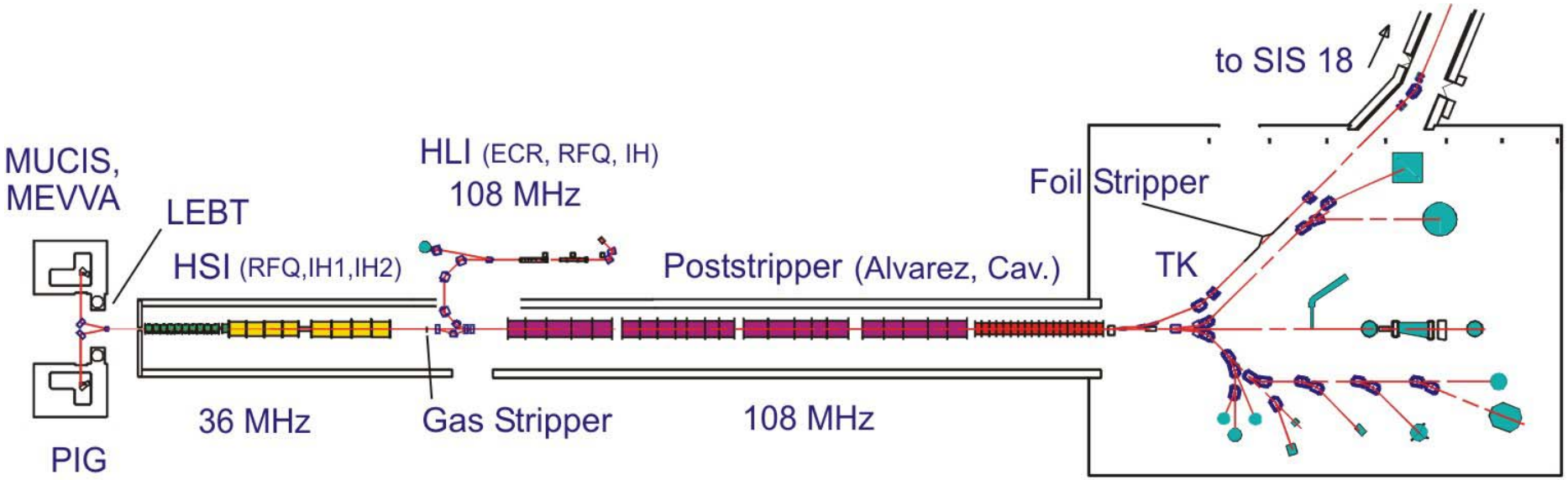
UNILAC-Upgrade: High Current Development wrt U^{28+}

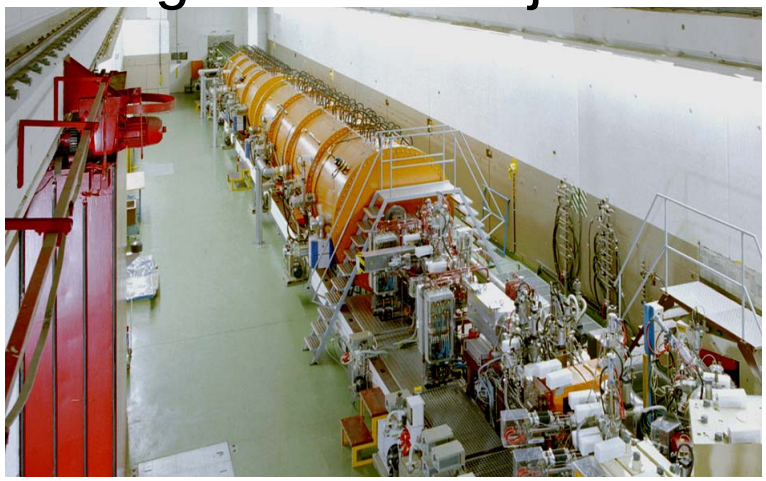
W. Barth

- Heavy Ion Linear Accelerator UNILAC
- High Current Project (HSI-Upgrade 1999)
- Unilac Upgrade Program (2007)
  - HSI Frontend I
  - Stripper Sections
  - Alvarez Matching
- Status of the Unilac High Current Performance
- FAIR-UNILAC-Upgrade (>2007)
  - HSI-Frontend II
  - charge separator
  - Beam Diagnostics
- End to end simulations
- Outlook

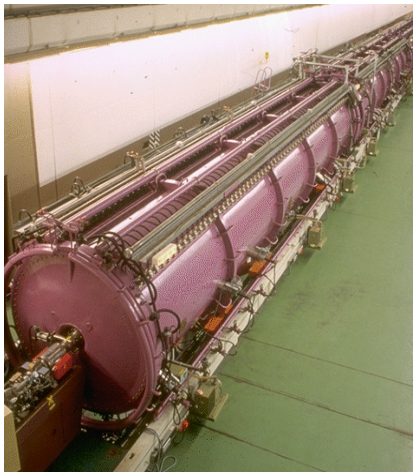
The GSI UNIversal Linear ACcelerator



High Current Injector



Alvarez



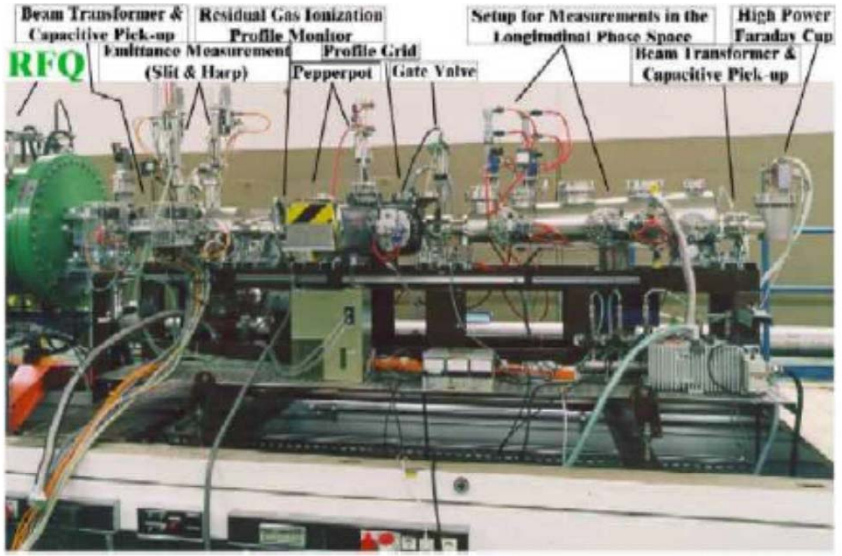
Single Gap Resonators

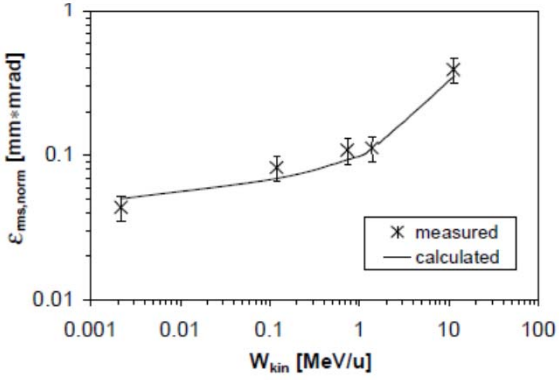
High Current Project (HSI-Upgrade 1999)

HSI-Assembly&Commissioning milestones

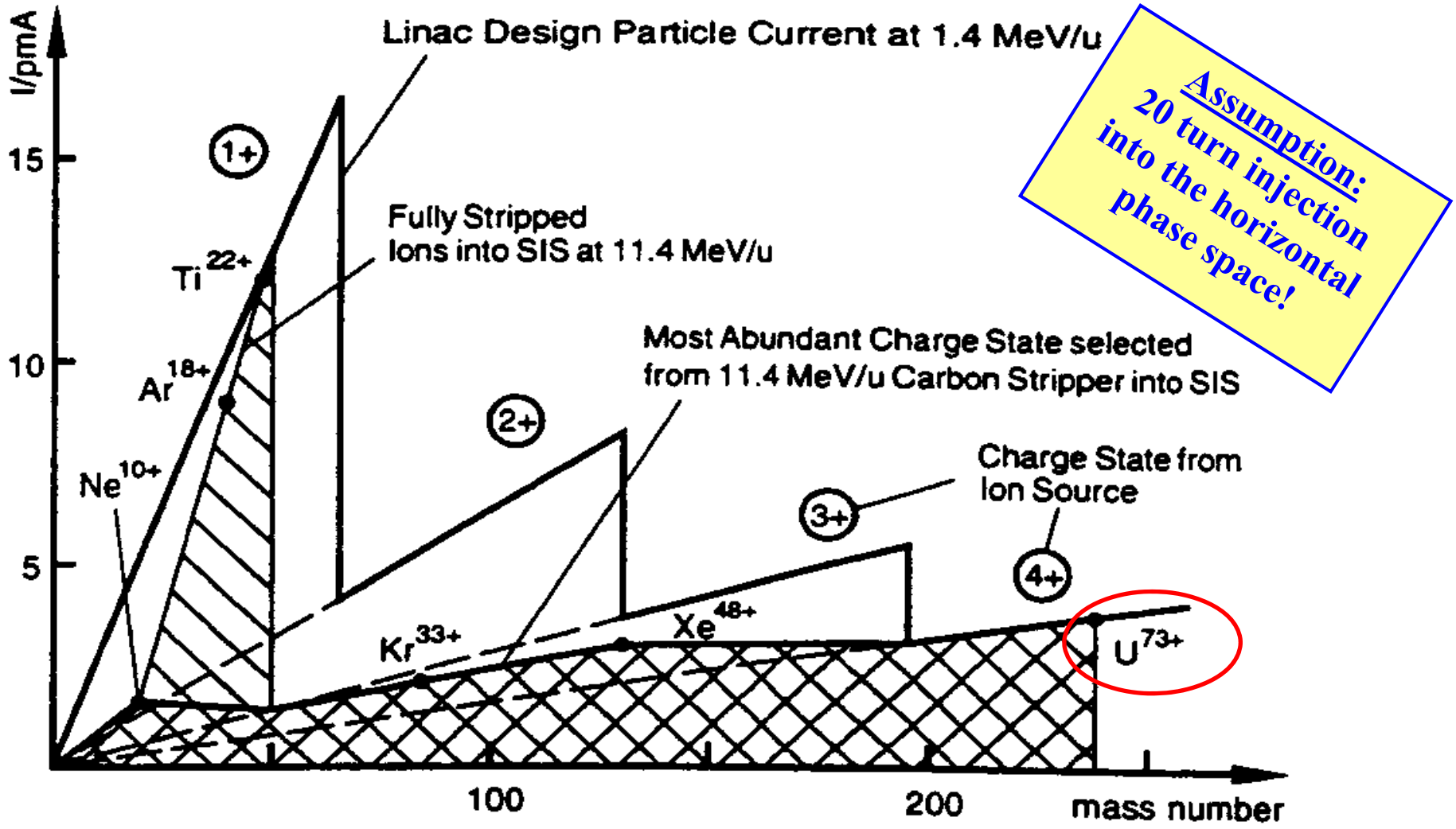
Dec. 98	Last operation-shift with Wideröe injector
Jan.-Feb. 99	Disassembly of Wideröe and rf, installation of LEBT section
March 99	Successful commissioning of LEBT
April-May 99	Mounting IH-RFQ and first acceleration up to 120 keV/u
June 99	Beam tests with Super Lens, achieving 10 mA Ar^{1+} at RFQ exit
July 99	Assembly of IH1, verification of beam acceleration up to 743 keV/u
August 99	Completing HSI with IH2 and stripper section
2.Sept. 99	Proof of acceleration up to 1.4 MeV/u, further on: 80% IH-transmission for highest argon intensities (8 mA)
October 99	Upgrade of transfer line to SIS and mounting of matching section to Alvarez
November 99	Establishing three beam operation, complete Alvarez transmission at highest current
Since Nov. 99	HSI in routine operation
February 2000	Achievement of the 90%-rf levels, first 1.4 MeV/u U^{4+} beam (3 mA)

