# FIRST STEPS IN PHYSICAL TREATING OF THE COLLINEAR CLUSTER TRI-PARTITION MECHANISM

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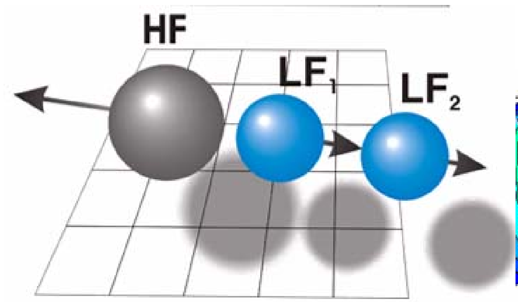
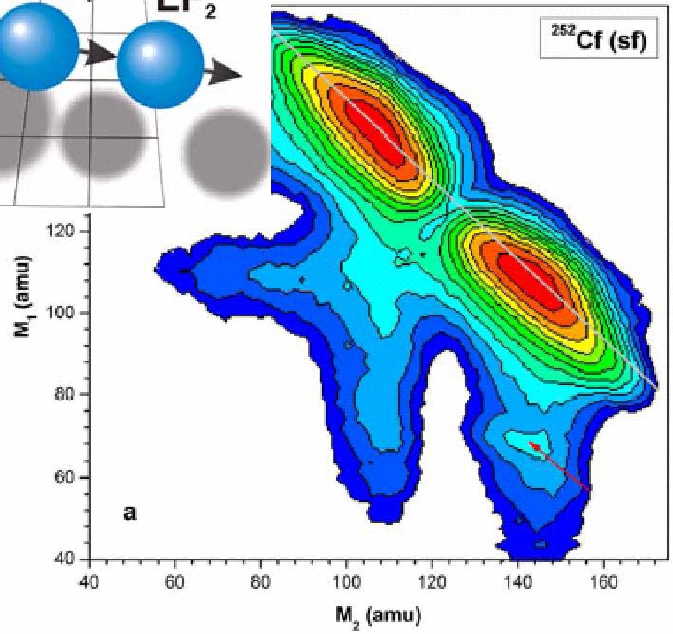
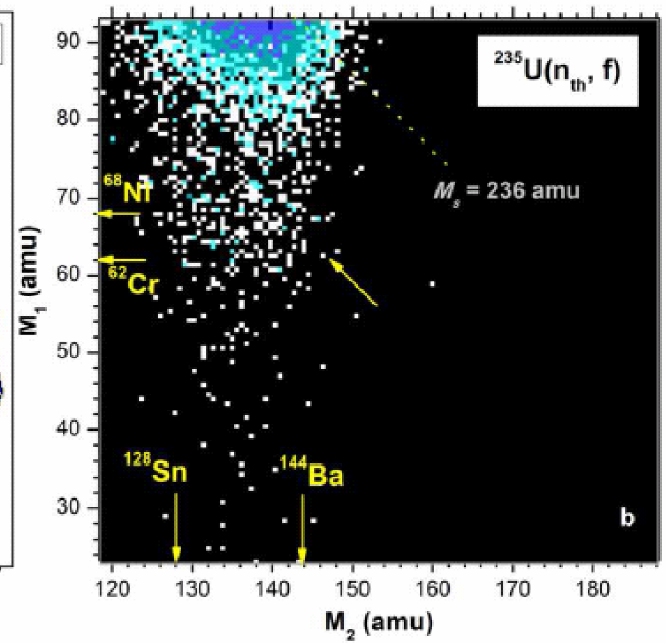
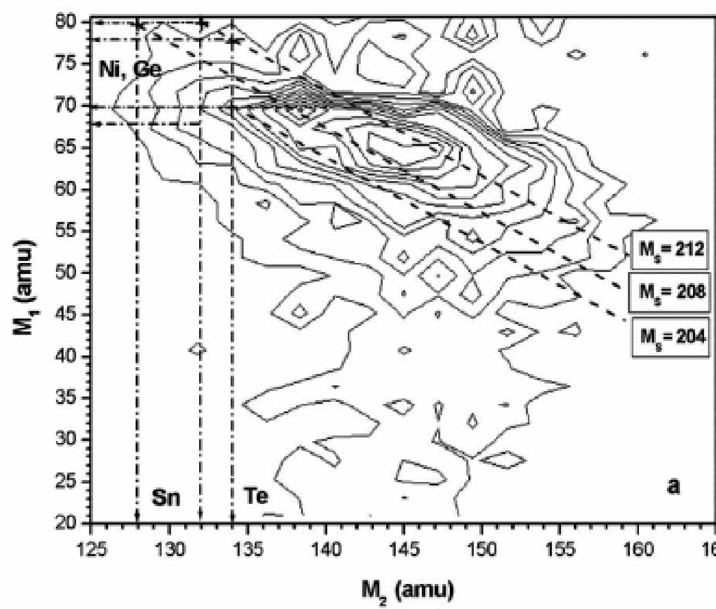
[2]National Nuclear Research University "MEPHI", 115409 Moscow, Russia
[3]Helmholtz-Zentrum Berlin, Glienickerstr. 100, 14109 Berlin, Germany

