www.superheavies.de
c.e.duellmann@gsi.de

Superheavy element research at GSI

Christoph E. Düllmann

Johannes Gutenberg University Mainz

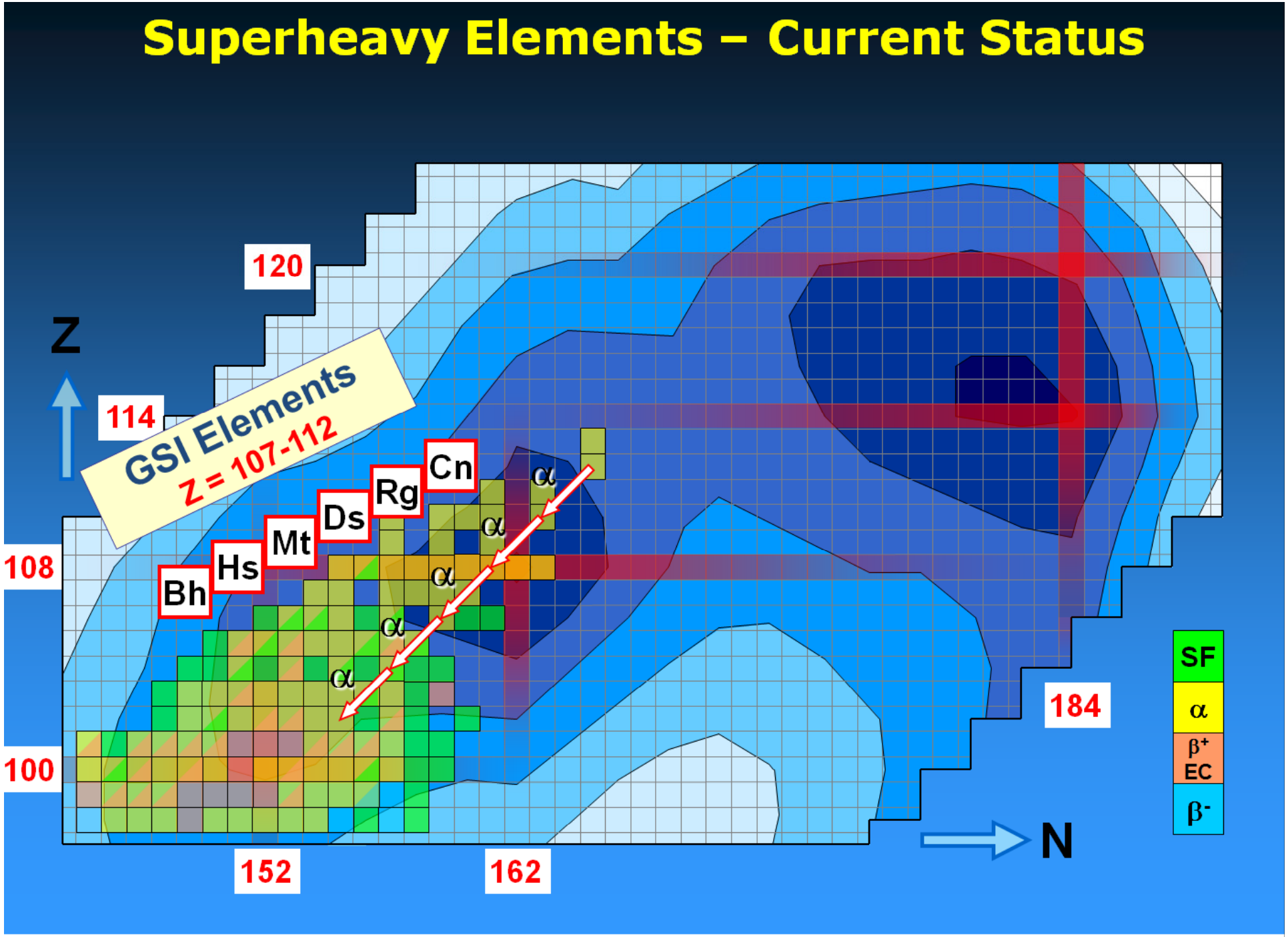
GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt

Helmholtz Institute Mainz

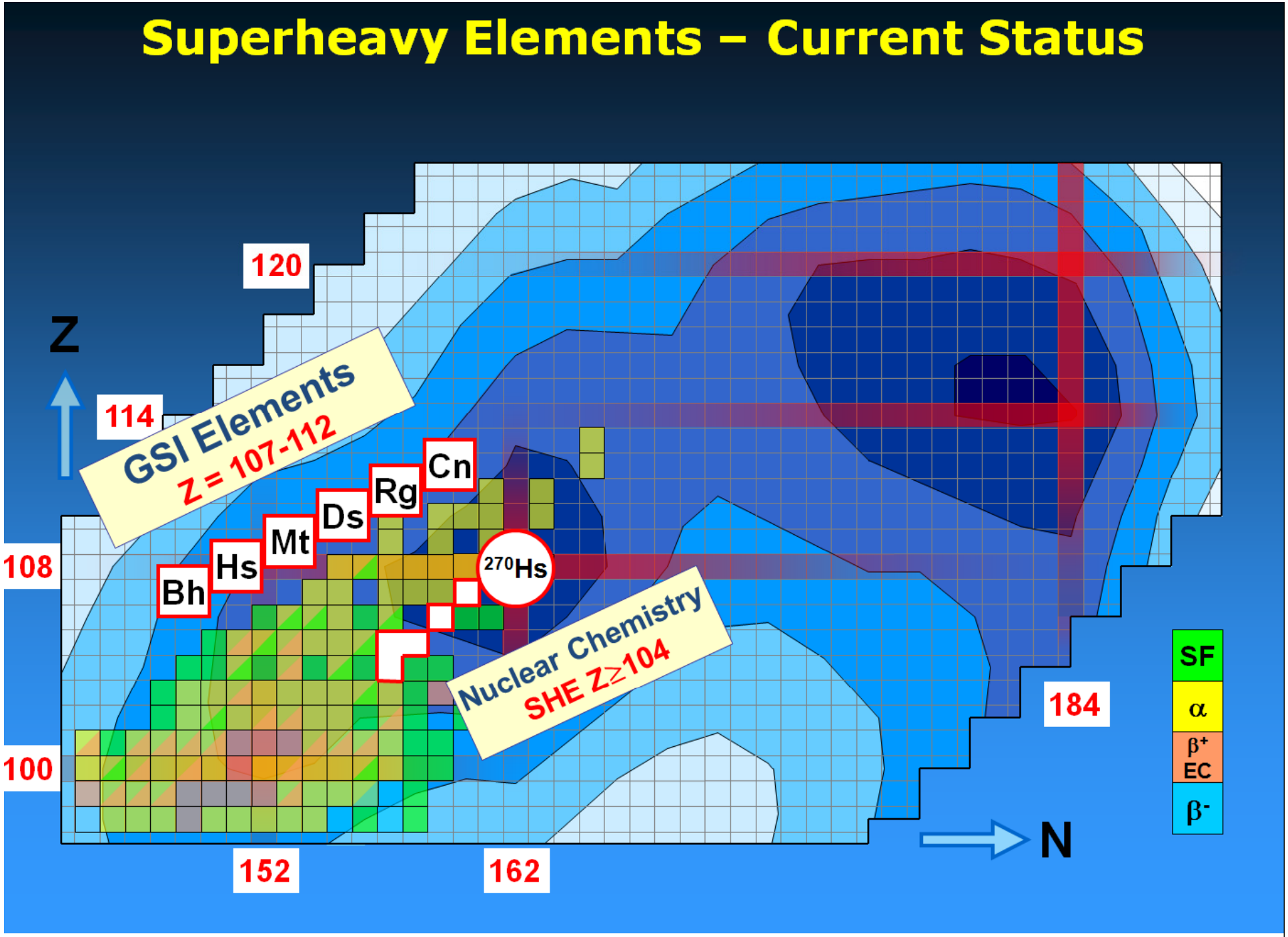
4th International Conference on the Chemistry and Physics of the Transactinide Elements

