Synthesis of SH-nuclei

current/future experiments
and
strategy

Yuri Oganessian

Flerov Laboratory of Nuclear Reaction JINR, Dubna

Workshop on FUture SuperHeavy Element Strategy
FUSHE 2012; May 13-16, 2012 Weilrod, Germany

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

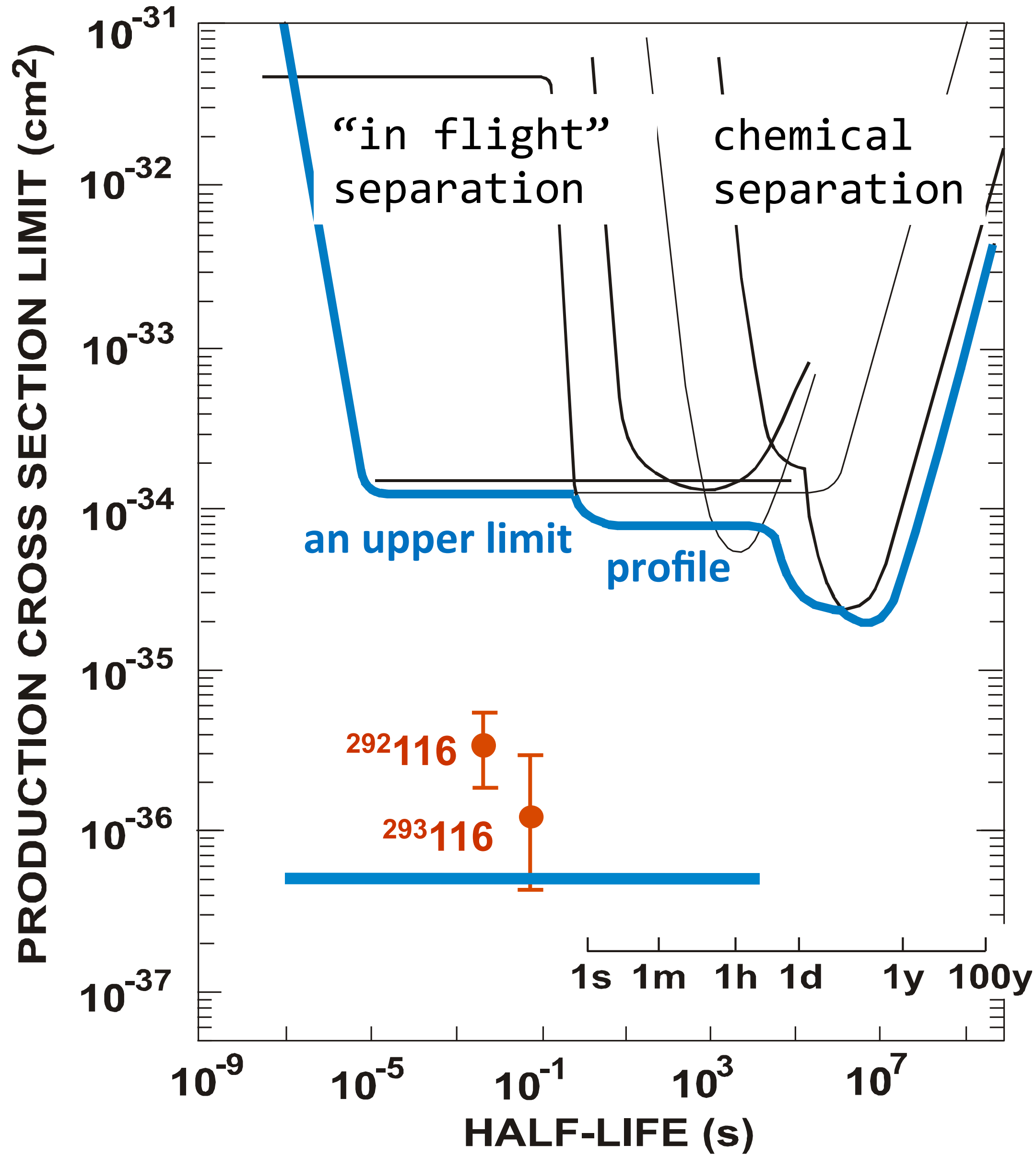
Yu. Oganessian 2012

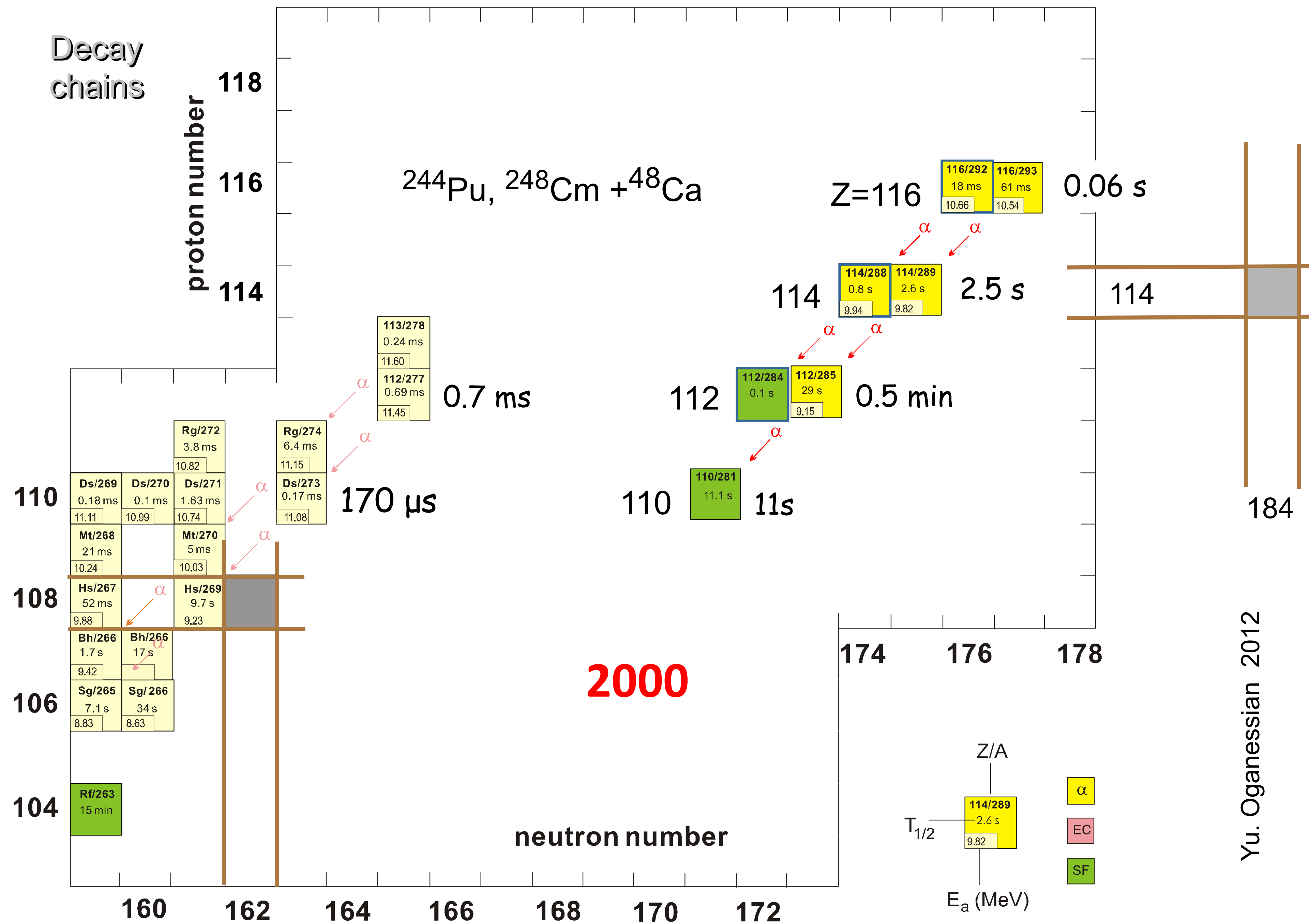
GSI, Darmstadt, Germany*
LBL, UC Berkeley, CA
Univ. of Mainz, Germany
LANL, Los Alamos, NM
EIR, Würenlingen, Switzerland

1985

FLNR, Dubna
LLNL, Livermore

2000

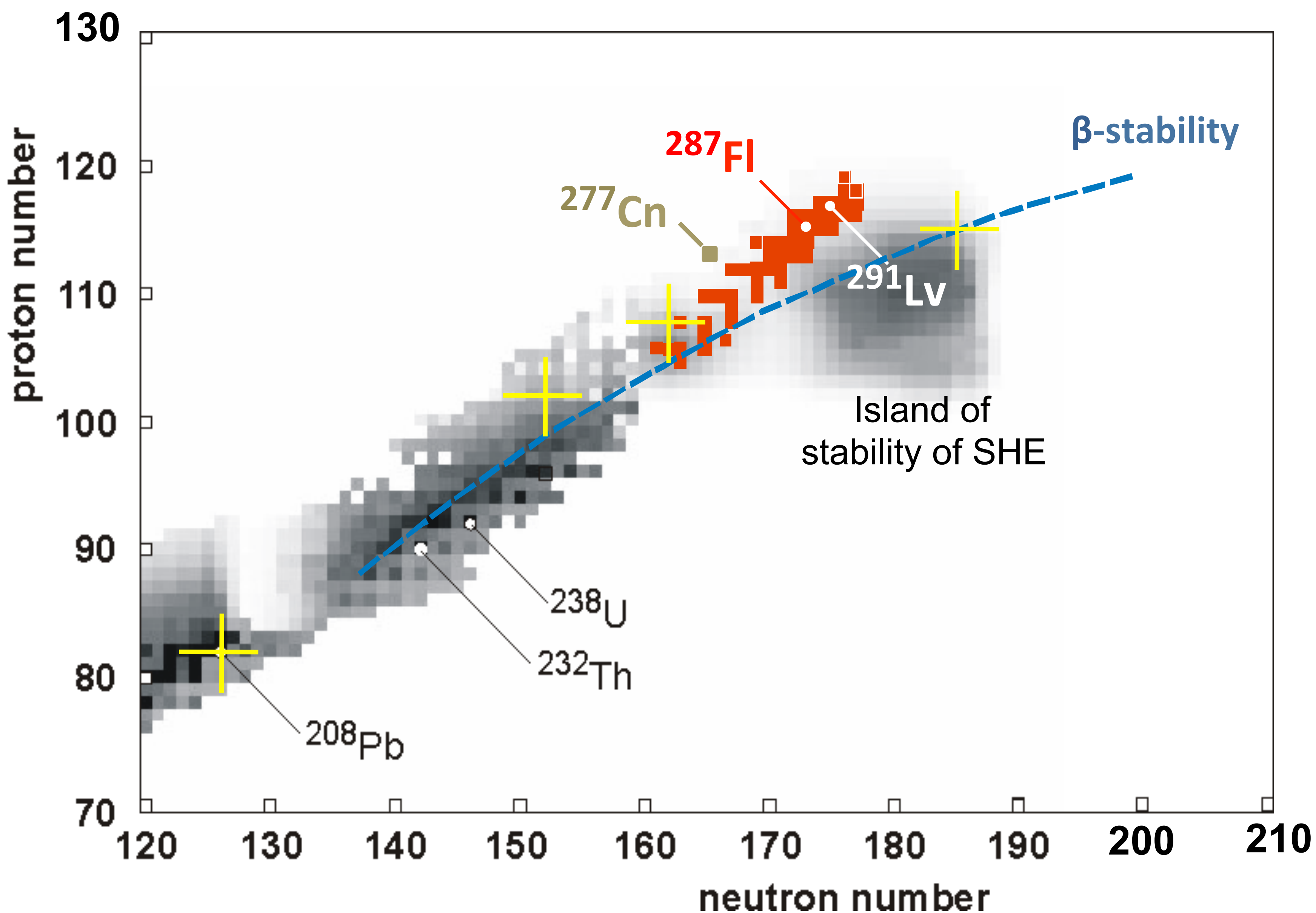




Decay chains
proton number
neutron number
^{244}Pu, ^{248}Cm +^{48}Ca
Z=116
116/292
18 ms
10.66
116/293
61 ms
10.54
0.06 s
114/288
0.8 s
9.94
114/289
2.6 s
9.82
2.5 s
112/284
0.1 s
112/285
29 s
9.15
0.5 min
110/281
11.1 s
11s
113/278
0.24 ms
11.60
112/277
0.69 ms
11.45
0.7 ms
Rg/272
3.8 ms
10.82
Rg/274
6.4 ms
11.15
Ds/269
0.18 ms
11.11
Ds/270
0.1 ms
10.99
Ds/271
1.63 ms
10.74
Ds/273
0.17 ms
11.08
170 μs
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
α
118
116
114
112
110
108
106
104
160
162
164
166
168
170
172
174
176
178
184
2000
Z/A
$T_{1/2}$
E_a (MeV)
α
EC
SF
Yu. Oganessian 2012

Confirmations 2007-2010

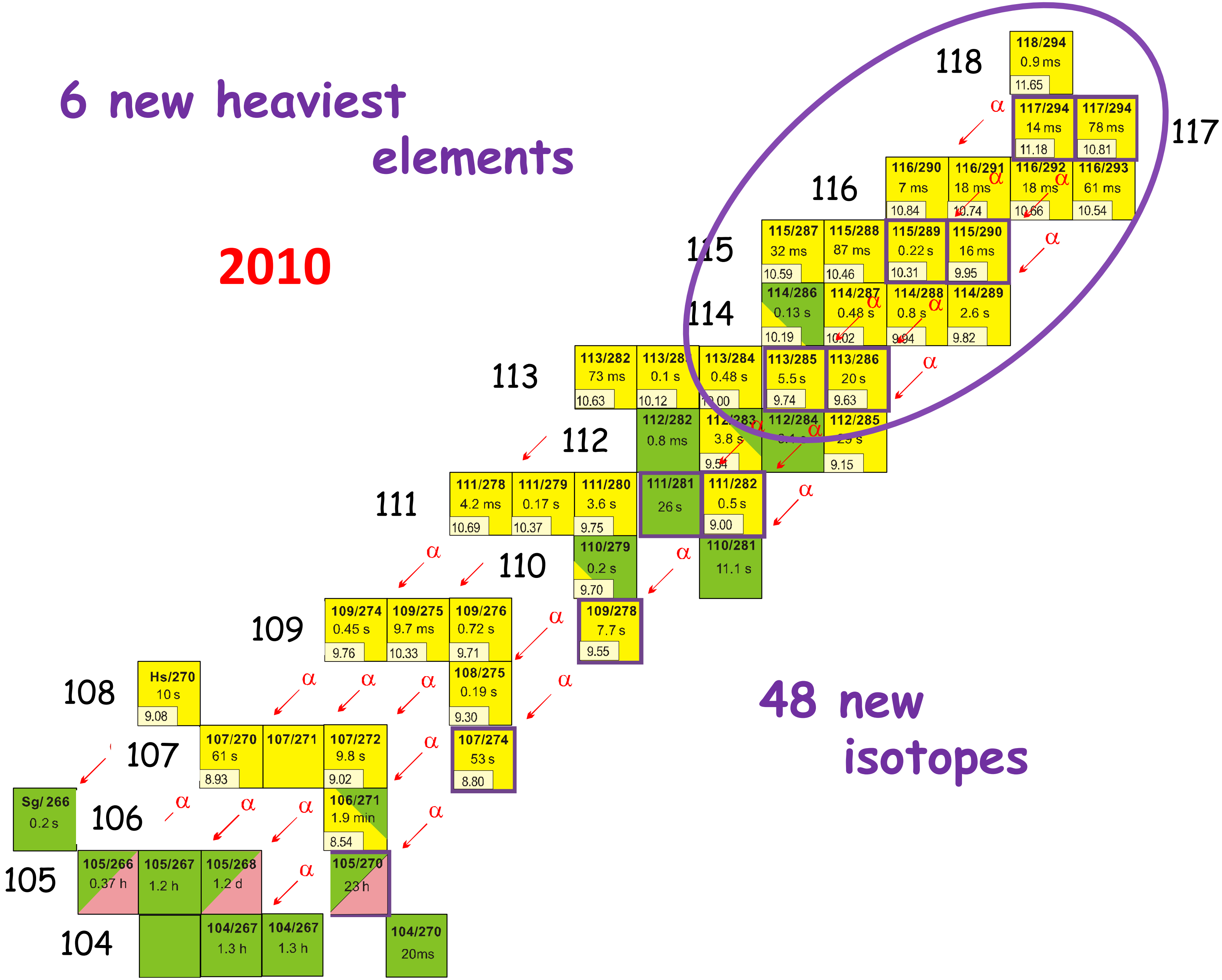
A/Z	Setup	Laboratory	Publications
$^{283}112$	SHIP	GSI Darmstadt	Eur. Phys. J. A32, 251 (2007)
$^{283}112$	COLD	PSI-FLNR (JINR)	NATURE 447, 72 (2007)
$^{286, 287}114$	BGS	LRNL (Berkeley)	P.R. Lett. 103, 132502 (2009)
$^{288, 289}114$	TASCA	GSI – Mainz	P.R. Lett. 104, 252701 (2010)
$^{292, 293}116$	SHIP	GSI Darmstadt	Eur. Phys. J. A48, 62 (2012)



