

Passion for Science
2019

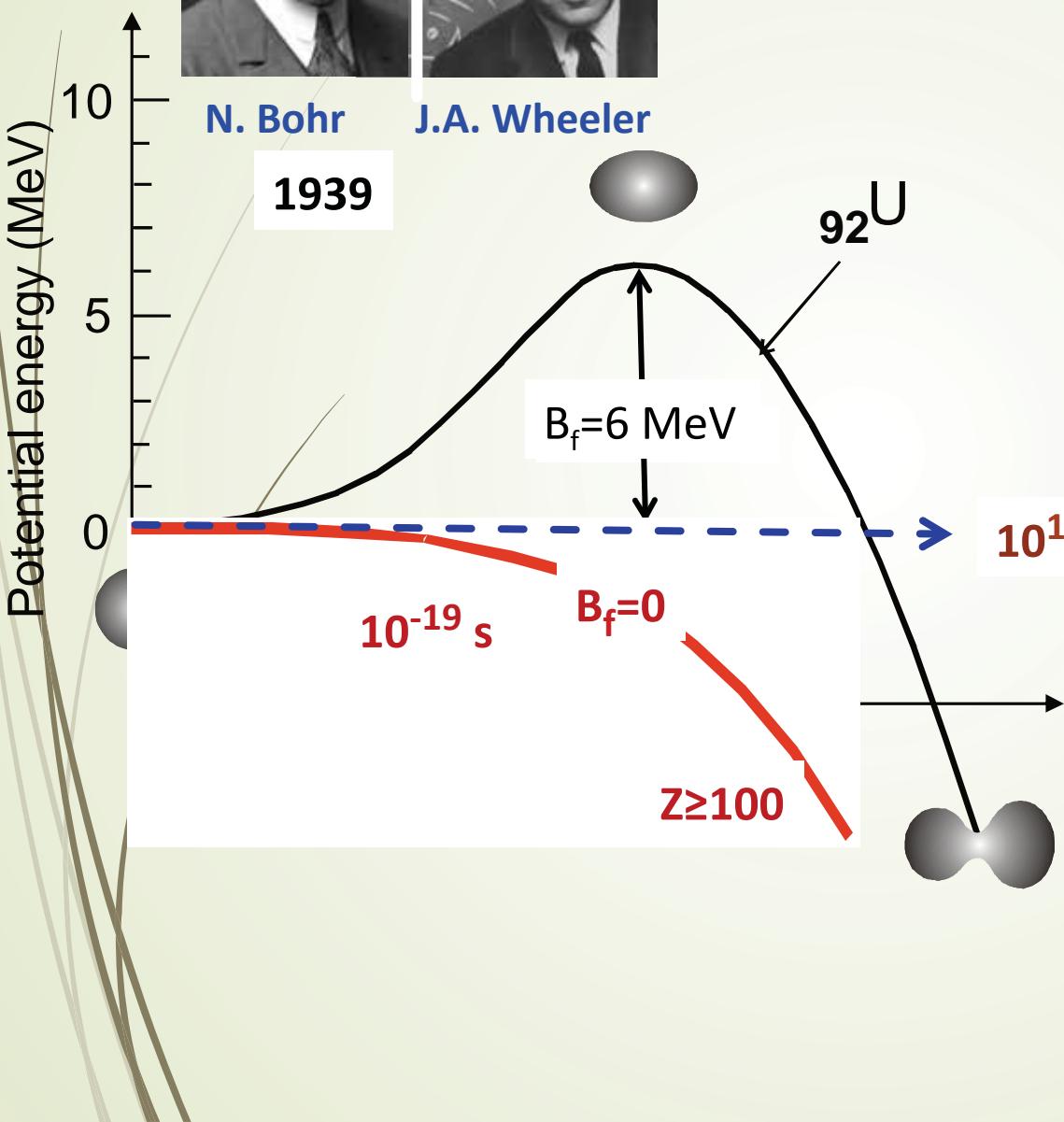


The discovery of new heavy elements

Mikhail ITKIS, Yuri OGANESSION

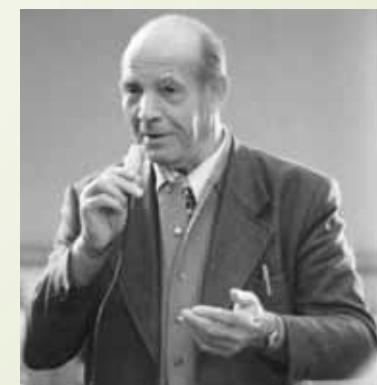
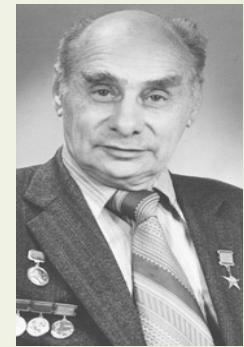
November 06-07, 2019 Bologna, Italy

Nuclear fission



1940

G.N. Flerov



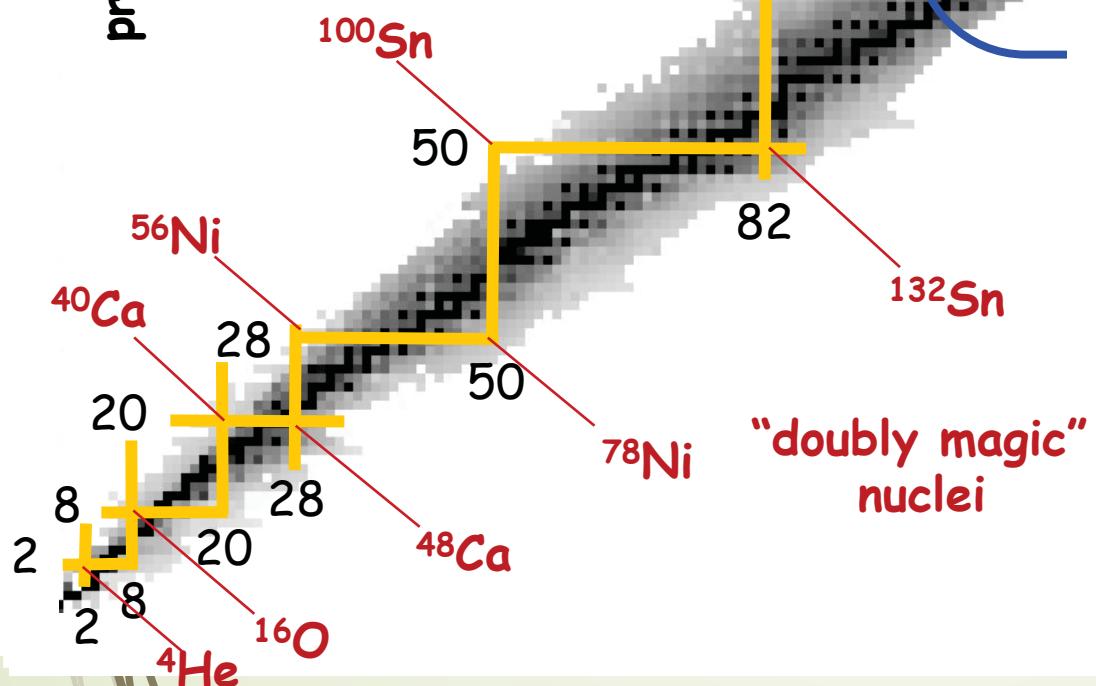
K.A. Petrzhak

Nuclear shells and the “magic numbers”



About 3000 nuclei are known today

protons



“doubly magic” nuclei

$Z=82$

^{208}Pb

126

Now let us consider the nuclei heavier than lead

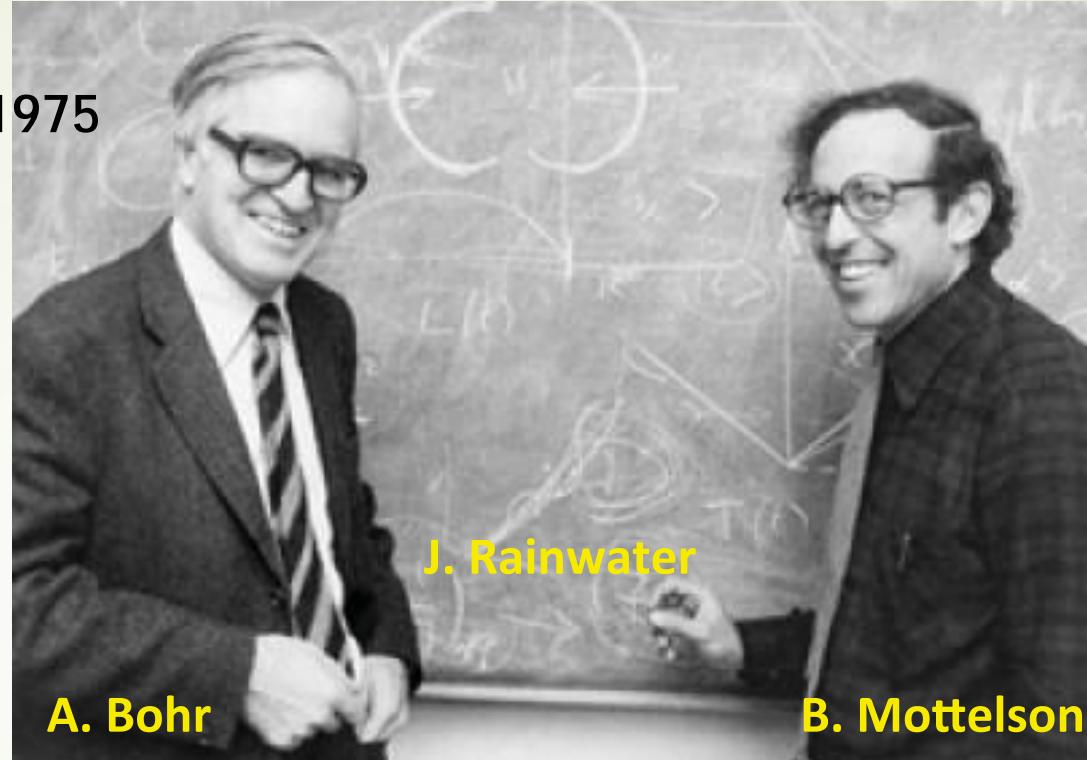
Spontaneous Fission

Among them
9 nuclei are doubly magic

neutrons



The Nobel Prize in Physics 1975



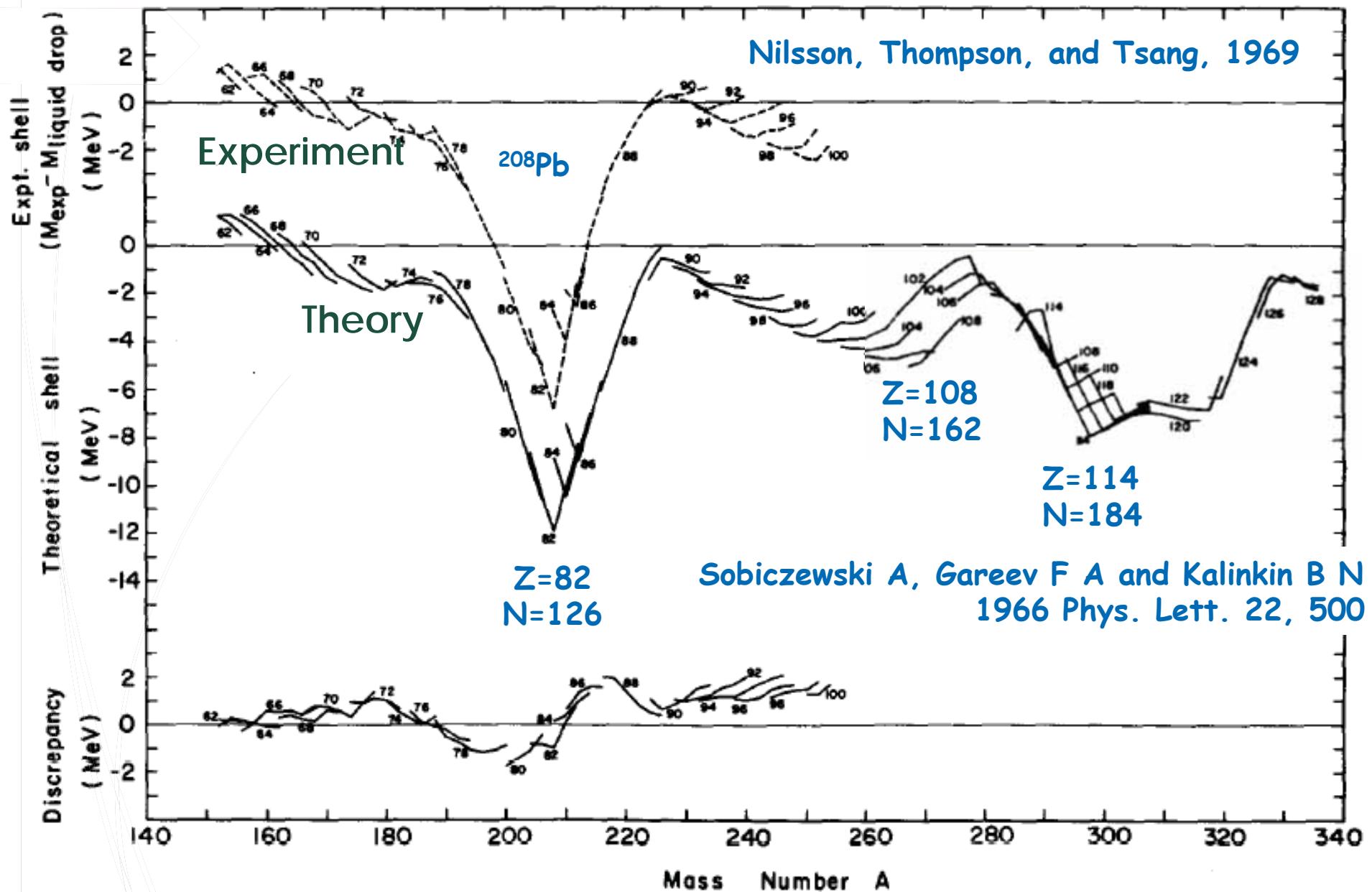
A. Bohr

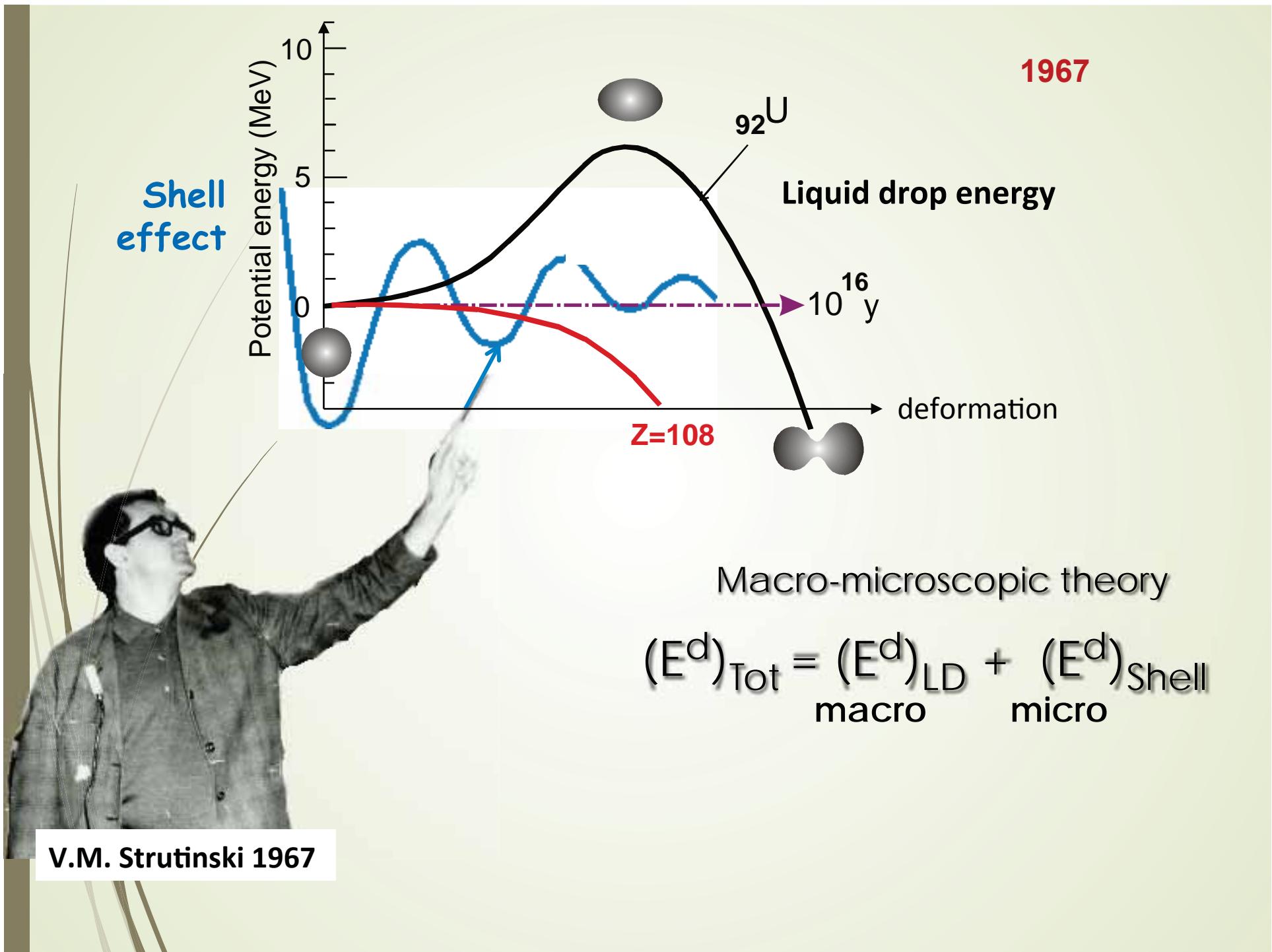
J. Rainwater

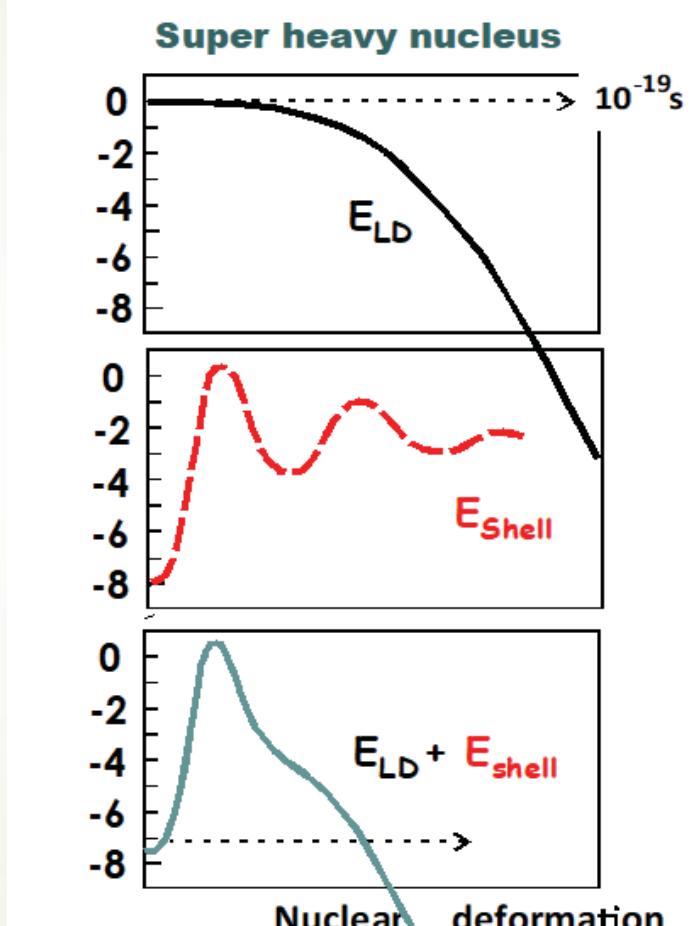
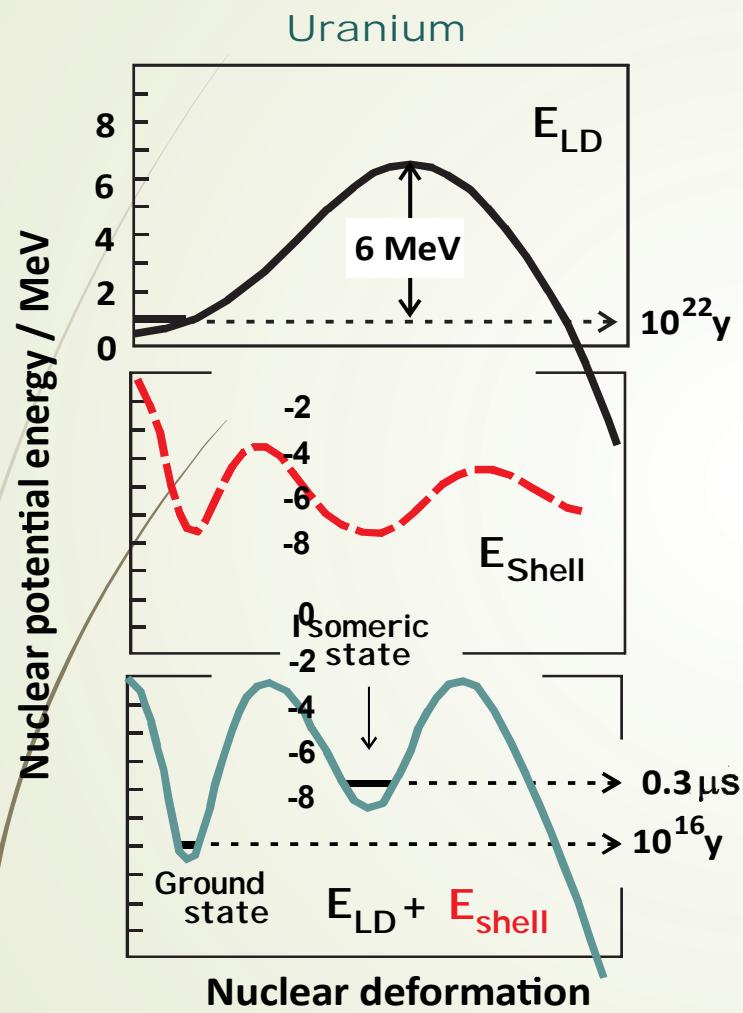
B. Mottelson

