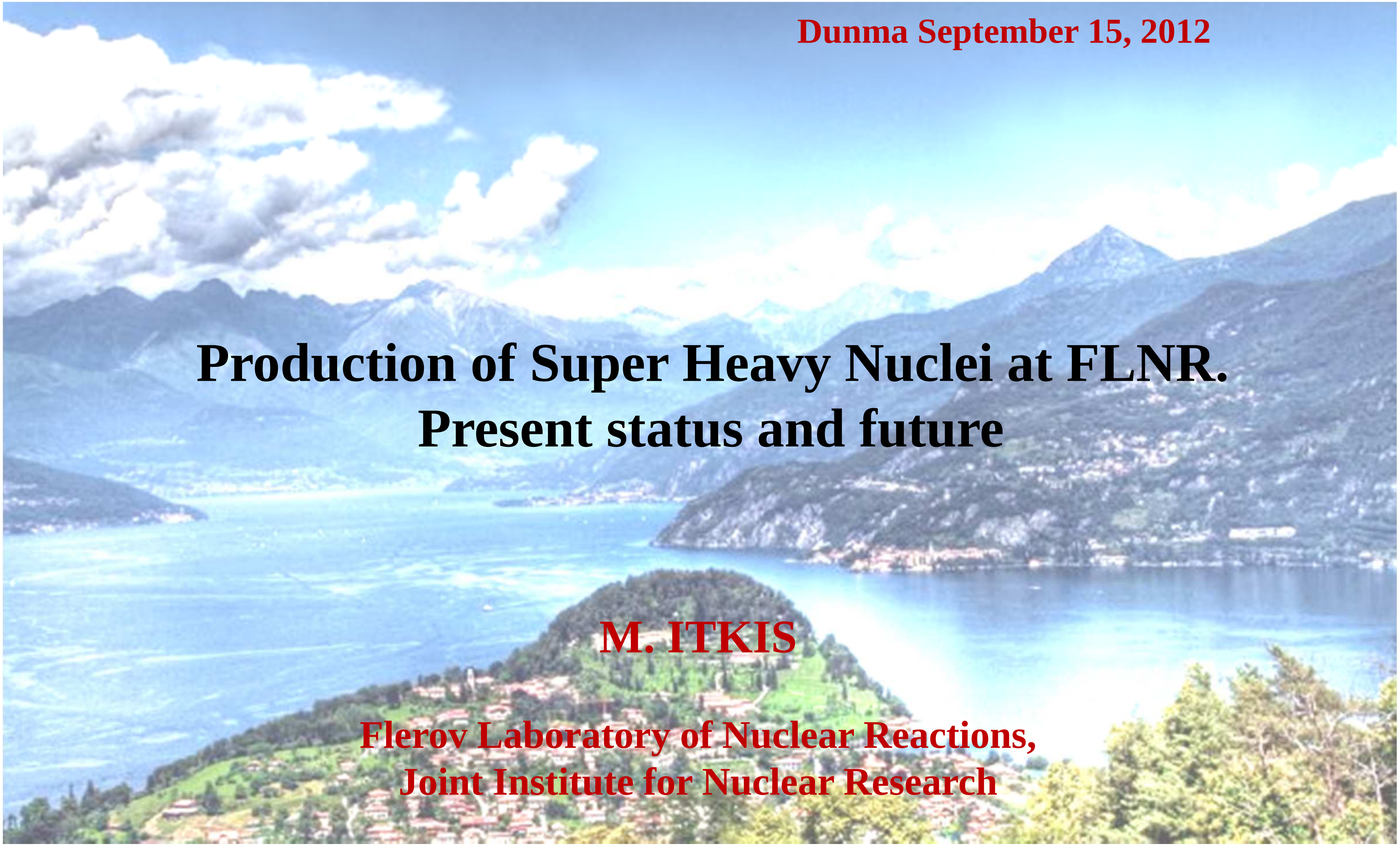


Dunma September 15, 2012

Production of Super Heavy Nuclei at FLNR.
Present status and future

M. ITKIS

Flerov Laboratory of Nuclear Reactions,
Joint Institute for Nuclear Research

BASIC DIRECTIONS of RESEARCH

1. Heavy and superheavy nuclei:

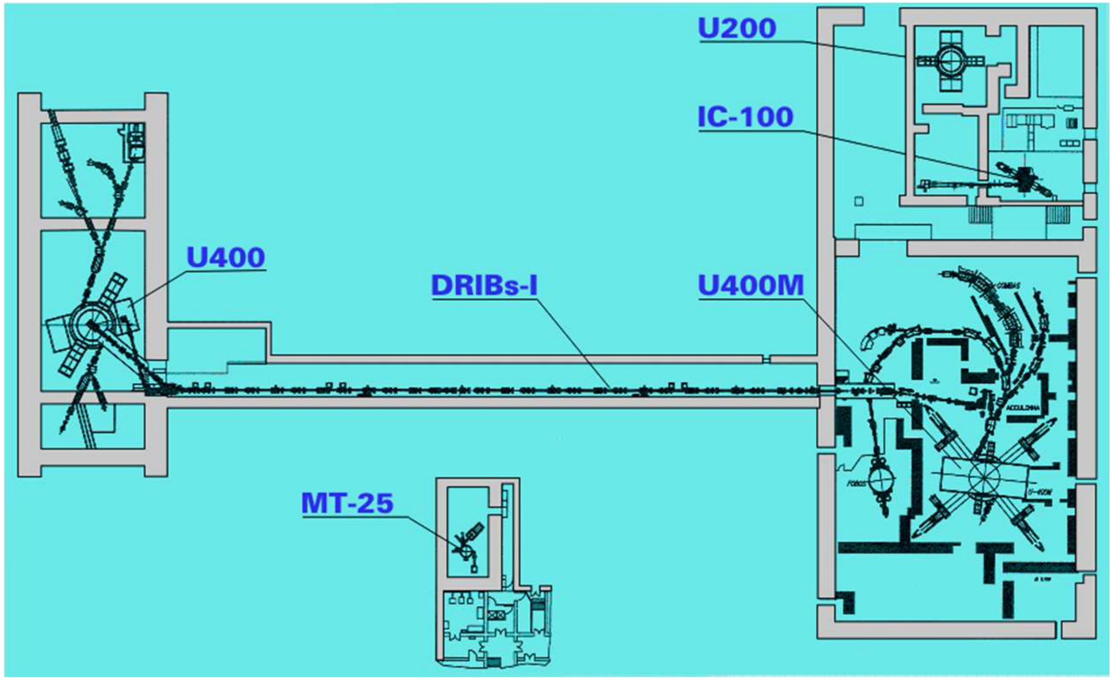
- synthesis and study of properties of superheavy elements;
- chemistry of new elements;
- fusion-fission and multi-nucleon transfer reactions;
- nuclear- , mass-, & laser-spectrometry of SH nuclei.

2. Light exotic nuclei:

- properties and structure of light exotic nuclei;
- reactions with exotic nuclei.

3. Radiation effects and physical groundworks of nanotechnology

JINR's advantages



- Unique beams of heavy ions: ^{48}Ca - ^{58}Fe, ^{6}He, ^{8}He
- Beam on target time up to 12,000 hours/year
- Unique actinide targets ^{237}Np – ^{249}Cf
- Cryogenic D-T- target
- Advanced experimental set-ups
- Highly-qualified scientists and engineers

Broad international cooperation:

JINR Member States, Germany, the USA, Finland, France, Italy, Japan, Switzerland, etc.

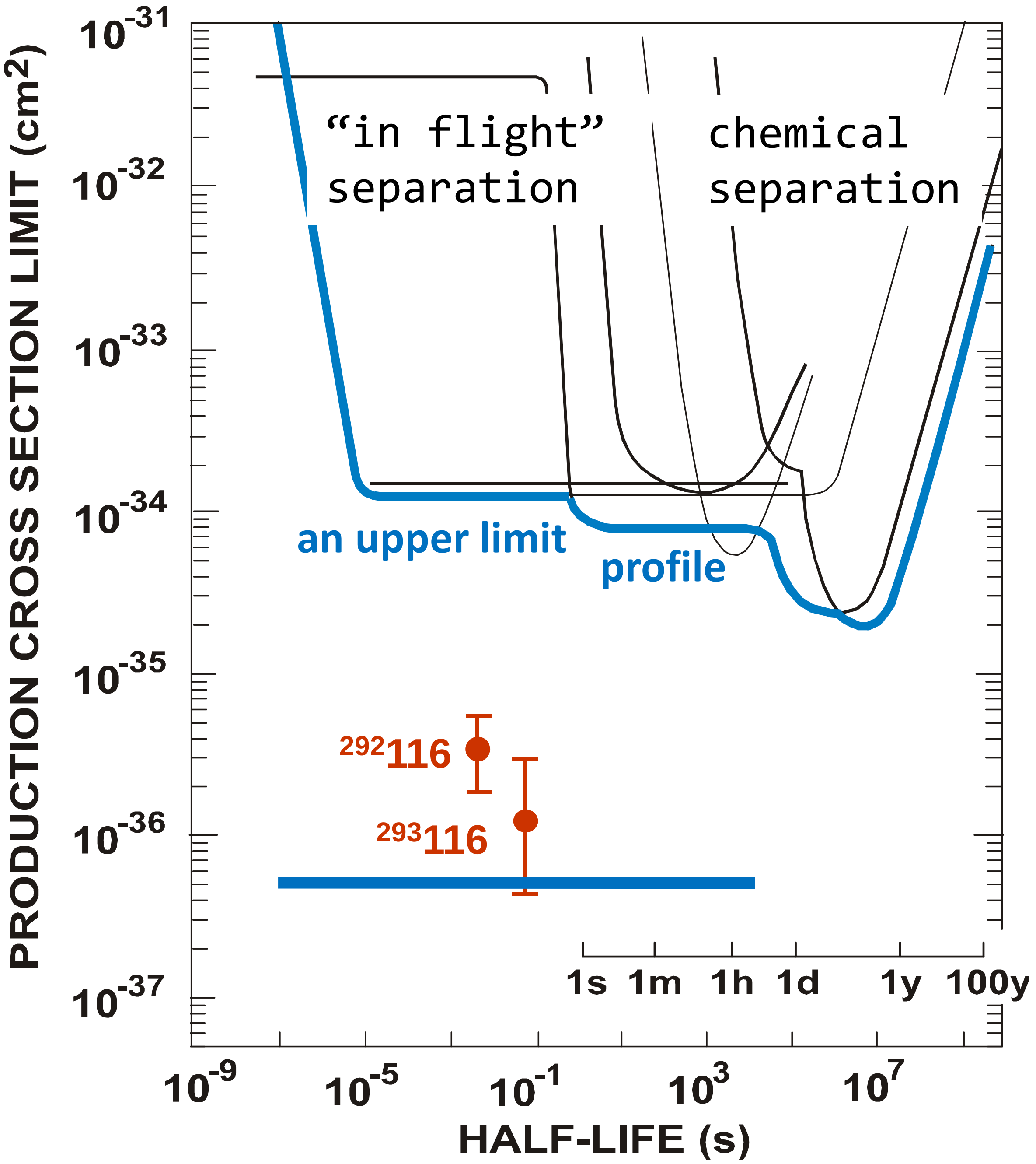
Search for Element 116 in ^{248}Cm + ^{48}Ca reaction

