Impact of fusion-fission and Quasifission on the SHE prodaction

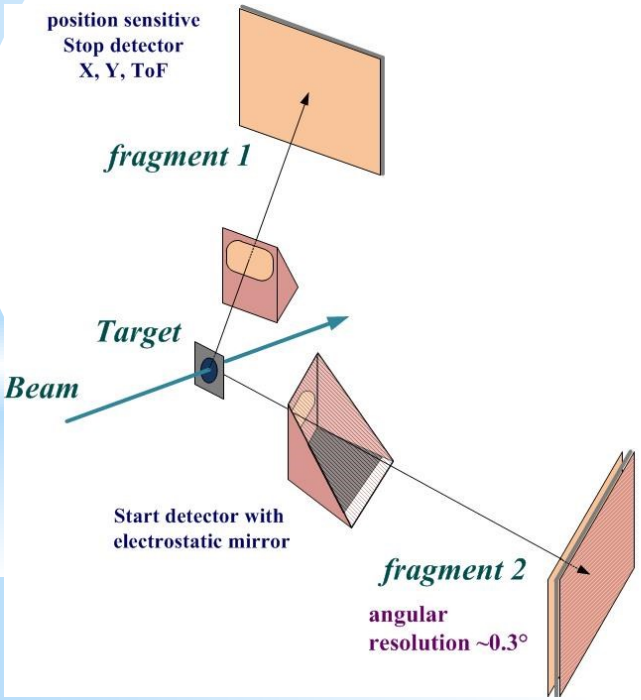
M.Itkis

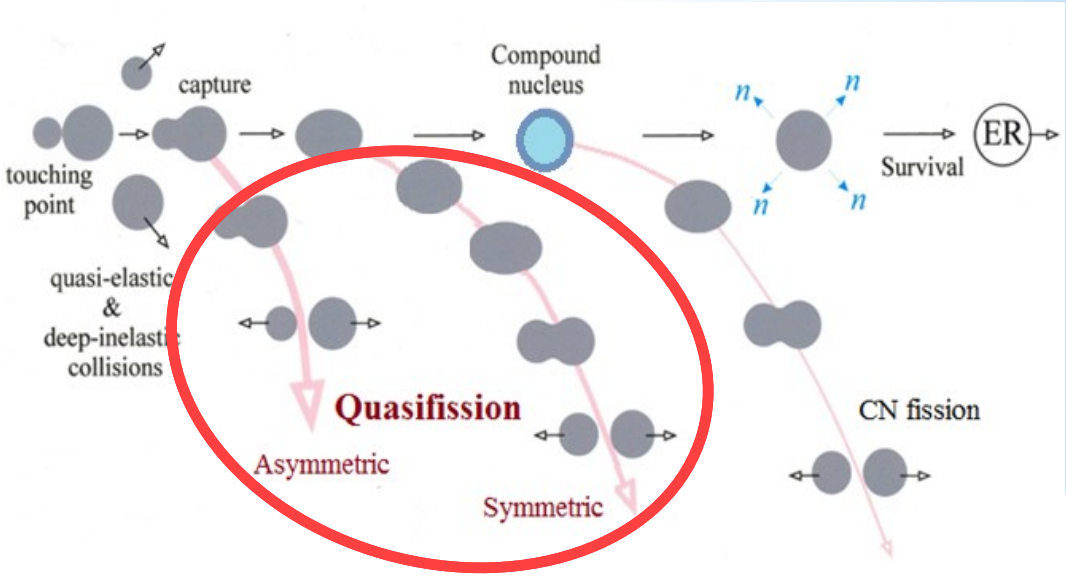
Venice, 13-17 May 2019

* Reaction channels in the collisions of heavy ions

Double arm Time-of-Flight spectrometer CORSET

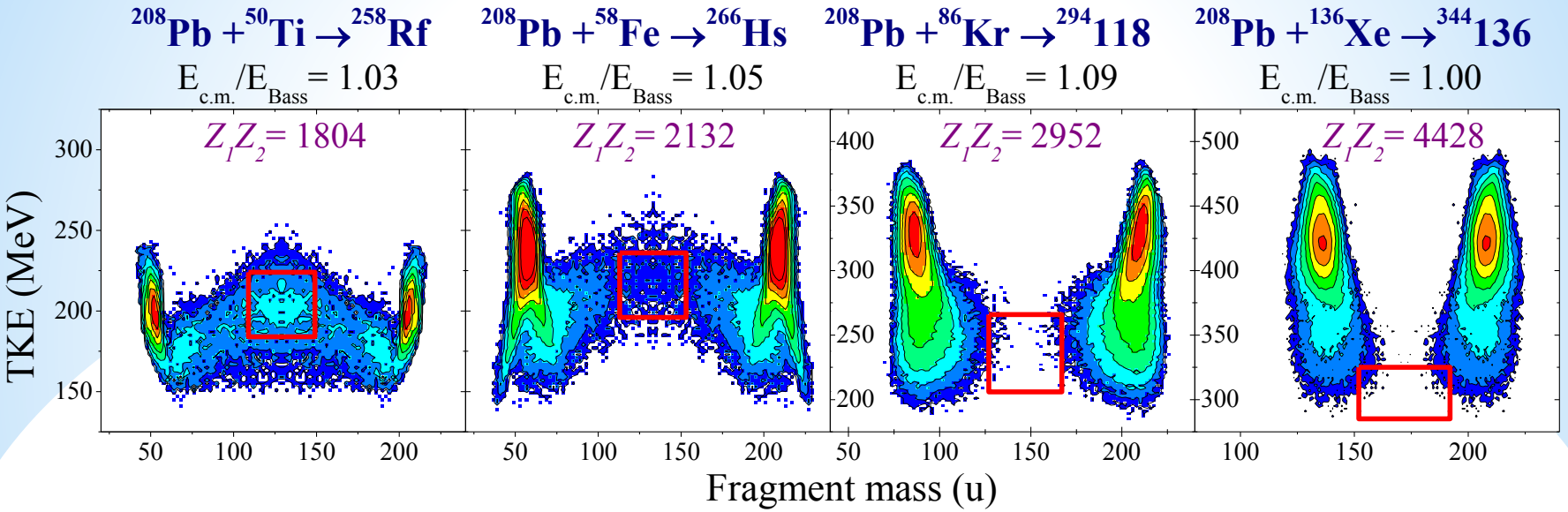
The study of binary channel of heavy-ion-induced reactions (fusion-fission, quasifission and deep-inelastic processes).



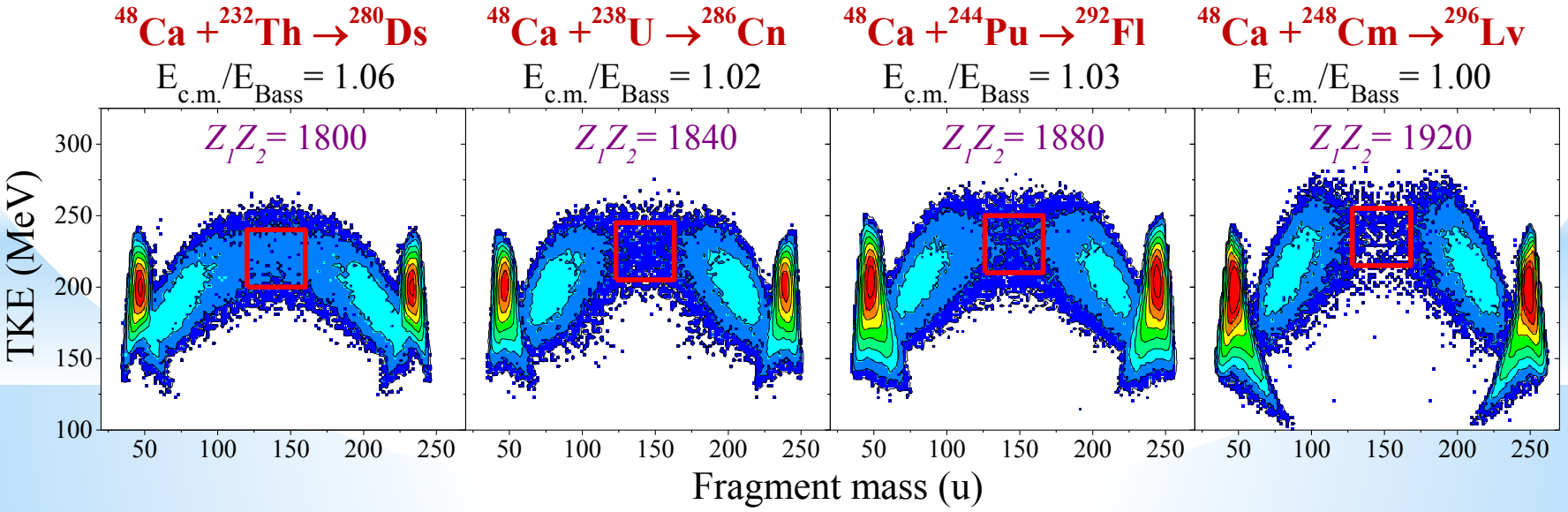


Time resolution	**150-180 ps**
ToF base	10-30 cm
ToF arm rotation range	15°-165°
Solid angle	100 -200 msr
Angular resolution	0.3°
Mass resolution	**2-4 u**