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

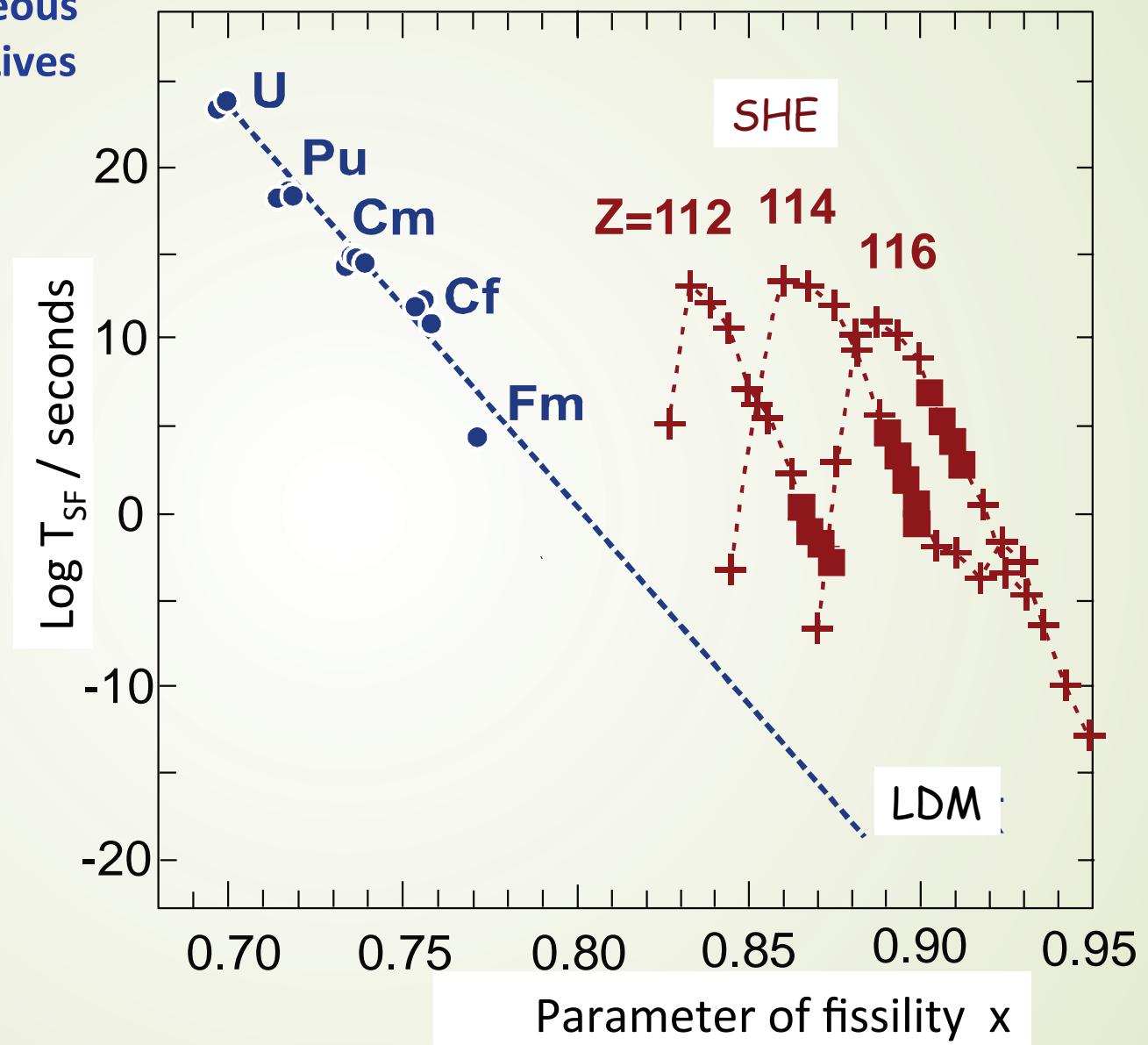
Shell effect in the nuclear ground states (mass defect)

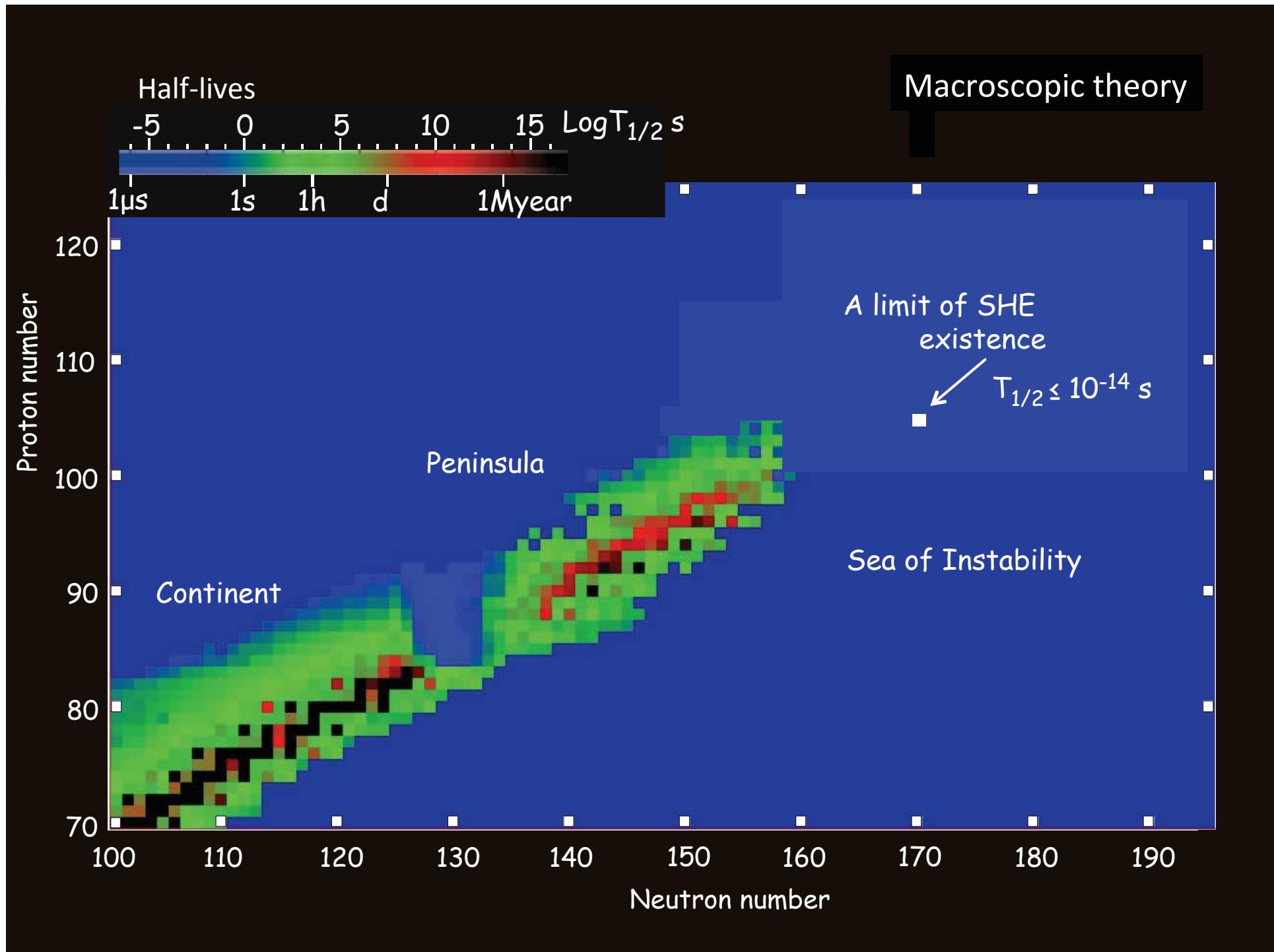


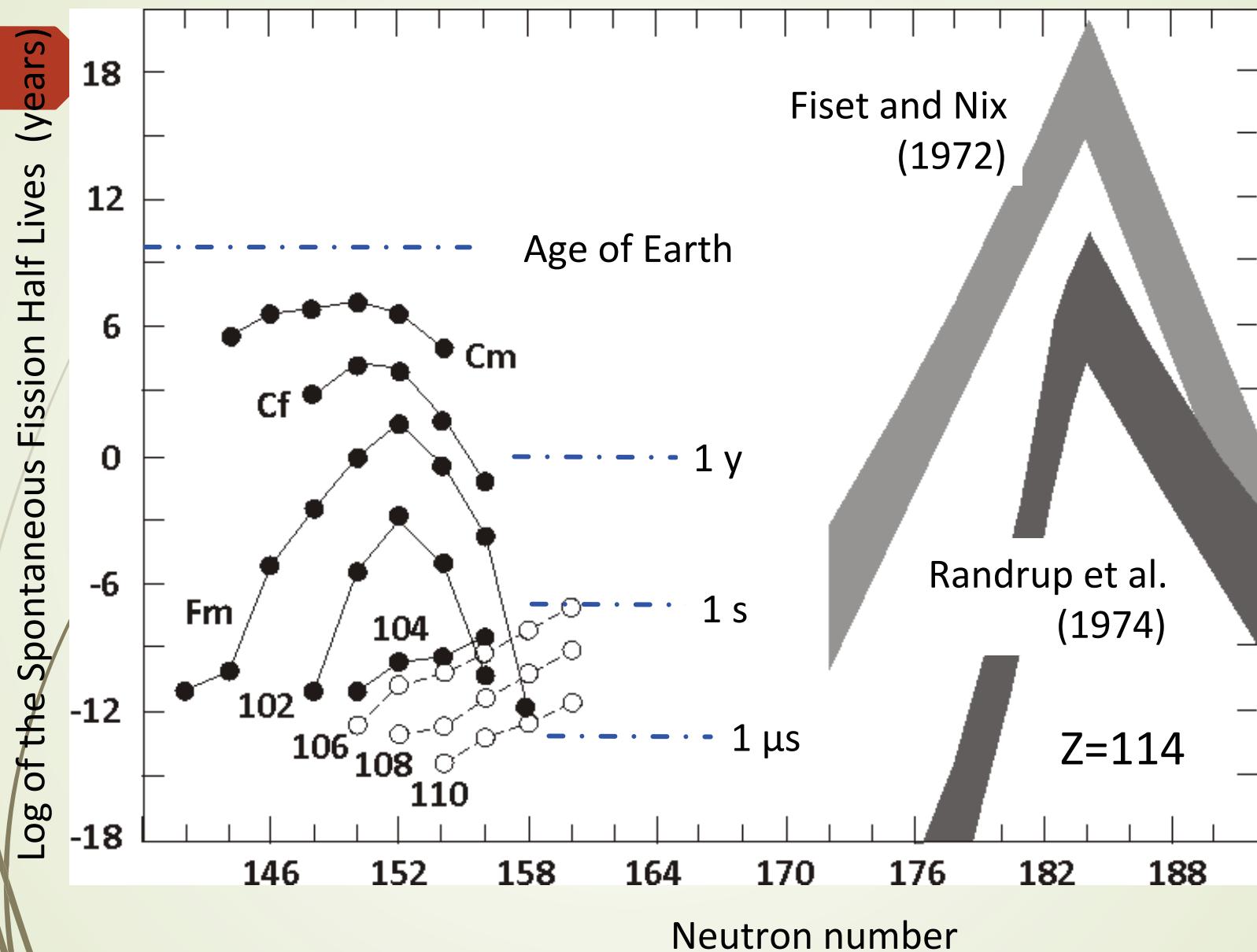


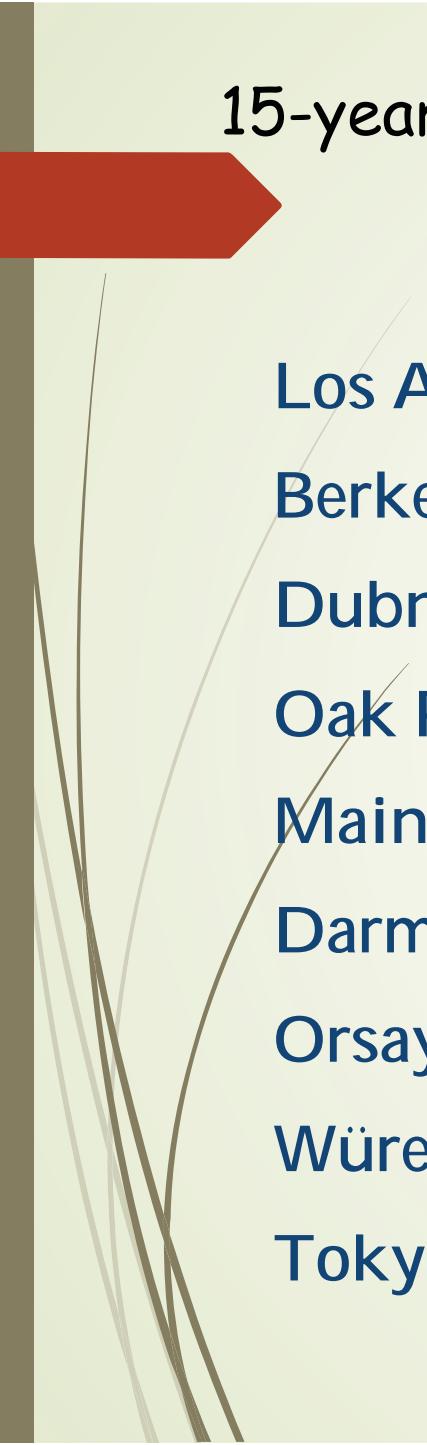


Partial Spontaneous
Fission Half-Lives









15-year long assault on the "Islands of Stability"

1970-1985

Los Alamos (USA)

Berkeley (USA)

Dubna (JINR)

Oak Ridge (USA)

Mainz (Germany)

Darmstadt (Germany)

Orsay (France)

Würenlingen (Switzerland)

Tokyo (Japan) some later

The task of every laboratory was:

To find the method of producing

Search in nature:

earth/lunar objects, cosmic rays,

Artificial synthesis:

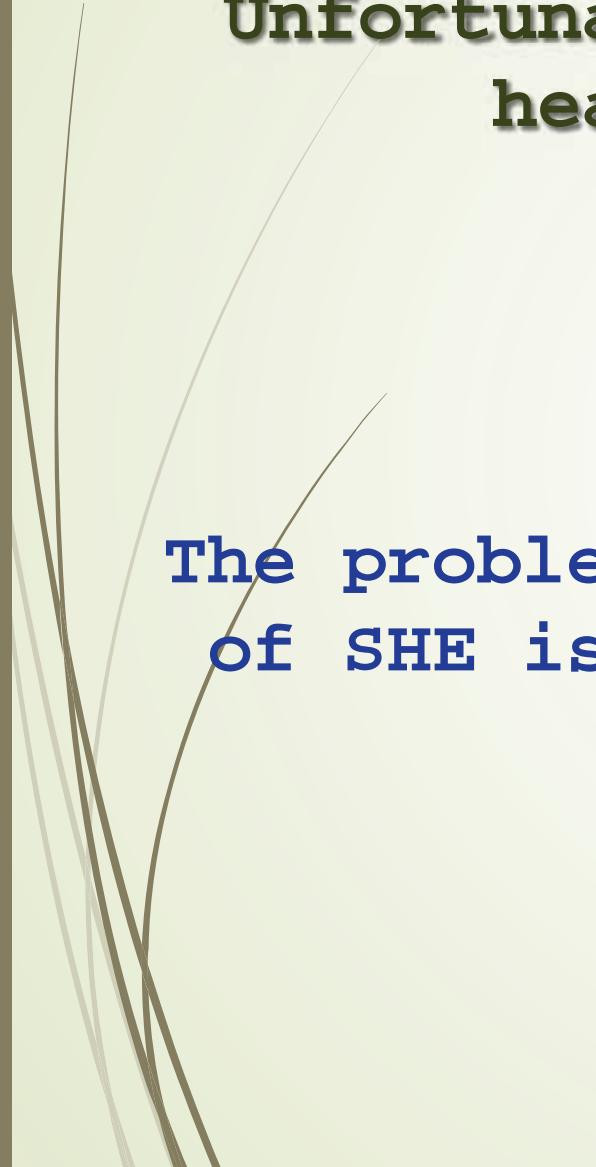
**high-flux reactor,
nuclear explosion,
powerful accelerator**

To develop setups:

