PERSPECTIVES OF THE STUDY OF COLLINEAR CLUSTER TRI-PARTITION OF HEAVY NUCLEI

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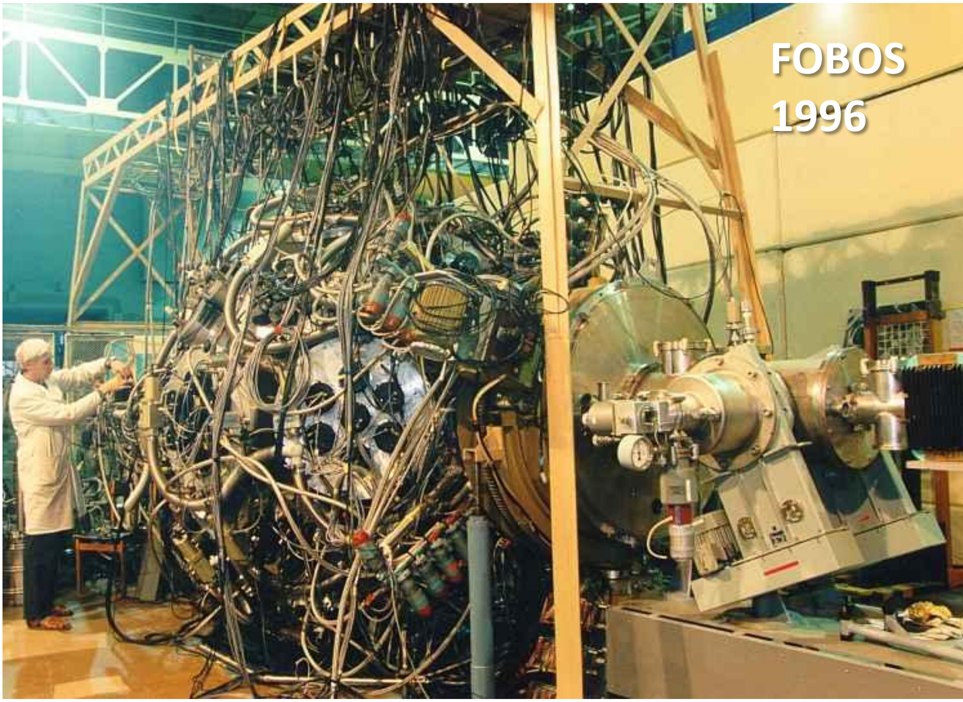


CCT progress from ISINN to ISINN

13 - proposal for the exp @ IBR-2

14 - status of the exp in the cave 6b

15 - preliminary results

16 - detailed report

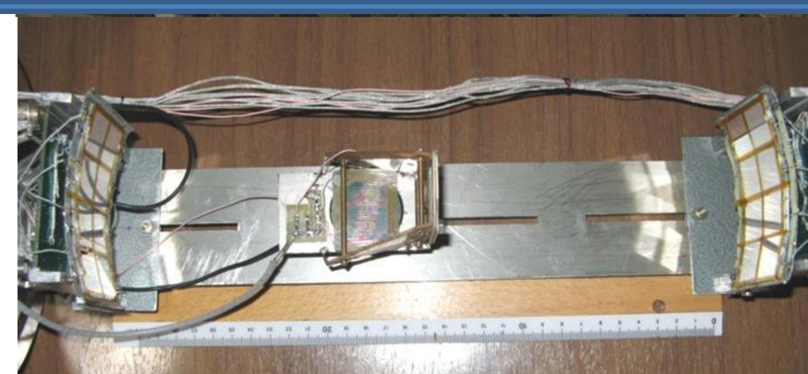
17 - triple correlations from ^{232}Th+d

18 - COMETA progress report (posters)

19 - first & interesting COMETA data

20 – first CCT physics & ion guide proposal

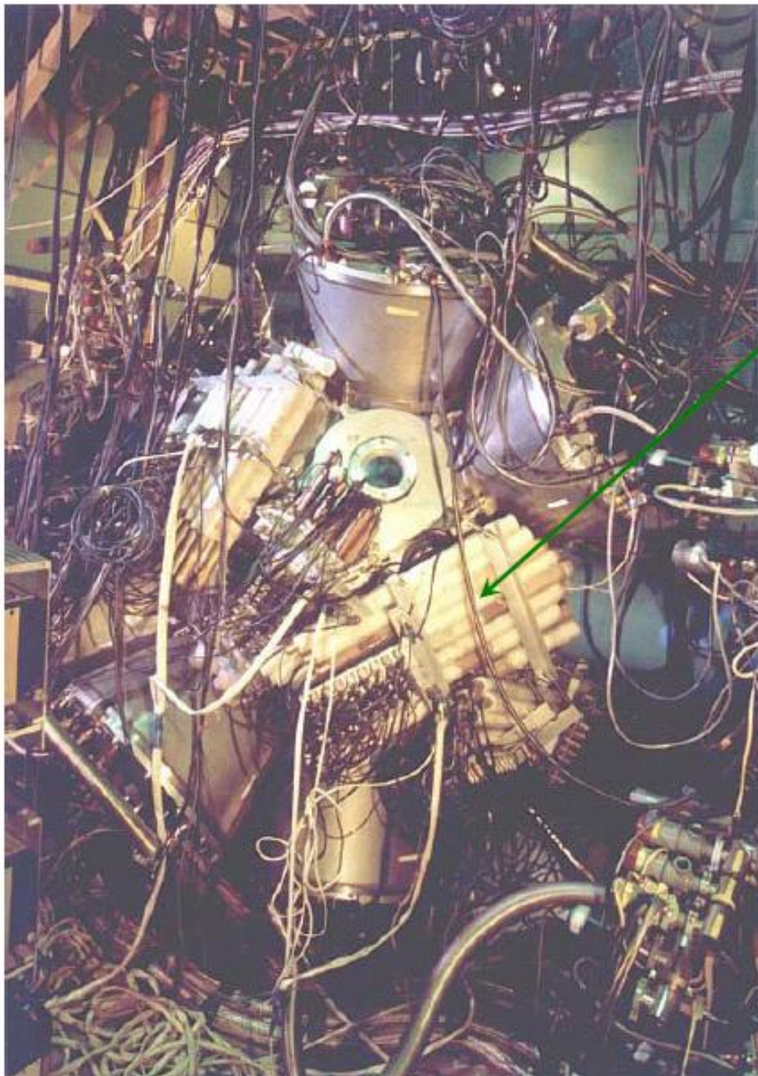
21 – new phenomena & instruments progress



I. CCT Instruments review

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

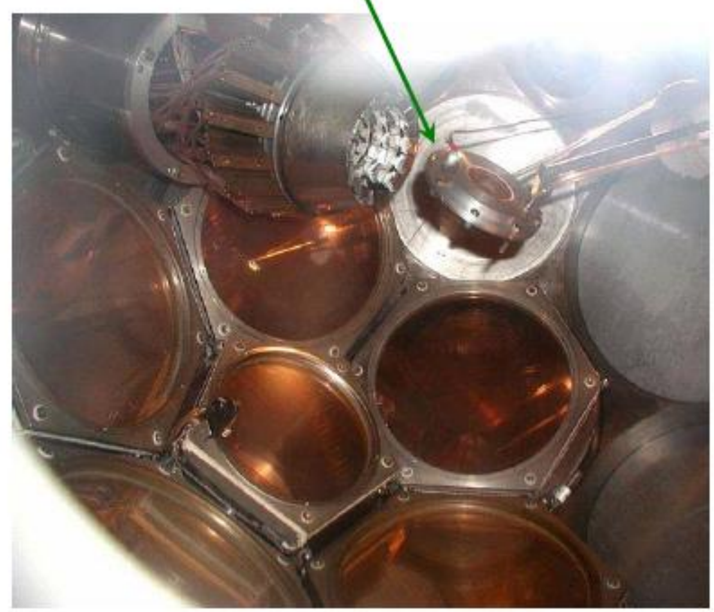
missing mass approach, Z -sensitive variables & experimental neutron multiplicity ν_{exp} for selection of the CCT events