Cold fusion reactions



Hot fusion reactions

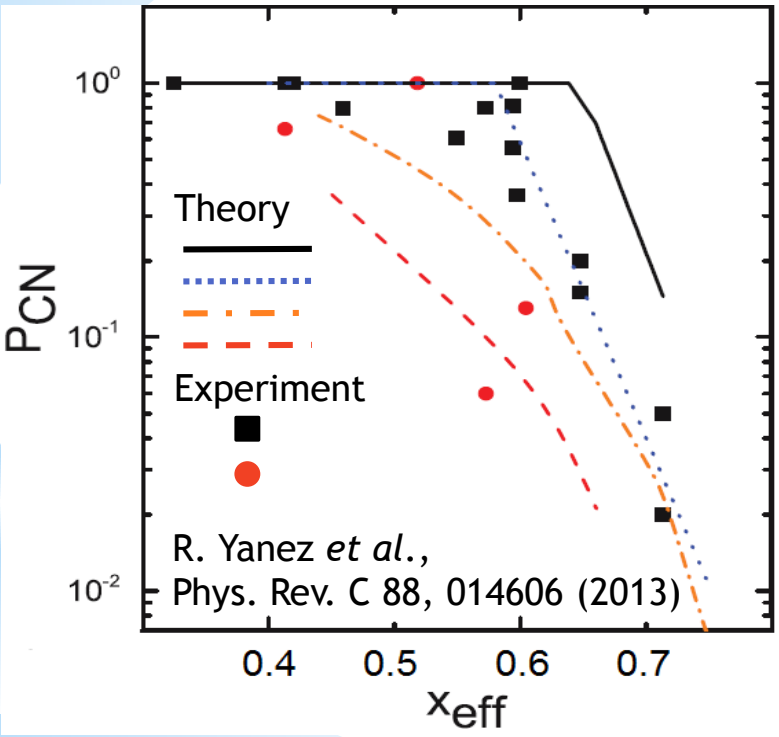


* Fusion Probability

$$\sigma_{ER} = \sigma_{capture} \times P_{CN} \times W_{survival}$$

$$\sigma_{capture} = \sigma_{QF} + \sigma_{CNF} + \sigma_{ER}$$

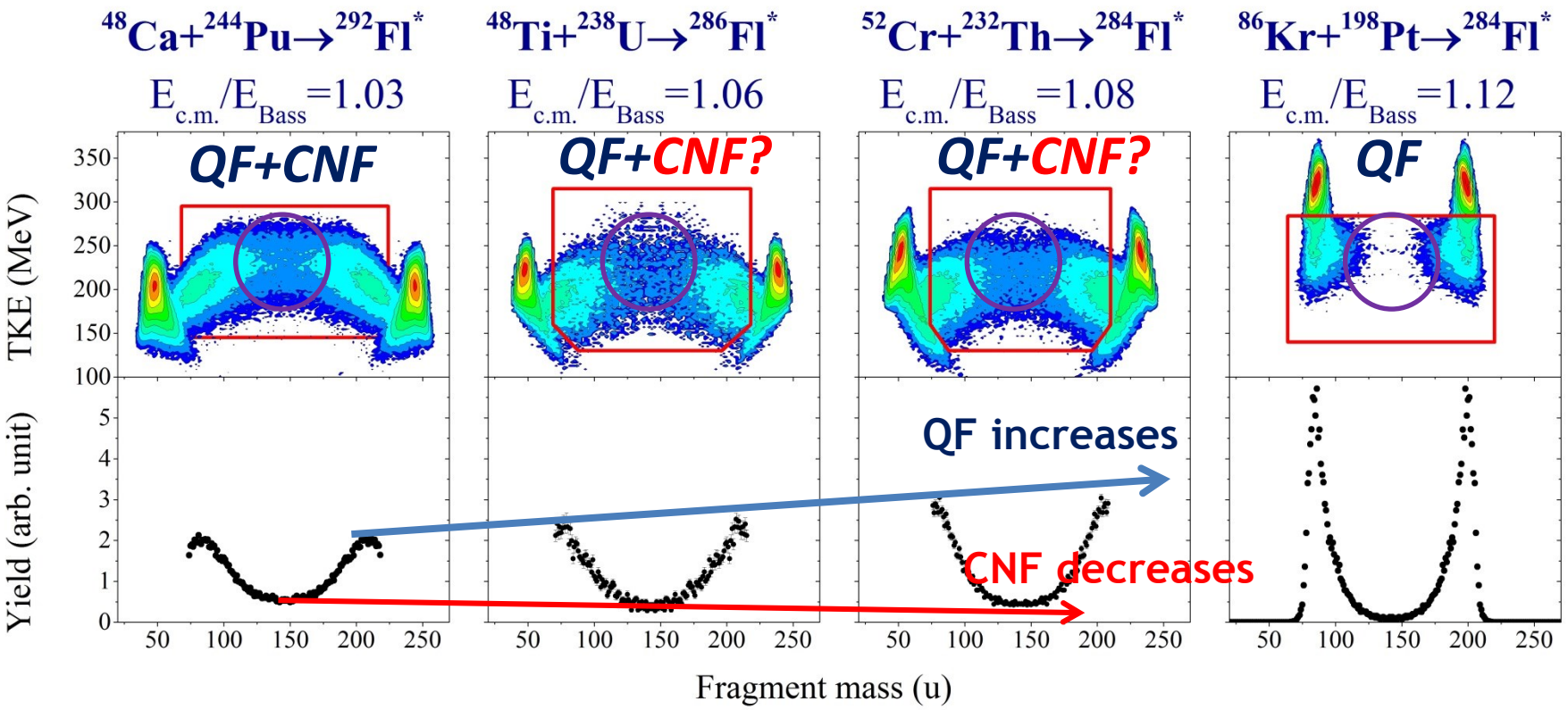
Strongly vary from each other!



The experimental measurements of fusion probability show the general dependence of P_{CN} upon fissility.

Mass-energy distributions of binary fragments formed in the reactions $^{48}Ti+^{238}U$, $^{52}Cr+^{232}Th$, $^{84,86}Kr+^{198}Pt$ leading to the formation of composite systems with Z=114 at energies near the Coulomb barrier have been studied to estimate the decrease rate of fusion probability at the transition from the reactions with ^{48}Ca to Ti and Cr ions.

* Mass and Energy distributions in the reactions leading to the formation of Z=114



