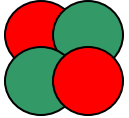
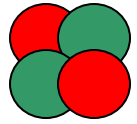




The Superheavy Element Programme at TASCA @ GSI/FAIR



Ulrika Forsberg
on behalf of the TASCA collaboration
September 29, 2016
NUSTAR Week, York



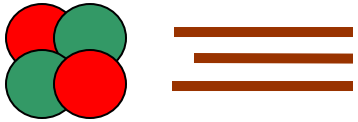
Superheavy elements



new sub-collaboration in

NUSTAR@FAIR

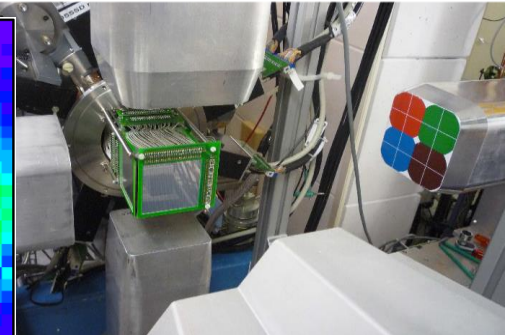
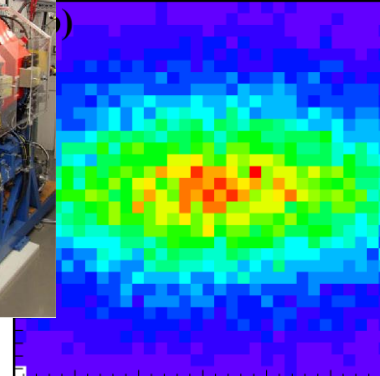
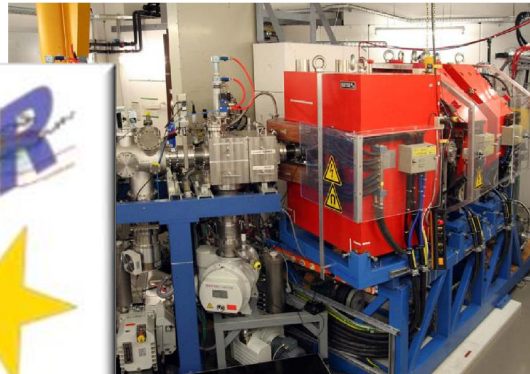
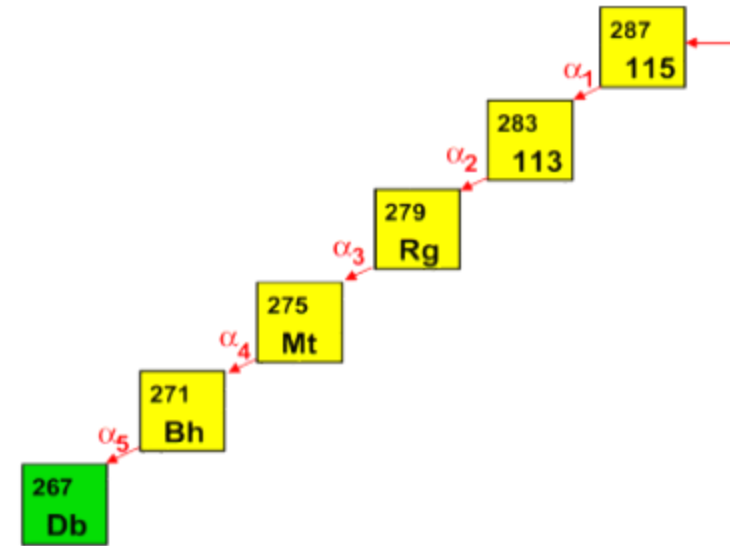




Outline



- Superheavy elements (SHE)
- The TASCA separator
- Experiments and main results
- Plans for the future

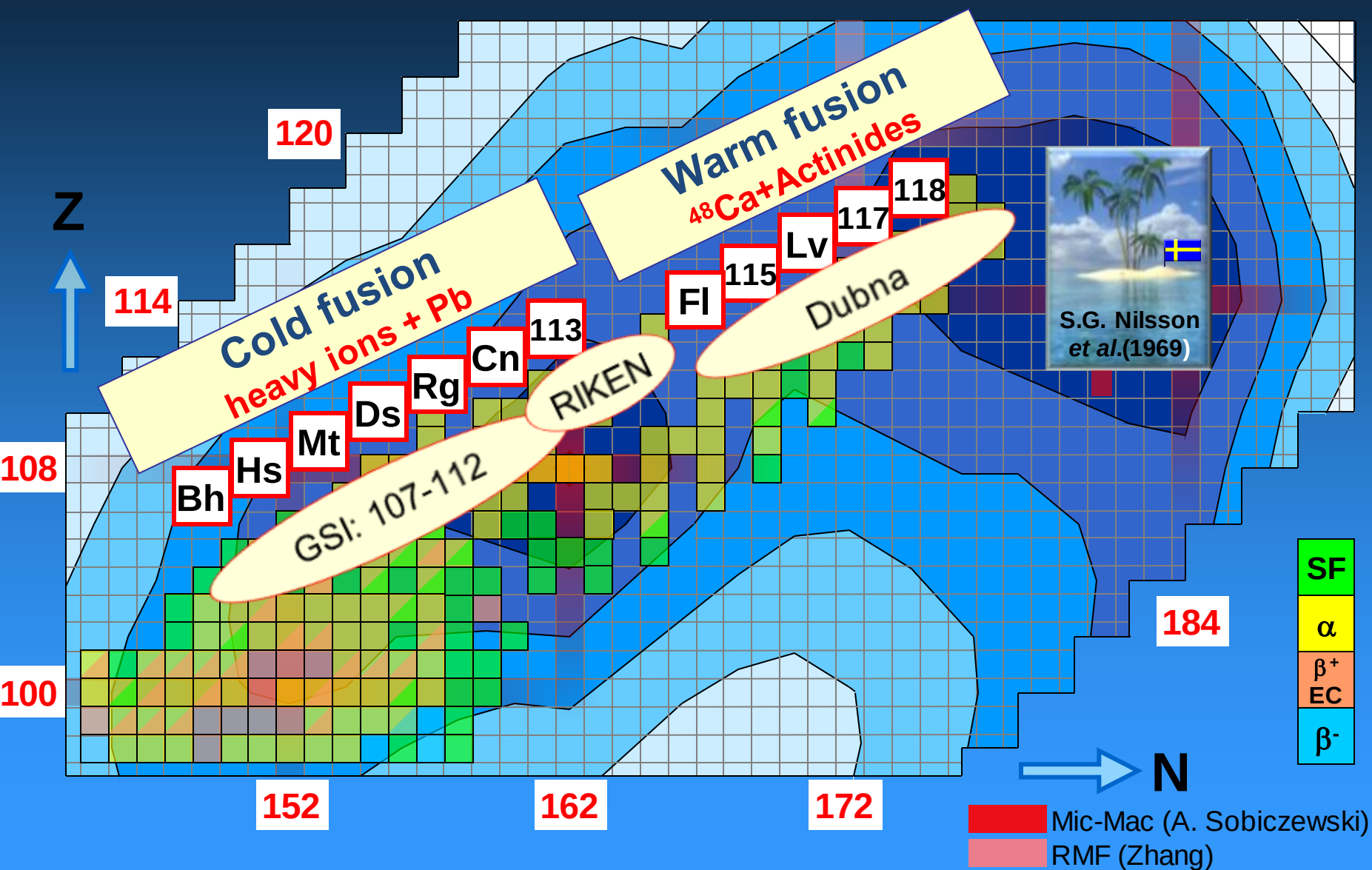




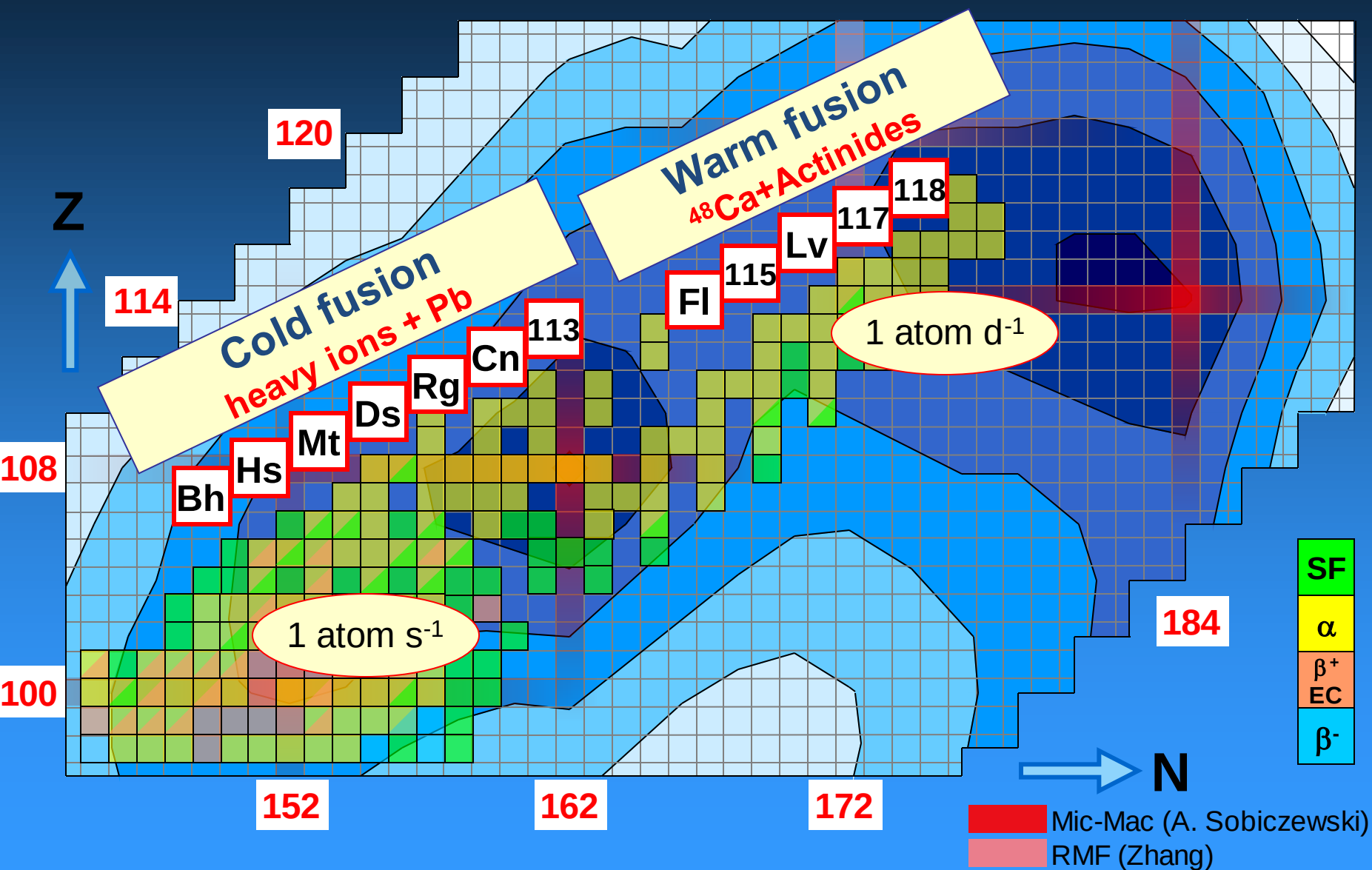
Superheavy elements: $Z \geq 104$

Group #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	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
5	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
6	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
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cp	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
			* Lanthanoids	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	
			** Actinoids	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	

