OBSERVATION OF FISSION ISOMERS AMONG FRAGMENTS OF SPONTANEOUS AND INDUCED FISSION OF HEAVY NUCLEI

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A.N. Solodov[1], V.E. Zhuchko[1], Z.I. Goryainova[1], O.V. Strekalovsky[1], E.A. Kuznetsova[1], A.O. Zhukova[1]

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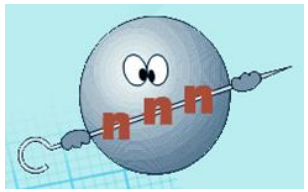
International support



ISINN 30

Our congratulations
and special thanks to the organizers:
for tracking progress of this study
from ISINN to ISINN

ISINN-10 - first neutron-gated data with FOBOS

ISINN-13 – proposal for the exp @ IBR-2
ISINN-14 – status of the exp in the cave 6b
ISINN-15 – preliminary results
ISINN-16 – detailed report

miniFOBOS @IBR-2

ISINN-17 – triple correlations from ^{232}Th+d
ISINN-18 – COMETA progress report (posters)
ISINN-19 – first & interesting COMETA data
ISINN-20 – first CCT physics & Ion Guide proposal

COMETA ^{252}Cf

ISINN-21 – first indications of shape isomers in FF
ISINN-22 – new results on shape isomers in wide range
ISINN-23 – first “flash”-data
ISINN-25 – understanding the results and feeding theoretical discussion

SIS strong indication

ISINN-26
ISINN-27
ISINN-28
ISINN-29

True quaternary fission
Shape isomer study progress
Physics models
VEGA first steps

Photo-fission studies

An inspiration for the study of Collinear Cluster Tripartition

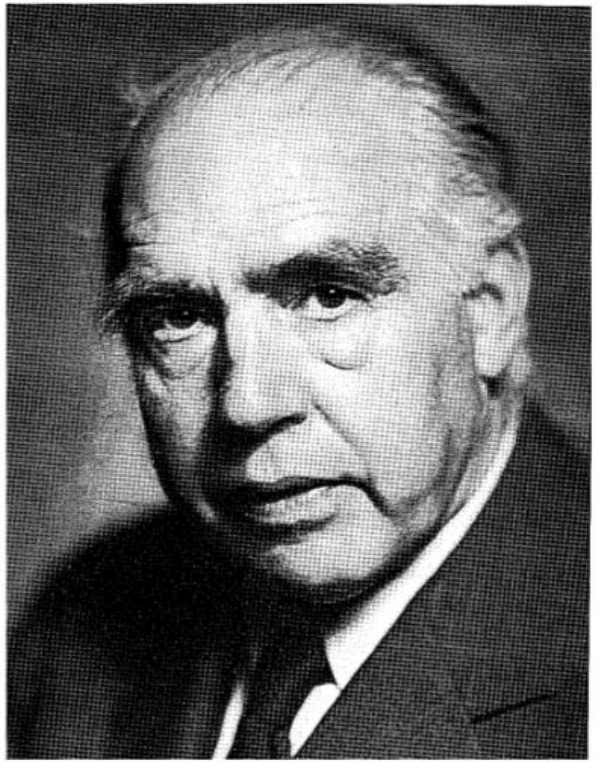


Fig. 3. Niels Bohr

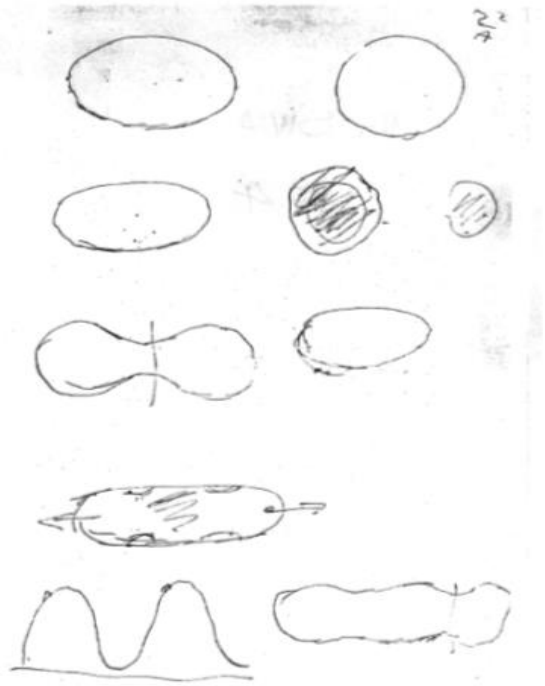
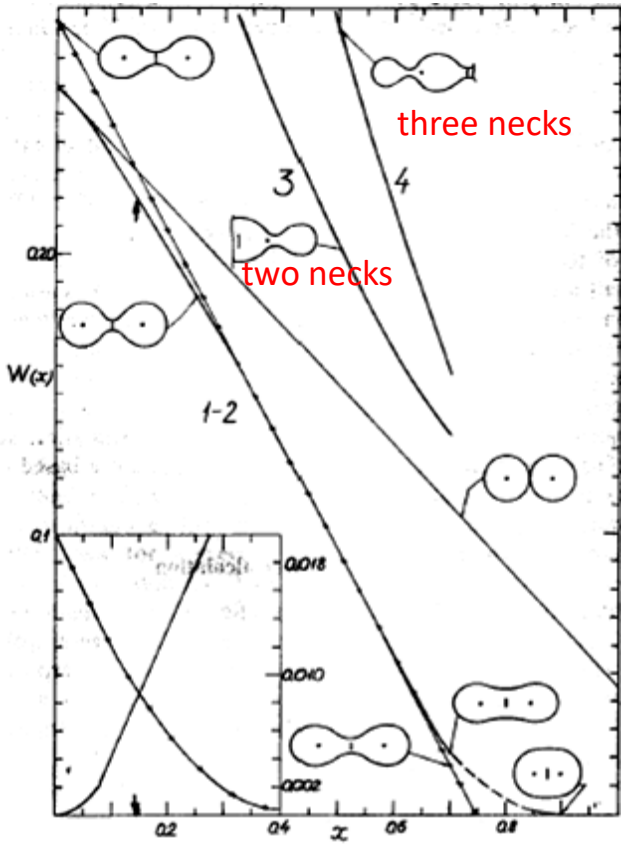


Fig. 4. Bohr's notes, 7^{th} October 1950, his 65^{th} birthday.

…what if the strong electric repulsion would stretch out the post-saddle shape into a sufficiently long cylinder that would actually prefer to divide into three rather than two pieces? This would not be unexpected, because for Uranium the energy released in a division into three equal fragments is actually greater than into two.

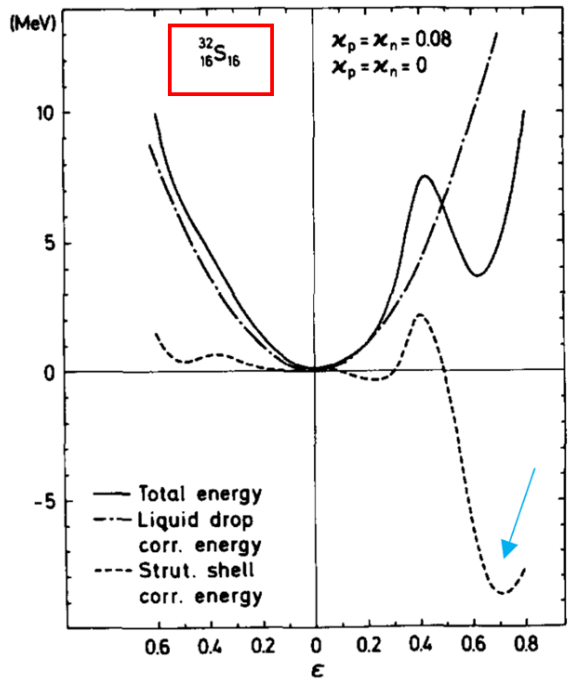
SYMMETRICAL SHAPES OF EQUILIBRIUM FOR A LIQUID DROP MODEL

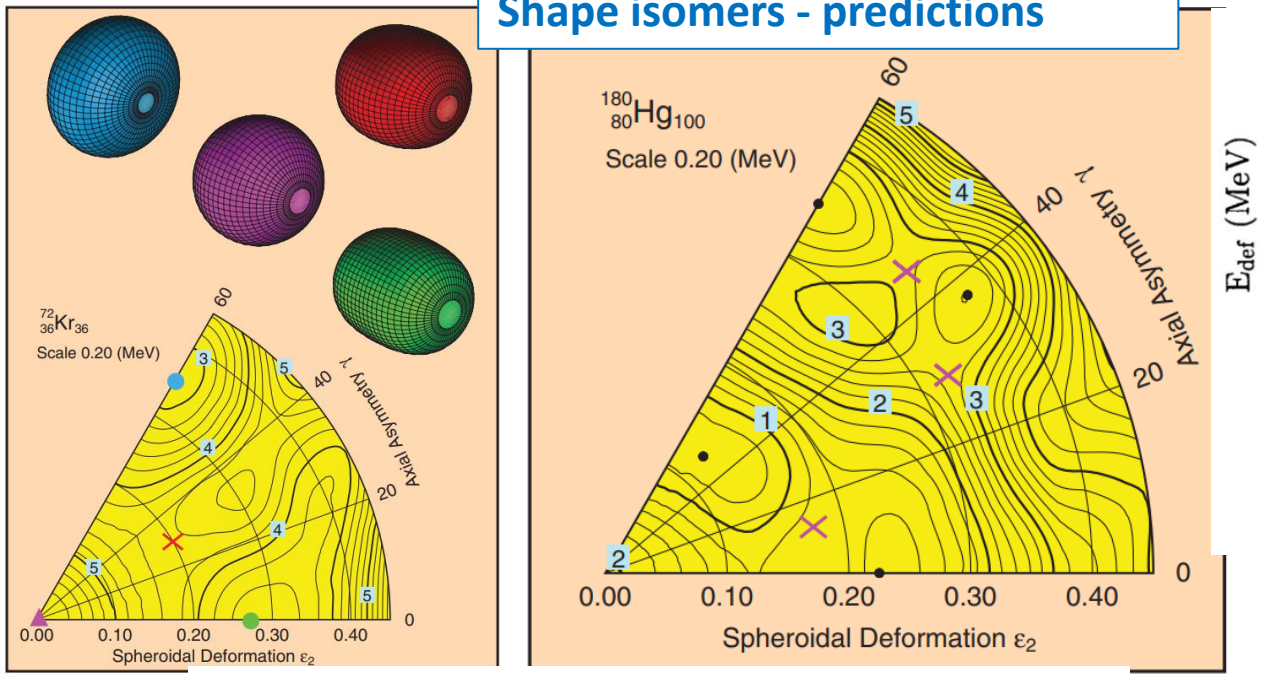
V.M. STRUTINSKY, N.Ya. LYASHCHENKO and N.A. POPOV

