The XXII International Baldin Seminar on High Energy Physics Problems

At the End of the Nuclear Map

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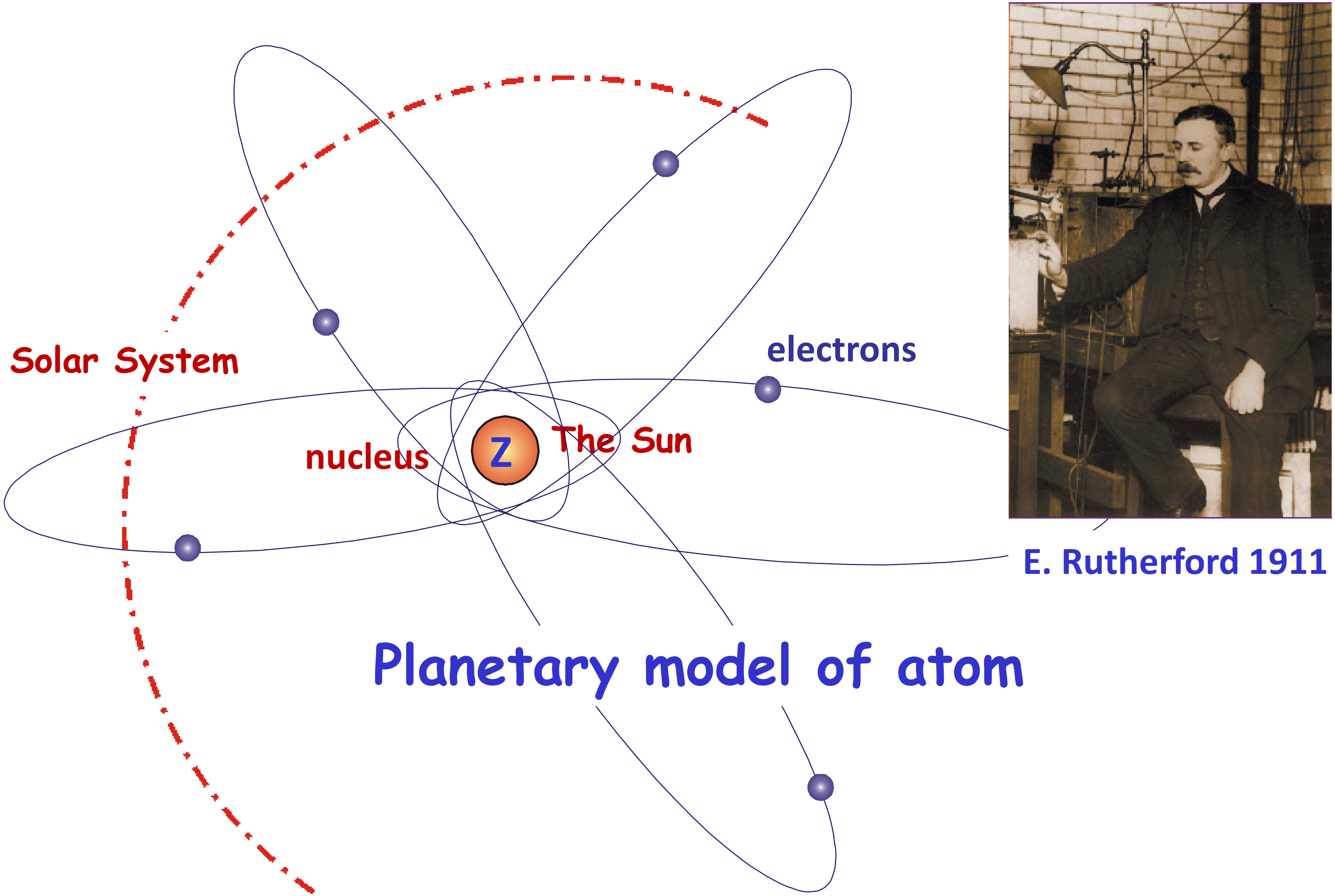
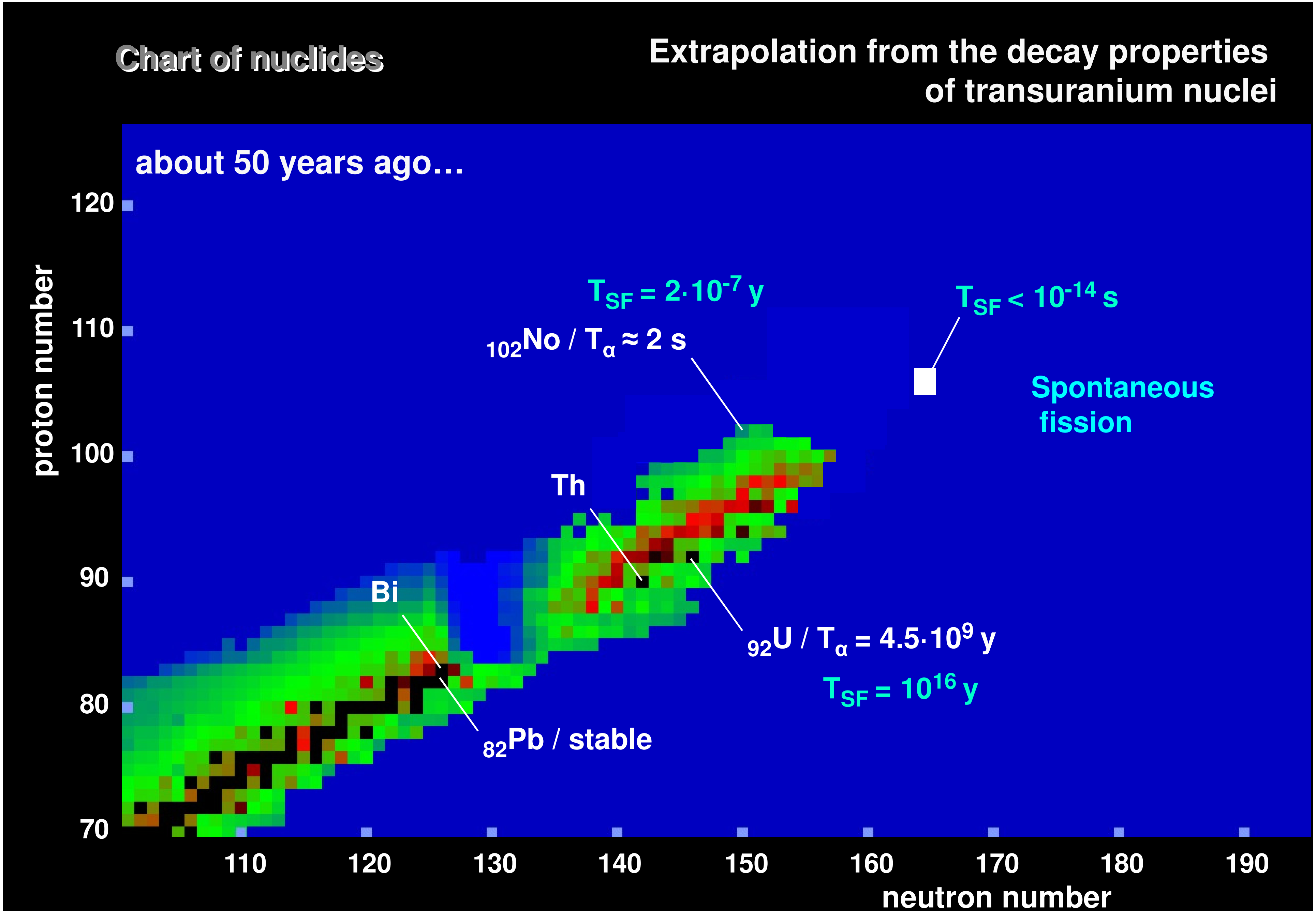
141980 DUBNA, Moscow region, RF

"Relativistic Nuclear Physics and Quantum Chromodynamics"
JINR September 15-20, 2014 in Dubna, Russia.


Solar System
electrons
nucleus
Z
The Sun
E. Rutherford 1911
Planetary model of atom

Today we will discuss:

- How big a nucleus may be,
- What is a maximum number of protons and neutrons it may contain,
- What is the limit of atomic nuclei mass and how it is determined.



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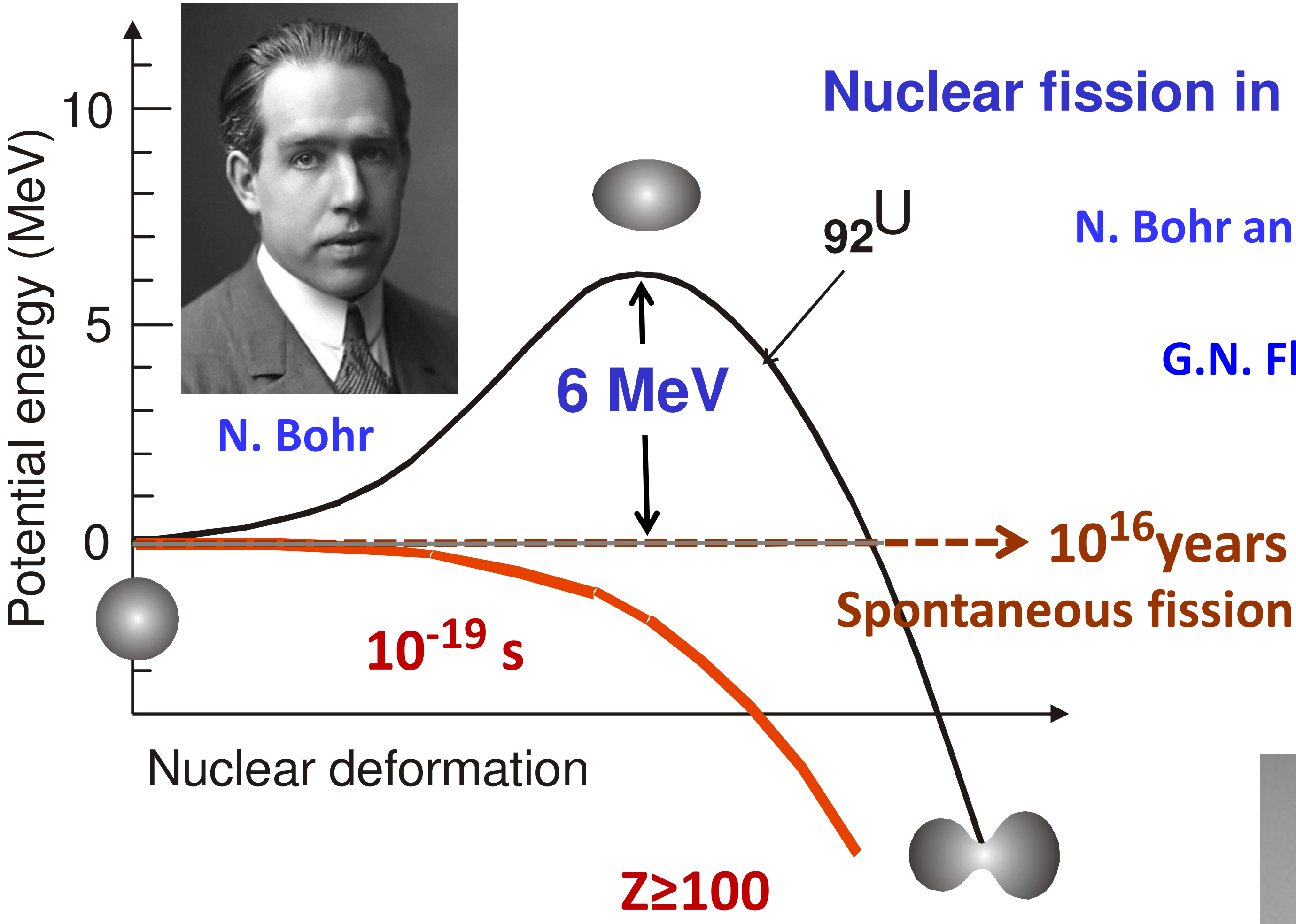
In the first attempts of describing the properties of nuclear matter a daring supposition was made that atomic nucleus is an object similar to a drop of positively charged liquid, the so called

G. Gamow 1928

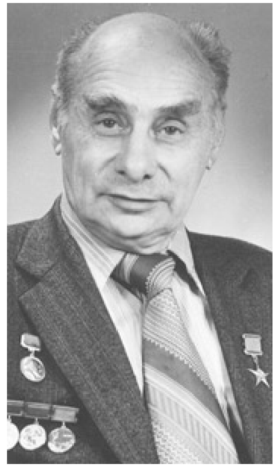
Nuclear Charge Liquid-Drop Model

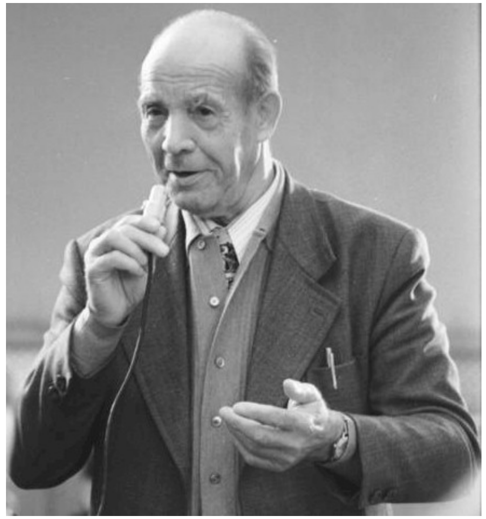
Nuclear fission in Liquid Drop Model

N. Bohr and J. A. Wheeler



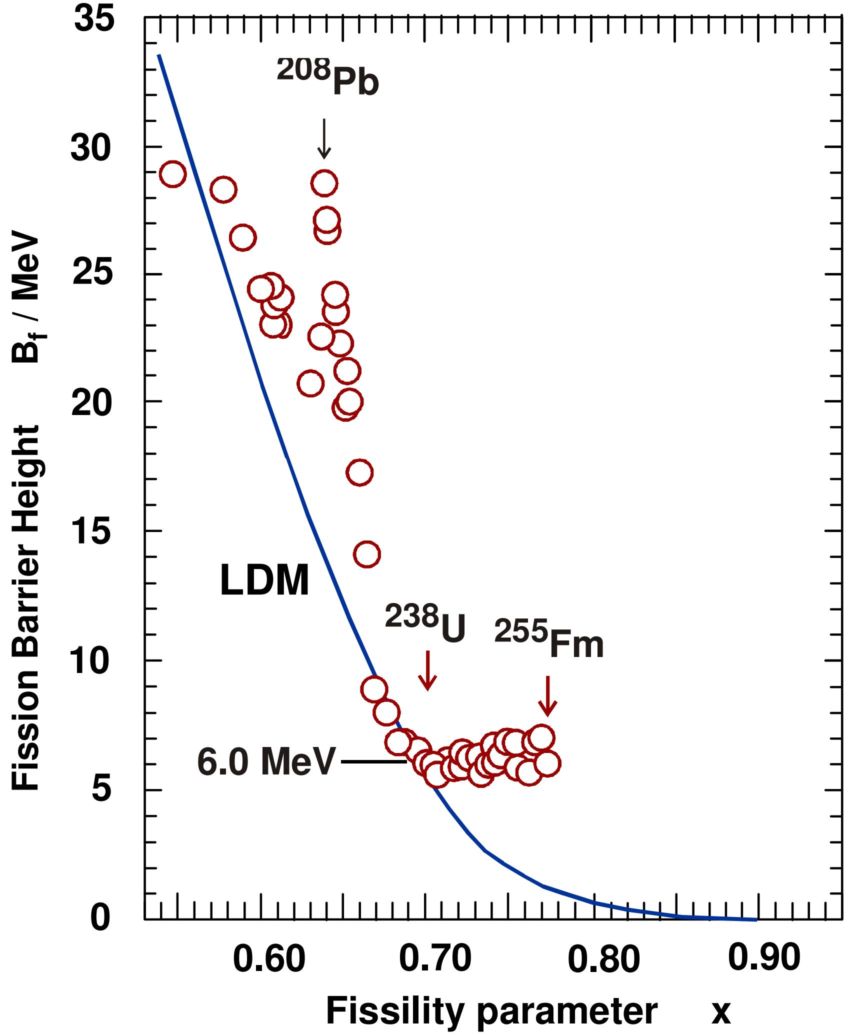
G.N. Flerov

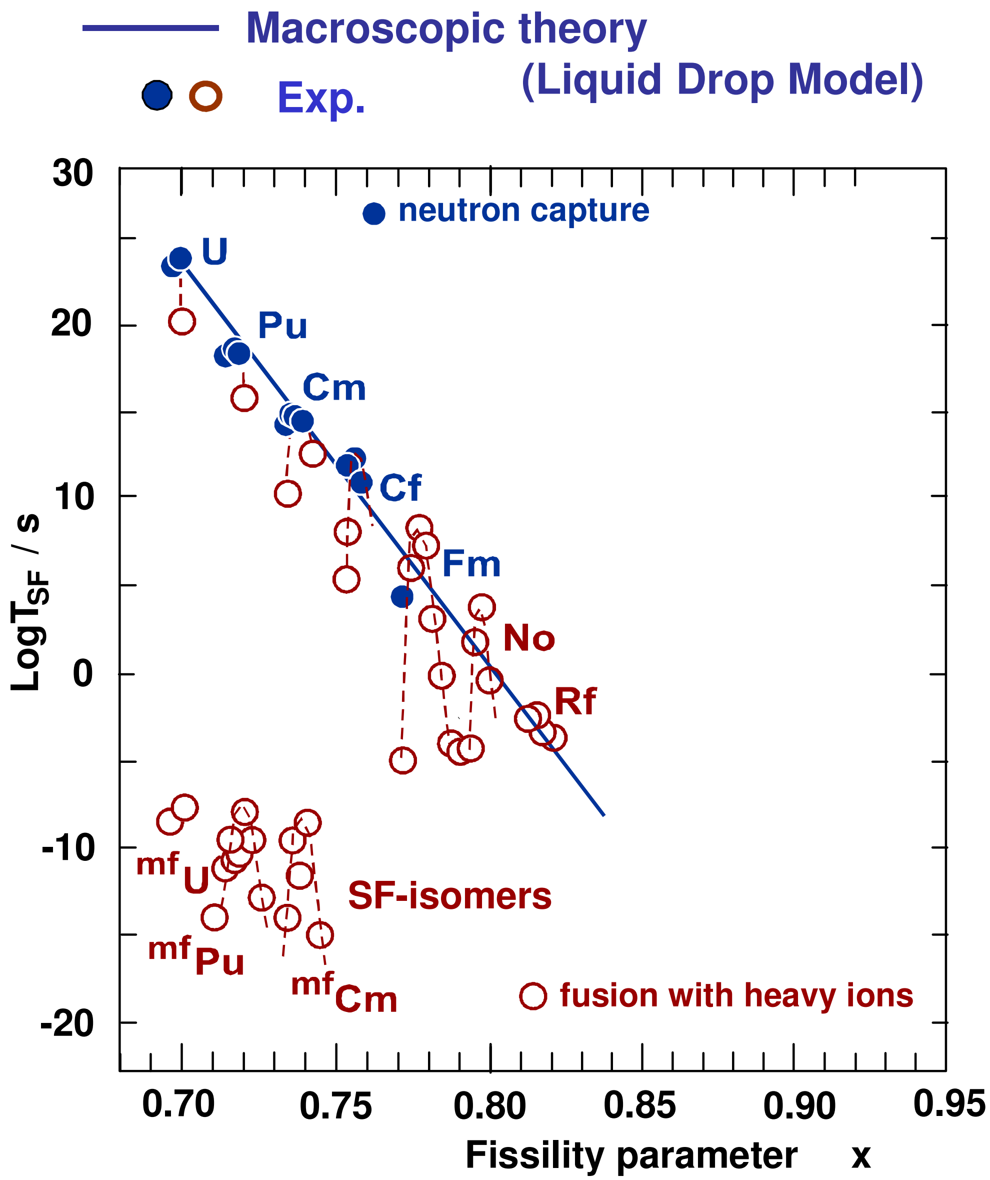




K.A. Petrzhak

Spontaneous Fission





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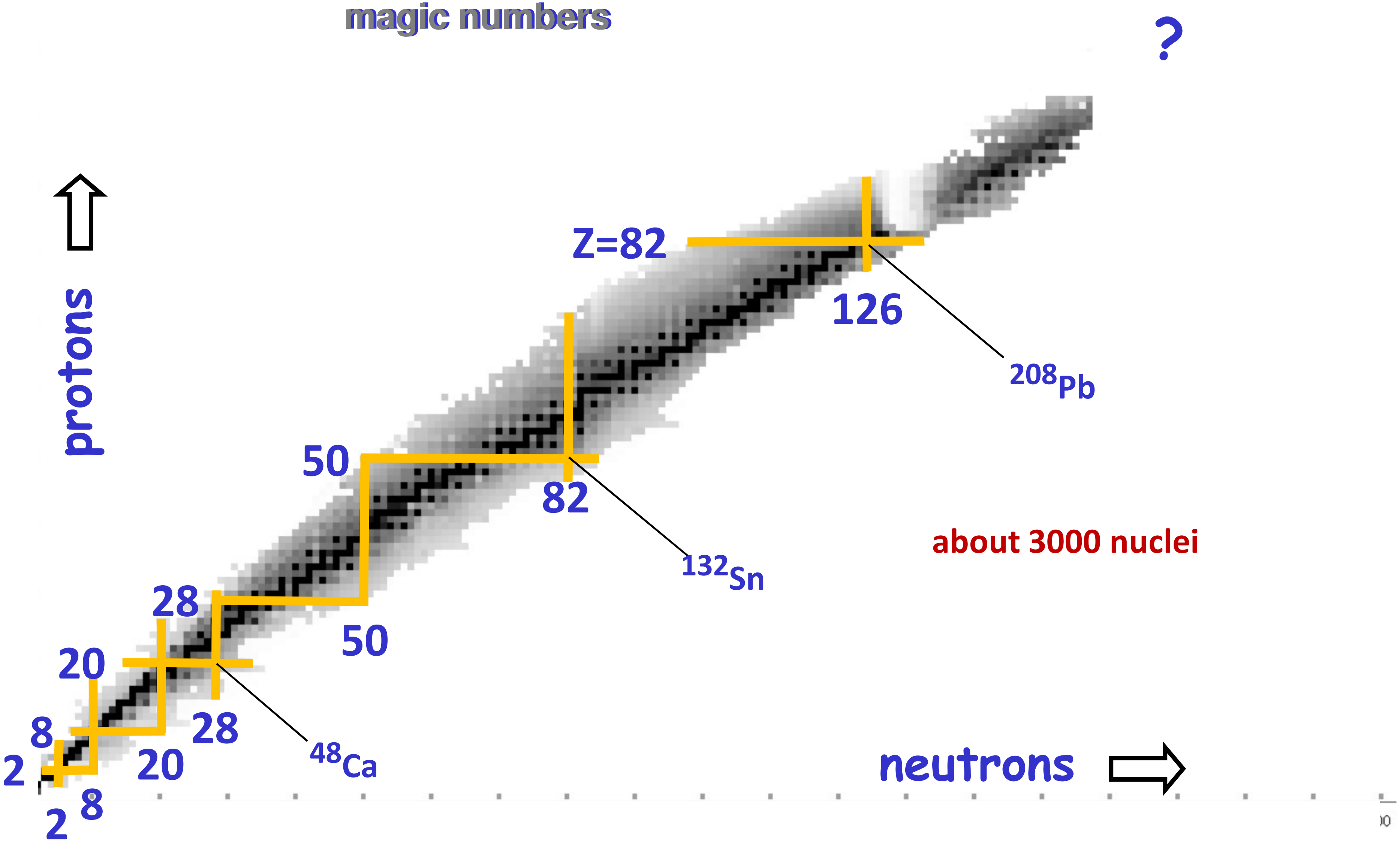
Shells

