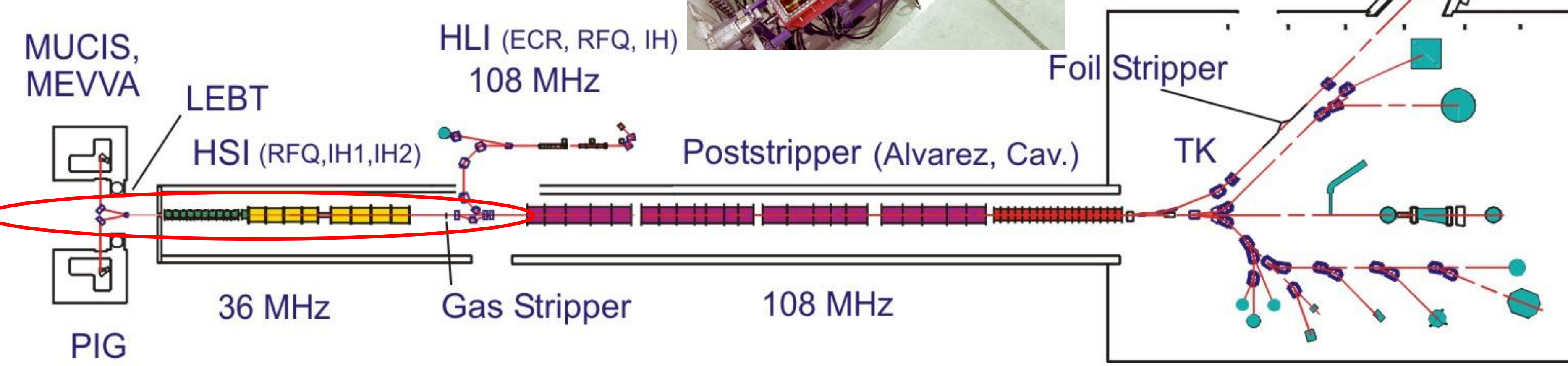
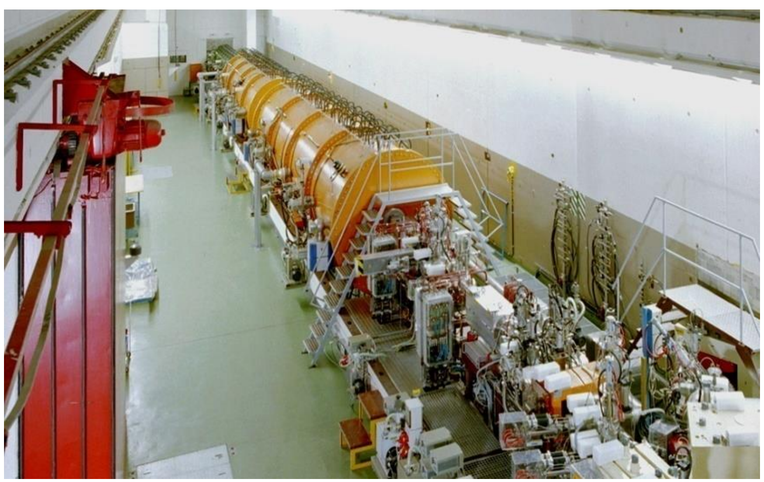
The GSI UNIversal Linear ACcelerator

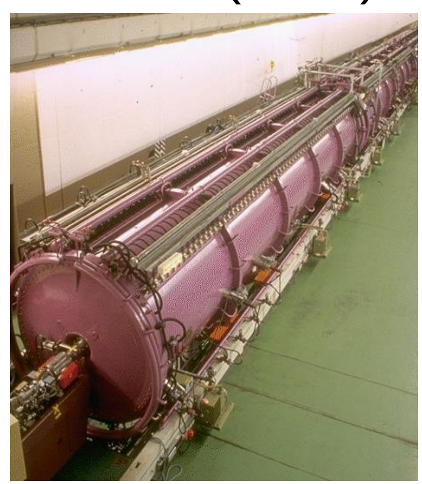
High Charge State Injector (1991)



High Current Injector (1999)