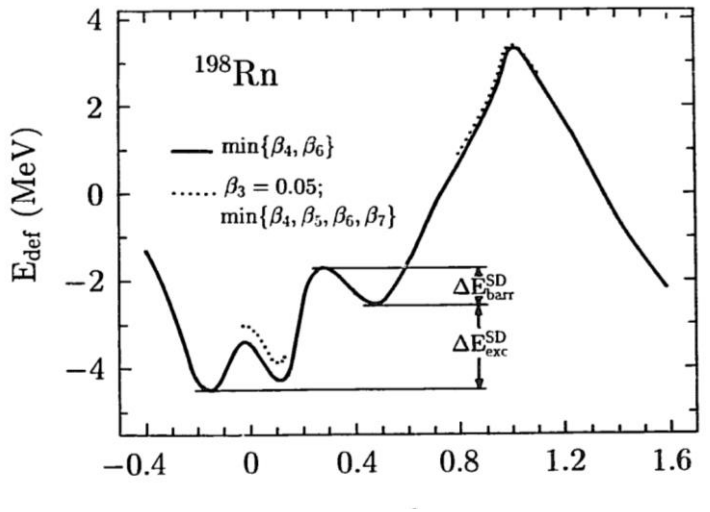


Nucl. Phys. **46** (1963) 639

Shape isomers - predictions







Volume 41B, number 2 PHYSICS LETTERS 18 September 1972

PRL 103, 212501 (2009) PHYSICAL REVIEW LETTERS week ending 20 NOVEMBER 2009

Nuclear Physics A529 (1991) 289–314
North-Holland

STRUCTURE OF SUPERDEFORMED STATES IN Au–Ra NUCLEI

W. SATUŁA[a,b], S. ĆWIOK[c], W. NAZAREWICZ[b,c], R. WYSS[a,d] and A. JOHNSON[a]

SHELL STRUCTURE FOR DEFORMED NUCLEAR SHAPES

R. K. SHELINE *, I. RAGNARSSON and S.G. NILSSON
Department of Mathematical Physics, Lund Institute of Technology, Lund, Sweden

When one of these additional minima is sufficiently deep, then the nucleus may exist in a state corresponding to the energy and shape of this minimum; this state is a shape isomer. The lifetime of the shape isomer will depend on the overlap between the nuclear wavefunctions of the shape isomer and the ground state, the excitation energy of the shape isomer, and the height of the saddle separating the shape isomer and the ground state.

Thus, the existence of numerous shape isomer states even in the same isotope are predicted in the wide range of nuclei from very light one as ^{32}S up to super-heavy.

Global Calculation of Nuclear Shape Isomers

Peter Möller,[1,*] Arnold J. Sierk,[1] Ragnar Bengtsson,[2] Hiroyuki Sagawa,[3] and Takatoshi Ichikawa[4,†]

Atomic Data and Nuclear Data Tables 98 (2012) 149–300

Contents lists available at SciVerse ScienceDirect

Atomic Data and Nuclear Data Tables

journal homepage: www.elsevier.com/locate/adt

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Nuclear shape isomers

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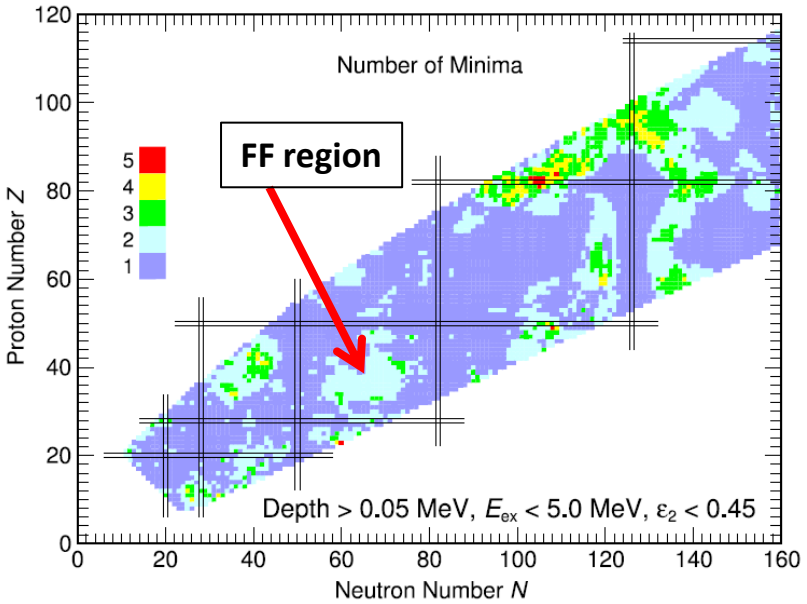
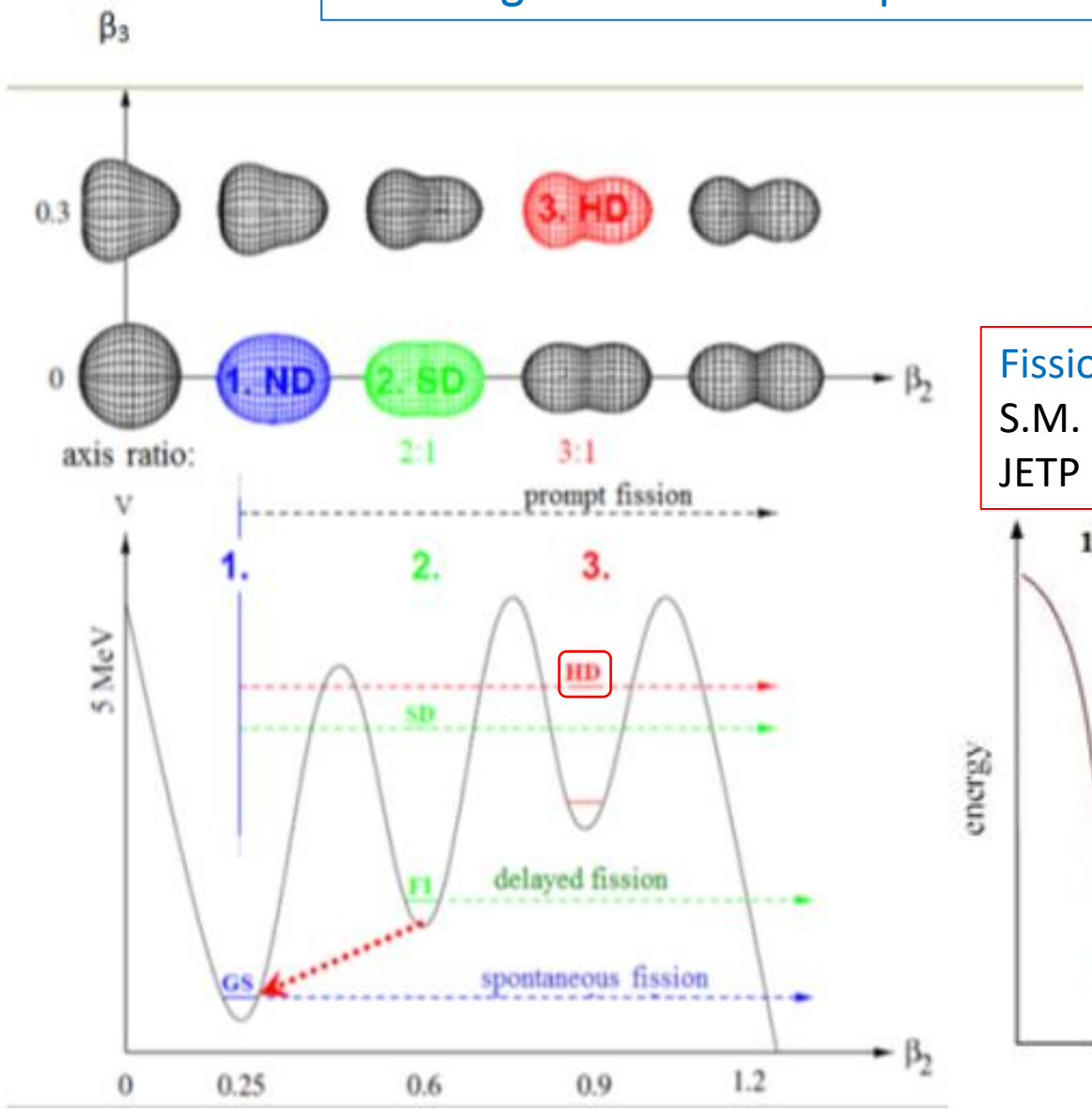
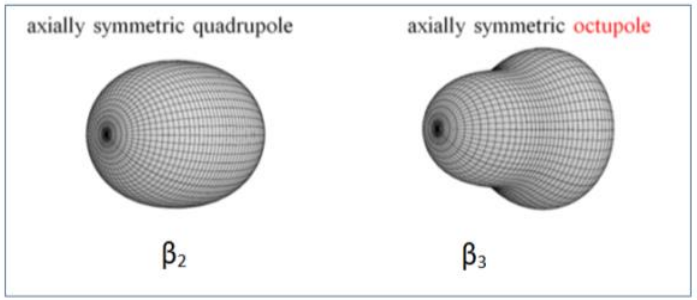
[a] Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, United States
[b] Department of Mathematical Physics, Lund Institute of Technology, P.O. Box 118, SE-22100 Lund, Sweden
[c] Center for Mathematical Sciences, University of Aizu, Aizu-Wakamatsu, Fukushima 965-80, Japan
[d] Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

We calculate potential-energy surfaces as functions of spheroidal (ϵ2), hexadecapole (ϵ4), and axial asymmetry (γ) shape coordinates for 7206 nuclei from A = 31 to A = 290. We tabulate the deformations and energies of all minima deeper than 0.2 MeV and of the saddles between all pairs of minima. The tabulation is terminated at N = 160....
We also present potential-energy contour plots versus ϵ2 and γ for 1224 even–even nuclei in the region studied. We can identify nuclei for which a necessary condition for shape isomers occurs, namely multiple minima in the calculated potential-energy surface.



