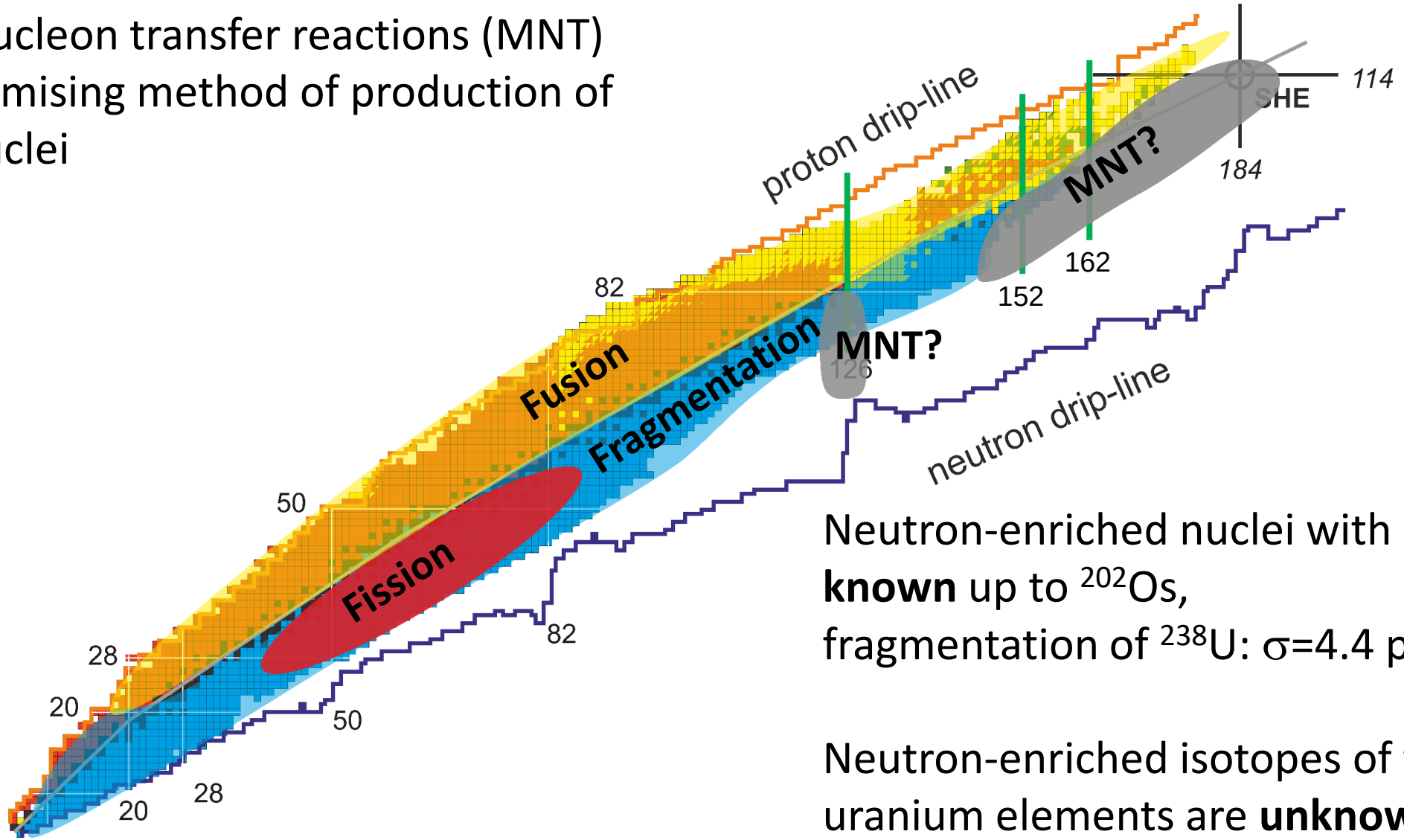
EMMI workshop
“New avenues for the low-energy NUSTAR program at GSI/FAIR”
September 16-17, 2021

Synthesis of neutron-enriched nuclei near closed neutron shells N=126, 152, 162

Alexander Karpov and Vyacheslav Saiko

Methods of production of new nuclei

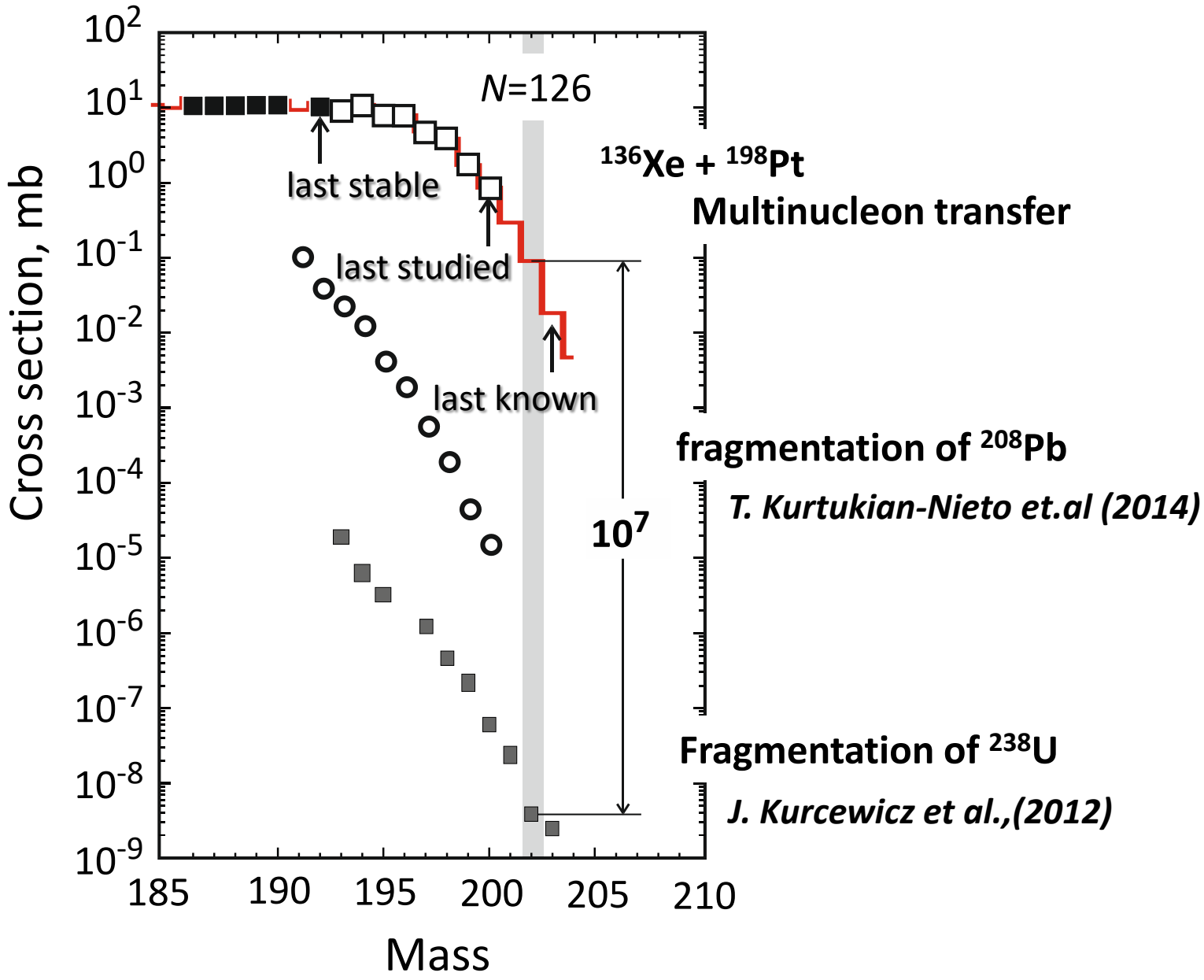
Multinucleon transfer reactions (MNT) is a promising method of production of new nuclei