	HSI entrance	HSI exit	Alvarez entrance	SIS injection
Ion species	$^{238}U^{4+}$	$^{238}U^{4+}$	$^{238}U^{28+}$	$^{238}U^{73+}$
El. Current [mA]	16.5	15	12.5	4.6
Part. per 100µs pulse	$2.6\cdot10^{12}$	$2.3\cdot10^{12}$	$2.8\cdot10^{11}$	$4.2\cdot10^{10}$
Energy [MeV/u]	0.0022	1.4	1.4	11.4
ΔW/W	-	$\pm4\cdot10^{-3}$	$\pm2\cdot10^{-3}$	$\pm2\cdot10^{-3}$
ε_{nx} [mm mrad]	0.3	0.5	0.75	0.8
ε_{ny} [mm mrad]	0.3	0.5	0.75	2.5



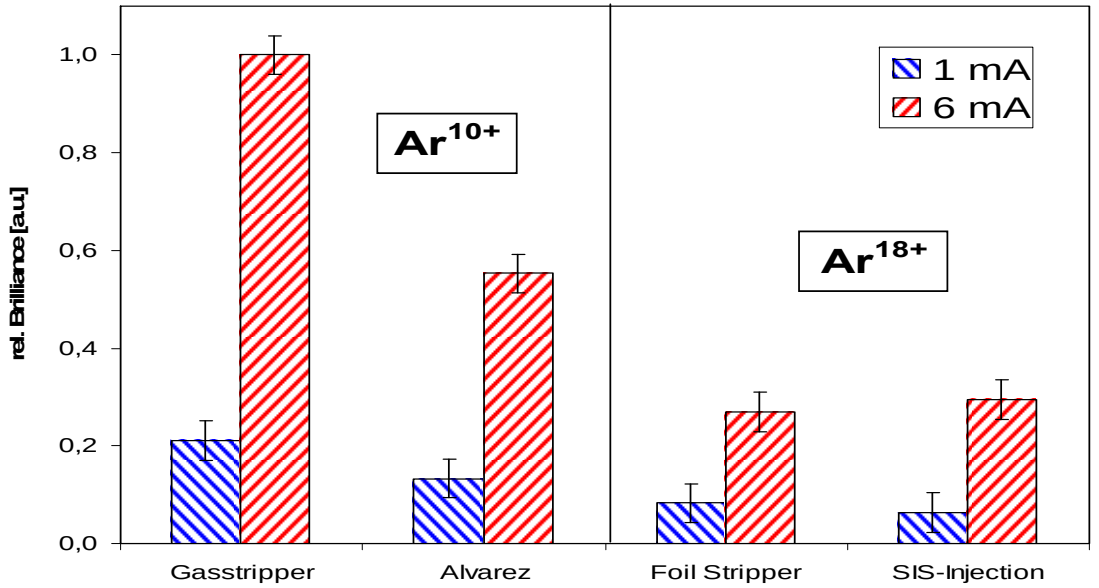


Intensity Upgrade
(Achievement of the SIS18-space charge limit)

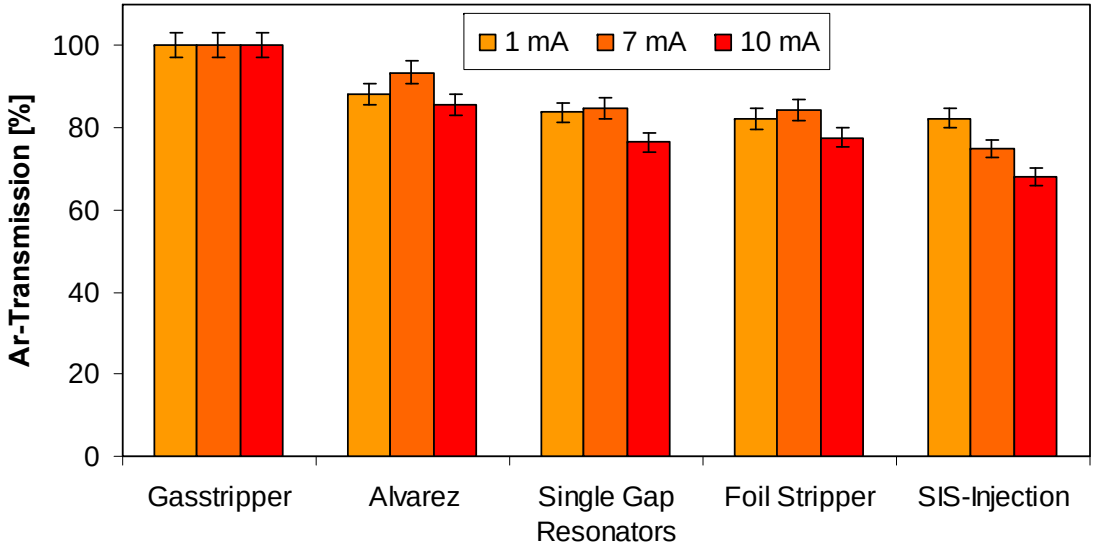


Status of the UNILAC High Current Performance (1999)

Beam Brilliance



Beam transmission



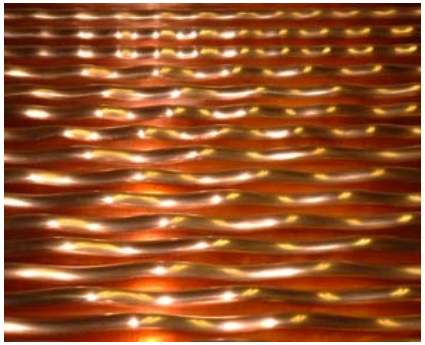
UNILAC-Upgrade Program I

- 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 Diagnostic
- Machine Investigations: Frontend, Alvarez-matching, transfer line-emittance measurements

