www.superheavies.de
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Quest for Superheavy Elements

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Helmholtz Institut Mainz

Ecole Joliot-Curie "Nucleus through the looking glass – High intensity stable and ISOL beam frontier"

La Villa Clythia – Fréjus – France – September 30-October 05, 2012

What's on the menu this week?

Lesson 1:

-Discovery of the transuranium elements: Z=93 - 112

-Stability of superheavy elements I

Lesson 2:

-Discovery of the transuranium elements: Z=113- ...

-Stability of superheavy elements II

Lesson 3:

-Reactions: synthesis of SHE

-Search for new elements at GSI

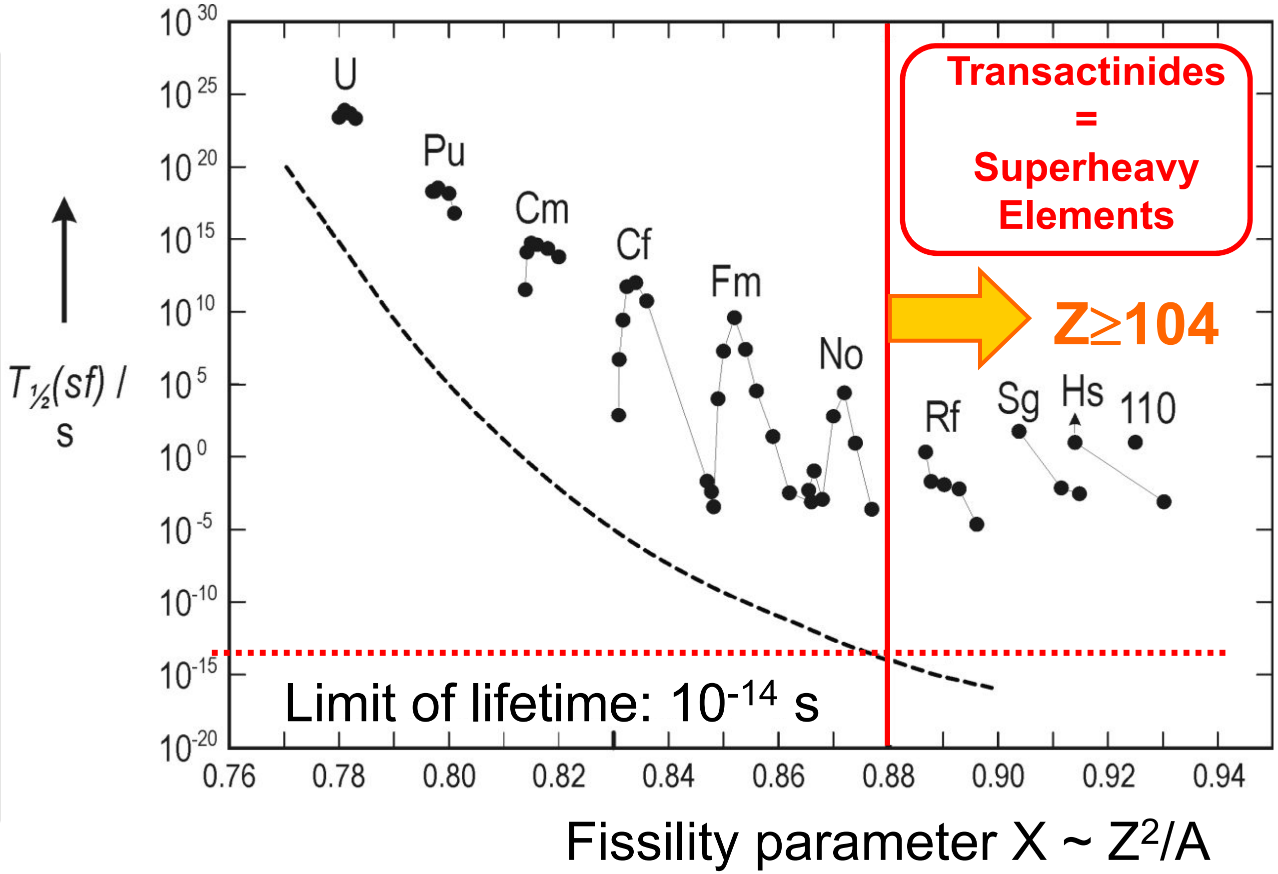
What is a superheavy element

Assumptions:

1.) "... composite nuclear systems that live less than about 10^{-14} seconds (the generally accepted upper limit for a compound nucleus lifetime) shall not be considered a new element."

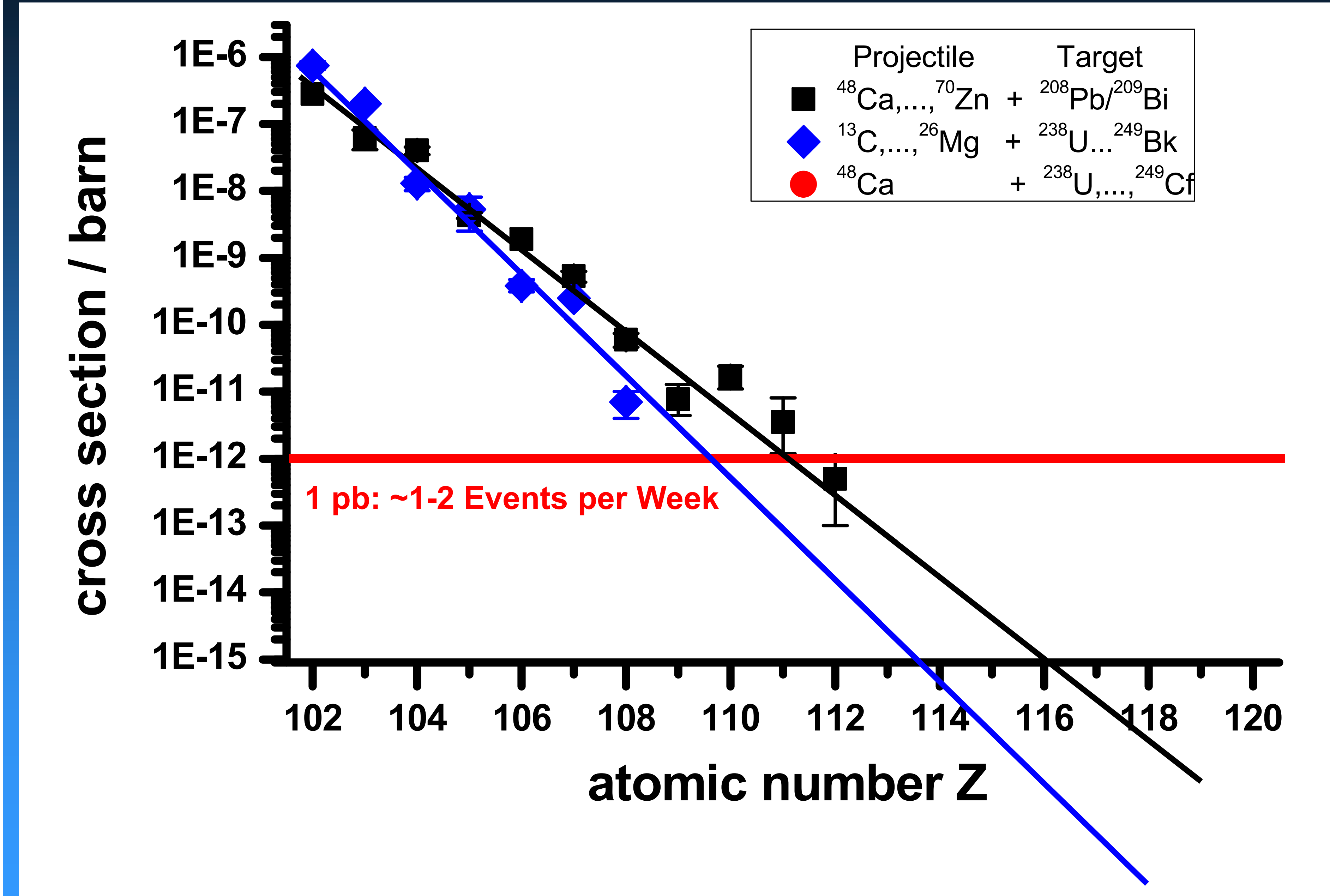
B.G. Harvey et al. Science 193 (1976) 1271

2.) "Superheavy Elements" is a synonym for "elements which only exixts because of their (microscopical) shell stability."



