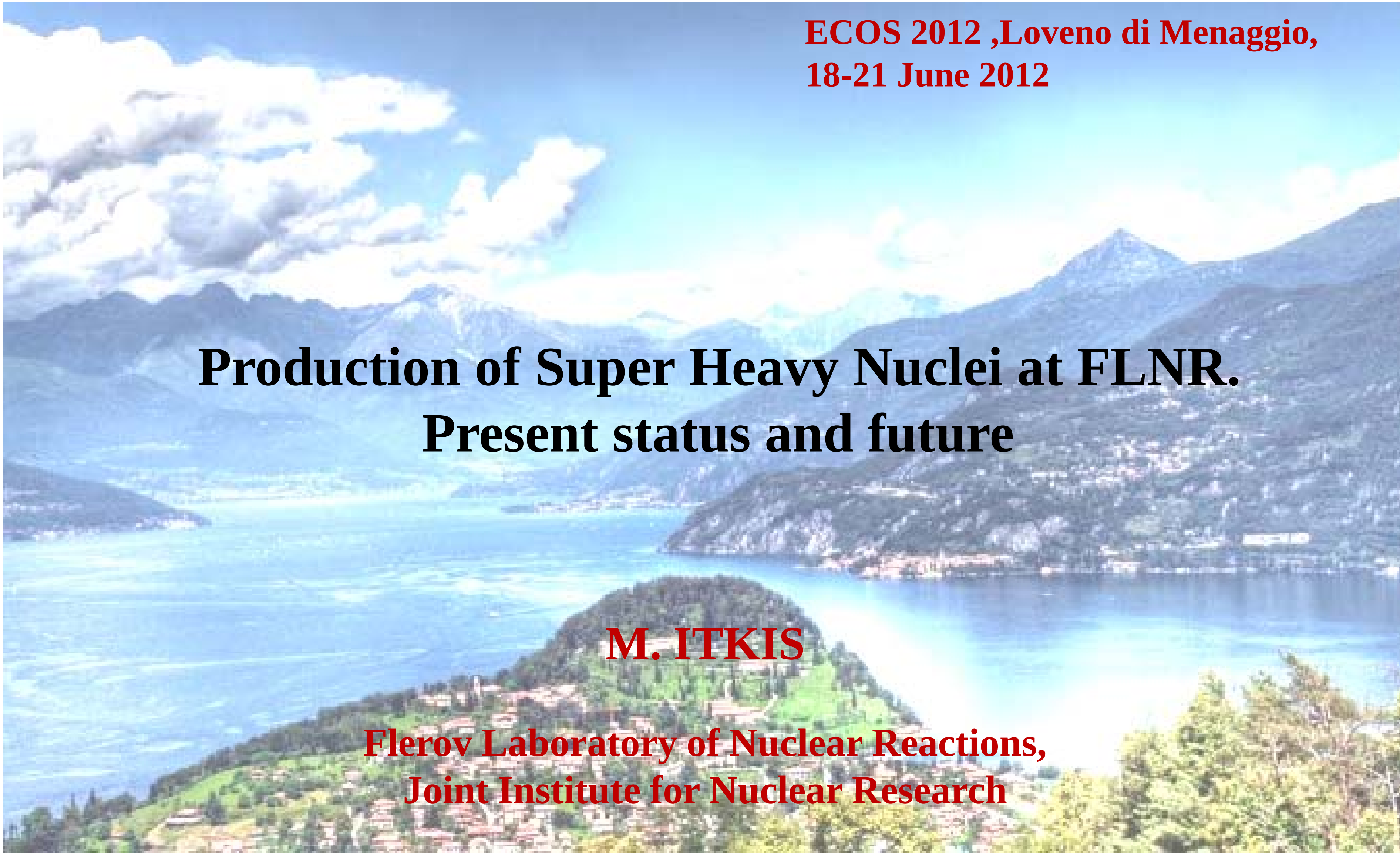


ECOS 2012 ,Loveno di Menaggio,
18-21 June 2012

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:

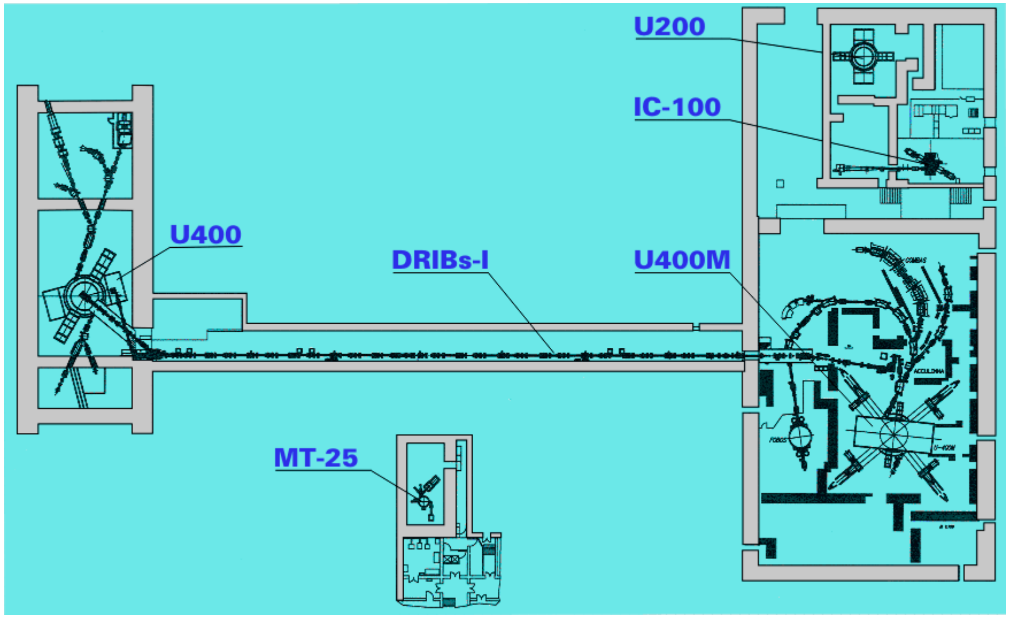
- synthesis and study of properties of superheavy elements;
- chemistry of new elements;
- fusion-fission and multi-nucleon transfer reactions;
- nuclear- , mass-, & laser-spectrometry of SH nuclei.

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.

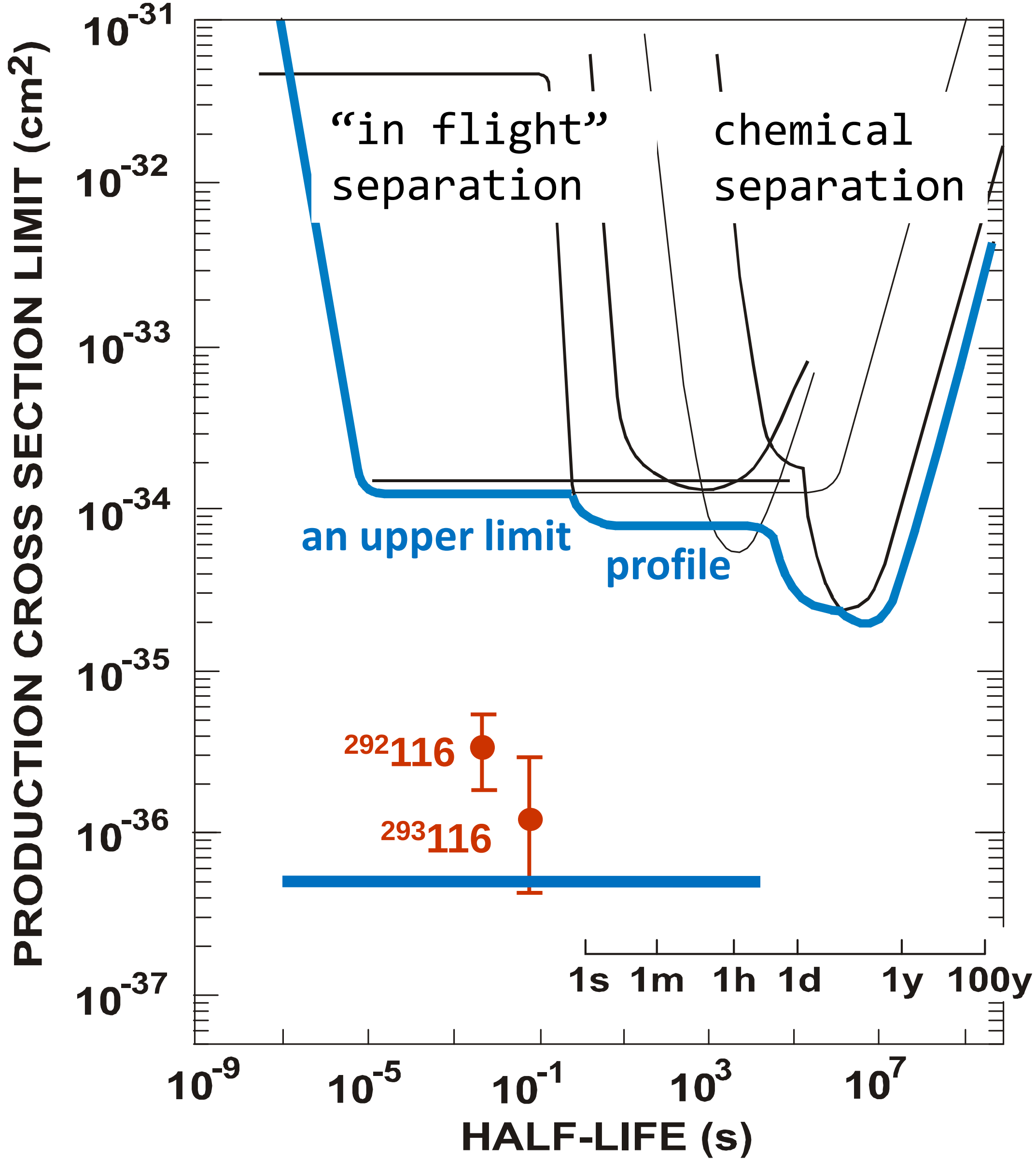
Search for Element 116 in $^{248}Cm + ^{48}Ca$ reaction

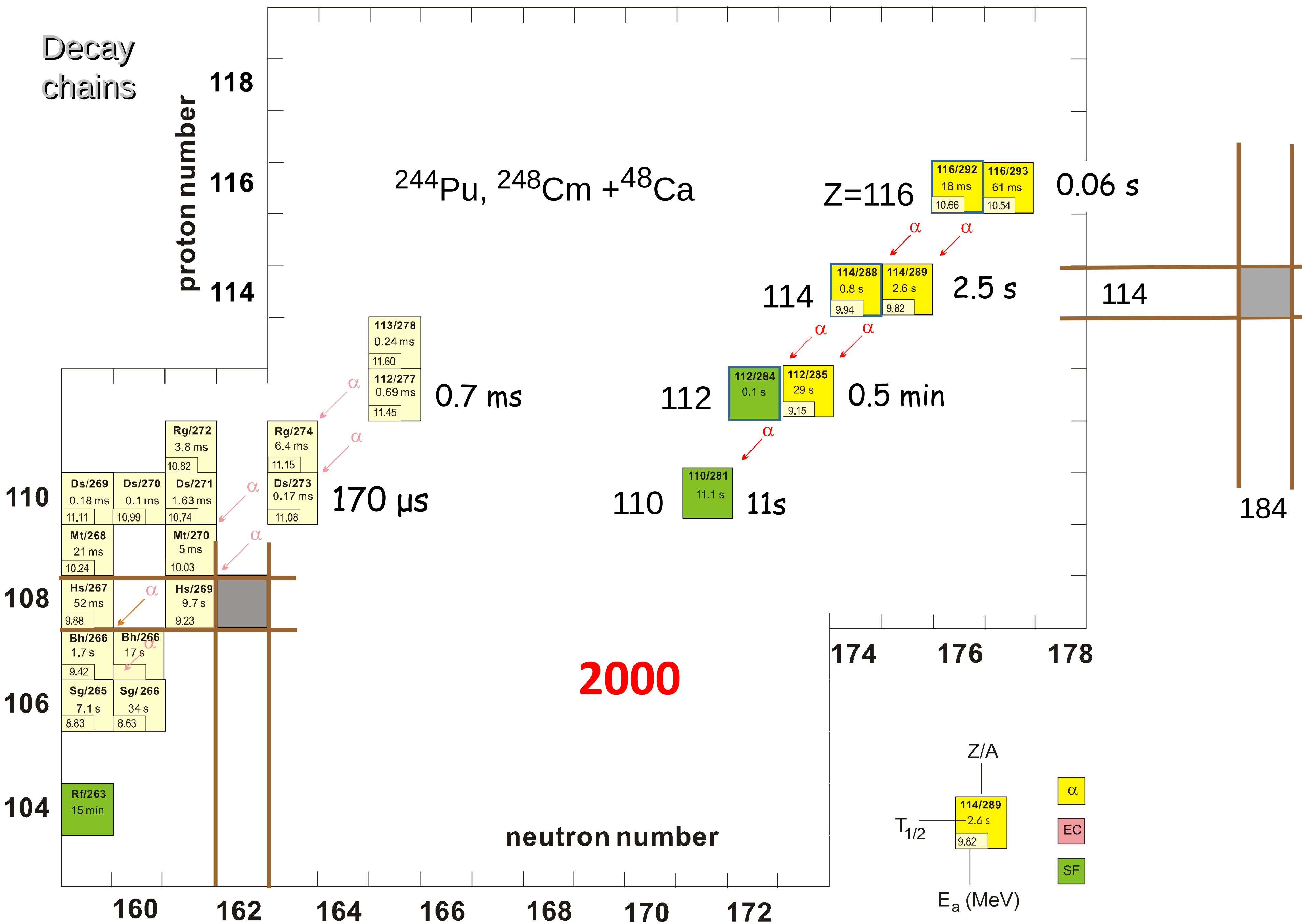
GSI, Darmstadt, Germany*
LBL, UC Berkeley, CA
Univ. of Mainz, Germany
LANL, Los Alamos, NM
EIR, Würenlingen, Switzerland

1985

FLNR, Dubna
LLNL, Livermore

2000




Decay chains
proton number
neutron number
118
116
114
110
108
106
104
160
162
164
166
168
170
172
174
176
178
184
244Pu, 248Cm +48Ca
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
2000
Z/A
114/289
2.6 s
9.82
T1/2
Ea (MeV)
α
EC
SF