TAN 11, Sochi, Russia, September 05-11, 2011

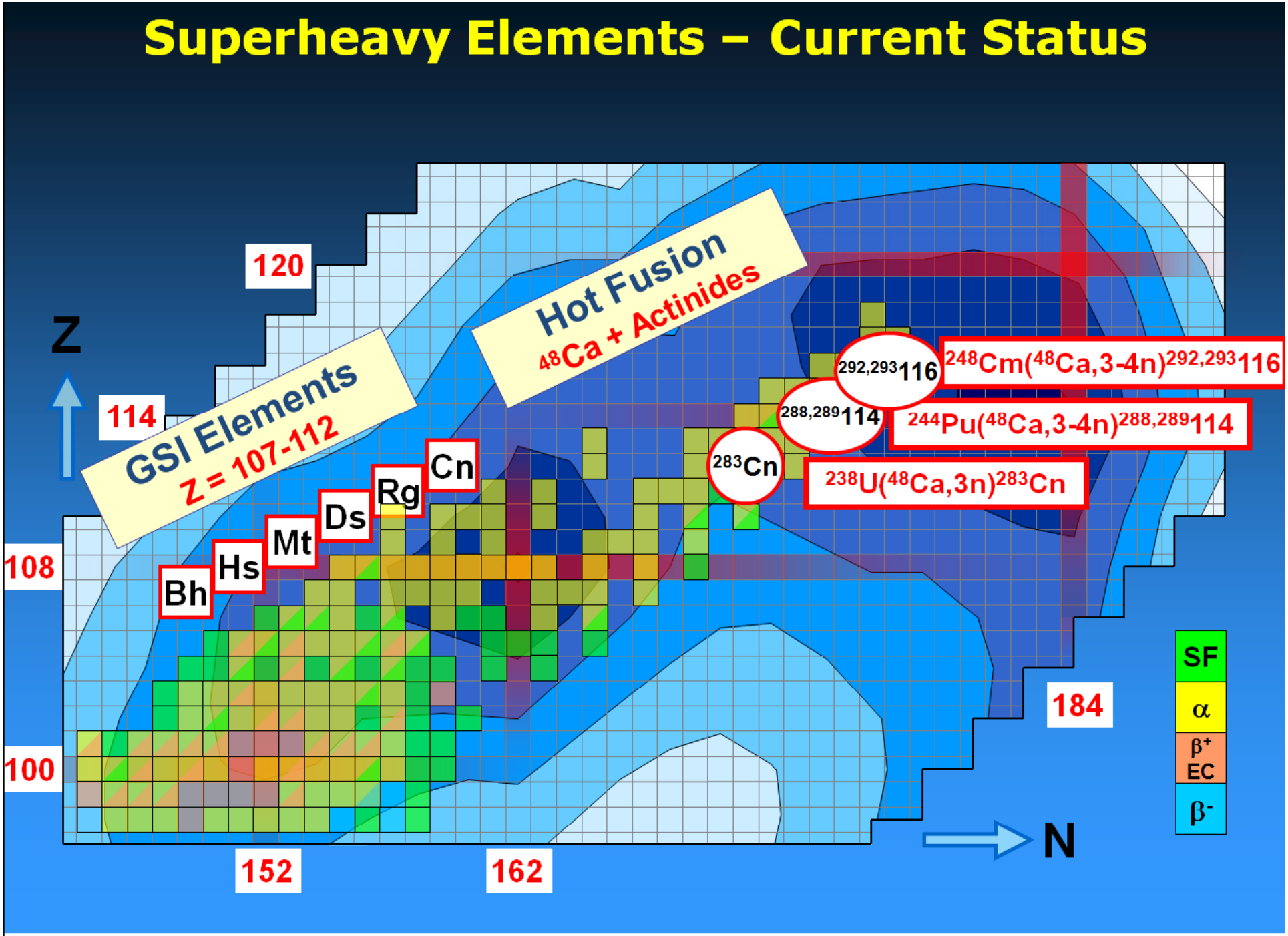
Superheavy Elements – Current Status



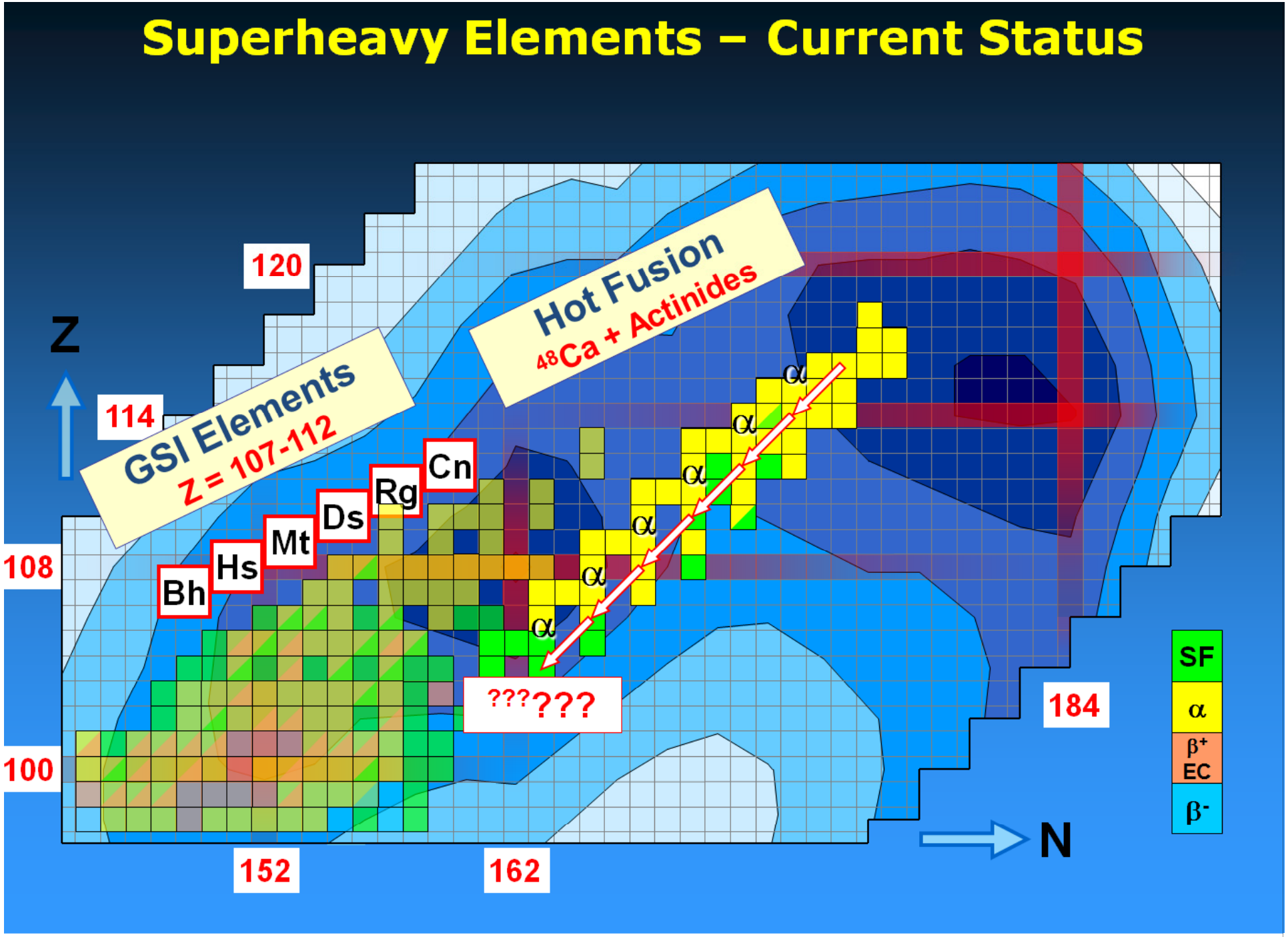
Superheavy Elements – Current Status



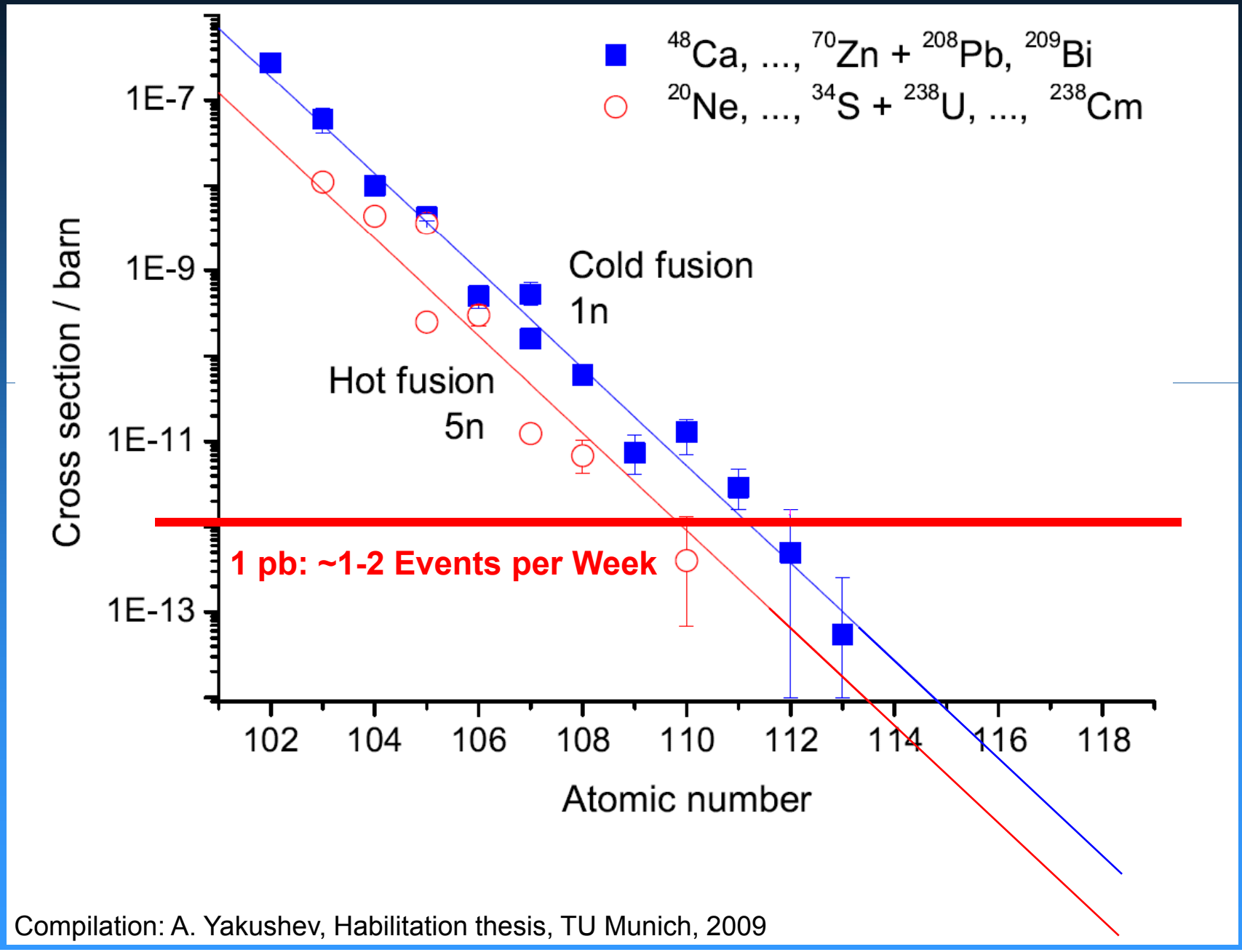
Superheavy Elements – Current Status



Superheavy Elements – Current Status

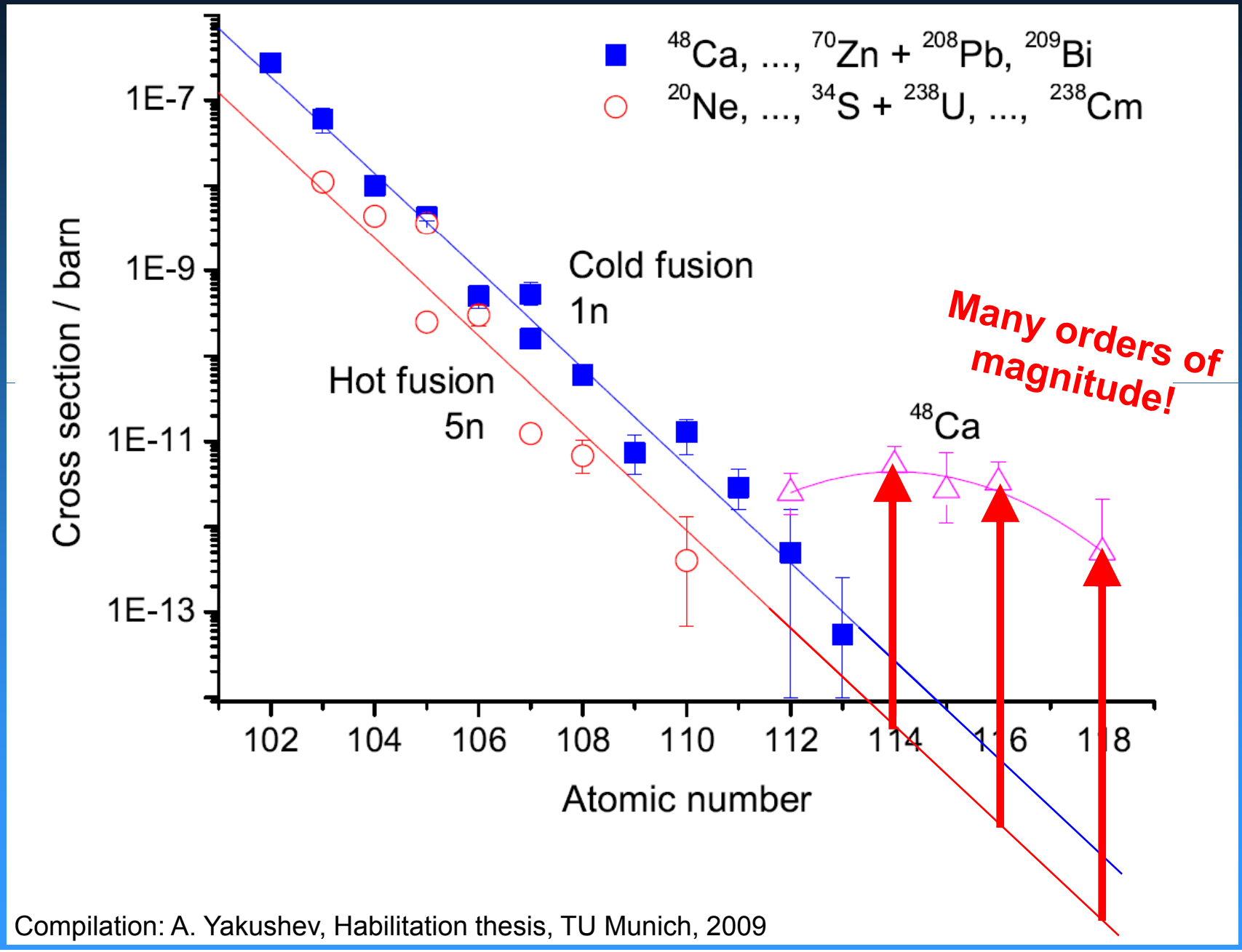


Cross Sections in Hot / Cold / ^{48}Ca Induced Fusion Reactions



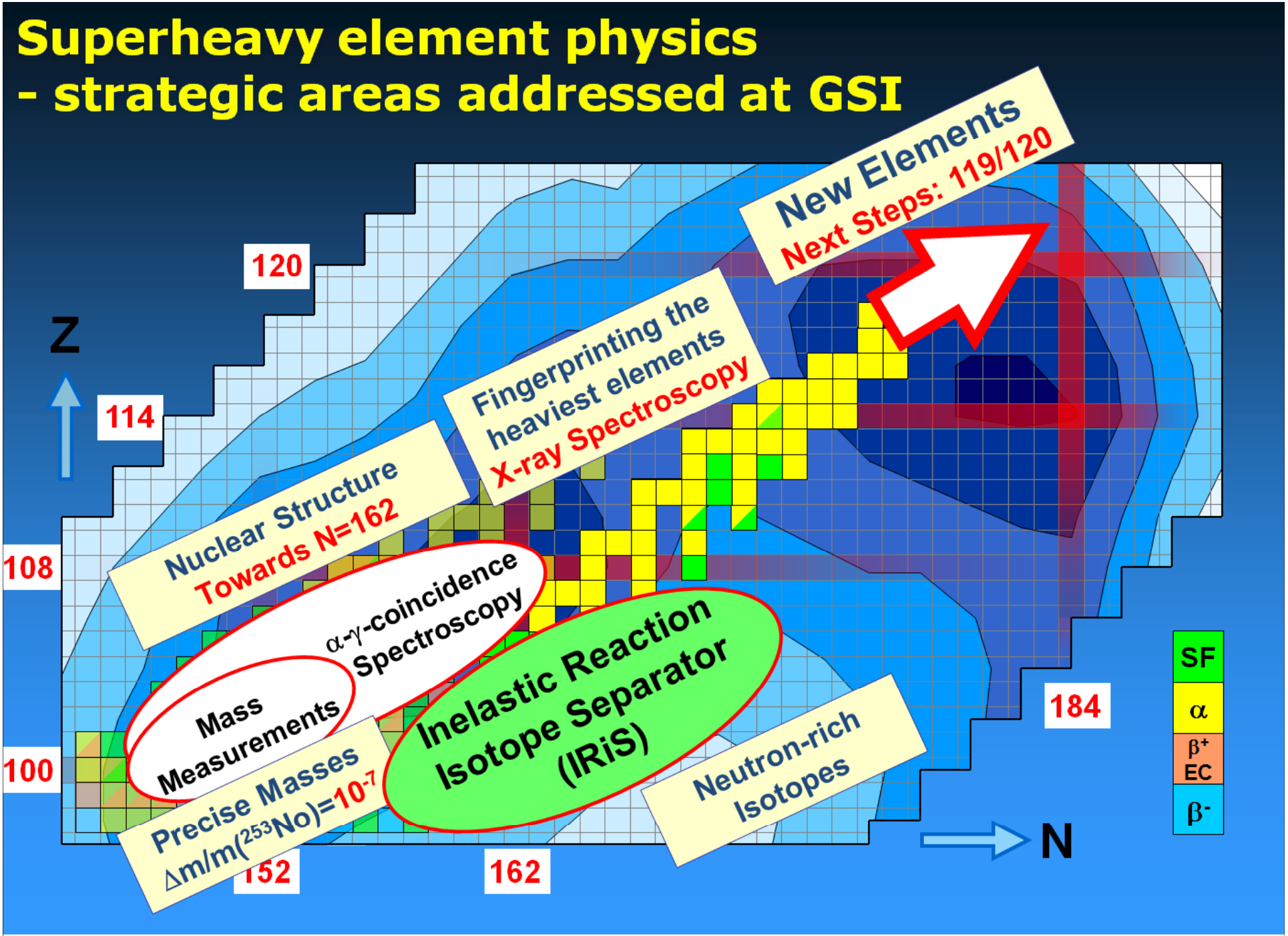
Compilation: A. Yakushev, Habilitation thesis, TU Munich, 2009

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

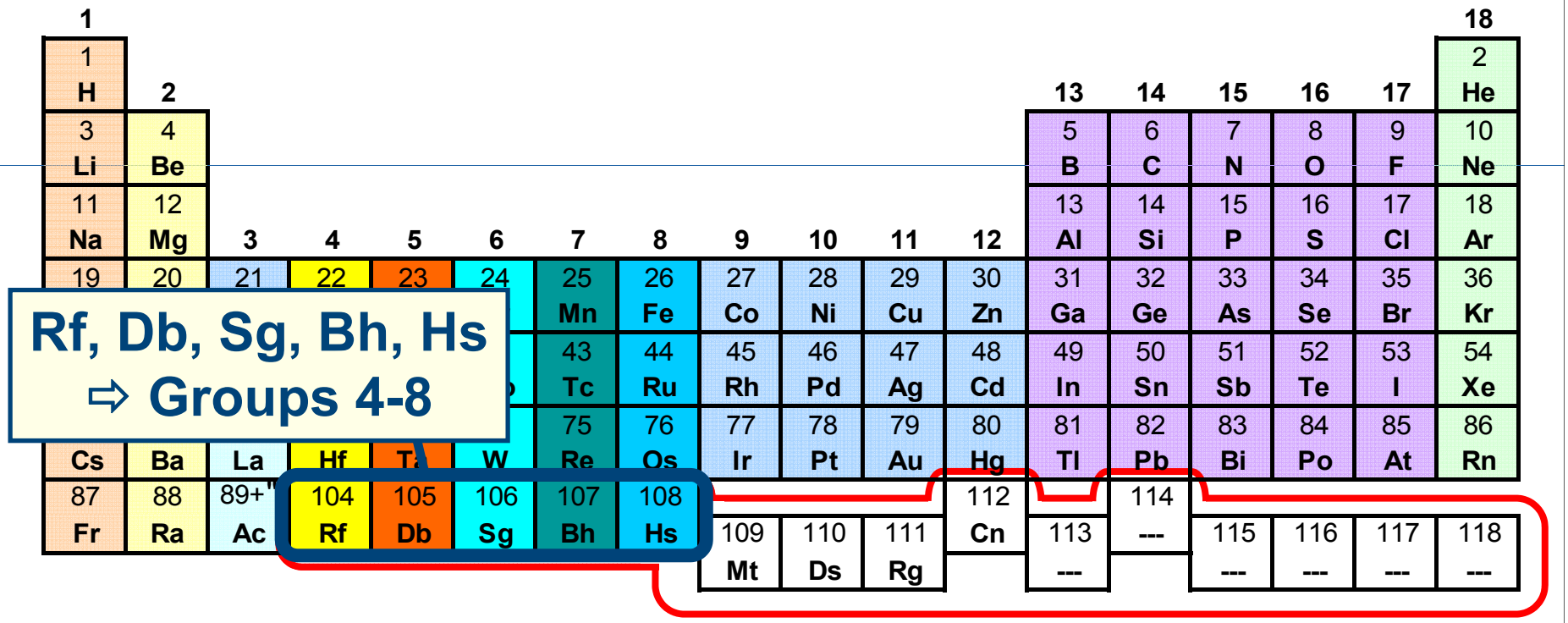


Compilation: A. Yakushev, Habilitation thesis, TU Munich, 2009

Superheavy element physics - strategic areas addressed at GSI



Chemistry of Superheavy Elements



	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	3	4	5	6	7	8	9	10	11	12	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
	19	20	21	22	23	24	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
							43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
	Cs	Ba	La	Hf	Ta	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 ---	115 ---	116 ---	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

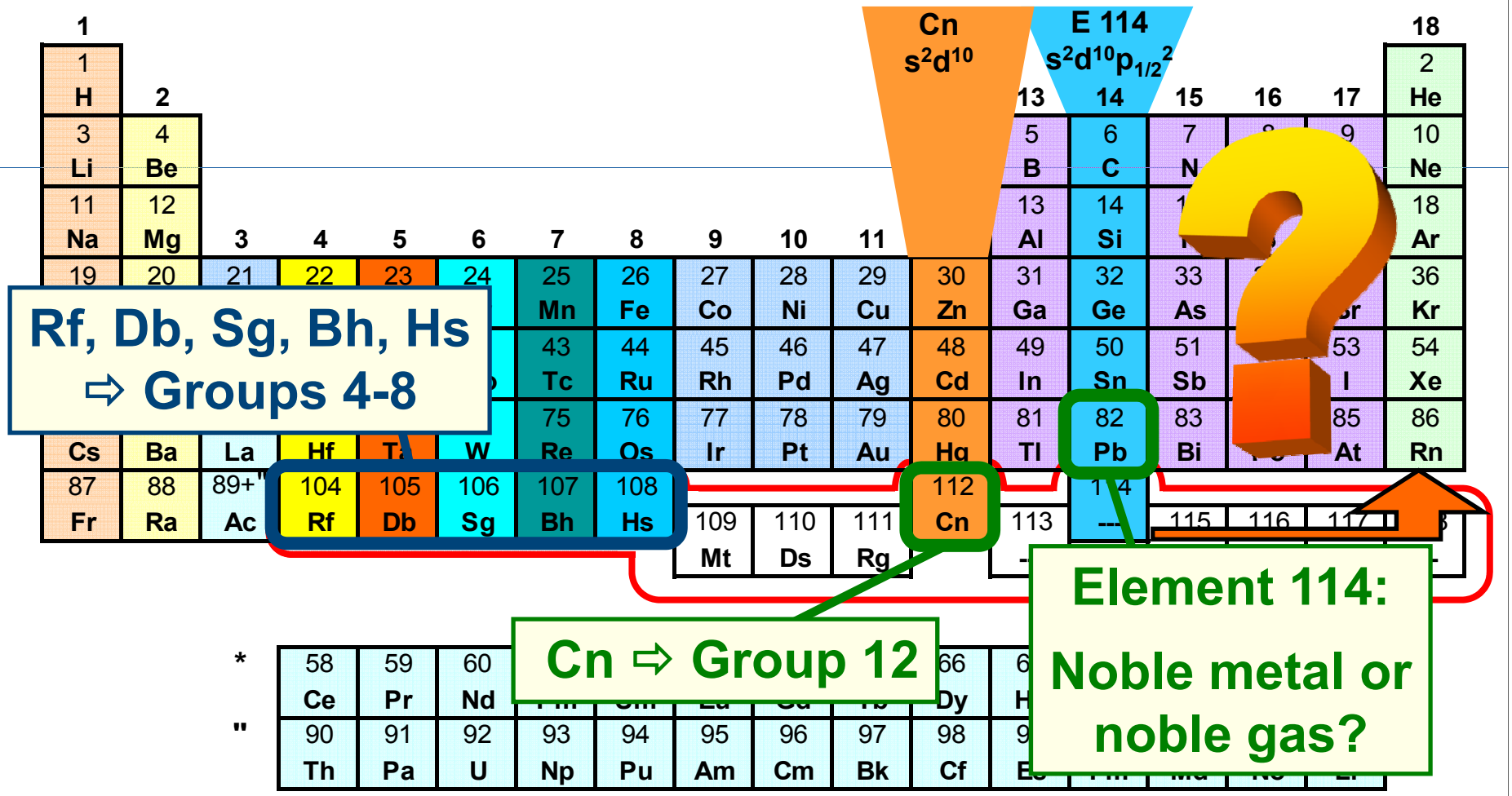
Are elements 112, 114, and 118 relatively inert gases?

Kenneth S. Pitzer

Department of Chemistry and Inorganic Materials Research Division of the Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720

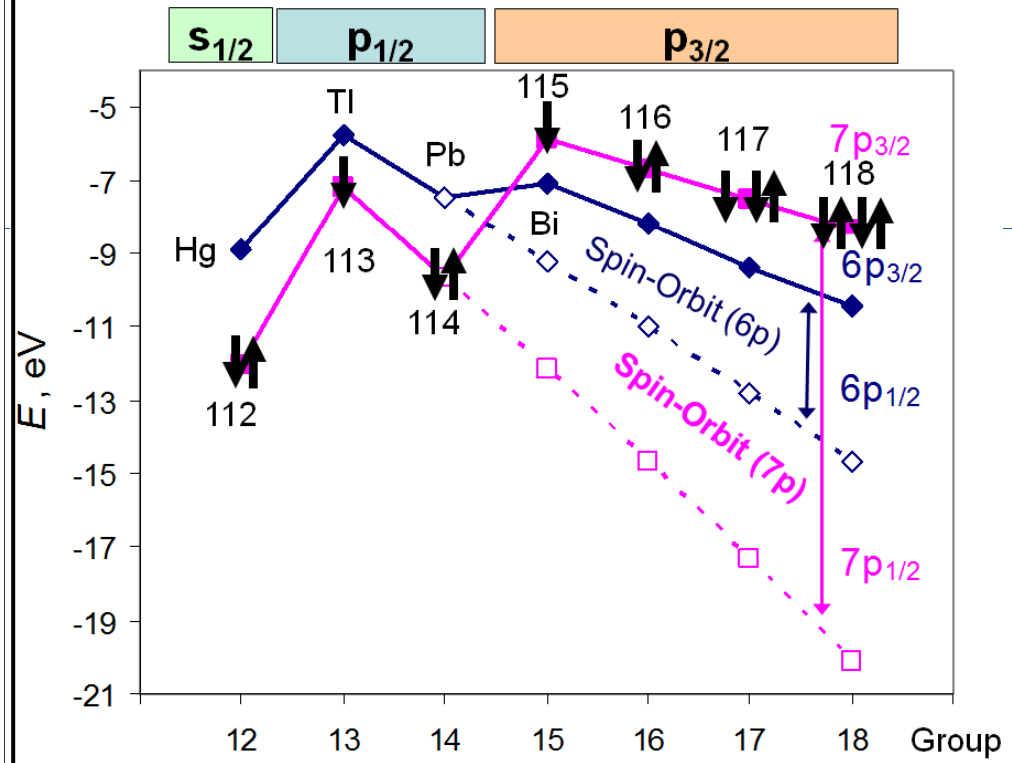
(Received 14 April 1975)

The Journal of Chemical Physics, Vol. 63, No. 2, 15 July 1975 1032



Theoretical Chemistry of SHE

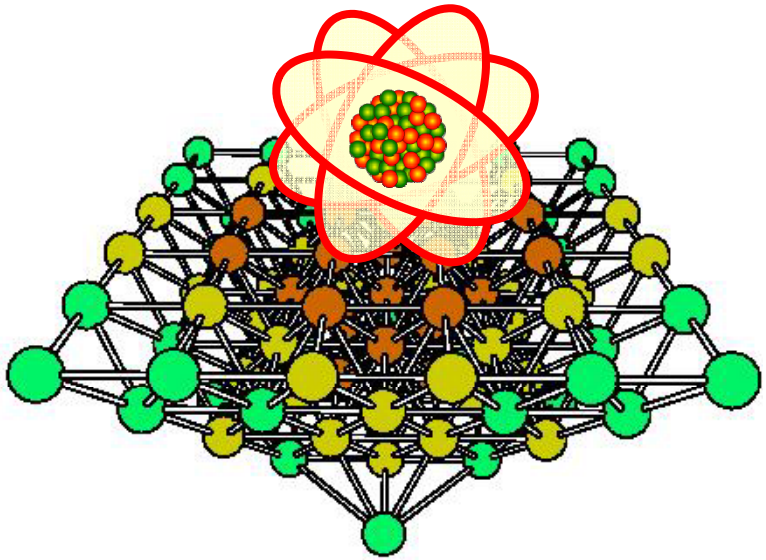
Atomic calculations



V. Pershina, "Electronic Structure and Chemistry of Heaviest Elements" in *Relativistic Methods for Chemists*; Eds: Leszczynski/Ishikawa; Springer (2010) 451

Adsorption of SHE on various surfaces (e.g., Au; SiO_2;...)

