Nuclei from the Island of SHE

Yuri Oganessian

Flerov Laboratory of Nuclear Reactions
Joint Institute for Nuclear Research

International Conference "Nuclear Structure 2012"
Aug.13-17/ 2012, Argonne National Laboratory, USA

The report focuses on experimental verification of the fundamental predictions of the microscopic theory concerning existence an "islands of stability" among hypothetical super heavy elements

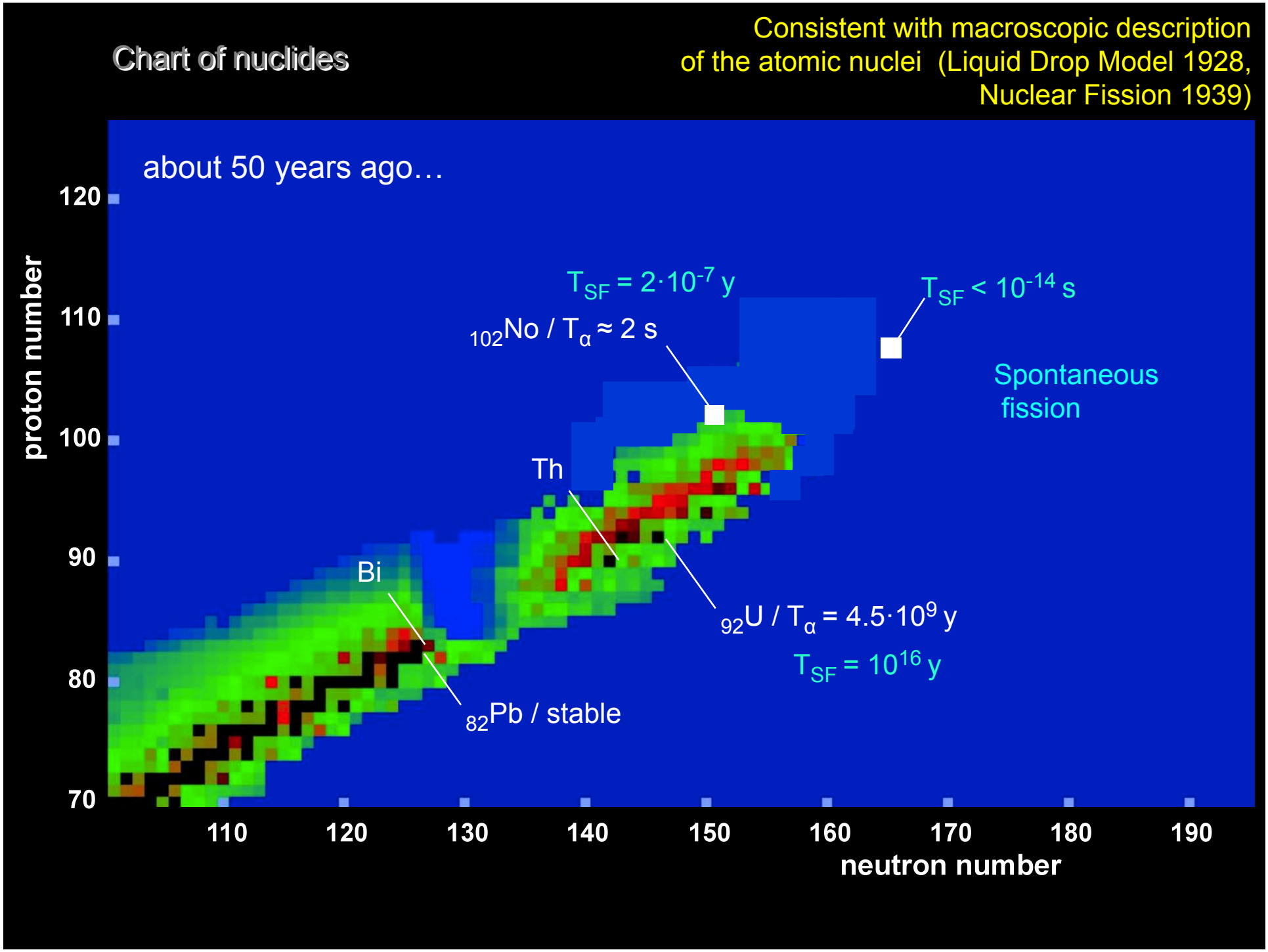
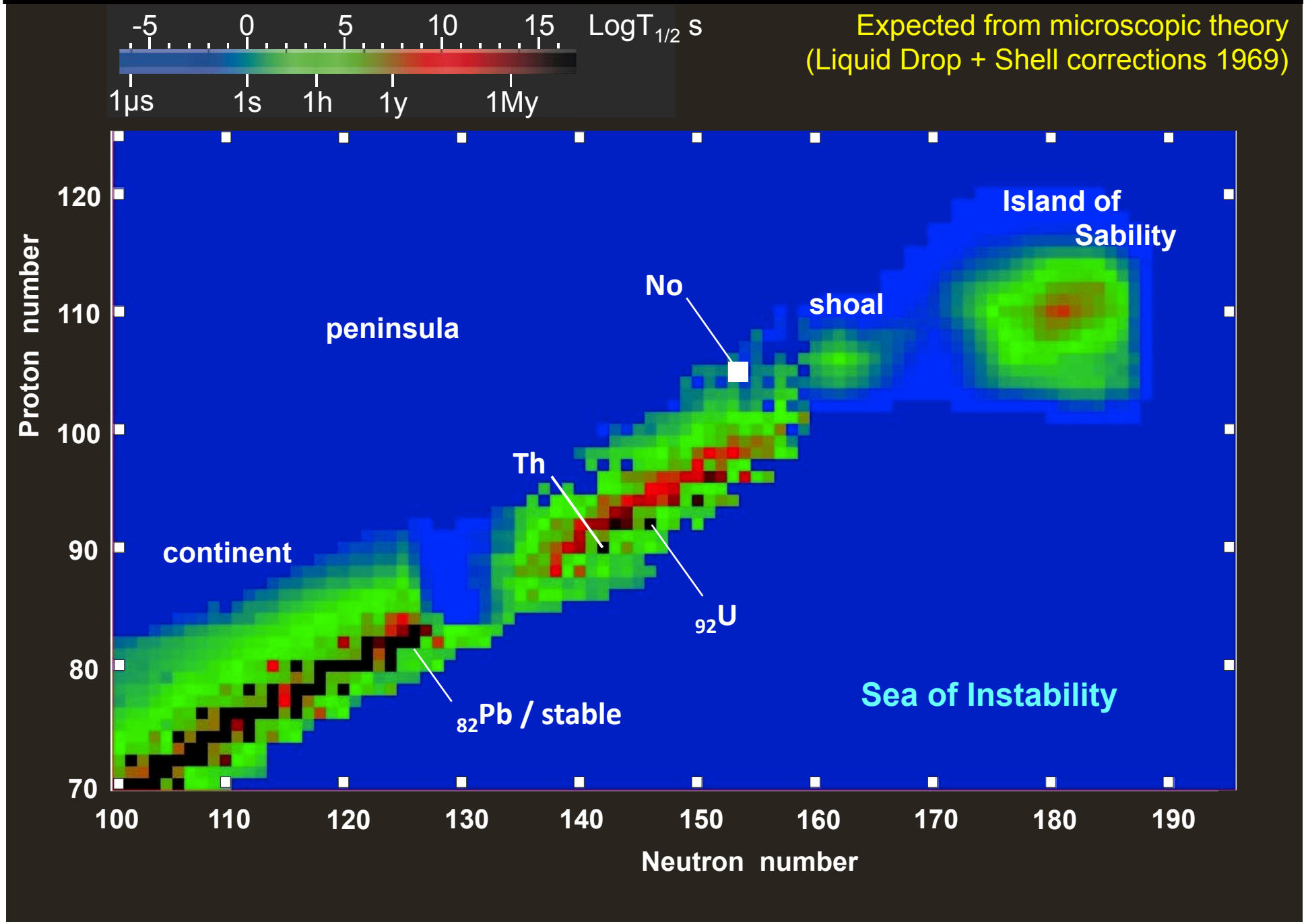


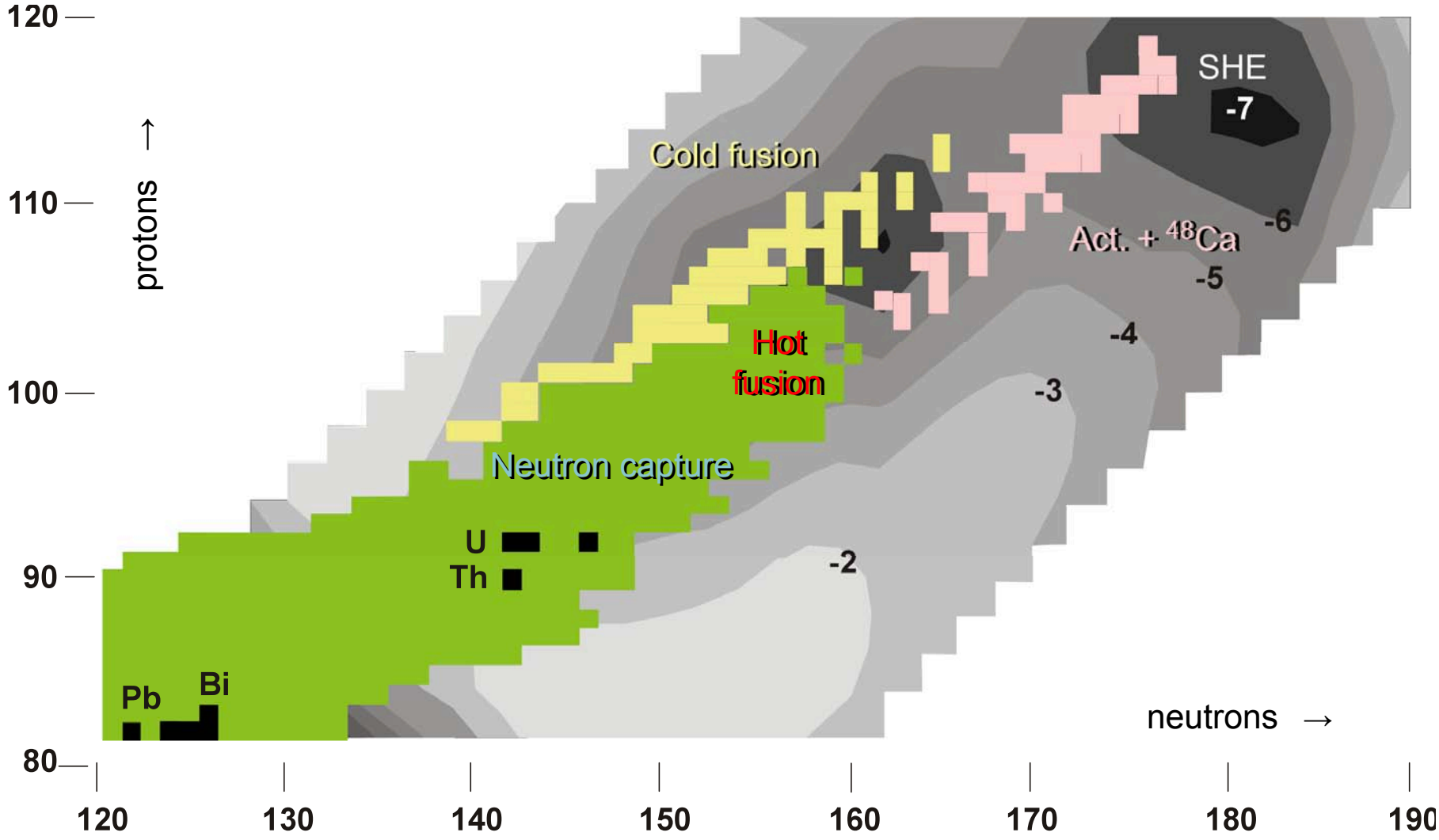
Chart of nuclides
Consistent with macroscopic description of the atomic nuclei (Liquid Drop Model 1928, Nuclear Fission 1939)
about 50 years ago…
$T_{SF} = 2 \cdot 10^{-7}$ y
$_{102}$No / $T_\alpha \approx 2$ s
$T_{SF} < 10^{-14}$ s
Spontaneous fission
Th
Bi
$_{92}$U / $T_\alpha = 4.5 \cdot 10^9$ y
$T_{SF} = 10^{16}$ y
$_{82}$Pb / stable
proton number
120
110
100
90
80
70
110
120
130
140
150
160
170
180
190
neutron number

New lands


-5
0
5
10
15
LogT1/2 s
1μs
1s
1h
1y
1My
Expected from microscopic theory
(Liquid Drop + Shell corrections 1969)
Island of
Sability
No
shoal
peninsula
Th
continent
92U
82Pb / stable
Sea of Instability
Proton number
120
110
100
90
80
70
100
110
120
130
140
150
160
170
180
190
Neutron number

