Exotic Archaeology: Searching for Superheavy Elements in Nature and Dating of Human DNA with the ^{14}C Bomb Peak

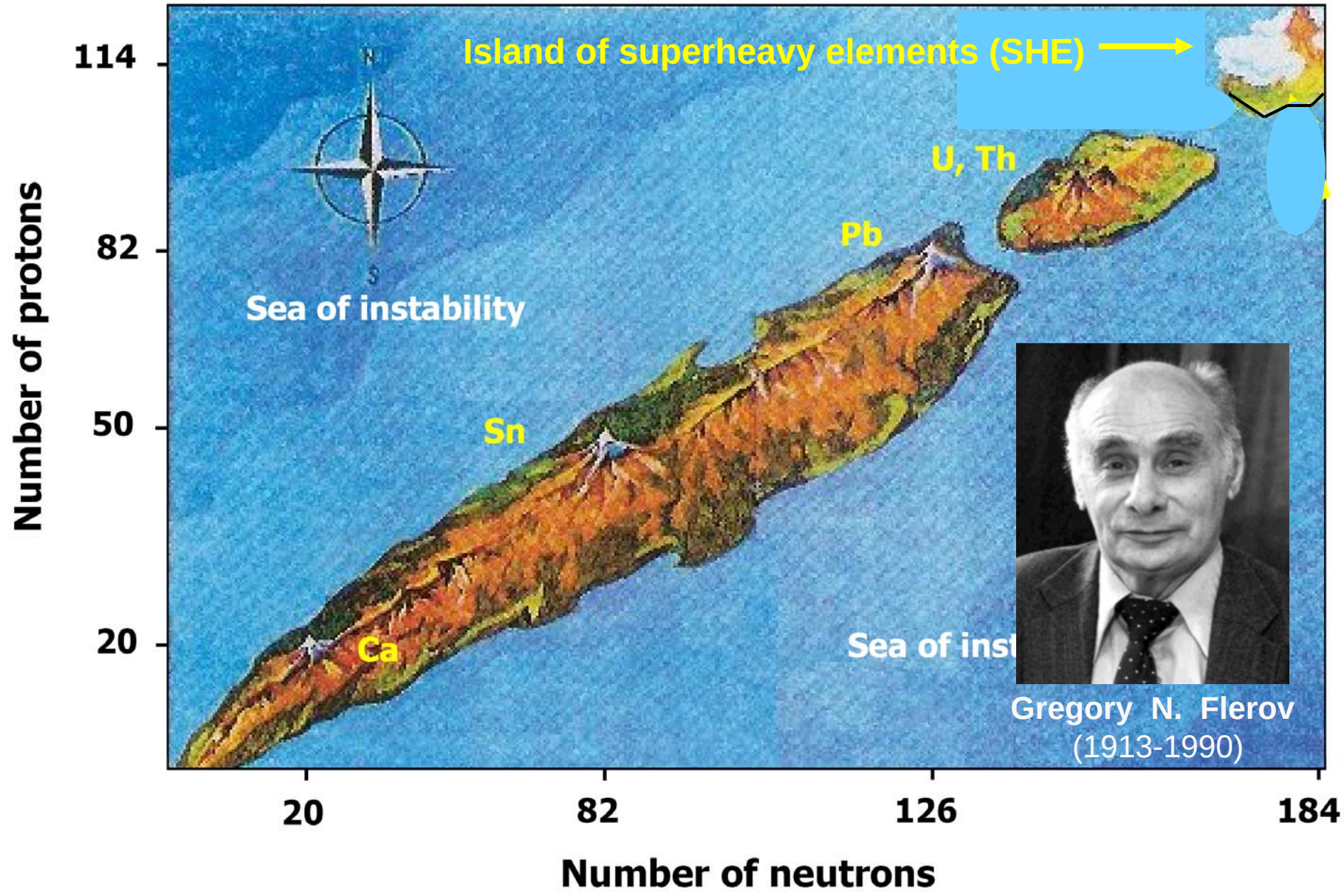
Walter Kutschera
Vienna Environmental Research Accelerator (VERA)
Faculty of Physics, University of Vienna

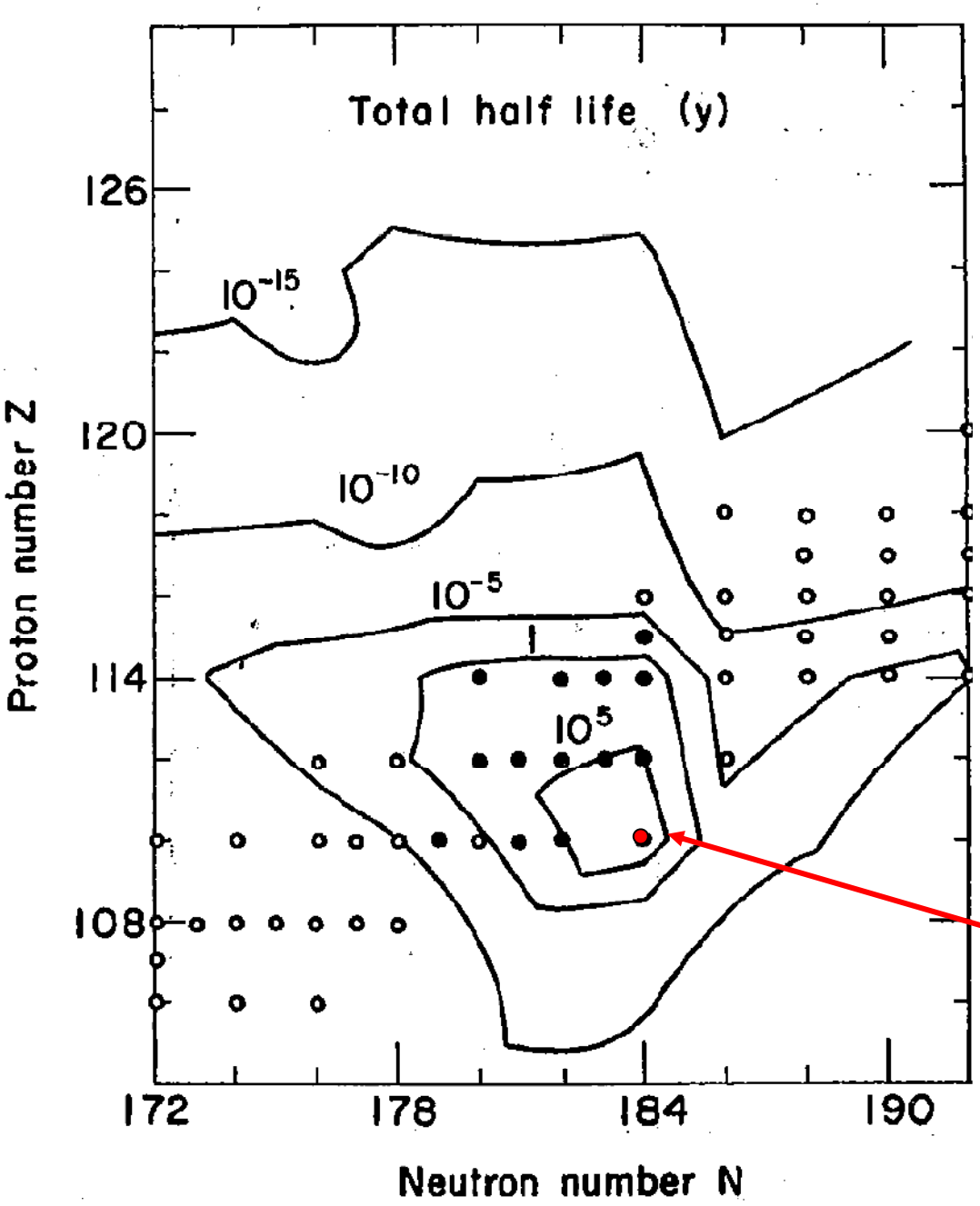
Beyond 2010: Fifth International Conference on Beyond the Standard Models of Particle Physics, Cosmology and Astrophysics
Cape Town, 1-6 February 2010

Searching for Superheavy Elements in Nature

Early History of Superheavy Elements (SHE)

In the late 1960s, shell model corrections of the liquid drop model led to a region of stability for superheavy elements: Myers & Swiatecky, Nilsson, Strutinsky, Nix, Möller, ...





E. O. Fiset and J. R. Nix
Calculation of Half-Lives for Superheavy Nuclei
Nucl. Phys. A 193 (1972) 647- 671

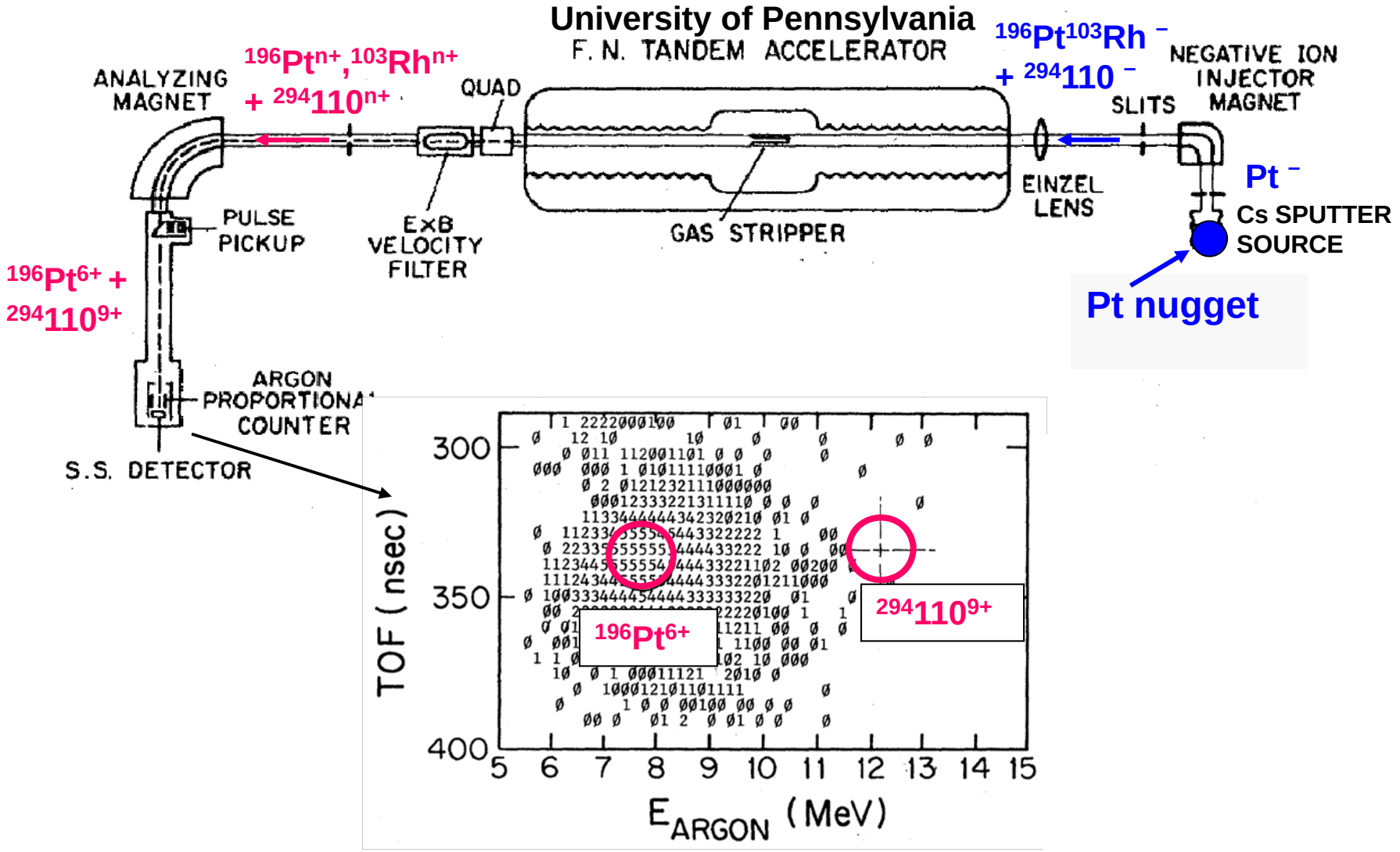
Contour plot of calculated total half-life for even superheavy nuclei. The solid points indicate ß-stable nuclei whose total half-life is longer than 1 y, and the open circles ß-stable nuclei whose total half-life is shorter than 1 y.

,

^{294}110, Eka-Pt
$t_{1/2} = 2.5 \times 10^{9}$ y

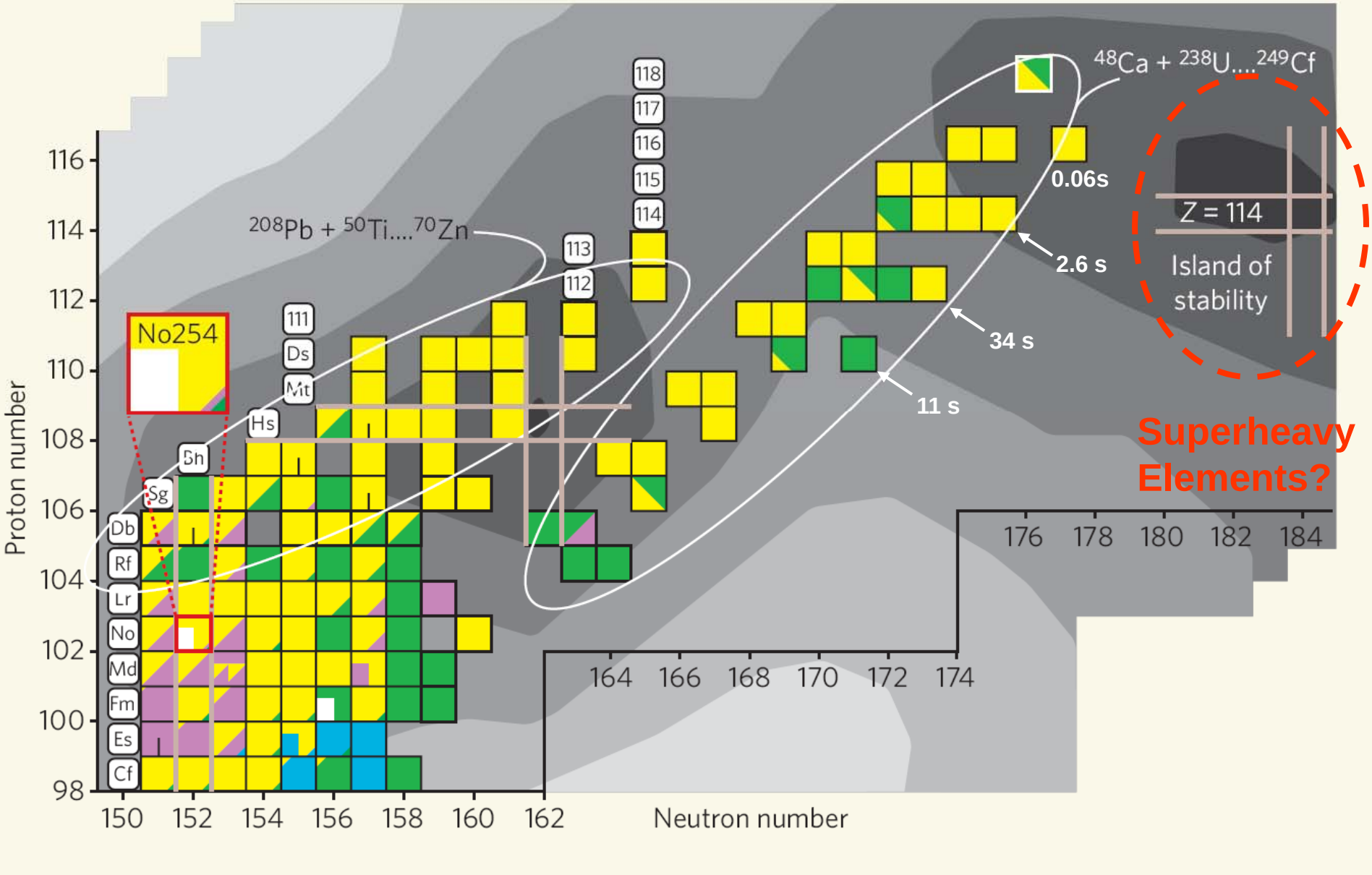
Early Search for the Superheavy Nuclide $^{294}110$ in a Natural Platinum Nugget with Accelerator Mass Spectrometry