Neutron-enriched nuclei with N=126: **known** up to ^{202}Os, fragmentation of ^{238}U: σ=4.4 pb

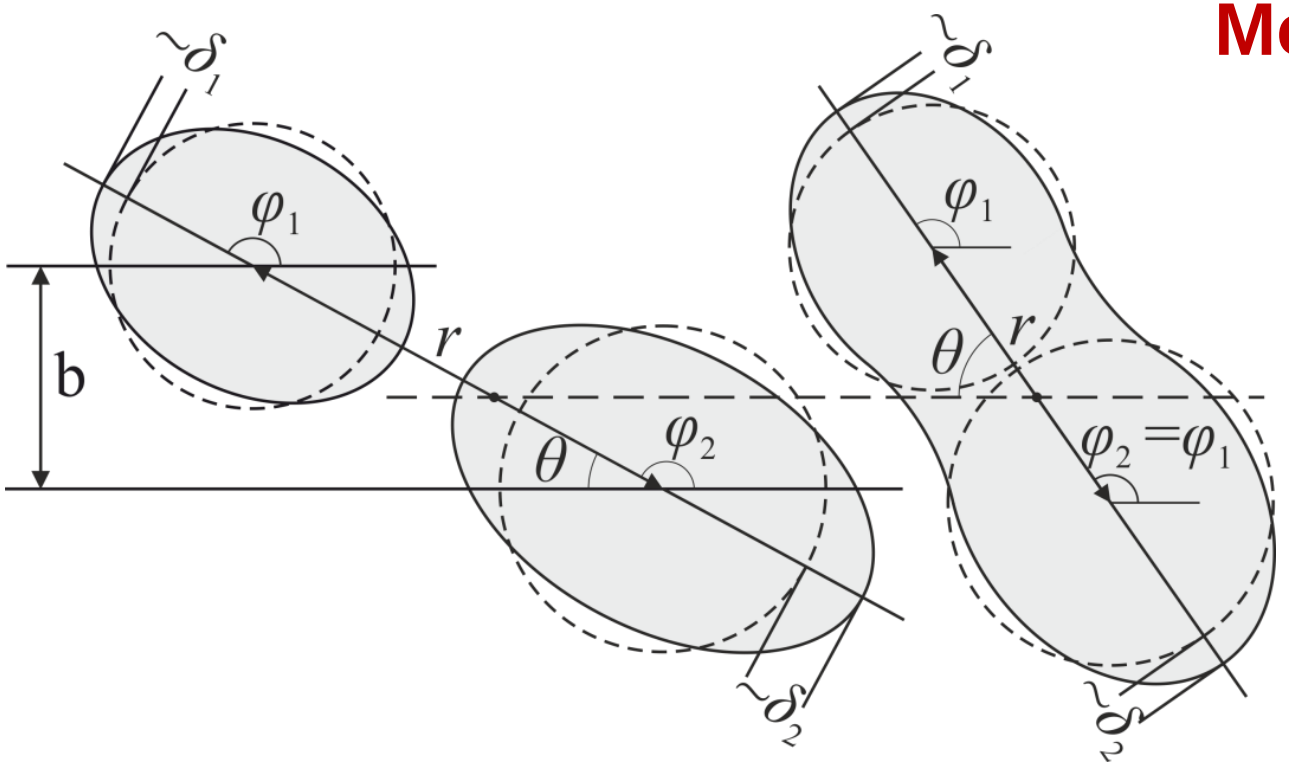
Neutron-enriched isotopes of trans-uranium elements are **unknown**

Production of neutron-enriched Os isotopes



Model

A.V. Karpov and V.V. Saiko,
Phys. Rev. C 96, 024618 (2017)
Phys. Rev. C 99, 014613 (2019)



$$\dot{q}_i = \mu_{ij} p_j,$$

$$\dot{p}_i = T\left(\frac{\partial S}{\partial q_i}\right)_{E_{tot}} - \sum_{j,k} \gamma_{ij}\mu_{jk} p_k + \sum_j \theta_{ij}\xi_j$$

system of Langevin equations

driving, friction and random forces

r – distance between centers of nuclei

$\delta_{1,2}$ – ellipsoidal deformations

η_A – mass asymmetry

η_Z – charge asymmetry

$$\eta_A = \frac{A_1 - A_2}{A_{CN}} \qquad \eta_Z = \frac{Z_1 - Z_2}{Z_{CN}}$$

θ – angle between symmetry axis and beam direction

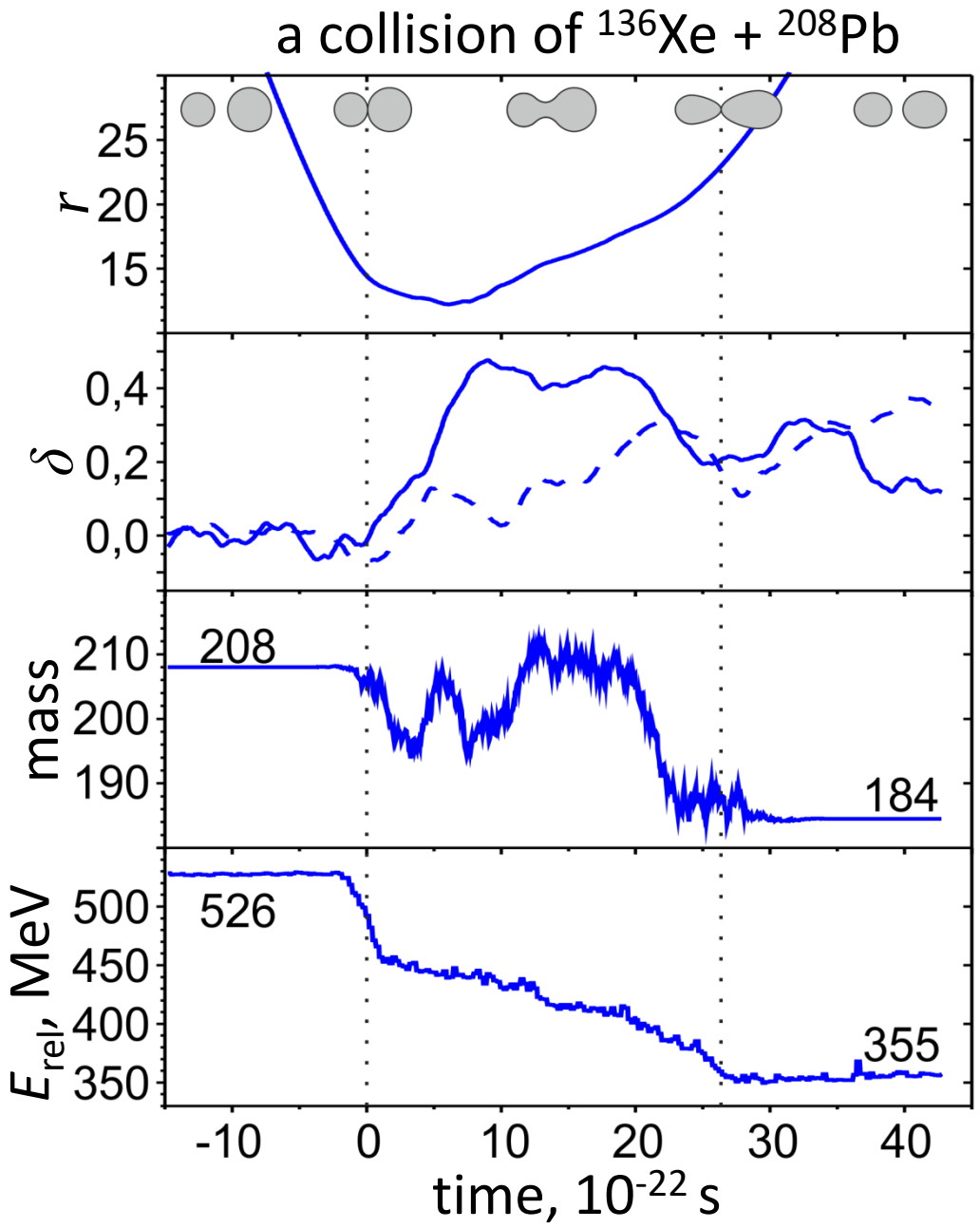
$\varphi_{1,2}$ – angles of rotation of nuclei in the reaction plane

