NEW SIDES OF THE COLLINEAR CLUSTER TRI-PARTITION SCENARIO

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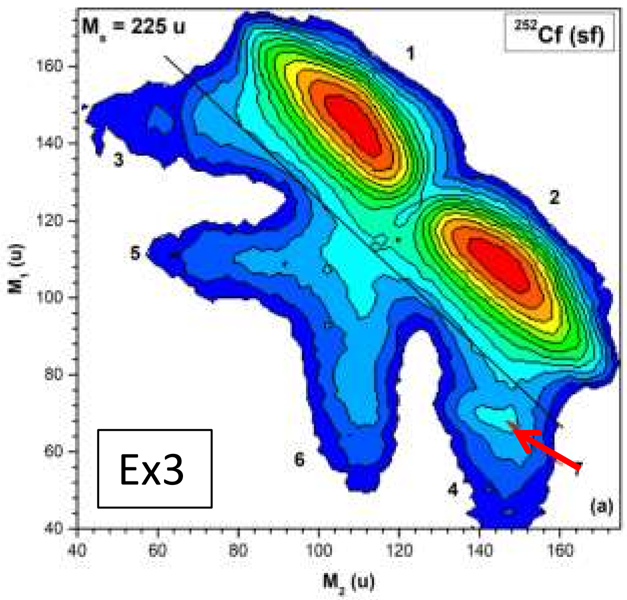
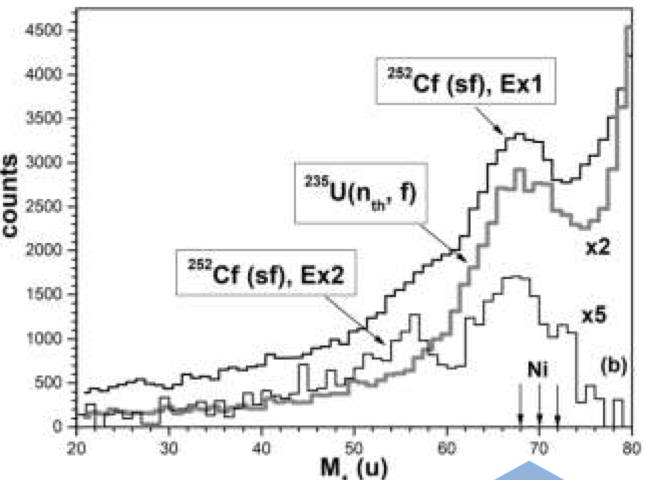
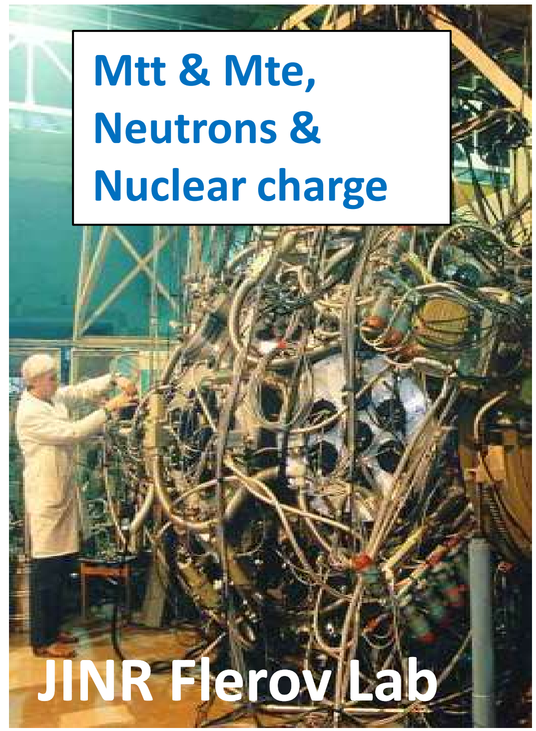
Experimental background

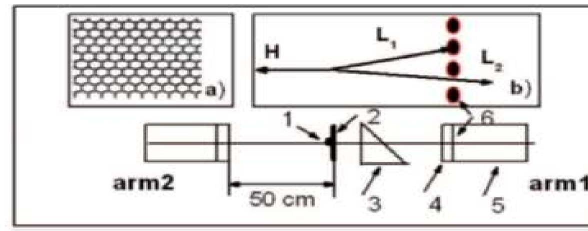
Our experimental background: FOBOS setup and its modifications

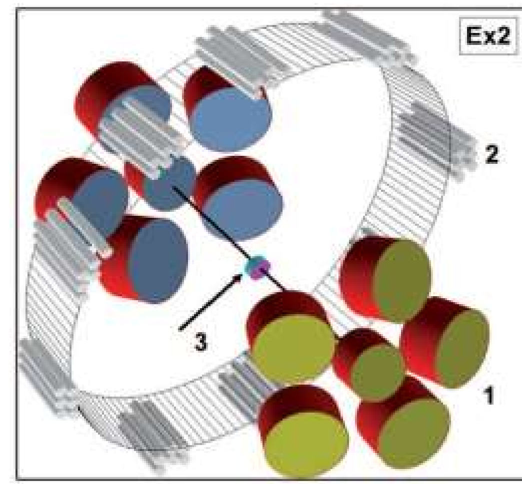


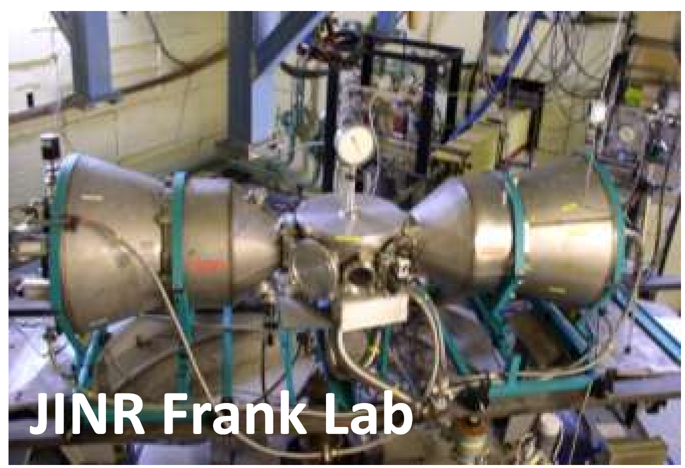


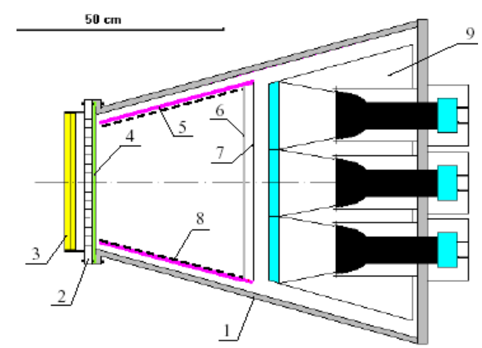
“Ni-bump”





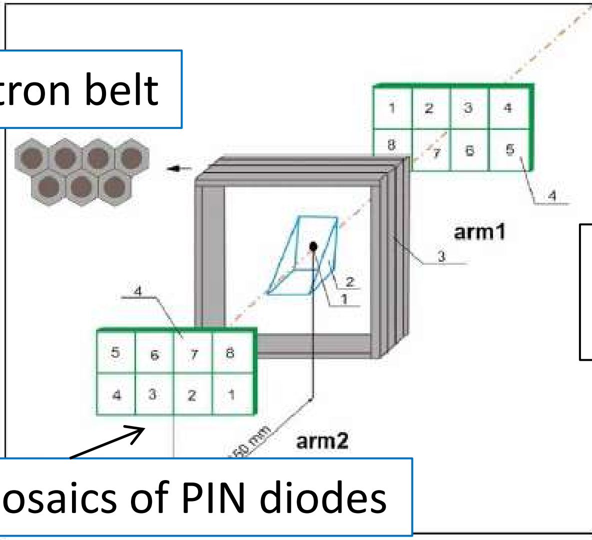






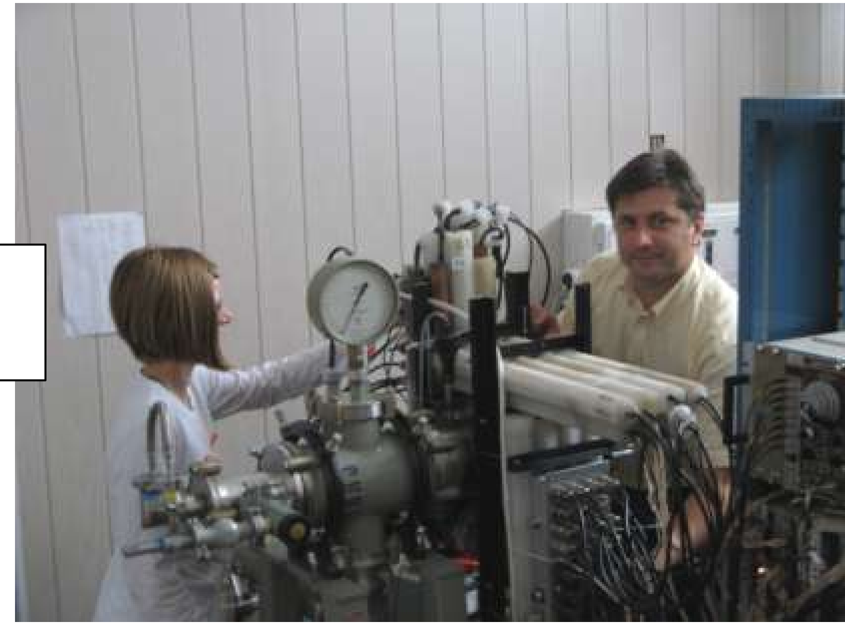
Our experimental background: family of COMETA spectrometers

