SEARCHING FOR NEW KIND OF FISSION ISOMERS IN ACTINIDE NUCLEI

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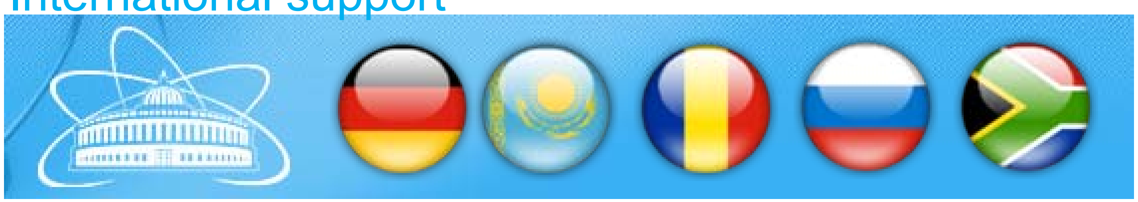
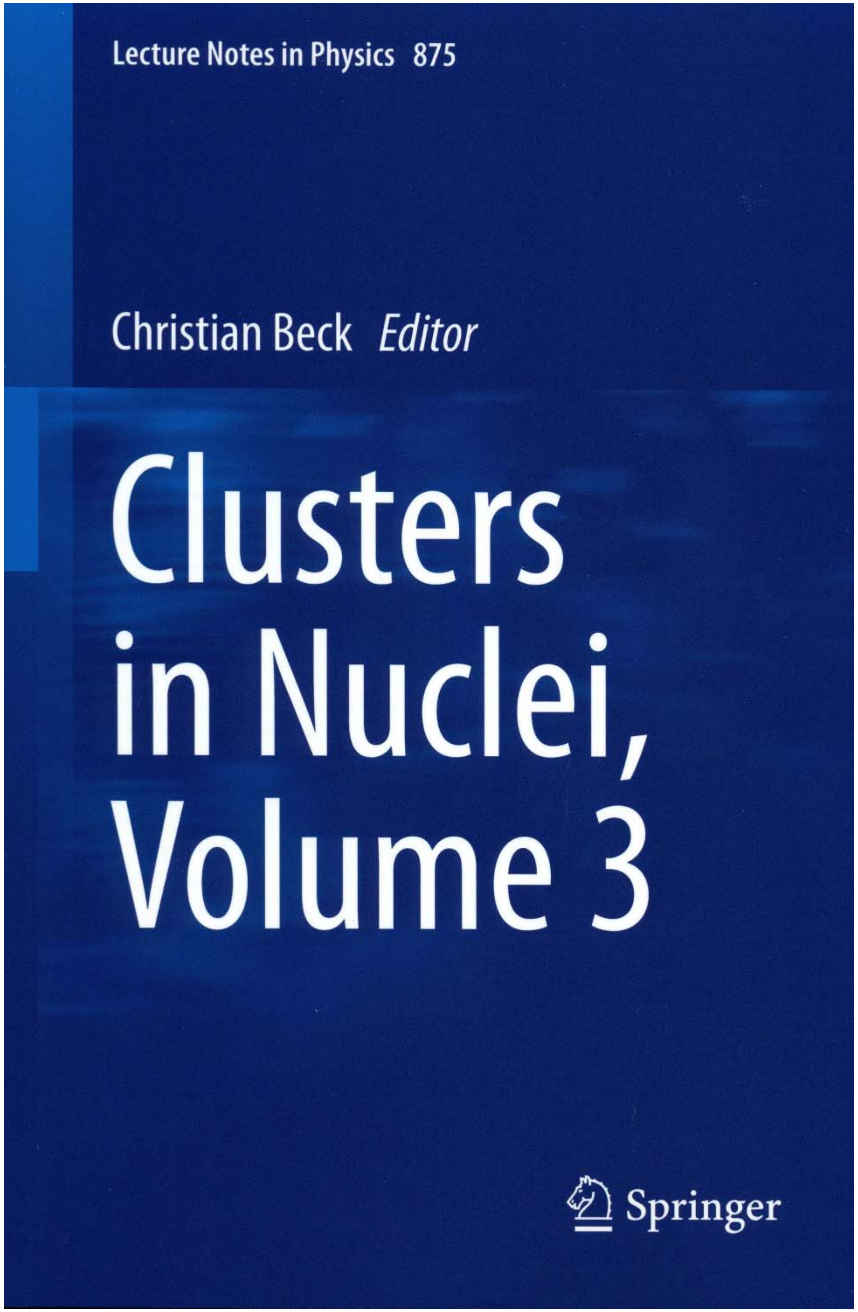
[2] *National Nuclear Research University “MEPHI”, Moscow, Russia;*
[3] *University of Stellenbosch, Faculty of Military Science,*

International support

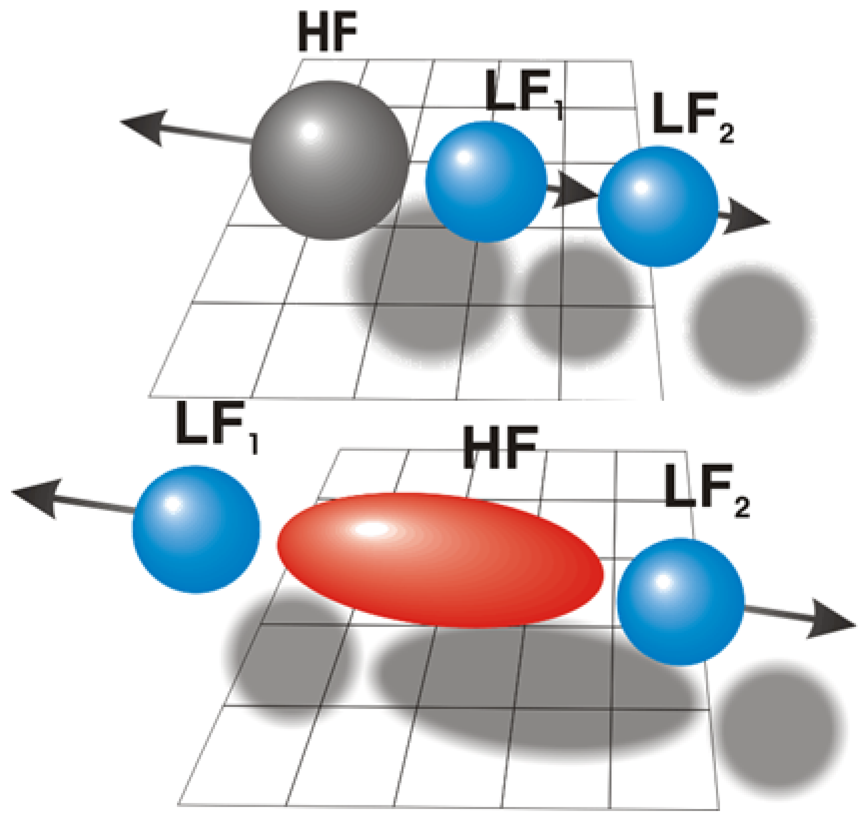




D.V. Kamanin, Yu. V. Pyatkov

"Clusters in Nuclei - Vol.3"

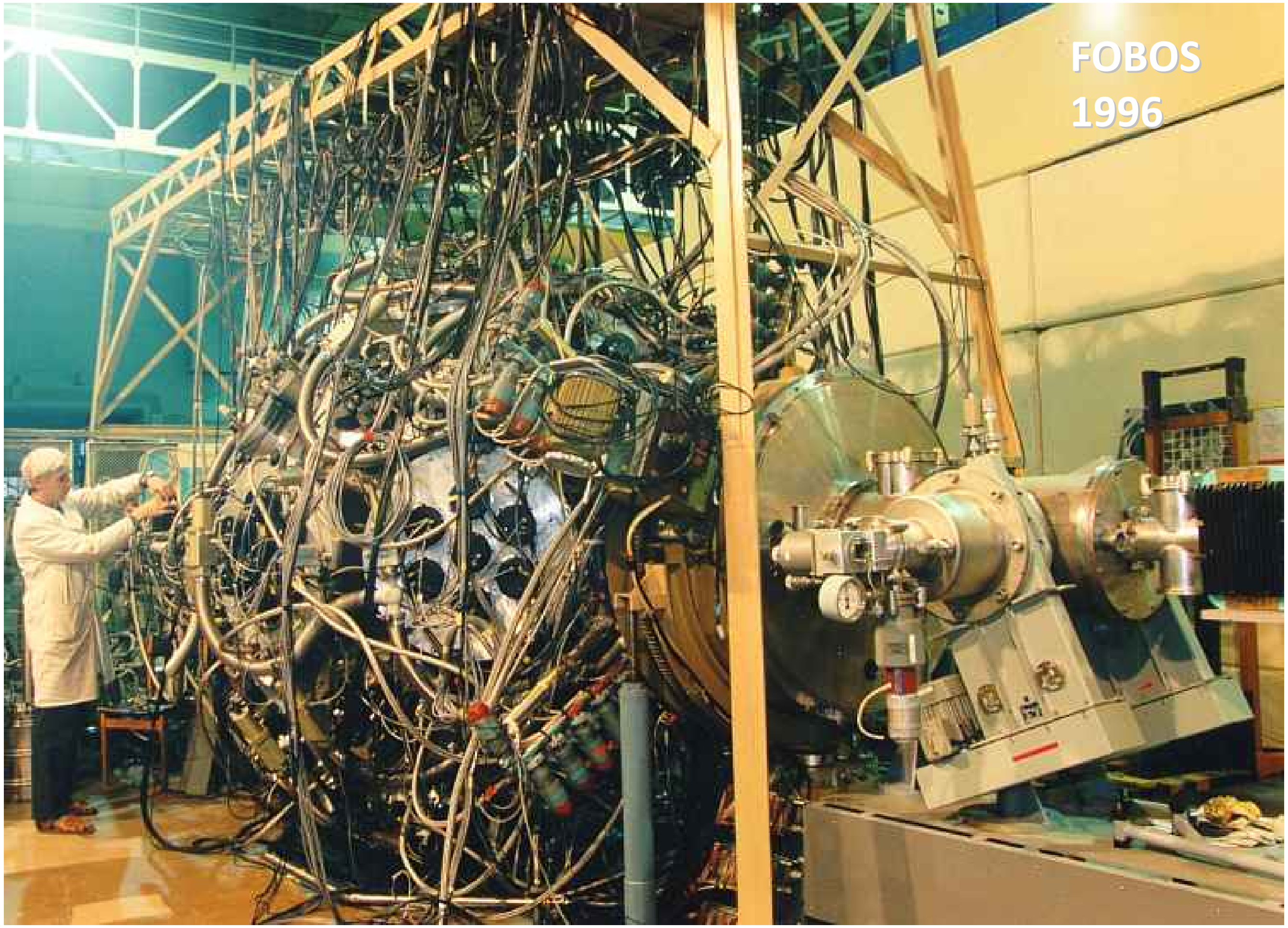
ed. by C. Beck, Lecture Notes in Physics 875, pp. 183-246 (**2013**)



Collinear Cluster Tripatition

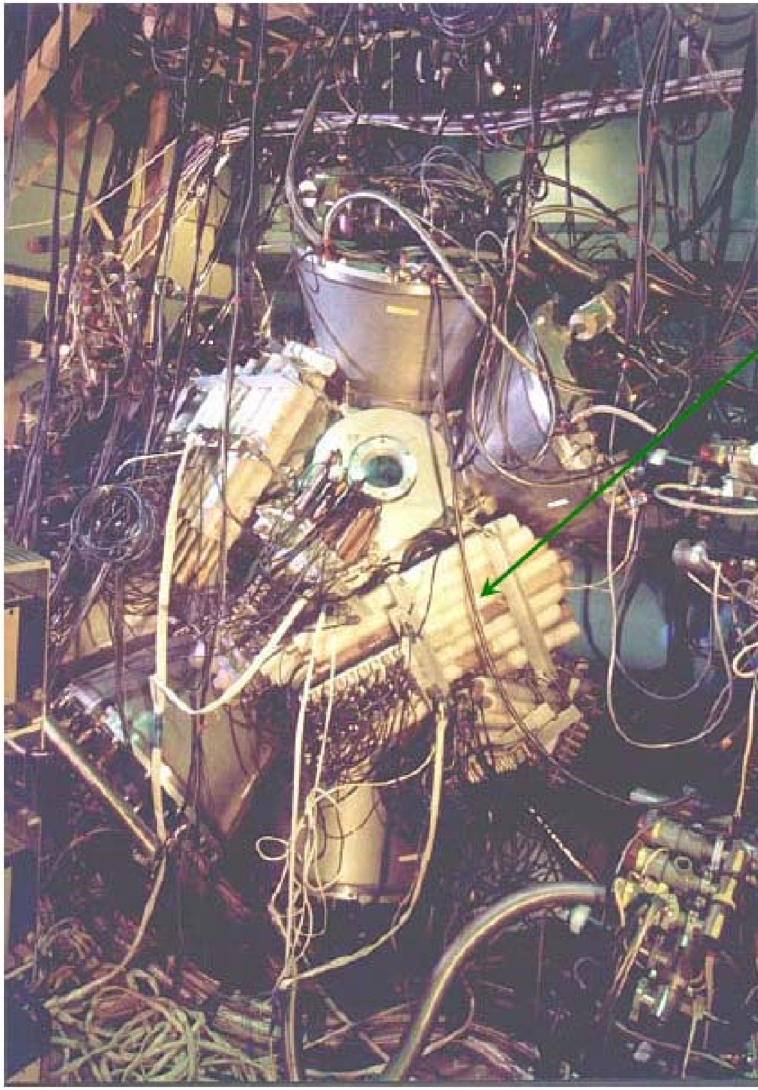
More publications: *fobos.jinr.ru*

FOBOS setup



Experimental steps: FOBOS →modified FOBOS →mini-FOBOS→COMETA

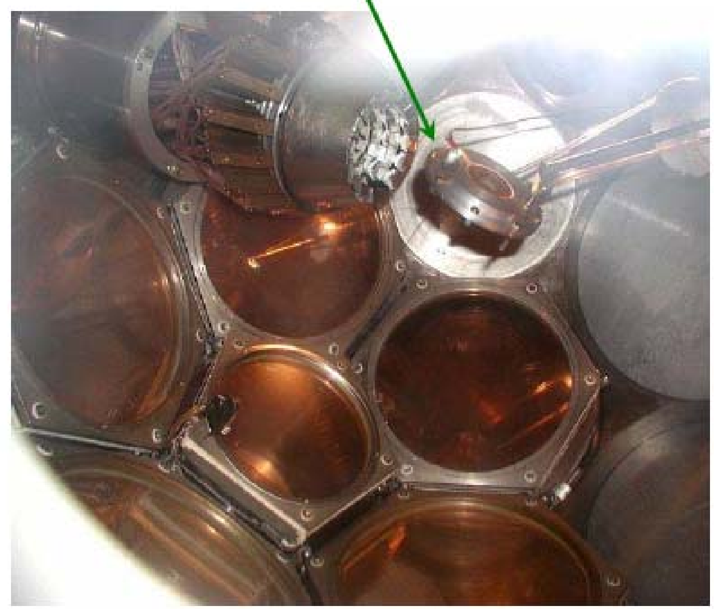
missing mass approach, Z -sensitive variables & experimental neutron multiplicity ν_{exp} for selection of the CCT events



