

События, о которых пойдет речь, могли случиться:

в городе Новосибирске

в городе Ростове-на-Дону

вблизи города Икша (40 км от Москвы)...





Зал Ускорителя



А произошли эти события на берегу Волги в Дубне, в ОИЯИ, когда в по решению II сессии Ученого ОИЯИ, приказом директора института Д.И. Блохинцева от 20 мая 1957 года была создана новая Лаборатория под руководством проф. Г.Н. Флерова

First accelerator for heavy ion beam production

Cyclotron U-300, Dubna 1958



the task was: to obtain a beam of ^{14}N ions with
an energy of MeV and an intensity of 1 μA

Dubna
1958

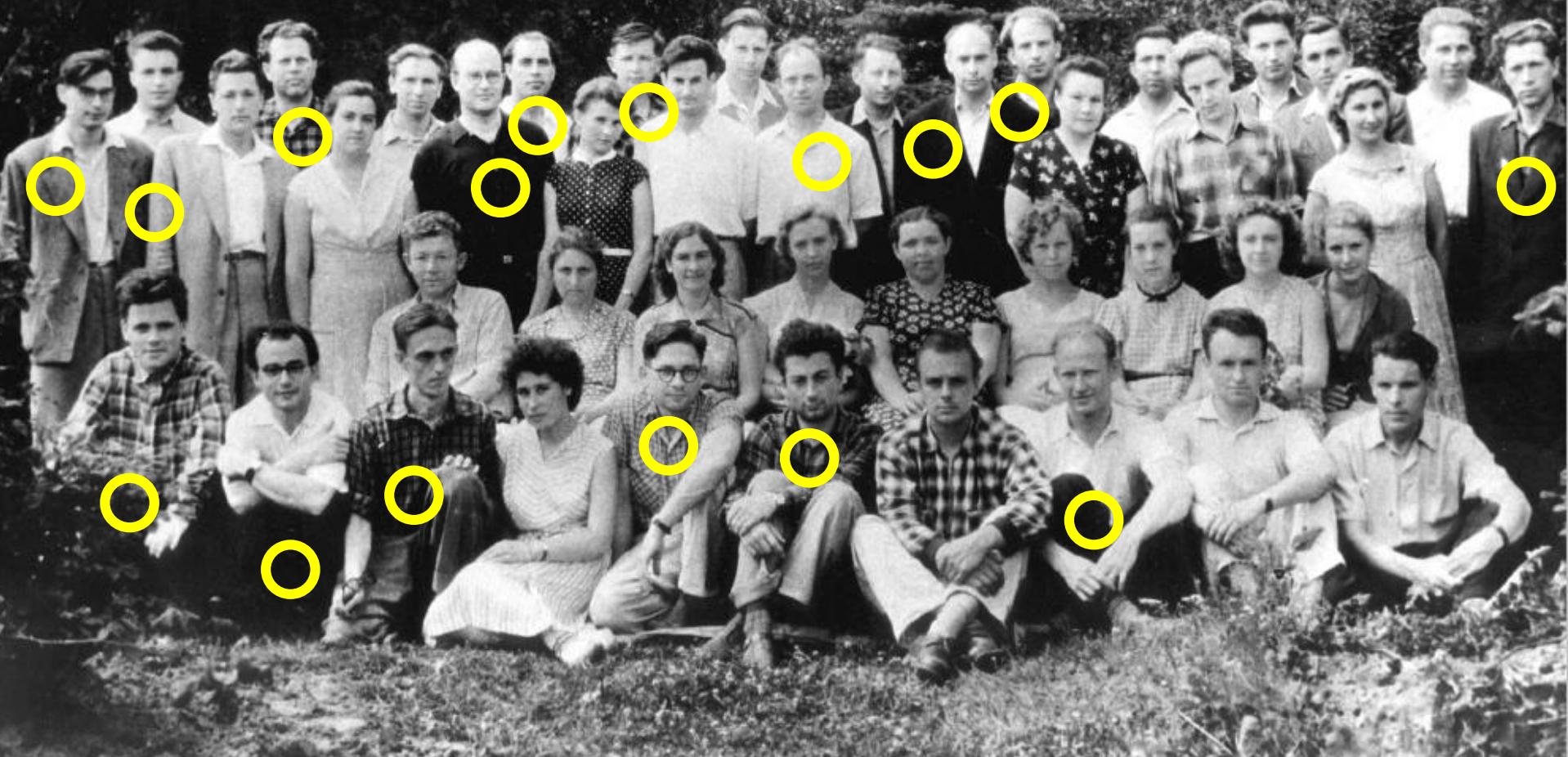
by Pavel Zolnikov



1959

Команда ЛЯР – детский сад ЛИПАН, сектор №7: Слева направо, 1-ый нижний ряд: В.Л.Михеев, Г.М.Тер-Акопьян, В.А.Друин, Г.Саламатина, В.А.Карнаухов, Ю.Ц.Оганесян, Скобкин, Ю.В.Лобанов, ?, ?. 2-ой нижний ряд: токарь + женщины. 3-ий верхний ряд: Б.А.Гвоздев, ?, ?, ?, Харисов, А.С.Пасюк, В.М.Плотко, Л.Гусева, Ю.Чубруков, Б.Мясоедов, С.М.Поликанов, Герлик, Г.Н.Флеров, Н.И.Тарантин, ?. Д.Клочков, лаборант-химик, ?, ?, завхоз, инженер-электронщик, К.А.Гаврилов. 1959 г.

Команда ЛЯР – детский сад ЛИПАН, сектор №7: Слева направо, 1-ый нижний ряд: В.Л.Михеев, Г.М.Тер-Акопьян, В.А.Друин, Г.Саламатина, В.А.Карнаухов, Ю.Ц.Оганесян, Скобкин, Ю.В.Лобанов, ?, ?. 2-ой нижний ряд: токарь + женщины. 3-ий верхний ряд: Б.А.Гвоздев, ?, ?, ?, Харисов, А.С.Пасюк, В.М.Плотко, Л.Гусева, Ю.Чубруков, Б.Мясоедов, С.М.Поликанов, Герлик, Г.Н.Флеров, Н.И.Тарантин, ?, ?. Д.Клочков, лаборант-химик, ?, ?, завхоз, инженер-электронщик, К.А.Гаврилов. 1959 г.



Осень 1959 г. Перед отъездом в Дубну (16 из 43 на фото)

К 65-летию ЛЯР им. Г.Н. Флерова

Границы и структура атомных ядер

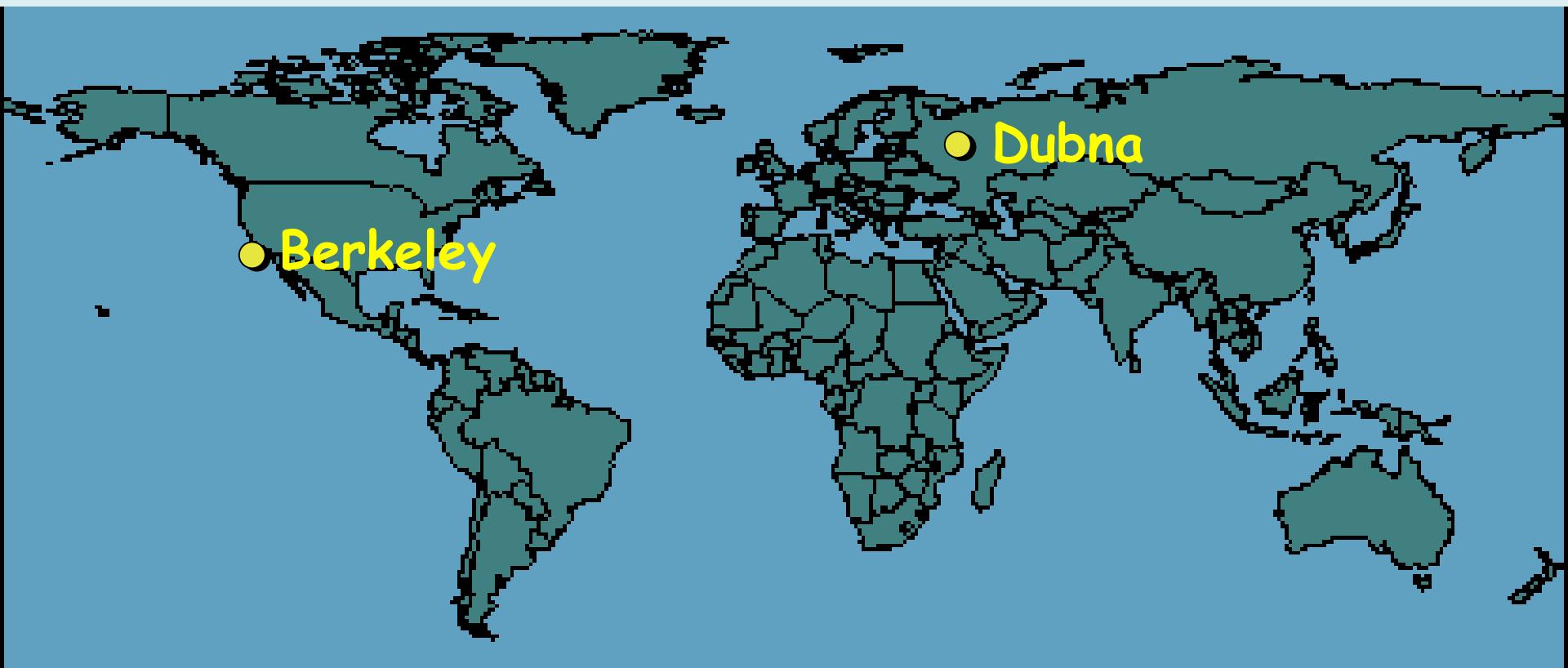
Ю.Ц. Оганесян

Лаборатория ядерных реакций ОИЯИ

Семинар ОИЯИ

26 мая 2022 г., ЛТФ ОИЯИ, Дубна

Heavy ion physics:



● Pioneers

1955-1965

D.I.Mendeleev's Periodic Table - Classification of Chemical Elements



1834 - 1907

G.T. Seaborg

1	Hydrogen H	2	Beryllium Be	3	Lithium Li	4	Magnesium Mg	5	Scandium Sc	6	Titanium Ti	7	Vanadium V	8	Chromium Cr	9	Manganese Mn	10	Iron Fe	11	Cobalt Co	12	Nickel Ni	13	Copper Cu	14	Zinc Zn	15	Aluminum Al	16	Silicon Si	17	Phosphorus P	18	Oxygen O	19	Potassium K	20	Calcium Ca	21	Rubidium Rb	22	Strontium Sr	23	Yttrium Y	24	Zirconium Zr	25	Niobium Nb	26	Molybdenum Mo	27	Tantalum Ta	28	Tungsten W	29	Rhenium Re	30	Palladium Pd	31	Rhodium Rh	32	Platinum Pt	33	Silver Ag	34	Cadmium Cd	35	Gallium Ga	36	Germanium Ge	37	Cesium Cs	38	Barium Ba	39	Hafnium Hf	40	Tantalum Ta	41	Osmium Os	42	Iridium Ir	43	Promethium Pm	44	Platinum Pt	45	Gold Au	46	Mercury Hg	47	Thallium Tl	48	Lead Pb	49	Antimony Sb	50	Bismuth Bi	51	Polonium Po	52	Astatine At	53	Rubidium Rb	54	Strontium Sr	55	Yttrium Y	56	Zirconium Zr	57	Niobium Nb	58	Molybdenum Mo	59	Tantalum Ta	60	Tungsten W	61	Rhenium Re	62	Palladium Pd	63	Rhodium Rh	64	Platinum Pt	65	Silver Ag	66	Cadmium Cd	67	Gallium Ga	68	Germanium Ge	69	Antimony Sb	70	Bismuth Bi	71	Polonium Po	72	Francium Fr	73	Radium Ra	74	Actinium Ac	75	Lanthanum La	76	Curium Ce	77	Praseodymium Pr	78	Neodymium Nd	79	Promethium Pm	80	Samarium Sm	81	Europium Eu	82	Gadolinium Gd	83	Terbium Tb	84	Dysprosium Dy	85	Holmium Ho	86	Erbium Er	87	Thulium Tm	88	Ytterbium Yb	89	Lutetium Lu
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Artificial synthesis of elements

1940

D.I.Mendeleev's Periodic Table of the Chemical Elements

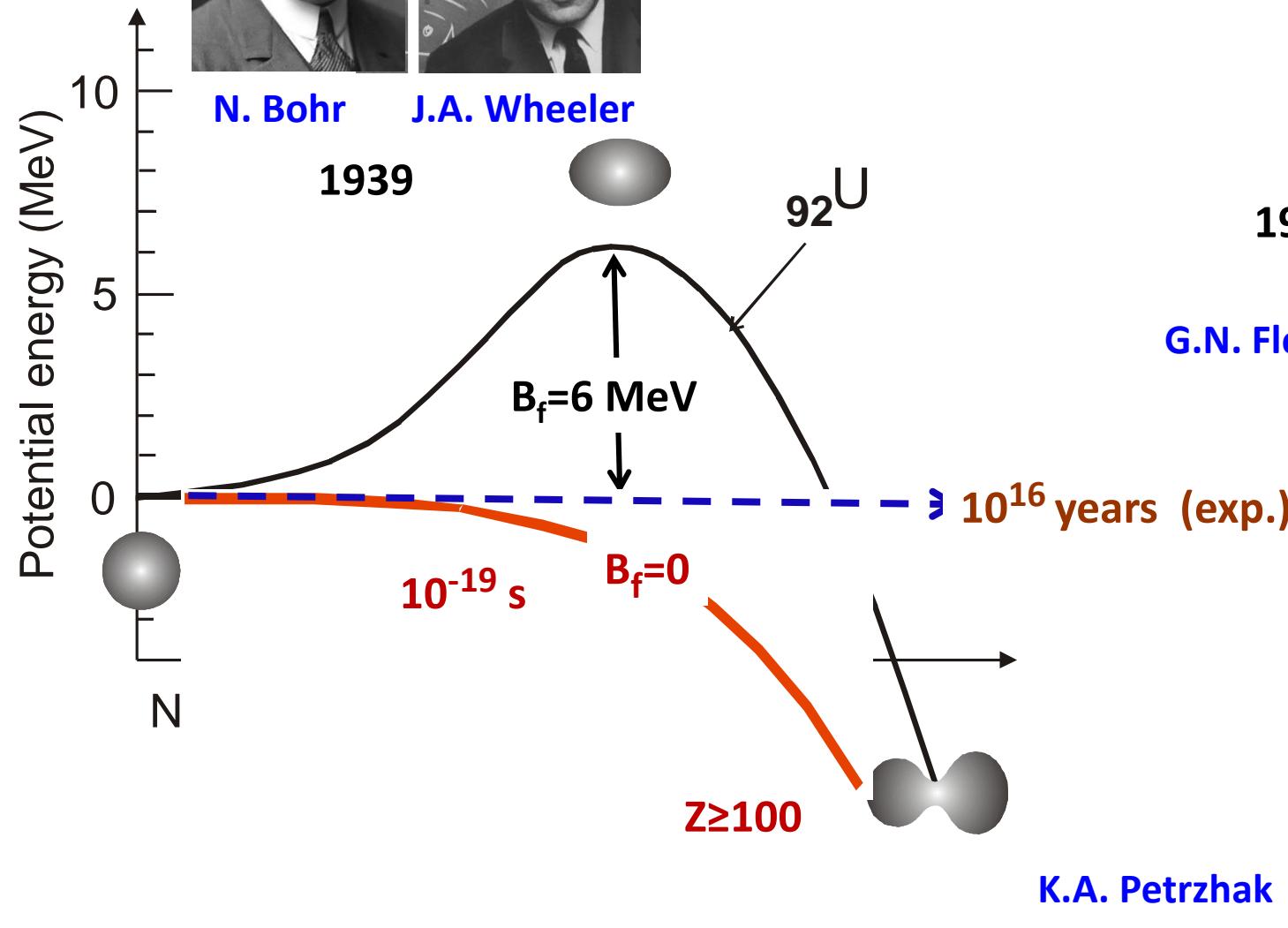


1834 - 1907

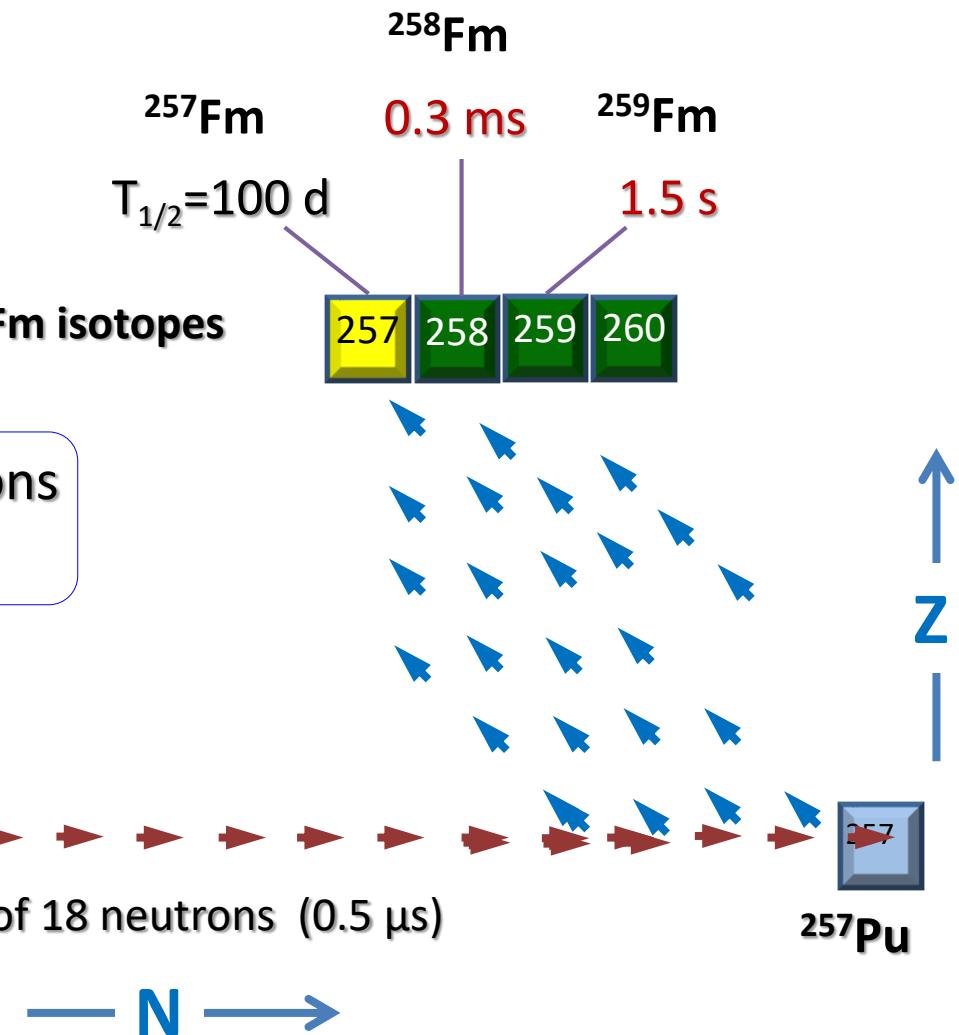
The figure is a comprehensive periodic table of elements, spanning from Hydrogen (H) at atomic number 1 to Fermium (Fm) at atomic number 1907. The table is organized into groups and periods, with each element represented by a colored square containing its symbol and atomic number. A legend on the left identifies eight element series: Nonmetals (green), Noble Gases (light green), Other Metals (purple), Transition metals (red), Alkaline earth metals (yellow), Alkali metals (blue), Lanthanide series (orange), and Actinide series (brown). A second legend on the right indicates physical states: Solid (white), Liquid (light blue), Gas (pink), and Synthetic (dark blue). A central callout box at the bottom center contains the text "Protons & neutrons" with arrows pointing towards the left and right sides of the table.

the method was limited to the synthesis of Fermium ($Z = 100$)