$\mu_{ij} = m_{ij}^{-1}$ – mass tensor

γ_{ij} – dissipation tensor

θ_{ij} – amplitude of random force

ξ_i – random value



Model

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each **trajectory** of a collision provides:

- Z and A of fragments,
- scattering angle,
- kinetic energy,
- excitation energy,
- reaction time,
- …

Final fragments are simulated by means of

- **statistical model** of decay of heavy excited nuclei,
- **GEF** code http://nrv.jinr.ru

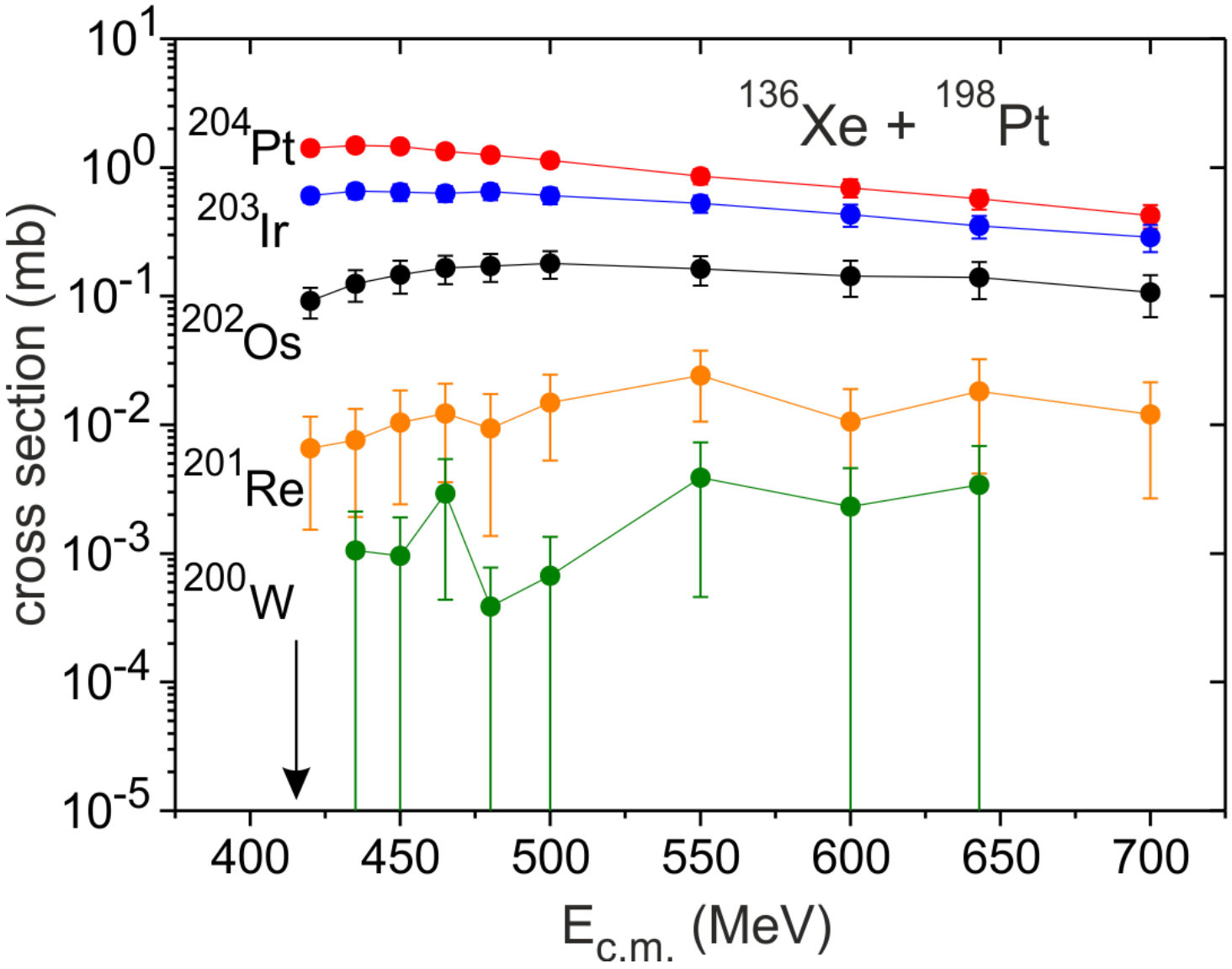
http://www.khschmidts-nuclear-web.eu/GEF.html

differential reaction cross section:

$$\frac{d^4\sigma}{dZdAd\Omega dE}(Z,A,E,\theta)=\int_0^{b_{\max}}\frac{\Delta N(b,Z,A,E,\theta)bdb}{N_{tot}(b)\Delta Z\Delta A\sin\theta\Delta\theta\Delta E}$$

