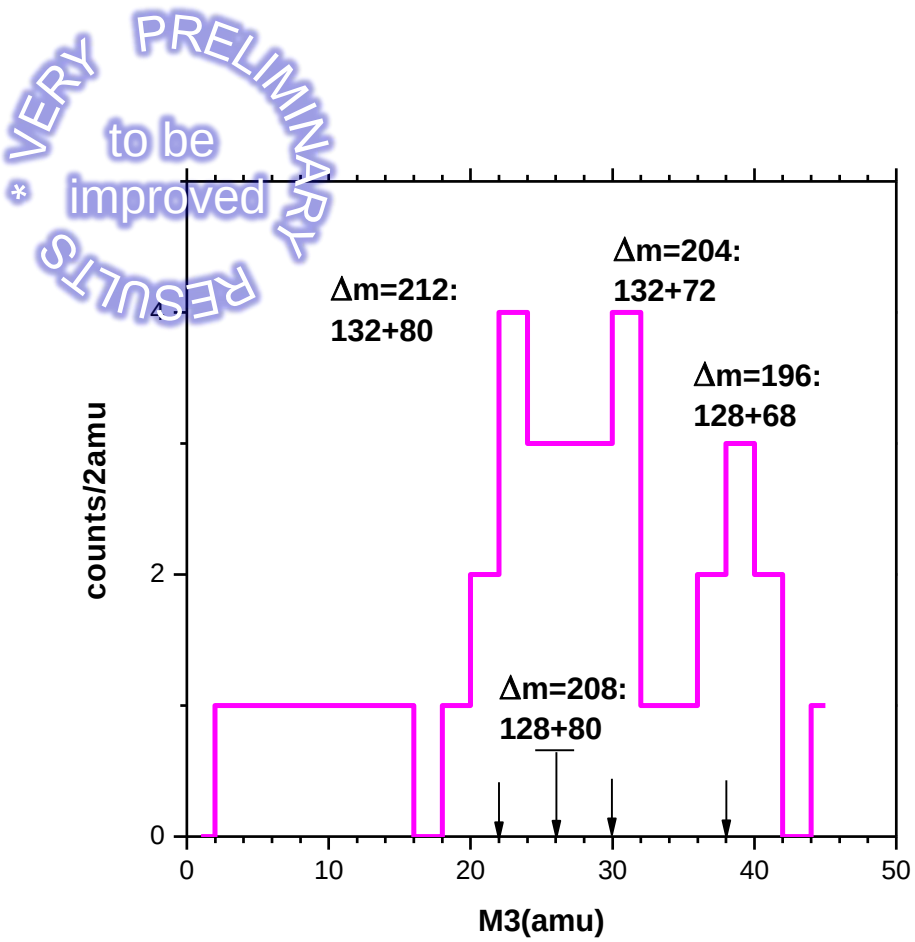


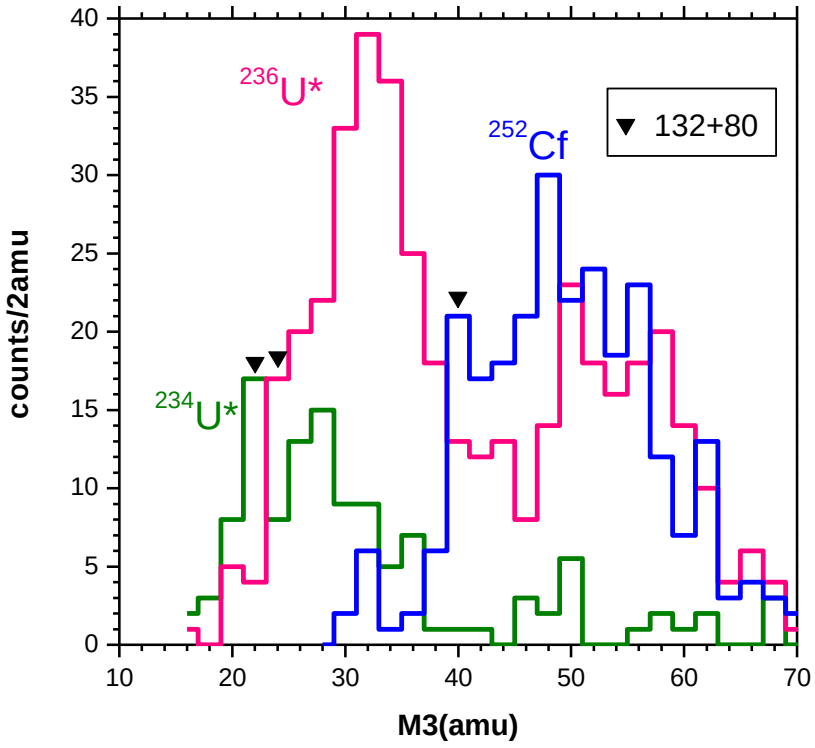


Total mass measured

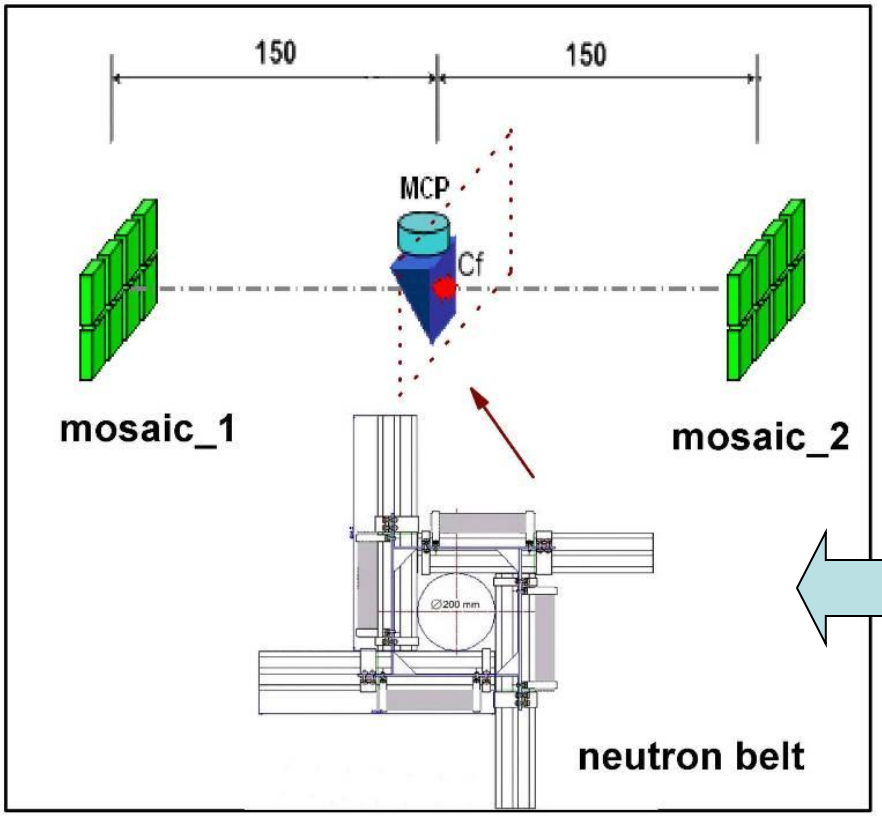