M. Schädel, 2007

Cross Sections in Hot / Cold / ^{48}Ca Induced Fusion Reactions



Map of the Nuclear Landscape

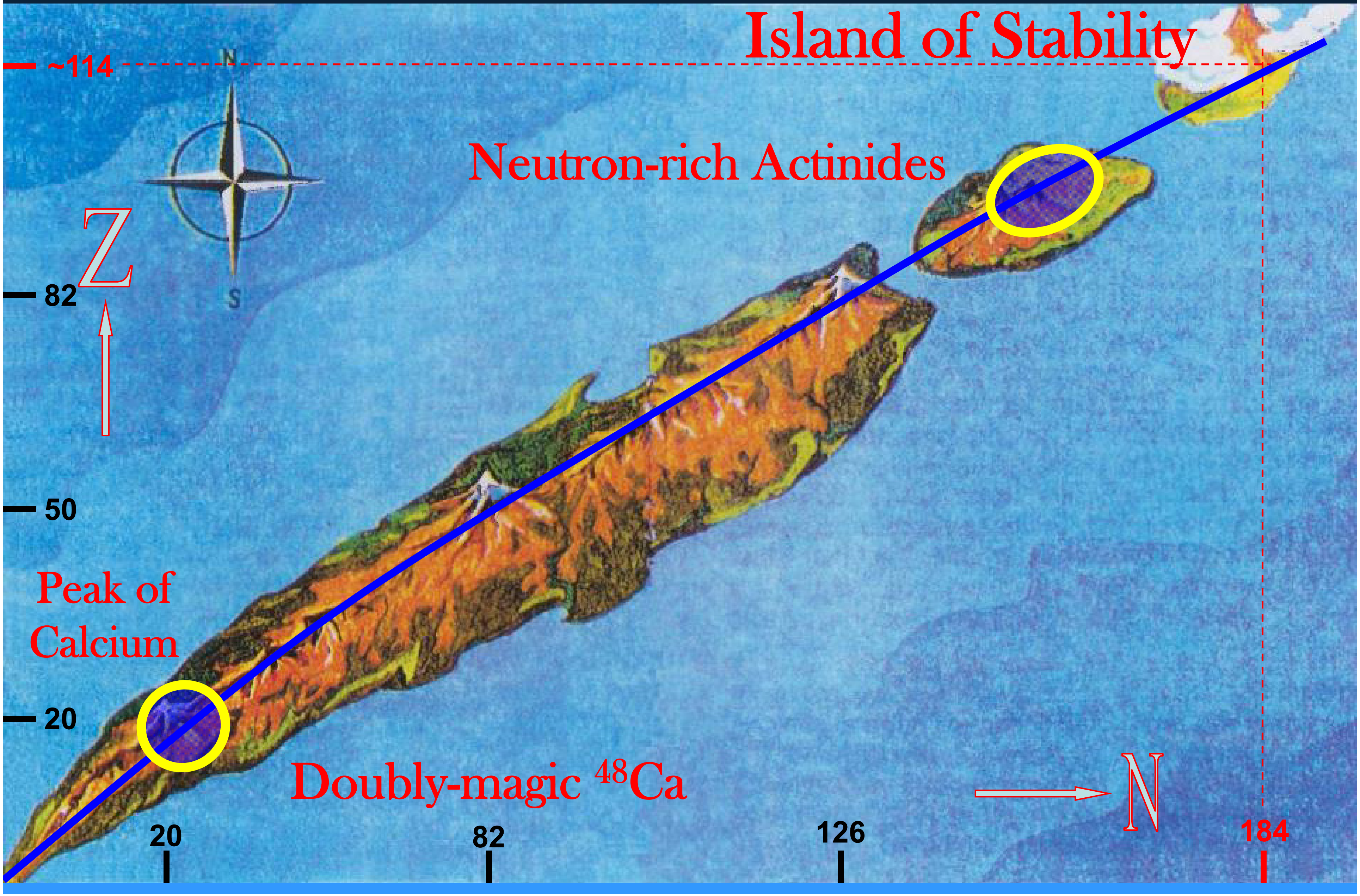


Chart of nuclei
September 2012

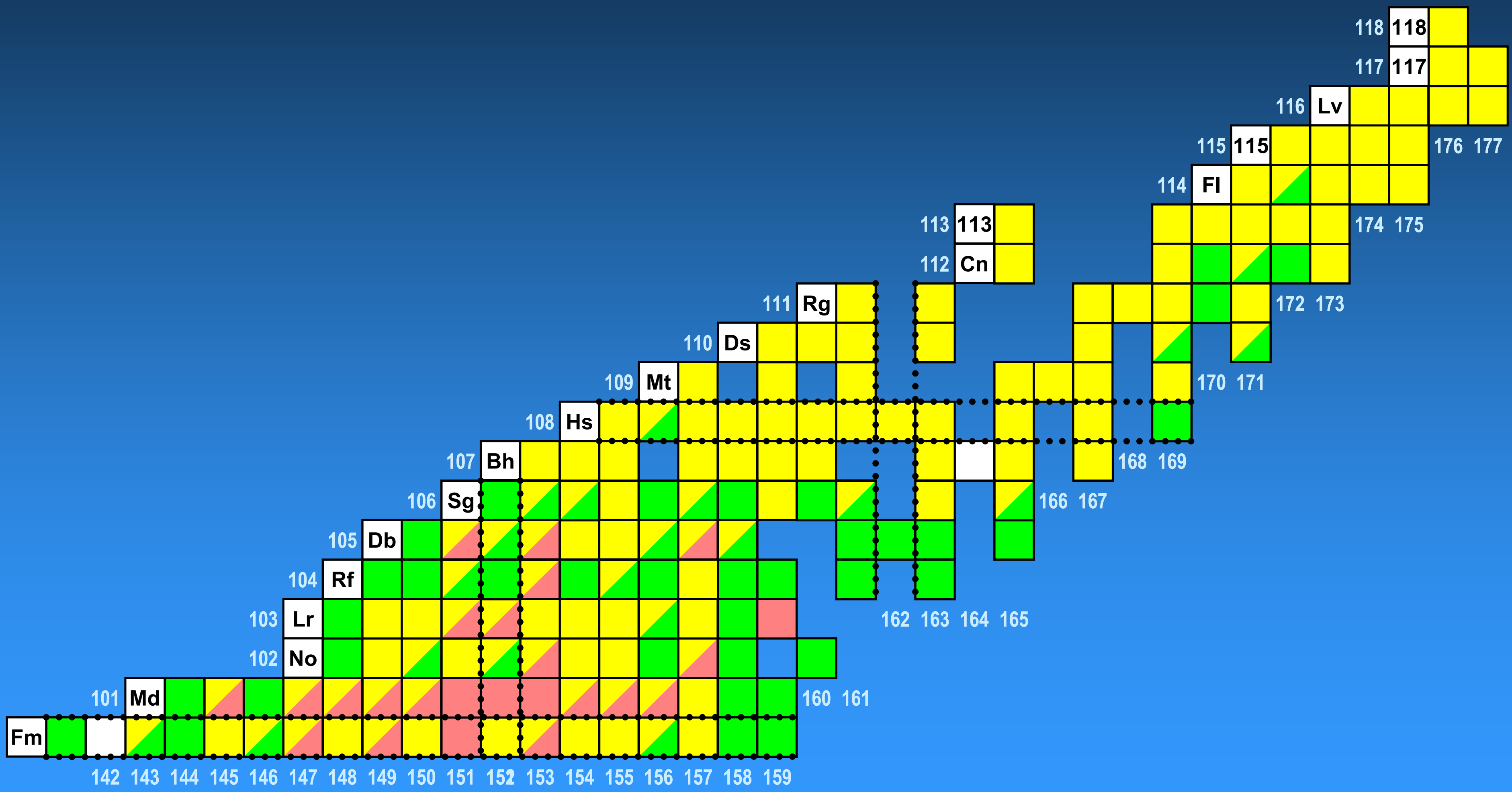
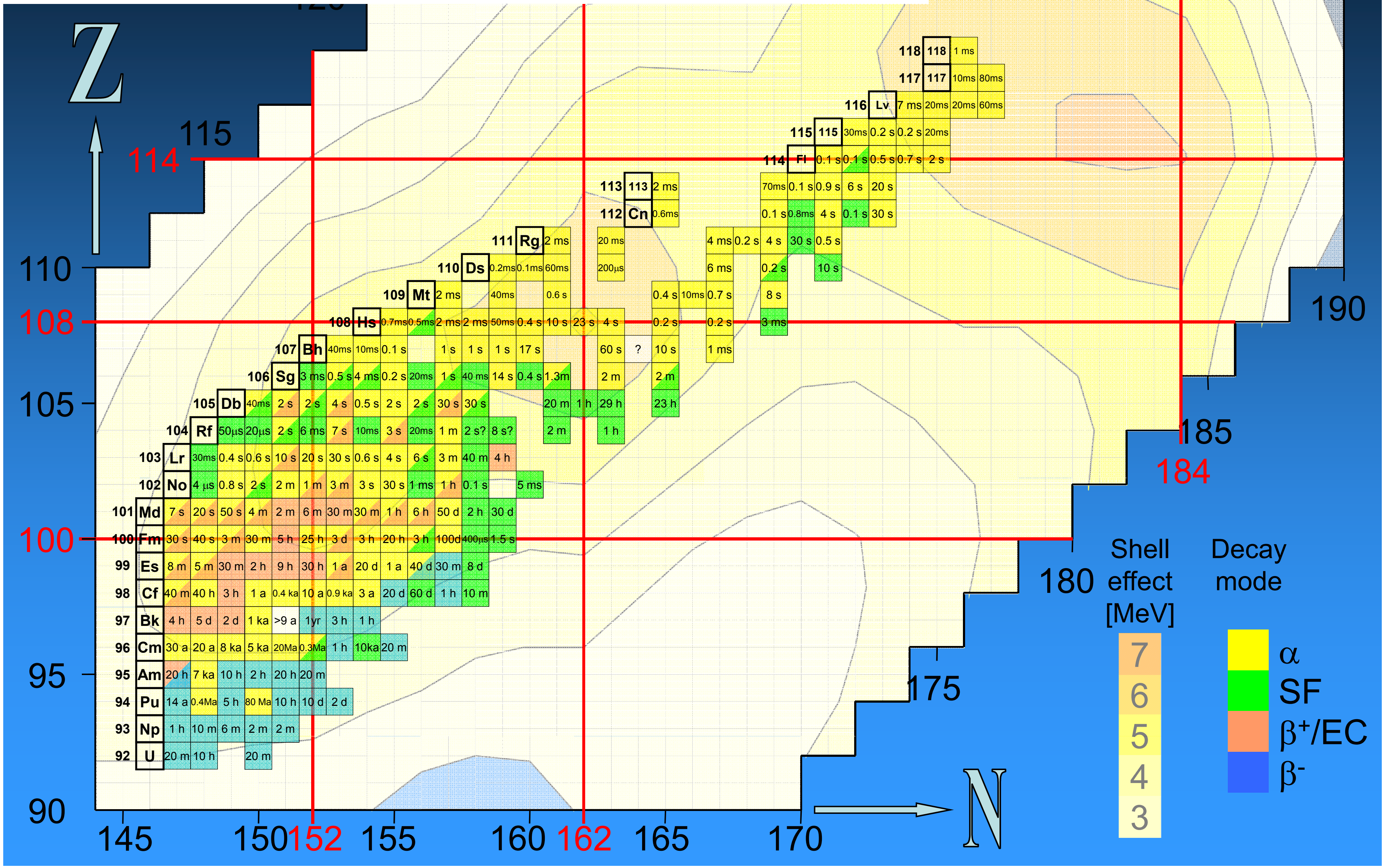
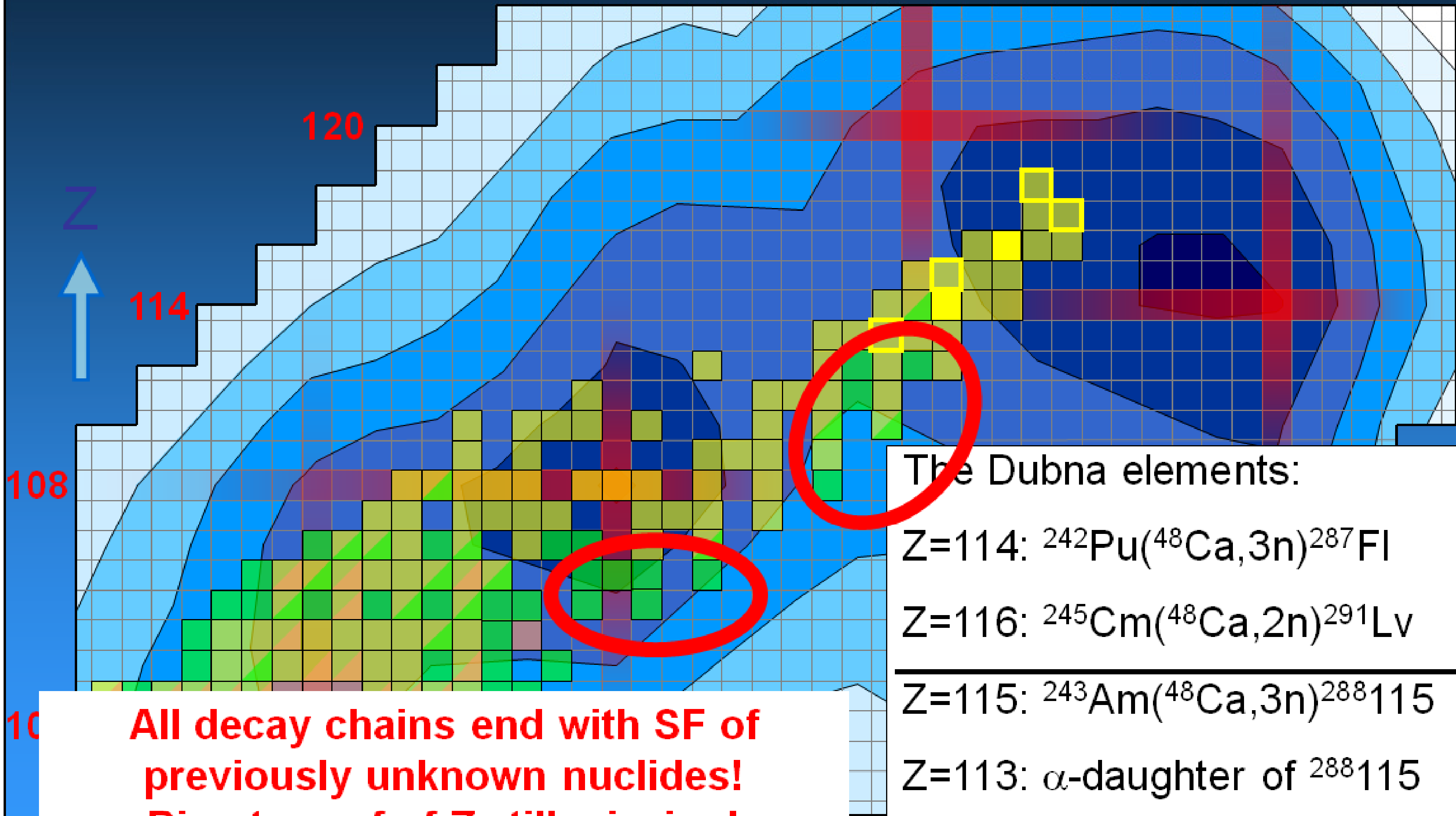


Chart of nuclei, Sep. 2012

Conturs: calculated shell stabilization energies
(Sobiczewski et al., local mic-mac for heavy elements Z≥100)



New Elements from Dubna (^{48}Ca+An)



All decay chains end with SF of previously unknown nuclides! Direct proof of Z still missing!

The Dubna elements:

Z=114: ^{242}Pu(^{48}Ca,3n)^{287}Fl

Z=116: ^{245}Cm(^{48}Ca,2n)^{291}Lv

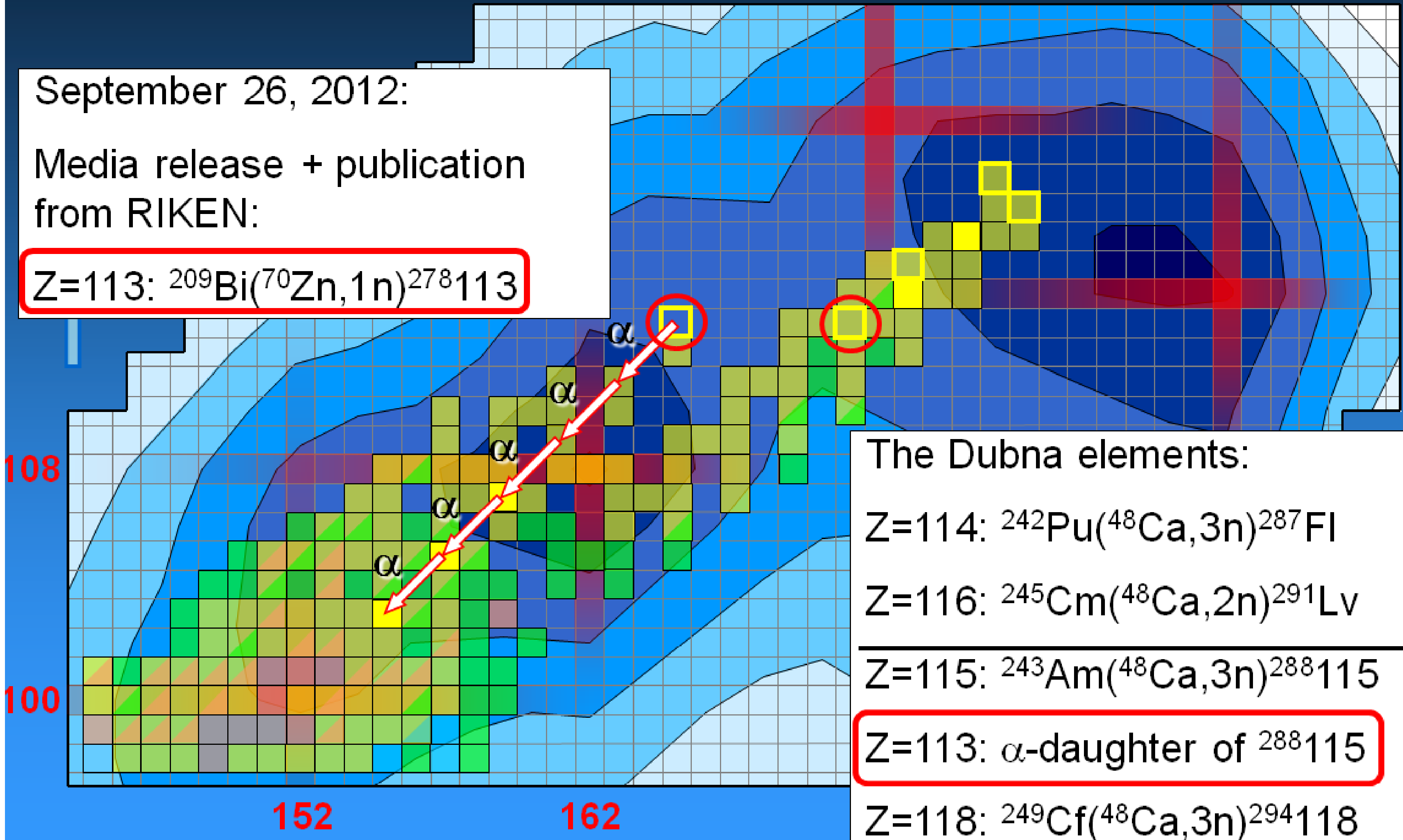
Z=115: ^{243}Am(^{48}Ca,3n)^{288}115

Z=113: α-daughter of ^{288}115

Z=118: ^{249}Cf(^{48}Ca,3n)^{294}118

Z=117: ^{249}Bk(^{48}Ca,4n)^{293}117

New Elements from Dubna (^{48}Ca+An) ...and news from RIKEN



September 26, 2012:

Media release + publication from RIKEN:

Z=113: ^{209}Bi(^{70}Zn,1n)^{278}113

The Dubna elements:

Z=114: ^{242}Pu(^{48}Ca,3n)^{287}Fl

Z=116: ^{245}Cm(^{48}Ca,2n)^{291}Lv

Z=115: ^{243}Am(^{48}Ca,3n)^{288}115

Z=113: α-daughter of ^{288}115

Z=118: ^{249}Cf(^{48}Ca,3n)^{294}118

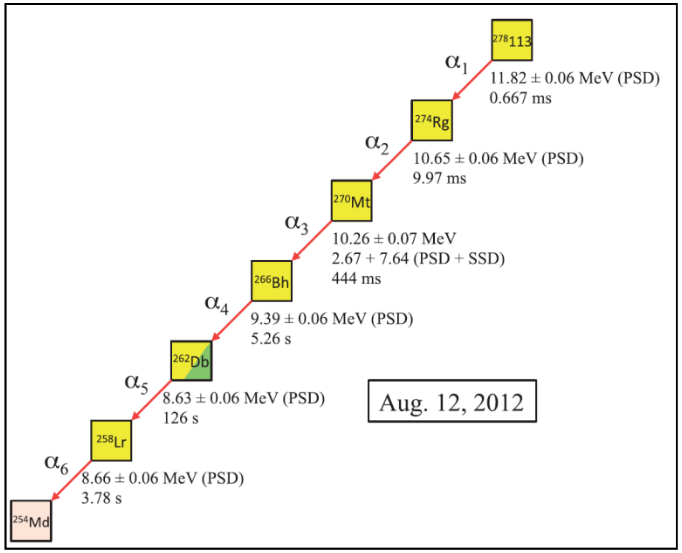
Z=117: ^{249}Bk(^{48}Ca,4n)^{293}117

New Elements from Dubna (^{48}Ca+An) and news from RIKEN

Science

AAAS

September 26, 2012



Japanese Physicists Claim Clinching Observation of New Superheavy Element

by Daniel Clery on 26 September 2012, 4:26 PM | 1 Comment

Email Print | 1 More PREVIOUS ARTICLE NEXT ARTICLE

The claim sounds simple enough: Physicists in Japan say they have made a new superheavy atom, element 113, which lies at the border of the periodic table. However, the backstory is far more complicated. And it illustrates just how arcane the business of spotting new superheavy elements can be.

