TASCA 21

GSI, Darmstadt, June 21 - 23, 2021
18th Workshop on
Recoil Separator for Superheavy Element Chemistry

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Direct coupling of liquid-phase chemical setups for heaviest element studies to a recoil separator

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Current state of liquid-phase experiments: Categories

- **Motivation**
- ***Design of the Vacuum to Liquid Transfer Chamber (VLTC)***
- ***SRIM simulations***
- ***Fission fragment experiments***
- ***Coupling to ion exchanging alpha detectors***
- ***Conclusion***

[1] Y. Nagame, J. V. Kratz, and M. Schädel, "Chemical studies of elements with Z ≥ 104 in liquid phase," Nuclear Physics A, vol. 944, pp. 614–639, 2015.

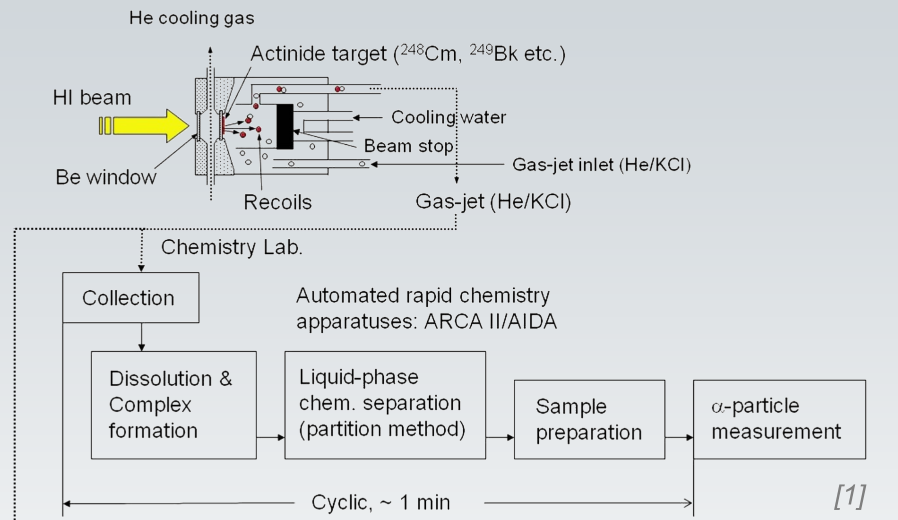
State of liquid-phase chemistry experiments: Categories

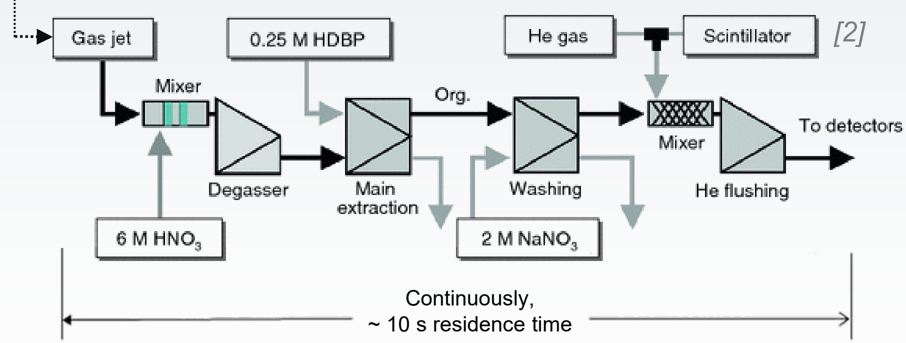
Experimental setups can be categorized in:

- **Discontinuous** (cyclic) operating systems e.g. ARCA, AIDA or ALOHA...
  - *Chromatographic experiments*
  - *α and SF detection with Si detectors*

- **Continuous** operating systems e.g. SISAK
  - *Liquid-liquid extraction experiments*
  - *α, β and SF detection with liquid scintillation*

- With this systems, the chemical properties of the first three super heavy elements in aq. solution were studied
  - *Where ^{265}Sg ($t_{1/2}$ $14.4\ s\ ^{+3.7}_{-2.5}\ s$) could only be investigated indirectly*





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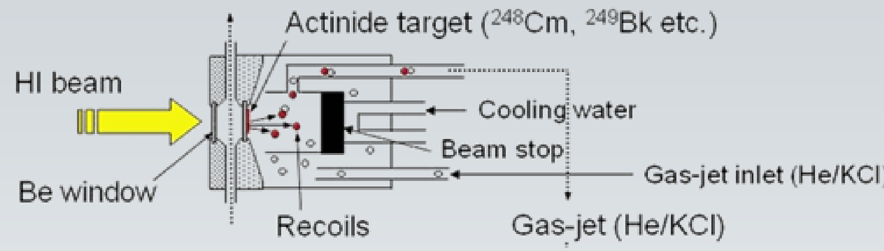
State of liquid-phase chemistry experiments: Optimizations

Further, experiments can be categorized in:

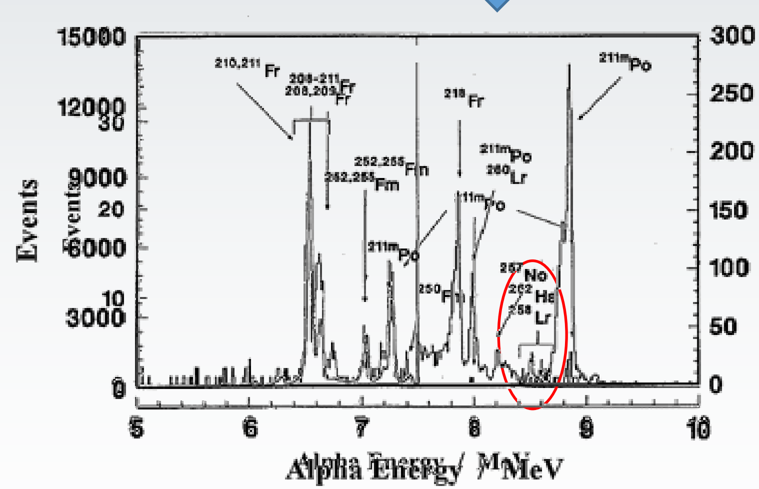
1. Stopping of evaporation residues **before** separation
   - *All nuclear reaction products are transported to the chemical experiment*
   - *High selectivity in the chemical experiment is required in order to detect decays of SHE*
   - *After successful separation of the nuclear by-products from the SHEs under investigation, α decay can be clearly detected by high-resolution α spectrometry with Si detectors…*

[1]



Chemical experiment

[2]