Yuri Oganessian. “Synthesis of SH-nuclei” FUSHE 2012, May14, 2012, Weilrod, Germany

6 new heaviest elements

2010

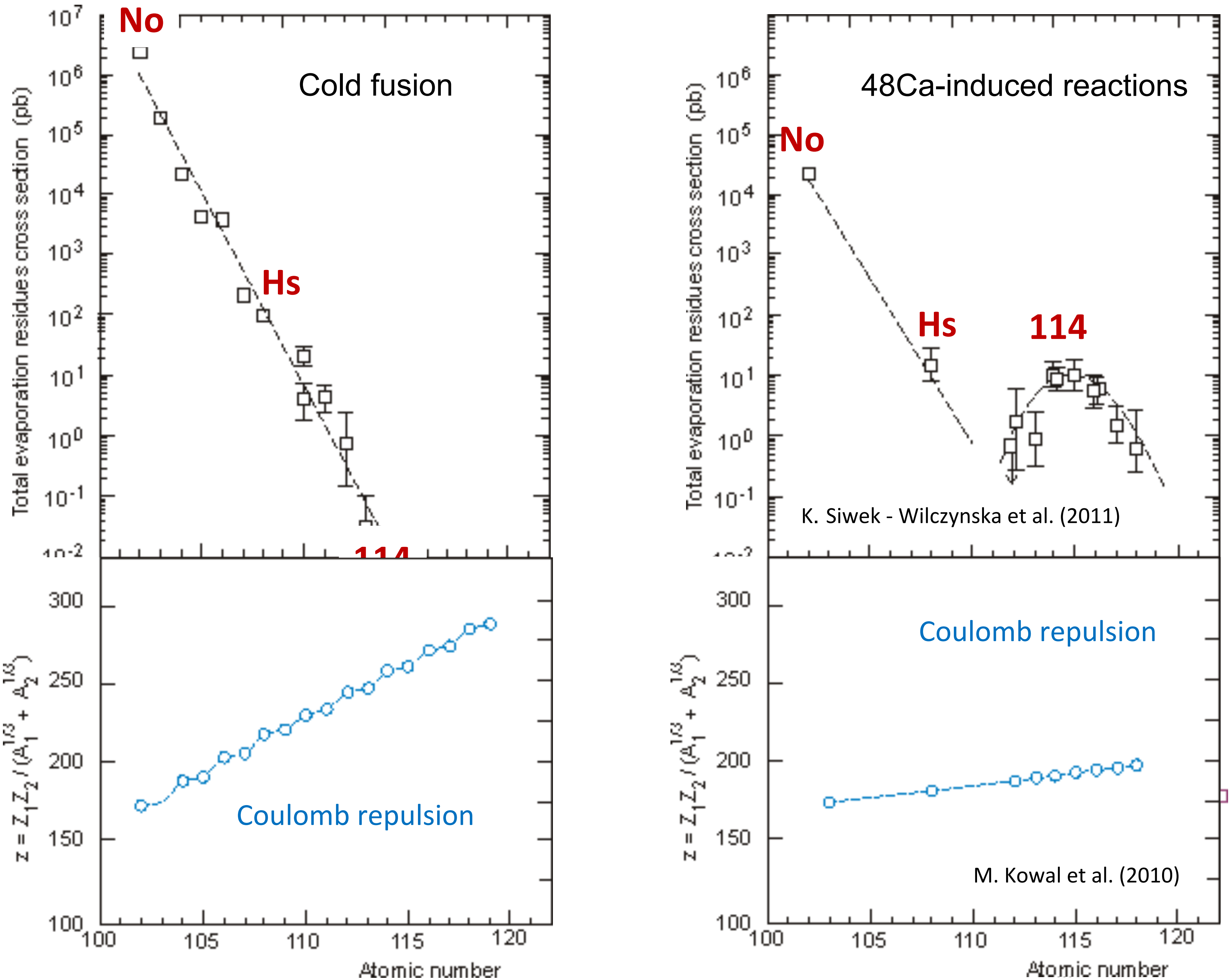


48 new isotopes

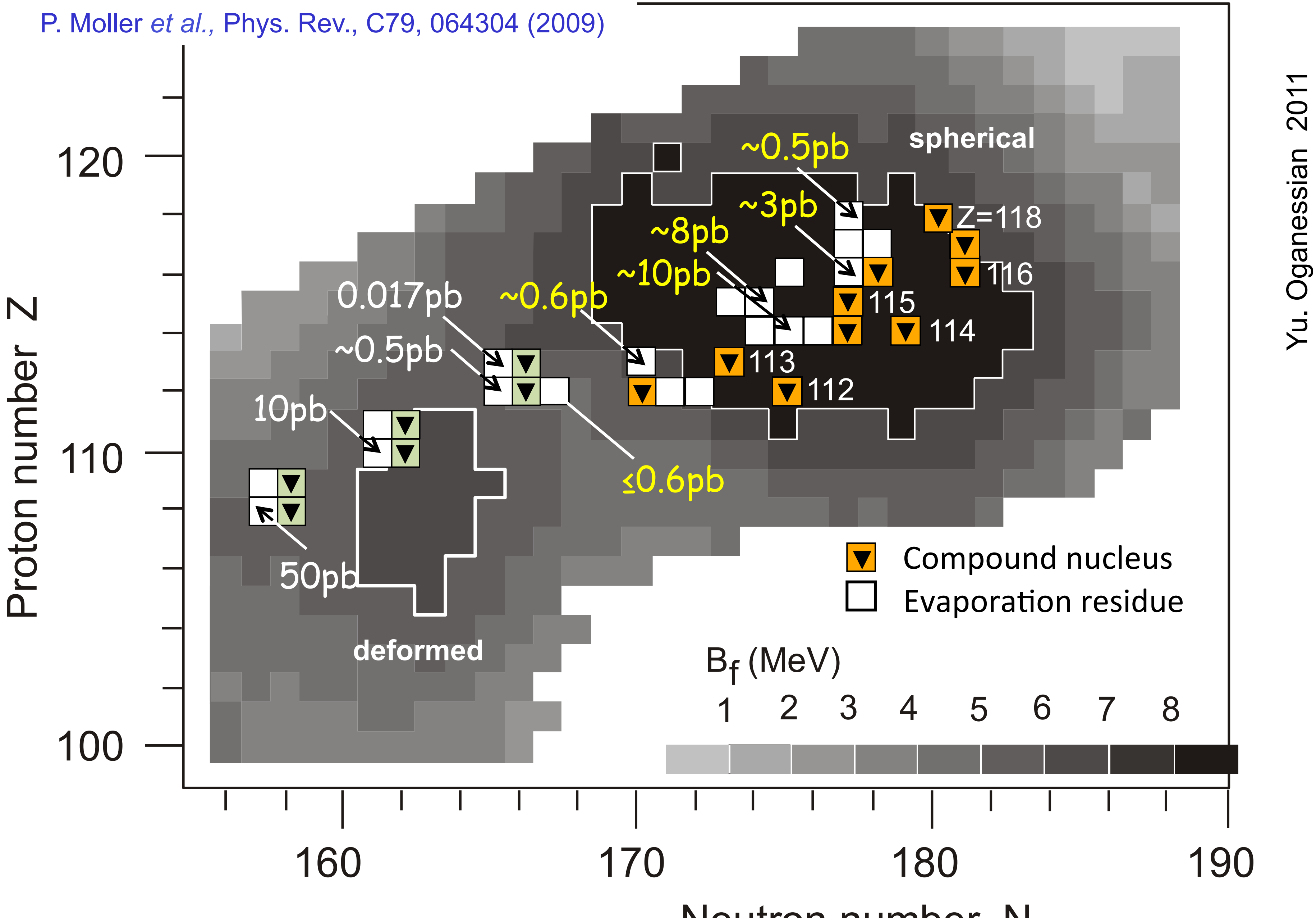
Yu. Oganessian 2011

Reactions of synthesis

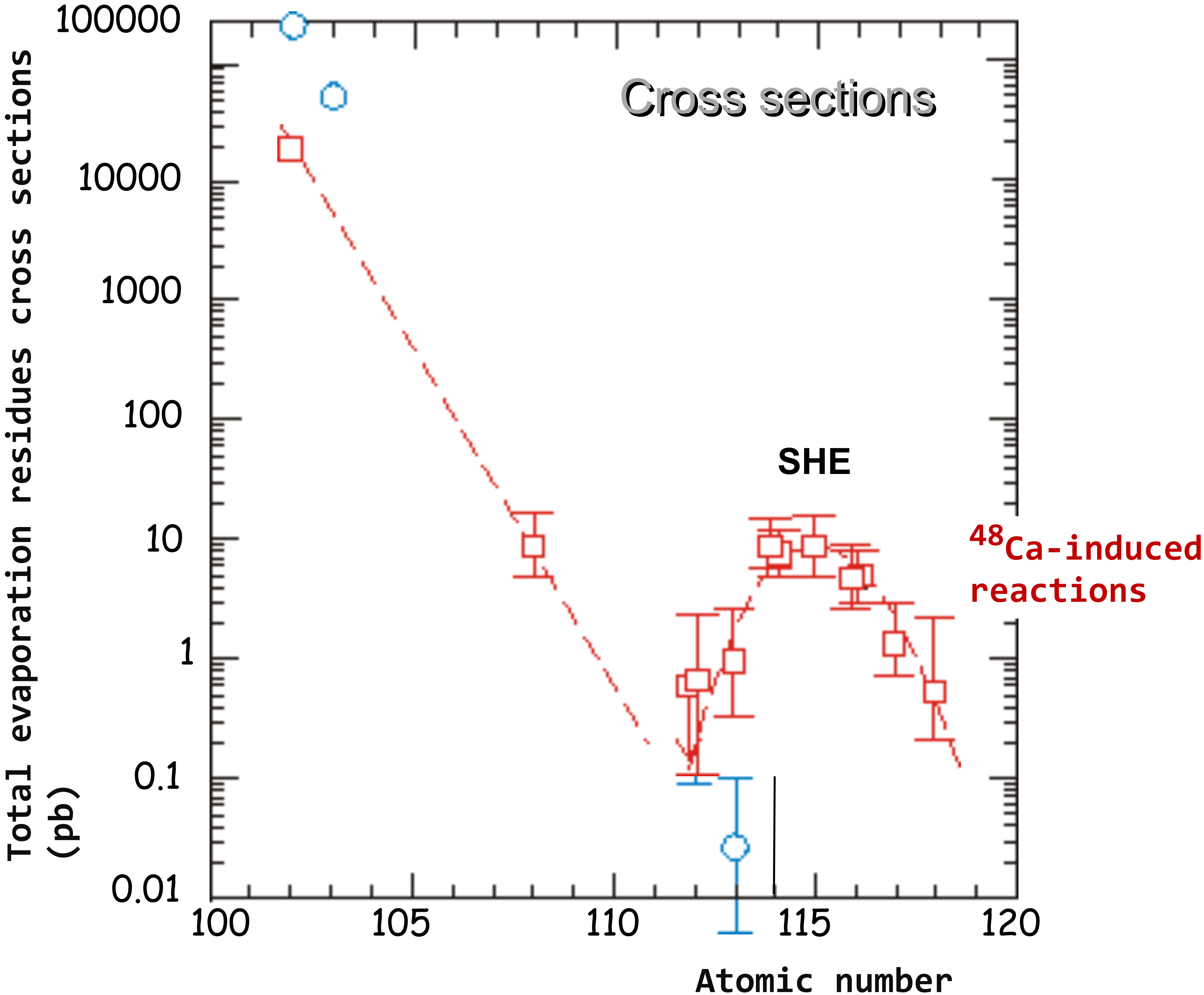
cold & hot fusion



No
Cold fusion
Hs
114
Total evaporation residues cross section (pb)
Coulomb repulsion
48Ca-induced reactions
No
Hs
114
K. Siwek - Wilczynska et al. (2011)
Total evaporation residues cross section (pb)
Coulomb repulsion
M. Kowal et al. (2010)
Atomic number
Atomic number



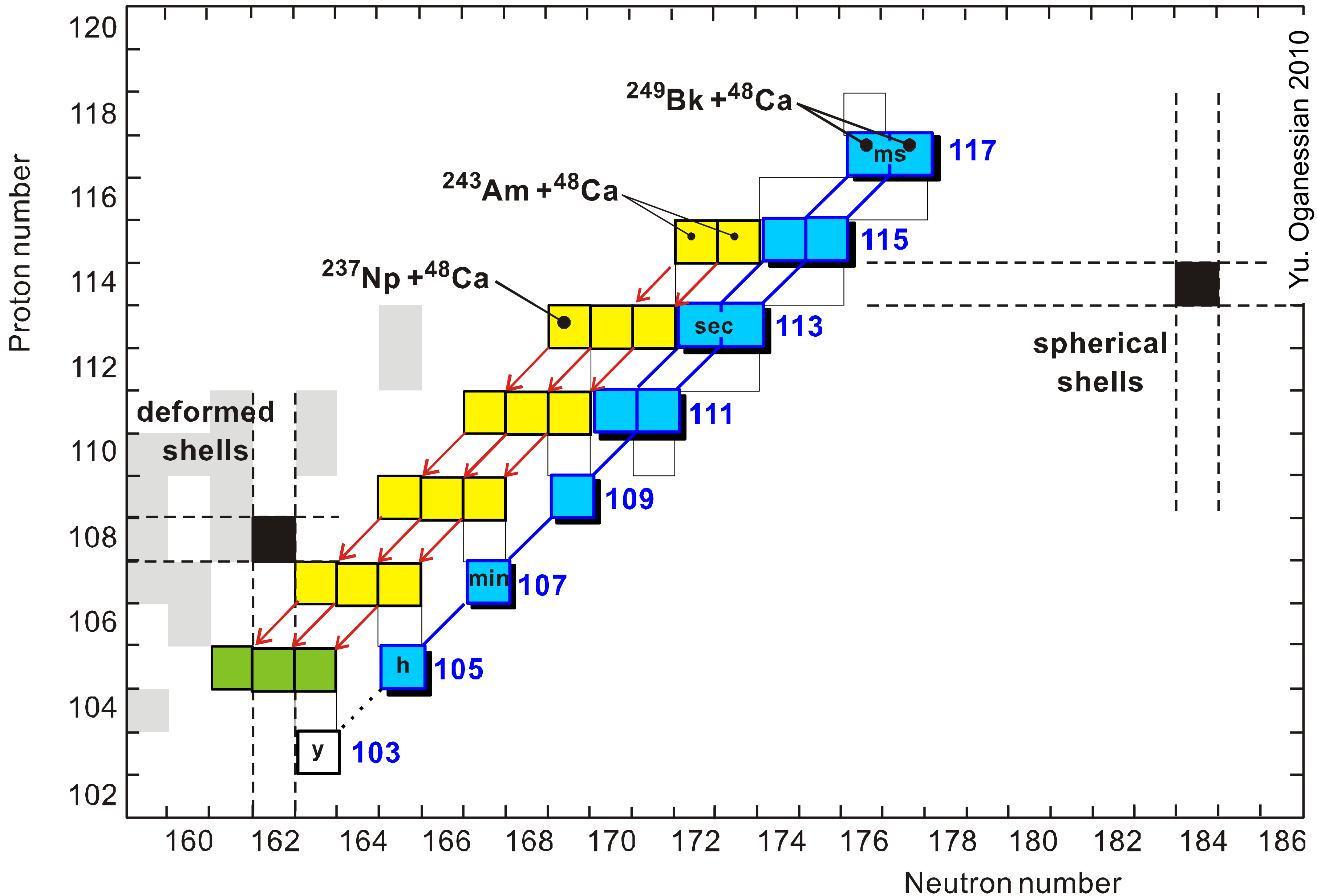
Yuri Oganessian. “Synthesis of SH-nuclei” FUSHE 2012, May14, 2012, Weilrod, Germany



