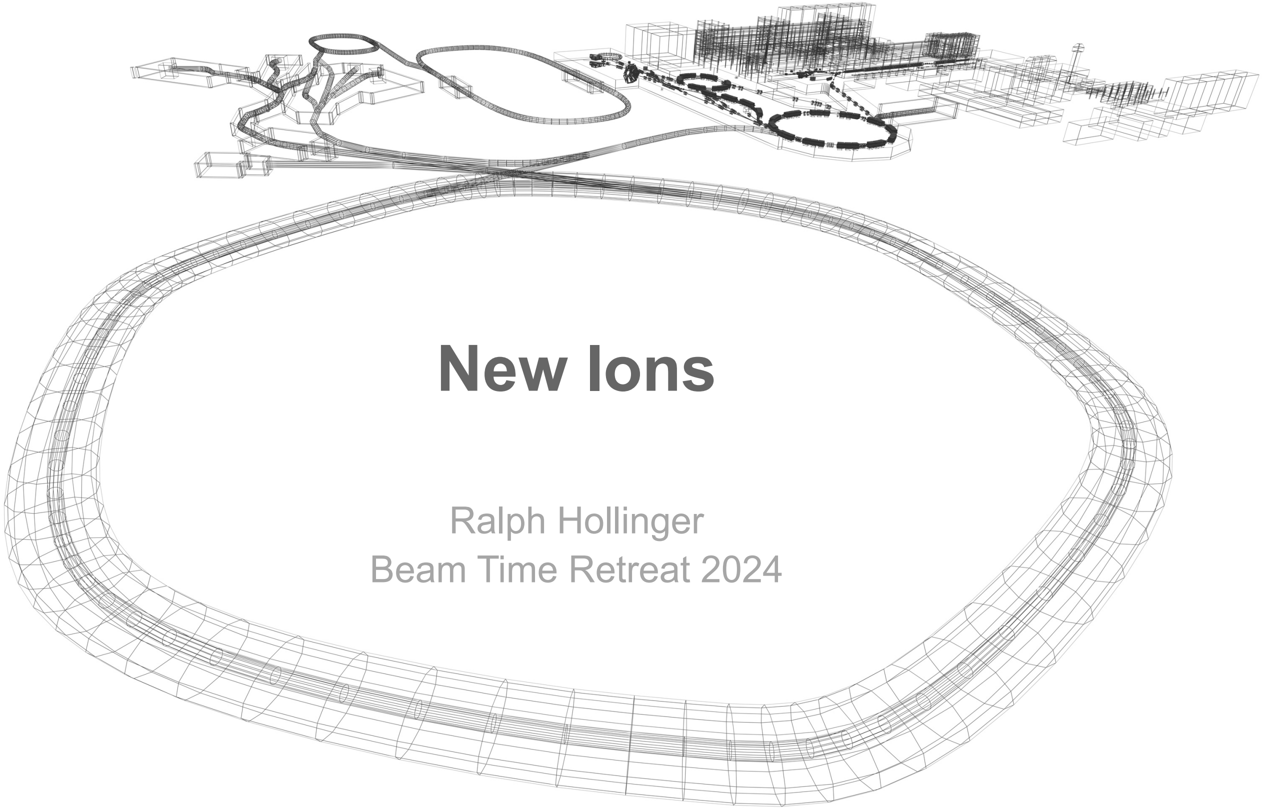
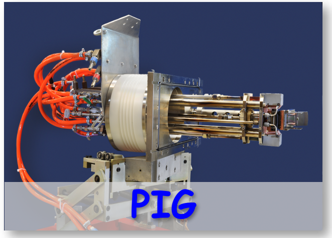


