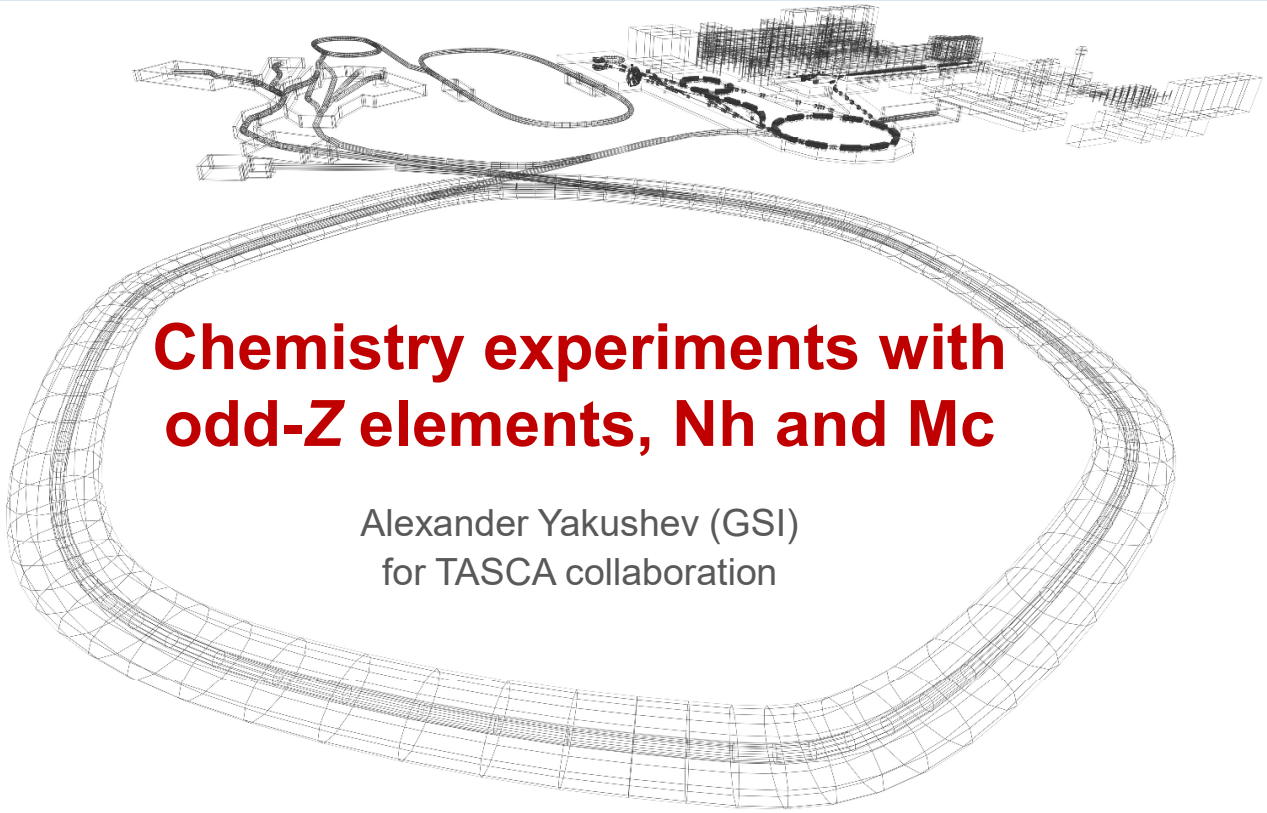
TASCA 21
TASCA Workshop, GSI Darmstadt 21-23.06.2021



Chemistry experiments with odd-Z elements, Nh and Mc

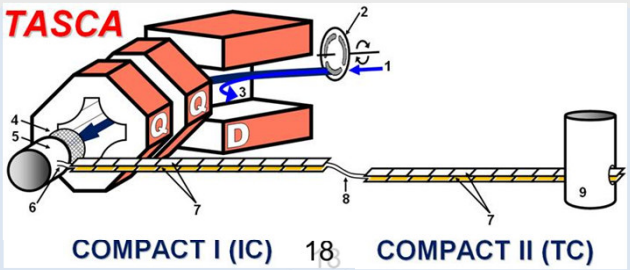
Alexander Yakushev (GSI)
for TASCA collaboration

Outline

- Introduction/Motivation
- Experimental methods
- Status of previous chemical studies on Nh
- Preliminary results of recent chemical studies at ***TASCA***