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

1985

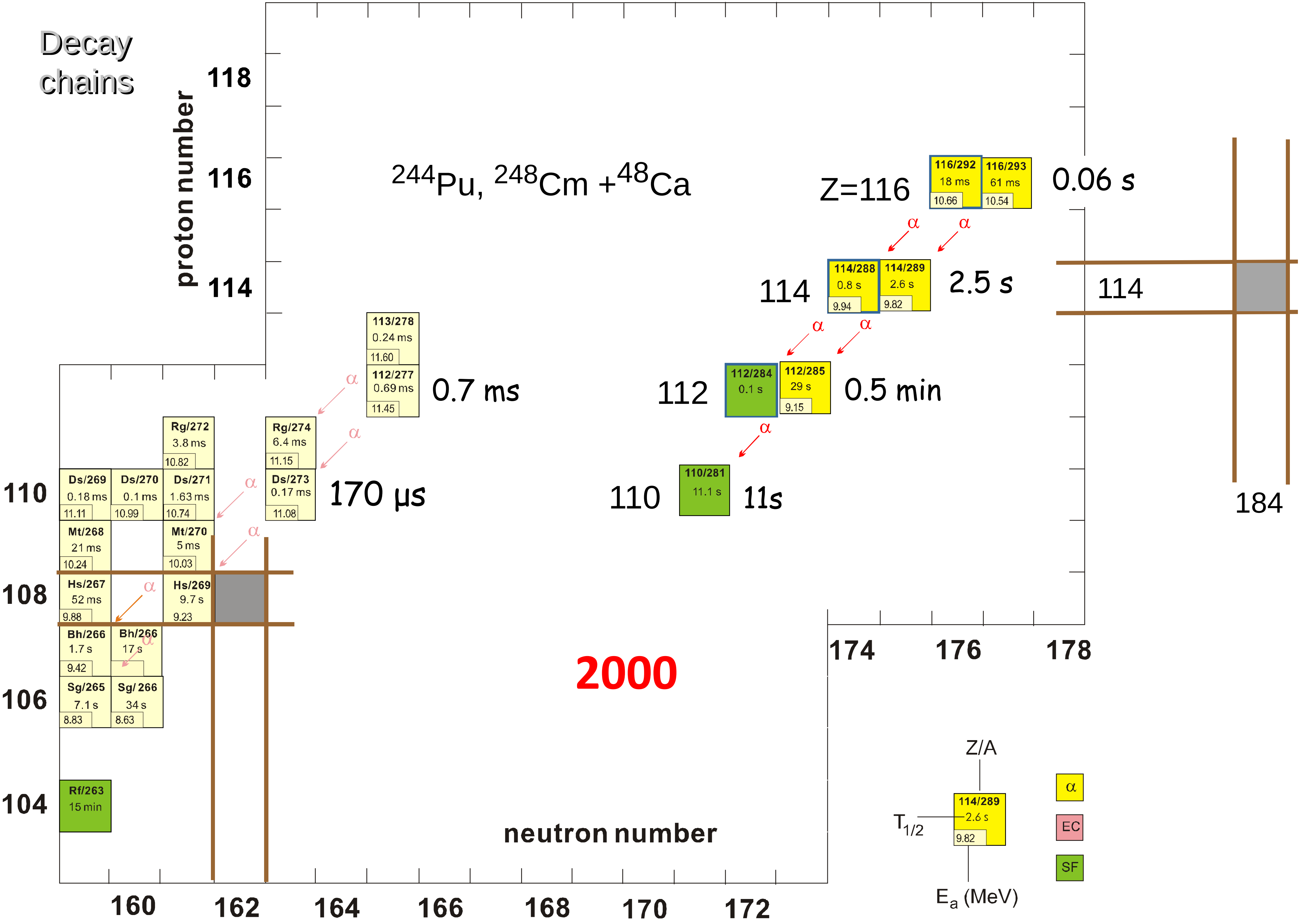
FLNR, Dubna
LLNL, Livermore

2000



Decay chains

^{244}Pu, ^{248}Cm + ^{48}Ca



2000

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

Press Release 30.05.2012

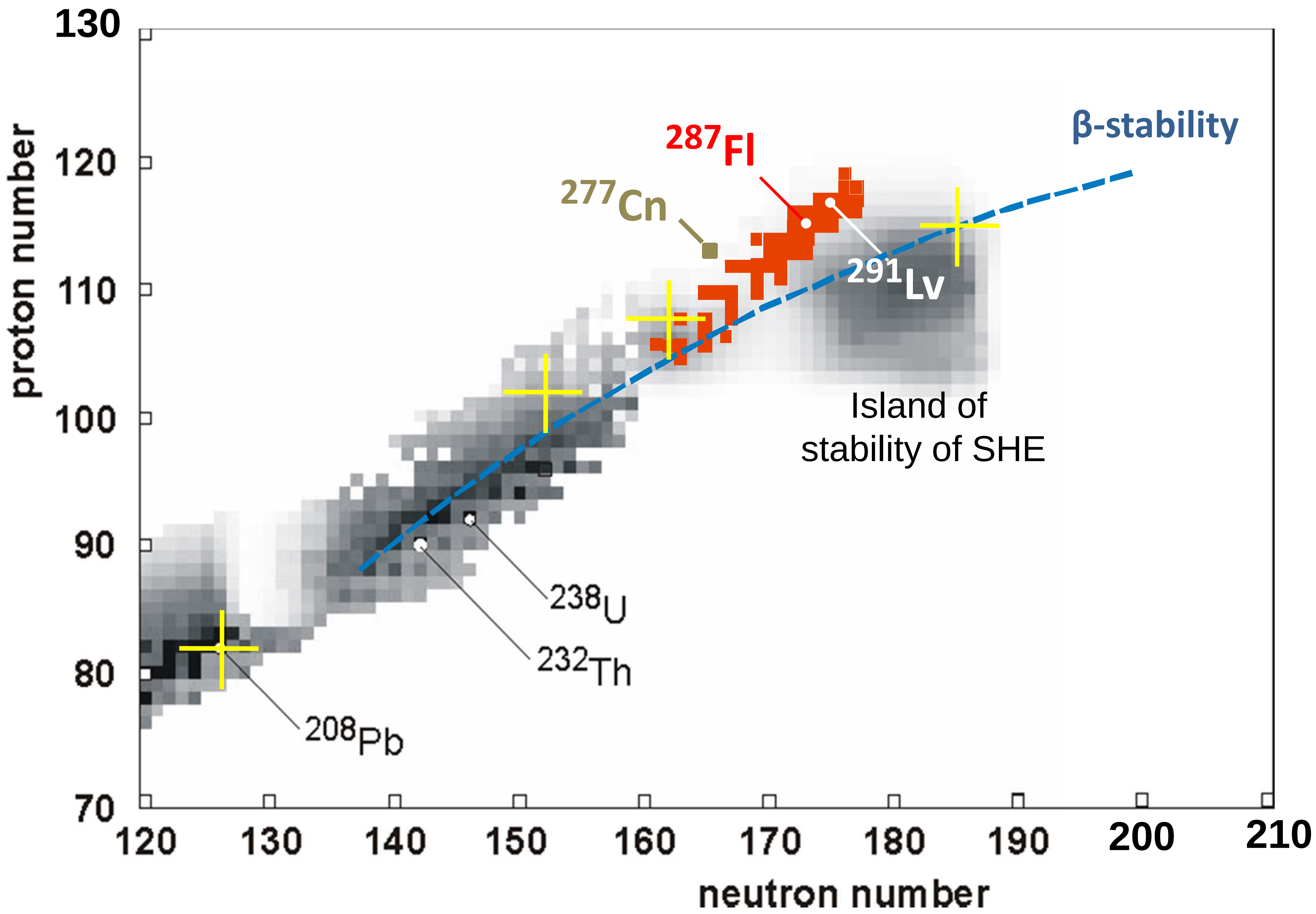
Press Release 30.05.2012 21:27

Element 114 is Named Flerovium and Element 116 is Named Livermorium

Priority for the discovery of these elements was assigned to the collaboration between the Joint Institute for Nuclear Research (Dubna, Russia) and the Lawrence Livermore National Laboratory (Livermore, California, USA).

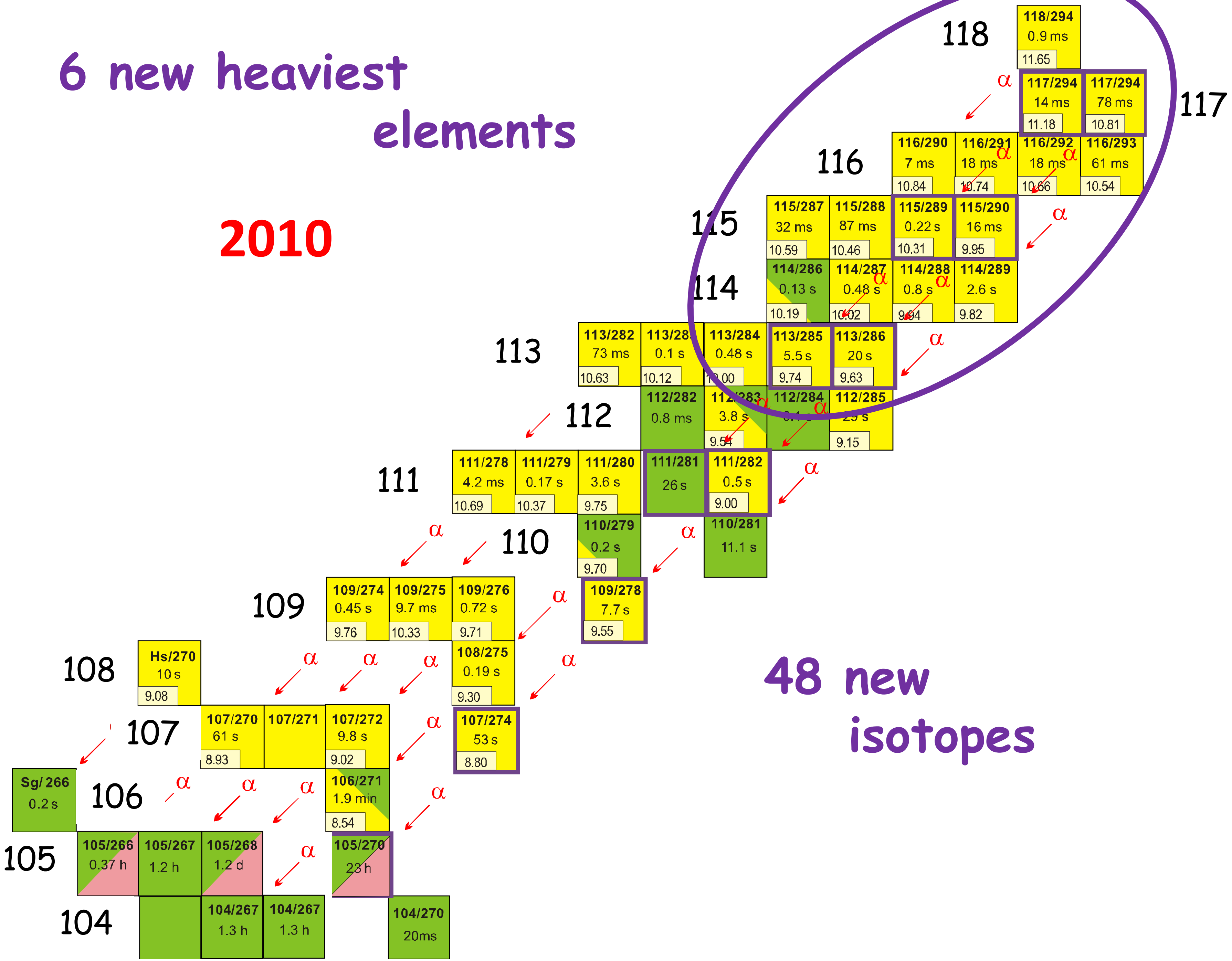
The name **flerovium** will honor the Flerov Laboratory of Nuclear Reactions where superheavy elements are synthesised. Georgiy N. Flerov (1913 – 1990) – was a renowned physicist, author of the discovery of the spontaneous fission of uranium, pioneer in heavy-ion physics, and founder in the Joint Institute for Nuclear Research the Laboratory of Nuclear Reactions (1957).

The name **livermorium** honors the Lawrence Livermore National Laboratory. A group of researchers of this Laboratory with the heavy element research group of the Flerov Laboratory of Nuclear Reactions took part in the work carried out in Dubna on the synthesis of superheavy elements including element 116.

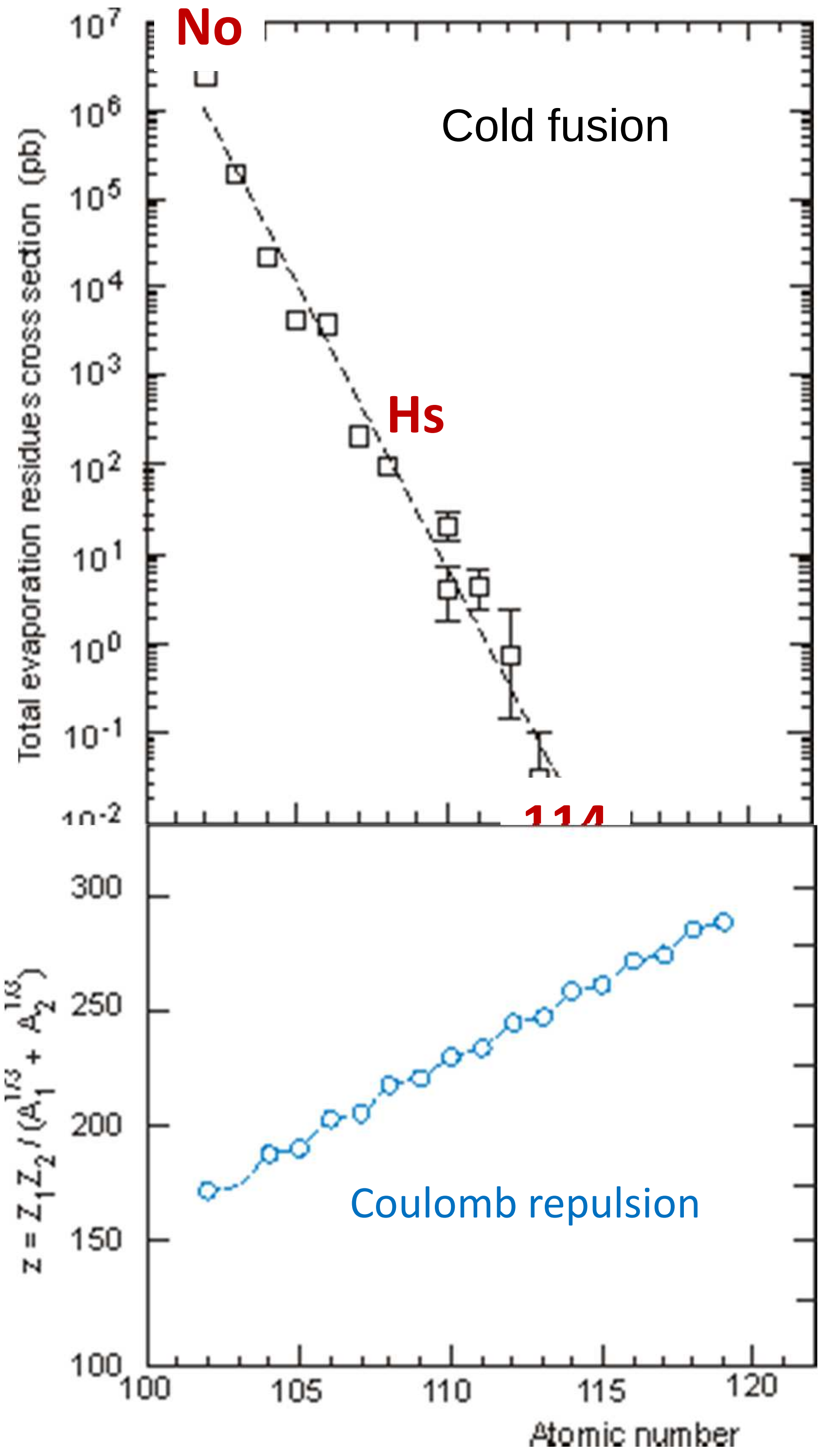

130
120
110
100
90
80
70
proton number
120
130
140
150
160
170
180
190
200
210
neutron number
287Fl
277Cn
291Lv
β-stability
Island of
stability of SHE
238U
232Th
208Pb

