High intensity metallic beams for superheavy elements

How to get several particle-micro amperes of metallic beams on target with MIVOC and INDUCTIVE methods?

B. JP. Gall[1], Z. Asfari[1], J. Piot[1,4], J. Rubert[1,†], H. Faure[1], D. Rouvel[1], M. Filliger[1], O. Dorvaux[1]
J. Ärje[2], H. Koivisto[2], R. Seppälä[2], P.T. Greenlees[2],
S. Bogomolov[3], V. Loginov[3], A. Bondarchenko[3], A. Yeremin[3],
F. Lemagnen[4], C. Barue[4], B. Osmond[4], P. Jardin[4],
M. Kidera[5], H. Haba[5], K Morimoto[5], K. Morita[5]

[1] Institut Pluridisciplinaire Hubert Curien, F-67037 Strasbourg, France,
[2] Department of Physics, University of Jyväskylä, FIN-40014 Jyväskylä, Finland,
[3] FLNR / JINR, Joliot-Curie 6, Dubna, Moscow region, 141980 Russia,
[4] GANIL, CEA/DSM / CNRS/IN2P3, Bd Henri Becquerel, 14076 Caen, France,
[5] Nishina Center, RIKEN, Wako-shi, Saitama 351-0198, Japan

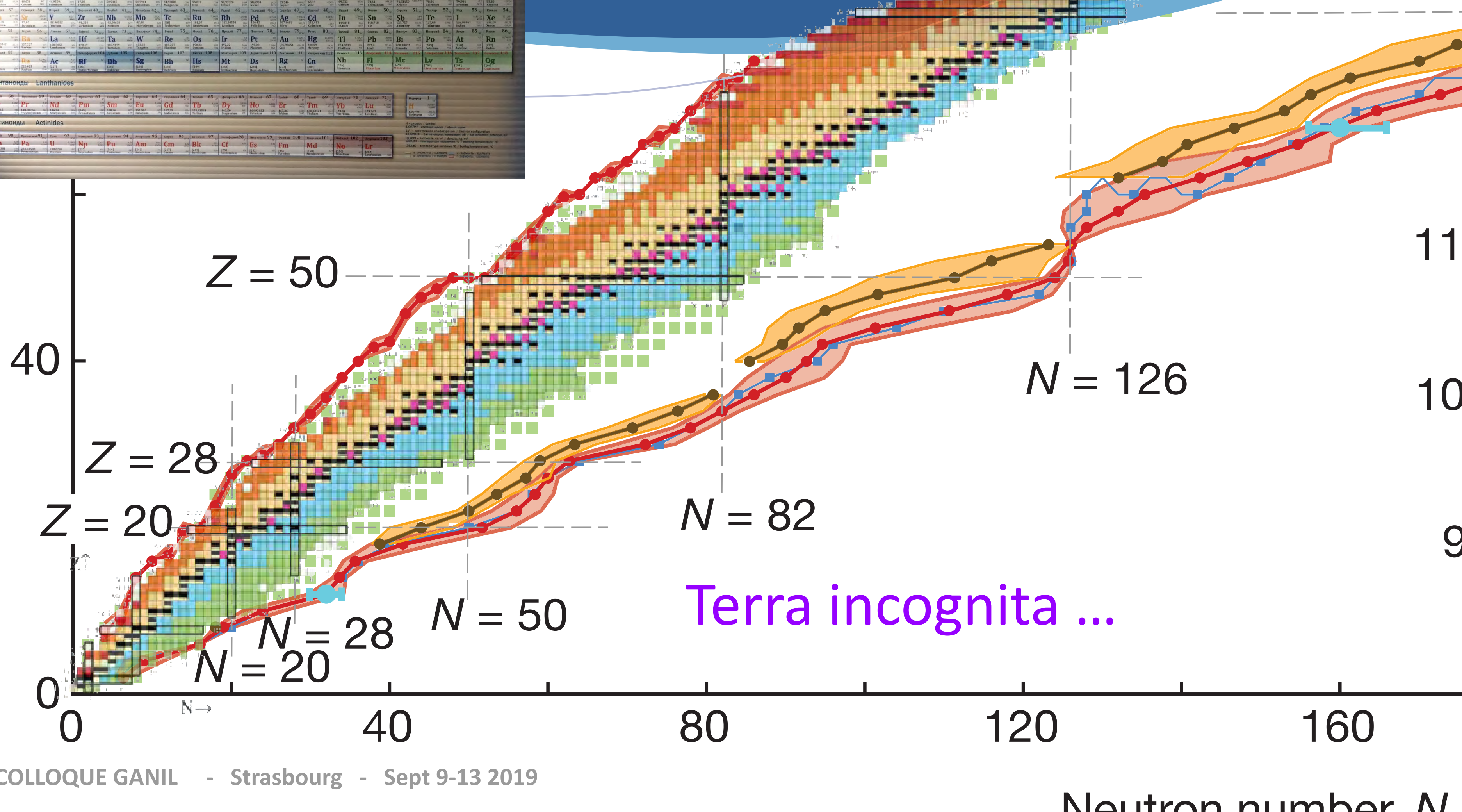
IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

cnrs dépasser les frontières

INC
INEE
IN2P3

Periodic table of elements

Our landscape …



$^{50}_{22}Ti_{28} + ^{208}_{82}Pb_{126} \Rightarrow ^{258}_{104}Rf_{154}$ (CN) $\Rightarrow ^{256}_{104}Rf_{152} + 2n$

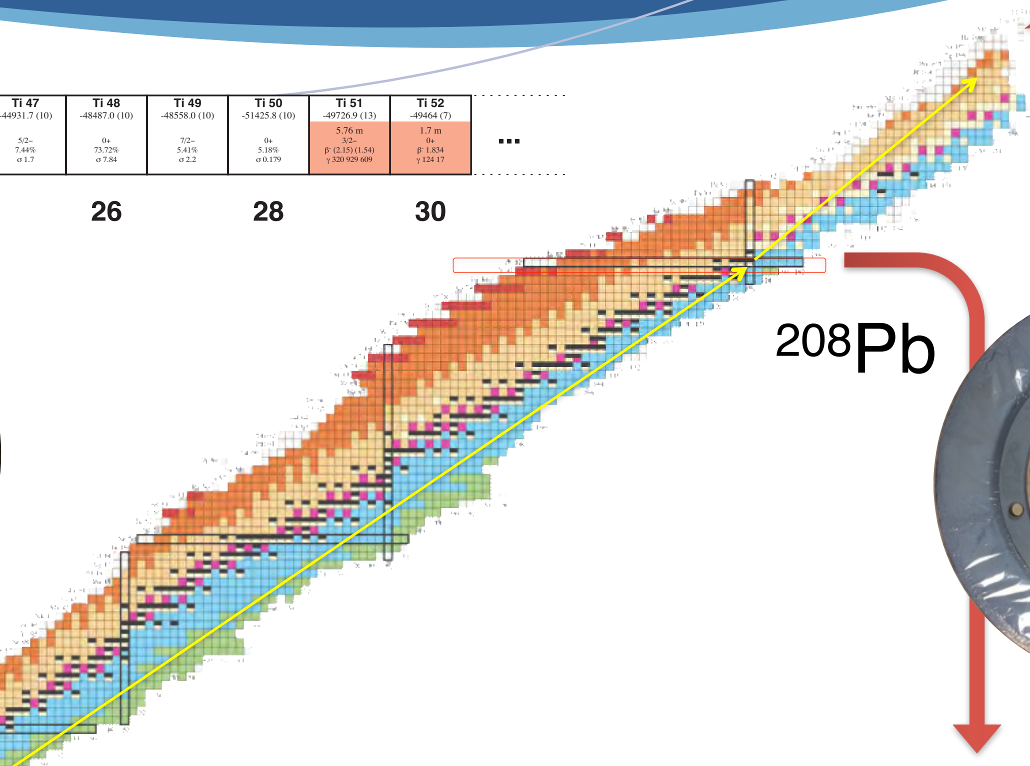
^{256}Rf

Z=22

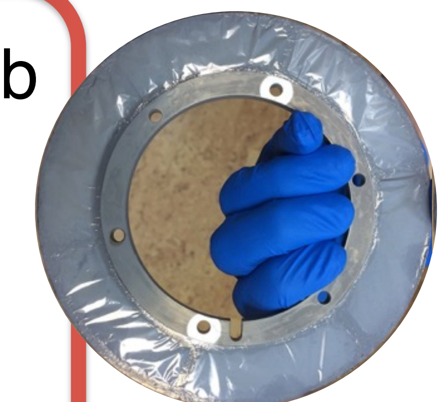
Ti	...	Ti 44	Ti 45	Ti 46	Ti 47	Ti 48	Ti 49	Ti 50	Ti 51	Ti 52	...
Titanium 47.867 σ 6.09		-37548.3 (8) 59.2 a 0+ ε γ 78* 68* 146 w σ 1.1	-39006.9 (12) 184.8 m 7/2− β⁺ 1.044 (0.32) w...,ε γ 720 1408 w 1661 w 425 w 1236 w...	-44125.3 (11) 0+ 8.25% σ 0.59	-44931.7 (10) 5/2− 7.44% σ 1.7	-48487.0 (10) 0+ 73.72% σ 7.84	-48558.0 (10) 7/2− 5.41% σ 2.2	-51425.8 (10) 0+ 5.18% σ 0.179	-49726.9 (13) 5.76 m 3/2− β⁻ (2.15) (1.54) γ 320 929 609	-49464 (7) 1.7 m 0+ β⁻ 1.834 γ 124 17	

N= 22 24 26 28 30

^{50}Ti



^{208}Pb

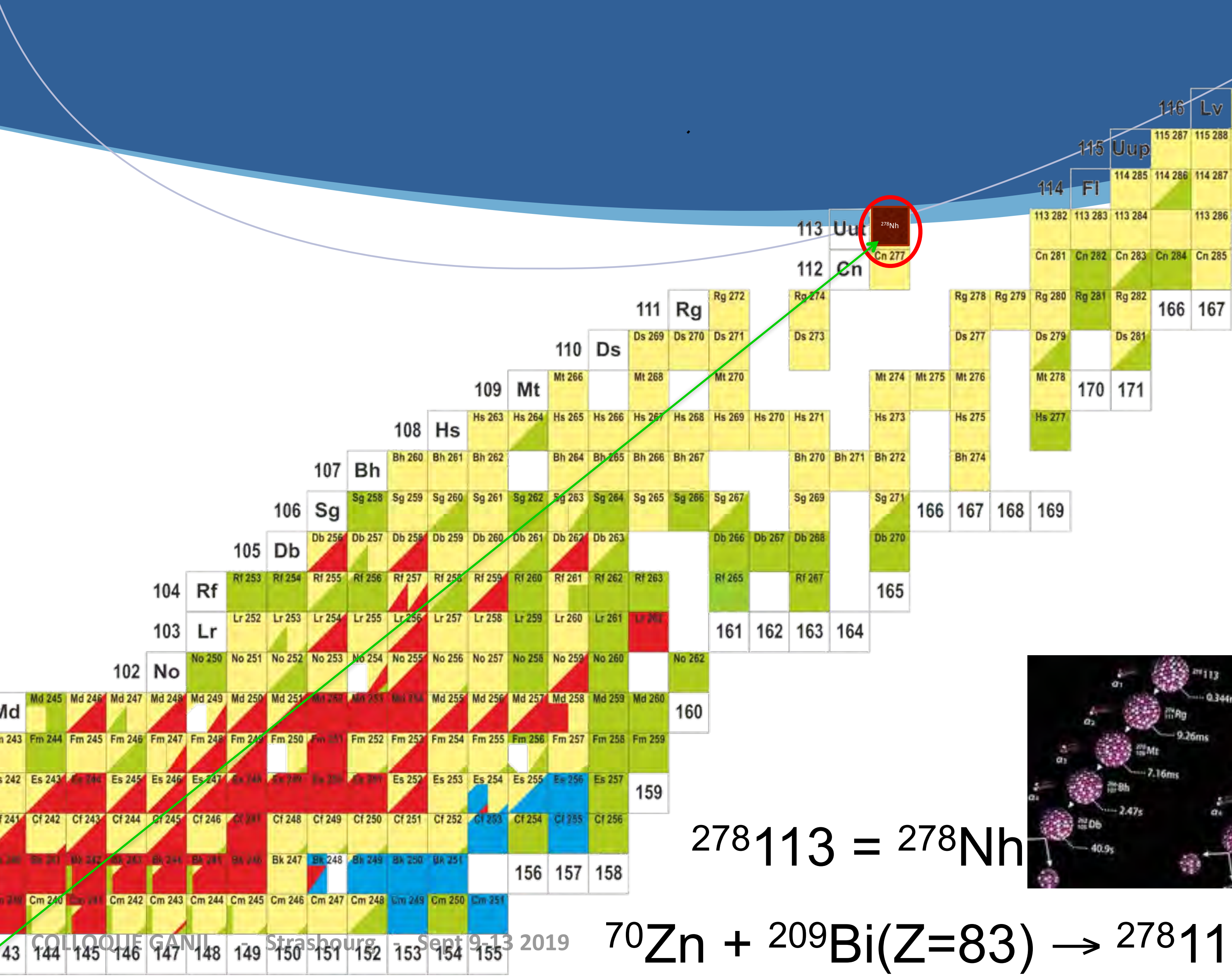


Z=82

Pb	...	Pb 202	Pb 203	Pb 204	Pb 205	Pb 206	Pb 207	Pb 208	Pb 209	Pb 210	...
Lead 207.2 σ 0.171		-25948 (10) 3.53 h 9− ↓ 961 422 787... ε γ 490 460 390 241... 52.5E3 a 0+ ε no γ	-24801 (7) 480ms 29/2− ↓ 839 258 874 634 1027... 6.3 s 13/2+ ↓ 825 820 5 ? vw 51.87h 5/2− ε γ 279 401 681	-25123.5 (29) 1.120 h 9− ↓ 899 912 375 622 289... ≥ 1.4E17 a 0+ 1.4% σ 661 mb	-23783.7 (29) 5.54 ms 13/2+ ↓ 26 e⁻ 988 284 703 310 1014... 1.53E7 a 5/2− ε no γ	-23800.6 (29) 0+ 24.1% σ 6.3 mb +26.6 mb	-22467.1 (29) 806 ms 13/2+ ↓ 570 1064 1/2− 22.1% σ 610 mb	-21763.6 (29) 0+ 52.4% σ 230 μb $σ_α$ 8 μb	-17629 (3) 3.253 h 9/2+ β⁻ 0.6446 no γ	-14743 (3) 22.3 a 0+ β⁻ 0.0170 0.0610 γ 47 e⁻ α 3.72 vw σ 0.5	