Superheavy Elements: $Z \geq 104$

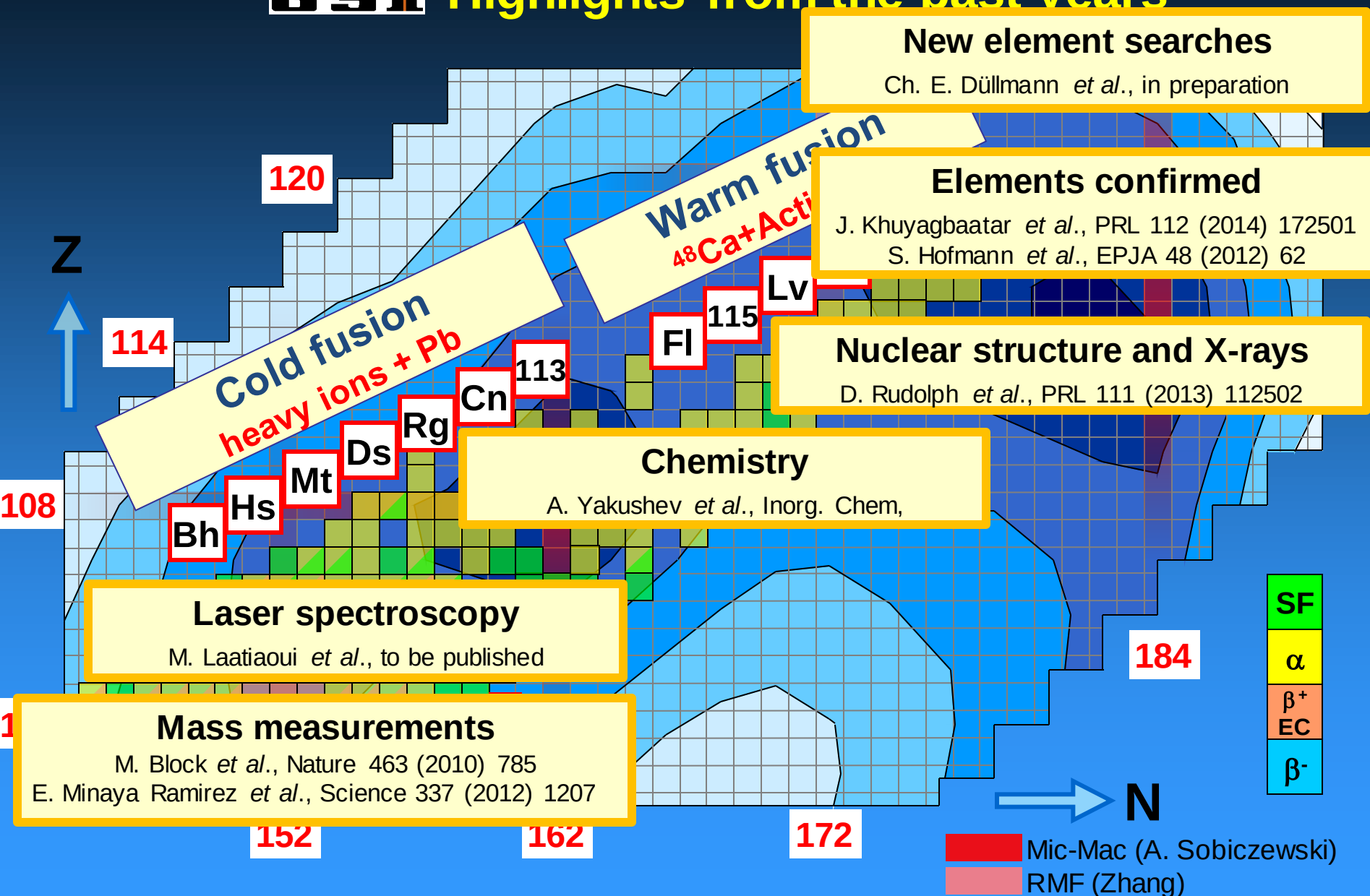


Superheavy Elements

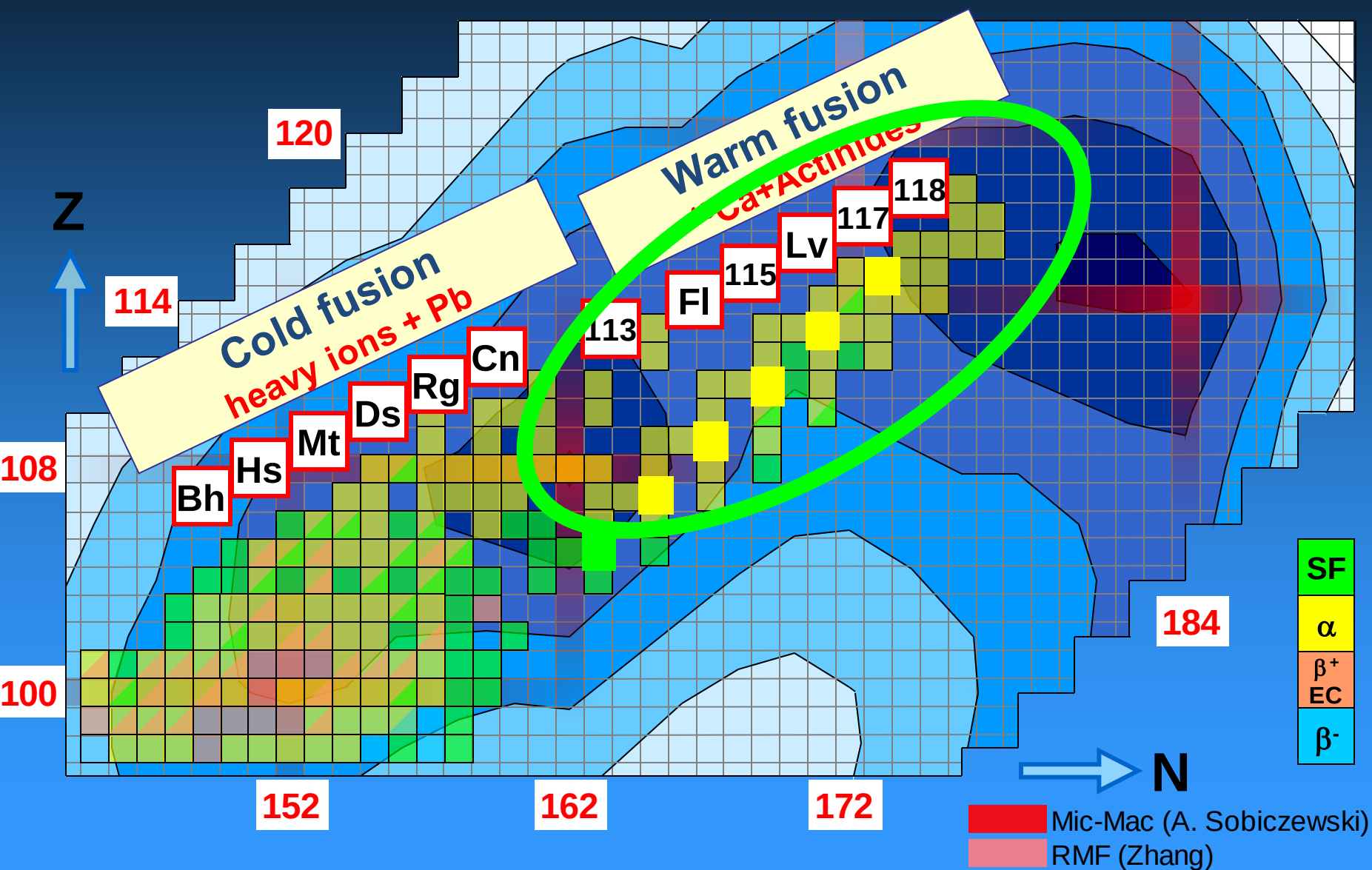


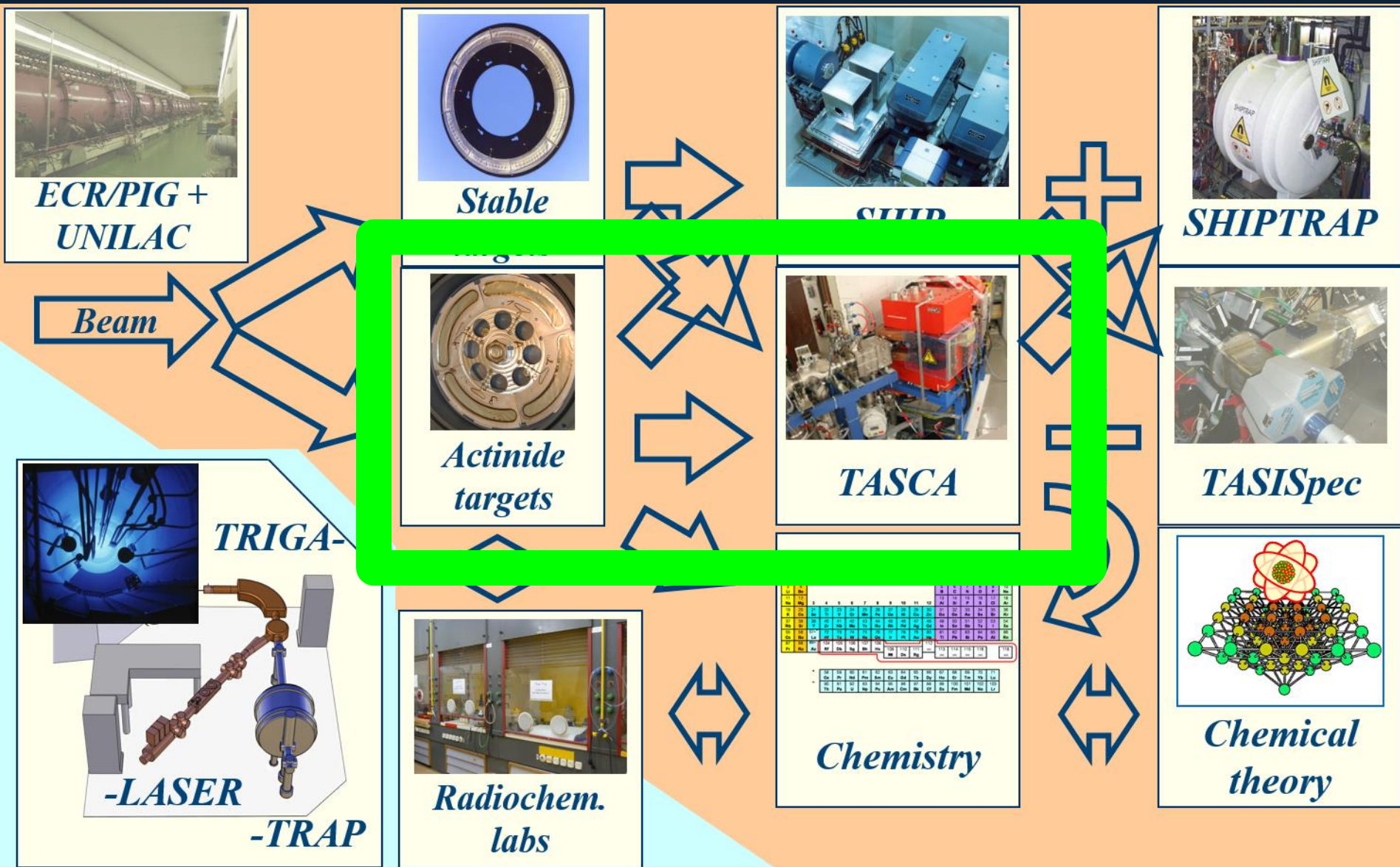
Superheavy Elements

– GSI Highlights from the past years



Superheavy Elements





The *TASCA* Collaboration





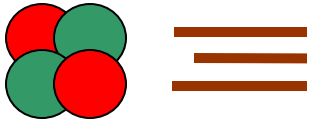