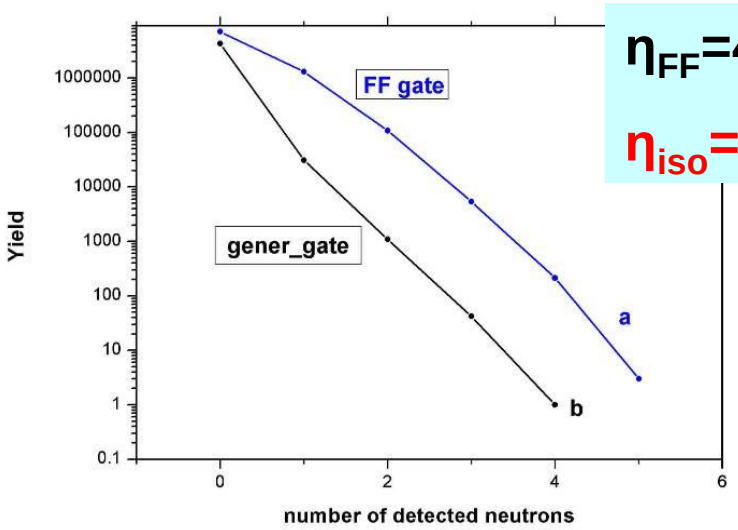
Mass of third particle





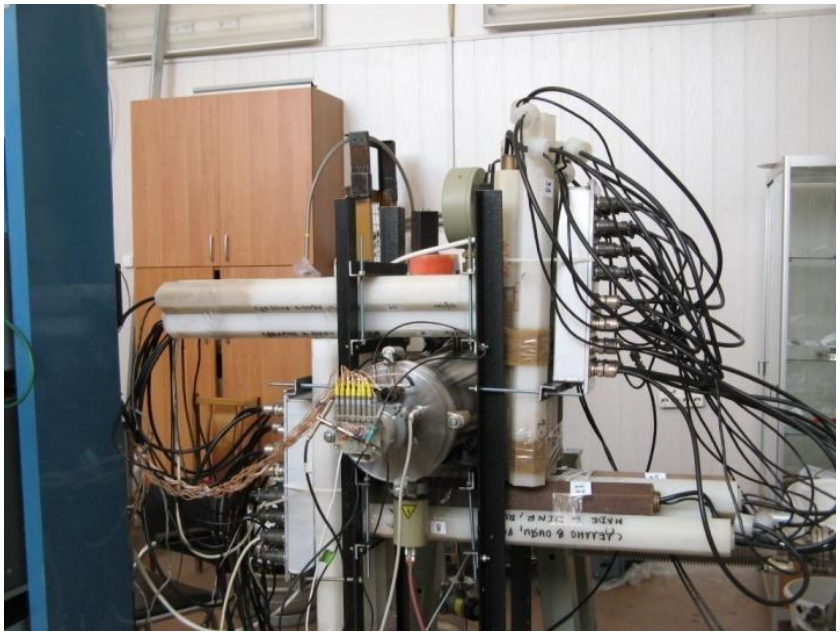
Direct registration of all the CCT products: COMETA setup (FLNR, JINR)