Yu. Oganessian 2012

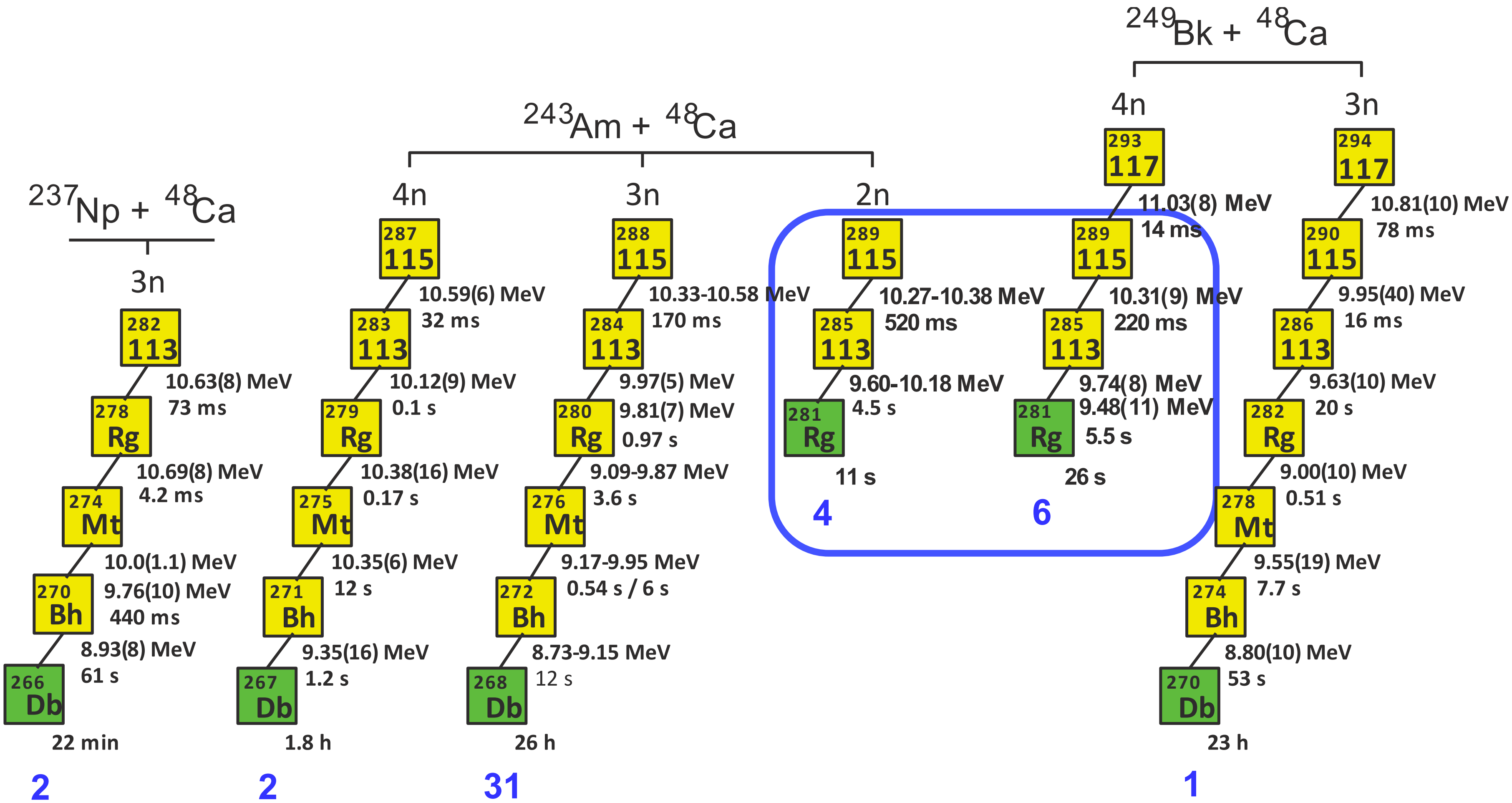
Current experiments 2012-2013

Z = 113, 115 and 117

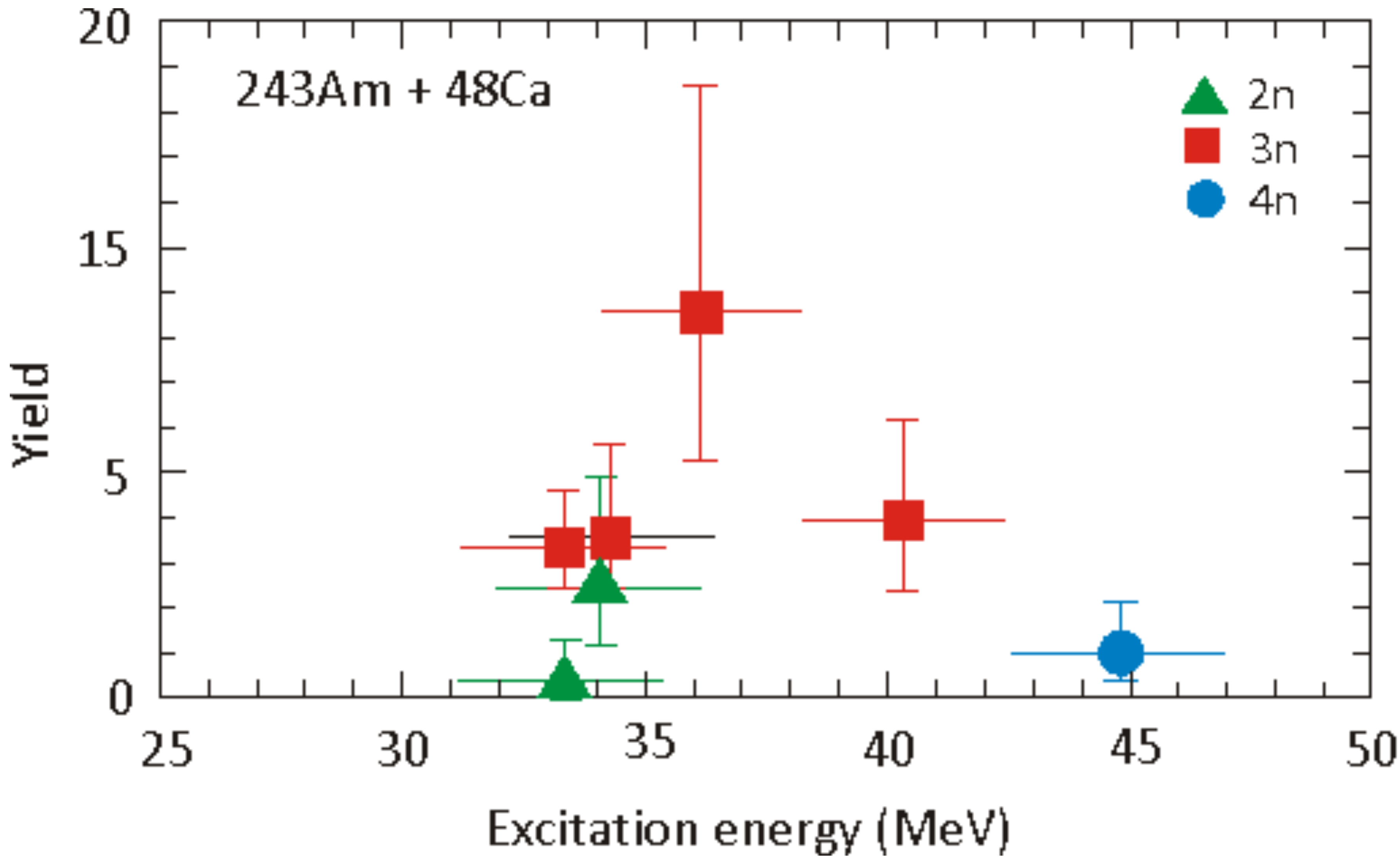


Yu. Oganessian. Synthesis of Element 117. April 14, 2010, Dubna

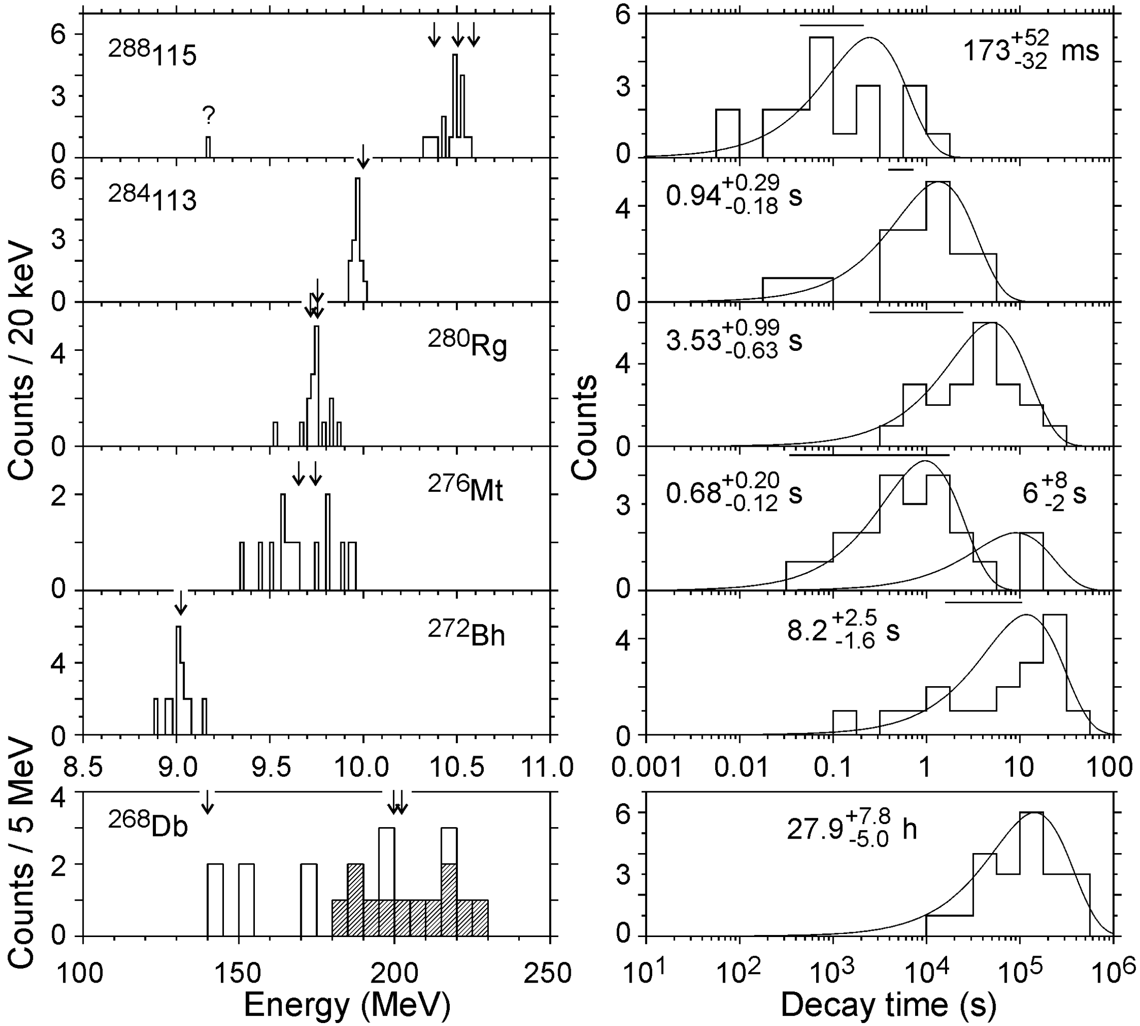
odd Z nuclei

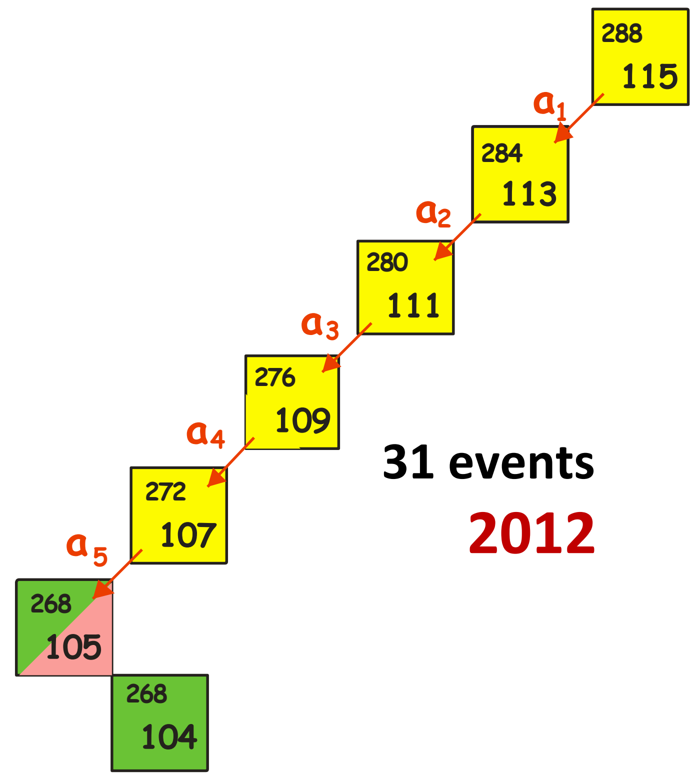


number of the detected chains


243Am + 48Ca
2n
3n
4n
Yield
Excitation energy (MeV)
0
5
15
20
25
30
35
40
45
50

Reaction: $^{243}Am + ^{48}Ca \rightarrow 3n +$



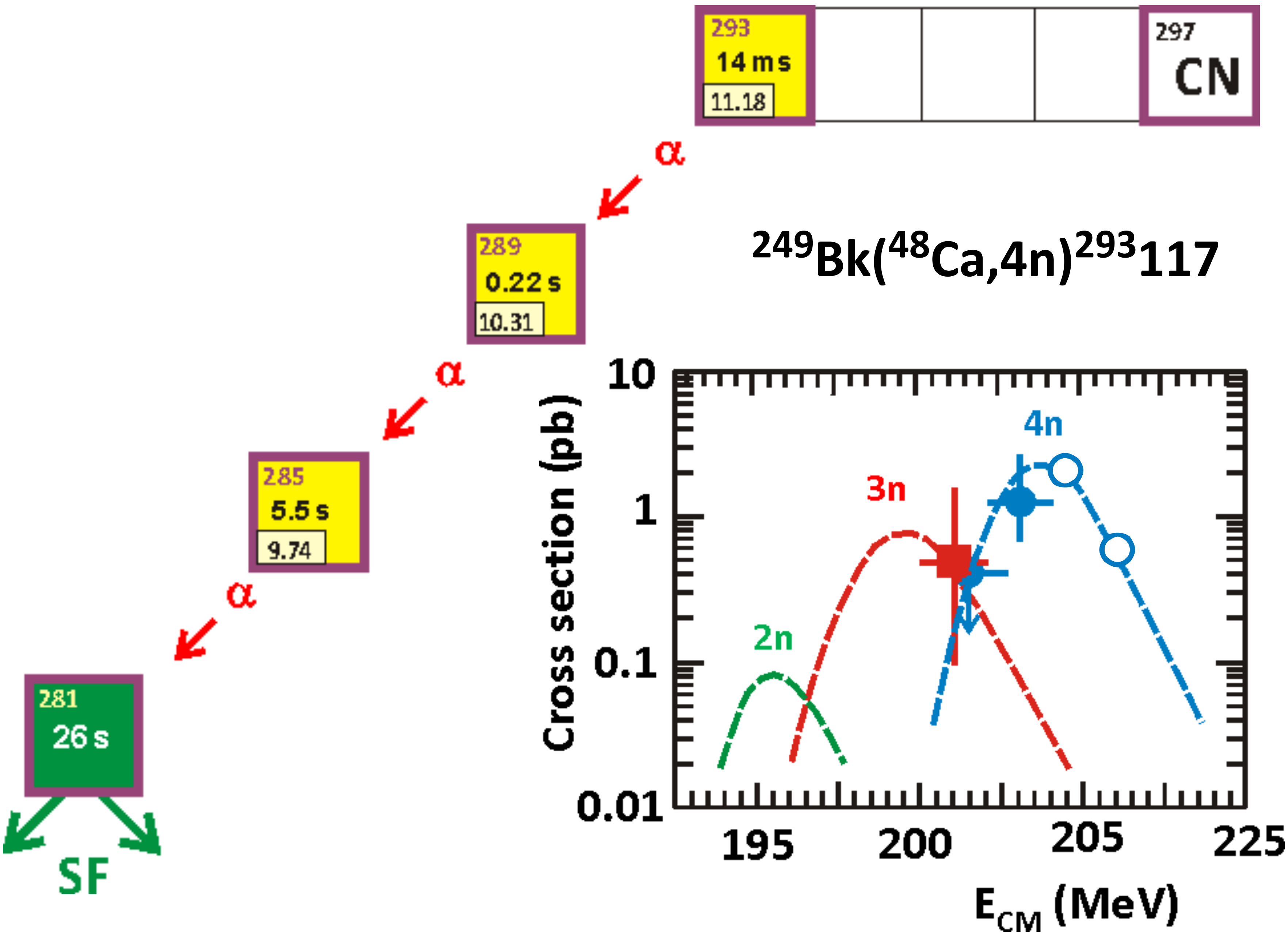


31 events

2012

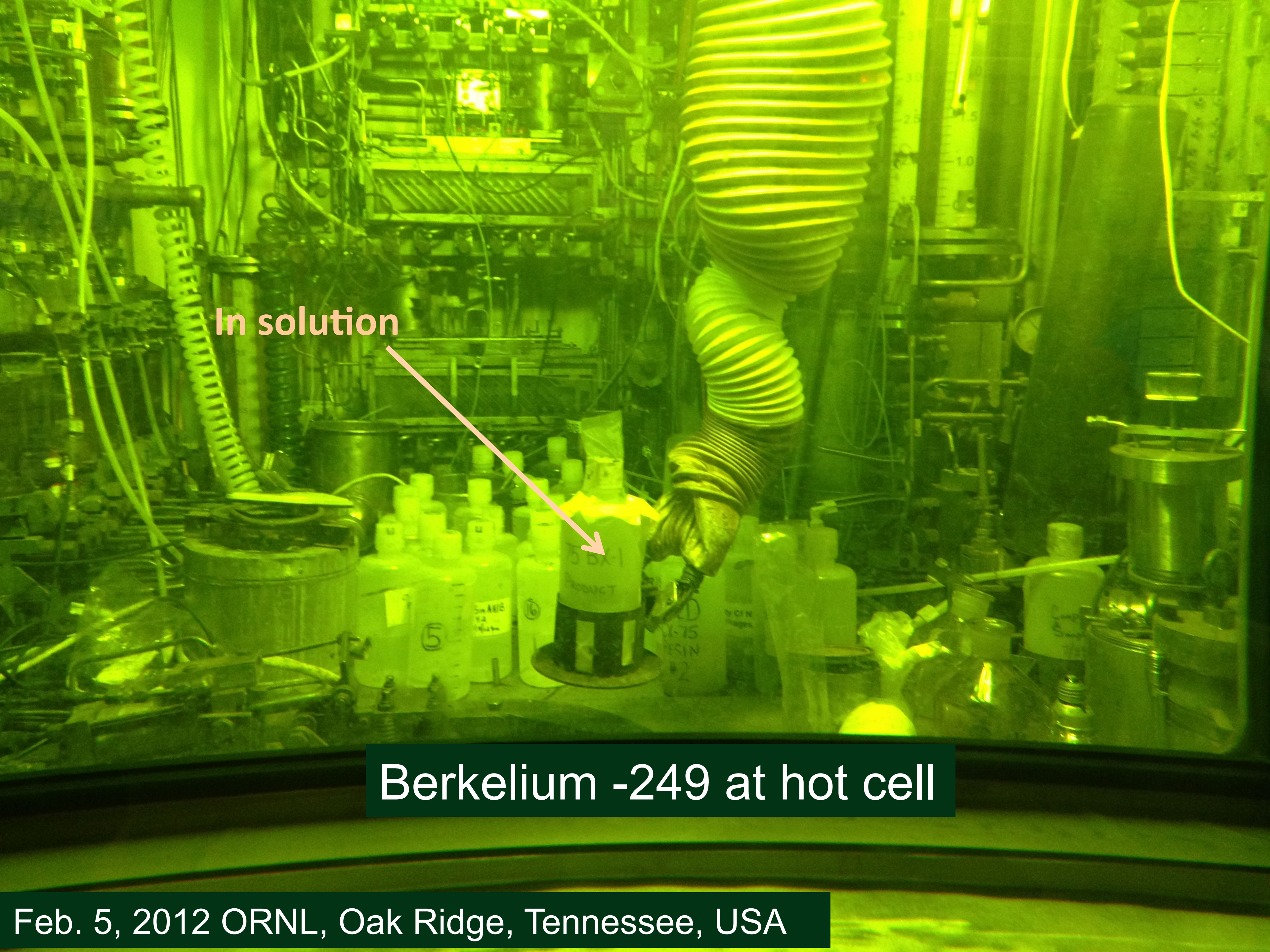
Yuri Oganessian. "Synthesis of SH-nuclei" FUSHE 2012, May14, 2012, Weilrod, Germany

$^{249}Bk(^{48}Ca,4n)^{293}117$



^{249}Bk-target

second round


In solution
Berkelium -249 at hot cell
Feb. 5, 2012 ORNL, Oak Ridge, Tennessee, USA