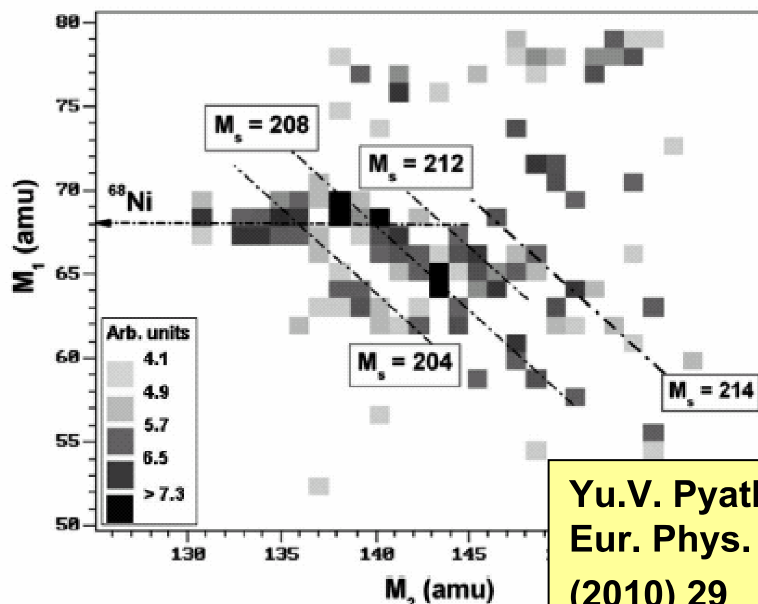
# Experimental background



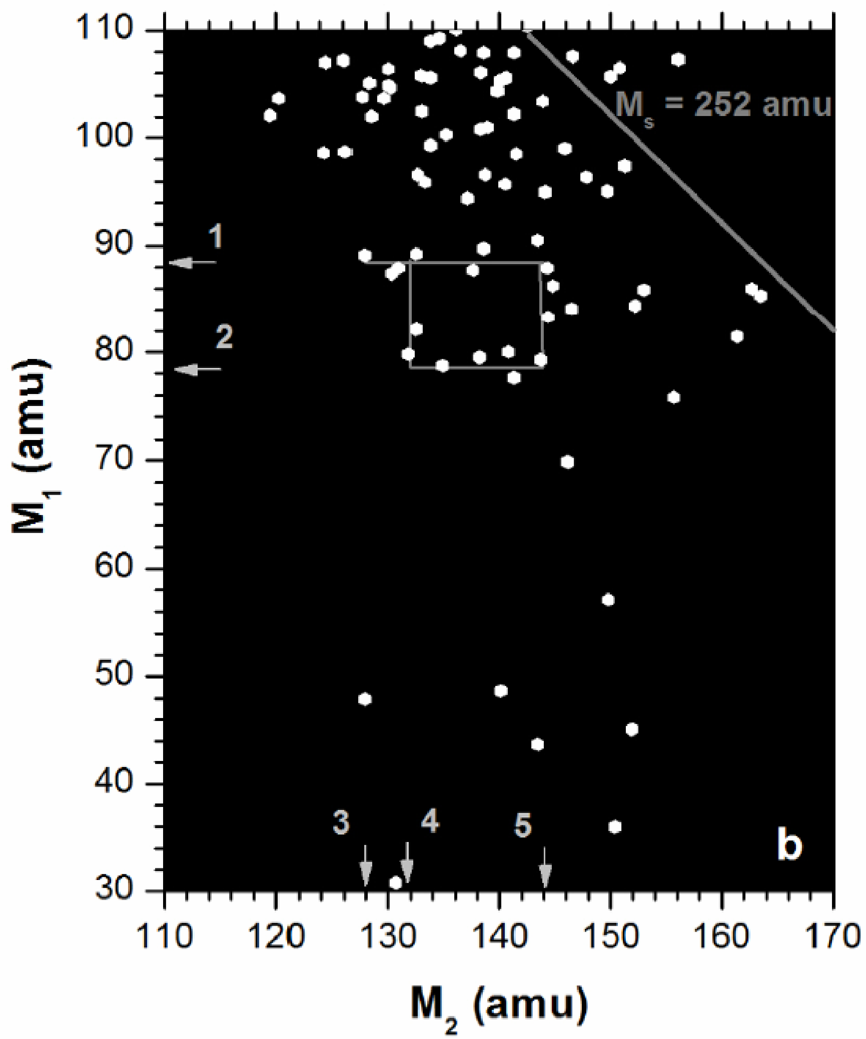



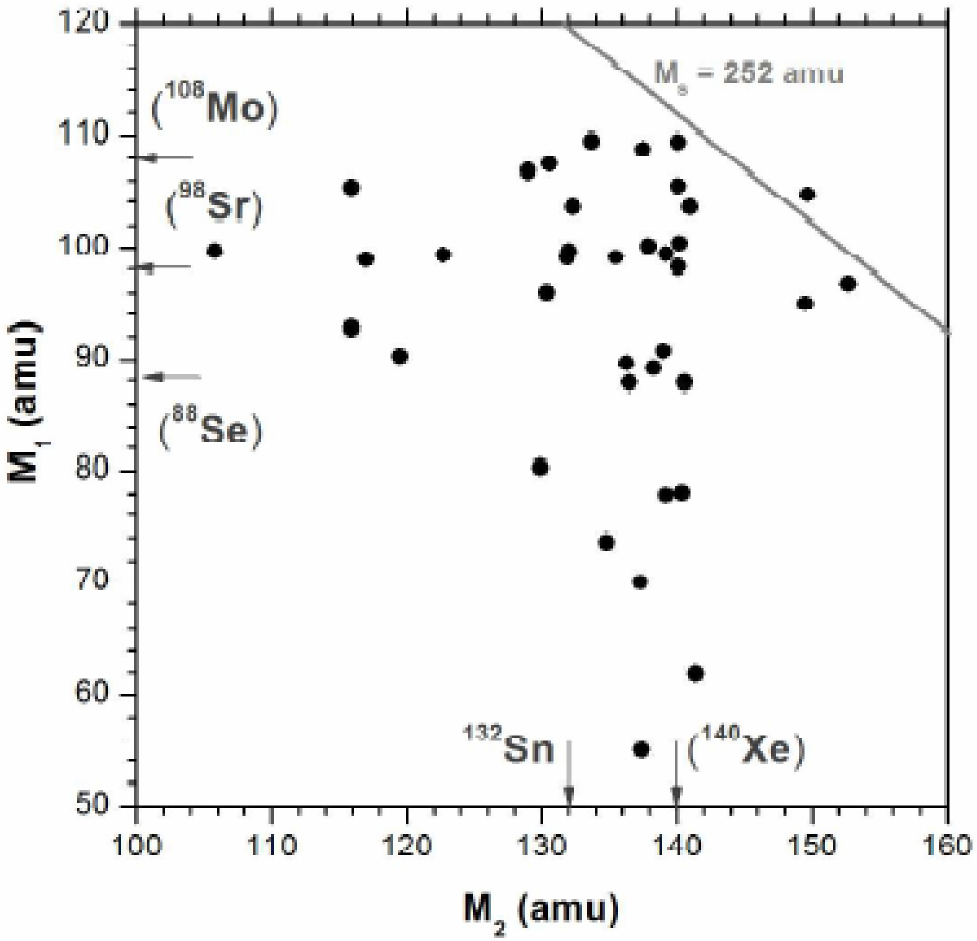




**Yu.V. Pyatkov et al., Eur. Phys. J. A 45 (2010) 29**

# Experimental background

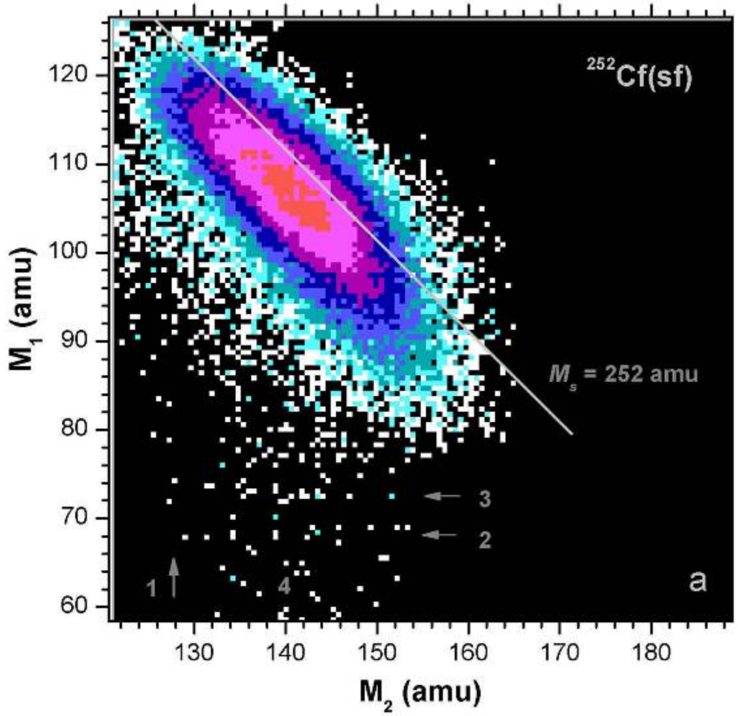



FOBOS, selection by the experimental neutron multiplicity

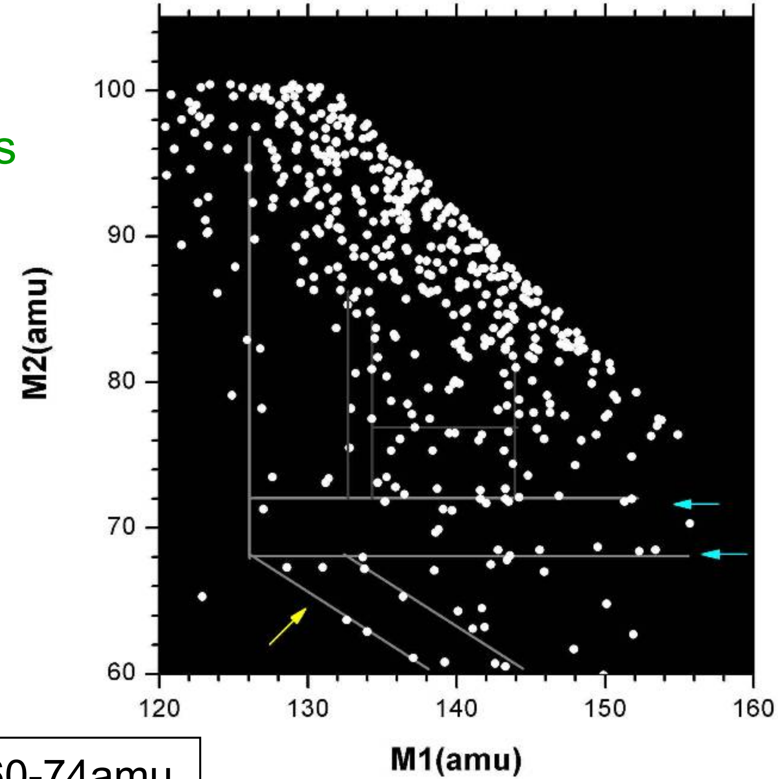


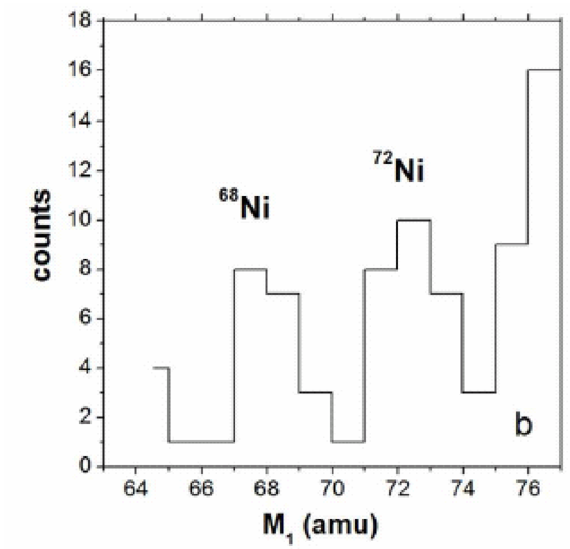

COMETA, selection by the experimental neutron multiplicity

# Experimental background

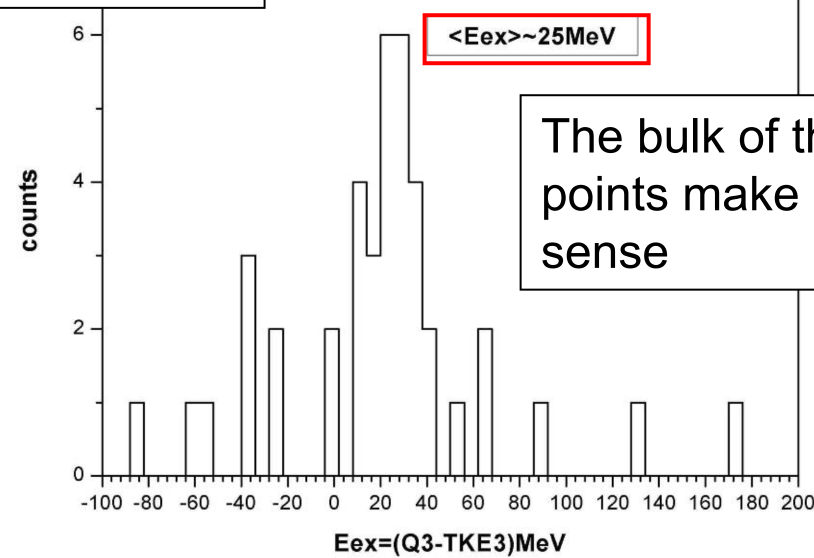



Any gates



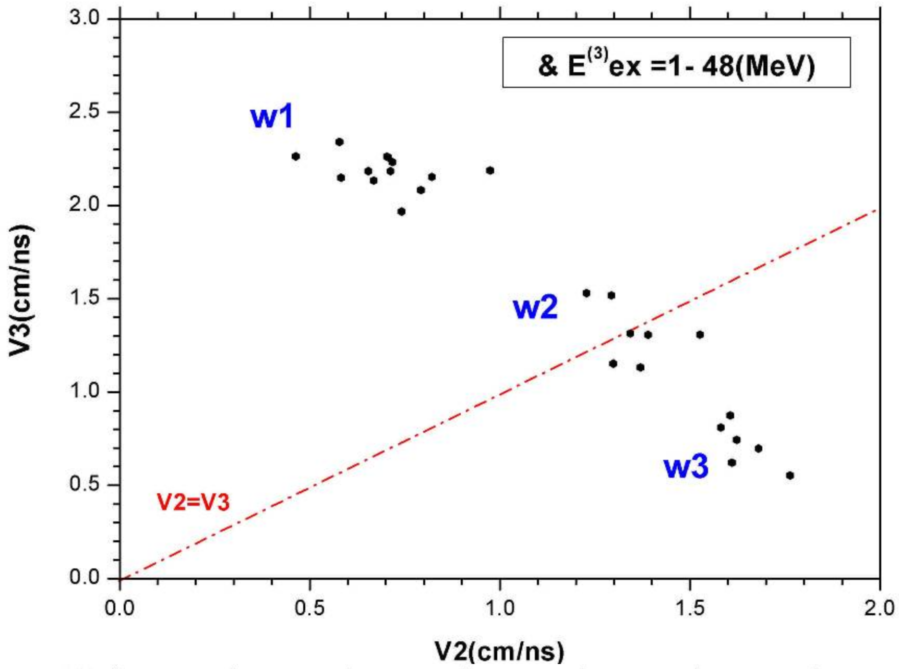



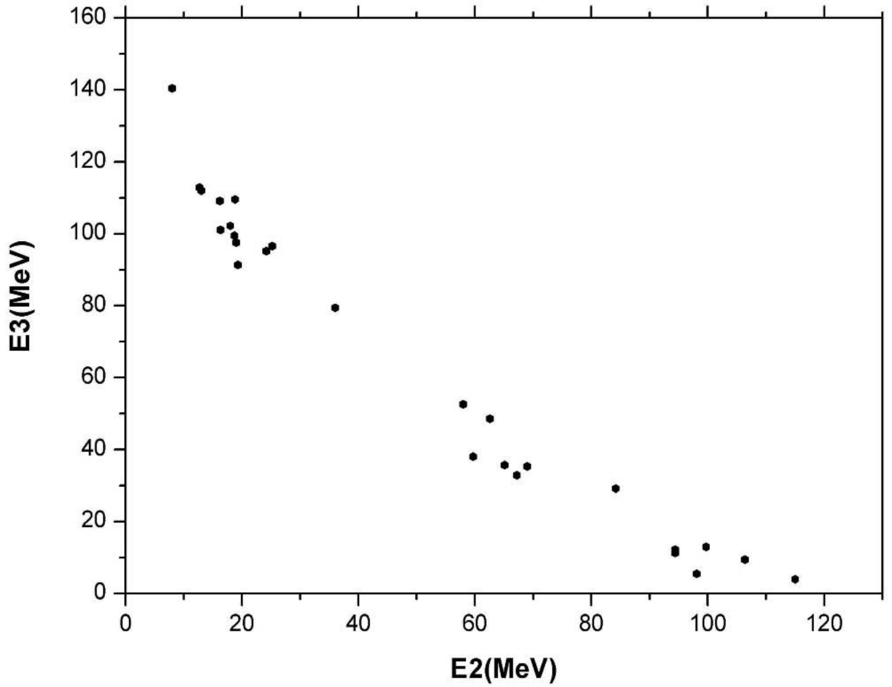

&M2=60-74amu




The bulk of the points make sense

# Velocities and energies of the light CCT partners



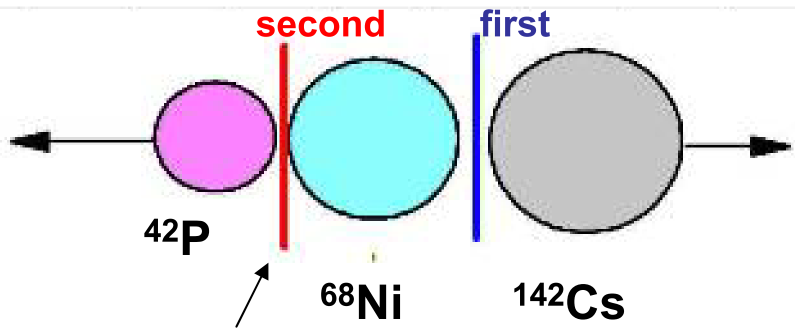




