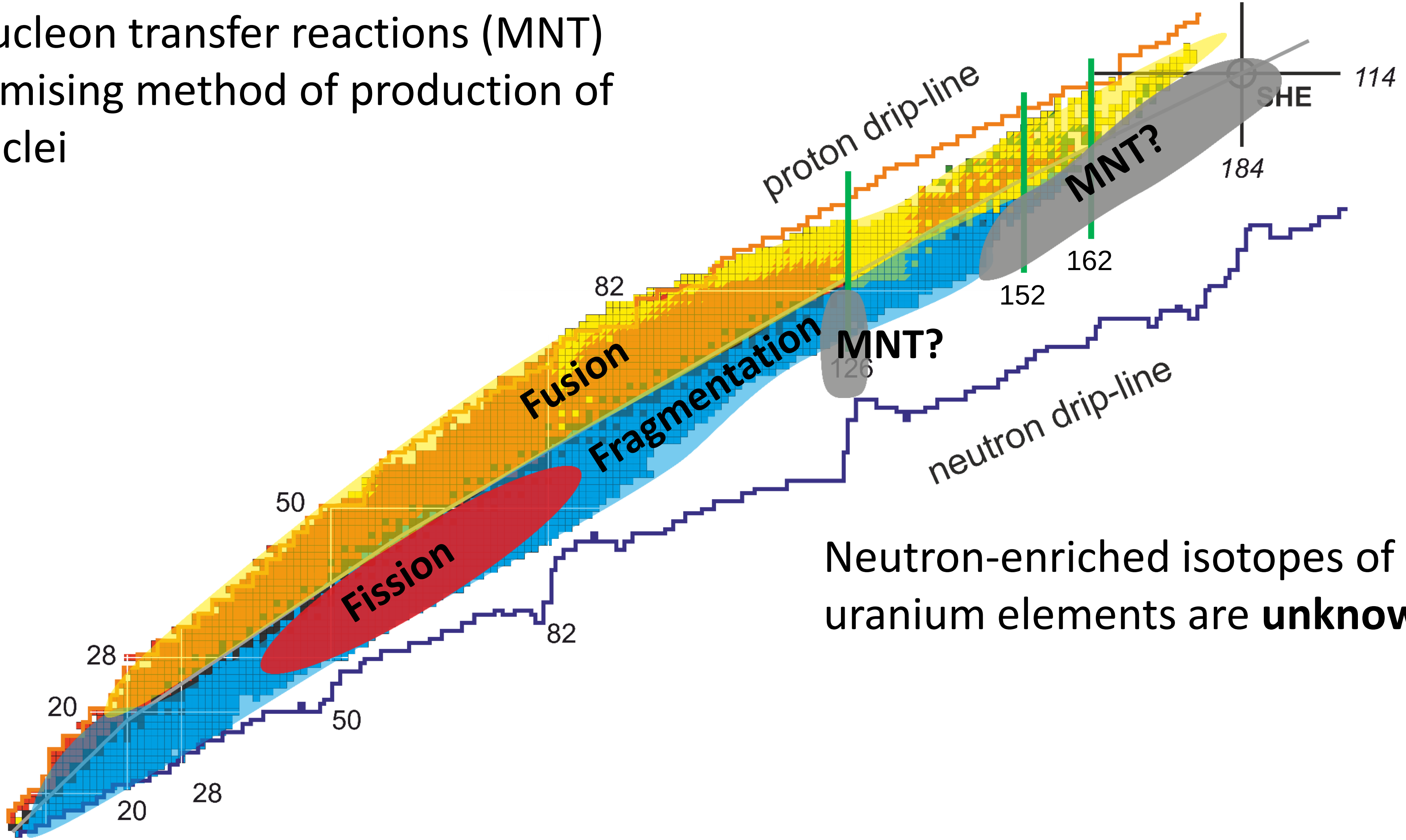
The International Workshop on
Elementary Particles and Nuclear Physics
April 24-29, 2022

Multinucleon transfer reactions as a method of production of neutron-enriched isotopes of transuranium elements

