LXX International Conference “NUCLEUS 2020. Nuclear physics and elementary particle physics. Nuclear physics technologies”

Investigation of binary processes in reactions $^{36}Ar+^{144,154}Sm$ and $^{68}Zn+^{112}Sn$ leading to the formation of neutron-deficient $^{180,190}Hg$ composite systems

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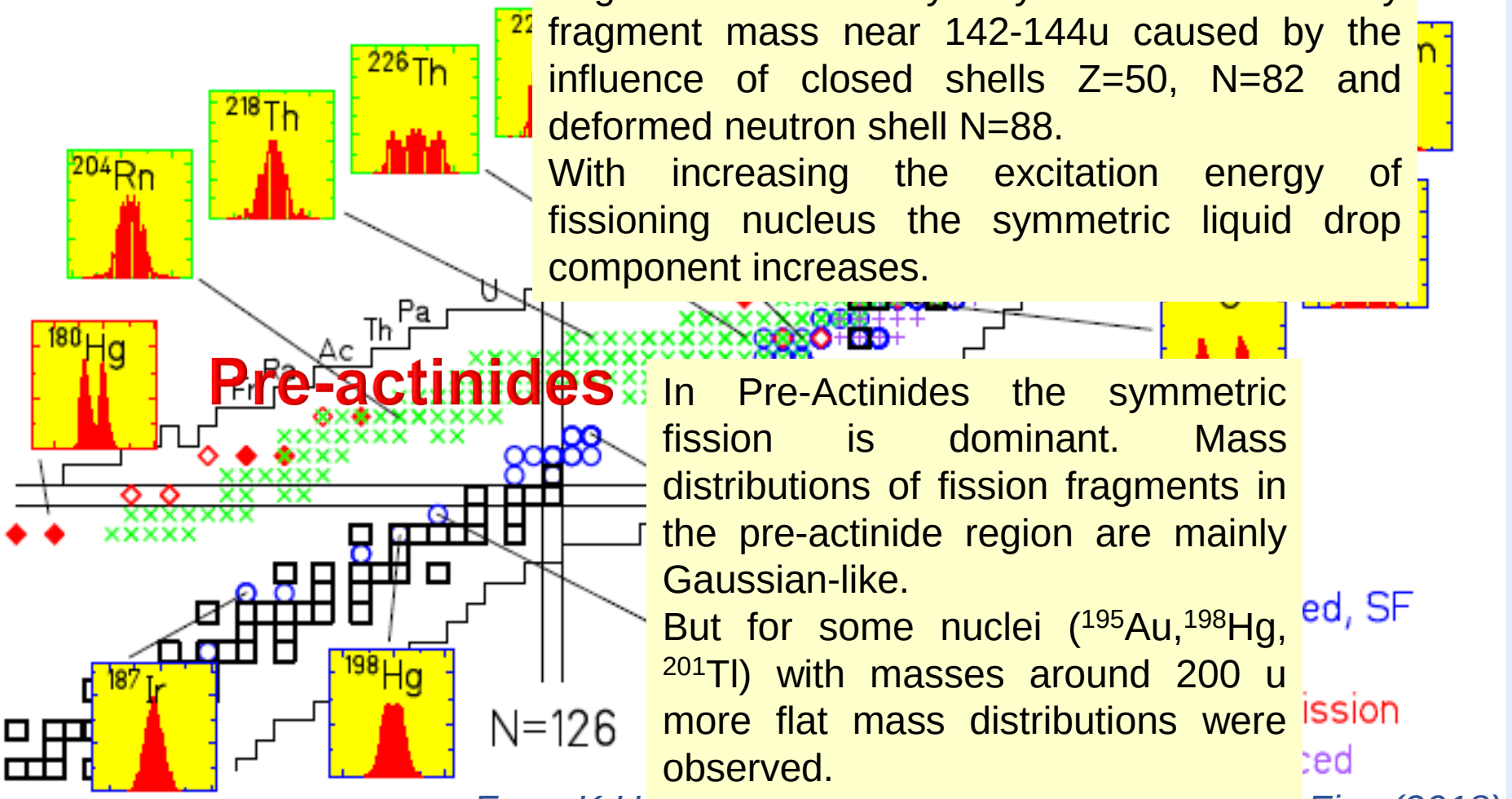
Fission properties of nuclei

Actinides

In spontaneous and low energy fission of actinide nuclei the mass distributions of fission fragments are mainly asymmetric with heavy fragment mass near 142-144u caused by the influence of closed shells Z=50, N=82 and deformed neutron shell N=88.
With increasing the excitation energy of fissioning nucleus the symmetric liquid drop component increases.

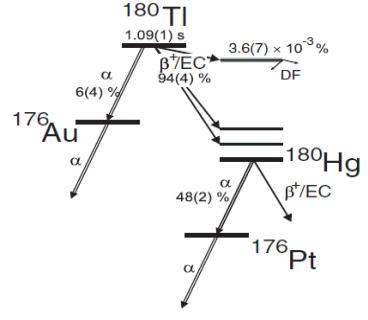


Pre-actinides

In Pre-Actinides the symmetric fission is dominant. Mass distributions of fission fragments in the pre-actinide region are mainly Gaussian-like.
But for some nuclei (^{195}Au,^{198}Hg, ^{201}Tl) with masses around 200 u more flat mass distributions were observed.

From K.H. Schmidt, B. Jurado, Rev. Prog. Nucl. Fiss (2018)

From A.Andreev et al., PRL105 (2010), 252502



Fission of ^{180}Hg at E*<10MeV

It has been found that fission fragment mass distribution of the post-β decay daughter nucleus ^{180}Hg is asymmetric with the most probable heavy and light masses and Z values of **A_H=100, Z_H=44** and **A_L=80, Z_L=36.**

The average **TKE** is **134.6 MeV** with a width of sigma 5.6 MeV.