SHE chemistry at GSI

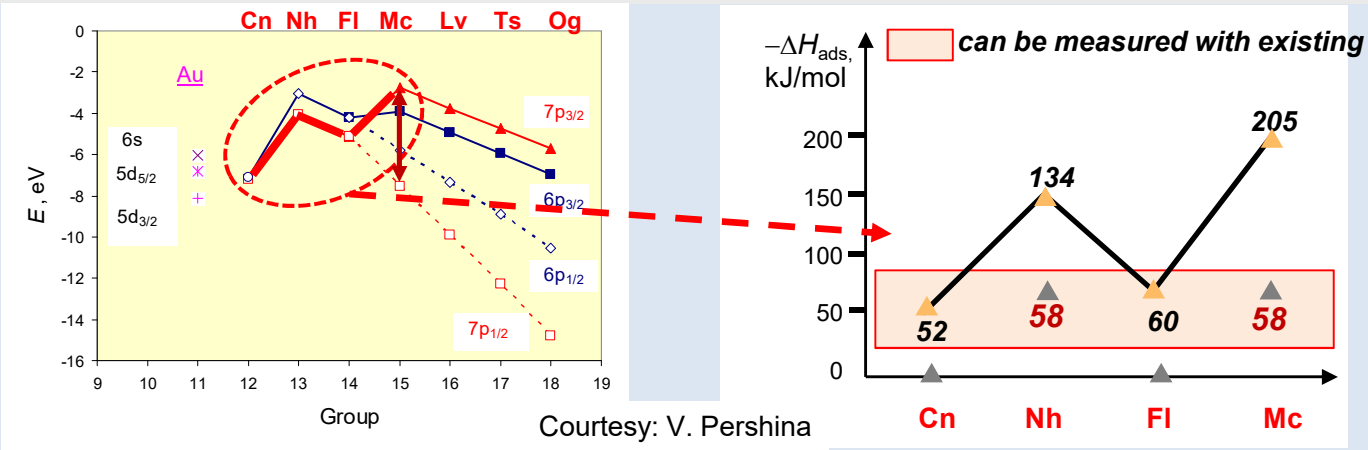
Method: gas chromatography
Setup: *TASCA* + COMPACT



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
H 1																	He 2
Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
Cs 55	Ba 56	La* 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88	Ac+ 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112	Nh 113	Fl 114	Mc 115	Lv 116	Ts 117	Og 118

*Lanthanides	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
+Actinides	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103

Theory: unpaired electron changes chemical properties



Courtesy: V. Pershina

HOAO energies of SHEs compared to their homologs

ADF BAND calculations of adsorption enthalpy on Au (▲) and SiO_2 (▲)

Theory: **Cn, Nh, Fl:**: Pershina et al. *JCP* (2009)

Nh, Mc: V. Pershina, M. Ilias, A. Yakushev, *Inorg. Chem.* (2021) doi.org/10.1021/acs.inorgchem.1c01076

Exp.: **Cn**: $-\Delta H_{ads} = 52^{+4}_{-3}$ **kJ/mol** R. Eichler et al. *Nature* 447 (2007)

Fl: $-\Delta H_{ads} = 34^{+54}_{-11}$ **kJ/mol** R. Eichler et al. *RCA* 98 (2010)

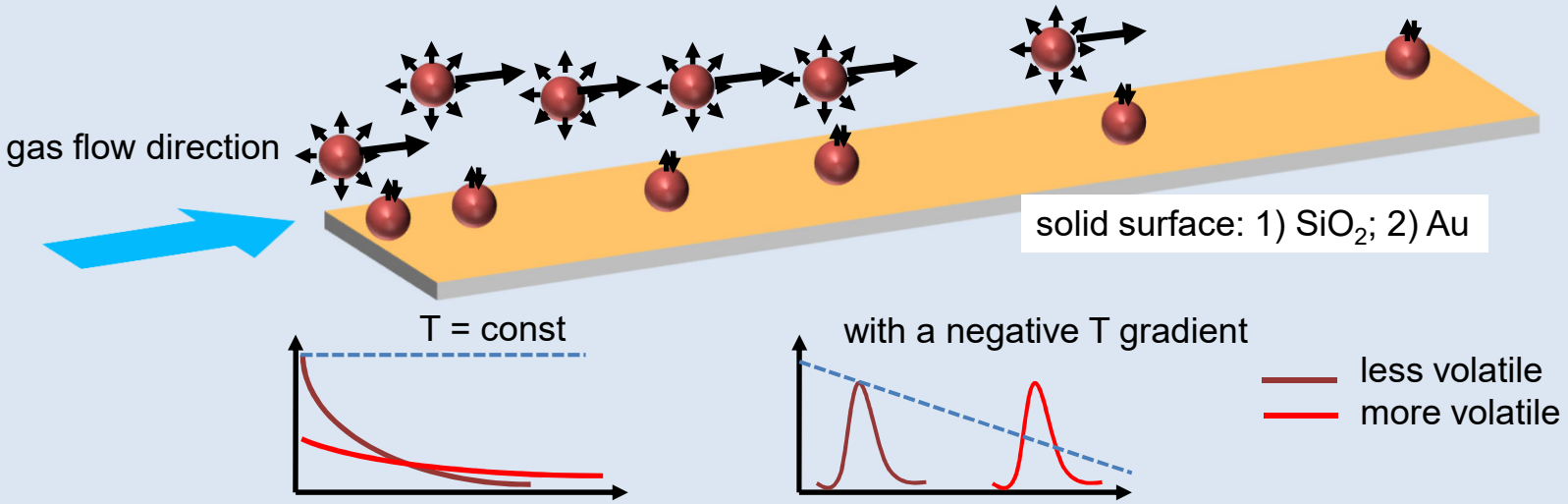
Fl: $-\Delta H_{ads} > 48$ **kJ/mol** A. Yakushev et al. *Inorg. Chem.* 53 (2014)

