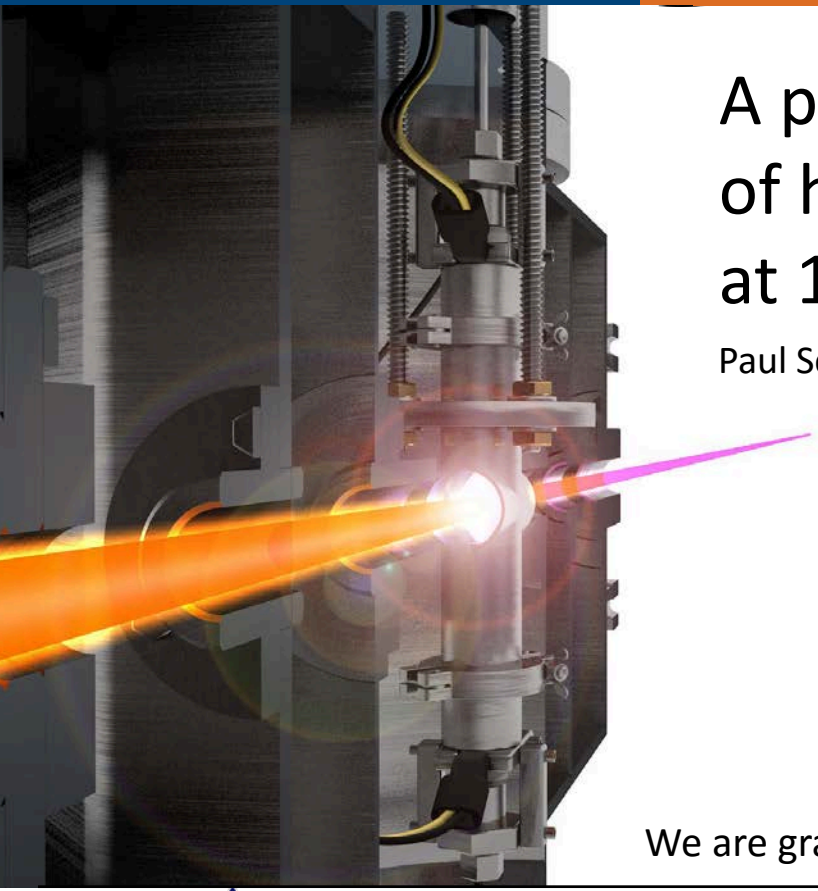

A pulsed gas-stripper for stripping of high-intensity, heavy-ion beams at 1.4 MeV/u at the GSI UNILAC

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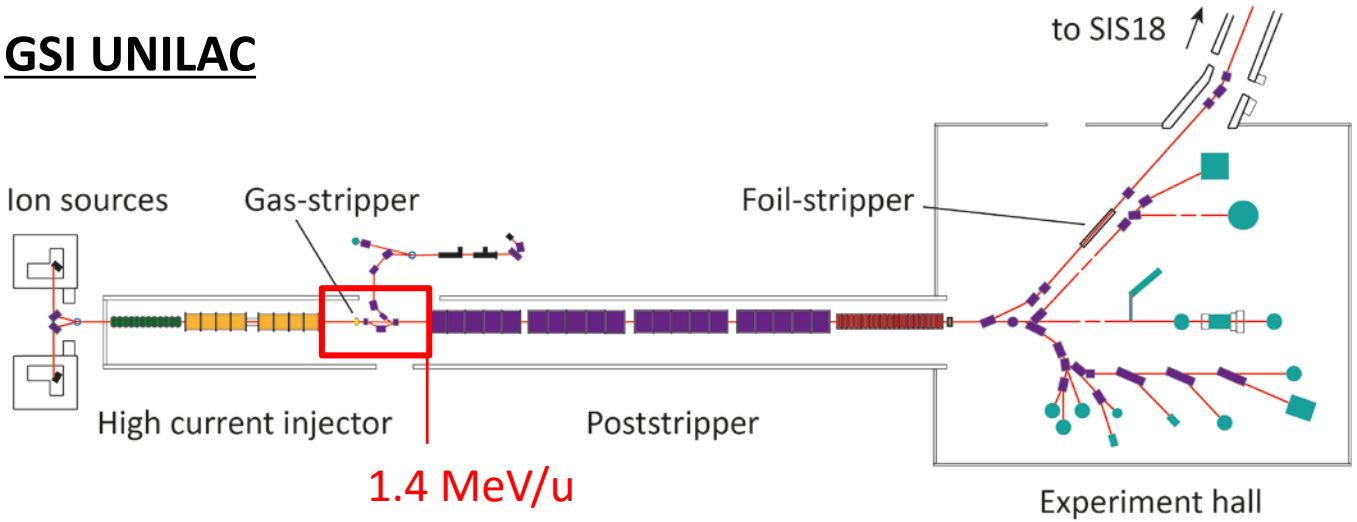
We are grateful for the support of the GSI ion-source and UNILAC staff.