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

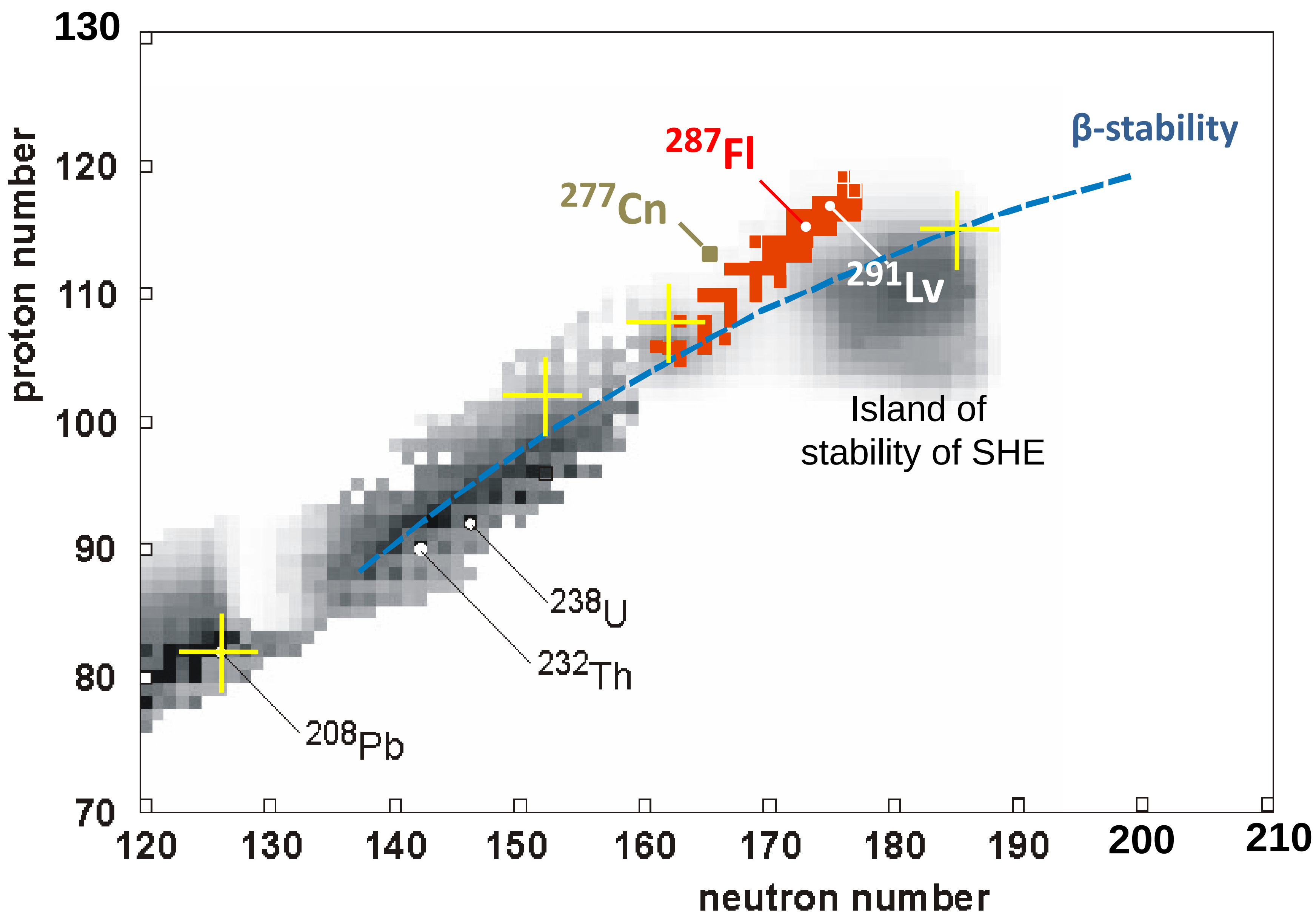
Press Release 30.05.2012 21:27

Element 114 is Named Flerovium and Element 116 is Named Livermorium

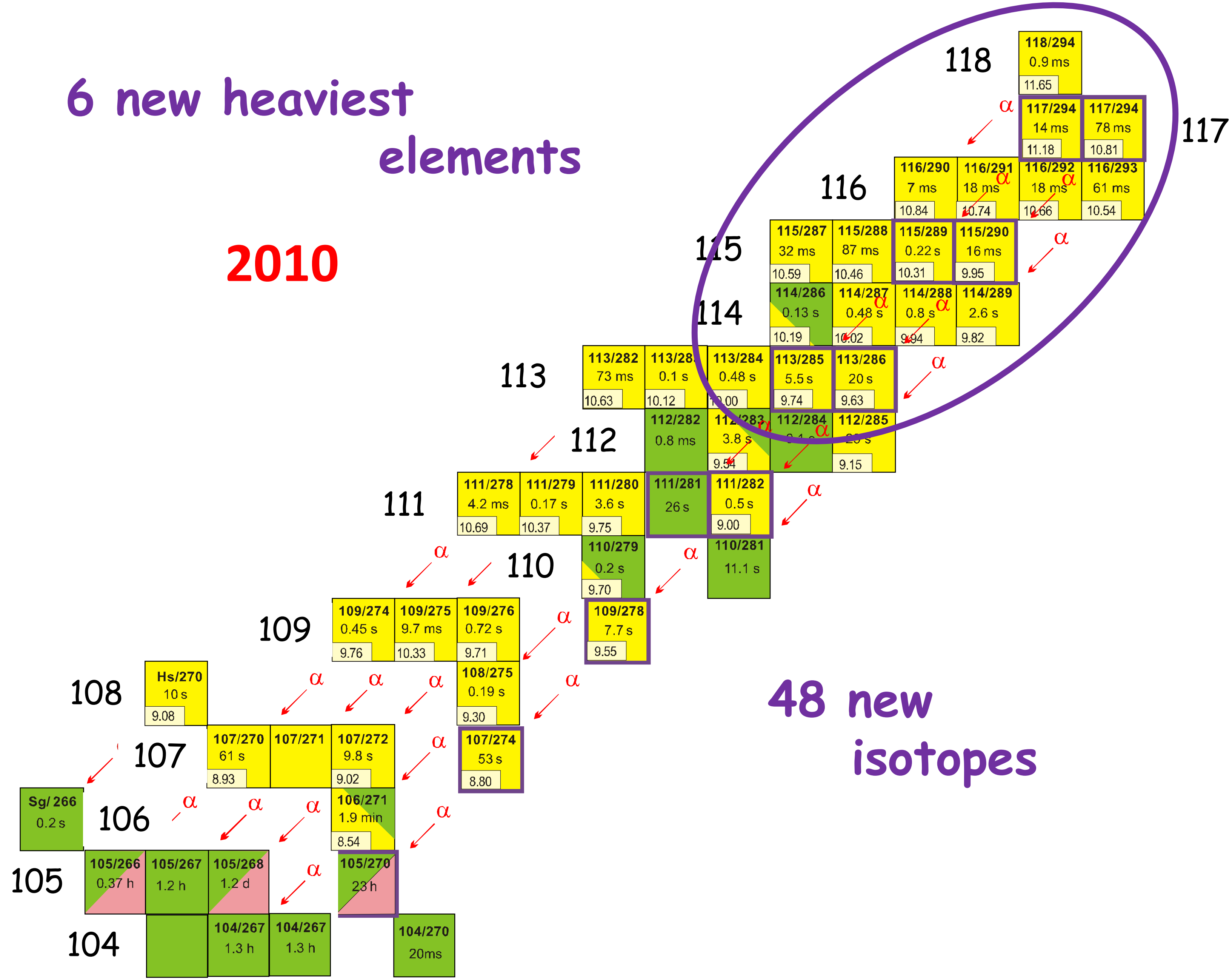
Priority for the discovery of these elements was assigned to the collaboration between the Joint Institute for Nuclear Research (Dubna, Russia) and the Lawrence Livermore National Laboratory (Livermore, California, USA).

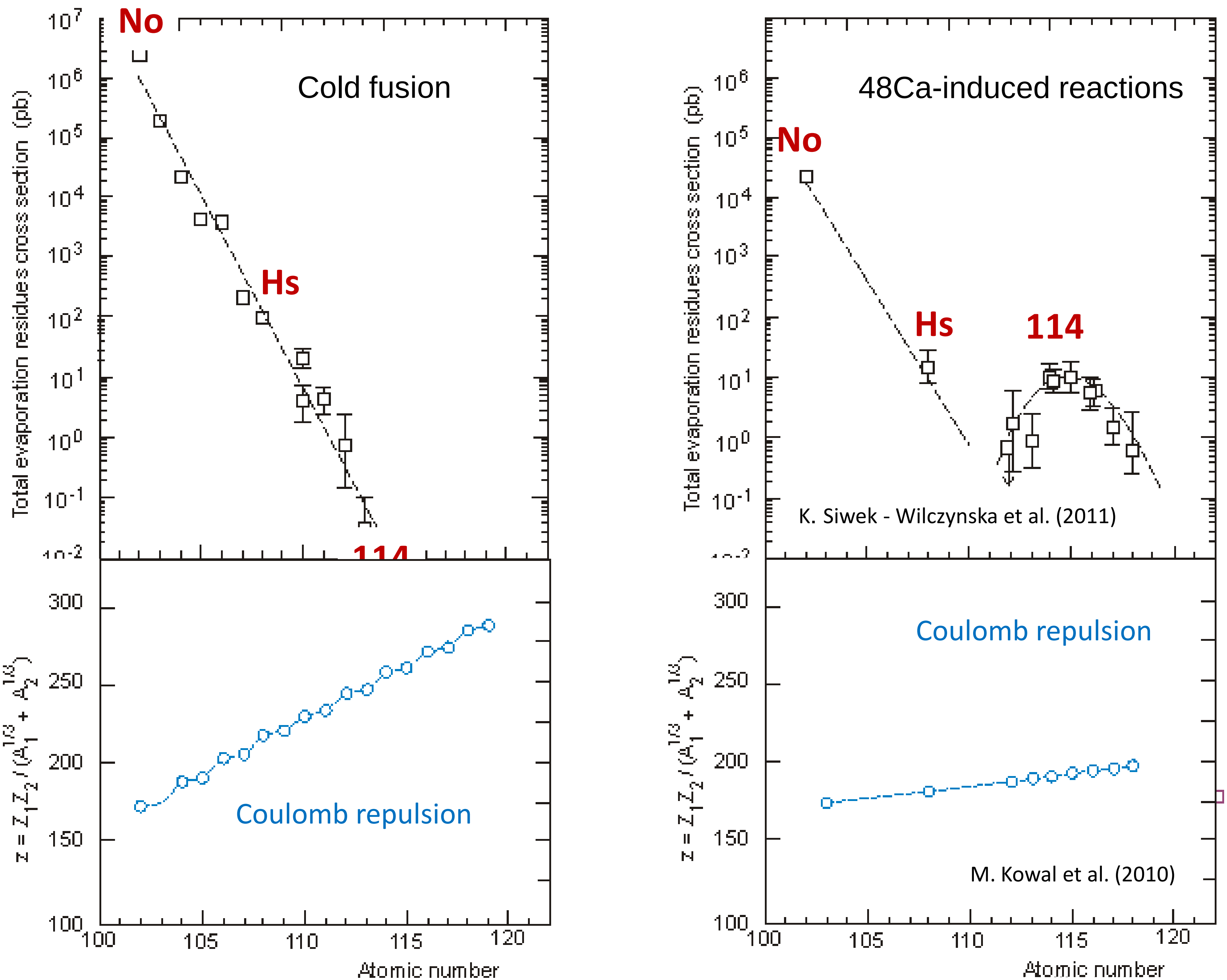
The name flerovium will honor the Flerov Laboratory of Nuclear Reactions where superheavy elements are synthesised. Georgiy N. Flerov (1913 – 1990) – was a renowned physicist, author of the discovery of the spontaneous fission of uranium, pioneer in heavy-ion physics, and founder in the Joint Institute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

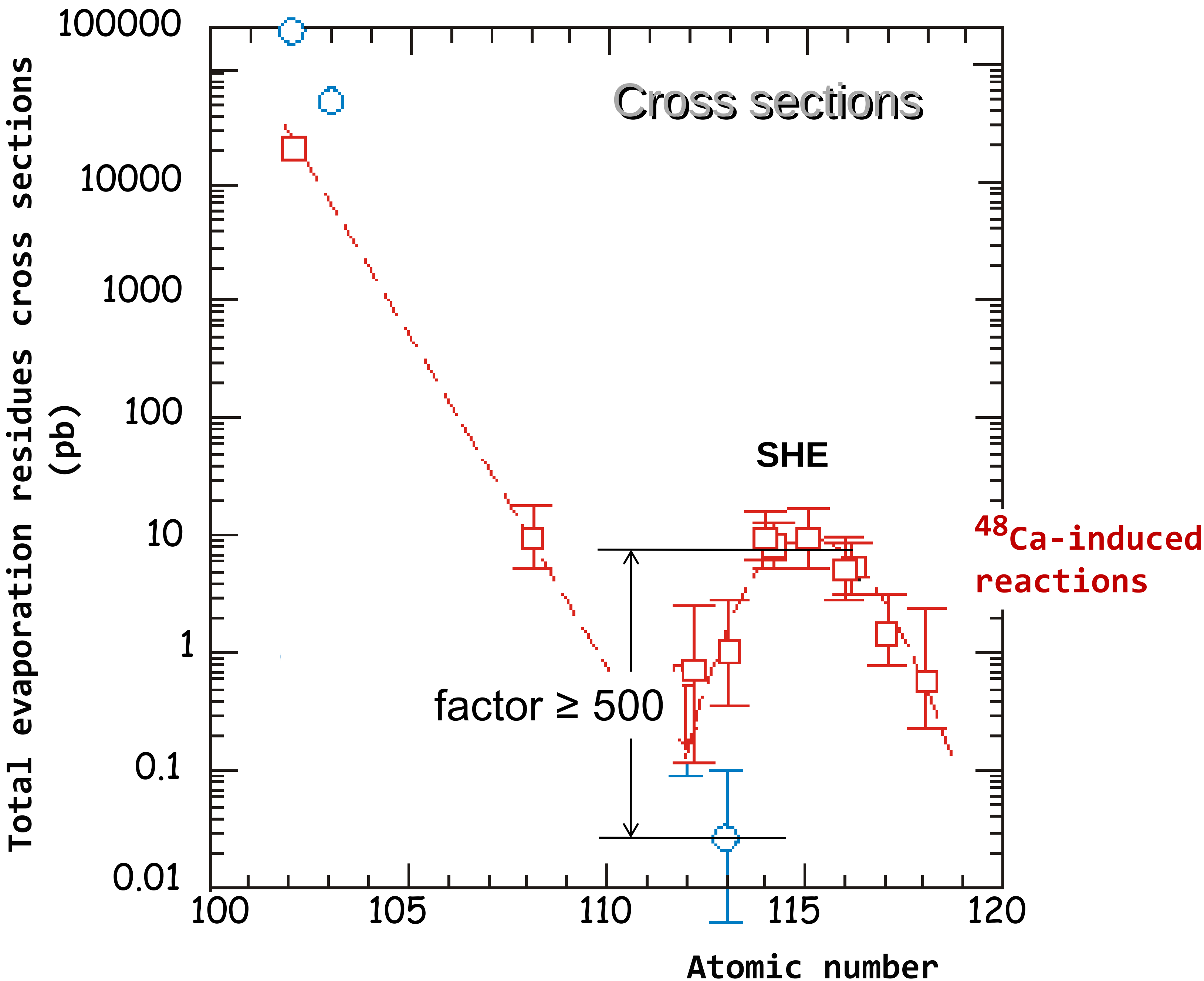


130
120
110
100
90
80
70
proton number
120
130
140
150
160
170
180
190
200
210
neutron number
287Fl
277Cn
291Lv
β-stability
Island of
stability of SHE
238U
232Th
208Pb