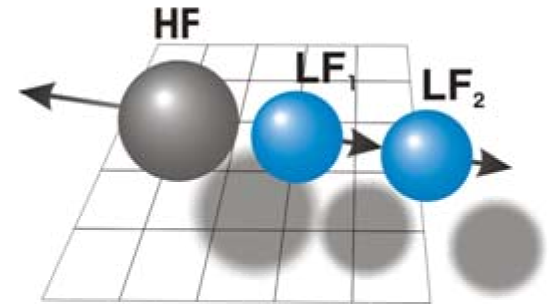
Double arm spectrometer
6+6 modules

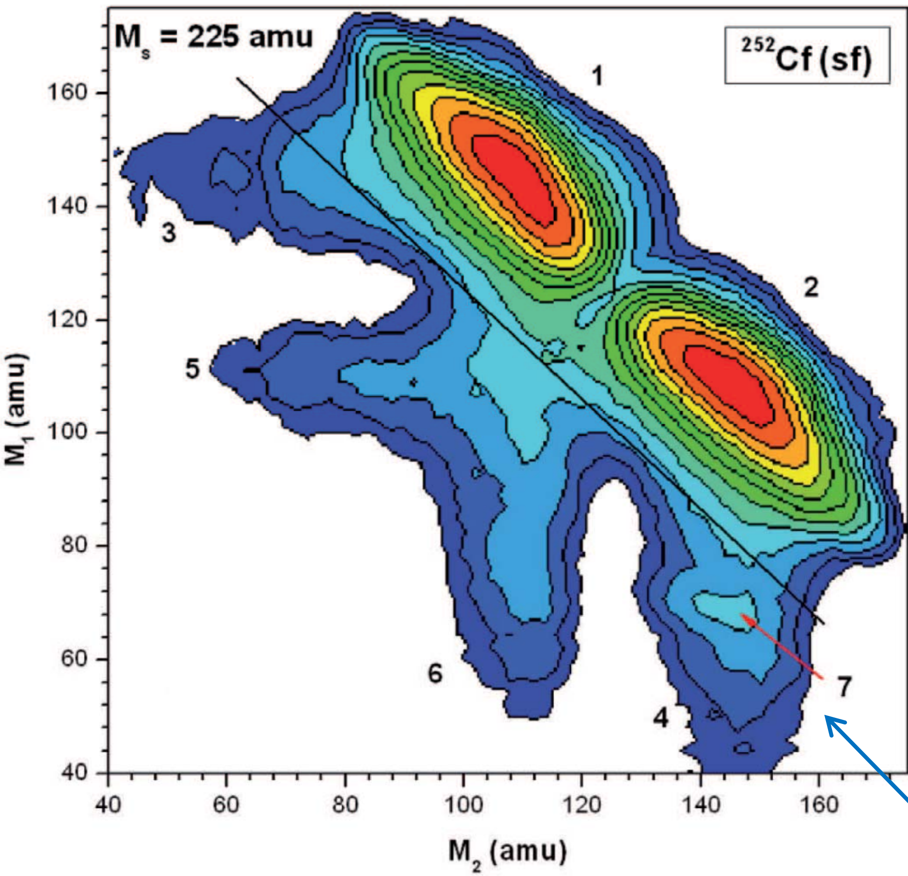
Neutron belt of FOBOS
140 ^{3}He (7 bar) conuters
In PE-moderator

Start PAC
with internal ^{252}Cf source

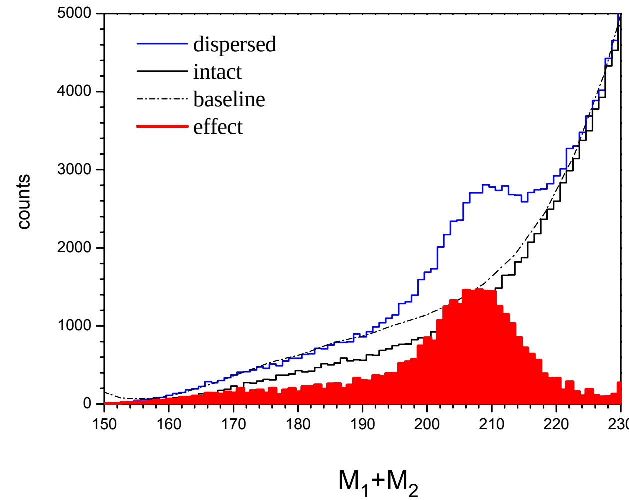


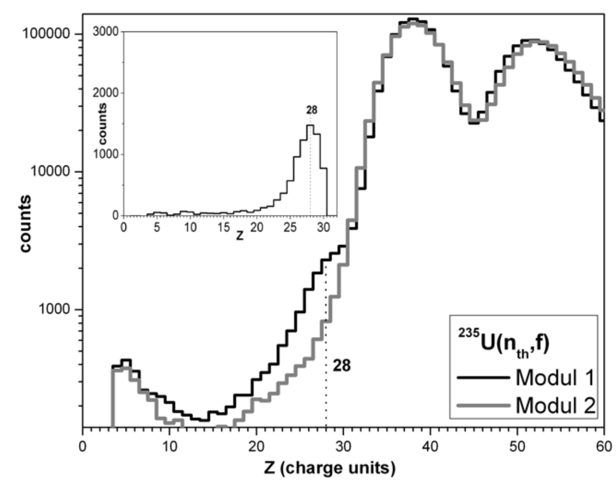
CCT gross-structure (bump) in ^{252}Cf (sf)





Difference between the arms

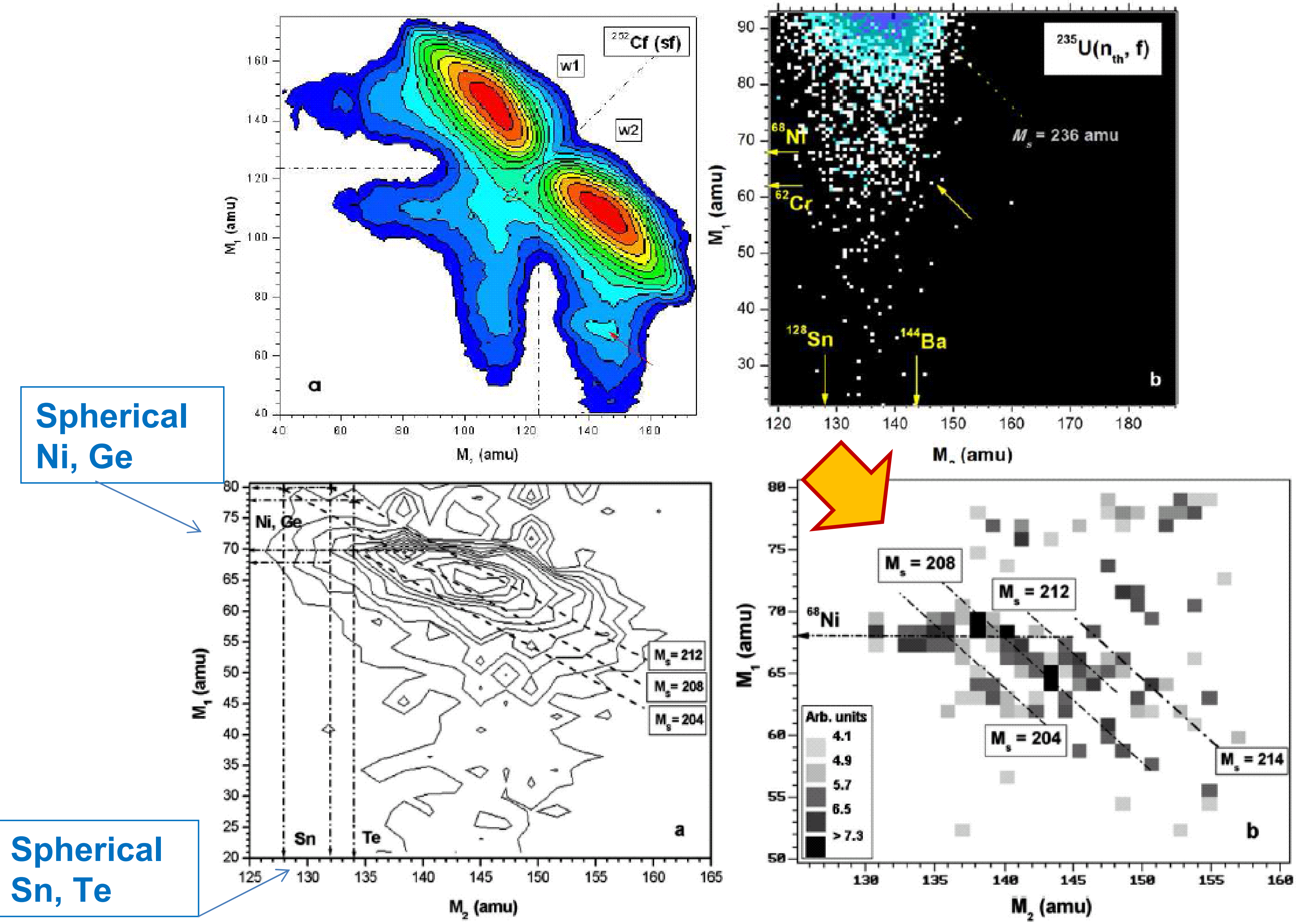




Pyatkov, Kamanin et al.,
Eur. Phys. J. A 45, 29–37 (2010)

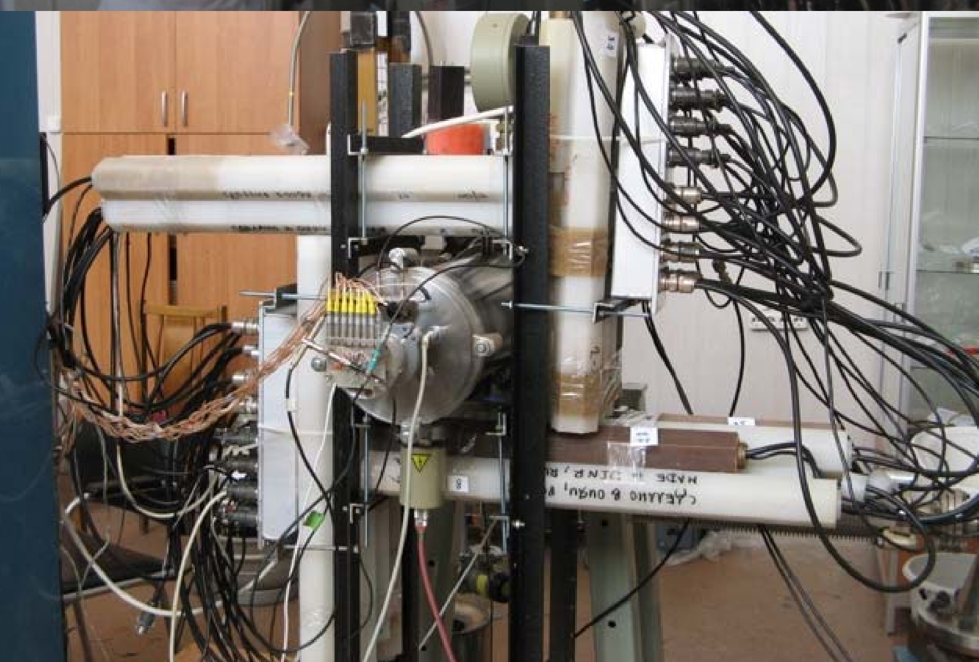
Effect is seen in the arm from the side of scattering foil only.

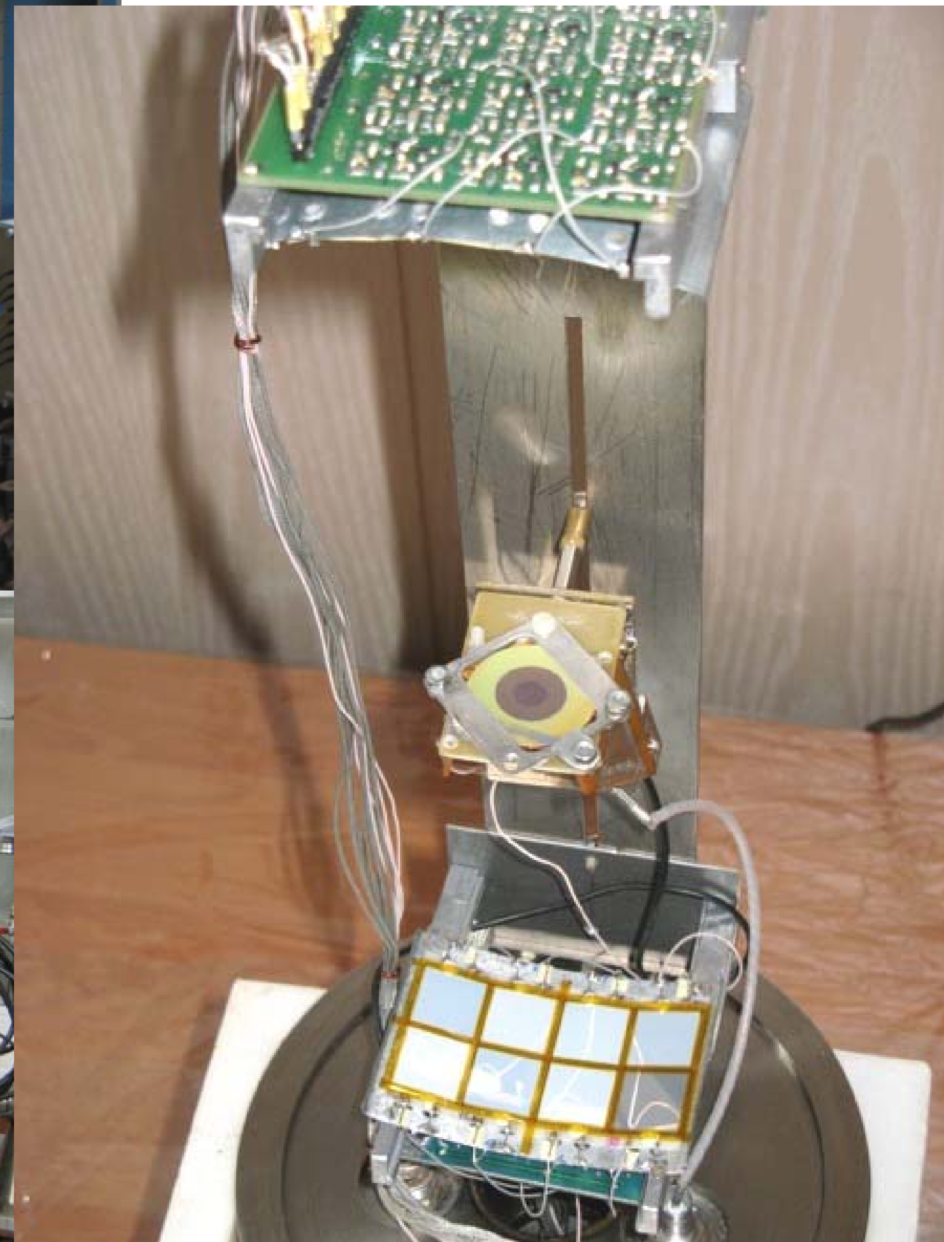
"Ni-bump" in M_1-M_2 plots & its internal structure. FOBOS & mini-FOBOS