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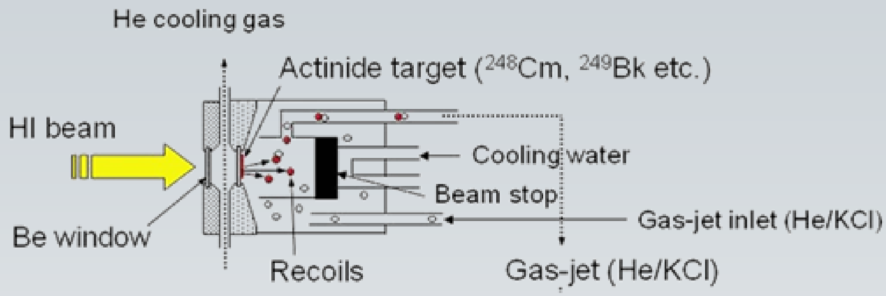
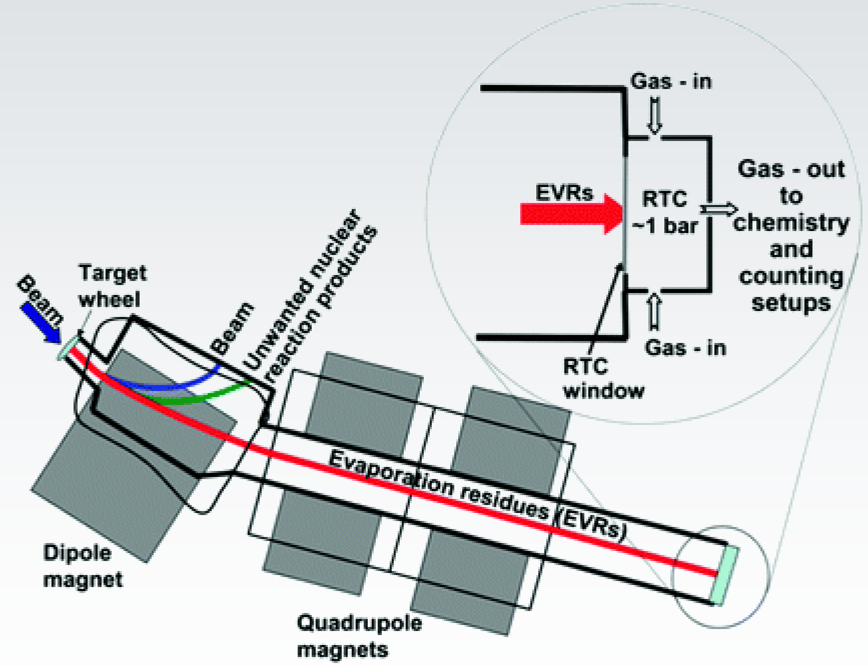
State of liquid-phase chemistry experiments: Optimizations

<u>Further, experiments can be categorized in:</u>

2. Stopping of evaporation residue **after** separation
   - *Unwanted nuclear reaction products and the (unreacted) primary beam are filtered physically…*
   - *Coupling a chemical experiment with a physical pre-separator simplifies the chemical experiments & reduces the spectral background*

- Pioneer experiment at the **B**erkeley **G**as-filled **S**eparator (BGS) coupled through a gas jet system with the SISAK system
  - *Successful experiments with the ^{257}Rf ($t_{1/2}$ $4.4\ s\ ^{+0.6}_{-0.5}\ s$) were possible due to this coupling*





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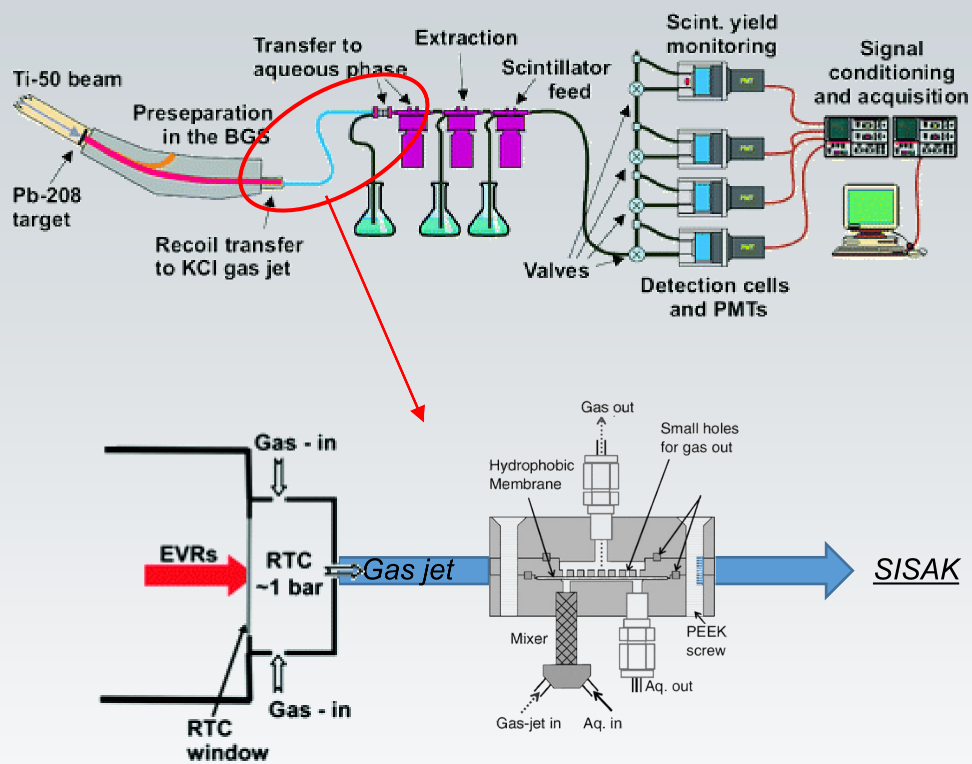

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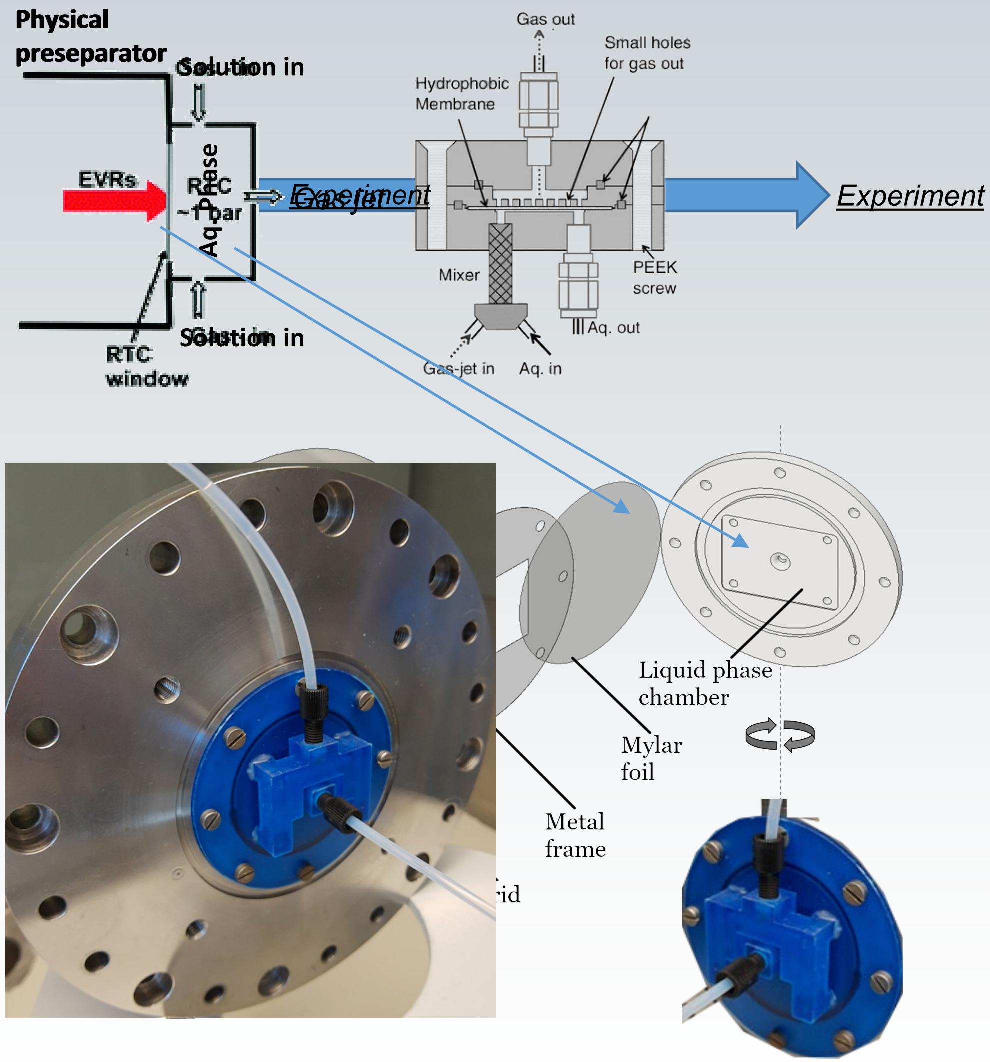
The Vacuum to Liquid Transfer Chamber (VLTC)