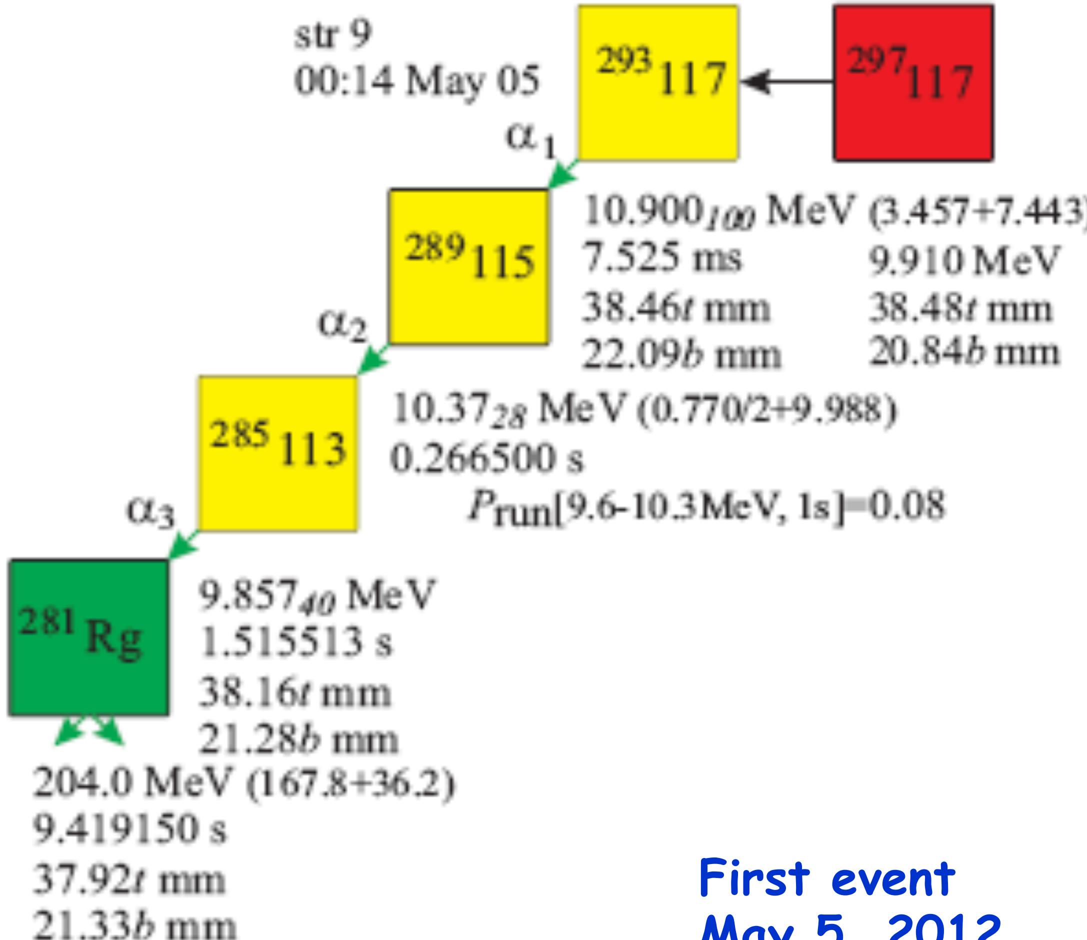
T

ω = 170(

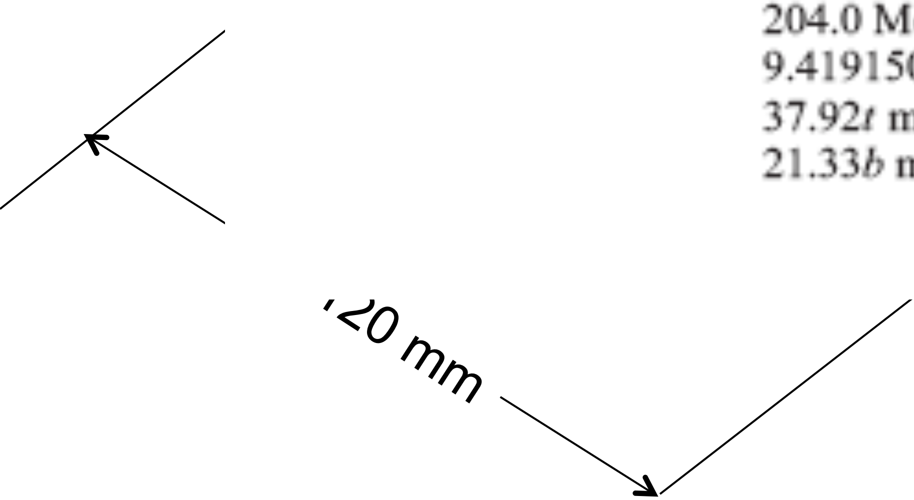
)2

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

E^*=39. MeV

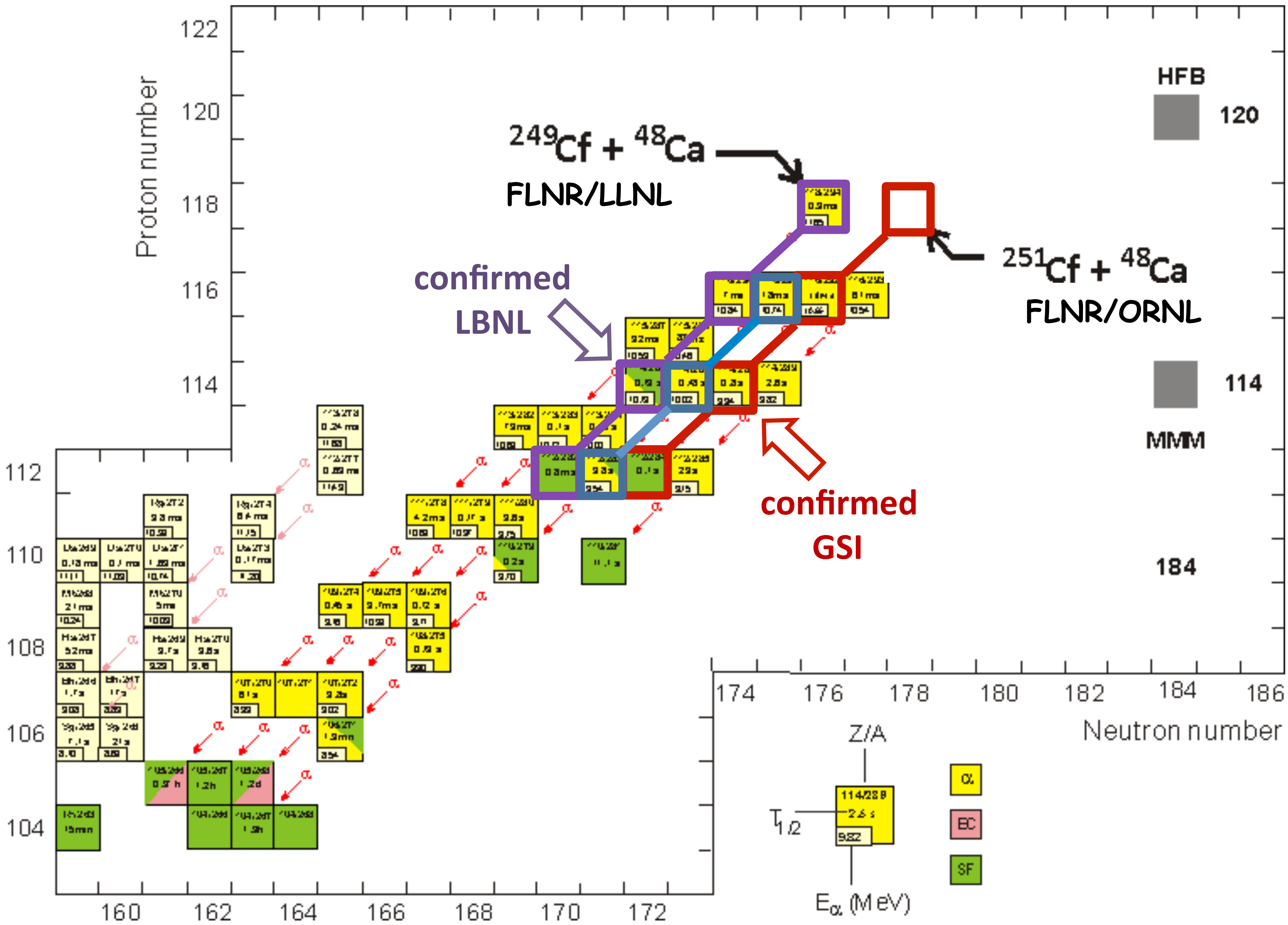


First event
May 5, 2012



target-making
April 20, 2012

$Z = 118$

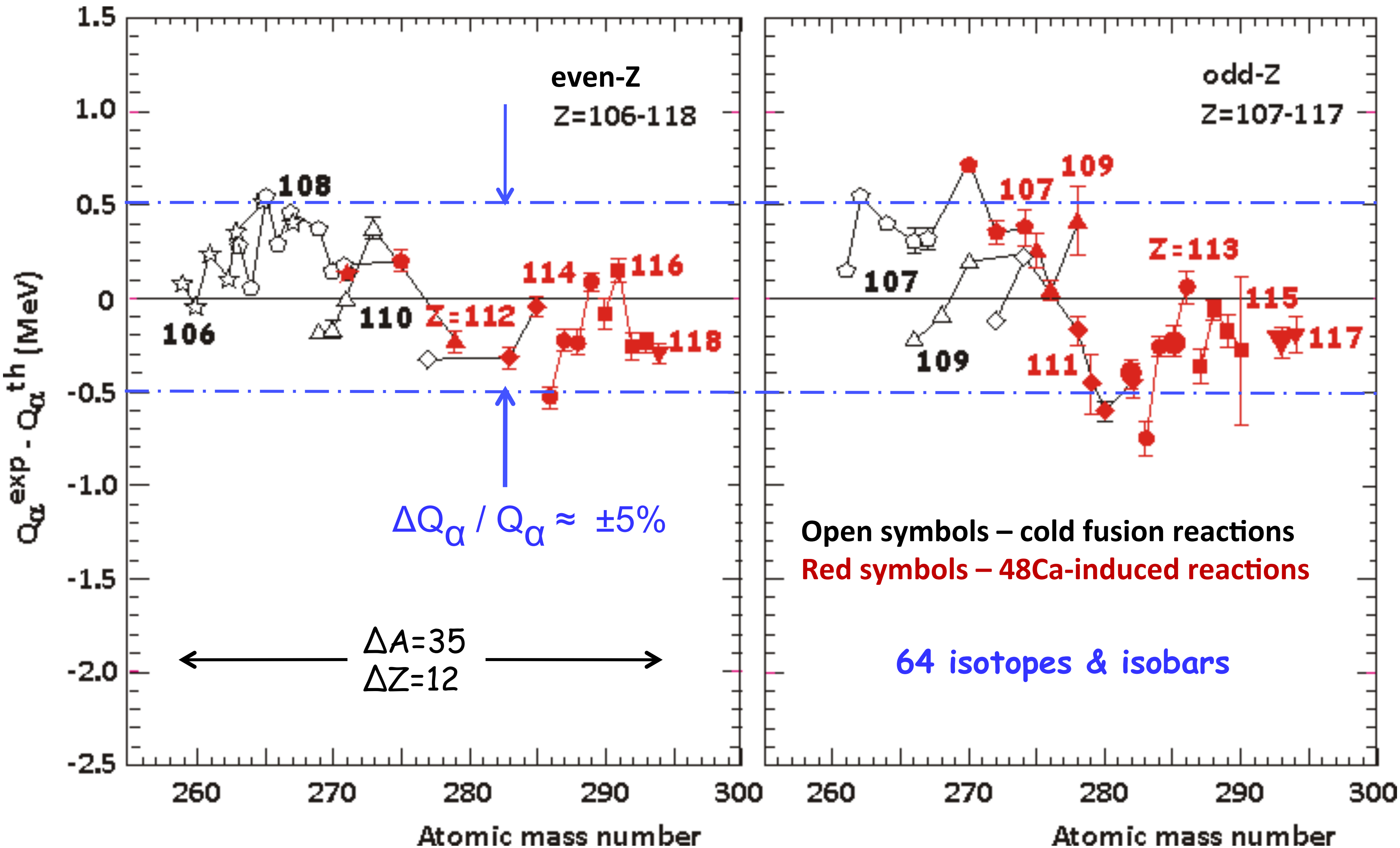


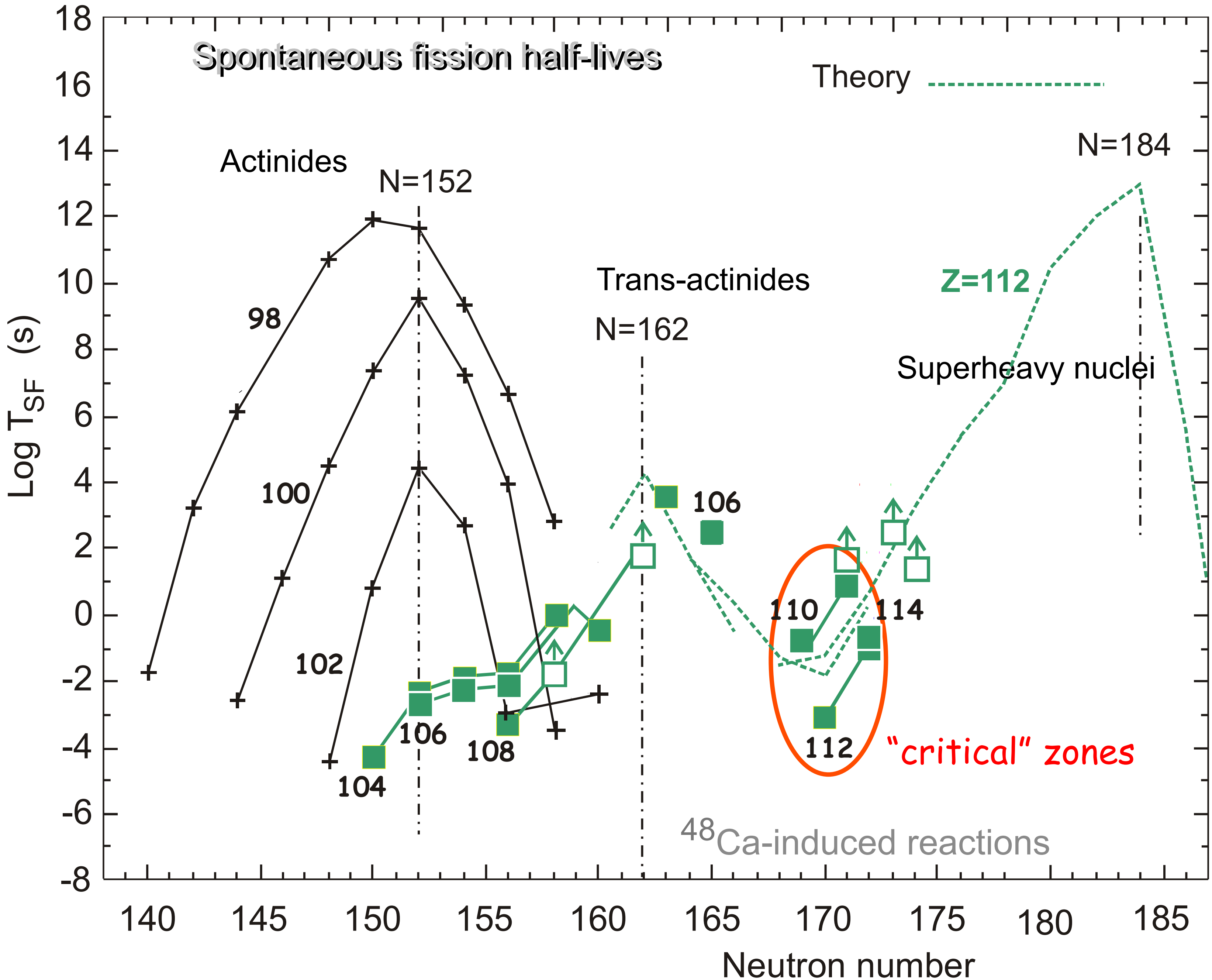
$^{249}Cf + ^{48}Ca$
FLNR/LLNL
$^{251}Cf + ^{48}Ca$
FLNR/ORNL
confirmed
LBNL
confirmed
GSI
HFB
120
114
MMM
184
Proton number
Neutron number
Z/A
114/288
2.6 s
$T_{1/2}$
9.82
E_α (MeV)
α
EC
SF

Decay properties of SH-nuclei