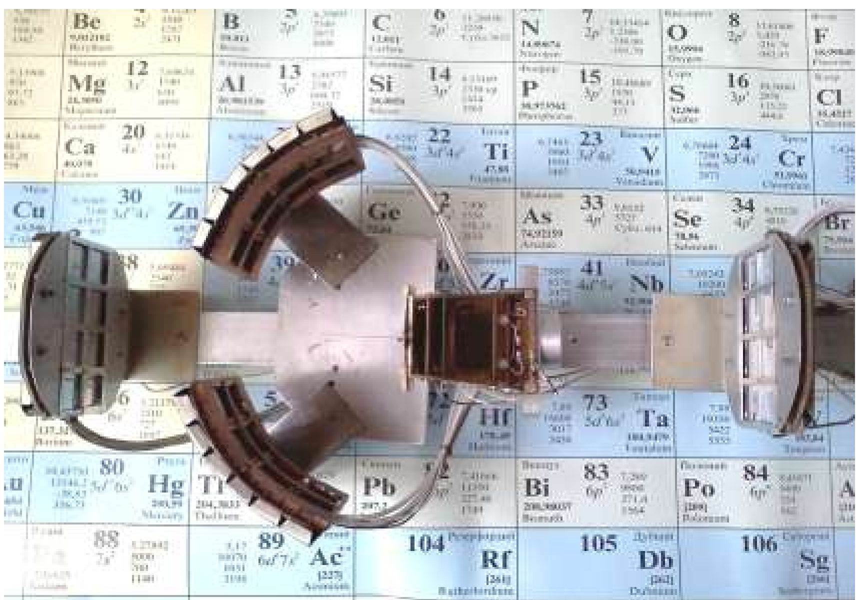
neutron belt



mosaics of PIN diodes

Mtt & Mte, neutrons

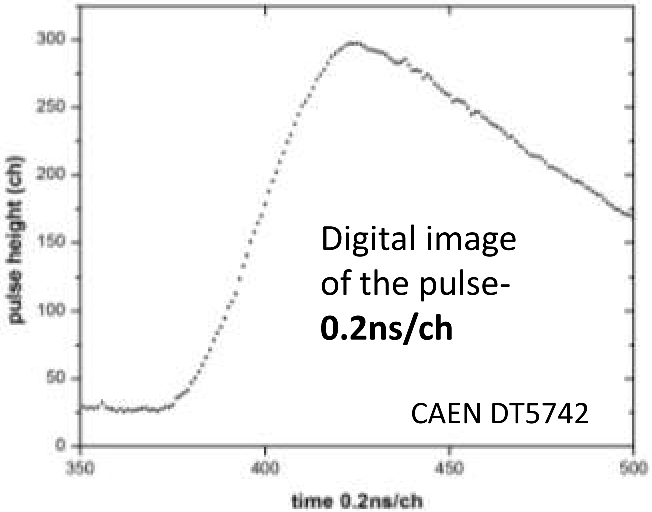




COMETA (COrrelation Mosaic E-T Array)

New modified experimental methodic

Experimental approach: fast flash-ADC & modified data processing



PHD:

$$E = E_{det} + R(M,E), \qquad (1)$$

$$R(M,E) = \frac{\lambda \cdot E}{1+\varphi \cdot \dfrac{E}{M^2}} + \alpha \cdot ME + \beta \cdot E\,, \qquad (2)$$

$$E = \frac{M \cdot V^2}{1.9297} \qquad (3)$$

$$\longrightarrow \qquad G(\{\lambda, \varphi, \alpha, \beta\}, M, V) = 0$$

Combining equation (1), (2) and (3), we obtain:

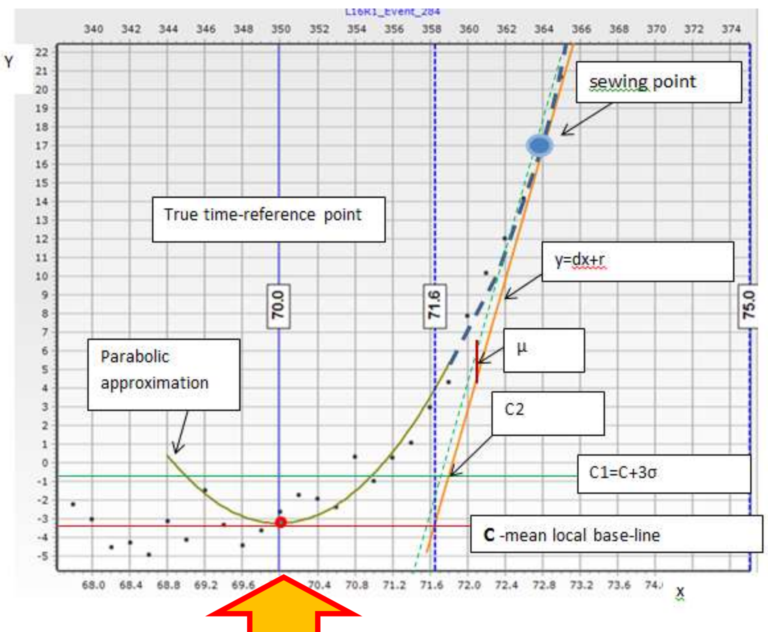
$$G = \frac{MV^2}{k} - [E_{\text{det}} + \frac{\lambda \cdot \dfrac{MV^2}{k}}{1+\varphi \cdot \dfrac{V^2}{Mk}} + \alpha \cdot \frac{M^2V^2}{k} + \beta \cdot \frac{MV^2}{k}] = 0\,,$$

where $k = 1.9297$.

$$\min \quad F = [(<ML_T> - <ML>)^2 + (<MH_T> - <MH>)^2] + \mu \sum_{M_{TE}} \frac{(Y(M_{TE}) - Y_T(M_{TE}))^2}{Y(M_{TE})}$$

PD:

$$\Delta t_p = \gamma \frac{M^{1/6} E^{1/2}}{\;} \qquad \text{(used in Ex2)}$$

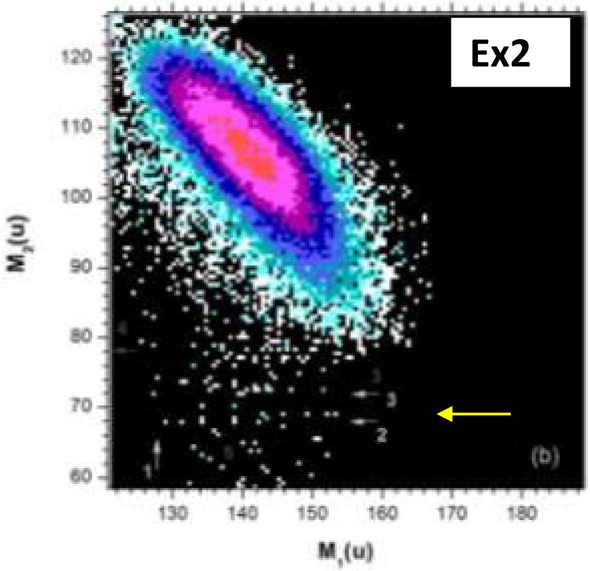


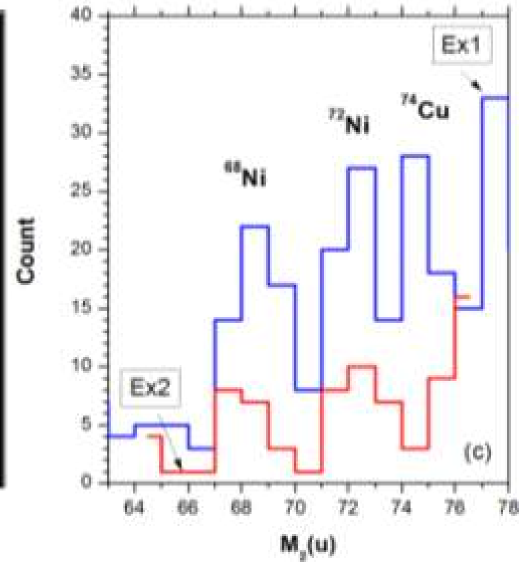
True time reference point

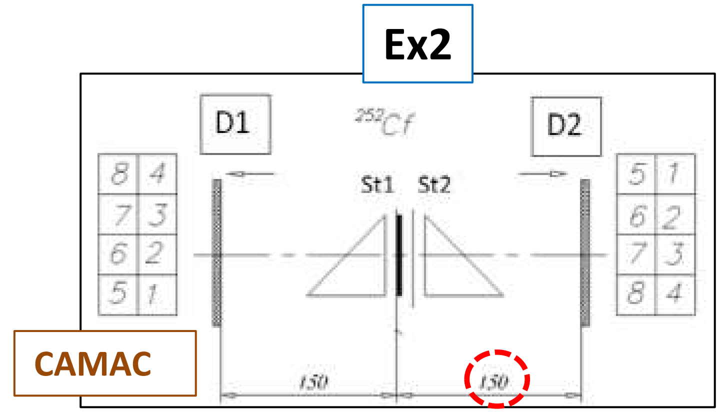
A new off-line method of time-pickoff “sewing-parabola”