Se

M

fro

Z=

108

10

Fl

Lv

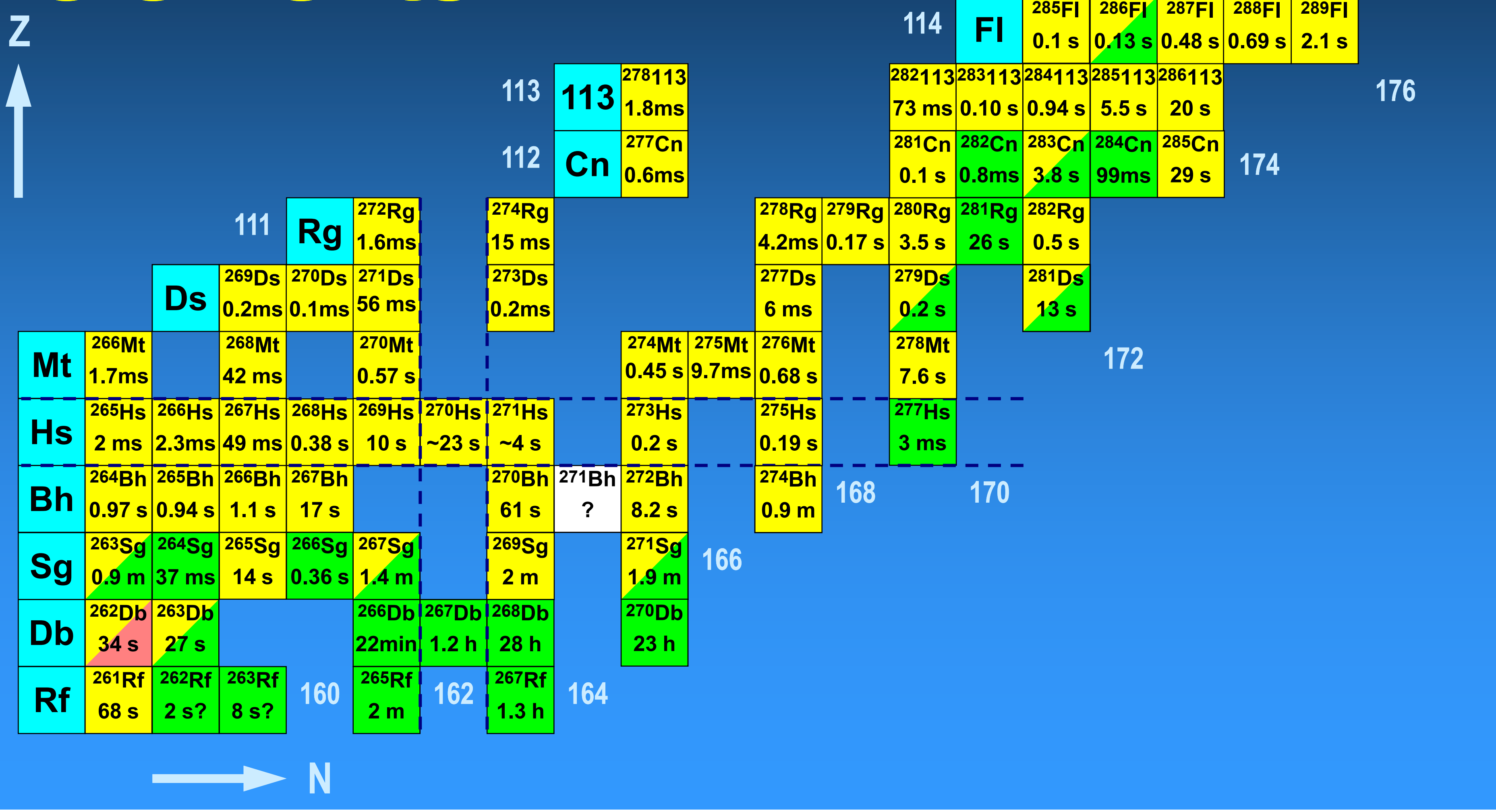
115

15

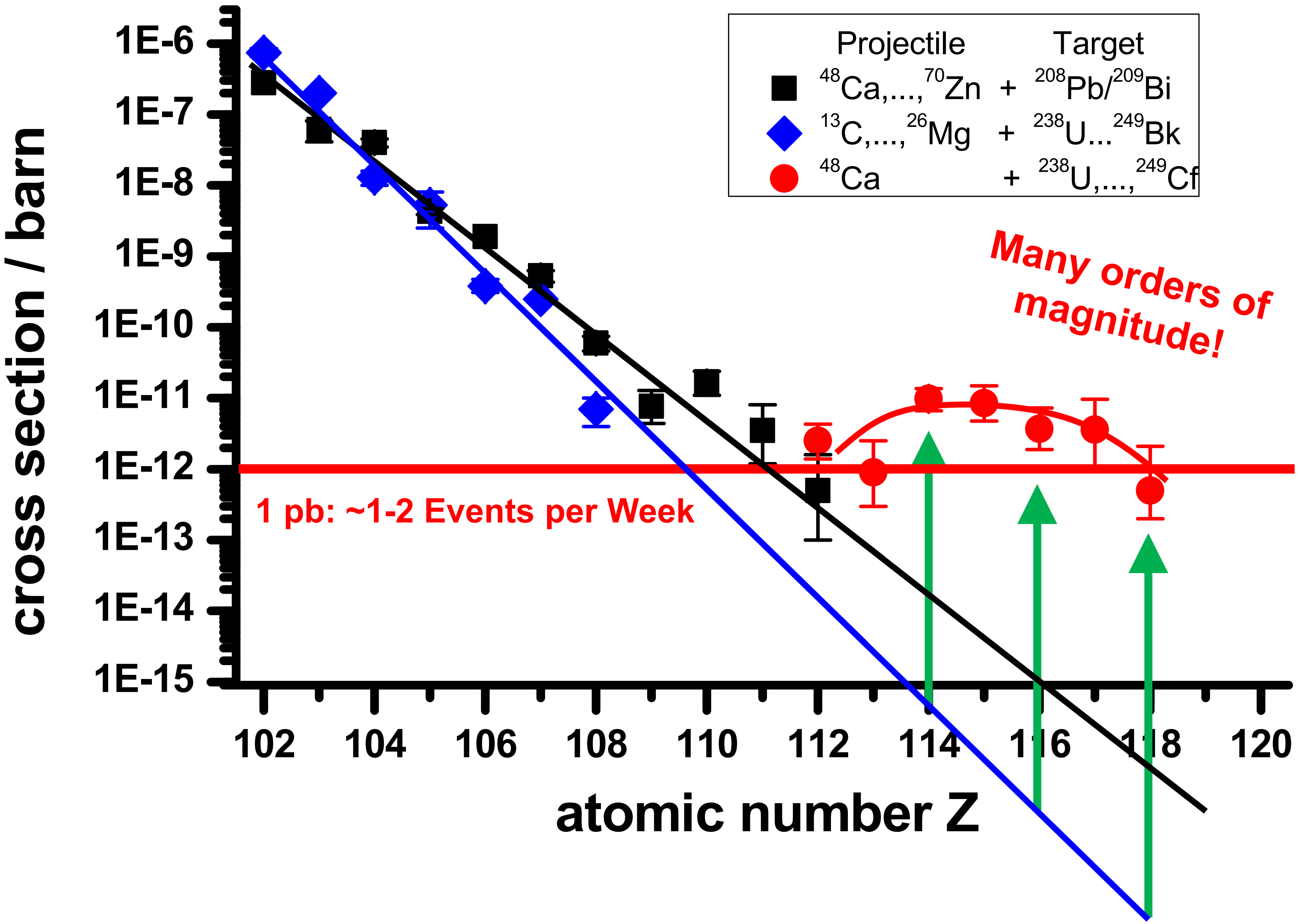
Z=116: Cf(Ca,3n) 118

Z=117: ^{249}Bk(^{48}Ca,4n)^{293}117

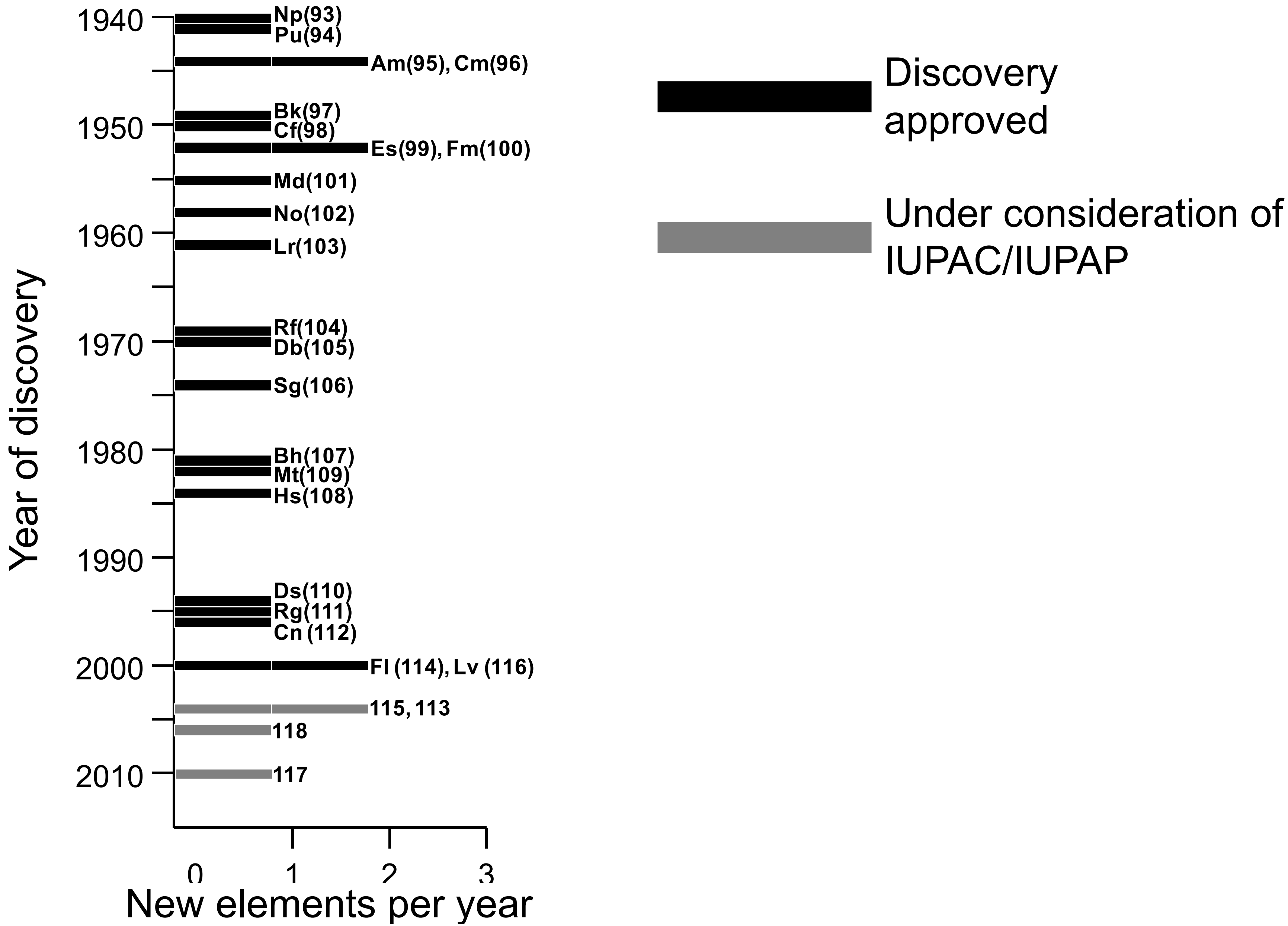
Neutron rich superheavy elements



Cross Sections in Hot / Cold / ^{48}Ca Induced Fusion Reactions



Discovery of the transuranium elements



Superheavy elements 2012: 15 out of 118 (13%!)

Z	Name	Symbol
104	Rutherfordium	Rf
105	Dubnium	Db
106	Seaborgium	Sg
107	Bohrium	Bh
108	Hassium	Hs
109	Meitnerium	Mt
110	Darmstadtium	Ds
111	Roentgenium	Rg
112	Copernicium	Cn
113	(yet unnamed)	(uut) / E113
114	Flerovium	Fl
115	(yet unnamed)	(uup) / E115
116	Livermorium	Lv
117	(yet unnamed)	(uus) / E117
118	(yet unnamed)	(uuo) / E118

The periodic table of the elements 2012

Radio elements:

10 natural radioelements●

28 Synthetic elements●

(thereof 26 transuranics)

(thereof 15 transactinides = 13%)

} 38 von 118 (>30%!)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H**																	2 **He**
3 **Li**	4 **Be**											5 **B**	6 **C**	7 **N**	8 **O**	9 **F**	10 **Ne**
11 **Na**	12 **Mg**											13 **Al**	14 **Si**	15 **P**	16 **S**	17 **Cl**	18 **Ar**
19 **K**	20 **Ca**	21 **Sc**	22 **Ti**	23 **V**	24 **Cr**	25 **Mn**	26 **Fe**	27 **Co**	28 **Ni**	29 **Cu**	30 **Zn**	31 **Ga**	32 **Ge**	33 **As**	34 **Se**	35 **Br**	36 **Kr**
37 **Rb**	38 **Sr**	39 **Y**	40 **Zr**	41 **Nb**	42 **Mo**	43● **Tc**	44 **Ru**	45 **Rh**	46 **Pd**	47 **Ag**	48 **Cd**	49 **In**	50 **Sn**	51 **Sb**	52 **Te**	53 **I**	54 **Xe**
55 **Cs**	56 **Ba**	57+* **La**	72 **Hf**	73 **Ta**	74 **W**	75 **Re**	76 **Os**	77 **Ir**	78 **Pt**	79 **Au**	80 **Hg**	81 **Tl**	82 **Pb**	83● **Bi**	84● **Po**	85● **At**	86● **Rn**
87● **Fr**	88● **Ra**	89+● **Ac**	104● **Rf**	105● **Db**	106● **Sg**	107● **Bh**	108● **Hs**	109● **Mt**	110● **Ds**	111● **Rg**	112● **Cn**	113● **---**	114● **Fl**	115● **---**	116● **Lv**	117● **---**	118● **---**

*	58 **Ce**	59 **Pr**	60 **Nd**	61● **Pm**	62 **Sm**	63 **Eu**	64 **Gd**	65 **Tb**	66 **Dy**	67 **Ho**	68 **Er**	69 **Tm**	70 **Yb**	71 **Lu**
"	90● **Th**	91● **Pa**	92● **U**	93● **Np**	94● **Pu**	95● **Am**	96● **Cm**	97● **Bk**	98● **Cf**	99● **Es**	100● **Fm**	101● **Md**	102● **No**	103● **Lr**

Lessons learned

- All heaviest chemical elements have been discovered in physics experiments with recoil separators
- Reports on all elements up to Z=118 published
- Cross sections drop exponentially in "cold (1n)" and "hot (5n)" fusion experiments, but are almost constant from Z=112-118 in ^{48}Ca induced reactions

IUPAC rules on how a new element gets named

New Element?