New Ions

Ralph Hollinger
Beam Time Retreat 2024

Status of operation in 2024

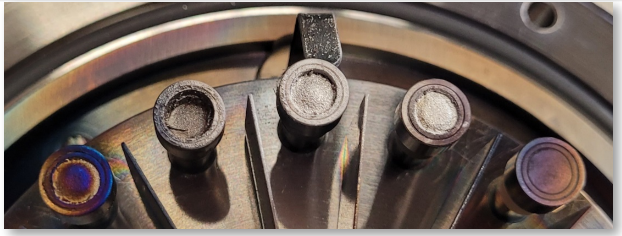


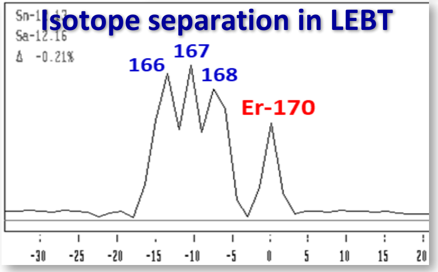
Ion species	Duty cycle	Intensity (RFQ, emA)	Ion source	Duration (days)
Physics run (February – June, 2024)				
$^{12}CH_3^+$	2 Hz / 0.45 ms	2.1	MUCIS-1990	22
$^{36}O_2^+$	1 Hz / 0.5 ms	4.4	VARIS	6
$^{36}Ar^{8+}$	CW	0.1	ECRIS	17
$^{40}Ar^{8+}$	CW	0.1	ECRIS	39
$^{40}Ar^{+}$	2 Hz / 0.7 ms	9	CHORDIS	8
$^{50}Ti^{2+}$	10 Hz / 1 ms 50 Hz / 5 ms	0.04	PIG	5 21
$^{52}Cr^{2+}$	50 Hz / 5 ms	0.14	PIG	14
$^{56}Fe^{2+}$	5 Hz / 1 ms	0.12	PIG	9
$^{58}Ni^{2+}$	1 Hz / 0.45 ms	3.3	VARIS	6
$^{100}Mo^{3+}$	2 Hz / 0.4 ms	0.5	VARIS	8
$^{170}Er^{3+}$	1 Hz / 0.45 ms	1.2	VARIS	11
$^{197}Au^{8+}$	25 Hz / 3 ms	0.04	PIG	26
$^{197}Au^{4+}$	1 Hz / 0.4 ms	3.8	VARIS	26
$^{238}U^{4+}$	1 Hz / 0.45 ms	14	VARIS	38

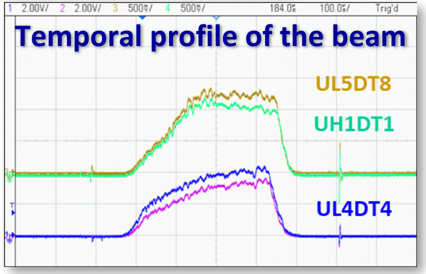
High Current Ion Sources

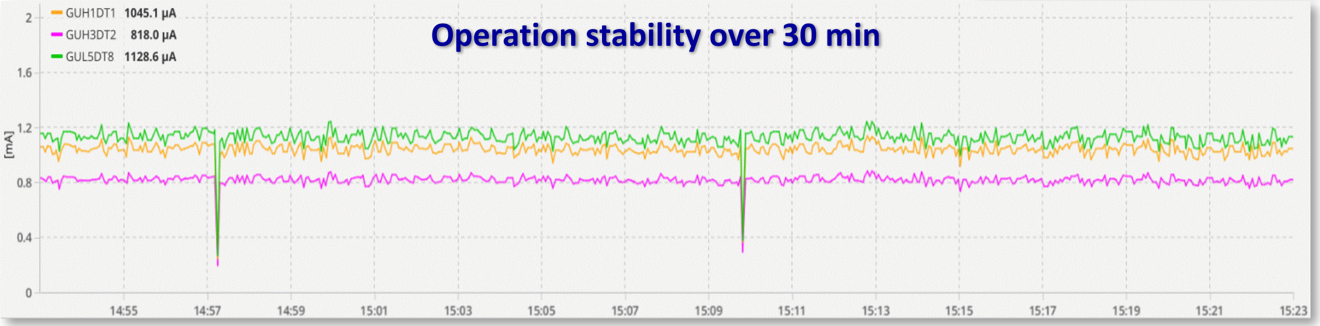
Establishing of $^{170}Er^{3+}$ beam from VARIS

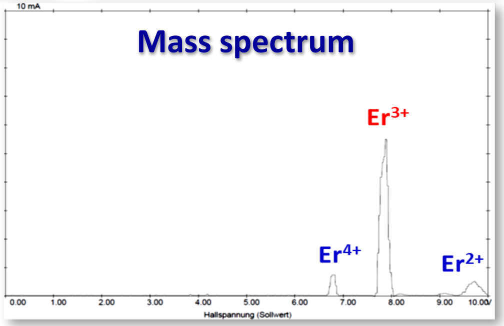
- **11 days of operation**
  1 Hz / 0.45 ms, request mode
- **Operation with natural material:**
  14.9% of **Er-170** in nat. composition
- **Clear separation of $^{170}Er^{3+}$ in the LEBT**
- **Beam intensity:**
  1.2 mA of **$^{170}Er^{3+}$** (UH1DT1) => **$2.5 \cdot 10^{11}$** in 100 µs
  0.3 mA of **$^{170}Er^{57+}$** (TK7DT3) => **$3.3 \cdot 10^{9}$** in 100 µs
- **Lifetime of a single cathode: > 10 hours**





