События, о которых пойдет речь, могли случиться:

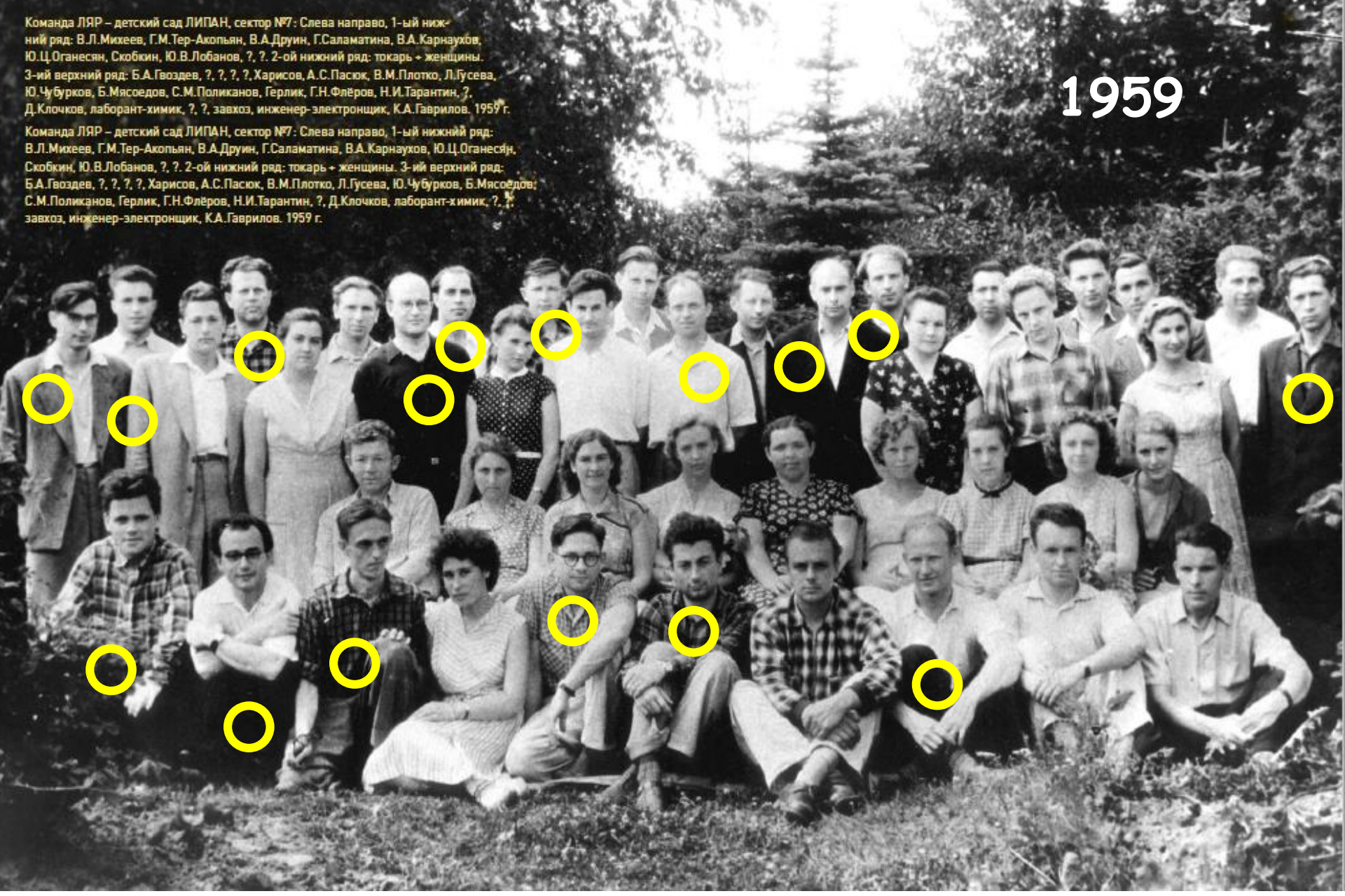
в городе Новосибирске
в городе Ростове-на-Дону
вблизи города Икша (40 км от Москвы)…

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



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.Чубурков, Б.Мясоедов, С.М.Поликанов, Герлик, Г.Н.Флёров, 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)

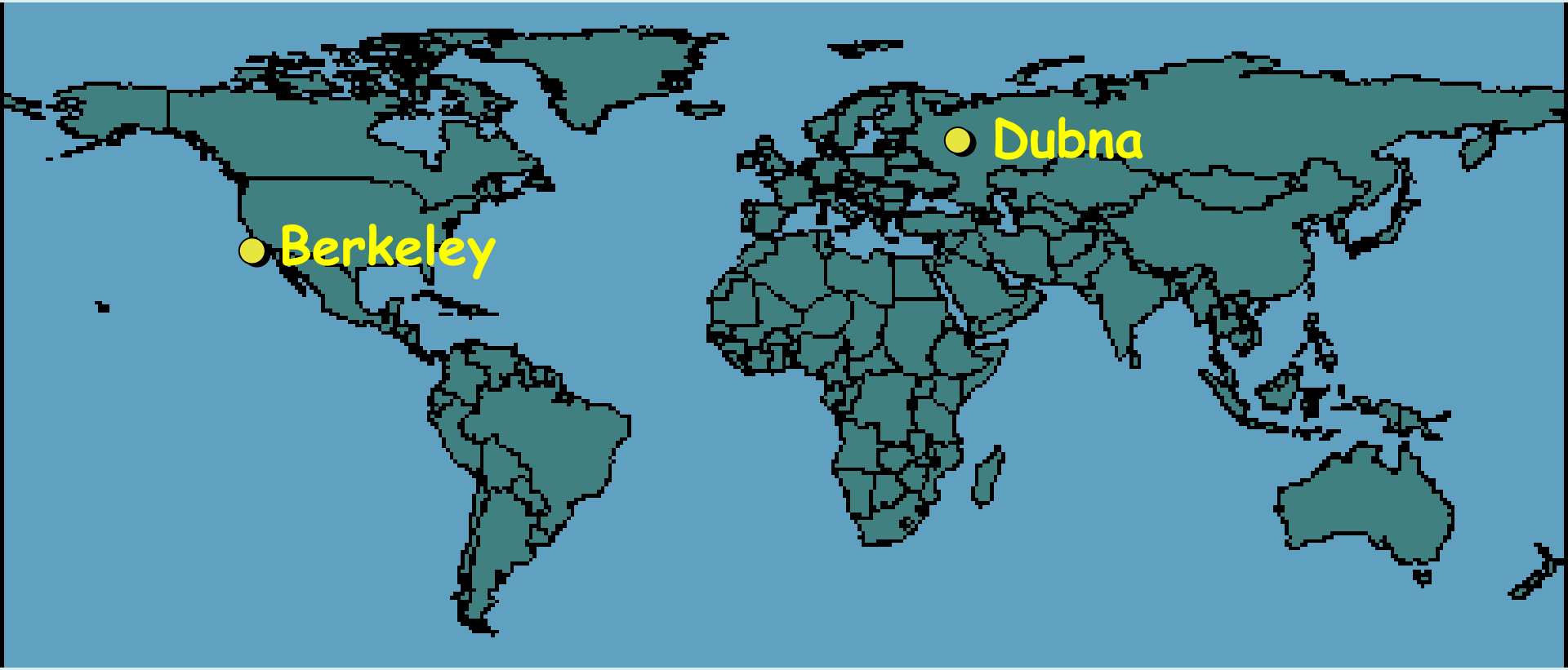
К 65-летию ЛЯР им. Г.Н. Флерова

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 Ta[illegible]cal Elements

1834 - 1907

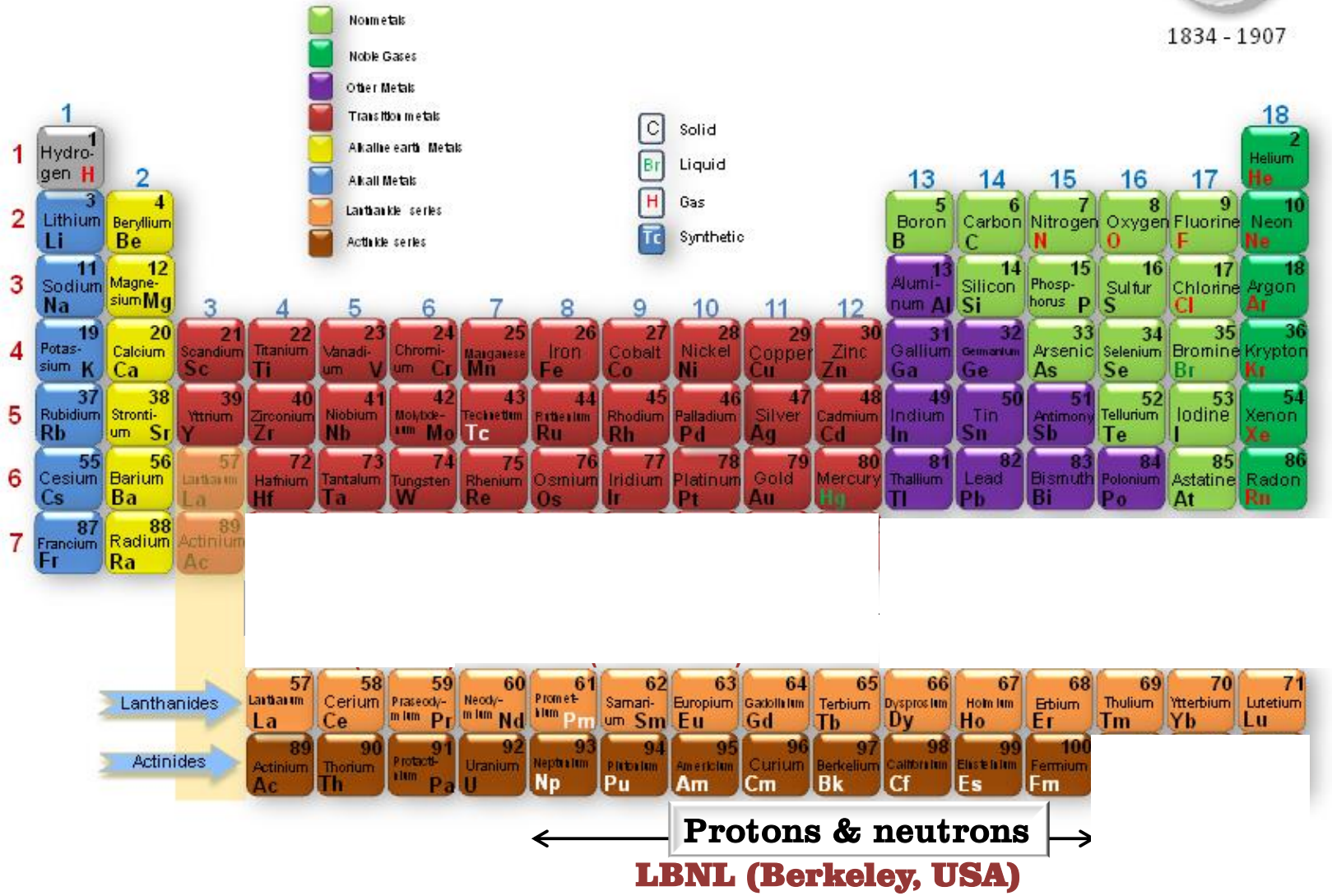
G.T. Seaborg

Artificial synthesis of elements

1940

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

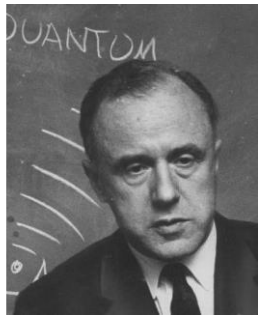
1834 - 1907



LBNL (Berkeley, USA)

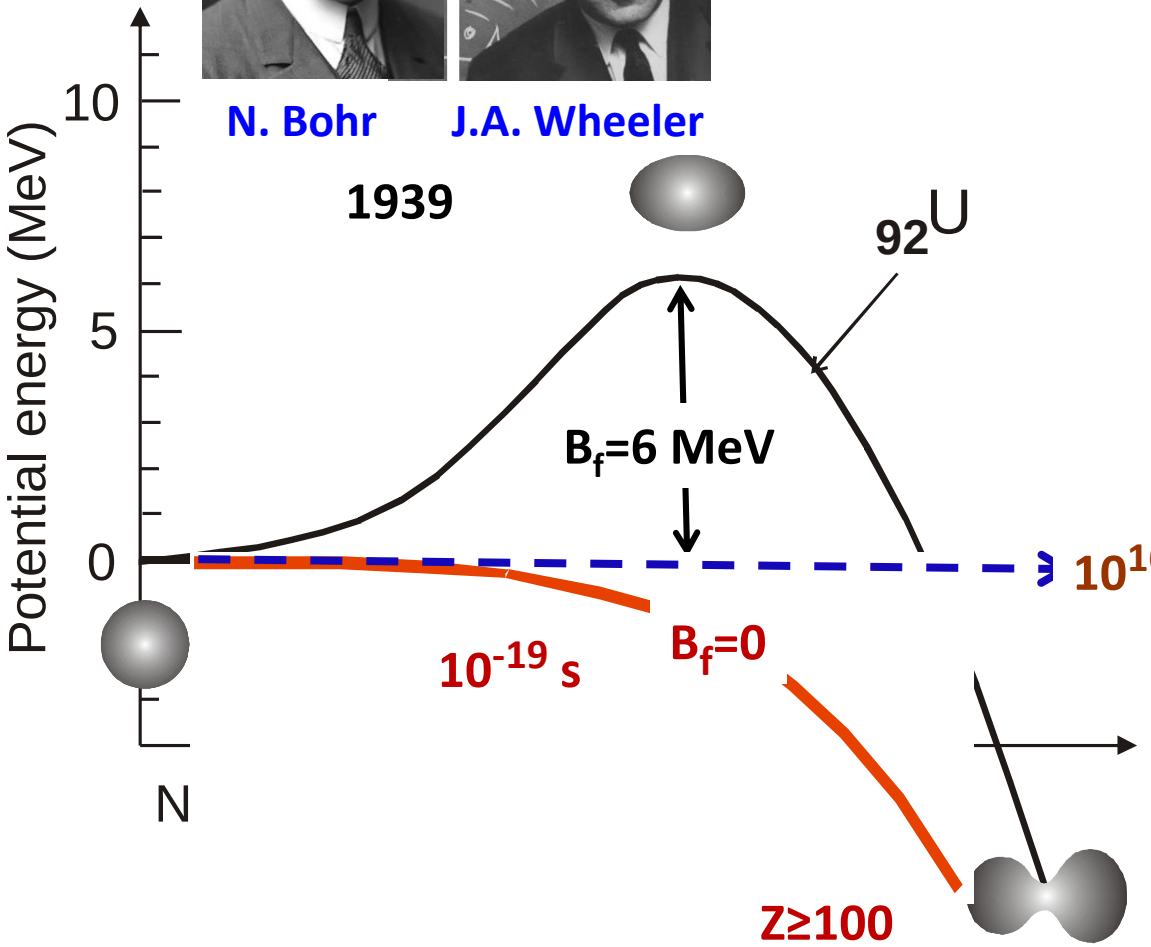
the method was limited to the synthesis of Fermium (Z = 100)

Nuclear fission



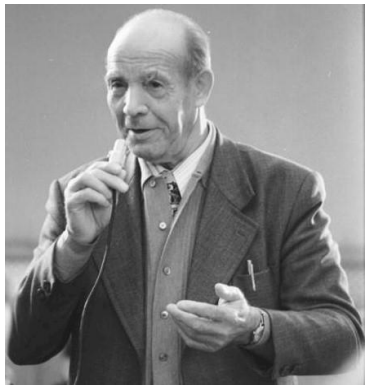
N. Bohr J.A. Wheeler

1939



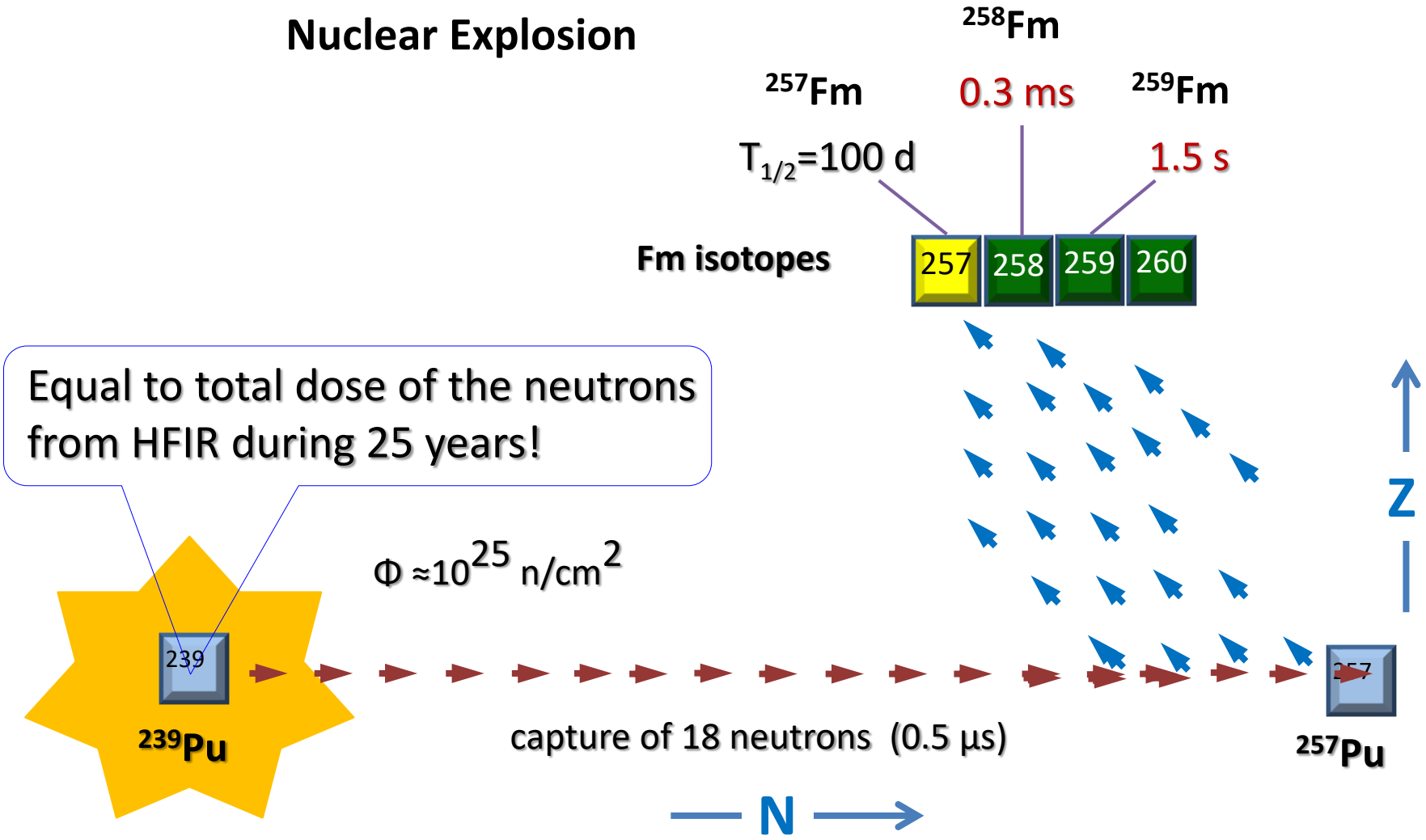
1940

G.N. Flerov



K.A. Petrzhak

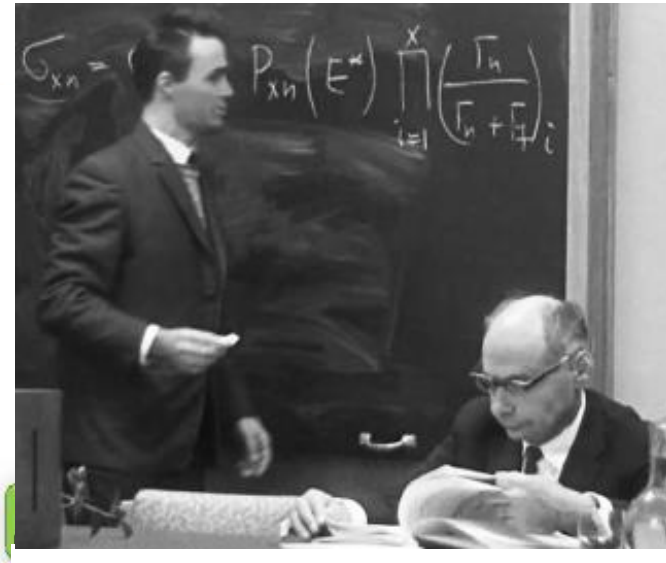
Nuclear Explosion



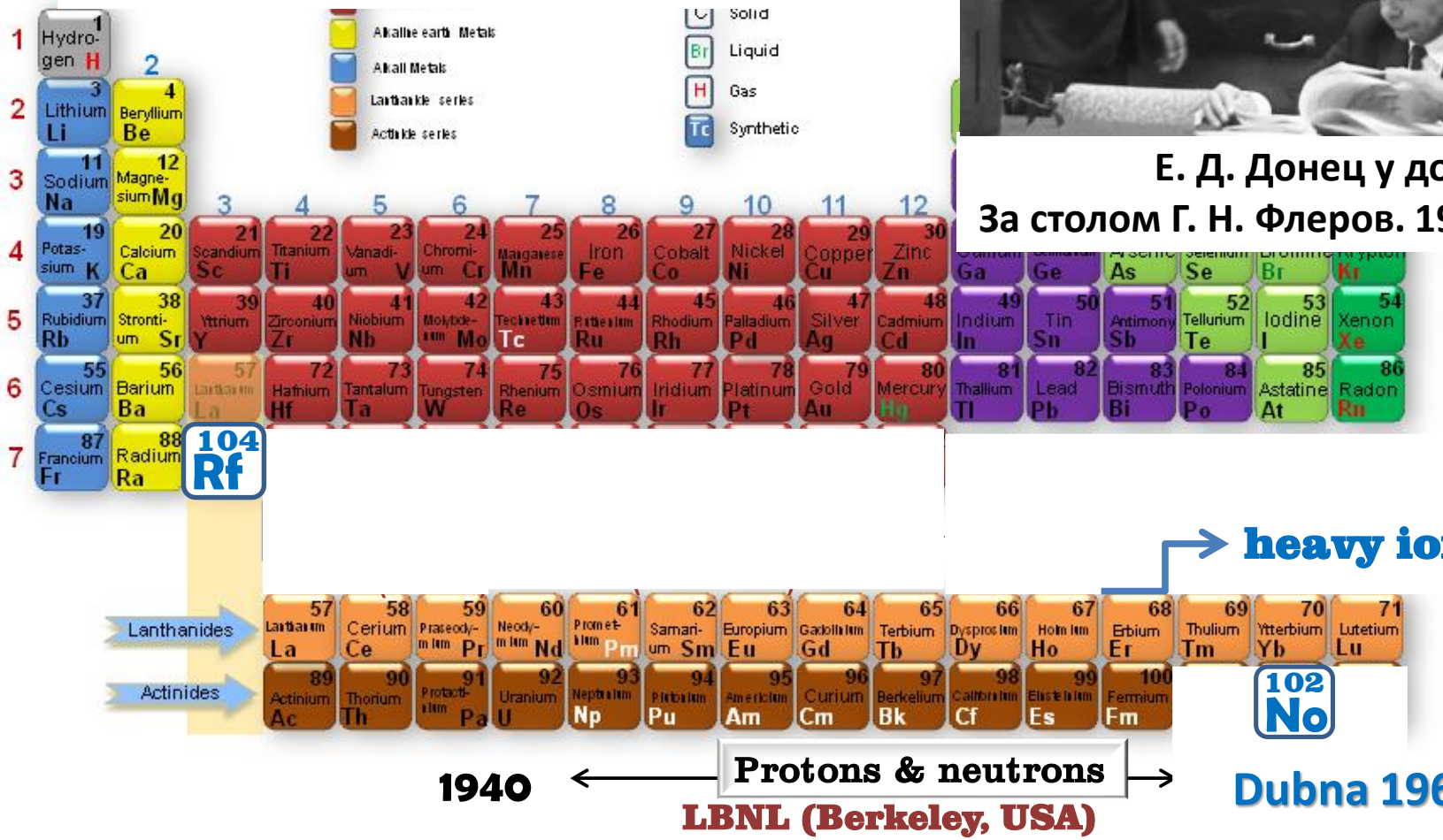
Синтез элемента 102 (ЛЯР 1963)

