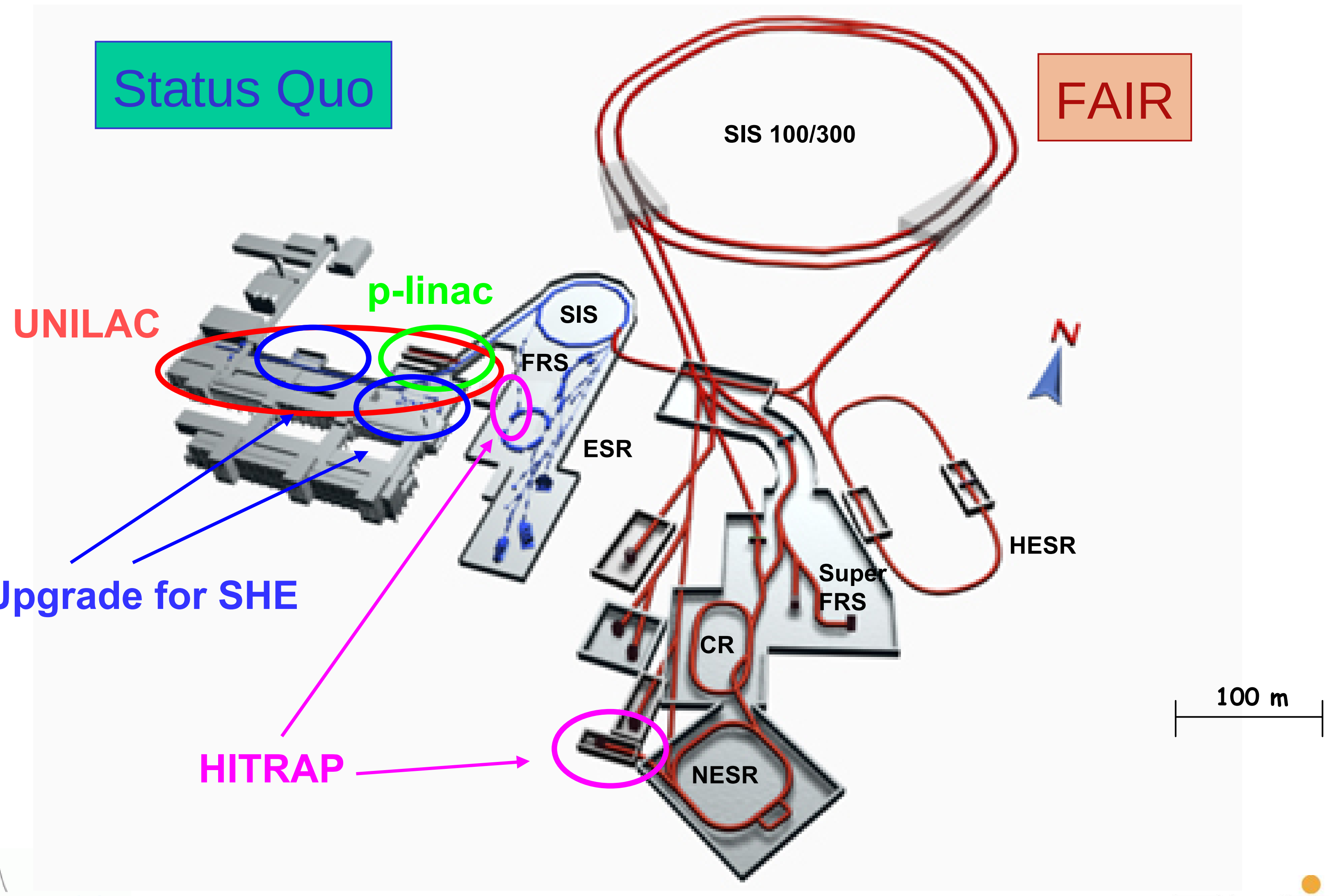
Development of the UNILAC towards a Megawatt Beam Injector

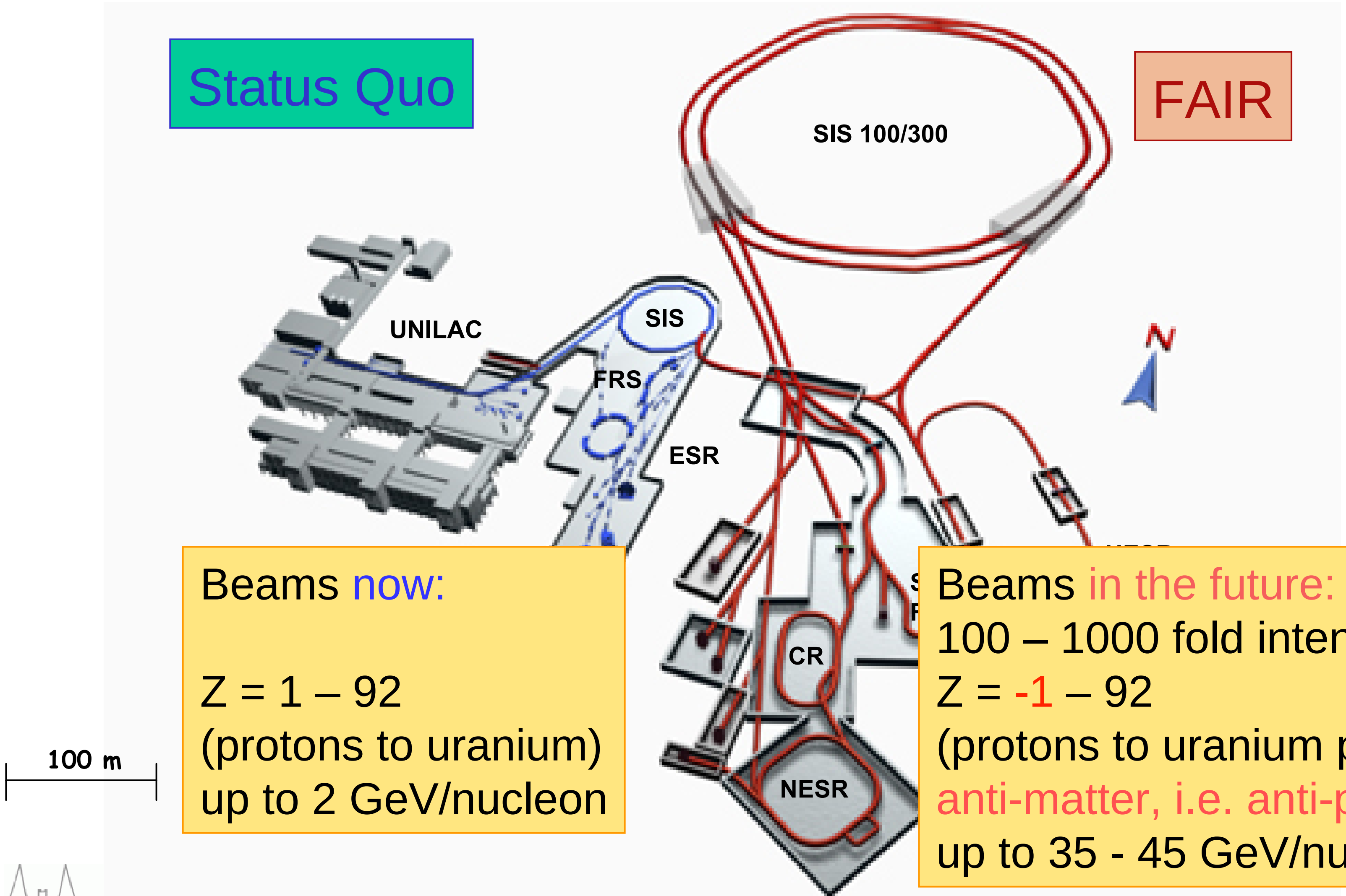
W. Barth, GSI - Darmstadt

1. GSI Accelerator Facility – Injector for FAIR
2. Heavy Ion Linear Accelerator UNILAC
3. SIS 18 – Intensity Upgrade Program and Requirements for FAIR
4. Unilac Upgrade Measures (since 2002)
   - HSI Upgrade (RFQ, Super Lens, IH)
   - Stripper Sections
   - Alvarez Matching
5. Status of the Unilac High Current Performance & further UNILAC Upgrade
6. A Proton Linac for SIS-Injection
7. Additional GSI-LINAC-Projects
8. Summary

Future Internationale Accelerator Facility at GSI: FAIR (Facility for Antiproton and Ion Research)



Future Internationale Accelerator Facility at GSI: FAIR (Facility for Antiproton and Ion Research)

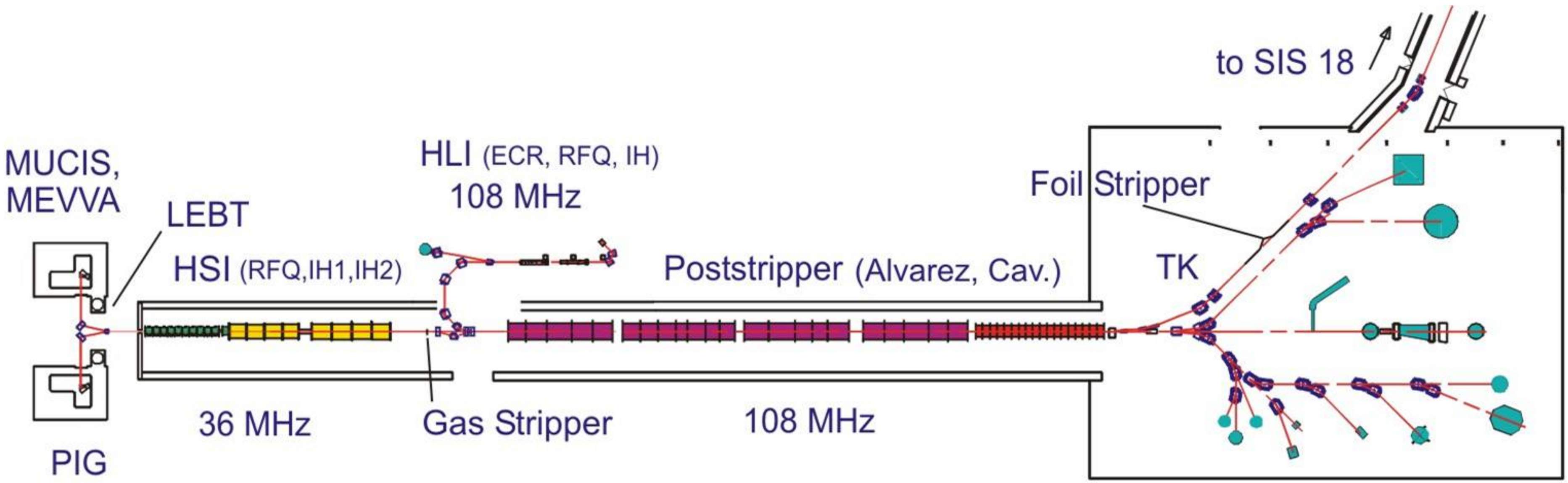


Beams now:

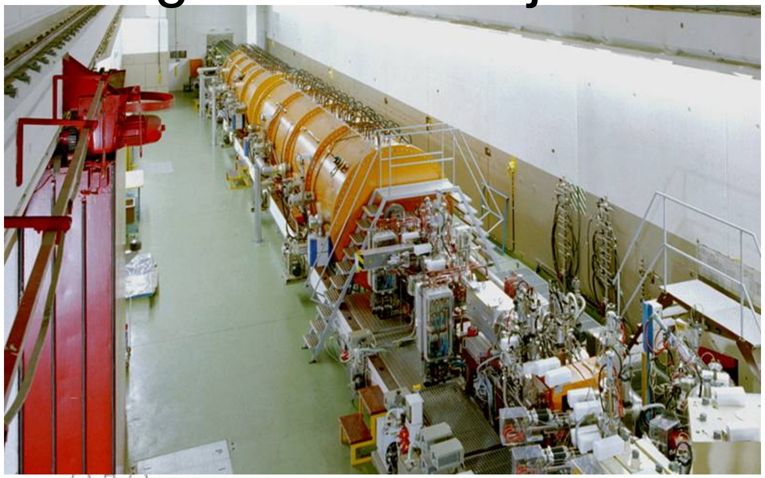
Z = 1 – 92
(protons to uranium)
up to 2 GeV/nucleon

Beams in the future:
100 – 1000 fold intensity
Z = -1 – 92
(protons to uranium plus anti-matter, i.e. anti-protons)
up to 35 - 45 GeV/nucleon

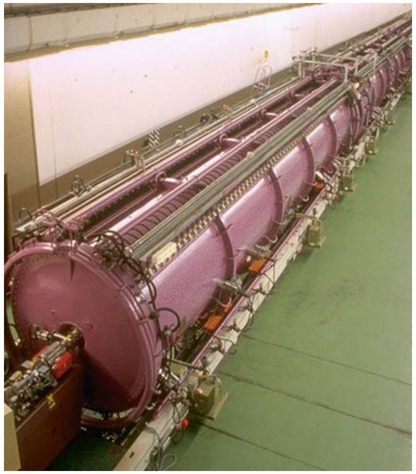
The GSI UNIversal Linear ACcelerator



High Current Injector



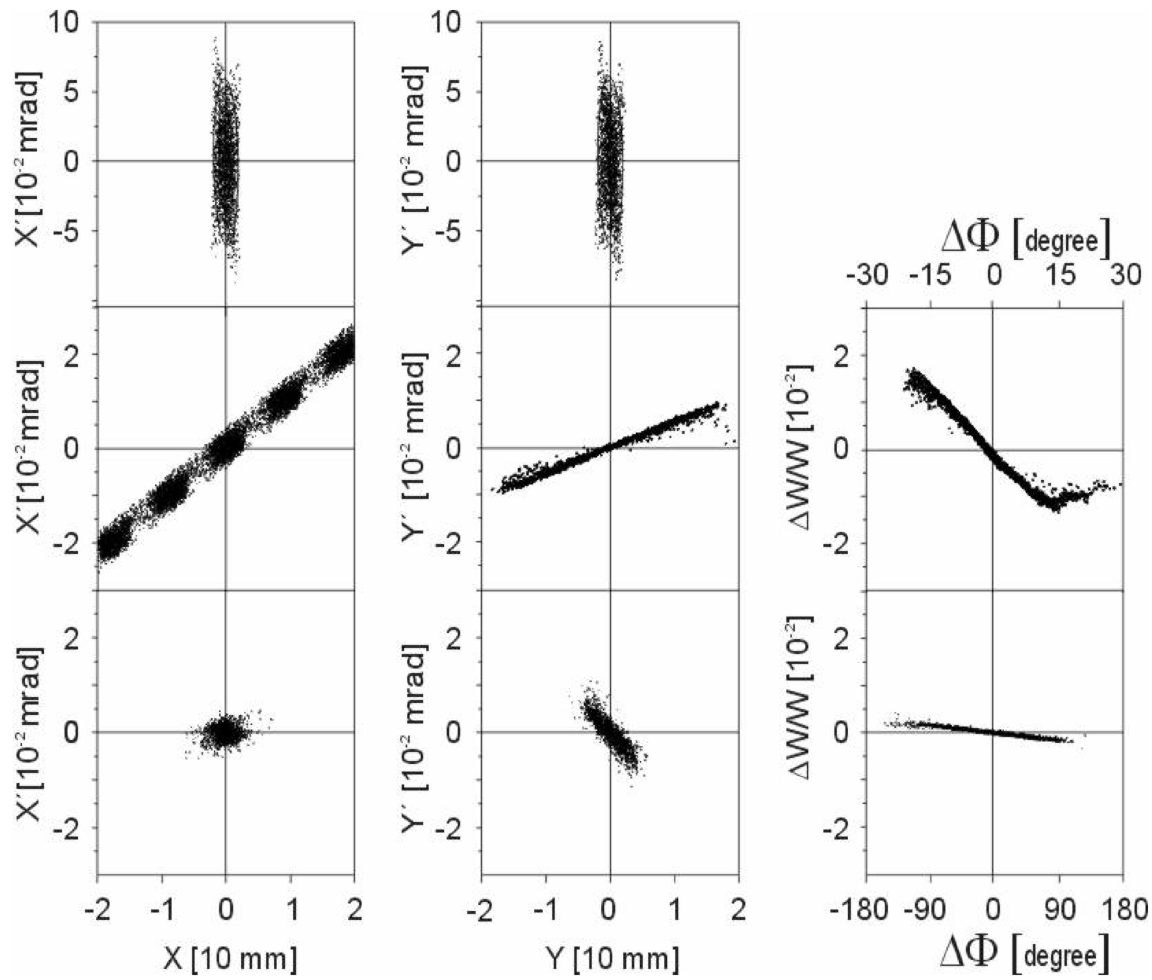
Alvarez



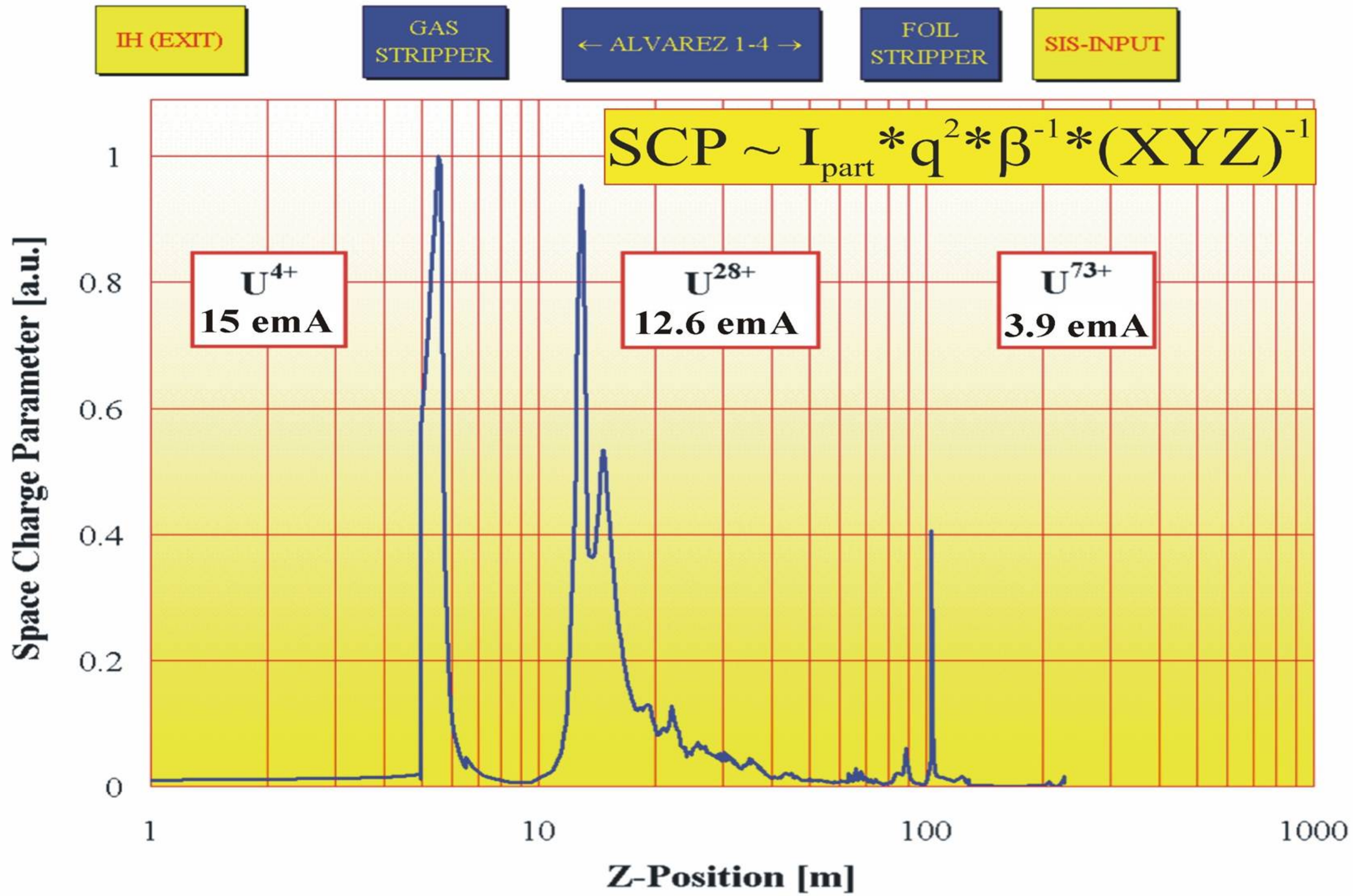
Single Gap Resonators

Multi Particle Simulations (LEBT - SIS-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)