Odd-*Z* elements Nh and Mc are predicted to be more reactive than elements with closed electron shells Cn and Fl

Chemical study by gas-solid chromatography

$$\tau = e^{-\frac{E_{des}}{RT}}$$ The residence time depends on E_{des} and T

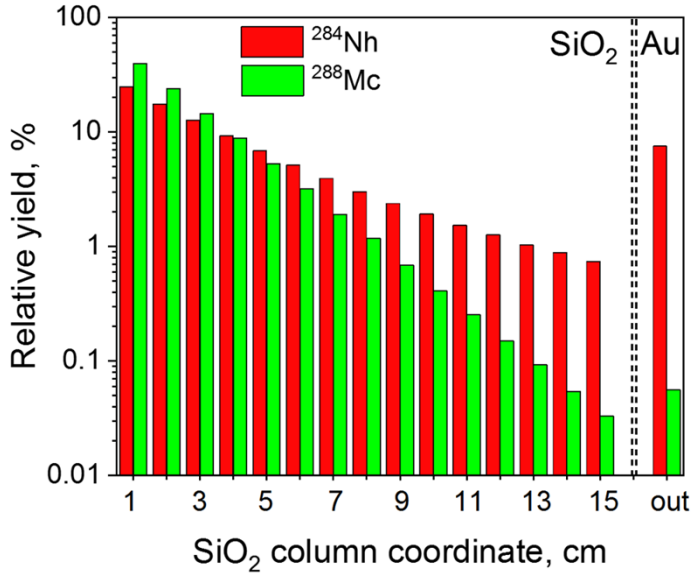
Interplay of the retention time and lifetime for the radioactive species

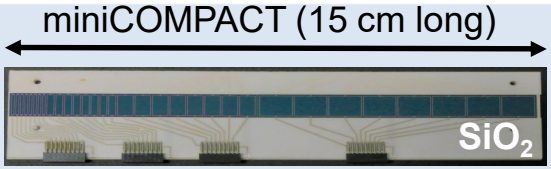


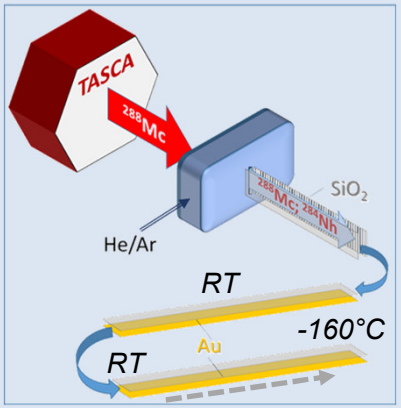
Theory: MC simulation of Mc and Nh adsorption on SiO_2

MC simulations for $\Delta H_{ads}(SiO_2)$:

Mc: -58 kJ/mol
Nh: -58 kJ/mol







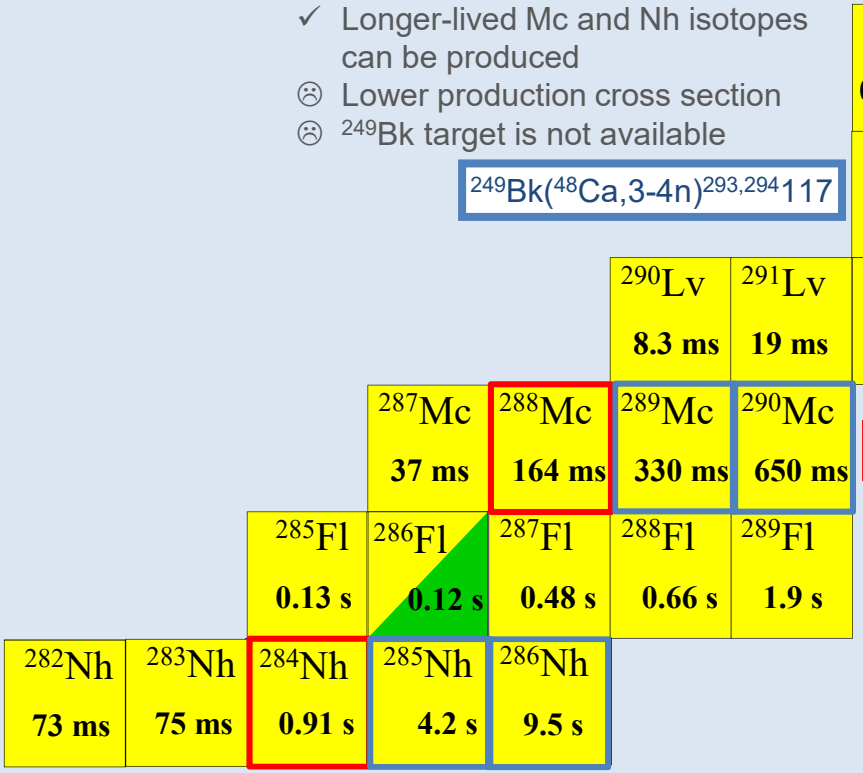
~90% of ^{284}Nh and ~100% of ^{288}Mc should be adsorbed on SiO_2 within the first 15 cm

V. Pershina, M. Ilias, A. Yakushev, *Inorg. Chem.* (https://doi.org/10.1021/acs.inorgchem.1c01076)

SHE isotopes for chemical studies

- ✓ Longer-lived Mc and Nh isotopes can be produced
- ☹ Lower production cross section
- ☹ ^{249}Bk target is not available

^{249}Bk(^{48}Ca,3-4n)^{293,294}117



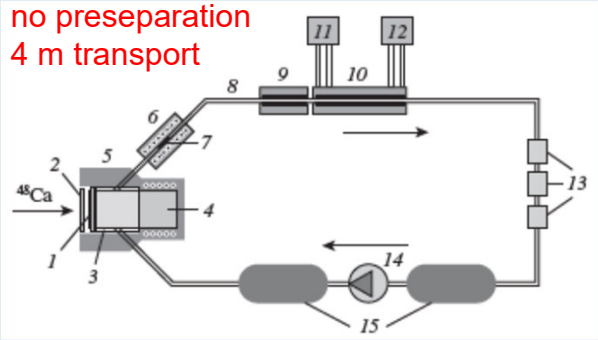
^{243}Am(^{48}Ca, 3n)^{288}115

- ✓ Production rates of ^{288}Mc / ^{284}Nh via ^{243}Am are similar to that of Fl
- ✓ ^{243}Am targets are available

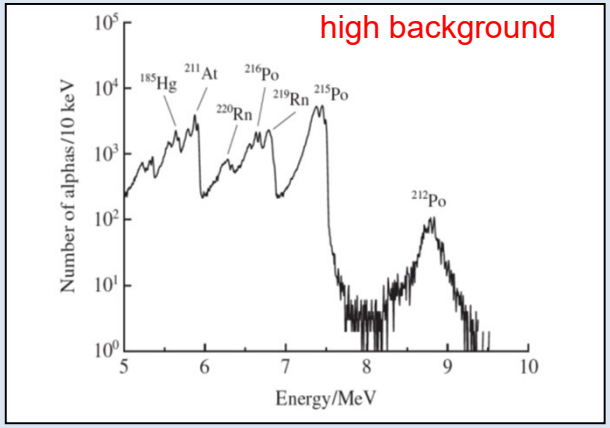
Yu. Ts. Oganessian, V. K. Utyonkov. Rep. Prog. Phys. 78 (2015) 036301

Previous chemical studies with Nh (I)

