TASCA

A New Tool in the Quest for Superheavy Element Studies

M. Schädel, D. Ackermann, L.-L. Andersson, J. Ballof, M. Block, R.A. Buda, W. Brüchle, I. Dragojević, Ch.E. Düllmann, J. Dvorak, K. Eberhardt, J. Even, J.M. Gates, J. Gerl, A. Gorshkov, P. Golubev, R. Graeger, K.E. Gregorich, E. Gromm, W. Hartmann, R.-D. Herzberg, F.P. Heßberger, D . Hild, R. Hoischen, A. Hübner, E. Jäger, J. Khuyagbaatar, B. Kindler, I. Kojouharov, J.V. Kratz, J. Krier, N. Kurz, S. Lahiri, D. Liebe, B. Lommel, M. Maiti, M. Mendel, E. Merchán, H. Nitsche, D. Nayak†, J. Nilssen, J.P. Omtvedt, K. Opel, P. Reichert, D. Rudolph, A. Sabelnikov, F. Samadani, H. Schaffner, B. Schausten, R. Schuber, E. Schimpf, A. Semchenkov, L. Stavsetra, J. Steiner, J. Szerypo, P. Thörle-Pospiech, A. Toyoshima, A. Türler, J. Uusitalo, N. Wiehl, H.-J. Wollersheim, T. Wunderlich, and A. Yakushev

Darmstadt · Berkeley · Jyväskylä · St. Petersburg · Kolkata · Tokai

München · München · Mainz · Oslo · Lund · Liverpool

TASCA

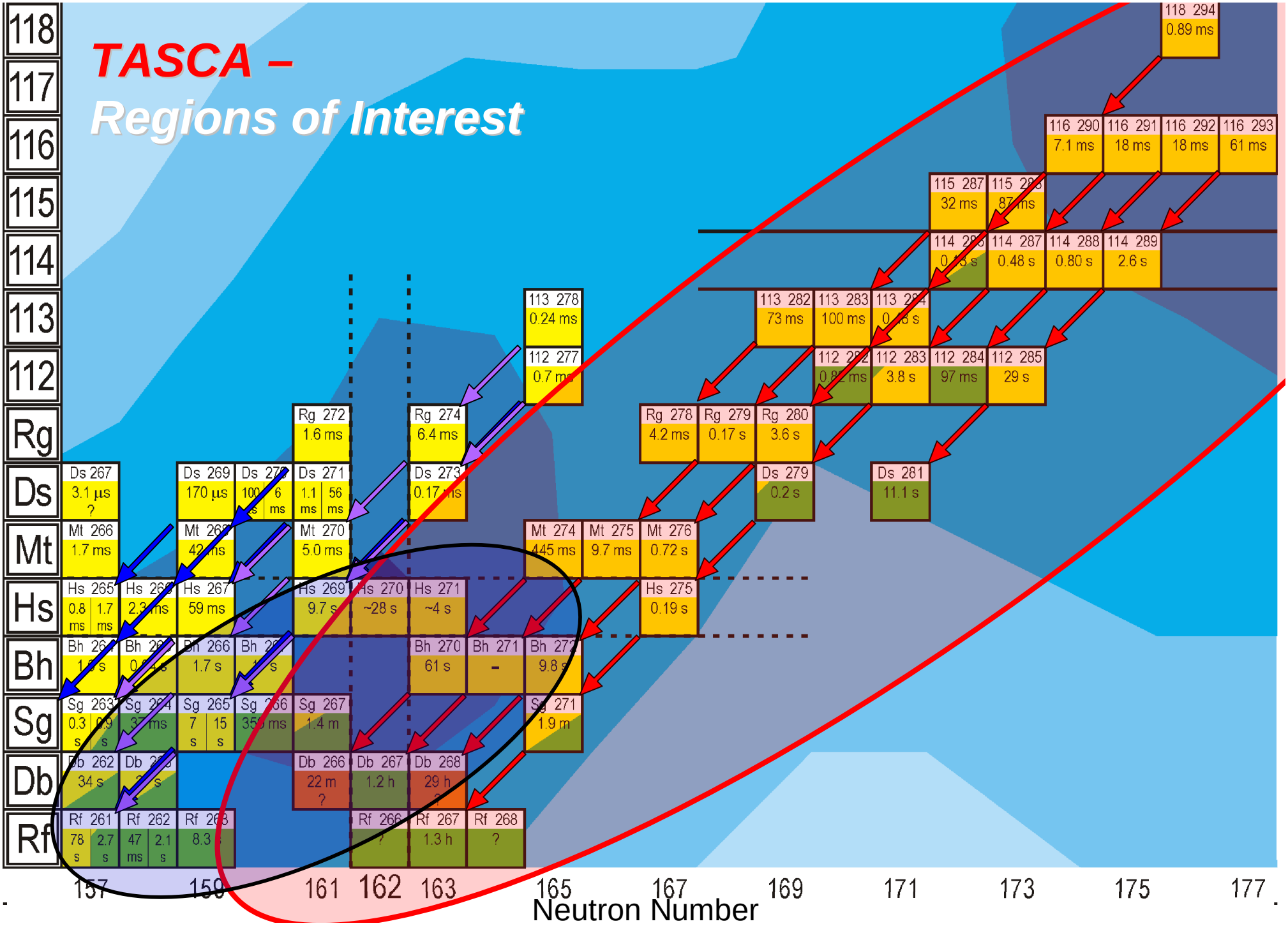
TransActinide Separator and Chemistry Apparatus

Gas-filled recoil separator
with maximized transmission (efficiency)
for transactinides (SHE)
from hot-fusion reactions with actinide targets,
in particular for:

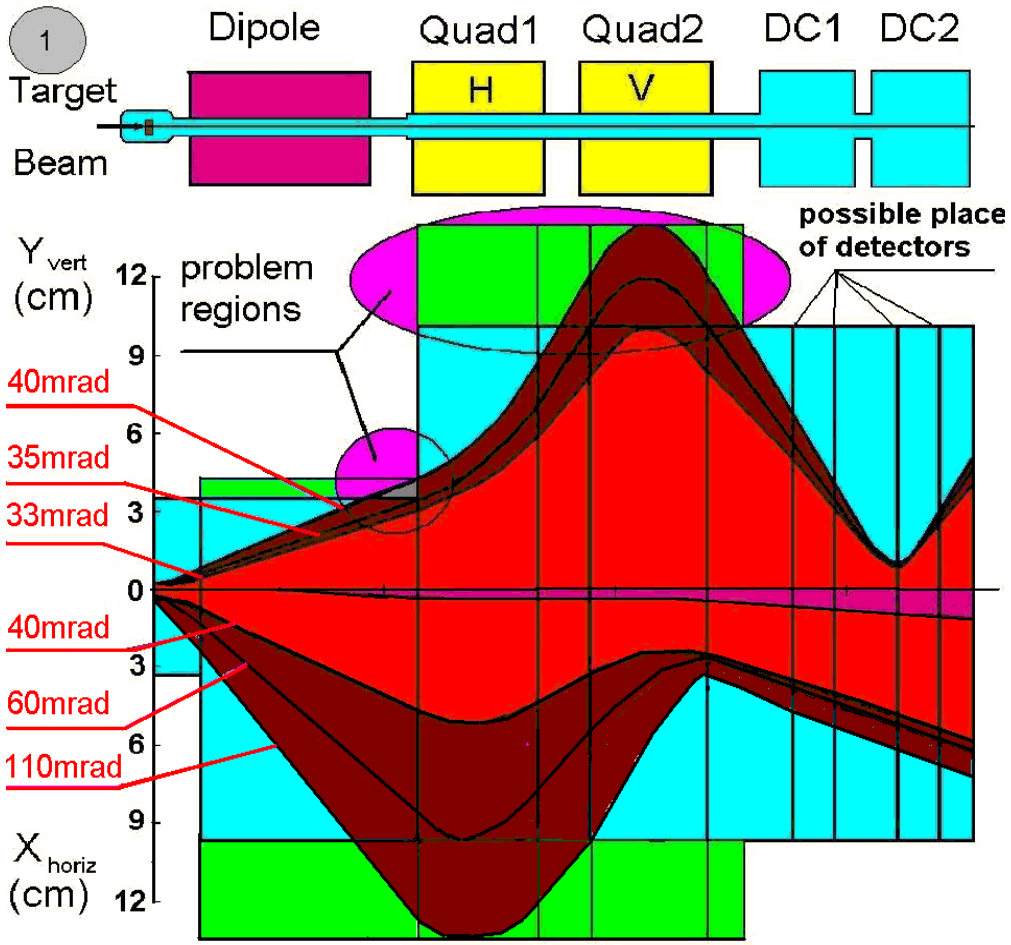
*** Chemical investigations of elements 104 -- 116**

*** Nuclear structure and nuclear reaction investigations of the most n-rich nuclides; Z ≥ 104**

*** "Chemistry" in the separator – probe the influence of the gas**


TASCA –
Regions of Interest
118
117
116
115
114
113
112
Rg
Ds
Mt
Hs
Bh
Sg
Db
Rf
118 294 0.89 ms
116 290 7.1 ms
116 291 18 ms
116 292 18 ms
116 293 61 ms
115 287 32 ms
114 287 0.48 s
114 288 0.80 s
114 289 2.6 s
113 278 0.24 ms
112 277 0.7 ms
113 282 73 ms
113 283 100 ms
112 283 3.8 s
112 284 97 ms
112 285 29 s
Rg 272 1.6 ms
Rg 274 6.4 ms
Rg 278 4.2 ms
Rg 279 0.17 s
Rg 280 3.6 s
Ds 267 3.1 µs ?
Ds 269 170 µs
Ds 271 1.1 ms 56 ms
Ds 273 0.17 ms
Ds 279 0.2 s
Ds 281 11.1 s
Mt 266 1.7 ms
Mt 270 5.0 ms
Mt 274 445 ms
Mt 275 9.7 ms
Mt 276 0.72 s
Hs 265 0.8 ms 1.7 ms
Hs 267 59 ms
Hs 269 9.7 s
Hs 270 ~28 s
Hs 271 ~4 s
Hs 275 0.19 s
Bh 266 1.7 s
Bh 270 61 s
Bh 271 -
Bh 272 9.8 s
Sg 265 7 s 15 s
Sg 267 1.4 m
Sg 271 1.9 m
Db 262 34 s
Db 266 22 m ?
Db 267 1.2 h
Db 268 29 h
Rf 261 78 s 2.7 s
Rf 262 47 ms 2.1 s
Rf 267 1.3 h
Rf 268 ?
157
159
161
162
163
165
167
169
171
173
175
177
Neutron Number

(HTM) DQ_hQ_v ← Configuration



High Transmission

TRANSPORT calculations, A. Semchenkov (2004); model reaction: $^{48}Ca + ^{238}U/^{244}Pu$ ➔ 112/114

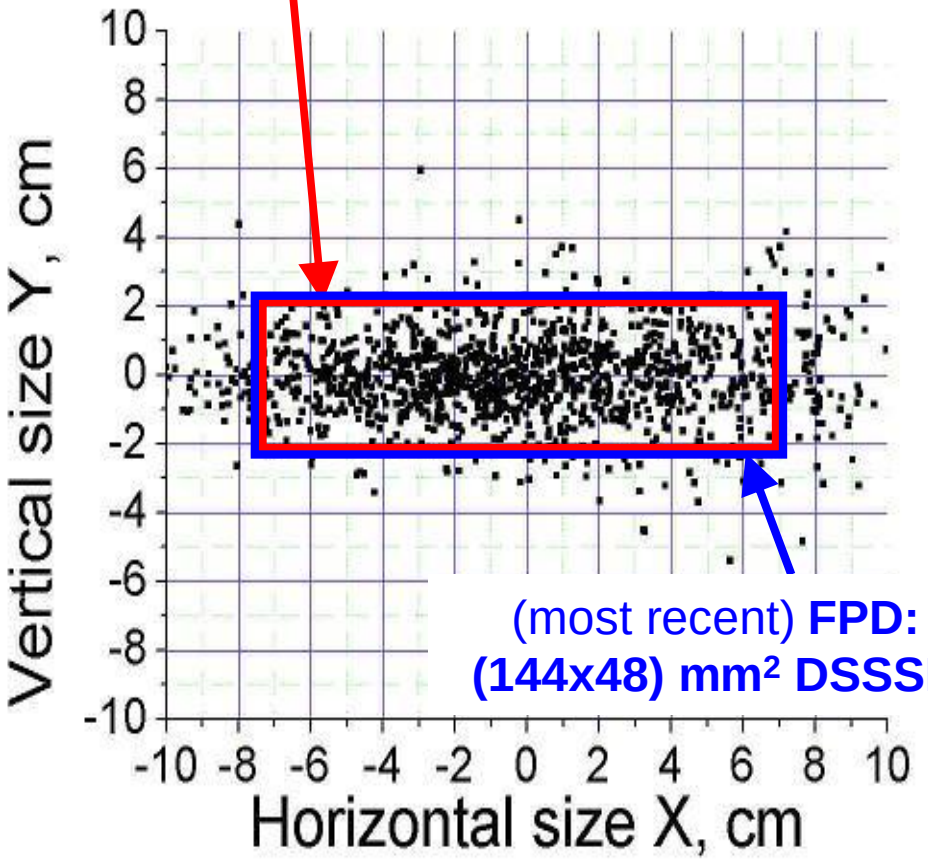
TASCA – The Preparation Phase: Monte-Carlo Simulations