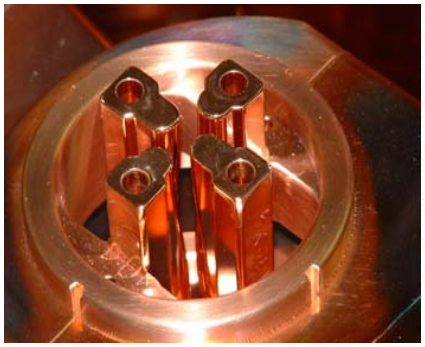
RFQ-Upgrade: New RFQ-Rods

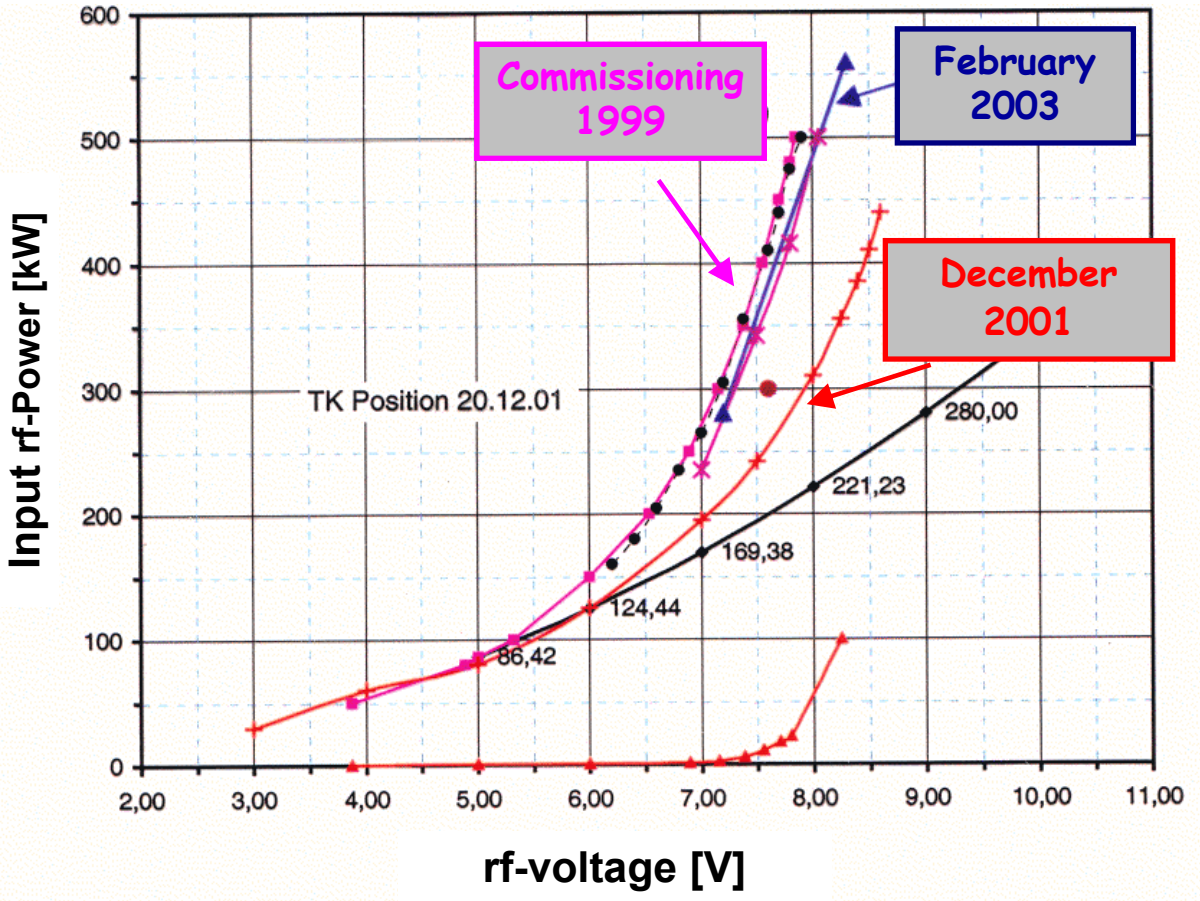
After
5 years of
operation

New
RFQ-rods

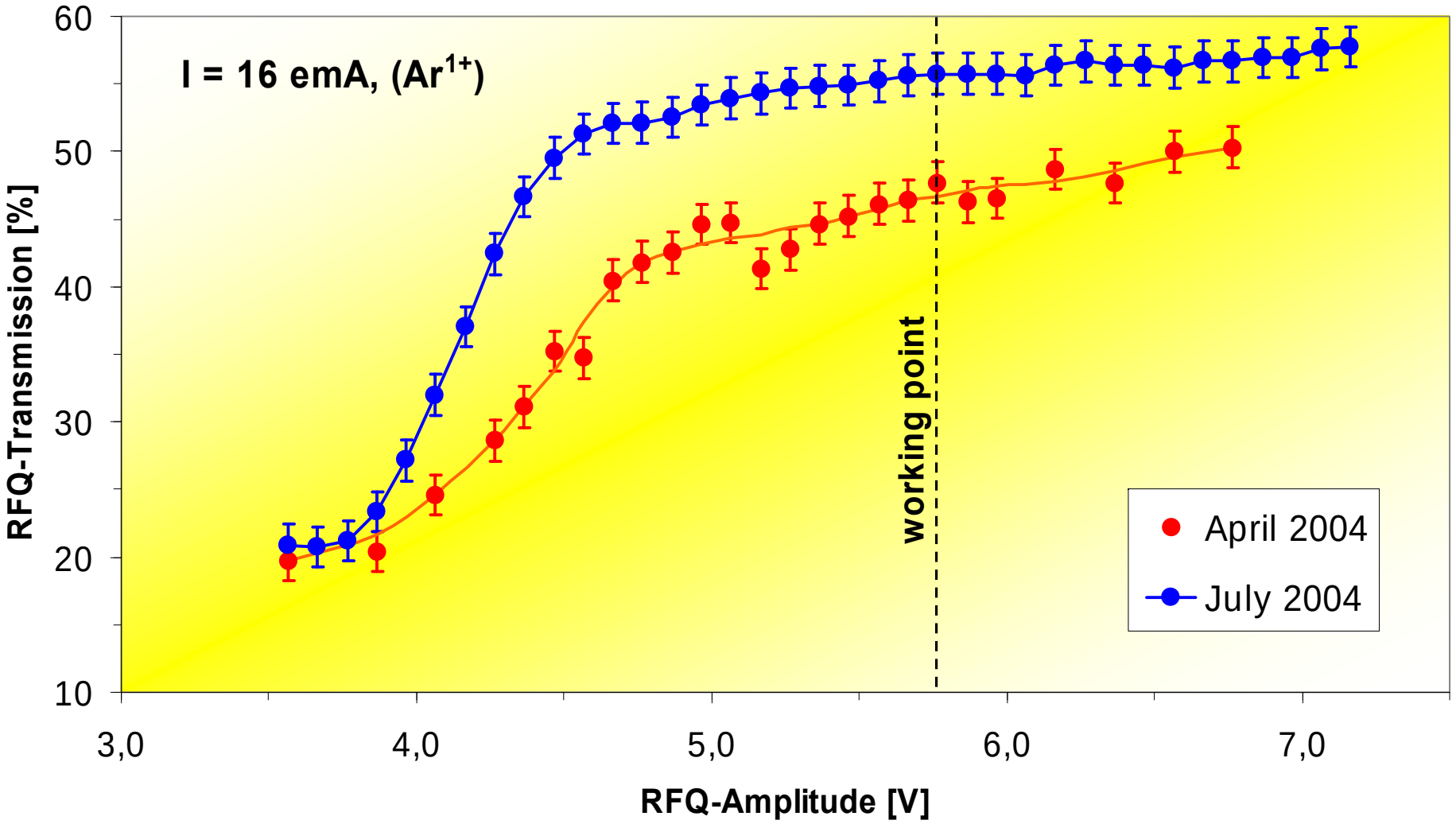


After
copper-
plating

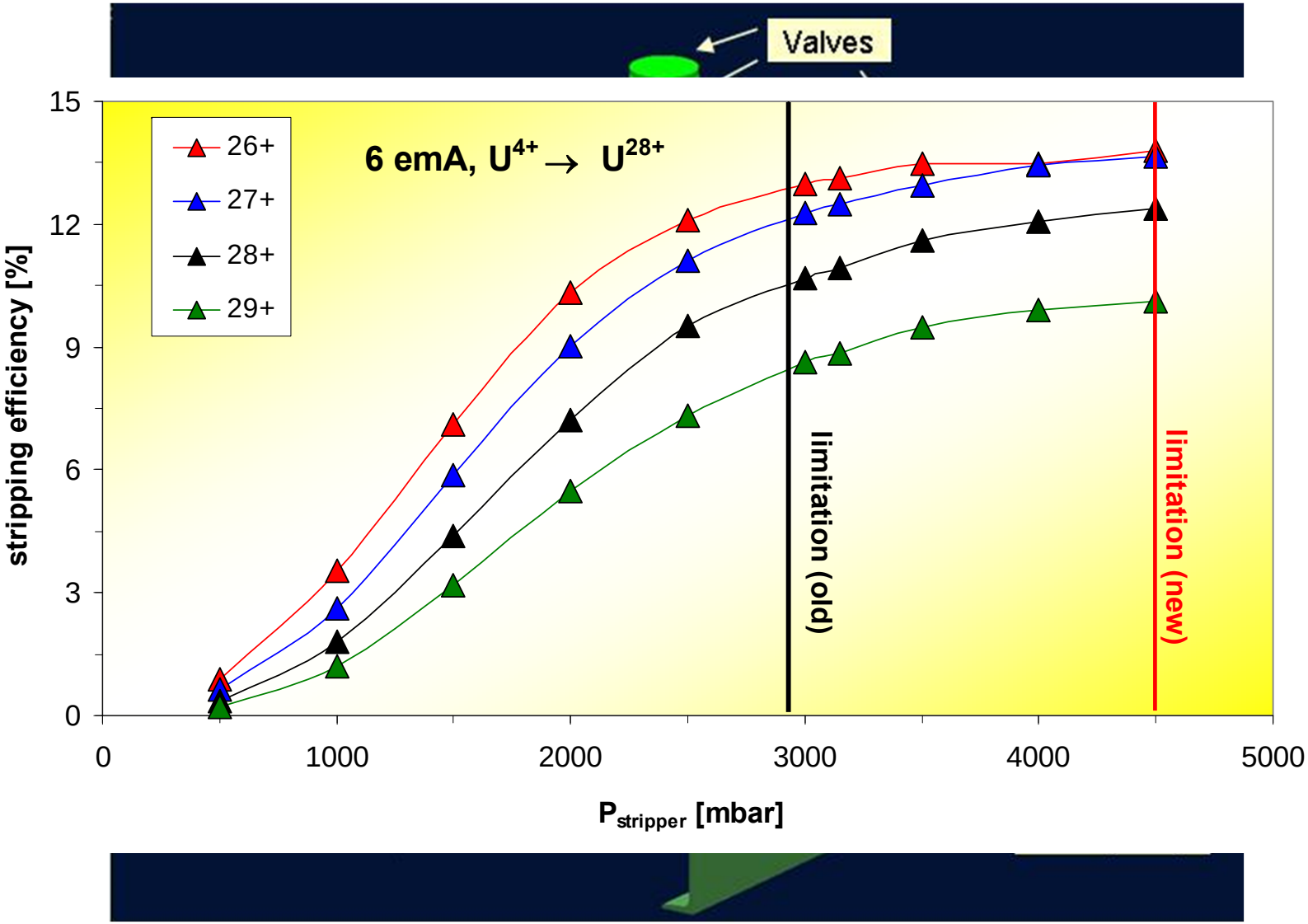




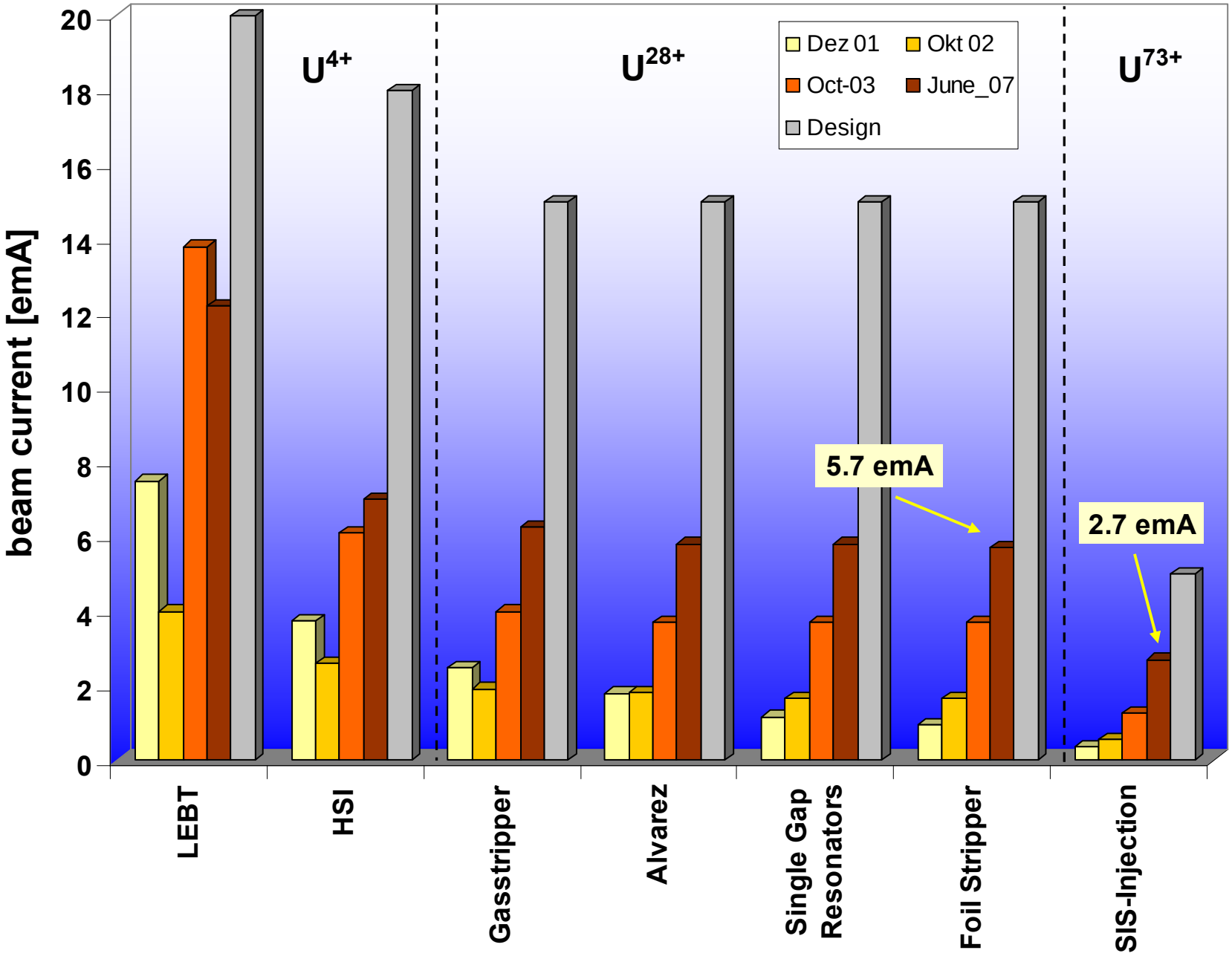
HSI-RFQ-Commissioning (7/2004)