N= 120 122 124 126 128

Cold fusion $^{208}Pb/^{209}Bi$



$^{278}113 = ^{278}Nh$

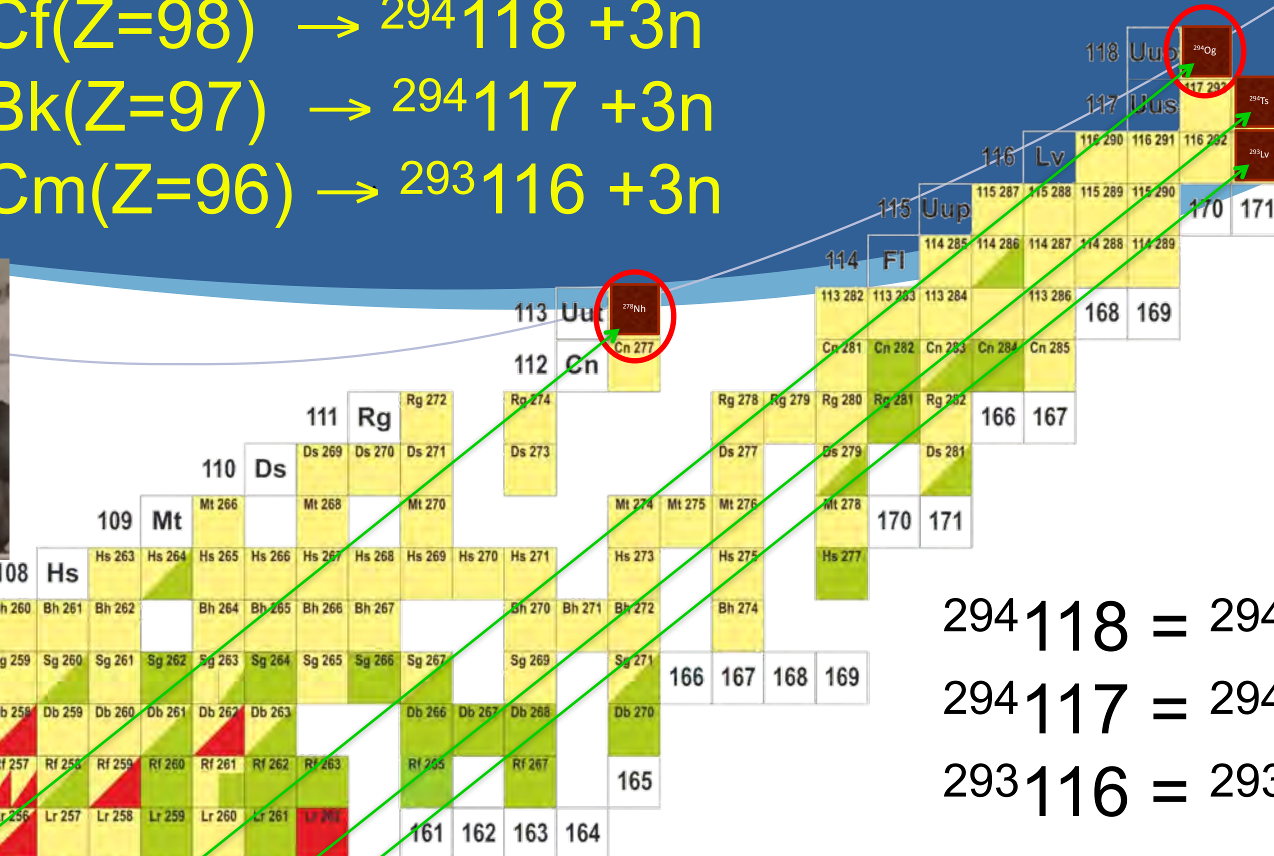
$$^{70}Zn + ^{209}Bi(Z=83) \rightarrow ^{278}113 + 1n$$

Cold fusion $^{208}Pb/^{209}Bi$ / hot fusion ^{48}Ca

$^{48}Ca + ^{249}Cf(Z=98) \rightarrow ^{294}118 + 3n$

$^{48}Ca + ^{249}Bk(Z=97) \rightarrow ^{294}117 + 3n$

$^{48}Ca + ^{248}Cm(Z=96) \rightarrow ^{293}116 + 3n$

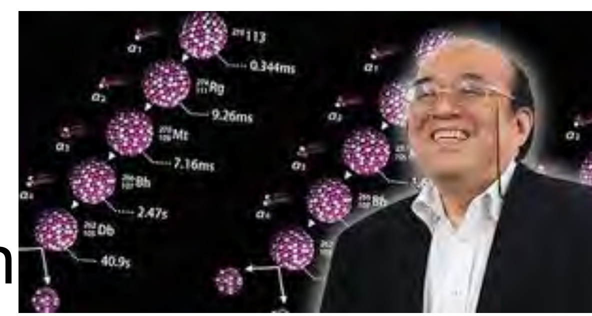


$^{294}118 = ^{294}Og$

$^{294}117 = ^{294}Ts$

$^{293}116 = ^{293}Lv$

$^{278}113 = ^{278}Nh$

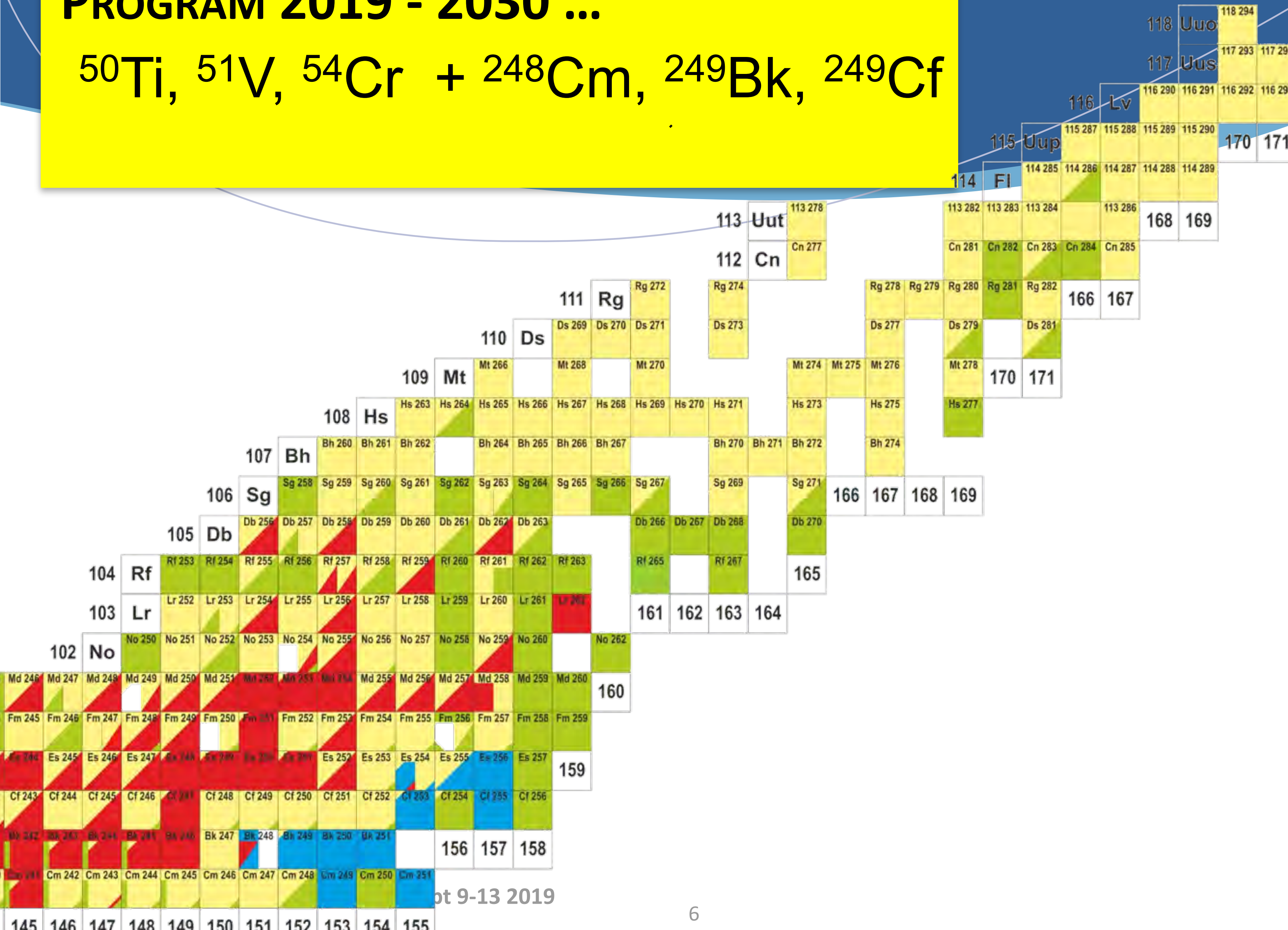


$^{70}Zn + ^{209}Bi(Z=83) \rightarrow ^{278}113 + 1n$

New beams for SHE... ^{50}Ti, ^{51}V, ^{54}Cr

PROGRAM 2019 - 2030 …

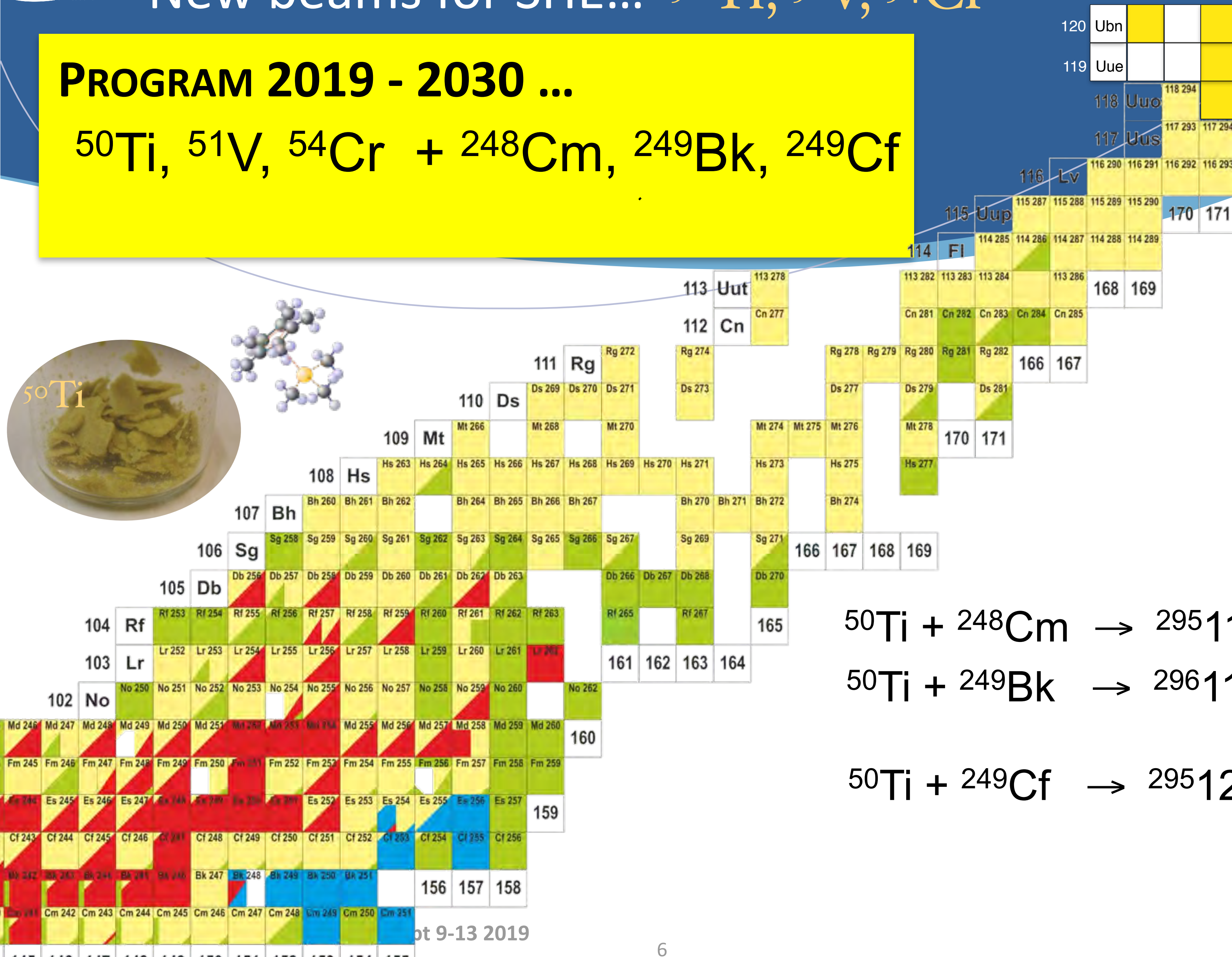
^{50}Ti, ^{51}V, ^{54}Cr + ^{248}Cm, ^{249}Bk, ^{249}Cf