New developments

- Instead of further optimizing the multi-stage process:
  1. *Thermalizing the EVR in gas*
  2. *Gas jet transport of the aerosols*
  3. *Phase transfer of the SHE to the aqeous phase*
  4. *Subsequent chemical experiment*

- A direct coupling between the low pressure side (“vacuum”) of a physical pre-separator and the liquid phase of a chemical experiment was designed

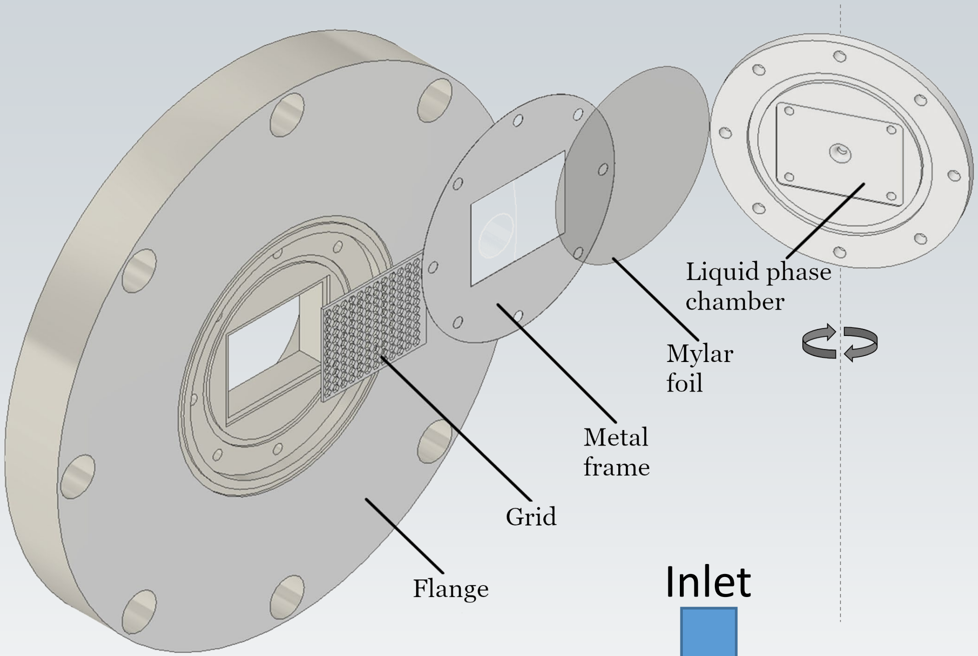
- Resulting in the **V**acuum to **L**iquid **T**ransfer **C**hamber (VLTC)

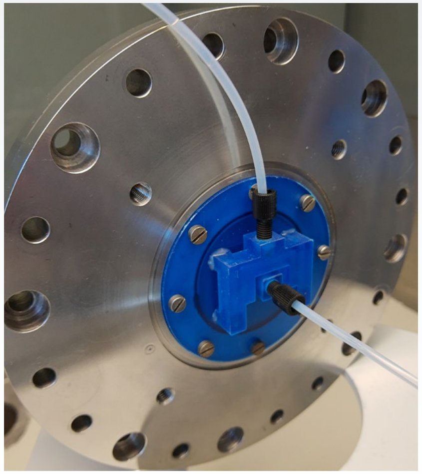


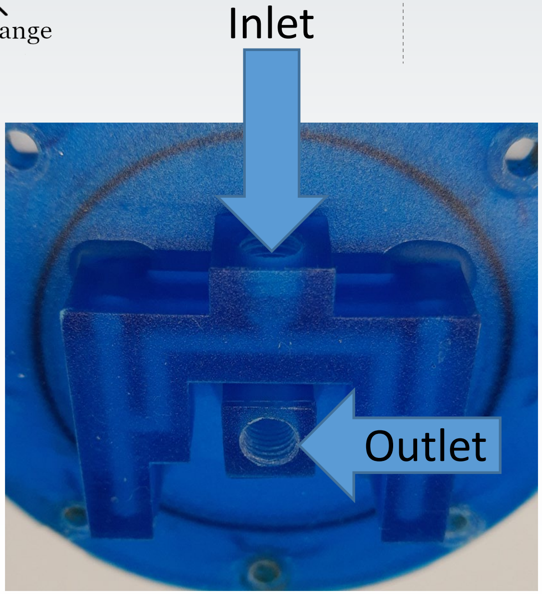
The Vacuum to Liquid Transfer Chamber (VLTC)

New developments

- Standard flange
  - *Window size: 1270 mm²*
- Grid
  - *80 % ion transparency*
- Metal frame
  - *Covered with 3.3 µm or 6.0 µm thin Mylar foil*
- Liquid phase chamber
  - *3D printed (PMMA-like)*
  - *Standard ¼-28 fitting connection*
  - *Sealing ring between Mylar Foil and Chamber*
  - *Chamber depth: 500 µm*
  - *Total volume 635.5 µl*