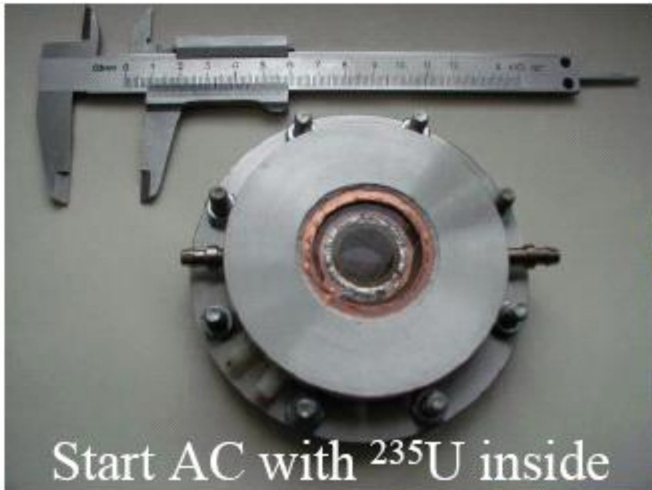
Double arm spectrometer
6+6 modules

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

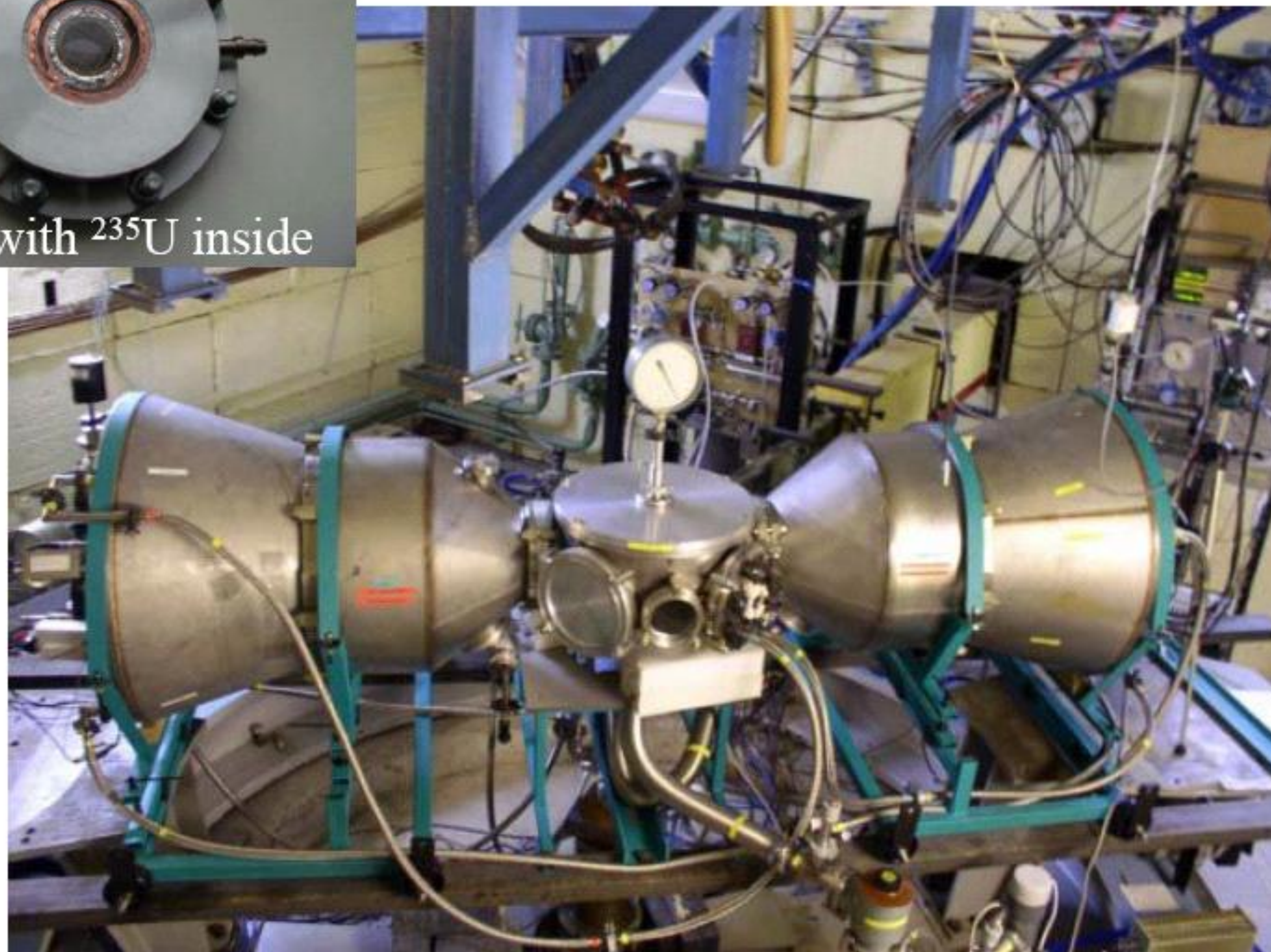
Start PAC
with internal ^{252}Cf source



MiniFOBOS in the cave 6b
of the reactor IBR-2

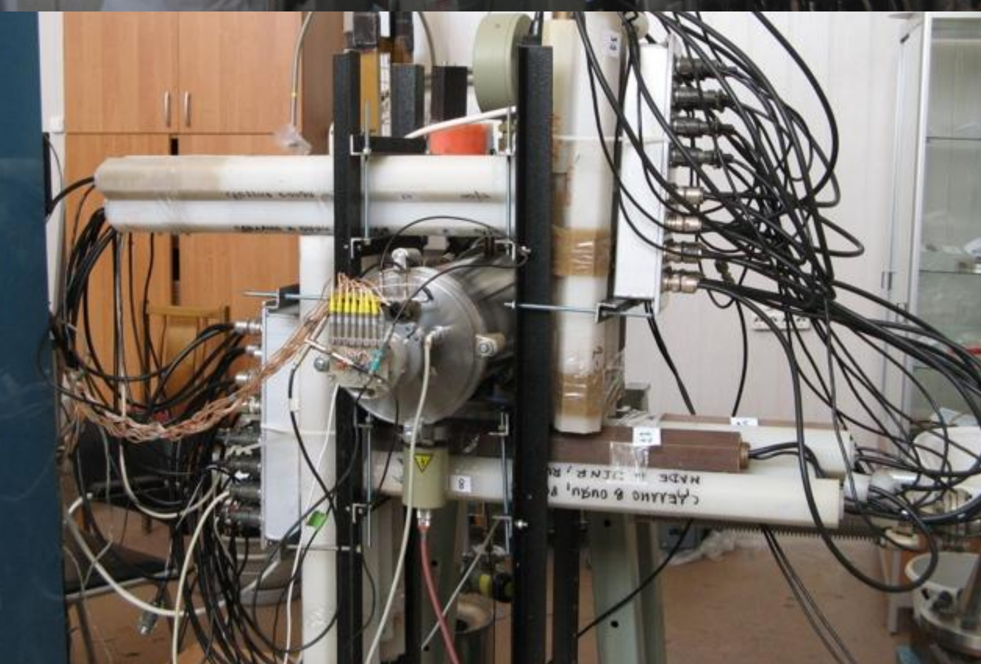


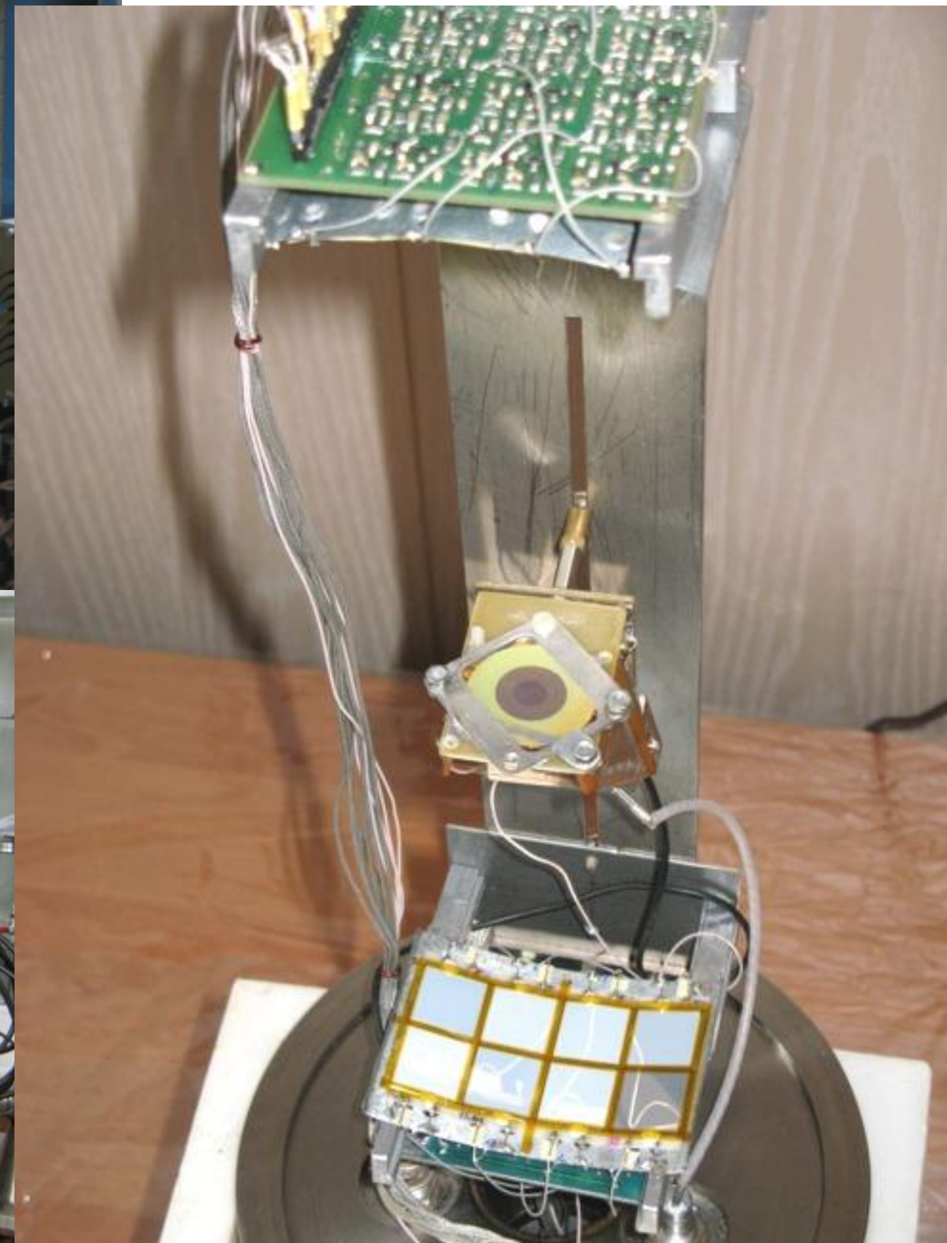
Start AC with ^{235}U inside



COMETA= COrrelation Mosaic E-T Array

MSc J. Papuga
Univ. Novi Sad, Serbia

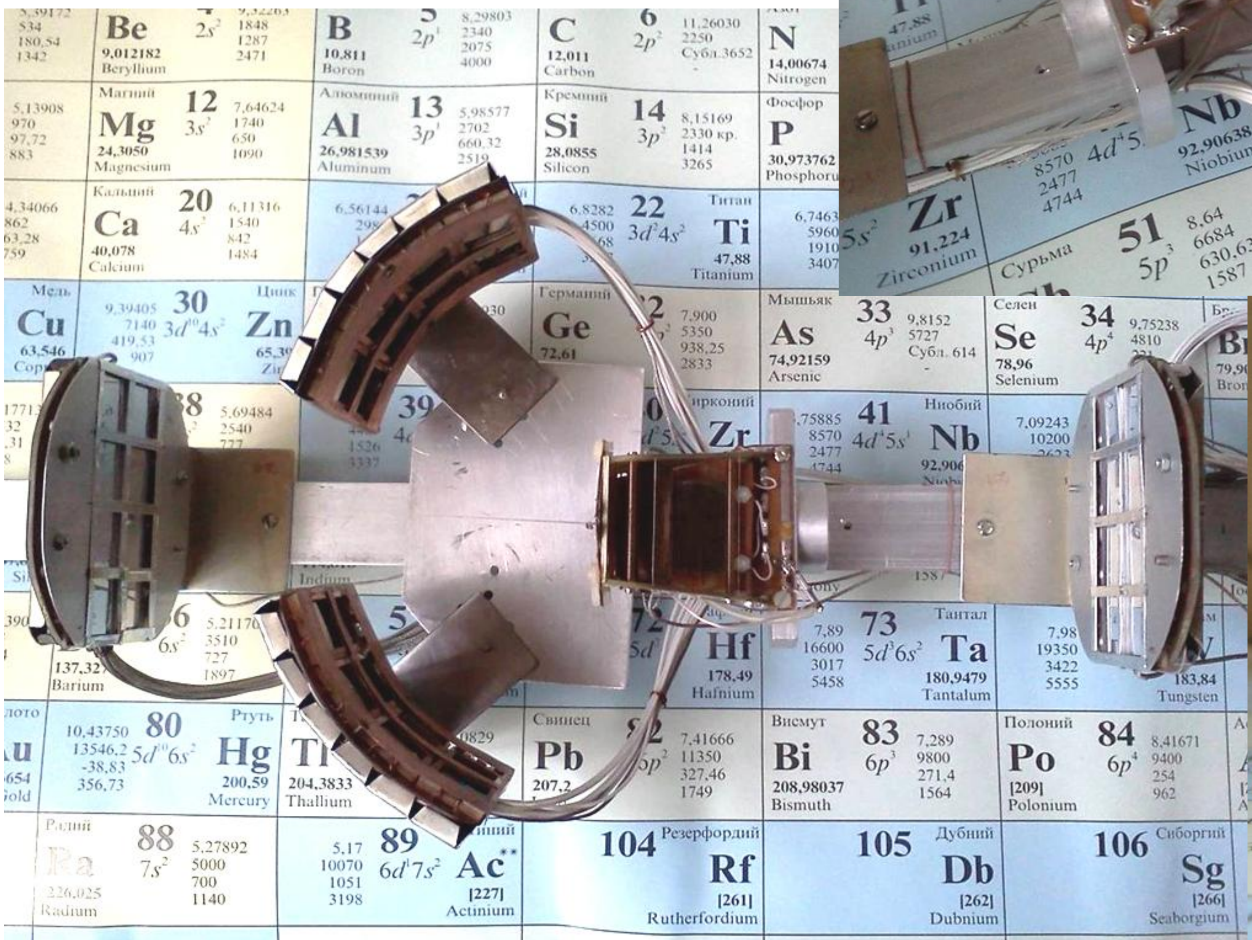


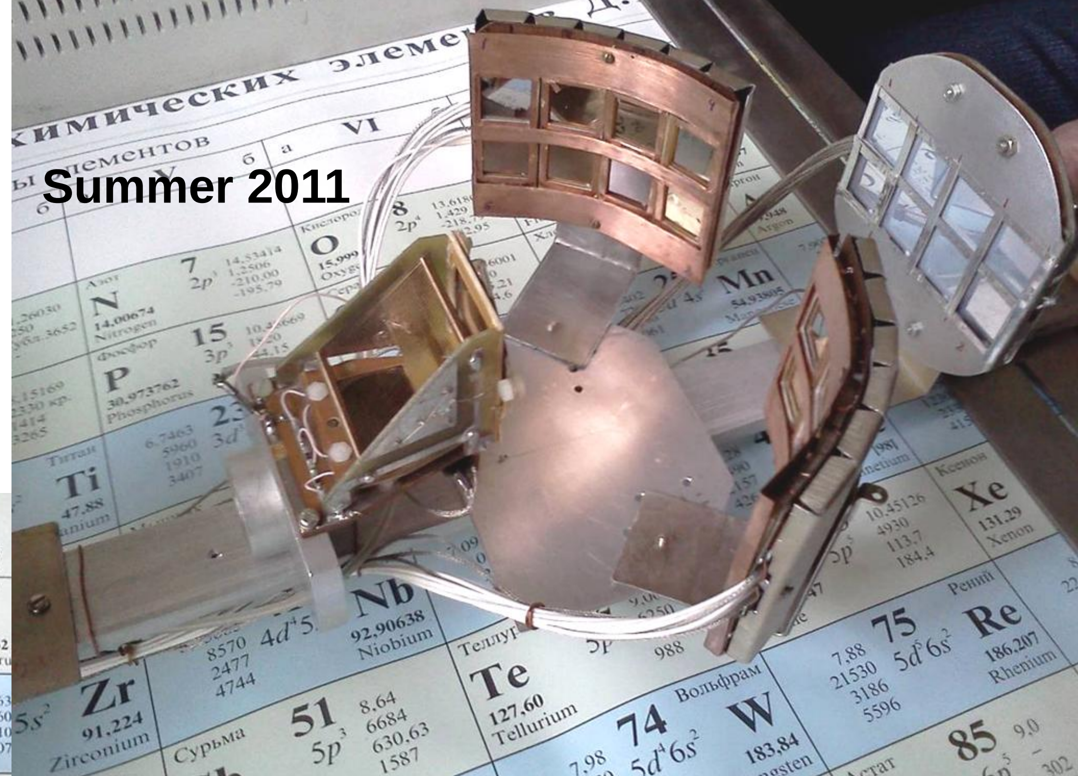


COMETA-2 setup, time-of-flight part

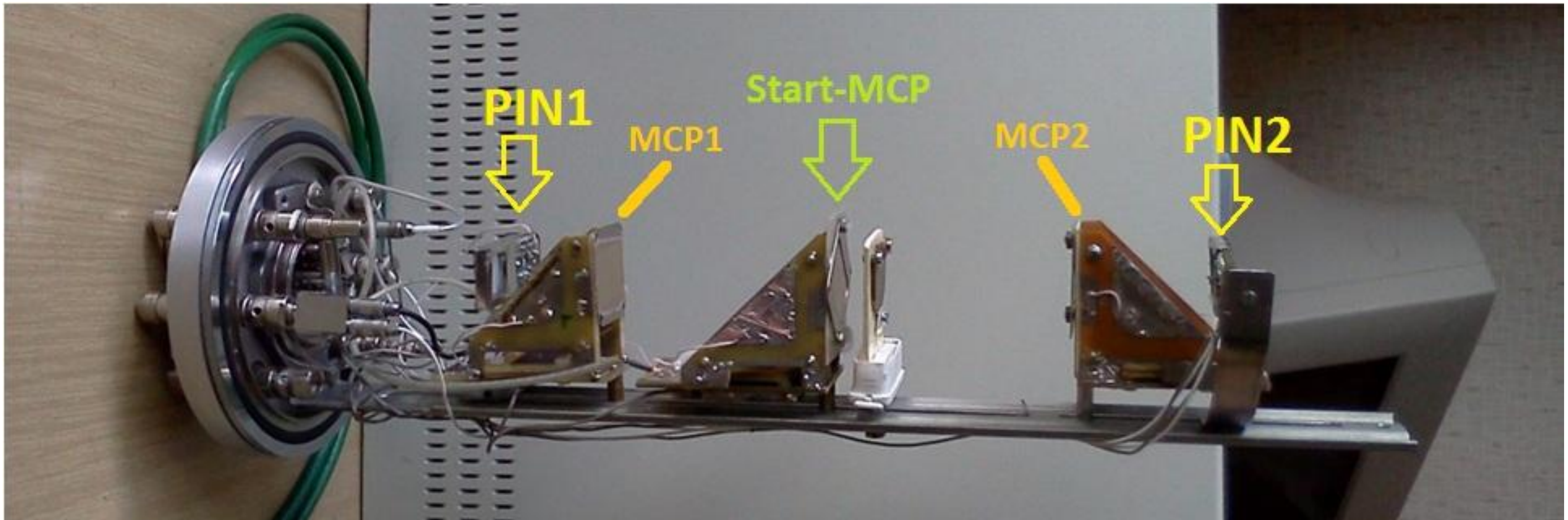
PIN-diodes 120˚& MCP

neutron belt 28 ^{3}He counters





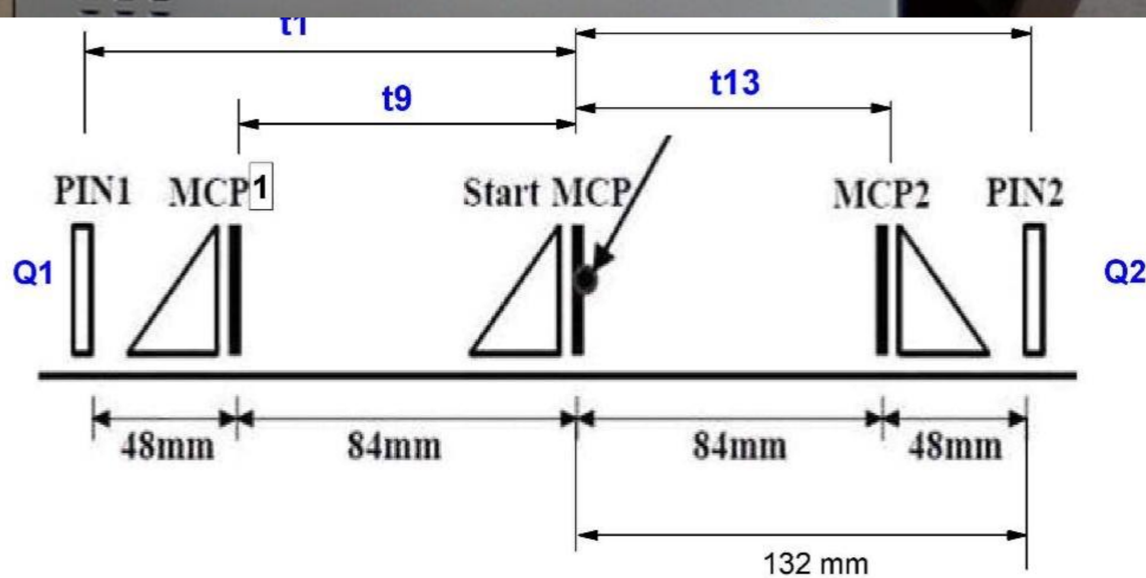
Linear Spectrometer = LIS



parametry

t1 Tof start-Pin1
t5 Tof start-Pin2
t9 Tof start-stop1
t13 Tof start-stop2
t16 Start-start