New beams for SHE… ^{50}Ti, ^{51}V, ^{54}Cr

PROGRAM 2019 - 2030 …

^{50}Ti, ^{51}V, ^{54}Cr + ^{248}Cm, ^{249}Bk, ^{249}Cf



^{50}Ti + ^{248}Cm → ^{295}118 +3n

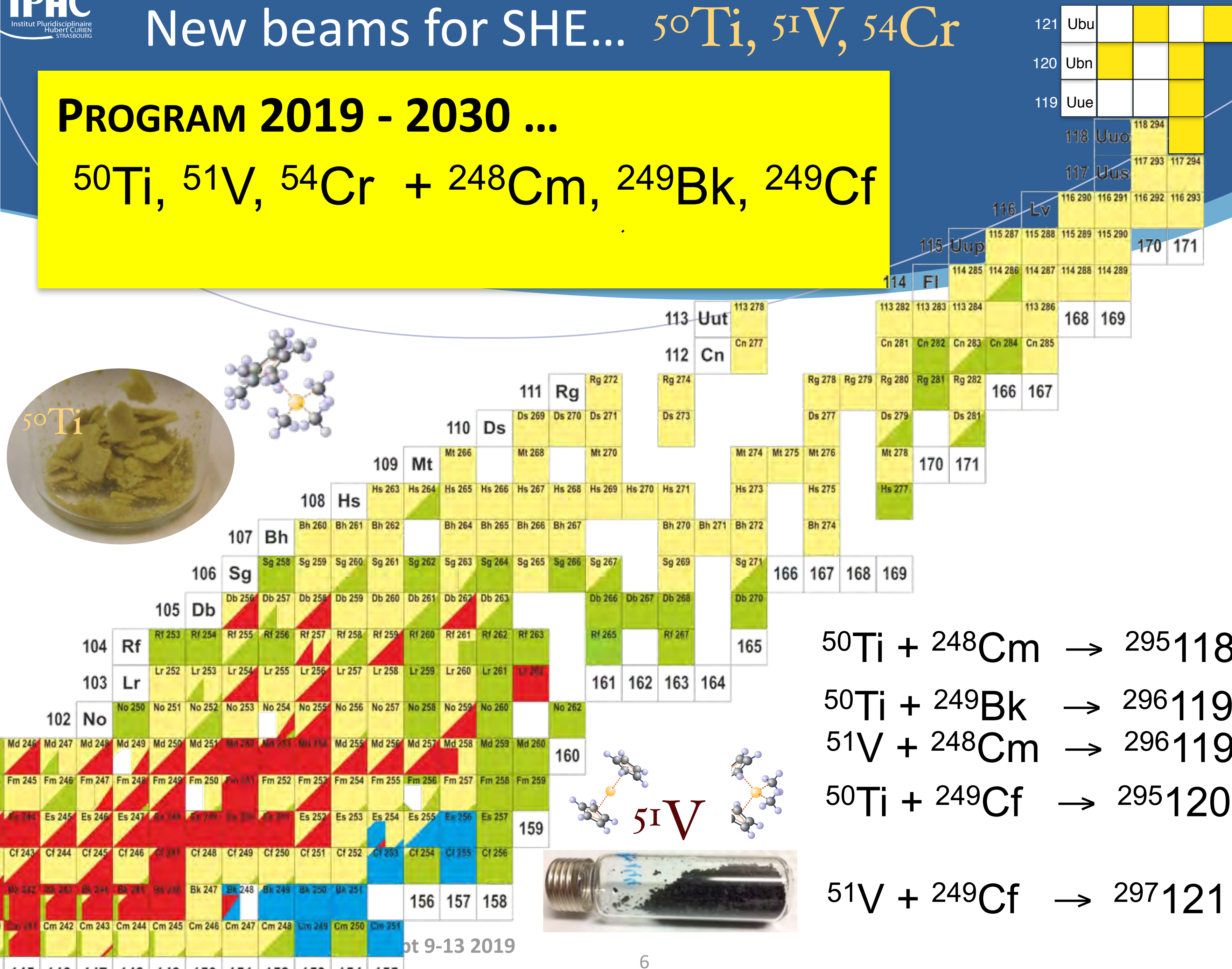
^{50}Ti + ^{249}Bk → ^{296}119 +3n

^{50}Ti + ^{249}Cf → ^{295}120 +4n

New beams for SHE… ^{50}Ti, ^{51}V, ^{54}Cr

PROGRAM 2019 - 2030 …

^{50}Ti, ^{51}V, ^{54}Cr + ^{248}Cm, ^{249}Bk, ^{249}Cf



^{50}Ti + ^{248}Cm → ^{295}118 +3n

^{50}Ti + ^{249}Bk → ^{296}119 +3n

^{51}V + ^{248}Cm → ^{296}119 +3n

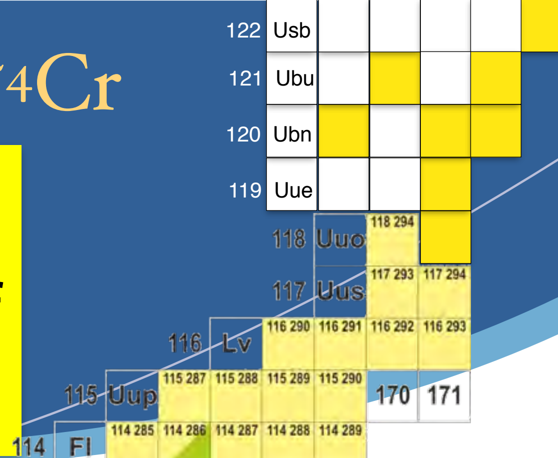
^{50}Ti + ^{249}Cf → ^{295}120 +4n

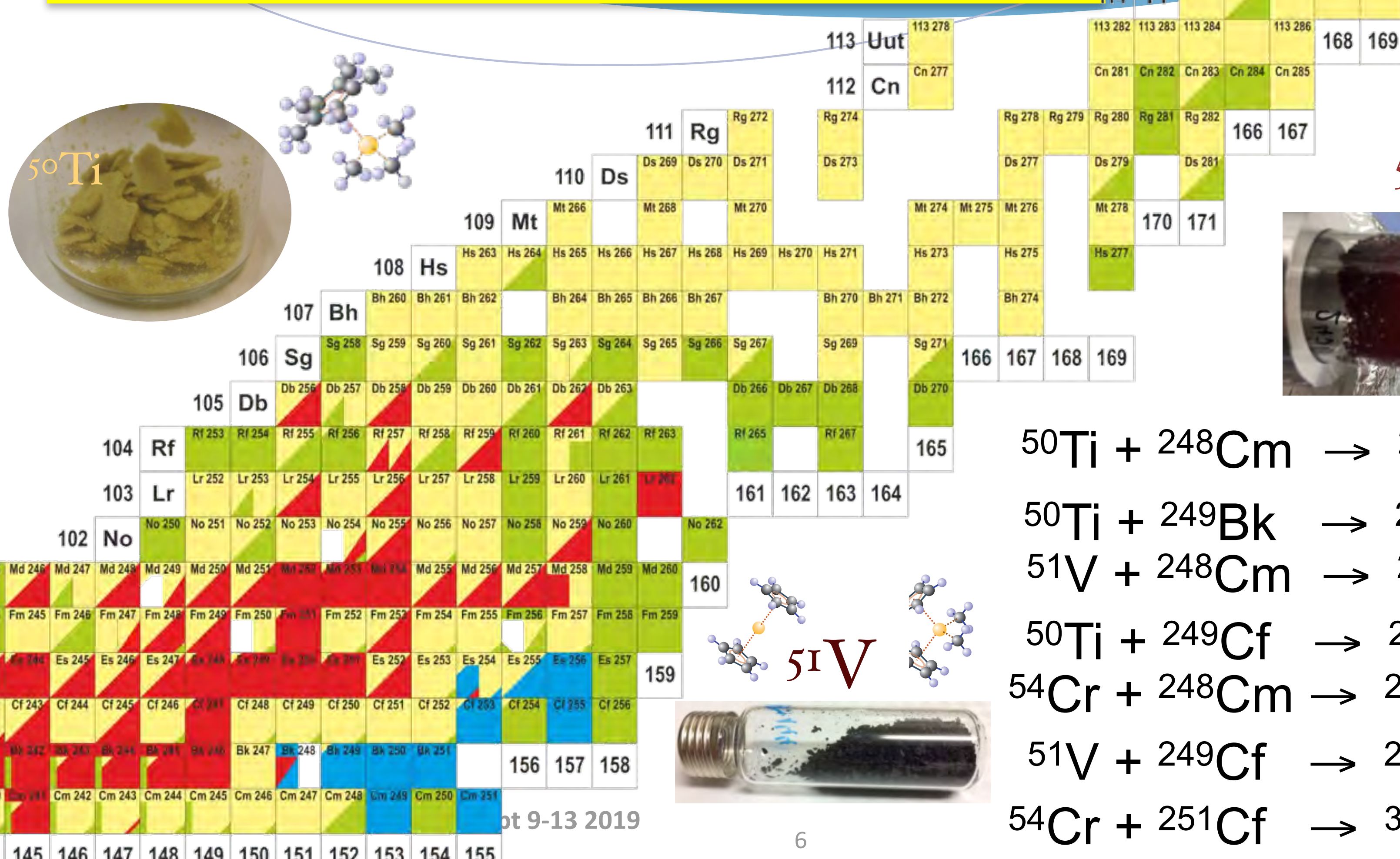
^{51}V + ^{249}Cf → ^{297}121 +3n

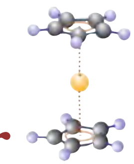
New beams for SHE… ^{50}Ti, ^{51}V, ^{54}Cr

PROGRAM 2019 - 2030 …

^{50}Ti, ^{51}V, ^{54}Cr + ^{248}Cm, ^{249}Bk, ^{249}Cf







54Cr

^{50}Ti + ^{248}Cm → ^{295}118 +3n

^{50}Ti + ^{249}Bk → ^{296}119 +3n

^{51}V + ^{248}Cm → ^{296}119 +3n

^{50}Ti + ^{249}Cf → ^{295}120 +4n

^{54}Cr + ^{248}Cm → ^{298}120 +4n

^{51}V + ^{249}Cf → ^{297}121 +3n

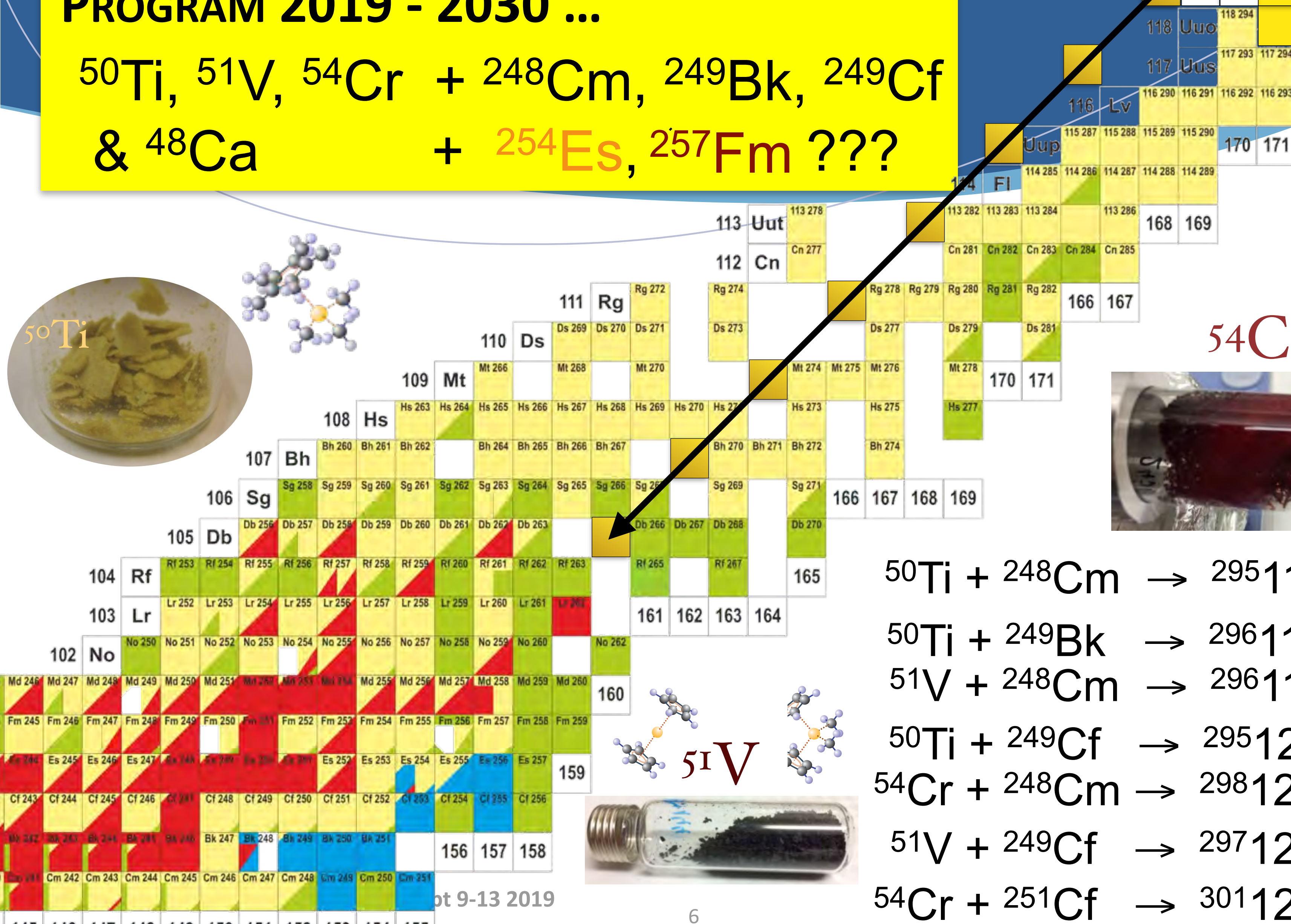
^{54}Cr + ^{251}Cf → ^{301}122 +4n

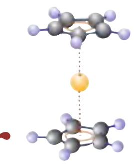
New beams for SHE... ^{50}Ti, ^{51}V, ^{54}Cr

PROGRAM 2019 - 2030 ...

^{50}Ti, ^{51}V, ^{54}Cr + ^{248}Cm, ^{249}Bk, ^{249}Cf

& ^{48}Ca + ^{254}Es, ^{257}Fm ???





^{50}Ti + ^{248}Cm → ^{295}118 +3n

^{50}Ti + ^{249}Bk → ^{296}119 +3n

^{51}V + ^{248}Cm → ^{296}119 +3n

^{50}Ti + ^{249}Cf → ^{295}120 +4n

^{54}Cr + ^{248}Cm → ^{298}120 +4n

^{51}V + ^{249}Cf → ^{297}121 +3n

^{54}Cr + ^{251}Cf → ^{301}122 +4n

What about cross sections ?