and

magic numbers



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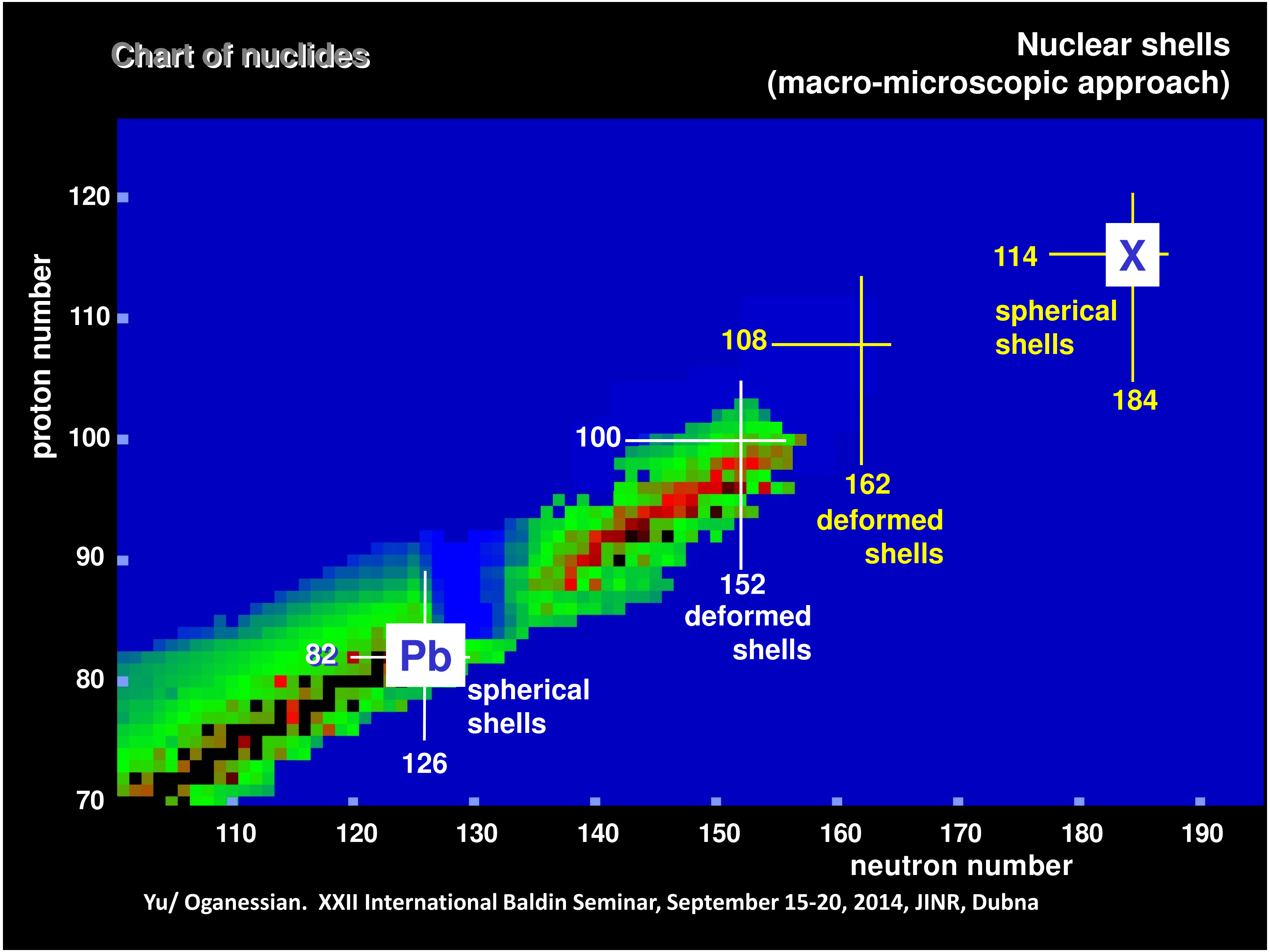
Chart of nuclides
Nuclear shells
(macro-microscopic approach)
proton number
neutron number
120
110
100
90
80
70
110
120
130
140
150
160
170
180
190
114
X
spherical
shells
184
108
162
deformed
shells
100
152
deformed
shells
82
Pb
spherical
shells
126
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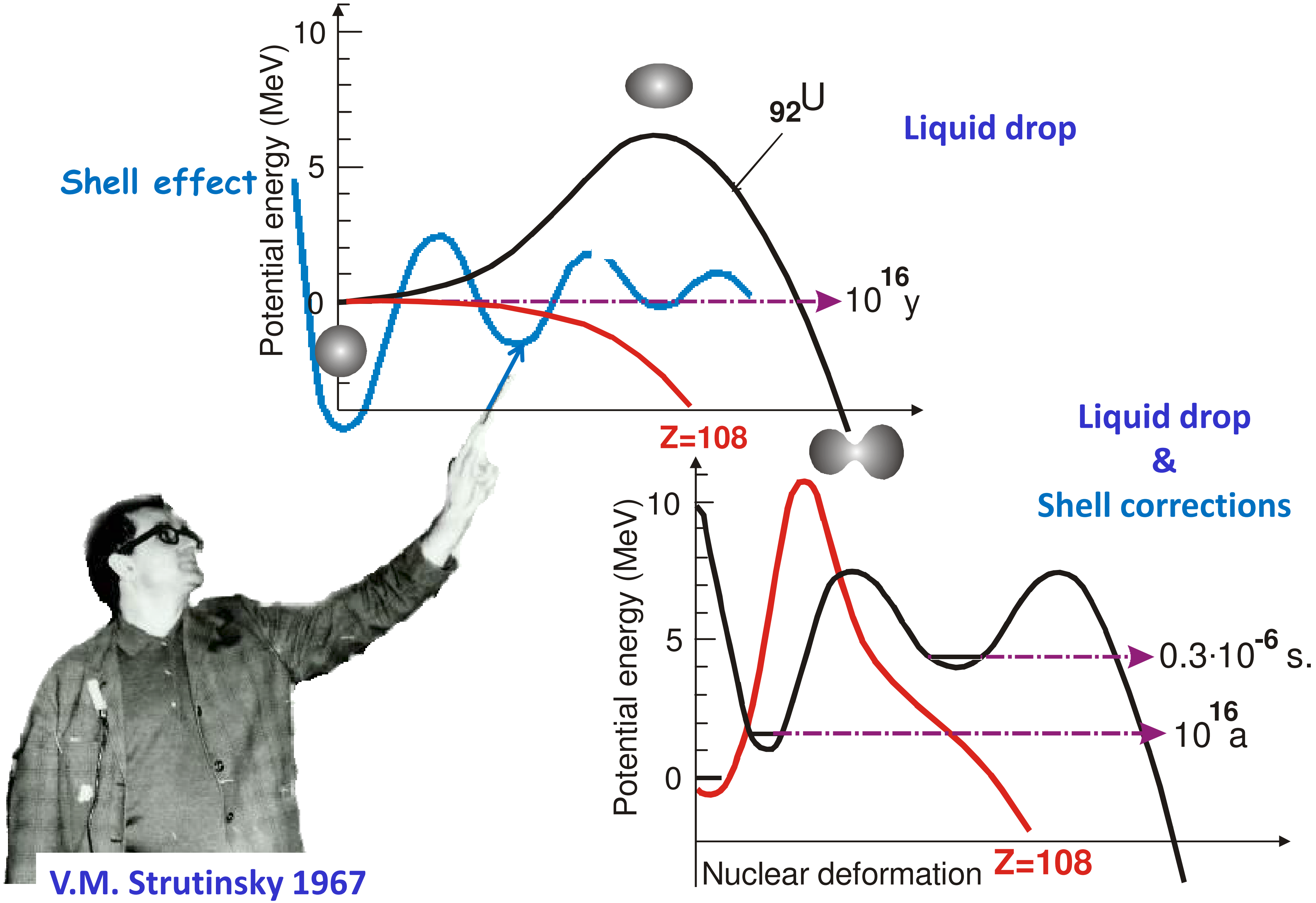

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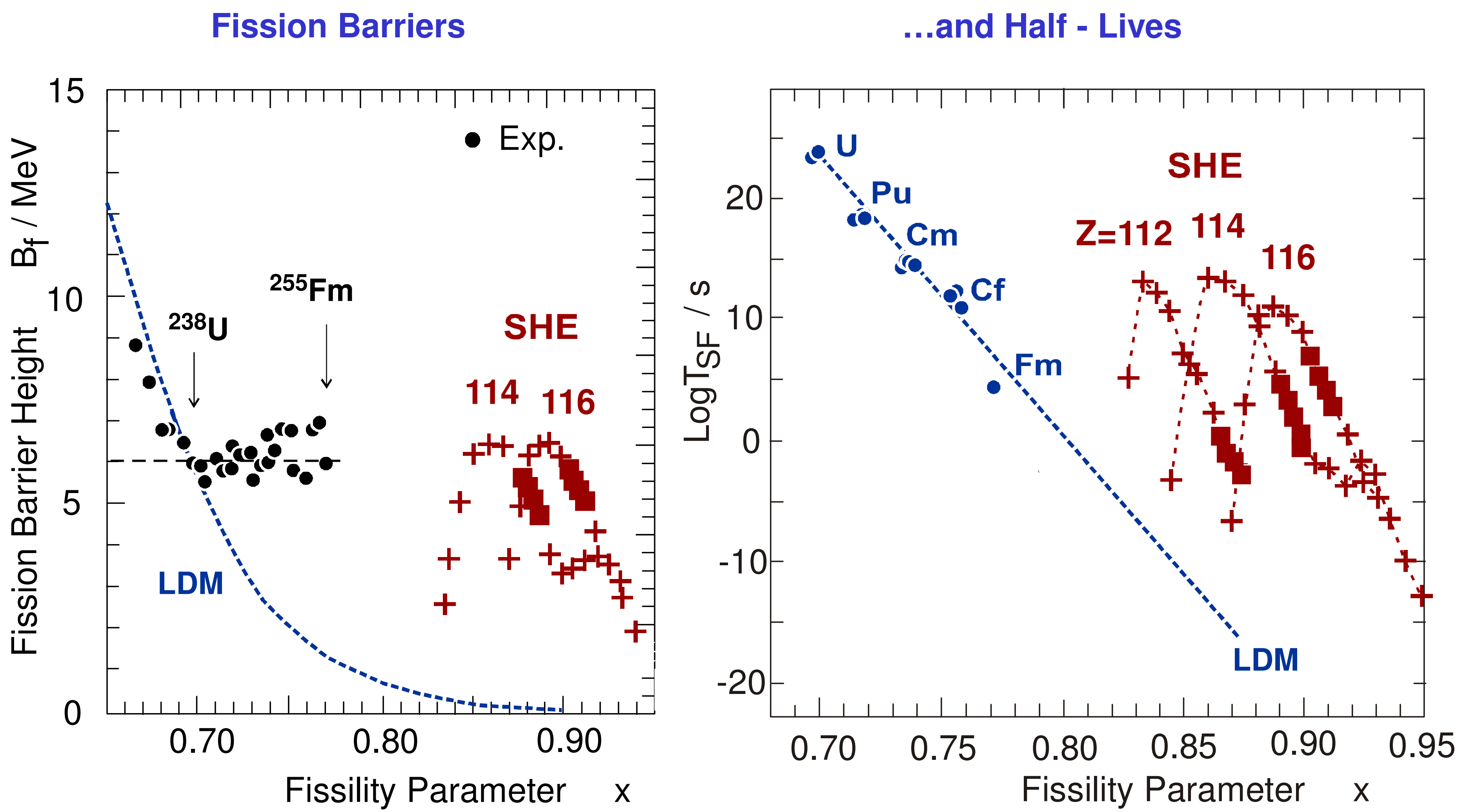
Predictions of the microscopic theory



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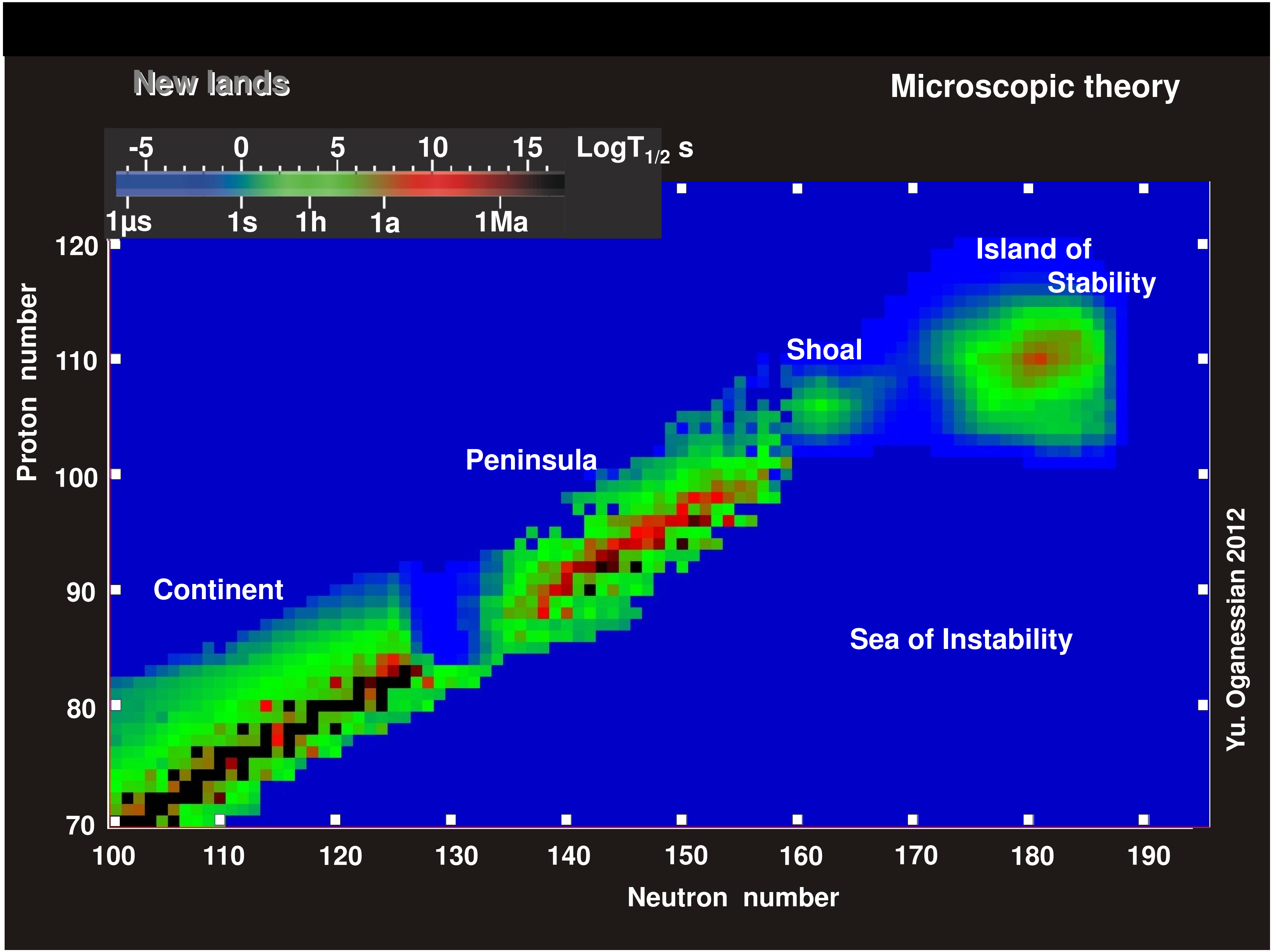
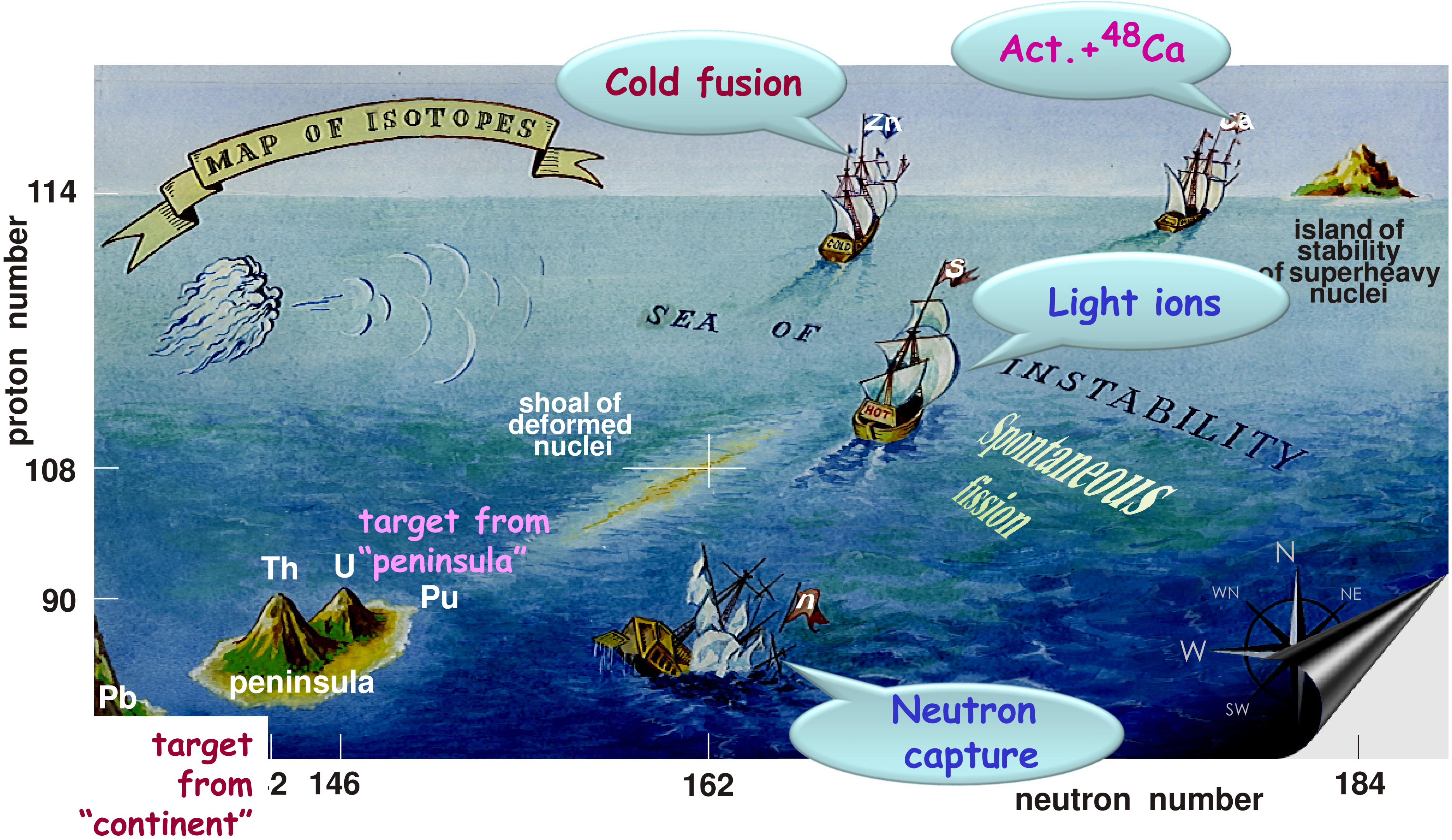


New lands
Microscopic theory
-5
0
5
10
15
LogT1/2 s
1µs
1s
1h
1a
1Ma
Island of
Stability
Shoal
Peninsula
Continent
Sea of Instability
Proton number
120
110
100
90
80
70
100
110
120
130
140
150
160
170
180
190
Neutron number
Yu. Oganessian 2012

Reaction of Synthesis

In laboratory conditions the heaviest elements are produced in collisions of massive nuclei at great velocities… (up to 1/10 of the speed of light

Reactions of synthesis



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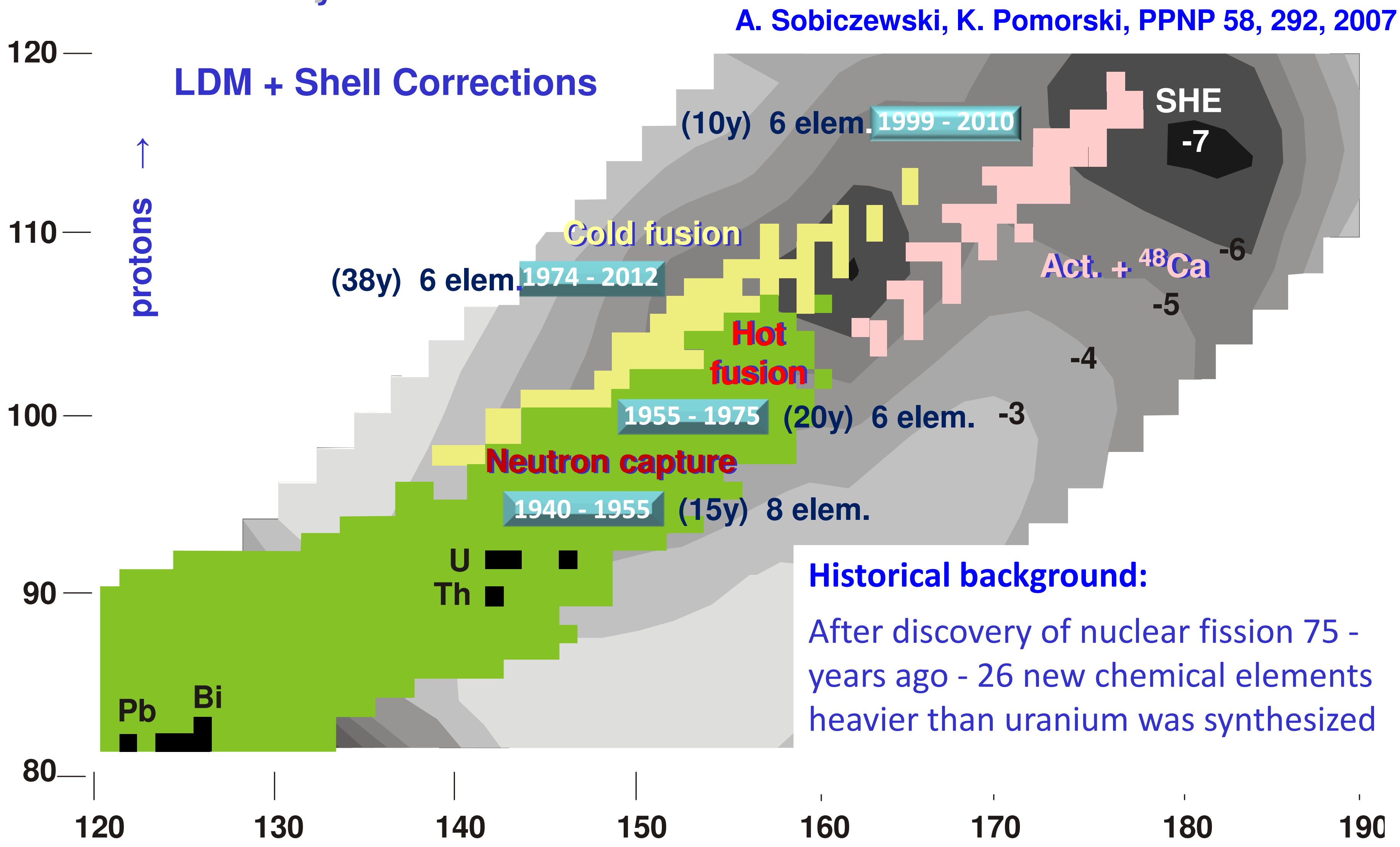
Reactions of Synthesis