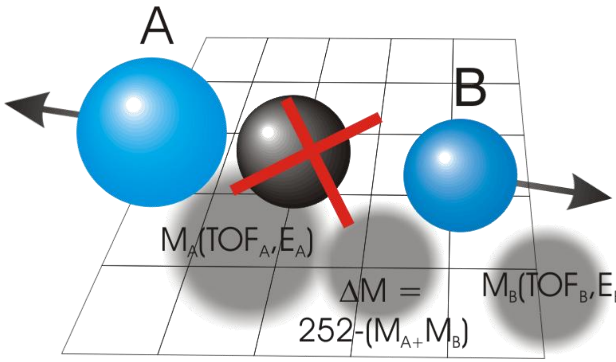
Q1 - энергия 1
Q2 - энергия 2

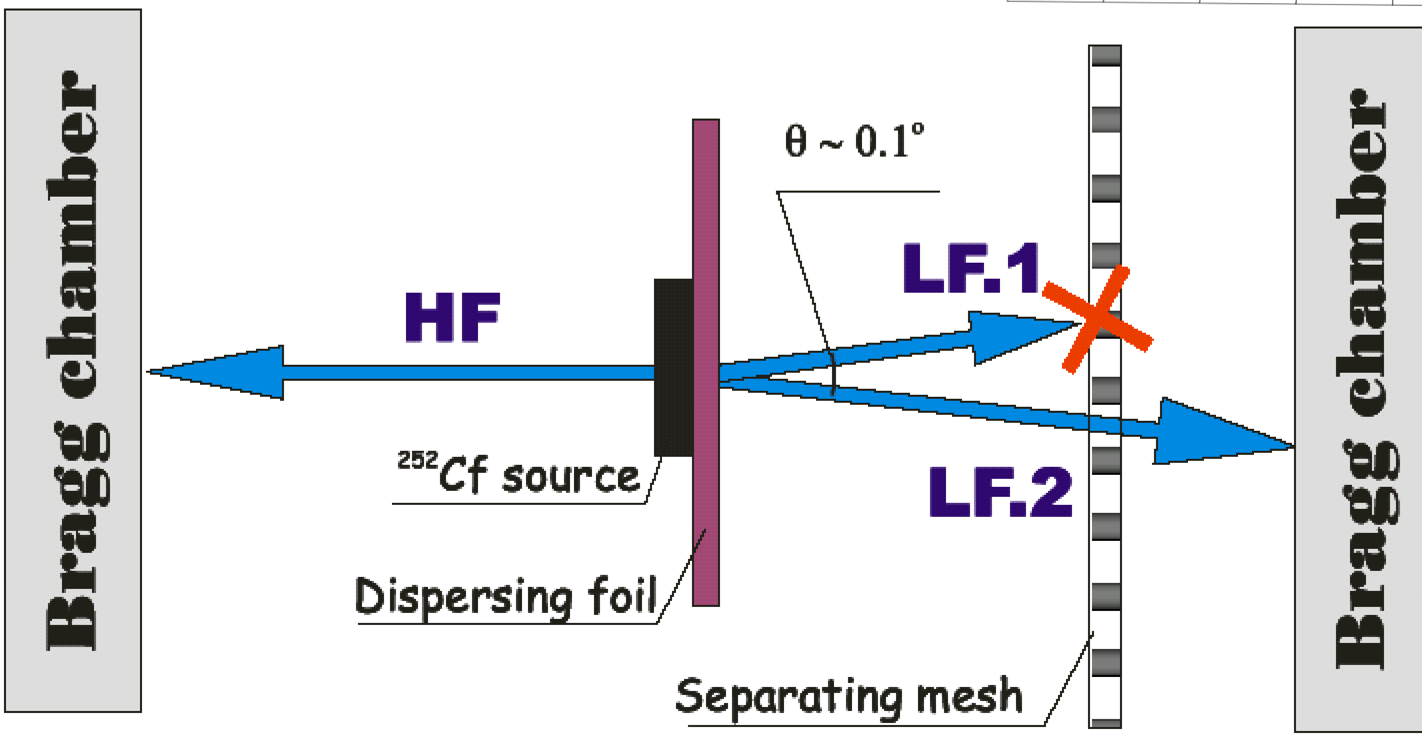


II. Main CCT observations

How to observe CCT @ FOBOS

by means of missing mass

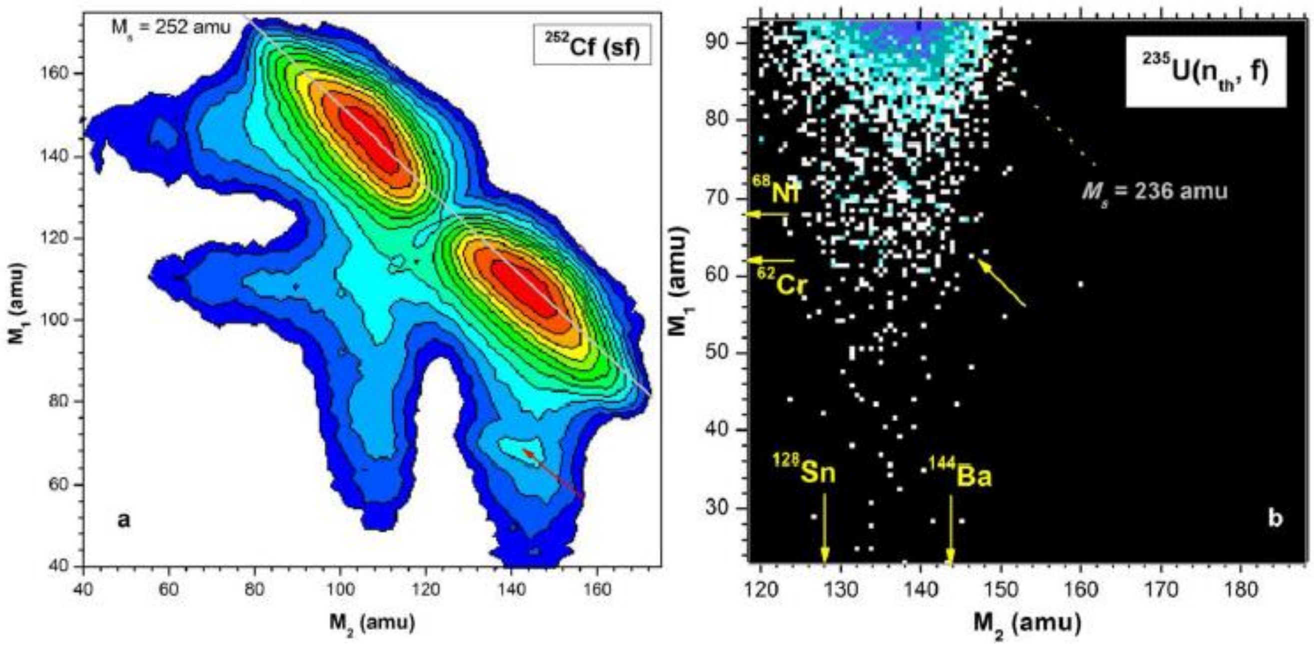


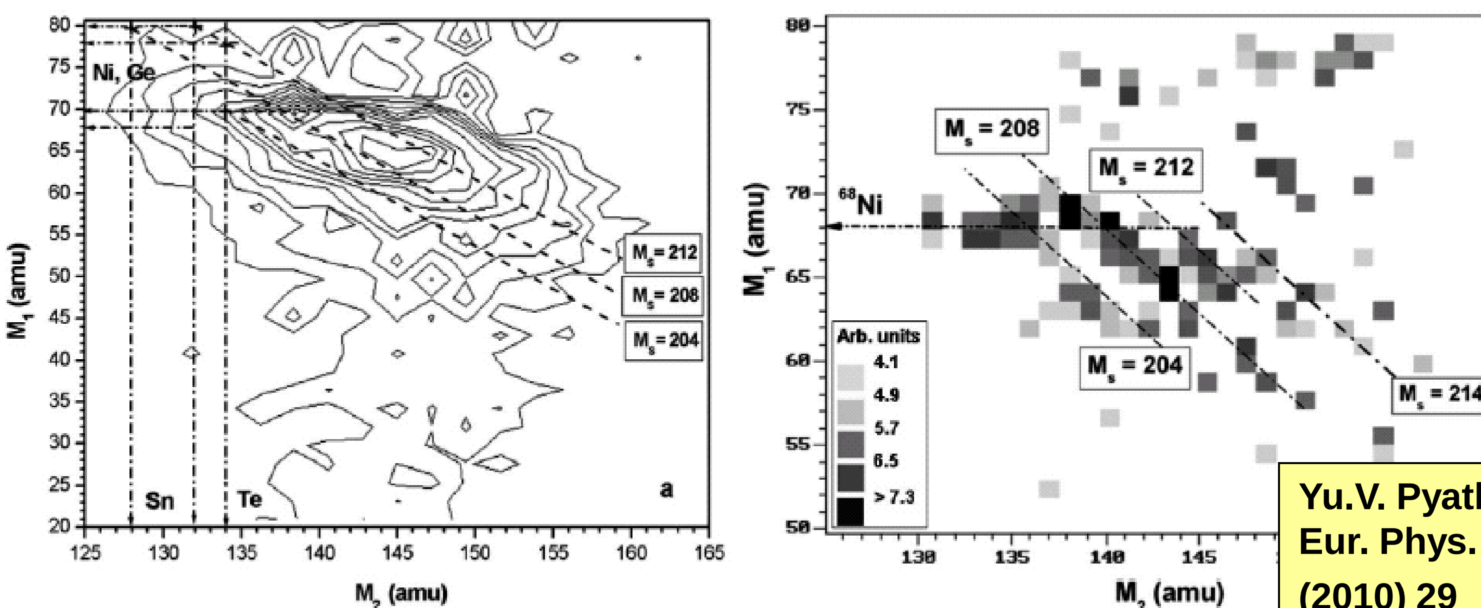


or the detector frames in COMETA

Peculiarities in Mass vs Mass plots like:
$M_{A,B}$ = const (horizontal or vertical lines)
M_{miss} = conts (tilted lines)

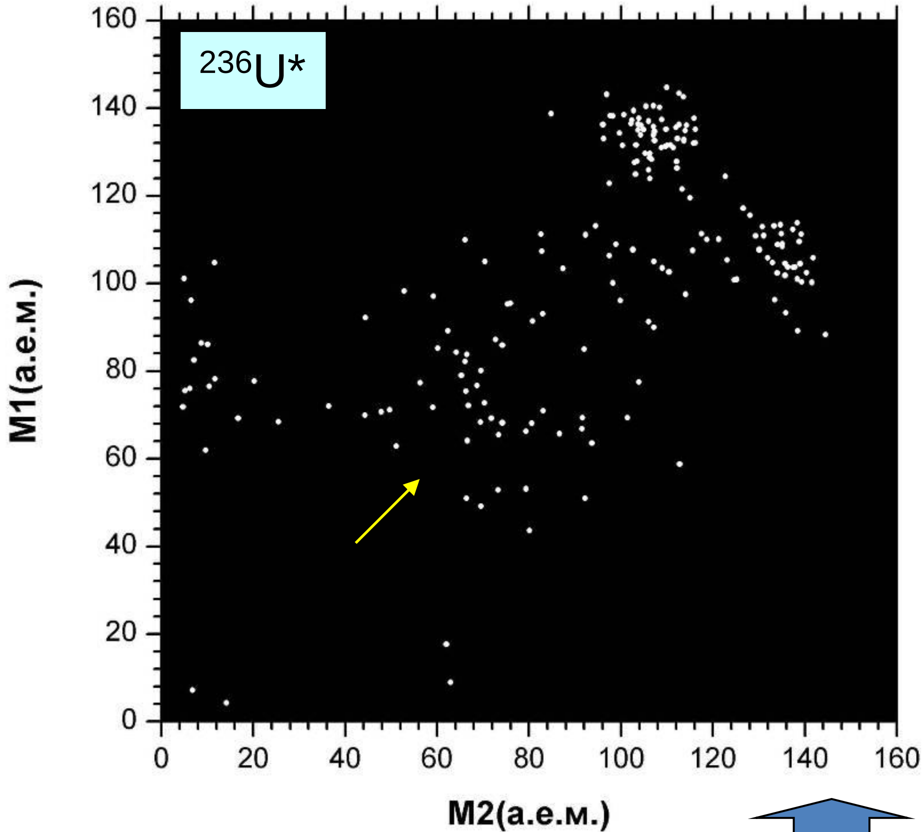
Experimental background –principal results





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

Selection of symmetric decays



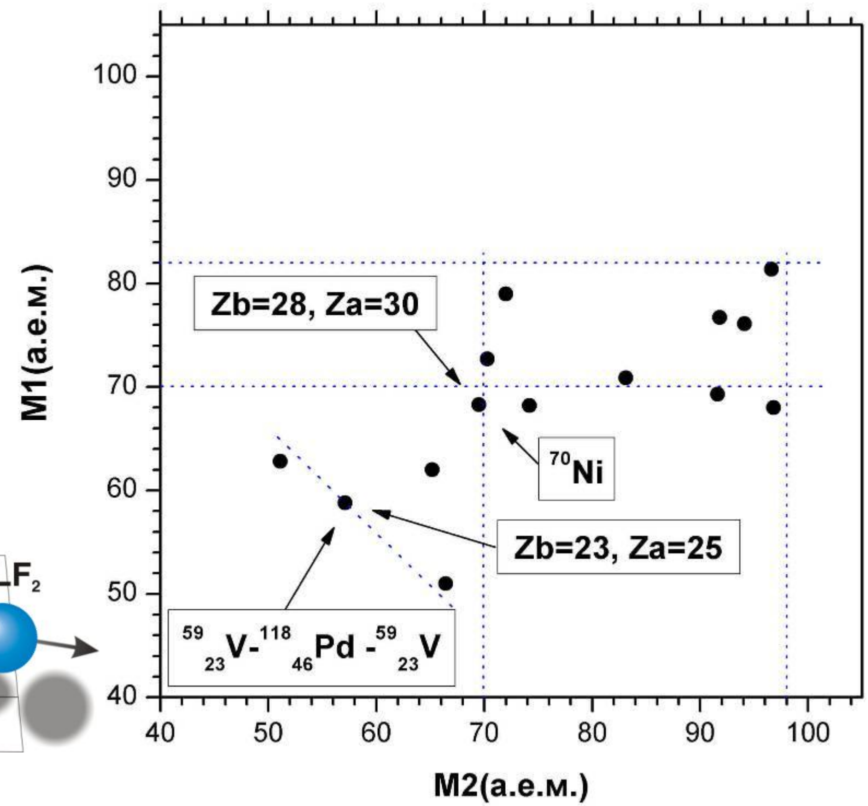
$V1 \approx V2$

$P1 \approx P2$

$Z1 \approx Z2$

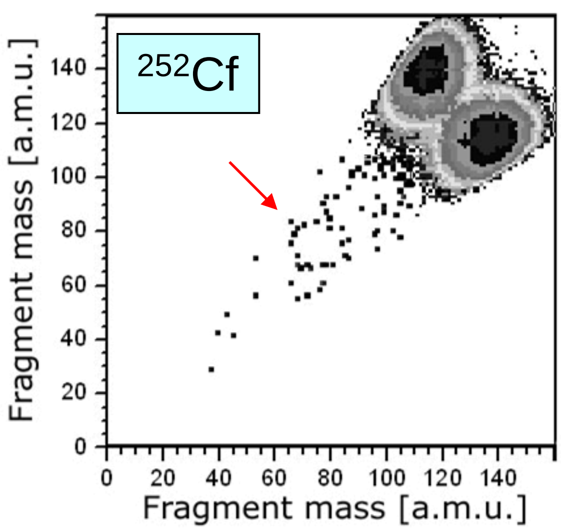
Each point:

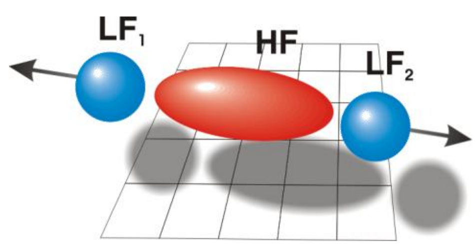
6 independent experimental parameters



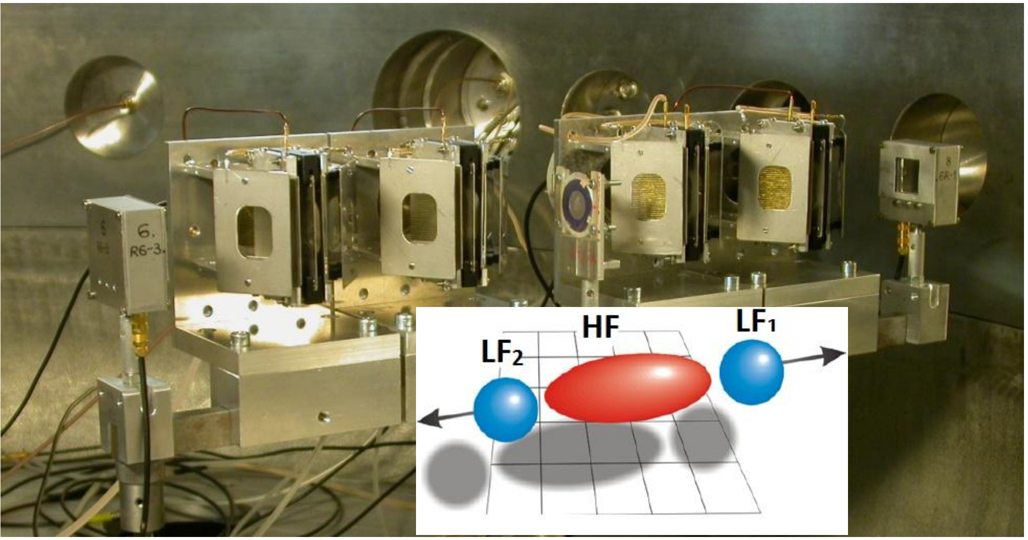
$V1 \approx V2$

$P1 \approx P2$

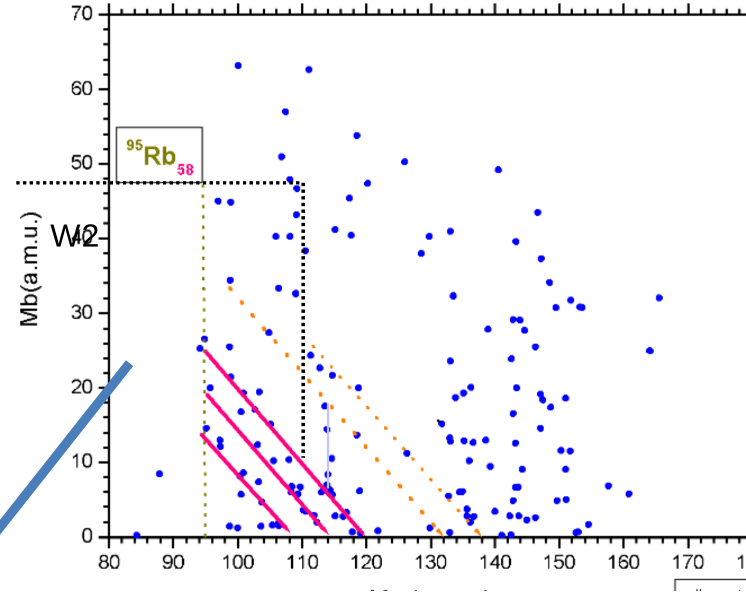


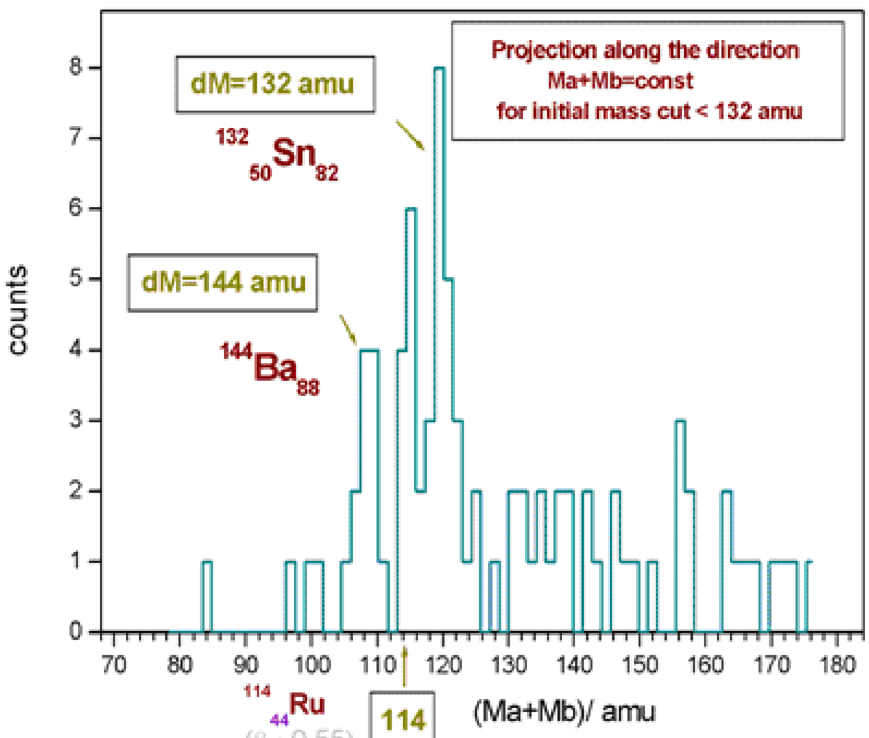


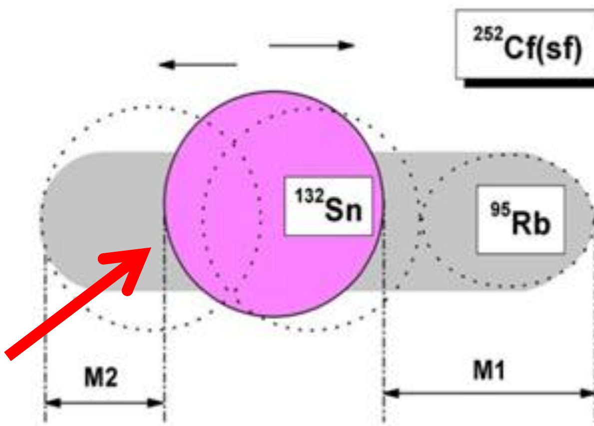
"Double cluster radioactivity"



Yamaletdinov, Ph.D. Thesis,
Jyväskylä, Finland,- 2007.