W. Stephens et al., Phys. Rev. C 21 (1980) 1964



Result: $^{294}110/Pt < 10^{-11}$

Conclusion: $t_{1/2} < 1.7 \times 10^8$ yr, if $^{294}110/Pt \sim 0.03$ in *Synthesis of SHE in r-Process*, Schramm and Fowler, Nature 231 (1971) 103



M.A. Stoyer, *Island ahoy!*, Nature 442 (2006) 876

A. Sobiczewski & K. Pomorski, Prog. Part. Nucl. Phys. 58 (2007) 292-349

Recent Searches for SHE in Nature with ICP-MS (Inductively Coupled Plasma Mass Spectrometry) by A. Marinov et al. (Hebrew University of Jerusalem) report the possible existence at abundance levels of 10^{-12} to 10^{-10}.

A. Marinov, I. Rodushkin, Y. Kashiv et al.
Existence of long-lived isomeric states in naturally-occurring neutron-deficient Th isotopes
Phys. Rev. C76 (2007) 021303(R).

A. Marinov, I. Rodushkin, Y. Kashiv et al.
Evidence for a long-lived superheavy nucleus with atomic mass number A=292 and atomic number Z~122 in natural Th
arXiv: 0804.3869 (April 2008).

A. Marinov, I. Rodushkin, A. Pape et al.
Existence of long-lived isotopes of a superheavy element in natural Au
arXiv: nucl-ex/0702051v1 (February 2007).

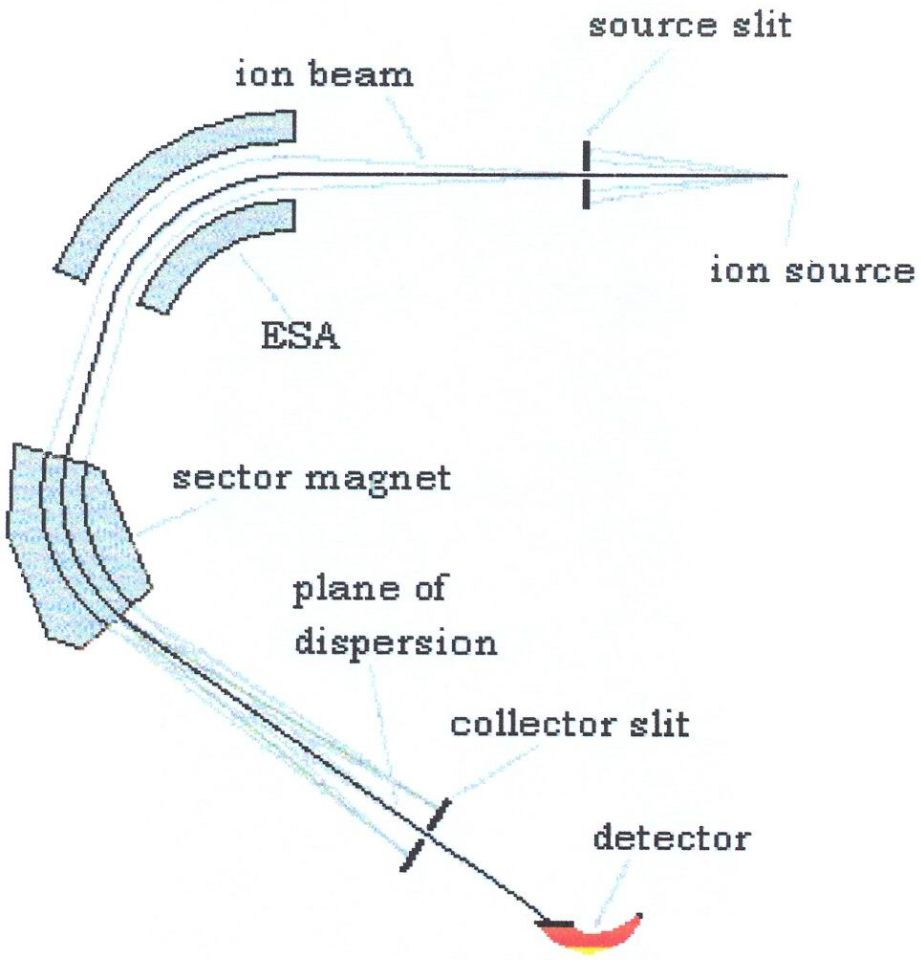
Inductively Coupled Plasma-Sector Field Mass Spectrometer (ICP-SFMS)

Plasma source at 6000-8000 K

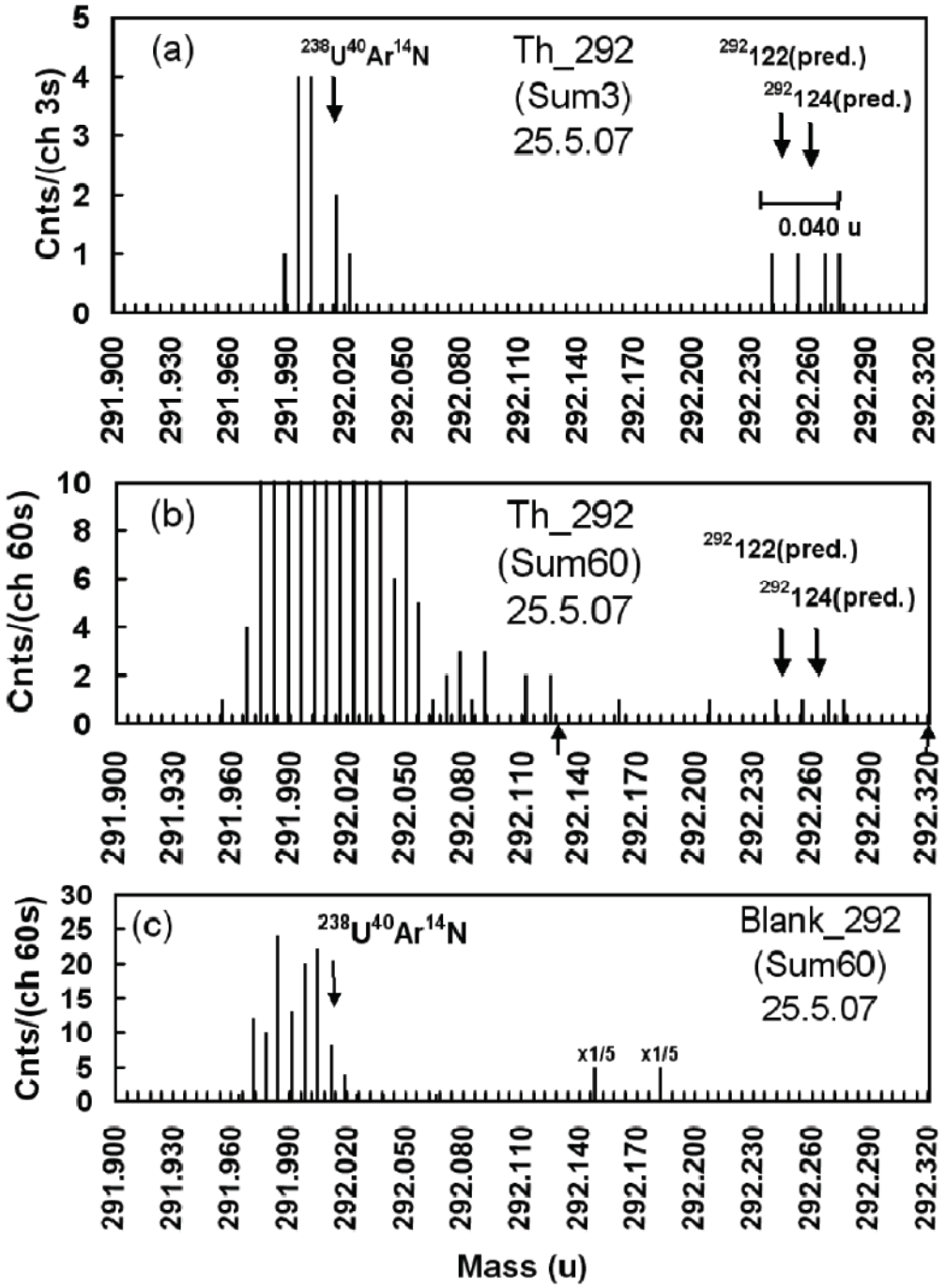
Mostly atoms from the source

Studied material: Thorium Solution

M/ΔM = 4000

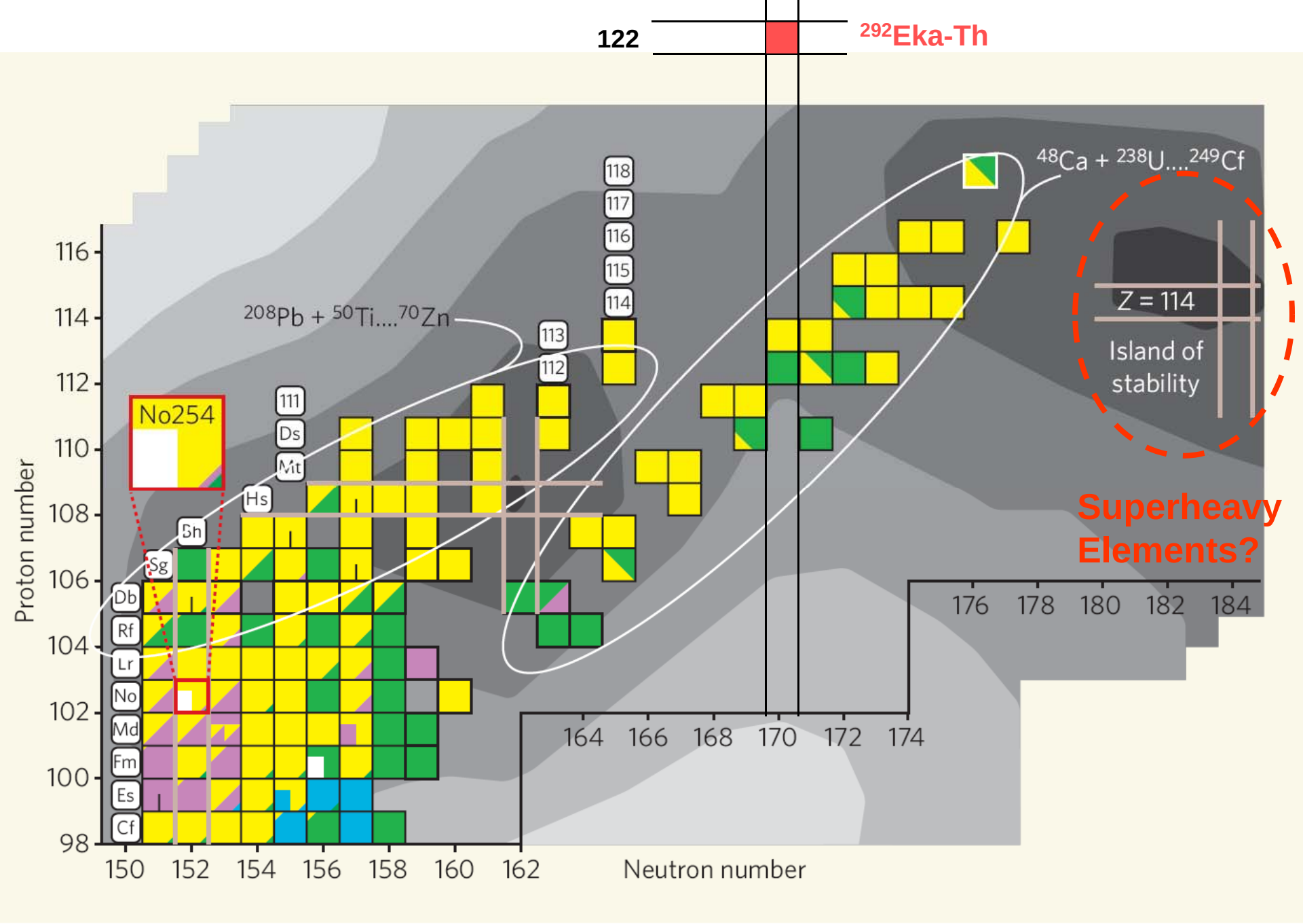


Courtesy of A. Marinov



Marinov et al., "Evidence for a long-lived superheavy nucleus with atomic mass number A=292 and atomic number Z~122 in natural Th", arXiv: 0804.3869 (April 2008)

