Searching for collinear ternary decays using “double-hit” approach

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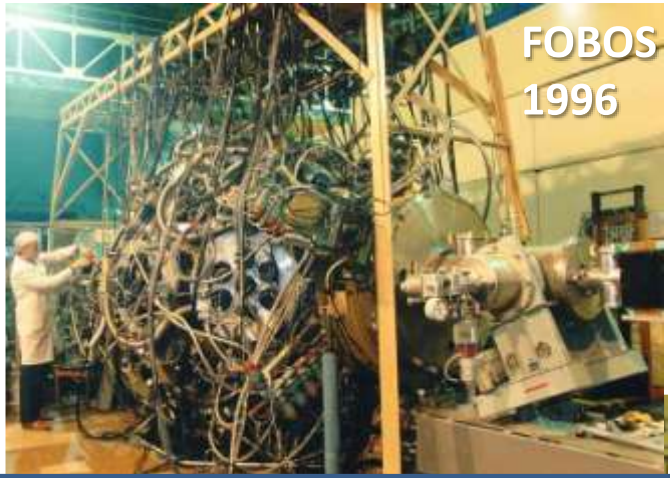
[4] University of Stellenbosch, Faculty of Military Science, Military Academy, South Africa.

Special thanks to the organizers:
Tracking CCT progress
from ISINN to ISINN



ISINN

10 - first neutron-gated data with FOBOS

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

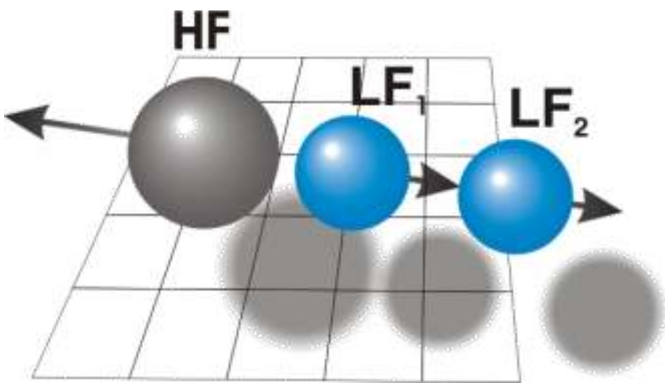
20 – first CCT physics & Ion Guide proposal

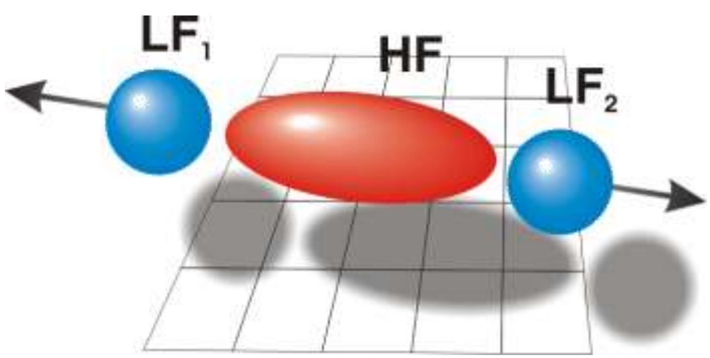
21 – first indications of shape isomers in FF

22 – new results on shape isomers in wide range

23 – first “flash”-data

Collinear cluster tri-partition (CCT) – status quo





Prescission ternary configurations under study

http://fobos.jinr.ru

Principal publications based on missing mass approach

PHYSICAL PROGRAM AND STATUS OF THE VEGA PROJECT

D.V. Kamanin[1], Yu.V. Pyatkov[2,1], A.A. Alexandrov[1], I.A. Alexandrova[1], N.A. Kondratyev[1], E.A. Kuznetsova[1], V. Malaza[3], N. Mkaza[3], V.N. Shvetsov[1], A.O. Strekalovsky[1], O.V. Strekalovsky[1], V.E. Zhuchko[1]

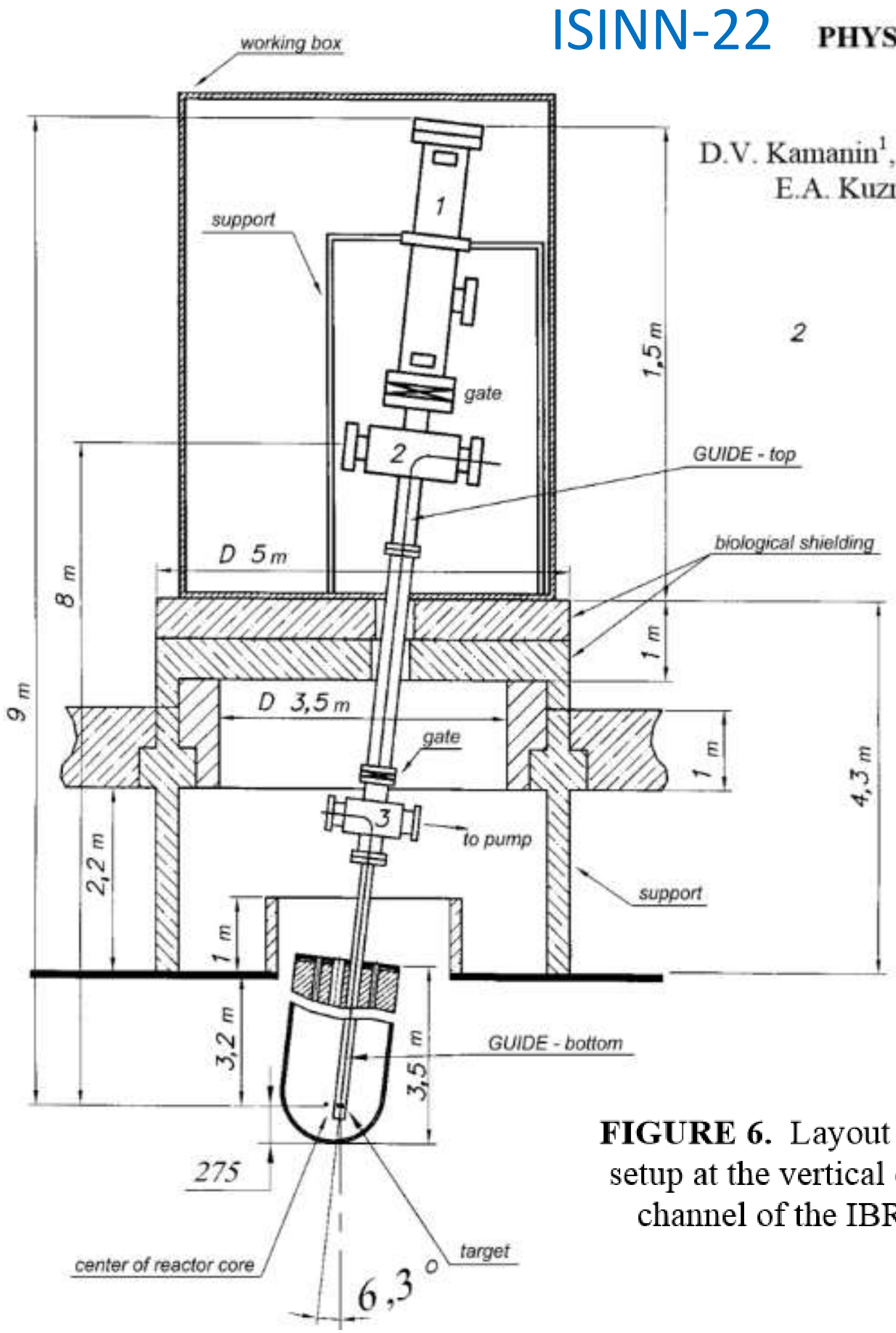
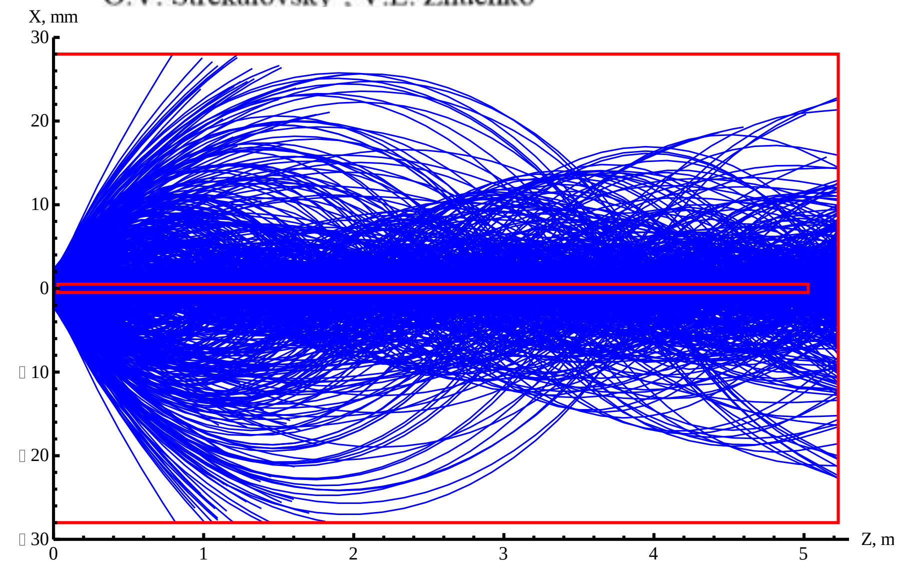


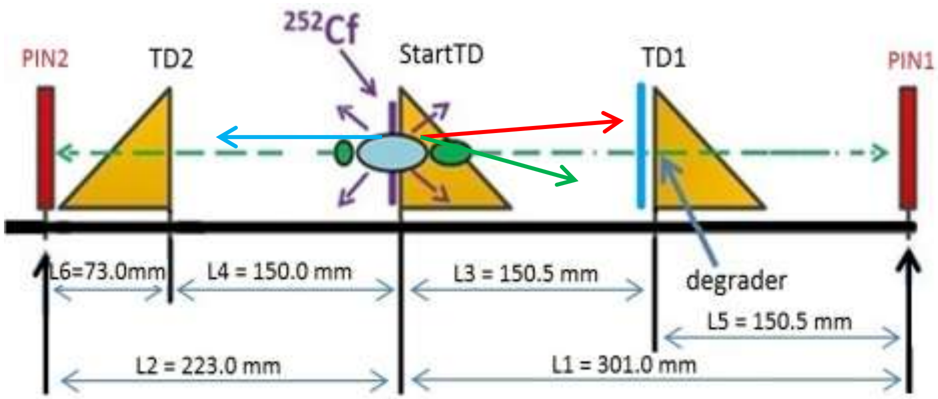
FIGURE 6. Layout of the VEGA setup at the vertical experimental channel of the IBR-2 reactor.