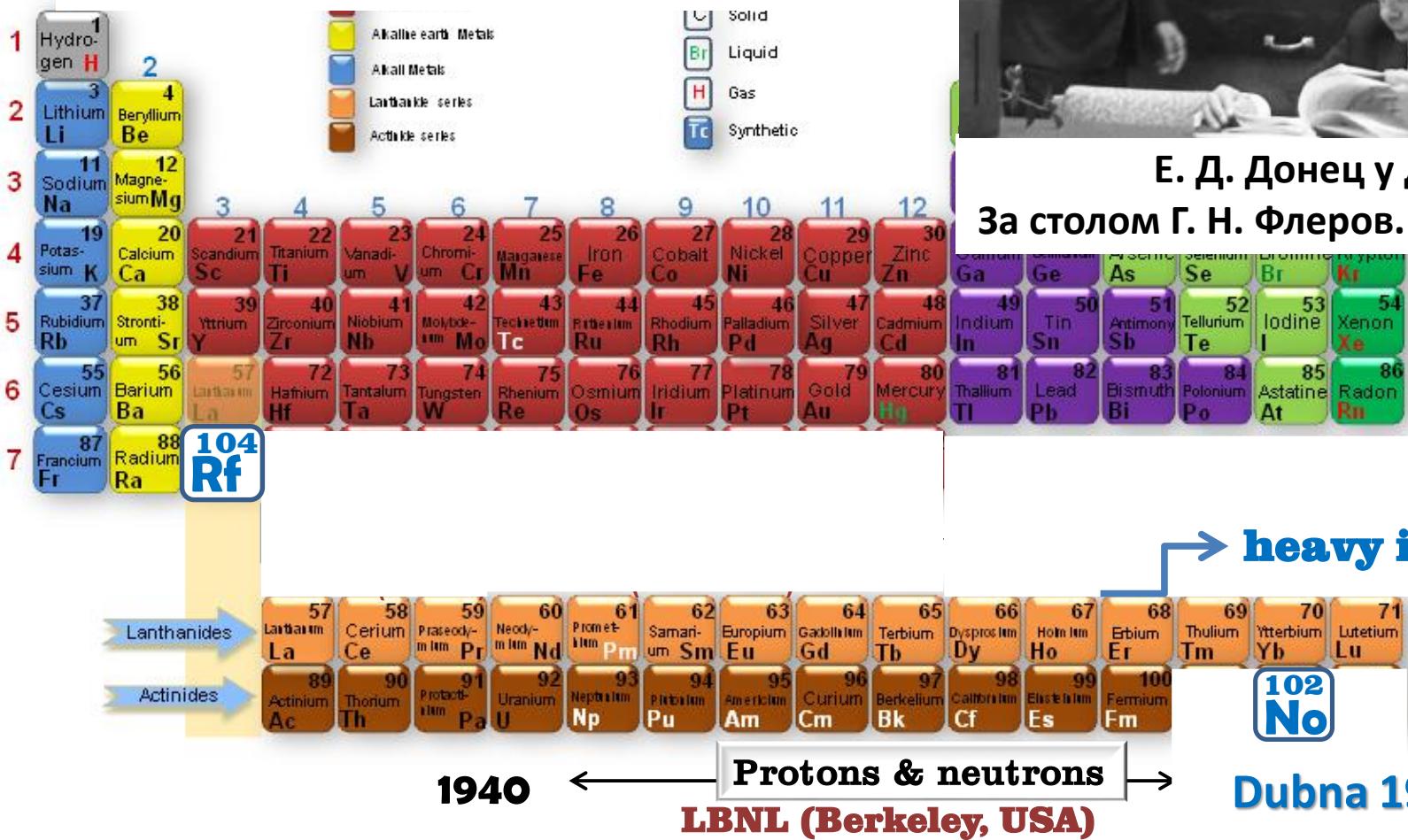
Nuclear fission



Nuclear Explosion

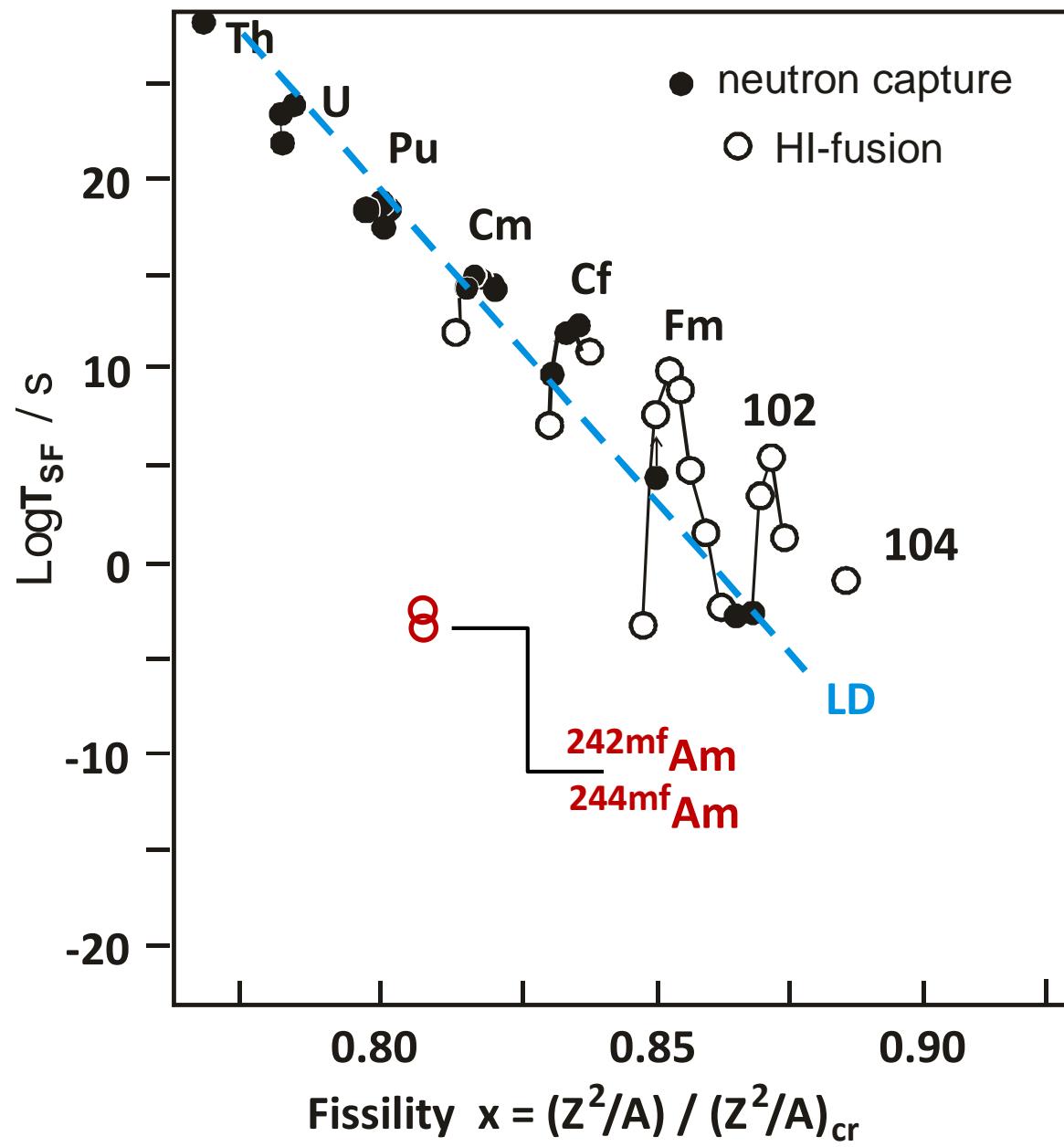


Синтез элемента 102 (ЛЯР 1963)

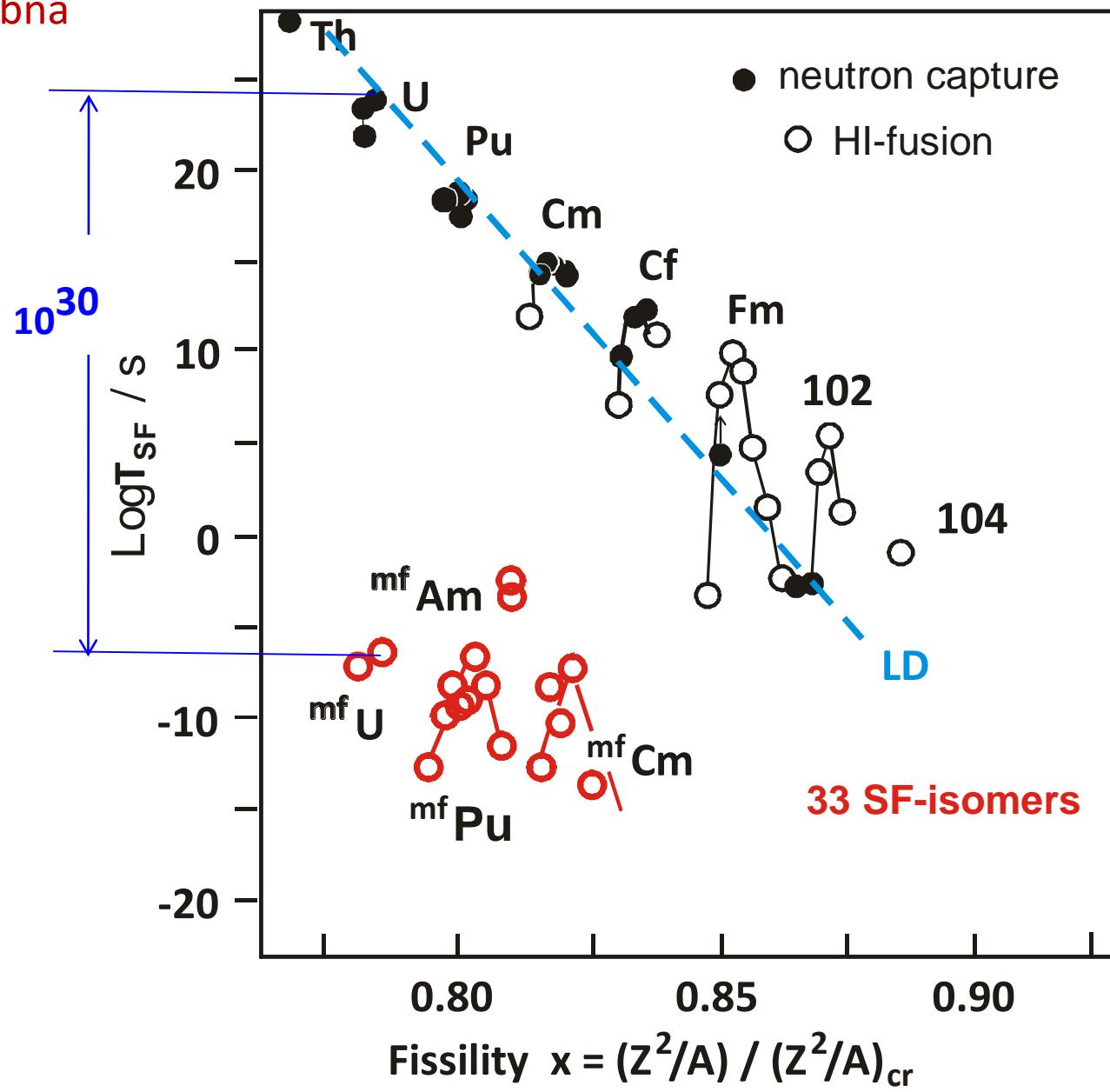


Открытие изомерии форм ядер (ЛЯР 1962)

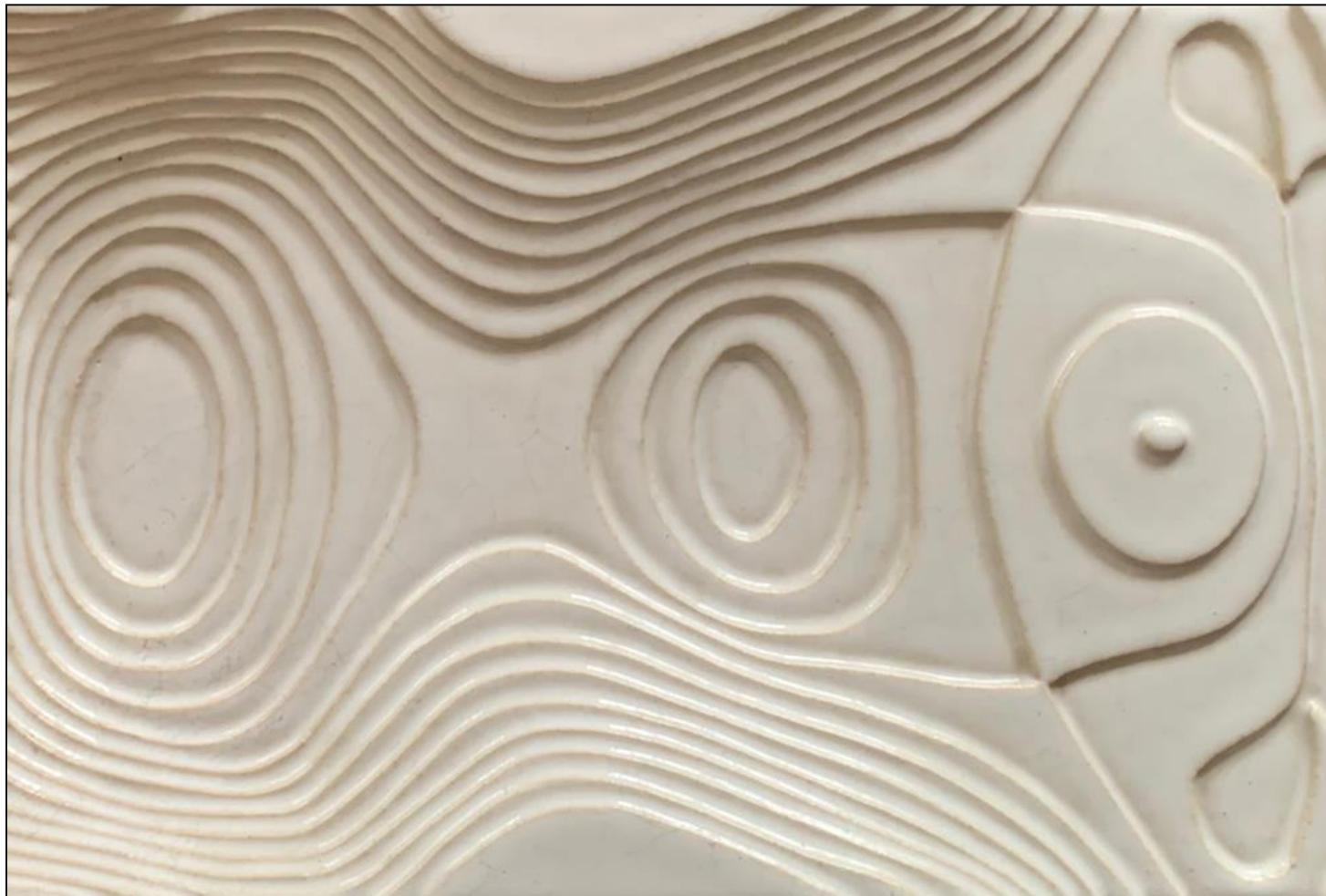
**Discovery SF-isomers
 ^{242m}Am and ^{244m}Am**



1962 JINR, Dubna

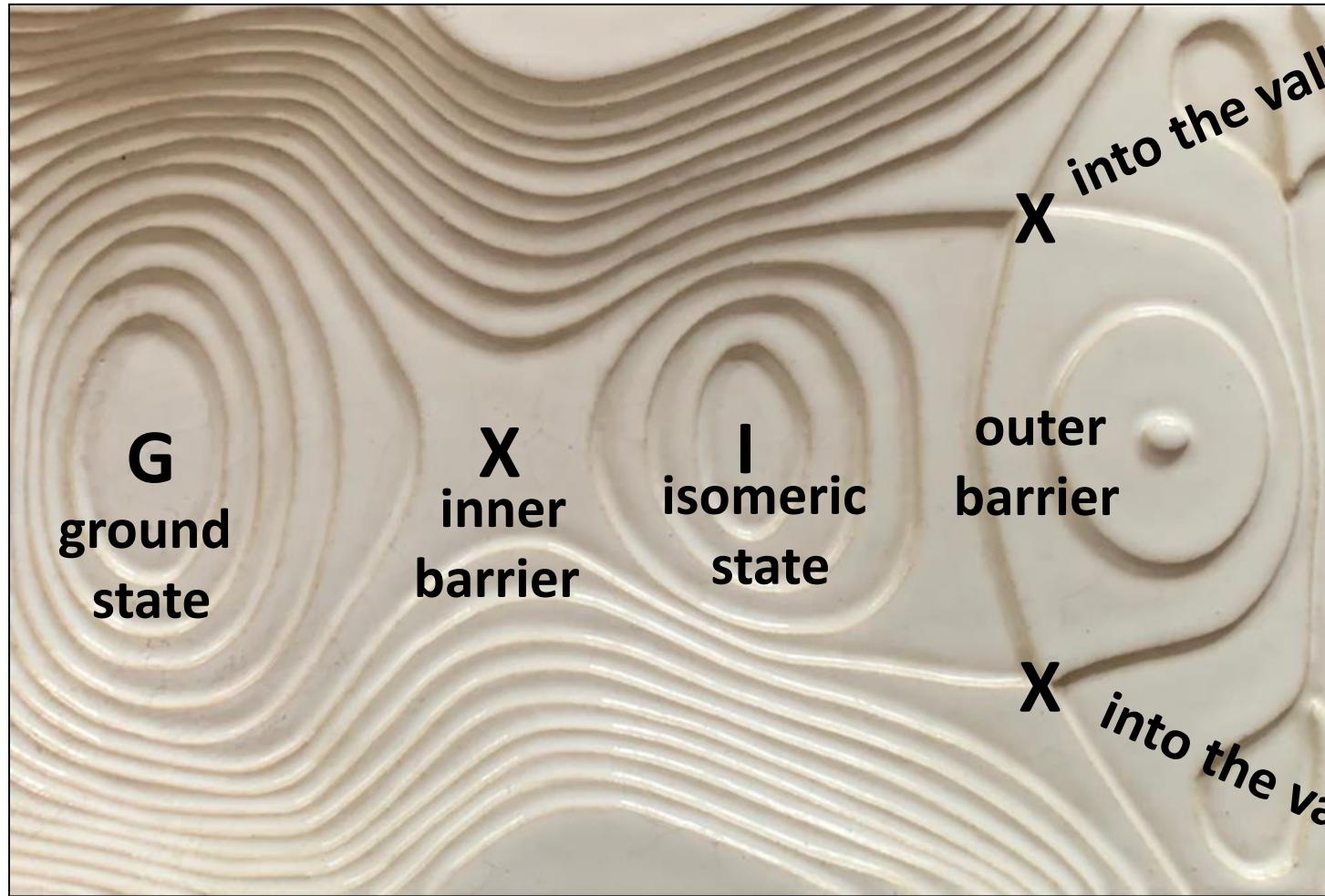


К 50-летию Г.Н. Флерова (1963)



Potential energy surface of the ^{242}Pu nucleus?

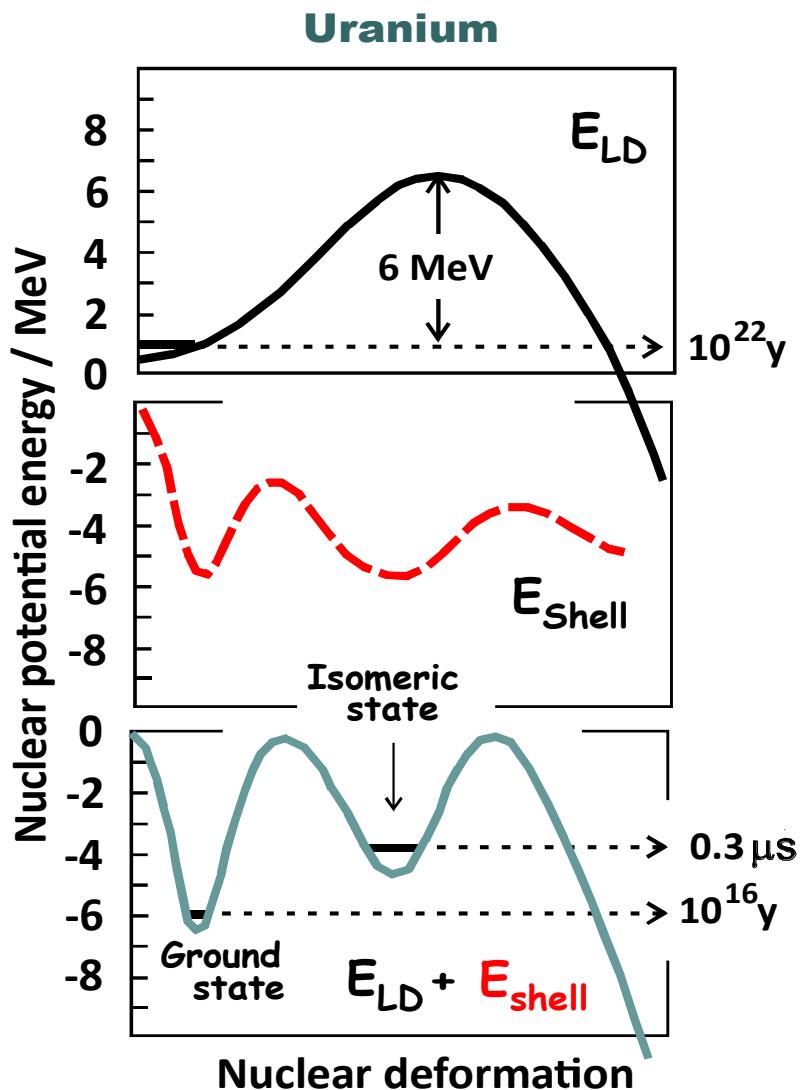
Deformation β_4



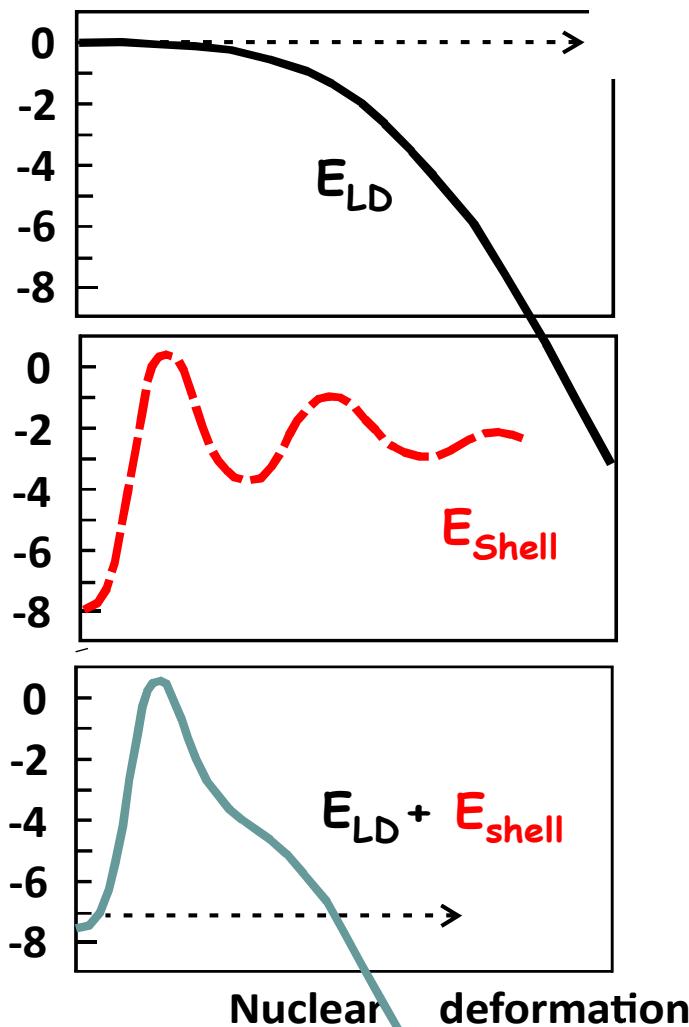
Deformation β_2 (elongation)