Production nuclei with *N*=126

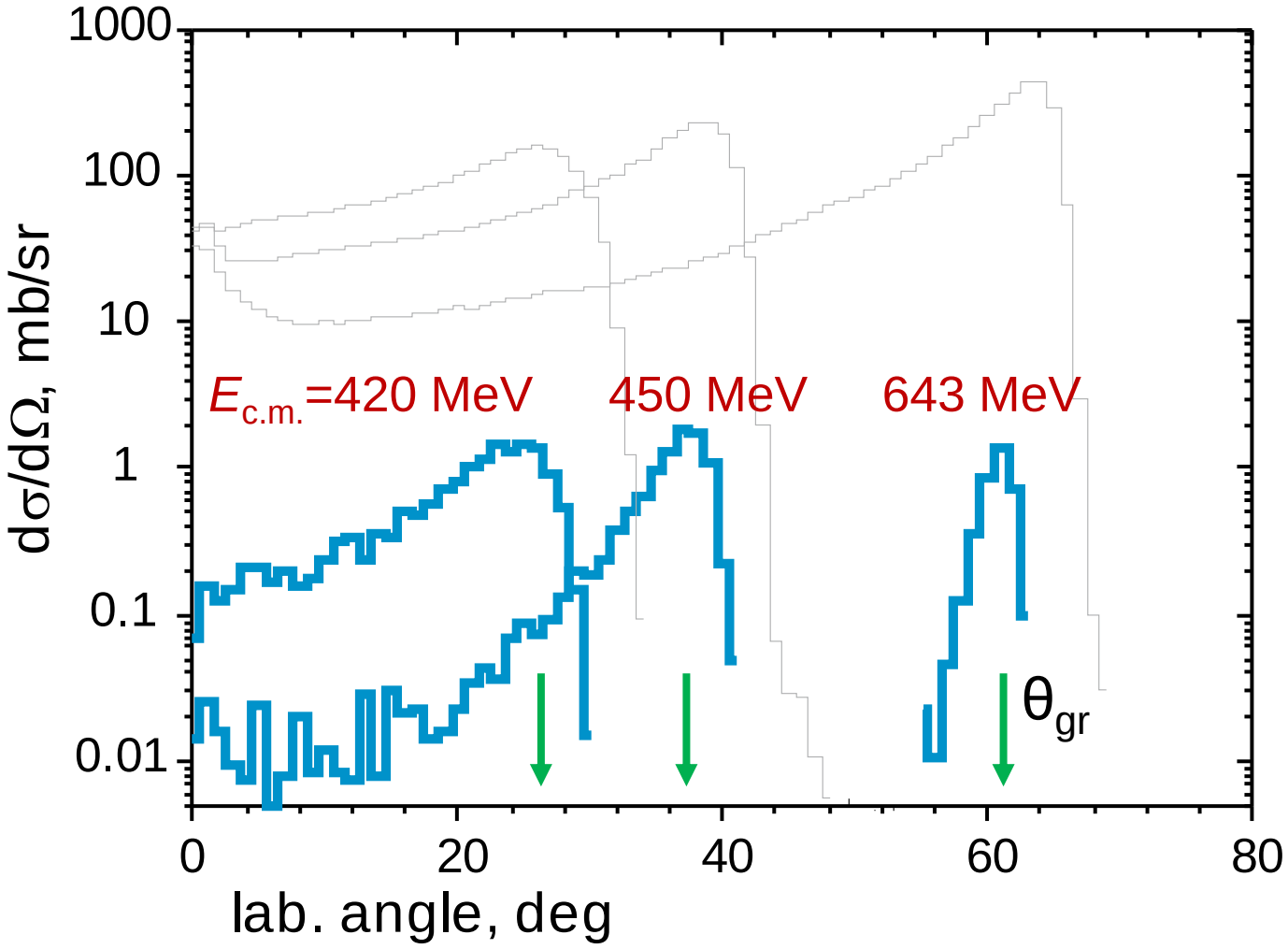
Optimal collision energy



Scattering angles

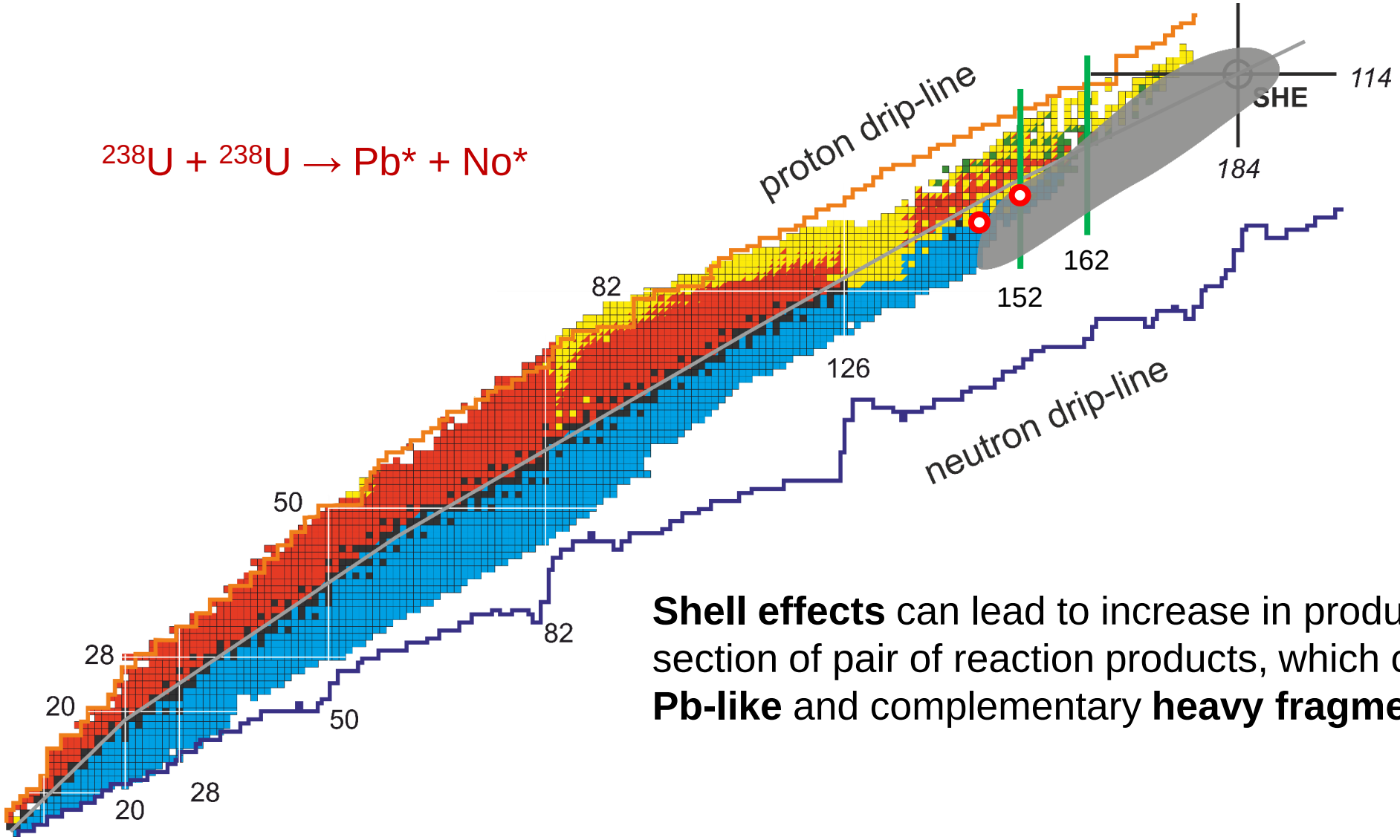
Ir isotopes

$^{136}Xe+^{198}Pt$



Production neutron-enriched isotopes of heavy and superheavy elements in collisions of two actinides (U + U, Cm, …)