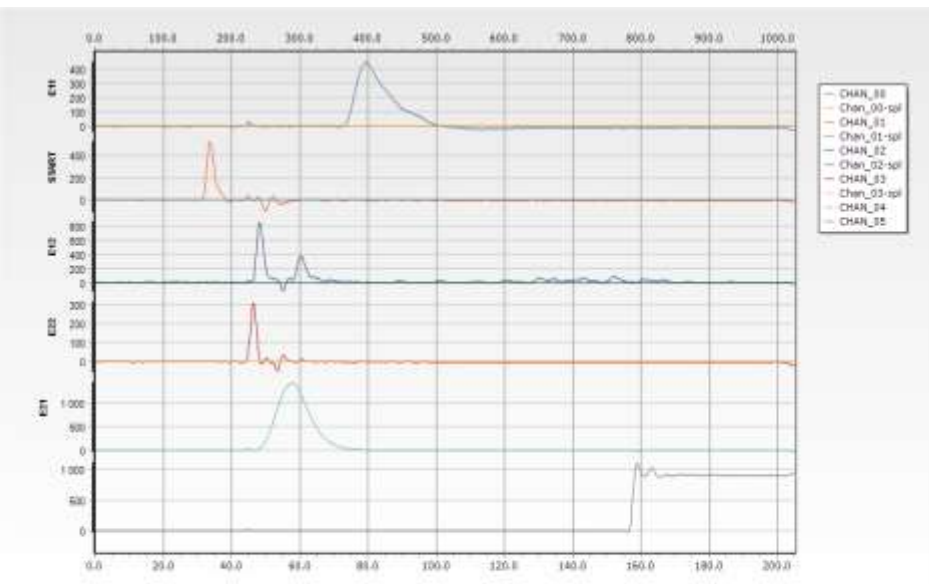
Trajectories in the linear VEGA channel

Motivation and expected effects for planning the experiments on the direct detection of all CCT partners

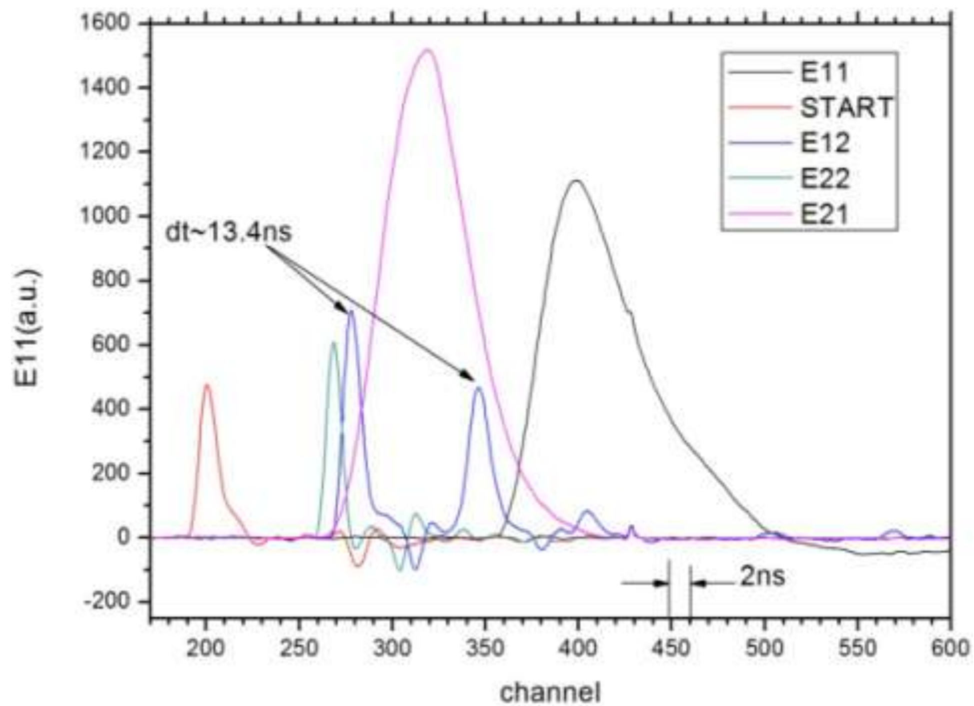
Double-hit registration mode for
direct detection of ternary events



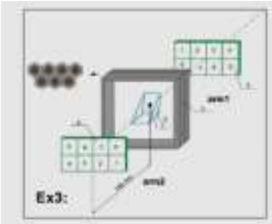
CAEN flash-ADC, 5 GHz sampling rate
200 ps per point



Typical timing chart of a fission event

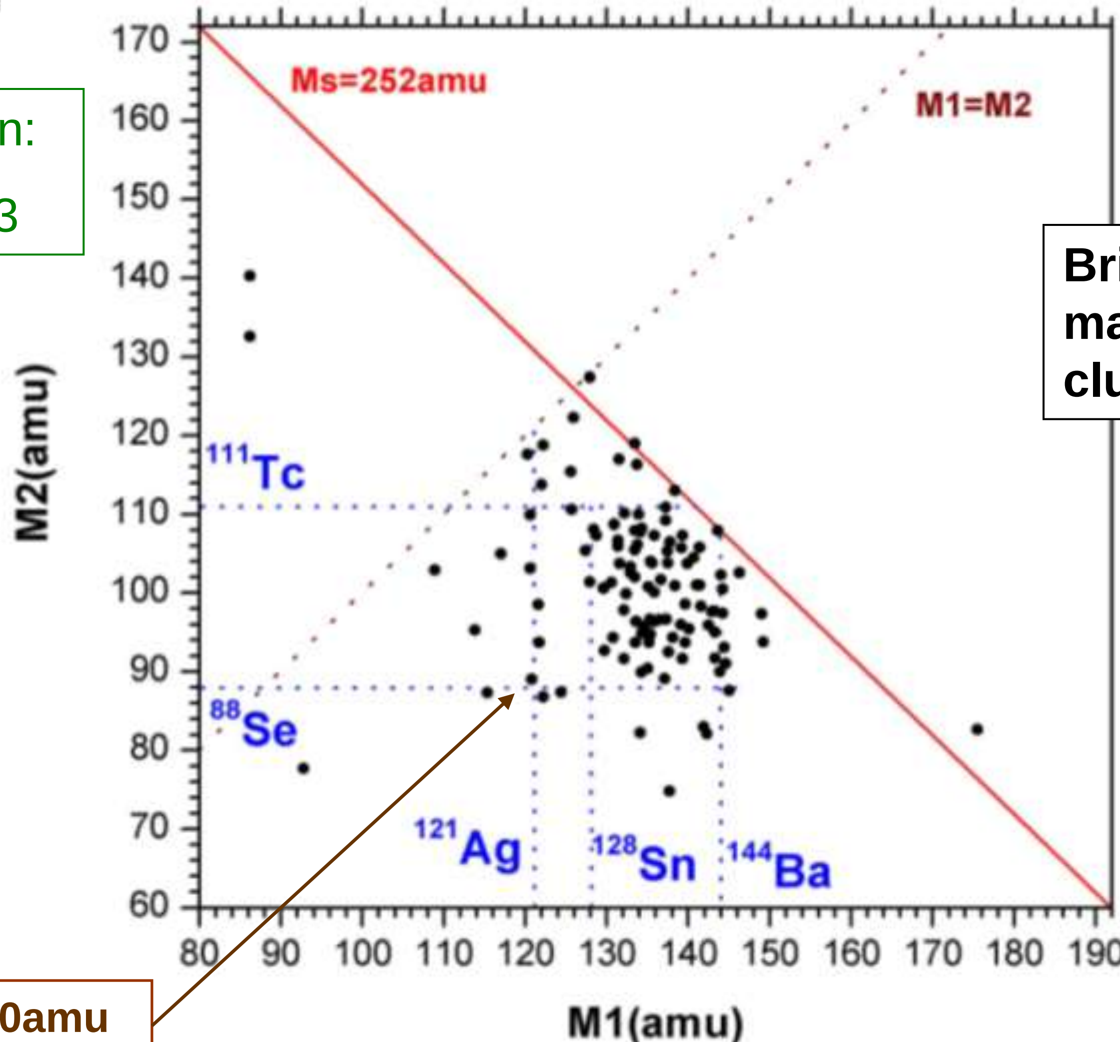


Ternary decays, all 3 fragments were detected



By definition:

m1>m2>m3

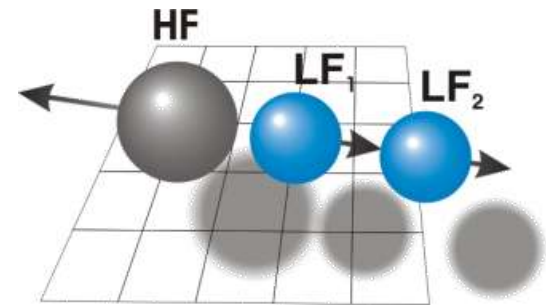


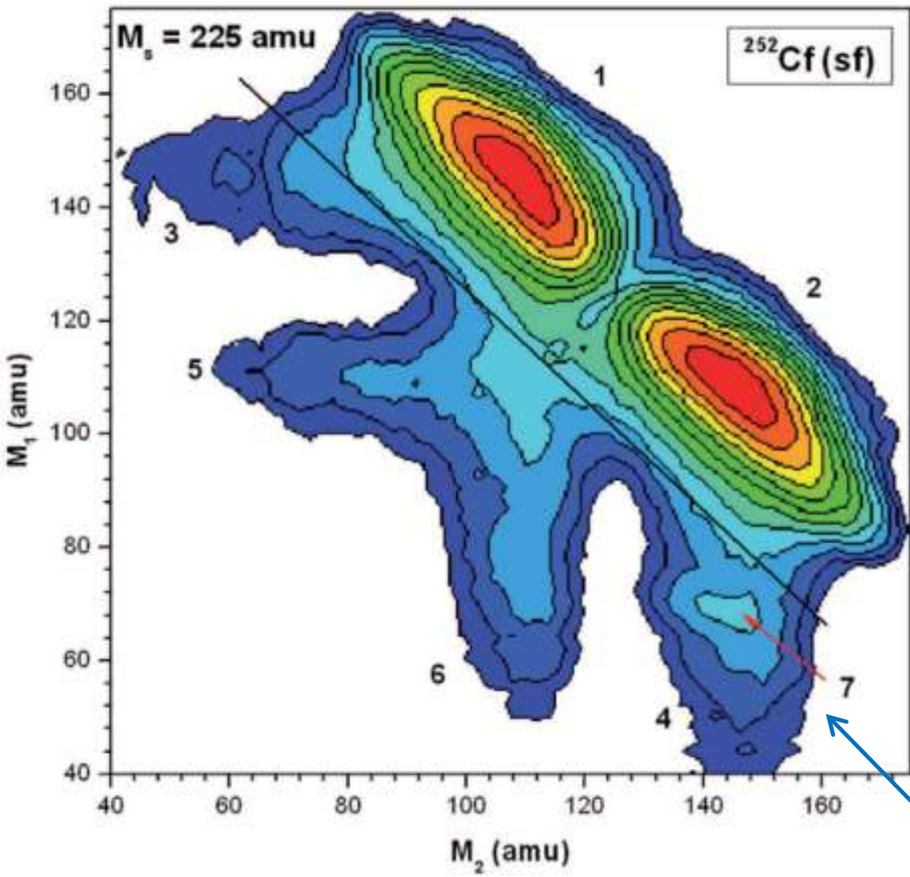
Bright manifestation of clustering

dM12s ~ 40amu

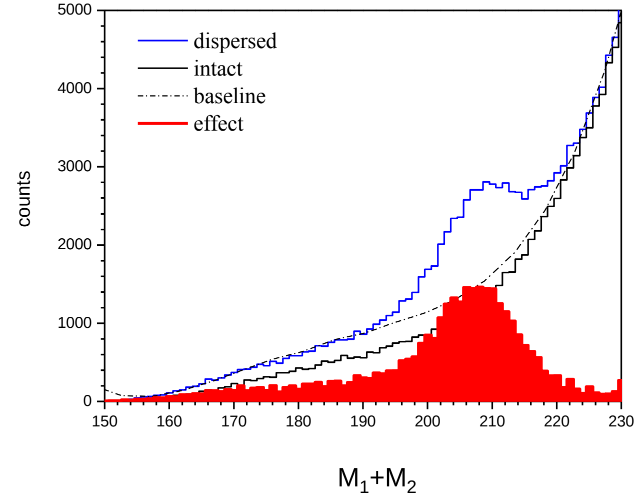
&Ms12<258

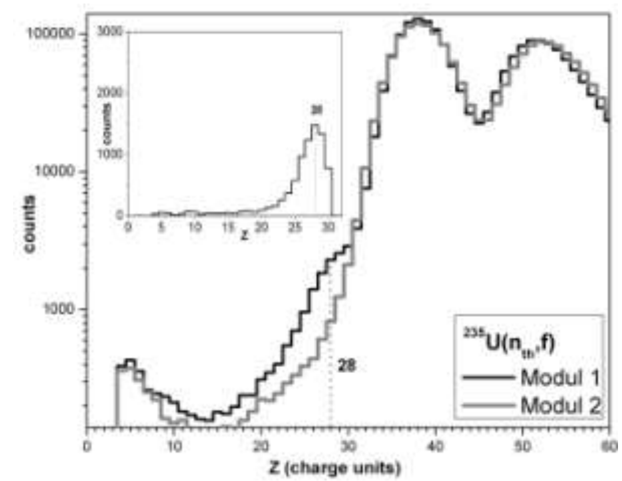
CCT gross-structure (bump) in ^{252}Cf (sf)





Difference between the arms

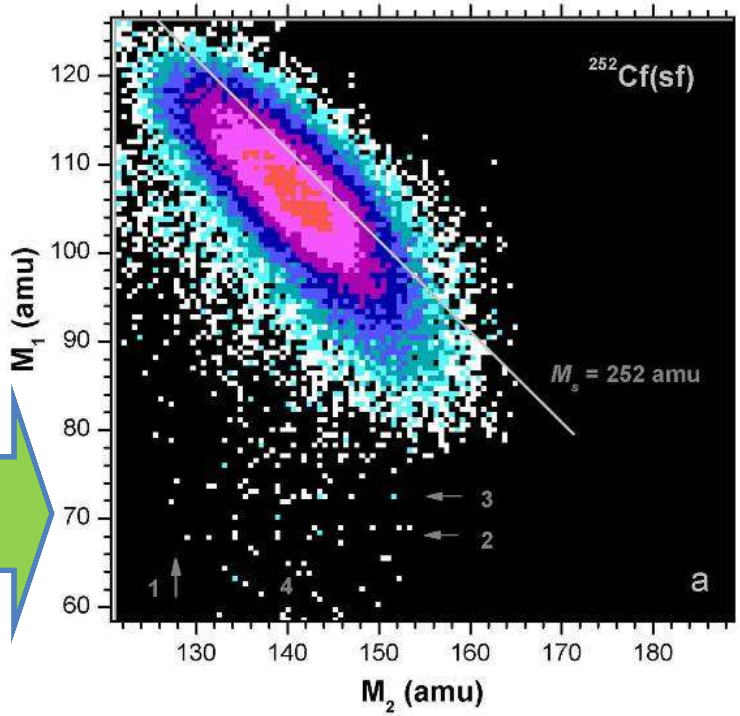




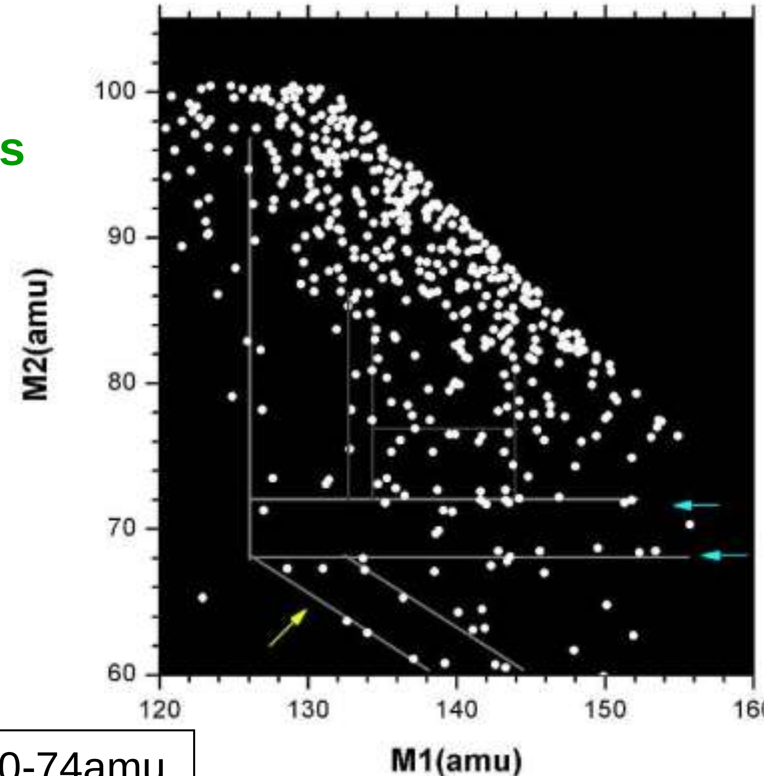
Pyatkov, Kamanin et al.,
Eur. Phys. J. A 45, 29–37 (2010)