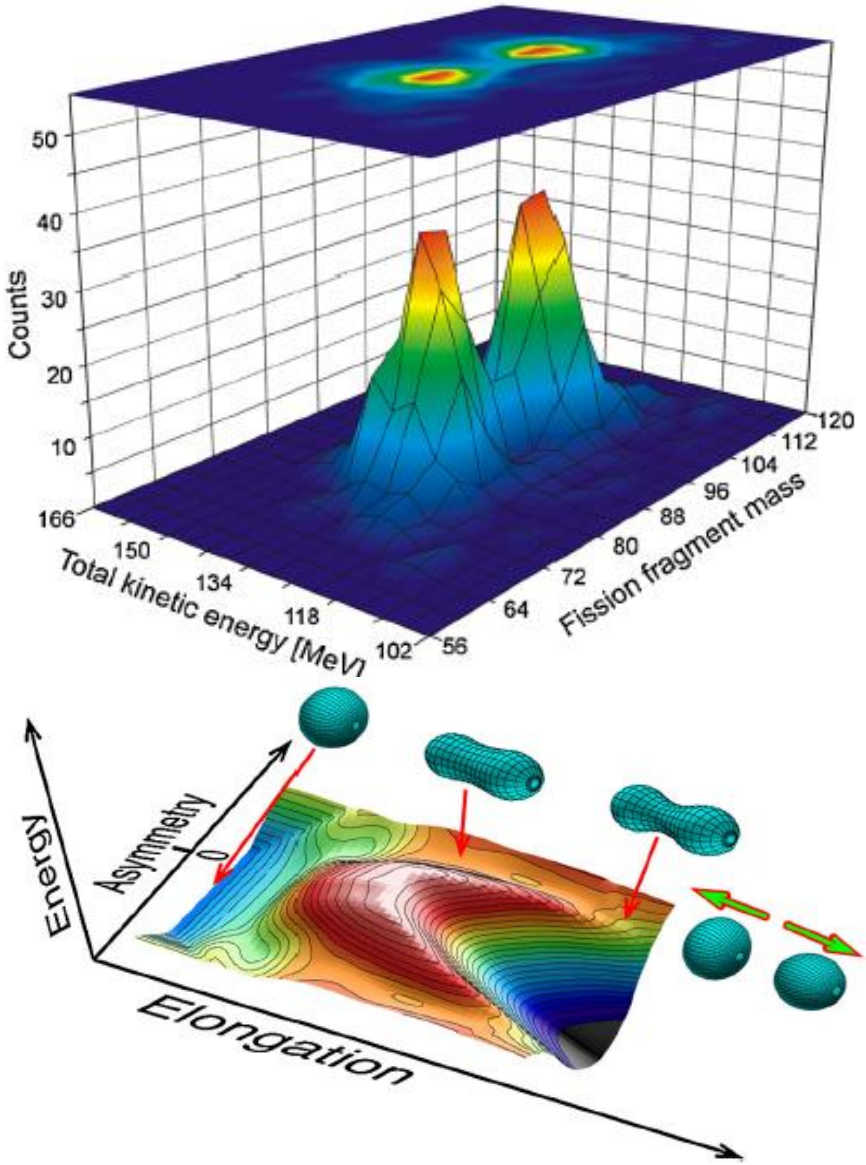


FIG. 5 (color online). A schematic representation of the potential-energy surface for ^{180}Hg in two dimensions (elongation and asymmetry) resulting from a five-dimensional analysis. The shapes shown, connected by arrows to their locations, are the ground state, the saddle point, and the point where the asymmetric valley disappears.

The main goals

- Investigation of fission properties of neutron-deficient nuclei of **$^{180,\ 190}$Hg** in dependence on the excitation energy and angular momentum, formed in the reactions:

  ^{36}Ar+^{144}Sm$\rightarrow$^{180}Hg

  ^{36}Ar+^{154}Sm$\rightarrow$^{190}Hg

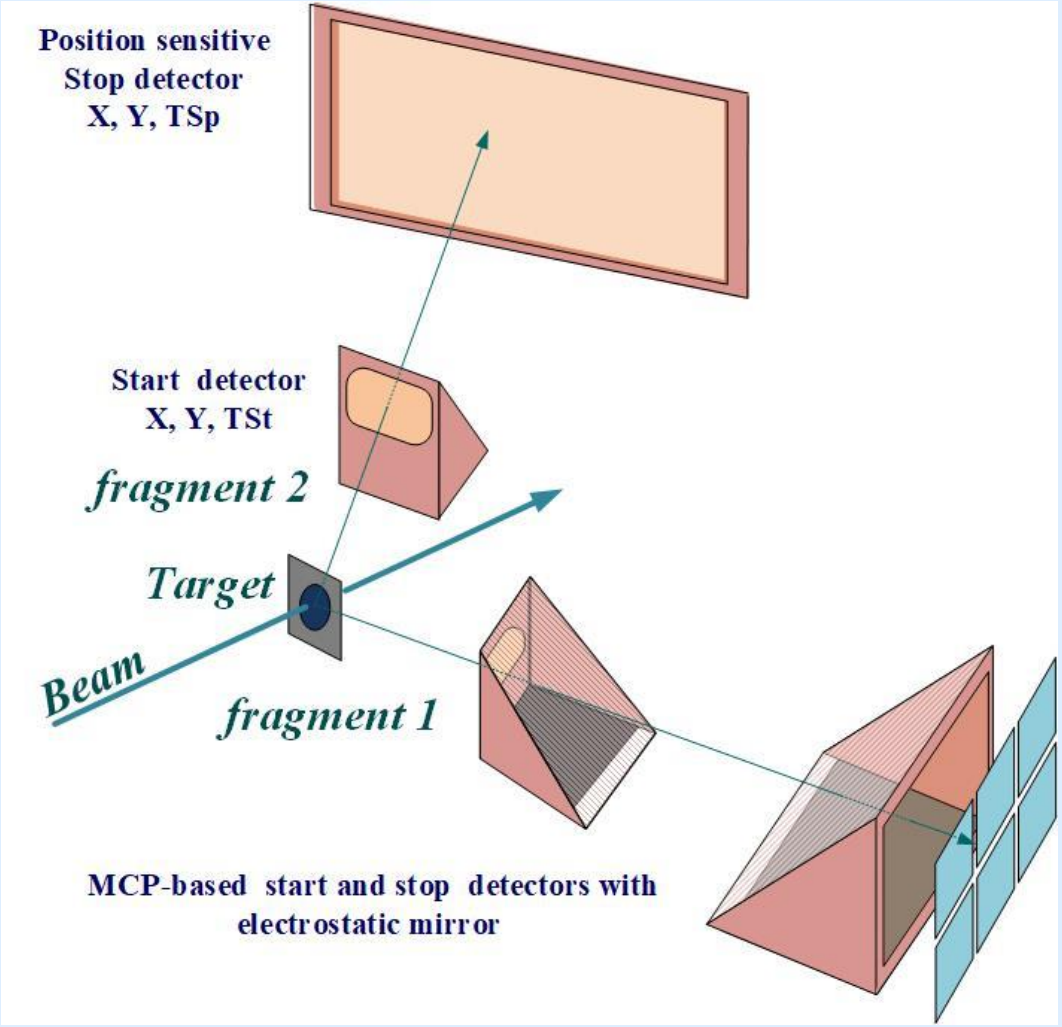
  at energies near and above the Coulomb barrier.