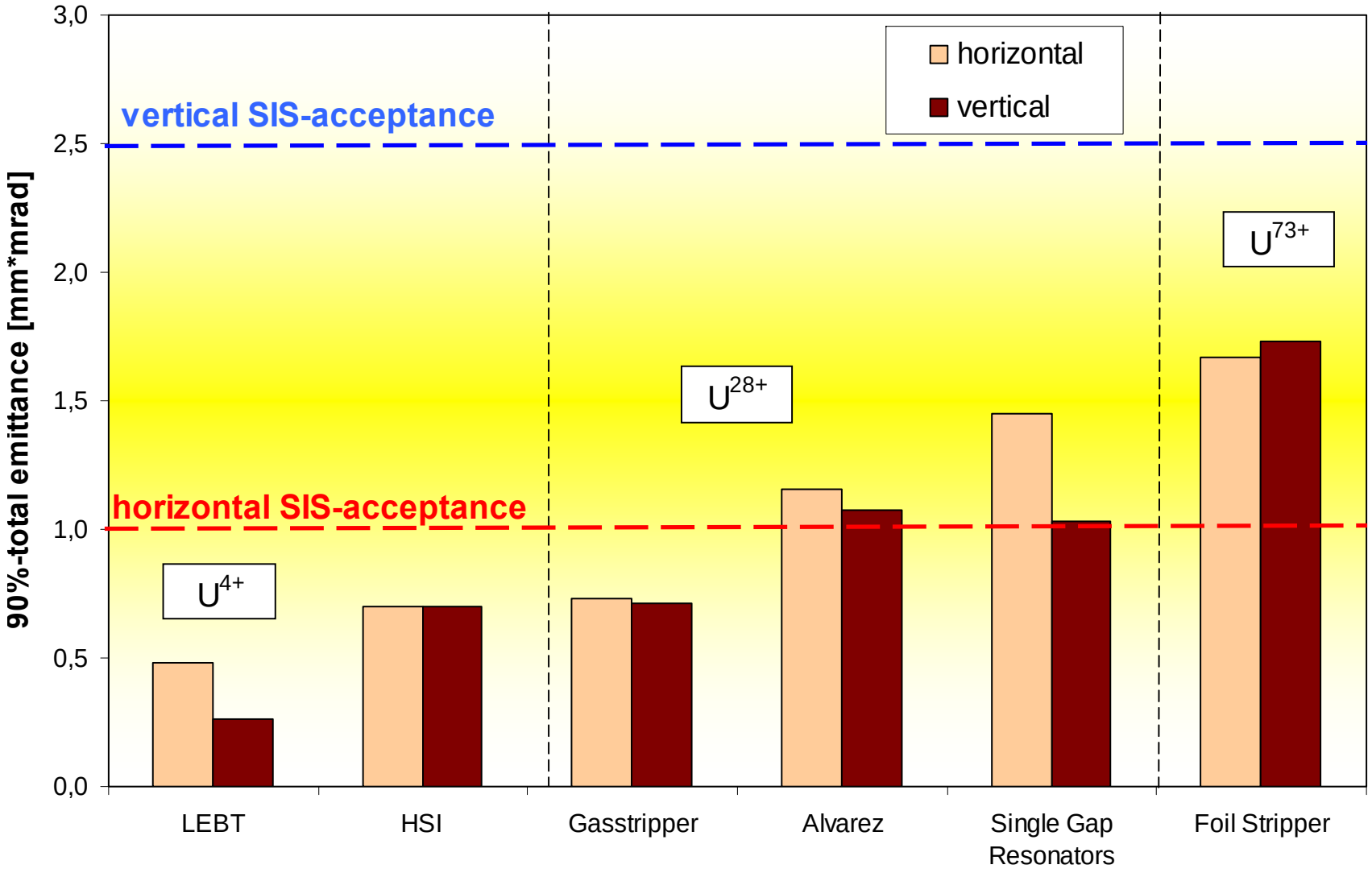
Increased Stripper Gas Density



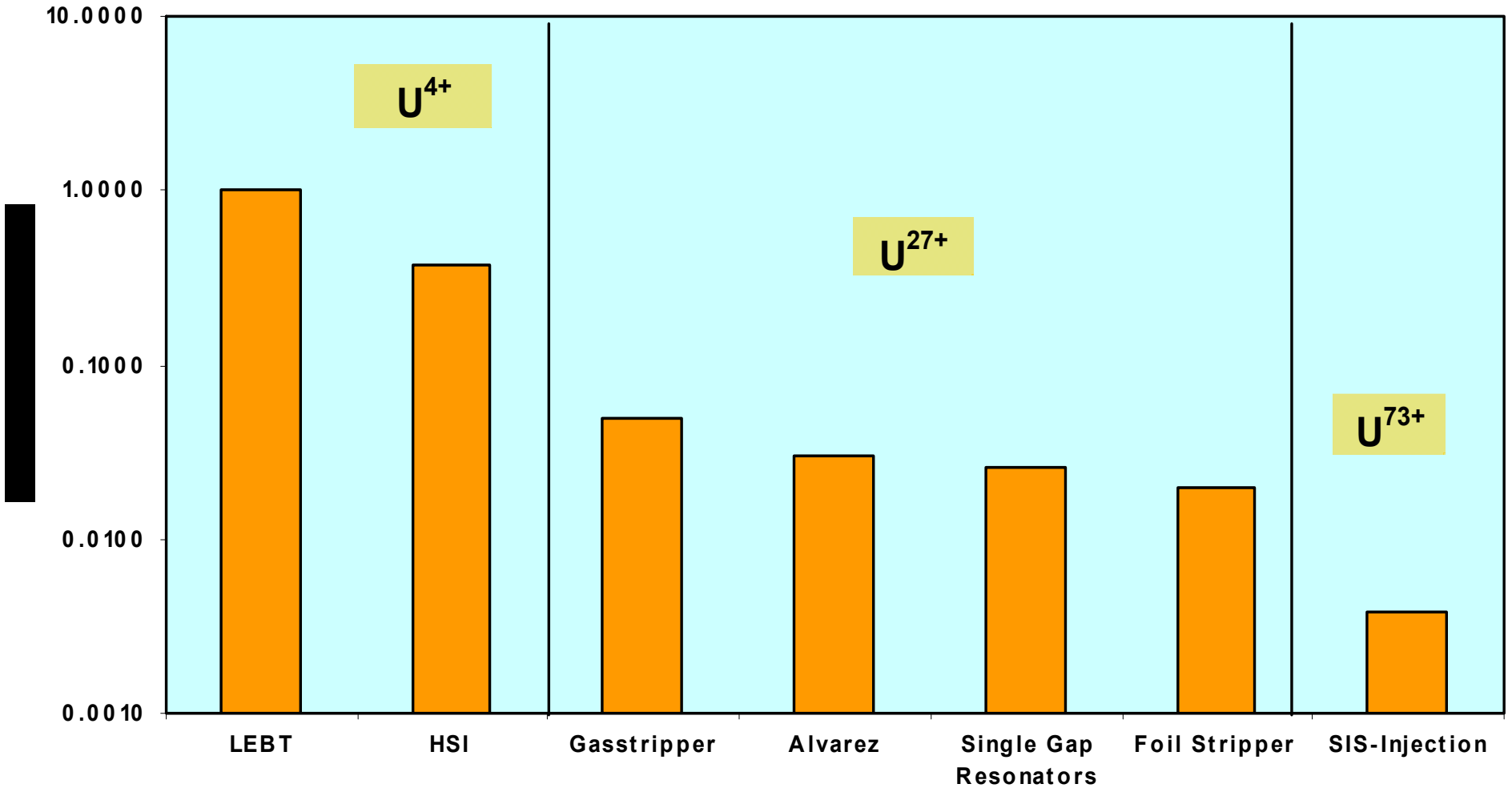
Status Quo


beam current [emA]
0
2
4
6
8
10
12
14
16
18
20
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 Quo


10.0000
1.0000
0.1000
0.0100
0.0010
U4+
U27+
U73+
LEBT
HSI
Gasstripper
Alvarez
Single Gap Resonators
Foil Stripper
SIS-Injection

Status of the UNILAC Uranium-Performance

	Measured	Design (1999)	required for FAIR
$^{238}U^{4+}$ Max. Beam Intensity I, (2.2 keV/u)	16 emA	16 emA	20 emA
I_{max}@beam power, (1.4 MeV/u)	6.5 emA @587 kW	15 emA@1250 kW	18 emA@1500 kW
Transv. Emittance (LEBT) (90%, total)	140 π·mm·mrad	120 π·mm·mrad	120 π·mm·mrad
Macropulse Length	150 µs	150 µs	150 µs
Reproducibility/Transversal Emittance	±4.5%	-	-
Beam loading, 7emA (IH2)	350 kW	590 kW (15 emA)	710 kW (18 emA)
U^{28+}			
Max. Beam Current, (1.4 MeV/u)	6.25 emA	12.6 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 $1.3 \cdot 10^{11}$	12.6 emA@1221 kW $2.8 \cdot 10^{11}$	15.0 emA@1453 kW $3.3 \cdot 10^{11}$
U^{73+} Max. Beam Intensity, 11.4 MeV/u, *Ionen/100µs*	2.7 emA $2.3 \cdot 10^{10}$	4.6 emA $3.9 \cdot 10^{10}$	3.5 emA $3.0 \cdot 10^{10}$
Transv. Emittance (11.4 MeV/u) (90%, tot.)	11.0 π·mm·mrad	5.0 π·mm·mrad	7.0 π·mm·mrad

UNILAC-Upgrade II (for FAIR)

(FAIR-Technical Report 2005)

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	σ_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

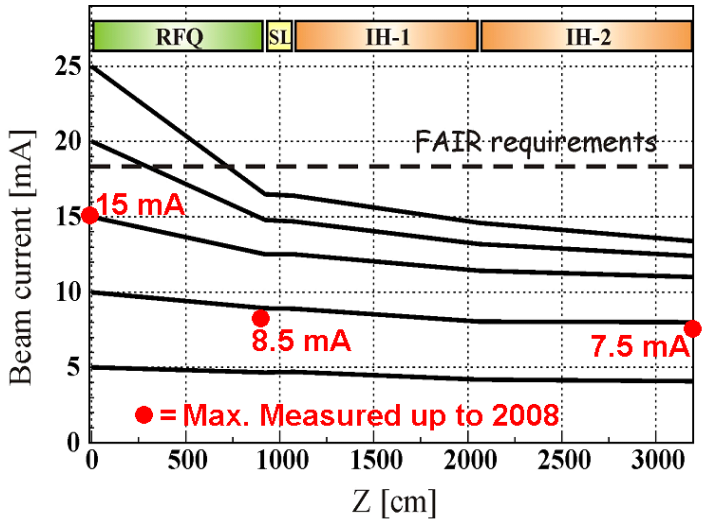
HSI-RFQ upgrade (2009)

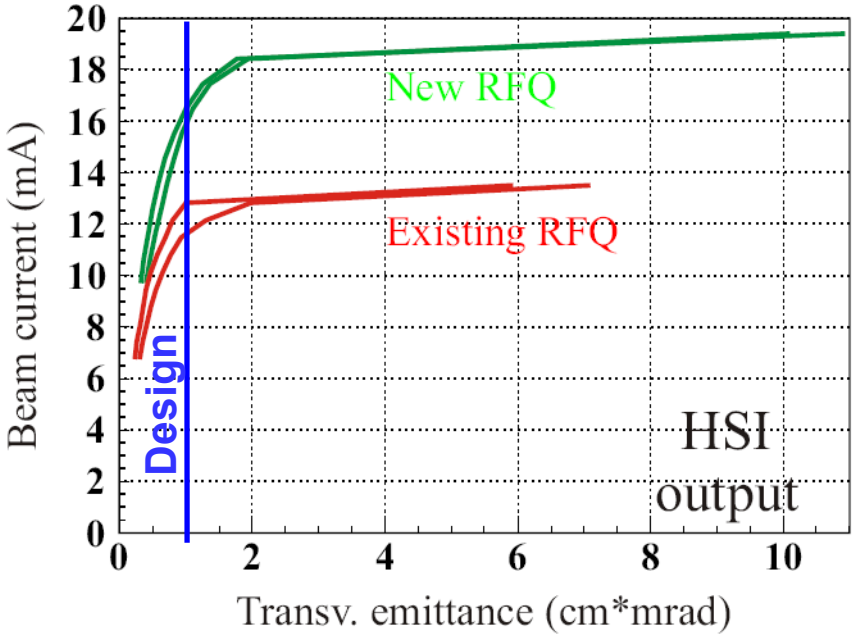
- Higher transverse acceptance and phase advance (keeping maximum field at the electrode surface)
- New Input Radial Matcher design → improved beam matching
- Improved beam dynamics for gentle buncher optimized for rapid and uniform separatrix filling →
- Resonant frequency shift with increased average 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**