$^{18}O + {}^{242}Pu \rightarrow {}^{260}No^* \rightarrow 4n + {}^{256}No$

$^{22}Ne + {}^{242}Pu \rightarrow {}^{264}Rf^* \rightarrow 4n + {}^{260}Rf$



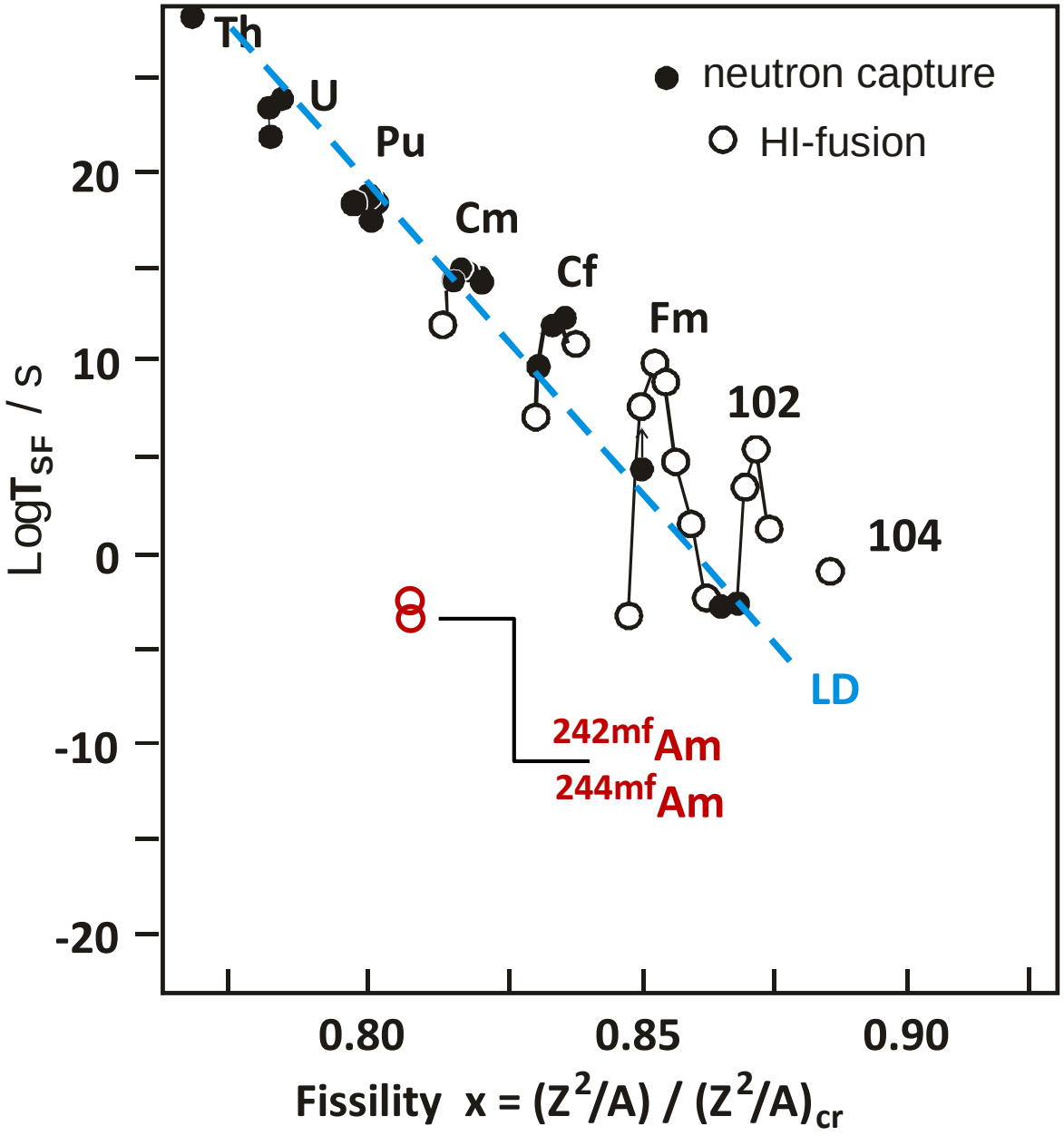
Е. Д. Донец у доски.
За столом Г. Н. Флеров. 1963 г



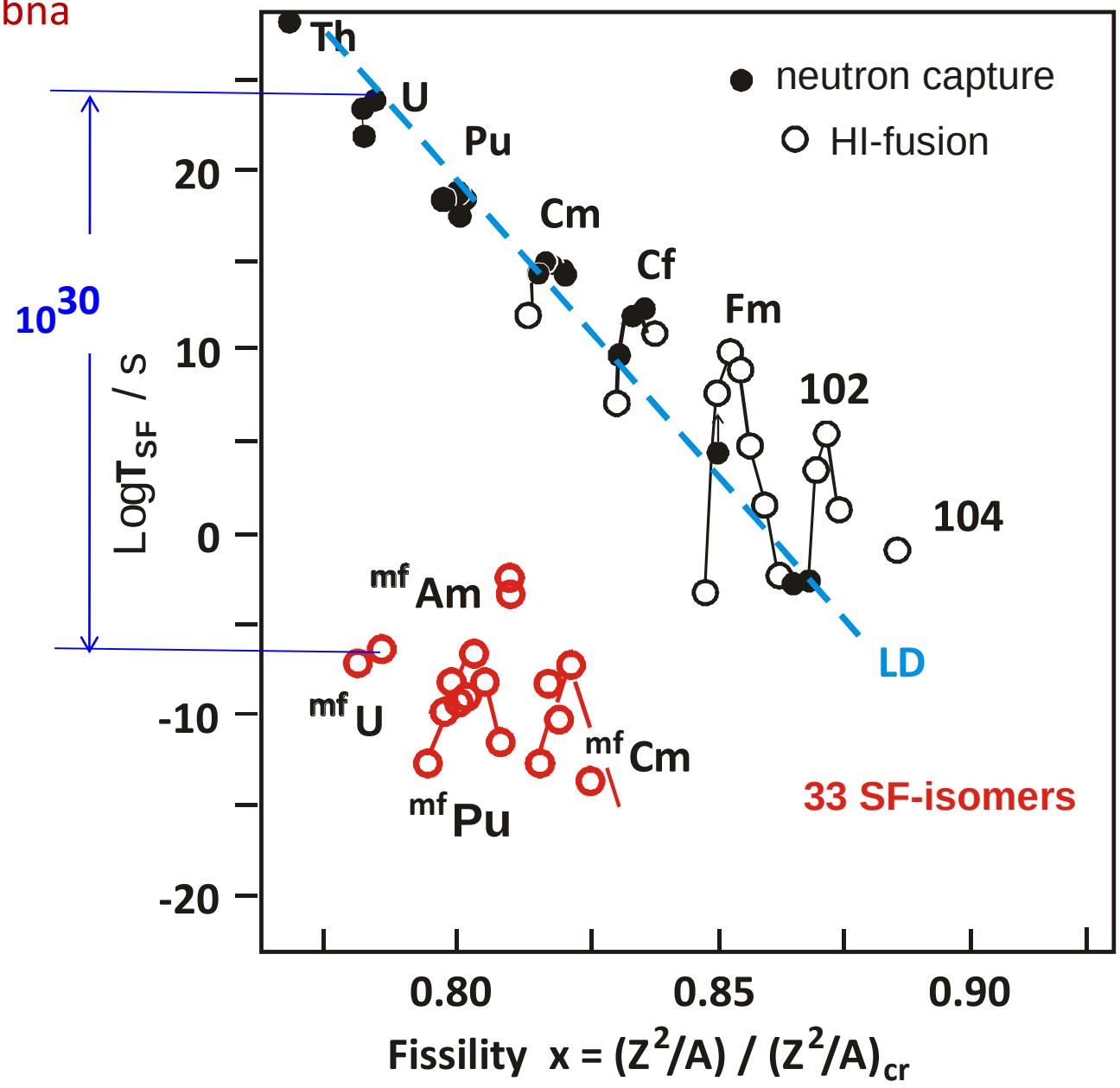
Открытие изомерии форм ядер (ЛЯР 1962)

1962 JINR, Dubna

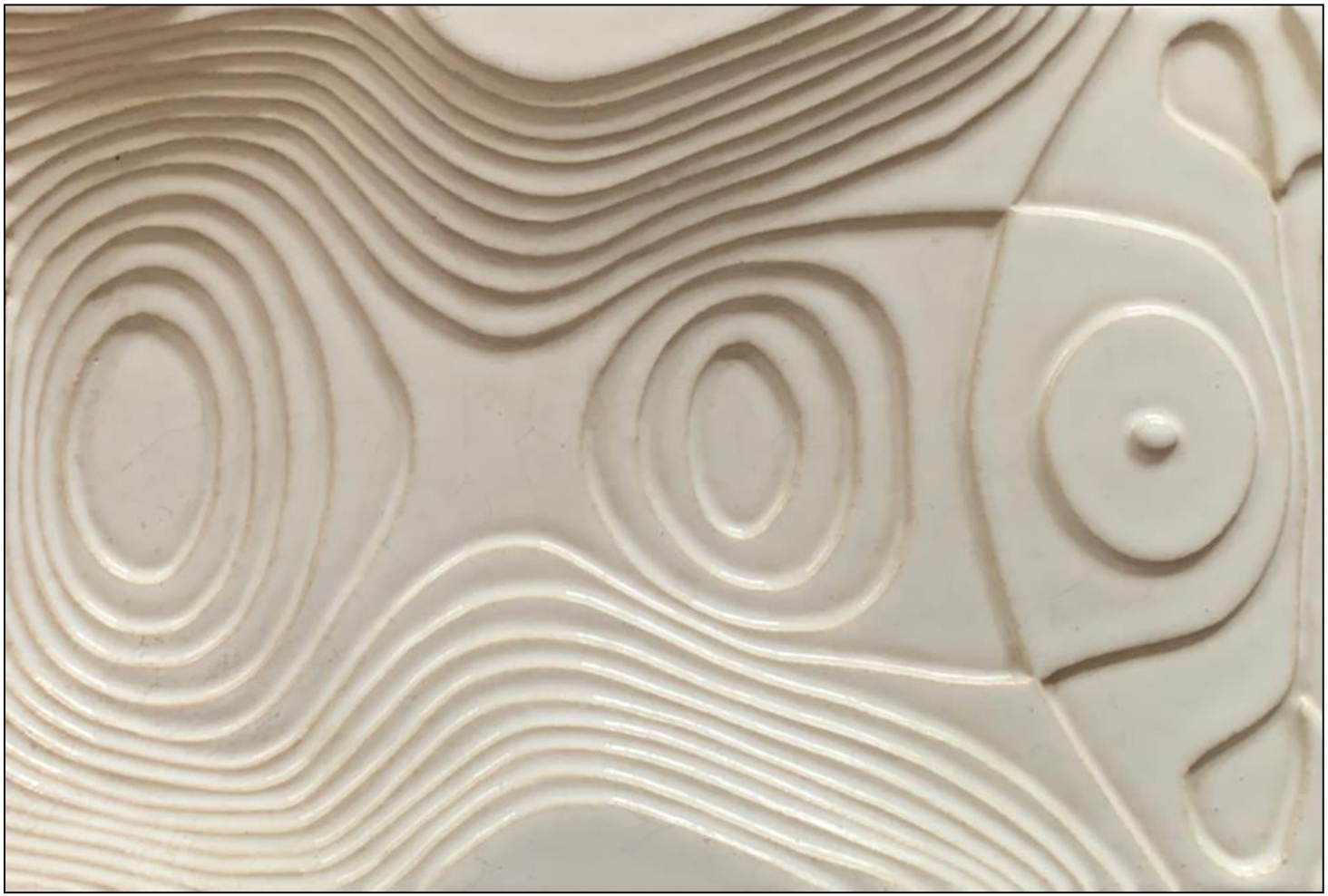
Discovery SF-isomers ^{242m}Am and ^{244m}Am



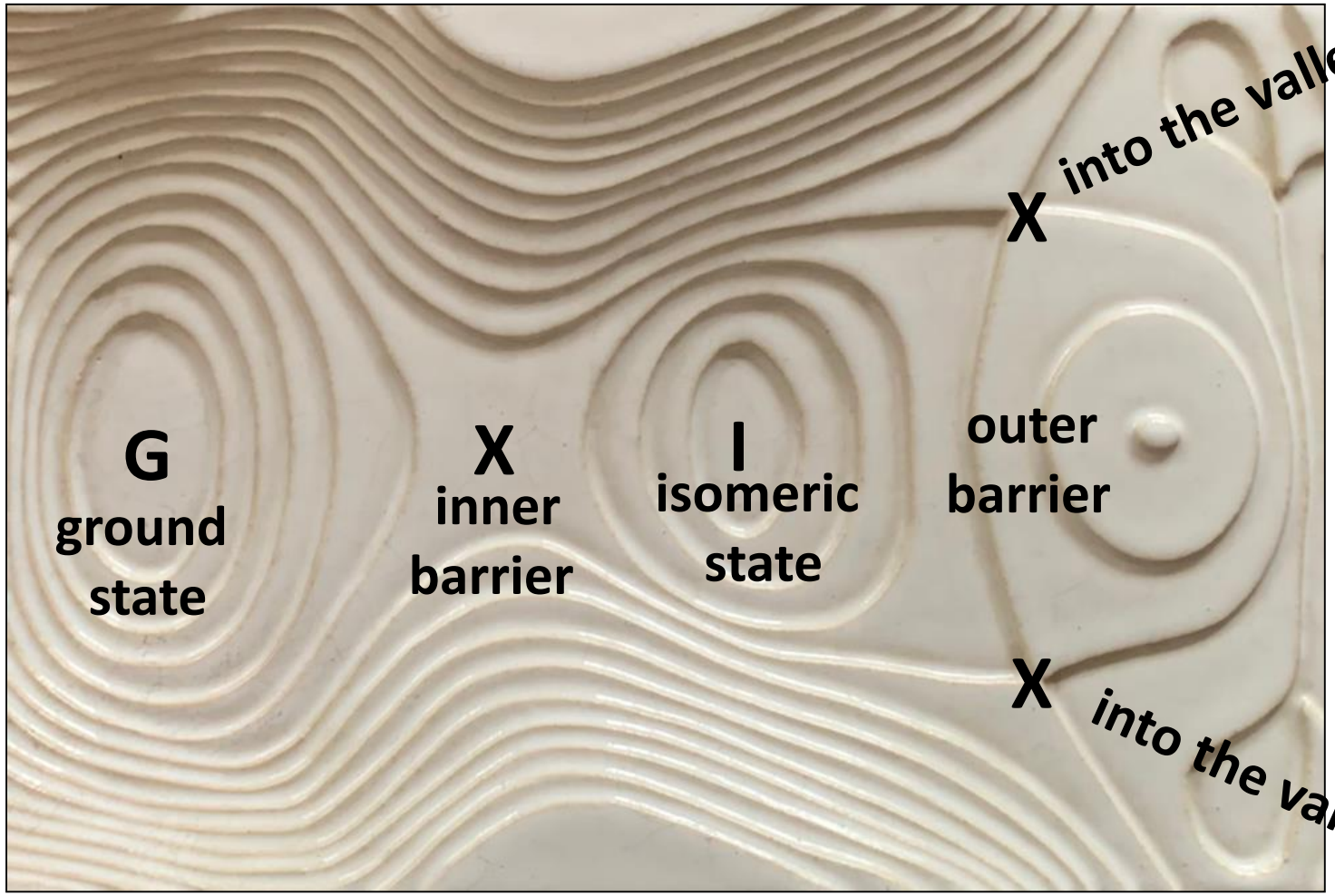
1962 JINR, Dubna



К 50-летию Г.Н. Флерова (1963)



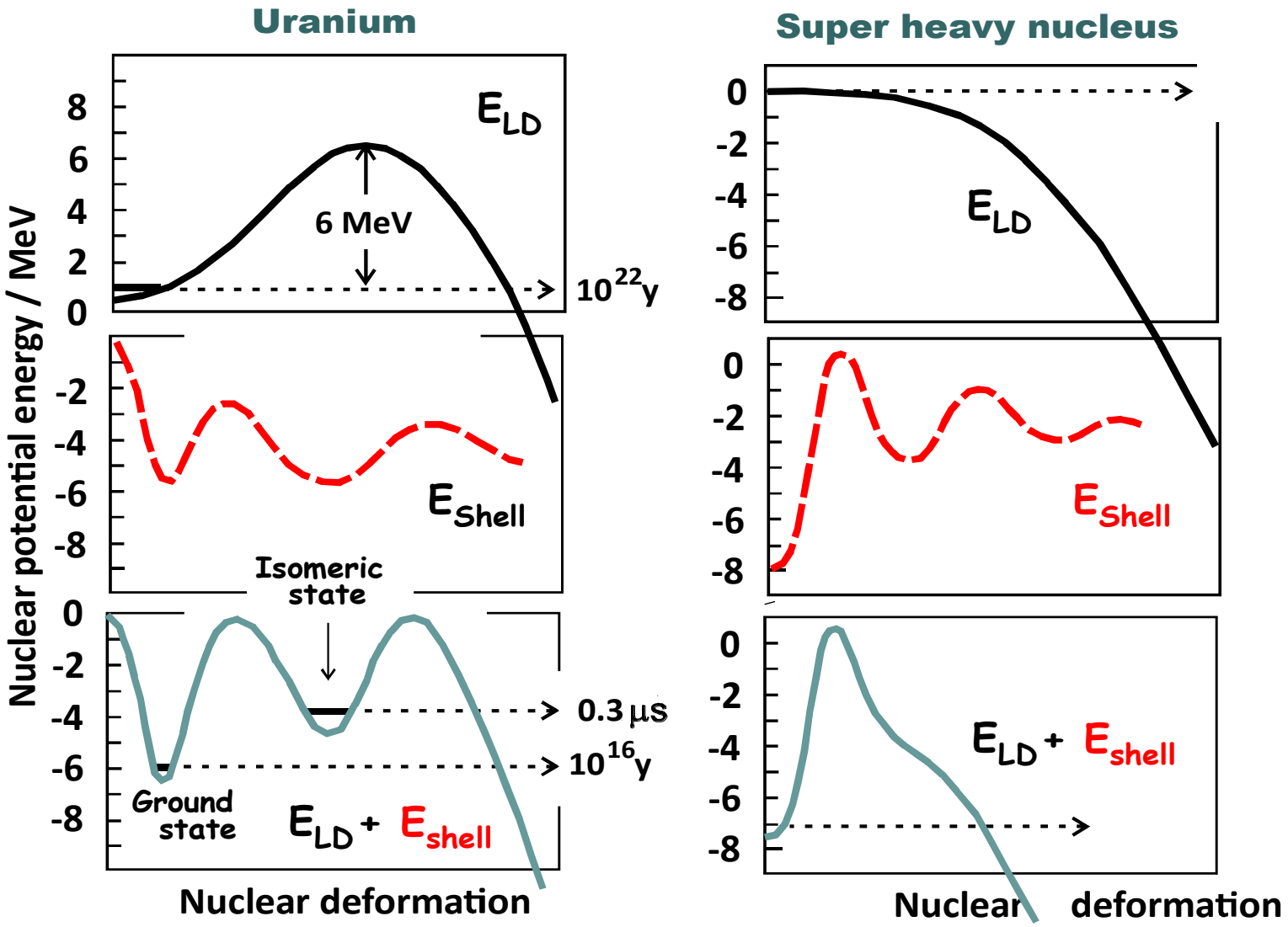
Potential energy surface of the ^{242}Pu nucleus?