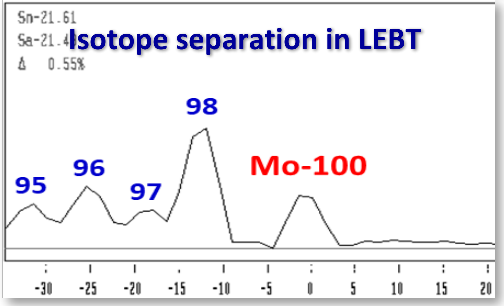


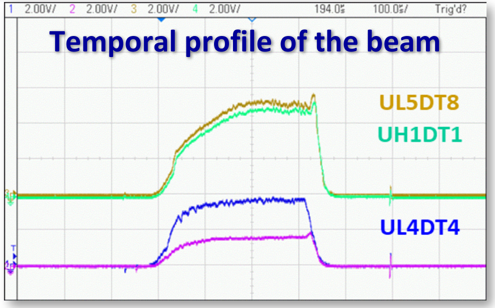


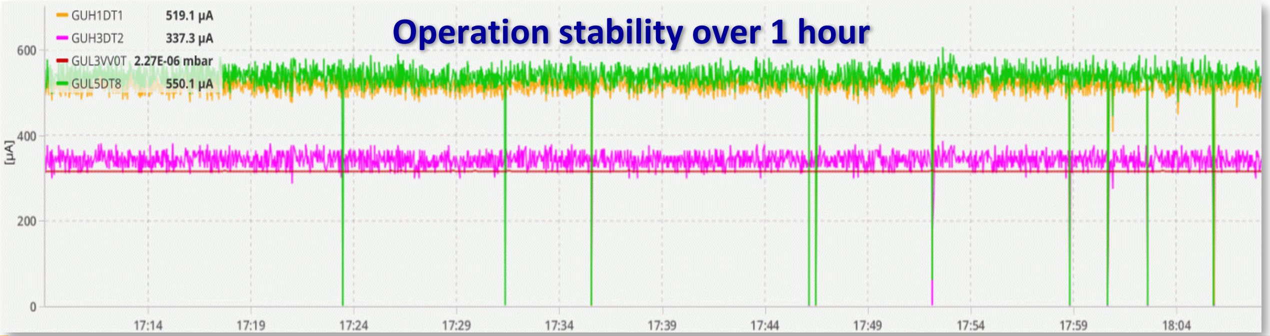


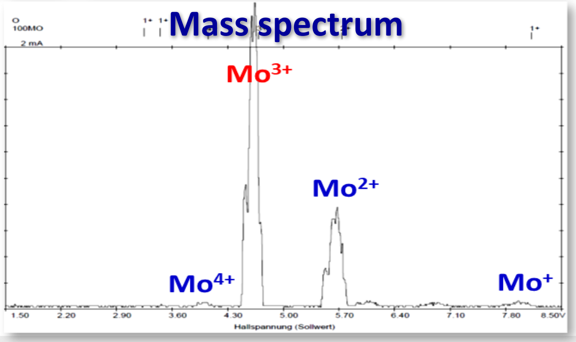
Establishing of $^{100}Mo^{3+}$ beam from VARIS

- **8 days of operation with a single source**
  2 Hz / 0.4 ms, request mode
- **Operation with natural material:**
  9.7% of **Mo-100** in nat. composition
- **Clear separation of $^{100}Mo^{3+}$ in the LEBT**
- **Beam intensity:**
  0.5 mA of **$^{100}Mo^{3+}$** (UH1DT1) => **$1 \cdot 10^{11}$** in 100 µs
  65 µA of **$^{100}Mo^{38+}$** (TK7DT3) => **$1.1 \cdot 10^{9}$** in 100 µs
- **Lifetime of a single cathode: > 24 hours**



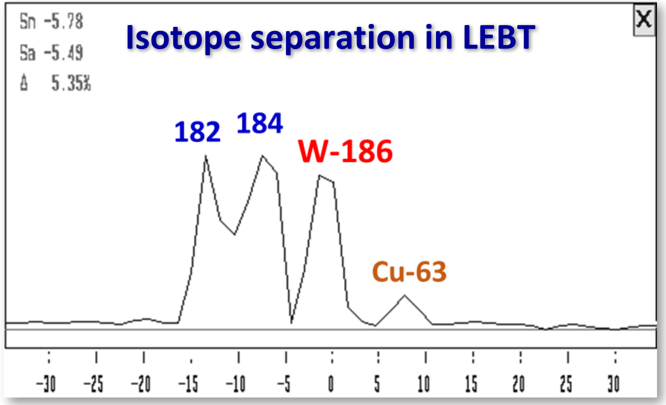




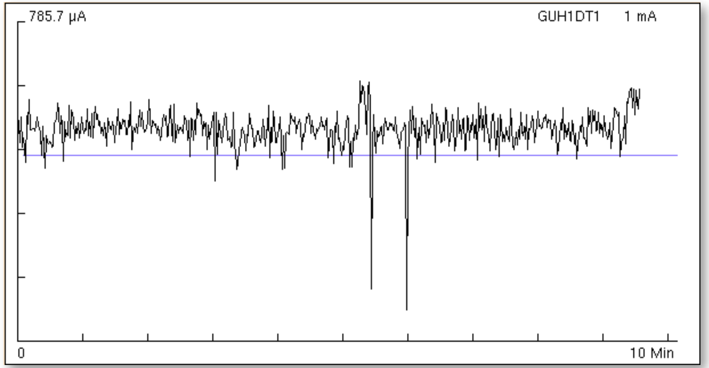


Development of new ion species for operation from VARIS: $^{198}Pt^{4+}$ and $^{186}W^{3+}$