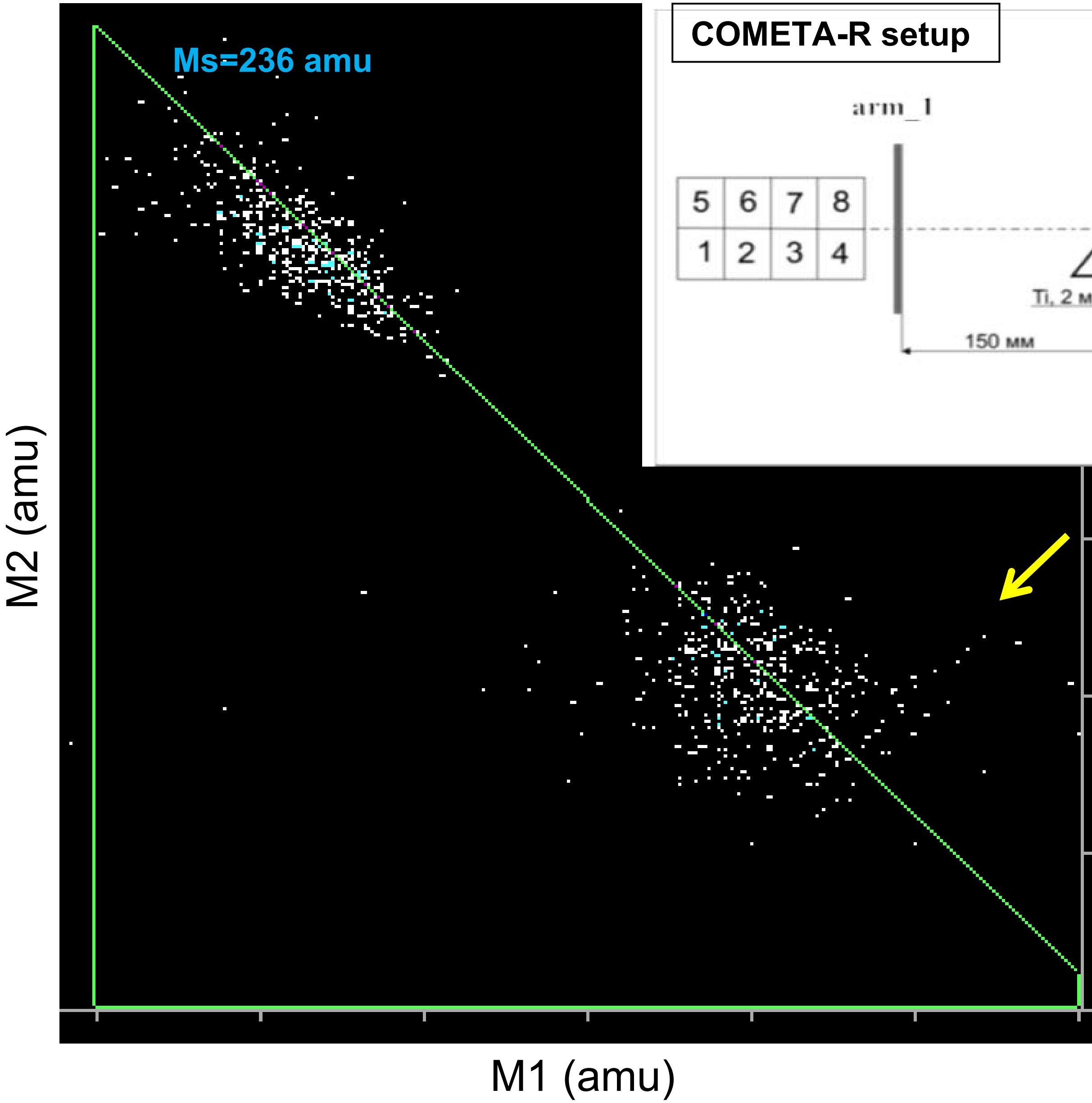
New experiments

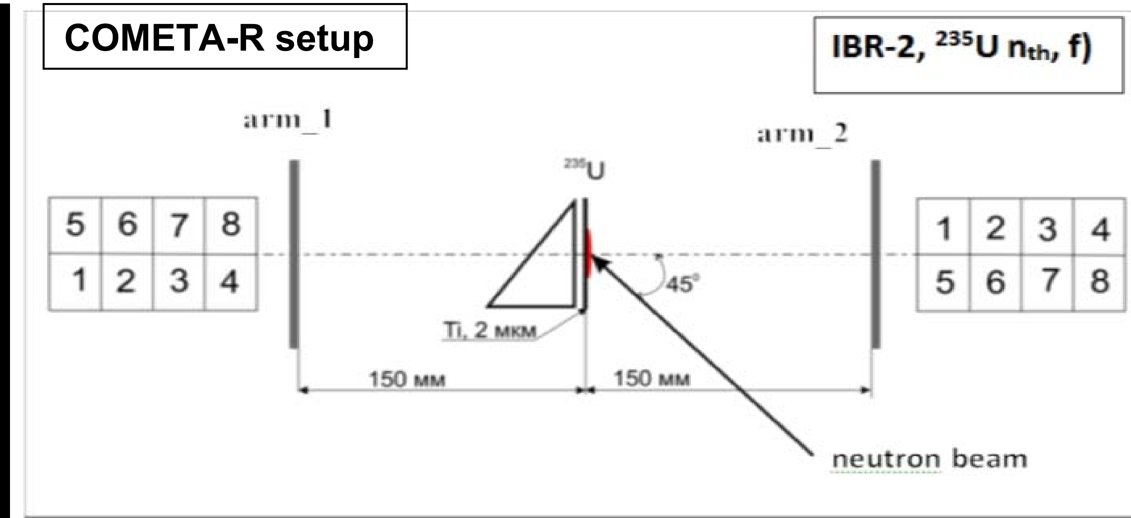
COMETA= COrrelation Mosaic E-T Array





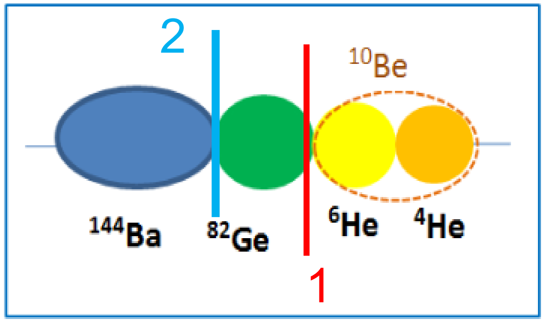
Mass-mass distribution from $^{235}U(n, f)$ reaction. Strange lines M1=M2+const





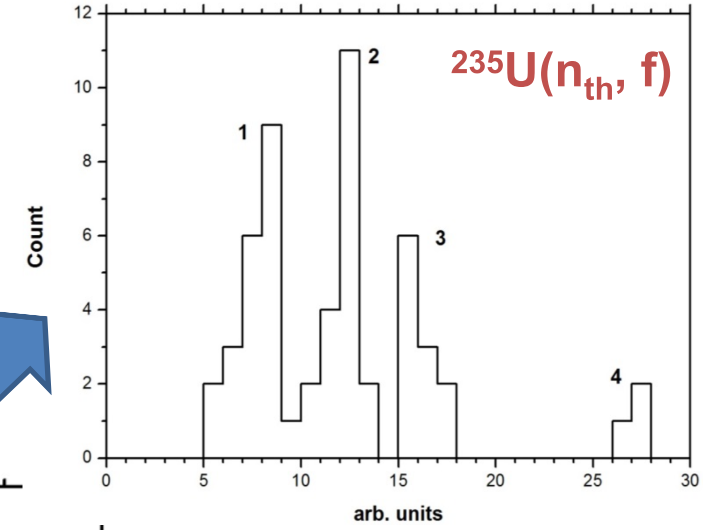
"Unphysical" prolongation of the lines into the region far above of the mass of the mother system…?!

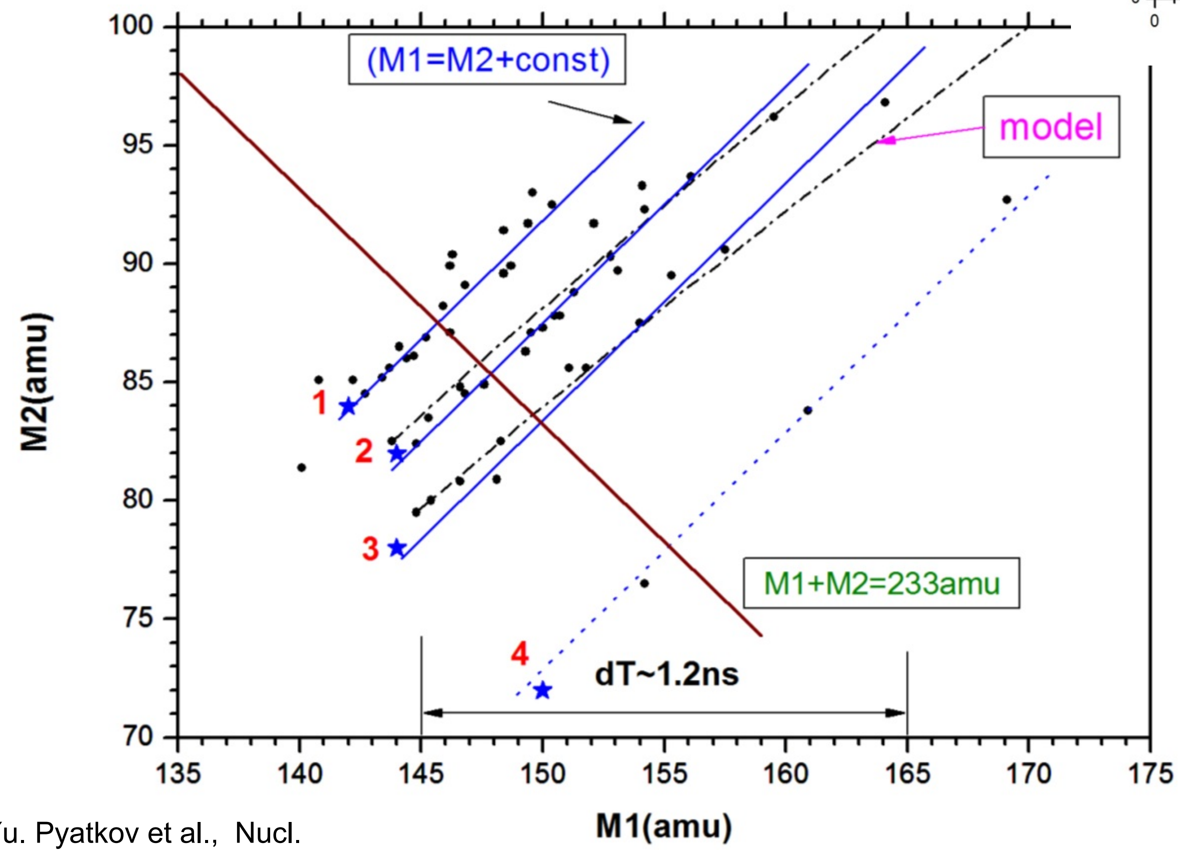
Line structures in detail



supposed config. №2

projection





Yisom ~10^{-4}/bin. fiss.

1) 85As-142Cs-10Be

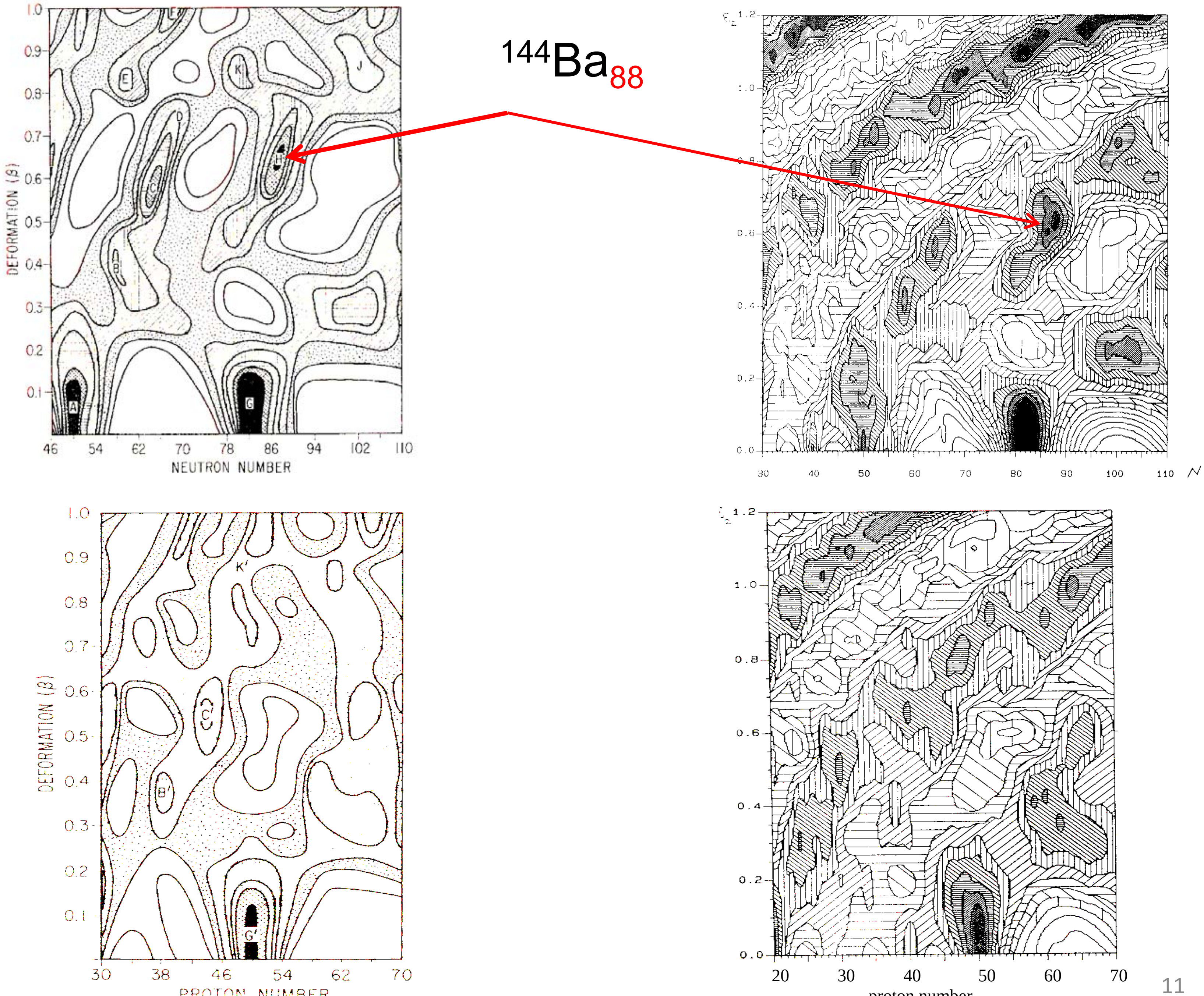
2) 82Ge-144Ba-10Be

3) 78Zn-144Ba-14C

4)72Ni-150Ce-14C

Two magic clusters & LCP

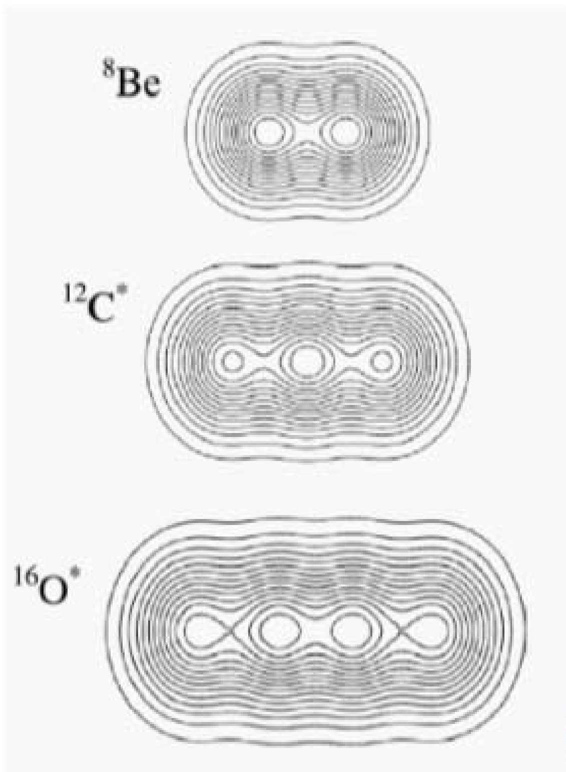
Yu. Pyatkov et al., Nucl. Phys. A 611 (1996) 355

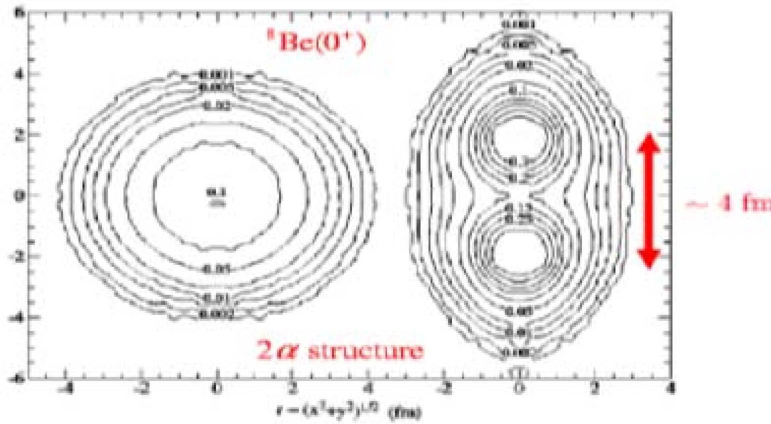


B.D. Wilkins et al., Phys Rev. C 14 (1976) 1832

(H.Märton, privat

Density distributions of ^{8}Be, ^{12}C and ^{16}O



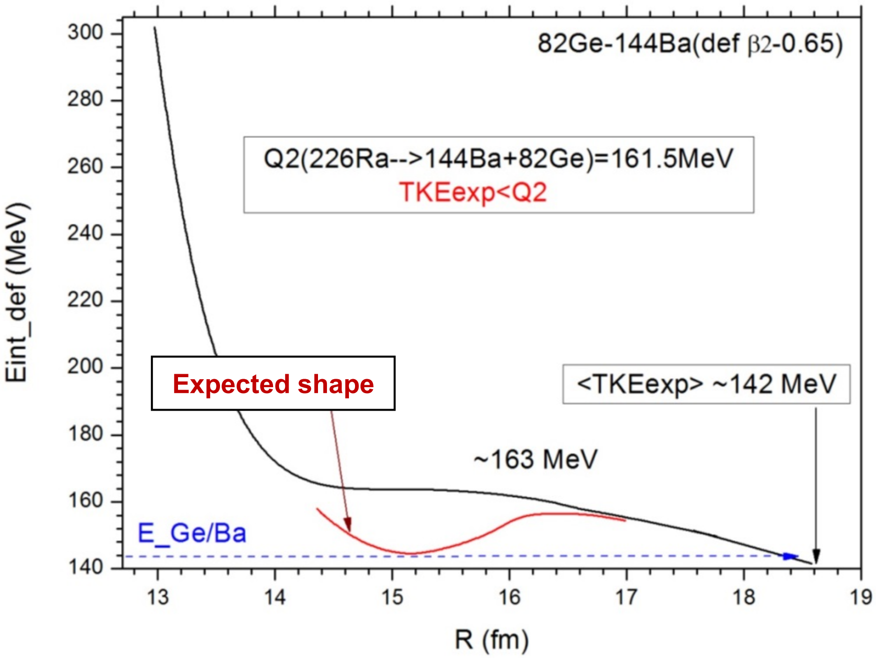


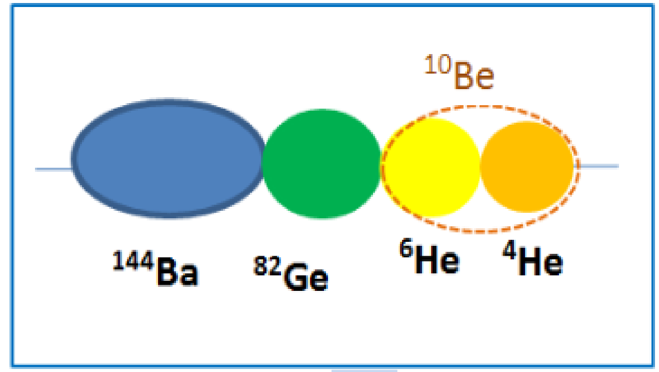
Quantum Monte Carlo *Ab-initio* Method (R.B. Wiringa. S.C. Pieper, P. Navratil)