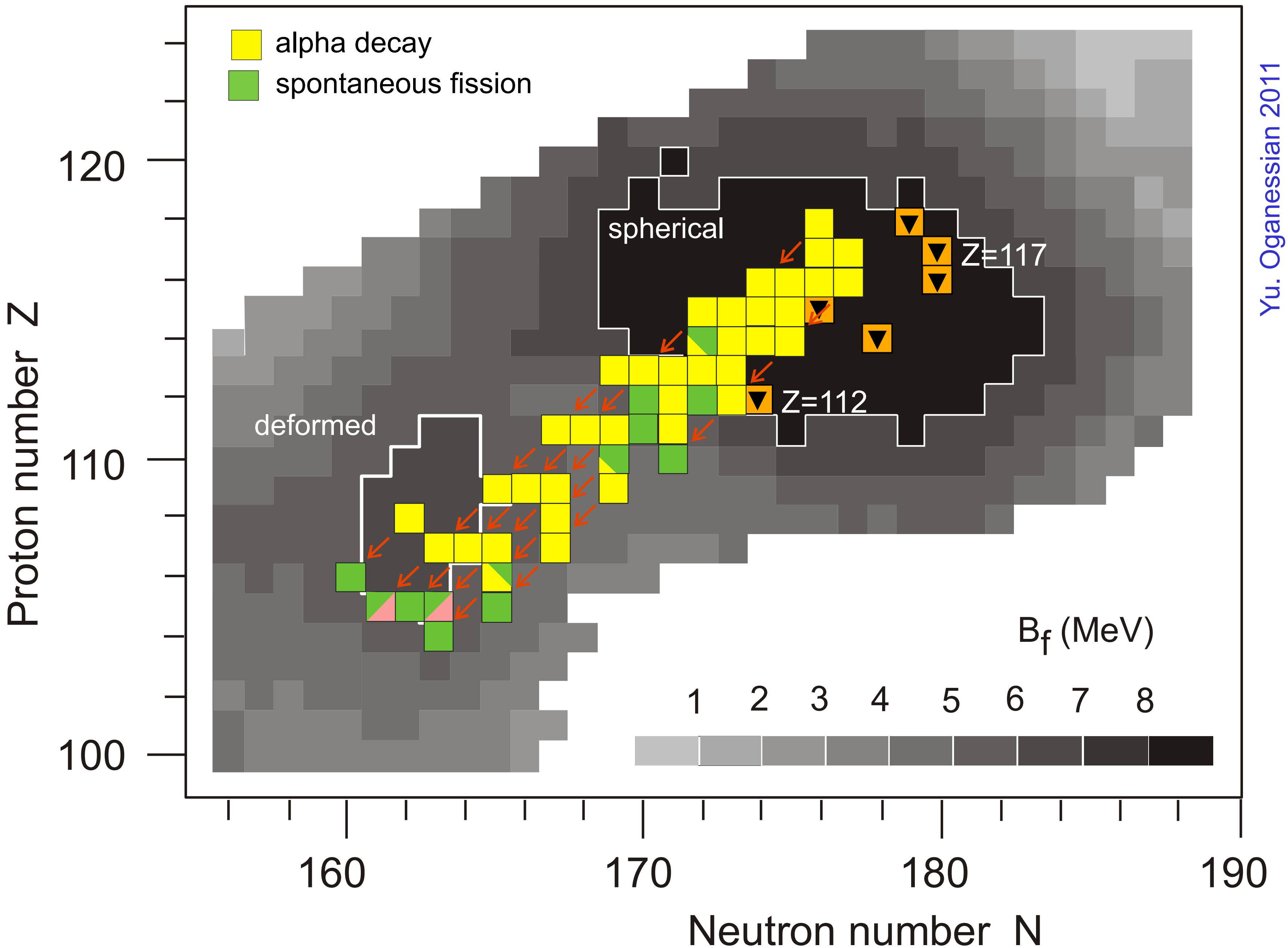
Alpha decay energy of the heaviest nuclei

Theory and experiment

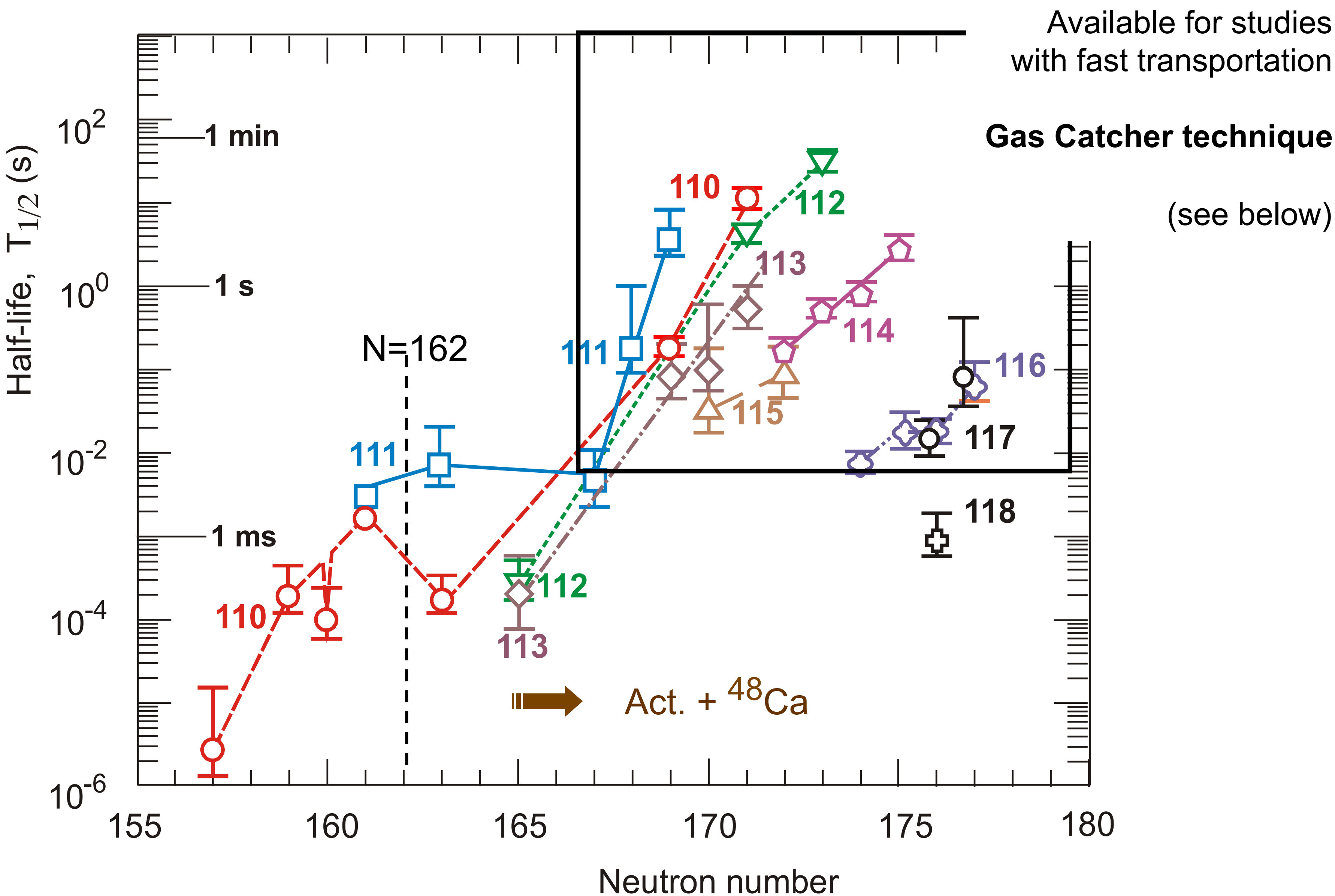




Spontaneous fission half-lives
Theory
Actinides
N=152
N=162
N=184
Trans-actinides
Superheavy nuclei
Z=112
98
100
102
104
106
108
110
112
114
"critical" zones
48Ca-induced reactions
Log T_{SF} (s)
Neutron number



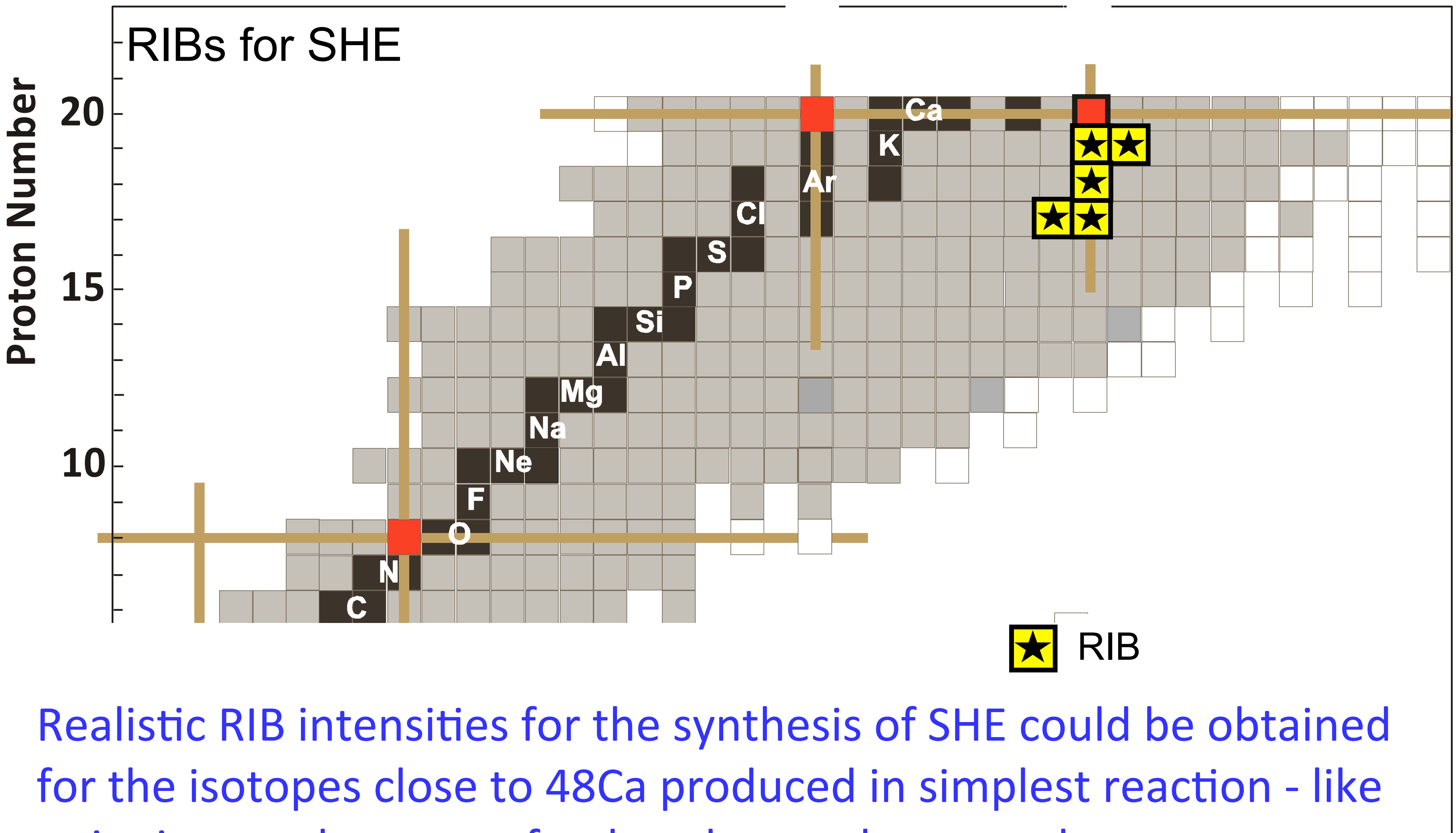
Yuri Oganessian. “Synthesis of SH-nuclei” FUSHE 2012, May14, 2012, Weilrod, Germany



Yuri Oganessian. “Synthesis of SH-nuclei” FUSHE 2012, May14, 2012, Weilrod, Germany