Introduction

GSI UNILAC

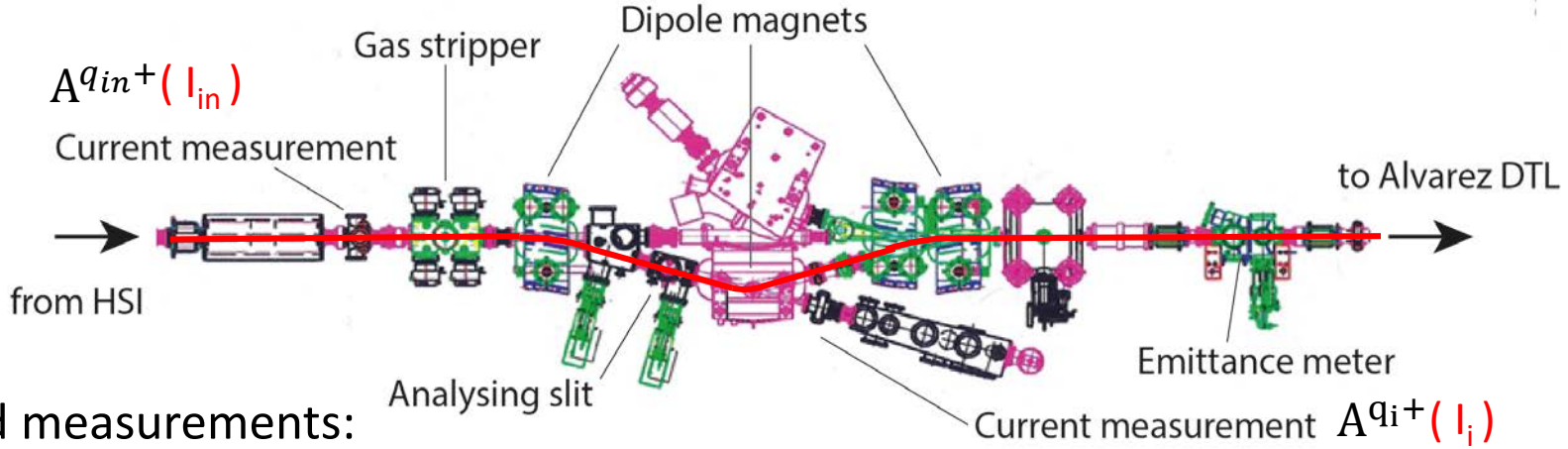


GSI UNILAC will be used as part of an injector system for FAIR

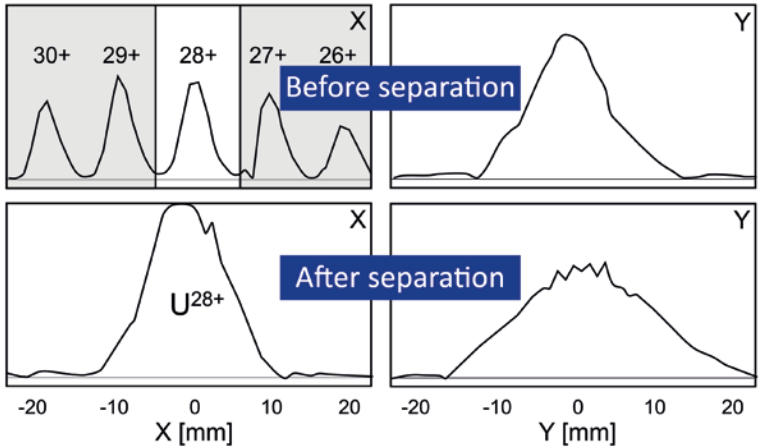
UNILAC upgrade program has started

$^{238}U^{28+}$-beam req.:	**SIS18 injection**
Electrical current [mA]	**15.0**
Particles/100 µs pulse	**$3.3 \cdot 10^{11}$**
ΔW/W	**± 0.002**
ε_x (total, norm.) [µm]	**0.8**

UNILAC gas stripper



Grid measurements:

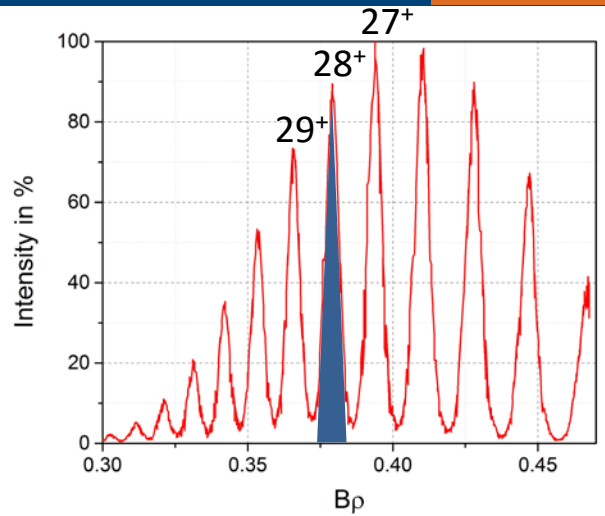


Charge separation:
3 dipole magnets + analysing slit

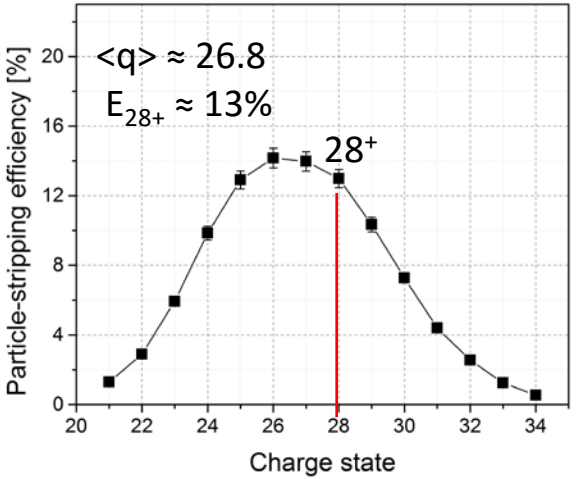
Stripping efficiency (into q_i^+):

$$E_{q_i} = \frac{I_i / q_i}{I_{in} / q_{in}}$$

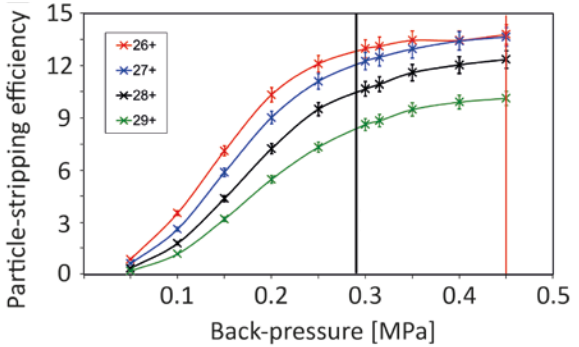
Current gas-jet stripper



$^{238}U + N_2$ (jet)



- Super-sonic N_2 gas-jet (Laval nozzle)
- Up to 0.45 MPa back-pressure
- Gas-flow: 22 l/min