TASCA

Beam

Target

Dipole

$Q_1 Q_2$

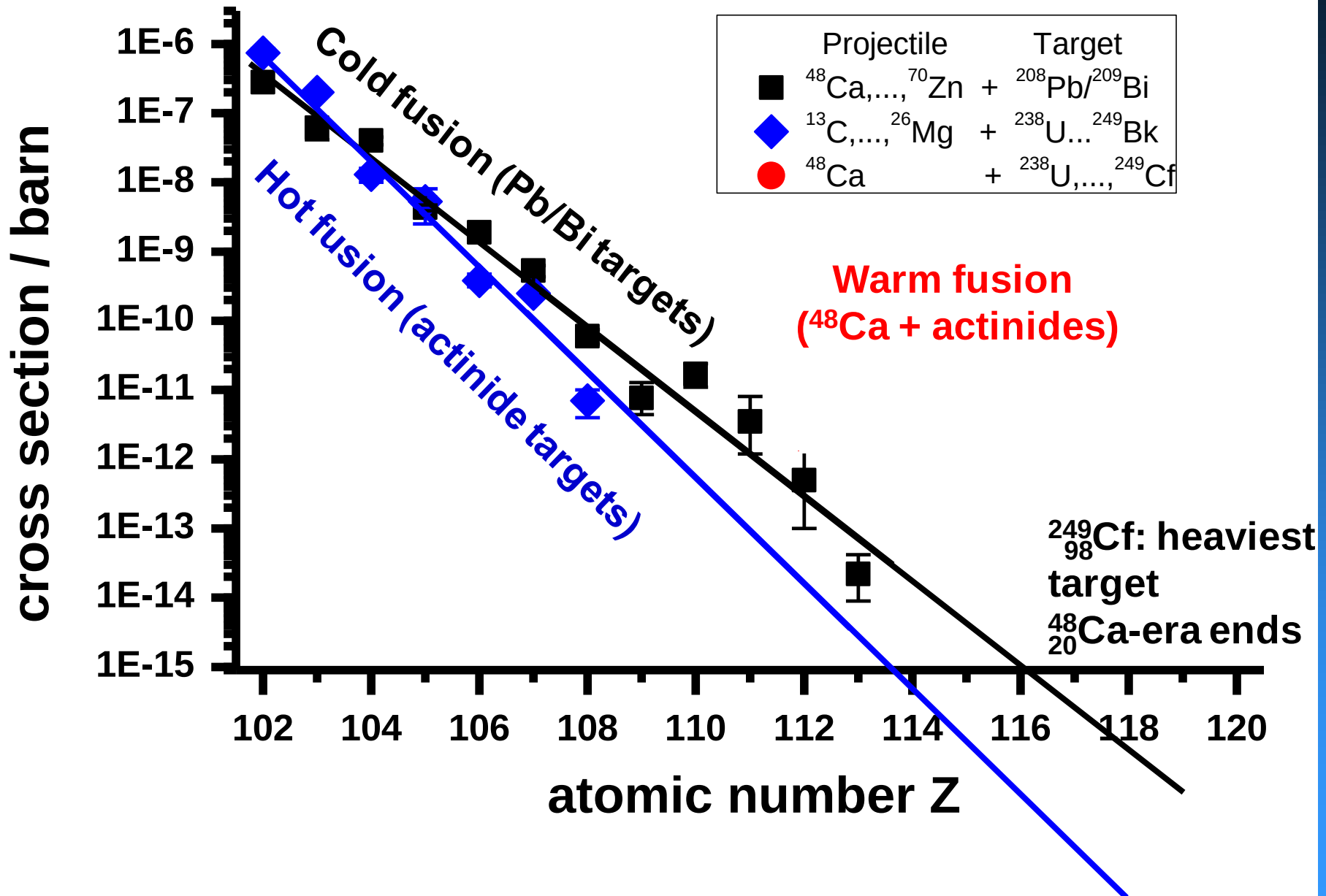


Search for element 120

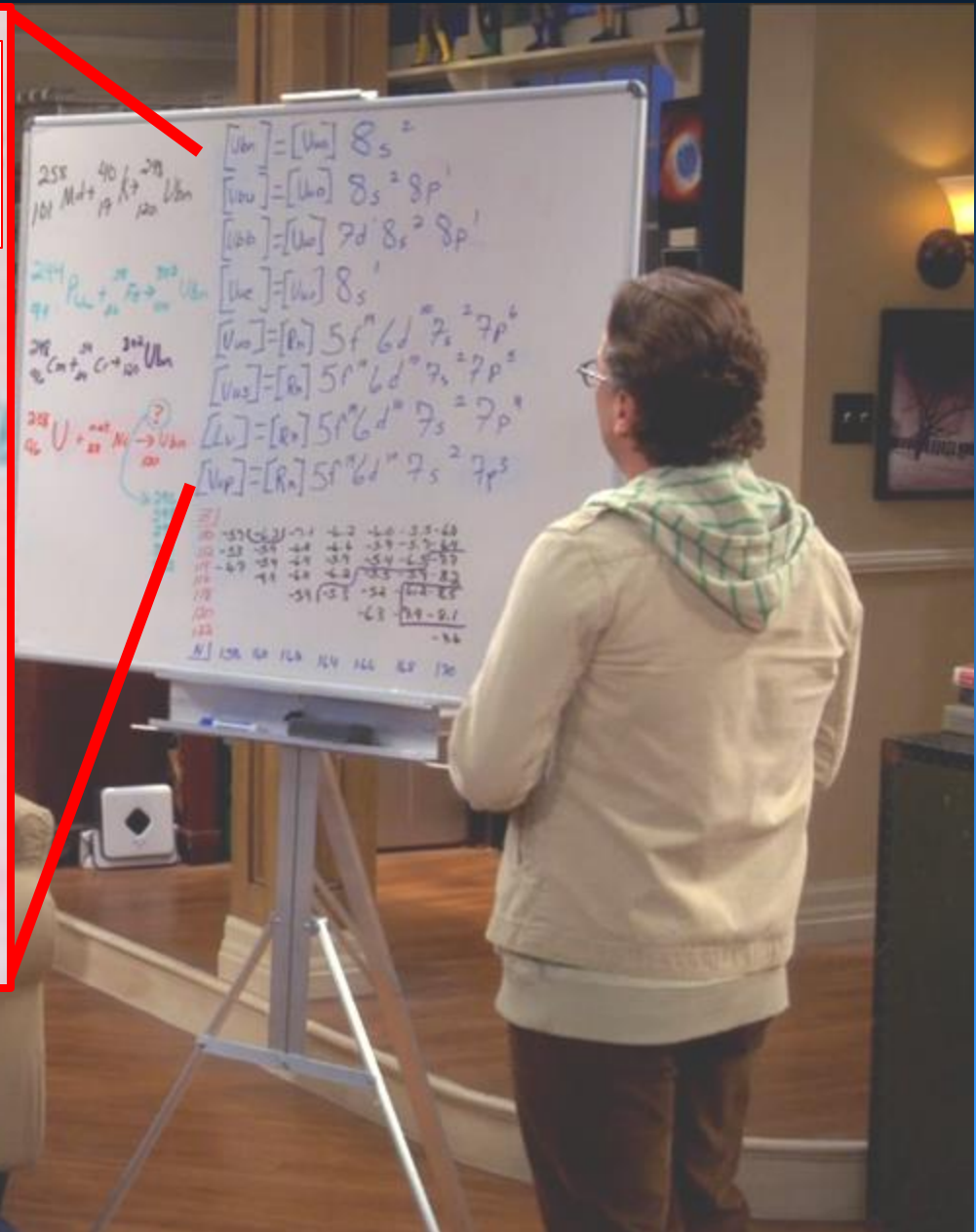
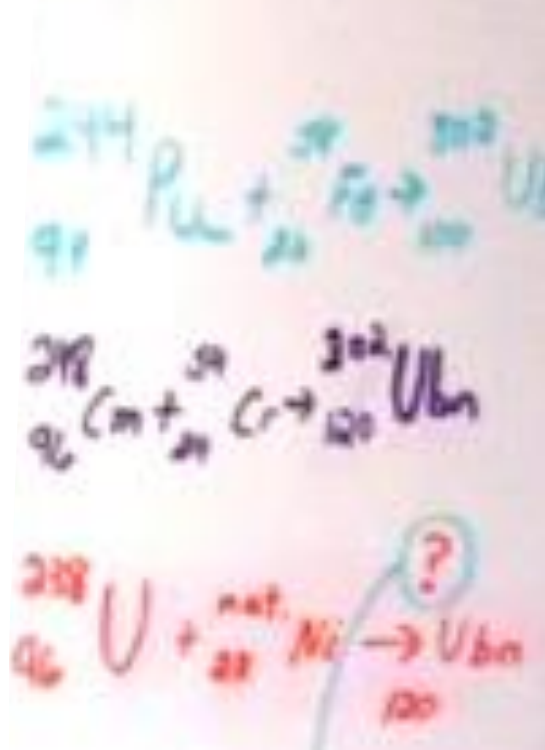


120
119
118
117
116
115
Fl
113

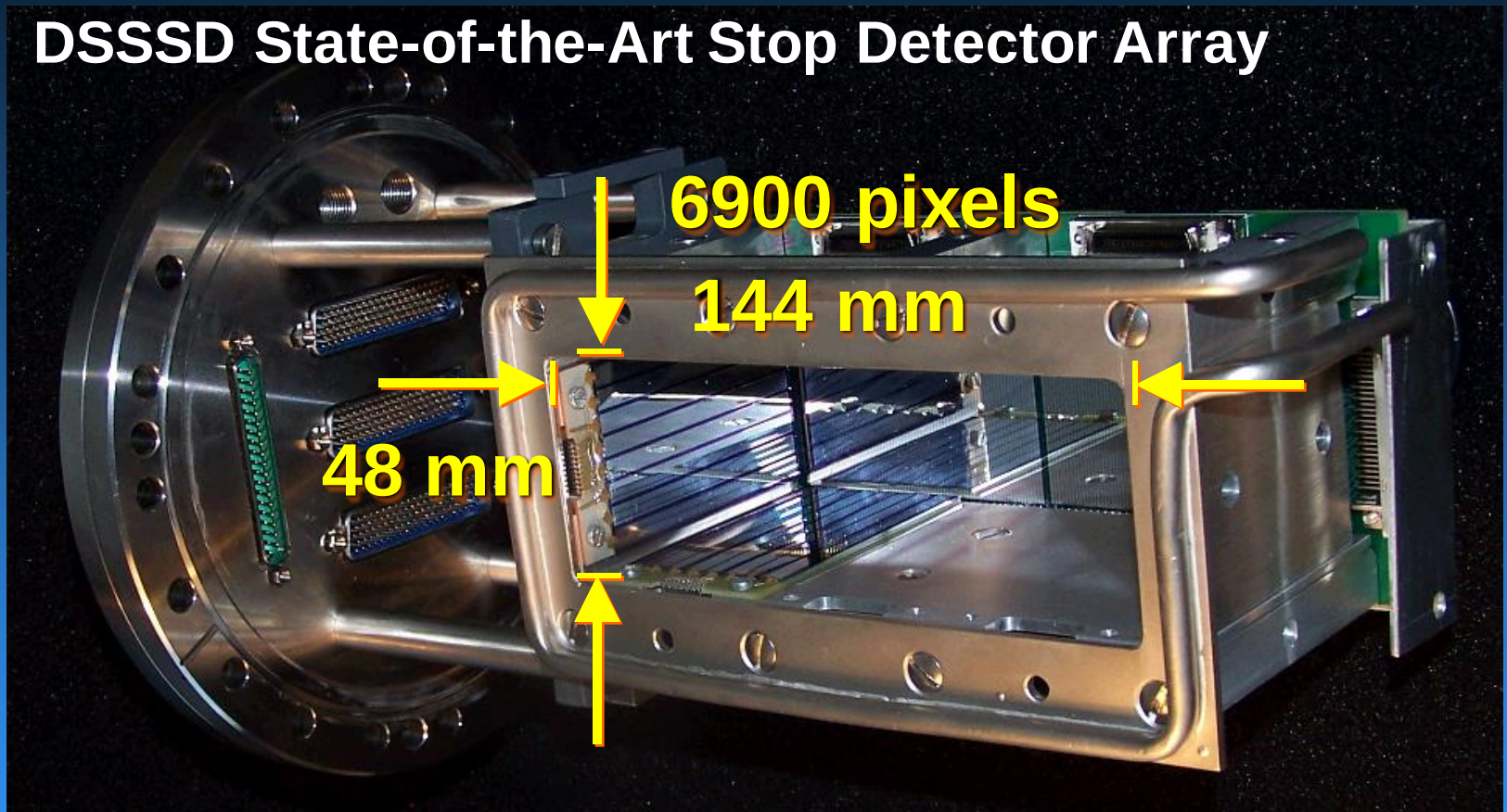
Synthesis of superheavy elements



How to synthesize element 120?