Ab-initio No-Core Shell Model (J.P. Draayer, J.P. Vary)

Deformed harmonic oscillator (M. Freer)

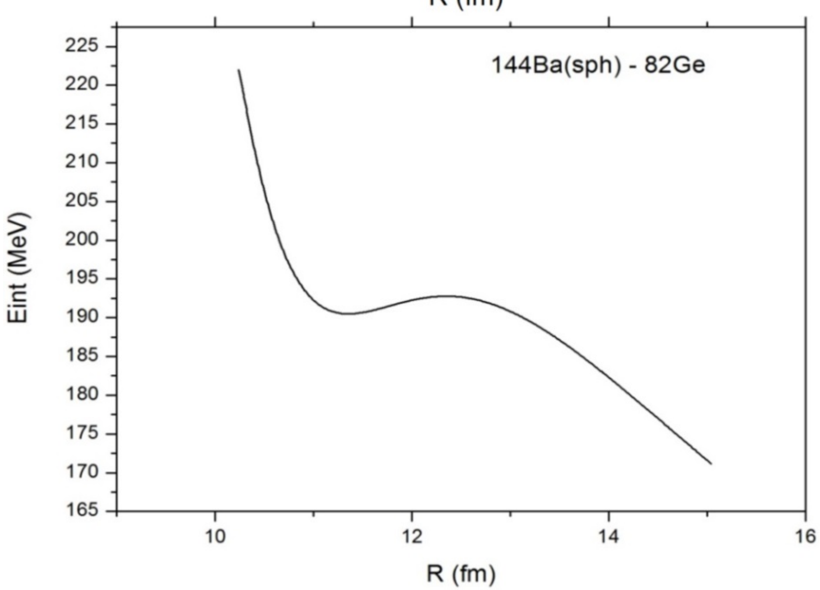
Interaction energies for one of the ternary prescission configurations, $^{235}U(n_{th}, f)$

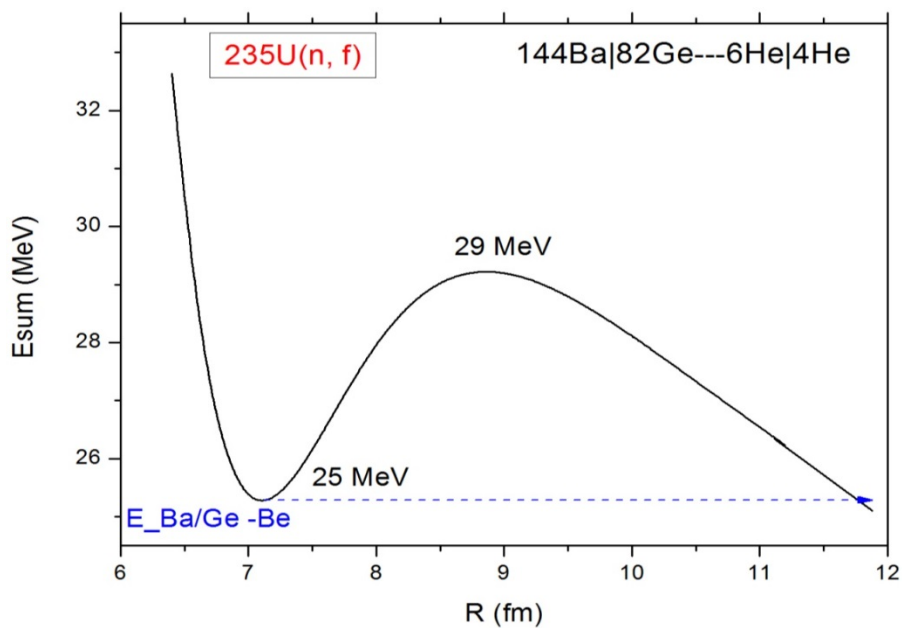




Q3 (236U + Bn)-->
82Ge+144Ba+10Be=173MeV

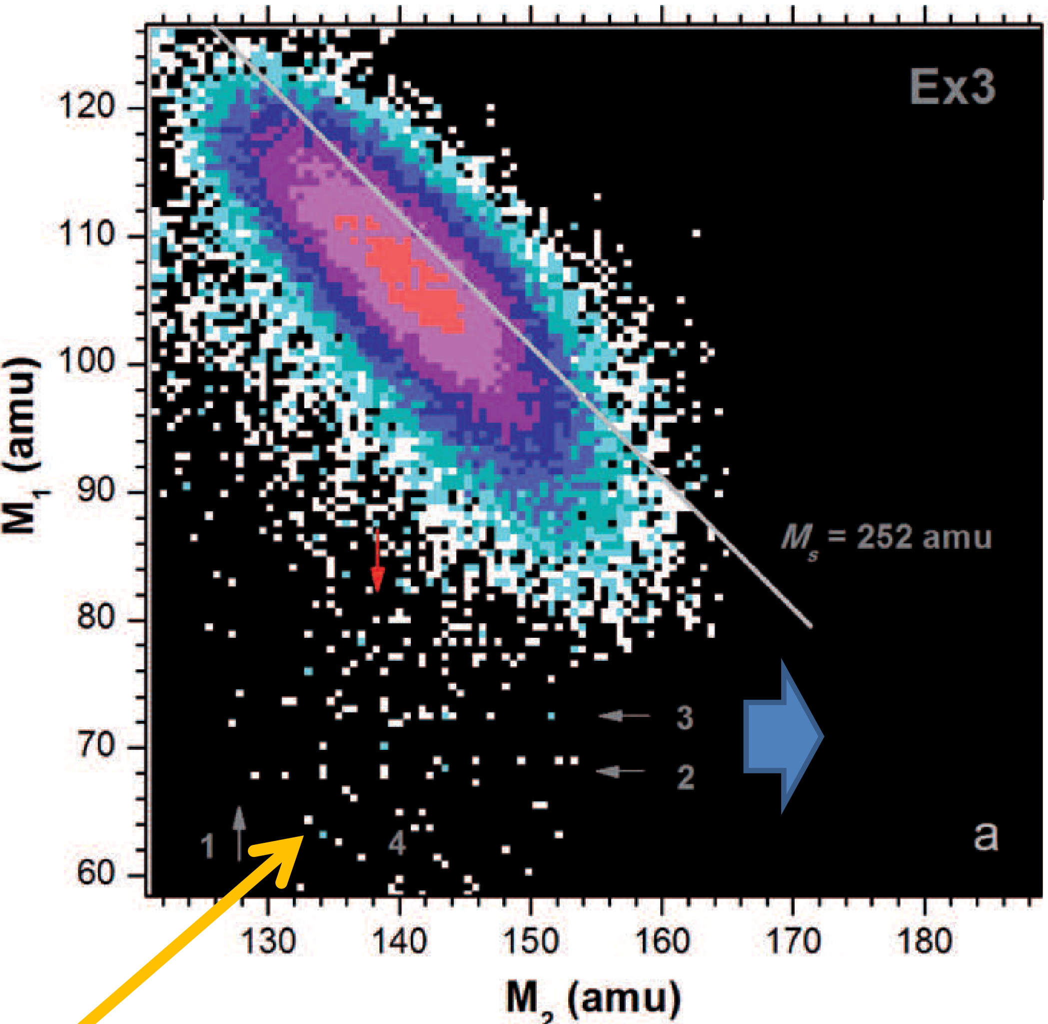
E_Ba/Ge-Be+E_Ge/Ba~<Q3



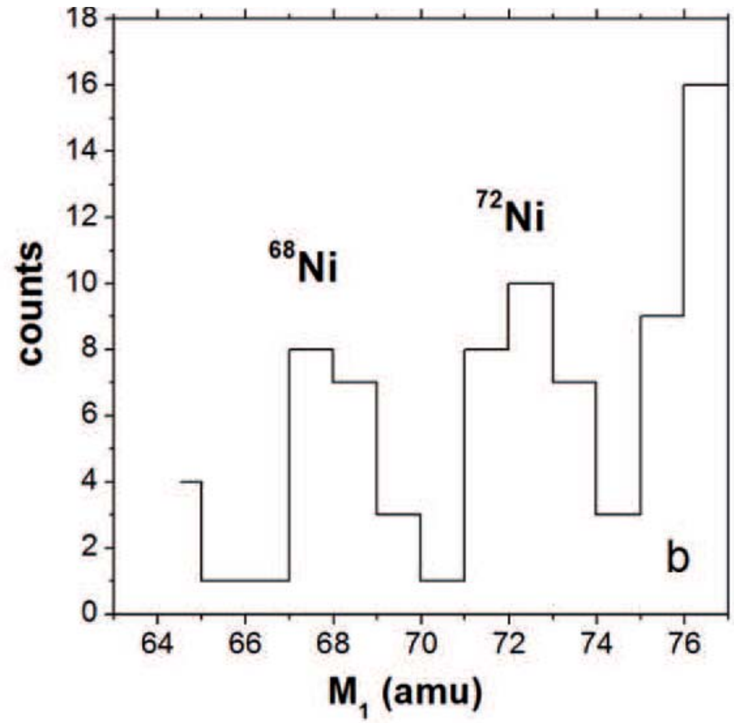


Strong dependence from the deformation

COMETA setup, ^{252}Cf(sf), M1+M2=const linear ridges



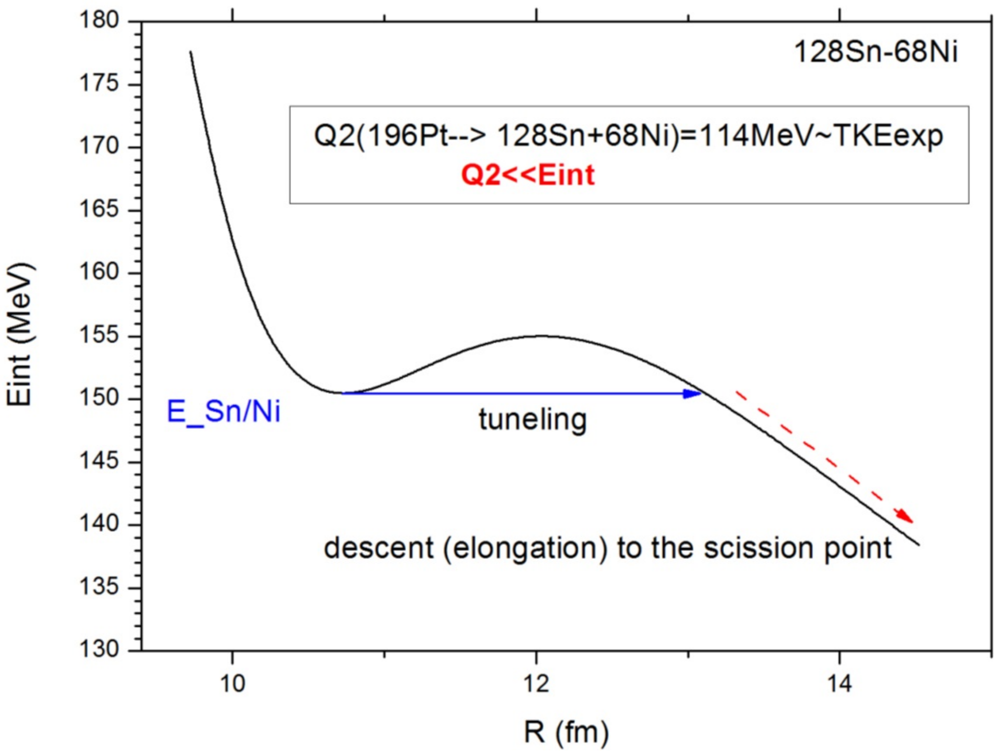
Projection onto M1 axis

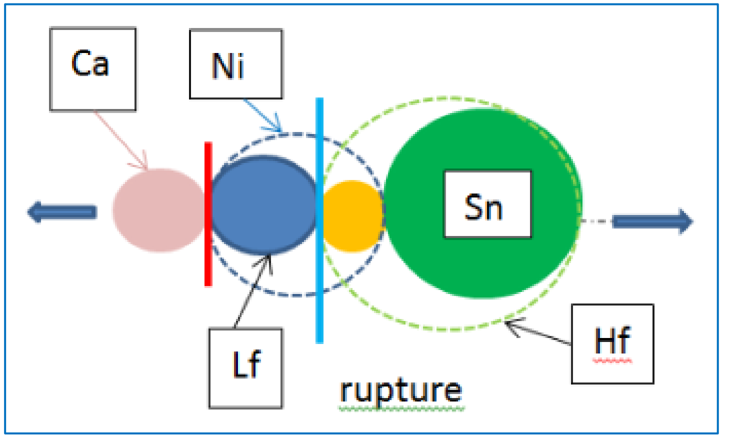


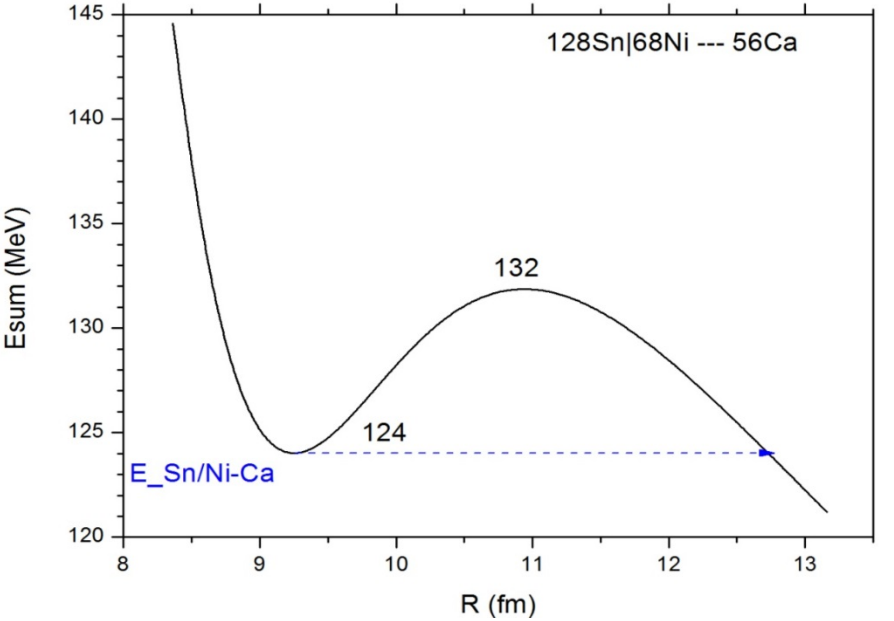
Y_ all tilted ridges ~10^{-4} /bin. fiss.

Two tilted diagonal lines with Ms = 196amu and Ms = 202amu (marked by number 4) start from the partitions **68/128** (**missing ^{56}Ca**)and **68/134** (missing **^{50}Ar**), respectively.

Interaction energies for spherical ternary system







Q3 (252Cf--> 128Sn+68Ni+56Ca)=235 MeV
E_Ni/Sn+ESn/Ni-Ca~274MeV>>Q3

E-conservation is met due to secondary clusterization of Ni

Thus, we assume a two-stage process:

1.Polar emission of the LCP (light HI) from the ternary prescission configuration based on two magic clusters.

2. Delayed fission of the residual di-nuclear system being in the shape isomeric state.

Discussion

Polar emission : previous experiments

The light charged particles emitted near to the fission axis were identified and their energy was measured using a semiconductor telescope consisting of a surface barrier (SB) 45 μm thick ΔE detector and a 1.7 mm thick Si(Li) drifted E-detector. Simultaneously, both fission fragments were registered in two SB detectors. The

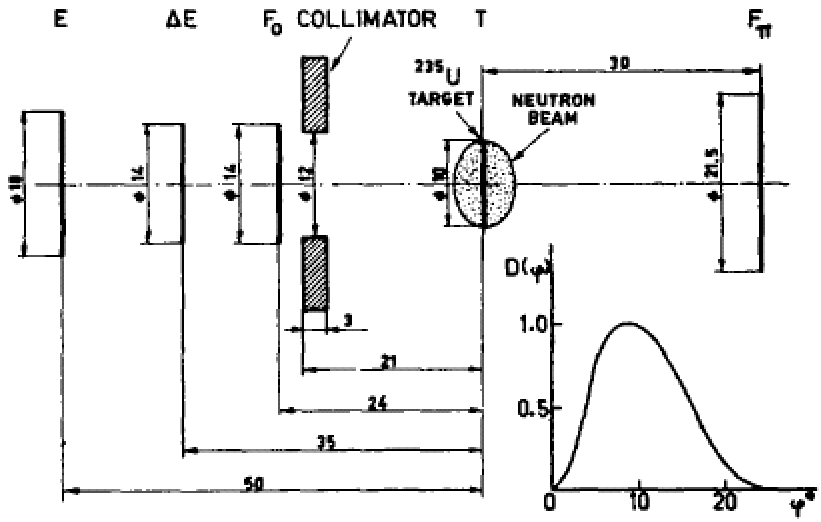


Fig. 1. Geometry of the experiment. The neutron beam passes perpendicularly to the plane of the figure. The symbol Ø denotes diameter. The resolution function $D(\varphi)$ shown in the right corner is the (arbitrarily normalized) probability distribution of registering the $E \wedge \Delta E \wedge F_0 \wedge F_\pi$ event, when the angle between the polar particle and F_0 fragment is equal to φ degrees.