- Analysis of the claim by IUPAC/IUPAP
- Publication of the analysis in *Pure and Applied Chemistry*
- Invitation of the credited group to propose a name
- Provisional recommendation presenting the proposed name
- Public review
- Final approval by the IUPAC Council
- Publication of the approved name in *Pure and Applied Chemistry*

Claim from Dubna for element 113

PHYSICAL REVIEW C **69**, 021601(R) (2004)

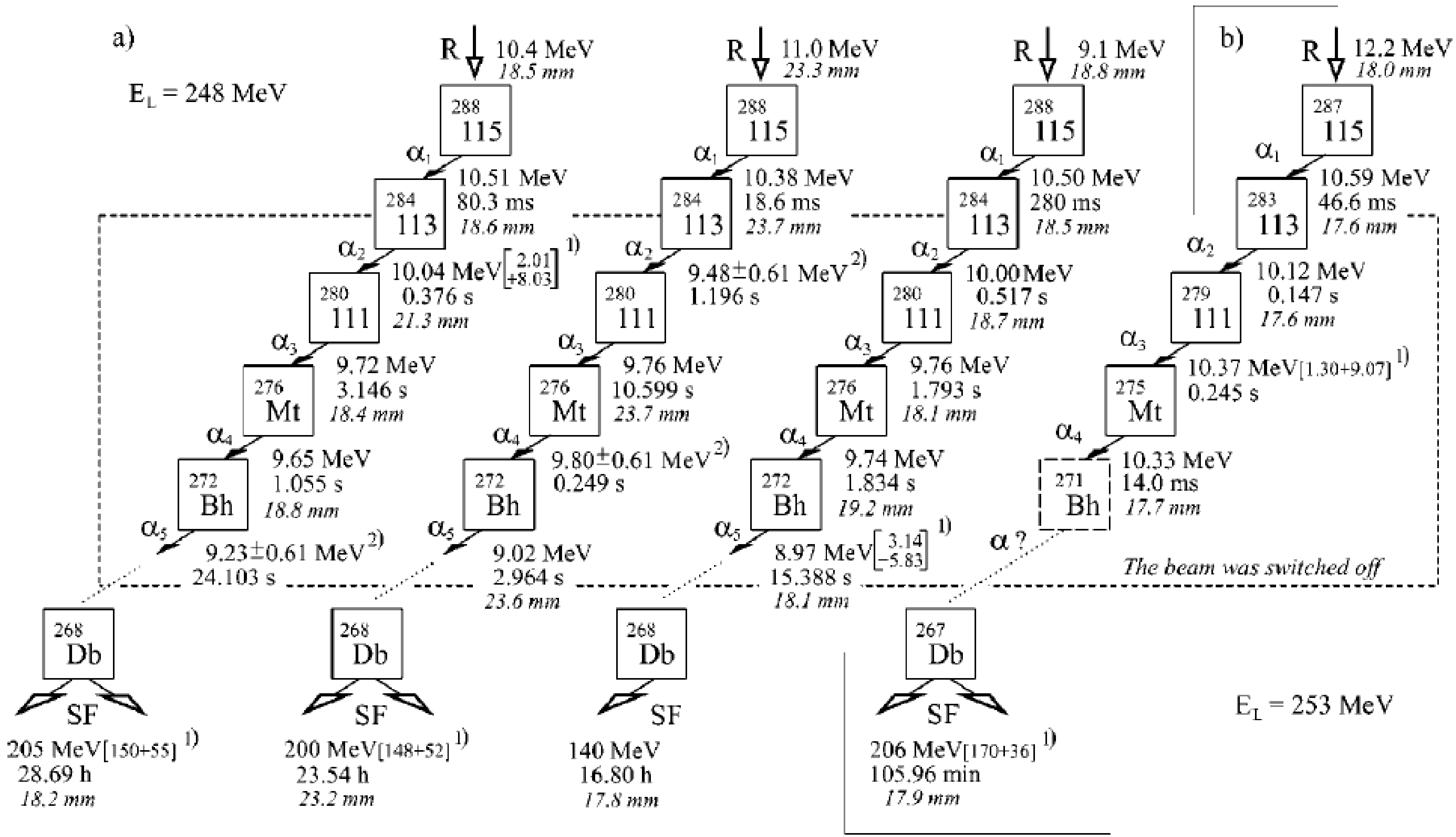
Experiments on the synthesis of element 115 in the reaction $^{243}Am(^{48}Ca, xn)^{291-x}115$

Yu. Ts. Oganessian, V. K. Utyonkoy, Yu. V. Lobanov, F. Sh. Abdullin, A. N. Polyakov, I. V. Shirokovsky, Yu. S. Tsyganov, G. G. Gulbekian, S. L. Bogomolov, A. N. Mezentsev, S. Iliev, V. G. Subbotin, A. M. Sukhov, A. A. Voinov, G. V. Buklanov, K. Subotic, V. I. Zagrebaev, and M. G. Itkis
Joint Institute for Nuclear Research, 141980 Dubna, Russian Federation

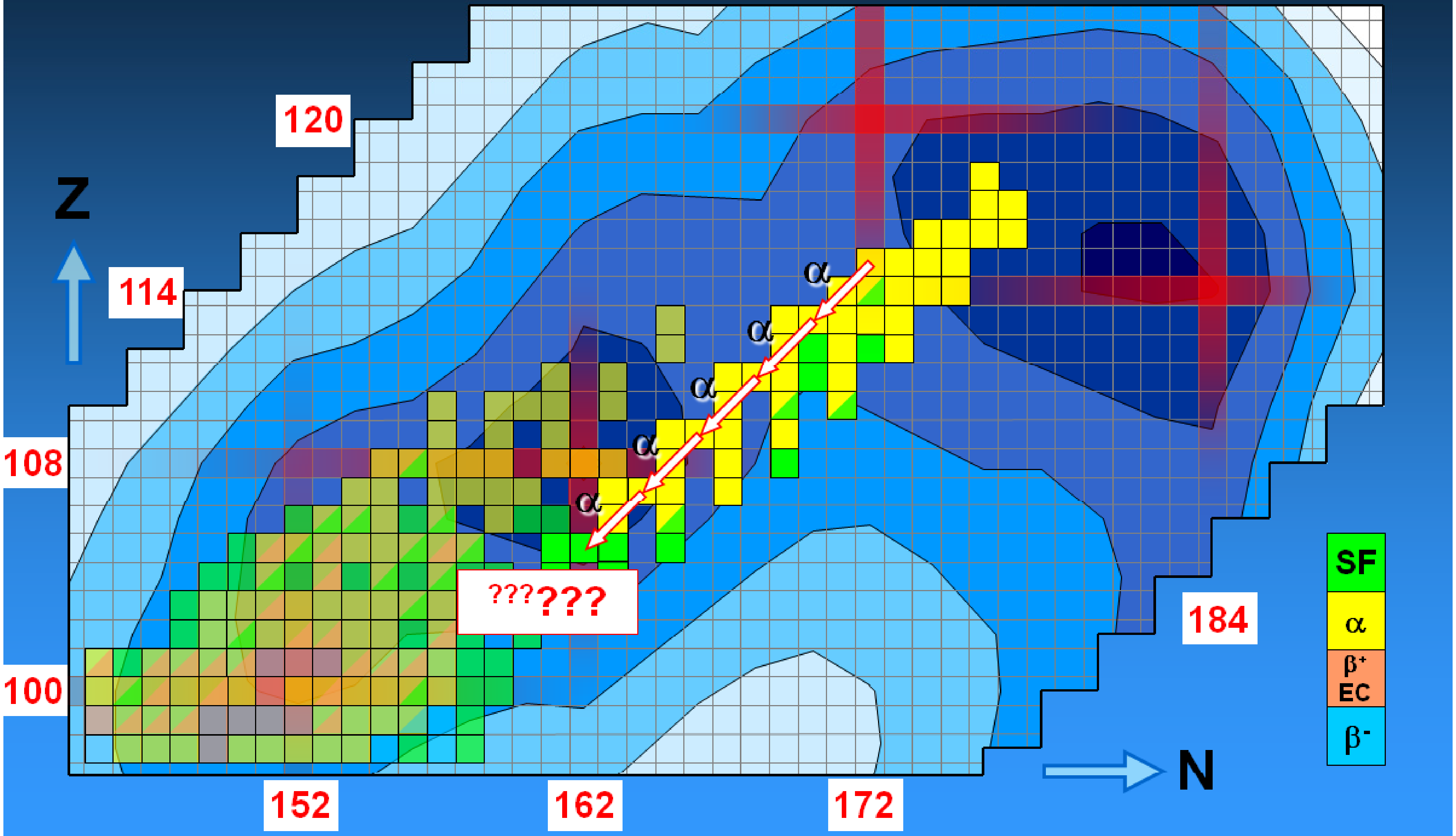
J. B. Patin, K. J. Moody, J. F. Wild, M. A. Stoyer, N. J. Stoyer, D. A. Shaughnessy, J. M. Kenneally, and R. W. Lougheed
University of California, Lawrence Livermore National Laboratory, Livermore, California 94551, USA

(Received 8 September 2003; published 2 February 2004; publisher error corrected 3 February 2004)

Claim from Dubna for element 113



The element 113/115 decay chains from Dubna



2011 IUPAC/IUPAP assessment of Dubna claim for element 113

113; *03 The collaboration of Oganessian et al. [13]*

In 2007, this collaboration investigated the hot fusion of ^{48}Ca with ^{237}Np and reported two four-member α-decay chains commencing at $^{282}113$, passing through ^{278}Rg, ^{274}Mt, and ^{270}Bh, and leading, in just one chain, to ^{266}Db decay by spontaneous fission with a 32 min lifetime. The first two events in each chain showed excellent mutual agreement for both decay energies and lifetimes. The third member gave lifetimes of 470 and 810 ms. None of the nuclides had been previously characterized.

JWP ASSESSMENT: The collaborations of Oganessian et al. at Dubna were essentially contemporaneous with those of Morita et al. at RIKEN. The results are encouraging but do not meet the criteria for discovery because of the paucity of events, the lack of connections to known nuclides, and the absence of cross-bombardments.

Claim from RIKEN for element 113

1st paper

Journal of the Physical Society of Japan
Vol. 73, No. 10, October, 2004, pp. 2593–2596

Experiment on the Synthesis of Element 113 in the Reaction $^{209}Bi(^{70}Zn,n)^{278}113$

Kosuke MORITA[1*], Kouji MORIMOTO[1], Daiya KAJI[1], Takahiro AKIYAMA[1,2], Sin-ichi GOTO[3], Hiromitsu HABA[1], Eiji IDEGUCHI[4], Rituparna KANUNGO[1], Kenji KATORI[1], Hiroyuki KOURA[5], Hisaaki KUDO[6], Tetsuya OHNISHI[1], Akira OZAWA[7], Toshimi SUDA[1], Keisuke SUEKI[7], HuShan XU[8], Takayuki YAMAGUCHI[2], Akira YONEDA[1], Atsushi YOSHIDA[1] and YuLiang ZHAO[9]

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[2]*Department of Physics, Saitama University, Sakura-ku, Saitama 338-8570*
[3]*Center for Instrumental Analysis, Niigata University, Ikarashi, Niigata 950-2181*
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[5]*Advanced Science Research Center, Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-1195*
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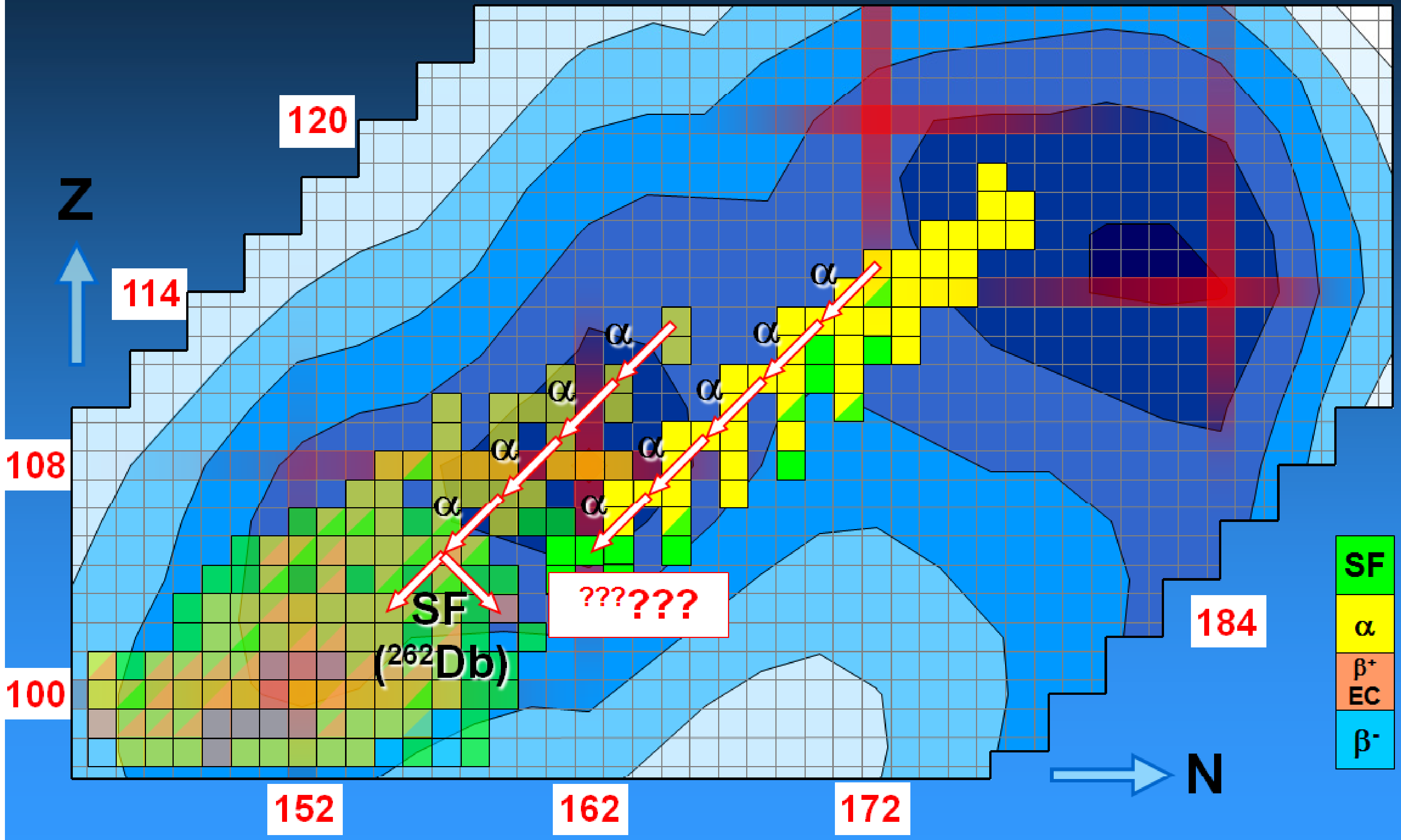
[7]*University of Tsukuba, Tsukuba, Ibaraki 305-8571*
[8]*Institute of Modern Physics, Chinese Academy of Science, Lanzhou 730000, China*
[9]*Institute of High Energy Physics, Chinese Academy of Science, Beijing 100039, China*

(Received July 30, 2004)

The element 113 decay chains from RIKEN



2011 IUPAC/IUPAP assessment of RIKEN claim for element 113

113; *02 The collaboration of Morita et al. [10,11]*

Production of two chains of α-emitting nuclides was reported by Morita et al. from the cold fusion reaction of a bismuth target with a ^{70}Zn beam at the RIKEN heavy-ion facility in Japan, the first in 2004 [10] and the second in 2007 [11]. The former study reports the α-chain commencing with $^{278}113$ proceeding through ^{274}Rg, ^{270}Mt, ^{266}Bh, and terminating via spontaneous fission decay assigned to ^{262}Db. All α-energies and lifetimes were measured. In the subsequent study, a very similar sequence was found but with some reproducibility difficulties. The full α-energy for ^{270}Mt was not measured; those for ^{266}Bh were in disagreement (9.08 vs. 9.77 MeV); and the lifetimes for ^{262}Db spontaneous fission were significantly different (41 vs. 0.8 s). For both chains, position-sensitive detectors were used. These provide a high degree of confidence that the observed decays are indeed sequential decays in each case. Nuclides reported in these chains do not correspond to established systems. But a single report of a triple-coincidence of α-emitters commencing with ^{266}Bh has been described by Wilk et al. [12]. Production was via the hot fusion $^{22}Ne + ^{249}Bk$ reaction, and the leading event had an α-particle energy of 9.29 MeV, within the uncertainties of the RIKEN results, with a lifetime of 1–10 s. It was followed by a 28 s α decay, not by spontaneous fission. The latter observation is in contrast to the RIKEN result.