DSSSD State-of-the-Art Stop Detector Array





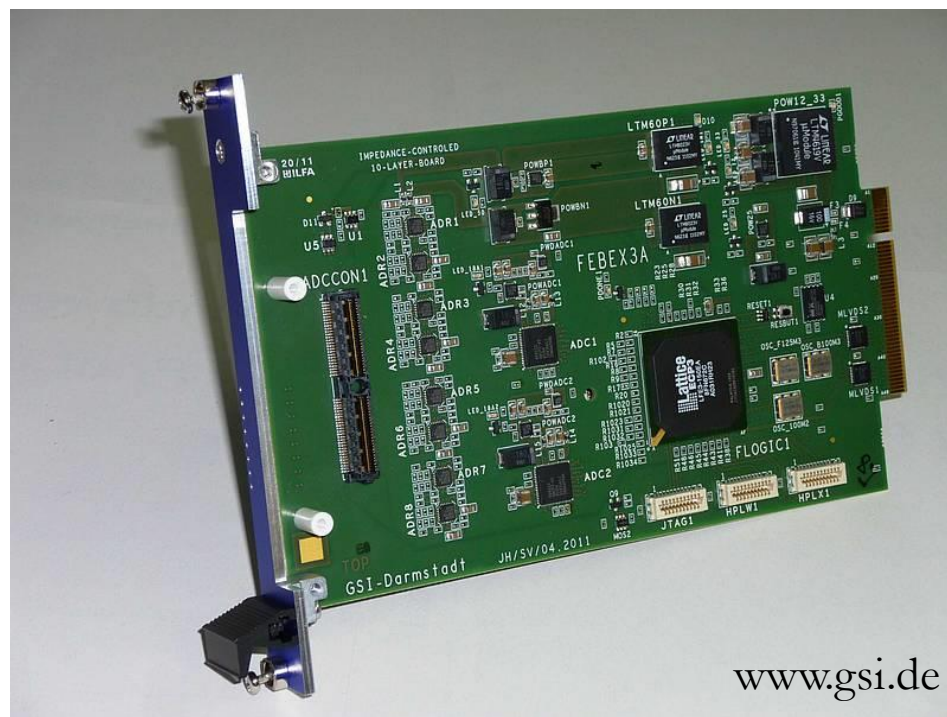
Electronics



Analogue electronics + **FEBEX** digital electronics

Developed at **GSI-EE**

60 MHz dead-time free
ADC sampling



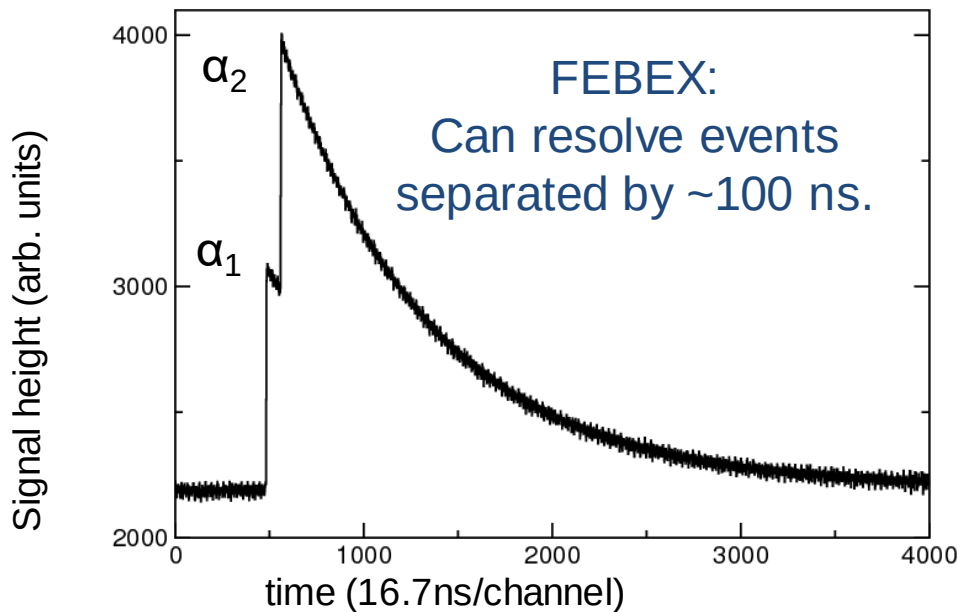
www.gsi.de



Electronics



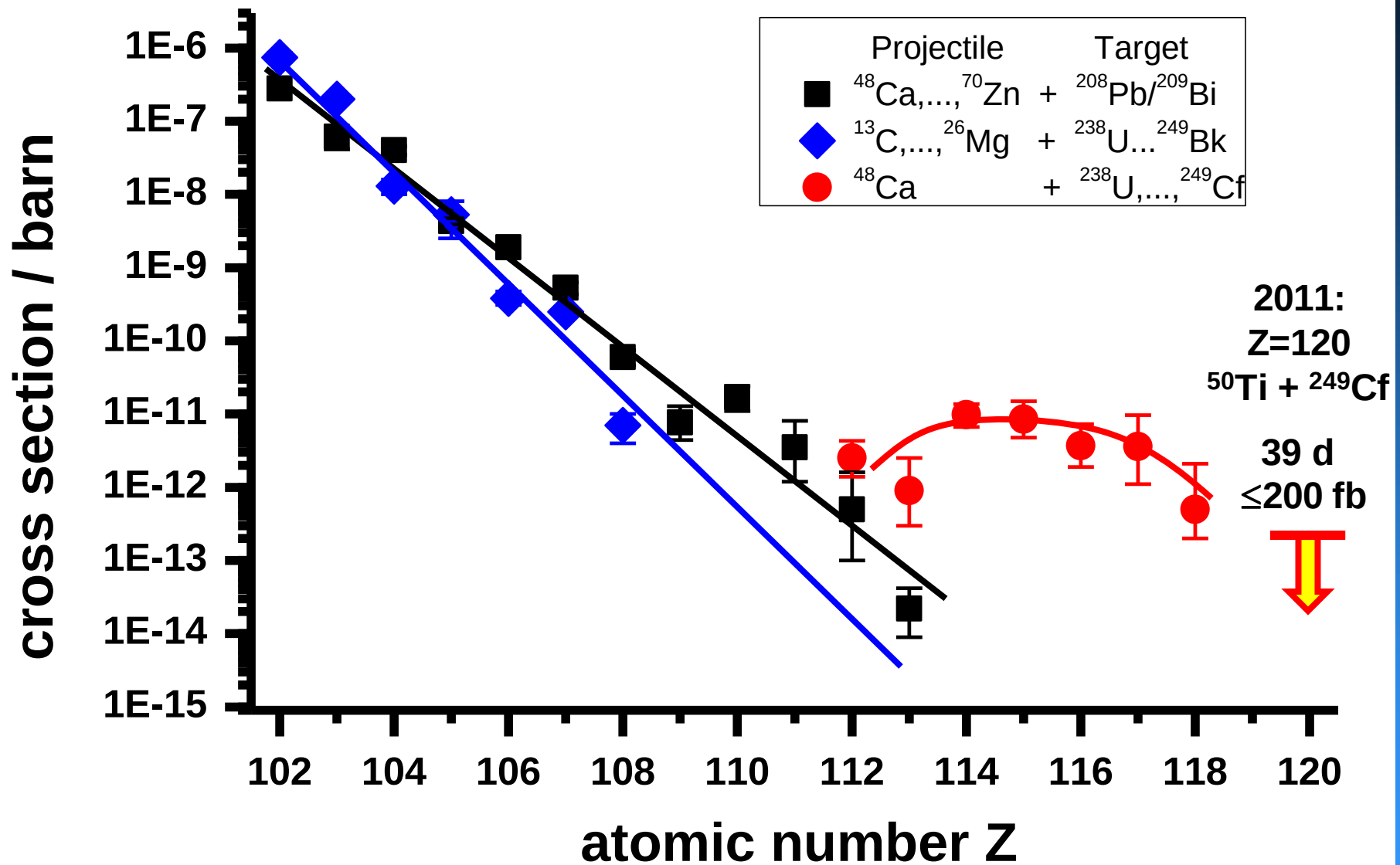
Analogue electronics + **FEBEX** digital electronics

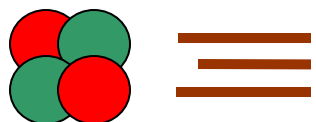


Fast decays from E120
can be measured

Two fast α decays of ~ 5 MeV
cannot be confused with
one α decay of ~ 10 MeV.

TASCA Search for element 120 in $^{50}\text{Ti} + ^{249}\text{Cf}$ reaction

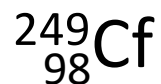
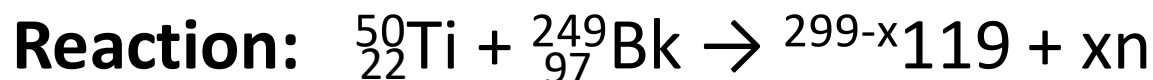




Search for E119



120
119
118
117
116
115
114
113



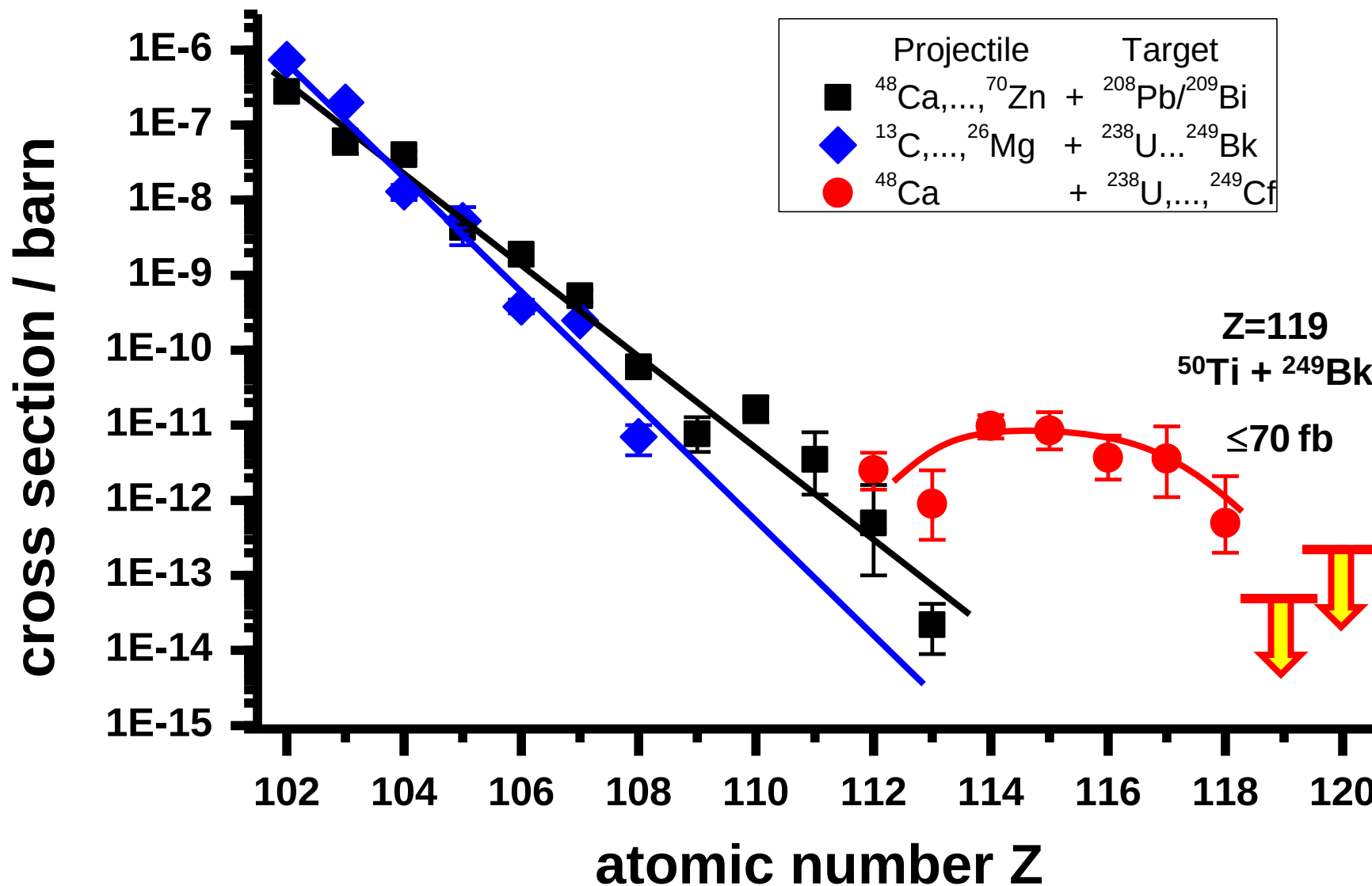
Production and separation:

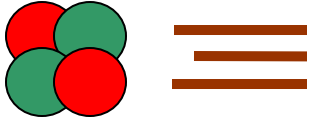


Target production:



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

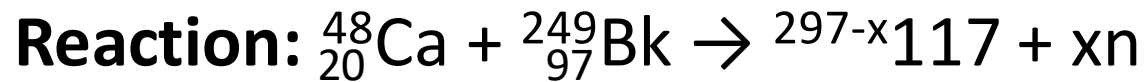




E117 confirmation



120
119
118
117
116
115
114
113



Element 117 among Top Ten Physics News Stories in 2014

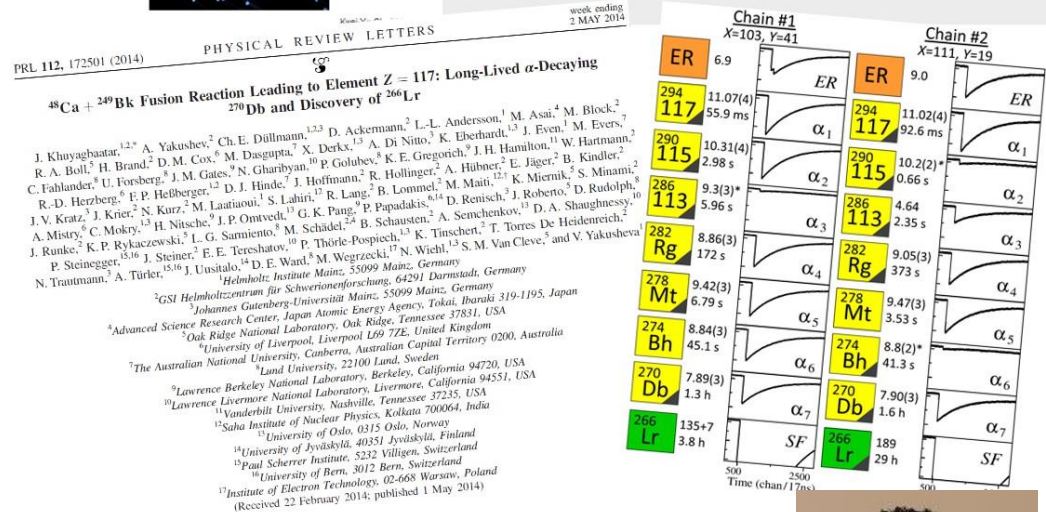
Every year, APS selects Top Ten Physics News Stories, which received largest public attention. The 2014 list includes highlights like

- intergalactic neutrinos from IceCube,
- Rosetta/Philae comet mission
- blue LEDs (physics nobel prize 2014)
- our Element 117
- ...

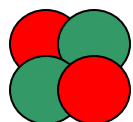
Synopsis: Element Z=117 Confirmed



⁴⁸Ca + ²⁴⁹Bk Fusion Reaction Leading to Element Z=117: Long-Lived α -Decaying ²⁷⁰Db and Discovery of ²⁶⁶Lr
J. Khuyagbaatar et al.
Phys. Rev. Lett. **112**, 172501 (2014)
Published May 1, 2014



J. Khuyagbaatar et al., Phys. Rev. Lett. 112 (2014) 172501

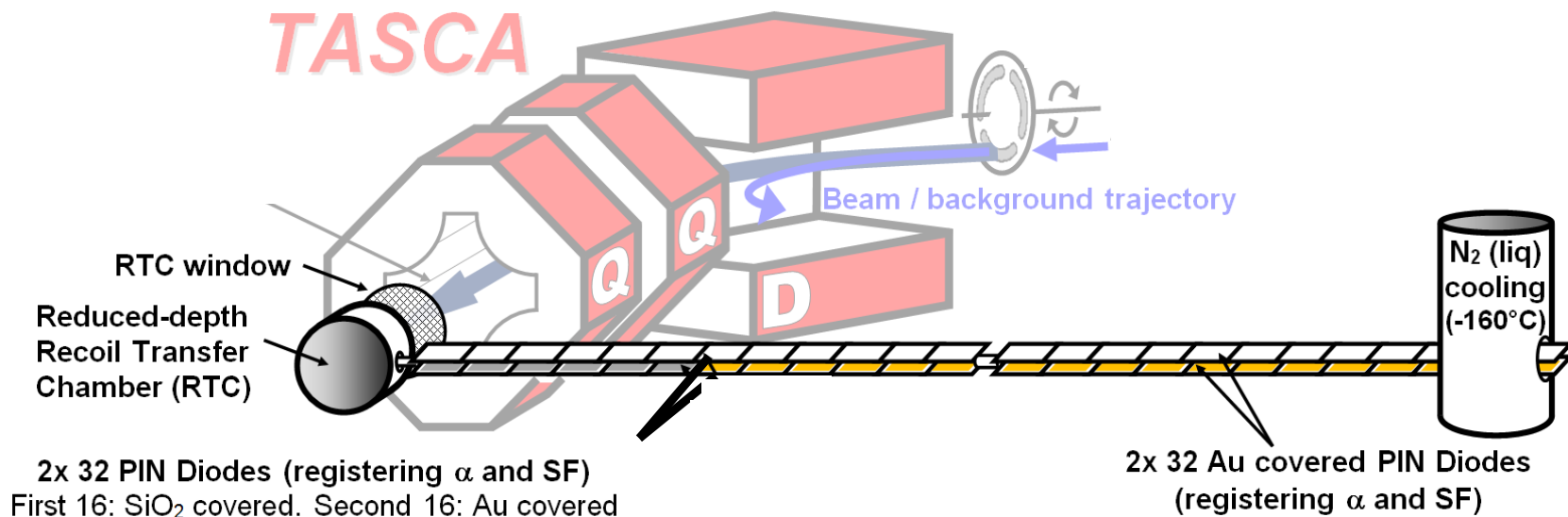


E114 & E113 Chemistry



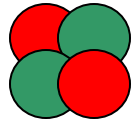
120	✓
119	✓
118	✗
117	✓
116	✗
115	✗
114	✓
113	✓

TASCA



COMPACT I
(IC SiO₂ & IC Au)