Extended cluster calculations: MAu_nAu_m



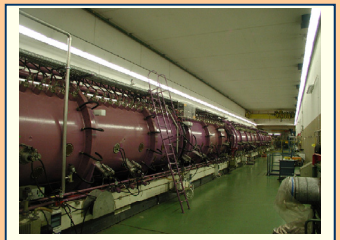
n = 34-36 m = 156

J. Anton et al., Phys. Rev. A 69 (2004) 012505
V. Pershina, et al., J. Chem. Phys. 13 (2009) 084713

Unique Combination for SHE Studies

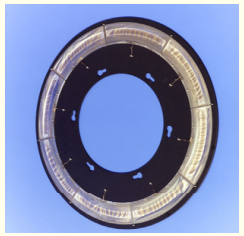
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

GSI

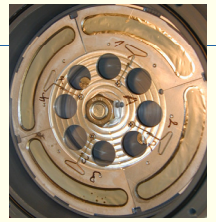


ECR + UNILAC

Beam



Stable targets



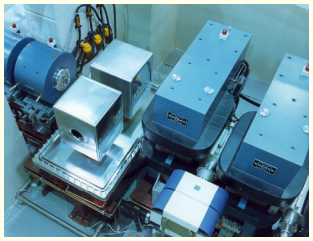
Actinide targets

TRIGA-

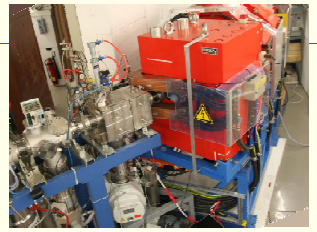
-LASER

-TRAP

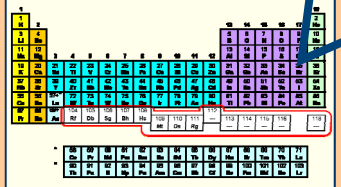
Radiochem. labs



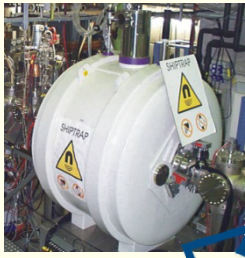
SHIP



TASCA

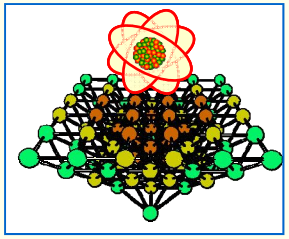


Chemistry



SHIPTRAP

TASISpec



Chemical theory

HIM – The New Helmholtz Institute Mainz

HELMHOLTZ GEMEINSCHAFT | GSI | Helmholtz-Institut Mainz | JOHANNES GUTENBERG UNIVERSITÄT MAINZ

HIM Director: Frank Maas

Helmholtz Institute Mainz (HIM)

3 Junior Research Groups
-
-J. Dvorak (IRiS)
(currently on leave of absence)
-

THEORY Floor

International Guests Programme

MAM	EMP	SPECF	SHE
Symmetry of Matter and Antimatter	*Hadron Structure with electomagn. Probes*	*Hadron Spectroscopy and Flavour*	*Stability and Properties of Superheavy Elements*
			Chemistry / *Physics*
			CED / N.N.

ACID *Accelerators and integrated Detectors*

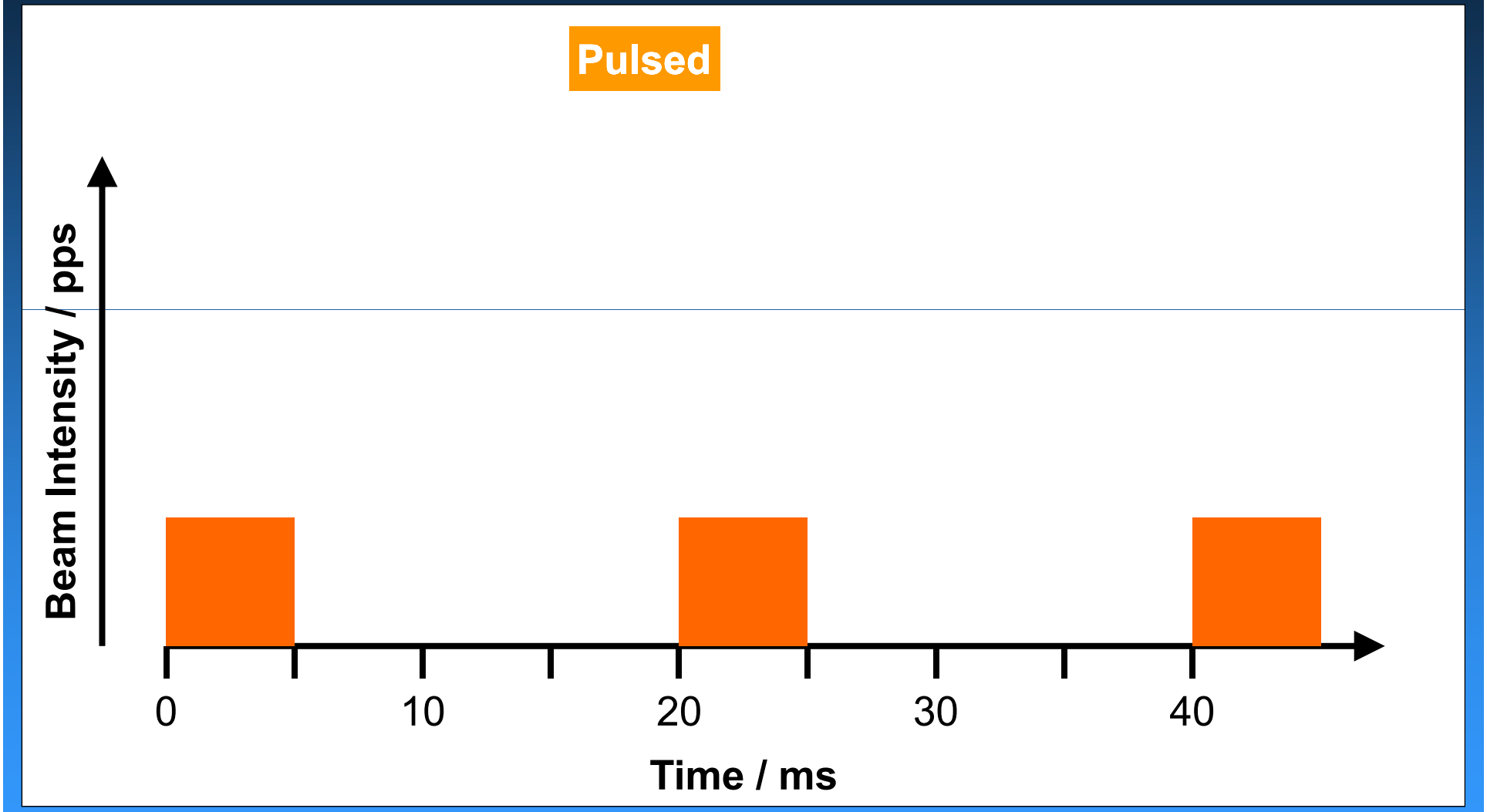
Toward a dedicated cw LINAC for SHE; ...

Administration

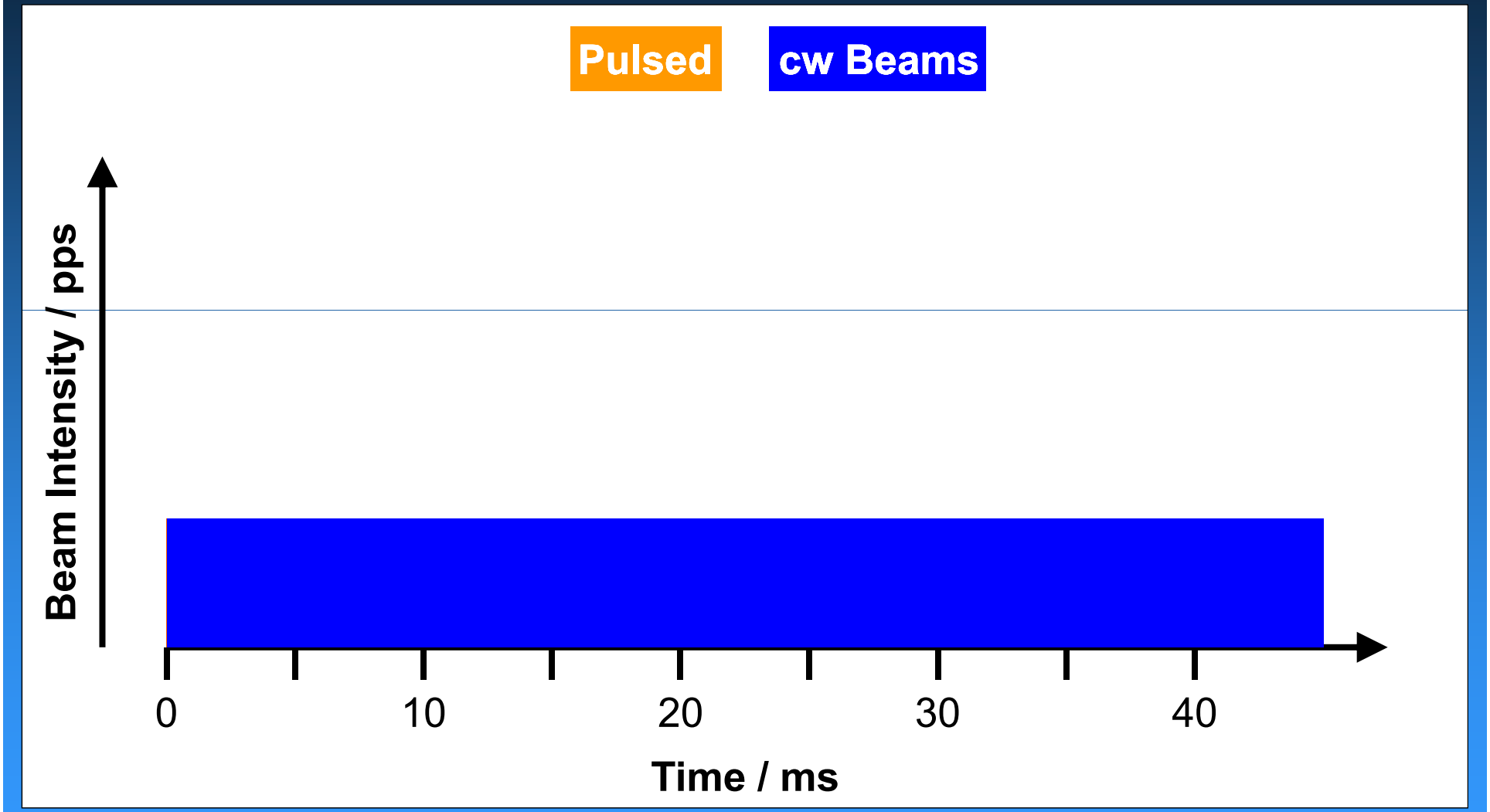
JG|U

At Mainz University (Institutes for Nuclear Physics, Nuclear Chemistry, Physics): 30 Full Time Equivalent (FTE) Personnel in Workshops and Laboratories

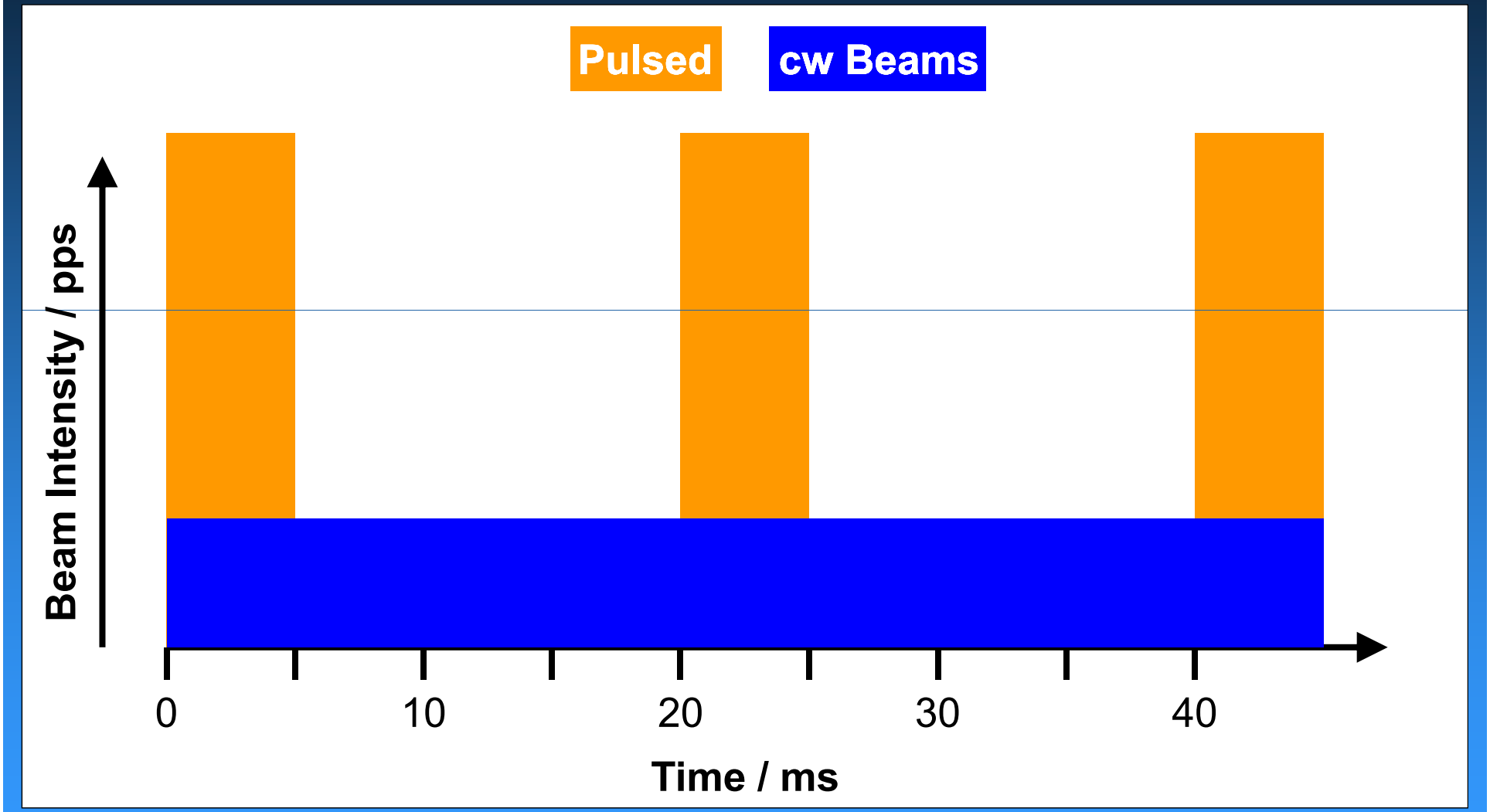
Toward A New Accelerator for SHE Research



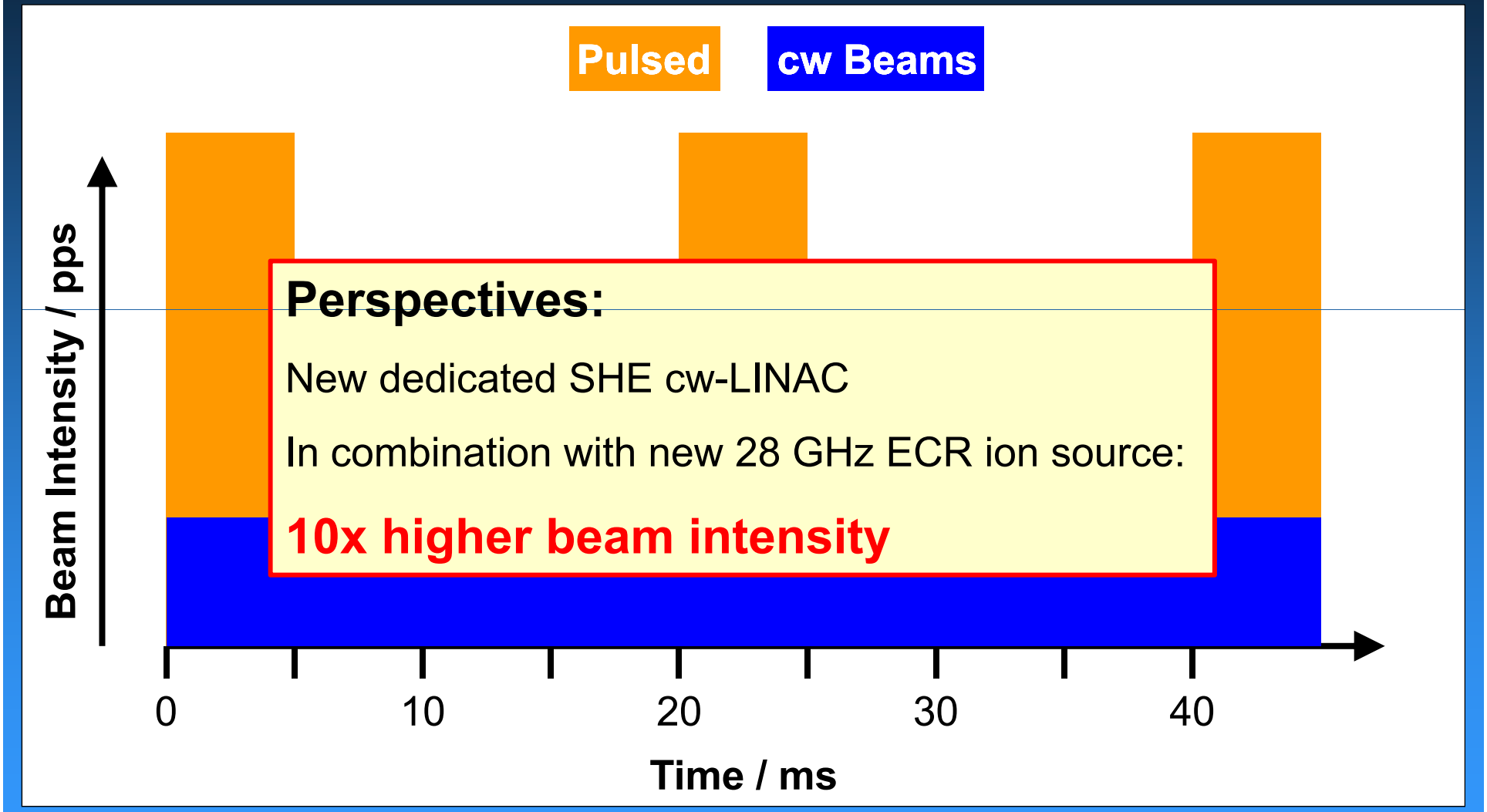
Toward A New Accelerator for SHE Research



Toward A New Accelerator for SHE Research



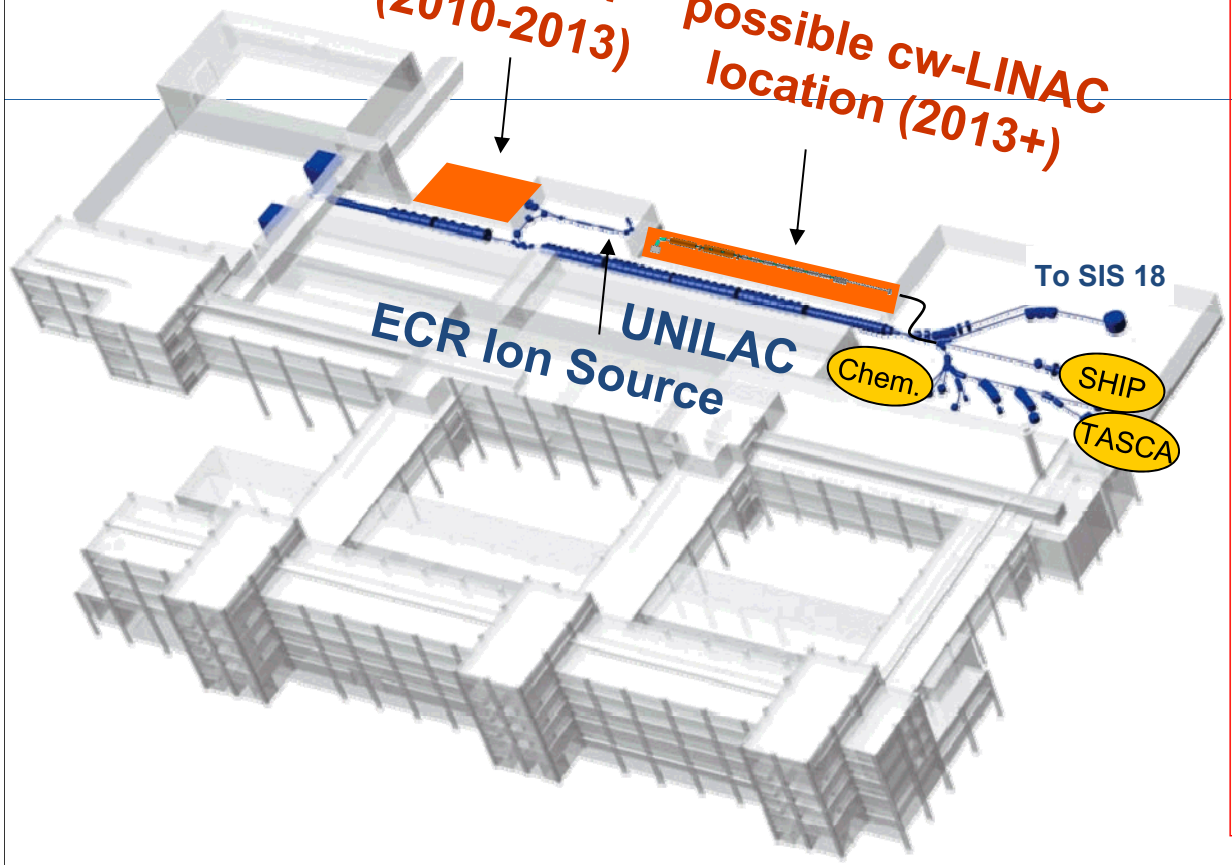
Toward A New Accelerator for SHE Research



