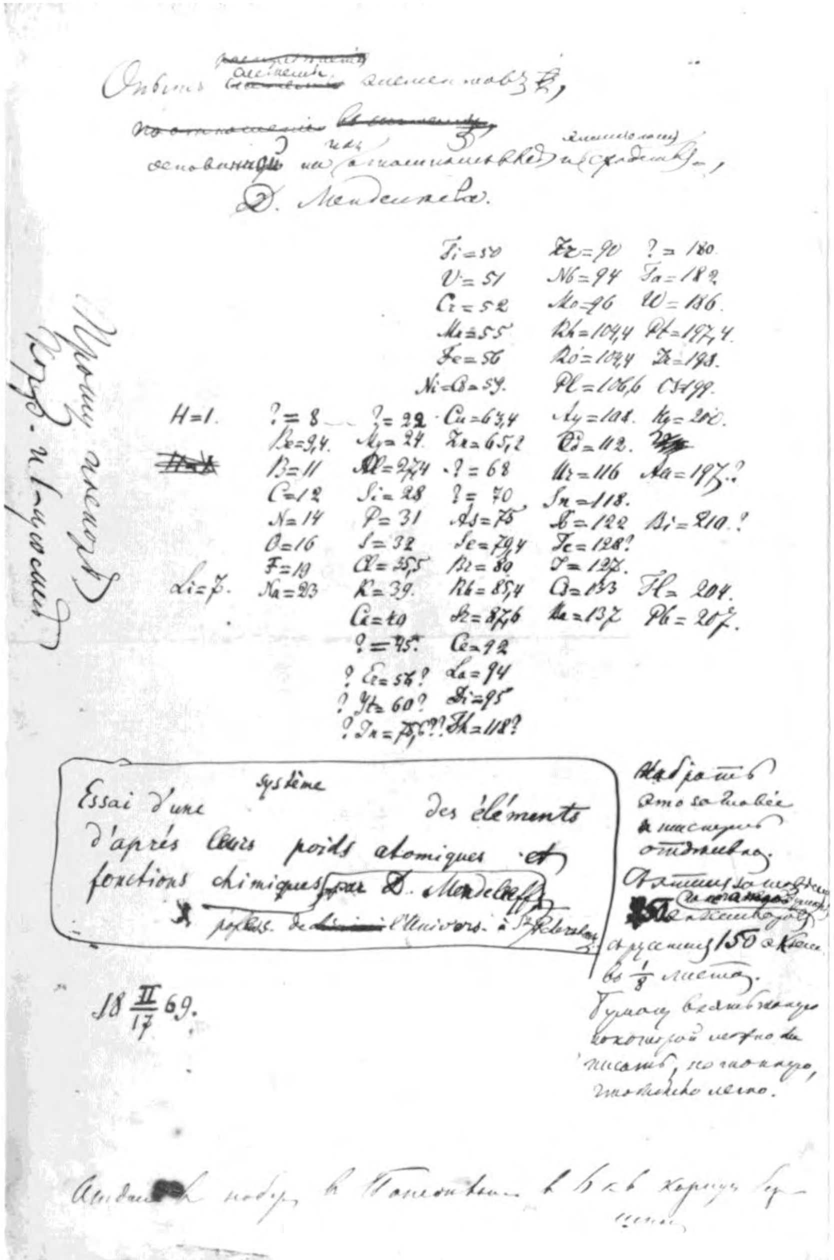
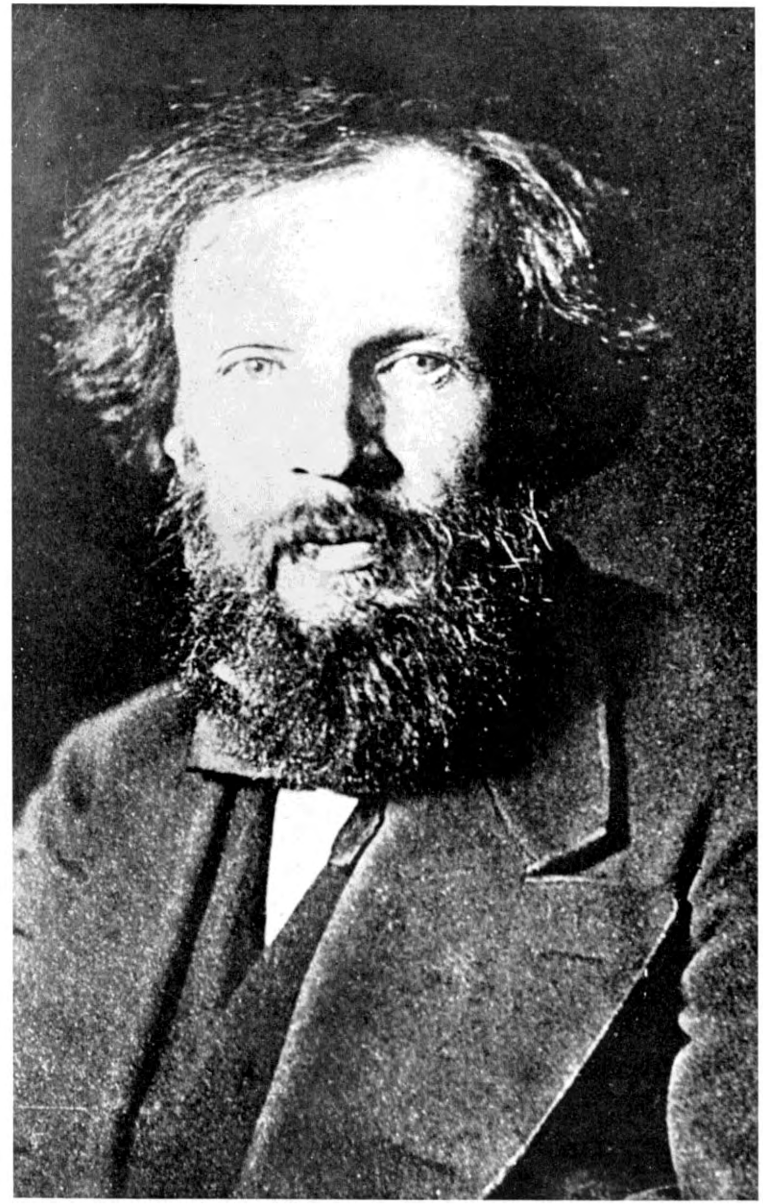
Mendeleev's Table (145 years ago, 63 elements)





Mendeleev's Table

период	ряд	I (а, б)	II (а, б)	III (а, б)	IV (а, б)	V (а, б)	VI (а, б)	VII (а, б)	VIII (а, б)		
		группы элементов									
1	I	Водород H 1 $1s^1$ 1,00794 Hydrogen							Гелий He 2 $1s^2$ 4,0026 Helium		
2	II	Литий Li 3 $2s^1$ 6,941 Lithium	Бериллий Be 4 $2s^2$ 9,012182 Beryllium	Бор B 5 $2p^1$ 10,811 Boron	Углерод C 6 $2p^2$ 12,011 Carbon	Азот N 7 $2p^3$ 14,00674 Nitrogen	Кислород O 8 $2p^4$ 15,9994 Oxygen	Фтор F 9 $2p^5$ 18,9984032 Fluorine	Неон Ne 10 $2p^6$ 20,1797 Neon		
3	III	Натрий Na 11 $3s^1$ 22,989768 Sodium	Магний Mg 12 $3s^2$ 24,3050 Magnesium	Алюминий Al 13 $3p^1$ 26,981539 Aluminum	Кремний Si 14 $3p^2$ 28,0855 Silicon	Фосфор P 15 $3p^3$ 30,973762 Phosphorus	Сера S 16 $3p^4$ 32,066 Sulfur	Хлор Cl 17 $3p^5$ 35,4527 Chlorine	Аргон Ar 18 $3p^6$ 39,948 Argon		
4	IV	Калий K 19 $4s^1$ 39,0983 Potassium	Кальций Ca 20 $4s^2$ 40,078 Calcium	Скандий Sc 21 $3d^14s^2$ 44,955910 Scandium	Титан Ti 22 $3d^24s^2$ 47,88 Titanium	Ванадий V 23 $3d^34s^2$ 50,9415 Vanadium	Хром Cr 24 $3d^54s^1$ 51,9961 Chromium	Марганец Mn 25 $3d^54s^2$ 54,93805 Manganese	Железо Fe 26 $3d^64s^2$ 55,847 Iron	Кобальт Co 27 $3d^74s^2$ 58,93320 Cobalt	Никель Ni 28 $3d^84s^2$ 58,6934 Nickel
	V	Медь Cu 29 $3d^{10}4s^1$ 63,546 Copper	Цинк Zn 30 $3d^{10}4s^2$ 65,39 Zinc	Галлий Ga 31 $4p^1$ 69,723 Gallium	Германий Ge 32 $4p^2$ 72,61 Germanium	Мышьяк As 33 $4p^3$ 74,92159 Arsenic	Селен Se 34 $4p^4$ 9,75238 78,96 Selenium	Бром Br 35 $4p^5$ 79,904 Bromine	Криптон Kr 36 $4p^6$ 83,80 Krypton		
5	VI	Рубидий Rb 37 $5s^1$ 85,4678 Rubidium	Стронций Sr 38 $5s^2$ 87,62 Strontium	Иттрий Y 39 $4d^15s^2$ 88,90585 Yttrium	Цирконий Zr 40 $4d^25s^2$ 91,224 Zirconium	Ниобий Nb 41 $4d^45s^1$ 92,90638 Niobium	Молибден Mo 42 $4d^55s^1$ 95,94 Molybdenum	Технеций Tc 43 $4d^55s^2$ [98] Technetium	Рутений Ru 44 $4d^75s^1$ 101,07 Ruthenium	Родий Rh 45 $4d^85s^1$ 102,90550 Rhodium	Палладий Pd 46 $4d^{10}$ 106,42 Palladium
	VII	Серебро Ag 47 $4d^{10}5s^1$ 107,8682 Silver	Кадмий Cd 48 $4d^{10}5s^2$ 112,411 Cadmium	Индий In 49 $5p^1$ 114,818 Indium	Олово Sn 50 $5p^2$ 118,710 Tin	Сурьма Sb 51 $5p^3$ 121,757 Antimony	Теллур Te 52 $5p^4$ 127,60 Tellurium	Иод I 53 $5p^5$ 126,90447 Iodine	Ксенон Xe 54 $5p^6$ 131,29 Xenon		
6	VIII	Цезий Cs 55 $6s^1$ 132,90543 Cesium	Барий Ba 56 $6s^2$ 137,327 Barium	Лантан La 57 $5d^16s^2$ 138,9055 Lanthanum	Гафний Hf 72 $5d^26s^2$ 178,49 Hafnium	Тантал Ta 73 $5d^36s^2$ 180,9479 Tantalum	Вольфрам W 74 $5d^46s^2$ 183,84 Tungsten	Рений Re 75 $5d^56s^2$ 186,207 Rhenium	Осмий Os 76 $5d^66s^2$ 190,23 Osmium	Иридий Ir 77 $5d^76s^2$ 192,22 Iridium	Платина Pt 78 $5d^96s^1$ 195,08 Platinum
	IX	Золото Au 79 $5d^{10}6s^1$ 196,96654 Gold	Ртуть Hg 80 $5d^{10}6s^2$ 200,59 Mercury	Таллий Tl 81 $6p^1$ 204,3833 Thallium	Свинец Pb 82 $6p^2$ 207,2 Lead	Висмут Bi 83 $6p^3$ 208,98037 Bismuth	Полоний Po 84 $6p^4$ [209] Polonium	Астат At 85 $6p^5$ [210] Astatine	Радон Rn 86 $6p^6$ [222] Radon		
7	X	Франций Fr 87 $7s^1$ 4,073 [223] Francium	Радий Ra 88 $7s^2$ 226,025 Radium	Актиний Ac 89 $6d^17s^2$ [227] Actinium	Резерфордий Rf 104 [261] Rutherfordium	Дубний Db 105 [262] Dubnium	Сиборгий Sg 106 [266] Seaborgium	Борий Bh 107 [267] Bohrium	Хассий Hs 108 [269] Hassium	Мейтнерий Mt 109 [268] Meitnerium	Дармштадтий Ds 110 [269] Darmstadtium
	XI	Рентгений Rg 111 [269] Roentgenium	112	113	Fl 114	115	Lv 116	117	118		

Водород H 1 $1s^1$ 1,00794 Hydrogen — атомный номер; символ; электронная конфигурация; атомная масса

s-элементы

p-элементы

d-элементы

f-элементы

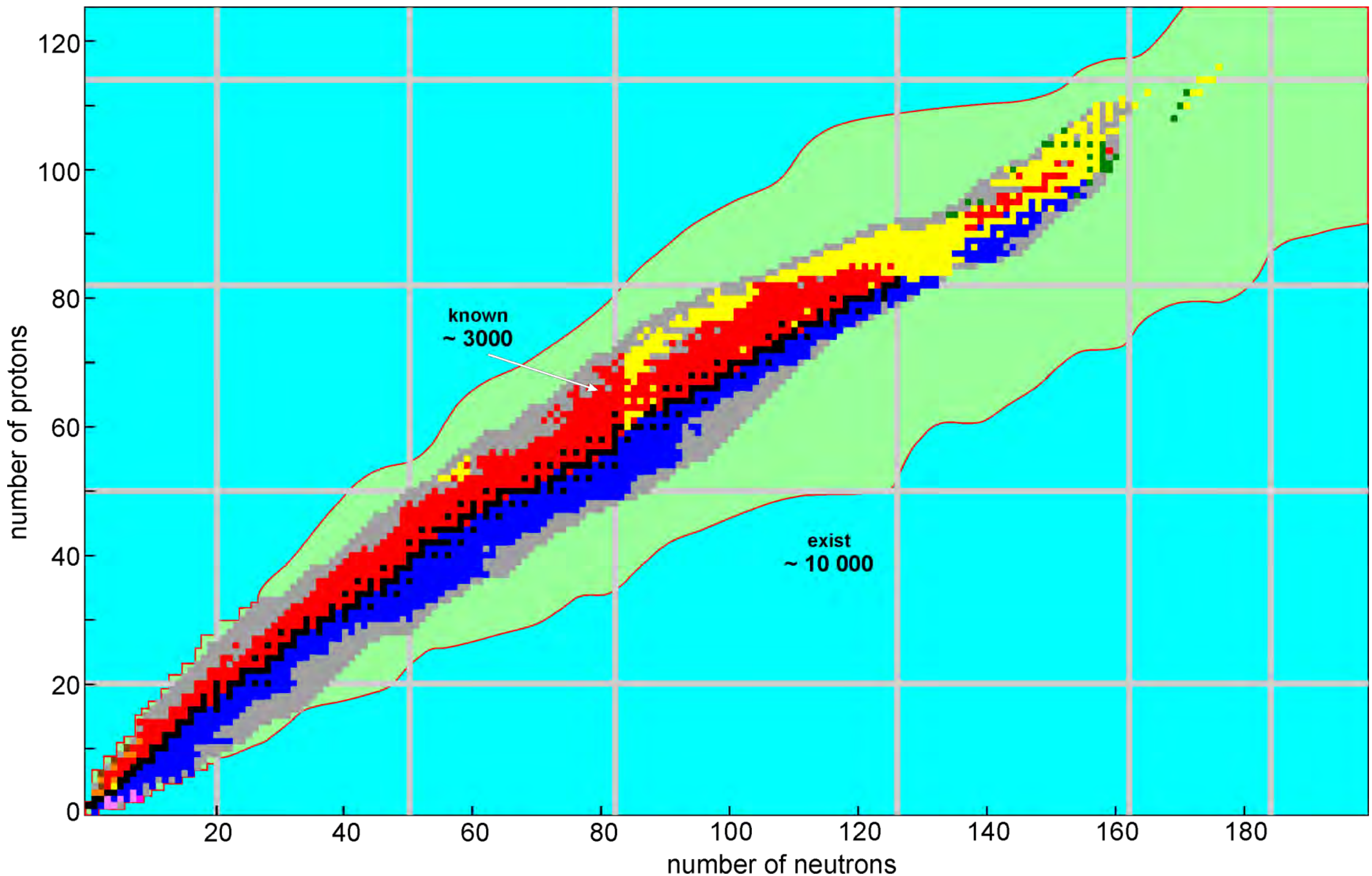
Лантаноиды Lanthanides

Церий Ce $4f^15d^1$ 140,115 Cerium	Празеодим Pr $4f^3$ 140,90765 Praseodymium	Неодим Nd $4f^4$ 144,24 Neodymium	Прометий Pm $4f^5$ [145] Promethium	Самарий Sm $4f^6$ 150,36 Samarium	Европий Eu $4f^7$ 151,965 Europium	Гадолиний Gd $4f^75d^1$ 157,25 Gadolinium	Тербий Tb $4f^9$ 158,92534 Terbium	Диспрозий Dy $4f^{10}$ 162,50 Dysprosium	Гольмий Ho $4f^{11}$ 164,93032 Holmium	Эрбий Er $4f^{12}$ 167,26 Erbium	Тулий Tm $4f^{13}$ 168,93421 Thulium	Иттербий Yb $4f^{14}$ 173,04 Ytterbium	Лютеций Lu $4f^{14}5d^1$ 174,967 Lutetium

Актиноиды Actinides

Торий Th $7s^26d^2$ 232,0381 Thorium	Протактиний Pa $5f^26d^1$ 231,03588 Protactinium	Уран U $5f^36d^1$ 238,0289 Uranium	Нептуний Np $5f^46d^1$ [237] Neptunium	Плутоний Pu $5f^6$ [244] Plutonium	Америций Am $5f^7$ [243] Americium	Кюрий Cm $5f^76d^1$ [247] Curium	Берклий Bk $5f^9$ [247] Berkelium	Калифорний Cf $5f^{10}$ [251] Californium	Эйнштейний Es $5f^{11}$ [252] Einsteinium	Фермий Fm $5f^{12}$ [257] Fermium	Менделевий Md $5f^{13}$ [258] Mendelevium	Нобелий No $5f^{14}$ [259] Nobelium	Лоуренсий Lr $5f^{14}6d^1$ [262] Lawrencium

Nuclear Map



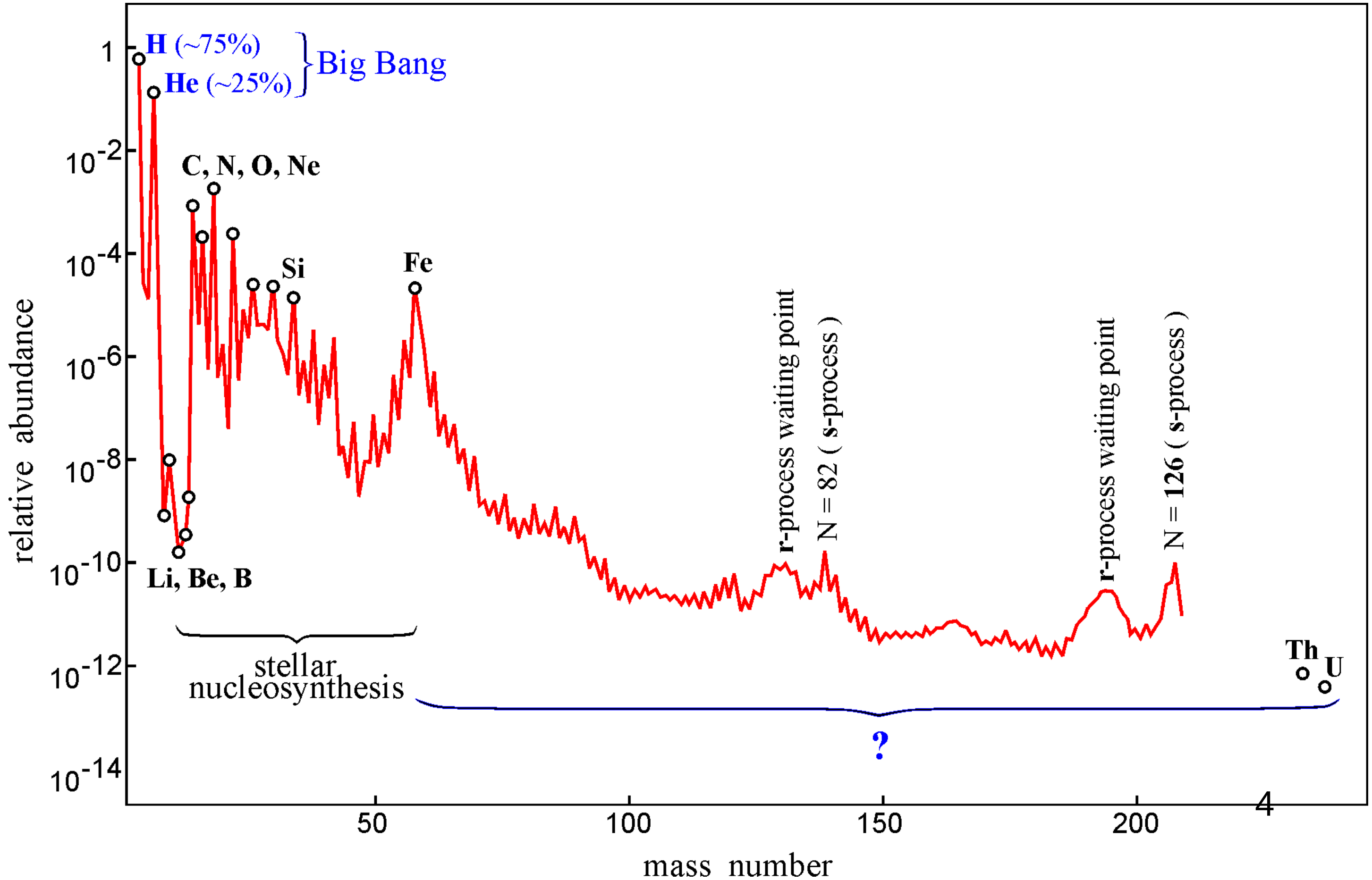
known
~ 3000
exist
~ 10 000
number of protons
number of neutrons
0
20
40
60
80
100
120
20
40
60
80
100
120
140
160
180

Abundance of Elements in the Universe

The 11 Greatest Unanswered Questions of Physics
(National Research Council, NAS, USA, 2002):

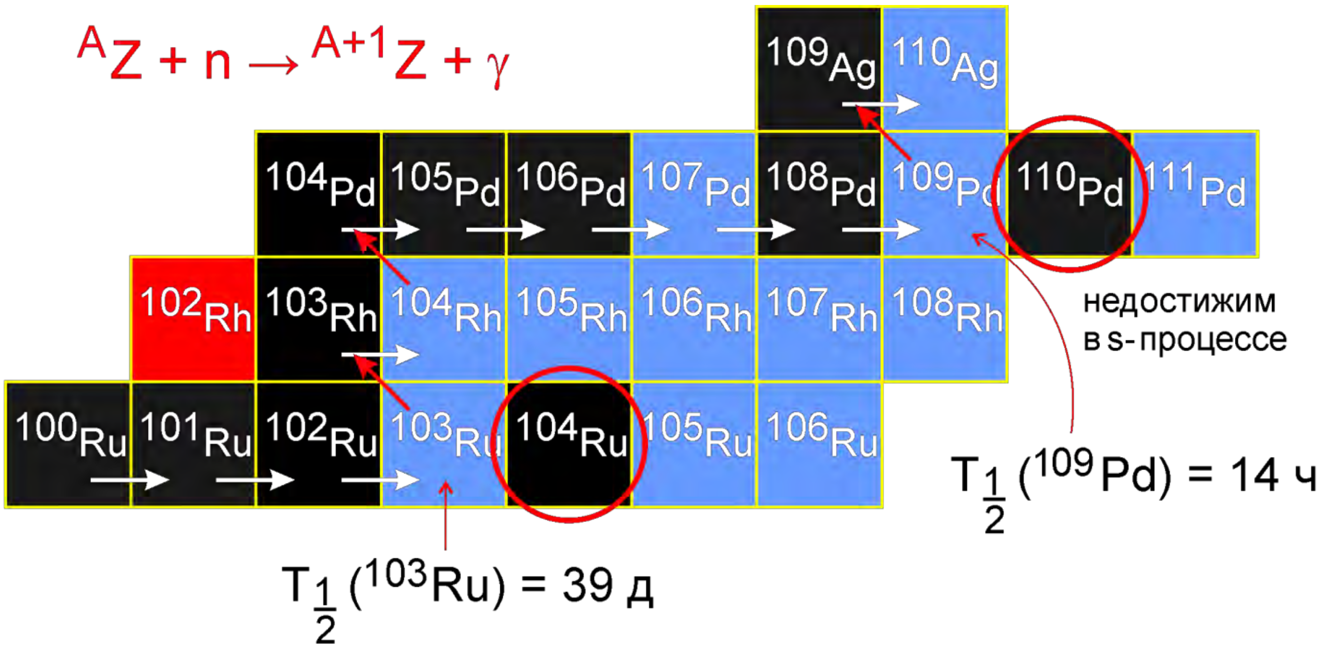
1. **What is dark matter?**
2. **What is dark energy?**
3. **How were the heavy elements from iron to uranium made?**
4. **Do neutrinos have mass?**