Historical background:

After discovery of nuclear fission 75 - years ago - 26 new chemical elements heavier than uranium was synthesized hot fusion

^{48}Ca-induced reactions

E_x = 35 - 45 MeV

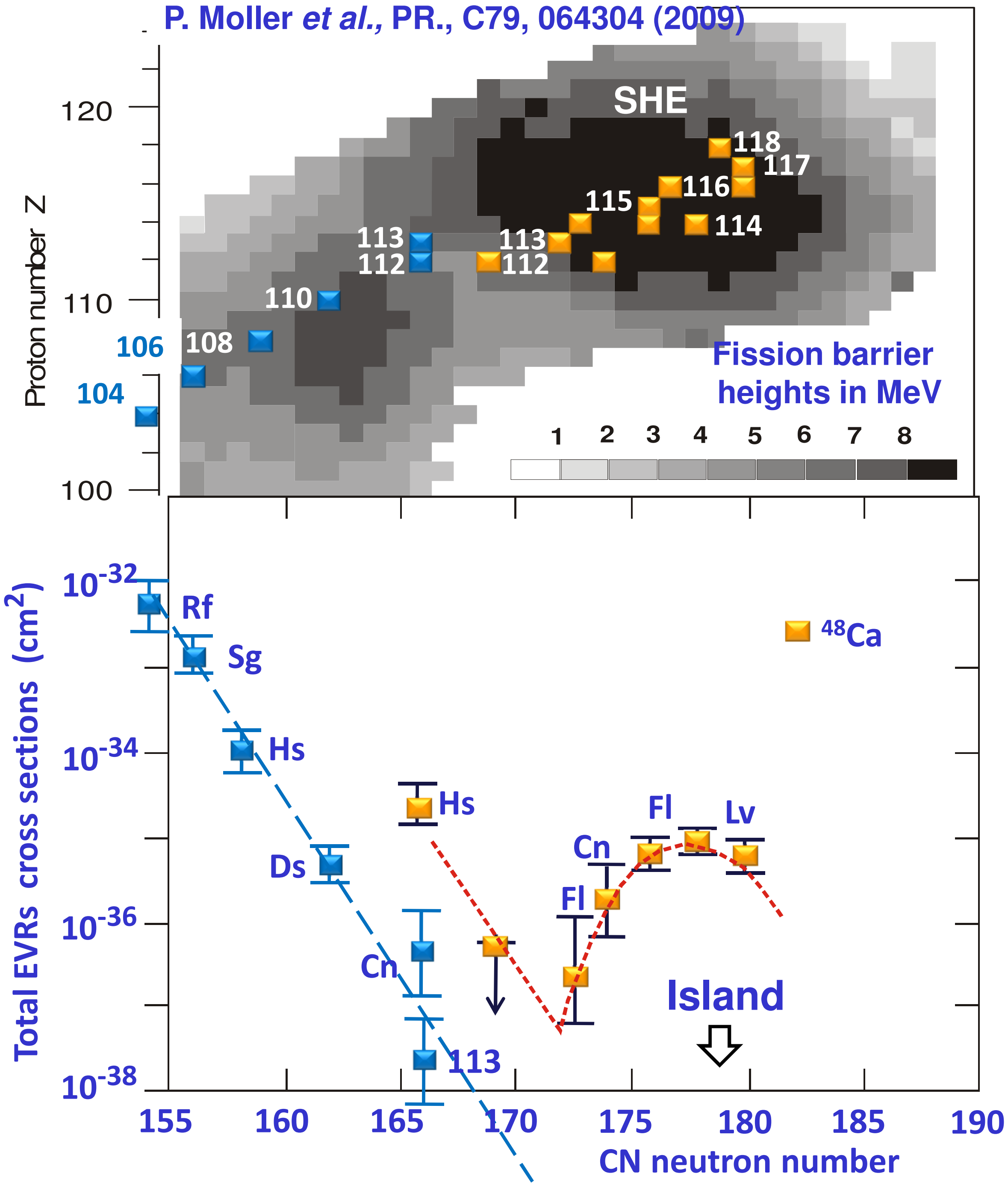
x = 3 – 4

cold fusion

^{208}Pb, ^{209}Bi + ^{50}Ti,……^{70}Zn

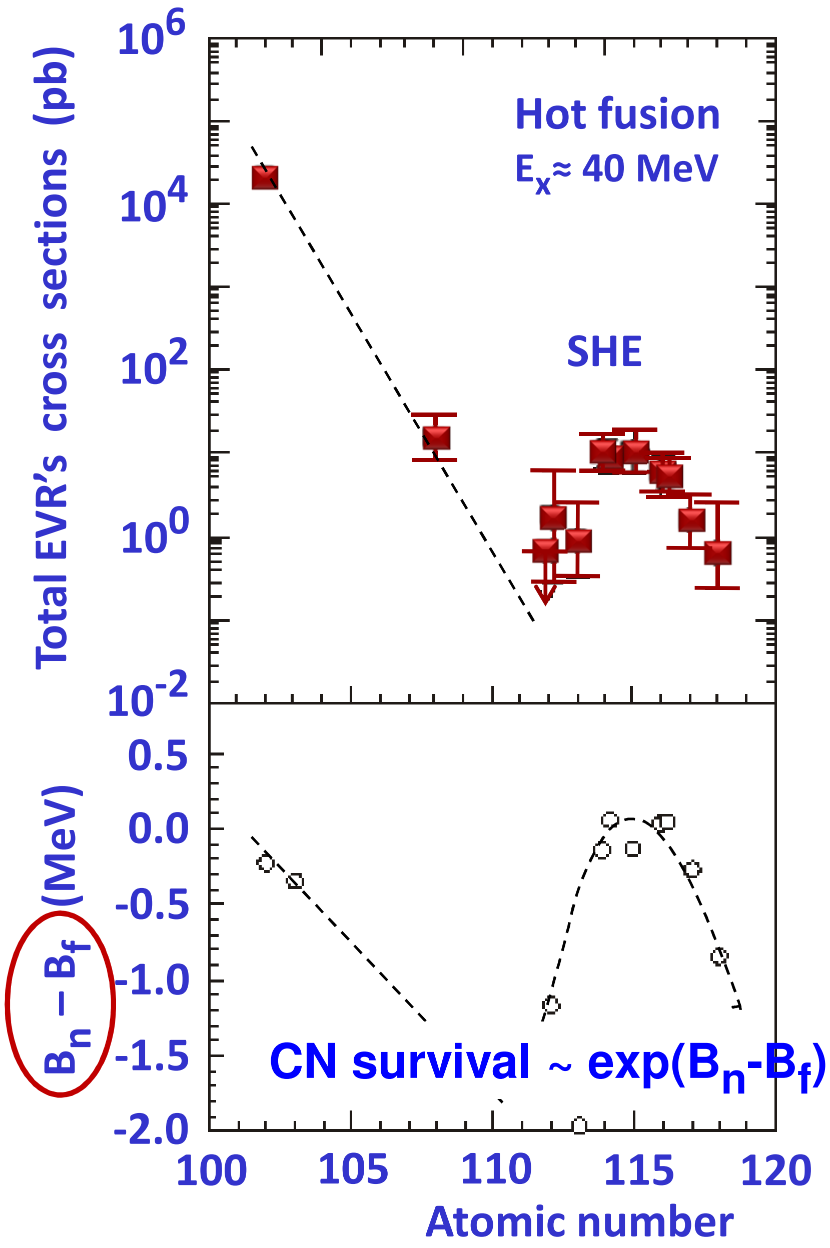
E_x = 12 - 15 MeV

x = 1



$$P_{sur} \sim P_{xn} \cdot \prod_{i=1}^{x} (\Gamma_{ni} / \Gamma_{fi})^{x}$$

$$\Gamma_n / \Gamma_f) \sim e^{-\frac{B_f - B_n}{T}}$$



K. Siwek-Wilczy´nska et al.,
PR C86, 014611 (2012)

TARGETS

Isotope	Target thickness mg/cm^2	Isotope enrichment %	Setup
233U	0.44	99.92	DGFRS
237Np	0.35	99.3	DGFRS
238U	0.35	99.3	DGFRS
242Pu	0.40	99.98	DGFRS
	1.40	**99.98**	**Chem.**
243Am	0.36	99.9	DGFRS
	1.20	**99.9**	**Chem.**
244Pu	0.38	98.6	DGFRS
245Cm	0.35	98.7	DGFRS
248Cm	0.35	97.4	DGFRS
249Bk	0.35	≥90	DGFRS
249Cf	0.30	≥90	DGFRS

48Ca - PROJECTILES

Energy:
235-250 MeV

Intensity:
1.0-1.2 pμA

Consumption:
0.5 mg/h

Beam dose:
up to $4.5 \cdot 10^{19}$

1998 - 2007

Experimental technique

Dubna Gas-Filled Recoil Separator

Transmission for:

EVR 35-40%

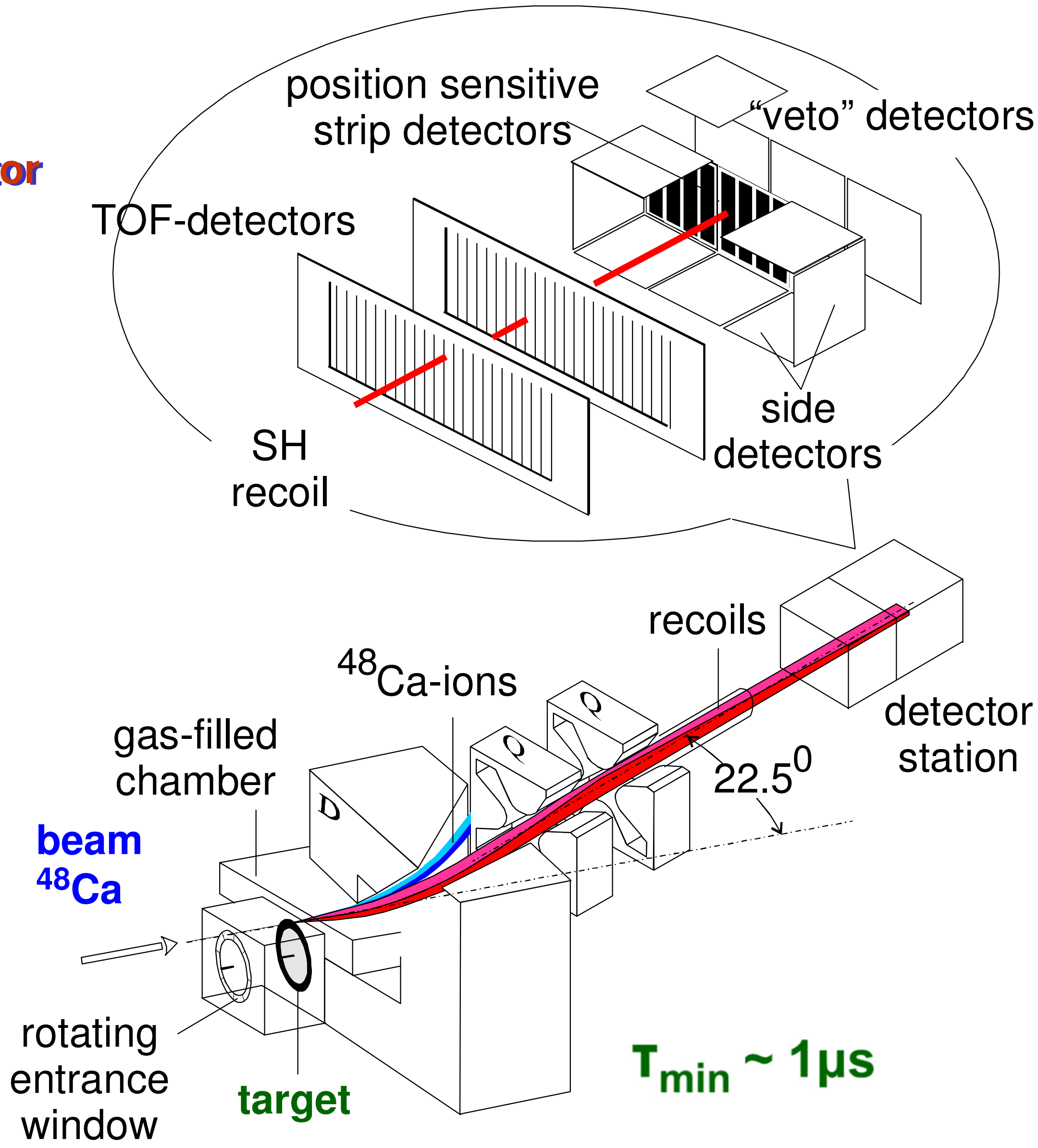
target-like 10^{-4}-10^{-7}

projectile-like 10^{-15}-10^{-17}

Registration efficiency:

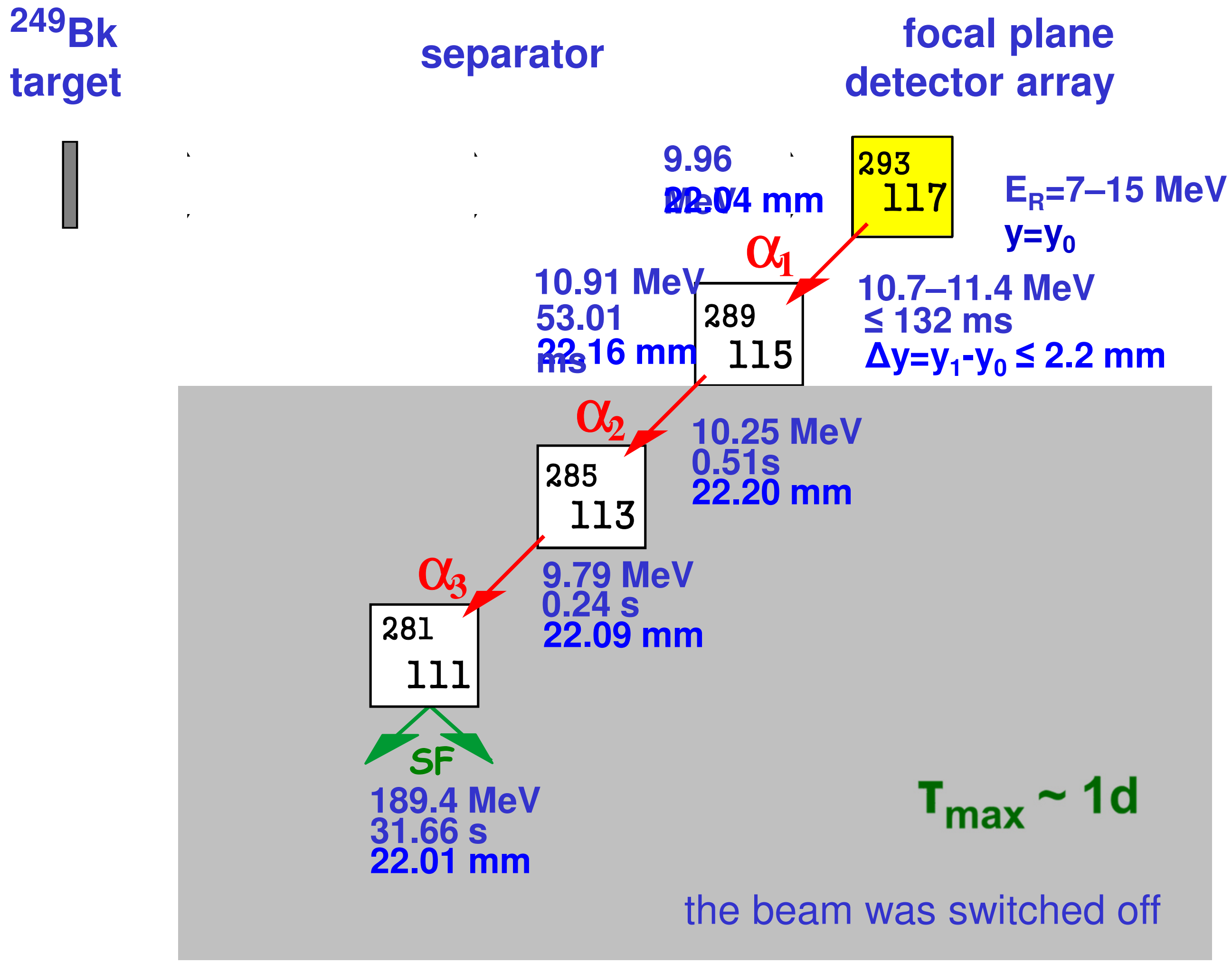
for α-particles 87%

for SF
single fragment 100%
two fragments ≈ 40%

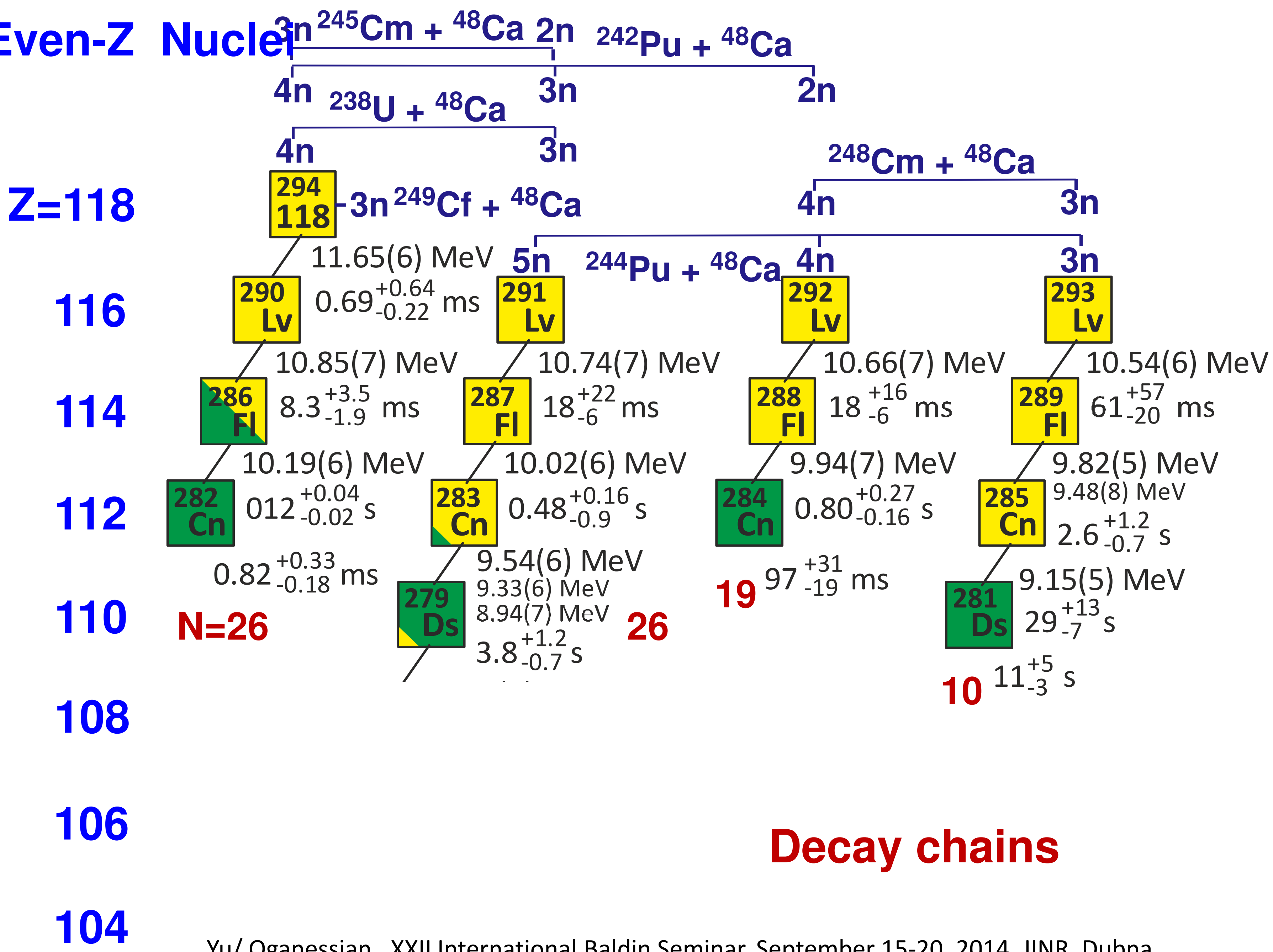


low-background detection scheme

Yu. Oganessian 2010



Even-Z Nuclei



Decay chains

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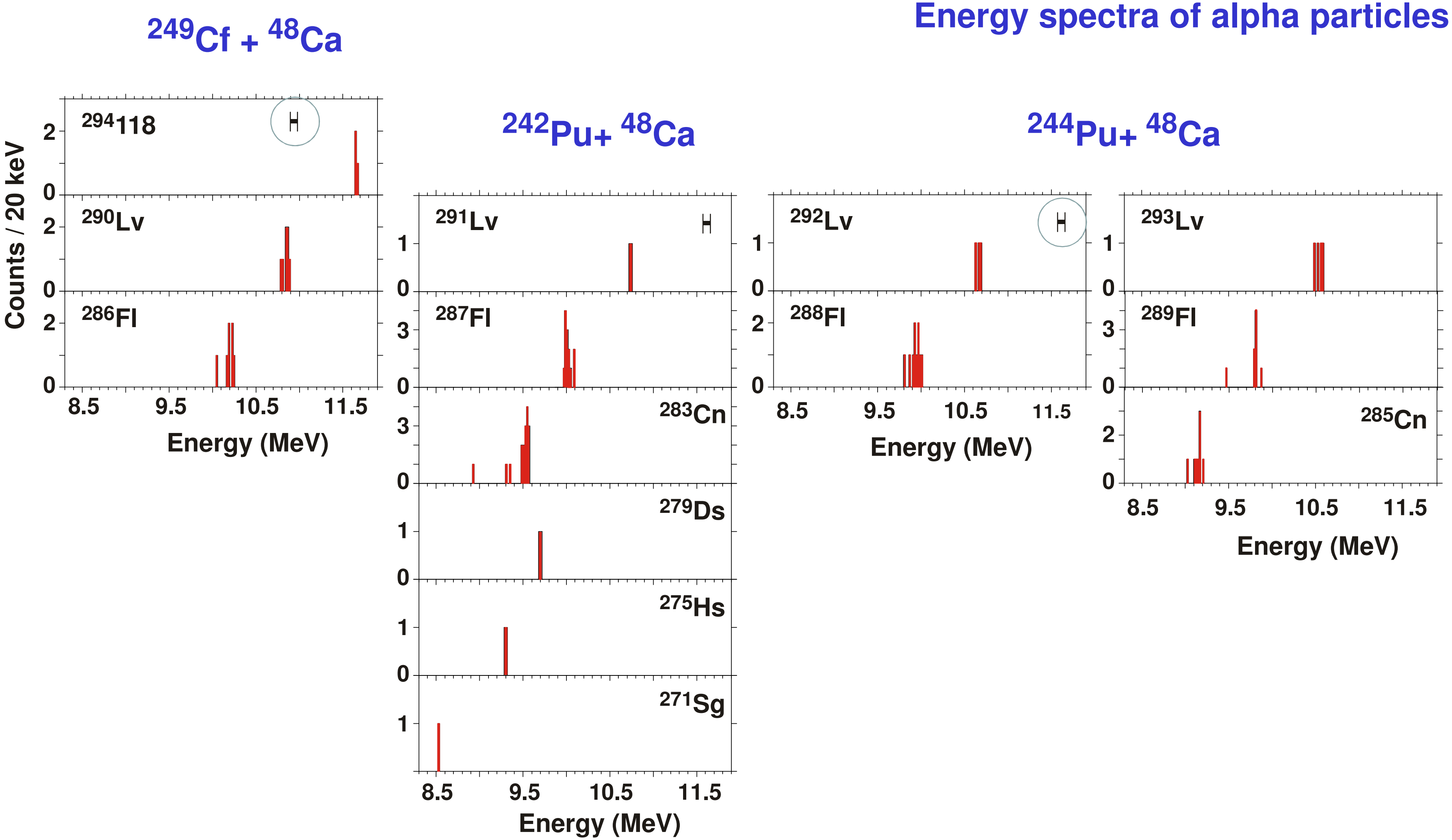
Even Z Nuclei

