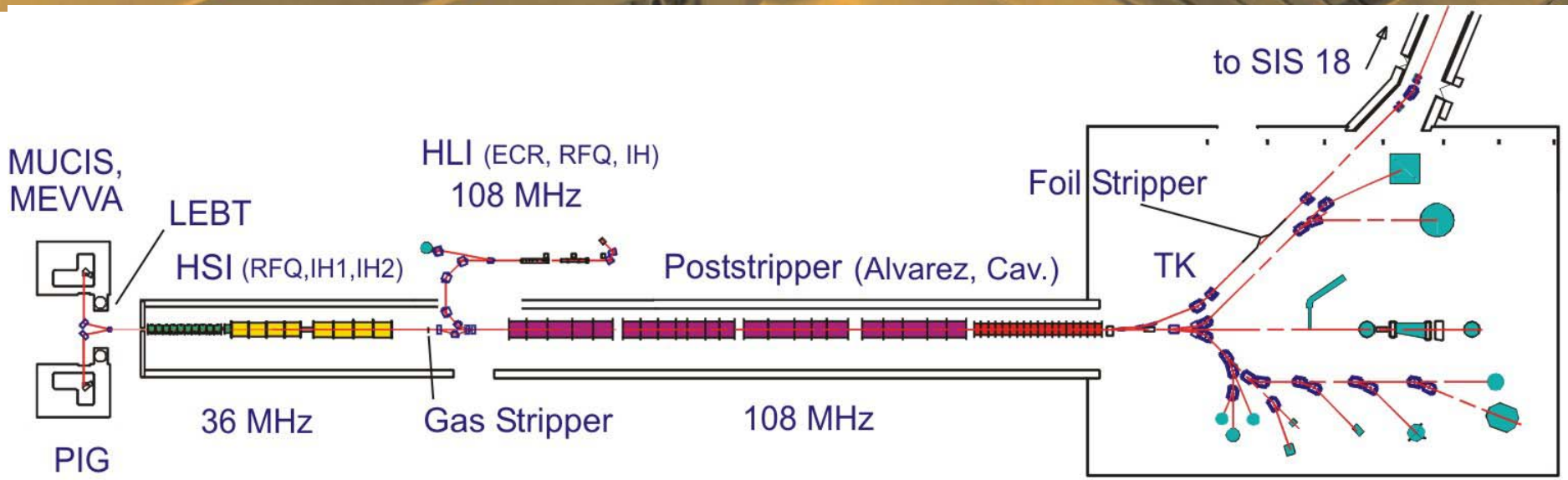
UNILAC Upgrade Measures

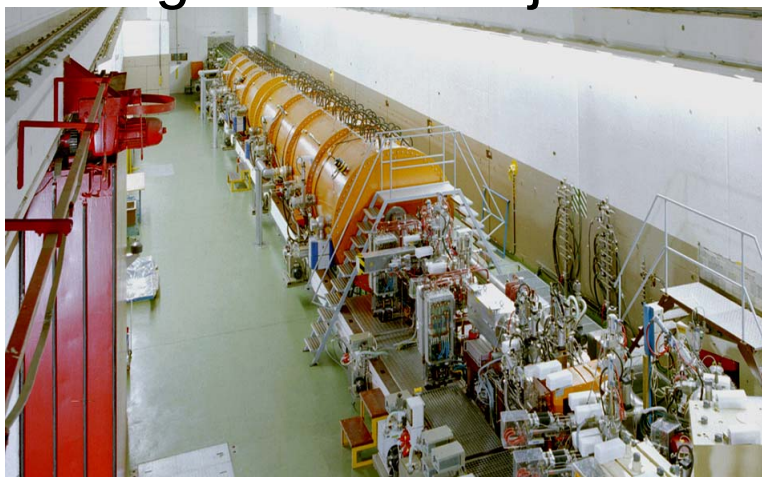
W. Barth, GSI - Darmstadt

1. Introduction
2. FAIR-requirements
3. Planned Unilac Upgrade Program
   - HSI Frontend
   - ALVAREZ Power Supplies
   - High Current Beam Diagnostics
4. Realized Upgrade Measures
   - Gas Stripper
   - Charge State Separator System
   - Alvarez Matching
   - ...
5. Status of the Unilac High Current Performance & further Upgrade
6. Schedule
7. Summary