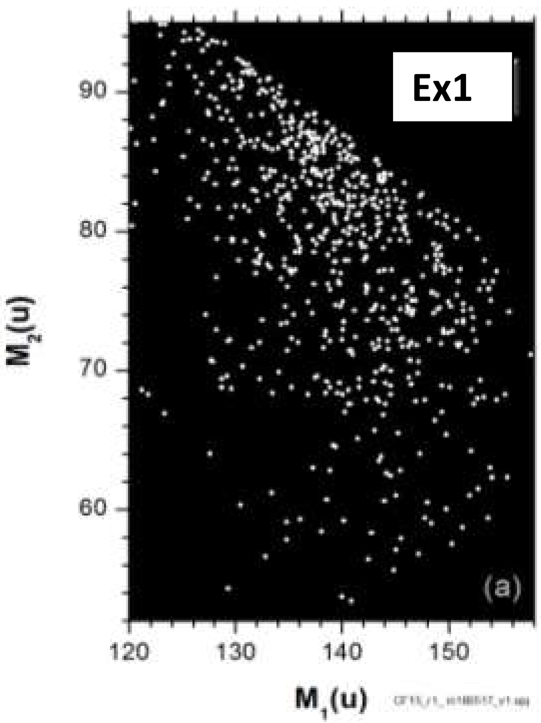
New results

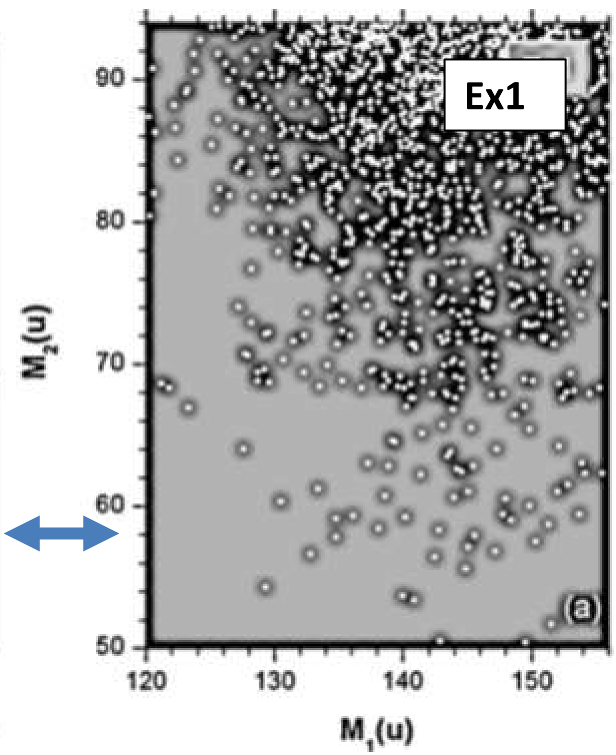
Comparison of the results from Ex1 (new) and Ex2

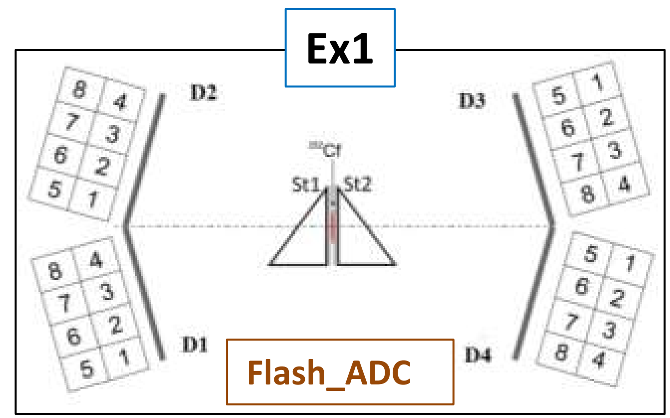




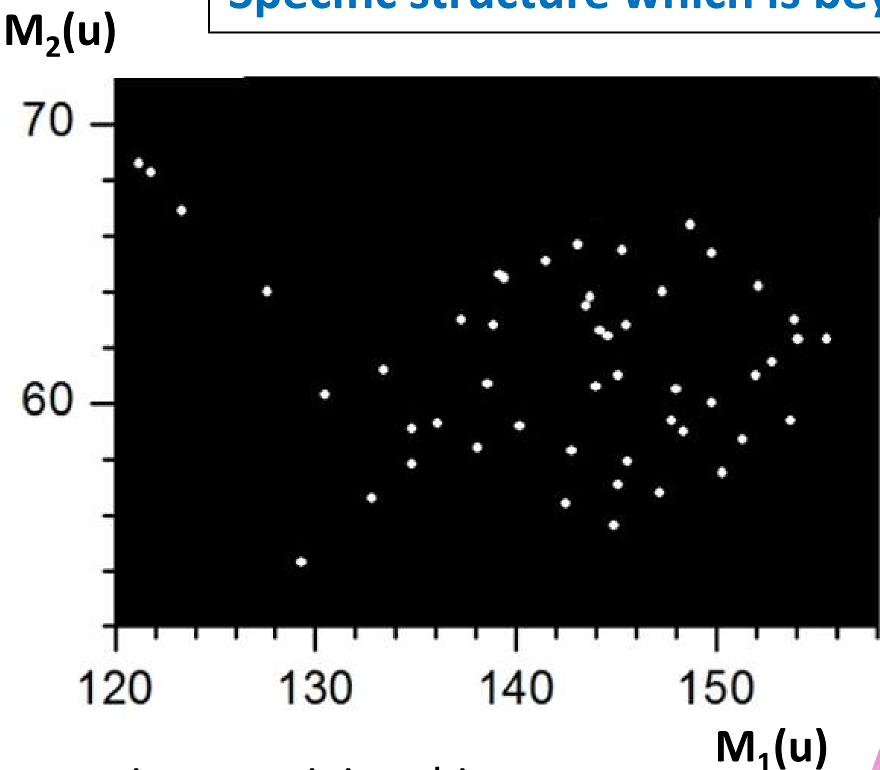








Specific structure which is beyond the consideration in the present talk



$M_1+M_2=const$

$M_1-M_2=const$

in our opinion this structure deserves the following mark:

"nuclear rose"

rose natural

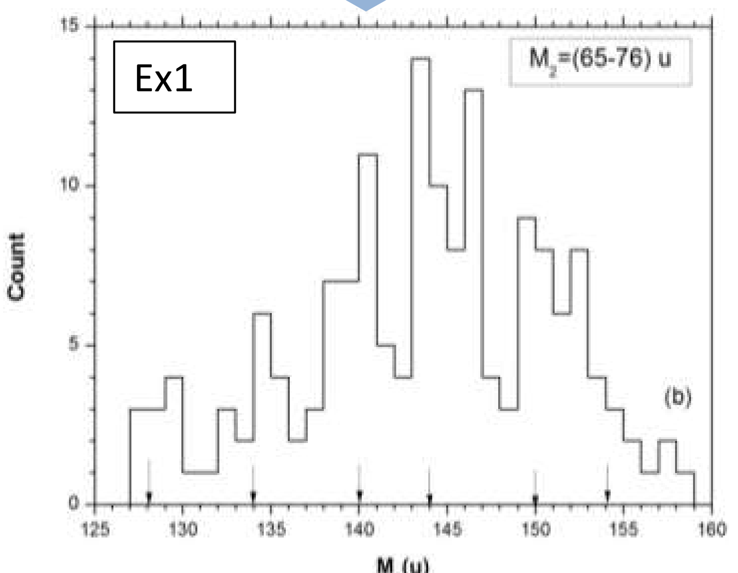
Comparison of the results from Ex1 (new) and Ex2

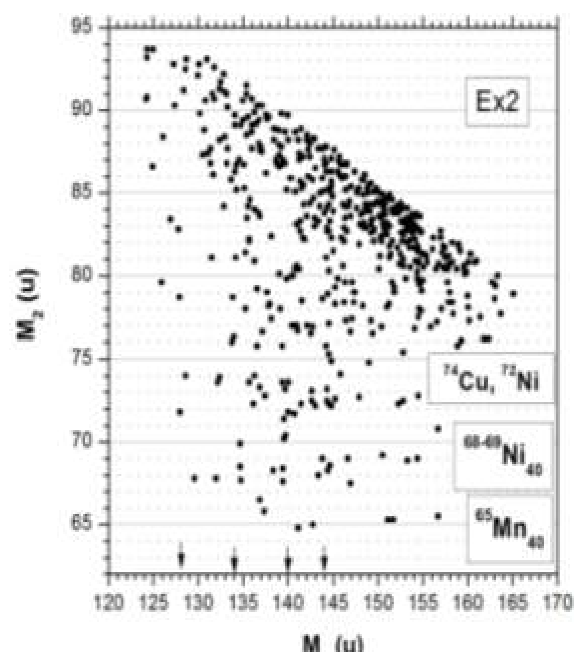
EXAMINATION OF EVIDENCE FOR COLLINEAR CLUSTER . . . PHYSICAL REVIEW C 96, 064606 (2017)

TABLE I. Results of the model calculations. Ternary partitions close to the experimental ones and based on magic constituents (marked in bold) are shown in square brackets. See the text for details.