Vyacheslav Saiko and Alexander Karpov

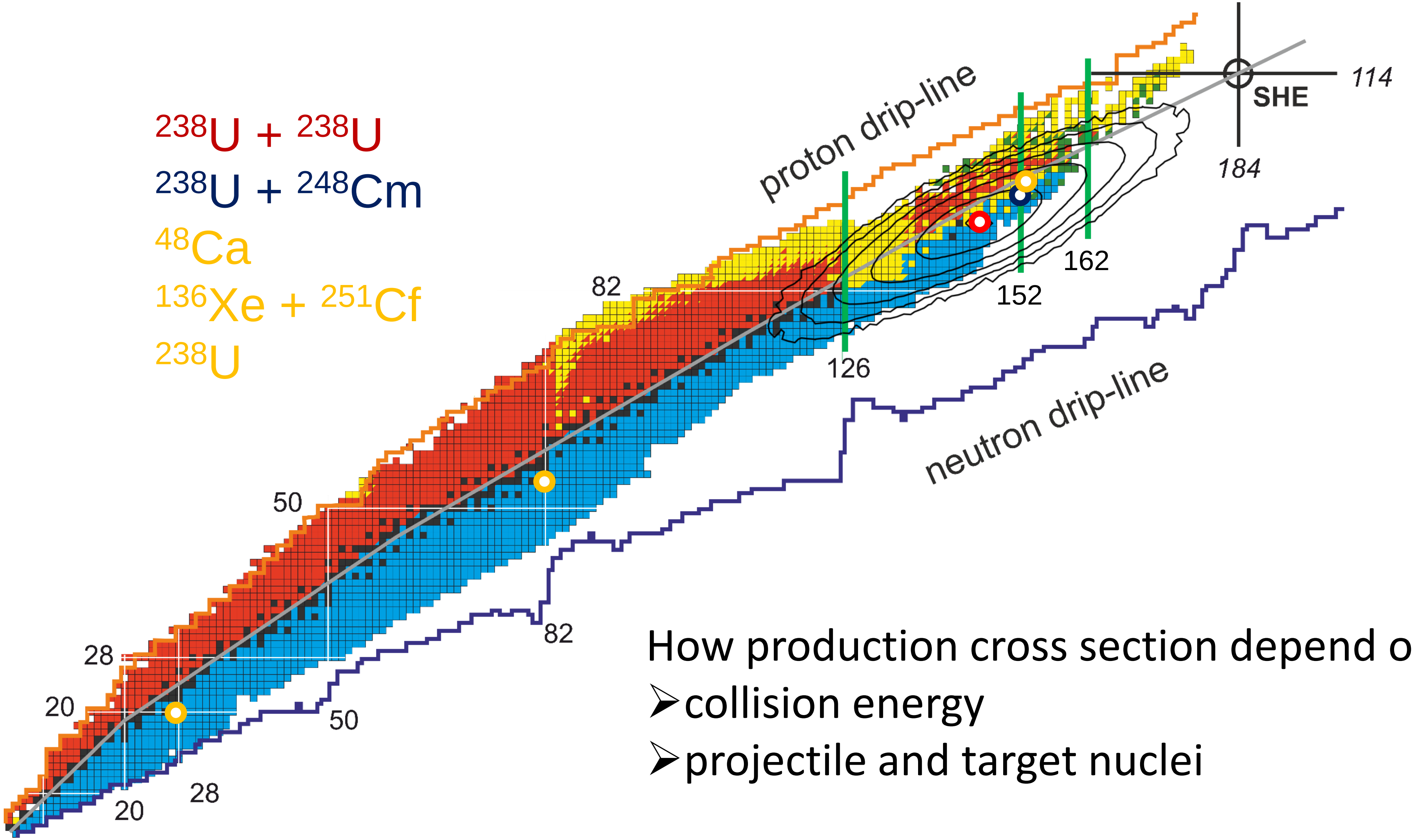
Methods of production of new nuclei

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



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

MNT reactions with actinides



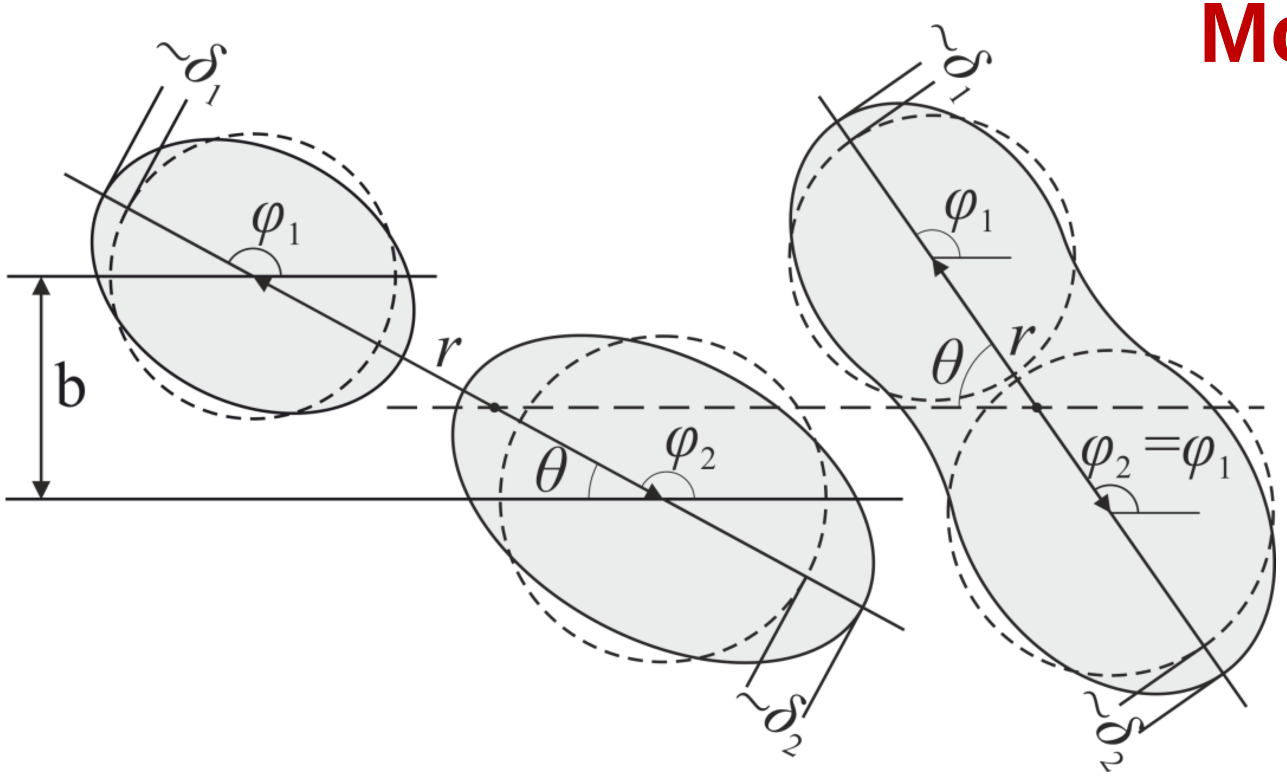
How production cross section depend on

- collision energy
- projectile and target nuclei

V.V. Saiko and A.V. Karpov, Eur. Phys. J. A 58, 41 (2022)