**separator/detector,
spectrometers,
chemical methods, etc.**

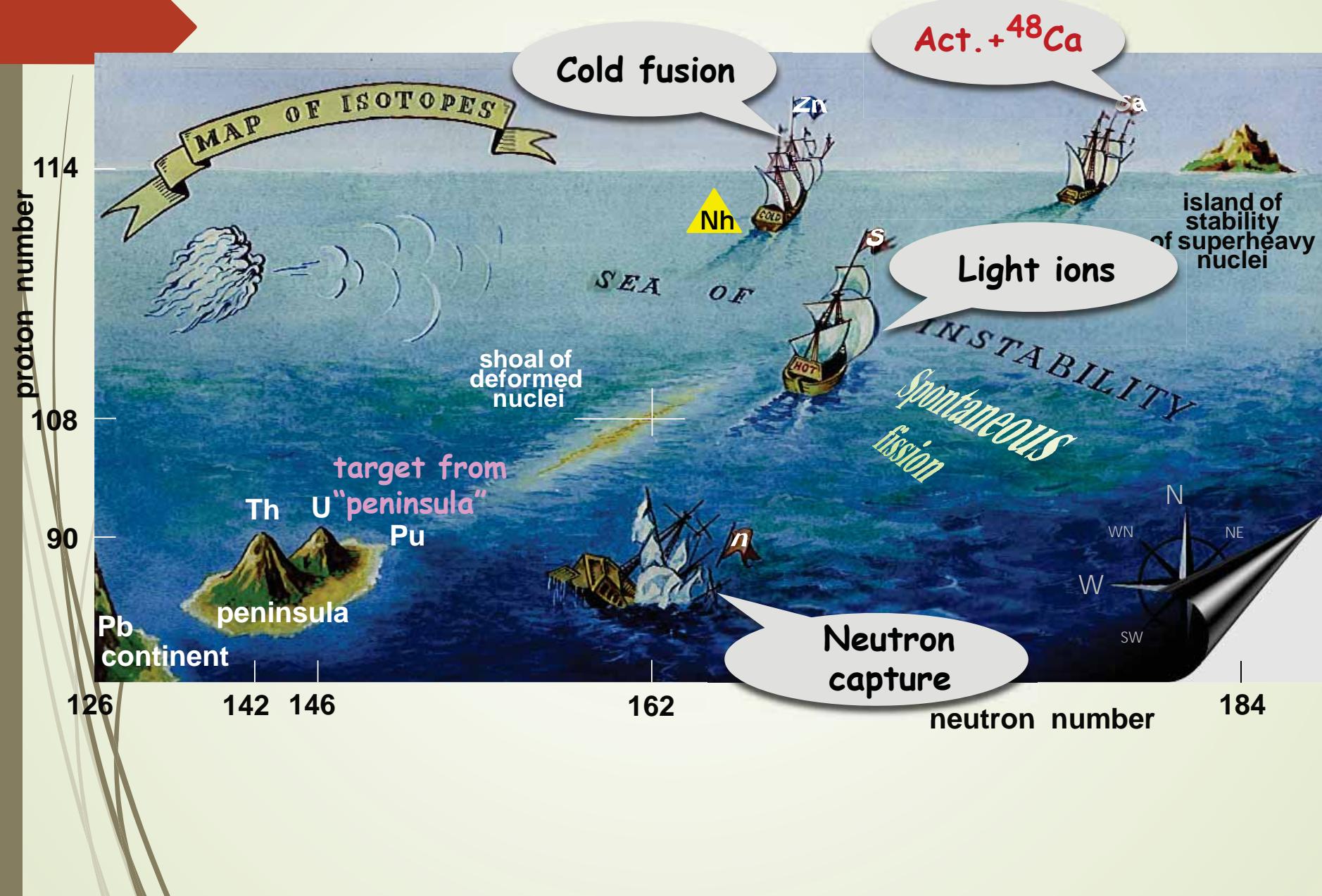


Unfortunately in all attempts super heavy elements were not found



The problem of artificial synthesis of SHE is related with reaction of synthesis

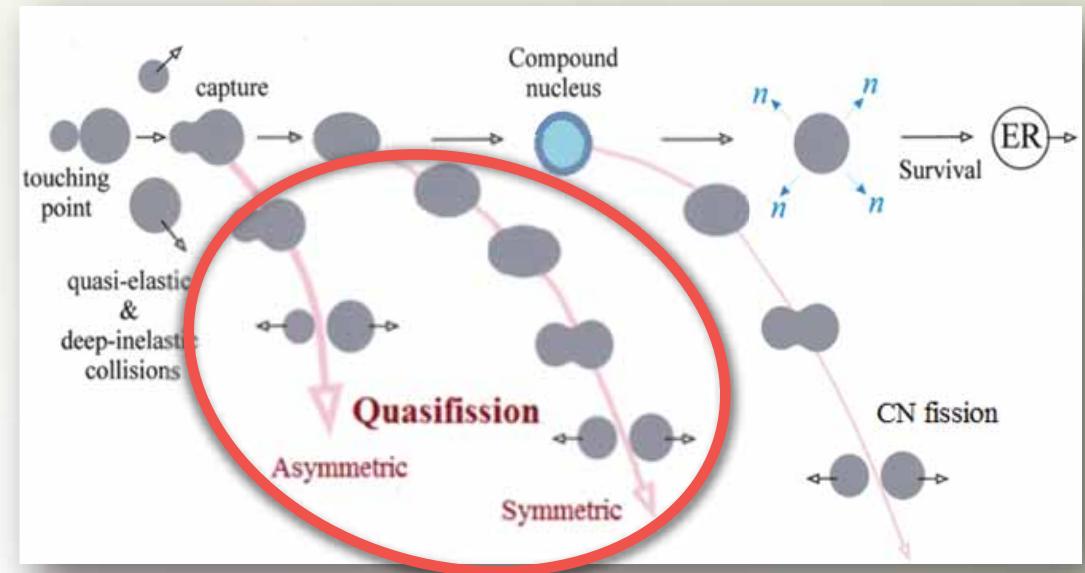
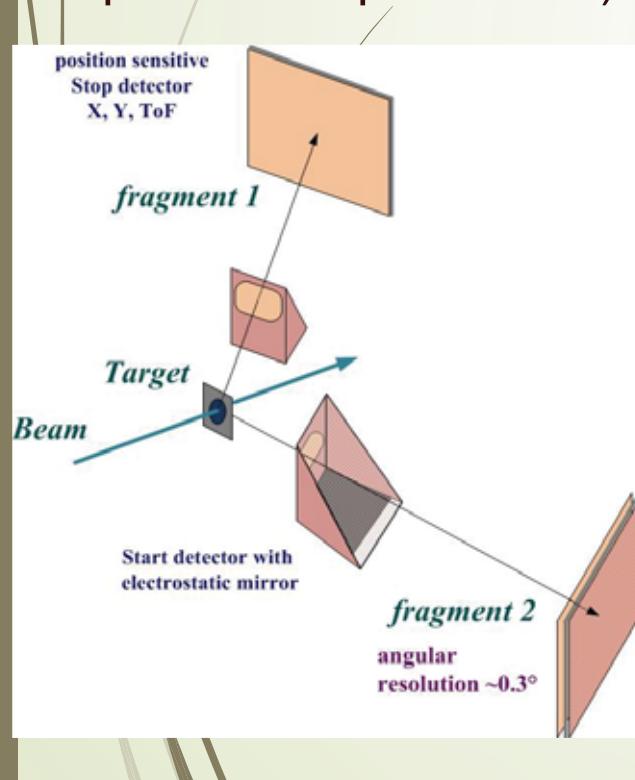
Reactions of synthesis



Reaction channels in the collisions of heavy ions

Double arm Time-of-Flight spectrometer CORSET

The study of binary channel of heavy-ion-induced reactions (fusion-fission, quasifission and deep-inelastic processes).



Time resolution	150-180 ps
ToF base	10-30 cm
ToF arm rotation range	15°-165°
Solid angle	100 -200 msr
Angular resolution	0.3°
Mass resolution	2-4 u

Cold fusion reactions



$$E_{\text{c.m.}}/E_{\text{Bass}} = 1.03$$



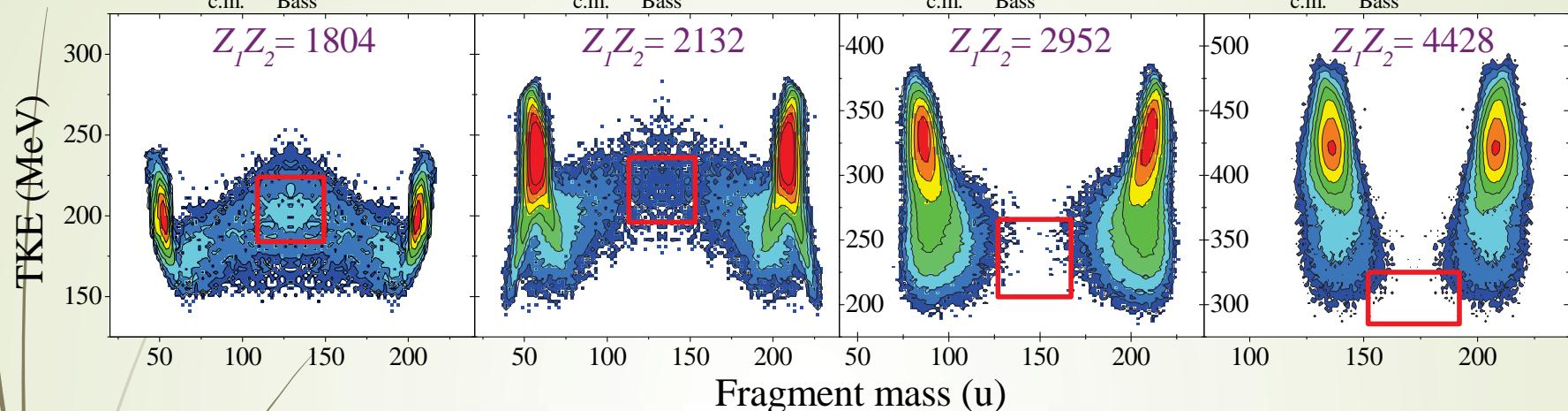
$$E_{\text{c.m.}}/E_{\text{Bass}} = 1.05$$



$$E_{\text{c.m.}}/E_{\text{Bass}} = 1.09$$



$$E_{\text{c.m.}}/E_{\text{Bass}} = 1.00$$



Hot fusion reactions



$$E_{\text{c.m.}}/E_{\text{Bass}} = 1.06$$



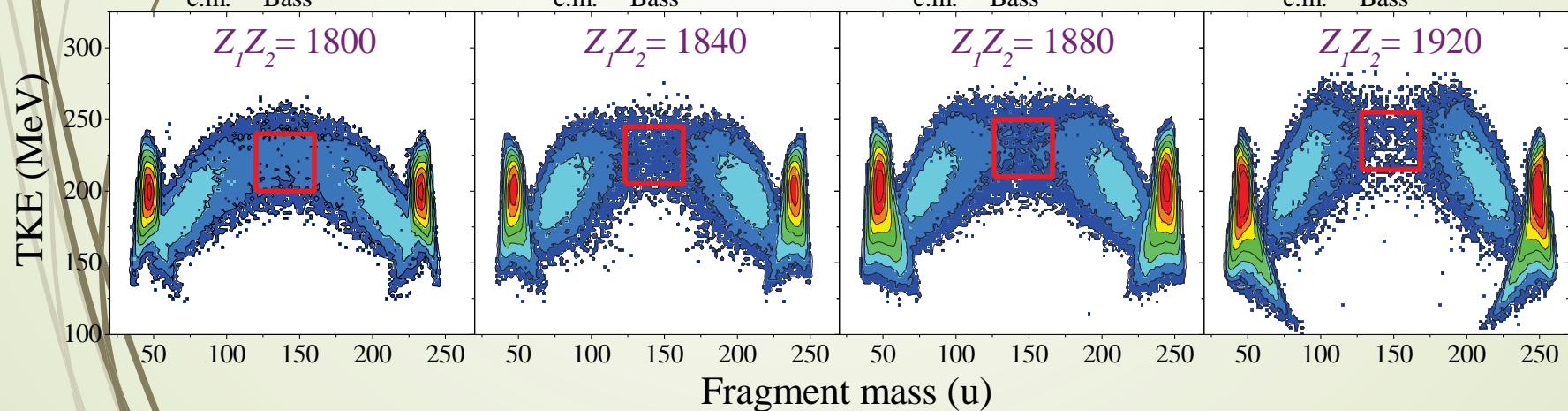
$$E_{\text{c.m.}}/E_{\text{Bass}} = 1.02$$



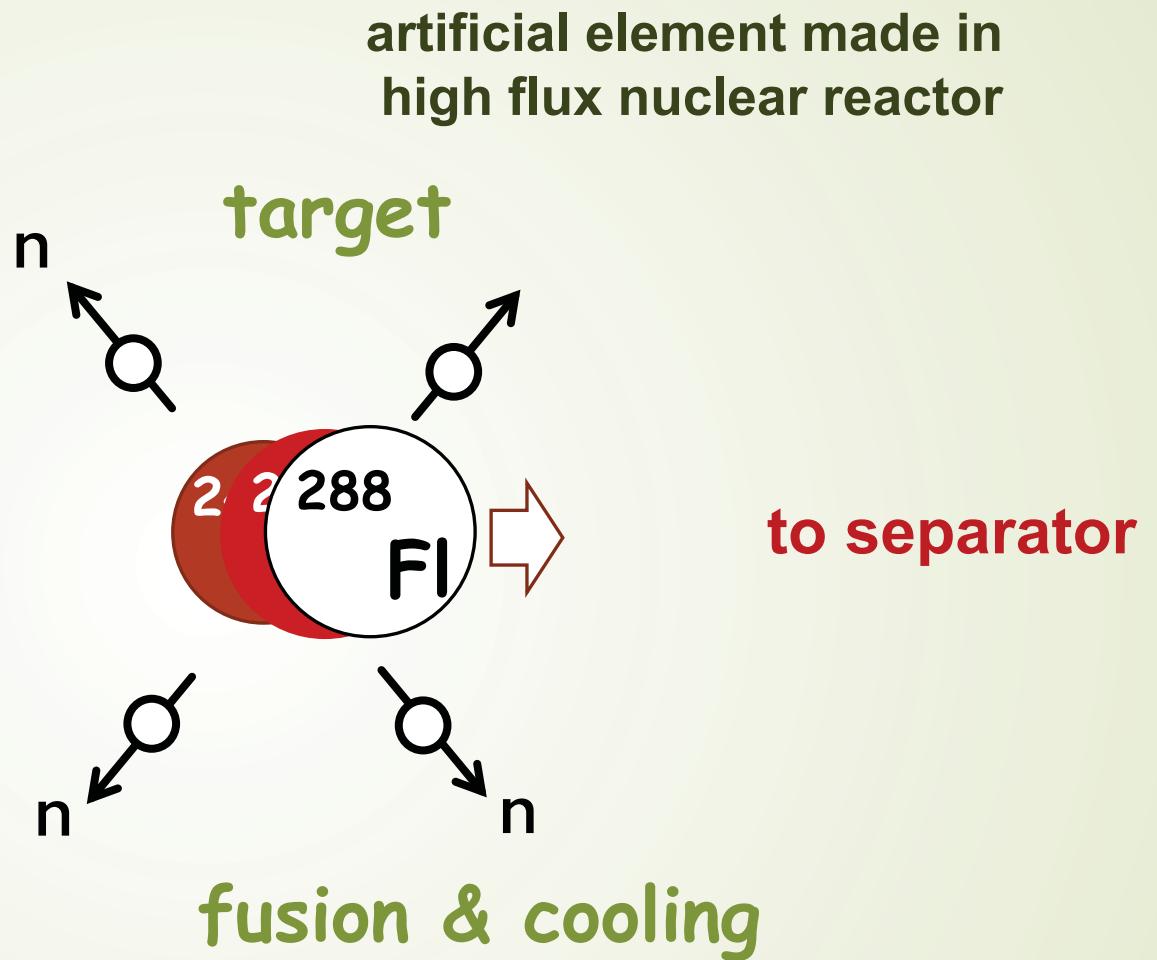
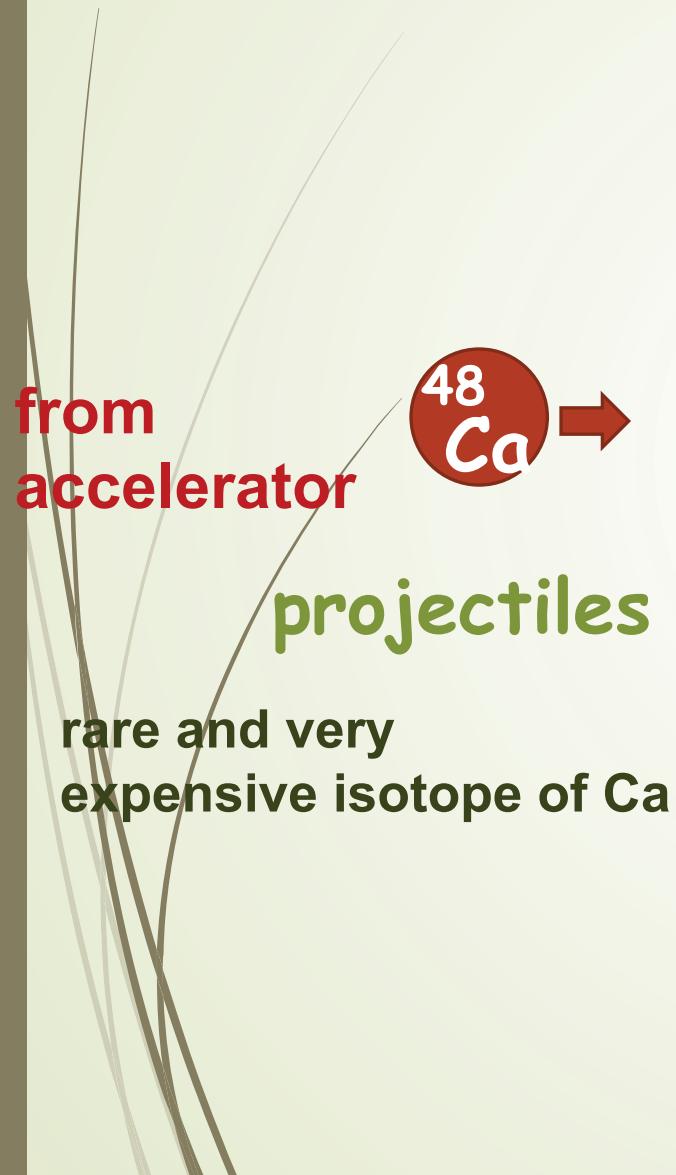
$$E_{\text{c.m.}}/E_{\text{Bass}} = 1.03$$



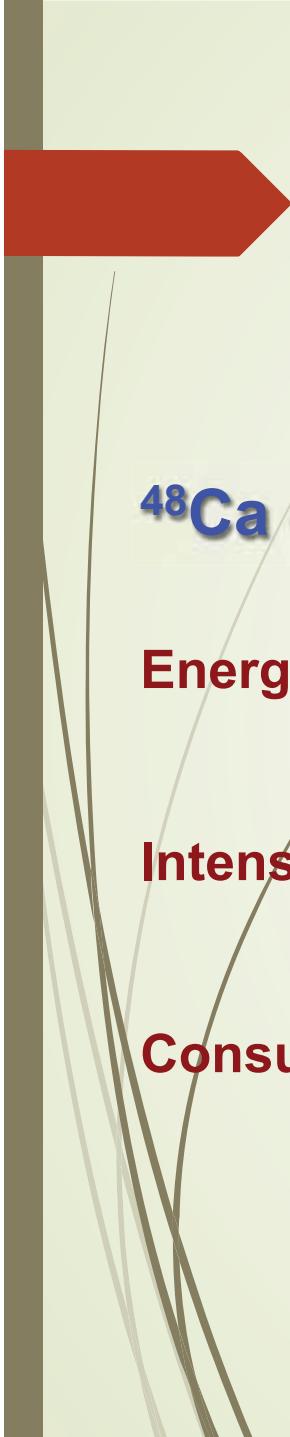
$$E_{\text{c.m.}}/E_{\text{Bass}} = 1.00$$



Reaction of synthesis



artificial element made in high flux nuclear reactor



Targets	Isotope	Facility	Isotope enrichment (%)
	^{233}U	SM-3	99.97
	^{238}U	-	
$^{48}\text{Ca} -\text{beam}$	^{237}Np	SM-3	99.3
Energy: 235-250 MeV	^{242}Pu	SM-3	99.98
	^{244}Pu	HFIR	98.6
Intensity: 1.0-1.2 pμA	^{243}Am	SM-3 / HFIR	99.9
Consumption: 0.5 mg/h	^{245}Cm	SM-3 / HFIR	98.7
	^{248}Cm	HFIR	97.4
	^{249}Bk	HFIR	97.3
	^{249}Cf	SM-3 / HFIR	97.3