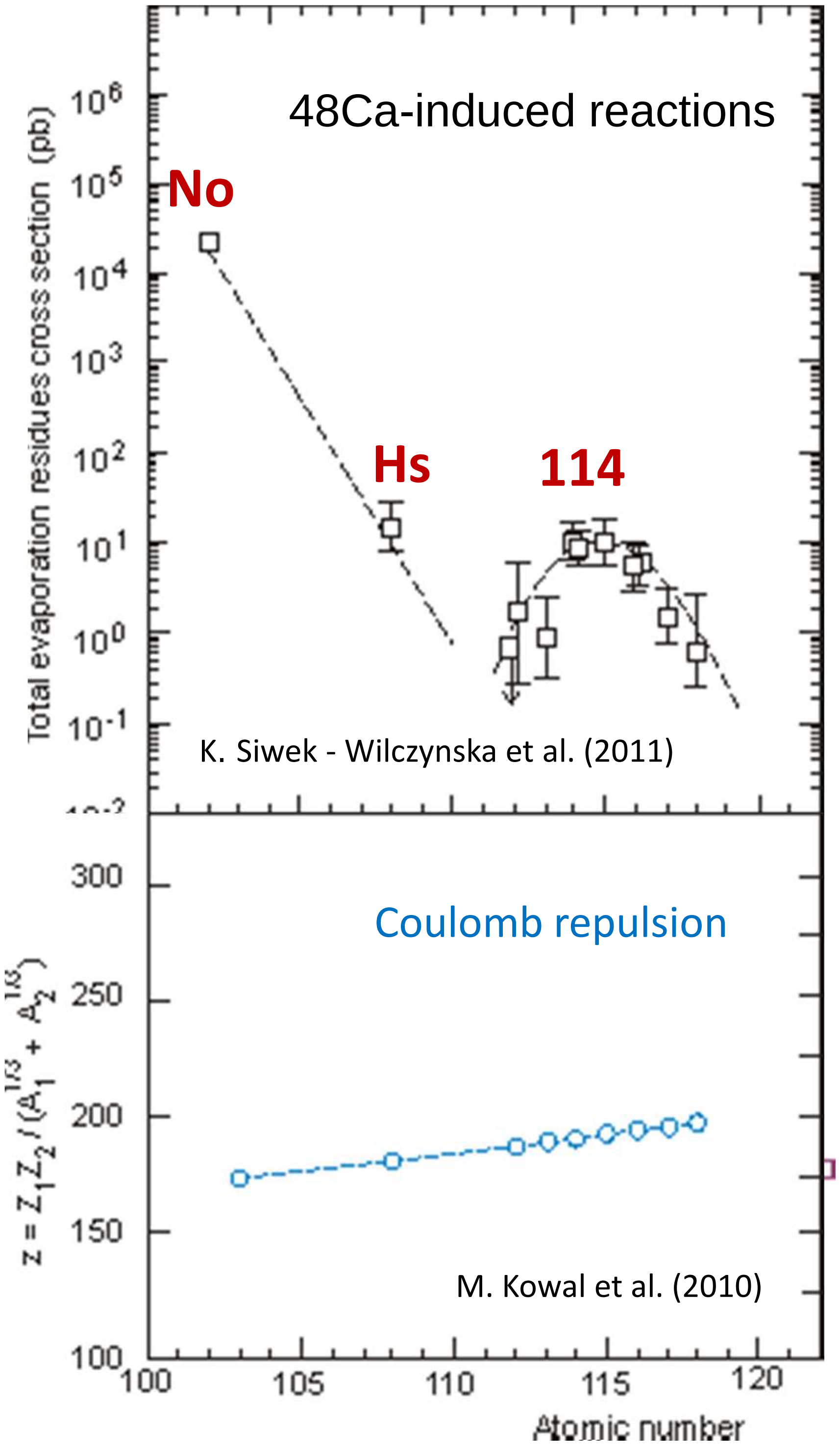
6 new heaviest elements

2010



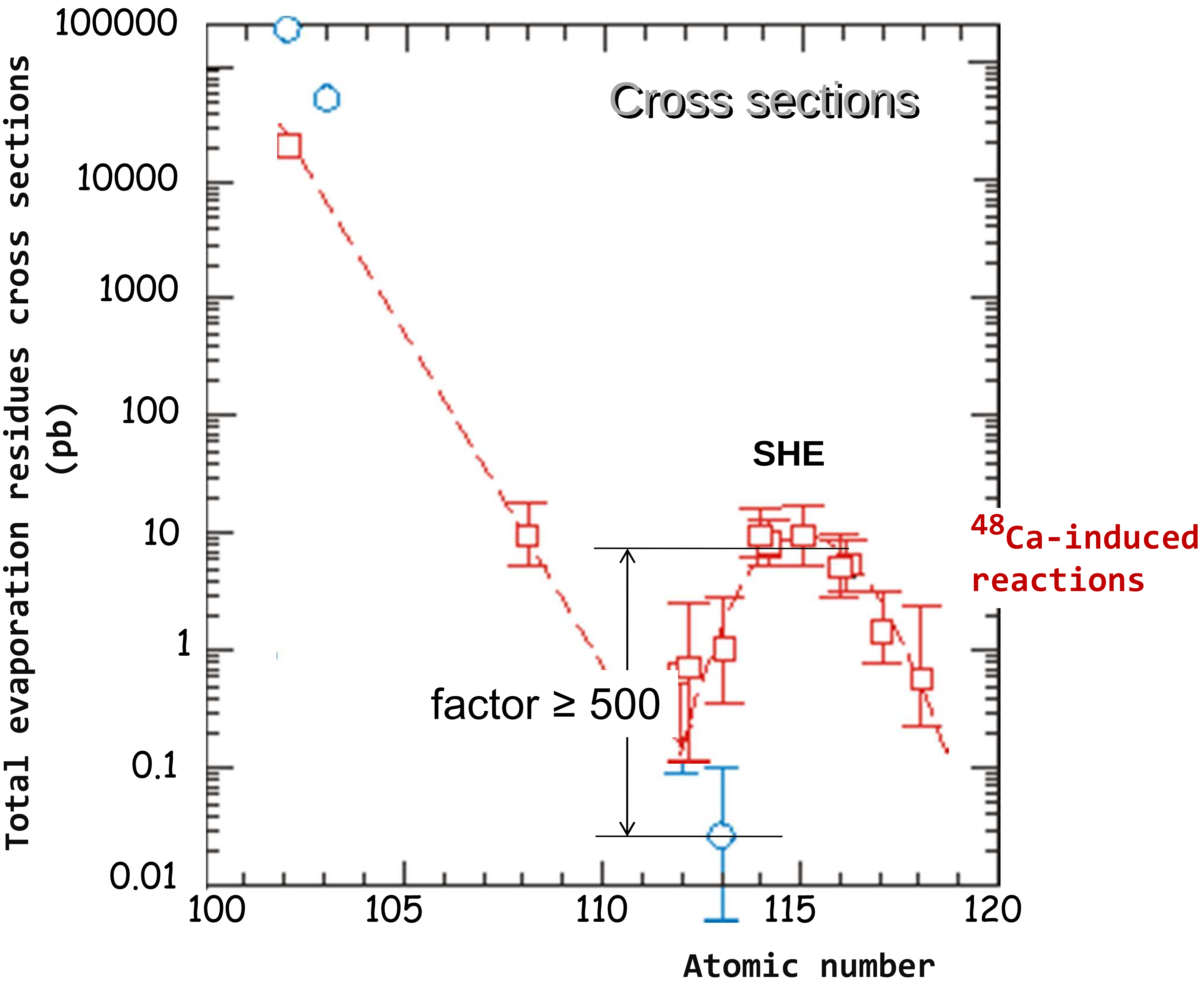
48 new isotopes





K. Siwek - Wilczynska et al. (2011)

M. Kowal et al. (2010)

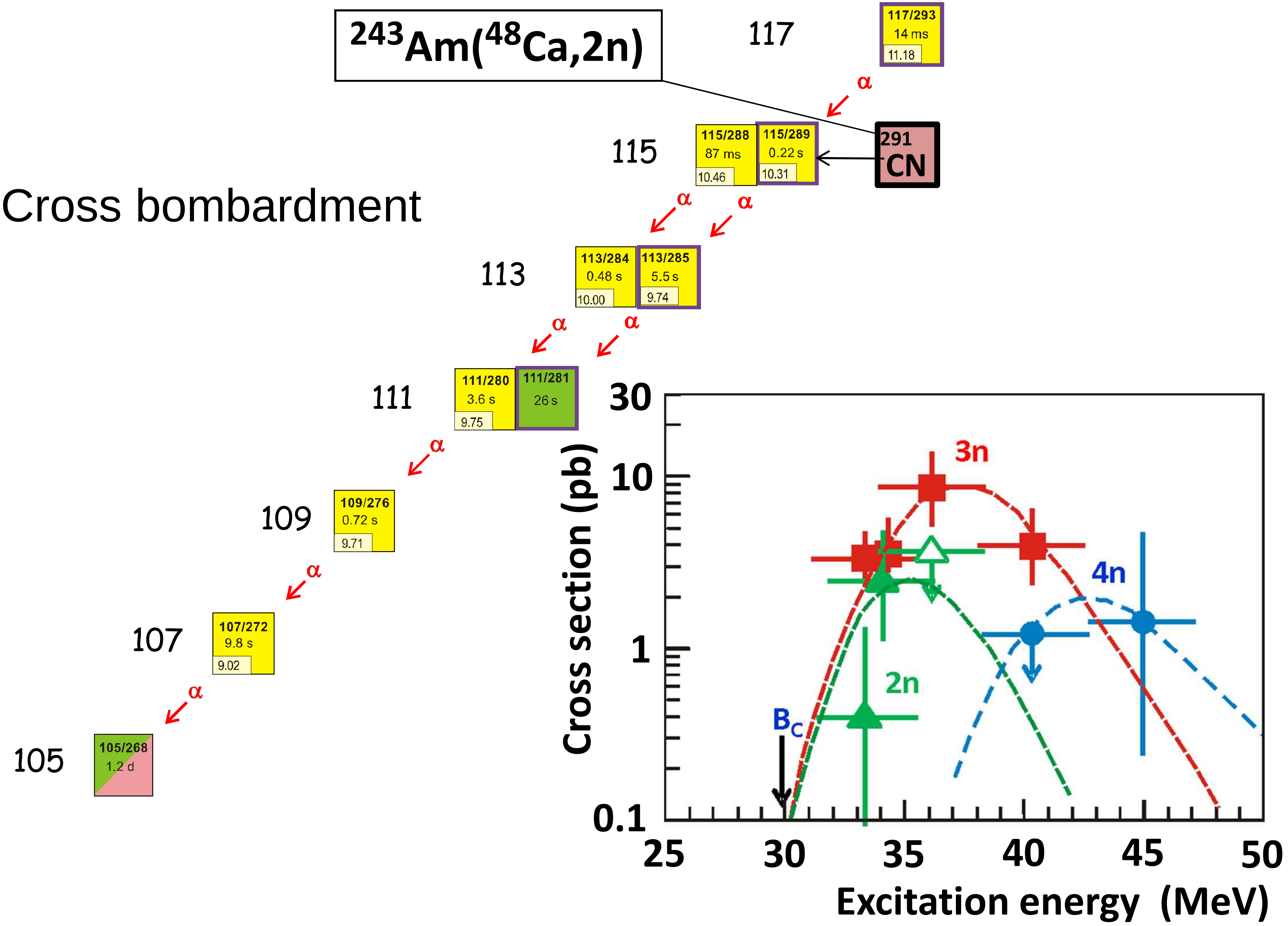

Cross sections
Total evaporation residues cross sections (pb)
100000
10000
1000
100
10
1
0.1
0.01
100
105
110
115
120
Atomic number
SHE
^{48}Ca-induced reactions
factor ≥ 500

Current experiments 2012–2013

The conformation of previous results for Z = 113, 115, 117 and 118

Cross bombardment

$^{243}Am(^{48}Ca,2n)$



291 CN

117/293 14 ms 11.18

115/288 87 ms 10.46

115/289 0.22 s 10.31

113/284 0.48 s 10.00

113/285 5.5 s 9.74

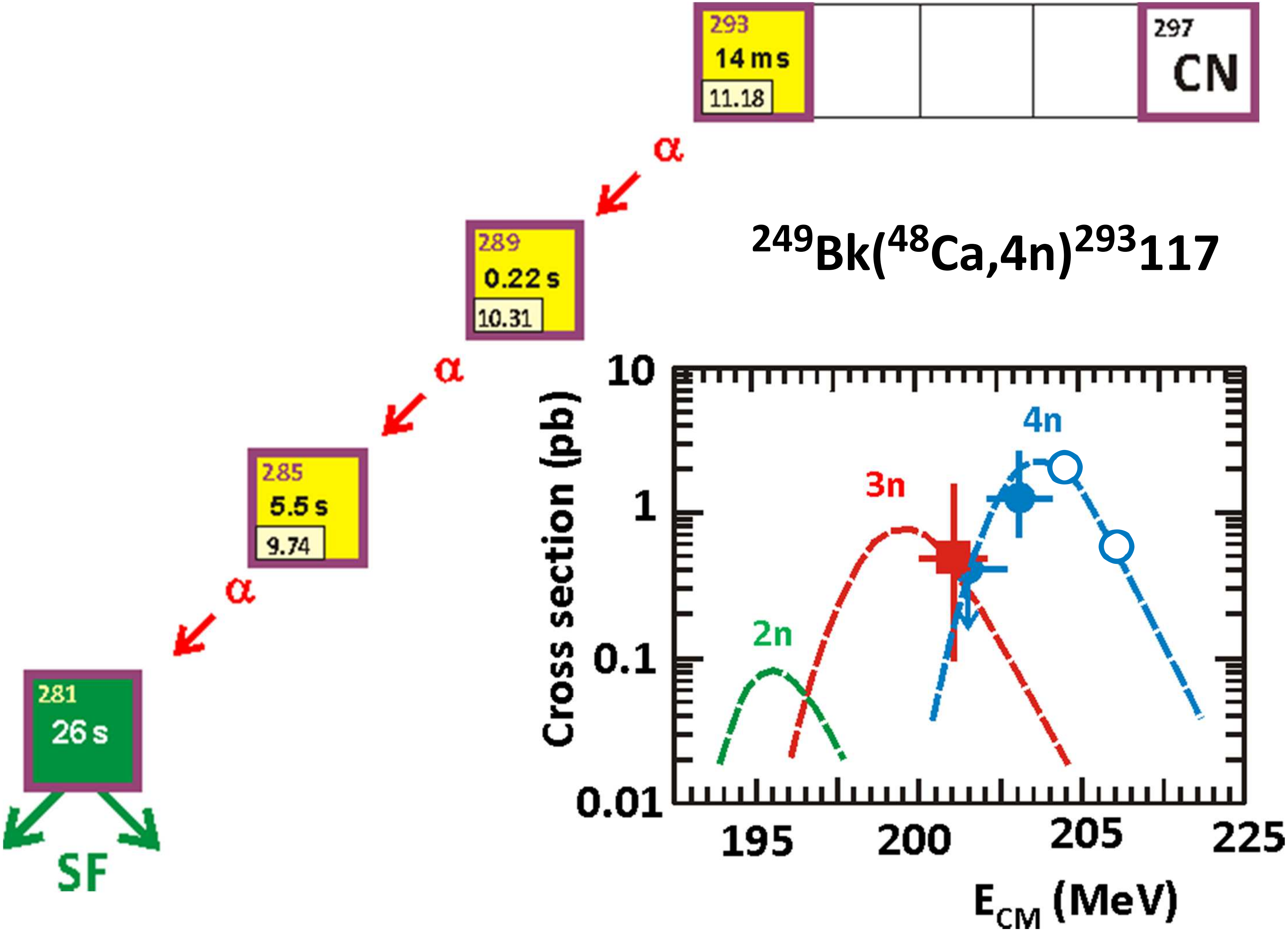
111/280 3.6 s 9.75

111/281 26 s

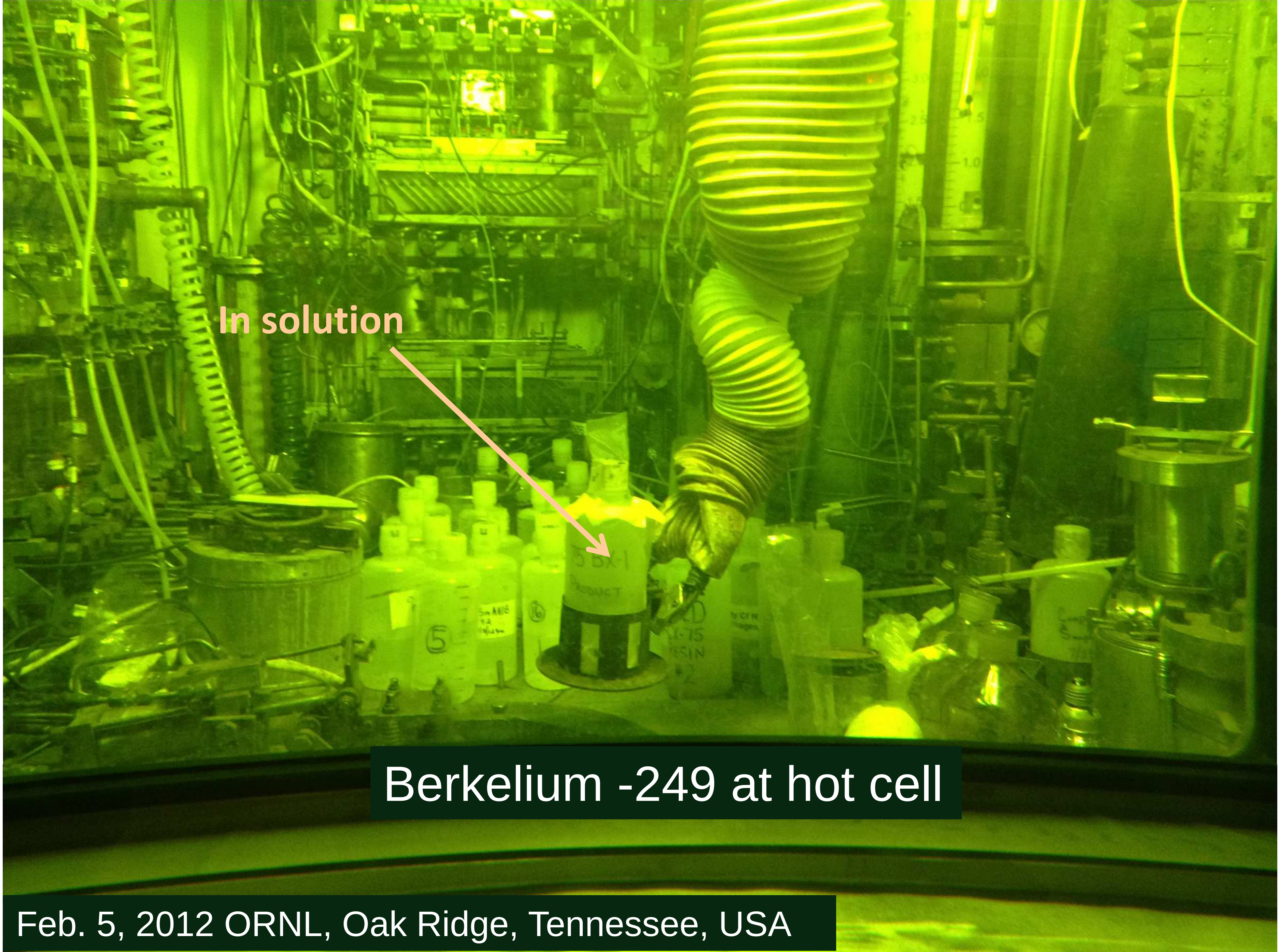
109/276 0.72 s 9.71

107/272 9.8 s 9.02

105/268 1.2 d

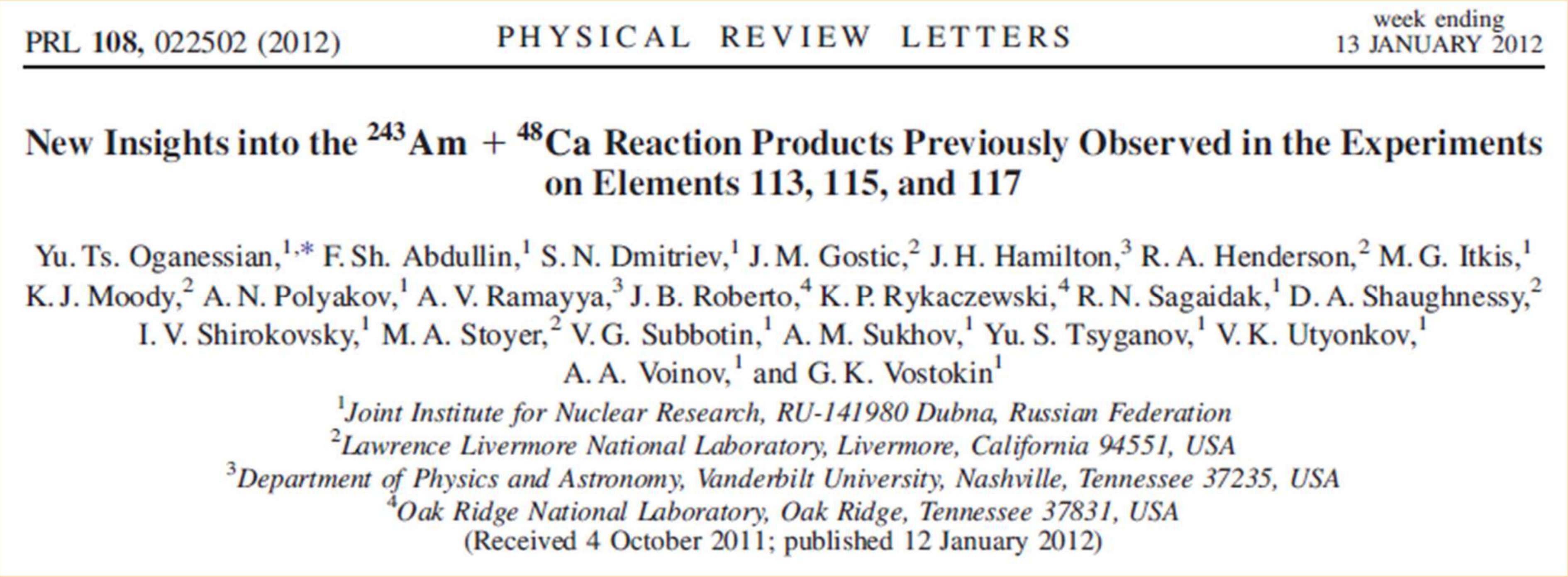


$^{249}Bk(^{48}Ca,4n)^{293}117$



Berkelium -249 at hot cell

Feb. 5, 2012 ORNL, Oak Ridge, Tennessee, USA



PRL 108, 022502 (2012) PHYSICAL REVIEW LETTERS week ending 13 JANUARY 2012

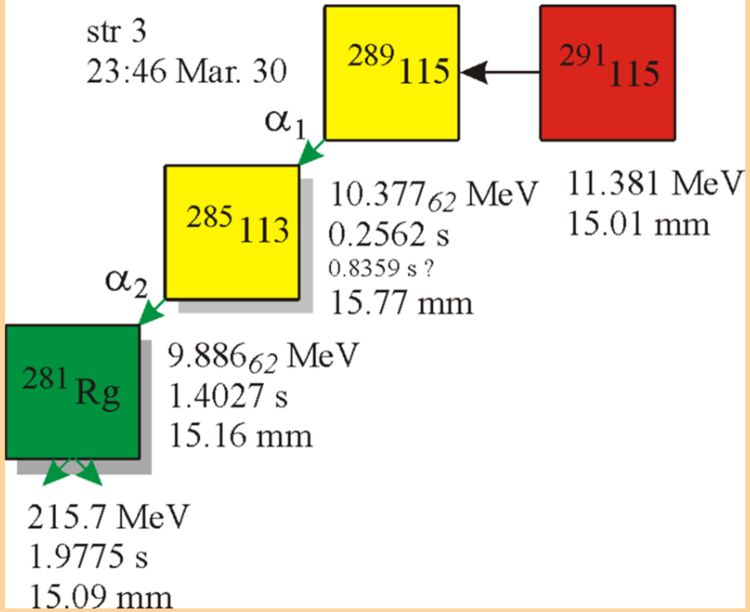
New Insights into the ^{243}Am + ^{48}Ca Reaction Products Previously Observed in the Experiments on Elements 113, 115, and 117