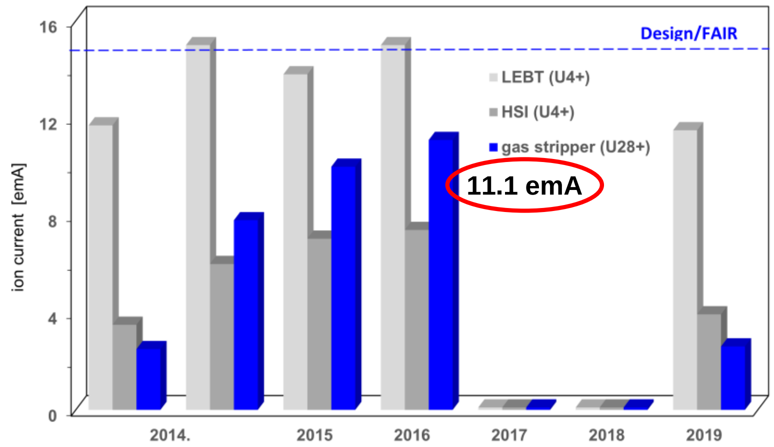
Alvarez (1975)



Single Gap Resonators (1975)

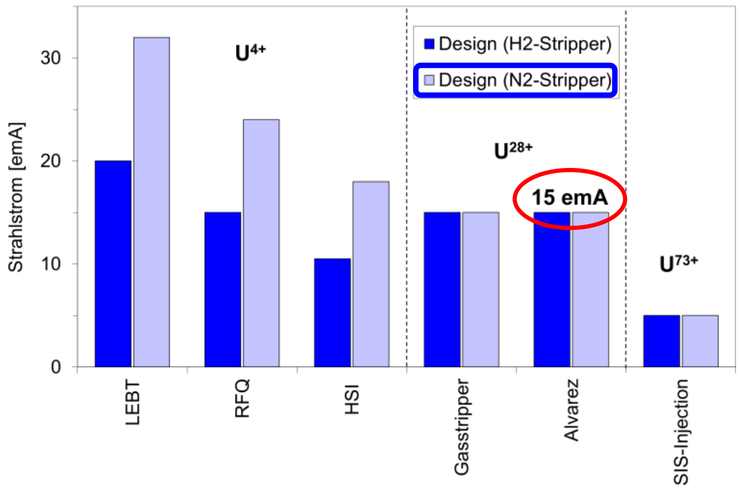
General HSI-Upgrade Guideline

1. Back to 2016-HSI-performance



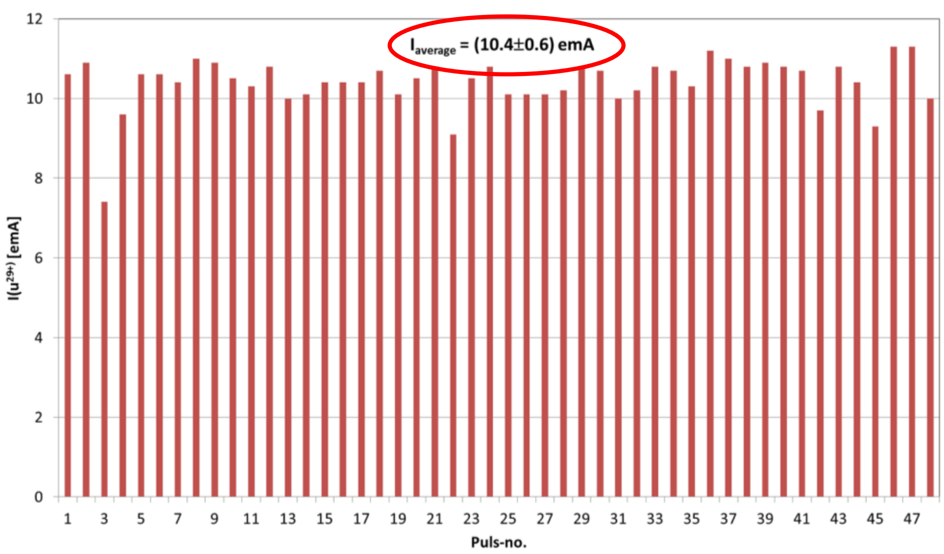
W. Barth, GSI-FAIR Scientific Report 2019, UNILAC-recommissioning with Uranium beam (2020)