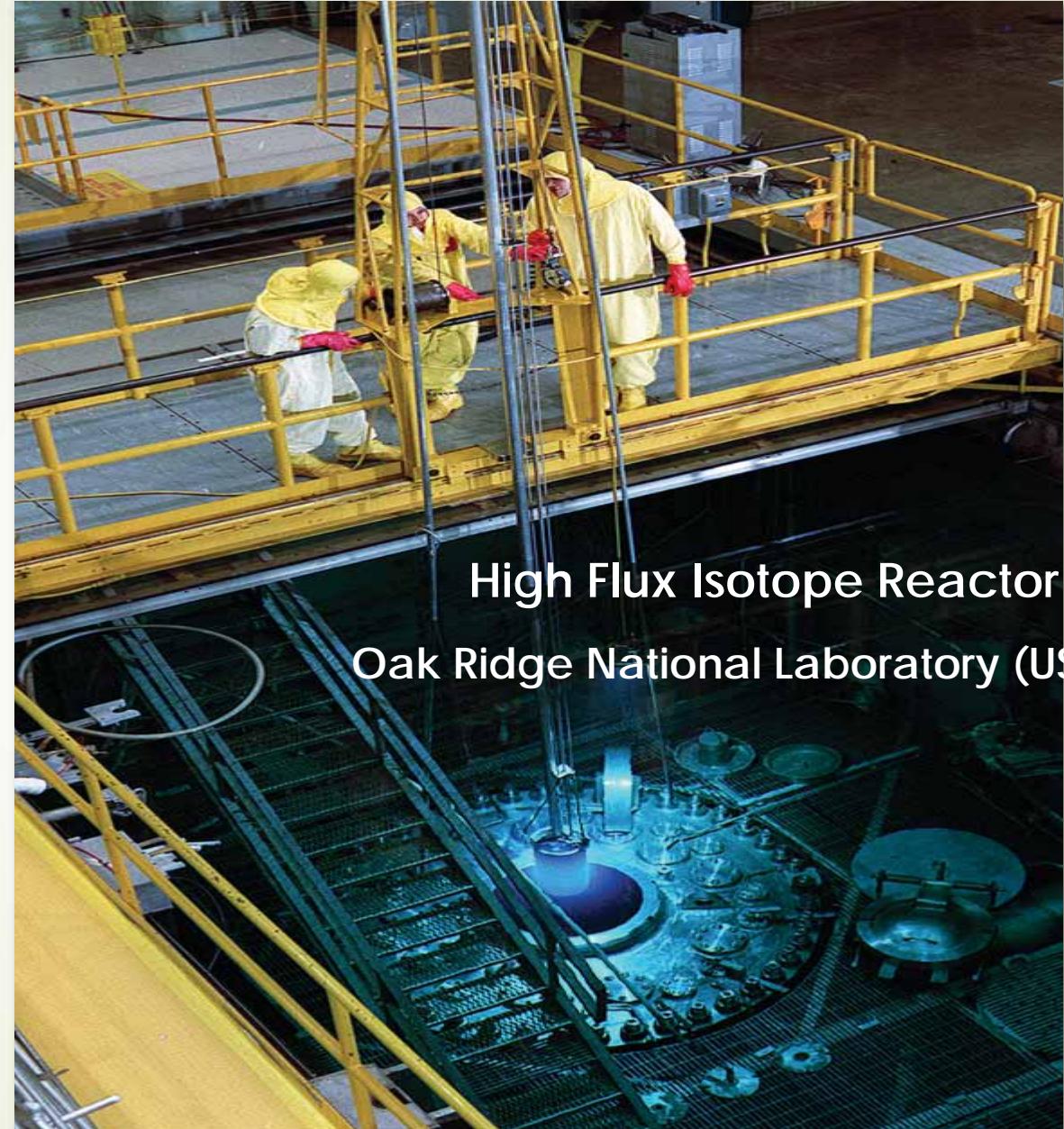
BEAM



TARGET

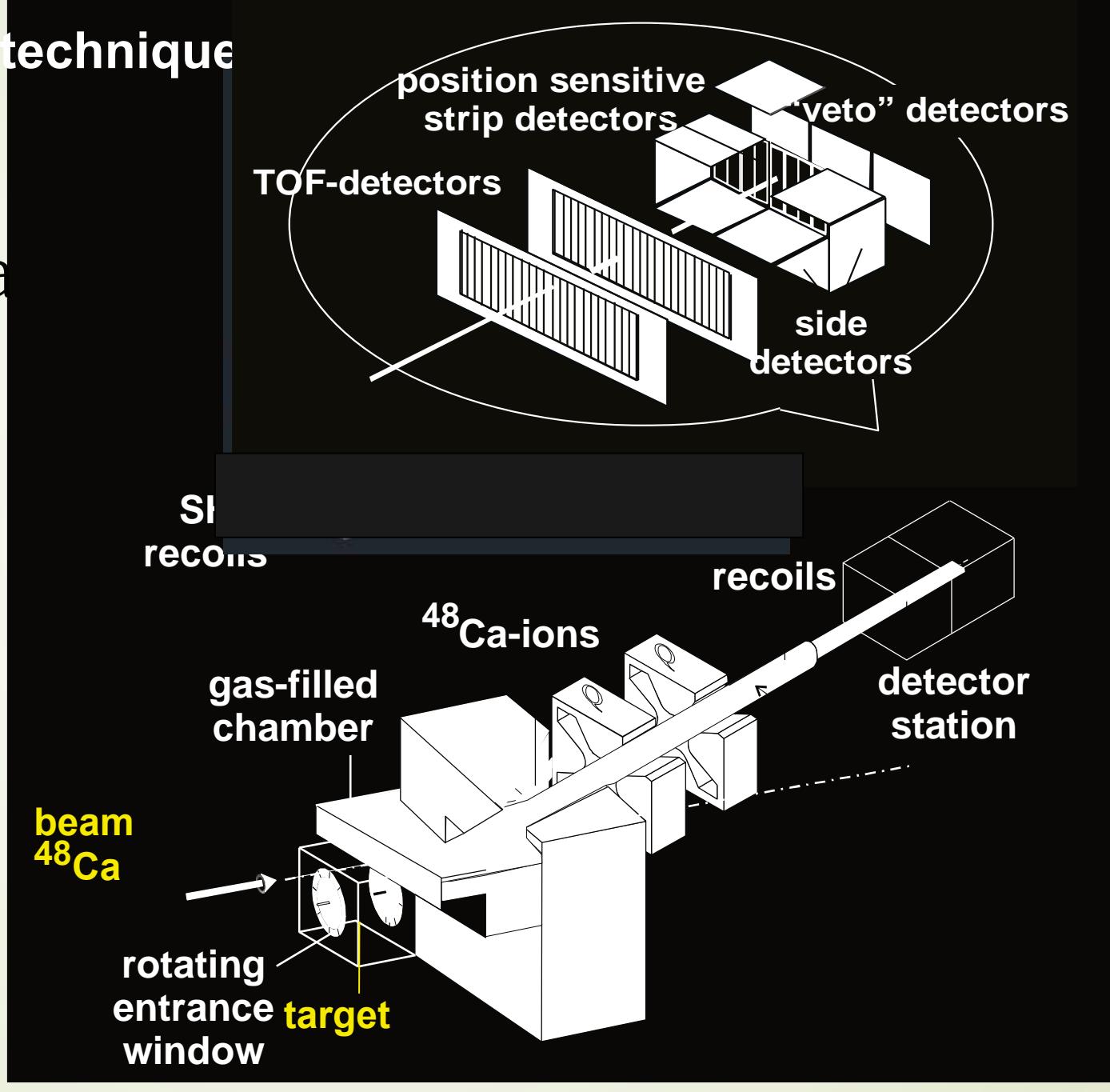
50 Ci

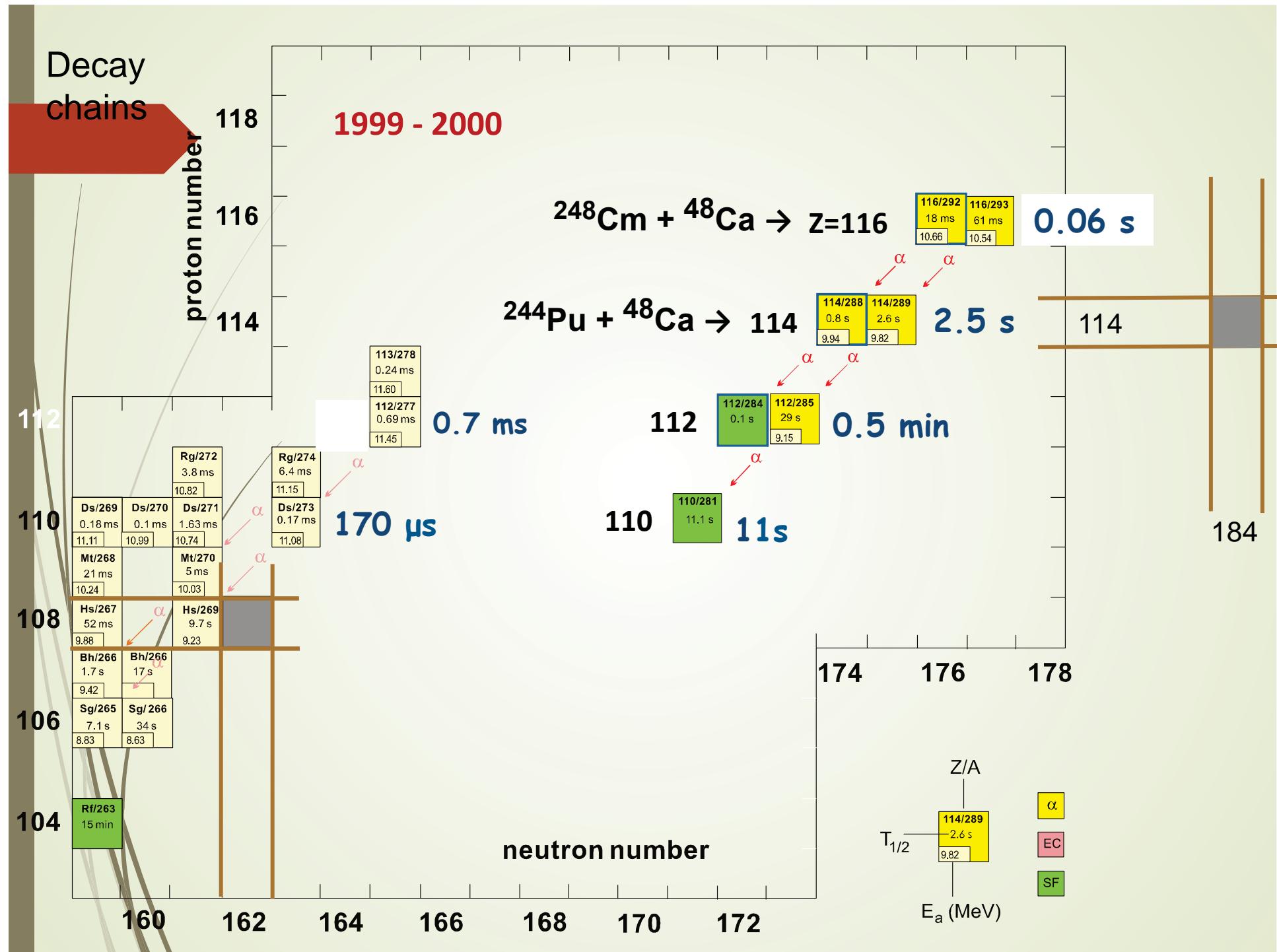
22 mg of ^{249}Bk
have been produced in
250 days irradiation
at HFIR (ORNL)



Experimental I technique

Dubna
Gas
Filled
Recoil
Separator

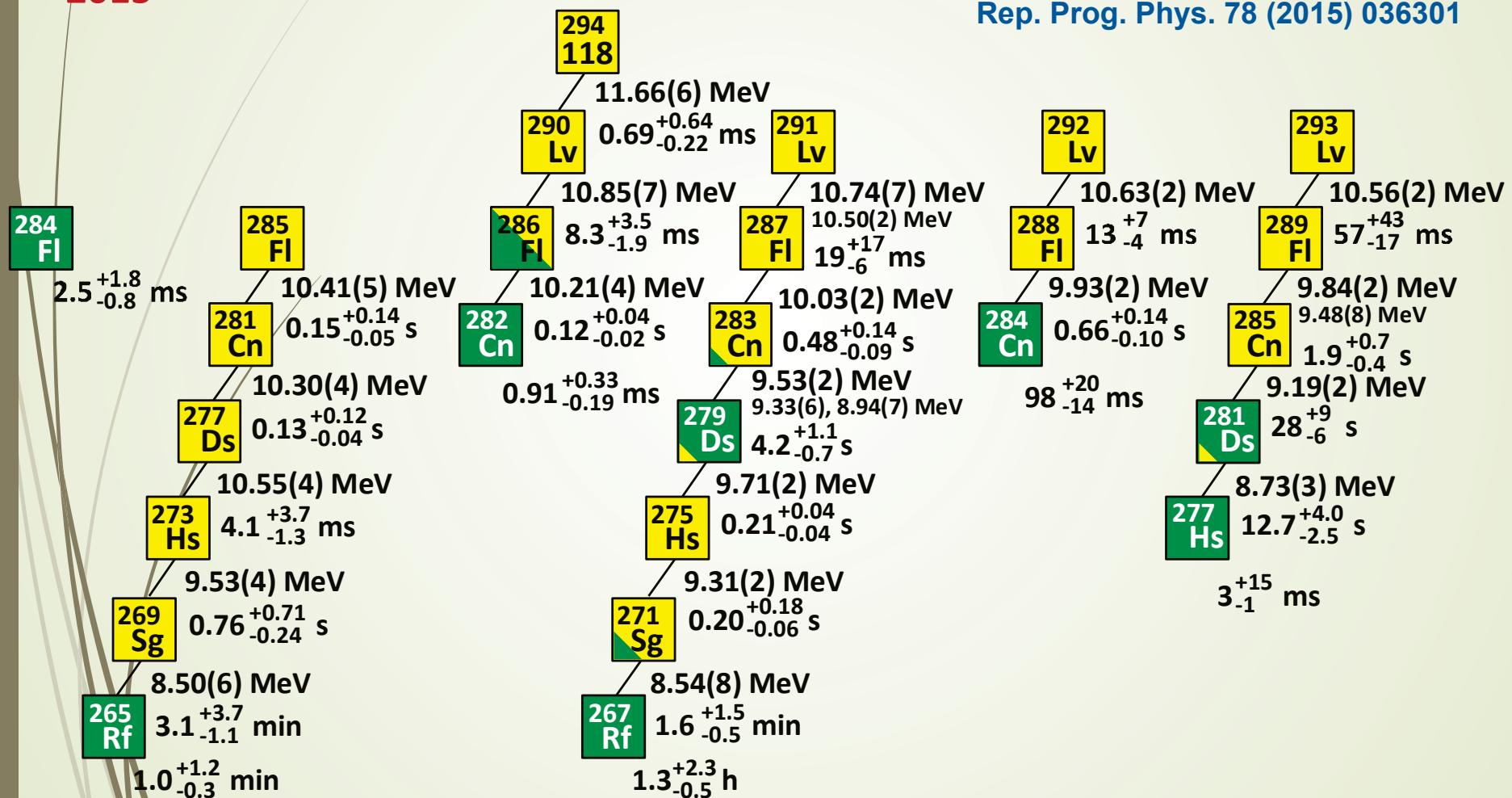




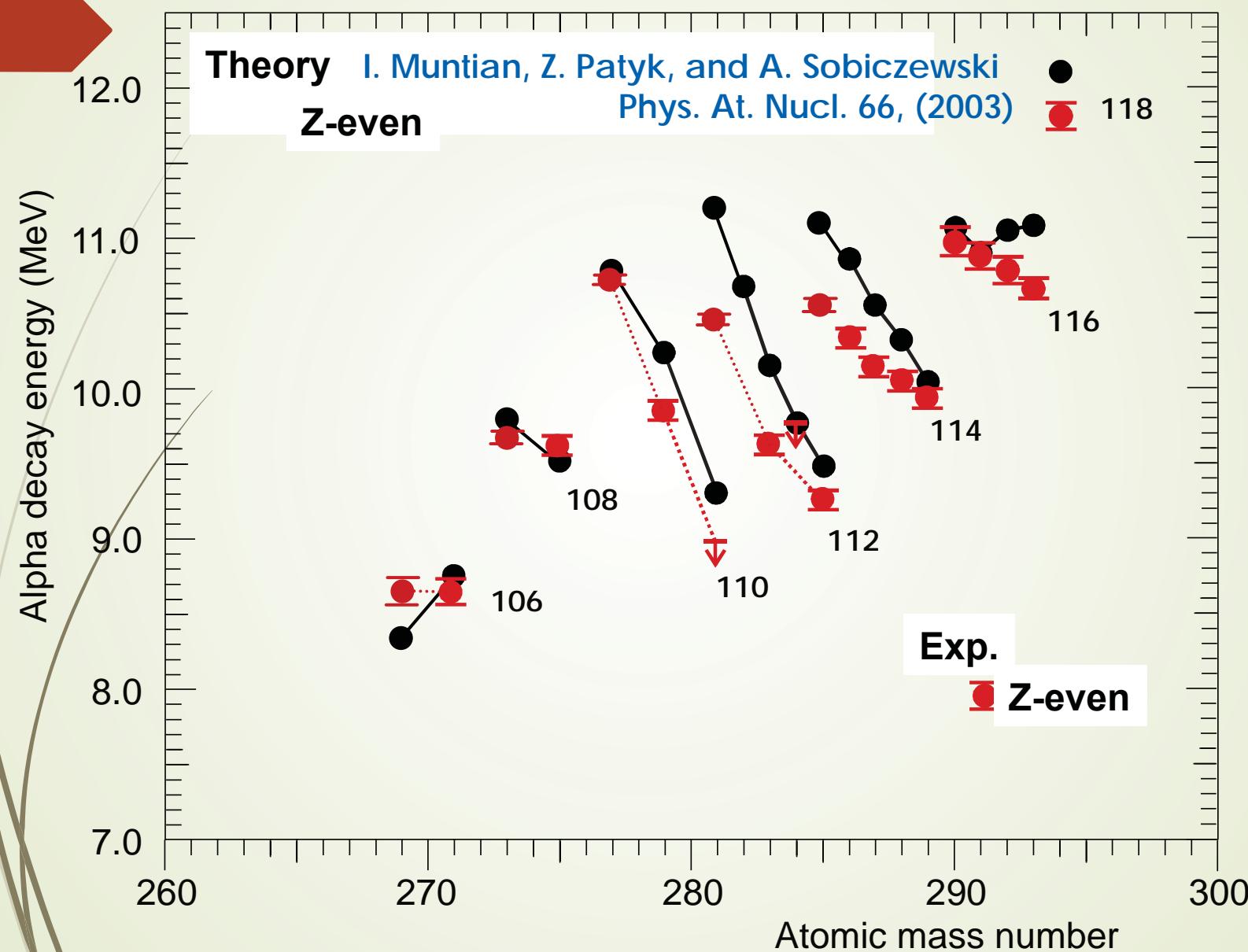
Summary decay properties of the Z-even isotopes observed
in ^{238}U , $^{240,242,244}\text{Pu}$, $^{245,248}\text{Cm}$ and $^{249}\text{Cf} + ^{48}\text{Ca}$ reactions