6 new heaviest elements
2010
48 new isotopes
118
117
116
115
114
113
112
111
110
109
108
107
106
105
104
118/294
0.9 ms
11.65
117/294
14 ms
11.18
117/294
78 ms
10.81
116/290
7 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
87 ms
10.46
115/289
0.22 s
10.31
115/290
16 ms
9.95
114/286
0.13 s
10.19
114/287
0.48 s
10.02
114/288
0.8 s
9.94
114/289
2.6 s
9.82
113/282
73 ms
10.63
0.1 s
10.12
113/284
0.48 s
113/285
5.5 s
9.74
113/286
20 s
9.63
112/282
0.8 ms
3.8 s
112/284
112/285
9.15
111/278
4.2 ms
10.69
111/279
0.17 s
10.37
111/280
3.6 s
9.75
111/281
26 s
111/282
0.5 s
9.00
110/279
0.2 s
9.70
110/281
11.1 s
109/274
0.45 s
9.76
109/275
9.7 ms
10.33
109/276
0.72 s
9.71
109/278
7.7 s
9.55
108/275
0.19 s
9.30
Hs/270
10 s
9.08
107/270
61 s
8.93
107/271
107/272
9.8 s
9.02
107/274
53 s
8.80
106/271
1.9 min
8.54
Sg/266
0.2 s
105/266
0.37 h
105/267
1.2 h
105/268
1.2 d
105/270
23 h
104/267
1.3 h
104/267
1.3 h
104/270
20ms
α



No
Cold fusion
Hs
114
Total evaporation residues cross section (pb)
Coulomb repulsion
$z = Z_1Z_2/(A_1^{1/3} + A_2^{1/3})$
Atomic number
48Ca-induced reactions
No
Hs
114
K. Siwek - Wilczynska et al. (2011)
Coulomb repulsion
M. Kowal et al. (2010)

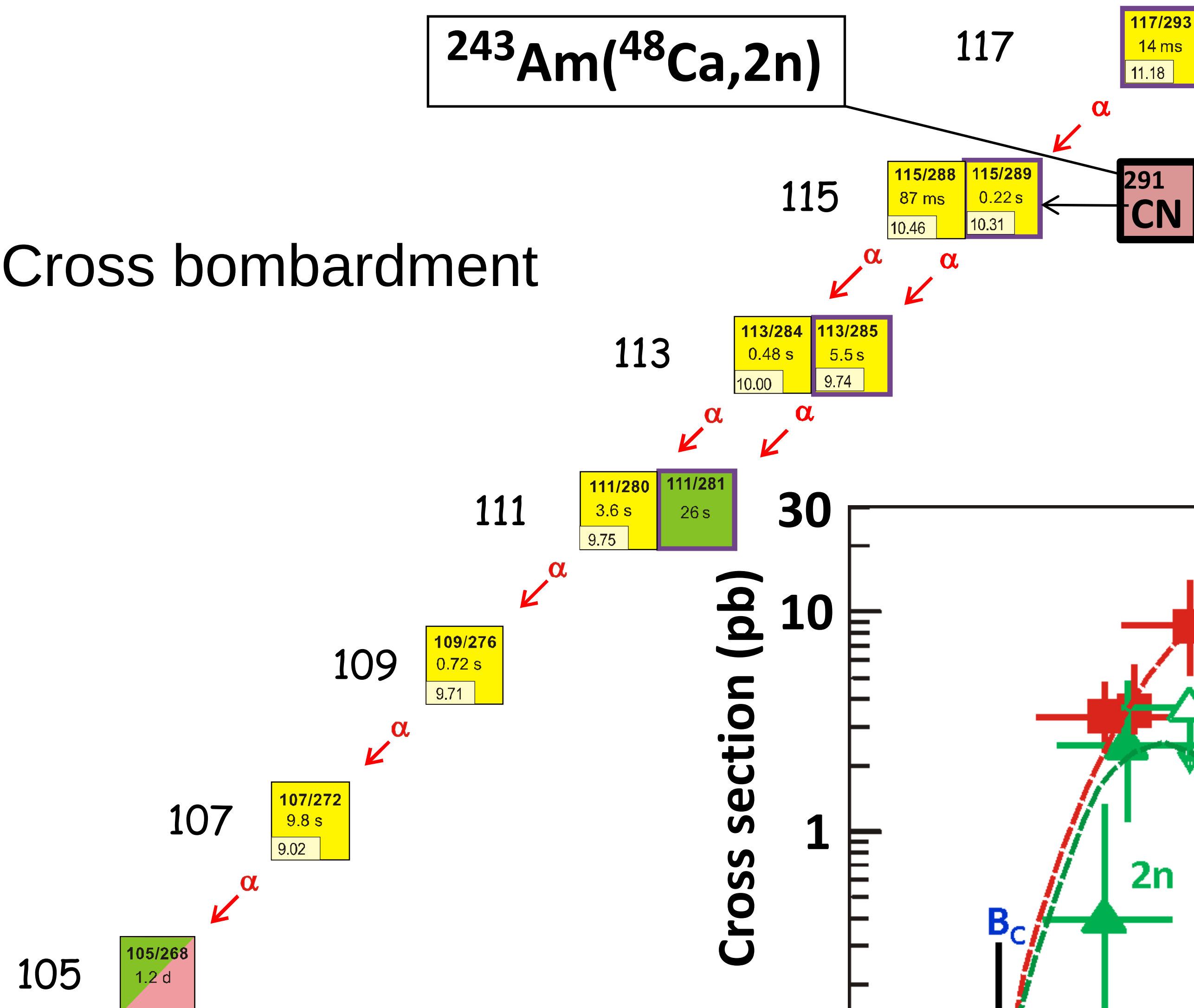


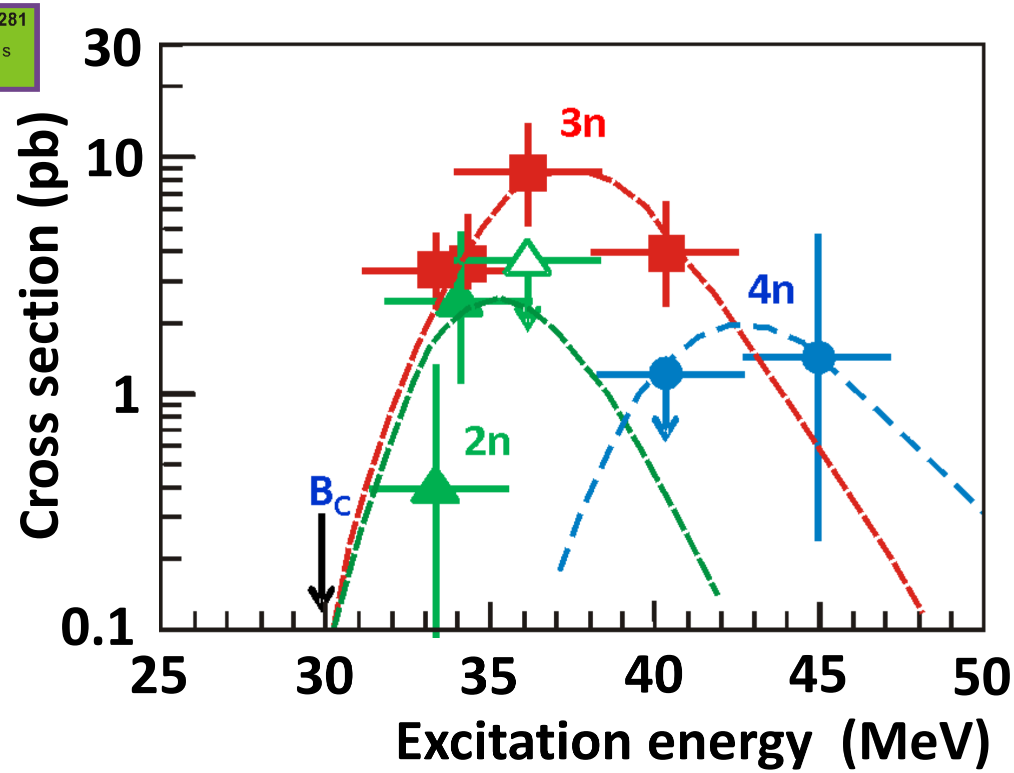
Cross sections
Total evaporation residues cross sections (pb)
100000
10000
1000
100
10
1
0.1
0.01
100
105
110
115
120
Atomic number
SHE
factor ≥ 500
48Ca-induced reactions