- Investigation of mass, energy and angular distributions of fissionlike fragments formed in the reaction **^{36}Ar+^{144}Sm$\rightarrow$^{180}Hg** at high angular momenta **$L>L(B_f=0)$**.

- Study of the entrance channel influence on the reaction dynamics comparing reactions **^{68}Zn+^{112}Sn** and **^{36}Ar+^{144}Sm** leading to the formation of the same composite system of ^{180}Hg.

Double arm spectrometer CORSET

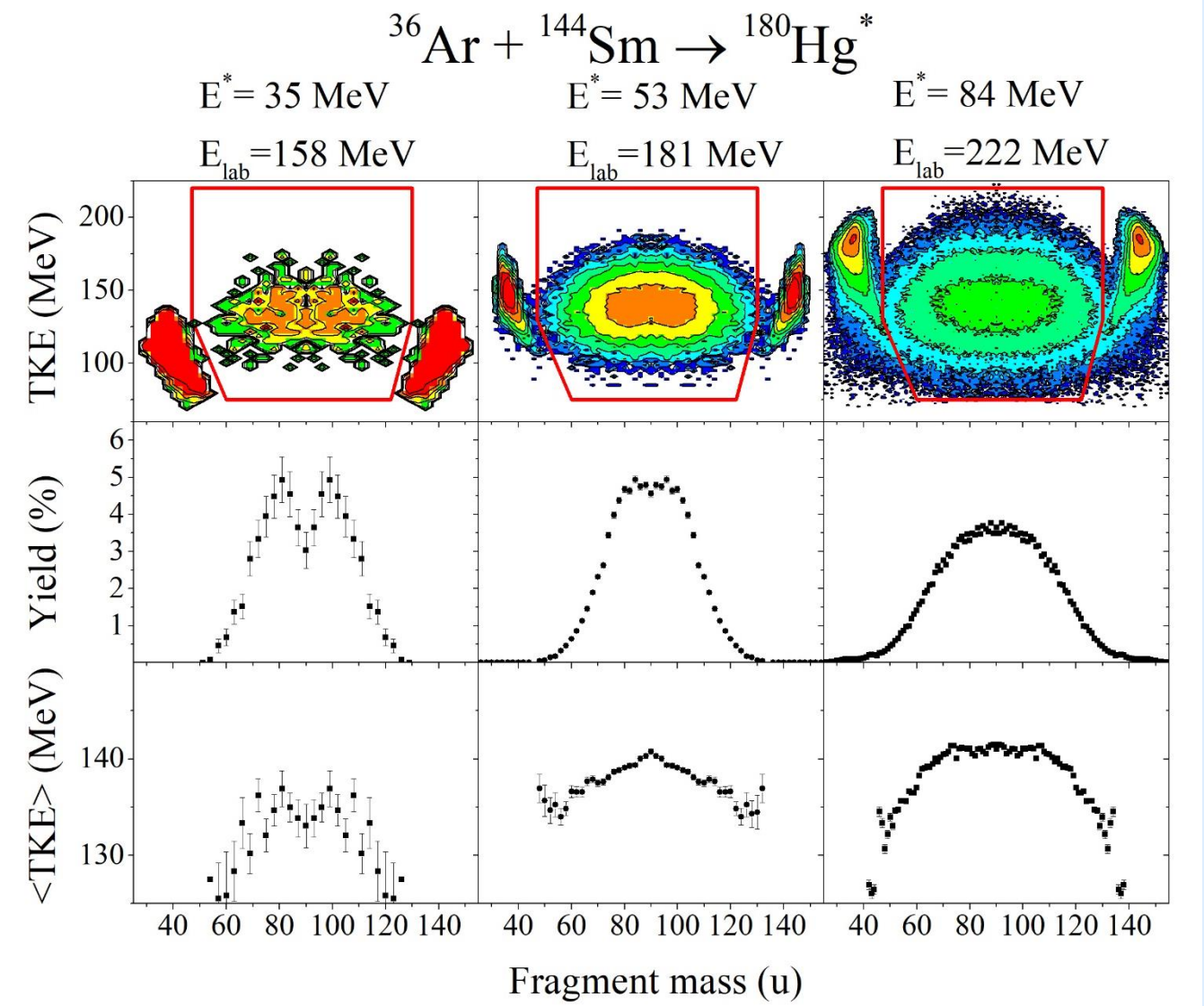
Mass-energy and angular distributions of fission fragments of neutron-deficient ^{180,190}Hg composite systems formed in the reactions ^{36}Ar + ^{144,154}Sm and ^{68}Zn + ^{112}Sn were measured using double arm time-of-flight spectrometer CORSET at energies near and above the Coulomb barrier.