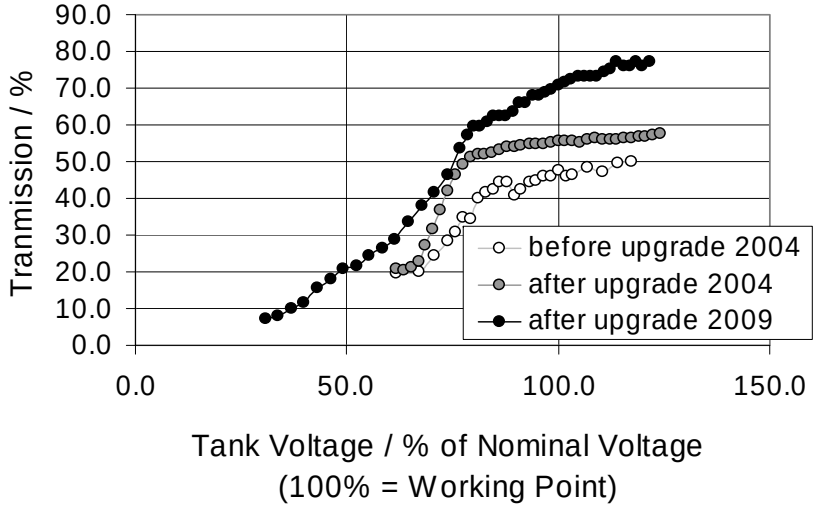
HSI-RFQ upgrade (2009)

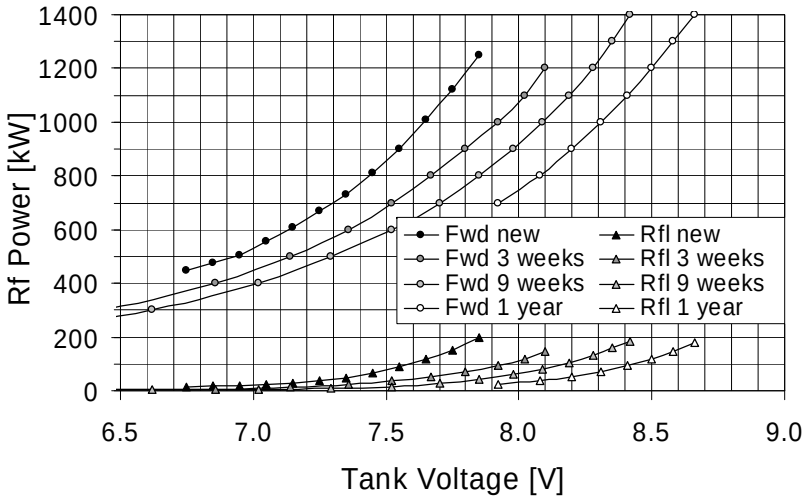
measurement for present RFQ :





simulation

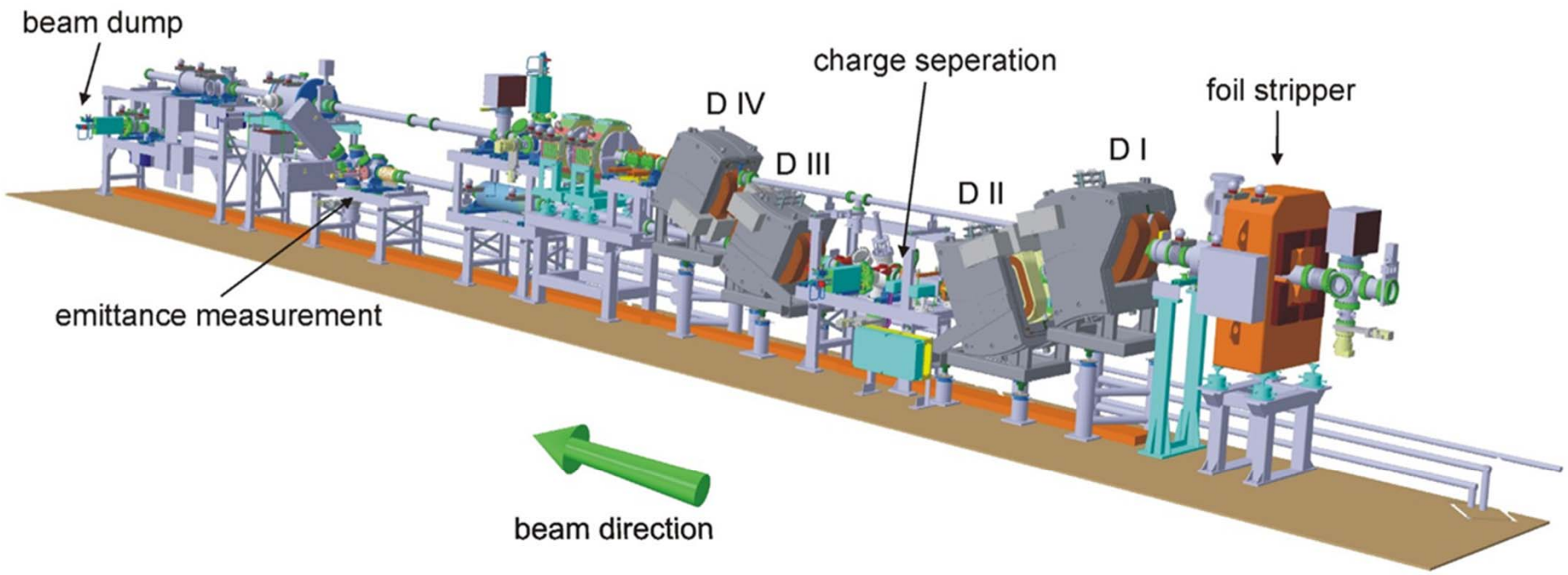




measurement

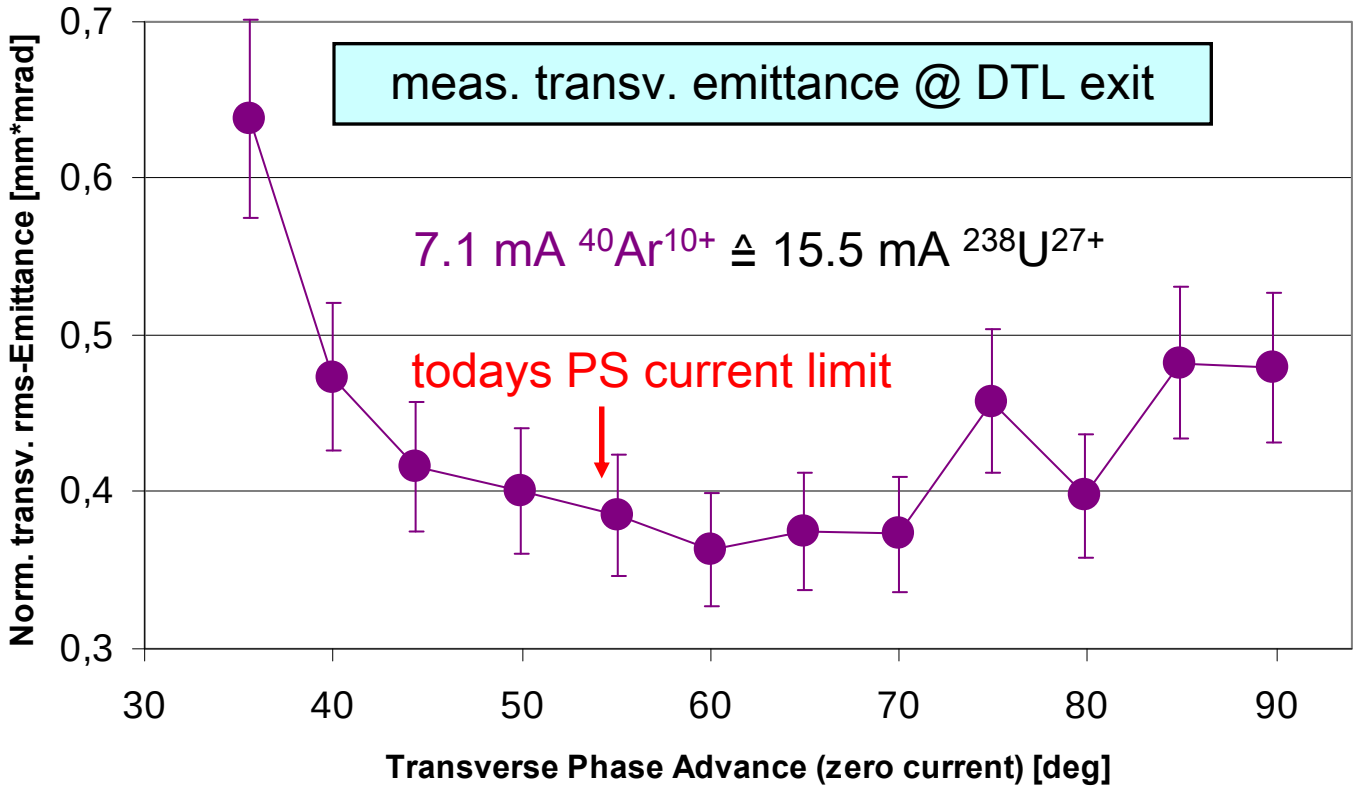
Charge State Separator

High Current operation (Uranium)



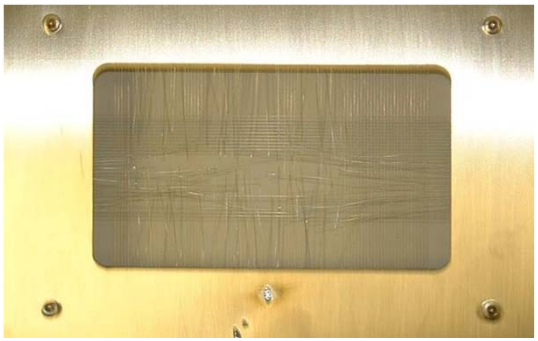
New Power Supplies for the UNILAC Alvarez dc-Magnets