No.	Locus	Nucl. configuration	R_{12}, fm	$E_{H\,sec}$ MeV	E_H, MeV	V_L, cm/ns	$V_{L\,sec}$, cm/ns	V_T, cm/ns
1	$w1b$	^{70}Ni–^{43}S–^{139}Xe [**^{70}Ni–^{42}S–^{140}Xe**]	⩽27	71	80.4 ± 1.8	0.71 ± 0.1		2.16 ± 0.06
2	$w1c$	^{70}Ni–^{39}Si–^{143}Ba [**^{70}Ni–^{38}Si–^{144}Ba**]	⩽30	58	69.5 ± 2.6	0.68 ± 0.06		2.19 ± 0.13
3	$w2b$	^{70}Ni–^{47}Ar–^{135}Te [**^{72}Ni–^{46}Ar–^{134}Te**]	⩽35		91.4 ± 3.1	1.30 ± 0.06	1.34	1.33 ± 0.22
4	$w2c$	^{70}Ni–^{40}S–^{142}Xe [**^{70}Ni–^{42}S–^{140}Xe**]	⩽35		77.9 ± 1.3	1.36 ± 0.03	1.34	1.31 ± 0.004
5	$w3b$	^{70}Ni–^{35}Al–^{147}La [**^{70}Ni–^{34}Mg–^{148}Ce**]	⩽32	60	76.6 ± 3.1	1.62 ± 0.04		0.78 ± 0.08
6	$w3c$	^{70}Ni–^{26}Ne–^{156}Nd [**^{70}Ni–^{28}Ne–^{154}Nd**]	⩽28	52	63.2 ± 2.3	1.68 ± 0.1		0.58 ± 0.05
7	bin. fiss.	^{70}Ni–^{50}Ca/^{132}Sn ^{182}Yb			TKE 141 MeV E_{Ni} = 102 MeV			

Ex2



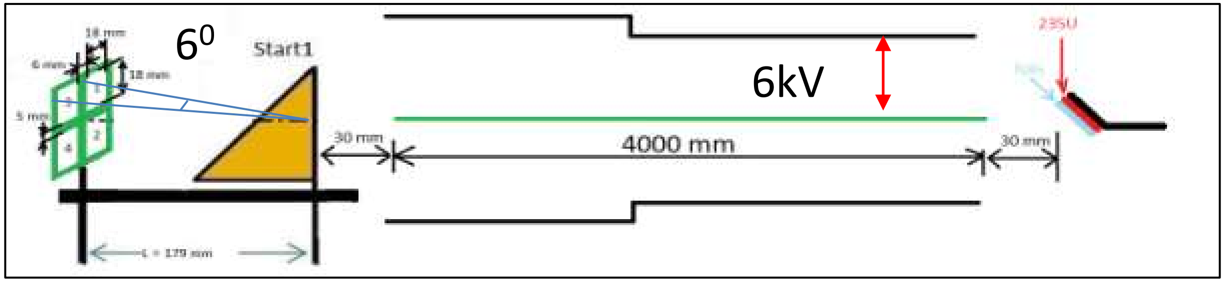


Z=28 & N=40

Ni &: ^{128}Sn, ^{134}Te, ^{140}Xe, ^{144}Ba, ^{150}Ce, ^{154}Nd

Ex3 at VEGA setup

frame~2^0



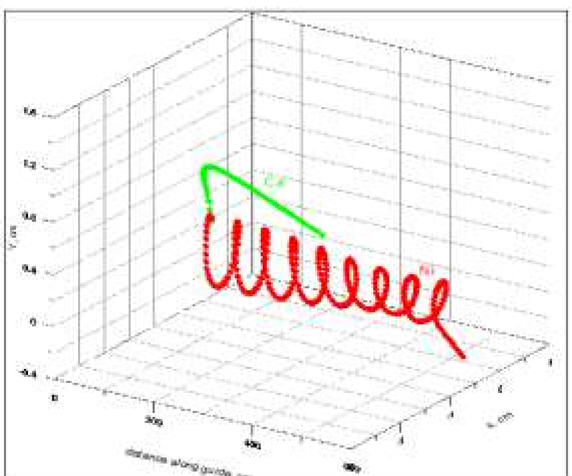
$\beta max \sim 1^0$
^{52}Ca,
E=57MeV

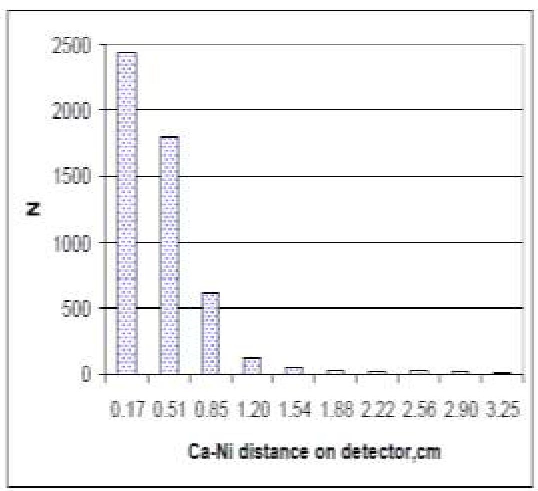
VEGA (**V-E G**uide based **A**rray) setup at the MT-25 microtrone in FLNR

Table 1. Parameters of the collinear CCT fragments chosen for the modeling

Isotope	*M* (amu)	*E* (MeV)	*v* (cm/ns)	*P* (amu*cm/ns)	*q* (units)	*E/q* kV
^{72}Ni	72	21	0.75	54	16	1312.5
^{52}Ca	52	57	1.46	76	4	14250
^{128}Sn	128	68	1.01	130	22	3090.9

parameters used for the calculations :*V0* = 10 kV, *s* = 0.1 mm, channel diameter (outer cylinder) is 56 mm, the length of one guide arm is 5 m, the target diameter is 5 mm.





Proc. ISINN 20, 2012

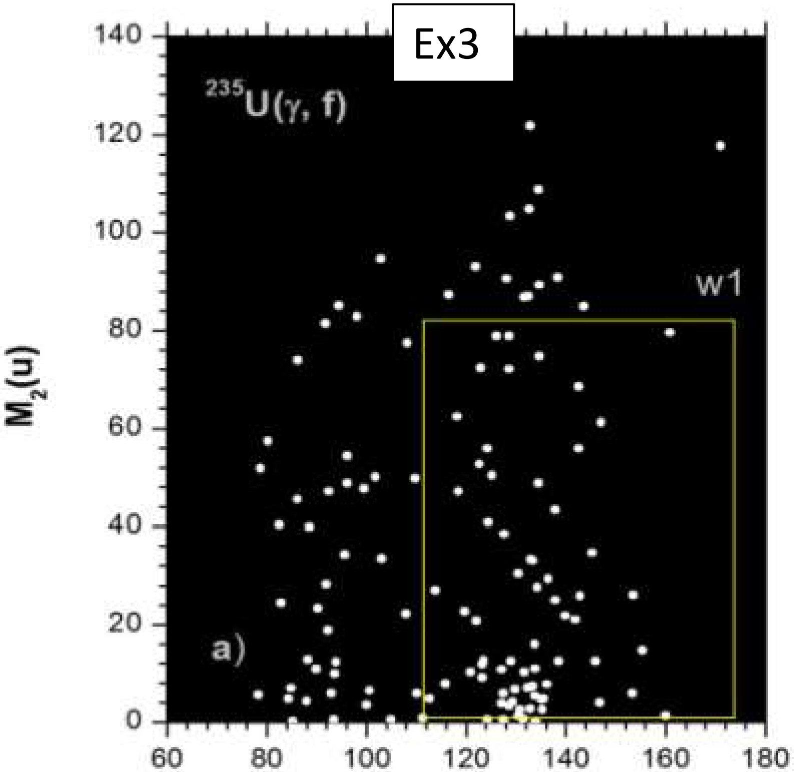
According to [5] the collection efficiency *Fc* of the guide for an extended, uniform, target of radius *b* equal to the tube (outer cylinder) radius *R* is estimated to be:

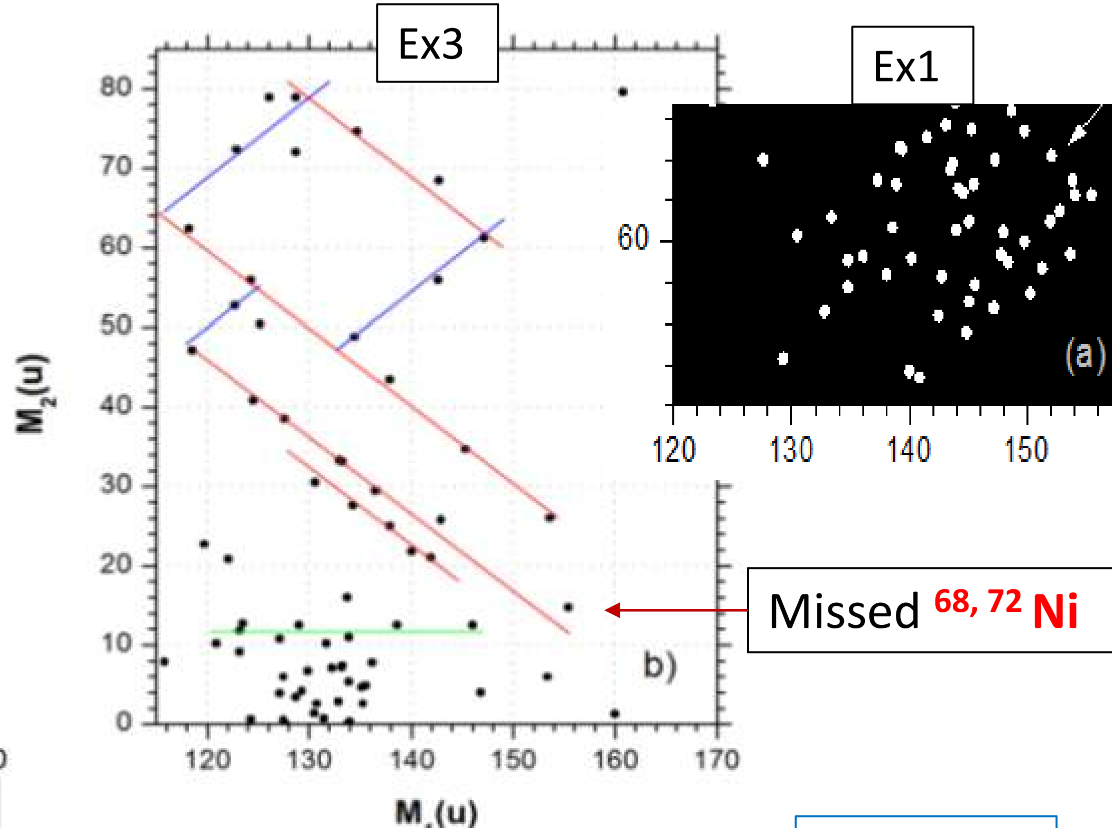
$$Fc = 0.153q\ V0/ \{E_{FF} \ln(R/s)\}, \qquad (1)$$

where *V0* is the potential difference between the two conductors,
EFF – is the kinetic energy of the fission fragment,
s – is the radius of the central wire of the guide,
q – ionic charge.