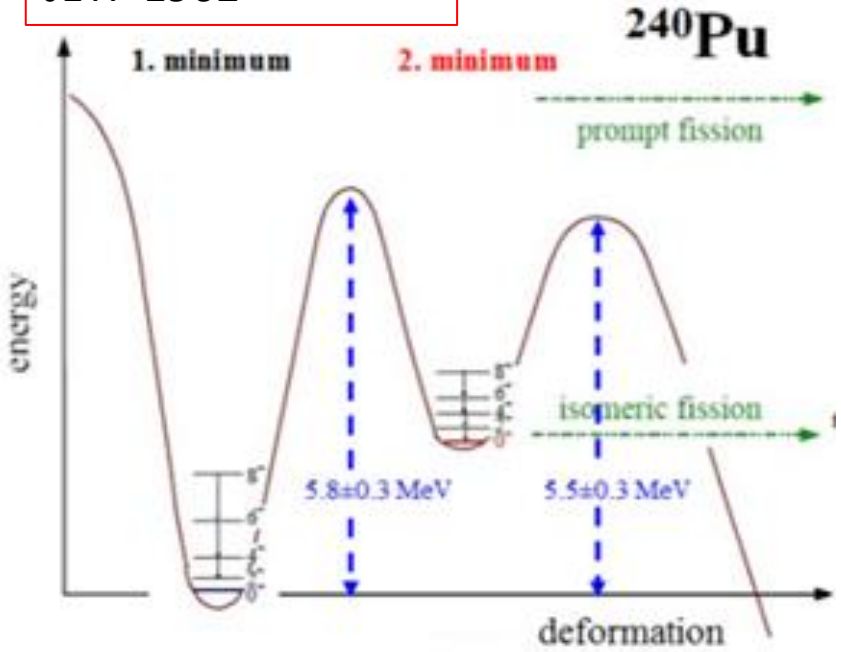
Next stage in studies of shape isomers : fission isomers



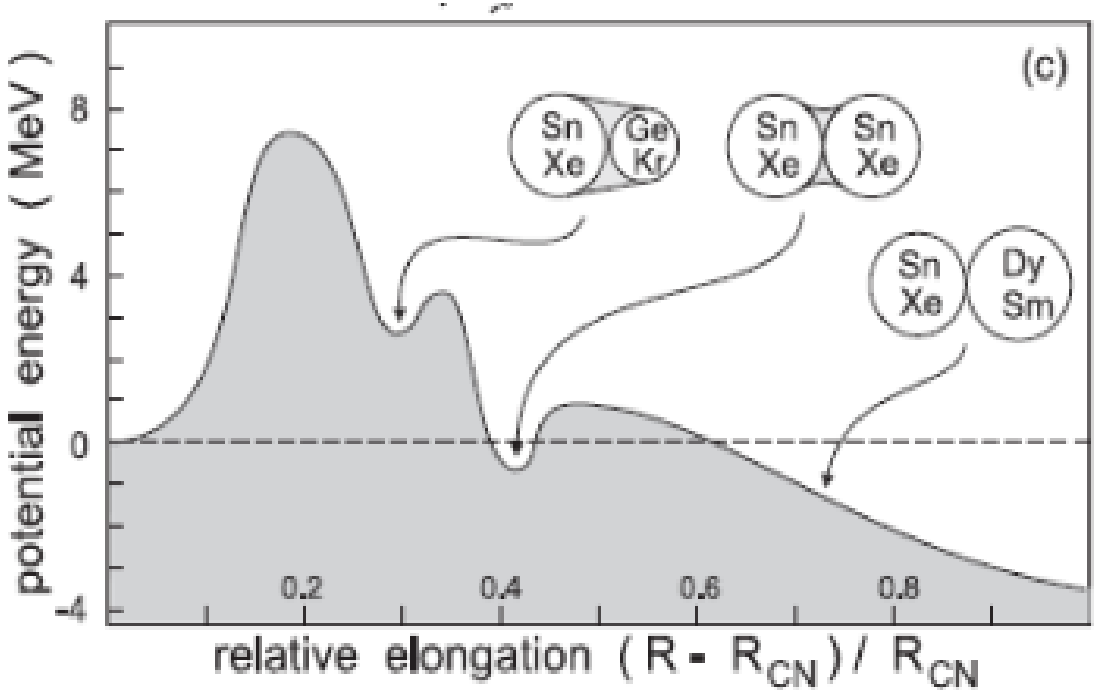


Fission isomers
S.M. Polikanov
JETP 1962

Discovered in
FLNR (JINR)



Shape Isomeric States in Super-Heavy Nuclei



Three-humped barrier calculated along the fission path of $^{296}_{116}$Lv (Livermorium).

"These intermediate minima correspond to the shape isomer states. From analysis of the driving potential we may definitely conclude that these isomeric states are nothing else but the two-cluster configurations with magic or semi-magic cores surrounded with a certain amount of shared nucleons."

V. ZAGREBAEV, W. GREINER

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

Are there fission isomers in the mass range of fission fragments?

Our experimental approach: measurement of each fragment mass independently

Peculiarities of E and TOF in PIN-diods

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

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

PHD:

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

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

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

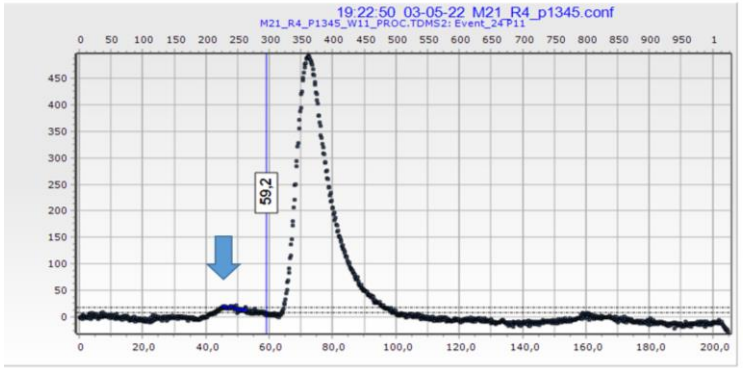
$$G = \frac{MV^2}{k} - [E_{det} + \frac{\lambda \cdot \frac{MV^2}{k}}{1+\varphi \cdot \frac{V^2}{Mk}} + \alpha \cdot \frac{M^2V^2}{k} + \beta \cdot \frac{MV^2}{k}] = 0,$$

where $k = 1.9297$.

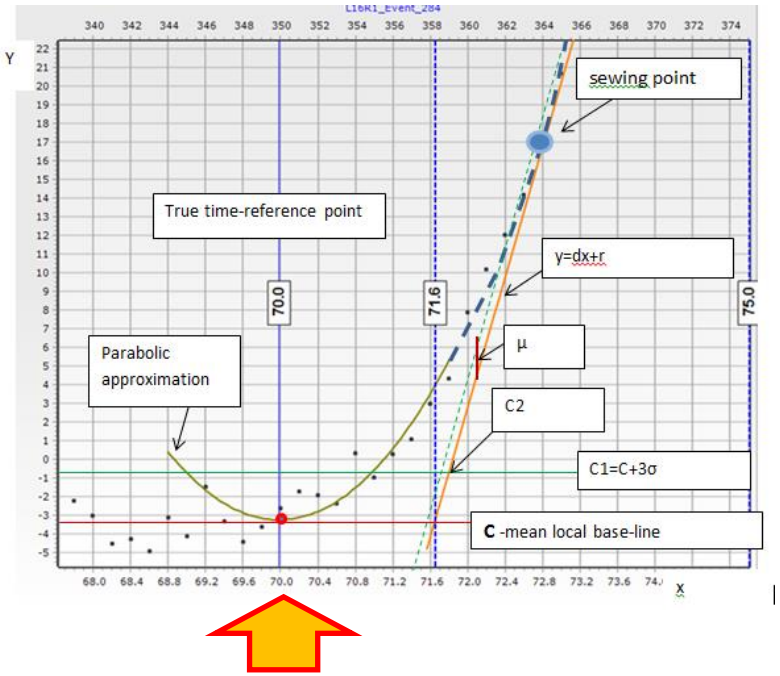
$$\min \quad F = [(< ML_T > - < ML >)^2 + (< MH_T > - < MH >)^2] + \mu \sum_{M_{TE}} \frac{(Y(M_{TE}) - Y_T(M_{TE}))^2}{Y(M_{TE})}$$

PD: $\Delta t_p = \gamma \frac{M^{1/6} E^{1/2}}{F}$ (used conventionally

CAEN DT5742



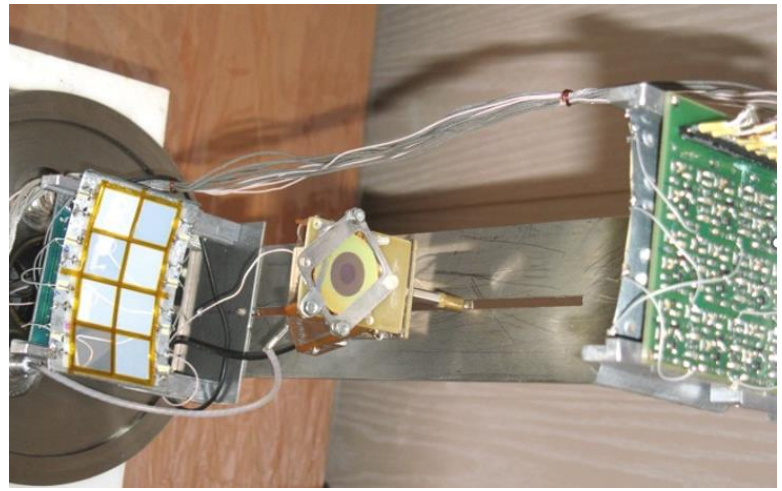
Inspection of the base-line fluctuations as a parameter for the events selection



Our know-how: true time reference point

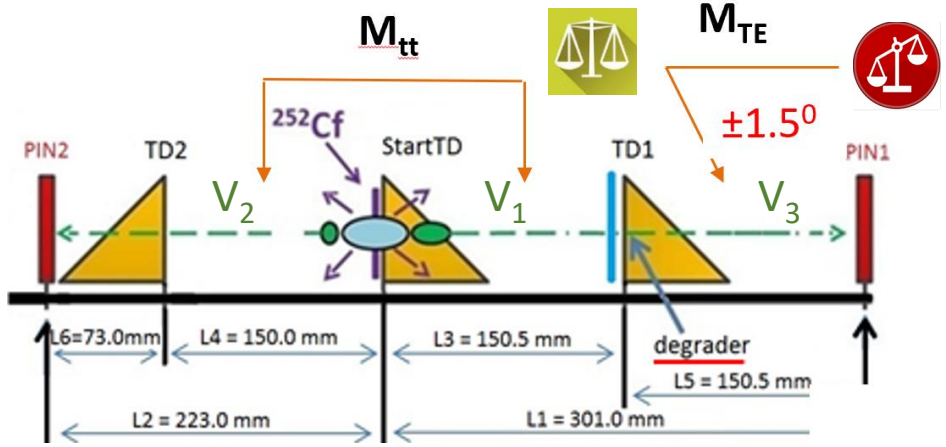
Digital image of the pulse **0.2ns/ch**

COMETA
(COrrelation **M**osaic **E-T A**rray)



- Mosaics of PIN and MCP
- Event by event processing of correlated masses
- Mass of each fragment from V&E
- Using of thick materials
- Pile-up and base line controlled