Space Charge Forces (for high current uranium beams) …



SIS 18 – Intensity Upgrade Program and requirements for FAIR

(a twentyfold mutiturn injection is supposed)

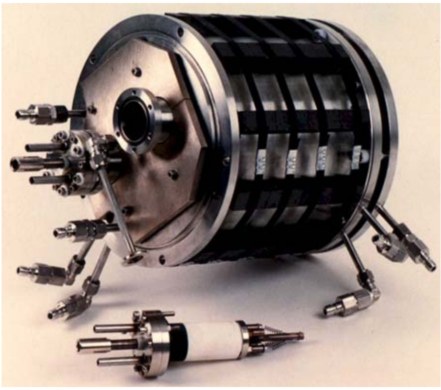
	HSI entrance	HSI exit	Alvarez entrance	SIS 18 injection	SIS 18 injection (FAIR)
ION SPECIES	$^{238}U^{4+}$	$^{238}U^{4+}$	$^{238}U^{28+}$	$^{238}U^{28+}$	$^{238}U^{28+}$
El. Current [mA]	16.5	15	12.5	8.4*	15
Part. per 100µs pulse	$2.6\cdot10^{12}$	$2.3\cdot10^{12}$	$2.8\cdot10^{11}$	$1.9\cdot10^{11}$*	$3.5\cdot10^{11}$
Energy [MeV/u]	0.0022	1.4	1.4	11.4	11.4
ΔW/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
$\varepsilon_{n,y}$ [mm mrad]	0.3	0.5	0.75	2.5	-

* in SIS-acceptance, as expected from multiparticle calculation

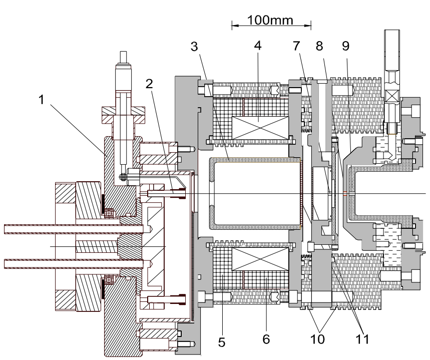
Unilac-Measures (since 2002)

- 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 *(S. Yaramishev, MOP08)*
- Reduction of the number of Single Gap Resonators
- Alignment
- High Current Beam Diagnostics *(A. Peters, MO202)*
- Machine Investigations: Frontend, Alvarez-matching, transfer line-emittance measurements *(S. Richter, MOP07)*

MUCIS- & MEVVA- Ion Sources



MUCIS
(Multi Cusp Ion Source)
(Emission Current Density ≤150 mA/cm²)



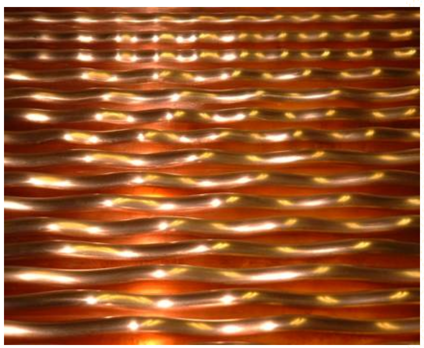
MEVVA
(MEtal Vacuum Vapor Arc Ion Source)
(Emission Current Density ≤150 mA/cm²)

		HSI-INJECTION	DESIGN
MUCIS	H_3^+	1.0 mA	0.8 mA
	D_3^+	2.0 mA	1.6 mA
	$^{12}C^+$	7.0 mA	3.2 mA
	$^{14}N^+$	4.0 mA	3.8 mA
	$^{18}O^+$	5.0 mA	4.8 mA
	$^{20}Ne^+$	5.5 mA	5.4 mA
	CO^+	6.0 mA	8.1 mA
	$^{40}Ar^{1+}$	**19.0 mA**	**10.8 mA**
	$^{86}Kr^{2+}$	8.0 mA	11.6 mA
	$^{129}Xe^{2+}$	0.75 mA	17.4 mA
MEVVA	$^{12}C^+$	5.5 mA	3.2 mA
	$^{48}Ti^{1+}$	3.0 mA	12.9 mA
	$^{48}Ti^{2+}$	20.0 mA	6.5 mA
	$^{48}Ti^{3+}$	20.0 mA	4.3 mA
	$^{52}Cr^{1+}$	6.0 mA	14.0 mA
	$^{58}Ni^{1+}$	10.0 mA	15.6 mA
	$^{92}Mo^{2+}$	6.0 mA	12.4 mA
	$^{238}U^{4+}$	**16.0 mA**	**16.0 mA**