Increase of stripping efficiency (U^{28+}) not feasible using the N_2-jet

Foil-stripping

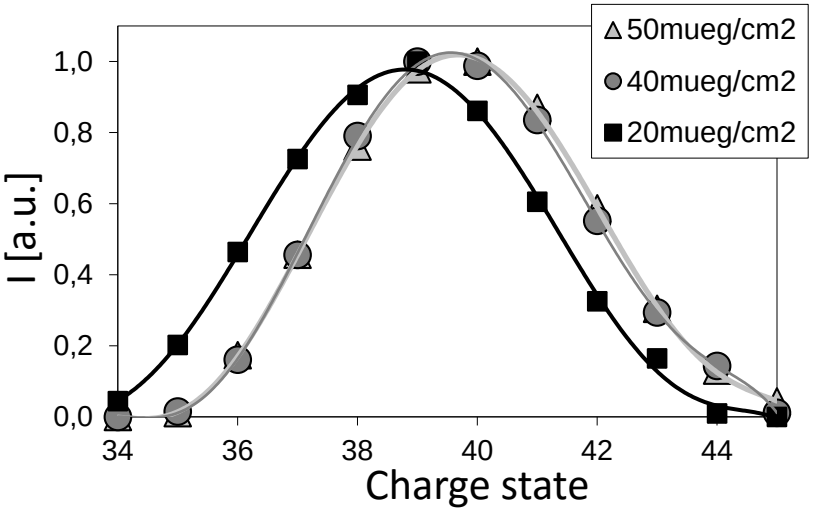
Measurements 2010

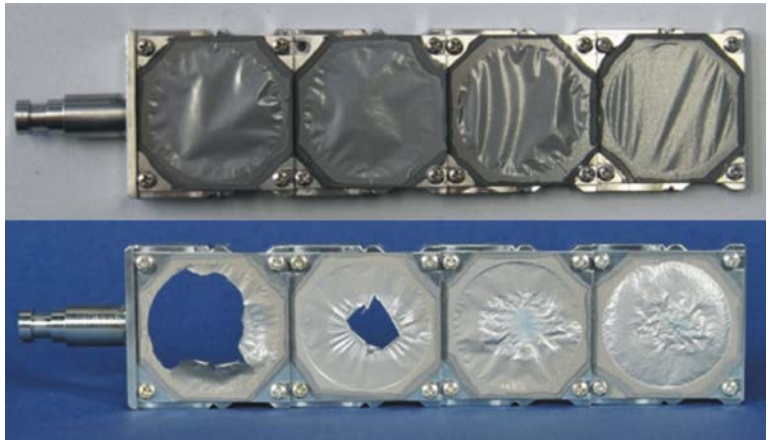
U^{4+}, 1.4 MeV/u, 100 µs, 2 Hz

Thickness: 20 to 50 µg/cm²

Irradiation: ≈ 5 mA (U^{4+})

Lifetime: ≤ 10 h





before

after

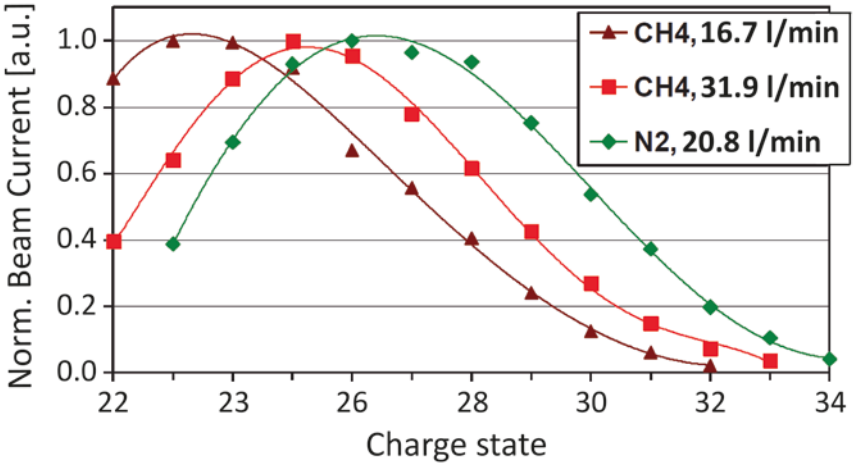
→ Limitation for low duty cylce

Use of stripper-foils not suited going for FAIR beam requirements

W. Barth et al., Proceedings of LINAC2010, Tsukuba, Japan, 154-156

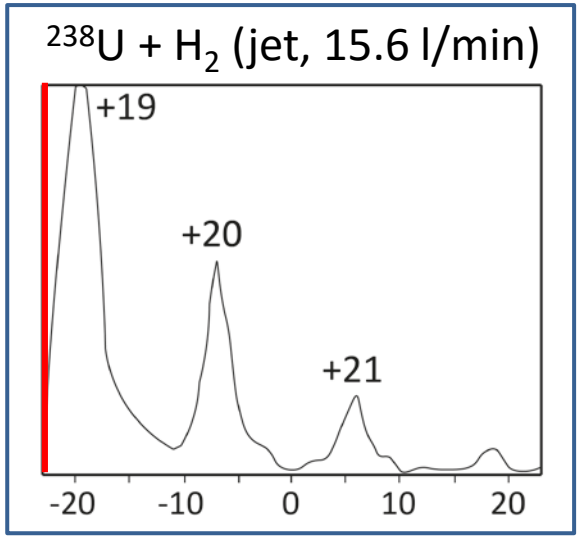
Other stripper-gases

Measurements 2013



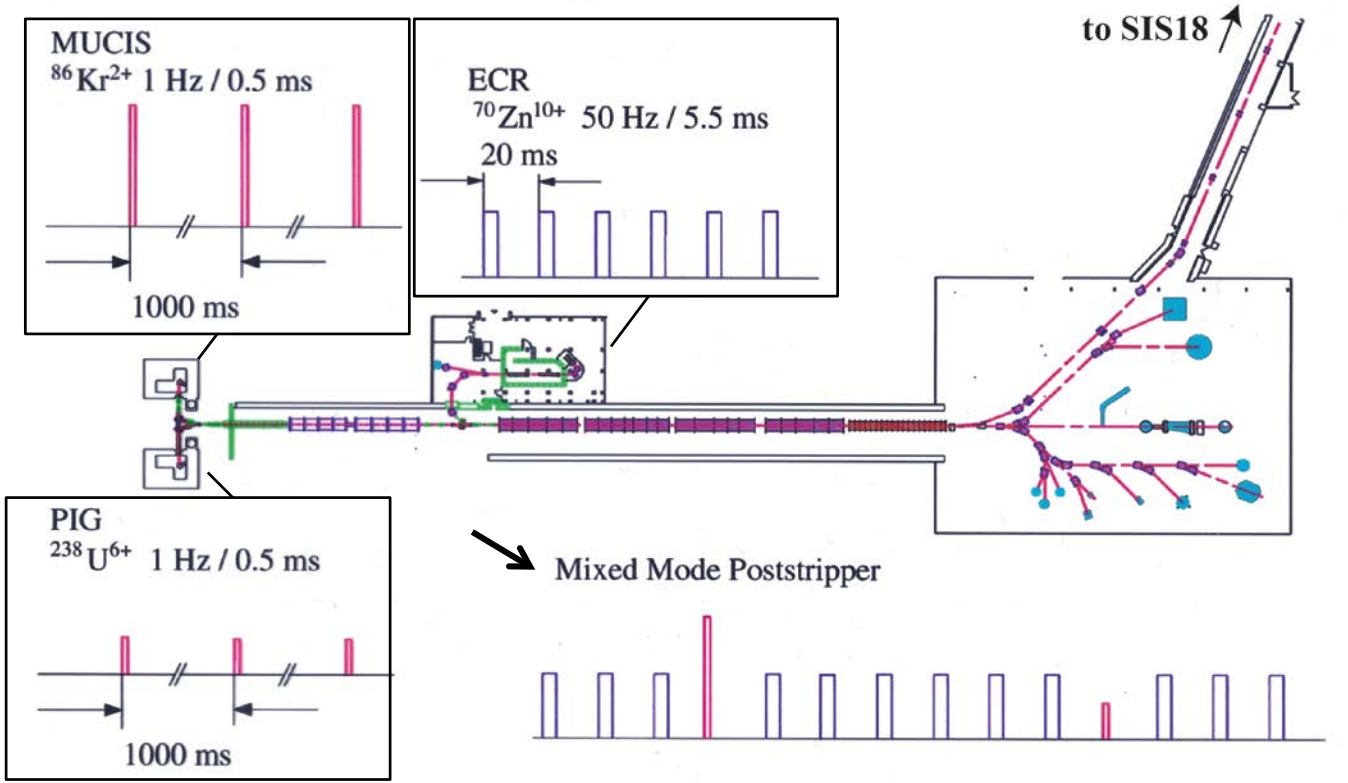
- Measurements with H_2-jet
- Populated charge states below +18
- Limitation: gas load