^{292}Eka-Th/^{232}Th = (1-10)x10^{-12}


122
292Eka-Th
48Ca + 238U....249Cf
208Pb + 50Ti....70Zn
Z = 114
Island of stability
Superheavy Elements?
No254
118
117
116
115
114
113
112
111
Ds
Mt
Hs
Sh
Sg
Db
Rf
Lr
No
Md
Fm
Es
Cf
Proton number
Neutron number
116
114
112
110
108
106
104
102
100
98
150
152
154
156
158
160
162
164
166
168
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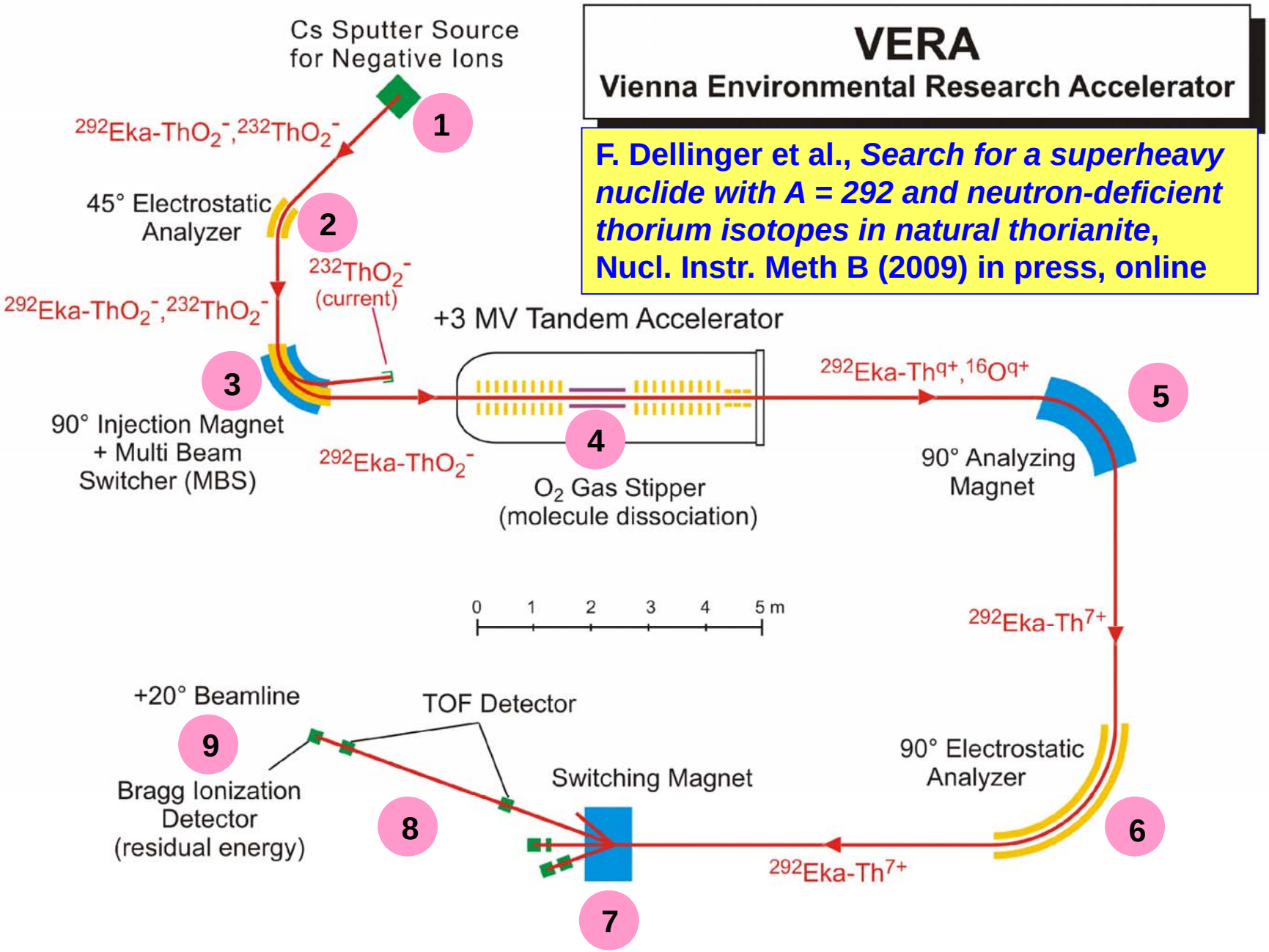
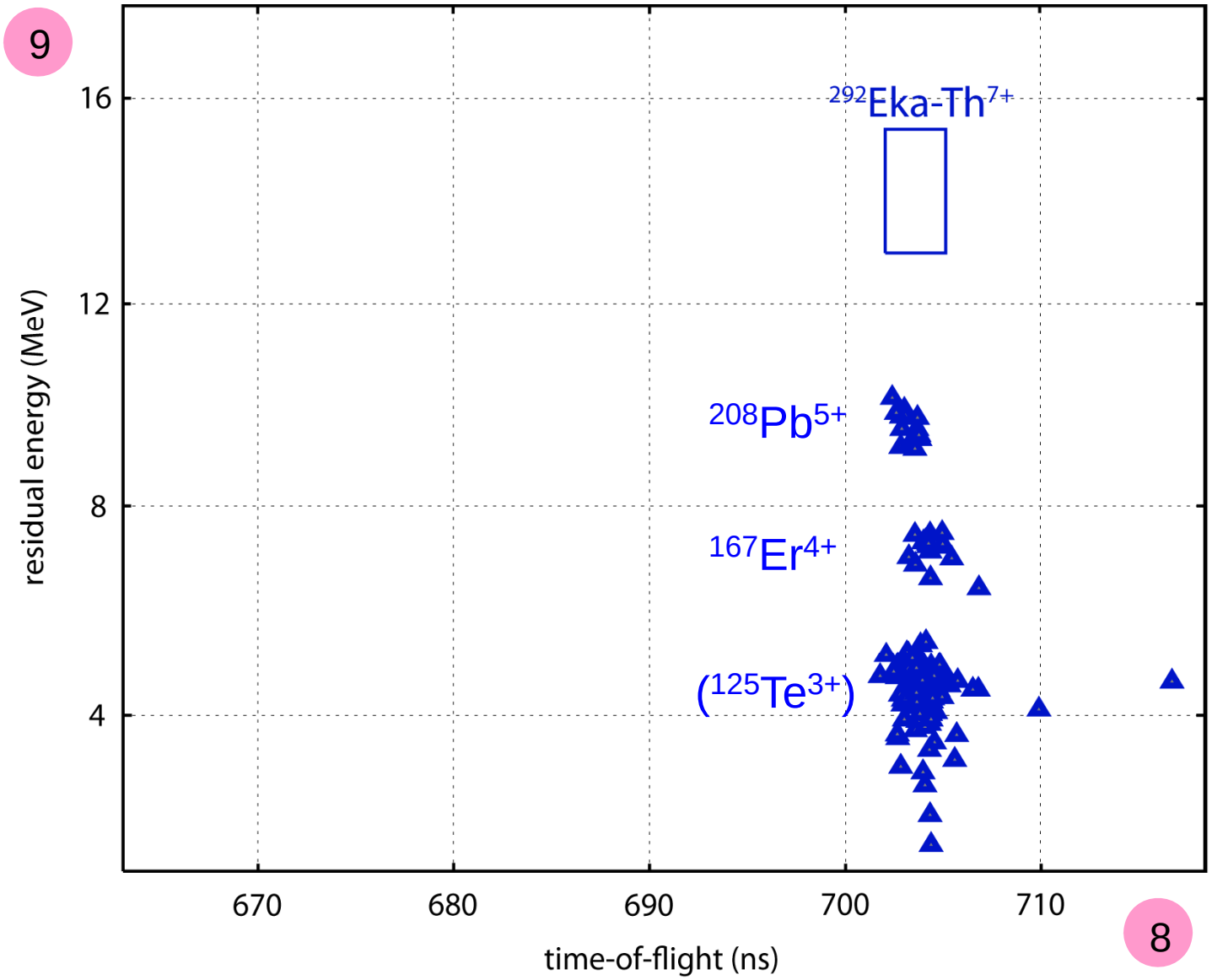
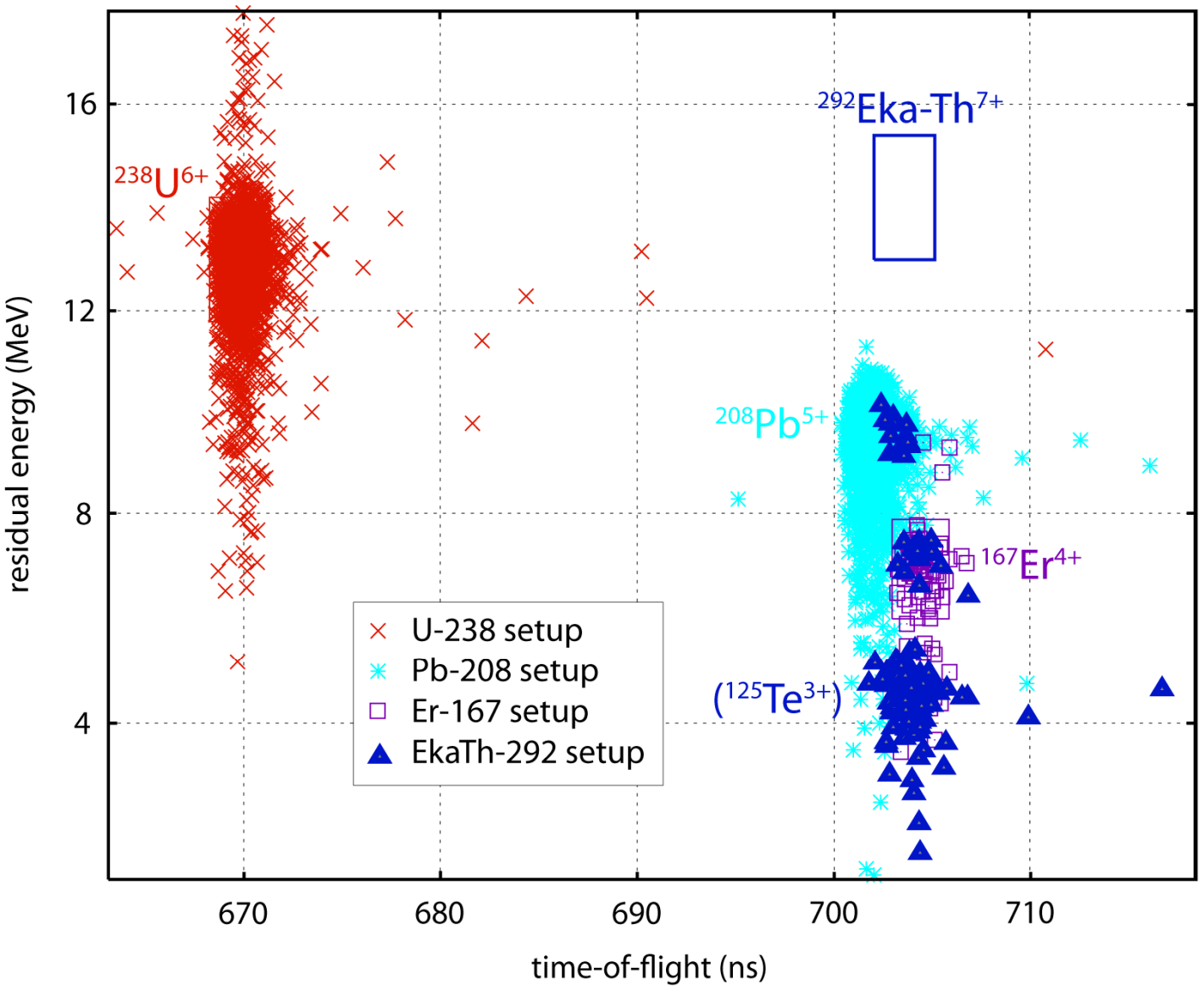
180
182
184

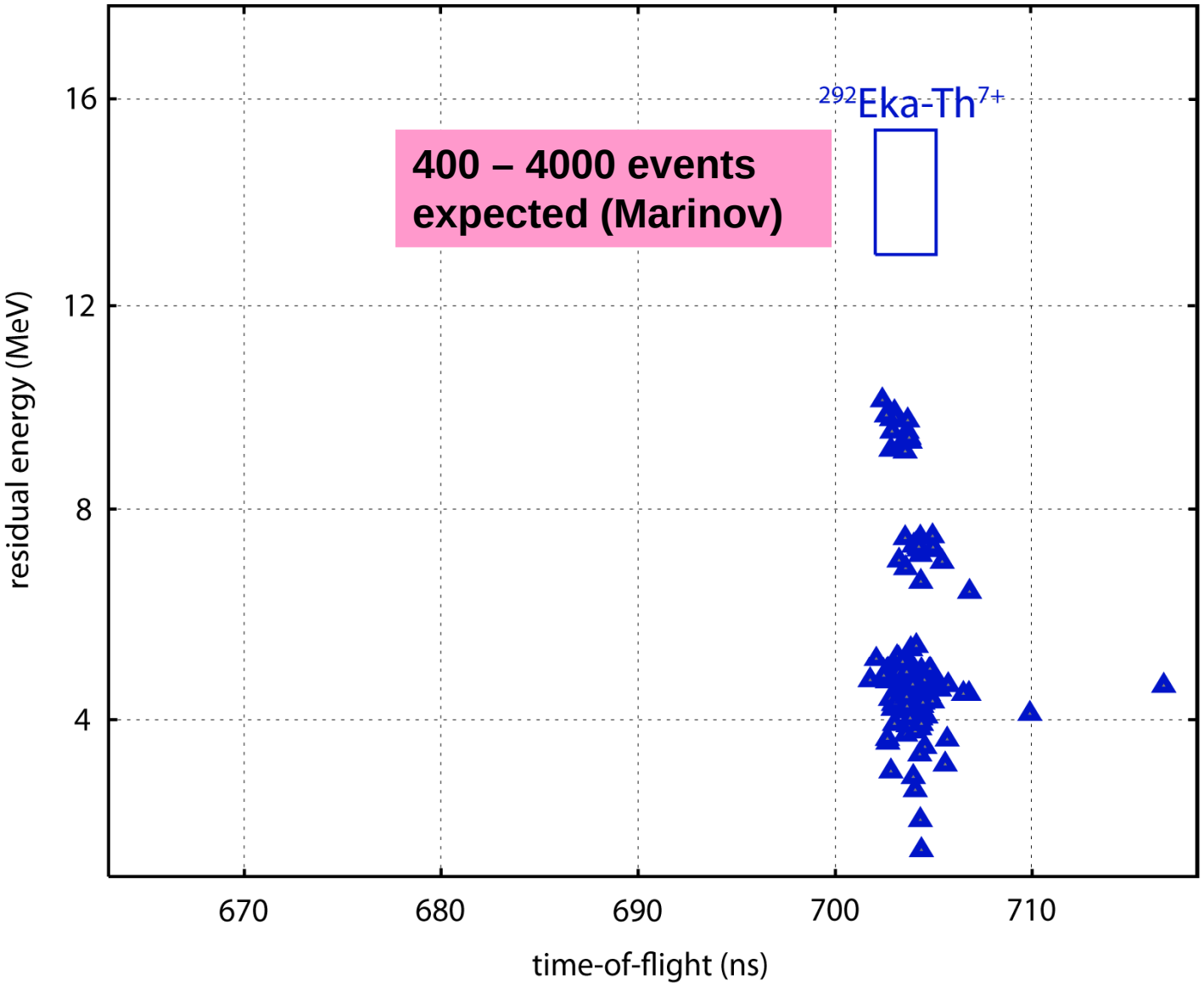

VERA
Vienna Environmental Research Accelerator
F. Dellinger et al., Search for a superheavy nuclide with A = 292 and neutron-deficient thorium isotopes in natural thorianite, Nucl. Instr. Meth B (2009) in press, online
Cs Sputter Source for Negative Ions
1
292Eka-ThO2-,232ThO2-
45° Electrostatic Analyzer
2
232ThO2- (current)
292Eka-ThO2-,232ThO2-
+3 MV Tandem Accelerator
3
90° Injection Magnet + Multi Beam Switcher (MBS)
292Eka-ThO2-
4
O2 Gas Stipper (molecule dissociation)
292Eka-Thq+,16Oq+
5
90° Analyzing Magnet
0 1 2 3 4 5 m
292Eka-Th7+
6
90° Electrostatic Analyzer
292Eka-Th7+
7
Switching Magnet
8
TOF Detector
9
+20° Beamline
Bragg Ionization Detector (residual energy)