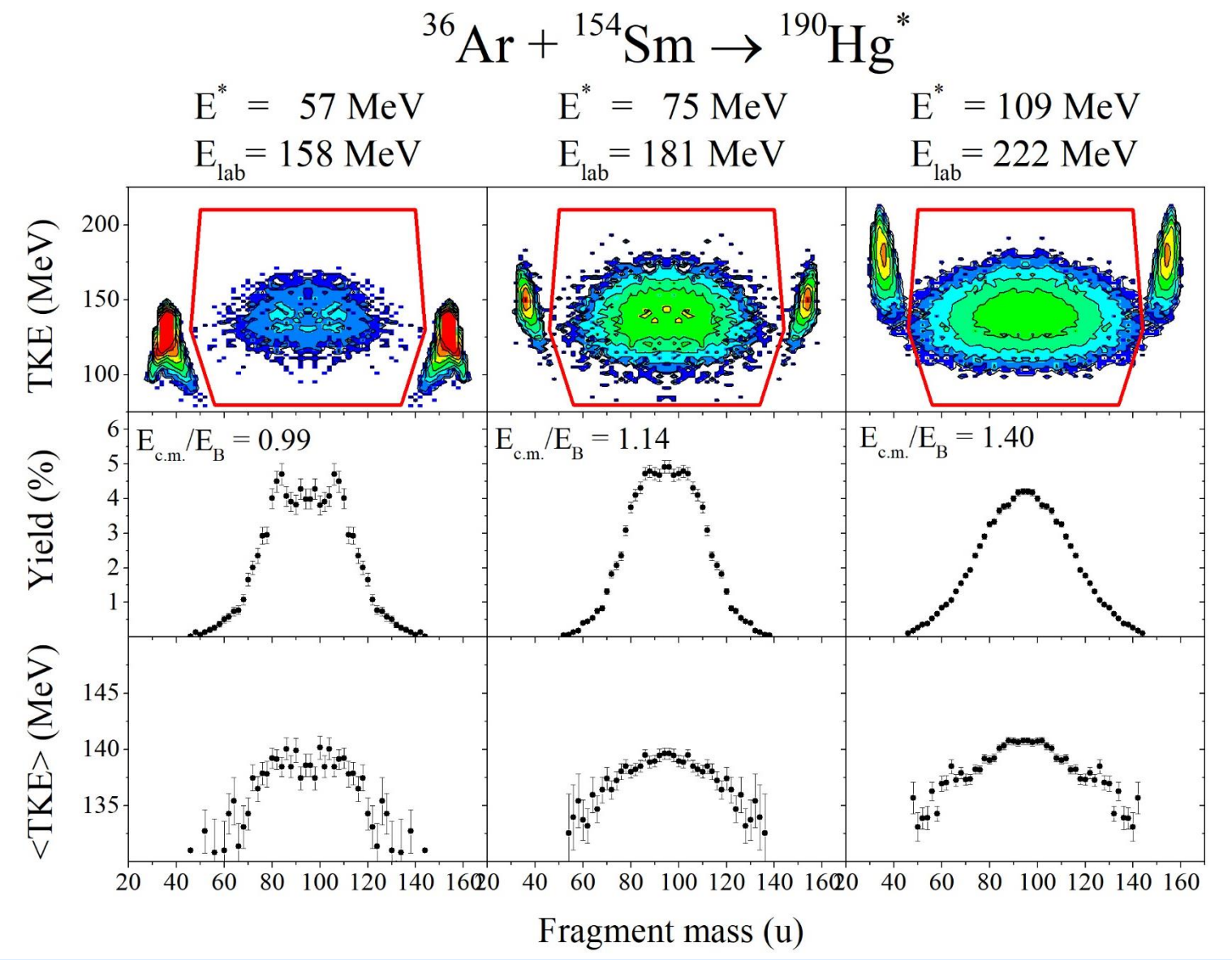
The experiments were carried out at the U400 cyclotron at the Flerov Laboratory of Nuclear Reactions (FLNR), Dubna, Russia, and K-130 cyclotron at the Physics Department of the Jyväskylä University, Finland.

Parameter	values
Time resolution	150-180ps
ToF base	10-30cm
ToF arm rotation range	15-165°
Acceptance	±10 -20°
Solid angle	100-200msr
Angular resolution (σ)	0.13
Mass resolution (σ)	1.7u
Energy resolution (σ)	4MeV

Mass-energy distributions of fission fragments formed in the reaction $^{36}Ar + ^{144}Sm \rightarrow ^{180}Hg^*$



Mass-energy distributions of fission fragments formed in the reaction $^{36}Ar + ^{154}Sm \rightarrow ^{190}Hg^*$