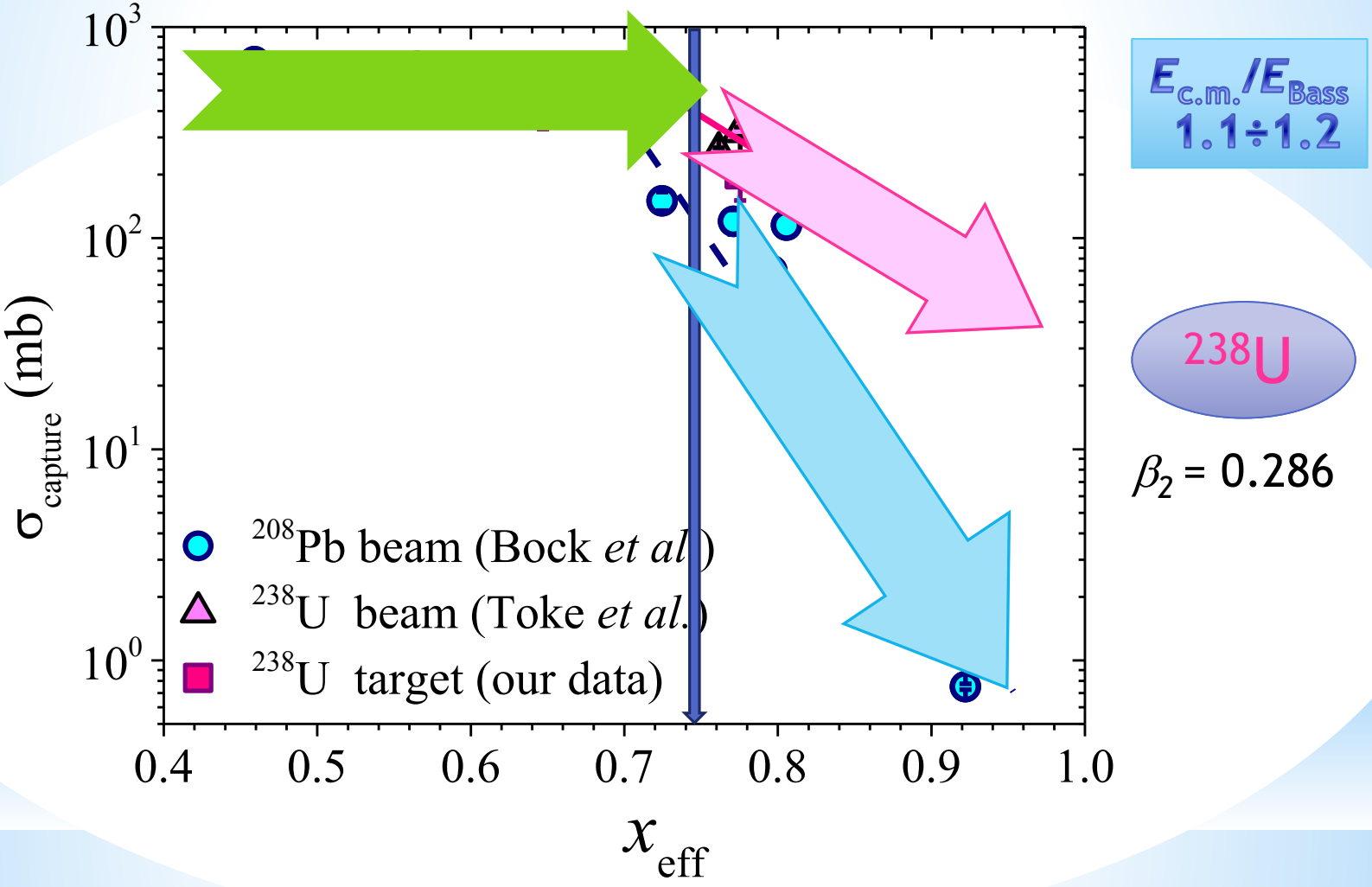
Z_tZ_p=1880
X_m=0.721

Z_tZ_p=2024
X_m=0.776

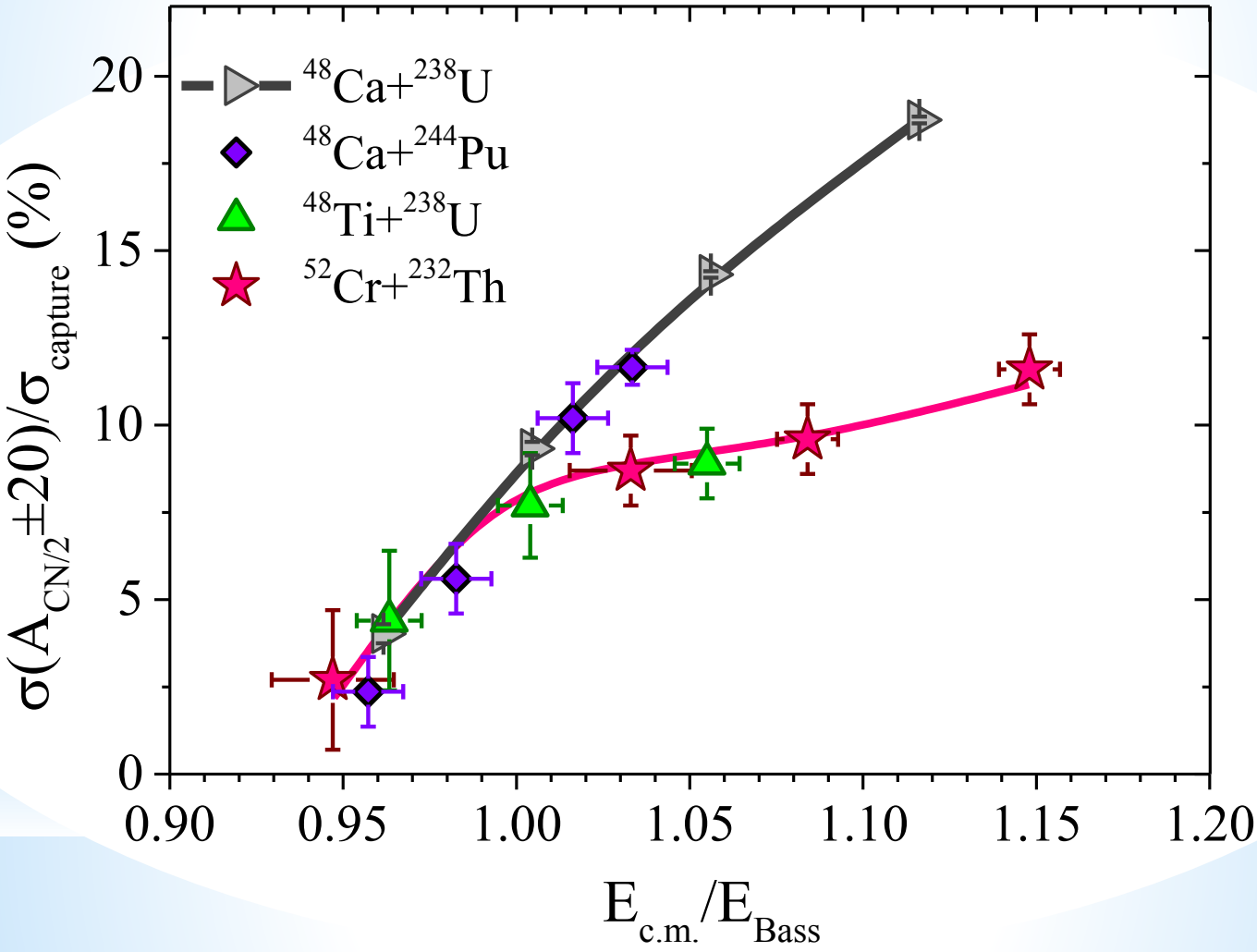
Z_tZ_p=2160
X_m=0.806

Z_tZ_p=2808
X_m=0.917

*Capture cross section



* Contribution of symmetric component into all fissionlike fragments



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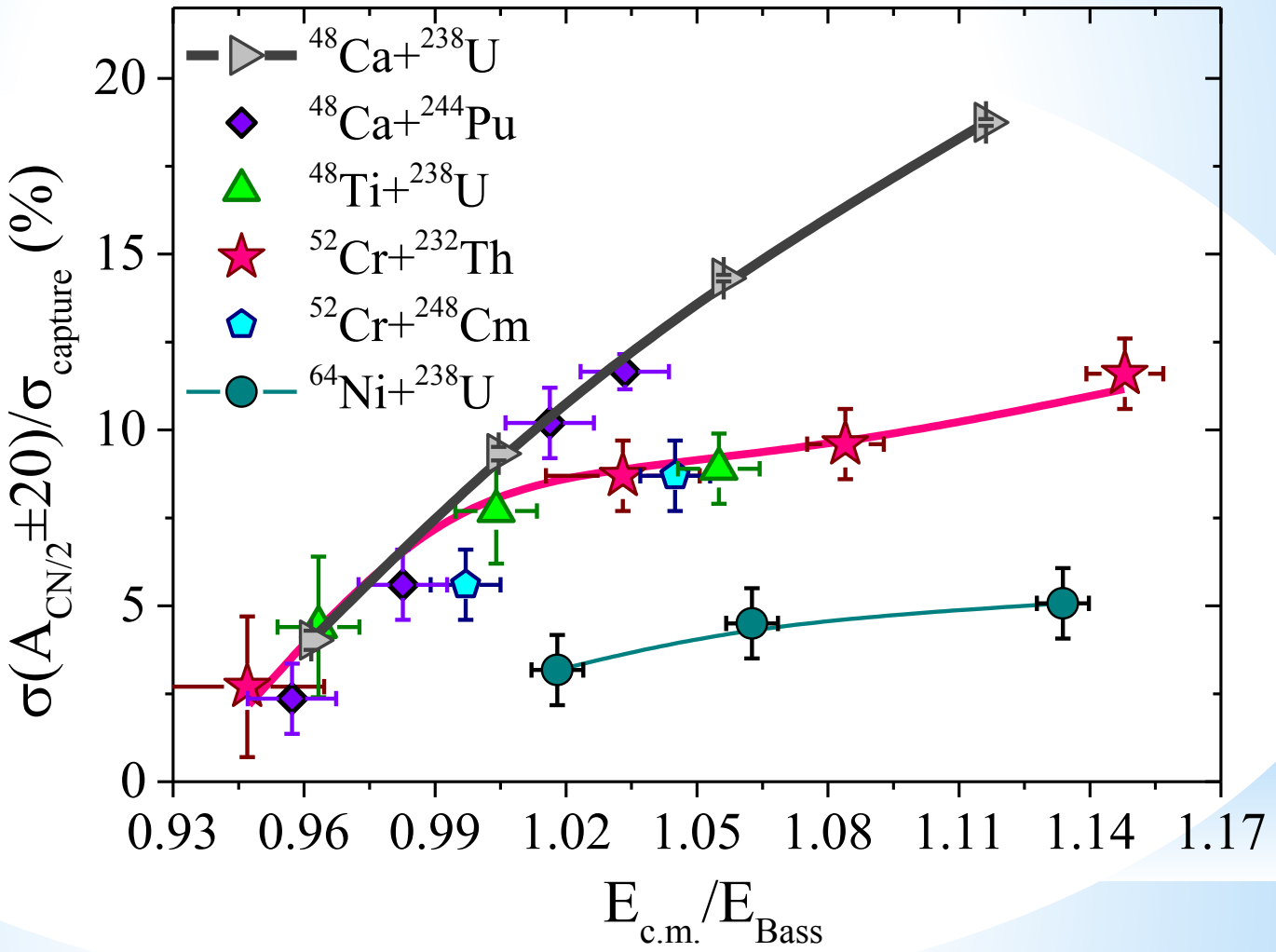
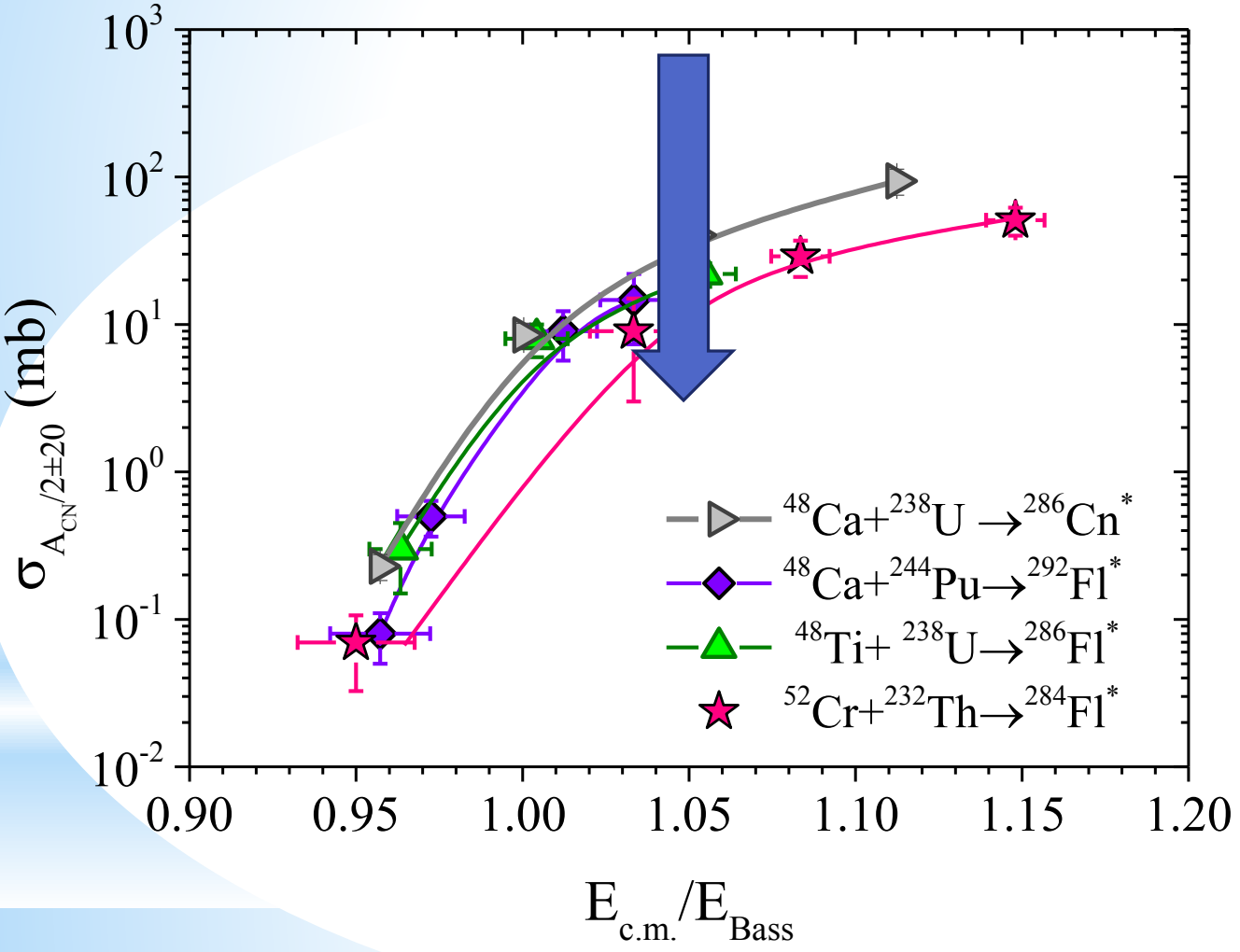