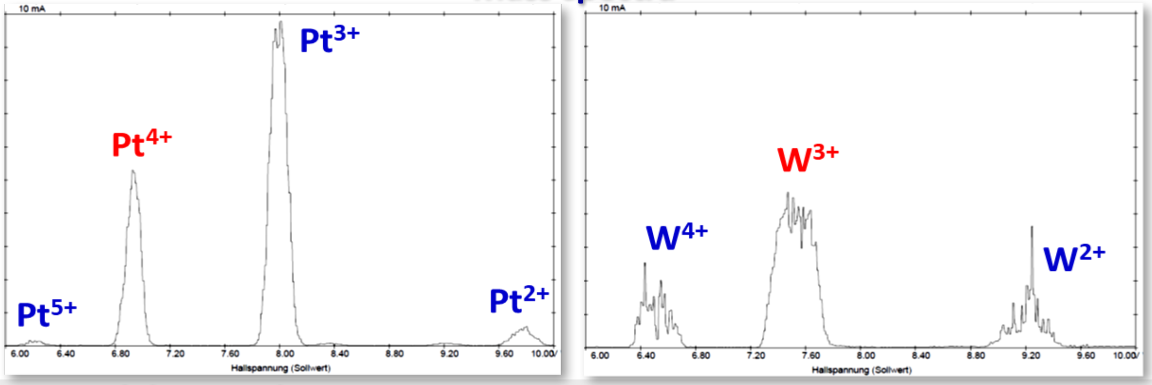
- $^{198}Pt^{4+}$ (**7.4%** in nat.) beam from natural Pt
  $^{186}W^{3+}$ (**28.4%** in nat.) beam from nat. W-Cu(15%) alloyment
- Operation mode: **1 Hz / 0.35 - 0.55 ms**
- Clear separation of both isotopes in the LEBT
- Beam intensity:
  0.7 mA of $^{198}Pt^{4+}$ (UH1DT1) => **$1\cdot10^{11}$** in 100 µs
  1 mA of $^{186}W^{3+}$ (UH1DT1) => **$2\cdot10^{11}$** in 100 µs



Operation stability of Pt^{4+} over 10 min



Mass spectra



Penning Ion Sources

$^{52}Cr^{2+}$ performance with PIG-source

52-Cr for experiments X8, Y7, Z6.

Duty cycle - 50 Hz / 5 ms

^{50}Cr (4.34 %), ^{52}Cr (83.8 %), ^{53}Cr (9.5%), ^{54}Cr (2.36 %)

Beam time: 14 days (7 PIG sources) = 2 days life time

Transmission

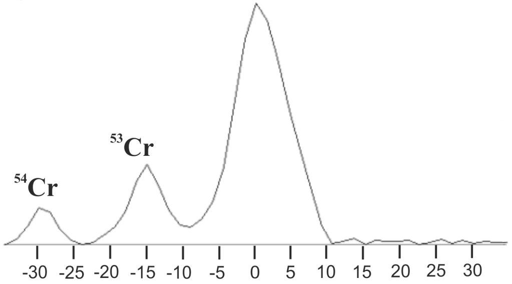
UH1DT1 ~ 110-200 μA

X8: UX8DT3 ~ 60-80 μA (1pμA)