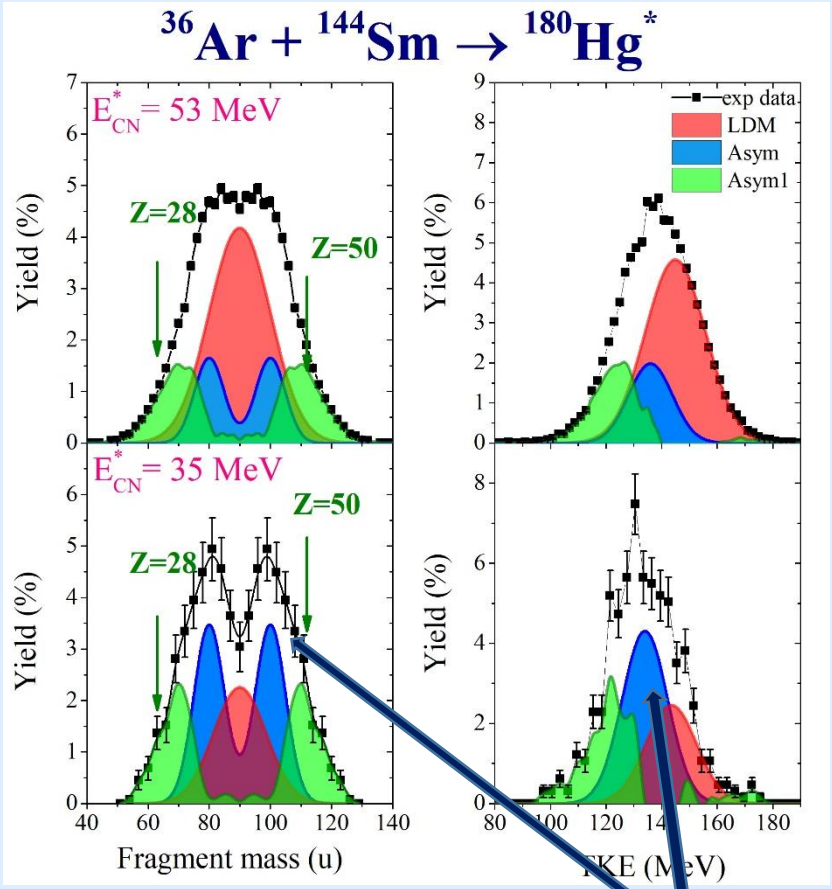


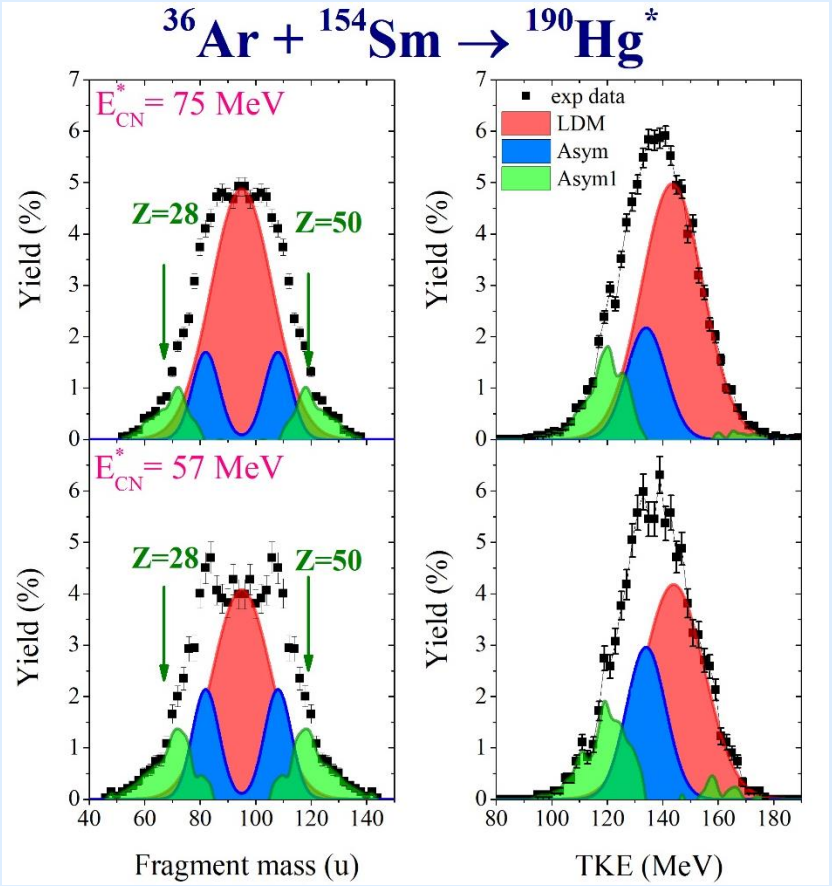
Symmetric and asymmetric modes in mass and energy distributions of fission fragments of ^{180,190}Hg

Symmetric component – Liquid Drop model (Gauss + Viola TKE)

Asymmetric component - A_L/A_H ~ **80 / 100** u for **^{180}Hg** and **83/107** u for **^{190}Hg**

Asymmetric component 1 – probably caused by proton shell at **Z=50**





β -delayed fission of ^{180}Tl (A.N.Andreyev et al.)

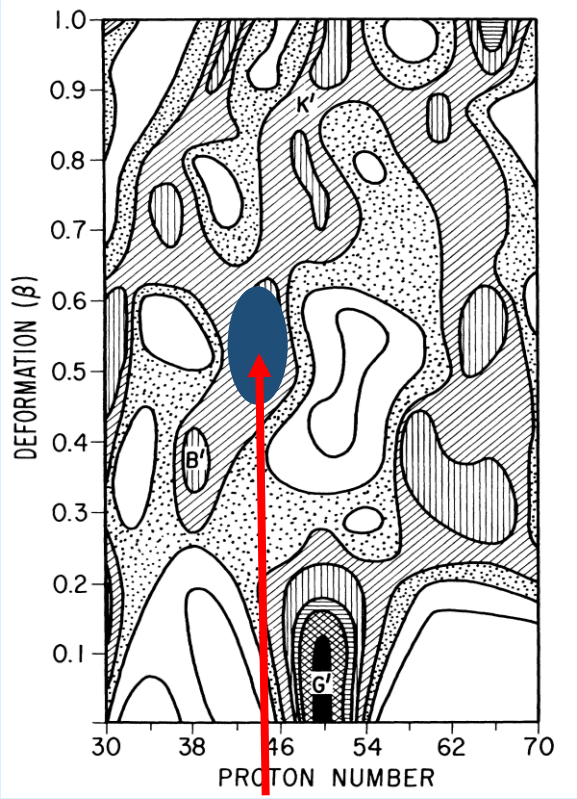
Possible influence of the deformed proton shell on fission of excited Hg*

The most probable values of Z of fragments pairs are
Z_L/Z_H~35/45
for the both fissioning nuclei ^{180,190}Hg.

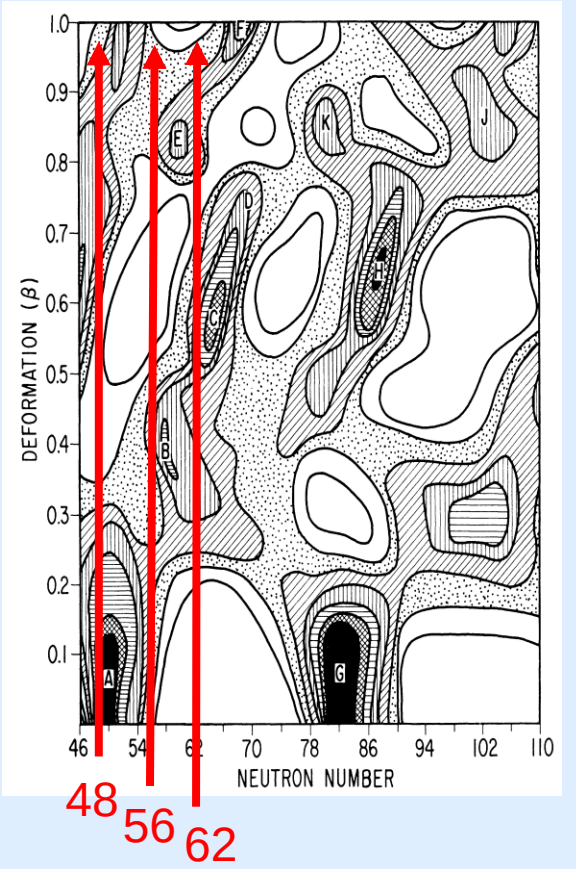
Neutron numbers are
N_L/N_H~44/56 for ^{180}Hg
N_L/N_H~48/62 for ^{190}Hg.

The deformed proton shell at **Z≈45** may affect on the fission of Hg isotopes leading to the formation of asymmetric fragments!