Search for superheavy element ^{292}Eka-Th



Search for superheavy element ^{292}Eka-Th


400 – 4000 events
expected (Marinov)
292Eka-Th7+
16
12
8
4
residual energy (MeV)
670
680
690
700
710
time-of-flight (ns)

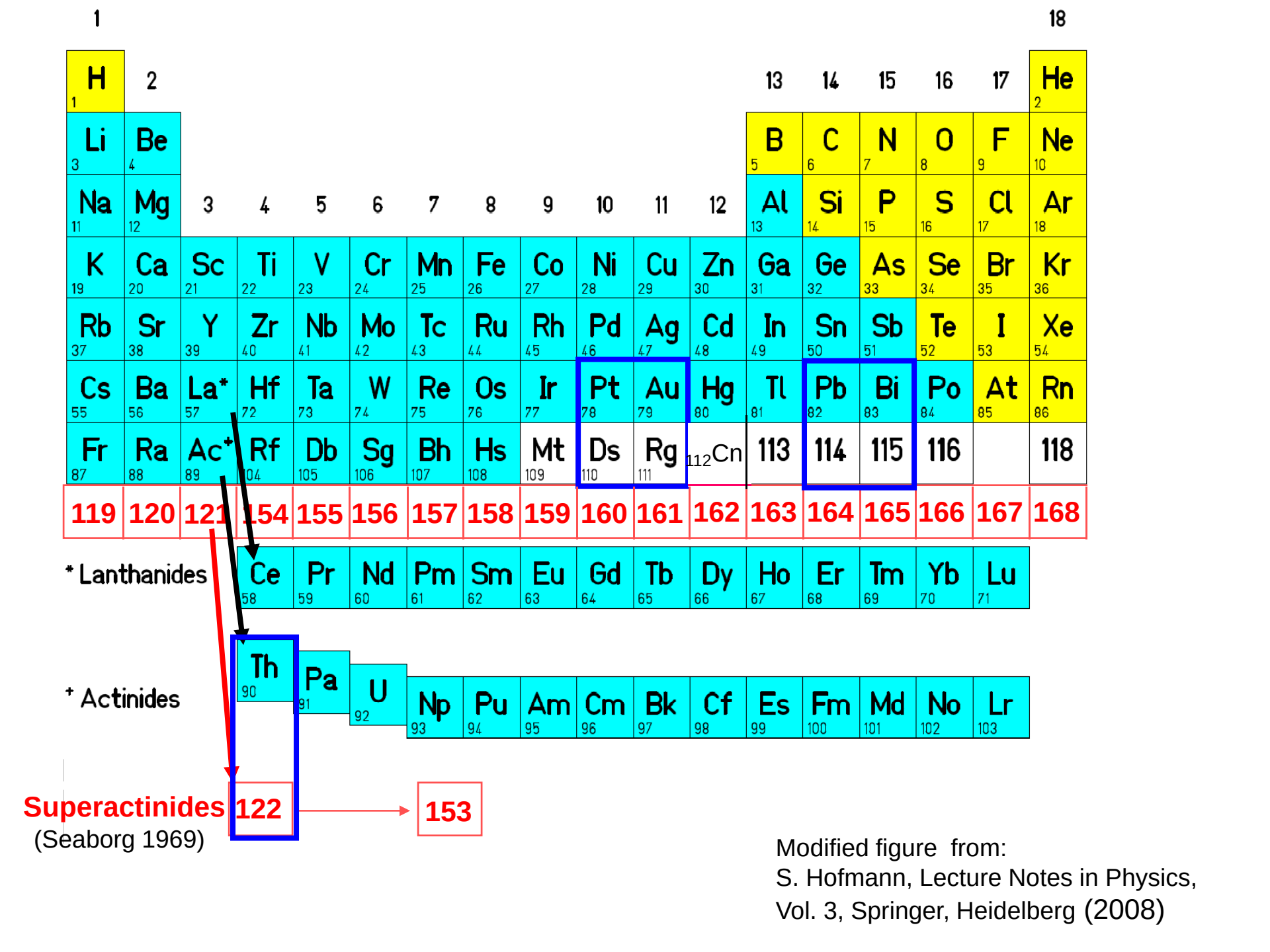
Abundance of the rare isotopes relative to ^{232}Th

Rare isotope	Events detected	Counting time (h)	$^{232}ThO_2^-$ (mC)	Abundance rel. to ^{232}Th		
				AMS		ICP-SFMS
				Vienna[a]	Munich[b]	Jerusalem[c]
^{292}Eka-Th	0	31.5	36	$<4\times10^{-15}$	not meas.	$(1\text{-}10)\times10^{-12}$
^{211}Th	0	6.6	12	$<5\times10^{-15}$	$<9.6\times10^{-13}$	$(1\text{-}10)\times10^{-11}$
^{213}Th	2	10.3	16	7×10^{-16} - 8×10^{-15}	$<1.2\times10^{-12}$	$(1\text{-}10)\times10^{-11}$
^{217}Th	1	10.3	16	1×10^{-16} - 6×10^{-15}	$<6.6\times10^{-13}$	$(1\text{-}10)\times10^{-11}$
^{218}Th	0	6.6	12	$<5\times10^{-15}$	$<2.4\times10^{-12}$	$(1\text{-}10)\times10^{-11}$

[a]Dellinger et al., Nucl. Instr. Meth. B (2009) in press, online

[b]Lachner et al., Phys. Rev C78 (2008) 064313

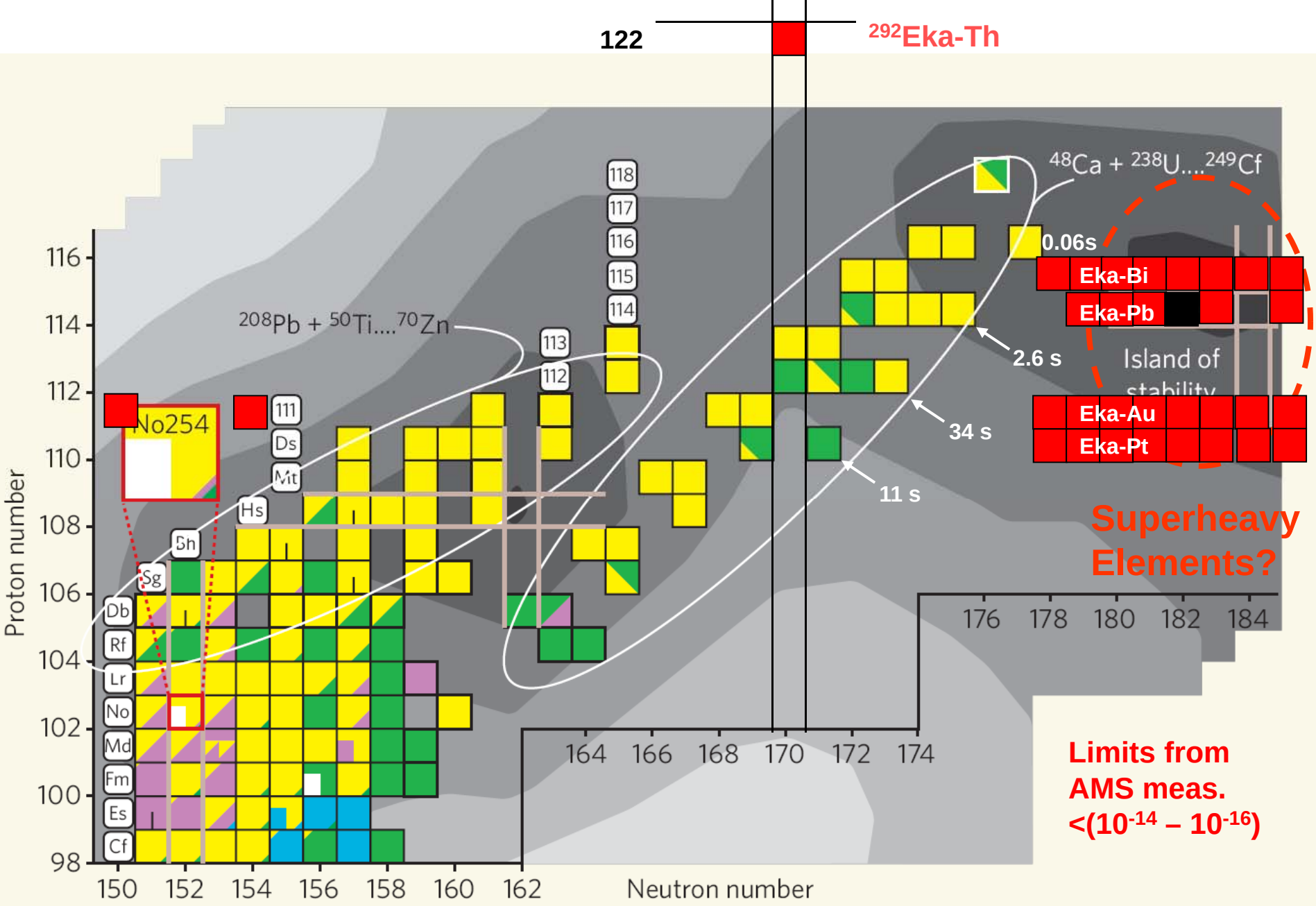
[c]Marinov et al., Phys. Rev. C76 (2007) 021303(R), ^{211,231,217,218}Th; (April 2008), ^{292}Eka-Th



Modified figure from:
S. Hofmann, Lecture Notes in Physics, Vol. 3, Springer, Heidelberg (2008)

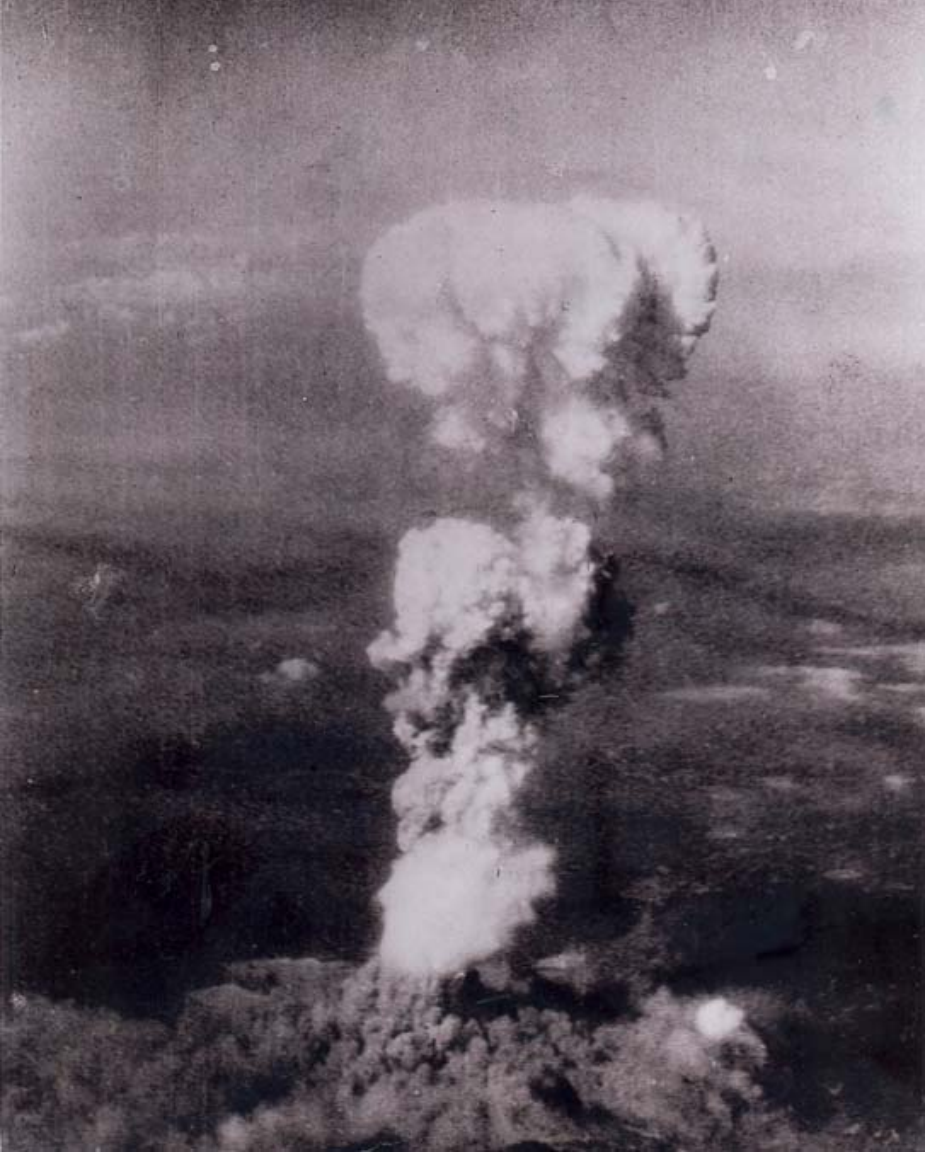
Materials investigated for searches of SHE at VERA

Element	eka-Elem.	Mass (amu)	Materials
Platin	110 (Ds)	planned	Nuggets of different origin
Gold	111 (Rg)	261, 265 289, 290, 291, 292 293, 294, 295, 296	Nuggets of different origin
Mercury	112	planned	Cinnabarit (HgS), neg. ions difficult
Thallium	113	planned	Avicennite (Tl_2O_3), Carlenite(Tl_2S) Lorandite ($TlAsS_2$)
Lead	114	295, 297, 299	Galenit (PbS) -> PbF_2 -> PbF_3^-
Bismuth	115	293, 294, 295, 296 297, 298, 299, 300	Bi(Alfa), Bismuth Ochre (Bi_2O_3)
Thorium	90 122	211,213, 217, 218 292	Thorianite (ThO_2), commercial Thorium Oxide, Marinov Oxide

