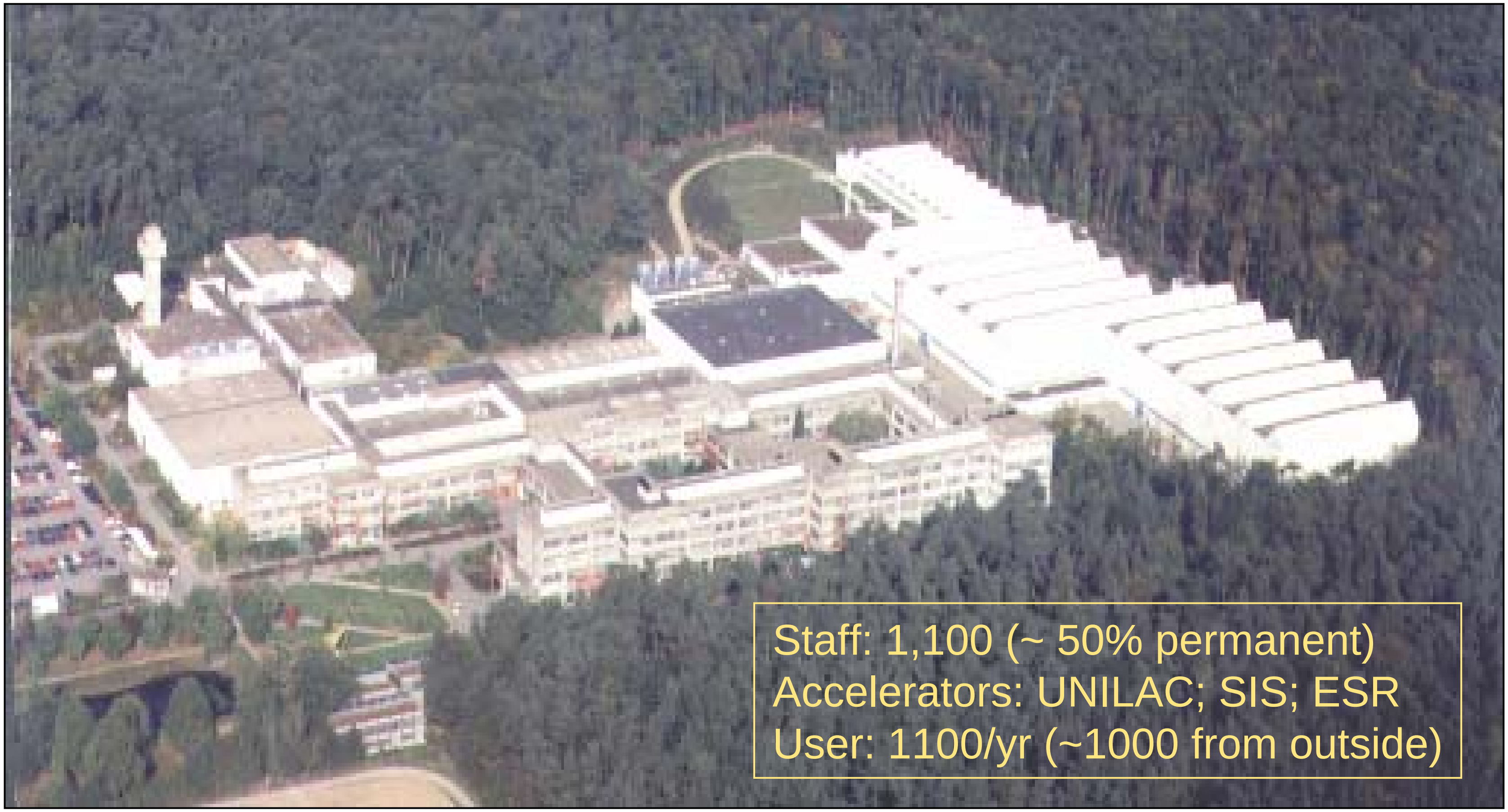
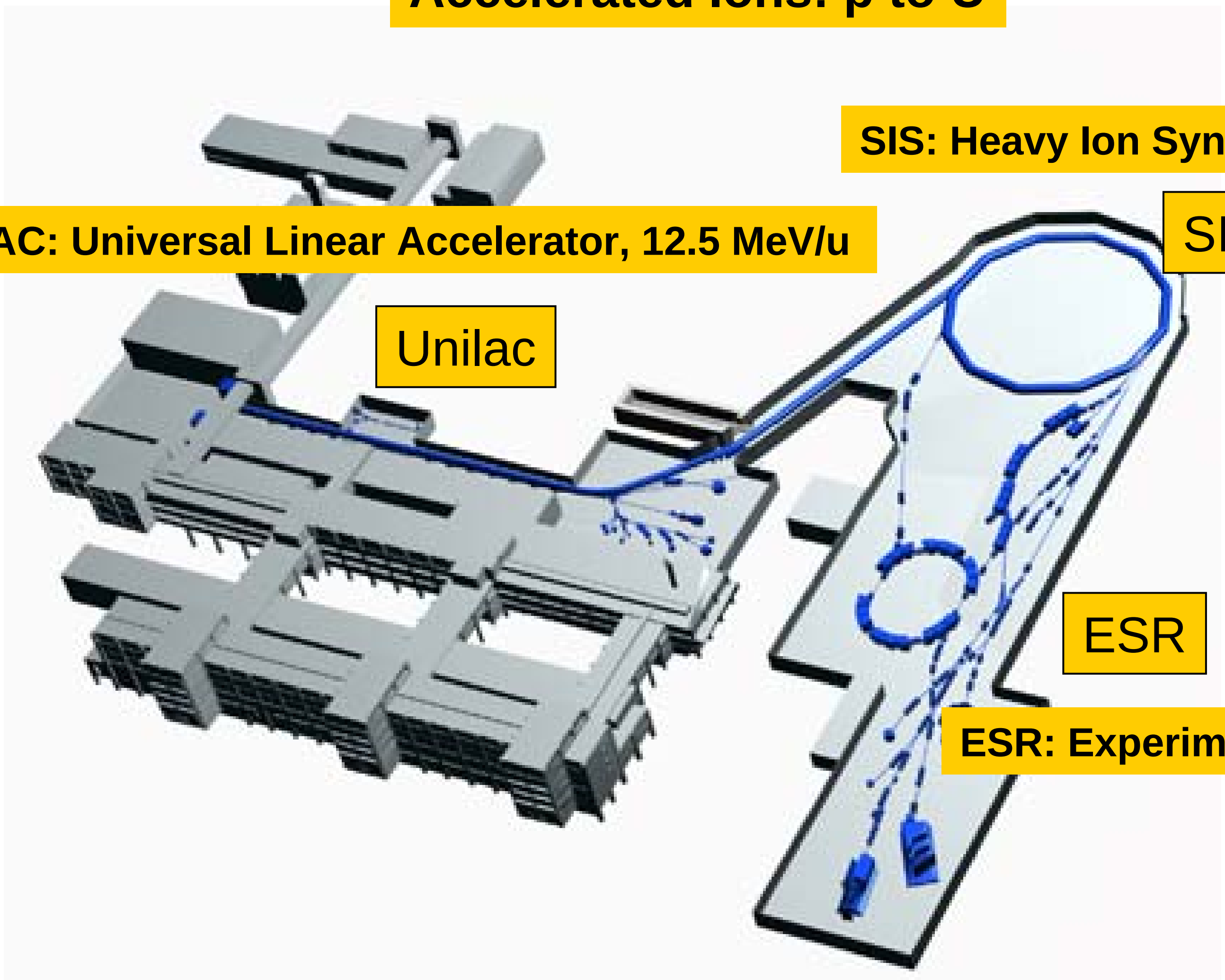
The GSI UNILAC Upgrade Program for FAIR Requirements