Proton shell corrections

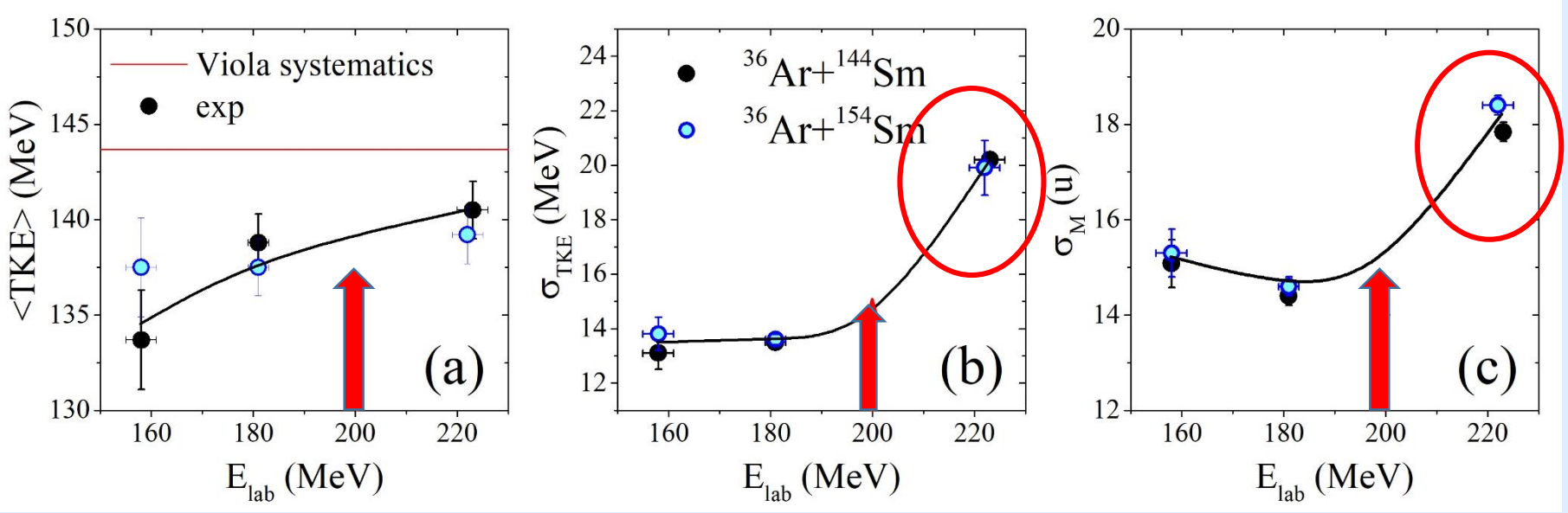


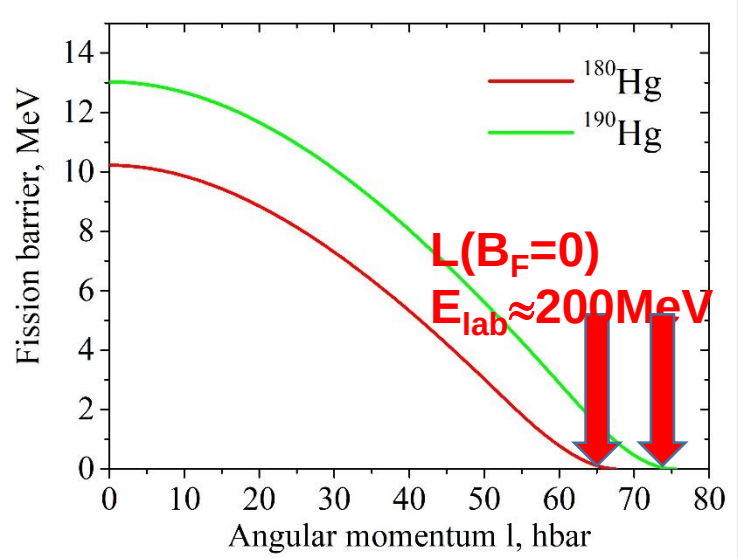
Neutron shell corrections



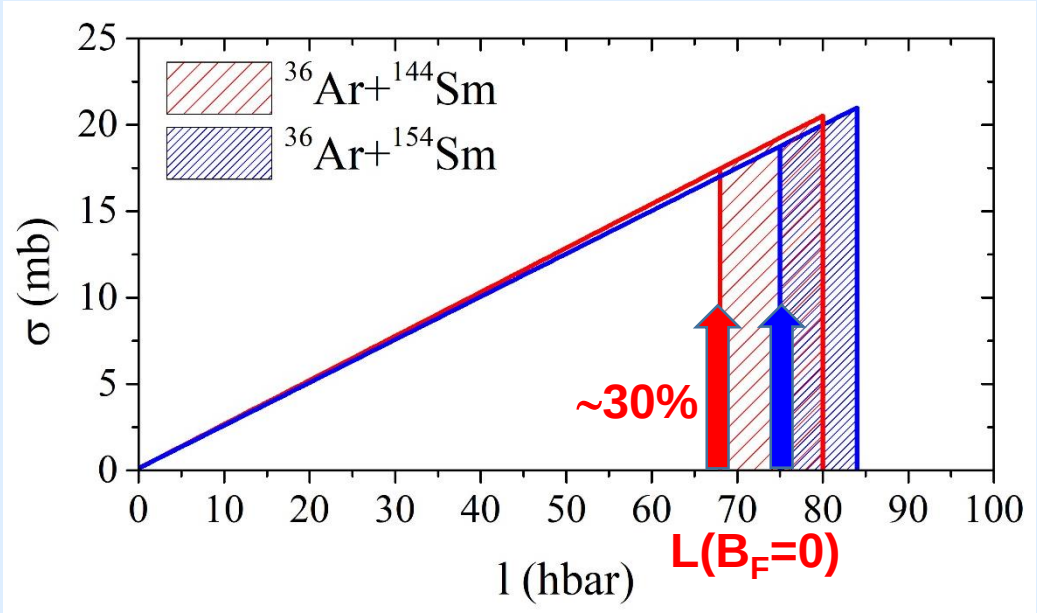
B.D.Wilkins et al. Phys. Rev C 14 (1976), V.5, p.1832