Toward a Dedicated SHE LINAC

UNILAC not suited for simultaneous
- **FAIR (A>180, ≤3 Hz, 100 μs pulses)**
- **SHE operation (A<80, long duty cycle)**

HELMHOLTZ GEMEINSCHAFT
Helmholtz-Institut Mainz



Paving the way for dedicated superconducting cw-LINAC:

Energy: 3.5-7.5 MeV/u

Uncertainty: <3 keV/u

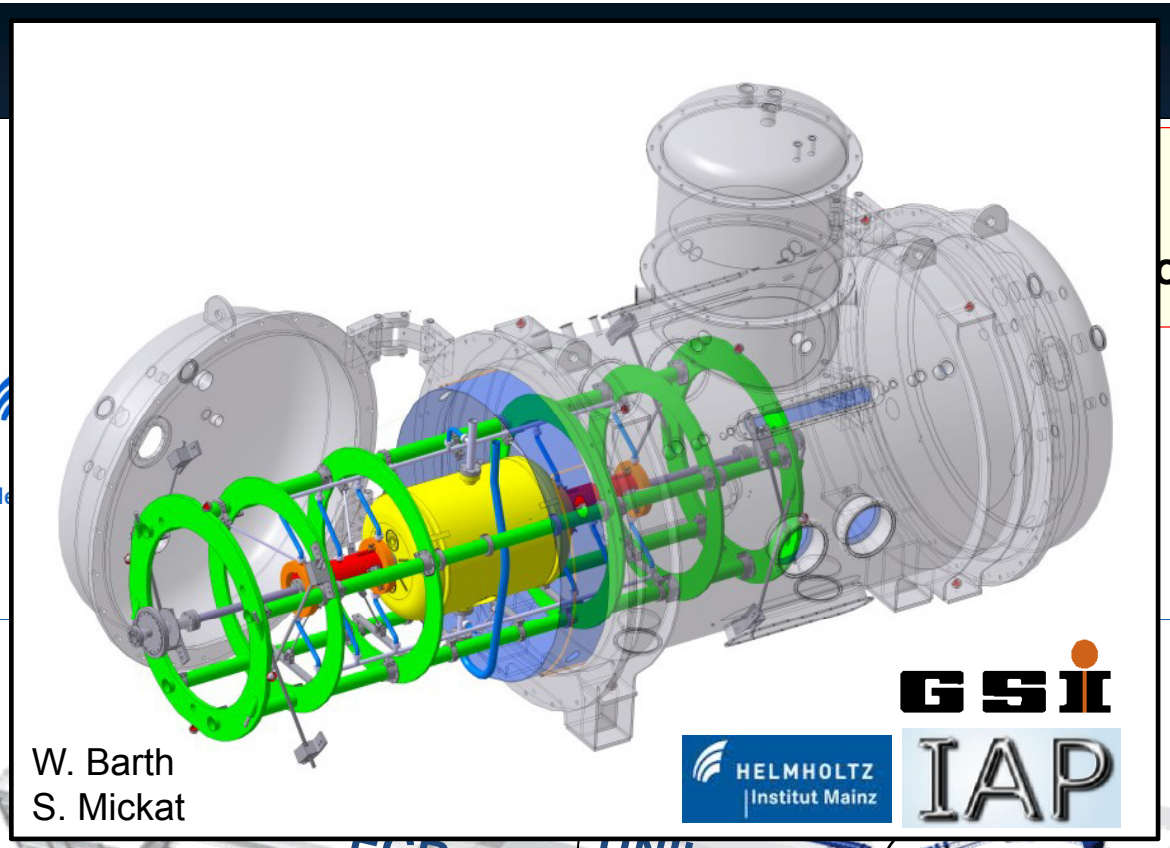
Duty cycle: 100%

Two Step Approach:

Construct first cavity as a prototype to demonstrate feasibility.
Beam test: 2013/14

Construction of full LINAC (2013-2017)

SHE LINAC



W. Barth
S. Mickat

HELMHOLTZ Institut Mainz

GSI IAP

(A>180, ≤3 Hz, 100 μs pulses)

operation (A<80, long duty cycle)

Paving the way for dedicated superconducting cw-LINAC:

Energy: 3.5-7.5 MeV/u

Uncertainty: <3 keV/u

Duty cycle: 100%

Two Step Approach:

Construct first cavity as a prototype to demonstrate feasibility.
Beam test: 2013/14

Construction of full LINAC (2013-2017)

The Darmstadt/Mainz SHE Community

Scientific staff
Technical staff
Diploma / PhD students

GSI Helmholtz Center for Heavy ion Research, Darmstadt:

SHE Chemistry (TASCA / X1) Department:

Ch.E. Düllmann, A. Yakushev, V. Pershina (Theory) [3]
E. Jäger, J. Krier, J. Runke (@ JG Univ. Mainz), B. Schausten, M. Grimm [5]

SHE Physics (SHIP/SHIPTRAP) Department:

F.P. Hessberger, N.N. (NF Rudolph), D. Ackermann, M. Block, S. Heinz, S. Hofmann [5]
H.-G. Burkhard [1]

Target Laboratory, Detector Laboratory, Experimental Electronics....

Johannes Gutenberg-University Mainz (Institute for Nuclear Chemistry):

Ch.E. Düllmann (SHE Chemistry), N.N. (NF Rudolph, SHE Physics); J.V. Kratz,
N. Trautmann, N. Wiehl [3]
J. Even, D. Hild, S. Klein, D. Renisch, A. Vascon [5]
Ch. Mokry, P. Thörle-Pospiech [2]

Transuranium Target Lab: K. Eberhardt *et al.*

Helmholtz Institute Mainz:

Ch.E. Düllmann (SHE Chem.), F.P. Hessberger (SHE Physics, interim), N.N. (NF Rudolph)
J. Dvorak (on leave), J. Khuyagbaatar, L.-L. Andersson, E. Rodriguez Minaya
J. Maurer, V. Yakusheva [6]

Current International Collaboration Partners

(SHE Chemistry / TASCA)

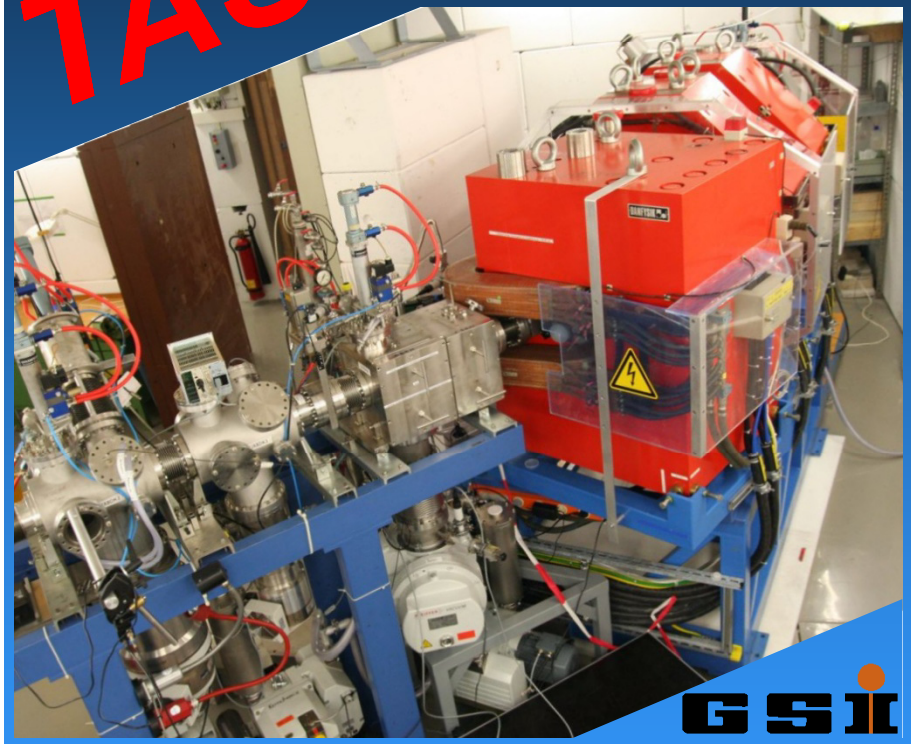
LBNL/UCB Berkeley (USA)
LLNL Livermore (USA)
Vanderbilt U (USA)
ORNL Oak Ridge (USA)
UNAL Bogota (Columbia)
U Liverpool (UK)
U Surrey (UK)

U Lund (Sweden)
U Jyväskylä (Finland)
U Oslo (Norway)
Chalmers U Gothenburg (Sweden)
PSI Villigen (Switzerland)
ITE Warschau (Poland)
SINP Kolkata (India)
IMP Lanzhou (China)
JAEA Tokai (Japan)

GSI
JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ
HELMHOLTZ ASSOCIATION
Helmholtz Institute Mainz

TransActinide Separator and Chemistry Apparatus
A Separator for Actinide Based Reactions

TASCA



www.gsi.de/tasca

M. Schädel, Eur. Phys. J. D 45 (2007) 67

A. Semchenkov et al., NIMB 266 (2008) 4153

Timeline

2002 goals defined

2003 community formed

2004 decision: gas-filled sep.

2005 start building TASCA
define commissioning prog.

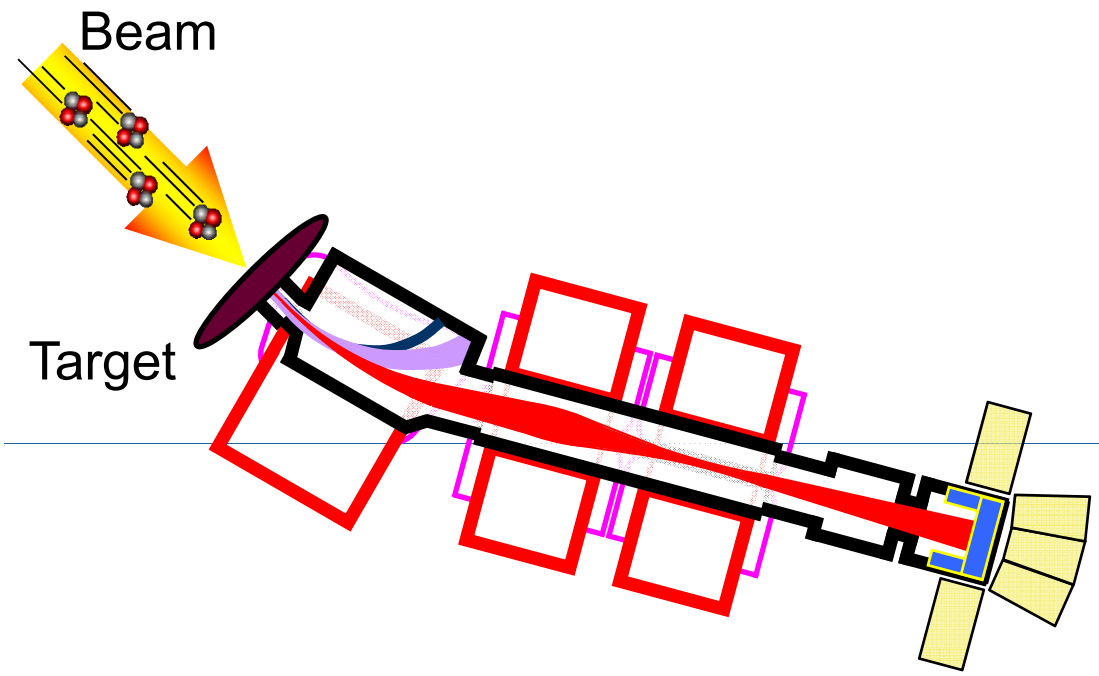
2006 first beam in cave (Jan.)
first EVR in focal plane det. (Apr.)

2006-2008
TASCA commissioning

2008 commissioning completed:
Transactinides reached! Z=104

2009 Heaviest Element at GSI: Z=114

Recoil Separators for SHE studies



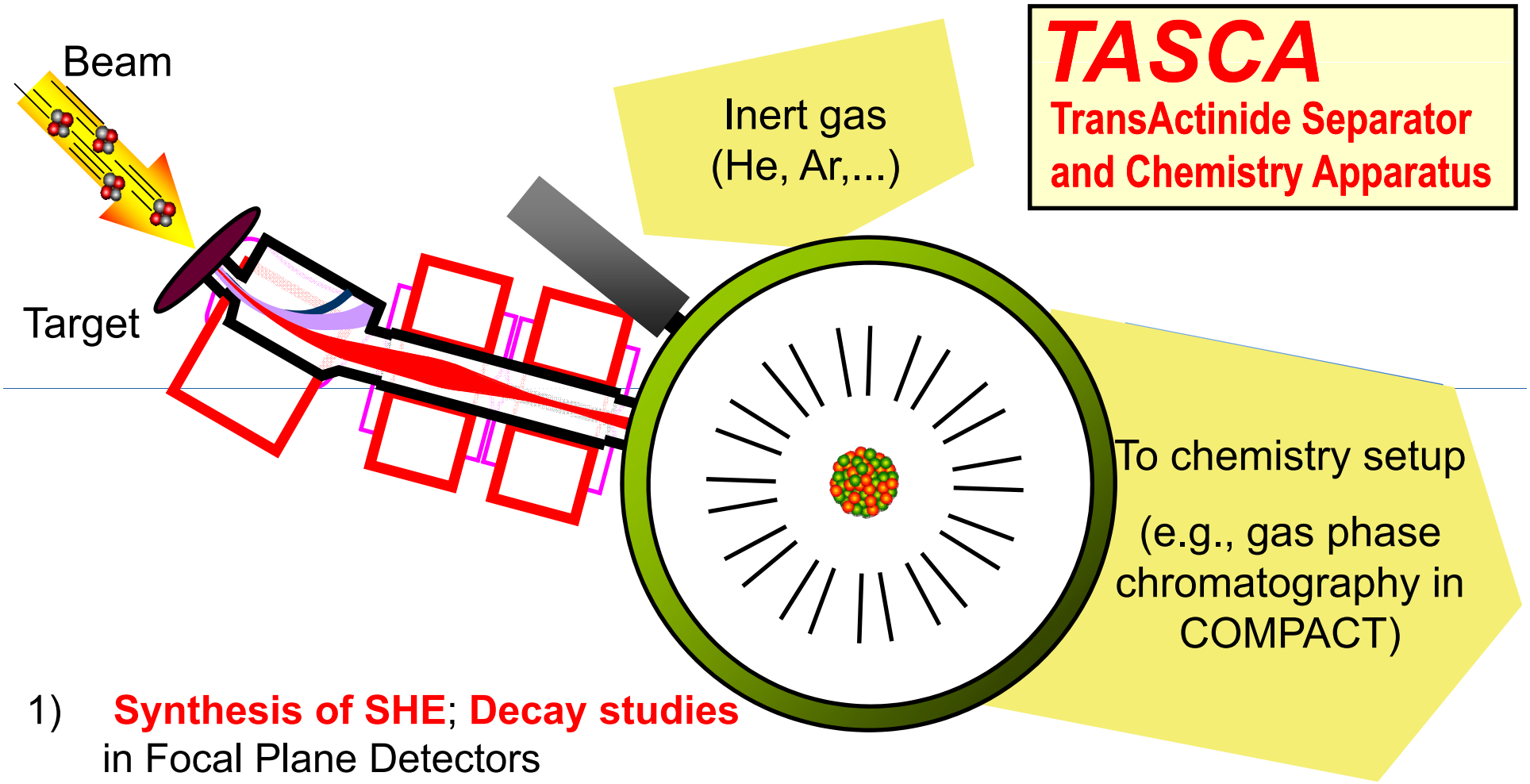
TASCA
TransActinide Separator and Chemistry Apparatus

Particle Detector (α; e^-; SF)

Photon Detector (γ; X)

1) **Synthesis of SHE**; **Decay studies** in Focal Plane Detectors

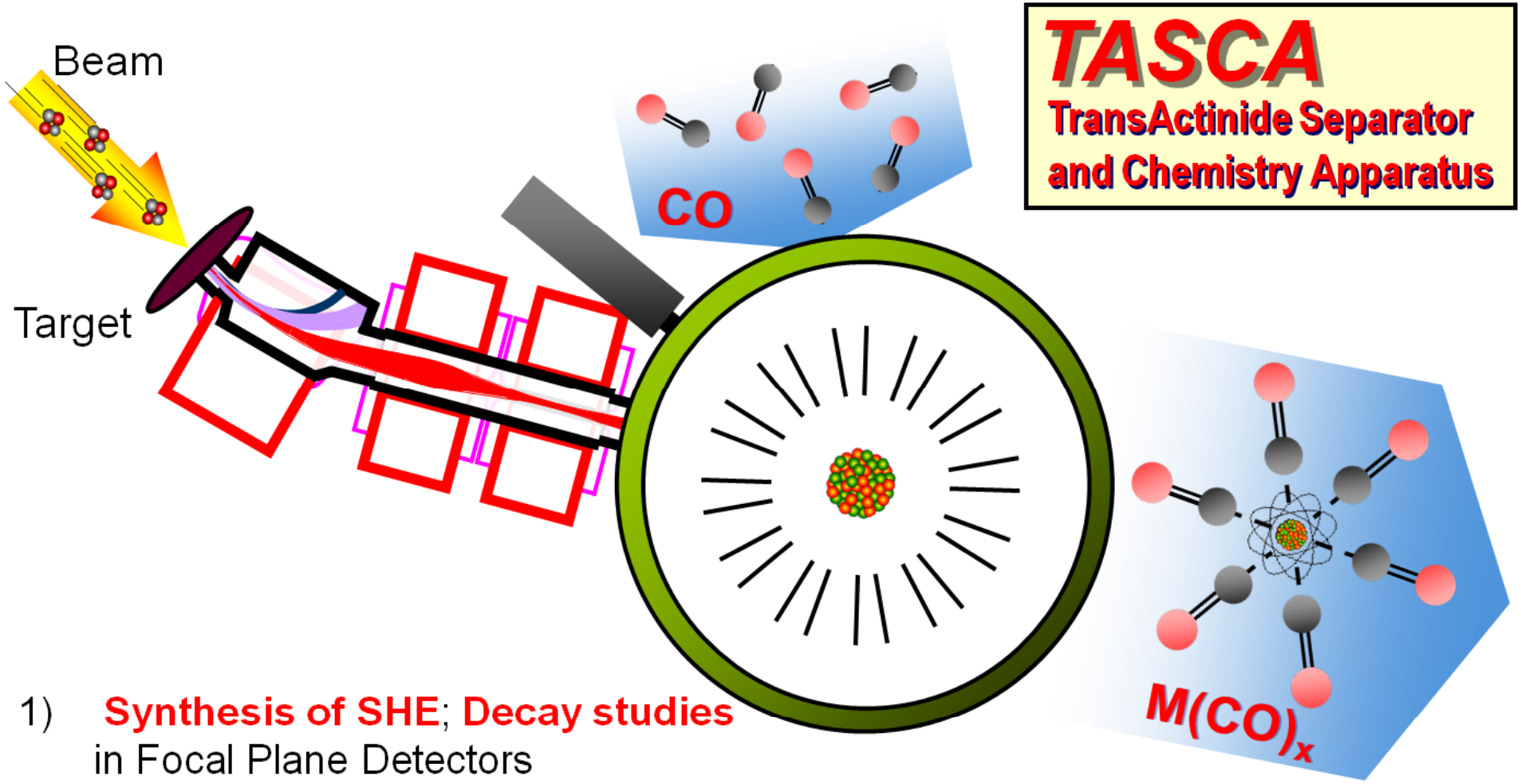
Recoil Separators for SHE studies



1) **Synthesis of SHE**; **Decay studies** in Focal Plane Detectors

2) Preseparated SHE for chemical studies under low-background conditions (Important for **volatile p-Elements Z=112, 114, ...**)