1999 - 2005

Energy spectra of alpha particles



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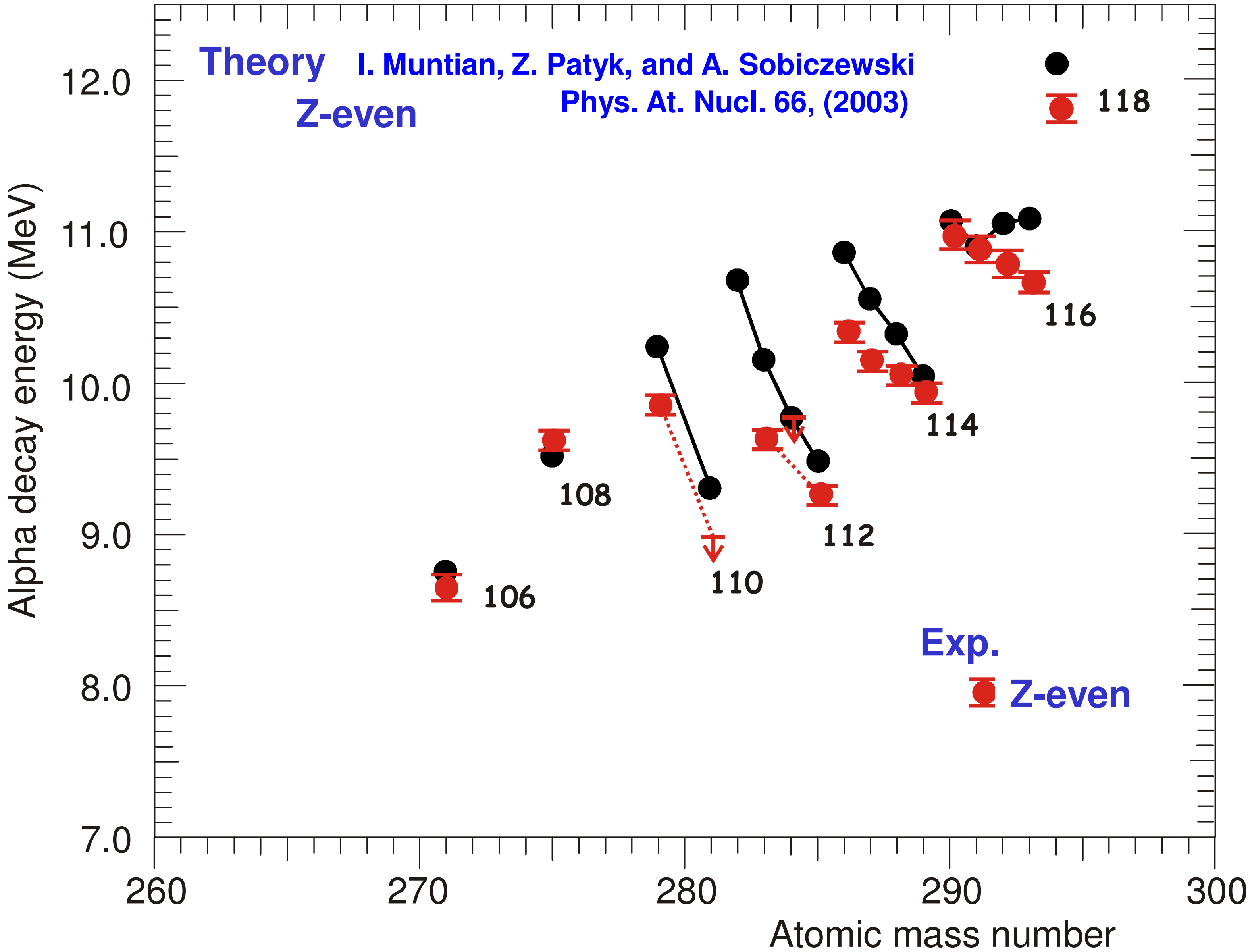
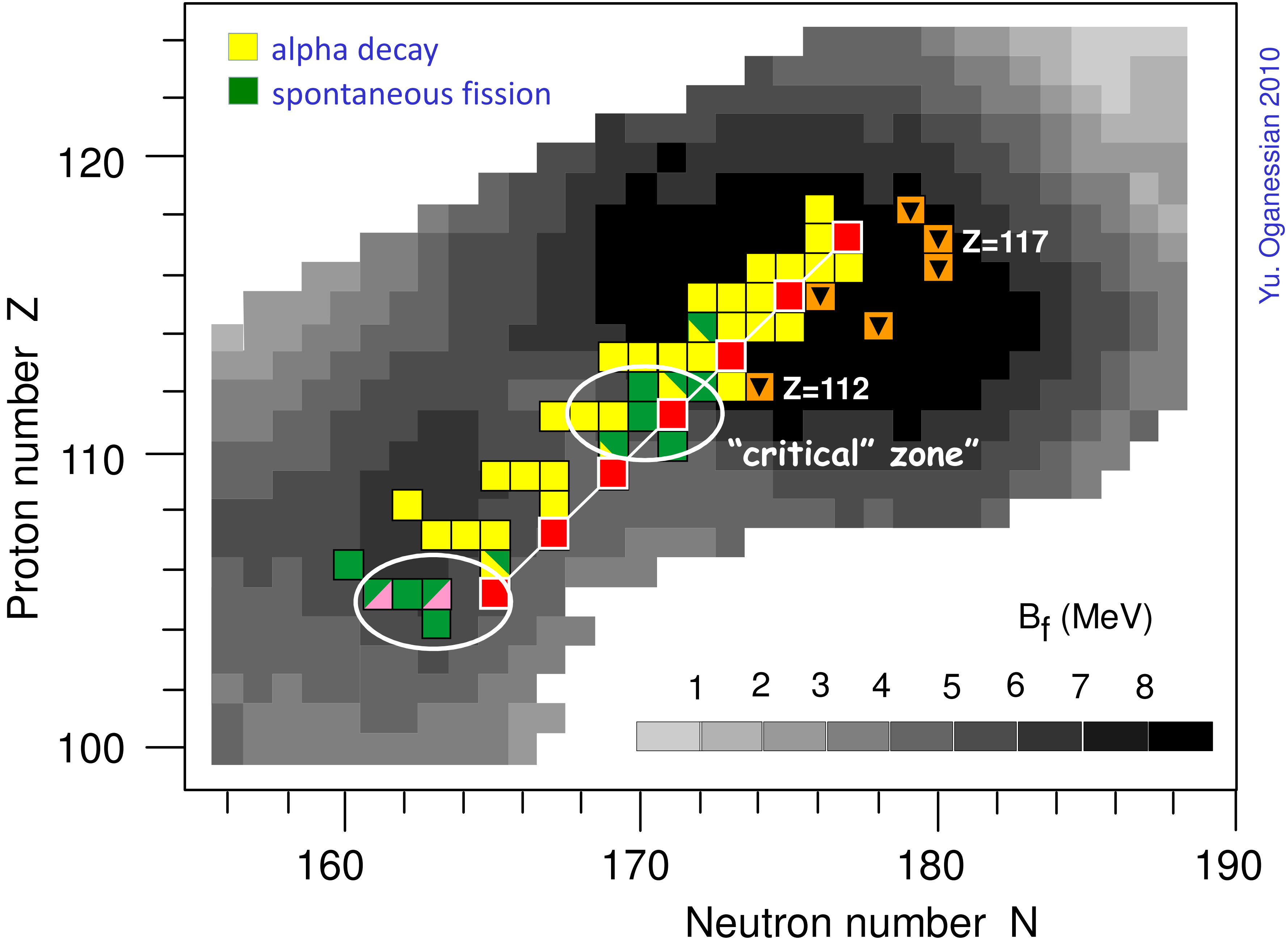
Alpha - decay



Theory
I. Muntian, Z. Patyk, and A. Sobiczewski
Phys. At. Nucl. 66, (2003)
Z-even
118
116
114
112
110
108
106
Exp.
Z-even
12.0
11.0
10.0
9.0
8.0
7.0
Alpha decay energy (MeV)
260
270
280
290
300
Atomic mass number



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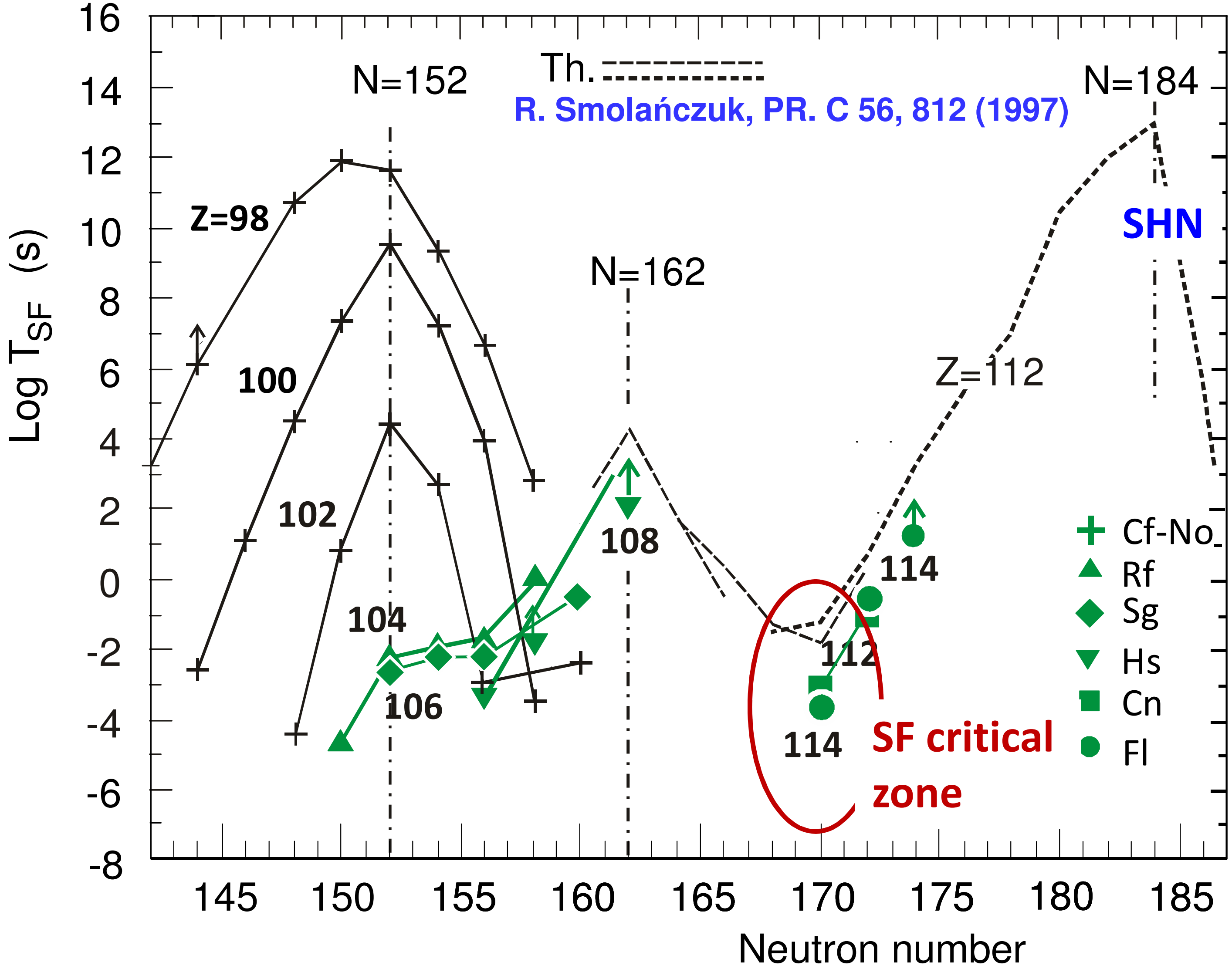
Spontaneous fission

even-even isotopes



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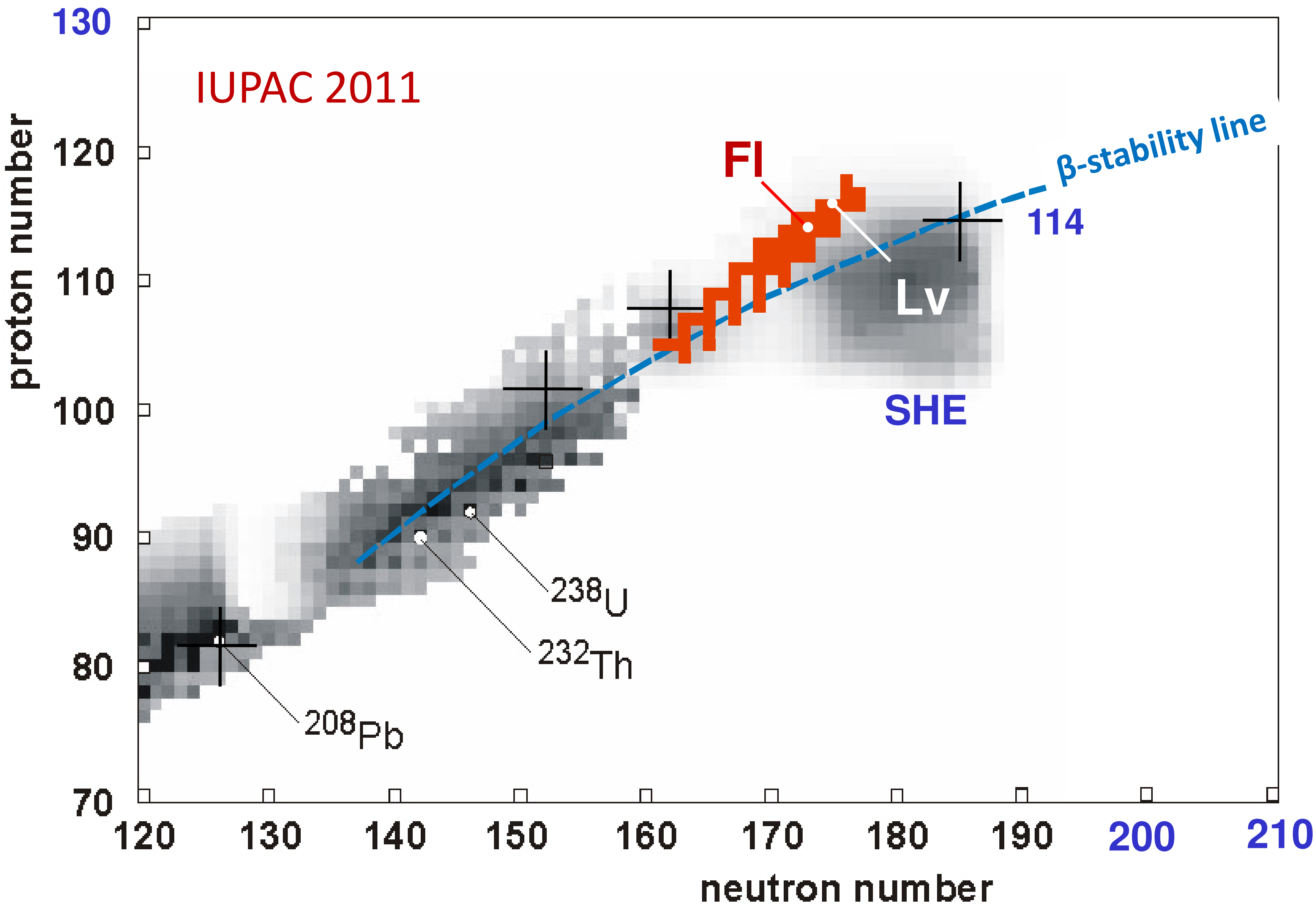

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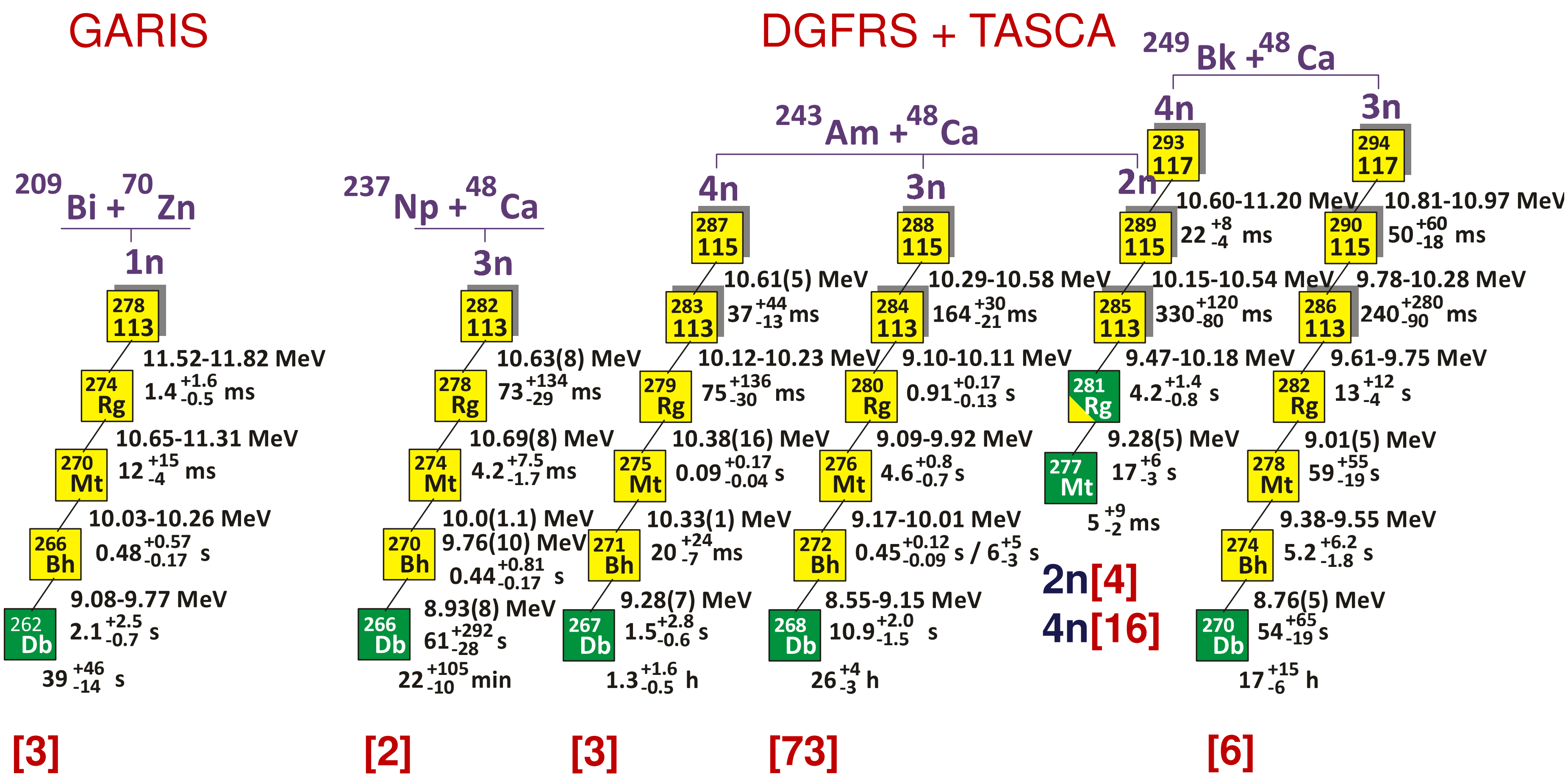
June, 2013