Deformation β_4

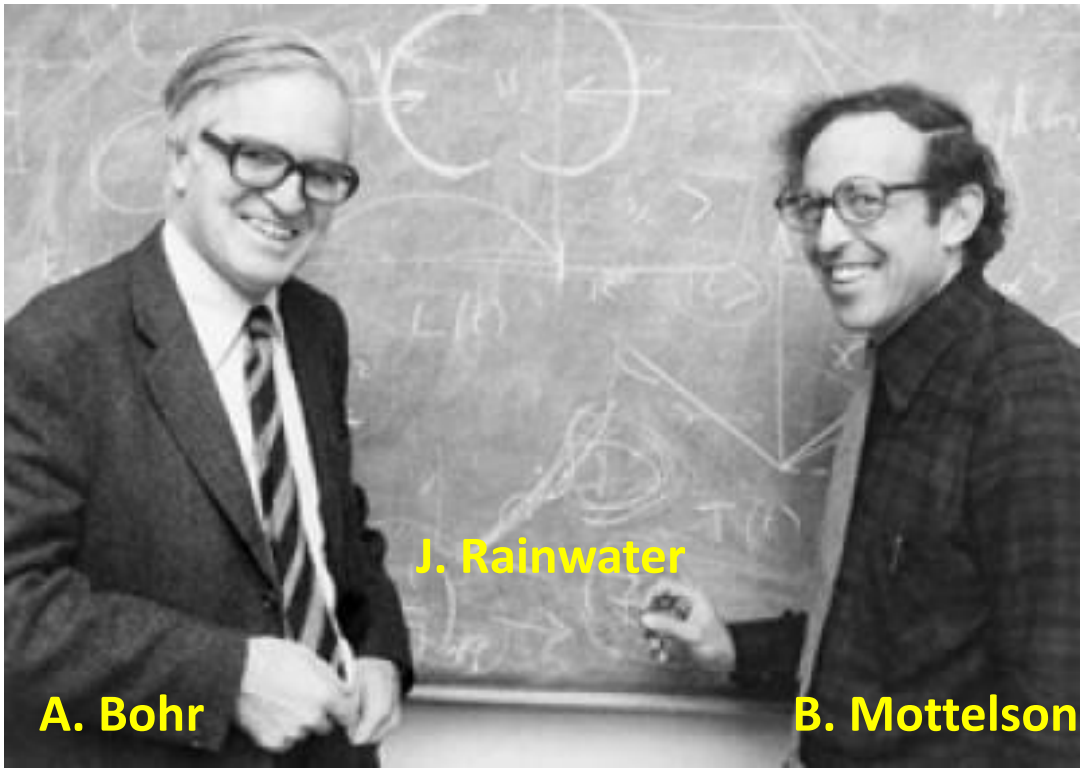
Deformation β_2 (elongation)

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



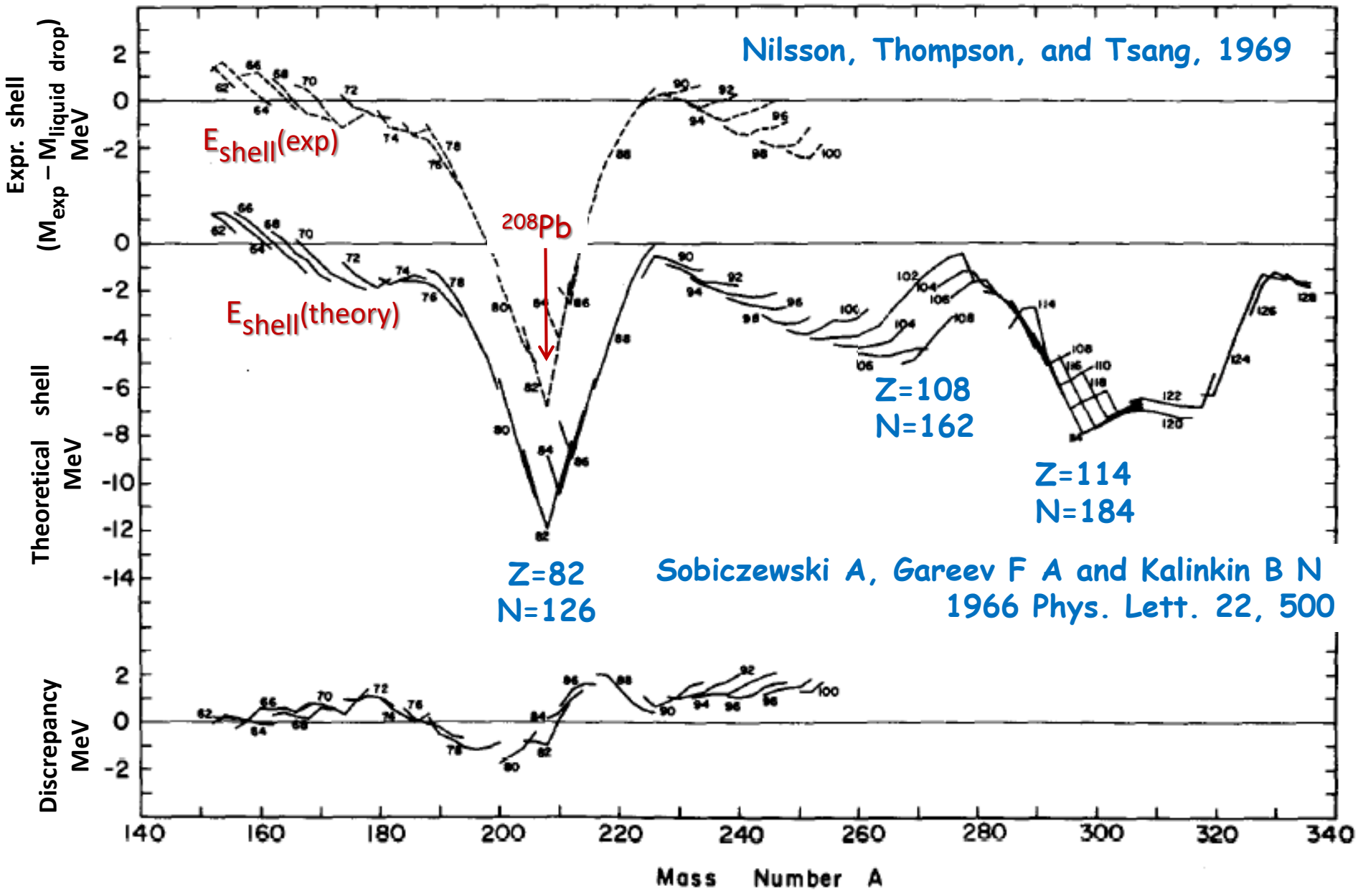
Острова стабильности сверхтяжелых ядер (ЛНФ / ЛЯР / ИАЭ 1966)

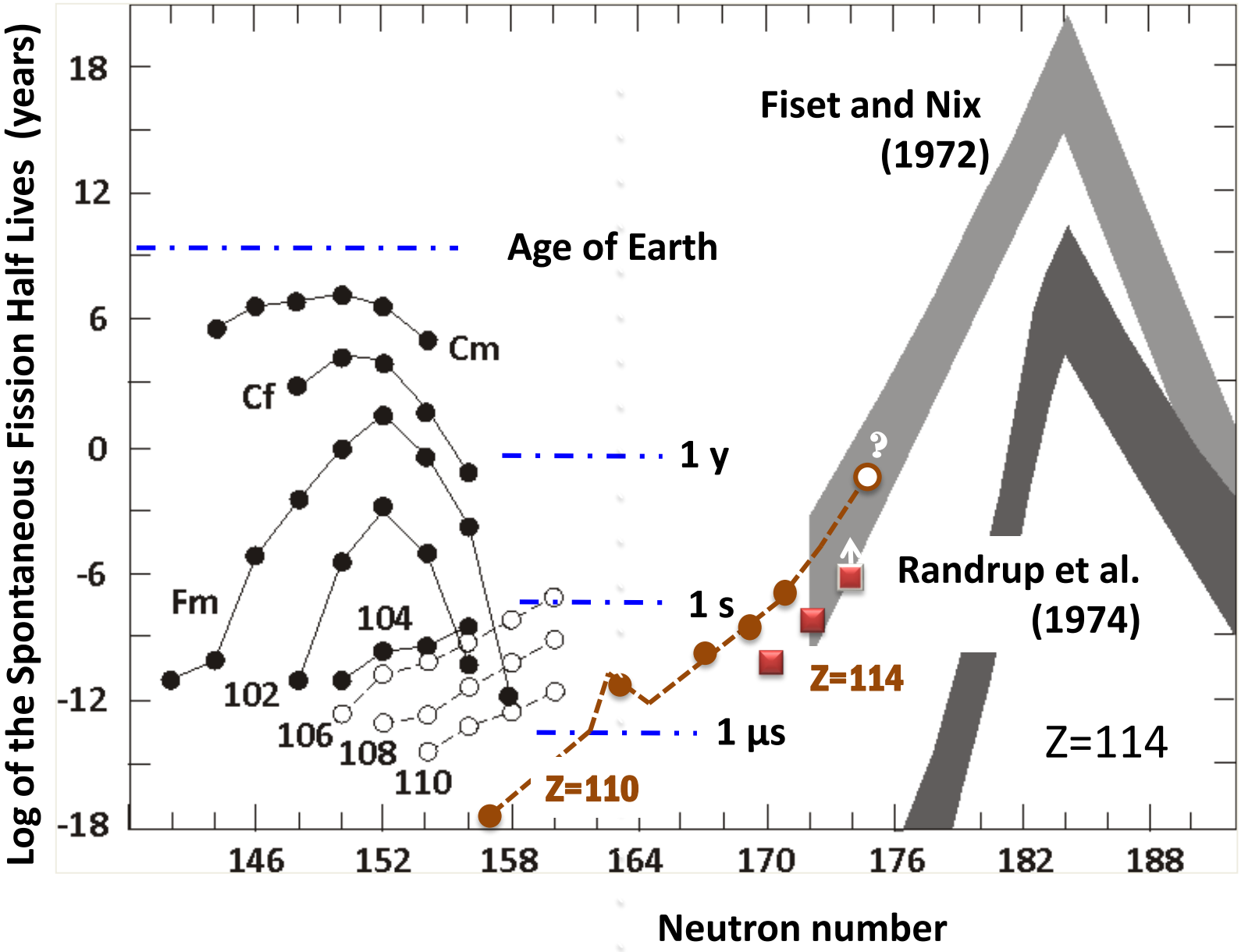
The Nobel Prize in Physics 1975

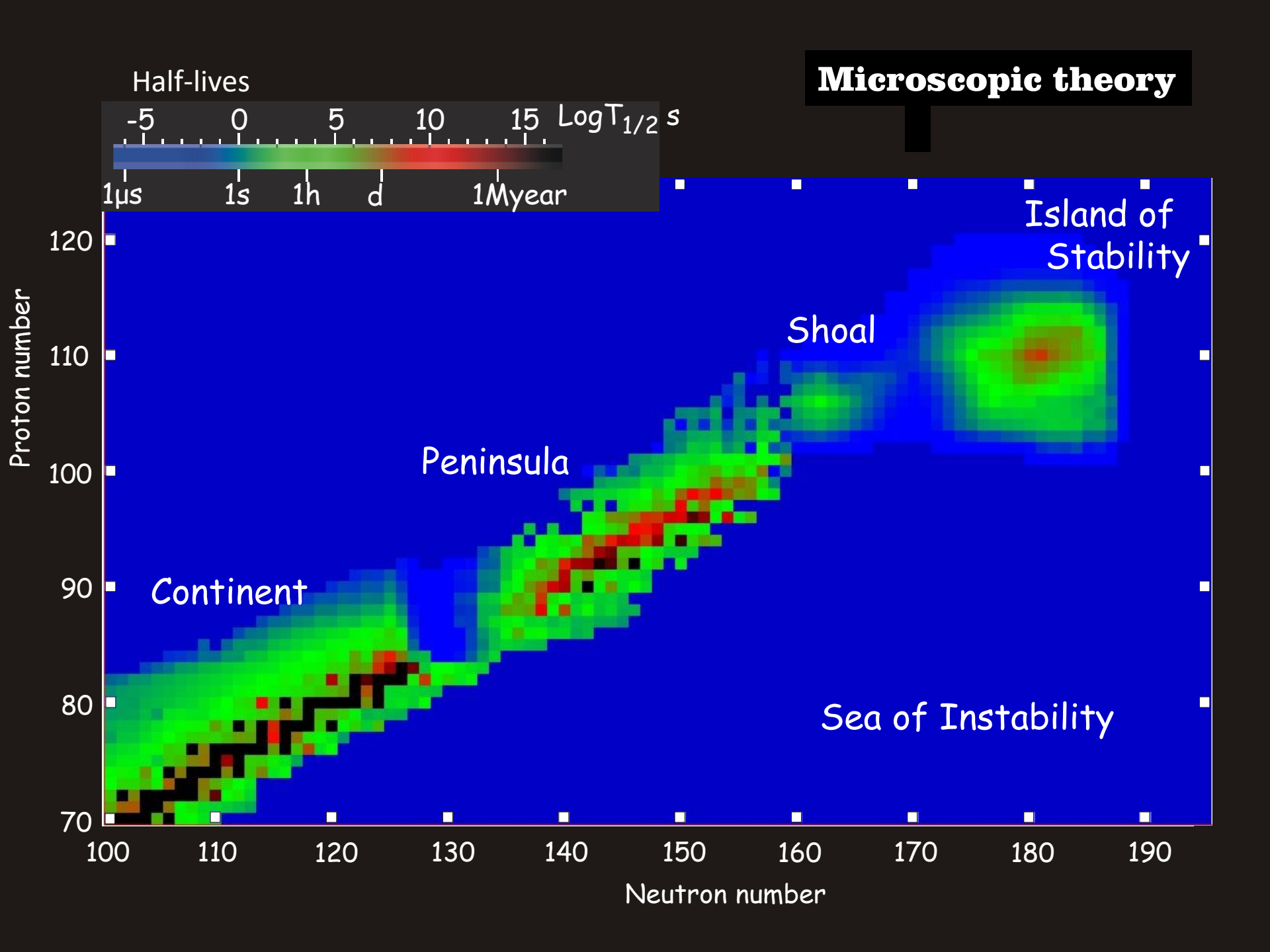


"for the discovery of the connection between collective motion and particle motion in atomic nuclei and the development of the theory of the structure of the atomic nucleus based on this connection".

Shell effect in the nuclear ground states (mass defect)

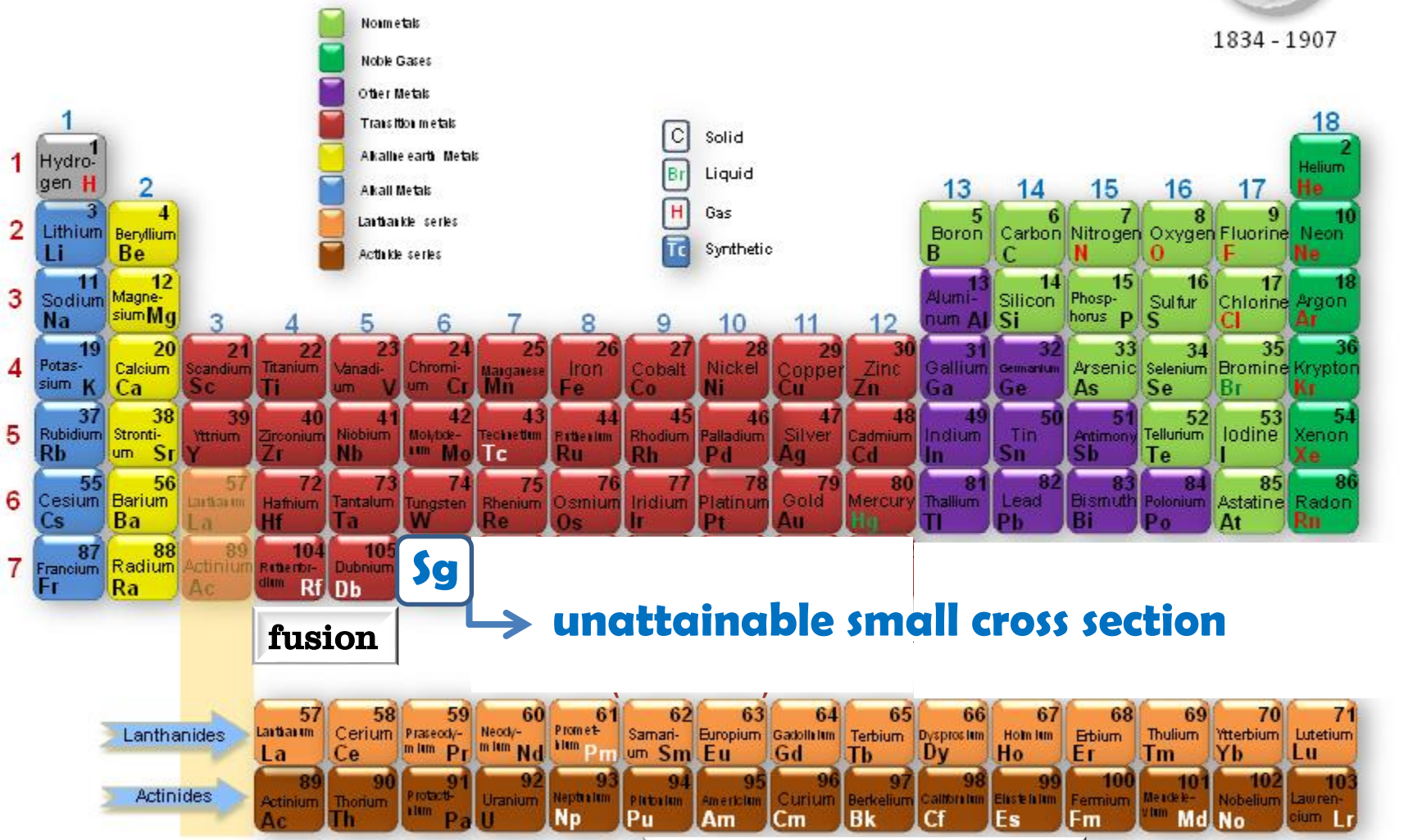



Log of the Spontaneous Fission Half Lives (years)
18
12
6
0
-6
-12
-18
146
152
158
164
170
176
182
188
Neutron number
Fiset and Nix
(1972)
Age of Earth
1 y
1 s
1 μs
Cm
Cf
Fm
104
102
106
108
110
Z=110
Z=114
?
Randrup et al.
(1974)
Z=114


Microscopic theory
Half-lives
-5
0
5
10
15
Log$T_{1/2}$ s
1μs
1s
1h
d
1Myear
Island of Stability
Shoal
Peninsula
Continent
Sea of Instability
Proton number
120
110
100
90
80
70
100
110
120
130
140
150
160
170
180
190
Neutron number

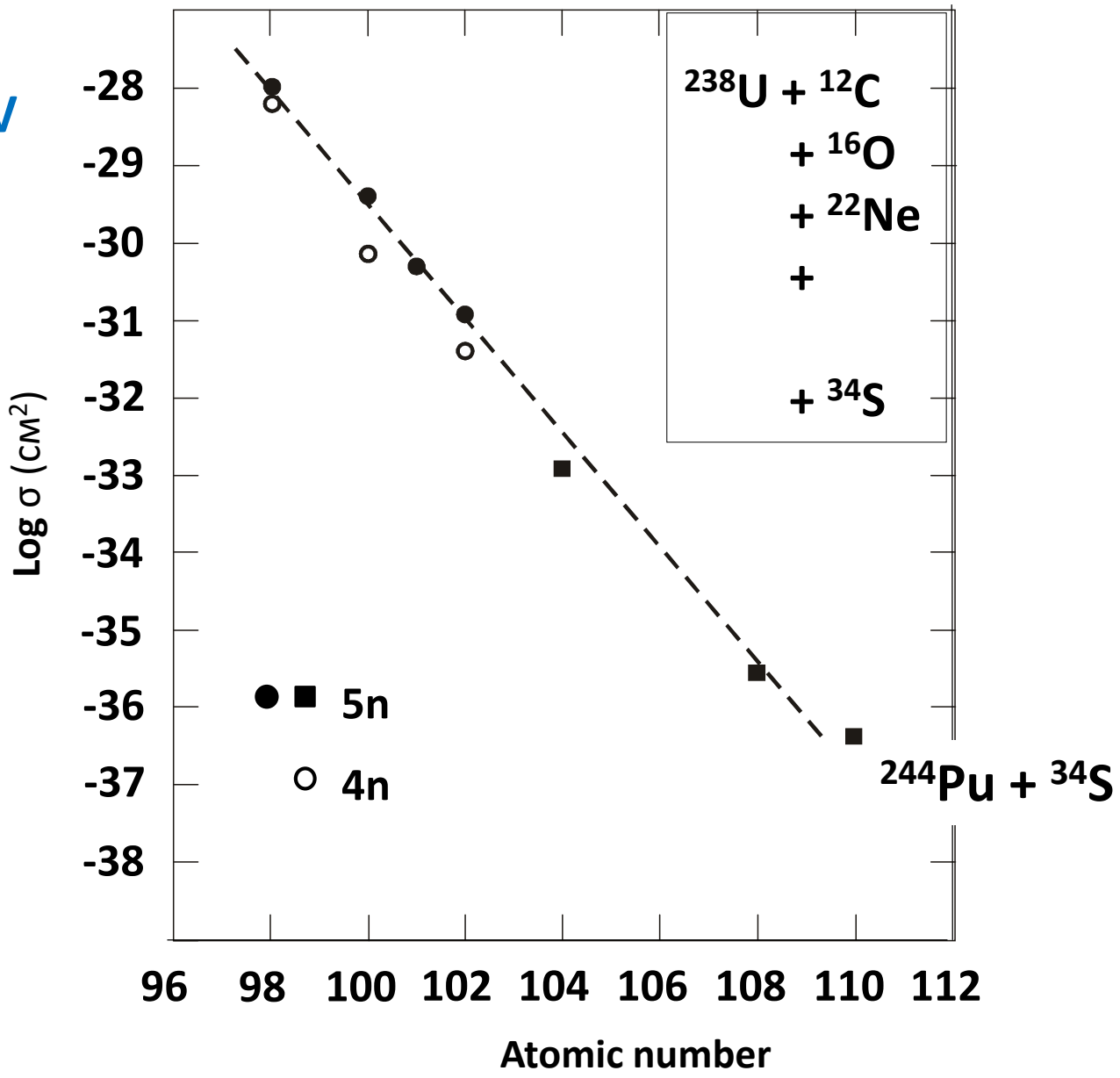
D.I.Mendeleev's Periodic Table of the Chemical Elements