$^{252}$Cf(sf),
binary fission:

<ML>=106.16amu
<EL>=102.54 MeV
<VL>=1.365cm/ns
--------- -----------
<MH>=142.17amu
<EH>=78.68 MeV
<VL>=1.033cm/ns
----------------- -----
<v>=3.773

First group (**w1**): **V3>V2, V1 ~ $V_{H\_bin}$, V2<< $V_{L\_bin}$;** **TKE** exp_3 =190MeV

Prescission configuration expected

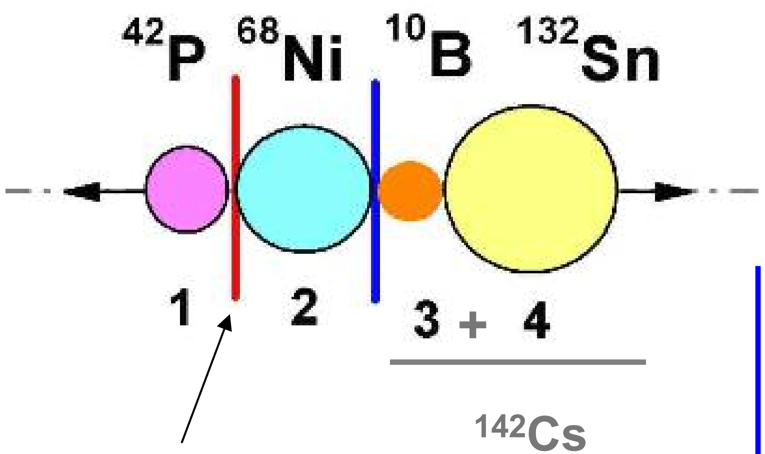



After full acceleration

Q3~207MeV; Eint=230MeV;

Eint > Q3 → <u>cold fission is interdicted</u>

**<u>Hypothesis</u>:** conservation of both magic clusters Ni&Sn along the path M2=const




After full acceleration

Q4~201MeV; Eint~223MeV; Eint>Q4;

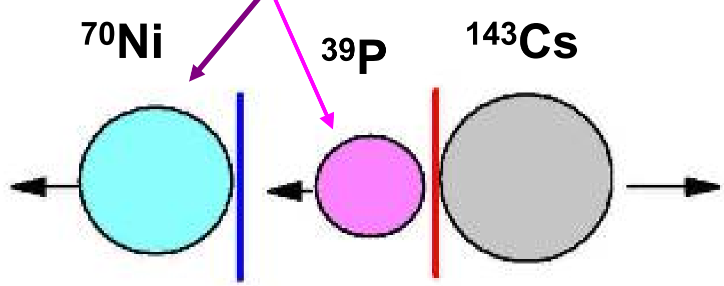
Eint(1,2_3+4)=187MeV ~ TKE exp_3

Vmod($^{42}$P)=1.99cm/ns~Vexp ($^{42}$P)=2.16 cm/ns;