JWP ASSESSMENT: The work of the collaboration of Morita et al. is very promising but has not met the criteria for discovery owing to the paucity of events, the absence of firm connection(s) to known nuclides, and the inconsistencies noted above.

New Result in the Production and Decay of an Isotope, $^{278}113$, of the 113th Element

Kosuke MORITA[1*], Kouji MORIMOTO[1], Daiya KAJI[1], Hiromitsu HABA[1], Kazutaka OZEKI[1], Yuki KUDOU[1], Takayuki SUMITA[2,1], Yasuo WAKABAYASHI[1], Akira YONEDA[1], Kengo TANAKA[2,1], Sayaka YAMAKI[3,1], Ryutaro SAKAI[4,1], Takahiro AKIYAMA[3,1], Shin-ichi GOTO[5], Hiroo HASEBE[1], Minghui HUANG[1], Tianheng HUANG[6], Eiji IDEGUCHI[7†], Yoshitaka KASAMATSU[1‡], Kenji KATORI[1], Yoshiki KARIYA[5], Hidetoshi KIKUNAGA[8], Hiroyuki KOURA[9], Hisaaki KUDO[5], Akihiro MASHIKO[10], Keita MAYAMA[10], Shin-ichi MITSUOKA[9], Toru MORIYA[10], Masashi MURAKAMI[5], Hirohumi MURAYAMA[5], Saori NAMAI[10], Akira OZAWA[11], Nozomi SATO[9], Keisuke SUEKI[11], Mirei TAKEYAMA[10], Fuyuki TOKANAI[10], Takayuki YAMAGUCHI[3], and Atsushi YOSHIDA[1]

[1]*RIKEN Nishina Center for Accelerator-Based Science, RIKEN, Wako, Saitama 351-0198, Japan*
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(Received August 29, 2012; accepted September 10, 2012; published online September 27, 2012)

New Result in t… …e 113th Element

Kosuke Morita[1]* … …eki[1], Yuki Kudou[1],
Takayuki Sumi… …ayaka Yamaki[3,1],
Ryutaro Sak… …ghui Huang[1],
Tianheng Hu… …shiki Kariya[5],
Hidetoshi Kiku… …ita Mayama[10],
Shin-ichi Mitsu… …[5], Saori Namai[10],
Akira Oza… … Tokanai[10],

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[2]Faculty… …10, Japan

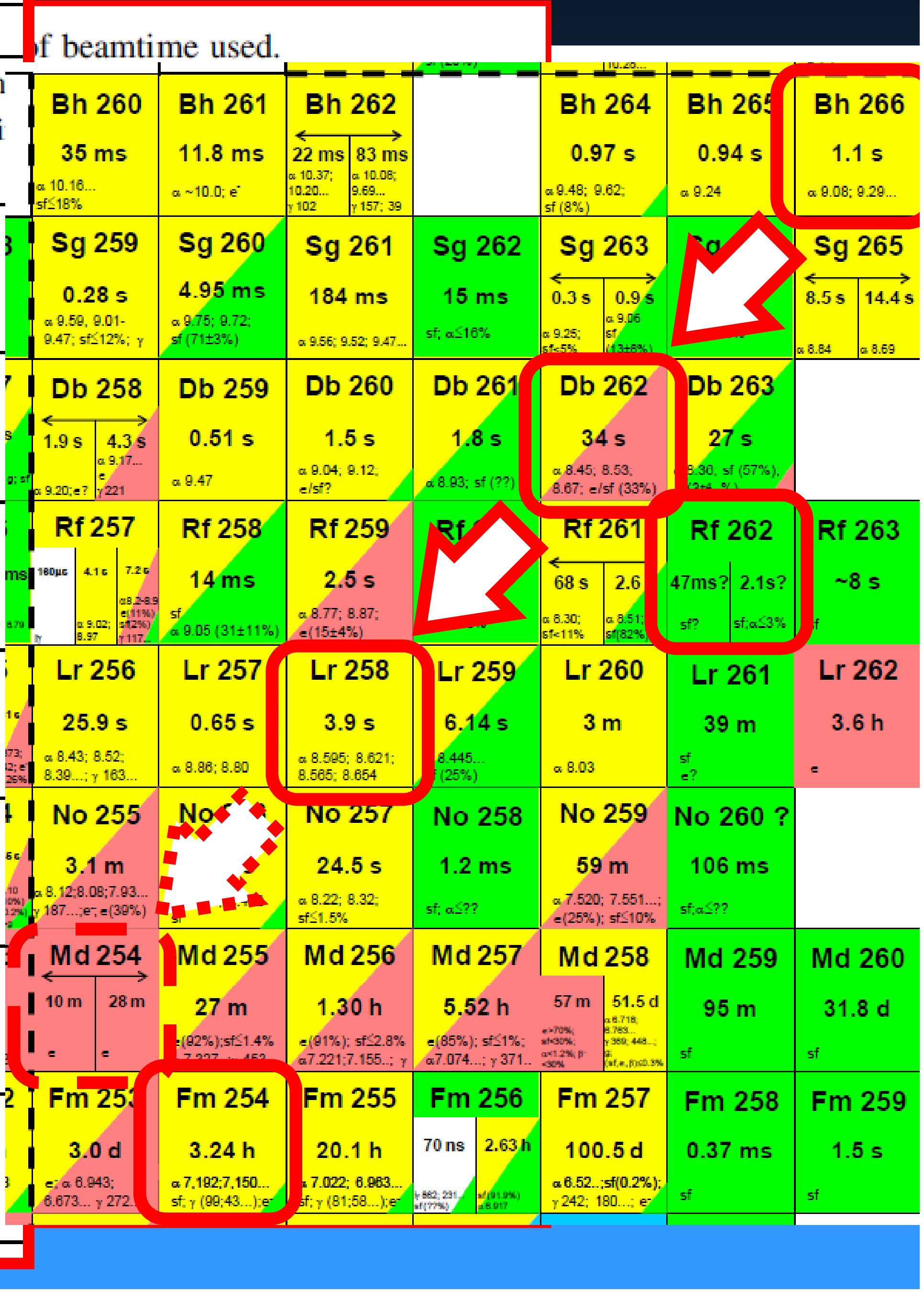
[6]Inst… …China
…n
[8]Rese… … Japan

(Recei… …7, 2012)

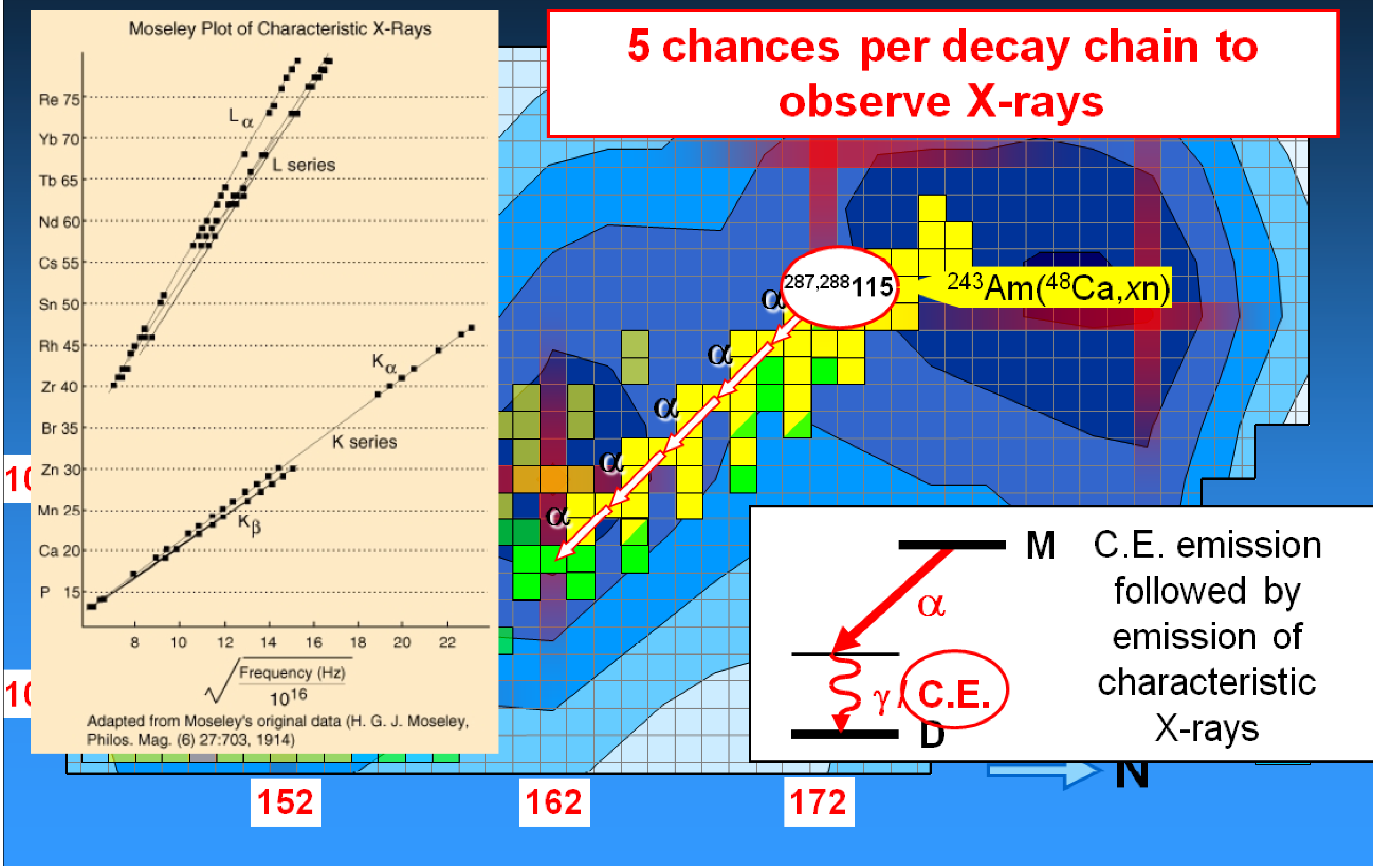
Table I. Summary of beamtime used.

Beamtime		Irradiation time (days)	Beam dose/sum ($\times 10^{19}$)	Number of observed events
year	month/day			
2003	9/5–12/29	57.9	1.24/1.24	0
2004	7/8–8/2	21.9	0.51/1.75	1
2005	1/20–1/23	3.0	0.07/1.82	0
2005	3/20–4/22	27.1	0.71/2.53	1
2005	5/19–5/21	2.0	0.05/2.58	0
2005	8/7–8/25	16.1	0.45/3.03	0
2005	9/7–10/20	39.0	1.17/4.20	0
2005	11/25–12/15	19.5	0.63/4.83	0
2006	3/14–5/15	54.2	1.37/6.20	0
2008	1/9–3/31	70.9	2.28/8.48	0
2010	9/7–10/18	30.9	0.52/9.00	0
2011	1/22–5/22	89.8	2.01/11.01	0
2011	12/2–12/19	14.4	0.33/11.34	0
2012	1/15–2/9	25.0	0.56/11.90	0
2012	3/13–4/17	33.7	0.79/12.69	0
2012	6/12–7/2	15.7	0.25/12.94	0
2012	7/14–8/18	32.0	0.57/13.51	1
Total		553	13.51	3

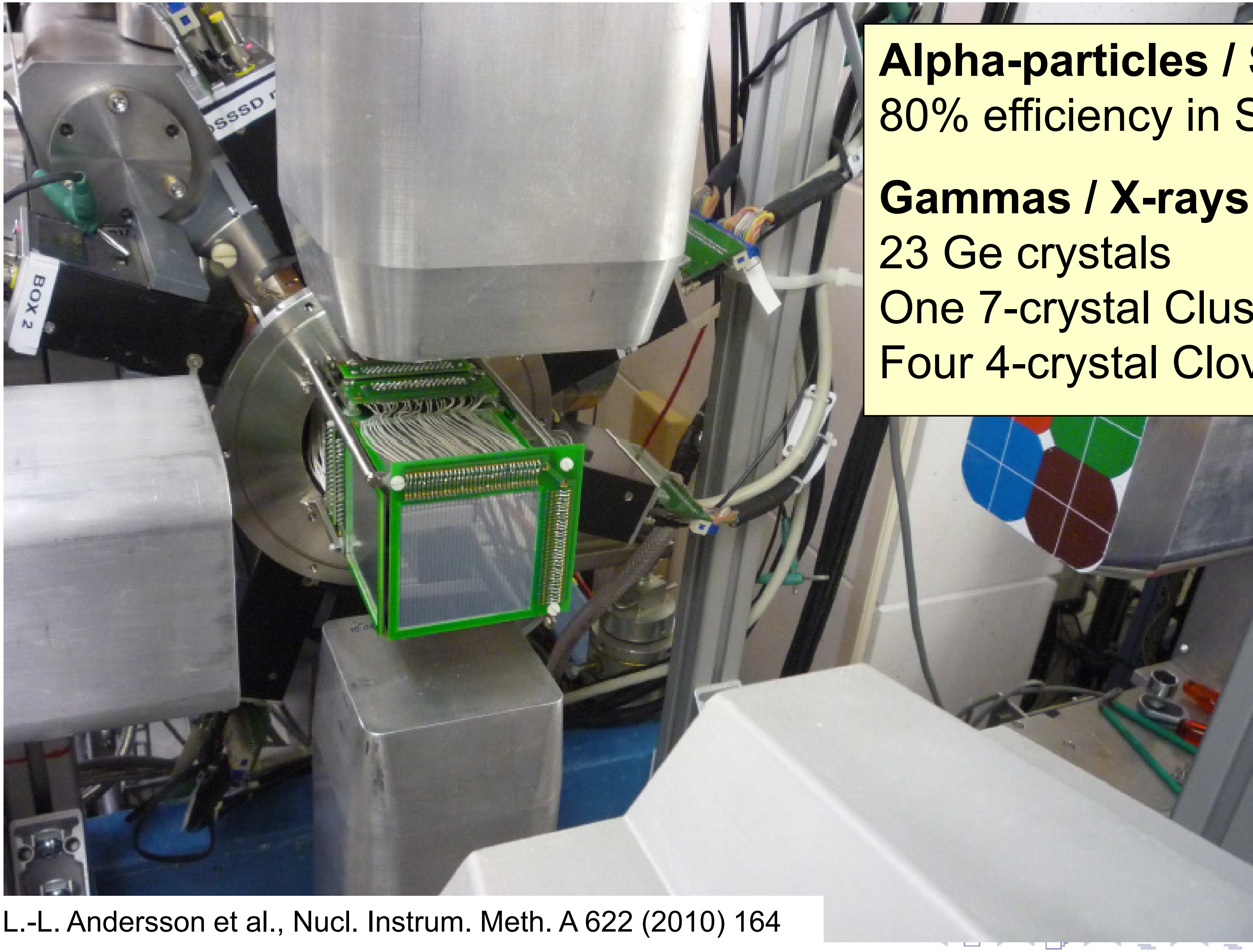
	Chain 1[1]	Chain 2[2]	Chain 3 (present)	
	E (MeV) ΔT Position	E (MeV) ΔT Position	E (MeV) ΔT Position	Assignmen mean lifeti
ER	36.75 44.6 ns (TOF) 30.3 mm	36.47 45.7 ns (TOF) 30.1 mm	41.91 42.6 ns (TOF) 4.9 mm	
α_1	11.68 (0.04) 0.344 ms 30.5 mm	11.52 (0.04) 4.93 ms 30.2 mm	11.82 (0.06) 0.667 ms 4.4 mm	$^{278}113$ $2.0^{+2.7}_{-0.7}$ ms
α_2	11.15 (0.07) 9.26 ms 30.4 mm	11.31 (0.07) 34.3 ms 29.6 mm	10.65 (0.06) 9.97 ms 4.8 mm	^{274}Rg 18^{+24}_{-7} ms
α_3	10.03 (0.07) 7.16 ms 29.8 mm	2.32 (escape) 1.63 s 29.5 mm	10.26 (0.07) 444 ms 5.1 mm	^{270}Mt $0.69^{+0.95}_{-0.26}$ s
α_4	9.08 (0.04) 2.47 s 30.9 mm	9.77 (0.04) 1.31 s 29.7 mm	9.39 (0.06) 5.26 s 4.9 mm	^{266}Bh $3.0^{+4.2}_{-1.1}$ s
F/α_5	204 (SF) 40.9 s 30.3 mm	192 (SF) 0.787 s 30.5 mm	8.63 (0.06) 126 s 4.5 mm	^{262}Db 56^{+77}_{-21} s
α_6	—	—	8.66 (0.06) 3.78 s 4.7 mm	^{258}Lr $3.8^{+1.8}_{-1.7}$ s