DQ_hQ_v **$^{48}Ca + ^{238}U \rightarrow ^{283}112$** **$DQ_vQ_h$**

High Transmission Mode **RTC** = Small Image size Mode

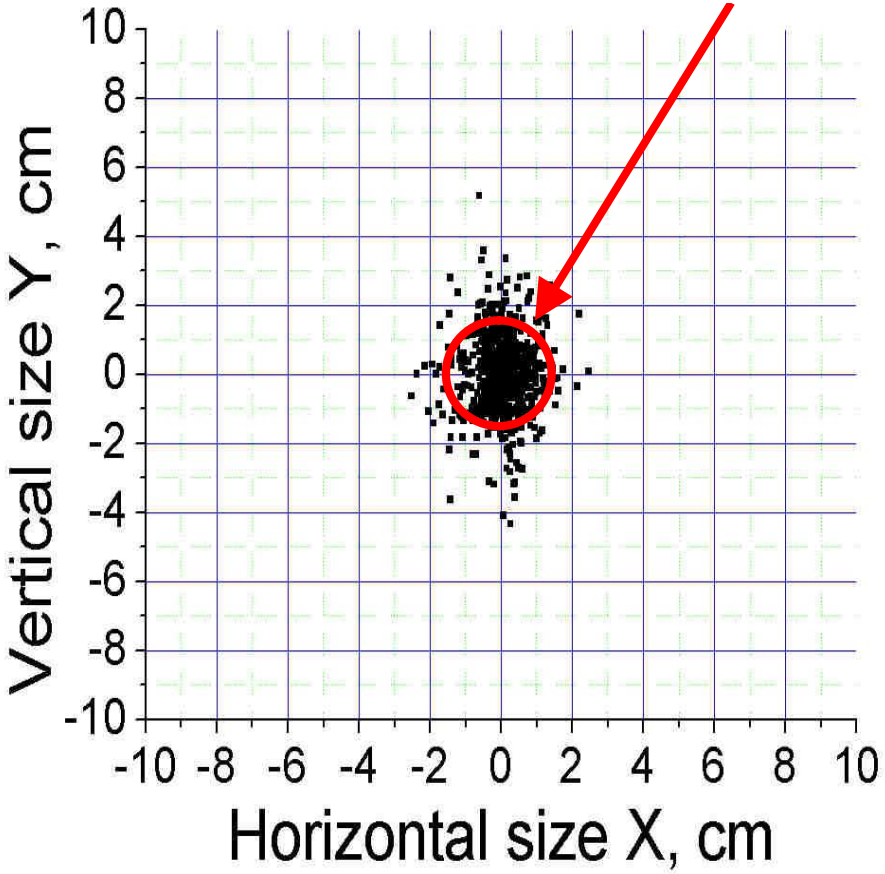
Recoil Transfer Chamber

HTM-RTC window:
14 * 4 = 56 cm²



(most recent) **FPD:**
(144x48) mm² DSSSD

SIM-RTC window:
ø3 cm ➔ 7 cm²



*** MC-Model: K.E. Gregorich**
Calculation: A. Semchenkov

Comparison of Gas-filled Separators in SHE Research

Measured / Estimated / Calculated Transmissions for:
$^{48}Ca + {}^{238}U/{}^{244}Pu$ ➔ 112/114

Separator	DGFRS	GARIS	BGS	TASCA	TASCA
Configuration	DQ_hQ_v	DQ_vQ_hD	Q_vD_hD	DQ_hQ_v	DQ_vQ_h
Transmission / %	35[&]	40*	49-59	**60[§]**	**35[§]**
Dispersion / mm/%	7.5	9.7	20	**9**	**1**

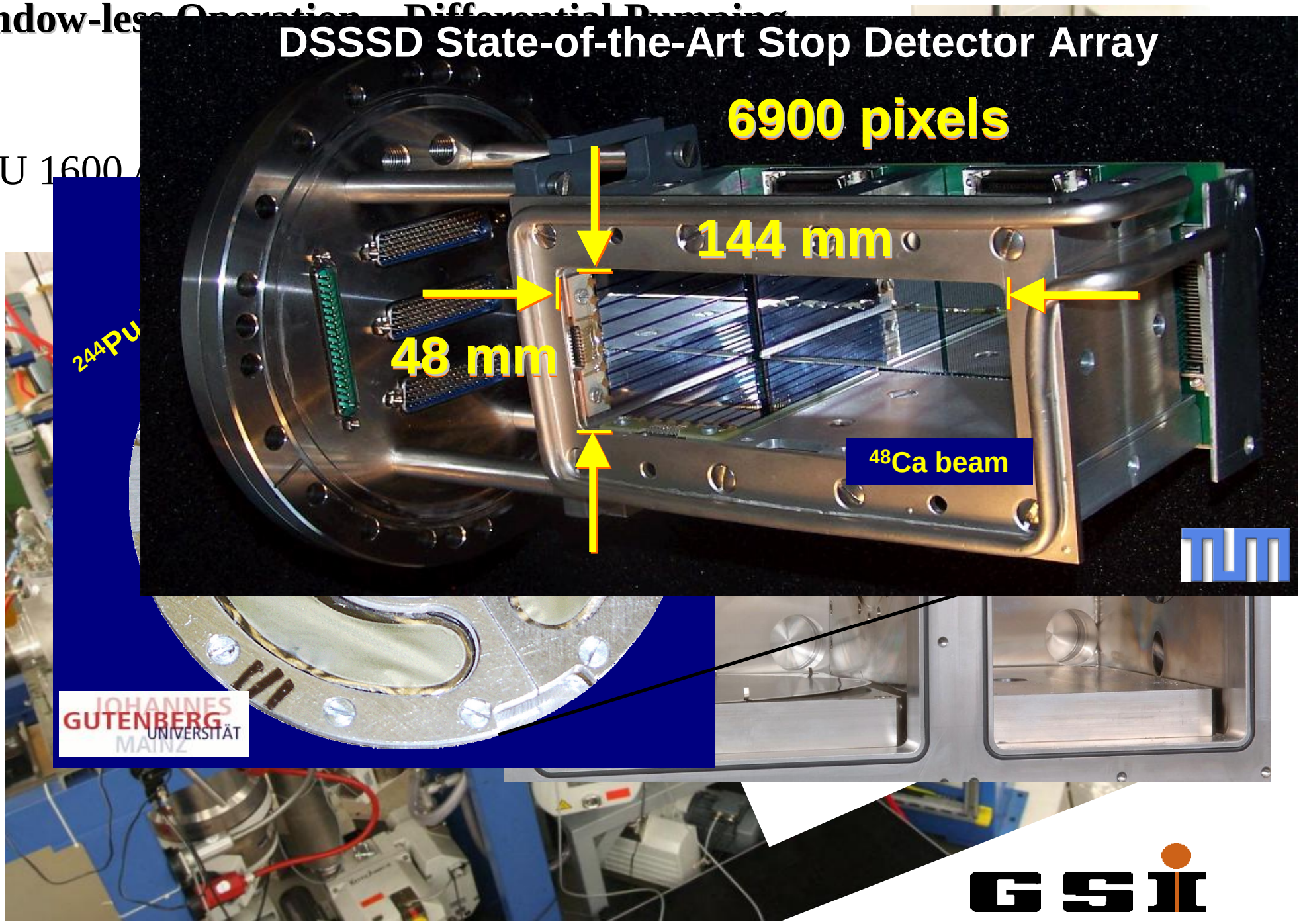
& Yu.Ts. Oganessian priv. comm.

*** Estim. from test reactions; K. Morita priv. comm.**

§ MonteCarlo simulation 400 µg/cm² target

Window-less Operation – Differential Pumping

TMU 1600 A



TASCA Commissioning Experiments: Nuclear Reactions

TASISpec: High efficiency
α-γ-CE-multi-coincidence in SIM

$^{22}Ne + ^{197}Au \rightarrow 4n + ^{215}Ac$

$^{40}Ar + ^{nat}Lu \rightarrow 5n + ^{210}Ac$

$Z_{CN} < 92$

$^{64}Ni + ^{150}Nd \rightarrow (3\text{-}6)n + ^{208\text{-}211}Ra$

$^{54}Cr + ^{nat}Gd \rightarrow (3\text{-}4)n + ^{208\text{-}211}Ra$

$^{64}Ni + ^{141}Pr \rightarrow 5n + ^{200}Fr$

$^{30}Si + ^{181}Ta \rightarrow (5\text{-}6)n + ^{205,206}Fr$

$^{64}Ni + ^{139}La \rightarrow 3n + ^{200}At$

$^{48}Ca + ^{152}Gd \rightarrow (4\text{-}5)n + ^{195,196}Po$

$^{22}Ne + ^{181}Ta \rightarrow (4\text{-}5)n + ^{198m,199}Bi$

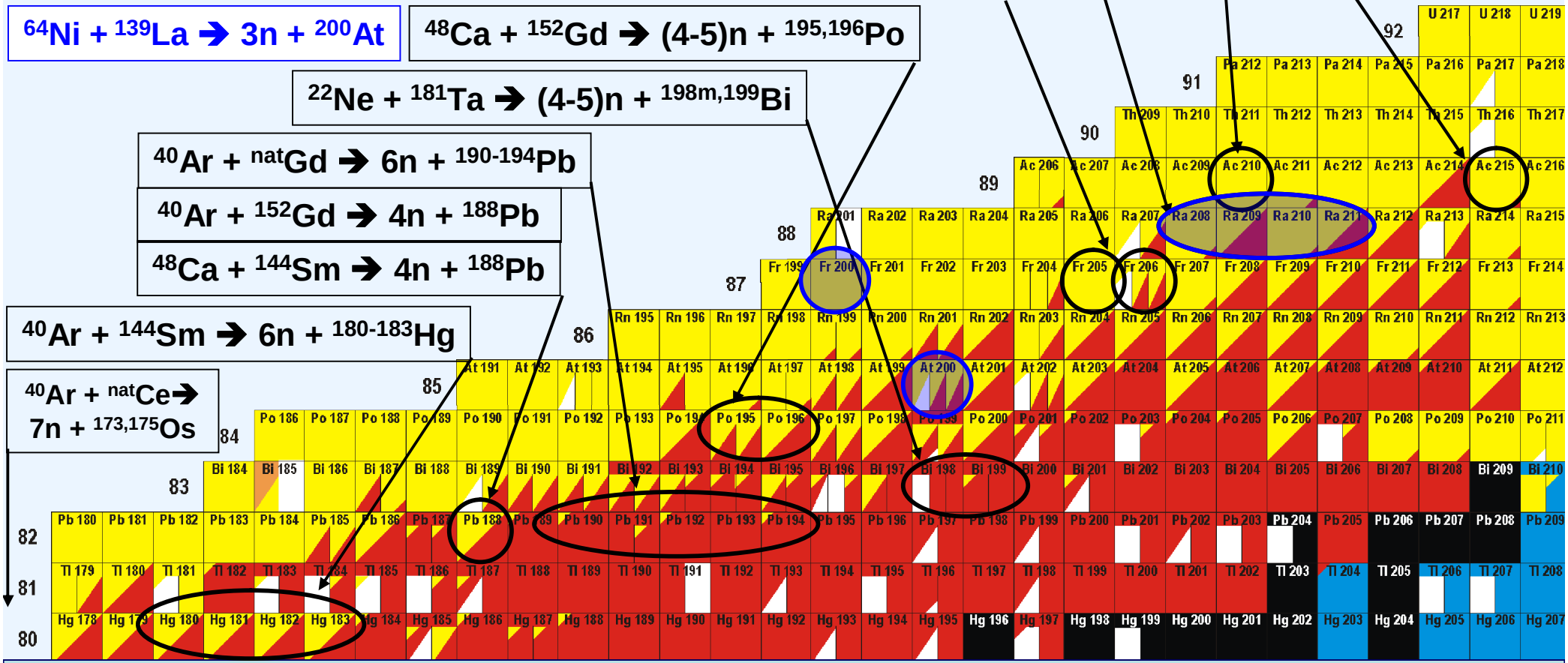
$^{40}Ar + ^{nat}Gd \rightarrow 6n + ^{190\text{-}194}Pb$