Good agreement

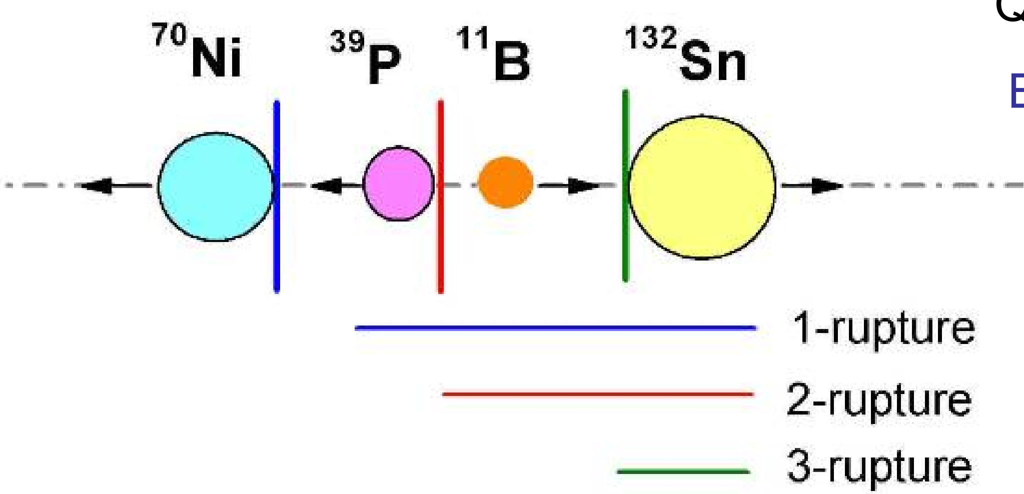
Second group (w2): **V3~V2**, **V1 ~ $V_{H\_bin}$,** **TKE**exp=178MeV

Dynamical blocking



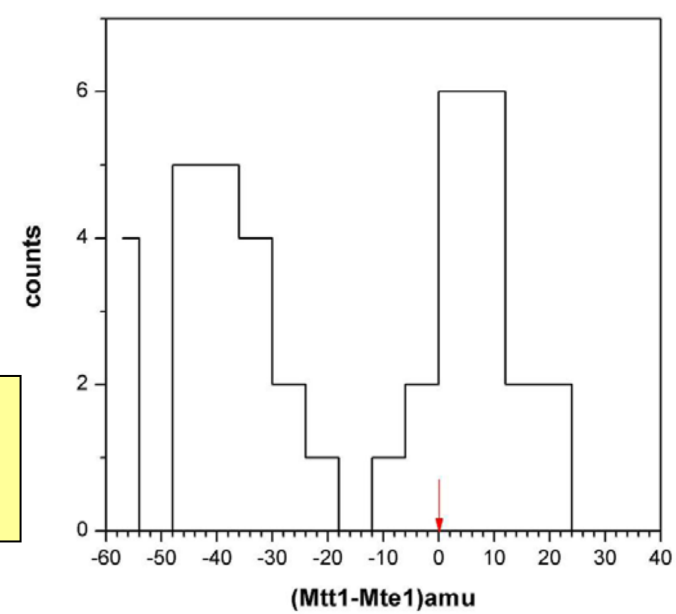

Q3~214MeV; Eint=229MeV;

Eint > Q3 →cold fission is interdicted




Q4~216MeV; Eint~188MeV;

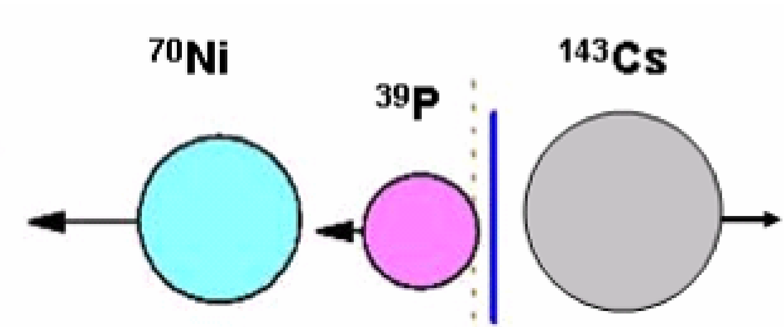
Eint ~TKEexp -- good agreement




Higher as compared to w1 case

E_free in scission lets quaternary decay

Third group (w3): **V3<V2, V1 ~ $V_{H\_bin}$,** **TKE**exp=178MeV

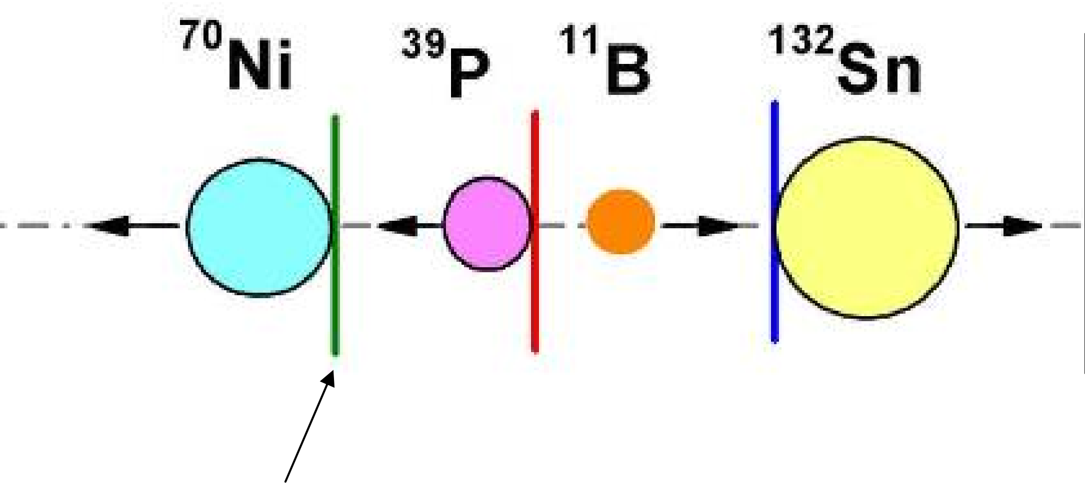



After full acceleration

Q3~214MeV; Eint=229MeV;

Eint > Q3;

(the same partners as in w2)




After full acceleration

Q4~216MeV; Eint~188MeV;

Eint ~TKEexp

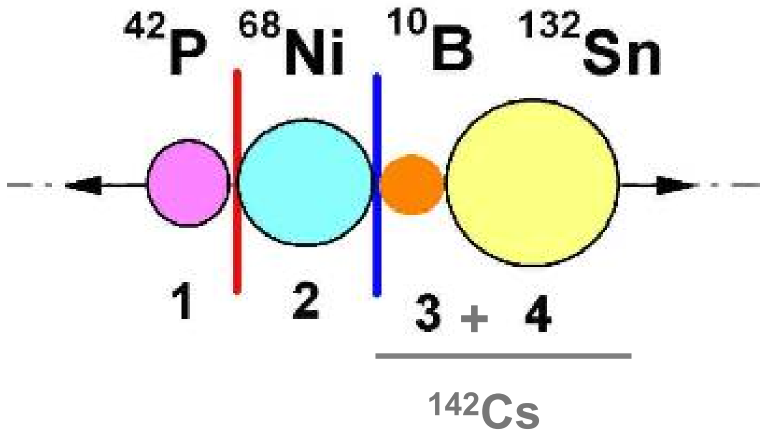
V(Ni)=1.73 ~ Vexp(Ni)=1.62cm/ns

good agreement

## Intermediate summary

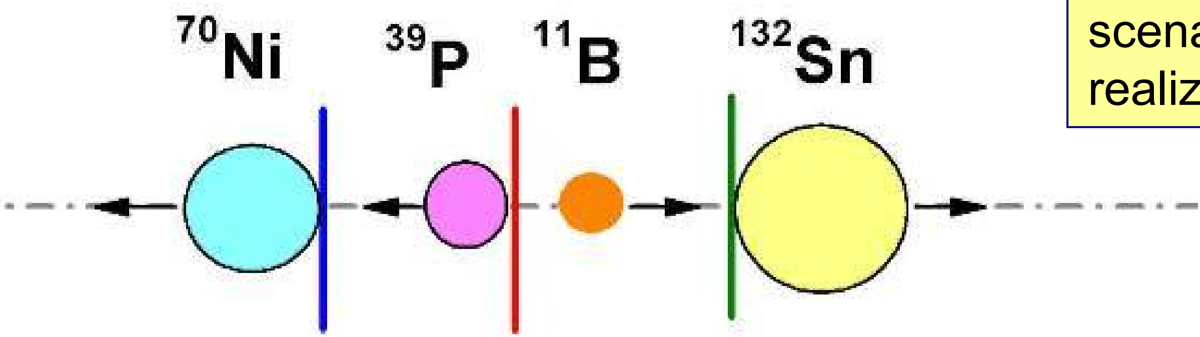
After full acceleration

1)