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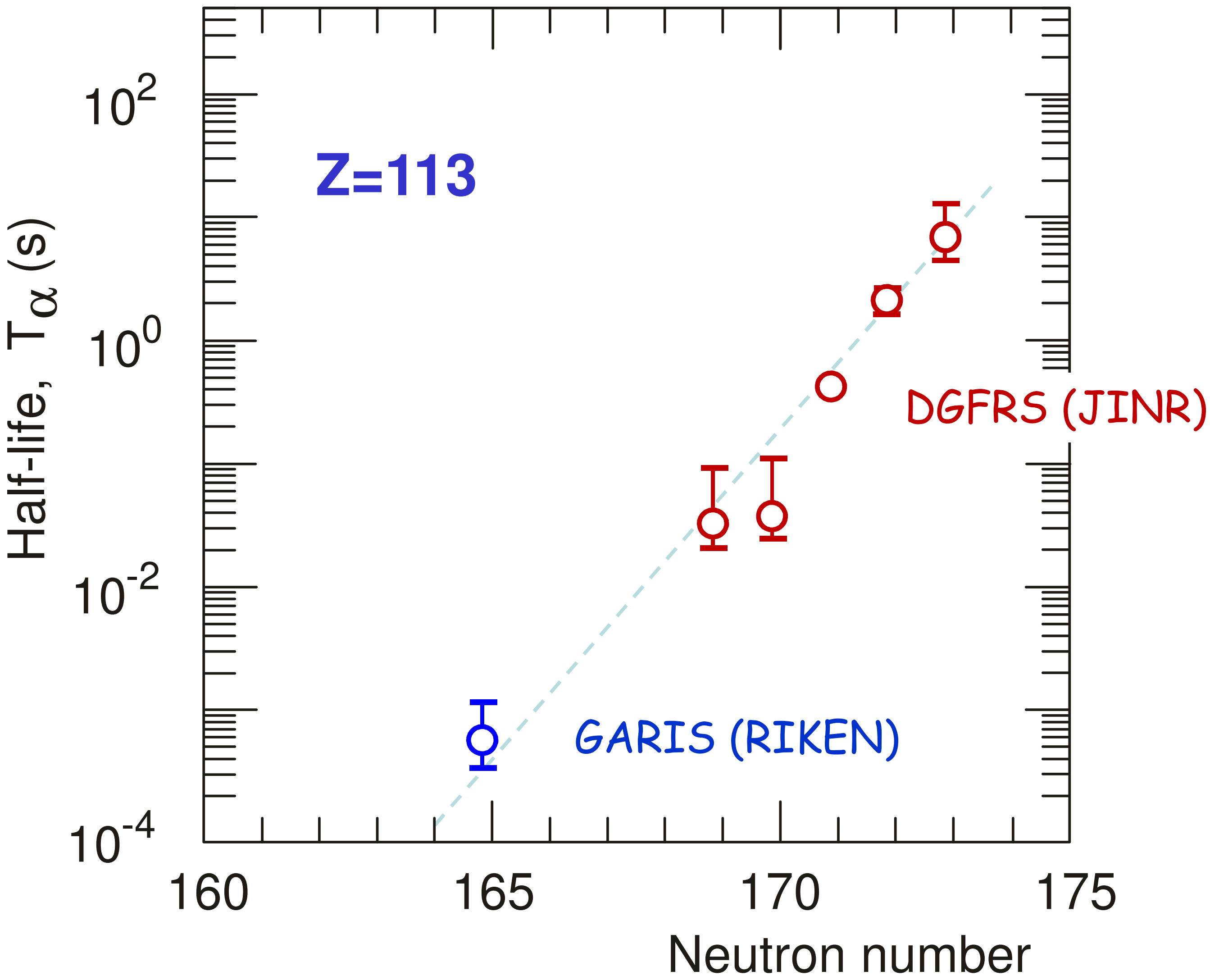

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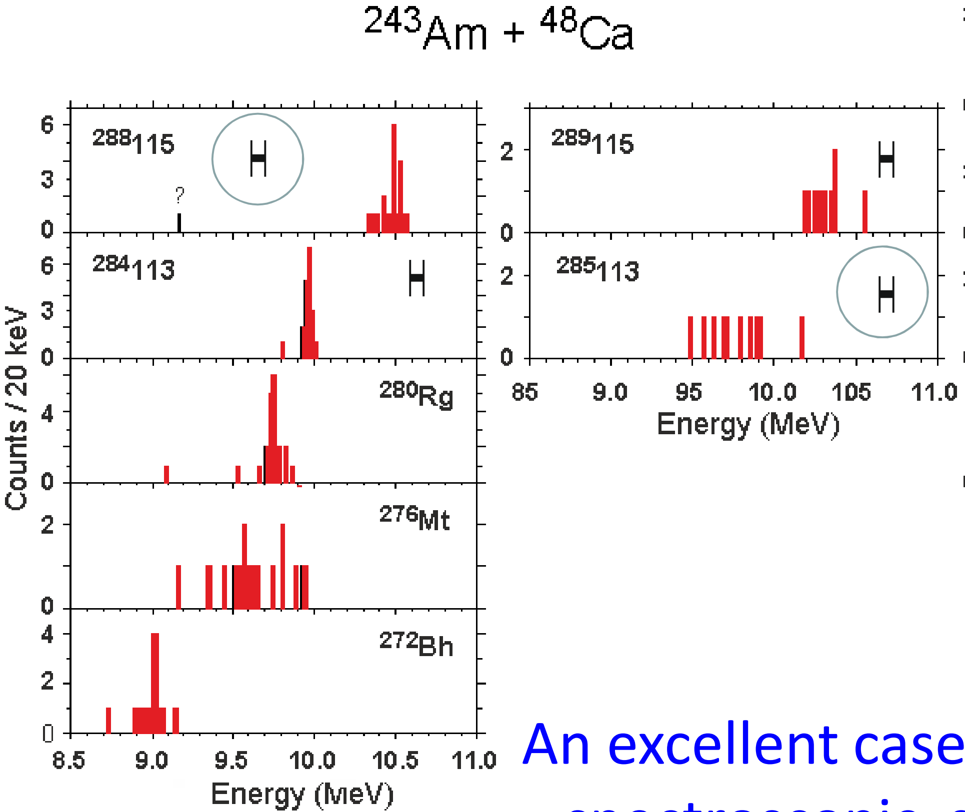
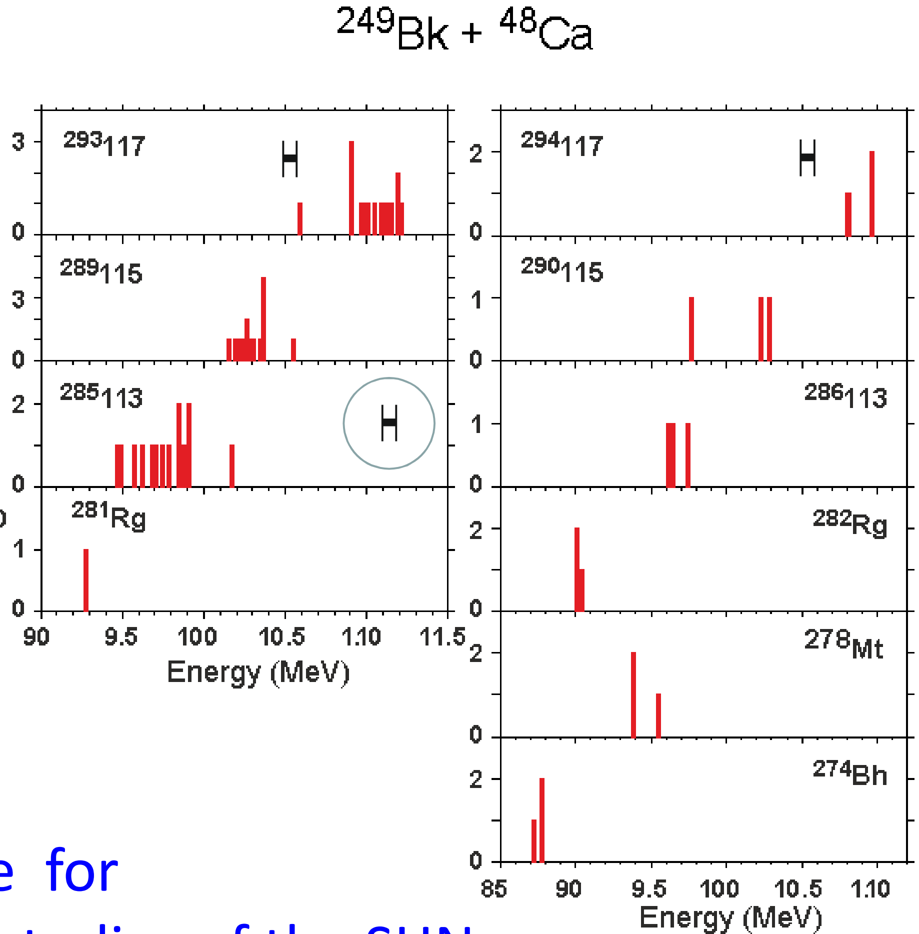
Odd Z Nuclei

2003 - 2012





An excellent case for spectroscopic studies of the SHN in <α-γ> coincidence experiments

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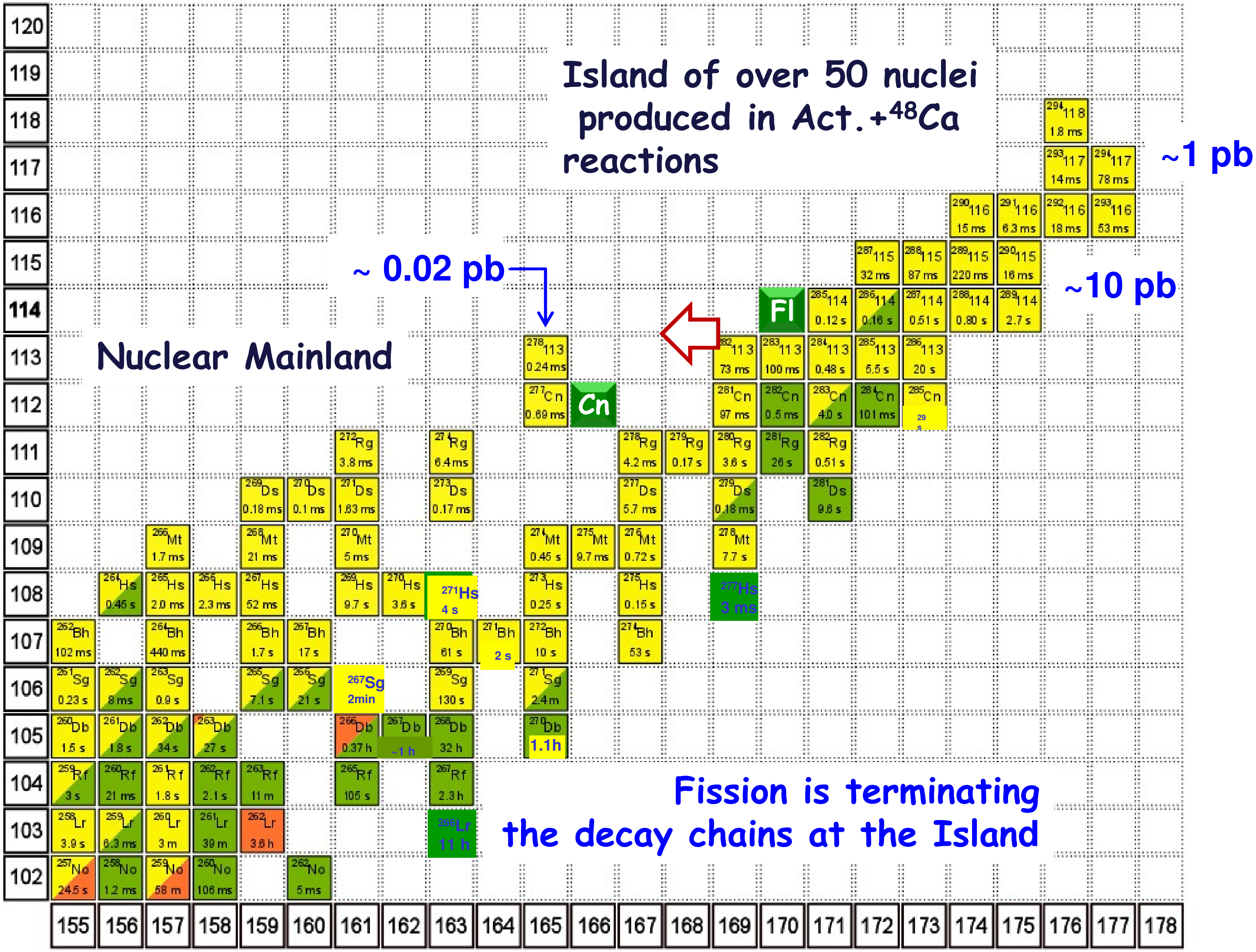
Confirmations of DGFRS data 2007 - 2014

A/Z	Setup	Laboratory	Publications
$^{283}112$	SHIP	GSI Darmstadt	Eur. Phys. J. A32, 251 (2007)
$^{283}112$	COLD	PSI-FLNR (JINR)	NATURE 447, 72 (2007)
$^{286,\,287}114$	BGS	LBNL (Berkeley)	P.R. Lett. 103, 132502 (2009)
$^{288,\,289}114$ $^{292,\,293}116$	TASCA SHIP	GSI – Mainz GSI Darmstadt	P.R. Lett. 104, 252701 (2010) Eur. Phys. J. A48, 62 (2012)
$^{287,\,288}115$ $^{293,\,294}117$	TASCA TASCA	GSI – Mainz GSI – Mainz	P.R. Lett. 111, 112502 (2013) P.R. Lett. 112, 172501 (2014)
$^{292,\,293}116$	GARIS	RIKEN Tokyo	Accelerator Progress Rep. (2013)

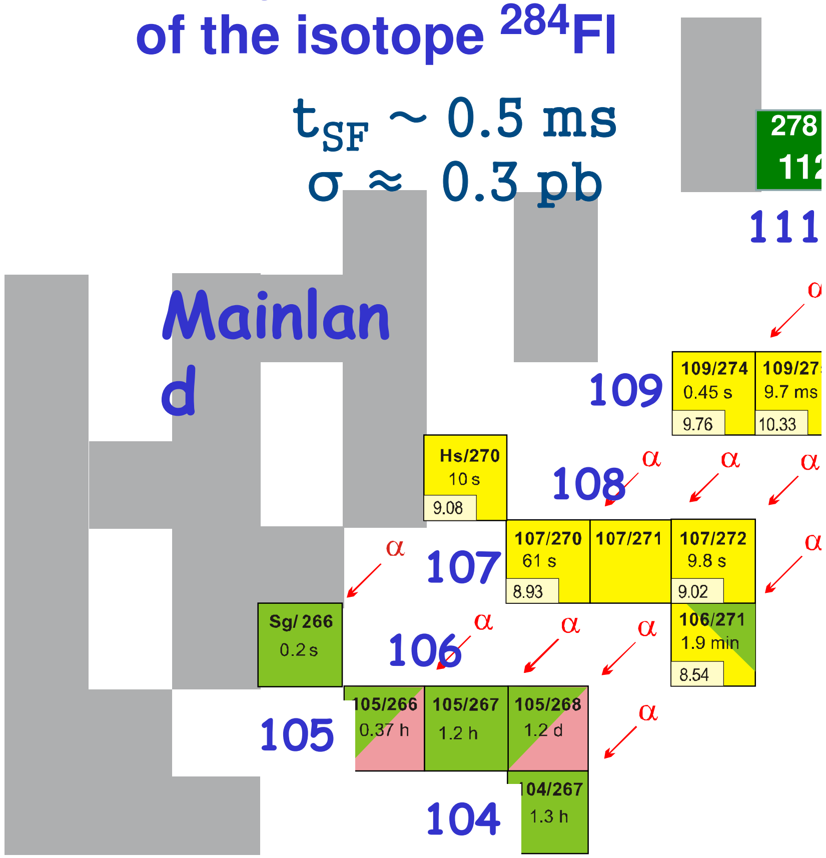


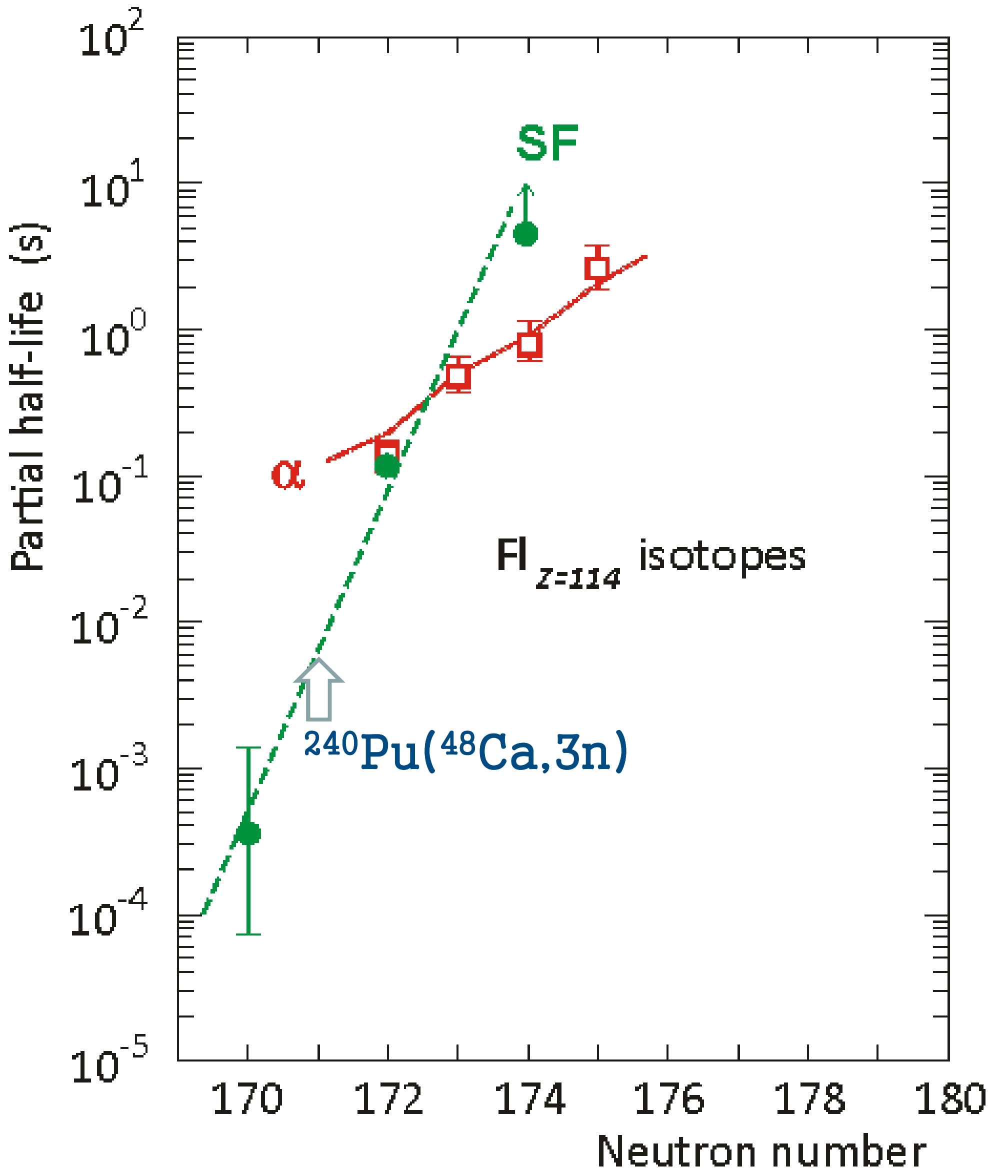
Island of over 50 nuclei produced in Act.+48Ca reactions
~1 pb
~ 0.02 pb
~10 pb
Fl
Cn
Nuclear Mainland
Fission is terminating the decay chains at the Island

$^{239}Pu(^{48}Ca,3n)$—

**There were only one event,
as a candidate for the decay
of the isotope ^{284}Fl**

$t_{SF} \sim 0.5$ ms
$\sigma \approx 0.3$ pb





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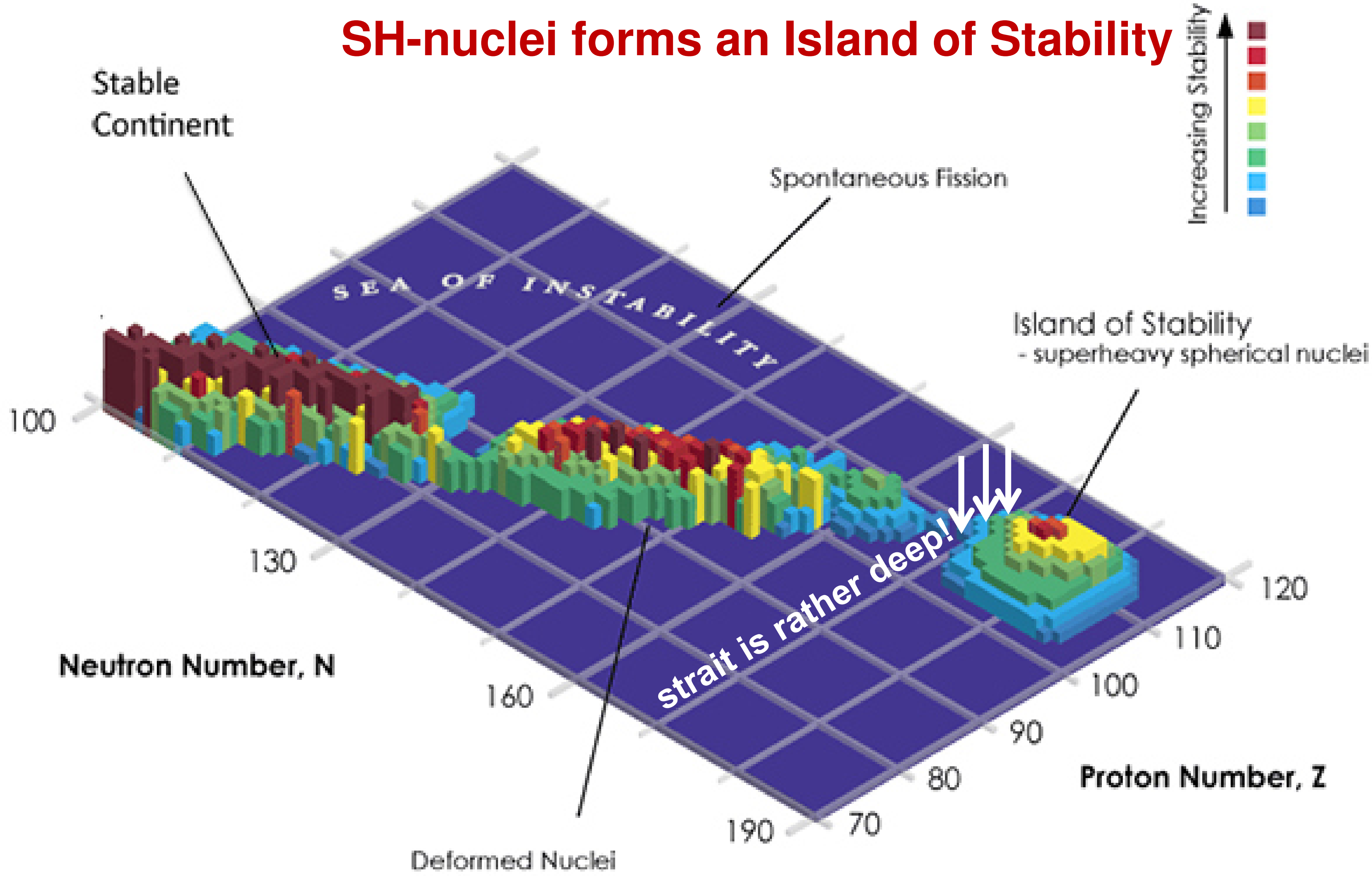
SH-nuclei forms an Island of Stability



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With Z >40% larger than that of Bi, the heaviest stable element, we see an impressive extension in nuclear survival.