Reaction of Synthesis

Reactions of Synthesis



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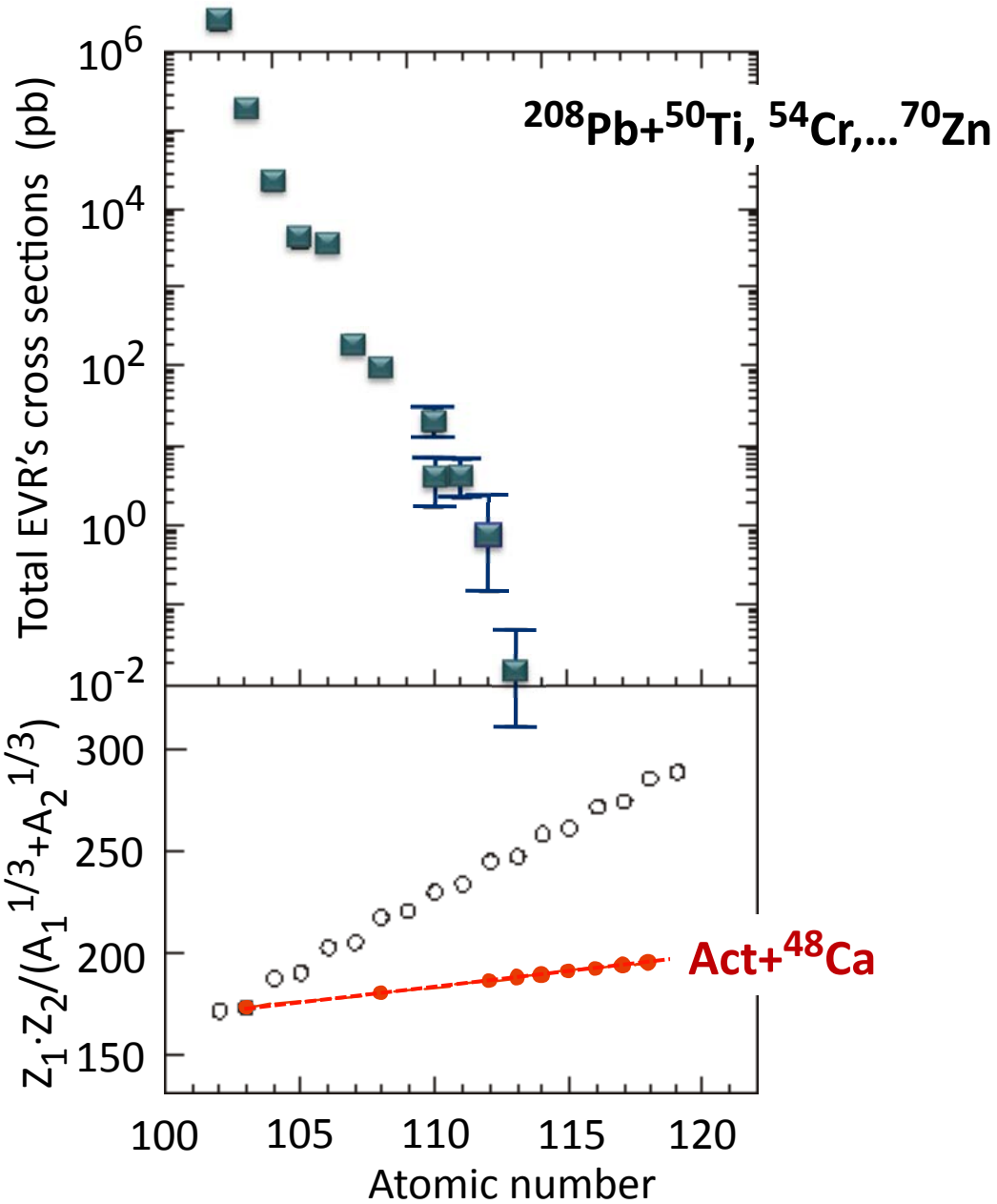


E_x=12-15 MeV

cold fusion

x = 1

x — number of evaporated neutrons

E_x = 36 - 42 MeV

hot fusion

x = 3 – 4

$$\sigma_{xn} \sim (\Gamma_n / \Gamma_f)^x$$

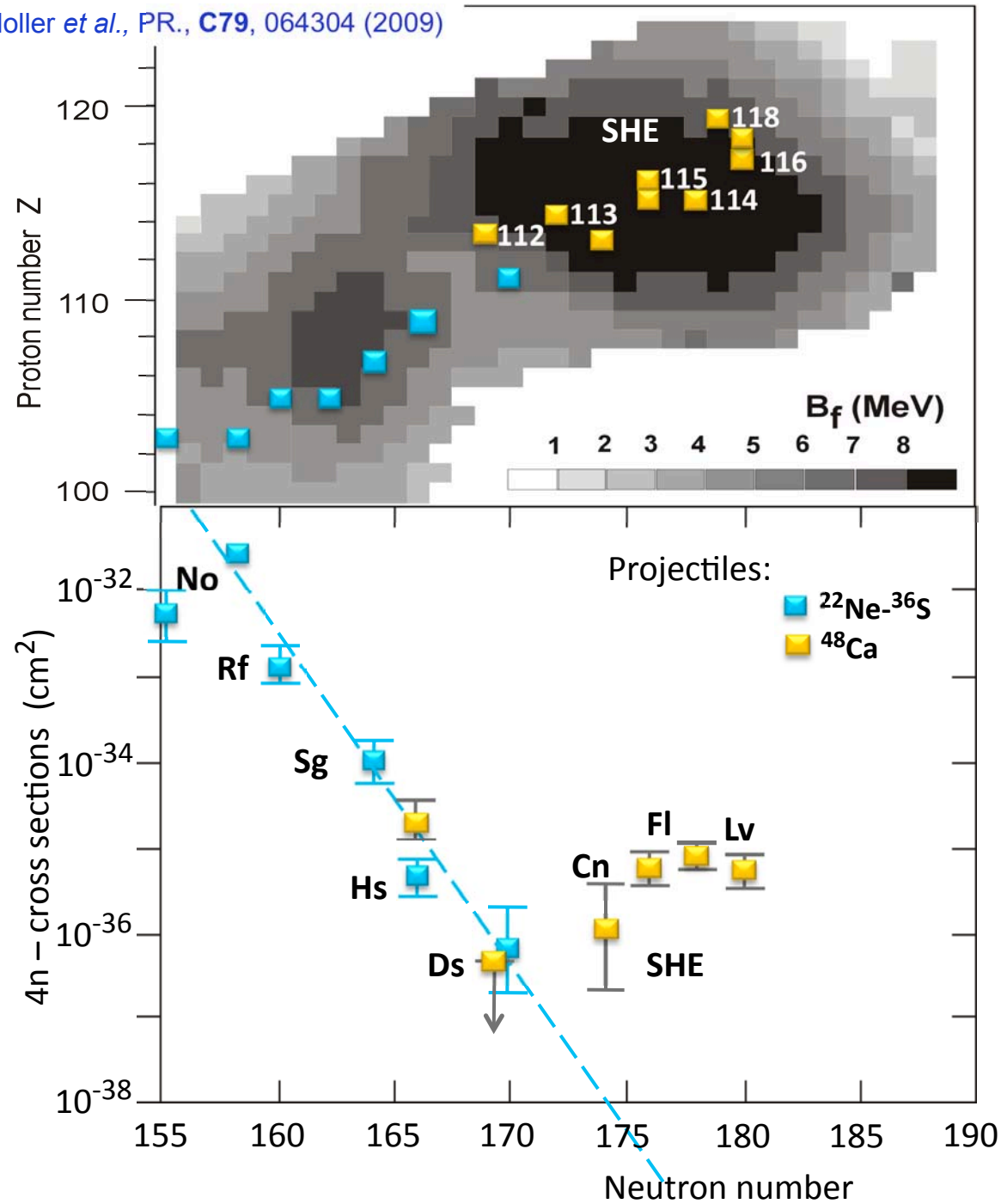
$$(\Gamma_n / \Gamma_f) \sim \exp (B_f - B_n) / T$$

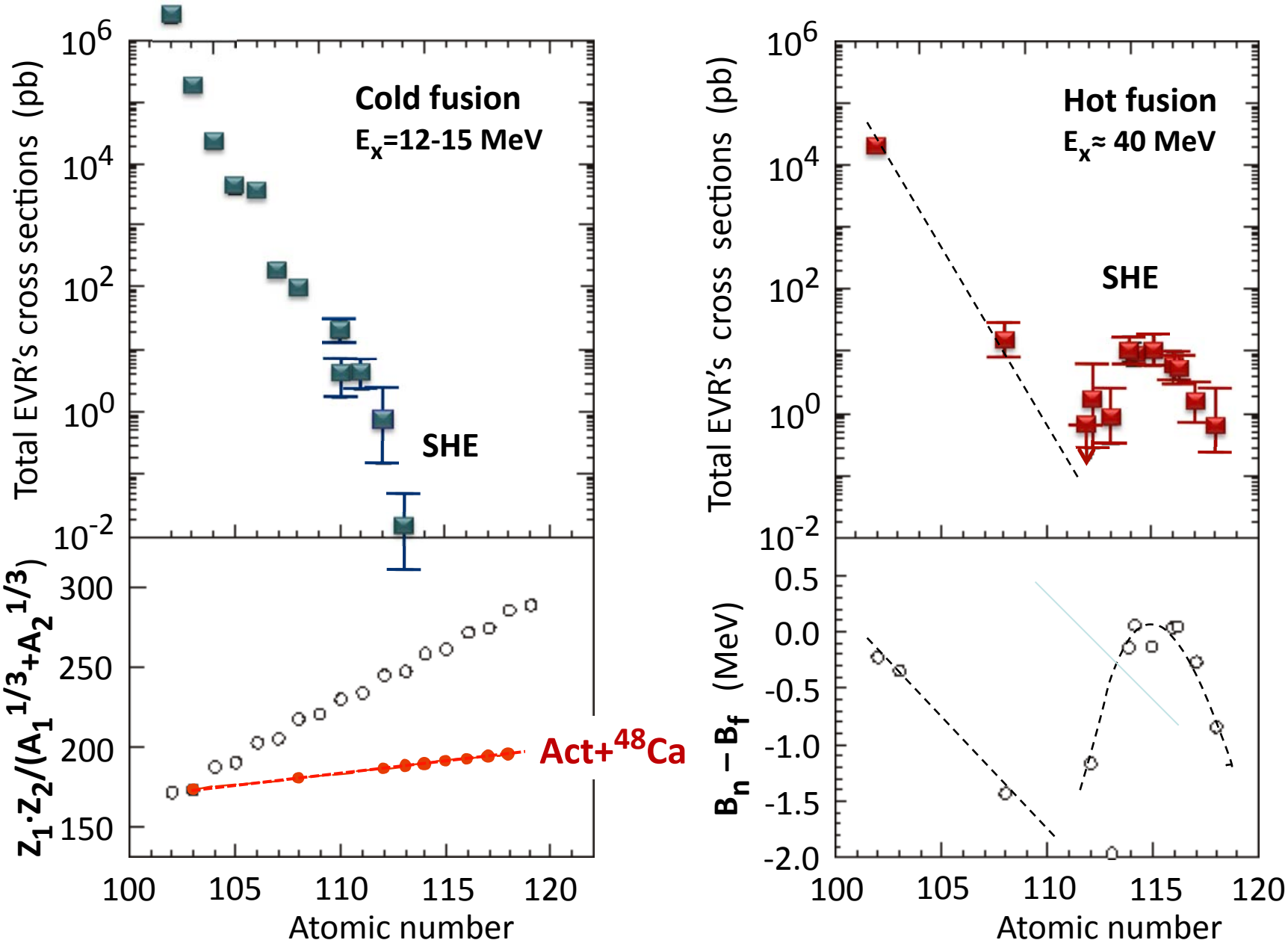
hot fusion

E_x = 40 - 45 MeV

x = 4 –5

P. Moller *et al.*, PR., **C79**, 064304 (2009)





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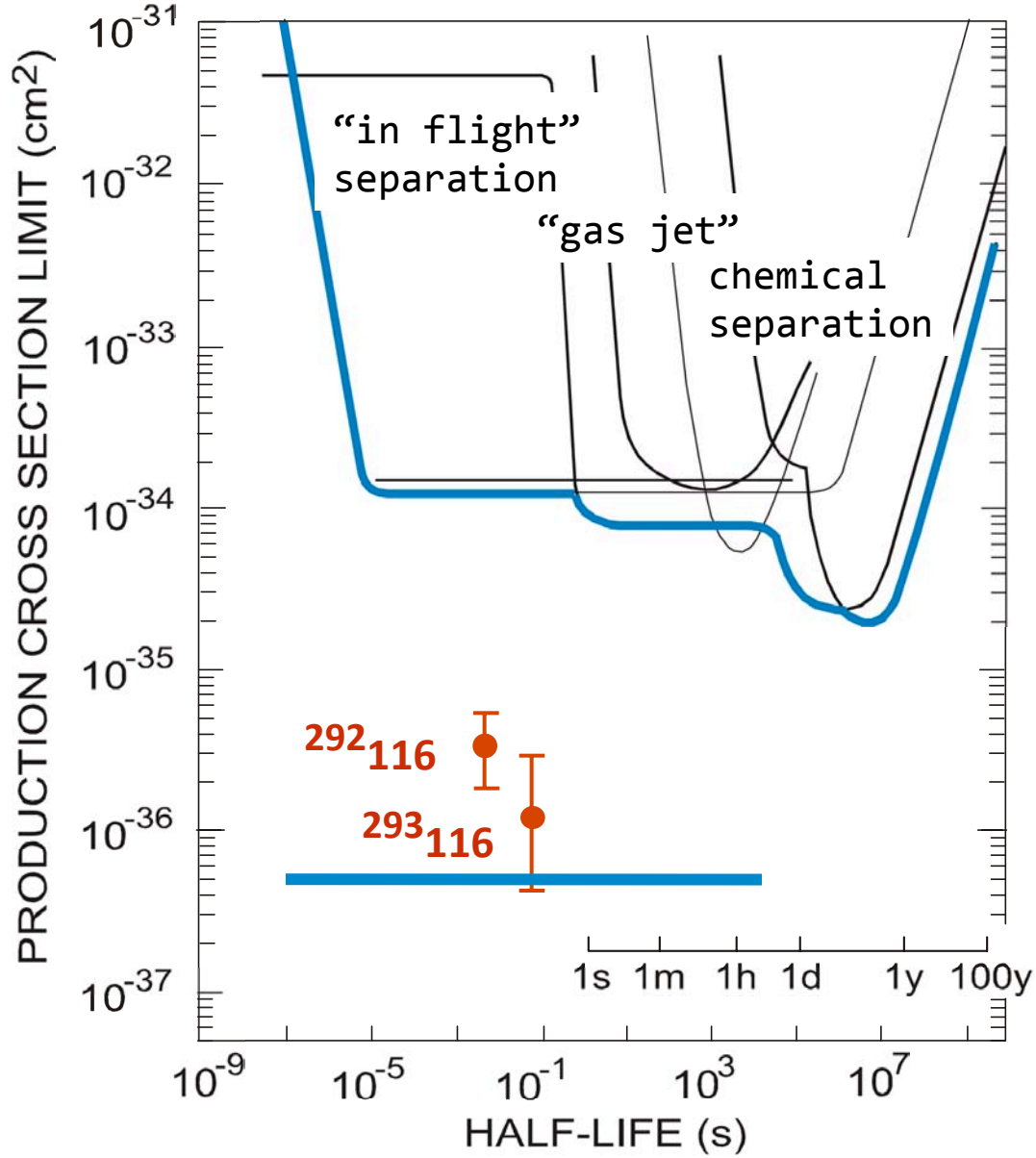
Search for Element 116 in $^{248}Cm + ^{48}Ca$ reaction