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

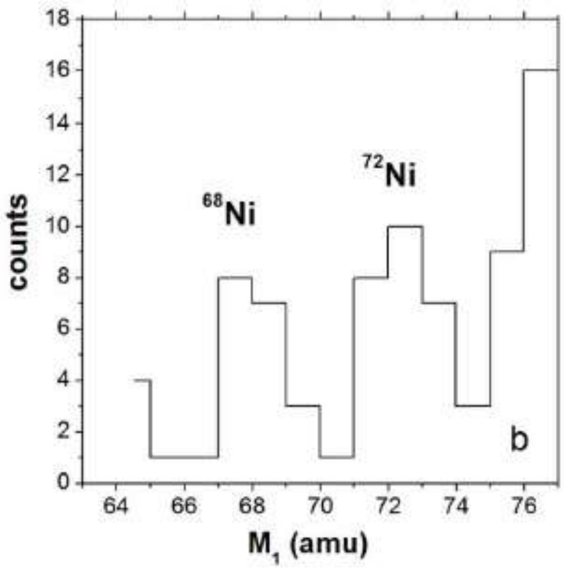
“Ni-bump” as the object of study

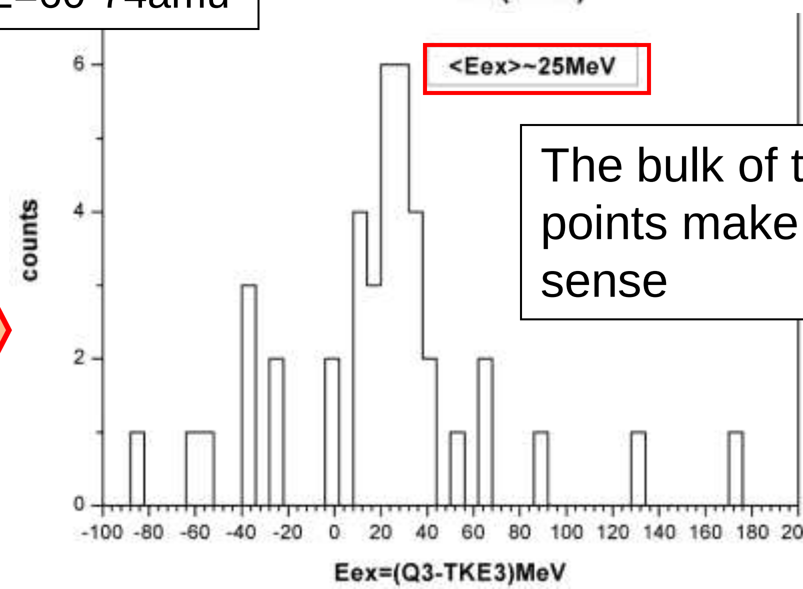


Any gates



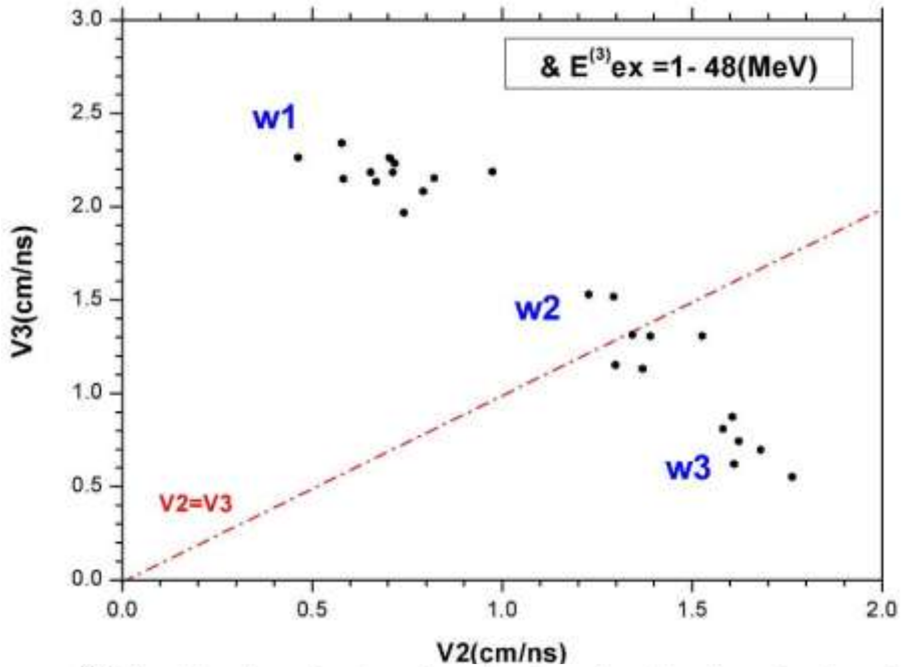
&M2=60-74amu





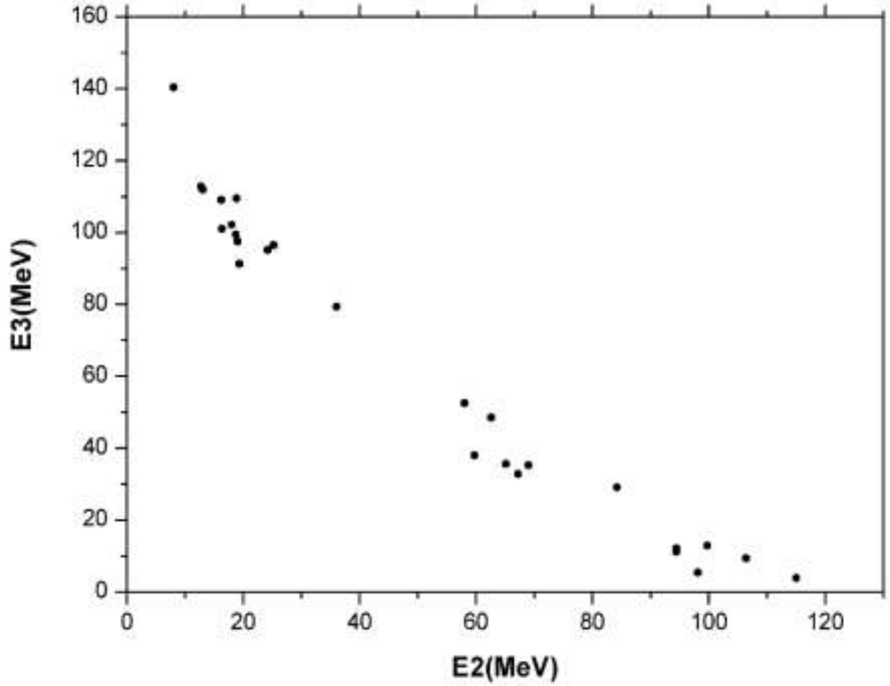
The bulk of the points make sense

Expected velocities and energies of the light CCT partners in the Ni-bump



Ternary (?) fission is supposed
Mass, energy and momentum conservation laws are used to estimate 3-rd fragment

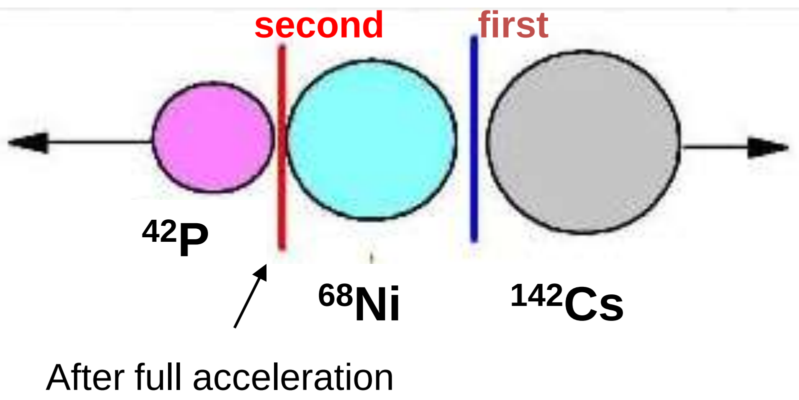
W3&W1 events: dTOF~**12, 15ns**
at the flight-pass of 15cm



^{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

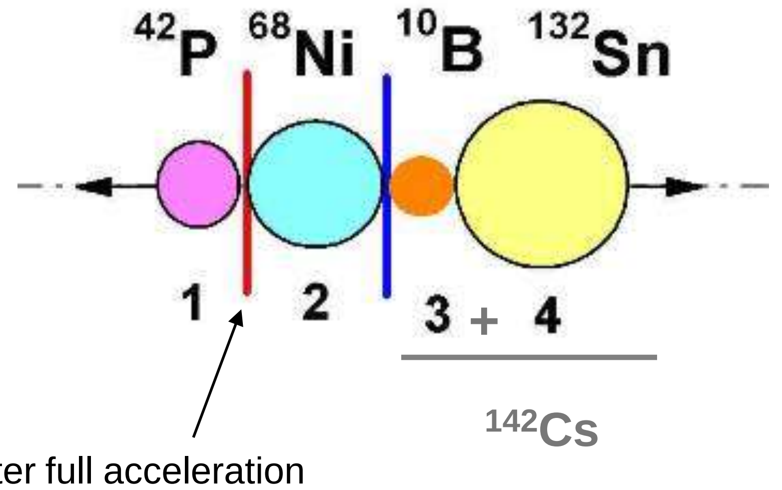
Prescission configuration expected



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



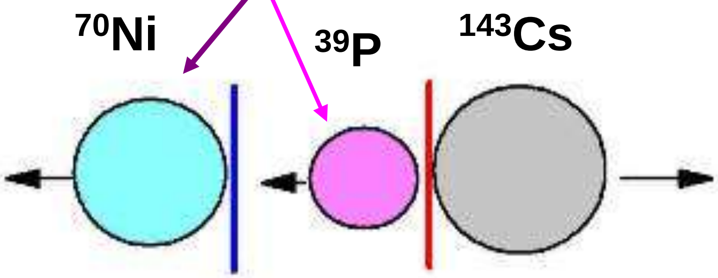
Q4~201MeV; Eint~223MeV; Eint>Q4;

Even quaternary cold decay is interdicted

Pyatkov et al., ISINN-20

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

Dynamical blocking

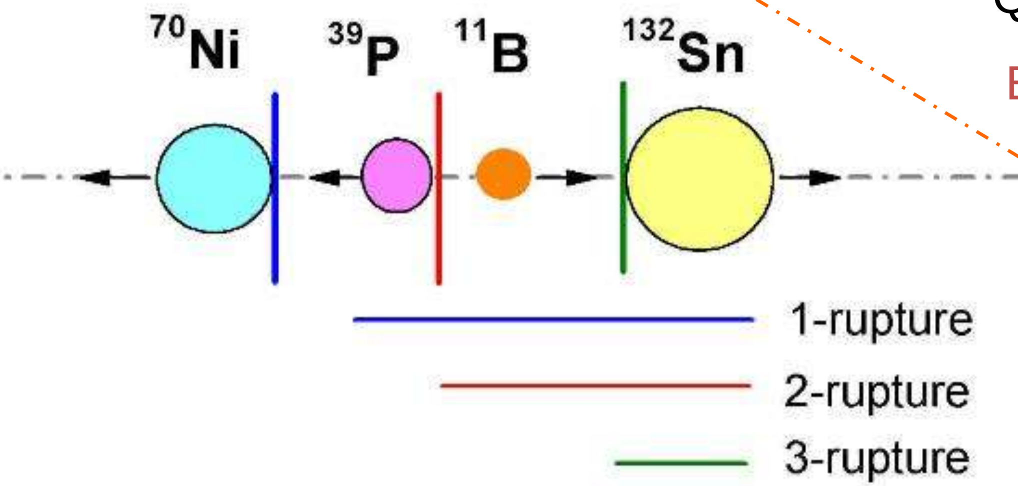


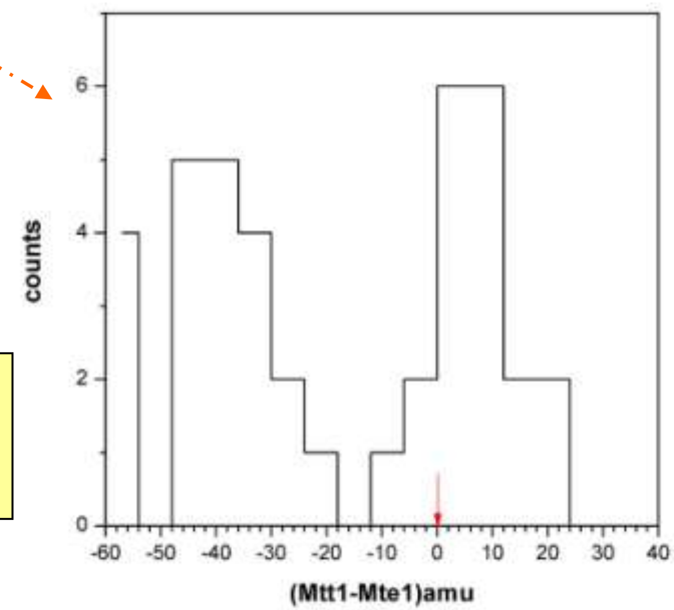
Q3~214MeV; Eint=229MeV;

Eint > Q3 → cold fission is interdicted

Q4~216MeV; Eint~188MeV;