With ^{50}Ti, ^{51}V, ^{52,54}Cr

Cross sections are coming down …

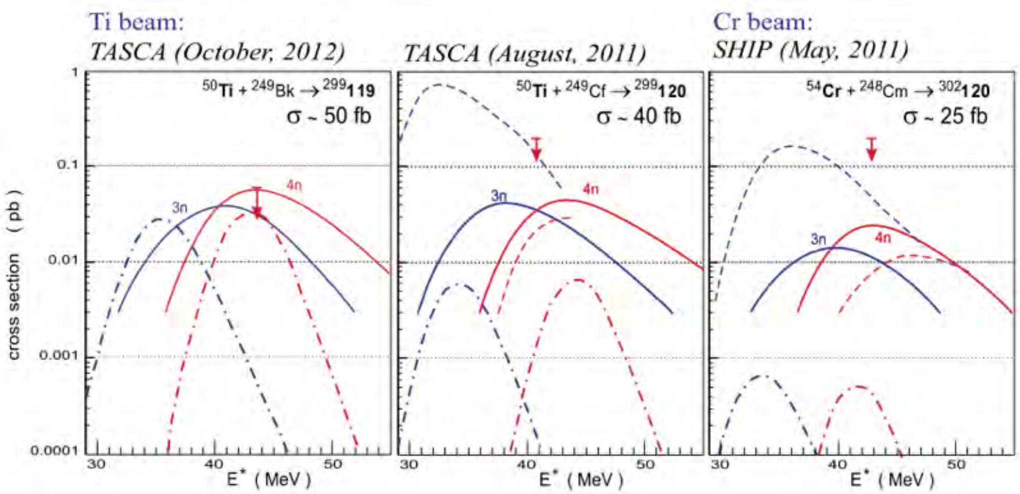
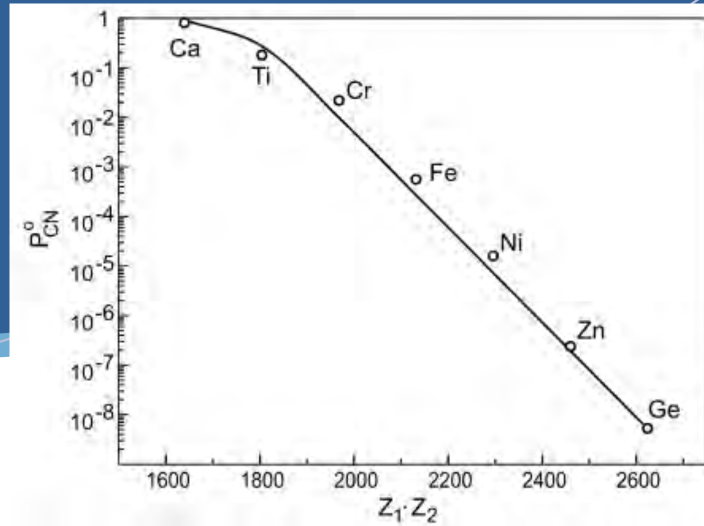


Fig. 31. Cross sections for the production of new elements 119 and 120 in the Ti and Cr induced fusion reactions predicted within the described above model (solid curves [71]) and by the "fusion-by-diffusion" model (dashed curves [91]). The latest calculations within the "fusion-by-diffusion" model [92] are shown by dash-dotted curves. The arrows indicate the upper limits reached in the corresponding experiments performed at GSI [93,94].



Zagrebaev V.I. et al., Nucl. Phys. A 944 (2015) 257-307

What about cross sections ?

With ^{50}Ti, ^{51}V, ^{52,54}Cr

Cross sections are coming down …

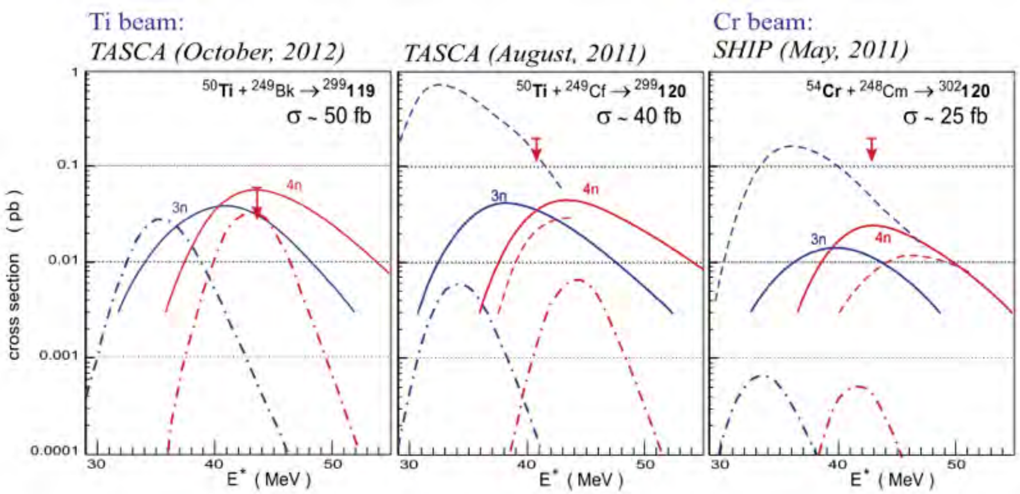
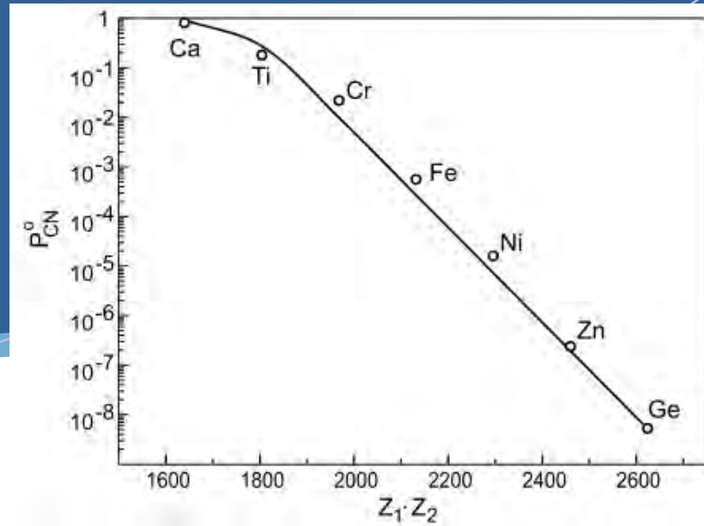


Fig. 31. Cross sections for the production of new elements 119 and 120 in the Ti and Cr induced fusion reactions predicted within the described above model (solid curves [71]) and by the "fusion-by-diffusion" model (dashed curves [91]). The latest calculations within the "fusion-by-diffusion" model [92] are shown by dash-dotted curves. The arrows indicate the upper limits reached in the corresponding experiments performed at GSI [93,94].



Zagrebaev V.I. et al., Nucl. Phys. A 944 (2015) 257-307

Need an increase by a factor of 10-20 for these very intense beams !

… and also target that sustain 5 - 10pμA

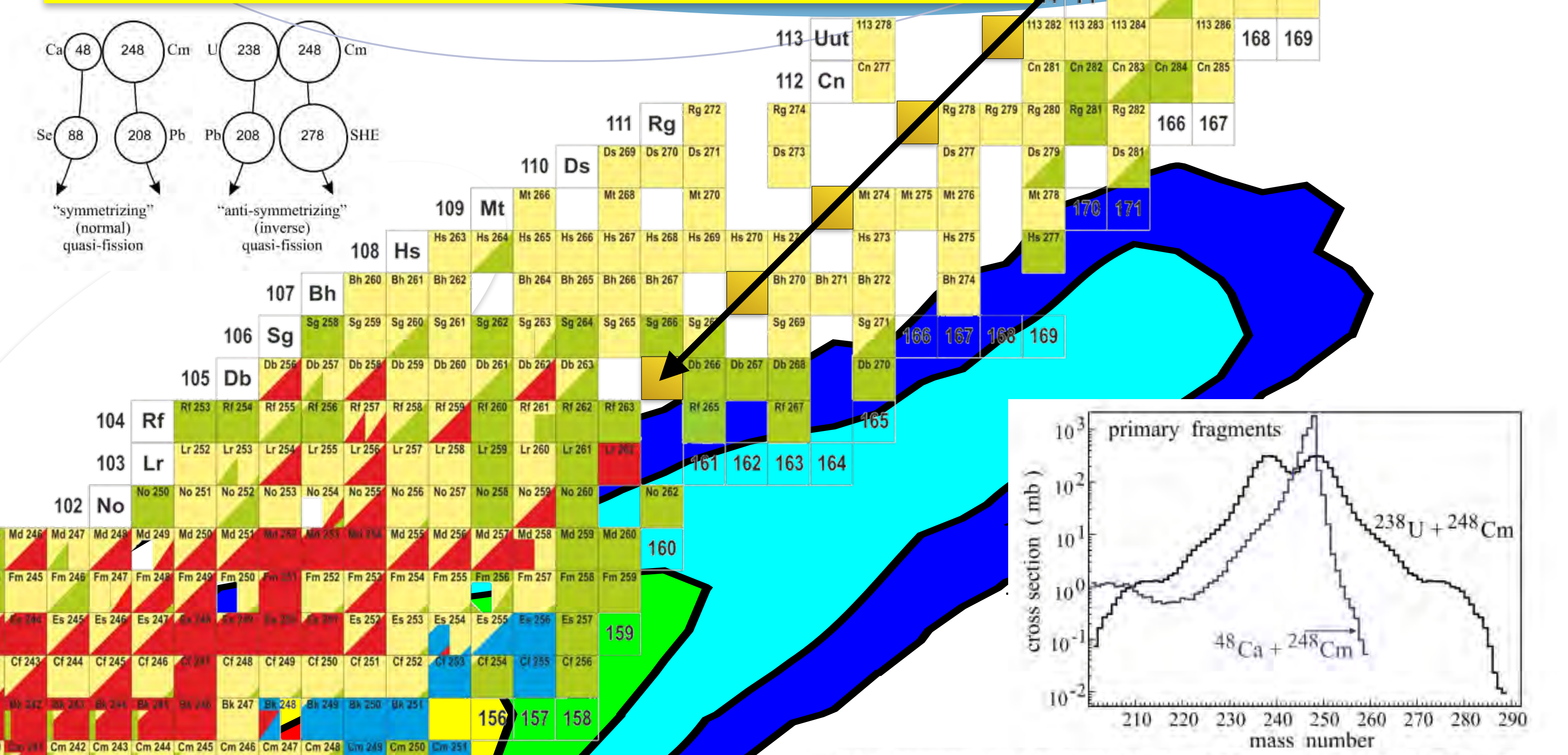
5 pμA x 30 MeV energy loss = 150W in beam spot !

New beams for SHE… ^{238}U…

PROGRAM 2019 - 2030 …

$^{238}U + ^{248}Cm$

(multinucleon transf.)



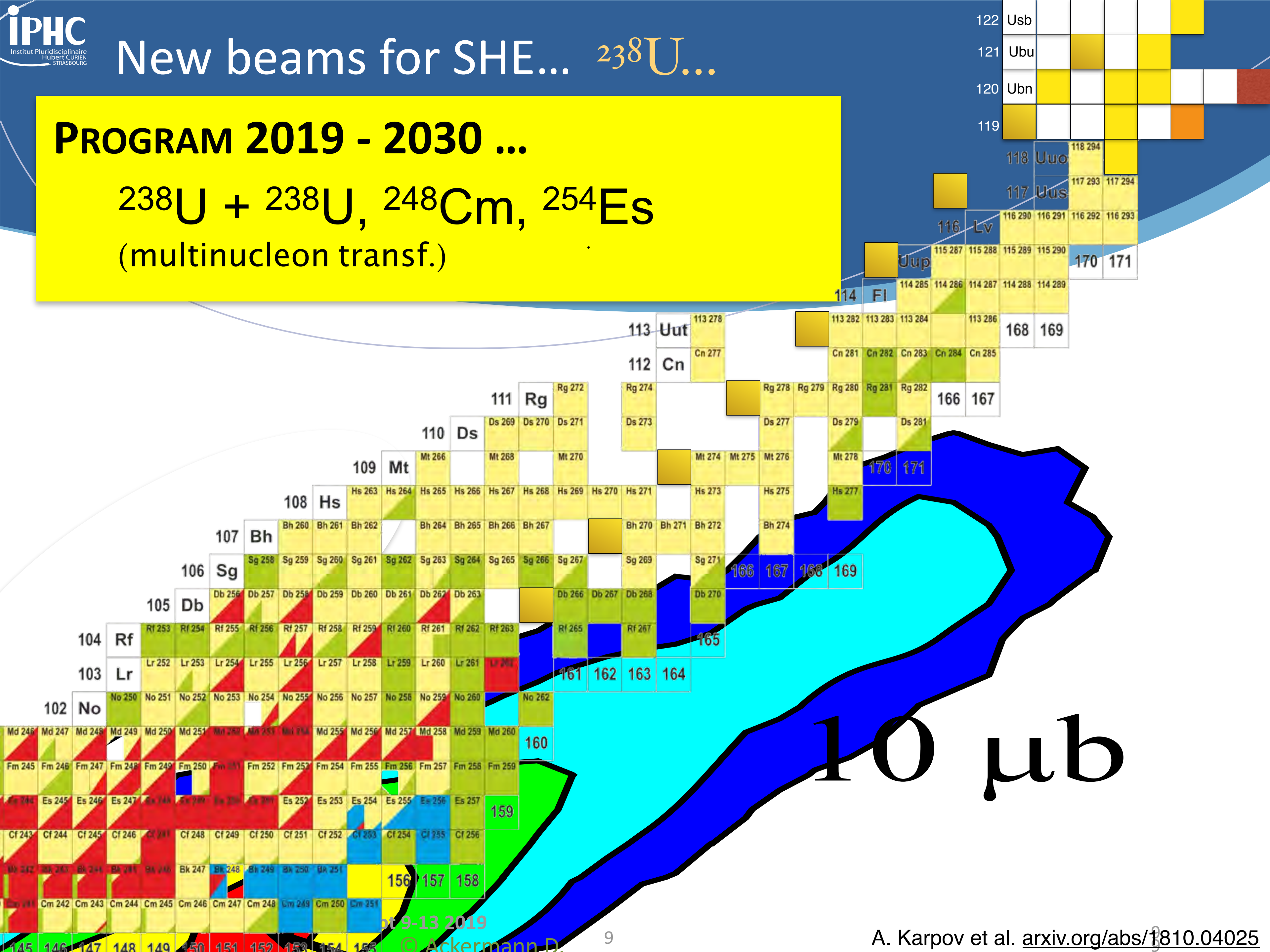
V.I. Zagrebaev, W. Greiner / Nuclear Physics A 944 (2015) 257–307

New beams for SHE… ^{238}U…

Program 2019 - 2030 …

$^{238}U + {}^{238}U, {}^{248}Cm, {}^{254}Es$

(multinucleon transf.)