Strong indication of the shape-isomer state in FF



Kinematical selection of the cold events-Yiso~10^{-3}/bin fiss

$\tau_{life} > 15$ns

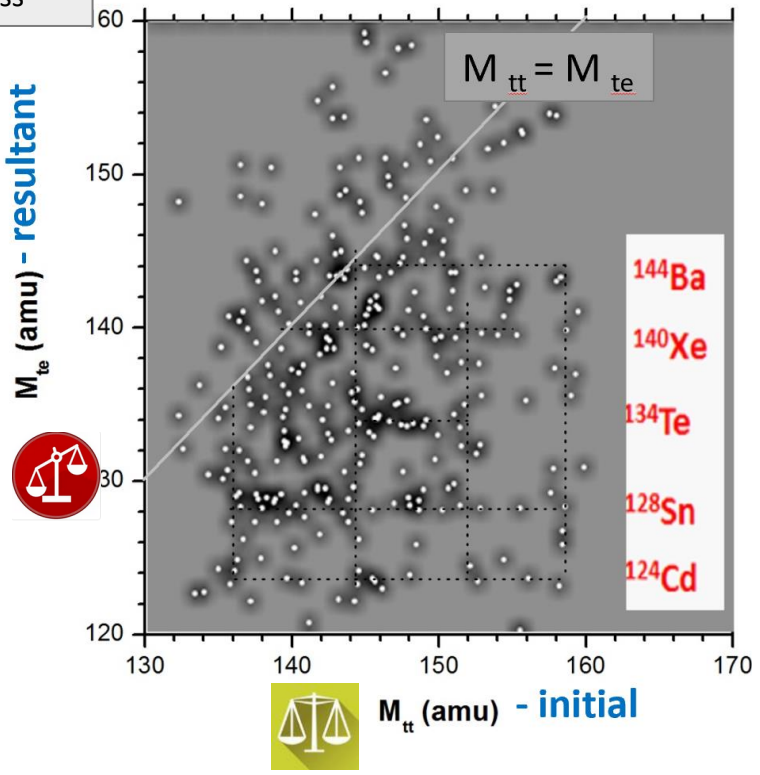
Double scaling of each fragment event by event

$M_{tt} = Mc/(1+V_1/V_2)$

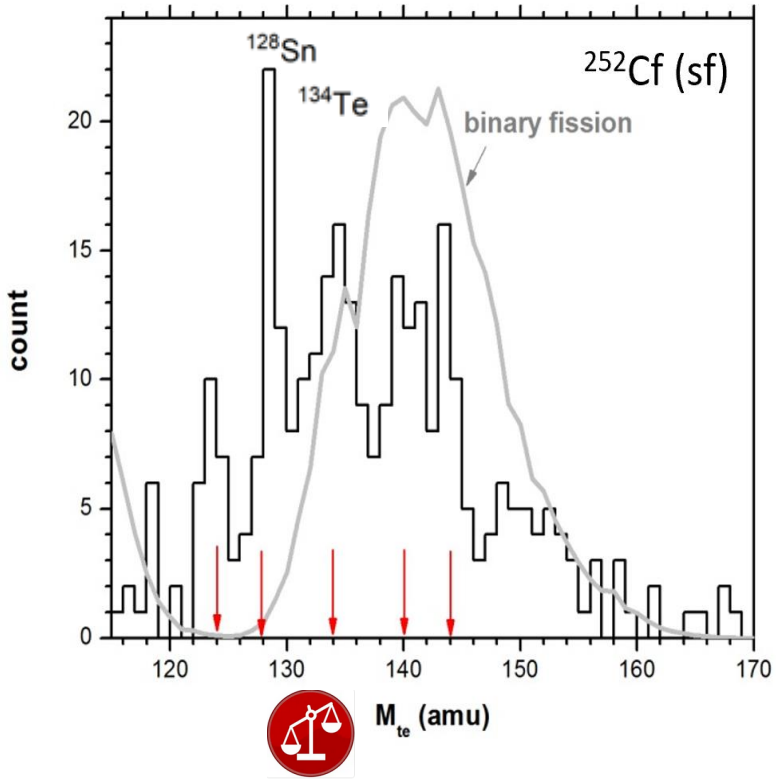
"initial" FF mass right after fission

$M_{TE}=2E/(V_3^2)$

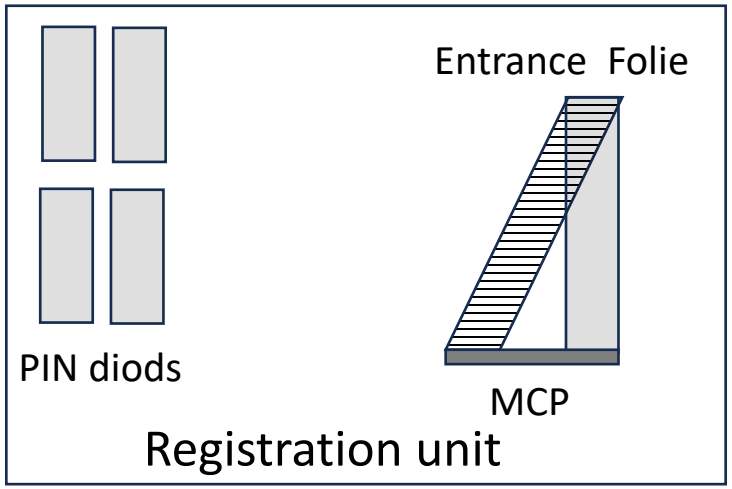
"resultant" FF mass in detector

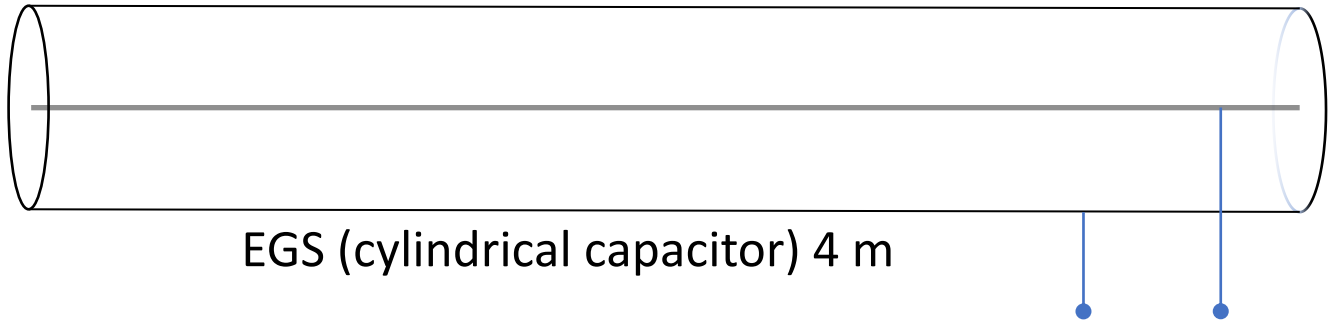


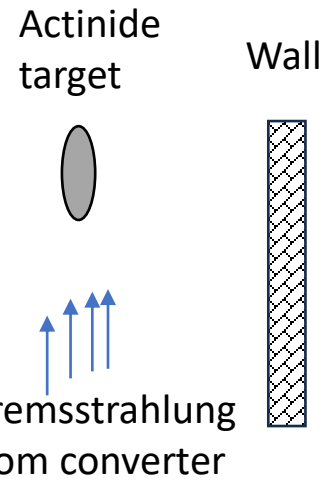
A "double-core system" revealed with a magic constituent

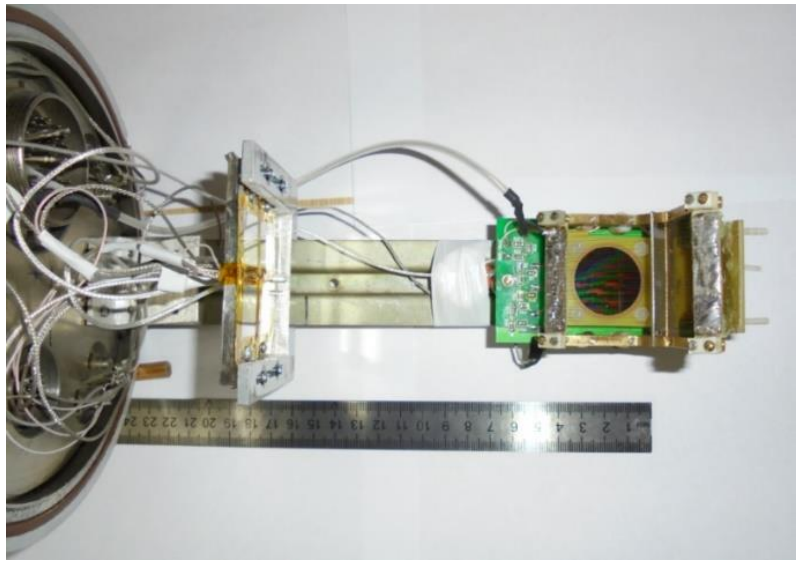


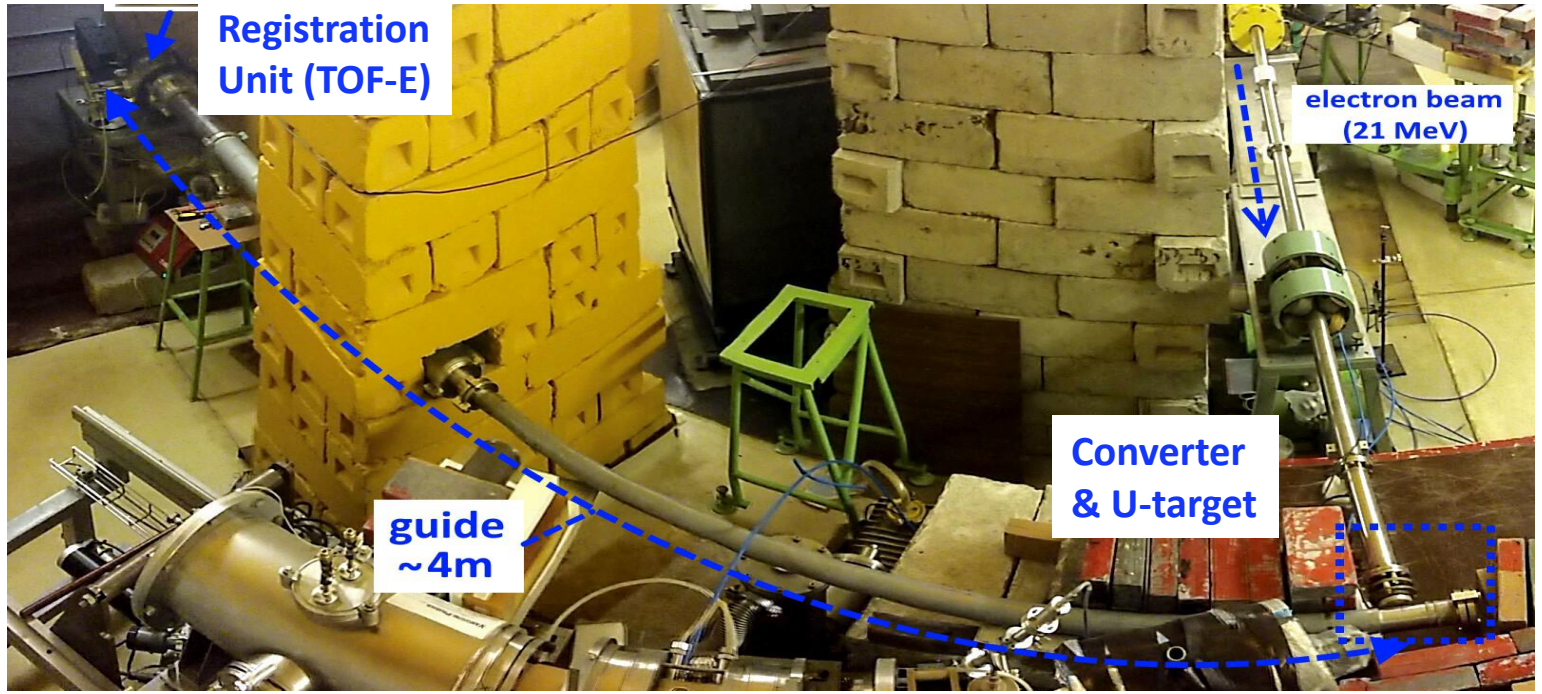
VEGA (V-E Guide based Array) at the electron beam of the MT-25 microtron in FLNR