Yu. Ts. Oganessian,[1,*] F. Sh. Abdullin,[1] S. N. Dmitriev,[1] J. M. Gostic,[2] J. H. Hamilton,[3] R. A. Henderson,[2] M. G. Itkis,[1] K. J. Moody,[2] A. N. Polyakov,[1] A. V. Ramayya,[3] J. B. Roberto,[4] K. P. Rykaczewski,[4] R. N. Sagaidak,[1] D. A. Shaughnessy,[2] I. V. Shirokovsky,[1] M. A. Stoyer,[2] V. G. Subbotin,[1] A. M. Sukhov,[1] Yu. S. Tsyganov,[1] V. K. Utyonkov,[1] A. A. Voinov,[1] and G. K. Vostokin[1]

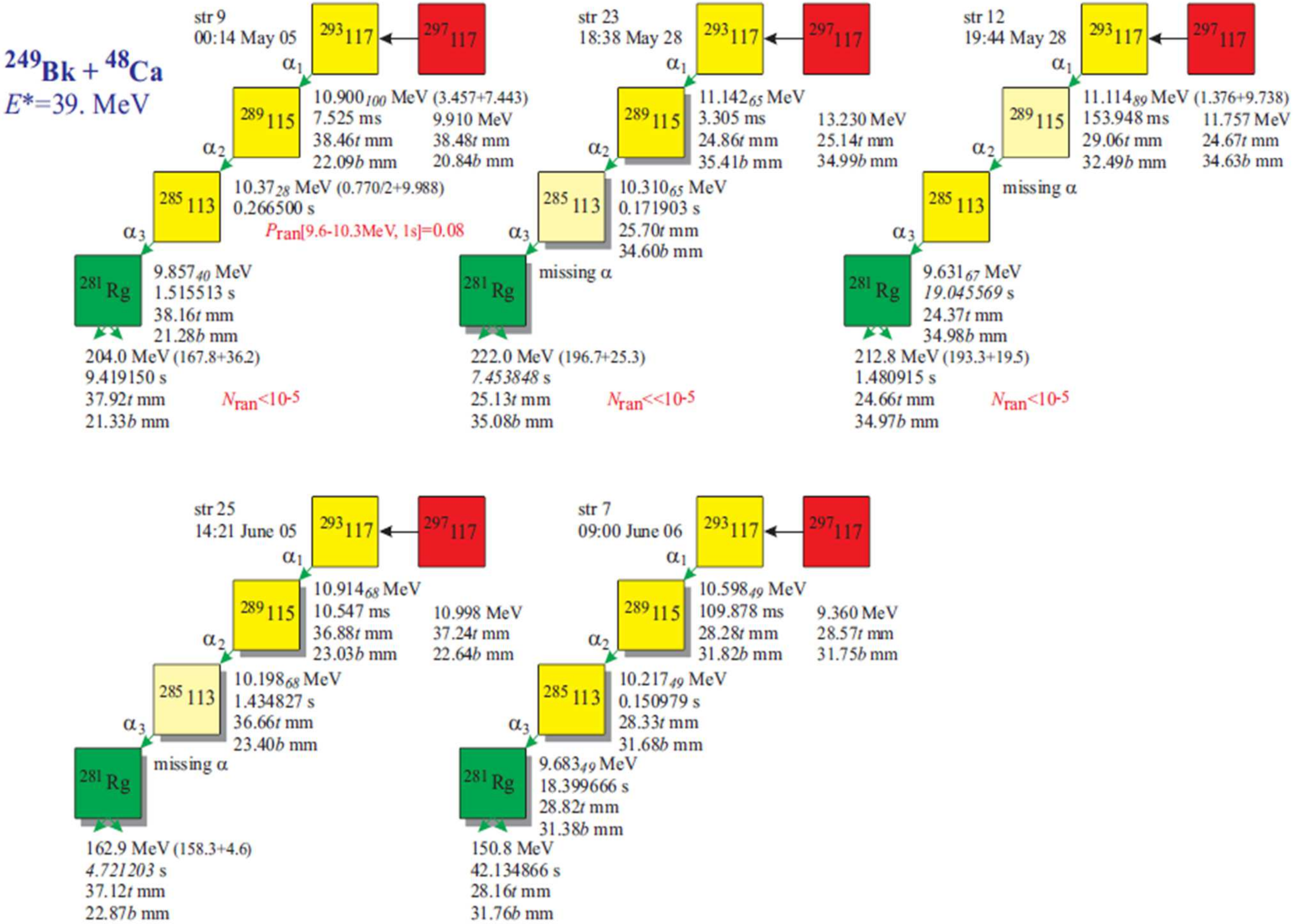
[1]*Joint Institute for Nuclear Research, RU-141980 Dubna, Russian Federation*
[2]*Lawrence Livermore National Laboratory, Livermore, California 94551, USA*
[3]*Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235, USA*
[4]*Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

(Received 4 October 2011; published 12 January 2012)

2*n* channel !



^{249}Bk + ^{48}Ca
E^*=39. MeV



str 9
00:14 May 05
α_1: 10.900$_{100}$ MeV (3.457+7.443)
7.525 ms
38.46*t* mm
22.09*b* mm
9.910 MeV
38.48*t* mm
20.84*b* mm
α_2: 10.37$_{28}$ MeV (0.770/2+9.988)
0.266500 s
P_{ran}[9.6-10.3MeV, 1s]=0.08
α_3: 9.857$_{40}$ MeV
1.515513 s
38.16*t* mm
21.28*b* mm
204.0 MeV (167.8+36.2)
9.419150 s
37.92*t* mm
21.33*b* mm
$N_{\text{ran}}<10^{-5}$

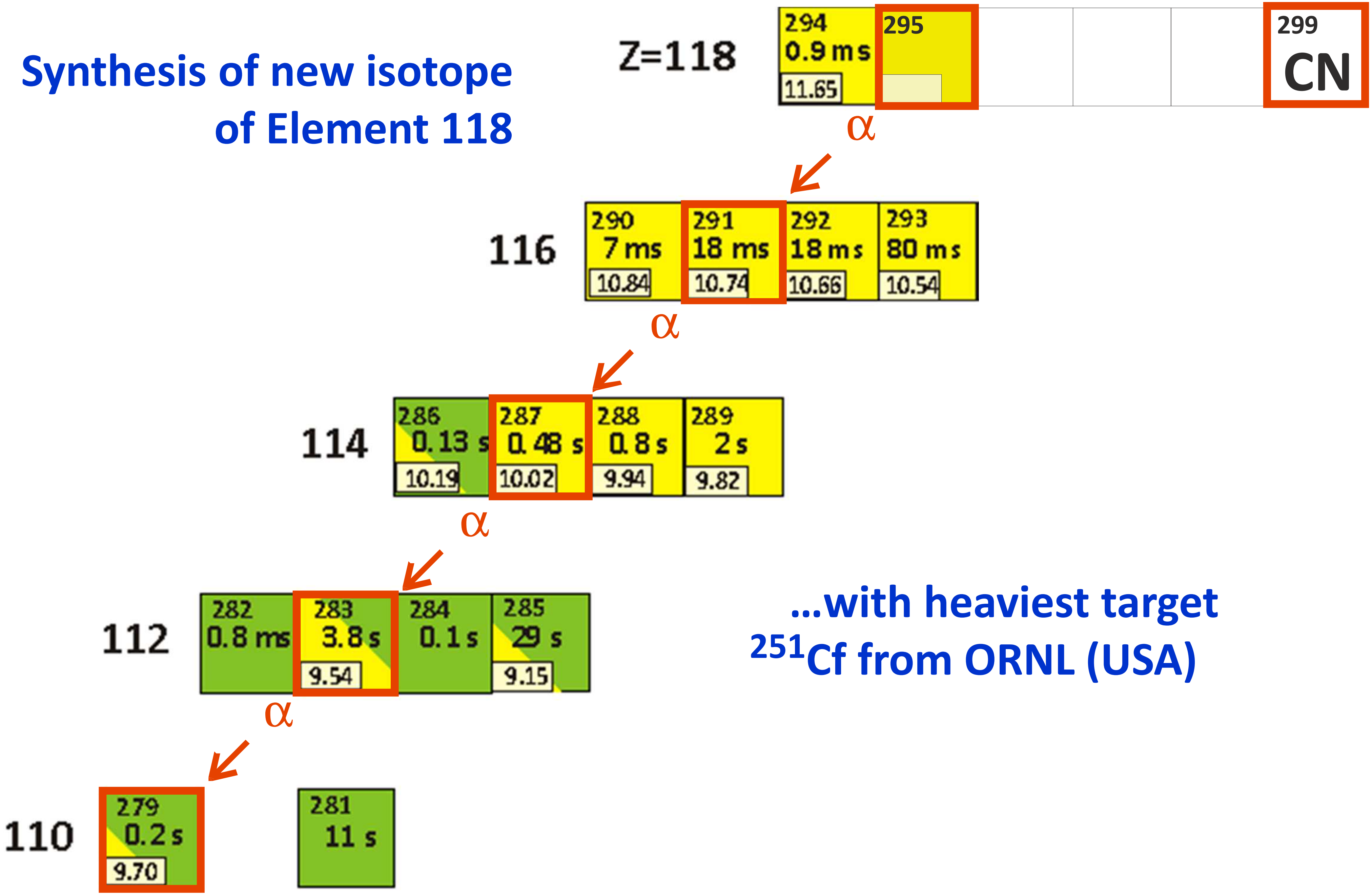
str 23
18:38 May 28
α_1: 11.142$_{65}$ MeV
3.305 ms
24.86*t* mm
35.41*b* mm
13.230 MeV
25.14*t* mm
34.99*b* mm
α_2: 10.310$_{65}$ MeV
0.171903 s
25.70*t* mm
34.60*b* mm
α_3: missing α
222.0 MeV (196.7+25.3)
7.453848 s
25.13*t* mm
35.08*b* mm
$N_{\text{ran}} \ll 10^{-5}$

str 12
19:44 May 28
α_1: 11.114$_{89}$ MeV (1.376+9.738)
153.948 ms
29.06*t* mm
32.49*b* mm
11.757 MeV
24.67*t* mm
34.63*b* mm
α_2: missing α
α_3: 9.631$_{67}$ MeV
19.045569 s
24.37*t* mm
34.98*b* mm
212.8 MeV (193.3+19.5)
1.480915 s
24.66*t* mm
34.97*b* mm
$N_{\text{ran}}<10^{-5}$

str 25
14:21 June 05
α_1: 10.914$_{68}$ MeV
10.547 ms
36.88*t* mm
23.03*b* mm
10.998 MeV
37.24*t* mm
22.64*b* mm
α_2: 10.198$_{68}$ MeV
1.434827 s
36.66*t* mm
23.40*b* mm
α_3: missing α
162.9 MeV (158.3+4.6)
4.721203 s
37.12*t* mm
22.87*b* mm

str 7
09:00 June 06
α_1: 10.598$_{49}$ MeV
109.878 ms
28.28*t* mm
31.82*b* mm
9.360 MeV
28.57*t* mm
31.75*b* mm
α_2: 10.217$_{49}$ MeV
0.150979 s
28.33*t* mm
31.68*b* mm
α_3: 9.683$_{49}$ MeV
18.399666 s
28.82*t* mm
31.38*b* mm
150.8 MeV
42.134866 s
28.16*t* mm
31.76*b* mm

Synthesis of new isotope of Element 118

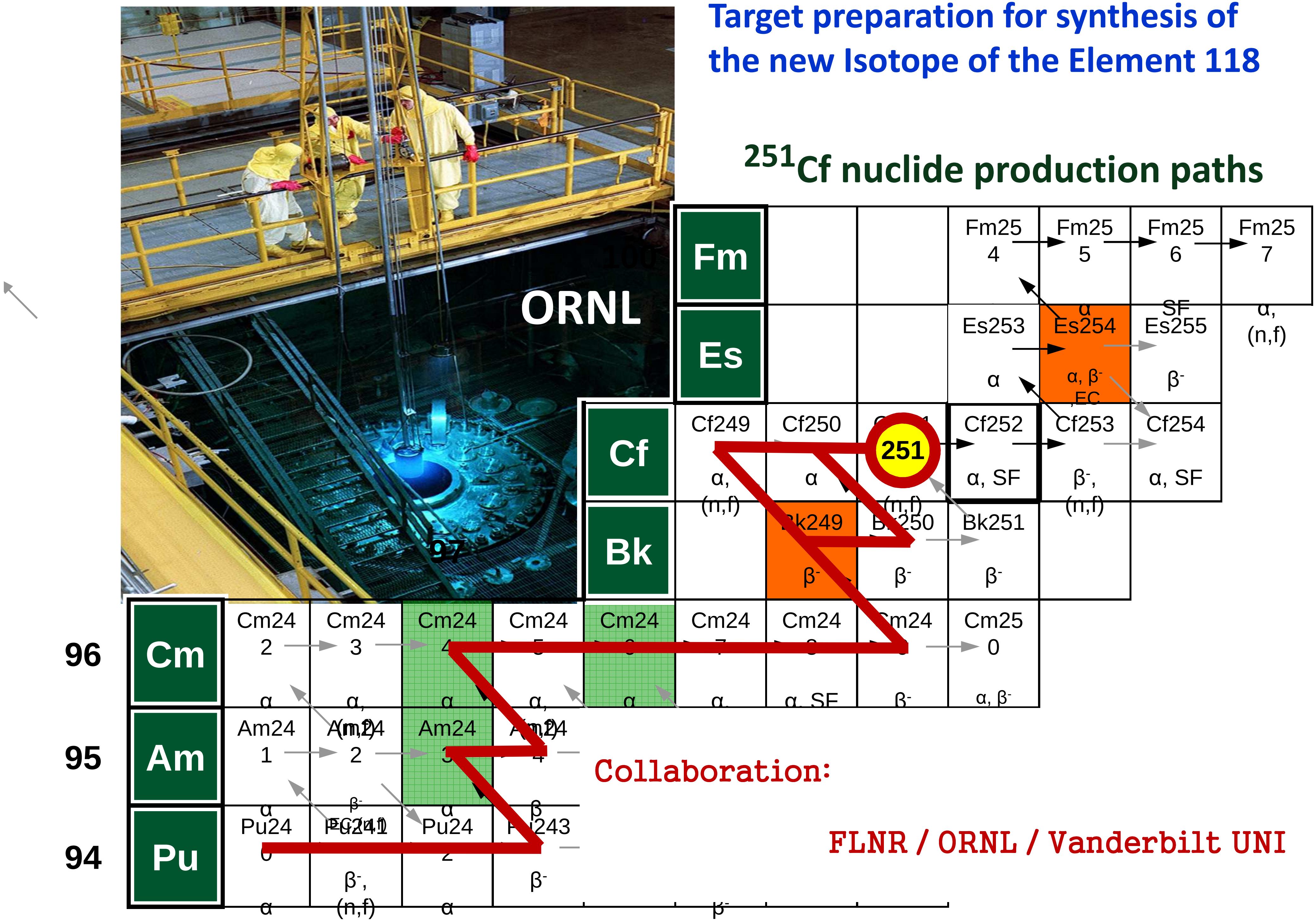


...with heaviest target ^{251}Cf from ORNL (USA)