$^{40}Ar + ^{152}Gd \rightarrow 4n + ^{188}Pb$

$^{48}Ca + ^{144}Sm \rightarrow 4n + ^{188}Pb$

$^{40}Ar + ^{144}Sm \rightarrow 6n + ^{180\text{-}183}Hg$

$^{40}Ar + ^{nat}Ce \rightarrow 7n + ^{173,175}Os$



TASCA Commissioning Experiments: Nuclear Reactions

$Z_{CN} > 92$

$^{22}Ne + ^{238}U \rightarrow 4\text{-}5n + ^{255,256}No$

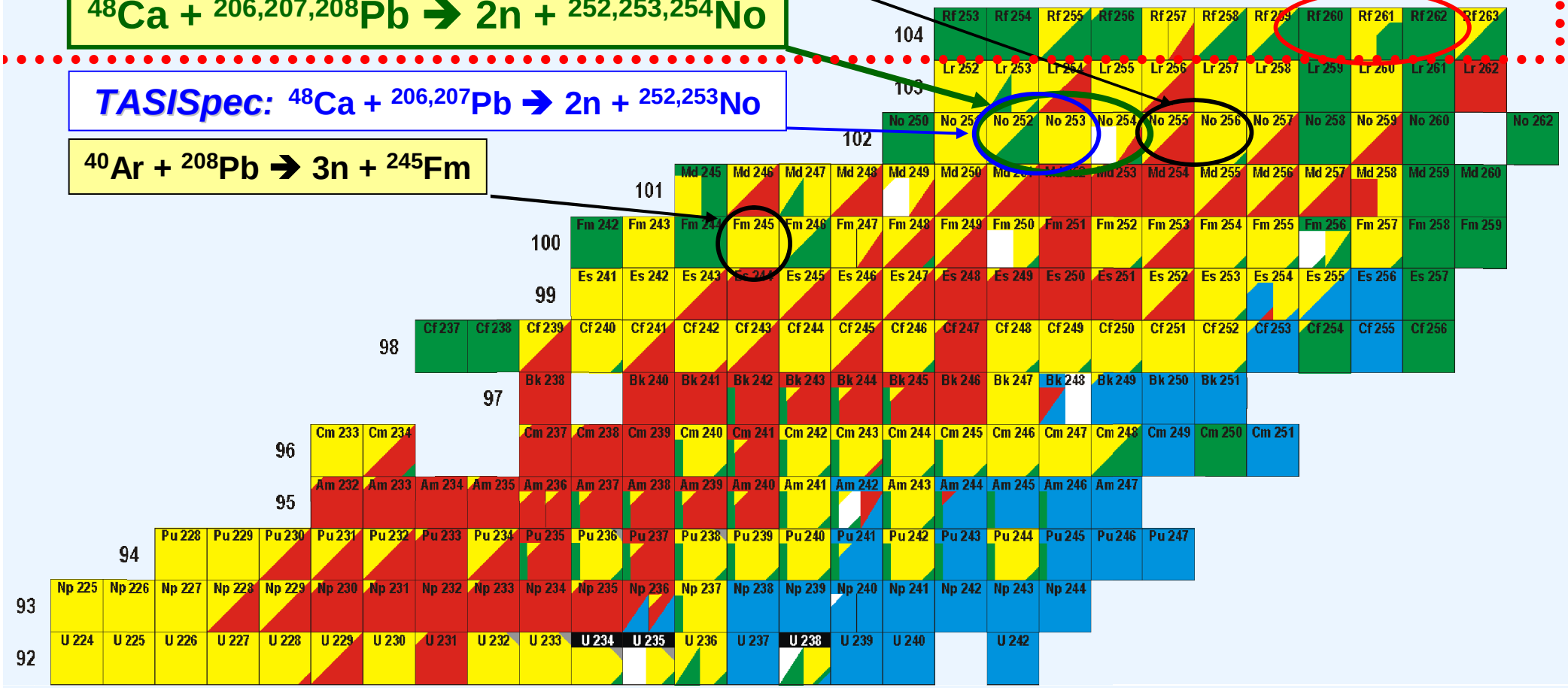
$^{48}Ca + ^{206,207,208}Pb \rightarrow 2n + ^{252,253,254}No$

TASISpec: $^{48}Ca + ^{206,207}Pb \rightarrow 2n + ^{252,253}No$

$^{40}Ar + ^{208}Pb \rightarrow 3n + ^{245}Fm$

$^{22}Ne + ^{244}Pu \rightarrow 4\text{-}6n + ^{260,261,262}Rf$

Trans-actinides



TASCA - Commissioning Phase: Parameter Studies

- Nuclear reactions

- **Target production** technique + target stability
- **Target thickness**
- **Gas pressure** (HTM, SIM)
- **Gases and mixtures He:H_2** (1:0, 3:1, 2:1, 1:1, 0:1)
- Charge state, **Bρ**; dipole stetting, best experimental⇔ theoretical value
- **Transmission** (HTM, SIM); (+ scattered, unwanted products)
- **Focus** (HTM, SIM)

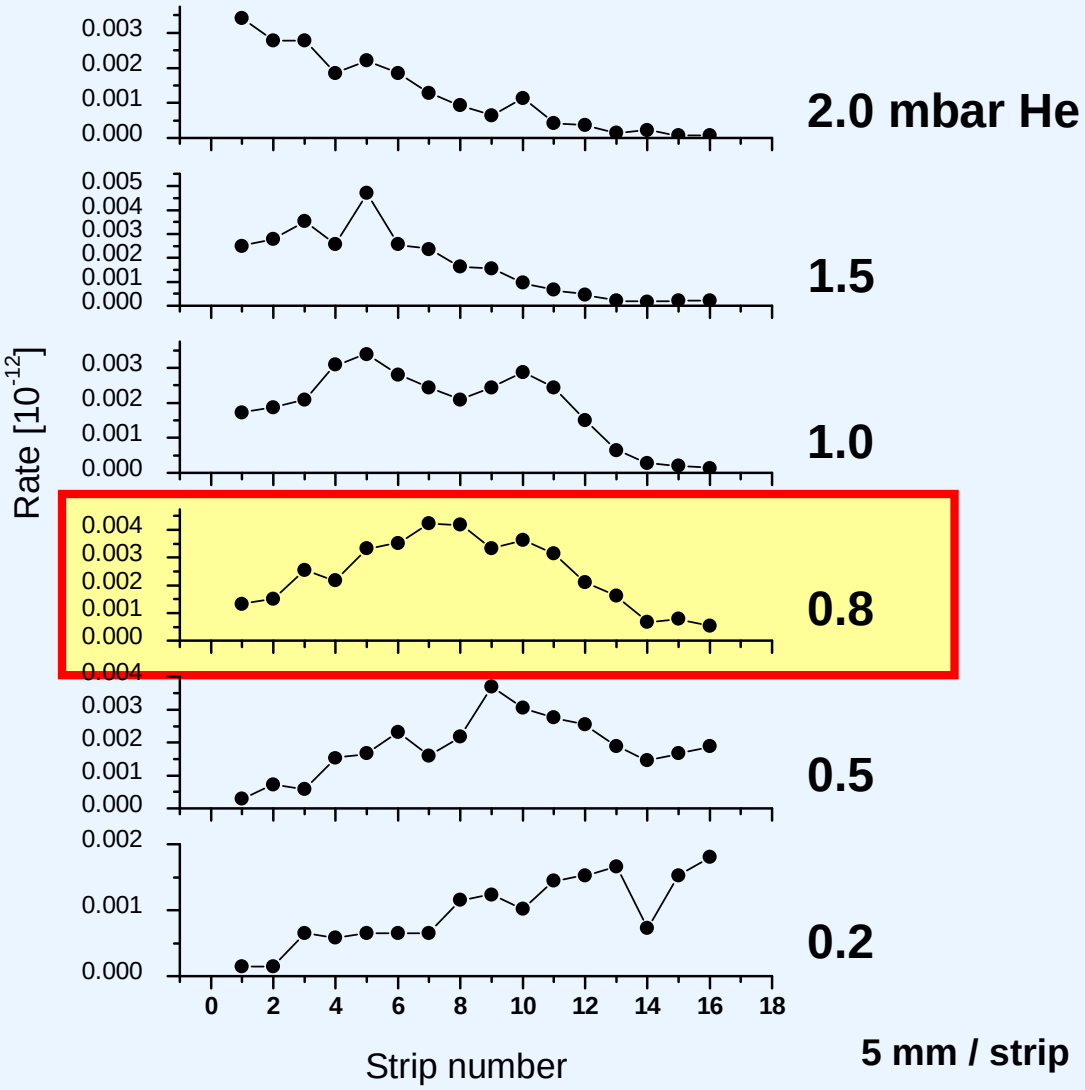
- **Detection systems**: **FPD**, **TUM-DSSD**, **Lund-DSSD** in ***TASISpec***

- **RTC** windows (incl. degrader) + chambers (HTM, SIM)
- **He-KCl jet transport** ➔ ROMA, ➔ ALOHA + ARCA
- **First aqueous chemistry**: Os (Hs-model), Rf (AIX)

