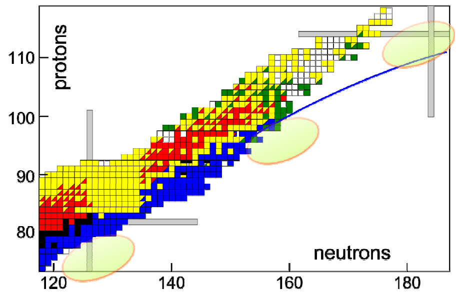
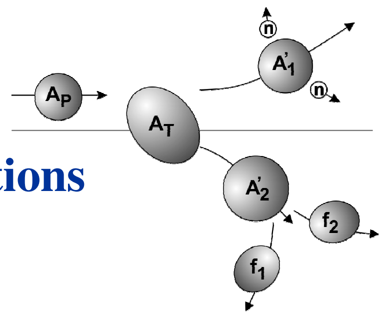
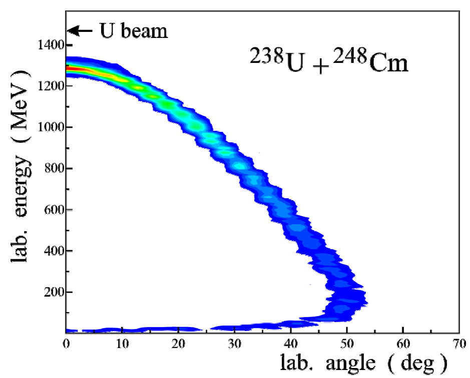
Near barrier collisions of transactinides: excitation functions and angular distributions of transfer reaction products