X into the valley of fission

$$E_{\text{tot}} = E_{\text{LD}} + \Delta E_{\text{Shell}}$$

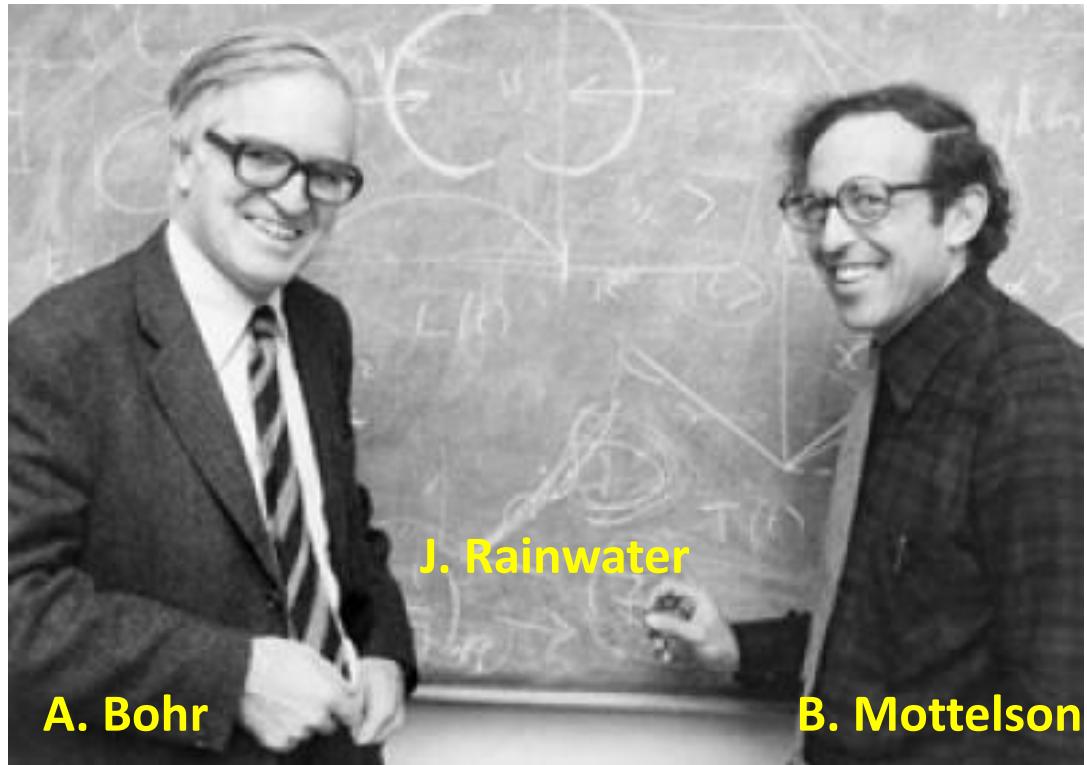


Super heavy nucleus



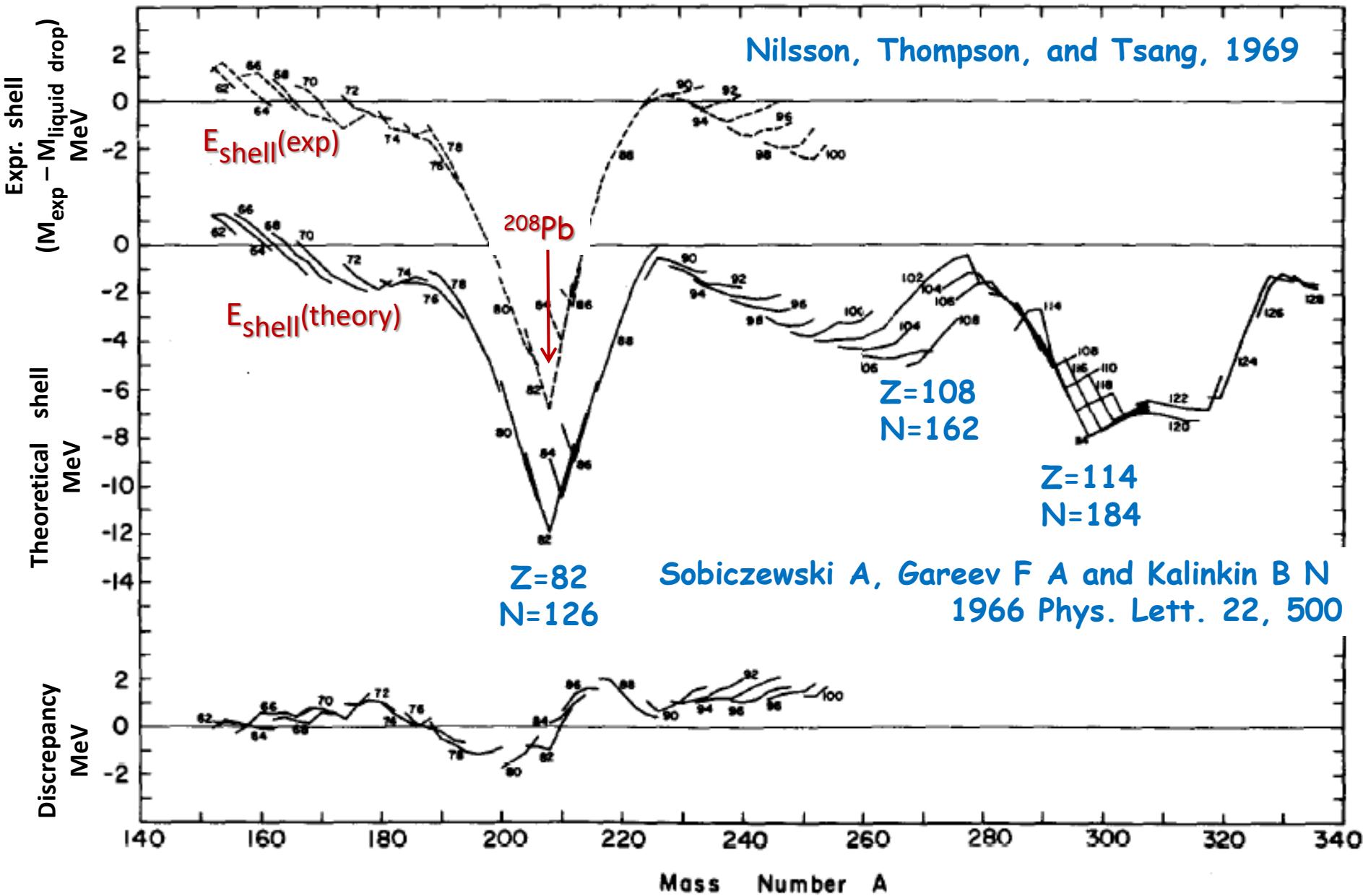
Острова стабильности сверхтяжелых ядер (ЛНФ / ЛЯР / ИАЭ 1966)

The Nobel Prize in Physics 1975

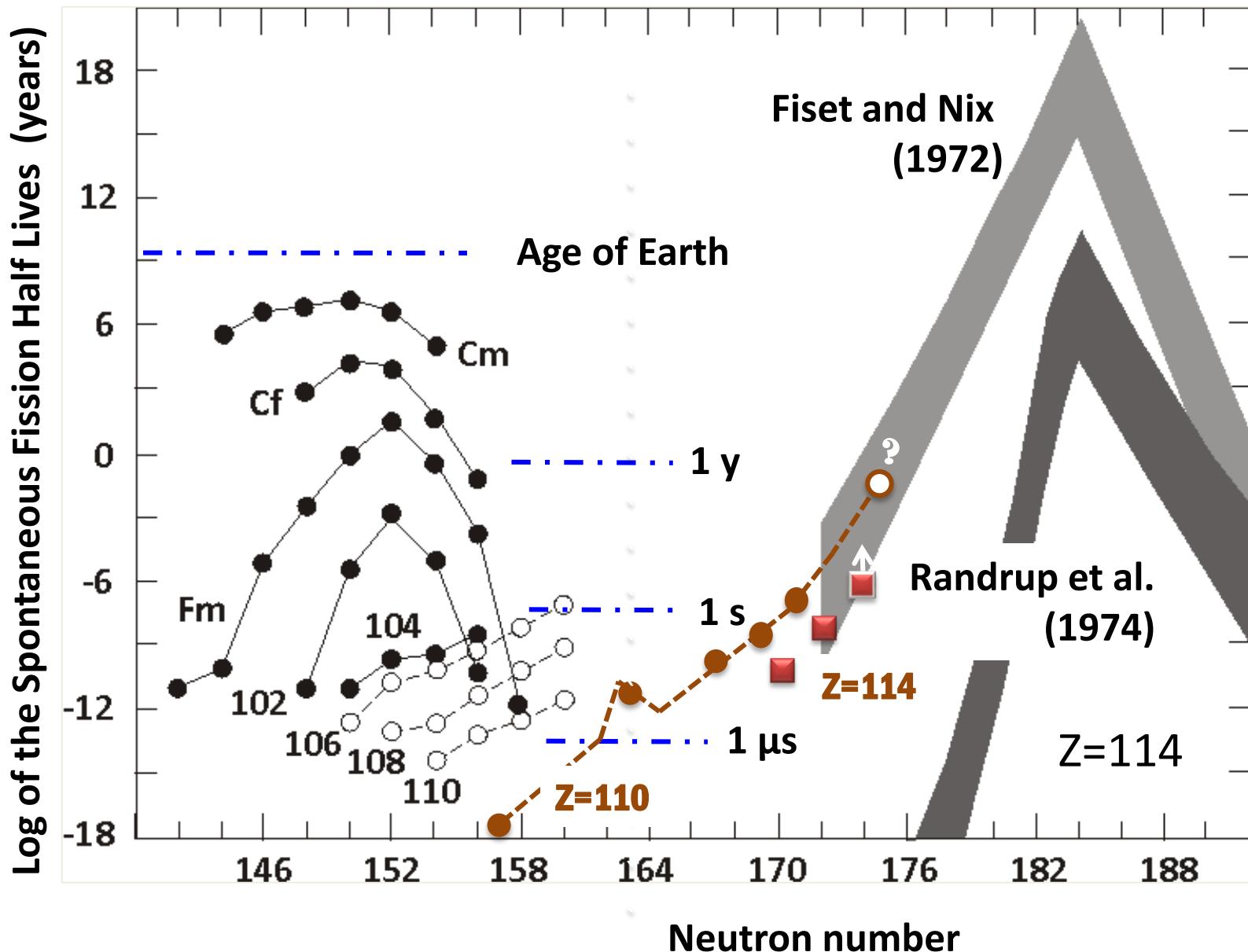


"for the discovery of the connection between collective motion and particle motion in atomic nuclei and the development of the theory of the structure of the atomic nucleus based on this connection".

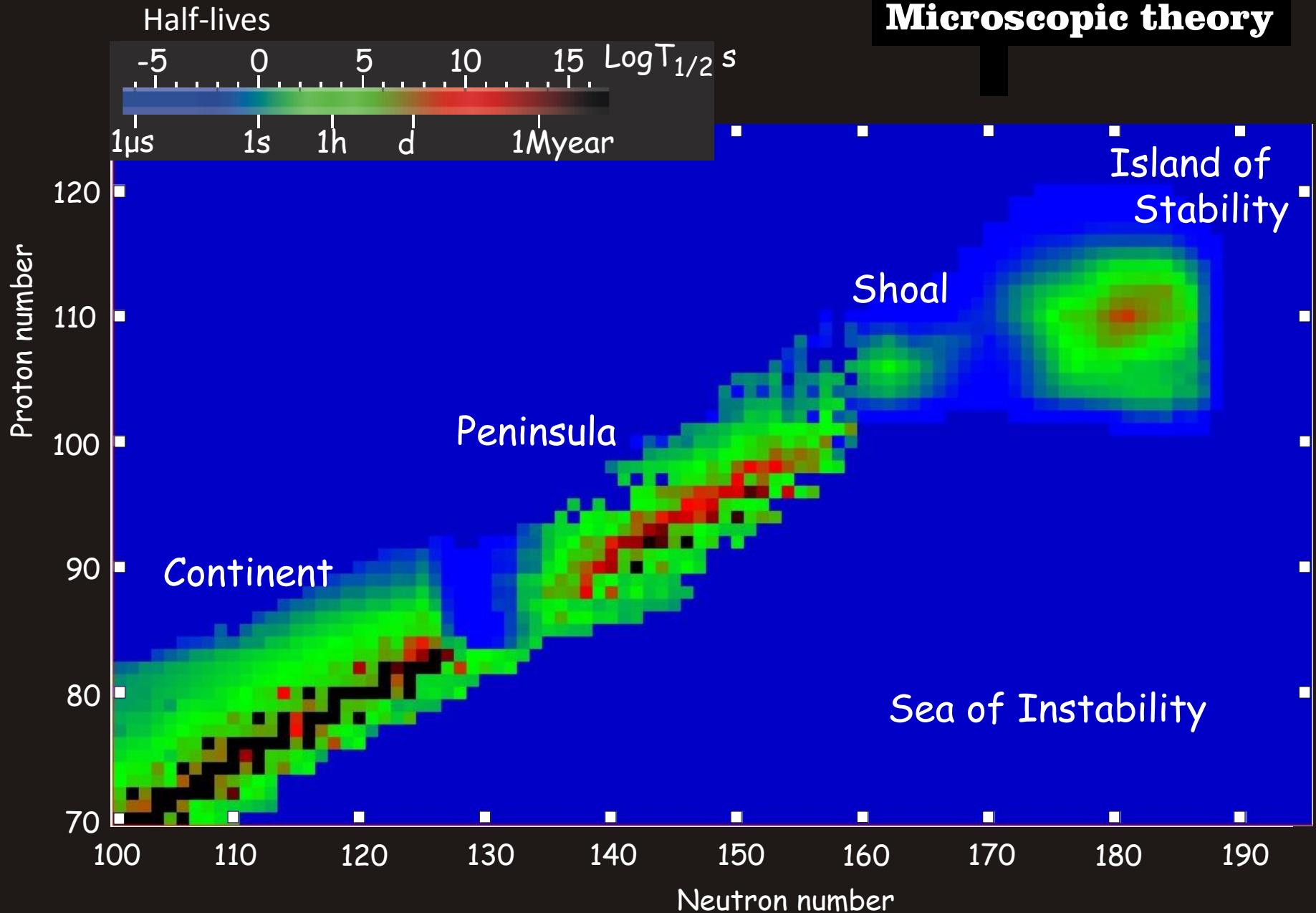
Shell effect in the nuclear ground states (mass defect)







Microscopic theory



D.I.Mendeleev's Periodic Table of the Chemical Elements



1834 - 1907

fusion

unattainable small cross section

Lanthanides

Actinides

57 Lanthanum La	58 Cerium Ce	59 Praseodym- ium Pr	60 Neodym- ium Nd	61 Promet- hium Pm	62 Samarium Sm	63 Europium Eu	64 Gadolinium Gd	65 Terbium Tb	66 Dysprosium Dy	67 Holmium Ho	68 Erbium Er	69 Thulium Tm	70 Ytterbium Yb	71 Lutetium Lu
89 Actinium Ac	90 Thorium Th	91 Protactin- ium Pa	92 Uranium U	93 Neptunium Np	94 Plutonium Pu	95 Americium Am	96 Curium Cm	97 Berkelium Bk	98 Californium Cf	99 Einsteinium Es	100 Fermium Fm	101 Mendelevium Md	102 Nobelium No	103 Lawrencium Lr

Protons & neutrons

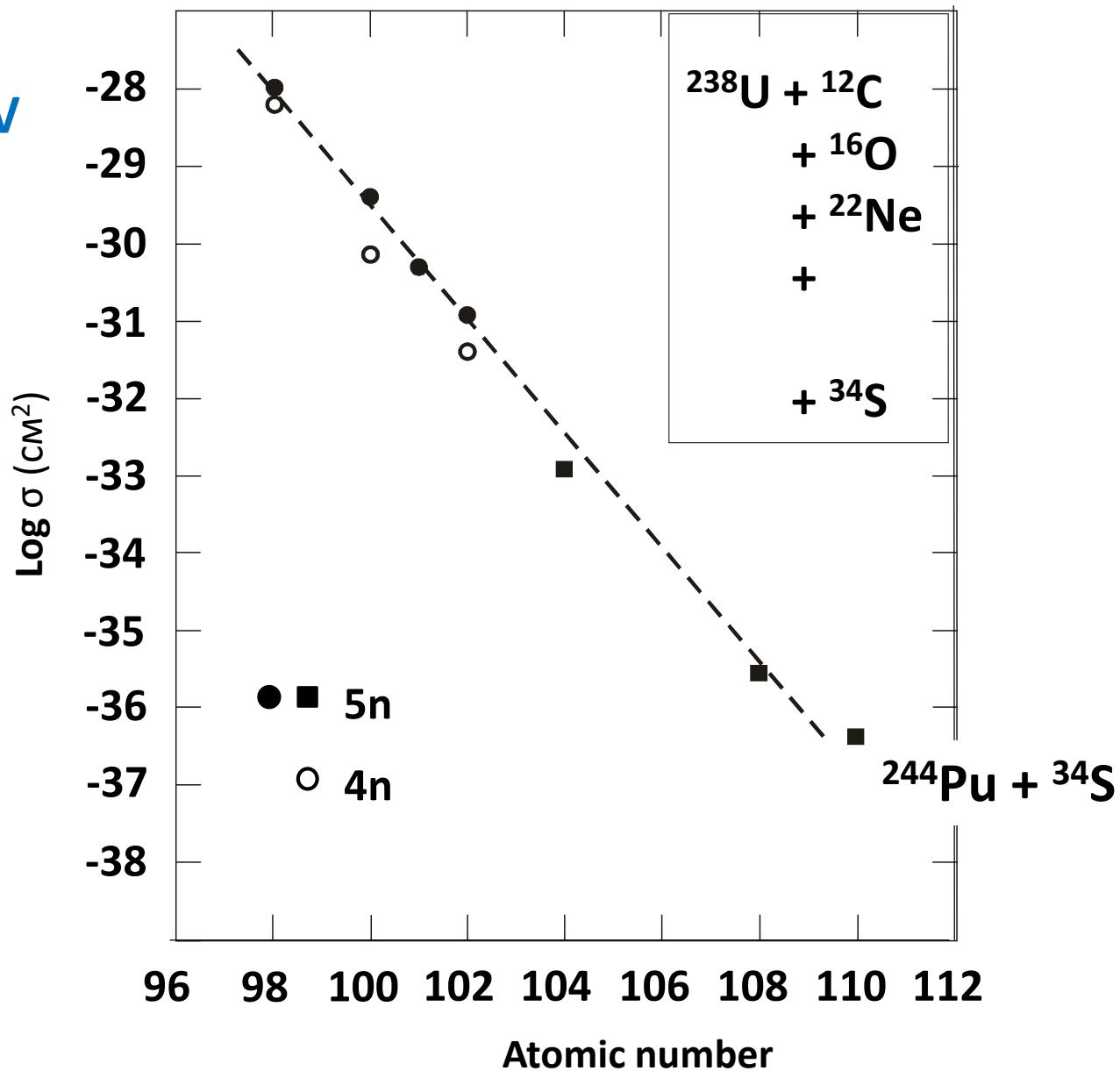
LBNL (Berkeley)

Heavy ion

LBNL ± FLNR

Hot fusion

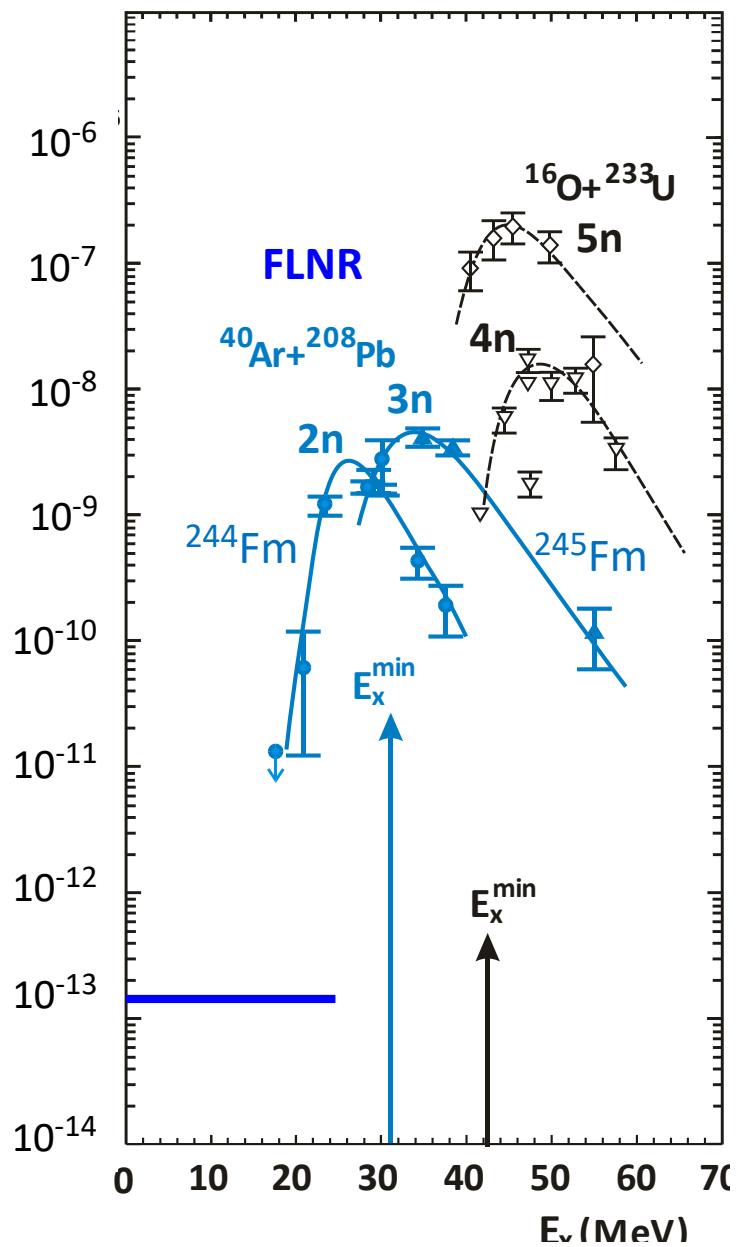
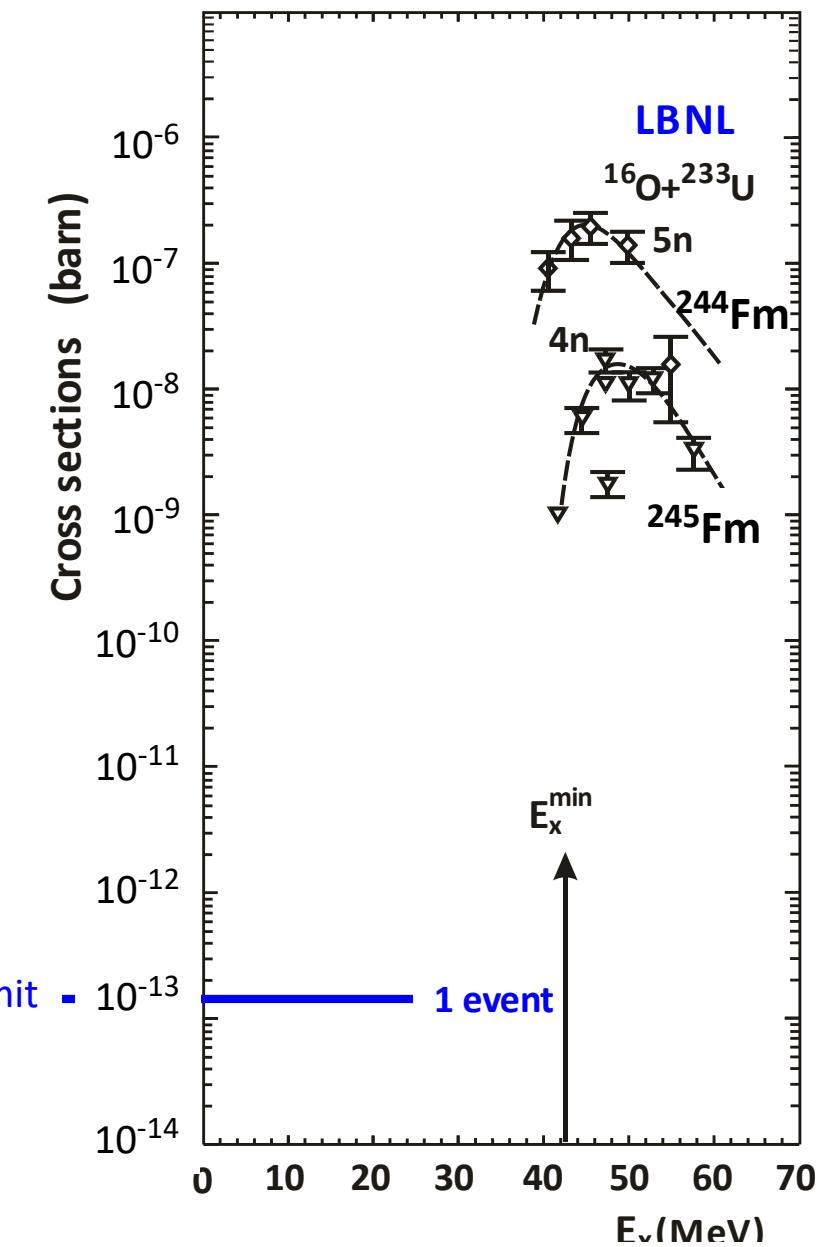
$E_x^{\min} = 40\text{-}55 \text{ MeV}$