η_{FF}=4.5%

η_{iso}=12%



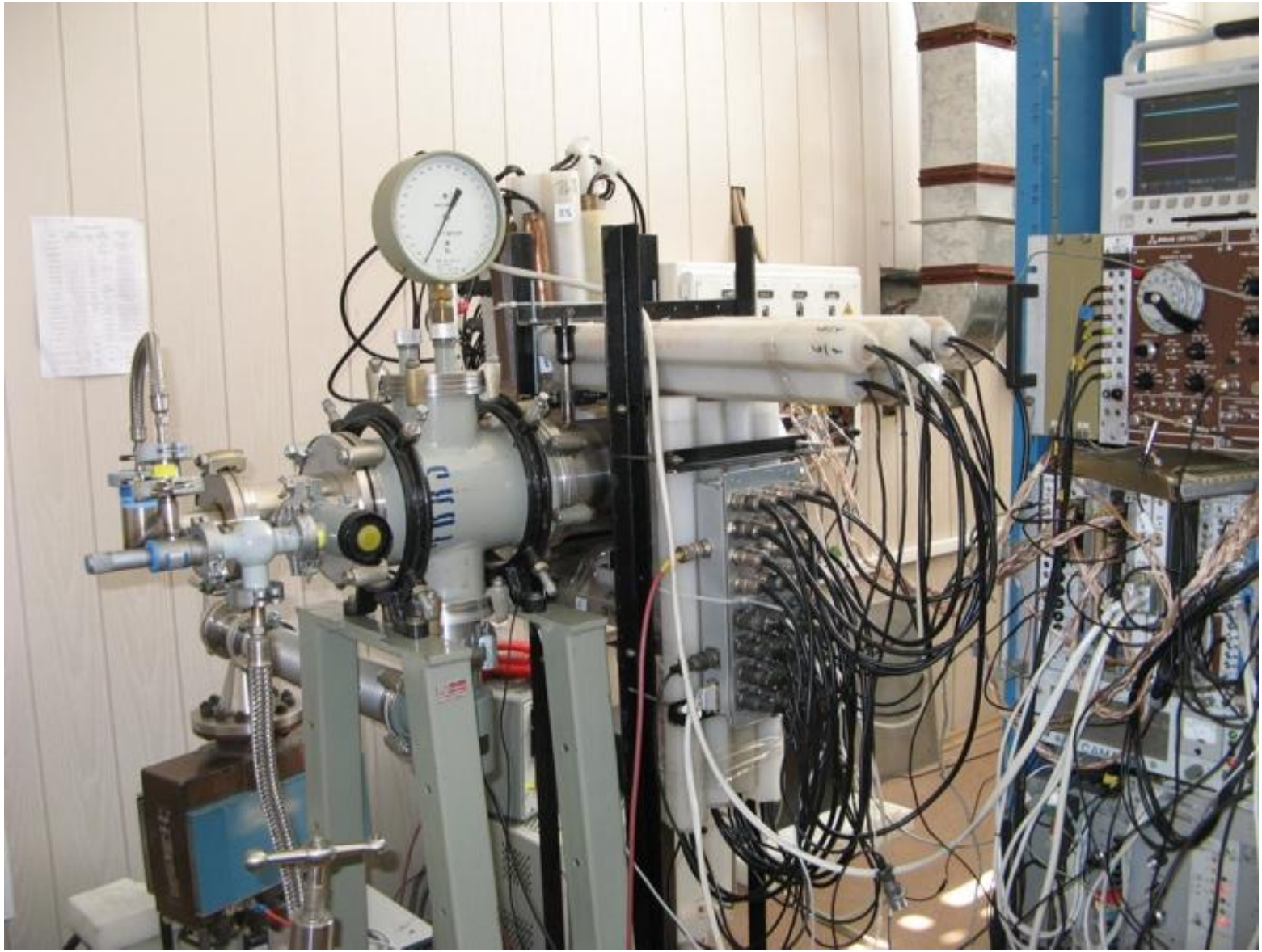
COrrelation Mosaic E-T Array

2 mosaics, 8 PIN diodes each;

MCP based “start” detector,

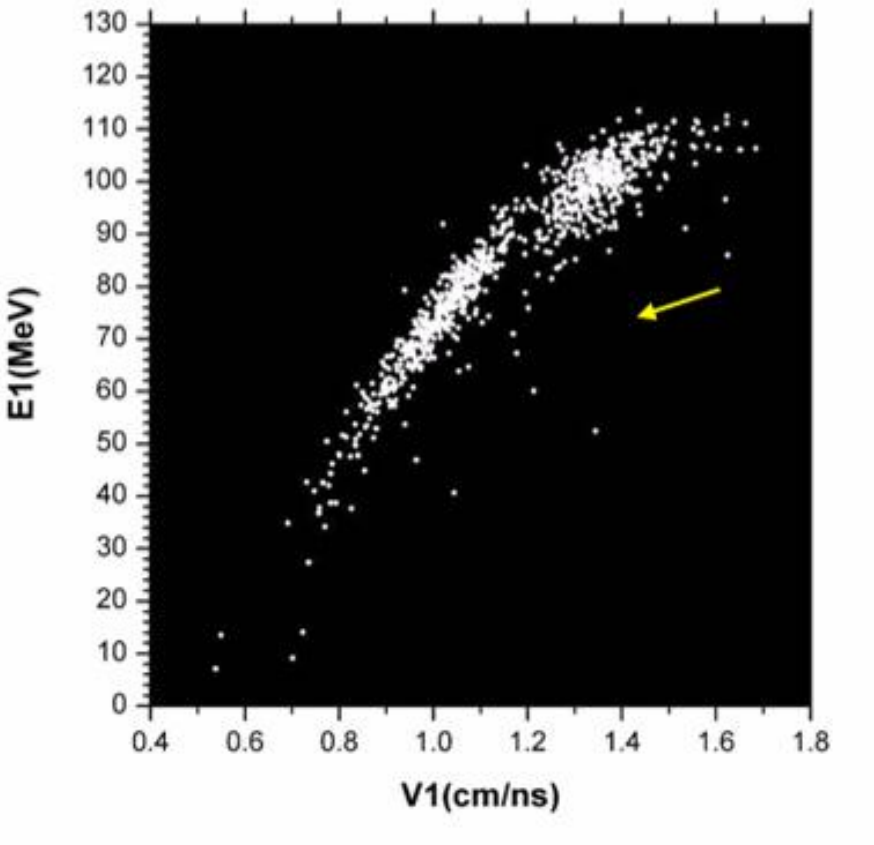
^{252}Cf source inside;

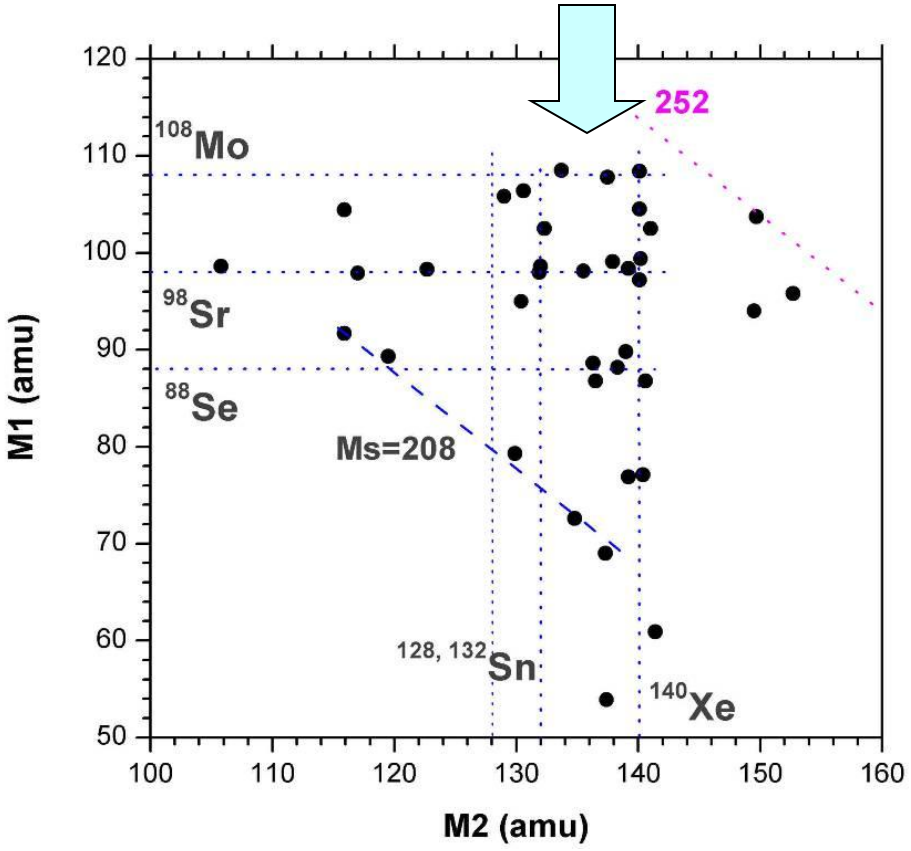
neutron belt -28 ^{3}He neutron counters



Front view of the COMETA setup

COMETA: neutron gated data, n=3





Conclusions.