1. Neutron-rich heavy and superheavy nuclei



2. Low-energy multi-nucleon transfer reactions



3. Excitation functions and energy-angular distributions of reaction products

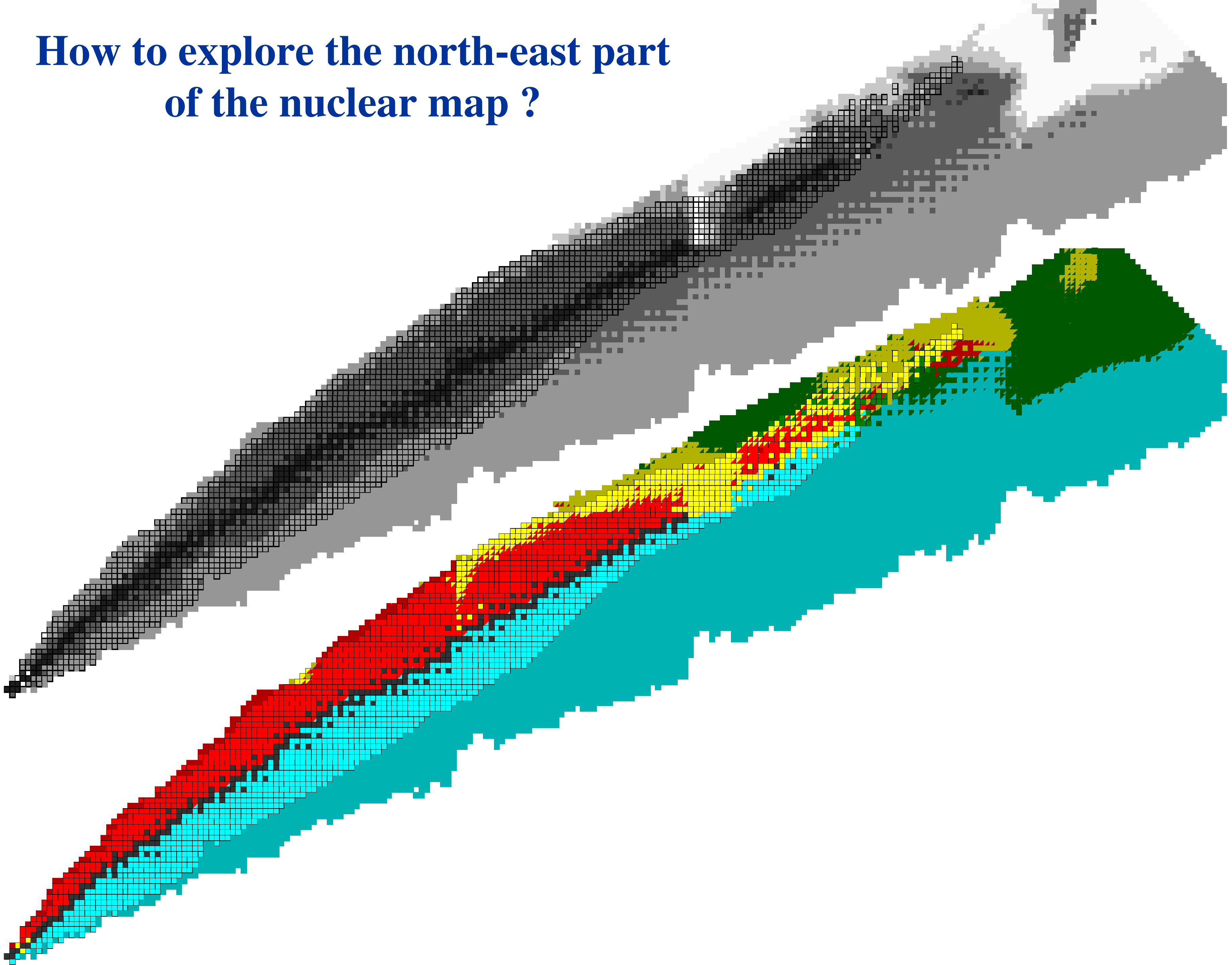
JINR, Dubna

Valery Zagrebaev and Walter Greiner

for 2^{nd} IRiS-10, Darmstadt, November 19, 2010

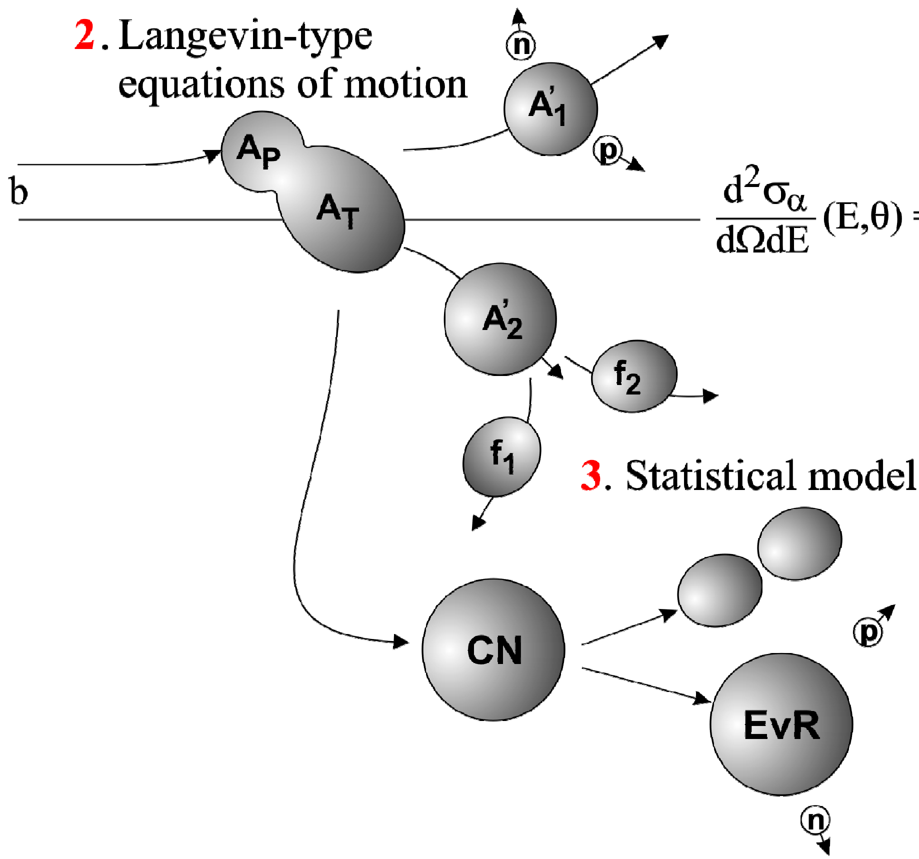
FIAS, Frankfurt

How to explore the north-east part of the nuclear map ?



Simulation of experiment and cross sections

1. Time-dependent driving potential $V(r,\xi;t)$:
Folding → Adiabatic Two-Center Shell Model

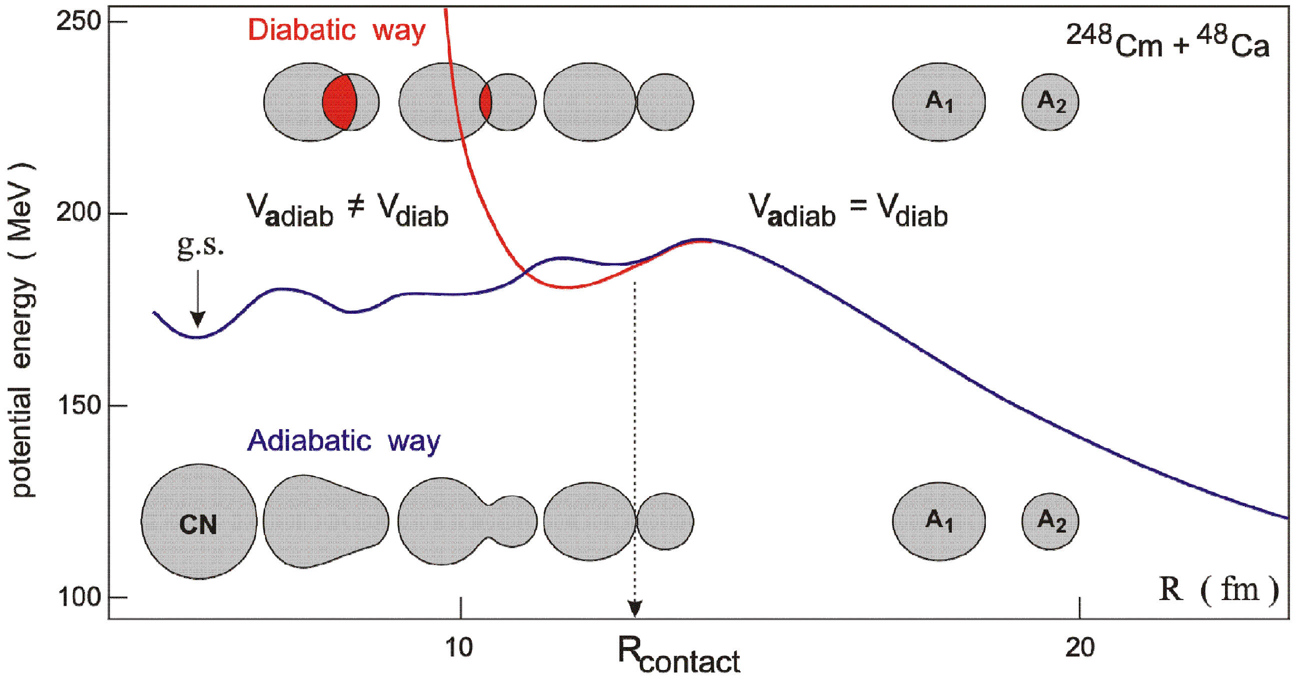


$$\frac{d^2\sigma_\alpha}{d\Omega dE}(E,\theta) = \int_0^\infty b\,db \; \frac{\Delta N_\alpha(b,E,\theta)}{N_{tot}(b)} \; \frac{1}{\sin(\theta)\Delta\theta\Delta E}$$

Dynamics: **10^6** tested events (trajectories),
Statistical model: **10^{-6}**(3n), **10^{-7}**(4n) survival probability
cross sections up to **0.1 pb** can be calculated

Time-dependent Driving Potential

$$V_{diabat}(R,\beta_1,\beta_2,\alpha,...) = V_{12}^{folding}(Z_1,N_1,Z_2,N_2;R,\beta_1,\beta_2,...) + M(A_1) + M(A_2) - M(Proj) - M(Targ)$$



$$V_{adiabat}(R,\beta_1,\beta_2,\eta,...) = M_{TCSM}(R,\beta_1,\beta_2,\eta,...) - M(Proj) - M(Targ)$$