GSI, Darmstadt, Germany*
LBL, UC Berkeley, CA
Univ. of Mainz, Germany
LANL, Los Alamos, NM
EIR, Würenlingen, Switzerland

1985

FLNR, Dubna
LLNL, Livermore, CA

2000



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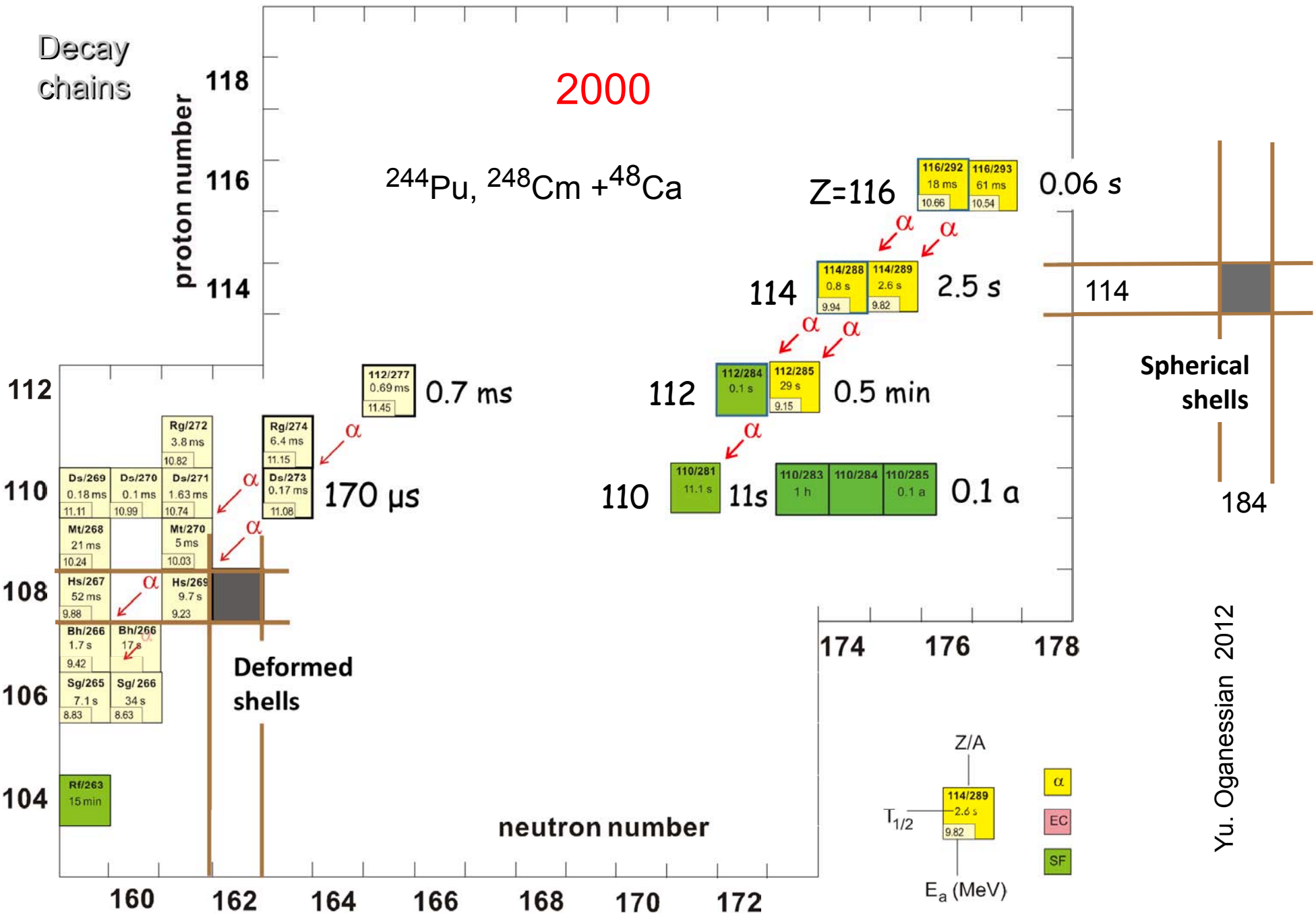
First reactions induced by ^{48}Ca ions

even-Z SH-nuclei and its decays


Decay chains
2000
^{244}Pu, ^{248}Cm +^{48}Ca
proton number
neutron number
Z=116
116/292 18 ms 10.66
116/293 61 ms 10.54
0.06 s
114/288 0.8 s 9.94
114/289 2.6 s 9.82
2.5 s
112/284 0.1 s
112/285 29 s 9.15
0.5 min
110/281 11.1 s
11s
110/283 1 h
110/284
110/285 0.1 a
0.1 a
112/277 0.69 ms 11.45
0.7 ms
Rg/274 6.4 ms 11.15
Ds/273 0.17 ms 11.08
170 µs
Rg/272 3.8 ms 10.82
Ds/269 0.18 ms 11.11
Ds/270 0.1 ms 10.99
Ds/271 1.63 ms 10.74
Mt/268 21 ms 10.24
Mt/270 5 ms 10.03
Hs/267 52 ms 9.88
Hs/269 9.7 s 9.23
Bh/266 1.7 s 9.42
Bh/266 17 s
Sg/265 7.1 s 8.83
Sg/266 34 s 8.63
Rf/263 15 min
Deformed shells
Spherical shells
114
184
Z/A
$T_{1/2}$
E_a (MeV)
α
EC
SF
Yu. Oganessian 2012

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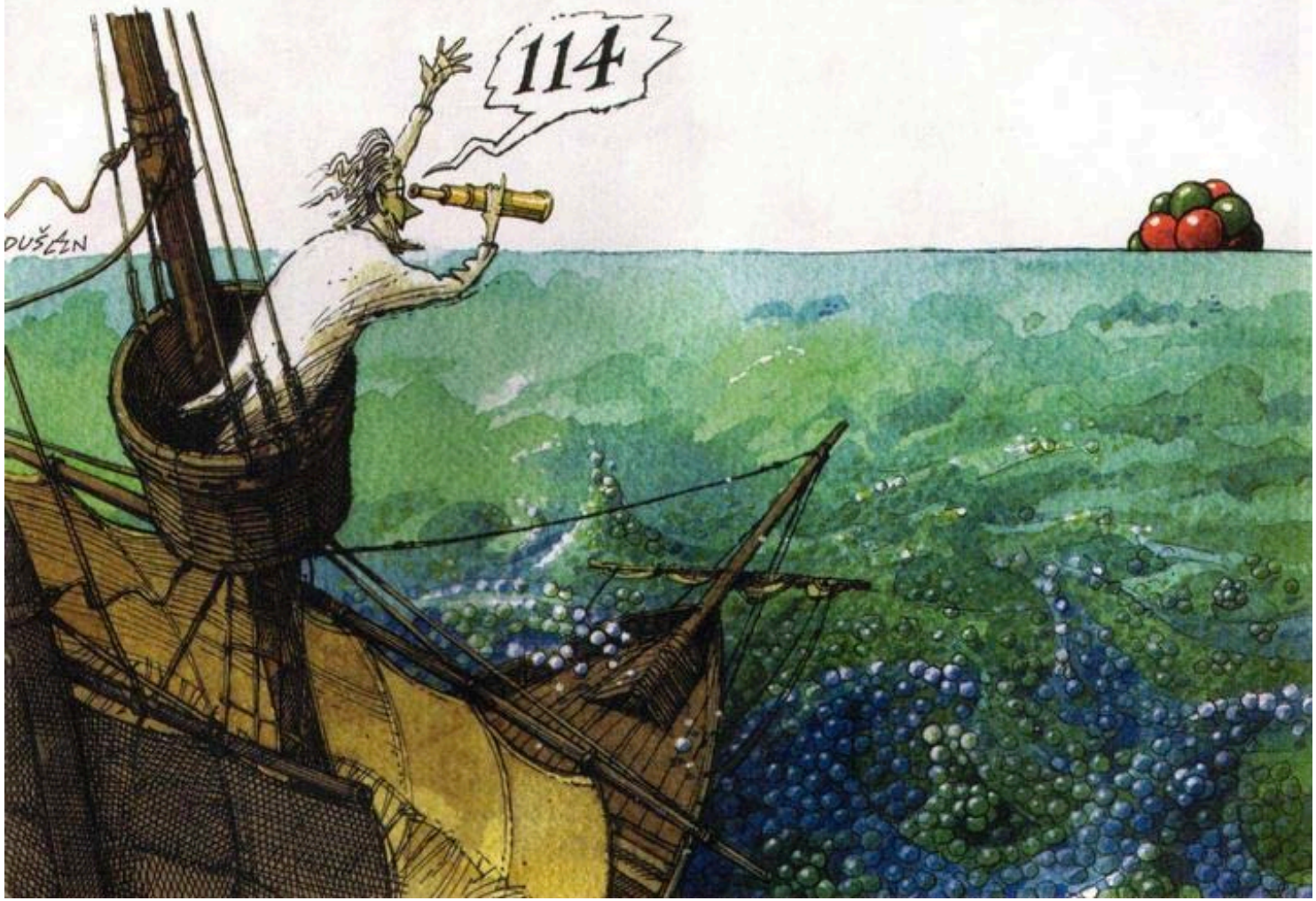
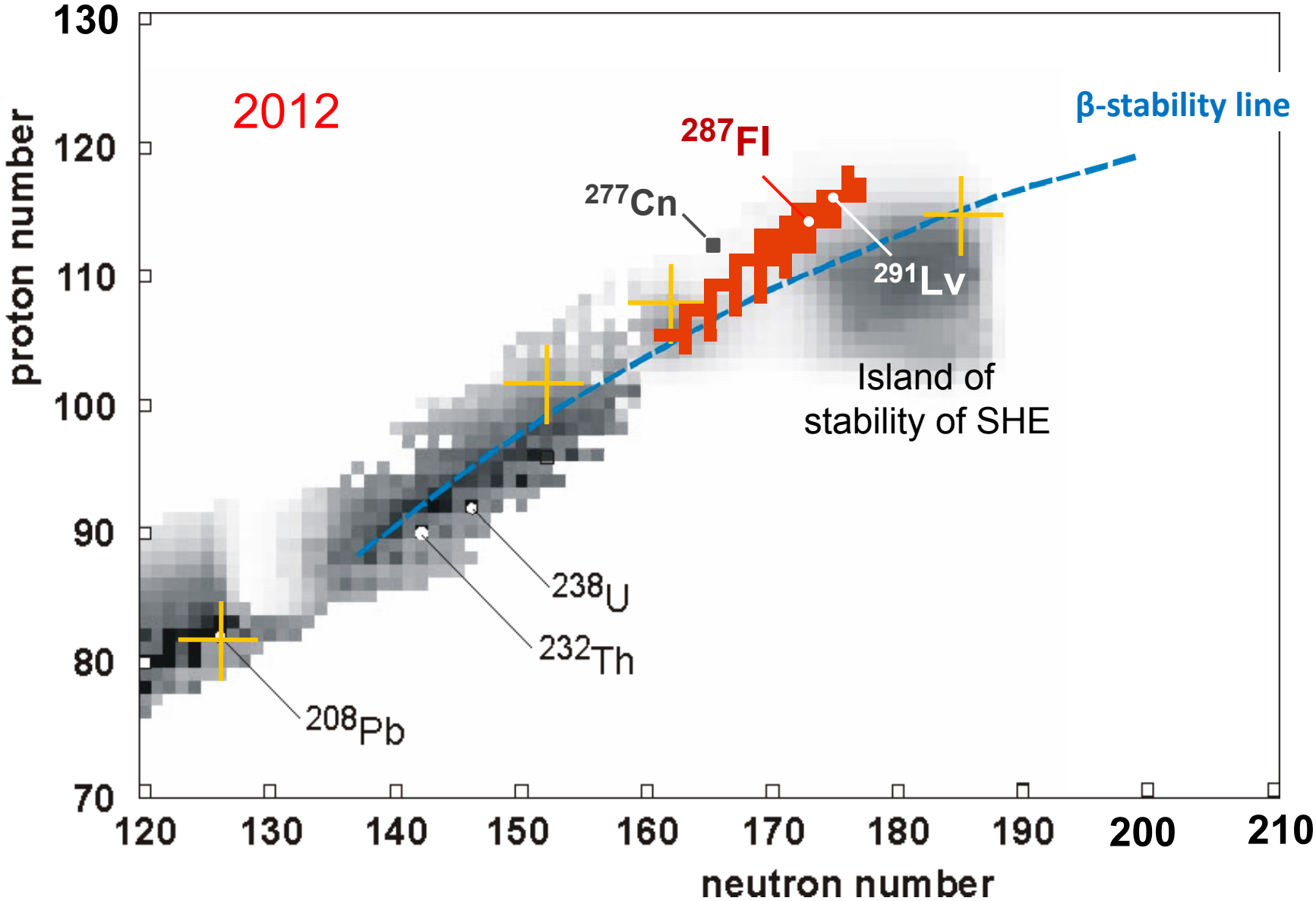
Voyage to SUPERHEAVY Island