1. By the direct detection of 3 fragments we confirmed the existence of the collinear cluster tri-partition (CCT) channel in the ^{252}CF(sf).

2. The middle light fragment of the 3-body chain observed is highly excited.

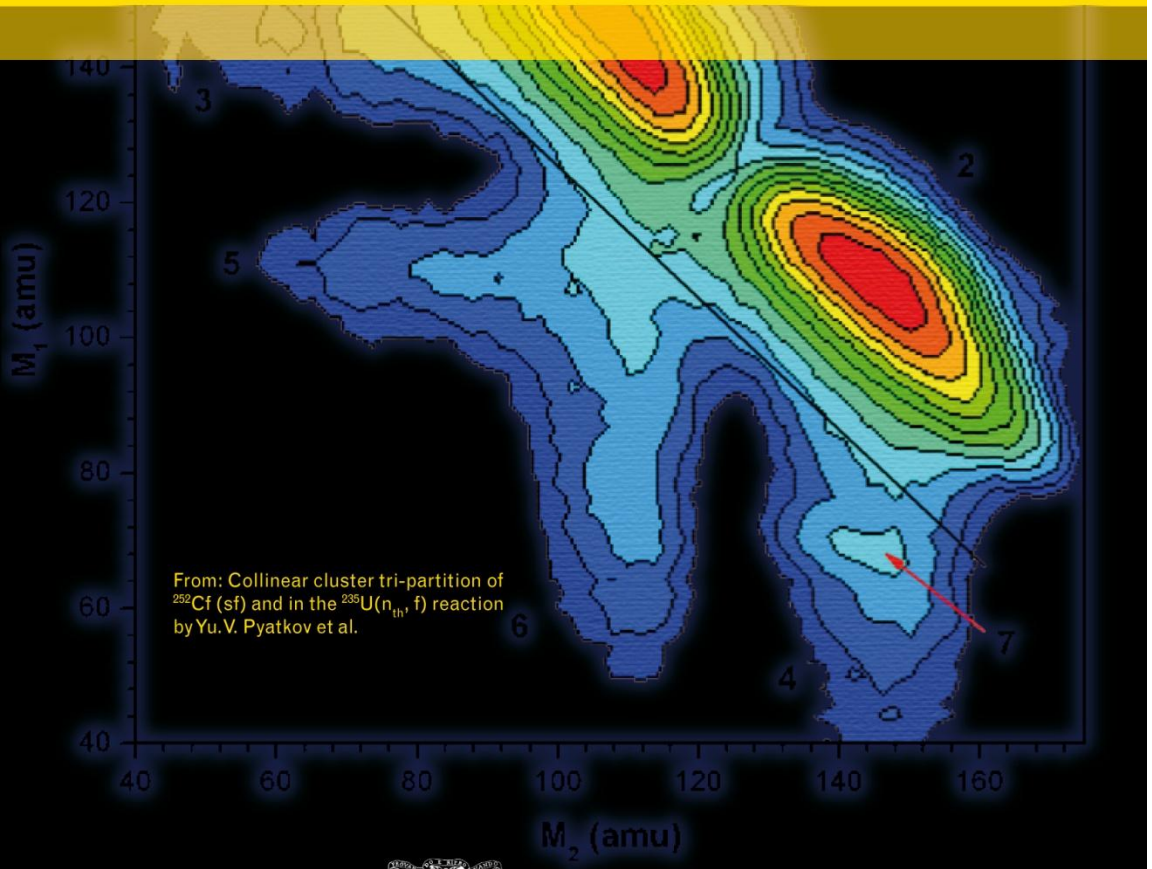
3. It stays almost at rest after scission of the system.