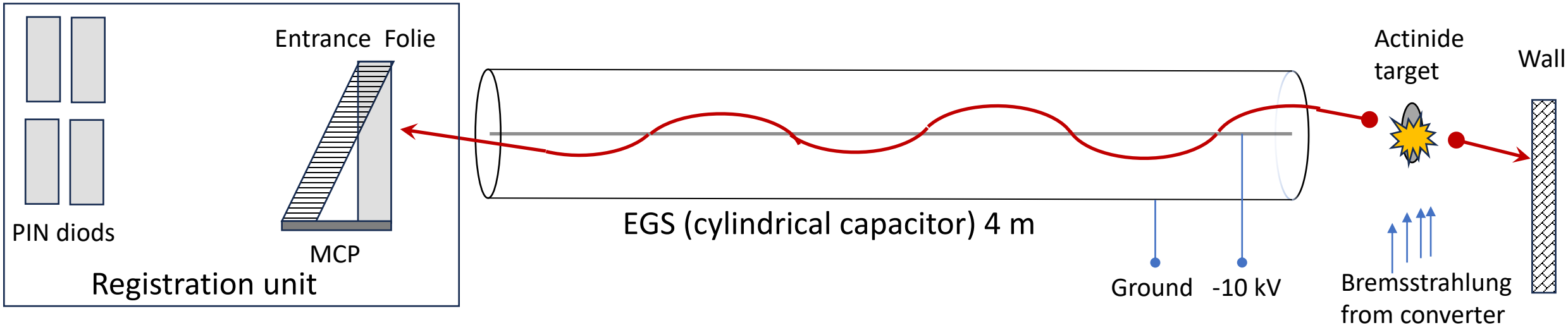


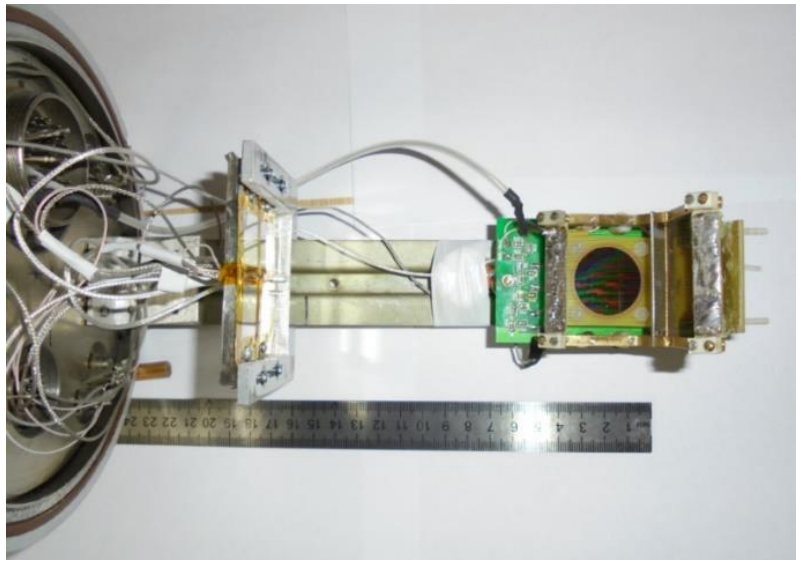


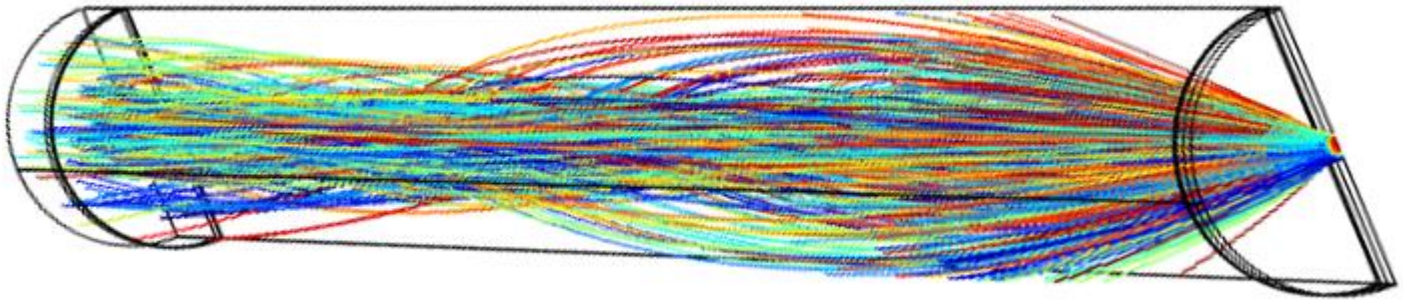




VEGA (V-E Guide based Array) at the electron beam of the MT-25 microtron in FLNR

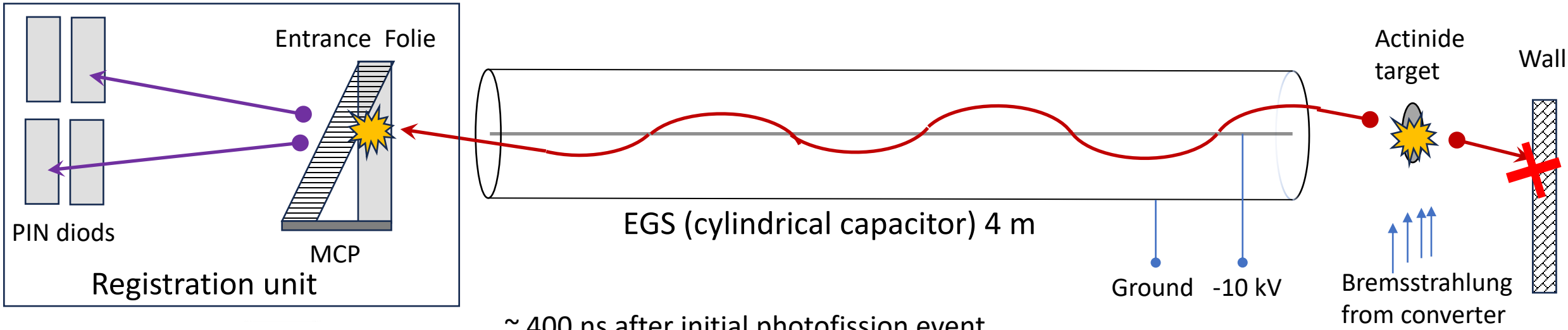




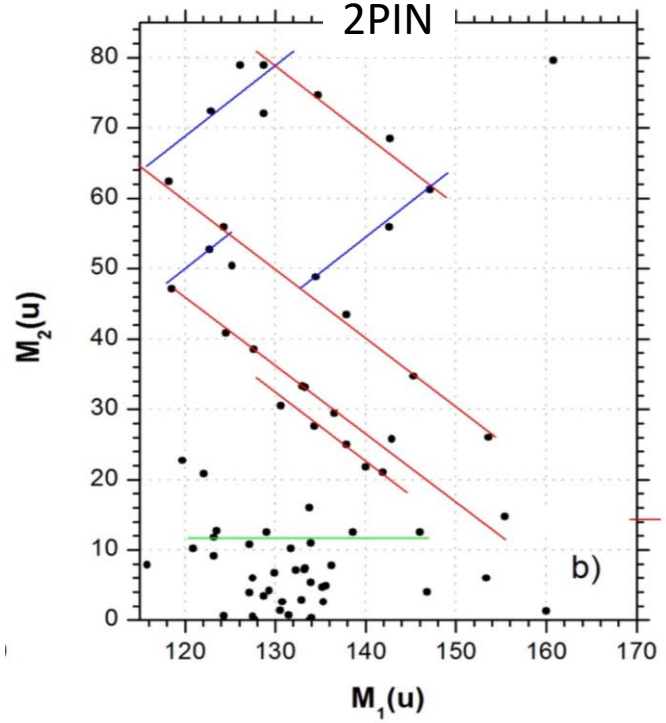


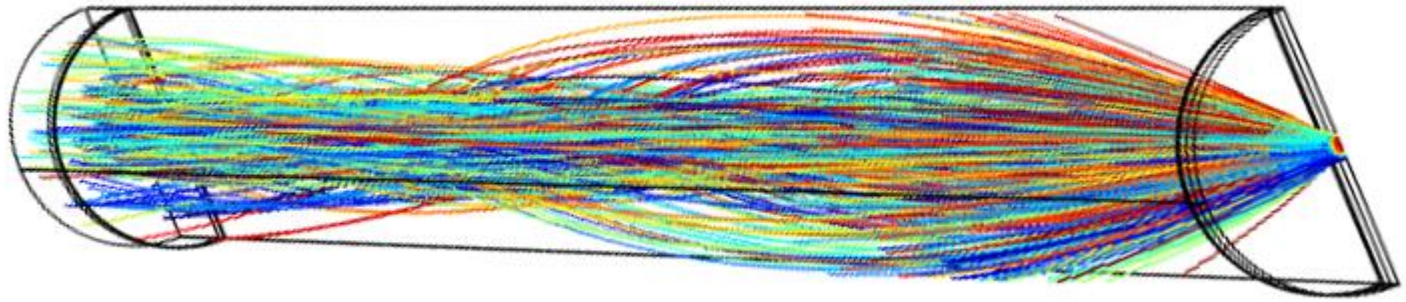
Modelling of the trajectories for fission fragments
Capturing angle is ~1°