$^{48}Ca + ^{206}Pb \rightarrow 2n + ^{252}No$ – He-pressure dependence

HTM

^{252}No in FPD - Horizontal distribution

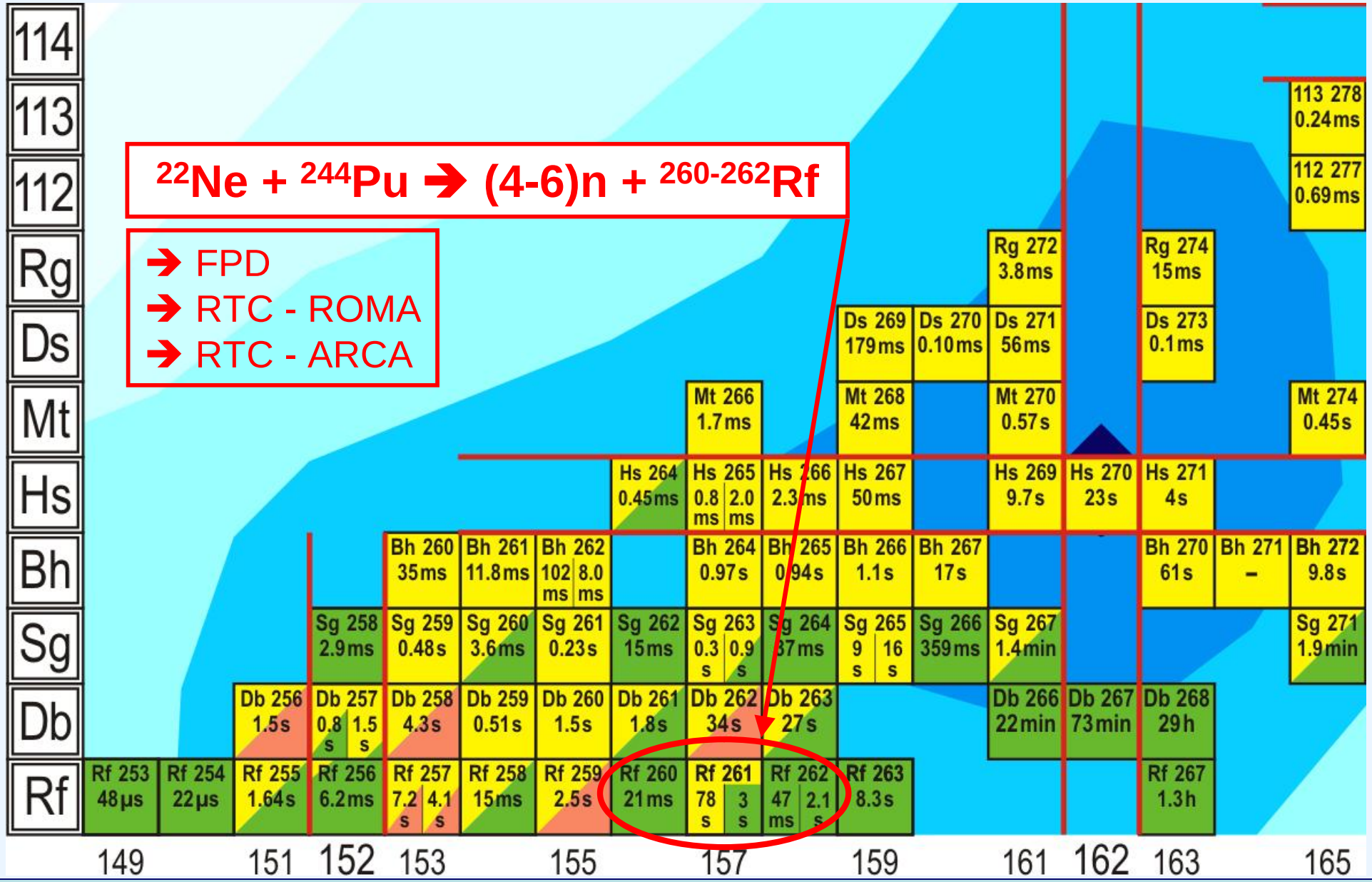


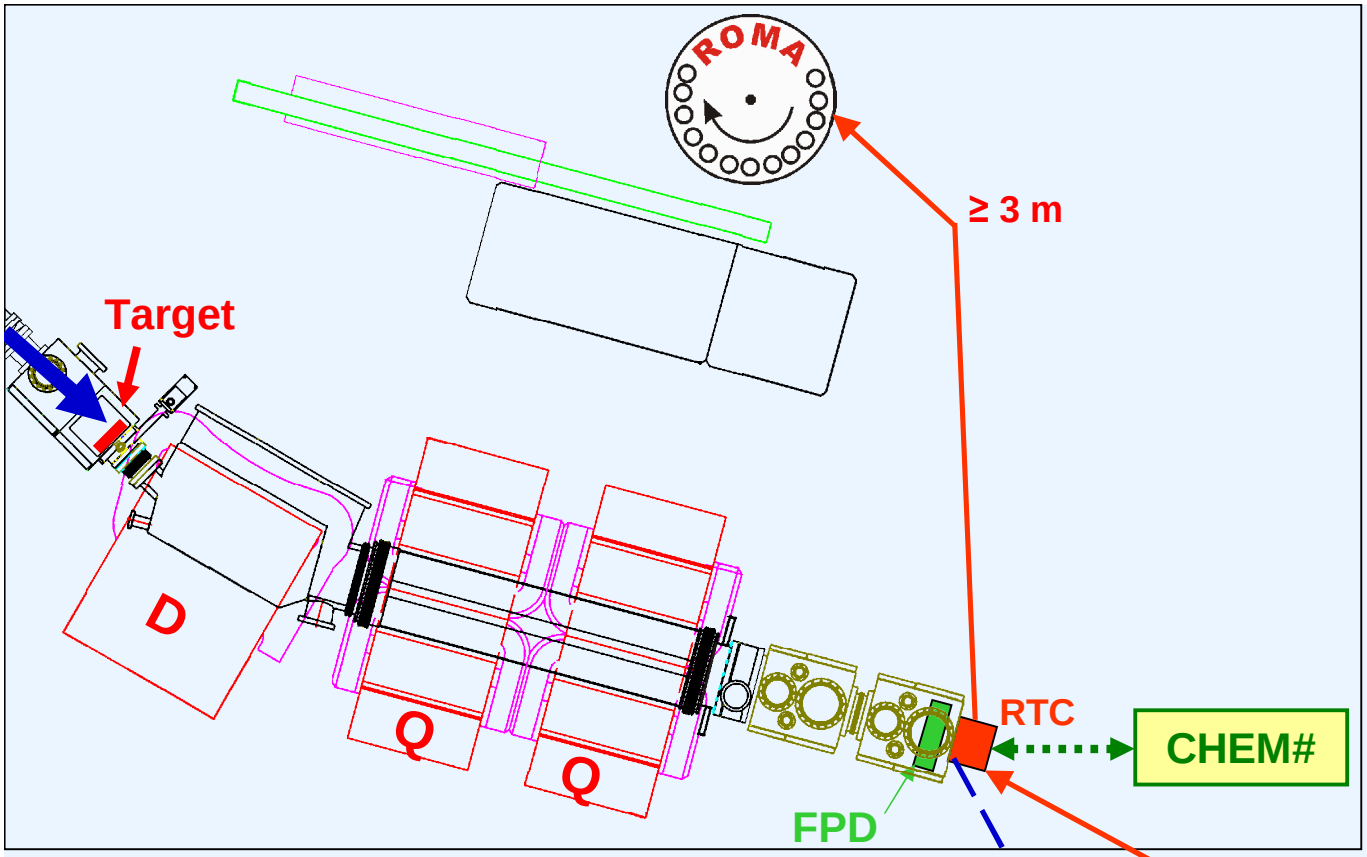
5 mm / strip

Preliminary !!!

J. Khuyagbaatar

TASCA Commissioning Experiments: First Transactinide





TASCA Cave X8

Fully automated, remote control:
COMPACT#, ...

Gas-jet **with cluster**
w/o cluster

10 m

CATCH / Detector
CHEM

SISAK*, ALOHA*, ARCA*, COMPACT#,..

*** Automated, personnel involved**

Radiochem.
"Warm Lab"

TASCA Commissioning Experiments: First Transactinide

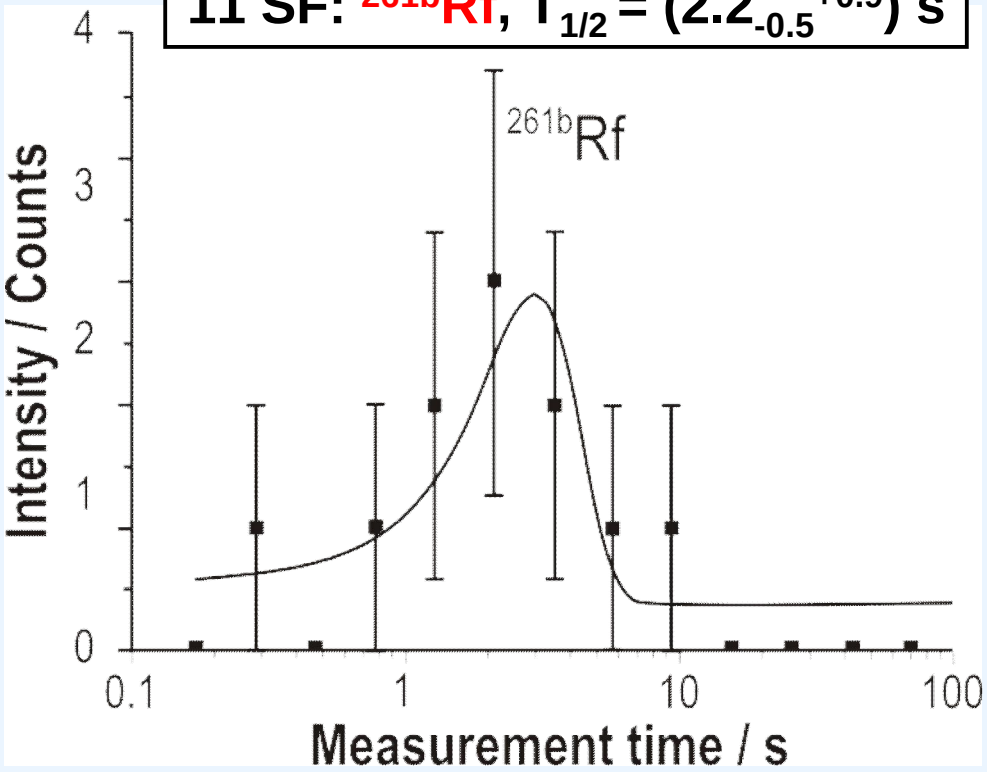
116 MeV ^{22}Ne + ^{244}Pu ➔ 5n + 78-s ^{261a}Rf / 2.7-s ^{261b}Rf

ROMA measurem.

28 α-α-correl., 149 α single, E_α = 7.8-8.5 MeV: ^{261a}Rf + ^{257}No-daughter

and

11 SF: ^{261b}Rf, $T_{1/2} = (2.2_{-0.5}^{+0.9})$ s



First "simultaneous" measurement of ^{261a}Rf and ^{261b}Rf cross section ratio ≈ 2.5 : 1

➔ **2.1-s SF activity previous assigned ^{262}Rf**
(M. Lane et al. PRC 53 (1996) 2893)
is presumably ^{261b}Rf (isomer in ^{261}Rf)
➔ **no isomer in ^{262}Rf**
➔ **re-assign fission properties**
(TKE and mass distribution systematics)

A. Gorshkov et al., GSI Sci. Rep. 2008, p. 140.

TASCA – First Transactinide Chemistry w/ Rf

TASCA → RTC
(140x40) mm²
1.2 µm Mylar window
1.2 bar He, 10 mm depth

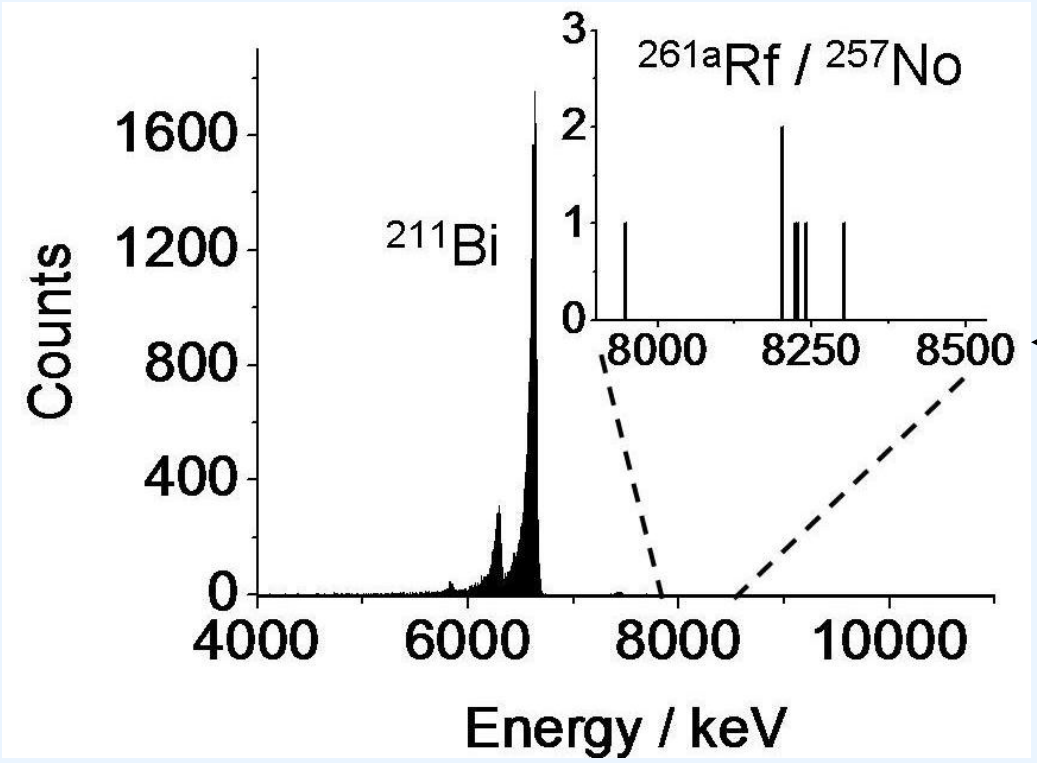
→

He-KCl jet
2.9 L/min
10 m capillary
2 mm i.d.