1834 - 1907



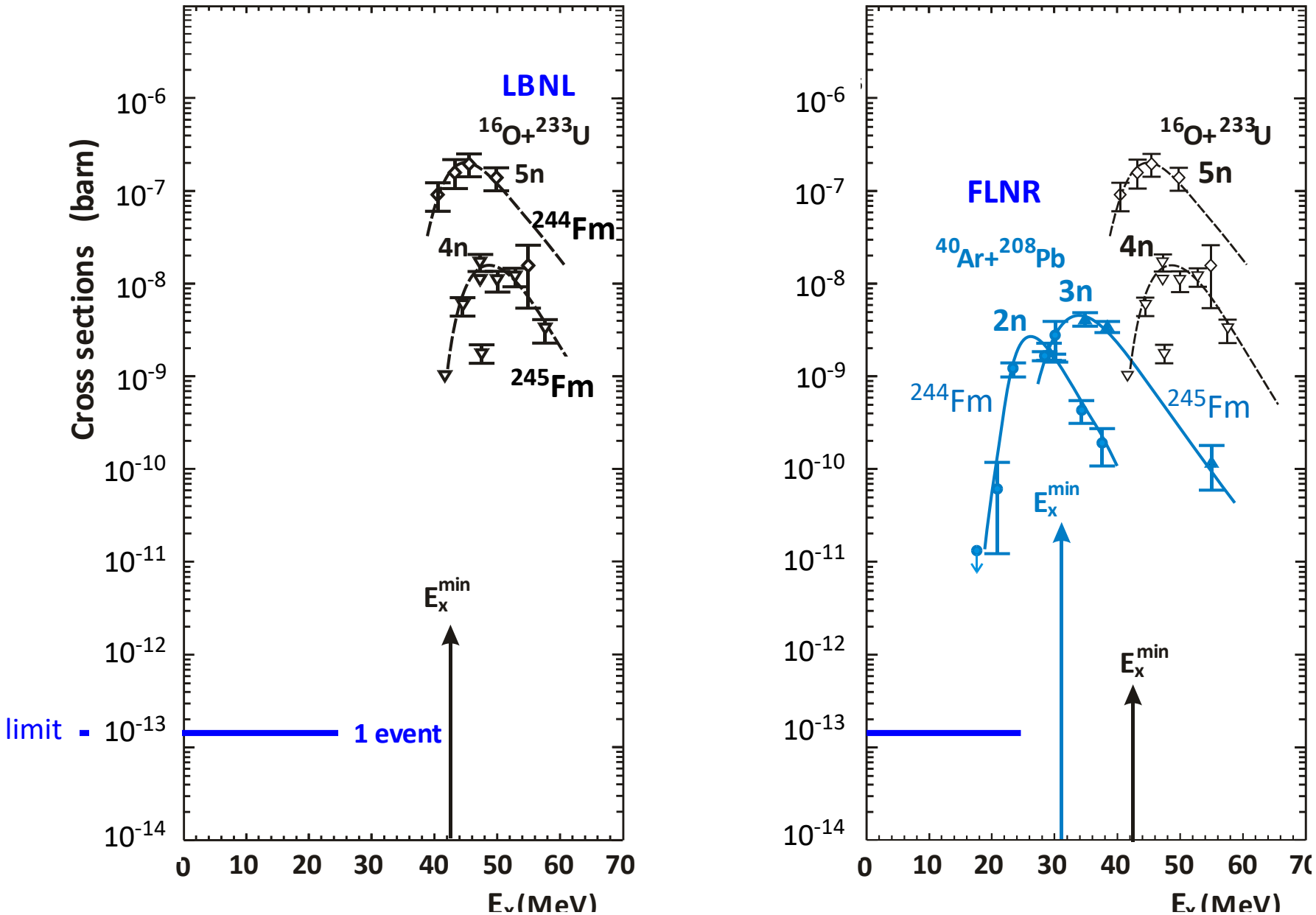
Hot fusion

E_x^{min} = 40-55 MeV

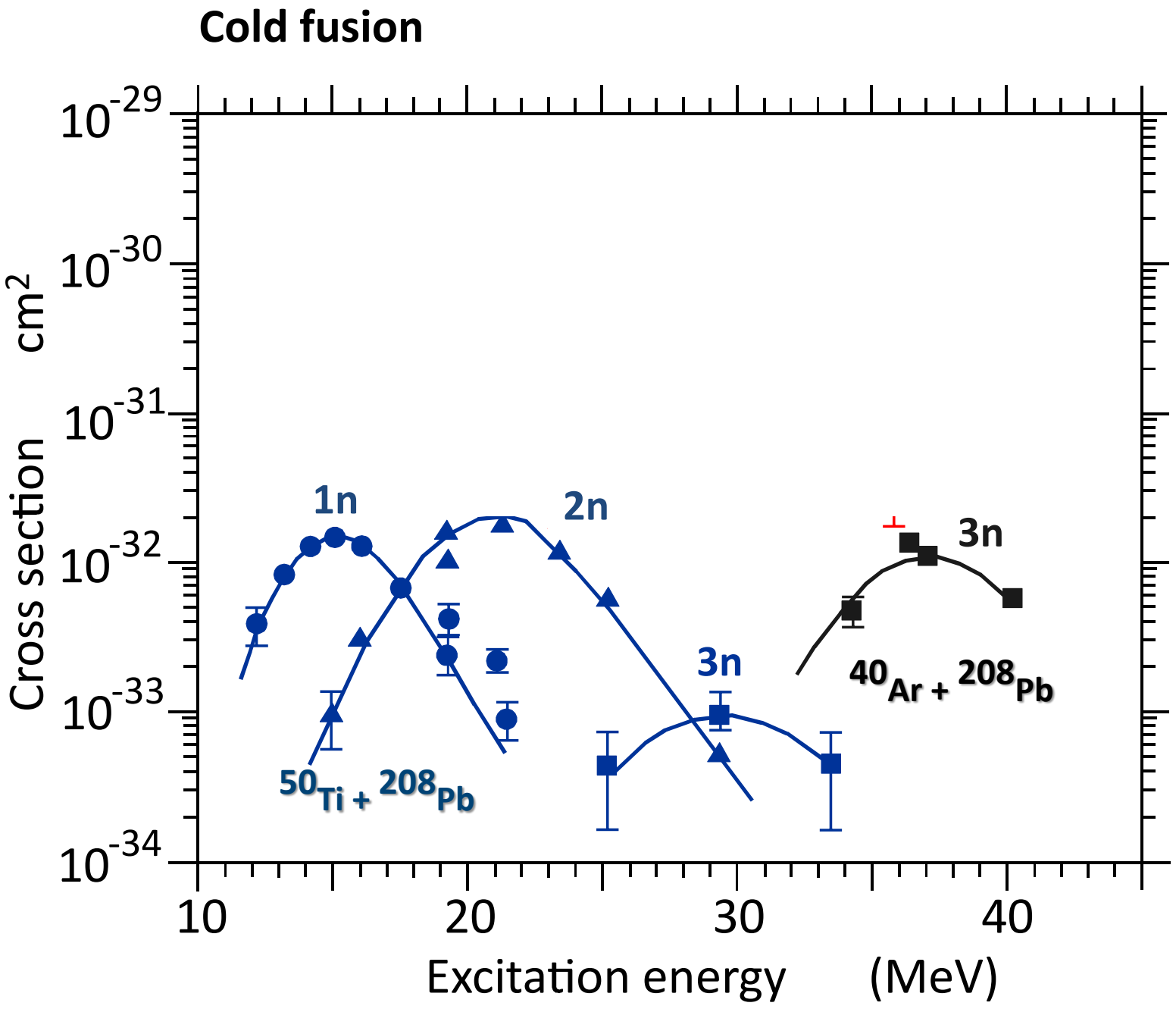


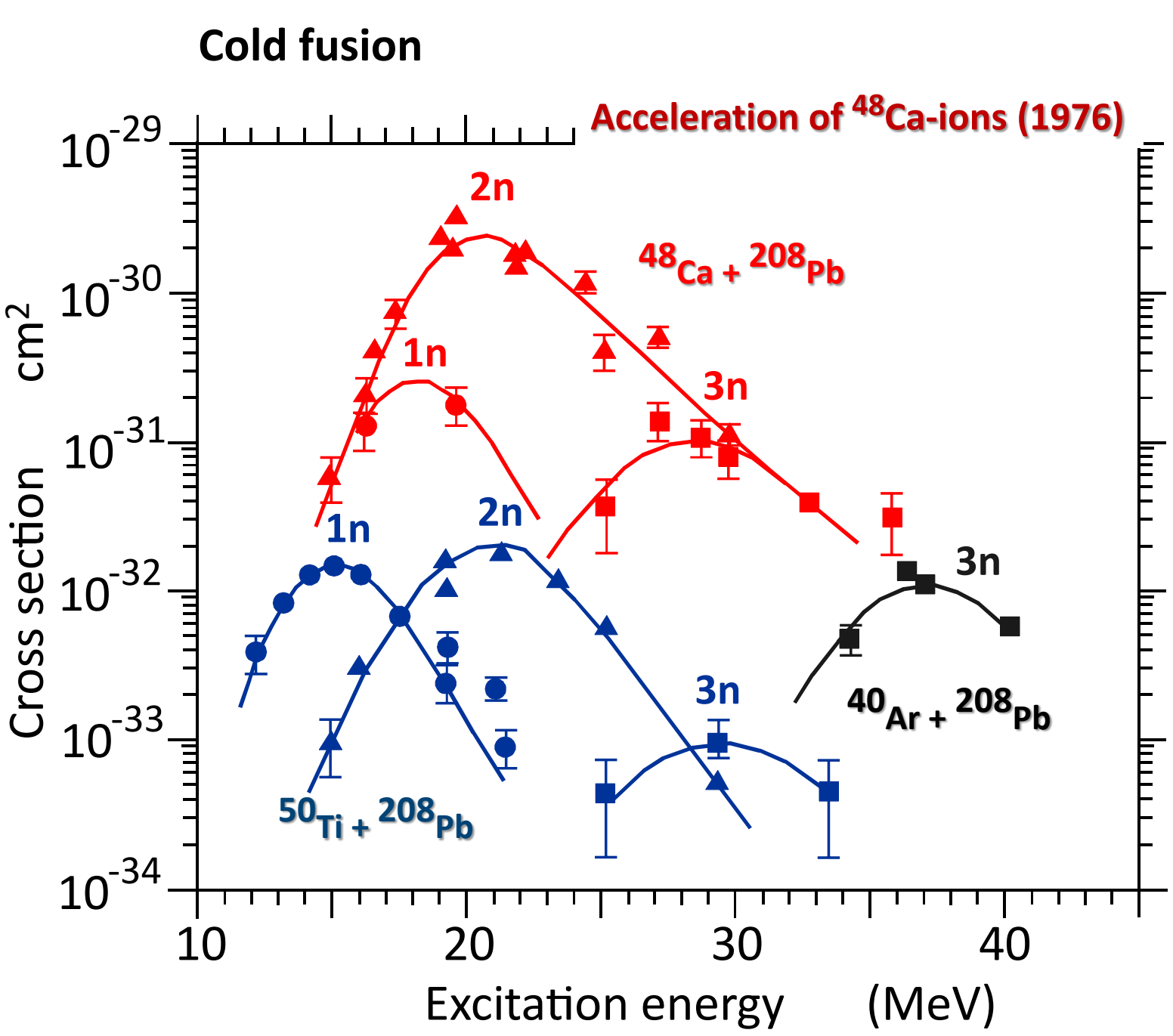

Dubna, 1972

Холодное слияние массивных ядер (ЛЯР 1974)

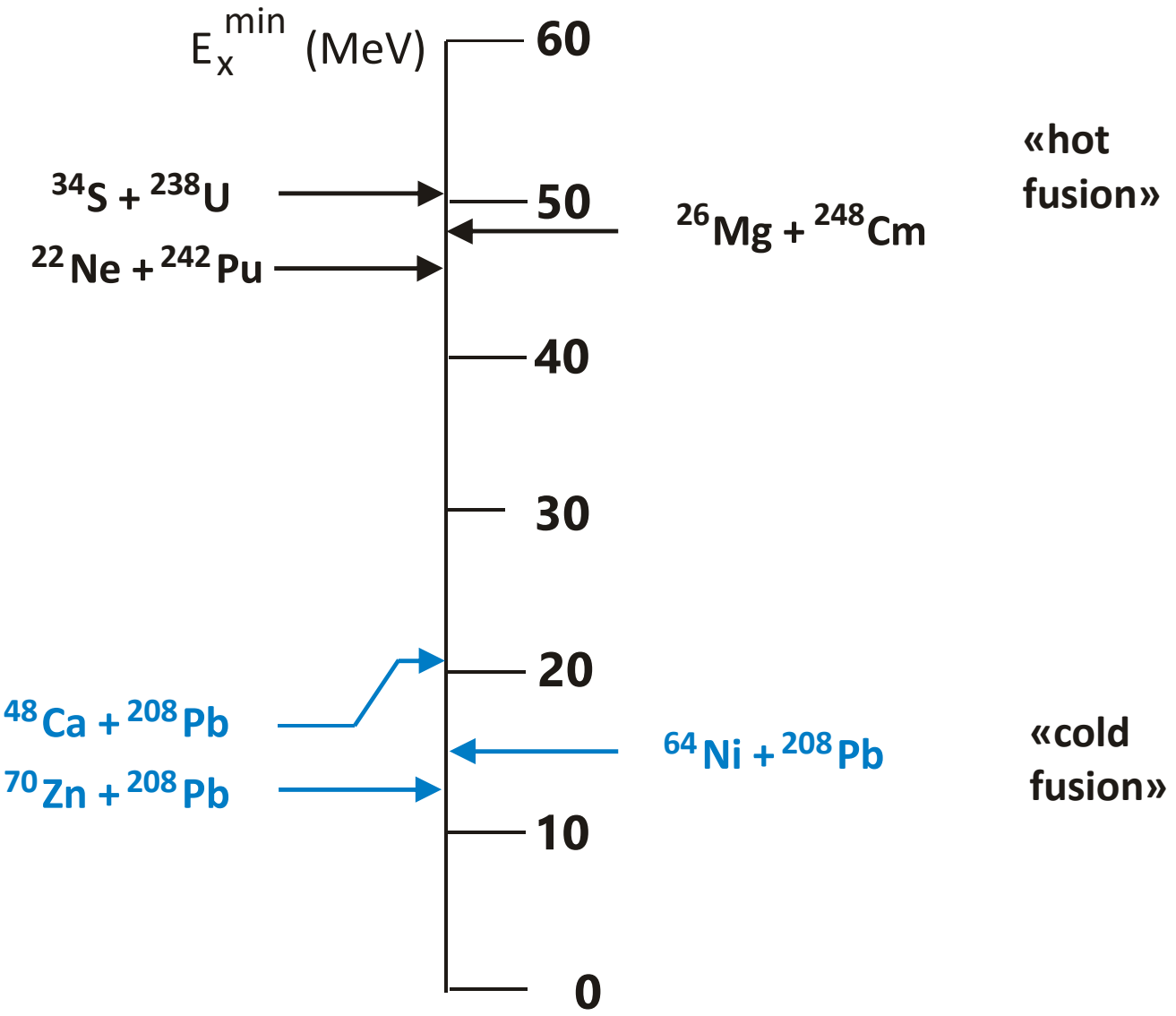

LBNL
$^{16}O+^{233}U$
5n
^{244}Fm
4n
^{245}Fm
E_x^{min}
1 event
limit
Cross sections (barn)
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
0 10 20 30 40 50 60 70
E_x(MeV)
FLNR
$^{16}O+^{233}U$
5n
4n
$^{40}Ar+^{208}Pb$
3n
2n
^{244}Fm
^{245}Fm
E_x^{min}
E_x^{min}

Cyclotron U-400 Dubna 1978

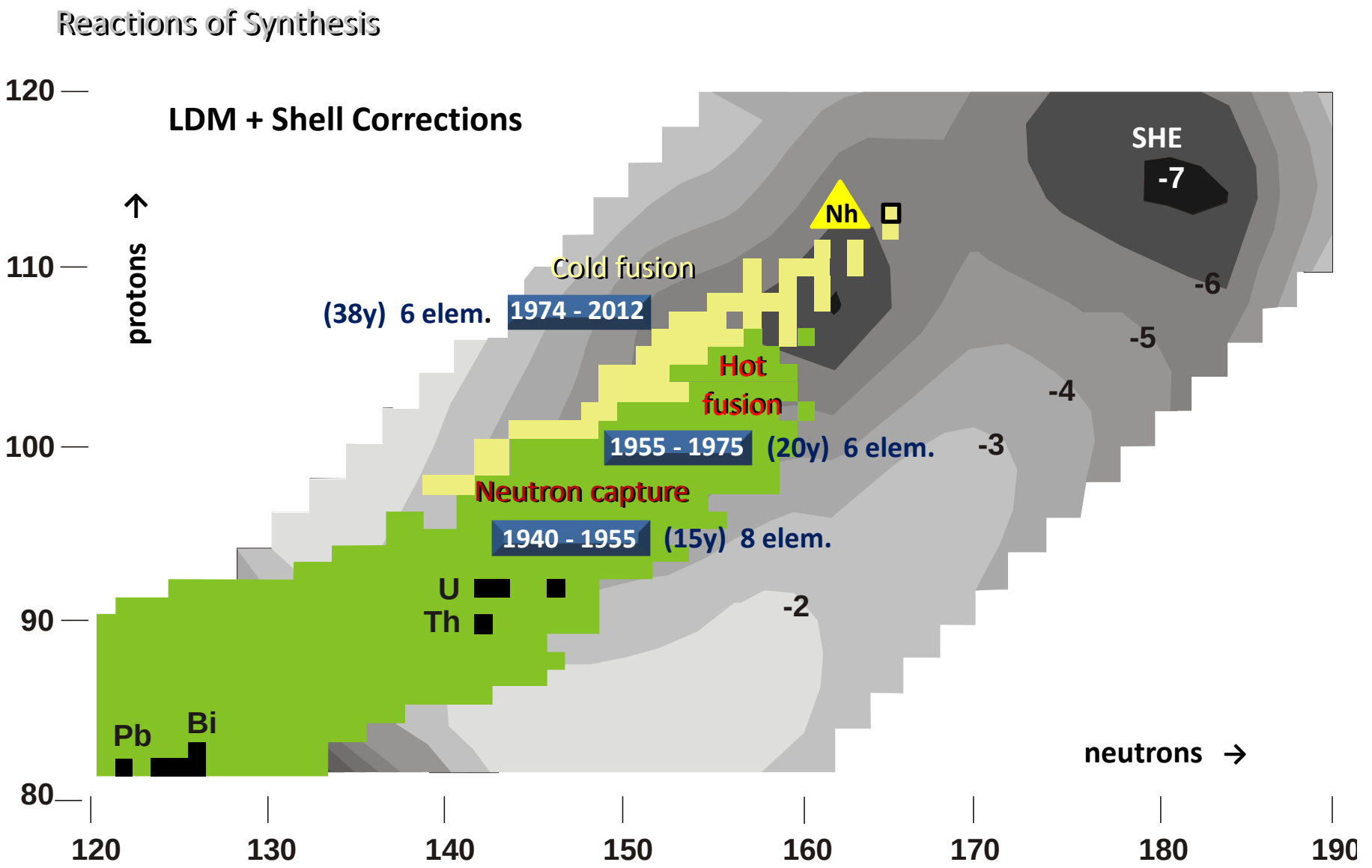

Cold fusion
Cross section cm2
10-29
10-30
10-31
10-32
10-33
10-34
10
20
30
40
Excitation energy (MeV)
1n
2n
3n
3n
50Ti + 208Pb
40Ar + 208Pb


Cold fusion
Acceleration of 48Ca-ions (1976)
2n
48Ca + 208Pb
1n
3n
1n
2n
3n
40Ar + 208Pb
3n
50Ti + 208Pb
Cross section cm2
10-29
10-30
10-31
10-32
10-33
10-34
10
20
30
40
Excitation energy (MeV)

The excitation energy of the compound nuclei at the Coulomb barrier



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


Reactions of Synthesis
LDM + Shell Corrections
120
110
100
90
80
protons →
SHE
-7
-6
-5
-4
-3
-2
Nh
Cold fusion
(38y) 6 elem.
1974 - 2012
Hot
fusion
1955 - 1975
(20y) 6 elem.
Neutron capture
1940 - 1955
(15y) 8 elem.
U
Th
Pb
Bi
neutrons →
120
130
140
150
160
170
180
190

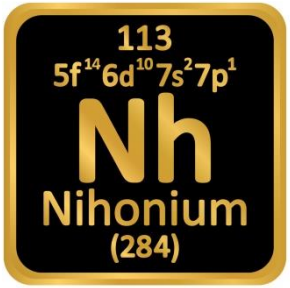

Тэнно-хэйка (天皇陛下)
Его Императорское Величество

Cold Fusion
(transactinides)

Compound nucleus

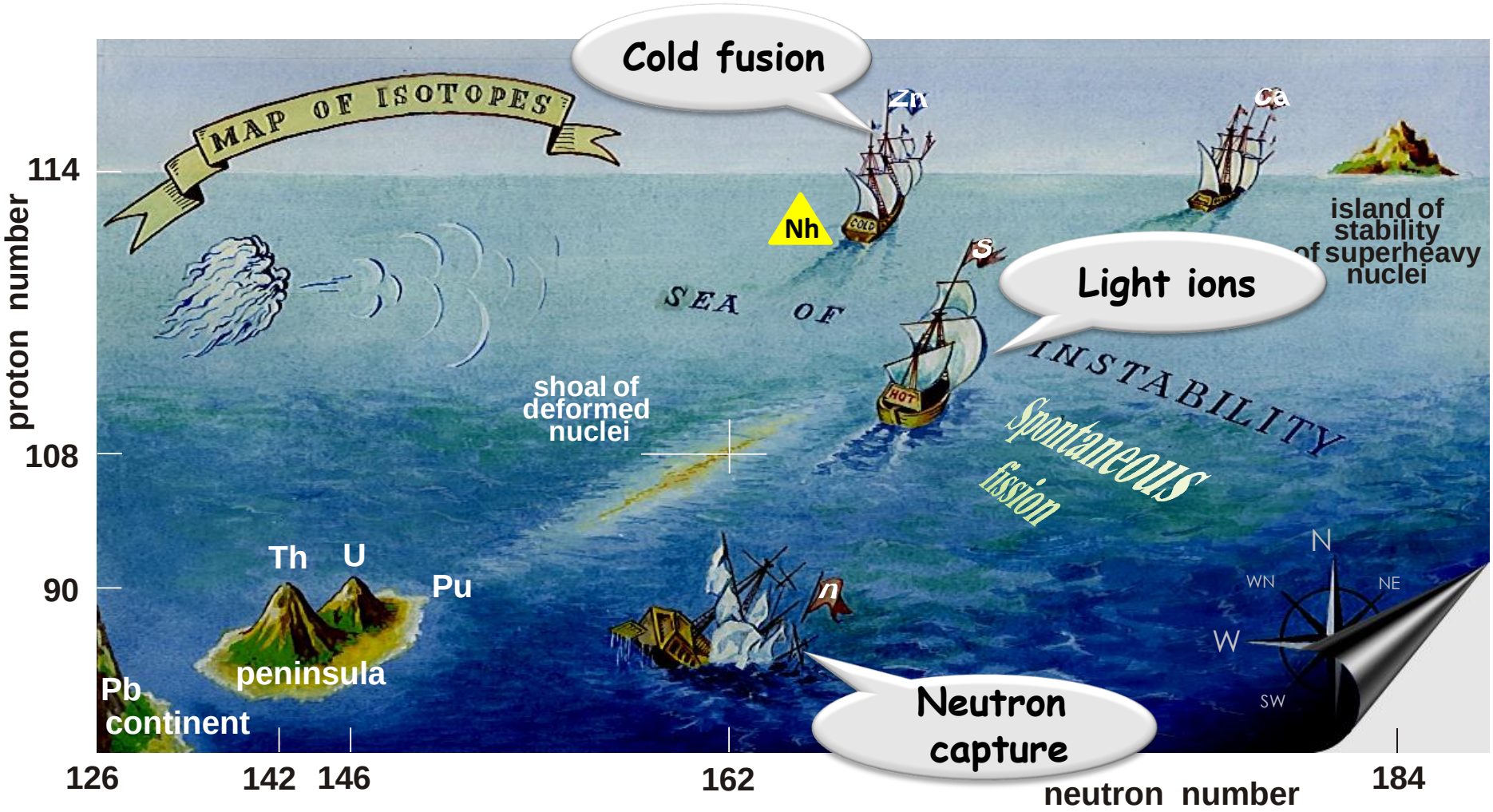
^{70}Zn ⇨ $E \approx B_{Bass}$

Projectile




Член-корр РАН
Н.П.Тарасова
Император
Нарухито

Reactions of synthesis



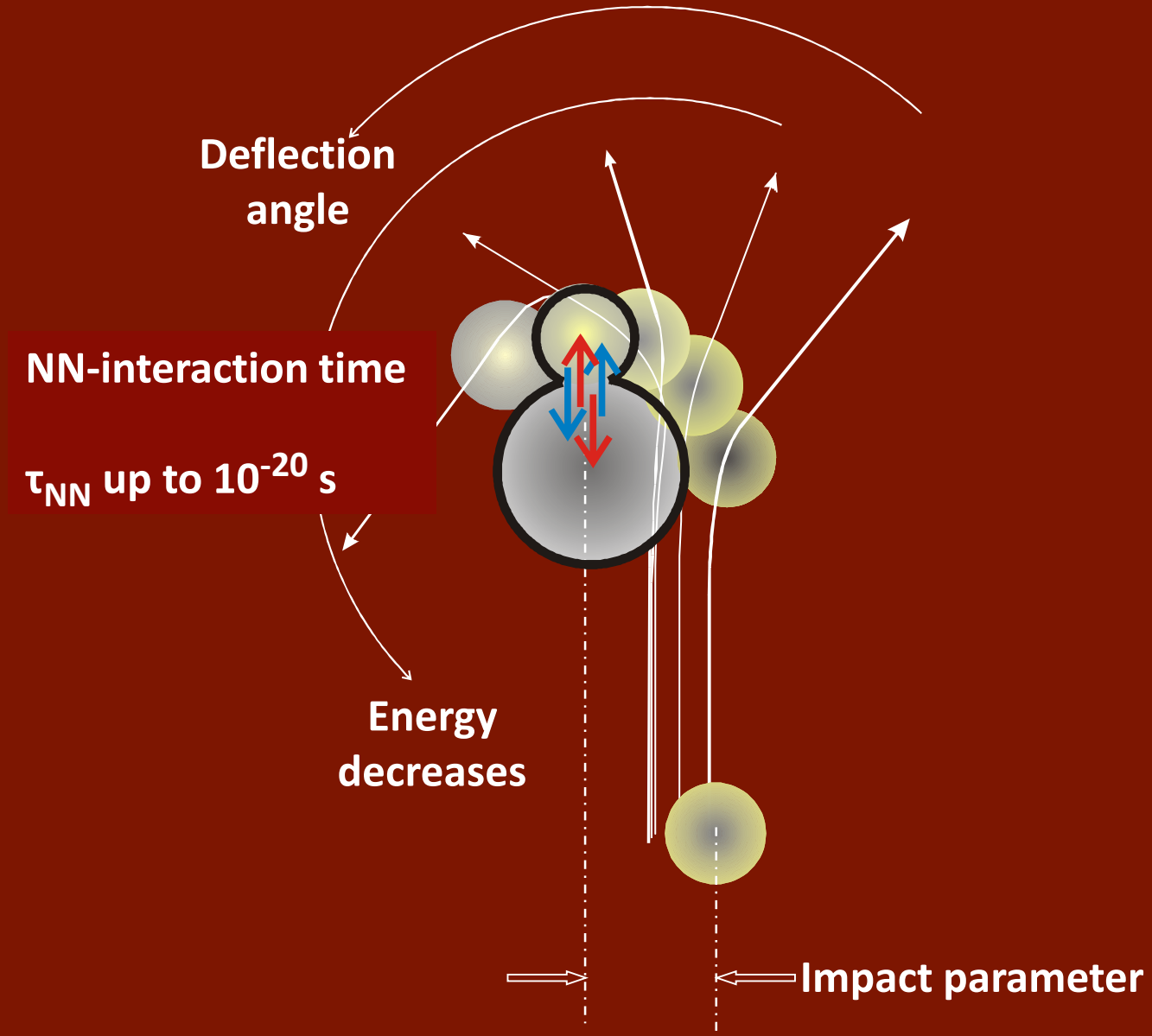
Реакции передачи нуклонов и фрагментации тяжелых ионов