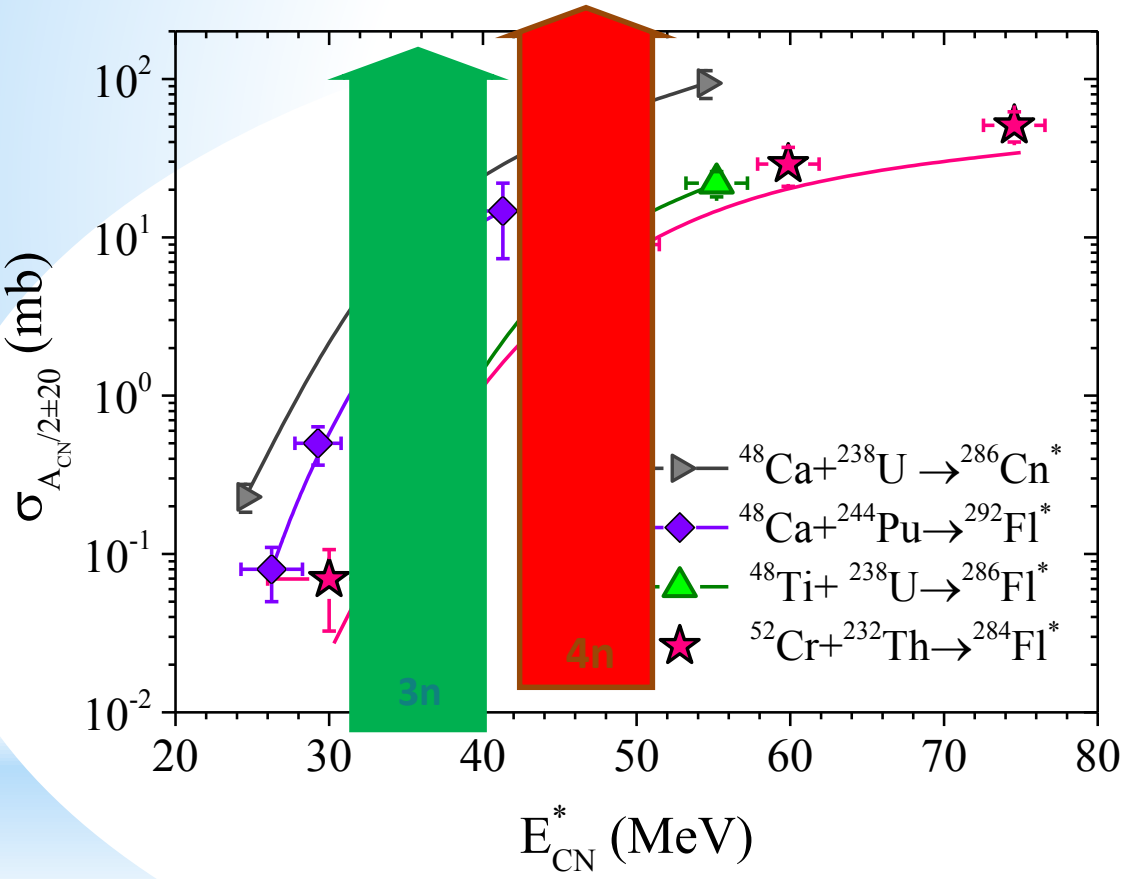
*CS of symmetric fragment formations



At energies above the barrier the CS for symmetric fragments formations decreases 2 times for the reaction $^{48}Ti+^{238}U$ and 4 times for the $^{52}Cr+^{232}Th$ compare with the $^{48}Ca+^{238}U$.

Note that a significant part of symmetric fragments may be connected with QF process. It is only upper limit for fission cross section!

* Cross sections of symmetric fragment formations



- **For 4*n* channel (E^*=40÷50MeV):**

$^{48}Ca+^{238}U \rightarrow ^{48}Ca+^{244}Pu$

$\sigma(A_{CN}/2\pm20)$ drops ~**2** times

$^{48}Ca+^{238}U \rightarrow ^{48}Ti+^{238}U$

$\sigma(A_{CN}/2\pm20)$ drops ~**10** times

- **For 3*n* channel (E^*=30÷40MeV):**

$^{48}Ca+^{238}U \rightarrow ^{48}Ca+^{244}Pu$

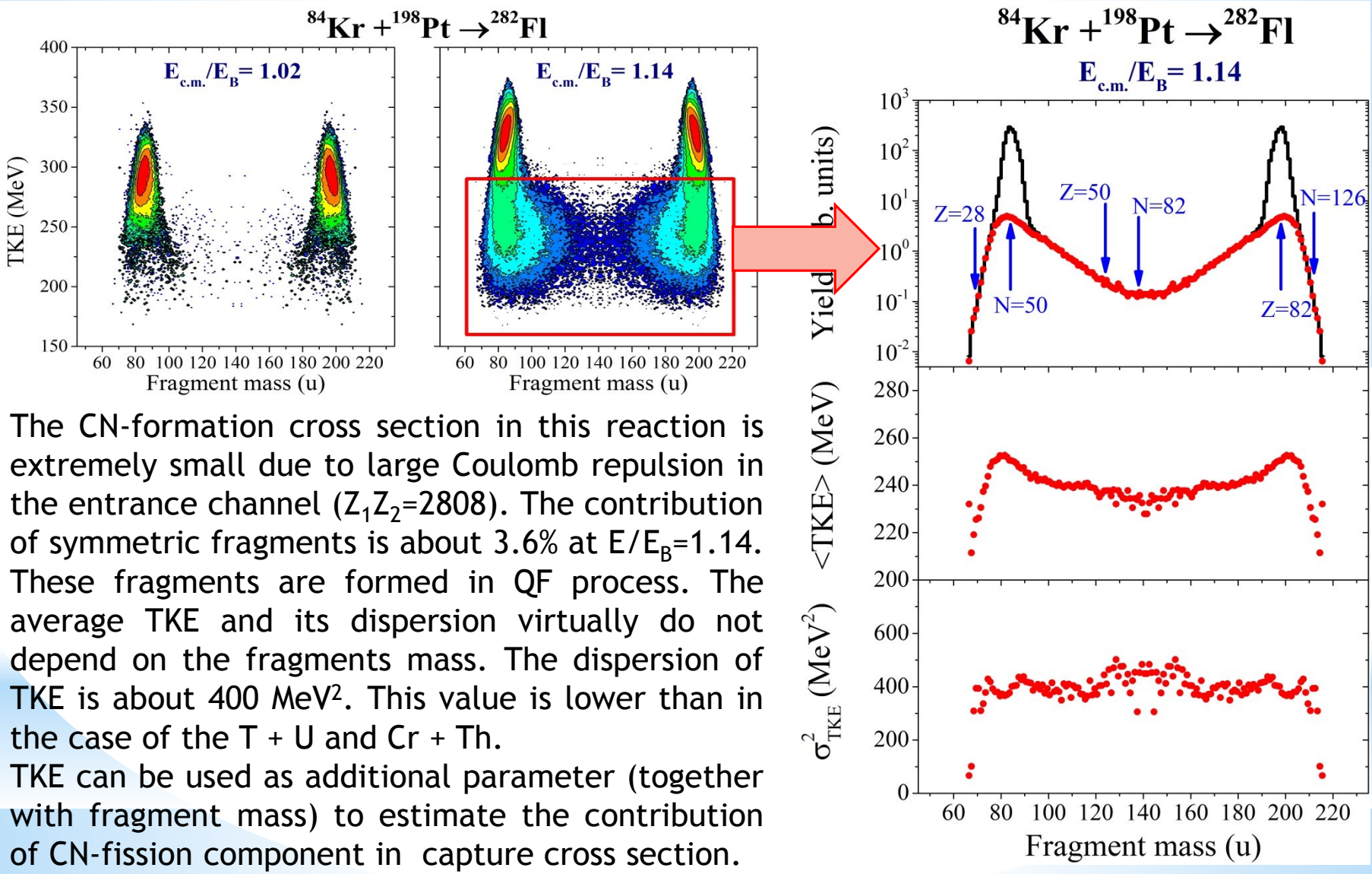
$\sigma(A_{CN}/2\pm20)$ drops ~**10** times

$^{48}Ca+^{238}U \rightarrow ^{48}Ti+^{238}U$

$\sigma(A_{CN}/2\pm20)$ drops ~**100** times

For the studied reactions the excitation energies at the barrier energy vary strongly (36MeV for the Ca+Pu, 44MeV for the Ti+U and 41MeV for the Cr+Th). It leads to decreasing the CS for the Ti+U and Cr+Th for 3n ER channel.