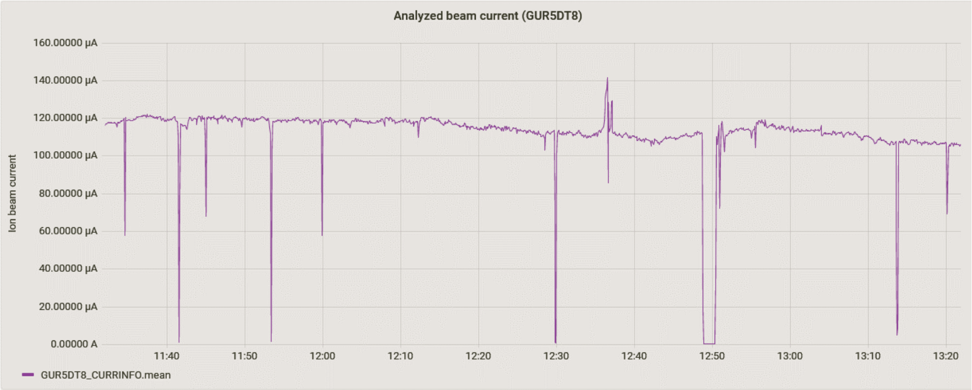
Y7: UYDT2 ~ 60 μA

Z6: UZ6DT1 ~ 34 μA

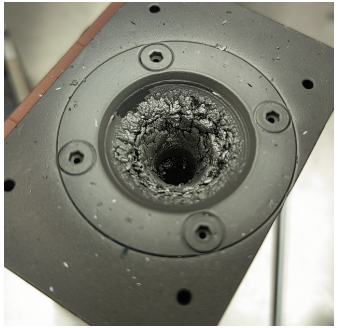
Profile grid GUR5DG7

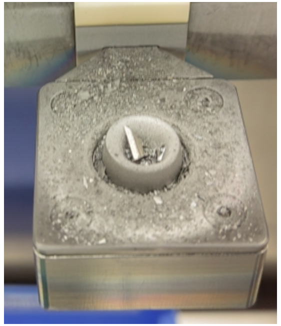


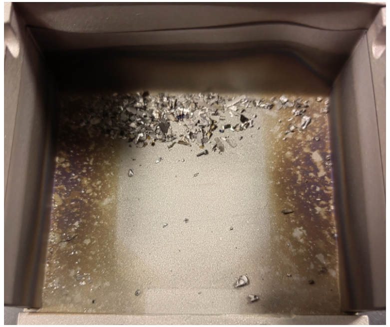
Operation stability over 2 hours



Service PIG sources

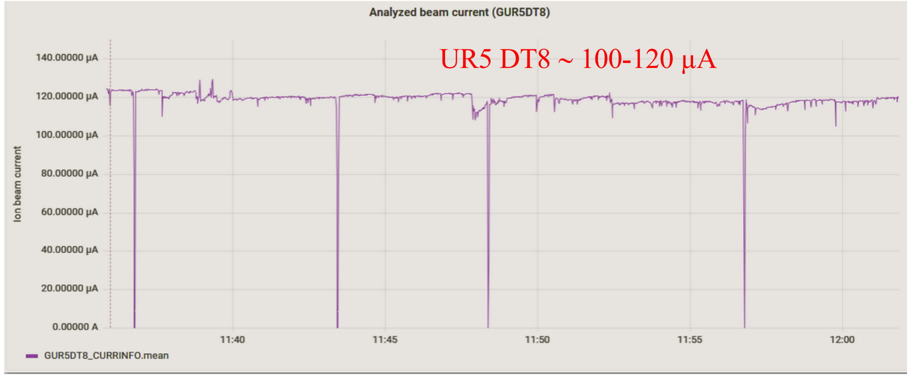


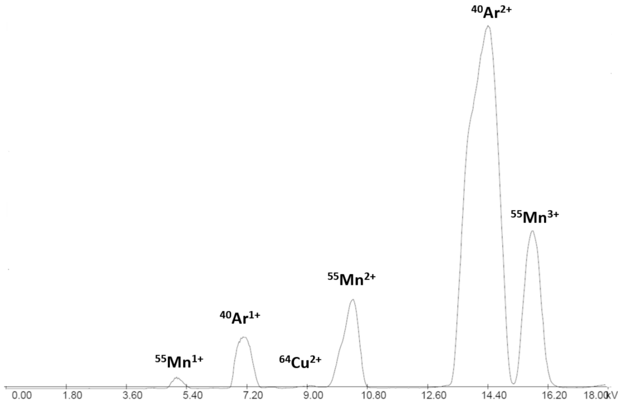




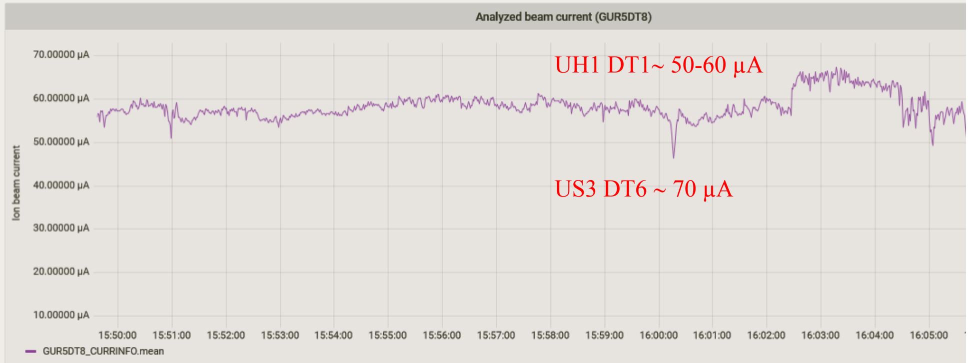
$^{55}Mn^{3+}$ and enriched $^{54}Cr^{2+}$ ongoing development