(ЛЯР, 1969 / GANIL, 1989)

Deep
Inelastic
Collisions

FLNR 1969-73

New type reactions
between complex nuclei

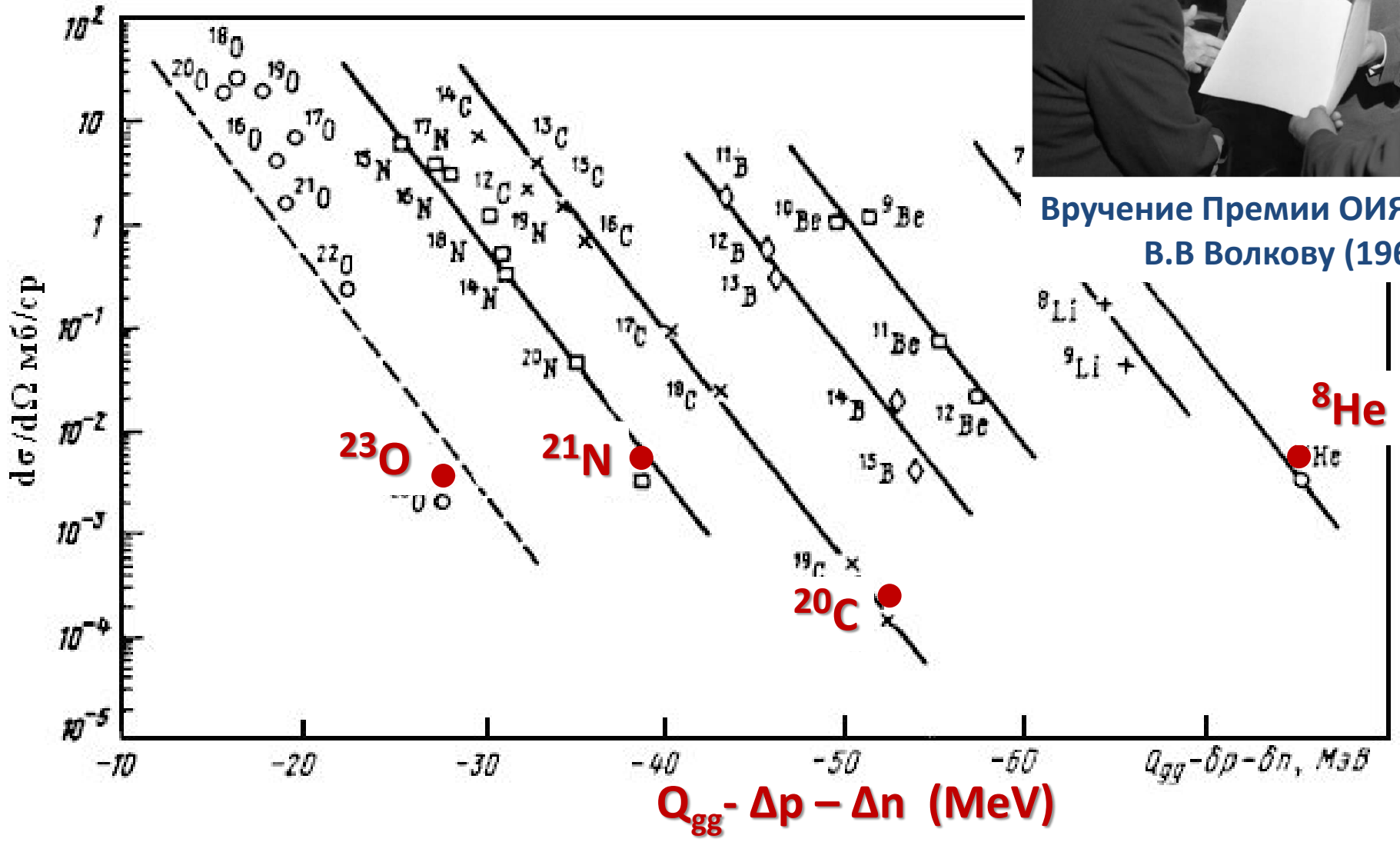


$^{22}Ne + {}^{232}Th \rightarrow {}^{23}O + {}^{231}U$

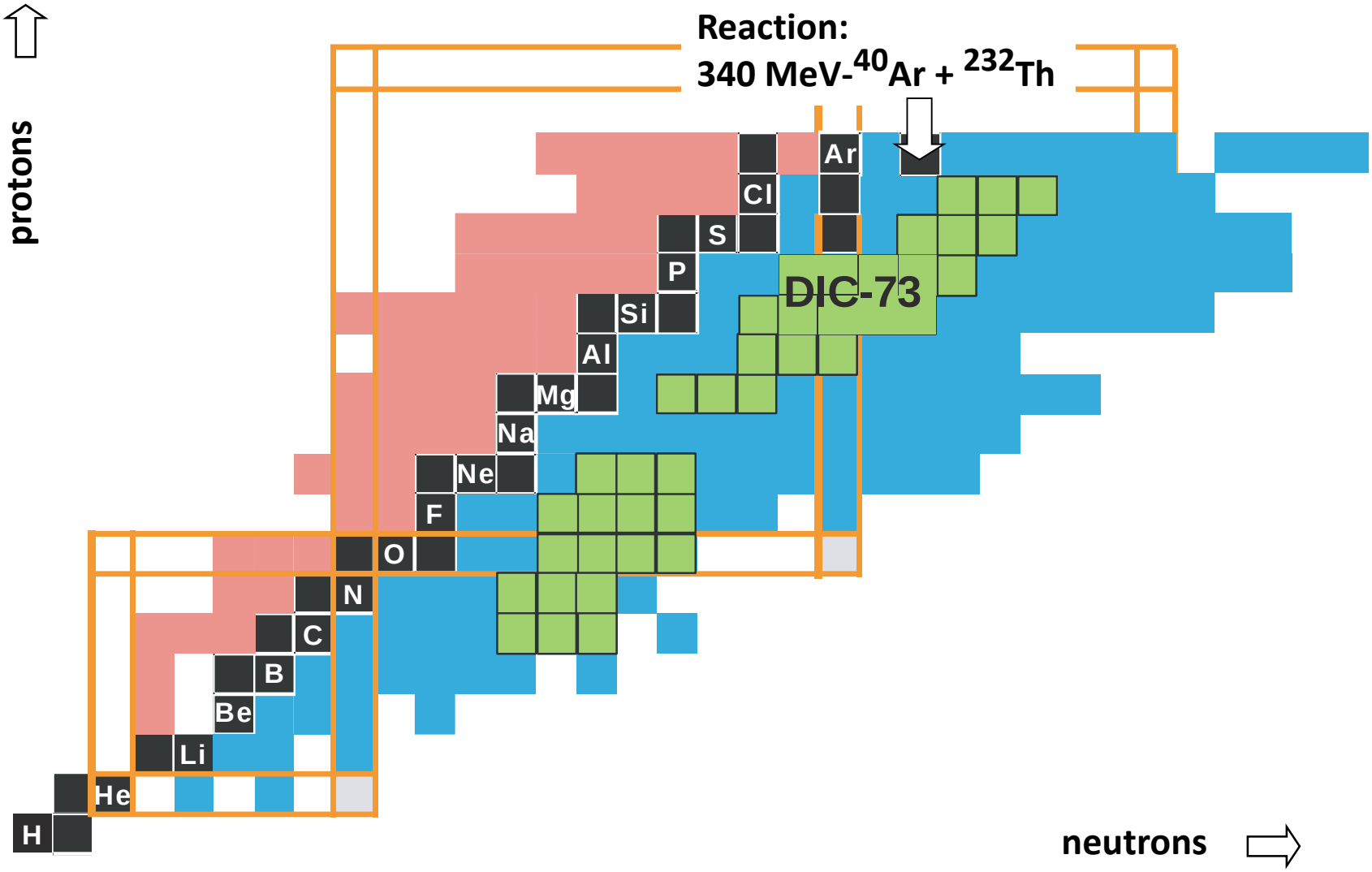
$\rightarrow {}^{20}C + {}^{234}Pu$

$\rightarrow {}^{8}He + {}^{246}Cf$

Вручение Премии ОИЯИ В.В Волкову (1969)