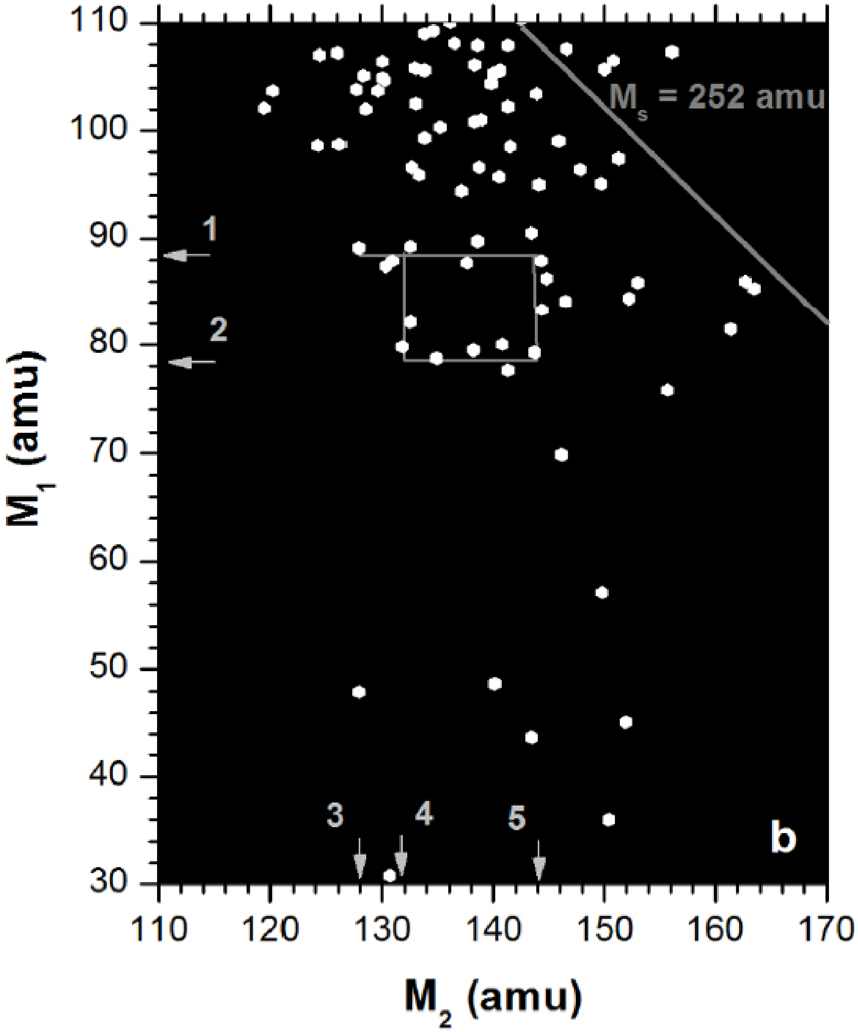




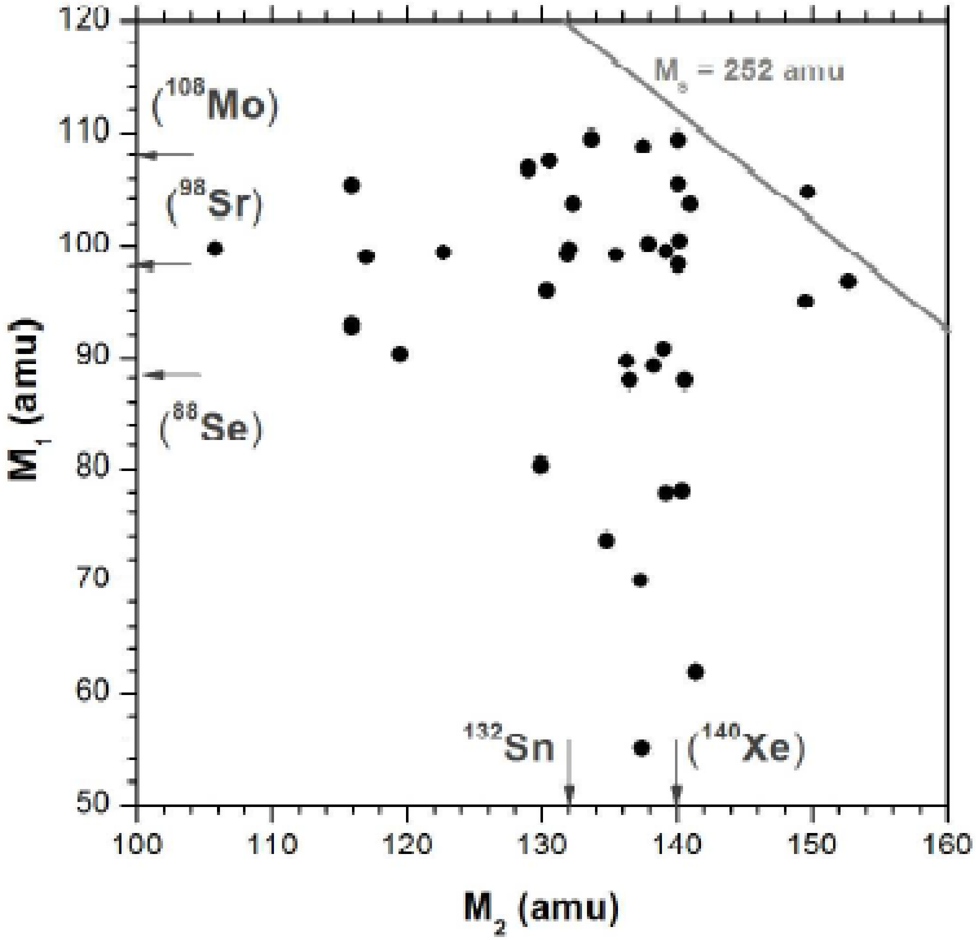
^{208}Pb?

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

Principal results FOBOS & COMETA

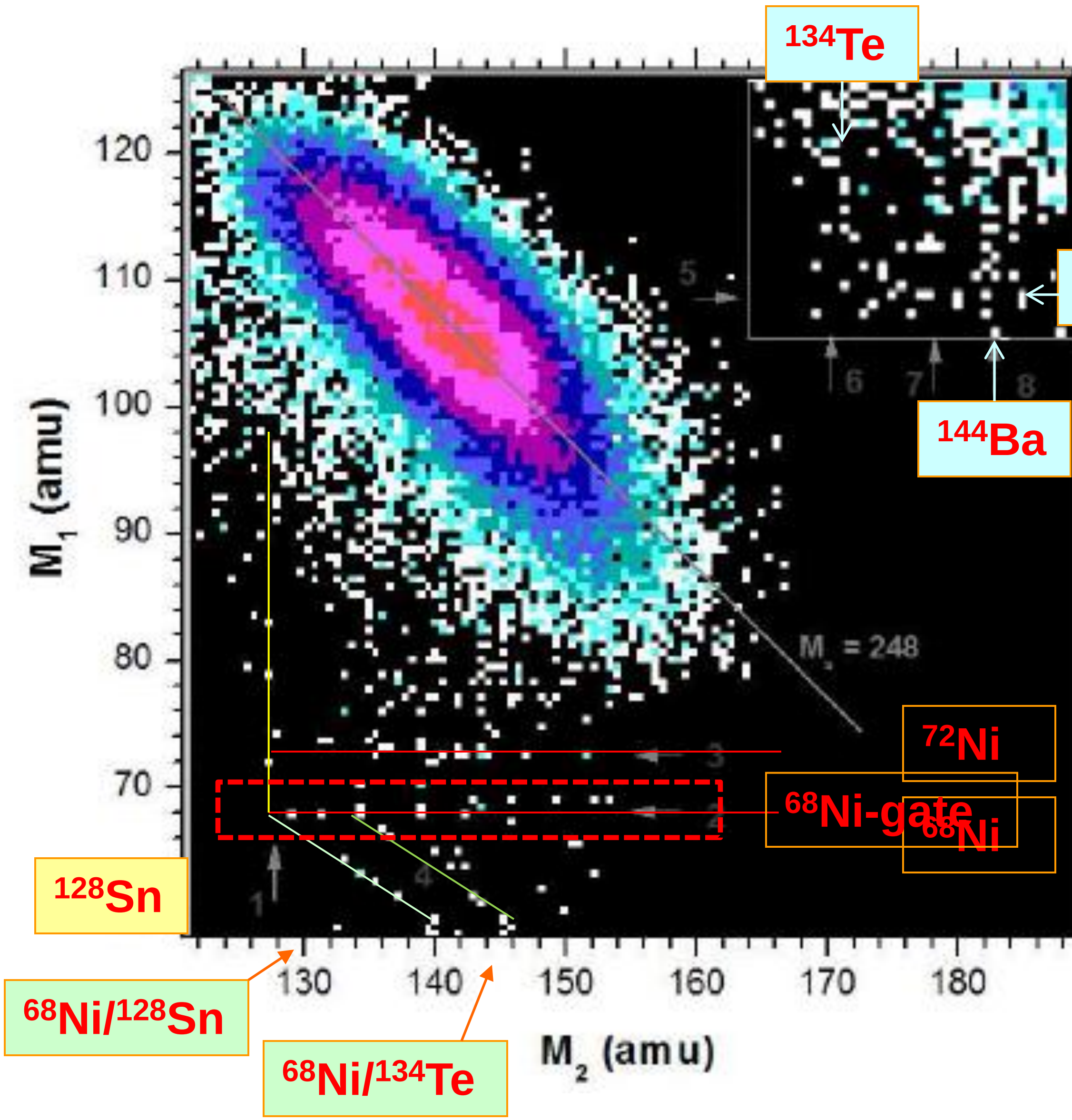


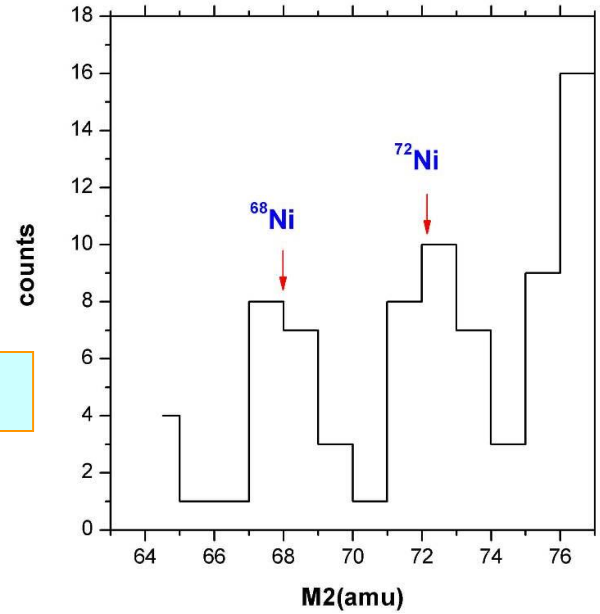
FOBOS, selection by the experimental neutron multiplicity

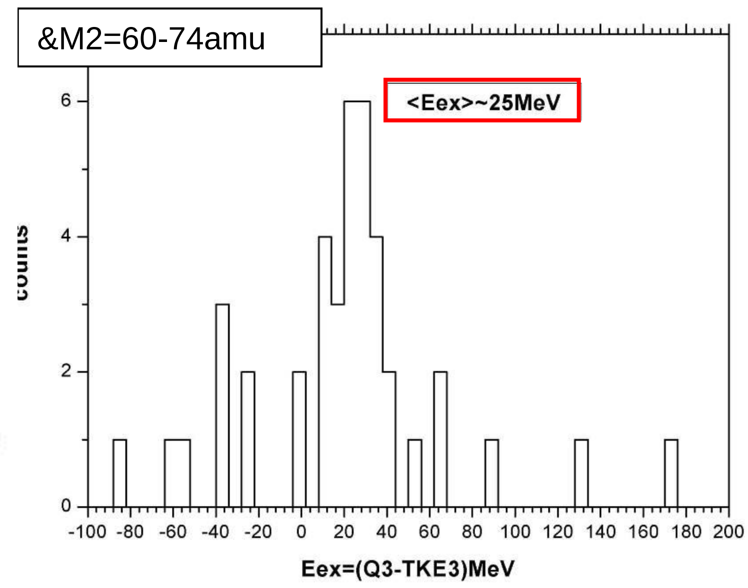


COMETA, selection by the experimental neutron multiplicity

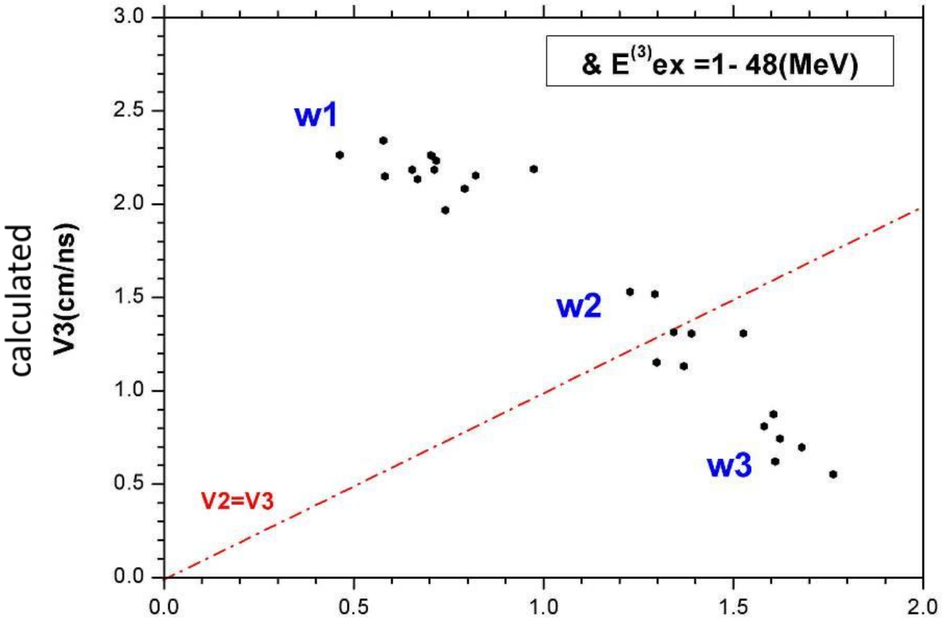
COMETA data: Ni-bump & Ge-bump without any gating







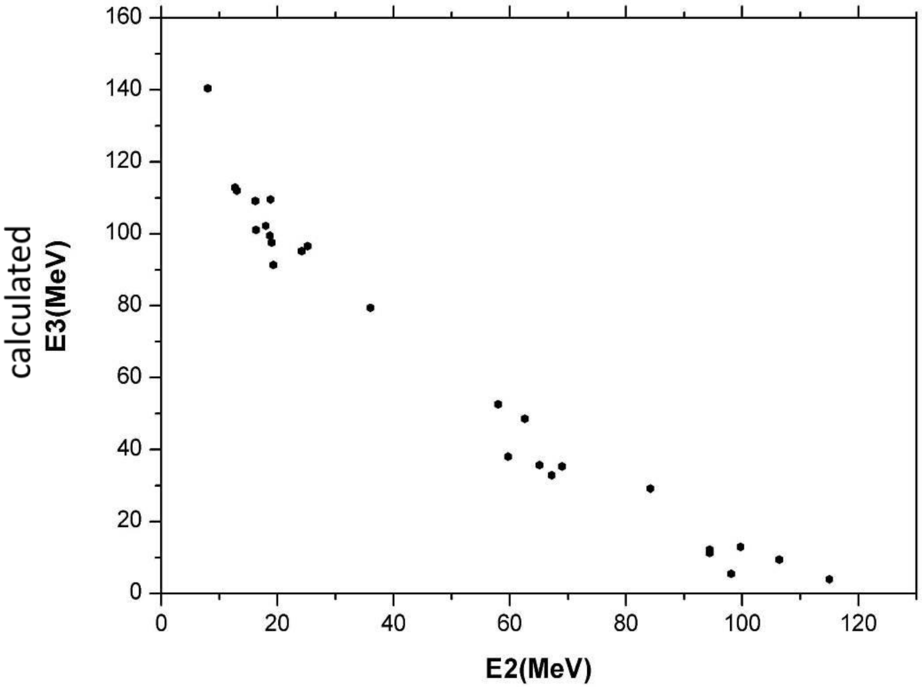
Velocities and energies of the light CCT partners in the Ni-68 window

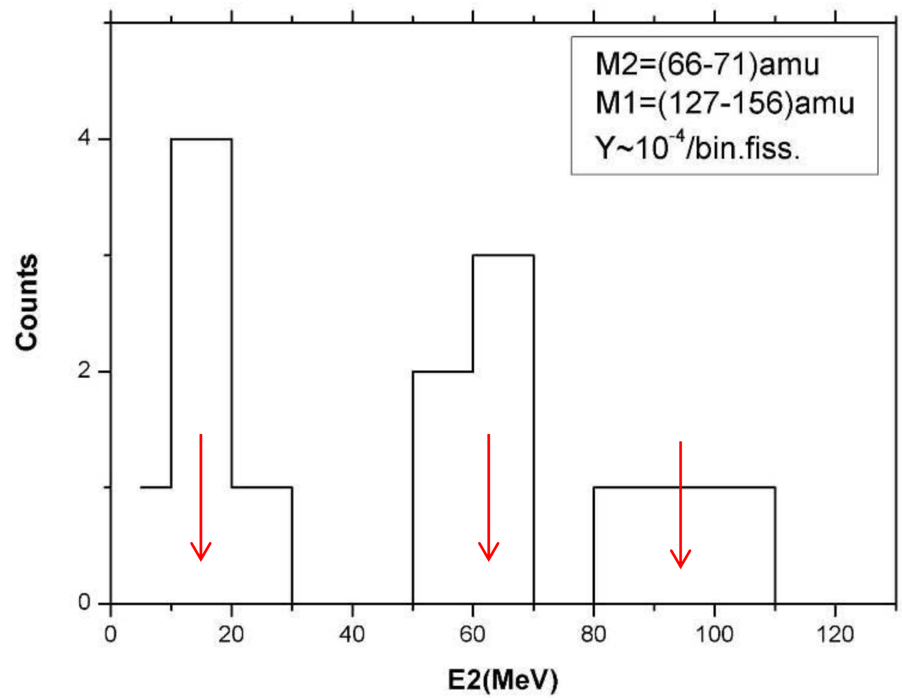


^{252}Cf(sf), binary fission:

<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

Message for Lohengrin spectrometer





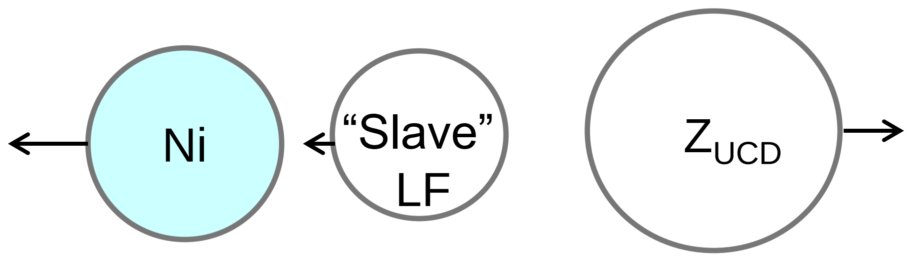
III. Quaternary CCT?