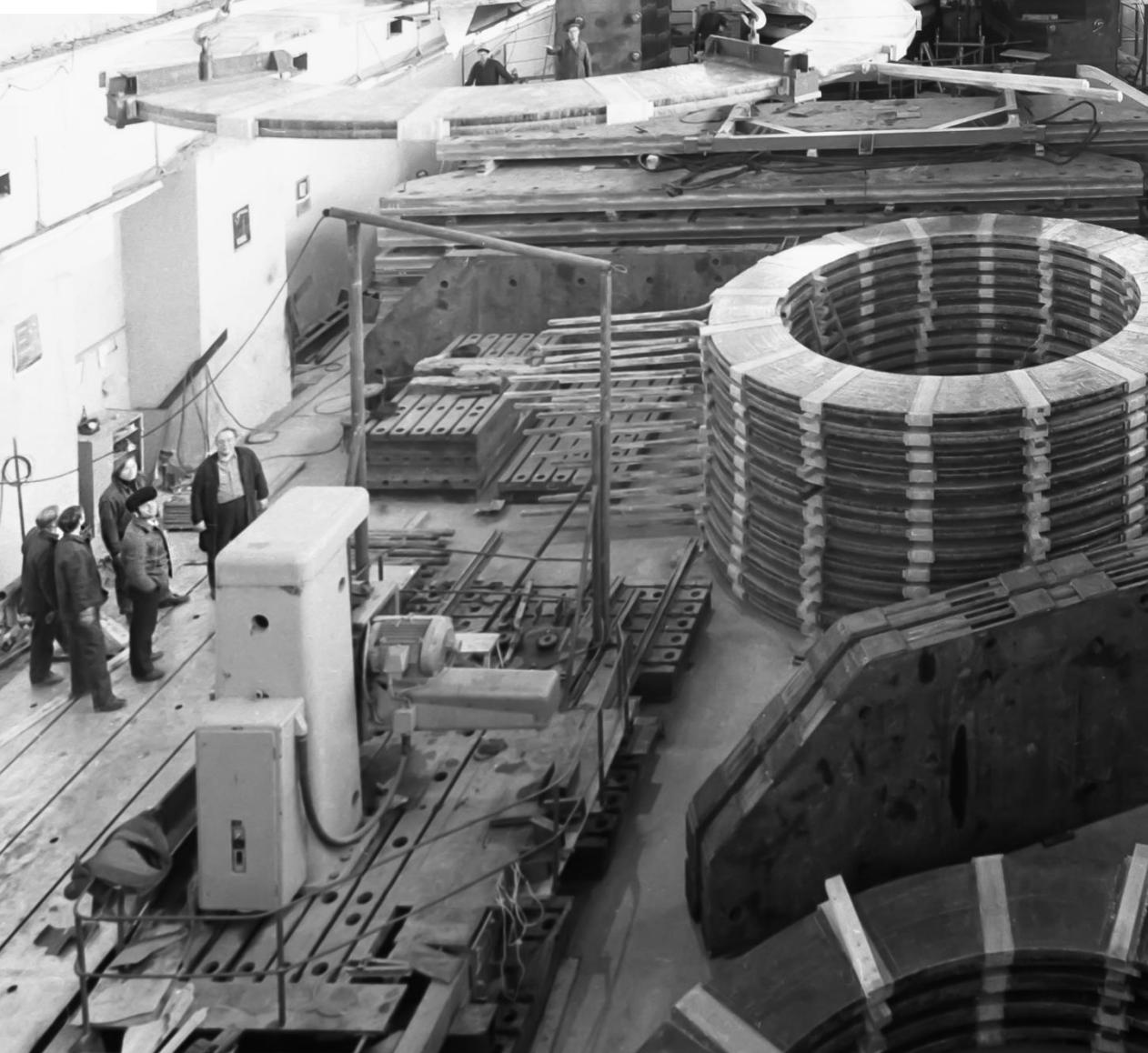
Dubna, 1972

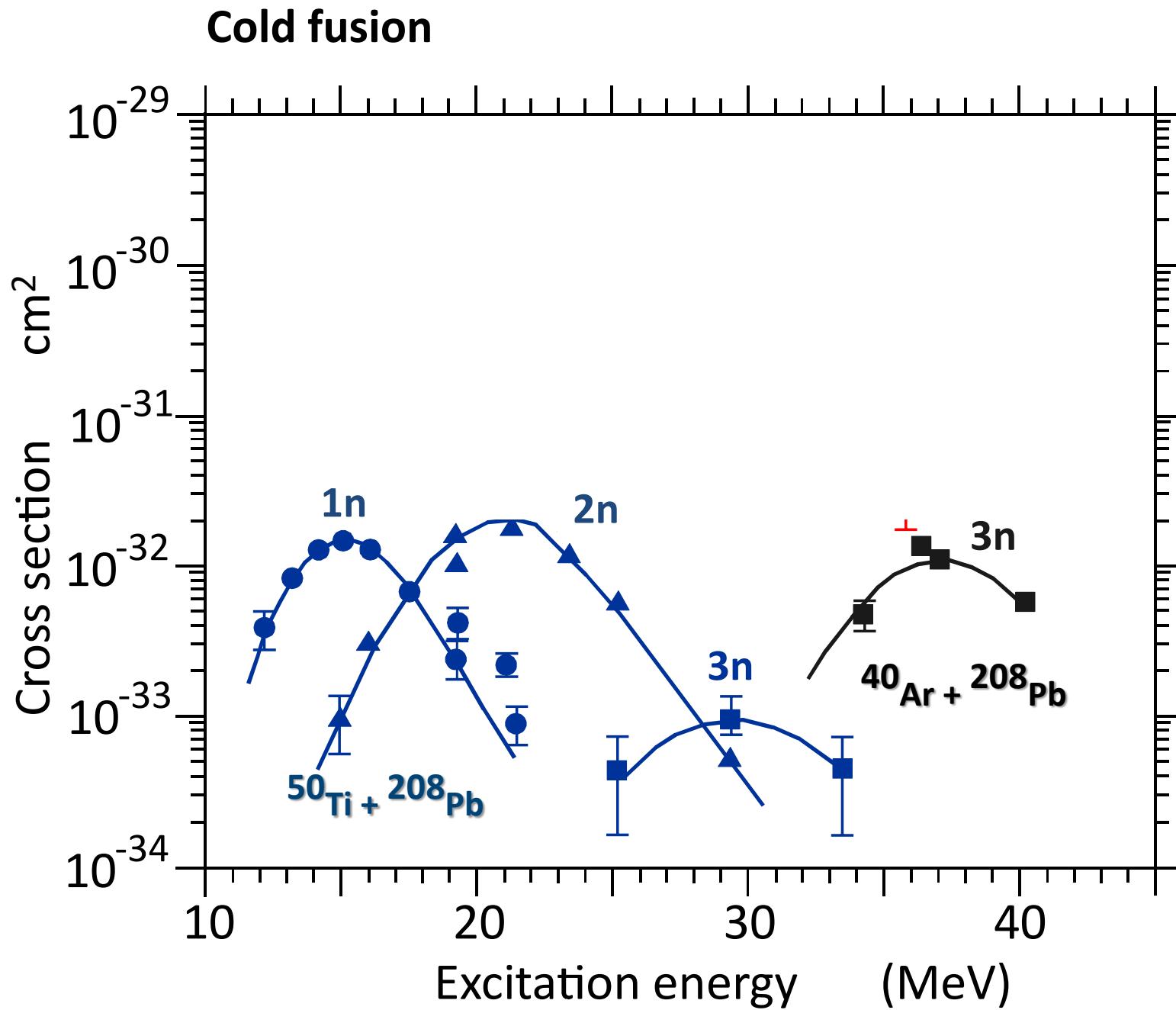
Холодное слияние массивных ядер (ЛЯР 1974)



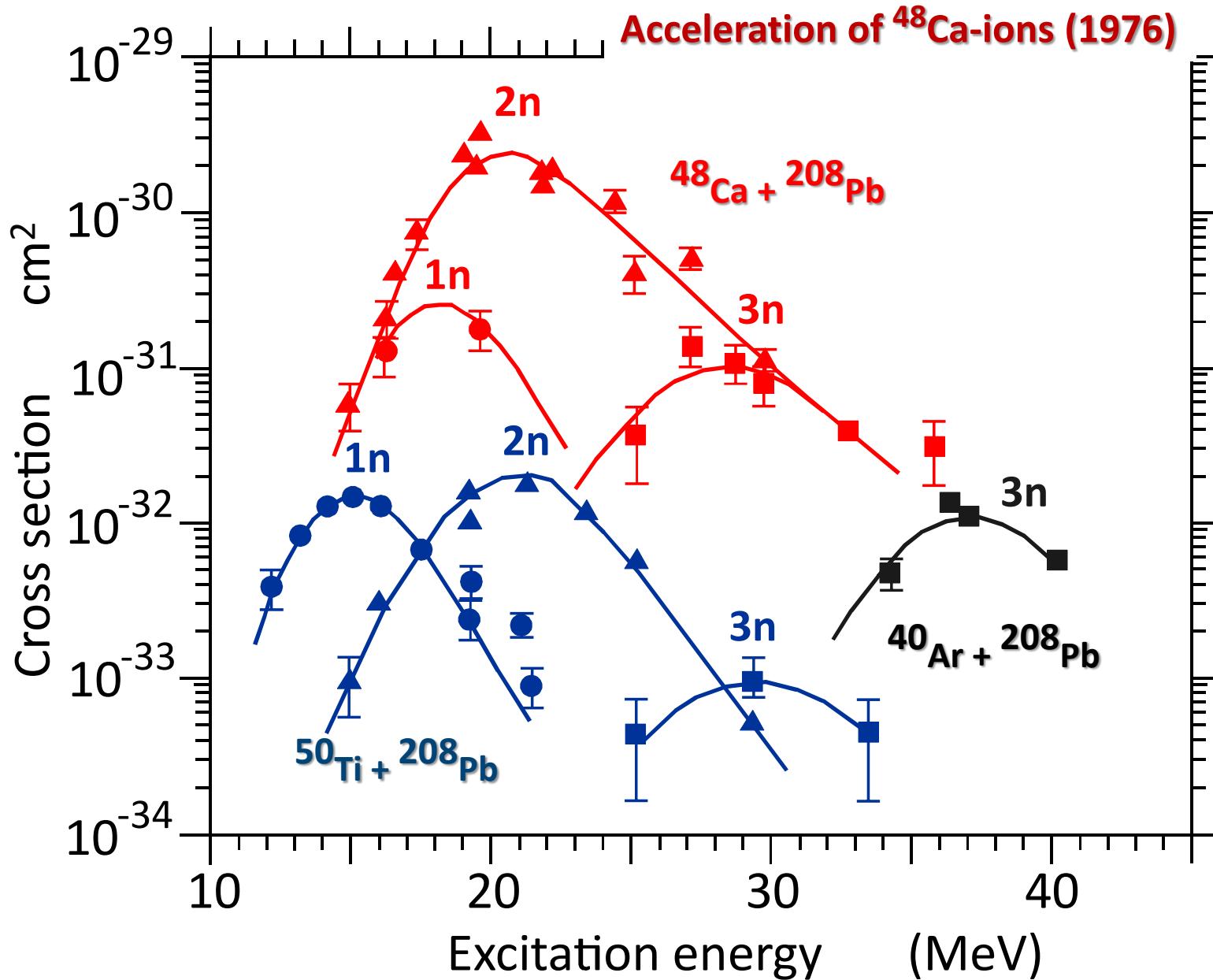


Cyclotron U-400 Dubna 1978

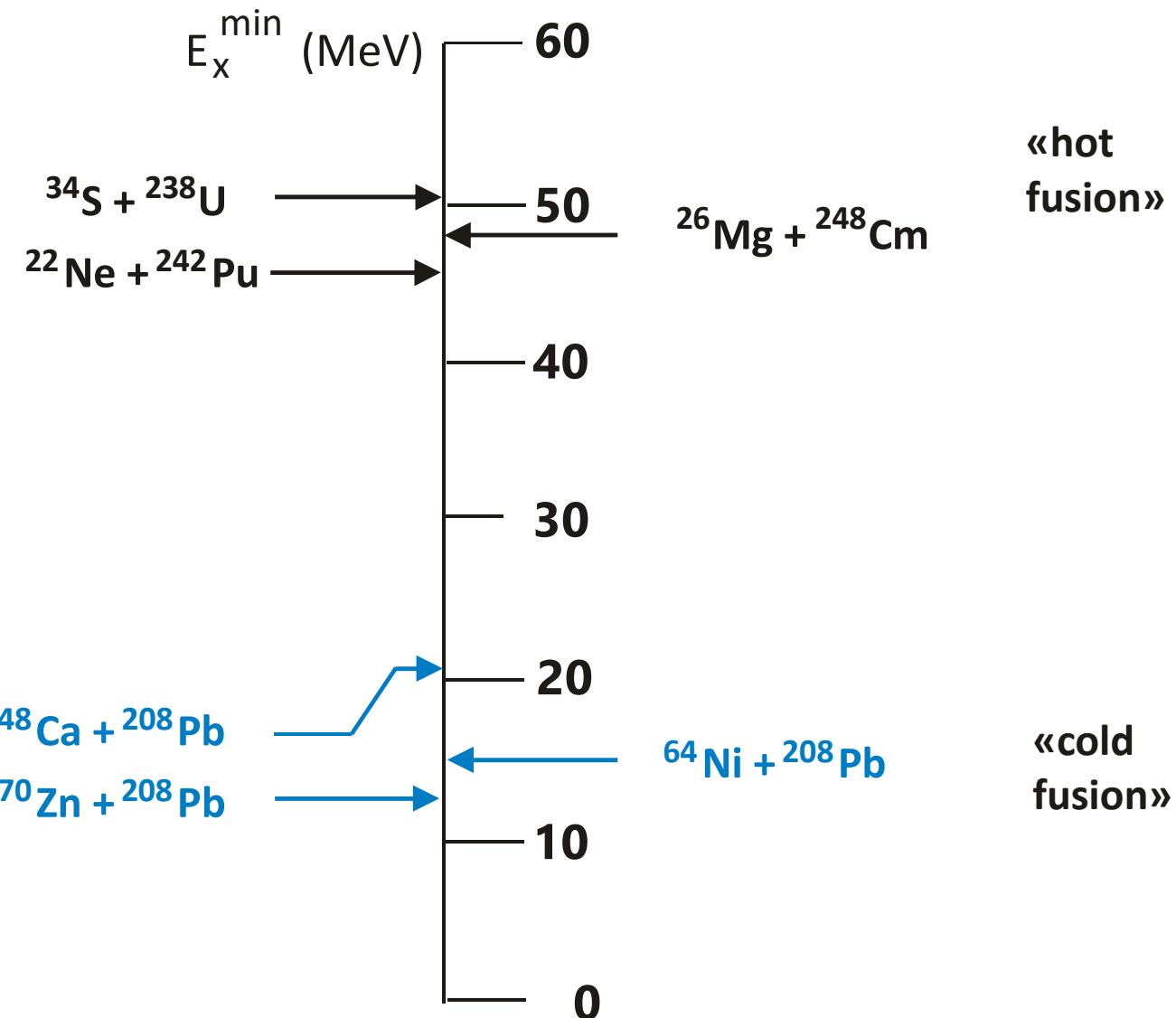


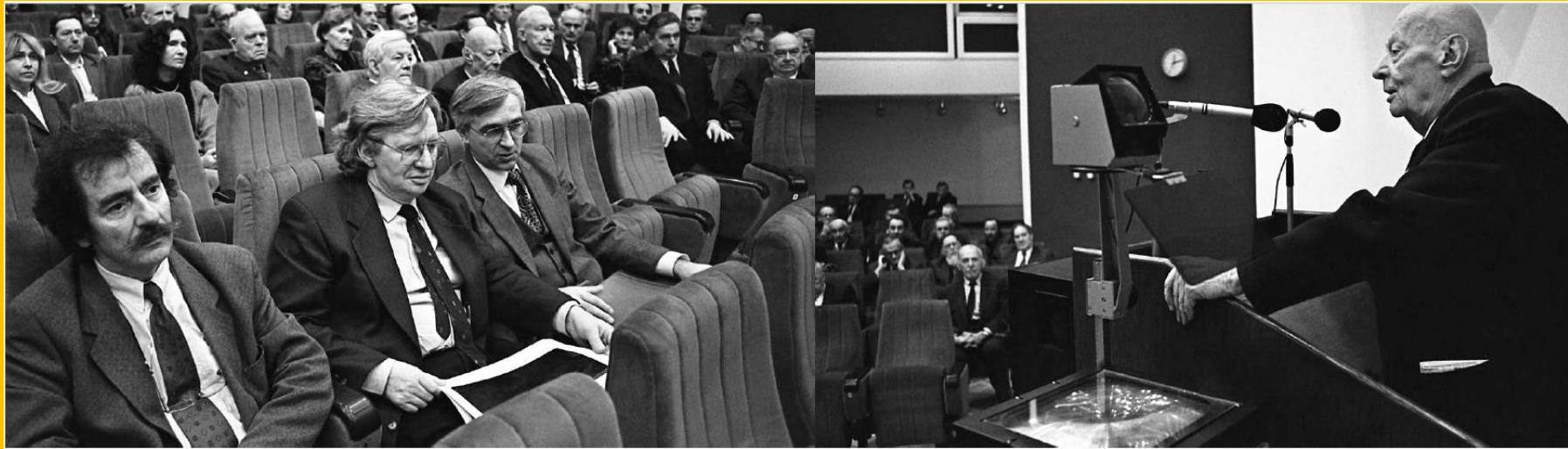


Cold fusion



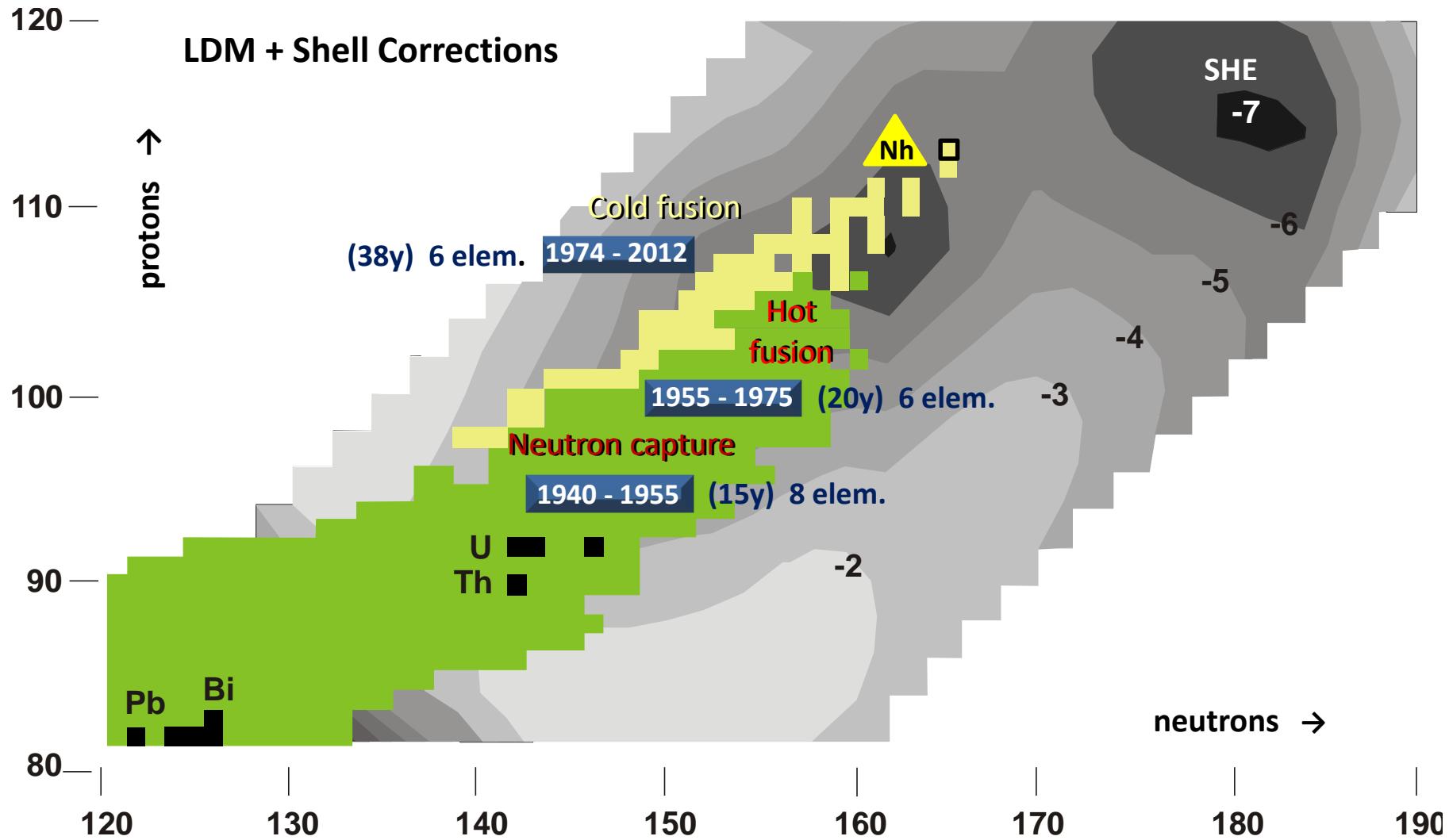
The excitation energy of the compound nuclei at the Coulomb barrier





Семинар памяти Г.Н. Флерова (Москва, РАН, 1991)