→

ARCA
Automated Rapid Chemistry Apparatus
t_{cycle} = 90 s
ε = 50%

^{22}Ne + ^{244}Pu → 5n + 68-s ^{261a}Rf



AIX
Anion Exchange Resin
MCI GEL CA08Y
22±5 µm

← **a) 7x10^{-4} M HF**
b) 1x10^{-3} M HF

← **5 M HNO_3**

← **no Rf**

← **7 events**

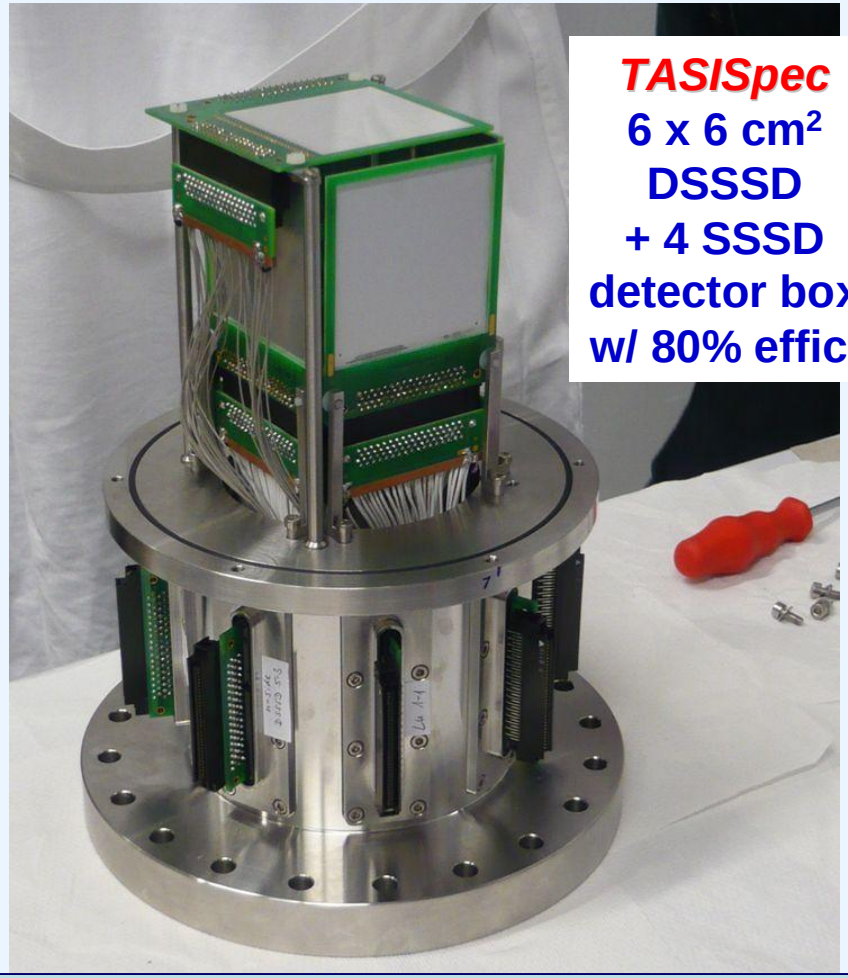
Rf Adsorption on AIX
preliminary
a) %ads ≥ 63 % in 7x10^{-4} M HF
b) %ads ≥ 73 % in 1x10^{-3} M HF

J. Even et al., GSI Scientific Report 2008, p. 143

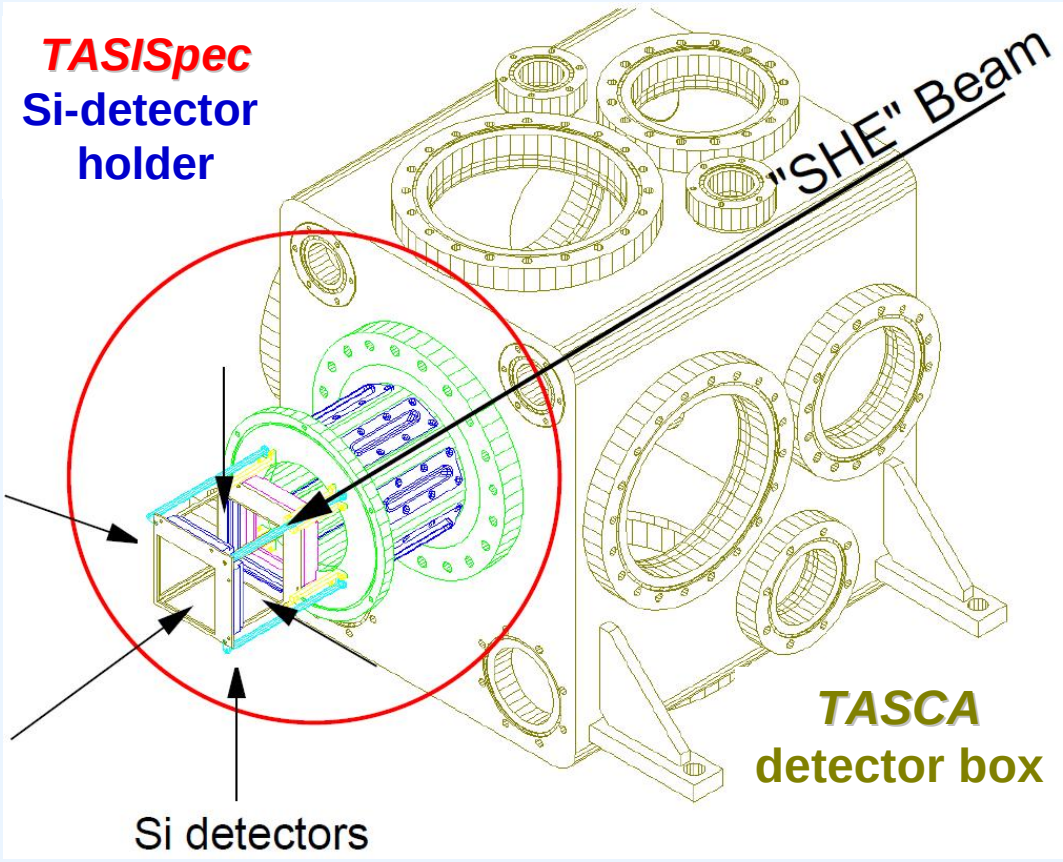
TASISpec – TAsca Small Image mode Spectroscopy

A new nuclear spectroscopy set-up - exploiting the SIM (< 3 cm spot) - γγ-, γ-CE-, CE-CE-, γγ-CE-multi-coincidence capabilities

➔ Unprecedented, highly efficient coincidence measurements

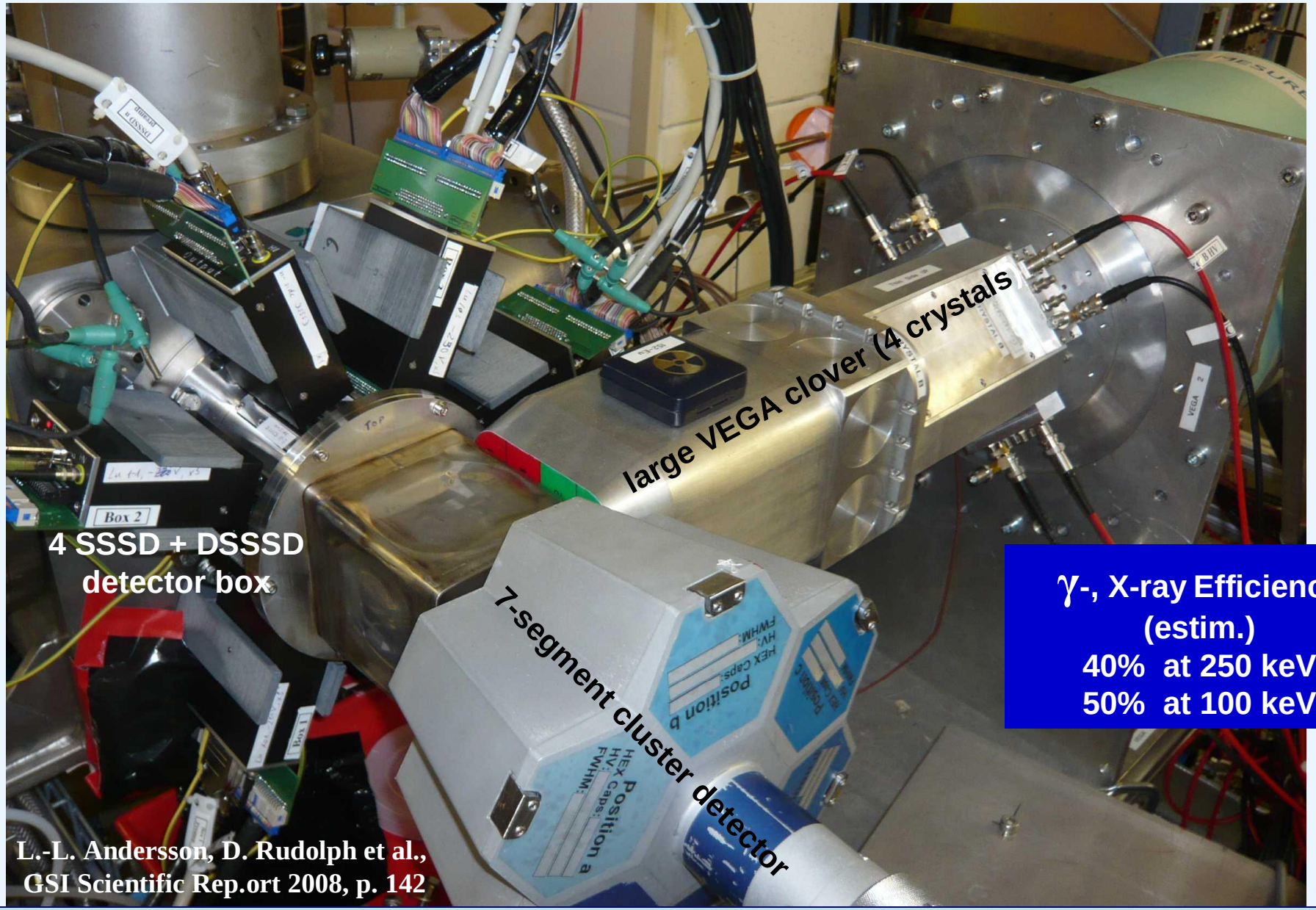


TASISpec
6 x 6 cm² DSSSD + 4 SSSD detector box w/ 80% effic.



L.-L. Andersson, D. Rudolph et al., GSI Scientific Rep. 2008, p. 142

TASISpec – TAsca Small Image mode Spectroscopy



TASCA – The Science Phase

The performance of *TASCA* -
as anticipated, well understood and under control
- very versatile
- world best efficiency
- .... very promising future

Scientific program of *TASCA*
in the Superheavy Element region
started successfully

Many THANKS to <u>everybody</u>

*in the **TASCA** collaboration !*

Thank you for your attention !