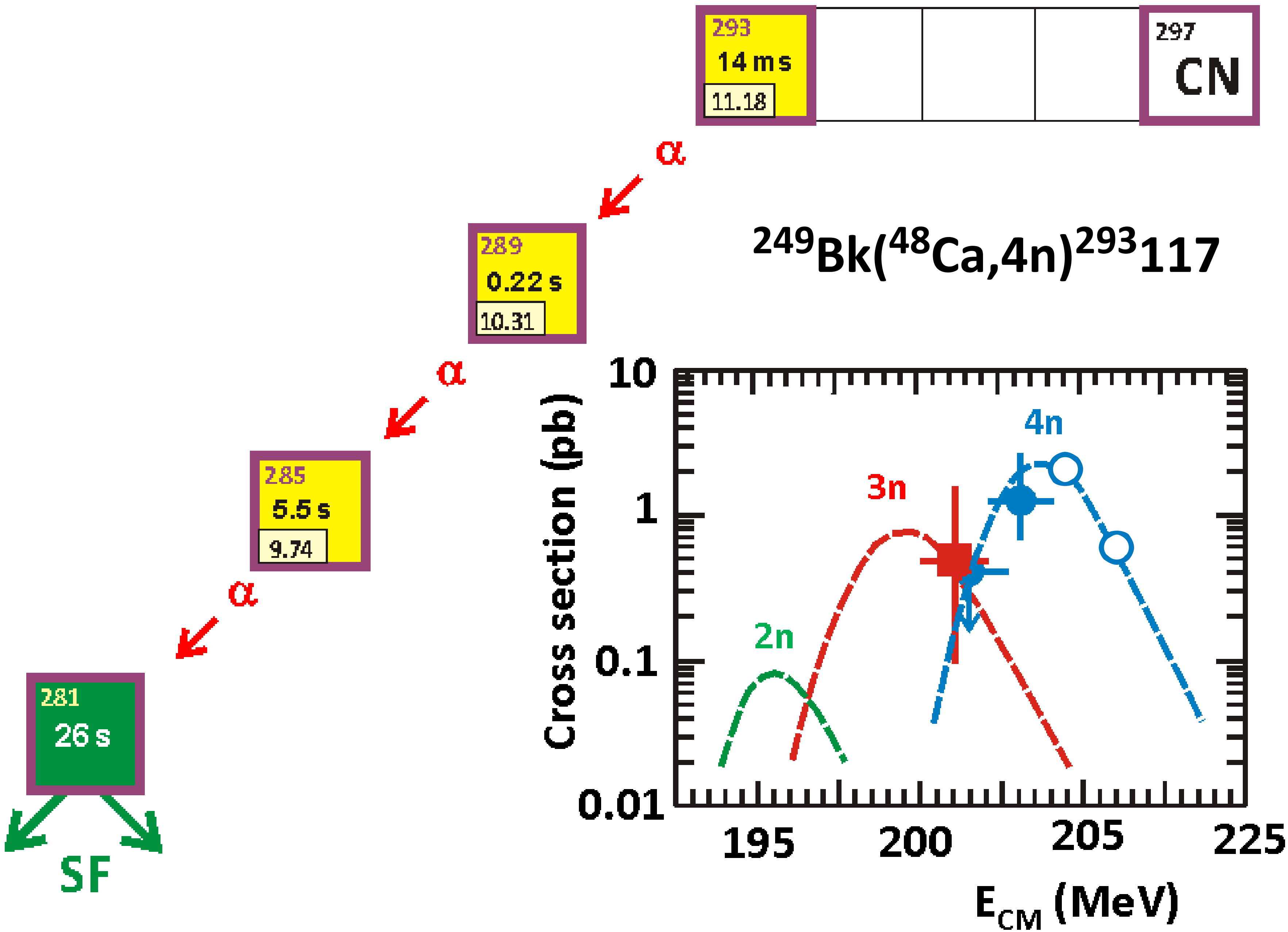
Current experiments 2012-2013

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

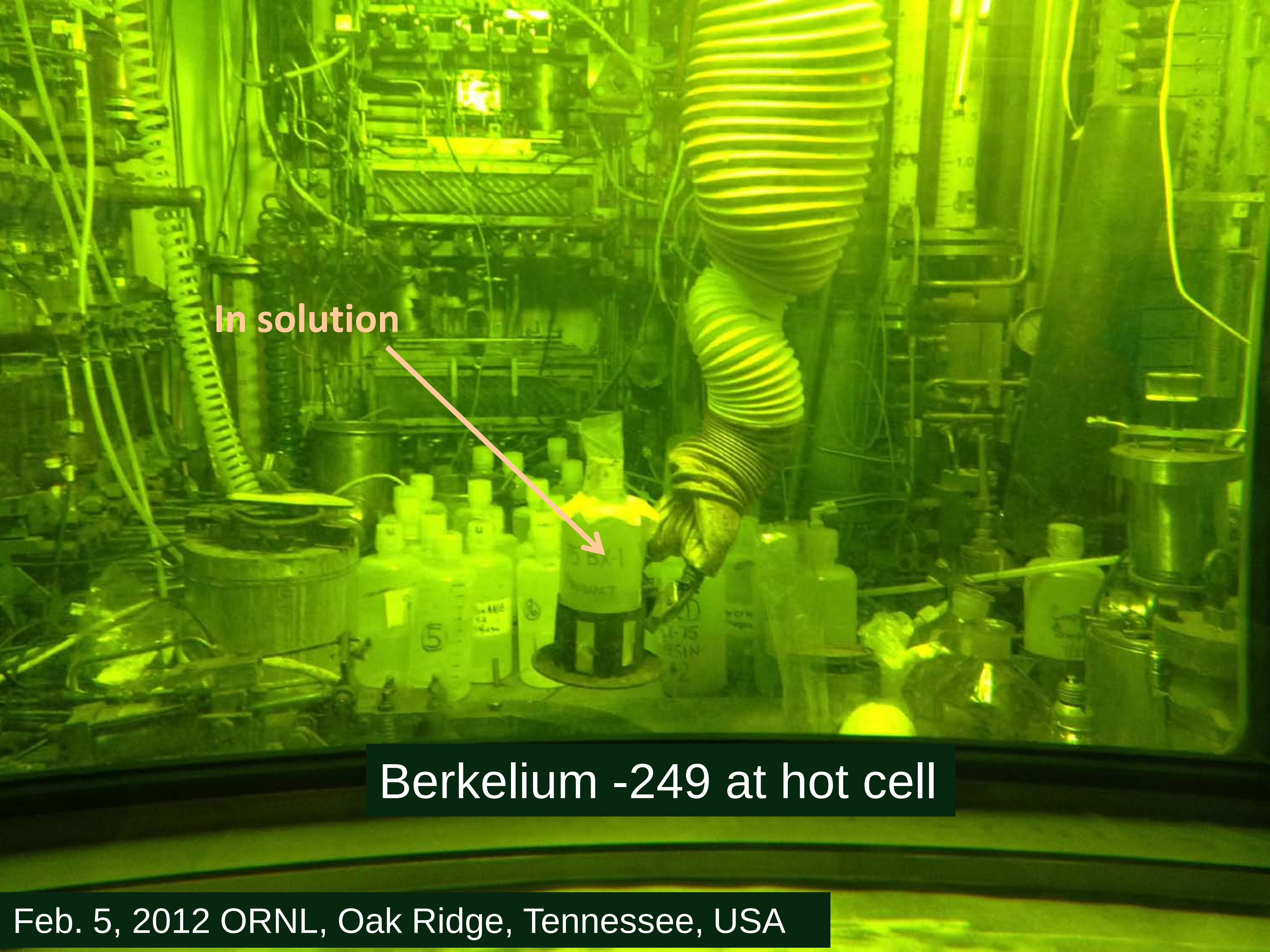
Cross bombardment







293
14 ms
11.18
297
CN
α
289
0.22 s
10.31
α
285
5.5 s
9.74
α
281
26 s
SF
249Bk(48Ca,4n)293117
Cross section (pb)
10
1
0.1
0.01
4n
3n
2n
195
200
205
225
ECM (MeV)



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

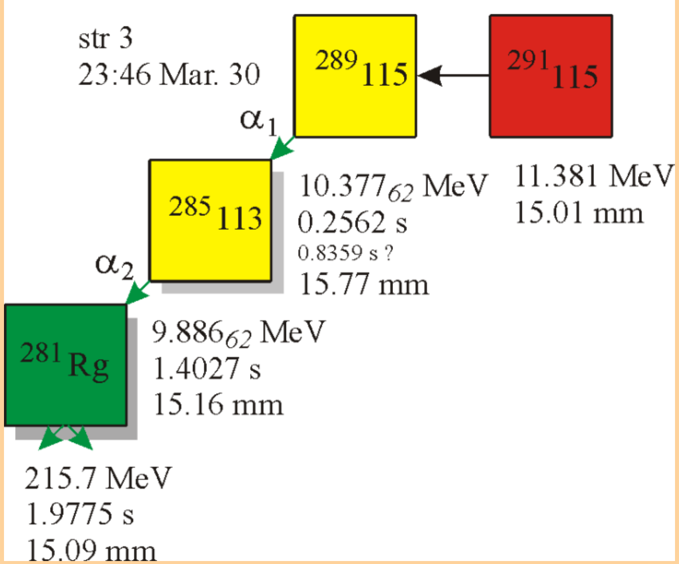
New Insights into the ^{243}Am + ^{48}Ca Reaction Products Previously Observed in the Experiments on Elements 113, 115, and 117

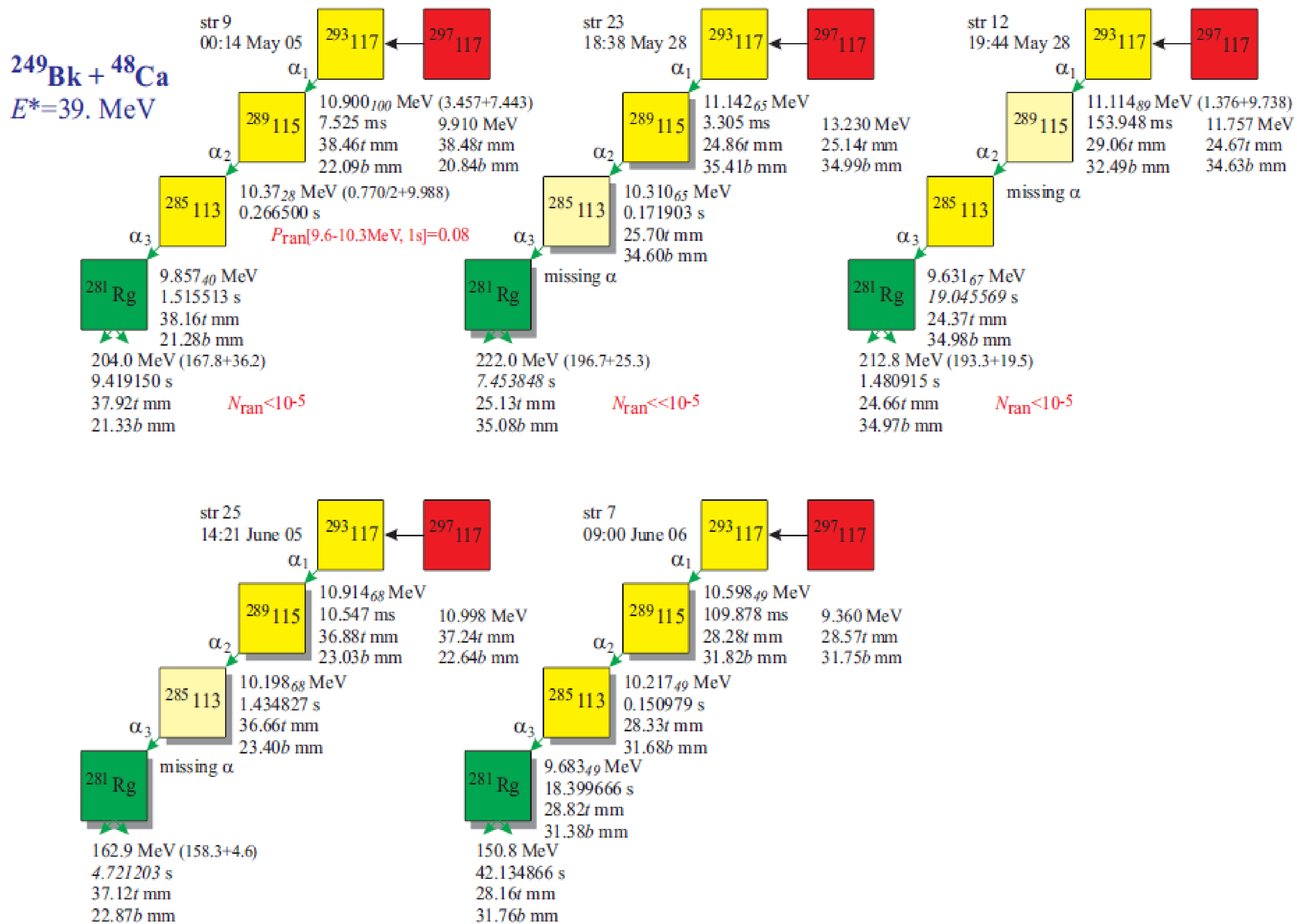
Yu. Ts. Oganessian,[1,*] F. Sh. Abdullin,[1] S. N. Dmitriev,[1] J. M. Gostic,[2] J. H. Hamilton,[3] R. A. Henderson,[2] M. G. Itkis,[1] K. J. Moody,[2] A. N. Polyakov,[1] A. V. Ramayya,[3] J. B. Roberto,[4] K. P. Rykaczewski,[4] R. N. Sagaidak,[1] D. A. Shaughnessy,[2] I. V. Shirokovsky,[1] M. A. Stoyer,[2]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

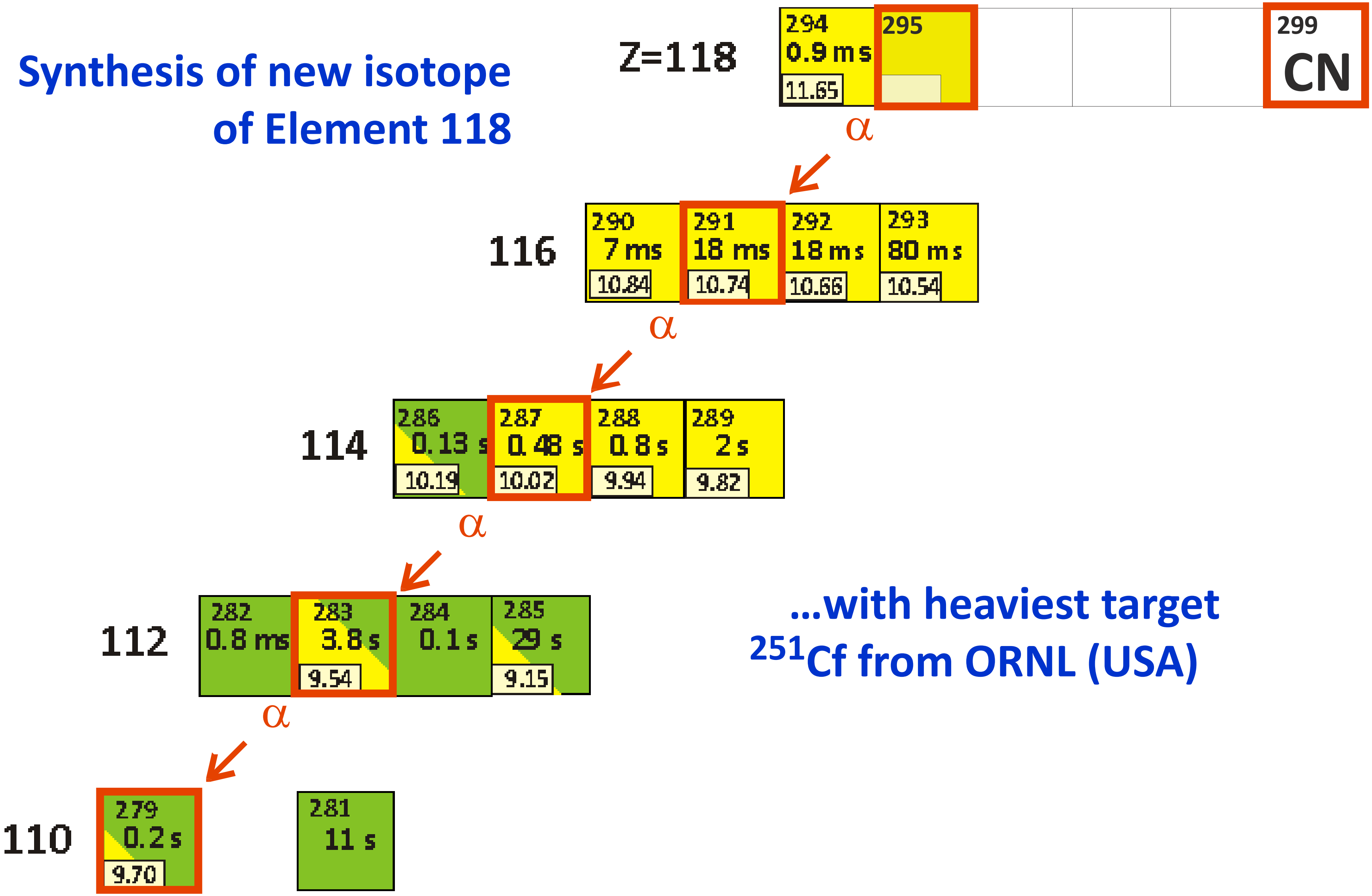
2*n* channel !