Reactions of Synthesis



Тэнно-хэйка (天皇陛下)
Его Императорское Величество



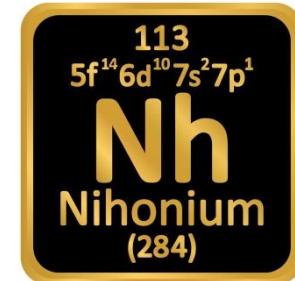
Cold Fusion (transactinides)



$$E \approx B_{Bass}$$

Projectile

Compound
nucleus

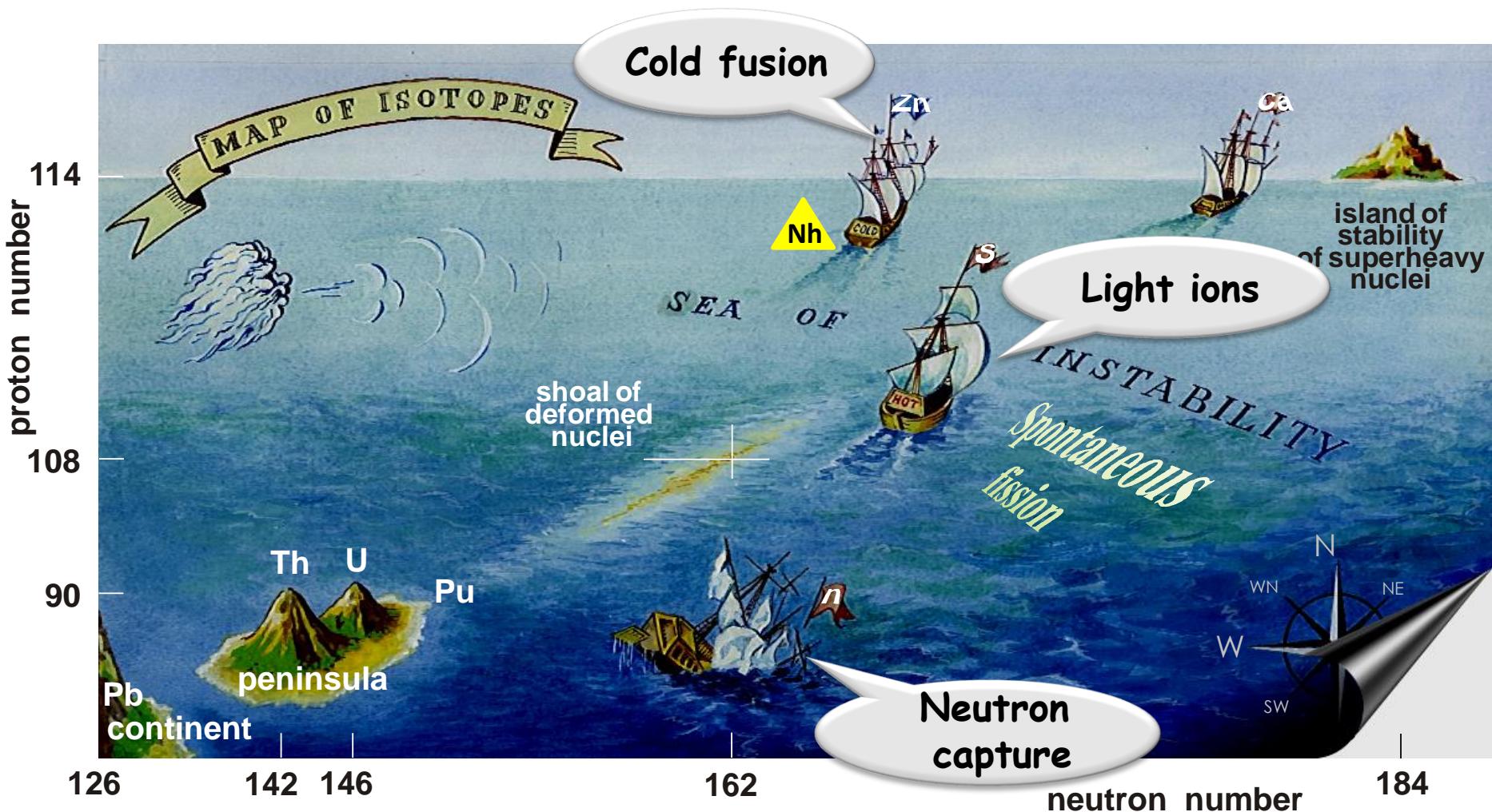


Член-корр РАН
Н.П.Тарасова

Император
Нарухито



Reactions of synthesis



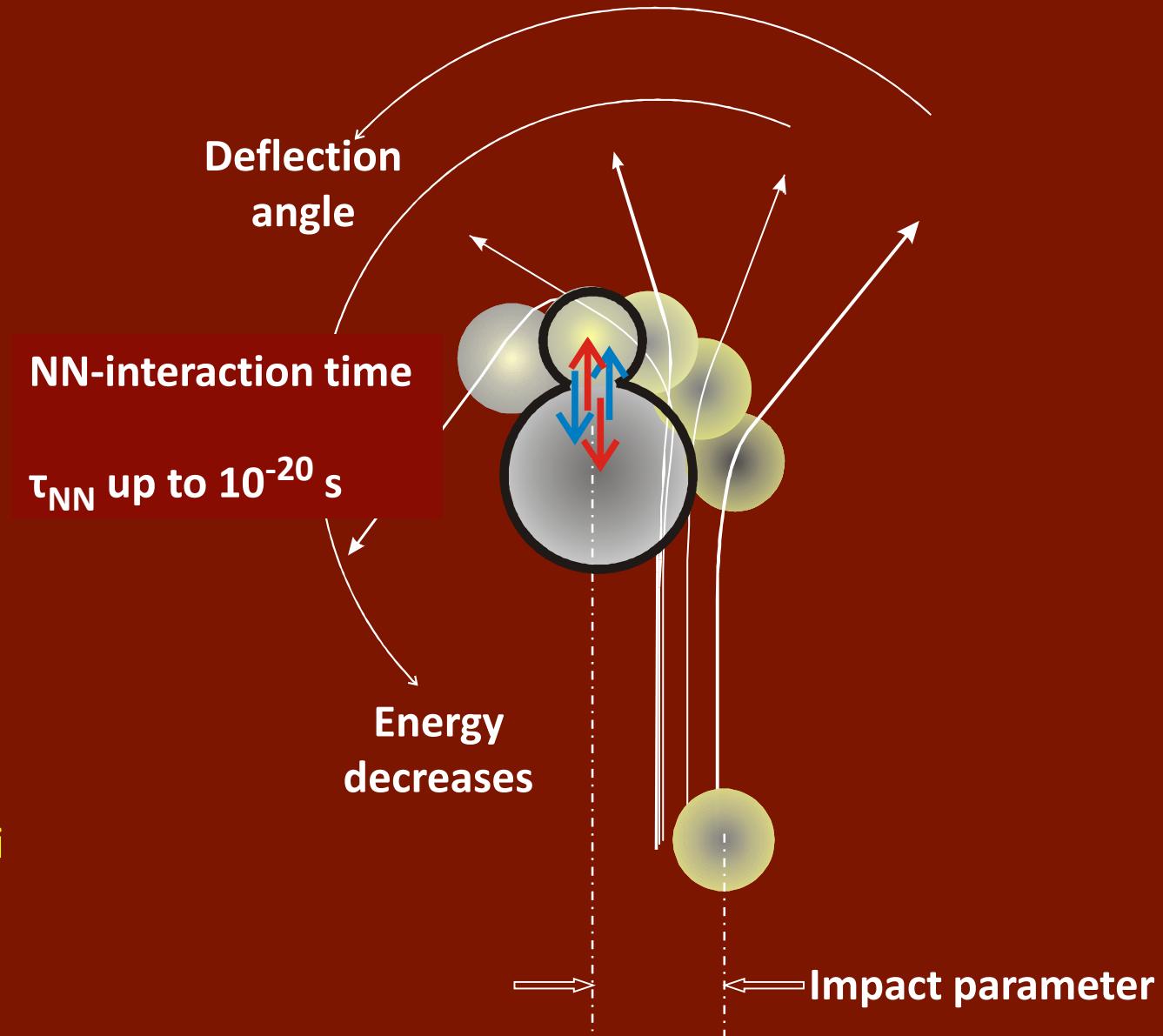
Реакции передачи нуклонов и фрагментации тяжелых ионов

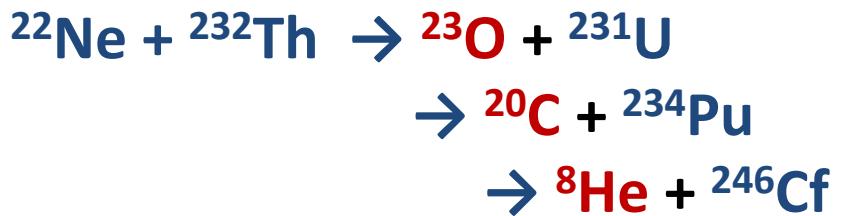
(ЛЯР, 1969 / GANIL, 1989)

Deep Inelastic Collisions

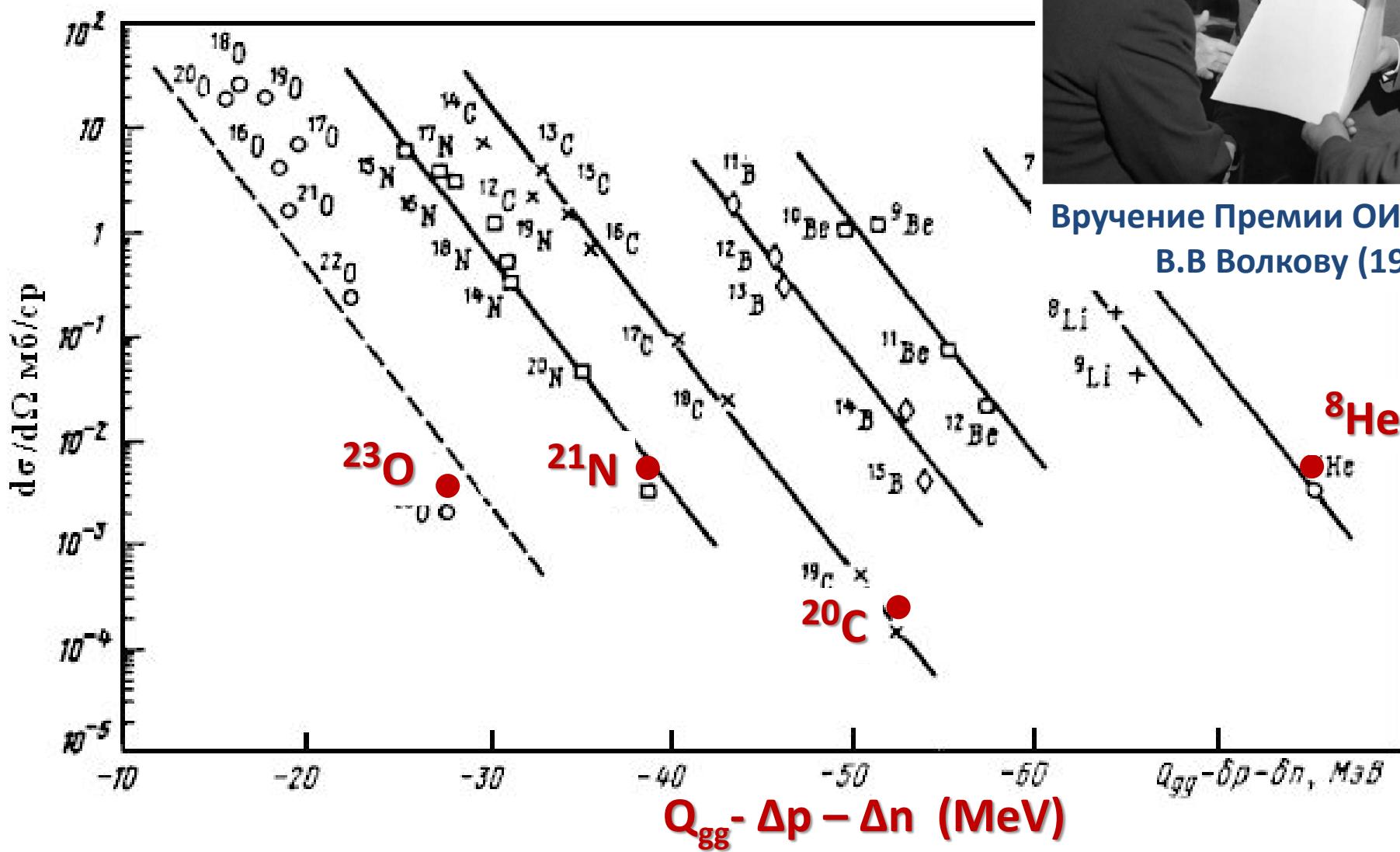
FLNR 1969-73

New type reactions
between complex nuclei

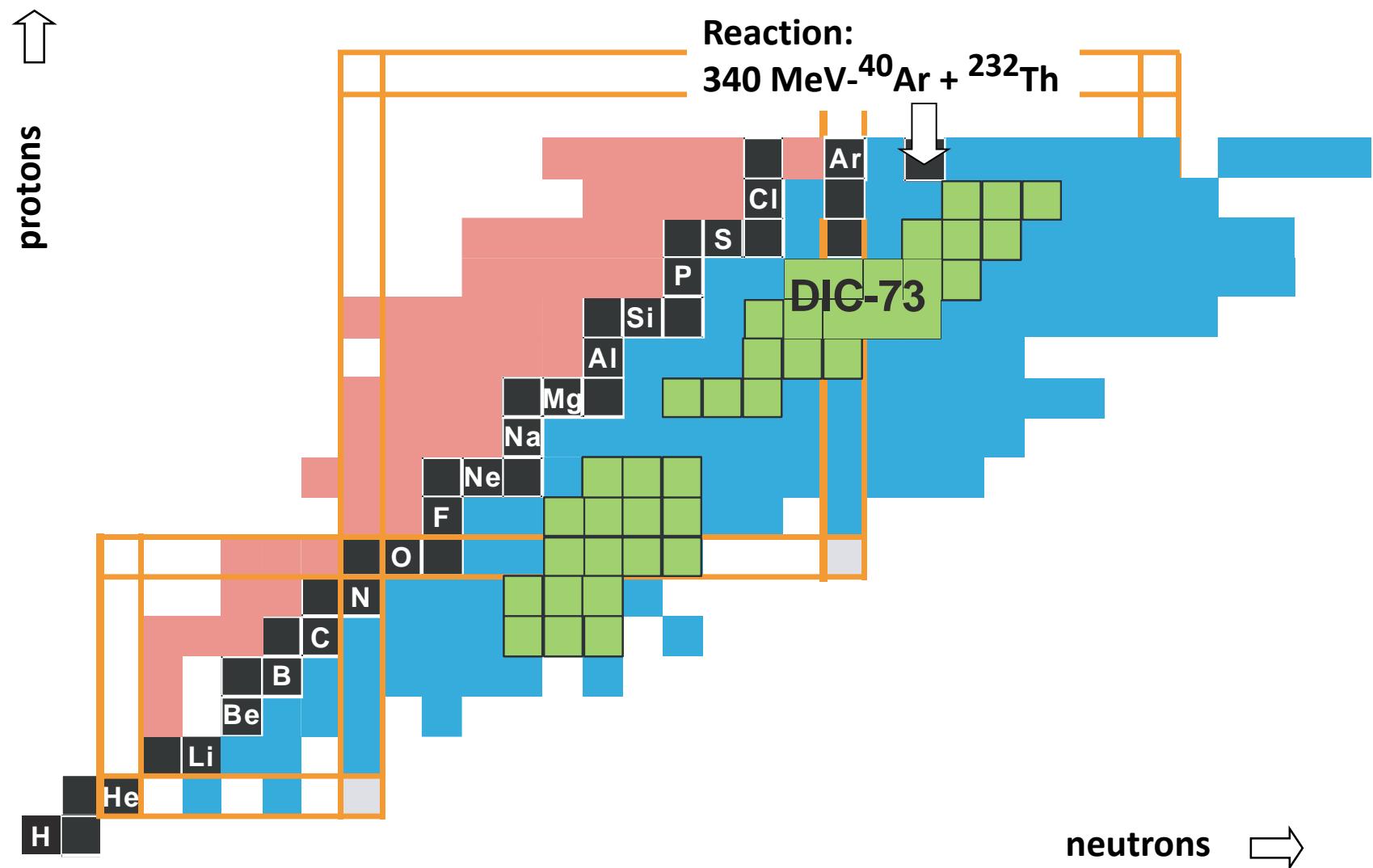




Вручение Премии ОИЯИ
В.В Волкову (1969)



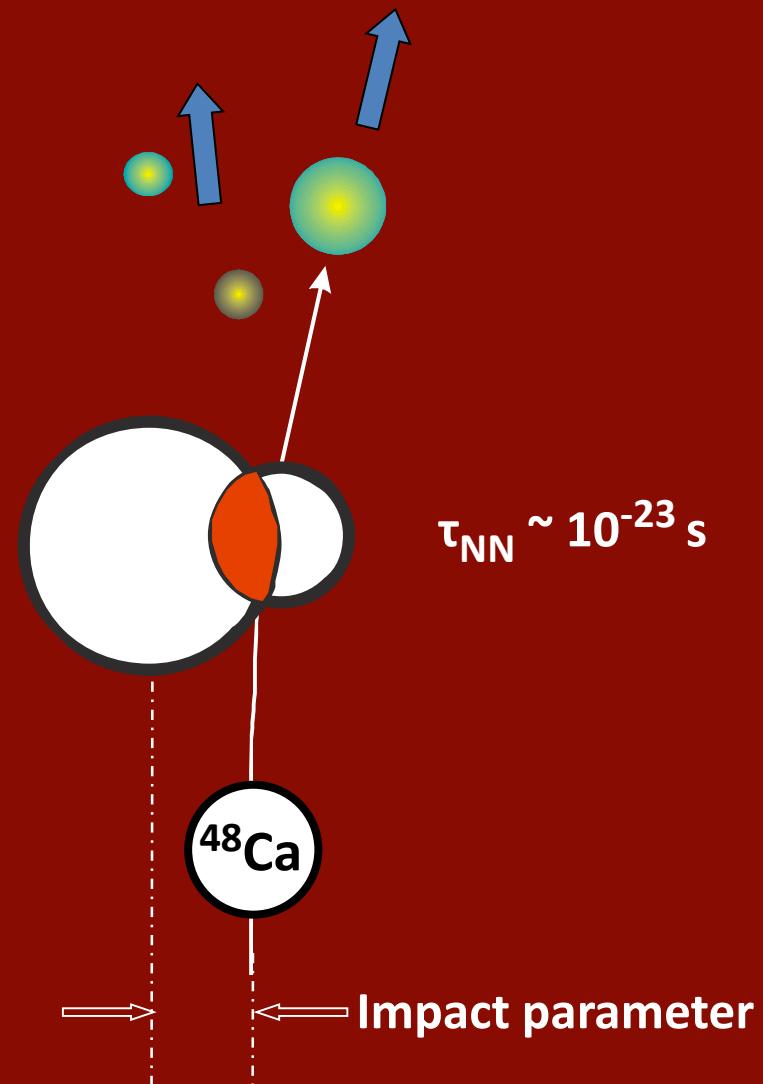
Deep Inelastic Collisions at the near-barrier energies



Fragmentation

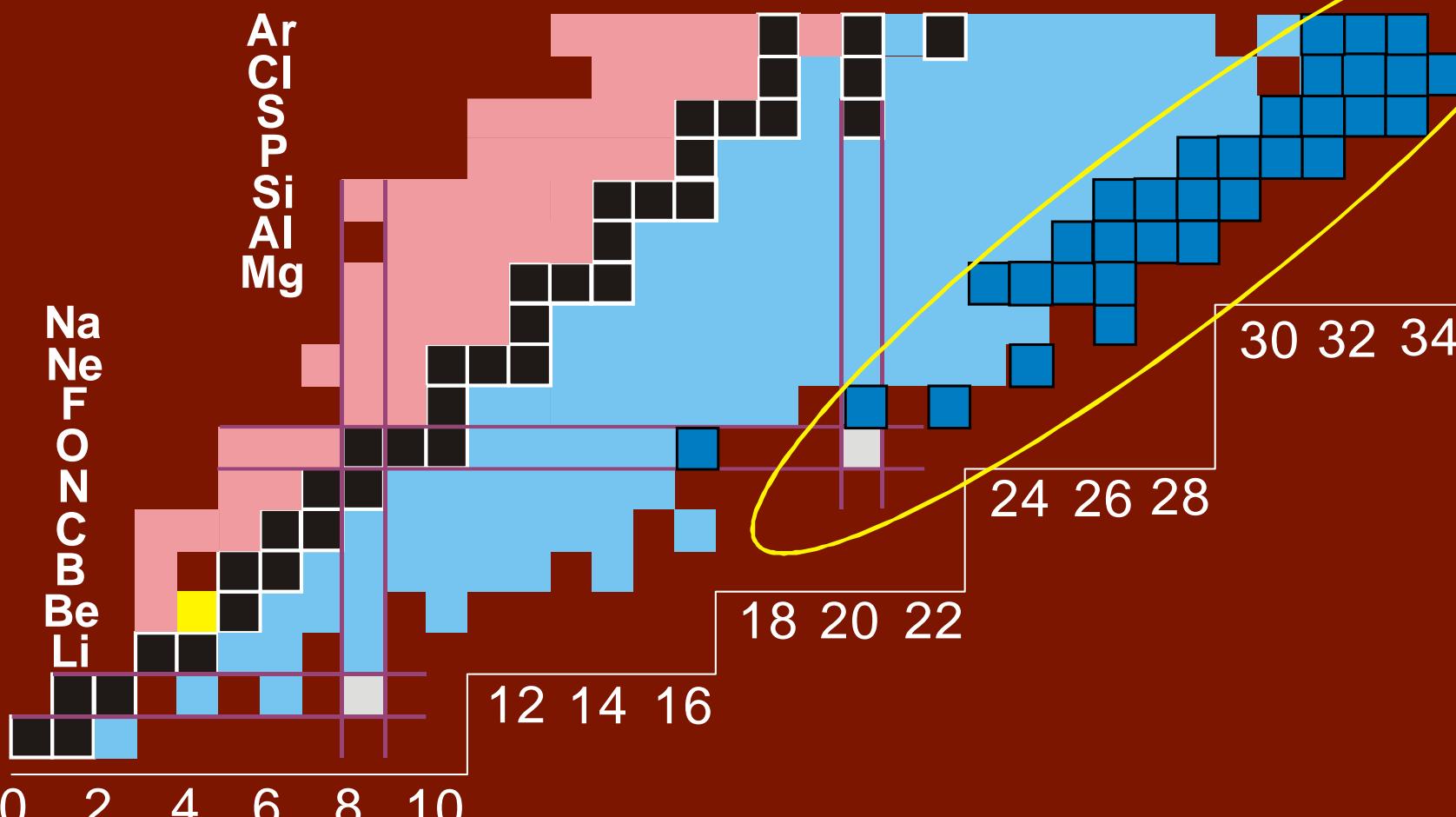
$E \sim 50-100 A \cdot \text{MeV}$

Small deflection angle



Caen (France) 1987

Fragmentation de ^{48}Ca



Z. Phys. A332, 189 (1989)

Новая улица в Кане (Нормандия)