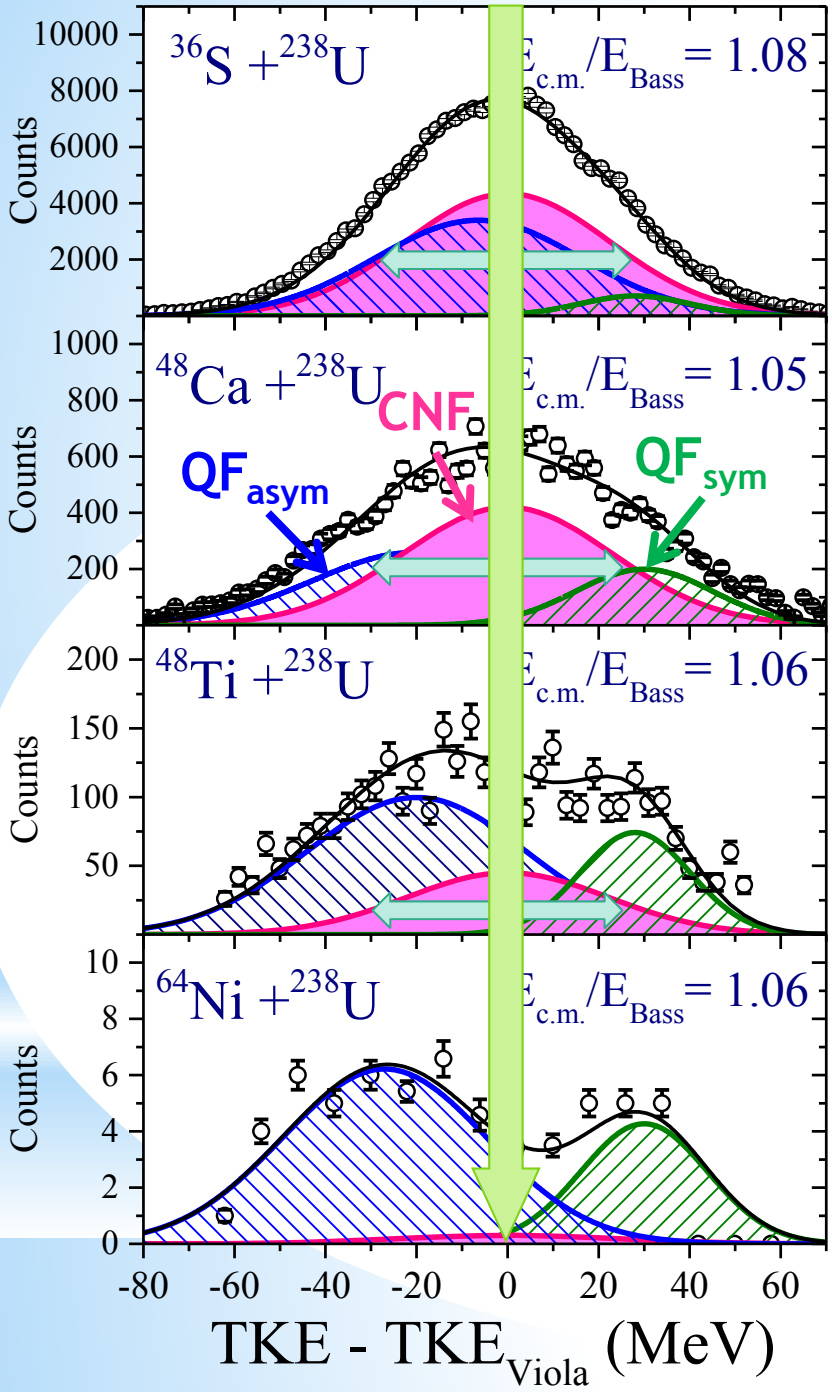
*The reaction $^{84}Kr+^{198}Pt$

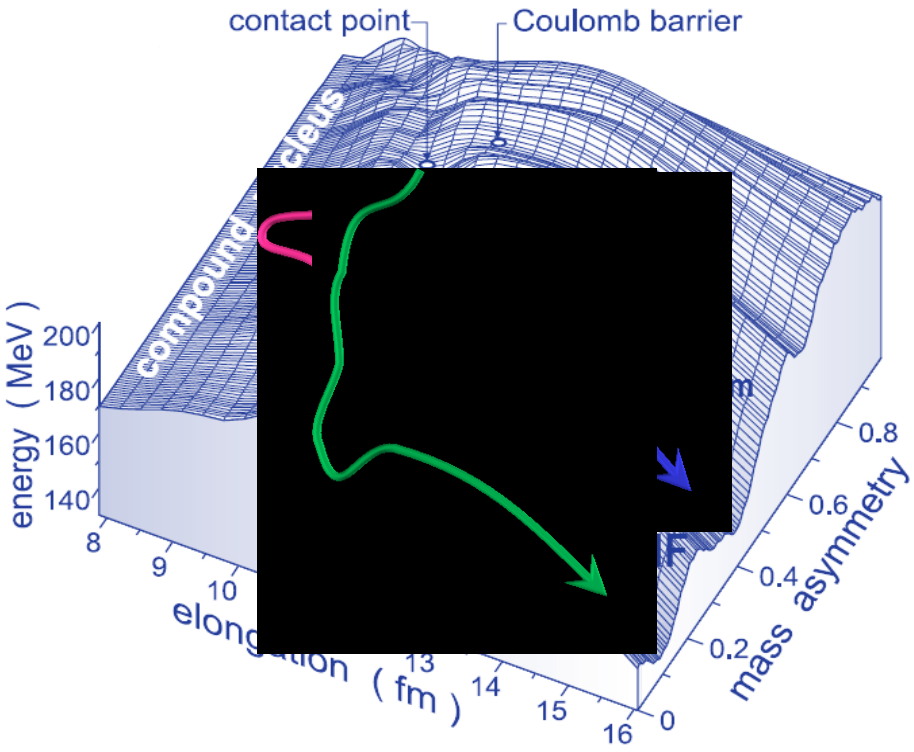


The CN-formation cross section in this reaction is extremely small due to large Coulomb repulsion in the entrance channel (Z_1Z_2=2808). The contribution of symmetric fragments is about 3.6% at E/E_B=1.14. These fragments are formed in QF process. The average TKE and its dispersion virtually do not depend on the fragments mass. The dispersion of TKE is about 400 MeV^2. This value is lower than in the case of the T + U and Cr + Th.

TKE can be used as additional parameter (together with fragment mass) to estimate the contribution of CN-fission component in capture cross section.

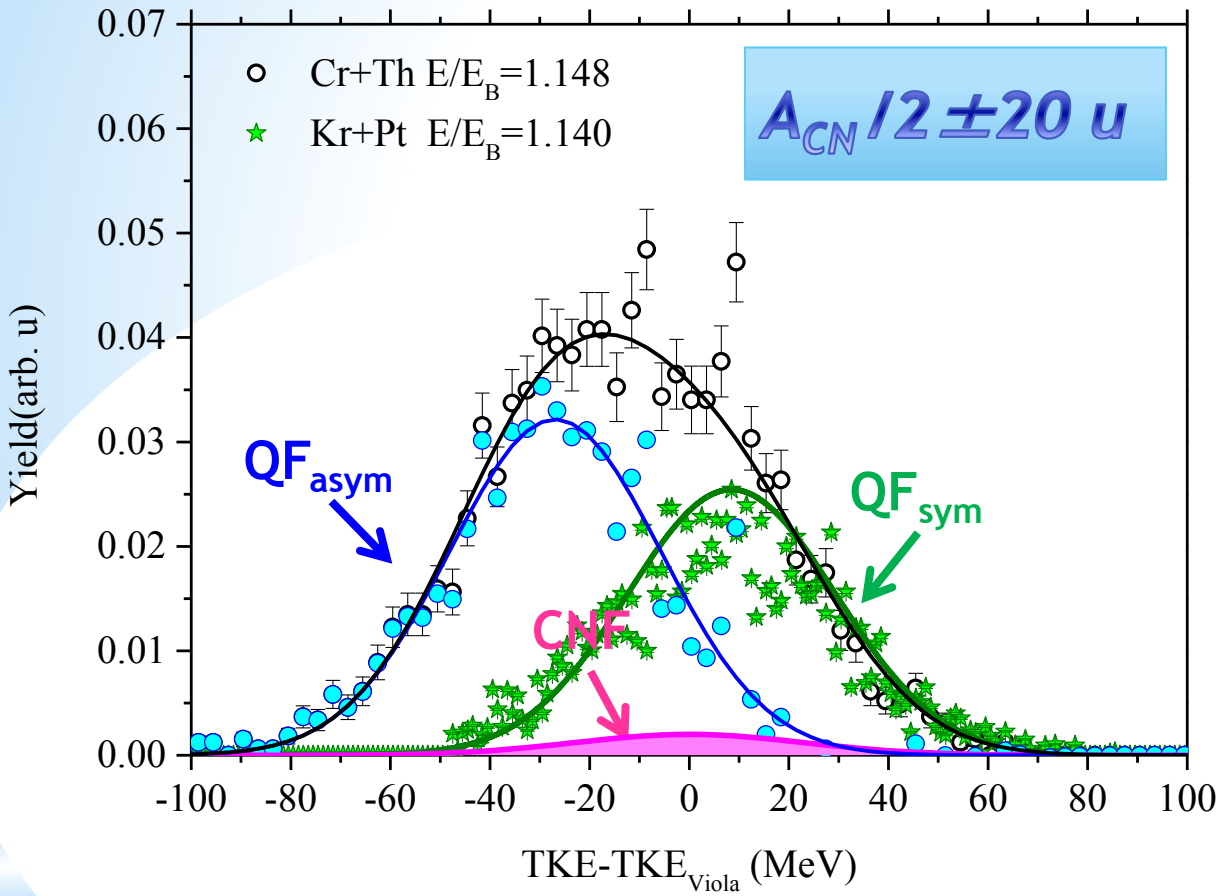
*TKE distributions





$A_{CN}/2 \pm 20$ u

*TKE distributions



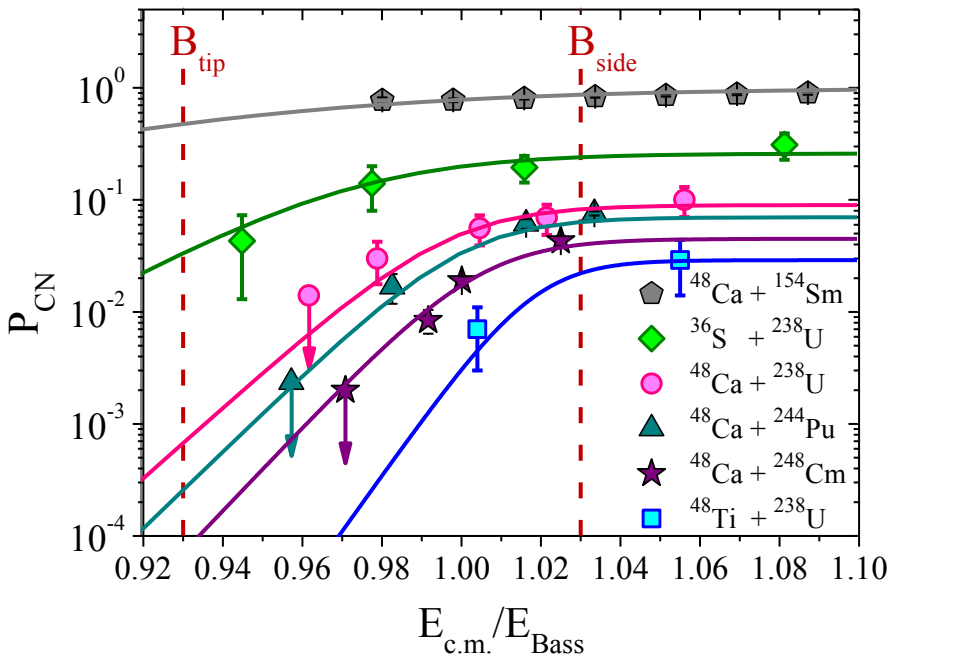
According to this decomposition of TKE distribution for the reaction $^{52}Cr+^{232}Th$ on QF_{sym} (assuming the same distribution as for the Kr+Pt), QF_{asym} and CNF (Viola systematics), the contribution of CNF is about **4%** for fragments with mass $A_{CN}/2\pm20u$.

The upper limit for CNF for the reaction $^{52}Cr+^{232}Th$ at energies $1.15E_B$ is only **0.4%** from capture CS. The estimated CNF cross section for the reaction $^{48}Ca+^{238}U$ is about **15%** from capture cross section.