no preseparation
4 m transport

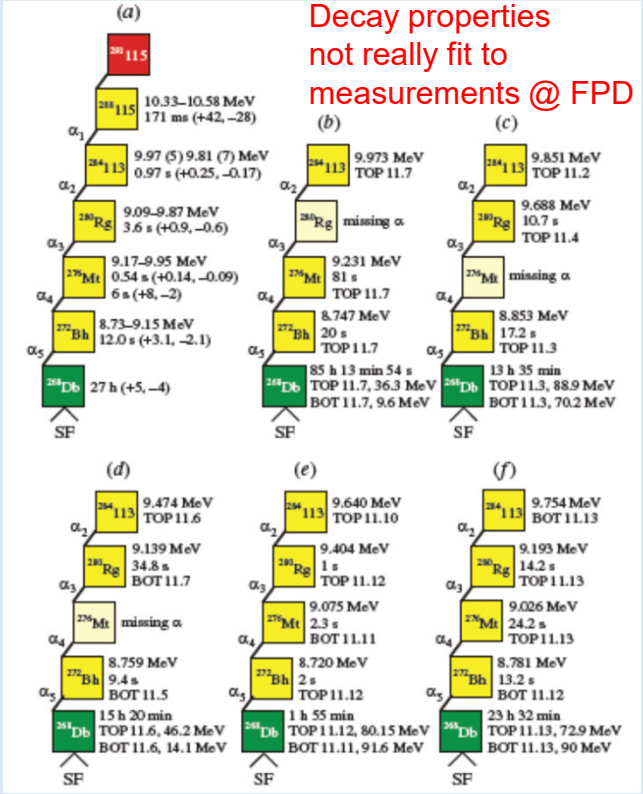


high background



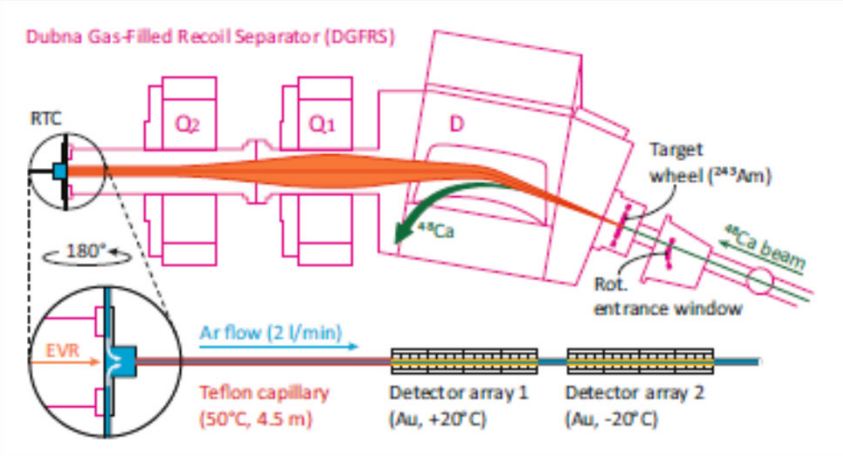
S. Dmitriev et al., *Mendeleev Commun.* 24 (2014)

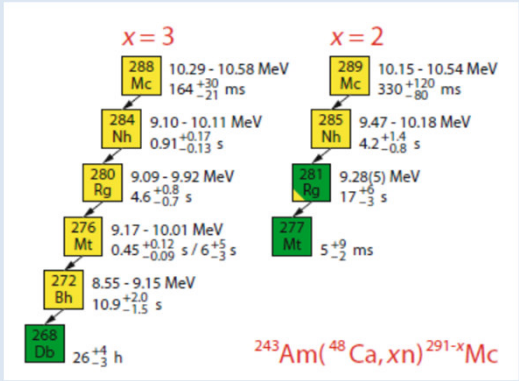
Decay properties
not really fit to
measurements @ FPD



Events were found on Au at room temperature

Previous chemical studies with Nh (II)





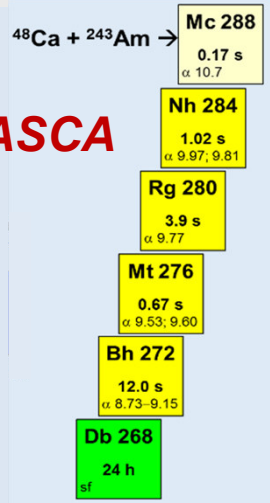
N. Aksenov et al., *Eur. Phys. J.* 53 (2017).

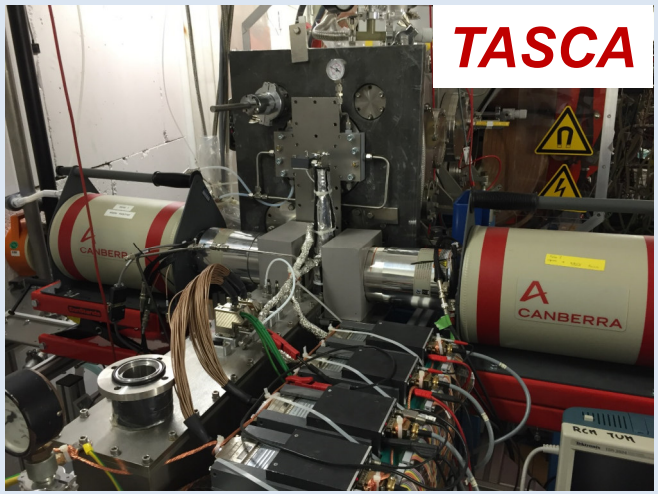
- Preseparation with DGFRS → low-background conditions
- 4.5 m transport through PTFE capillary
- **No events registered** → Nh adsorption on PTFE is high, $-\Delta H_{ads}$ > 45 kJ/mol
- ***➔Nh atoms are chemically reactive***