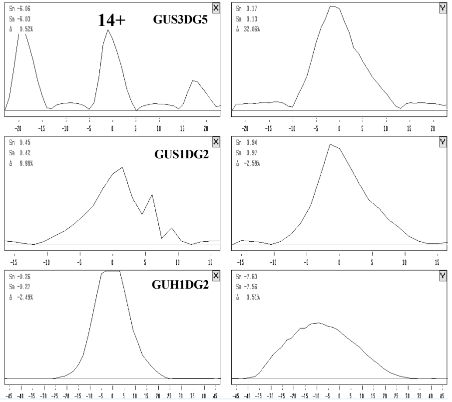
$^{55}Mn^{3+}$ (MnCu 5 %) (50 Hz / 5 ms)





$^{54}Cr^{2+}$ (NiCr 30 %) A/z=27 (50 Hz / 5 ms)





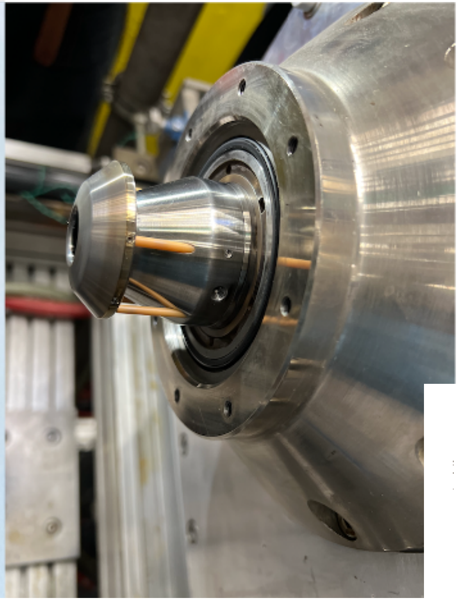
Only 170 mg available on the market

(price: up to 800 €/mg)

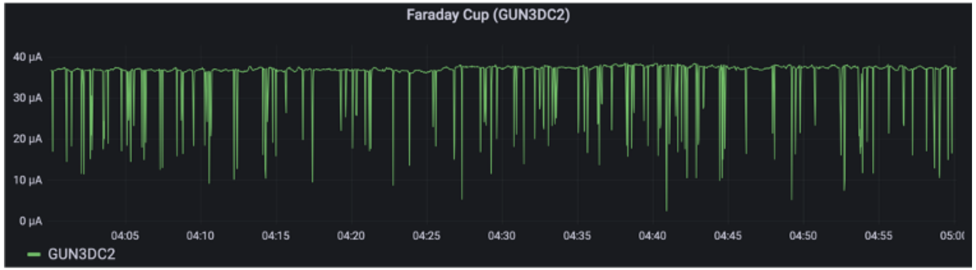
ECR Ion Source

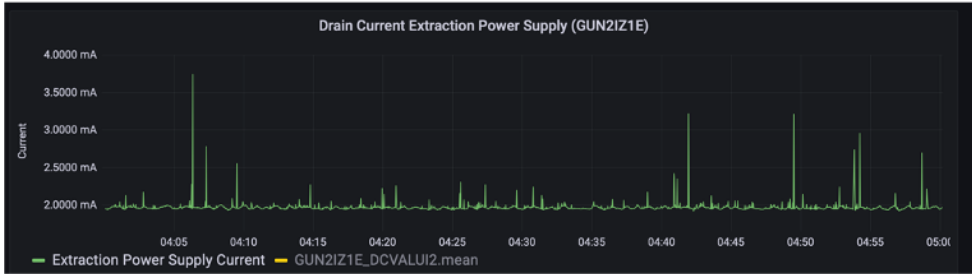
Establishment of ^{55}Mn and ^{54}Cr beams form the ECRIS

Ion species	Intensity (avg, eμA)	Consumption (mg/h)
$^{55}Mn^{9+}$	80	8.1
$^{54}Cr^{10+}$	50	8



$^{54}Cr^{10+}$ ion beam establishment test





^{54}Cr Test @ Engineering Run Experimental Results

Ion beam stability over time (up) and drain curent of the extraction power supply (down)