Approved by IUPAC

Target preparation for synthesis of the new Isotope of the Element 118

^{251}Cf nuclide production paths



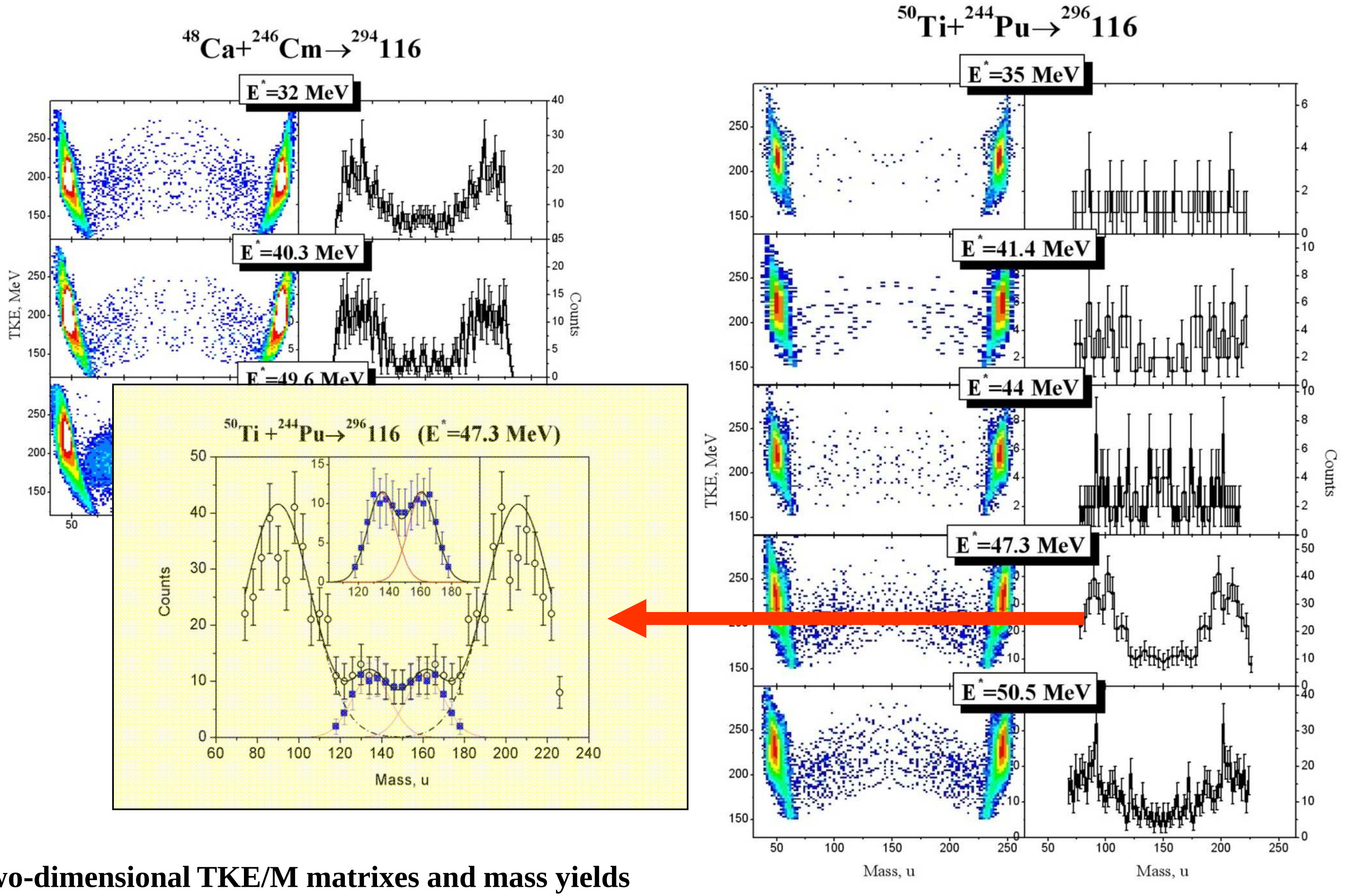
Collaboration:

FLNR / ORNL / Vanderbilt UNI

What is beyond 118 element?

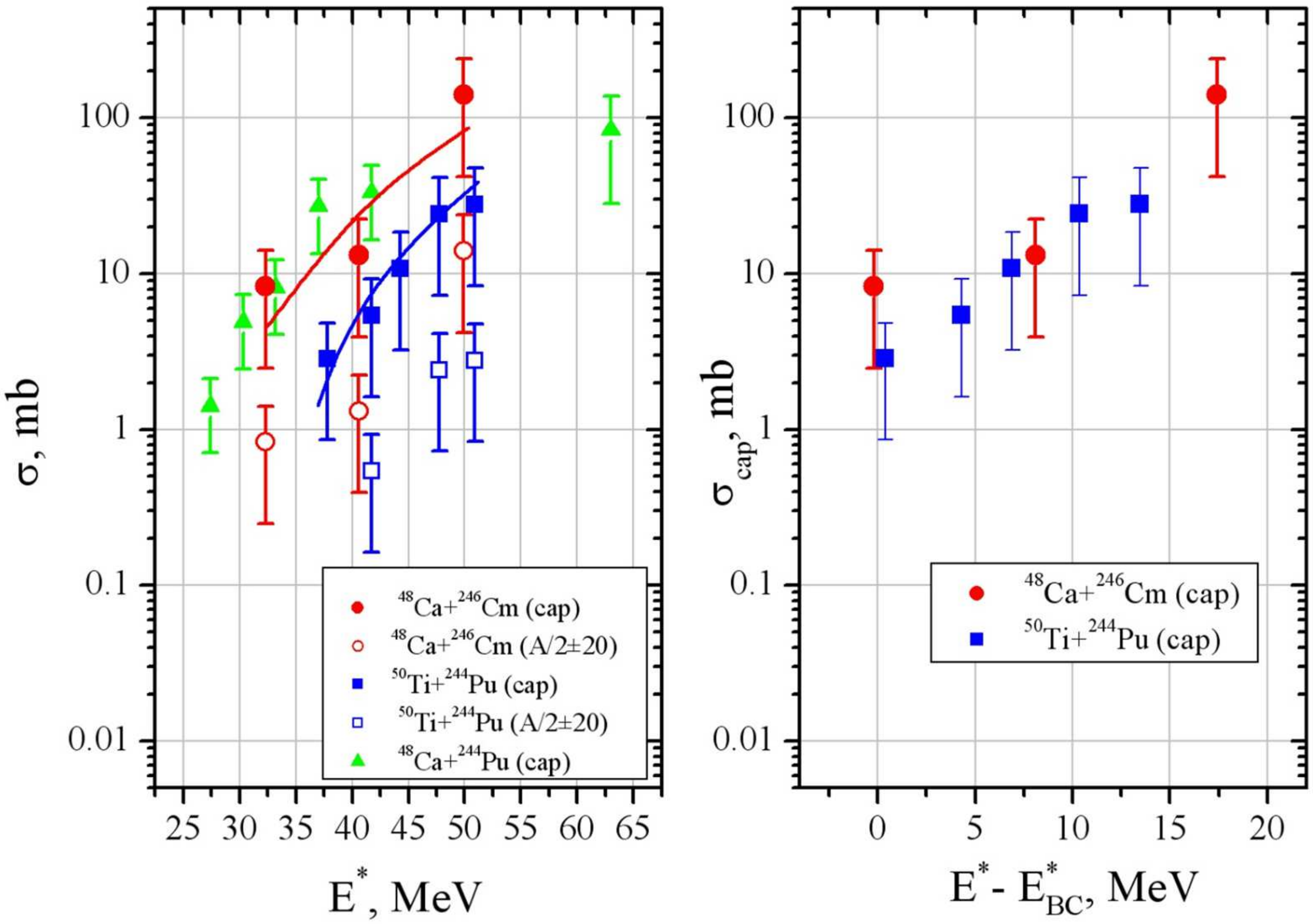
The search for new ways to SHE

The formation of $^{294}116$ in the reactions with ^{48}Ca and ^{50}Ti-ions



Two-dimensional TKE/M matrixes and mass yields for the reactions $^{48}Ca+^{246}Cm$ and $^{50}Ti+^{244}Pu$ at the excitation energies E*=32-50 MeV

Capture cross sections for the reactions ^{50}Ti+^{244}Pu and ^{48}Ca+^{246}Cm



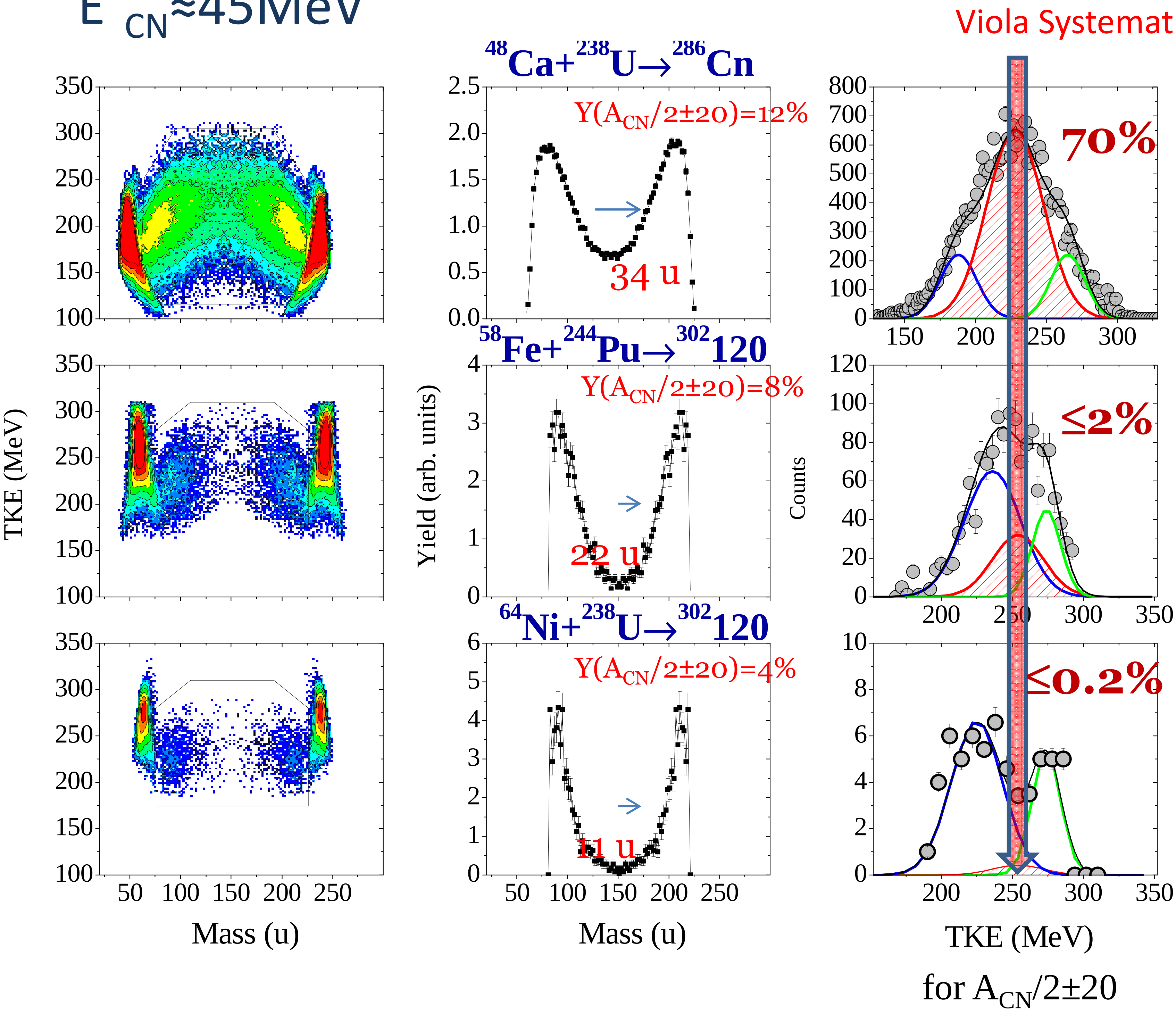
$E^*_{CN} \approx 45 MeV$

$Z_t Z_p$

1840

2444

2576



$\sigma_{ER} = 1 pb$

$\sigma_{ER} < 30 fb$

$\sigma_{ER} < 3 fb$

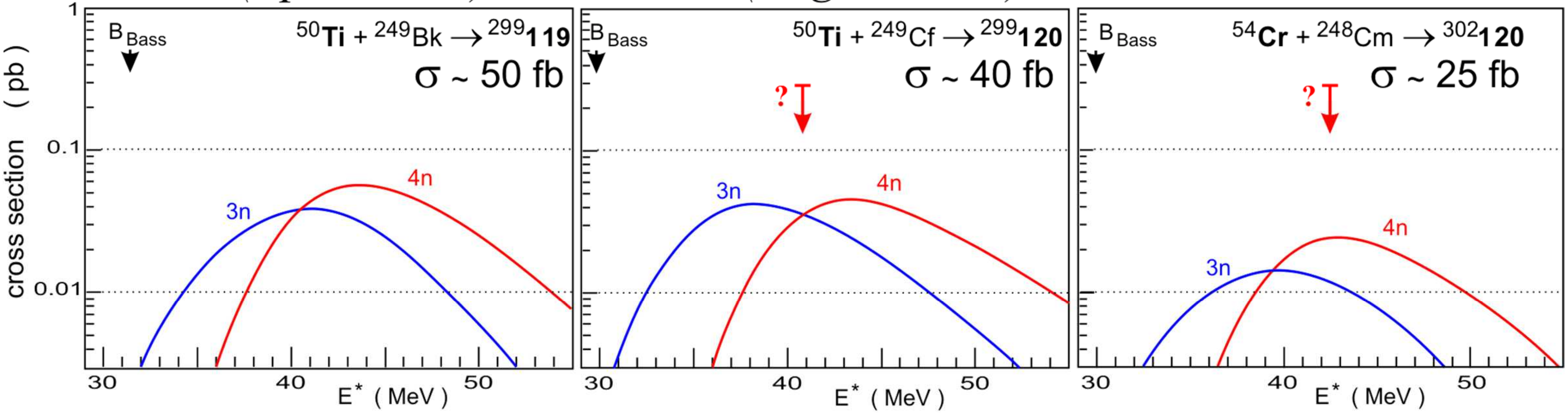
Beyond ^{48}Ca: ^{50}Ti and ^{54}Cr induced fusion reactions

Ti beam:

TASCA (April, 2012) *TASCA (August, 2011)*

Cr beam:

SHIP (May, 2011)