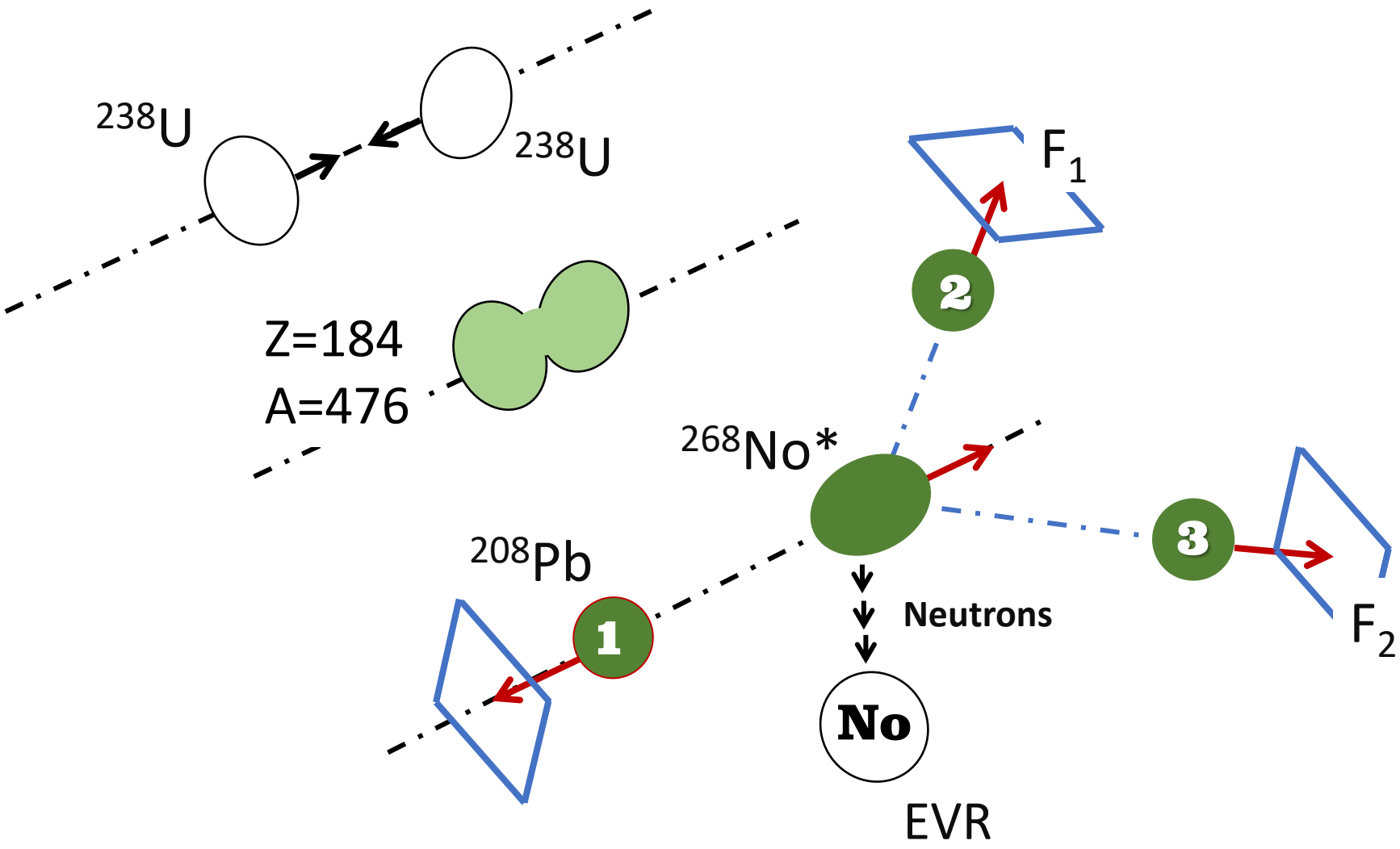
$^{238}U + {}^{238}U \rightarrow Pb^* + No^*$



Shell effects can lead to increase in production cross section of pair of reaction products, which consists of **Pb-like** and complementary **heavy fragment**

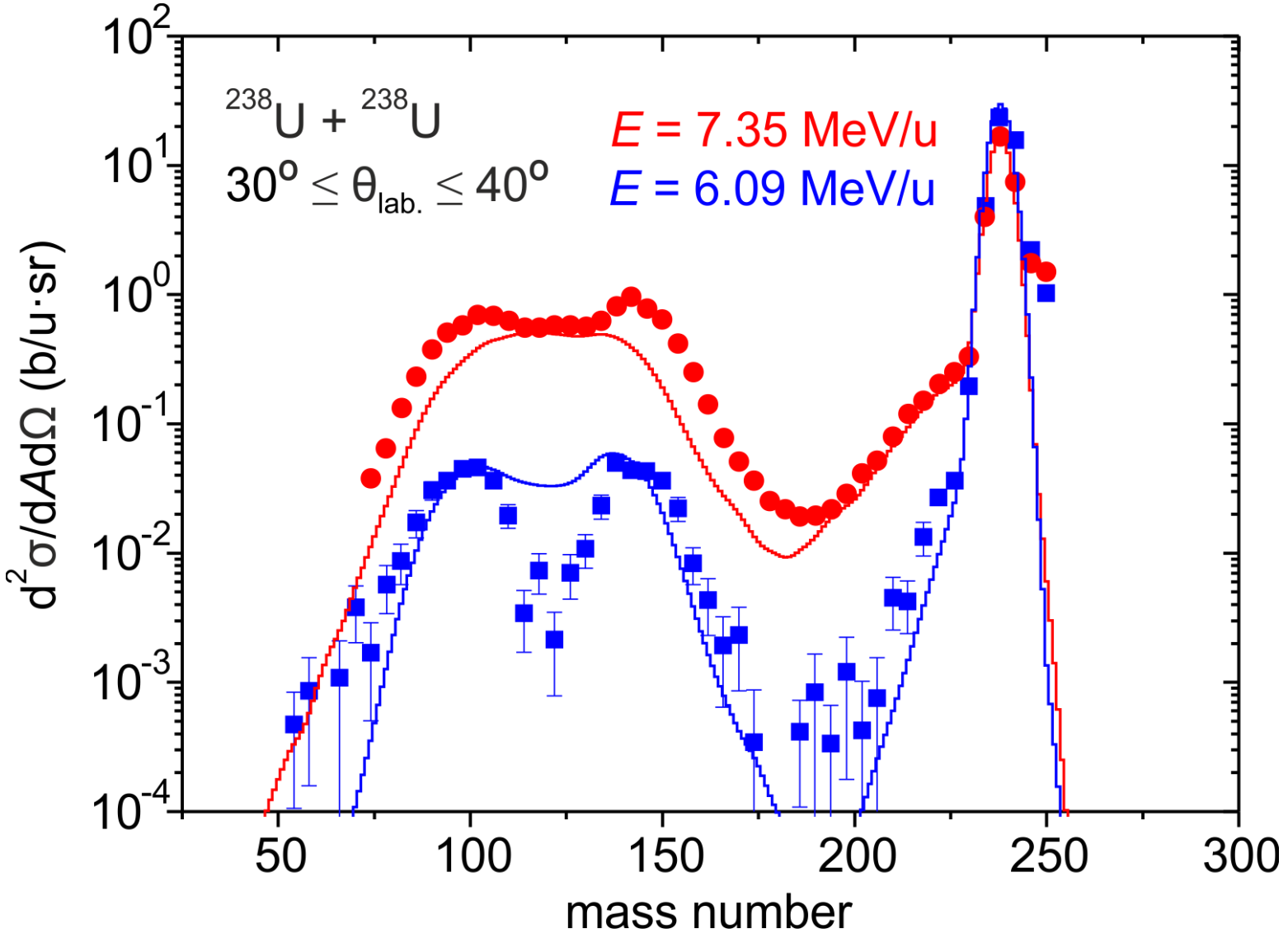
A.V. Karpov and V.V. Saiko, to be published (2021)