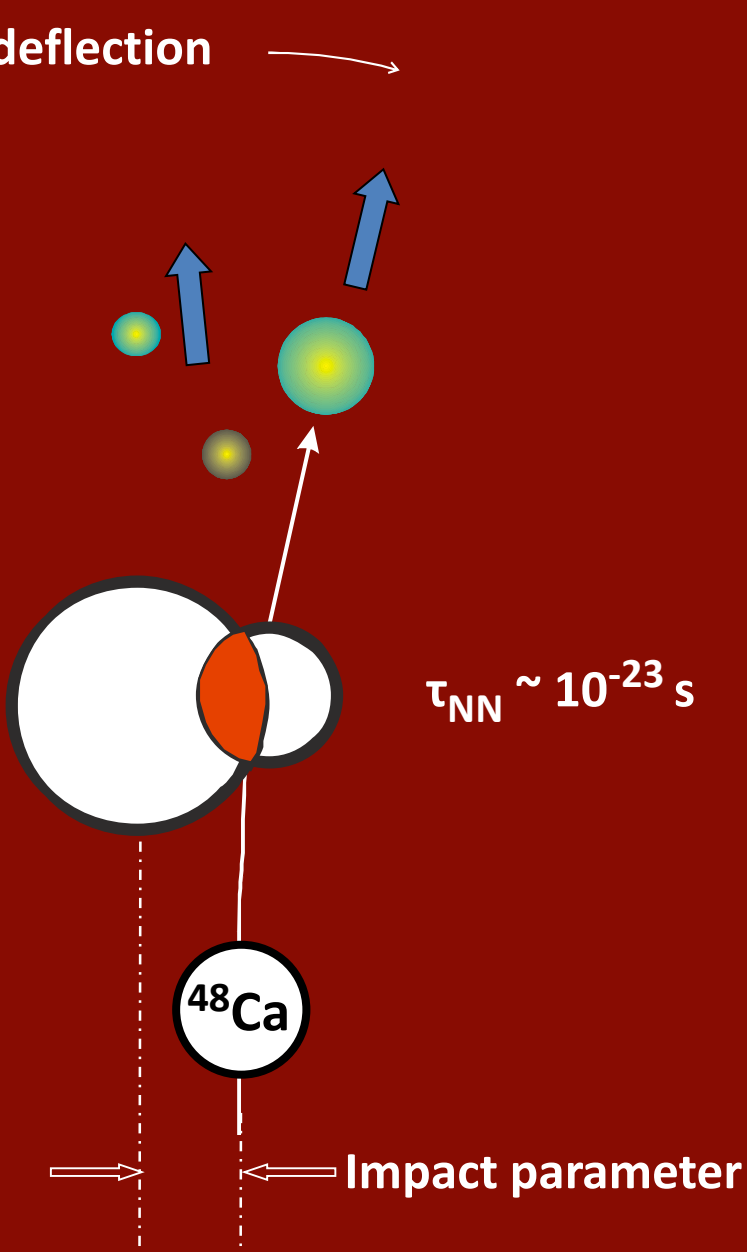


Deep Inelastic Collisions at the near-barrier energies

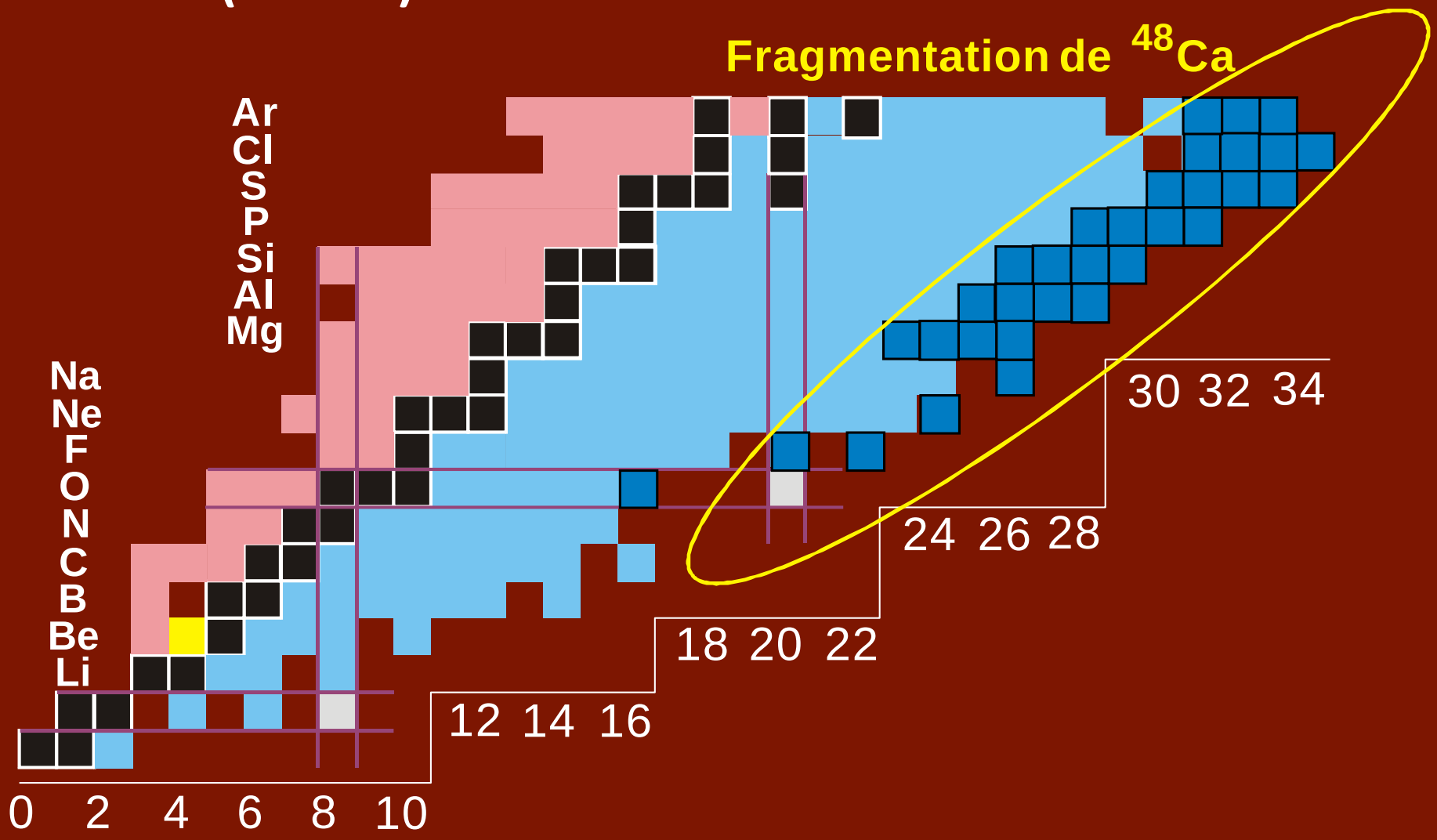


Fragmentation

E ~ 50-100 A·MeV

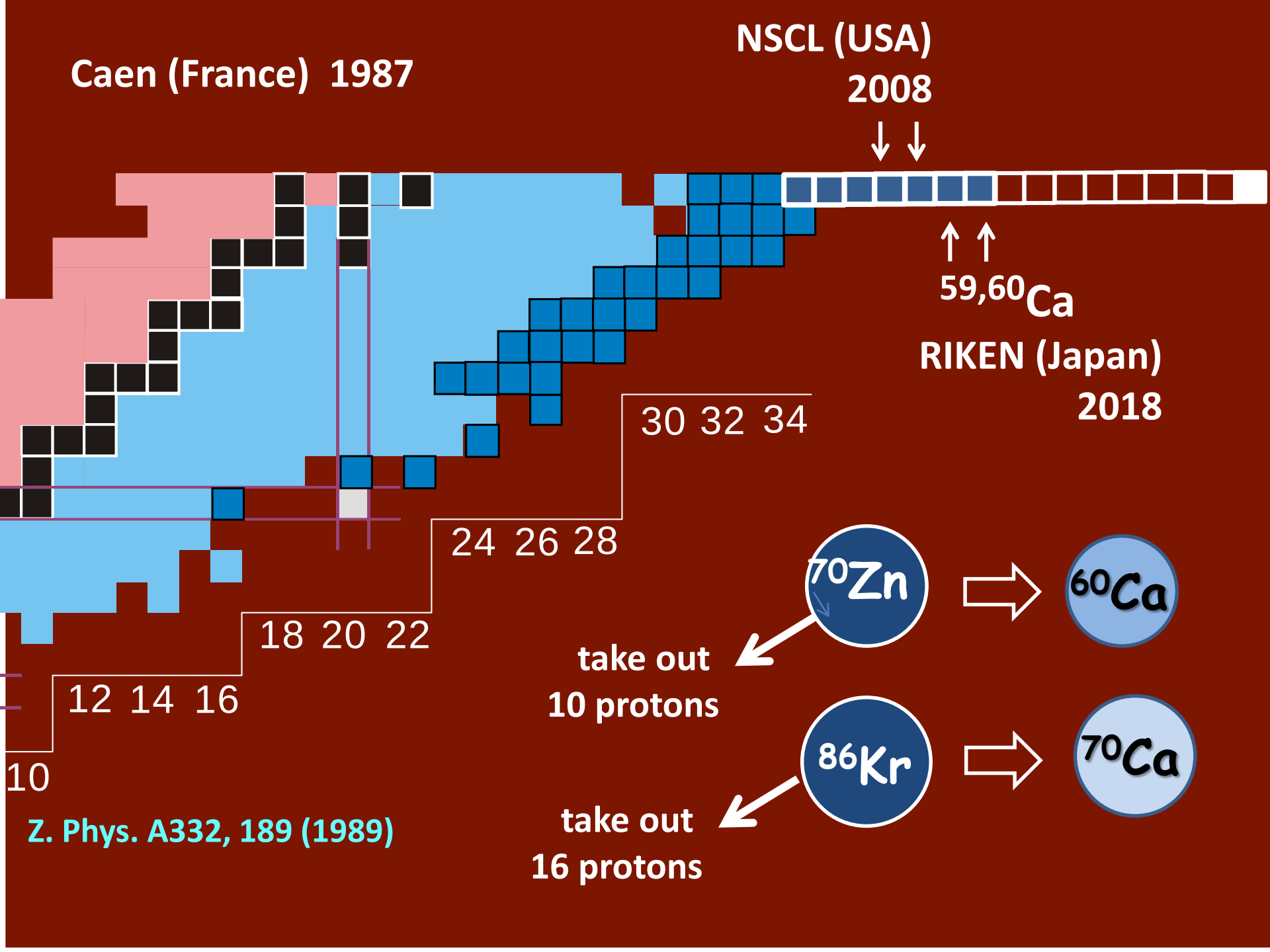


Caen (France) 1987

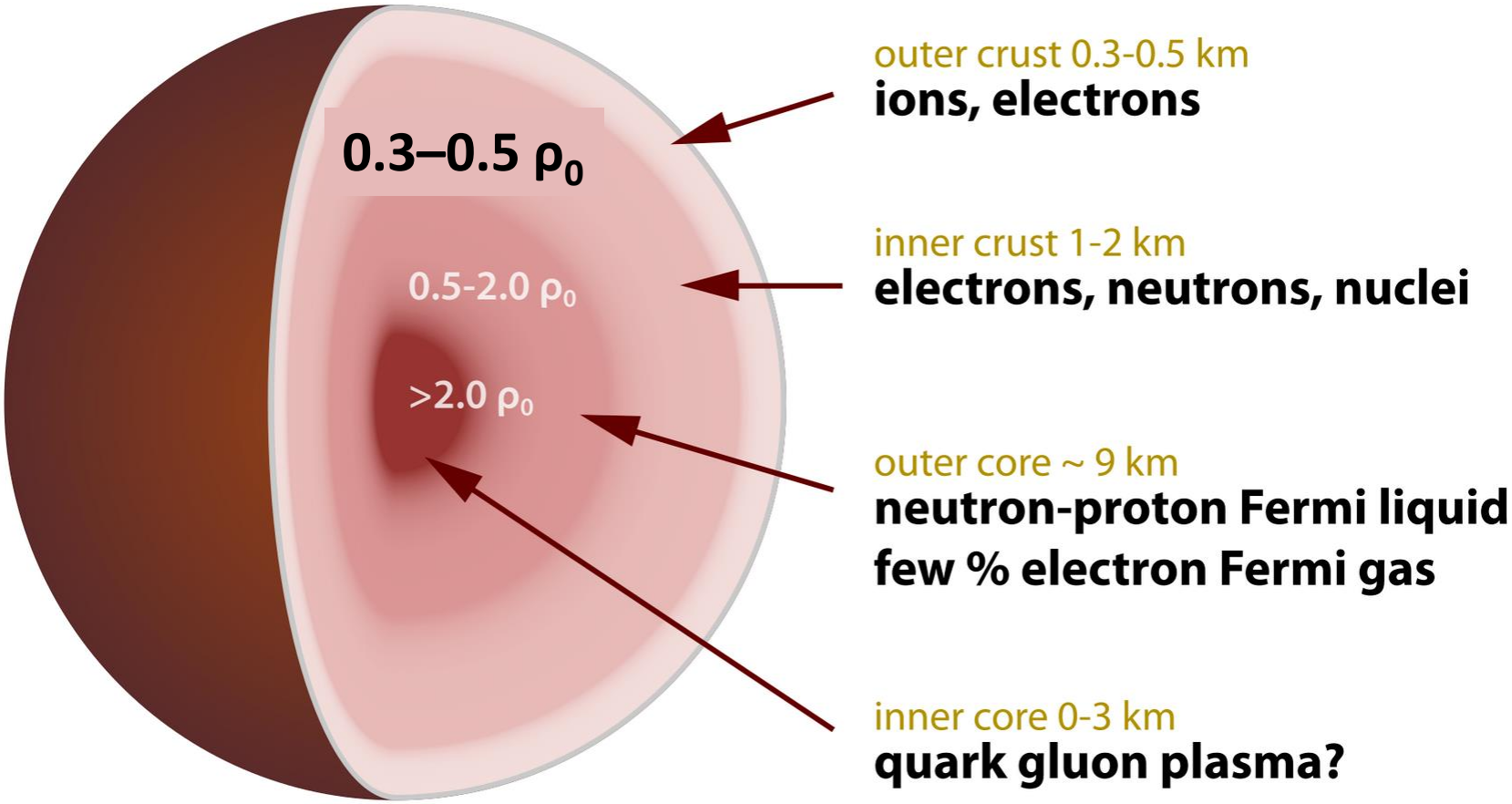


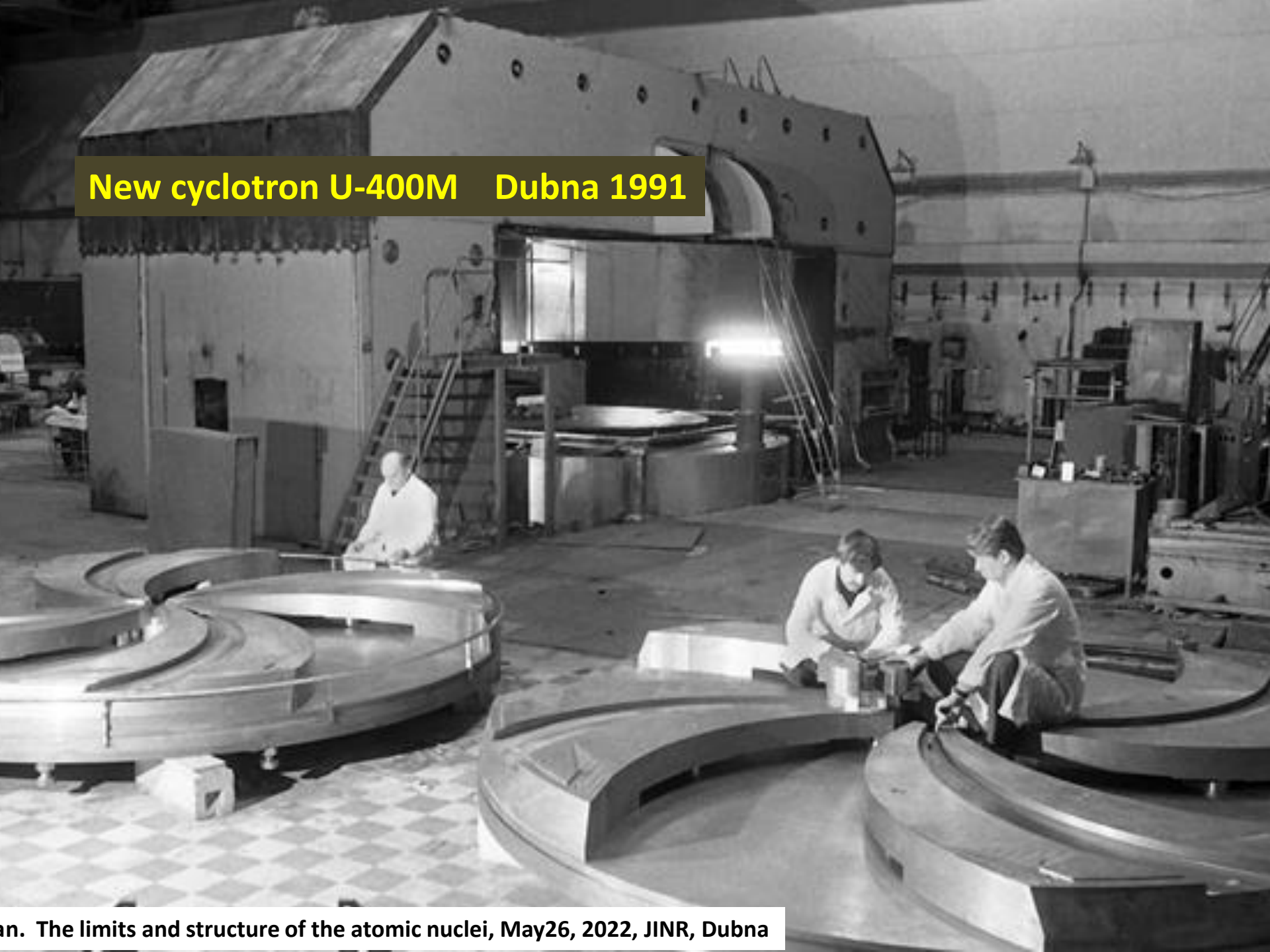
Z. Phys. A332, 189 (1989)

Новая улица в Кане (Нормандия)


Caen (France) 1987
NSCL (USA)
2008
59,60Ca
RIKEN (Japan)
2018
30 32 34
24 26 28
18 20 22
12 14 16
10
70Zn
60Ca
take out
10 protons
86Kr
70Ca
take out
16 protons
Z. Phys. A332, 189 (1989)

Cross-section of neutron star



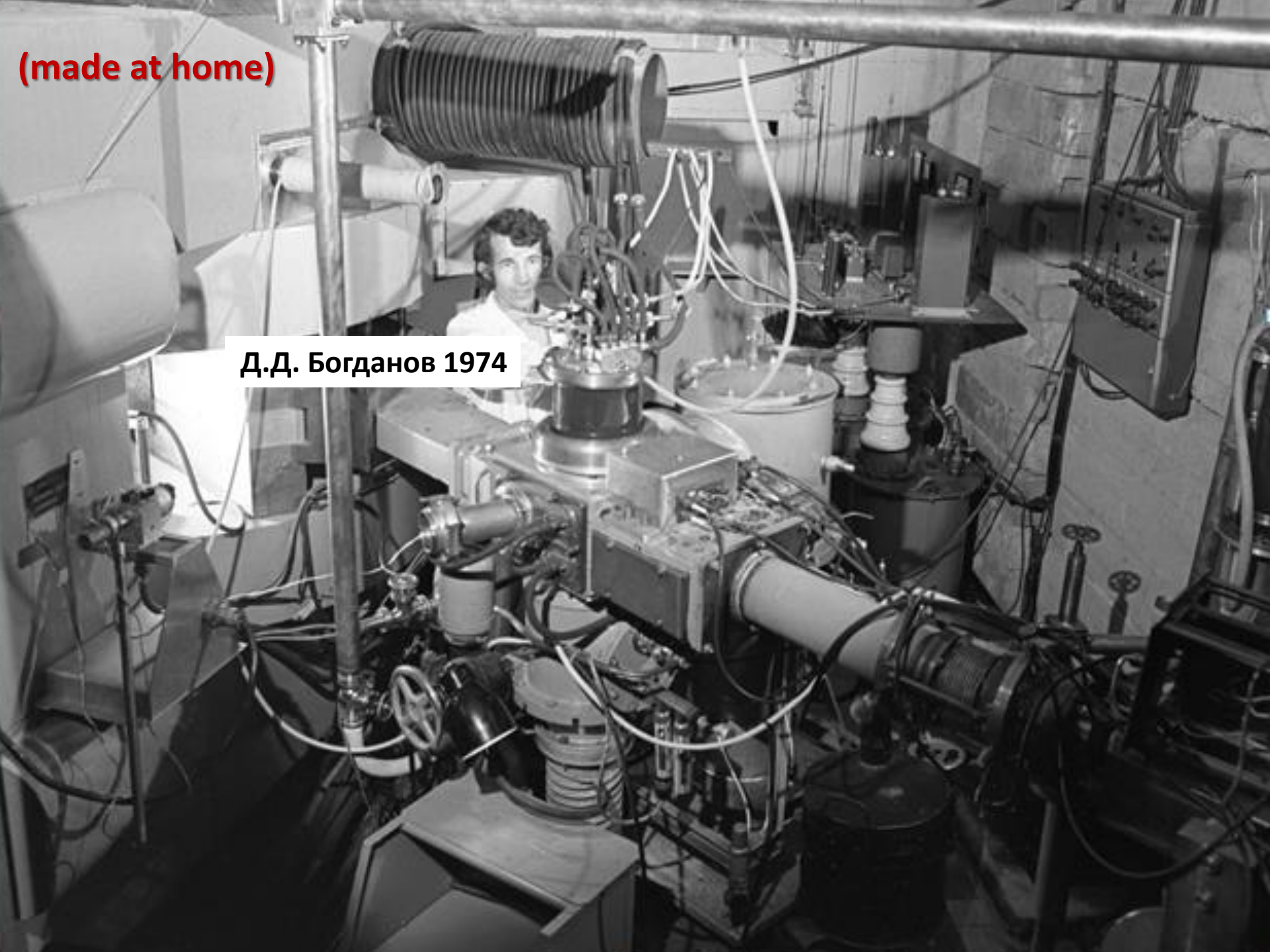

New cyclotron U-400M Dubna 1991

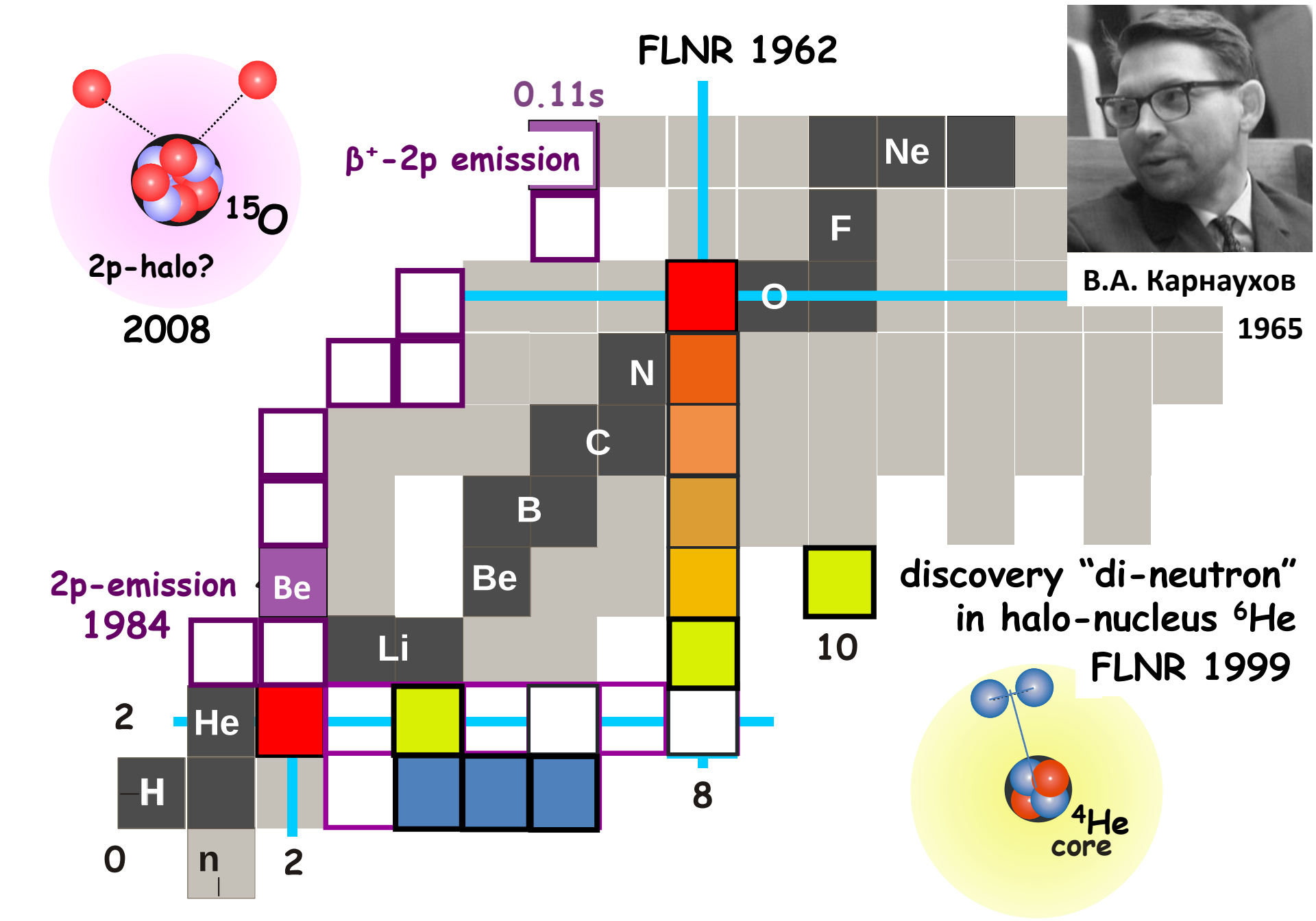
Прощальные проводы ускорителя – ветерана У300

2016 – first run

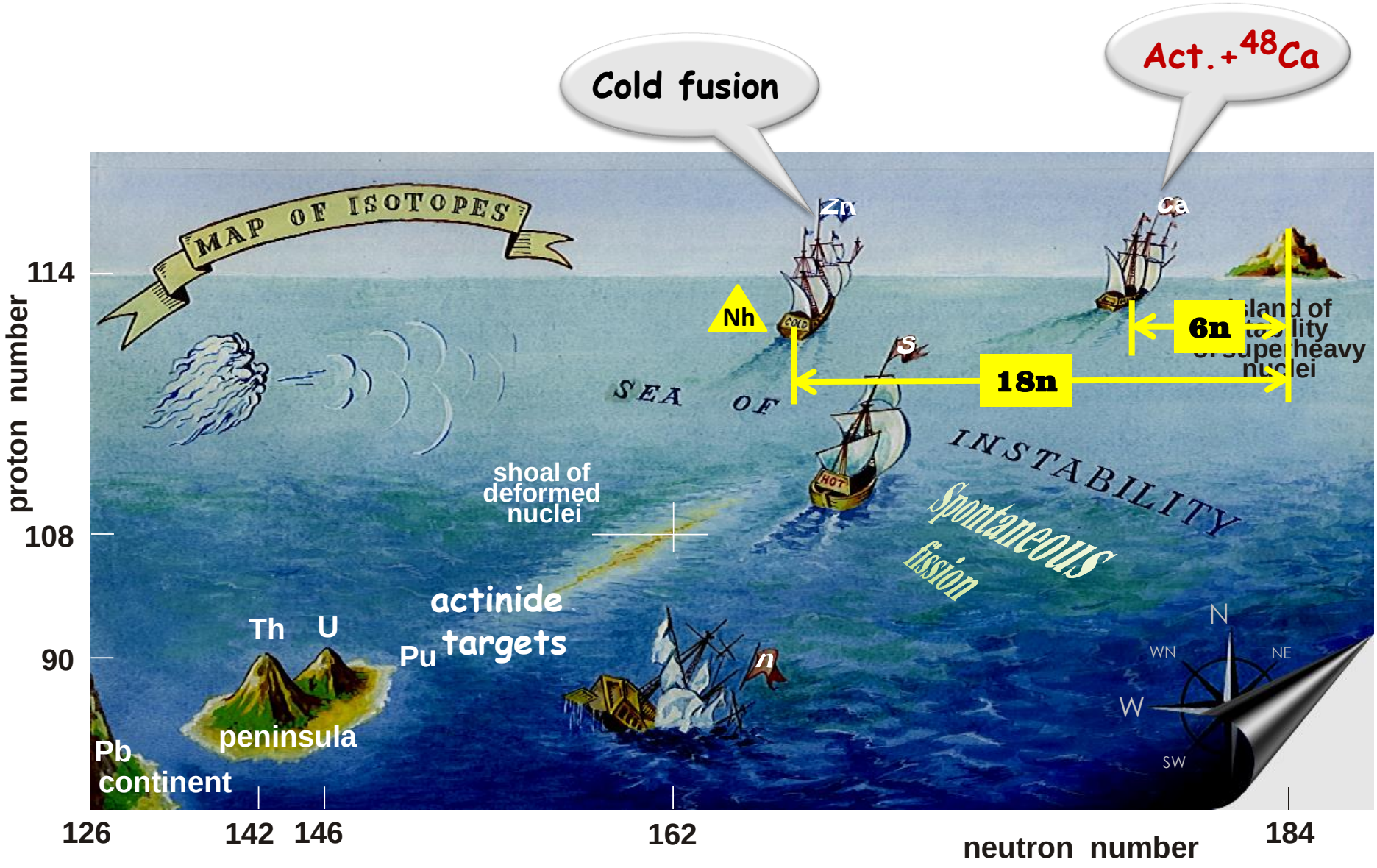
Это сейчас!
(made in France)

А тогда, 54 года до этого, впервые…


(made at home)
Д.Д. Богданов 1974

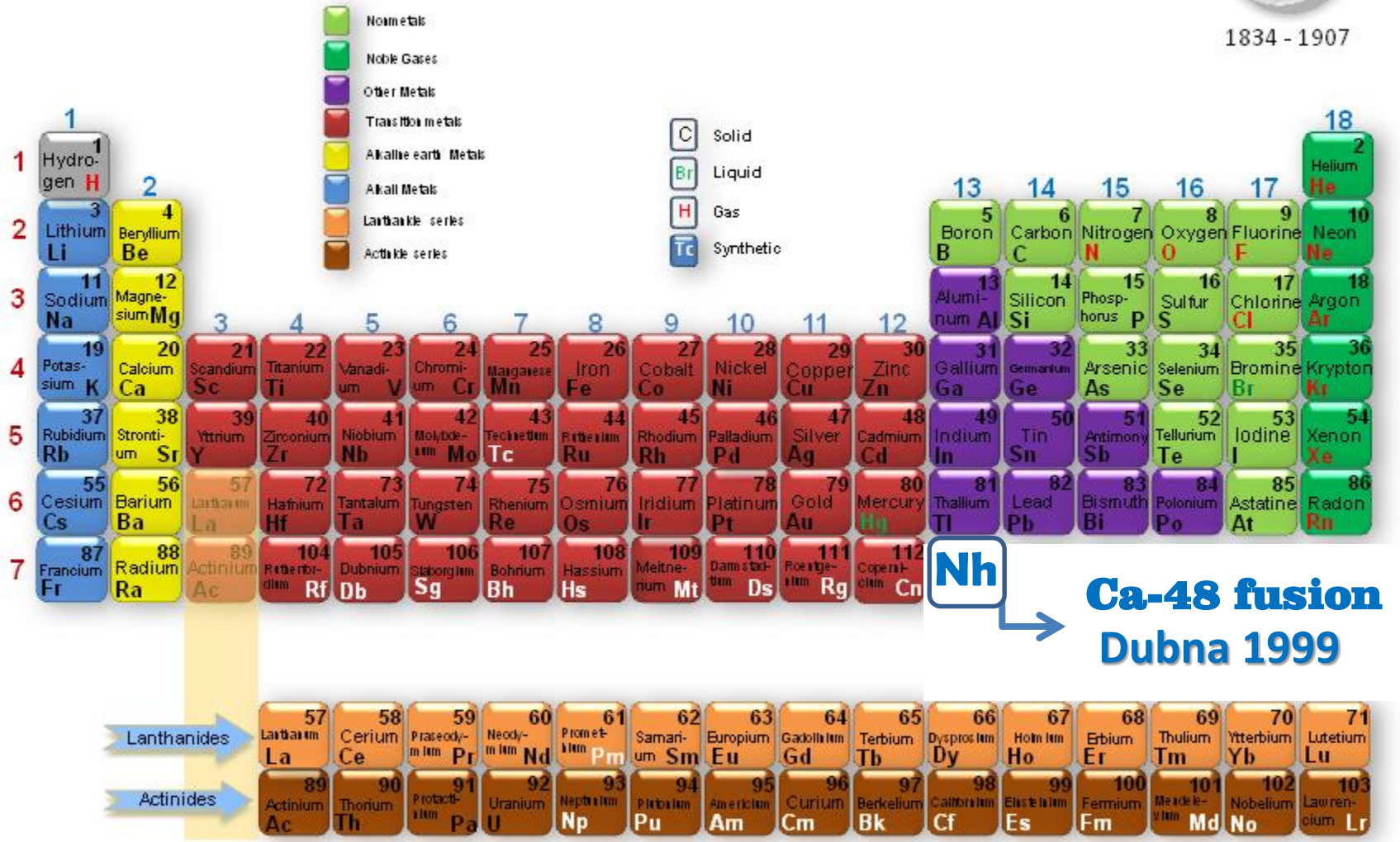

FLNR 1962
0.11s
β⁺-2p emission
Ne
F
O
N
C
B
Be
Be
Li
He
H
n
0
2
2
8
10
15O
2p-halo?
2008
2p-emission
1984
В.А. Карнаухов
1965
discovery "di-neutron"
in halo-nucleus 6He
FLNR 1999
4He
core

Синтез сверхтяжелых элементов (ЛЯР, 1999-2014)


Cold fusion
Act.+48Ca
MAP OF ISOTOPES
Zn
Ca
Nh
6n
18n
Island of stability of superheavy nuclei
SEA OF INSTABILITY
Spontaneous fission
shoal of deformed nuclei
actinide targets
Th
U
Pu
n
peninsula
Pb continent
N
WN
NE
W
SW
proton number
114
108
90
126
142
146
162
184
neutron number