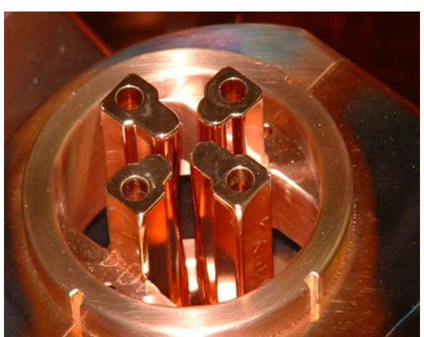
RFQ-Upgrade: New RFQ-Rods

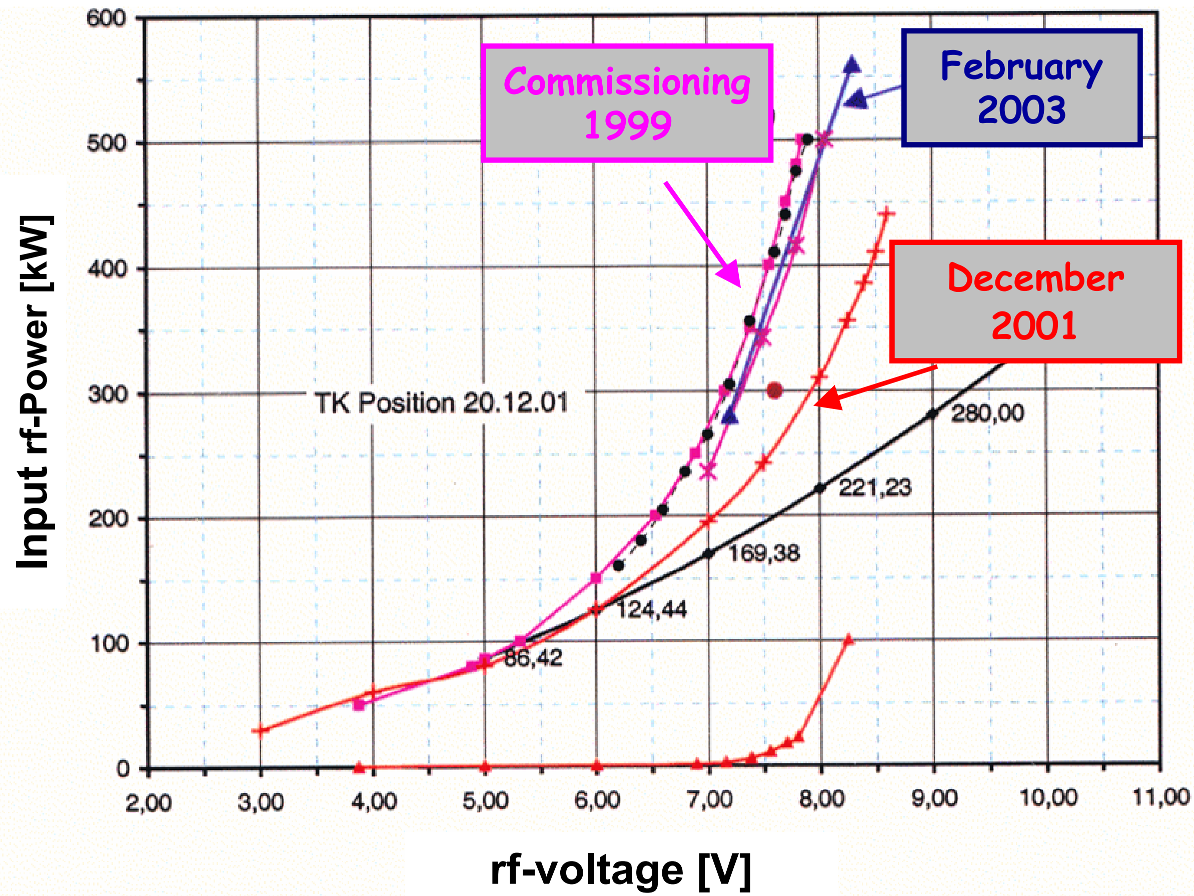
After
5 years of
operation

New
RFQ-rods

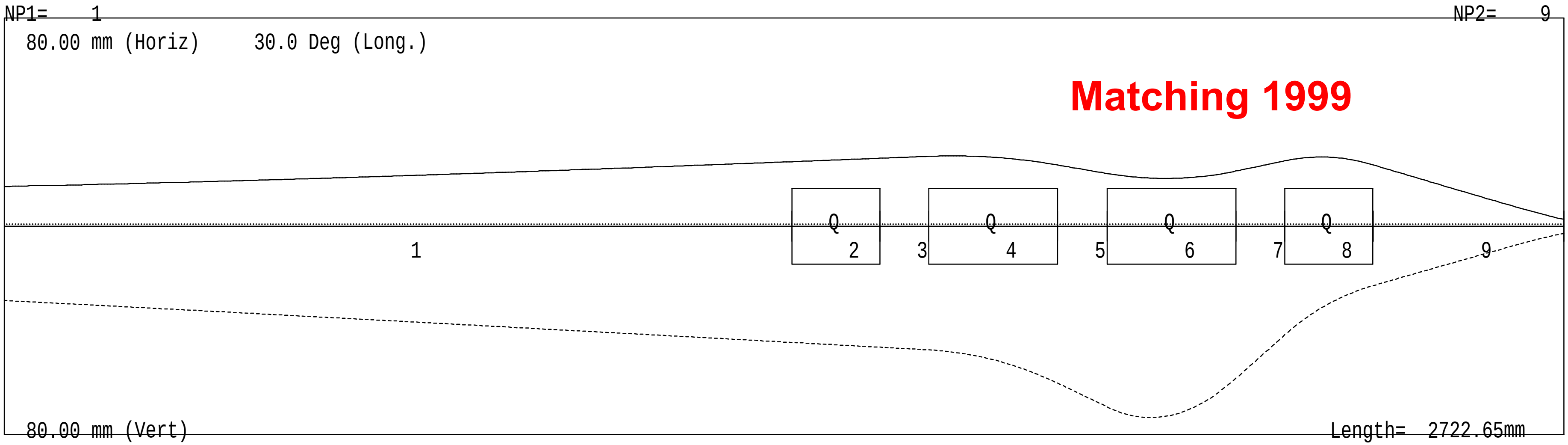


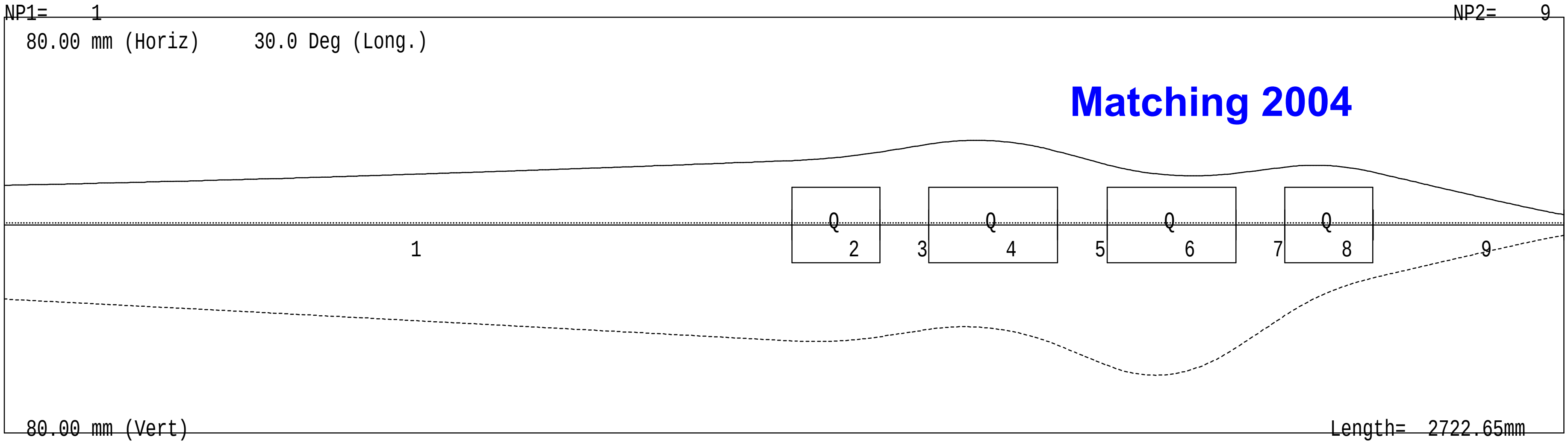
After
copper-
plating





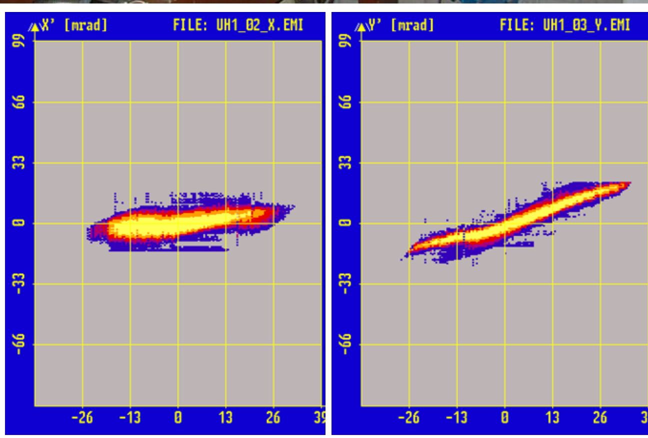
RFQ-Upgrade: Modified Input Radial Matcher





Test Bench Measurements in the HSI-LEBT (8 emA, U^{4+})