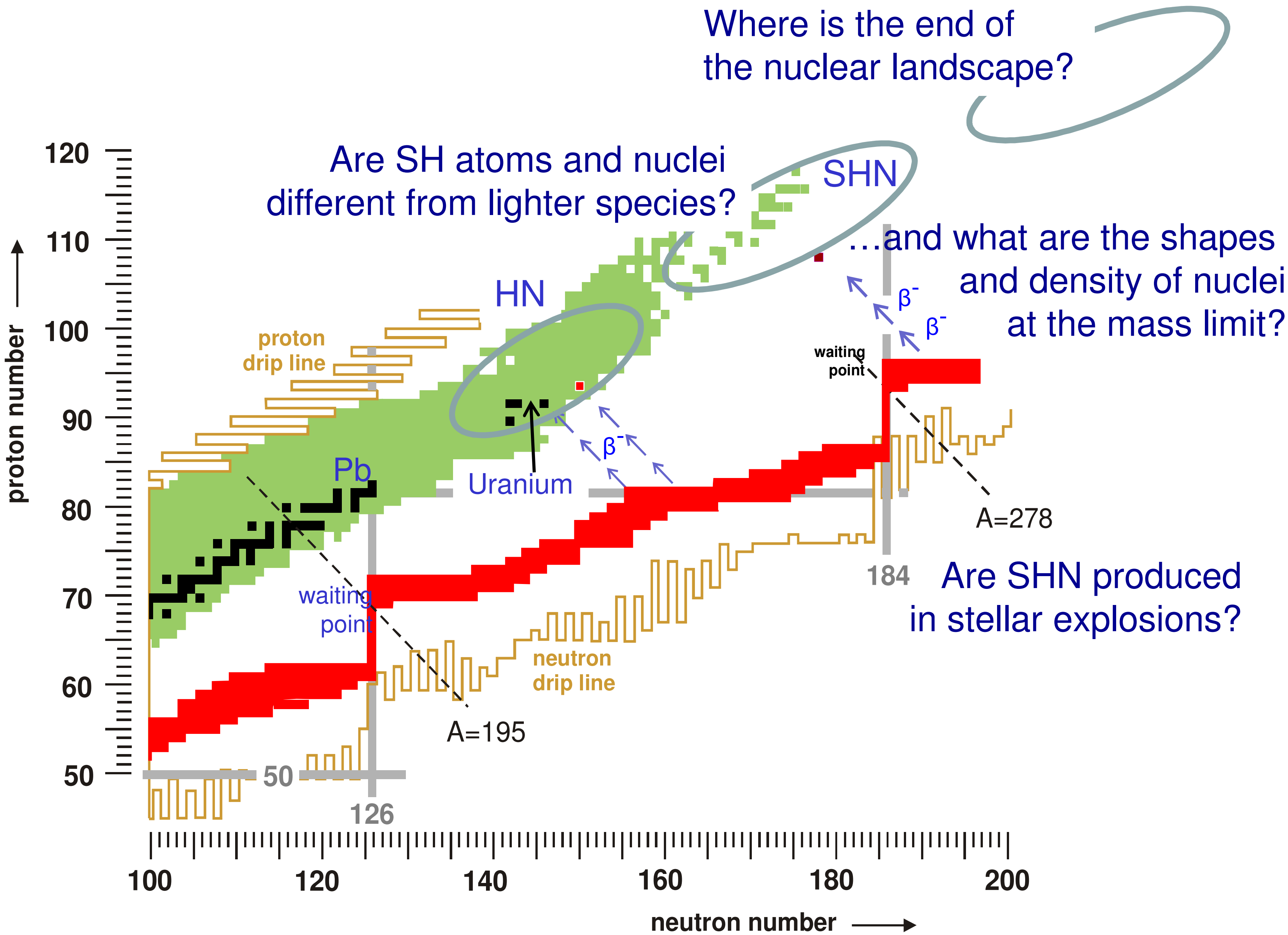
Although SHN are at the limits of Coulomb stability,

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

The fundamentals of the modern theory for mass limits of nuclear matter were given experimental verification.

The discovery of SHE raised a questions:

The discovery of SHE raised a questions:



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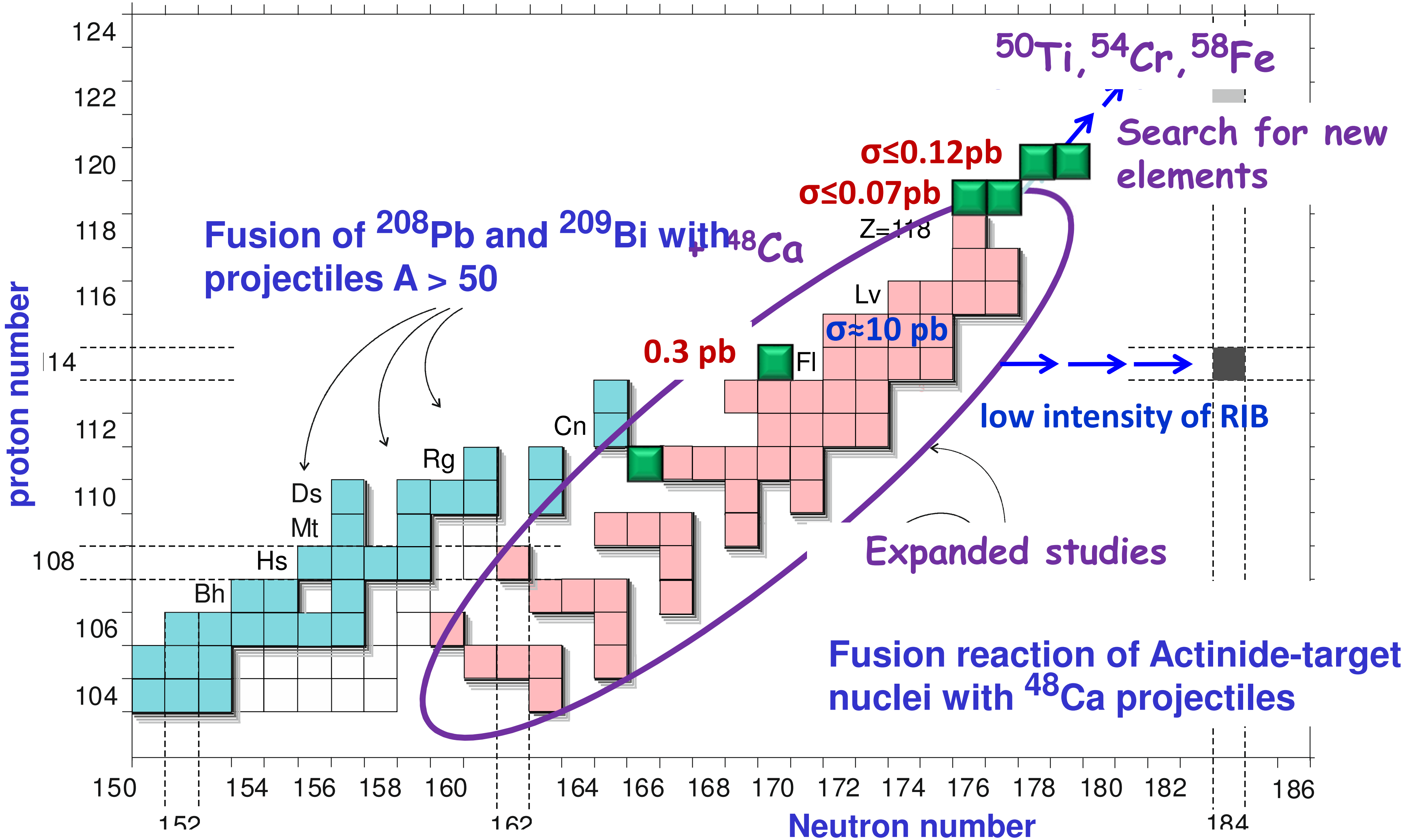

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Obviously...

the field of the research is limited
by the production of super heavy nuclei

Everything we know about SH-nuclei produced
in ^{48}Ca-induced reactions:

…allow us to think about a SHE-Factory
with production rate about 100 times higher
than what we currently have

Factory of SHE

SHE-Factory

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

To be increased
10 times

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

Factor 10-20

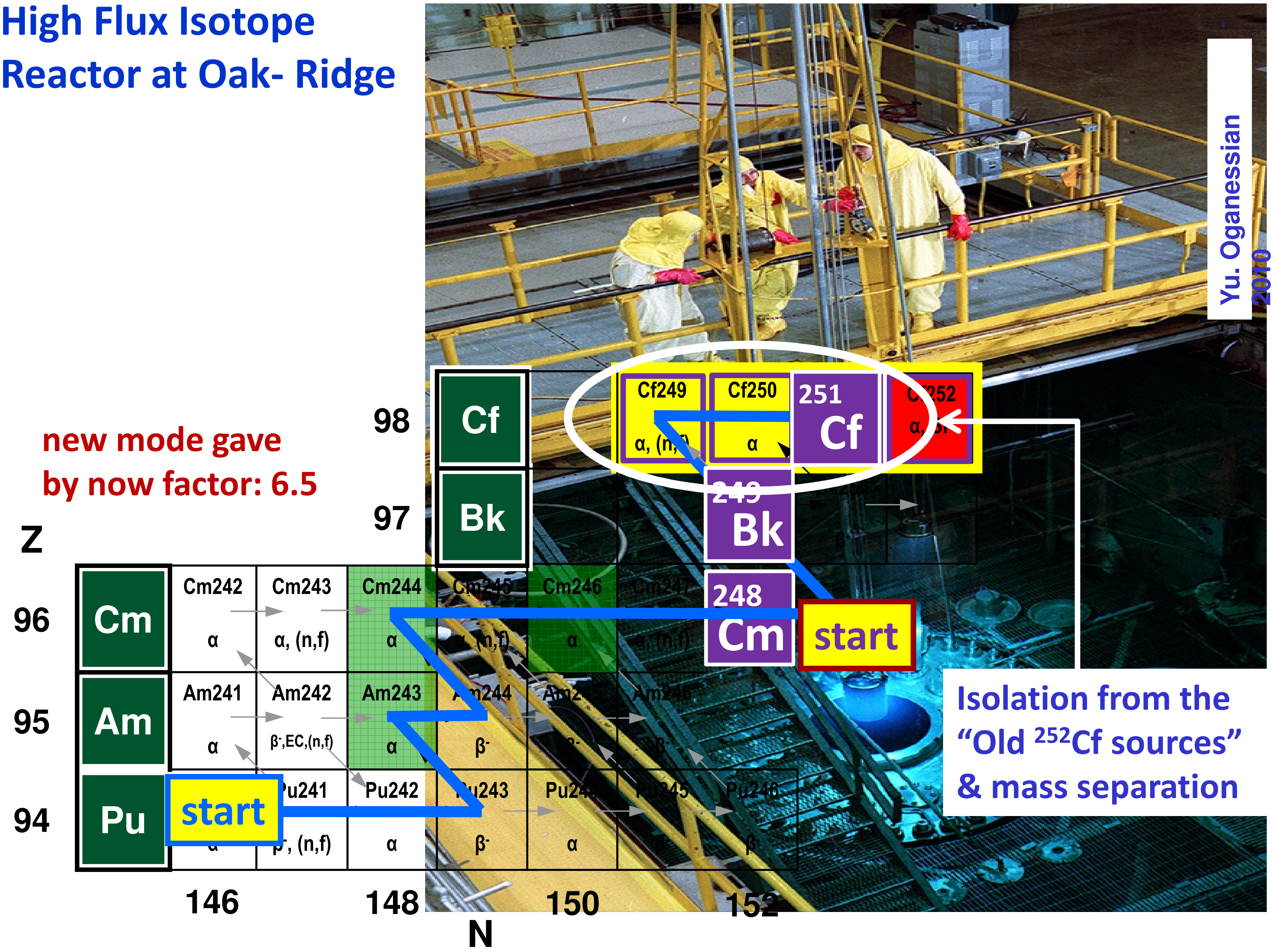
Depend of
target durability

SC- separator
& sophisticated
detectors

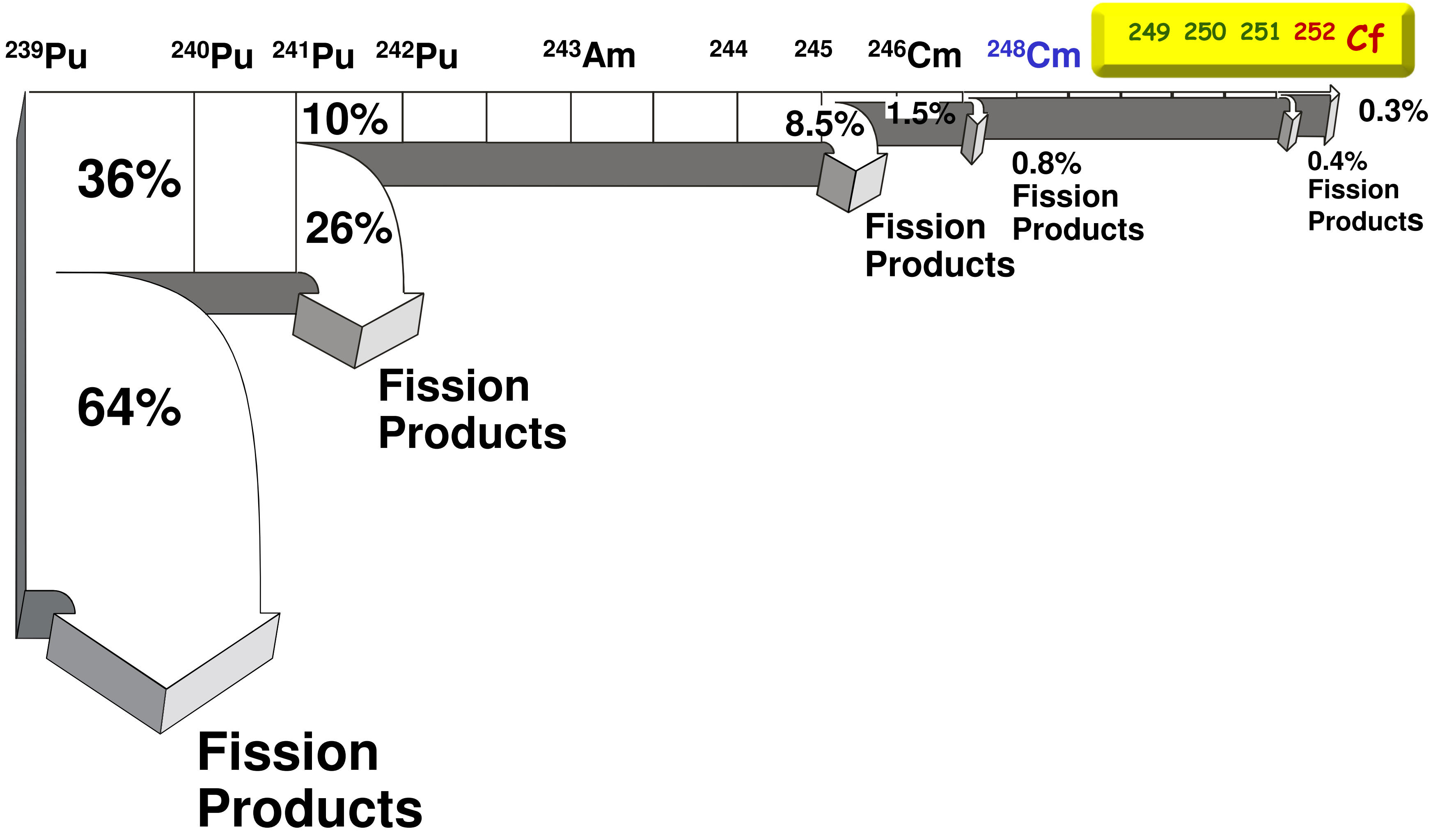
Factor 3-5
is closely linked
to the intellect

High Flux Isotope Reactor at Oak- Ridge

new mode gave
by now factor: 6.5



Fission Loss at Heavy Actinides



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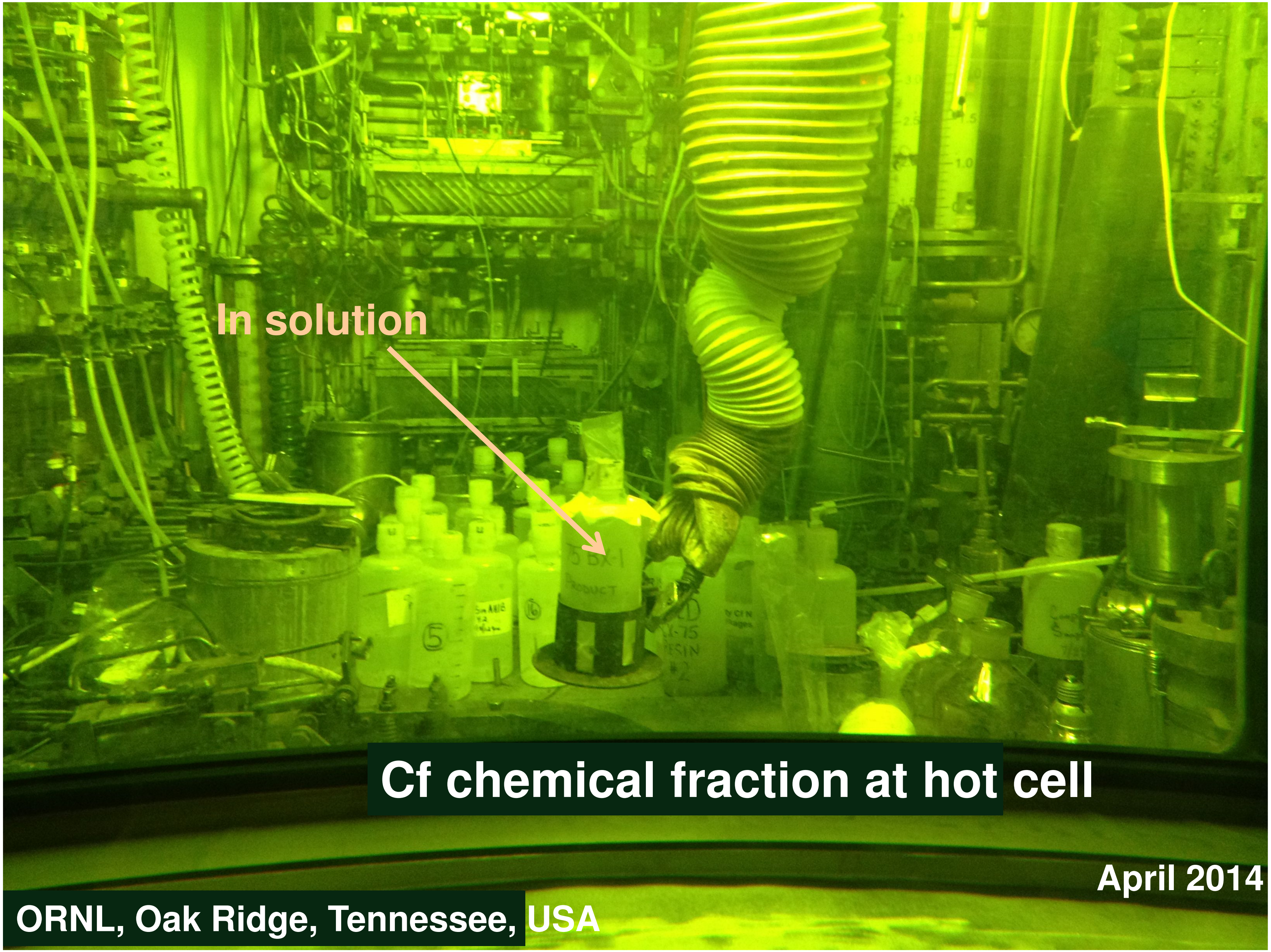
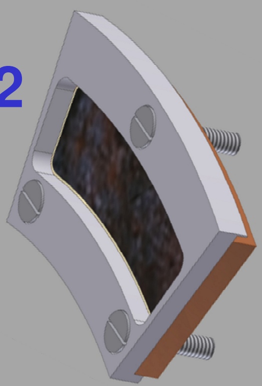

In solution
Cf chemical fraction at hot cell
April 2014
ORNL, Oak Ridge, Tennessee, USA

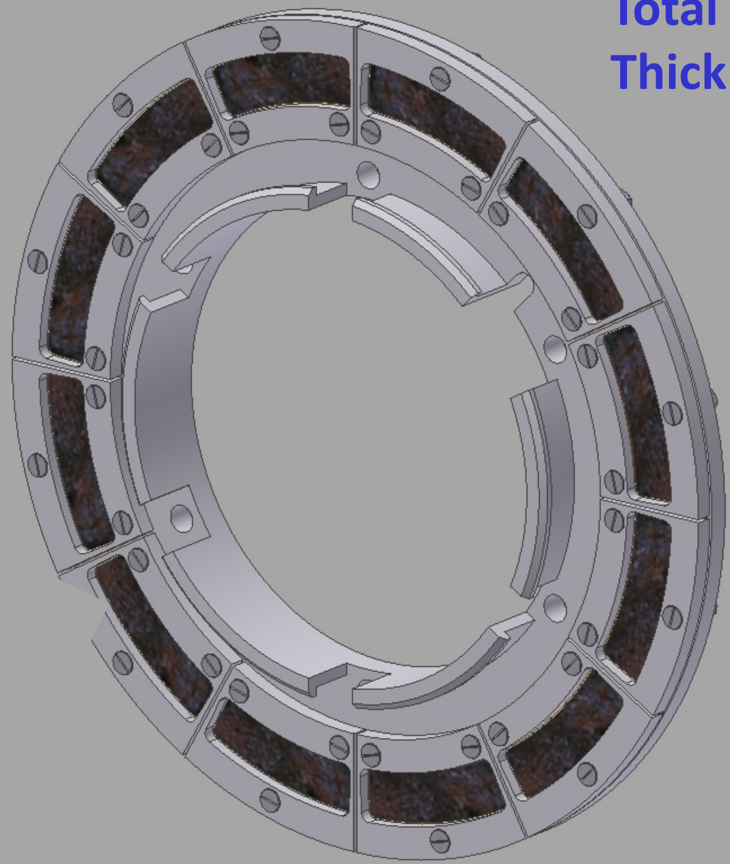
12 segments of rotational target made from mixed Cf-isotopes