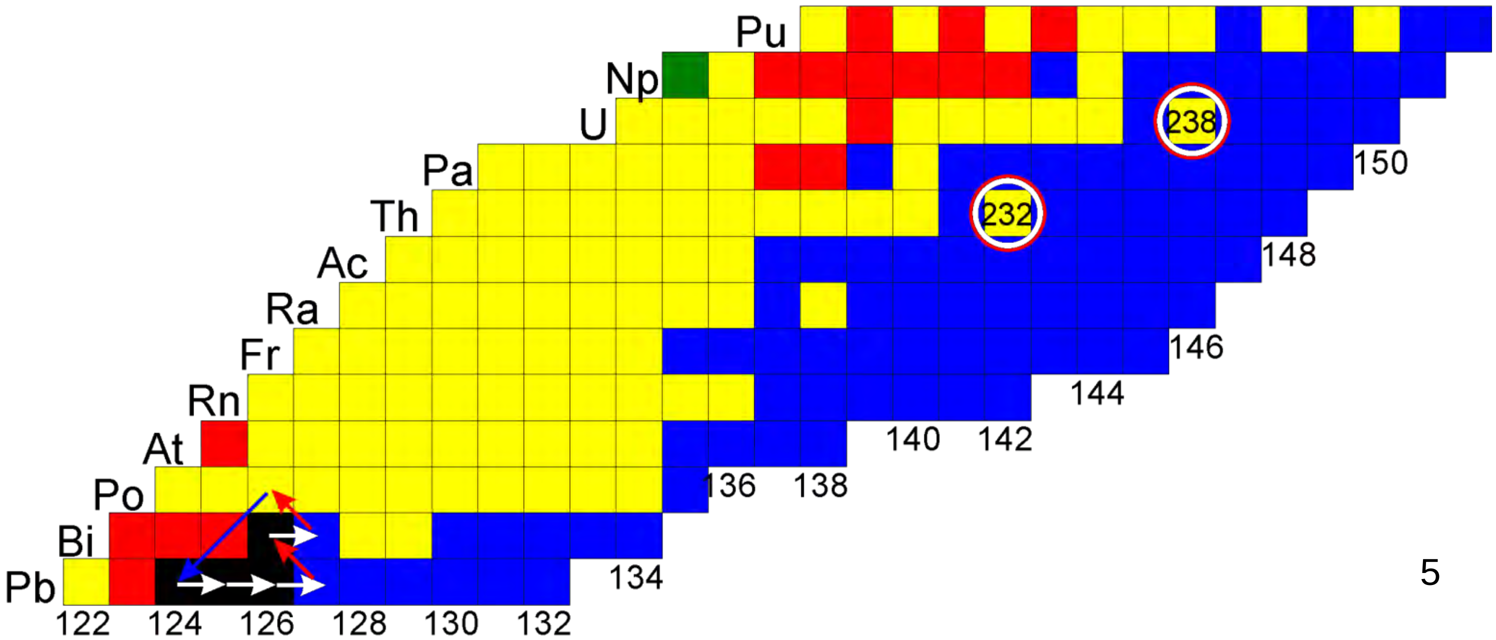
…



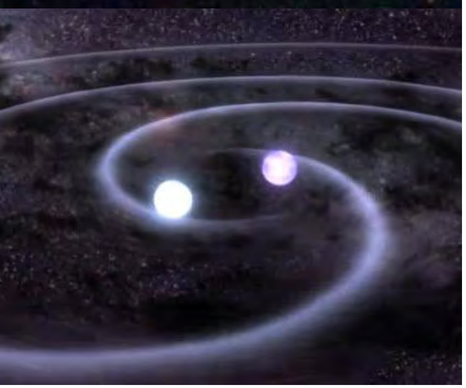
Limitation of s process

$^{A}Z + n \rightarrow {}^{A+1}Z + \gamma$



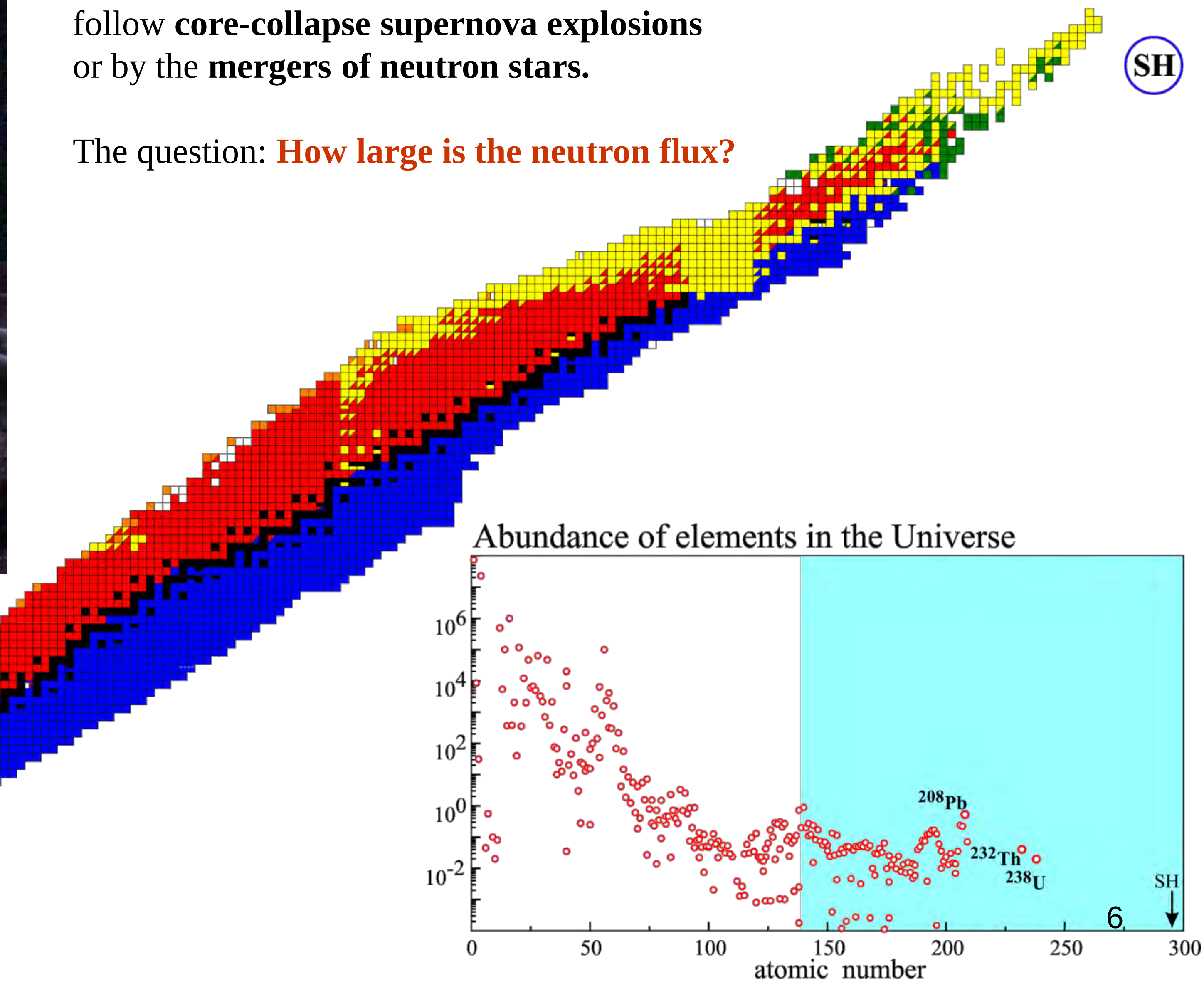


Formation of SH elements in astrophysical r-process



Strong neutron fluxes are expected to be generated by neutrino-driven proto-neutron star winds which follow **core-collapse supernova explosions** or by the **mergers of neutron stars.**

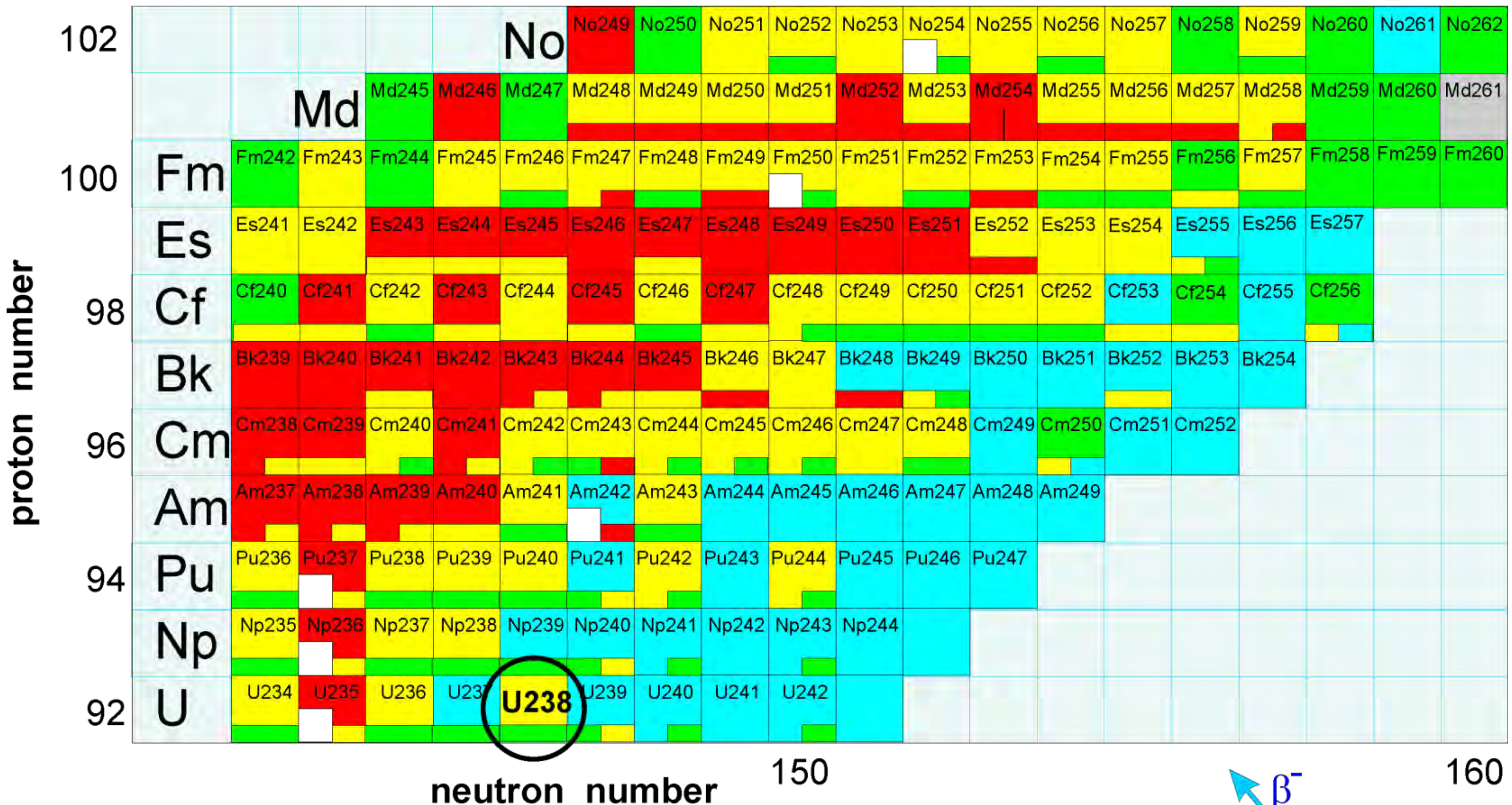
The question: **How large is the neutron flux?**



Search for SHE in cosmic rays

1971, Dubna, P. Fowler: Tracks of SHE !?

Hand-made chemical elements (reactors and nuclear explosion)



$$ {}^{241}_{95}\mathbf{Am}_{146} + n \to {}^{242}_{95}\mathbf{Am}_{147} \quad \beta^- $$

$$ {}^{241}_{94}\mathbf{Pu}_{147} \quad \beta^- $$

$$ {}^{239}_{94}\mathbf{Pu}_{145} + n \to {}^{240}_{94}\mathbf{Pu}_{146} + n \to {}^{241}_{94}\mathbf{Pu}_{147} $$

$$ \beta^- \qquad \beta^- $$

$$ {}^{239}_{93}\mathbf{Np}_{146} + n \to {}^{240}_{93}\mathbf{Np}_{147} $$

$$ \beta^- $$

$$ {}^{238}_{92}\mathbf{U}_{146} + n \to {}^{239}_{92}\mathbf{U}_{147}\ (23\,\text{min}) $$

β^- decay:

$$ n \to p + e^- + \tilde{\nu} $$

Nucleosynthesis by neutron capture

n_0 is the neutron flux

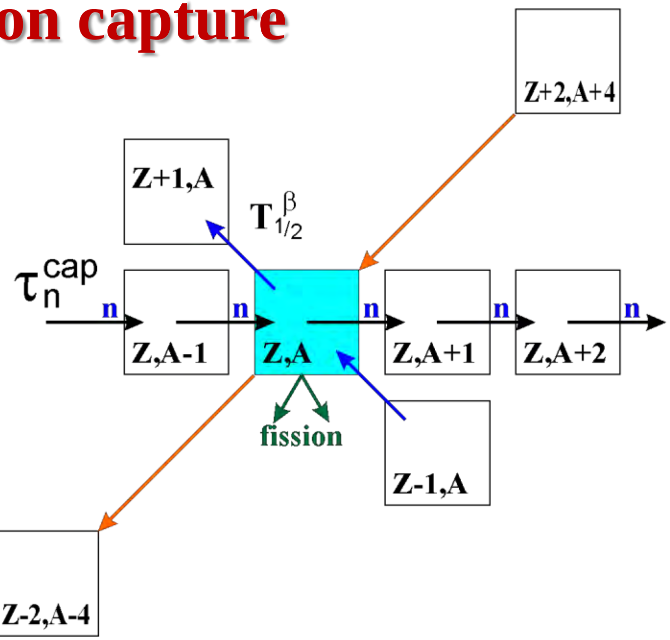
time of neutron capture

$$\tau_n^{cap} = \frac{1}{n_0 \times \sigma(n,\gamma)}$$

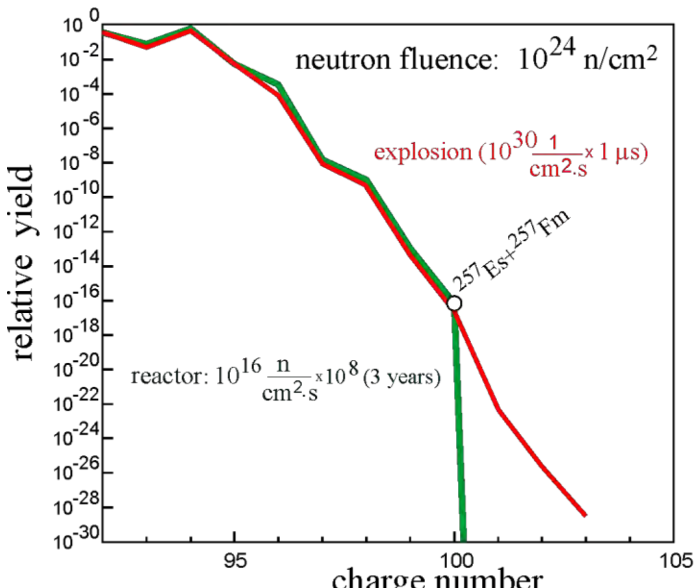
$$(Z,A) \rightarrow (Z,A+1) \text{ if } T_{1/2} > \tau_n^{cap}$$

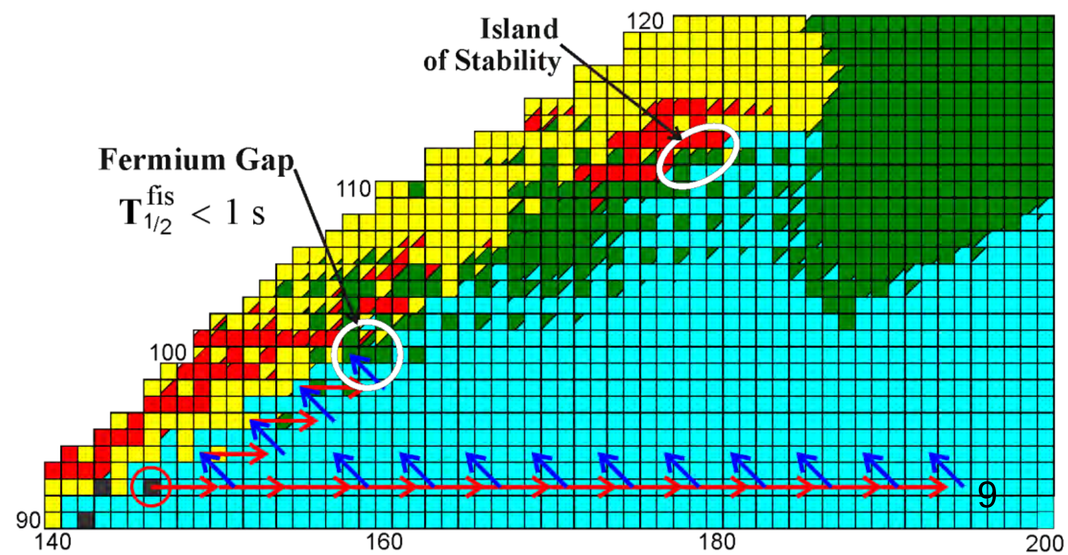
nuclear reactor: $\tau_n^{cap} \sim 1$ year

nuclear explosion: $\tau_n^{cap} \sim 1$ μs

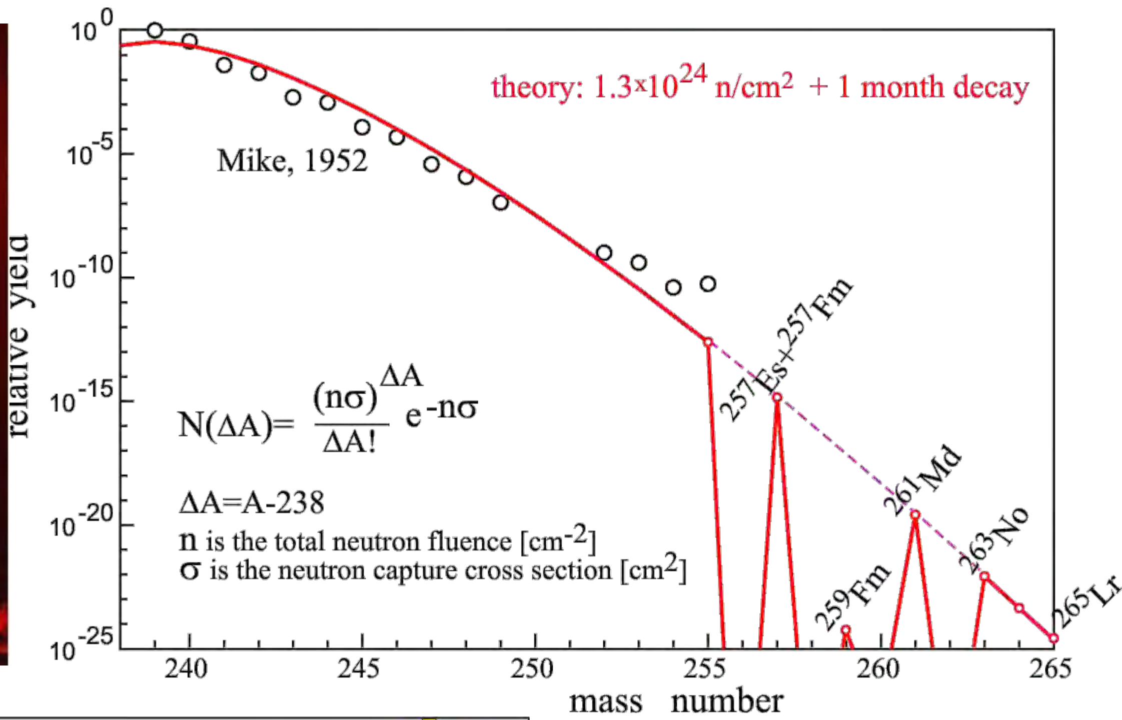


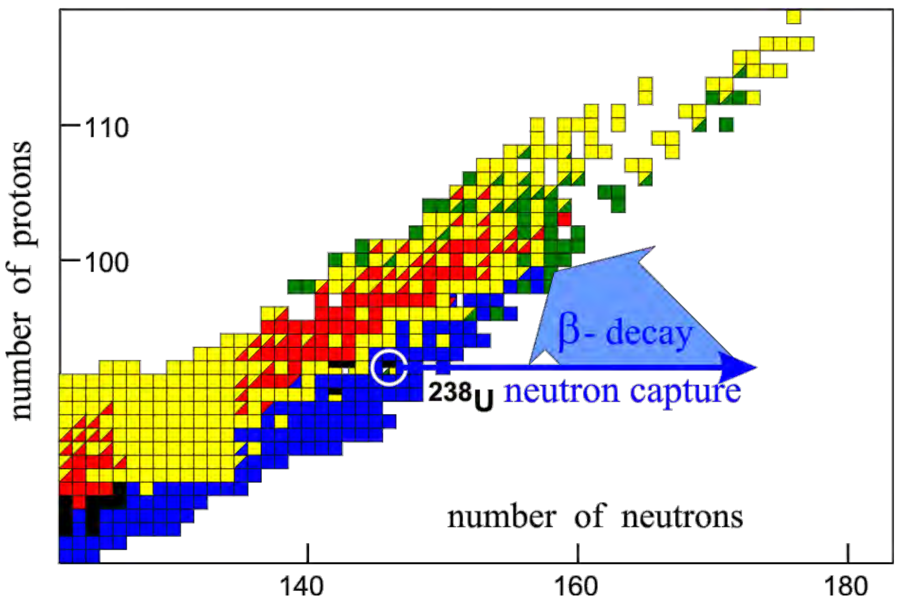
$$\frac{dN_{ZA}}{dt} = N_{ZA-1}\, n_0\, \sigma_{ZA-1}^{n\gamma} - N_{ZA}\, n_0\, \sigma_{ZA}^{n\gamma} - N_{ZA}\frac{\ln 2}{T_{ZA}^{\beta}} - N_{ZA}\frac{\ln 2}{T_{ZA}^{\alpha}} - N_{ZA}\frac{\ln 2}{T_{ZA}^{fis}} + N_{Z-1A}\frac{\ln 2}{T_{Z-1A}^{\beta}} + N_{Z+2A+4}\frac{\ln 2}{T_{Z+2A+4}^{\alpha}}$$





Rapid neutron capture in nuclear explosions

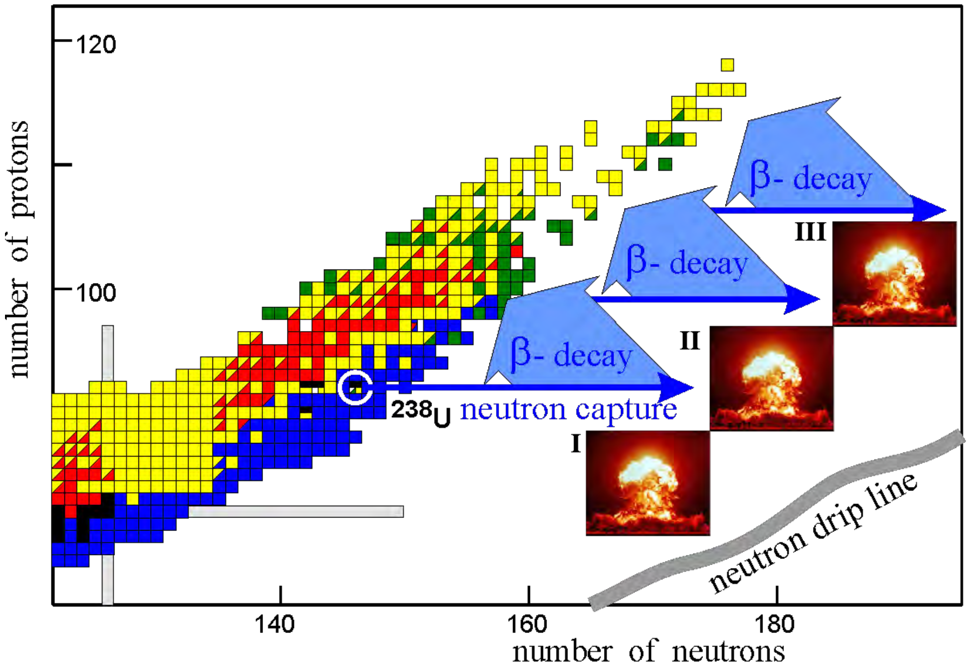


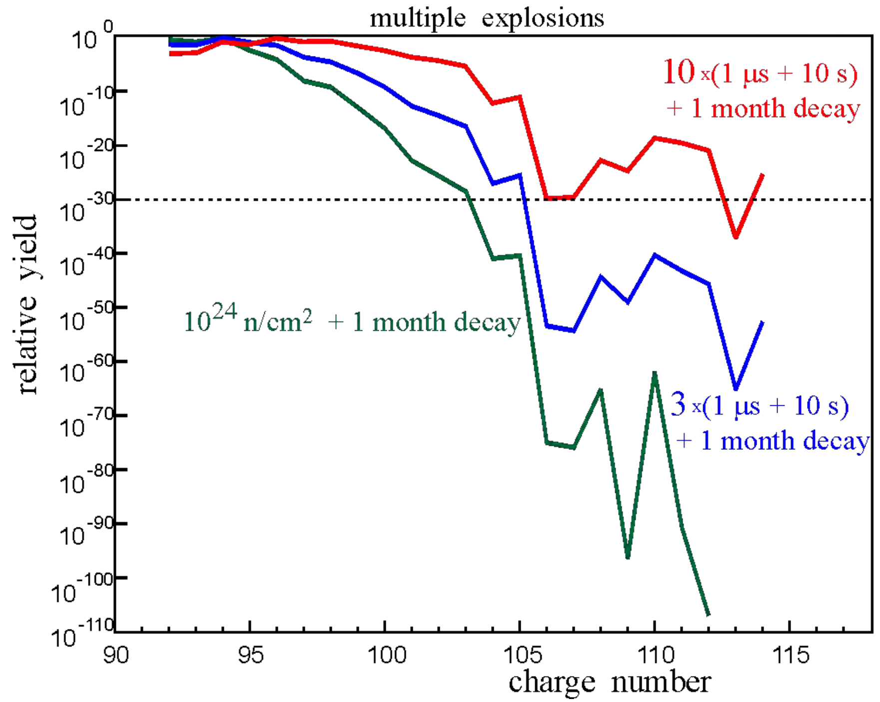


Multiple nuclear explosions

(proposed first by H.W. Meldner, PRL 28,1972)