$^{238}U + ^{238}U$: reaction products



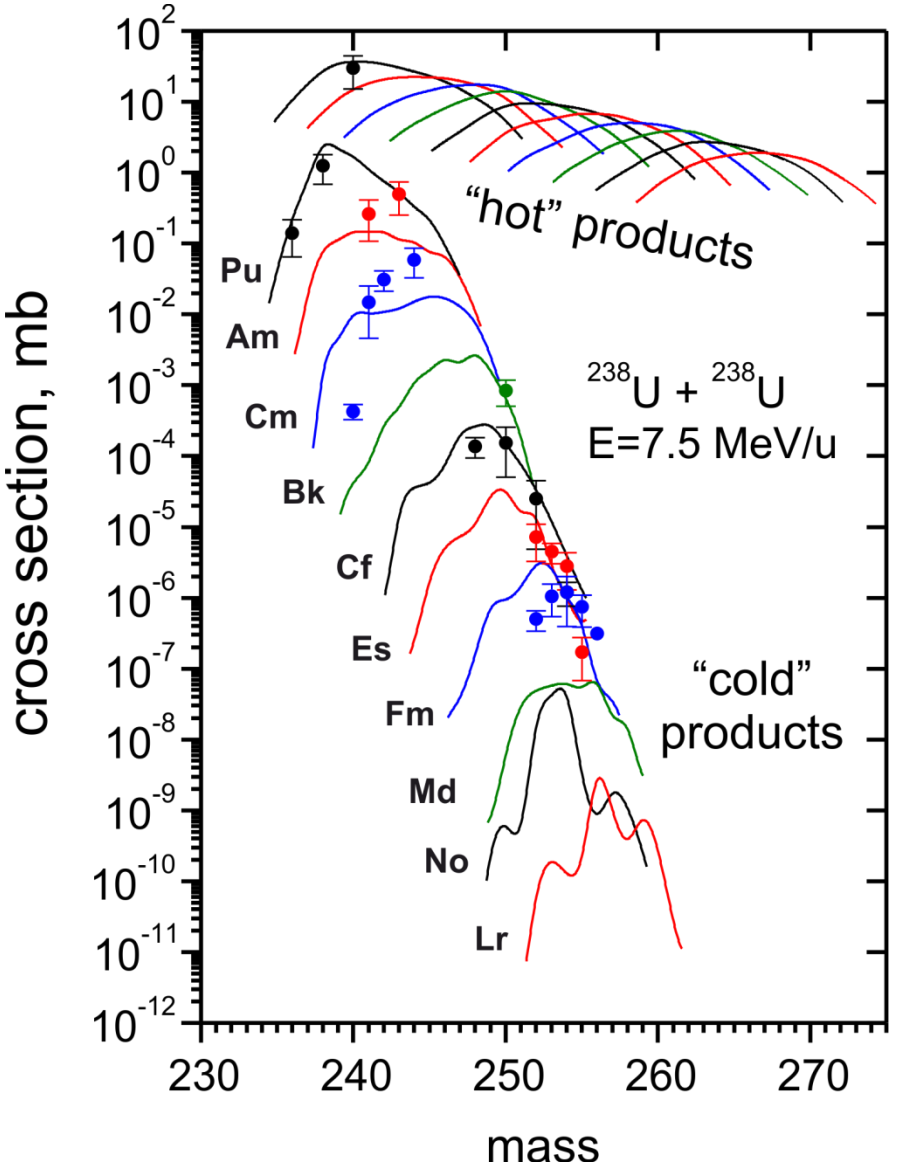
from Yu. Oganessian report

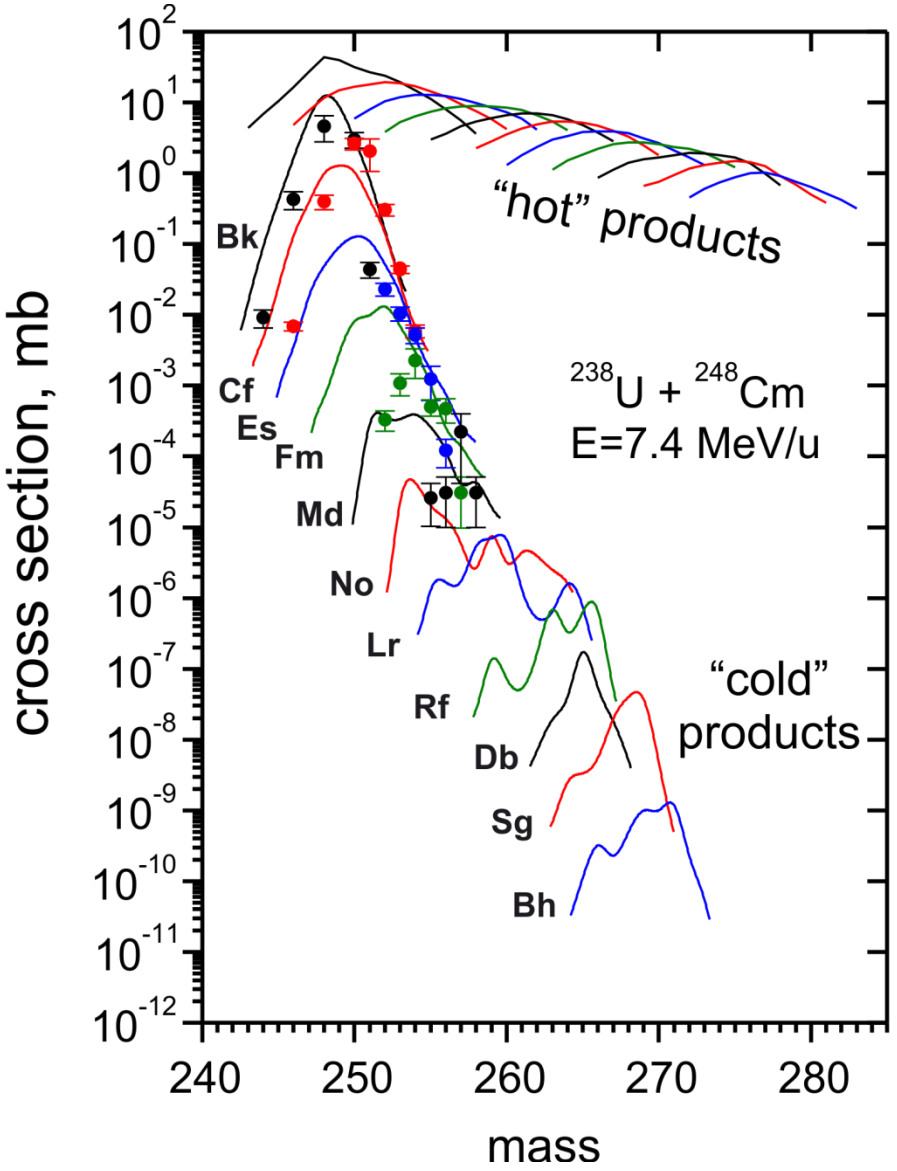
^{238}U + ^{238}U: reaction products



Exp.: C. Golabek et al., EPJA 43, 251 (2010)