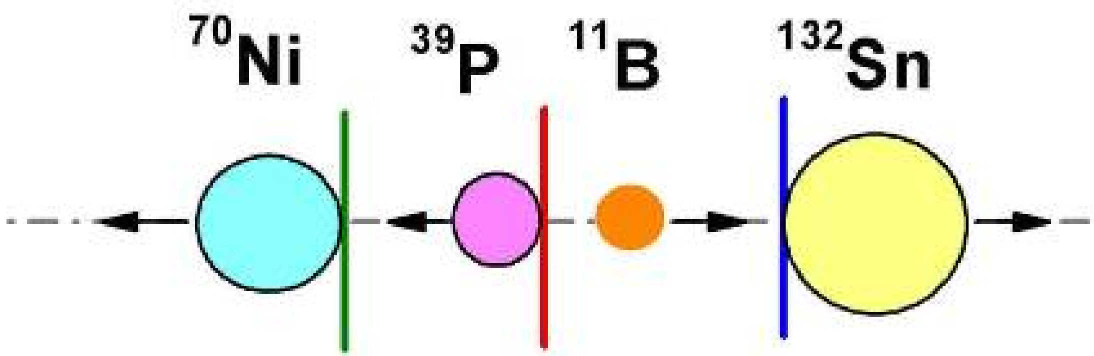



Dynamical blocking

2)



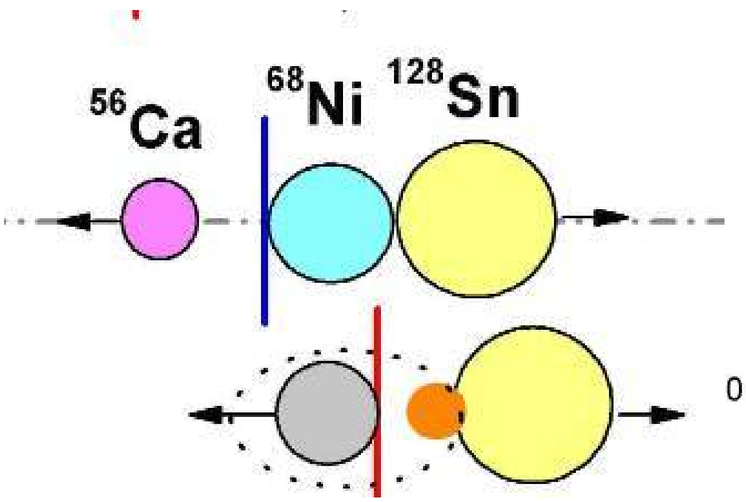

3)

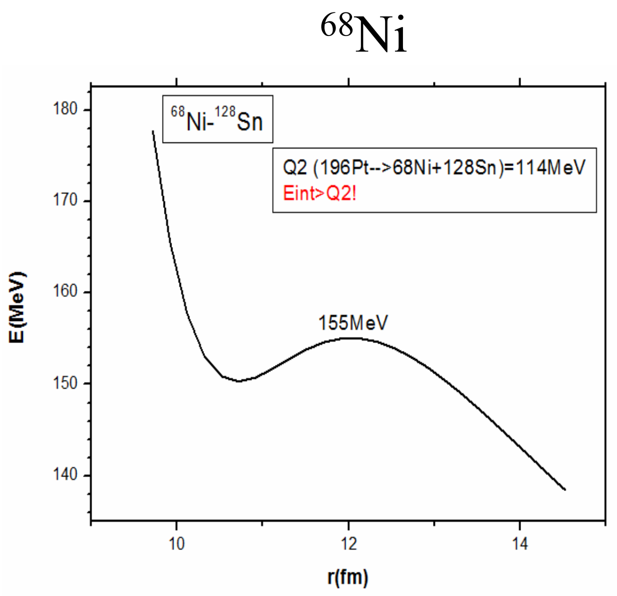



After full acceleration

Similar nuclear composition, but different sequence of partners and rupture scenarios are actually realized.