Edward Teller: Technically it is quite possible

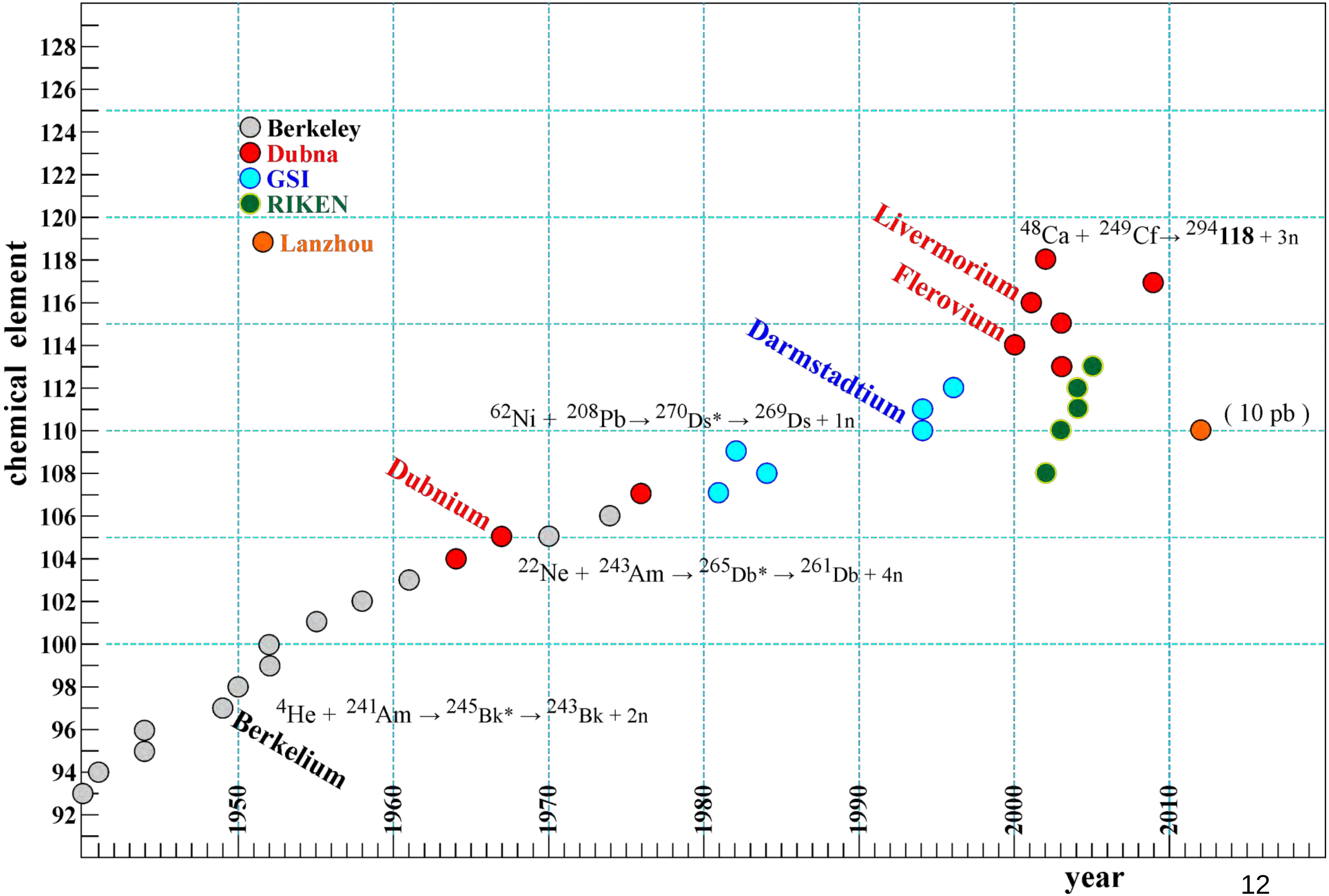




Probability for formation of element 112 increases by **90 orders** of magnitude **!**

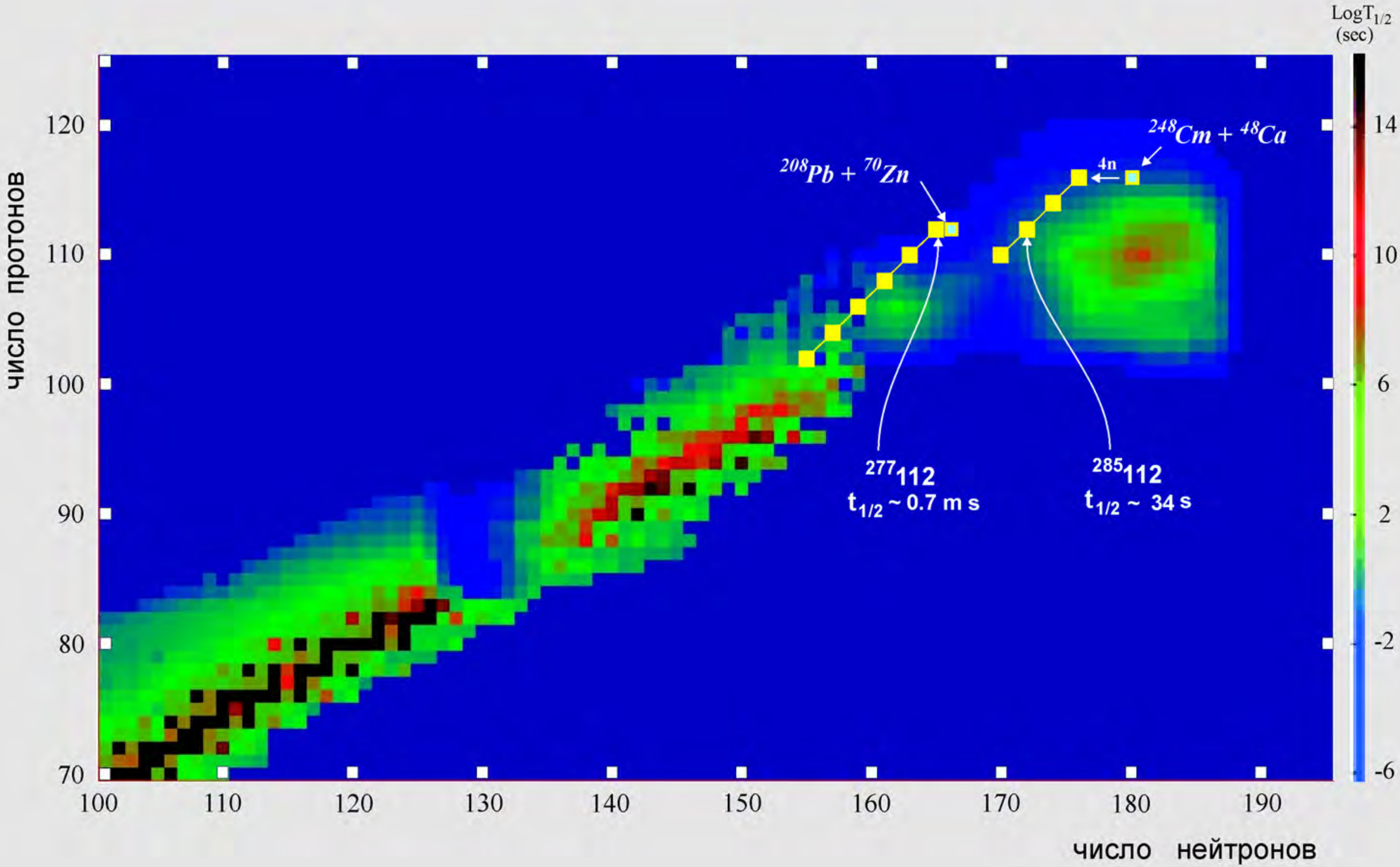
Pulsed nuclear reactors of the next generation ?

Hand-made elements (history)



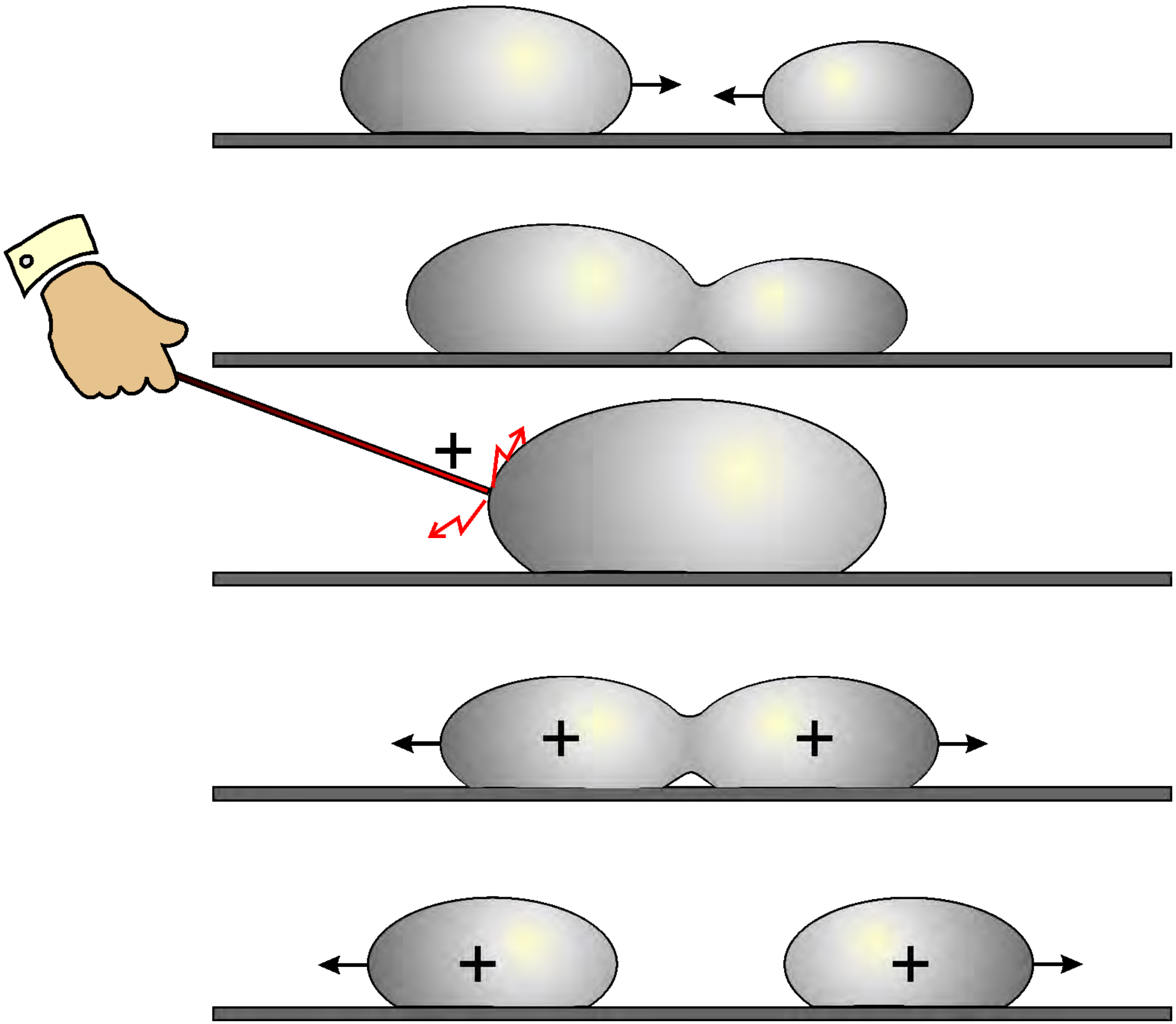
2012: a new player in the field: IMP, Lanzhou, China

Superheavy Elements (Island of Stability)

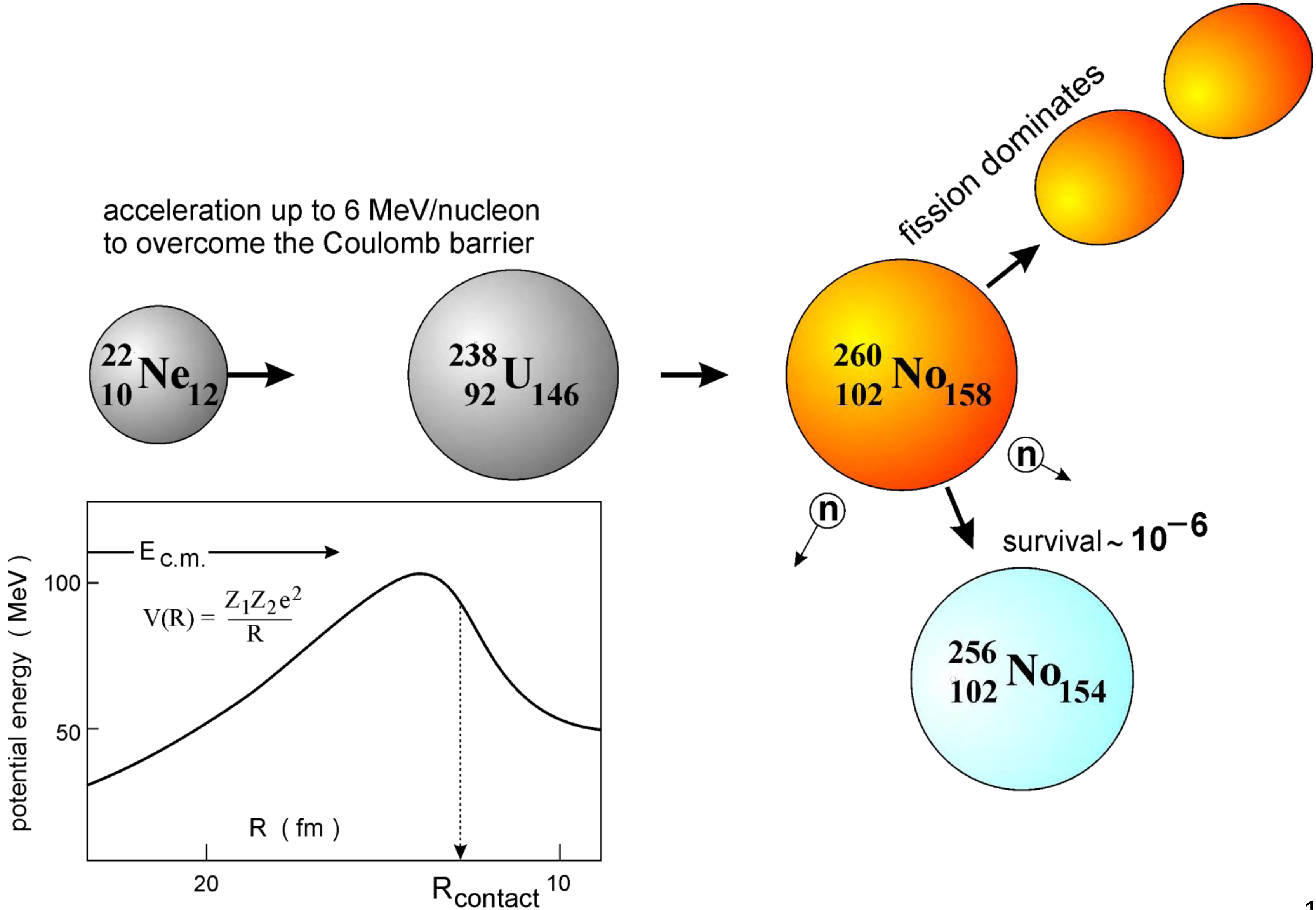


Why don't nuclei fuse ?

(example: two drops of mercury)



Synthesis of new elements in fusion reactions



Physics problems

(1) How to choose appropriate fusion reaction ?

«cold» synthesis: ^{208}Pb + ^{64}Ni, ^{70}Zn, … → ^{272}110, ^{278}112, … (GSI, Germany)

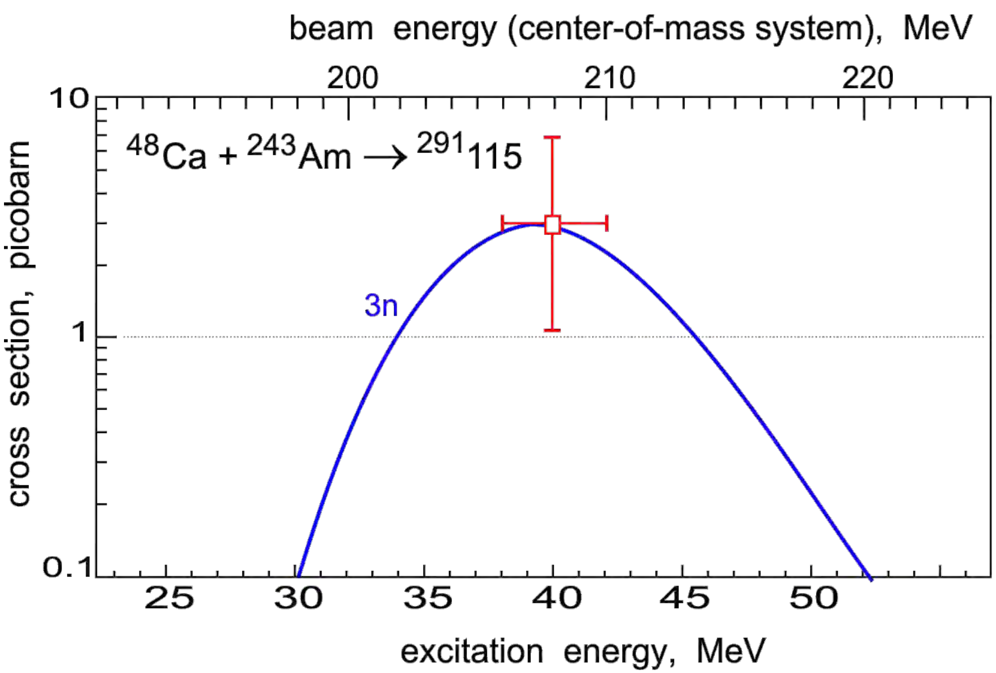
«hot» synthesis: ^{238}U, ^{244}Pu, ^{248}Cm, ^{249}Cf + ^{48}Ca → ^{286}112, ^{292}114 , ^{296}116 , ^{297}118 (Dubna)

Symmetric combinations: ^{148}Nd + ^{154}Sm → ^{302}122 ?

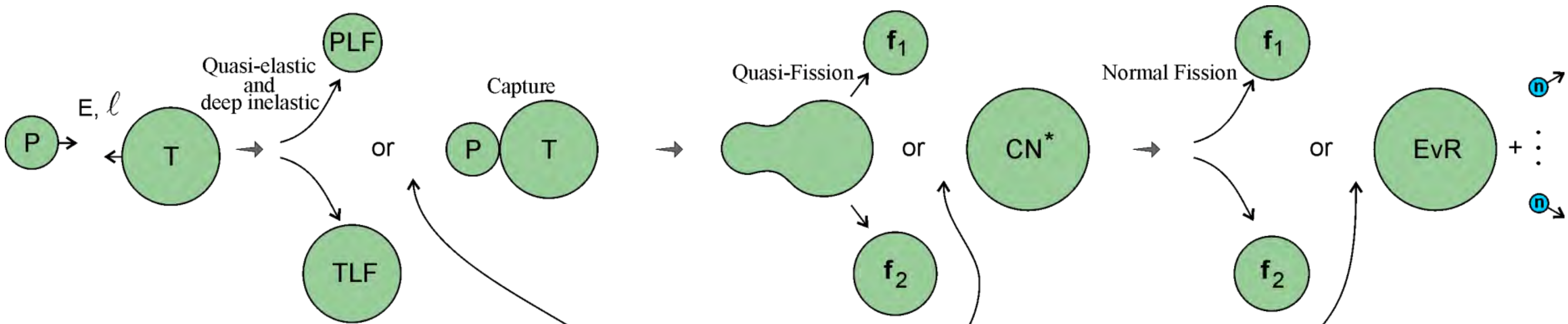
Radioactive ion beams of ^{132}Sn, etc. ?

(2) How to choose colliding energy ?

(3) How to estimate cross sections ?



Synthesis of SHE in fusion reactions (conventional view)



$$\sigma^{xn}_{ER}(E) = \frac{\pi}{k^2}\sum_{\ell=0}^{\infty}(2\ell+1)\cdot P_{cont}(\ell,E)\cdot P_{CN}(\ell,E^*)\cdot P_{xn}(\ell,E^*)$$

$$\sigma_{capture}(E) \overset{exp}{=} \sum (f^{all}_{1,2} + EvR), \quad \text{if} \quad f_1 f_2 \neq PLF, TLF$$

$$\sigma_{CN} \equiv \sigma_{fusion}(E) \overset{exp}{=} \sum (f^{NF}_{1,2} + EvR), \quad \text{if} \quad f^{NF}_{1,2} \neq f^{QF}_{1,2}$$

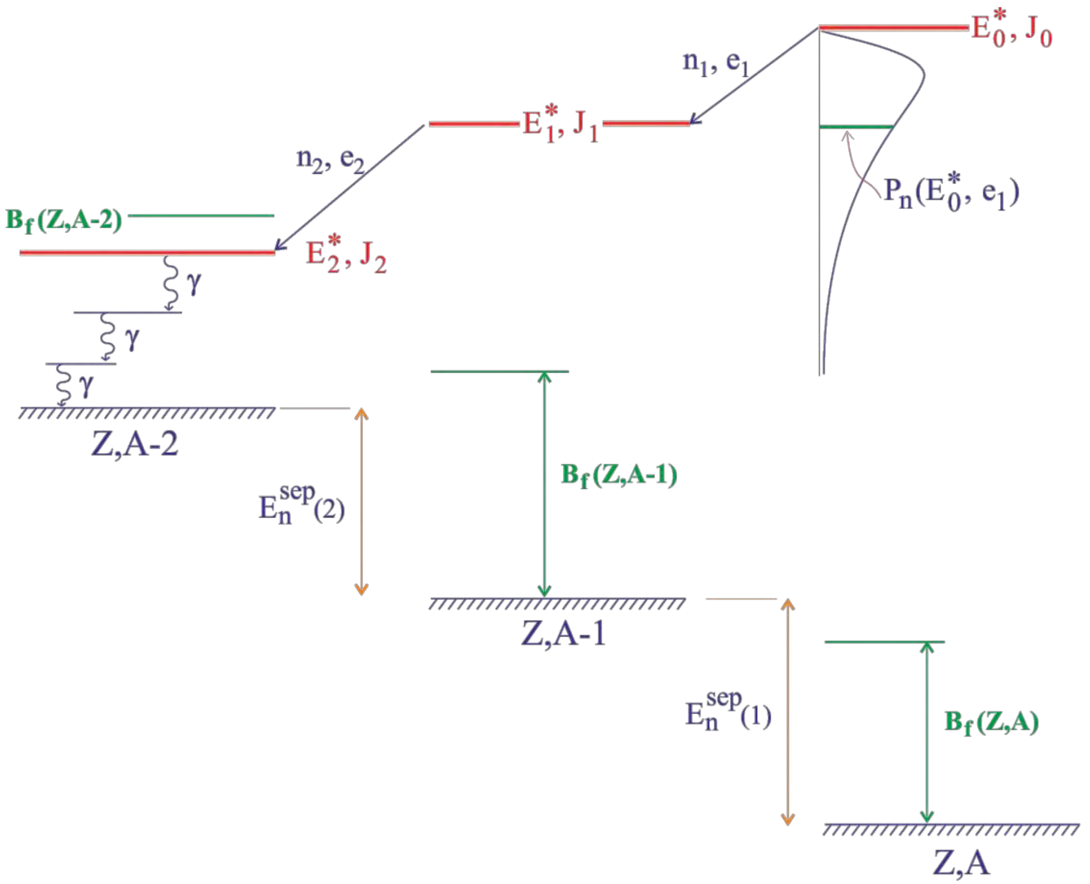
P_{cont} : Penetration probability of the multi-dimensional Coulomb barrier $V^B_C(r, \beta_1, \beta_2, \varphi_1, \varphi_2)$ - ?