Eint ~TKEexp -- good agreement



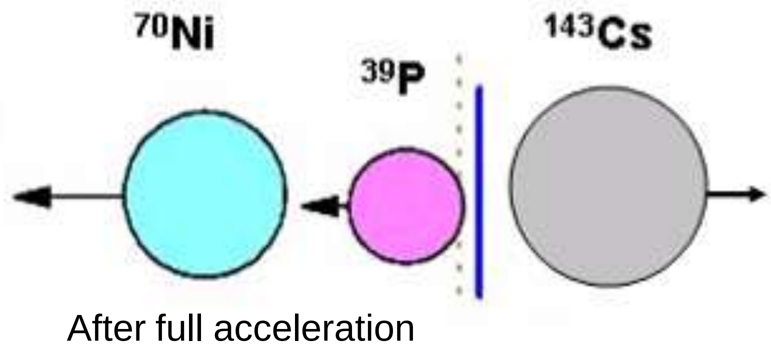


Higher as compared to w1 case

E_free in scission lets quaternary decay

Pyatkov et al., ISINN-20

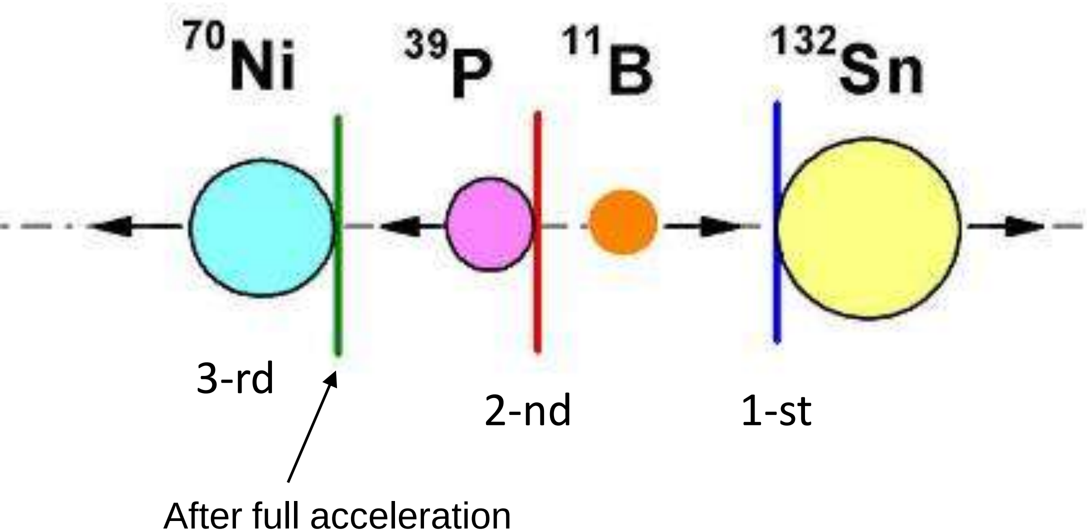
Third group (w3): V3<V2, V1 ~ V_{H_bin}, TKEexp=178MeV



Q3~214MeV; Eint=229MeV;

Eint > Q3;

(the same partners as in w2)



Q4~216MeV; Eint~188MeV;

Eint ~TKEexp

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

good agreement

Quaternary decay is expected

Pyatkov et al., ISINN-20

Physics Letters B 746 (2015) 223–229

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Multi-modal fission in collinear ternary cluster decay of ^{252}Cf(sf, fff)

W. von Oertzen [a,b,*], A.K. Nasirov [b,c,d], R.B. Tashkhodjaev [c,e]

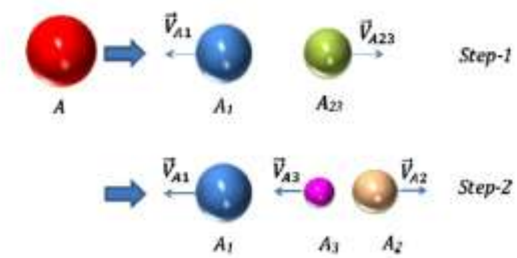
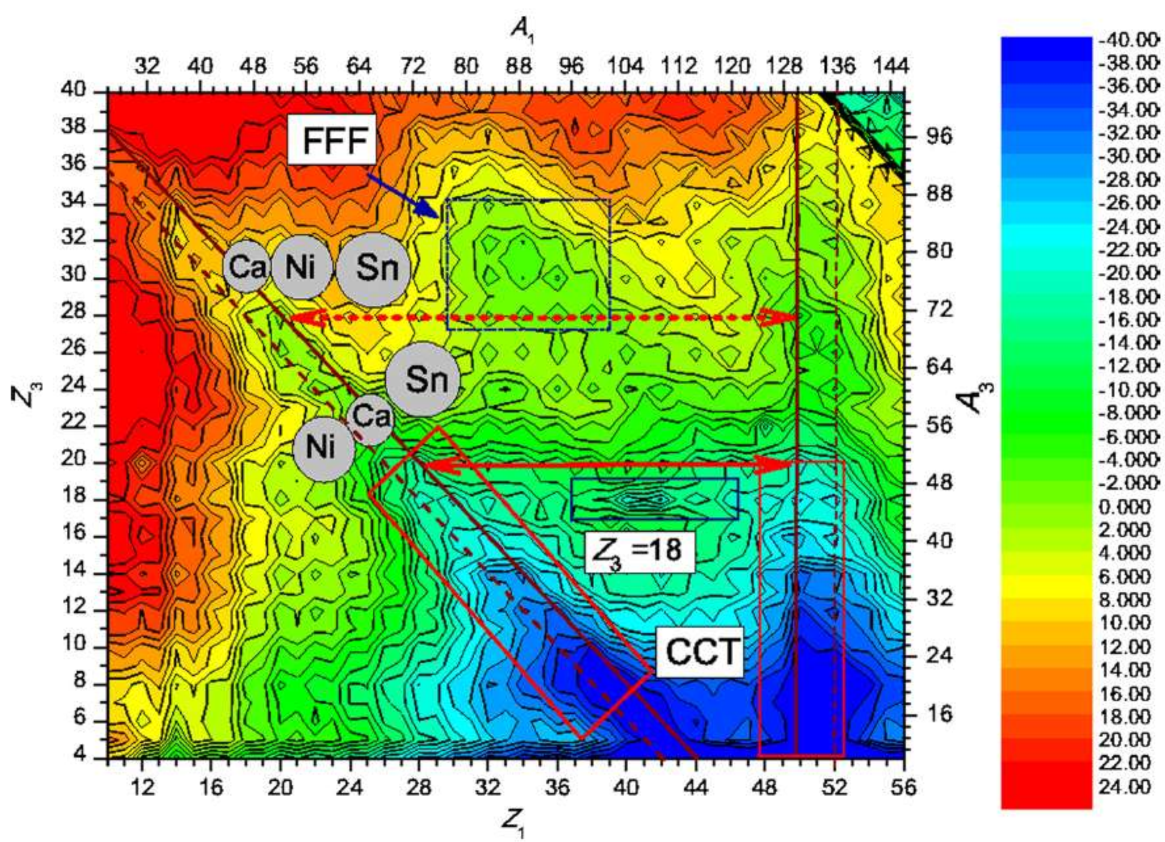
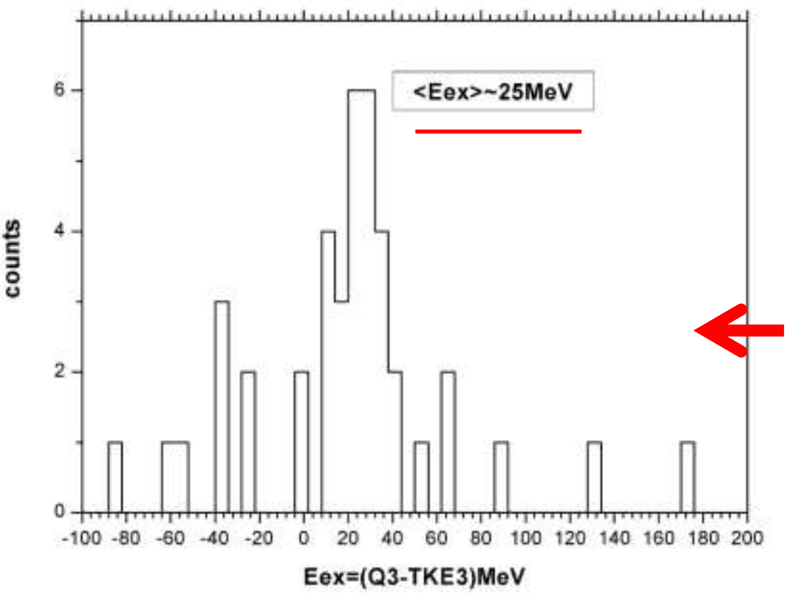


Fig. 1. (Color online.) Schematic illustration of collinear sequential ternary fission into three fragments of comparable mass (adopted from Ref. [24]).



Intermediate conclusions

1. **Cold** *ternary decay* (all partners are in the ground states) seems to be interdicted energetically: prescission ternary chain-like configuration provides too high potential energy as compared to Q3 value.
2. **Cold** *quaternary decay* is more favorable energetically and energy conservation law is met for some *quaternary prescission configurations.*



Nevertheless, ternary decay likely realizes via **deformed** states of the partners. At least estimations based on the experimental V&E values for two detected fragments give reasonable V&E values for missing 3-rd fragment (slide №5).

It should be stressed, that in the conventional binary fission one exclusive partition $^{132}Sn/^{120}Cd$ is known only provided *"true cold fission".* All others correspond to the deformed fragments at the scission point.

Intermediate conclusions

3. Next unclear point for simple models of ternary decay is a **rupture condition**. Interaction energies for the chain-like configurations were estimated for the bottoms of the corresponding inter-nuclear potentials. And how to overcome the barrier to the scission?

Definition of the ***scission point*** is a delicate problem even in binary fission. The most impressive description of the fission process was presented by Berge et al. (1984) in the frame of the time-dependent Hartry-Fock prescription. Descent of the fissioning nucleus along the fission valley (in red) is accompanied by the tunneling to the valley of two separated fragments (in blue) - the process giving rise to the ***scission line*.**

Evidently simple models of ternary fission stand very far from such level. The predictive power of the models should be regarded as absolutely insufficient for planning of the experiments.