Method of analysis of the missing mass data

Provided M(Ni), Z(Ni)=28, V(Ni)
and M(HF), V(HF)

Z(HF)= Z_{UCD}(M(HF))

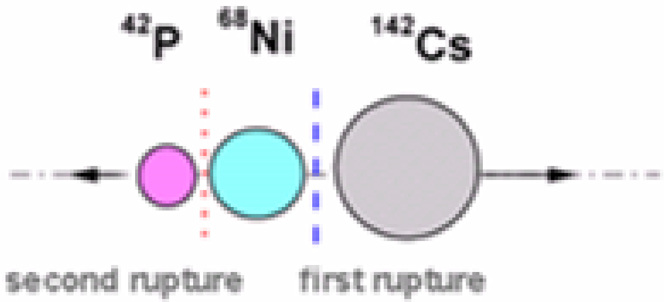
M(LF) = 252 - M(HF)
Z(LF) = 98 – Z(LF)
V(LF) - momentum conservation law



Measured   Calculated   Measured

First group (w1): V3>V2, V1 ~ V_{H_bin}, V2<< V_{L_bin}

Prescission configuration expected

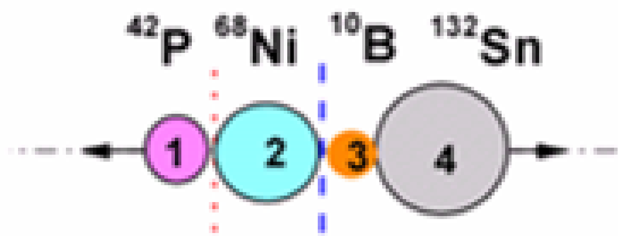


a

Q3~207MeV; Eint=270MeV;

Eint > Q3 → cold fission is interdicted

Hypothesis: conservation of both magic clusters Ni&Sn along the path M2=const



Q4~201MeV; Eint~256MeV; Eint>Q4;

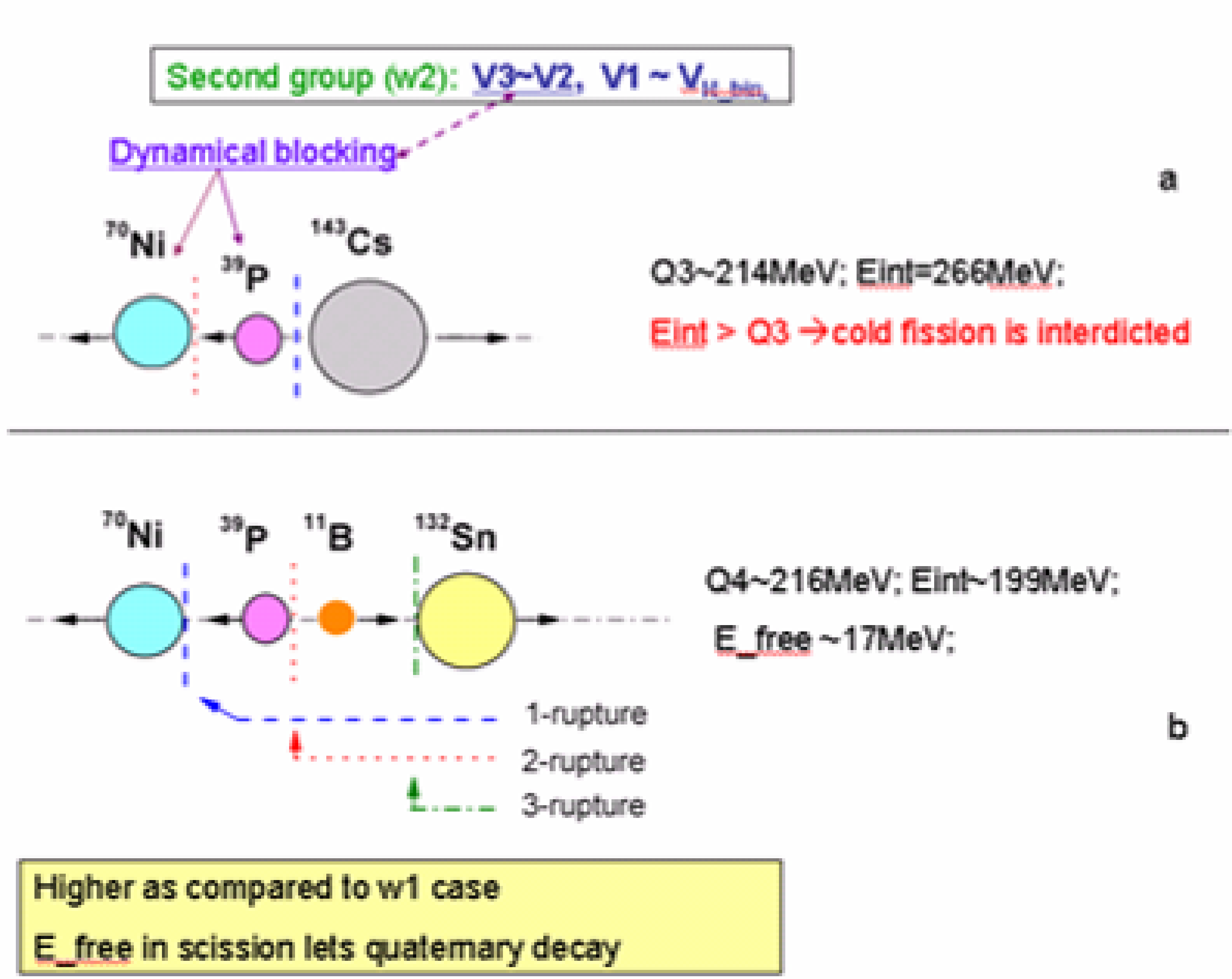
Eint(1,2_3+4)=220MeV; Eint>Q4;

b

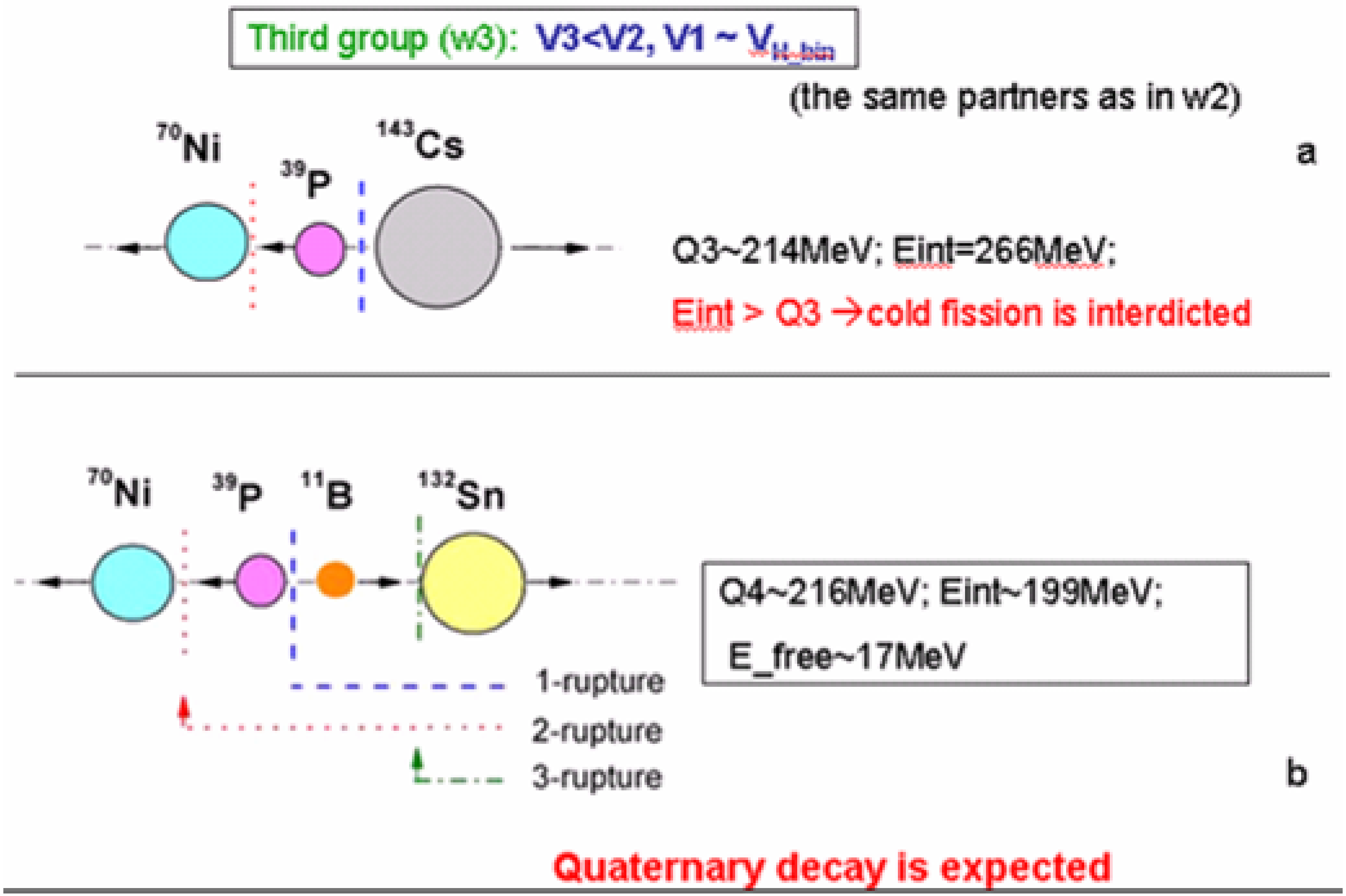
Q4~219MeV; Eint~243MeV; Eint>Q4;

Eint(1,2_3+4)=216MeV; Eint<Q4;

c

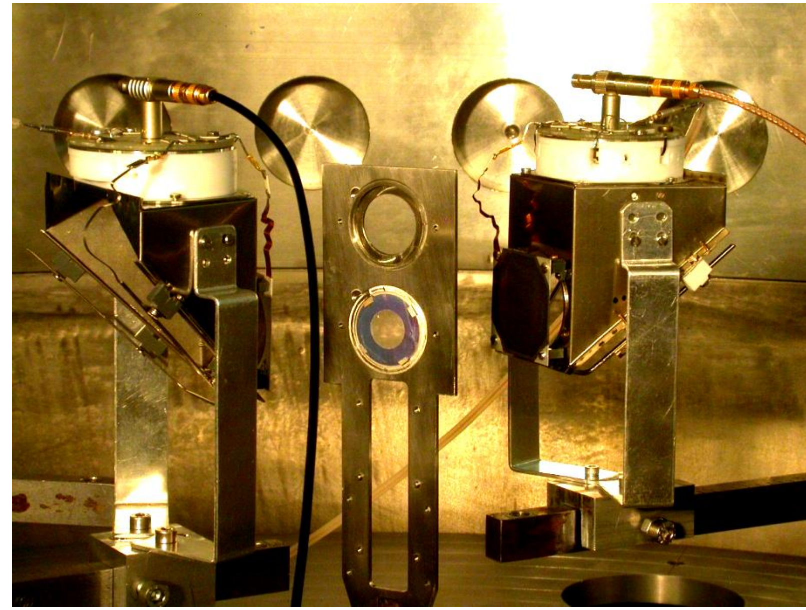


Second group (w2): V3~V2, V1 ~ V
Dynamical blocking
a
70Ni
39P
143Cs
Q3~214MeV; Eint=266MeV;
Eint > Q3 →cold fission is interdicted
70Ni
39P
11B
132Sn
Q4~216MeV; Eint~199MeV;
E_free ~17MeV;
1-rupture
2-rupture
3-rupture
b
Higher as compared to w1 case
E_free in scission lets quaternary decay

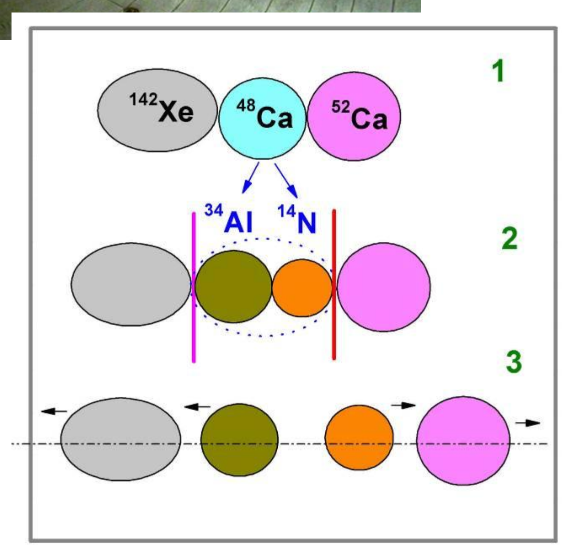


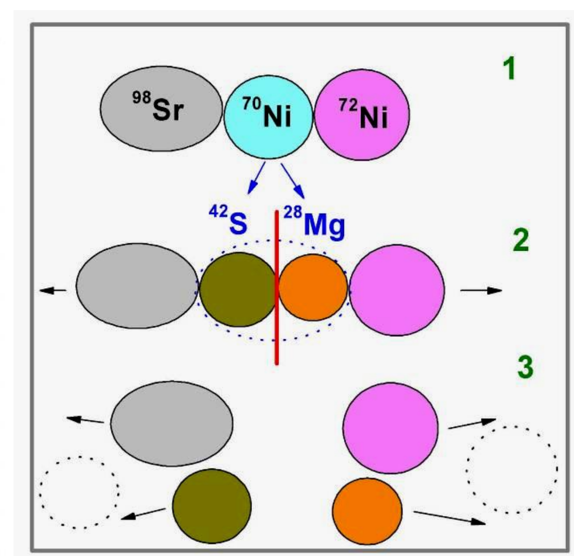
Third group (w3): V3<V2, V1 ~ V_H_bin
(the same partners as in w2)
70Ni
39P
143Cs
a
Q3~214MeV; Eint=266MeV;
Eint > Q3 →cold fission is interdicted
70Ni
39P
11B
132Sn
Q4~216MeV; Eint~199MeV;
E_free~17MeV
1-rupture
2-rupture
3-rupture
b
Quaternary decay is expected

Experiment in JYFL $^{235}U+\alpha$ (40 MeV)



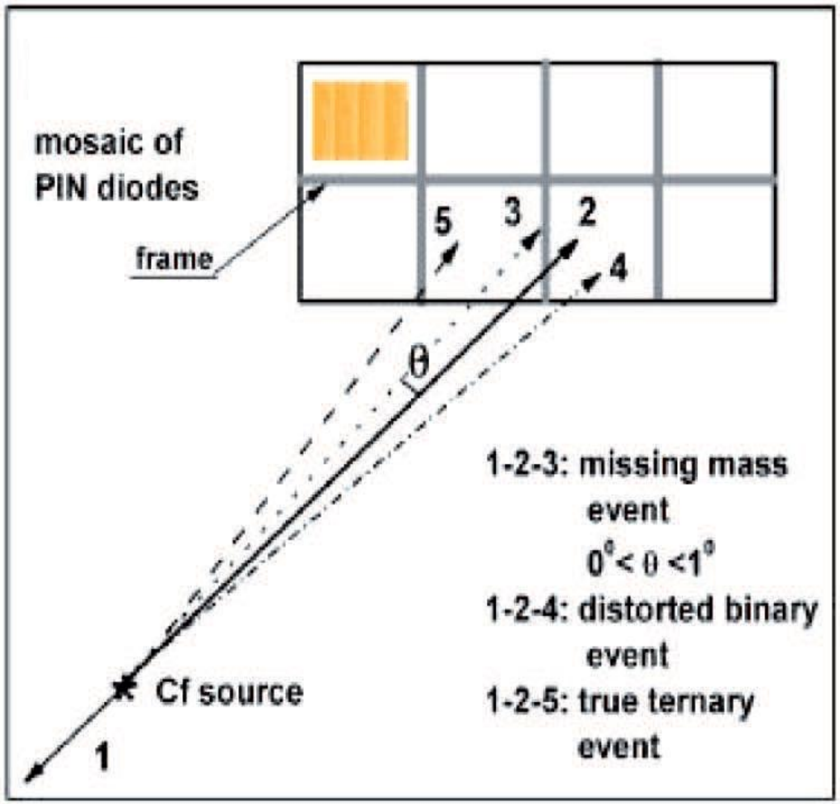
Indications of quaternary decays:





IV. Development of the instruments and inspiring the theory

Registration of the collinear fragments in the mosaic of PIN diodes



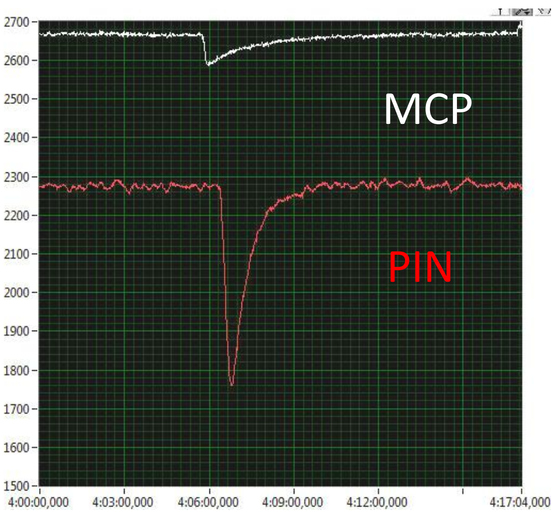
The geometry in Ex3 with the PIN diodes. Hitting the mosaic by a fork of fragments can give rise to three different types of events. Blocking can occur if the opening angle of the fork lies in the range 0 < < 1 (missing-mass event marked as 1-2-3). Both fragments of the fork can hit the same PIN diode (event 1-2-4). If > 1 the fragments forming the fork can be detected in two different PIN diodes (true ternary event 1-2-5).

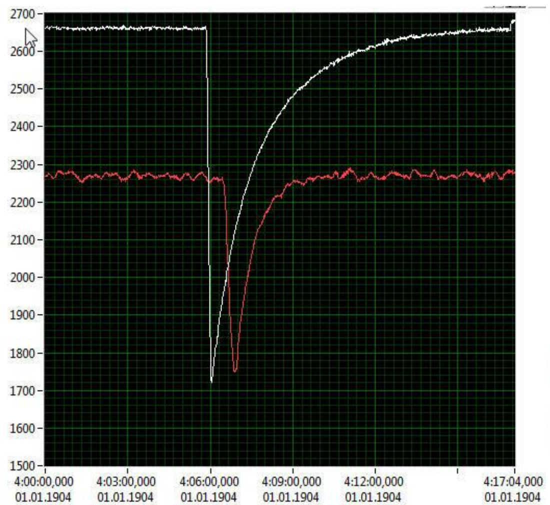
Double-hit detection mode:

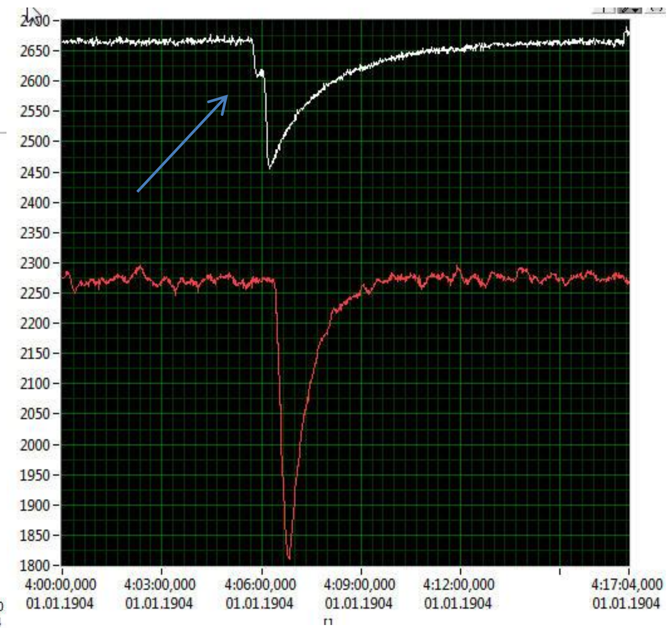
two fragments in the same detector simultaneously