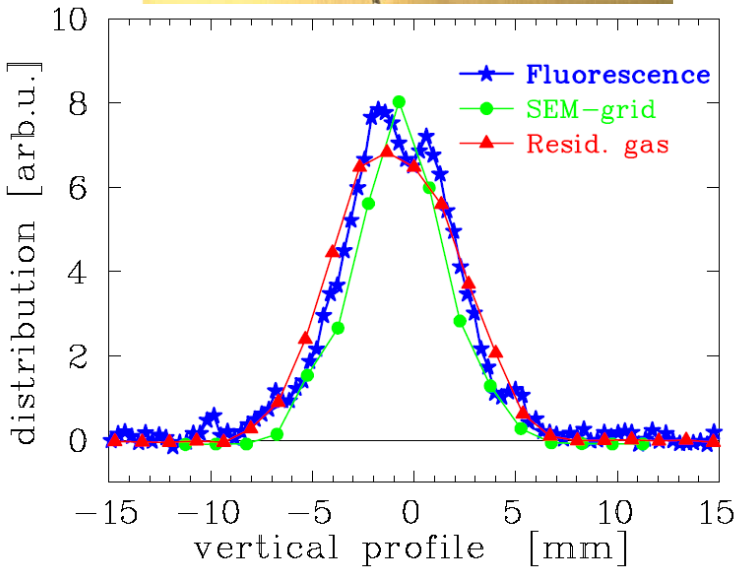
- The achieved ratio current / rms-emittance at DTL exit is too low for FAIR
- Design: 15.5 mA / 0.25 µm; Achieved: 4.4 mA / 0.43 µm
- One measure of improvement → reduction of emittance growth along DTL
- Exp. and simulation: possible by increasing DTL quad strengths



High Current Beam Diagnostics: Beam Induced Fluorescence Monitor

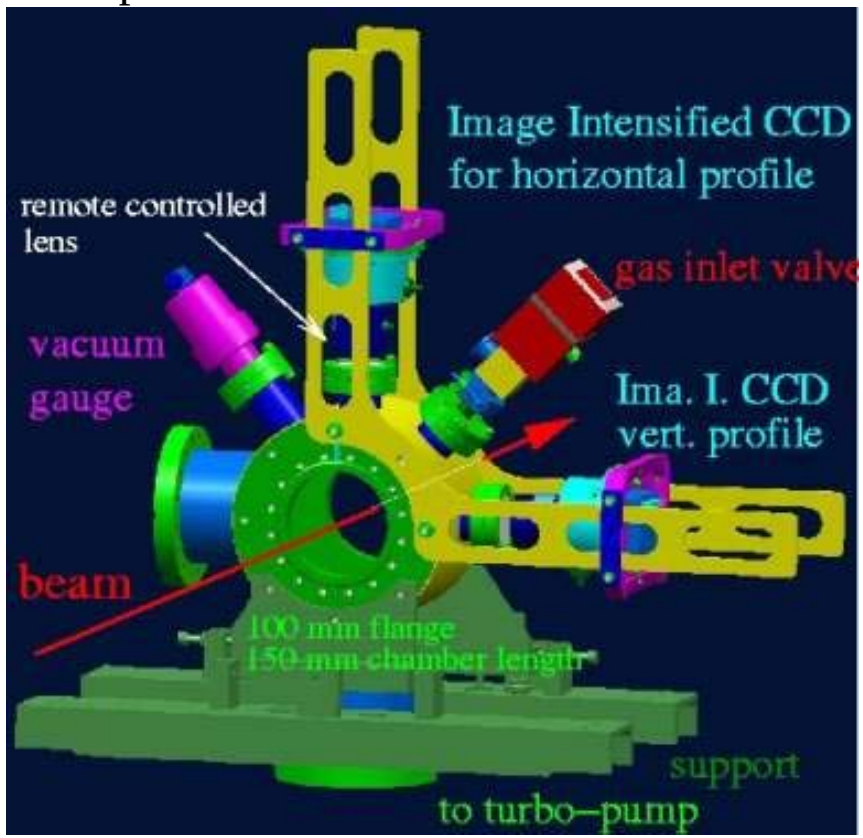
Damaged SEM-Grid





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)

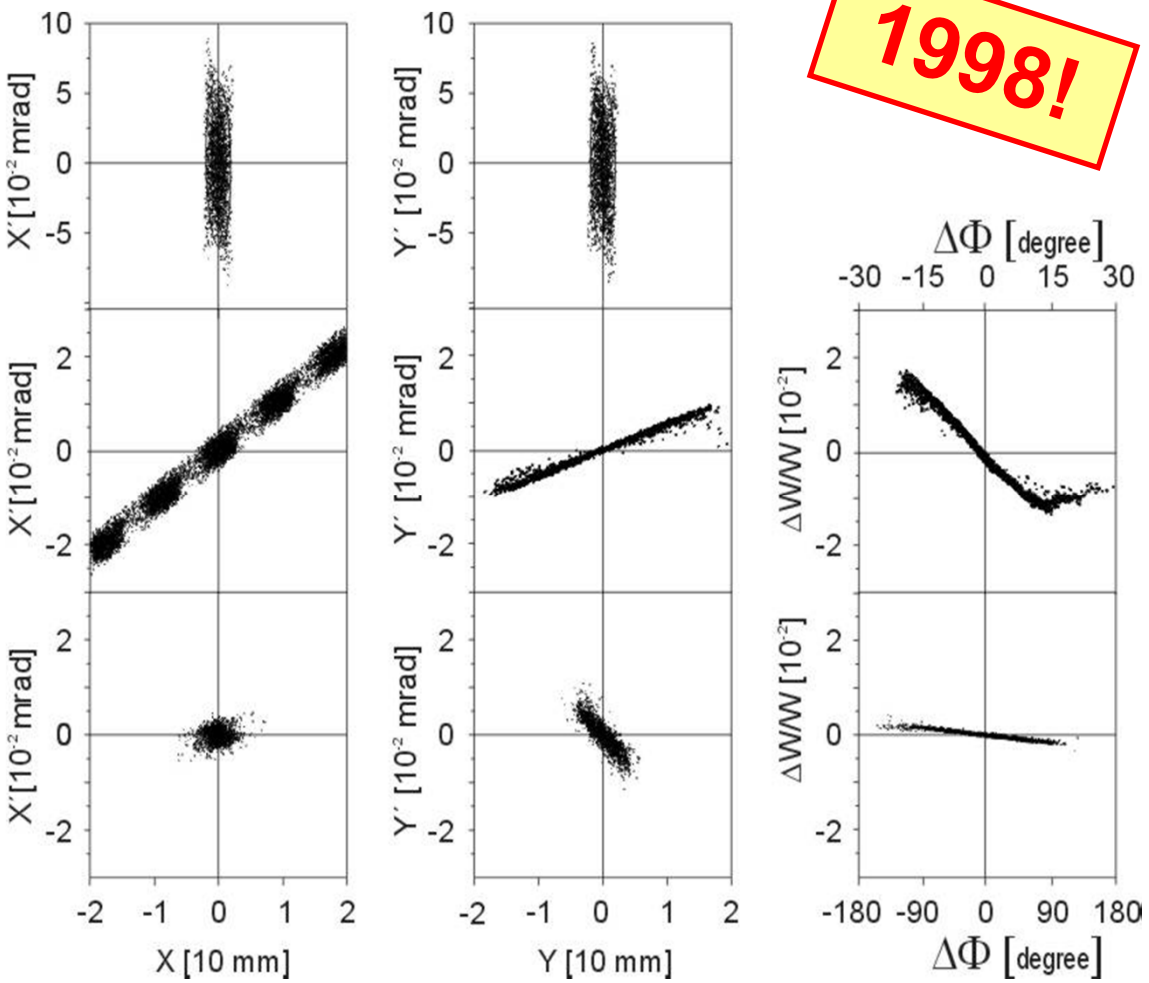
Compact chamber with 150 mm insertion:



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

Multi Particle Simulations (LEBT – SIS18-Injection)

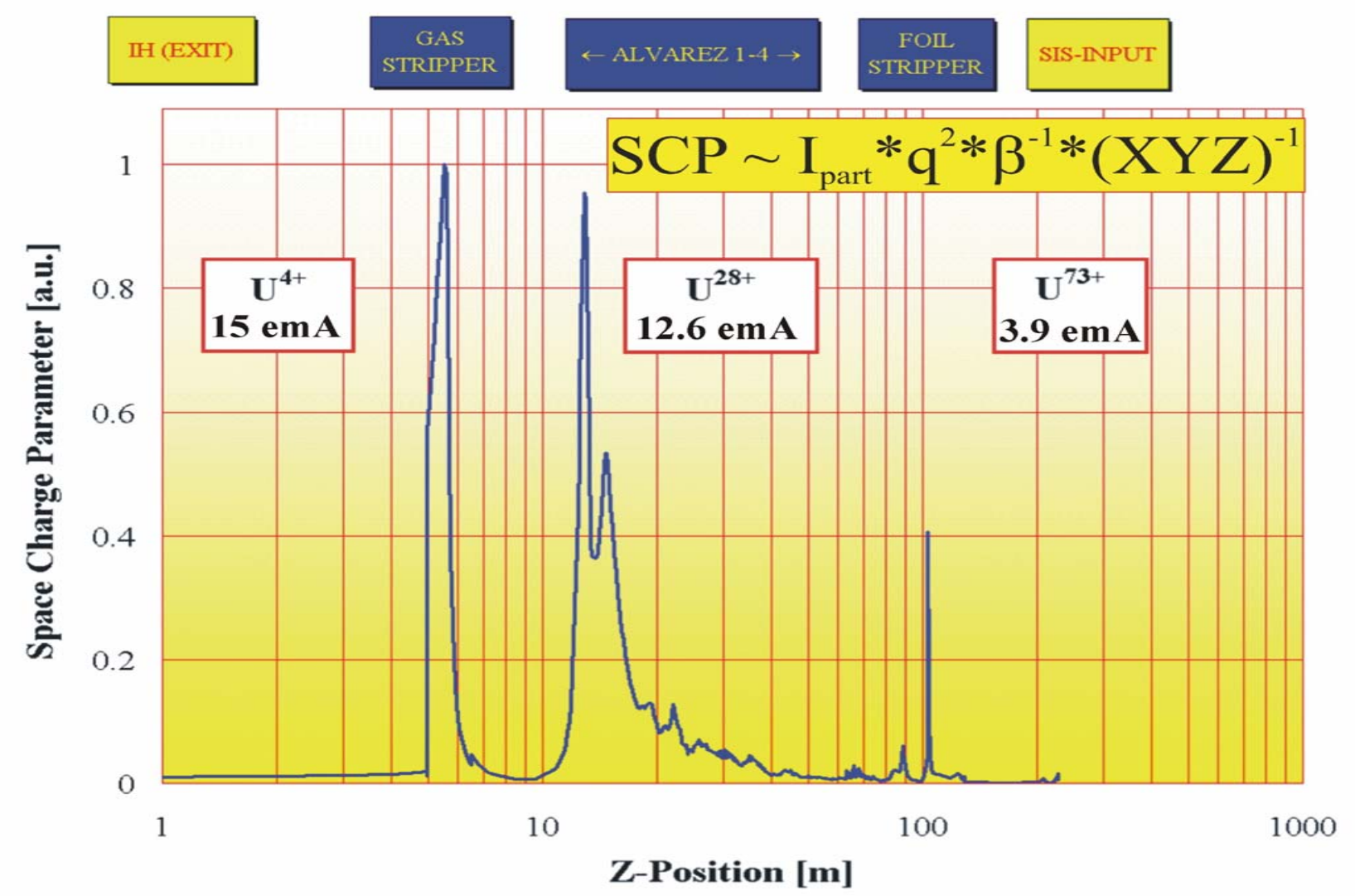
- LEBT (PARMILA-Transport)
- RFQ (PARMTEQ)
- IH-Section (LORAS)
- 1.4 MeV/u-Stripper Section (PARMILA-Transport)
- ALVAREZ (PARMILA)
- Single Gap Resonators (PARMILA-Transport)
- Transfer Line (PARMILA-Transport)
- 11.4 MeV/u-Stripper Section (PARMILA-Transport)
- Matching SIS 18 (PARMILA-Transport)