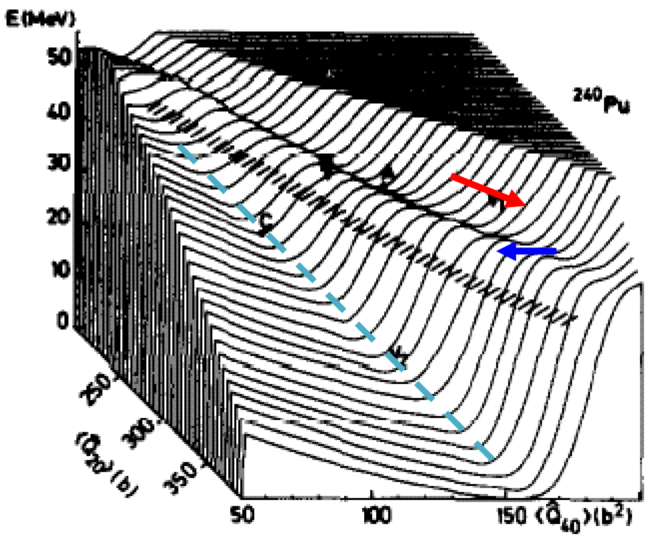
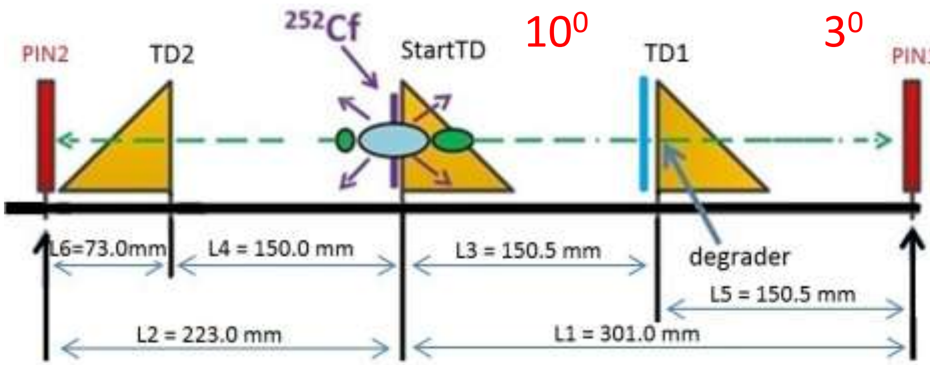


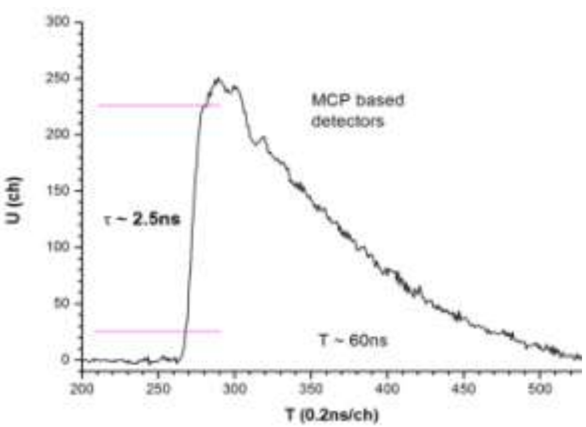
FIGURE 3
Potential energy surface of ^{240}Pu as a function of the elongation $\langle Q_{20}\rangle$ and necking-in $\langle Q_{40}\rangle$

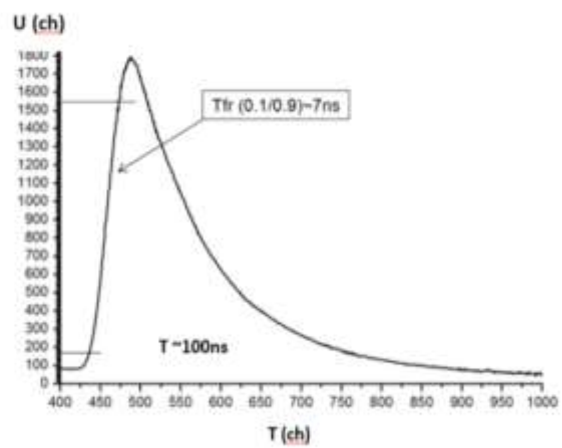
4. Thus, we have tried to verify the expectations followed from our previous experiments namely to detect two fragments hitting the same detector with known time-delay of about 12, 15ns