^{249}Bk + ^{48}Ca
E^*=39. MeV
str 9
00:14 May 05
293 117
297 117
α1
289 115
10.900 100 MeV (3.457+7.443)
7.525 ms
38.46t mm
22.09b mm
9.910 MeV
38.48t mm
20.84b mm
α2
285 113
10.37 28 MeV (0.770/2+9.988)
0.266500 s
Pran[9.6-10.3MeV, 1s]=0.08
α3
281 Rg
9.857 40 MeV
1.515513 s
38.16t mm
21.28b mm
204.0 MeV (167.8+36.2)
9.419150 s
37.92t mm
21.33b mm
Nran<10-5
str 23
18:38 May 28
293 117
297 117
α1
289 115
11.142 65 MeV
3.305 ms
24.86t mm
35.41b mm
13.230 MeV
25.14t mm
34.99b mm
α2
285 113
10.310 65 MeV
0.171903 s
25.70t mm
34.60b mm
α3
281 Rg
missing α
222.0 MeV (196.7+25.3)
7.453848 s
25.13t mm
35.08b mm
Nran<<10-5
str 12
19:44 May 28
293 117
297 117
α1
289 115
11.114 89 MeV (1.376+9.738)
153.948 ms
29.06t mm
32.49b mm
11.757 MeV
24.67t mm
34.63b mm
α2
missing α
285 113
α3
281 Rg
9.631 67 MeV
19.045569 s
24.37t mm
34.98b mm
212.8 MeV (193.3+19.5)
1.480915 s
24.66t mm
34.97b mm
Nran<10-5
str 25
14:21 June 05
293 117
297 117
α1
289 115
10.914 68 MeV
10.547 ms
36.88t mm
23.03b mm
10.998 MeV
37.24t mm
22.64b mm
α2
285 113
10.198 68 MeV
1.434827 s
36.66t mm
23.40b mm
α3
281 Rg
missing α
162.9 MeV (158.3+4.6)
4.721203 s
37.12t mm
22.87b mm
str 7
09:00 June 06
293 117
297 117
α1
289 115
10.598 49 MeV
109.878 ms
28.28t mm
31.82b mm
9.360 MeV
28.57t mm
31.75b mm
α2
285 113
10.217 49 MeV
0.150979 s
28.33t mm
31.68b mm
α3
281 Rg
9.683 49 MeV
18.399666 s
28.82t mm
31.38b mm
150.8 MeV
42.134866 s
28.16t mm
31.76b mm

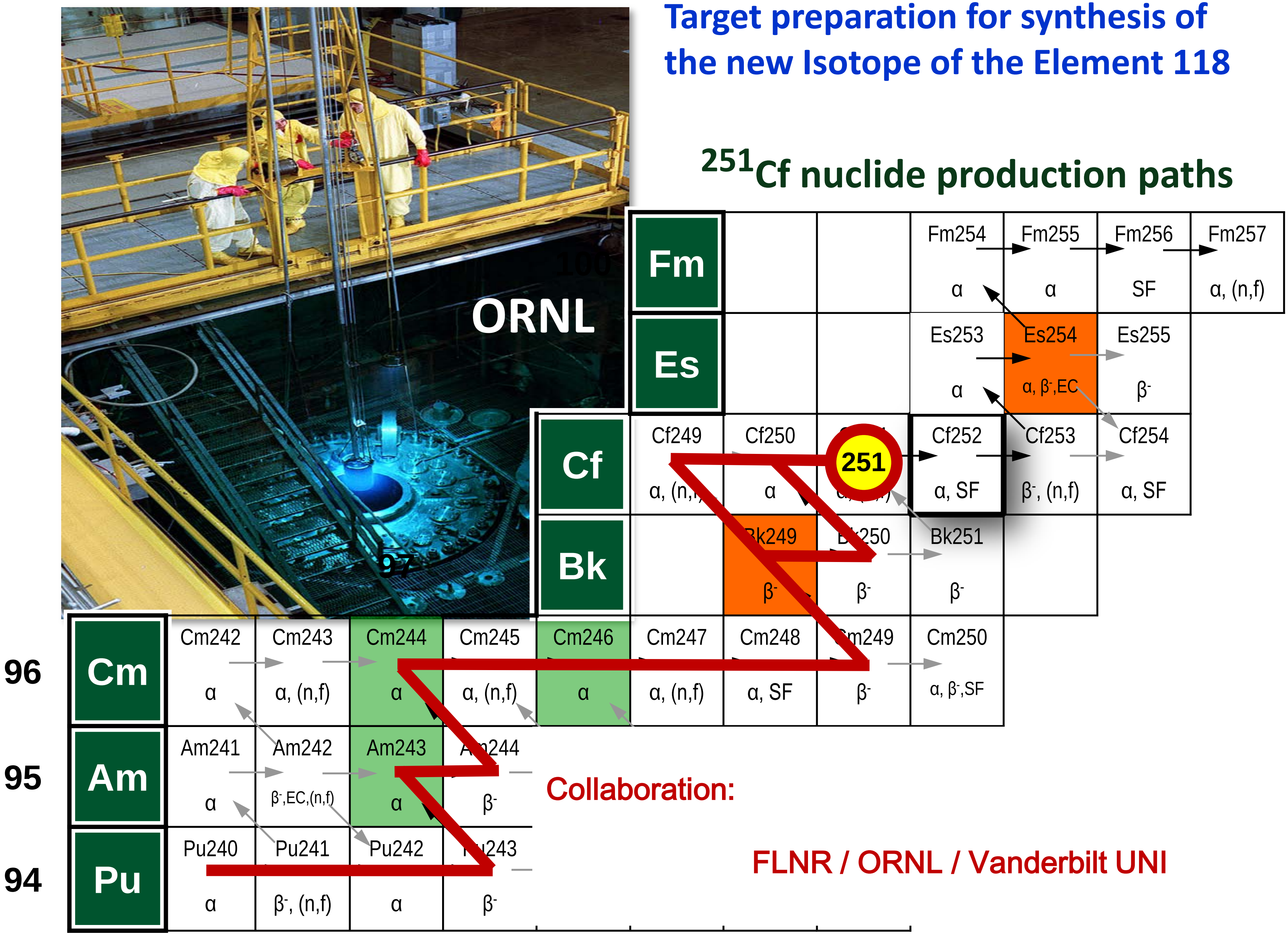
Synthesis of new isotope of Element 118



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

Approved by IUPAC

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



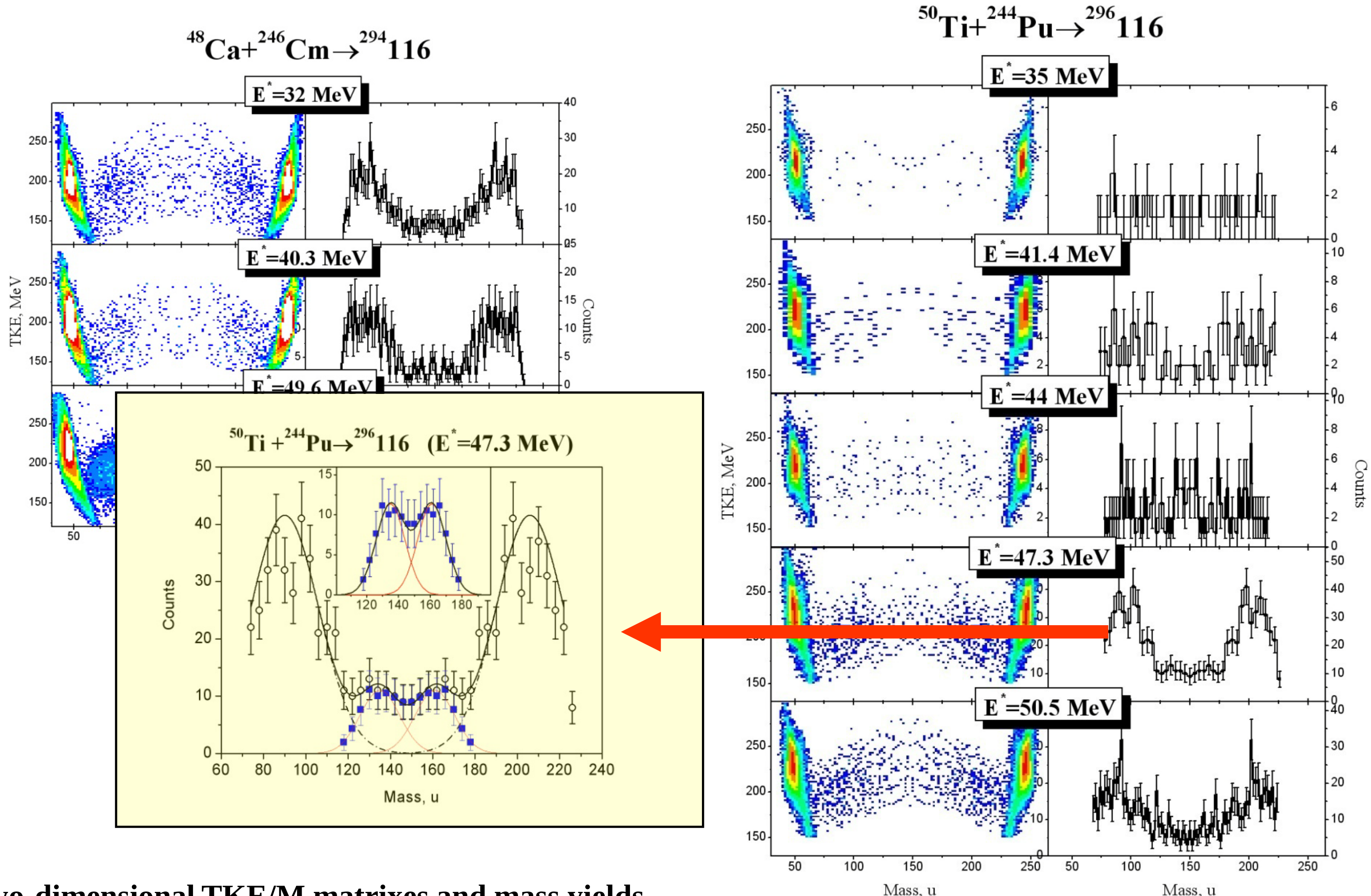
Collaboration:

FLNR / ORNL / Vanderbilt UNI

What is beyond 118 element?

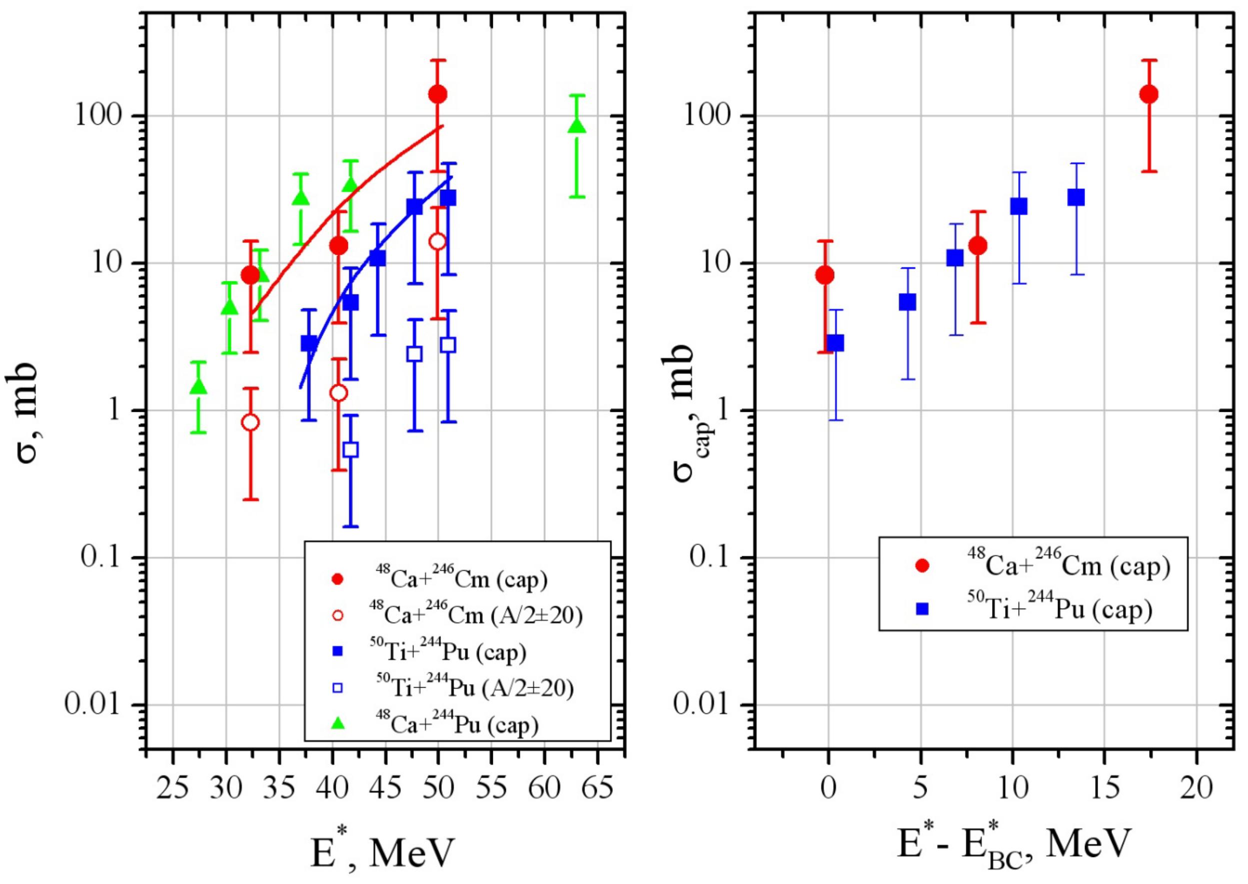
The search for new ways to SHE

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

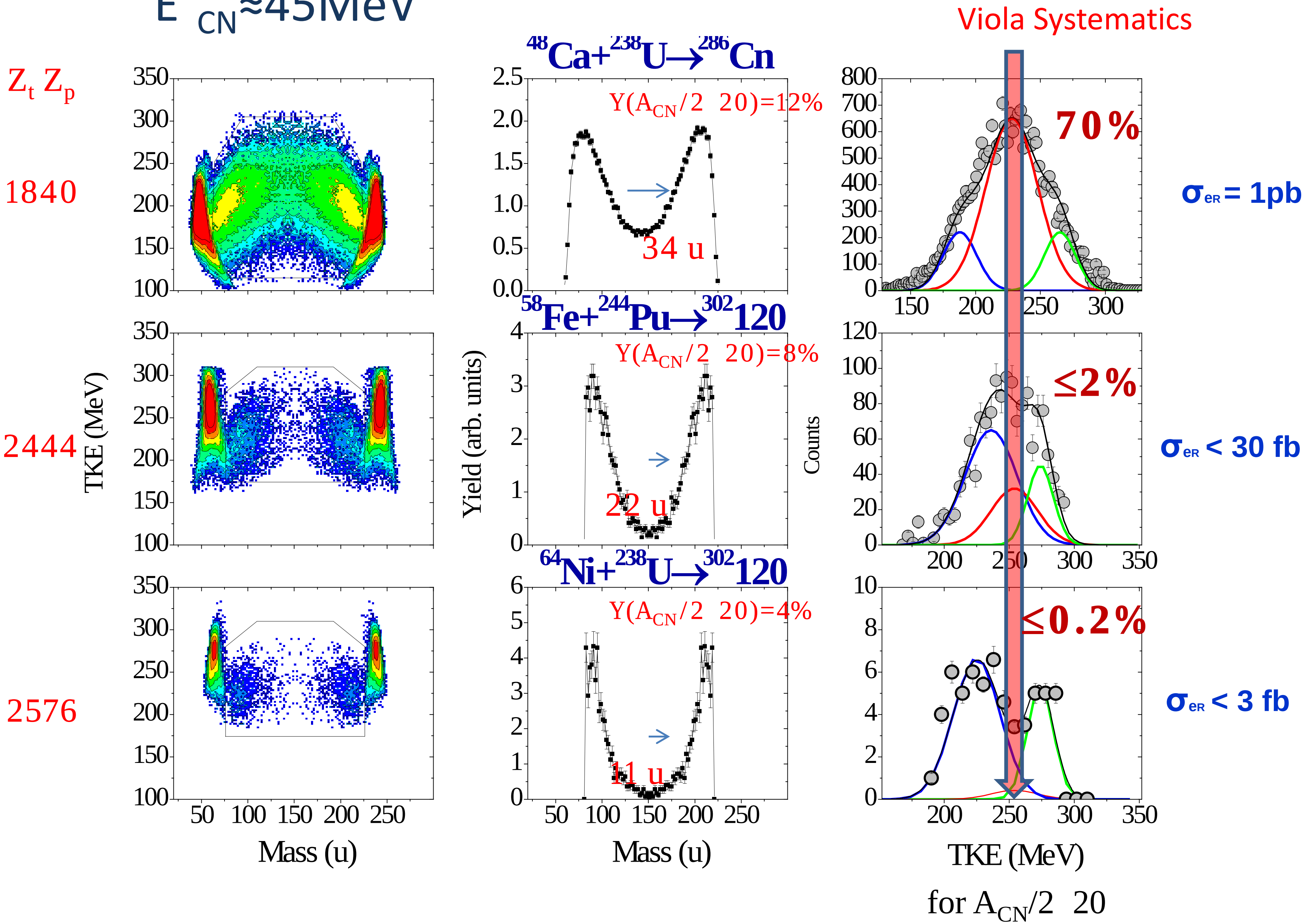


Two-dimensional TKE/M matrixes and mass yields for the reactions $^{48}Ca+^{246}Cm$ and $^{50}Ti+^{244}Pu$ at the excitation energies E*=32-50 MeV