30 μm detector (denoted F_0) was sufficiently thick to stop and register fission fragments going almost in the same direction as the light particles, protecting at the same time the telescope from fission fragments and α-radioactivity of the target.

The coincident (within 2 μs) pulses from the E, ΔE, F_0 and F_π detectors were analysed and stored event by event on magnetic tape by means of a Nuclear Data

MULTIPARAMETER STUDIES OF POLAR EMISSION IN ^{236}U FISSION

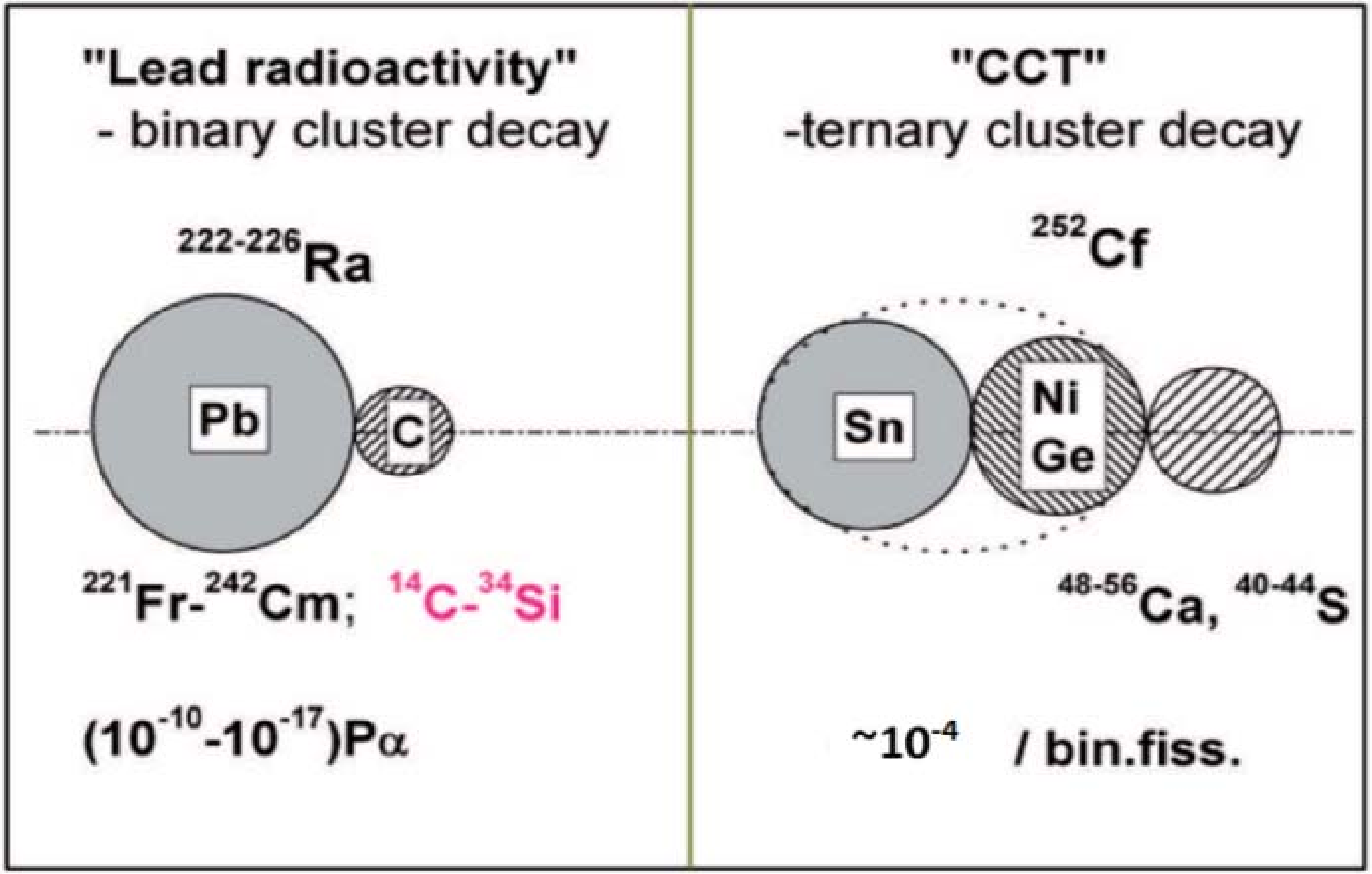
E. PIASECKI, M. SOWIŃSKI, L. NOWICKI, A. KORDYASZ, E. CIEŚLAK and W. CZARNACKI
Institute of Nuclear Research, Department IA, 05-400 Świerk, Poland†

Nuclear Physics **A255** (1975) 387—404

~10^{-5}/bin. fiss.

no chance to detect heavier LCP than Li

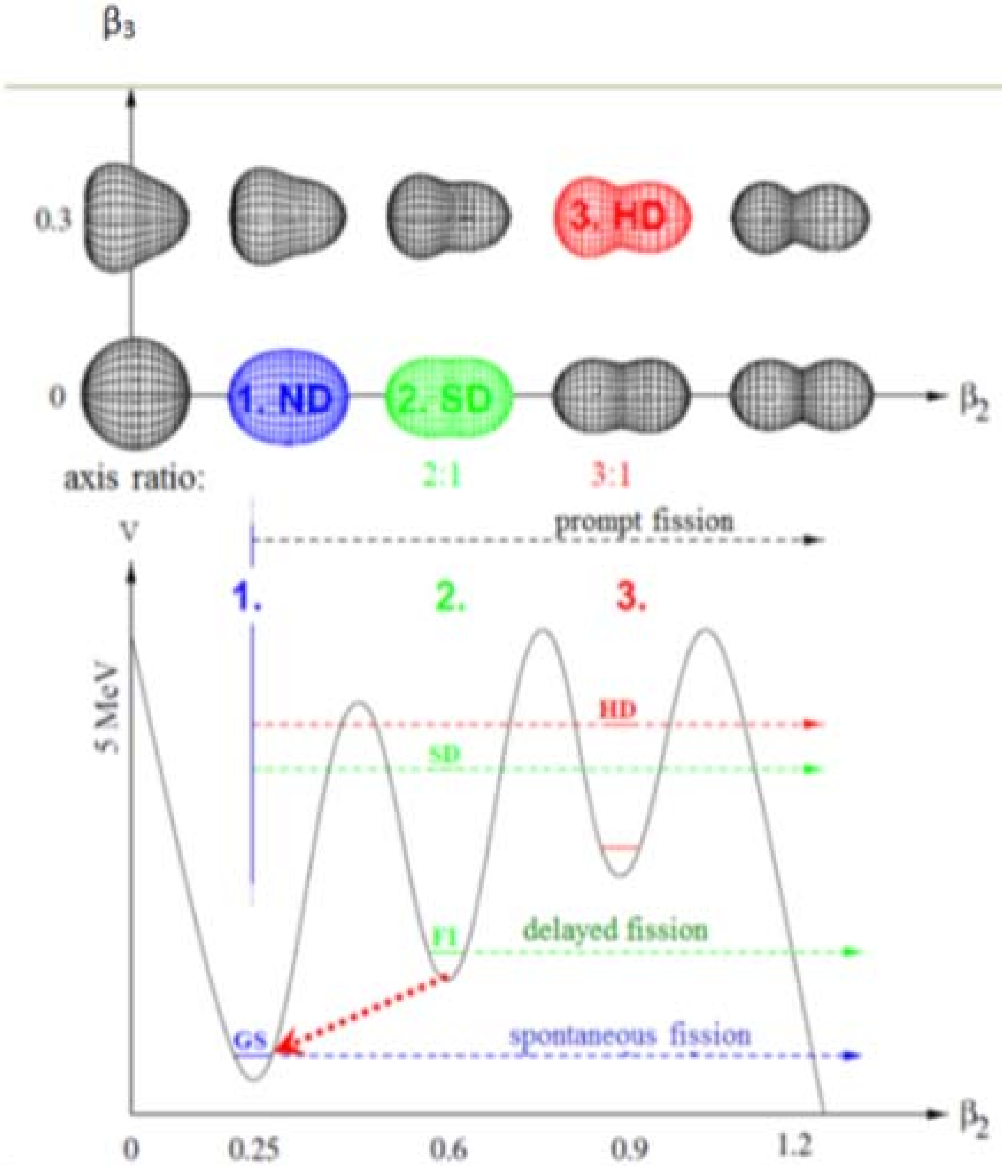
Comparison of the lead radioactivity & CCT

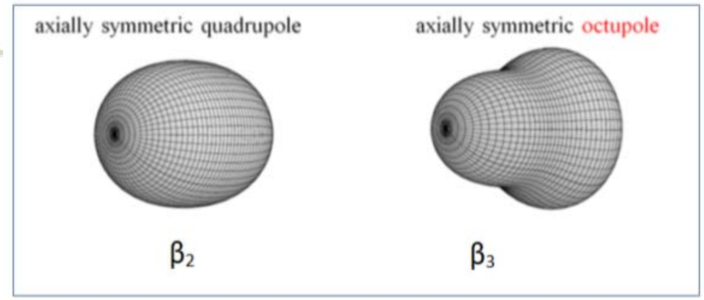


Thus the first stage of the new process observed is similar by physics behind to lead radioactivity. Changing of the Pb core to the pair of magic clusters dramatically increases the yield.

[Yu.V. Pyatkov, D.V. Kamanin, W. von Oertzen et al., Eur. Phys. J. A 45 (2010) 29]

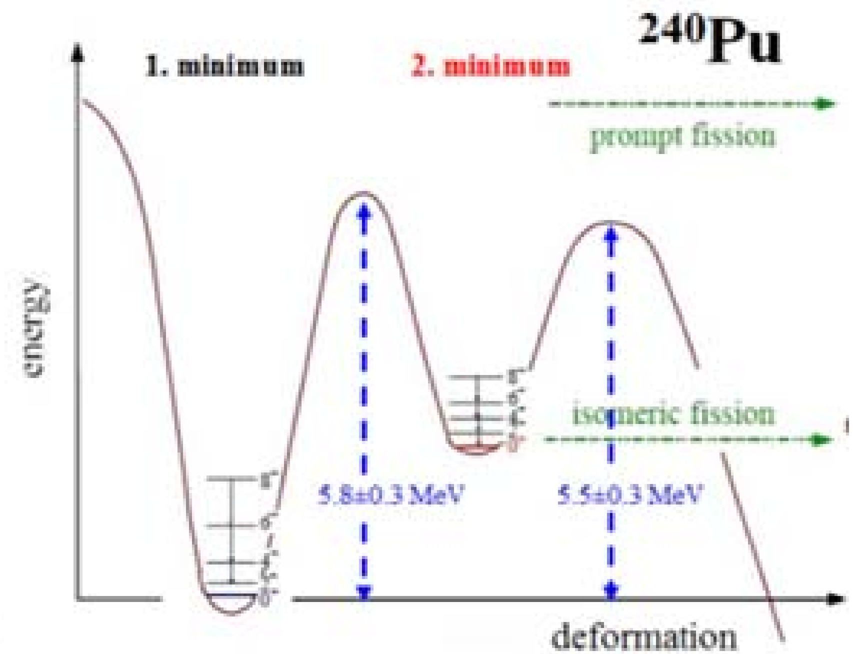
Second stage : fission isomers





Fission isomers
discovered by S.M. Polikanov
Sov. Phys. JETP 15 (1962) 106

Discovered in
FLNR (JINR)



Theoretical predictions of new kind of the isomeric states based on ternary configurations

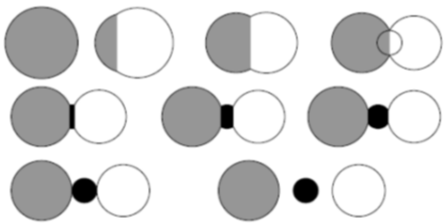


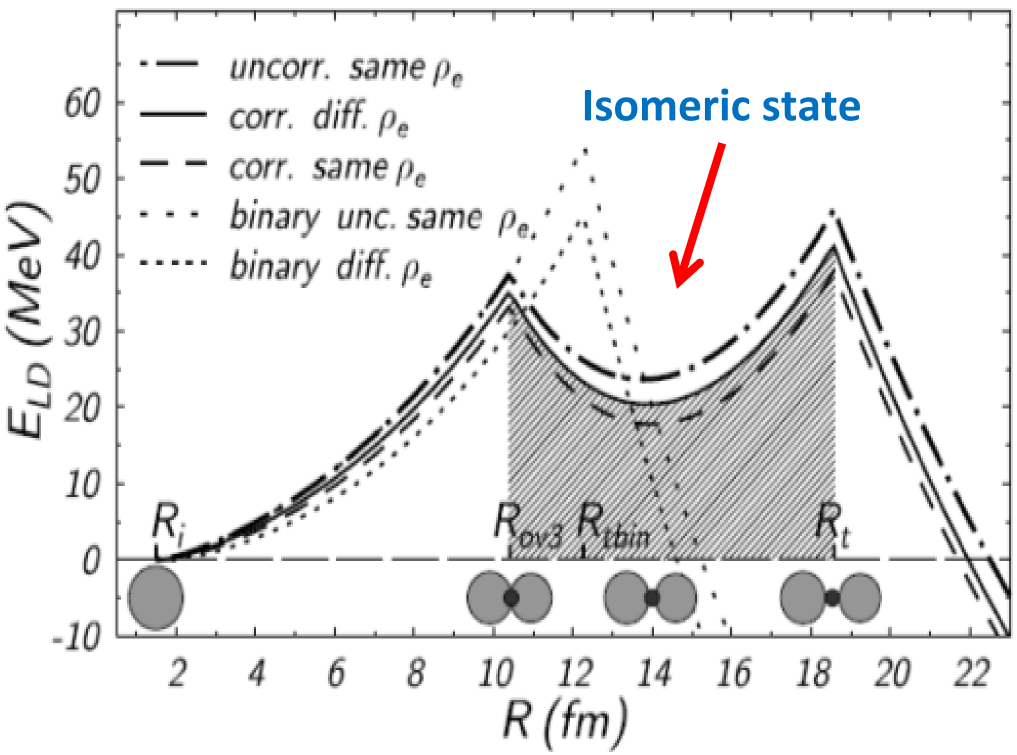
Figure 1. Evolution of nuclear shapes during the deformation process from one parent nucleus 252Cf to three separated fragments 146Ba, 10Be, and

J. Phys. G: Nucl. Part. Phys. **26** (2000) L97–L102

Nuclear qusi-molecular states in ternary fission

D N Poenaru†‡§_, B Dobrescu†, W Greiner‡_, J H Hamilton§ andA V Ramayya§

The half-lives of some quasimolecular states which could be formed in the 10Be and 12C accompanied fission of 252Cf are roughly estimated to be the order of 1 ns, and 1 ms, respectively.



The liquid drop model deformation energy versus separation distance for the 10Be accompanied cold fission of 252Cf with 132Sn and 100Zr heavy fragments. The new minimum appears in the shaded area from *Rov*3 to *Rt* .