SRIM Simulation applicability for SHE experiments

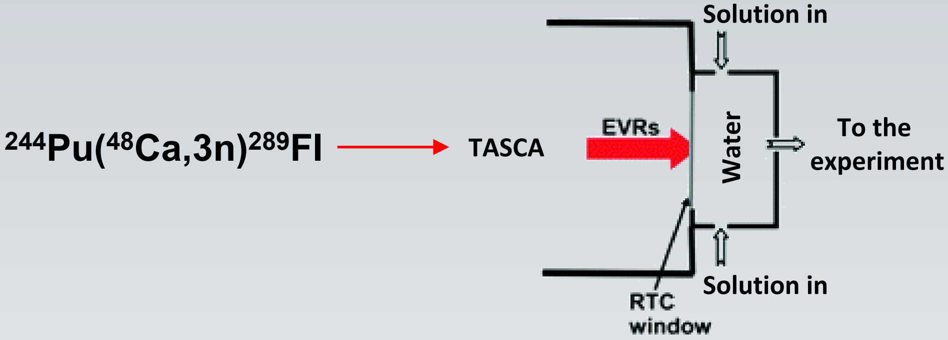
Proof of concept: 1. Simulations

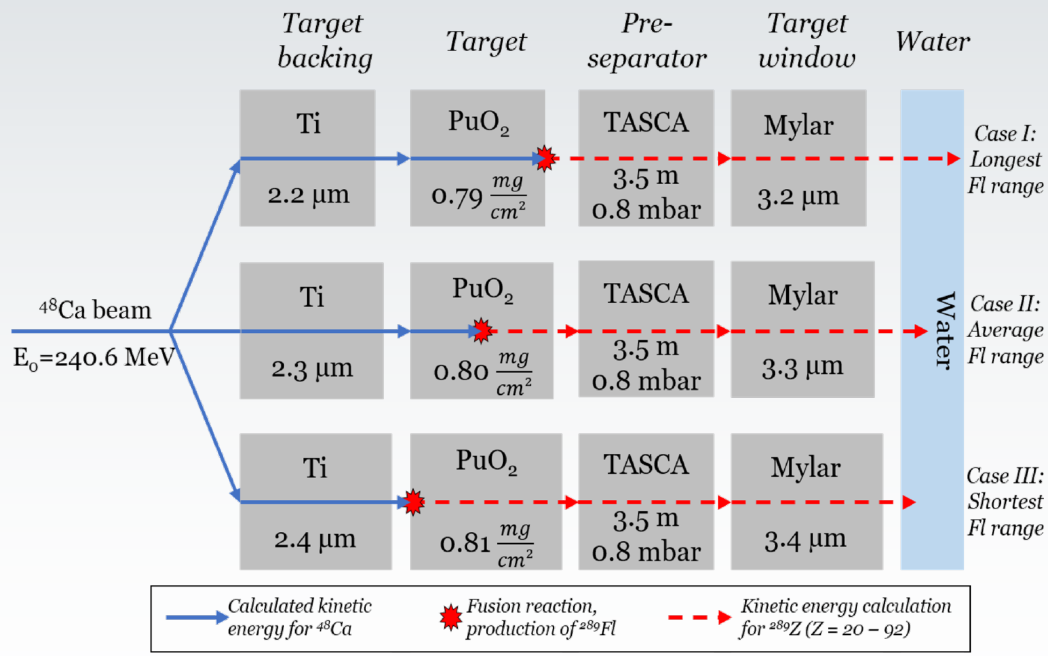
- In advance, simulations were carried out with SRIM on the feasibility of a VLTC…
  - *…using as example experiments with ^{289}Fl at TASCA [1].*
  - *The aim was to assess the transfer of an EVR directly after TASCA into the aqueous phase with the aid of a VLTC.*
- Three cases were considered:

Case I: Longest Fl range

Case II: Average Fl range

Case III: Shortest Fl range



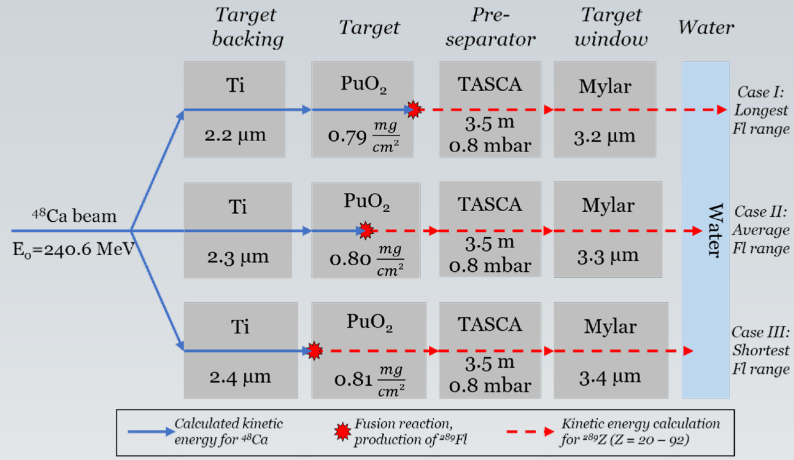


[1] A. Såmark-Roth, et al., "Spectroscopy along flerovium decay chains: Discovery of Ds 280 and an excited state in Cn 282," Phy. Rev. Let., vol. 126, no. 3, p. 032503, 2021.

SRIM Simulation applicability for SHE experiments

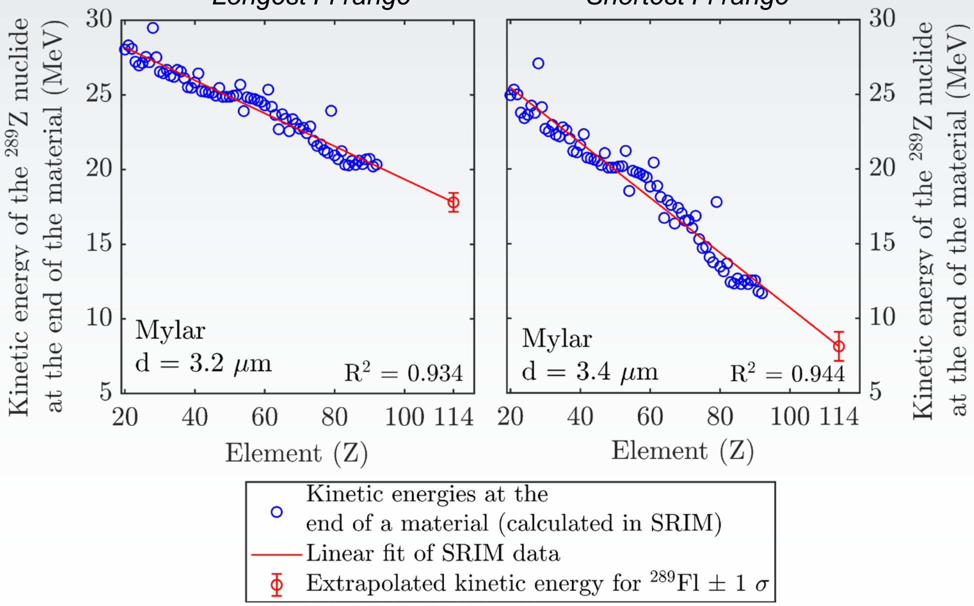
Proof of concept: 1. Simulations

- SRIM calculates only the ranges of elements up to uranium (Z = 92)
  - *Ranges were calculated for ^{289}Z nuclides (Z = 20 - 92) in each material and extrapolated to ^{289}Fl.*
  - *If ^{289}Fl still has kinetic energy when it leaves the Mylar foil, it is stopped in the liquid phase, completely.*



- In a VLTC with…
  - *…a **3.3 µm ± 0.1 µm** thin Mylar foil ^{289}Fl enters the liquid phase in all cases*
  - *…a **6.0 µm ± 0.2 µm** thin Mylar foil, ^{289}Fl enters the liquid phase in case I and II*