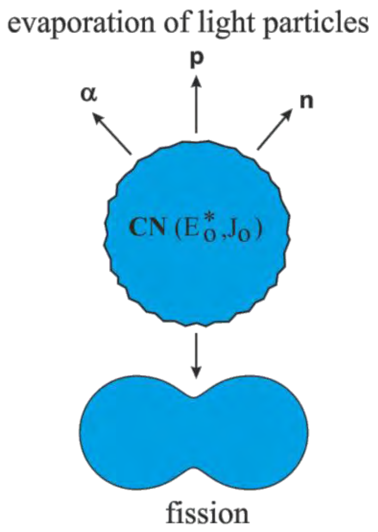
P_{CN} : Probability of CN formation (evolution in the space of shape parameters)

P_{xn} : Survival probability of excited CN (Statistical Model: Γ_n, Γ_f, E^{sep}_n, B_{fis})

http://nrv.jinr.ru/nrv/Fusion

Decay and survival of excited compound nucleus





Survival probability: CN $(E_0^*, J_0) \rightarrow$ **EvR**(g.s.) + xn + Nγ

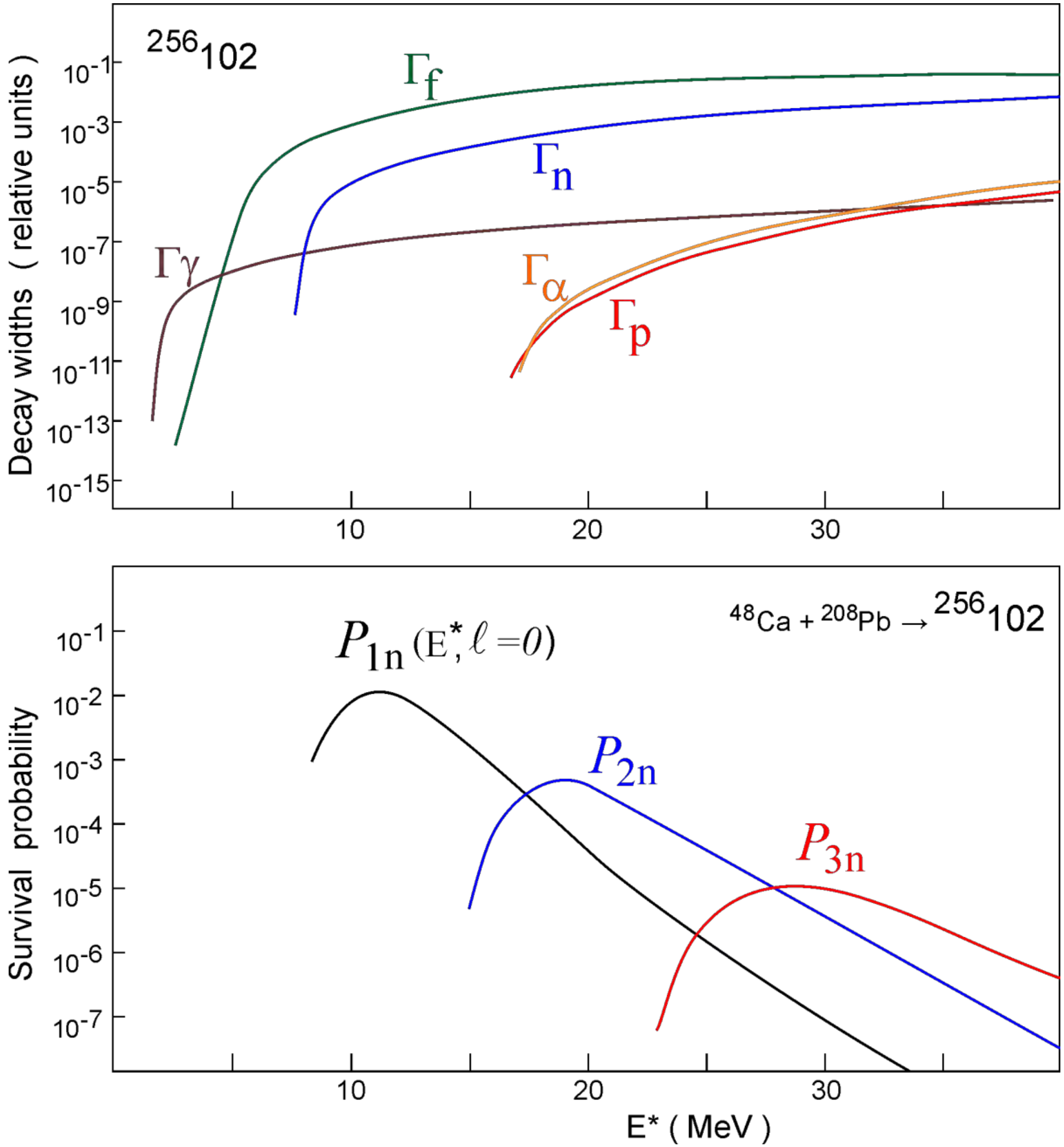
$$P_{xn} = \int_0^{E_0^*-E_n^{sep}(1)} \frac{\Gamma_n}{\Gamma_{tot}}(E_0^*, J_0)\ P_n(E_0^*, e_1)\, de_1 \int_0^{E_1^*-E_n^{sep}(2)} \frac{\Gamma_n}{\Gamma_{tot}}(E_1^*, J_1)\ P_n(E_1^*, e_2)\, de_2 \cdots \int_0^{E_1^*-E_n^{sep}(x)} \frac{\Gamma_n}{\Gamma_{tot}}(E_{x-1}^*, J_{x-1})\ P_n(E_{x-1}^*, e_x)\ G_{N\gamma}(E_x^*, J_x \rightarrow g.s.)\, de_x$$

Cross section for formation of evaporation residues:

$$\sigma_{EvR}^{xn}(E) = \frac{\pi}{k^2}\sum_{\ell}(2\ell+1)P(E,\ell)\cdot P_{CN}(E^*,\ell)\cdot P_{xn}(E^*,\ell)$$

http://nrv.jinr.ru/nrv/Statistical Model

Decay widths and survival probability



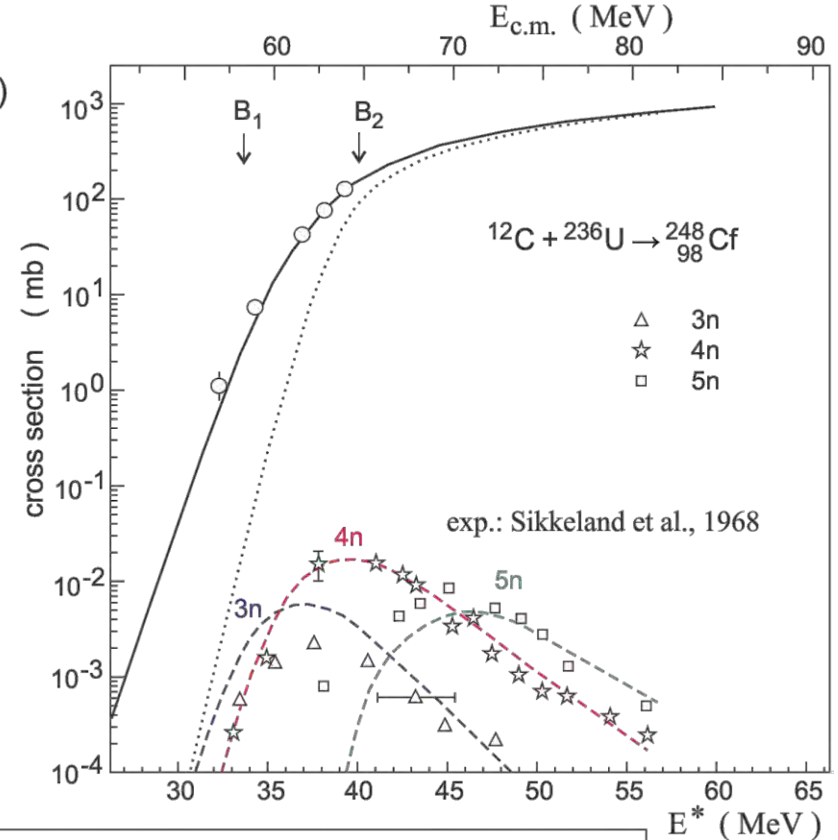
Fusion reactions with light projectiles

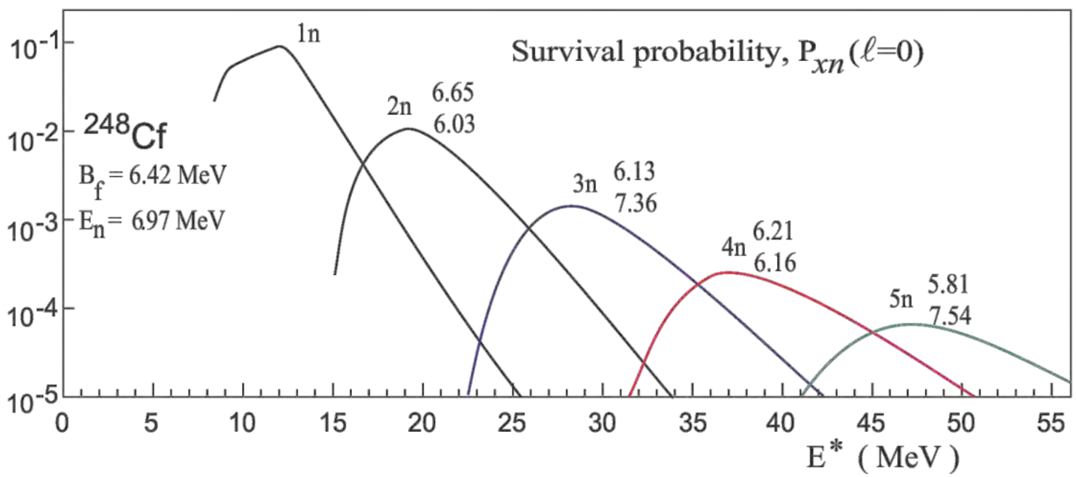
$$\sigma^{xn}_{EvR}(E) = \frac{\pi\hbar^2}{2\mu E}\sum_{\ell}(2\ell+1)P(\ell,E)\cdot P_{CN}(\ell,E^*)\cdot P_{xn}(\ell,E^*)$$

standard CC model

$= 1$

statistical model

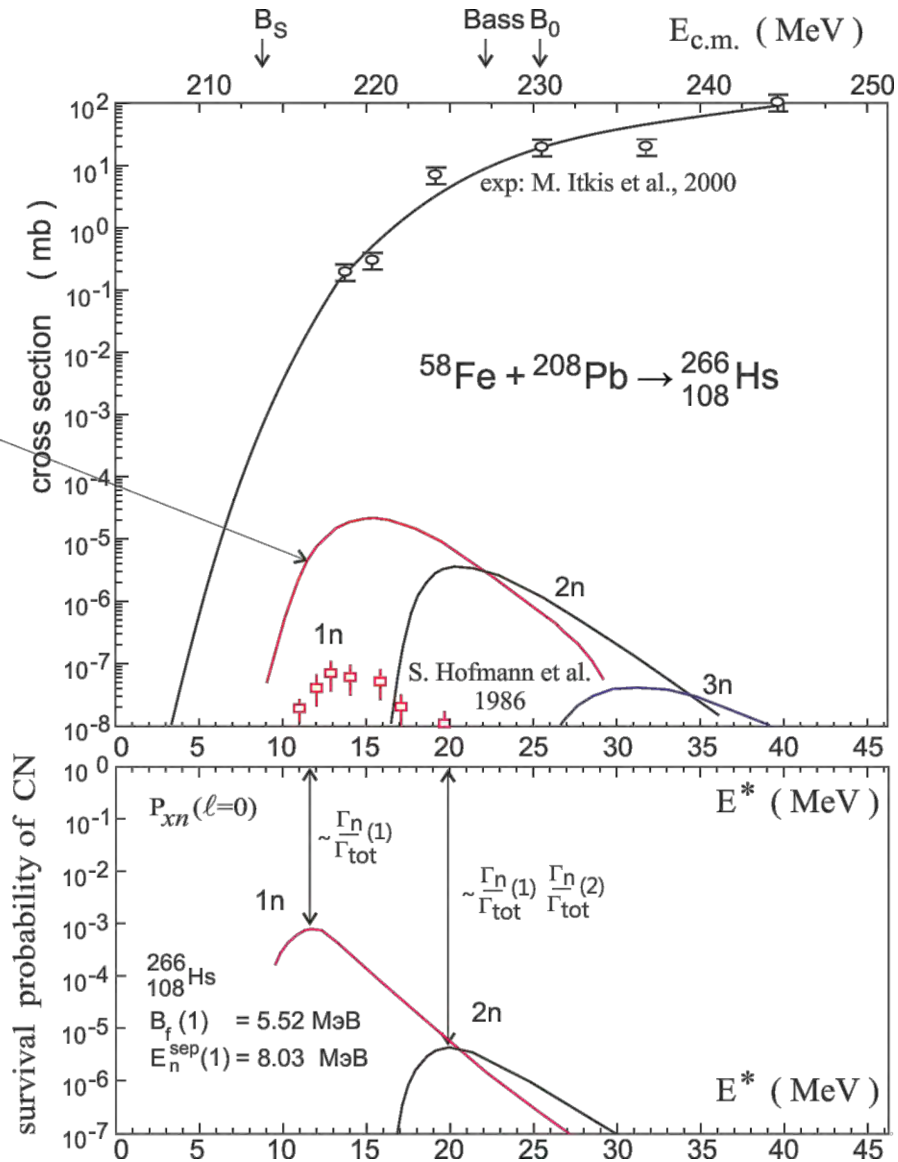




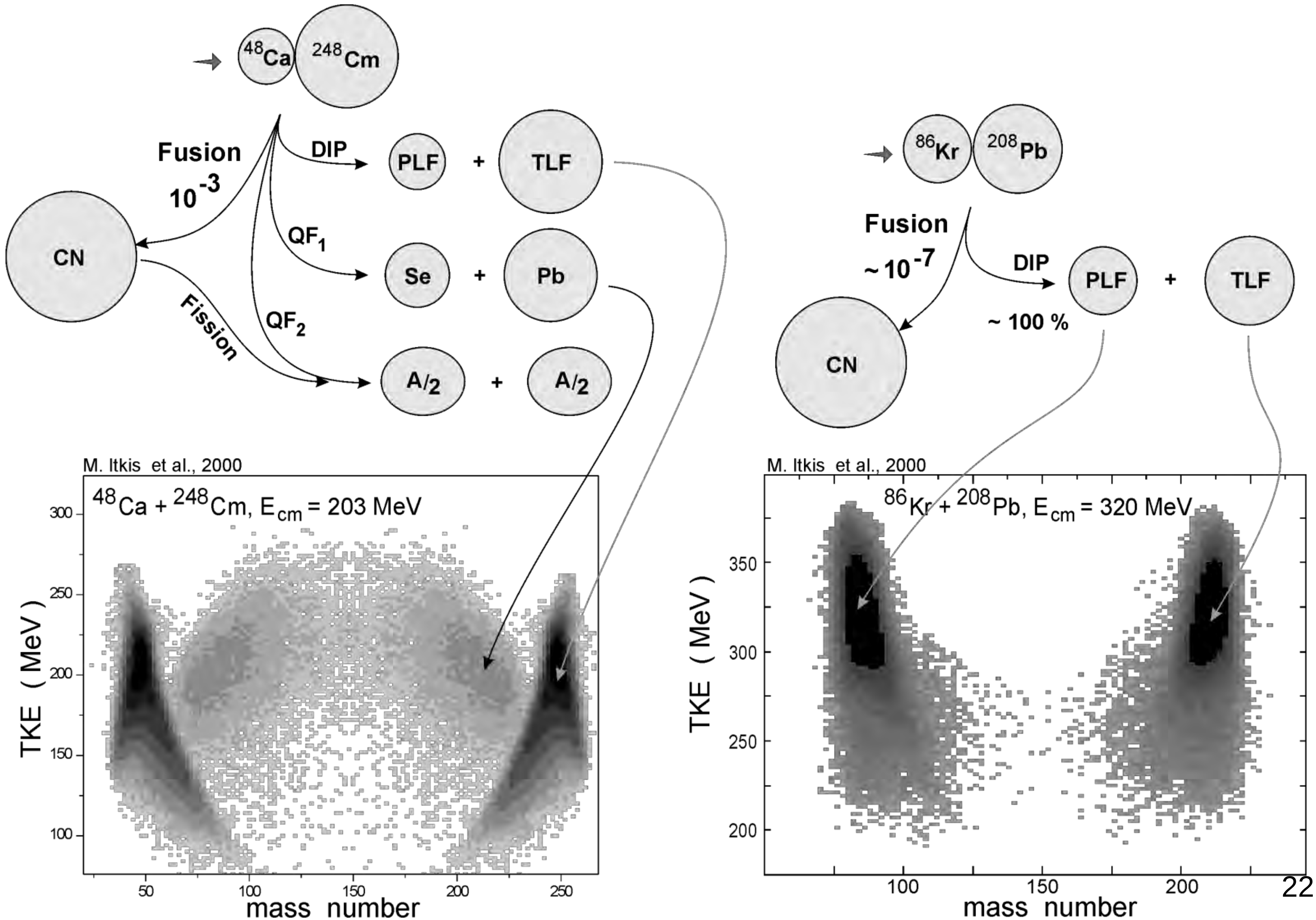
Formation of compound nucleus after contact, P_{CN} = ?

$$\sigma^{xn}_{EvR}(E) = \frac{\pi\hbar^2}{2\mu E}\sum_{\ell}(2\ell+1)P(\ell,E)\cdot P_{CN}(\ell,E^*)\cdot P_{xn}(\ell,E^*)$$

- $P(\ell,E)$ → standard CC model
- $P_{CN}(\ell,E^*)$ → = 1
- $P_{xn}(\ell,E^*)$ → statistical model



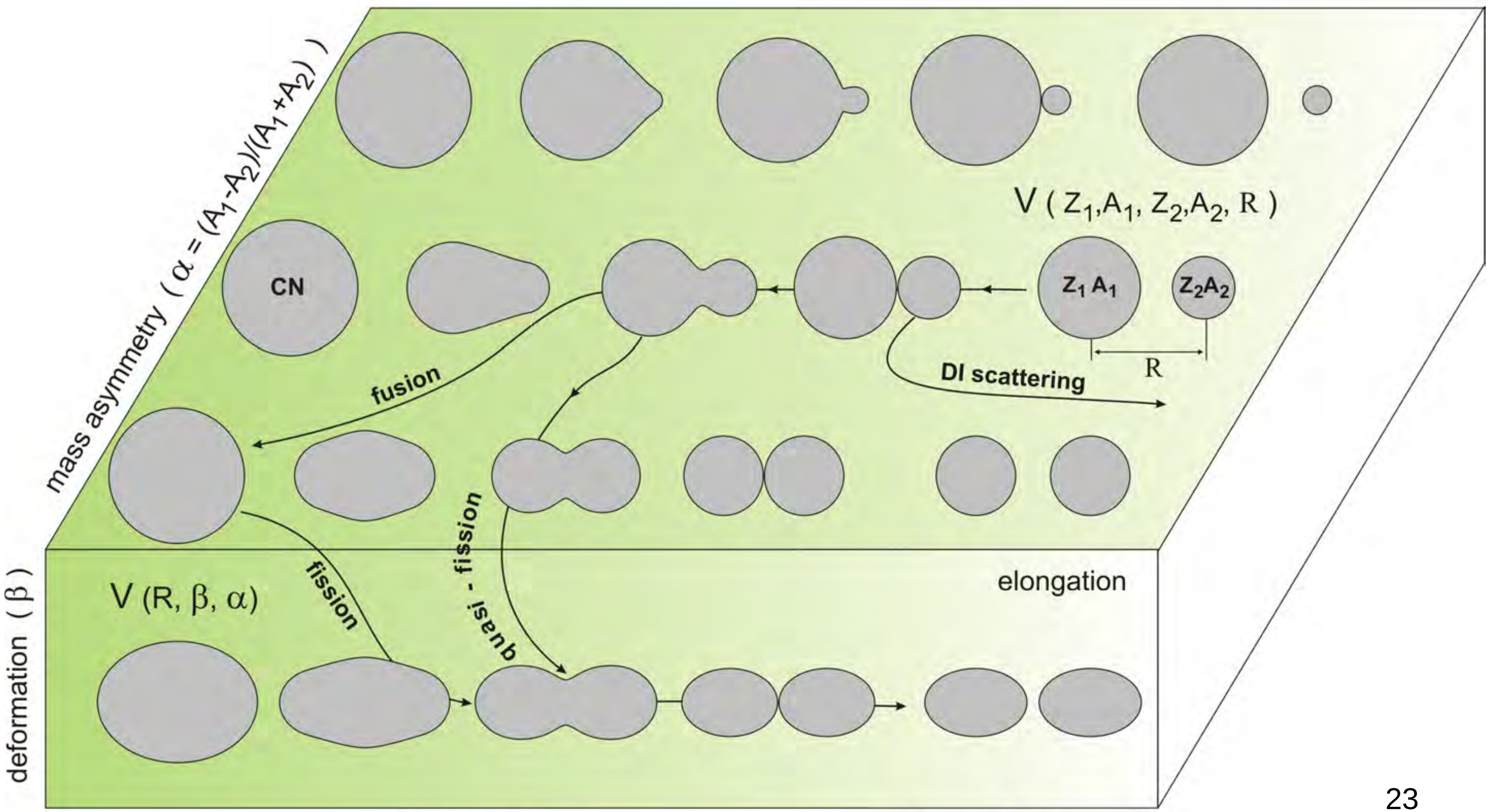
Competition of deep inelastic scattering, quasi-fission and fusion



Variables ?

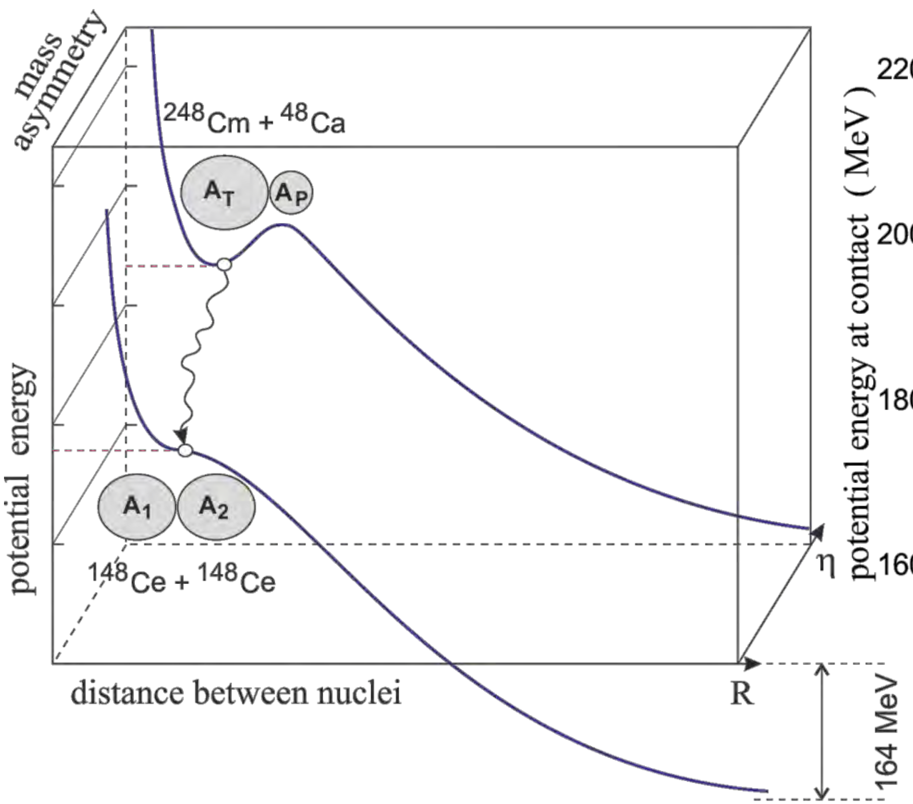
? - principal degrees of freedom: $\{ q_1, q_2, ...\}$,
? - potential energy surface: $V(q_1,q_2,...)$,
? - dynamic equations of motion: $dq_i/dt = ...$

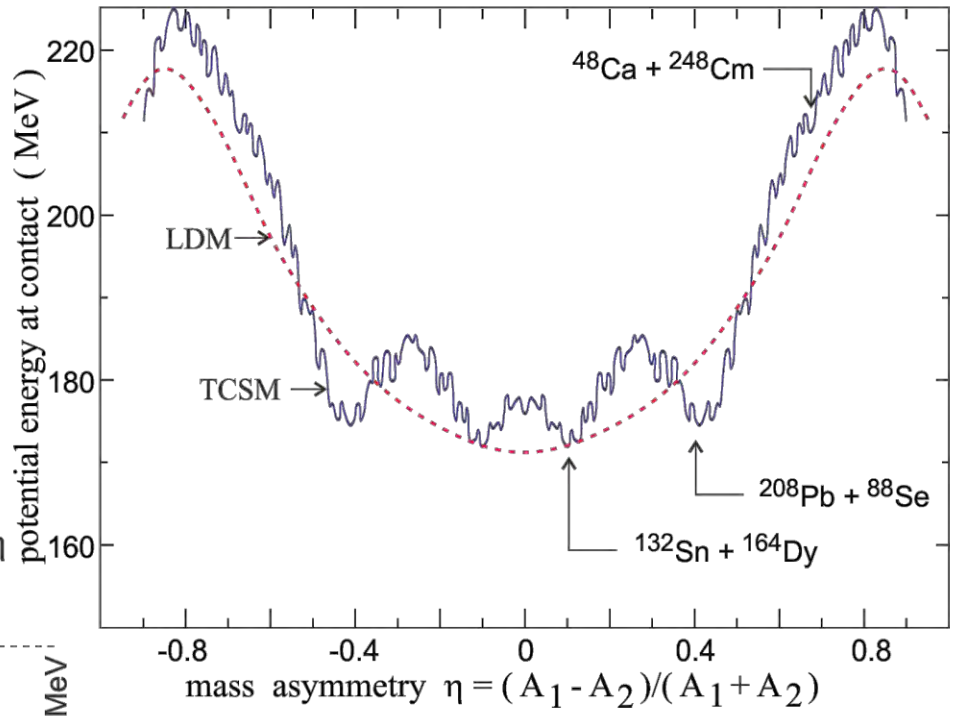
Common (unified) for all the processes:
Deep Inelastic, Quasi-Fission, Fusion-Fission !!!