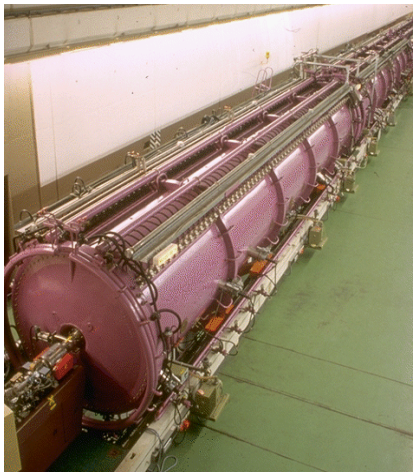
The GSI UNIversal Linear ACcelerator



High Current Injector



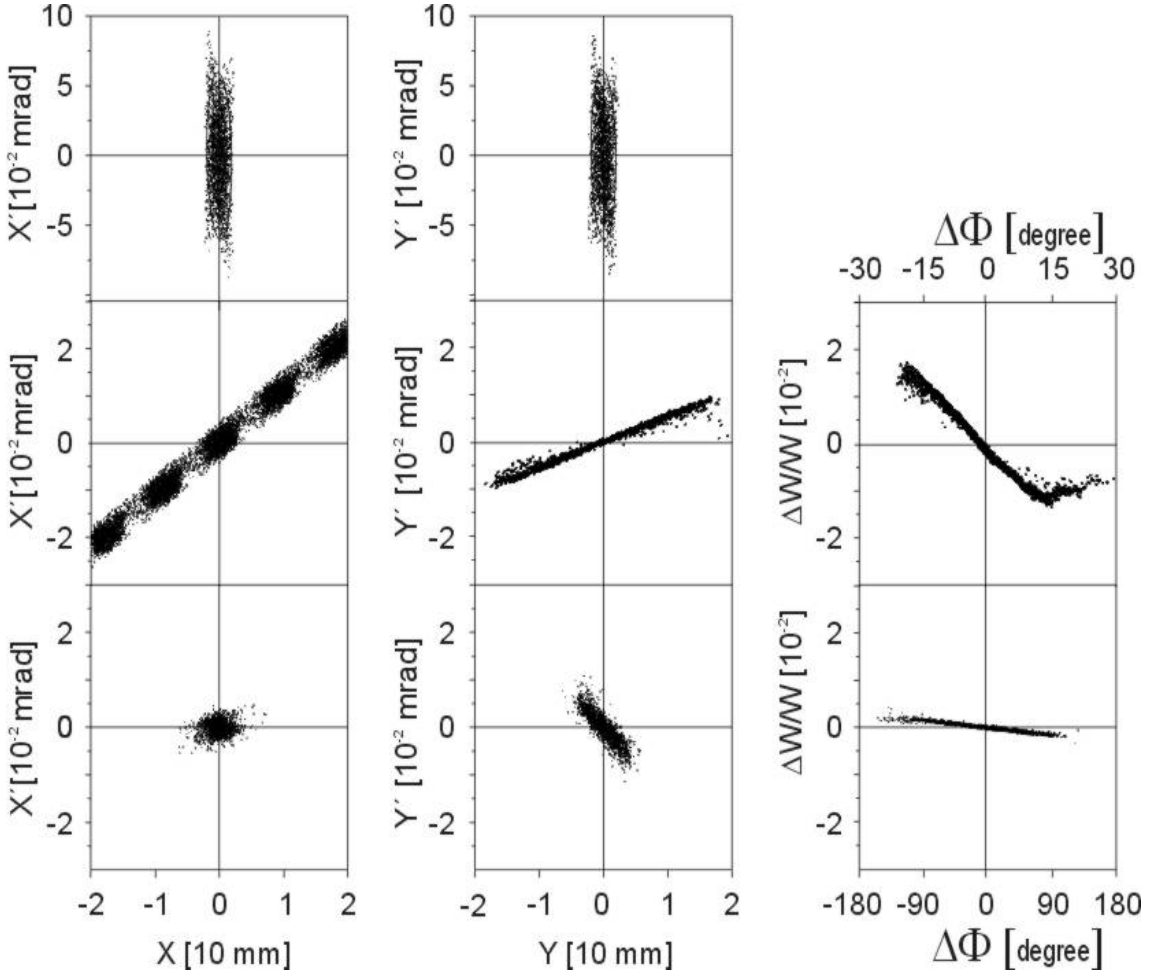
Alvarez



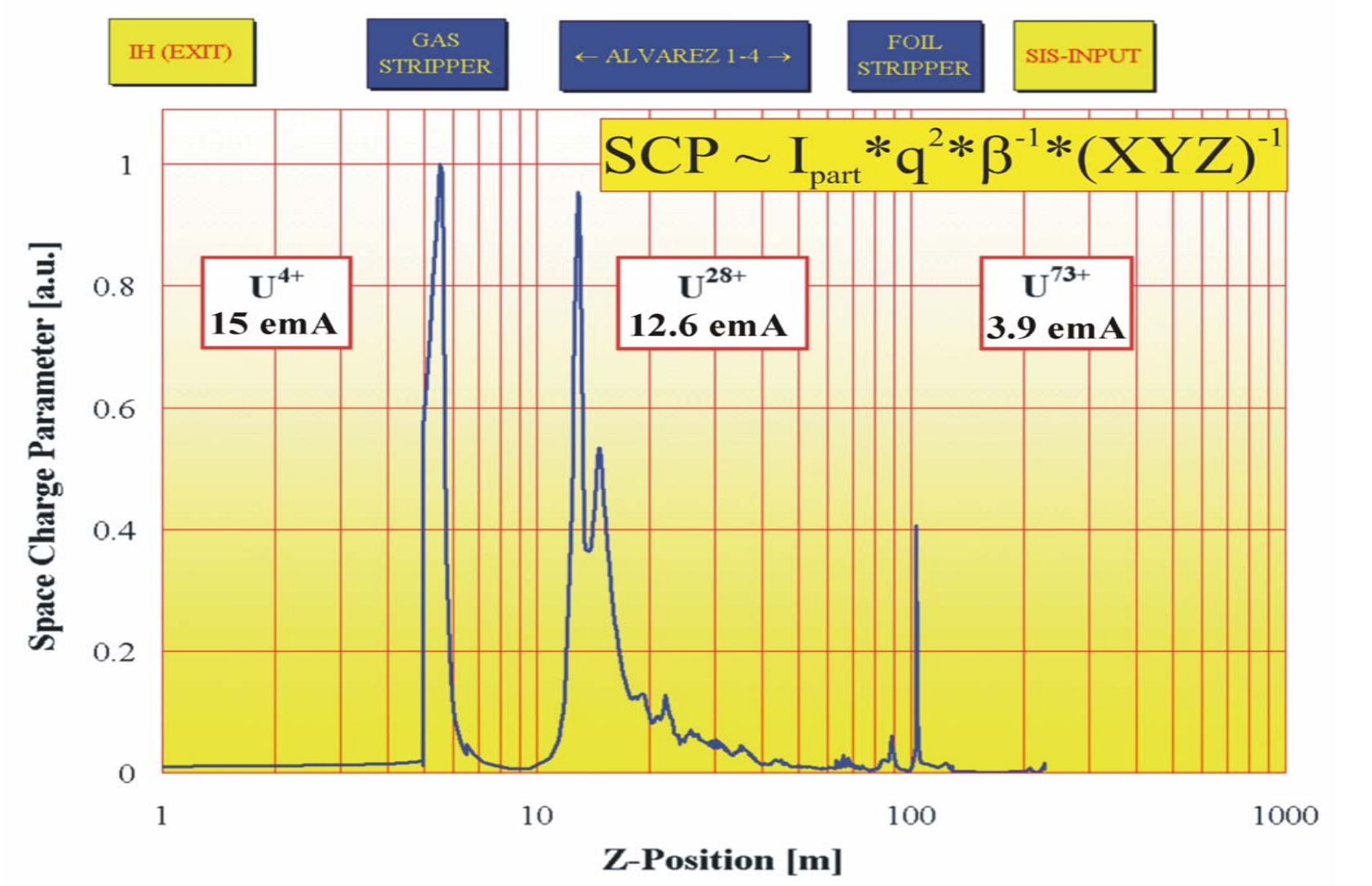
Single Gap Resonators

End to end Simulations

- LEBT (PARMILA-Transport)
- RFQ (PARMTEQ)
- IH-Section (LORAS)
- 1.4 MeV/u-Stripper Section (PARMILA-Transport)
- ALVAREZ (PARMILA)
- Single Gap Resonators (PARMILA-Transport)
- Transfer Line (PARMILA-Transport)
- 11.4 MeV/u-Stripper Section (PARMILA-Transport)
- Matching SIS 18 (PARMILA-Transport)



Space Charge Parameter



FAIR-Requirements

	Original Design	required for FAIR
$^{238}U^{4+}$ Max. Beam Intensity I, (2.2 keV/u)	16 emA	20 emA
I_{max}@beam power, (1.4 MeV/u)	15 emA@1250 kW	18 emA@1500 kW
Transv. Emittance (LEBT) (90%, total)	120 π·mm·mrad	120 π·mm·mrad
Macropulse Length	≤150 μs	≤150 μs
Beam loading (IH2)	590 kW (15 emA)	710 kW (18 emA)
U^{28+}		
Max. Beam Current, (1.4 MeV/u)	12.6 emA	15.0 emA
Max. Beam Intensity, 11.4 MeV/u, I_{max}@beam power Transfer to the SIS18 *Ions/100μs*	12.6 emA@1221 kW $2.8 \cdot 10^{11}$	15.0 emA@1453 kW $3.3 \cdot 10^{11}$
Transv. Emittance (11.4 MeV/u) (90%, tot.)	5.0 π·mm·mrad	7.0 π·mm·mrad
Pulse spread, Δp/p	0.001	0.001
U^{73+}		
Max. Beam Intensity, 11.4 MeV/u, *Ionen/100μs*	4.6 emA $3.9 \cdot 10^{10}$	5.0 emA $4.3 \cdot 10^{10}$
Transv. Emittance (11.4 MeV/u) (90%, tot.)	5.0 π·mm·mrad	7.0 π·mm·mrad
Pulse spread, Δp/p	0.001	0.001

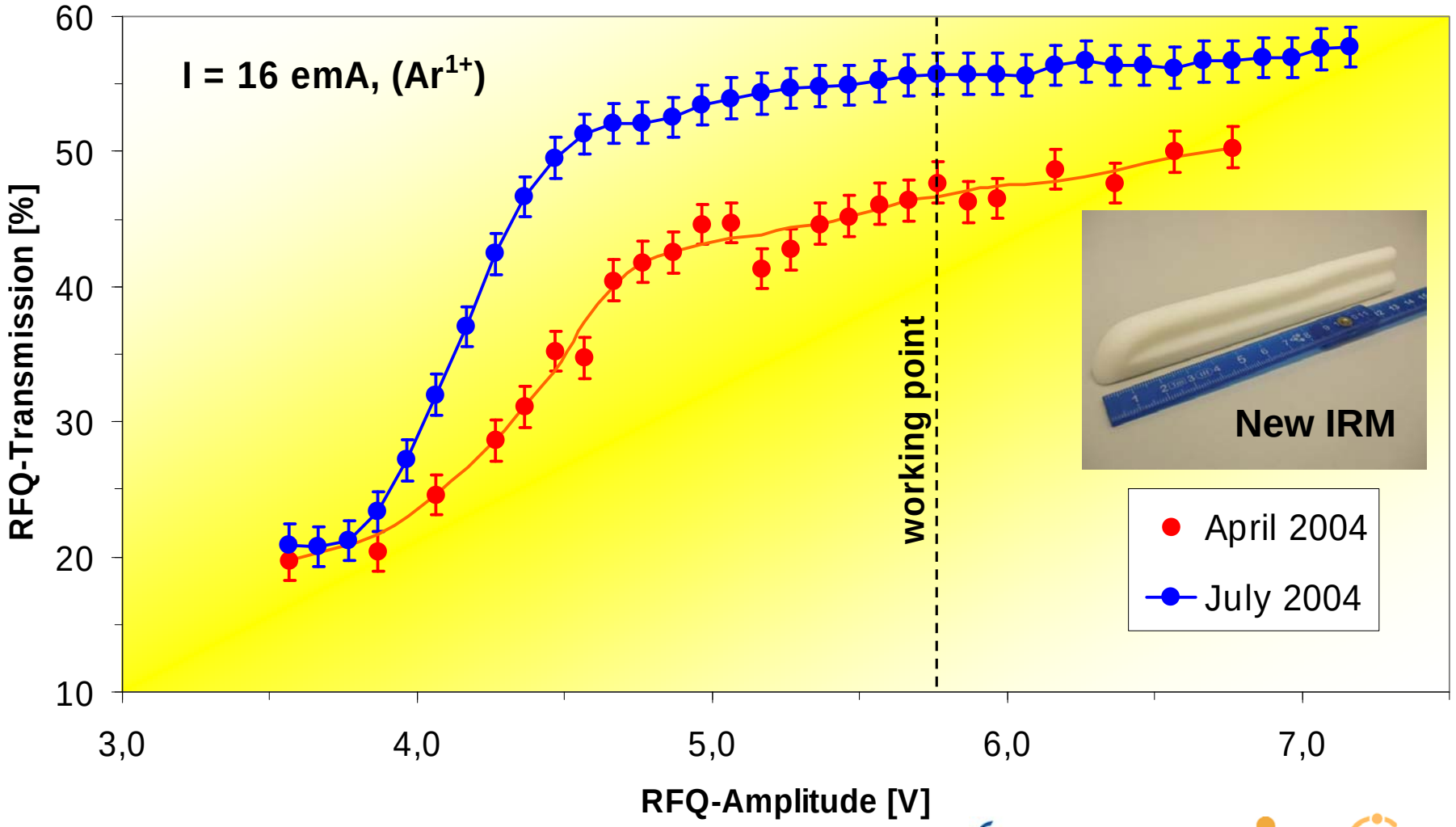
UNILAC-Upgrade for FAIR

(FAIR-Technical Report 2005)

Front End Upgrade

sub-project	***aim***
• High Current test bench → U^{4+}-ion source terminal for the High Current Injector • U^{4+}-Compact Low Energy Beam Transport	18 emA, U^{4+}, 1.4 MeV/u
• HSI-RFQ-Upgrade	
• Gasstripper	13% stripping efficiency for U^{28+}, 100 % transmission
• Power Supplies for 178 Alvarez-quadrupoles	$\sigma_o = 55°$, U^{28+} (improved beam quality)
• 11.4 MeV/u charge state separator	charge state separation for a 5 emA U^{73+} beam
• High Current beam diagnostics	Measurement of ion current, transmission, beam profile, position, energy, transverse and longitudinal emittance

HSI-RFQ-Upgrade (2004)