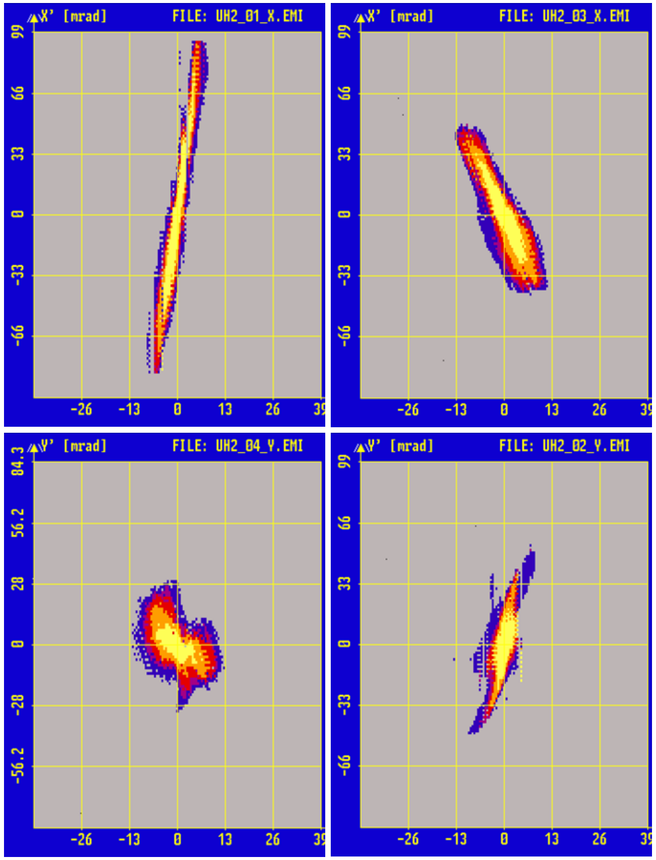
before Quadrupole Quartet



horizontal **vertical**

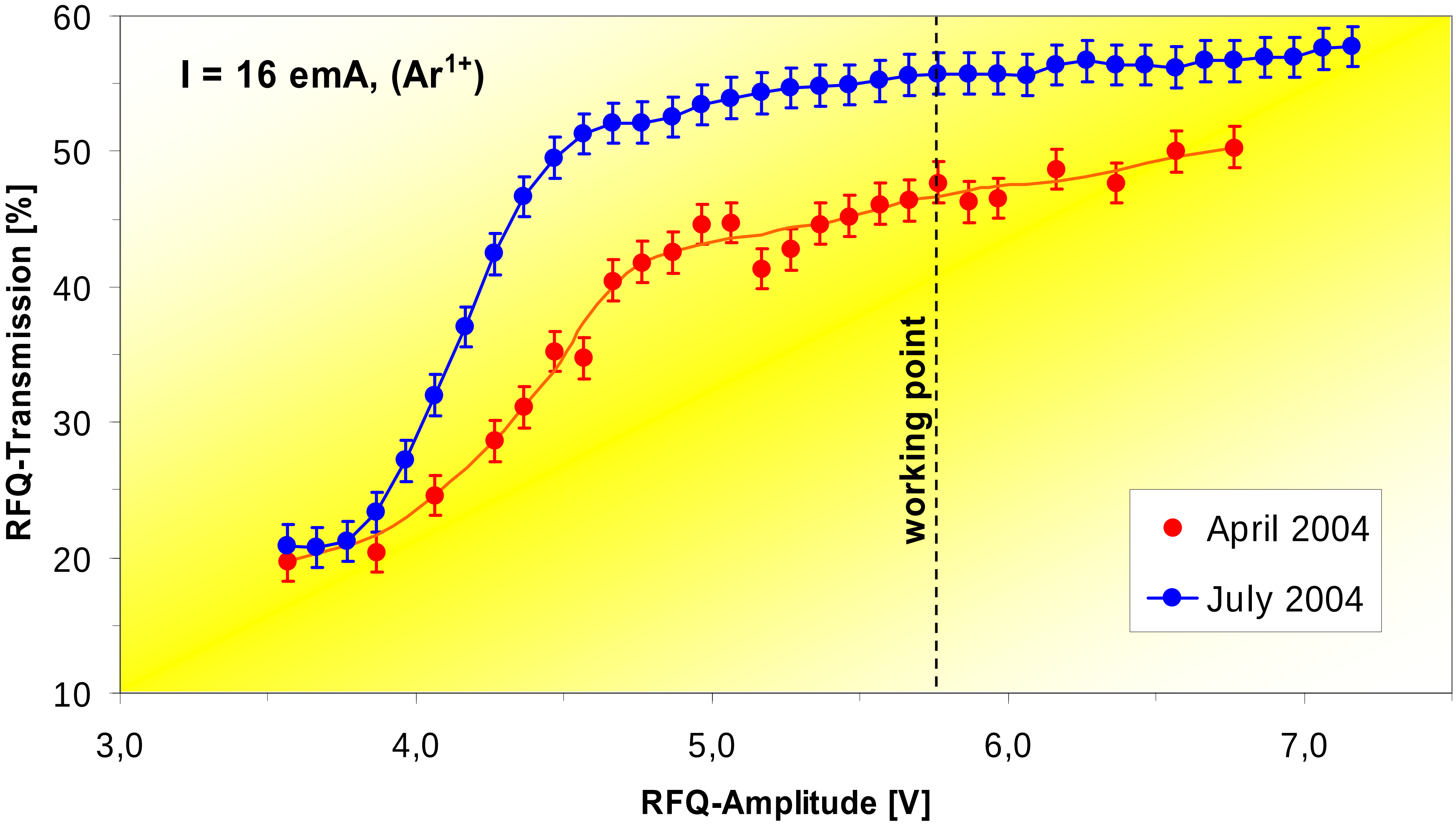
1999

2004

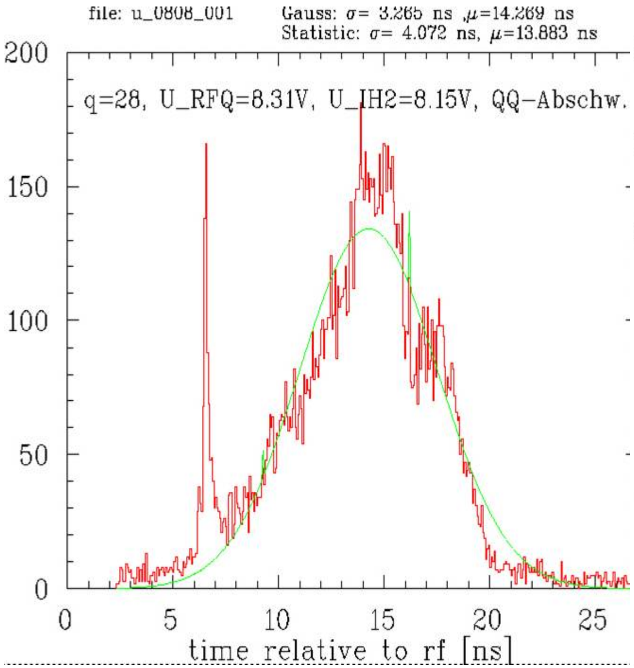


Emittance Growth:	**-19 % (3 %)**
Transmission:	**70 % (84 %)**

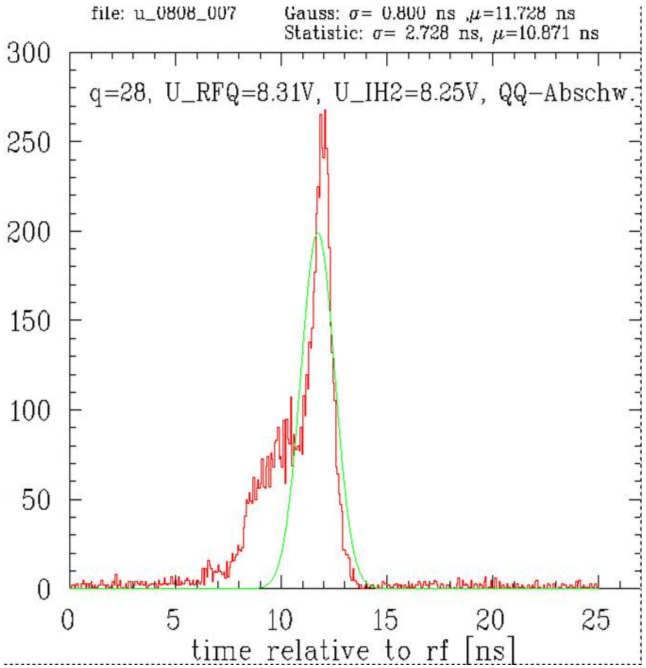
HSI-RFQ-Commissioning (7/2004)



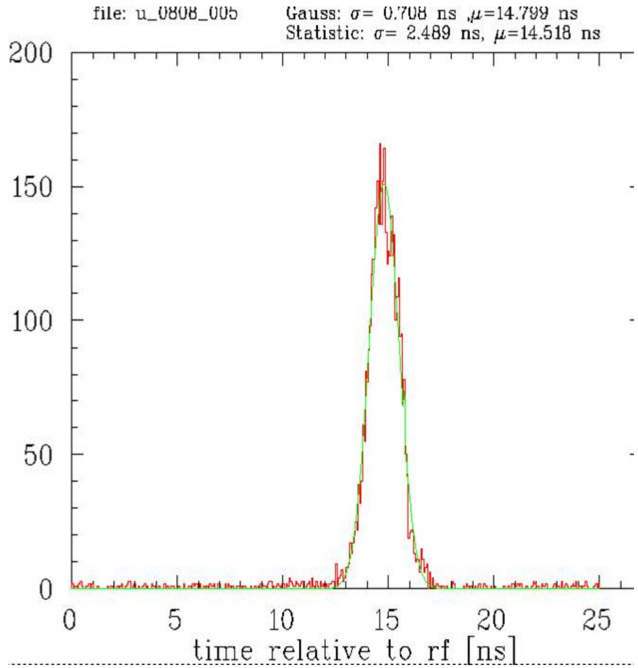
IH 2: Longitudinal Mismatch



U_{IH2} = 8.15 V

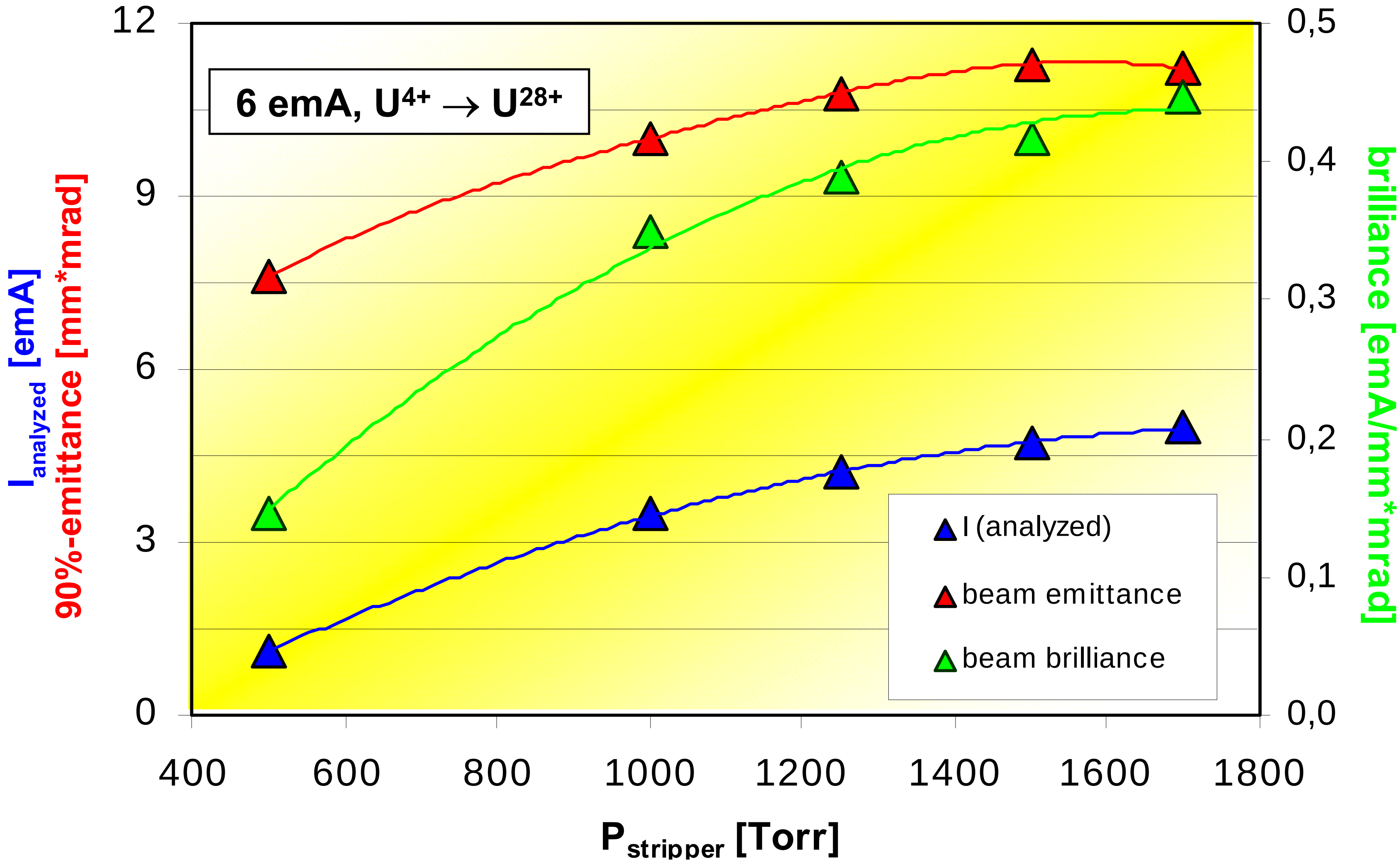


U_{IH2} = 8.25 V



U_{IH2} = 8.45 V

Increased Stripper Gas Density



Alvarez-Matching

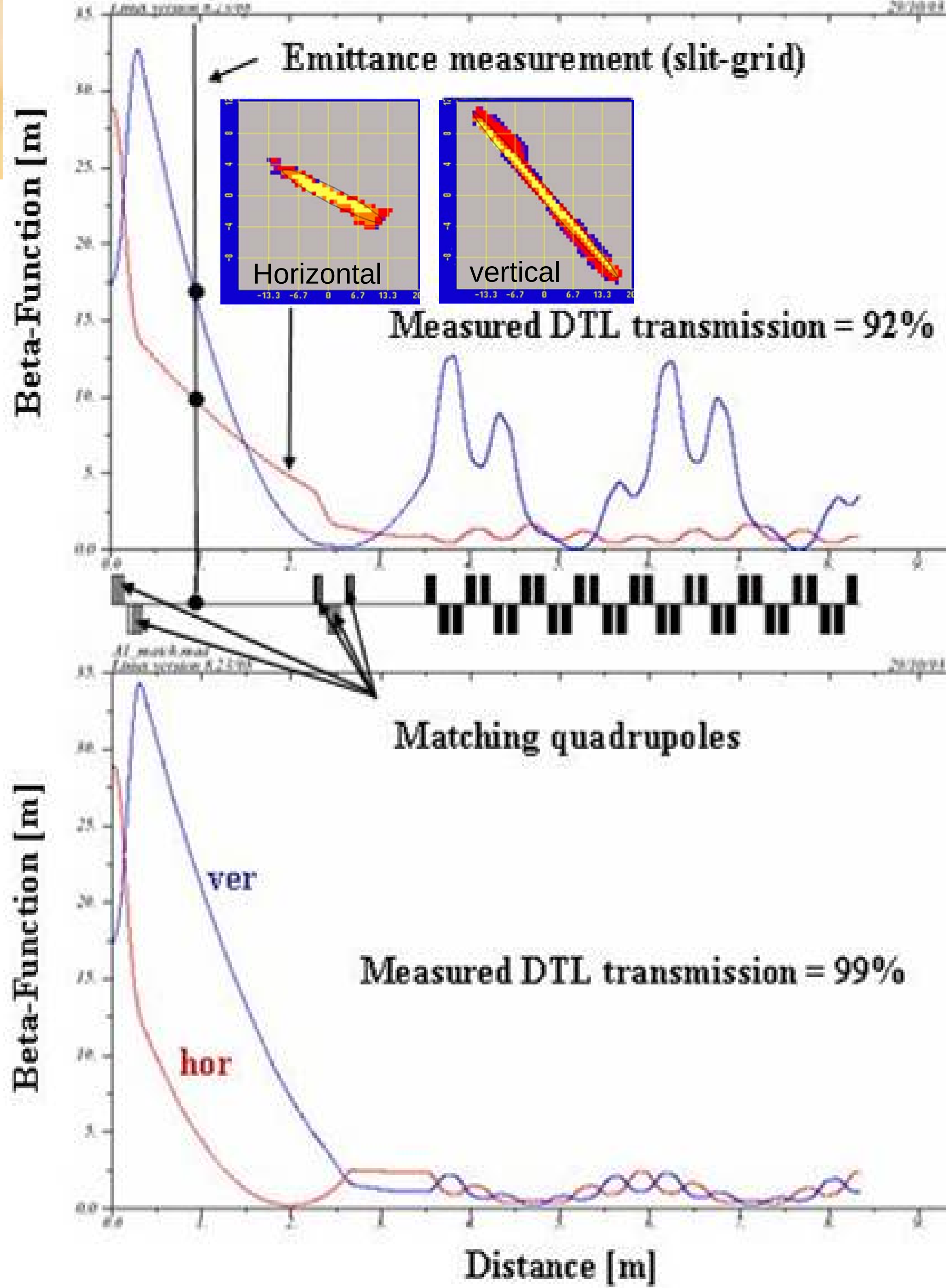
Emittance Measurement
before the DTL,
3.5 emA U^{28+}