Towards closed shell N=184

Synthesis SHE with RIB

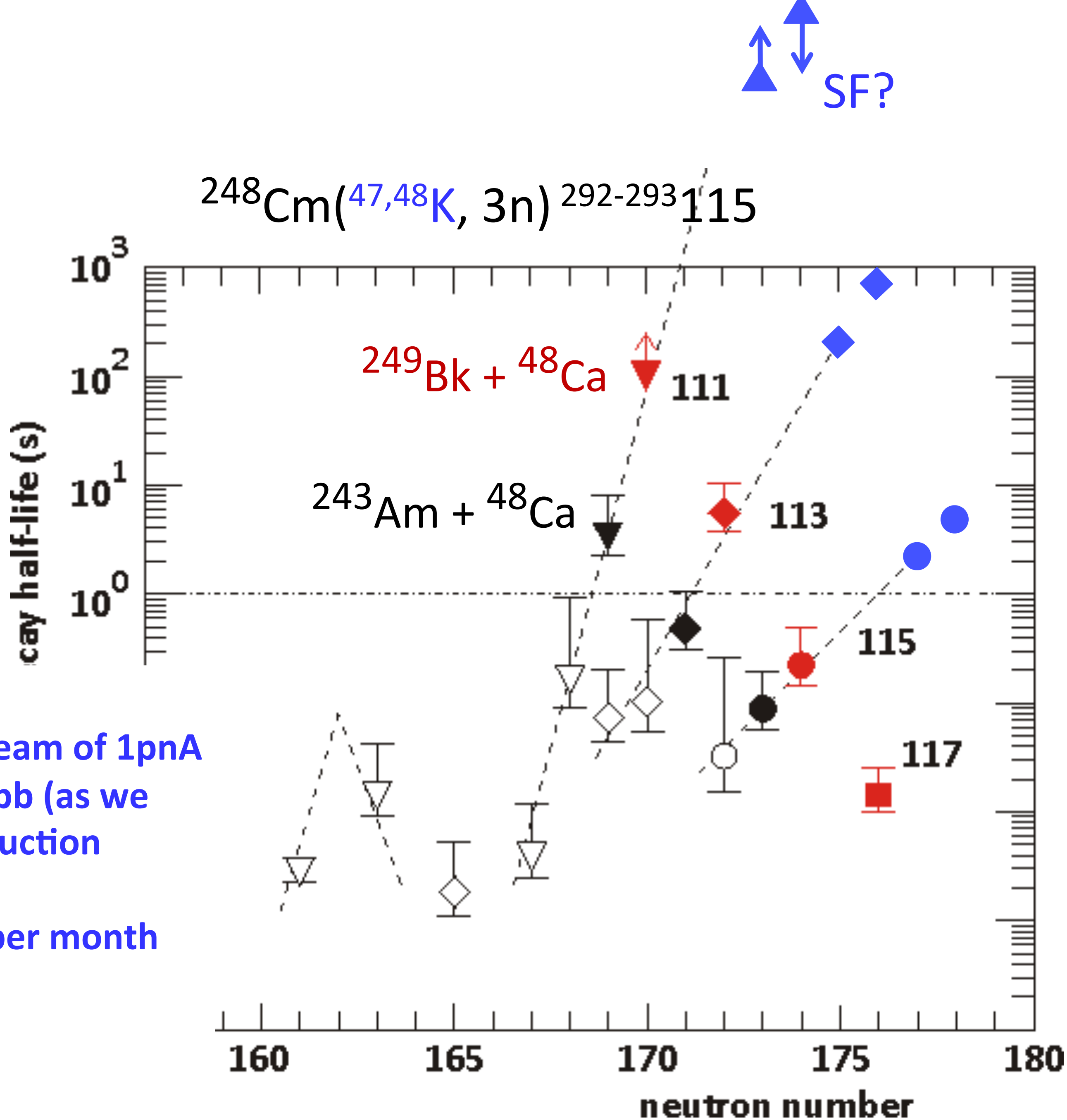


Realistic RIB intensities for the synthesis of SHE could be obtained for the isotopes close to 48Ca produced in simplest reaction - like stripping, nucleon transfer, knock-out, charge exchange etc.

an example:

One proton stripping reaction:
$^{48}Ca \rightarrow ^{47}K$ (17,5s)
or

Charge exchange reaction:
$^{48}Ca \rightarrow ^{48}K$ (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

Yuri Oganessian. “Synthesis of SH-nuclei” FUSHE 2012, May14, 2012, Weilrod, Germany

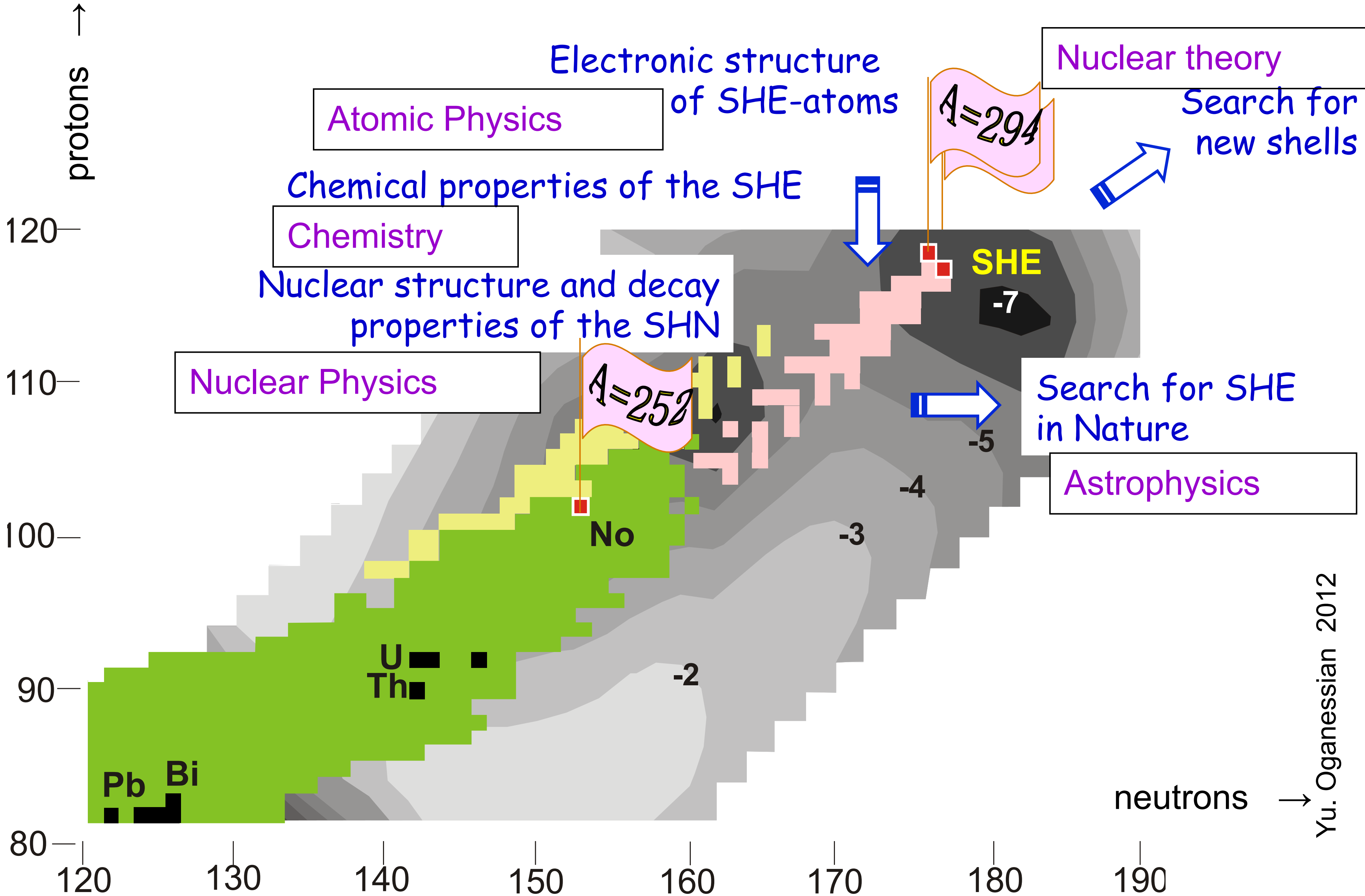
With Z >40% larger than that of Bi, the heaviest stable element, we see an impressive extension in nuclear survival.

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



Yuri Oganessian. "Synthesis of SH-nuclei" FUSHE 2012, May14, 2012, Weilrod, Germany

I would like to stop here and make a short conclusion:

- we have received an evidence
  that superheavy elements exist

- moreover we know how to produce them

- we know also roughly their decay properties

All this allows us to consider different approaches

to study the detailed properties of SHE

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

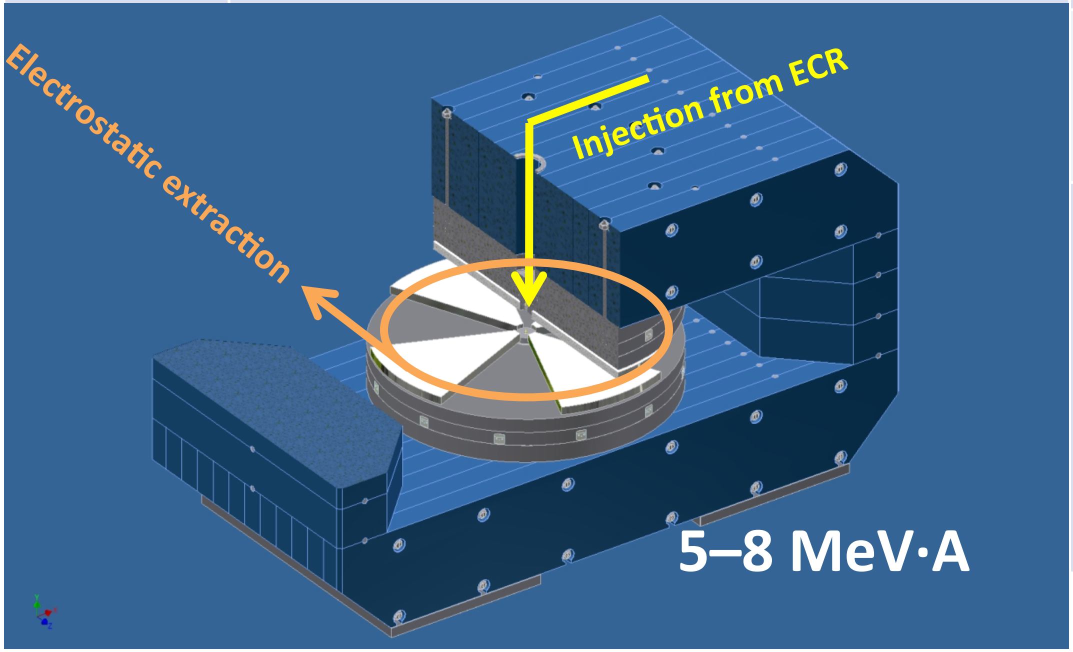
So I shall talk more about these opportunities and on our plans for the near and distant future.

Production

today: $4.5\cdot10^{19}$ with factory: $1.3\cdot10^{21}$

factor: 30

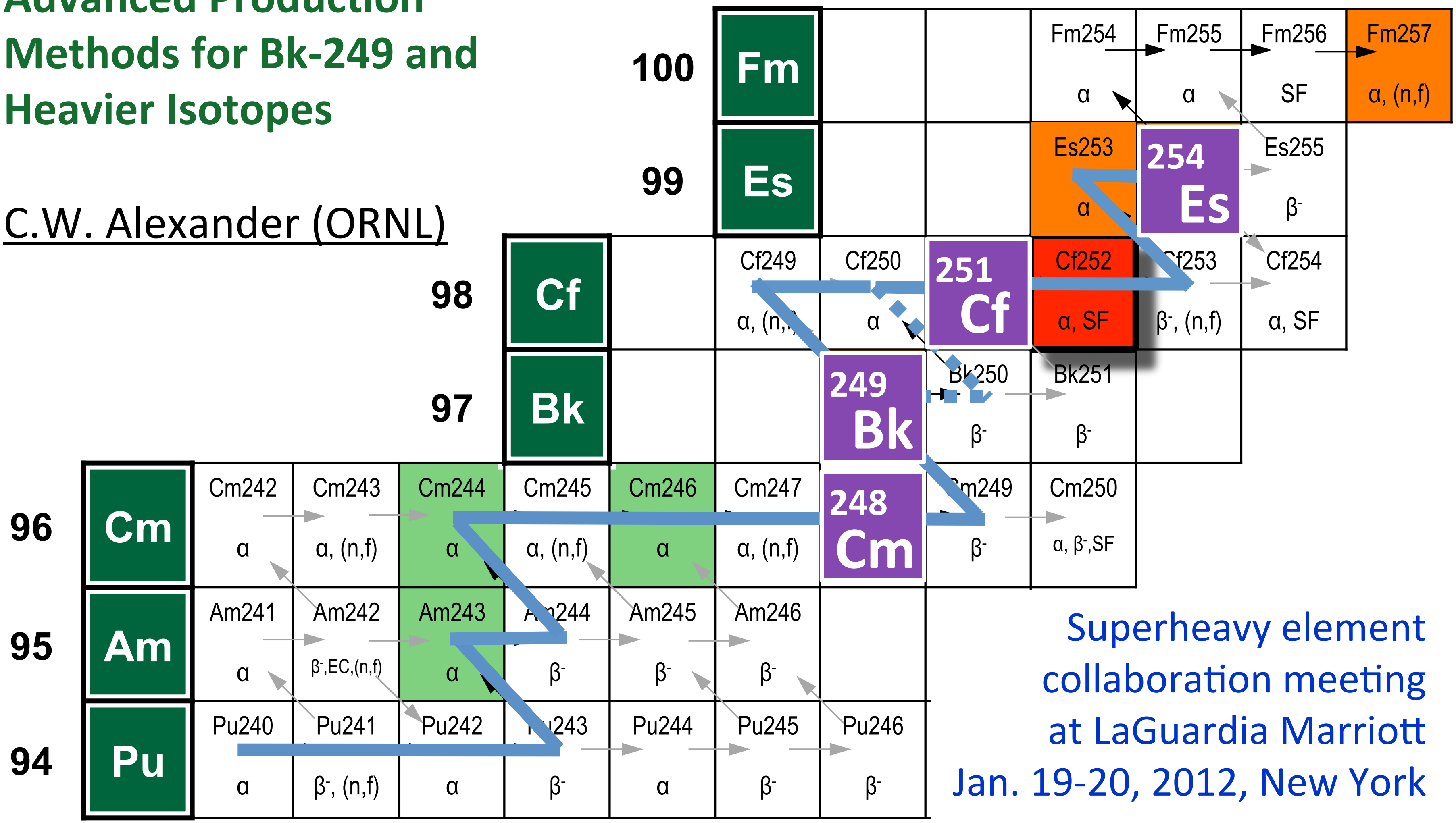
Increase a beam dose			
it requires to Increase:	**beam intensity**	and	**beam time**
	New accelerator		**SHE-Factory**
			~ 7000 h/year
			new laboratory



Transuranium Nuclide Production Paths

Advanced Production Methods for Bk-249 and Heavier Isotopes

C.W. Alexander (ORNL)



Superheavy element collaboration meeting at LaGuardia Marriott

Jan. 19-20, 2012, New York

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**

Along with the Bk-249 production the isotope **Cf-251: 8.77 mg** is also produced.

Enrichment of Cf-251 from the “old Cf-252 sources” using an electromagnetic separator at ORNL

Yu. Oganessian (FLNR) / J. Roberto (ORNL)

A new 10 mA Stable Electromagnetic Isotope Separator is operational at ORNL

Presented by **Brian J. Egle**
Super heavy element collaboration meeting
at LaGuardia Marriott
Jan. 19-20, 2012, New York


Kr separation, December 16, 2011

Prototype for a stable isotope enrichment facility comprised of multiple 100 mA devices

EMIS Design Parameters

$10.5 M

2014 - 2015

Parameter	Stable (current)	Actinide (goal)
Mass Range	20 to 208 amu	50 to 260 amu
Gas Efficiency	up to 10%	20 to 30%
Filament lifetime	20 to 40 hrs	> 100 hrs
Resolution	~500	~750
Feed rate [mg/hr]		5 mg/hr ^{all}Cf
Collector [mA]	10 mA	0.5 to 1 mA or greater
^{251}Cf separation		**1 mg/h**

Yuri Oganessian. "Synthesis of SH-nuclei" FUSHE 2012, May14, 2012, Weilrod, Germany

Es-254 Production

- LEAP was based on a complex series of unfiltered and filtered irradiations of **1.0 g of Cf-252**
- Predicted yields of Es-254, at reactor discharge, were 80 micrograms
- As a result, the useable yield was estimated to be **40 µg of Es-254** (Es-253 has gone through over 10 half-lives)

Element 119 could be produced with projectile heavier than Ca-48!