2. Meeting FAIR-requirements

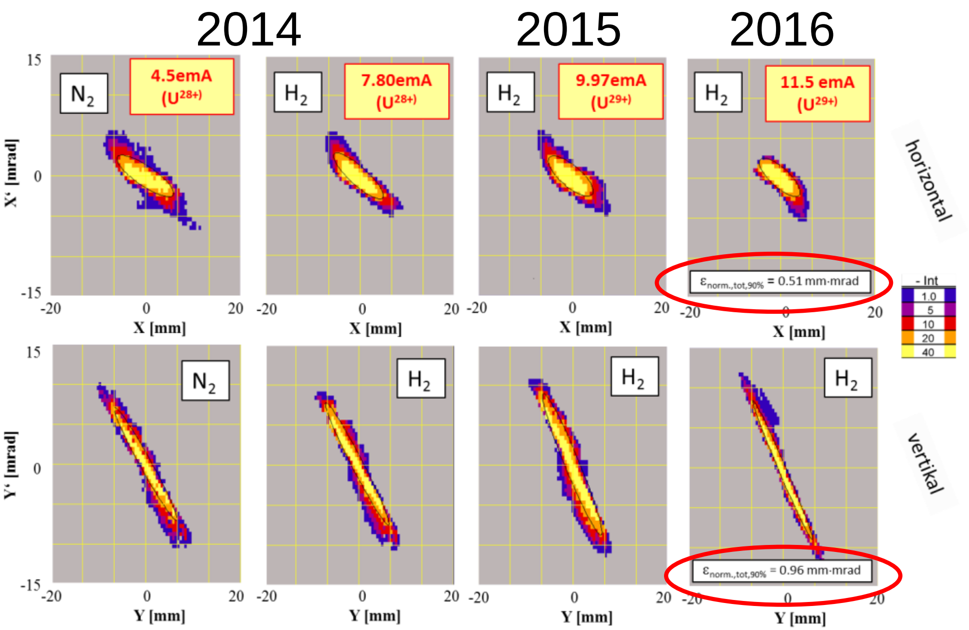


General HSI-Upgrade Guideline

U^{28+}-beam current

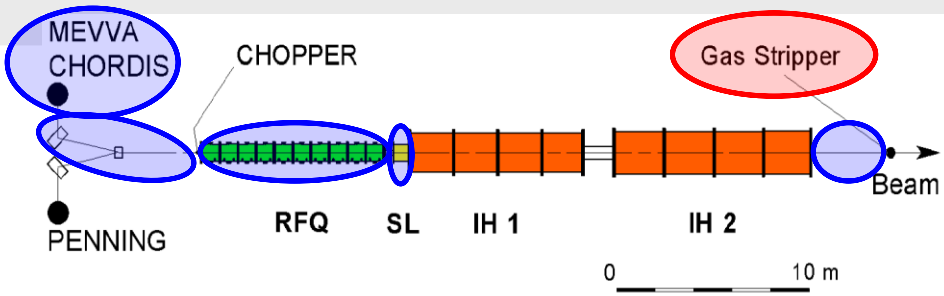


HSI beam emittance



Pushing the limits for uranium beam operation

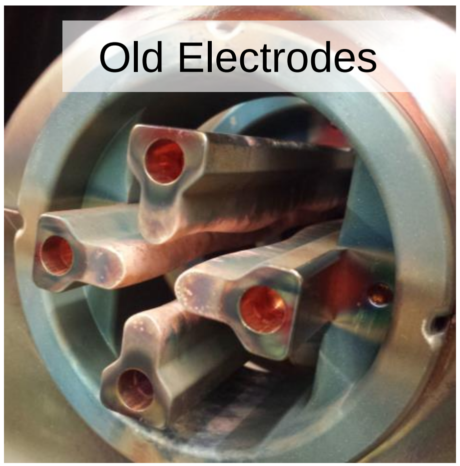
High Current Injector

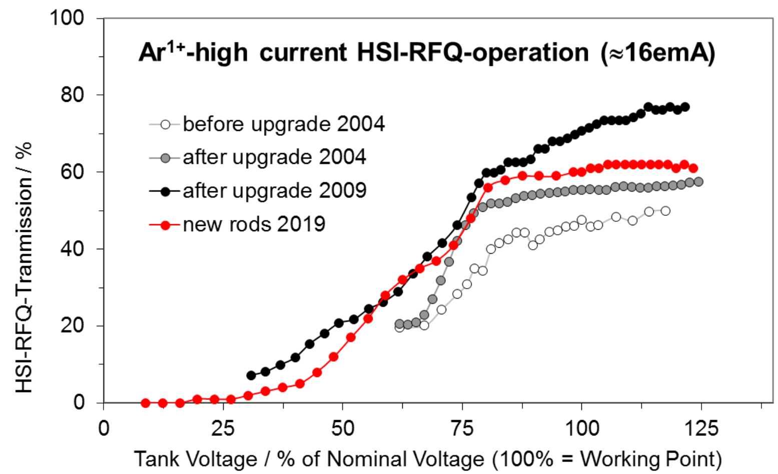


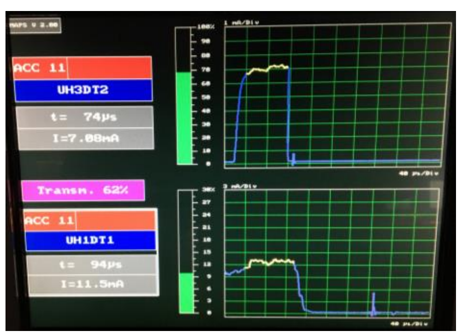
- **Ion Source:** Applying a multi-aperture (7-hole) extraction system at the VARIS ion source → Increased U^{4+}-intensity and improved primary beam brilliance (Terminal West + PRIDE => 20emA, U^{4+}, 250 mm·mrad)
- **Low Energy Beam Transport:** Improved LEBT-performance and RFQ-Matching using high brilliance Uranium beam from the VARIS → 75% RFQ-Transmission (I_{out} = 15 emA) (PRIDE)
- **RFQ:** RF optimization by adjusting plunger positions at the HSI RFQ tank and extensive rf-conditioning → Reduction of forwarded rf-power, yielding for reliable high-current uranium beam operation (Revised electrode design with trapezoidal shape)
- **MEBT:** Optimizing the beam transport between RFQ and IH DTL by increasing the transverse and longitudinal focusing strength (3%) → Reduction of beam loss, stable high current operation.(Revised design with improved QD (enlarged aperture, higher field strength and new SL-electrode design)
- **1.4 MeV/u-Transport Line: and gas stripper:** Adapting the quadrupole channel (matching the gas stripper) → 90% beam transmission, U^{4+} beam current of 7.6 emA available for heavy ion stripping. (H_2-gas stripper implementation => 15 emA, U^{28+}, 0.5 mm·mrad (hor.))
- **UNILAC-high current beam diagnostics (non destructive):** Beam transmission (MAPS), beam position (phase probe pickups), beam profile monitors (BIF) – Bunch Shape Monitor (transfer line)
- **Regular beam development program:** Ramp up UNILAC to 10 emA, U^{28+} at sufficient beam brilliance !
- **Reliable high current beam operation!**

HSI-RFQ-Upgrade (2019)

- New Quadrupole Quartett (2017/18) with thin walled beam tube (2019)
- HSI-RFQ: New Electrodes (2019) installed (2018: Rf-level limited to max. 74% of Design)







- 89% of the design Rf-level applied successfully
- Sufficient U^{4+}-RFQ-operation
- 50% of best HSI-performance (2016)
- U^{4+} => U^{28+} => U^{68+} (8.6 MeV/u)
- For SIS18-injection: 1.1 +/-0.1 emA ($7x10^9$ particles in a 0.07 ms pulse)