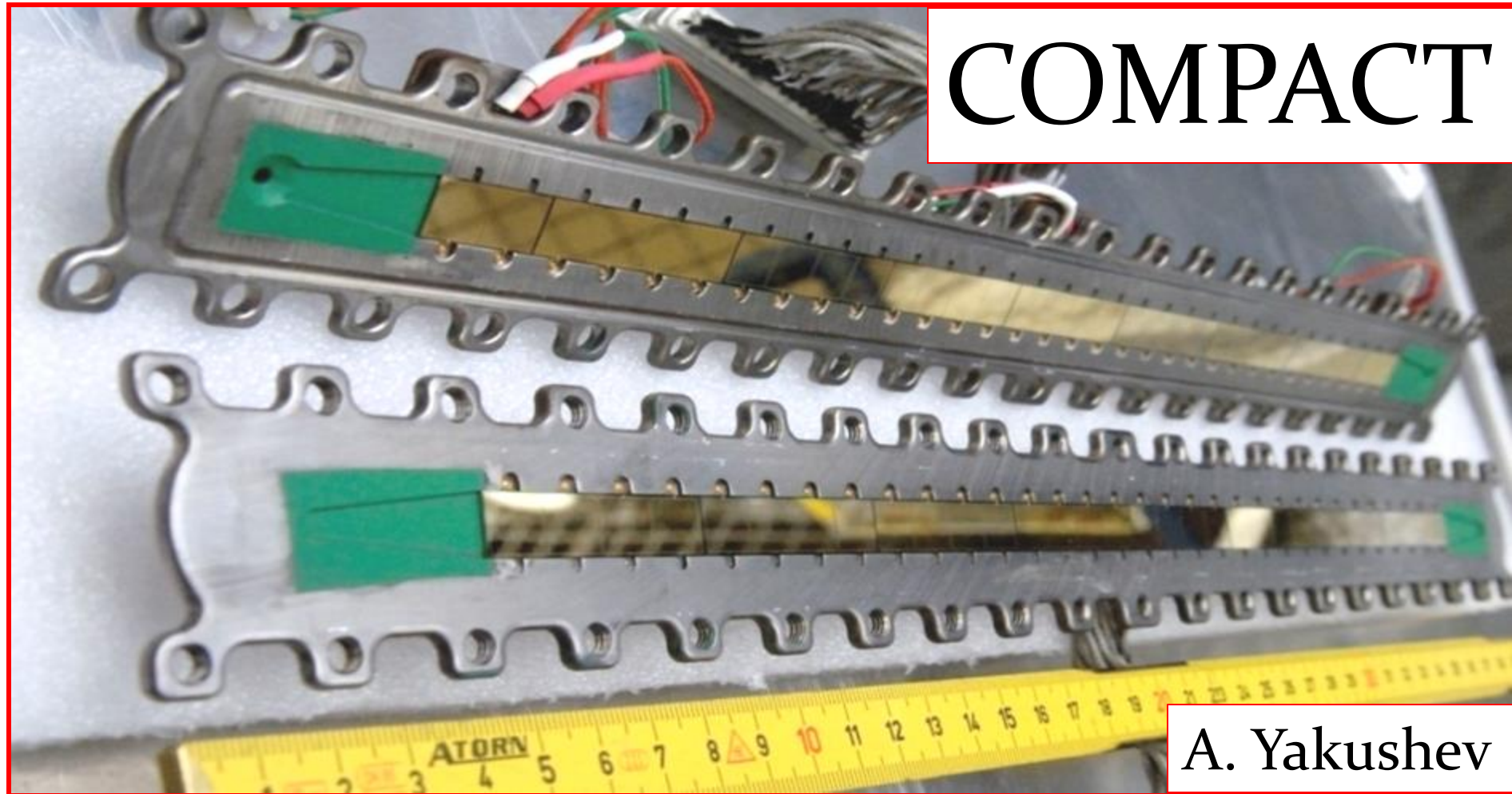
COMPACT II
(TC Au)



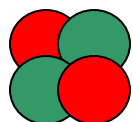
E114 & E113 Chemistry



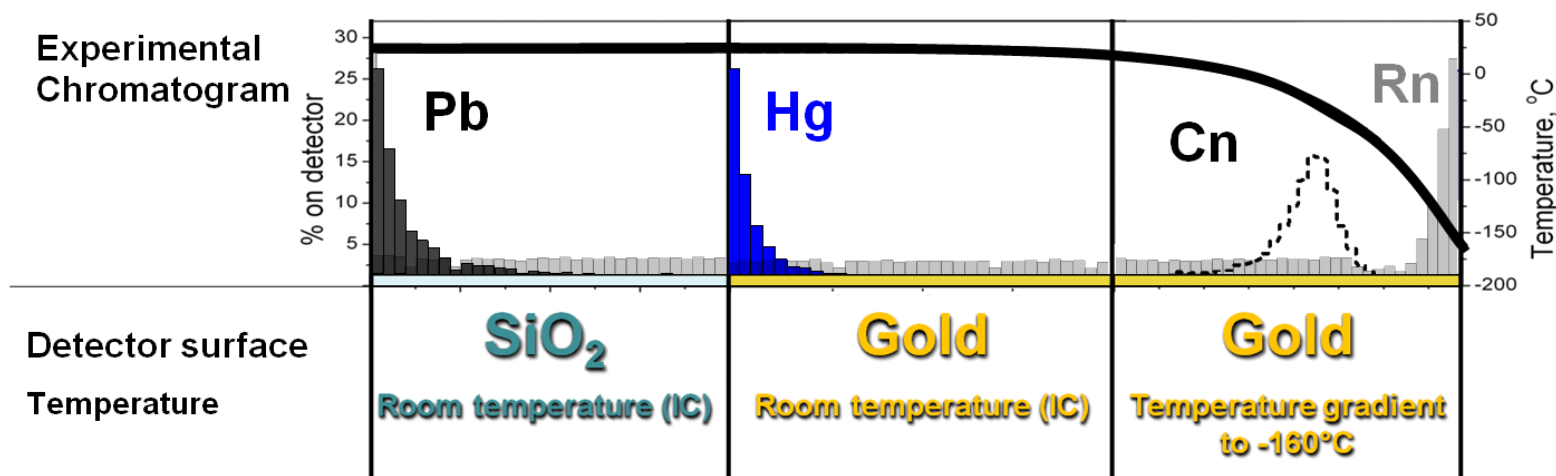
COMPACT



A. Yakushev



E114 & E113 Chemistry

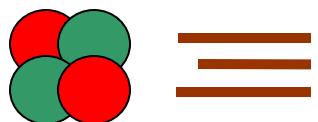


Results from first E114 exp:

A. Yakushev *et al.*, Inorg.
Chem. **53**, 1624 (2014)

... and subsequent exp:

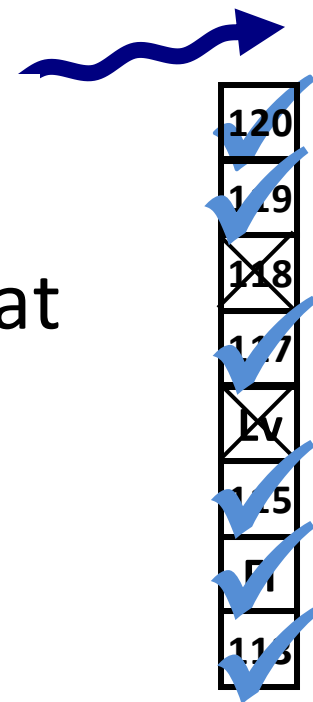
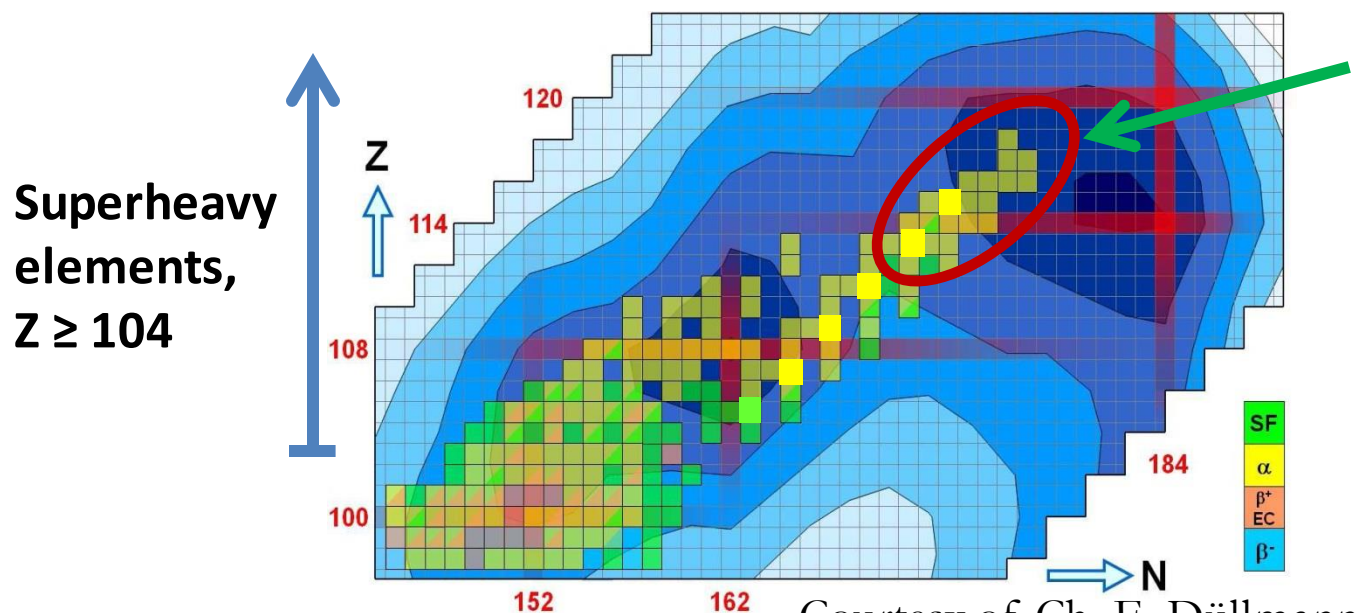
Stay tuned!



E115 Fingerprinting

^{48}Ca -induced reactions give chains that end by spontaneous fission

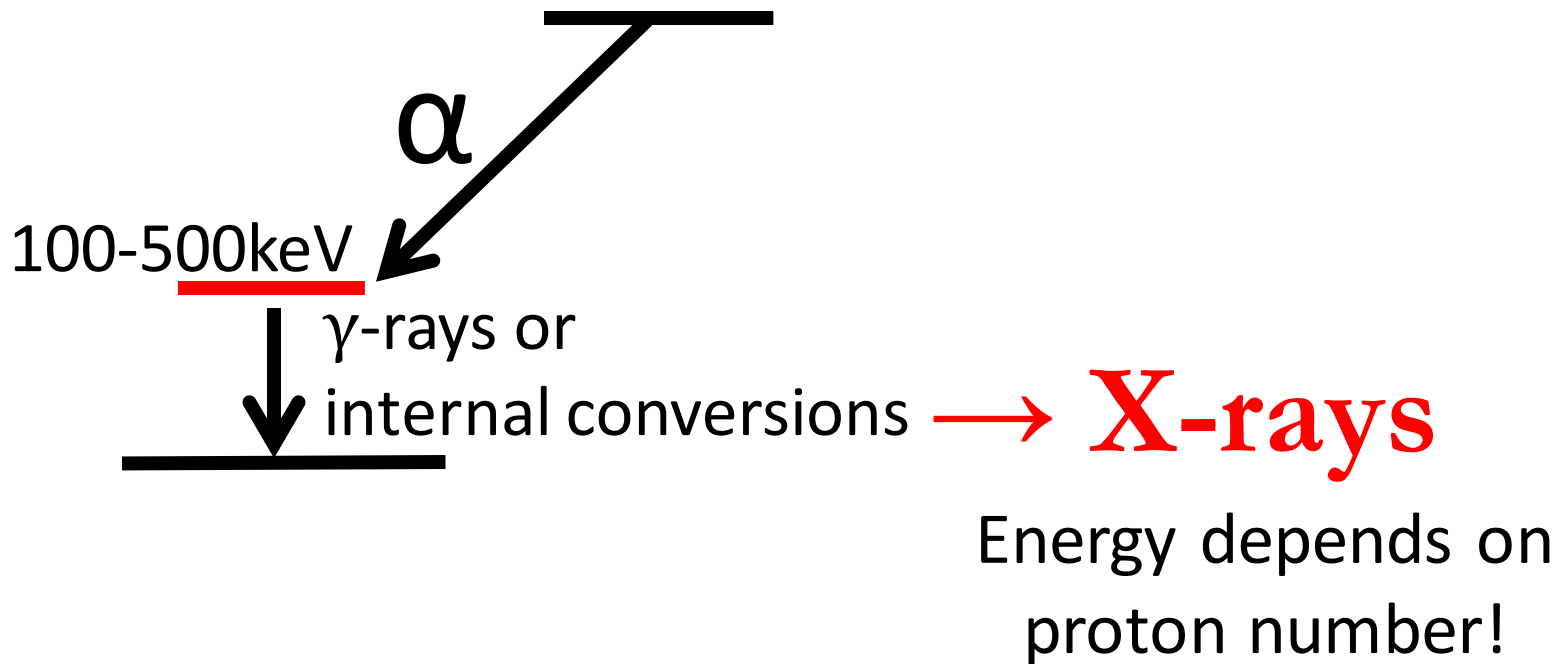
Yu.Ts.Oganessian, J. Phys.G34, R165 (2007) etc.



Need direct measurement of atomic numbers!

E115 Fingerprinting

Look for **characteristic X-rays** emitted in coincidence with α decays!