HSI-Front End Upgrade

Upgrade 0

- High Current test stand measurements
- RFQ-Upgrade

Upgrade I

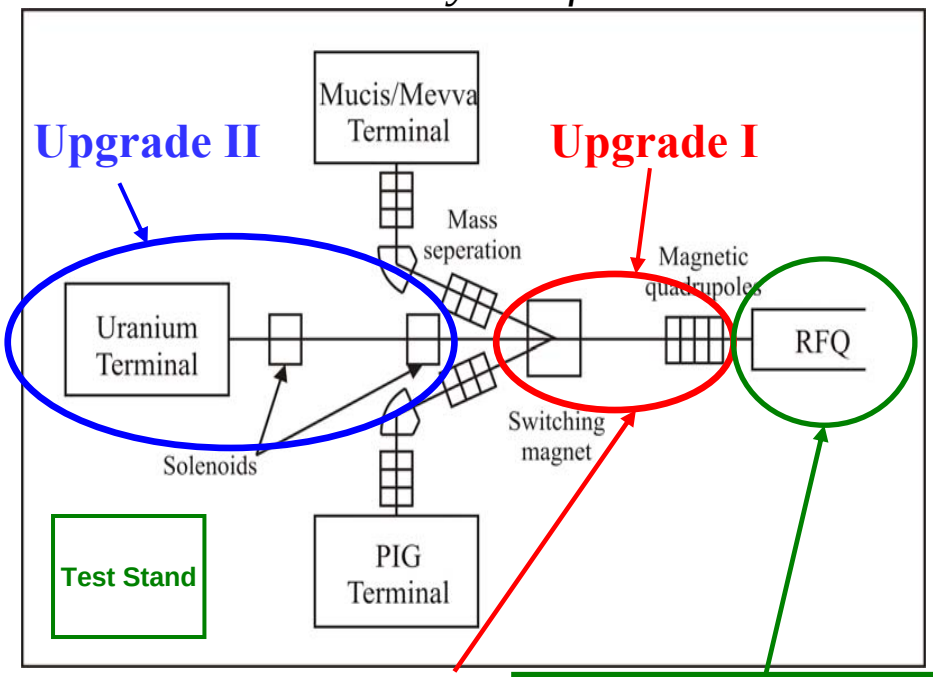
- Switching magnet with increased aperture
- Quadrupole quartet (matching to the RFQ) with increased apertures

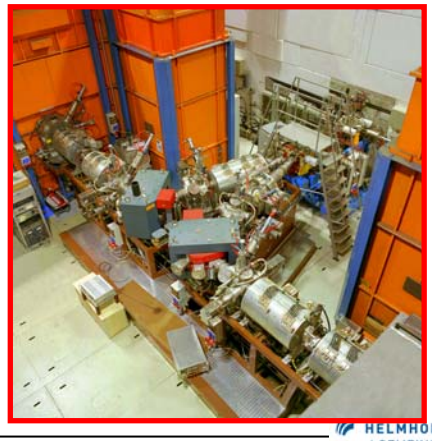
Upgrade II (Compact LEBT)

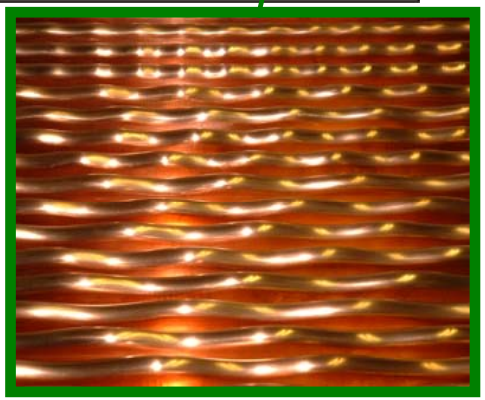
- Beam line with direct injection to the RFQ (integrated into the existing layout)

Beam Dynamics Simulations: Compact LEBT + New RFQ → 20 mA behind RFQ (= FAIR requirements)!

Schematic layout of the LEBT







HSI-RFQ upgrade (2009)

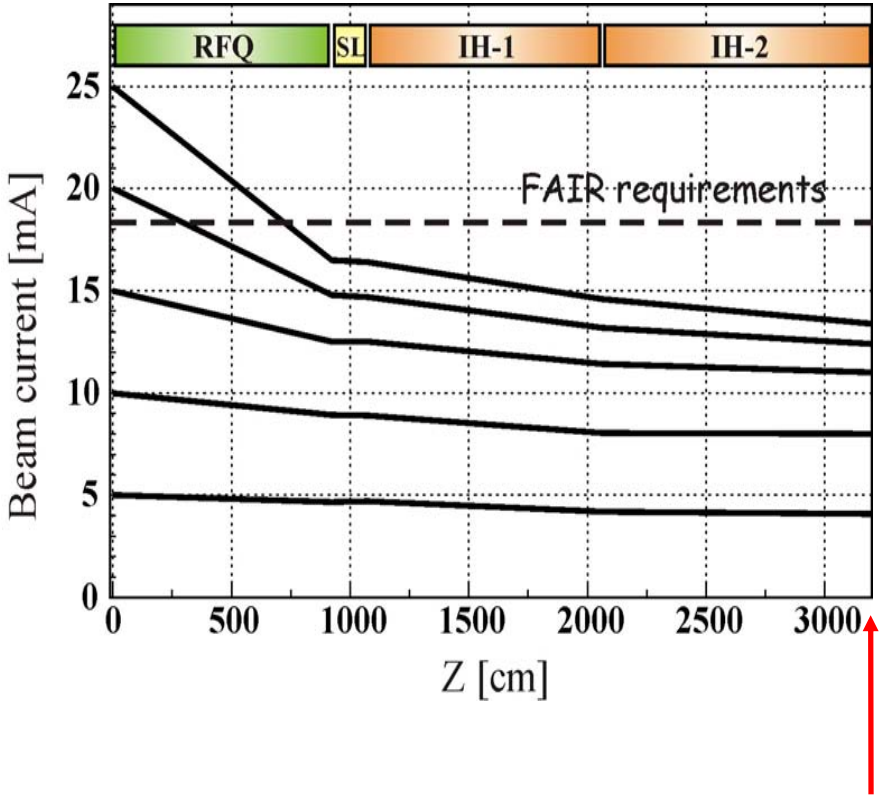
- Higher transverse acceptance and phase advance (keeping maximum field at the electrode surface)
- New Input Radial Matcher design → improved beam matching
- Improved beam dynamics for gentle buncher optimized for rapid and uniform separatrix filling →
- Resonant frequency shift with increased average radius and reduced electrode thickness can easily be compensated
- Beam dynamics studied with DYNAMION& PARMTEQ-M
- Beam intensity at HSI-RFQ output (18 mA of U^{4+} ions) meets the FAIR requirement

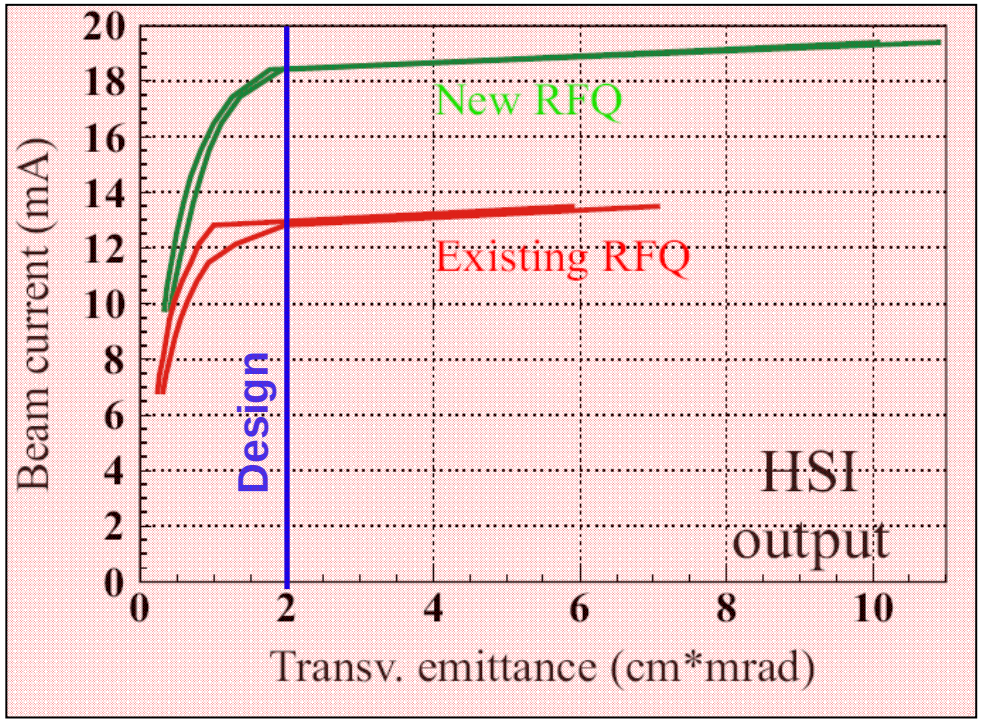
	Final Design	Existing Design
Voltage, kV	155.	125.
Average radius, cm	0.6	0.5245 – 0.7745
Electrode width, cm	0.84	0.9 – 1.08
Maximum field, kV/cm	312.0	318.5
Modulation	1.012 – 1.93	1.012 – 2.09
Synch. Phase, degree	-90^0 - -28^0	-90^0 - -34^0
Aperture, cm	0.410	0.381
Min. transverse phase advance, rad	0.555	0.45
Norm. transverse acceptance, cm mrad	0.0856	0.73
Output energy, MeV/u	0.120	≈ 0.1185
Number of cells with modulation	394	343
Length of electrodes, cm	921.74	921.74

HSI End to end simulation

measurement for present RFQ :