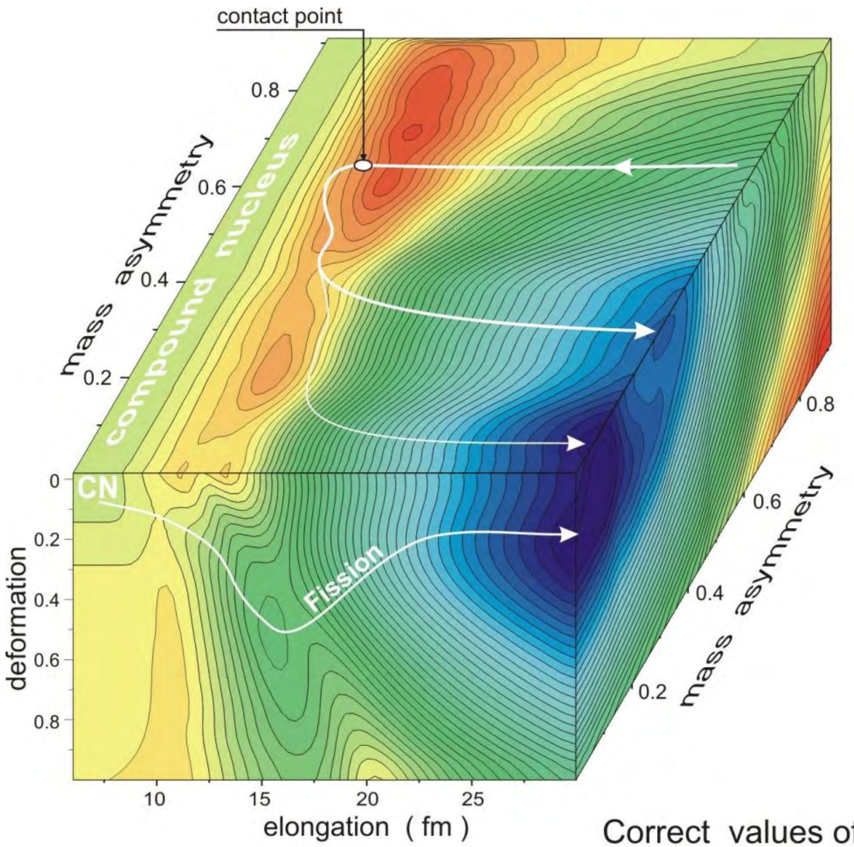
$V_{adiab} \neq V_{diab}$ $V_{adiab} = V_{diab}$

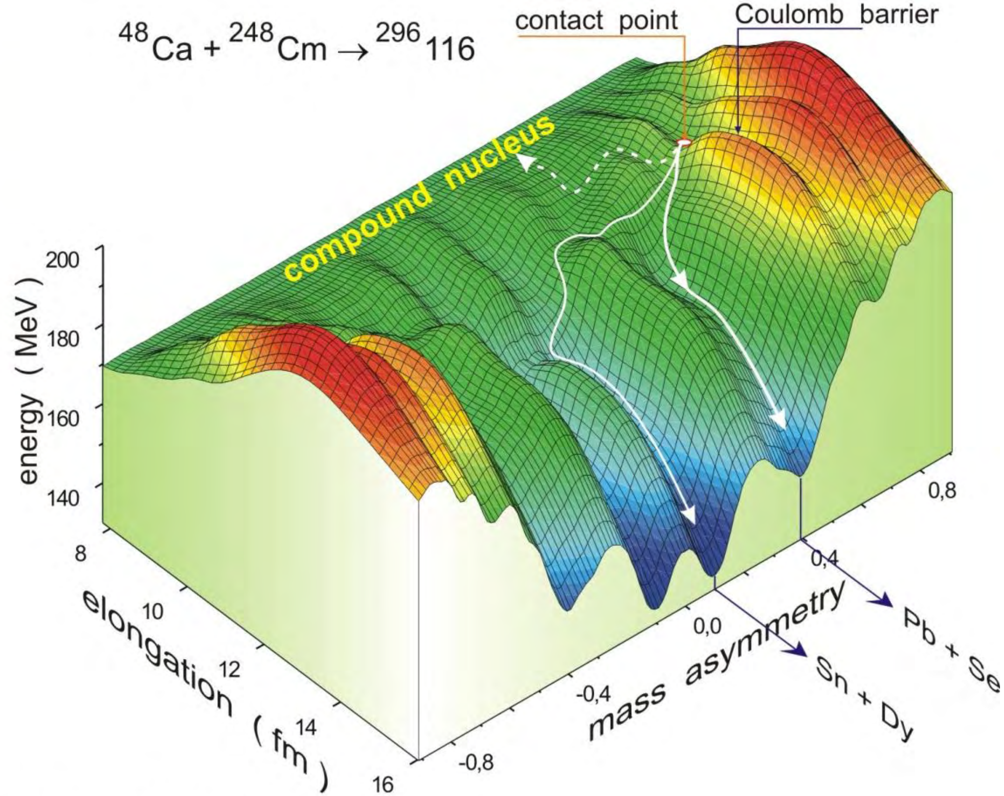
Potential Energy: Dependence on mass rearrangement





Potential Energy: Fusion, Fission and Quasi-Fission

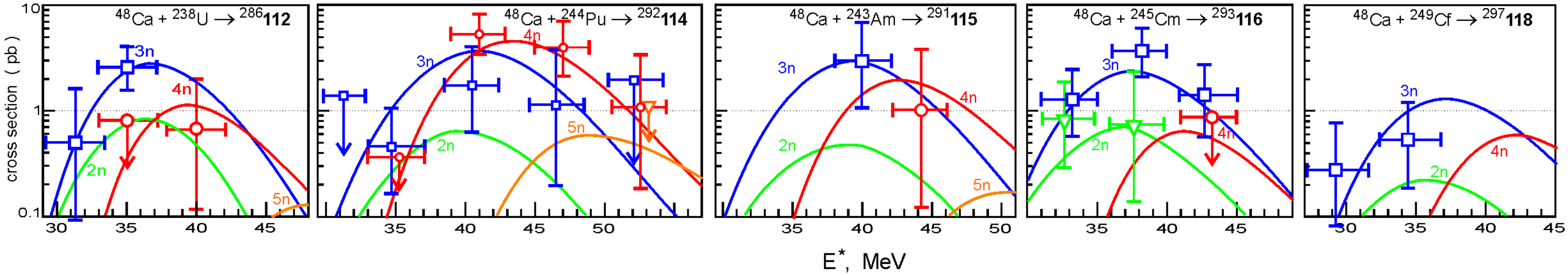




Correct values of the Coulomb barriers
and the height of the fission barrier of CN

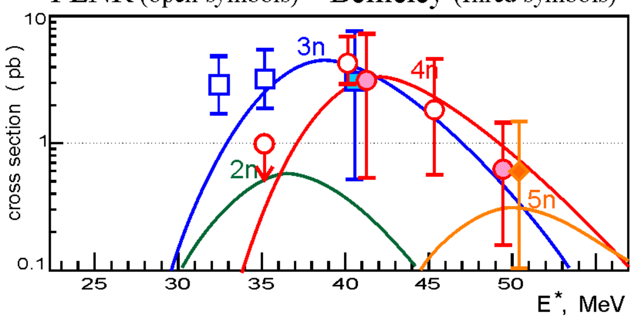
Predictive power of the theory for the hot fusion reactions

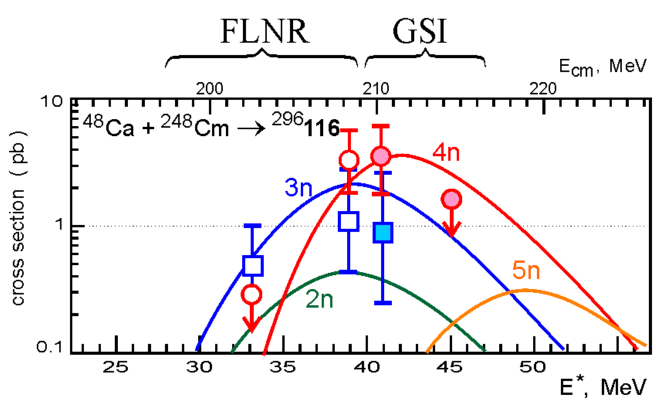
predictions of 2002



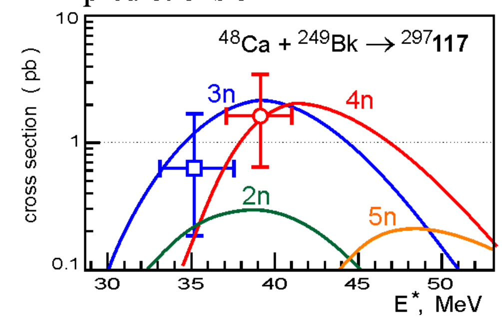
48Ca + 242Pu → 290114

FLNR (open symbols) Berkeley (filled symbols)

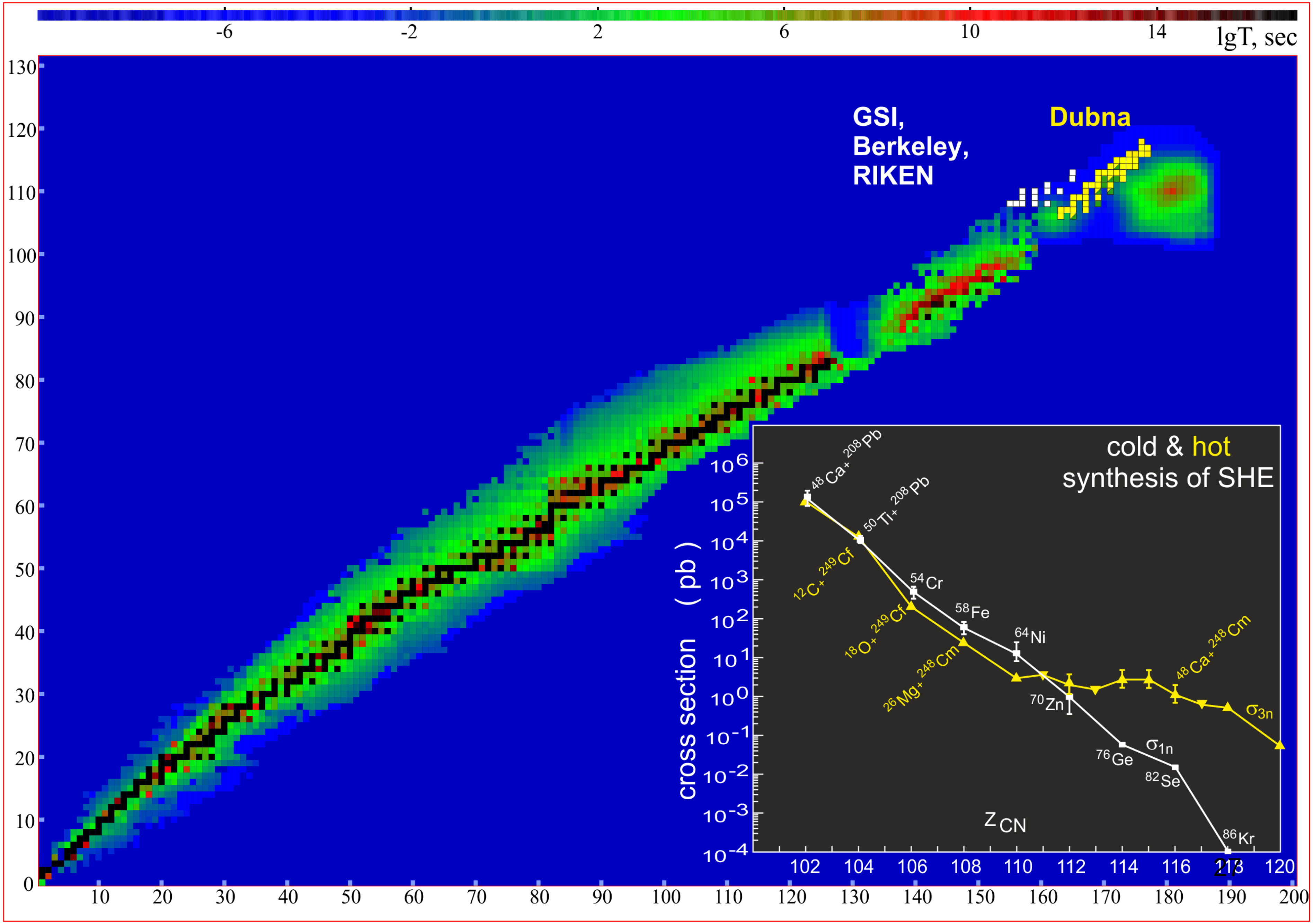




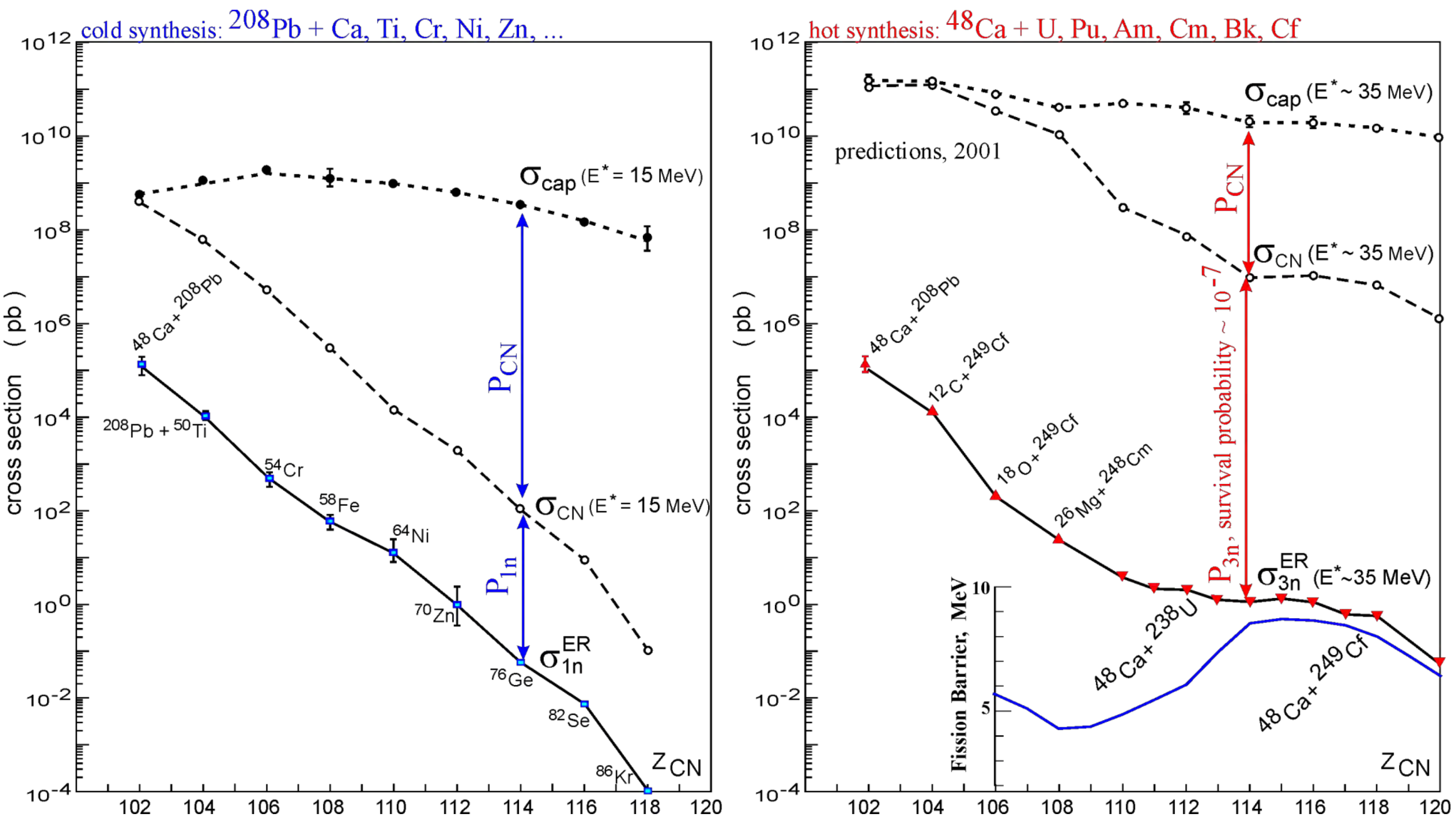
predictions of 2008



Synthesis of superheavy elements (cold and hot fusion)

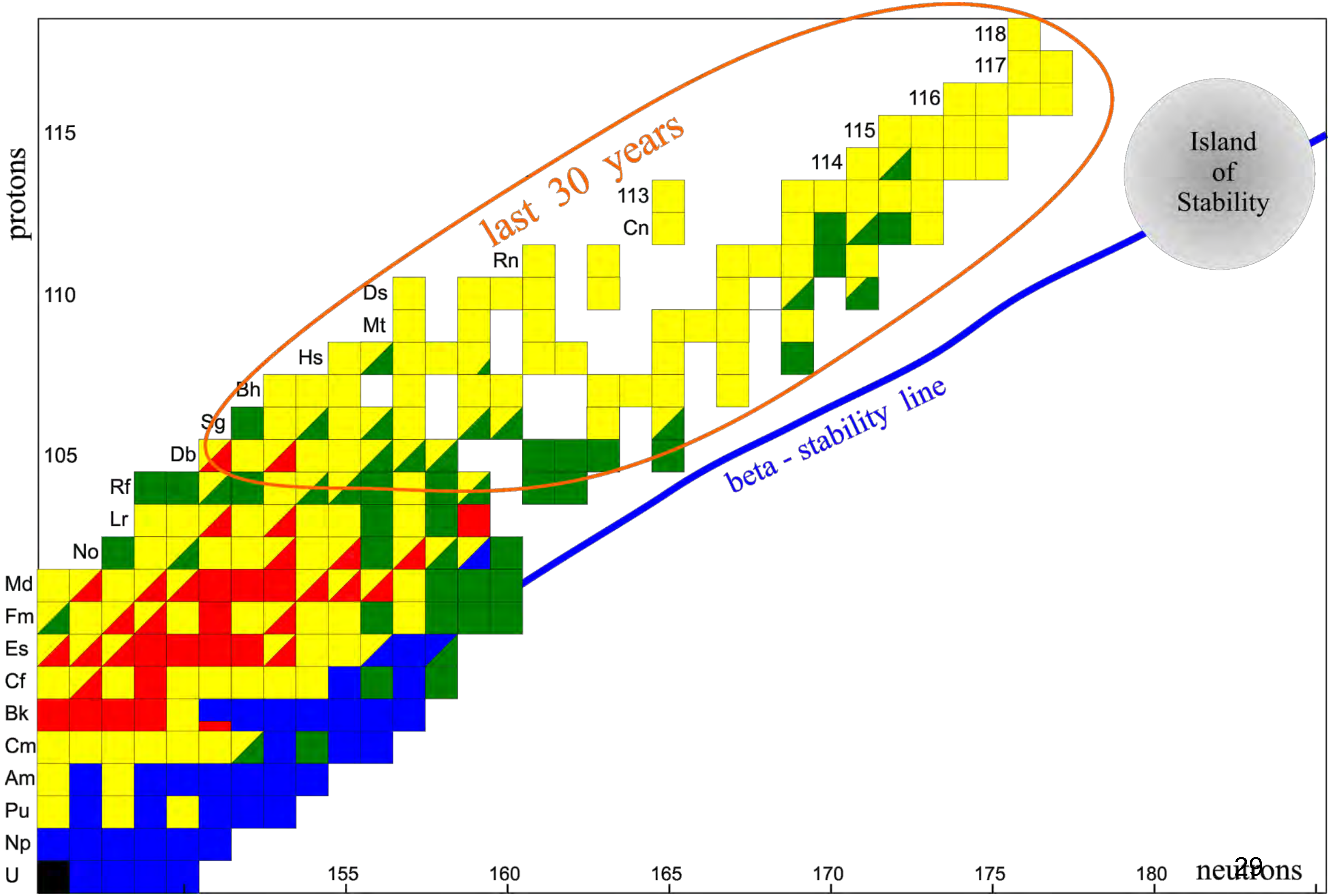


Cross sections of the "cold" and "hot" synthesis of SHE

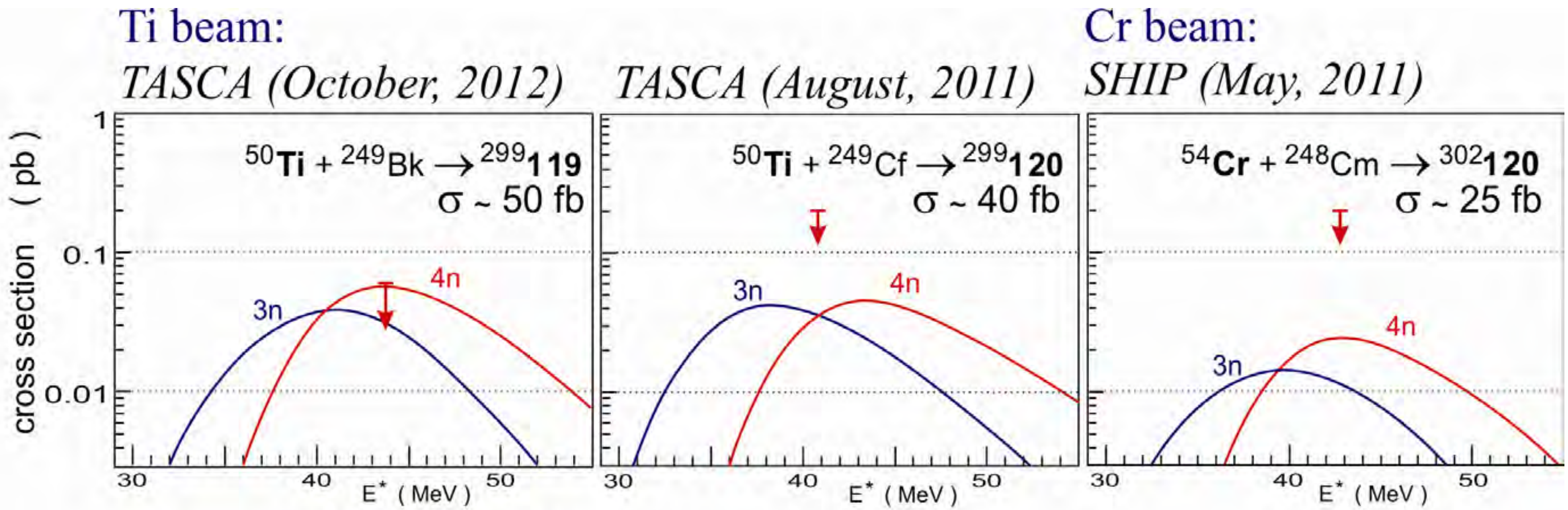


Cross sections for formation of SHE with Z=112-118 have been predicted to be nearly constant owing to increasing values of the fission barriers of formed CN

Great progress in synthesis of superheavy nuclei. What's the next?



New elements 119 and 120 are coming !