The element 113/115 decay chains from Dubna



TAsca Small Image mode SPECtroscopy



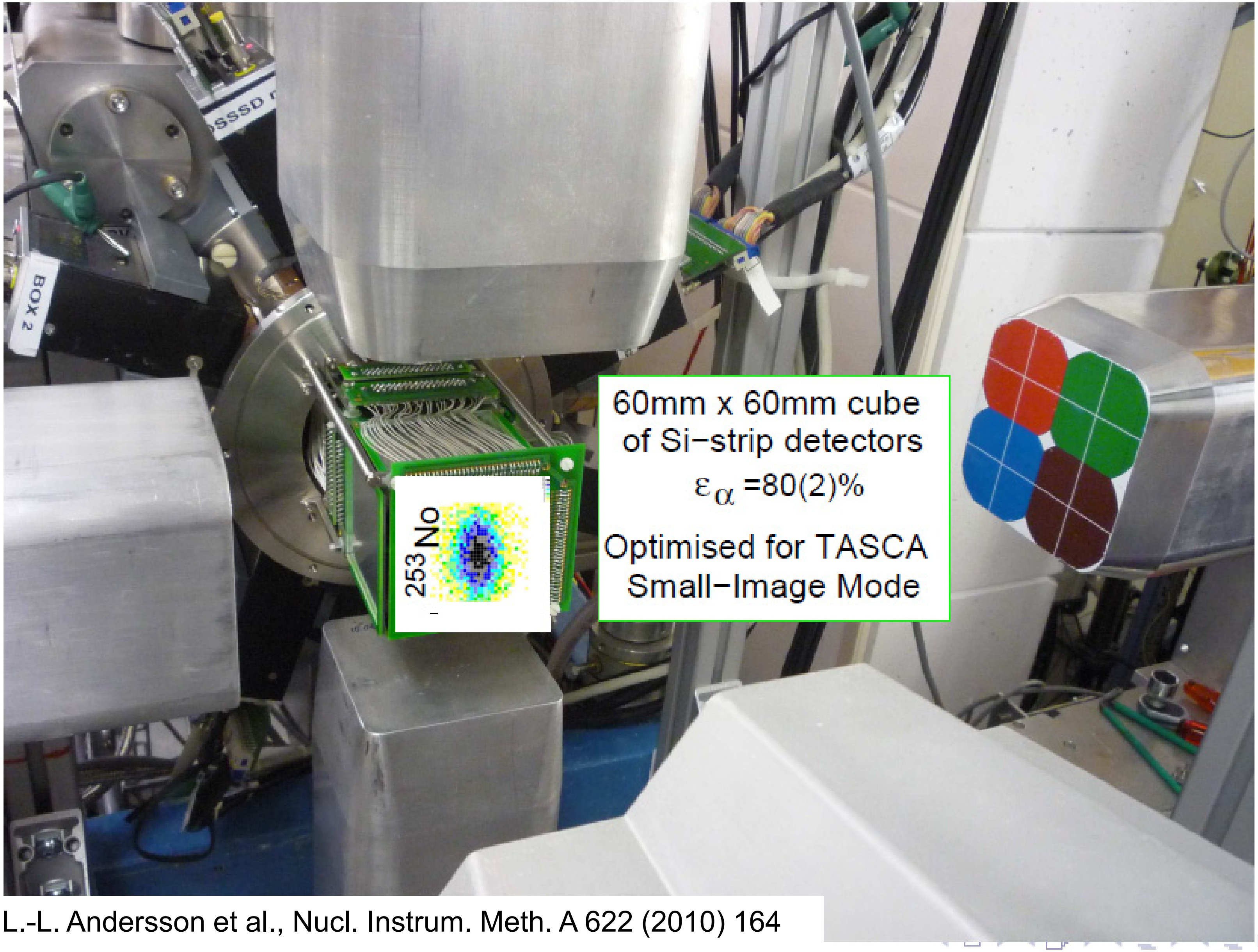
Alpha-particles / SF:
80% efficiency in Si Box

Gammas / X-rays:
23 Ge crystals
One 7-crystal Cluster
Four 4-crystal Clovers

L.-L. Andersson et al., Nucl. Instrum. Meth. A 622 (2010) 164

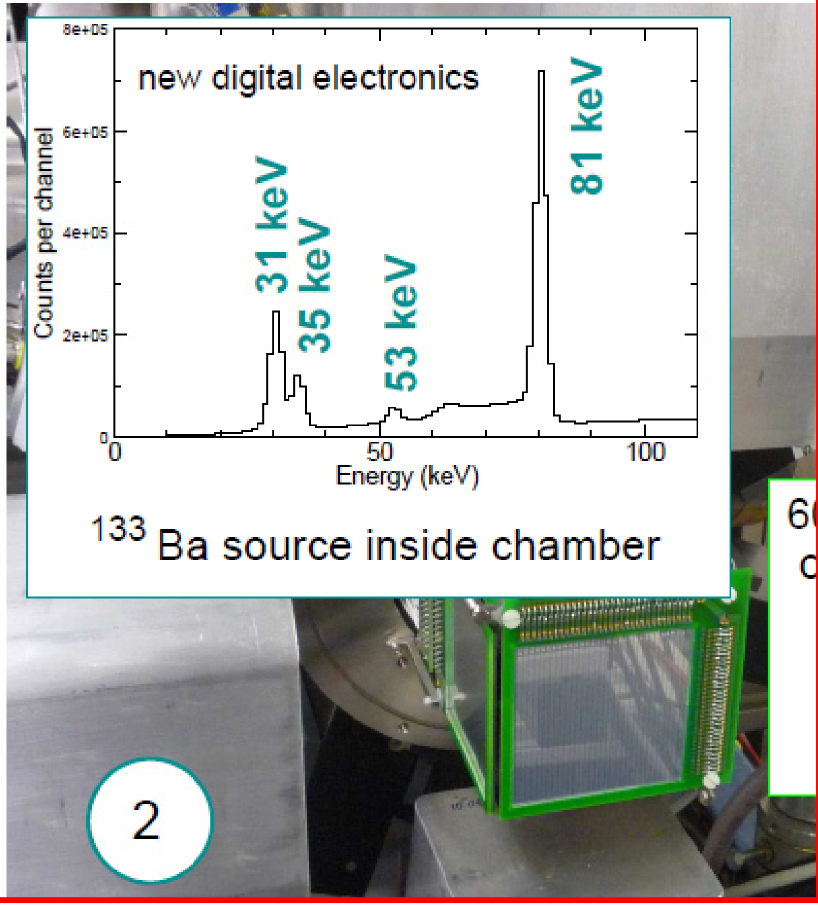
LUND UNIVERSITY

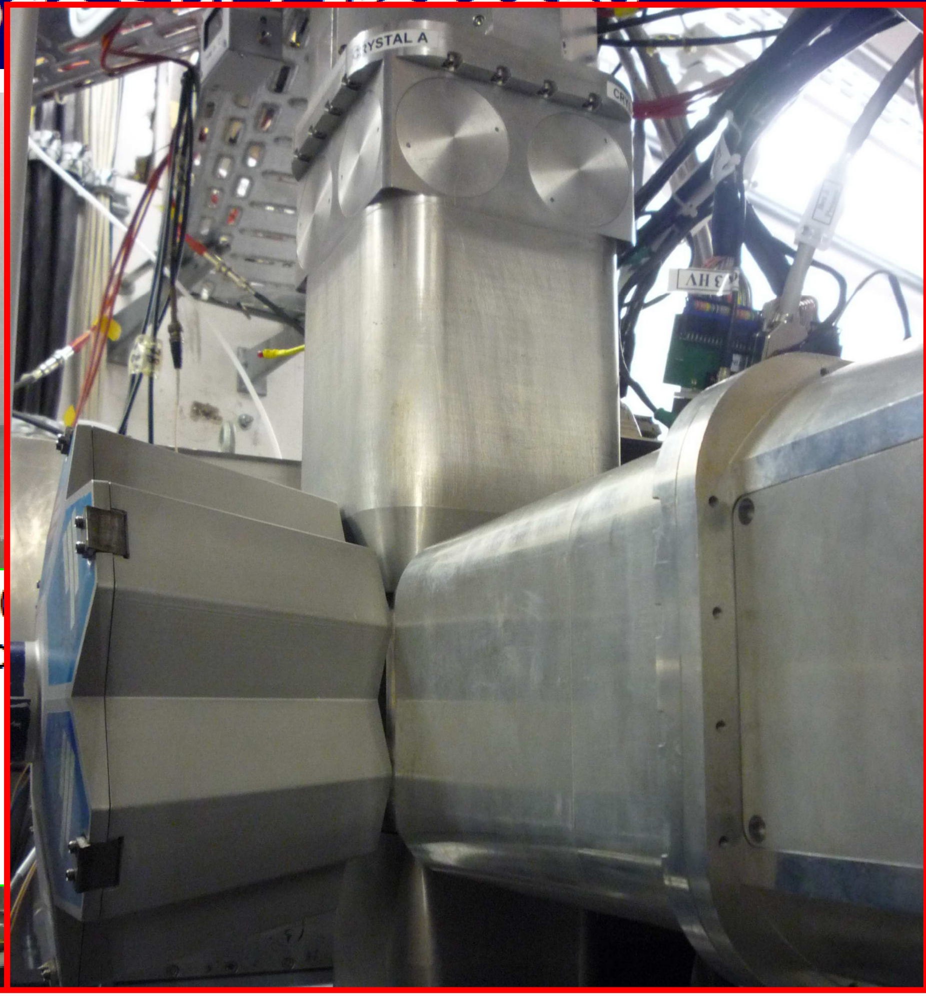
TAsca Small Image mode SPECtroscopy



L.-L. Andersson et al., Nucl. Instrum. Meth. A 622 (2010) 164

TAsca Small Image mode SPECtroscopy





- Detailed spectroscopy towards Z=108/N=162 (^{270}Hs)
  - → Input for SHE Island of Stability: **114** vs. **120** vs. **126**
- Fingerprinting SHE: Z identification via characteristic X-rays

Lessons learned

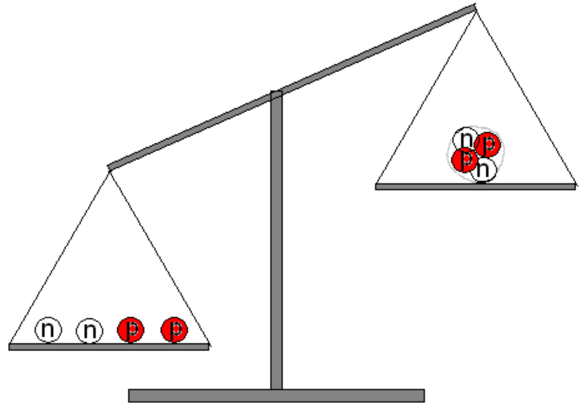
- Elements up to 112, and 114/116 named.
- All elements up to 118 claimed.
  113/115/117/118 not approved
- No atomic number directly measured for any element beyond 112 (113...)
- New (last week) data on E113 from RIKEN

Stability of SHE

The atomic mass / binding energy

Alpha decay

Mass ↔ Energy



A nucleus with Z protons and N neutrons
is lighter than Z protons + N neutrons

→ Mass is converted to (binding) energy

The mass of a nucleus (or, an atom) gives
direct information on its stability!

Relation between mass and energy:

$$E\,[J] = m\,[kg] \cdot (c\,[m/s])^2$$

Atomic masses are given in the unit "u" (unified atomic mass)

Definition: M(^{12}C) ≡ 12 u

Using c=299'792'458 m/s gives: $1\ \text{MeV}/c^2 \triangleq 1.073533 \cdot 10^{-3}\ \text{u}$
and $1\ \text{u} \triangleq 931.494\ \text{MeV}/c^2$.

(Calculations "in energy": [MeV] or [J]; Calculations "in mass": [MeV/c²] or [kg])

Atomic masses

$$M(Z,A) = Z \cdot M_H + (A-Z) \cdot M_N - BE/c^2$$

M(Z,A): Mass of the atom (MeV/c^2)

Z: Protonen number

A: Mass number

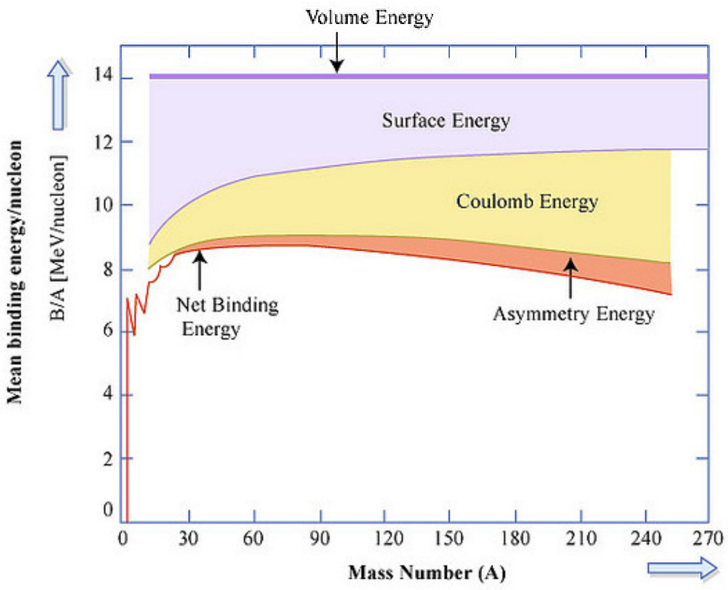
M_H: Mass of neutral H atom (938.791 MeV/c^2=1.007823 u)

M_N: Masse of neutron (939.573 MeV/c^2=1.008662 u)

BE: Binding energy (MeV)

The semi-empirical mass formula (SEMF)

BE consists of five contributions:



$E_v = a_v \cdot A$ $\quad a_v = 15.85\ \mathrm{MeV}/c^2$

$E_s = a_s \cdot A^{2/3}$ $\quad a_o = -18.34\ \mathrm{MeV}/c^2$

$E_c = a_c \cdot Z^2/A^{1/3}$ $\quad a_c = -0.71\ \mathrm{MeV}/c^2$

$E_a = a_a \cdot (Z-A/2)^2/A$ $\quad a_a = -92.86\ \mathrm{MeV}/c^2$

$$E_p = \begin{cases} +\delta & \text{for e,e-nuclei} \\ 0 & \text{for odd-A nuclei} \\ -\delta & \text{for o,o-nuclei} \end{cases}$$

$\delta = a_p \cdot A^{-1/2}$ $\quad a_p = 11.46\ \mathrm{MeV}/c^2$

Average deviation from experimental masses: <1%!