15 mA ≈ 8.5 mA ≈ 7.5 mA

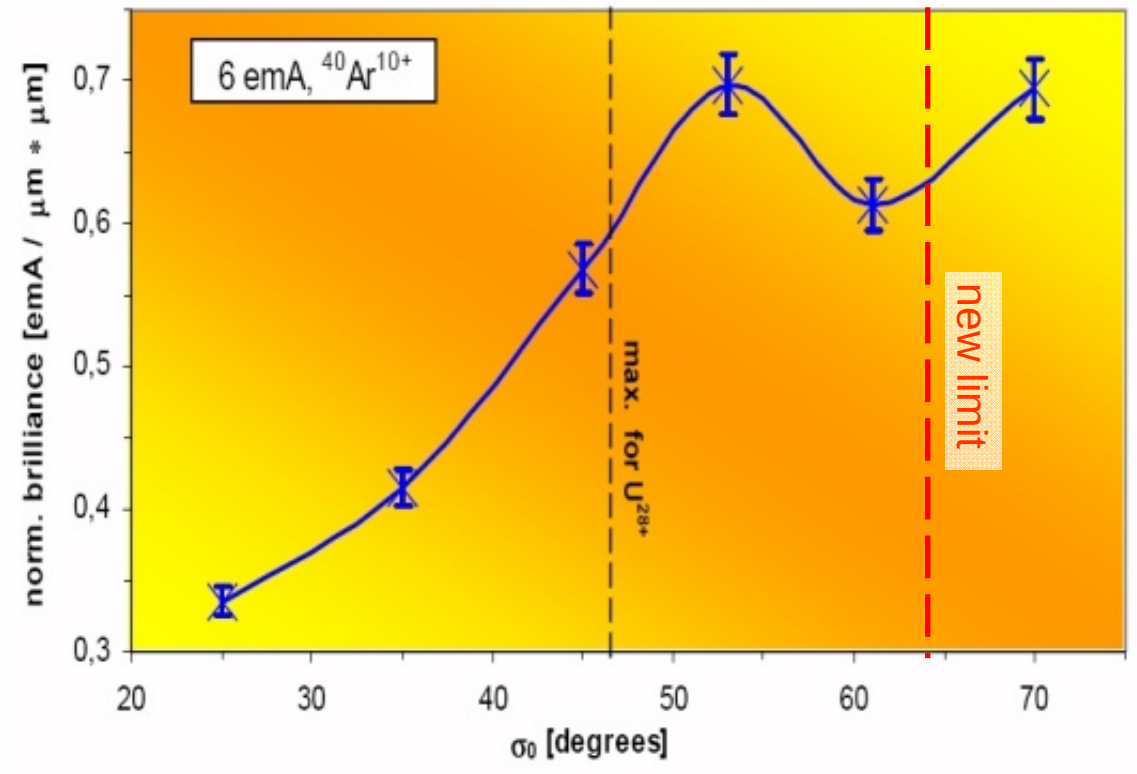




HSI output

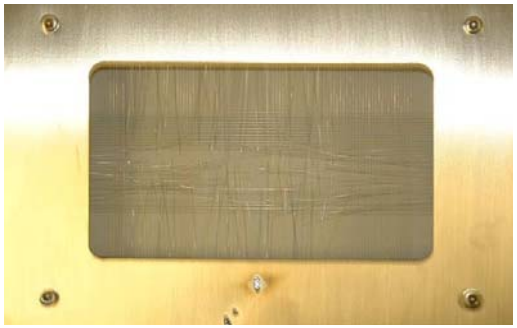
New Power Supplies for the UNILAC Alvarez dc-Magnets

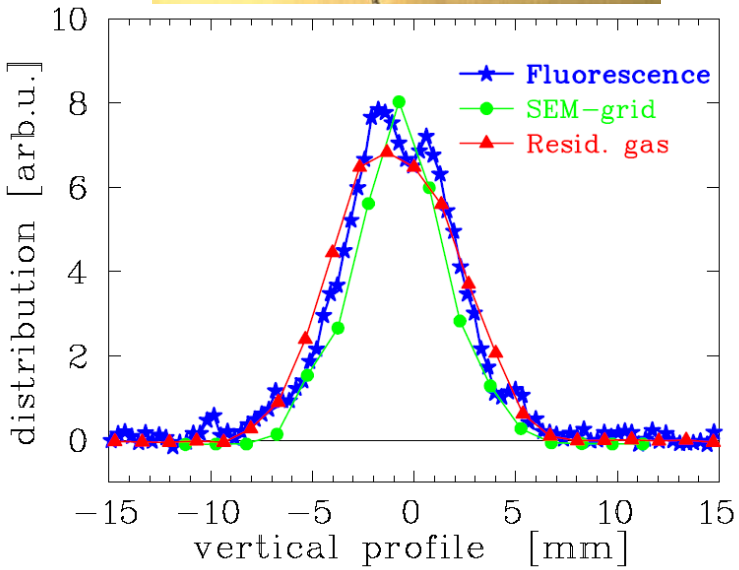
- The achieved ratio current / rms-emittance at DTL exit is too low for FAIR
- Design: 15.5 mA / 0.25 µm; Achieved: 4.4 mA / 0.43 µm
- One measure of improvement → reduction of emittance growth along DTL
- Exp. and simulation: possible by increasing DTL quad strengths



High Current Beam Diagnostics: Beam Induced Fluorescence Monitor

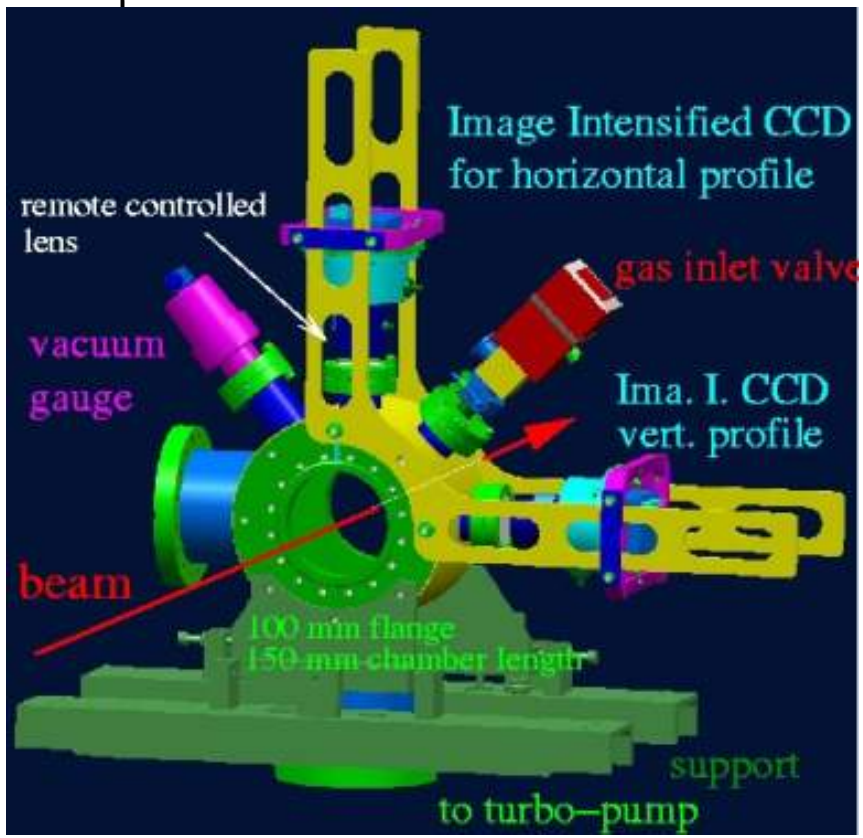
Damaged SEM-Grid





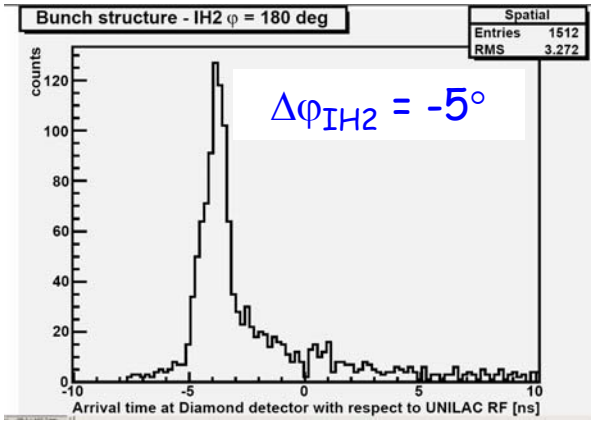
4.7 MeV/u Ar^{10+} beam
I=2.5 mA equals to 1011 particle
One single macro pulse of 200 μs
Vacuum pressure: p=10-5 mbar (N2)

Compact chamber with 150 mm insertion:

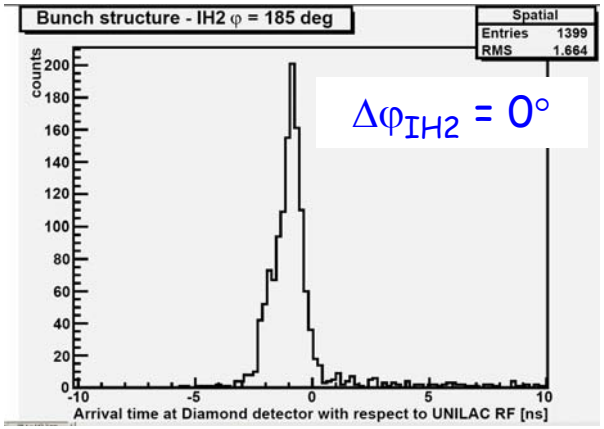


Large beam power → Non-intercepting method:
⇒ Beam Induced Fluorescence BIF
N_2 + Ion → (N_2^+)*+ Ion → N_2^+ + γ + Ion
With single photon detection scheme
⇒ installation.of seven BIF-stations