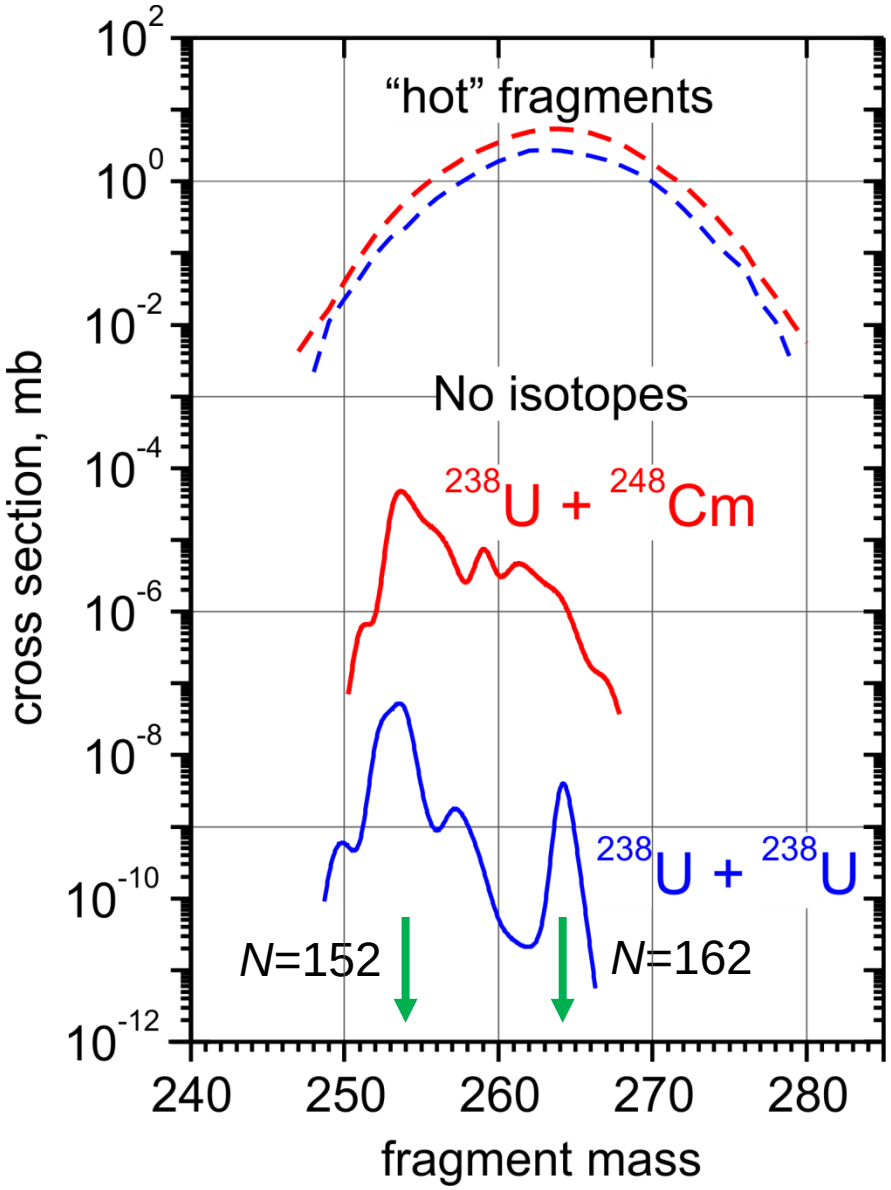
Synthesis of the heaviest products in U + U, Cm reactions

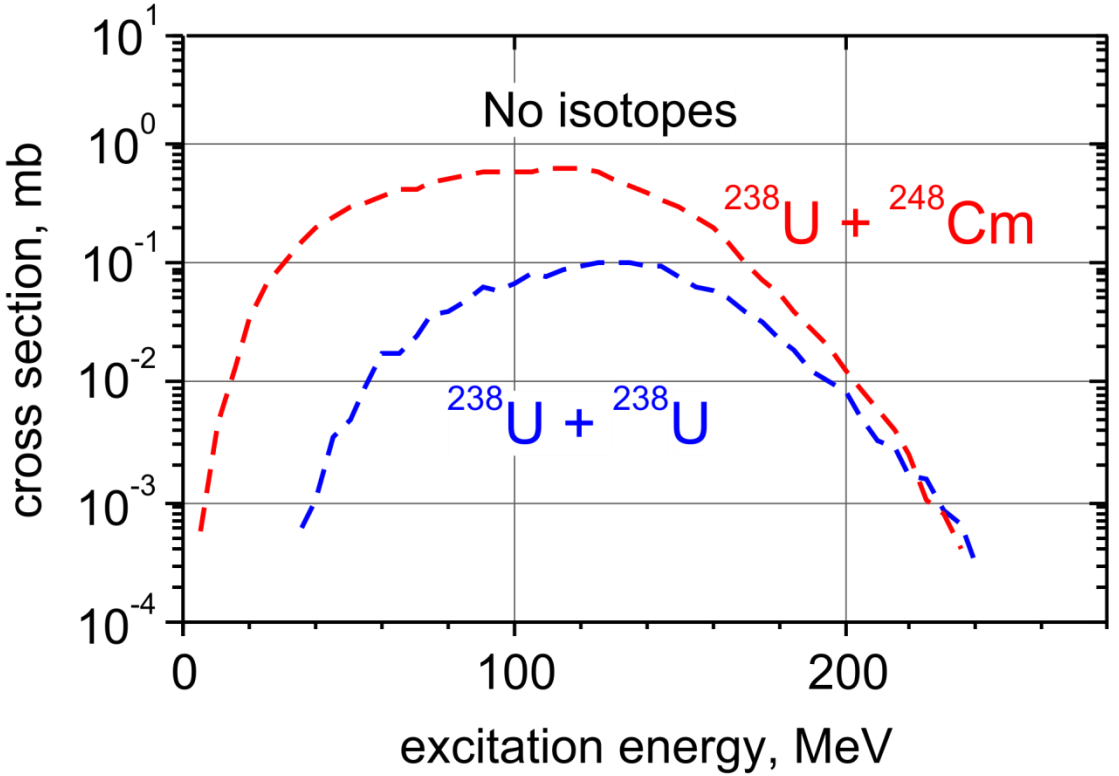




Exp.: M. Schadel et al., Phys. Rev. Lett. 41, 469 (1978), Phys. Rev. Lett. 48, 852 (1982)