A. Karpov et al. arxiv.org/abs/1810.04025

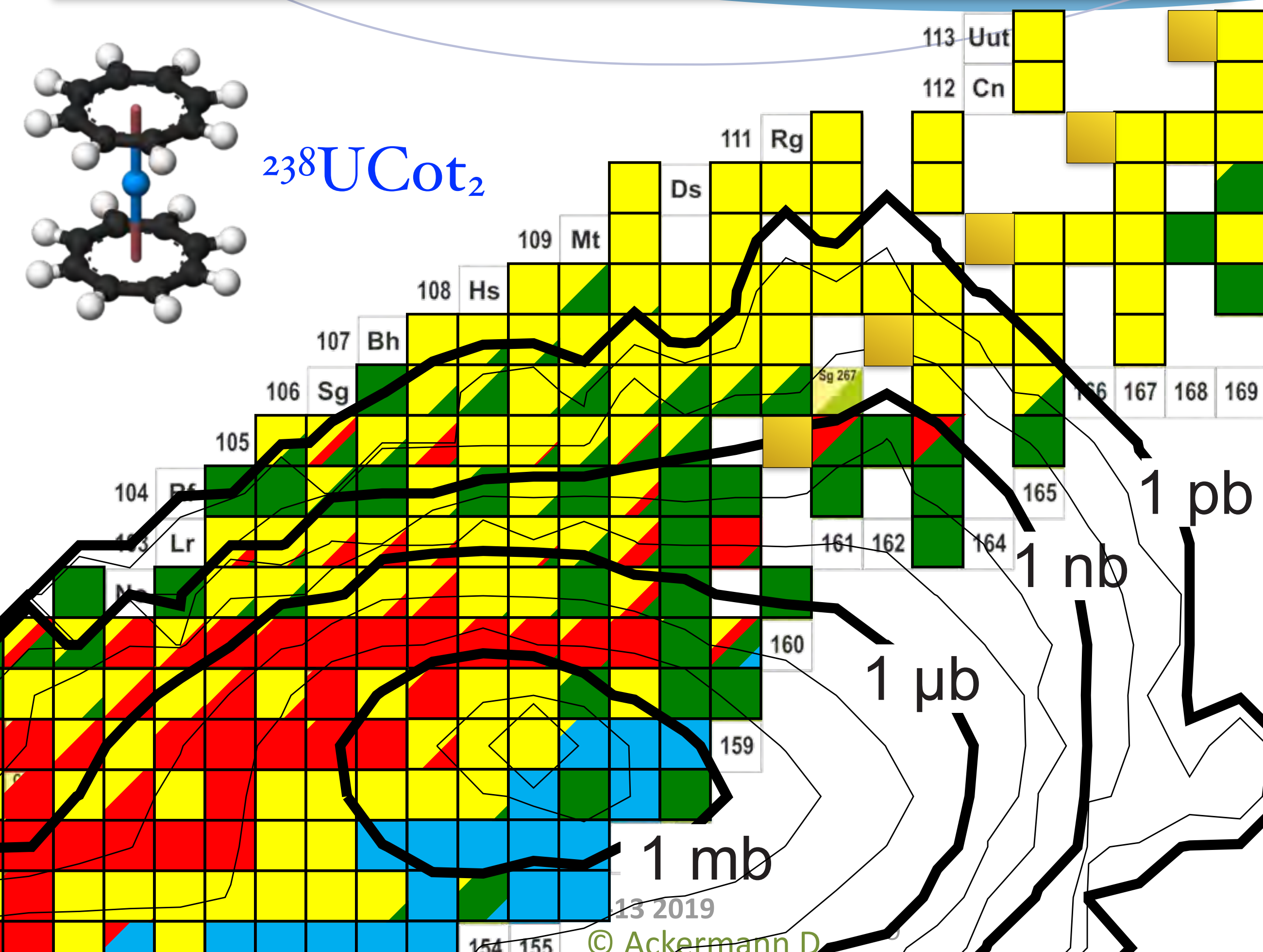
New beams for SHE... ^{238}U...

PROGRAM 2019 - 2030 ...

$^{238}U + ^{238}U, ^{248}Cm, ^{254}Es$

(multinucleon transf.)

$^{238}UCot_2$



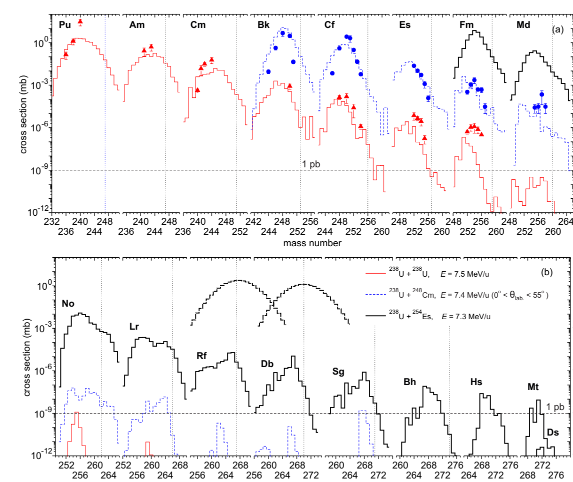


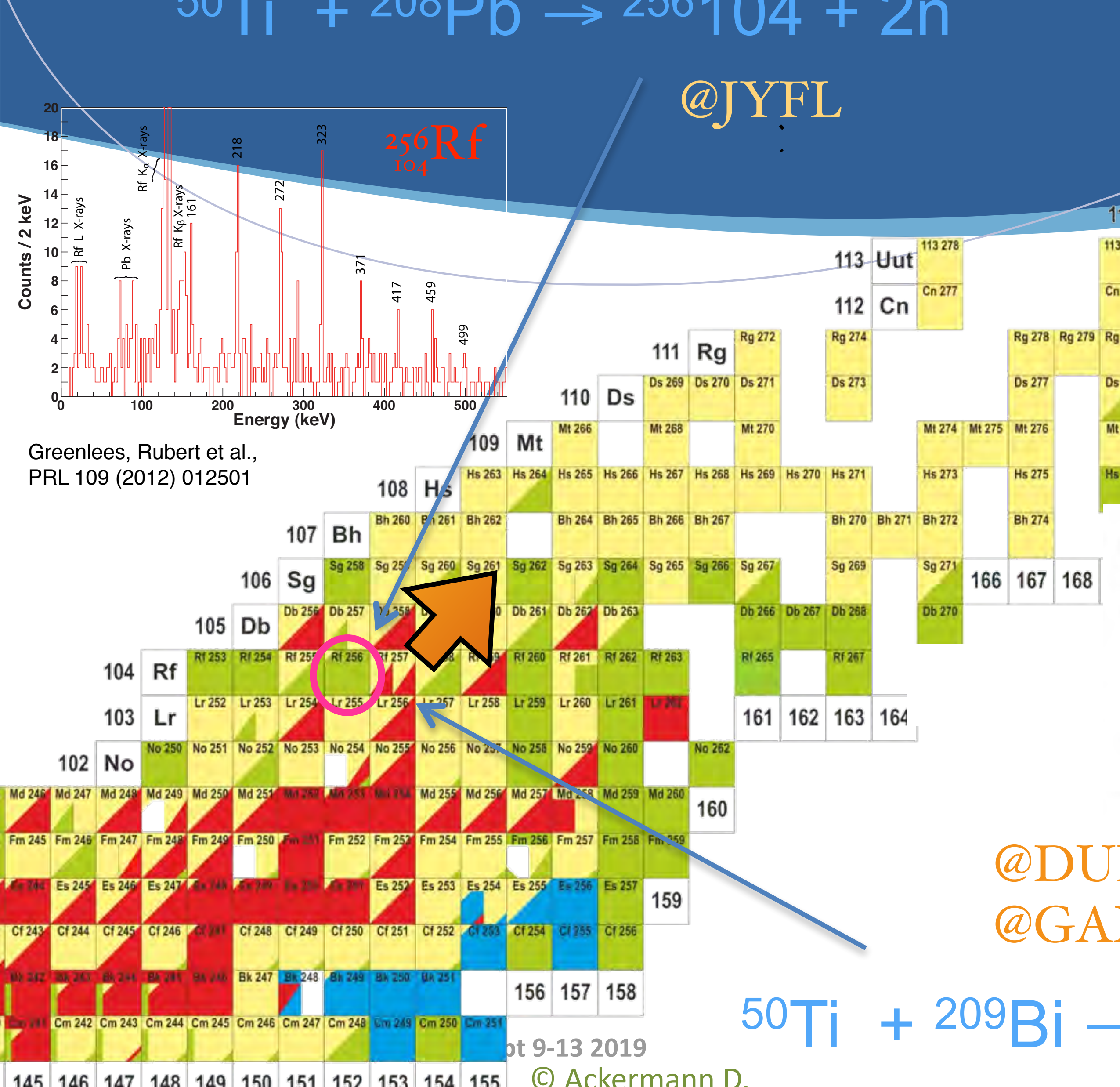
FIG. 9. Isotopic distributions of final above-target products obtained in collisions of actinides. The thin, dashed, and t histograms correspond to the results of the calculations for the reactions $^{238}U + ^{238}U$ ($E = 7.5$ MeV/u), $^{238}U + ^{248}Cm$ ($E =$ MeV/u), and $^{238}U + ^{254}Es$ ($E = 7.3$ MeV/u), respectively. The experimental data for the $^{238}U + ^{238}U$ reaction (trian are taken from Ref. [17], and for $^{238}U + ^{248}Cm$ (circles) are from Ref. [18]. For more details see the text. The heaviest kn isotopes of given chemical elements are indicated by the vertical dotted lines. The thick dashed curves show primary isot distributions of Rf and Db.

A. Karpov et al. arxiv.org/abs/1810.04025

Detailed spectroscopy of SHE with MIVOC ^{50}Ti

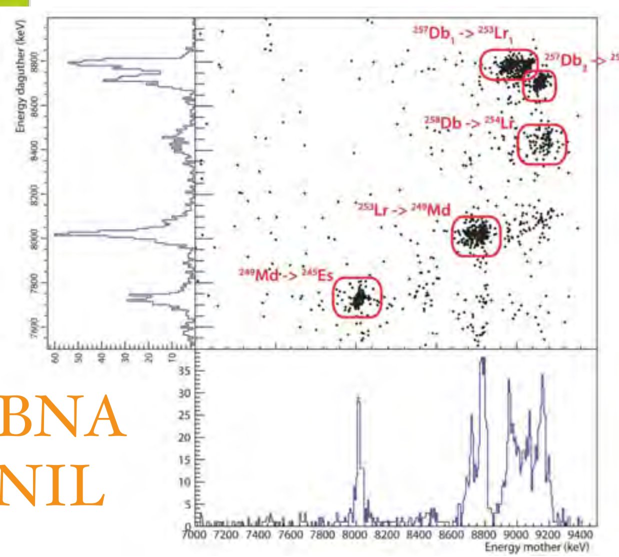
$^{50}Ti + ^{208}Pb \rightarrow ^{256}104 + 2n$

@JYFL



Greenlees, Rubert et al., PRL 109 (2012) 012501

P. Brionnet PhD thesis IPHC 2017



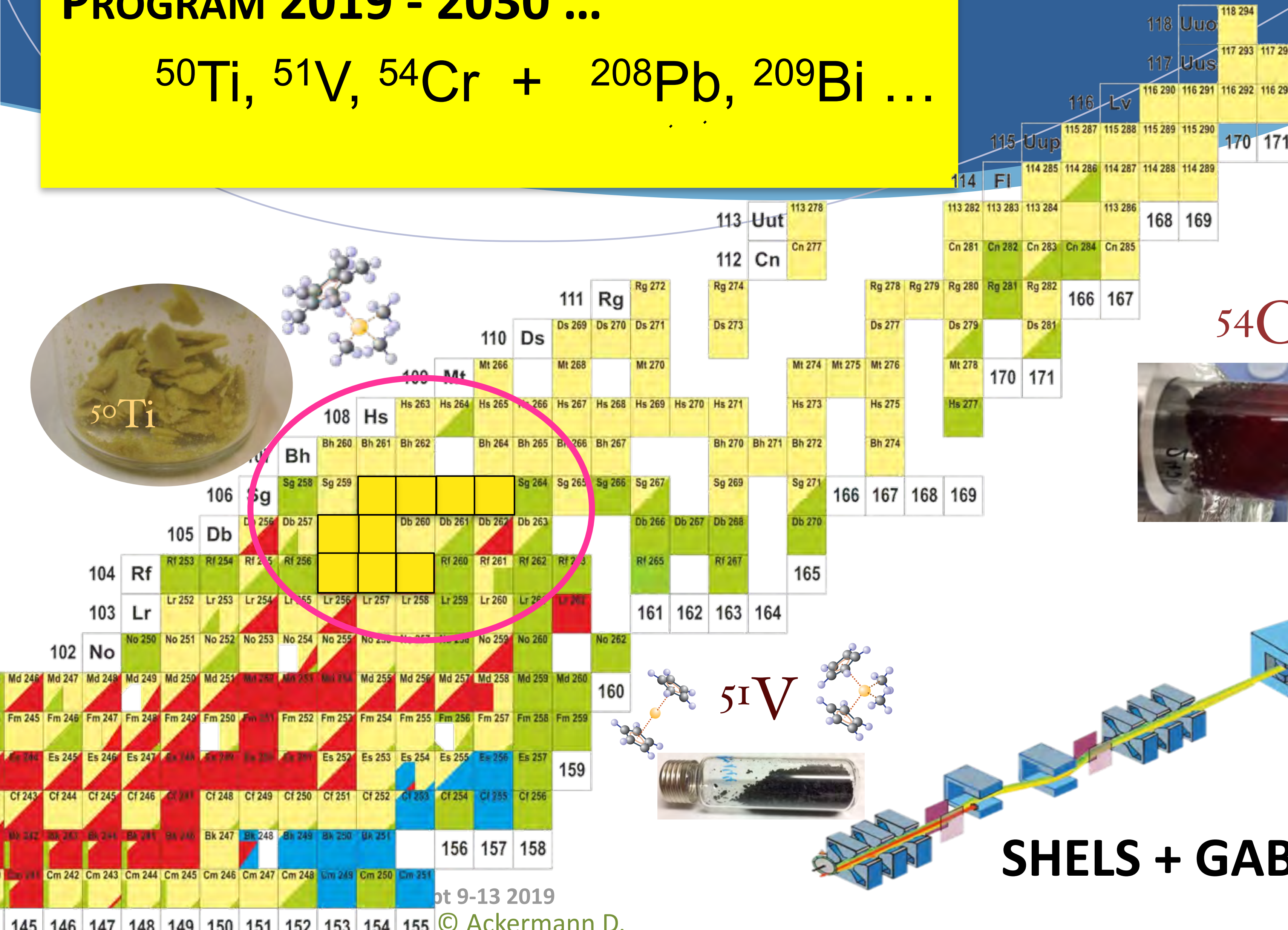
@DUBNA
@GANIL

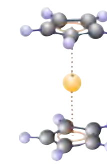
$^{50}Ti + ^{209}Bi \rightarrow ^{257}105 + 2n$