Confirmations 2007-2010

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	LRNL (Berkeley)	P.R. Lett. 103, 132502 (2009)
$^{288,\ 289}114$	TASCA	GSI – Mainz	P.R. Lett. 104, 252701 (2010)
$^{292,\ 293}116$	SHIP	GSI Darmstadt	Eur. Phys. J. A48, 62 (2012)



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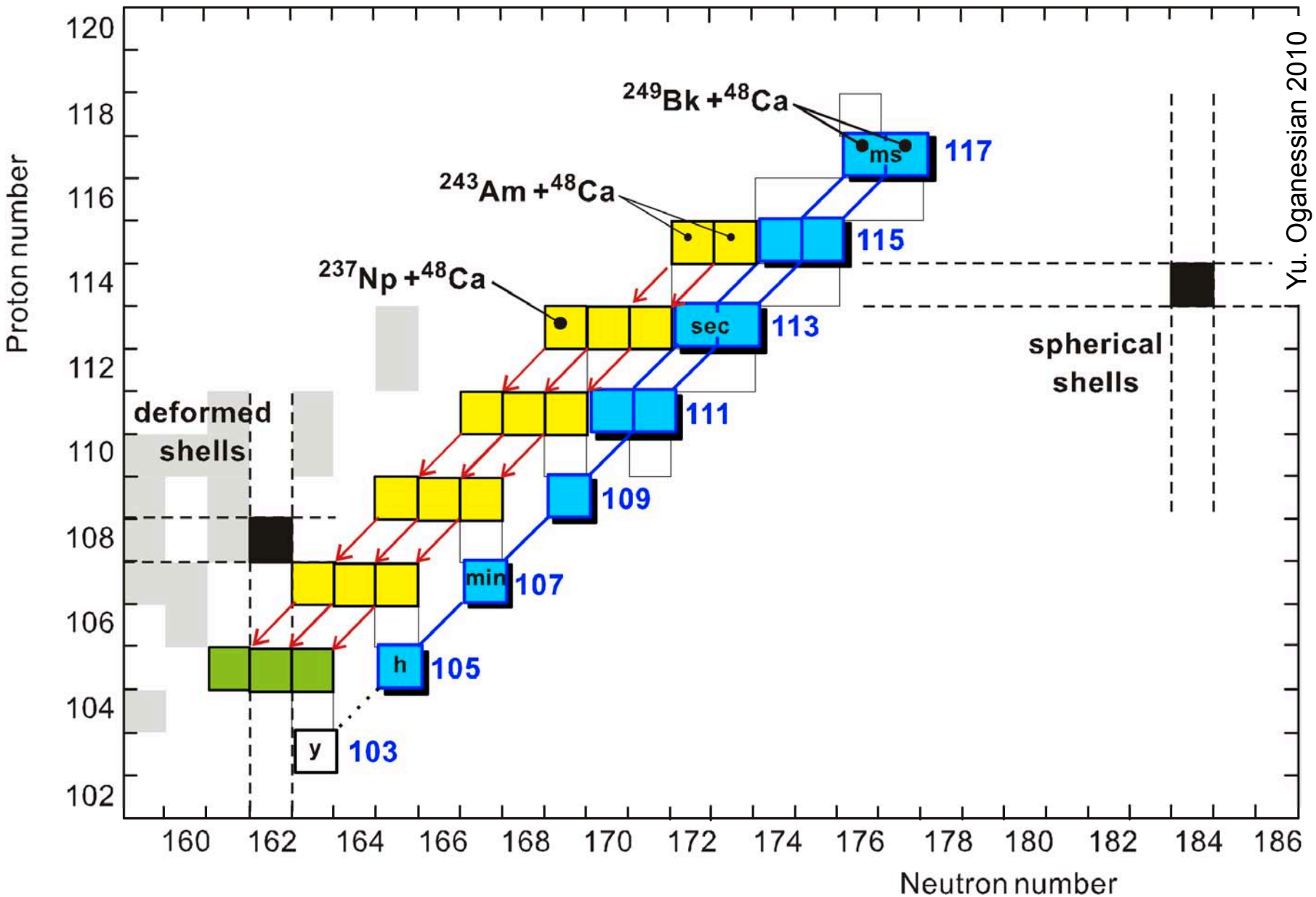
odd-Z super heavy nuclei



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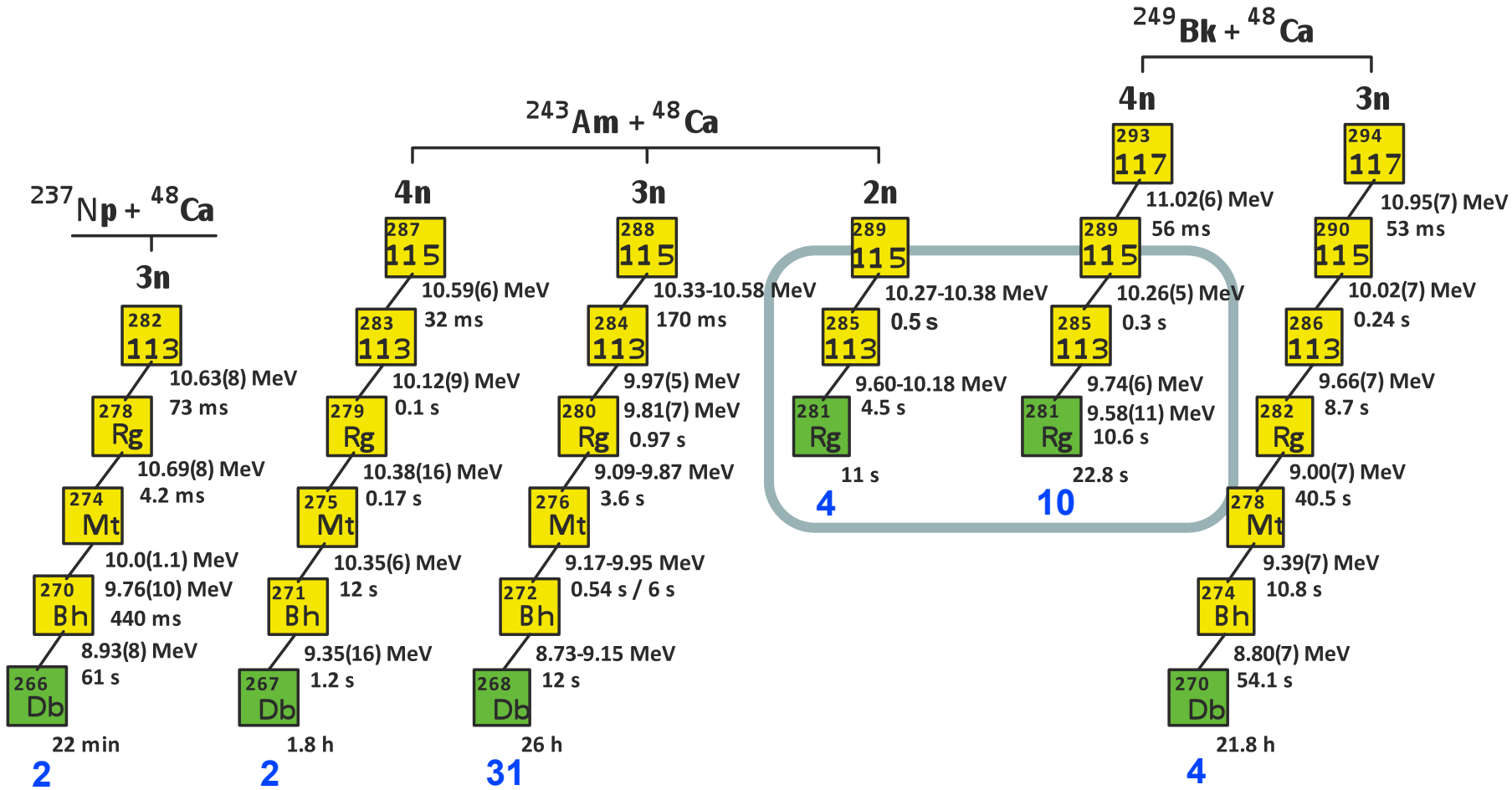
odd Z nuclei produced in ^{48}Ca-induced reactions