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

1834 - 1907

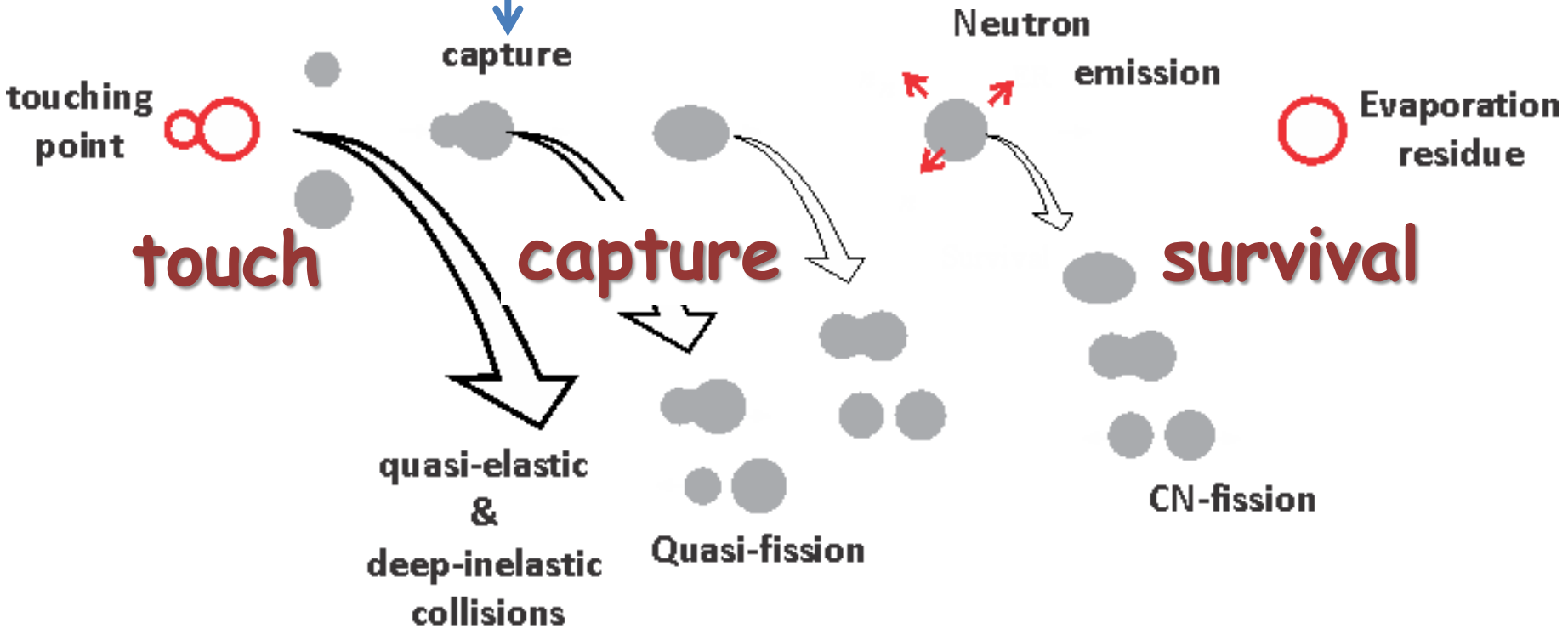


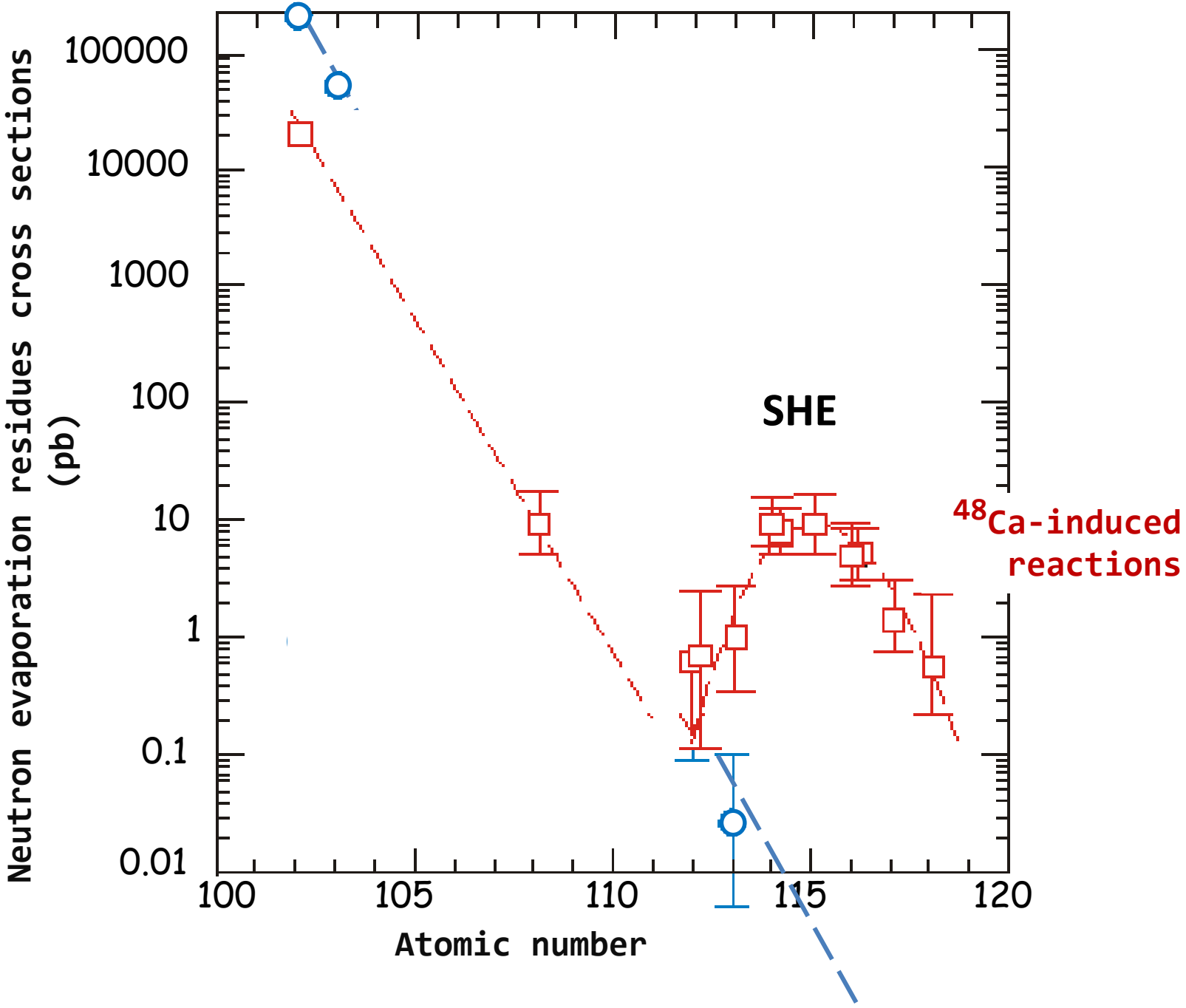
The model of nuclear fusion assumes that the incident particle and the target nucleus become indistinguishable after the collision and constitute the nucleus's particular excited state – **the compound nucleus**.

Niels Bohr, 1936

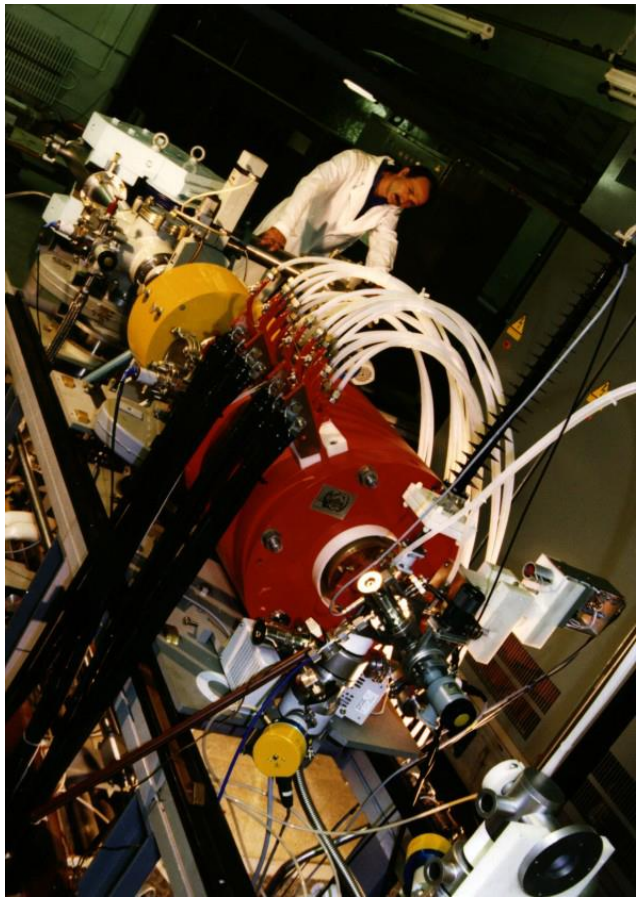
discovery of quasi-fission

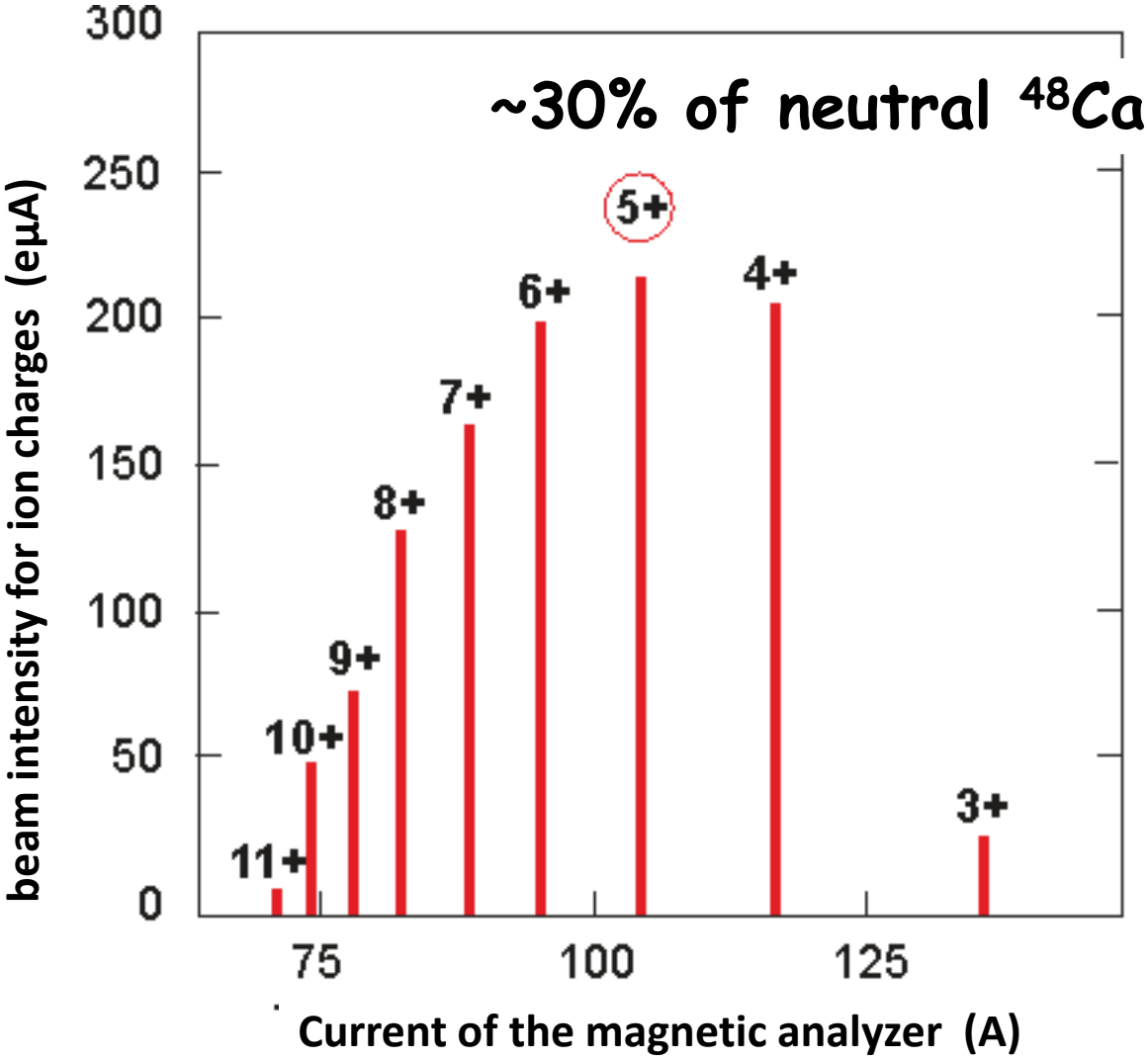
FLNR 1999




Neutron evaporation residues cross sections (pb)
100000
10000
1000
100
10
1
0.1
0.01
100
105
110
115
120
Atomic number
SHE
48Ca-induced reactions

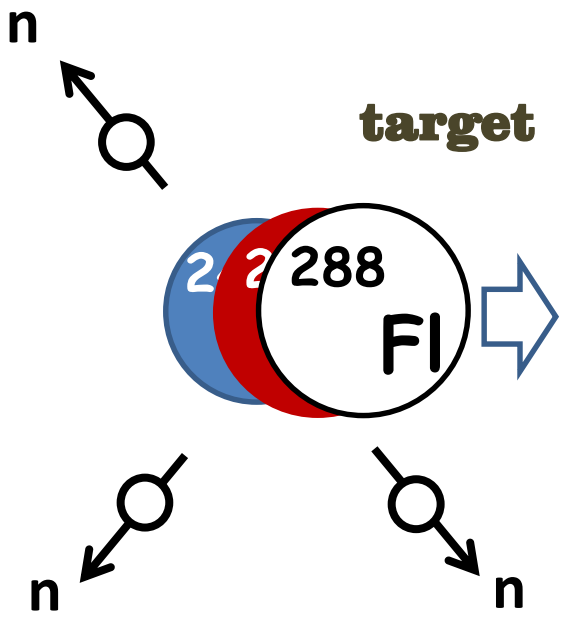
Ion charge distribution of Ca-48 extracted from 14 GHz ECR-ion source





New reaction of synthesis

artificial element produced with high flux nuclear reactor



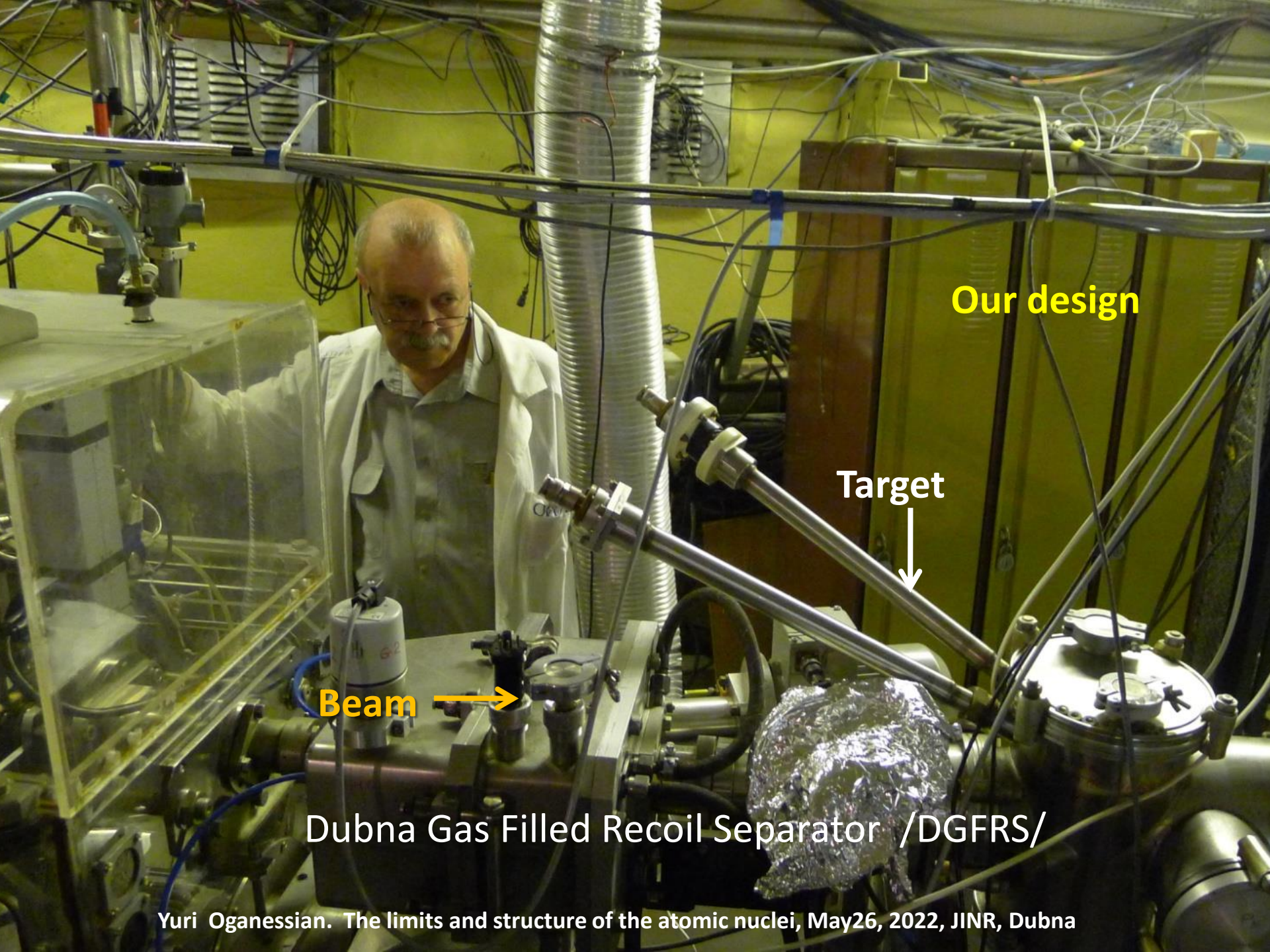
from accelerator

projectiles

to separator

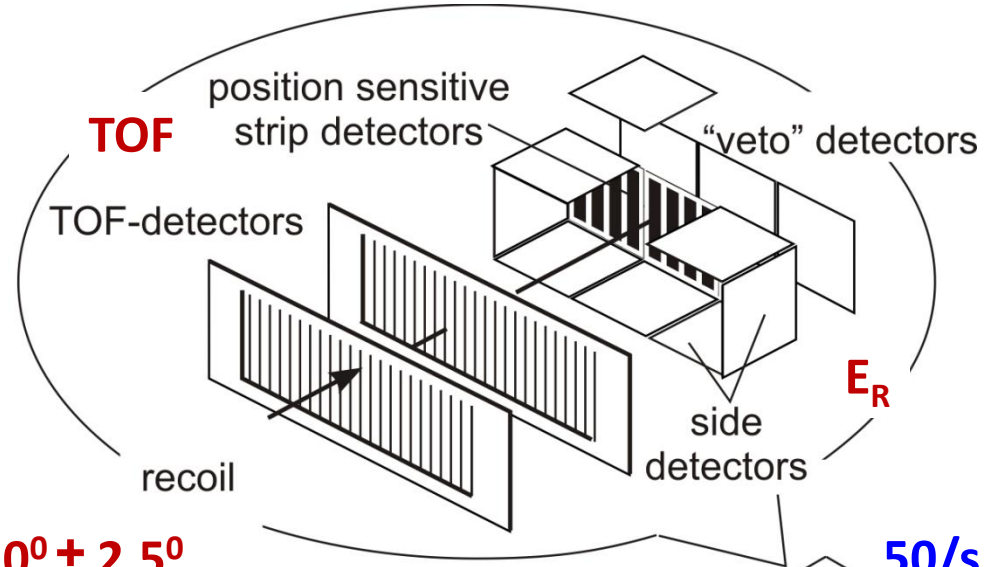
rare and very expensive isotope of Ca

fusion & cooling



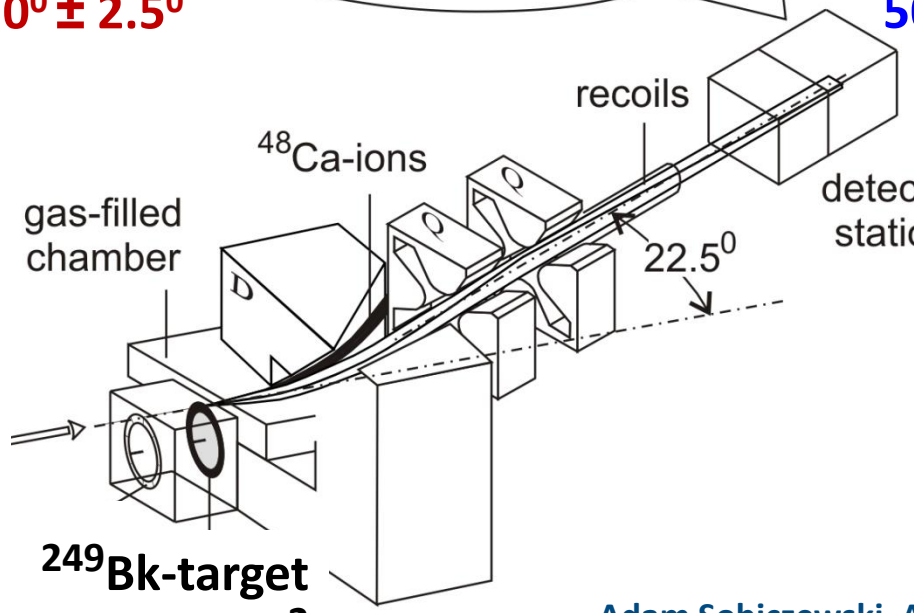
Dubna Gas Filled Recoil Separator /DGFRS/