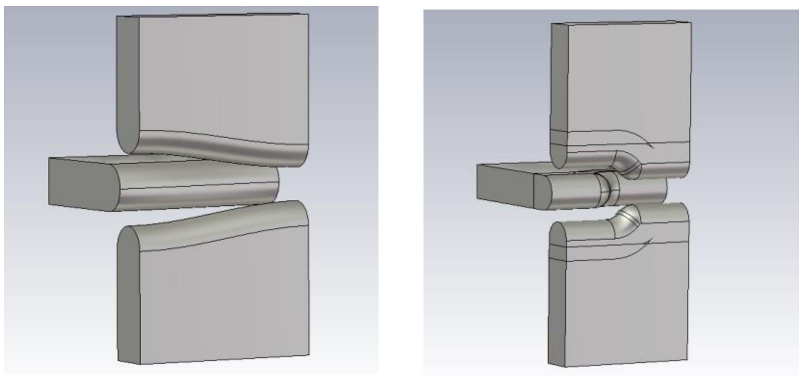
Recommendations addressed

R&D plan for a high intensity heavy ion RFQ with high reliability that meets the FAIR requirements?

General HSI-(RFQ) Guideline

- Back to 2016-performance (1)
- Meeting FAIR-requirements (2)

sinusoidal **trapezoidal**



M. Vossberg, R. Brodhage, M. Kaiser, F. Maimone, W. Vinzenz, S. Yaramyshev, GSI, Darmstadt, Germany, DESIGN STUDIES FOR THE PROTON-LINAC RFQ FOR FAIR, IPAC'15 (2015)

Schedule

2019: Exchange of RFQ-electrodes

2020: Advanced Rf-conditioning

2020: U^{4+}-operation

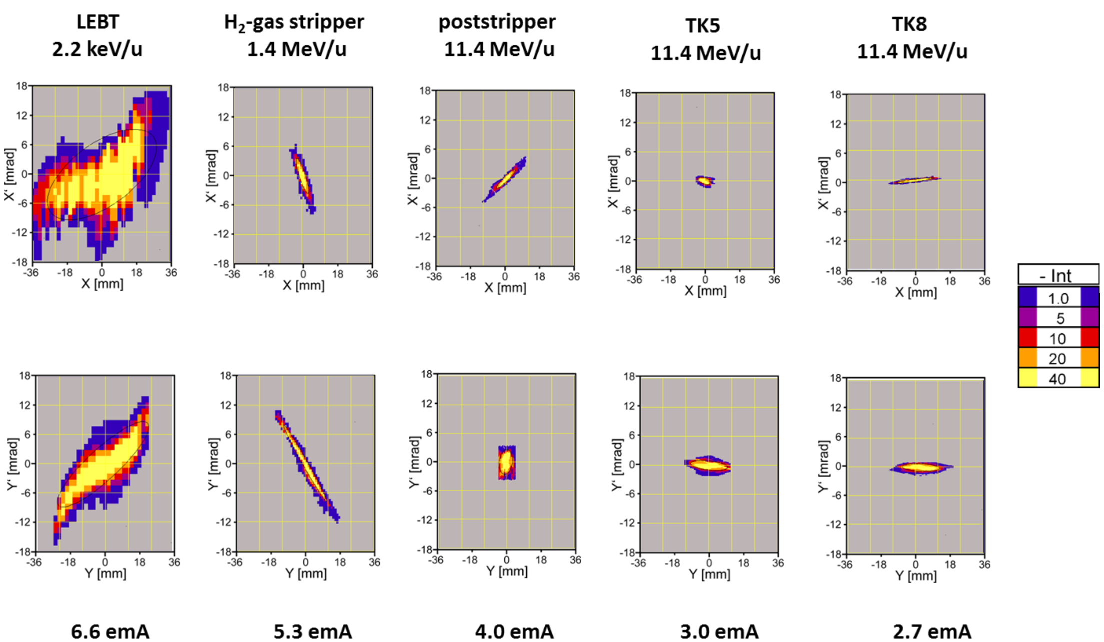
2022: Exchange of LEBT-QQ (1)