2003-2012



number of the detected chains

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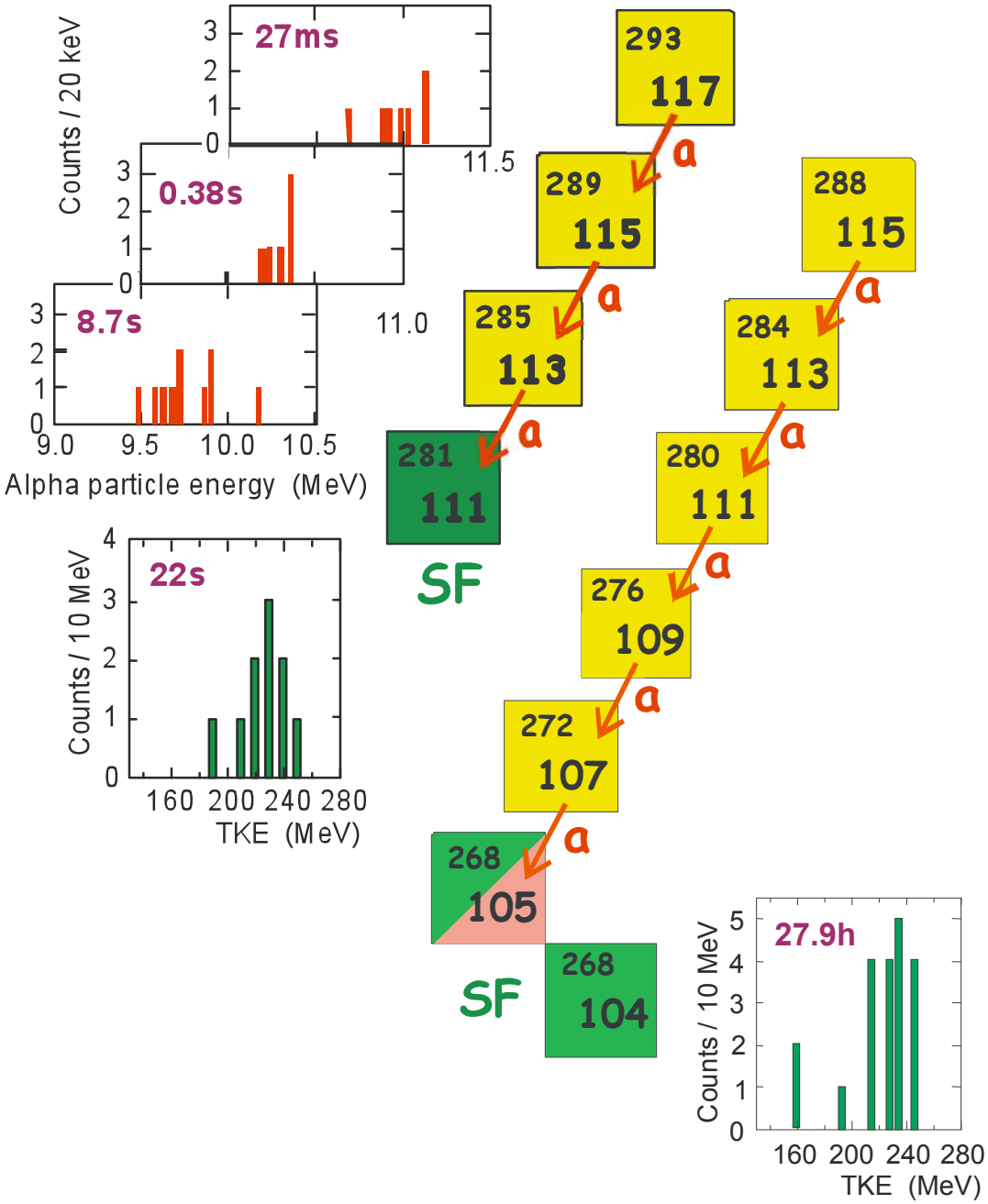
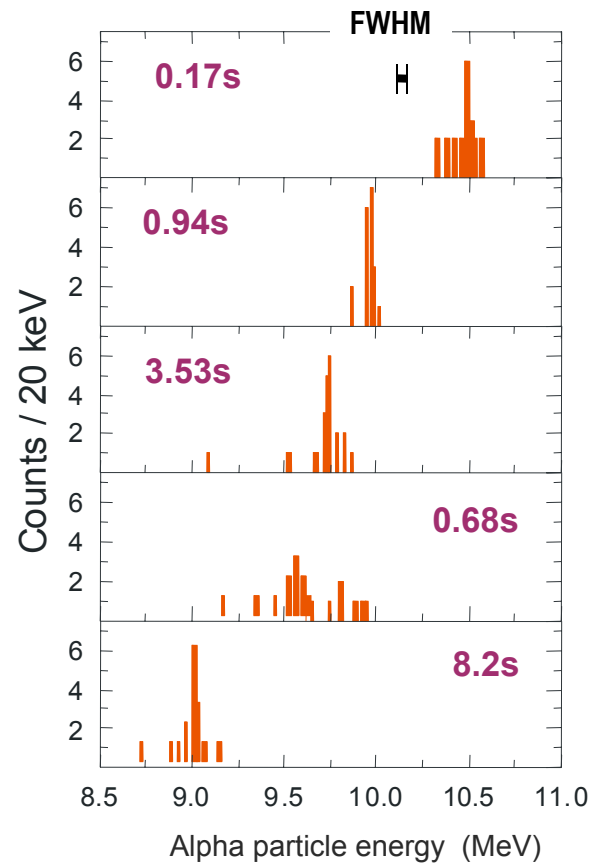
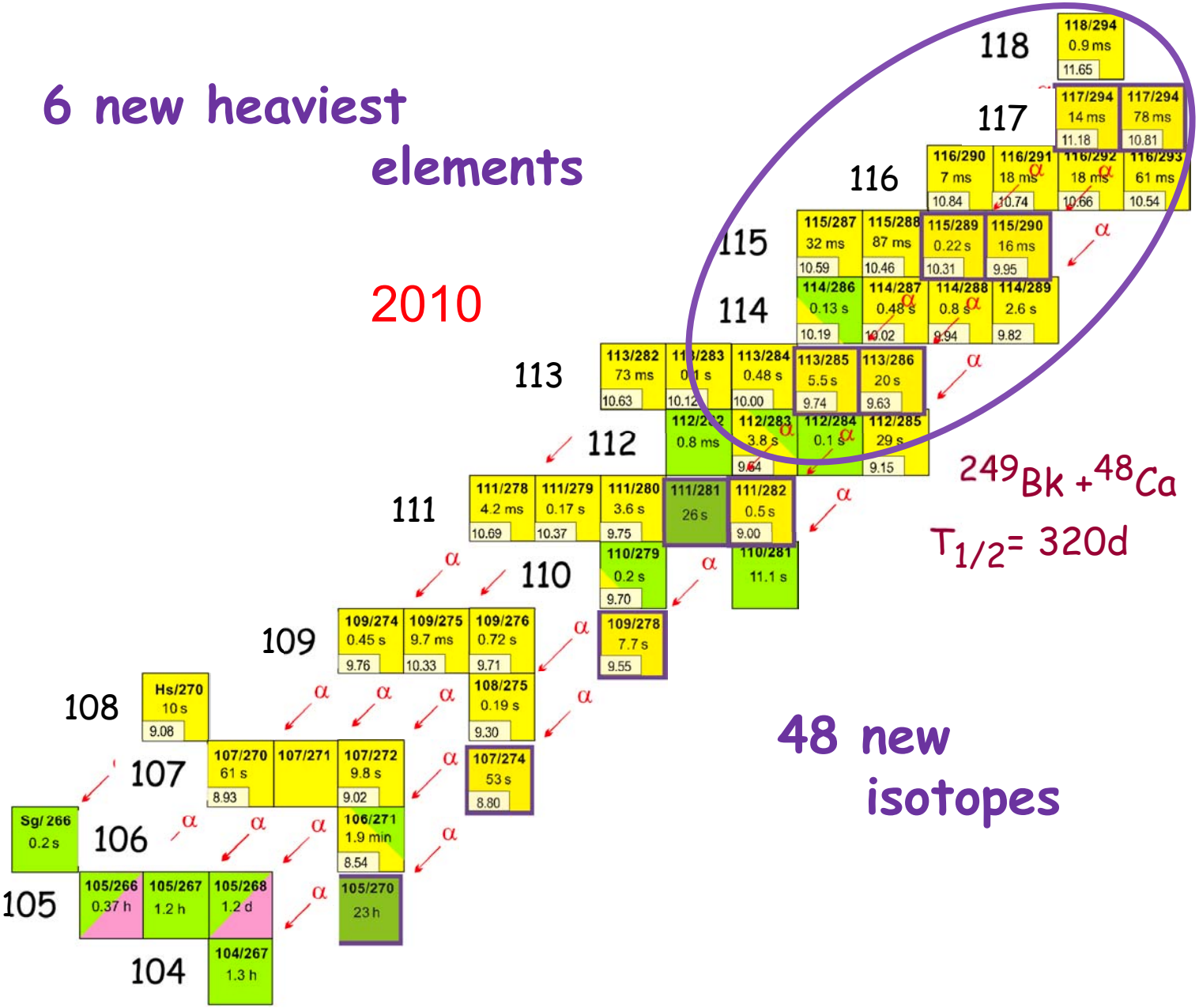




More in the next talk
(M. Stoyer, LLNL)

6 new heaviest elements

2010



$^{249}Bk + ^{48}Ca$

$T_{1/2}$= 320d

48 new isotopes

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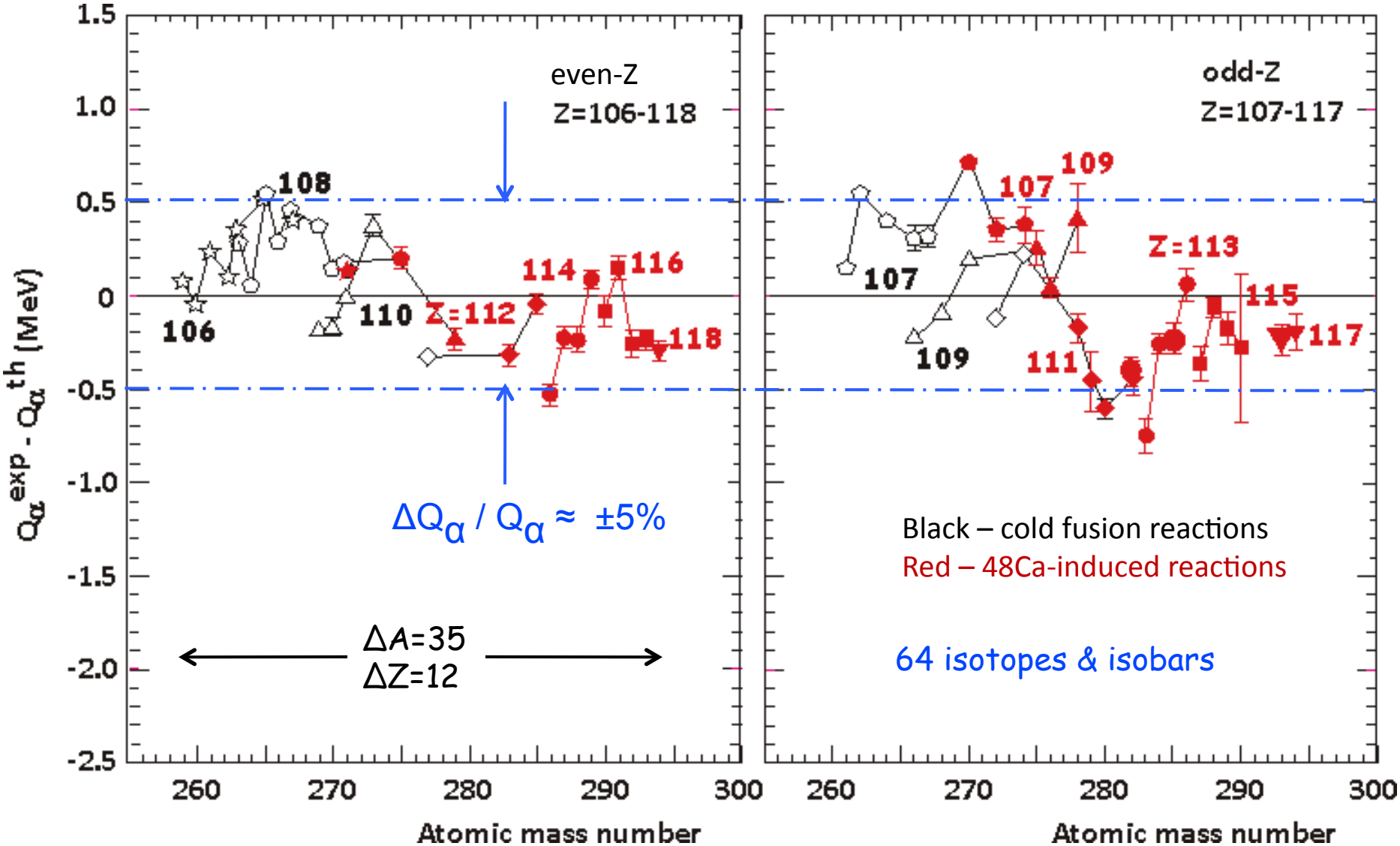
Decay properties of SH-nuclei

Alpha decay energy of the heaviest nuclei

Theory and experiment



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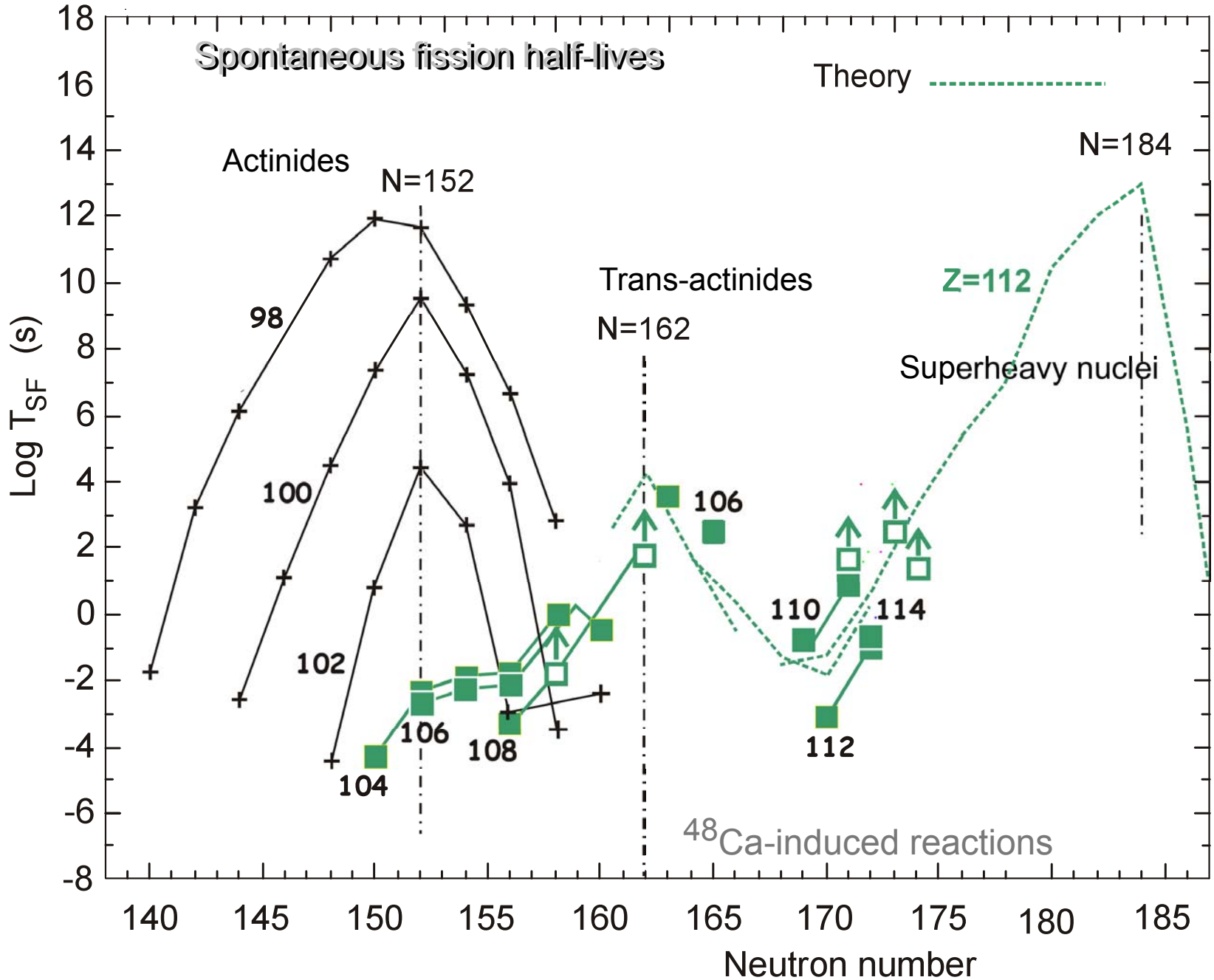
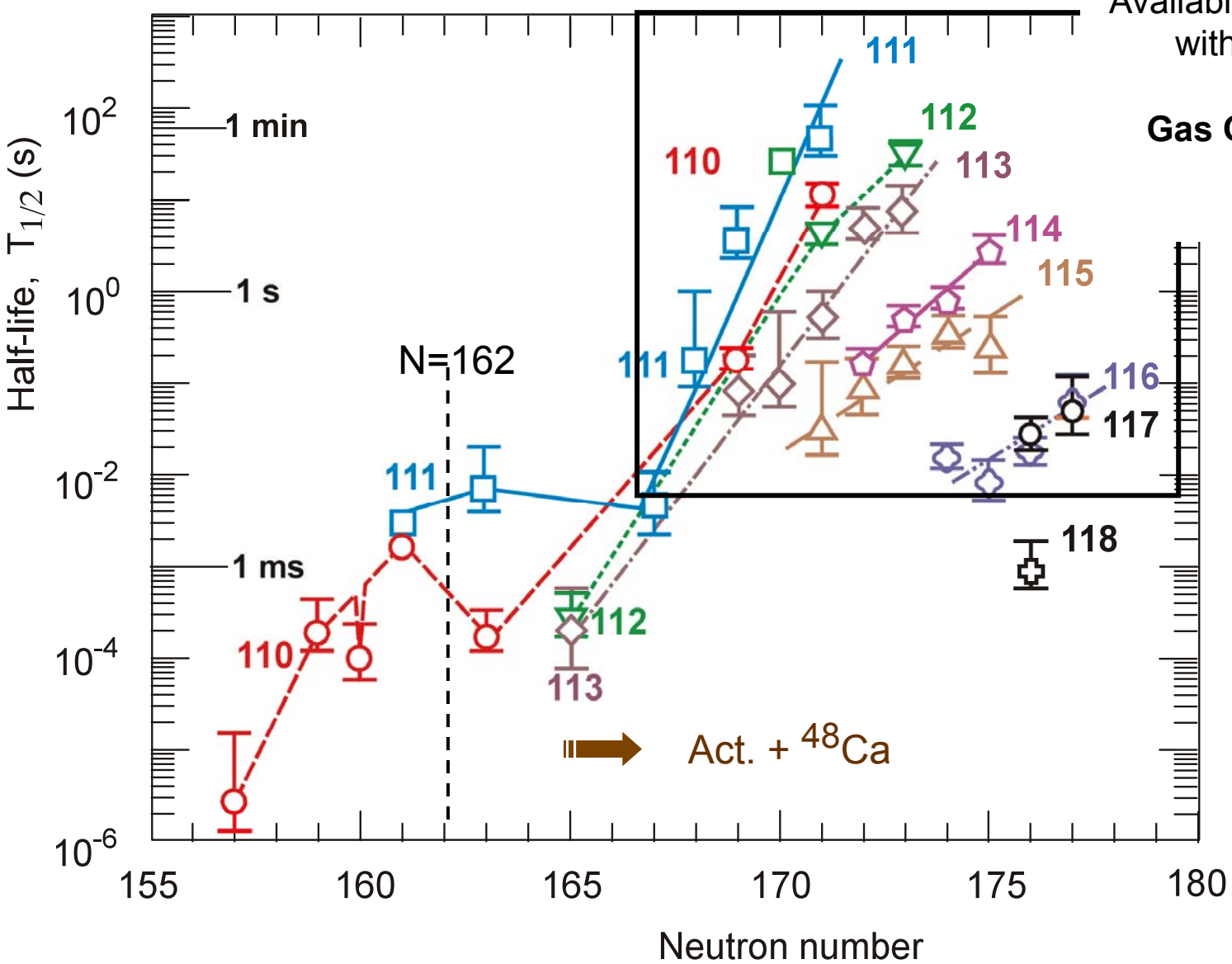