Case I: Longest Fl range — *Case III: Shortest Fl range*

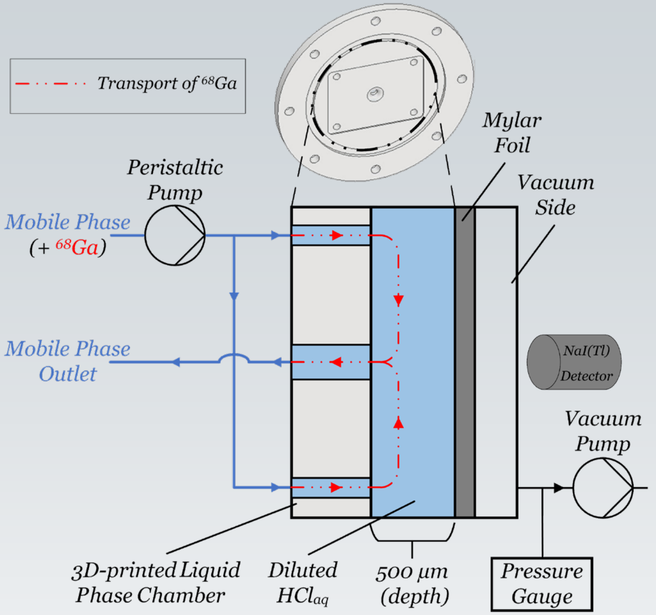


- Experimental proof: literature data shows, that SHE can be transferred through 6 µm Mylar foil

Residence time

Residence time studies

- Mean residence time (MRT) in the liquid phase chamber was determined with ^{68}Ga in 0.1 M HCl
  - *Vacuum side: 100 mbar and equipped with a shielded NaI(Tl) detector*
  - *The ^{68}Ga tracer solution was delivered through the liquid phase chamber with a peristaltic pump at 100 ml/min and 50 ml/min respectively*



- 50 mL/min

50 % *14.7 s ± 1.5 s*

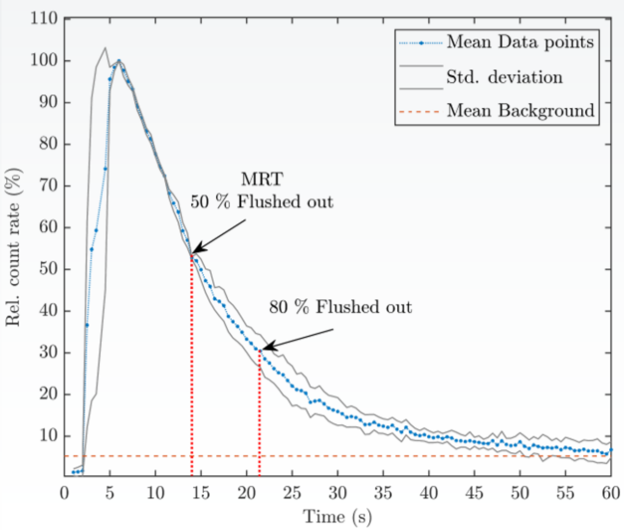
80 % *21.5 s ± 3.0 s*

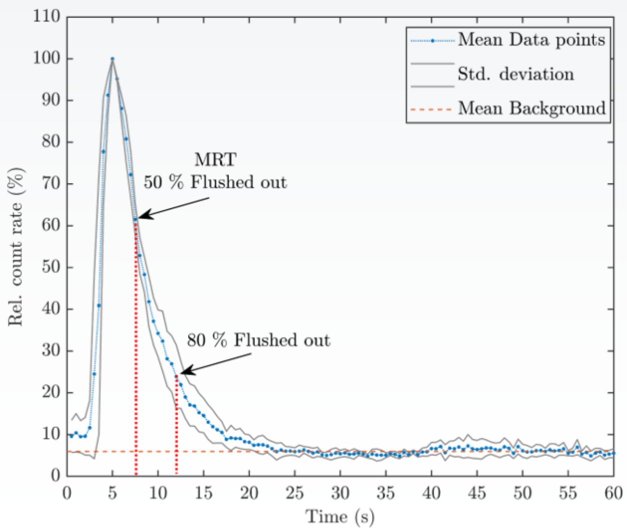
- 100 mL/min

50 % *7.7 s ± 1.0 s*

80 % *12.0 s ± 2.5 s*

- 50 % were eluted in ~ 12.5 ml

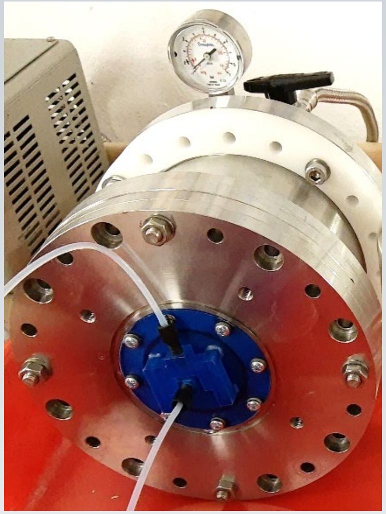


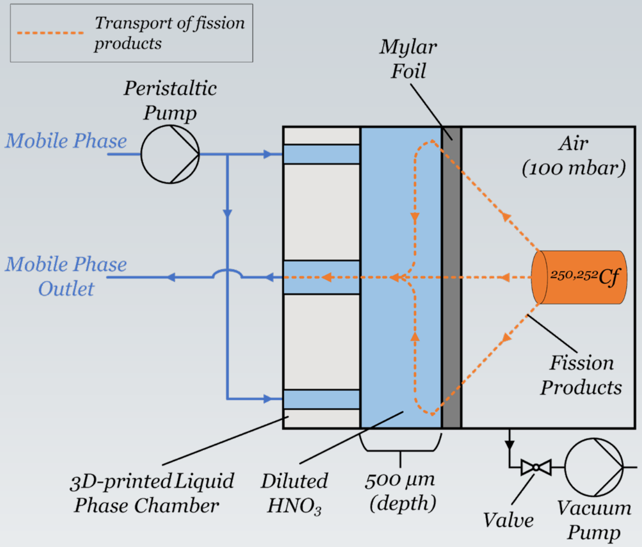


Proof of concept tests

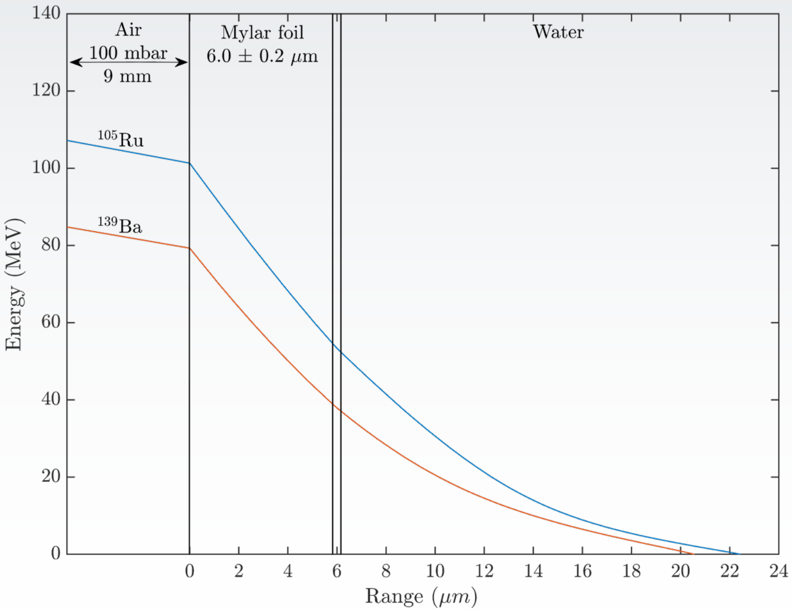
2. Fission fragment tests

- $^{250/252}Cf$ fission source
  - *Emission of light mass fragments (~ 104 u) with E_{kin} ~ 105 MeV*
  - *and heavy mass fragments (~ 140 u) with E_{kin} ~ 80 MeV*