Total weight	11.6 mg
Total surface	36 cm^2
Thickness	0.32 mg/cm^2

Segment

$^1/_{12}$





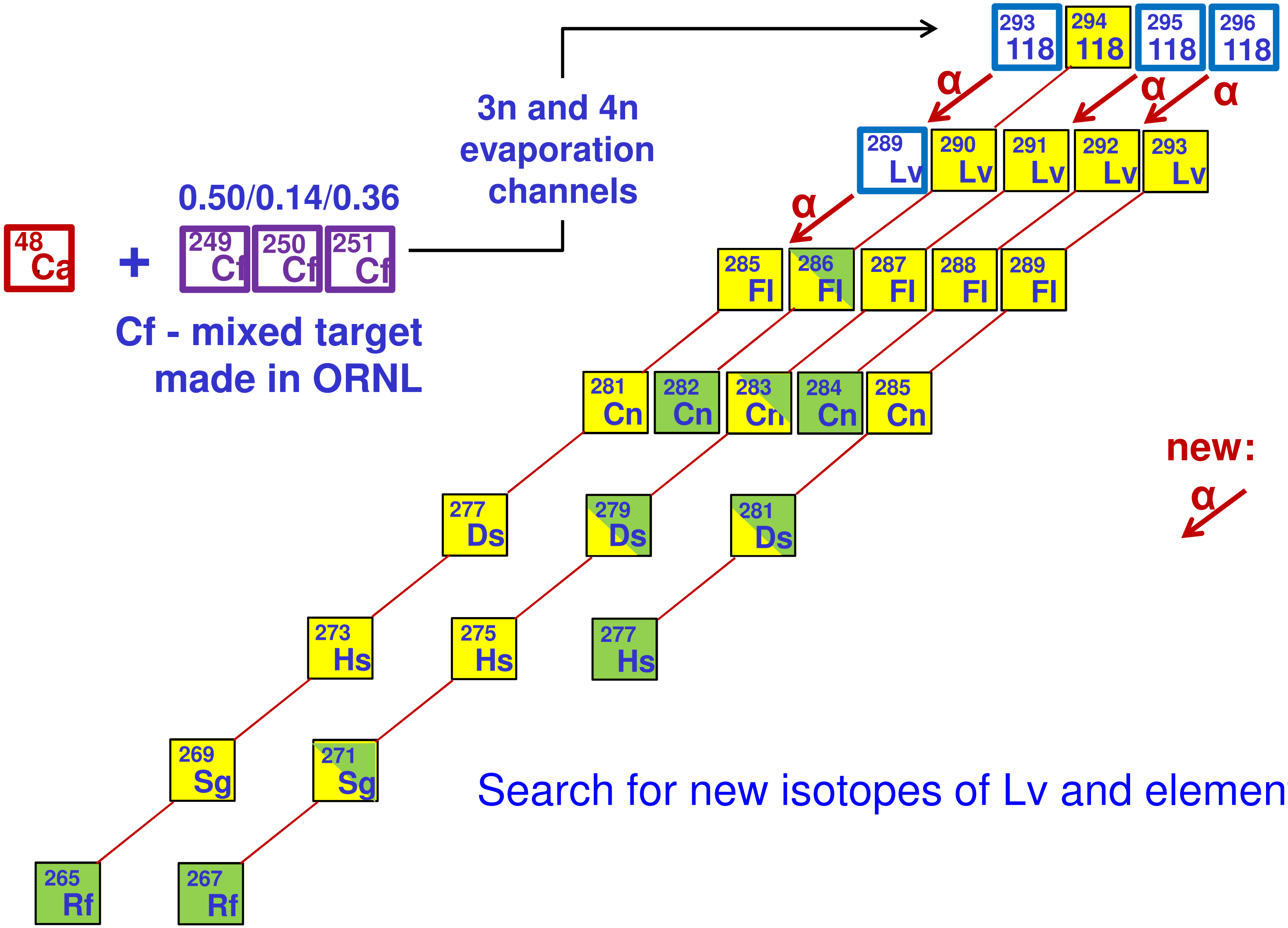
Cf-252	$3 \cdot 10^{-3}$ mg
Cf-251	4.19 mg
Cf-250	1.56 mg
Cf-249	5.84 mg

Oak Ridge National Laboratory, August, 2014

September 2014

Oak Ridge National Laboratory, USA

HEAVIEST NUCLEI

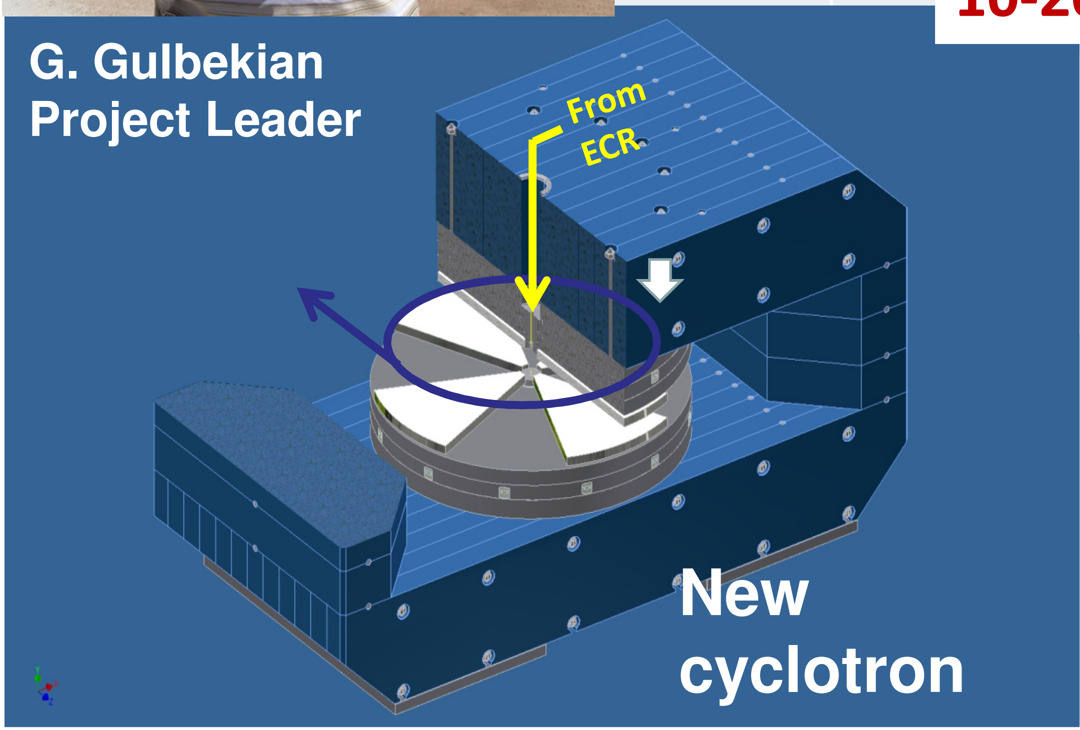


Search for new isotopes of Lv and element 118

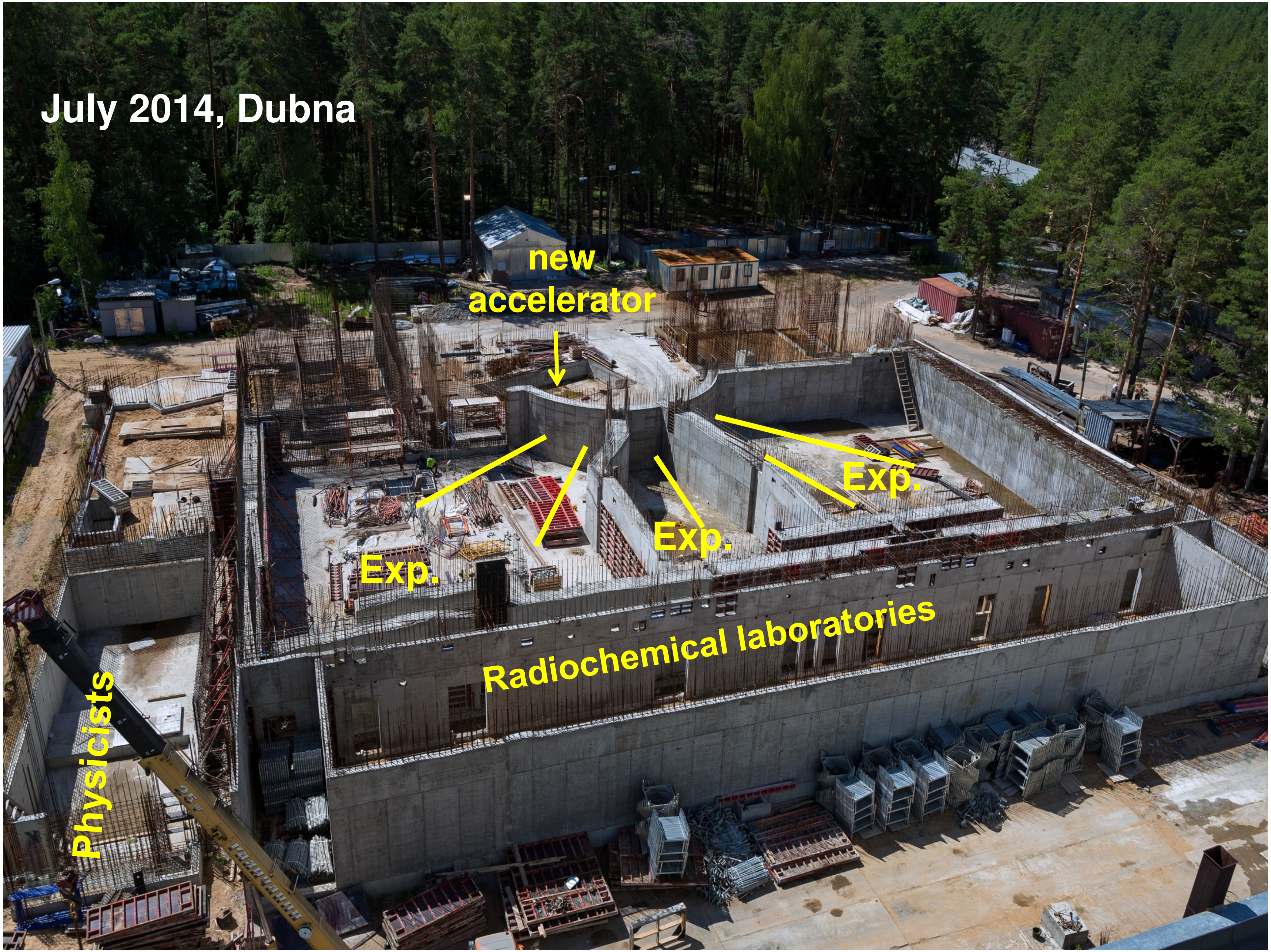
New accelerator and new Lab. in Dubna

today: ~ $5 \cdot 10^{19}$/y with Factory: $1.0 \cdot 10^{21}$/y

G. Gulbekian
Project Leader



	beam dose		factor: ~ 20
	Beam intensity	&	Beam time
	10-20 pμA		
			Factory
			~ 7000 h/year


July 2014, Dubna
new accelerator
Exp.
Exp.
Exp.
Radiochemical laboratories
Physicists


August 2014, Dubna


Novokramatorks
Ukraine
June 2014


Novokramatorks
Ukraine
UpRight AB38
UpRight
August 2014
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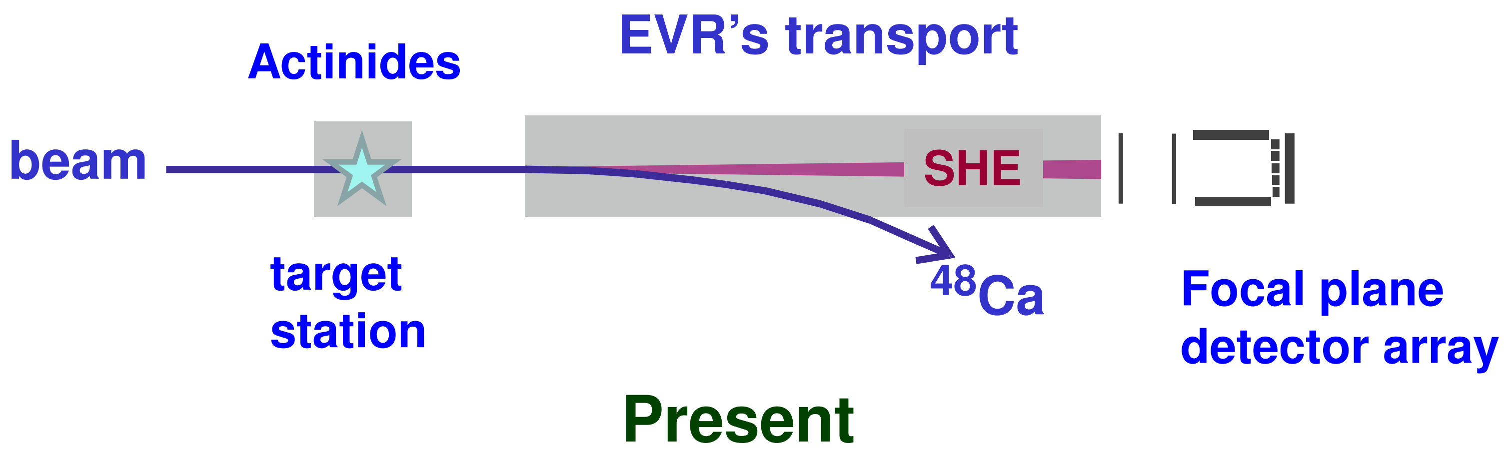
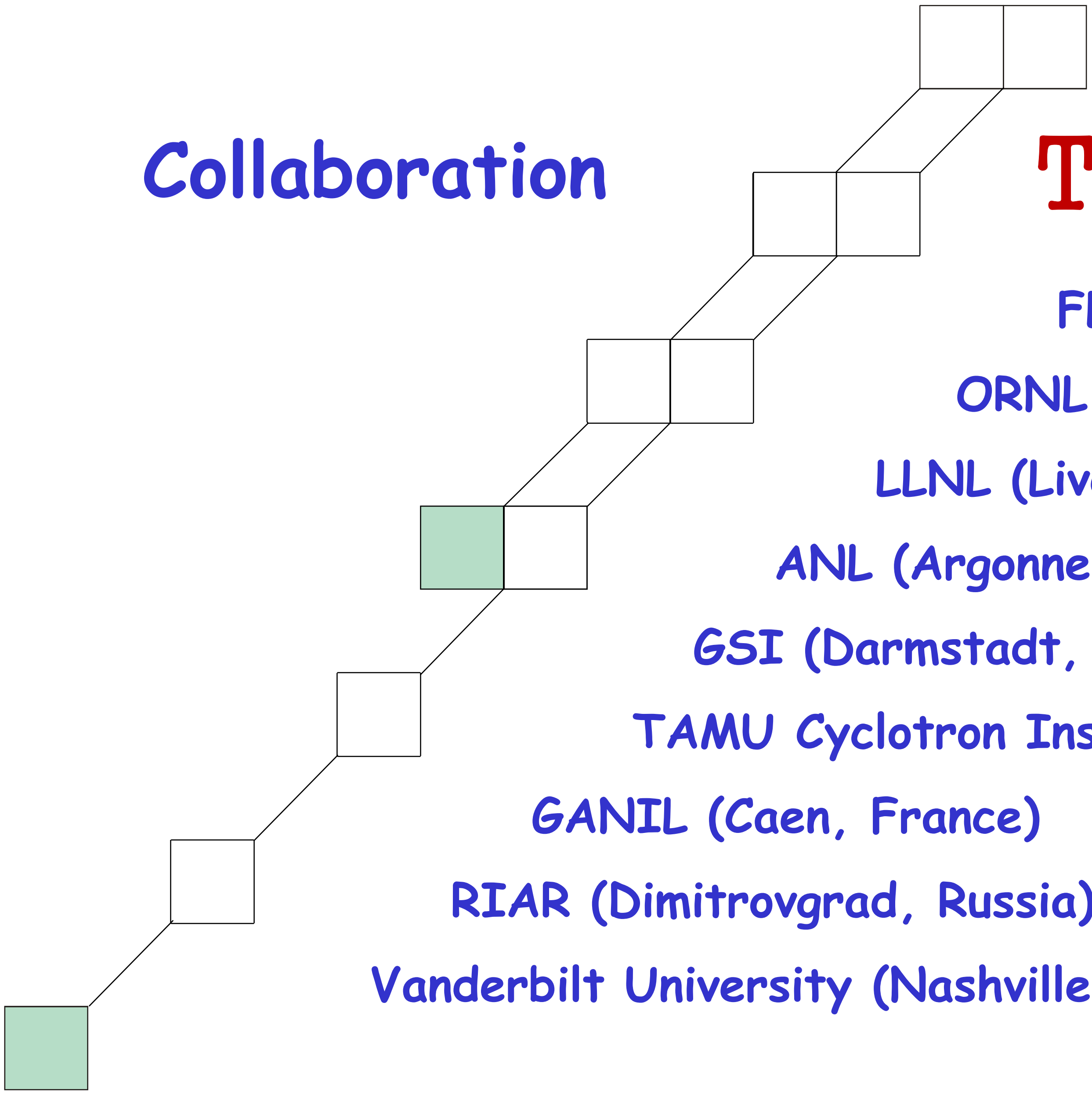
Scheme of the production and delivery SH-atoms to the detectors



Collaboration

Thank you



FLNR, JINR (Dubna)

ORNL (Oak-Ridge, USA)

LLNL (Livermore, USA)

ANL (Argonne, USA)

GSI (Darmstadt, Germany)

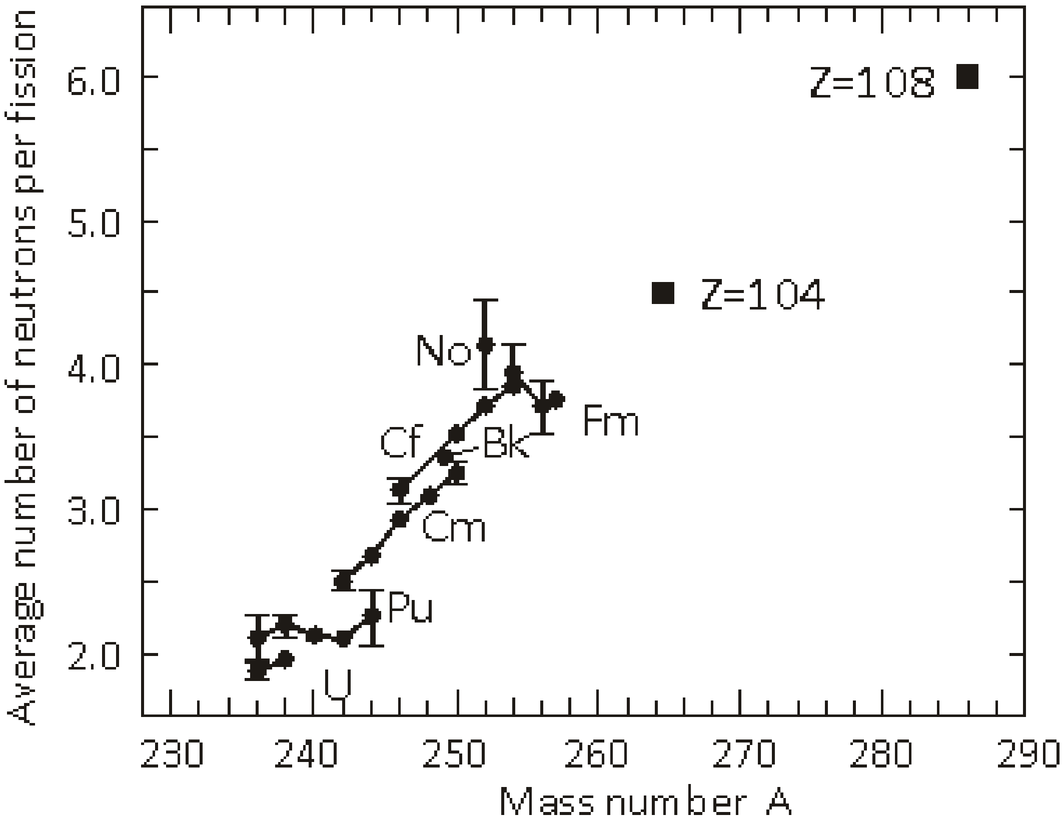
TAMU Cyclotron Institute (Texas, USA)

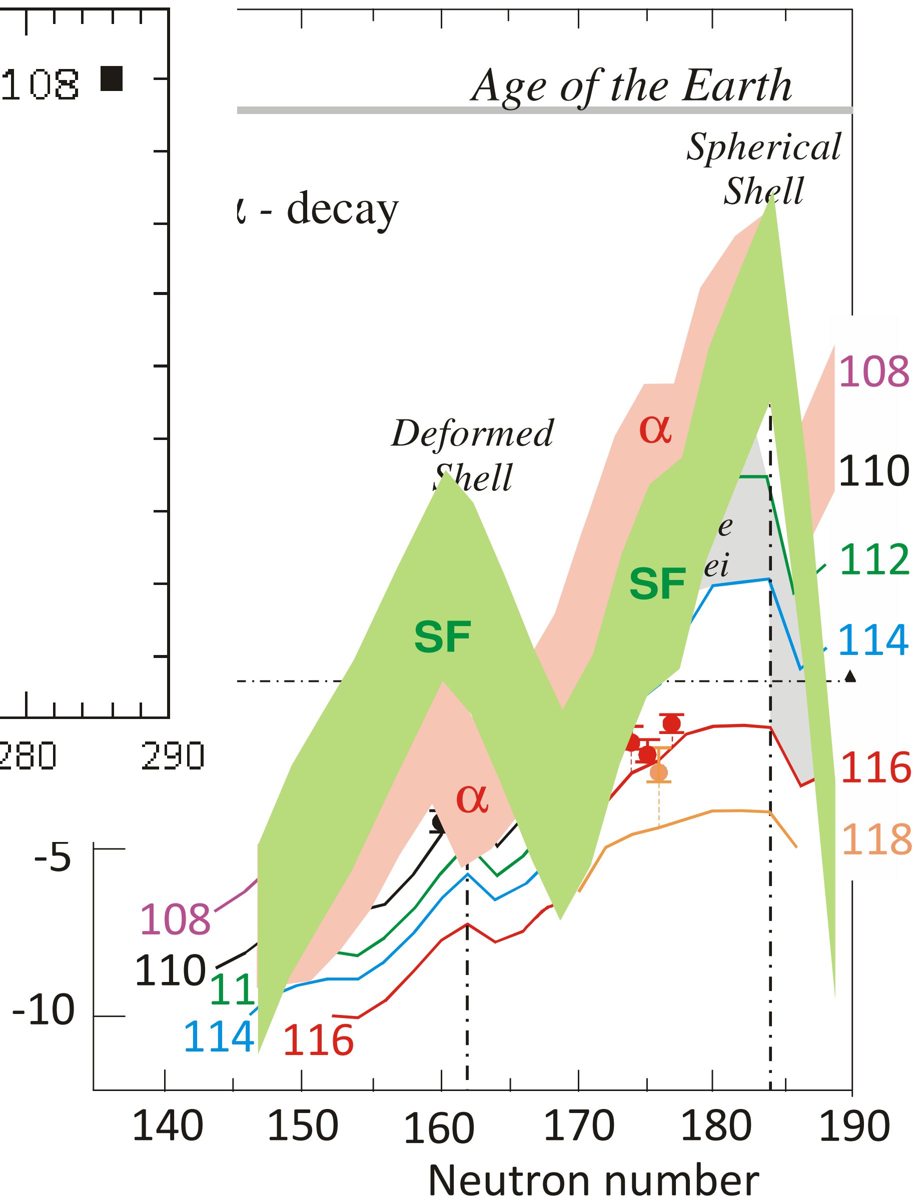
GANIL (Caen, France)