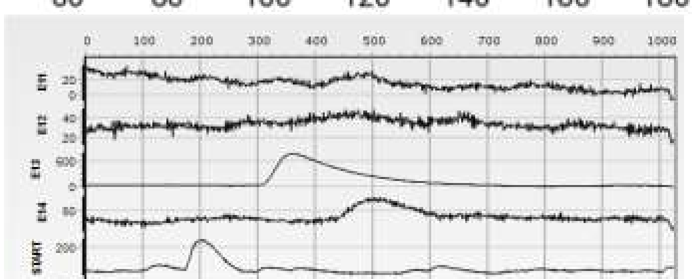
[5] N.C. Oakey, P.D. McFarlane, NIM. 1967. V. 49, 220

Ex3: two fragments in one arm & Ni missed ≡ CCT

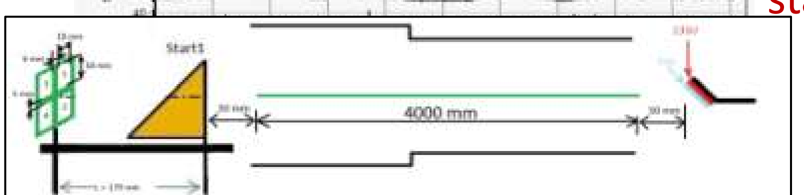




Missed $^{68, 72}Ni$



H
LL
start



Y(Ni _miss)~ 10^{-3}

τ_{life} > 400ns

for $^{68,72}Ni$ missed

<E1>=63.7 ~64MeV;

<E2>=2.97~ 3MeV;

<V1>=0.96 cm/ns;

<V2> =0.43 cm/ns

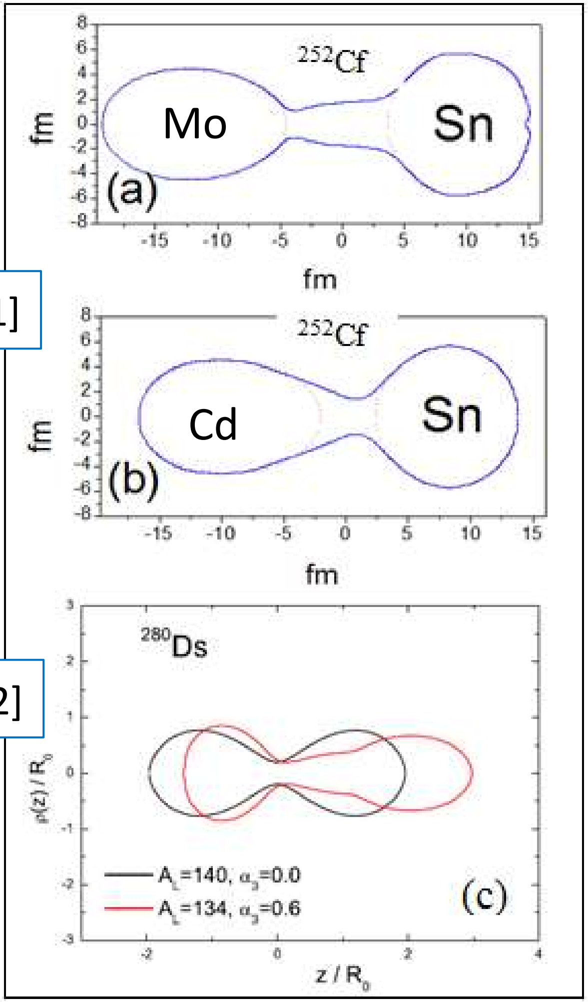
delayed brake-up in the start-foil

Discussion

What happens after 1-st rupture?

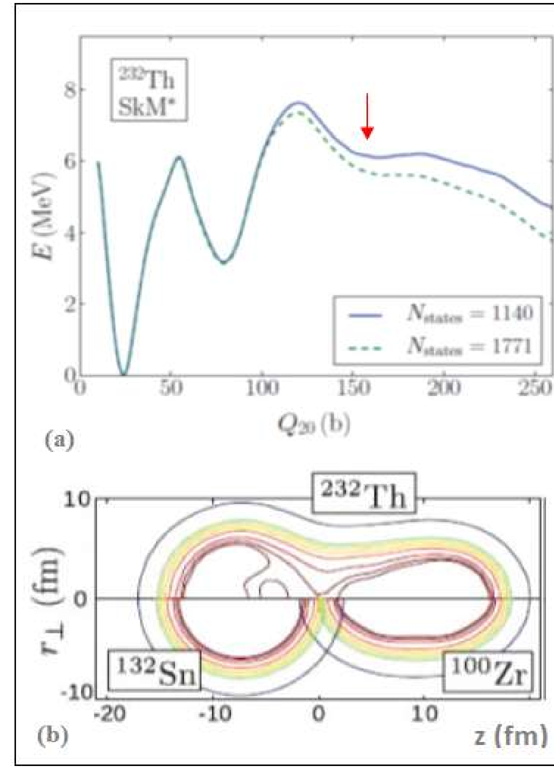
[1]

[2]



$E_3^*=Q_3-TKE_3 \approx 30$MeV
ν exp ~ 4 for Ni-bump:
good agreement;

H&L CCT partners are the magic nuclei -→all $E_3^* \approx E_2^*$ → in the deformed neck (Ca-like nucleus).
$E_3^* \approx$ Eb (Cd-like nucl. [3])
According to Ex3 Cd undergoes *delayed brake-up* in the MCP det. foil. -→
Likely fission isomer state in Cd was populated after 1 rupture

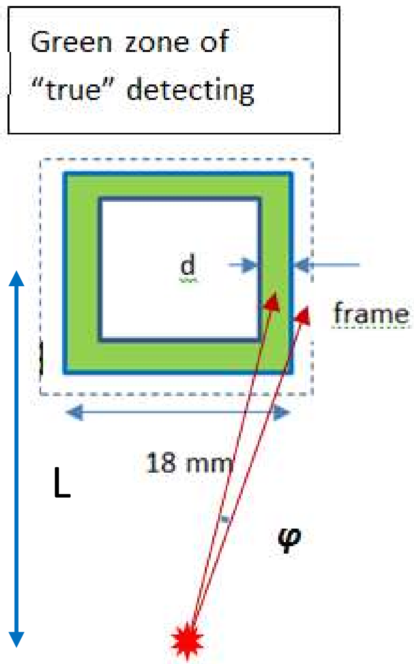


By analogy with the shapes for elongated Cf and Ds elongated Cd formed after 1^{st} rupture could evaluate to the shape "magic head+ elongated neck" – the shape typical for the 3-rd min (fission isomer state)

Potential-energy curve (fission barrier) for ^{232}Th calculated in the frame of the finite–temperature superfluid nuclear density functional theory [4]

1. Yu. V. Pyatkov, V. V. Pashkevich et al., Nucl. Phys. A **624**, (1997) 140
2. N.Carjan, F.A.Ivanyuk, Yu.Ts.Oganessian, Nucl. Phys. A 968 (2017) 453
3. P. M¨oller, et al., At. Data Nucl. Data Tables **59**, 185 (1995).
4. J. D. McDonnell et al., Phys. Rev C **87**, 054327 (2013)

Probability of the intermediate fragment brake-up in the start detector



On of the fork- tooth must be missed for the correct detection of an other one.

We suppose the doorway state for the CCT, at least manifested itself as the “Ni-bump”, corresponds to the differential neutron multiplicity

$Y(\nu_L/\nu_H = 4/0)$,

while the $Y(\nu=4)=30\%$.

It is known as well that

$[Y(\nu_L/\nu_H = 4/0)/ Y(\nu=4)]=5.13\%$

(appreciation to Dr. A. S. Vorobyev , from Gatchina, private comm.)

Thus

$Y(\nu_L/\nu_H = 4/0) = 1.54\times10^{-2}$ /per binary fission.

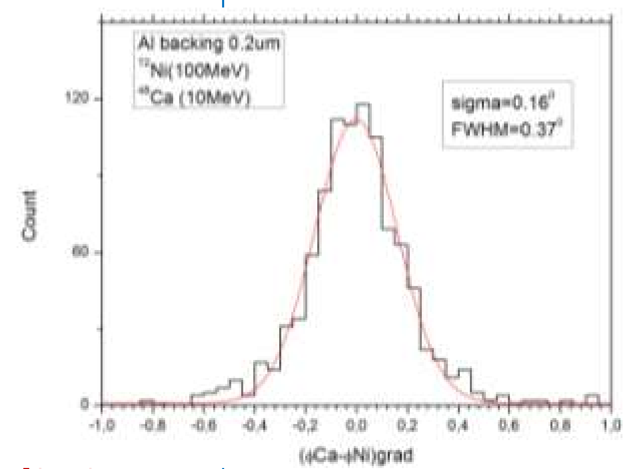


Table 1. Probability of the brake-up of the intermediate fragment in CCT per $(\nu_L/\nu_H = 4/0)$ state

L, mm	PIN, mm	φ, grad	Sgreen/Sall	Yexp(Ni)	Yall(Ni)	Pbrak-up/ν(4/0) state
150	18x18	1	0.5	2×10^{-4}	4×10^{-4}	3%
---	----	0.3	0.17	----	10^{-3}	10%

Summary

Summing up, the following scenario of the most populated CCT mode manifested itself as "Ni-bump" could be proposed.

1. The doorway state for the forthcoming CCT represents very elongated nuclear configuration of two magic clusters connected by the long neck.

2. The first rupture occurs near the surface of one of the magic constituents, predominantly, the heavy one.

3. After first rupture the intermediate nucleus gains the deformation and the shape corresponded to its fission isomer state.