- Measurements with CH_4-jet
- Comparison to N_2-jet shows lower average charge states
- Limitation: gas load



B. Schlitt et al., Proceedings of IPAC2013, Shanghai, China, 3779-3781

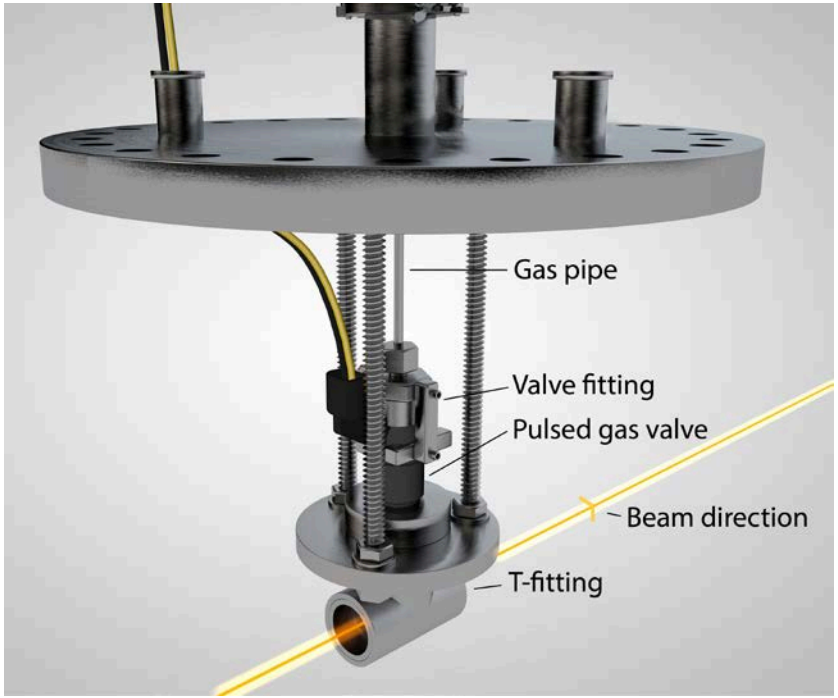
UNILAC beam operation



Short pulse operation (e.g.): **0.1 ms, 1 Hz**

Long pulse operation (e.g): **5 ms, 50 Hz**

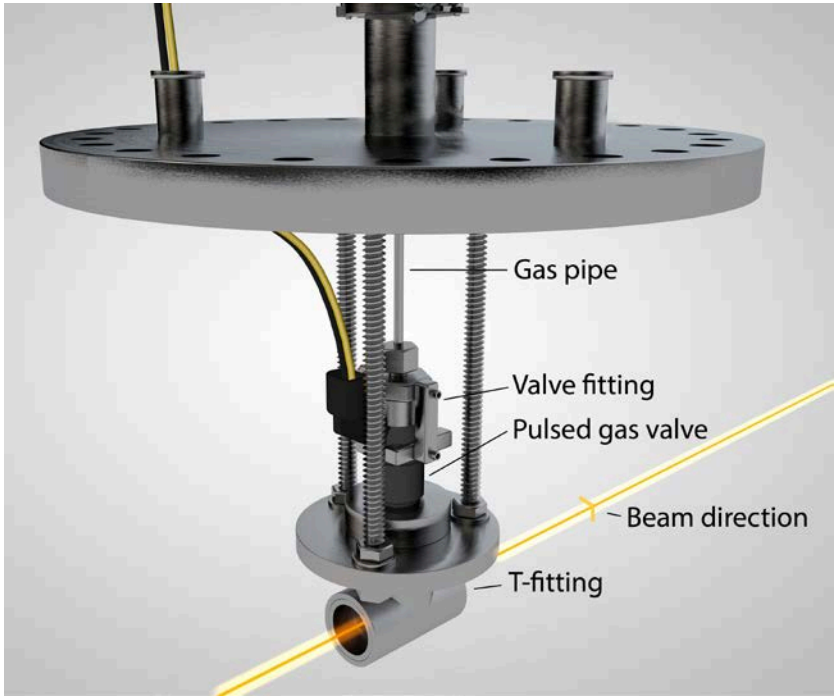
Pulsed gas cell

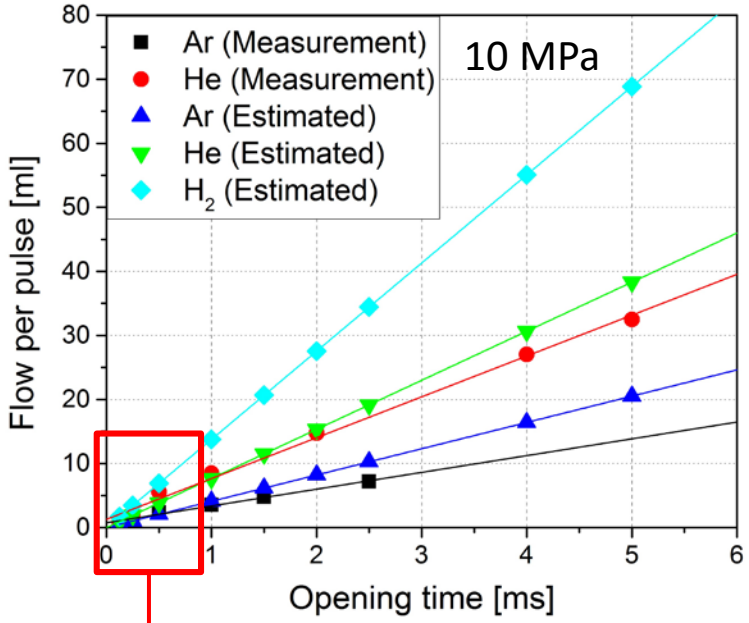


- Pulsed gas valve synchronized with the beam pulse timing
- Gas back-pressure up to 12 MPa
- Build-up added
  (ø = 22 mm, l = 44 mm)