Previous chemical studies with Nh (III)

2016: at *TASCA*

$^{48}Ca + ^{243}Am \rightarrow$





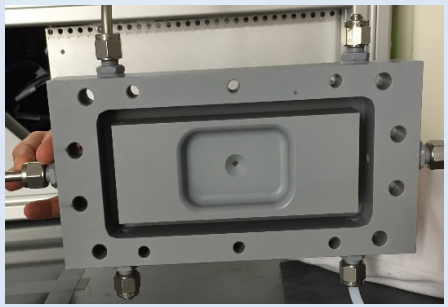
2016:

TASCA @ GSI (20 days)

Expected: 3-4 events

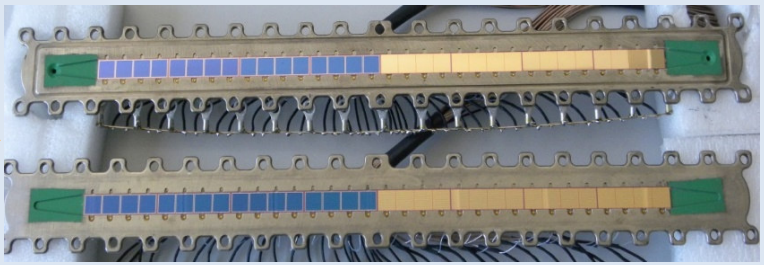
Registered: **zero events**

☹ not optimal quadrupole focusing



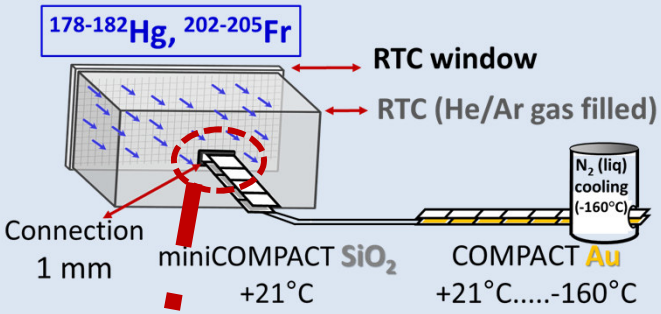
Transport via a 6 cm-long PTFE tube

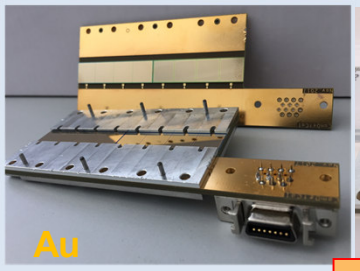
Adsorption study on SiO_2 and Au surfaces

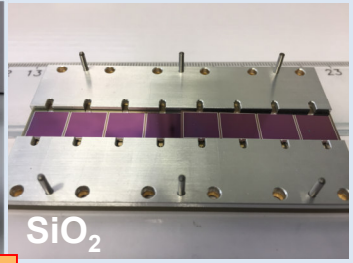


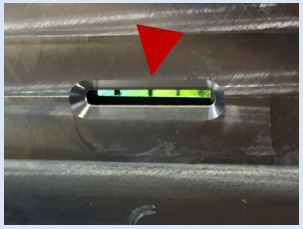
Preparations for the next Nh chemistry experiment (I)

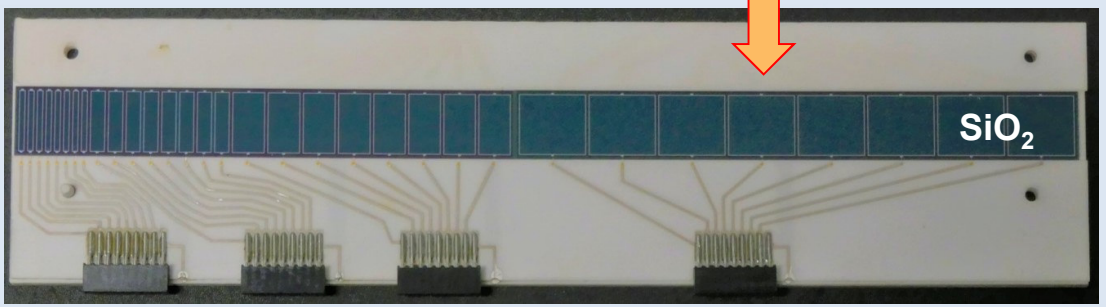
Direct connection of miniCOMPACT to the RTC