4. The life-time of the isomer state till the brake-up exceeds 400 ns.

5. The probability of the brake-up of the Cd-like fragment per one doorway state manifested itself in the binary fission via asymmetric neutron emission (ν_L/ν_H =4/0) is estimated to be in the range 3% - 10%.

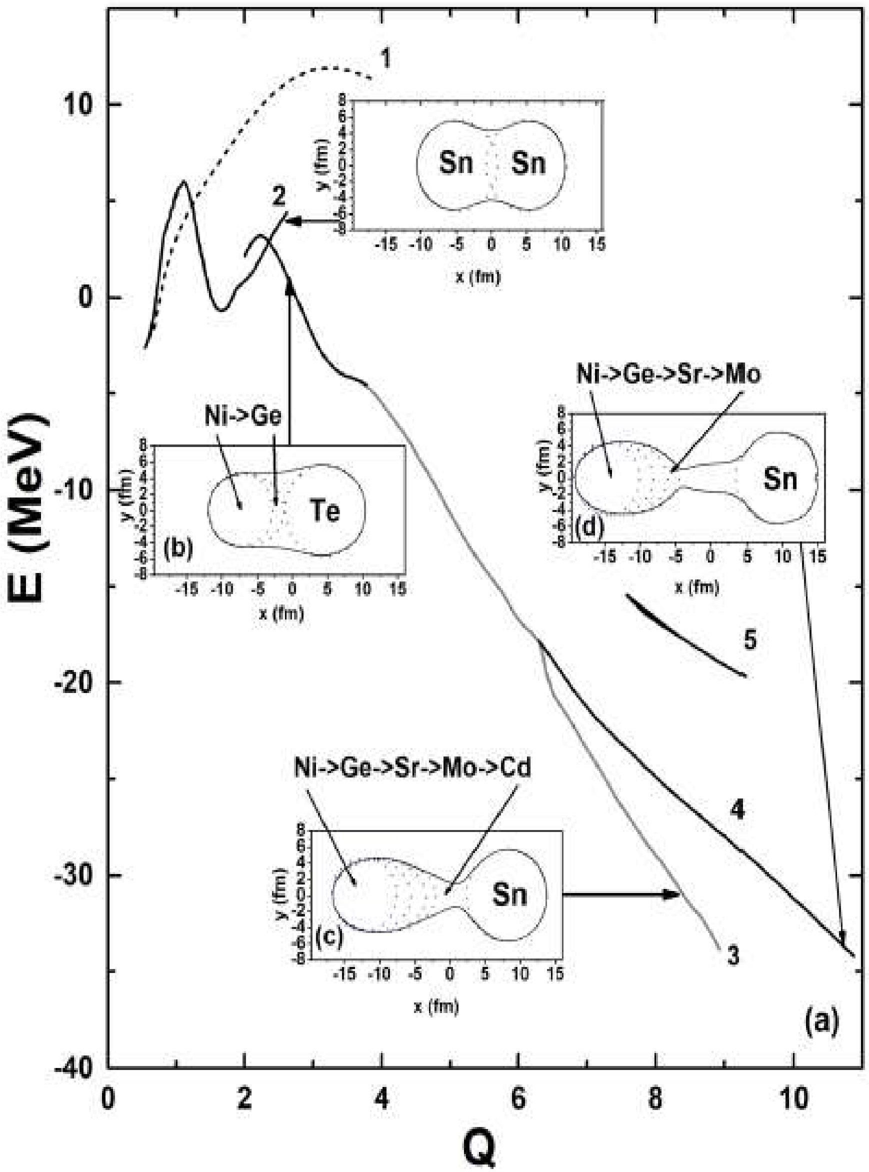
6. At the moment of the second rupture the deformation energy is concentrated mainly in the Ca-like nucleus which de-excites emitting 4 neutrons.

Just the kinematic mode where Ca stays almost at rest after the brake-up of Cd was identified by the neutron belt at the modified FOBOS spectrometer [EPJ A 2012].

Conclusions

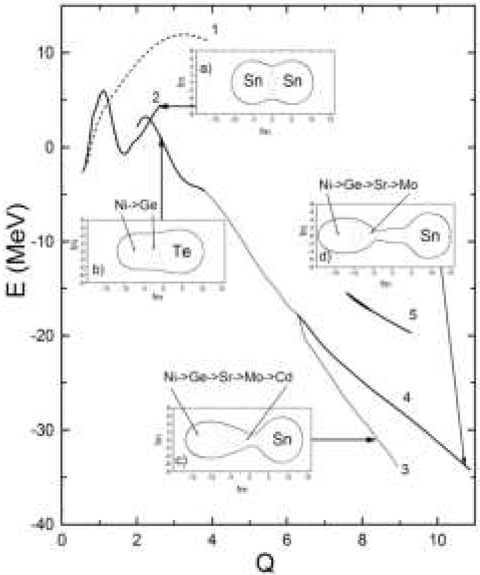
1. Experimental results with approximately three times higher statistics obtained at the COMETA spectrometer confirmed the main features of the Ni-bump.

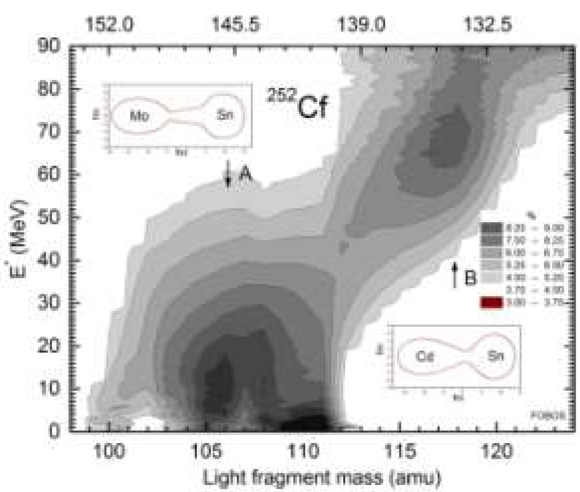
2. With the help of the VEGA setup reliable direct detection of two CCT partners in one spectrometer arm is achieved. The life time of the fission isomer state linked with the CCT channel observed exceeds 400 ns.

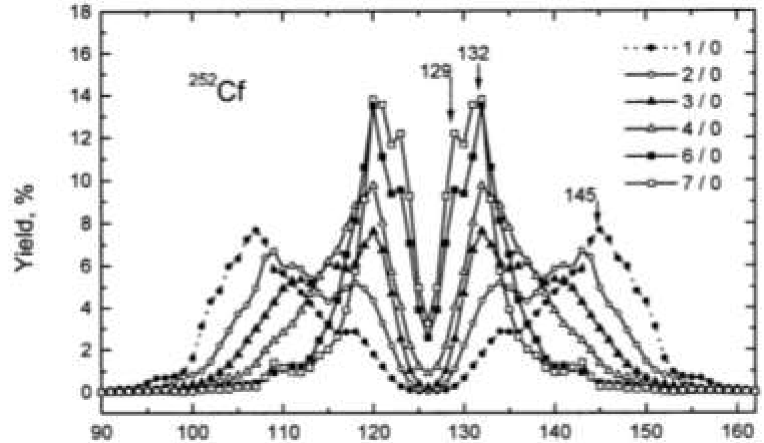


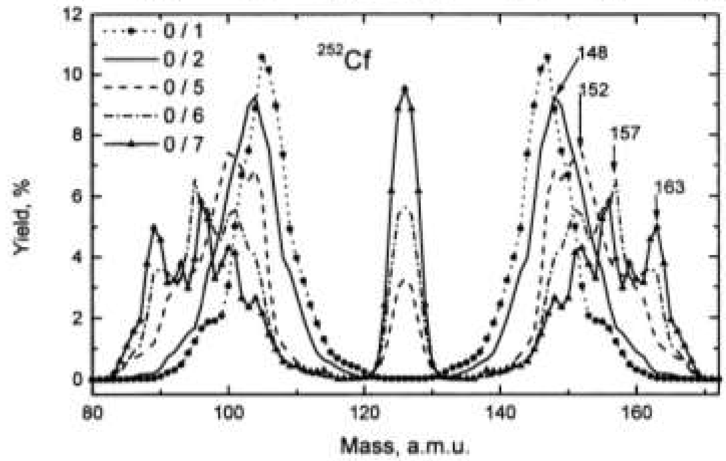
Yu. V. Pyatkov, V. V. Pashkevich, et al., Nucl. Phys. A 624, 140 (1997).

Strongly deformed prescission shapes of the ^{252}Cf nucleus









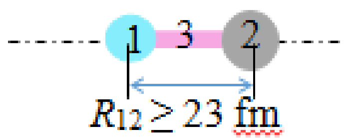
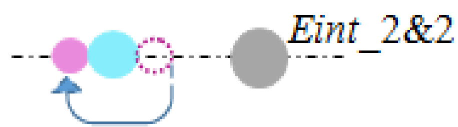
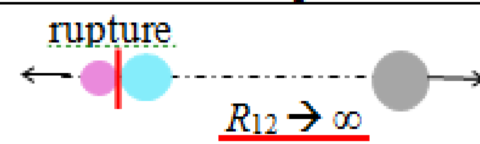
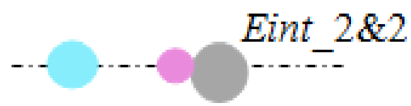
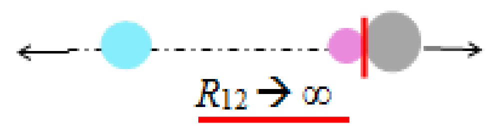
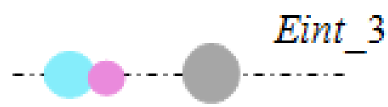
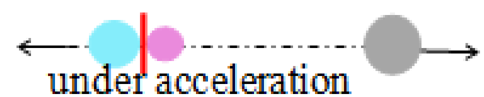
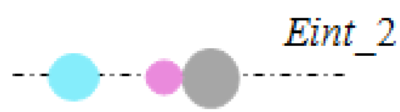
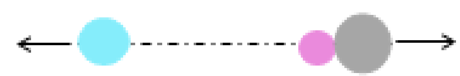
Yu.V. Pyatkov, V.V. Pashkevich, Yu.E. Penionzhkevich et al., Nucl. Phys. A. **624**, 140 (1997).