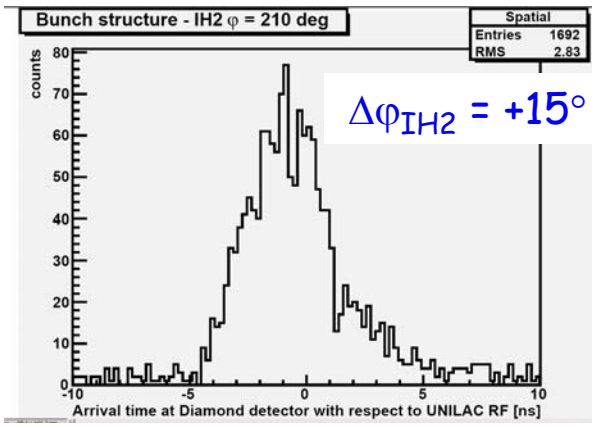
HSI-Bunchstructure Measurement



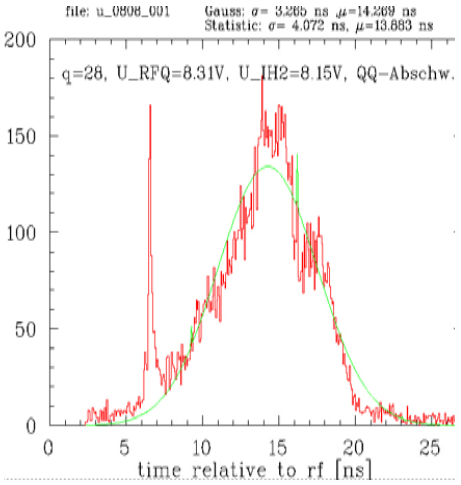
$\Delta\varphi_{IH2}$ = -5°



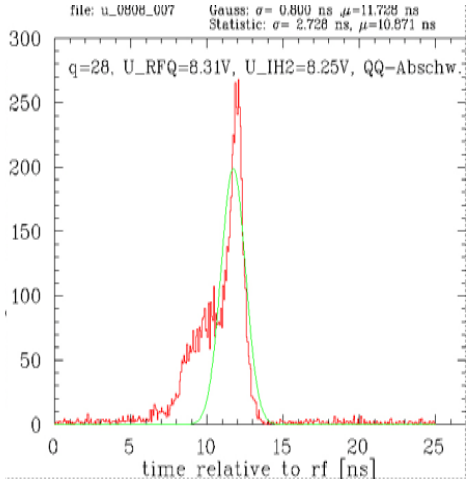
$\Delta\varphi_{IH2}$ = 0°



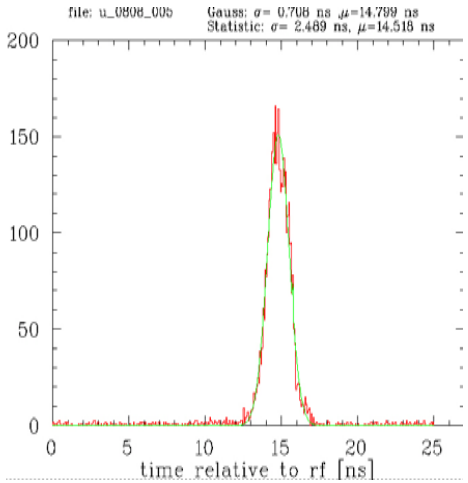
$\Delta\varphi_{IH2}$ = +15°



ΔU_{IH2} = -3.5 %

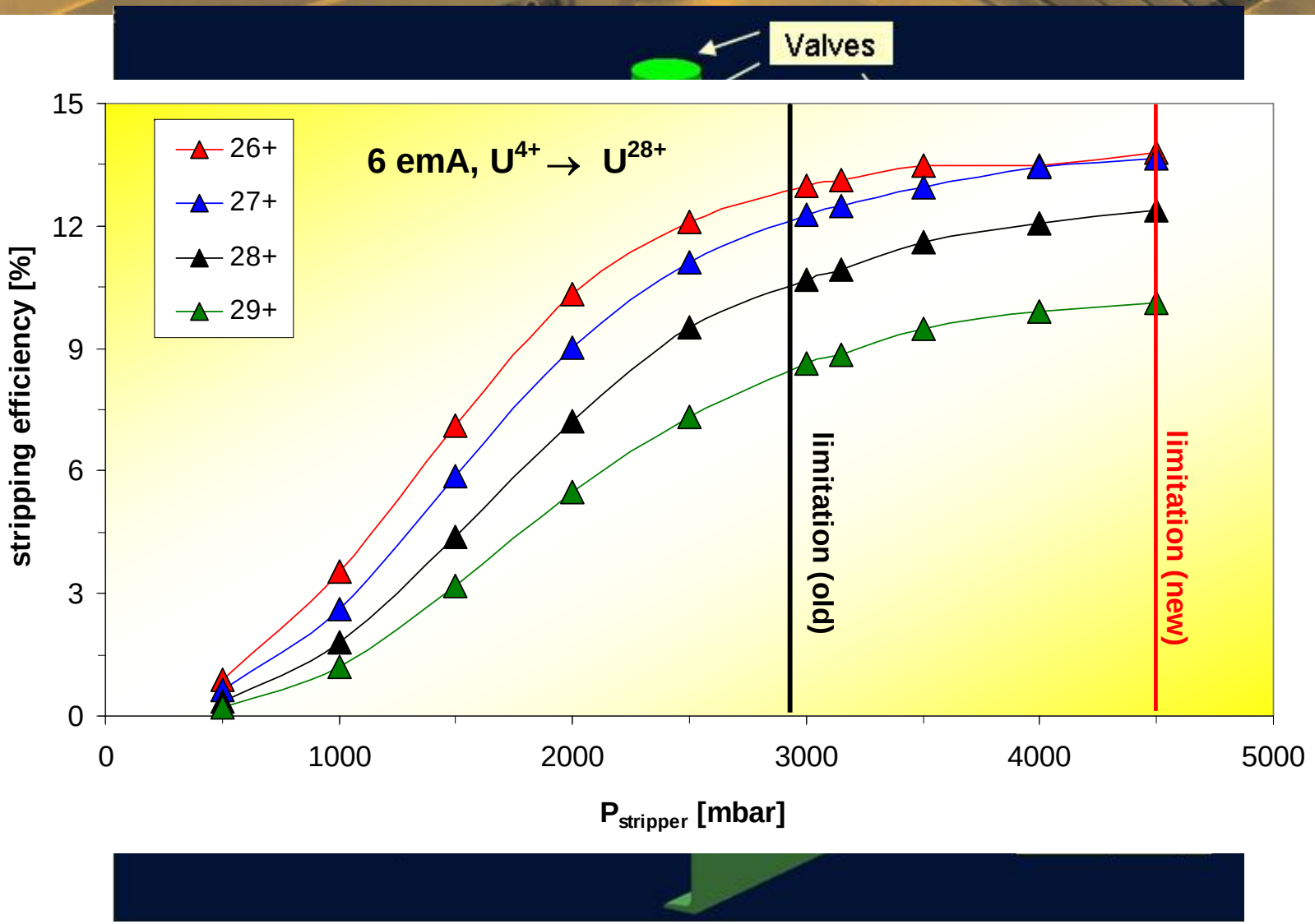


ΔU_{IH2} = -2.5 %



ΔU_{IH2} = 0 %

Increased Stripper Gas Density



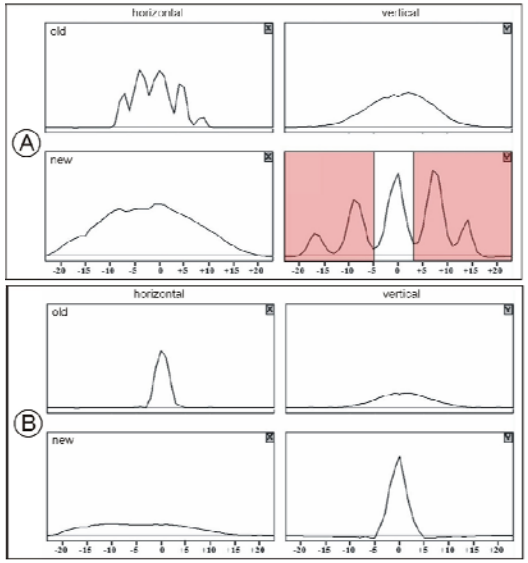
Charge State Separator

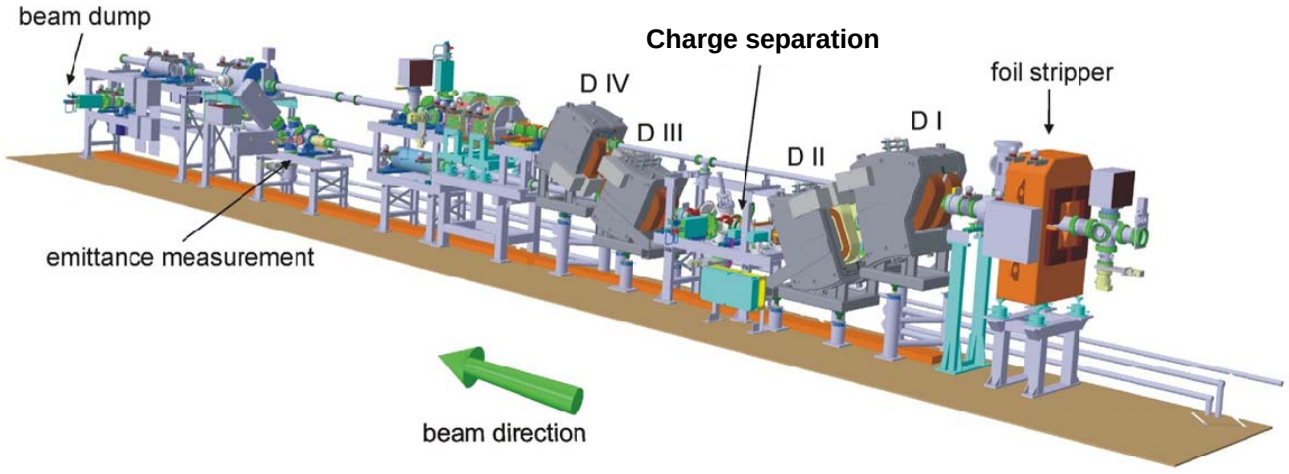
Installation: January 2008

<u>Improvement of:</u>

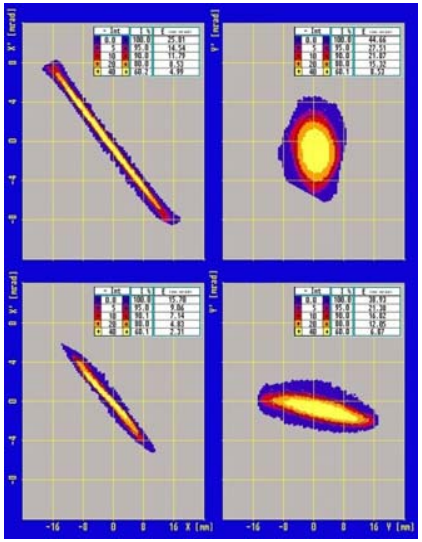
- **Charge Resolution Capability**
- **High Intensity Beam Quality**
- **High Current Beam Diagnostics**
- **Operation Flexibility/Simplification**