EXTRA

TASCA – Design Studies: *TRANSPORT* Calculations

Model reaction for design studies:

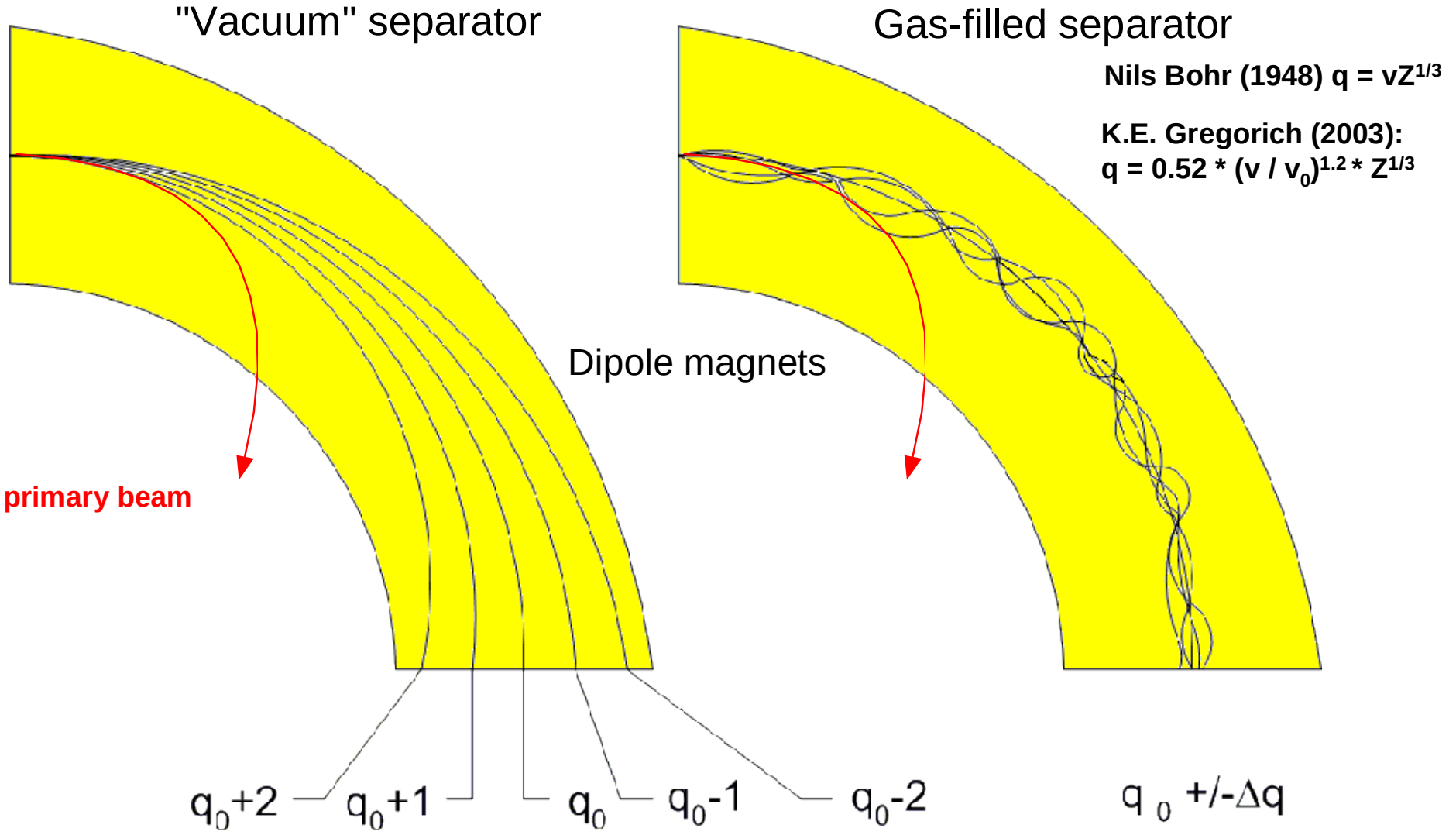
- **^{48}Ca** (238.8 MeV) + **^{238}U** (0.5 mg/cm^2) -> ^{286}112* -> **^{283}112 + 3n**
- 54 % of ^{283}112 will appear within ±40 mrad
  (simulation: K.E.Gregorich, LBL)

Input parameters:

- Horizontal and vertical beam size: ± 2.5 mm
- Horizontal and vertical beam inclination: ± 40 mrad
- Momentum dispersion: ± 5% (92% of all ^{283}112)
- Magnetic rigidity: 2.24 T*m

***TRANSPORT* calculation by A. Semchenkov**

TASCA - The Preparation Phase



Comparison of Gas-filled Separators in SHE Research

Measured / Estimated / Calculated Transmissions for:
$^{48}Ca + {}^{238}U/{}^{244}Pu \rightarrow 112/114$

Separator	DGFRS	GARIS	BGS	TASCA	TASCA
Configuration	DQ_hQ_v	DQ_vQ_hD	Q_vD_hD	DQ_hQ_v	DQ_vQ_h
Transmission / %	35[&]	40*	49-59	**60[§]**	**35[§]**
Dispersion / mm/%	7.5	9.7	20	**9**	**1**
Length / m	4.0	5.8	4.7	3.5	3.5
Bend. angle / deg	23	45+10	70	30	30
$B\rho_{max}$ / Tm	3.1	2.16	2.5	2.4	2.4
Solid angle / msr	8.8	12.2	45	13.1	4.3

& Yu.Ts. Oganessian priv. comm.

* Estim. from test reactions; K. Morita priv. comm.

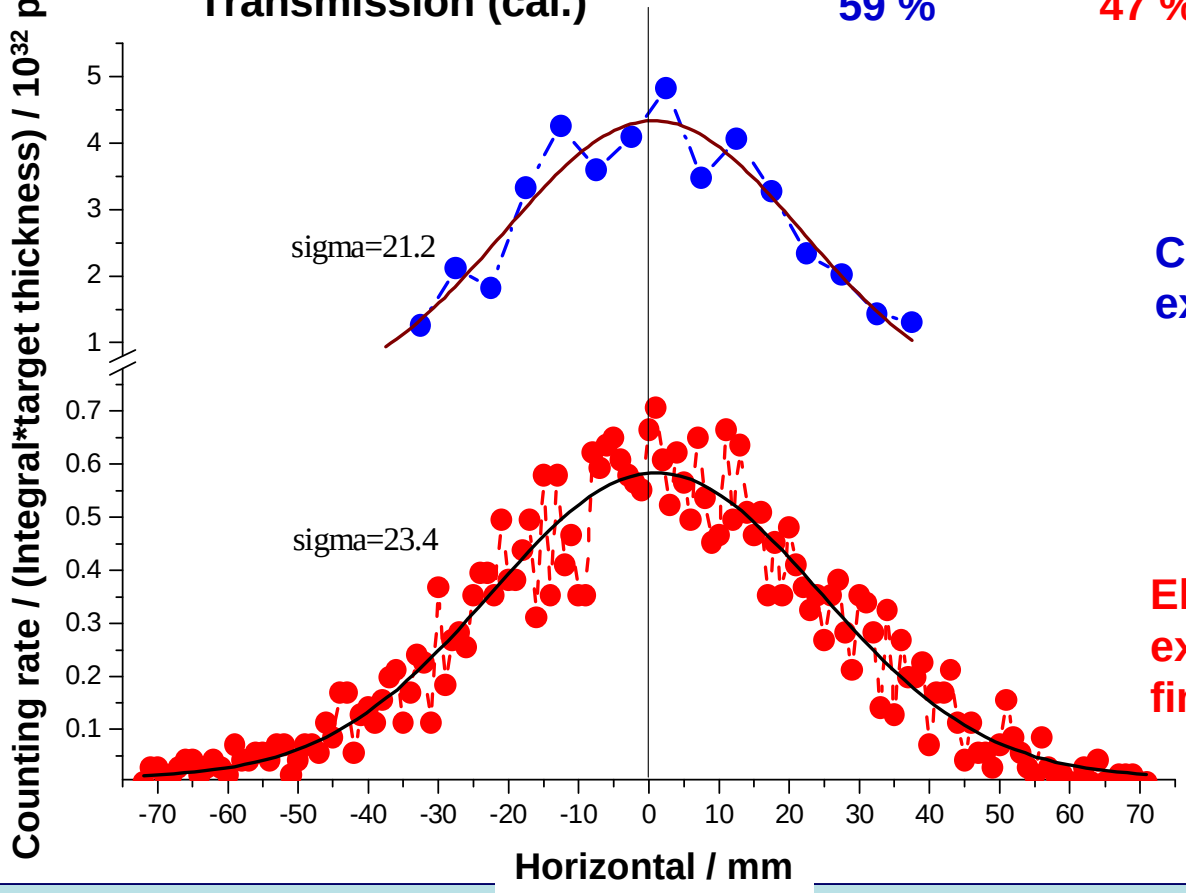
§ MonteCarlo simulation 400 µg/cm^2 target

TASCA – The Commissioning Phase

Preliminary on-line analysis

$^{48}Ca + ^{208}Pb \rightarrow ^{254}No + 2n$

	T013f002	T018f013
Beam intergral	3.27 E15	5.23 E15
Target thickness	429	468 µg/cm^2
Number of ^{254}No	1786	2475
Transmission (cal.)	59 %	47 %



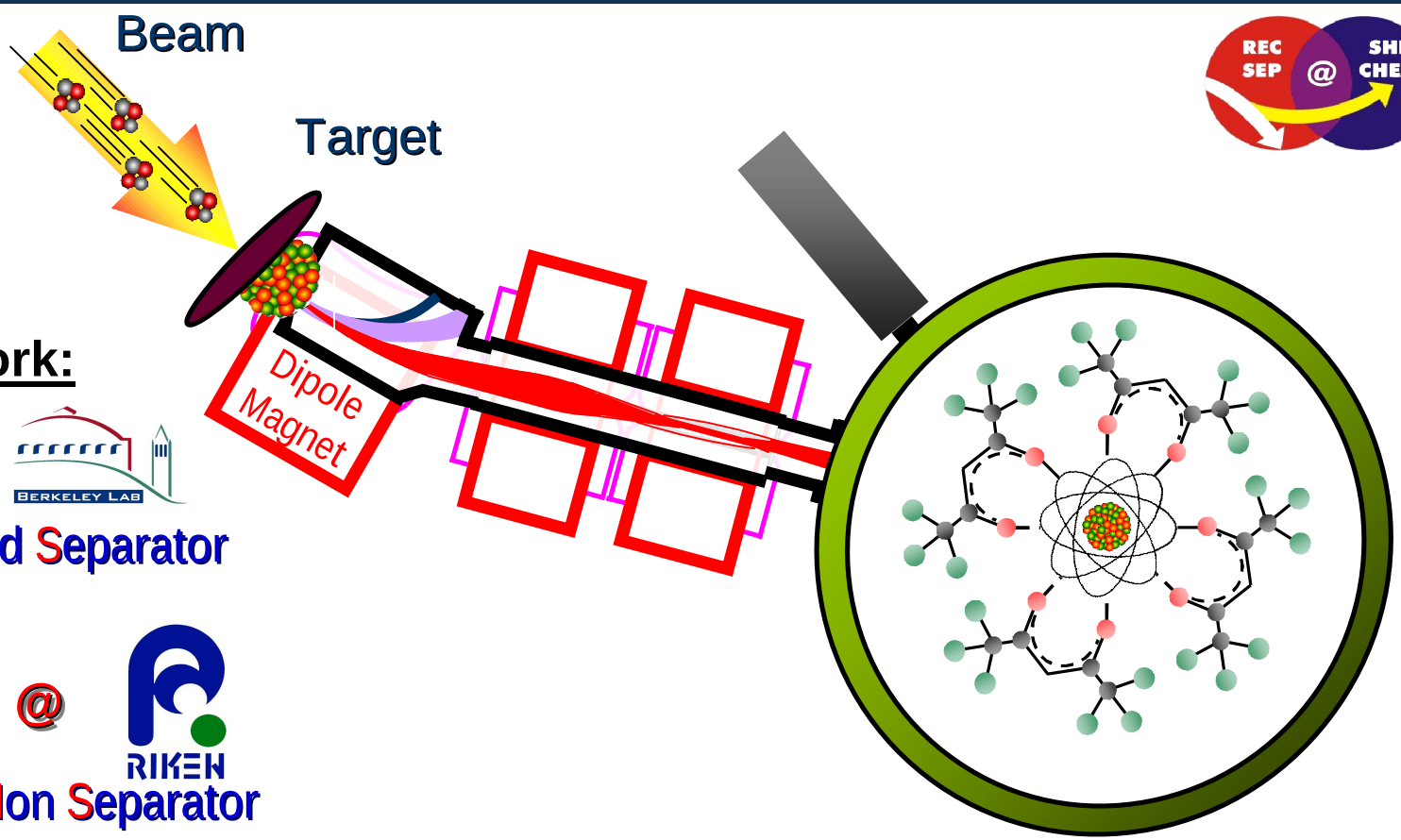
Commissioning experiment

Element 144 experiment preparation / final performance check

Courtesy
J. Khuyagbaatar

Transactinide Chemistry – New Approach

Preseparation w/ Gas-filled Recoil Separator



REC SEP @ SHE CHEM

Pioneering work:

BGS @ Berkeley Lab

Berkeley Gas-filled Separator

New devices:

GARIS @ RIKEN

GAs-filled Recoil Ion Separator

DGFRS @ FLNR

Dubna Gas-Filled Recoil Separator

TASCA @ GSI

TransActinide Separator and Chemistry Apparatus

Courtesy
Ch. E. Düllmann

TASCA Commissioning Experiments: First Transactinide

116 MeV ^{22}Ne + ^{244}Pu → 5n + 78-s ^{261a}Rf / 2.7-s ^{261b}Rf

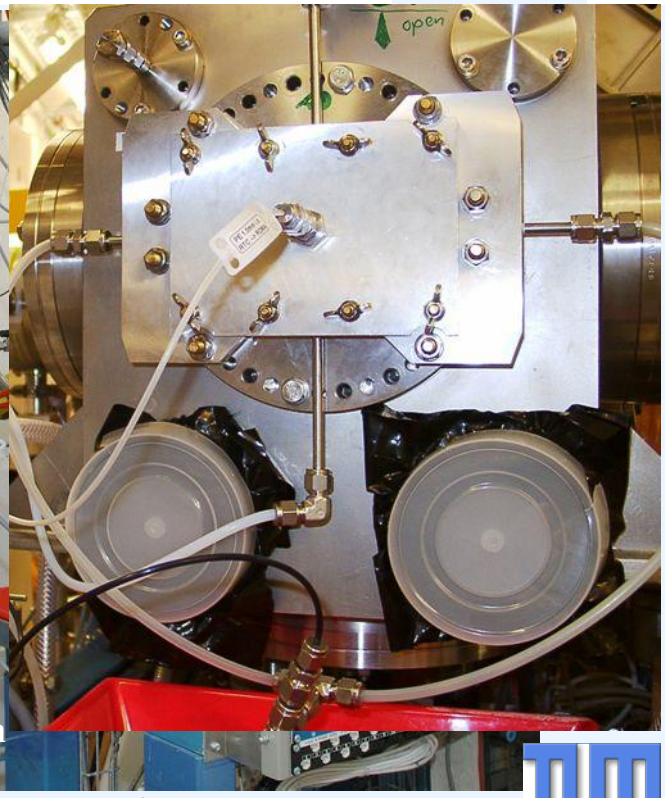
RTC
(140x40) mm²
1.2 µm Mylar window
1.2 bar He, 10 mm depth

→

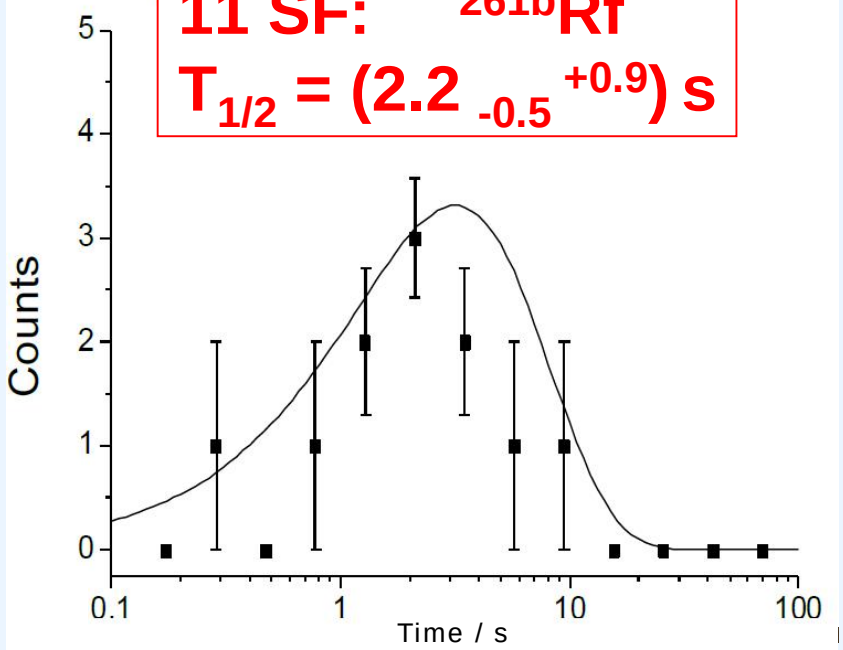
He-KCl jet
3.45 L/min
4 m capillary
2 mm i.d.

→

ROMA
Rotating wheel On-line Multidetector Analyzer
a) t_{step} = 35 s
b) t_{step} = 2.5 s



11 SF: ^{261b}Rf
$T_{1/2} = (2.2\ ^{+0.9}_{-0.5})$ s



A. Gorshkov et al., GSI Sci. Rep. 2008, p. 140

TASCA@GSI DARMSTADT

HELMHOLTZ GEMEINSCHAFT

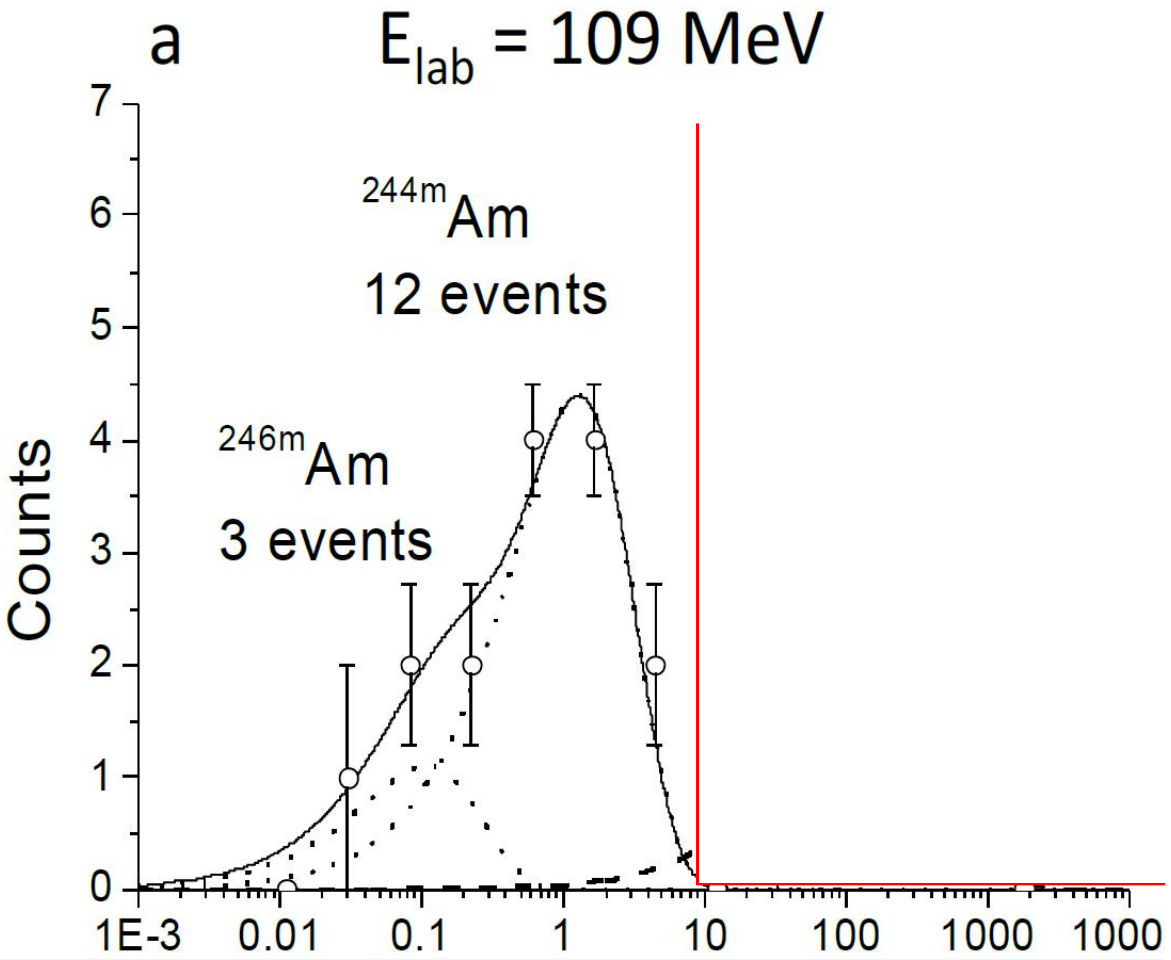
TASCA Commissioning Experiments: First Transactinide

109 MeV ^{22}Ne + ^{244}Pu ➔ 4n + ^{262}Rf

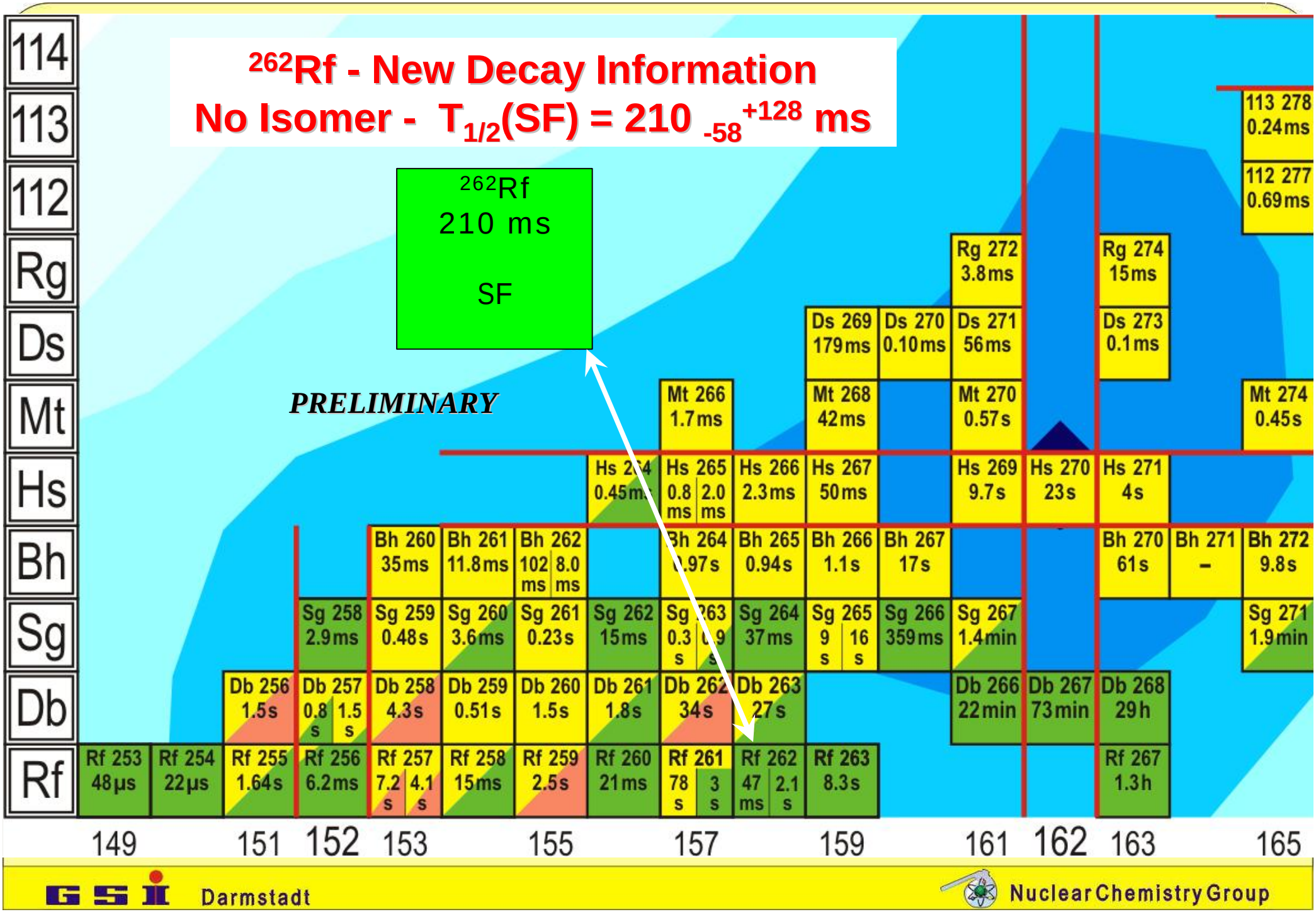
PSSD - FPD

15 EVR-SF in PSSD position-time-correlations
E_{EVR}= 7.5±5 MeV; Δt ≤ 4 ms
➔ in agreement w/ 2-components
a) $T_{1/2}$ (^{246mf}Am) = 76 µs
b) $T_{1/2}$ (^{244mf}Am) = 0.9 ms