Fast fission of excited ^{180,190}Hg* at E_{lab} =222 MeV

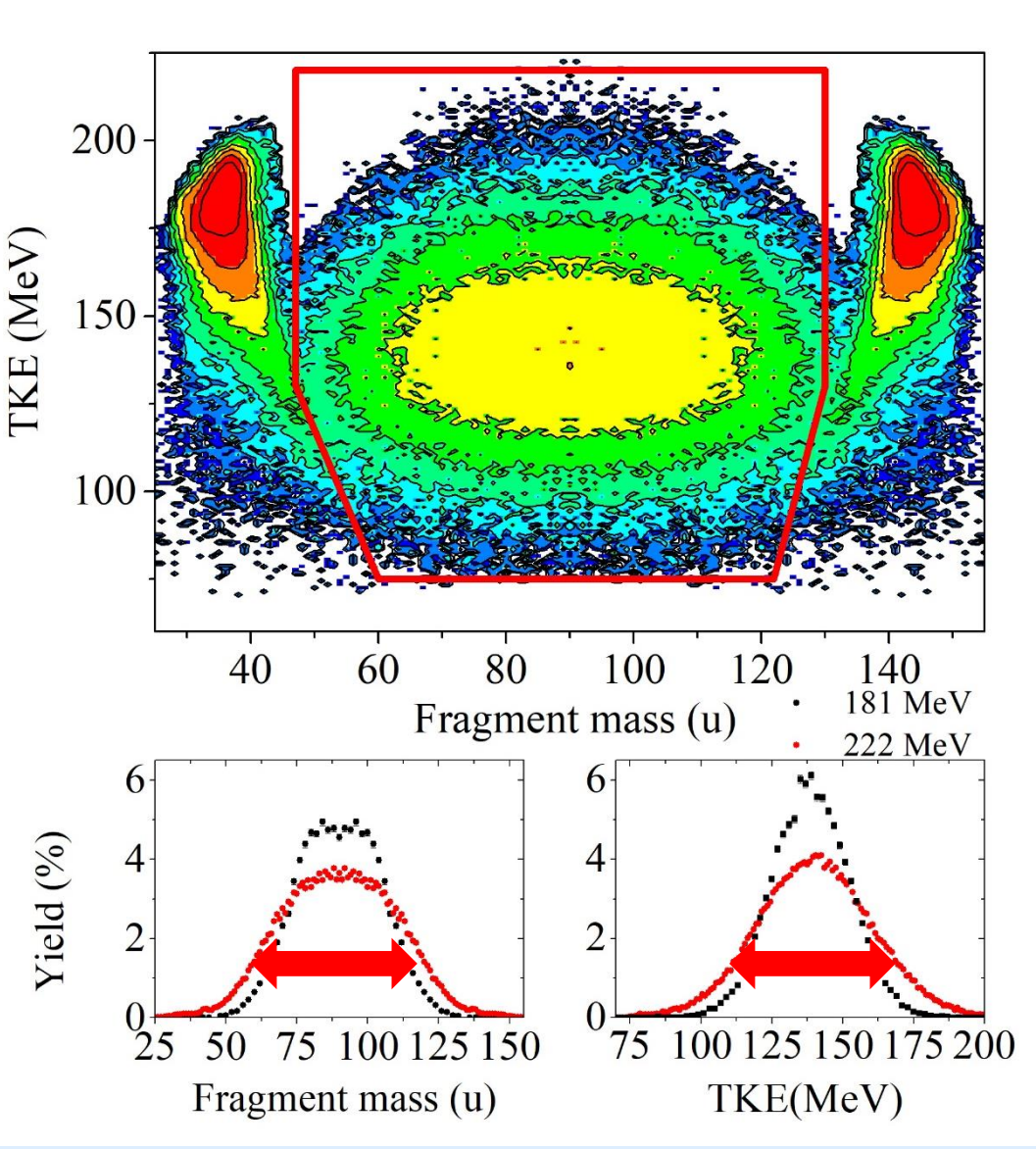


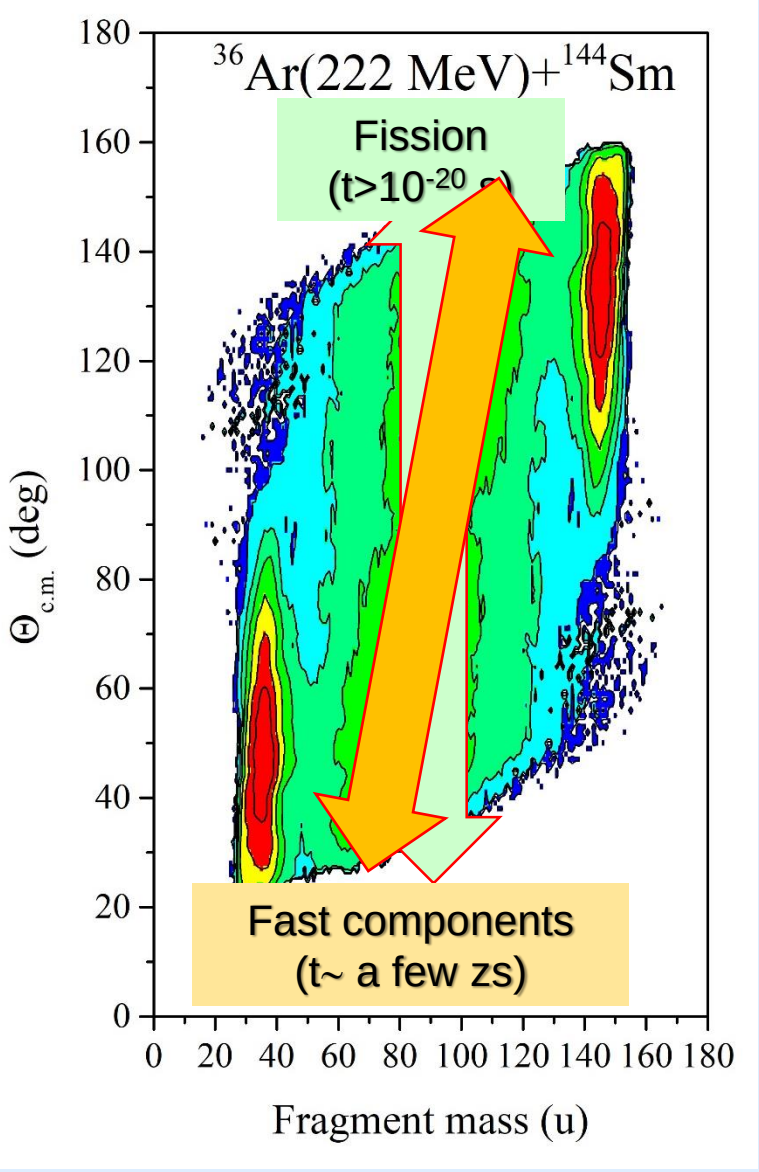


A.J.Sierk, PRC33(1986)2039

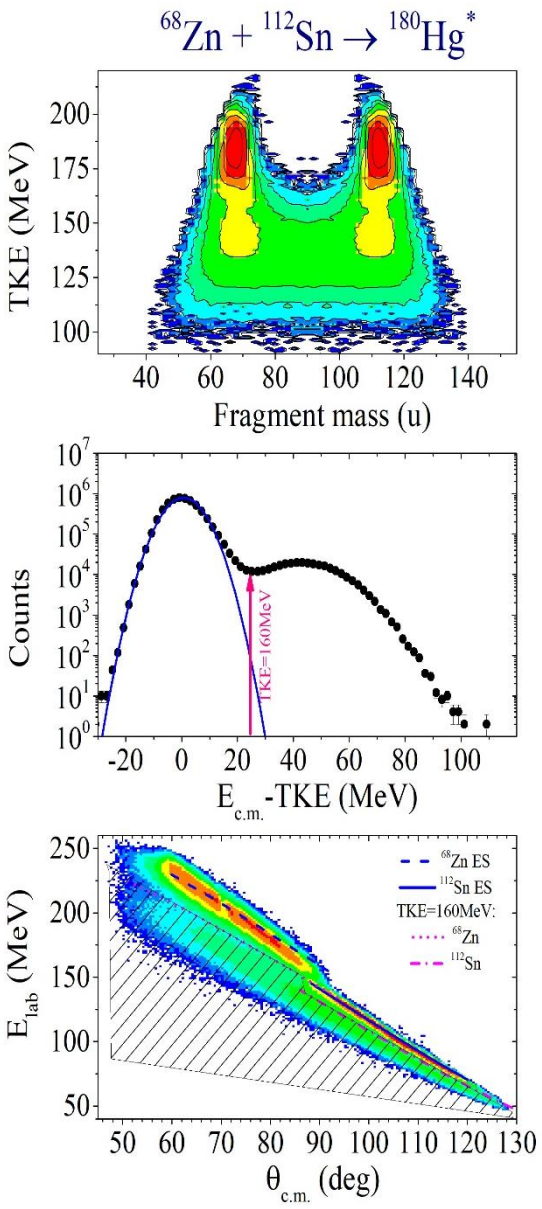


Fast fission in the $^{36}Ar+^{144}Sm$ at E_{lab} =222 MeV





The comparison of mass-energy distributions obtained in the reactions $^{36}Ar+^{144}Sm$ and $^{68}Zn+^{112}Sn$ leading to the formation of $^{180}Hg^*$

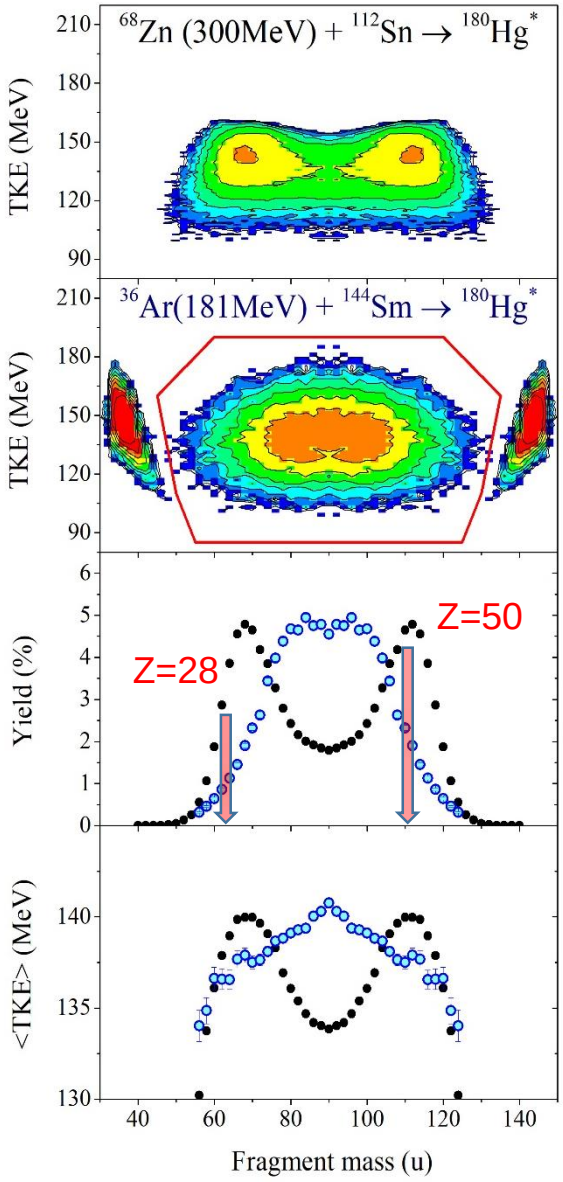


Mass-energy distributions of fragments formed in the reaction $^{68}Zn+^{112}Sn$ differ significantly from the reaction $^{36}Ar+^{144}Sm$.

The difference is due to **quasifission (QF)** in the reaction **$^{68}Zn+^{112}Sn$**.

Contribution of QF is more than **60%**. It is quite **surprising** since the properties of the entrance channel for the both reactions are favorable for CN formation.

Parameter	^{68}Zn	^{36}Ar
Coulomb parameter Z_1Z_2	1500	1116
Mean fissility parameter x_m (D. Hinde)	0.695	0.634
Asymmetry α_0	0.24	0.60
E_{lab} (MeV)	300	181
E^*_{CN} (MeV)	48	53
<L>(ħ)	55	41
L_{crit} (ħ)	70	52
Θ_{lab} (deg)	45±14	60±19
Θ_{gr} (deg)	72.8	91.2



Conclusions

- **Asymmetric component** in mass and energy distributions of fission fragments of ^{180,190}**Hg***, formed in the reactions ^{36}**Ar+**^{144,154}**Sm**, are observed even at excitation energies of **75MeV**.