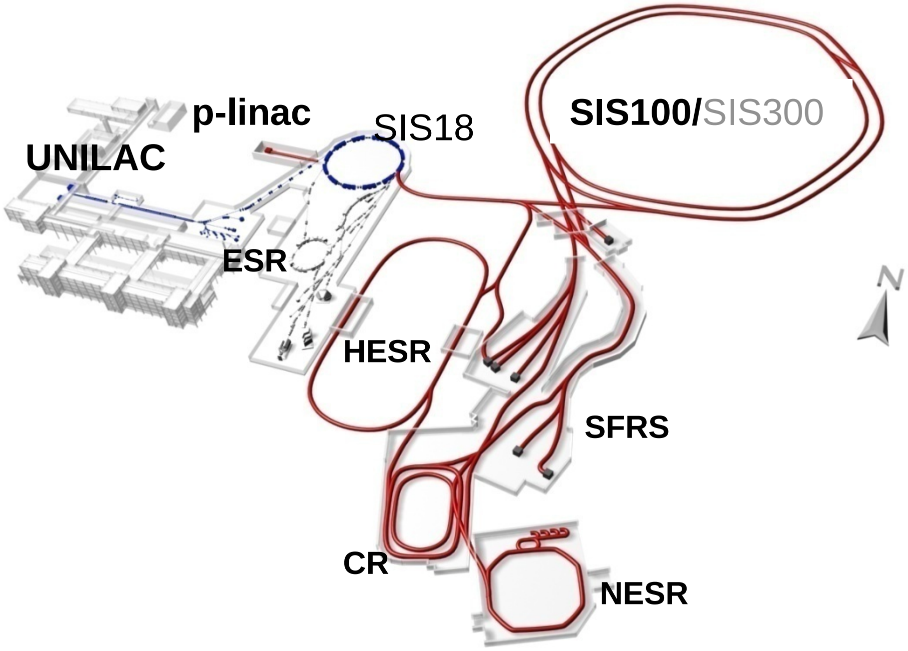
Member of Helmholtz Community

Present accelerators

Accelerated Ions: p to U



FAIR Beam Data



Primary beams

10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
10^{11}/s $^{238}U^{73+}$
100-1000 fold intensities
4x10^{13}/s 30 GeV Protons

Sekundary beams

wide range of radioactive beams
up to 1.5 - 2 GeV/u;
intensity gain of factor 10 000
Antiprotons 3 - 30 GeV

Storage and cooler rings

Radioactive beams
e – A(RIB) Collider
10^{11} stored and cooled 3 - 15 GeV pbars

Key technologies

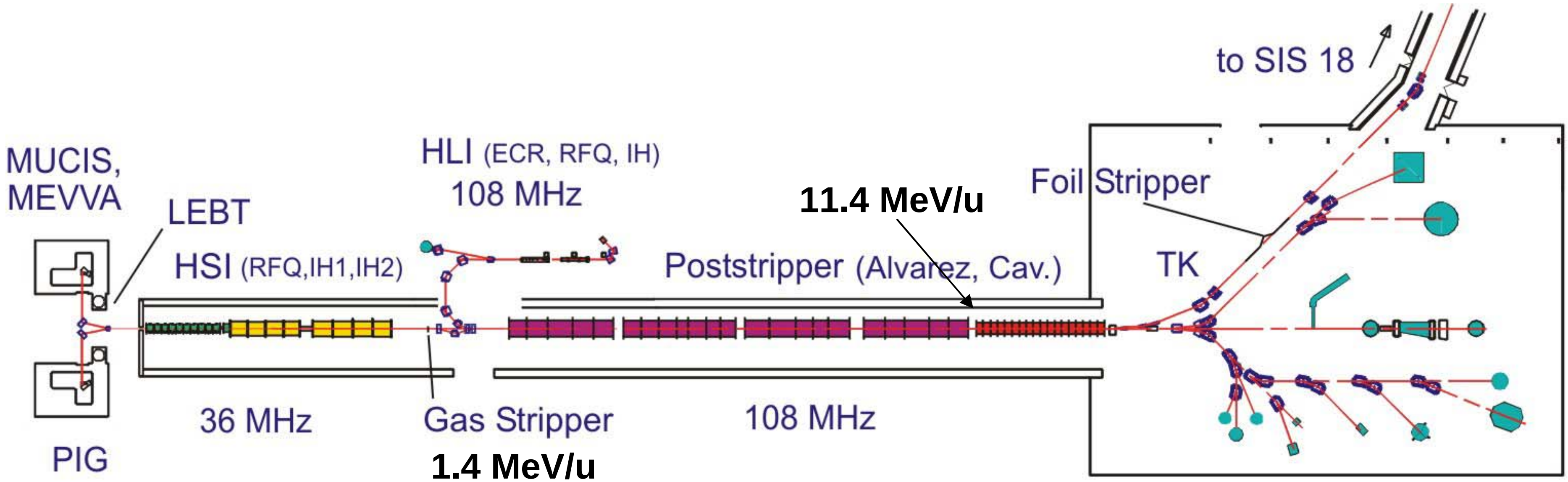
- Cooled beams
- Fast ramped super conducting magnets