Theoretical predictions

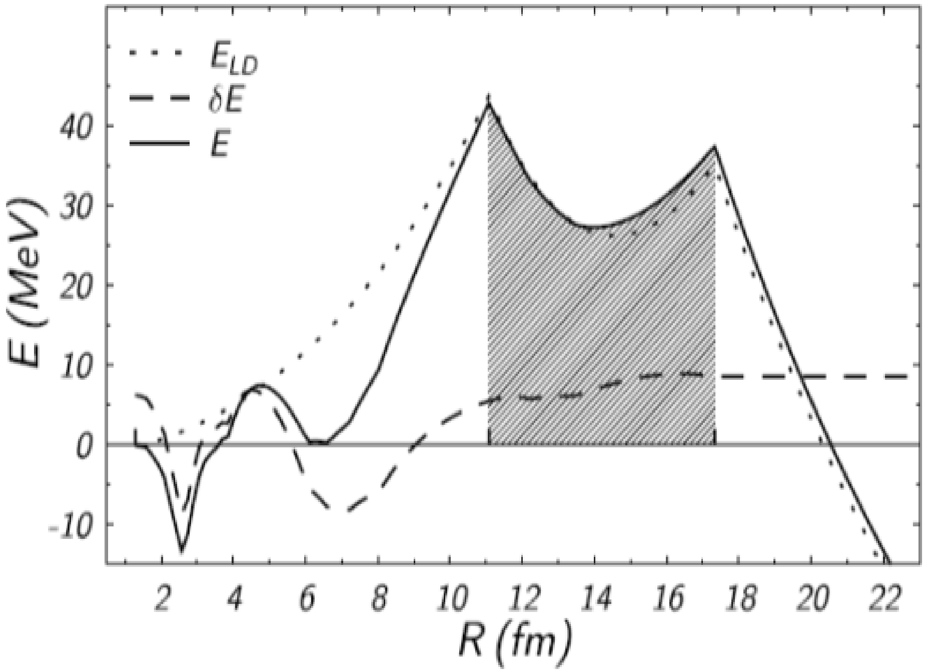


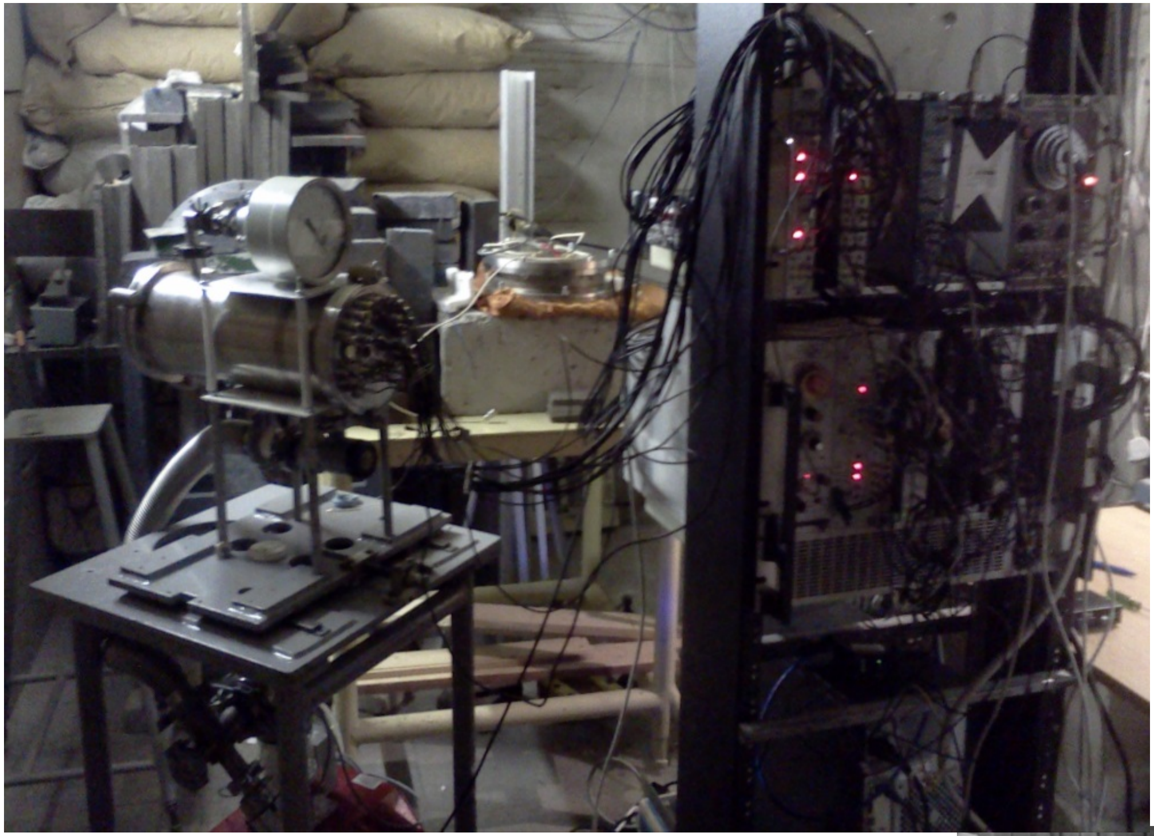
Figure 3. The liquid drop model, *E*LD, the shell correction, *δE*, and the total deformation energies, *E*, for the 10Be accompanied cold fission of 252Cf with 146Ba and 96Sr heavy fragments. The new minimum appears in the shaded area from *Rov*3 to *Rt* .

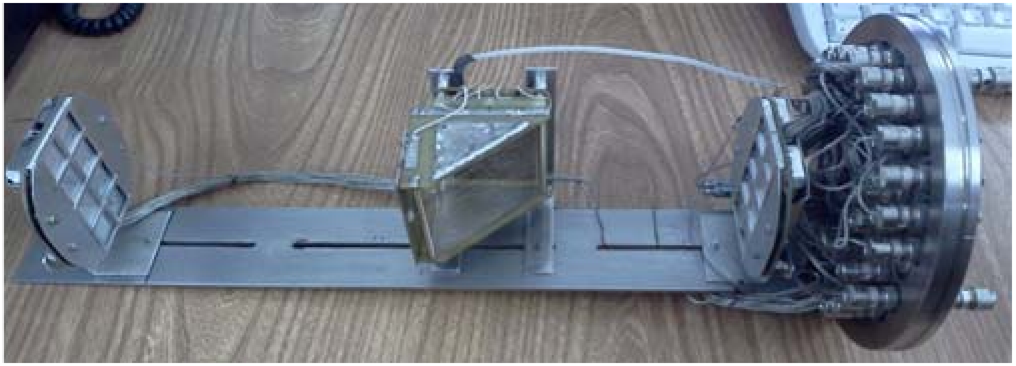
Table 1. Calculated half lives of some quasi-molecular states ^{252}Cf.

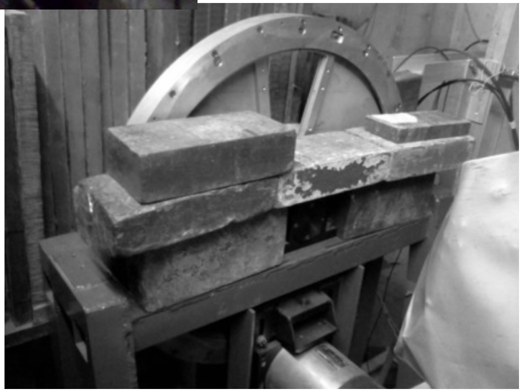
Particle	Fragments		Q_{exp} (MeV)	K	log T(s)
^{10}Be	^{132}Sn	^{110}Ru	220.183	19.96	−11.87
	^{138}Te	^{104}Mo	209.682	25.23	−9.59
	^{138}Xe	^{104}Zr	209.882	26.04	−9.23
	^{146}Ba	^{96}Sr	201.486	22.98	−10.56
^{12}C	^{147}La	^{93}Br	196.268	39.80	−3.26
	^{142}Ba	^{98}Kr	199.896	42.71	−1.99
	^{140}Te	^{100}Zr	209.728	38.21	−3.95
	^{132}Sn	^{108}Mo	223.839	31.46	−6.88

In red: ^{12}C accompanied ternary decay with half lives **~ 1ms & 10ms**

Layout of the COMETA-R spectrometer at the channel 11b of the IBR-2 reactor

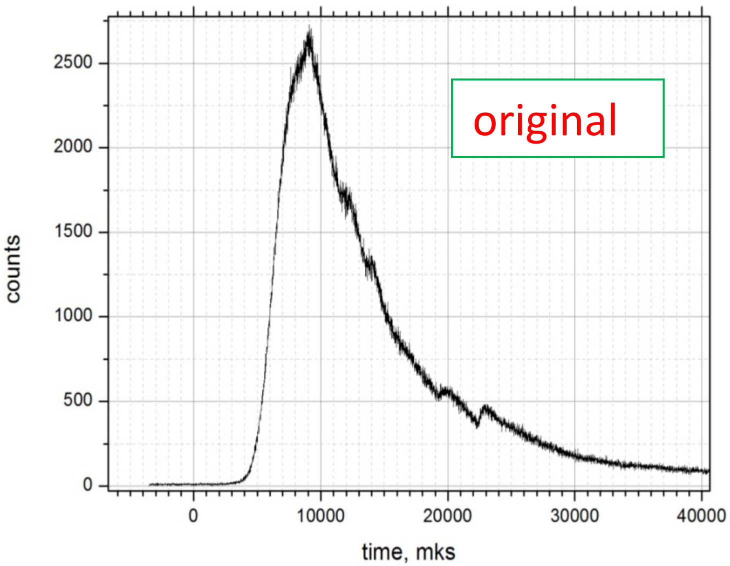


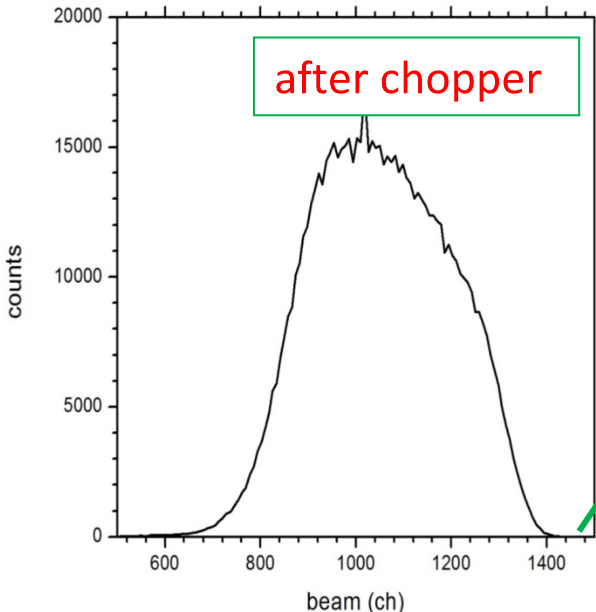


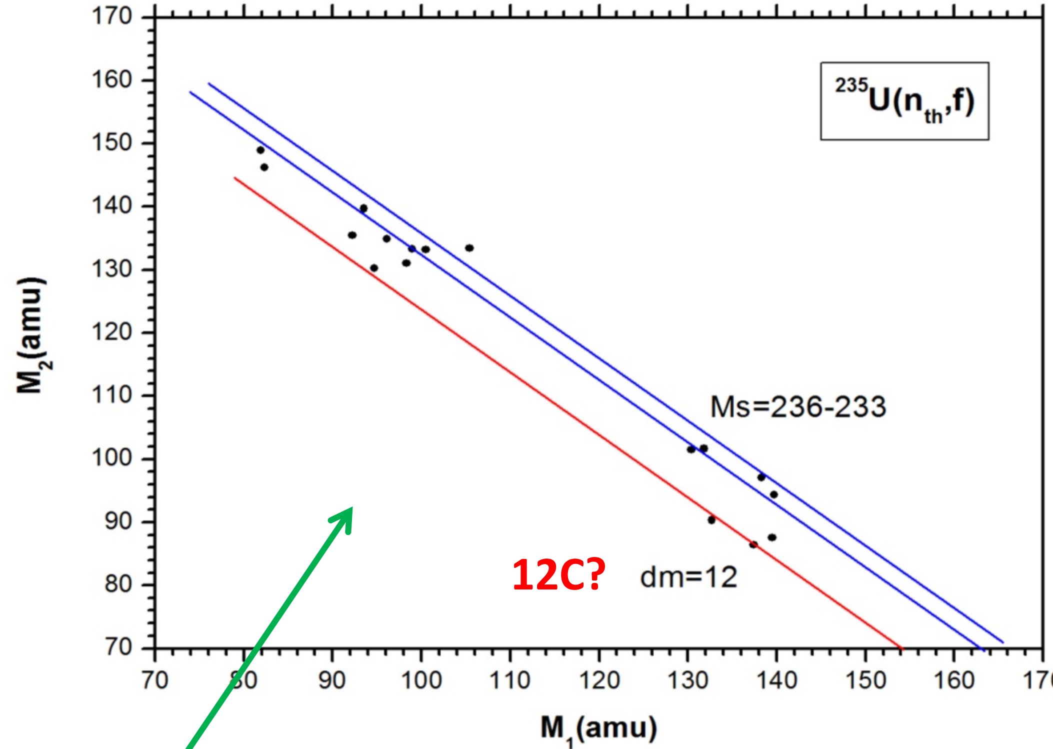


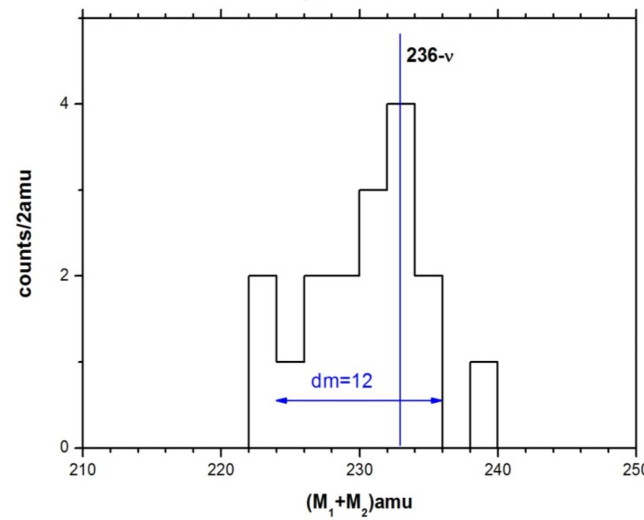
Very preliminary result, IBR-2, COMETA-R setup

Neutron bunch shape:

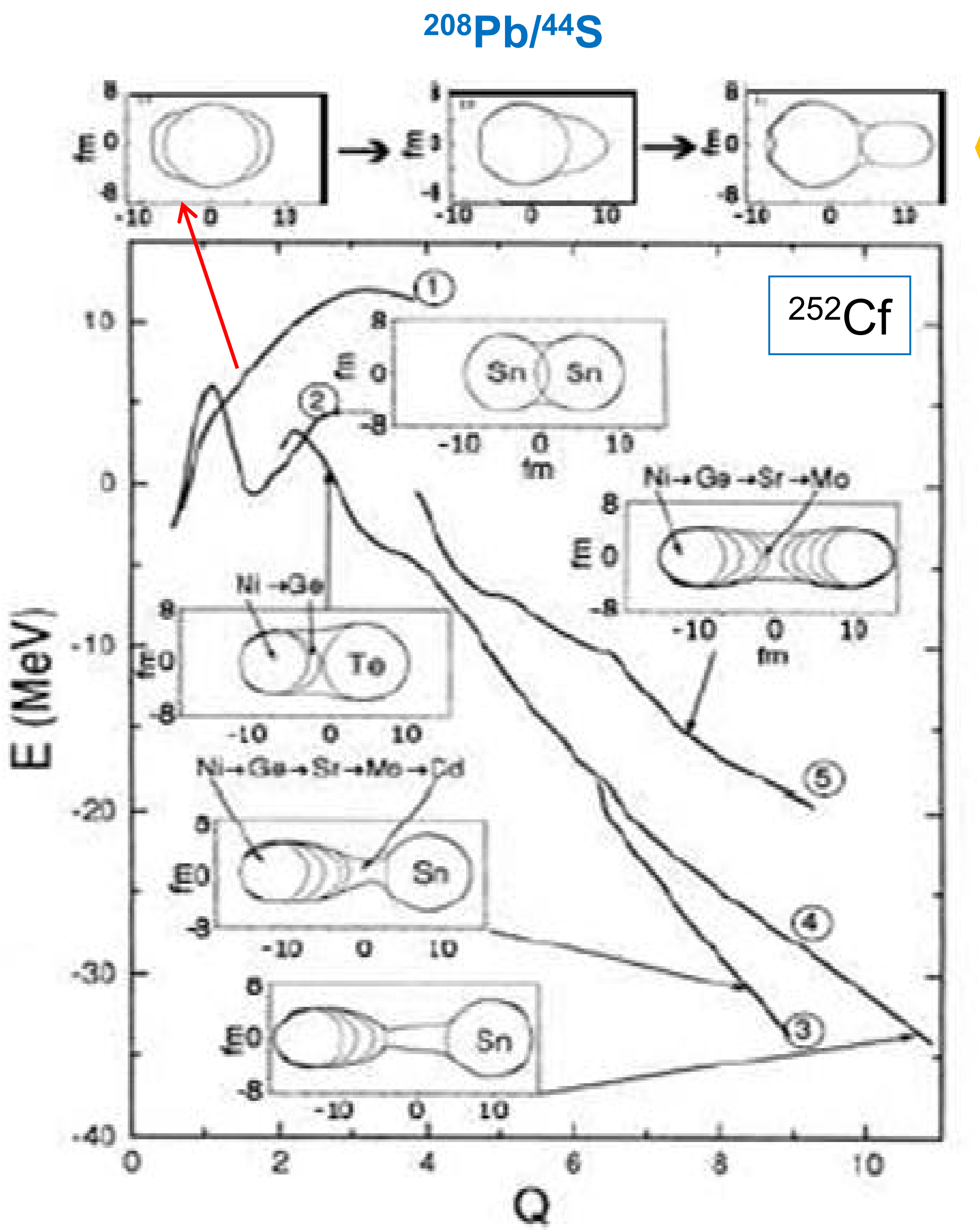








HI-radioactivity

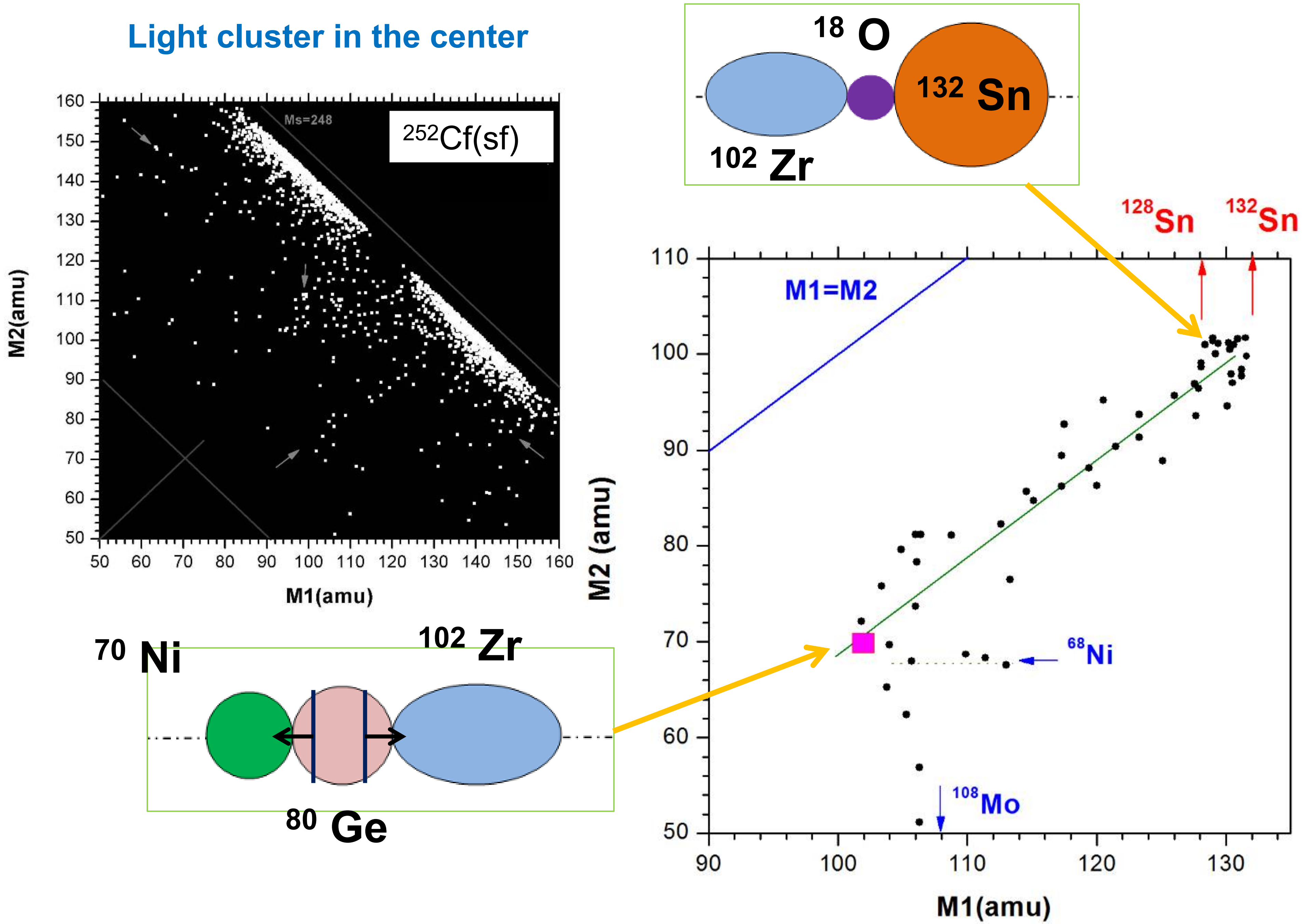


Heavy ion or lead radioactivity valley.
Evidently, extremely low populated.

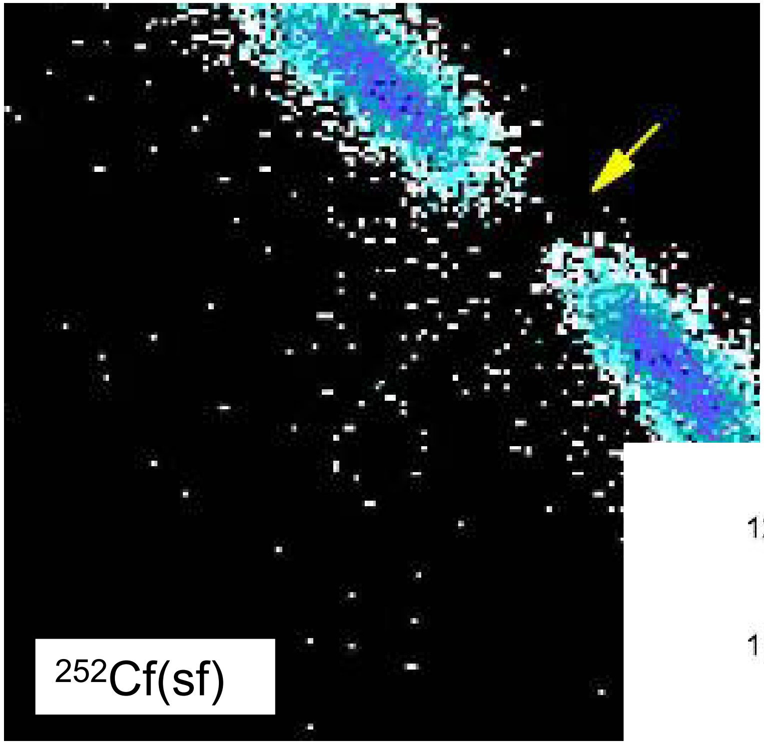
Potential energy of the fissioning nucleus ^{252}Cf corresponding to the bottoms of the potential valleys, as a function of Q, proportional to its quadrupole moment.

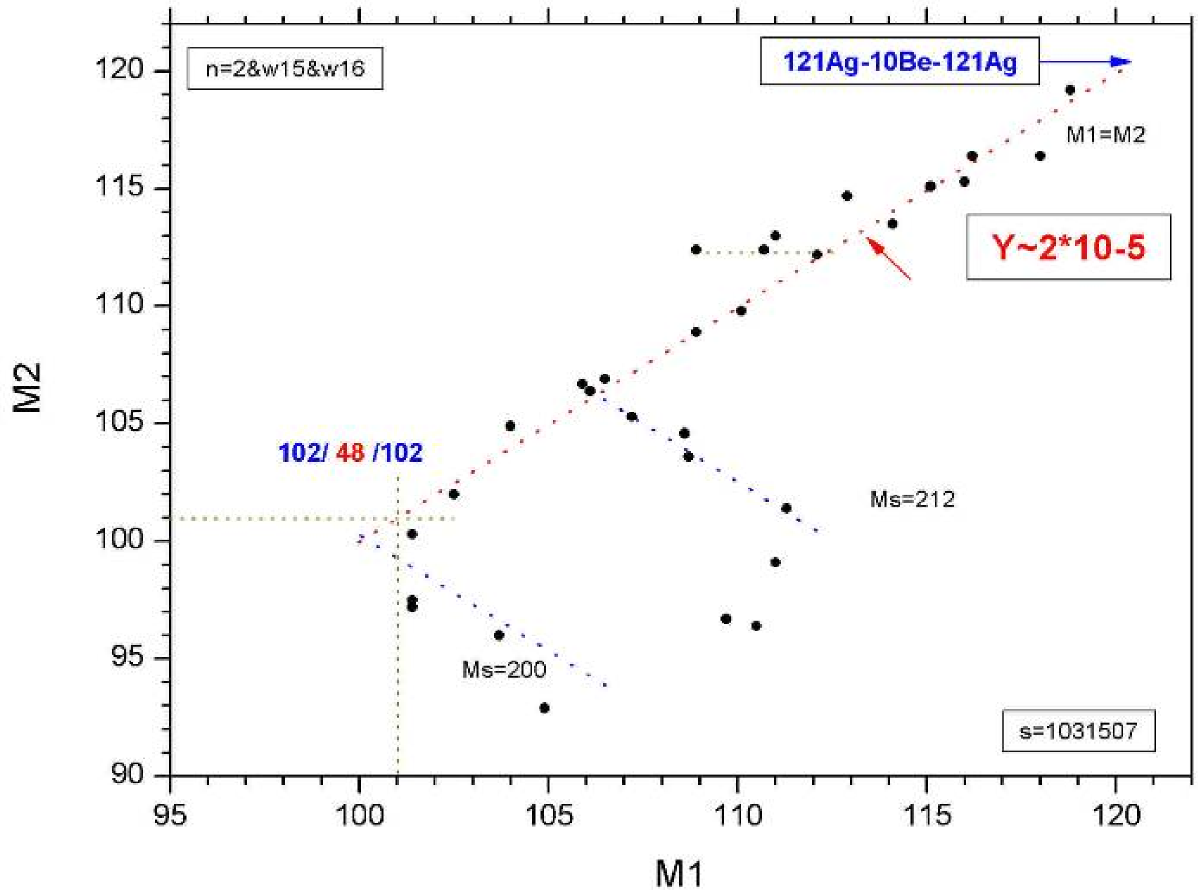
V.V. Pashkevich,
private communication

Light cluster in the center

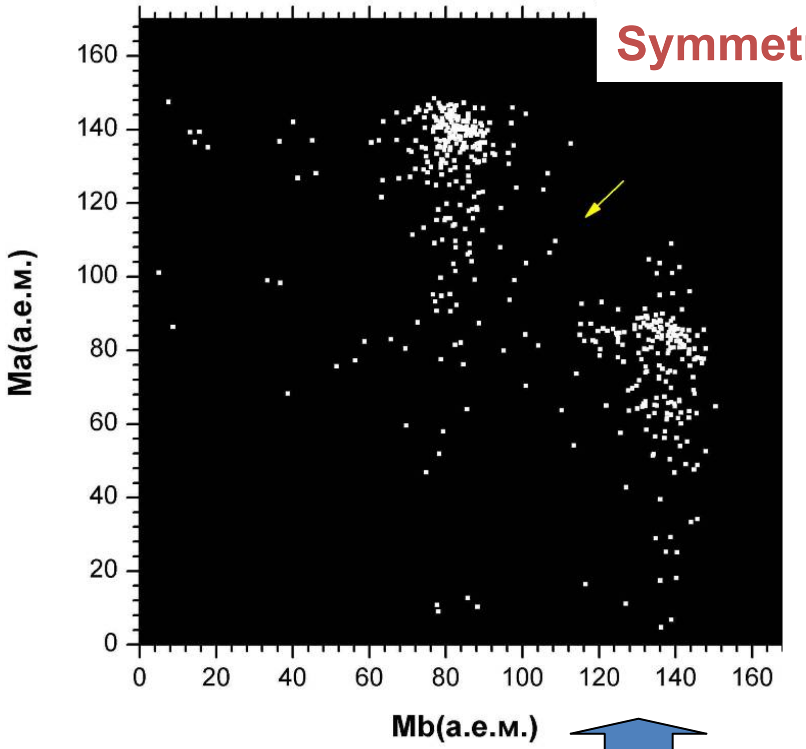


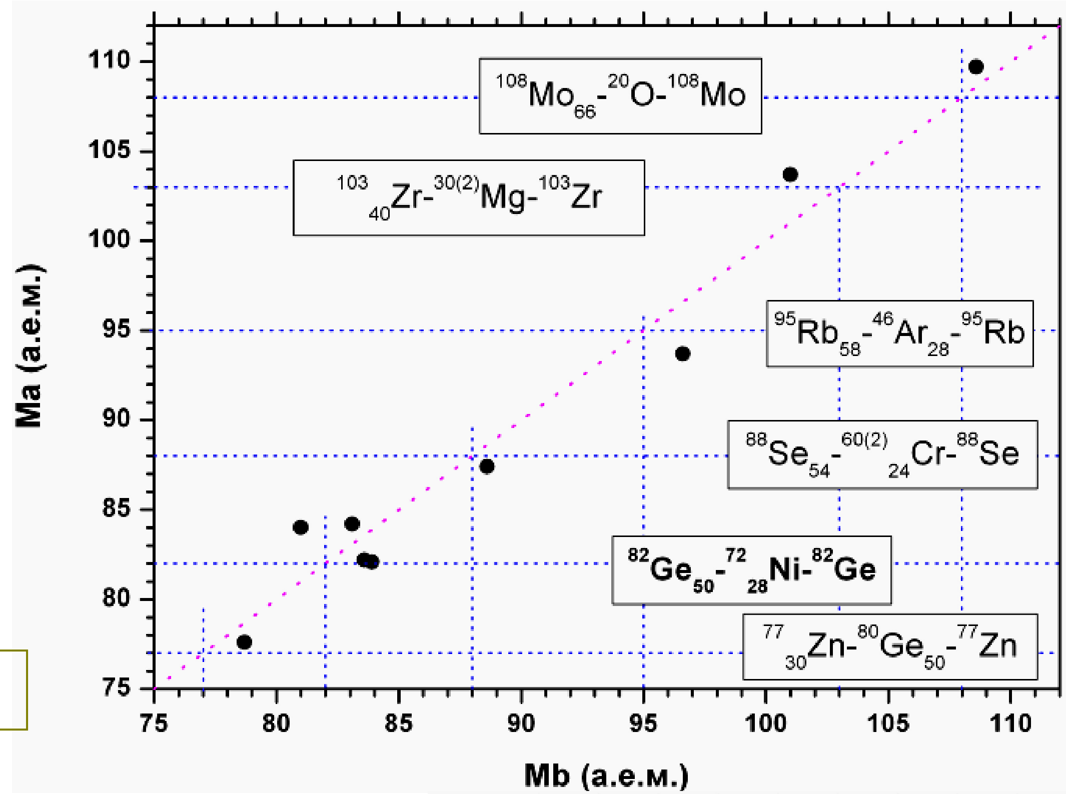
Light cluster in the center



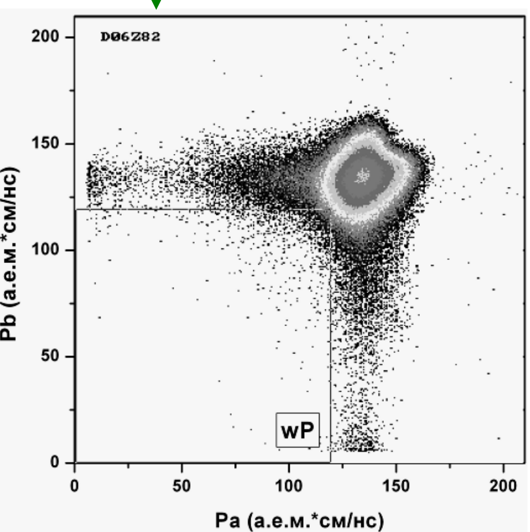


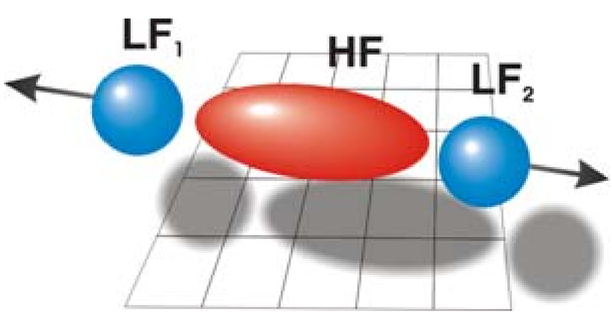
Symmetric cluster configurations in the CCT of $^{236}U^*$