Betafunction (before Matching)

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

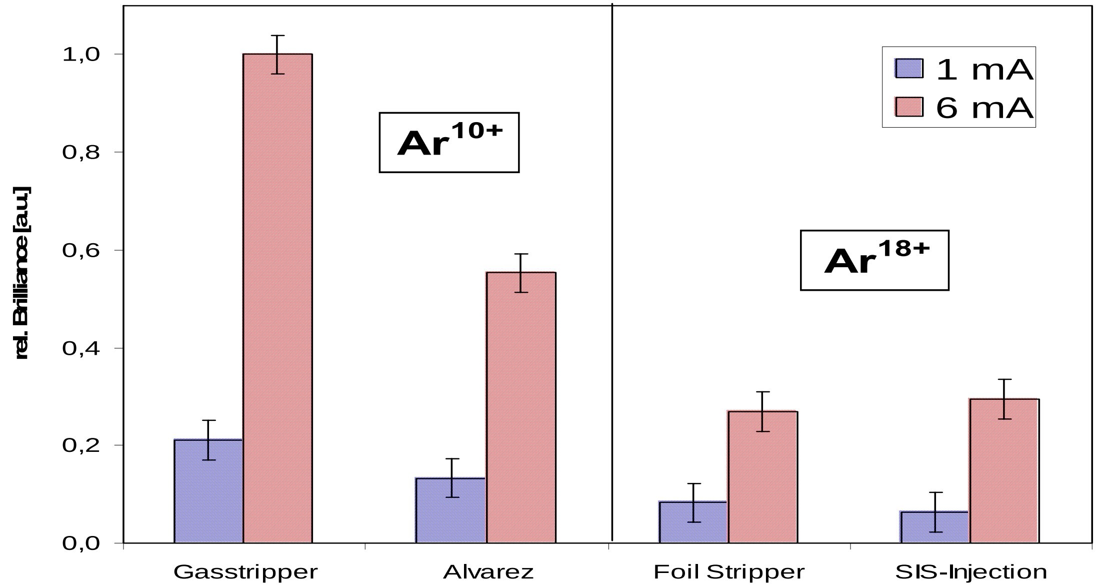
Betafunction (afterMatching)

(S. Yaramishev, MOP08)

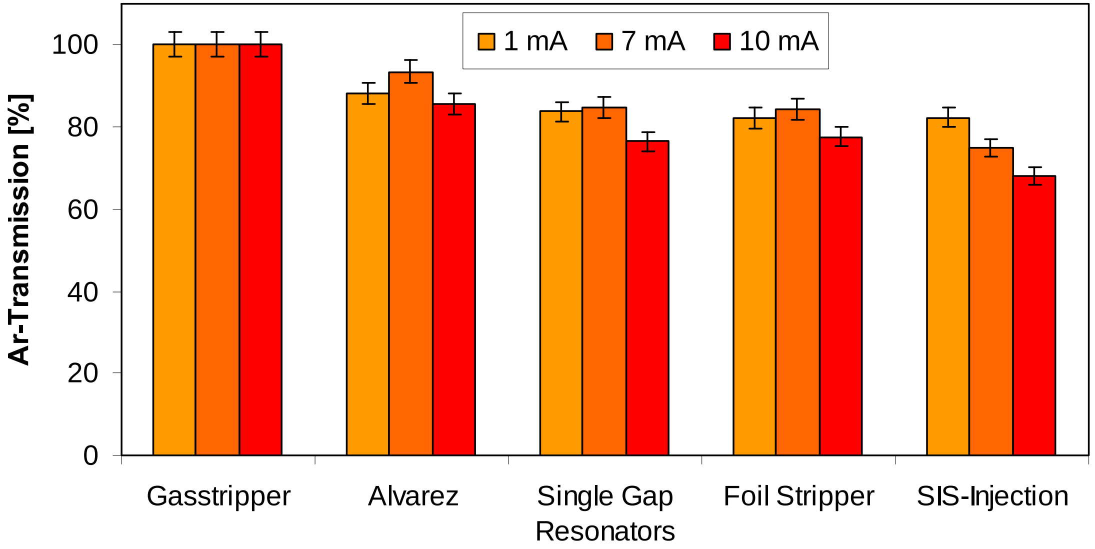


Status of the UNILAC High Current Performance

Beam Brilliance



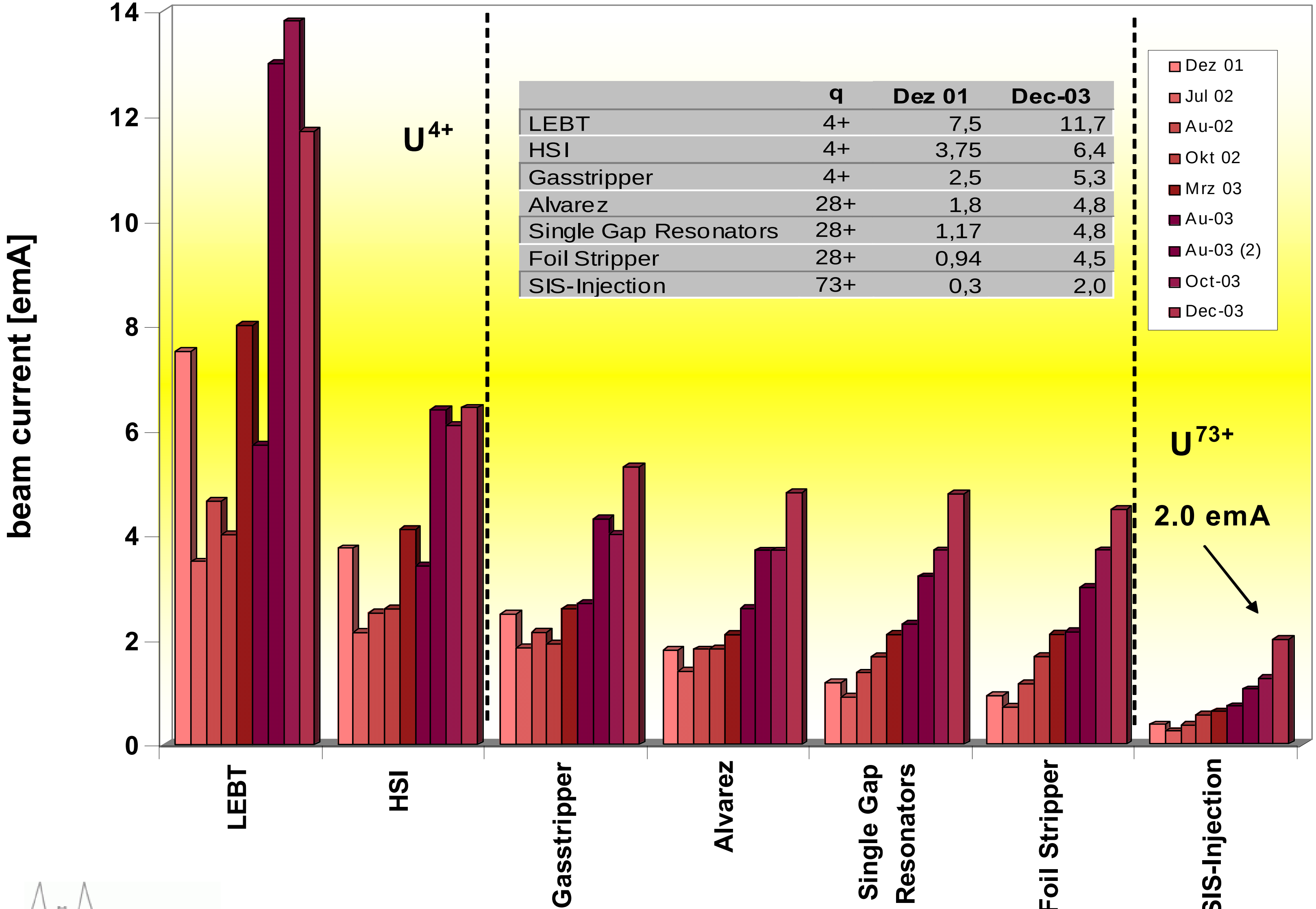
Beam transmission



LINAC2004 LÜBECK

GSI

Status of the UNILAC Uranium-Performance



	q	Dez 01	Dec-03
LEBT	4+	7,5	11,7
HSI	4+	3,75	6,4
Gasstripper	4+	2,5	5,3
Alvarez	28+	1,8	4,8
Single Gap Resonators	28+	1,17	4,8
Foil Stripper	28+	0,94	4,5
SIS-Injection	73+	0,3	2,0

Status of the UNILAC Uranium-Performance II

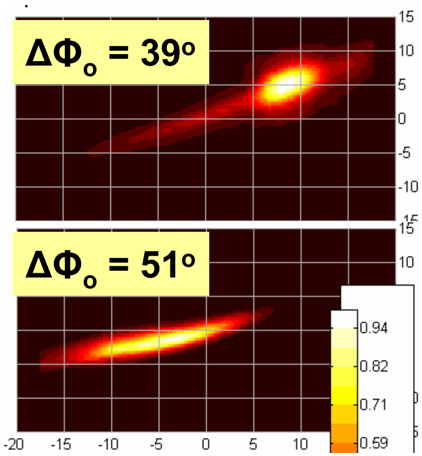
	Measured	Design	required for FAIR
$^{238}U^{4+}$ Max. Beam Intensity I, (2.2 keV/u)	16 emA	16 emA	20 emA
I_{max}@beam power, (1.4 MeV/u)	6.5 emA @545 kW	15 emA@1250 kW	18 emA@1500 kW
Transv. Emittance (LEBT) (90%, total)	140 π·mm·mrad	120 π·mm·mrad	120 π·mm·mrad
Macropulse Length	150 μs	150 μs	150 μs
Reproducibility/Transversal Emittance	±4.5%	-	-
Beam loading, 6emA (IH2)	300 kW	590 kW (15 emA)	710 kW (15 emA)
U^{28+}			
Max. Beam Current, (1.4 MeV/u)	5.0 emA	12.6 emA	15.0 emA
Max. Beam Intensity, 11.4 MeV/u, I_{max}@beam power Transfer to the SIS18 *Ions/100μs*	4.5 emA@440 kW *$1.0 \cdot 10^{11}$*	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*	2.0 emA *$1.7 \cdot 10^{10}$*	4.6 emA *$3.9 \cdot 10^{10}$*	3.5 emA $3.0 \cdot 10^{10}$
Transv. Emittance (11.4 MeV/u) (90%, tot.)	10.0 π·mm·mrad	5.0 π·mm·mrad	7.0 π·mm·mrad