New beams for SHE… ^{50}Ti, ^{51}V, ^{54}Cr

PROGRAM 2019 - 2030 …

^{50}Ti, ^{51}V, ^{54}Cr + ^{208}Pb, ^{209}Bi …





54Cr

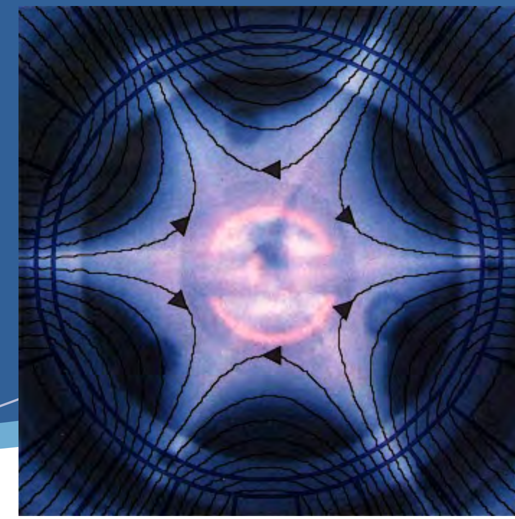
Magic beams for SHE… $^{40,48}Ca$, ^{50}Ti, ^{51}V, $^{52,54}Cr$

- Z=20
- N=20,28

Calcium	Scandium	Titanium	Vanadium	Chromium
Z=20	Z=21	Z=22	Z=23	Z=24
Isotopes	Isotope	Isotopes	Isotopes	Isotopes
^{40}Ca 96,9 % N=20				
^{42}Ca 0,6 % N=22				
^{43}Ca 0,1 % N=23				
^{44}Ca 2,0 % N=24	^{45}Sc 100 % N=24	^{46}Ti 8,0 % N=24		
		^{47}Ti 7,3 % N=25		
^{46}Ca 0,004 % N=26		^{48}Ti 73,8 % N=26		^{50}Cr 4,3% N=26
		^{49}Ti 5,5 % N=27	^{50}V 0,25 % N=27	
^{48}Ca 0,2 % N=28		^{50}Ti 5,4 % N=28	^{51}V 99,75 % N=28	^{52}Cr 83,8% N=28
				^{53}Cr 9,5 % N=29
				^{54}Cr 2,4 % N=30
T_{fusion} = 842 °C	T_{fusion} = 1541 °C	T_{fusion} = 1668 °C	T_{fusion} = 1910 °C	T_{fusion} = 1907 °C
$T_{boiling}$ = 1484 °C	$T_{boiling}$ = 2836 °C	$T_{boiling}$ = 3287 °C	$T_{boiling}$ = 3407 °C	$T_{boiling}$ = 2671 °C

Intense metallic beams

- Bring titanium in the ECR plasma
- Generate high charge states



Différentes techniques

Penning Ion Gauge

ionization by an electric discharge (metal titanium)

TiO_2 Ti (M)

Sputtering

TiO_2 Ti (M)

tear away out of an enriched rod (metal titanium)

Inductive Oven

high temperature sublimation from a metallic or oxyde pellet

TiO_2 Ti (M)

MIVOC

sublimation of organometallic compounds

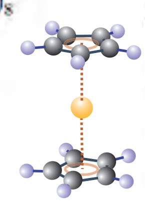
$TiCl_4$ TiO_2

First Titanium MIVOC beams

- Need stable organometallic compound
- with enough vapor pressure

TABLE I. The MIVOC compounds that have been used for the production of metal ion beams.

Element	Compound
Mg	$Mg(C_5H_5)_2$
Si	$Si\{Si[(CH_3)_3]\}_4$
Cr	$Cr(C_5H_5)_2$ or $Cr(CO)_6$
Fe	$Fe(C_5H_5)_2$
Co	$Co(C_5H_5)_2$ or $Co_2(CO)_8$
Ni	$Ni(C_5H_5)_2$
Ge	$Ge(C_2H_5)_4$
Mo	$Mo(CO)_6$
Ru	$Ru(C_5H_5)_2$
I	I_2CH_2
W	$W(CO)_6$
Os	$Os(C_5H_5)_2$



H. Koivisto et al., NIM B 187 (2002)111

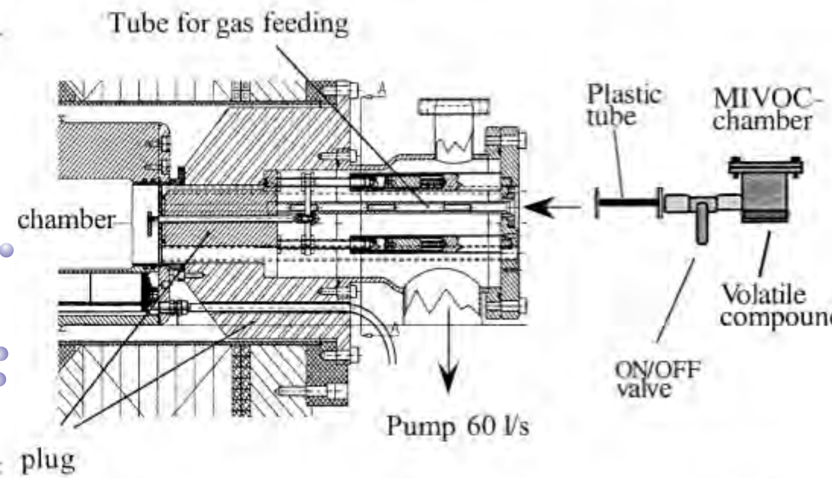
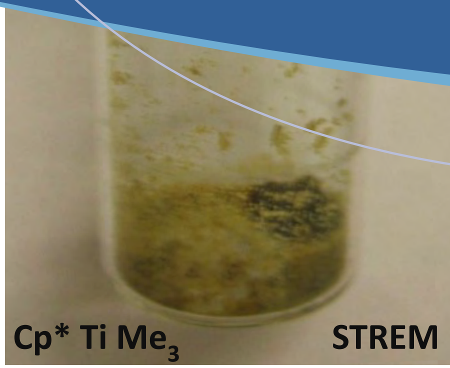
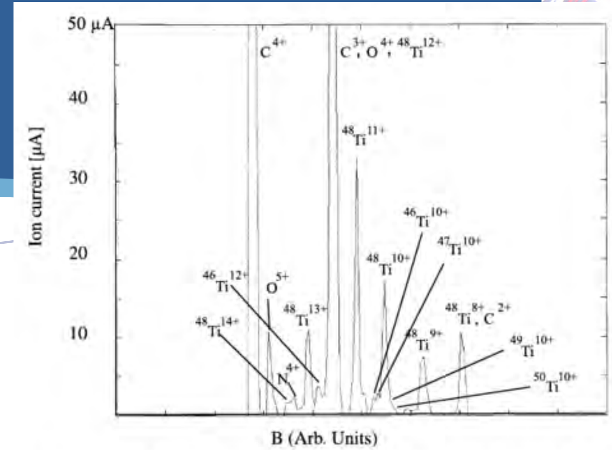


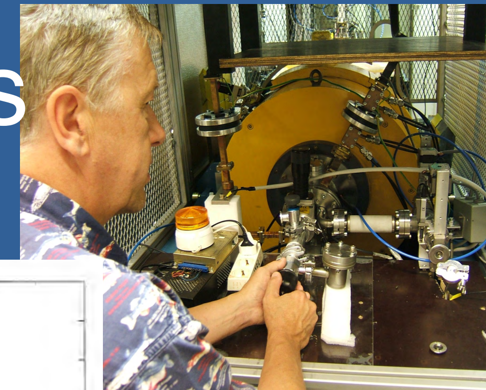
Fig. 2. The MIVOC chamber connection to the injection side of the JYFL 14 GHz ECRIS.

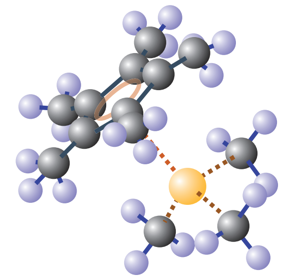
First titanium MIVOC beams

- test all commercial available
- Oxygen-free (Ti getter)







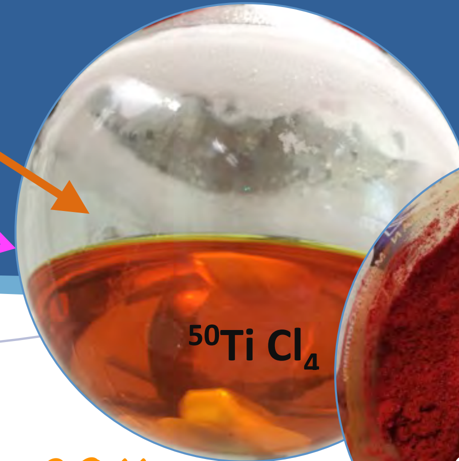


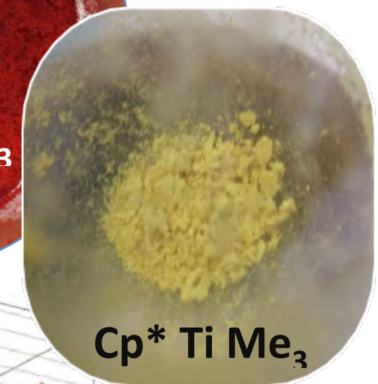
Intensities of measured Ti ion beams from H. Koivisto et al., NIM B 187 (2002)111

Isotope/ charge	8+	9+	10+	11+	12+	13+
^{46}Ti 7.9%	3.6*	4.7 *	4.8 *	4.8 *	3.9	1.6 *
^{47}Ti 7.3%	3.3 *	4.3 *	4.4 *	4.4 *	3.6 *	1.4 *
^{48}Ti 73.9%	33	43	44	45	36 *	14.3
^{49}Ti 5.5%	2.5 *	3.2 *	3.3 *	3.3 *	2.7 *	1.1 *
^{50}Ti 5.3%	2.5 *	3.2 *	3.3 *	3.3 *	2.7 *	1.1 *

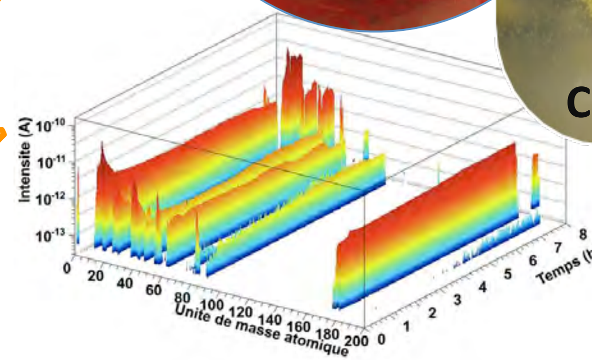
The abundance of the titanium isotopes in natural titanium is also shown. The asterisk denotes intensities estimated from the intensity of the same charge state of a different isotope. The extraction voltage was 10 kV.

Isotopic titania: Cp* 46,47,Nat,50Ti Me3



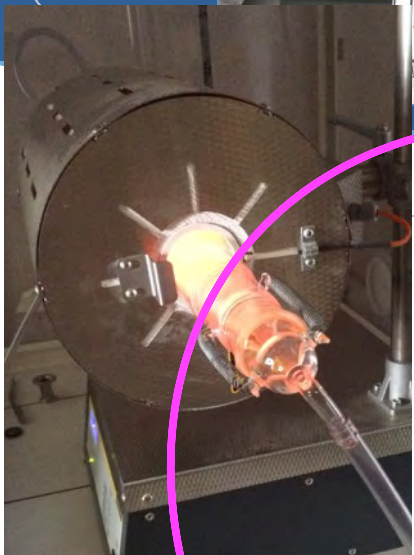


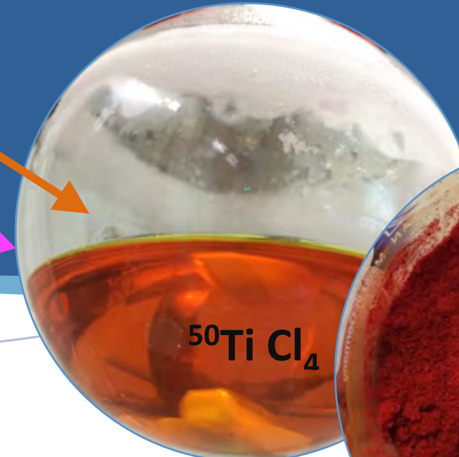
enabled MIVOC
from 48Ti & 50Ti
-> @JYFL from 2011
-> @ Dubna Sept 2017
-> @ Ganil Sept 2017
-> @ RIKEN Sept 2017

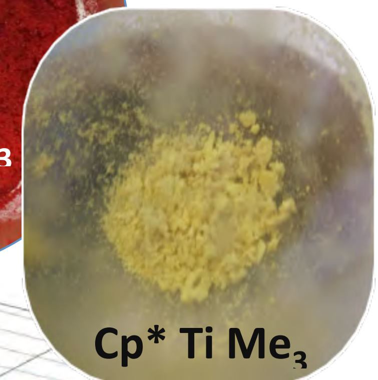


0,5 pµA chopped on target

Isotopic titania: Cp* ^{46,47,Nat,50}Ti Me$_3$







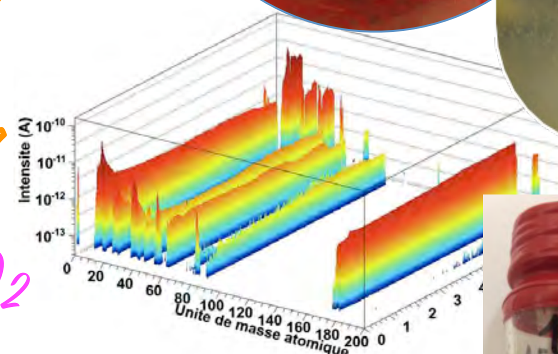
enabled MIVOC from ^{48}Ti & ^{50}Ti

-> @JYFL from 2011

-> @ Dubna Sept 2017

-> @ Ganil Sept 2017

-> @ RIKEN Sept 2017



Reprocess or start form TiO$_2$

enabled MIVOC from

- ^{47}Ti (JYFL April 2017)
- ^{46}Ti (Dubna Sept 2017)

Next step: several μA !!!