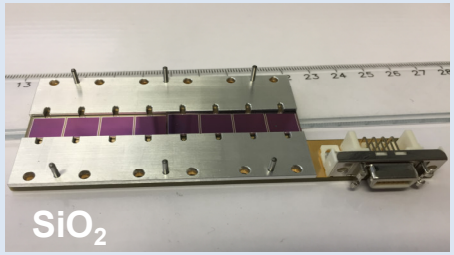


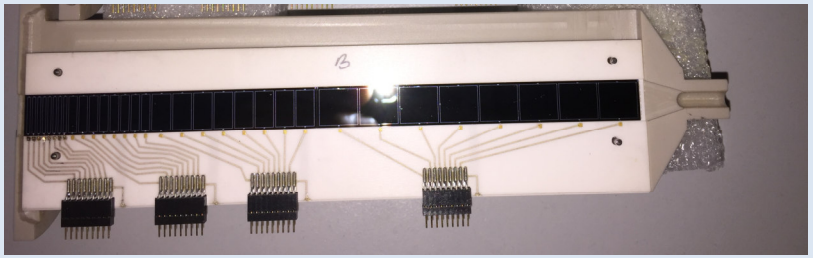


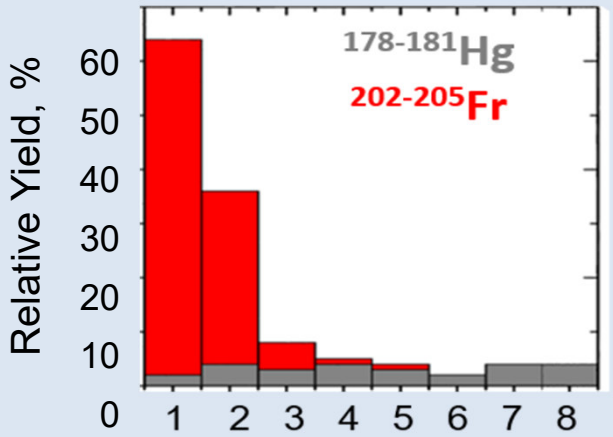


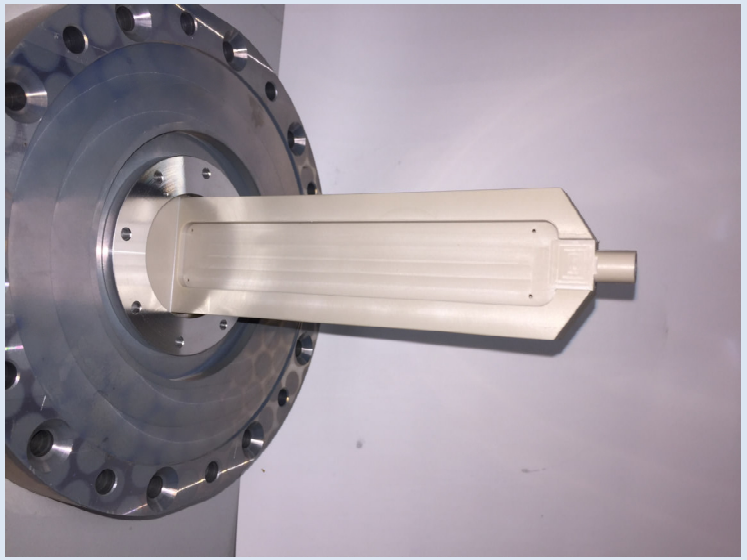
Advanced miniCOMPACT with 32 strips

Preparations for the next Nh chemistry experiment (II)