Caen (France) 1987

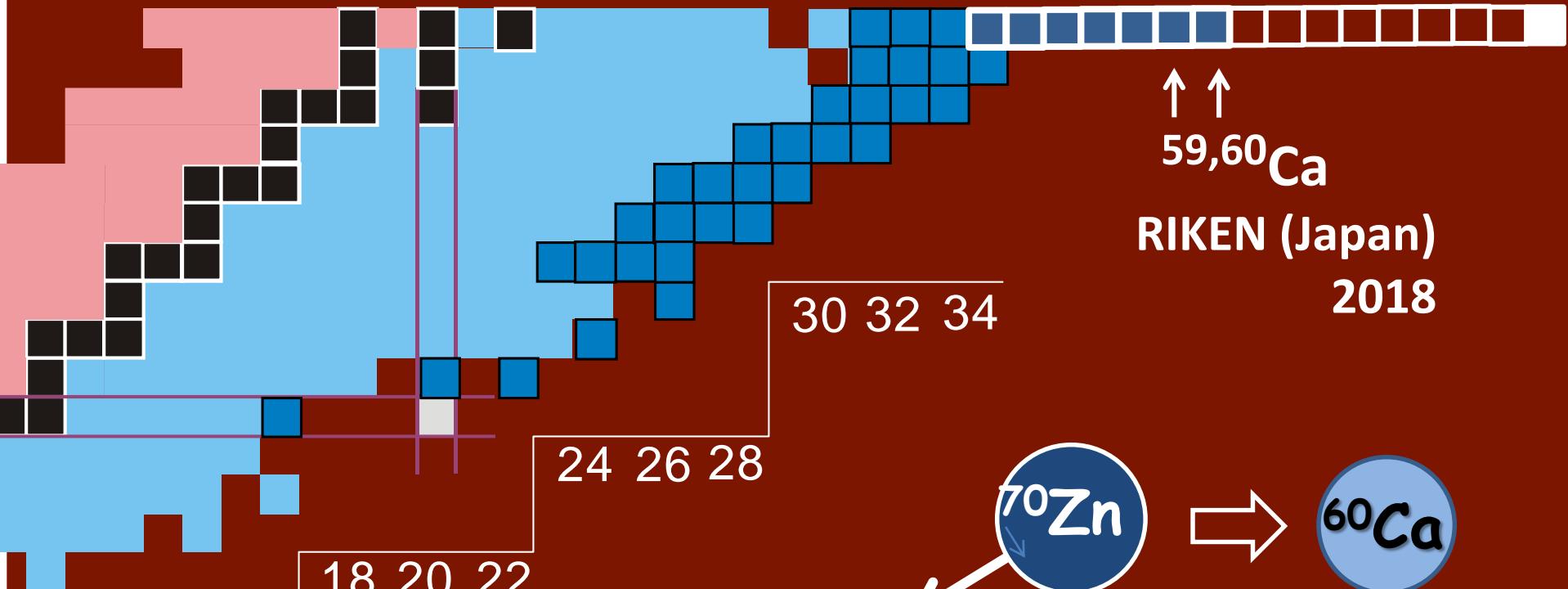
NSCL (USA)

2008



$\uparrow \uparrow$
 $59,60\text{Ca}$

RIKEN (Japan)
2018



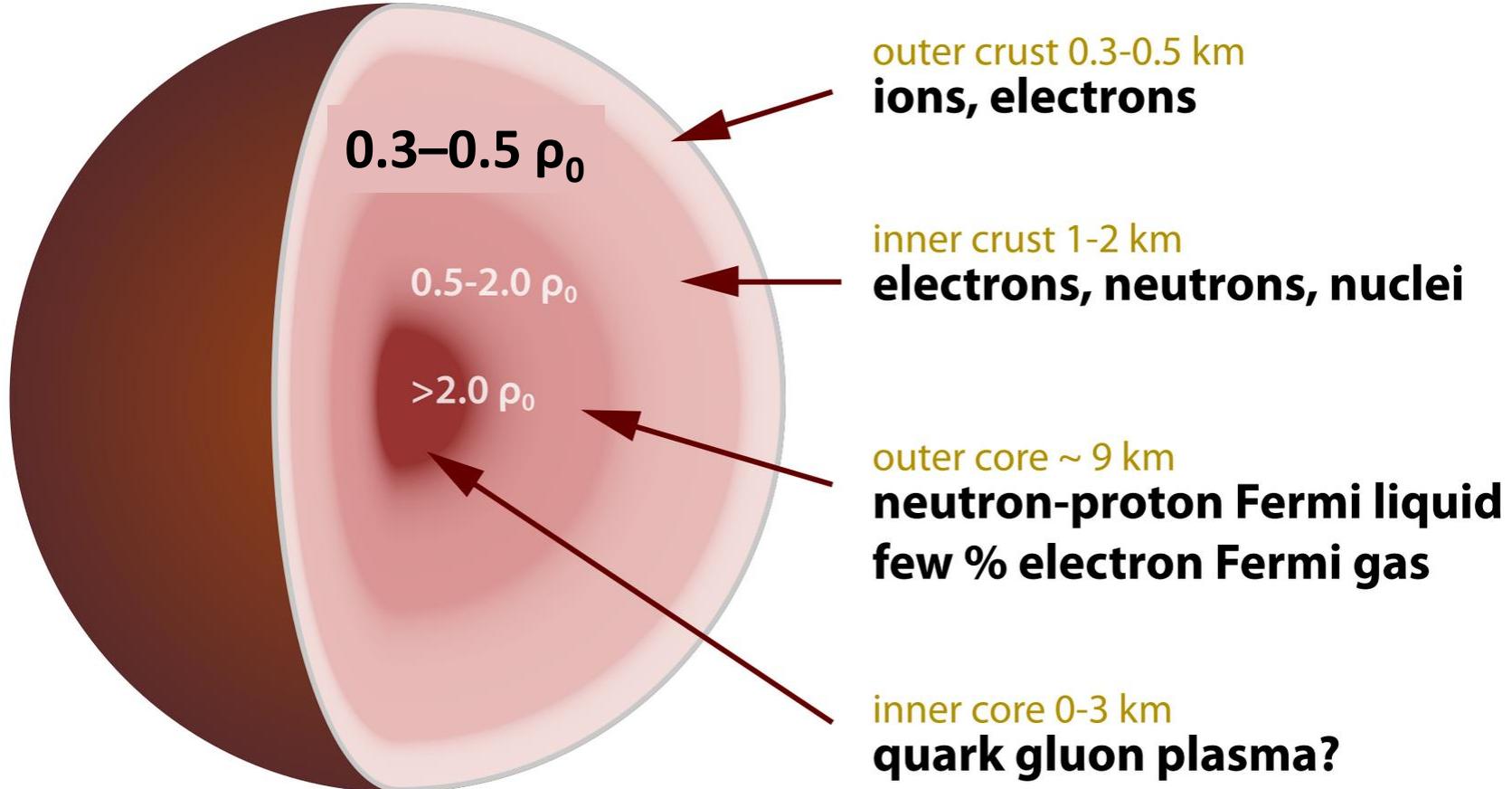
take out
10 protons



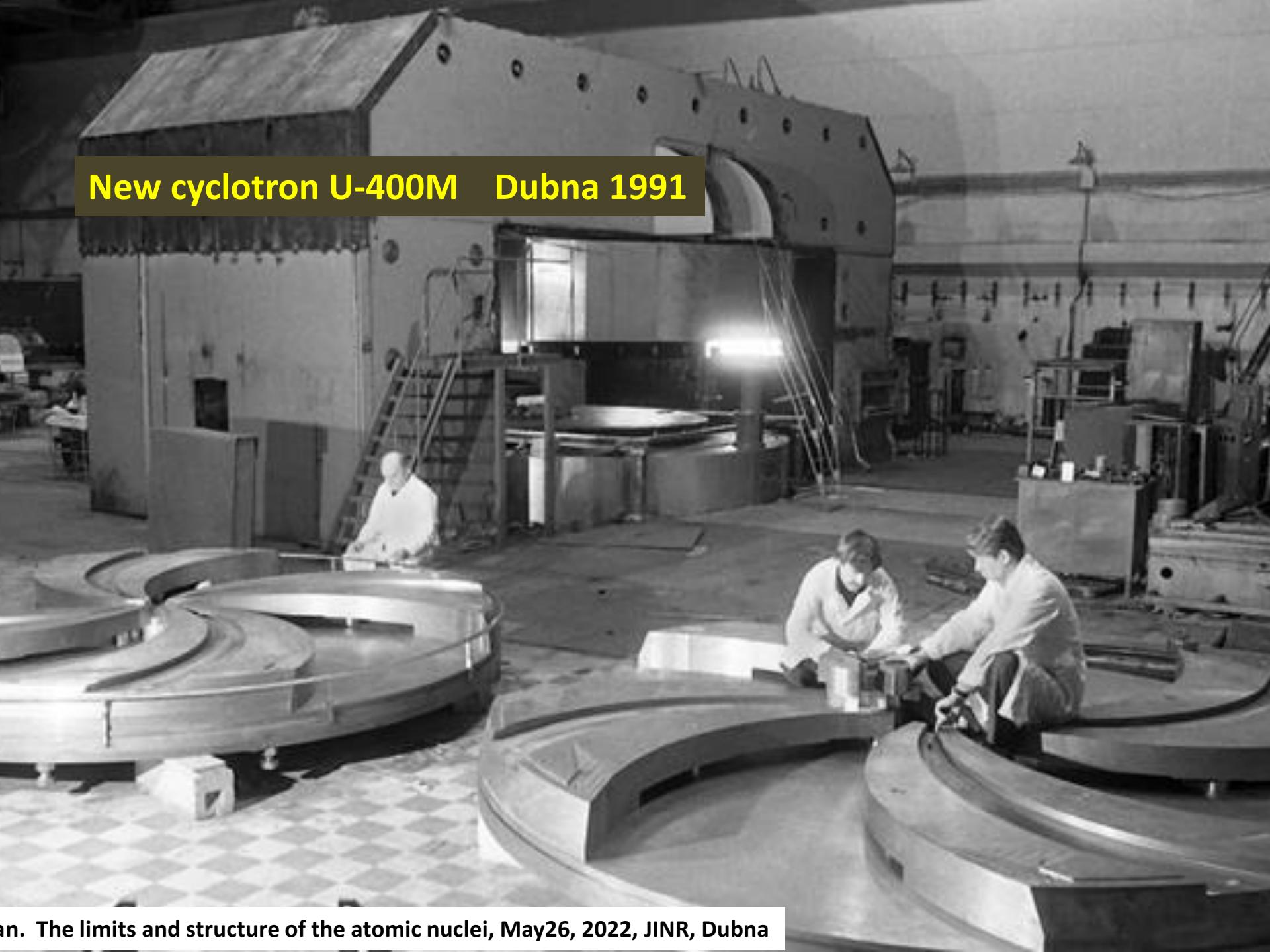
take out
16 protons



Cross-section of neutron star



New cyclotron U-400M Dubna 1991





Главный конструктор
НИИЭФА (Ленинград),
И. Ф. Малышев

Почетный директор ЛЯР
акад. Г. Н. Флеров

Прощальные проводы ускорителя - ветерана УЗОО

2016 - first run

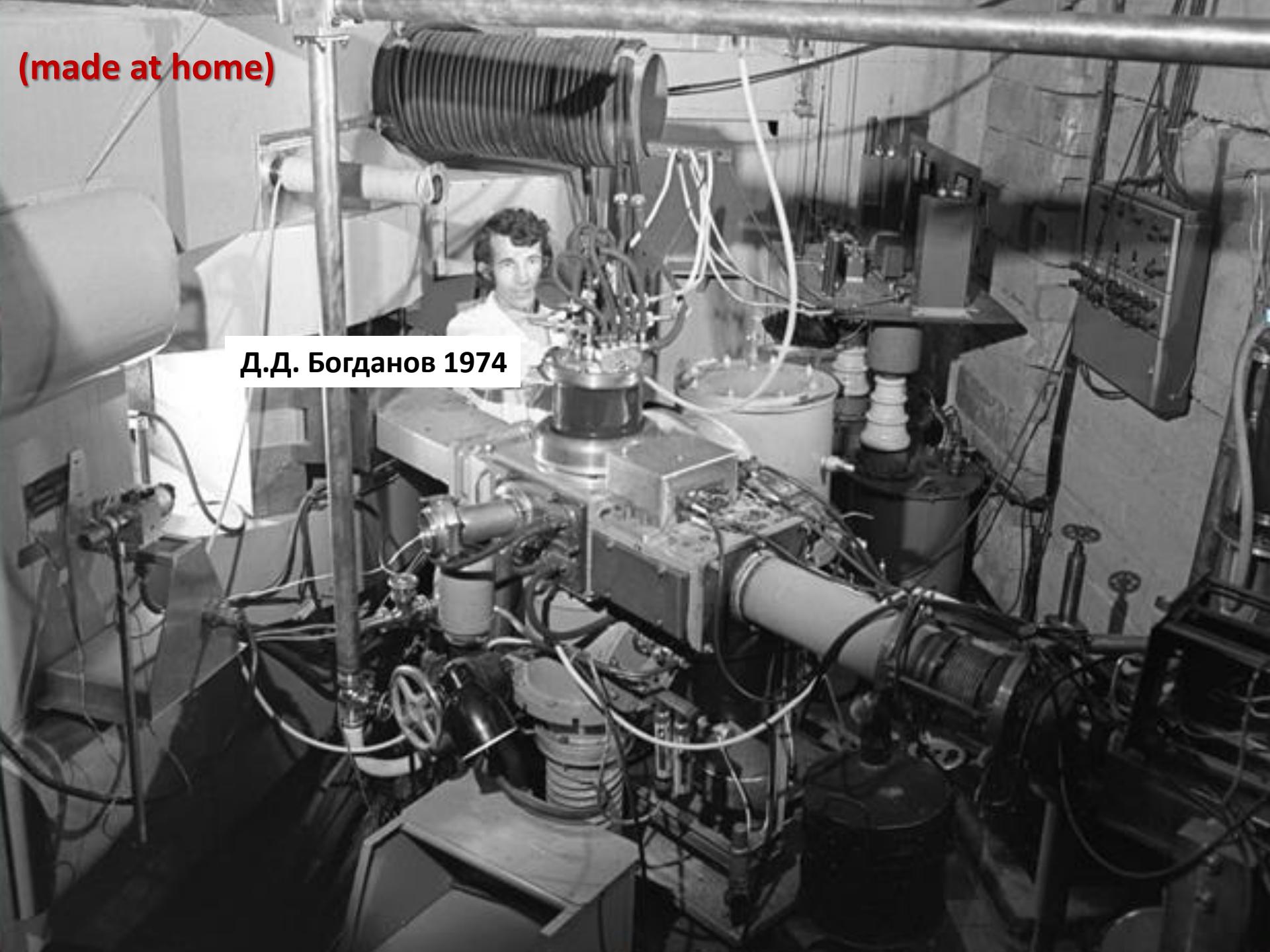
Это сейчас!
(made in France)

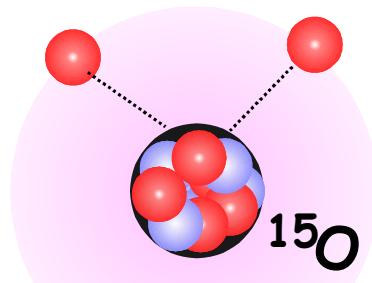
А тогда, 54 года до
этого, впервые...



(made at home)

Д.Д. Богданов 1974





2008

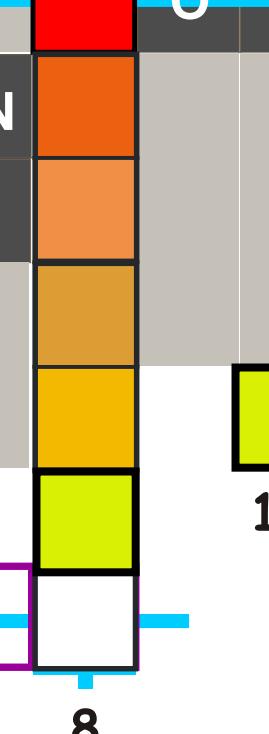
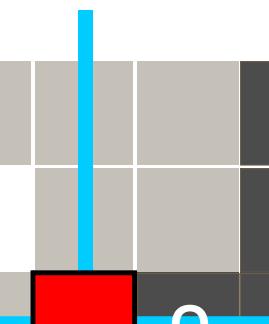
2p-emission
1984

2
H
n
2

FLNR 1962

0.11s

$\beta^+ - 2p$ emission



Ne

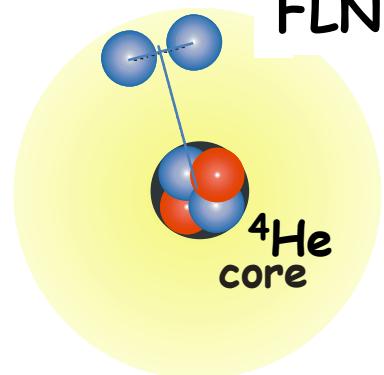
F

O

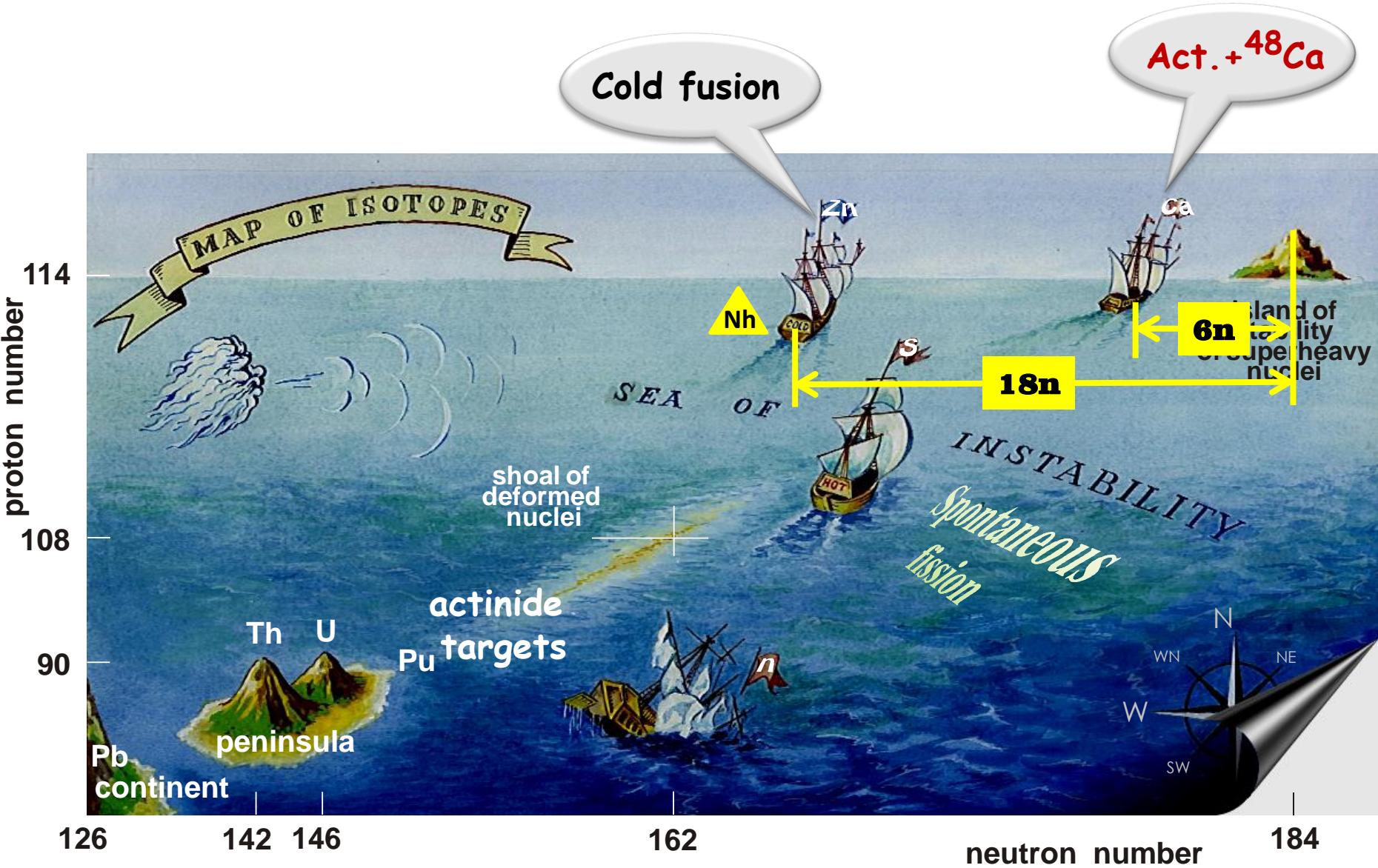
B.A. Карнаухов

1965

discovery "di-neutron"
in halo-nucleus ${}^6\text{He}$
FLNR 1999



Синтез сверхтяжелых элементов (ЛЯР, 1999-2014)



D.I.Mendeleev's Periodic Table of the Chemical Elements



1834 - 1907

The figure displays a periodic table of elements with various properties indicated by color-coding:

- Nonmetals** (Green): Hydrogen (H), Helium (He), Nitrogen (N), Oxygen (O), Fluorine (F), Neon (Ne), Carbon (C), Silicon (Si), Phosphorus (P), Sulfur (S), Chlorine (Cl), Argon (Ar), Selenium (Se), Bromine (Br), Krypton (Kr), Xenon (Xe), Radon (Rn).
- Noble Gases** (Light Green): Helium (He), Neon (Ne), Argon (Ar), Krypton (Kr), Xenon (Xe), Radon (Rn).
- Other Metals** (Purple): Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Bismuth (Bi), Polonium (Po), Astatine (At).
- Transition metals** (Red): Iron (Fe), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Rhodium (Rh), Palladium (Pd), Silver (Ag), Cadmium (Cd), Indium (In), Tin (Sn), Antimony (Sb), Tellurium (Te), Iodine (I), Bismuth (Bi), Polonium (Po), Astatine (At).
- Alkaline earth Metals** (Yellow): Lithium (Li), Beryllium (Be), Magnesium (Mg), Calcium (Ca), Strontium (Sr), Barium (Ba), Radium (Ra).
- Alkali Metals** (Blue): Hydrogen (H), Sodium (Na), Potassium (K), Rubidium (Rb), Cesium (Cs), Francium (Fr).
- Lanthanide series** (Orange): Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Promethium (Pm), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb), Lutetium (Lu).
- Actinide series** (Brown): Actinium (Ac), Thorium (Th), Protactinium (Pa), Uranium (U), Neptunium (Np), Plutonium (Pu), Americium (Am), Curium (Cm), Berkelium (Bk), Calameium (Cf), Einsteinium (Es), Fermium (Fm), Mendelevium (Md), Nobelium (No), Lawrencium (Lr).