10 EVR-SF in PSSD position-time-correlations
0.8 < E_{EVR} < 3.5 MeV, E_{SF} > 80 MeV
➔ $T_{1/2}$ (correlat. time) = 190_{-45}^{+85} ms
$T_{1/2}$ (Literature) = 47 ms and 2.1 s in contradiction

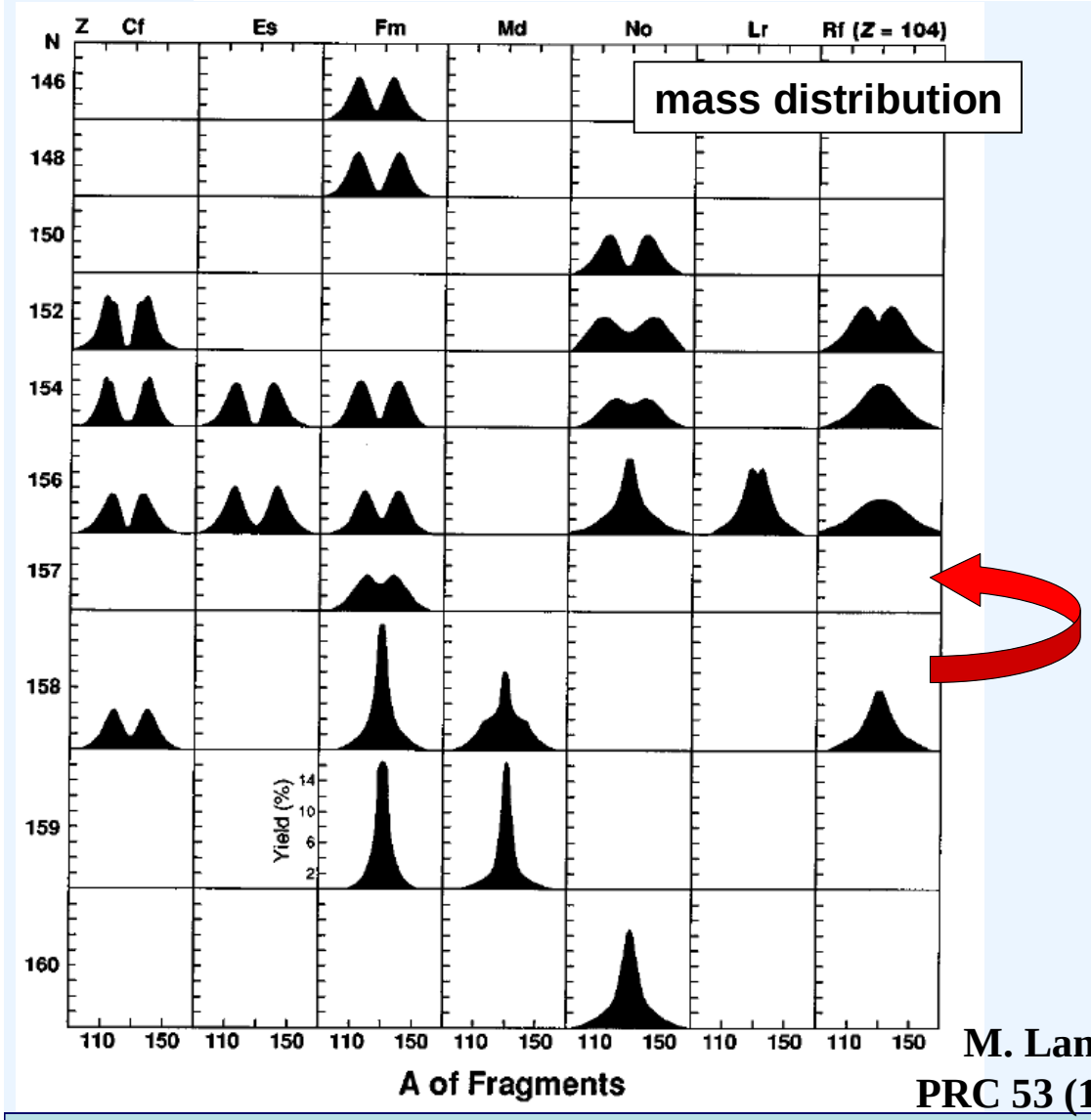


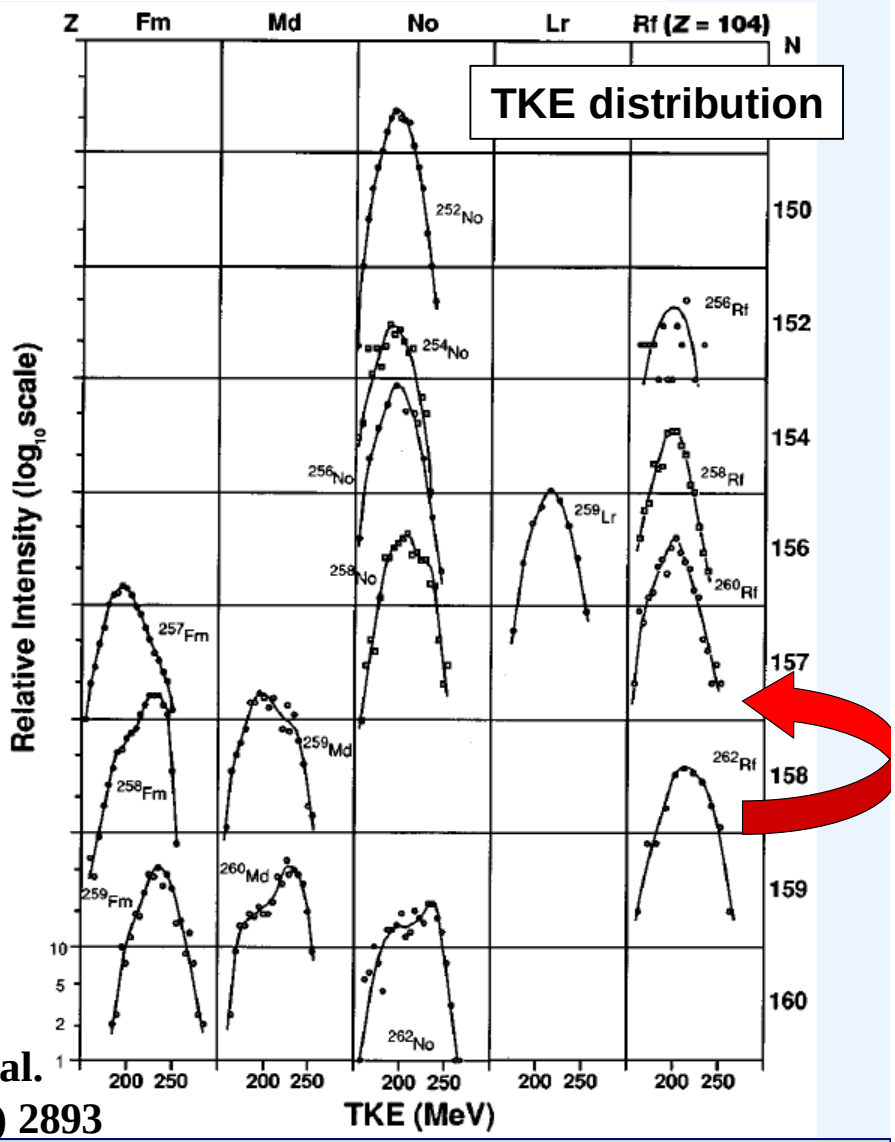
A. Gorshkov et al., GSI Sci. Rep. 2008, p. 140, (revised) CHE7 Workshop Mainz, 2009


262Rf - New Decay Information
No Isomer - T1/2(SF) = 210 -58+128 ms
262Rf
210 ms
SF
PRELIMINARY
114
113
112
Rg
Ds
Mt
Hs
Bh
Sg
Db
Rf
Rf 253 48µs
Rf 254 22µs
Rf 255 1.64s
Rf 256 6.2ms
Rf 257 7.2 s 4.1 s
Rf 258 15ms
Rf 259 2.5s
Rf 260 21ms
Rf 261 78 s 3 s
Rf 262 47 ms 2.1 s
Rf 263 8.3s
Db 256 1.5s
Db 257 0.8 s 1.5 s
Db 258 4.3s
Db 259 0.51s
Db 260 1.5s
Db 261 1.8s
Db 262 34s
Db 263 27s
Db 266 22min
Db 267 73min
Db 268 29h
Sg 258 2.9ms
Sg 259 0.48s
Sg 260 3.6ms
Sg 261 0.23s
Sg 262 15ms
Sg 263 0.3 s
Sg 264 37ms
Sg 265 9 s 16 s
Sg 266 359ms
Sg 267 1.4min
Sg 271 1.9min
Bh 260 35ms
Bh 261 11.8ms
Bh 262 102 ms 8.0 ms
Bh 264 0.97s
Bh 265 0.94s
Bh 266 1.1s
Bh 267 17s
Bh 270 61s
Bh 271 –
Bh 272 9.8s
Hs 264 0.45ms
Hs 265 0.8 ms 2.0 ms
Hs 266 2.3ms
Hs 267 50ms
Hs 269 9.7s
Hs 270 23s
Hs 271 4s
Mt 266 1.7ms
Mt 268 42ms
Mt 270 0.57s
Mt 274 0.45s
Ds 269 179ms
Ds 270 0.10ms
Ds 271 56ms
Ds 273 0.1ms
Rg 272 3.8ms
Rg 274 15ms
112 277 0.69ms
113 278 0.24ms
149
151
152
153
155
157
159
161
162
163
165
GSI Darmstadt
Nuclear Chemistry Group

TASCA Commissioning Experiments: First Transactinide

≈ 2.5-s ^{261b}Rf – SF properties re-assigned (*PRELIMINARY!*)





M. Lane et al.
PRC 53 (1996) 2893

TASCA – Nuclear Reactions + Parameters Studied

Product	xn	Project.	Target	HTM Dip/Quad	SIM Dip/Quad	Target thick	Gas	Gas press	Det/Electr	RTC	ROMA	Chem
Os-173,175	7n	Ar-40	Ce-nat	x			He			x		AC
Hg-180-183	6n	Ar-40	Sm-144	x	x	x	He	x	G,M	x		GC
Pb-188	4n	Ca-48	Sm-144	x	x	x	He		G,M			
Pb-188	4n	Ar-40	Gd-152	x		x	He		G			
Pb-194-196	4-5n	Ar-40	Gd-nat	x	x	x	He		G	x		
Bi-198m,199	4-5n	Ne-22	Ta-181	x	x		He	x	G CATCH			
Po-195,196	4-5n	Ca-48	Gd-152	x			He		G	x	x	
At-200	*3n*	*Ni-64*	*La-139*		*TASISpec*		*He*		*TASIS*			
Fr-205-206	5-6n	Si-30	Ta-181	x	x		He, VAC	x	G,M			
Fr-200	*5n*	*Ni-64*	*Pr-141*		*TASISpec*		*He*		*TASIS*			
Ra-208-211	3-4n	Cr-54	Gd-nat	x	x		He	x	G			
Ra-208-211	*3-6n*	*Ni-64*	*Nd-150*		*TASISpec*		*He*		*TASIS*			
Ac-210	5n	Ar-40	Lu-nat	x	x		He,N2,mix	x	G,M			
Ac-215	4n	Ne-22	Au-197	x	x	x	He,H2,mix	x	G			
Fm-245	3n	Ar-40	Pb-208	x	x		He	x	G	x	x	
No-252	2n	Ca-48	Pb-206	x	x,*TASISpec*		He	x	G,TASIS	x	x	
No-253	2n	Ca-48	Pb-207	x	*TASISpec*		He		G,M,TASIS			
No-254	2n	Ca-48	Pb-208	x	x		He,H2,mix	x	G			
No-255	5n	Ne-22	U-238	x	x		He,H2,mix	x	G,M	x	x	
No-256	4n	Ne-22	U-238	x			He					
Rf-260	6n	Ne-22	Pu-244	x			He,H2,mix		G,M			
Rf-261	5n	Ne-22	Pu-244	x			He			x	x	AC
Rf-262	4n	Ne-22	Pu-244	x			He,H2,mix		G,M			
Background	*no*	*Ca-48*	*Pu-244*	*x*	*TASISpec*		*He,H2,mix*	*x*	*G,M,TASIS*			