Model

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



system of Langevin equations

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

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

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

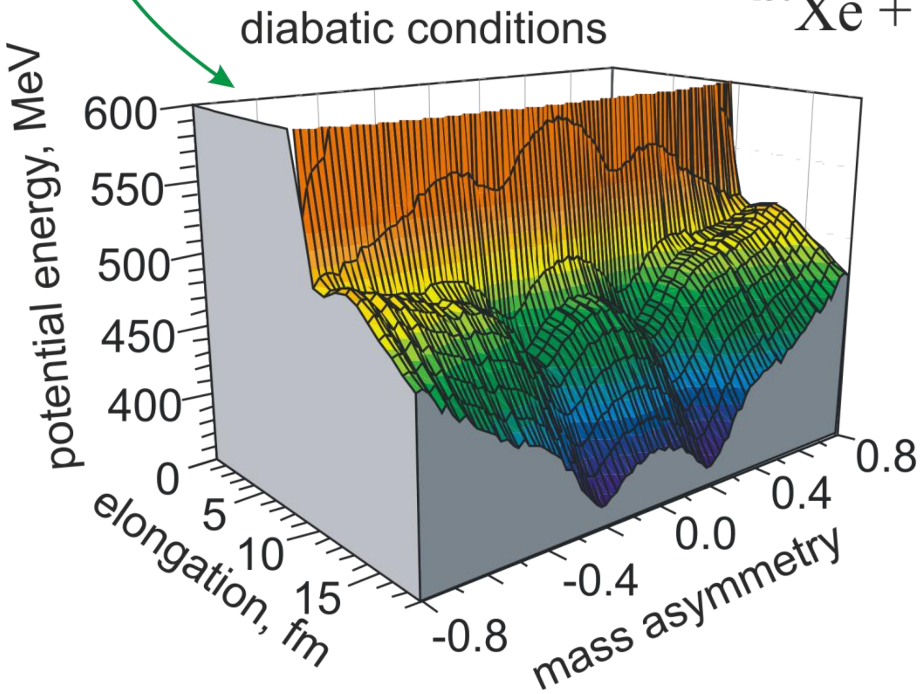
Potential energy

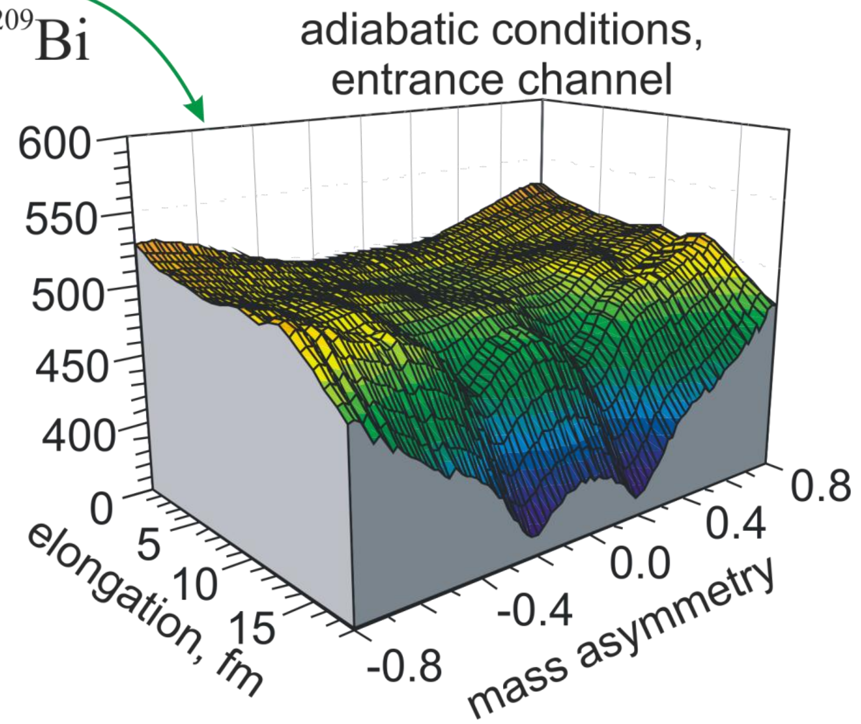
V. Zagrebaev, A. Karpov et al., Phys. Part. Nucl. 38, 469 (2007)
http://nrv.jinr.ru

$$V(t) = V_{\text{diab}} \exp\left(-\frac{t}{\tau_{DA}}\right) + V_{\text{adiab}}(t)\left(1 - \exp\left(-\frac{t}{\tau_{DA}}\right)\right), \quad \tau_{DA} = 10^{-22}\ \text{s}$$

$$V_{\text{adiab}}(t) = V^{\text{in}}_{\text{adiab}} \exp\left(-\frac{t}{\tau_{\varepsilon}}\right) + V^{\text{out}}_{\text{adiab}}\left(1 - \exp\left(-\frac{t}{\tau_{\varepsilon}}\right)\right), \quad \tau_{\varepsilon} = 10^{-20}\ \text{s}$$