Identification

- Decay into known daughters
- X-ray technique
- Collinear laser spectroscopy
- Mass measurement*
- Precise mass measurement (isotope / isobar separation)
- Chemistry

etc.

But for the specific CN-reaction:

- Excitation energies of the SH-compound nuclei are 35-50 MeV only,
- Maximum cross section of EVR's is reached close to the Coulomb barrier
- Cooling process takes place by emission of 3-5 neutrons
- Evaporation of charged particle (p, α, ..) is strongly suppressed …

The mass measurement of the recoiling nuclei or its daughters seems to be essential and sufficient for the identification of the new isotopes.

Gas catcher for SHE

Transmission for:

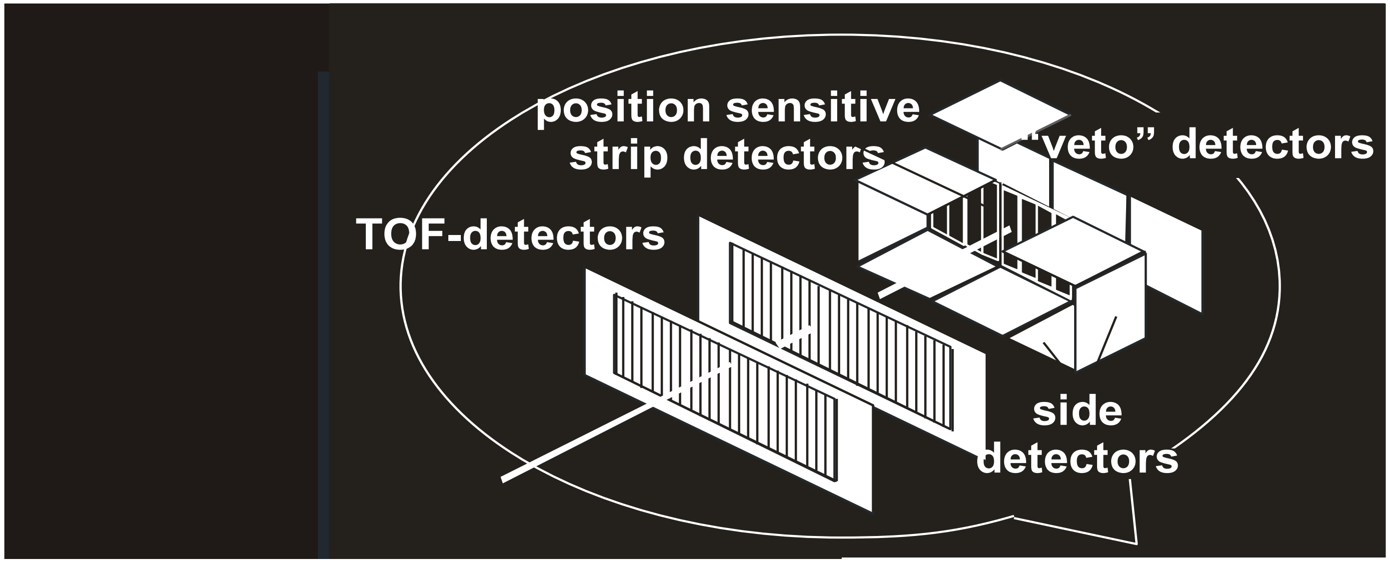
EVR 35-40%

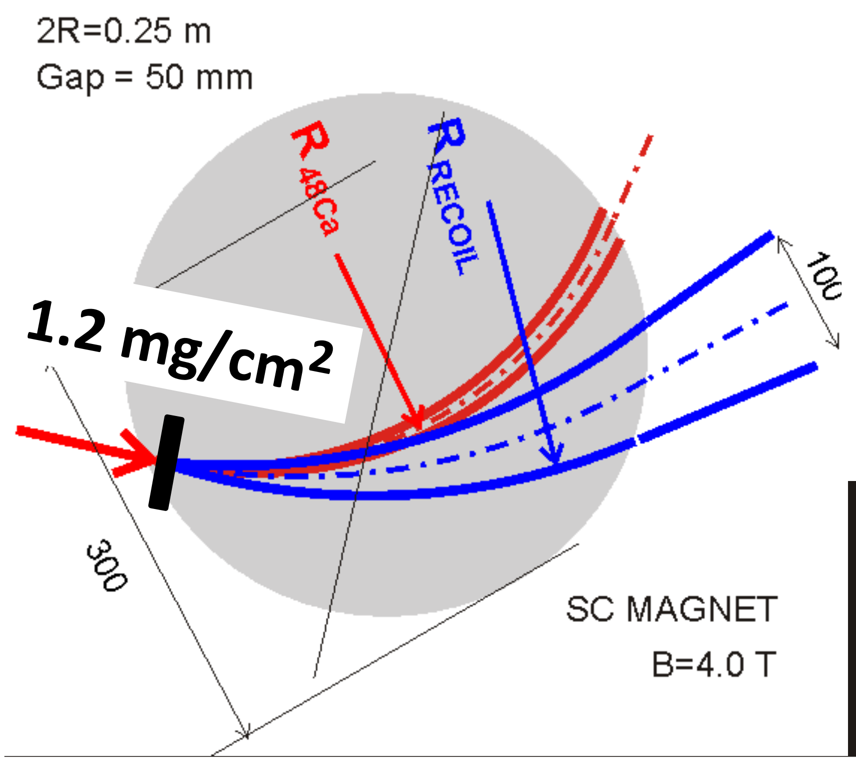
target-like

10^{-7} (1)

beam-like

10^{-17} (10^{-7})



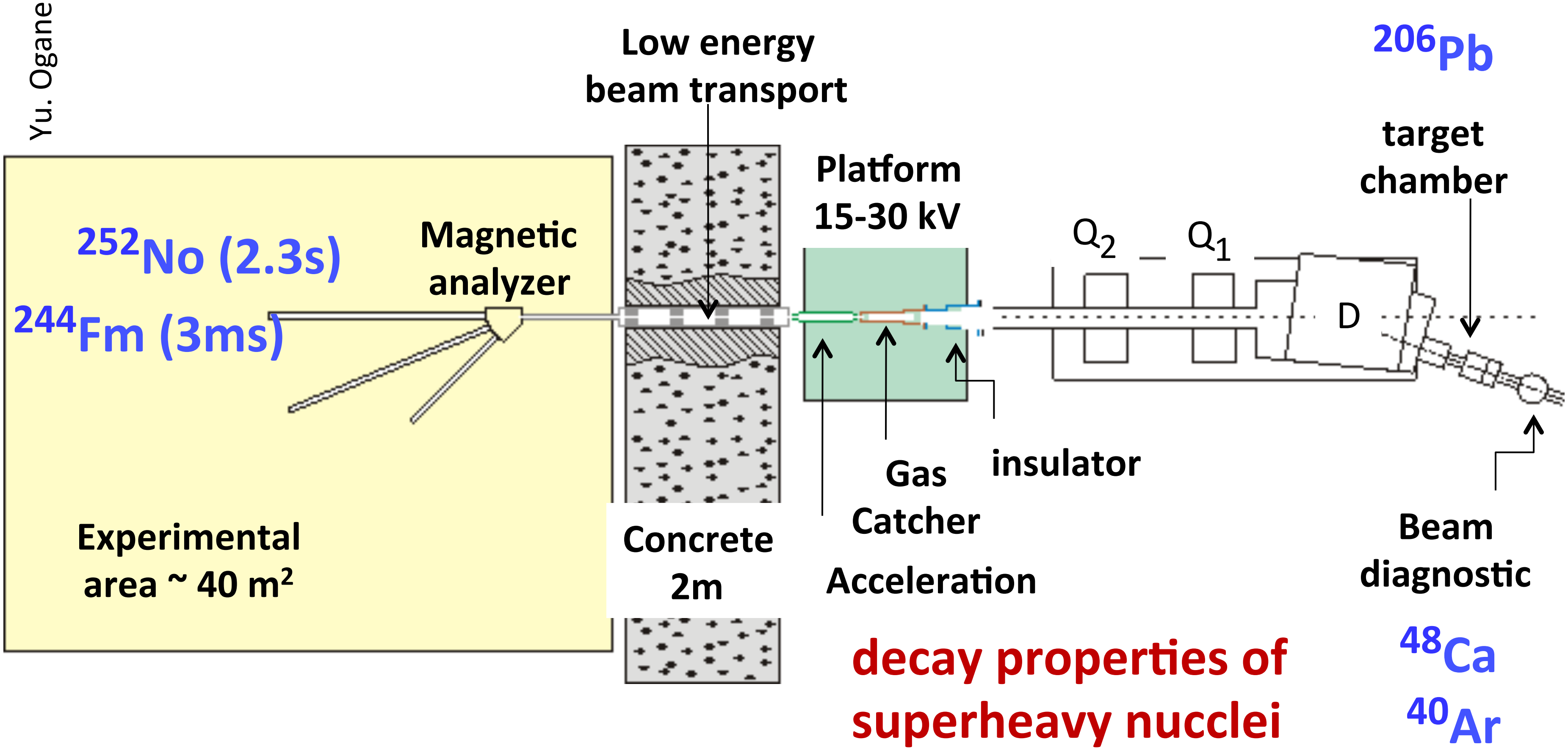


Gas Catcher

target
0.3 mg/cm²

Yu. Oganessian 2011

Gas Catcher at DGFRS (2012)



decay properties of superheavy nucclei

On line studies of SHE with Gas Catcher

SHE in Dubna

2012 – 2016

and after…

Gain factors for the production of Superheavy nuclei

Current experiments — Z=113, 115, 117 and 118 — 2.5pμA

2010	2011	2012	2013	2014	2015	2016	2017

U-400 & DGFRS — Z= 117 — 1

Experimental hall — independent work — 2.5-5.0

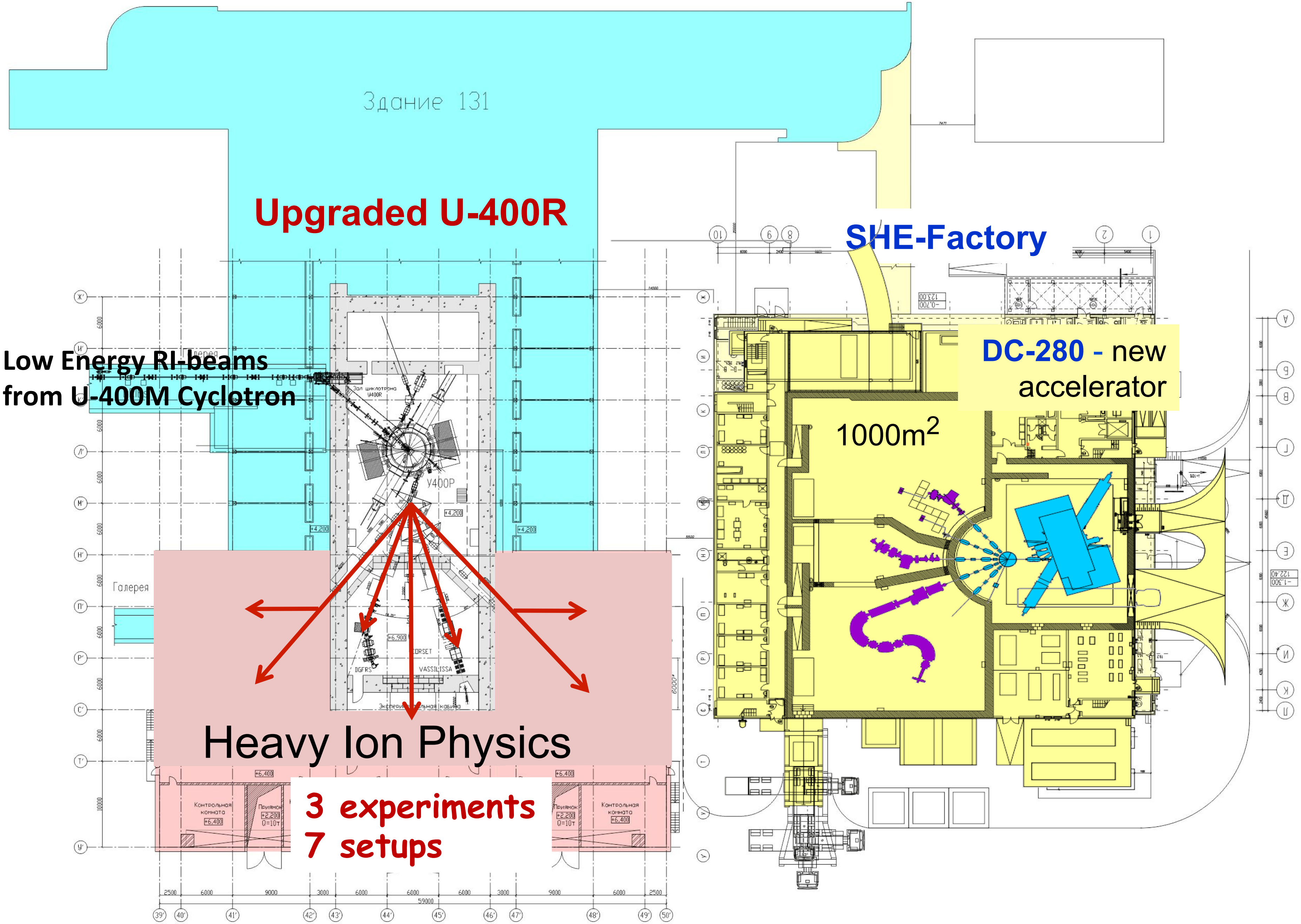
New type experimental facilities — SC separator + Gas catcher — 3.0-4.0

New Accelerator — 10-20 pμA — 15

Yuri Oganessian. "Synthesis of SH-nuclei" FUSHE 2012, May14, 2012, Weilrod, Germany

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**)	**3000 - 5000**
State of readiness	75%	In course of design

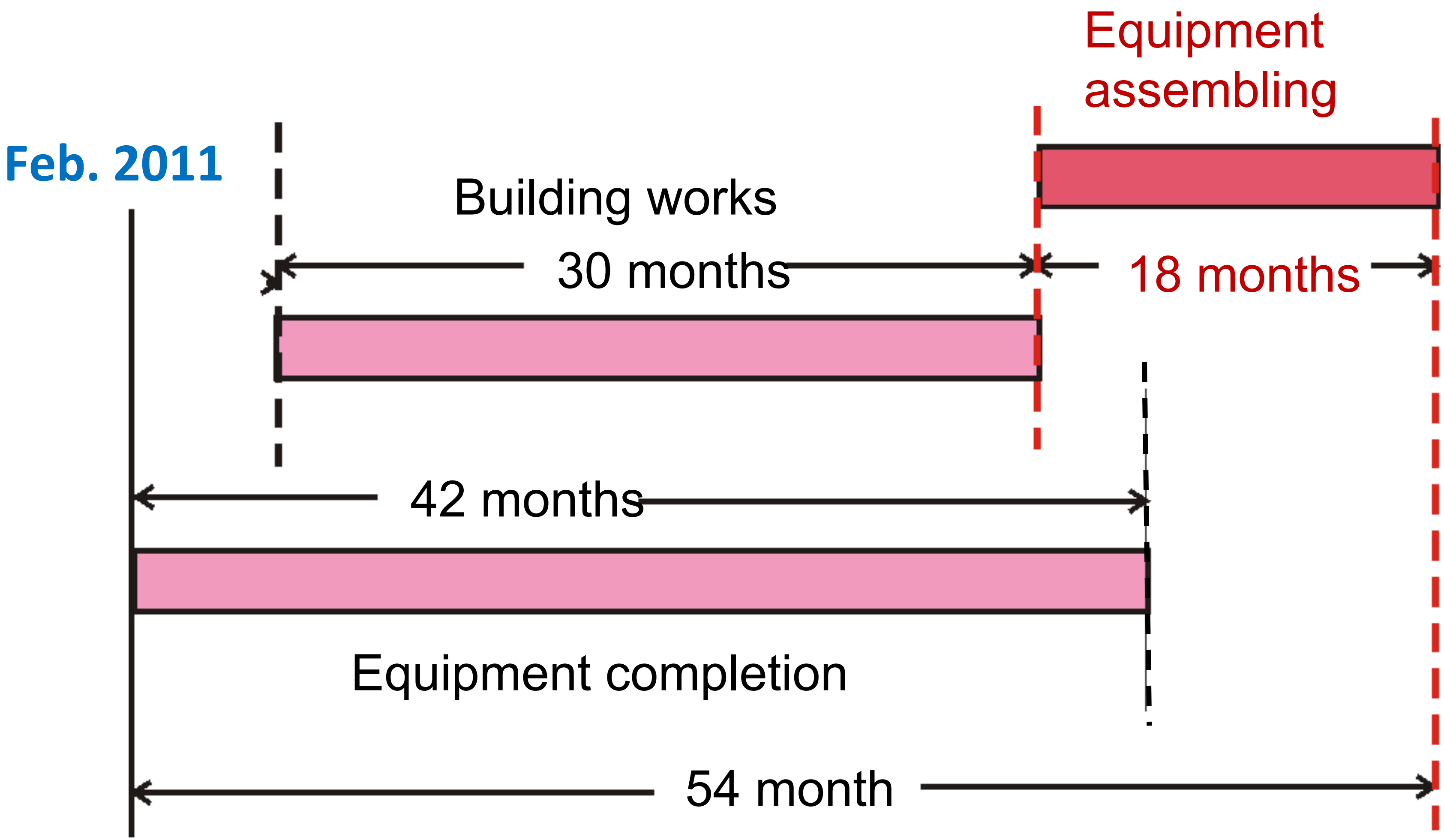


Yuri Oganessian. "Synthesis of SH-nuclei" FUSHE 2012, May14, 2012, Weilrod, Germany