TASiSpec

TASCA

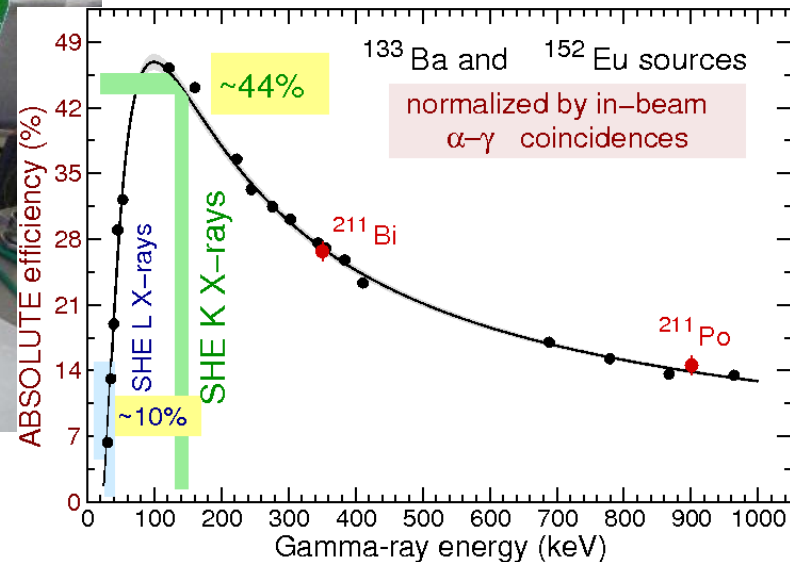
CLOVER

CLOVER

CLOVER

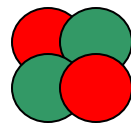
CLOVER

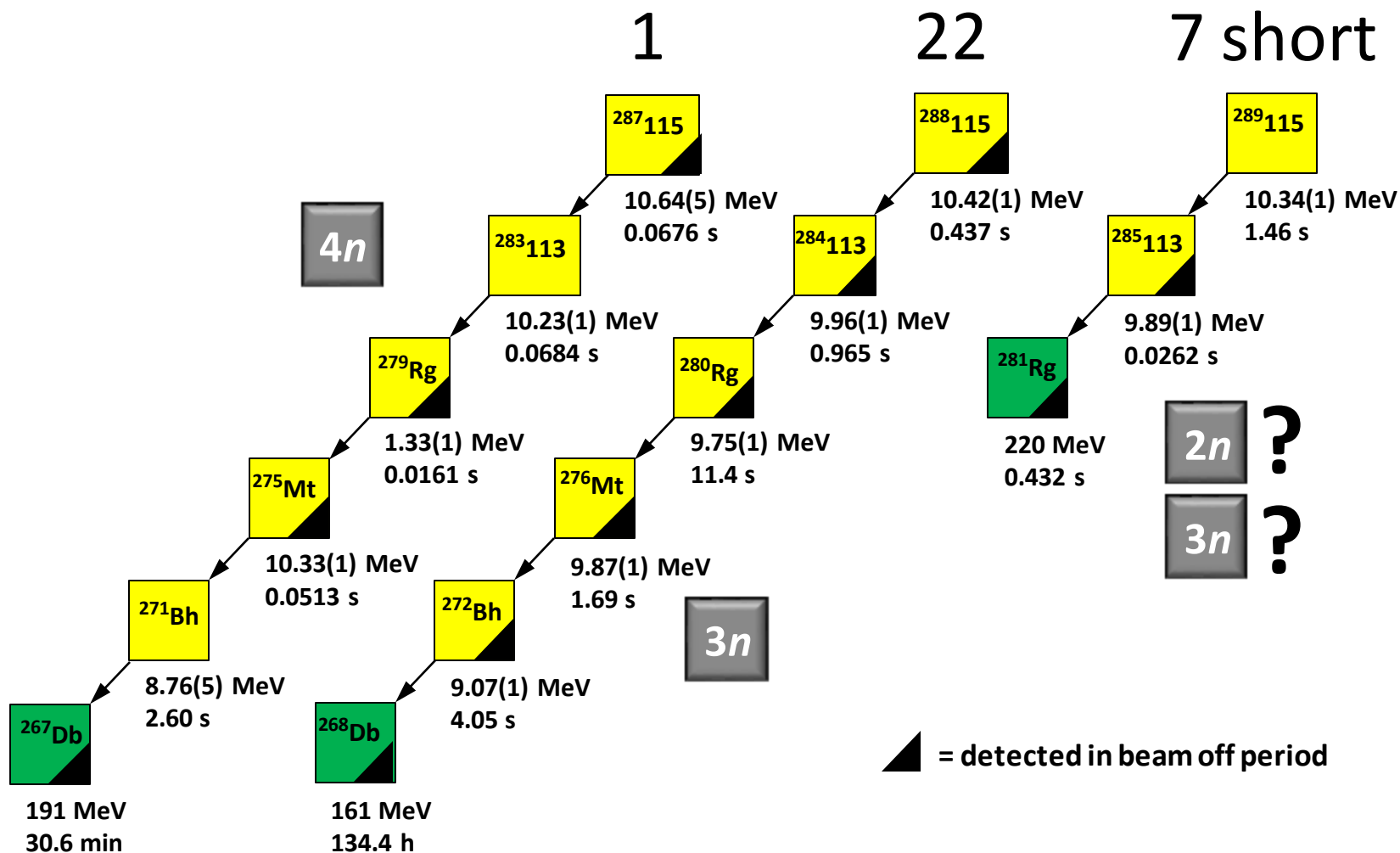
CLUSTER



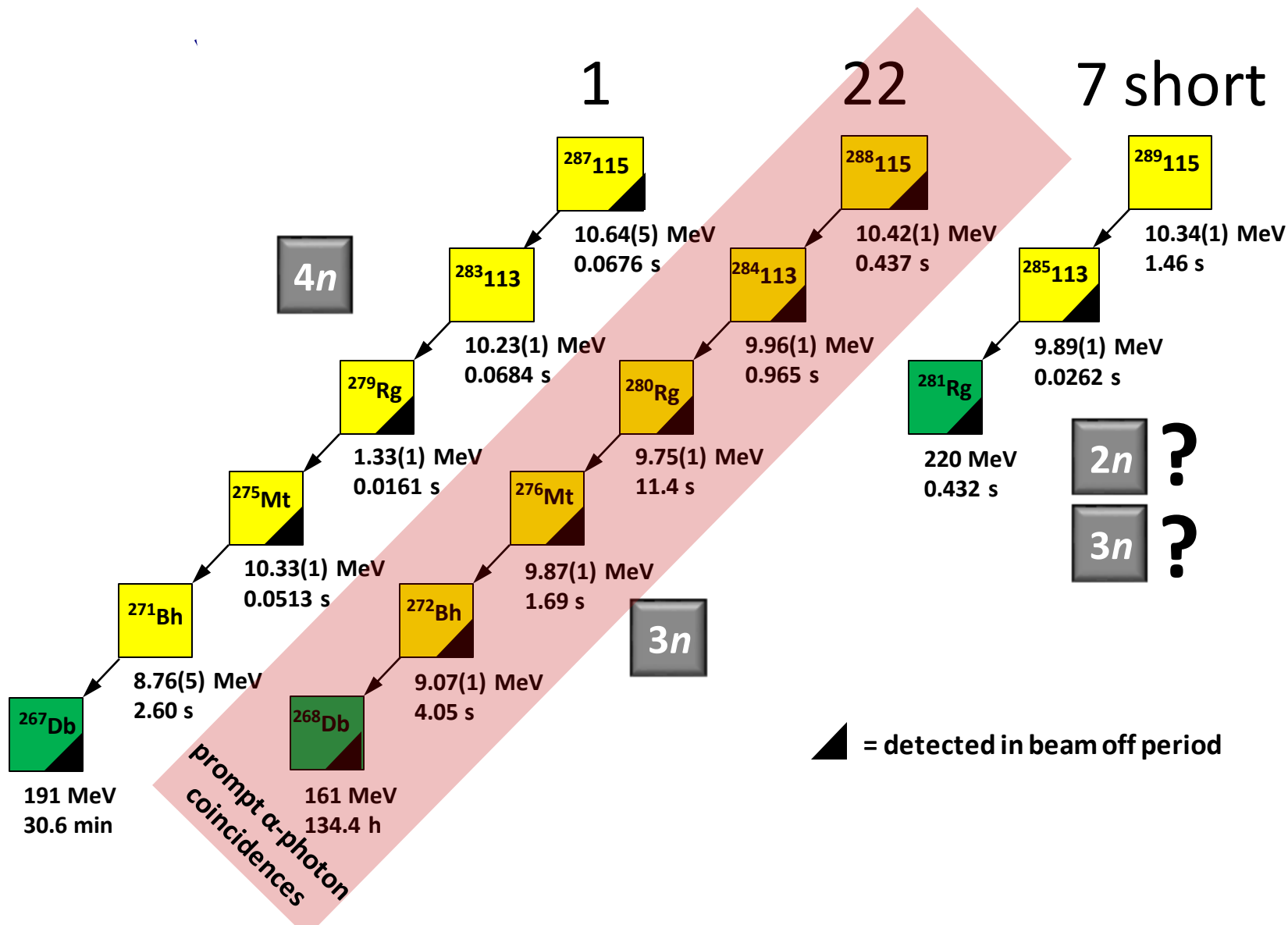
1 Implantation DSSSD (1024 pixels)
4 box-DSSSDs (1024 pixels)
=> ~80% α -detection efficiency

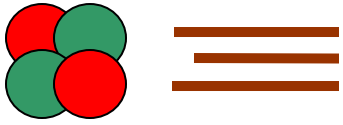
4 Ge Clover (4*4 crystals)
1 Ge Cluster (7 crystals)
=> ~40% γ -detection eff. at 150 keV

 $\equiv$ 30 chains detected in 18 days

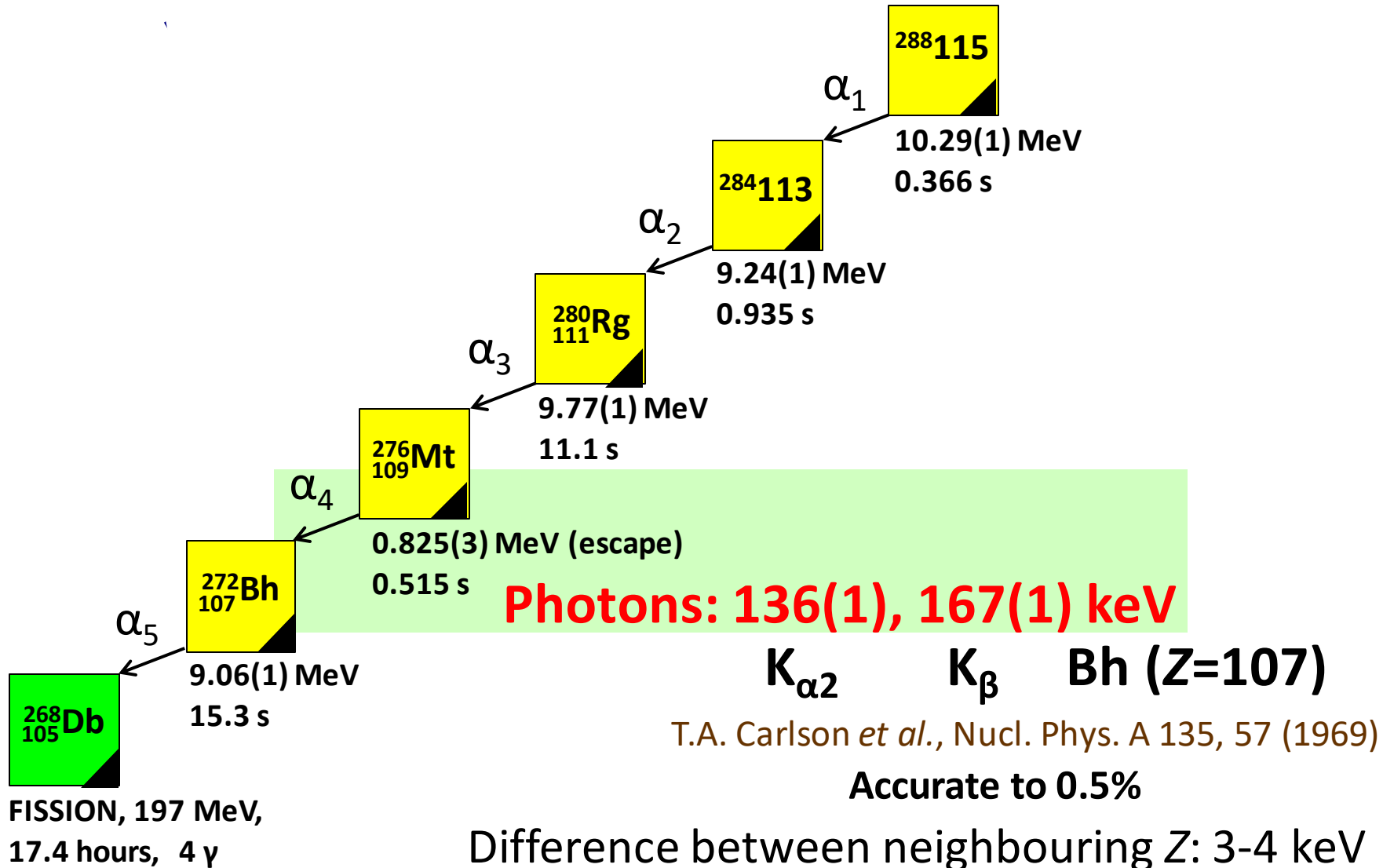


 $\equiv$ 30 chains detected in 18 days





Potential X-rays



... among the Top Ten **APS Physics Newsmakers of 2013!**

PHYSICAL REVIEW LETTERS **111, 112502 (2013)**

D. Rudolph,^{1,*} U. Forsberg,²
Ch. E. Düllmann,^{2,3,4} J. M. Gates,⁵
J. V. Kratz,⁴ K. Rykaczewski,⁶
D. Cox,⁷ X. Derkx,^{3,4} K. E.
I. Kojouharov,² N. Kurz,² B.
I. Ragnarsson,¹ J. Runke,
N. Traut



LUNDS
UNIVERSITET



HIM

⁸Advanced Science Re

²GSI Helmholtz

⁴John

⁵Lawrence

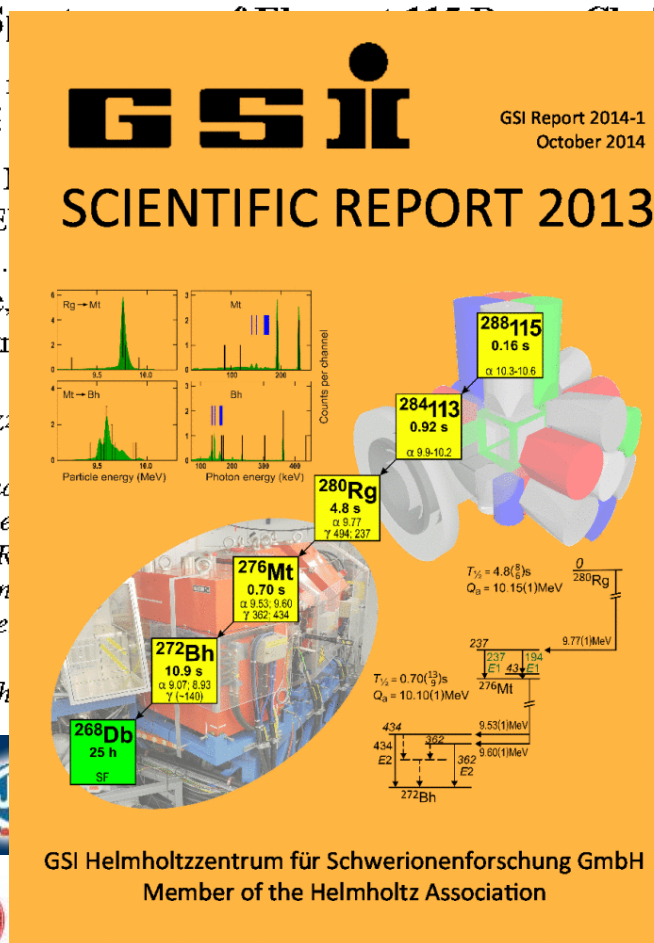
⁶Oak R

⁷Un

¹⁰Paul Sch



UNIVERSITY OF
LIVERPOOL



L. Andersson,³ A. Di Nitto,⁴
R.-D. Herzberg,⁷ J. Khuyagbaatar,³
ck,² H. Brand,² B. G. Carlsson,¹
iger,² B. Kindler,² J. Krier,²
I. P. Omtvedt,⁹ P. Papadakis,⁷
h,^{3,4} T. Torres,² T. Traut,⁴
Wiehl^{3,4}



nstadt, Germany

many

4720, USA

I, USA

dom

araki 319-1195, Japan

Switzerland

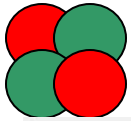
Special thanks to ...