Establishment of ^{55}Mn and ^{54}Cr beams form the ECRIS

Ion species	Intensity (avg, eμA)	Consumption (mg/h)
$^{55}Mn^{9+}$	80	8.1
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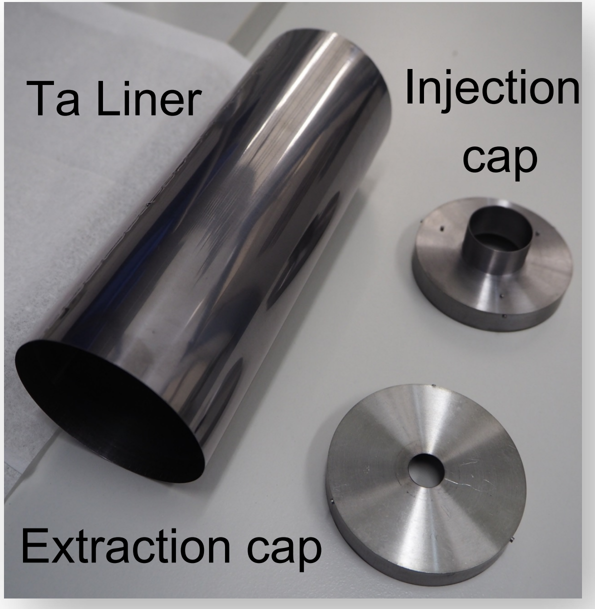
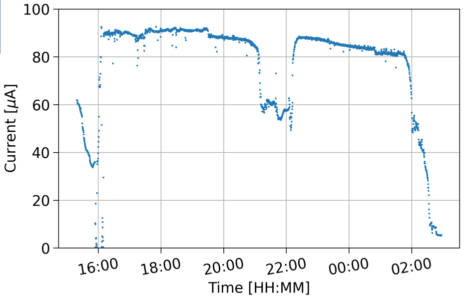
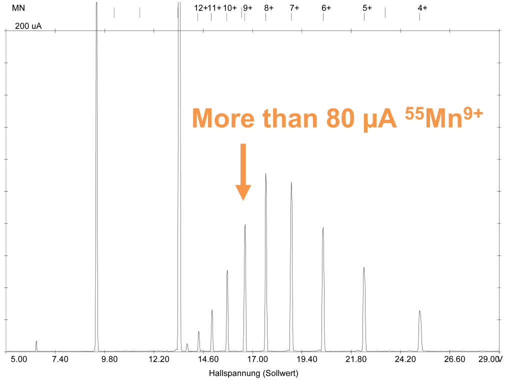


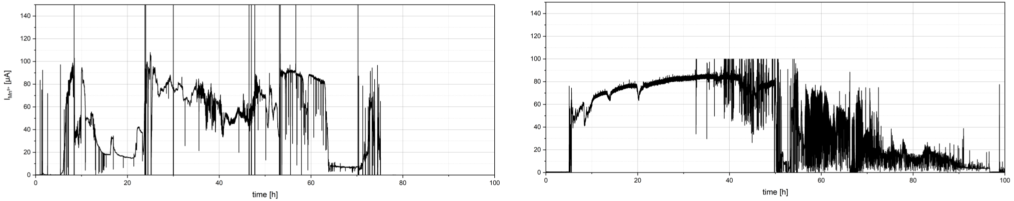
$^{55}Mn^{9+}$ ion beam establishment test



$^{55}Mn^{9+}$ intensity at the Faraday Cup with liner



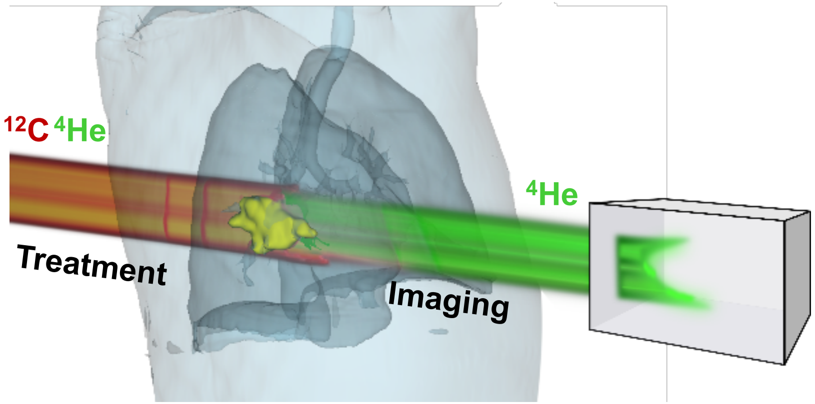
^{55}Mn charge states distribution



$^{55}Mn^{9+}$ ion beam stability over time with liner (left) and w/o (right)

Dual Beam (C-He) from ECR

Dual isotope beams: carbon radiotherapy and helium online monitoring



courtesy of C. Graeff / L. Volz

- **Particle therapy: Bragg peak based**
- **Highly localised dose distribution / highly conformal**
- **But: steep dose gradient → sensitivity to range uncertainties**
  - **inter-/intra-fractional anatomic changes**
  - **Uncertainties in planning**
  - **Patient set-up**
  - **Motion induced range variation**
- **One solution: mixed carbon-helium ion beams (90 % C, 10 % He*)**
  - **Similar mass-to-charge-ratio**
  - **Range of He ~3 times larger than C at same energy/nucleon**
  - **Carbon for irradiation**
  - **Helium passes patient for online monitoring**

➢ **Online range verification: extraordinary increase in precision of conformal dose**

***extra dose < 1 %**

- C. Graeff et al (2018), https://doi.org/10.1016/j.ejmp.2018.06.099
- L. Volz et al (2020), Phys. Med. Biol. 65 055002
- D. Mazzucconi et.al (2018), https://doi.org/10.1002/mp.13219
- Ch. Graeff, L. Volz, M. Durante, Prog. Part. Nucl. Phys., vol. 131, p. 104046, Jul. 2023
- Jennifer J Hardt et al., 2024 Phys. Med. Biol. in press.