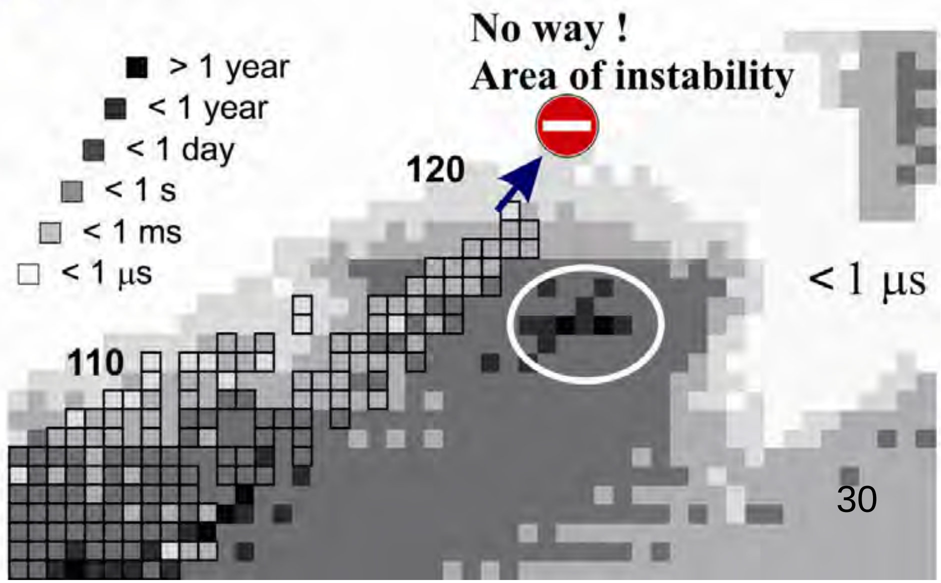


our predictions (PRC 2008):

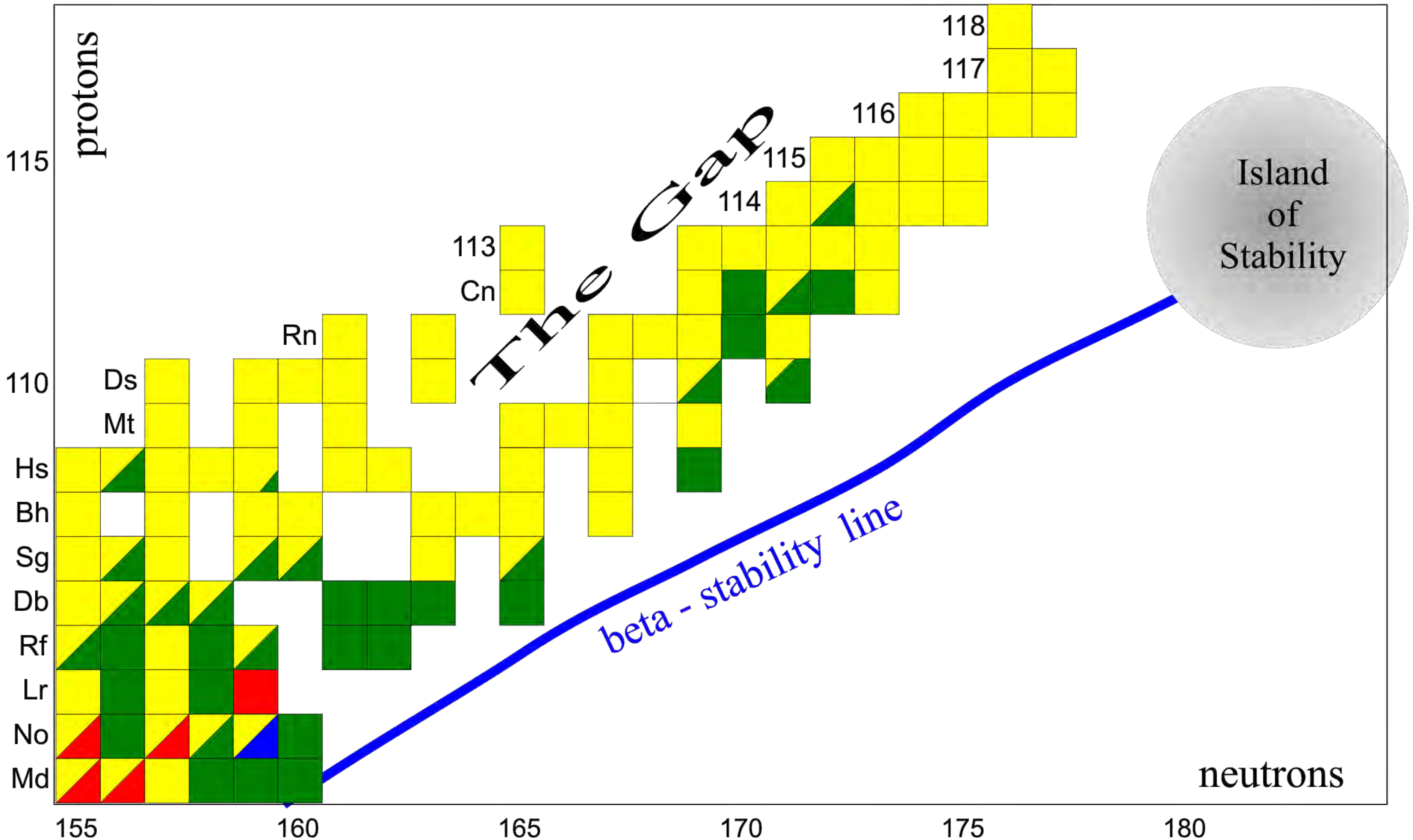
factor $\frac{1}{20}$ as compared to ^{48}Ca

Approaching the area of instability:

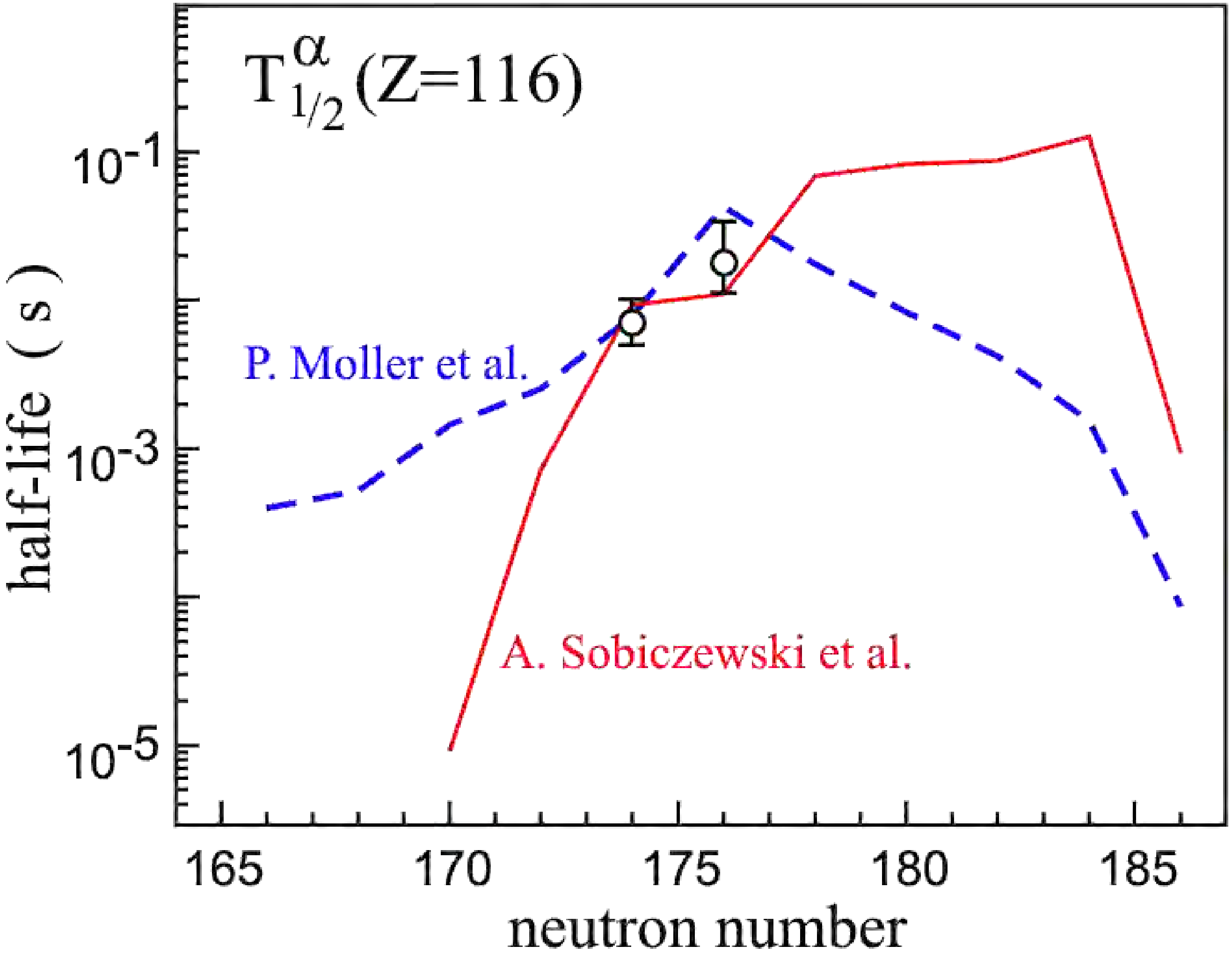
Probably, these elements are the last ones
which will be synthesized
in the nearest future



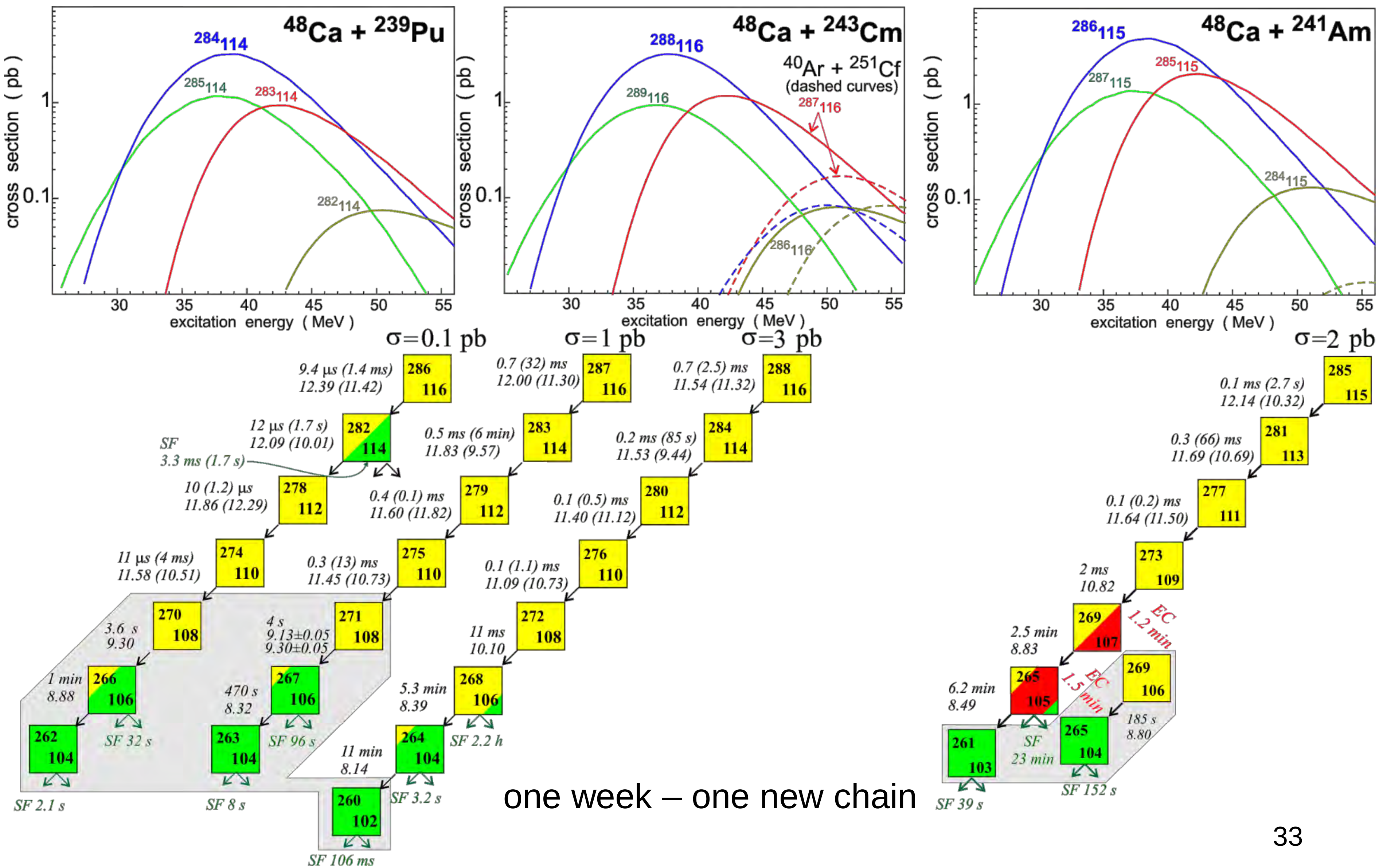
The gap in SH mass area must be filled somehow



Our ability of predictions in superheavy mass area

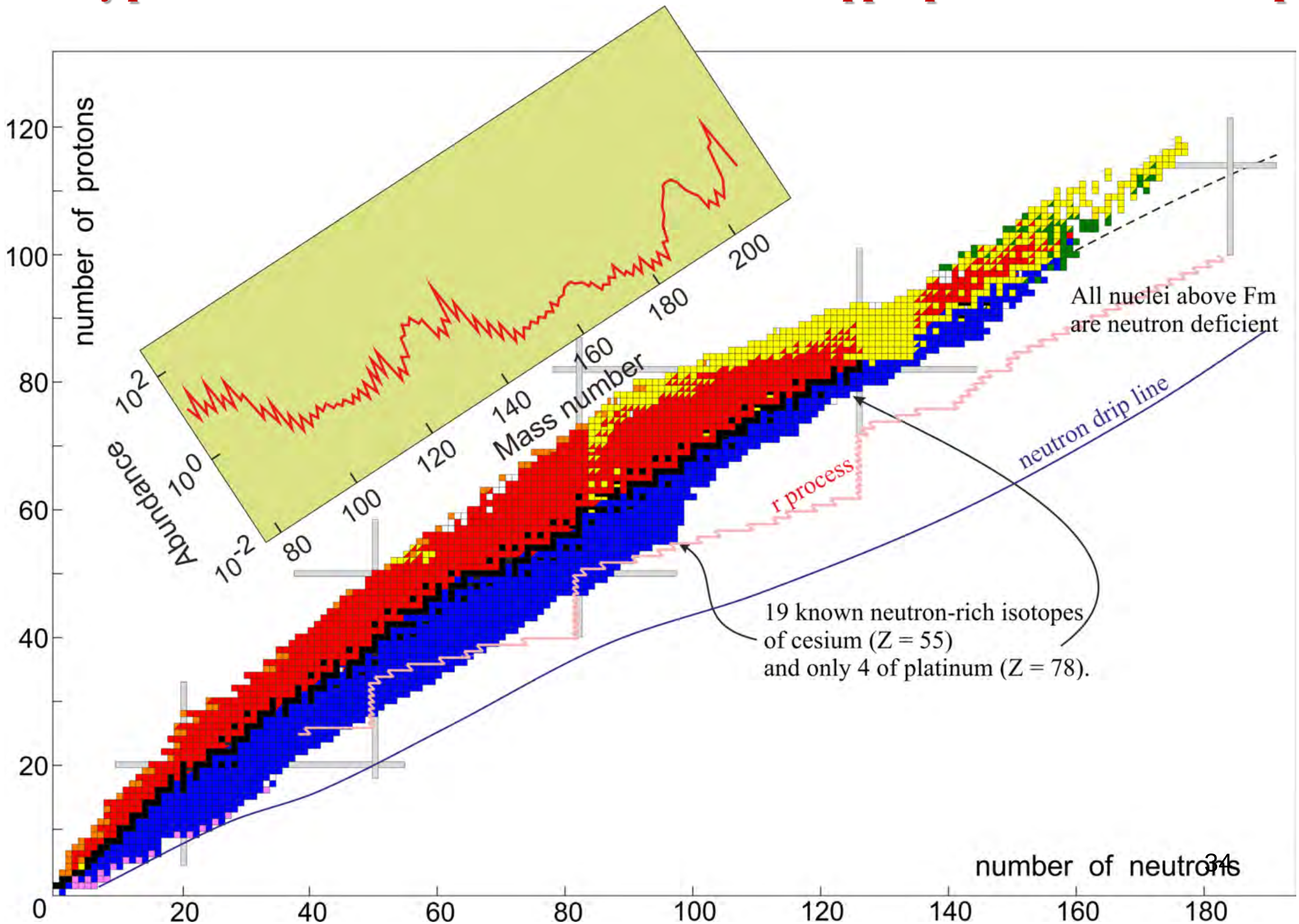


Predicted cross sections are high enough to perform experiments at available facilities just now

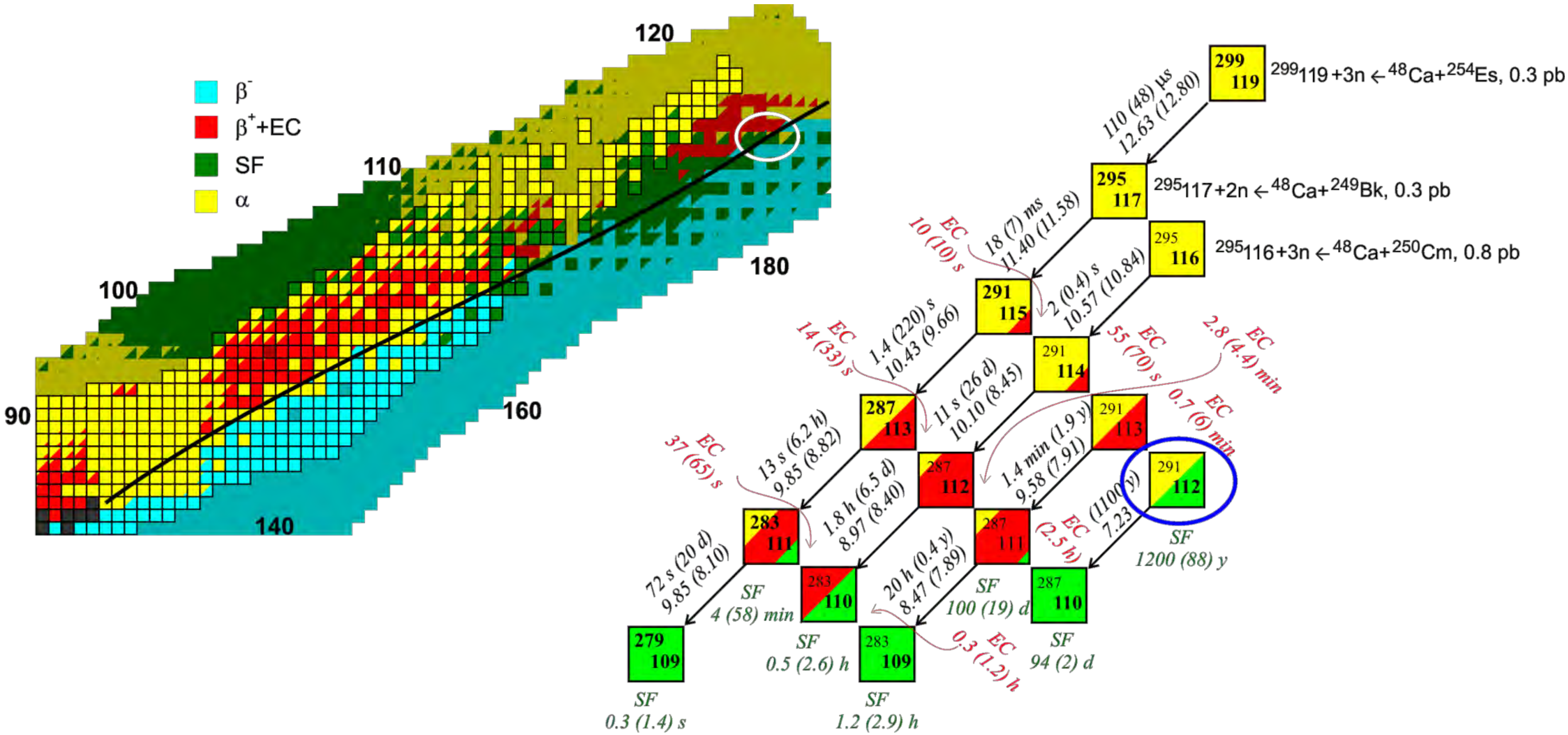


one week – one new chain

Mostly proton-rich nuclei were studied so far in the upper part of the nuclear map



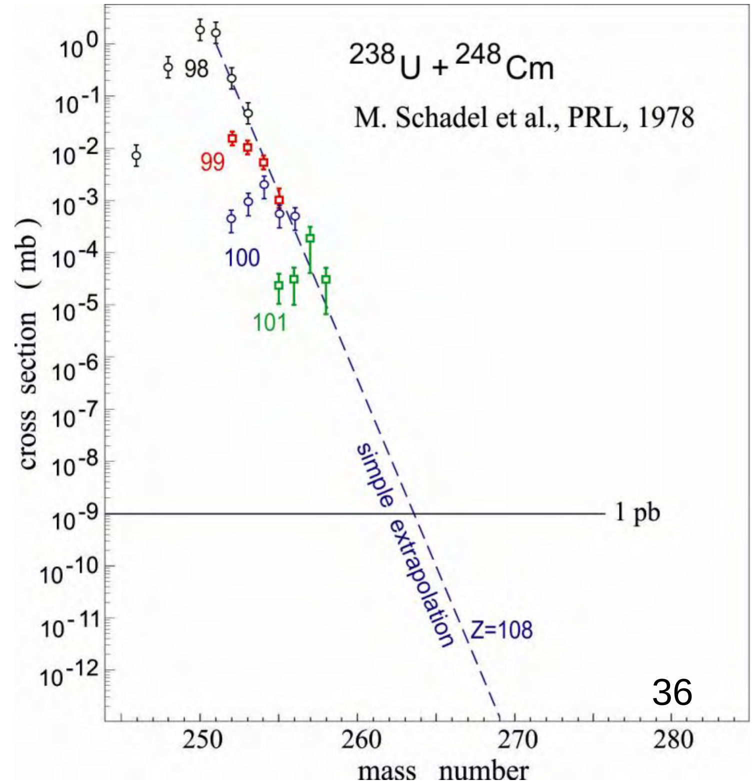
Narrow pathway to the island of stability just by fusion reactions !



Synthesis of SH nuclei in **transfer reactions**

[1] E. K. Hulet *et al.*, Phys. Rev. Lett. **39**, 385 (**1977**).
[2] M. Schaedel *et al.*, Phys. Rev. Lett. **41**, 469 (**1978**).
[3] H. Essel, K. Hartel, W. Henning, P. Kienle, H. J. Koerner, K. E. Rehm, P. Sperr,W.Wagner, and H. Spieler, Z. Phys. A **289**, 265 (**1979**).
[4] H. Freiesleben, K. D. Hildenbrand, F. P uhlhofer, W. F. W. Scneider, R. Bock, D. V. Harrach, and H. J. Specht, Z. Phys. A **292**, 171 (**1979**).
[5] H. Gaeggeler *et al.*, Phys. Rev. Lett. **45**, 1824 (**1980**).
[6] M. Schaedel *et al.*, Phys. Rev. Lett. **48**, 852 (**1982**).
[7] K. J. Moody, D. Lee, R. B. Welch, K. E. Gregorich, G. T. Seaborg, R. W. Lougheed, and E. K. Hulet, Phys. Rev. C **33**, 1315 (**1986**).
[8] R. B. Welch, K. J. Moody, K. E. Gregorich, D. Lee, and G. T. Seaborg, Phys. Rev. C **35**, 204 (**1987**).
…

… a long history.
Isotopes of Fm and Md were synthesized 30 years ago.



Theoretical models of transfer reactions

Multi-nucleon transfers in damped collisions

Master equation
L.G. Moretto and J.S. Sventek, Phys. Lett. B **58**, 26 (1975)

Fokker-Plank equation
W. Norenberg, Phys. Lett. B **52**, 289 (1974)

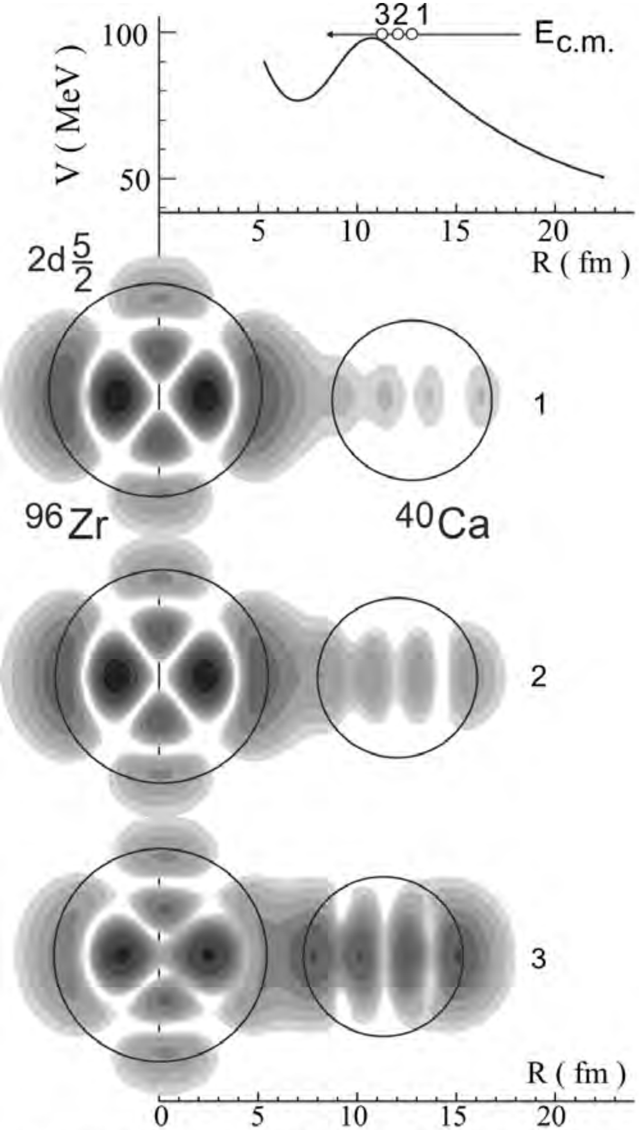
Langevin equations
P. Frobrich and S.Y. Xu, Nucl. Phys. **A477**, 143 (1988)

Semi-classical approaches
E. Vigezzi and A. Winther, Ann. Phys. (N.Y.) **192**, 432 (1989).
V.I. Zagrebaev, Ann. Phys. (N.Y.) **197**, 33 (1990).