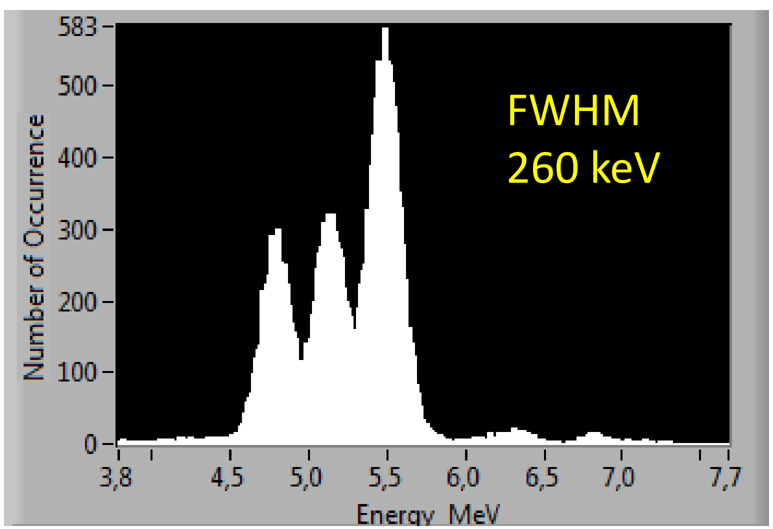

LIS
15/05/2013

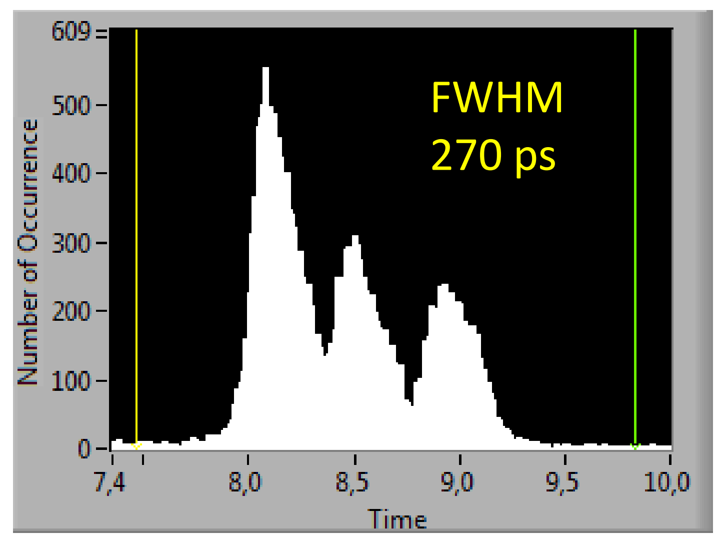
Fast flash ADC technique application





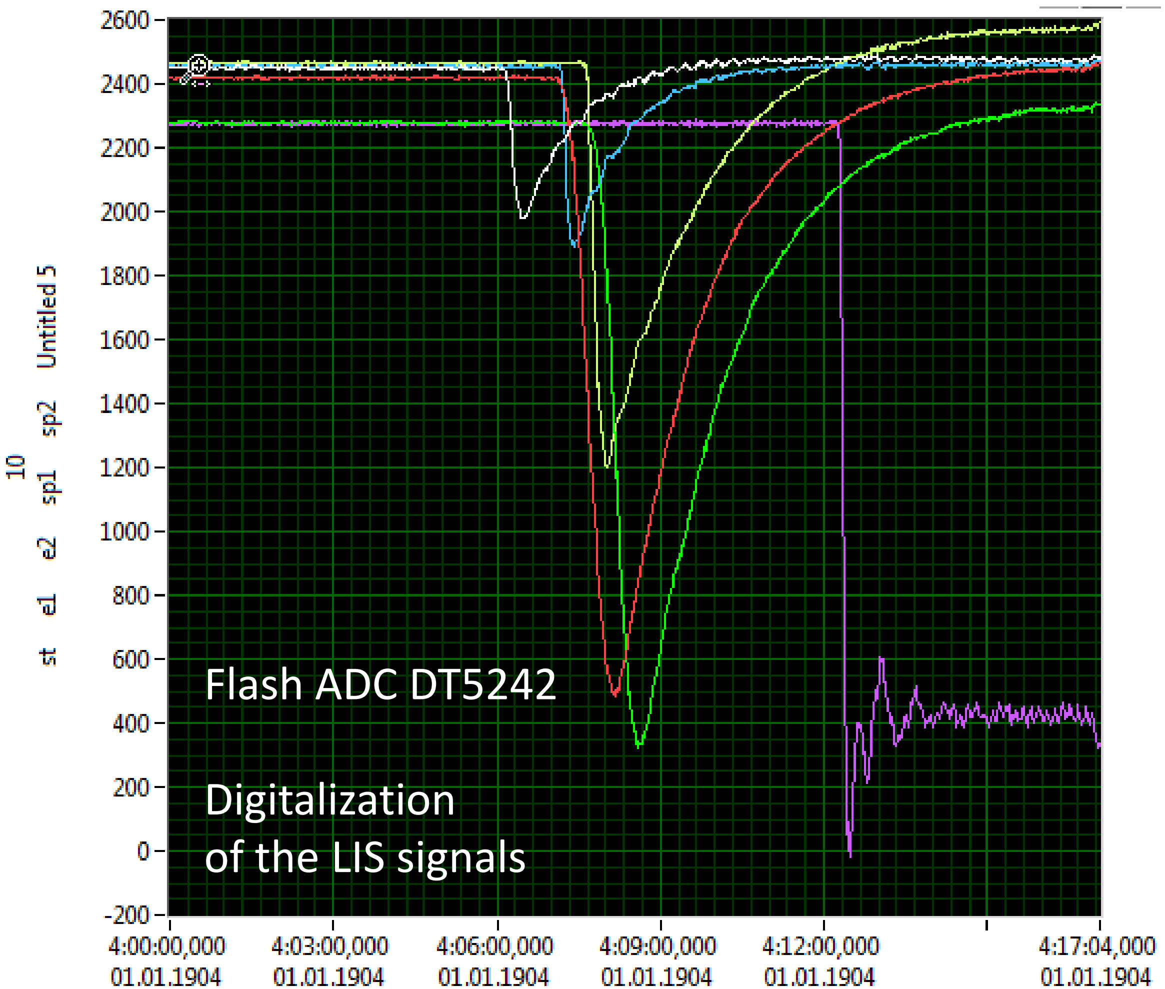






Cocktail: Pu-238 Pu-239 U-233

4,824 MeV 5,155 MeV 5,499 MeV

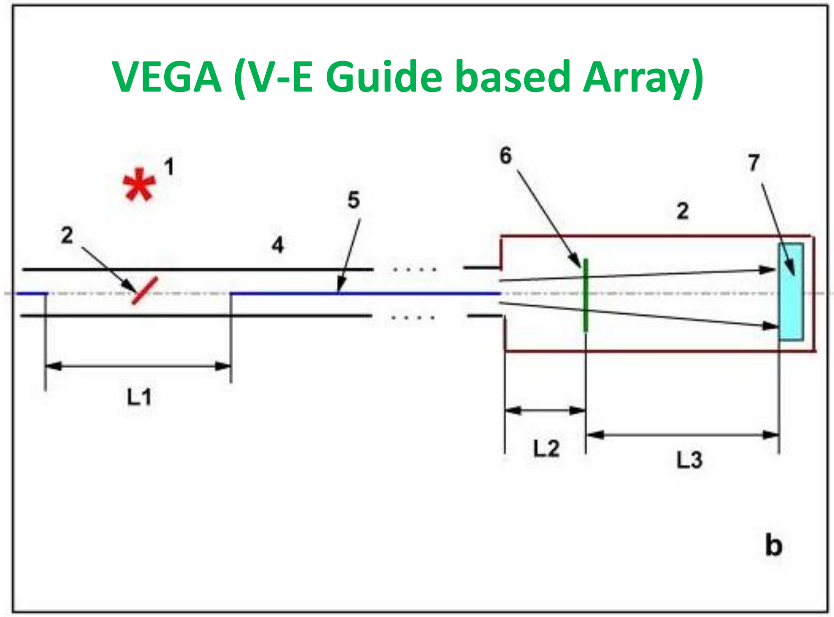


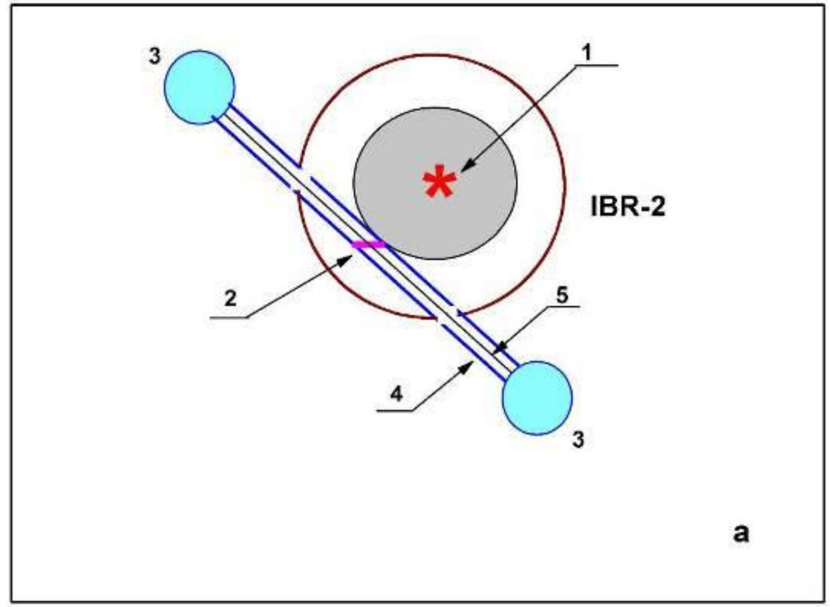
In order to solve a pile-up problem (resolution of two pile –up impulses of a priori unknown shapes)

Long flight path but constant efficiency

EGS

Electrostatic guide system (EGS)





Schematically view of the setup (a) and one of two experimental chambers at the ends of the guide with the detectors inside (b). Active zone (1), target (2), detectors chambers (3), reactor channel (4), central filament of the guide (5), “start” detector (6), mosaic of PIN-diodes (7).

$$F_c = 0.153q\, V_0 / \{E_{FF} \ln(R/s)\}$$

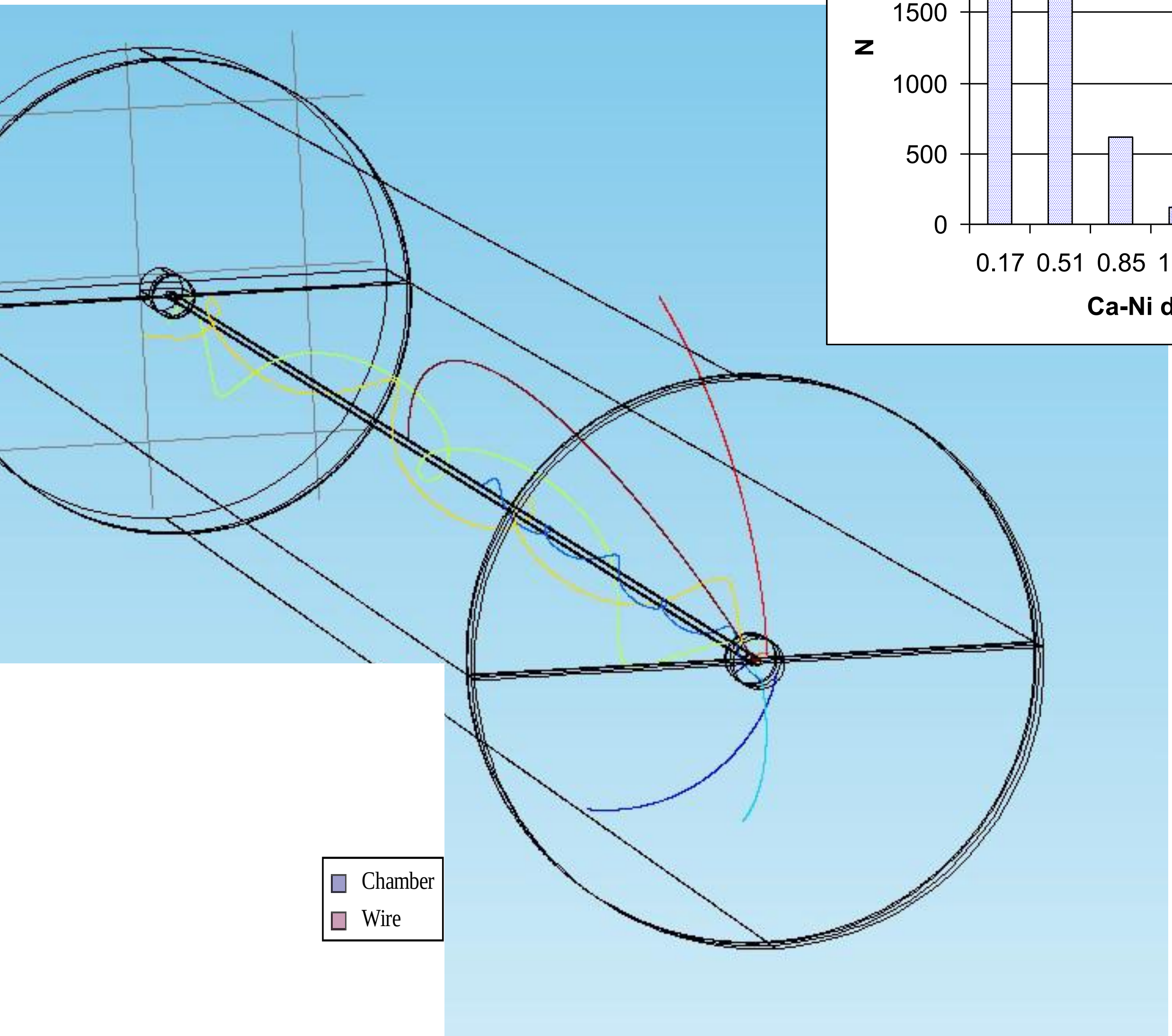
V_0 – is the potential difference between the two conductors,

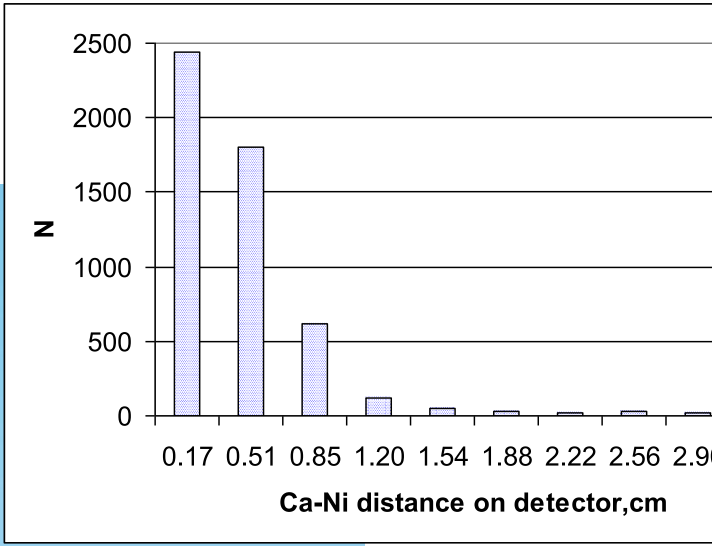
E_{FF} – is the kinetic energy of the fission fragment,

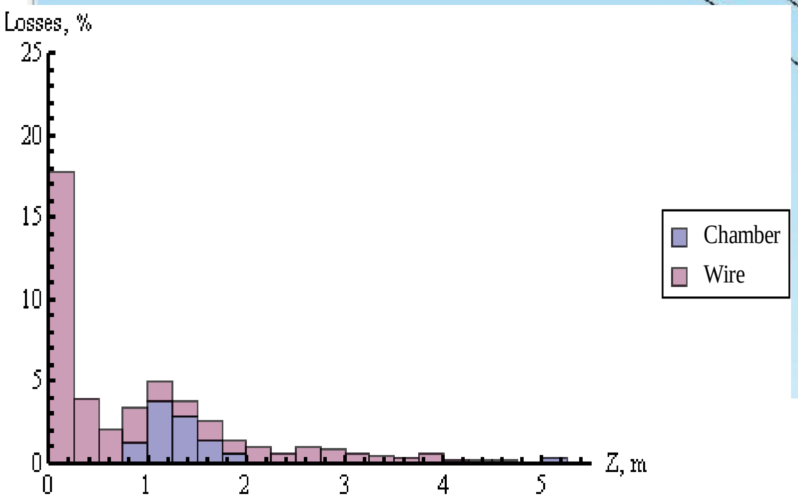
s - is the radius of the central wire of the guide.

N.C. Oakey, P.D. McFarlane NIM 49(1967) 220.
A.A. Alexandrov et al., NM A303 (1991) 323.

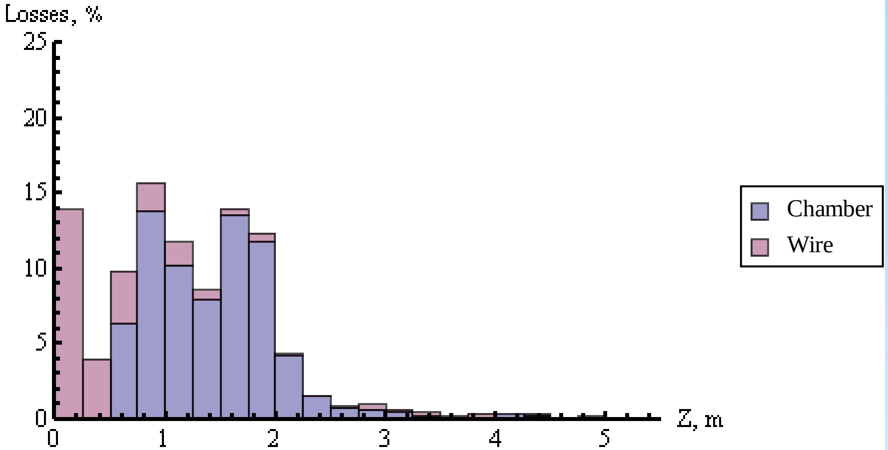
Particle trajectories in straight guide





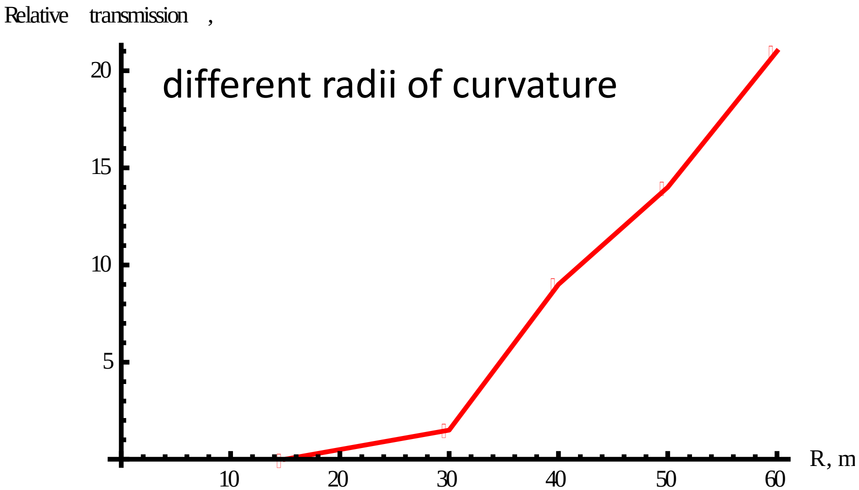


Particle trajectories in curved guide

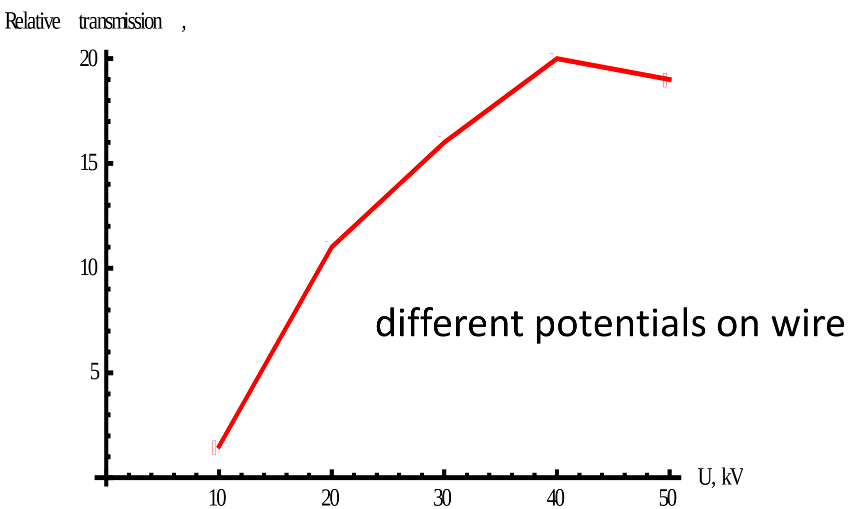


Is optimization possible?