FAIR beam intensity and beam quality requirements

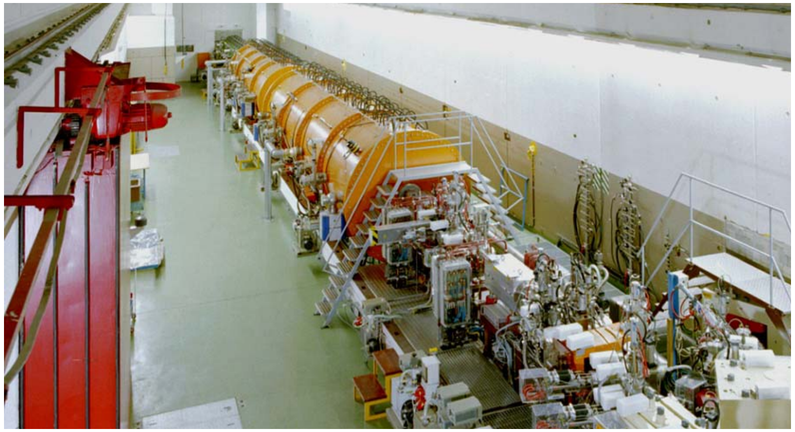
SIS space charge limit is reached by four 100 µs injections with each fifteen Multiturns. Uranium reference beam intensities:

	HSI entrance	HSI exit	Alvarez entrance	SIS 18 injection
ION SPECIES	$^{238}U^{4+}$	$^{238}U^{4+}$	$^{238}U^{28+}$	$^{238}U^{28+}$
El. Current [mA]	20	18	15	15
Part. per 100µs pulse	$3 \cdot 10^{12}$	$2.4 \cdot 10^{12}$	$3.2 \cdot 10^{11}$	$3.2 \cdot 10^{11}$
Energy [MeV/u]	0.0022	1.4	1.4	11.4
$\Delta W/W$	-	$\pm 4 \cdot 10^{-3}$	$\pm 2 \cdot 10^{-3}$	$\pm 2 \cdot 10^{-3}$
$\varepsilon_{n,x}$ [mm mrad]	0.3	0.5	0.75	1.0
$\varepsilon_{n,y}$ [mm mrad]	0.3	0.5	0.75	2.5