Spontaneous fission half-lives
Theory
Actinides
N=152
N=184
Trans-actinides
N=162
Z=112
Superheavy nuclei
98
100
102
104
106
108
106
110
112
114
^{48}Ca-induced reactions
Log T_{SF} (s)
Neutron number
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
140
145
150
155
160
165
170
175
180
185



Available for of-line studies with fast transportation

Gas Catcher technique

(see below)

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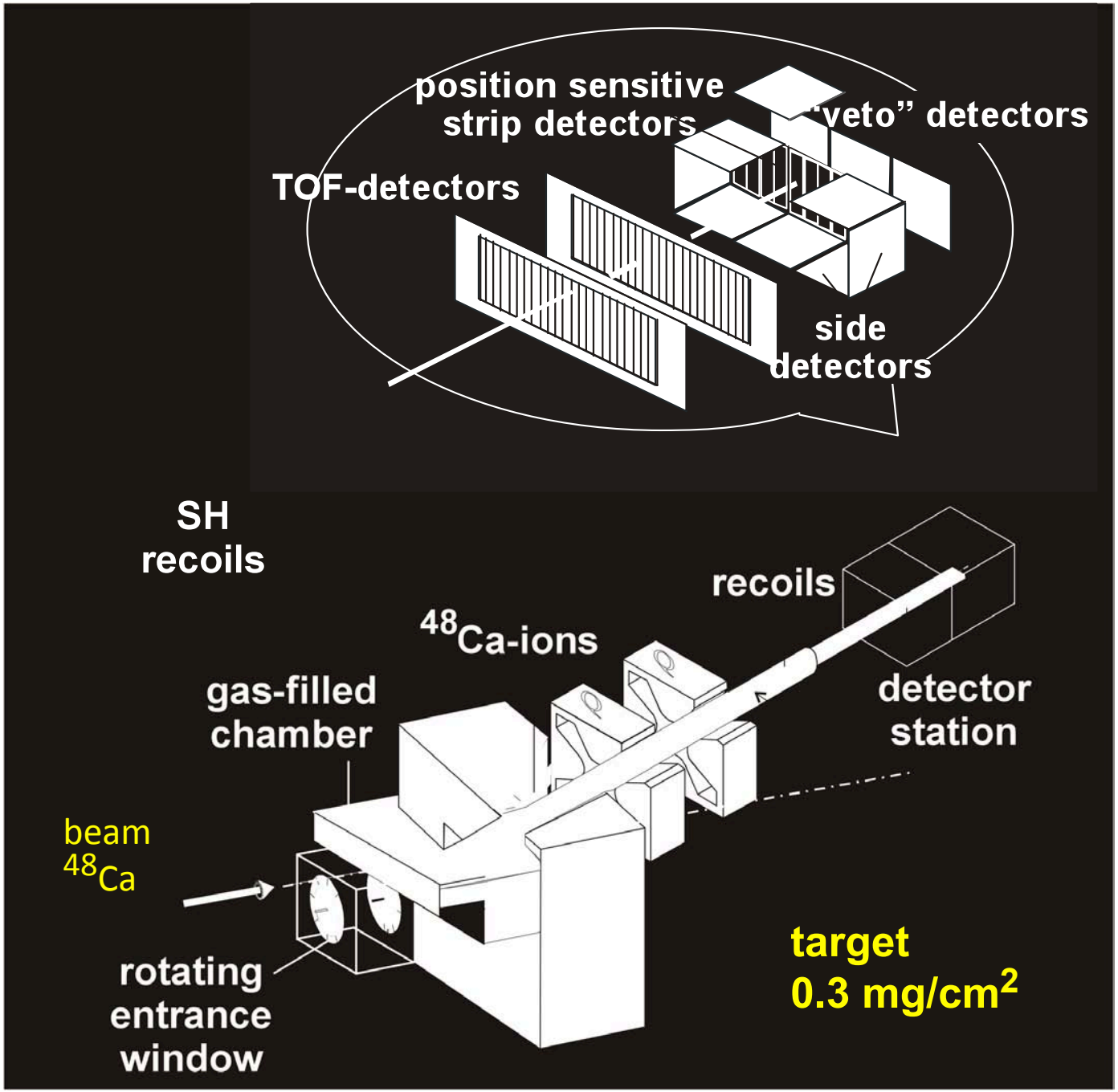
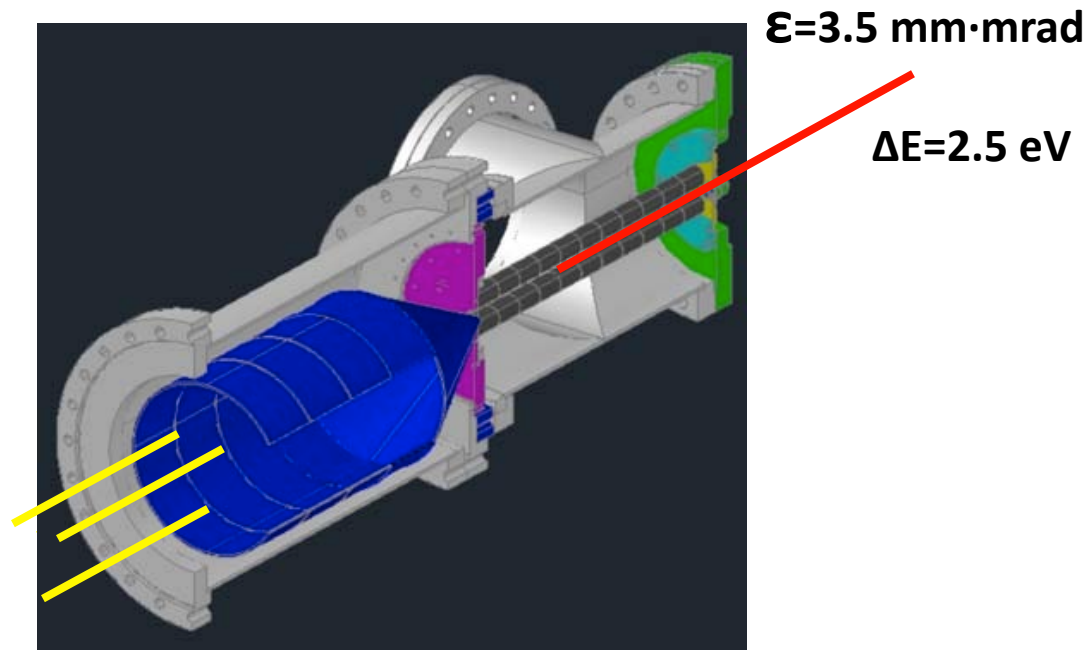
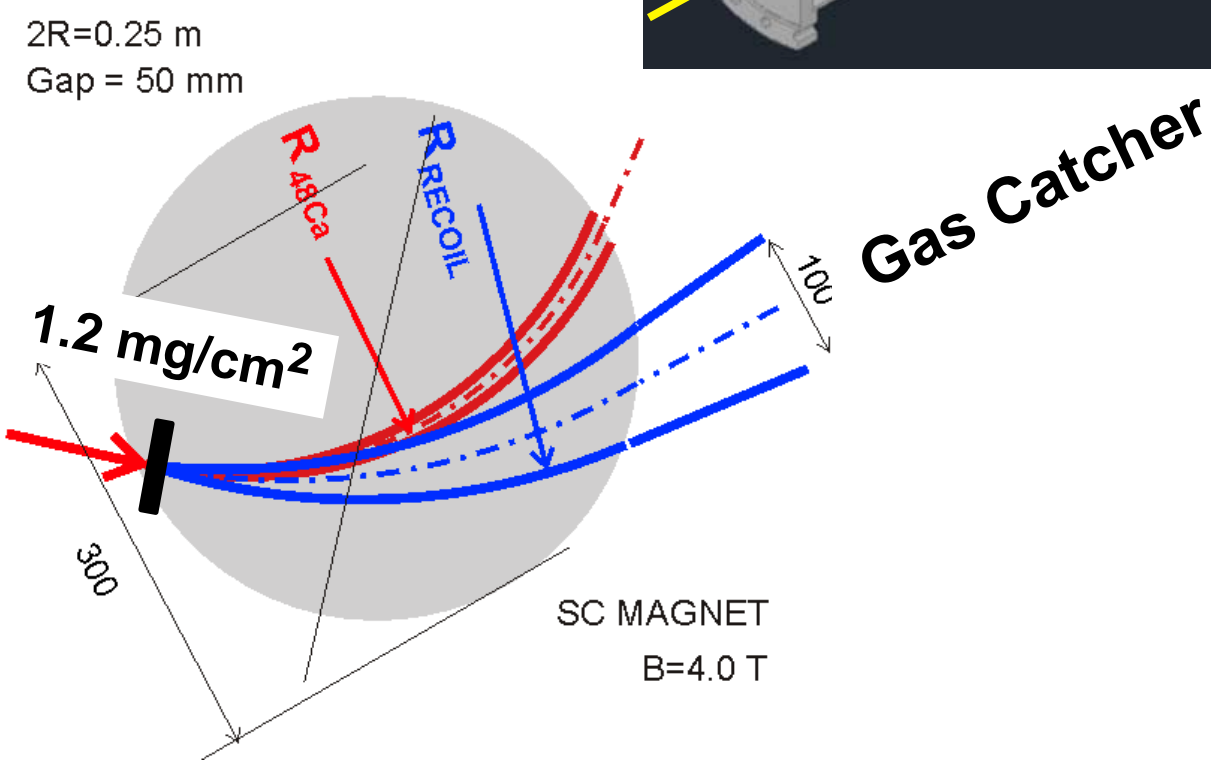

position sensitive
strip detectors
"veto" detectors
TOF-detectors
side
detectors
SH
recoils
recoils
48Ca-ions
gas-filled
chamber
detector
station
beam
48Ca
rotating
entrance
window
target
0.3 mg/cm2

Guy Savard (ANL)