BOSCH injection valve: Exemplary

Pulsed gas cell

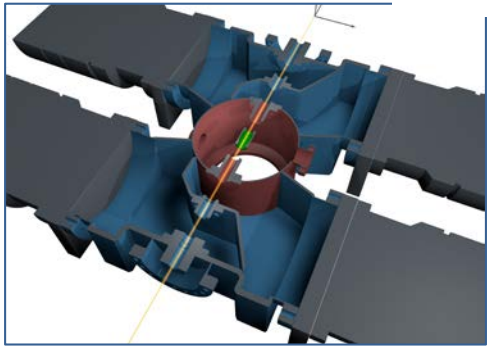


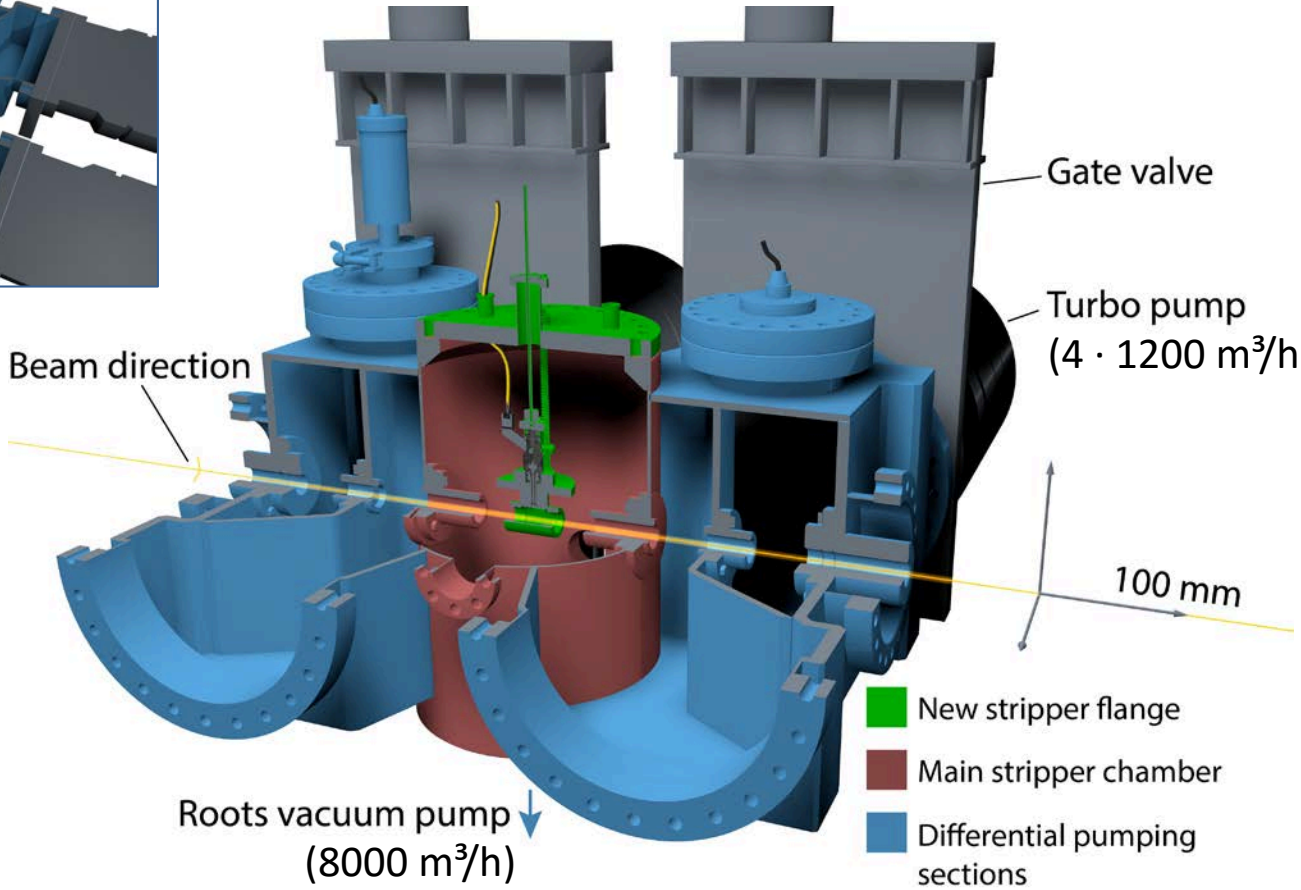


^{238}U-operation: 0.5 ms opening time

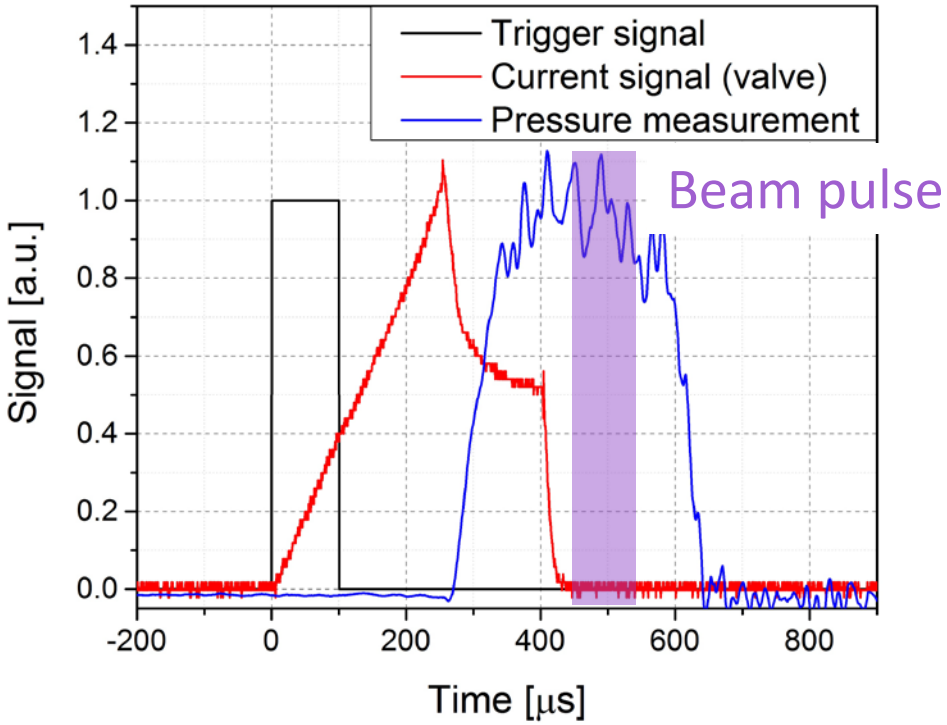
Estimated gas flow: ≤ 10 ml/pulse → ≤ 0.6 l/min at 1 Hz repetition rate