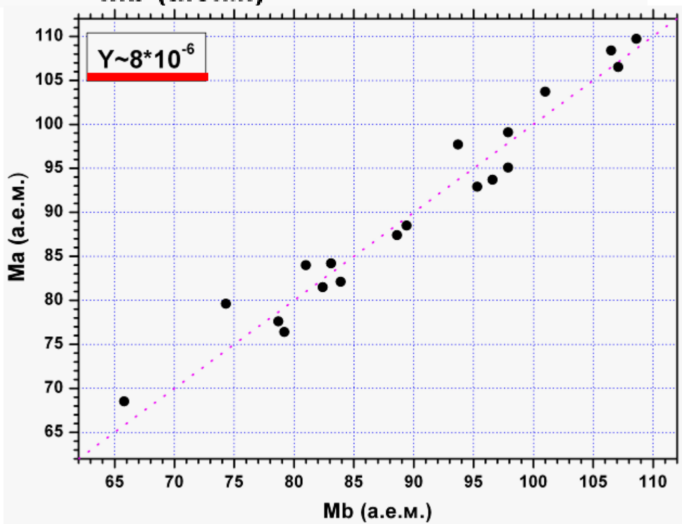




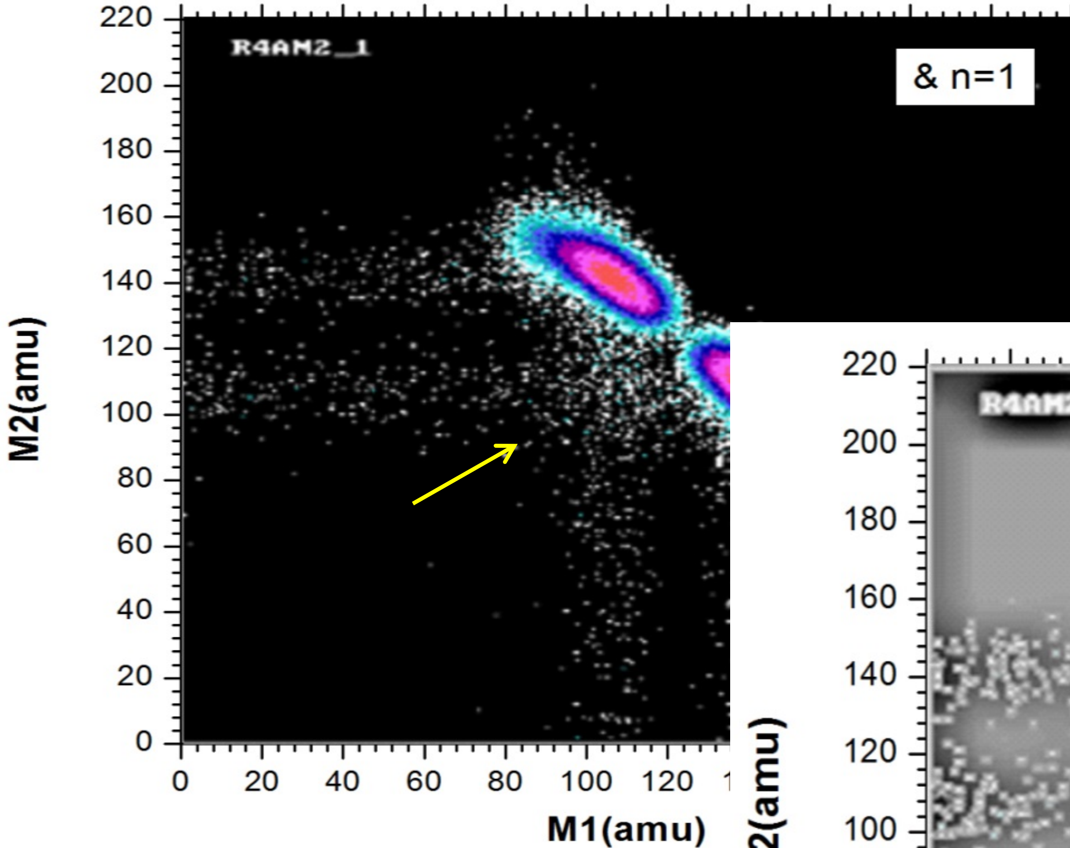
Momentum & Drift_time selection

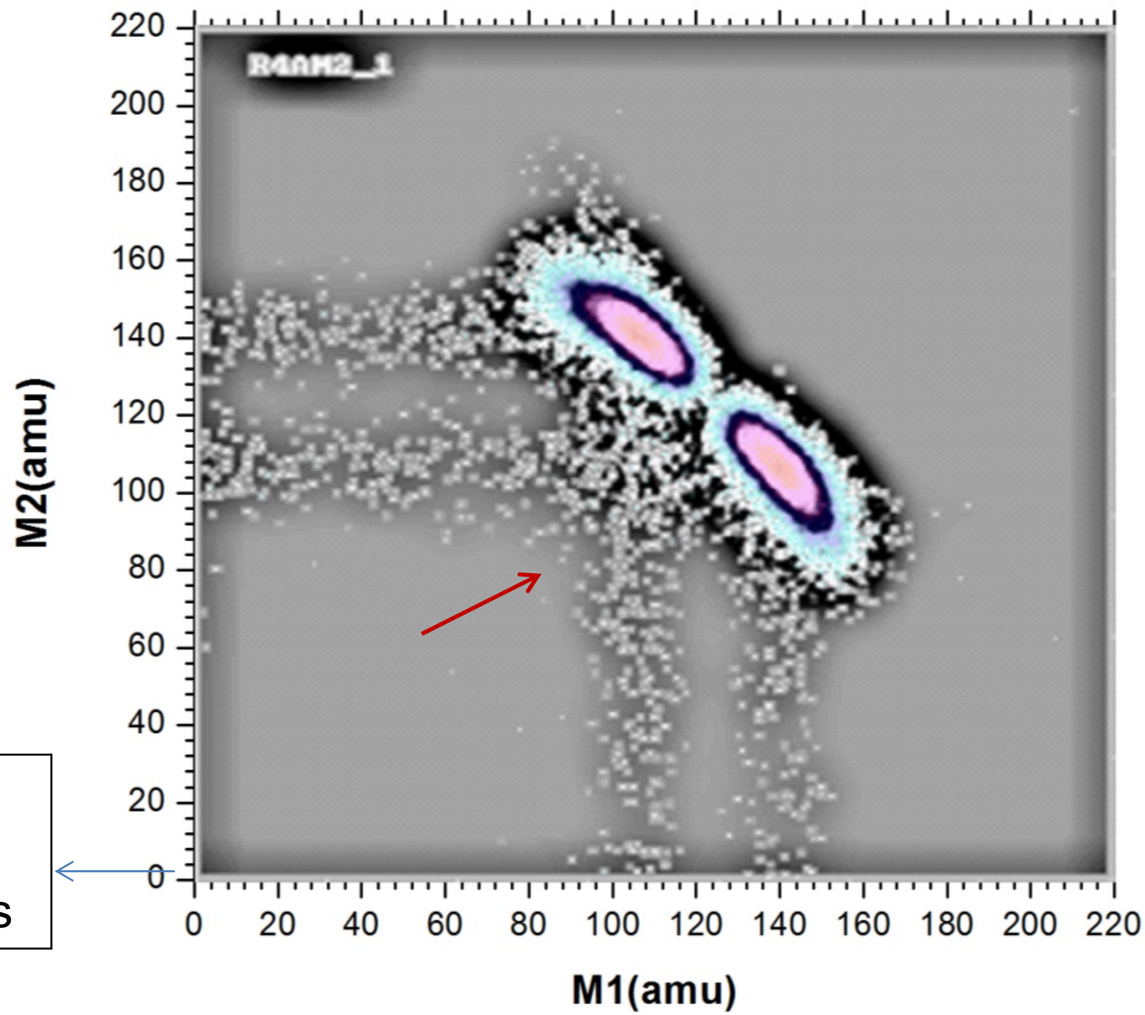






Similar structures in $^{252}Cf(sf)$.
COMETA setup





At least one of the initial clusters (M1) is expected to be a magic deformed nucleus

Conclusions

Experimental evidences are obtained in favor of realization of a new kind of the ternary decay of low excited actinides.

Two-stage process is observed including

1.Polar emission of the LCP (light ion) from the ternary prescission configuration based on two magic clusters.

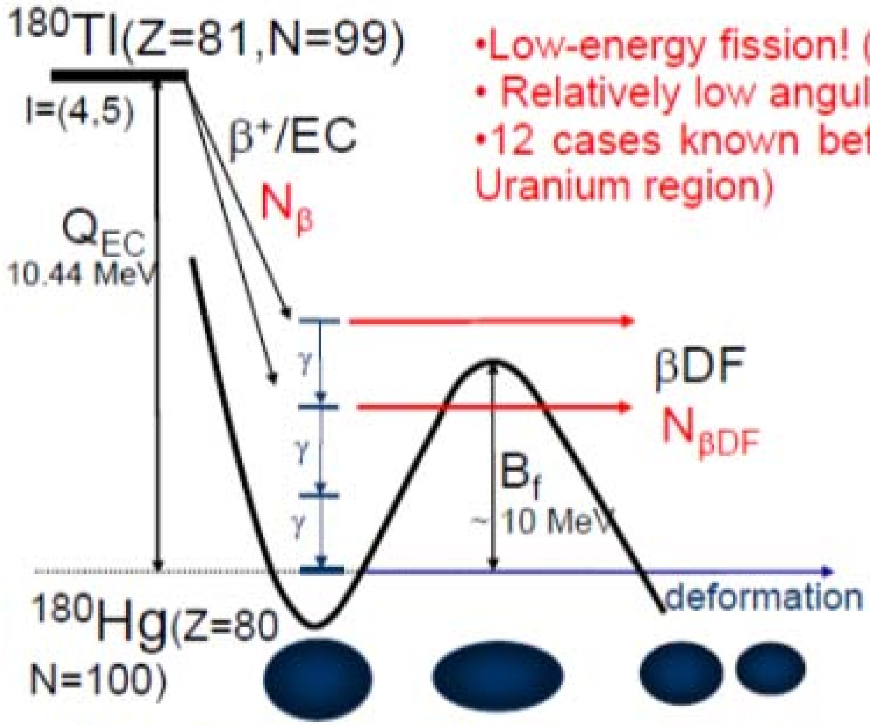
2. Delayed fission of the residual di-nuclear system being in the shape isomeric state.

According to the features observed the process could be called:
Ligh ion delayed Isomeric Fission (LIF)

Thank you for attention!

Beta-Delayed Fission

Discovery: $^{232,234}Am$ (1966, Dubna)



- Low-energy fission! (E^*~3-12 MeV, limited by Q_{EC})
- Relatively low angular momentum of the state
- 12 cases known before our work (neutron-deficient Uranium region)

βDF branch

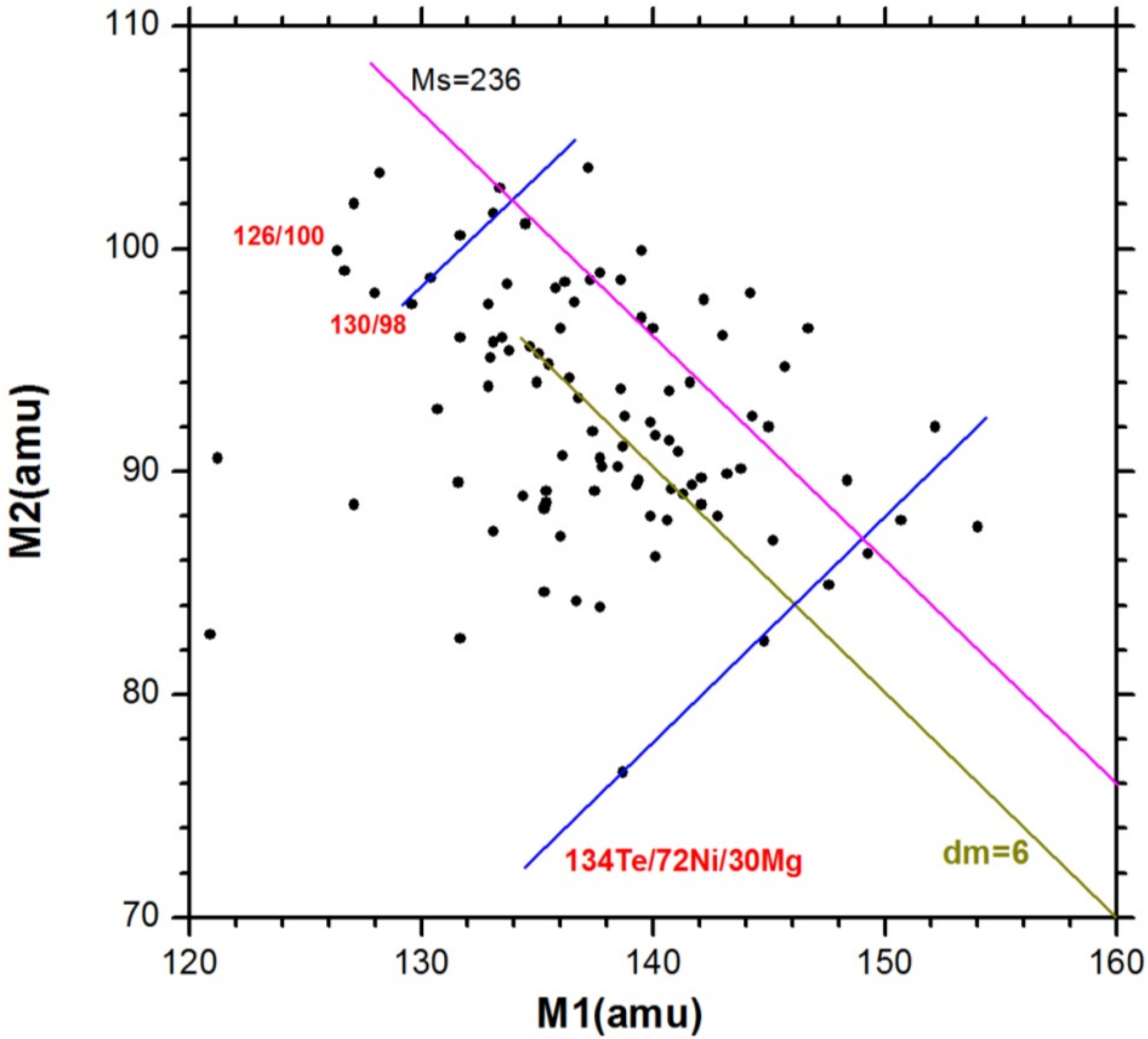
$$P_{\beta DF} = \frac{N_{\beta DF}}{N_{\beta}}$$

$P_{\beta DF}$ depends strongly on:

- Q_{EC} of the parent: the higher Q_{EC}, the larger the $P_{\beta DF}$
- B_f of the daughter: the lower B_f, the larger the $P_{\beta DF}$
- Actually, Q_{EC}-B_f and β-strength S_β are the most important parameters

http://asrc.jaea.go.jp/soshiki/gr/chiba_gr/workshop2/&Andreyev.pdf

The same in the larger scale



Presumable scenario:
1.Preformation of the chain – 2 magic clusters &LCP;
2.Emitting of the LCP (^{4,6}He… here);
3. Delayed second rupture making magic clusters free.

Thus 2 magic clusters formed nucleus in the shape isomeric state.

Key words:

1. Prescission shape under analysis is only rough approximation – actually the contact zones are much larger, what should increases the nuclear part of the interaction. It can be filled in the frame of the proximity approach.
2. “sudden” approximation
3. Proximity ~ S of the intersection of the nuclei

SEARCHING FOR NEW KIND FISSION ISOMERS IN ACTINIDE NUCLEI

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Conventional fission isomers are due to the specific double humped structure of the fission barrier with rather deep second well for some of the actinide nuclei. The barrier can be called "the binary one" keeping in mind that binary fission appears to occur during the descent of the system from this barrier. Evidently, a dumbbell-like shape of the system is expected in the vicinity of the scission point. Ternary prescission configurations leading to the delayed ternary fission have been also considered from the theoretical point of view [1]. We discuss first experimental results demonstrating delayed fission after emitting of the light ion. By analogy with known "beta delayed fission" such phenomenon can be called "**L**CP delayed **F**ission of **I**somer (LFI)". Schematic scenario of the process is presented in Fig.1.

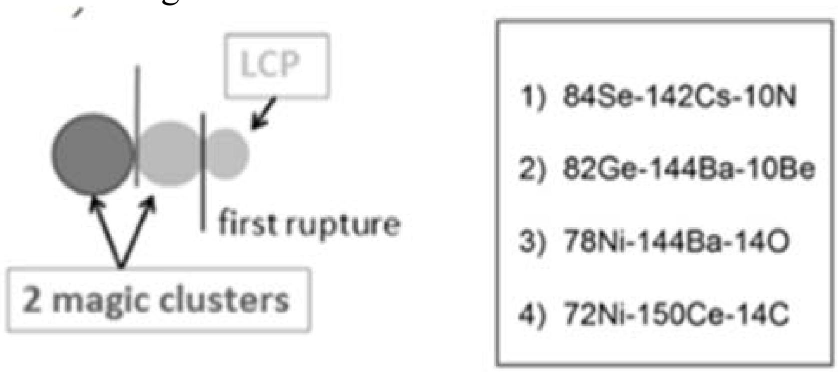

Fig. 1. Schematic illustration of the scenario of LCP delayed fission of isomer (LFI) and ternary prescission configurations decisive for the effect observed.

1. D.N.Poenaru *et al.* // J. Phys. G: Nucl. Part. Phys. 2000. V.26. P.97.