Time-dependent driving potential has to be used

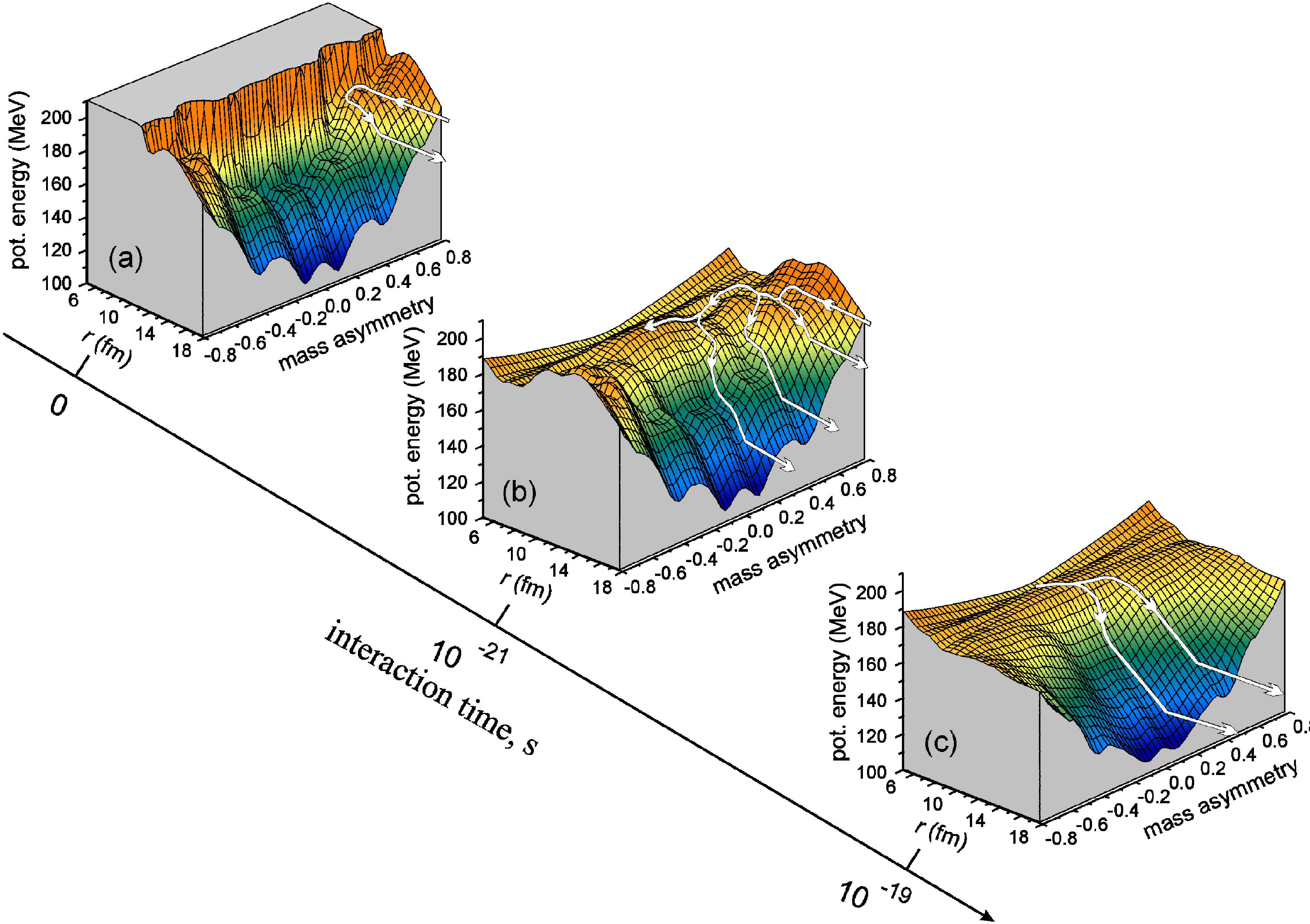
$$V(t) = V_{diab}(\xi)\cdot\exp(-\frac{t_{int}}{\tau_{relax}}) + V_{adiab}(\xi)\cdot[1-\exp(-\frac{t_{int}}{\tau_{relax}})]$$

$\tau_{relax} \sim 10^{-21}$ s

the same degrees of freedom ($\xi = R, \theta, \varphi_1, \varphi_2, \beta_1, \beta_2, \eta_Z, \eta_N$) *!*

All forces, $F_i(t) = -\partial V/\partial \xi_i$, *are quite smooth*

Time-dependent Driving Potential



System of coupled Langevin type Equations of Motion

Variables: $\{R, \theta, \varphi_1, \varphi_2, \beta_1, \beta_2, \eta_Z, \eta_N\}$

Most uncertain parameters:

μ_0, γ_0 - nuclear viscosity and friction,

λ_Z^0, λ_N^0 - nucleon transfer rate

$$\frac{dR}{dt} = \frac{p_R}{\mu_R}$$

$$\frac{d\vartheta}{dt} = \frac{\ell}{\mu_R R^2}$$

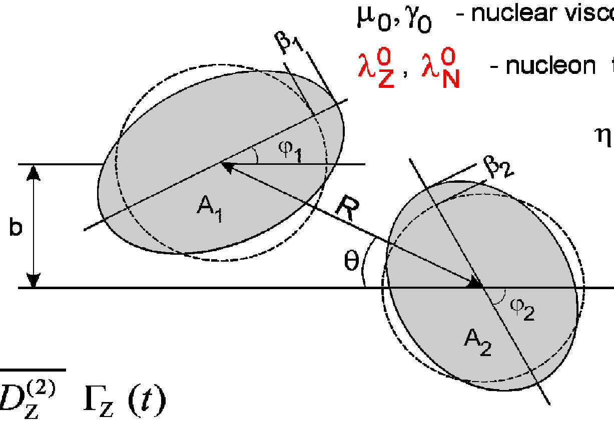
$$\frac{d\varphi_1}{dt} = \frac{L_1}{\Im_1}, \quad \frac{d\varphi_2}{dt} = \frac{L_2}{\Im_2}$$

$$\frac{d\beta_1}{dt} = \frac{p_{\beta 1}}{\mu_{\beta 1}}$$

$$\frac{d\beta_2}{dt} = \frac{p_{\beta 2}}{\mu_{\beta 2}}$$

$$\frac{d\eta_Z}{dt} = \frac{2}{Z_{CN}} D_Z^{(1)} + \frac{2}{Z_{CN}} \sqrt{D_Z^{(2)}}\ \Gamma_Z(t)$$

$$\frac{d\eta_N}{dt} = \frac{2}{N_{CN}} D_N^{(1)} + \frac{2}{N_{CN}} \sqrt{D_N^{(2)}}\ \Gamma_N(t)$$



$$\eta = \frac{A_1 - A_2}{A_1 + A_2}$$

$$\eta_Z = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

$$\eta_N = \frac{N_1 - N_2}{N_1 + N_2}$$

$$\lambda_Z^0 = \lambda_N^0 = \frac{\lambda^0}{2}$$

$$\frac{dp_R}{dt} = -\frac{\partial V}{\partial R} + \frac{\ell^2}{\mu_R R^3} + \left(\frac{\ell^2}{2\mu_R^2 R^2} + \frac{p_R^2}{2\mu_R^2}\right)\frac{\partial \mu_R}{\partial R} + \frac{p_{\beta 1}^2}{2\mu_{\beta 1}^2}\frac{\partial \mu_{\beta 1}}{\partial R} + \frac{p_{\beta 2}^2}{2\mu_{\beta 2}^2}\frac{\partial \mu_{\beta 2}}{\partial R} - \gamma_R \frac{p_R}{\mu_R} + \sqrt{\gamma_R T}\,\Gamma_R(t)$$

$$\frac{d\ell}{dt} = -\frac{\partial V}{\partial \vartheta} - \gamma_{\rm tang}\left(\frac{\ell}{\mu_R R} - \frac{L_1}{\Im_1}a_1 - \frac{L_2}{\Im_2}a_2\right) R + \sqrt{\gamma_{\rm tang} T}\,\Gamma_{\rm tang}(t)$$