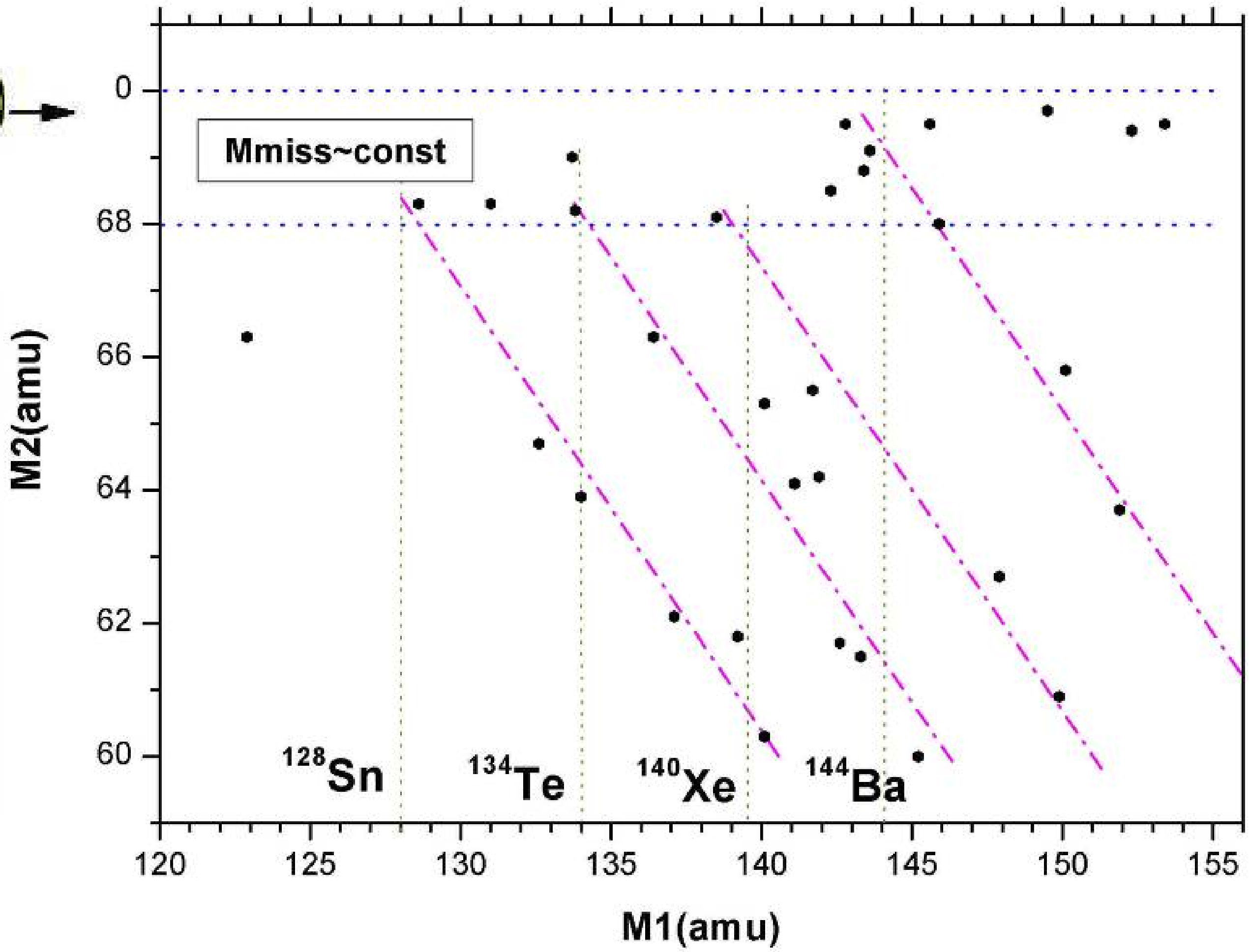
## Structure: tilted ridges

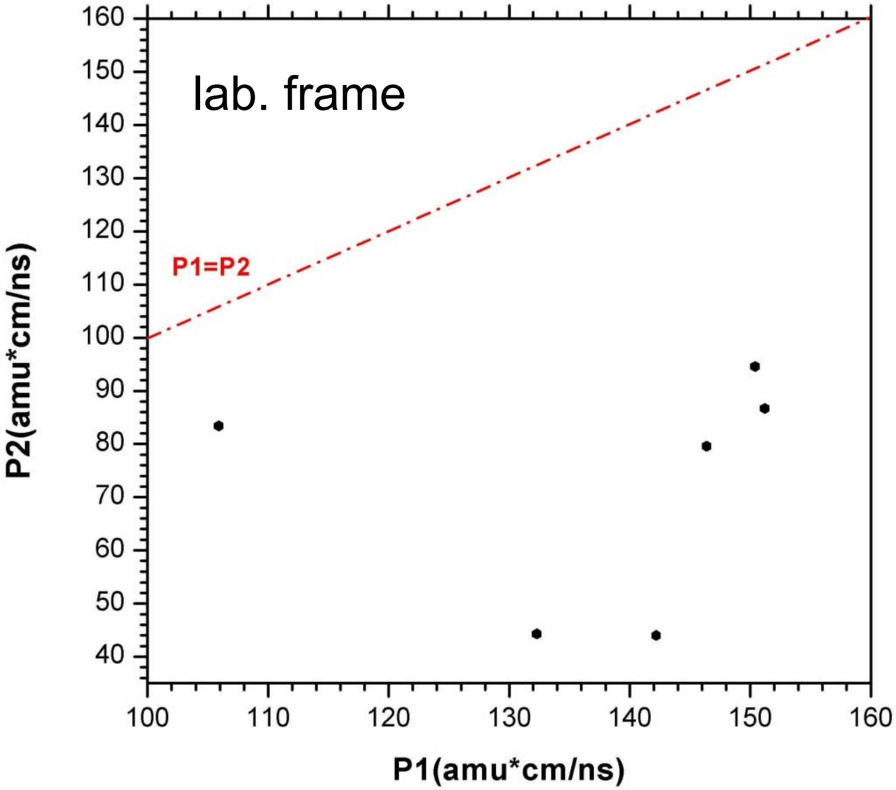



Clustering of $^{68}Ni$ – likely extension of the Ikeda rule

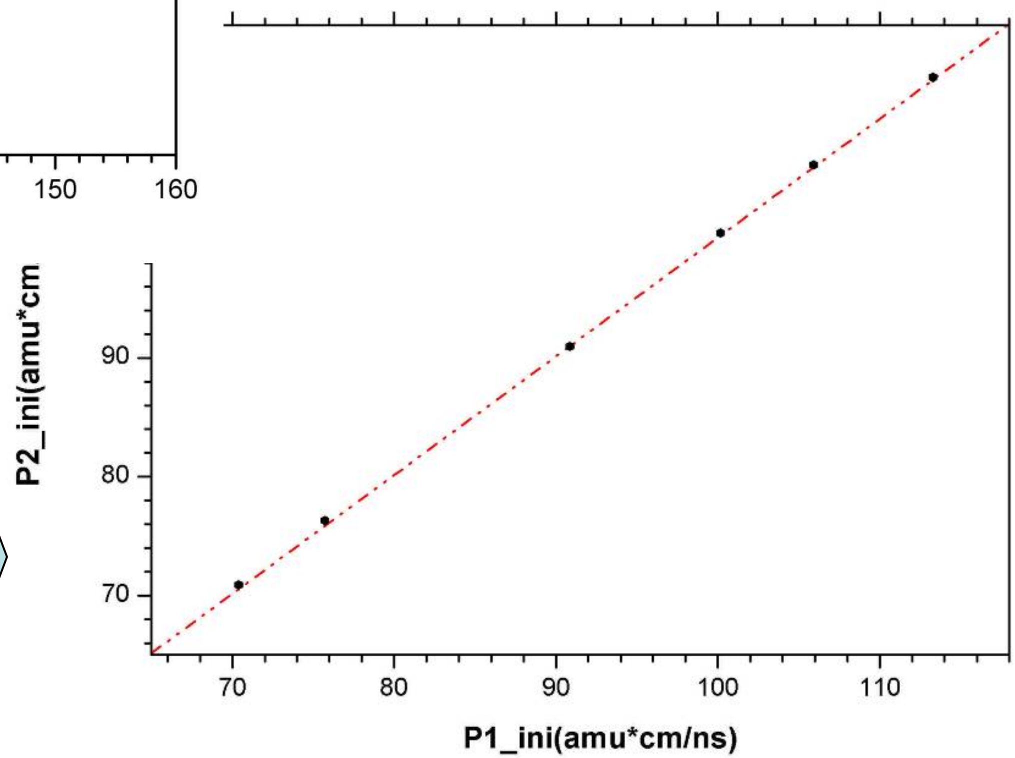
The mass of the missing fragment M3=const





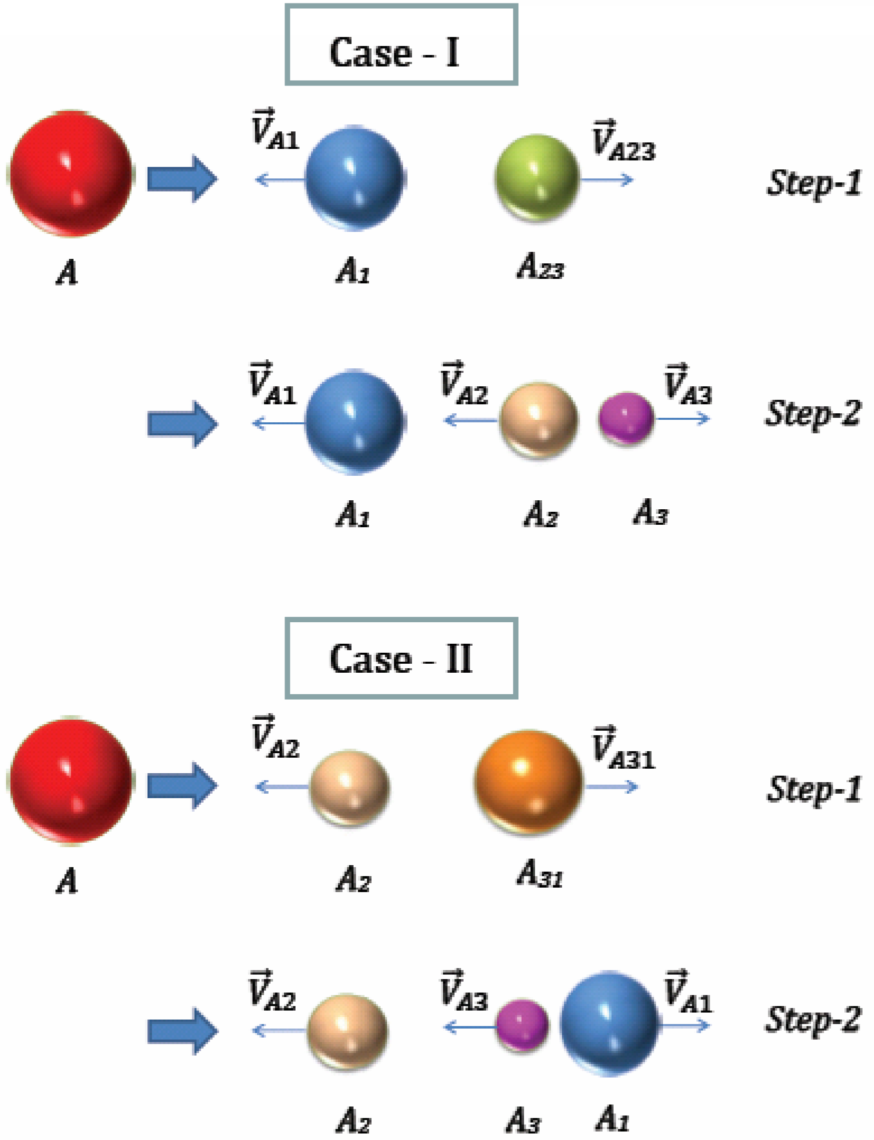

**Really sequential two-step process**

Linear momenta
in the initial system
“two magic clusters”



## CCT: theoretical models put forward so far.

# Kinetic energies of fragments in ternary splitting of $^{252}$Cf




Only one CCT combination
**Sn-Ca-Ni**
is analyzed in the frame of a rather artificial model.

Nevertheless, a principal peculiarity of the energy spertra of the light CCT partners is reproduced, namely their two-component composition (low energy and high energy peaks)