Measured beam profile





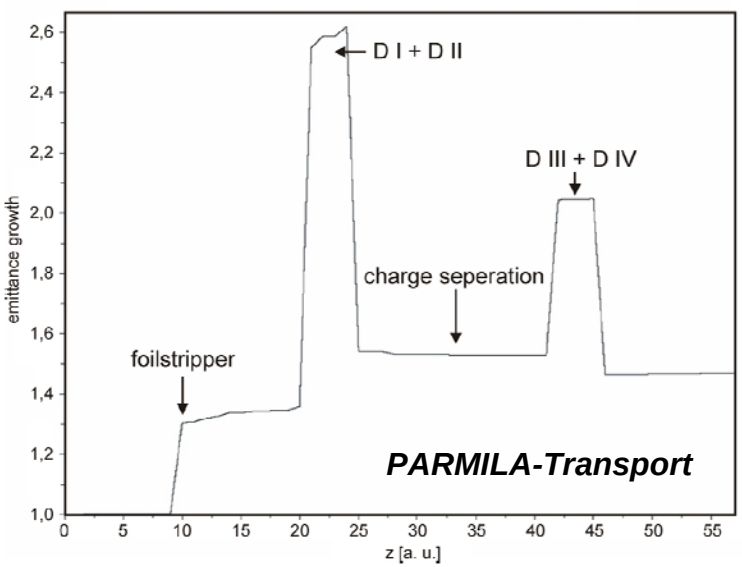
Beam commissioning of the Charge State Separator system



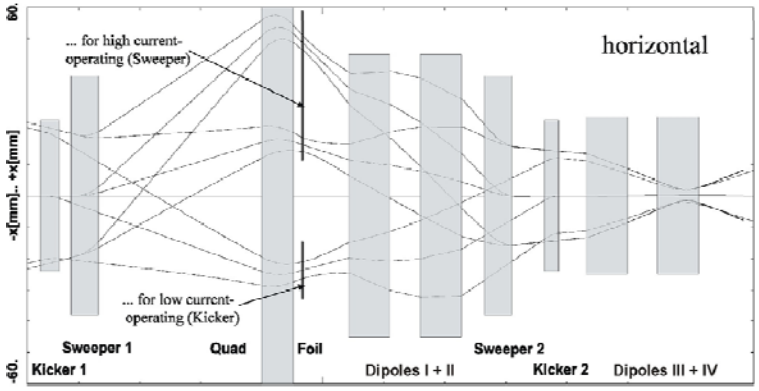
Measurement:
$^{40}AR^{18+}$-Beam Emittances (90 %)

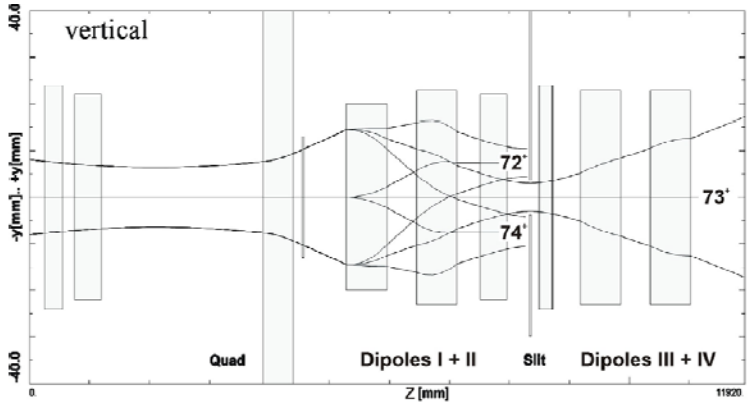
($4\cdot\varepsilon_{rms}$ [µm])	high current		low current	
	hor.	vert.	hor.	vert.
behind D II	9,0	17,6	6,9	7,1
SIS injection	**5,9**	**8,1**	**5,9**	**5,6**

High Current Emittance Growth



Beam Dynamics





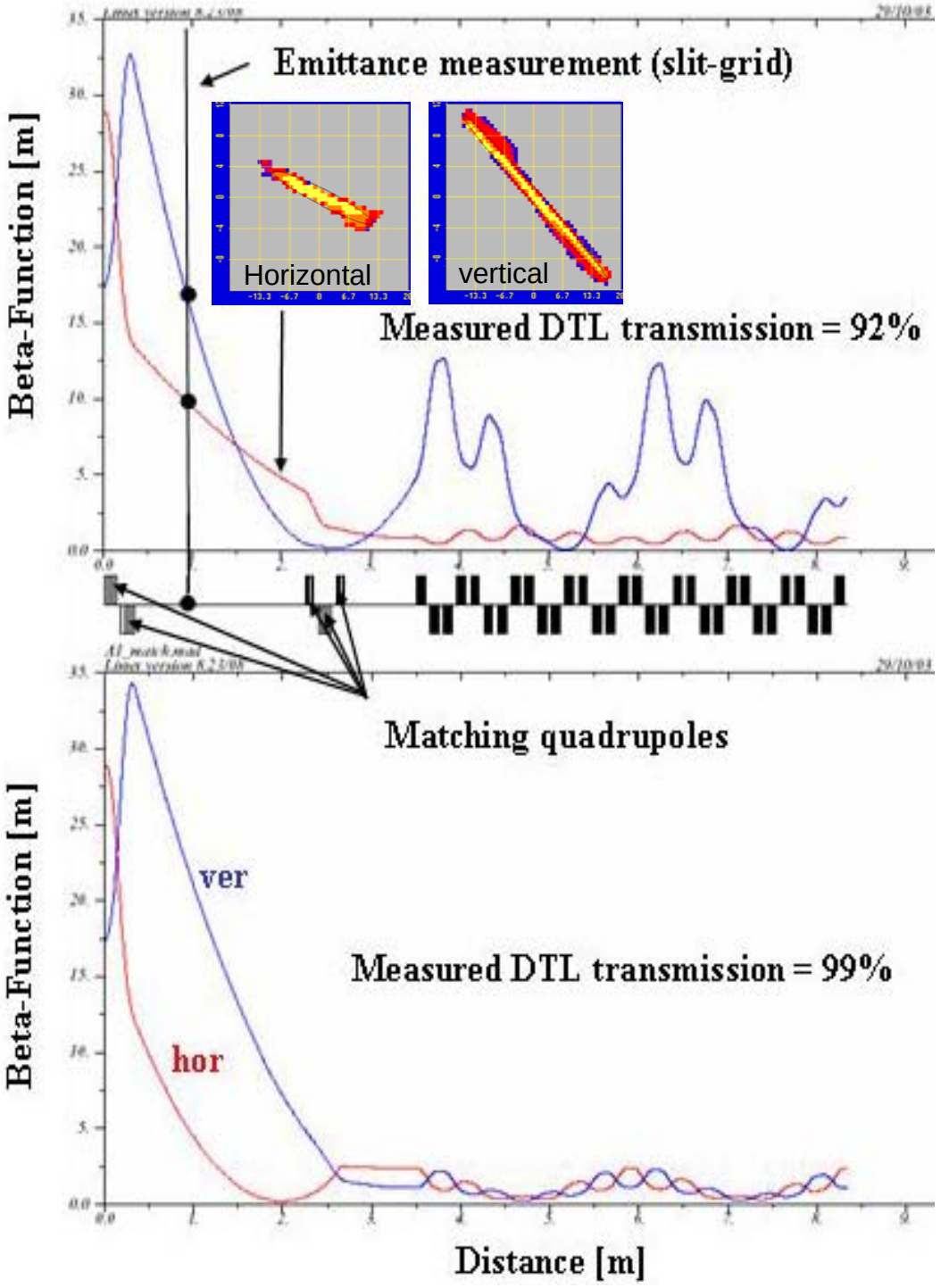
Alvarez-Matching

Emittance Measurement before the DTL, 3.5 emA U^{28+}

Betafunction (before Matching)

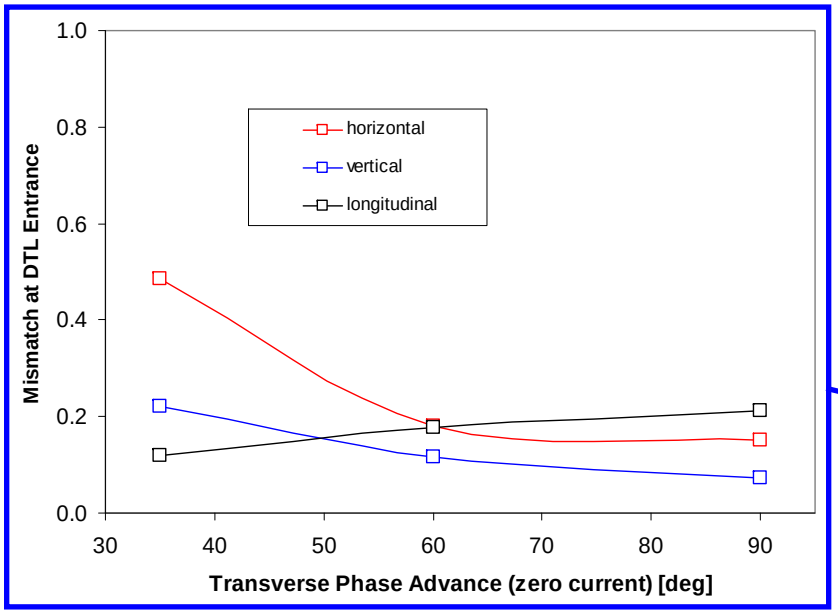
Alvarez DTL-Transmission:
92 % (before)
99 %. (after)