$^{136}Xe + ^{209}Bi$

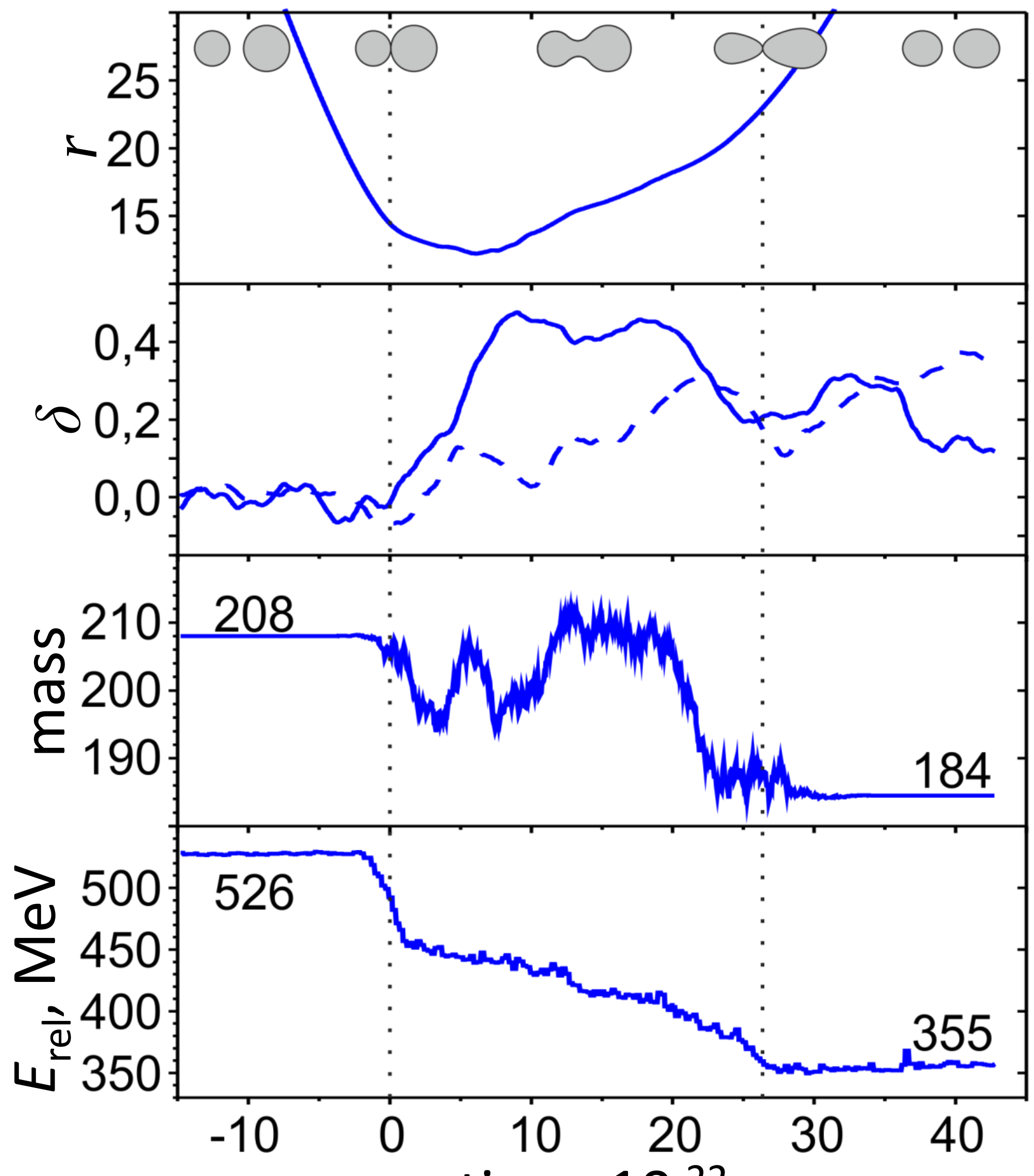




Model

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

a collision of $^{136}Xe + ^{208}Pb$



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

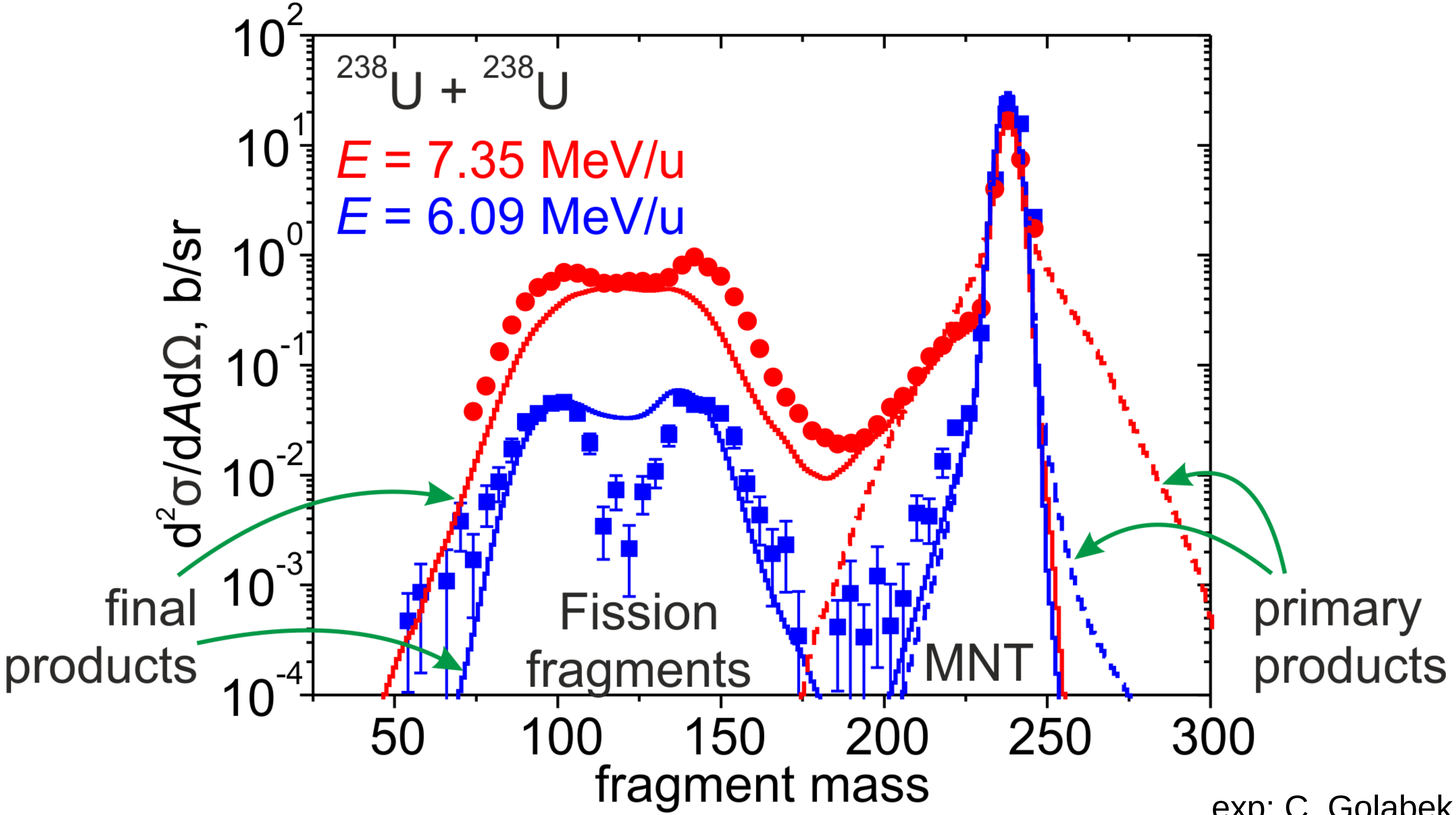
http://nrv.jinr.ru

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

differential reaction cross section:

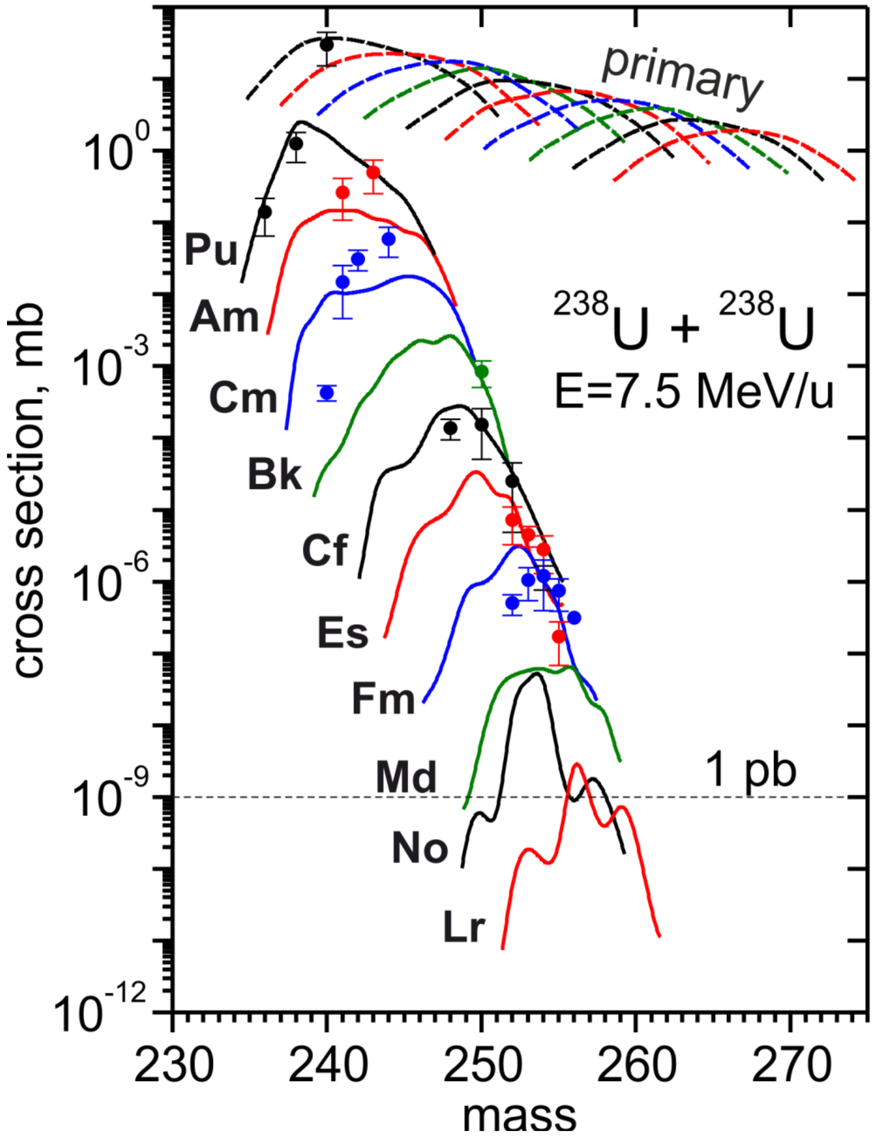
$$\frac{d^4\sigma}{dZdAd\Omega dE}(Z,A,E,\theta)=\int_0^{b_{max}}\frac{\Delta N(b,Z,A,E,\theta)bdb}{N_{tot}(b)\Delta Z\Delta A\sin\theta\Delta\theta\Delta E}$$