Pulsed gas cell

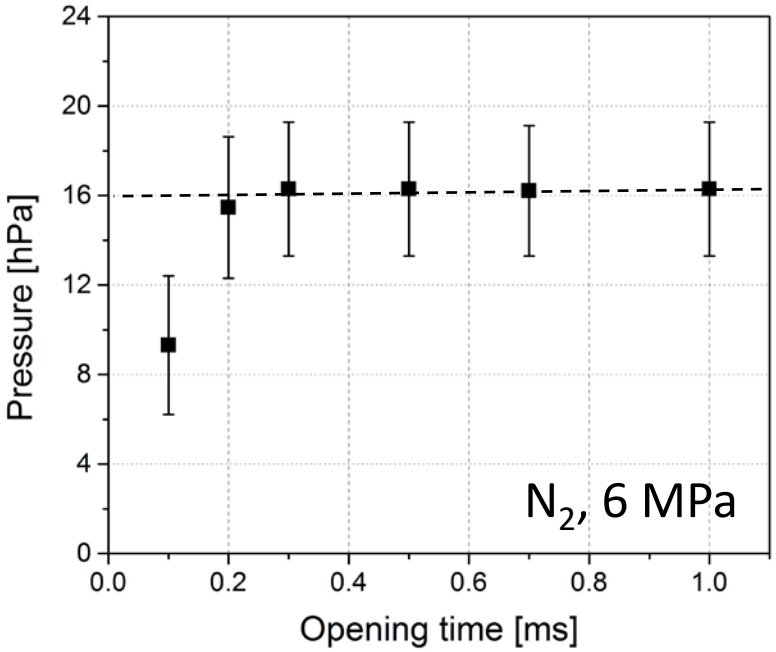




Pulsed gas cell

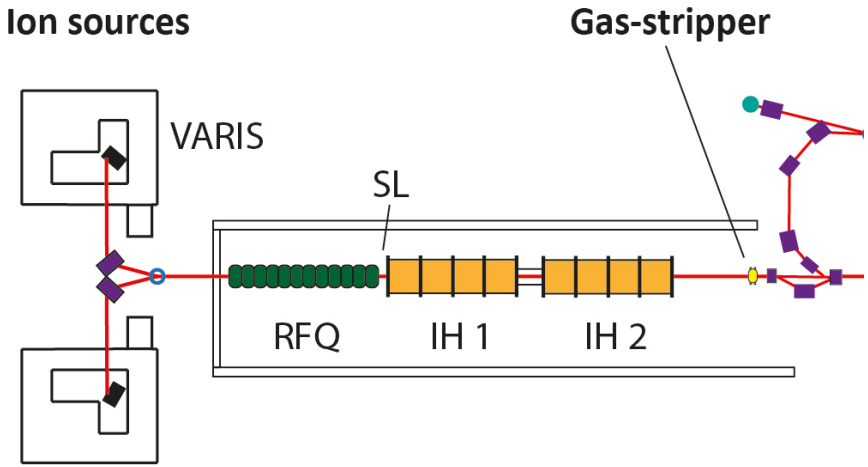


Exemplary measurement:



100 µs U-beam → Opening time: 500 µs (for maximum gas density)

U^{4+}-beam production



Vacuum ARc Ion Source (VARIS)*

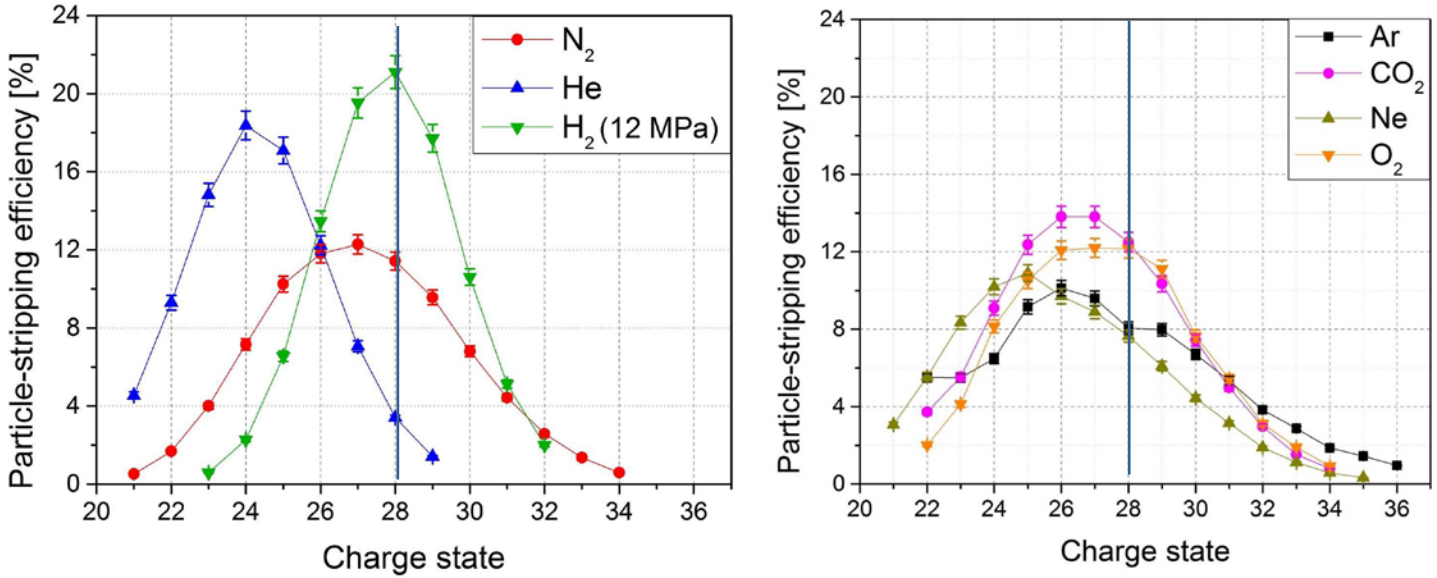
- 67% in U^{4+}
- 25 mA analysed U^{4+} current
- > 80% pulse to pulse stability

Optimization of the pre-stripper UNILAC for high-current U transport.