VEGA (V-E Guide based Array) at the electron beam of the MT-25 microtron in FLNR



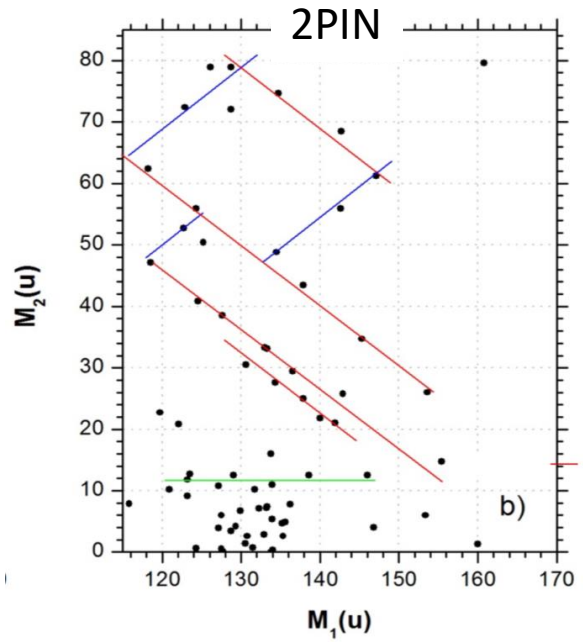
~ 400 ns after initial photofission event





Modelling of the trajectories for fission fragments
Capturing angle is ~1°

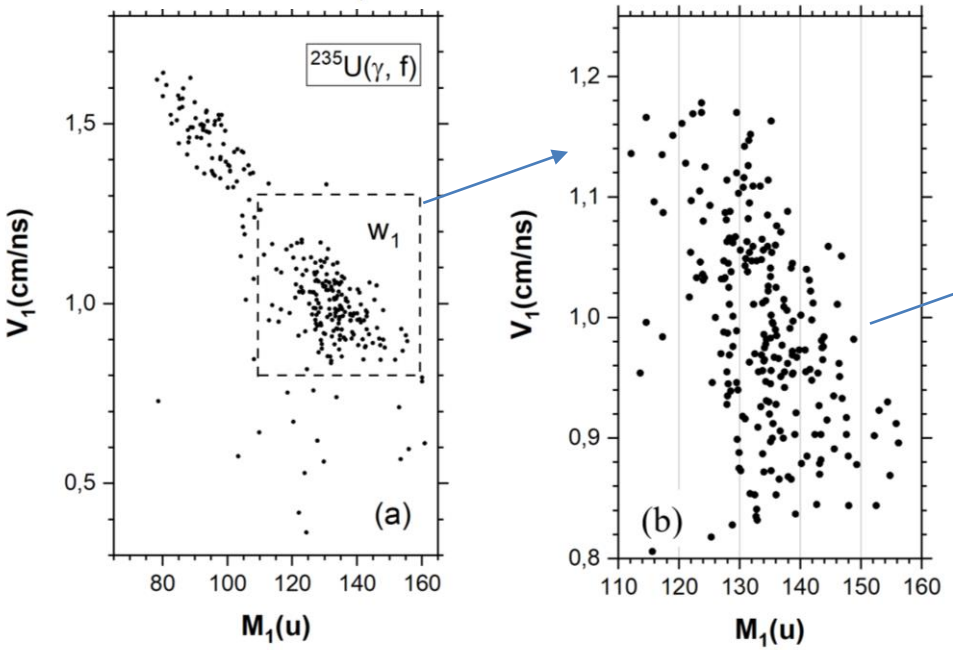
Tin and Tellurium "fingers" in the fragment mass spectra of ^{235}U(γ, f)

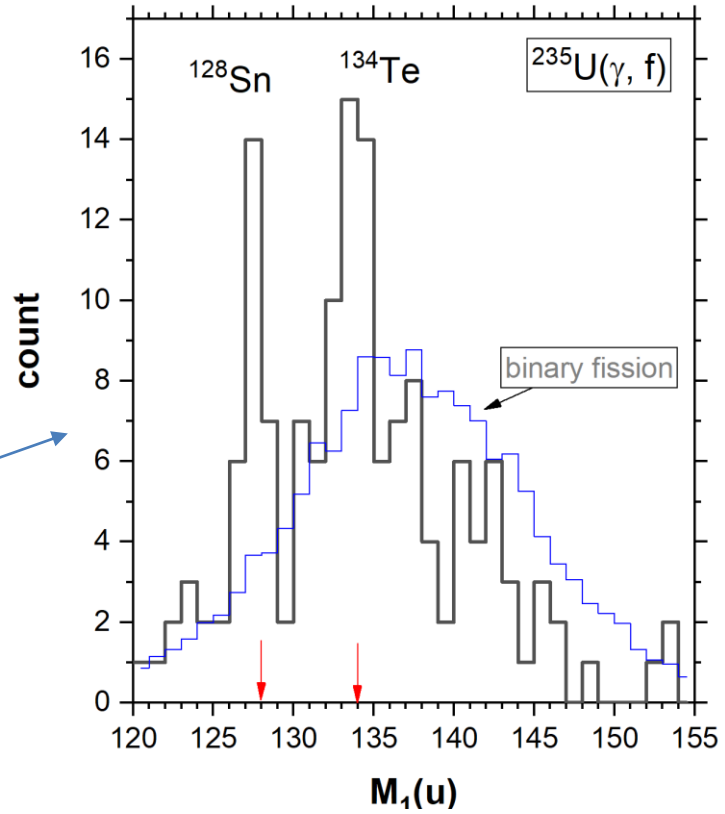


Similar result of the break-up of heavy FFs of two different mother systems in two different foils were observed: magic nuclei of ^{128}Sn and ^{134}Te demonstrate themselves as the cores of the deformed heavy fission fragments being in the shape isomer states.

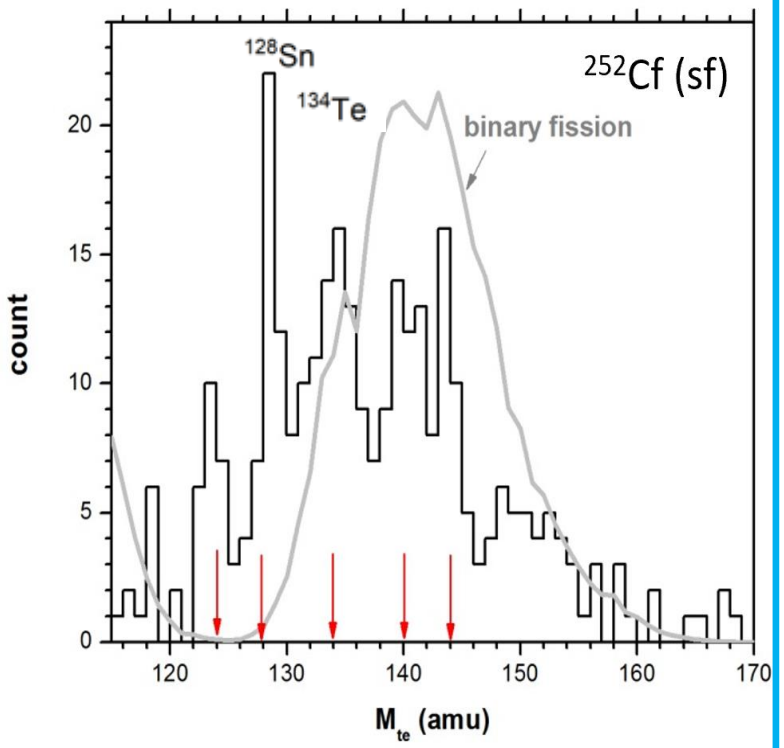
Decay after 400 cm drift in EGS

τ_{life} > 400ns



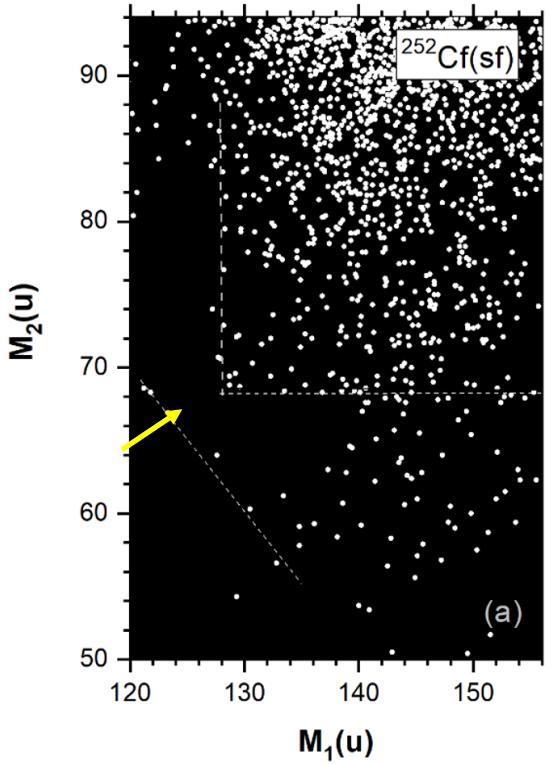


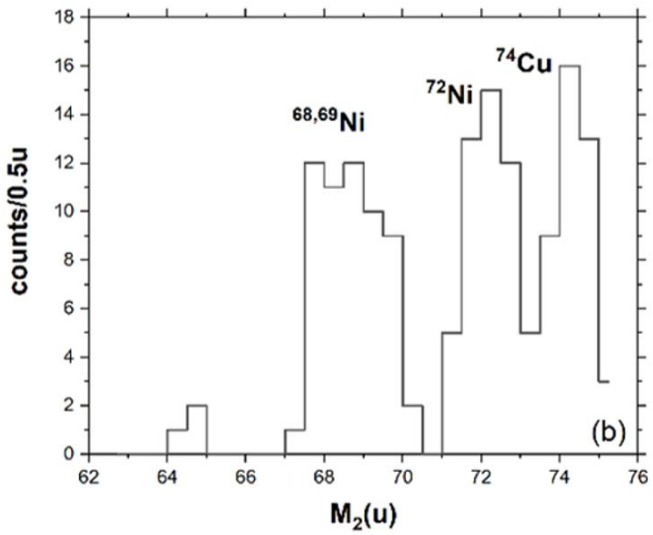
^{252}Cf (sf) to compare



Long lived history: CCT → fission isomers. The same physics.