The European Physical Journal volume 45 · number 1 · july · 2010

EPJ A

Recognized by European Physical Society

Hadrons and Nuclei



Società Italiana di Fisica

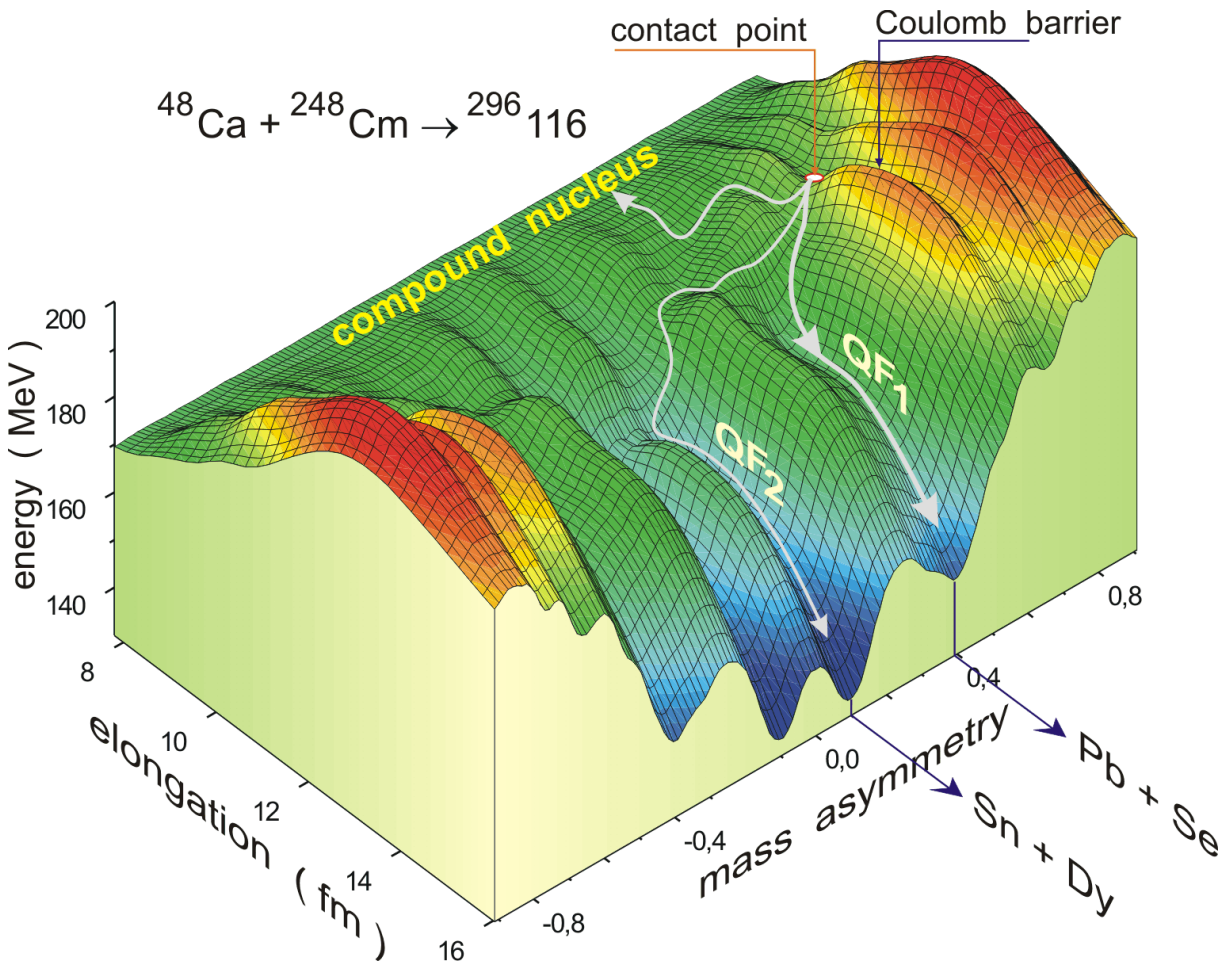
Springer

Collinear cluster tri-partition of ^{252}Cf (sf) and in the ^{235}U(n_{th}, f) reaction

Yu.V. Pyatkov, D.V. Kamanin, W. von Oertzen, A.A. Alexandrov, I.A. Alexandrova, O.V. Falomkina, N.A. Kondratjev, Yu.N. Kopatch, E.A. Kuznetsova, Yu.E. Lavrova, A.N. Tyukavkin, W. Trzaska and V.E. Zhuhcko

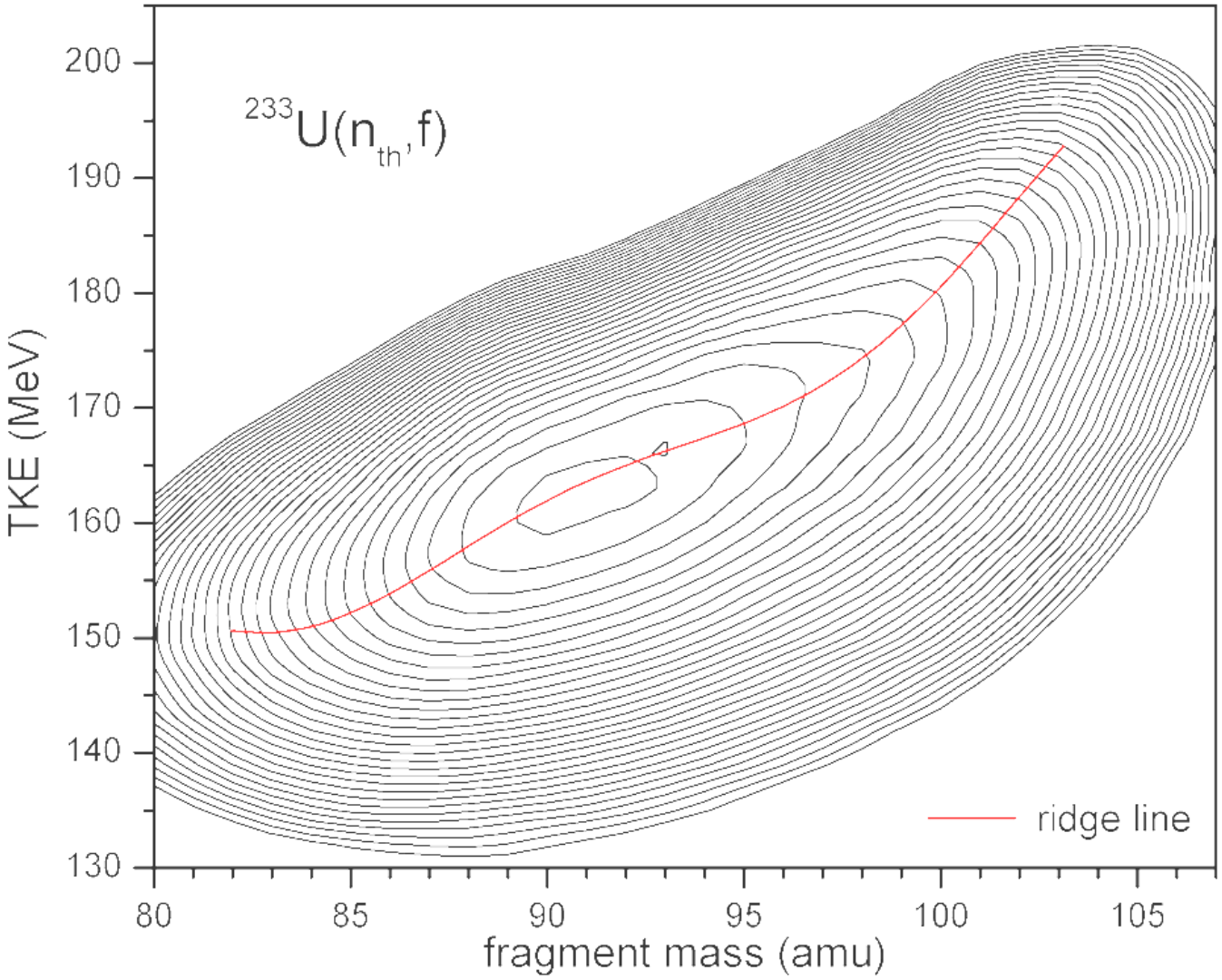
Eur. Phys. J.
A 45, 29–37 (2010)