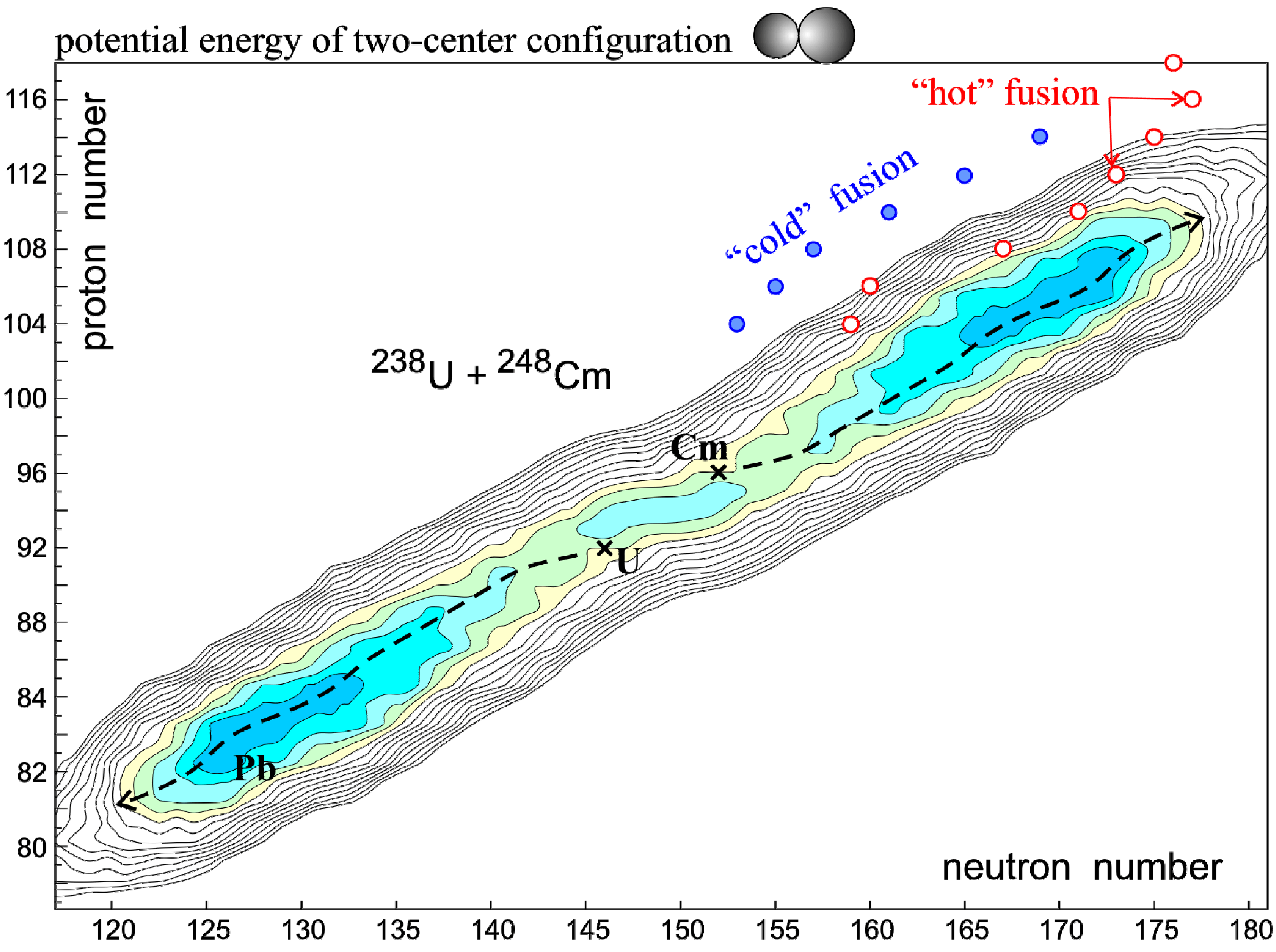
$$\frac{dL_1}{dt} = -\frac{\partial V}{\partial \varphi_1} + \gamma_{\rm tang}\left(\frac{\ell}{\mu_R R} - \frac{L_1}{\Im_1}a_1 - \frac{L_2}{\Im_2}a_2\right) a_1 - \frac{a_1}{R}\sqrt{\gamma_{\rm tang} T}\,\Gamma_{\rm tang}(t)$$

$$\frac{dL_2}{dt} = -\frac{\partial V}{\partial \varphi_2} + \gamma_{\rm tan}\left(\frac{\ell}{\mu_R R} - \frac{L_1}{\Im_1}a_1 - \frac{L_2}{\Im_2}a_2\right) a_2 - \frac{a_2}{R}\sqrt{\gamma_{\rm tang} T}\,\Gamma_{\rm tang}(t)$$