UNILAC



ENSAR





E115 is everywhere...



element 115 bob lazar



Upload



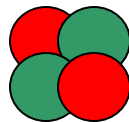
The summer of Bob Lazar - Spacing Out! Ep 58

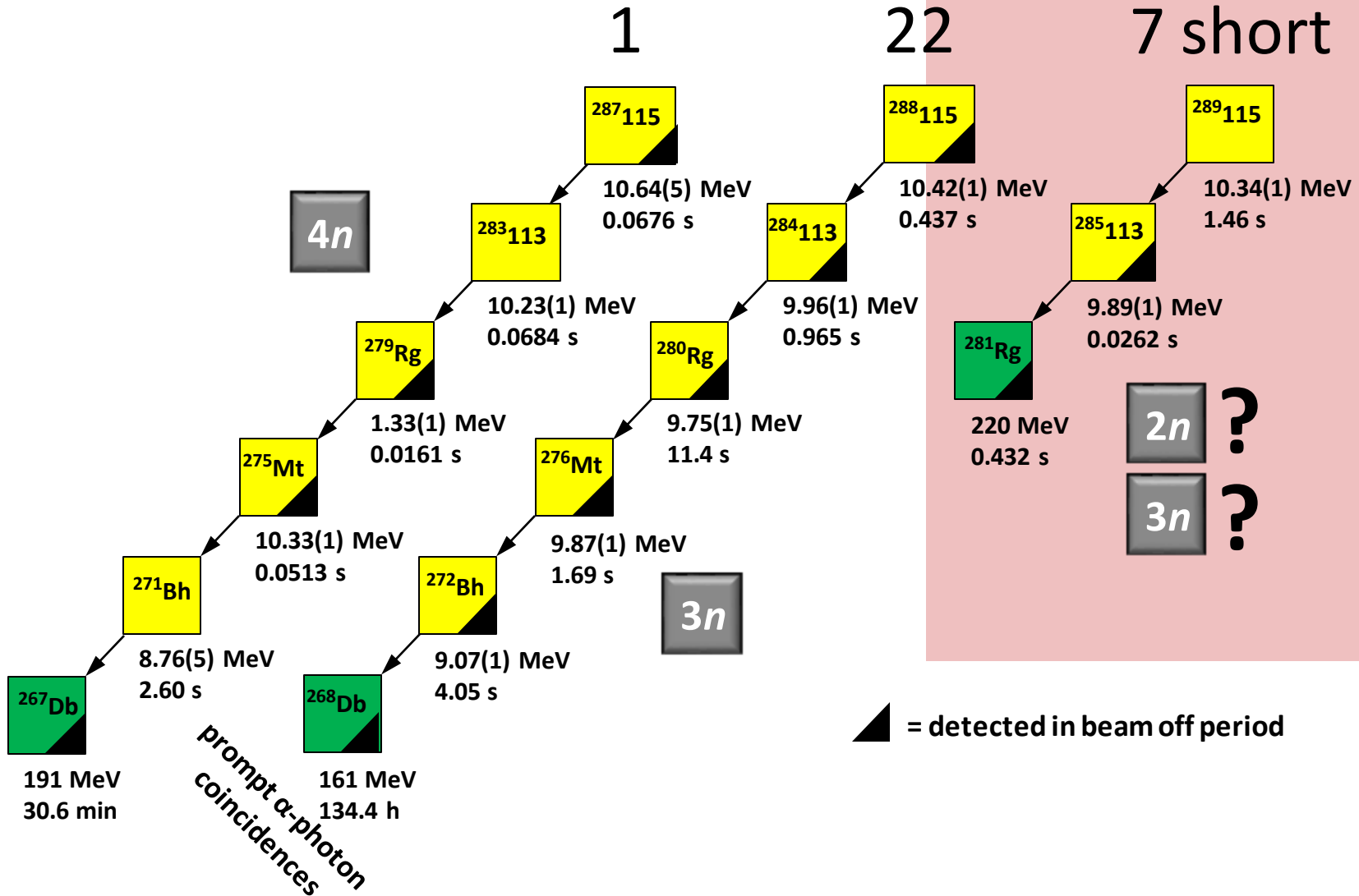


The Answer to Call of Duty Zombies - Element 115 + Orgone = Aet...



Let's Play Tomb Raider III - Part 42 - Element 115

 $\equiv$ 30 chains detected in 18 days

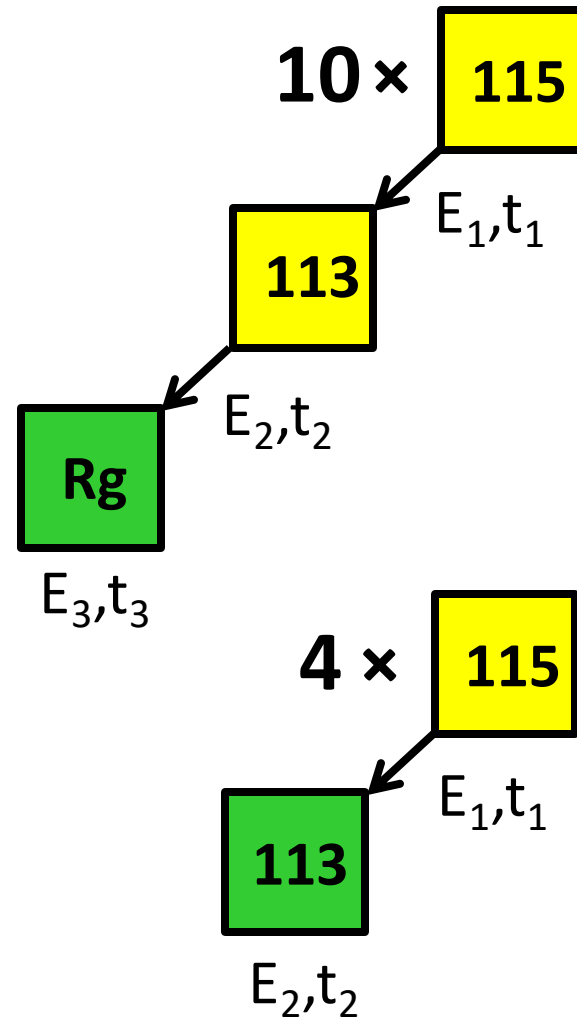


TASCA

Dubna

BGS

No.	E_1 (MeV) Δt_1 (s)	E_2 (MeV) Δt_2 (s)	E_3 (MeV) Δt_3 (s)
T1	10.51(1) 0.227	242^a 0.378	
T2	1.45(1)^b 0.0645	211 0.366	
T3	10.54(4) ^c 0.261	9.95(5)^c 1.15	196 0.343
T4	10.34(1) 1.46	9.89(1) 0.0262	218^a 0.432
T5	10.49(4)^c 0.345	9.97(1) 0.369	135 14.4
T6	10.53(1) 0.210	9.89(5)^c 1.05	230^a 8.27
T7	0.541(3)^b 0.815	3.12(1)^b 2.33	230^a 2.89
D1	10.377(62) 0.2562	9.886(62) 1.4027	215.7 1.9775
D2	10.540(123) ^c 0.0661	9.916(72) 1.5500	214.9^a 2.3638
D3	10.373(50) 2.3507	9.579(50) 22.5822	141.1 60.1855
D4	10.292(170) ^c 0.0536	10.178(55) 0.4671	182.2^a 0.0908
B1	10.49(5) 0.214	9.82(2) 1.54	107 7.57
B2	10.49(2) 0.0591	187^a 0.824	
B3	10.22(2) 0.0455	128 0.0142	

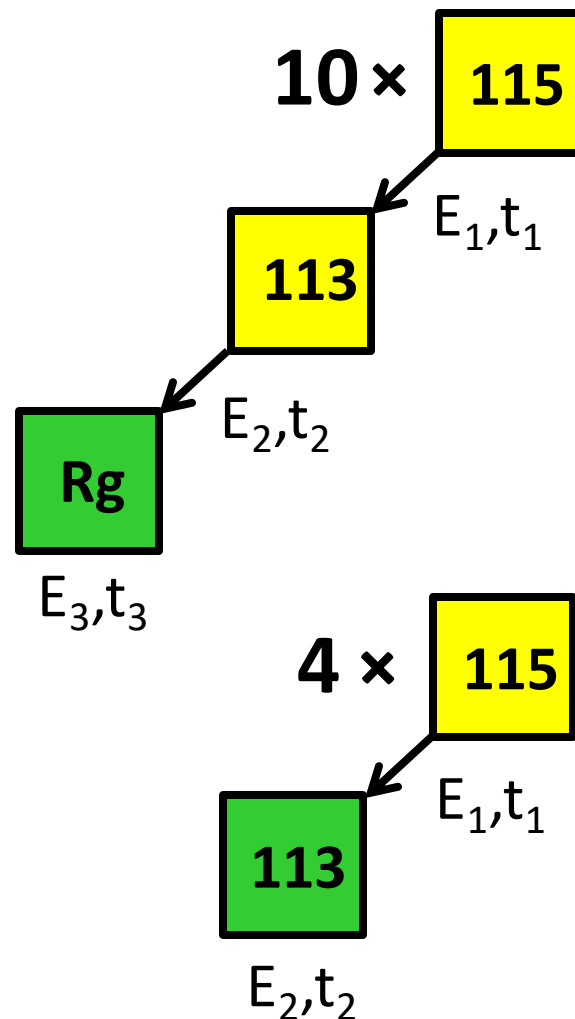


TASCA

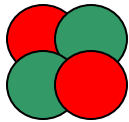
Dubna

BGS

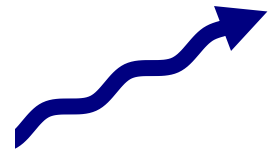
No.	E_1 (MeV) Δt_1 (s)	E_2 (MeV) Δt_2 (s)	E_3 (MeV) Δt_3 (s)
T1	10.51(1) 0.227	242 ^a 0.378	
T2	1.45(1) ^b 0.0645	211 0.366	
T3	10.54(4) ^c 0.261	9.95(5) ^c 1.15	196 0.343
T4	10.34(1) 1.46	9.89(1) 0.0262	218 ^a 0.432
T5	10.49(4) ^c 0.345	9.97(1) 0.369	135 14.4
T6	10.53(1) 0.210	9.89(5) ^c 1.05	230 ^a 8.27
T7	0.541(3) ^b 0.815	3.12(1) ^b 2.33	230 ^a 2.89
D1	10.377(62) 0.2562	9.886(62) 1.4027	215.7 1.9775
D2	10.540(123) ^c 0.0661	9.916(72) 1.5500	214.9 ^a 2.3638
D3	10.373(50) 2.3507	9.579(50) 22.5822	141.1 60.1855
D4	10.292(170) ^c 0.0536	10.178(55) 0.4671	182.2 ^a 0.0908
B1	10.49(5) 0.214	9.82(2) 1.54	107 7.57
B2	10.49(2) 0.0591	187 ^a 0.824	
B3	10.22(2) 0.0455	128 0.0142	