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



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



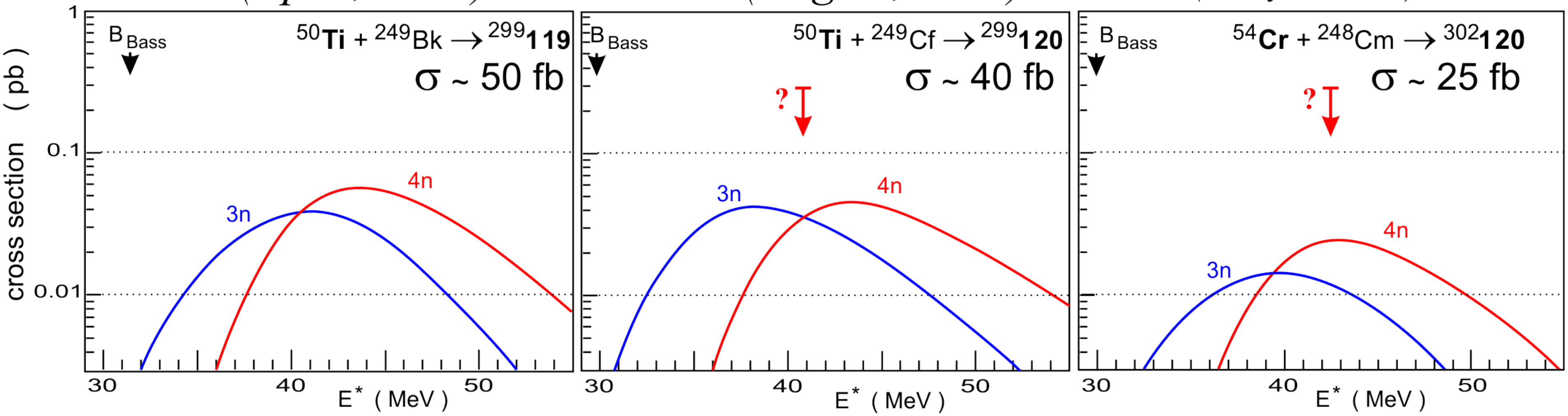
Beyond ^{48}Ca: ^{50}Ti and ^{54}Cr induced fusion reactions

Ti beam:

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

Cr beam:

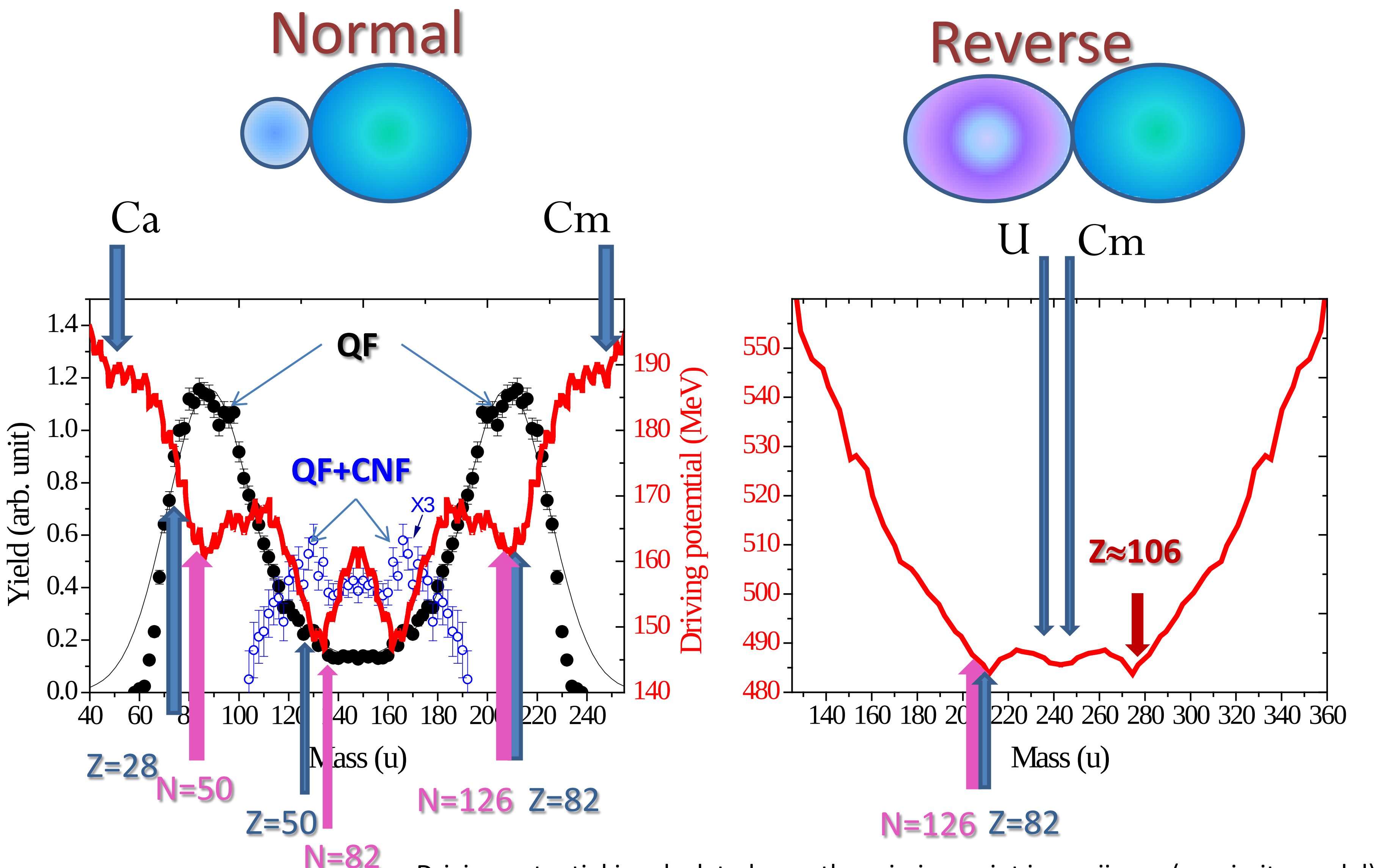
SHIP (May, 2011)



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

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

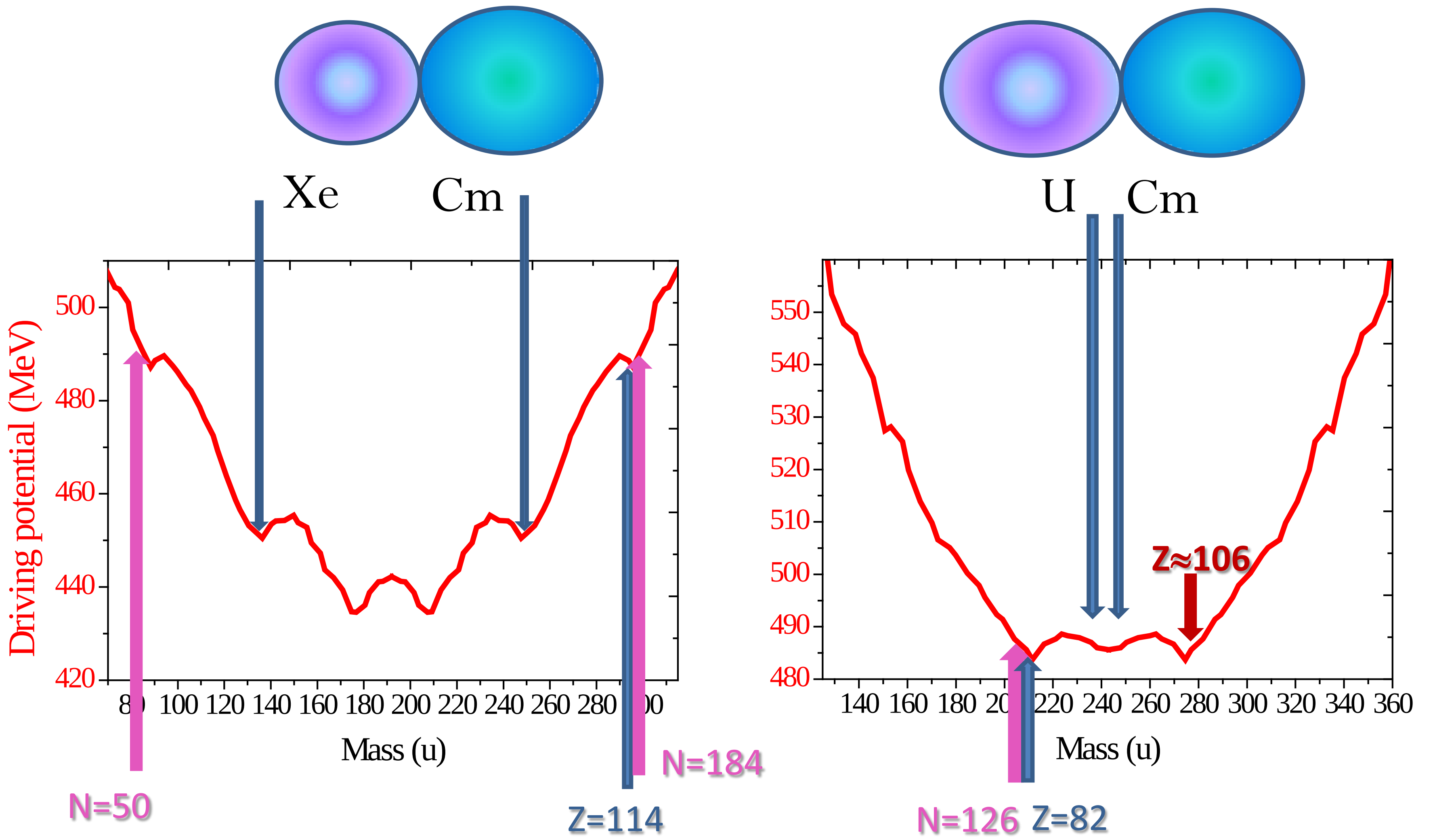
Asymmetric QF



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

Asymmetric QF

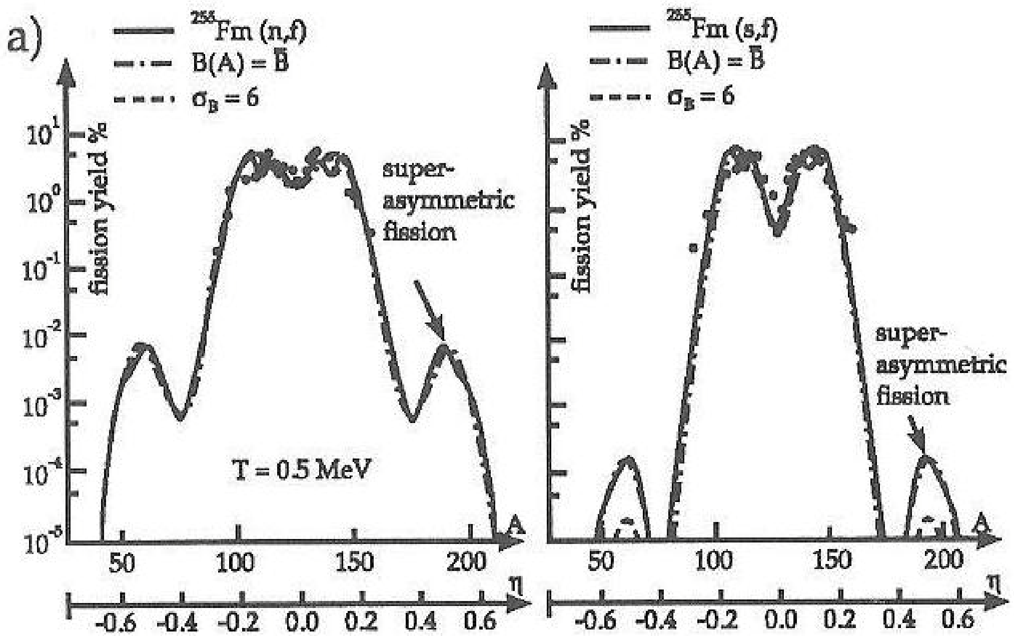
Reverse

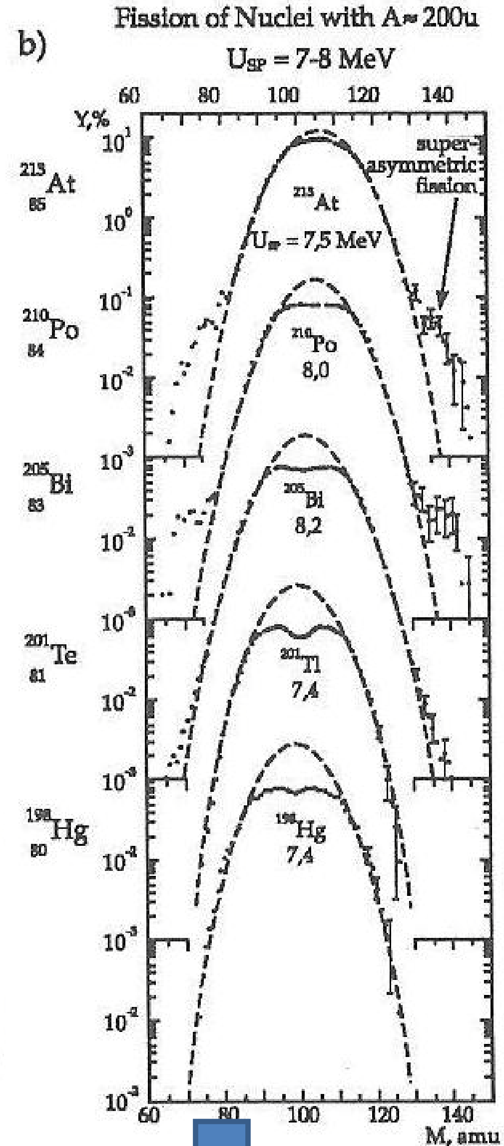


nrv.jinr.ru
(proximity model)