*R. Hollinger, M. Galonska, 2005, NIM B 239, 227-244

^{238}U-beam measurements

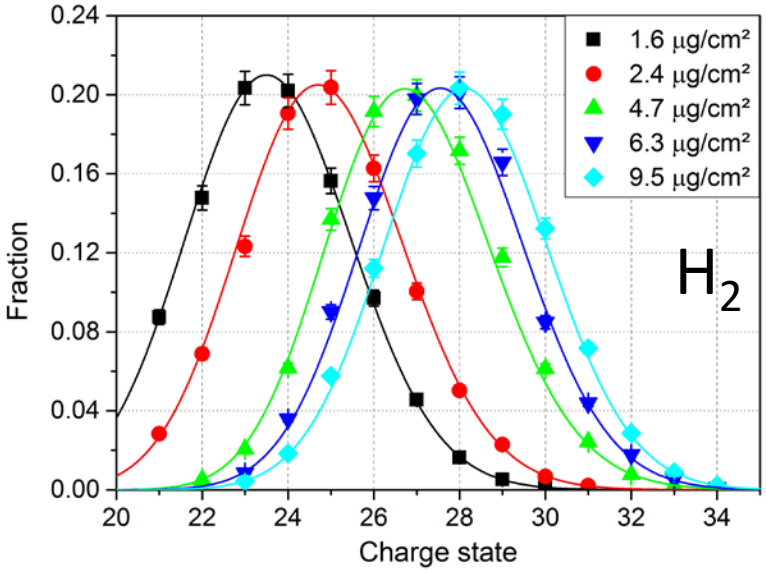
Equilibrated charge state distributions (exception: H_2)

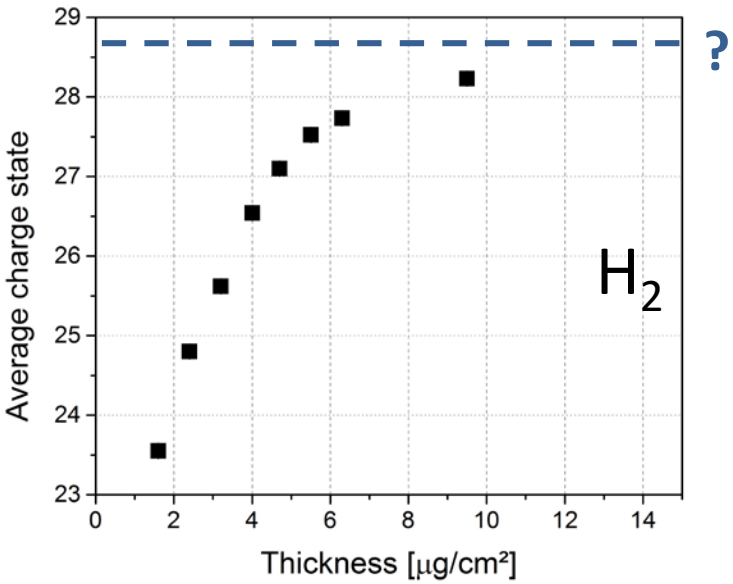


Applied gases: H_2, He, Ne, N_2, O_2, Ar, CO_2

More narrow charge state distributions for light gas targets (H_2, He)
→ increased stripping efficiency

^{238}U-beam measurements



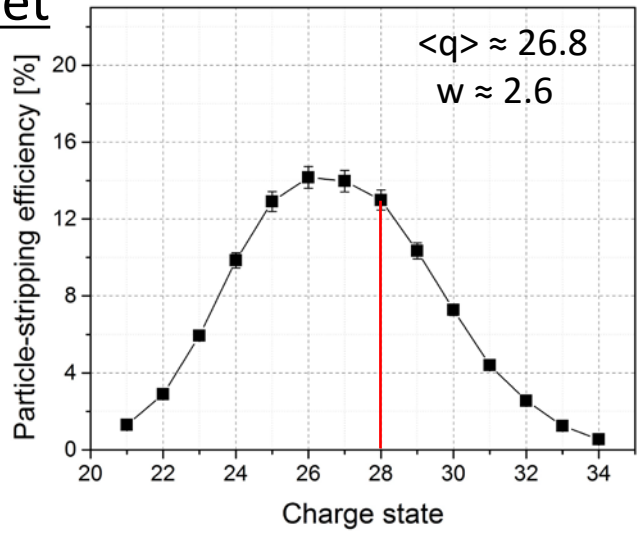


- Target thickness estimated from energy-loss measurements using SRIM*
- Achieved target thickness for H_2 insufficient to reach equilibrium
- Higher gas density needed

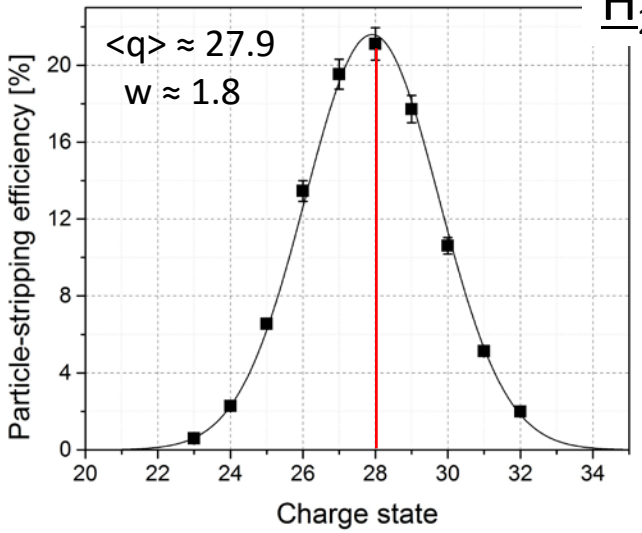
*J. F. Ziegler, J. P. Biersack, and M. D. Ziegler, The Stopping and Range of Ions in Solids Vol. 1 (2008)