Y of ν_{tot} = 6 and ν_L / ν_H = **6/0**: **2.19 %** and **0.72 %** for ^{248}Cm and ^{252}Cf resp.

V.A. Kalinin, V.N. Dushin, V.A. Jakovlev et al., In Proceedings of the “Seminar on Fission Pont D’Oye V”, Castle of Pont d’ Oye, Habay-la-Neuve, Belgium, 16–19 September, 2003, p. 73–82.

Scenarios of the CCT modes manifested in “Ni-bump”

TABLE I. (Color online). Pictograms illustrated scenarios of different CCT modes observed in experiment. See text for details.

row №	Label of the locus in Fig. 3(d)	Prescission configuration of the system	System configuration after the first rupture	System configuration at the moment of the second rupture
1	*w*1*b* *w*1*c*			
2	*w*2*b* *w*2*c*	—— “ ——		
3	*w*3*b* *w*3*c*	—— “ ——		
4	binary fission	—— “ ——		

Energies of the detected fragments in Ex1 and Ex2

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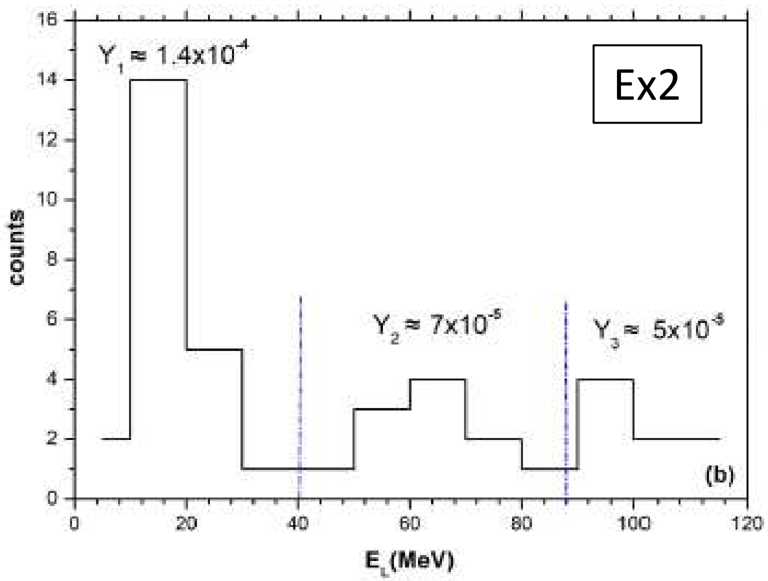
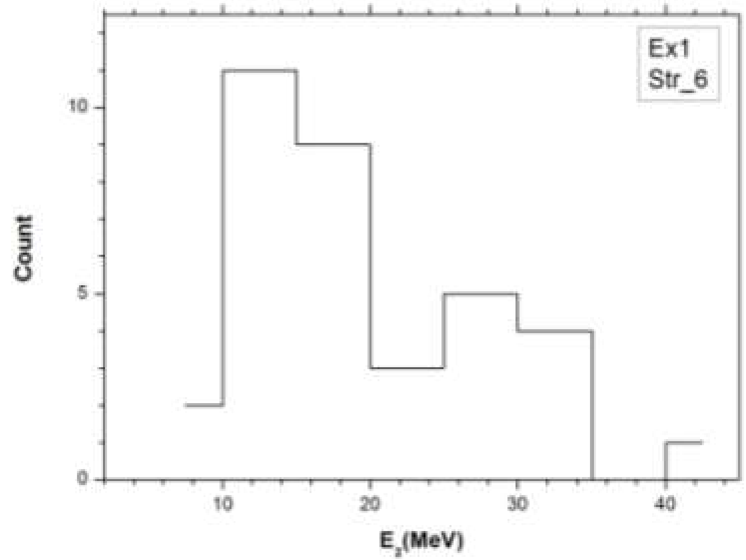
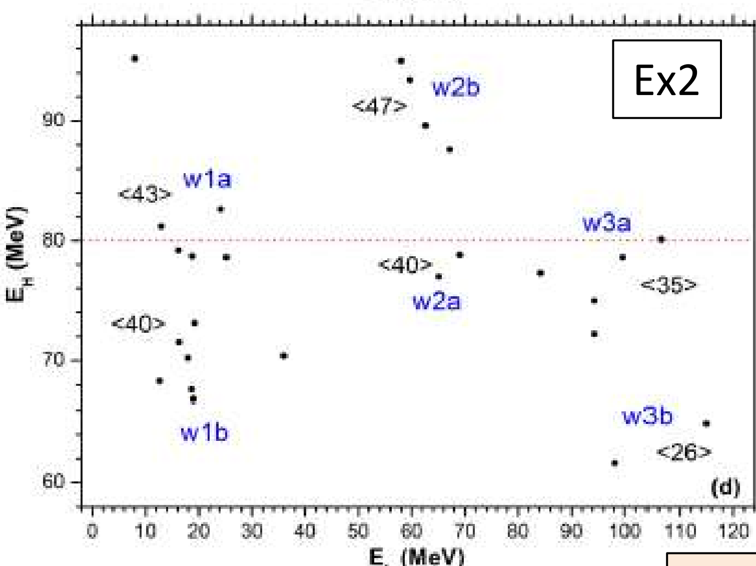
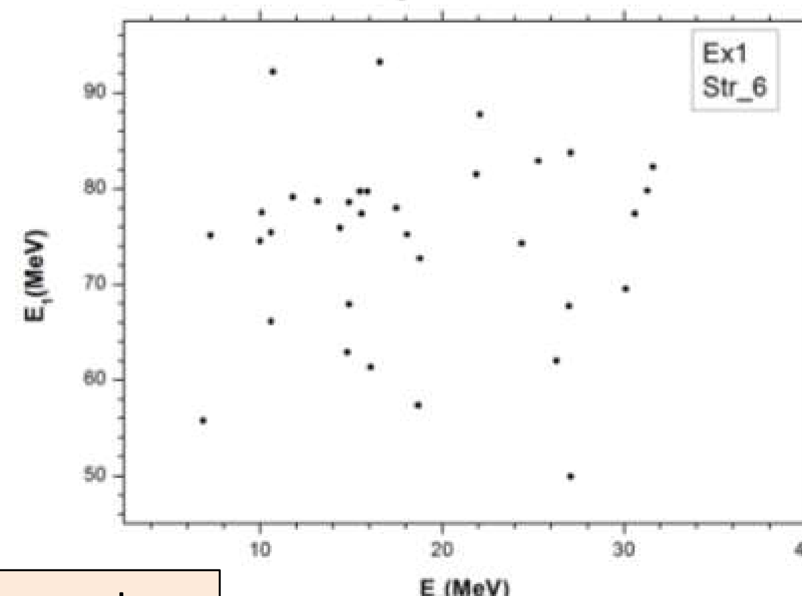








similar results

Clustering in Stable and Exotic Light Nuclei

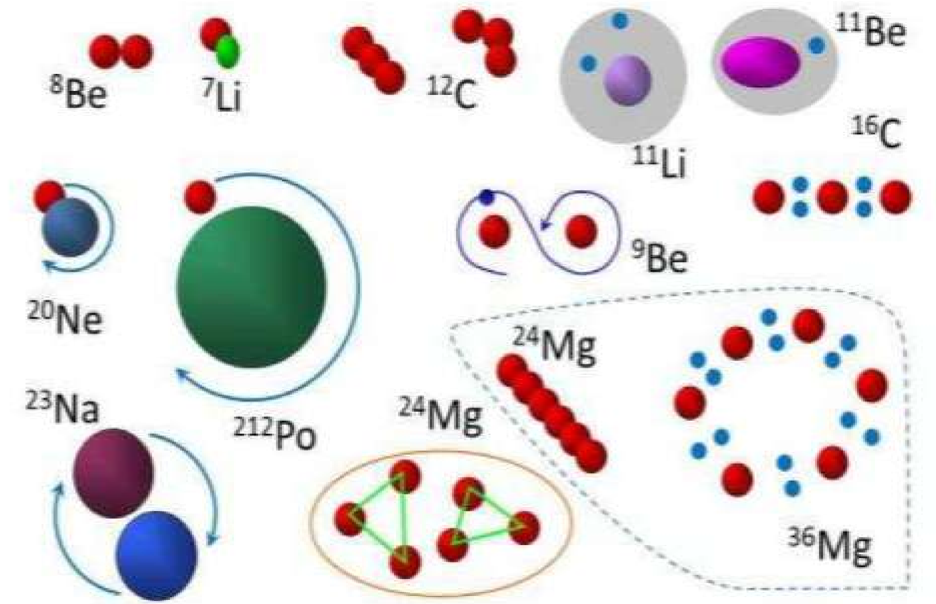


Fig. 1. Different types of clustering behaviour identified in nuclei, from small clusters outside a closed shell, to complete condensation into α particles, to halo nucleons outside of a normal core, have been discussed the last two or three decades [14,15]. This figure was adapted from Ref. [13,14] courtesy from W. Catford.