2015

Yu Ts Oganessian and V K Utyonkov,
Rep. Prog. Phys. 78 (2015) 036301

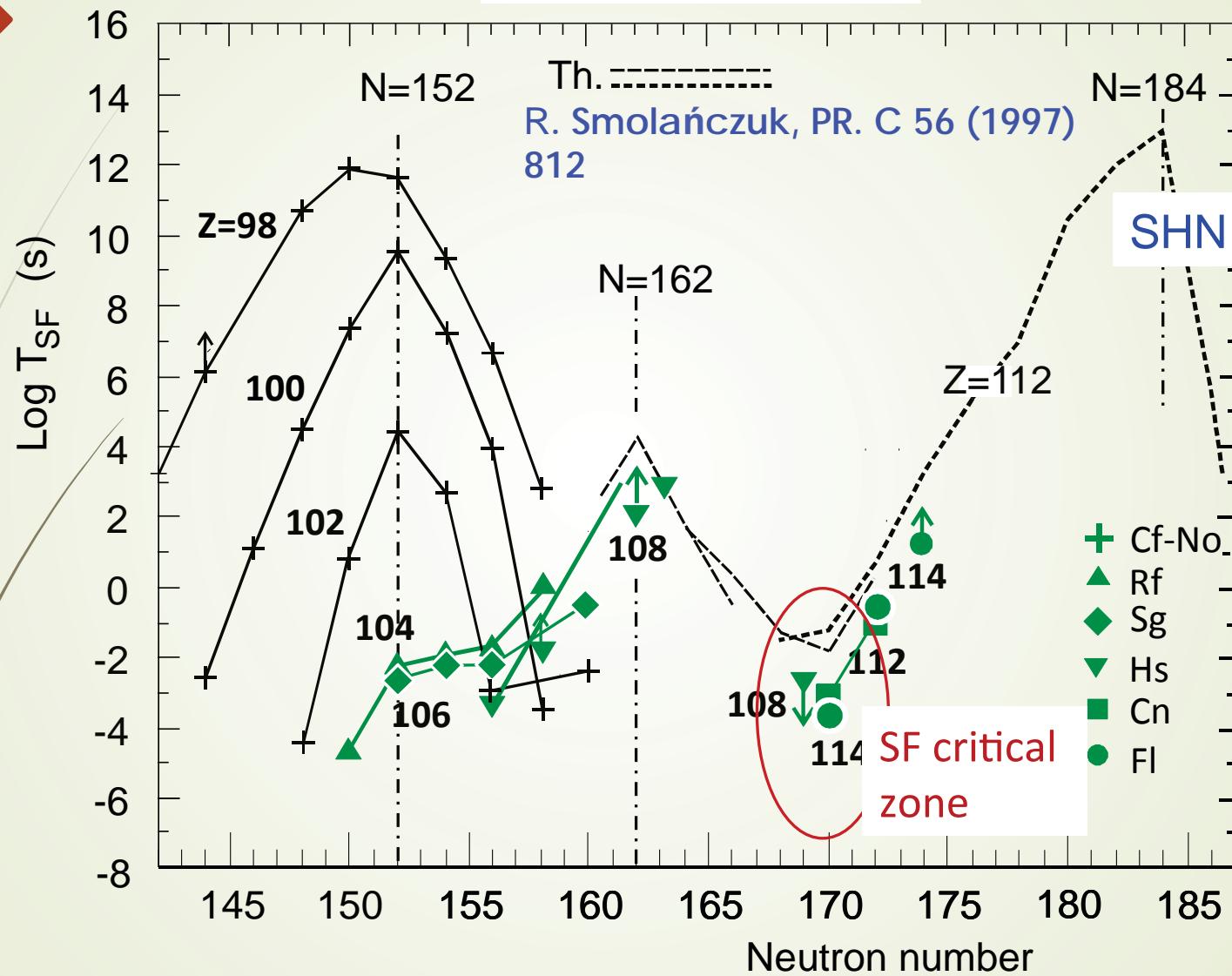


Alpha - decay



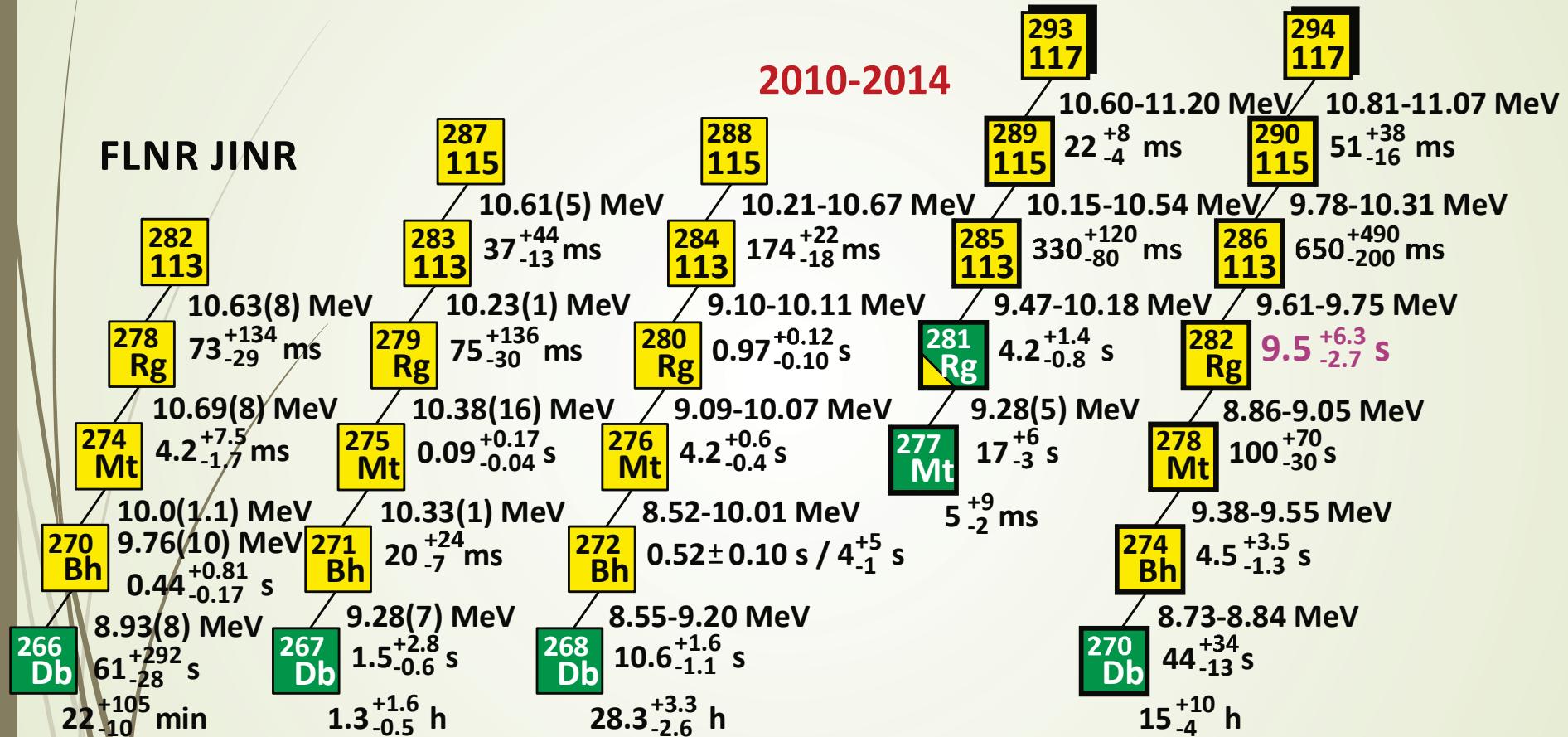
Spontaneous fission

even-even isotopes



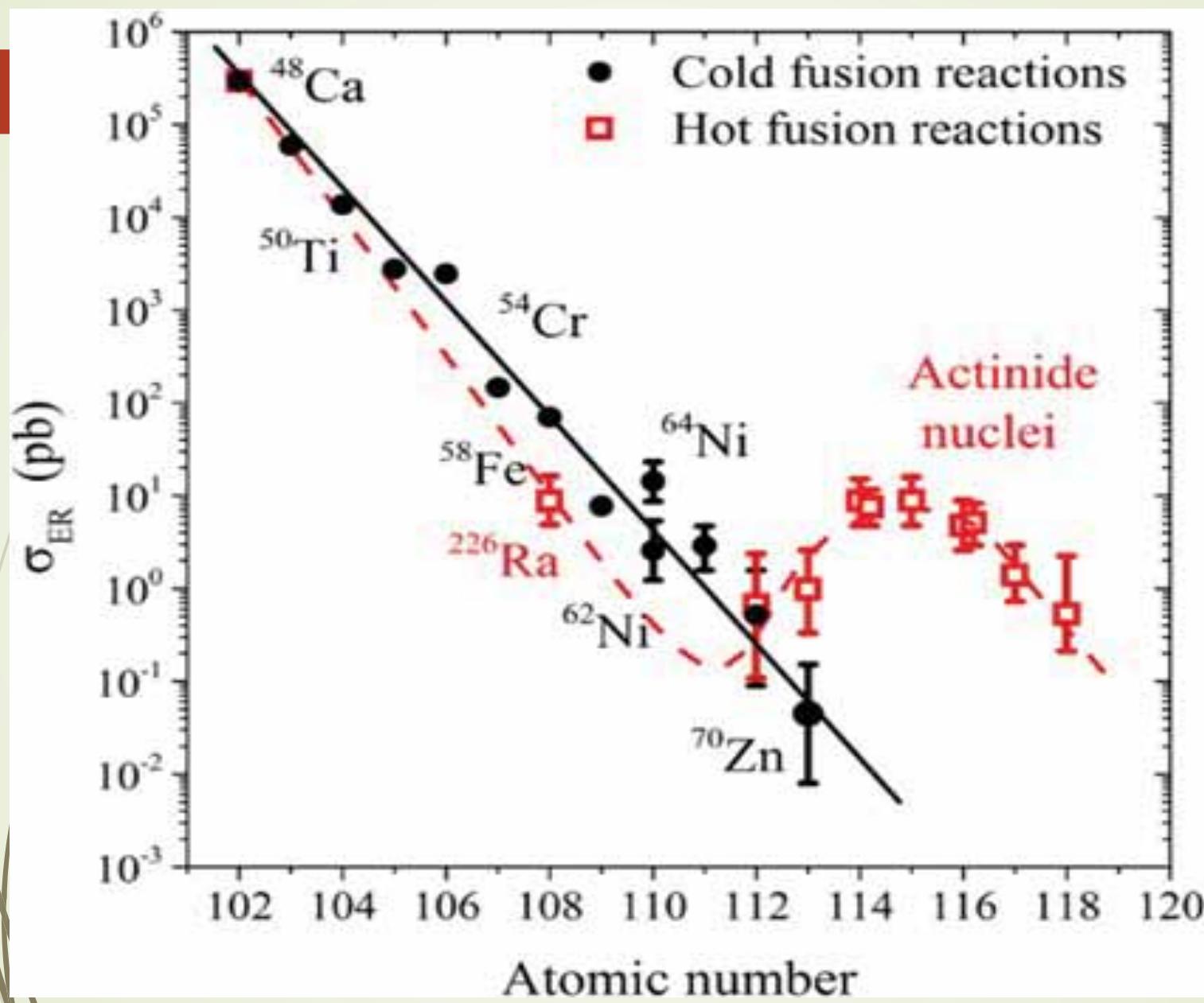
Summary decay properties of the isotopes of elements 113, 115, and 117
 observed in ^{237}Np , ^{243}Am and $^{249}\text{Bk} + ^{48}\text{Ca}$ reactions

FLNR JINR

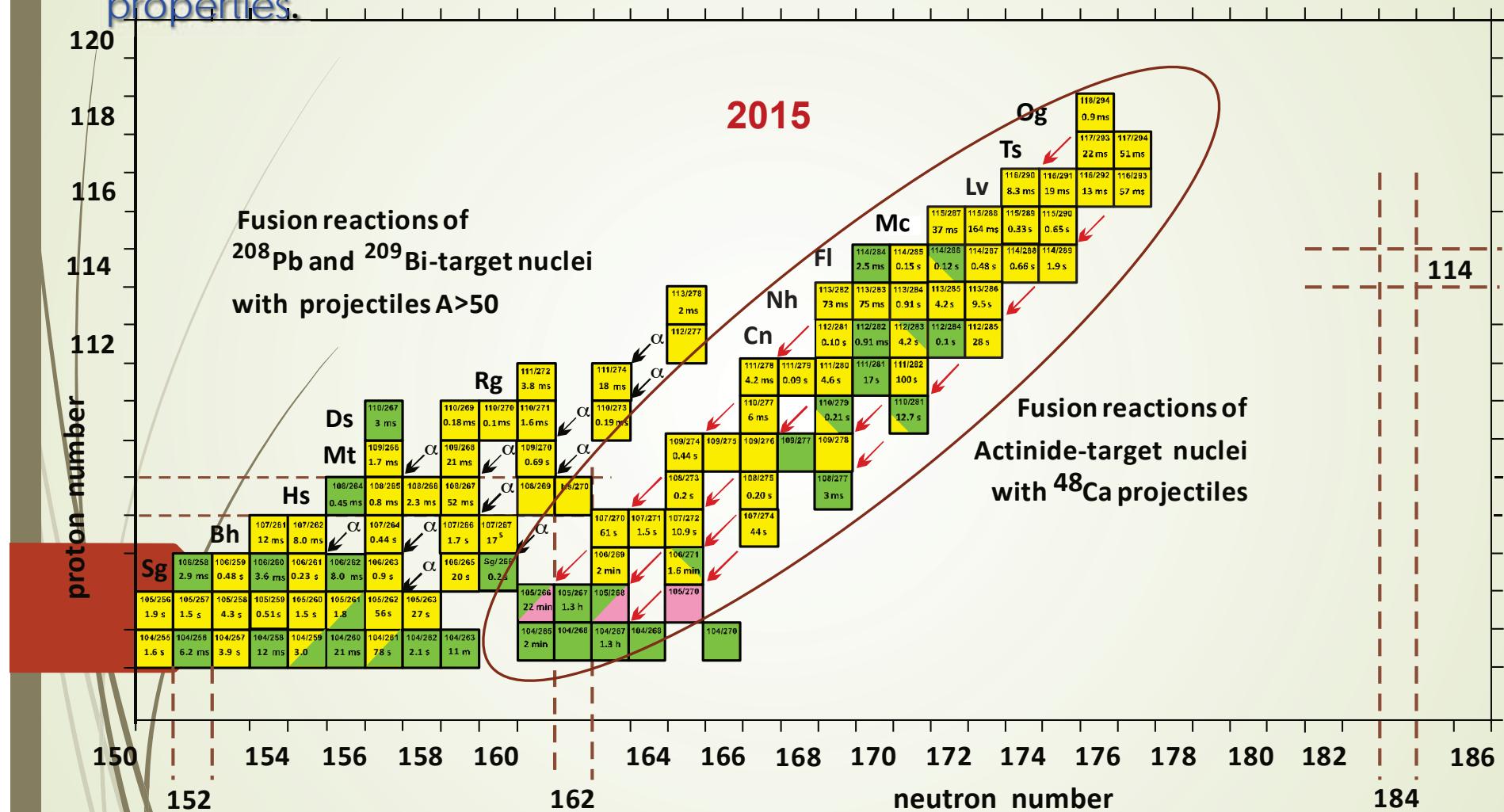


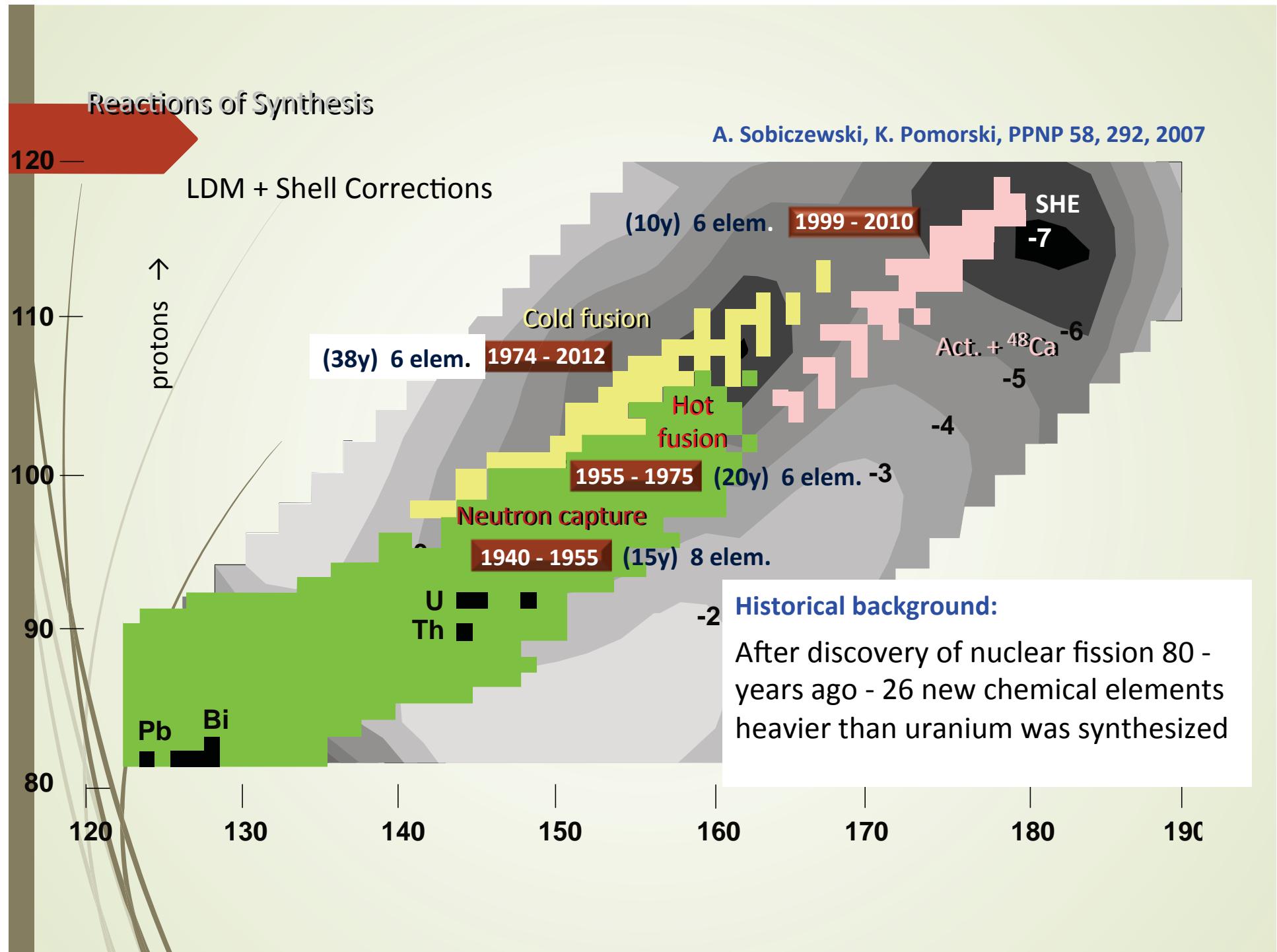
Confirmations of DGFRS data 2007 - 2014

A/Z	Setup	Laboratory	Publications
283112	SHIP	GSI Darmstadt	Eur. Phys. J. A32, 251 (2007)
283112	COLD	PSI-FLNR (JINR)	NATURE 447, 72 (2007)
286, 287114	BGS	LBNL (Berkeley)	P.R. Lett. 103, 132502 (2009)
288, 289114	TASCA	GSI – Mainz	P.R. Lett. 104, 252701 (2010)
292, 293116	SHIP	GSI Darmstadt	Eur. Phys. J. A48, 62 (2012)
287, 288115	TASCA	GSI – Mainz	P.R. Lett. 111, 112502 (2013)
293, 294117	TASCA	GSI – Mainz	P.R. Lett. 112, 172501 (2014)
292, 293116	GARIS	RIKEN Tokyo	Accelerator Progress Rep. (2013)



Super heavy islanders and their daughter products are
a large family of the 55 new neutron-rich isotopes with unique
properties.





ith $Z > 40\%$ larger than that of Bi, the heaviest stable element, we see an impressive extension in nuclear survivability.

Although SHN are at the limits of Coulomb stability,

- shell stabilization lowers ground-state energy,
 - creates a fission barrier,
 - and thereby enables SHN to exist.

The fundamentals of the modern theory concerning the mass limits of nuclear matter have obtained experimental verification



**Meanwhile, the discovery of the SHE,
like the opening of the Pandora's box,
has poured out many unexpected problems.**

among them:

- Where are the super heavy elements located in the Periodic Table?
- Are they similar to their light homologues?
- Where is the boundary of the Periodic Table and how many elements can it contain?

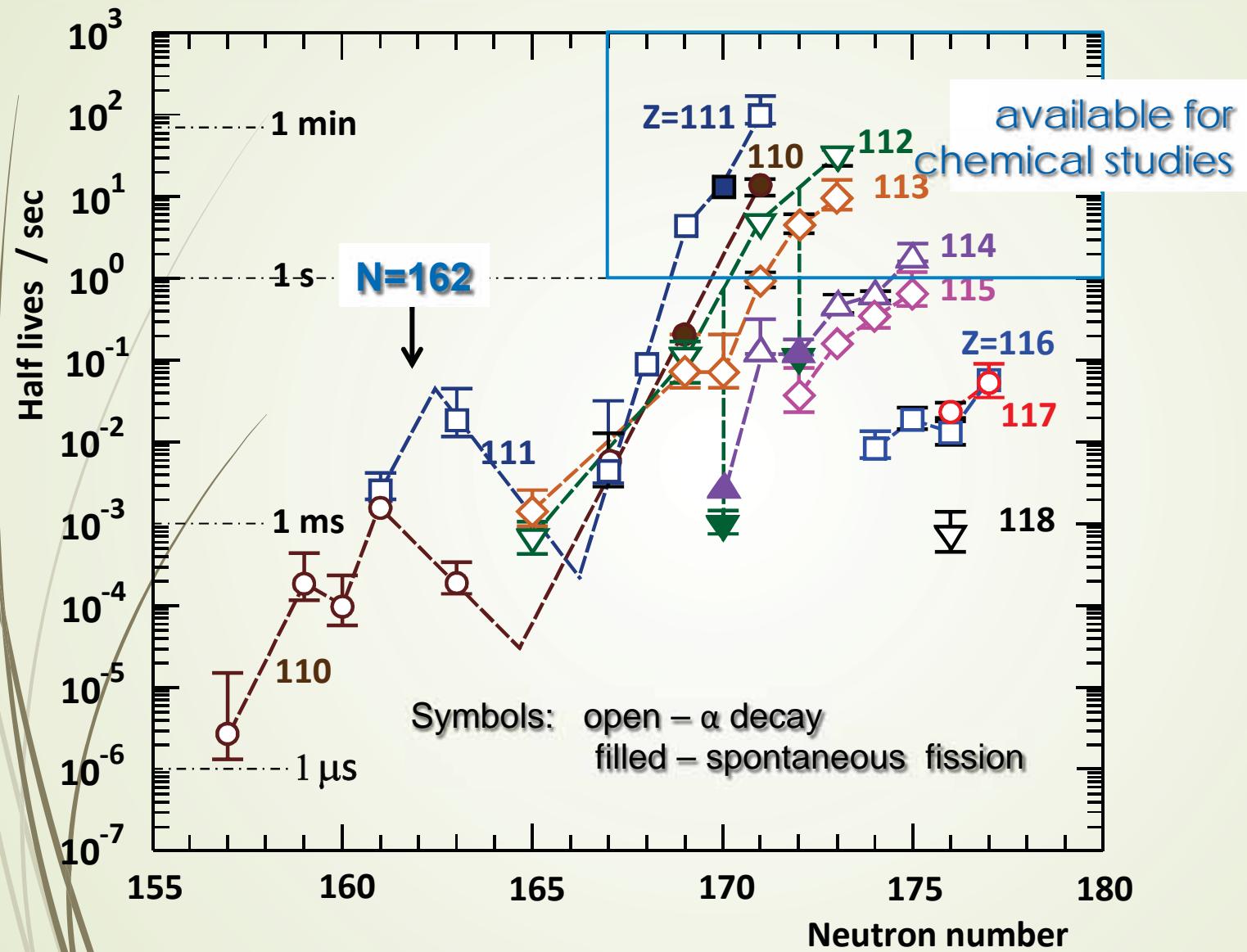


Where are the super heavy elements located
in the Periodic Table?