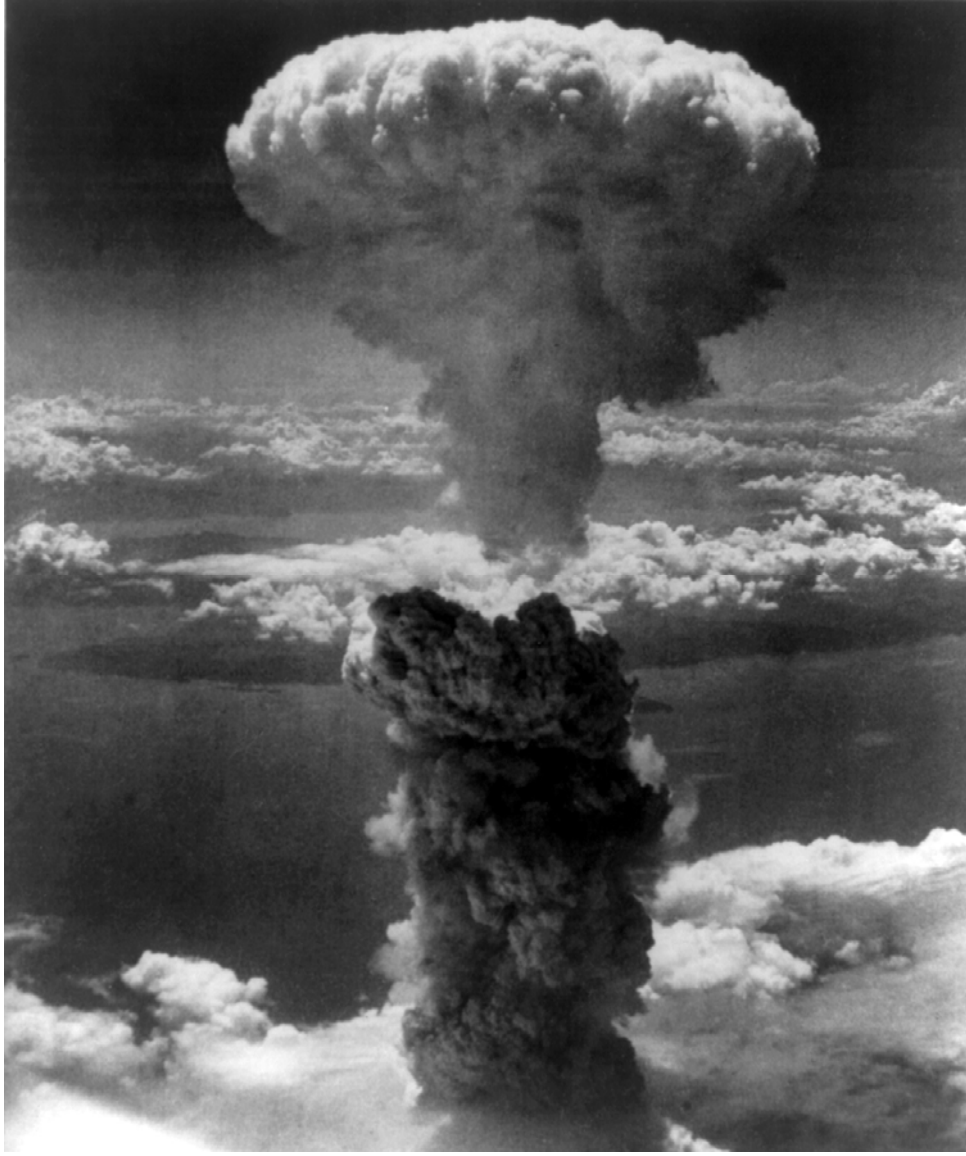


Preliminary results of extended SHE search

The Ugly and the Beautiful: Utilizing the ^{14}C Bomb Peak



The mushroom cloud over Hiroshima
after the dropping of *Little Boy* (U bomb)
6-Aug-1945

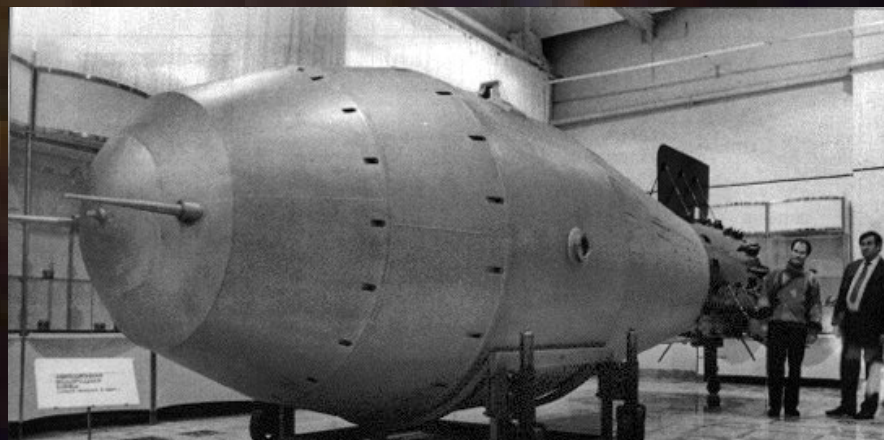


The mushroom cloud over Nagasaki
after the dropping of *Fat Man* (Pu bomb)
9-Aug-1945

Mike H-bomb test, 10.4 Megaton
(~700 Hiroshima bombs)
Enewetak Atoll, 1 Nov1952

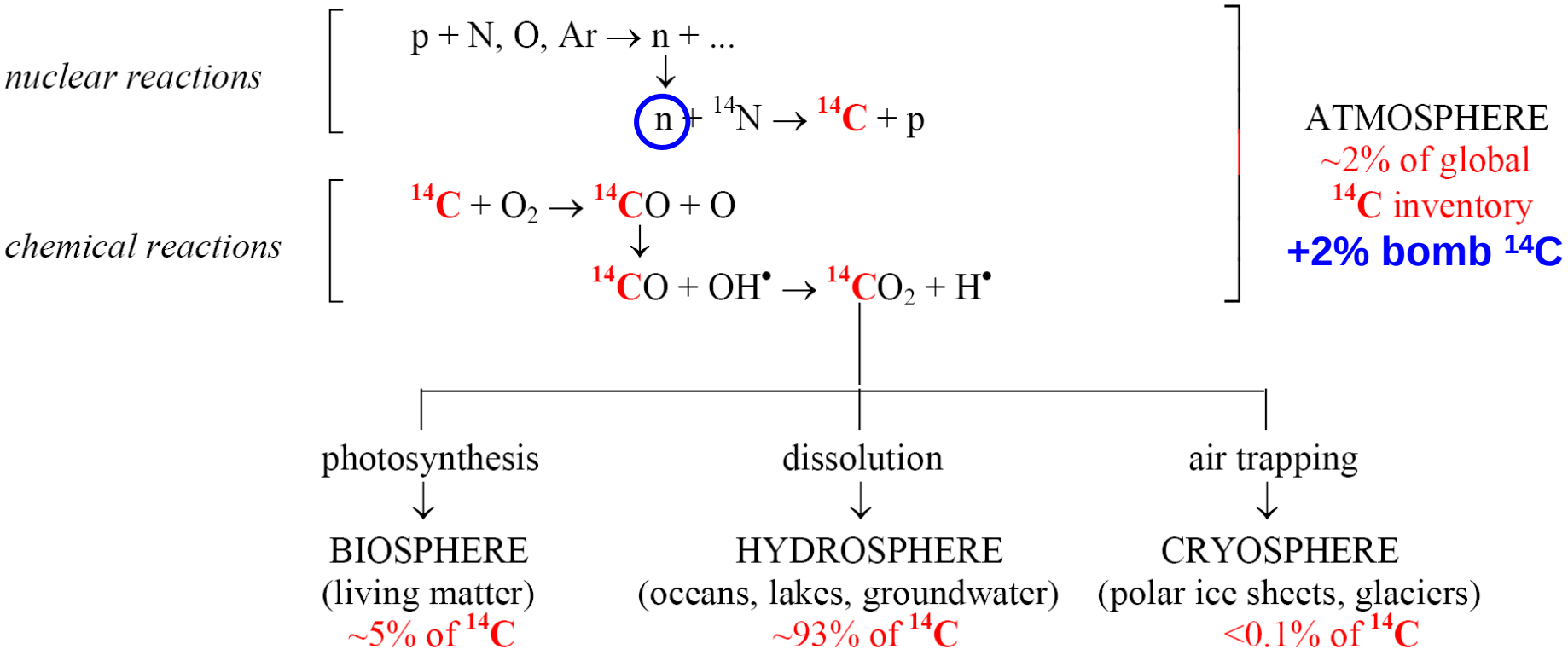
Bravo H-bomb test, 15 Megaton
(~1000 Hiroshima bombs)
Bikini Atoll, 1 March 1954

Tsar H-bomb test, 50 Megaton
(~3500 Hiroshima bombs)
Novaya Zemlya, 30 Oct 1961



John F. Kennedy signing the Nuclear Test Ban Treaty on 7 October 1963 in the White House, Washington D.C. (6 weeks later he was assassinated in Dallas, Texas)

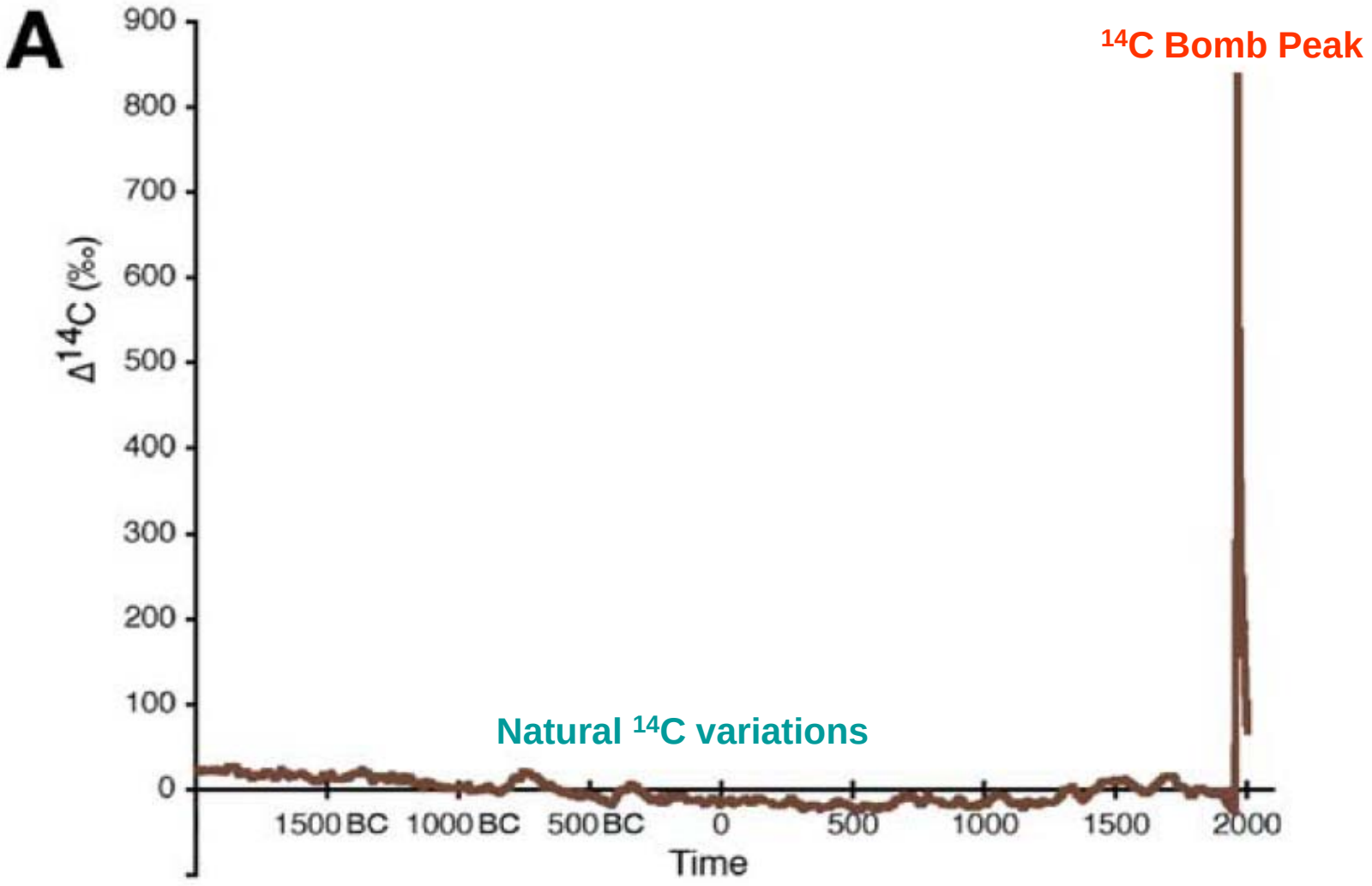
Cosmic ray production and distribution of ^{14}C (half-life = 5730 years)