Few-nucleon transfers (GRAZING)

A. Winther, Nucl. Phys. **A594**, 203 (1995)
http://personalpages.to.infn.it/nanni/grazing

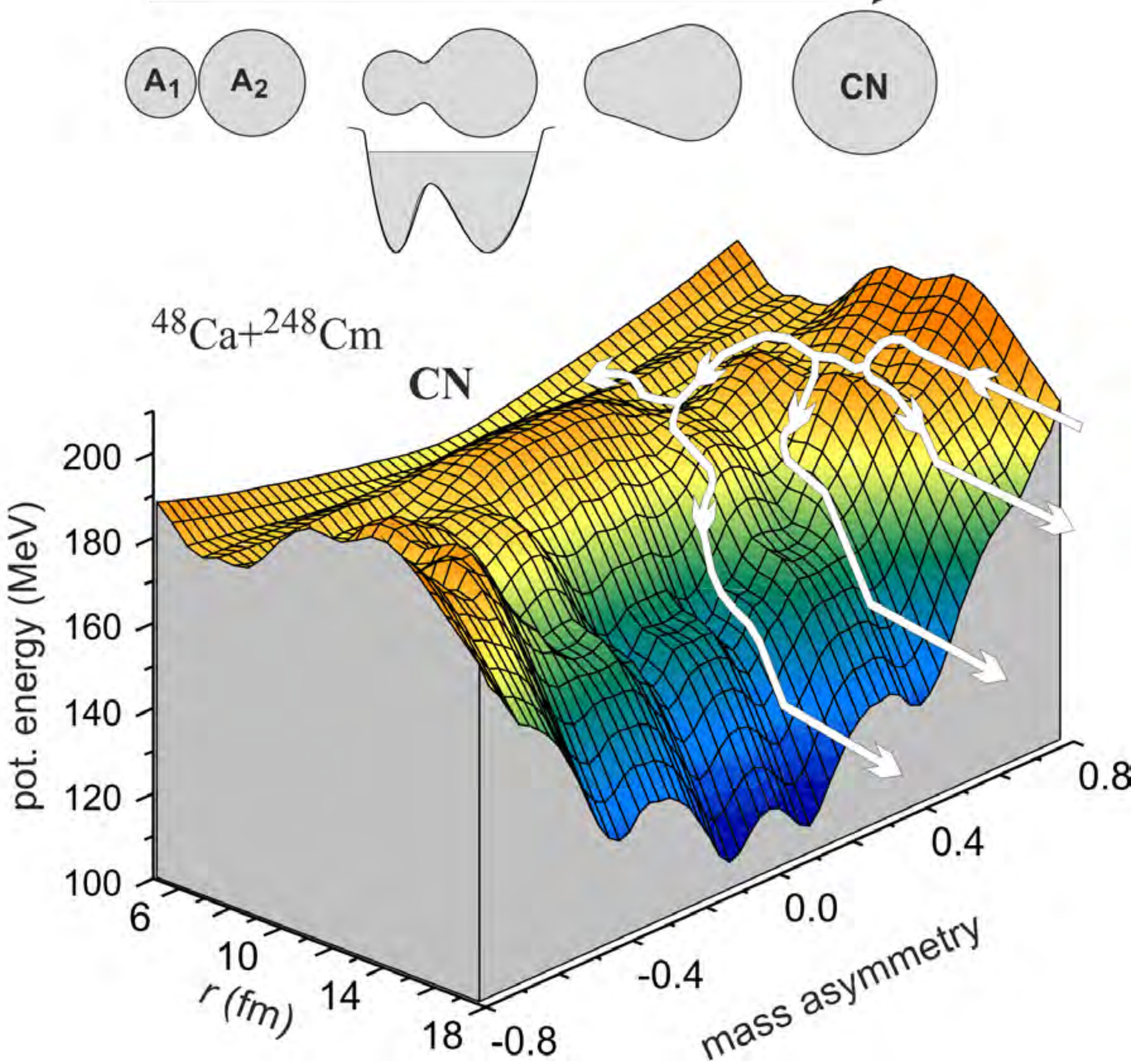
Adiabatic dynamics of low-energy heavy ion collisions and nucleon transfers



time-dependent Schrödinger equation for single particle wave functions

(Zagrebaev, Samarin, Greiner, 2007);

- overlapped mean fields
- two-center shell model
- adiabatic potential energy



System of coupled Langevin type Equations of Motion

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

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

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

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

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

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

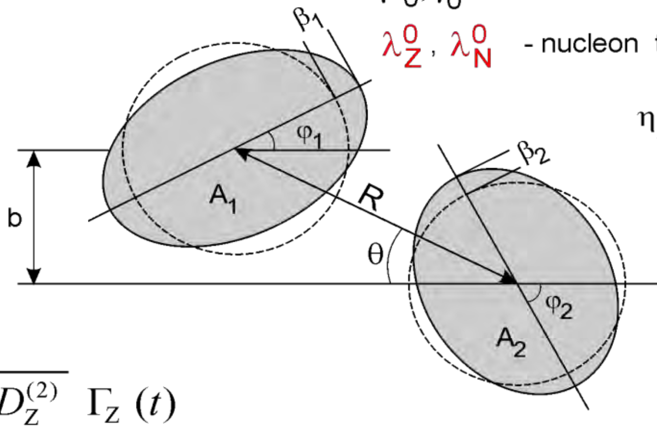
$$\frac{d\eta_Z}{dt} = \frac{2}{Z_{CN}} D_Z^{(1)} + \frac{2}{Z_{CN}} \sqrt{D_Z^{(2)}}\ \Gamma_Z(t)$$

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

Most uncertain parameters:

μ_0, γ_0 - nuclear viscosity and friction,

λ_Z^0, λ_N^0 - nucleon transfer rate



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

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

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

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

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

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

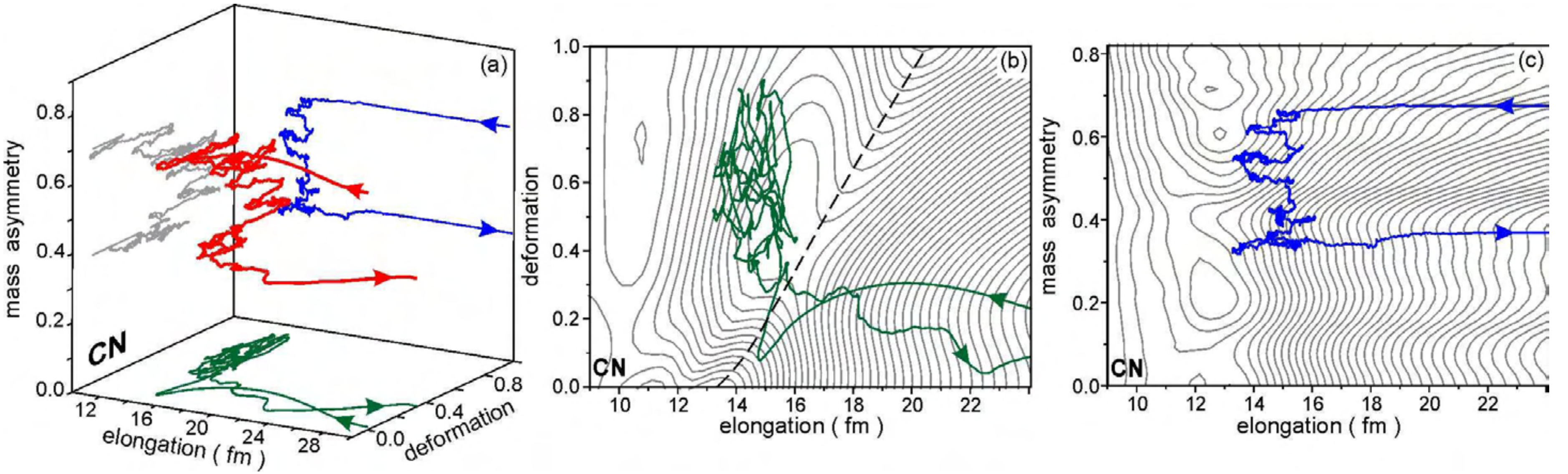
$$\frac{dL_1}{dt} = -\frac{\partial V}{\partial \varphi_1} + \gamma_{tang}\left(\frac{\ell}{\mu_R R} - \frac{L_1}{\Im_1} a_1 - \frac{L_2}{\Im_2} a_2\right) a_1 - \frac{a_1}{R}\sqrt{\gamma_{tang} T}\,\Gamma_{tang}(t)$$

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

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

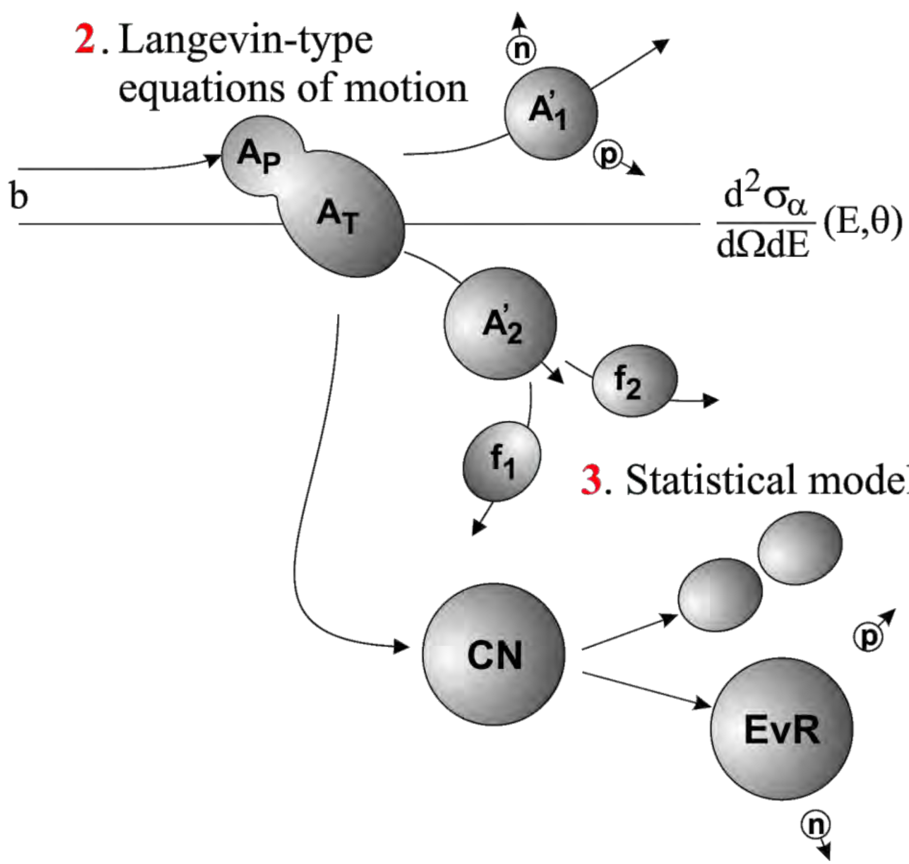
$$\frac{dp_{\beta 2}}{dt} = -\frac{\partial V}{\partial \beta_2} + \frac{p_{\beta 1}^2}{2\mu_{\beta 1}^2}\frac{\partial \mu_{\beta 1}}{\partial \beta_2} + \frac{p_{\beta 2}^2}{2\mu_{\beta 2}^2}\frac{\partial \mu_{\beta 2}}{\partial \beta_2} + \left(\frac{\ell^2}{2\mu_R^2 R^2} + \frac{p_R^2}{2\mu_R^2}\right)\frac{\partial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

Typical trajectory in the “distance-deformation-mass asymmetry” space (48Ca + 248Cm, E=210 MeV)



Simulation of experiment. Cross sections

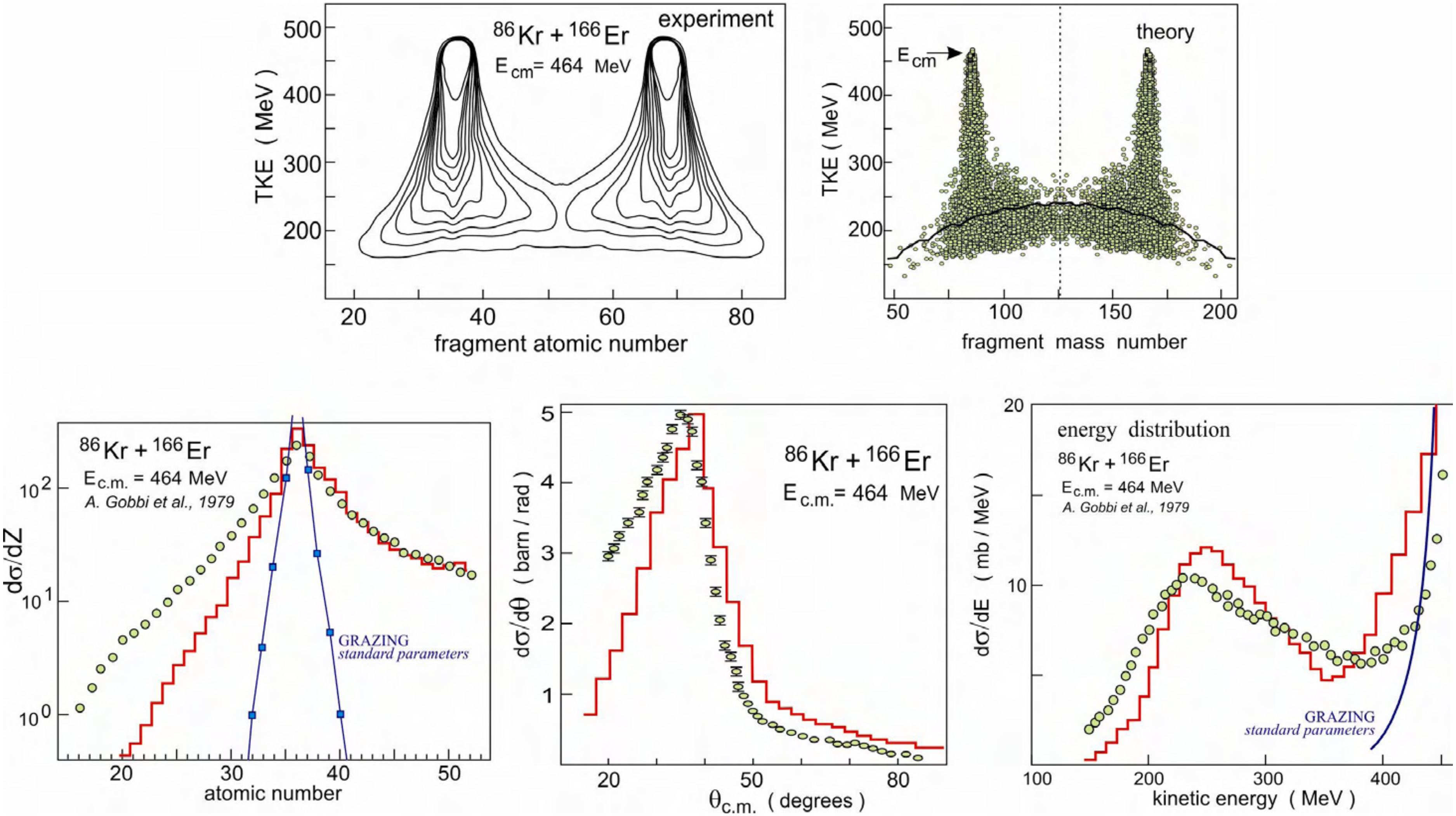
1. Time-dependent driving potential V(r,ξ;t):
Folding → Adiabatic Two-Center Shell Model



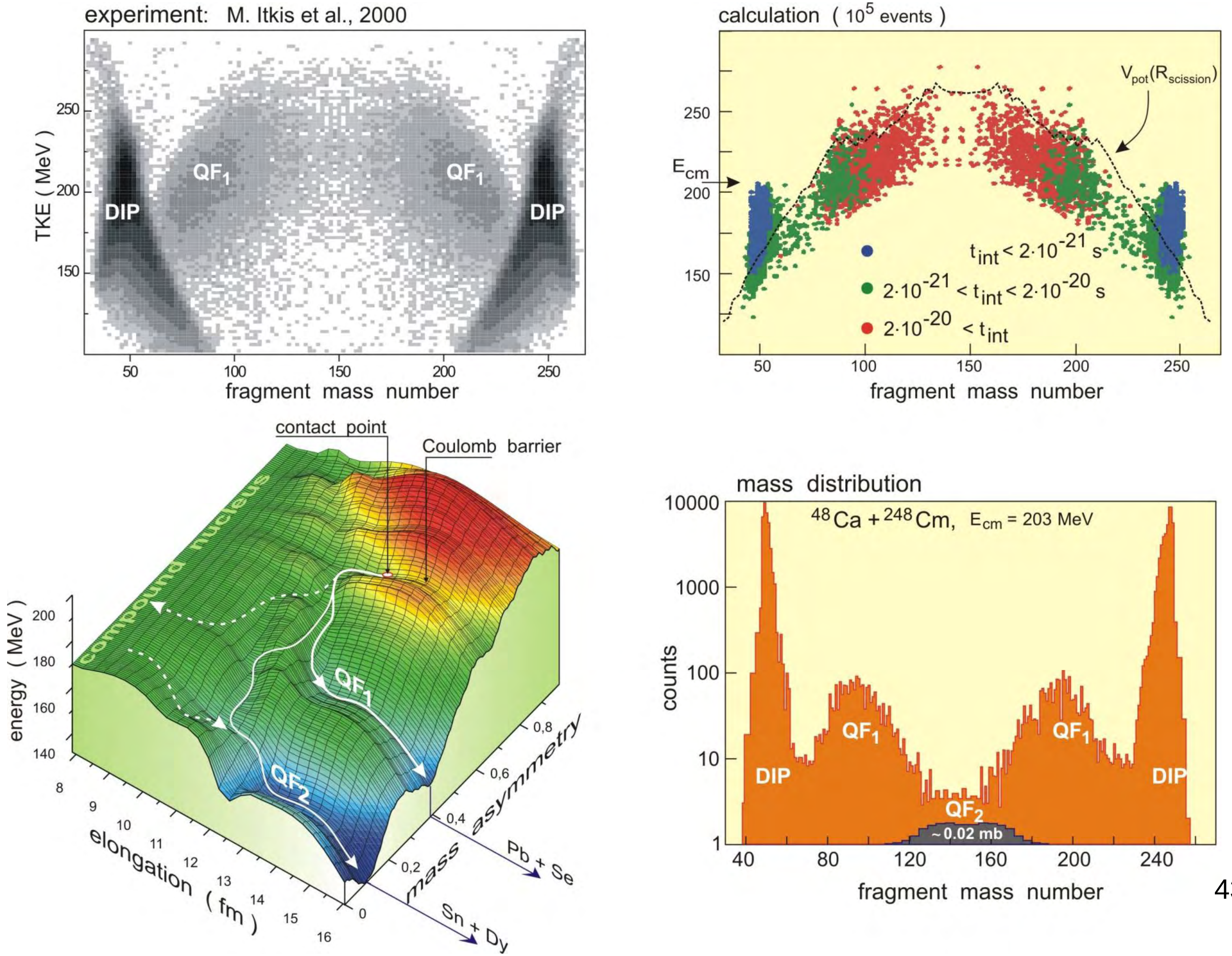
$$\frac{d^2\sigma_\alpha}{d\Omega dE}(E,\theta) = \int_0^\infty b db \, \frac{\Delta N_\alpha(b,E,\theta)}{N_{tot}(b)} \, \frac{1}{\sin(\theta)\Delta\theta\Delta E}$$

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

Quite satisfactory agreement with experiments on DI scattering

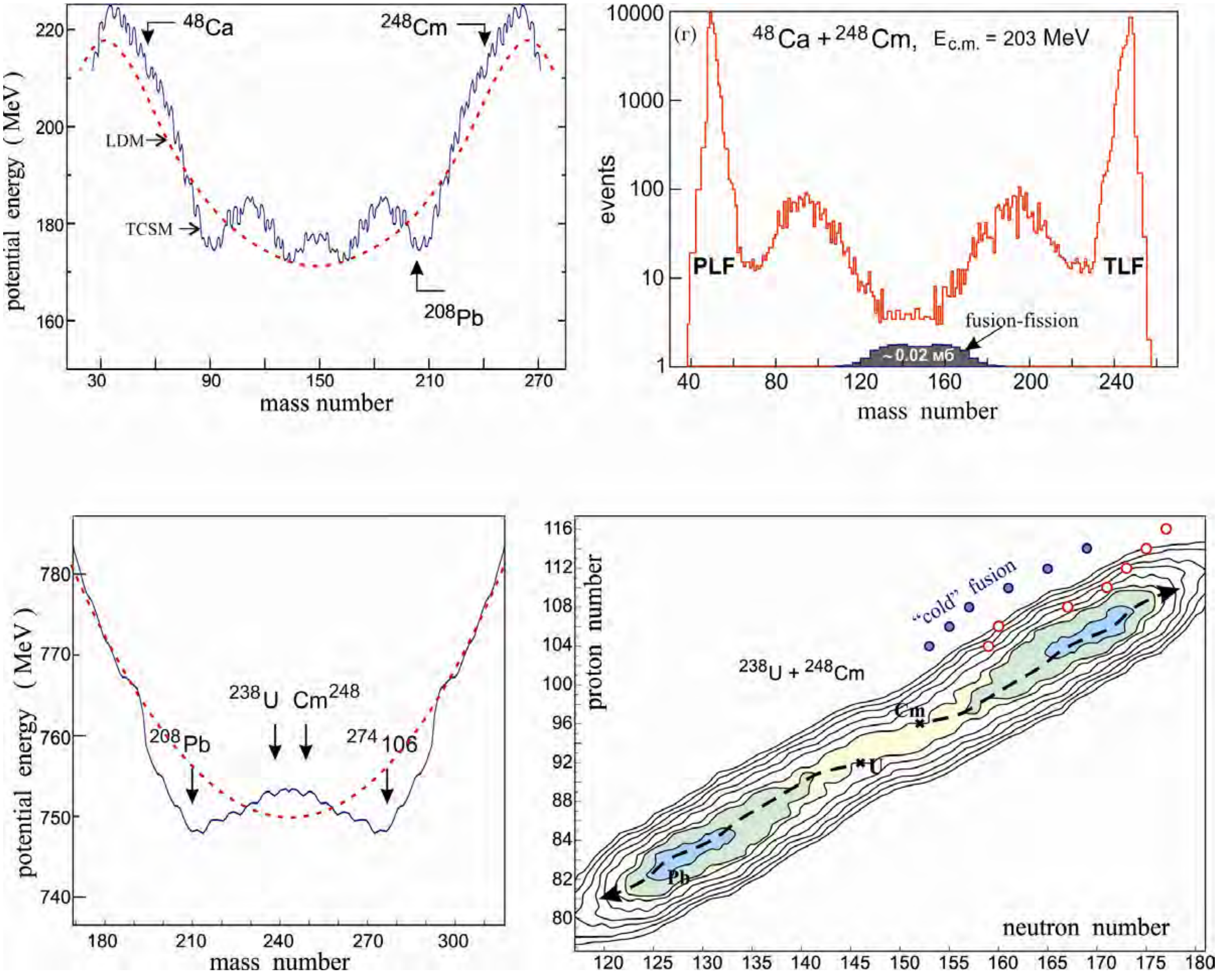


Quasi-Fission process is understood quite well
(example: $^{48}Ca + ^{248}Cm$)