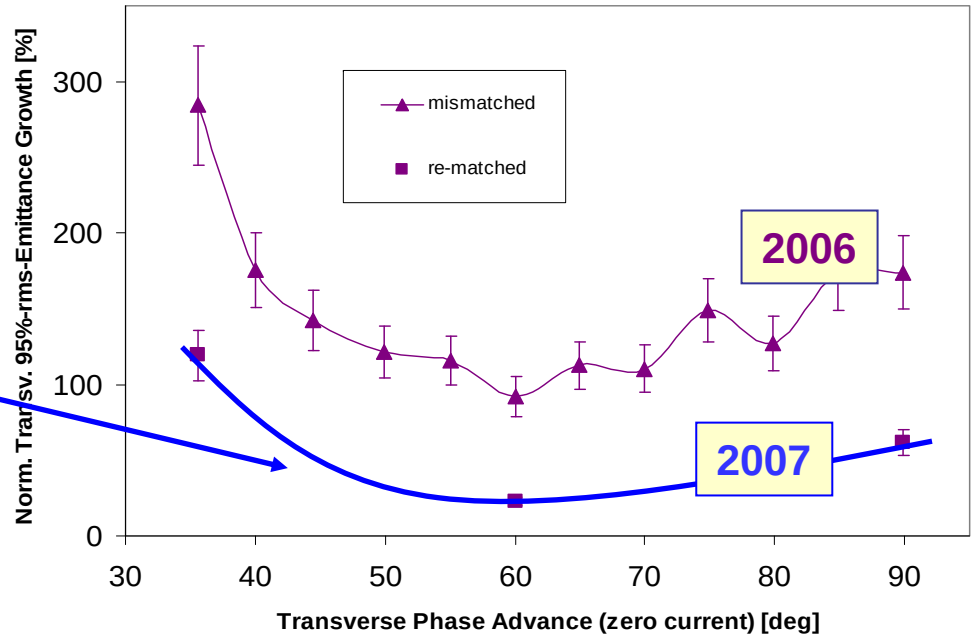
Betafunction (afterMatching)



Reduction of Mismatch

- new algorithm used to rms-match a (measured) initial distribution to periodic DTL
- test of matching by re-measuring emittance growth



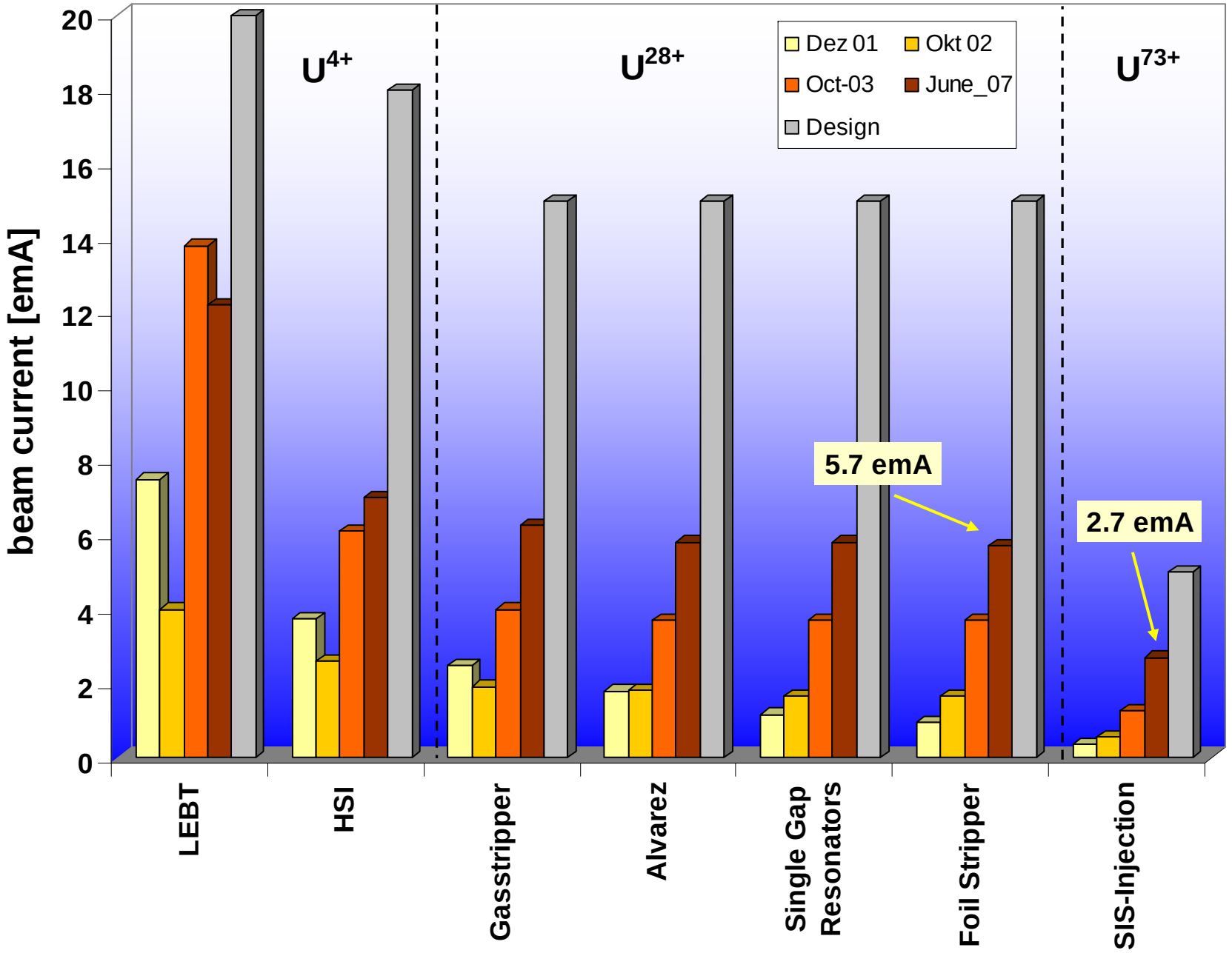


- significant reduction of emittance growth by rms-matching including space charge

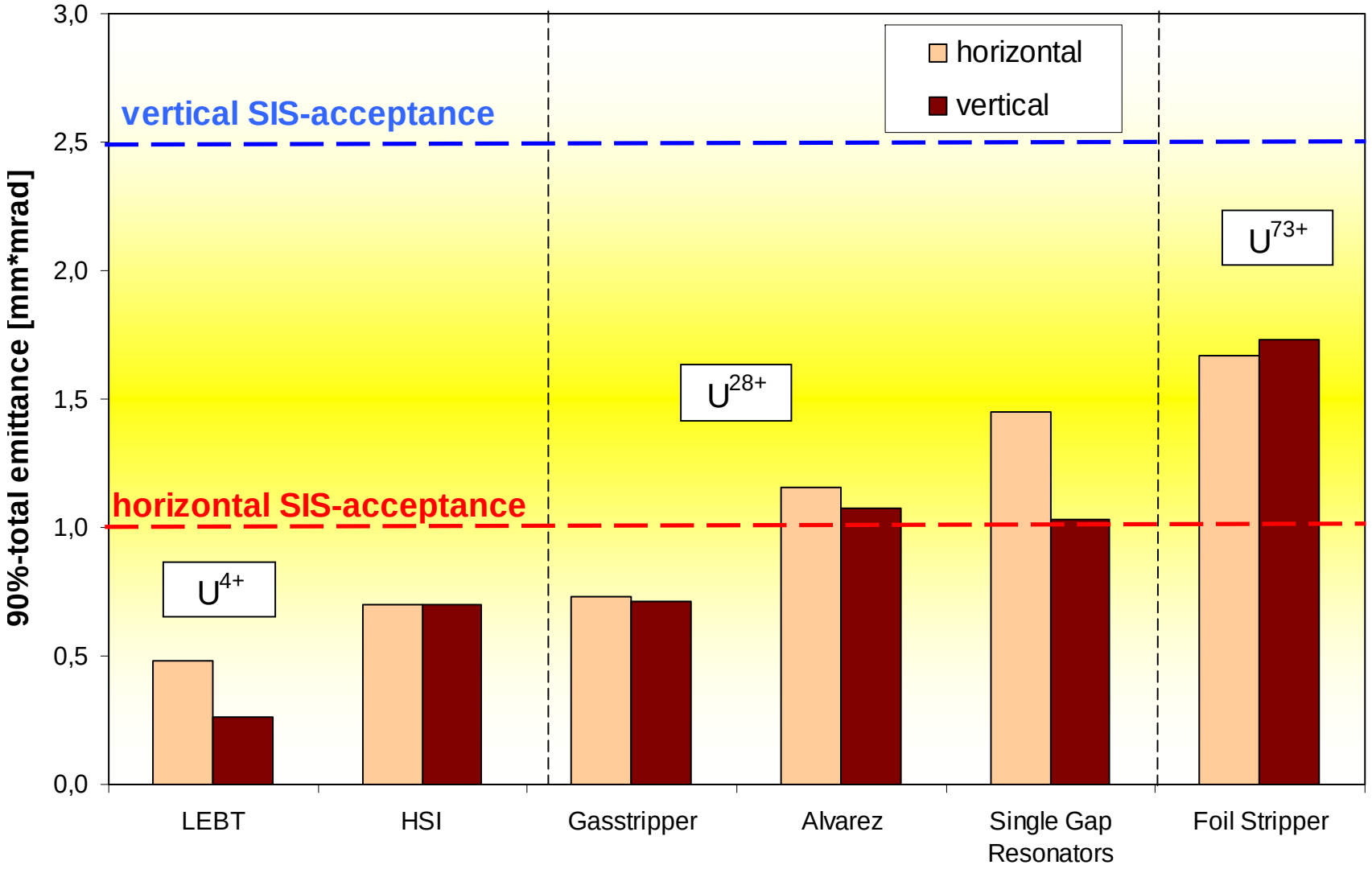
Former Unilac-Measures

- MEVVA-Ion Source: Further development, improvement of operation lifetime, beam stability, …
- RFQ-Upgrade: Exchange of RFQ-rods, modified IRM
- Super Lens-Upgrade: Improved rf-performance
- IH 1: New Triplet-Lens
- Investigation of the longitudinal HSI-beam quality
- Increased stripper gas density
- Matching to the ALVAREZ-DTL under space charge conditions
- Reduction of the number of Single Gap Resonators
- Alignment
- High Current Beam Diagnostics
- Machine Investigations: Frontend, Alvarez-matching, transfer line-emittance measurements