Superasymmetric fission of superheavy nuclei

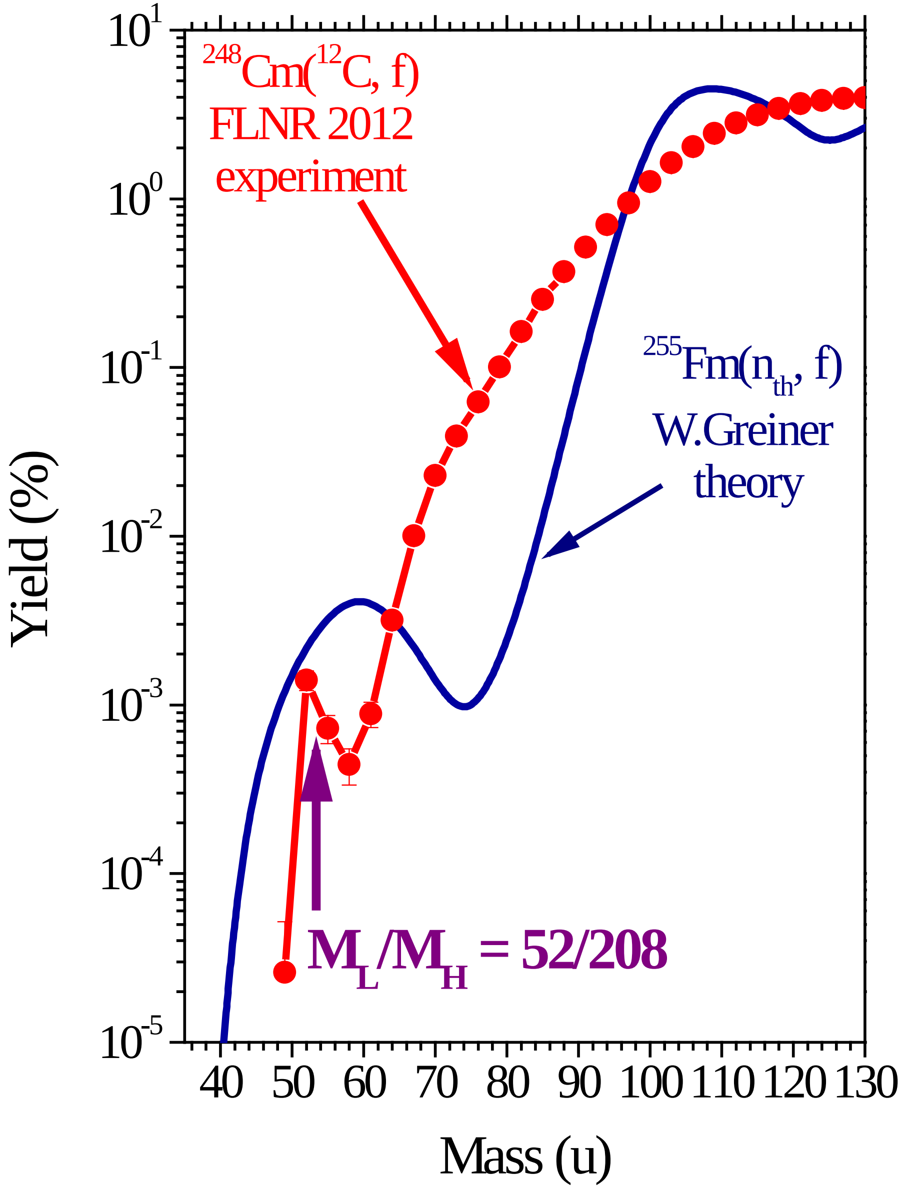
W. Greiner (International Workshop on Fusion Dynamics at the Extremes, 25-27May 2000)





Superasymmetric fission of nuclei with A~200 u

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



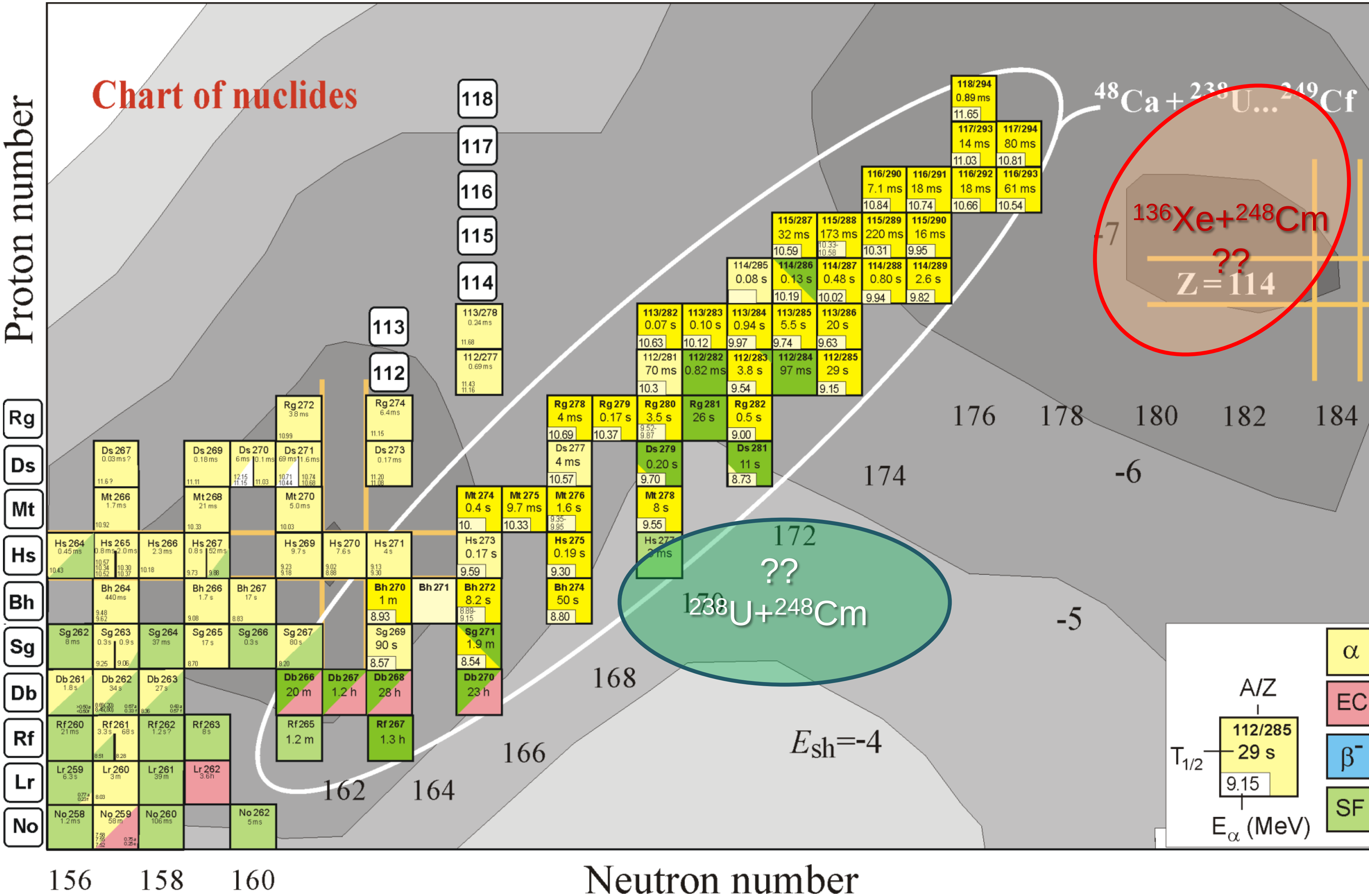
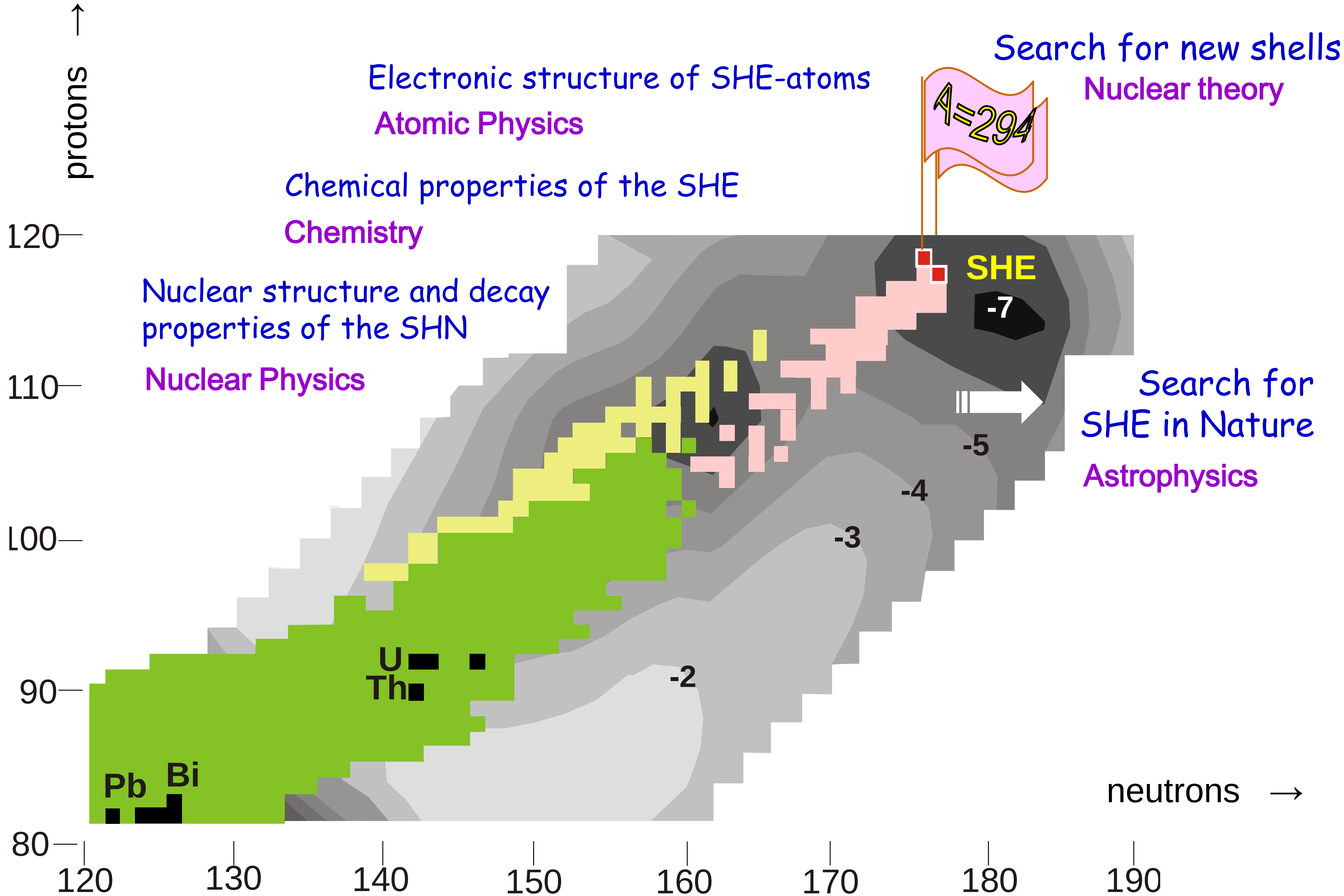


Chart of nuclides
Proton number
Neutron number
118
117
116
115
114
113
112
Rg
Ds
Mt
Hs
Bh
Sg
Db
Rf
Lr
No
156
158
160
162
164
166
168
170
172
174
176
178
180
182
184
-4
-5
-6
-7
E_{sh}=-4
^{48}Ca + ^{238}U...^{249}Cf
^{136}Xe+^{248}Cm
??
Z = 114
??
^{238}U+^{248}Cm
118/294 0.89 ms 11.65
117/293 14 ms 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
113/278
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
112/277
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
Rg 272
Rg 274
Rg 278 4 ms 10.69
Rg 279 0.17 s 10.37
Rg 280 3.5 s
Rg 281 26 s
Rg 282 0.5 s 9.00
Ds 267
Ds 269
Ds 270
Ds 271
Ds 273
Ds 277 4 ms 10.57
Ds 279 0.20 s 9.70
Ds 281 11 s 8.73
Mt 266
Mt 268
Mt 270
Mt 274 0.4 s 10.
Mt 275 9.7 ms 10.33
Mt 276 1.6 s
Mt 278 8 s 9.55
Hs 264
Hs 265
Hs 266
Hs 267
Hs 269
Hs 270
Hs 271
Hs 273 0.17 s 9.59
Hs 275 0.19 s 9.30
Bh 264
Bh 266
Bh 267
Bh 270 1 m 8.93
Bh 271
Bh 272 8.2 s
Bh 274 50 s 8.80
Sg 262
Sg 263
Sg 264
Sg 265
Sg 266
Sg 267
Sg 269 90 s 8.57
Sg 271 1.9 m 8.54
Db 261
Db 262
Db 263
Db 266 20 m
Db 267 1.2 h
Db 268 28 h
Db 270 23 h
Rf 260
Rf 261
Rf 262
Rf 263
Rf 265 1.2 m
Rf 267 1.3 h
Lr 259
Lr 260
Lr 261
Lr 262
No 258
No 259
No 260
No 262
A/Z
112/285
29 s
9.15
$T_{1/2}$
E_{α} (MeV)
α
EC
β^-
SF



protons
120
110
100
90
80
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
A=294
SHE
-7
-5
-4
-3
-2
Search for SHE in Nature
Astrophysics
U
Th
Pb
Bi
neutrons
120
130
140
150
160
170
180
190