Element properties are also indicated by icons:

- Solid** (Grey box): Most elements.
- Liquid** (Light Blue box): Bromine (Br).
- Gas** (White box with red border): Hydrogen (H), Helium (He).
- Synthetic** (Dark Blue box): Technetium (Tc), Promethium (Pm), Neptunium (Np), Plutonium (Pu), Americium (Am), Curium (Cm), Berkelium (Bk), Calameium (Cf), Einsteinium (Es), Fermium (Fm), Mendelevium (Md), Nobelium (No), Lawrencium (Lr).

A blue arrow points from the bottom right towards the following text:

Ca-48 fusion
Dubna 1999

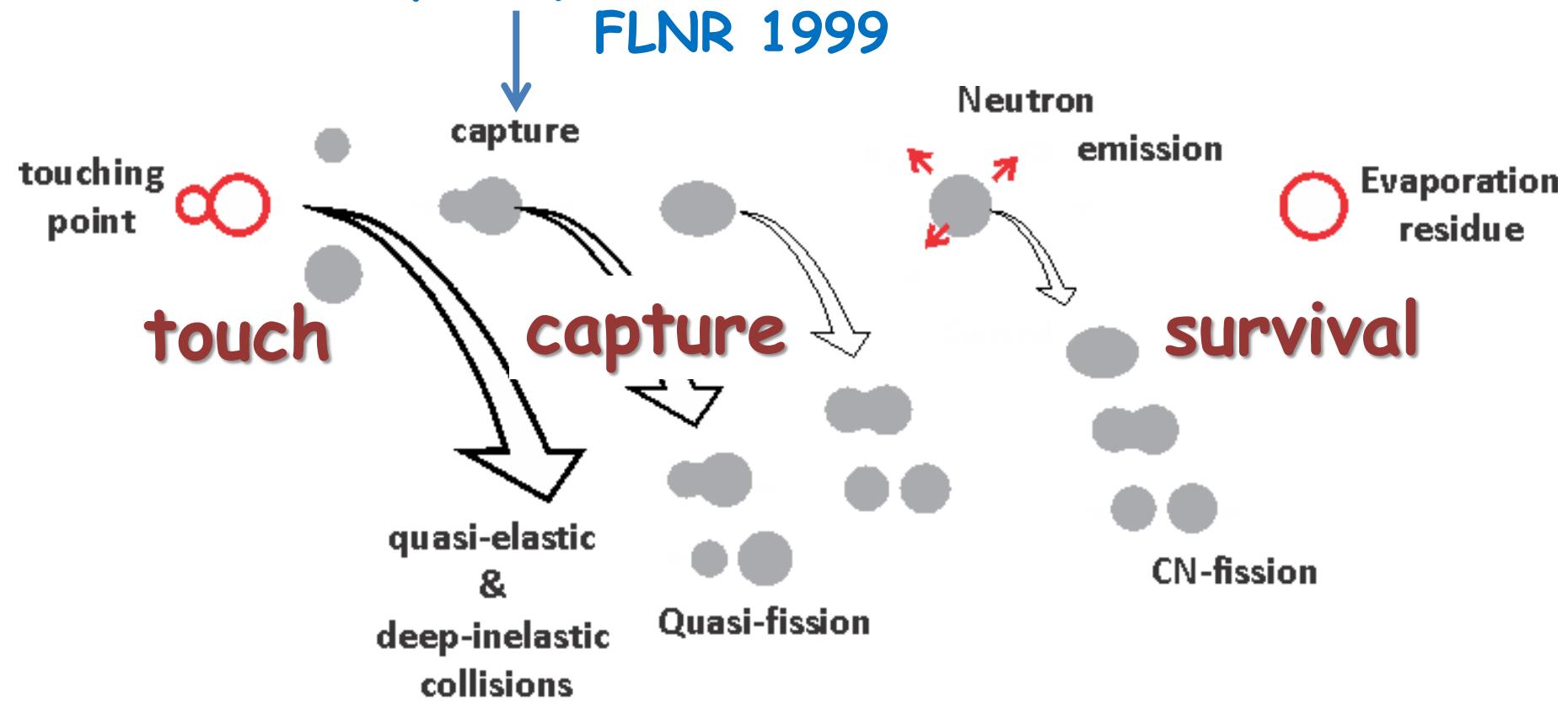
Yuri Oganessian. The limits and structure of the atomic nuclei, May26, 2022, JINR, Dubna

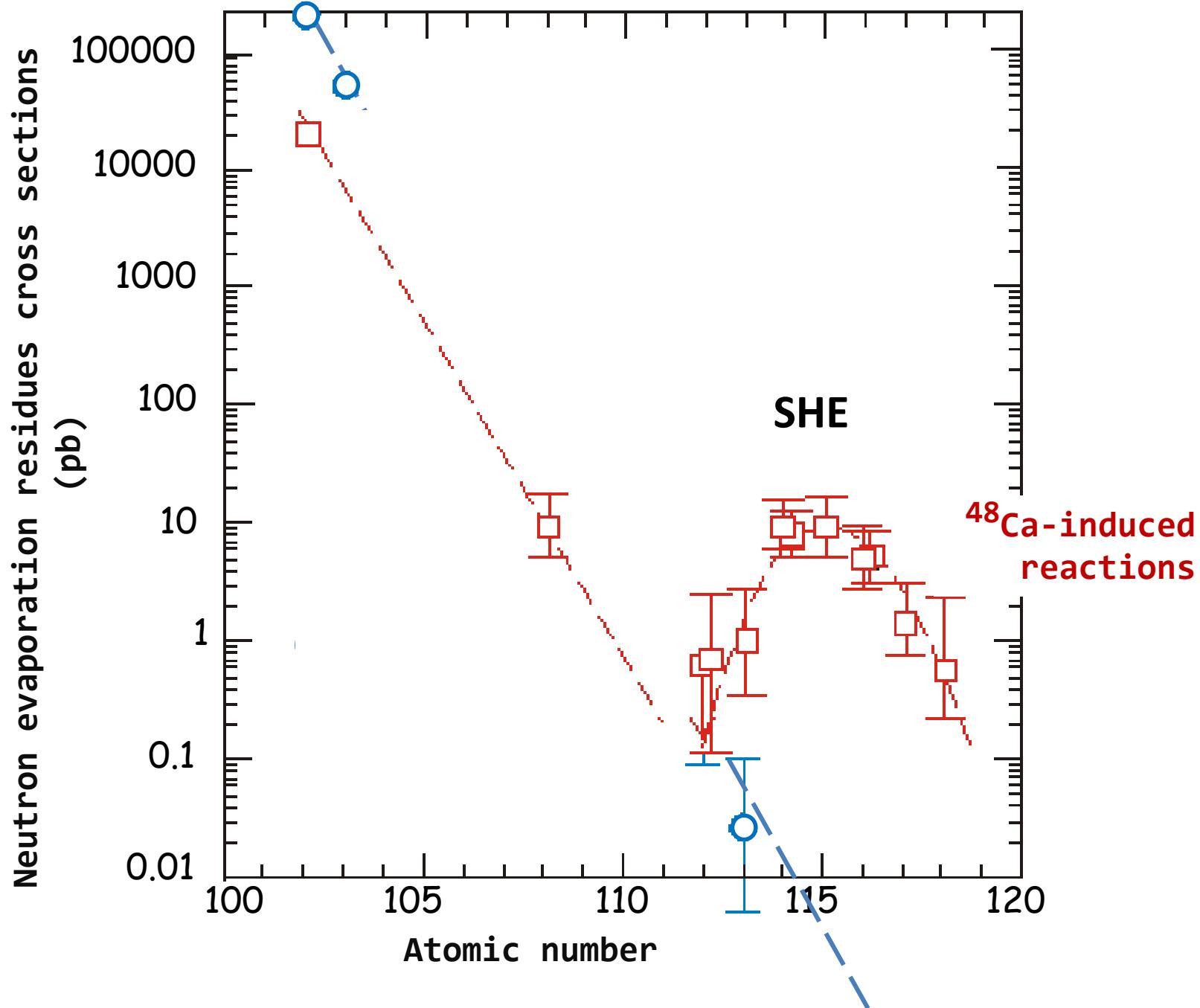
The model of nuclear fusion assumes that the incident particle and the target nucleus become indistinguishable after the collision and constitute the nucleus's particular excited state - **the compound nucleus**.

Niels Bohr, 1936

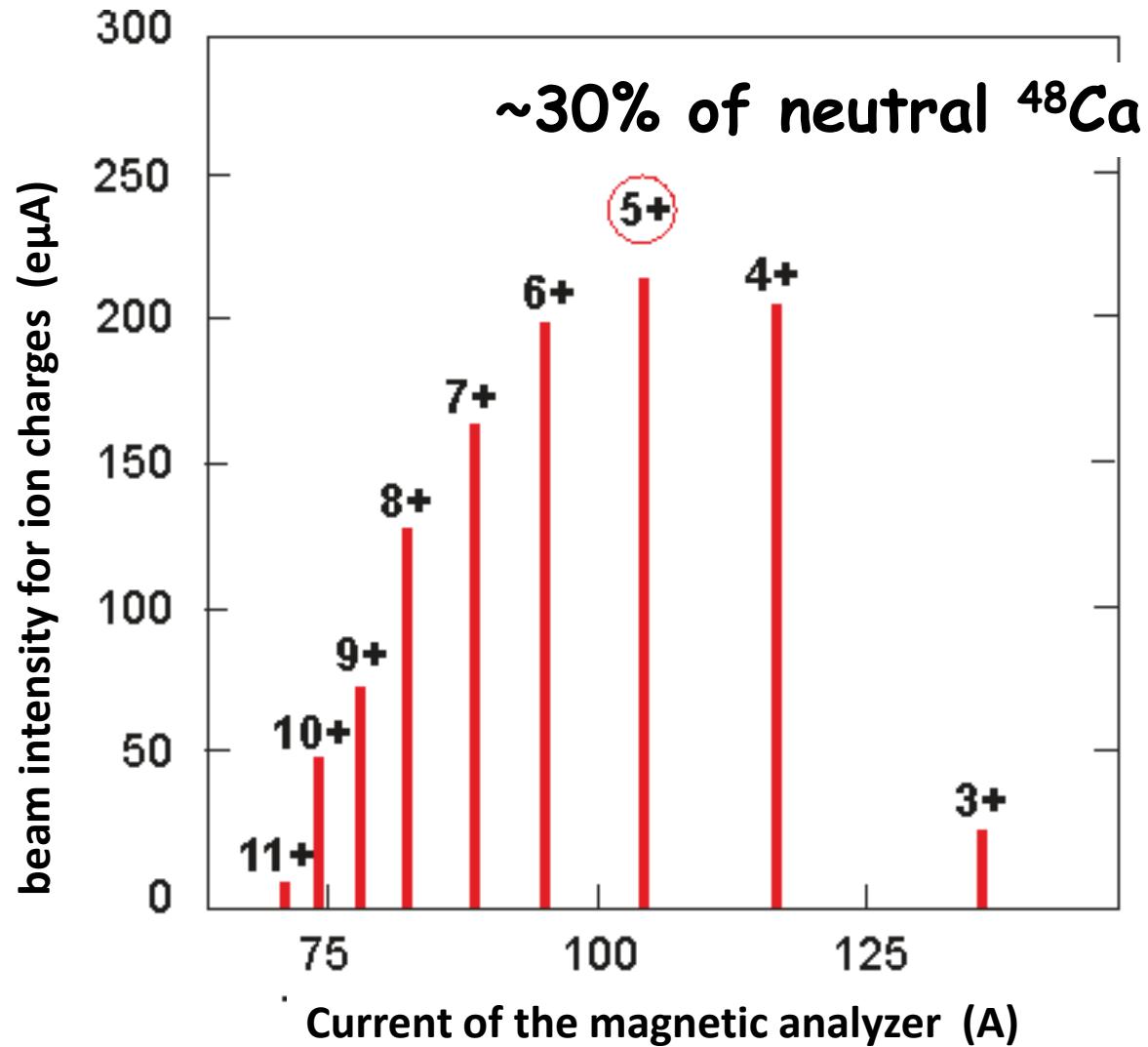
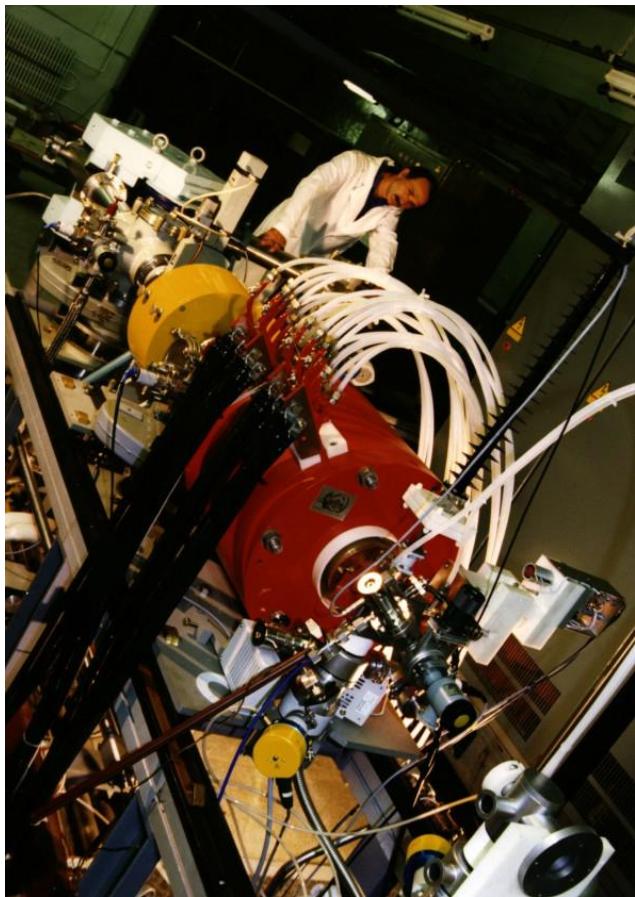
discovery of quasi-fission

FLNR 1999





Ion charge distribution of Ca-48 extracted from 14 GHz ECR-ion source



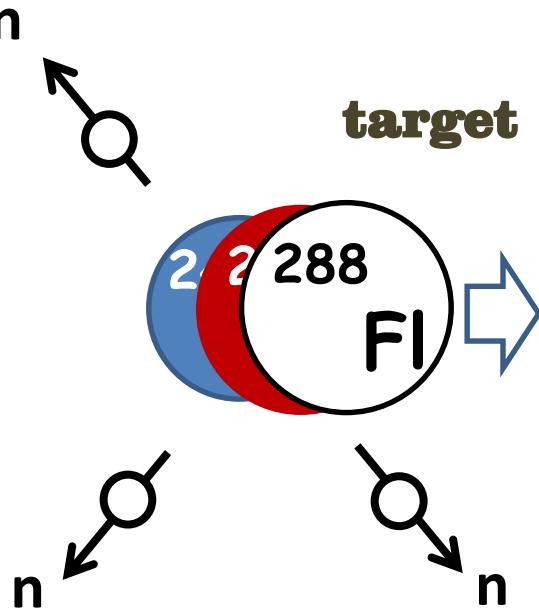
New reaction of synthesis

*artificial element produced
with high flux nuclear reactor*

**from
accelerator**

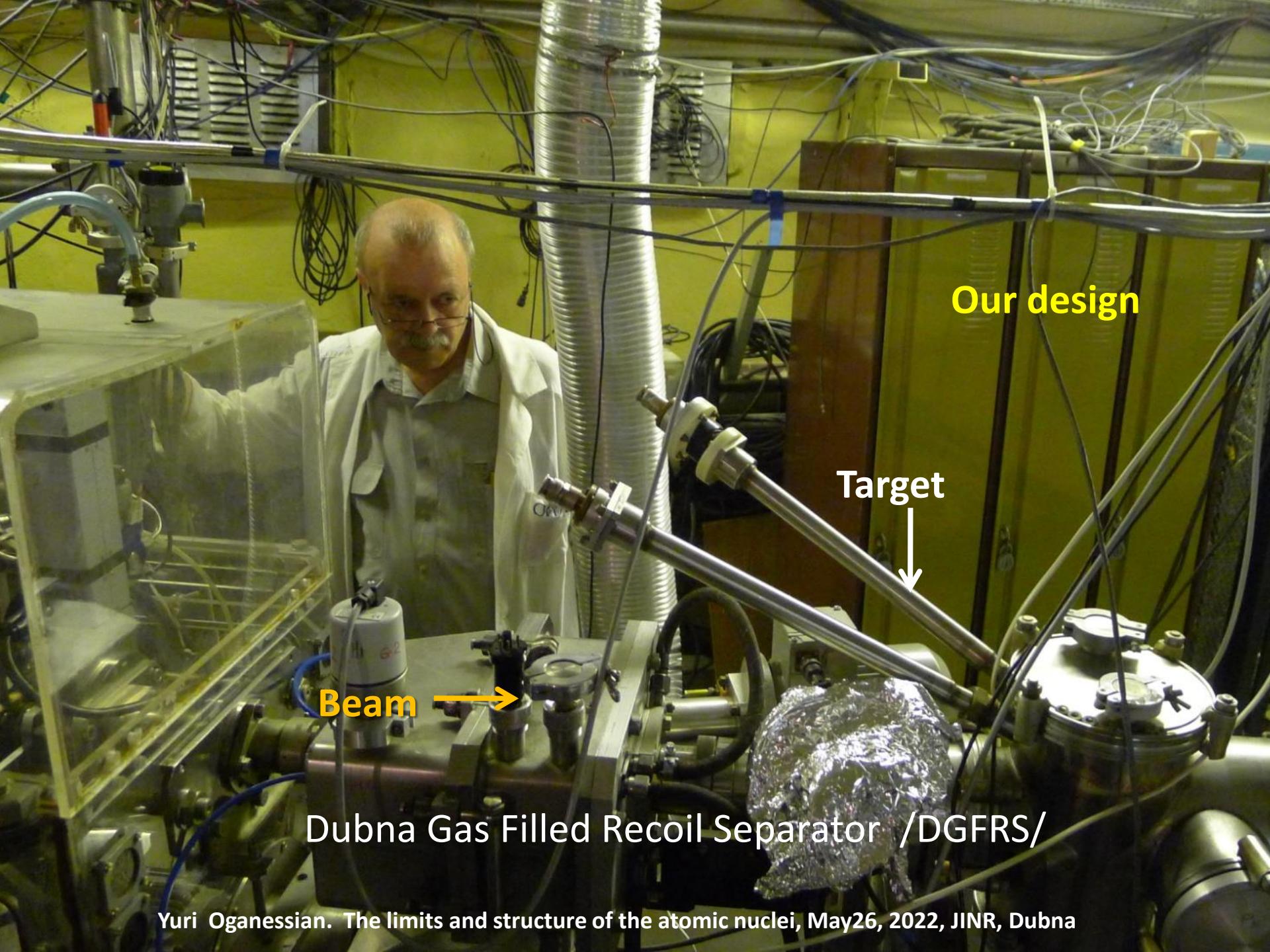
^{48}Ca 

**rare and very
expensive isotope of Ca**



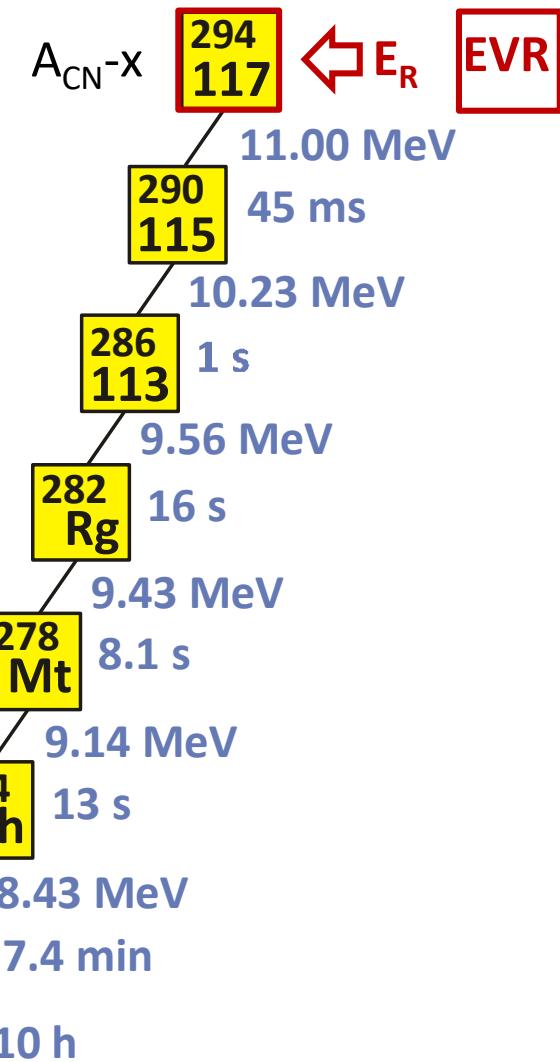
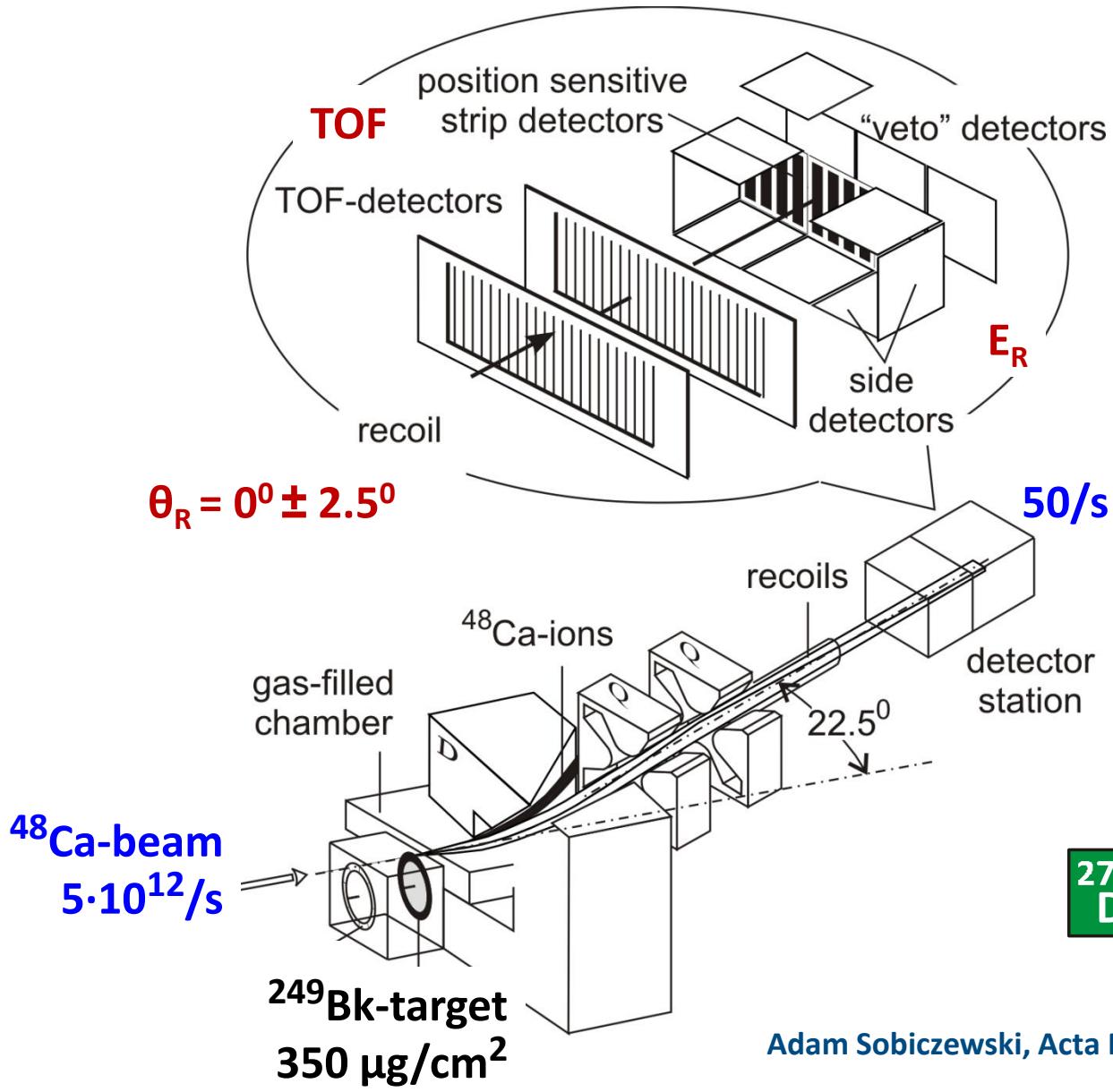
to separator

fusion & cooling



Dubna Gas Filled Recoil Separator /DGFRS/

Dubna Gas-Filled Recoil Separator



Adam Sobiczewski, Acta Phys. Pol. B 41, 157 (2010).