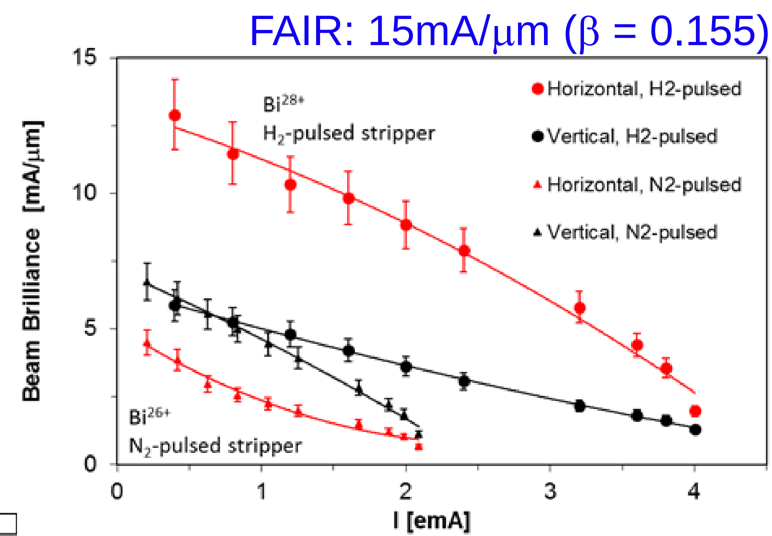
≥2023: Improved RFQ-electrode design (2)

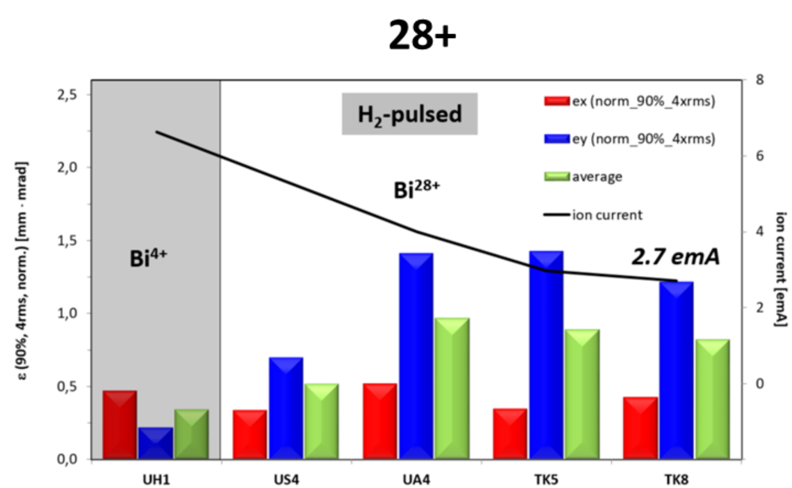
- lower RF-voltage (RF-power)
- higher acceleration efficiency