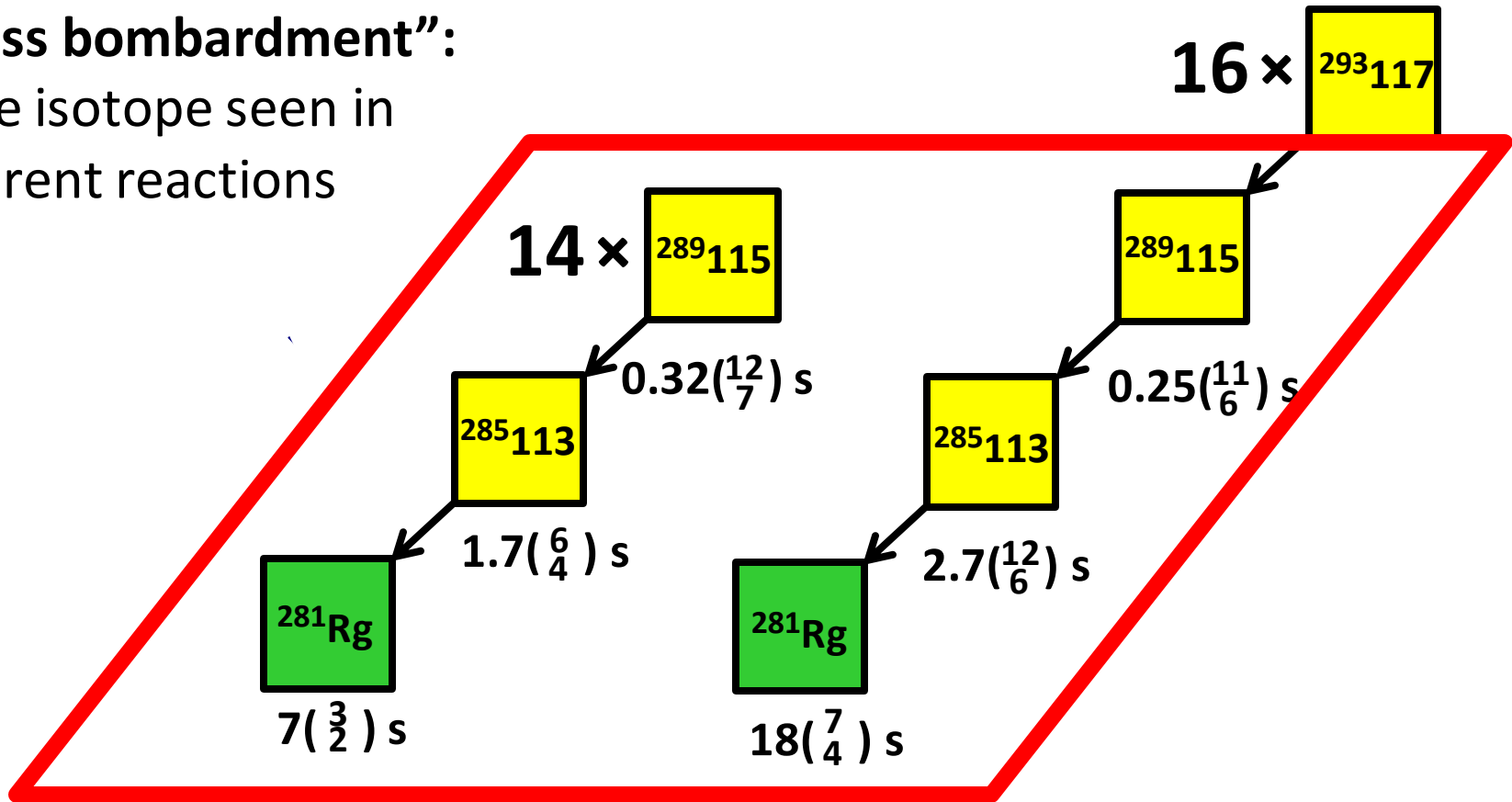
NOT a set of chains
following the same decay
path! (<1% error risk)



E115-E117



"Cross bombardment":
same isotope seen in
different reactions



NOT a set of chains following the
same decay path! ($\ll 1\%$ error risk)

IUPAC Technical Report

Paul J. Karol^{a,*}, Robert C. Barber, Bradley M. Sherrill, Emanuele Vardaci
and Toshimitsu Yamazaki

Discovery of the elements with atomic numbers $Z = 113, 115$ and 117 (IUPAC Technical Report)

DOI 10.1515/pac-2015-0502

Received December 14, 2015; accepted December 22, 2015

Abstract: The fourth IUPAC/IUPAP Joint Working Party (JWP) on the priority of claims to the discovery of new elements 113, 115, 117 and 118 has reviewed the relevant literature pertaining to several claims. In accordance with the Criteria for the discovery of elements previously established by the 1991 IUPAC/IUPAP Transfermium Working Group (TWG), and reinforced in subsequent IUPAC/IUPAP JWP discussions, it was determined that the RIKEN collaboration has fulfilled those Criteria for element $Z = 113$. The Dubna–Livermore–Oak Ridge collaborations claims for 115 and 117 are also in compliance. The discussion of element $Z = 118$ will appear in a subsequent report. A synopsis of experiments and related efforts is presented along with some commentary guiding future applications of the Criteria.

Names and Symbols of the Elements with Atomic Numbers 113, 115, 117 and 118

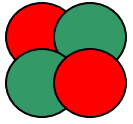
Provisional Recommendations

Abstract: A joint IUPAC/IUPAP Working Party (JWP) has confirmed the discovery of the elements with atomic numbers 113, 115, 117 and 118. In accord with IUPAC procedures, the discoverers proposed names as follows:

- * Nihonium and symbol Nh, for the element with $Z = 113$,
- * Moscovium with the symbol Mc, for the element with $Z = 115$,
- * Tennessine with the symbol Ts, for the element with $Z = 117$, and
- * Oganesson with the symbol Og, for the element with $Z = 118$.

After careful checking the Inorganic Chemistry Division recommends these proposals for acceptance and they were adopted by IUPAC by the Bureau on (*date to be inserted, after the 5 months public review*) as delegated to act by the IUPAC Council meeting on 12-13 August 2015.

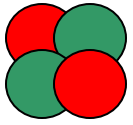
**Open for public review
until November 8 2016**



Future



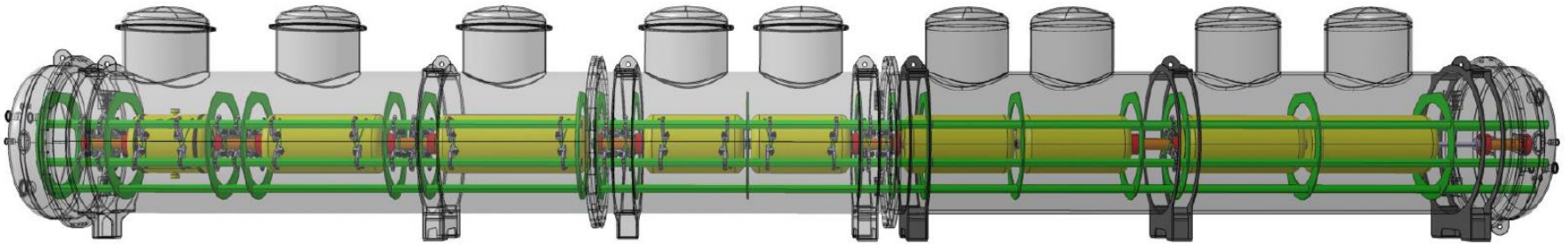
Since UNILAC is not suited for simultaneous acceleration of beams for SIS100 and SHE research...



Future



New **dedicated** sc cw LINAC is planned!

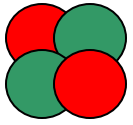


Energy: 3.5-7.5 MeV/u

Uncertainty: <3 keV/u

Duty cycle: 100%

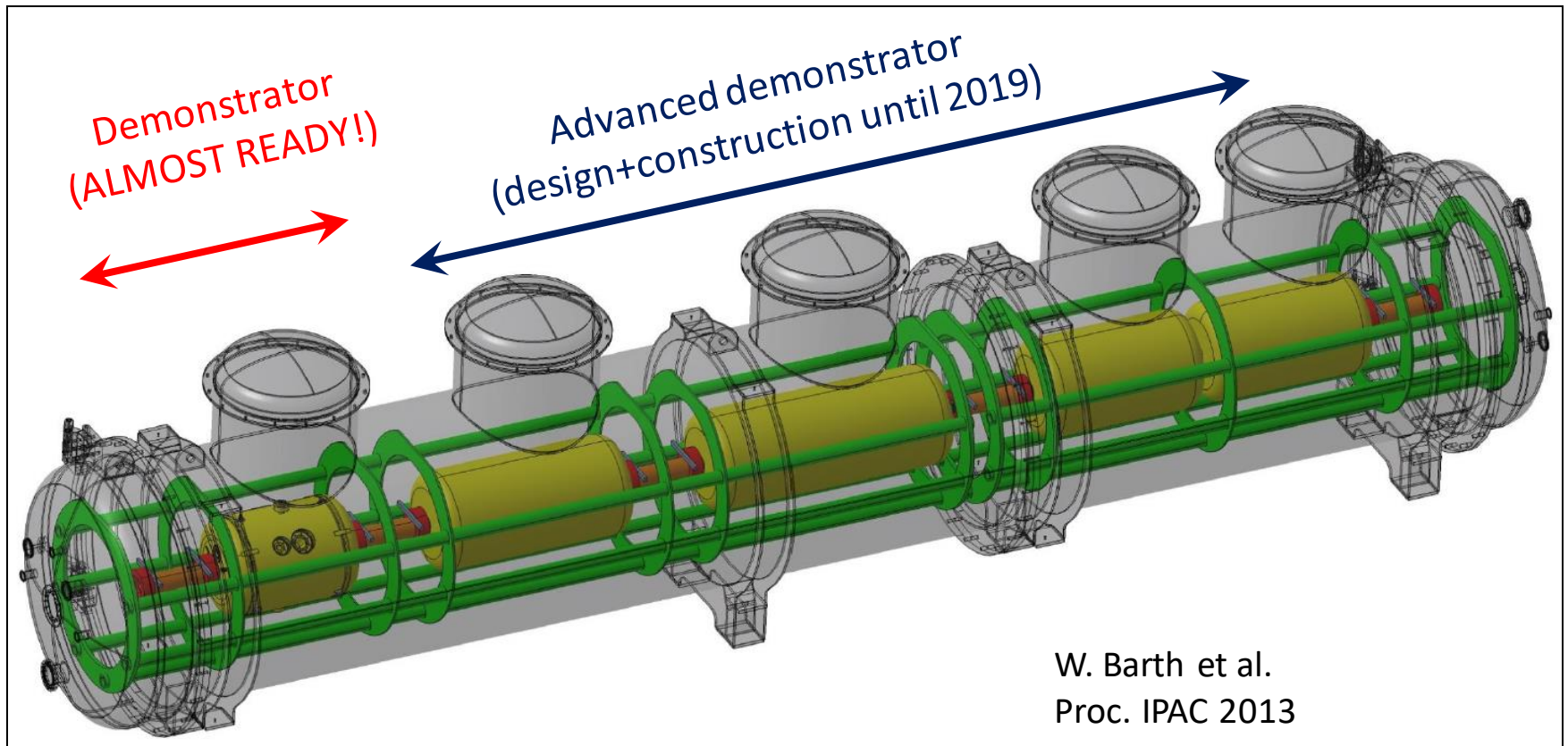
Length: 13.5 m

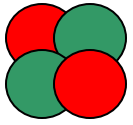


Future



Step 1: Build demonstrator unit



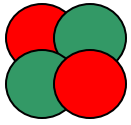


Future

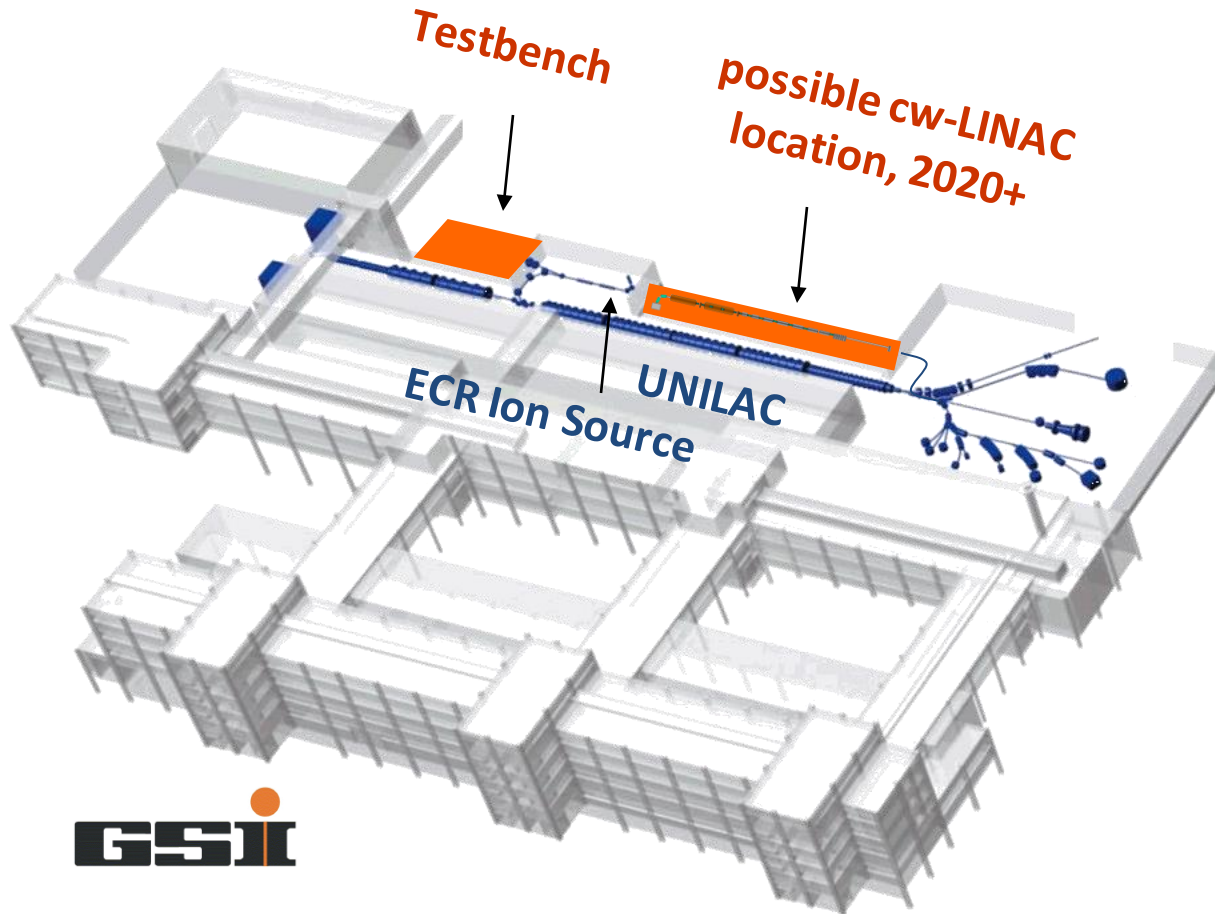


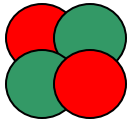
Nov. 19, 2015: Delivery of cryostat to GSI





Future





Future



Superheavy element research:

- new elements
- nuclear spectroscopy
- laser spectroscopy
- X-ray fingerprinting
- chemistry
- mass measurements
- ...