22 года совместной работы



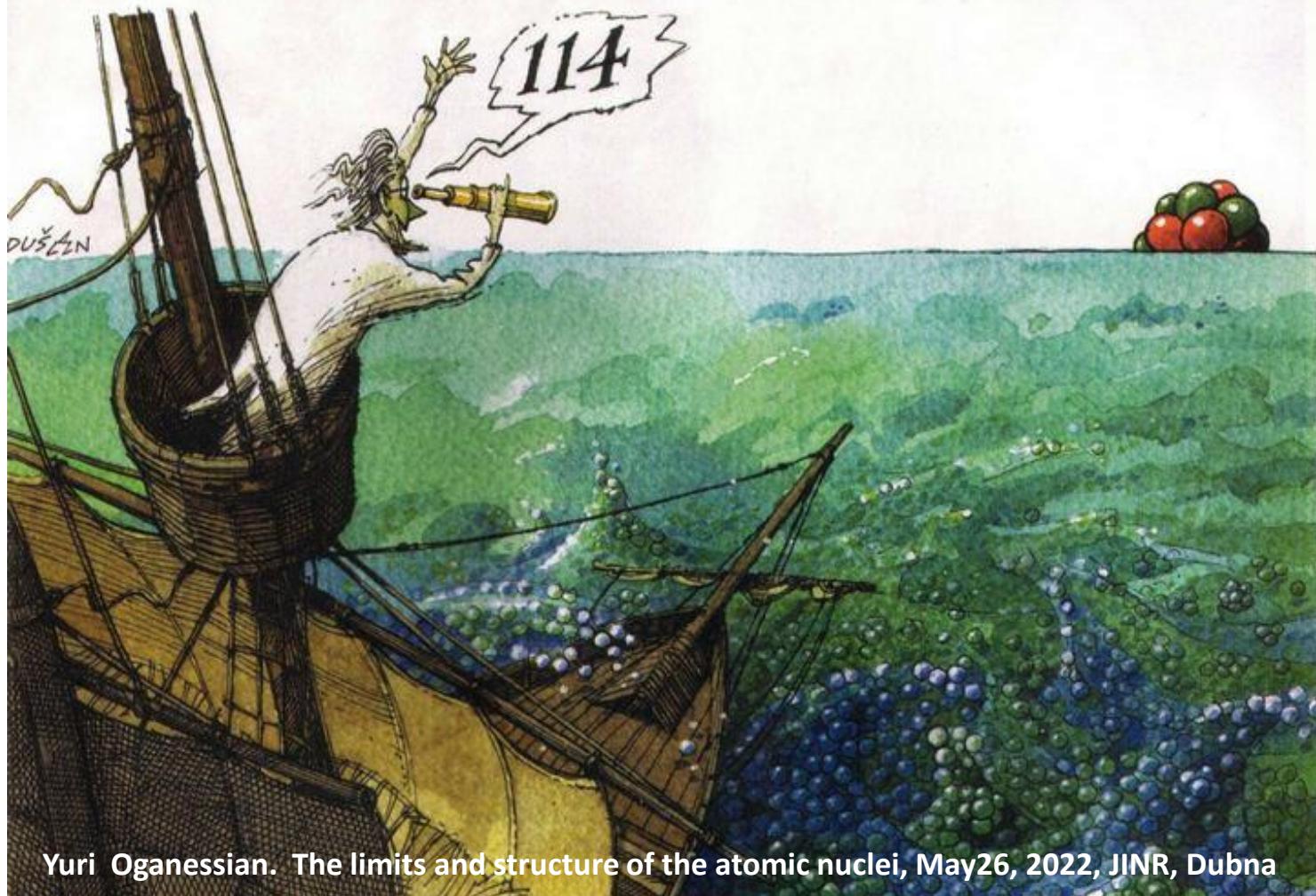
22 years teamwork

SCIENTIFIC
AMERICAN

JANUARY 2000 VOL. 282 NO 1

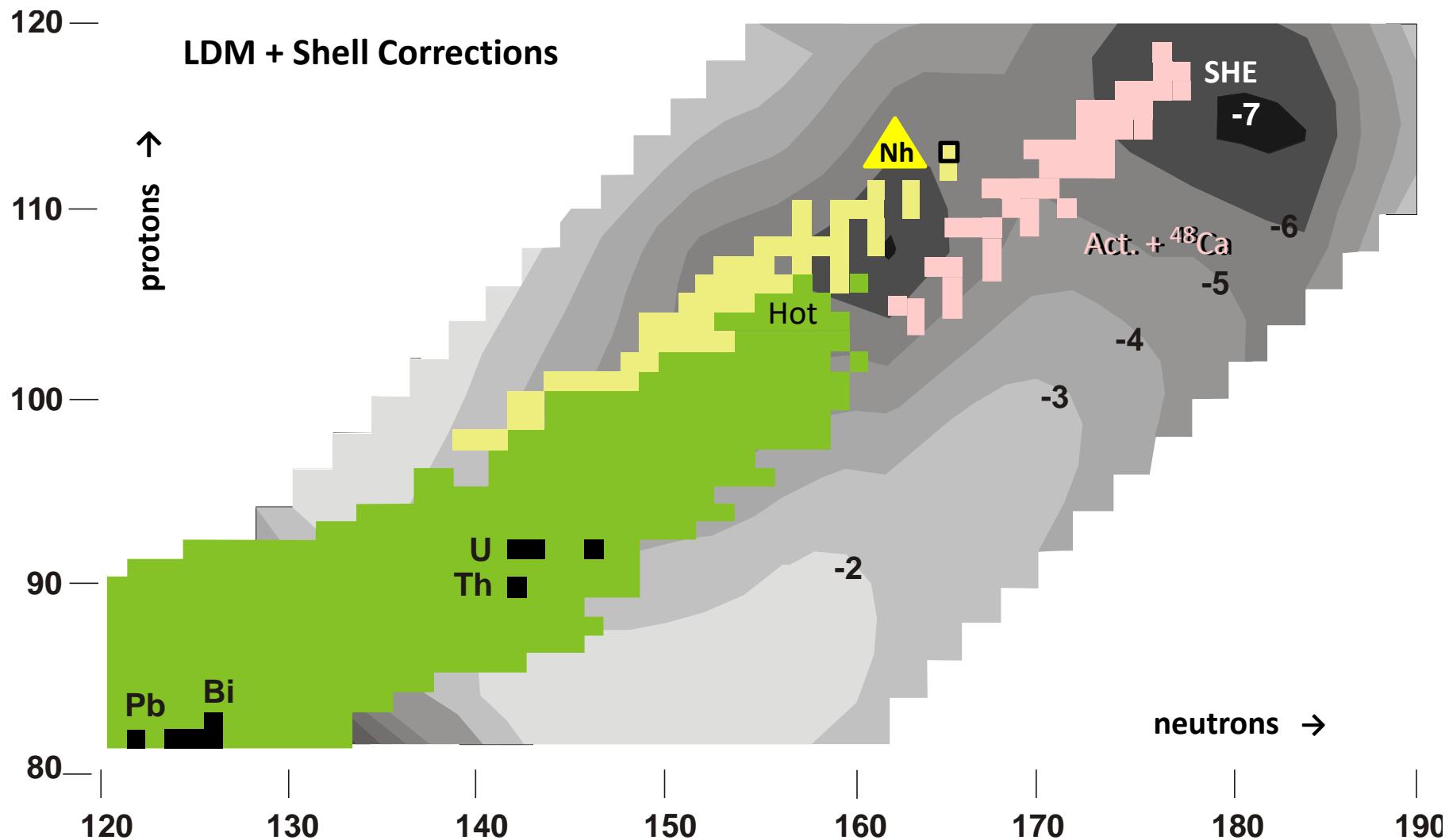
2000

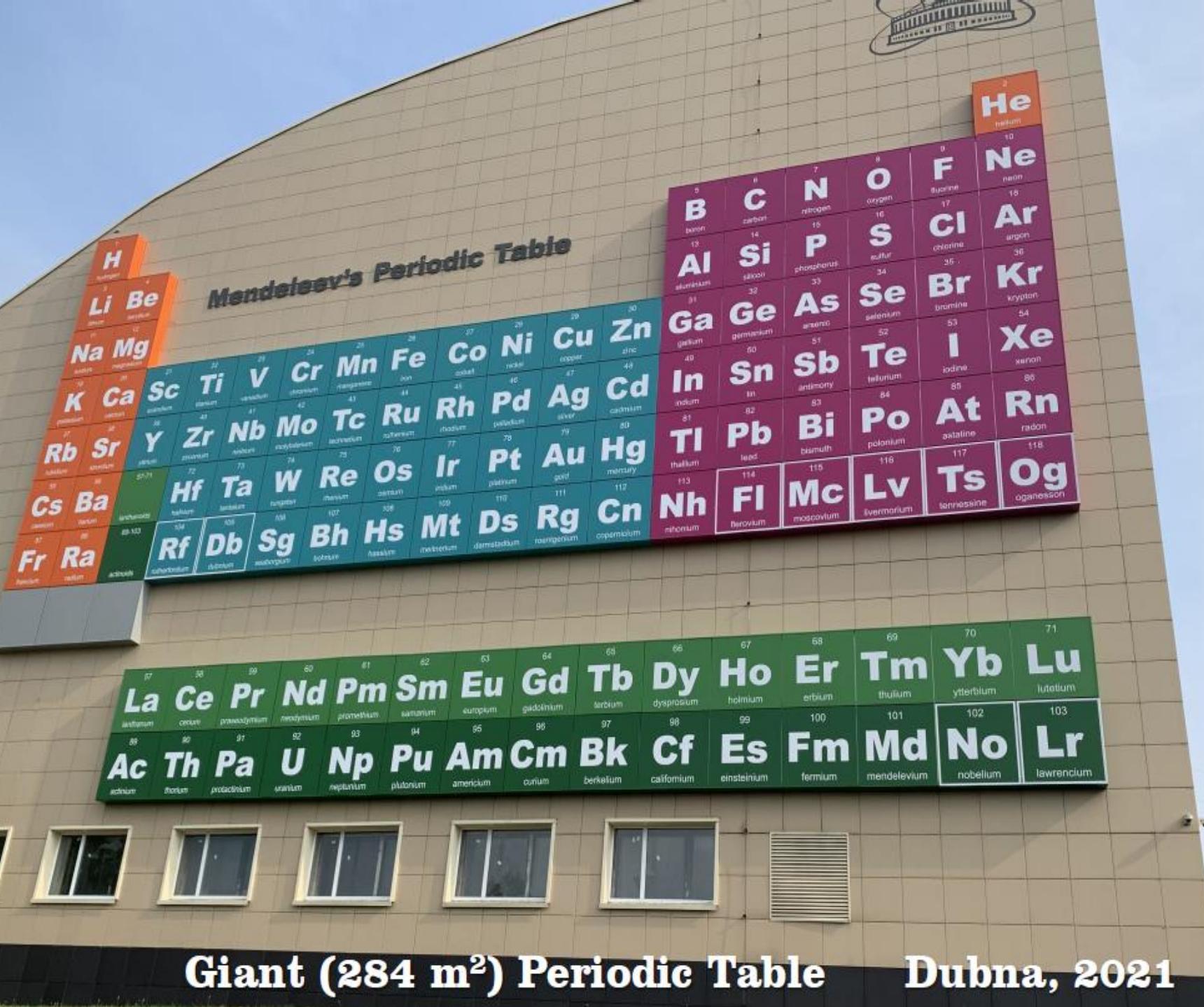
Voyage to SUPERHEAVY Island



Reactions of Synthesis

2010





August 2017, Dubna



SHE-Factory

Yuri Oganessian. The limits and structure of the atomic nuclei, May26, 2022, JINR, Dubna

Projectile	Intensity Ion/s	
^{20}Ne	$1 \cdot 10^{14}$	
^{48}Ca	$6 \cdot 10^{13}$	
^{50}Ti	$3 \cdot 10^{13}$	
^{70}Zn	$2 \cdot 10^{13}$	
^{86}Kr	$3 \cdot 10^{13}$	
^{100}Mo	$2 \cdot 10^{12}$	
^{124}Sn	$2 \cdot 10^{12}$	
^{136}Xe	$2 \cdot 10^{13}$	
^{208}Pb	$1 \cdot 10^{12}$	
^{238}U	$1 \cdot 10^{11}$	

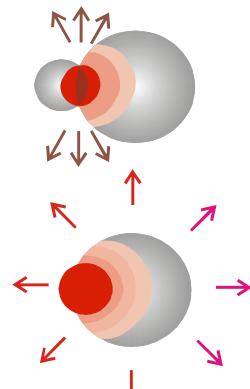


New cyclotron DC-280

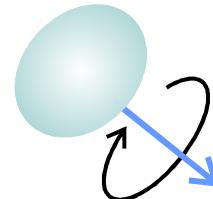
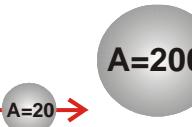
Yuri Oganessian. The limits and structure of the atomic nuclei, May26, 2022, JINR, Dubna

Epilogue

After it has been shown that a nucleus can endure

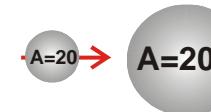


high
temperature



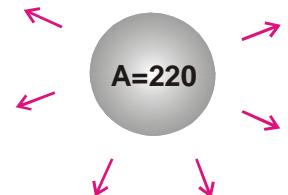
huge
rotation

spin up to 66h



a giant
deformation

axes
up to 3:1

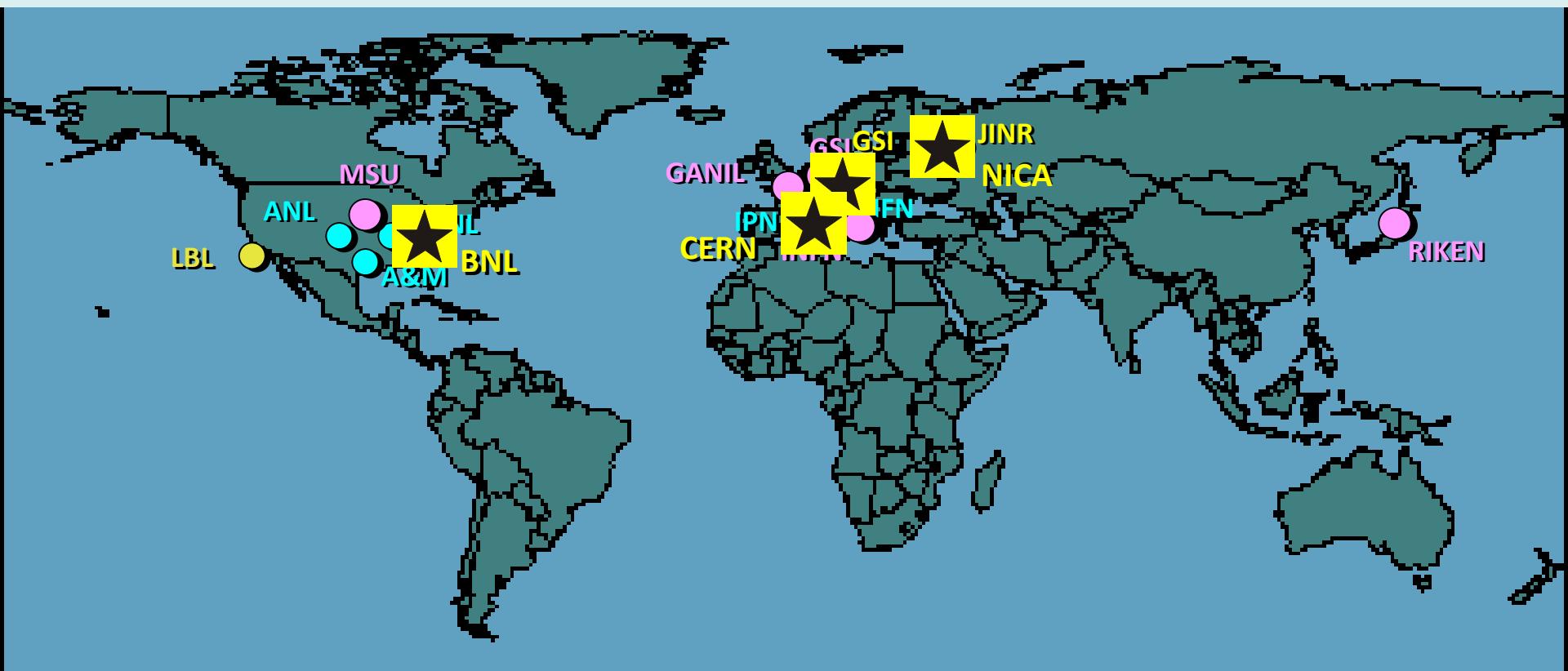


and finally survive....

$T \sim \text{few MeV} (> 10^{10} \text{ K})$

Heavy ion physics:

from the beginning to now...



● Pioneers

● Heavy ion accelerators

● Heavy Ion National Laboratories



Heavy Ion Colliders

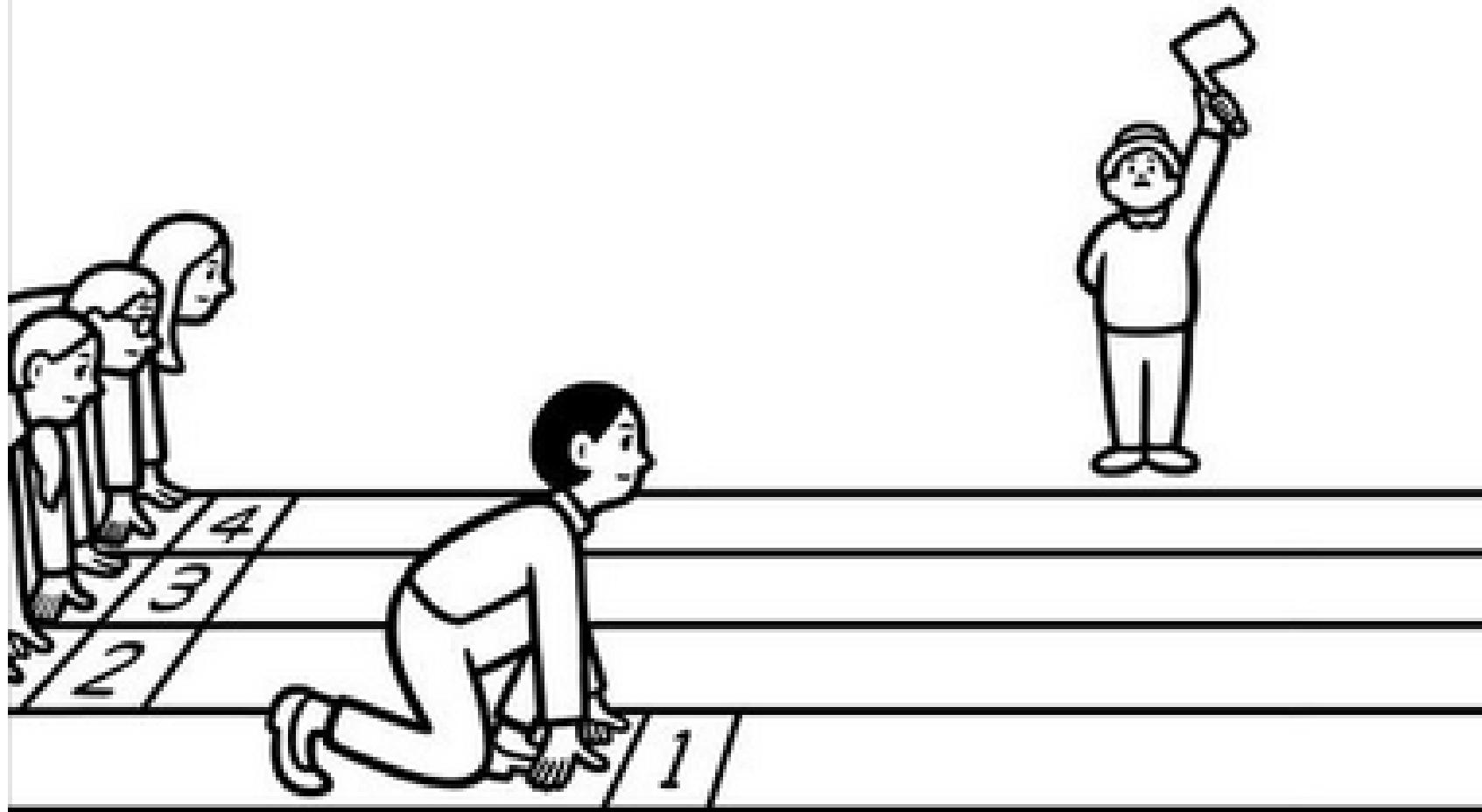
Мечты

Как-то Г.Н. Флеров спросил меня, знаю ли я самую заветную мечту экспериментатора?

На самом деле их (мечты) две:

1. Ты спишь, сидишь в кино, играешь в теннис, обедаешь, а эксперимент идет...
2. Чтобы у тебя были сильные конкуренты. Очень сильные, быть может, самые сильные. Но, все-таки так, чтобы они были бы всегда чуть-чуть позади!

ahead start



Спасибо за внимание!