Dual Beam (C, He) from ECR

EXPERIMENTAL SET-UP

14.5 GHz CAPRICE ECRIS

- Used for therapy at GSI
- Medical centres use ECR ion sources

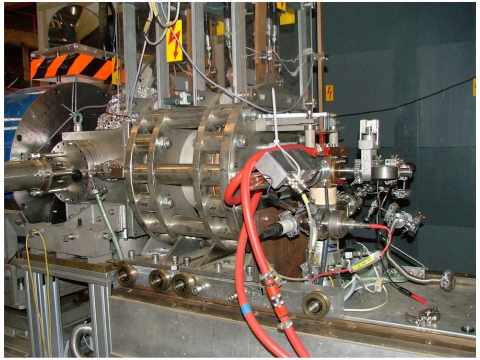
Measurement of

- Mass spectra (no distinction between C^{3+}/$^4He^+$)
- Beam current (no distinction between C^{3+}/$^4He^+$)
- **Optical emsission lines (approximate C-to-He ratio)**

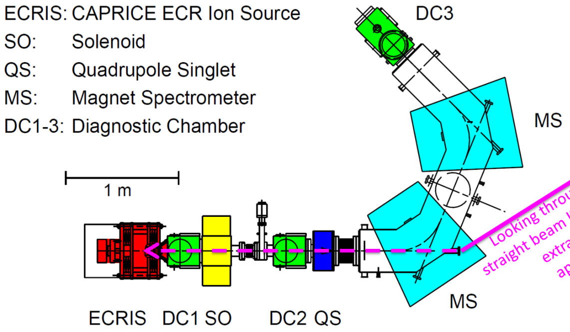
ELEMENTS COMBINATIONS

- **CH_4 und ^3He: C^{4+}, $^3He^+$ M/Q=3** ✘
- **CH_4 und ^4He: C^{3+}, $^4He^+$ M/Q=4** ✔
  - **≤ 150 μA $^{12}C^{3+}$ upstream UNILAC**
  - **≈ 4 to 5 μA He^+**
  - **Minimum oxygen contamination ($^{16}O^{4+}$)**

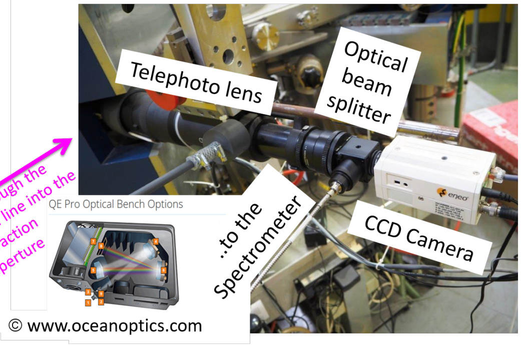
ECR Ion source



LEBT



Optical spectrometer



Dual Beam (C, He) from ECR

EXPERIMENTAL SET-UP

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ELEMENTS COMBINATIONS

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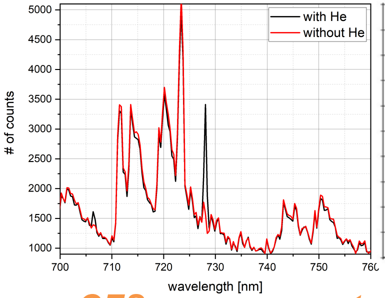
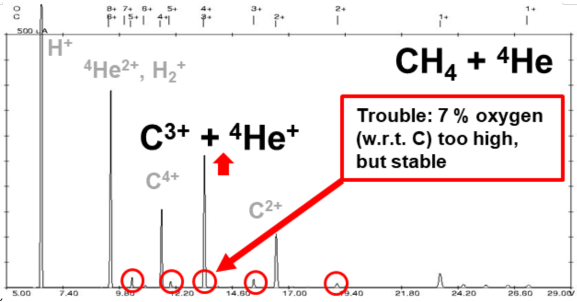
- **CH_4 und ^{4}He: C^{3+}, $^{4}He^{+}$ M/Q=4 ✔**
  - **≤ 150 μA $^{12}C^{3+}$ upstream UNILAC**
  - **≈ 4 to 5 μA He^{+}**
  - **Minimum oxygen contamination ($^{16}O^{4+}$)**

ESTABLISHMENT OF C-He DUAL BEAM

- Mixed beam: CH_4 as main gas and ^{4}He auxiliary gas.
- Tested a steady $^{12}C^{3+}$ carbon ion beam of approximately 150 eμA containing a helium particle fraction of about 10 %, i.e. approx. 15 eμA ($^{4}He^{+}$).
- Set the C^{3+} ion beam and followed by stepwise adding Helium while recording the OES lines of carbon (wavelength 465 nm) and helium (728 nm) and the corresponding CSD to estimate the C-to-He ratio.



OES measurement (He I peak at 728 nm)



Thank you for your attention