**K.R. Vijayaraghavan, W. von Oertzen, M. Balasubramaniam, et al., EPJ A (2012) 48: 27**

# Comparison with the model calculations

Case_2

Case_1

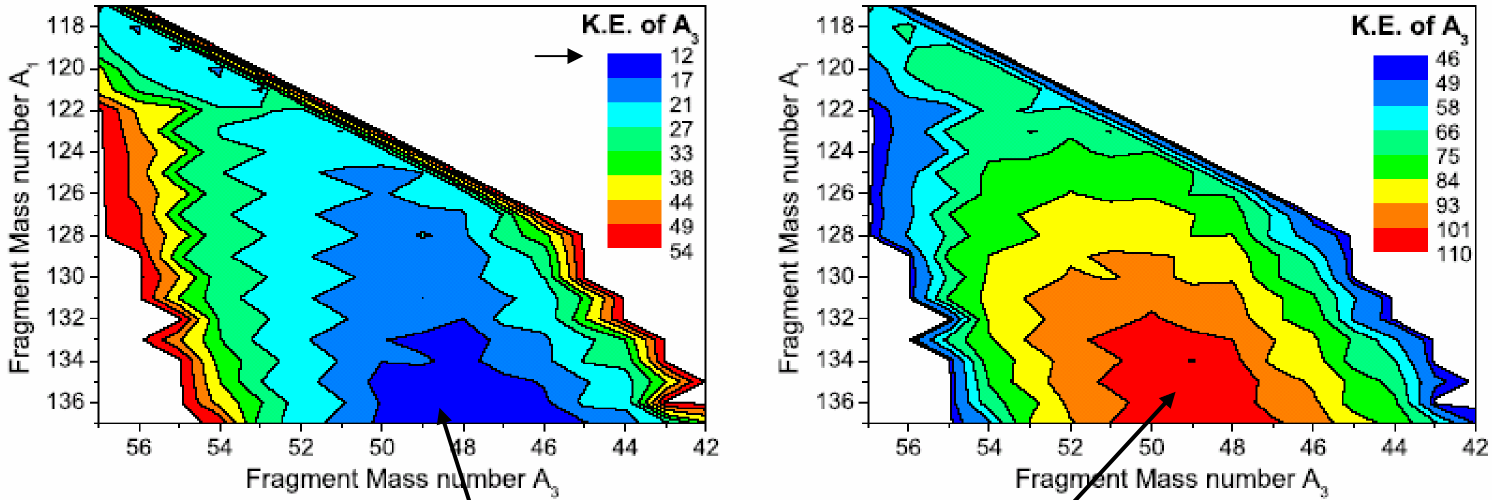
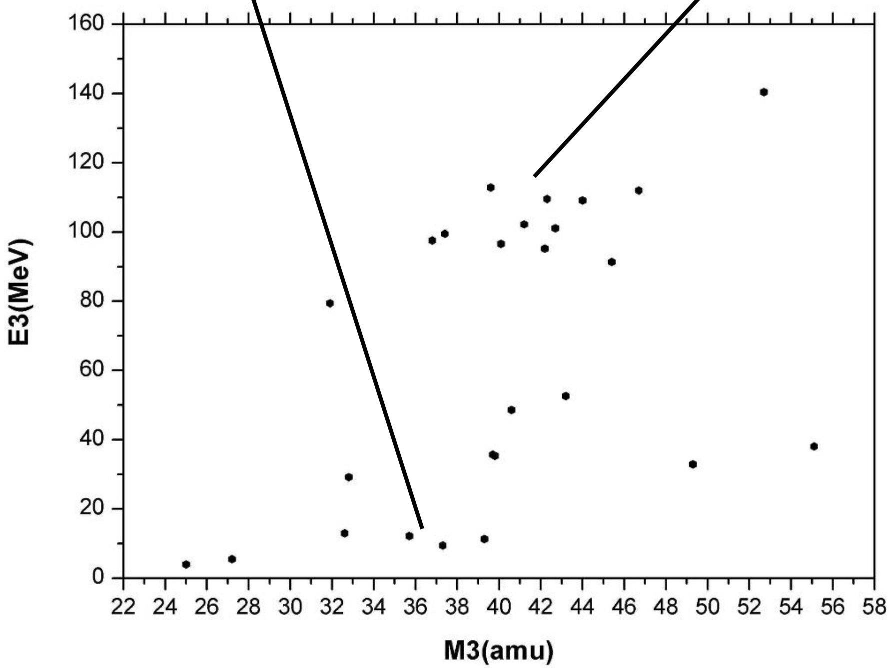



Fig. 5. (Color online) Kinetic energies of fragments ${}^{A_3}$Ca plotted as a function of the fragment mass numbers $A_1$ and $A_3$. These results (in the left-side frame) correspond to the positive-sign solution of eq. (23), and (right side) the negative-sign solution, respectively.

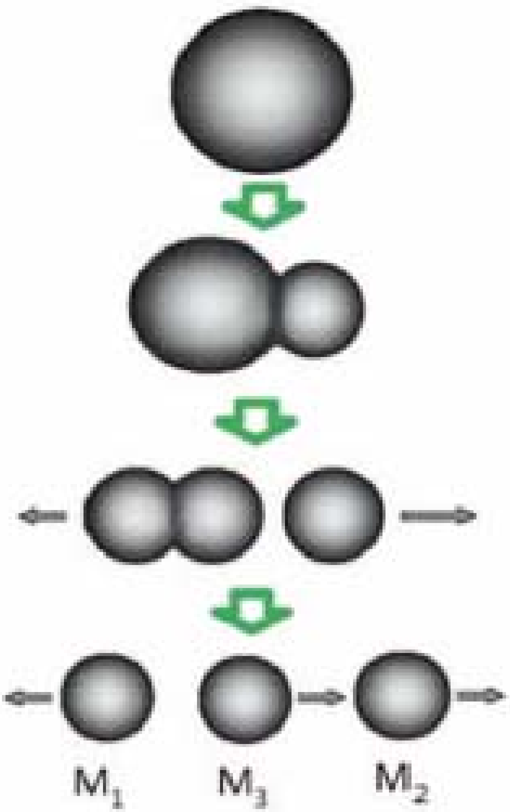



Our experiment

Y1

R.B. Tashkhodjaev, A.K. Nasirov and W. Scheid Eur. Phys. J. A (2011) 47: 136

# Collinear cluster tripartition as sequential binary fission in the $^{235}U(n_{th}, f)$ reaction




(basing on the dinuclear system concept)

A principle conclusion of the paper that the CCT process can be presented as a sequential binary fission process is based on absolutely arbitrary treating of our experimental data.

**Our massage to the theory:**
**specific linear structures (trajectories in the mass correlation space) should be understood at least qualitatively.**

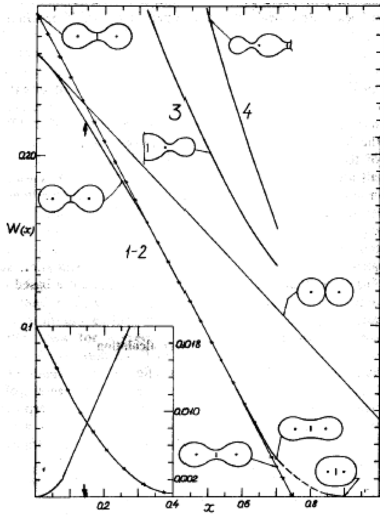
## Слайд 15

**Y1** Yuri; 22.05.2012

## Conclusions

1. Strict energy restrictions rule the CCT process what results in variety of exit kinematical parameters of the CCT partners in dependence of their prescission configuration and time scenario of the ruptures.
2. More consistent theoretical models are needed for description of the CCT process.

# Positive theory background

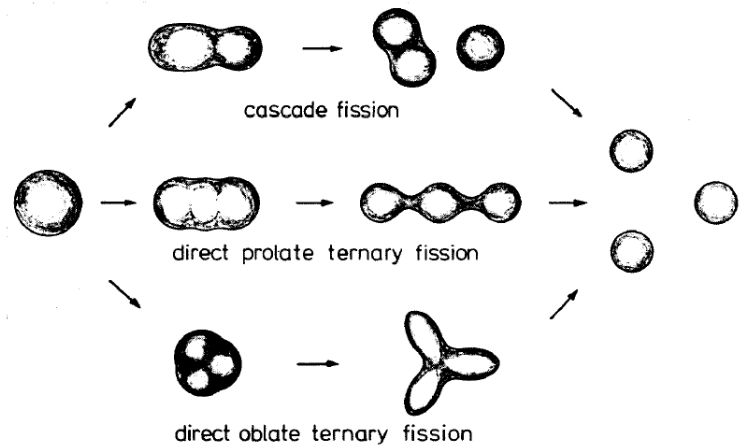



SYMMETRICAL SHAPES OF EQUILIBRIUM FOR A LIQUID DROP MODEL

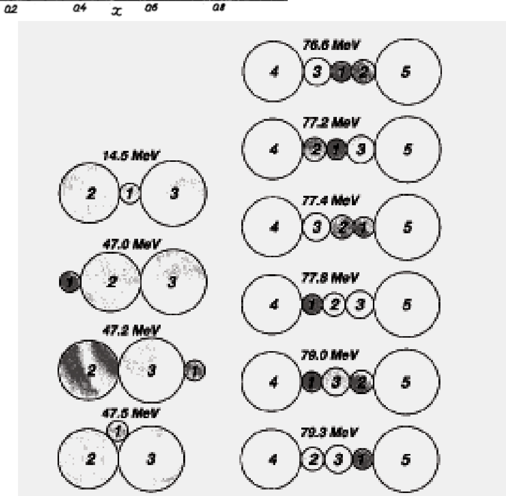
V.M. STRUTINSKY, N.Ya. LYASHCHENKO and N.A. POPOV