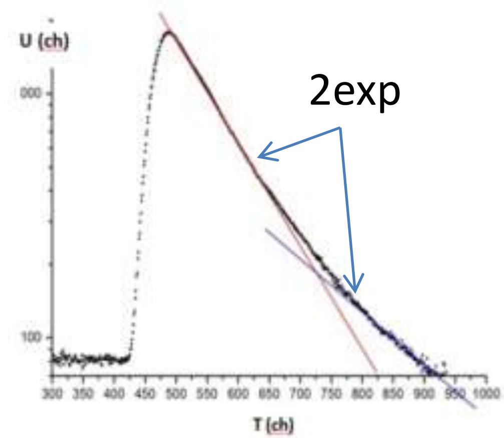
Experiments & results

LIS spectrometer in the flash-ADC mode, Exp1 -“long” signals

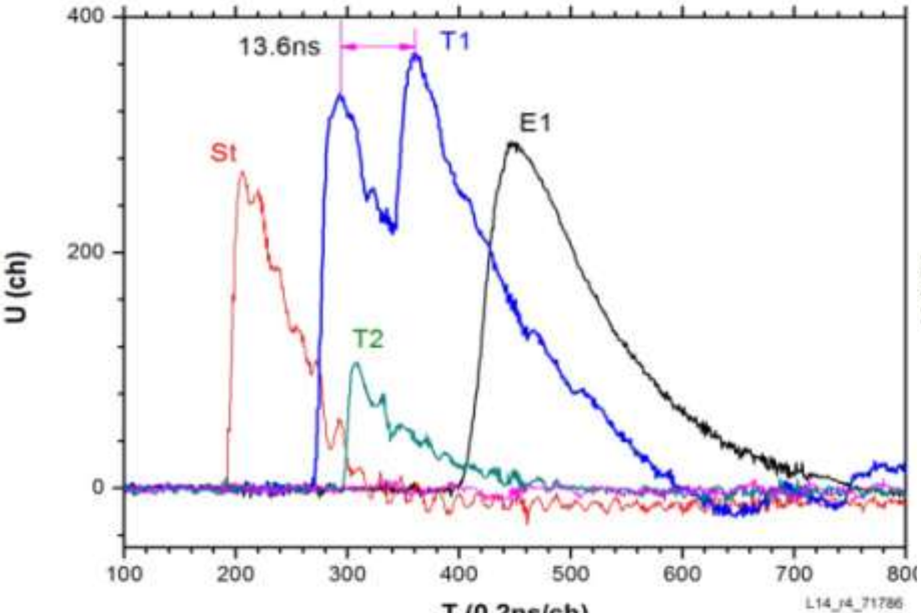


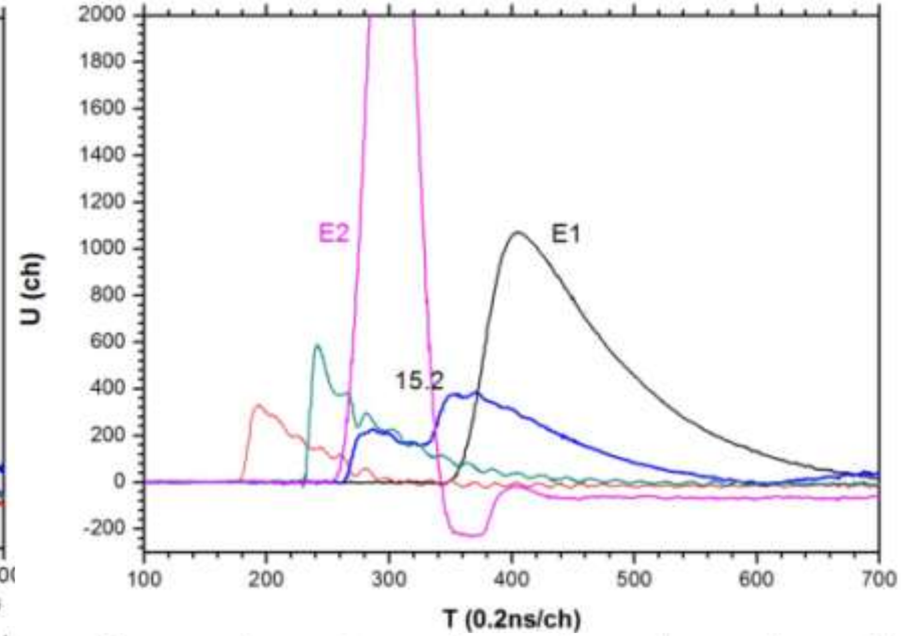


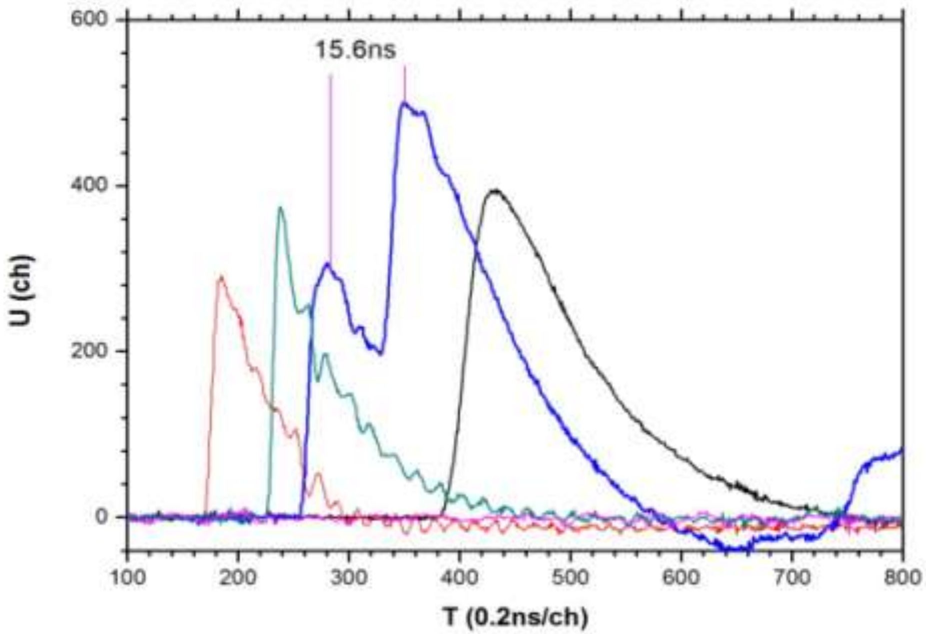


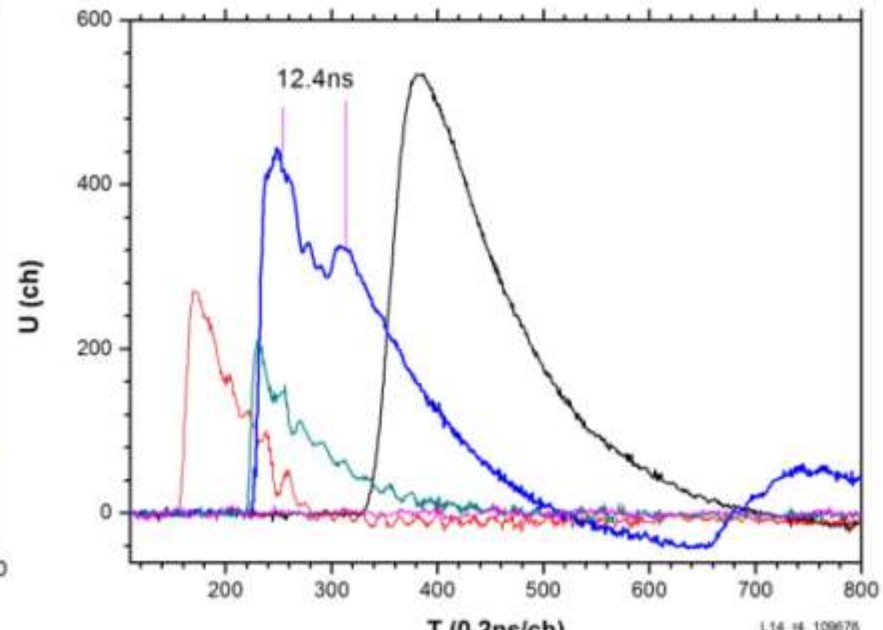


Typical double-hit events (Exp1 – “long” signals)