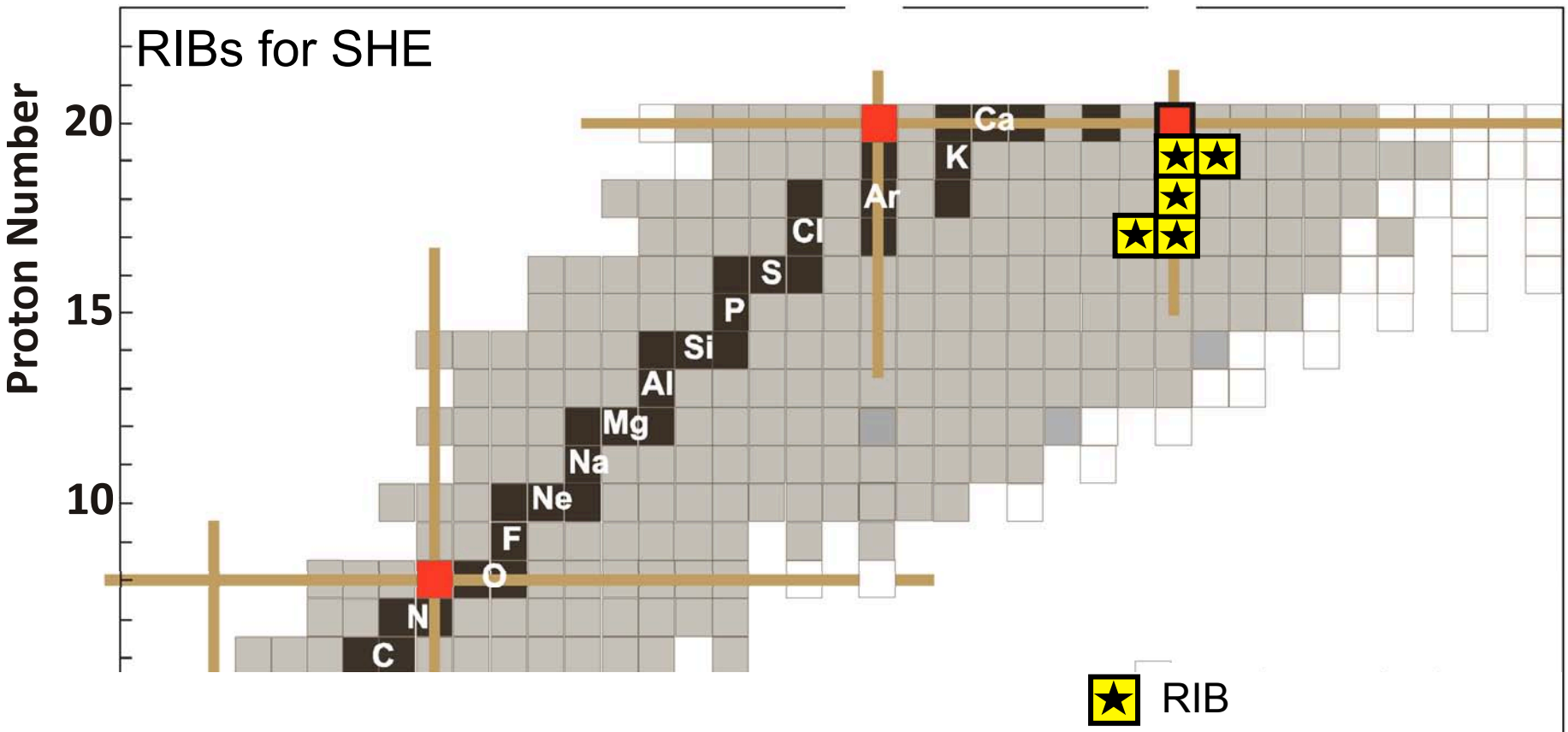
Greg Chubarian
(CI Texas A&M University)





Towards closed shell N=184

Synthesis SHE with RIB



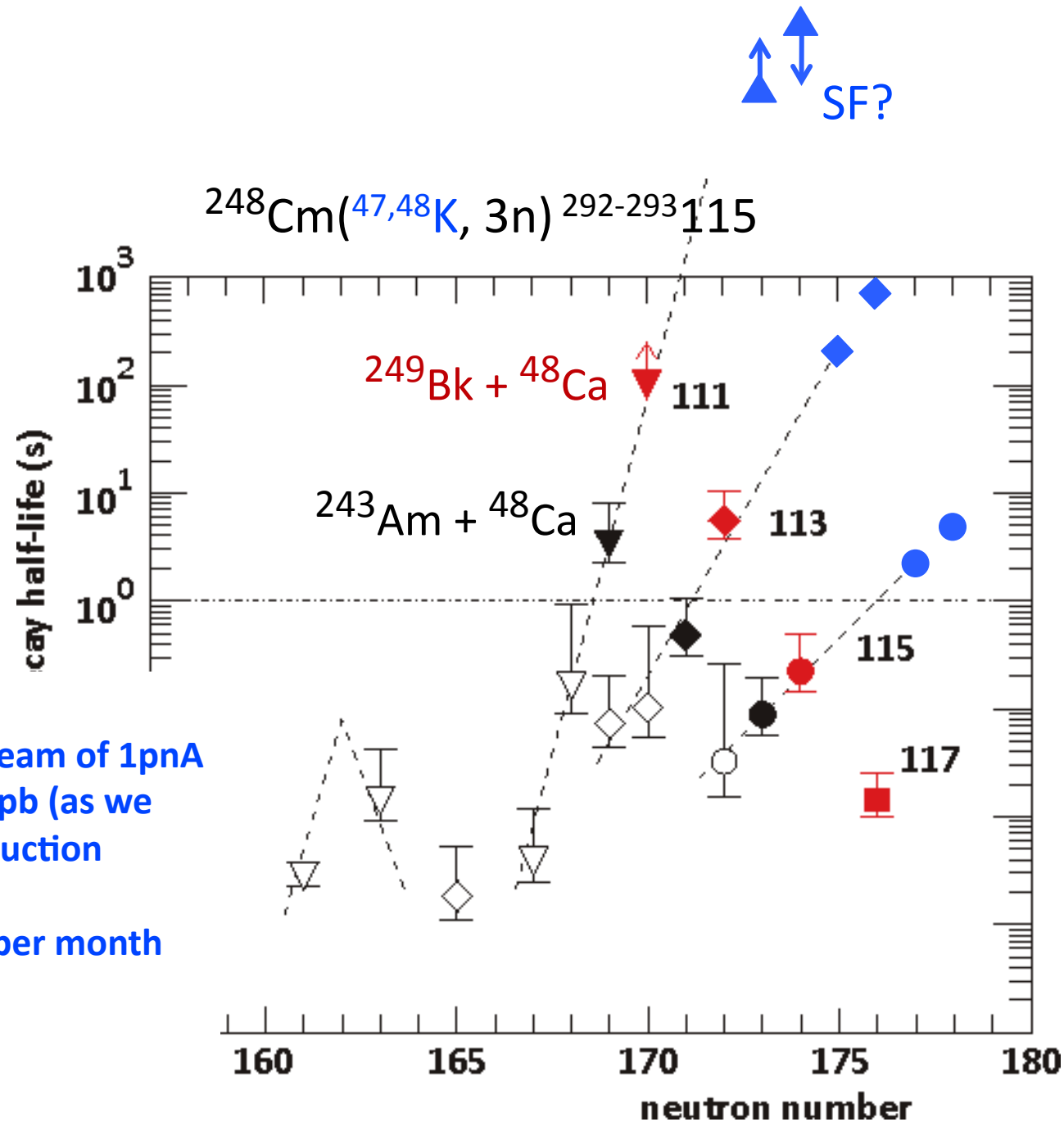
Realistic RIB intensities for the synthesis of SHE could be obtained for the isotopes close to ^{48}Ca produced in simplest reaction - like stripping, nucleon transfer, knock-out, charge exchange etc.

an example:

One proton stripping reaction:
^{48}Ca → ^{47}K (17,5s)

or

Charge exchange reaction:
^{48}Ca → ^{48}K (6,8s)



At the intensity of $^{47-48}$K-beam of 1pnA and 3n-cross section of 10 pb (as we have today) expected production rate of $^{292-293}$115 nuclei is about 1 per month

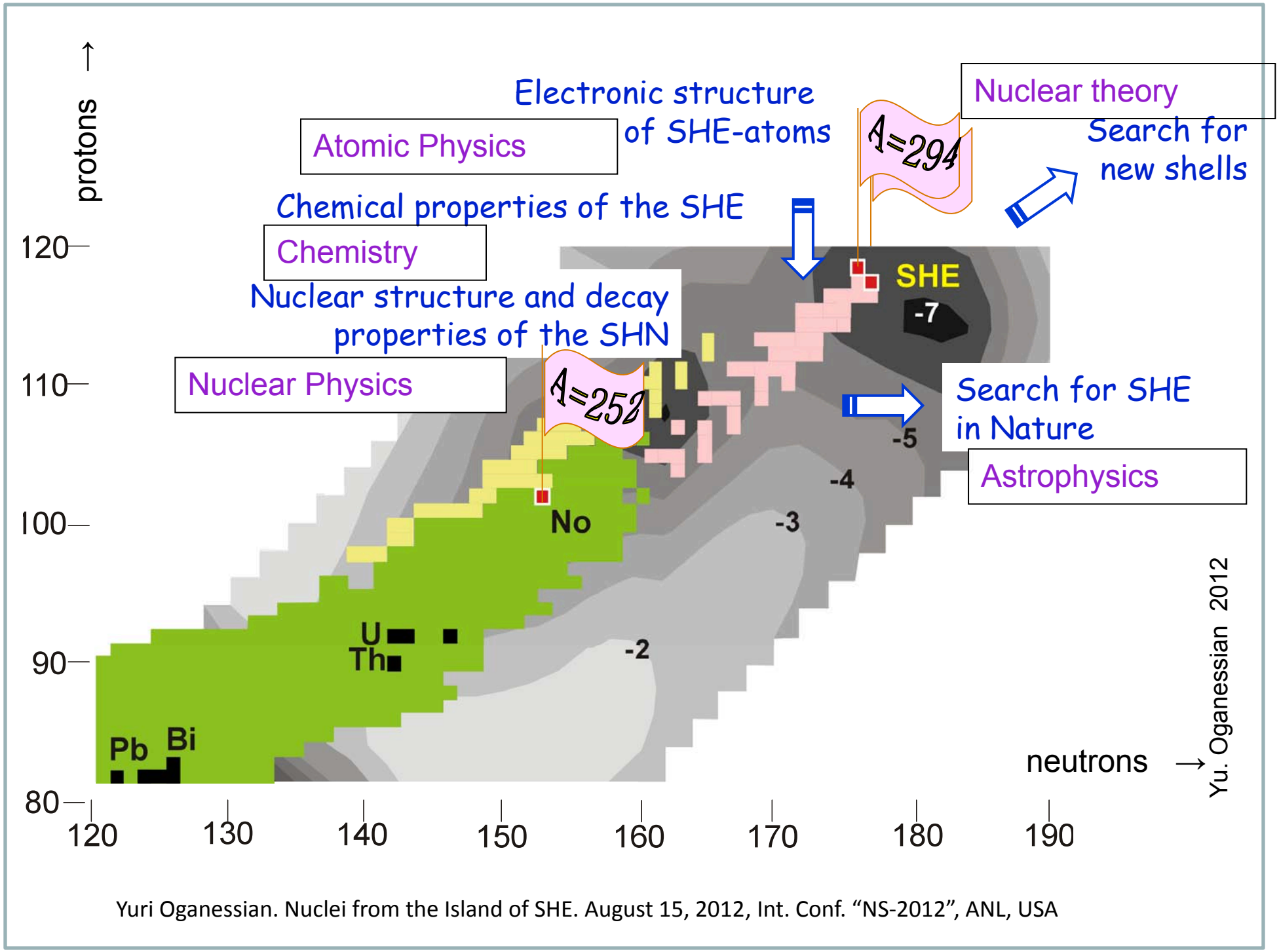
With Z >40% larger than that of Bi, the heaviest stable element, we see an impressive extension in nuclear survival.

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.

Consequences



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Let me stop here and make a short summary:

- we have received an evidence that SHE exist
- moreover we know roughly their decay properties
- know how to produce them

However, we producing them in very small quantities, much less than could be reached with modern technique

So, I would like to talk about these opportunities and about our plans for the near and distant future.

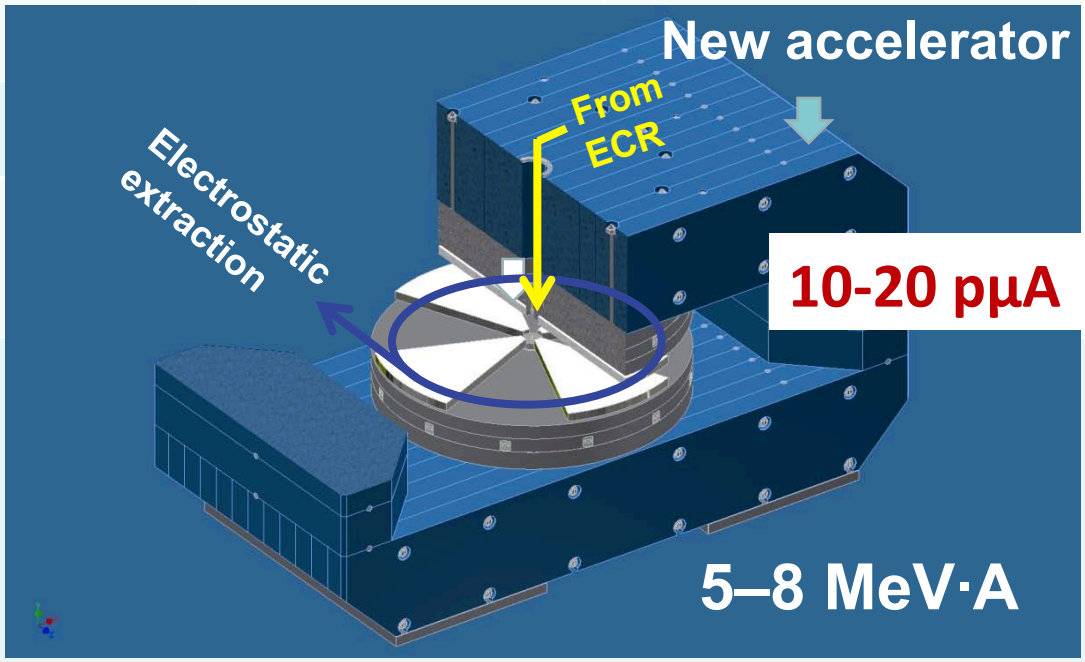
Production

today: $4.5 \cdot 10^{19}$ with factory: $1.3 \cdot 10^{21}$

factor: 30

Increase a beam dose

it requires to Increase:	**beam intensity**	and	**beam time**
			⇩
			SHE-Factory
			⇩
			~ 7000 h/year
			⇩



a limit of the beam intensity is defined entirely by target resistance and available amount of target material