Status of High Current Heavy Ion Beam Performance

2020: Heavy ion beam studies: Bi^{4+} => Bi^{28+}





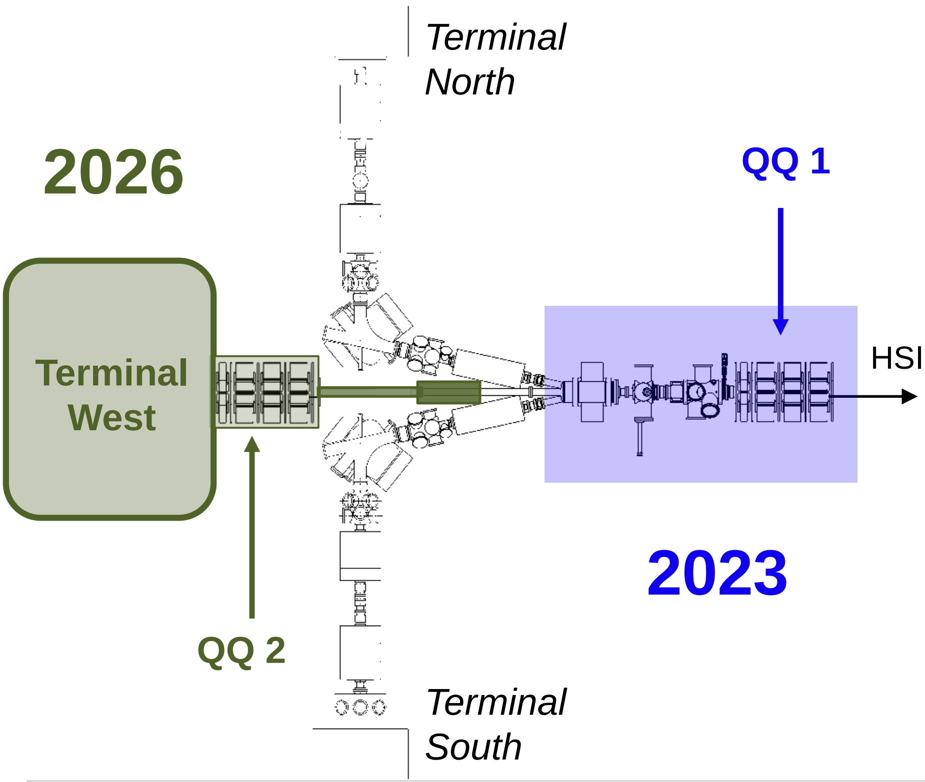


Full HSI-performance (2016: 11.1 emA, U^{28+} @1.4 MeV/u) => 6.2emA*@SIS-injection!

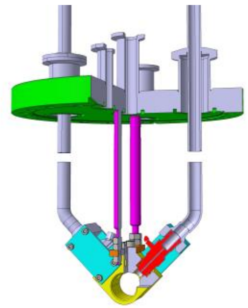
* ≈1.0×10^{11} U^{28+}-particles (70µs)

Further UNILAC-Upgrade

- <u>PR</u>e <u>I</u>njector <u>DE</u>dicated for Uranium operation (PRIDE)

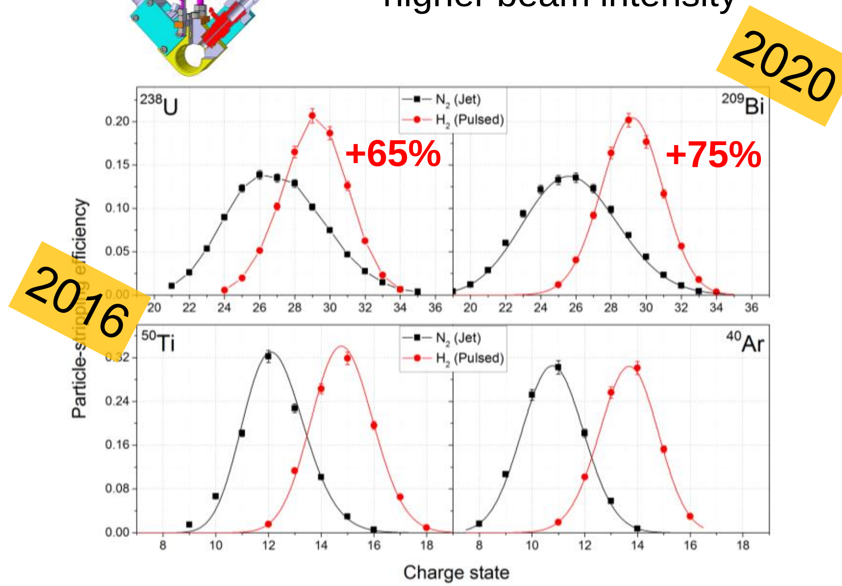


- Pulsed H_2-Gasstripper (**2024**)



Heavy ions (U, Bi):

- more narrow distribution
- increased stripping efficiency
- higher beam intensity



FAIR: 15 mA U^{28+} at 11.4 MeV/u;

Required at RFQ entrance: **20 mA U^{4+} (inside 250 μm)**

Low Z-gas stripping witth improved heavy ion stripping efficiency: **+65% => 15 mA U^{28+} (inside 1 μm)**

TecNote "Further steps towards realization of the PRe Injector DEdicated for Uranium operation (PRIDE)" I