Potential energy landscape



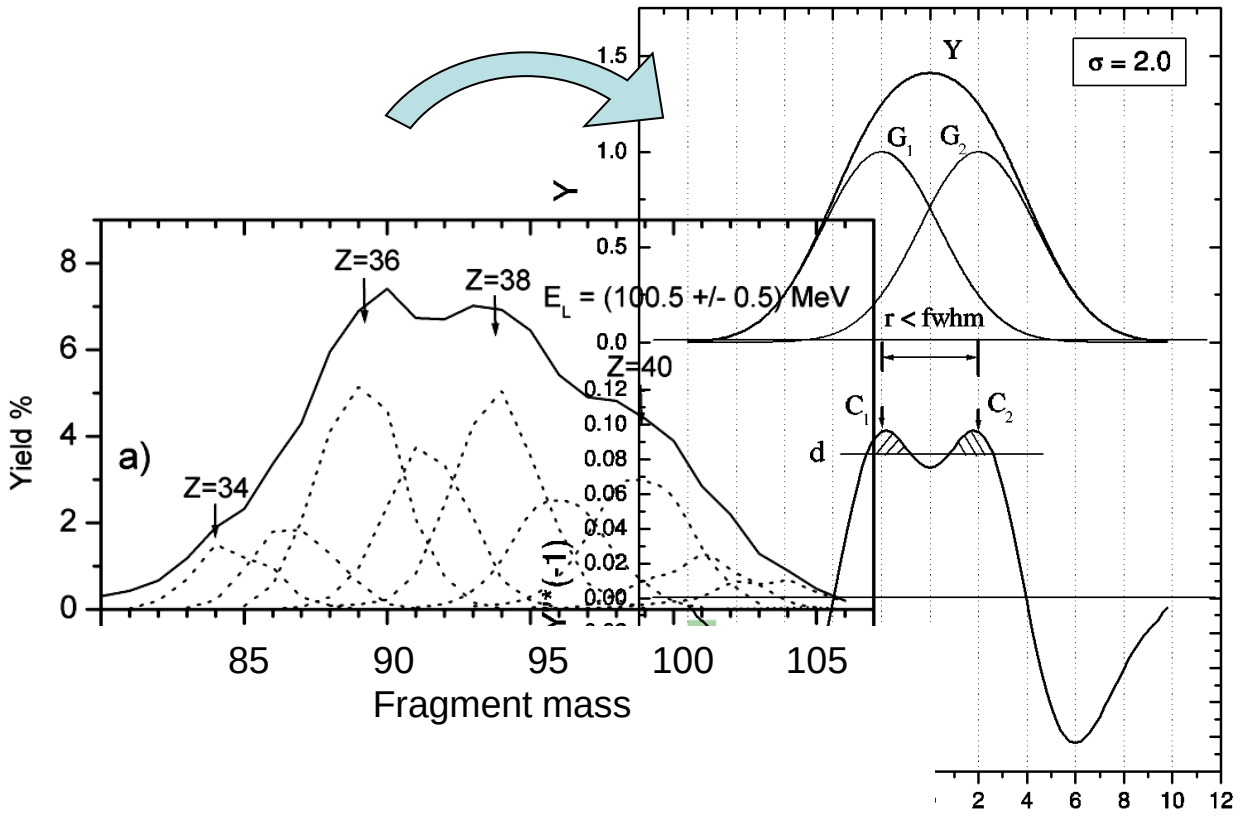
V.I. Zagrebaev, FLNR, JINR

Fine structures of mass-energy distribution



The typical contour map of the experimental mass-energy distribution

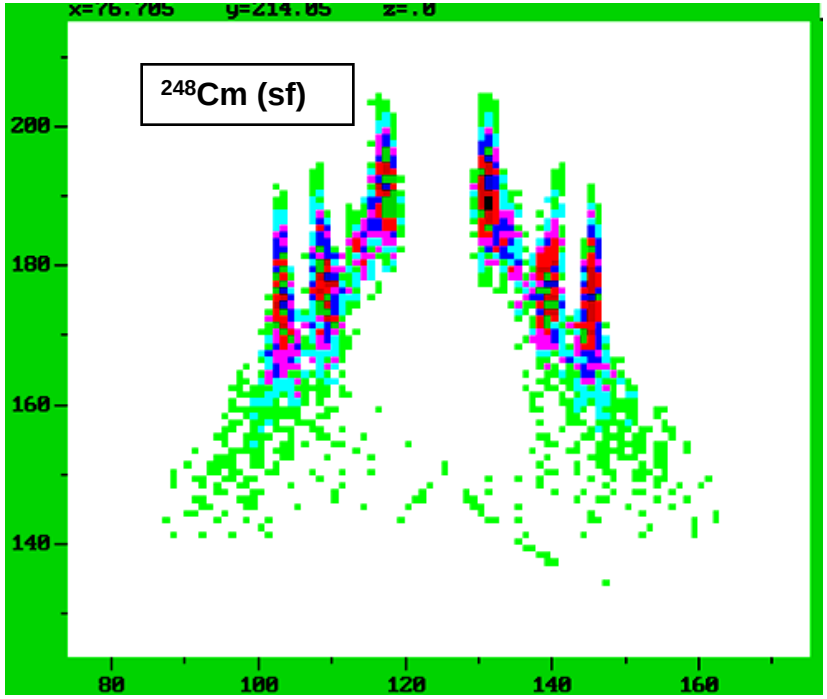
Fine structure of the mass (charge) distribution