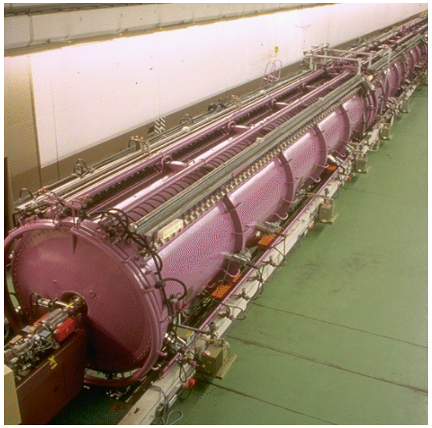
The UNILAC



High Current Injector

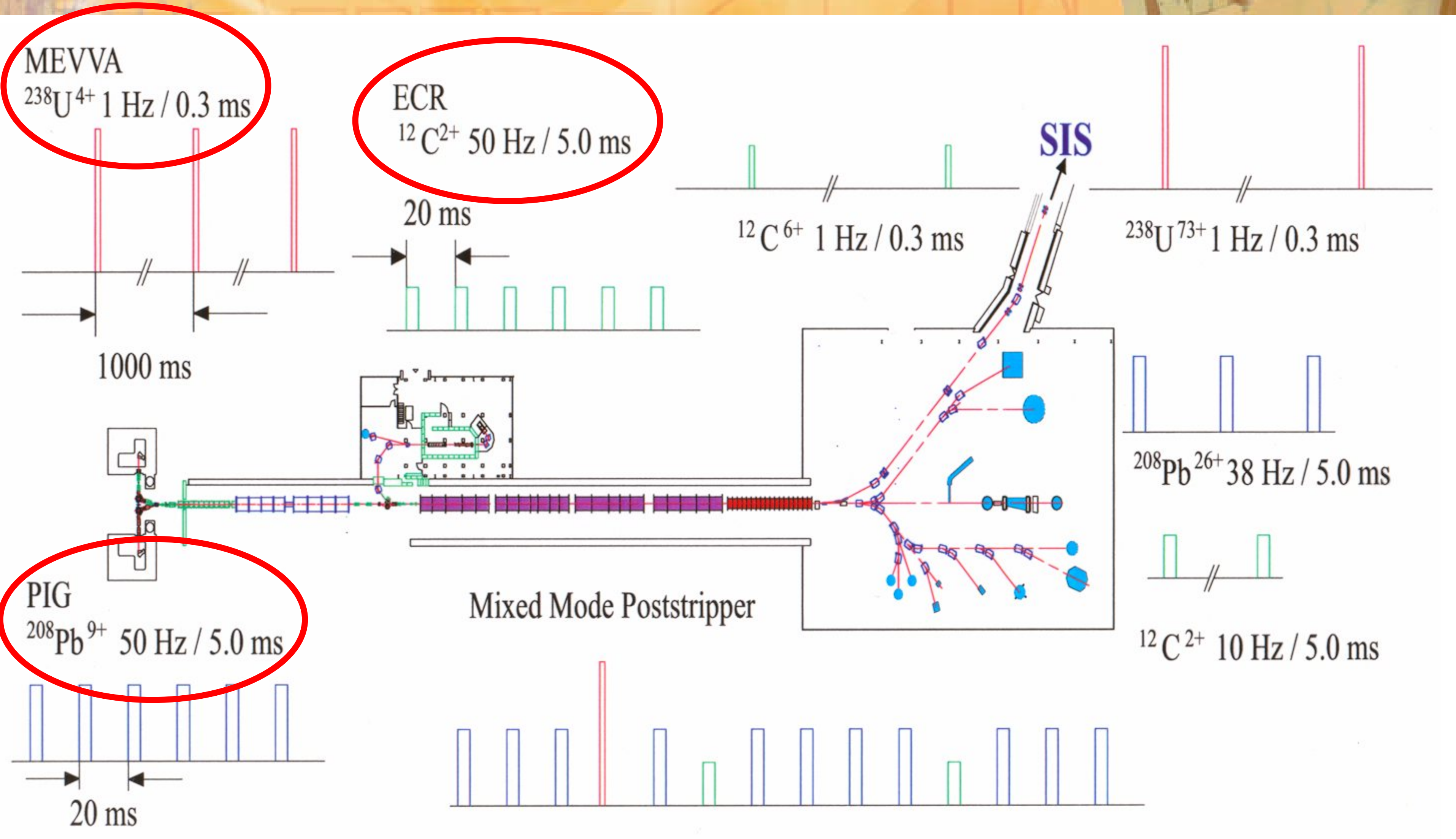


Alvarez

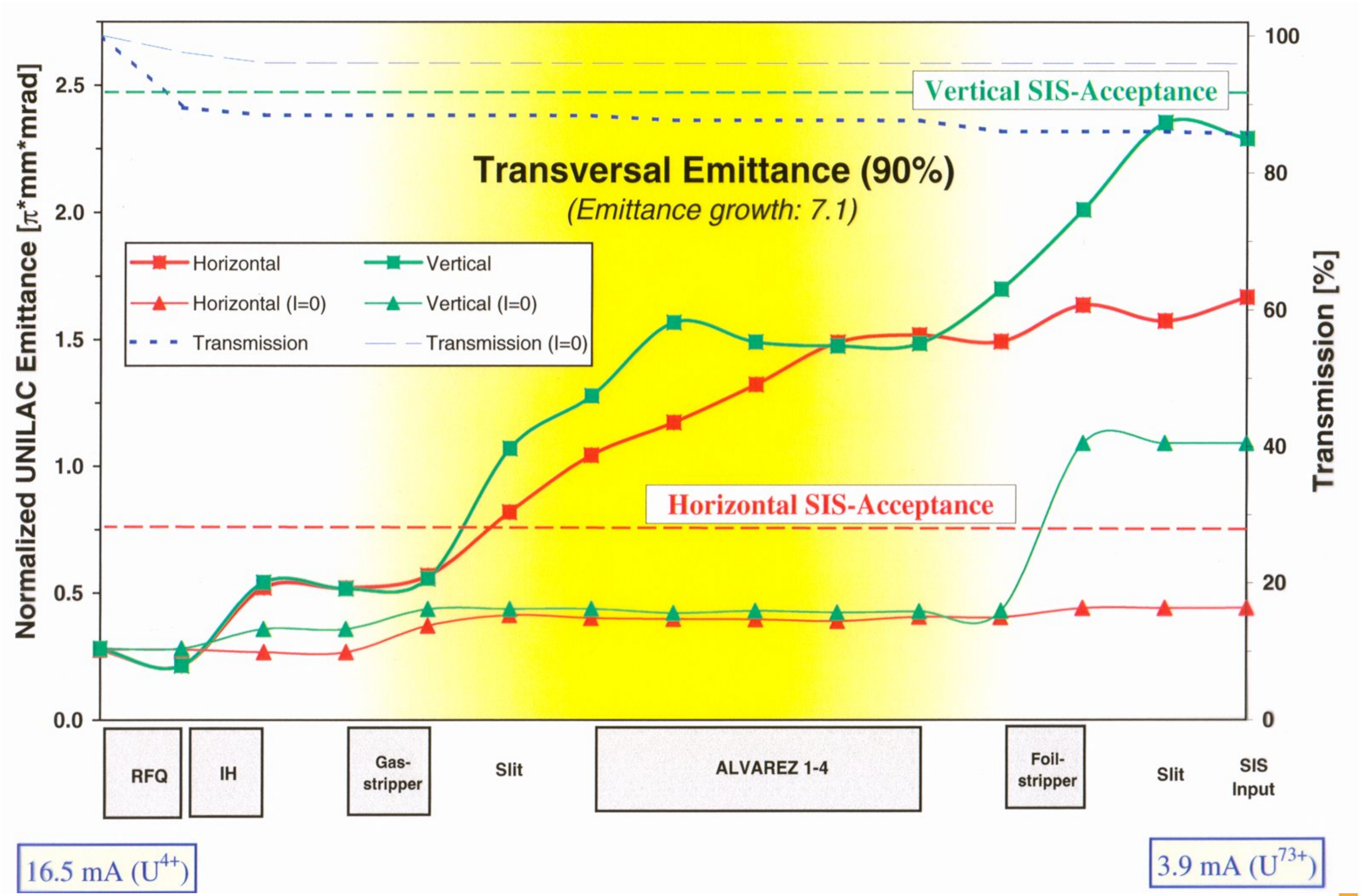