Recoil Separators for SHE studies

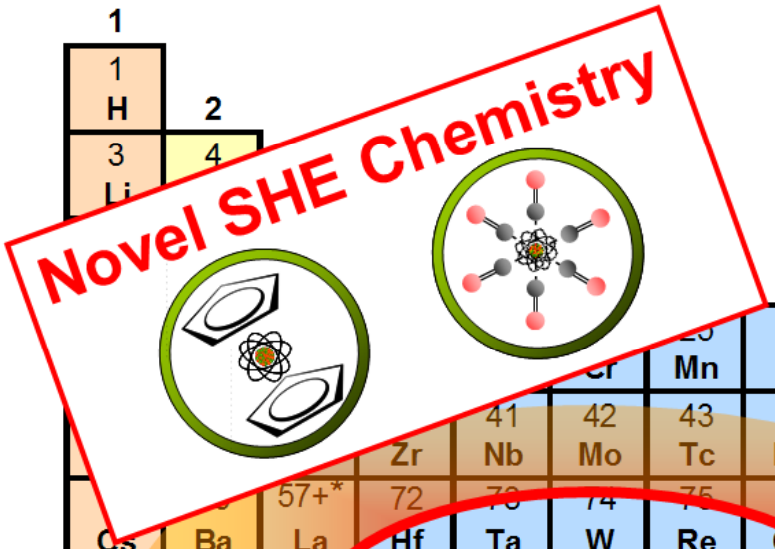


1) **Synthesis of SHE**; **Decay studies** in Focal Plane Detectors

2) Preseparated SHE for chemical studies under low-background conditions (Important for **volatile p-Elements Z=112, 114, ...**)

3) Preseparated SHE available in beam-free environment for study of new SHE chemical compounds (**organometallic,...**), Z~104-108

Superheavy Element Chemistry



Chemistry of New Elements with Single Atoms

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H				5 B	6 C	7 N											2 He
3 Li	4											13 Al					10
							26 Fe	27 Co	28 Ni	29						Br	36 Kr
		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45					Sn	51 Sb	52 Te	53 I	54 Xe
Cs	Ba	57+* La	72 Hf	73 Ta	74 W	75 Re	76 Os	Ir			Hg	81 Tl	82 Pb	83 Bi	Po	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 ---	115 ---	116 ---	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

10 Years of Element 114 History: 1999-2009

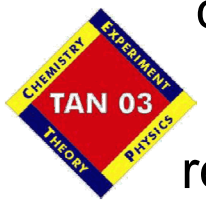
1999/07: Discovery of $^{287}114$ from $^{48}Ca+^{242}Pu$ claimed at VASSILISSA feeding ~3-min SF-decaying ^{283}Cn

1999/10: Discovery of $^{289}114$ from $^{48}Ca+^{244}Pu$ feeding a long-lived chain (~30 min) to ^{277}Hs claimed at DGFRS

2000/09: Discovery of $^{288}114$ from $^{48}Ca+^{244}Pu$ claimed at DGFRS

2000/12 Observation of $^{288}114$ as daughter of $^{292}116$ from $^{48}Ca+^{248}Cm$ claimed at DGFRS

2002/12 Observation of $^{286}114$ as grand-daughter of $^{294}118$ in $^{48}Ca+^{249}Cf$ claimed at DGFRS

2003 

At TAN03 in Napa (for me):
reassigning isotopes:
289 disappears. 288→289; new isotope 288; new properties 287: daughter is 4-s α-decaying ^{283}Cn. Published in 2004.

2007/07 Chemical study of Cn using daughter of $^{287}114$, PSI @ Dubna

2009/09 Independent observation of $^{286,287}114$ at BGS

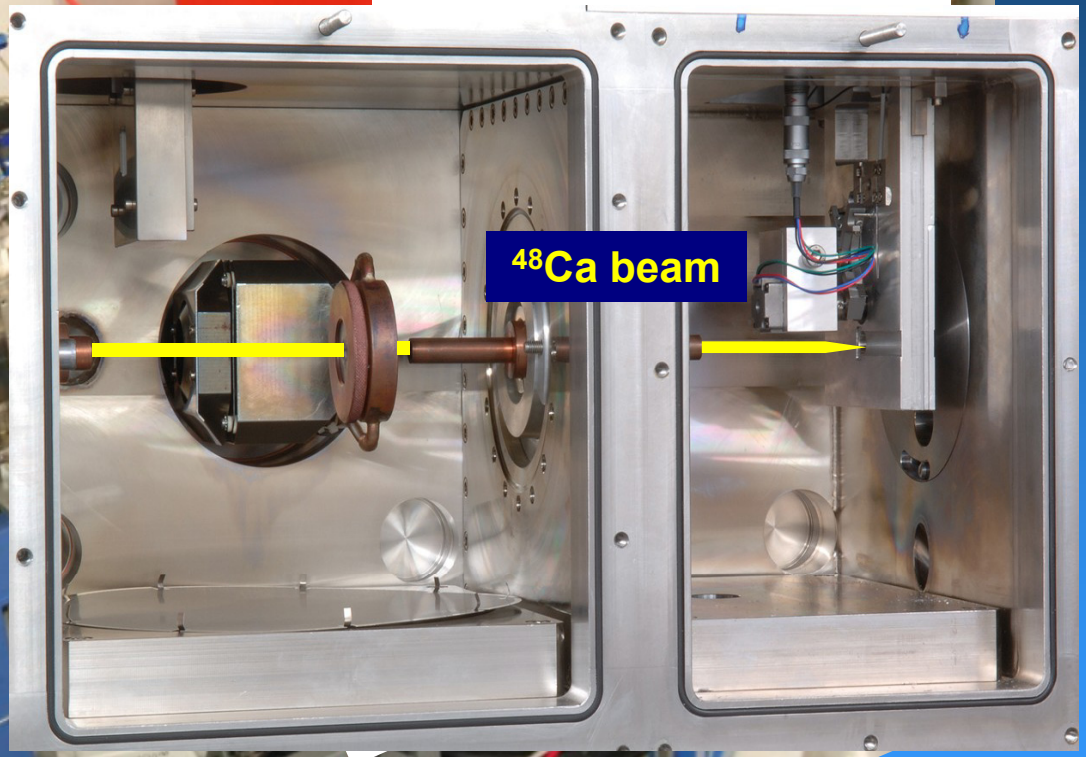
The *TASCA* Element 114 Physics Collaboration

GSI Darmstadt (D)	D. Ackermann, M. Block, W. Brüchle, Ch.E. Düllmann, H. Essel, W. Hartmann, F.P. Heßberger, A. Hübner, E. Jäger, J. Khuyagbaatar, B. Kindler, J. Krier, N. Kurz, B. Lommel, M. Schädel, B. Schausten, E. Schimpf, J. Steiner
TU Munich (D)	J.M. Gates, A. Gorshkov, R. Graeger, A. Türler, A. Yakushev
Univ. Mainz (D)	K. Eberhardt, J. Even, D. Hild, J.V. Kratz, D. Liebe, J. Runke, P. Thörle-Pospiech, N. Wiehl
Univ. Liverpool (UK)	L.-L. Andersson, R.-D. Herzberg, E. Parr
LBNL / UC Berkeley (USA)	J. Dvorak, P.A. Ellison, K.E. Gregorich, H. Nitsche
SINP Kolkata (IND)	S. Lahiri, M. Maiti
Univ. Oslo (N)	J.P. Omtvedt, A. Semchenkov
Univ. Lund (S)	D. Rudolph
U Jyväskylä	J. Uusitalo
ITE Warsaw (PL)	M. Wegrzecki


TASCA
www.gsi.de/tasca

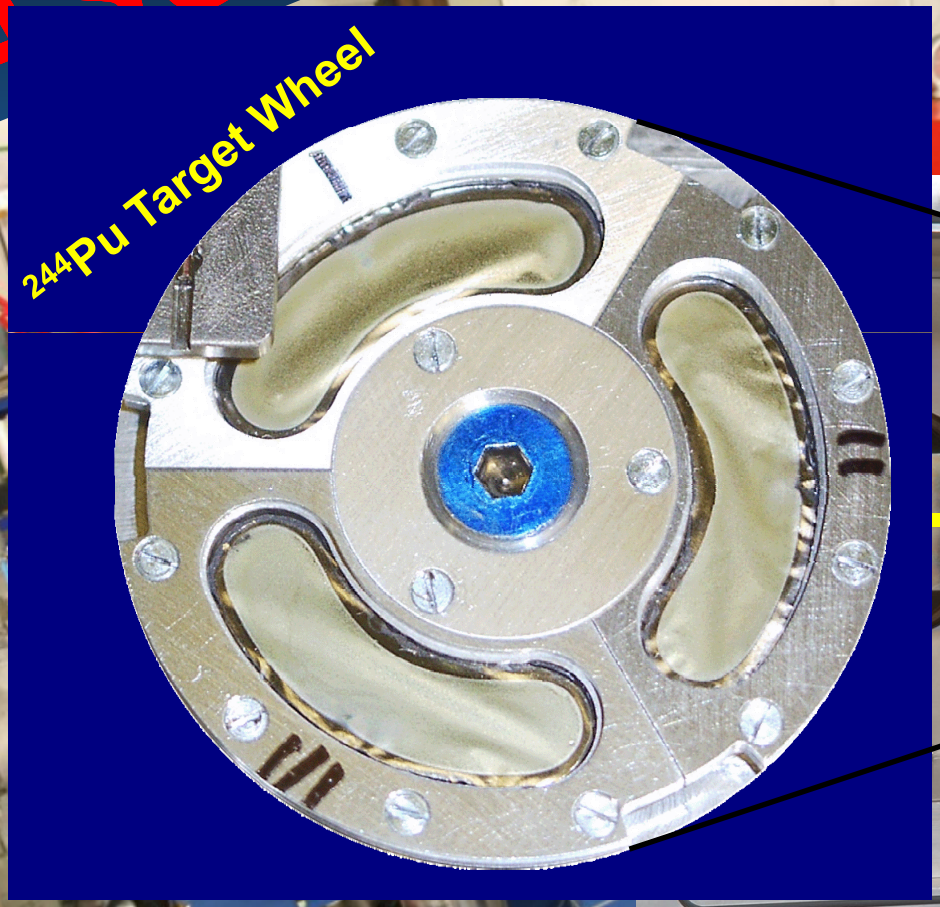
TASCA

Target Chamber
side view

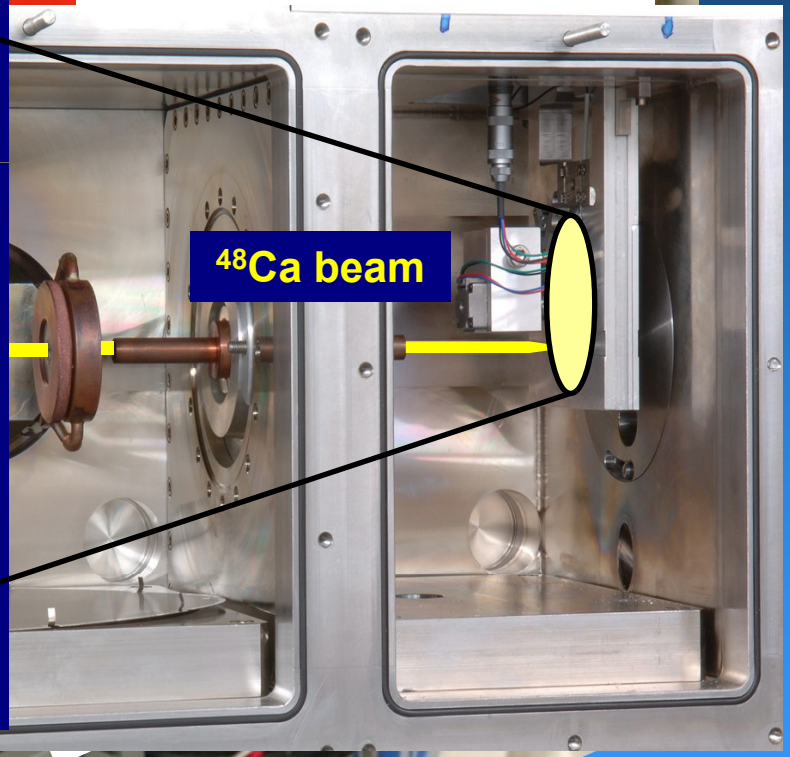


www.gsi.de/tasca

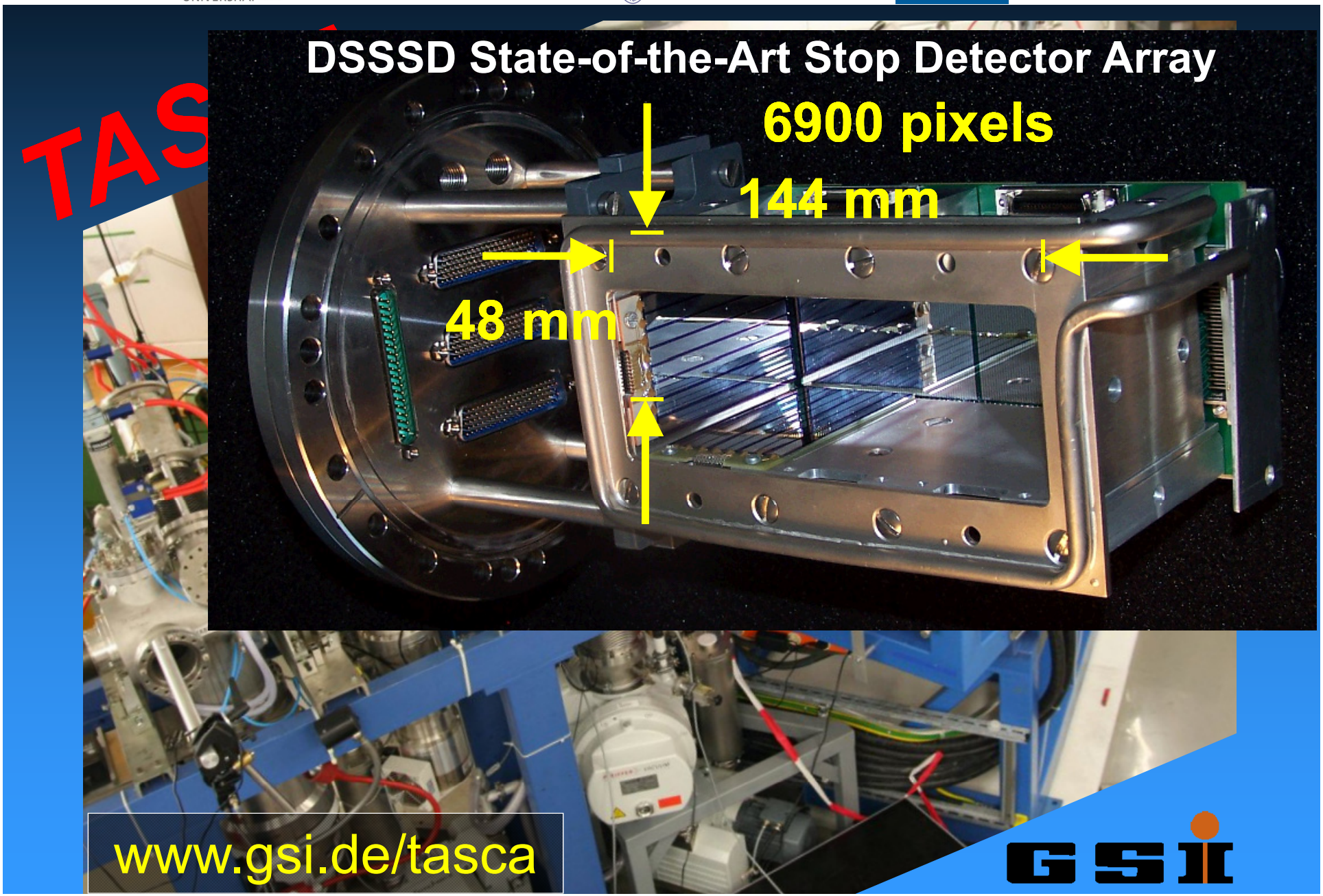
TASCA



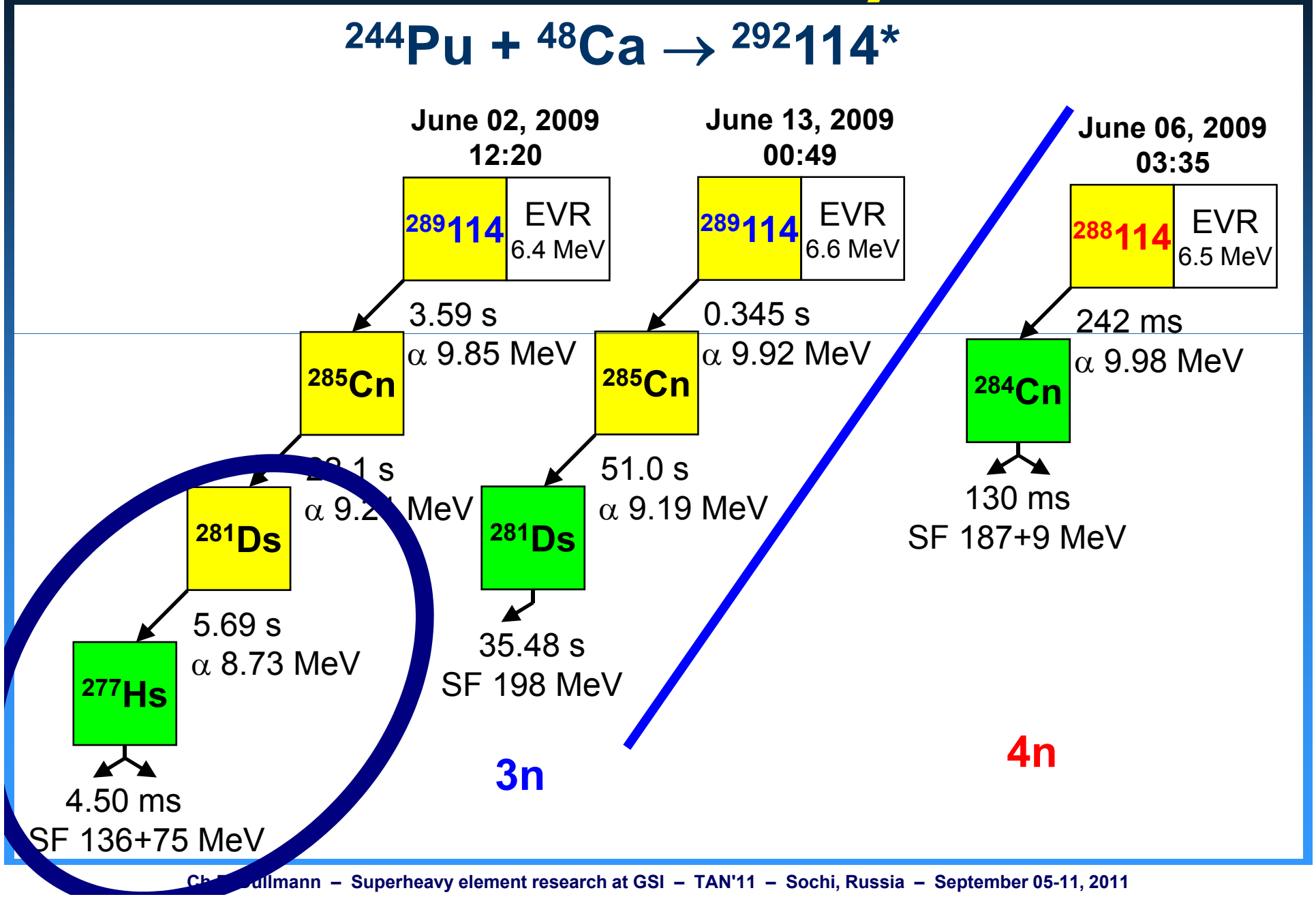
Target Chamber
side view



www.gsi.de/tasca


DSSSD State-of-the-Art Stop Detector Array
6900 pixels
144 mm
48 mm
TAS
www.gsi.de/tasca