Are they similar to their light homologues?

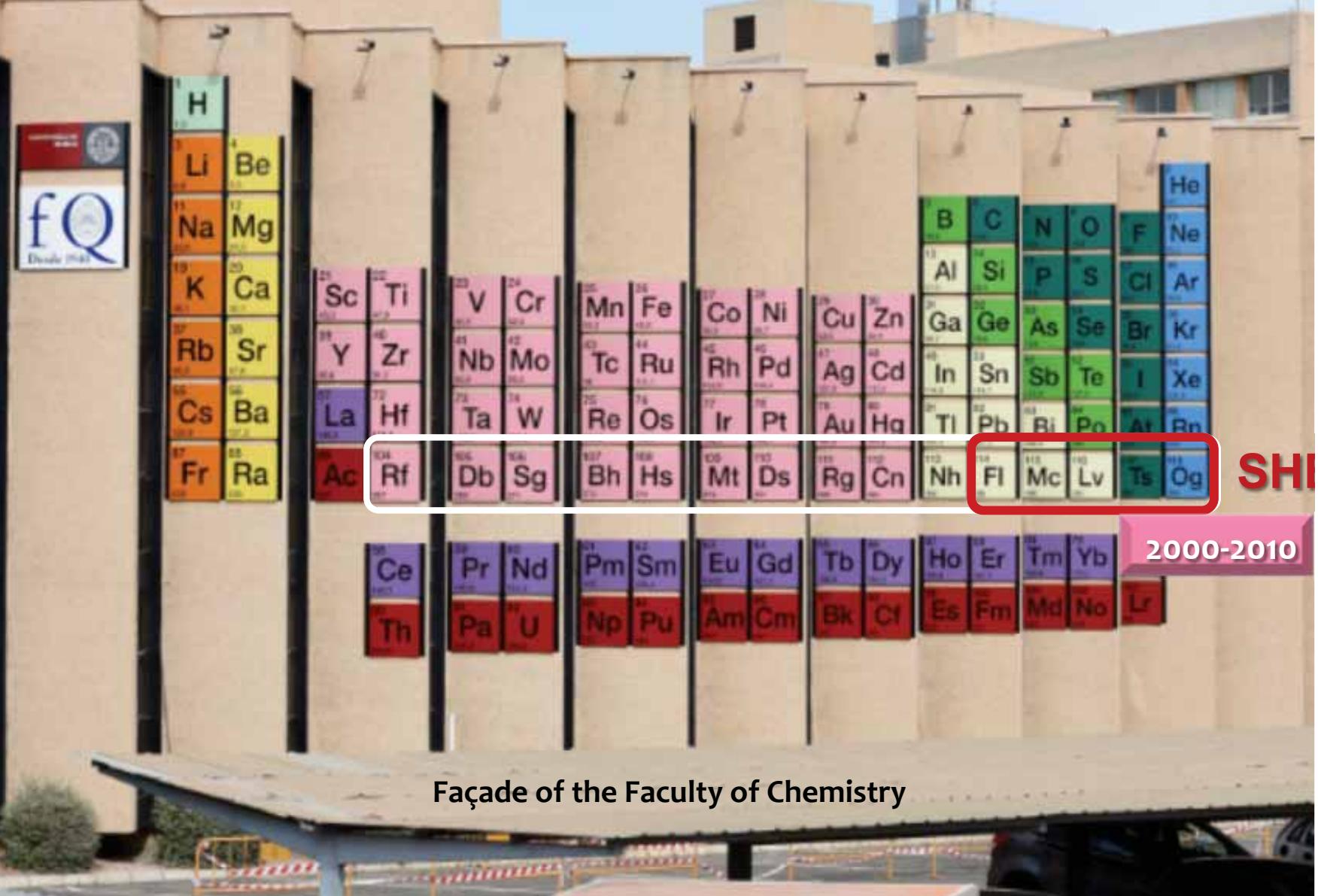
Where is the boundary of the Periodic Table
and how many elements can it contain?

Decay modes and the half-lives of the isotopes with $Z \geq 110$



University of Murcia
(Spain)

Giant (150 m²) Periodic Table
2017



Periodic Table Z=1-138

Calculated in non-relativistic Dirac-Fock approximation

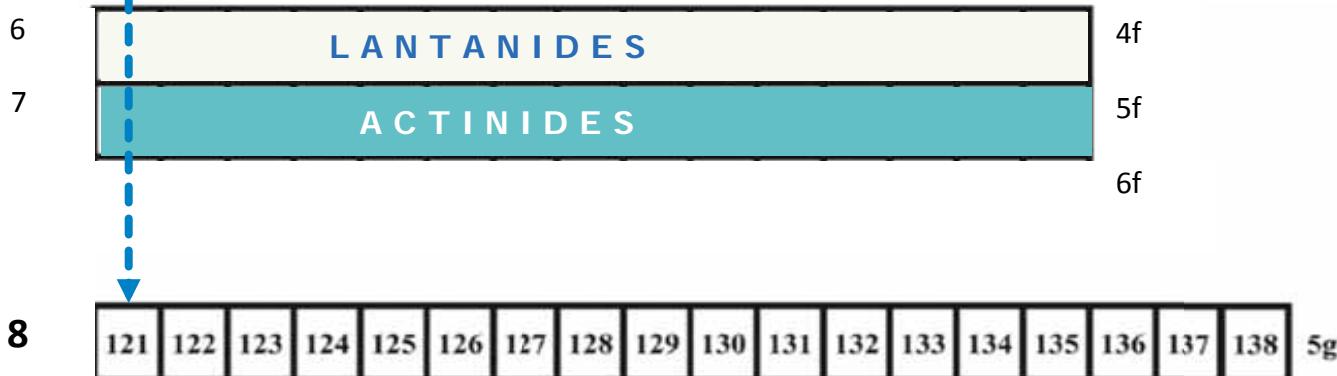
Calculated in non-relativistic
Dirac-Fock approximation

Sir
William
1904

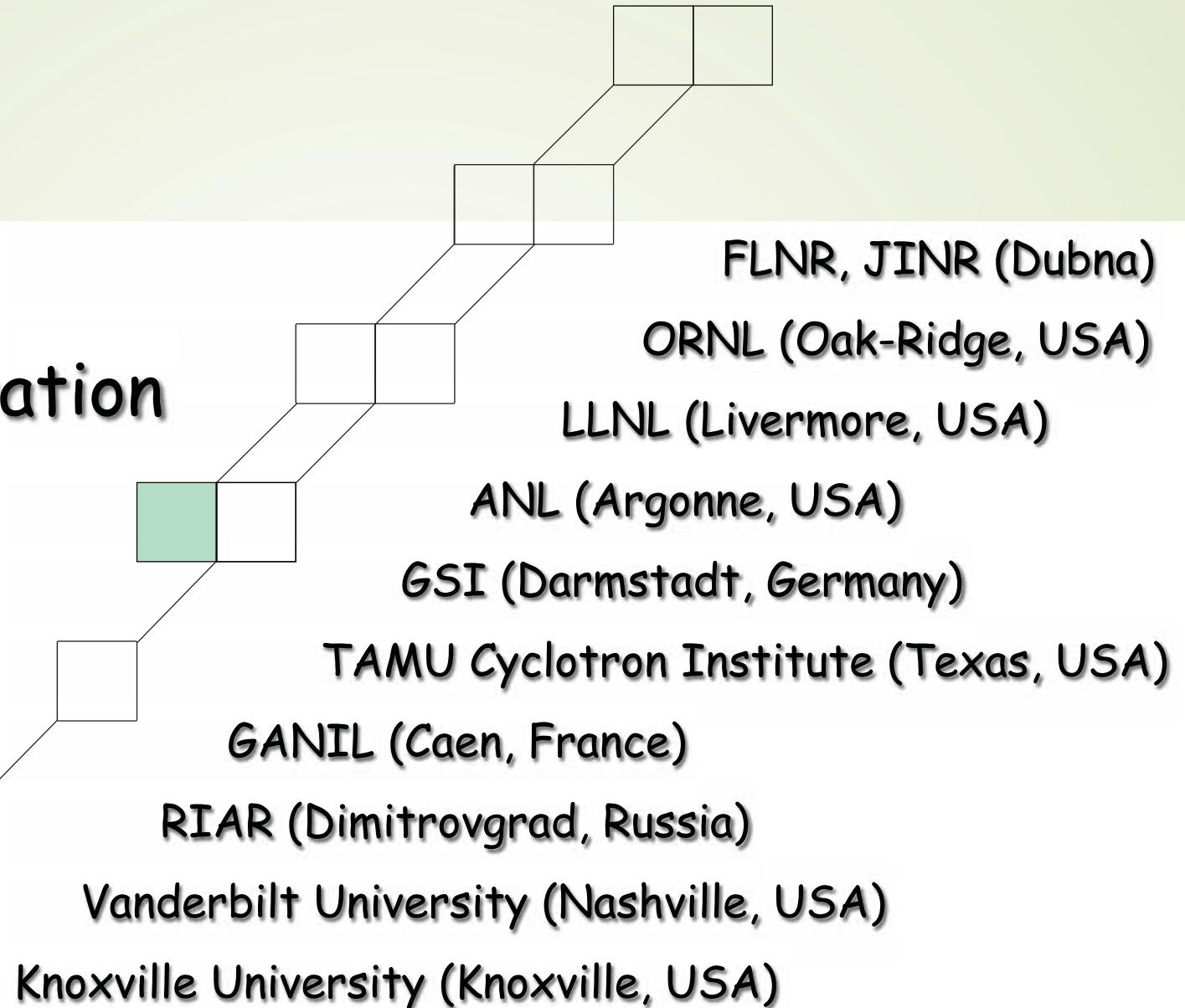
2004

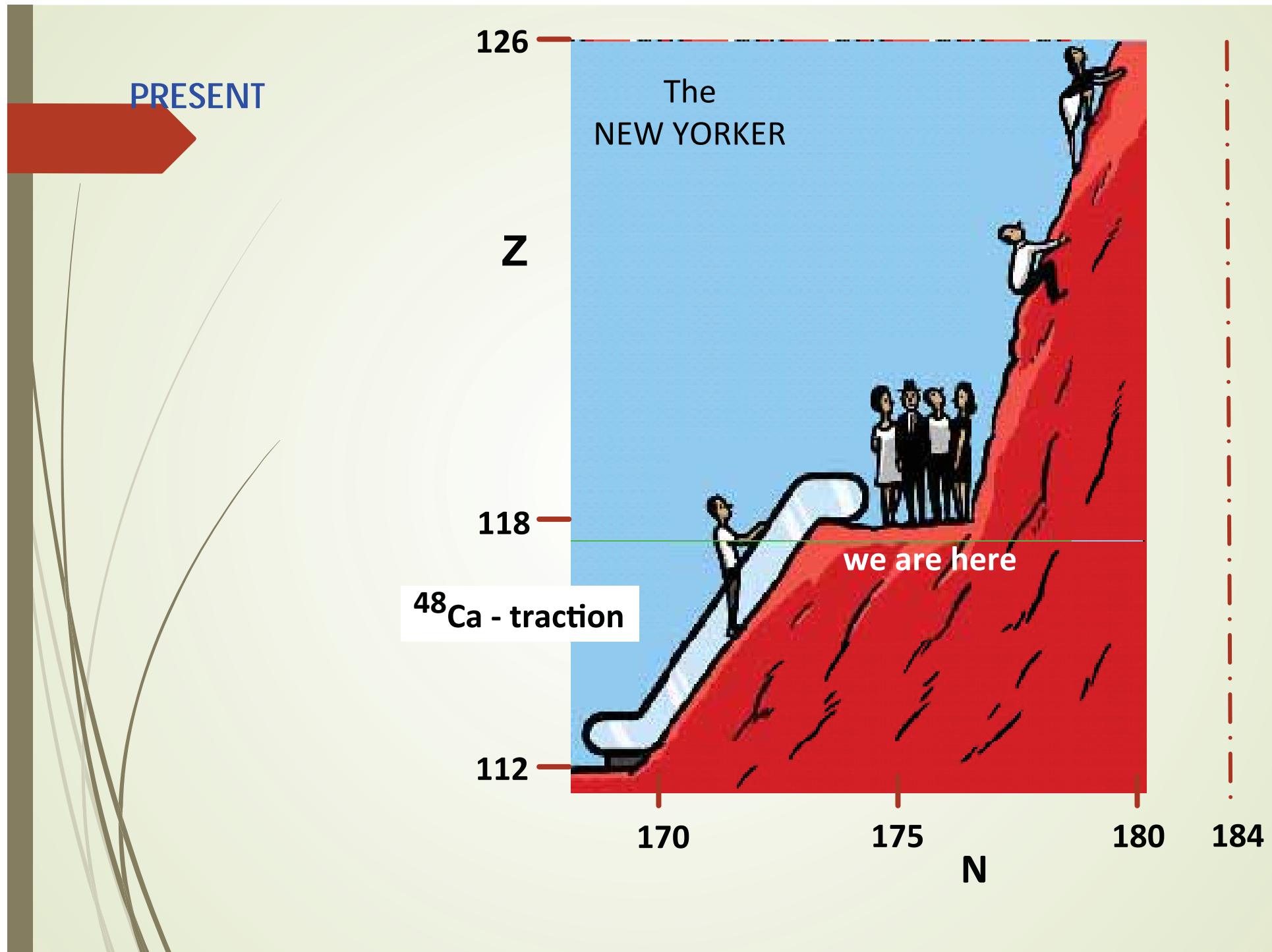
Completion of the 7-th row

Does element 118 look like a noble gas?



Collaboration





* Search for superheavies

What is the next step?

→ Ti, Cr, Ni₇ Fe₁₂₀

Proton number

Og
Ts

249 Cf + 48 Ca Og 294
0.69 ms
11.66
249 Bk + 48 Ca Ts 293
22 ms Ts 294
51 ms

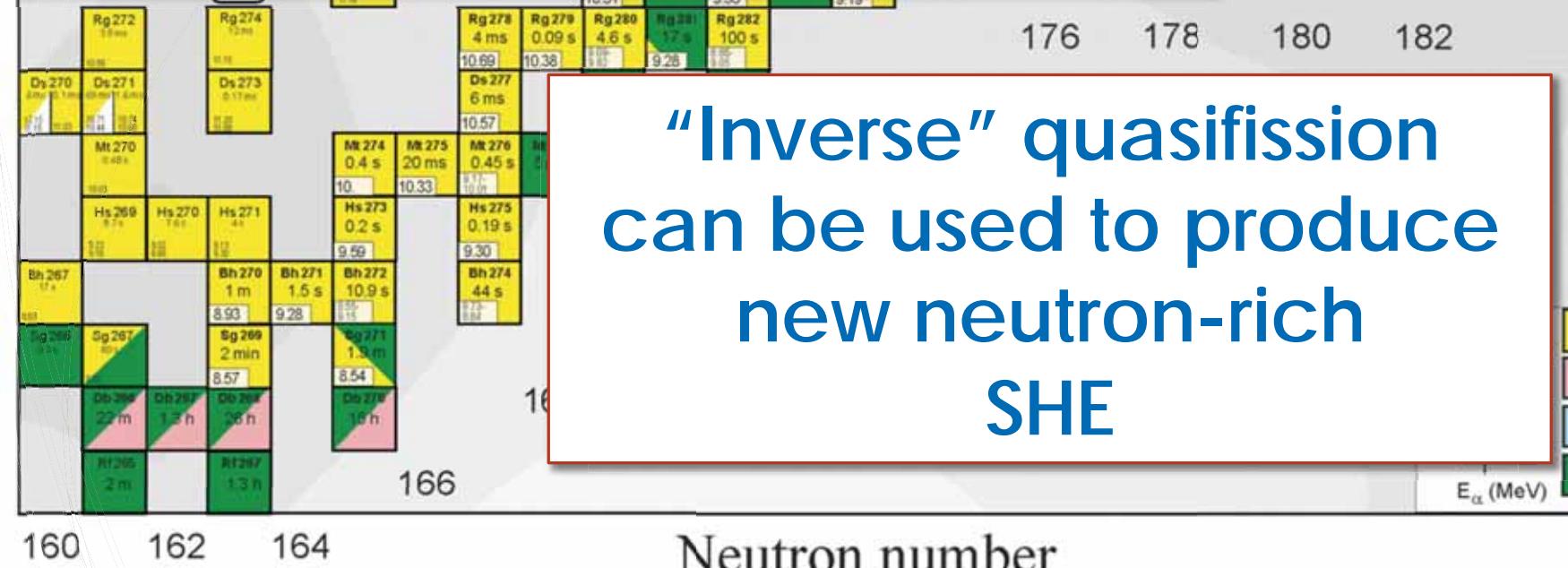
Still far from the “island of stability” !!!

Z = 114

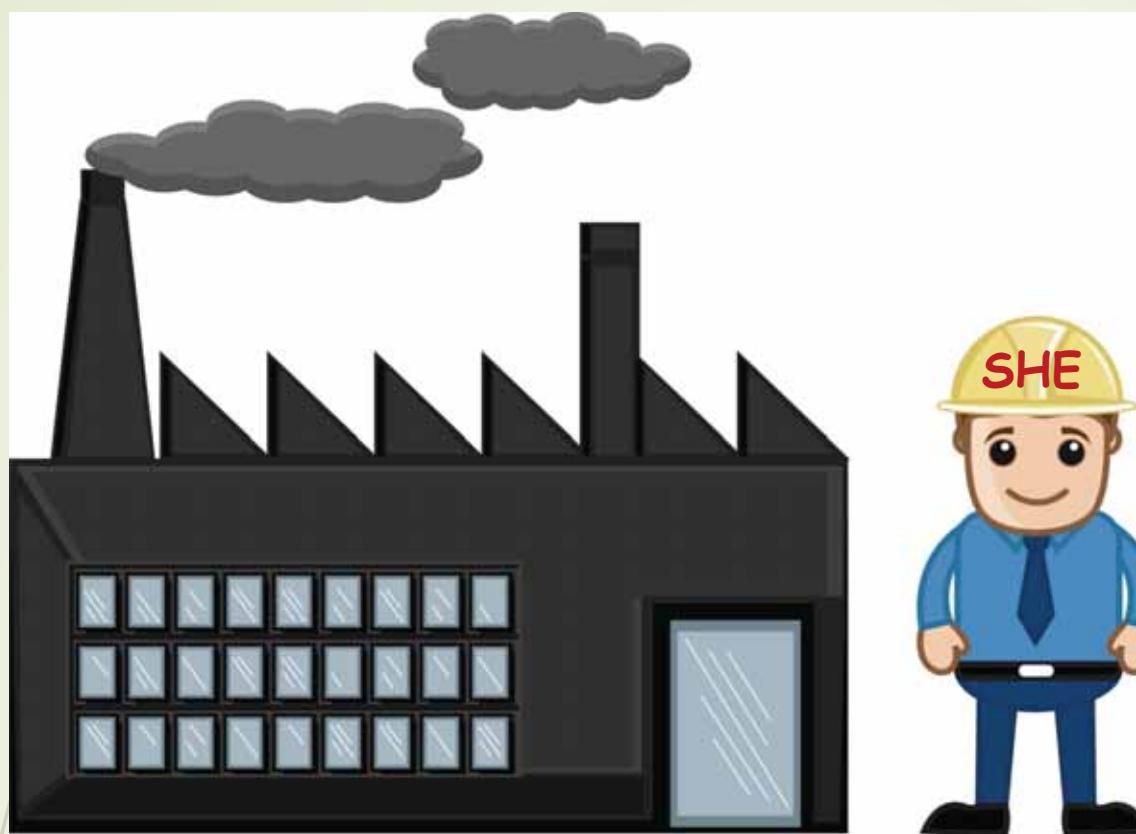
184

What is the next double magic superheavy nucleus?