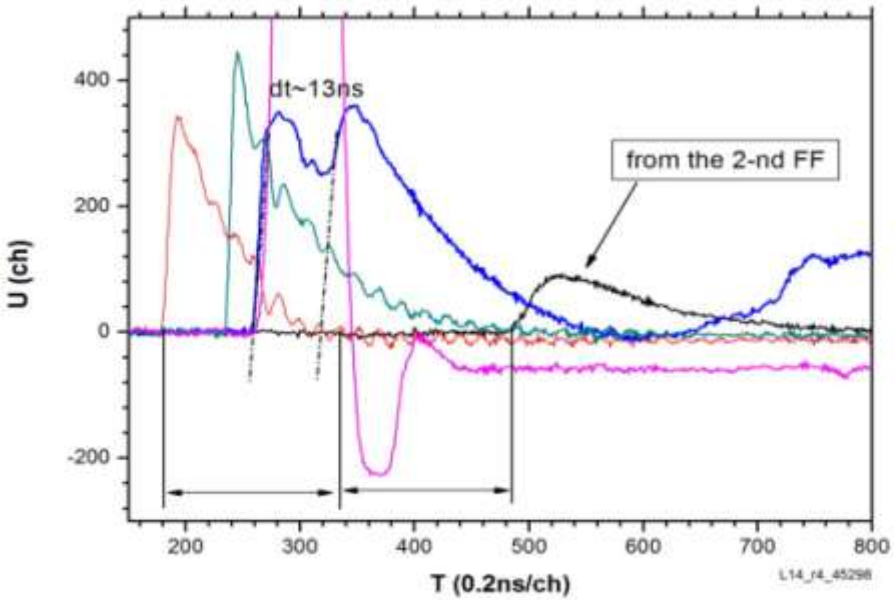


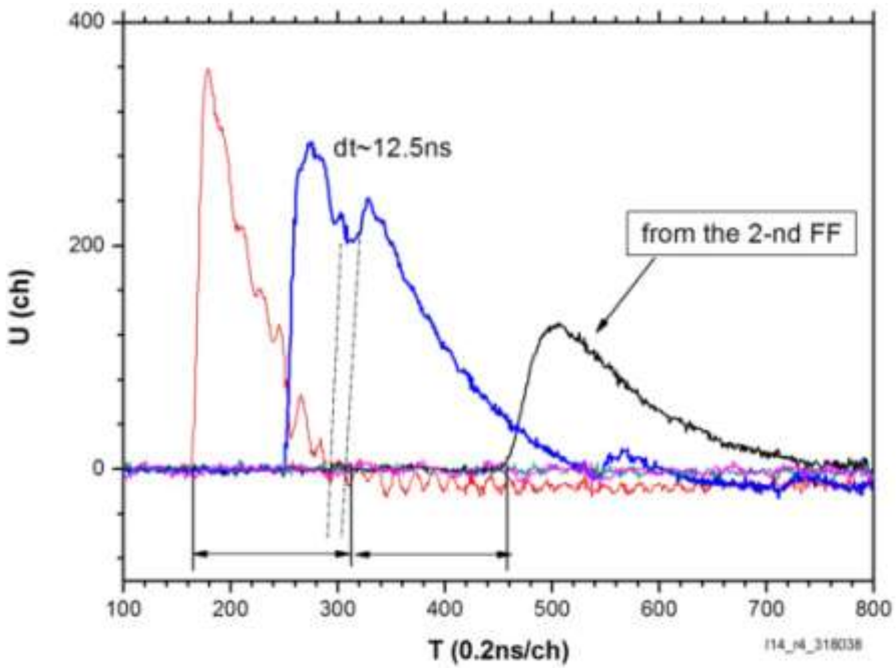




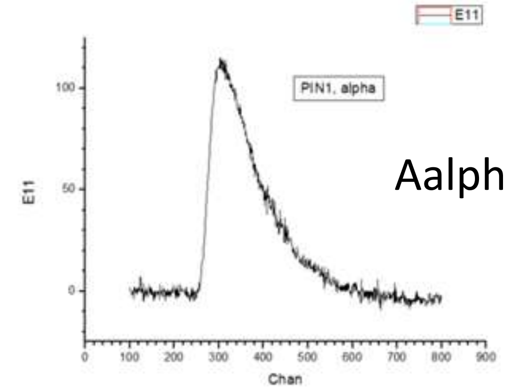


Exp1-unambiguous ternary events

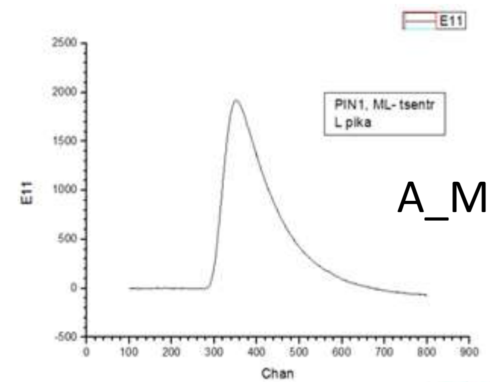




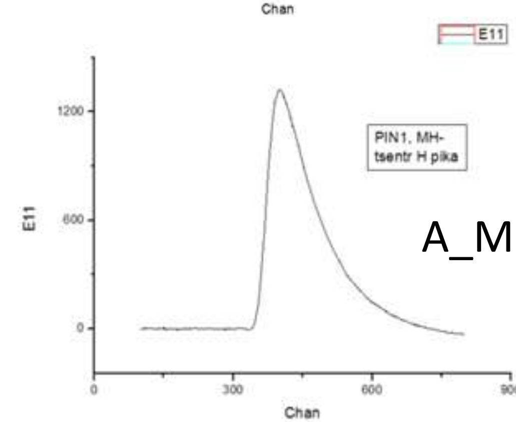
Typical signals in PIN-1



Aalpha~120ch

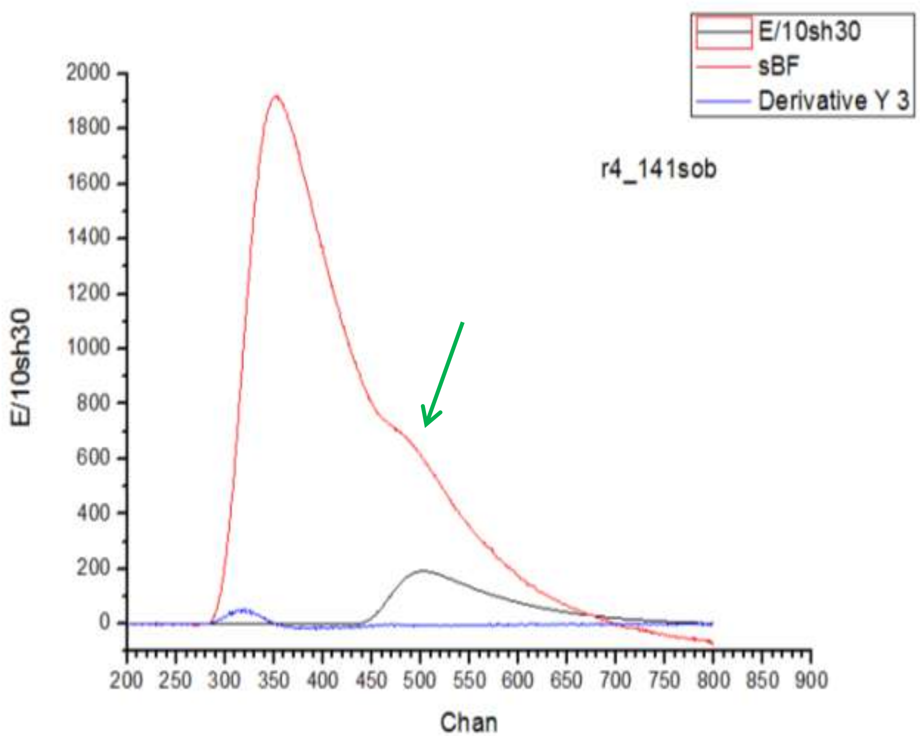


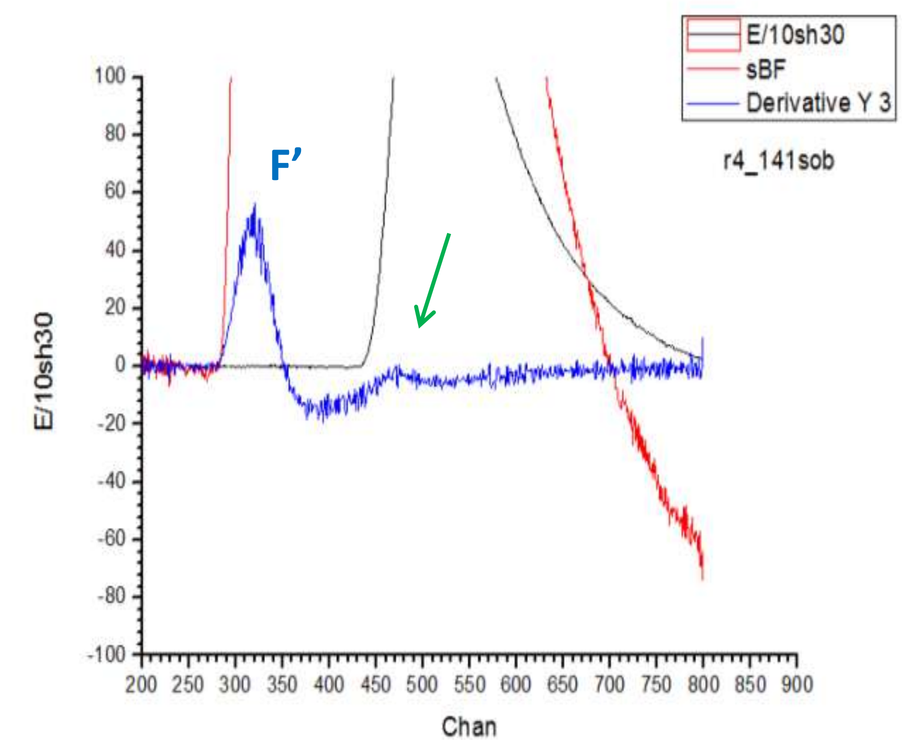
A_ML ~ 2000ch



A_MH ~ 1300ch

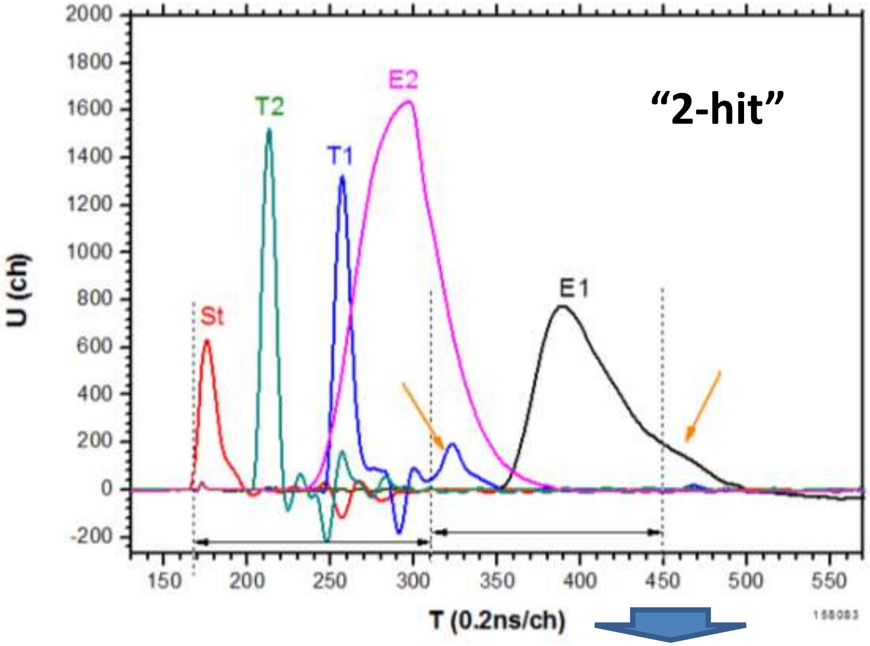
Modeling of the pile-up events in the PIN diode (Exp-1)

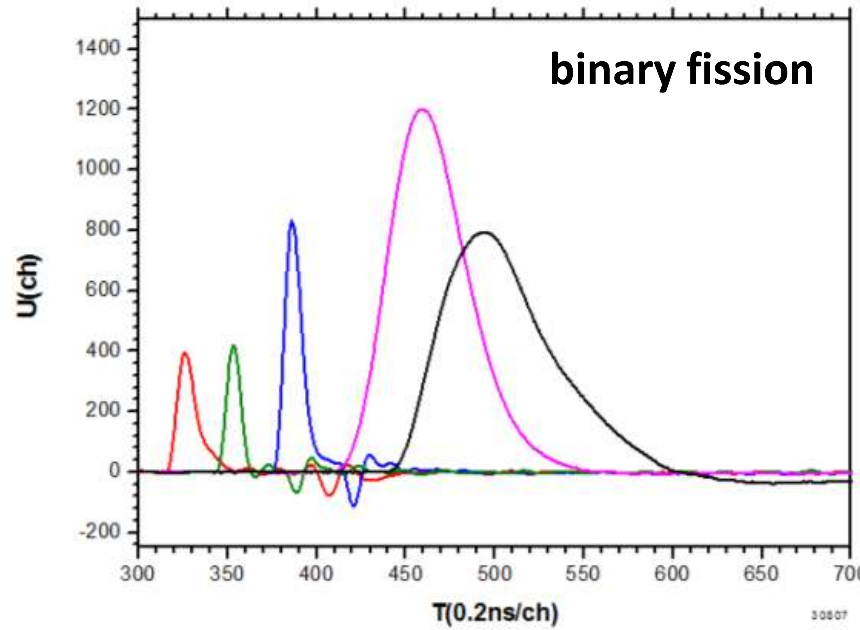


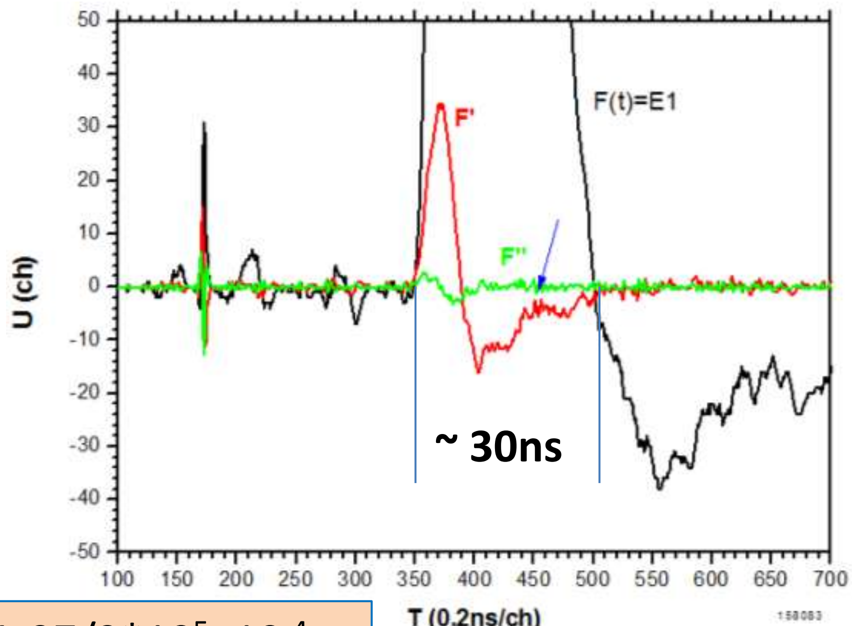


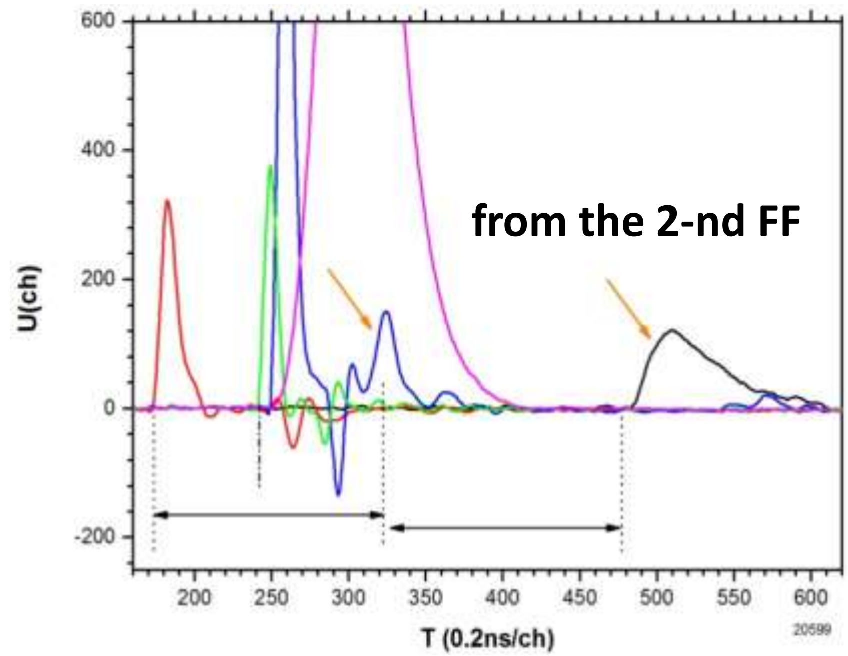
Threshold level for detecting of the pile-up FF approximately : **dTOF~ 30ns at A1/A2>10**

Typical double-hit events (Exp2 – “short” signals)









$Y=27/2*10^{5}\sim10^{-4}$

Conclusions

1. Approximately **sixty double-hit events** were detected by the timing MCP based detectors using fast flash-ADC.
2. Parameters of the events observed agree with the predictions based on our previous data (“Ni-bump”) treated as the results of ternary decays (CCT).

3. More detailed analysis of the double-hit events detected still in progress.
4. Unique experience has gained from sampling MCP and PIN signals with Fast Flash ADC. In particular the non-parametric approach to the time reference of PIN signal is developed – see our poster “Time-of-flight measurements using Si PIN diodes with the heavy ion beams”

Estimation of the possible background

<table>
<tr>
<td>
143Ba=2grad   27Al = 4grad
E=37.5MeV   E=42.5MeV
V=0.71   V=1.73
TOF15cm =21.12   TOF15cm =8.67
dTOF=12.45ns
-------- --------
106Mo=20   27Al = 30
E=37.6MeV   E=68.4MeV
V=0.82   V=2.2
TOF15cm =18.29   TOF15cm =6.8
dTOF=11.49ns
</td>
<td>
143Ba=10   16O = 30
E=51.1MeV   E=28.9MeV
V=0.83   V=1.86
TOF15cm =18   TOF15cm =8.06
dTOF=9.9ns
----- ------------
106Mo=10   16O = 30
E=57.8MeV   E=48.2MeV
V=1.024   V=2.4
TOF15cm =14.64   TOF15cm =6.25
dTOF=8.4ns
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</tr>
</table>