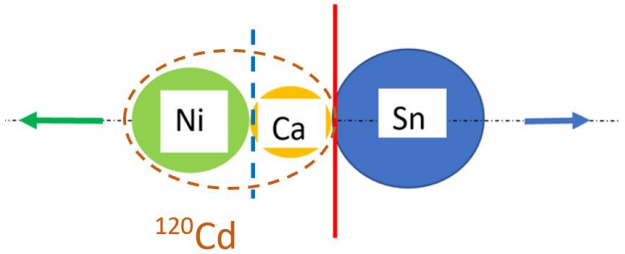
COMETA



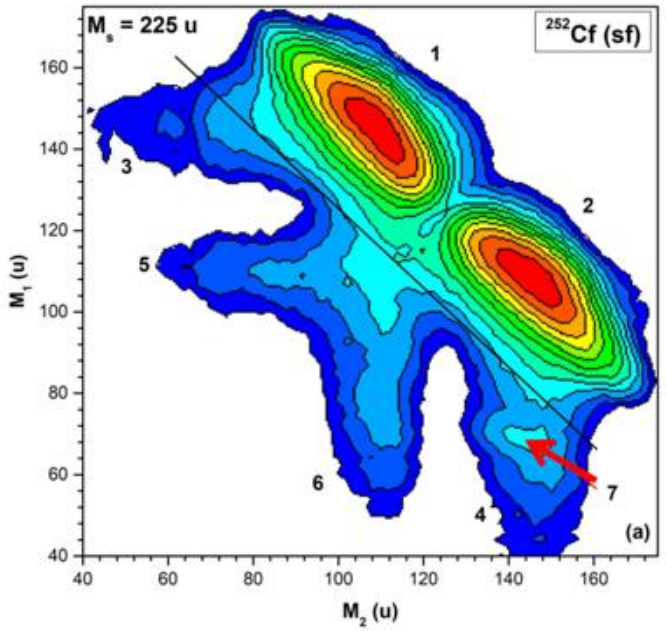


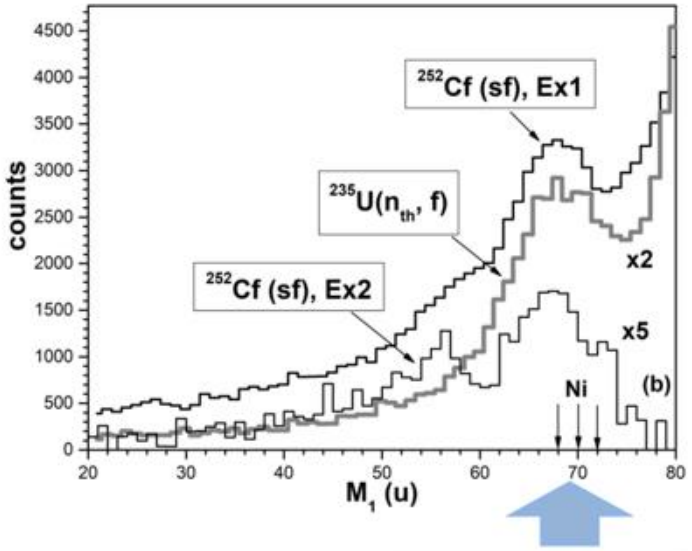
"rhombic meander"
M_1+M_2=const
M_1-M_2=const

Ni & **Sn** FFs were really detected in the **opposite arms** due to the **break-up** of the **light** FF in the backing



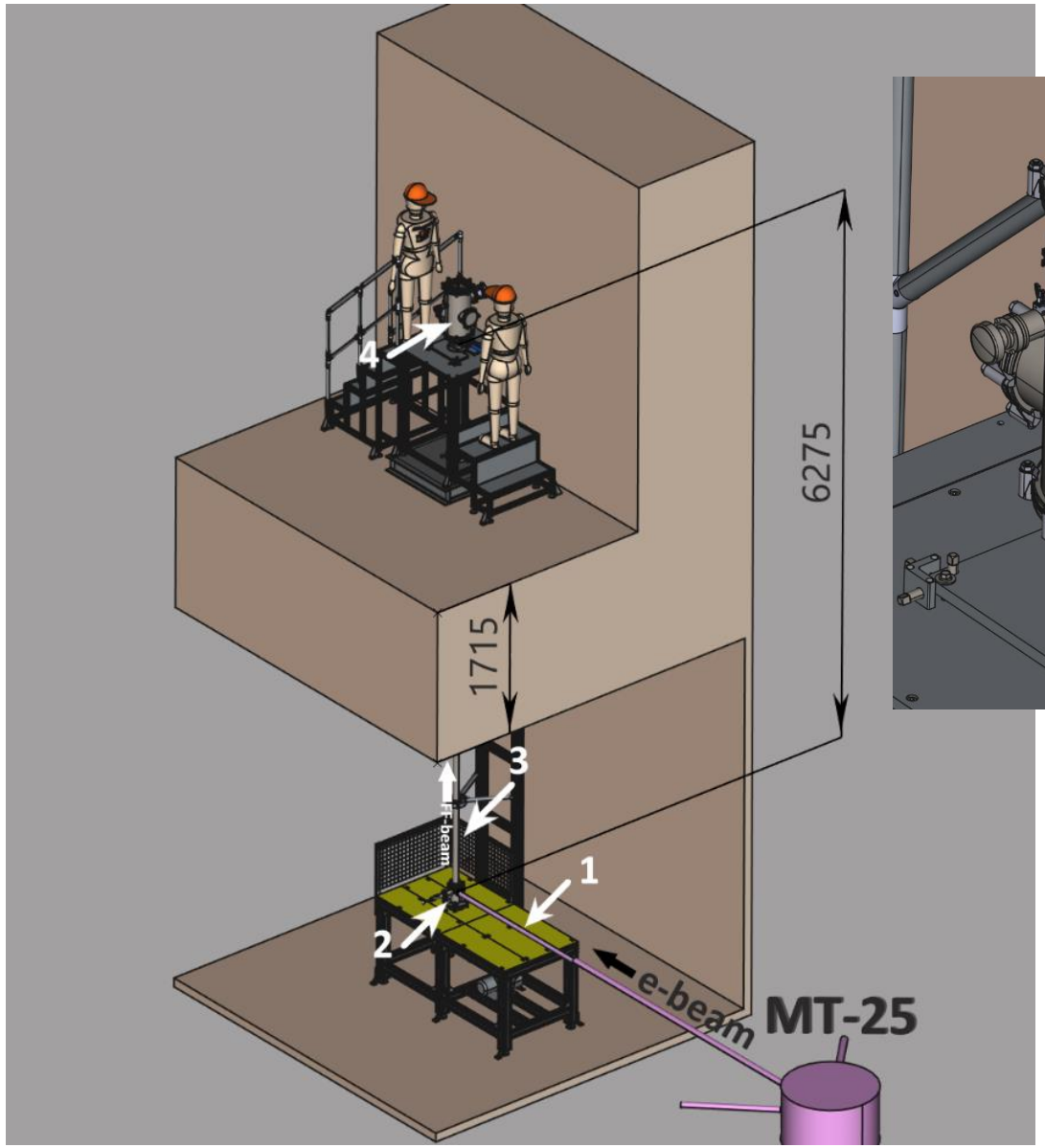
FOBOS

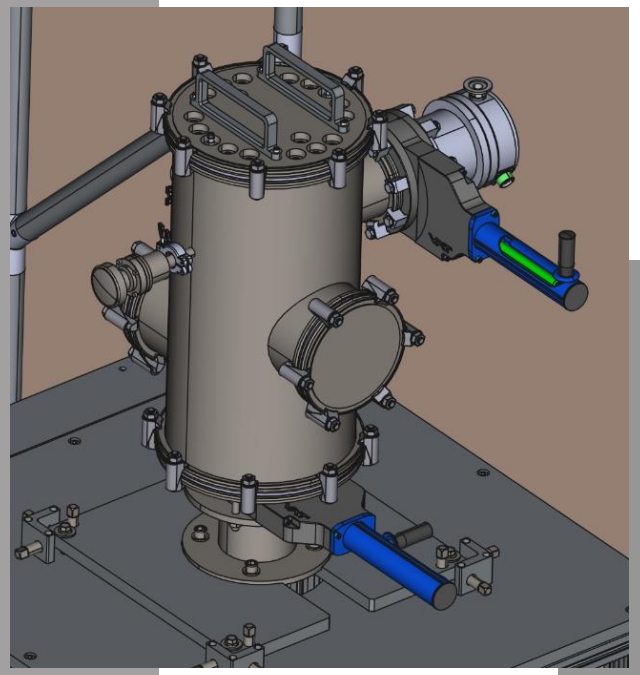




"Ni-bump"

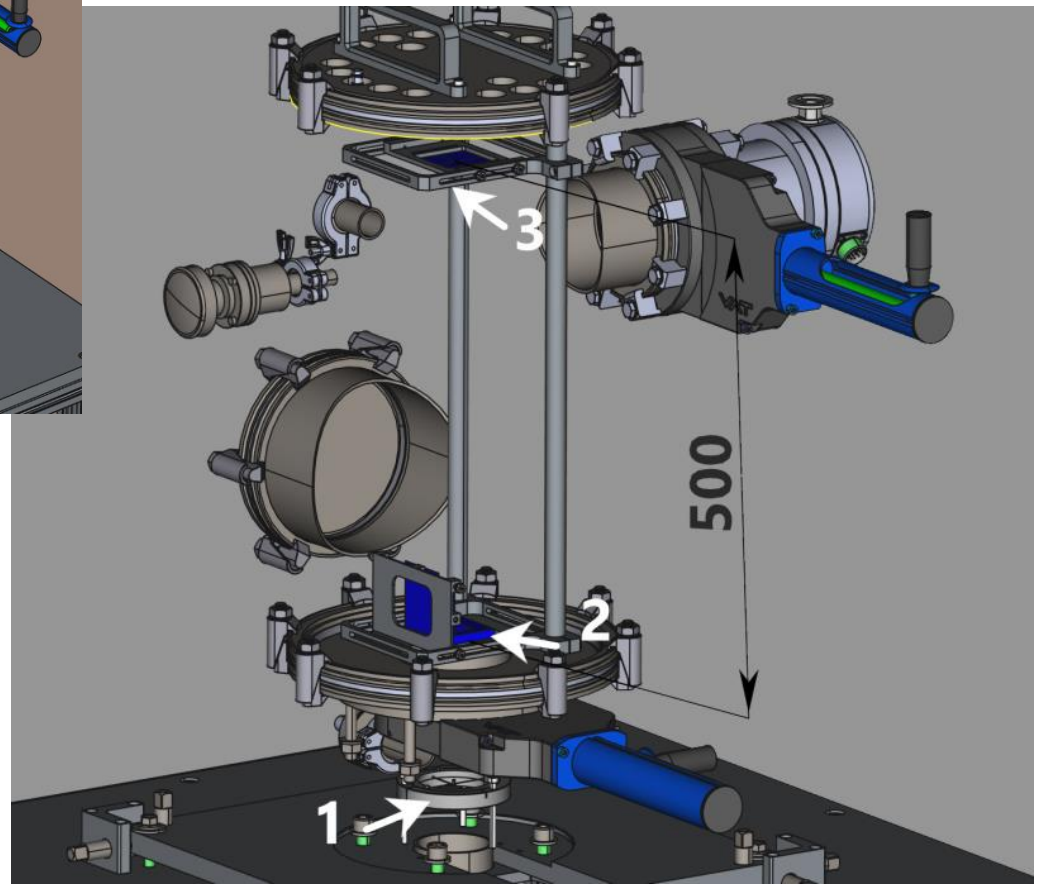
VEGA-m project drawings. Planning low background measurements.