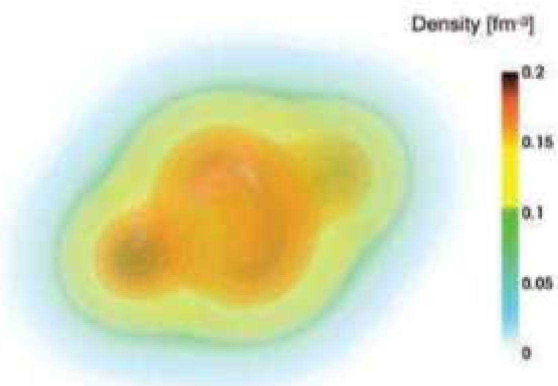
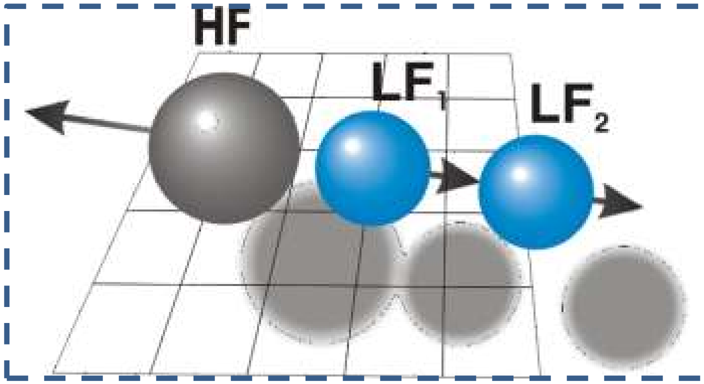


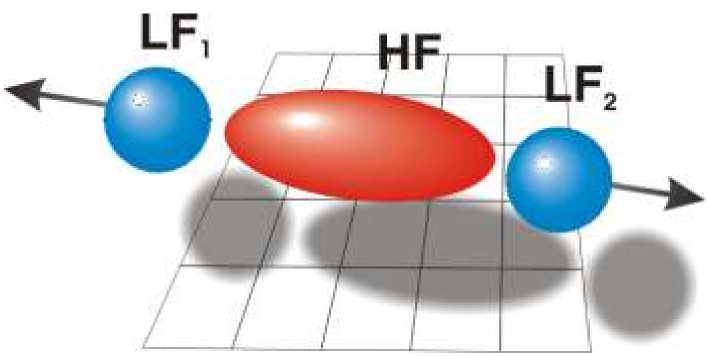
Fig. 7. Self-consistent ground-state densities of the nucleus ^{20}Ne as calculated with EDF (see text for details). Densities (in units of fm^{-3}) are plotted in the intrinsic frame of reference that coincides with the principal axes of the nucleus. This figure has been adapted from Ref. [130] courtesy from E. Kahn and J.-P. Ebran.

Fig. 2. Schematic illustration of the structures of molecular shape isomers in light neutron-rich isotopes of nuclei consisting of α-particles, ^{16}O- and ^{14}C-clusters plus some covalently bound neutrons (Xn means X neutrons) [26]. The so called "Extended Ikeda-Diagram" with α-particles (left panel) and ^{16}O-cores (middle panel) can be generalized to ^{14}C-cluster cores (right panel. The lowest line of each configuration corresponds to parts of the original Ikeda diagram. However, because of its deformation, the ^{12}C nucleus is not included, as it was earlier. The numbers represent the threshold energy dissociating the ground state into the respective cluster configuration. Threshold energies are given in MeV. This figure has been adapted courtesy from W. von Oertzen [26].

(IJMPE Special Cluster, C. Beck, Clustering in Stable and Exotic Light Nuclei, 2016)

Collinear cluster tri-partition (CCT) – status quo





Prescission ternary configurations supposed to be in game

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Examination of evidence for collinear cluster tri-partition

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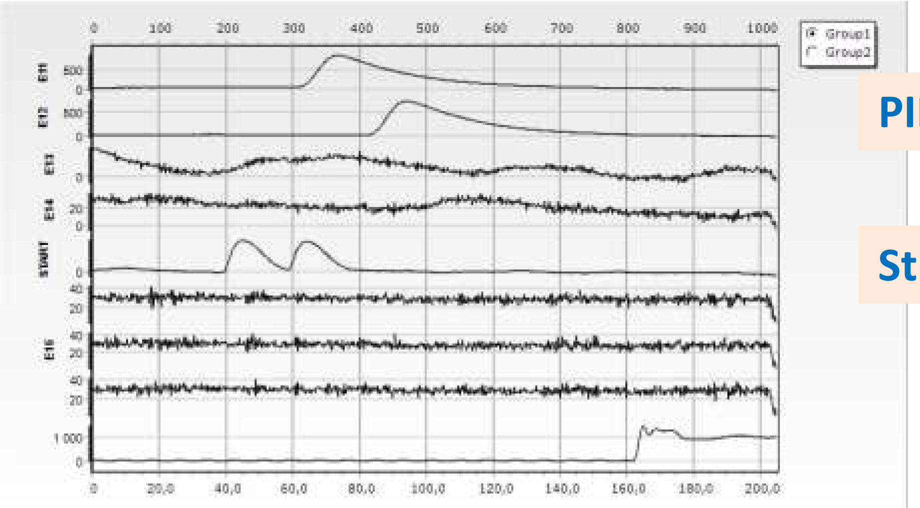
(Received 10 August 2017; published 11 December 2017)

Background: In a series of experiments at different time-of-flight spectrometers of h
manifestations of a new at least ternary decay channel of low excited heavy nuclei. D

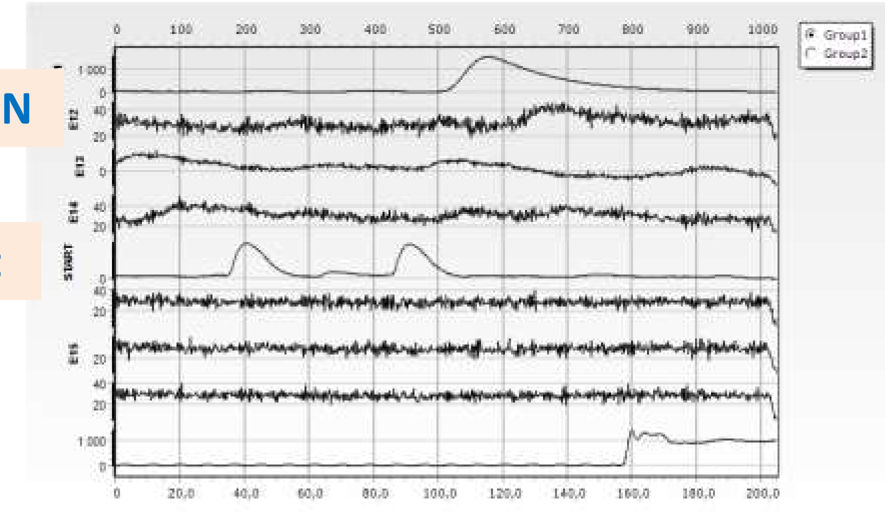
http://fobos.jinr.ru/

Ex3: different animals in the zoo but all big enough (against interferences)



PIN

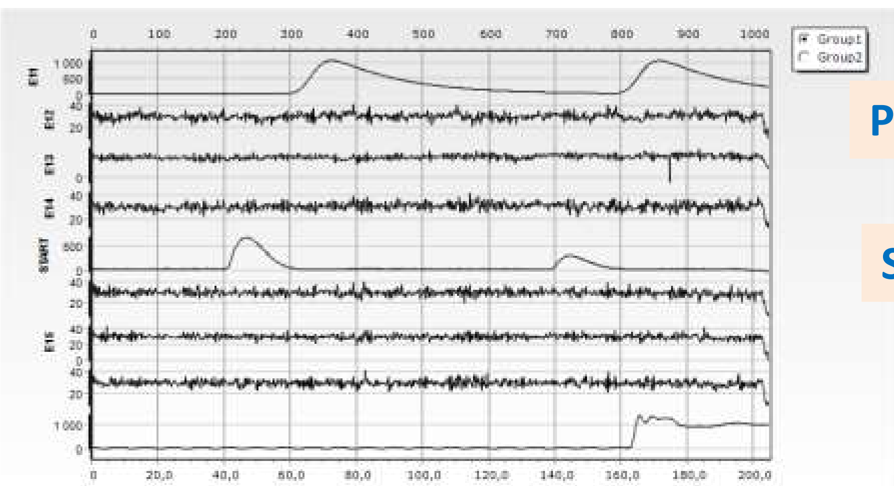
St



almost overlapping

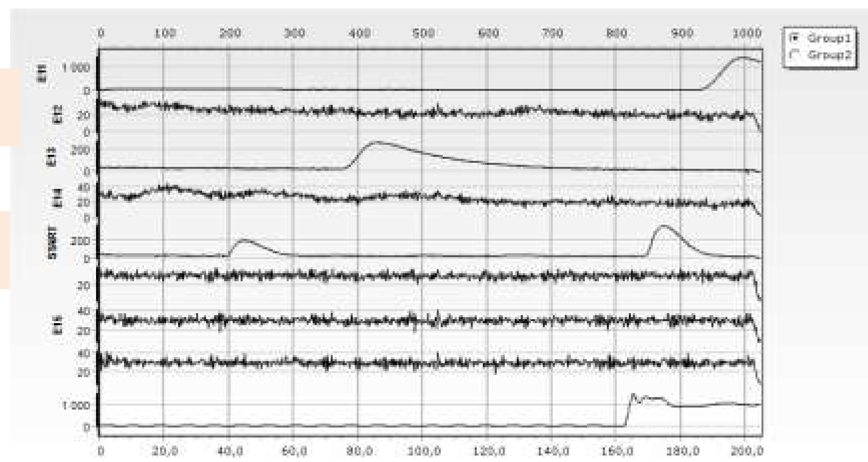
Time vertex ? - to be found…

one FF is missed



PIN

St



double-hit

FF is at the limit of the gate