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Example: BE of ^{12}C

E_v:	190.20 $\mathrm{MeV/c^2}$
E_s:	-96.13 $\mathrm{MeV/c^2}$
E_c:	-11.16 $\mathrm{MeV/c^2}$
E_a:	0.00 $\mathrm{MeV/c^2}$
E_p:	3.31 $\mathrm{MeV/c^2}$
BE:	86.22 $\mathrm{MeV/c^2}$
$M(^{12}C)$:	12.00636 u

$\rightarrow$why not12.0000 u ?

Example: BE of ^{261}Rf

E_v:	4136.85 $\mathrm{MeV/c^2}$
E_s:	-749.02 $\mathrm{MeV/c^2}$
E_c:	-1201.65 $\mathrm{MeV/c^2}$
E_a:	-249.85 $\mathrm{MeV/c^2}$
E_p:	0.00 $\mathrm{MeV/c^2}$
BE:	1936.33 $\mathrm{MeV/c^2}$
$M(^{261}Rf)$:	261.095 u

for comparison: AME2003: 261.109 u

The α decay

Example: $^{248}Cm \rightarrow {}^{244}Pu + {}^{4}He$

$\Delta(^{248}Cm) = \Delta(^{244}Pu) + \Delta(^{4}He) + Q$ ($\Delta(Z,A)$ [MeV/c^2] = M(Z,A)[u] – A[u] is the mass excess)

Decay energy: Q_α [MeV]= $\{\Delta(^{248}Cm) - [\Delta(^{244}Pu) + \Delta(^{4}He)]\}c^2$

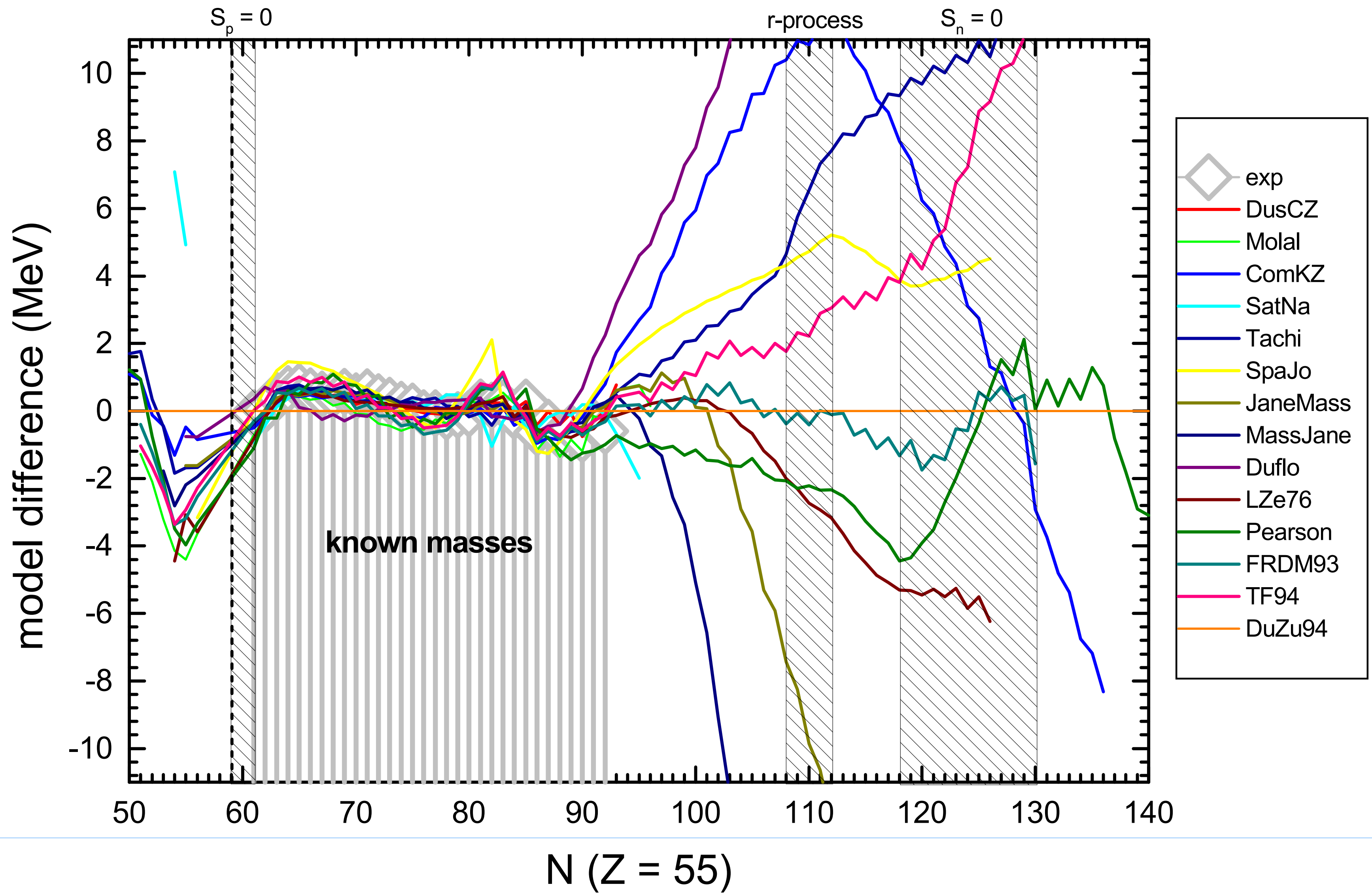
Q_α is distributed between the α particle and the daughter. From momentum conservation follows the energie of the α particle:

$$E_\alpha\left(^{248}Cm\right) = Q_\alpha \cdot \frac{M\left(^{244}Pu\right)}{M(^{248}Cm)}$$

and the recoil energy of the daughter

$$E_D\left(^{248}Cm\right) = Q_\alpha \cdot \frac{M\left(^{4}He\right)}{M(^{248}Cm)}$$

Cs-Isotopes: mass in different mass models



K. Blaum, Phys. Rep. 425 (2006) 1

Prediction of E_α

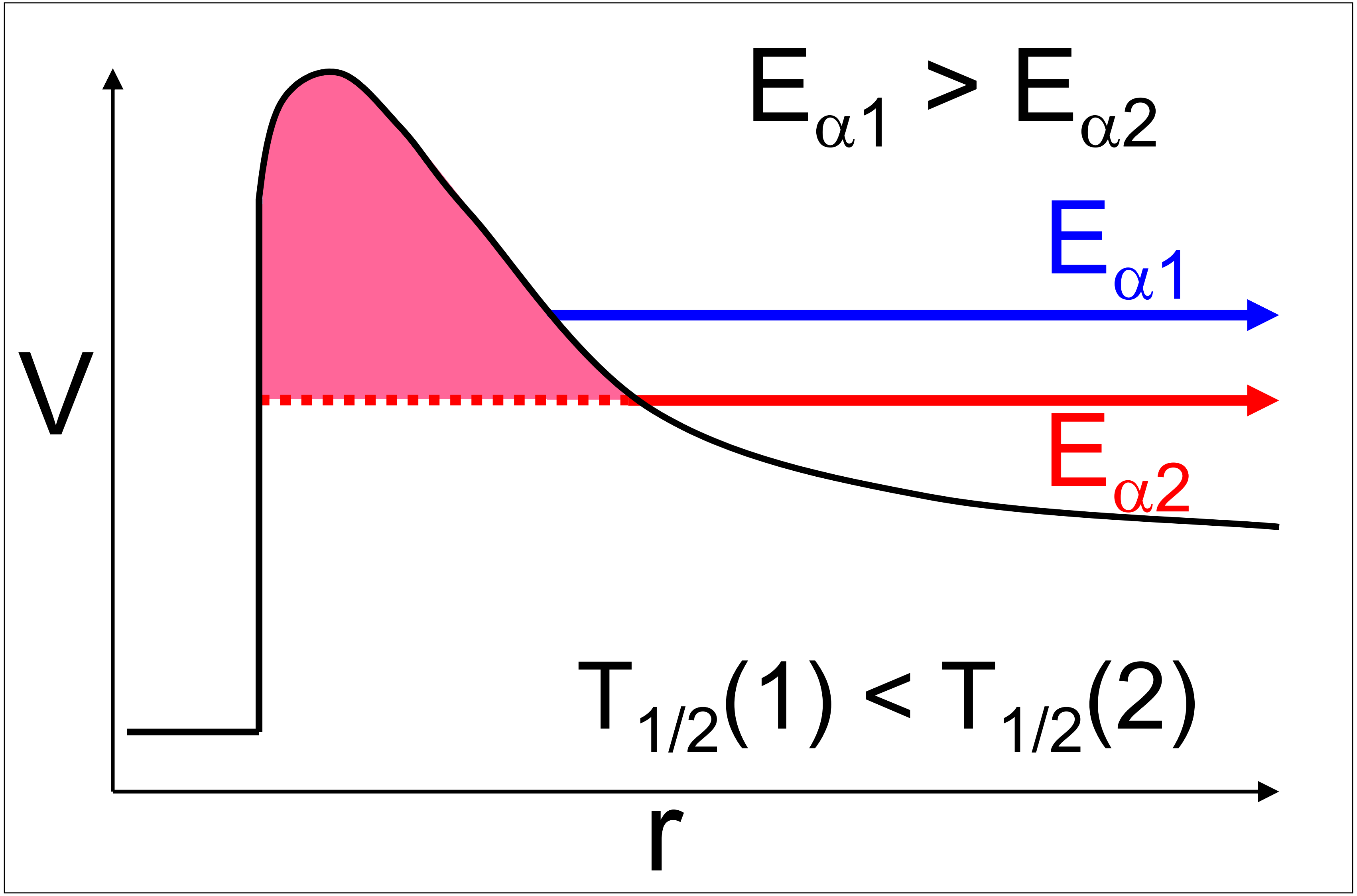
Example: $^{248}Cm \rightarrow {}^{244}Pu + {}^{4}He$

$Q = \{\Delta(^{248}Cm) - [\Delta(^{244}Pu) + \Delta(^{4}He)]\}c^2$

	SEMF	AME 2003
$\Delta(^{248}Cm)$:	53.485 MeV/c^2	67.392±0.005 MeV/c^2
$\Delta(^{244}Pu)$:	45.658 MeV/c^2	59.806±0.005 MeV/c^2
$\Delta(^{4}He)$:	--	2.42491565±0.00000006 MeV/c^2
$Q_\alpha(^{248}Cm)$	5.402 MeV	5.16173 ±0.00025 MeV
E_α (^{248}Cm)	5.315 MeV	5.08 MeV

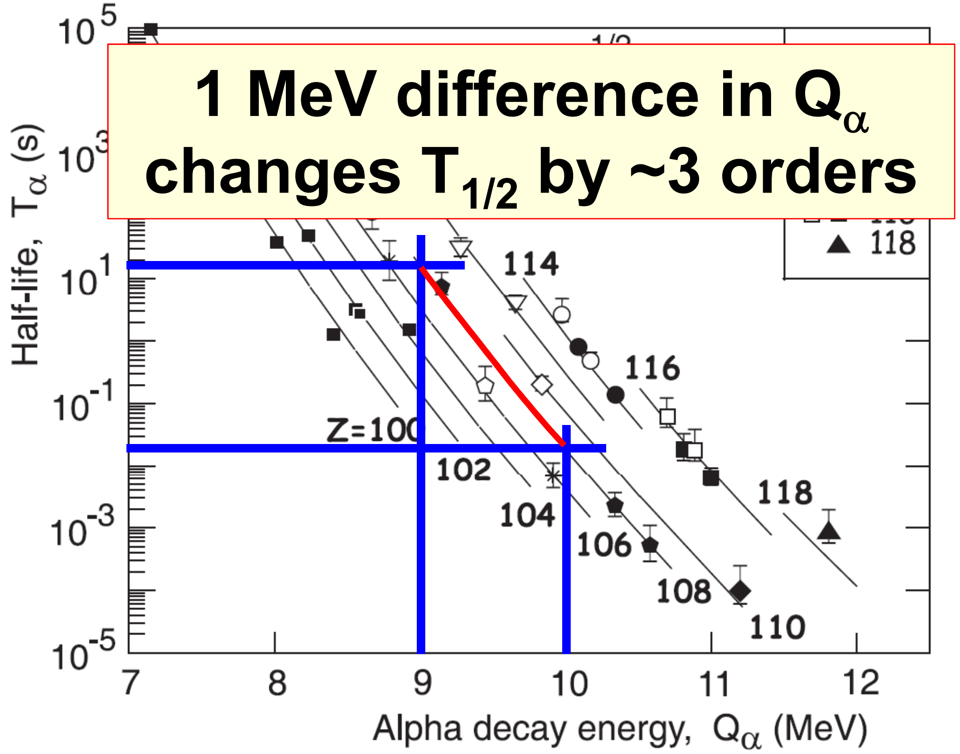
^{248}Cm α-decay energy of the simple SEMF is precise to about 5%

Nuclear Physics 101: α-Decay



Q_α [MeV]= $\{\Delta(\text{Mother}) – [\Delta(\text{Daughter}) + \Delta(^4\text{He})]\}c^2$

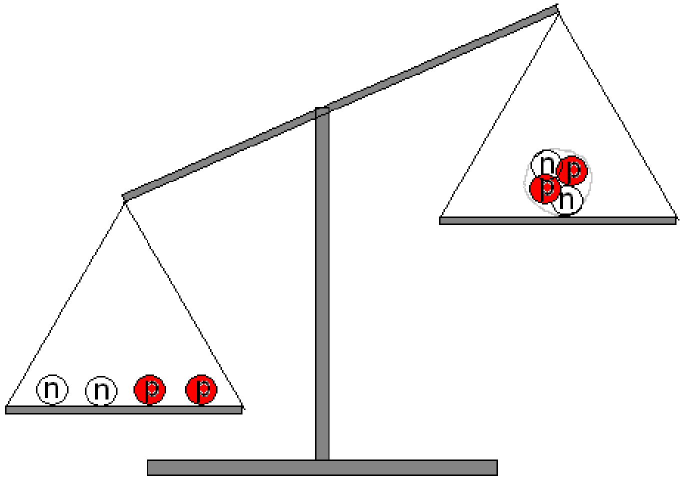
Geiger-Nuttall's rule in the region of the heaviest elements



Oganession, Radiochim. Acta 2012

Realististic estimate of stability of superheavy elements – including the border of the Periodic Table – requires good knowledge of nuclear masses