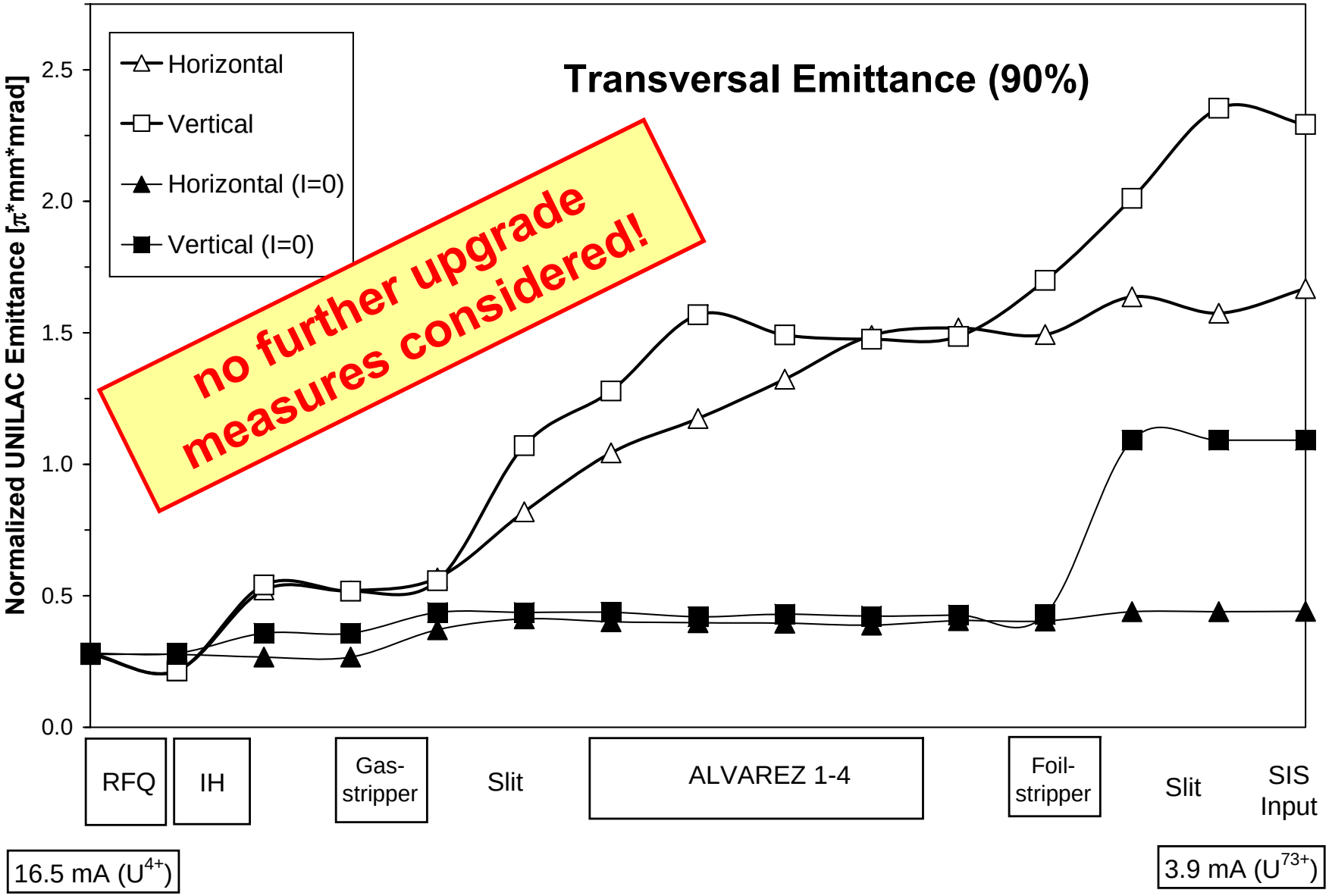


1998!

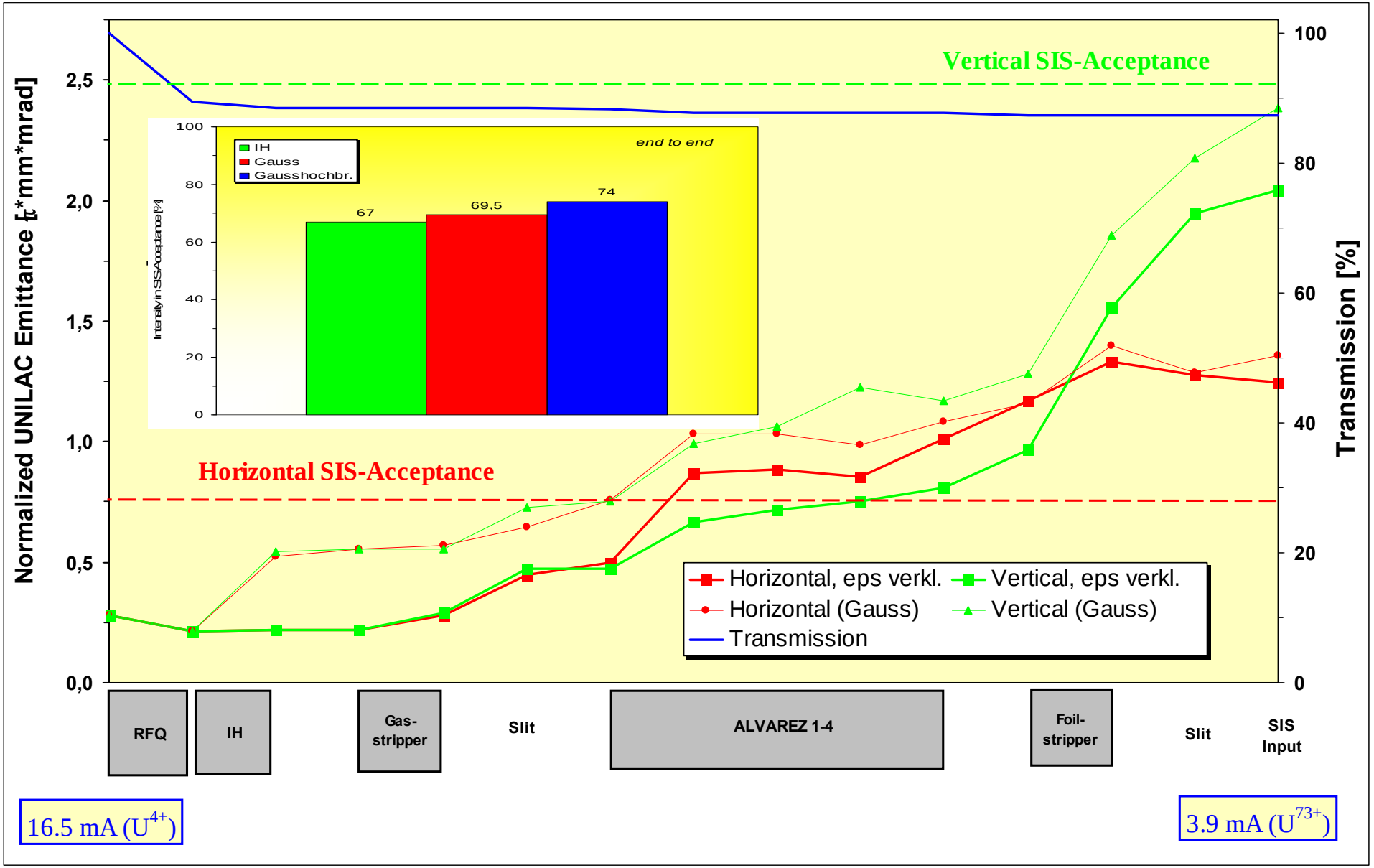
no further upgrade measures considered!

Space Charge Forces (for high current uranium beams) …



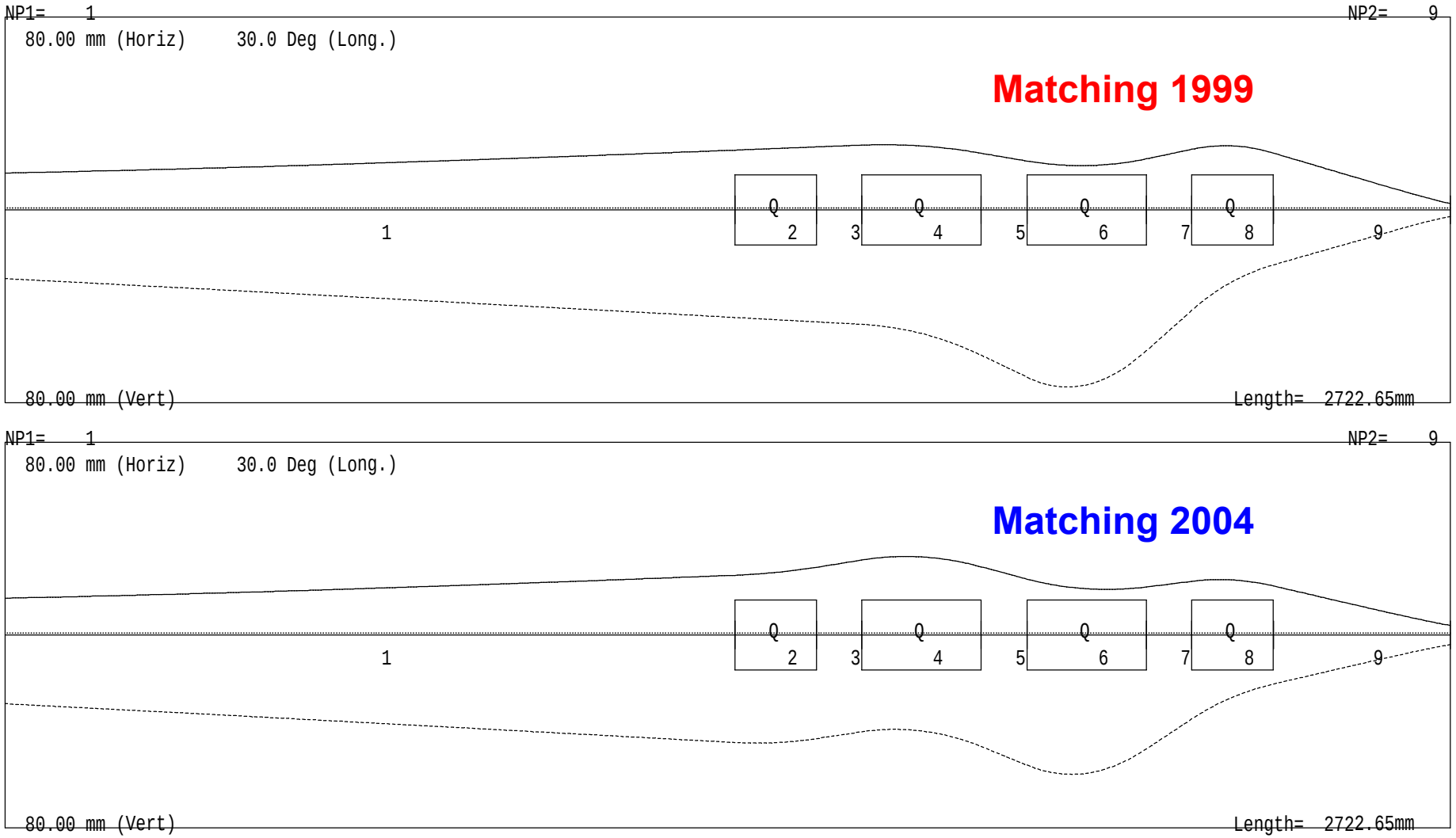

Transversal Emittance (90%)
Horizontal
Vertical
Horizontal (I=0)
Vertical (I=0)
no further upgrade measures considered!
Normalized UNILAC Emittance [π*mm*mrad]
2.5
2.0
1.5
1.0
0.5
0.0
RFQ
IH
Gas-stripper
Slit
ALVAREZ 1-4
Foil-stripper
Slit
SIS Input
16.5 mA (U4+)
3.9 mA (U73+)