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

Beams from Cp* ^{50}Ti Me$_3$

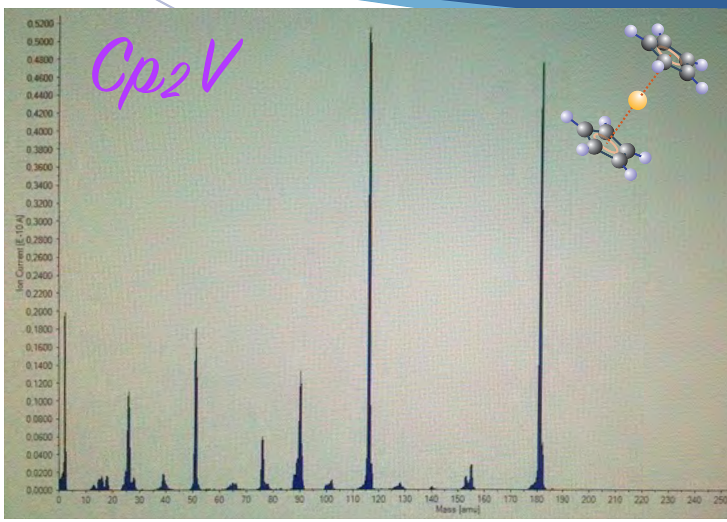
IPHC (Z. Asfari, B. Gall, J. Piot, J. Rubert, H. Faure, M. Filliger)
JYFL (J. Ärje, R. Seppälä, H Koivisto, P. Greenlees)
GANIL (F. Lemagnen, P Leherissier, C. Barue B. Osmond, J. Piot)
JINR (S. Bogomolov, V. Loginov, A. Yeremin)
RIKEN (M. Kidera, K. Morimoto, K. Morita)

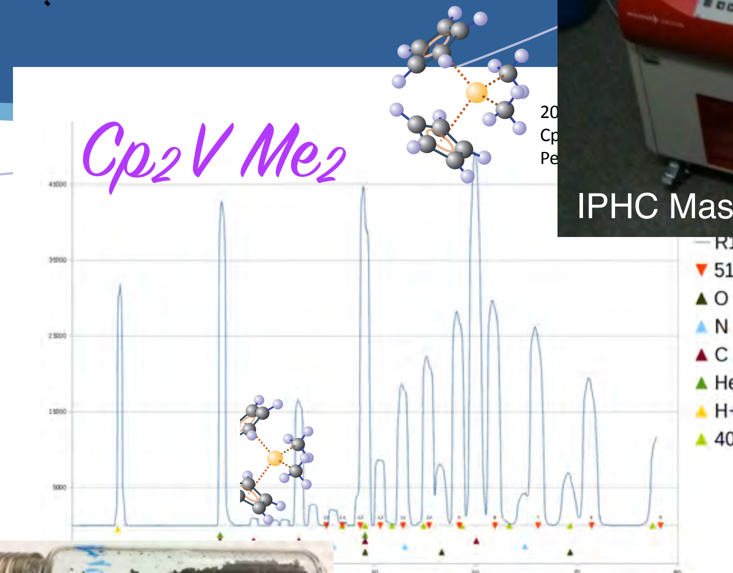
	beam out of source		on target	trans.	cons.
JYFL	4.5eμA (11^+) = 0.4 pμA	==>	0.022 pμA	5.5%	~1.2 mge/h
	(^{50}Ti beam with ECRIS2 source TiO2 in inductive oven)				
	19 eμA (11^+) = 1.7 pμA	==>	0.044 pμA	2.6%	~0.6 mge/h
	(^{50}Ti beam with ECRIS2 source MIVOC Cp*TiMe3)				
GANIL	28 eμA (10^+) = 2.8 pμA	==>	0.450 pμA	16.0%	~0.2 mge/h
	(^{50}Ti beam with ECR4 source)				
DUBNA	55 eμA (5^+) = 11.0 pμA	==>	0.490 pμA	4.5%	~0.6 mge/h
	(^{50}Ti beam with U400M ECR4M source)				
	67 eμA (10^+) = 6.7 pμA		(^{48}Ti beam with DECRIS-2M @ test bench)		
	80 eμA (5^+) = 16.0 pμA		(^{50}Ti beam with DECRIS-2M @ test bench)		
RIKEN	11 eμA (11^+)= 1.0 pμA	==>	0.330 pμA	30,0%	~5-6 mge/h
	(^{48}Ti beam with high T° oven)				
	14 eμA (11^+)= 1.3 pμA		(^{48}Ti beam with RILAC 18 GHz ECRIS)		
	15 eμA (11^+)= 1.5 pμA	==>	0.450 pμA	33,0%	~0.5 mge/h
	(^{50}Ti beam with RILAC 18 GHz ECRIS)				

Next step: several pμA !!!

Vanadium MIVOC beams

Identification of 2 possible MIVOC of Vanadium





tested at RILAC ECR 18GHz ion source: 15 eμA (11^+)= 1.4 pμA
8 eμA (12^+)= 0.7 pμA

(~0,5 pμA on target)

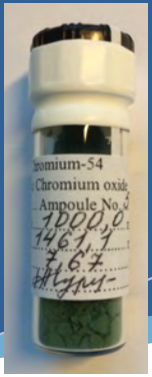
Need further comparison test between Cp$_2$V Me$_2$ and Cp$_2$V compounds

Chromocene: Cp_2Cr

Synthesis @IPHC Strasbourg from Cr_2O_3

2018 success

Cr_2 O_3



Cp_2 Cr

Cr Cl_3

Very pure compound (recristalized Cp2Cr)

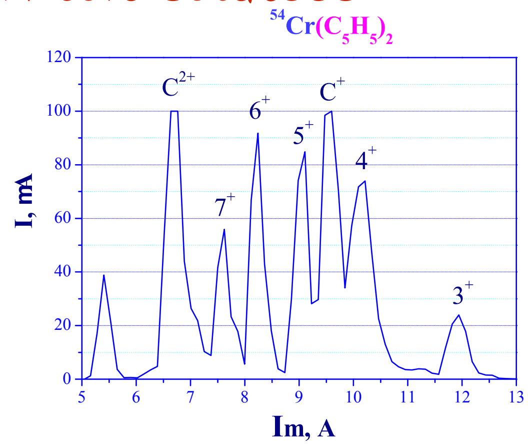
Process efficiency ~50% , but we work on reprocess

Tested on DUBNA ECR ion sources

Successfully extracted

5+ -> 95 µA

=> 19 pµA …

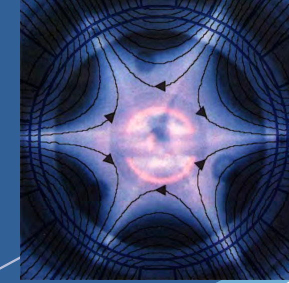


~1 pµA on target expected

Study of fission of E120 in Dubna 2019

MIVOC beams exist: ^{50}Ti, ^{51}V, ^{52,54}Cr

R&D 2019: ^{238}Ucot$_2$



Present-day MIVOC beam up to 0,9 pµA without chopper

Need an increase by a factor of 10-20 for these very intense beams !

-> New machine (SHE Factory) => no more foil extraction

-> Higher beam transport efficiency

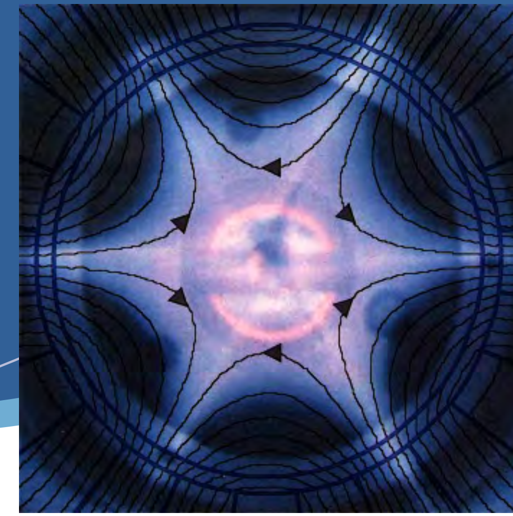
-> New ECR sources (DECRIS-PM & DECRIS-SC)

… increase of RF frequency 14 -> 28 GHz … Gelles law => $i \sim f^2$

… 60 GHz high field (5T) source proto in development in France (LPSC) …

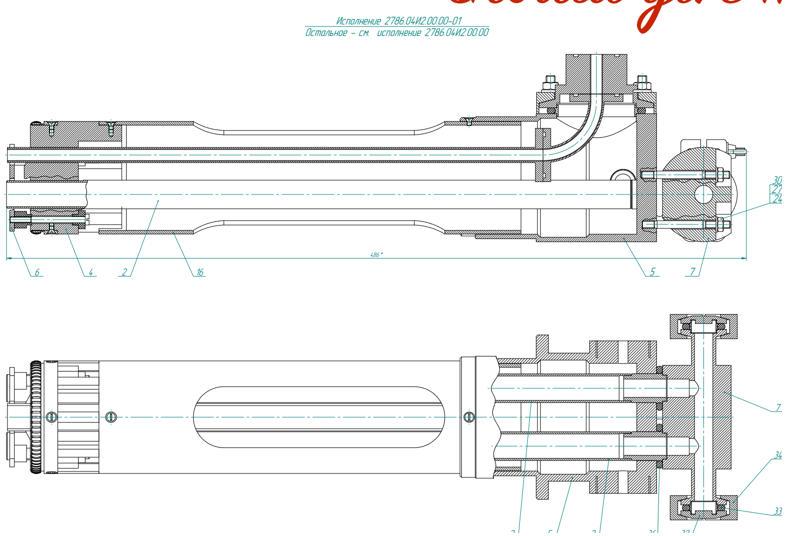
-> Better coupling MIVOC to ECR plasma

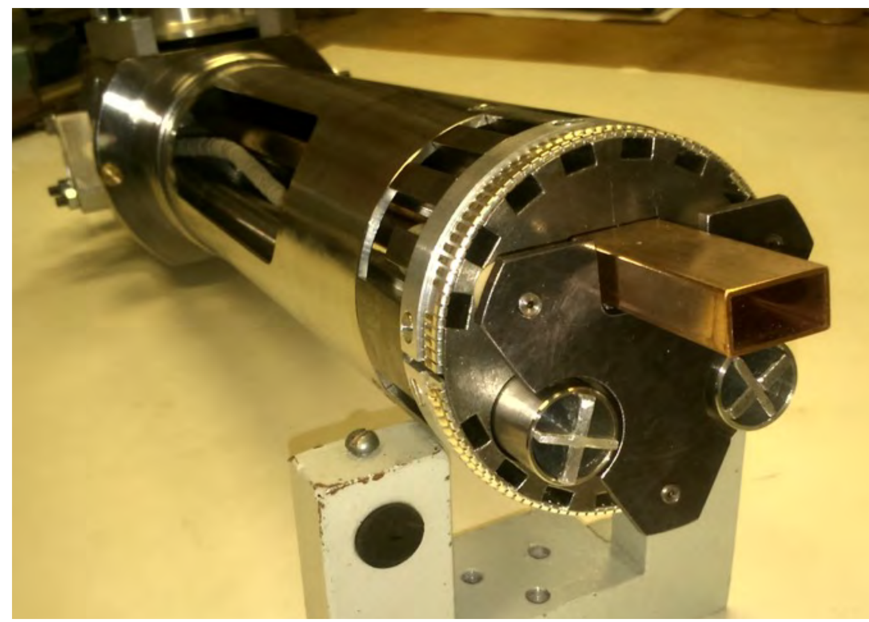
Better plasma coupling



New internal feed for FLNR ECR4M

Better coupling MIVOC - plasma
Better vacuum conditions
=> should give more beam …



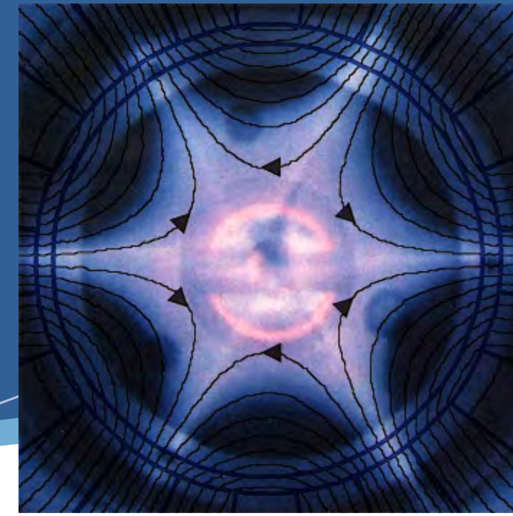


Need test time & test bench …

(c) S. Bogomolov

Titanium beams

- Bring titanium in the ECR plasma
- Generate high charge states



Différentes techniques

Penning Ion Gauge

ionization by an electric discharge (metal titanium)

TiO_2 Ti (M)

Sputtering

TiO_2 Ti (M)

tear away out of an enriched rod (metal titanium)

Inductive Oven

high temperature sublimation from a metallic or oxyde pellet

TiO_2 Ti (M)