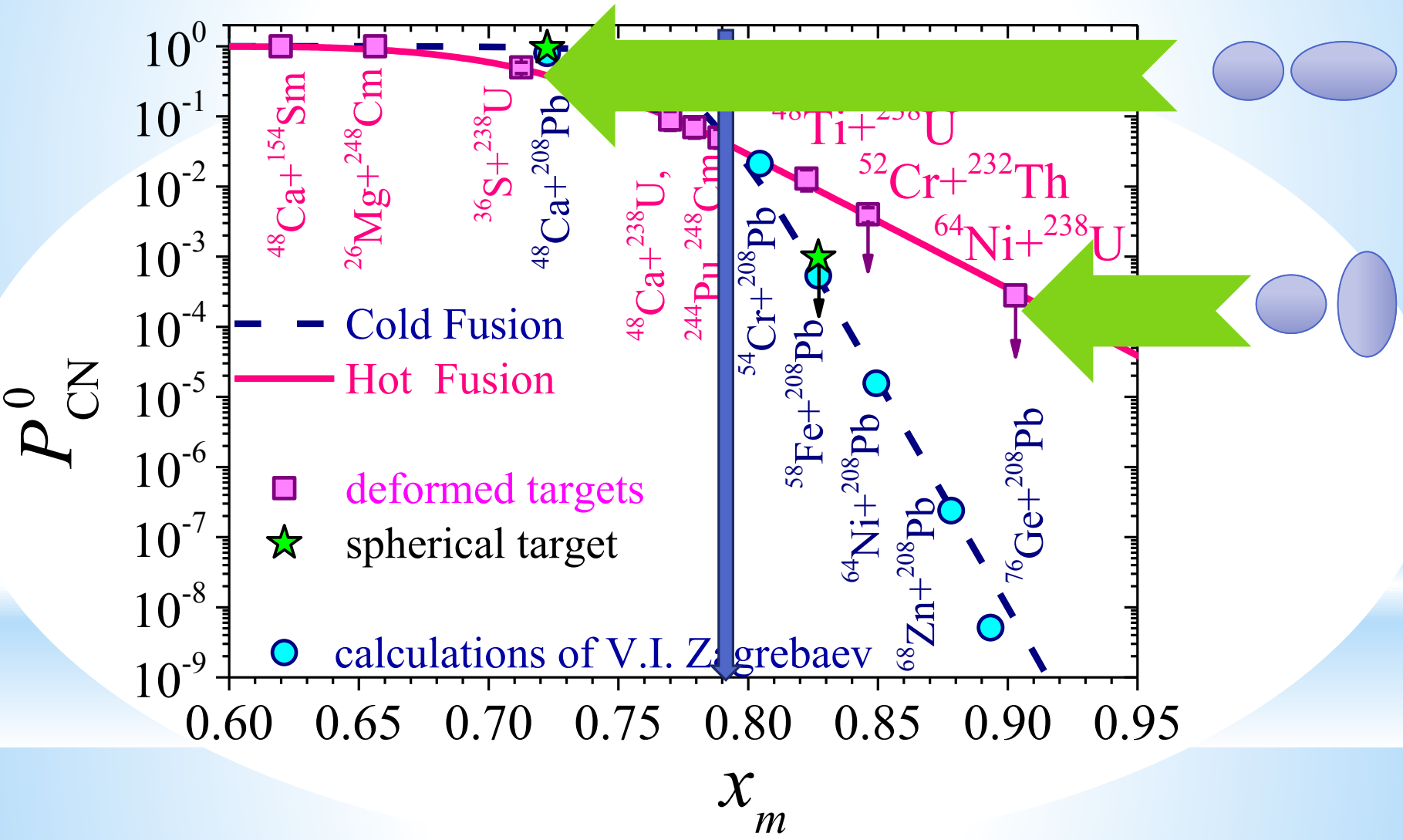
$^{48}Ca+^{238}U \rightarrow {}^{52}Cr+^{232}Th$ CNF CS drops more than **40** times!

* Fusion probability in the reactions with strongly deformed nuclei

$$P_{CN}(E_{c.m.}) = P_0 / \{1 + \exp[\alpha(\beta - E_{c.m.}/E_{Bass})]\}$$



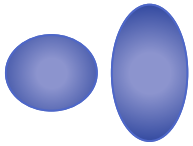
* Fusion Probability in Cold and Hot fusion reactions



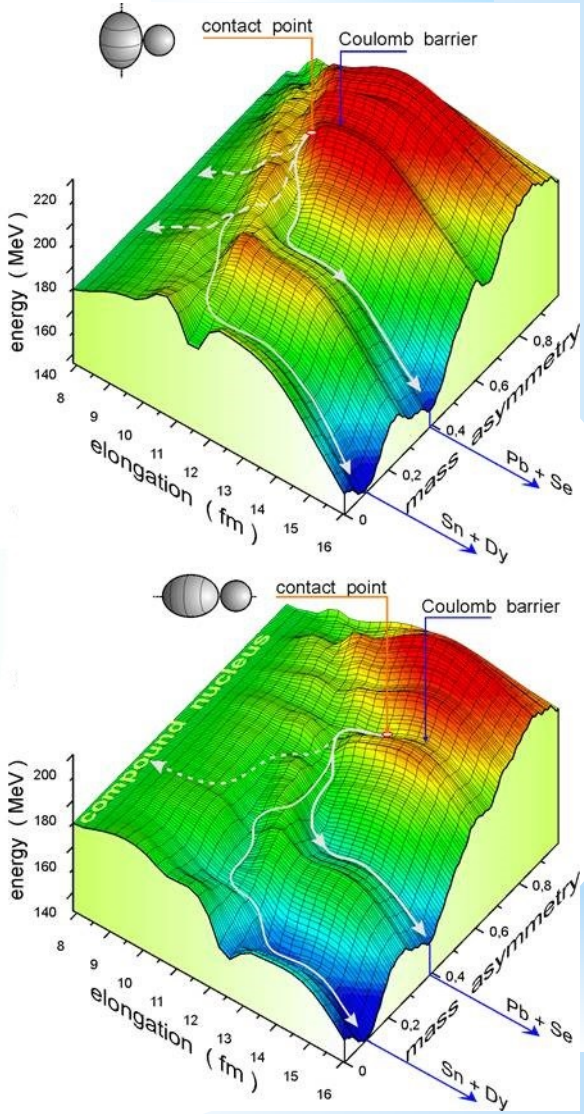
* Orientation effect of deformed interacting nuclei on reaction mechanism

Axial configuration

Equatorial configuration



$^{48}Ca+^{248}Cm$

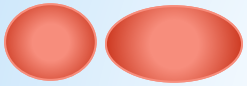


Reactions with oriented target nuclei will allow to increase the CN formation cross section (about one order of magnitude) due to the selection of equatorial configurations.

- The possibility to produce of polarized actinide targets (use for example $UO_2Rb(NO_3)_3$ *From J.M. Daniels and J. Goldemberg Rep. Prog. Phys. 25 (1962) 301*
- The degree of orientation which can be achieved
- Radiation damage of oriented targets

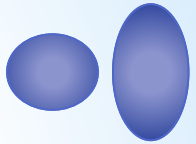
V.I. Zagrebaev, DANF2006

* Orientation effect of deformed interacting nuclei on reaction mechanism



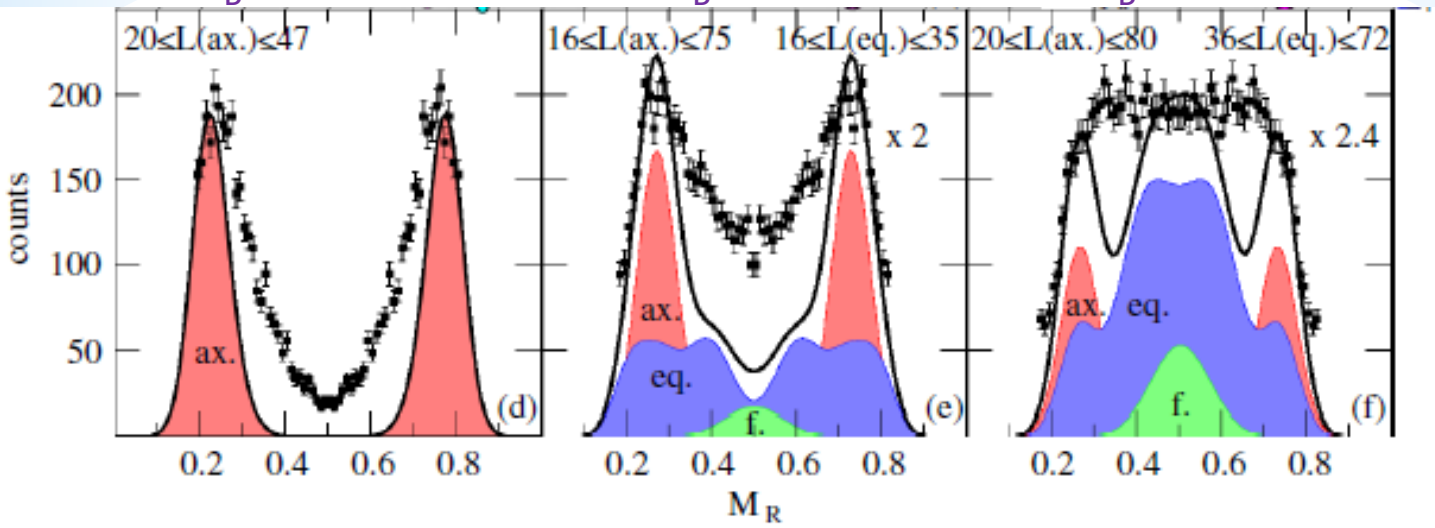
Axial configuration

Equatorial configuration



$^{40}Ca+^{238}U$

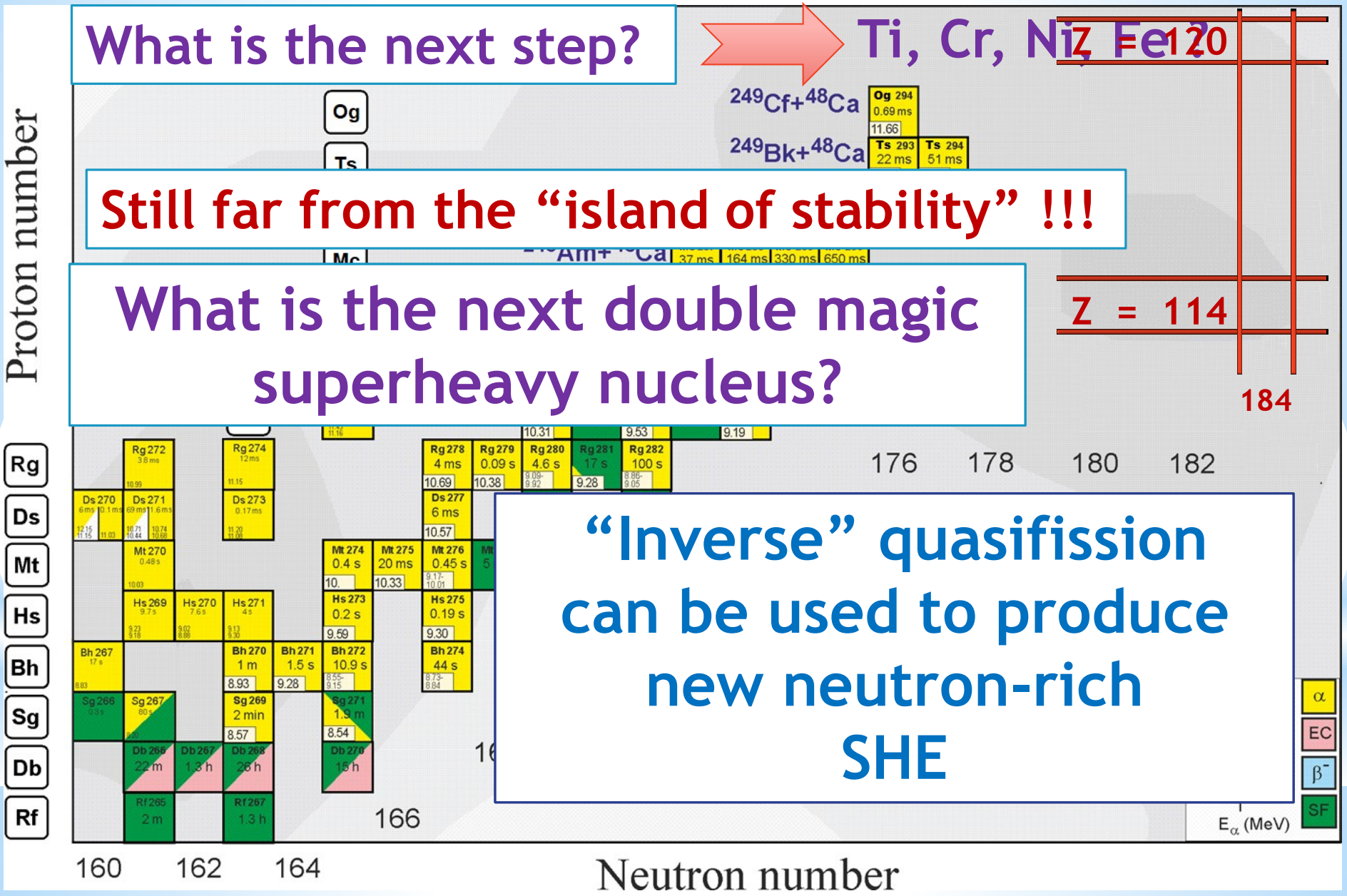
$E/E_B=0.946$ $E/E_B=1.044$ $E/E_B=1.142$