Outlook


Normalized UNILAC Emittance [π*mm*mrad]
Transmission [%]
Vertical SIS-Acceptance
Horizontal SIS-Acceptance
end to end
IH
Gauss
Gausshochbr.
67
69,5
74
Intensity in SIS Acceptance [%]
Horizontal, eps verkl.
Vertical, eps verkl.
Horizontal (Gauss)
Vertical (Gauss)
Transmission
RFQ
IH
Gas-stripper
Slit
ALVAREZ 1-4
Foil-stripper
Slit
SIS Input
16.5 mA (U4+)
3.9 mA (U73+)

Backup

RFQ-Upgrade: Modified Input Radial Matcher



HSI-LEBT Upgrade

Upgrade 0

- High Current test stand measurements

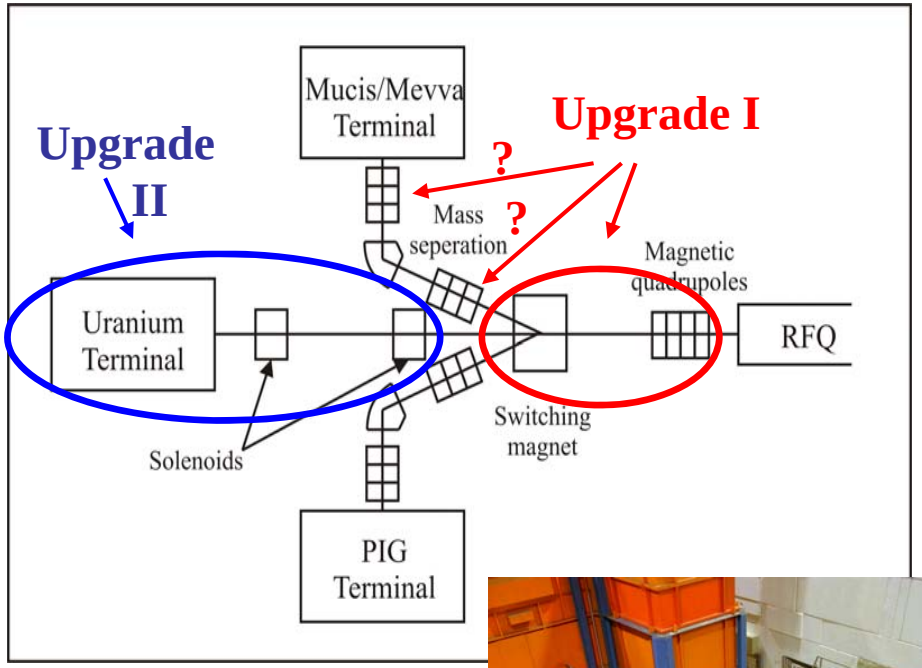
Upgrade I

- 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)

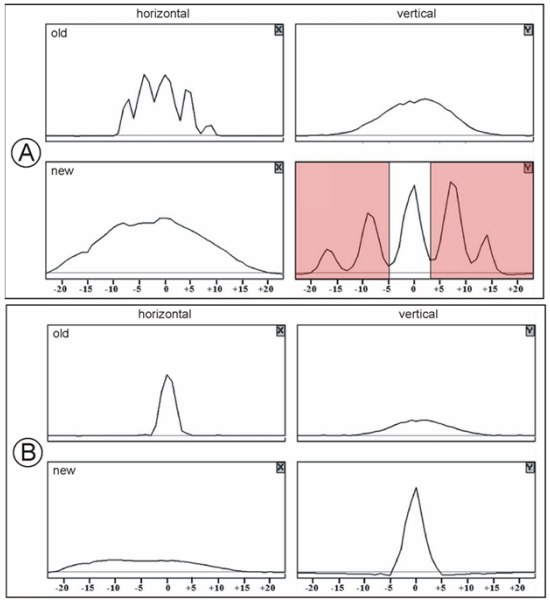
Schematic layout of the LEBT



Previous simulations: Compact LEBT + New RFQ
→ 20 mA behind RFQ !

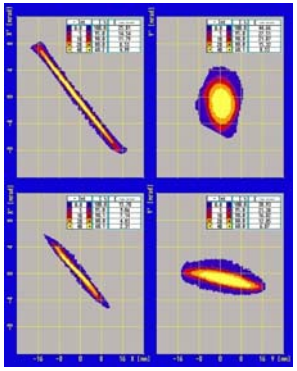
Beam commissioning of the Charge State Separator system

Charge Separation

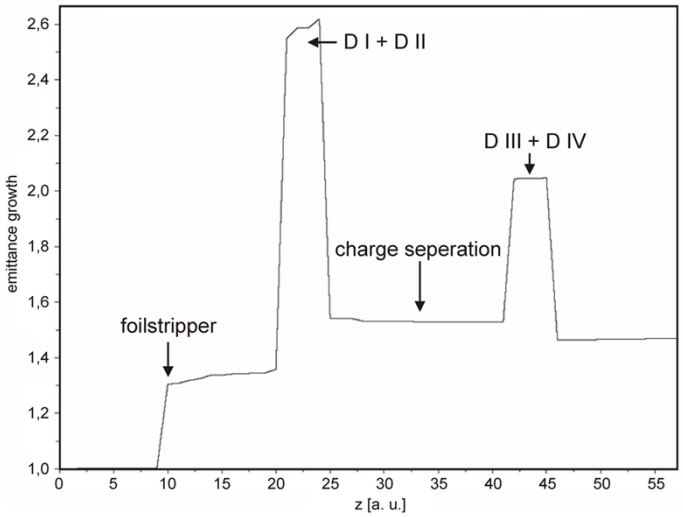


$^{40}AR^{18+}$-Beam Emittances (90 %)

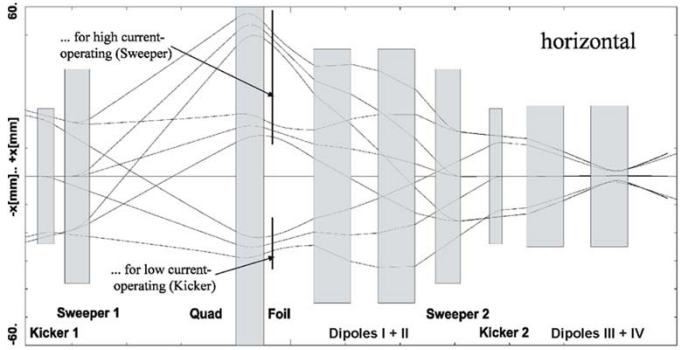
($4\cdot\varepsilon_{rms}$ [µm])	high current		low current	
	hor.	vert.	hor.	vert.
behind D II	9,0	17,6	6,9	7,1
SIS injection	5,5	8,1	5,9	5,6

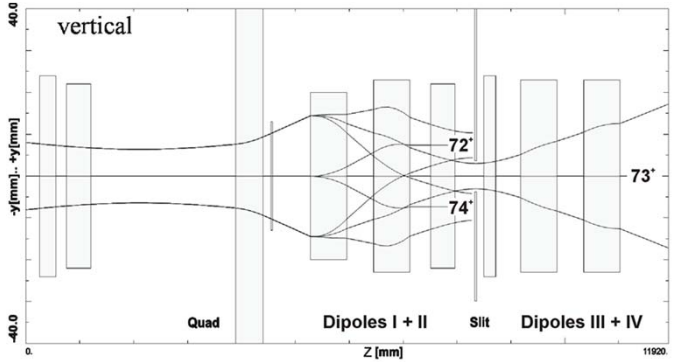


High Current Emittance Growth



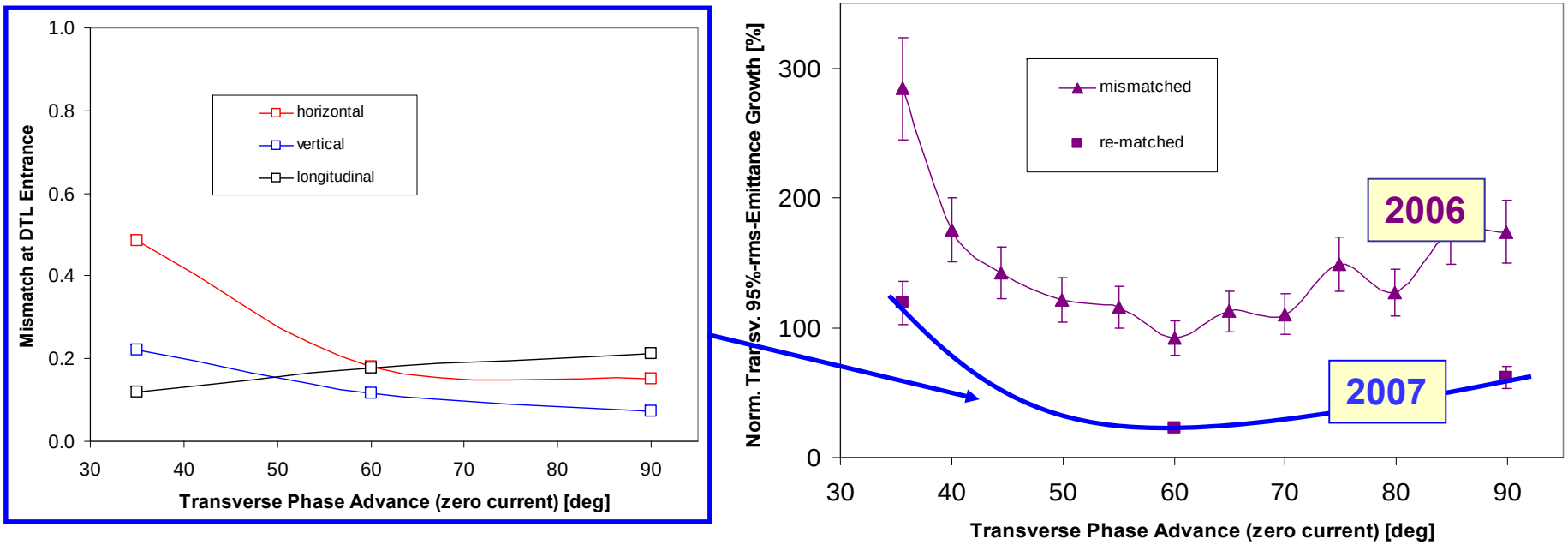
Beam Dynamics





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