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

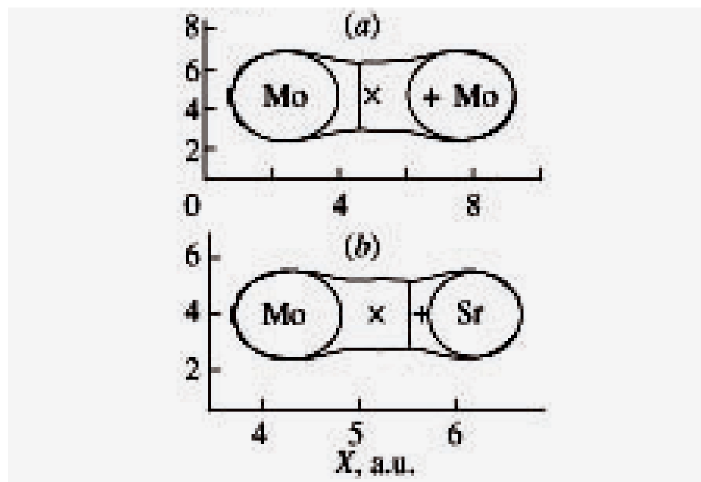
**two-neck and three-neck shapes**




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

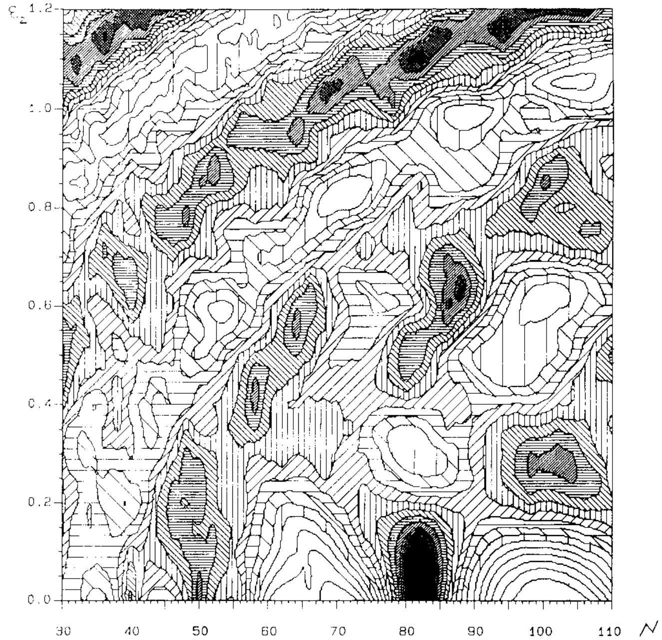


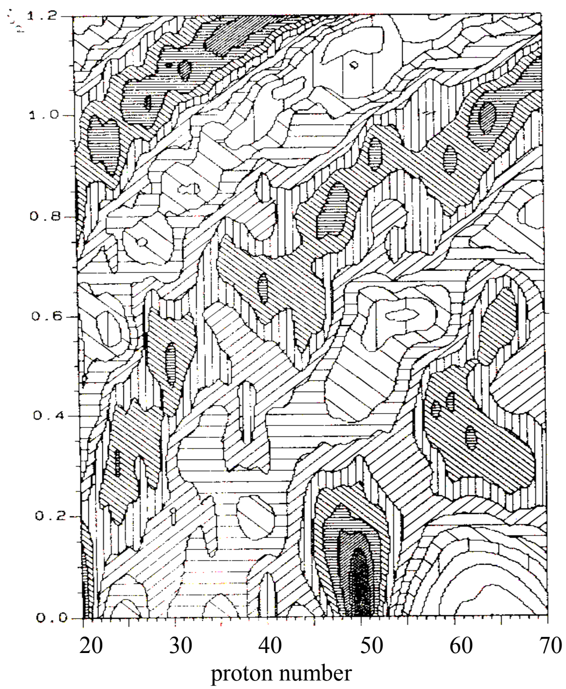

**Aligned and compact configurations for α-accompanied and α+$^{6}$He+$^{10}$Be accompanied cold fission of $^{252}$Cf**
**D.N. Poenaru et al., Phys. Rev. C 59 (1999) 3457**




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

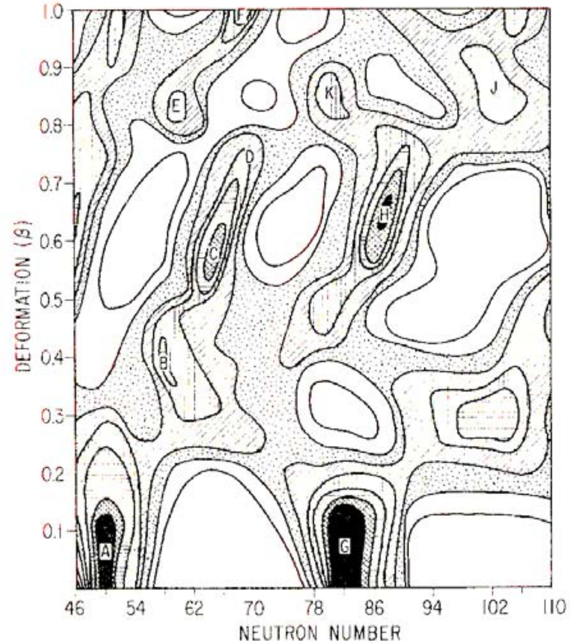
Three-clustering
In quasi-fisison
V. Zagrebaev,
2007

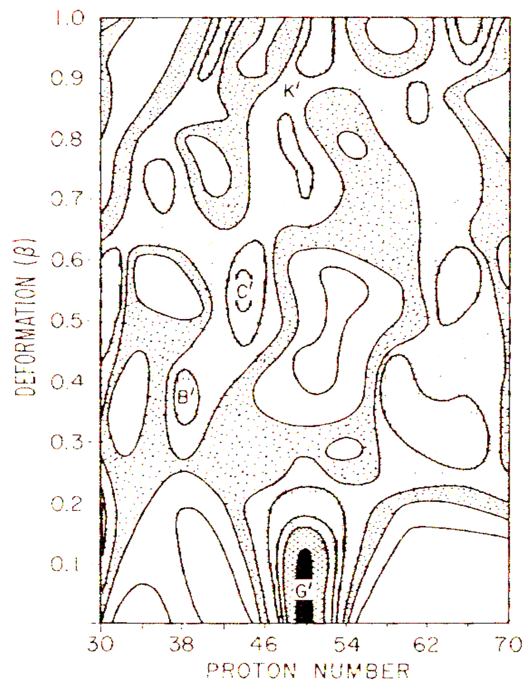



(H.Märton, private communication)

$\varepsilon_2 = 0.95\beta_2$




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

**Sequential (cascade) ternary fission**

(excitation energy of a heavy fragment is enough for the second scission appears to occur).
$^{238}$U, $^{197}$Au + $^{22}$Ne (185 MeV)
$^{209}$Bi, $^{238}$U + $^{40}$Ar (310 MeV)

**Karamian S.A., Kuznetsov I.V., Oganessian Yu.Ts. and Penionzkevich Yu.E.,**

**Jadernaja Fizika 5 (1963) 959**

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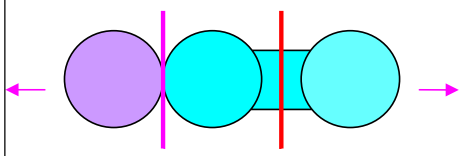
Two and three-body exit channels in the reactions
$^{84}$Kr + $^{166}$Er → $^{252}$100
$^{129}$Xe + $^{122}$Sn → $^{251}$104 at 12.5 MeV/u
"A fast two-step mechanism where a sequential fission-like process follows a deep inelastic collision with very large energy losses. **An orientation of the fission axis is approximately collinear with the axis of the first fission.** All the properties observed present consistent evidence for a new phenomenon of non-equilibrium fission"

**P.Gläßel et al., Z. Phys. A310 (1983) 189**

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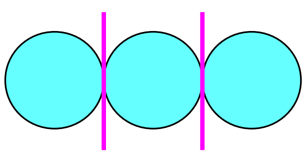
"Besides the already observed sequential binary process, **the presence of prompt ternary break-up of the composite system is revealed** in
$^{32}$S + $^{59}$Co → $^{91}$ Tc
$^{32}$S + $^{63}$Cu → $^{95}$Rh
reactions at 5.6 MeV/u. **The decay appears to occur in a collinear configuration.** In spite of the large energy dissipation some events shows structure effects, i.e. the possible **presence of slustering phenomena** in the reaction (at least one fragment is an **α-like nucleus**) "

**L.Vannuci et al., Eur.Phys. J. A 7 (2000) 65**



**prompt ternary break-up of a collinear configuration**

# Background

| **Cluster radioactivity** | | **Binary decays** |
|---|---|---|
| $^{222-226}Ra$ ◊ $^{14}C$ <br> **H.J. Rose and G.A. Jones, Nature 307 (1984) 245** | $^{221}Fr$ ÷ $^{242}Cm$ ◊ $^{14}C$ ÷ $^{34}Si$ <br> $(10^{-10} \div 10^{-17})\ P_{\alpha}$ <br> **“Lead radioactivity”** | |
| **Cold fission** | | |
| | **“Tin radioactivity” ...** | |

| **Light α – cluster nuclei** | |
|---|---|
| “Ikeda et al. [Suppl. Prog. Phys. (Japan) Extra (1969) 464] speculated a rang of different cluster structures might occur in $^{24}Mg$ nucleus: $\alpha + {}^{20}Ne$, $^{8}Be + {}^{16}O$, $^{12}C + {}^{12}C$, $^{12}C + {}^{12}C_{chain}$ and a **6α chain state**. There is now evidence for all these different structures [B.R. Fulton, Z. Phys A349 (1994) 227]” | **Multicomponent nuclear molecules** |

# Mass yields by F.Gőnnenwein and M.Mutterer