Status Quo


beam current [emA]
20
18
16
14
12
10
8
6
4
2
0
U4+
U28+
U73+
Dez 01
Okt 02
Oct-03
June_07
Design
5.7 emA
2.7 emA
LEBT
HSI
Gasstripper
Alvarez
Single Gap Resonators
Foil Stripper
SIS-Injection

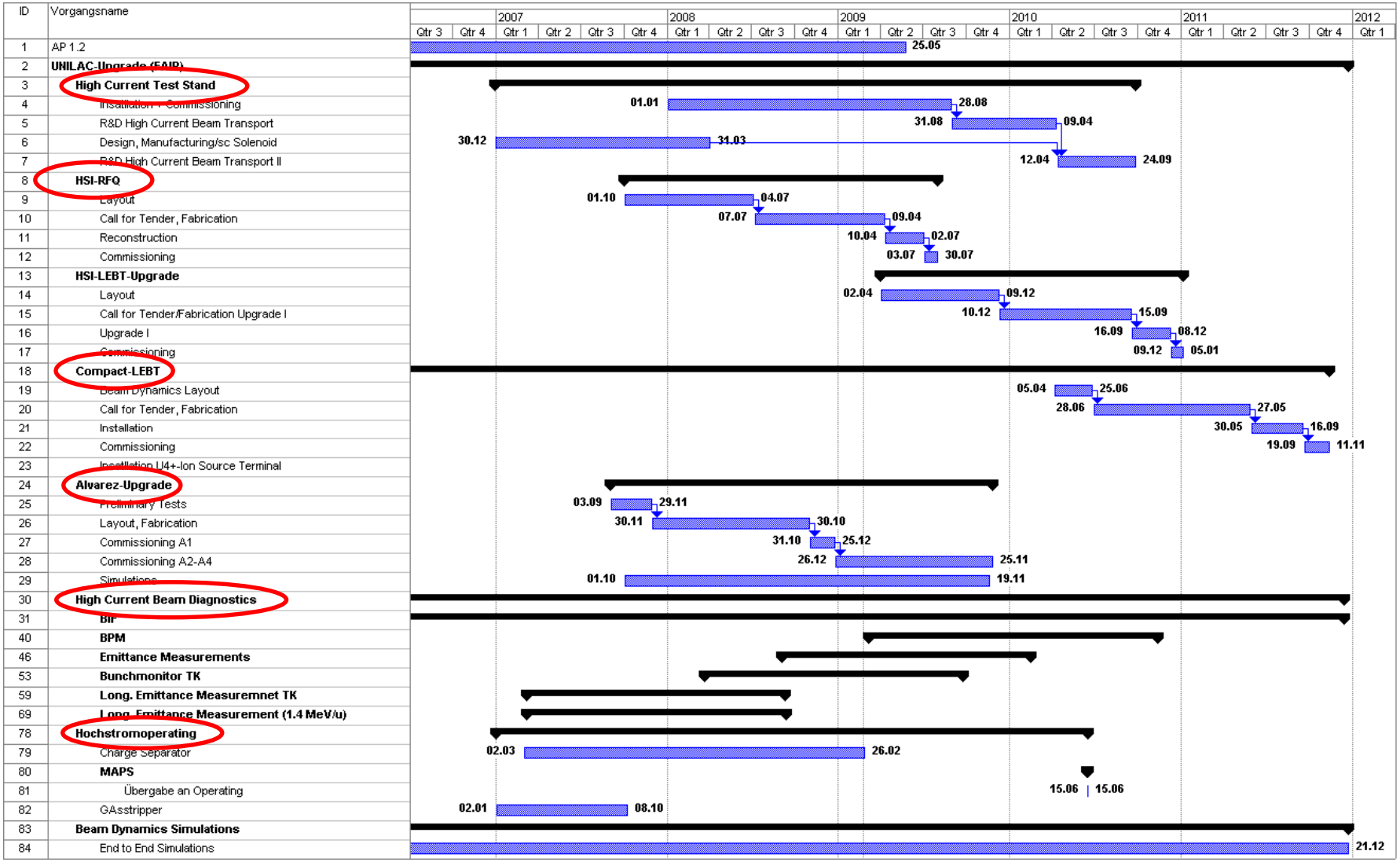
Status Quo


3,0
2,5
2,0
1,5
1,0
0,5
0,0
90%-total emittance [mm*mrad]
horizontal
vertical
vertical SIS-acceptance
horizontal SIS-acceptance
U4+
U28+
U73+
LEBT
HSI
Gasstripper
Alvarez
Single Gap Resonators
Foil Stripper

Status of the UNILAC Uranium-Performance

	Measured	required for FAIR
$^{238}U^{4+}$ Max. Beam Intensity I, (2.2 keV/u)	16 emA	20 emA
I_{max}@beam power, (1.4 MeV/u)	6.5 emA @587 kW	18 emA@1500 kW
Transv. Emittance (LEBT) (90%, total)	140 π·mm·mrad	120 π·mm·mrad
Macropulse Length	150 µs	150 µs
Beam loading (IH2)	350 kW (7.0 emA)	710 kW (18 emA)
U^{28+}		
Max. Beam Current, (1.4 MeV/u)	6.25 emA	15.0 emA
Max. Beam Intensity, 11.4 MeV/u, I_{max}@beam power Transfer to the SIS18 *Ions/100µs*	5.7 emA@567 kW $1.3 \cdot 10^{11}$	15.0 emA@1453 kW $3.3 \cdot 10^{11}$
U^{73+}		
Max. Beam Intensity, 11.4 MeV/u, Ionen/100µs	2.7 emA $2.3 \cdot 10^{10}$	3.5 emA $3.0 \cdot 10^{10}$
Transv. Emittance (11.4 MeV/u) (90%, tot.)	11.0 π·mm·mrad	7.0 π·mm·mrad

Schedule


ID
Vorgangsname
2007
2008
2009
2010
2011
2012
Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1 Qtr 2 Qtr 3 Qtr 4 Qtr 1
1 AP 1.2
2 UNILAC-Upgrade (FAIR)
3 High Current Test Stand
4 Installation + Commissioning
5 R&D High Current Beam Transport
6 Design, Manufacturing/sc Solenoid
7 R&D High Current Beam Transport II
8 HSI-RFQ
9 Layout
10 Call for Tender, Fabrication
11 Reconstruction
12 Commissioning
13 HSI-LEBT-Upgrade
14 Layout
15 Call for Tender/Fabrication Upgrade I
16 Upgrade I
17 Commissioning
18 Compact-LEBT
19 Beam Dynamics Layout
20 Call for Tender, Fabrication
21 Installation
22 Commissioning
23 Installation U4+-Ion Source Terminal
24 Alvarez-Upgrade
25 Preliminary Tests
26 Layout, Fabrication
27 Commissioning A1
28 Commissioning A2-A4
29 Simulations
30 High Current Beam Diagnostics
31 BIF
40 BPM
46 Emittance Measurements
53 Bunchmonitor TK
59 Long. Emittance Measuremnet TK
69 Long. Emittance Measurement (1.4 MeV/u)
78 Hochstromoperating
79 Charge Separator
80 MAPS
81 Übergabe an Operating
82 GAsstripper
83 Beam Dynamics Simulations
84 End to End Simulations
25.05
01.01
28.08
31.08
09.04
30.12
31.03
12.04
24.09
01.10
04.07
07.07
09.04
10.04
02.07
03.07
30.07
02.04
09.12
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26.12
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01.10
19.11
02.03
26.02
15.06
15.06
02.01
08.10
21.12

Summary & Outlook

- An extended upgrade program in the UNILAC in combination with machine investigations resulted in a uranium beam intensity of up to 5.7 emA (28+) for the injection into the synchrotron SIS 18.
- High Current UNILAC-Upgrade: Mainly the improved ion source performance, the increased stripper gas density, the improved DTL-performance, the charge state separator system, and the use high current beam diagnostics devices were responsible for the successful development program.
- FAIR-requirements: The UNILAC-upgrade will be continued with an advanced optimization program at the High Current Ion Source Test Stand, the upgrade of a new front end for U^{4+} (ion source terminal – LEBT –RFQ), stronger power supplies for the Alvarez quads and beam diagnostics devices, sufficient for the operation with megawatt heavy ion beams (until 2011).
- Limited "multi beam operation" in the main DTL. No high duty factor beam in parallel to the operation of the UNILAC as a FAIR-injector.
- The UNILAC (since more than 35 years in operation) will serve as an high current injector for FAIR at first - long term perspectives are under discussion.