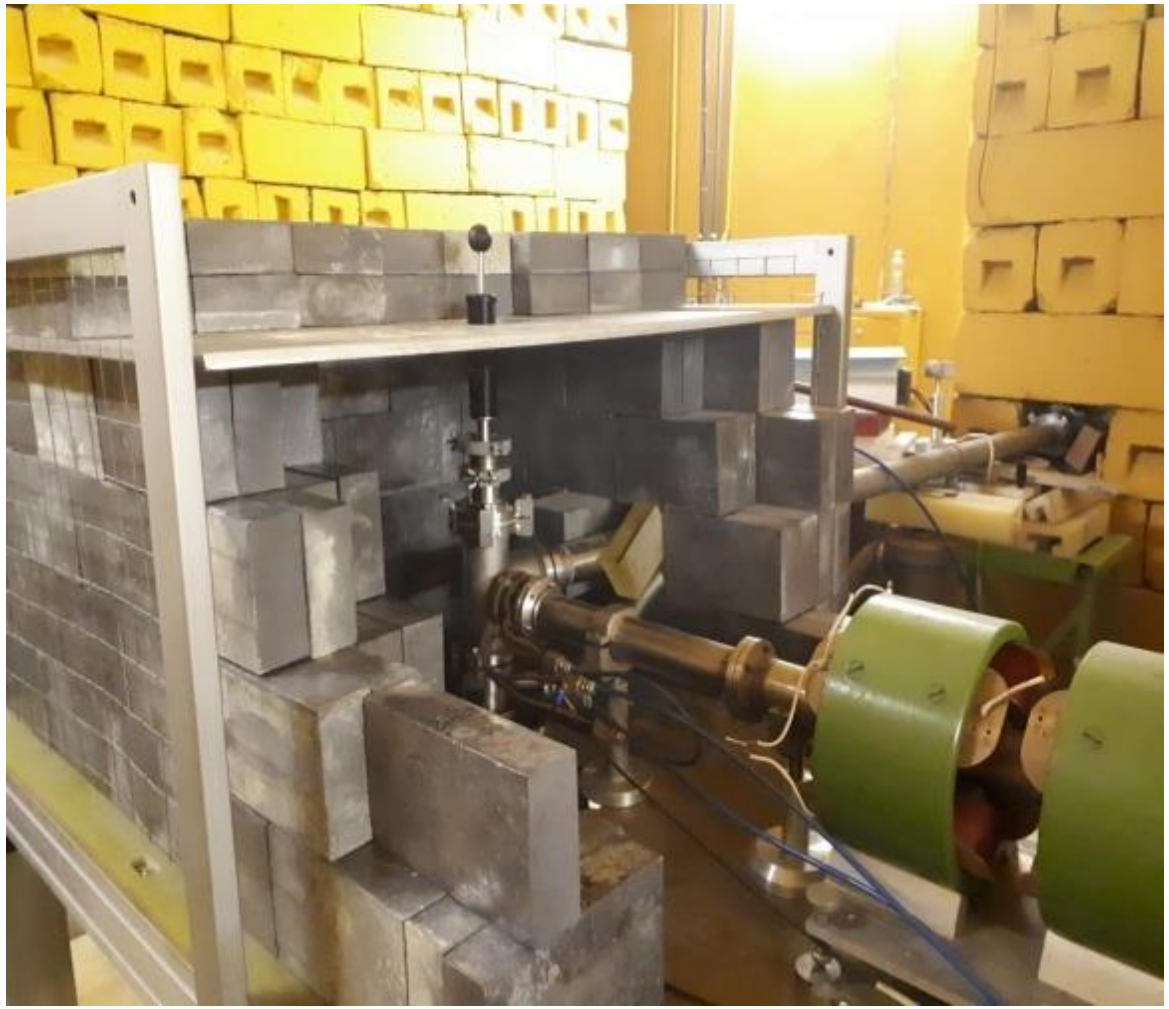


Tentative Plan:

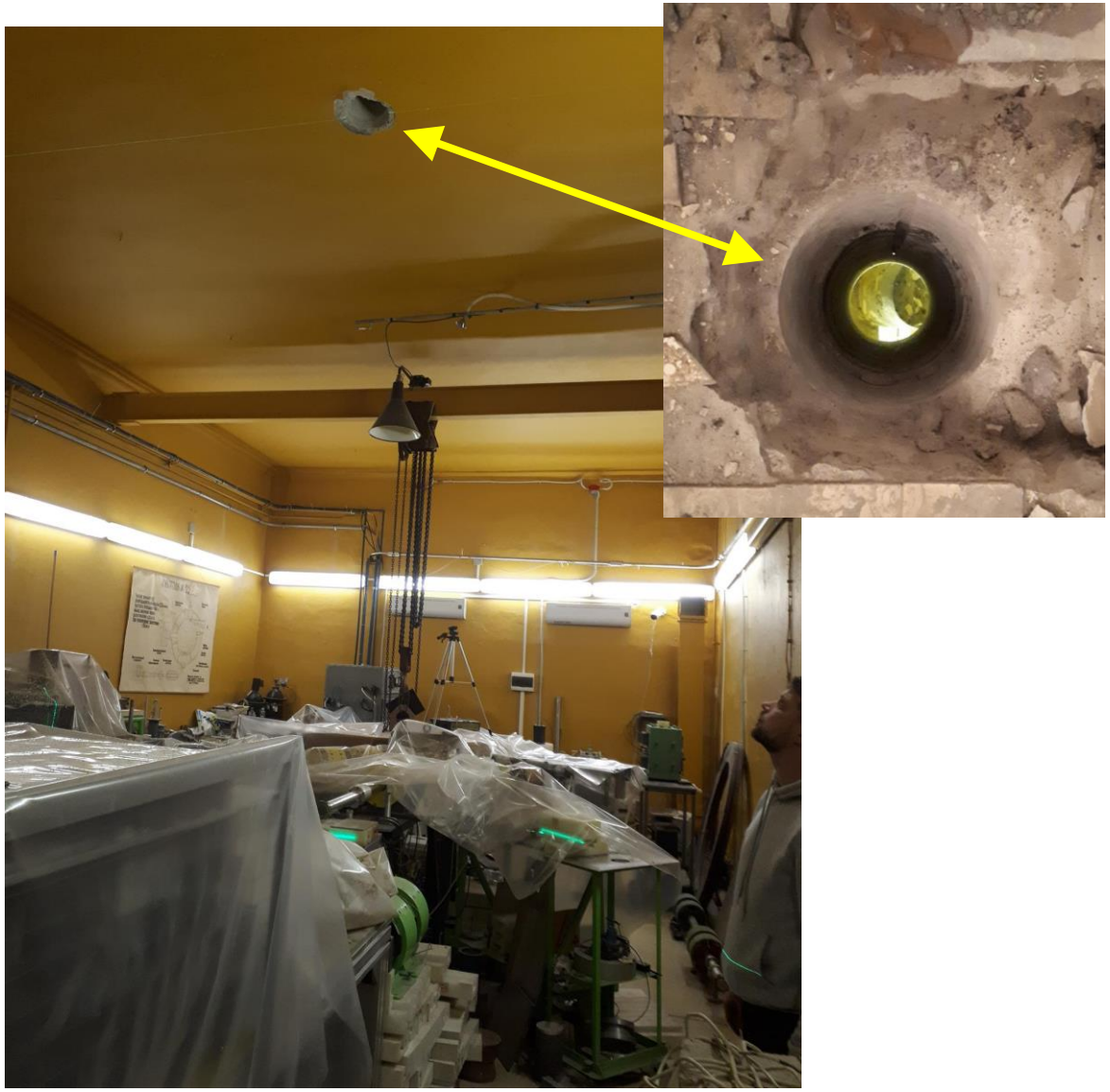
-	Delivery of constructions	August 2024
-	Assembling	September
-	In beam test	November
-	First Experiment	Spring 2025



Converter and target in local shielding



A way to the “low-background” lab



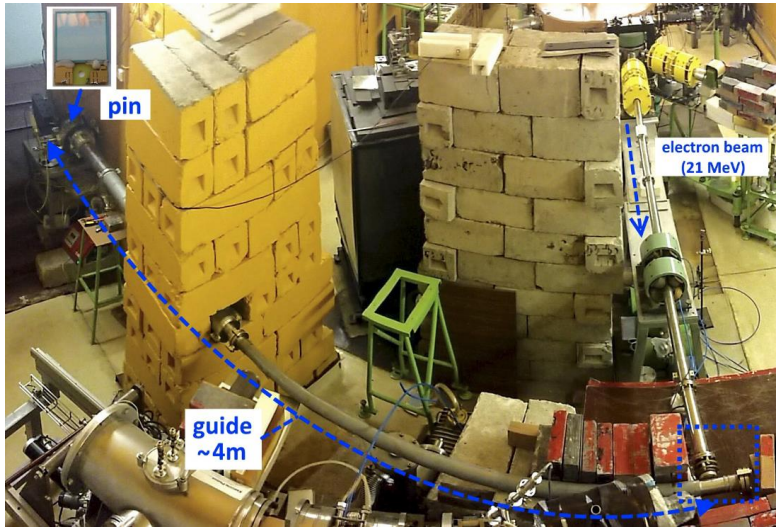
Conclusions & way forward @2025

1. In the framework of the different experimental approaches, the induced fission (break-up) of a certain part of fission fragments through the shape-isomer states was discovered.
2. The life time of at least some of such states exceeds 400 ns**.**
3. The shape-isomer state in fission fragment manifests itself via delayed break-up of the fragment in a solid-state foil.

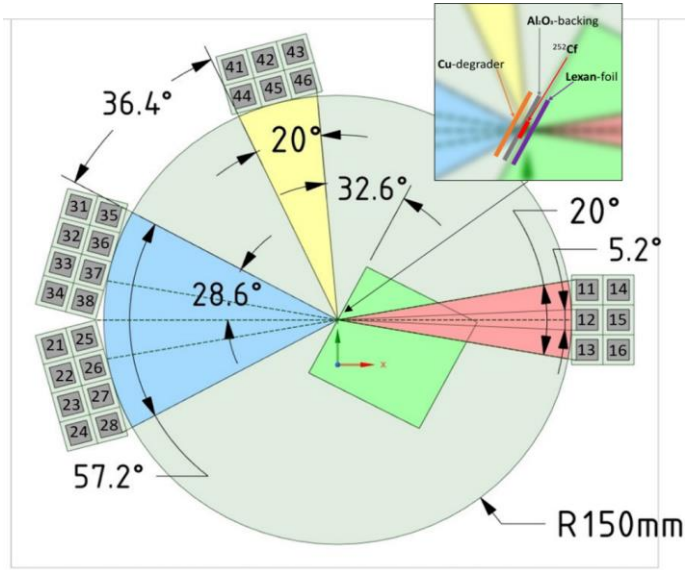
Our publications

http://fobos.jinr.ru/

Photo-fission @ MT-25 ^{239}Pu target expected



Study of angular correlations at COMETA-F with ^{252}Cf



COMETA-R experiment at IBR-2 with a new thin chamber