solved doublet by
erivative method

Proton odd-even staggering

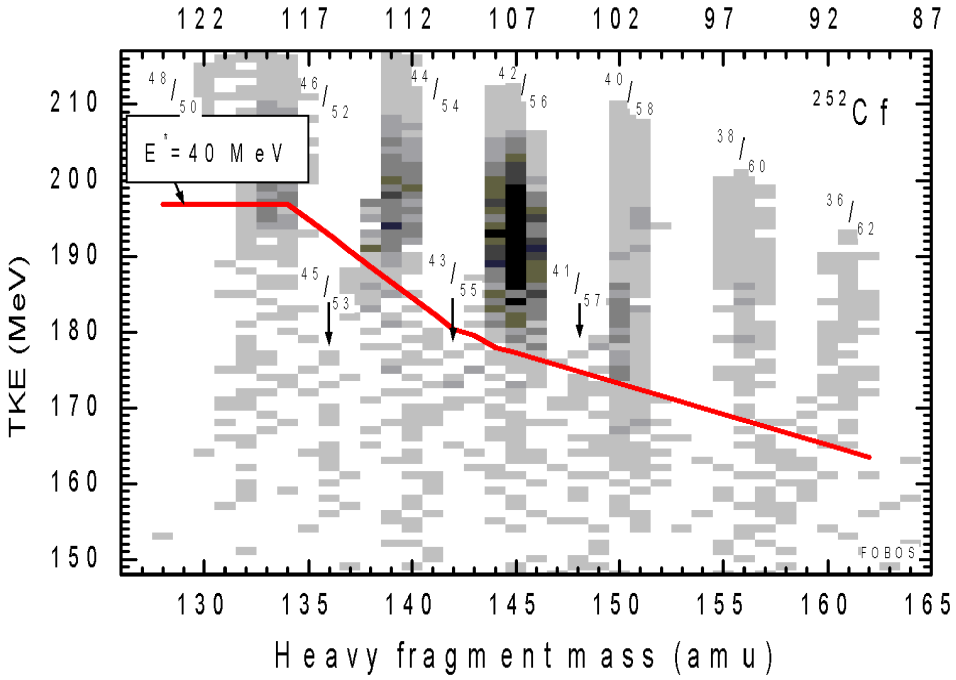
E-E method



mass (amu)

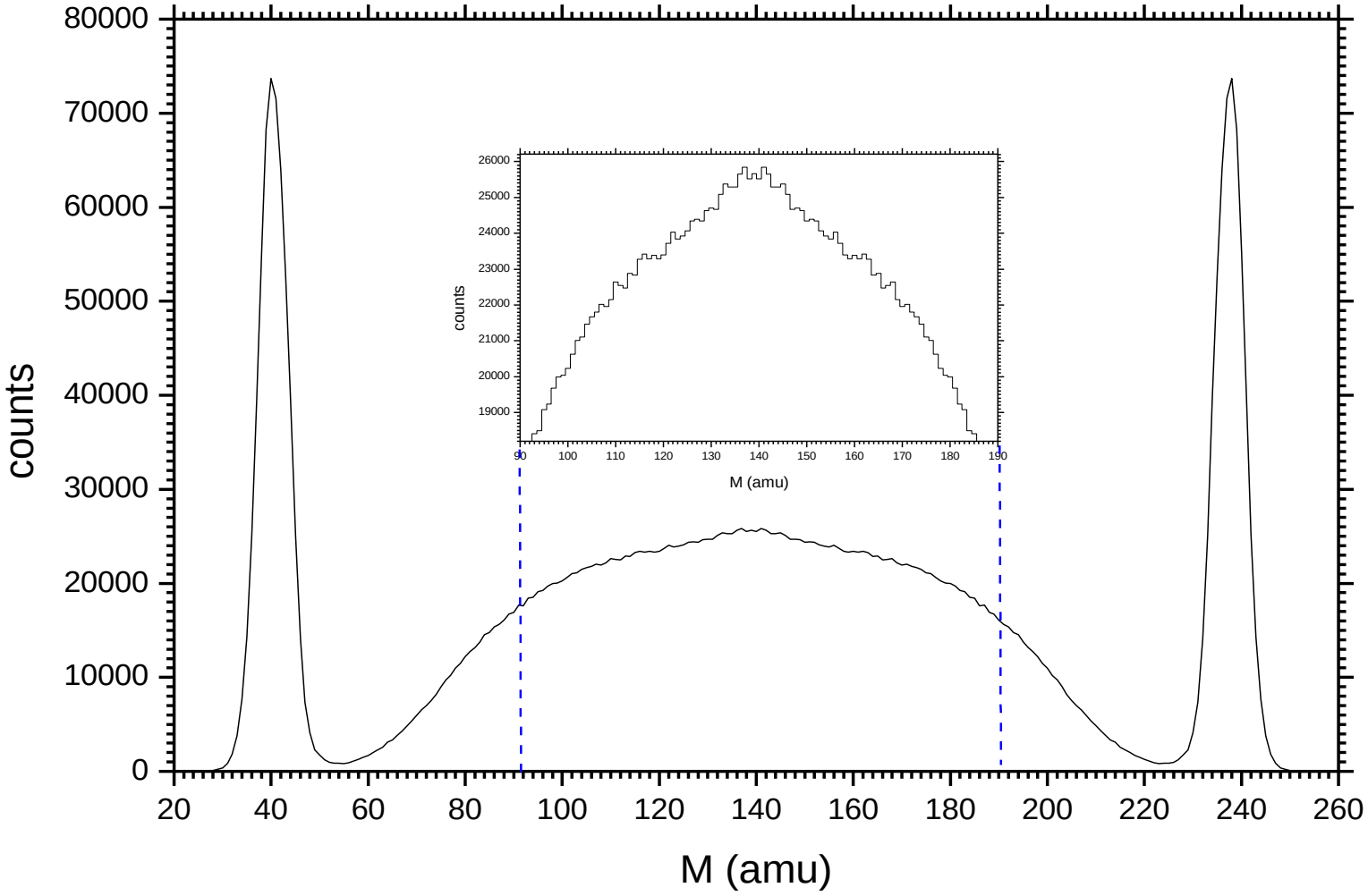
V. Kalinin et al.

TOF-TOF method (FOBOS setup)



Yu.V.Pyatkov, Nucl. Phys. A 624 (1997) 140

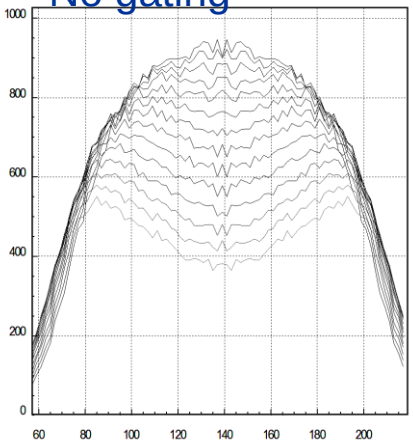
$^{238}U+^{40}Ar$ (275 MeV)→$^{278}110$



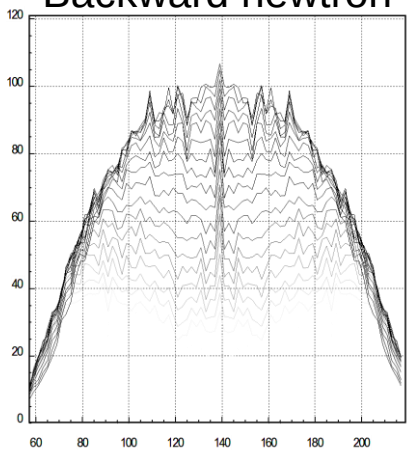
Projection of TKE vs. fragment mass matrix collected in the reaction ^{238}U + ^{40}Ar at E_{Ar} = 275 MeV. The inset shows enlarged center part of the plot revealing small but statistically significant ripples.