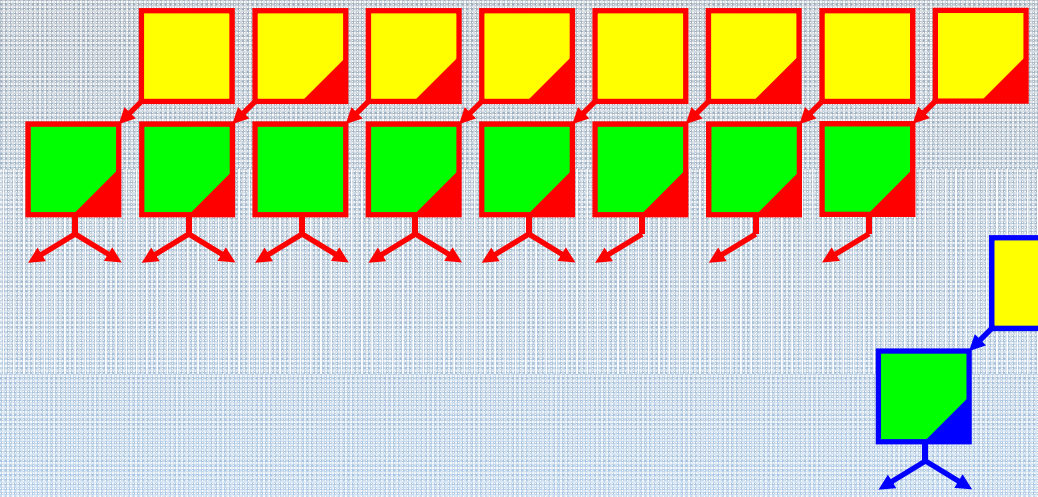
Three Kinds of Decay Chains



Observed Decay Chains

8 chains from $^{288}114$ (4n)

2 chains from $^{289}114$ (3n)

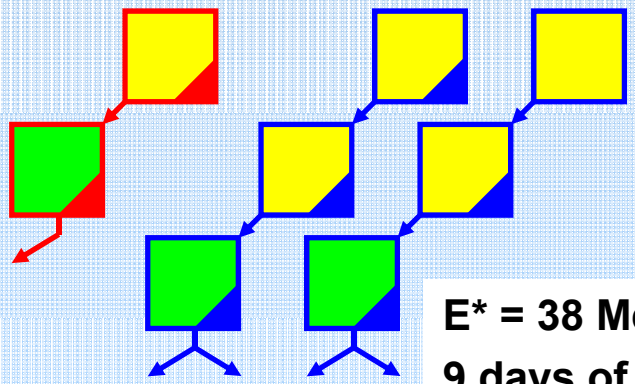


E* = 42 MeV

14 days of beamtime

1 chains from $^{288}114$ (4n)

2 chains from $^{289}114$ (3n)



E* = 38 MeV

9 days of beamtime

Summary:

9x $^{288}114$

4x $^{289}114$

α decay

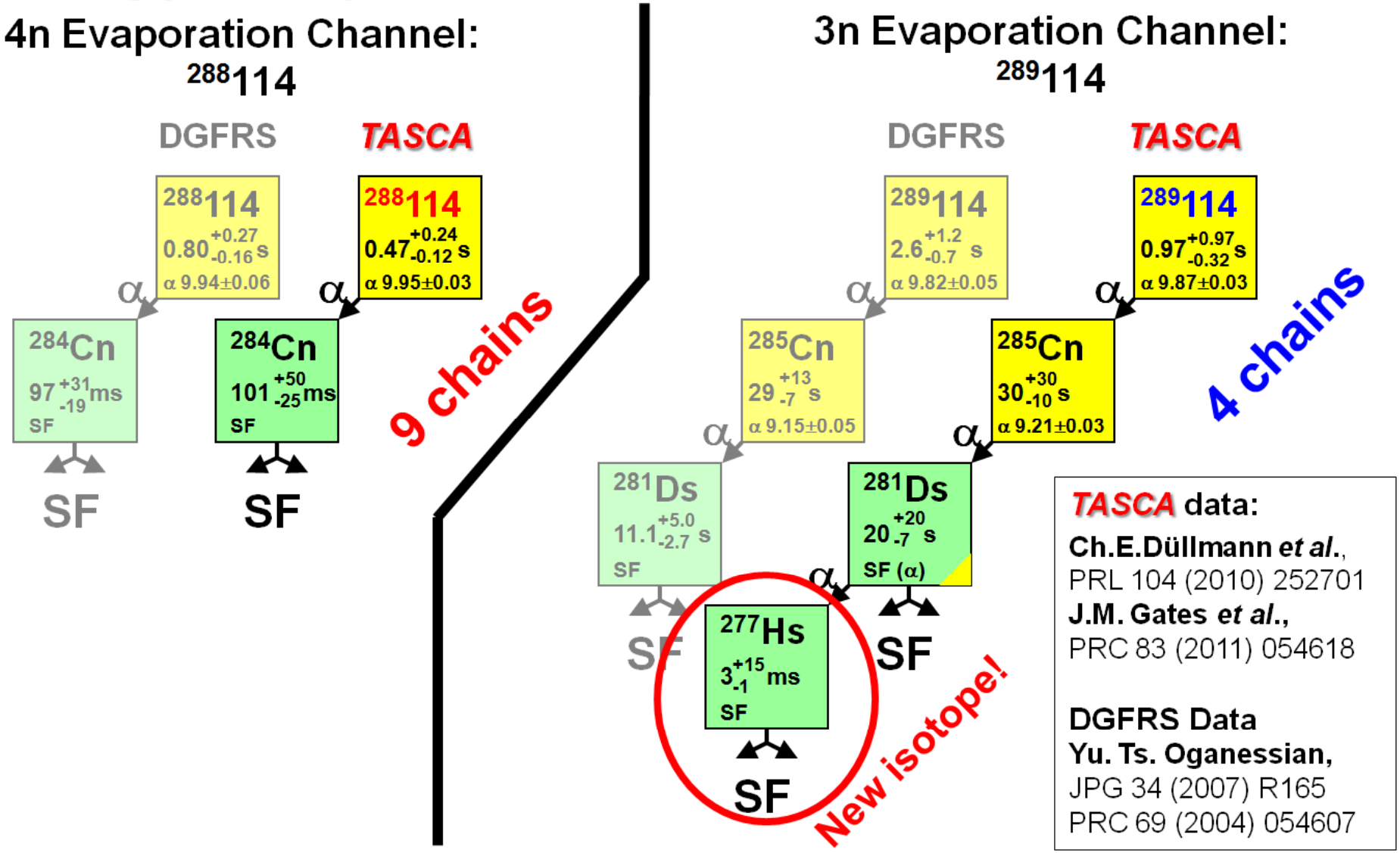
SF

outside of beam pulse

The Element 114 *TASCA* Experiment

13 Decay Chains in 22 Days → Highest SHE Detection Rate

$^{48}Ca + ^{244}Pu \rightarrow {}^{292}114^* \rightarrow {}^{288}114 + 4n$ / $^{289}114 + 3n$

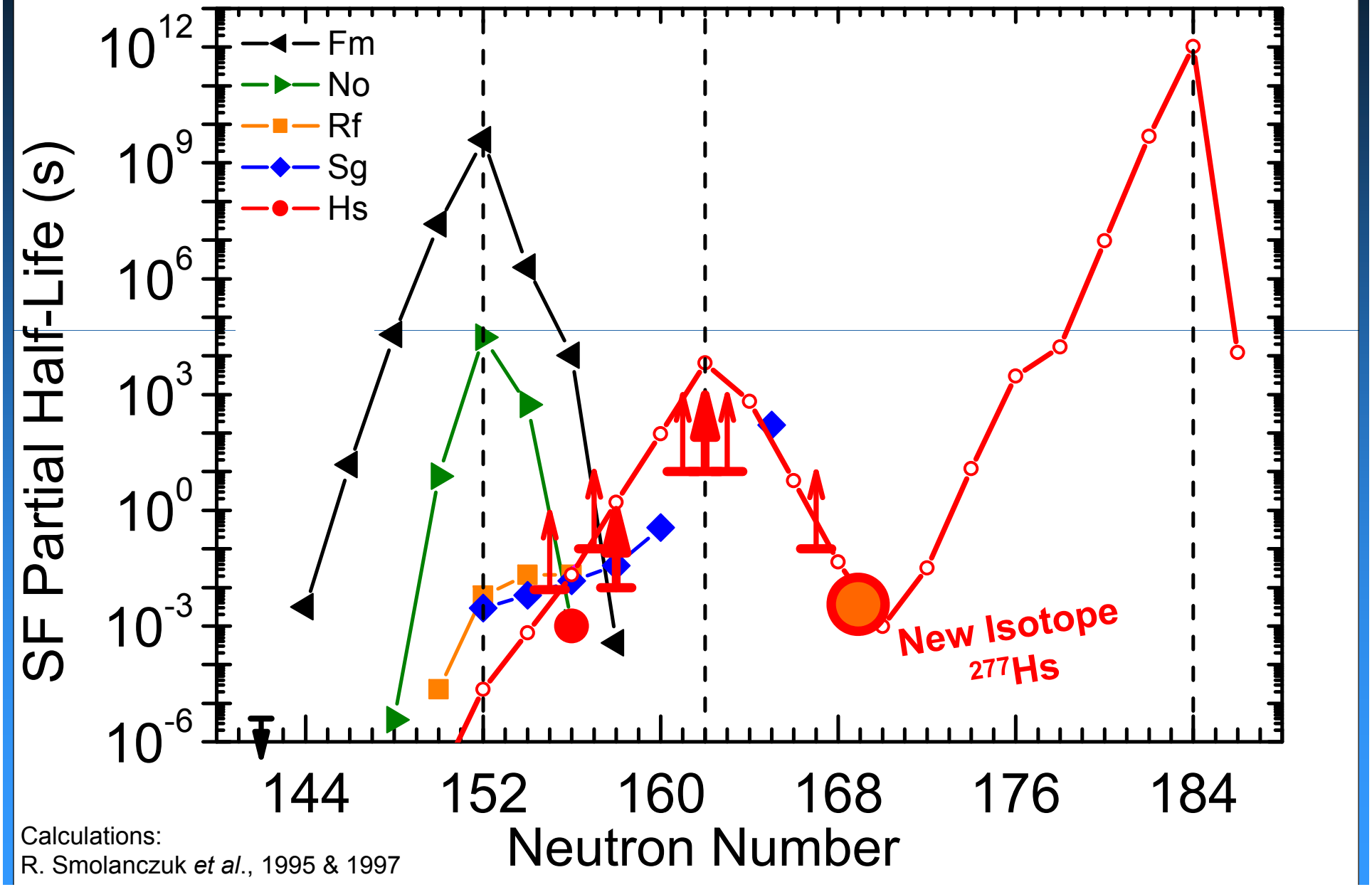


***TASCA* data:**

Ch.E.Düllmann *et al.*,
PRL 104 (2010) 252701
J.M. Gates *et al.*,
PRC 83 (2011) 054618

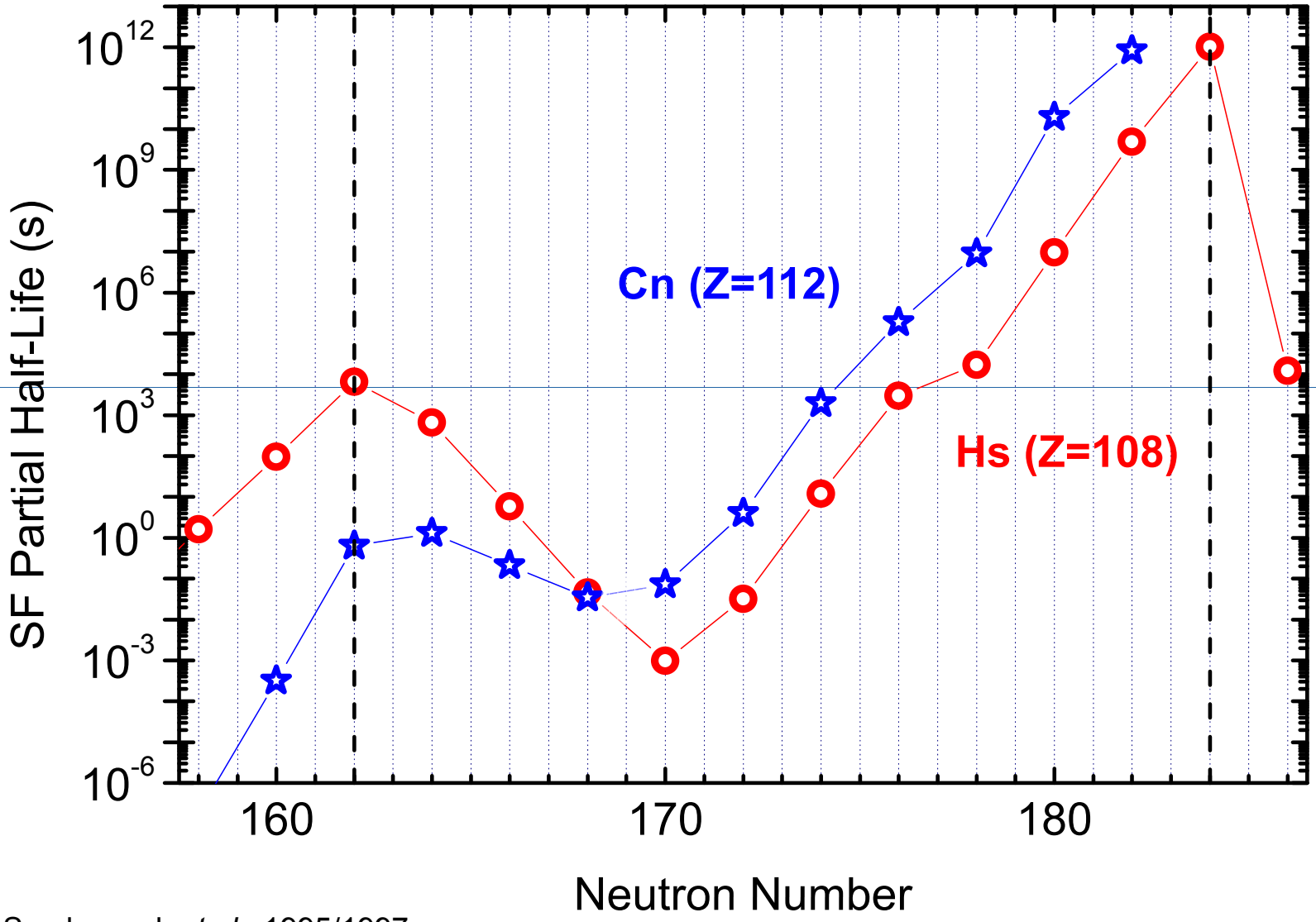
DGFRS Data
Yu. Ts. Oganessian,
JPG 34 (2007) R165
PRC 69 (2004) 054607

Systematics of SF Half-Lives



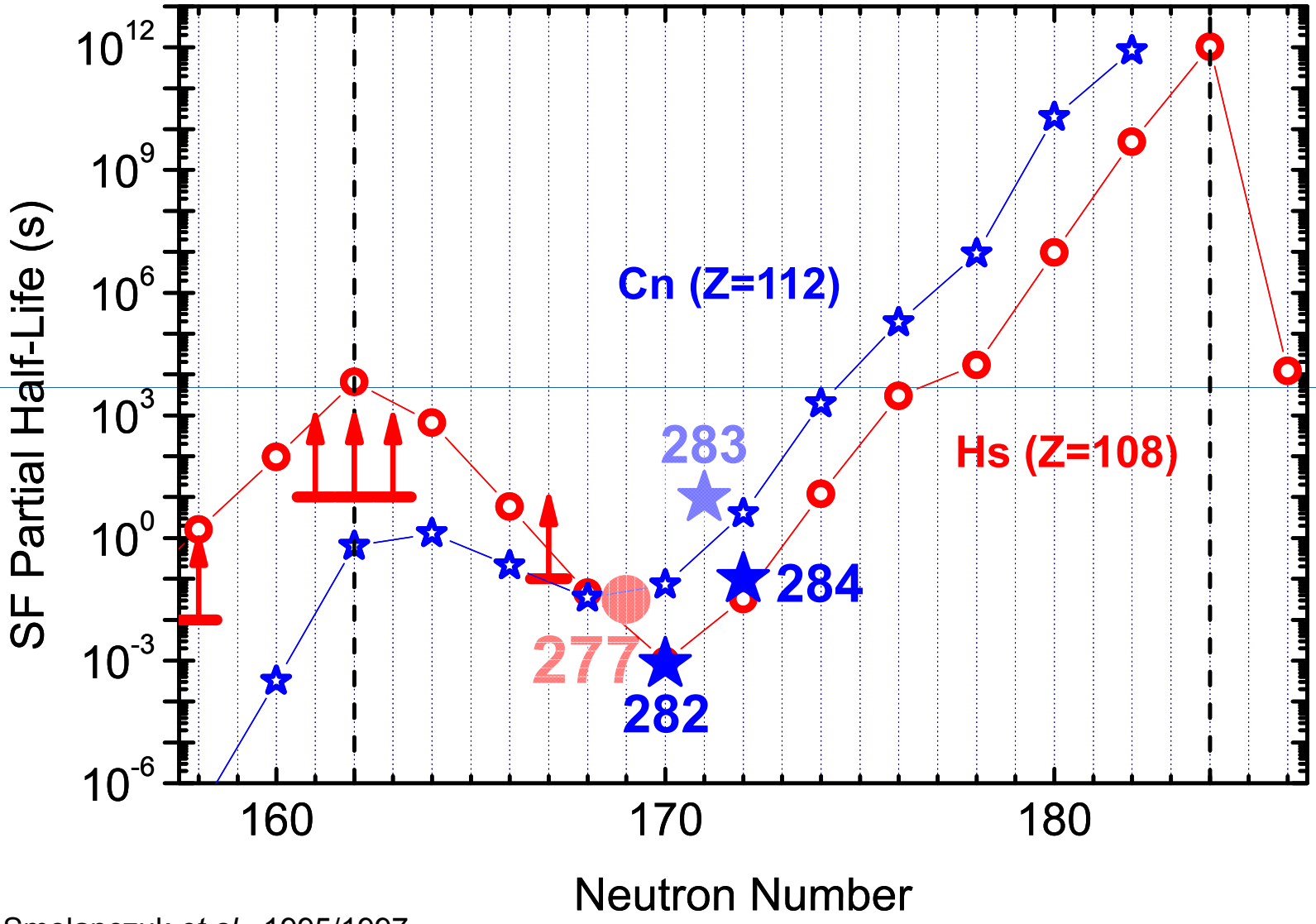
Calculations:
R. Smolanczuk *et al.*, 1995 & 1997