- $^{250/252}Cf$ source was installed on the vacuum side of the VLTC
  - *The setup was also simulated in SRIM*
  - *Required chamber depth: 23 µm*
  - *Total depth (liquid phase chamber): 500 µm*



Proof of concept tests

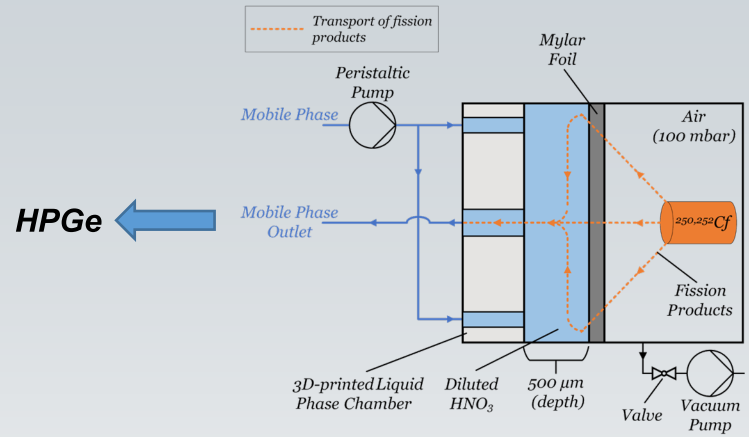
2. Fission fragment tests

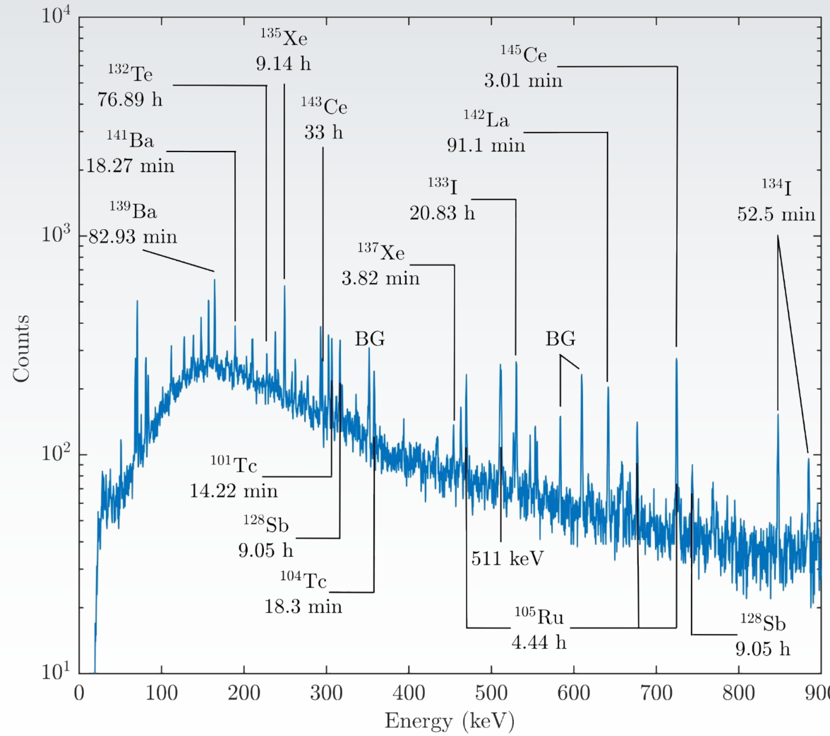
- $^{250/252}Cf$ fission fragments were collected in the liquid phase chamber over time
- Subsequent measurement of 10 ml samples (HPGe)

***γ*-spectrometry results for 10 ml samples**

Fission Product	Collected yield [%]
^{97}Zr	41 ± 12
^{105}Ru	51 ± 16
^{132}Te	34 ± 9
^{139}Ba	35 ± 9
^{143}Ce	40 ± 7

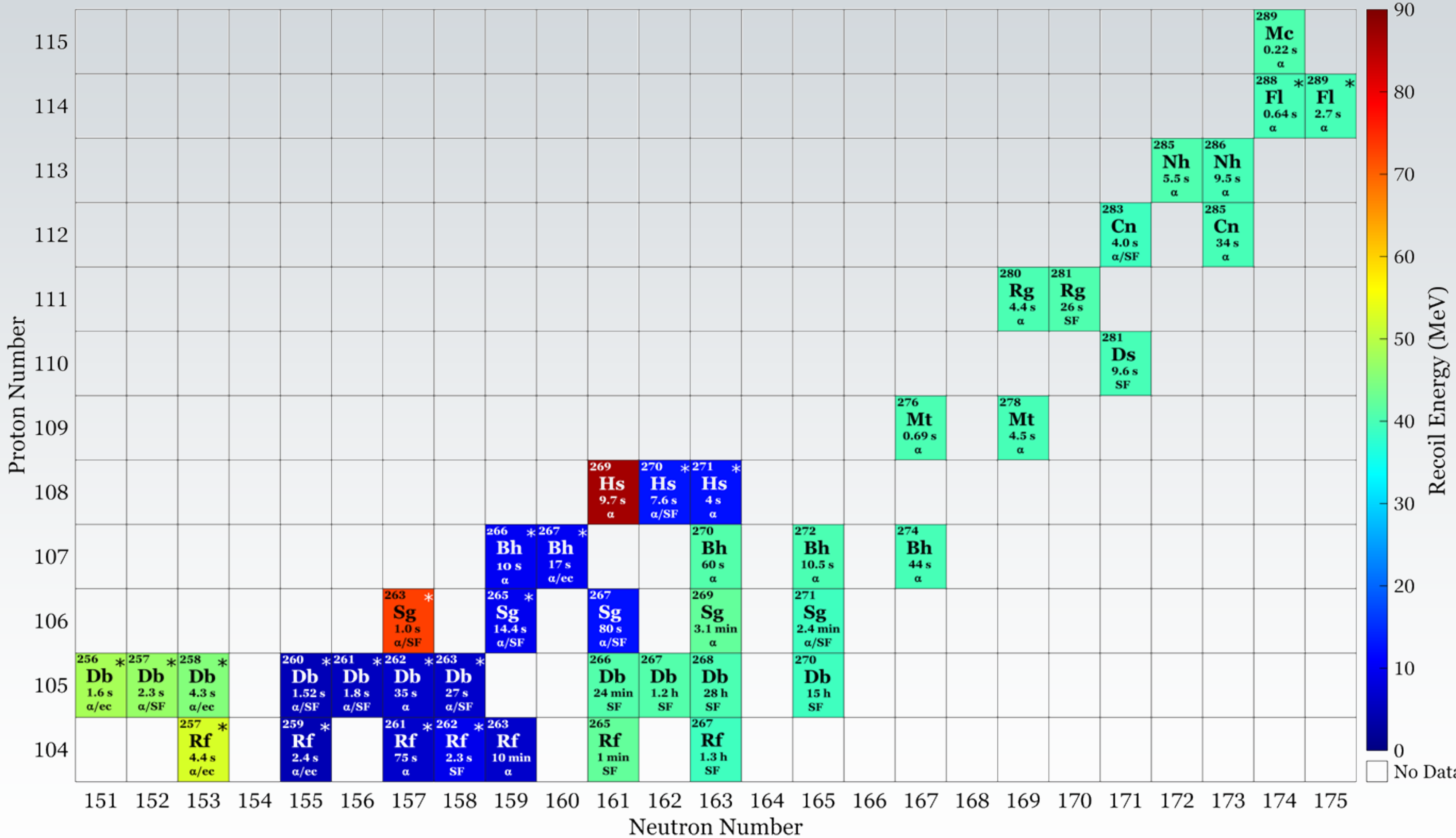
- Fission fragments of light and heavy mass peaks were observed