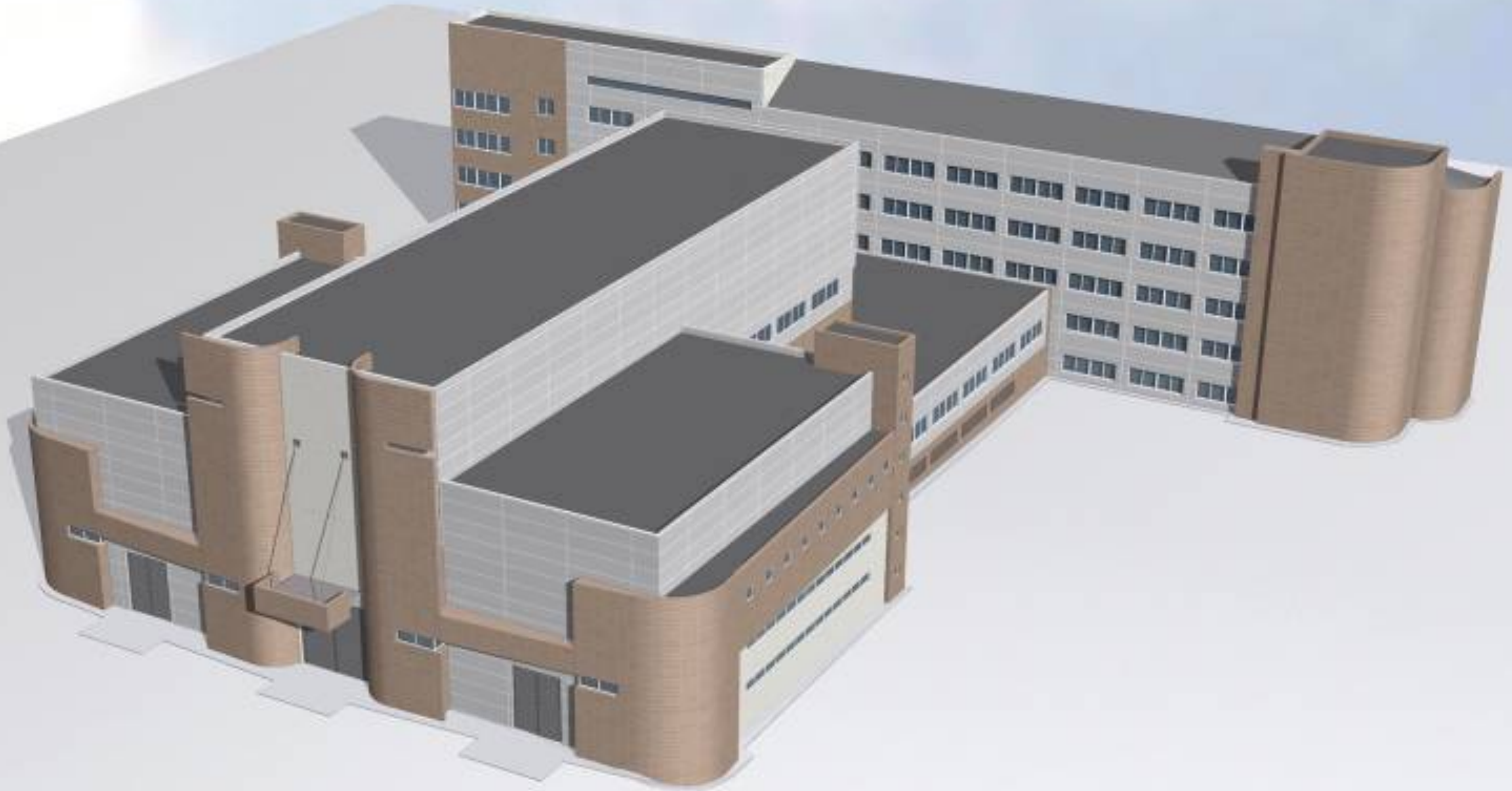
FLNR backside in January 2012

April 16, 2012

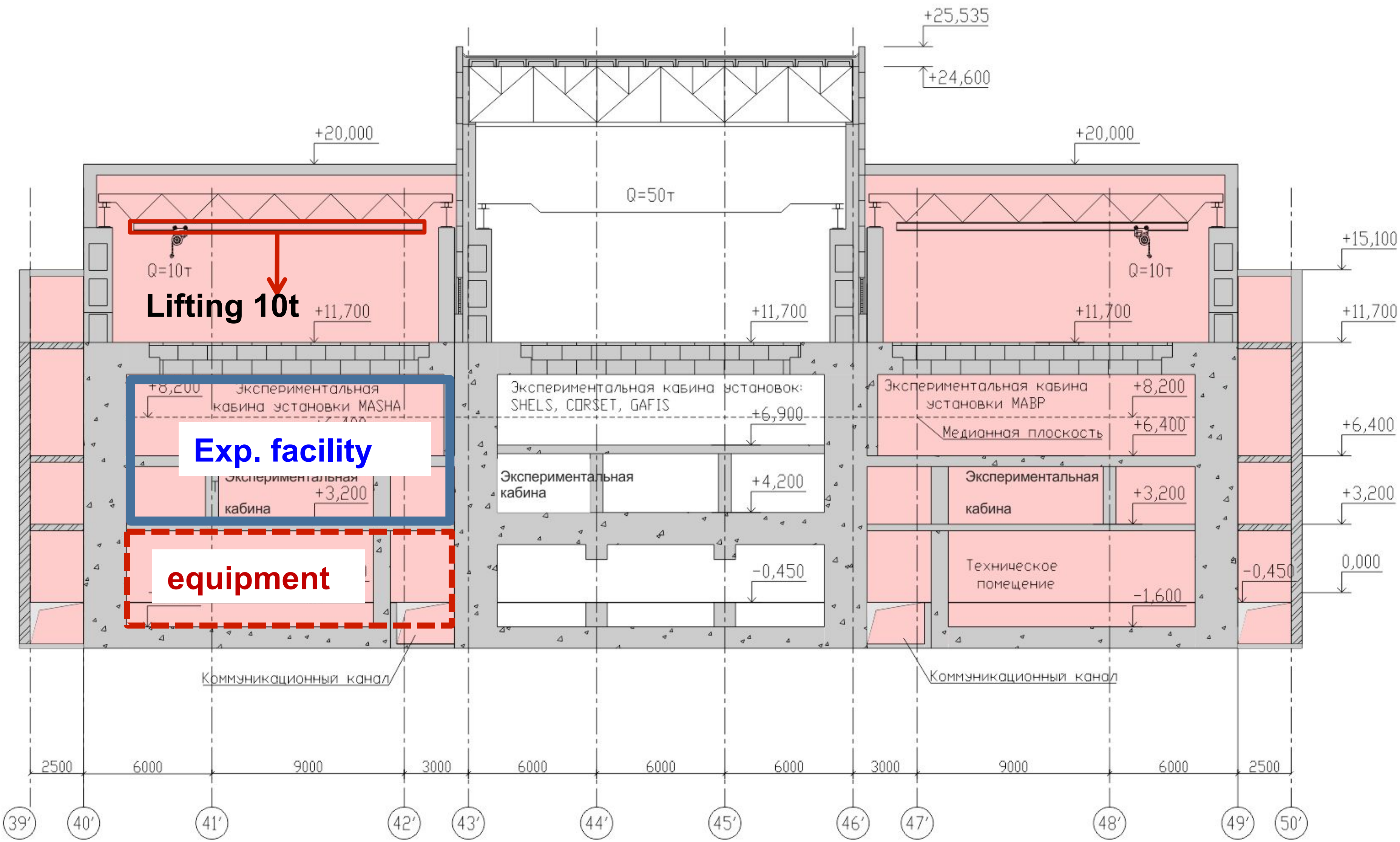
Schedule for SHE-Factory



Building 131 of FLNR (JINR) after renovation

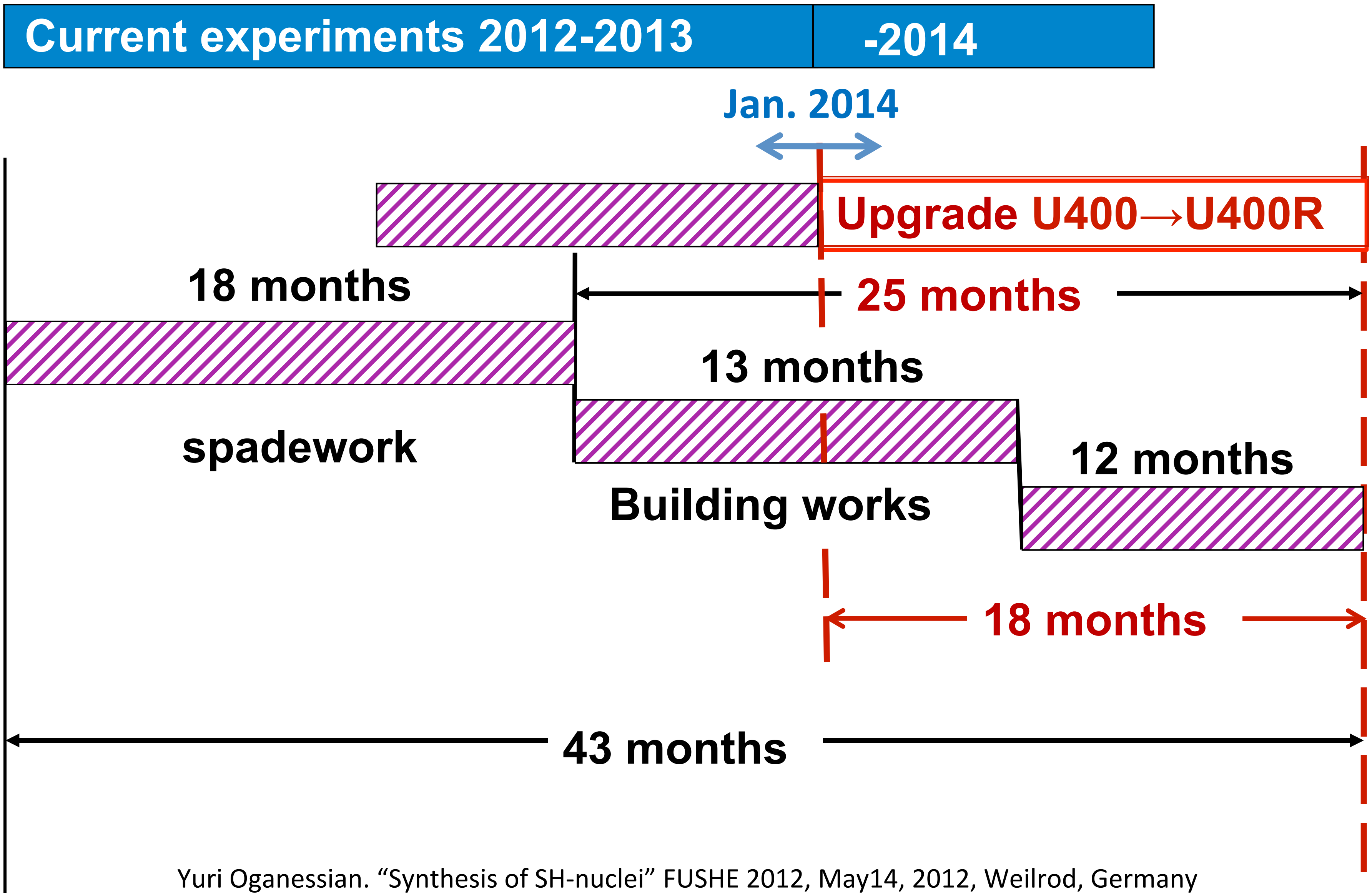


Cross section of the building 131 (FLND) after renovation

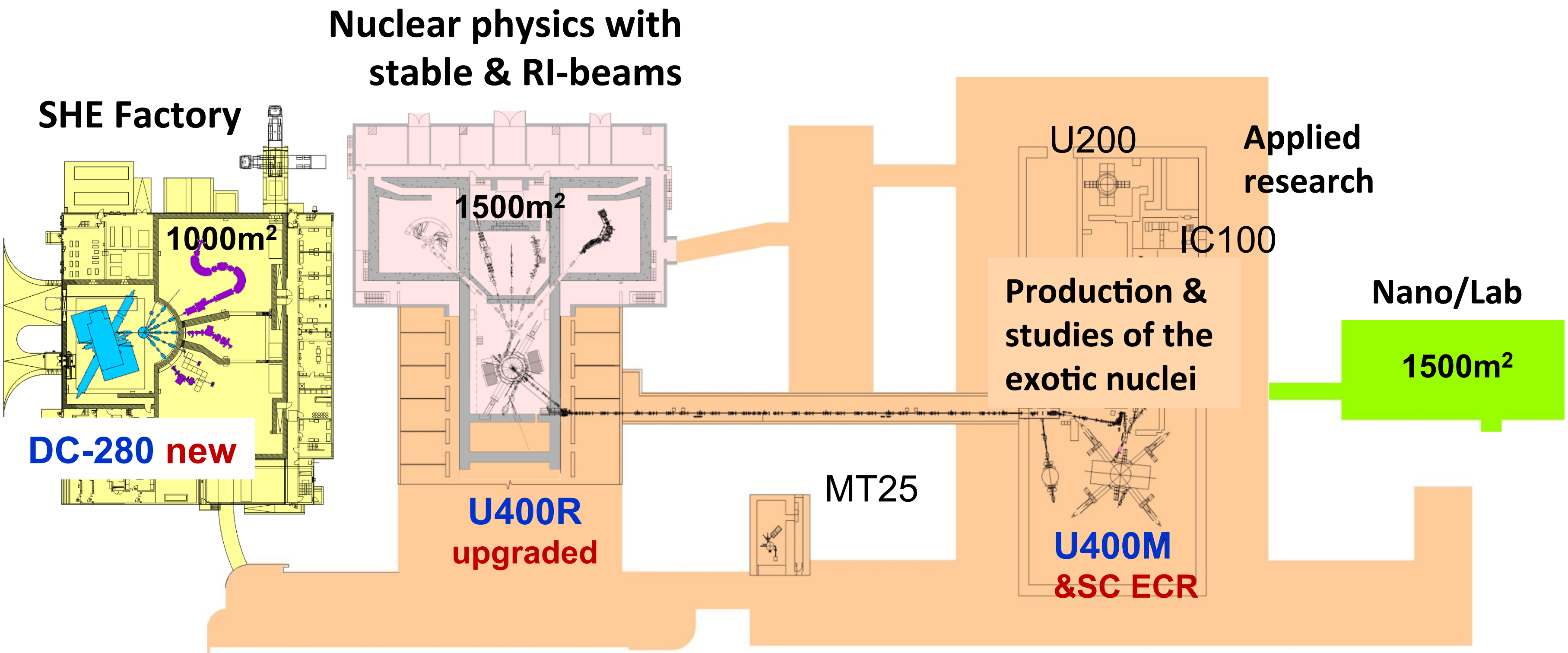


Yuri Oganessian. “Synthesis of SH-nuclei” FUSHE 2012, May14, 2012, Weilrod, Germany

Schedule for U400R



FLNR (JINR) – 2016



U400M-U400R Accelerator Complex

Thank you

Collaboration

FLNR, JINR (Dubna)

ORNL (Oak-Ridge, USA)

LLNL (Livermore, USA)

ANL Argonne, USA

RIAR (Dimitrovgrad, Russia)

Vanderbilt University (Nashville, USA)

xn @ p,xn cross sections with ^{18}O and ^{22}Ne projectiles