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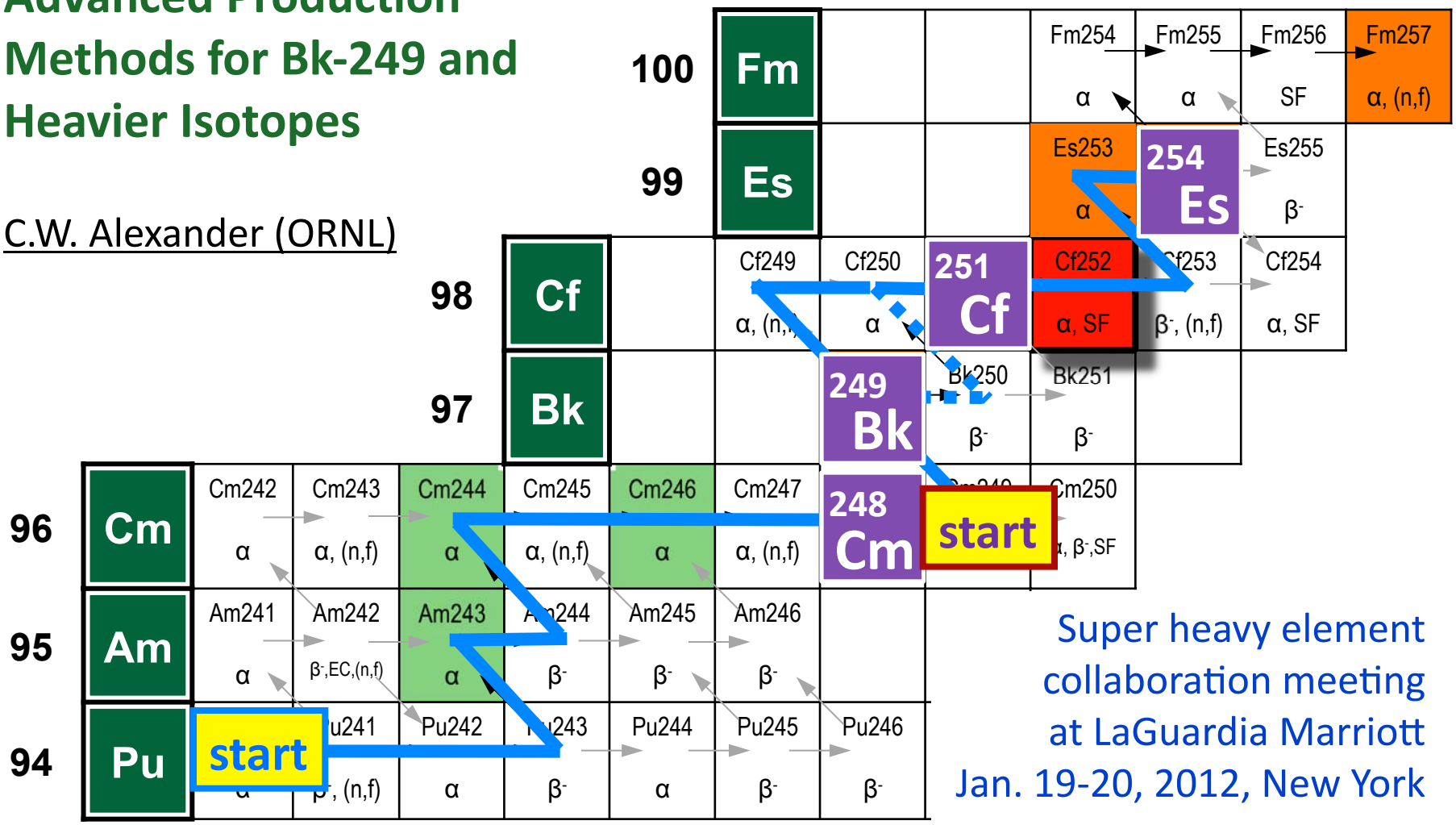
Transuranium Nuclide Production Paths

Advanced Production Methods for Bk-249 and Heavier Isotopes

C.W. Alexander (ORNL)



Super heavy element collaboration meeting at LaGuardia Marriott Jan. 19-20, 2012, New York

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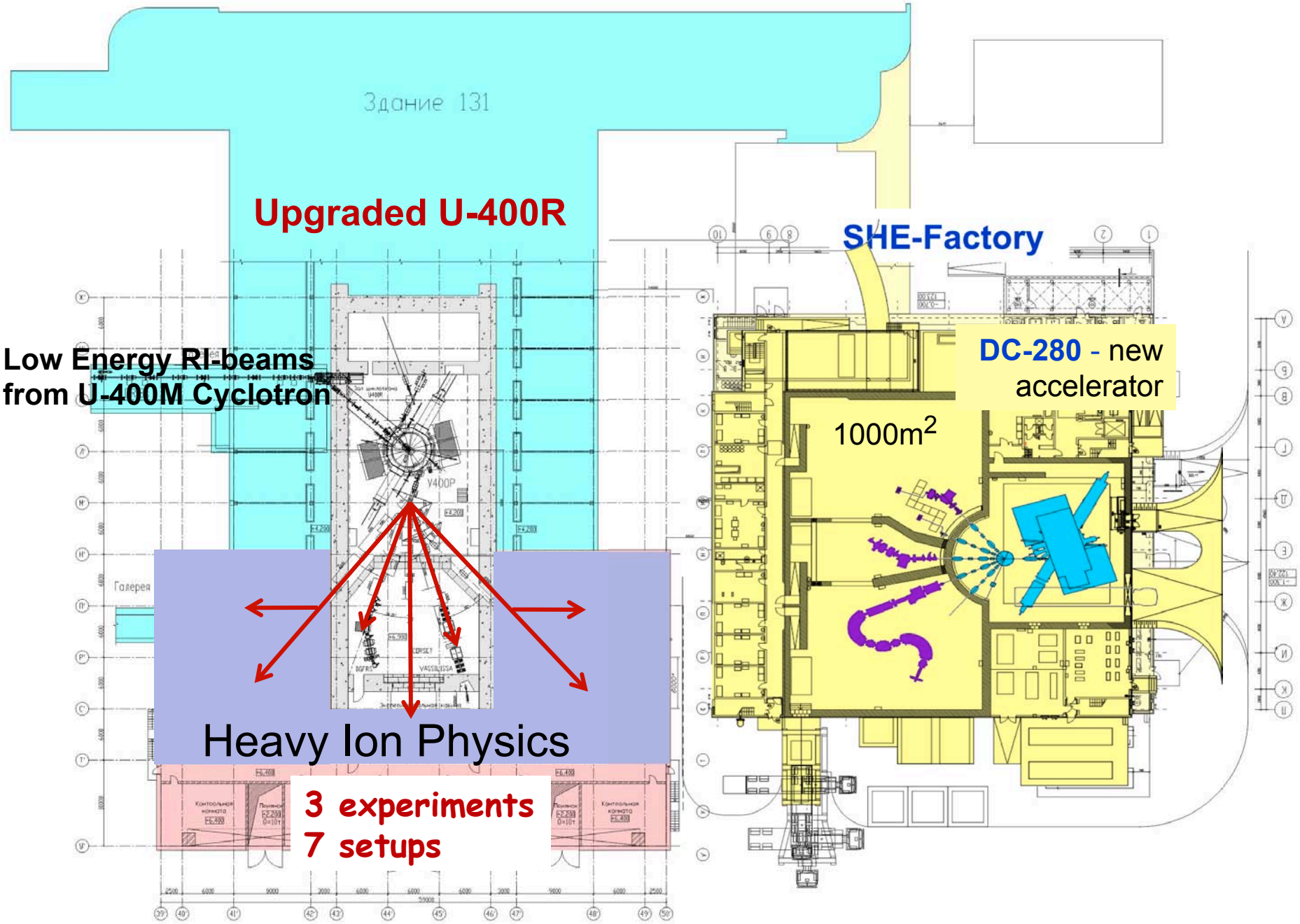
Bk-249 Production

- Routinely produced from a mix of Cm isotopes (Cm-244 to Cm-248) but production rate can be increased by irradiating a **Cm-248 target**
- **Thermal neutron filtering** may lead to large and more efficient Bk-249 production gains
- With a perfect Cd cutoff of the thermal neutron flux and target material consisting of **1.0 g of Cm-248** (97%) and a HFIR cycle time of 23 days:
  - **Seven HFIR cycles yields: 82.8 mg Bk-249**

ACCELERATORS

Beam parameters	HI-Physics U-400R	SHE-Factory DC-280
Projectiles	Stable and **RIB ($T_{1/2}$ > 0.1s)**	Stable only
Projectile masses	4He – 238U	40Ar – 86Kr
Energy range	0.5 – 27.0 MeV/n	5 – 8 MeV/n
Energy resolution	0.5%	1.5%
Beam intensity (for 48Ca)	2.5 pμA	10-20 pμA
SHE-research program	≤30%	~100%
Registered decay chains of SHN (per year)	120 (now **30**)	**~5000**
State of readiness	75%	In course of design



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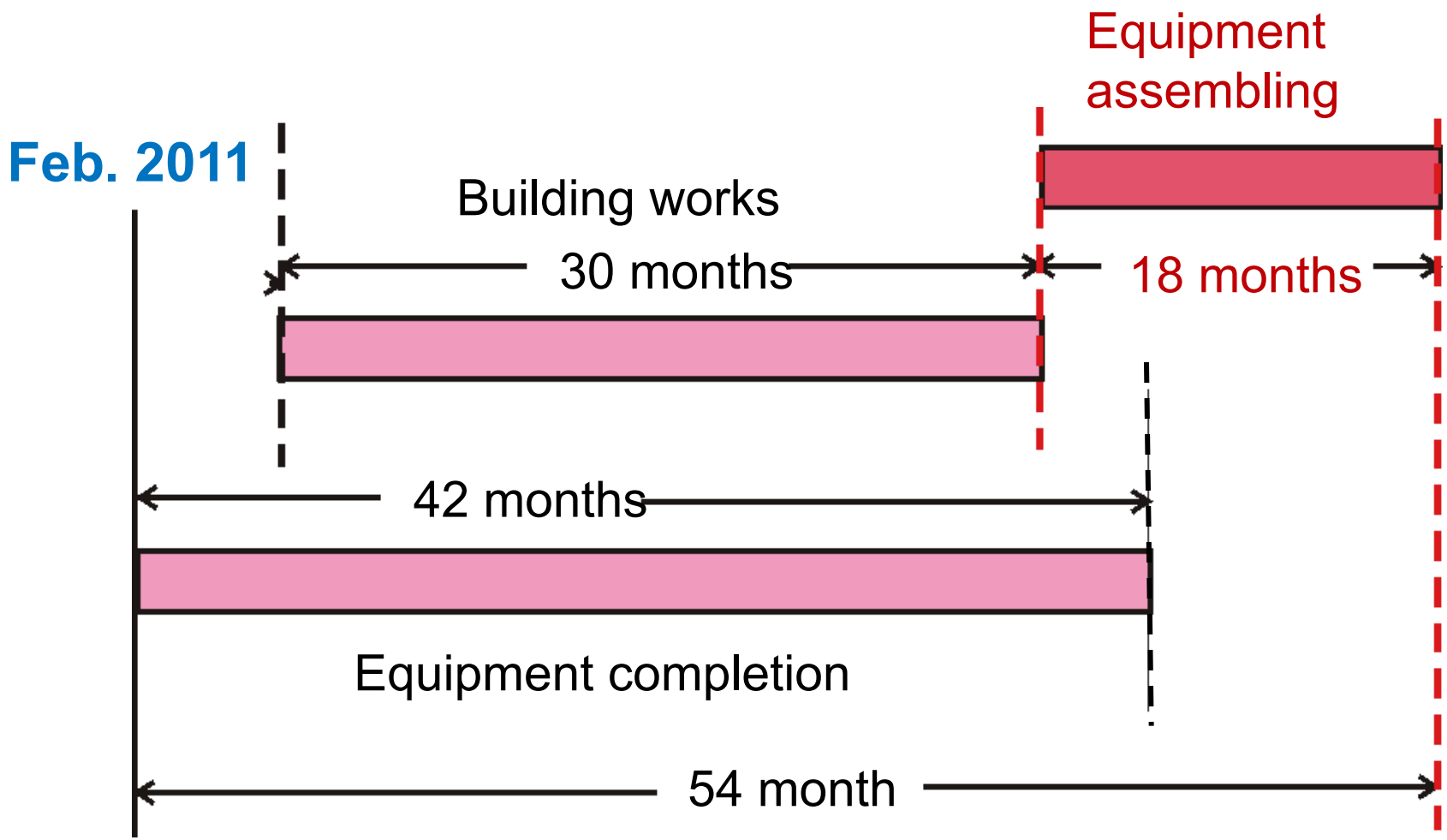
Schedule for SHE-Factory



Collaboration

Thank you

FLNR, JINR (Dubna)

ORNL (Oak-Ridge, USA)

LLNL (Livermore, USA)

ANL (Argonne, USA)

TAMU Cyclotron Institute (Texas, USA)

RIAR (Dimitrovgrad, Russia)

Vanderbilt University (Nashville, USA)