Applicability of the VLTC for SHEs

- Which SHEs can be investigated with the VLTC system? [1]



[1] M. Schädel and D. Shaughnessy, Eds., The Chemistry of Superheavy Elements, 2nd ed. Springer, 2014.

VLTC Paper

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Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Available online 18 June 2021, 165486

In Press, Journal Pre-proof

Speeding up liquid-phase heavy element chemistry: Development of a vacuum to liquid transfer chamber (VLTC)

Dominik Krupp [a], Christoph E. Düllmann [b, c, d], Lotte Lens [a], Jon Petter Omtvedt [e], Alexander Yakushev [c], Ulrich W. Scherer [a]

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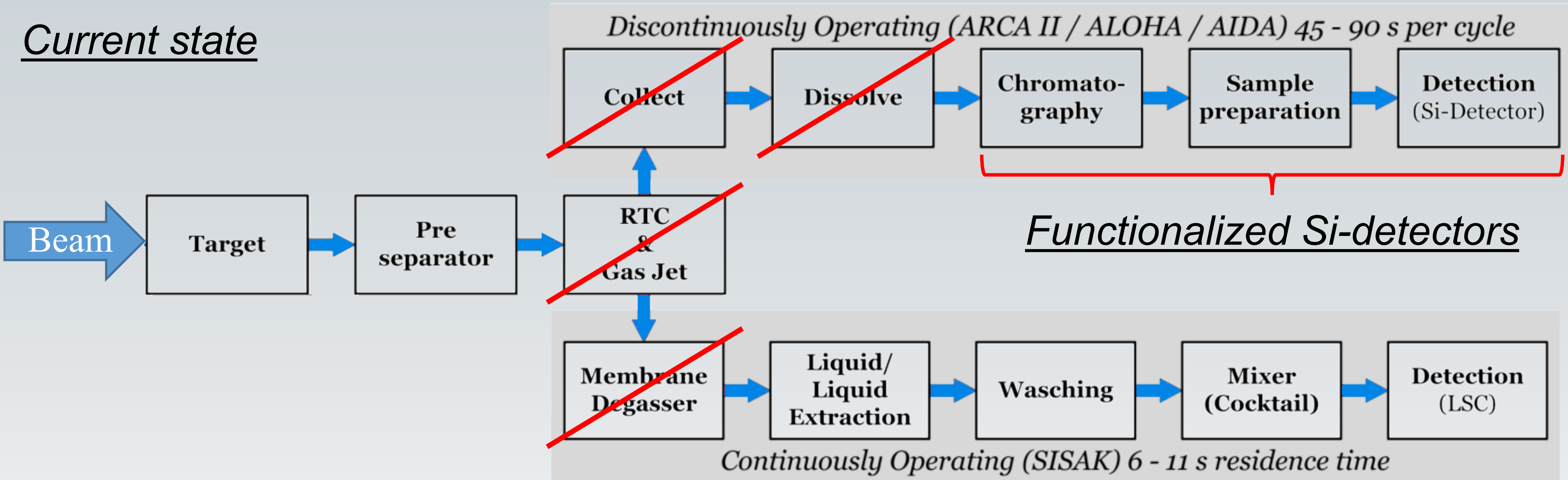
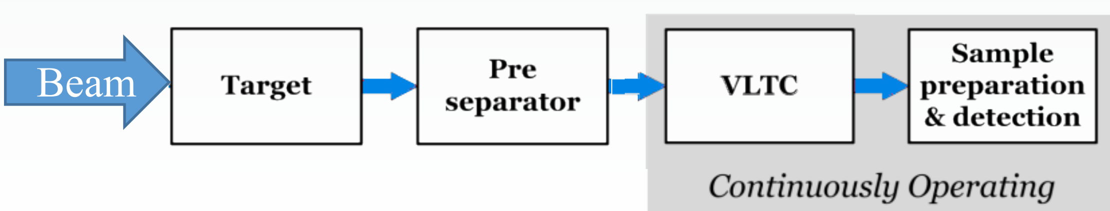
Direct coupling of liquid-phase chemical setups to a recoil separator

Current state



New developments

- Direct coupling of the vacuum side of a physical preseparator with the liquid phase of a chemical experiment → development of a **V**acuum to **L**iquid **T**ransfer **C**hamber (VLTC)
- Followed by continuous operating chemical experiments, e.g. equipped with functionalized Si-detectors [1] TASCA 2019?



Functionalized Si-detectors

<u>*New ways of a faster α spectrometry*</u>

- µl-flow cells equipped with Si-detectors

- Si-detectors were chemically modified (functionalized)
  - *Depending on the functional groups, e.g. cation exchanger (R-SO_3H)*
  - *Accumulation of radionuclides on the detector surface*
  - *Combined chemical separation and detection*

- Coupling the functionalized a detectors with the VLTC for continuous fast liquid phase chemistry experiments

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Prototype development of ion exchanging alpha detectors

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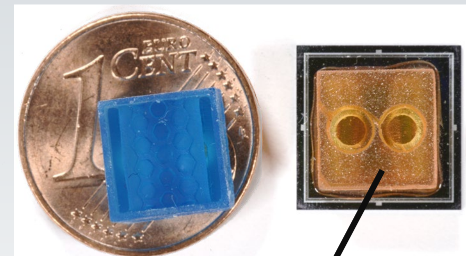