U^{28+}-intensity record

N_2-jet



H_2 pulsed



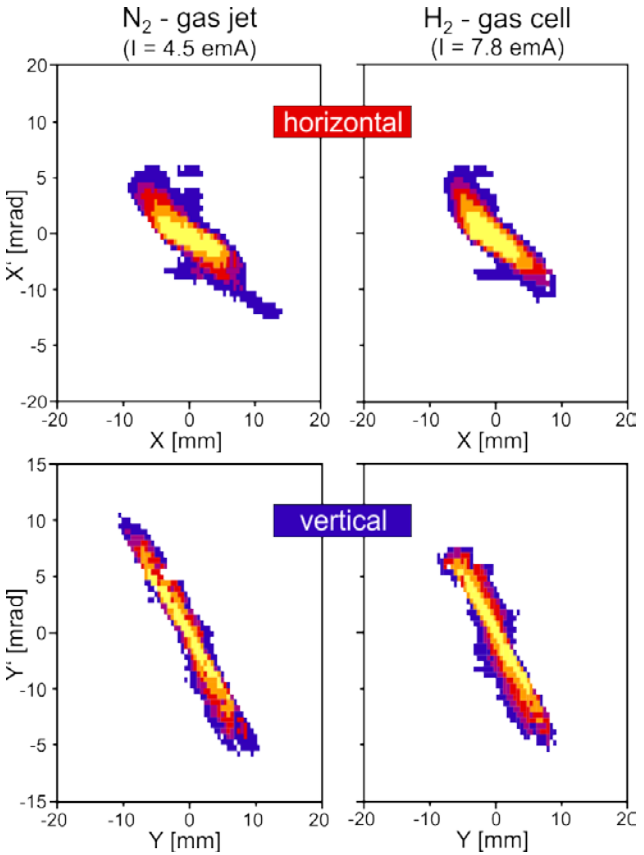
	N_2 gas-jet	H_2 pulsed gas-cell
Back-pressure [MPa]	**0.4**	**8**
U^{4+} current (HSI) [mA]	**≈ 6**	
Maximum U^{28+} current [mA]	**4.5**	**7.8**
Stripping efficiency (28^+)	**12.7 %**	**20.4 %**

W. Barth et al., Phys. Rev. ST AB 18 (2015) 040101

U^{28+}-intensity record

	N_2 gas-jet	H_2 pulsed gas-cell
Maximum U^{28+} current [mA]	**4.5**	**7.8**
Energy-loss [keV/u]	**20**	**12**
ε_x (90%, total, norm.) [µm]	**0.76**	**0.7**
ε_y (90%, total, norm.) [µm]	**0.84**	**0.93**
Horizontal beam brilliance [mA/µm]	**5.32**	**10.03**

FAIR requirement	
ε_x (total, norm.) [µm]	**0.8**
U^{28+} current [mA]	**15**
Horizontal beam brilliance [mA/µm]	**18.75**

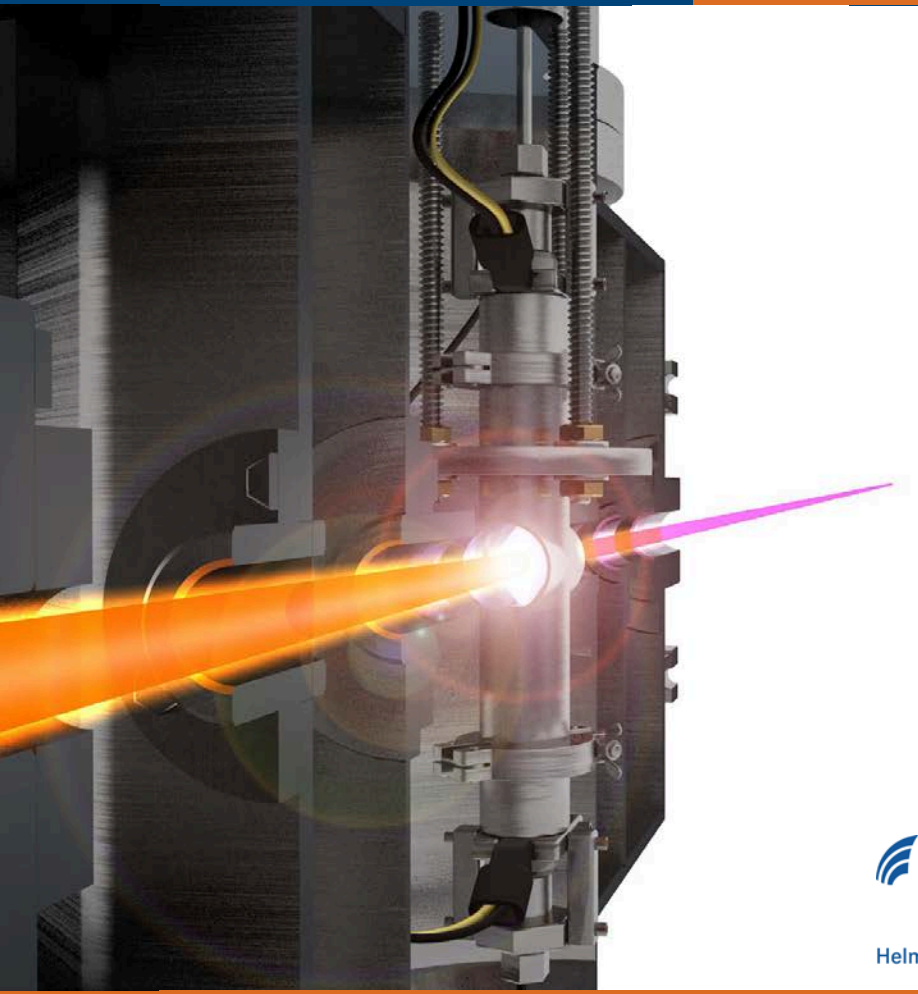


W. Barth et al., Phys. Rev. ST AB 18 (2015) 040101

Conclusion

- Increased gas densities for the stripping process achieved using the new pulsed gas cell
- Practical use of light gas targets enabled and tested
- Stripping efficiencies into U^{28+} increased by 60% using the pulsed gas cell with H_2 ...
- ... at similar beam quality
- U^{28+}-intensity record achieved at the GSI UNILAC

Measurements using uranium and titanium beams with a new modified setup in October 2015



Thank you!