Dubna Gas-Filled Recoil Separator



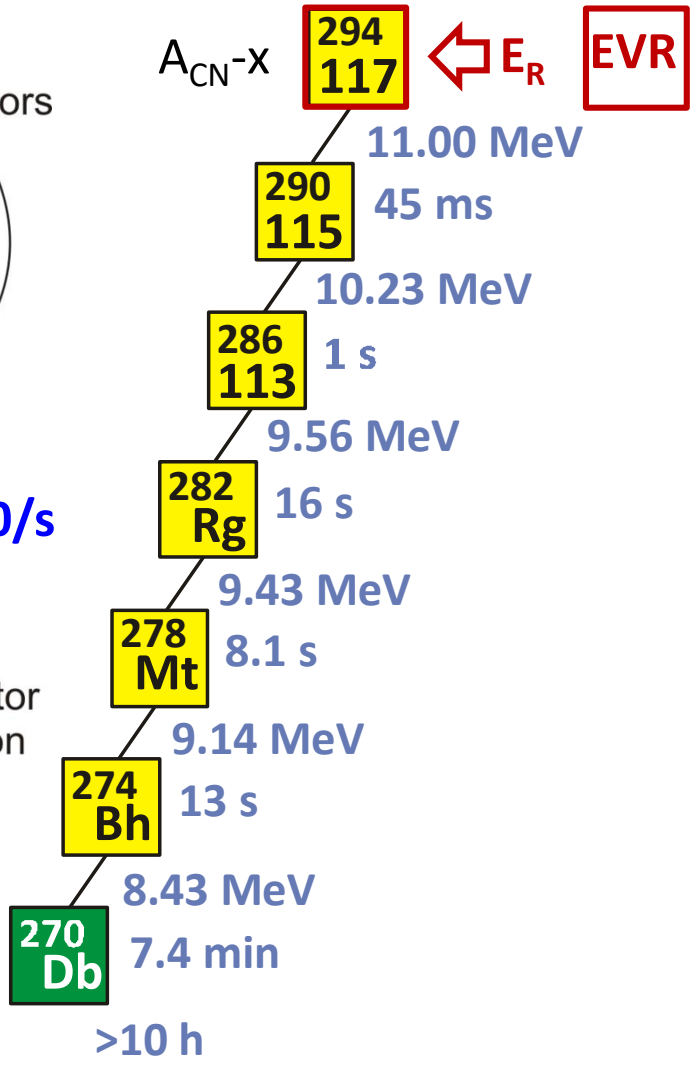
$\theta_R = 0^0 \pm 2.5^0$

50/s



^{48}Ca-beam
$5 \cdot 10^{12}$/s

^{249}Bk-target
350 μg/cm^2



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

22 года совместной работы

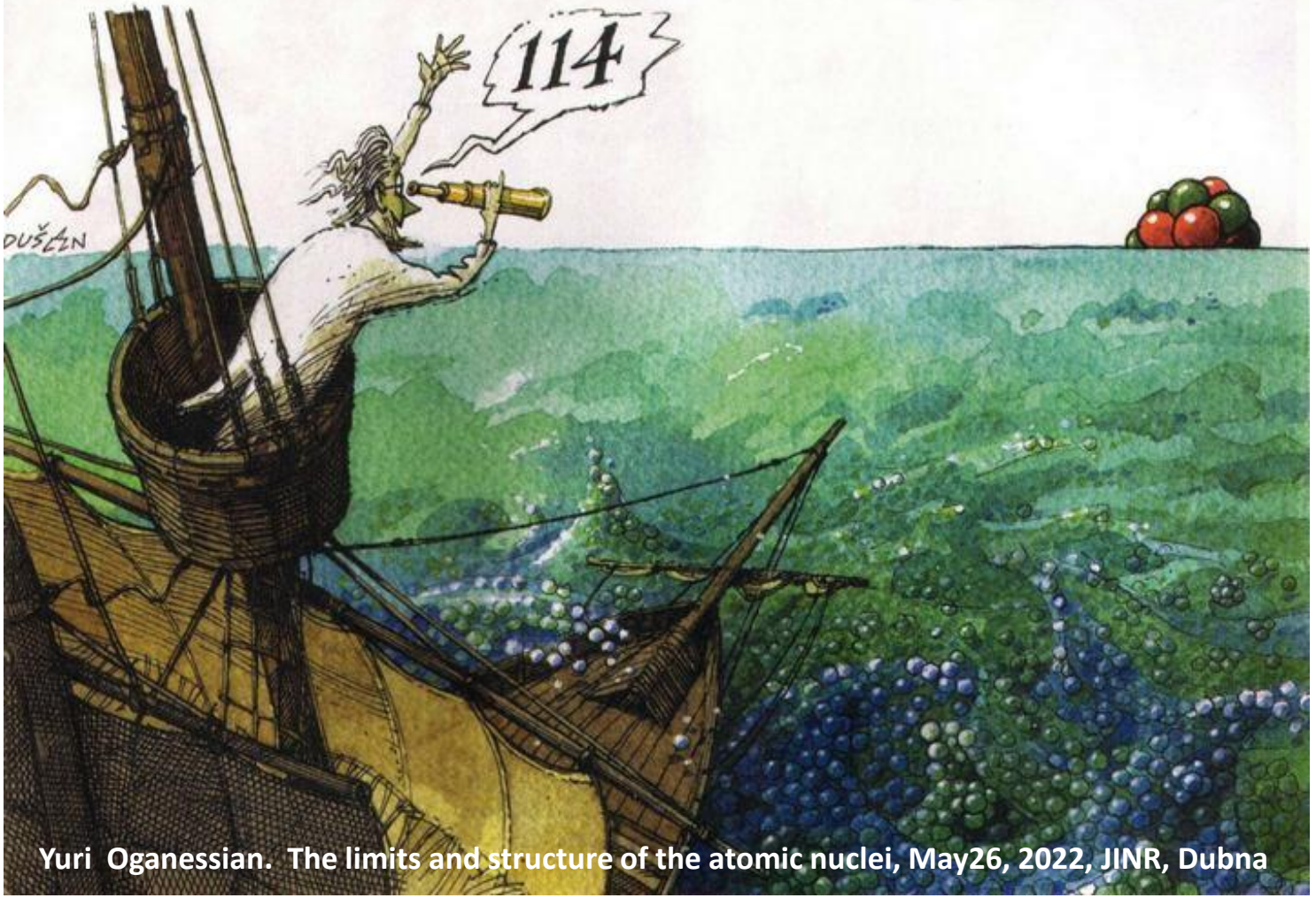
22 years teamwork

SCIENTIFIC AMERICAN

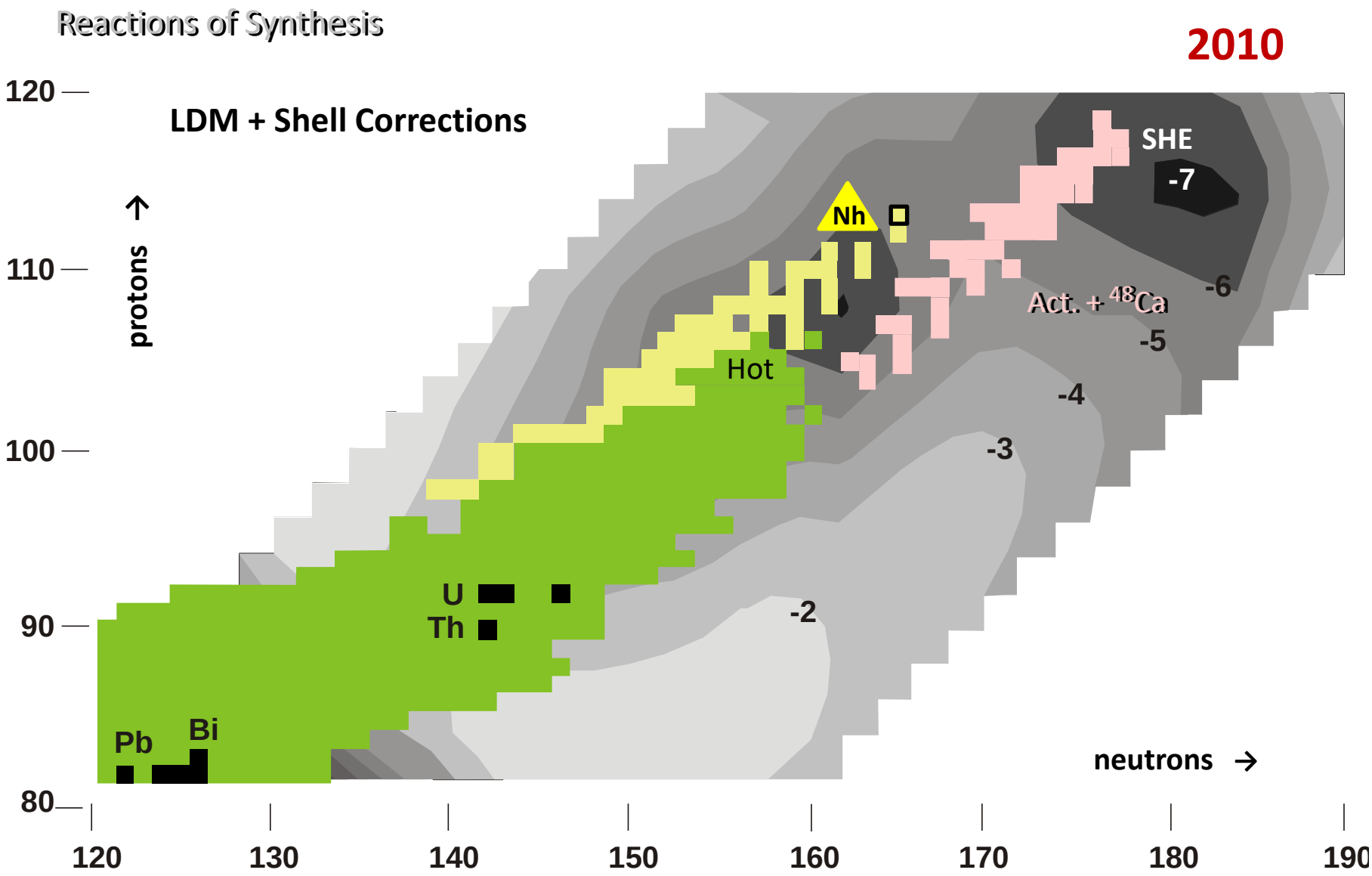
JANUARY 2000 VOL. 282 NO 1

2000

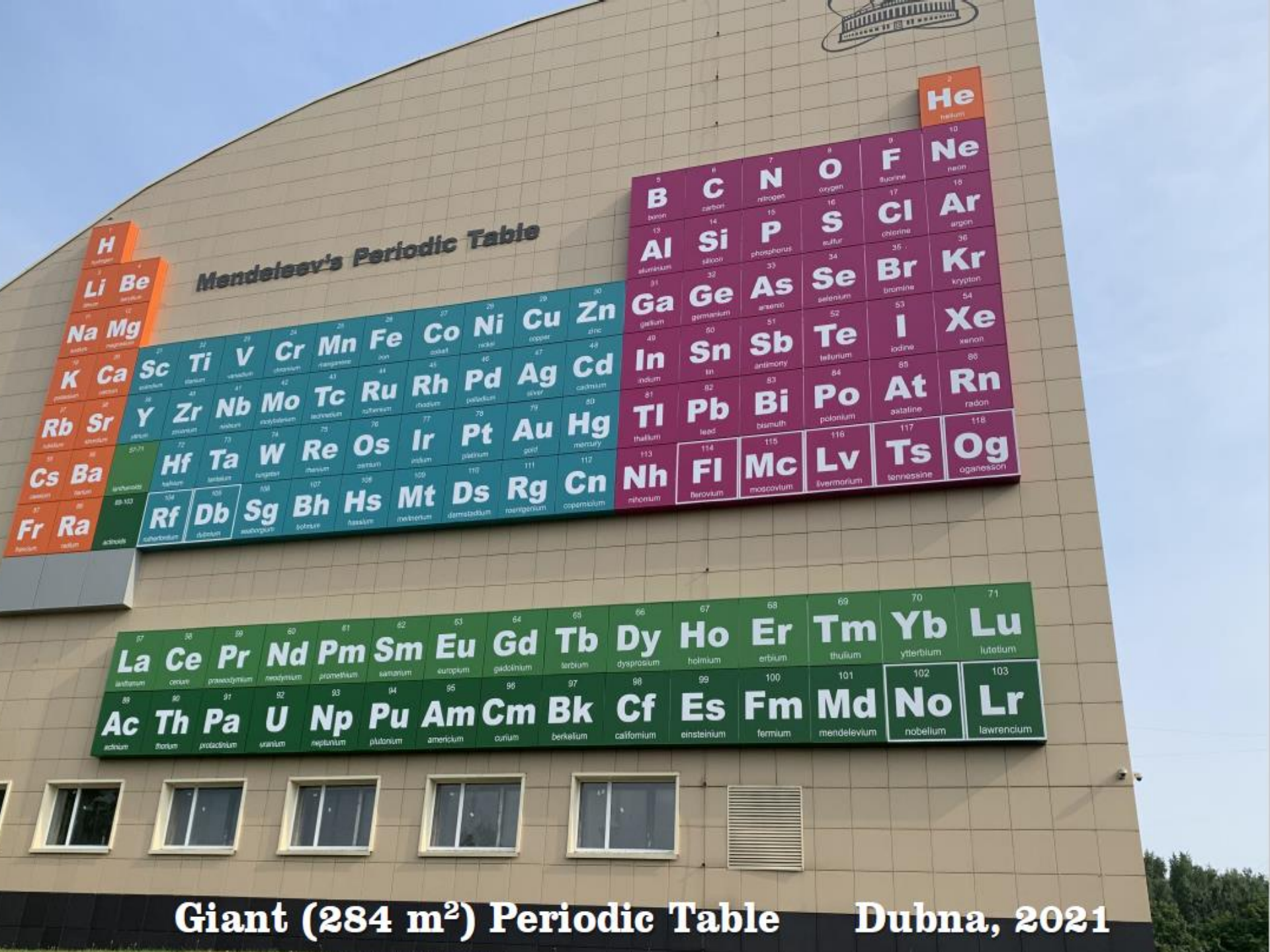
Voyage to SUPERHEAVY Island



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

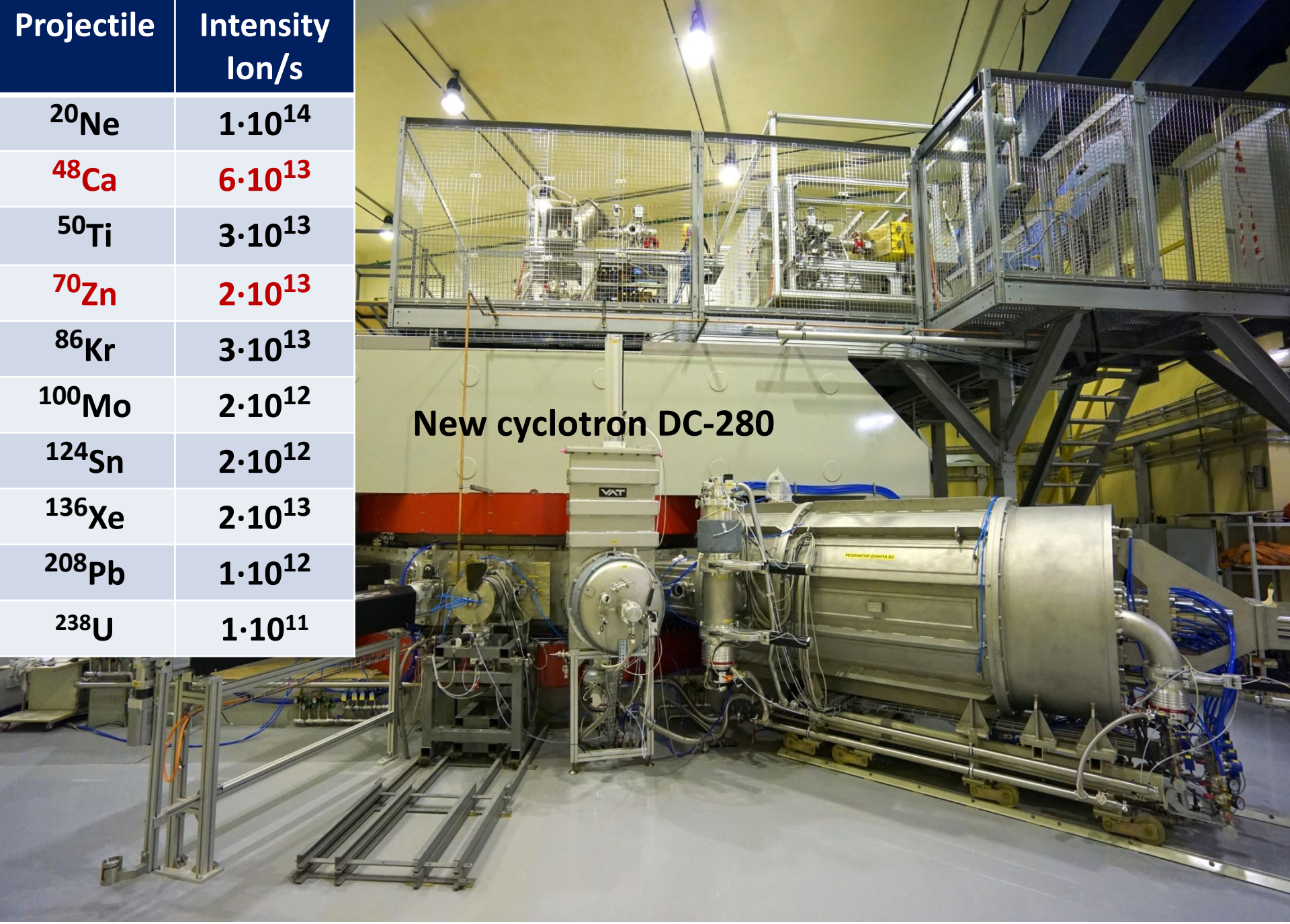


Yuri Oganessian. The limits and structure of the atomic nuclei, May26, 2022, JINR, Dubna


Mendeleev's Periodic Table
Giant (284 m²) Periodic Table Dubna, 2021

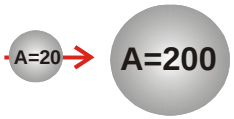
August 2017, Dubna

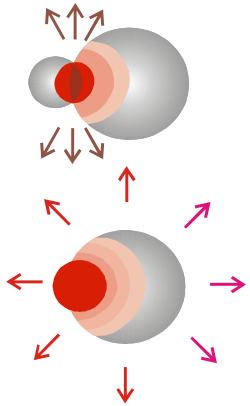
Projectile	Intensity Ion/s
^{20}Ne	$1 \cdot 10^{14}$
^{48}Ca	$6 \cdot 10^{13}$
^{50}Ti	$3 \cdot 10^{13}$
^{70}Zn	$2 \cdot 10^{13}$
^{86}Kr	$3 \cdot 10^{13}$
^{100}Mo	$2 \cdot 10^{12}$
^{124}Sn	$2 \cdot 10^{12}$
^{136}Xe	$2 \cdot 10^{13}$
^{208}Pb	$1 \cdot 10^{12}$
^{238}U	$1 \cdot 10^{11}$



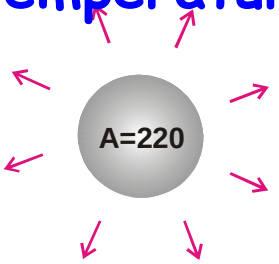
Epilogue

After it has been shown that a nucleus can endure

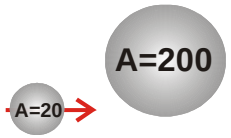


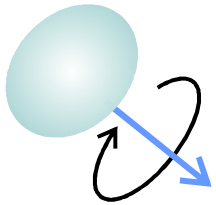


high temperature



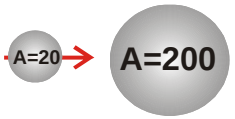
T ~ few MeV (>10^{10} K)





huge rotation

spin up to 66h



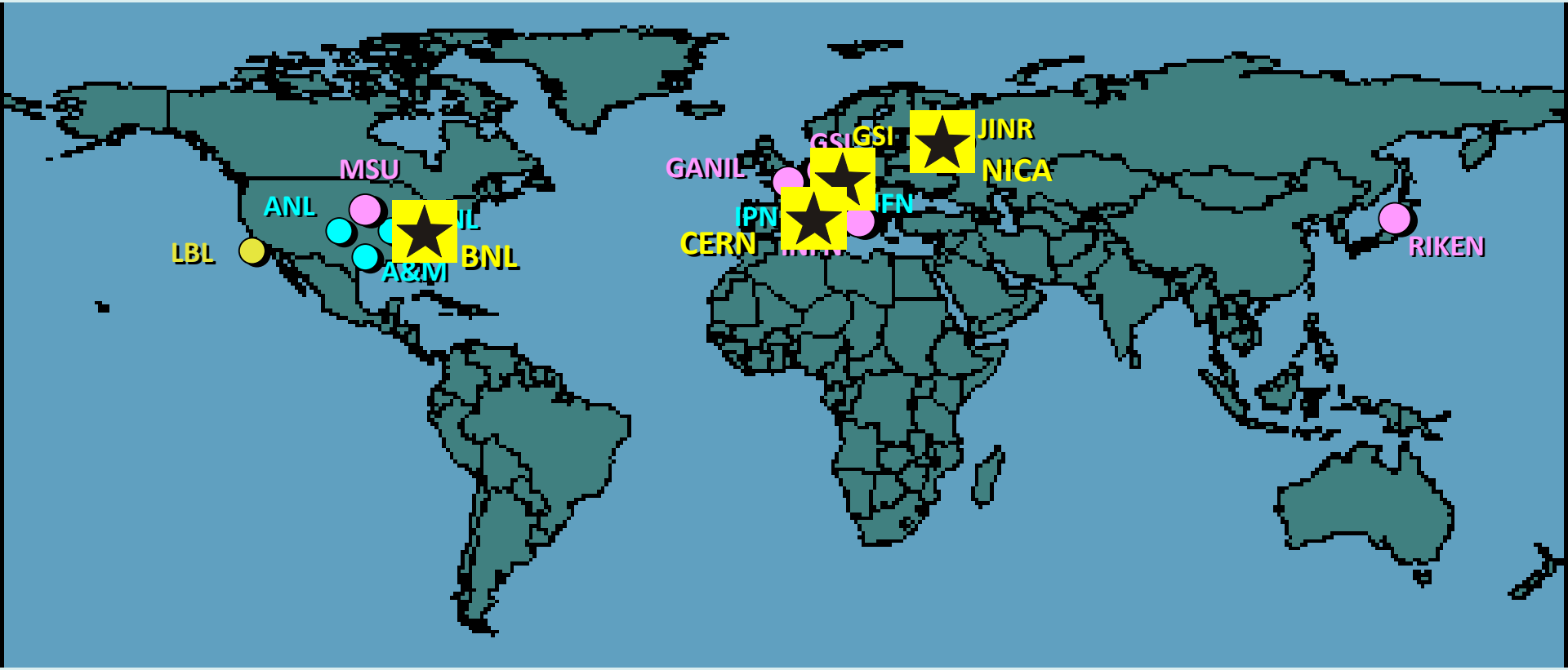
a giant deformation

axes up to 3:1

and finally survive….

Heavy ion physics:

from the beginning to now…



- Pioneers
- Heavy ion accelerators
- Heavy Ion National Laboratories
- ★ Heavy Ion Colliders

Мечты

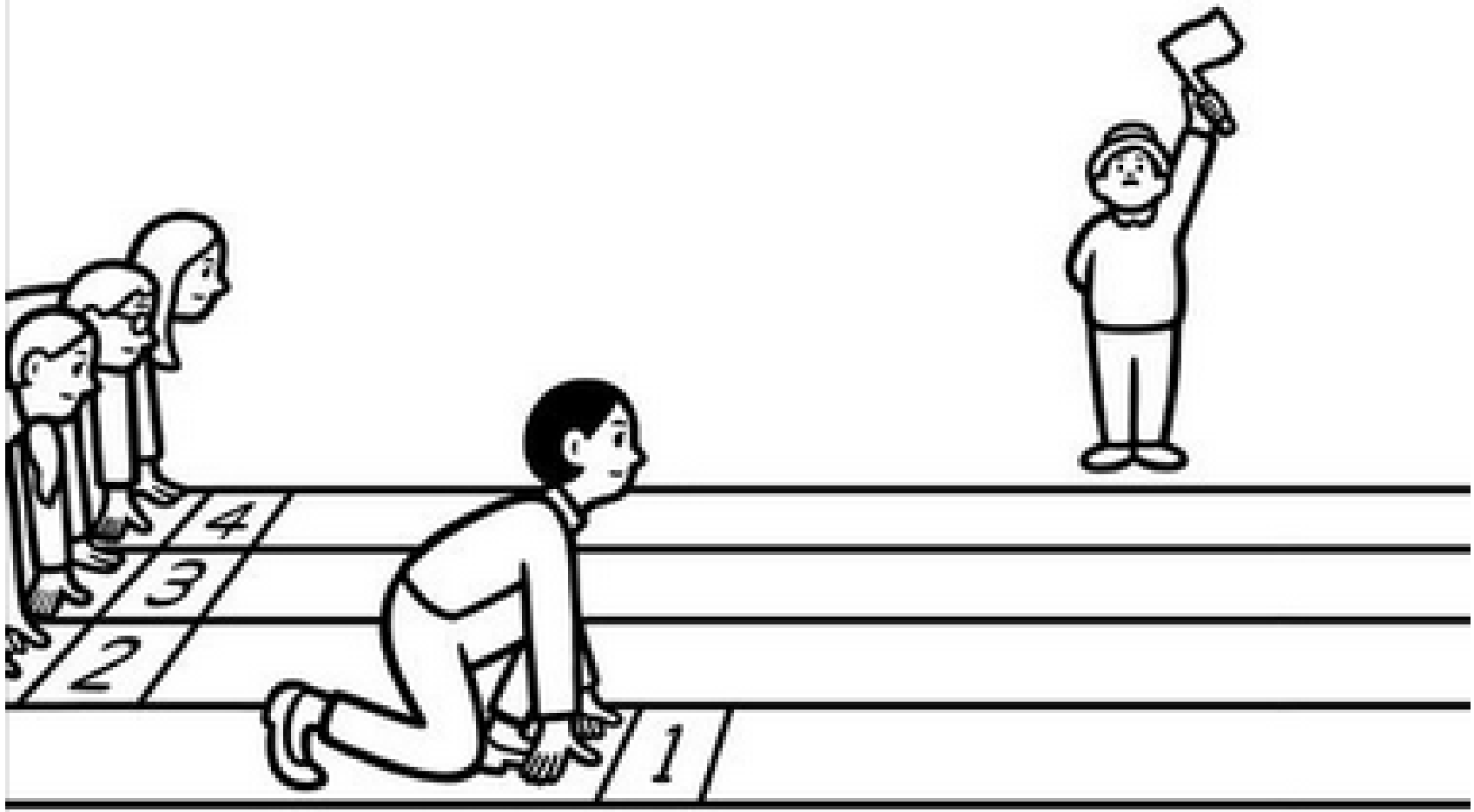
Как-то Г.Н. Флеров спросил меня, знаю ли я самую заветную мечту экспериментатора?

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!