Rg
Ds
Mt
Hs
Bh
Sg
Db
Rf



FUTURE



SHE-Factory



Superheavy Elements (SHE) Factory – the Goals

➤ **Experiments at the extremely low ($\sigma < 100$ fb) cross sections:**

- Synthesis of new SHE in reactions with ^{50}Ti , ^{54}Cr ... (119, 120);
- Shaping of the region of SHE (synthesis of new isotopes of SHE);
- Study of decay properties of SHE;
- Study of excitation functions.

➤ **Experiments requiring high statistics:**

- Nuclear spectroscopy of SHE;
- Precise mass measurements;
- Study of chemical properties of SHE.

SHE-Factory joining of efforts

Isotope production:
Cm-248
Bk-249
Cf-251

To be increased
10 times

Factor 10-20

Depend of
target durability

New accelerator
High beam
dose of : Ca-48
Ti-50
Ni-64

SC- recoil separator
equipped with
Gas Catcher
On-line separator
& sophisticated
Detectors

Factor 3-5

is closely linked
to the intellect

1

March 2012, Dubna



August 2017, Dubna



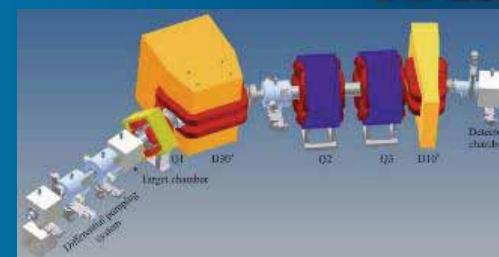
SHE-Factory

SuperHeavy Elements (SHE) Factory

SHE Factory Building



High-current cyclotron
DC-280



New gas-filled separator

Commissioning of the Superheavy Elements Factory



SHE Factory building



Gas-Filled Recoil Separator



DC-280 cyclotron:
(26 December 2018-first test beam)

Day-one experiments at SHE Factory

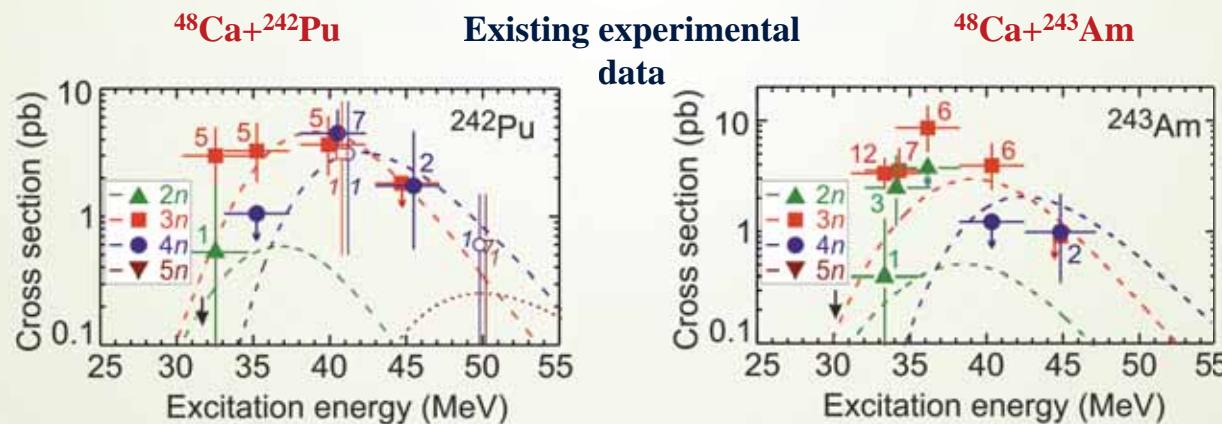
Test experiments I:

Test of functionalities of all the systems of the accelerator and gas-filled separator
 $^{40}\text{Ar}+\text{natDy}$ and $^{18}\text{O}+^{208}\text{Pb}$

Test experiments II:

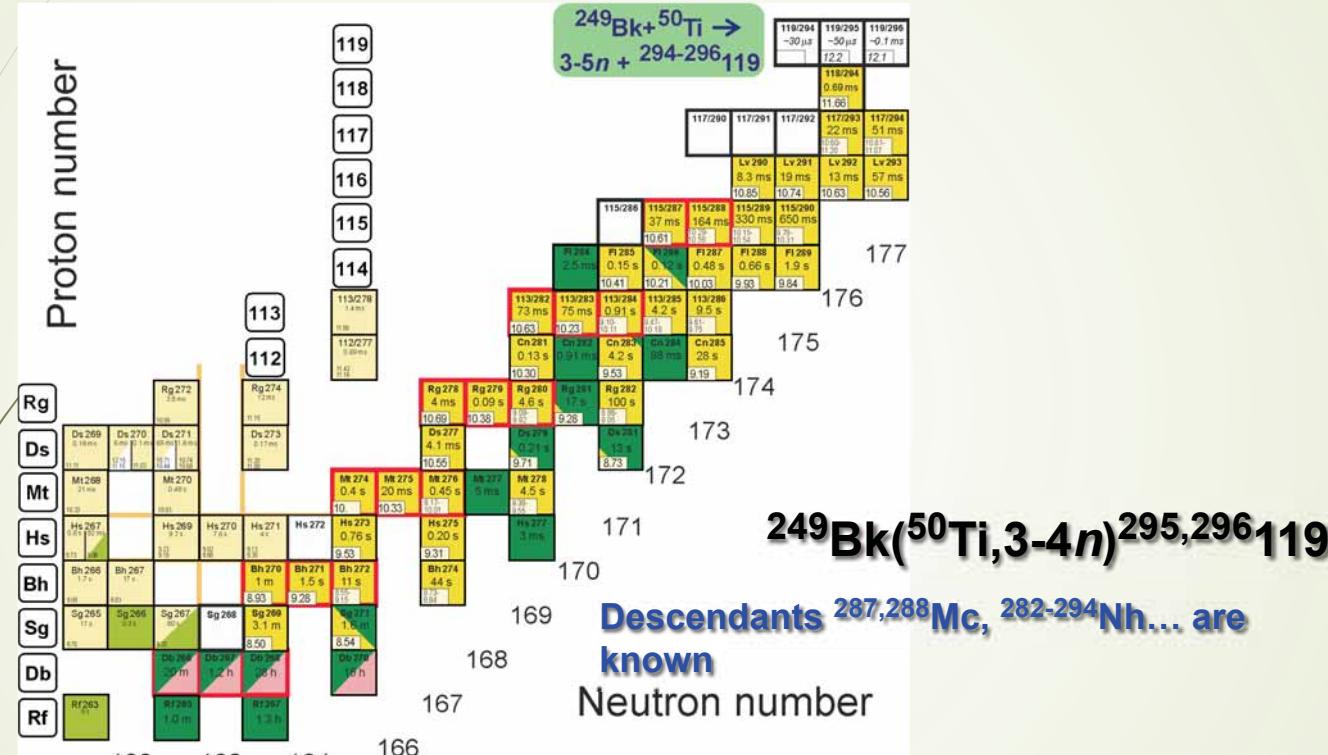
$^{48}\text{Ca}+^{242}\text{Pu}$ and $^{48}\text{Ca}+^{243}\text{Am}$

1. Enough material to prepare “big” targets
2. Well-studied in previous experiments
3. Relatively large cross sections



First experiments at SHE Factory

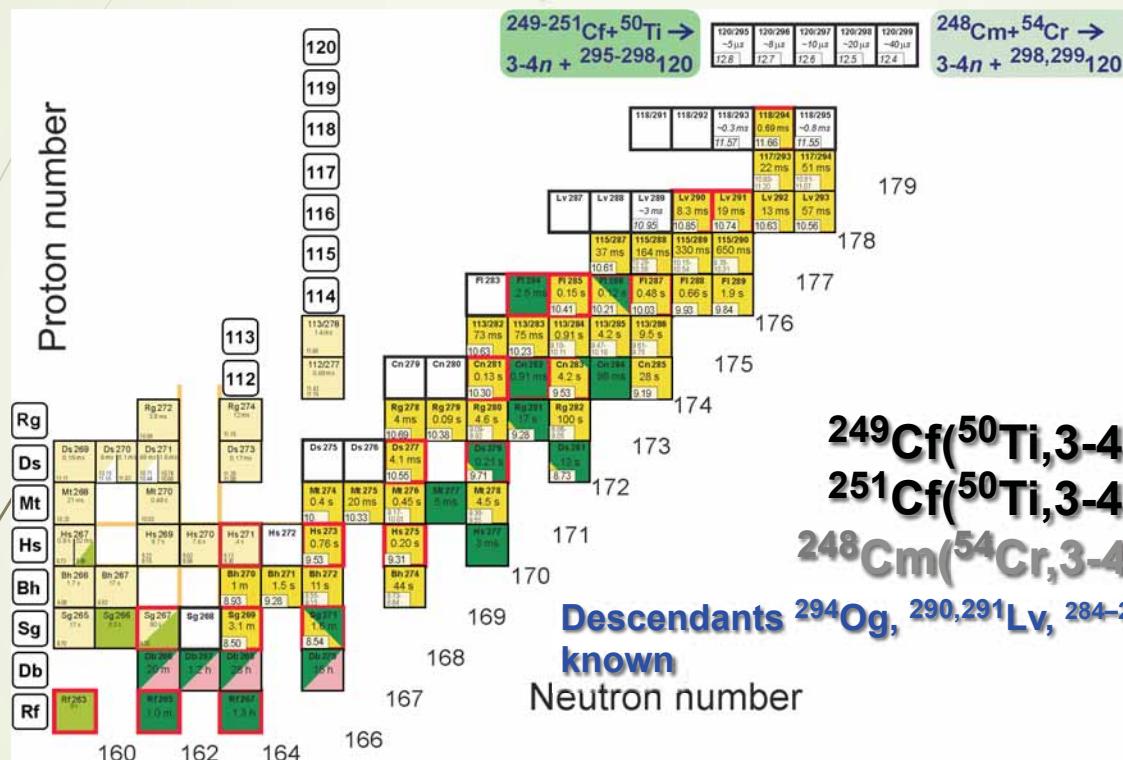
Synthesis of new element 119



$s=50 \text{ fb}, h_t=0.3 \text{ mg/cm}^2, \epsilon_{\text{coll}}=0.6, I_{\text{beam}}=3 \text{ pma} \rightarrow \approx 1 \text{ event per month}$

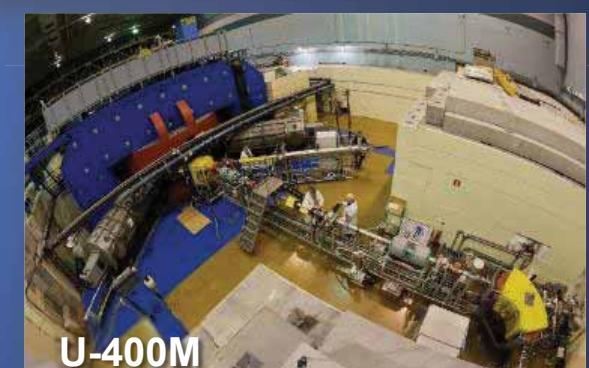
First experiments at SHE Factory

Synthesis of new element 120



$s=50\text{ fb}$, $h_t=0.3\text{ mg/cm}^2$, $\epsilon_{\text{coll}}=0.6$, $I_{\text{beam}}=3\text{ pmA} \rightarrow \approx 1\text{ event per month}$

Dubna Radioactive Ion Beam accelerator complex (DRIBs)





Road to Terra Incognita. God bless us!

Thank You!

First experiment

Production of the isotope ^{288}Mc ($Z=115$) in reaction:



^{243}Am – target

30-50 mg

^{48}Ca – beam intensity

5 p μ A.

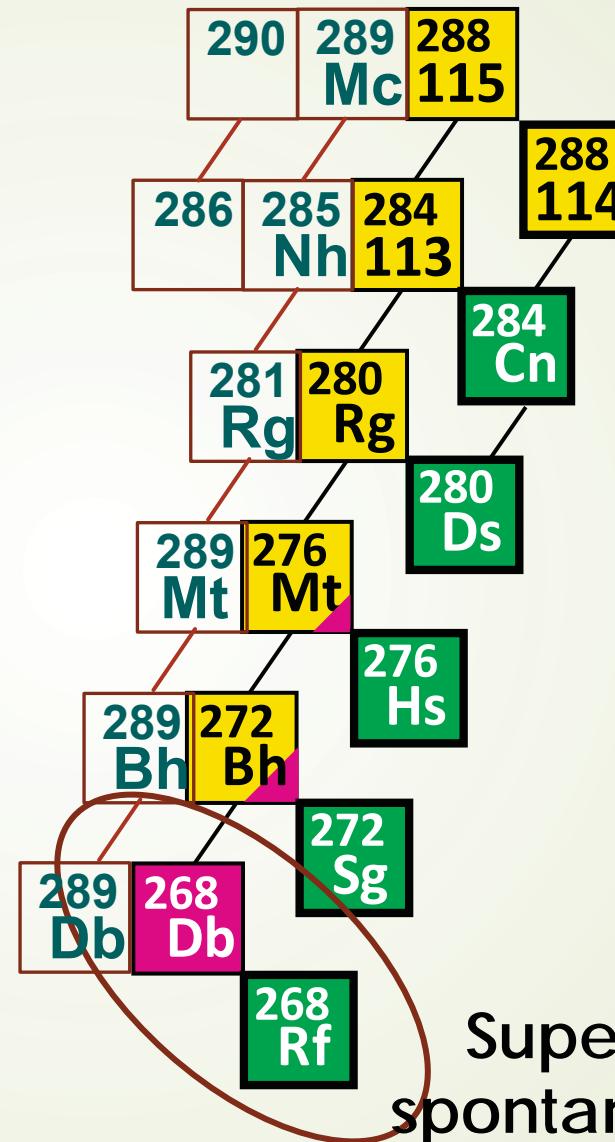
Beam time

50 days

April 2019

Demonstration experiment

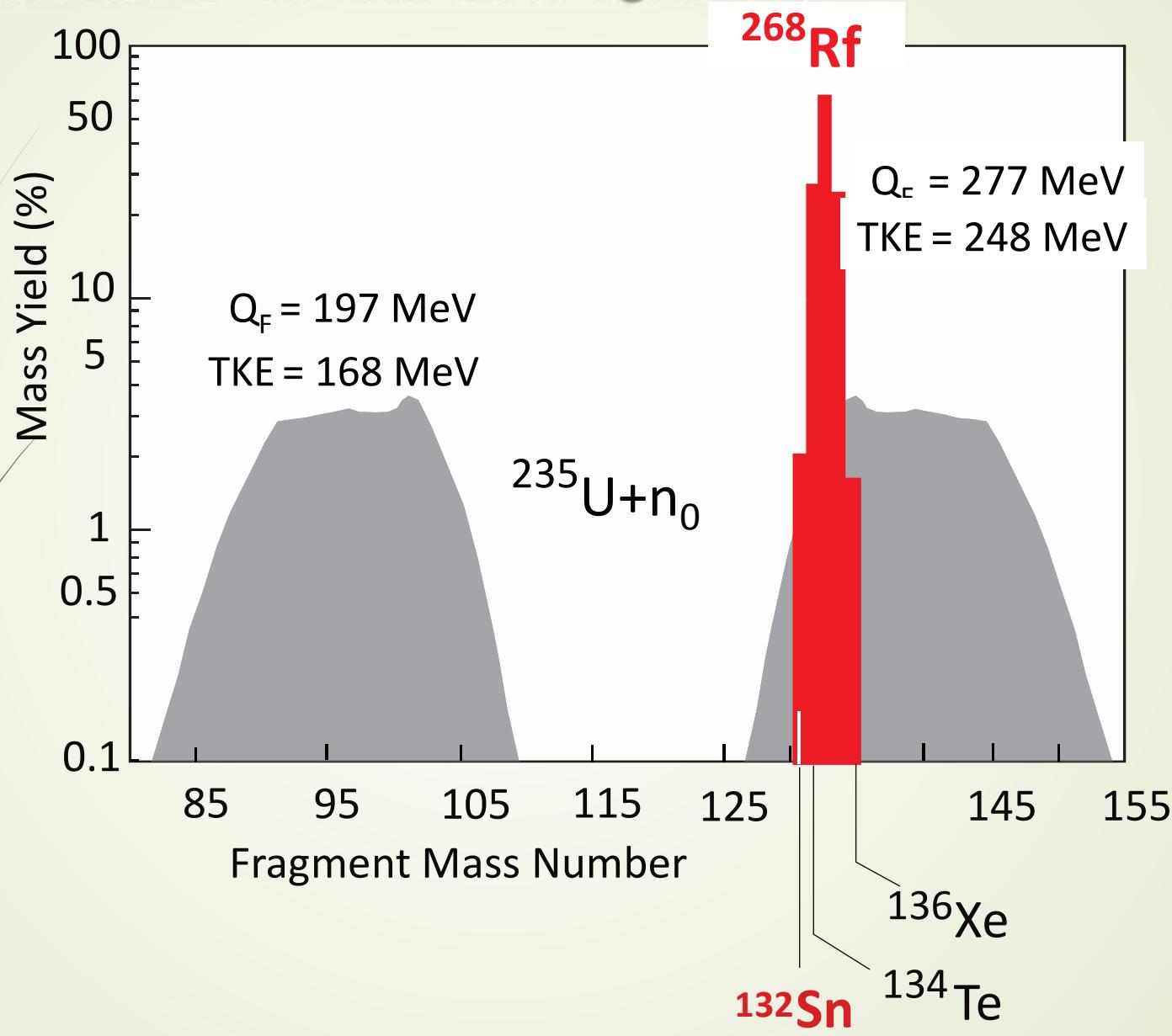
Rare reaction
channels
leading to SHE



Rare decays
 $EC \rightarrow SF$

Super-symmetric
spontaneous fission

Mass Distribution of the Fission Fragments



Second experiment

Production of the isotope ^{287}Fl ($Z=114$) in reaction:



^{242}Pu – target

30-50 mg

^{48}Ca – beam intensity

5 p μ A.