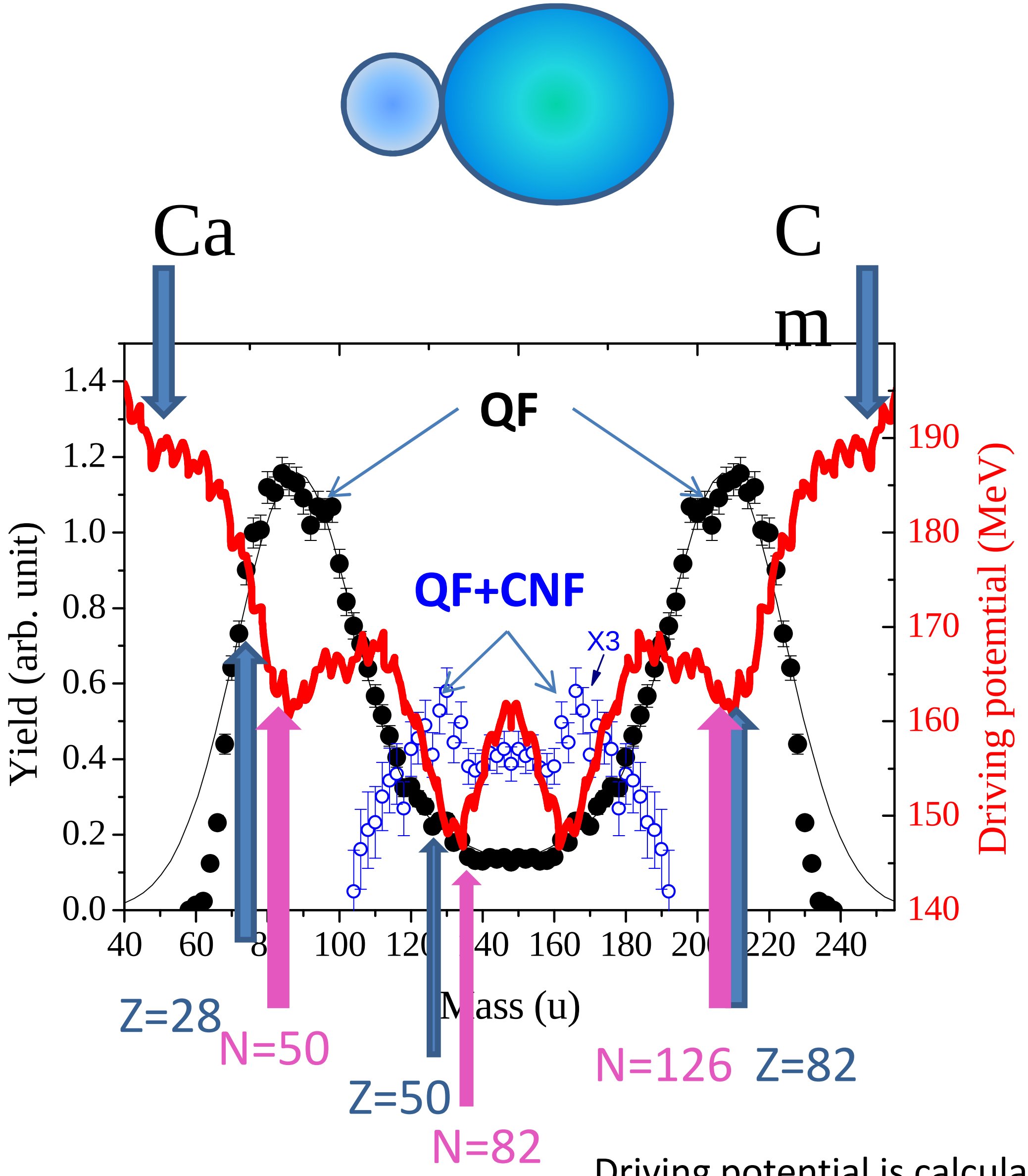


factor $\frac{1}{20}$ as compared to ^{48}Ca

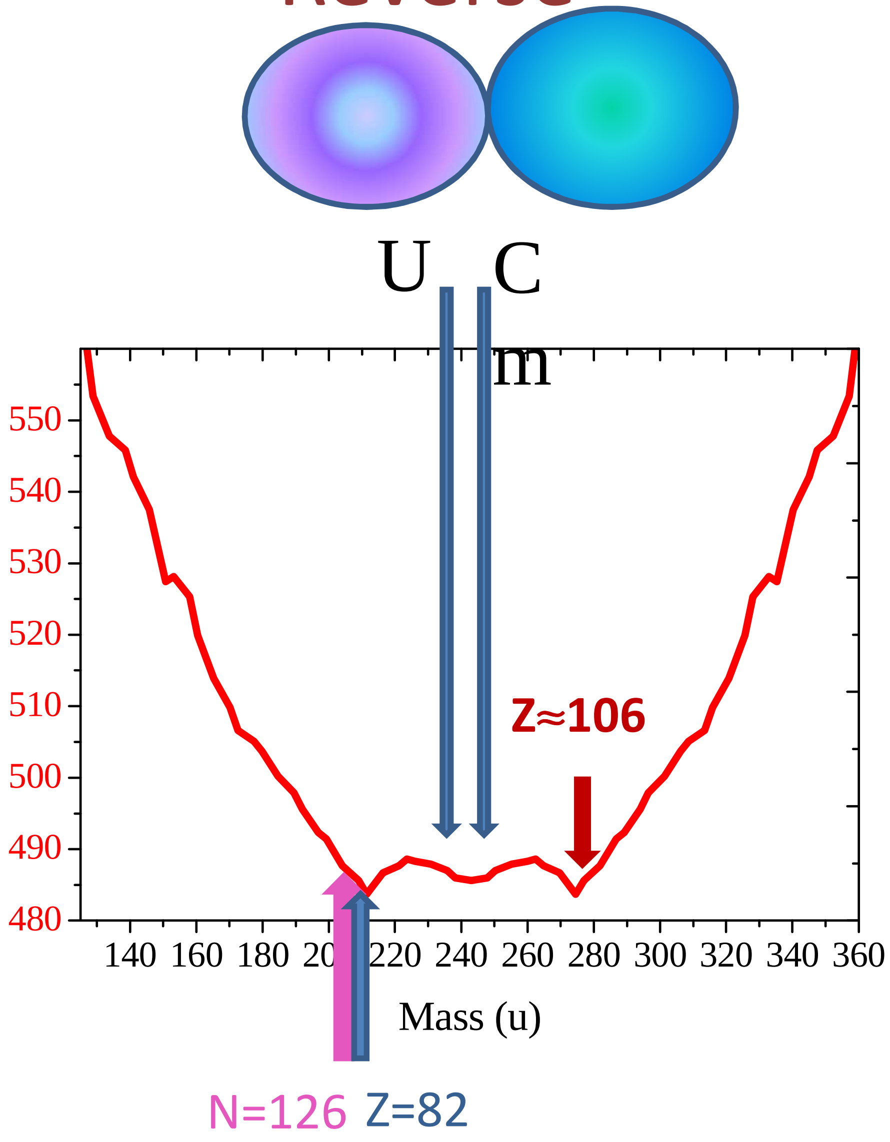
Probably these elements are the last ones
which will be synthesized in the nearest future

Asymmetric QF

Normal



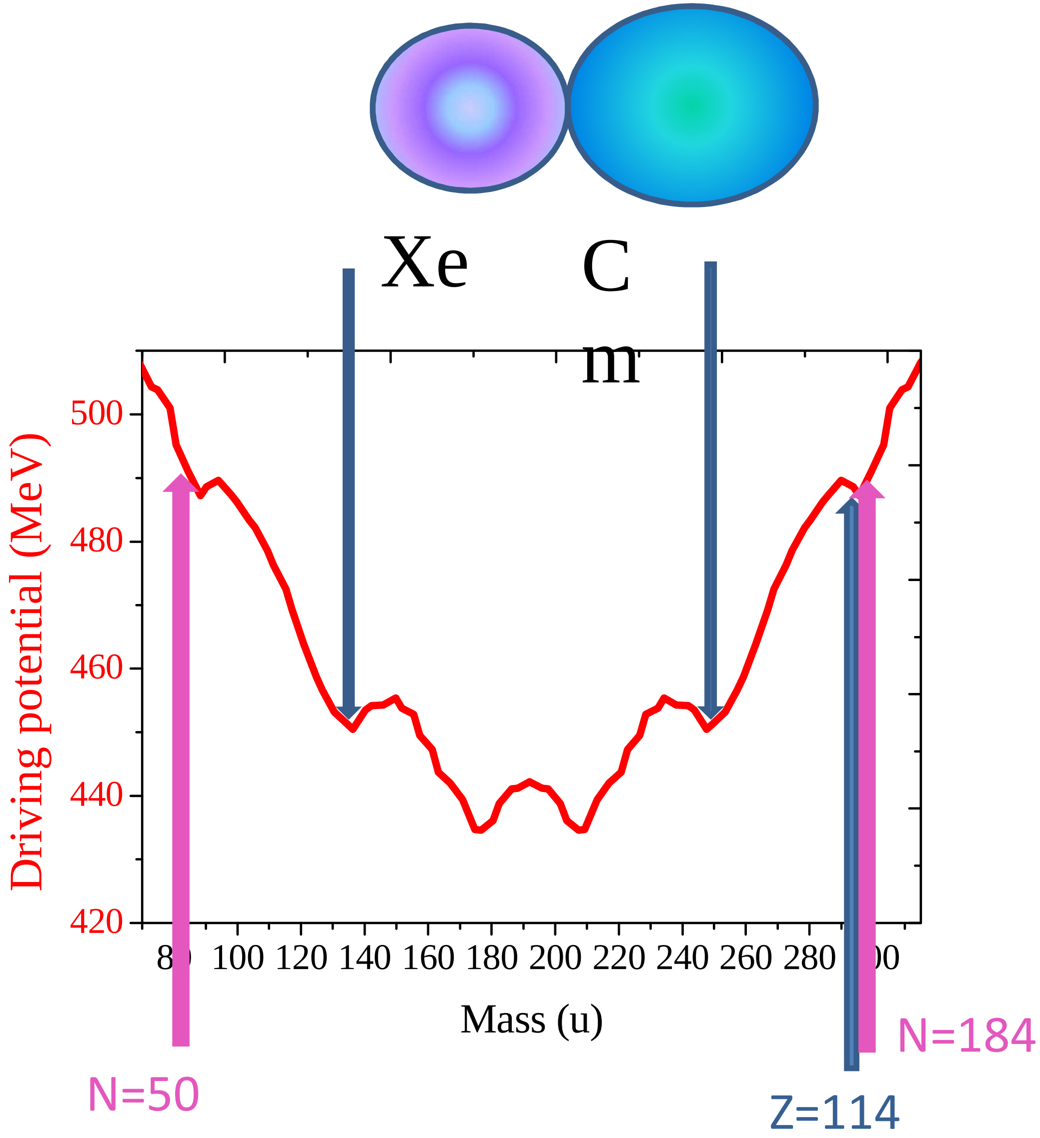
Reverse

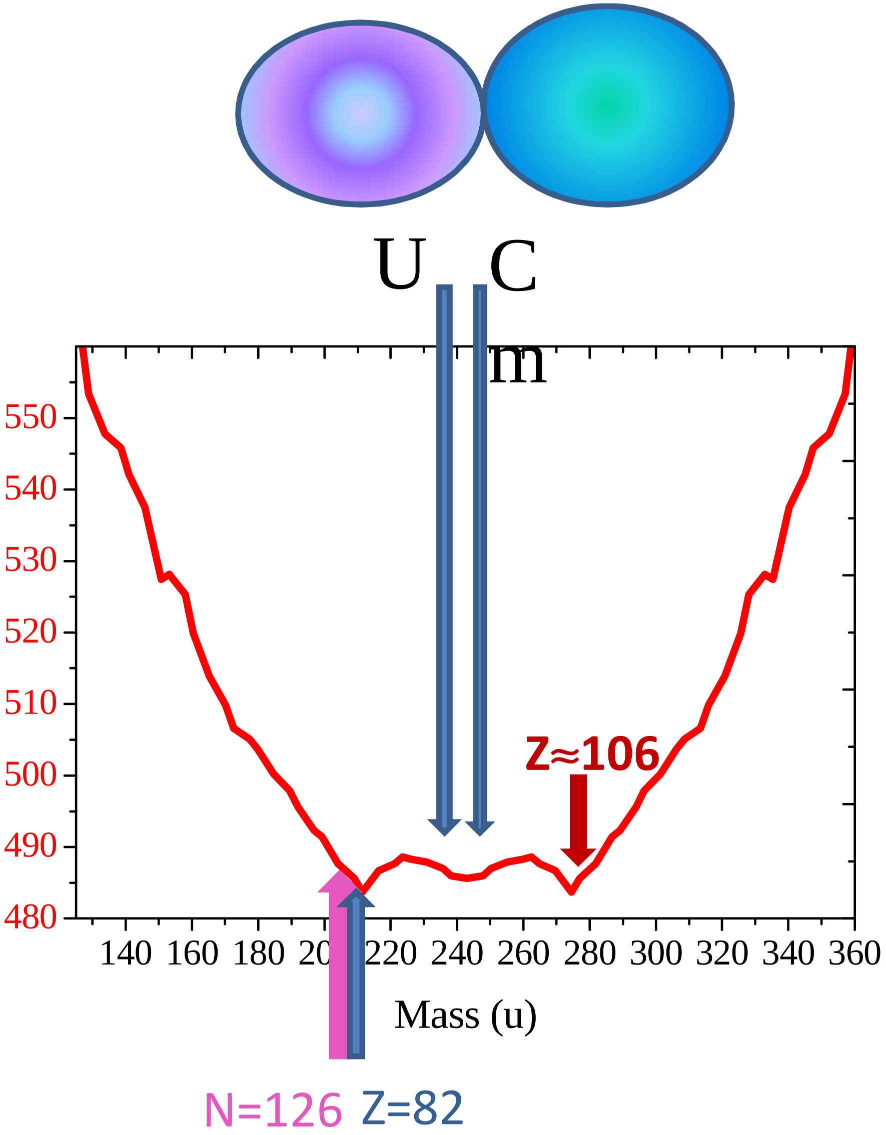


Driving potential is calculated near the scission point in nrv.jinr.ru (proximity model)

Asymmetric QF

Reverse

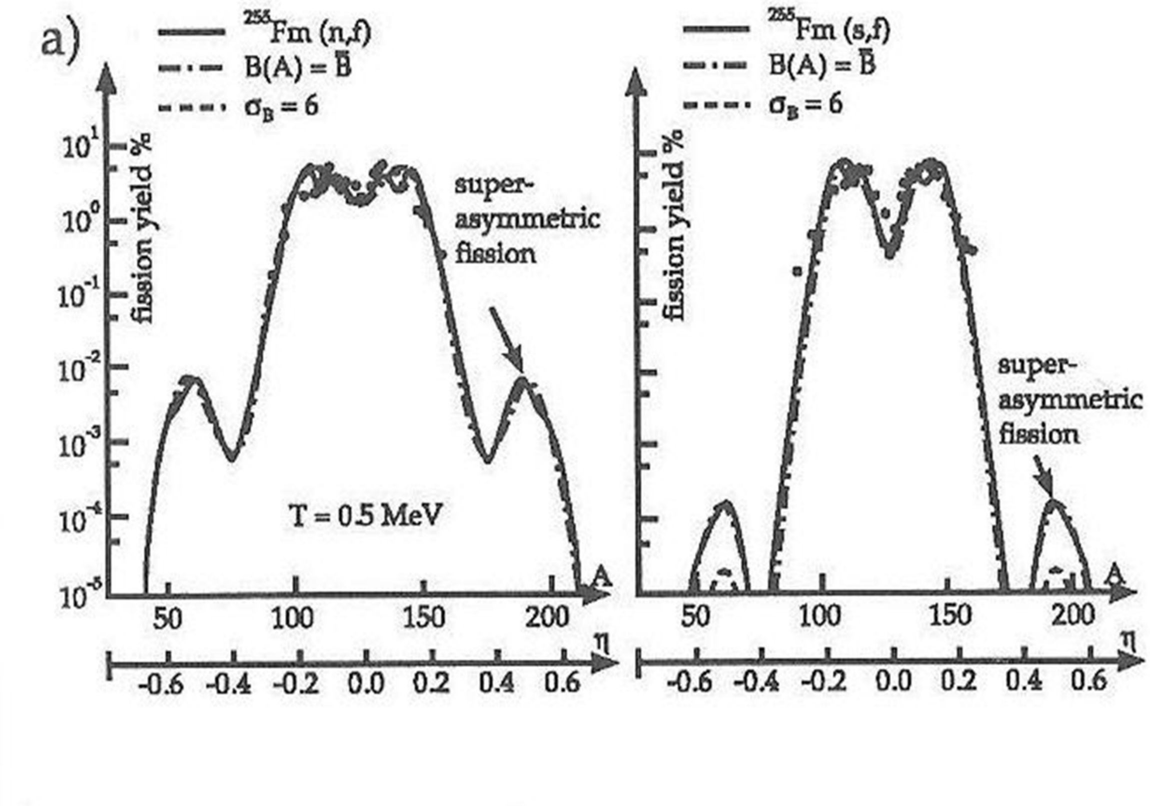


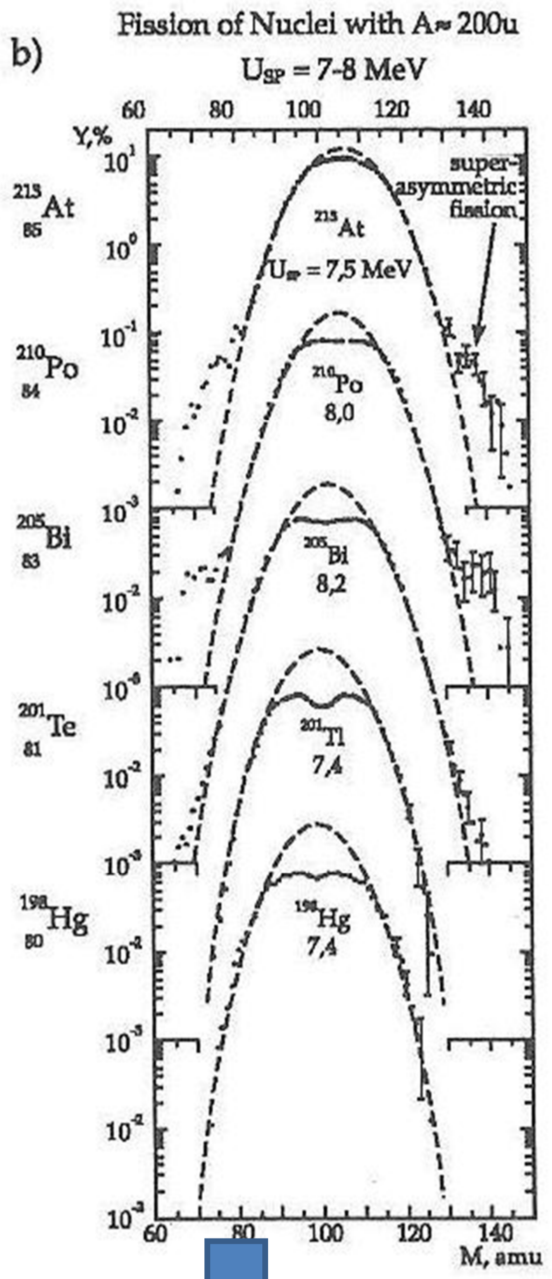


nrv.jinr.ru
(proximity model)