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

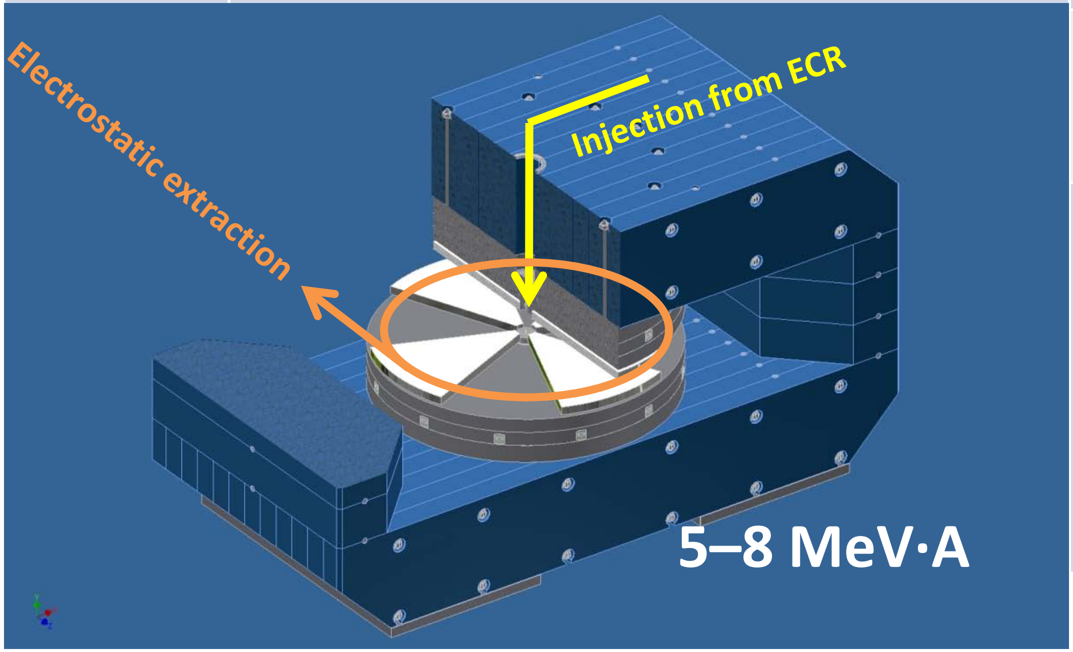
However, we produce them in very small quantities,
much less than could be reached with modern
experimental technique

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

Production

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

Increase a beam dose			**factor: 30**
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

	2010	2011	2012	2013	2014	2015	2016	2017

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

U-400 & DGFRS — Z=117 — 1

Experimental hall — independent work — 2.5-5.0

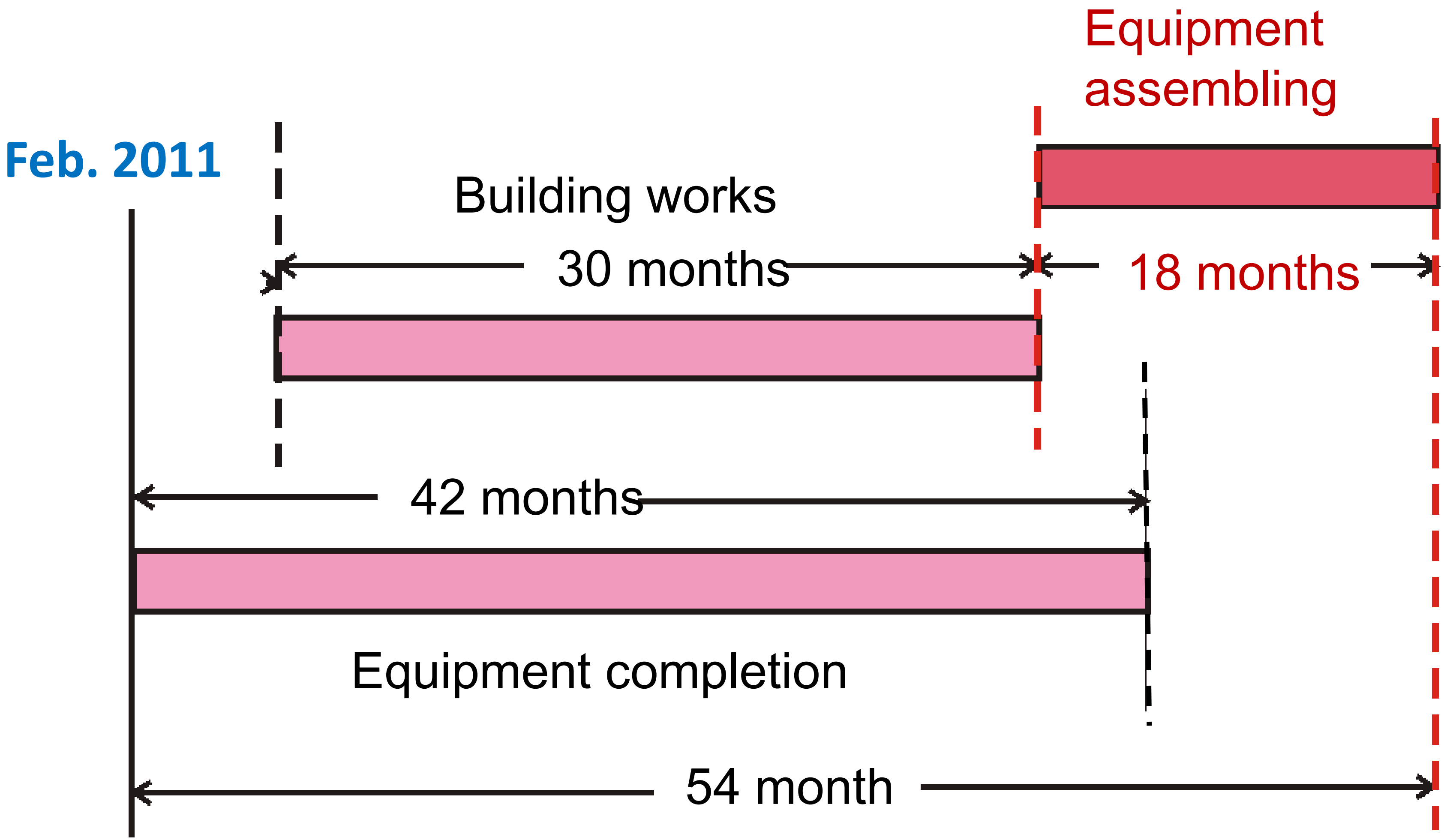
New type experimental facilities — SC separator + Gas catcher — 3.0-4.0

New Accelerator — 10-20 pμA — 15

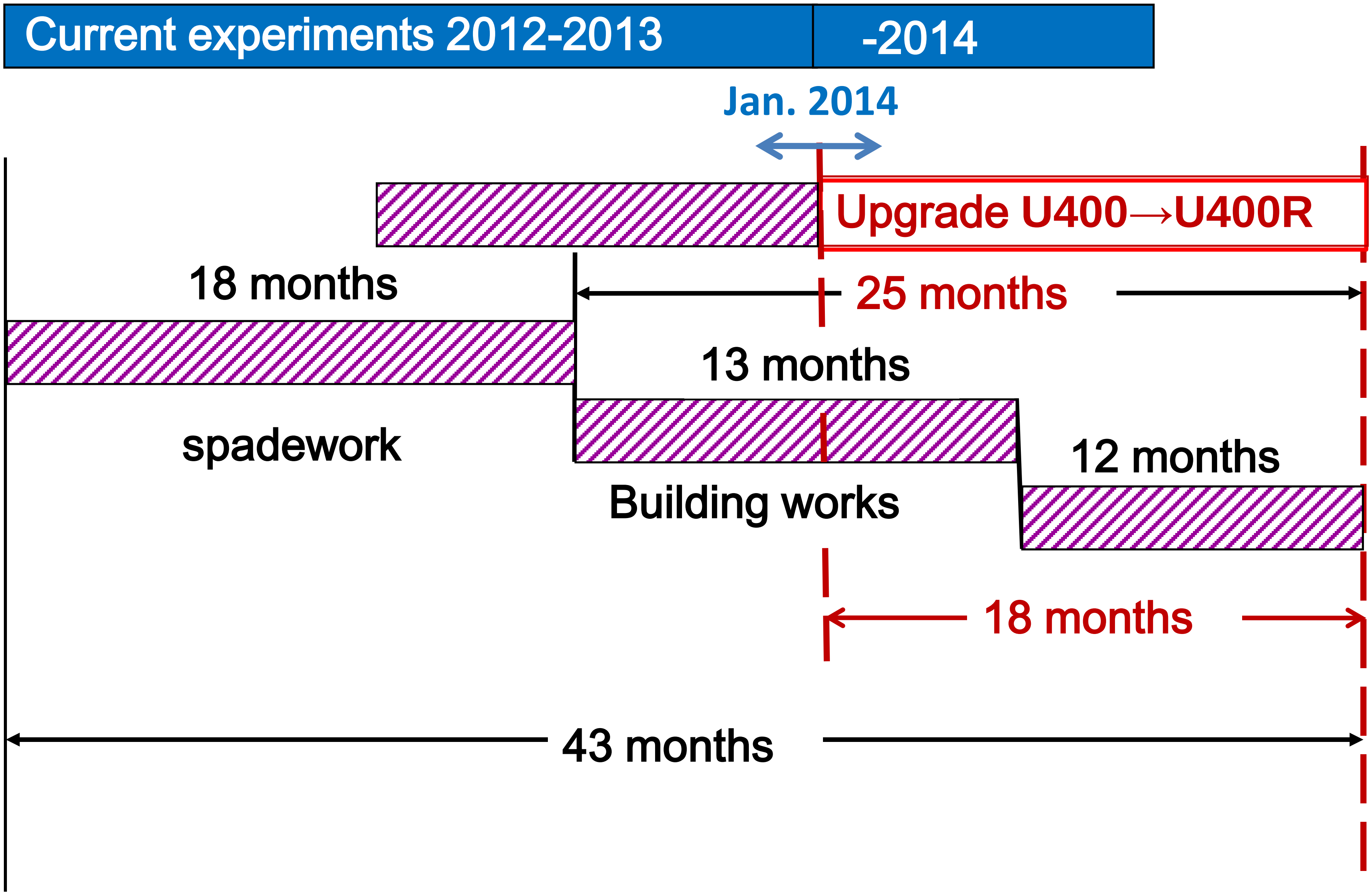
FLNR backside in January 2012

April 16, 2012 SHE factory

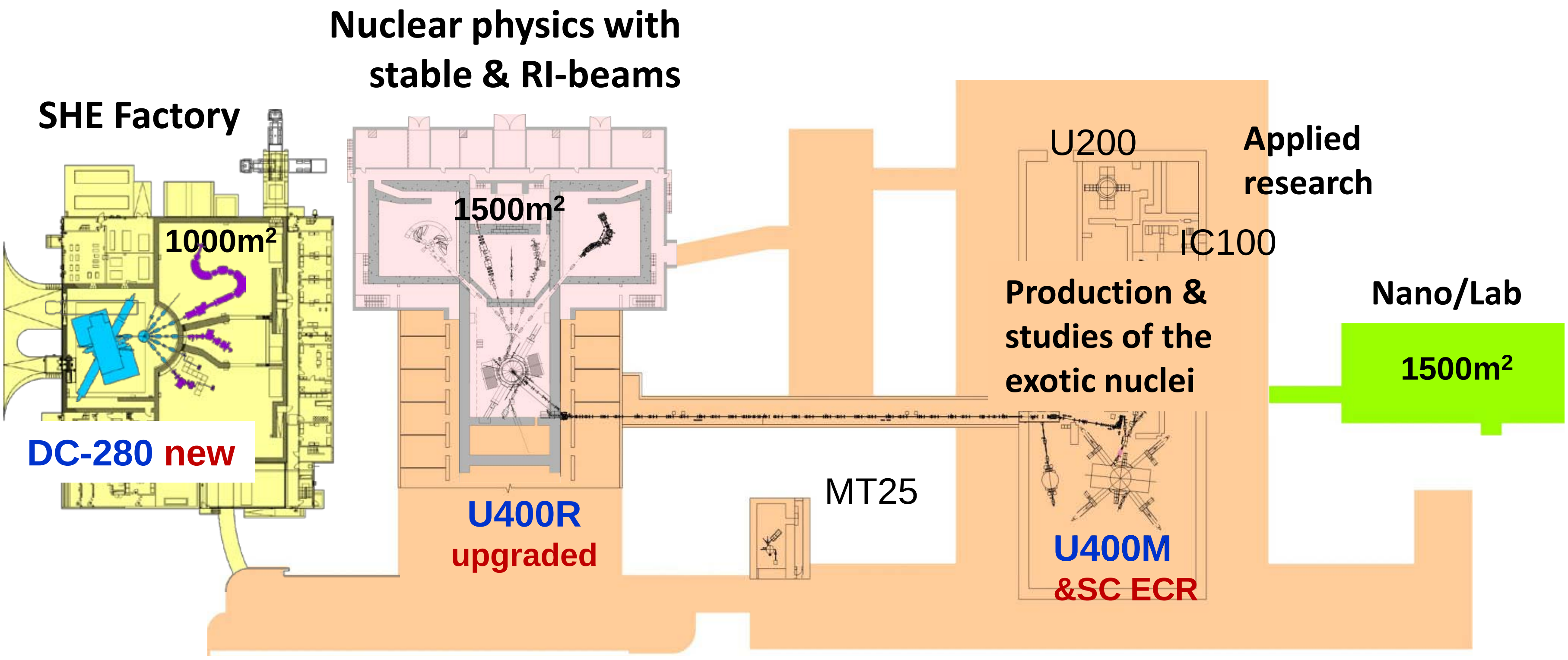
Schedule for SHE-Factory



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.**