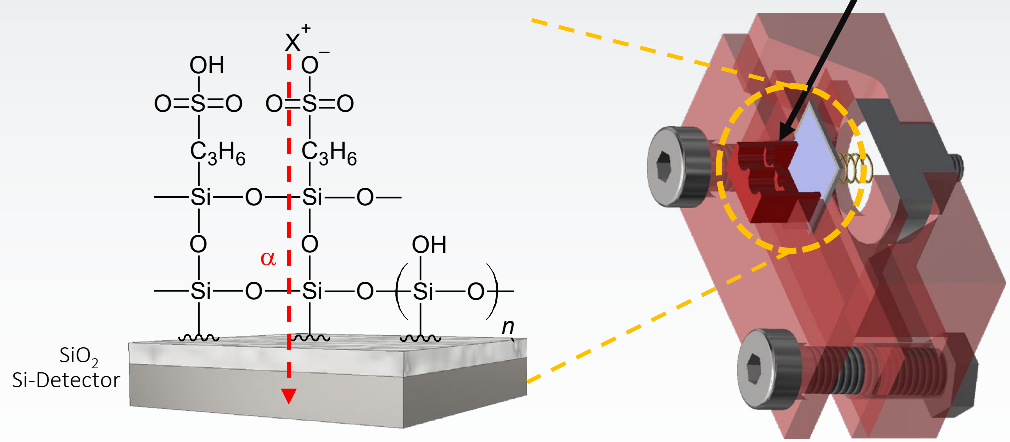

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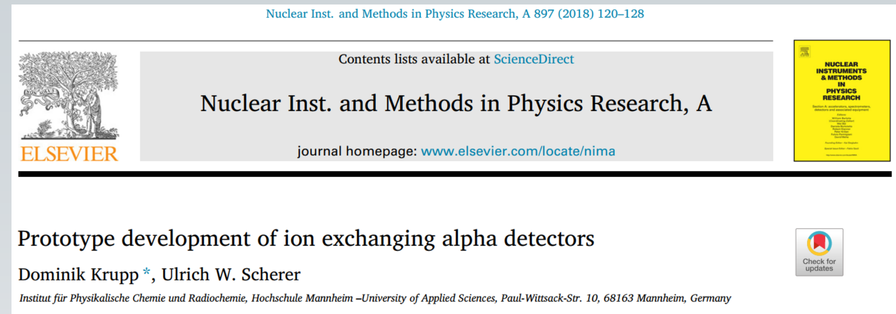
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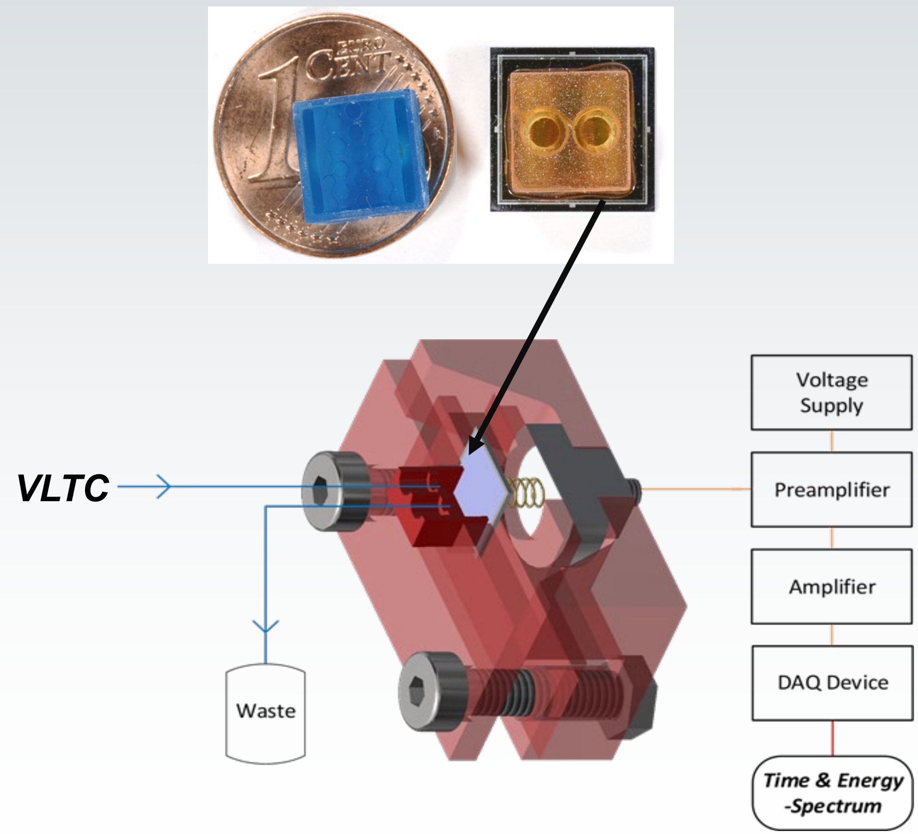
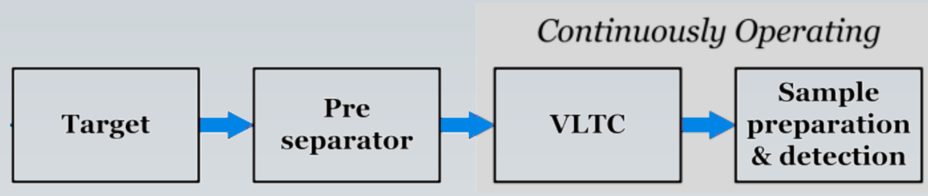


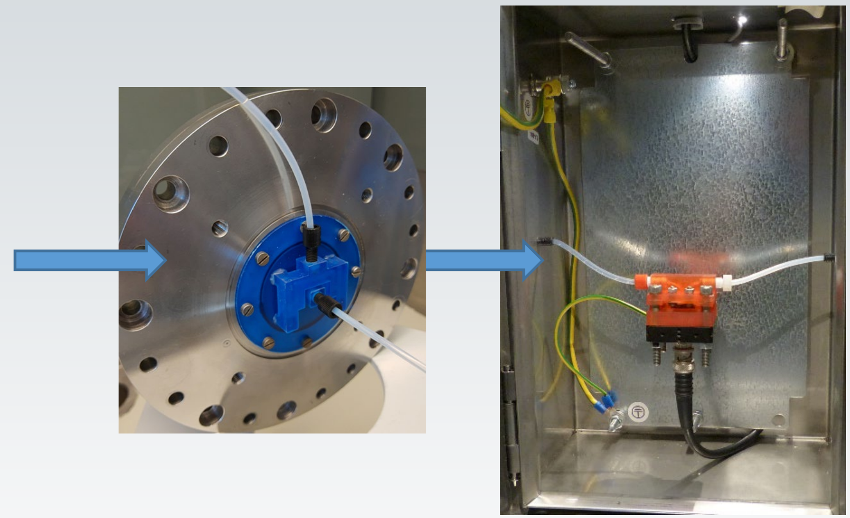
Conclusion



New ways of a faster α spectrometry

- Conventional liquid phase SHE chemistry experiments consist of several preparation steps, each with its time and yield budget

- With the **V**acuum to **L**iquid **T**ransfer **C**hamber (VLTC) several steps are bypassed
  - *Resulting in a faster and more efficient transport of SHE from a physical preseparator into the liquid phase*



- By coupling the VLTC with flow cells, equipped with functionalized α detectors continuous experimental runs with Si-detectors can be realized

- This opens the perspective for trans-seaborgium chemistry in the aqueous phase in the future

TASCA 21

GSI, Darmstadt, June 21 - 23, 2021
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Thank you for your attention!

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