Superasymmetric fission of superheavy nuclei

W. Greiner (International Workshop on Fusion Dynamics at the Extremes, 25-27May 2000)

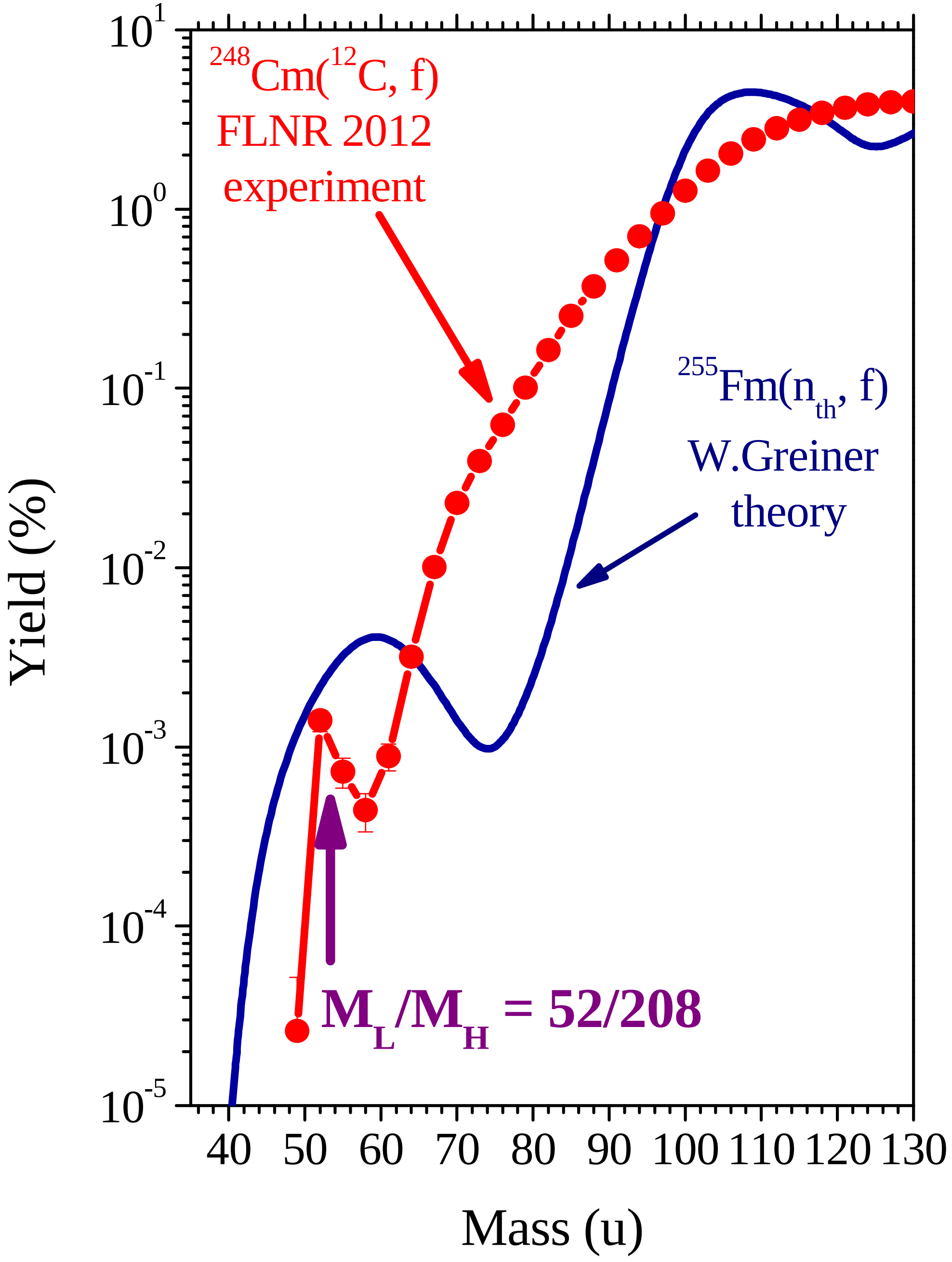




Superasymmetric fission of nuclei with A~200 u

M.G. Itkis, "Perspectives in Nuclear fission" Tokai, Japan, 14-16 March 2012

$^{12}C+^{248}Cm \rightarrow ^{260}No$



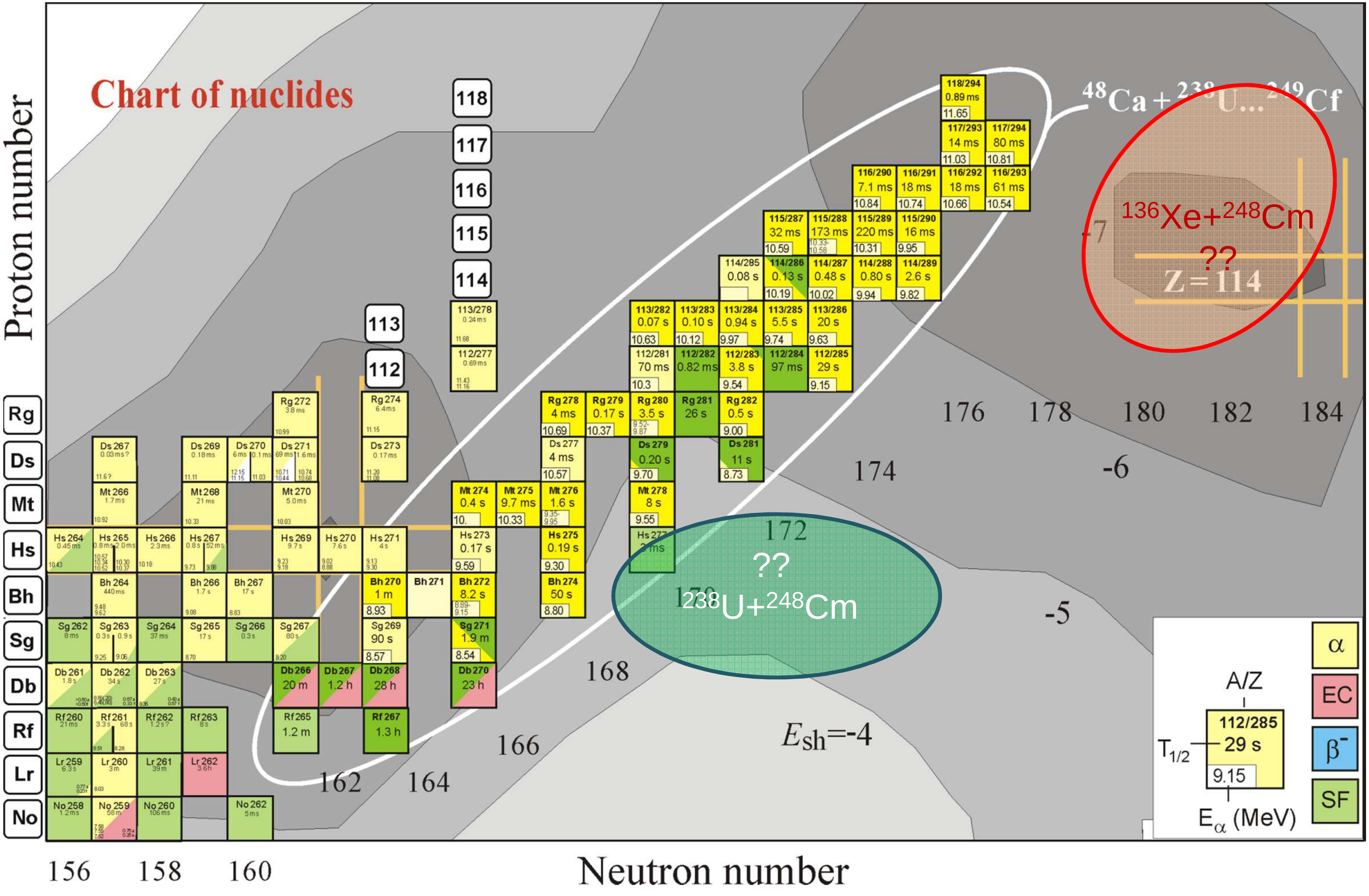
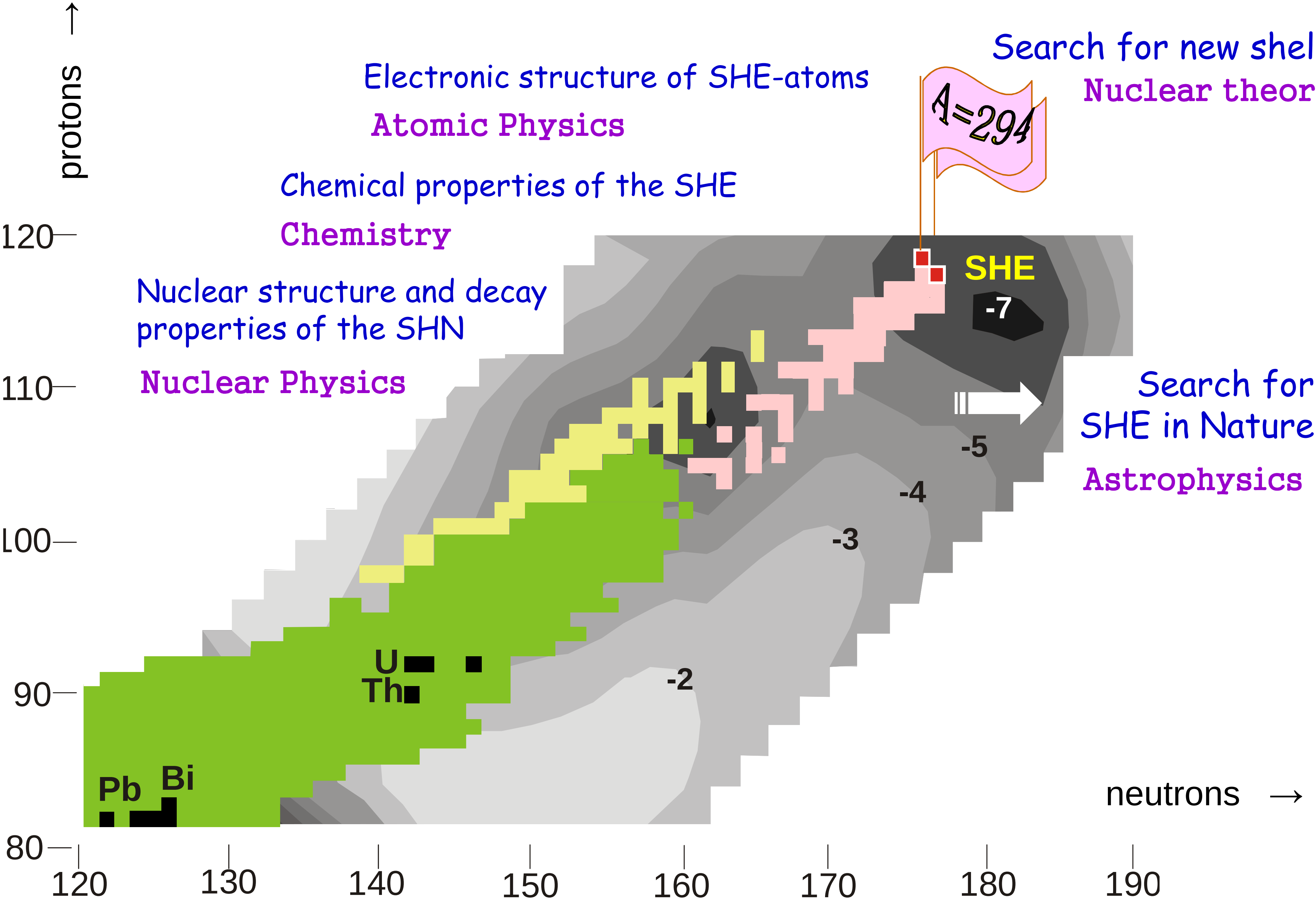


Chart of nuclides
Proton number
Neutron number
^{48}Ca + ^{238}U... ^{249}Cf
^{136}Xe+^{248}Cm
??
Z = 114
??
^{238}U+^{248}Cm
118
117
116
115
114
113
112
Rg
Ds
Mt
Hs
Bh
Sg
Db
Rf
Lr
No
156
158
160
162
164
166
168
170
172
174
176
178
180
182
184
E_{sh}=-4
-5
-6
-7
118/294 0.89 ms 11.65
117/293 14 ms 11.03
117/294 80 ms 10.81
116/290 7.1 ms 10.84
116/291 18 ms 10.74
116/292 18 ms 10.66
116/293 61 ms 10.54
115/287 32 ms 10.59
115/288 173 ms
115/289 220 ms 10.31
115/290 16 ms 9.95
114/285 0.08 s
114/286 0.13 s 10.19
114/287 0.48 s 10.02
114/288 0.80 s 9.94
114/289 2.6 s 9.82
113/282 0.07 s 10.63
113/283 0.10 s 10.12
113/284 0.94 s 9.97
113/285 5.5 s 9.74
113/286 20 s 9.63
112/281 70 ms 10.3
112/282 0.82 ms
112/283 3.8 s 9.54
112/284 97 ms
112/285 29 s 9.15
A/Z
$T_{1/2}$
E_α (MeV)
α
EC
$β^-$
SF



Electronic structure of SHE-atoms

Atomic Physics

Chemical properties of the SHE

Chemistry

Nuclear structure and decay properties of the SHN

Nuclear Physics

Search for new shells

Nuclear theory

Search for SHE in Nature

Astrophysics

SHE in Dubna

2012 – 2016

and after…

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

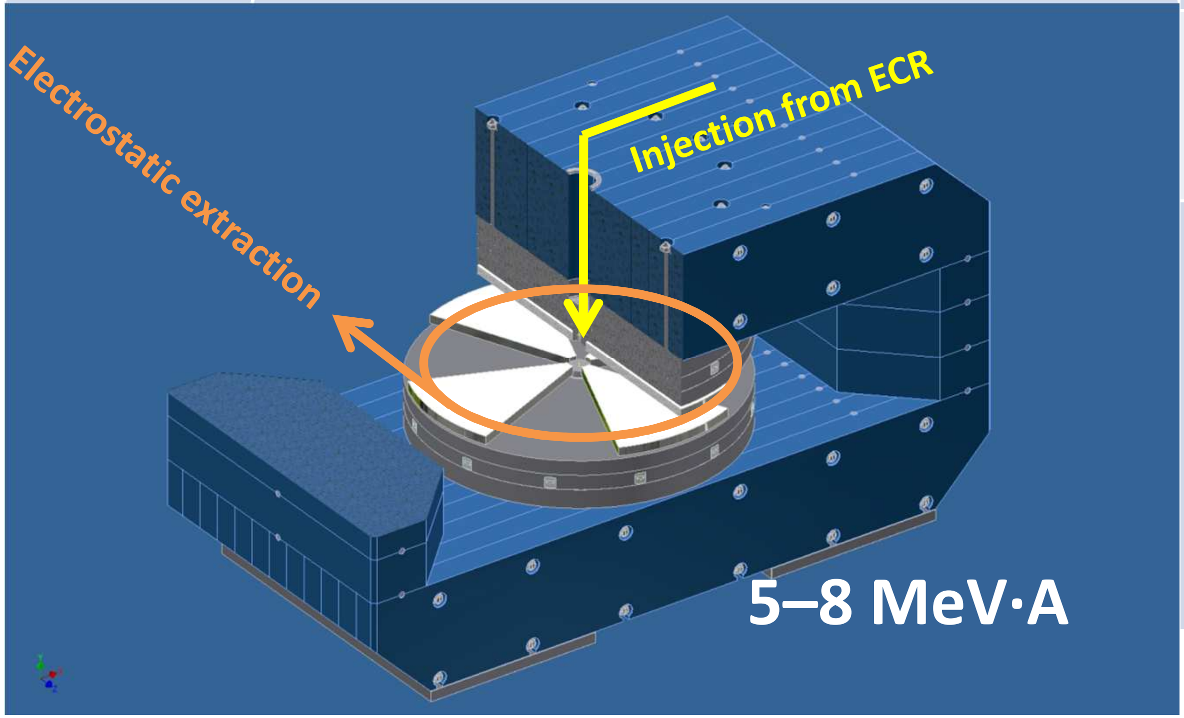
So I shall talk more about these opportunities and on our plans for the near and distant future.