Systematics of SF beyond N=162



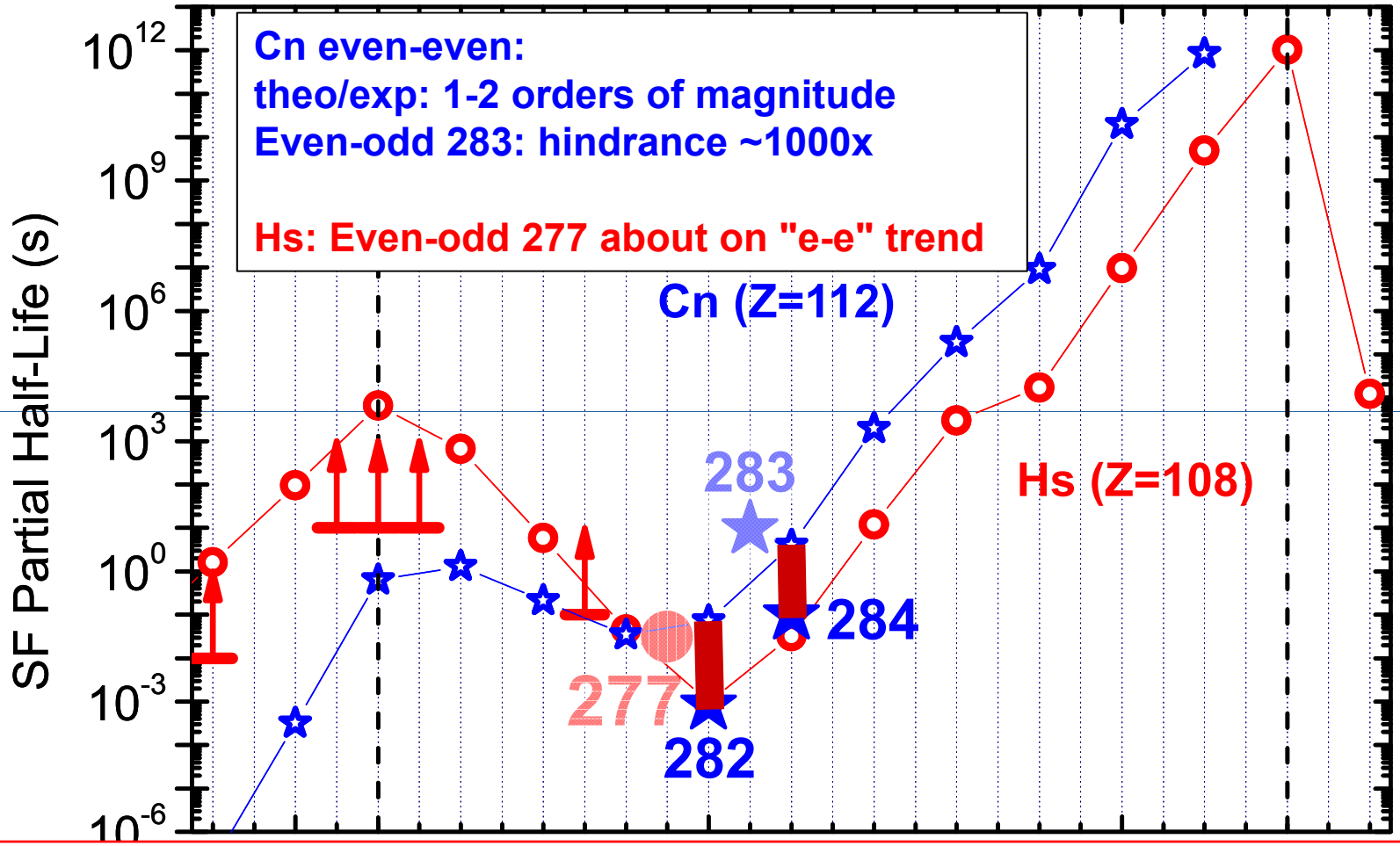
Theory: Smolanczuk *et al*., 1995/1997
Exp Cn: Oganessian *et al*. 2007
Exp Hs: Hofmann *et al*. (266); Dvorak *et al*. (269-271) Gates *et al*. / Düllmann *et al*. (277)

Systematics of SF beyond N=162



Theory: Smolanczuk *et al*., 1995/1997
Exp Cn: Oganessian *et al*. 2007
Exp Hs: Hofmann *et al*. (266); Dvorak *et al*. (269-271) Gates *et al*. / Düllmann *et al*. (277)

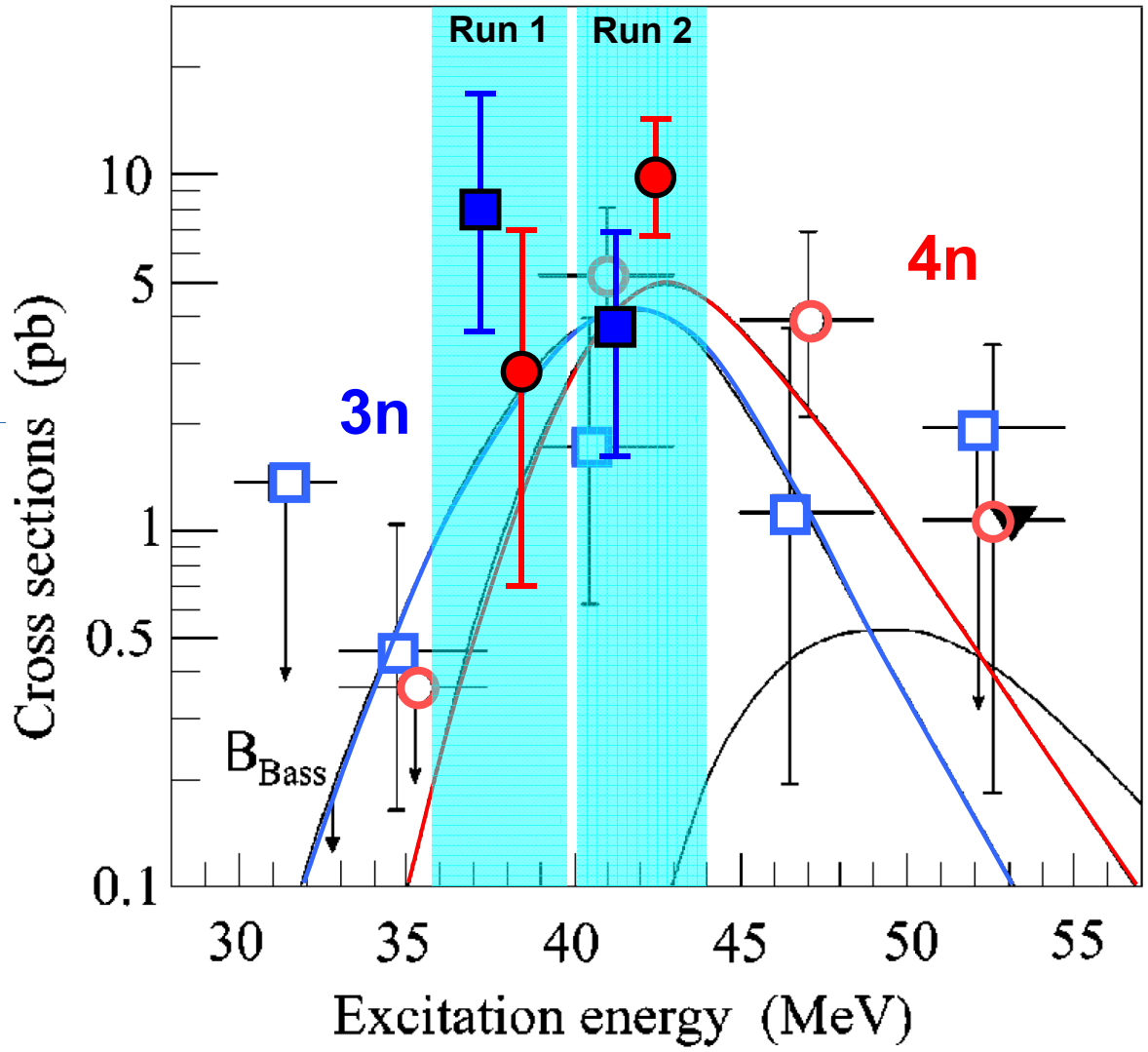
Systematics of SF beyond N=162



Theory seems to slighty underestimate fall-off of $T_{1/2}$(sf) beyond N=162

Exp Hs: Hofmann *et al.* (266); Dvorak *et al.* (265-271) Gates *et al.* / Düllmann *et al.* (277)

^{244}Pu+^{48}Ca: High cross sections for element 114 confirmed



Error bars include statistical errors.
TASCA systematic error is estimated to 14%.

Energies studied at *TASCA*

Dubna Data

Oganessian *et al.*,
J. Phys. G, 2008

***TASCA* Data**

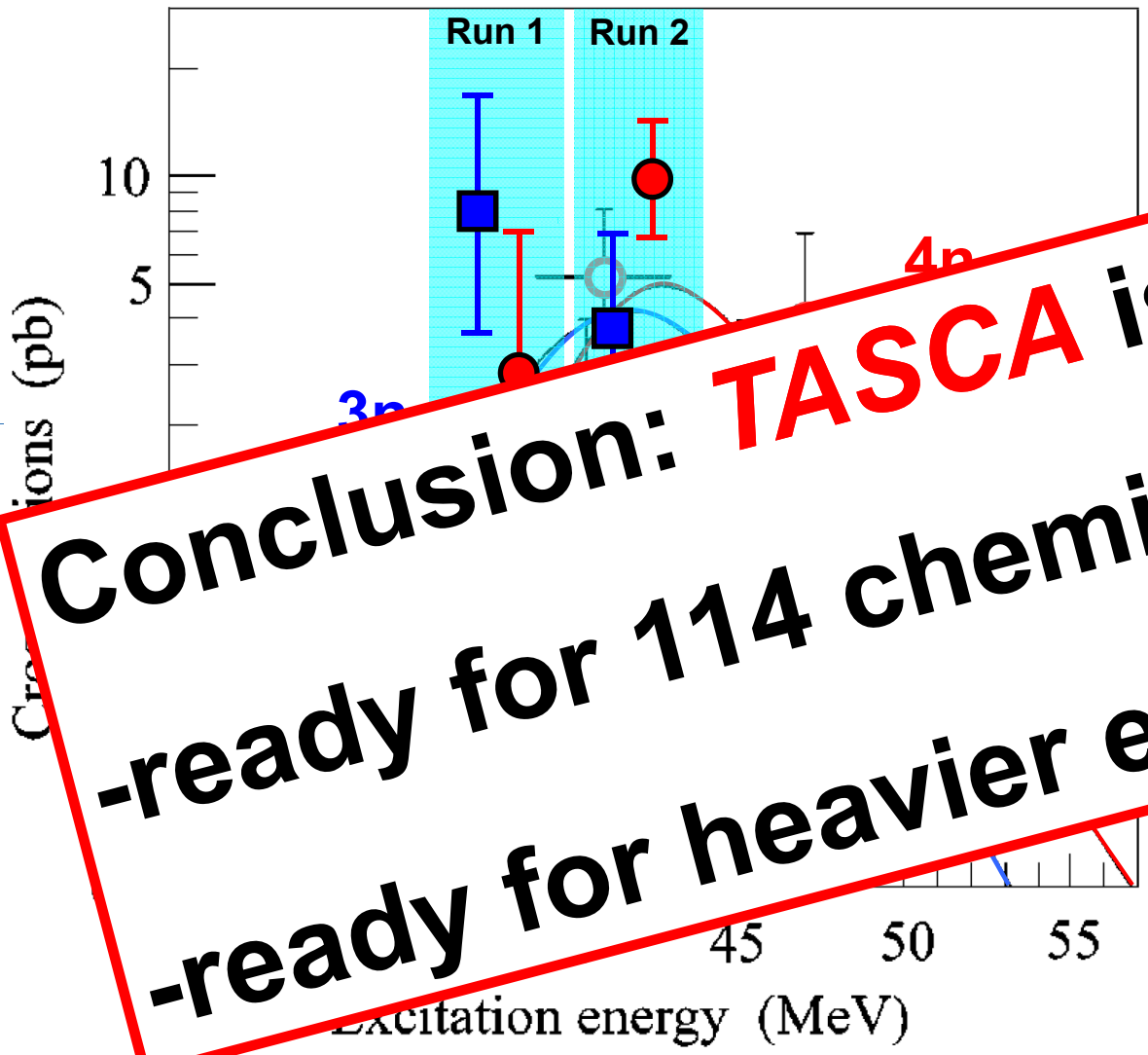
Ch.E. Düllmann *et al.*,
PRL 104 (2010) 252701
J.M. Gates et al.,
PRC 83 (2011) 054618

Theory

V. Zagrebaev,
NPA 734 (2004) 164

10 pb! Largest σ for the "classical SHE around Z=114"

^{244}Pu+^{48}Ca: High cross sections for element 114 confirmed



Energies studied at *TASCA*

Conclusion: *TASCA* is
-ready for 114 chemistry
-ready for heavier elements

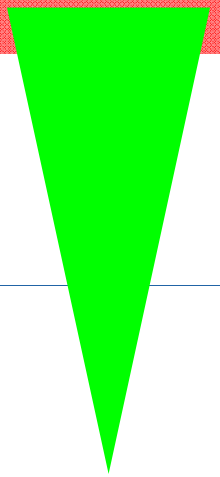
NPA 734 (2004) 164

10 pb! Largest σ for the "classical SHE around Z=114"

Error bars include statistical errors.
TASCA systematic error is estimated to 14%.

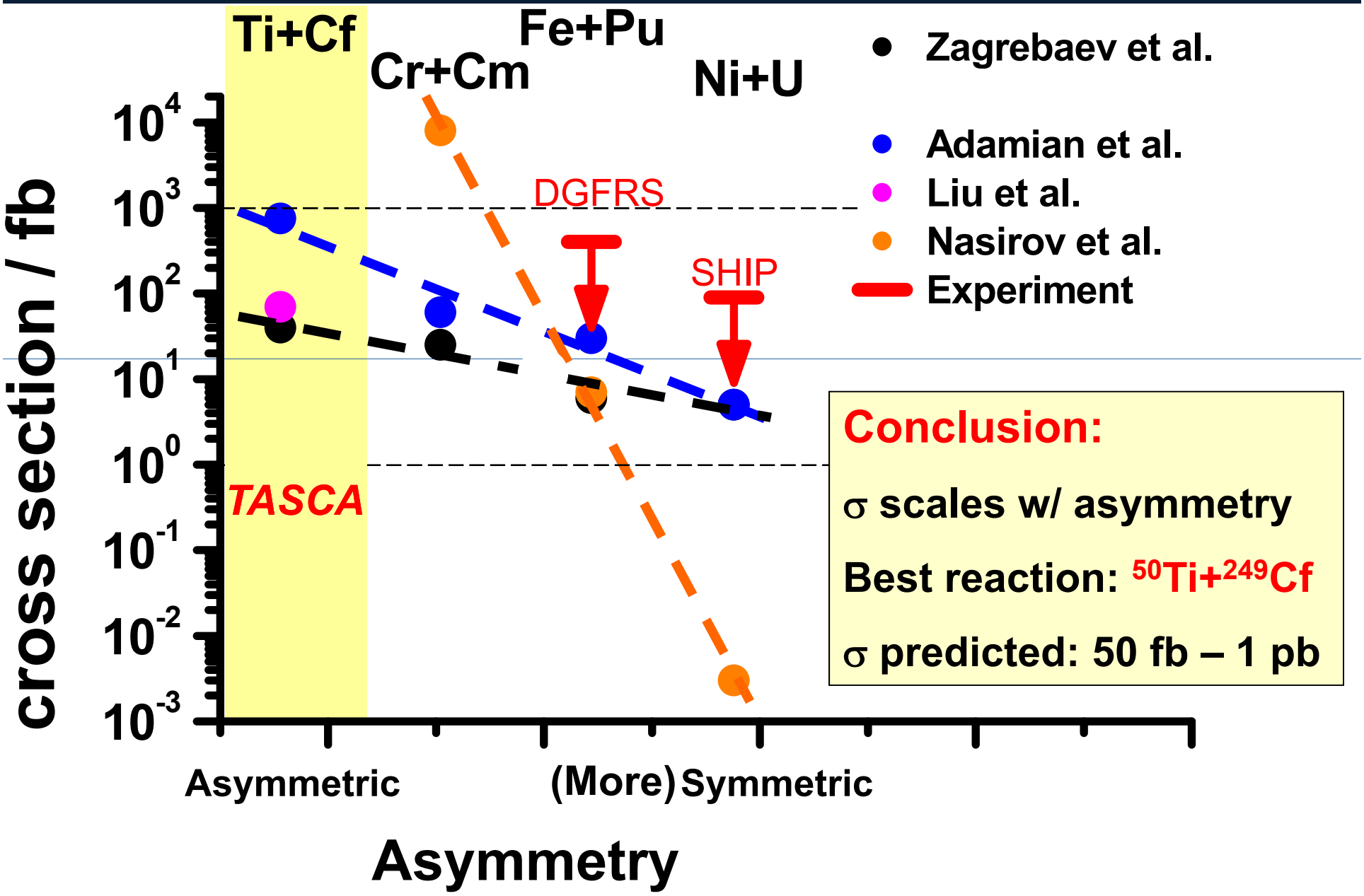
Making new elements

E120

Z_{Beam}	Beam	Target	Asymmetry	$E^*@B_{Bass}$
22	^{50}Ti	^{249}Cf		31.7
23	^{51}V	^{249}Bk		35.9
24	^{54}Cr	^{248}Cm		33.0
25	^{55}Mn	^{243}Am		34.5
26	^{58}Fe	^{244}Pu		33.9
27	^{59}Co	^{237}Np		32.9
28	^{64}Ni	^{238}U		27.3

Similar arguments for E119 hint at $^{50}Ti+^{249}Bk$ as the preferred reaction

Choice of the optimum reaction: example E120



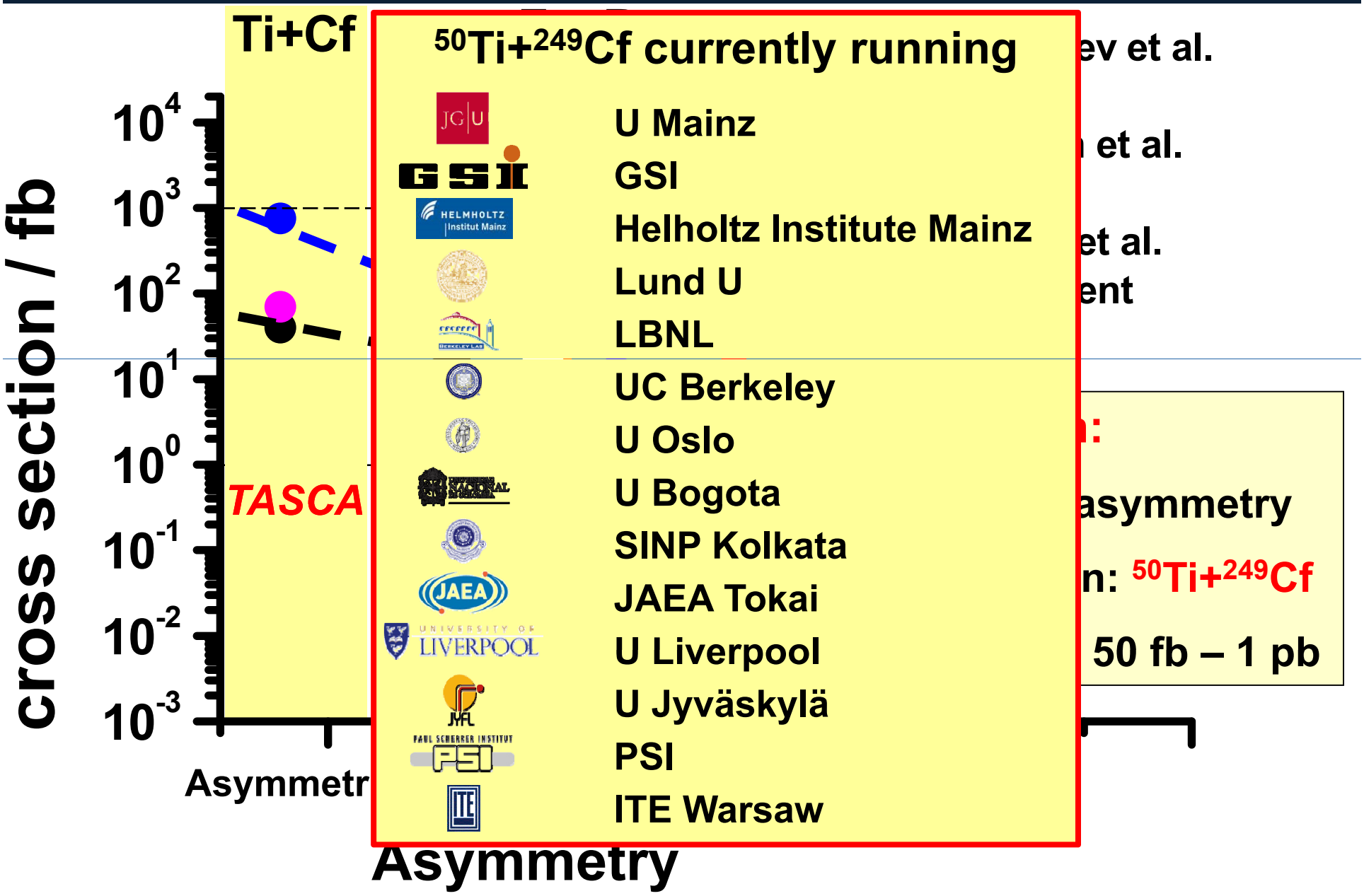
Conclusion:

σ scales w/ asymmetry

Best reaction: $^{50}Ti+^{249}Cf$

σ predicted: 50 fb – 1 pb

Choice of the optimum reaction: example E120

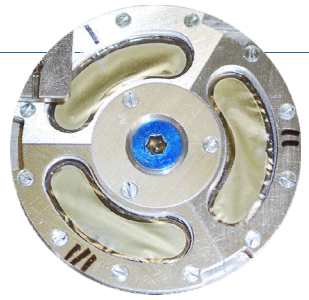


Getting ready for element 120 at TASCA (I)

A new high-intensity transuranium target wheel for *TASCA*

Used for E114:

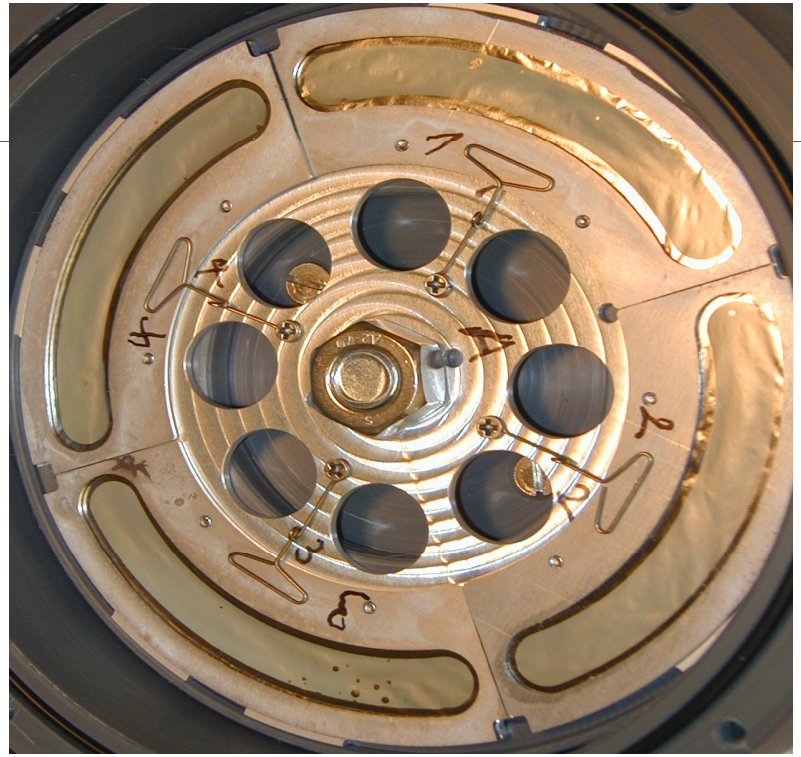
Ø Target Wheel: 32.5 mm
Ø Beam Spot: 6 mm



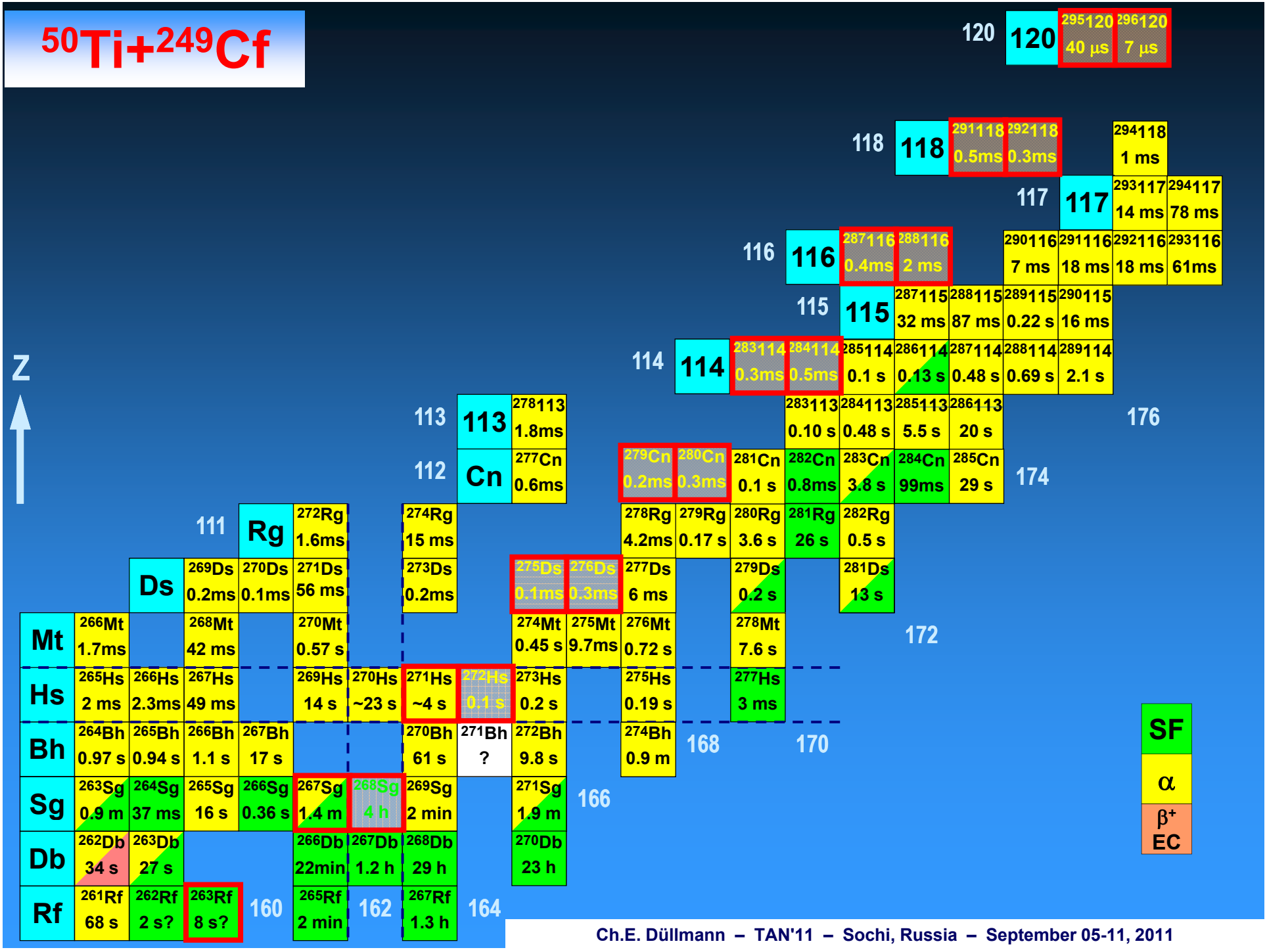
400 particle·nA

Currently in use for E120:

Ø Target Wheel: 100 mm
Ø Beam Spot: 8 mm



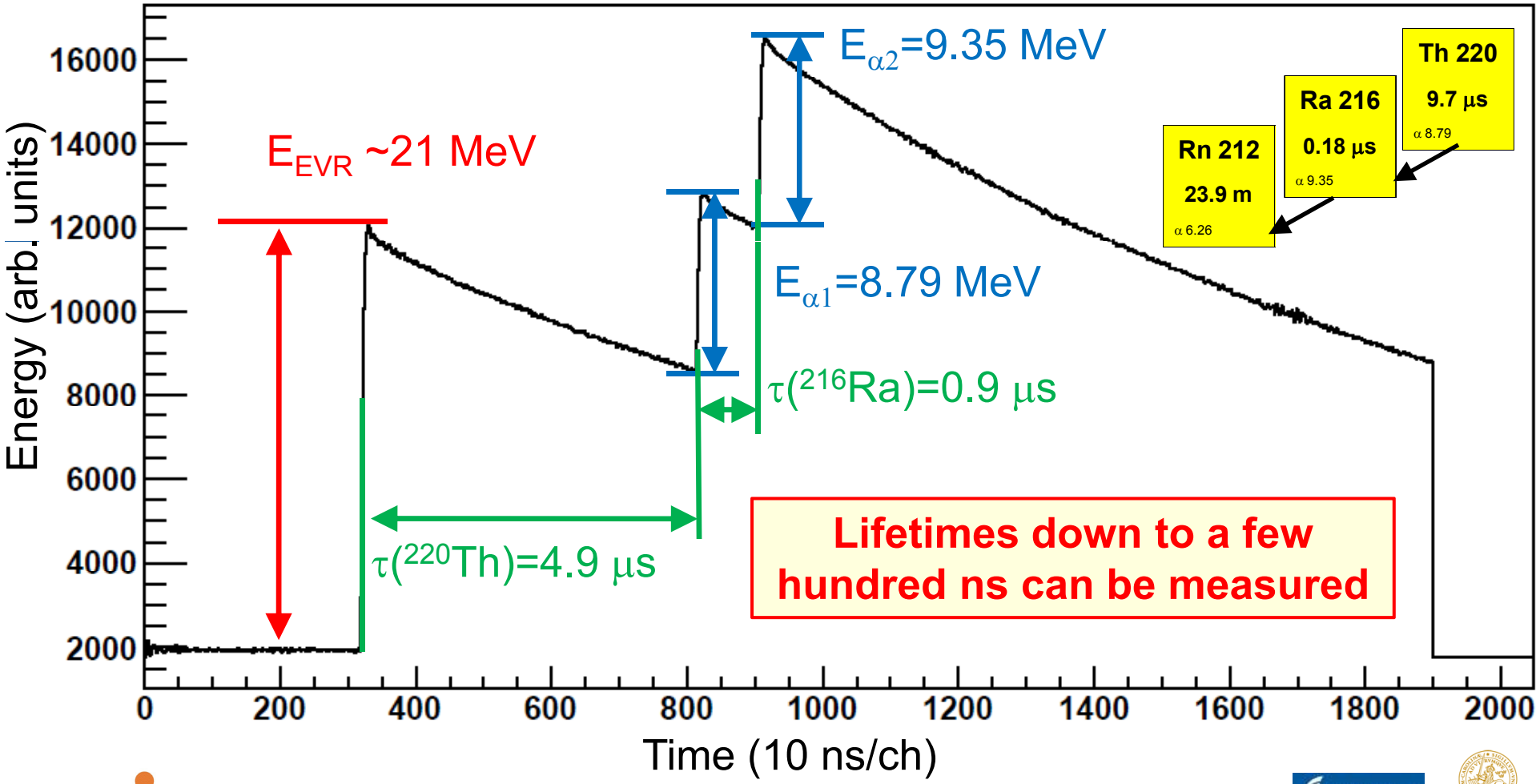
Target wheel tested up to
2.5 particle·μA


50Ti+249Cf
120
120
295120 40 µs
296120 7 µs
118
118
291118 0.5ms
292118 0.3ms
294118 1 ms
117
117
293117 14 ms
294117 78 ms
116
116
287116 0.4ms
288116 2 ms
290116 7 ms
291116 18 ms
292116 18 ms
293116 61ms
115
115
287115 32 ms
288115 87 ms
289115 0.22 s
290115 16 ms
114
114
283114 0.3ms
284114 0.5ms
285114 0.1 s
286114 0.13 s
287114 0.48 s
288114 0.69 s
289114 2.1 s
113
113
278113 1.8ms
283113 0.10 s
284113 0.48 s
285113 5.5 s
286113 20 s
112
Cn
277Cn 0.6ms
279Cn 0.2ms
280Cn 0.3ms
281Cn 0.1 s
282Cn 0.8ms
283Cn 3.8 s
284Cn 99ms
285Cn 29 s
111
Rg
272Rg 1.6ms
274Rg 15 ms
278Rg 4.2ms
279Rg 0.17 s
280Rg 3.6 s
281Rg 26 s
282Rg 0.5 s
Ds
269Ds 0.2ms
270Ds 0.1ms
271Ds 56 ms
273Ds 0.2ms
275Ds 0.1ms
276Ds 0.3ms
277Ds 6 ms
279Ds 0.2 s
281Ds 13 s
Mt
266Mt 1.7ms
268Mt 42 ms
270Mt 0.57 s
274Mt 0.45 s
275Mt 9.7ms
276Mt 0.72 s
278Mt 7.6 s
Hs
265Hs 2 ms
266Hs 2.3ms
267Hs 49 ms
269Hs 14 s
270Hs ~23 s
271Hs ~4 s
272Hs 0.1 s
273Hs 0.2 s
275Hs 0.19 s
277Hs 3 ms
Bh
264Bh 0.97 s
265Bh 0.94 s
266Bh 1.1 s
267Bh 17 s
270Bh 61 s
271Bh ?
272Bh 9.8 s
274Bh 0.9 m
Sg
263Sg 0.9 m
264Sg 37 ms
265Sg 16 s
266Sg 0.36 s
267Sg 1.4 m
268Sg 4 h
269Sg 2 min
271Sg 1.9 m
Db
262Db 34 s
263Db 27 s
266Db 22min
267Db 1.2 h
268Db 29 h
270Db 23 h
Rf
261Rf 68 s
262Rf 2 s?
263Rf 8 s?
265Rf 2 min
267Rf 1.3 h
160
162
164
166
168
170
172
174
176
Z
SF
α
β+
EC
Ch.E. Düllmann – TAN'11 – Sochi, Russia – September 05-11, 2011

Getting ready for element 120 at TASCA (II)

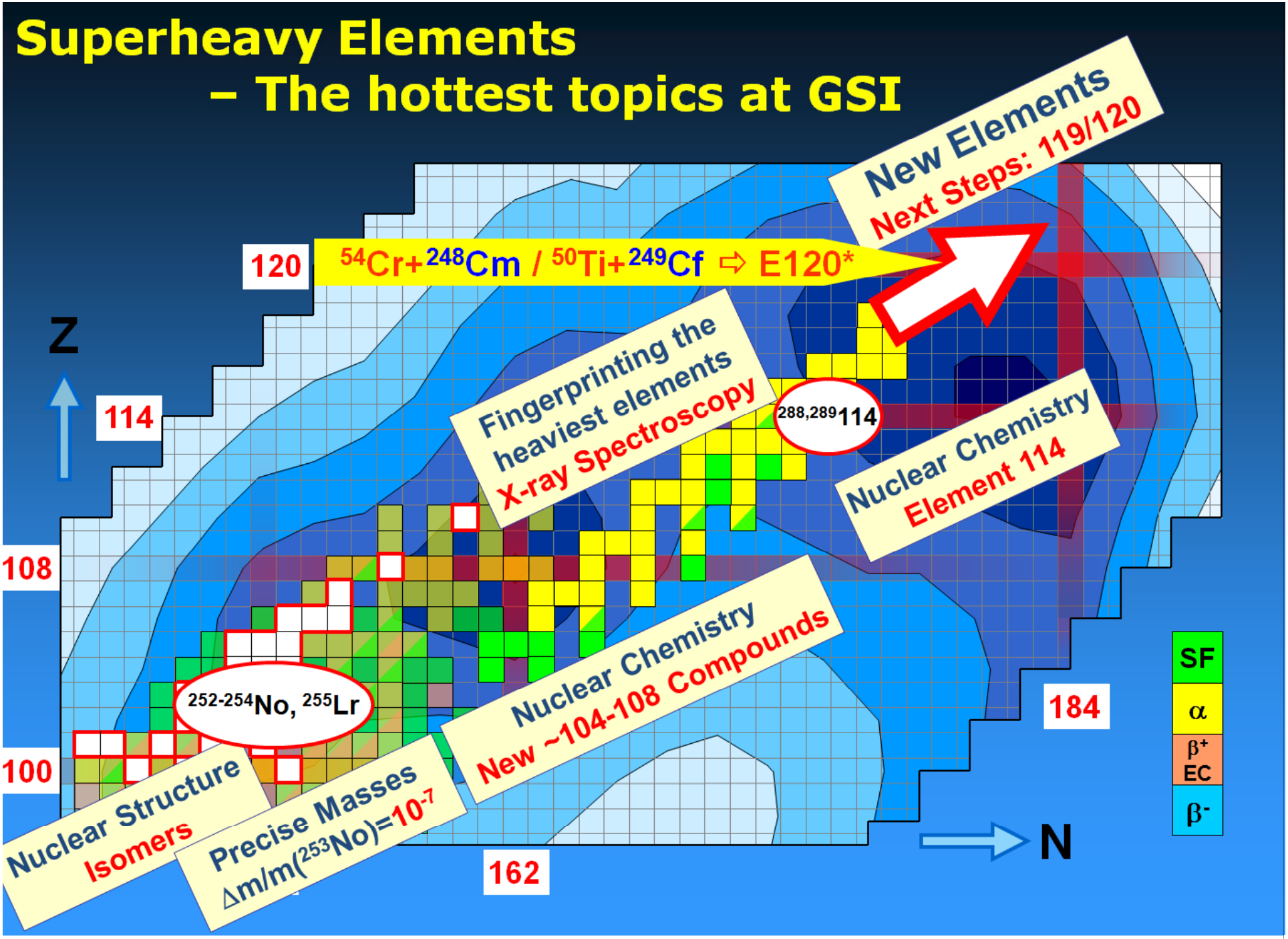
A new digital data acquisition system for μs-isotopes

Test reaction: $^{176}Yb(^{48}Ca,4n)^{220}Th$



GSI Experimental Electronics Dept. (N. Kurz)

L.G. Sarmiento (Test reaction) / J. Khuyagbaatar (E120 run)


Superheavy Elements
– The hottest topics at GSI
New Elements
Next Steps: 119/120
120
54Cr+248Cm / 50Ti+249Cf ⇨ E120*
Z
114
Fingerprinting the heaviest elements
X-ray Spectroscopy
288,289114
Nuclear Chemistry
Element 114
108
252-254No, 255Lr
Nuclear Chemistry
New ~104-108 Compounds
100
Nuclear Structure
Isomers
Precise Masses
Δm/m(253No)=10-7
162
184
N
SF
α
β+
EC
β-

Summary: SHE @ GSI

A broad research program covering
nuclear physics; nuclear chemistry; atomic physics

Recent highlights: **Element 114**: 10 pb opens new avenues
Direct **mass measurements** up to Lr
Chemical studies of element 114

Unique **set of experimental facilities** at GSI/JGU

Institutional strategic strengthening of SHE: **HIM**

Outlook: Hunt for **elements 119 and 120**
Z-fingerprinting with TASISpec
SHIP/TRAP: **masses** into **SHE-region** (Z≥104)
Nuclear structure & reaction studies
Chemistry: **E114(+)** / **new compound classes**
New dedicated **SHE cw LINAC**