A. Adonin, W. Barth, R. Hollinger, H. Vormann, S. Yaramyshev (07.10.2020)

- **Two step approach to realize PRIDE**
  A. Upgrade of existing matching line to RFQ (2023)
  B. Terminal West and beam transport to existing matching line (2026)
- **The general beamline layout is fixed**
  - Terminal West– Quadrupole Quartet (QQ new) with large aperture – iris aperture – Quadrupole Triplet – switching magnet – Quadrupole Quartet (QQ old) – HSI-RFQ (Matching In).
- **Step A**
  - Replacement of new QQ (in front of RFQ) by old QQ in order to obtain high transmission (with optimal beam brilliance) through entire HSI by providing proper RFQ-matching for heavy ion beams.
    References: https://www.gsi.de/fileadmin/Beschleunigerbetrieb/Dokumente/UNILAC_Report_ACC_Exp_05_06_2020.pdf, S. Yaramyshev et al., ADVANCED BEAM MATCHING TO A HIGH CURRENT RFQ, proc. of LINAC14, Geneva, Switzerland (2014): http://accelconf.web.cern.ch/LINAC2014/papers/tupp059.pdf
  - Power supplies for old QQ are kept at already installed position.
  - Replacement of switching magnet (UH1MU2) with enlarged vertical aperture (total inner height of 77 mm) as a start value of an iterative optimization process of beam line designer with NCM- and EPS-department.

TecNote "Further steps towards realization of the PRe Injector DEdicated for Uranium operation (PRIDE)" II

A. Adonin, W. Barth, R. Hollinger, H. Vormann, S. Yaramyshev (07.10.2020)

- **Step B**
  - The new QQ, enlarged for the original design aperture of 150 mm, has to be installed directly behind Terminal West.
  - For new QQ the four existing new power supplies (in d.c. mode) fulfill all requirements to catch the beam from ion source.
  - Power supply for new QQ are kept at already installed position in BH1 basement.
  - The distance from Terminal West to switching magnet has to be optimized further providing for proper beam dynamics.
- **Resource issues and further time schedule**
  - Replacement of QQ together with installation of new switching magnet (shutdown 2022/23).
  - Design, specification and ordering of new switching magnet will start end of 2020, to allow for installation of switching magnet in shutdown 2022/23.
- **PRIDE-upgrade follows the general HSI-upgrade guideline**
  - Back to 2016-HSI-performance (Step A)
  - Meeting FAIR-requirements (Step B)

References: W. Barth et al., High brilliance uranium beams for the GSI FAIR, Phys. Rev. ST Accel. Beams 20, 050101 (2017)

Attachments

UNILAC-Design Beam Parameters

Commissioning of the 1.4 MeV/u High Current Heavy Ion Linac at GSI, Winfried Barth

DESIGN BEAM PARAMETERS AT UNILAC AND SIS INJECTION

Requirements to obtain the SIS space charge limit
(a twentyfold multiturn injection is supposed)

FAIR

	HSI entrance	HSI exit	Alvarez entrance	SIS injection	SIS injection (FAIR)
ION SPECIES	$^{238}U^{4+}$	$^{238}U^{4+}$	$^{238}U^{28+}$	$^{238}U^{73+}$	$^{238}U^{28+}$
El. Current [mA]	16.5	15	12.5	4.6	15
Part. per 100µs pulse	$2.6\cdot10^{12}$	$2.3\cdot10^{12}$	$2.8\cdot10^{11}$	$4.2\cdot10^{10}$	$3.5\cdot10^{11}$
Energy [MeV/u]	0.0022	1.4	1.4	11.4	11.4
$\Delta W/W$	-	$\pm4\cdot10^{-3}$	$\pm2\cdot10^{-3}$	$\pm2\cdot10^{-3}$	$\pm2\cdot10^{-3}$
$\varepsilon_{n,x}$ [mm mrad]	0.3	0.5	0.75	0.8	0.8-1.1
$\varepsilon_{n,x}$ [mm mrad]	0.3	0.5	0.75	2.5	“

LINAC 2000

Comparison of HSI-Transmission