Production

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

factor: 30

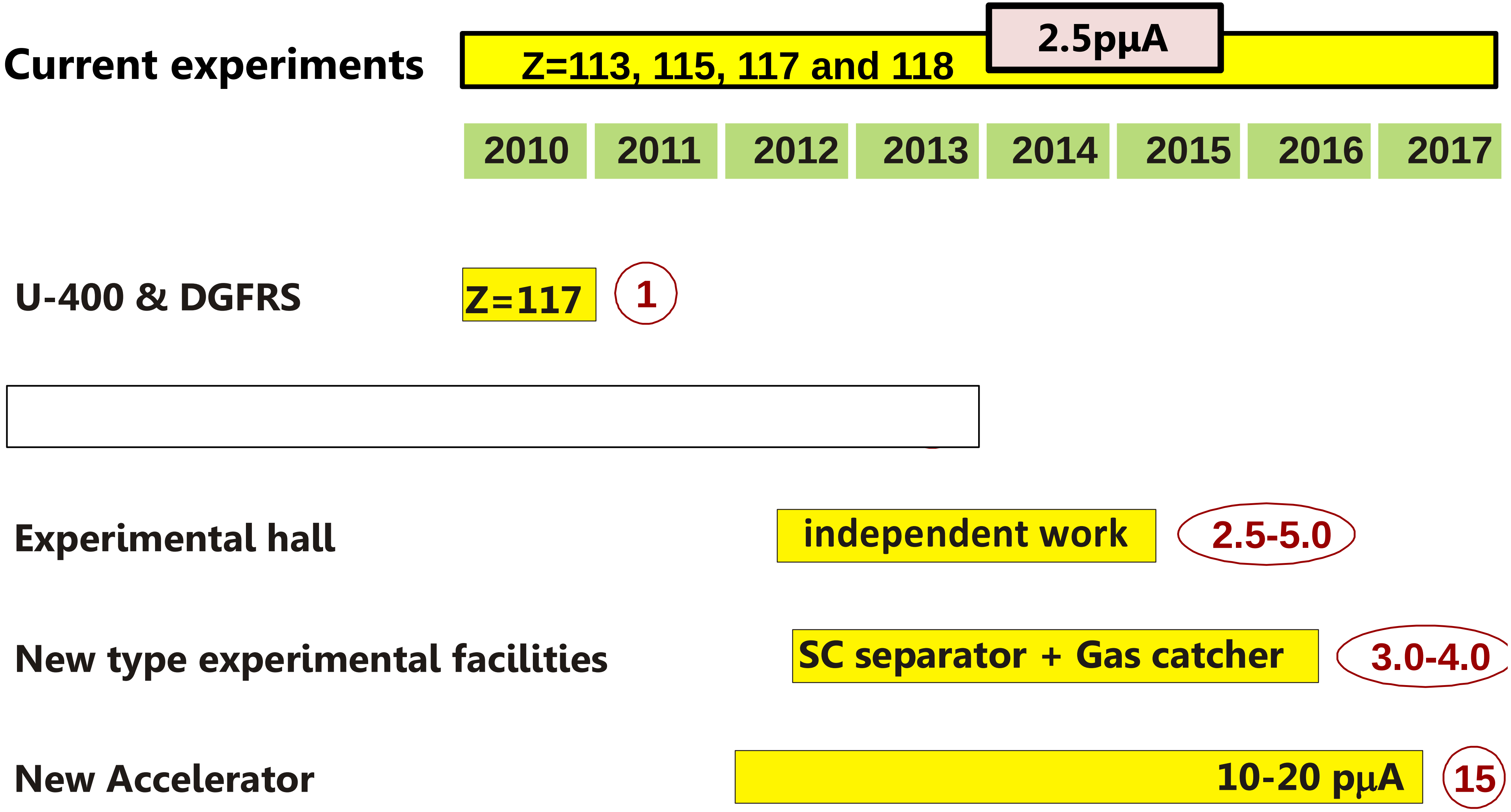
Increase a beam dose			
it requires to Increase:	**beam intensity**	and	**beam time**
	⇩		⇩
	New accelerator		**SHE-Factory**
			⇩ **~ 7000 h/year**
			⇩ **new laboratory**



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

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

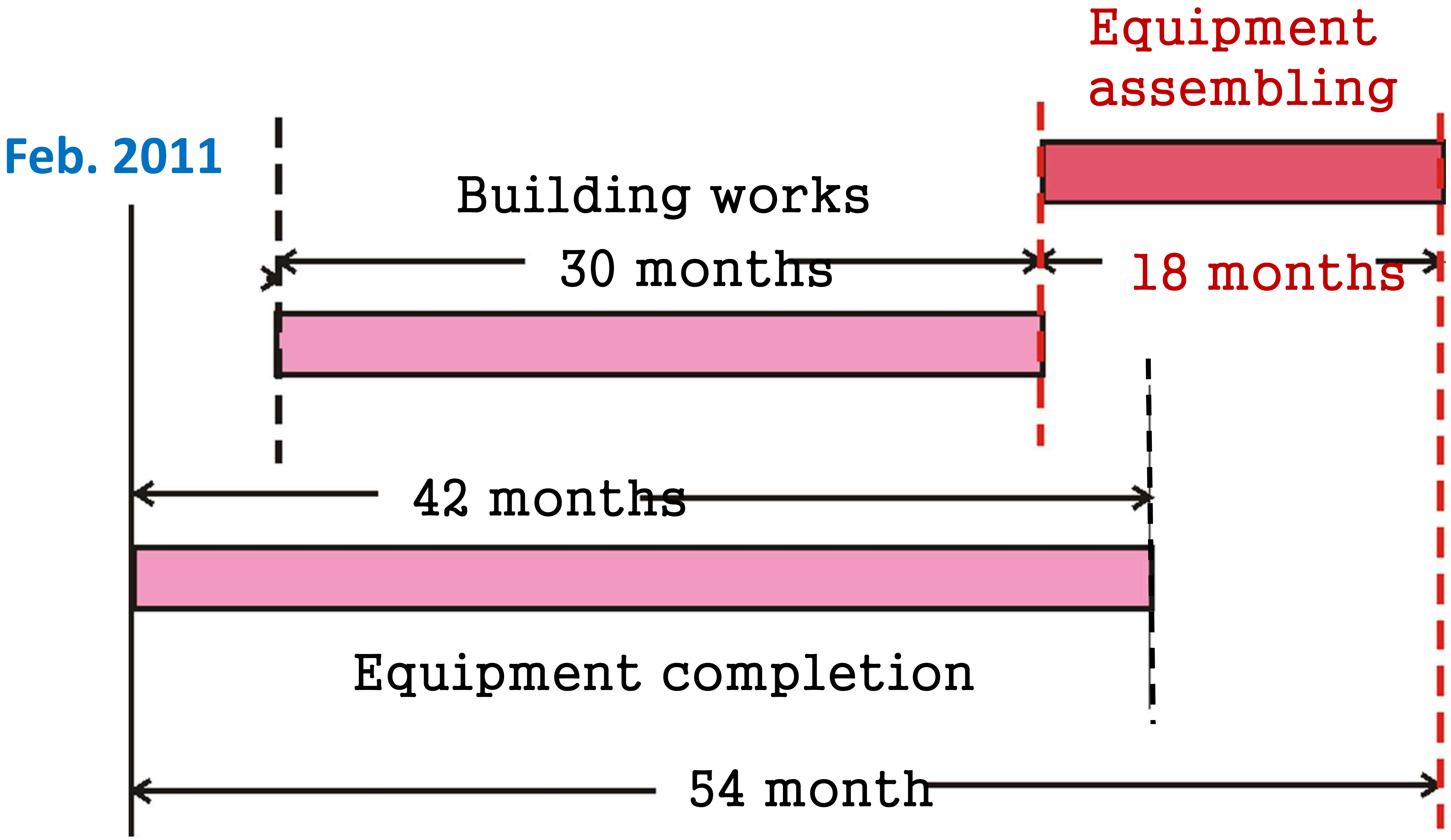
15

FLNR backside in January 2012

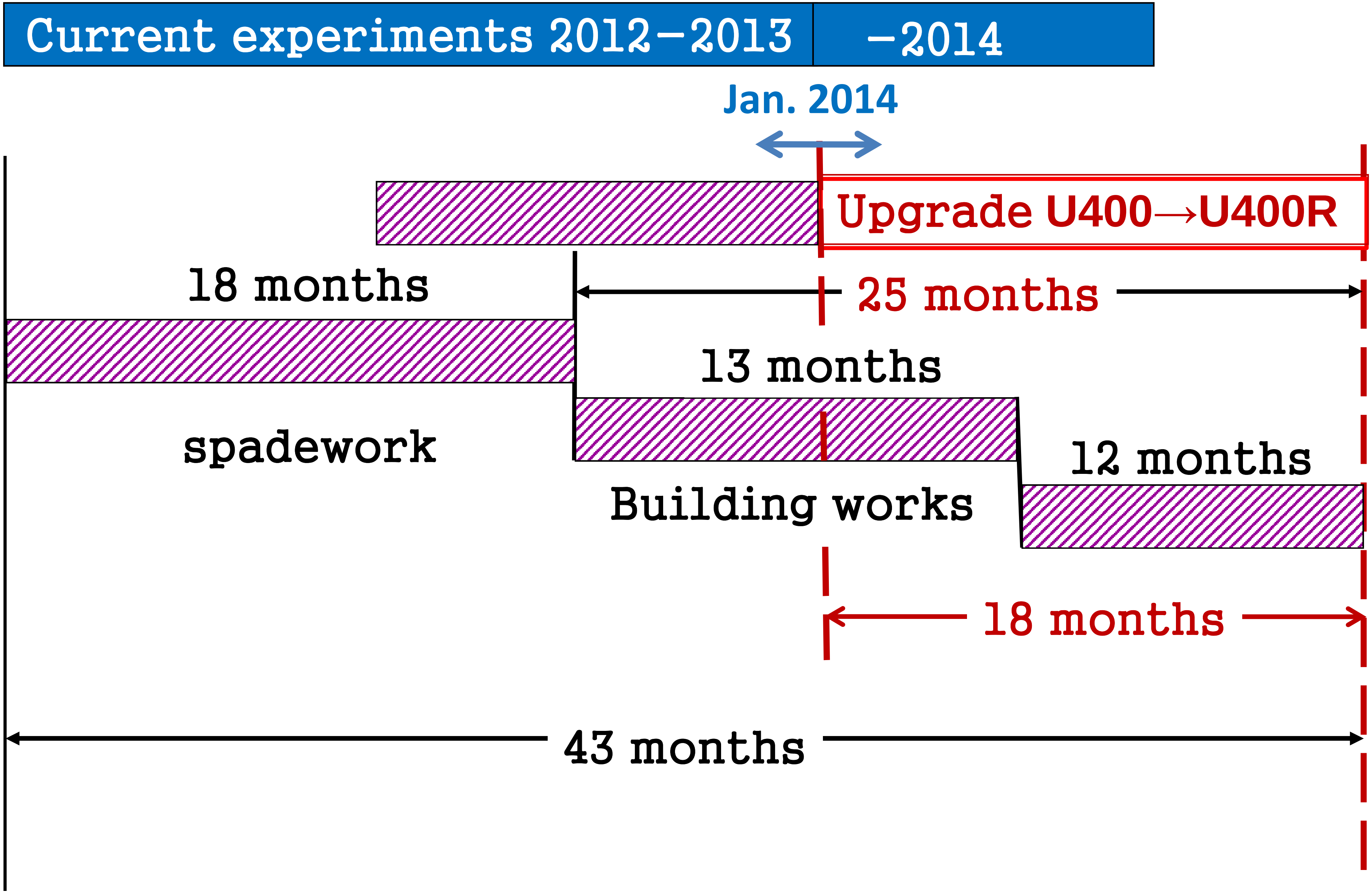
SHE-Factory

April 16, 2012 SHE factory

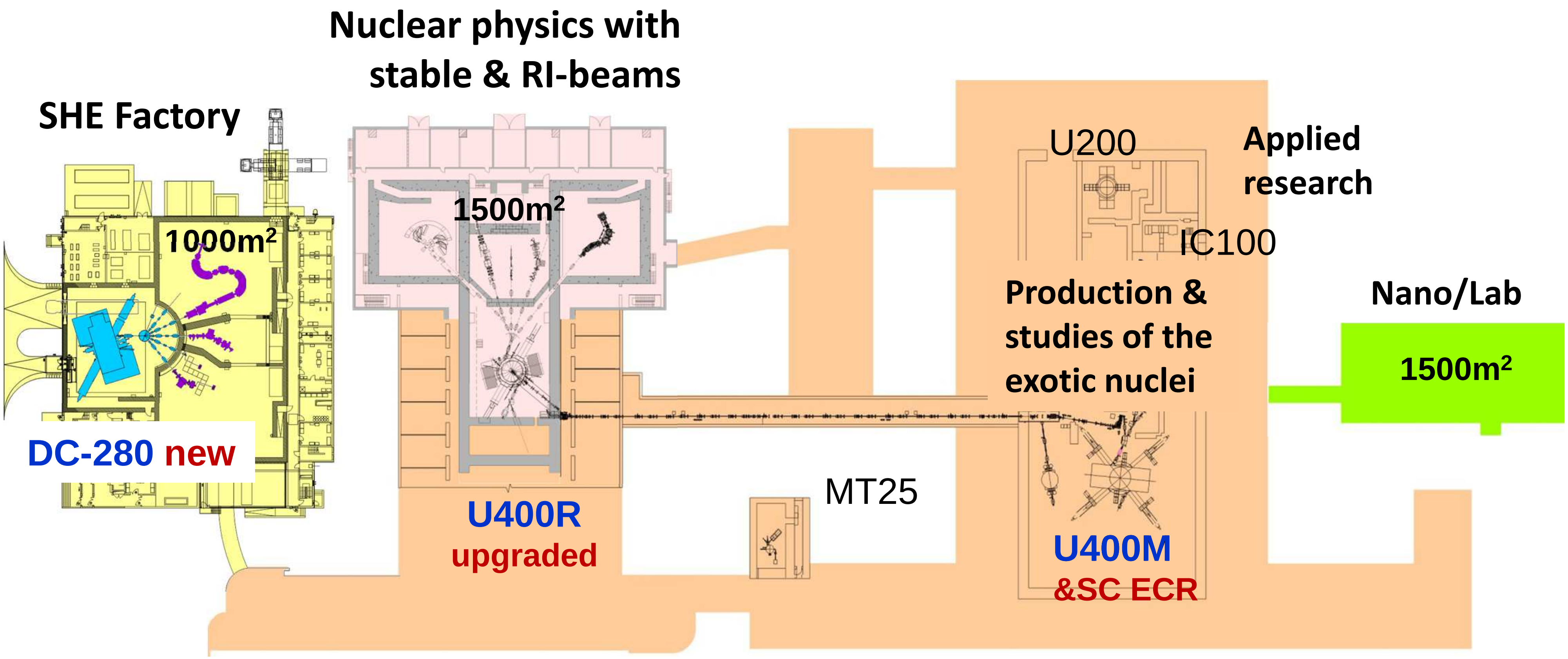
Schedule for SHE-Factory



Schedule for U400R



FLNR (JINR) – 2016



U400M-U400R Accelerator Complex

Conclusion

- **While the relative contribution of QF to the capture cross section mainly depends on the reaction entrance channel properties, the features of asymmetric QF are determined essentially by the driving potential of a composite system.**
- **The fragment yield increases when the both formed fragments are close to nuclear shells as in the case of QF (asymmetric QF), as well as in the case of fusion-fission (bimodal fission, asymmetric fission, superasymmetric fission) .**
- **At the transition from Ca to Ni projectiles the contribution of QF process rises sharply and Ni ions is not suitable for the synthesis of element Z=120 in the complete fusion reactions.**
- **An alternative way for further progress in SHE can be achieved using the deep-inelastic or QF reactions. To estimate the formation probabilities of SHE in these reactions the additional investigations are needed.**