- For asymmetric fission the most probable heavy and light masses A and proton numbers Z are: A_H**=100,** Z_H**=45** and A_L**=80,** Z_L**=35** for ^{180}**Hg** and A_H**=107,** Z_H**=45** and A_L**=83,** Z_L**=35** for ^{190}**Hg**. This may be caused by the influence of deformed proton shell **Z≈45**. The asymmetric component caused by the influence of Z_H**=50** has been also found for the both fissioning nuclei ^{180,190}**Hg**.
- Similarly to the actinide fission, the symmetric component of mass distribution increases with increasing excitation energy. However, contrary to the actinide nuclei, the energy of the asymmetric fission is lower than that for the symmetric one.
- For the highest energy E_{lab}=222 MeV when L_{cr}**>L(**B_f**=0)** the **fast component** in mass-angular distribution of fissionlike fragments formed in the reaction ^{36}**Ar+**^{144}**Sm** has been found. The broadening of the mass and energy distributions have been also observed. This happens due to the contribution of **fast fission** process at L>L(B_f=0).
- The comparative study of the reaction ^{68}**Zn+**^{112}**Sn** leading to the same composite system as the reaction ^{36}**Ar+**^{144}**Sm** at similar excitation energy and angular momentum has shown that mass-energy distributions differ significantly due to the large contribution of **quasifission** process in the case of the reaction with ^{68}**Zn** ions.

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