Transmission efficiency of R=30 curve guide relative to reference straight one



R, m	Relative transmission, %
15	0
30	1.5
40	9
50	14
60	21

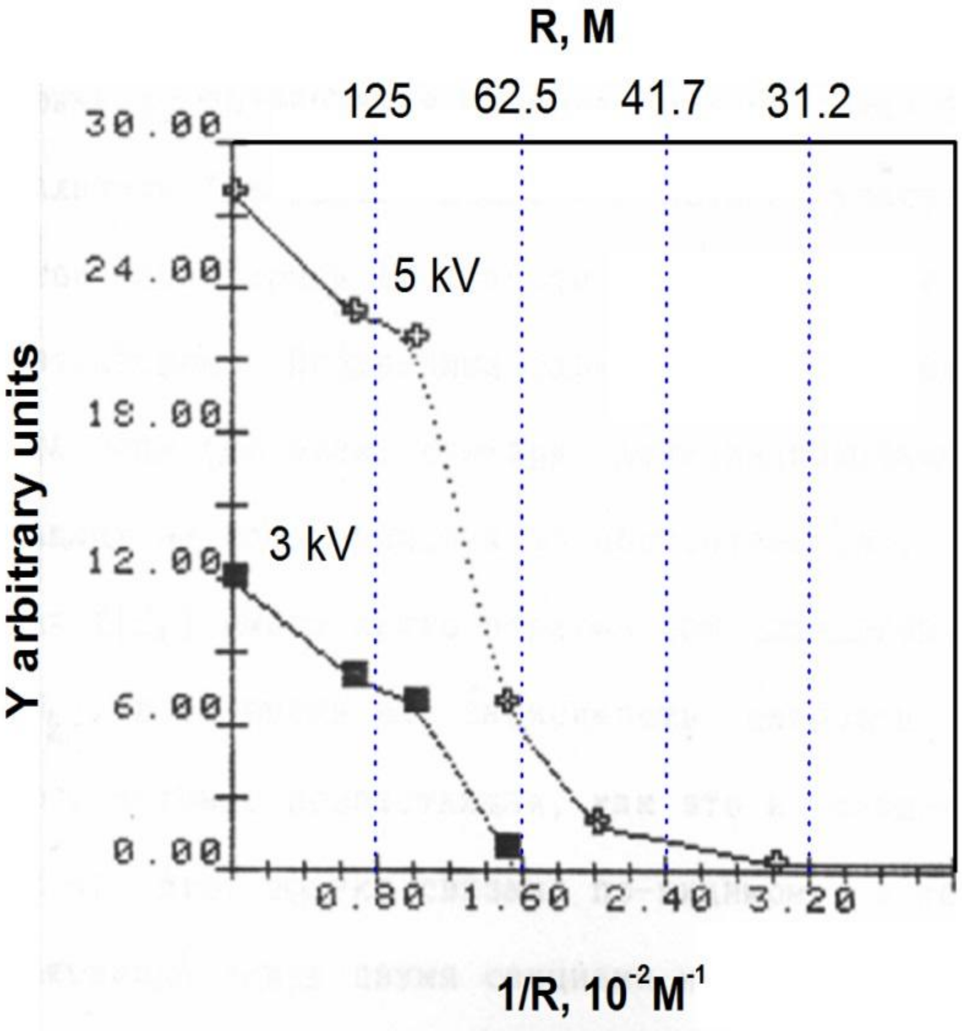


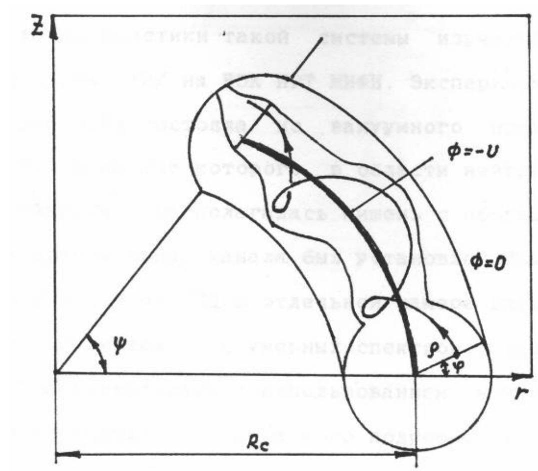
U, kV	Relative transmission, %
10	1.5
20	11
30	16
40	20
50	19

different diameters of vacuum chamber

d, mm	Relative transmission, %
23	7
56	1.5

Curved electrostatic guide system



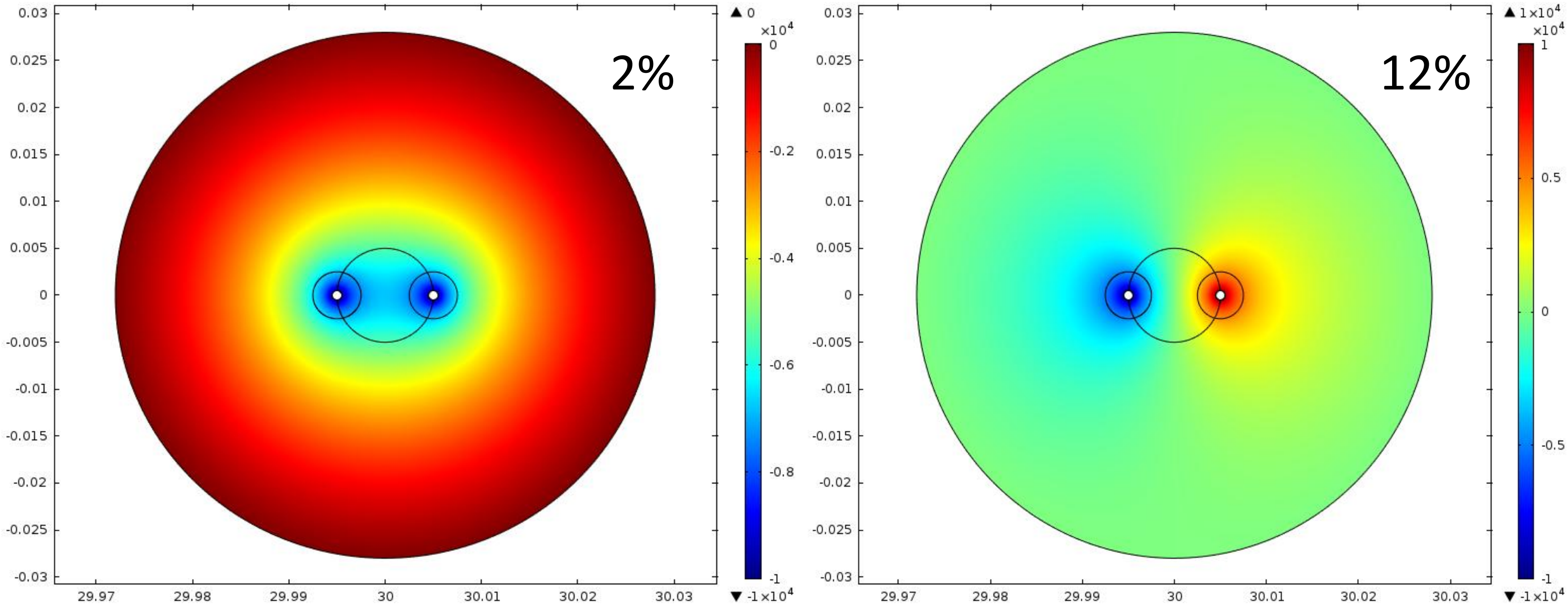


Test version:
L=6.5 M
D=22 mm
d= 0.1 mm
Rings inside through 1M

---> Pulsed HV ?

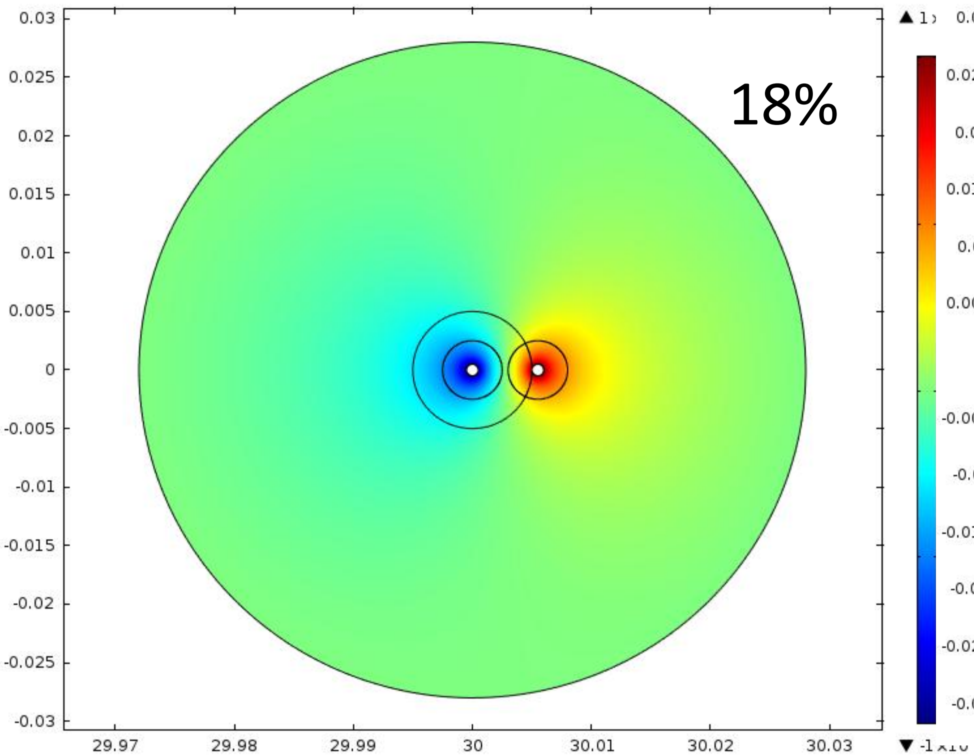
Is optimization possible?

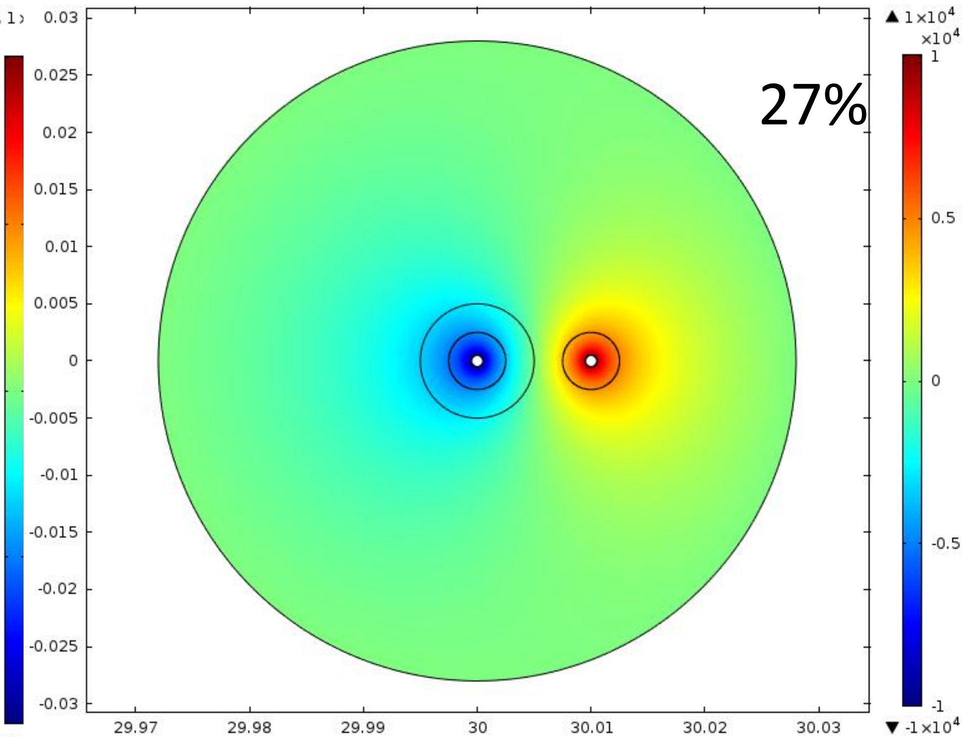
Distribution of the potential and transmission efficiency of R=30 curve guide relative to reference straight one



Is optimization possible?

Distribution of the potential and transmission efficiency of R=30 curve guide relative to reference straight one





What it the average ionic charge?

Review of Wittkower и Betz, 1972

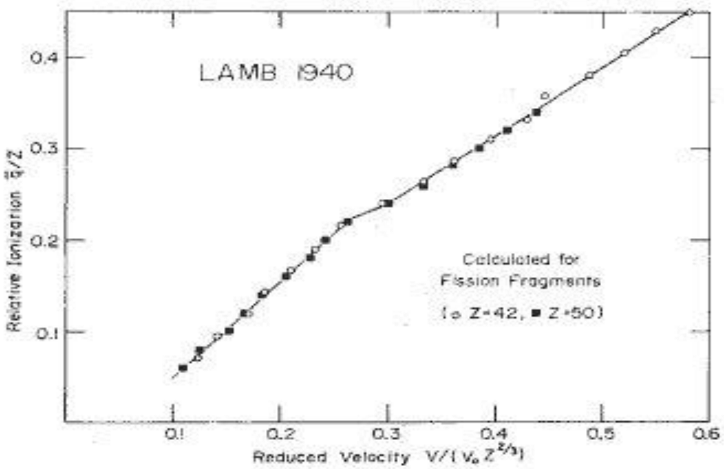


FIG. 5.1. Average relative equilibrium ionization of ions of nuclear charge 42 and 50 calculated by Lamb (1940) for a dilute gas stripper, plotted as a function of the reduced ion velocity $v/(v_0 Z^{2/3})$.

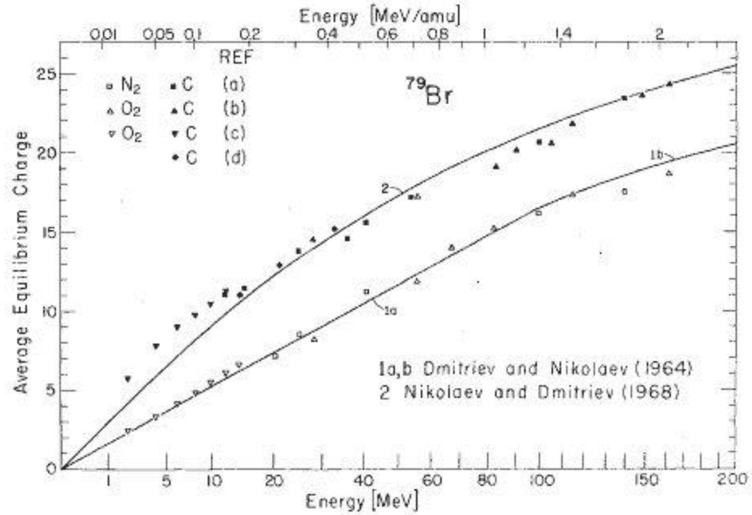


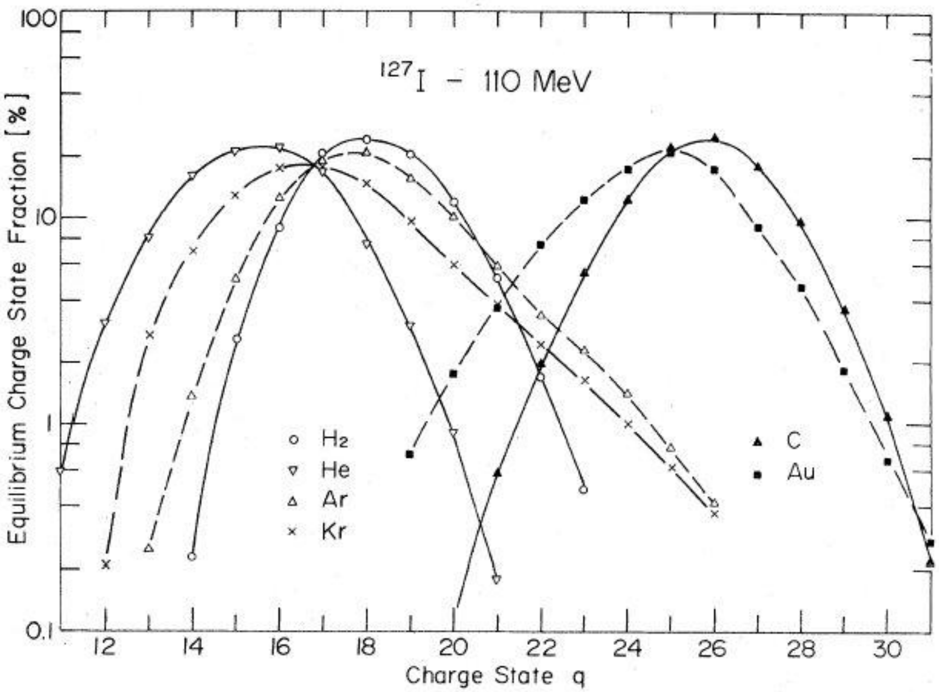
FIG. 5.7. Average equilibrium charge of bromine ions stripped in nitrogen and oxygen gas (open symbols), and in carbon foils (full symbols), plotted as a function of the projectile energy. Experimental results are taken from Table V.1: (a) Moak *et al.* (1968) and Datz *et al.* (1971); (b) Grodzins *et al.* (1967); (c) Wittkower and Ryding (1971); (d) Almqvist *et al.* (1962). Semi-empirical estimates: 1a, b, Dmitriev and Nikolaev (1964), Eqs. (5.4) and (5.5); 2, Nikolaev and Dmitriev (1968), Eq. (5.8).