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



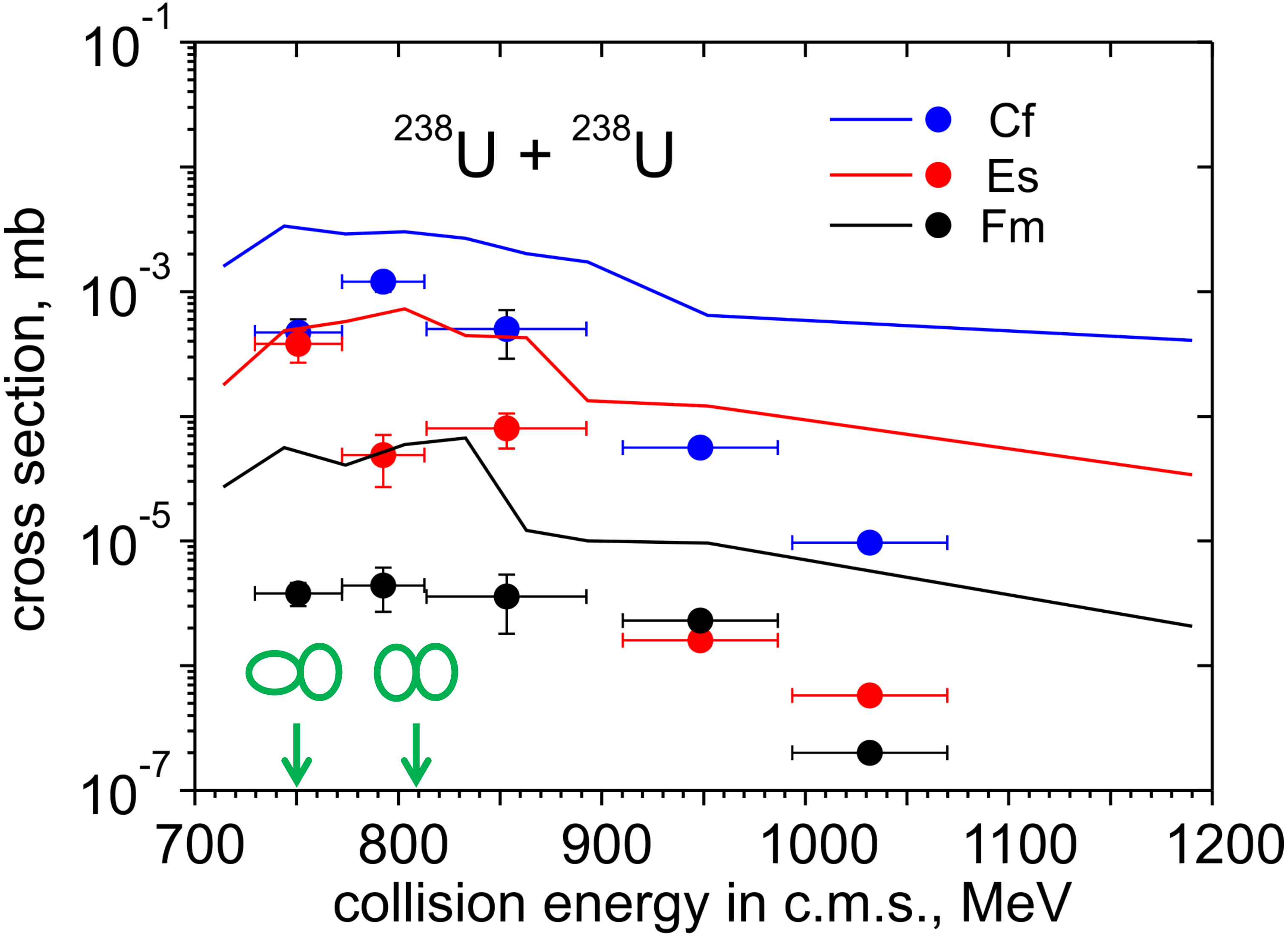
exp: C. Golabek et al.,
Eur. Phys. Jour. A 43, 251 (2010)

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



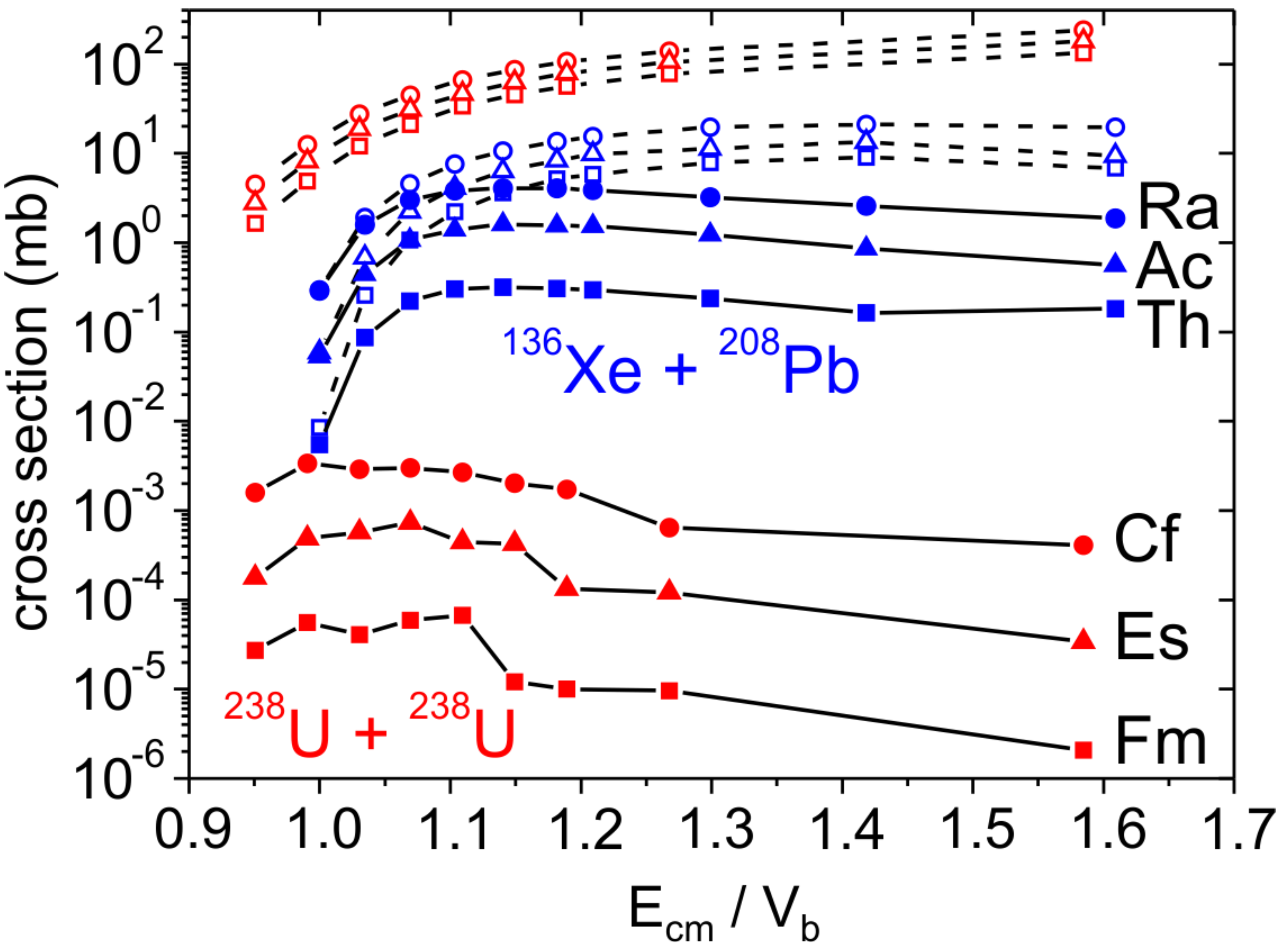
exp.: M. Schadel et al., Phys. Rev. Lett. 41, 469 (1978)