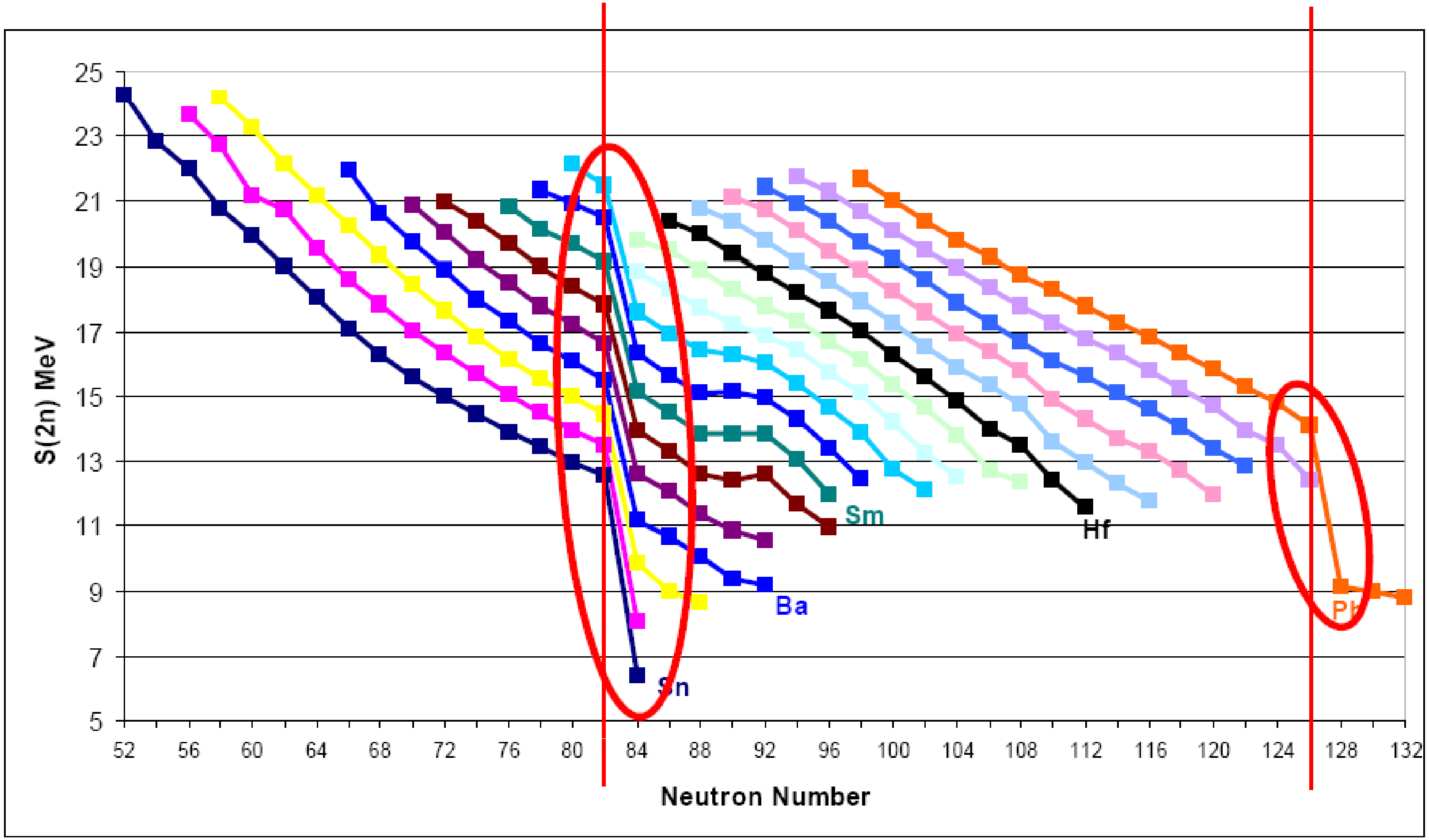
Experimental weighing of the atom



$$E=mc^2$$

The perfect balance tells us about nuclear binding energy → stability of a nucleus

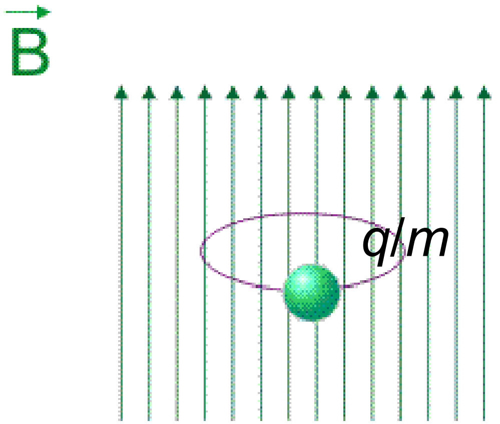
Shell structure from masses



$$S_{2n}(Z,N) = m(Z,N-2) - m(Z,N) + 2m_n$$

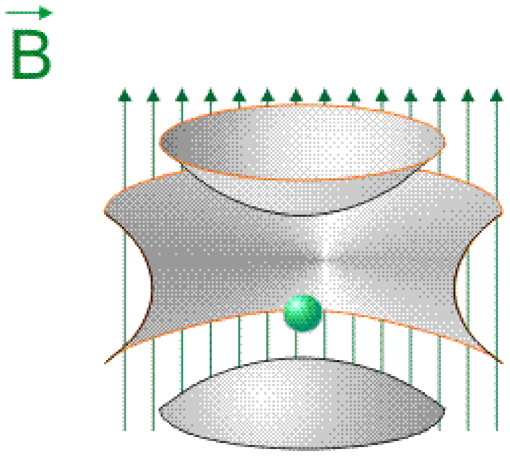
M. Block

Principle of a Penning trap



PENNING trap

- Strong homogeneous magnetic field
- Weak electric quadrupole field



Cyclotron frequency: $f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$

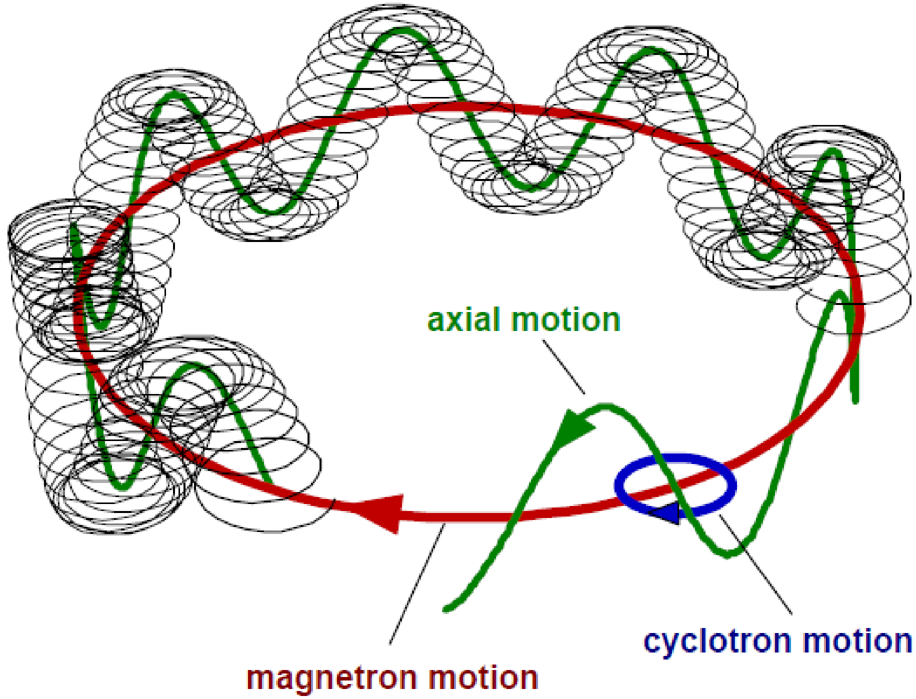
typical values: $B = 7$ T, $A = 133$, $f_c \approx 800$ kHz

L. S. Brown and G. Gabrielse, Rev. Mod. Phys. 58 (1986) 233

G. Gabrielse, Int. J. Mass Spectr. 279, (2009) 107

M. Block

Penning traps for most highly precise atomic mass measurements



Precision: 10-25 keV/c^2

M. Block

SHIPT

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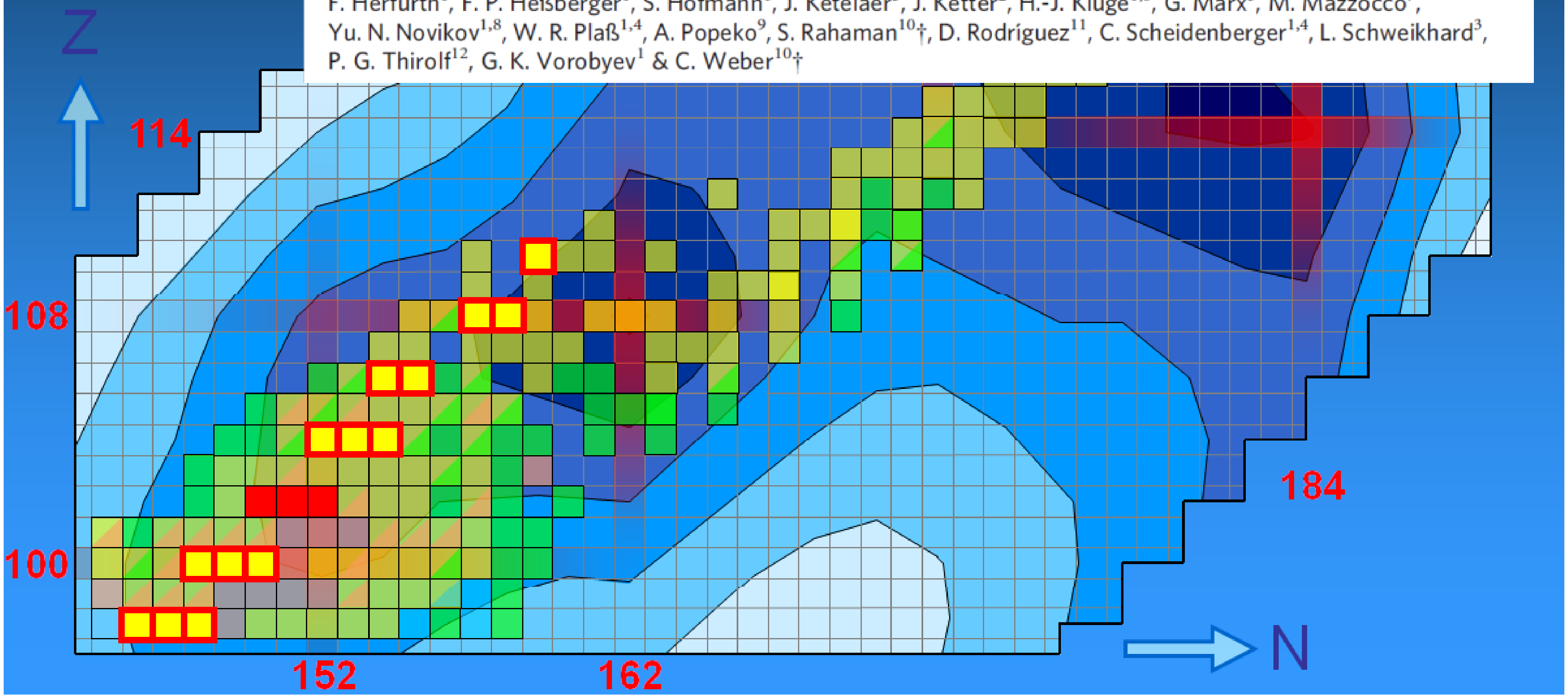
LETTERS

Direct mass measurements above uranium bridge the gap to the island of stability

M. Block[1], D. Ackermann[1], K. Blaum[2], C. Droese[3], M. Dworschak[1], S. Eliseev[2], T. Fleckenstein[4], E. Haettner[4], F. Herfurth[1], F. P. Heßberger[1], S. Hofmann[1], J. Ketelaer[5], J. Ketter[2], H.-J. Kluge[1,6], G. Marx[3], M. Mazzocco[7], Yu. N. Novikov[1,8], W. R. Plaß[1,4], A. Popeko[9], S. Rahaman[10]†, D. Rodríguez[11], C. Scheidenberger[1,4], L. Schweikhard[3], P. G. Thirolf[12], G. K. Vorobyev[1] & C. Weber[10]†



SHIPTRAP 2012

Direct Mapping of Nuclear Shell Effects in the Heaviest Elements

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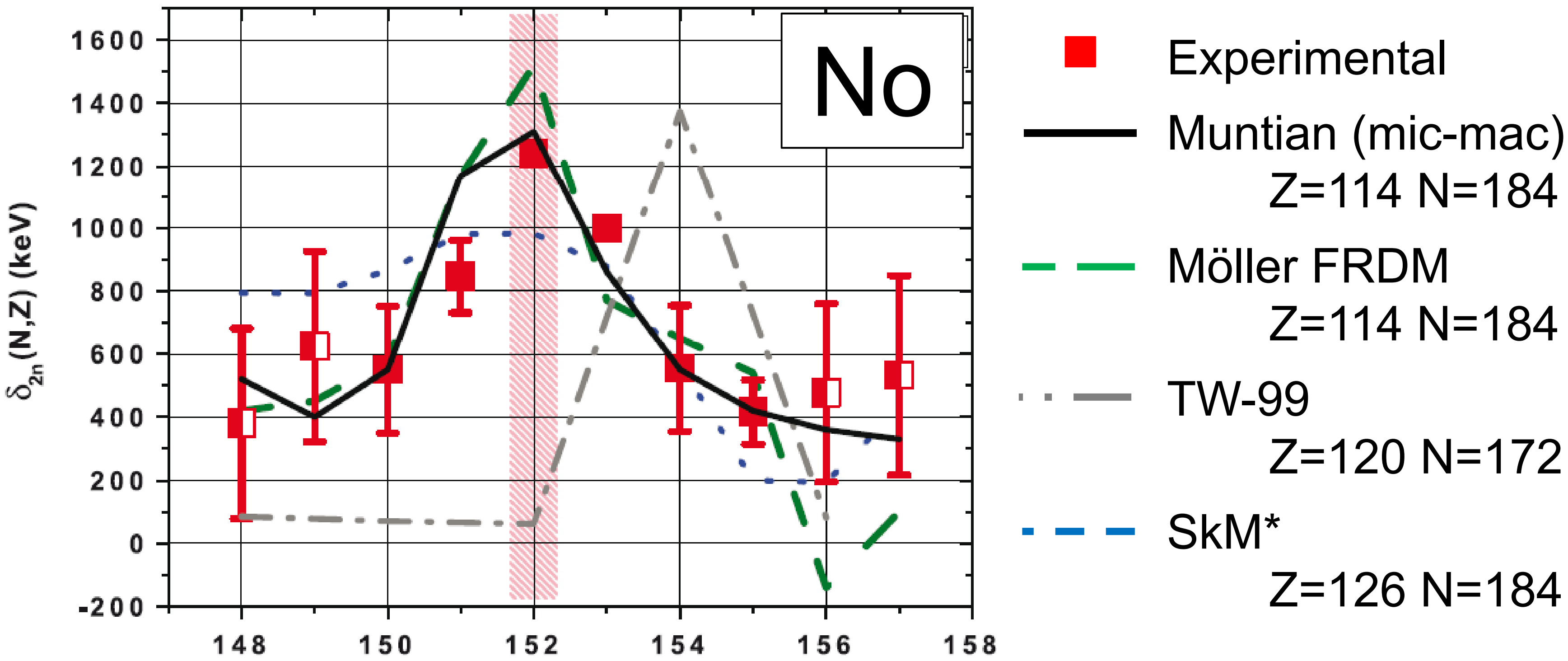

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