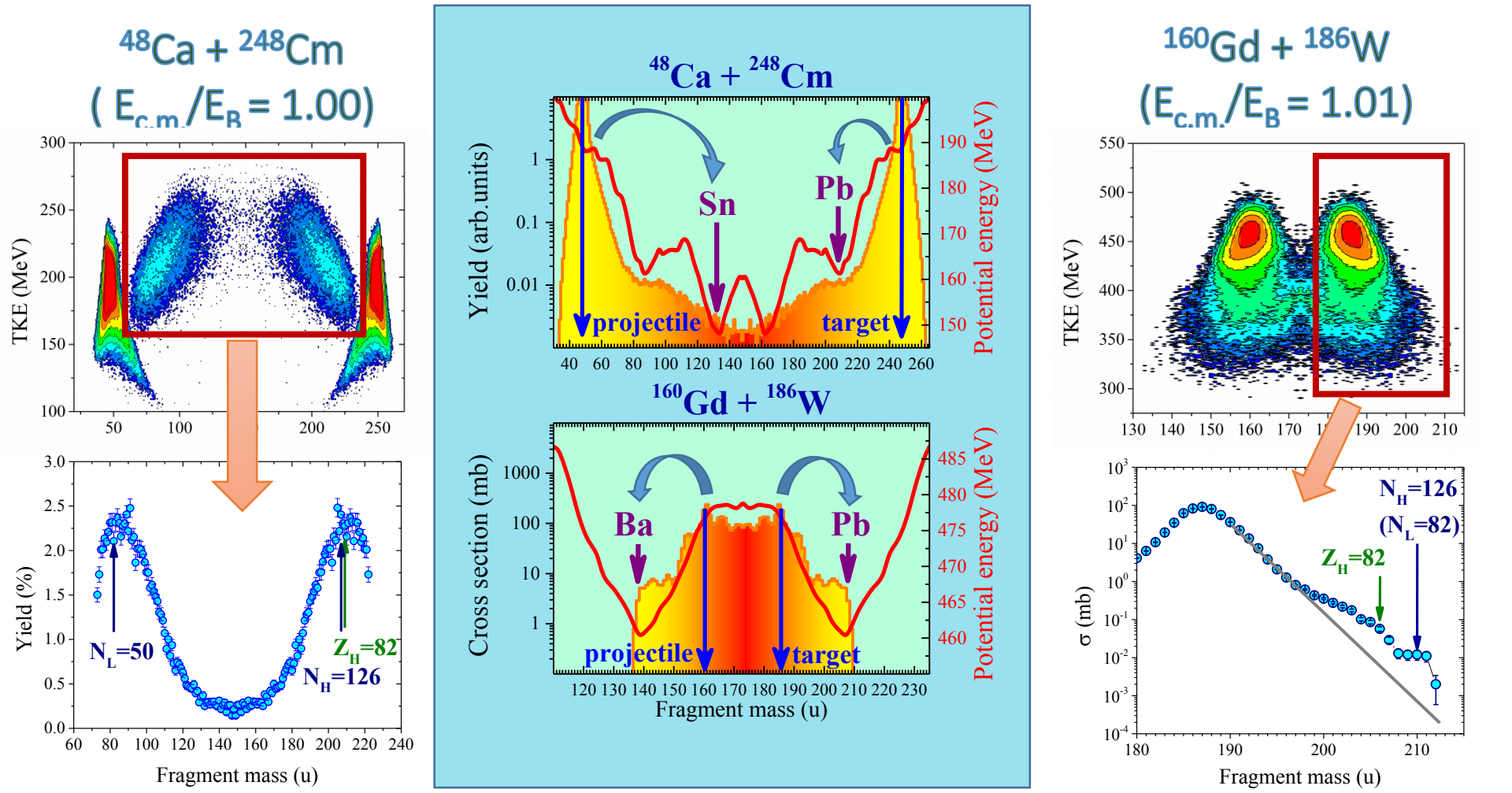
From A. Wakhle et al., Phys. Rev. Lett 113, 182502 (2014)
ax - axial configurations; eq .-equatorial configurations

It was demonstrated within microscopic quantum calculations an unexpected interplay between the orientation of the prolate deformed ^{238}U with quantum shell effects in the fragments. In particular, calculations show that only collisions with the tip of ^{238}U produce quasifission fragments in the magic Z =82 region, while collisions with the side are the only ones that may result in fusion.

*Search for superheavies



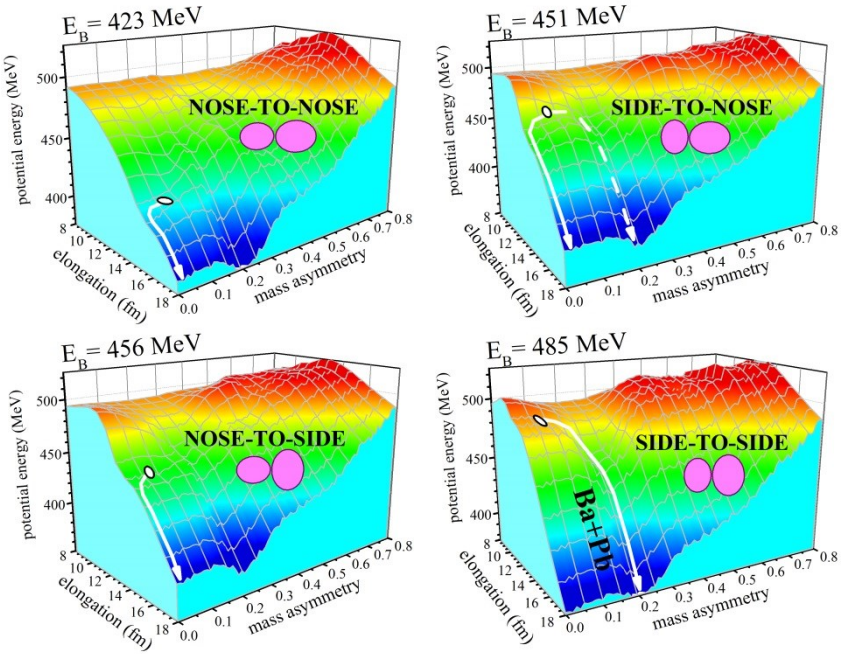
Normal ← Quasifission → Inverse



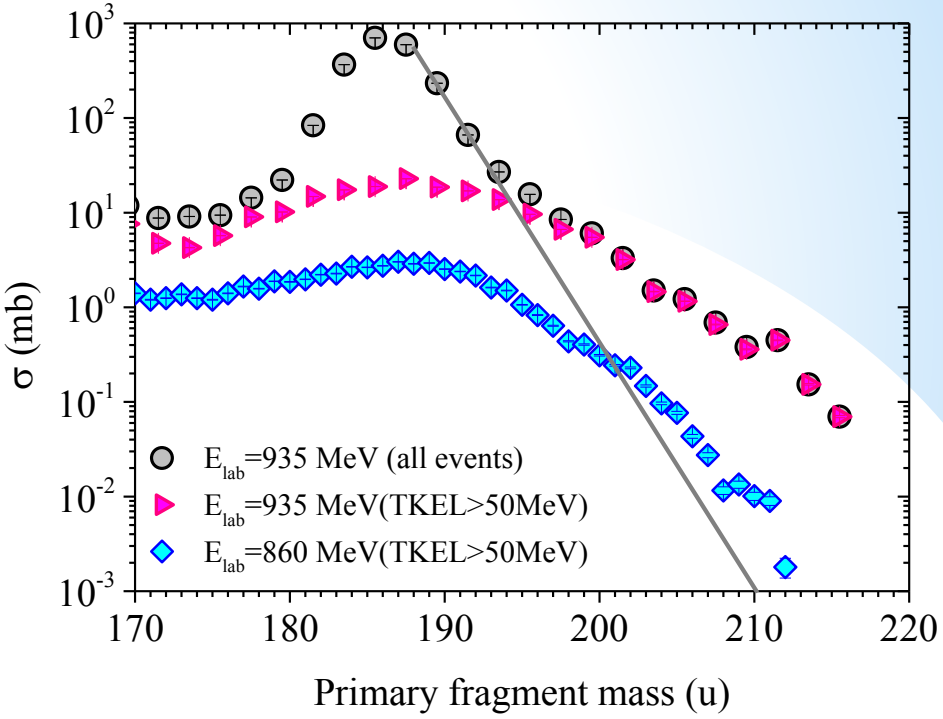
The **inverse** quasifission process proposed to produce SHE in collisions of transactinides and the role of shell effects in inverse QF can be studied in the experiments with **less heavy nuclei** [**V. Zagrebaev and W. Greiner, J.Phys.G 34 (2007) 2265**].

* Orientation effect in the reaction $^{186}W+^{160}Gd$

Calculated by A. Karpov



E.M. Kozulin et al, to be published



The resent study of the reaction $^{186}W+^{160}Gd$ shows that the orientation effect caused by the strong deformation of colliding nuclei also plays an important role in the formation of the reaction fragments that can give a gain in the yield of Pb-like fragments in the case of side-to-side configurations. At energy 935 MeV which is above the barrier for side-to-side collision it was found that the formation cross sections of Pb-like fragments with mass~208u on about 50 time higher than for fragments formed in the $^{160}Gd+^{186}W$ at energy 860 MeV.