Optimal energy *for heavier elements*

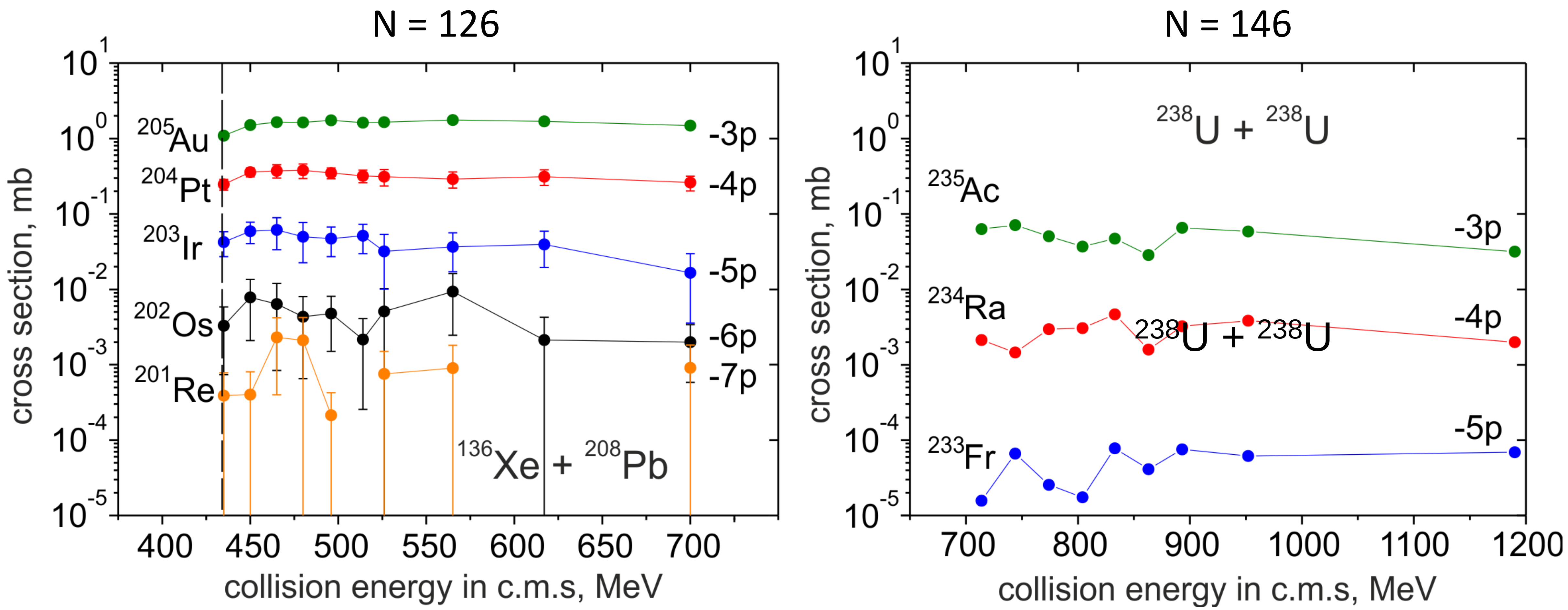


exp.: J.V. Kratz, et. al,
Phys. Rev. C 88, 054615 (2013)