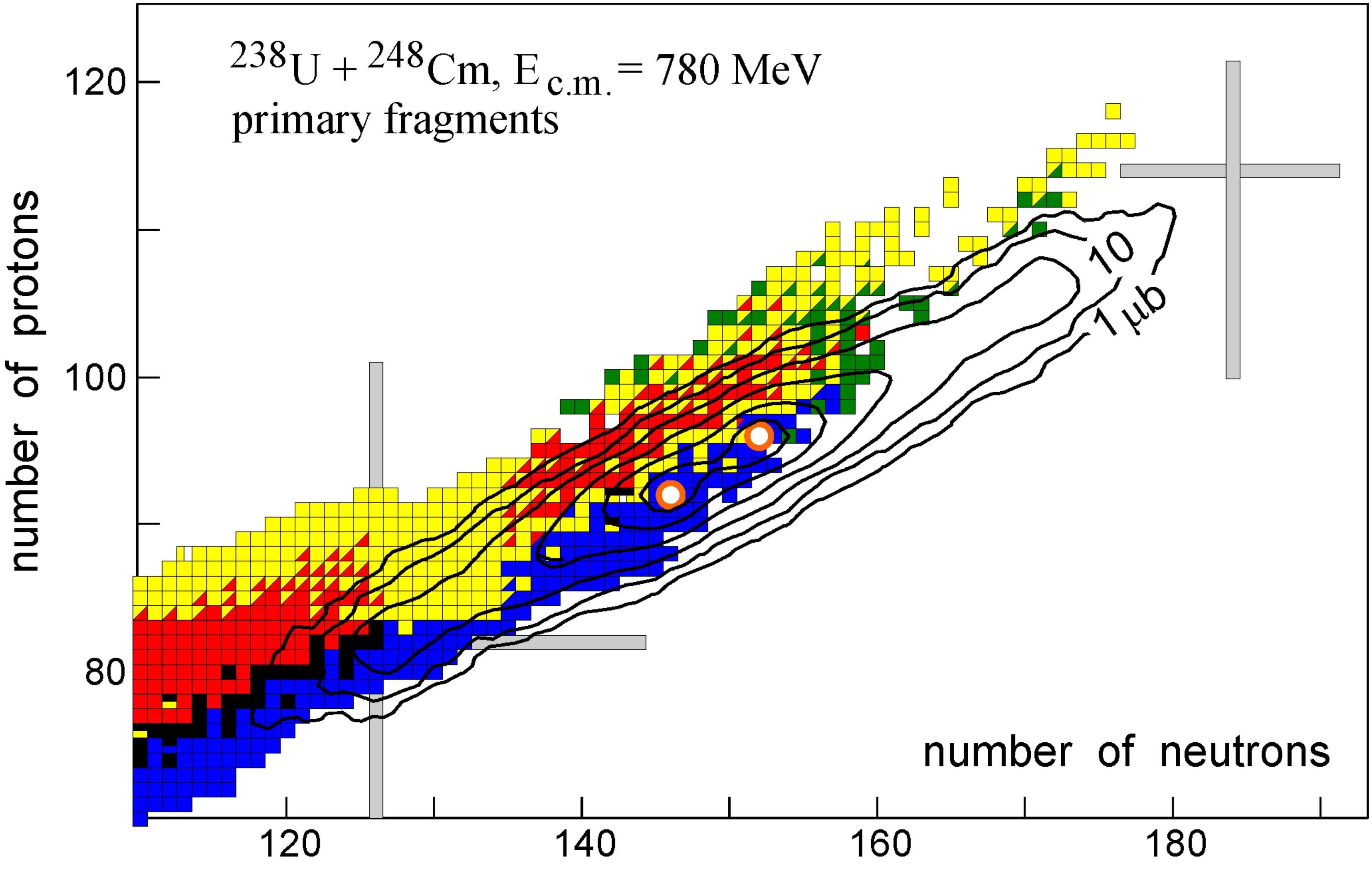


Shell effects: lead valley

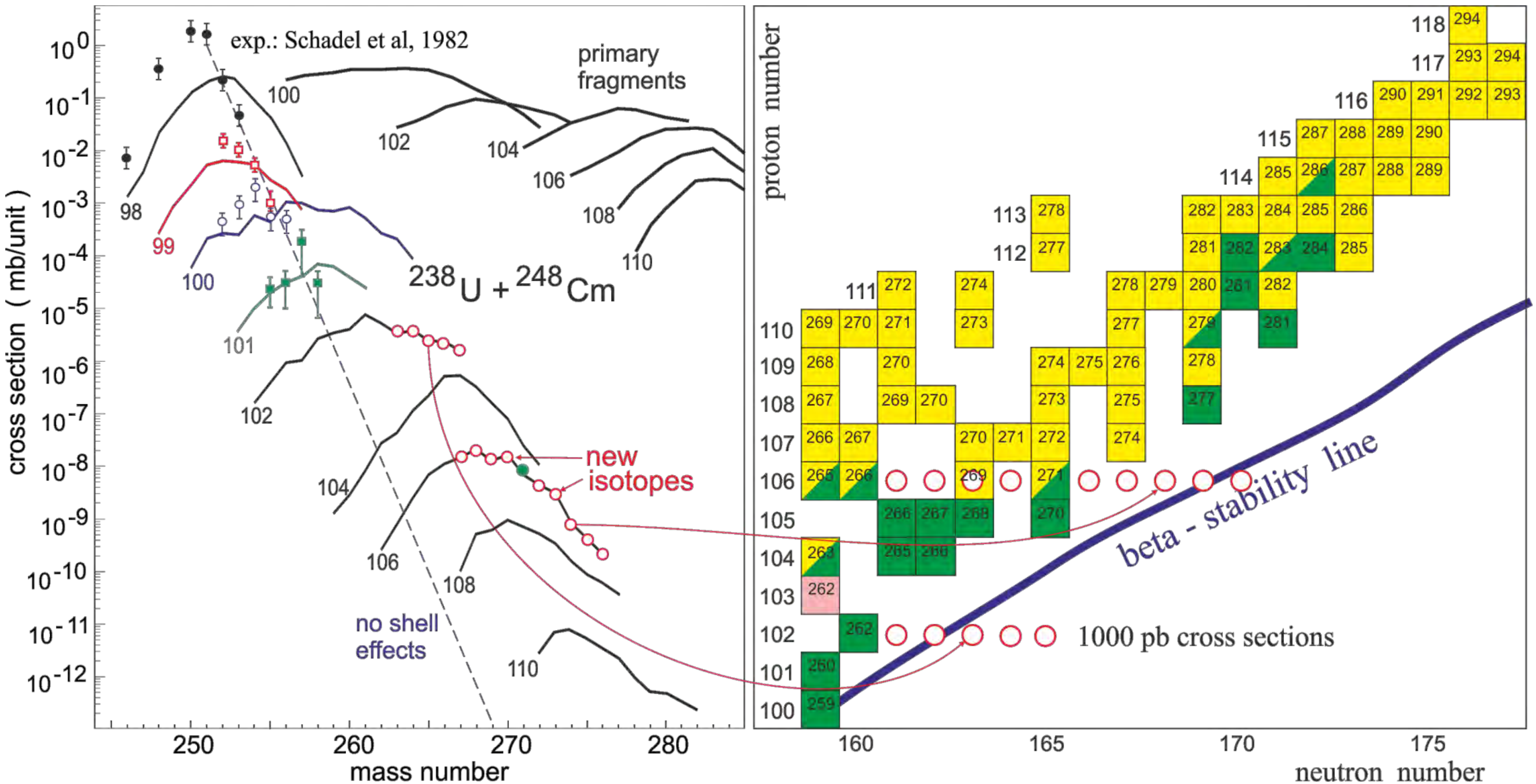
normal (symmetrizing) and inverse (anti-symmetrizing) quasi-fission



238U + 248Cm. Primary fragments

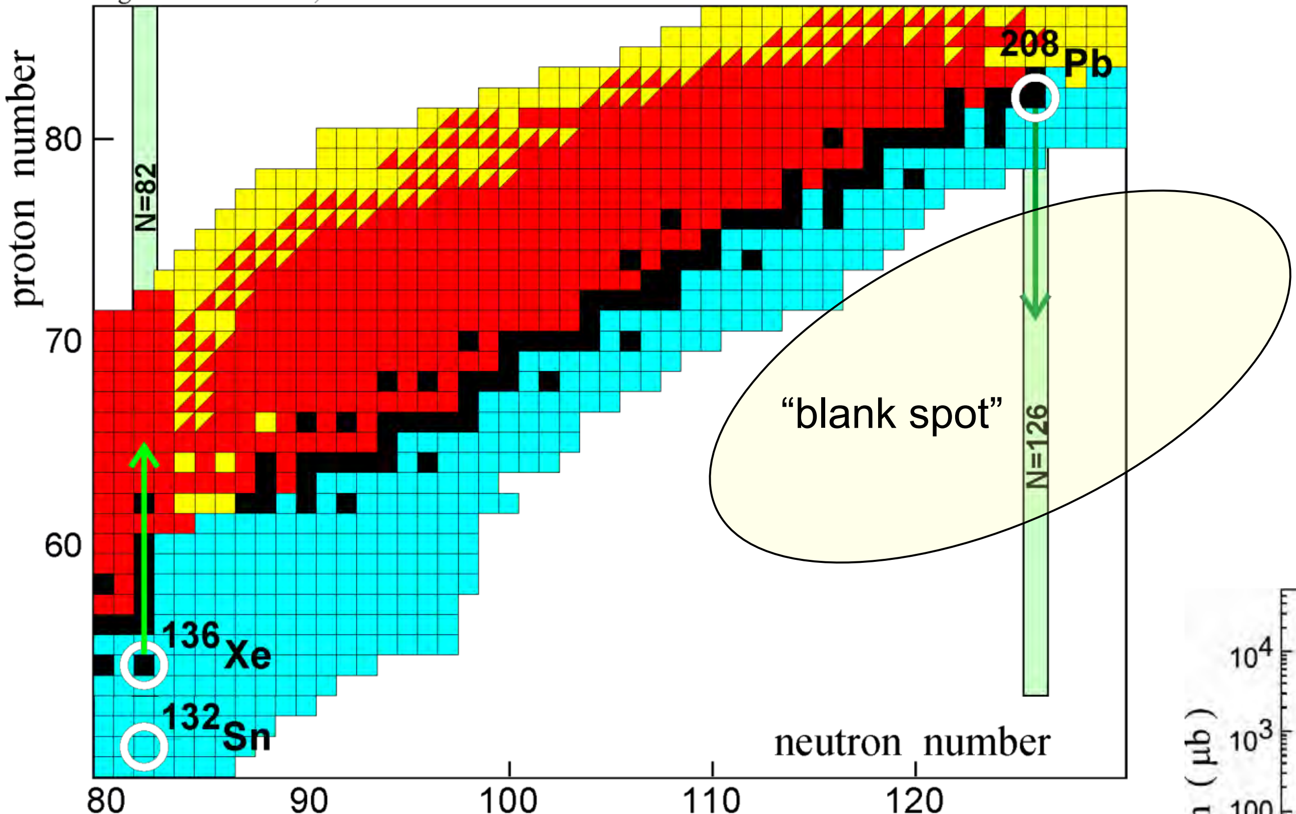


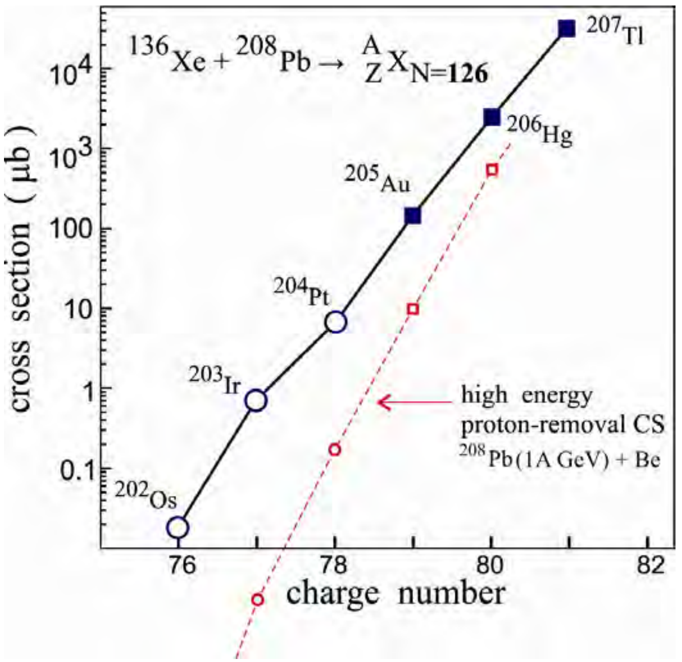
Production of transfermium nuclei along the line of stability looks quite possible in multi-nucleon transfer reactions



Production of new heavy nuclei in the region of N=126

Zagrebaev & Greiner, PRL 2008





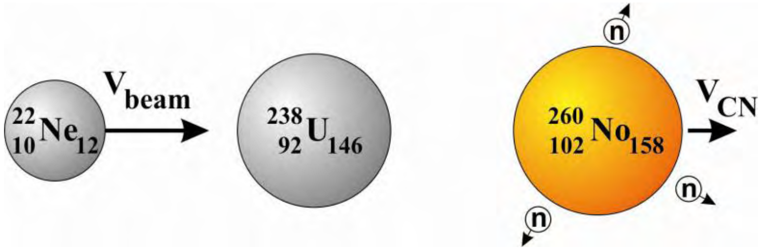
proton transfer along the neutron closed shells:

$$^{136}Xe_{N=82} + {}^{208}Pb_{N=126} \rightarrow {}^{136+\Delta Z}X_{N=82} + {}^{208-\Delta Z}Y_{N=126} + Q \approx 0$$

Reactions with $Q \approx 0$ are very favorable for proton transfer

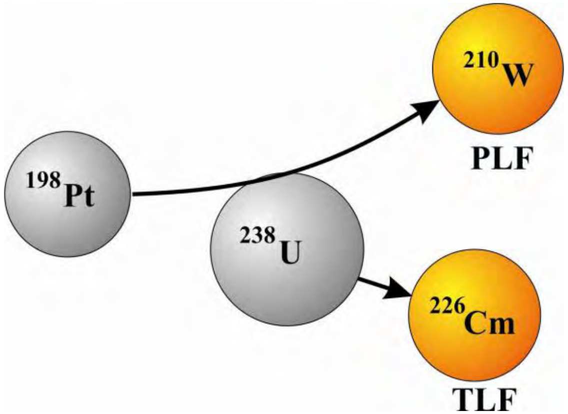
The use of ^{132}Sn is even better !

Fusion reactions



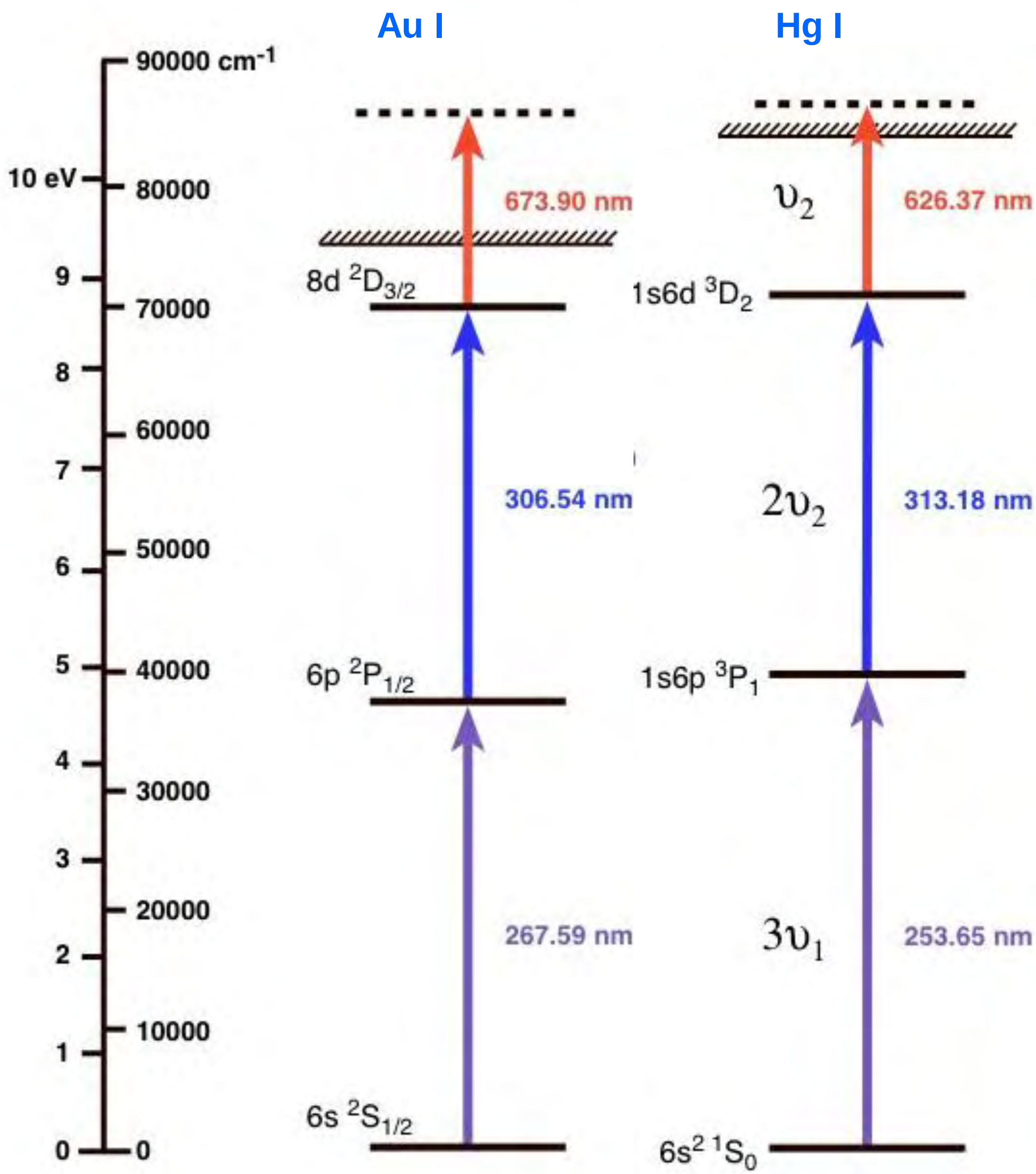
How to separate a given nucleus from all the other transfer reaction products ?

Transfer reactions



Available separators are not applicable !

Selective laser ionization ! (Au & Hg as an example)



Ionization Schemes

Au I

Level	Energy, cm^{-1}	Configuration	Wavelength, nm	
E_0	0	$6s\ ^2S_{1/2}$	λ_1	267.6
E_1	37358.99	$6p\ ^2P_{1/2}$	λ_2	306.5
E_2	69971.42	$8d\ ^2D_{3/2}$	λ_3	673.9

Chemical series	Transition metals
Group, Period, Block	11, 6, *d*
Atomic mass	196.96655(2) g/mol
Electron configuration	[Xe] $4f^{14}\ 5d^{10}\ 6s$
Ionization potential	74408.88 cm^{-1} (9.22553 eV)

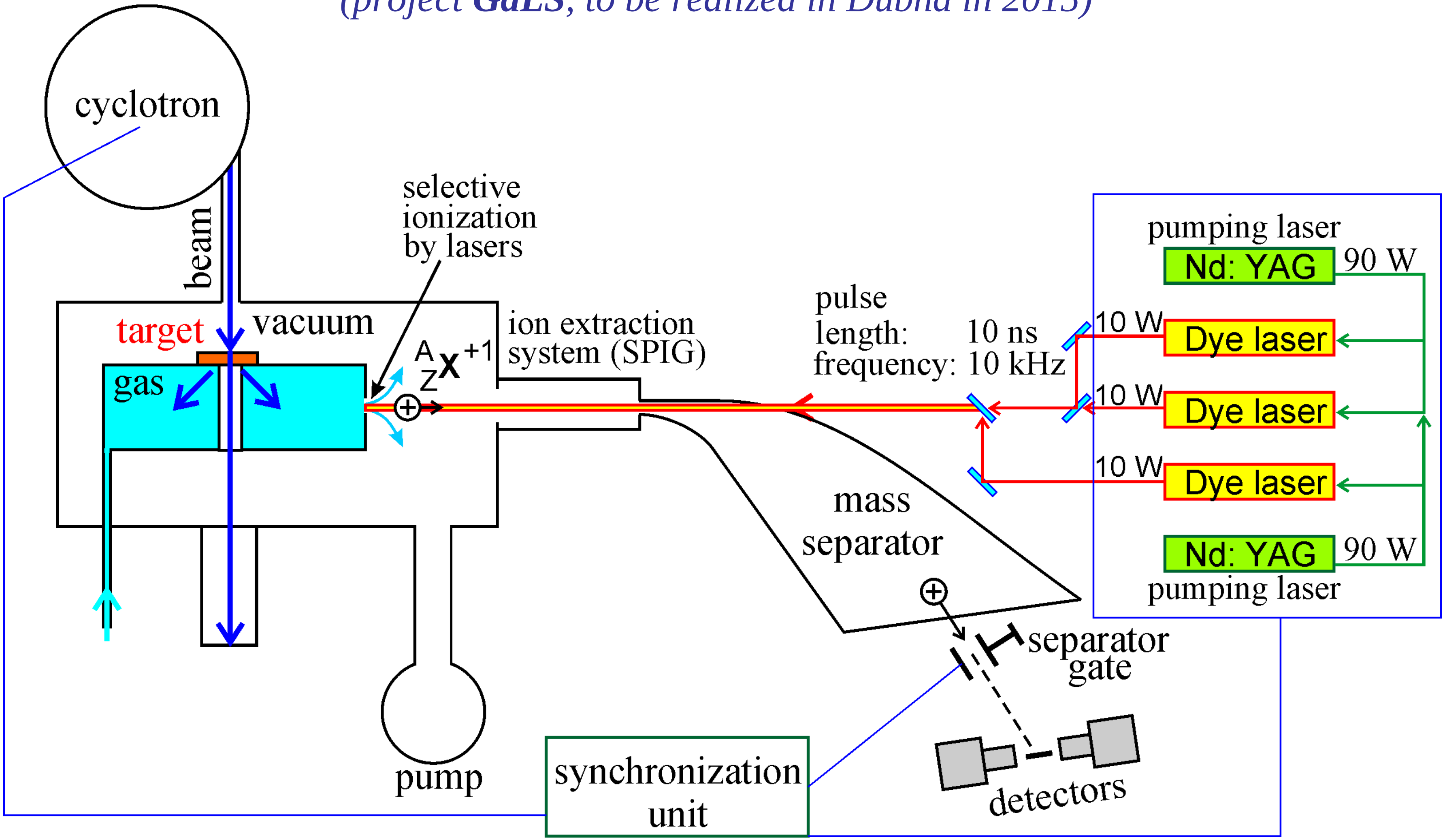
Hg I

Level	Energy, cm^{-1}	Configuration	Wavelength, nm	
E_0	0	$6s^2\ ^1S_0$	λ_1	253.65
E_1	39412.30	$6s\ 6p\ ^3P_1$	λ_2	313.18
E_2	71396.22	$6s\ 6d\ ^3D_2$	λ_3	626.37

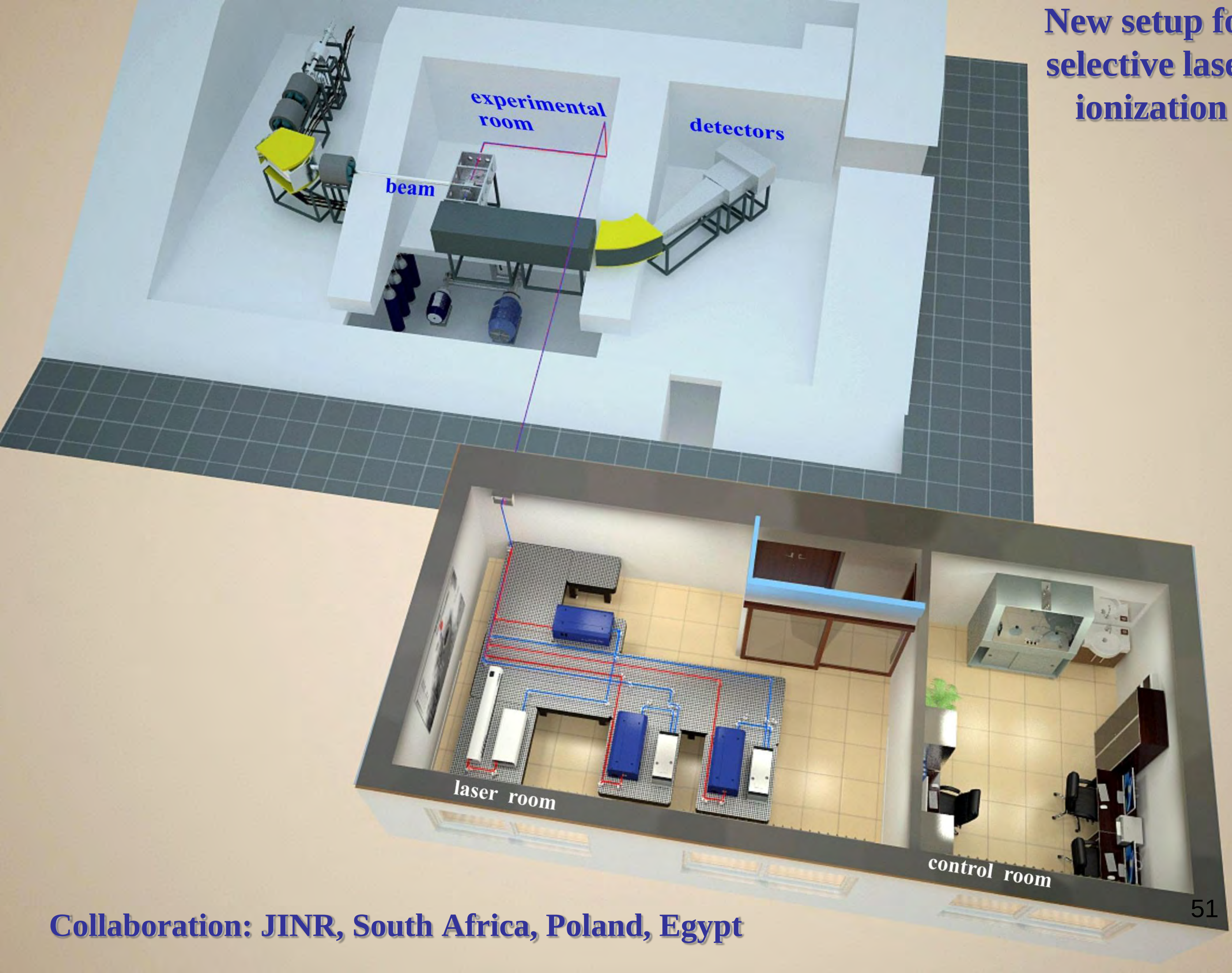
Chemical series	
Group, Period, Block	12, 6, *d*
Atomic mass	200.59(2) g/mol
Electron configuration	[Xe] $4f^{14}\ 5d^{10}\ 6s^2$
Ionization potential	84184.1 cm^{-1} (10.4375 eV)

New setup for selective laser ionization of multi-nucleon transfer reaction products stopped in gas

*(project **GaLS**, to be realized in Dubna in 2015)*



New setup for selective laser ionization



Collaboration: JINR, South Africa, Poland, Egypt