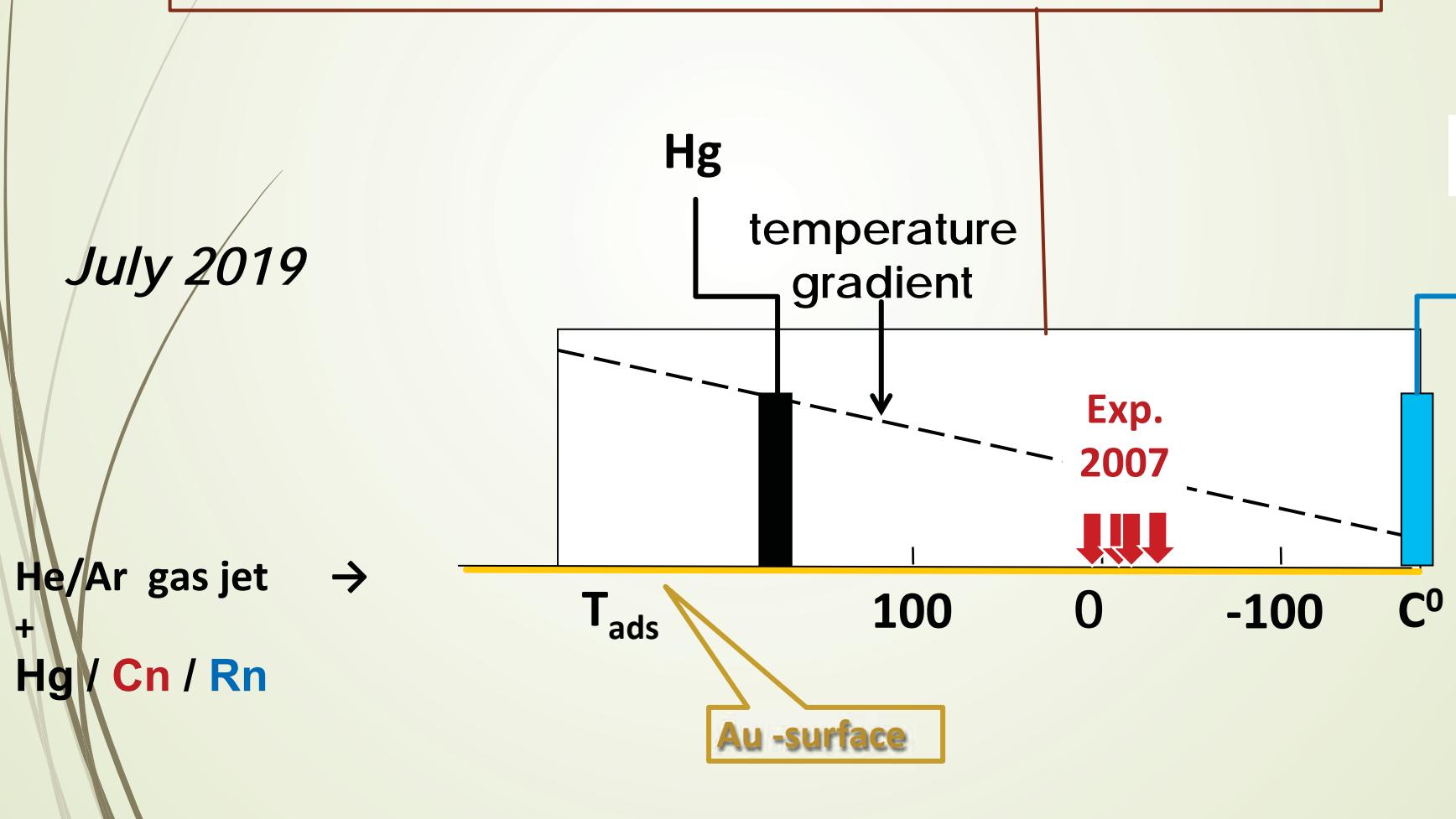
Beam time

50 days

July 2019

Eka-Mercury and Eka-Lead (relativistic effect)

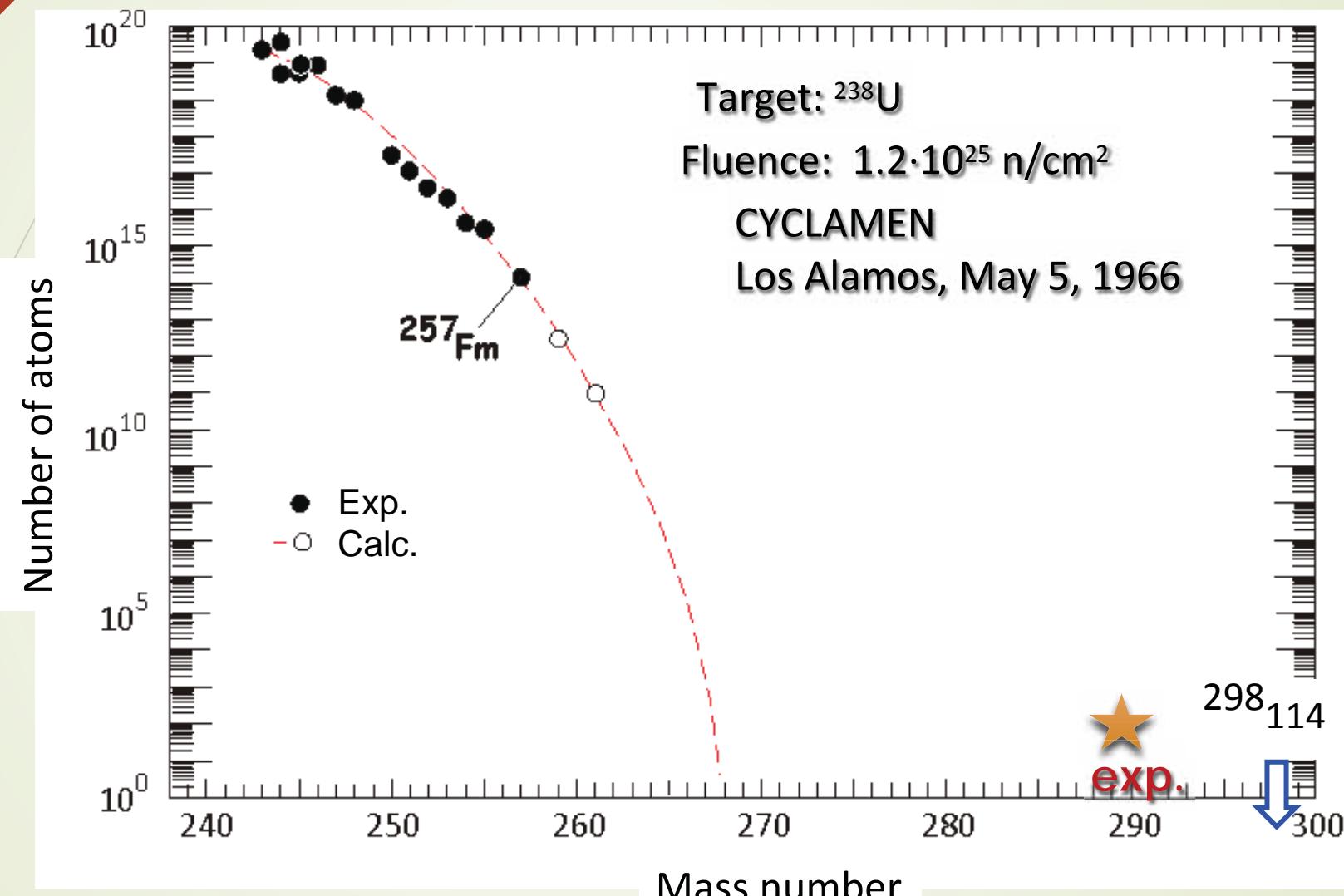
with ~ 500 events of the ^{283}Cn and ~ 100 events of ^{287}Fl
we would like to have a temperature distribution of the
[Cn·Au] and [Fl·Au] compounds



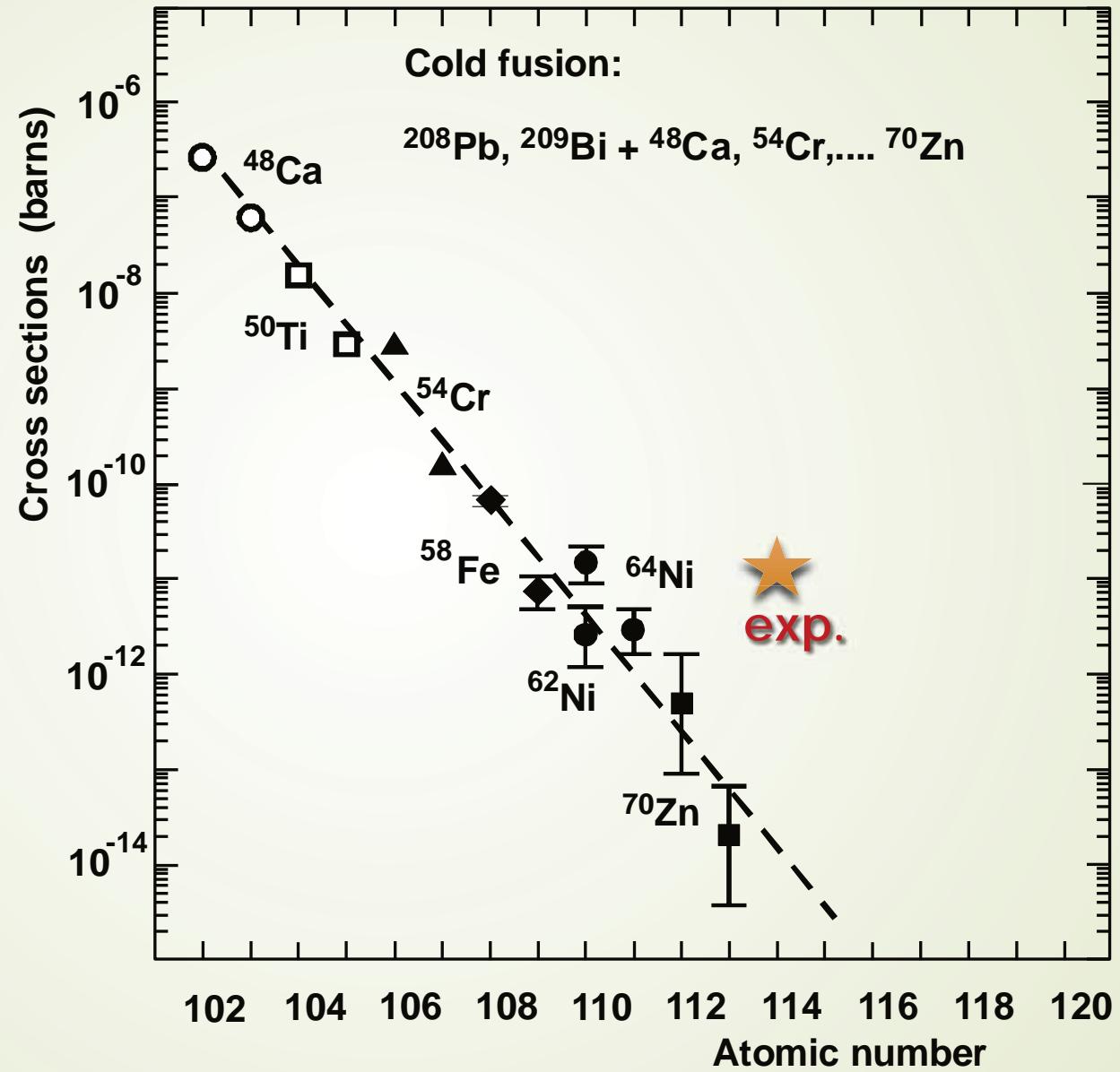


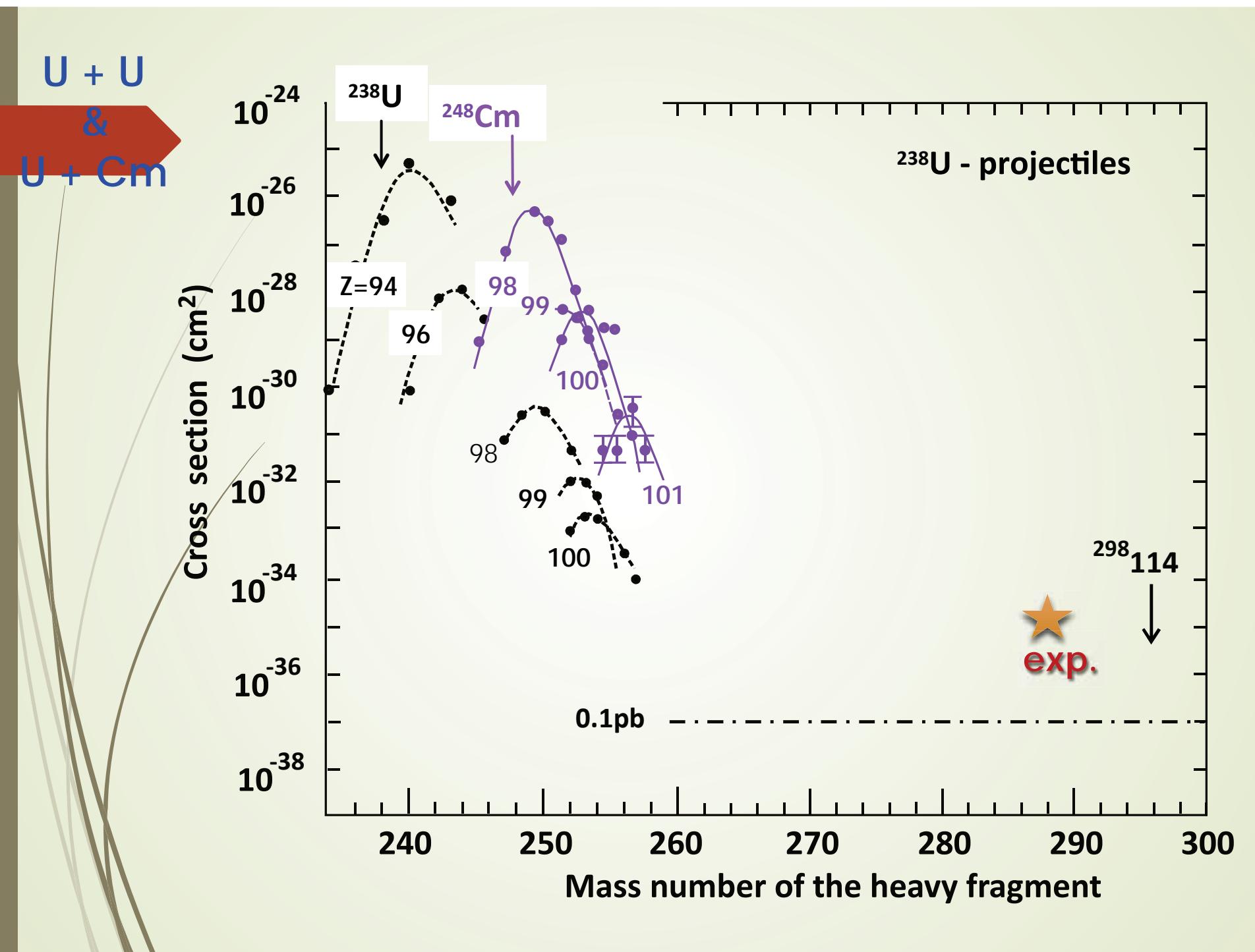
Neutron Capture

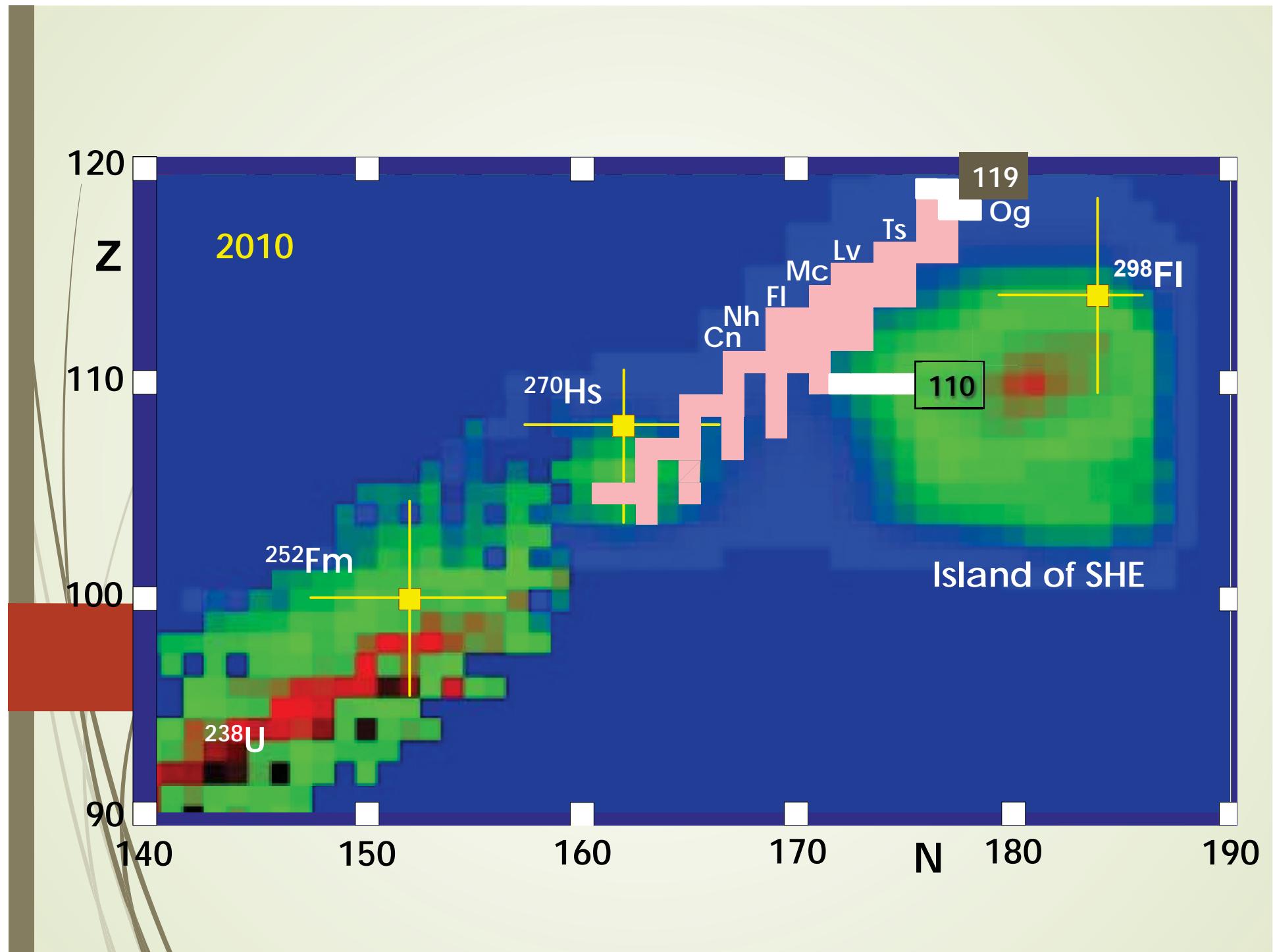
Attempts to synthesize super heavy elements by the use of nuclear explosion (5 attempts of 550 tests)



Cold Fusion





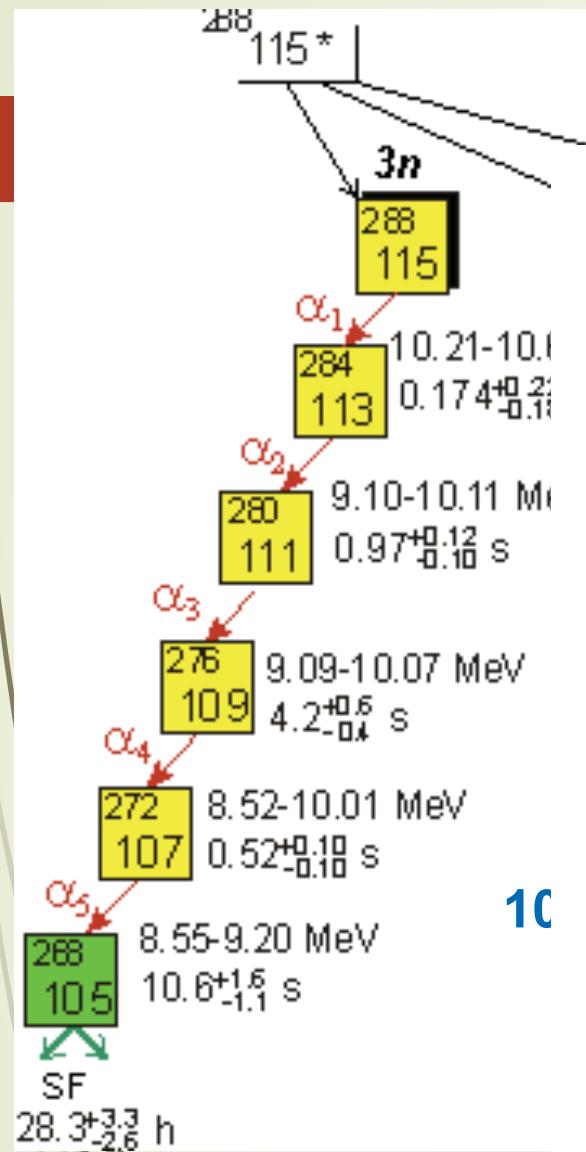


University of Murcia
(Spain)

Giant (150 m²) Periodic Table
2017

H																									He
Li		Be																							
Na		Mg																							
K		Ca																							
Rb		Sr																							
Cs		Ba																							
Fr		Ra																							
																									Og
119																									
Ce		Pr	Nd		Pm	Sm		Eu	Gd		Tb	Dy		Ho	Er		Tm	Yb	Lu						
Th		Pa	U		Np	Pu		Am	Cm		Bk	Cf		Es	Fm		Md	No							

Façade of the Faculty of Chemistry



FLNR + GSI + LBNL

Juhee Hong, G. G. Adamian, and N. V. Antonenko PRC