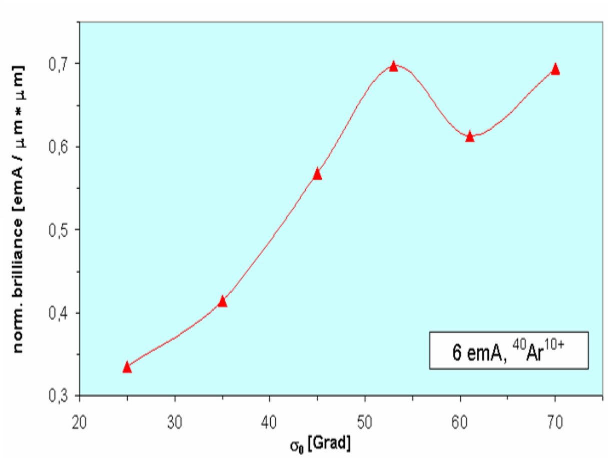
Further Upgrade Measures (2005-2009)

- High Current Test Bench for the investigation of the Ion Source (Post acceleration)
- Dedicated U^{4+}-High Current-Frontend (Compact-LEBT@RFQ)
- Further investigation of the high current matching to Alvarez-DTL
- Increased zero current phase advance in the Alvarez-DTL
- High Current Beam Diagnostics in the whole UNILAC
- Compact Charge Separator for the separation of U^{73+} under sc-conditions
- Further development of simulation tools
- Extended High Current UNILAC machine experiments

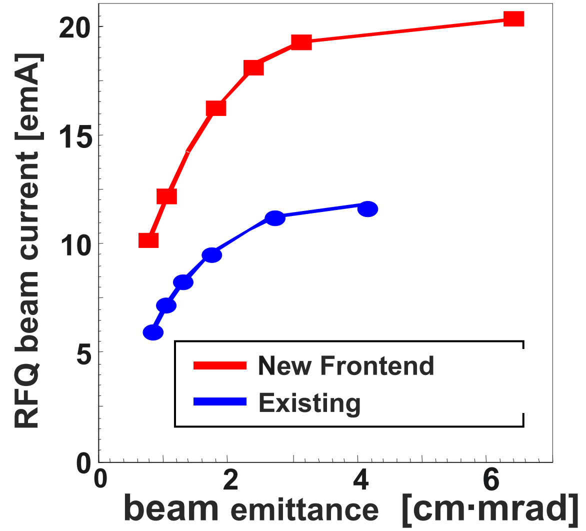
Main Upgrade Measures (2005-2009)

Alvarez-Upgrade(new Power Supplies)