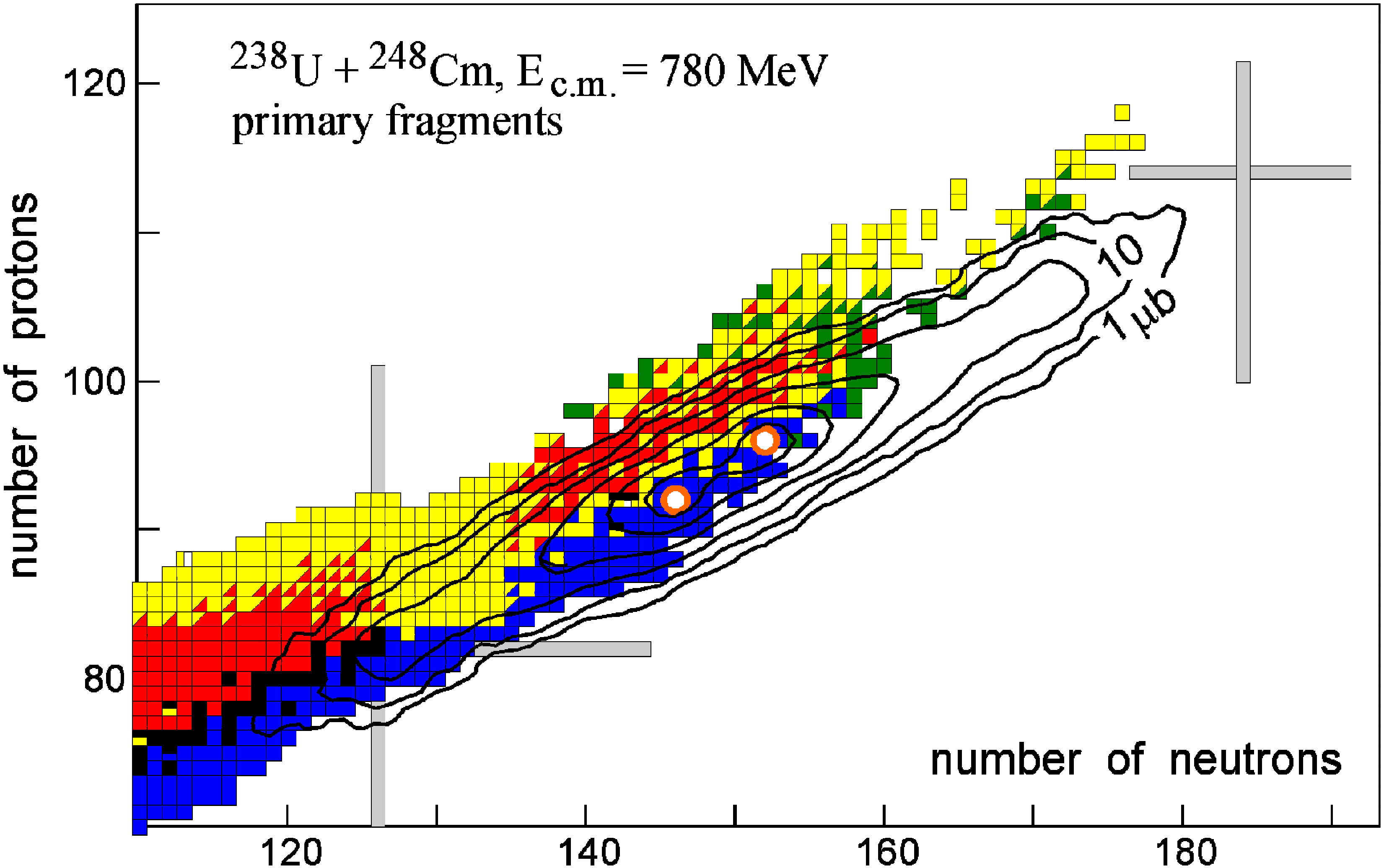
$$\frac{dp_{\beta 1}}{dt} = -\frac{\partial V}{\partial \beta_1} + \frac{p_{\beta 1}^2}{2\mu_{\beta 1}^2}\frac{\partial \mu_{\beta 1}}{\partial \beta_1} + \frac{p_{\beta 2}^2}{2\mu_{\beta 2}^2}\frac{\partial \mu_{\beta 2}}{\partial \beta_1} + \left(\frac{\ell^2}{2\mu_R^2 R^2} + \frac{p_R^2}{2\mu_R^2}\right)\frac{\partial \mu_R}{\partial \beta_1} - \gamma_\beta \frac{p_{\beta 1}}{\mu_{\beta 1}} + \sqrt{\gamma_{\beta 1} T}\,\Gamma_{\beta 1}(t)$$

$$\frac{dp_{\beta 2}}{dt} = -\frac{\partial V}{\partial \beta_2} + \frac{p_{\beta 1}^2}{2\mu_{\beta 1}^2}\frac{\partial \mu_{\beta 1}}{\partial \beta_2} + \frac{p_{\beta 2}^2}{2\mu_{\beta 2}^2}\frac{\partial \mu_{\beta 2}}{\partial \beta_2} + \left(\frac{\ell^2}{2\mu_R^2 R^2} + \frac{p_R^2}{2\mu_R^2}\right)\frac{\partial \mu_R}{\partial \beta_2} - \gamma_\beta \frac{p_{\beta 2}}{\mu_{\beta 2}} + \sqrt{\gamma_{\beta 2} T}\,\Gamma_{\beta 2}(t)$$

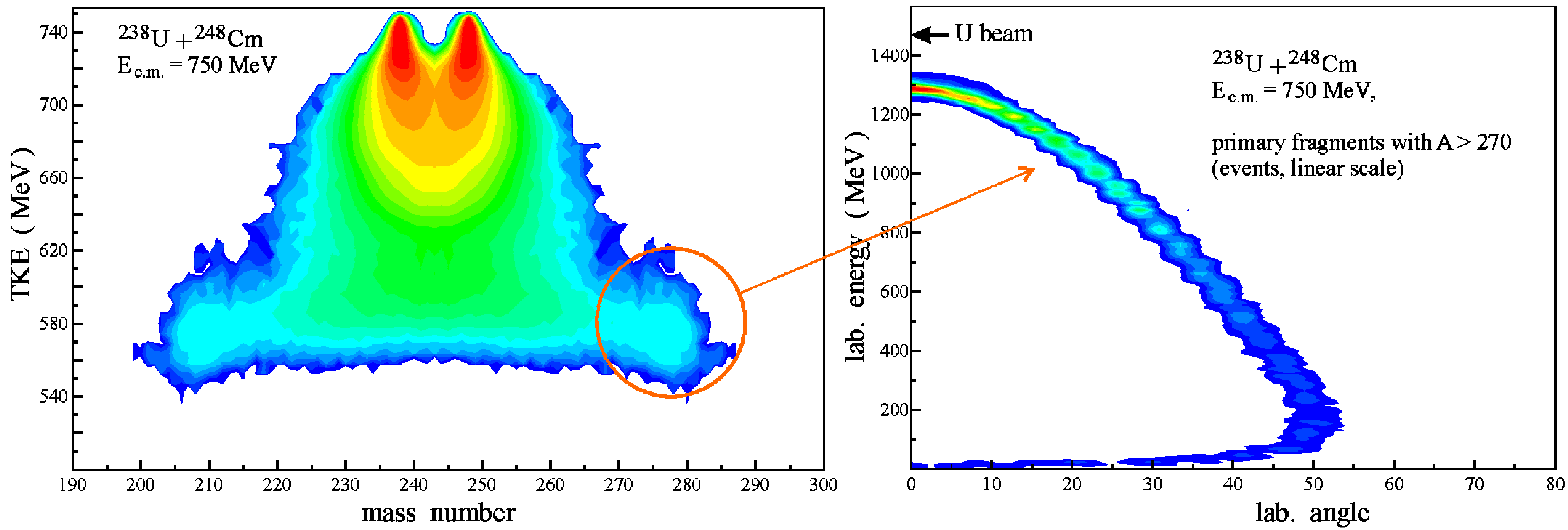
Production of more neutron-rich SH nuclei in low-energy collisions of heavy ions