RIAR (Dimitrovgrad, Russia)

Vanderbilt University (Nashville, USA)

Theory and Experiment





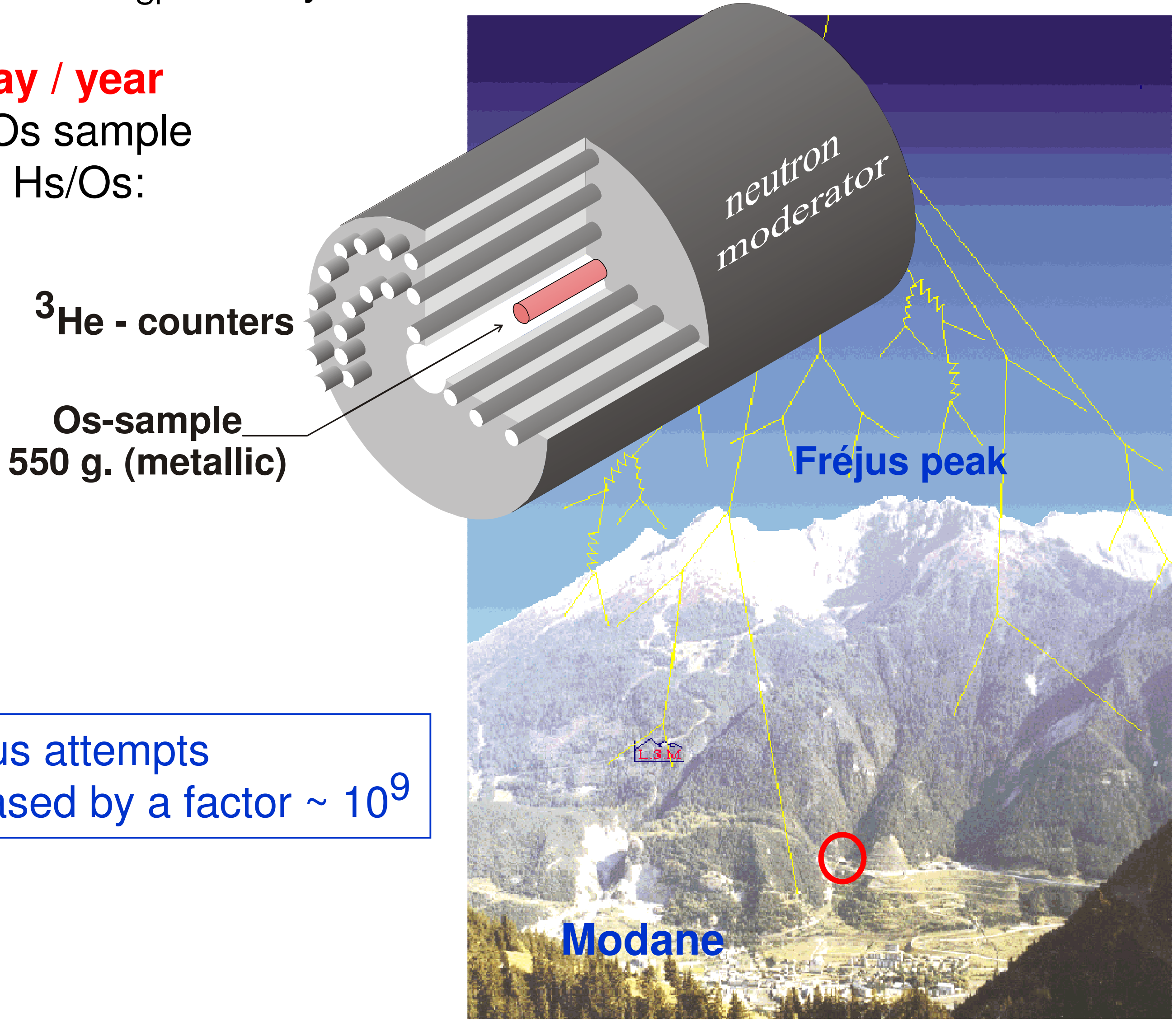
Assuming for the SH-nuclide $T_{SF} = 10^9$ years

the counting rate **1 decay / year**
from a 1000-g metallic Os sample
corresponds to the ratio Hs/Os:

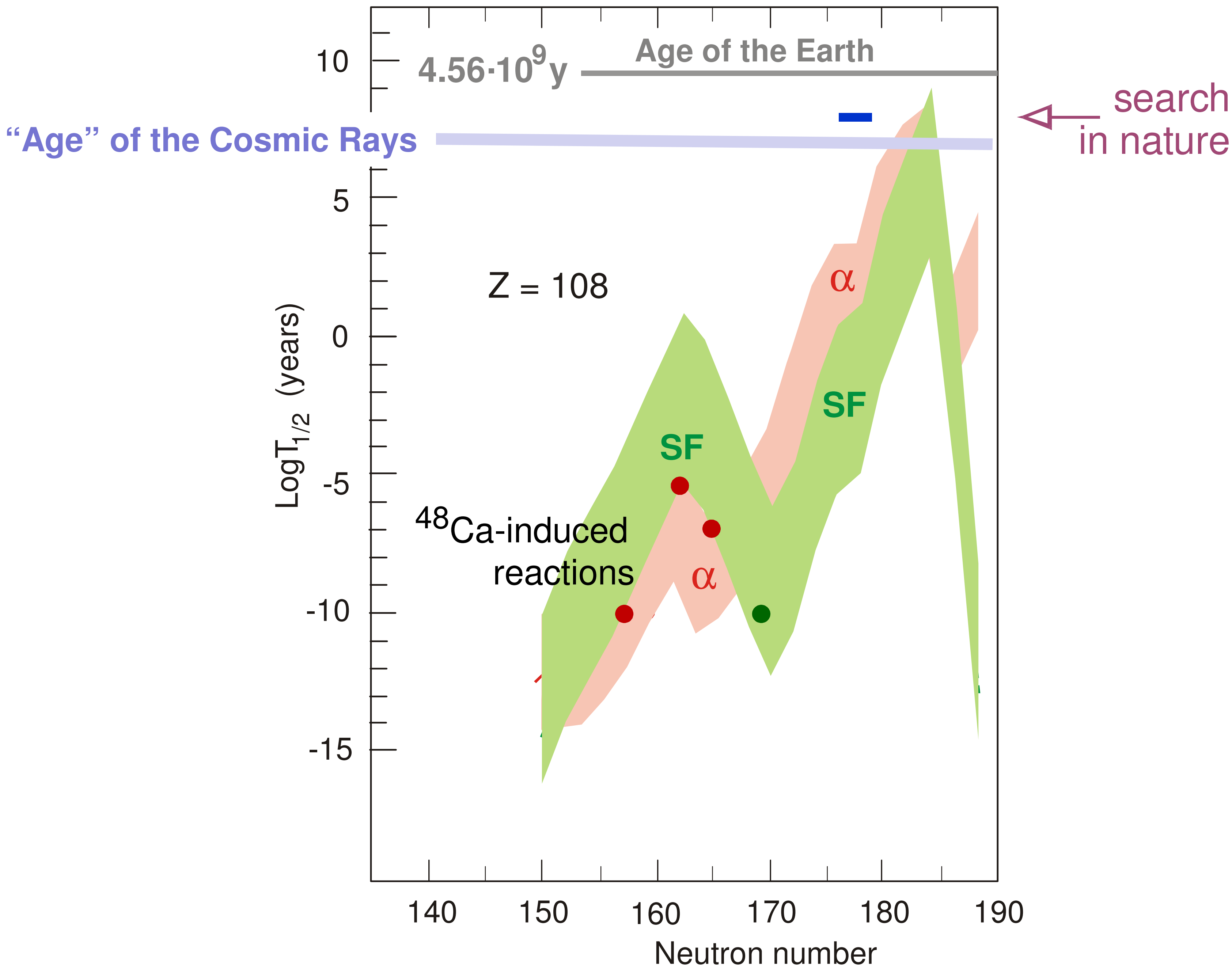
~ 7·10^{-16} g/g

or ~ **10^{-23} g/g**

in the Earth's crust
or in the meteorit's
matter

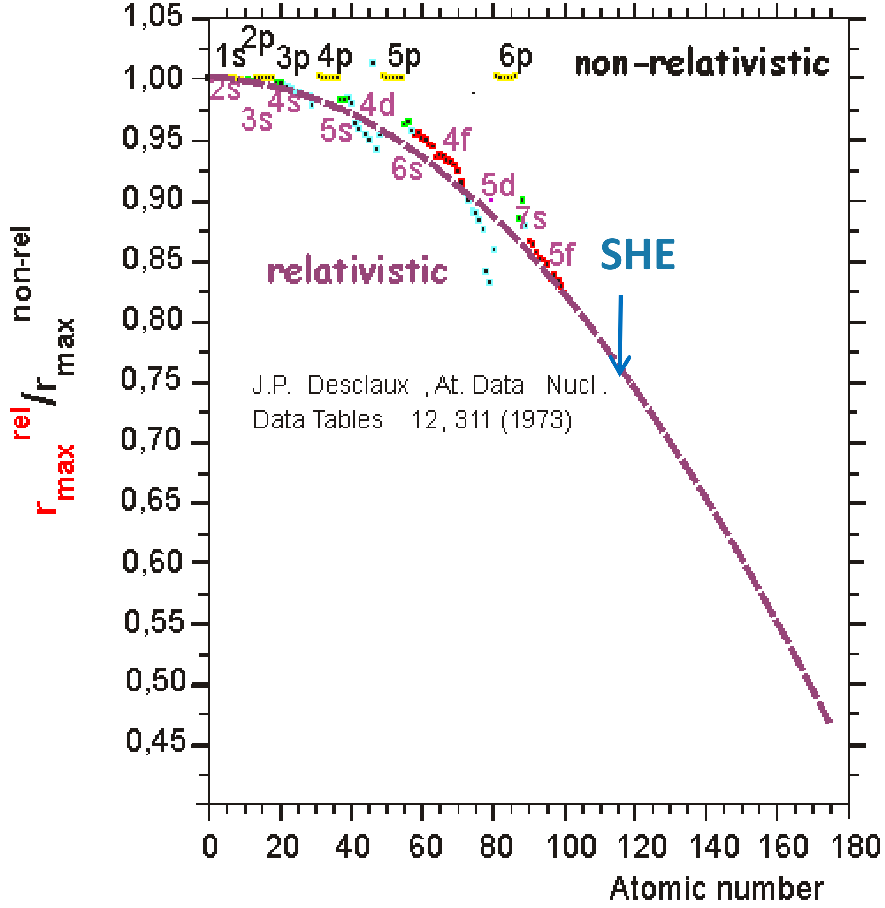


compared with previous attempts
the sensitivity is increased by a factor ~ 10^9

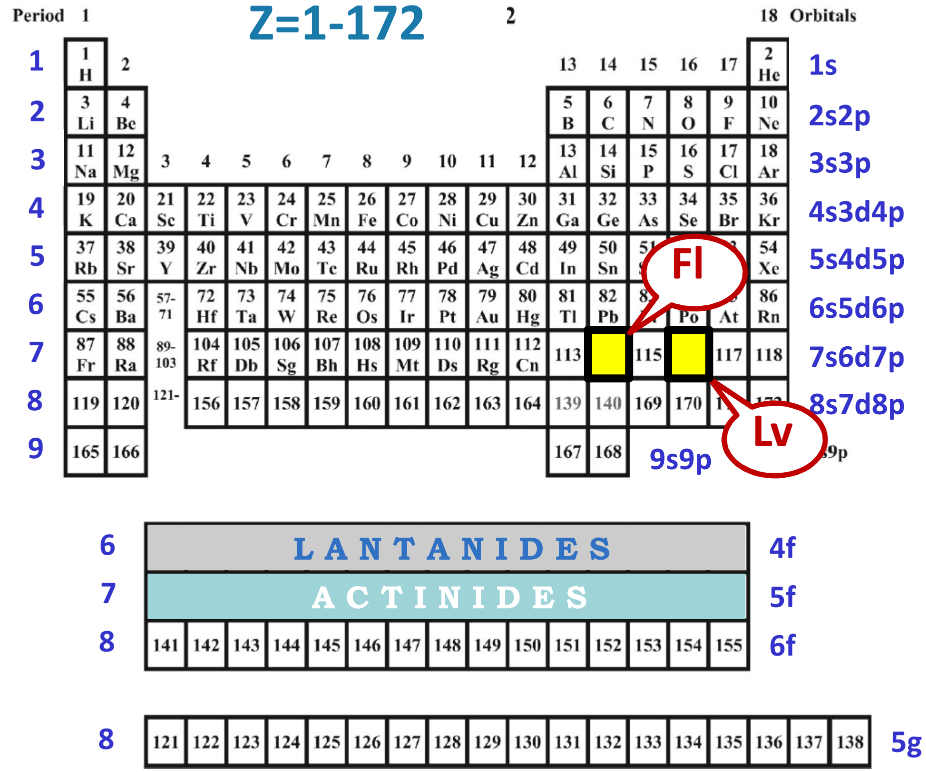


“Age” of the Cosmic Rays
4.56·10^9 y
Age of the Earth
search
in nature
10
5
0
-5
-10
-15
LogT1/2 (years)
Z = 108
SF
SF
α
α
48Ca-induced
reactions
140
150
160
170
180
190
Neutron number

Relativistic Contraction



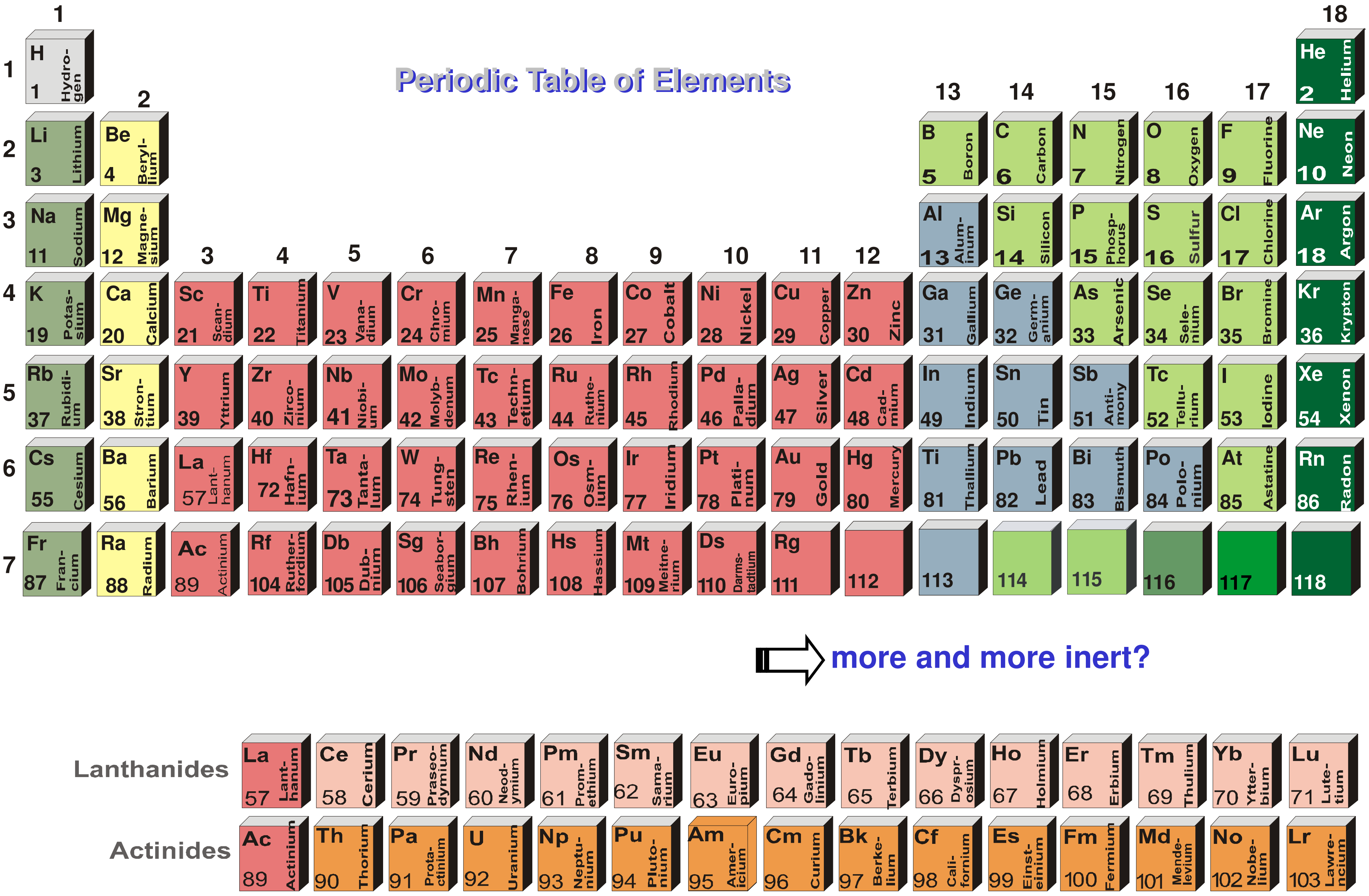
Periodic Table
Z=1-172



Periodic Table based on Dirac-Fock calculations (non-relativistic)

P. Pyykkö Phys. Chem. Chem. Phys. 13, 161-168 (2011)

Periodic Table of Elements



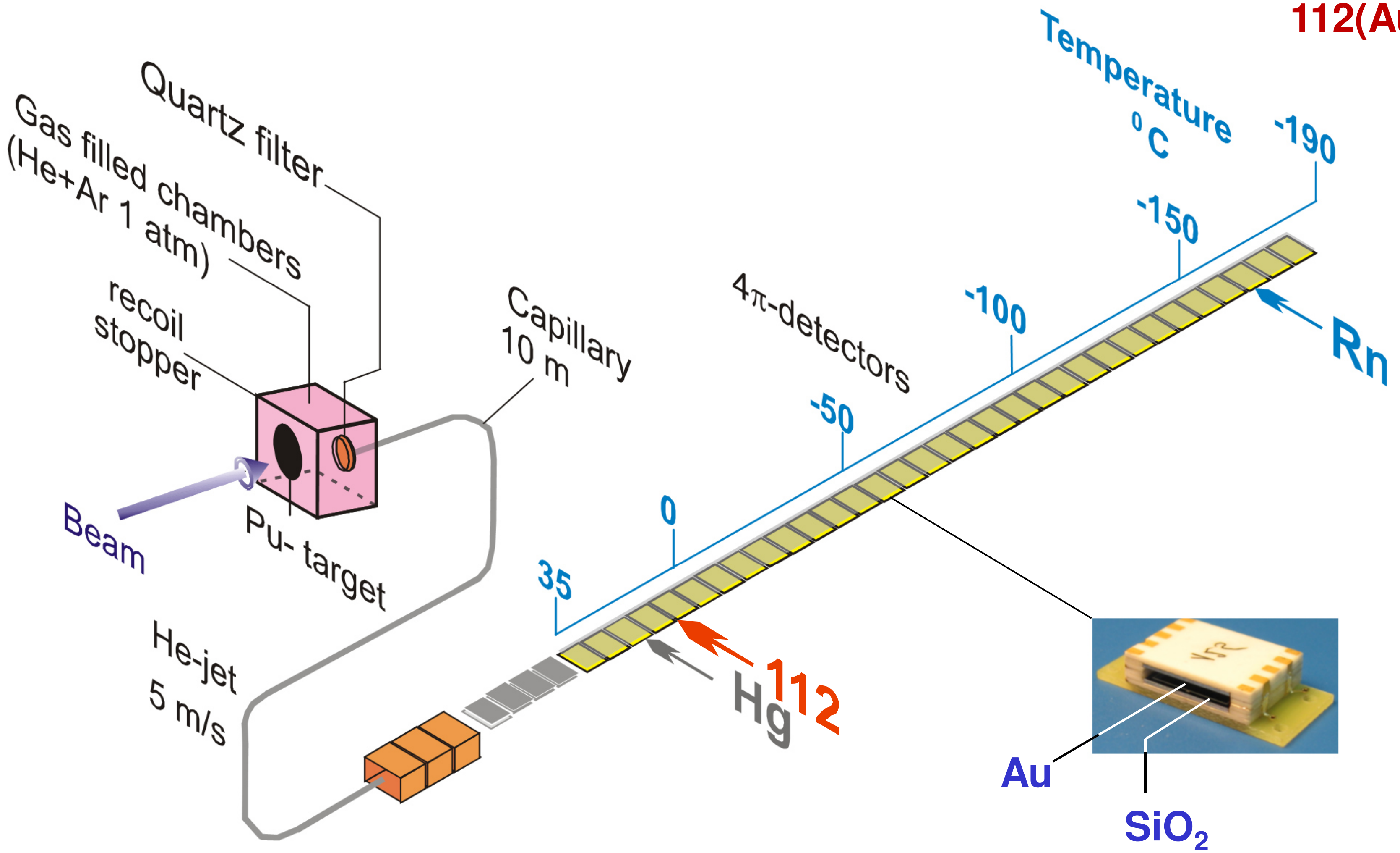
Yu. Oganessian."At the End of the Periodic Table" 2013 SCNAT Annual Congress, Nov.22, Winterthur, Switzerland

R. Eichler, H. Gâggeler *et al.*, Nature 447 (2007) 72

Reaction:

$^{242}Pu(^{48}Ca,3n)^{287}114[0.5s] \rightarrow \alpha \rightarrow ^{283}112[3.6s]$

Compounds:
Hg(Au)
and
112(Au)



Element 112 is a noble metal – like Hg!