Equilibrium isotopic abundance of cosmogenic ^{14}C on Earth

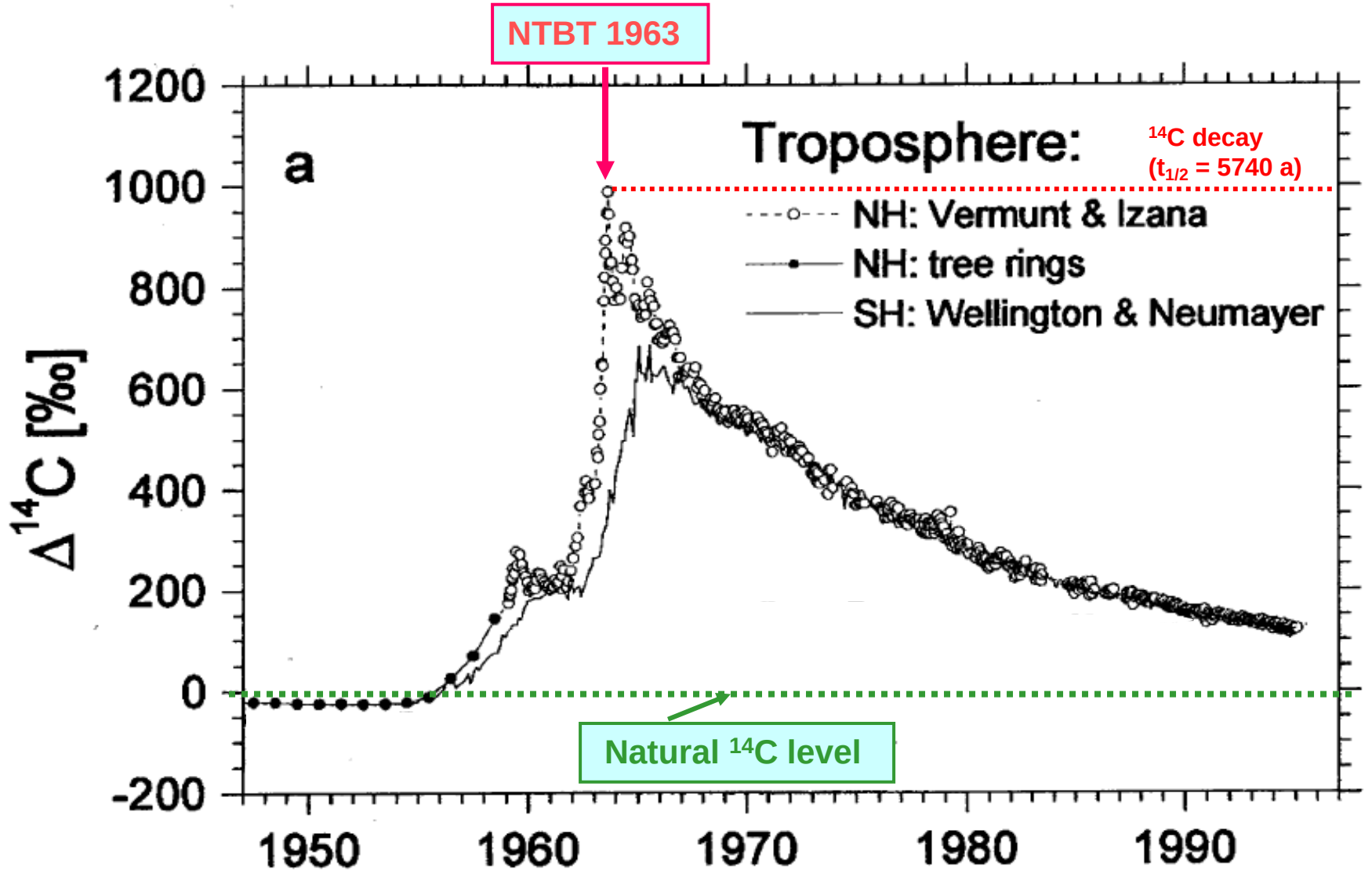
^{12}C (0.99)	^{13}C (0.01)	^{14}C (1.2×10^{-12})
stable	stable	radioactive

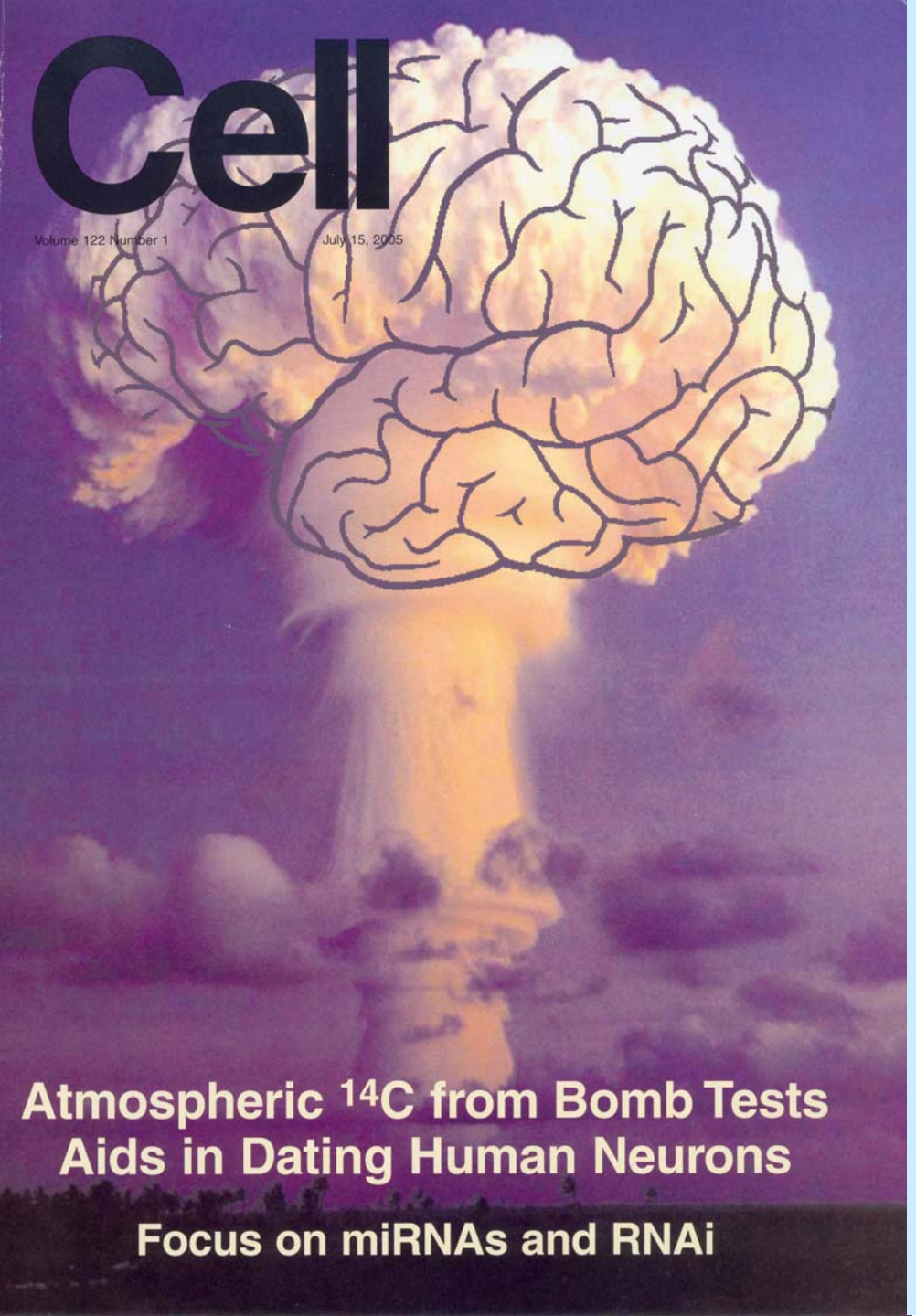
Variation of the ^{14}C content in atmospheric CO_2 during the last 4000 Years



Long-term observations of $\Delta^{14}C$ in atmospheric CO_2 in the northern and in the southern hemisphere

Levin and Hesshaimer, Univ. Heidelberg, Radiocarbon 42/1 (2000) 69





Retrospective Birth Dating of Cells in Humans

Kirsty L. Spalding et al.

Department of Cell and Molecular Biology, Medical Nobel Institute, Karolinska Institute, Stockholm

Cell, Vol. 122 (15 July 2005) 133-143

^{14}C in genomic DNA reflects the age of cells

“Most molecules in a cell are in constant flux, with the unique exception of genomic DNA, which is not exchanged after a cell has gone through its last division.

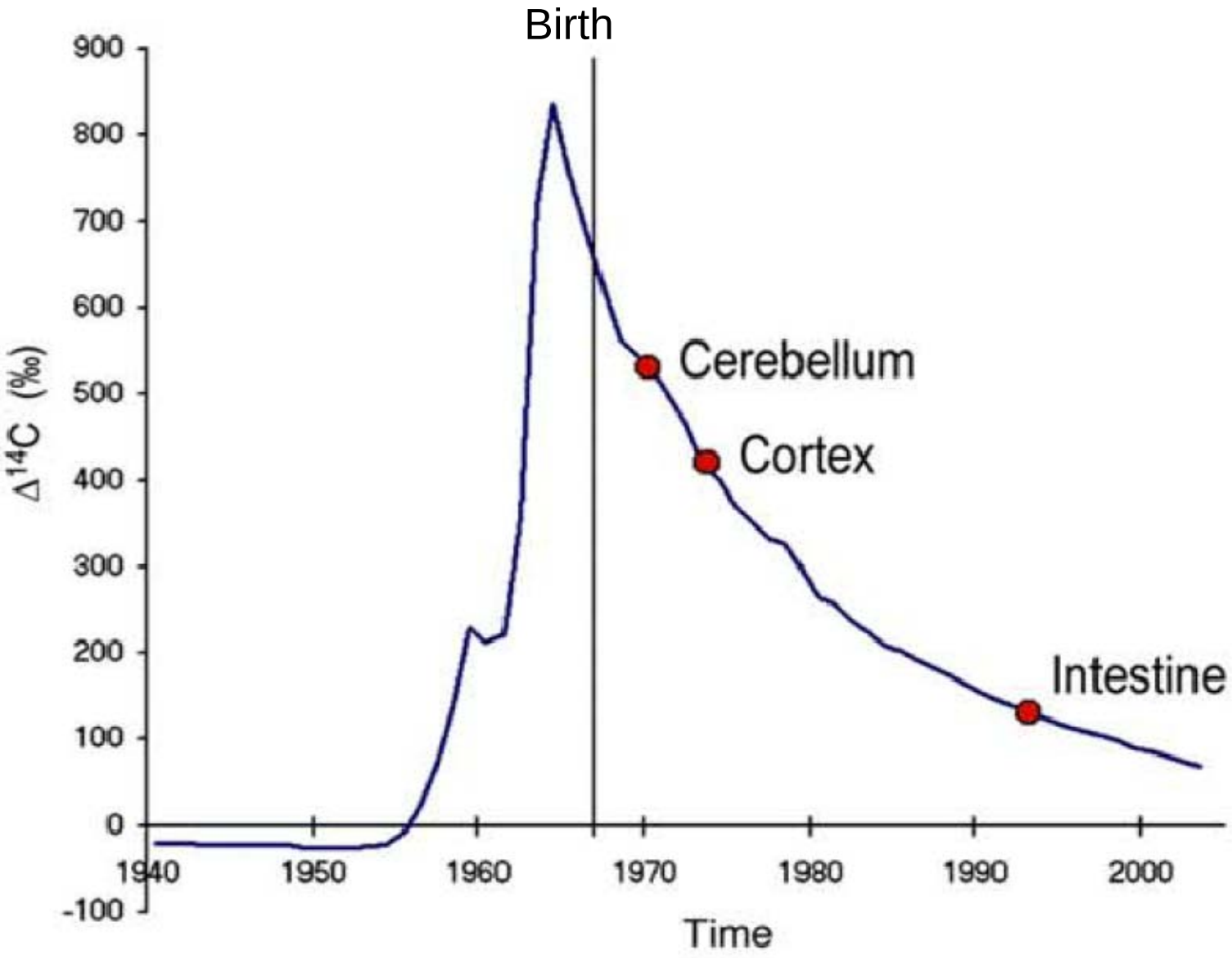
The level of ^{14}C integrated into genomic DNA should thus reflect the level in the atmosphere at any given point, and we hypothesized that determination of ^{14}C levels in genomic DNA could be used to retrospectively establish the birth date of cells in the human body.”

K.L. Spalding et al., *Cell* 122 (15 July 2005) 133-143

Some facts about human DNA and ^{14}C

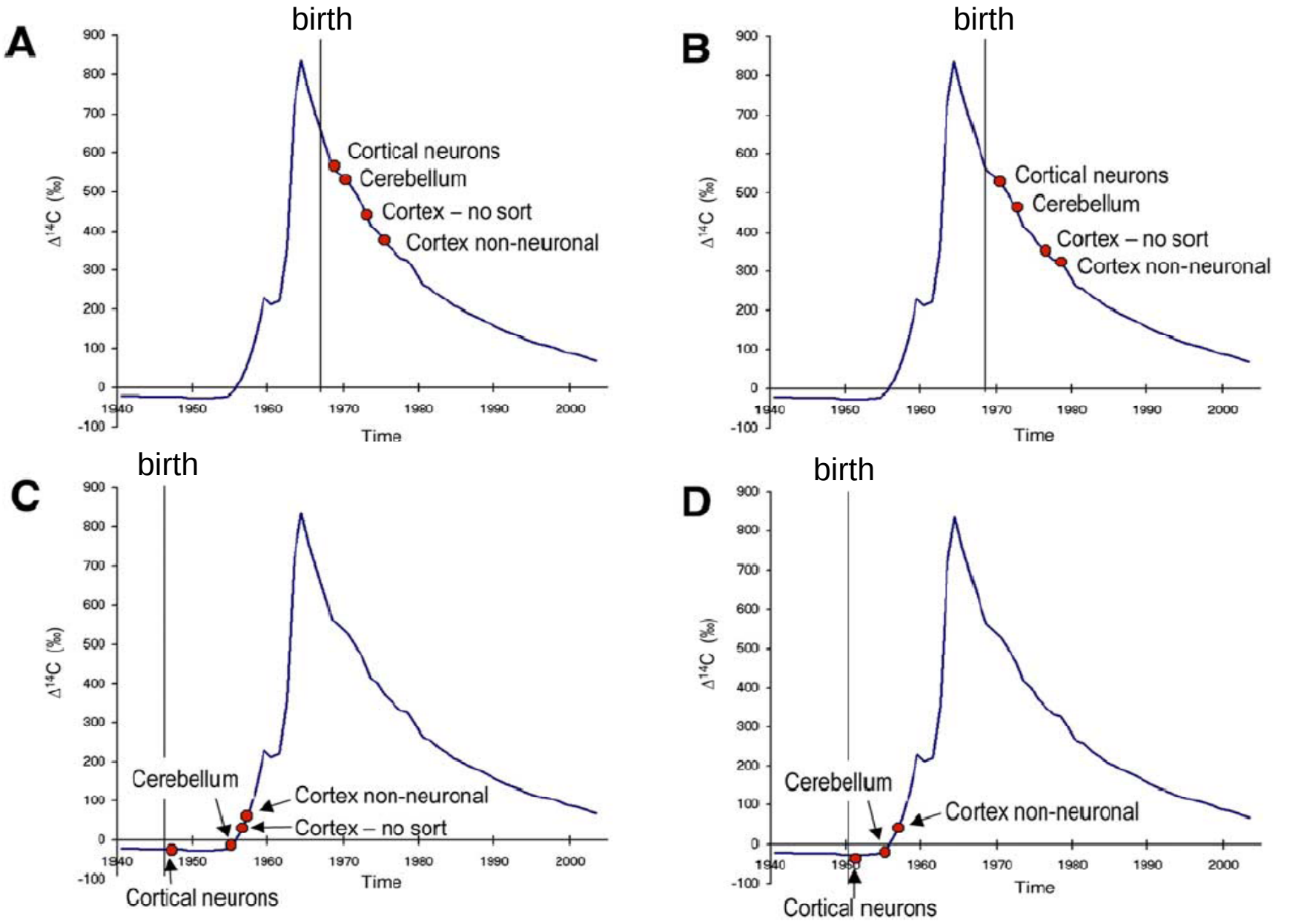
(A physicist's view)