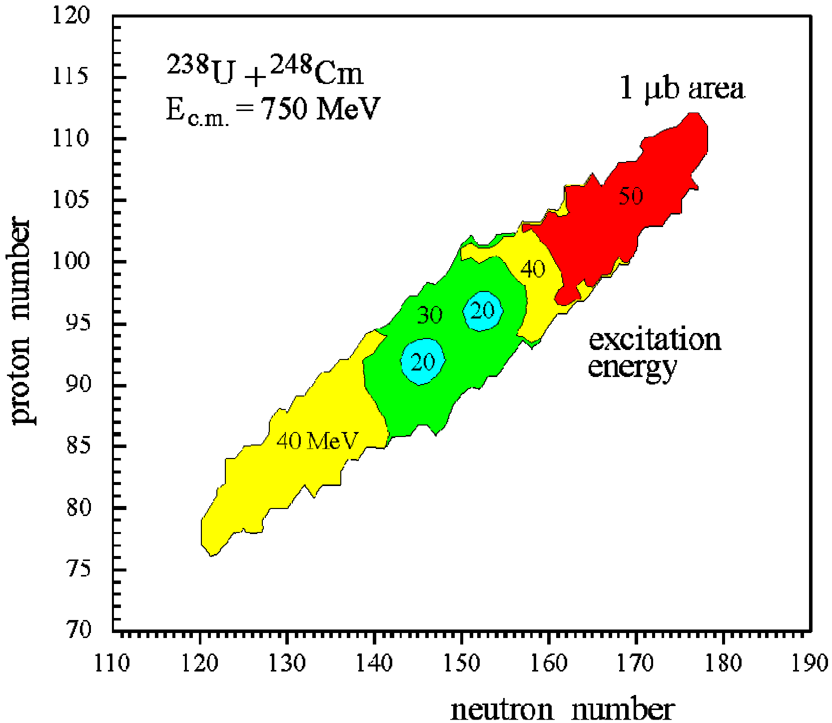
238U + 248Cm. Primary fragments

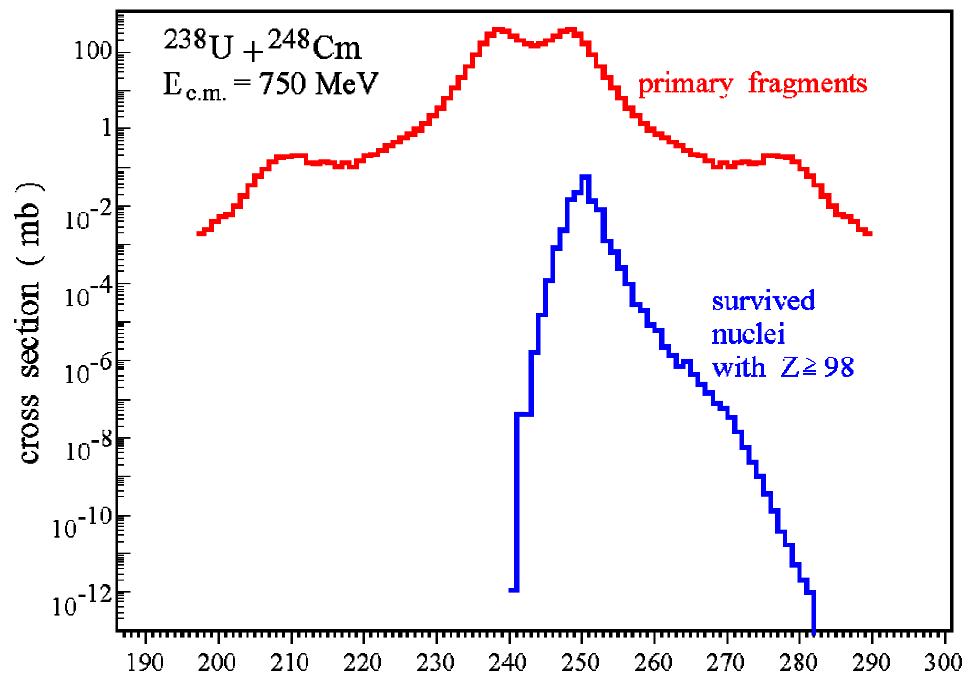


238U + 248Cm. Energy and angular distributions

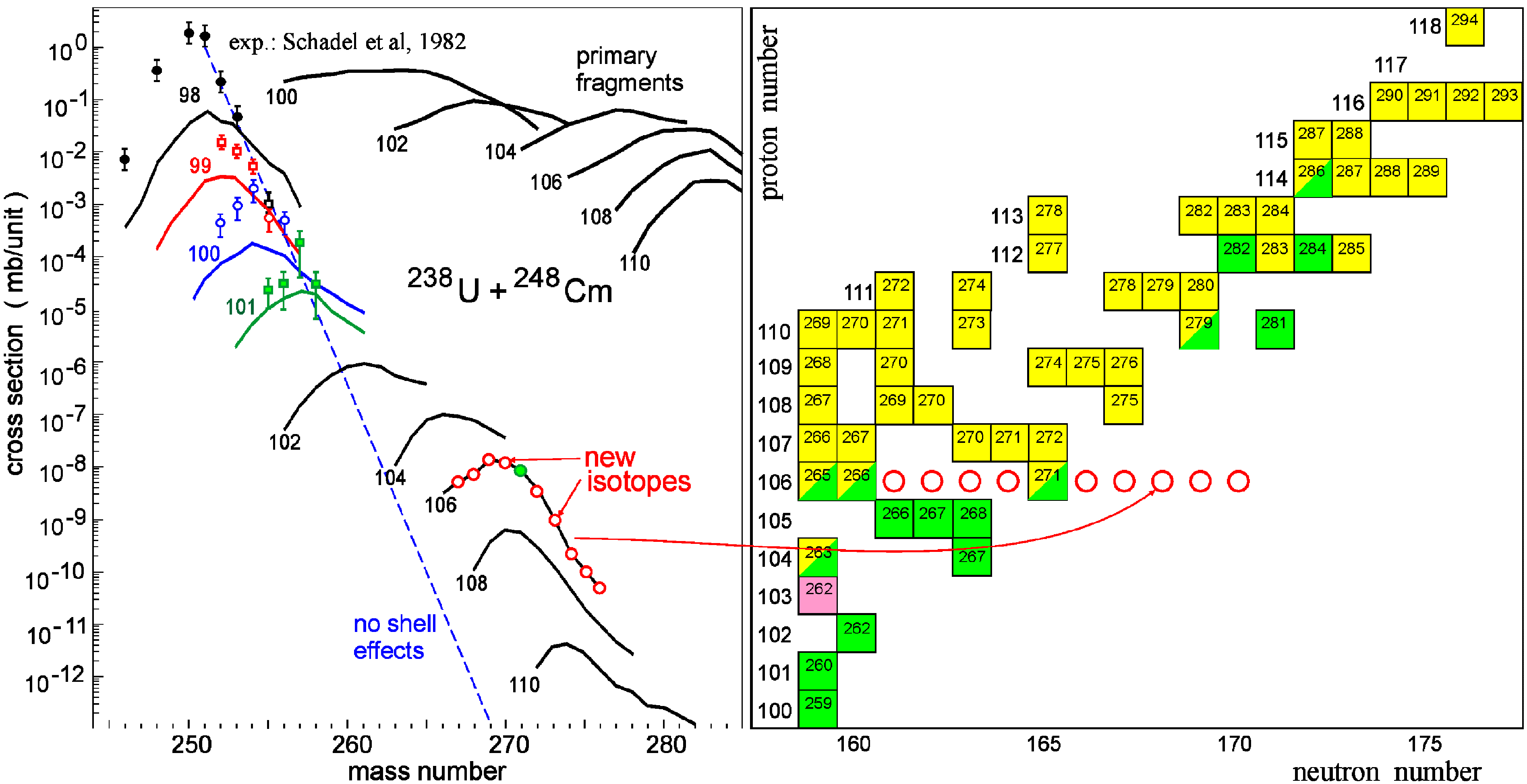


238U + 248Cm. Excitation energies and survival probability