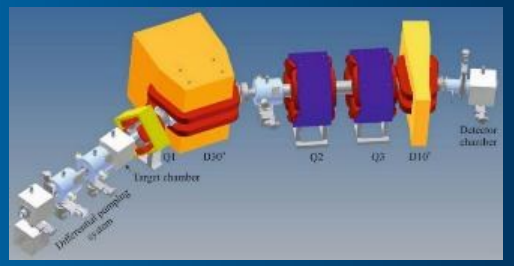
* Superheavy Elements (SHE) Factory – the Goals

- **Experiments at the extremely low (σ<100 fb) cross sections:**
  - Synthesis of new SHE in reactions with ^{50}Ti, ^{54}Cr ...(119, 120);
  - Shaping of the region of SHE (synthesis of new isotopes of SHE);
  - Study of decay properties of SHE;
  - Study of excitation functions.

- **Experiments requiring high statistics:**
  - Nuclear spectroscopy of SHE;
  - Precise mass measurements;
  - Study of chemical properties of SHE.

SuperHeavy Elements (SHE) Factory

High-current cyclotron DC-280

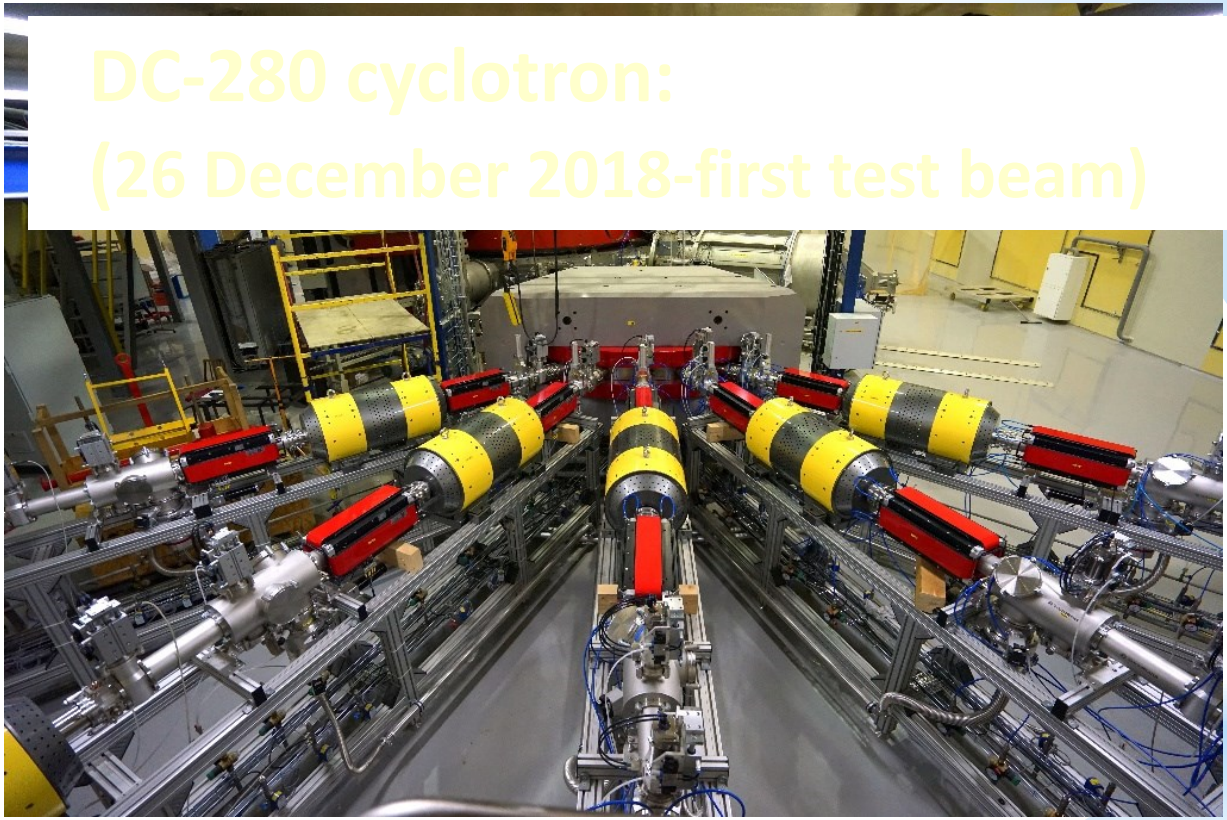


New gas-filled separator

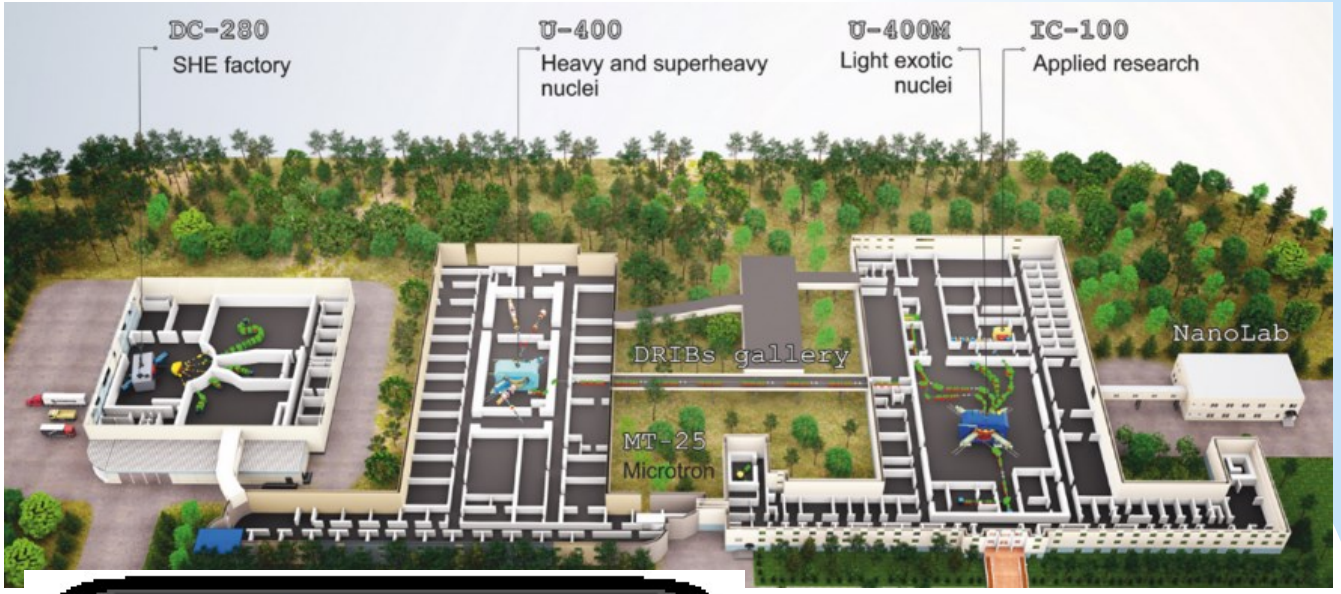
SHE Factory building

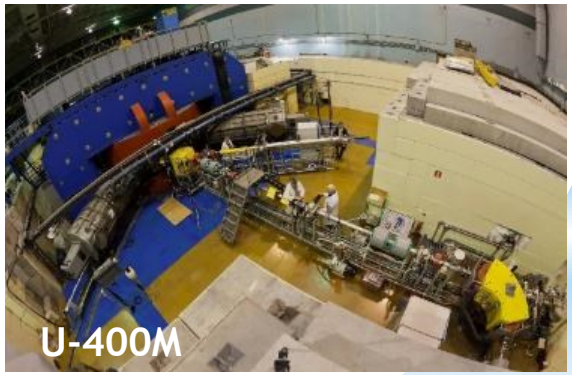
Gas-Filled Recoil Separator

DC-280 cyclotron:
(26 December 2018-first test beam)



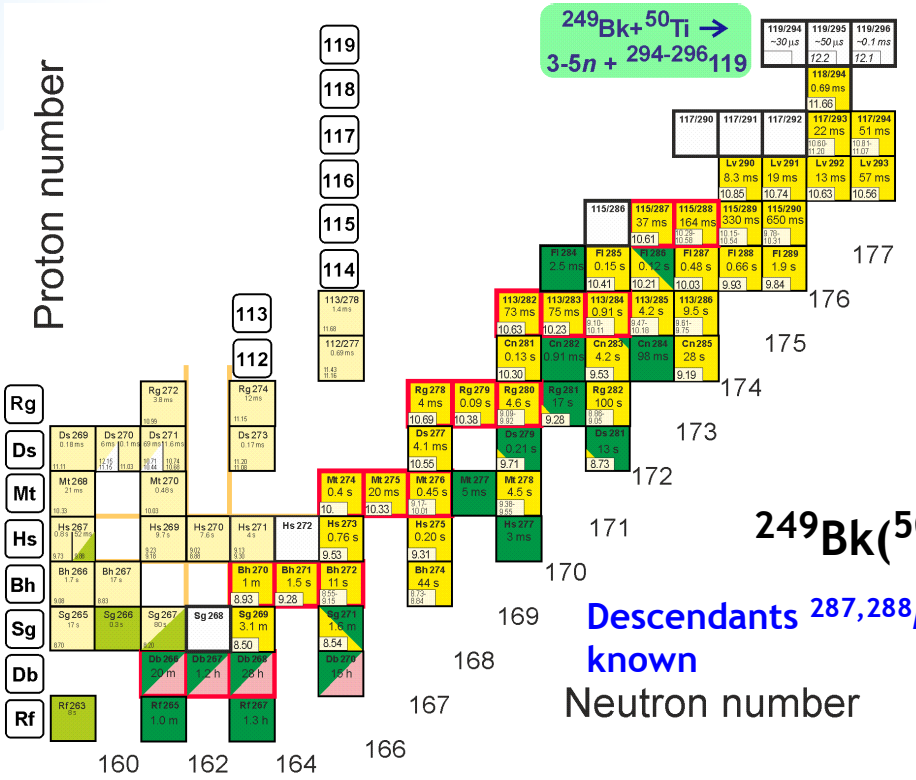
Dubna Radioactive
Ion Beam ac
comple DRIB





First experiments at SHE Factory

Synthesis of new element 119



$^{249}Bk(^{50}Ti, 3\text{-}4n)^{295,296}119$

Descendants $^{287,288}Mc$, $^{282\text{-}294}Nh$… are known

s=50 fb, h_t=0.3 mg/cm^2, ε_{coll}=0.6, I_{beam}=3 pmA → ≈1 event per month

Thank You!