$^{238}U+^{40}Ar$ (275 MeV)→$^{278}110$

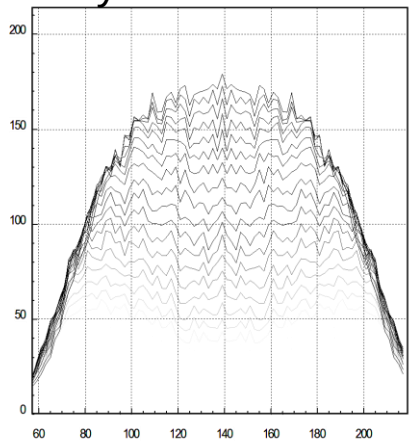
No gating



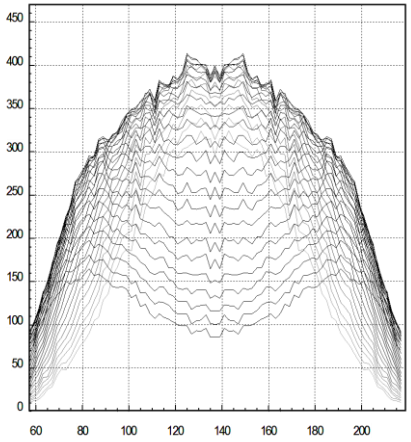
Backward newtron



Any neutron



Gamma



Mean values of sequential 2 MeV wide slices of the TKE-M matrix

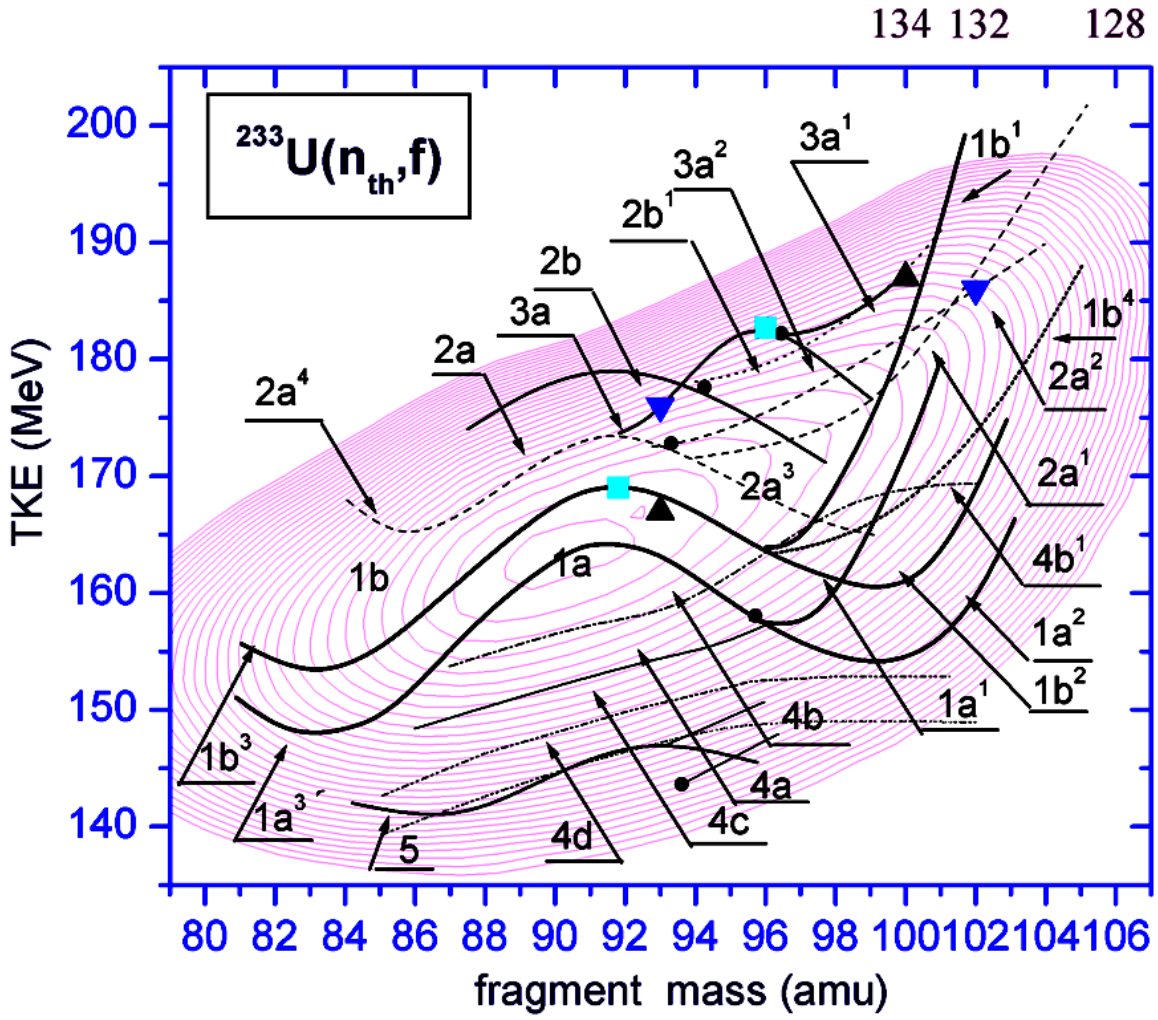


Fig.1 A map of the fine structures in the M-TKE distribution of the fission fragments originated from the reaction ^{233}U (n_{th},f), superimposed on the contour map of the experimental mass-energy distribution.

Yu.V. Pyatkov et al.,
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Is that's true what we see?