Production of neutron-rich SHE in low-energy collisions of heavy actinide nuclei



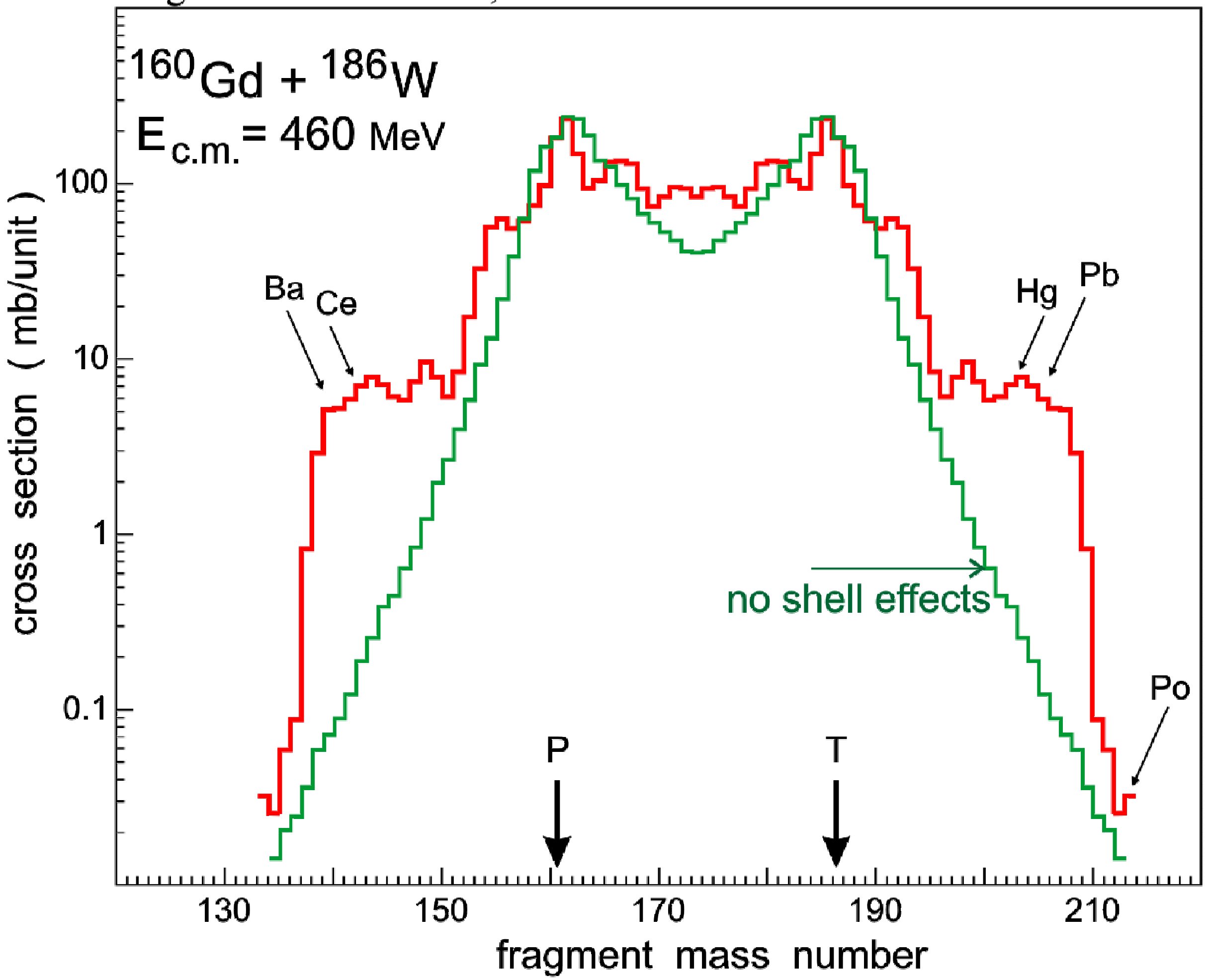
How much is a role of the shell effects in damped collisions ?

^{160}Gd + ^{186}W

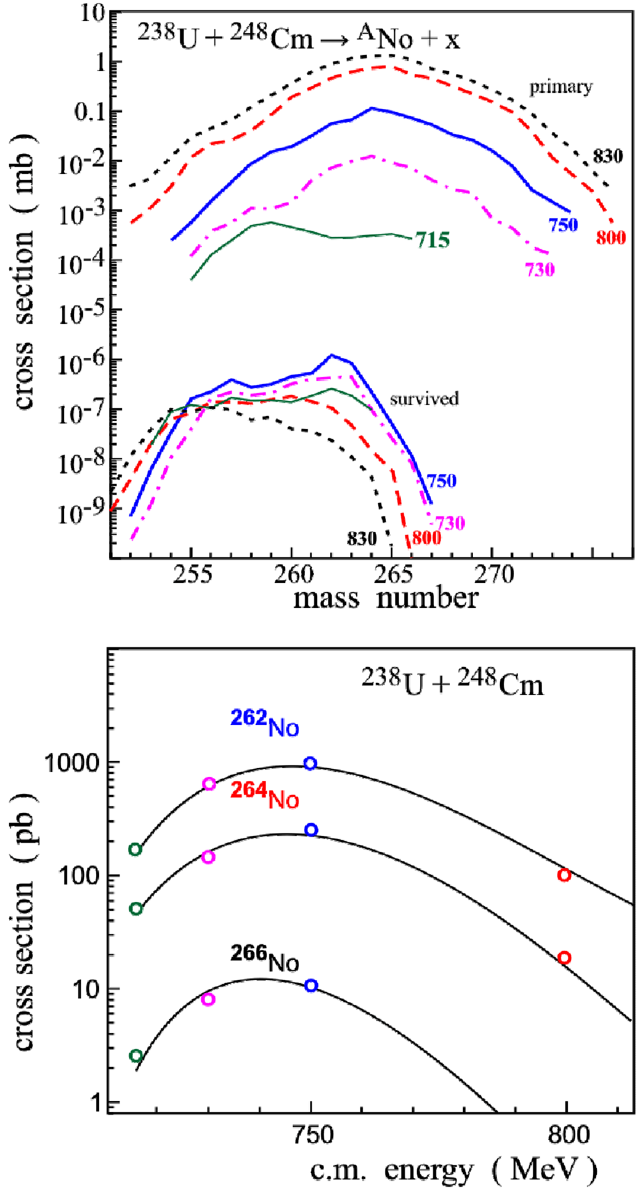
(proposal for a new experiment)