Universal Dmitriev and Nikolaev formula (1968) for the ions with the energy more that 100 MeV for solid targets

$q/Z = [\,1+(Z^{-\alpha}v/v_0)^{-1/k}]^{-k}$,

$v_0 = 3.6 \cdot 10^8$ cm/c, $k = 0.6$, $\alpha = 0.45$.

How wide is the ionic charge distribution?



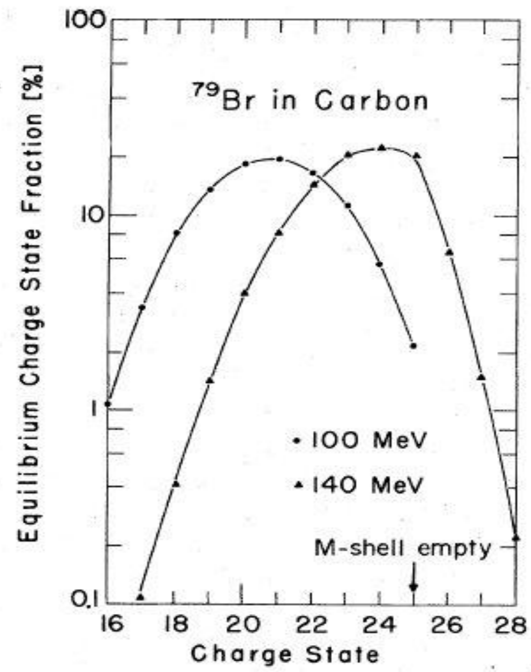
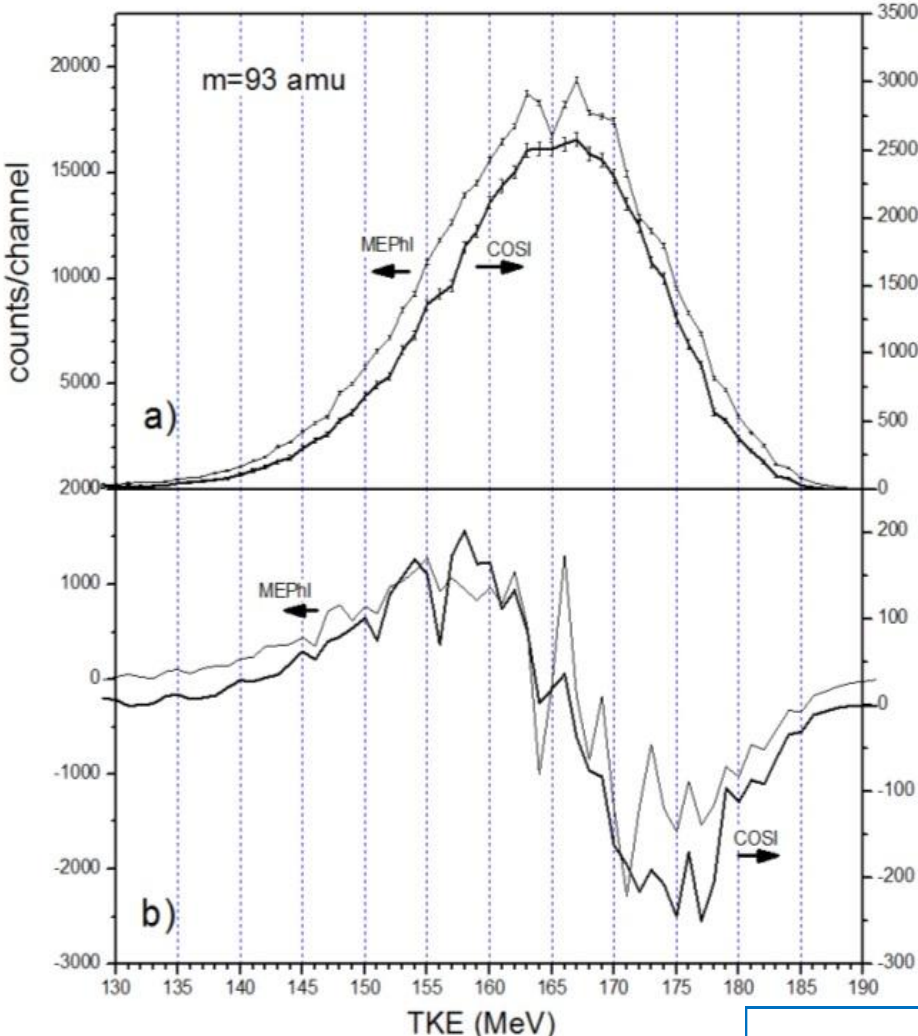
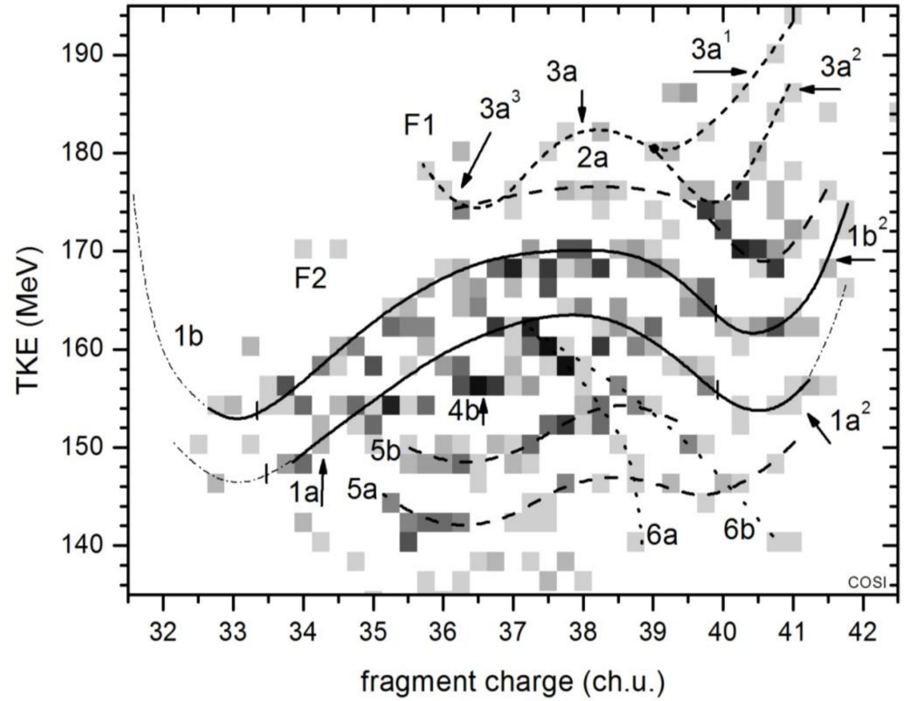


FIG. 5.16. Equilibrium charge state distributions for bromine ions, stripped in a carbon foil at 100 and 140 MeV; from Moak *et al.* (1967, 1968).

Review of Wittkower и Betz, 1972

Comparison with the results obtained at the Cosi fan tutte spectrometer





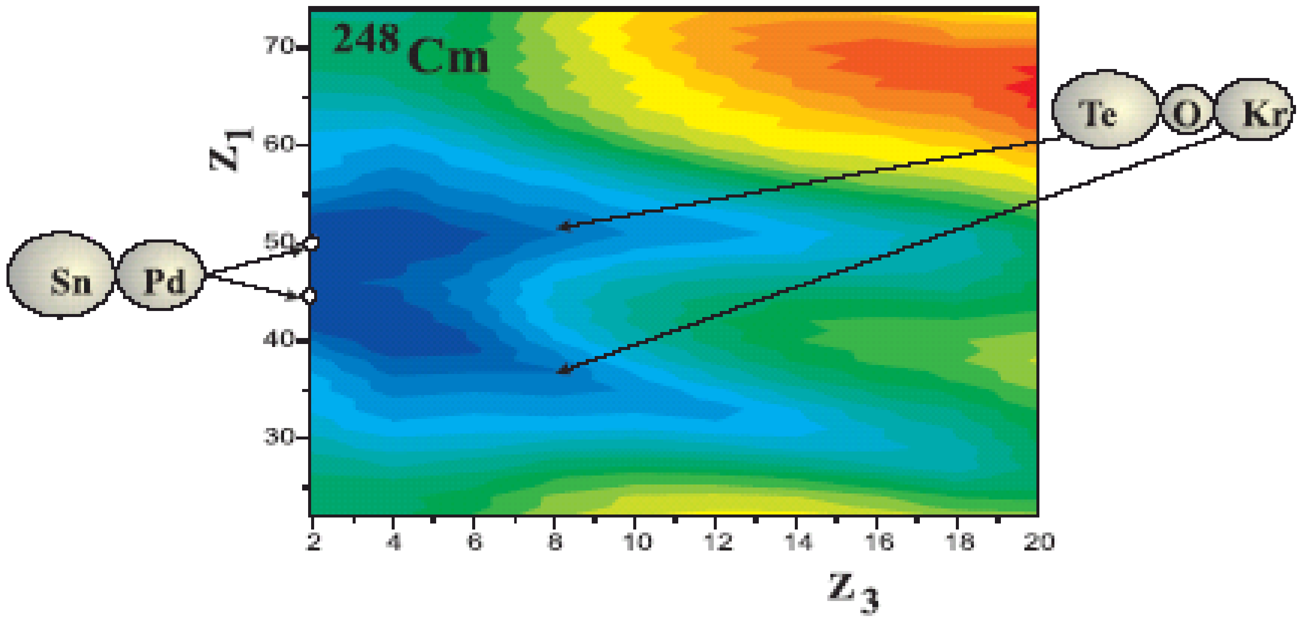
Courtesy to Prof F. Goennenwein

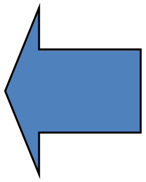
FS is more pronounced in the EGS data

Bottom of the valley →E* →int. convers. →q →Y EGS

EGS: new physical parameter namely *ionic charge* is included in the game by nontrivial way – to visualize the valleys on the potential energy surface of the decaying system.

Theoretical support





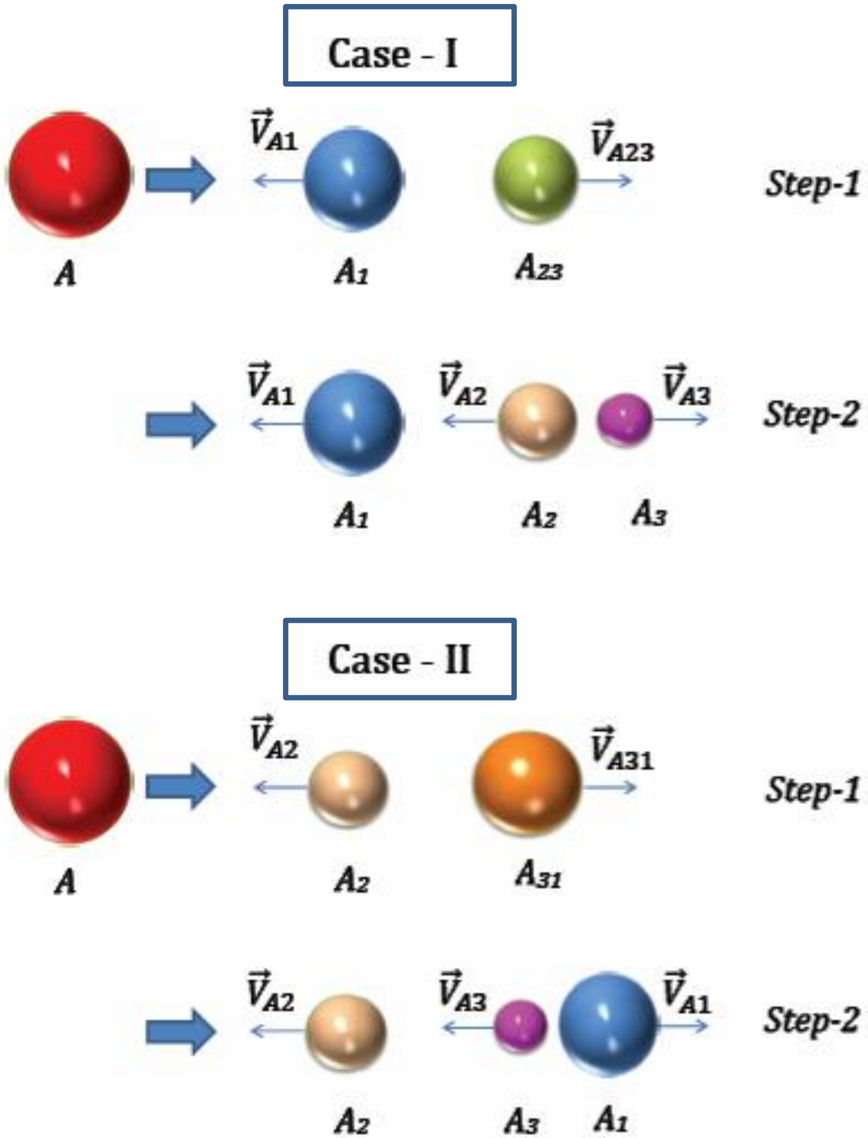
Landscape of the potential energy surface for three-body clusterization of ^{248}Cm.

Though the combinations like Te–O–Kr or Sn–O–Sr are located not so high up on the potential energy surface (10 to 20 MeV), and they are quite reachable due to fluctuations at several tens of MeV of excitation energy.

V. Zagrebaev and W. Greiner

Proc. Internat. Symp. on Atomic Cluster Collisions (ISACC07), GSI Darmstadt, 2007, (Imperial College Press, London, 2008), Eds. J.-P. Connerade and A. V. Solov'yov, pp. 23-33

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

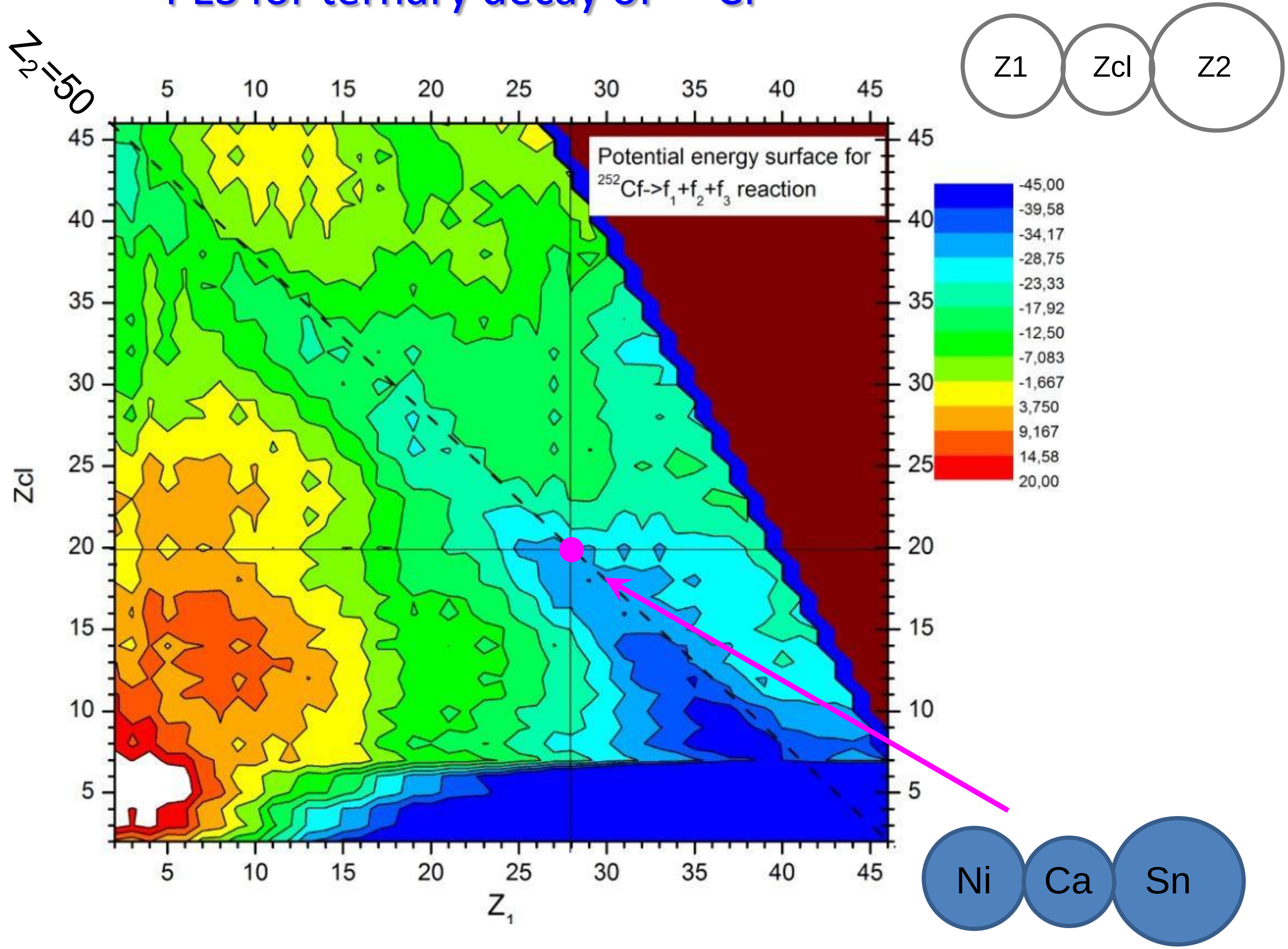


Only one CCT combination **Sn-Ca-Ni** is analyzed in the frame of a rather artificial model.

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

PES for ternary decay of ^{252}Cf



Courtesy of Dr. A.Nasirov, BLTP JINR. Private communication 17.09.2012

CCT @ DUBNA (ALUSHTA)

the dreams towards

ISINN-22

1. COMETA-R/FADC at reactor beam

Measurements with 235-U to be started

2. VEGA design and modeling

3. COMETA & LIS new experiments

Next report by Prof. Pyatkov