Basic composition of DNA:	Macromolecule with $3x10^9$ basepairs
Chem. sum formula per bp:	$C_{20}H_{23}N_7O_{13}P_2$ and $C_{19}H_{22}N_8O_{13}P_2$
Molecular weight:	~630 daltons per base pair, total ~$1.9x10^{12}$ Da
Mass of DNA per cell:	2 DNA per cell = 2 x 3 pg = 6 pg
Mass of carbon (40 wt% C):	2.4 pg
Totel length of DNA per cell:	2 x $3x10^9$ x (0.34 nm) = 2 m
C atoms of DNA per cell:	2 x $3x10^9$ x (20 C) = **$1.2x10^{11}$ C atoms**
$^{14}C/^{12}C$:	**$1.2x10^{-12}$**
DNA of 10 cells:	**~1 ^{14}C atom**
15 million cells:	1.5 million ^{14}C atoms
C from DNA of 15 million cells:	~36 µg C
Total ^{14}C detection efficiency:	~2% → ~ 30,000 ^{14}C atoms detected



^{14}C dates from DNA extracted from the respectic cells

Spalding et al., Cell 122 (2005) 133



Cortical neurons and non-neuronal cells have different renewel rates

Spalding et al., Cell 122 (2005) 133

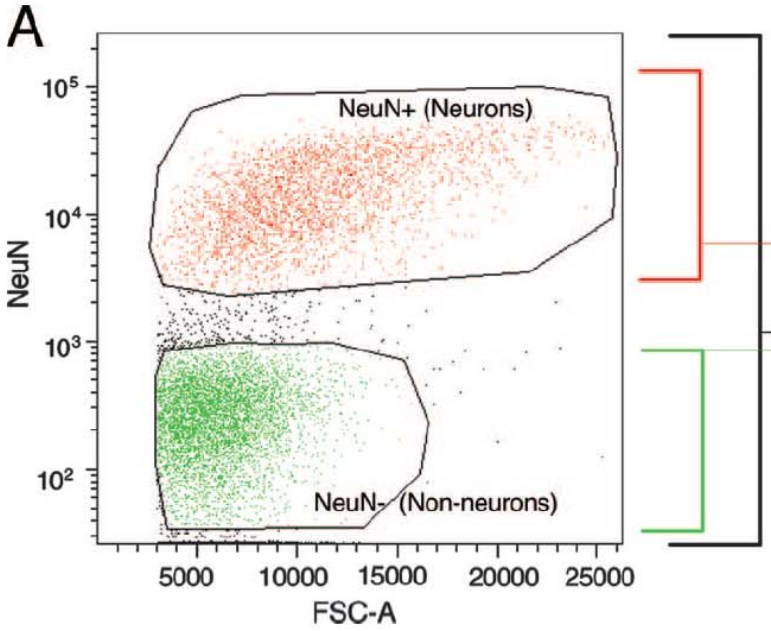
Topics studied with ^{14}C bomb peak dating of DNA

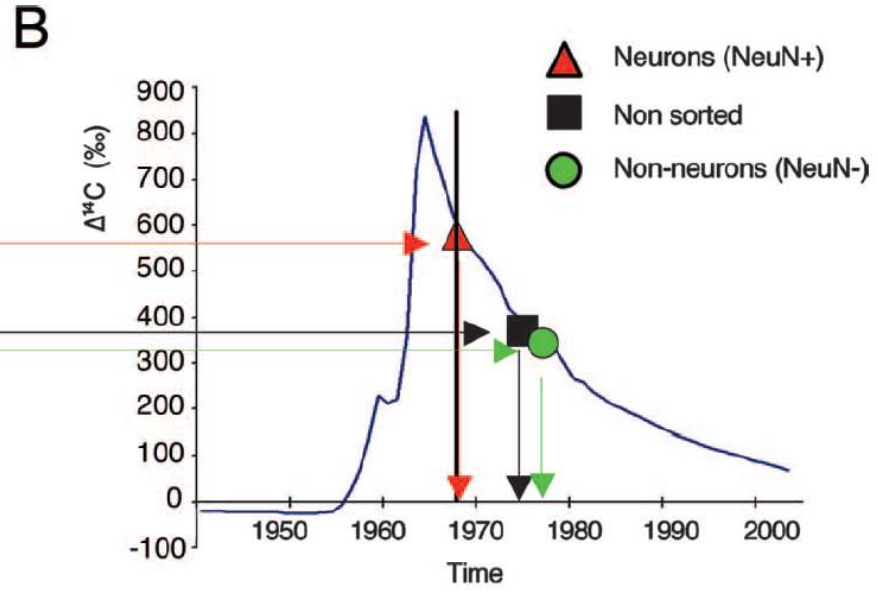
- **Reproduction of cells in different parts of the human brain**
  K. Spalding et al., Cell 122 (2005) 133

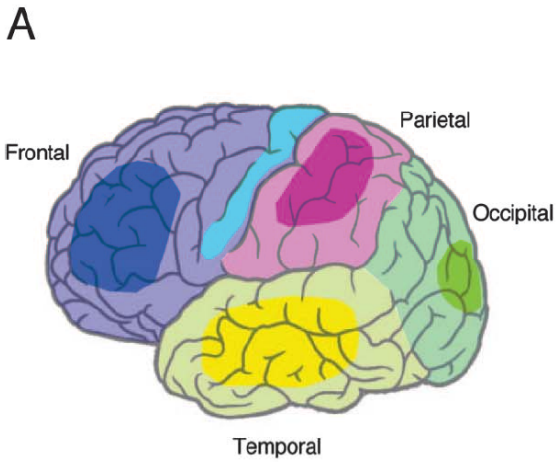
- **Neocortical neurogenesis in humans is restriced to development**
  R.D. Bahardwaj et al., PNAS 103 (2006) 12564

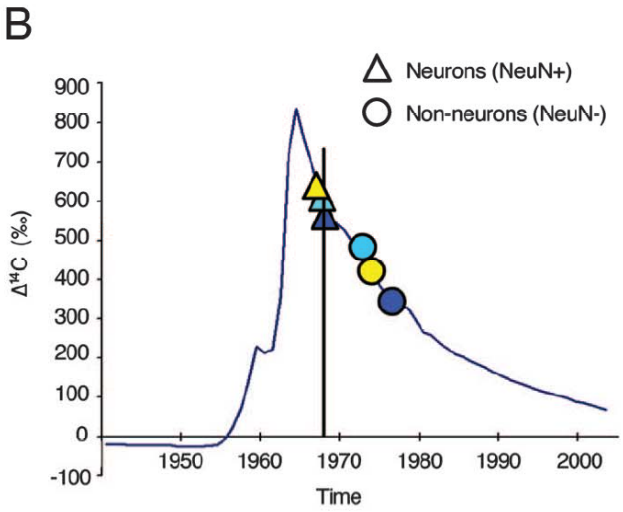
- **Dynamics of fat cell turnover in humans**
  K. Spalding et al., Nature 453 (2008) 783

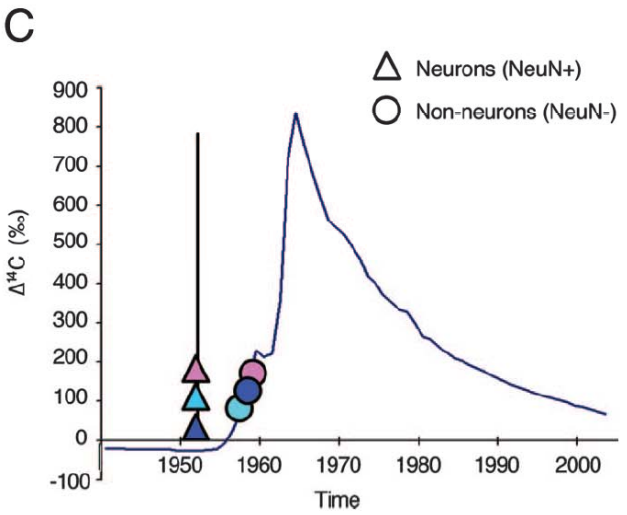
- **Evidence for cardiomyocyte (heart cell) renewal in humans**
  O. Bergmann et al., Science 324 (2009) 98





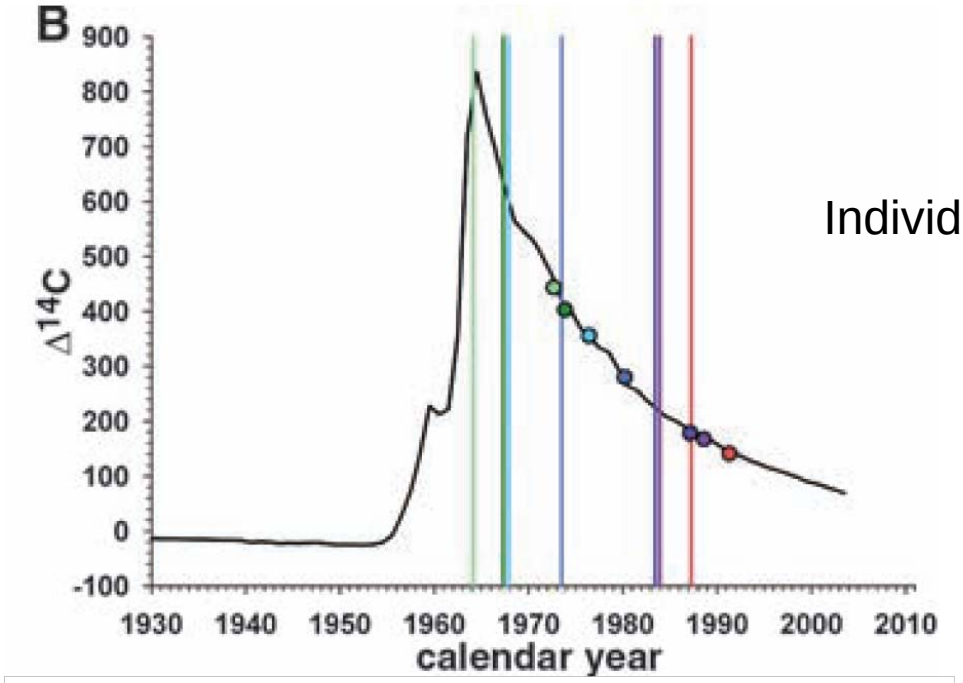






Determination of the age of neocortical neurons

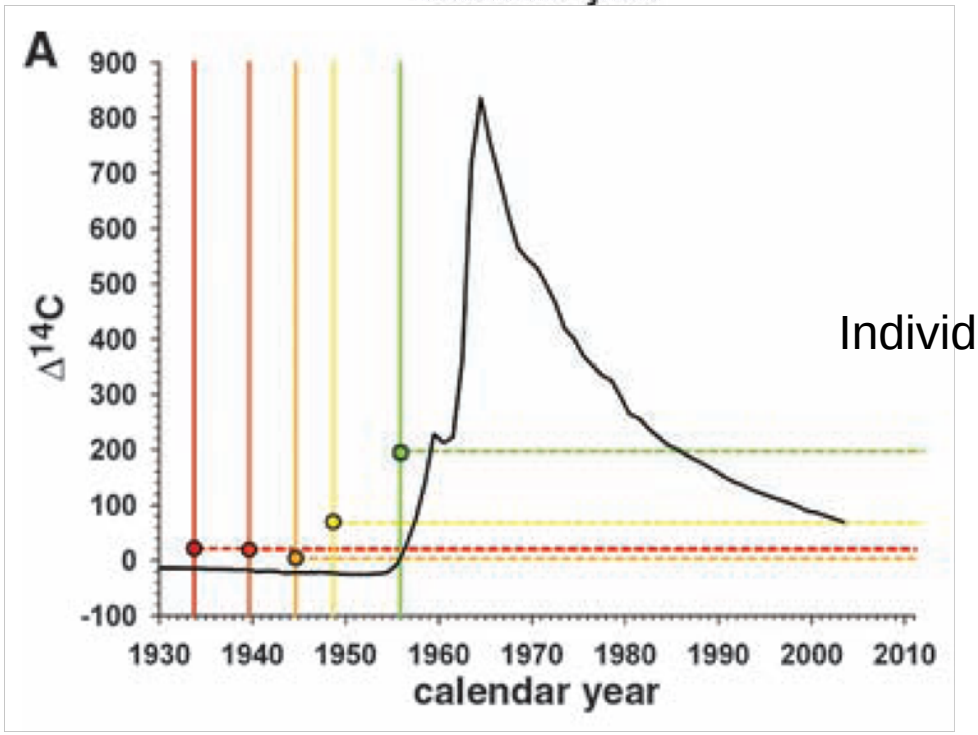
Bhardwaj et al., PNAS 103 (2006) 12564



Individuals born after the ^{14}C bomb peak

Evidence for renewel of human heart cells (cardiomyocytes)

Bergmann et al., Science 324 (2009) 98



Individuals born before the ^{14}C bomb peak

The technical challenge

To develop ^{14}C AMS for µg-carbon samples. The DNA extracted from 10 human cell contains only one ^{14}C atom. For special sections of the brain little material is available.