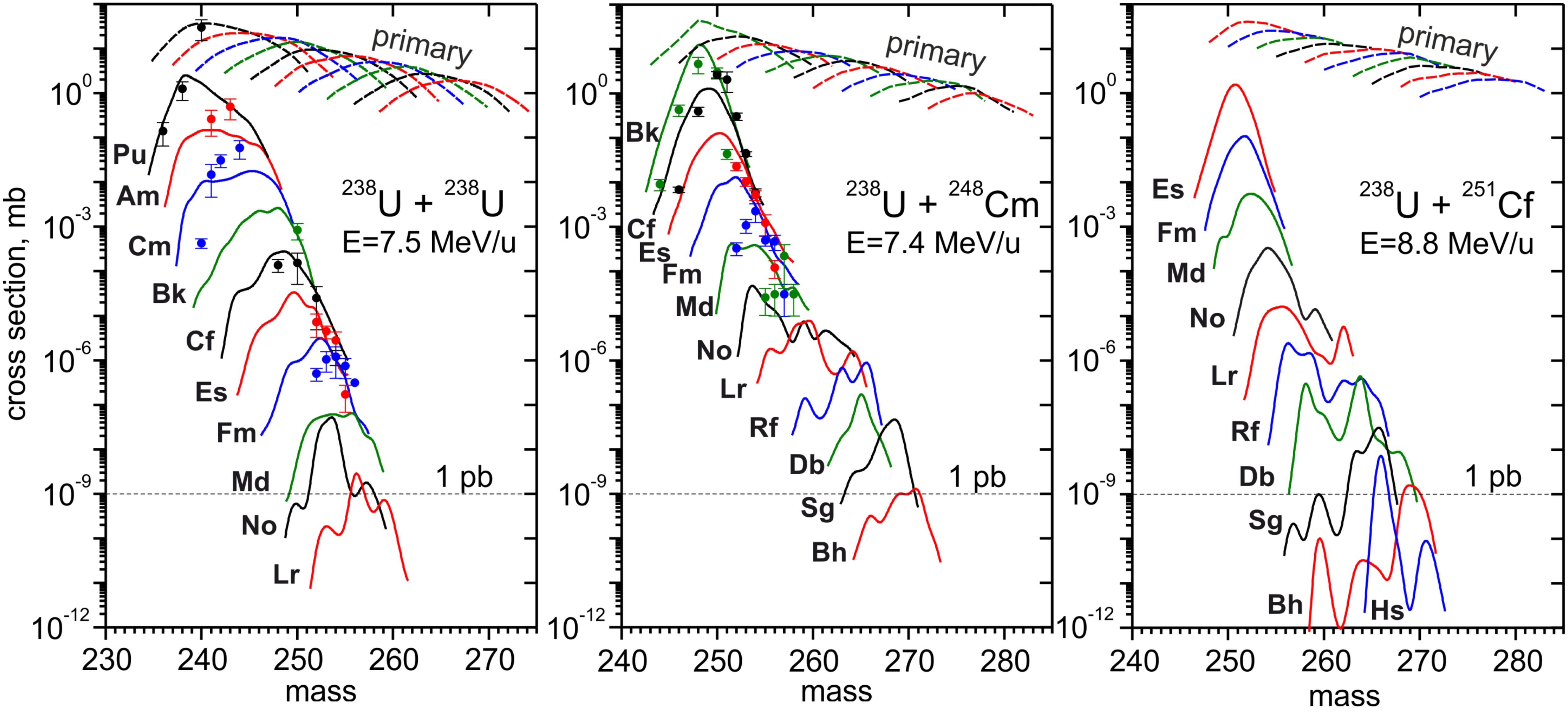
Optimal energy *for heavier elements*



Optimal energy *for neutron-rich nuclei*

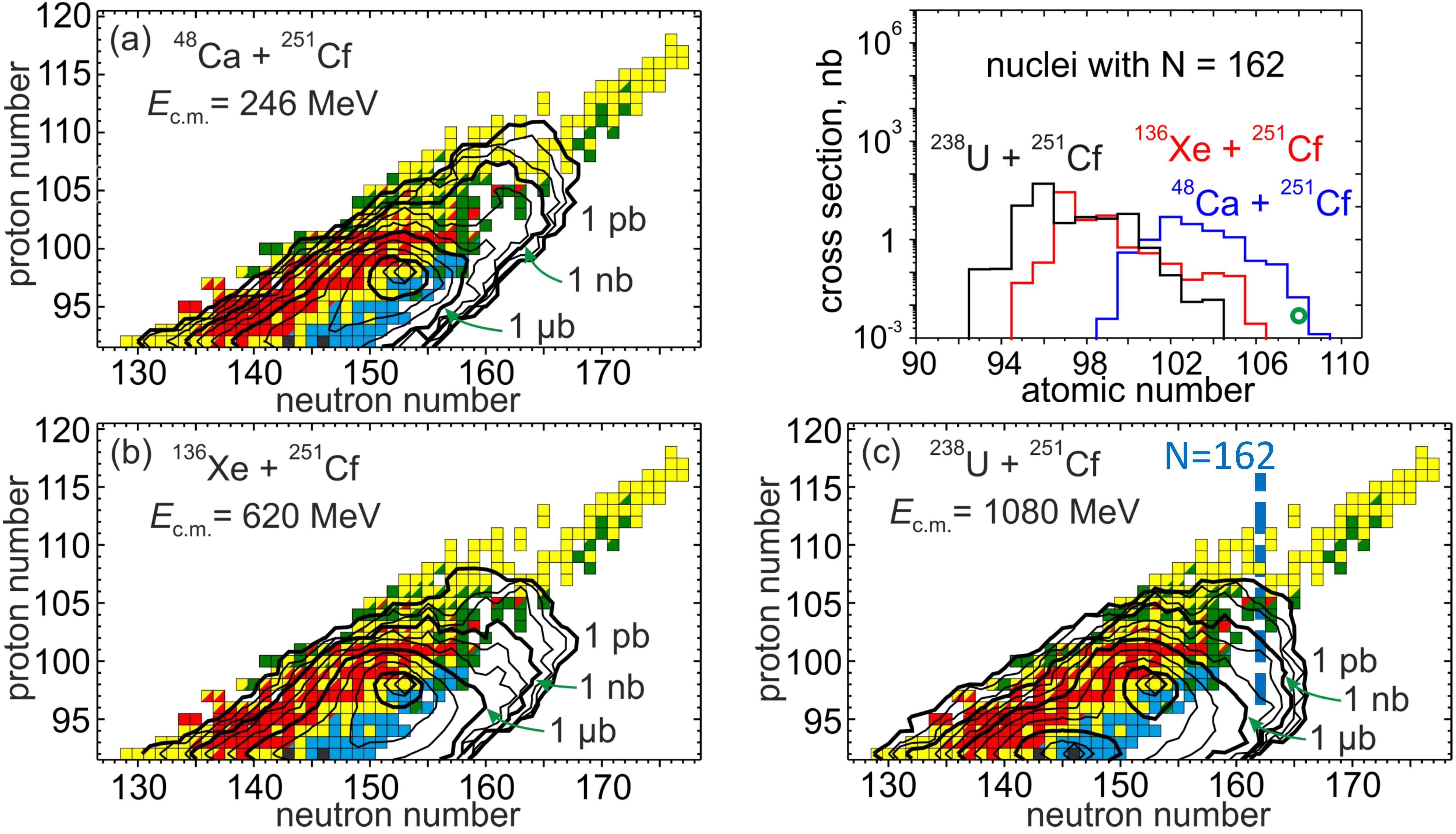


^{238}U-induced MNT reactions



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

MNT reactions with ^{251}Cf



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 reactions with actinides was done in the framework of the dynamical model.

Neutron-rich isotopes of transuranium elements can be produced in a MNT reaction with neutron-rich actinide target combining with neutron-rich heavy projectile. Optimal collision energy is slightly above the coulomb barrier. For example, production cross sections of yet-unknown nuclei in the ^{238}U + ^{251}Cf reaction exceeds 1 μb level.

Thank you for attention!