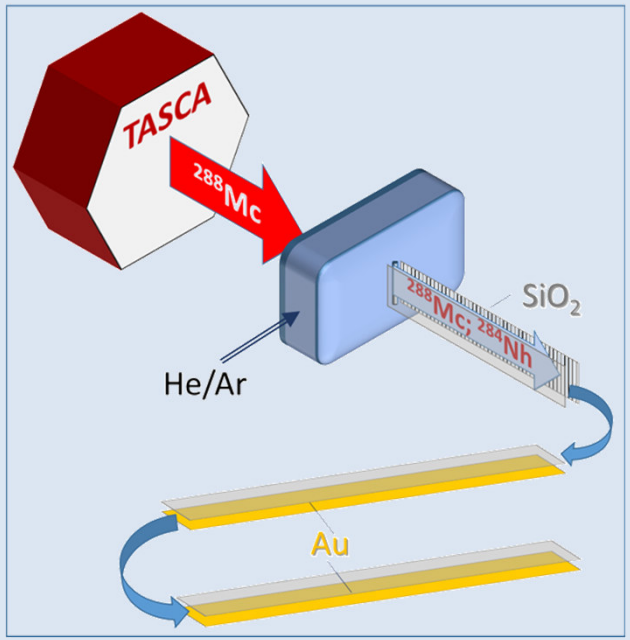


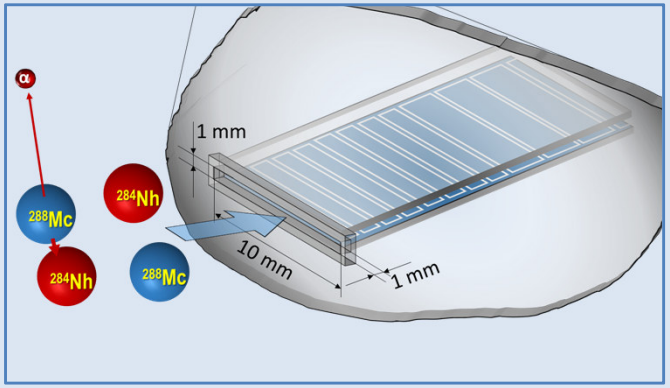




Fr (reactive metal) adsobs on SiO_2
Hg (vol. metal) passes SiO_2 and adsorbs on Au

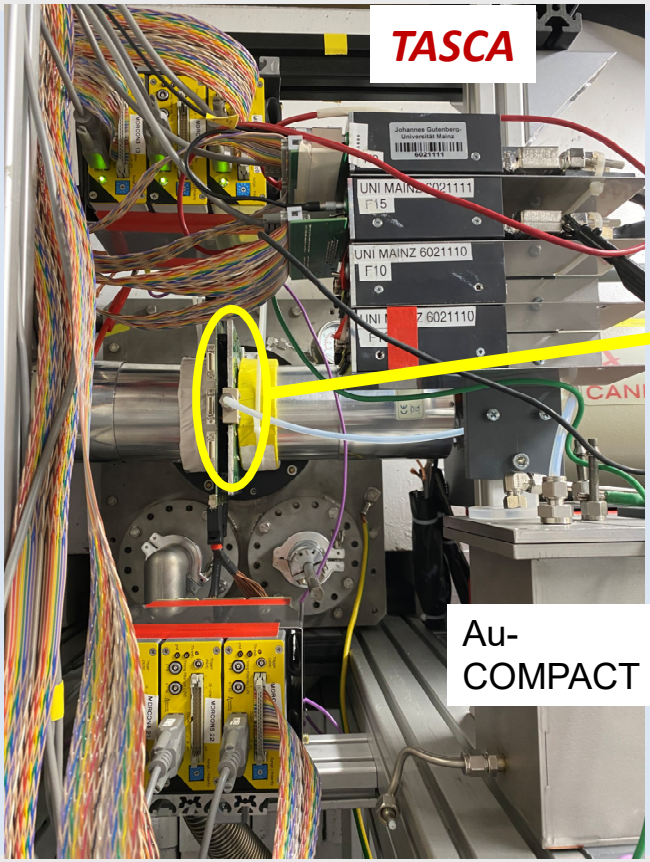
2020: Mc and Nh chemistry experiment at TASCA

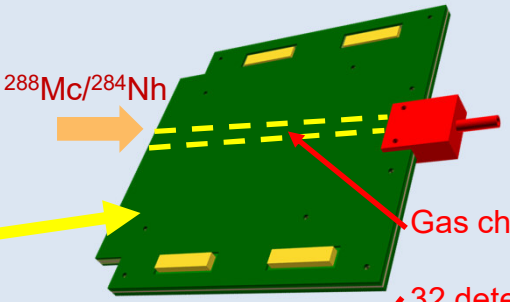


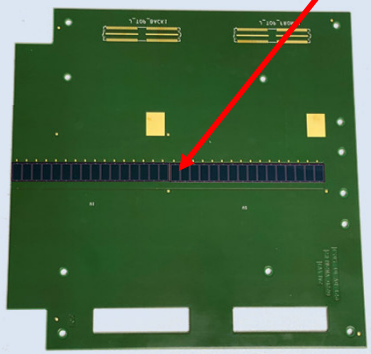


SiO_2-covered miniCOMPACT was connected to the RTC exit, following with two Au-covered COMPACT detectors

2021: Second run of the Mc/Nh chemistry experiment at TASCA







April 2021: TASCA

The first SiO_2-covered detector was modified

Summary and outlook

- First observation of moscovium (Z = 115) in a chemistry experiment
- High chemical yield -a number of decay chains from ^{288}Mc and ^{284}Nh was observed
- Odd-Z SHE elements Nh and Mc are chemically reactive towards a SiO_2 surface
- Observed interaction of Nh and Mc with the SiO_2 surface agrees with theory
- Nh adsorbs strongly on Au
- A higher statistics for Mc is required → a faster transport from a gas stopping chamber to a detector

Thanks

to all TASCA collaborators

to BMBF financial support

to the ion source and accelerator staff

to the GSI laboratories:
experimental electronics
detector lab
target lab

and to all of you for attention!

Bundesministerium für Bildung und Forschung

FAIR Phase 0 Research Program