Synthesis of the heaviest products in U + U, Cm reactions

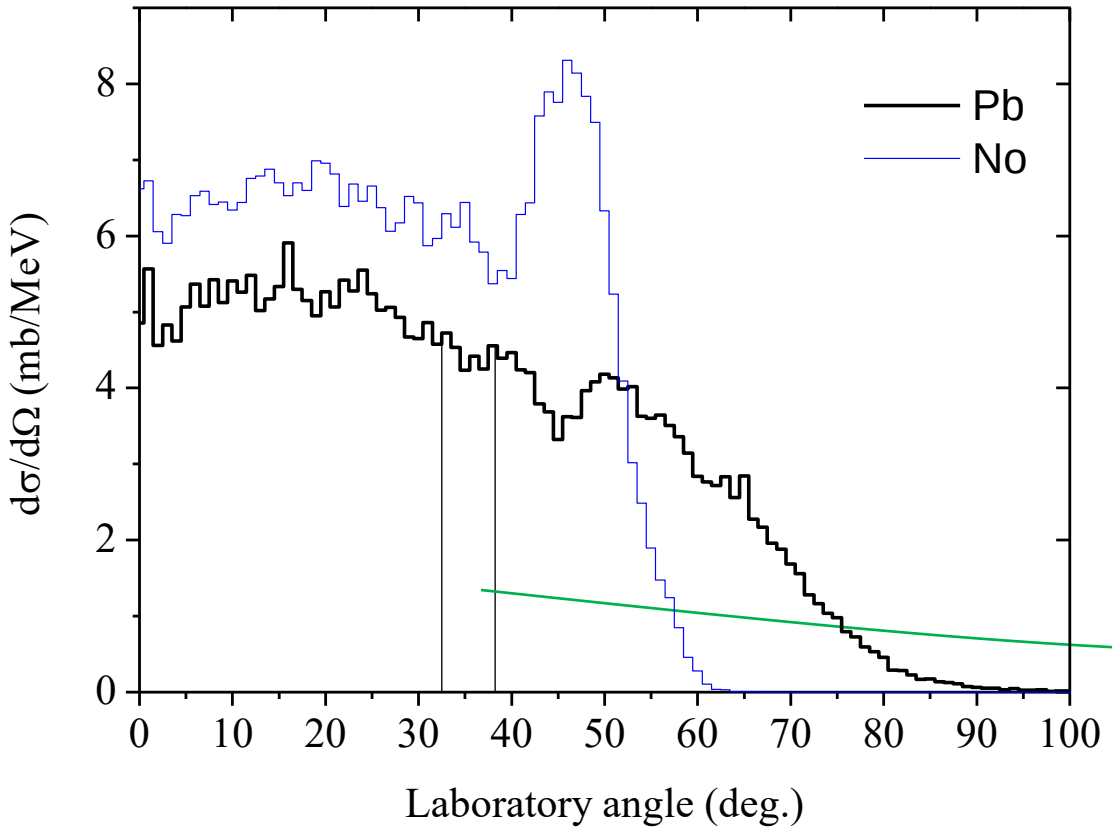


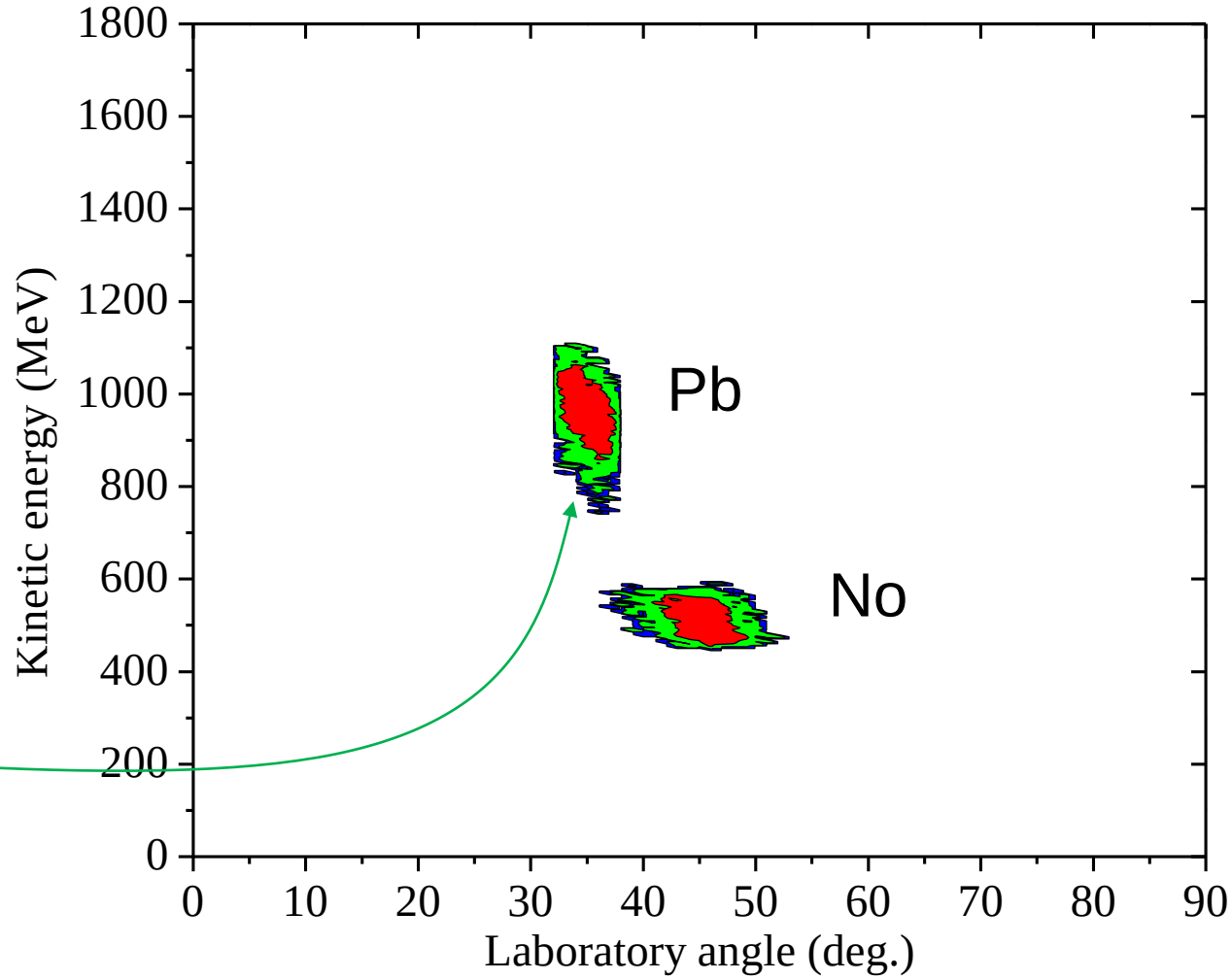


Kinematics of reaction products in U + U reaction

U + U -> Pb + No

E = 7 MeV/u





Summary

Multidimensional dynamical approach based on Langevin equations is a powerful tool to simulate heavy-ion collisions at low energies. It can describe main characteristics of multinucleon transfer reactions and predict reaction cross sections.

Theoretical analysis of possibility to synthesize new neutron-rich nuclei in multinucleon transfer reaction within this dynamical model was done. Optimal conditions for corresponding experiments, like collision energy and angular range were determined.

Thank you for attention!