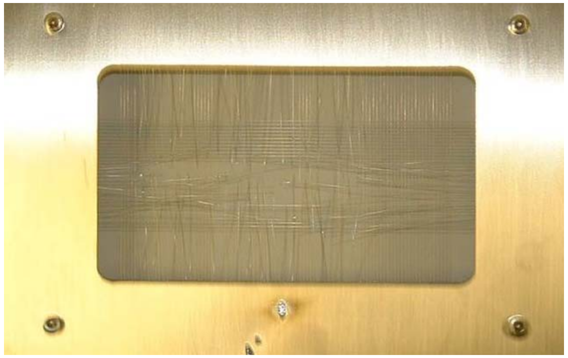




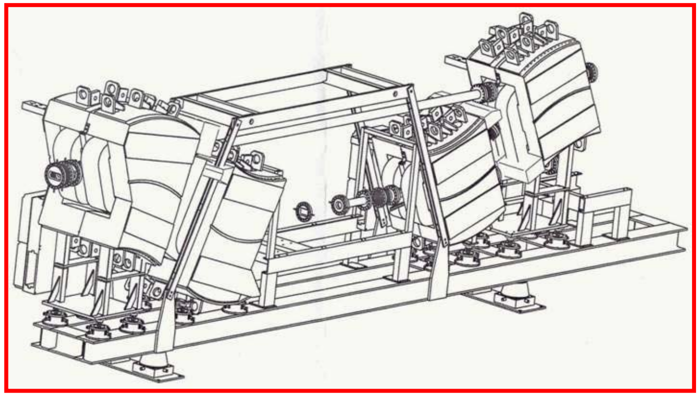
Dedicated U^{4+} Frontend-System

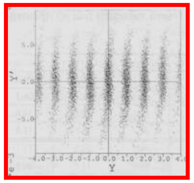


High Current Beam Diagnostics

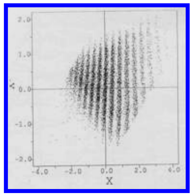


Compact Charge Separator



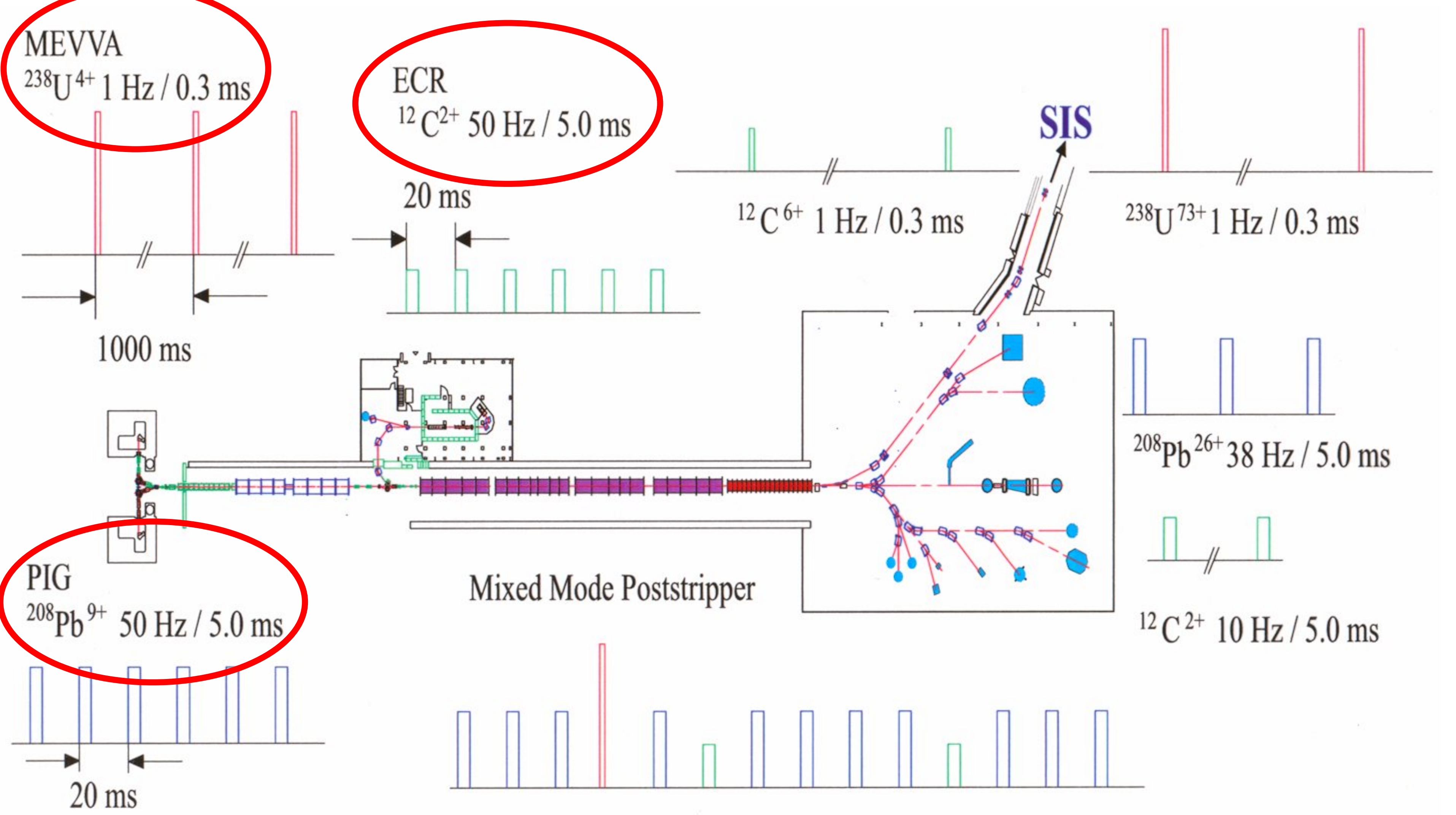


new



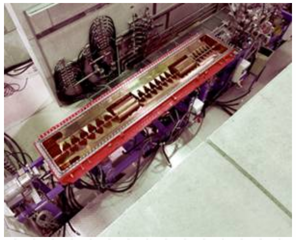
old

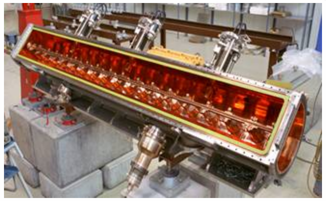
Example of UNILAC 3-Beam Operation

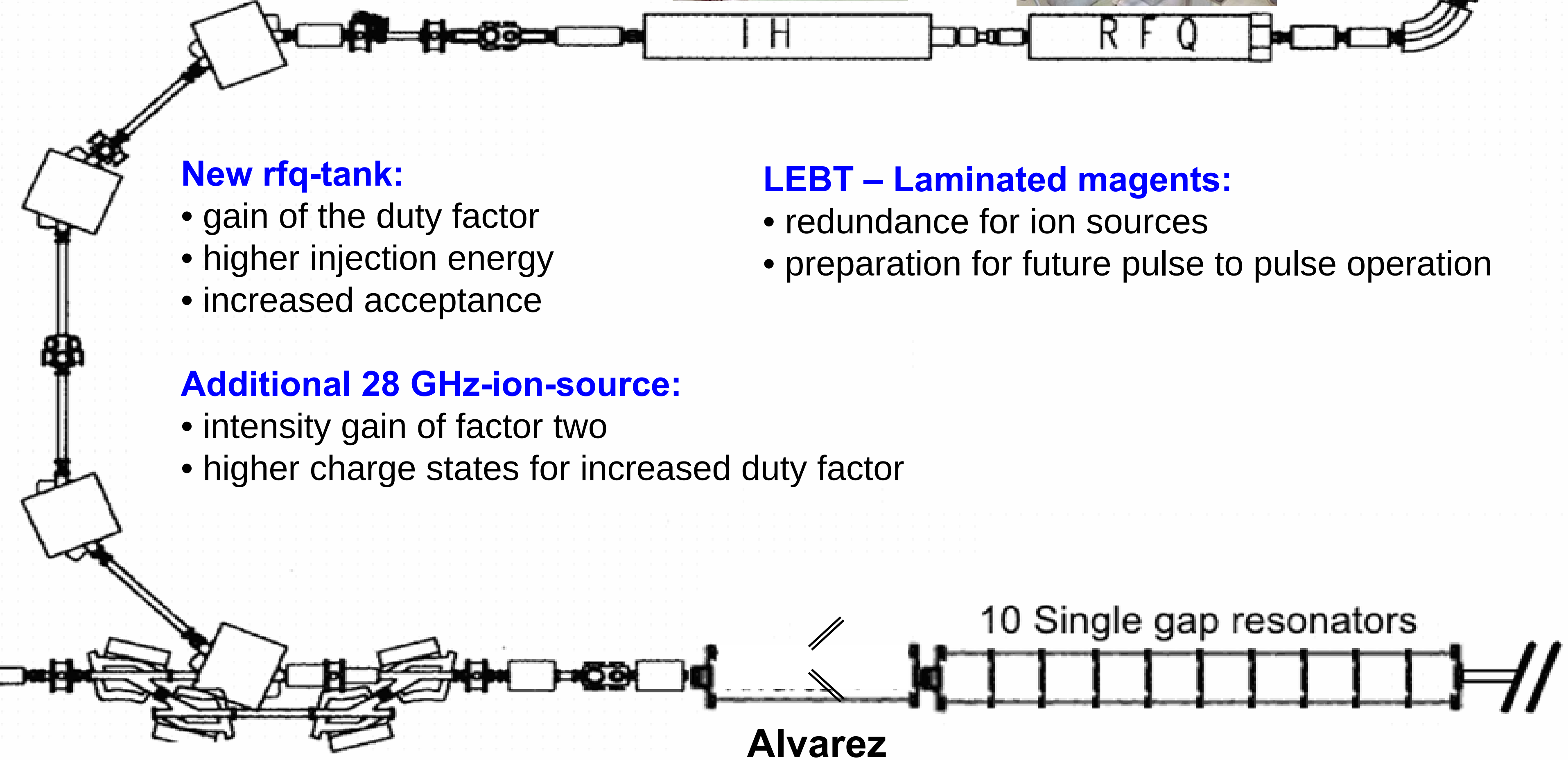


Upgrade of the UNILAC for Super Heavy Element Production

- **50% duty factor**
  (presently: 25 %, A/$\xi \leq$8)
- **intensity-gain factor x2**





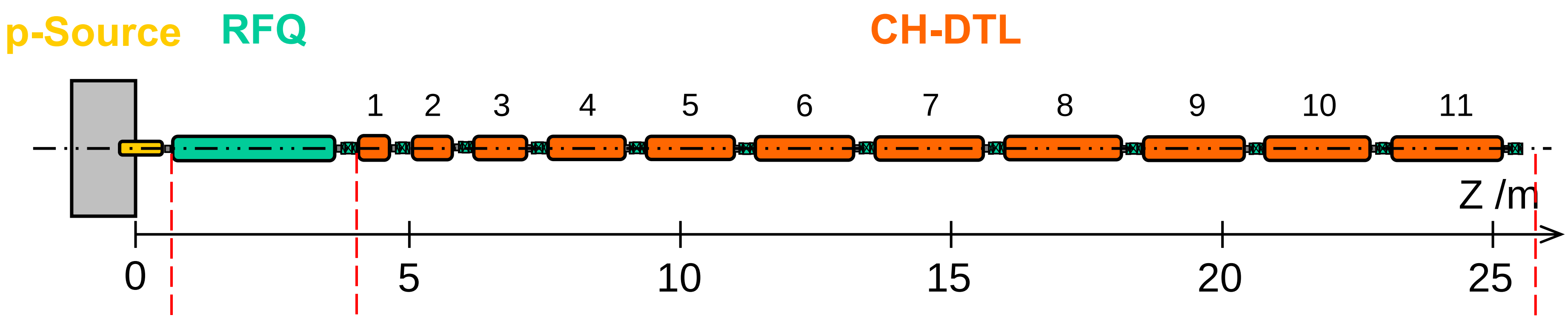


New rfq-tank:
- gain of the duty factor
- higher injection energy
- increased acceptance

LEBT – Laminated magents:
- redundance for ion sources
- preparation for future pulse to pulse operation

Additional 28 GHz-ion-source:
- intensity gain of factor two
- higher charge states for increased duty factor

Proton Linac



95 keV

3 MeV

W_{out} = 70 MeV

I = 70 mA

Source	H⁺, ECR, 95 keV, 110 mA
LEBT	2-solenoid focusing 95 keV, 100 mA, 0.3 µm*
RFQ (4-rod or 4-windows)	3 MeV, 90 mA, 0.4 µm* *(norm.,rms)
DTL – Section rel. momentum spread rf pulse length beam pulse length max. repetition rate	352.21 MHz, rt, 11 CH-structures 70 MeV, 70 mA, 2.8 µm** $\pm 5 \cdot 10^{-4}$ 250 µs 100 µs 5 Hz **(norm., tot)

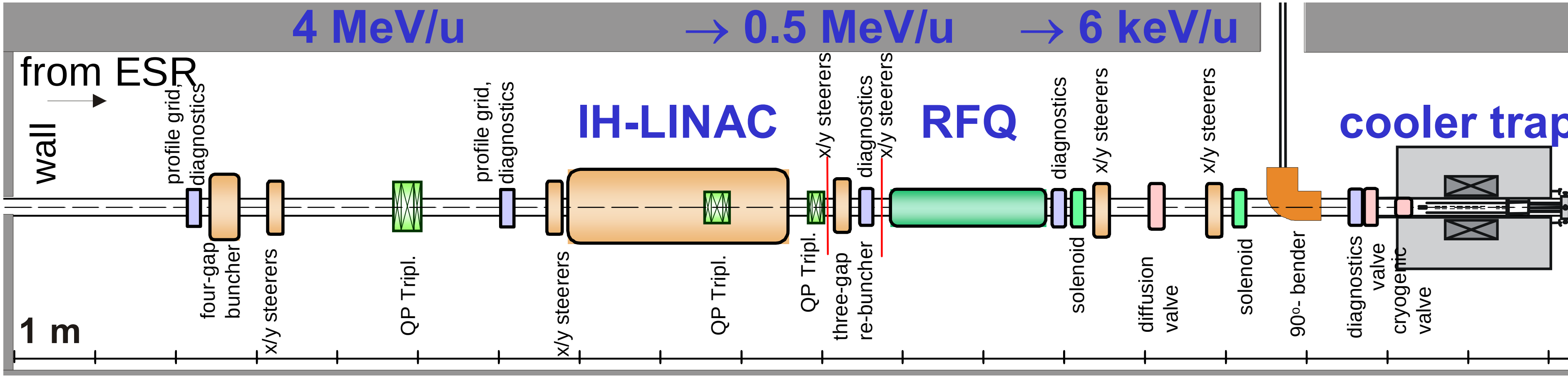
L. Groening, MOP06

R. Tiede, MOP12

Z. Li, MOP20

A. Schempp, THP11

Decelerator for the Heavy Ion TRAP



HITRAP Section	Energy [MeV/u]	ΔT/T	$\varepsilon_{x,n}$ (= $\varepsilon_{y,n}$) [π·mm· mrad]	ε_x (= ε_y) [π·mm·mrad]	total Transmission	particles/ spill
ESR	5.0	$4.8 \cdot 10^{-4}$	0.093	0.9		$1 \cdot 10^6$ measured
	4.0		0.1	1.0	100%	$(6 \cdot 10^5)$ estimated
	3.0	$2 \cdot 10^{-4}$	0.06	0.7		$2 \cdot 10^5$ measured
Entrance Prebuncher	4.0	$4.8 \cdot 10^{-4}$	0.2	2.2	100 %	$6 \cdot 10^5$
Entrance IH	4.0	$\pm 1.3 \cdot 10^{-2}$	0.2	2.2	28 %	$1.7 \cdot 10^5$
Exit IH / Entr. RFQ	0.5	$\pm 2 \cdot 10^{-2}$	0.24	7.3	28 %	$1.7 \cdot 10^5$
Exit RFQ	0.006	$\pm 7 \cdot 10^{-2}$	0.37	100	26 %	$1.5 \cdot 10^5$
LEBT, entrance of trap	0.006	$\pm 7 \cdot 10^{-2}$	0.37	100	21 %	$1.2 \cdot 10^5$

L. Dahl, MOP05
C.A. Kitegi, MOP10

Summary

- An extended upgrade program in the UNILAC in combination with machine investigations resulted in a seven times higher uranium beam intensity offered for the injection into the synchrotron SIS 18.
  2.0 emA (73+), 4.5 emA (28+) → **0.45 MW beam power**
- Mainly the improved ion source performance, an upgrade of the HSI-structures, the increased stripper gas density, the optimization of the Alvarez-matching, and the use of various newly developed beam diagnostics devices were responsible for the successful development program.
- FAIR-requirements: The UNILAC-upgrade will be continued with the investigation of a new front end for U^{4+} , stronger power supplies for the Alvarez quads, a charge state separator system and beam diagnostics devices, sufficient for the operation with megawatt heavy ion beams.
- Primary proton beam intensities will be increased by a new proton linac (to be commissioned in 2007).
- The decelerator for the HITRAP should be ready for operation in 2008.
- Advanced SHE experimental program: Improvement of the average target luminosity for medium heavy ions in the MeV/u-range (linac development program 2005-2009).