Zagrebaev and Greiner, 2007

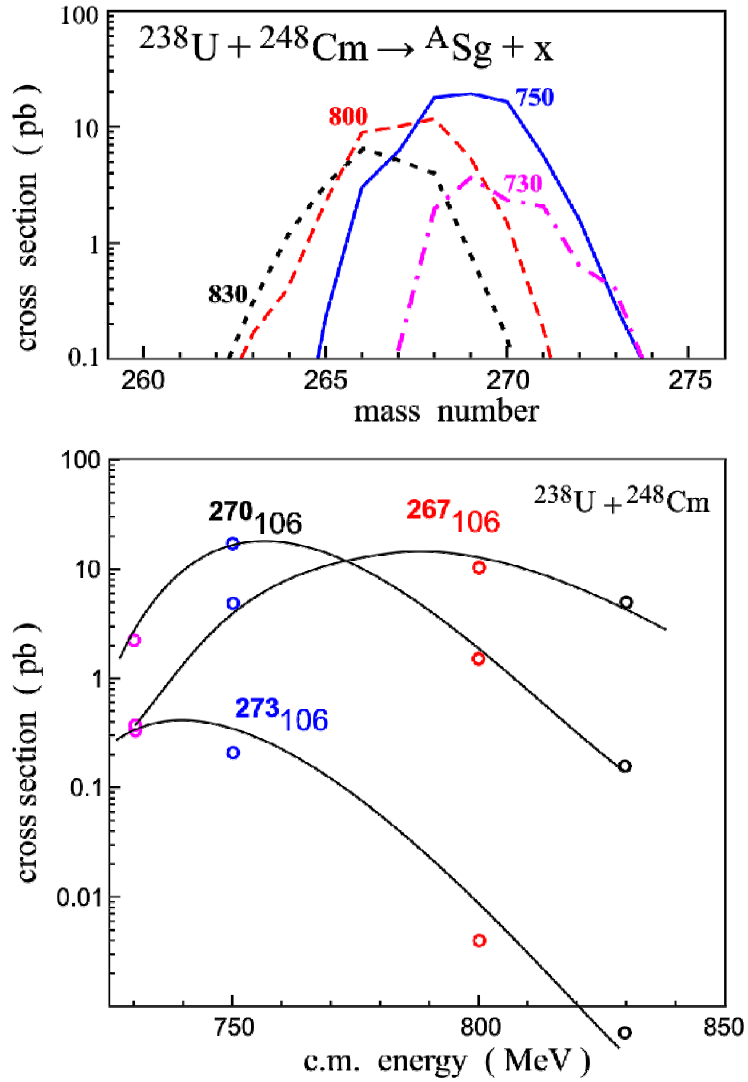
Experiment: W. Loveland et al., 2010



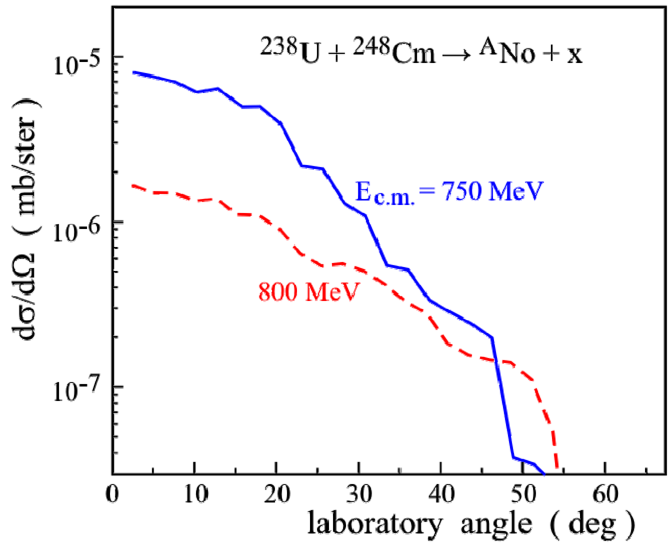
Excitation functions for production of neutron-rich SHE in low-energy collisions of heavy actinide nuclei

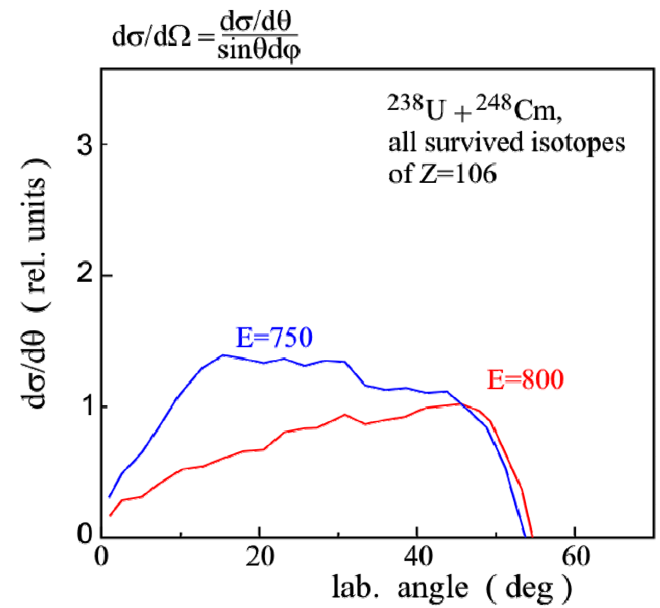


Excitation functions for production of neutron-rich SHE in low-energy collisions of heavy actinide nuclei

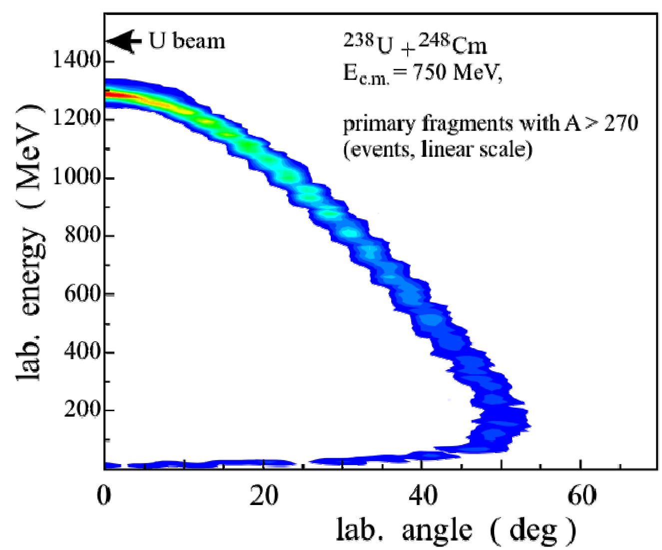


Angular distribution of neutron-rich SHE produced in low-energy collisions of heavy actinide nuclei





$$\frac{d\sigma}{d\Omega}^{\text{elastic}}(20^{o}) = \begin{matrix} 1.3\times10^{4}\ \text{mb/sr (U - like)} \\ 2.2\times10^{2}\ \text{mb/sr (Cm-like)} \end{matrix}$$



Summary ?