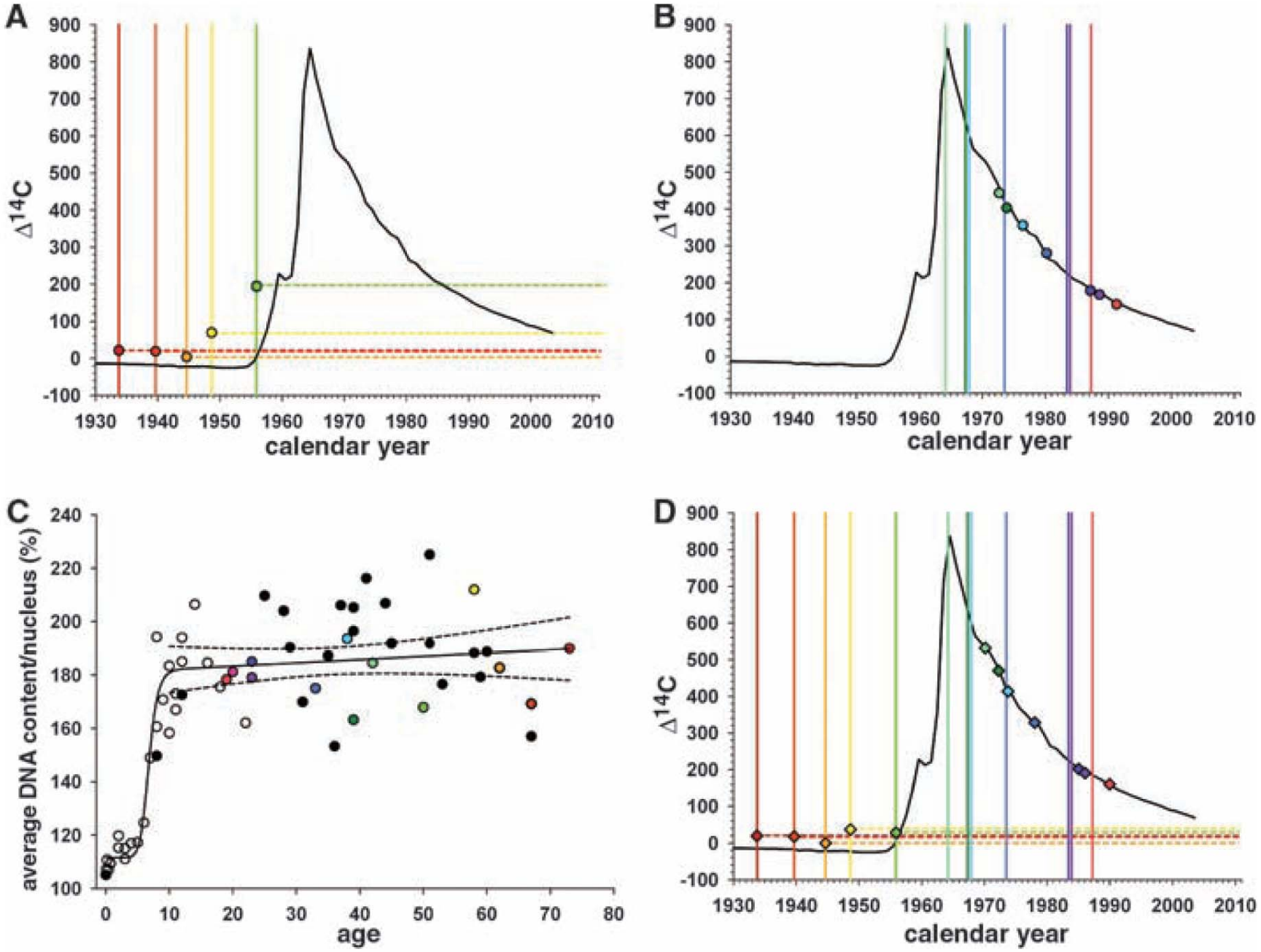
Conclusion

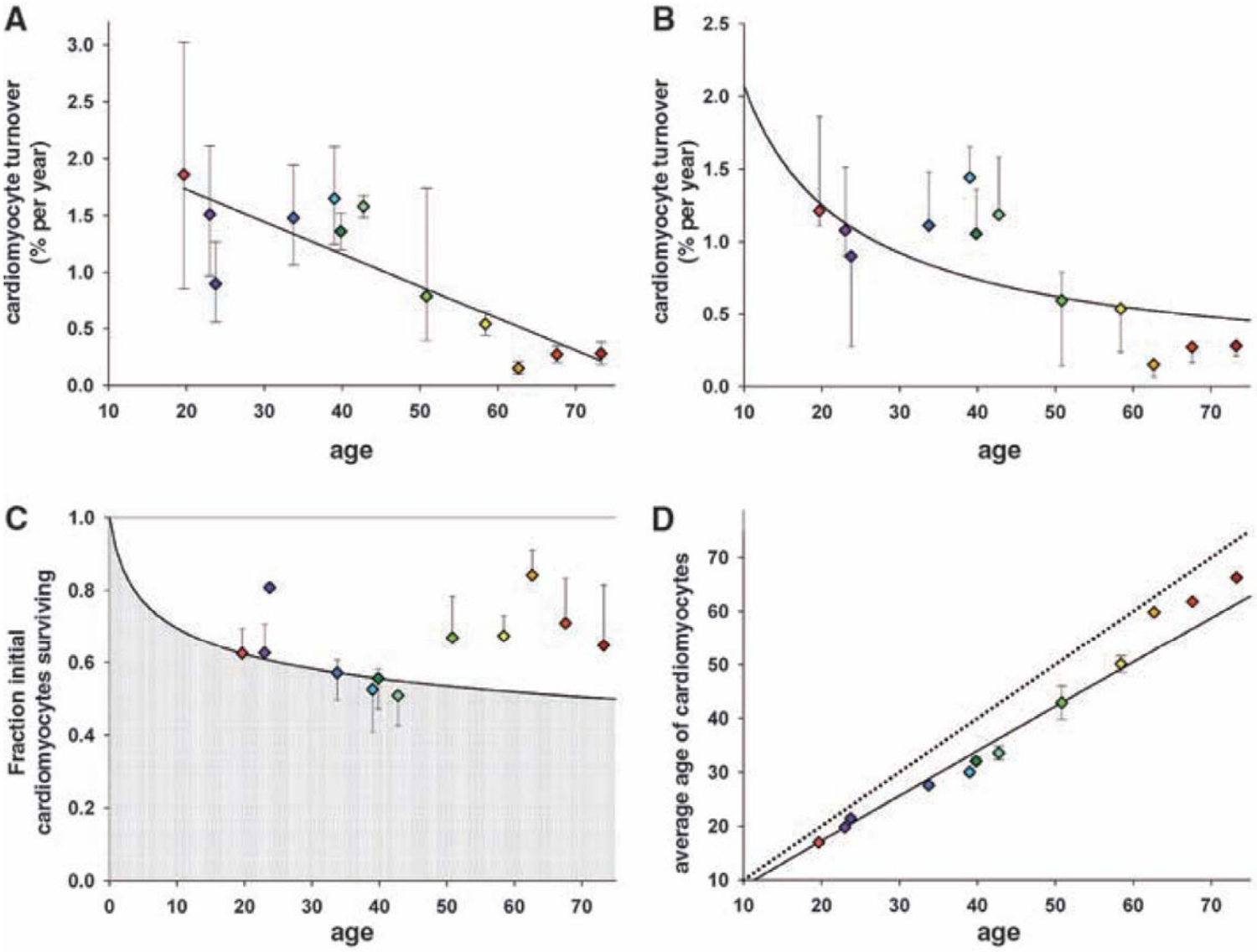

Cape of Good Hope

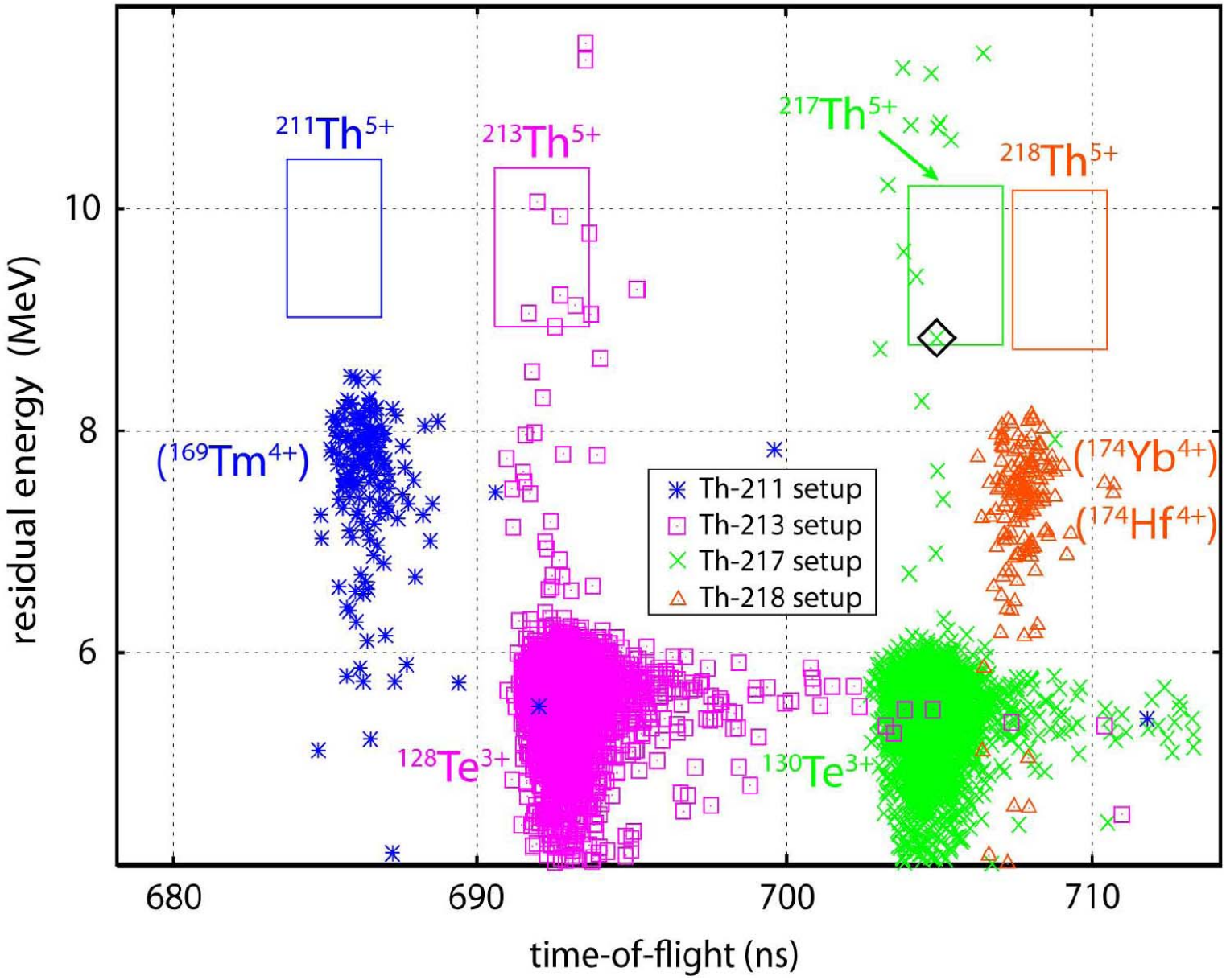

Photo: Georg Wolschin

It is better to be roughly right than precisely wrong.

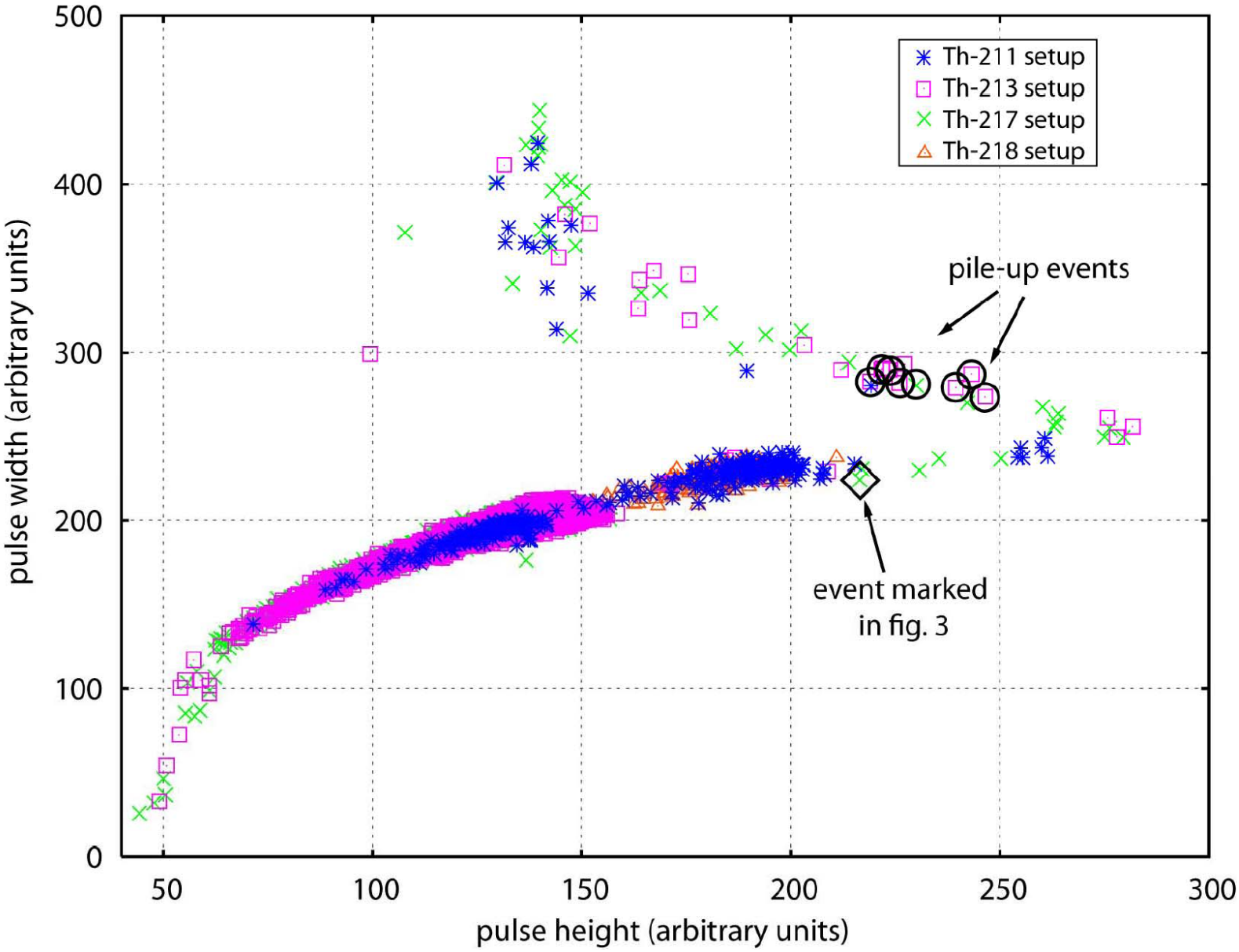
– Einstein


A
B
C
D
Δ14C
calendar year
average DNA content/nucleus (%)
age
900
800
700
600
500
400
300
200
100
0
-100
1930
1940
1950
1960
1970
1980
1990
2000
2010
240
220
180
160
140
120
10
20
30
40
50
60
70
80


A
cardiomyocyte turnover (% per year)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10
20
30
40
50
60
70
age
B
cardiomyocyte turnover (% per year)
2.5
2.0
1.5
1.0
0.5
0.0
10
20
30
40
50
60
70
age
C
Fraction initial cardiomyocytes surviving
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
60
70
age
D
average age of cardiomyocytes
70
60
50
40
30
20
10
10
20
30
40
50
60
70
age



Search for neutron-deficient thorium isotopes



Identification of pile-up events