MIVOC

sublimation of organometallic compounds

$TiCl_4$ TiO_2

Titanium beams

- Bring titanium in the ECR plasma
- Generate high charge states

Inductive oven (JYFL)

- Heating up to 2000°C
- Induction in Mo
- W crucible (IPHC)

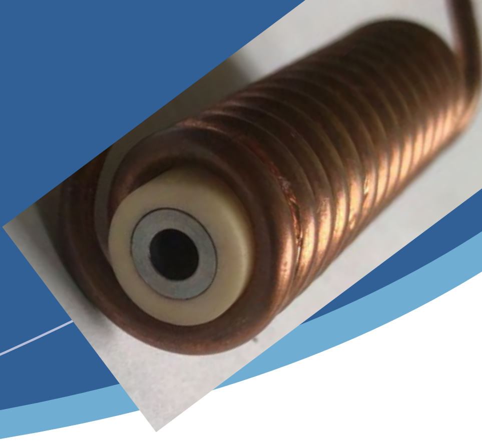
©M. Savonen

J. PIOT PhD Thesis

Ti (M) pellets	TiO_2 pellets
M.P. 1668°C	M.P. 1885°C
Needs reduction of TiO_2	Direct use

one got 4.5 eµA out of ECRIS2 @JYFL

Inductive oven



Ongoing R&D @ IPHC Strasbourg

Aim …

- Heating up to 3000°C
- Small size
- Thermal screening

Time table :

- Study phase in 2018
- Size 2 oven S1 2019
- Size 1 oven S2 2019

2017:

- *First inductive tests @ IPHC*

2018:

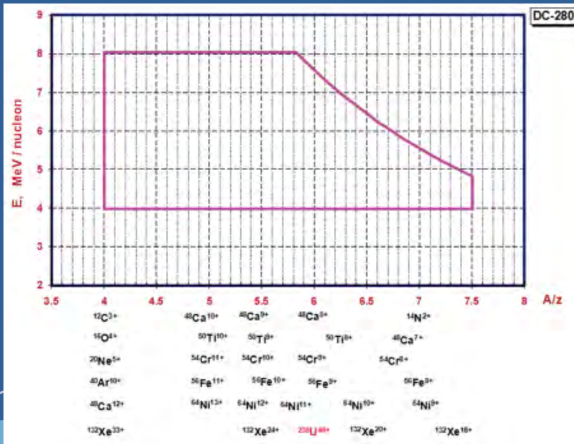
- *Gather power &vacuum parts*

2019:

- *HT tests + CC*
- *Vacuum Prototype*
- *tests in Dubna*
- *tests in Grenoble & GANIL*

should also give several pμA beams

Expected Ti beams …



Extrapolated Intensities @ DC280

DC-280

- DECRIS-PM (14 GHz)
- DECRIS-SC (18GHz)
- SHE > 5.8 - 6.2 MeV/A
- transmission close to 50%
- A=50 K = 280

  => q =7^+ or 8^+

Measured beam out of source

ECR4M	55 eμA	(5^+)	=	11.0 pμA
(^{50}Ti beam with U400M ECR4M source)				
DECRIS2M	67 eμA	(10^+)	=	6.7 pμA
	80 eμA	(5^+)	=	16.0 pμA
DECRISPM	90 eμA	(9^+)	=	10.0 pμA

Extrapolations (… 0,5 x 0,6 = 30%)

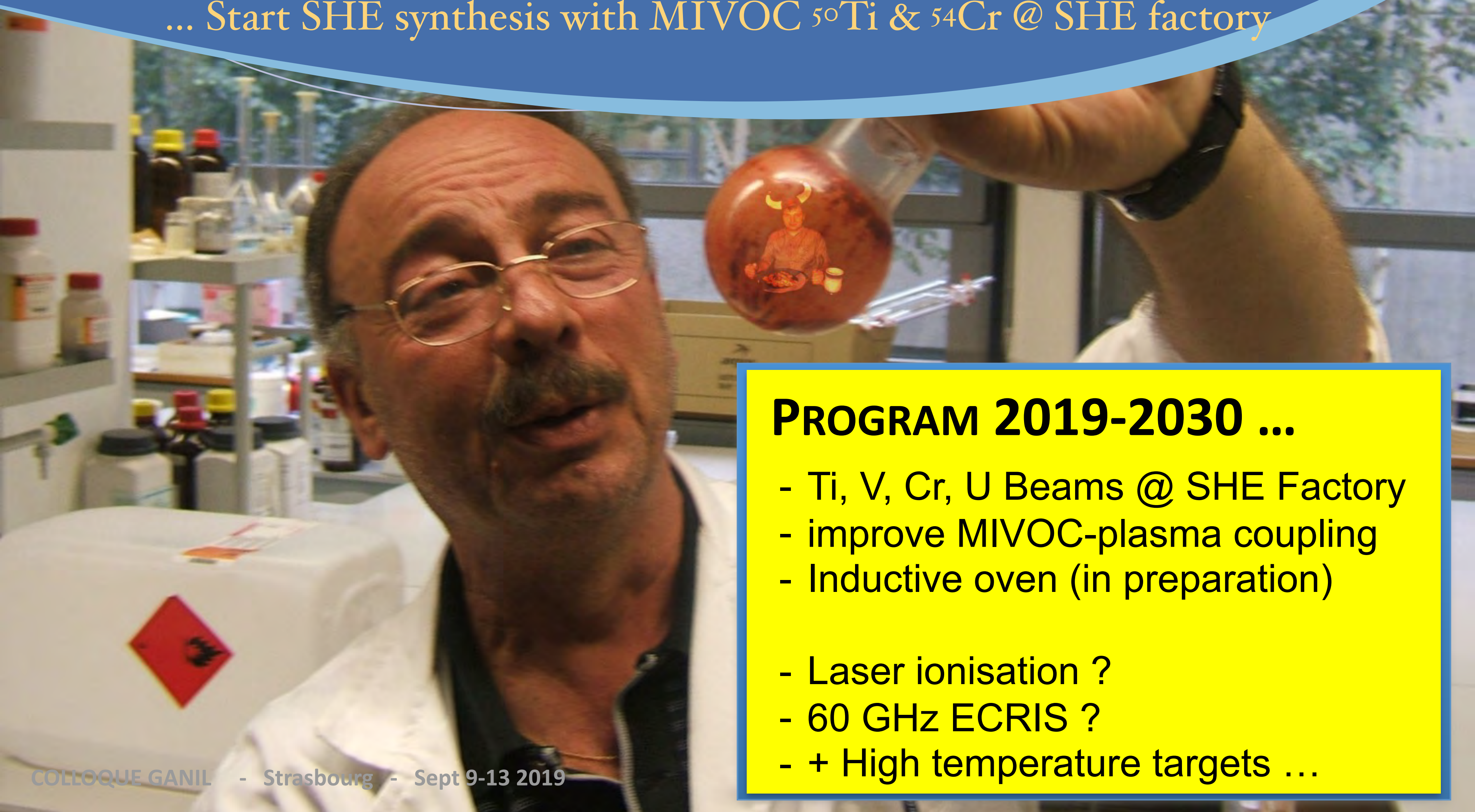
DECRISPM	(9+)	=	3 pμA
DECRISPM	(hyp. 8+)	=	2-5 pμA
DECRIS2M	(x 1,65)	=	3-8 pμA

… and more with inductive !

Summary

- ^{50}Ti MIVOC beams coming close to the pµA level => 2-8 pµA on DC280,
- Almost one year of integrated beam on target (JYFL, FLNR, GANIL, RIKEN)
- Already nice results with ^{50}Ti MIVOC (^{256}Rf, ^{257}Db),
- New MIVOC compounds of Vanadium and Chromium,
- R&D for ^{238}U MIVOC should give results soon.

... Start SHE synthesis with MIVOC ^{50}Ti & ^{54}Cr @ SHE factory



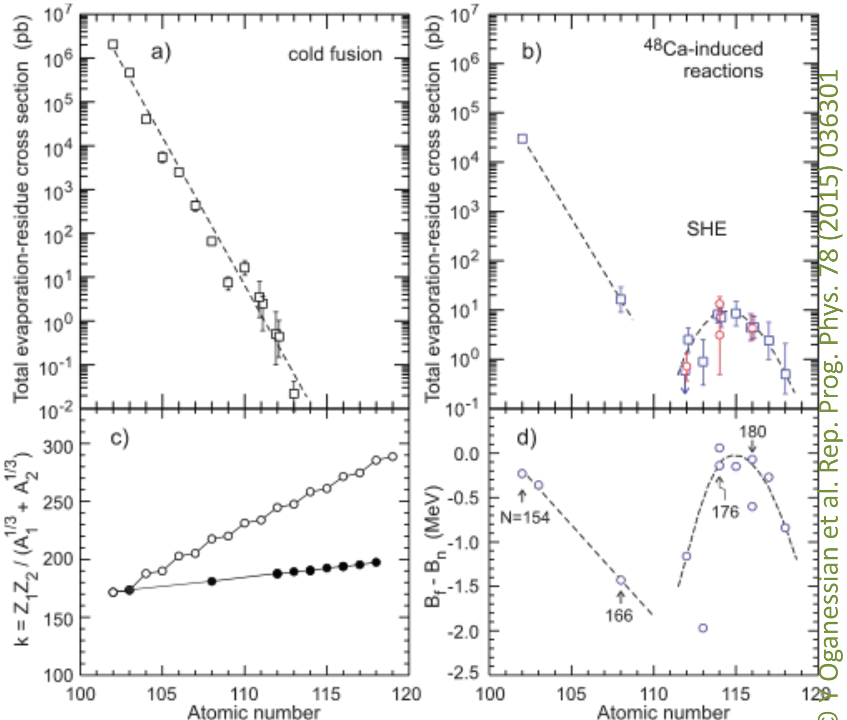
PROGRAM 2019-2030 ...

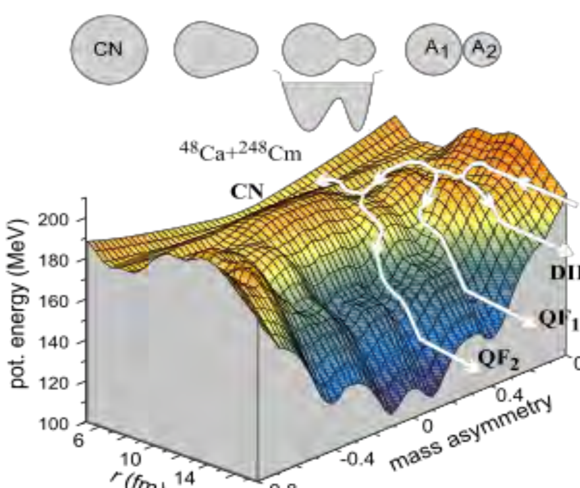
- Ti, V, Cr, U Beams @ SHE Factory
- improve MIVOC-plasma coupling
- Inductive oven (in preparation)

- Laser ionisation ?
- 60 GHz ECRIS ?
- + High temperature targets …

Thank you for your attention

SHE STATUS …





Z	N	A	Nombre observés	Mode de décroissance	E_α (MeV)	Demi-vie
118	176	294	4	α	11.66±0.06	$0.69^{+0.64}_{-0.22}$ms
117	177	294	5	α	10.81-11.07	51^{+38}_{-16}ms
	176	293	15	α	10.60-11.20	22^{+8}_{-4}ms
116	177	293	5	α	10.56±0.02	57^{+43}_{-17}ms
	176	292	9	α	10.63±0.02	13^{+7}_{-4}ms
	175	291	4	α	10.74±0.07	19^{+17}_{-6}ms
					10.50±0.02	
	174	290	11	α	10.85±0.07	$8.3^{+3.5}_{-1.9}$ms
115	175	290	6	α	9.78-10.31	650^{+490}_{-200}ms
	174	289	16	α	10.15-10.54	330^{+120}_{-80}ms
	173	288	46	α	10.29-10.58	164^{+30}_{-21}ms
	172	287	3	α	10.61±0.05	37^{+44}_{-13}ms
114	175	289	16	α	9.84±0.02	$1.9^{+0.7}_{-0.4}$s
					9.48±0.08	
	174	288	35	α	9.93±0.03	$0.66^{+0.14}_{-0.10}$s
	173	287	19	α	10.03±0.02	$0.48^{+0.14}_{-0.09}$s
	172	286	27	$\alpha : 0.6 SF : 0.4$	10.21±0.04	$0.12^{+0.04}_{-0.02}$s
	171	285	1	α		$0.13^{+0.60}_{-0.06}$s
113	173	286	6	α	9.61-9.75	$9.5^{+6.3}_{-2.7}$s
	172	285	17	α	9.47-10.18	$4.2^{+1.4}_{-0.8}$s
	171	284	47	α	9.10-10.11	$0.91^{+0.17}_{-0.13}$s
	170	283	2	α	10.23±0.01	75^{+136}_{-30}ms
	169	282	2	α	10.63±0.08	73^{+134}_{-29}ms
112	173	285	17	α	9.19±0.02	28^{+9}_{-6}s
	172	284	37	SF		98^{+20}_{-14}ms
	171	283	33	α :1 SF≤0.1	9.53±0.02	$4.2^{+1.1}_{-0.7}$s
					9.33±0.06	
					8.94±0.07	
	170	282	14	SF		$0.91^{+0.33}_{-0.19}$ms
	169	281	1	α	10.31±0.04	$0.10^{+0.46}_{-0.05}$s
111	171	282	6	α	8.86-9.05	100^{+70}_{-30}s
	170	281	20	α :0.1 SF :0.9	9.28±0.05	17^{+6}_{-3}s
	169	280	45	α	9.09-9.92	$4.6^{+0.8}_{-0.7}$s
	168	279	3	α	10.38±0.16	90^{+170}_{-40}ms
	167	278	2	α	10.69±0.08	$4.2^{+7.5}_{-1.17}$ms
110	171	281	17	α :0.07 SF :0.93	8.73±0.03	$12.7^{+4.0}_{-2.5}$s
	169	279	36	α :0.1 SF :0.9	9.71±0.02	$0.21^{+0.04}_{-0.04}$s
	167	277	1	α	10.57±0.04	$0.006^{+0.027}_{-0.003}$s

TABLE 1.1 – Tableau récapitulatif des derniers éléments super lourds observés.