Single Gap Resonators

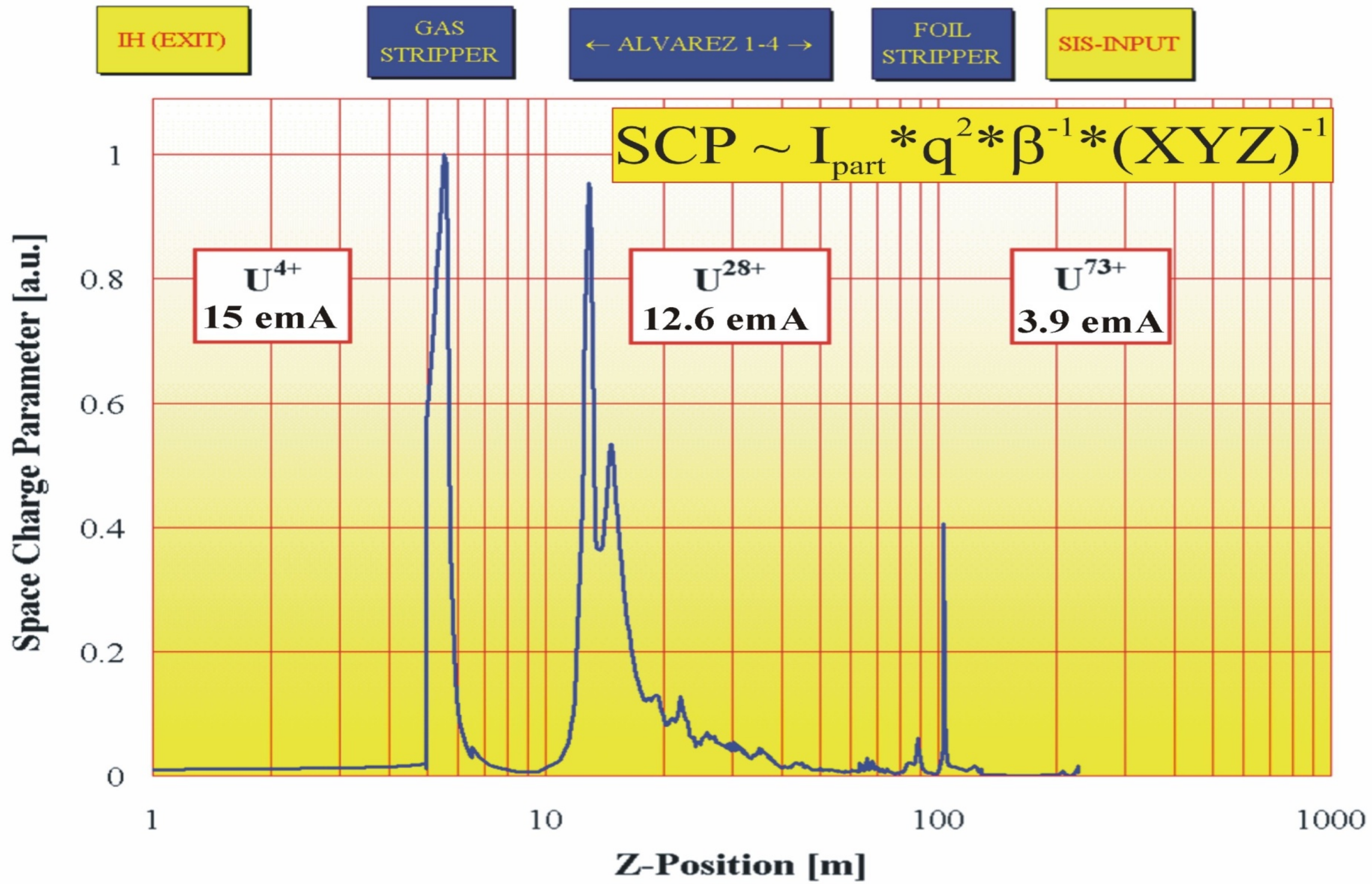
Example of three beam pulse-to-pulse operation



Transverse emittance growth along the UNILAC

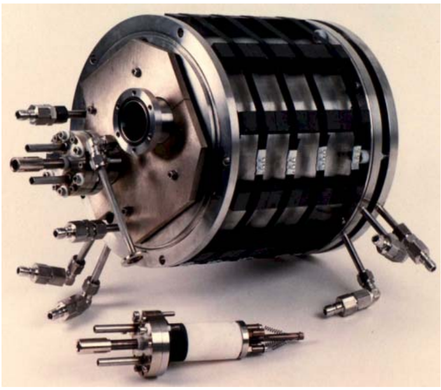


Space charge forces along the UNILAC

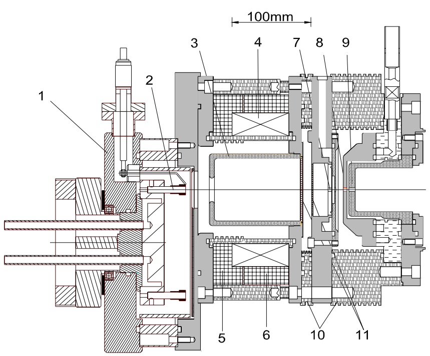


Calculated by PARMILA and PARMTRA codes

MUCIS & MEVVA- Ion Sources



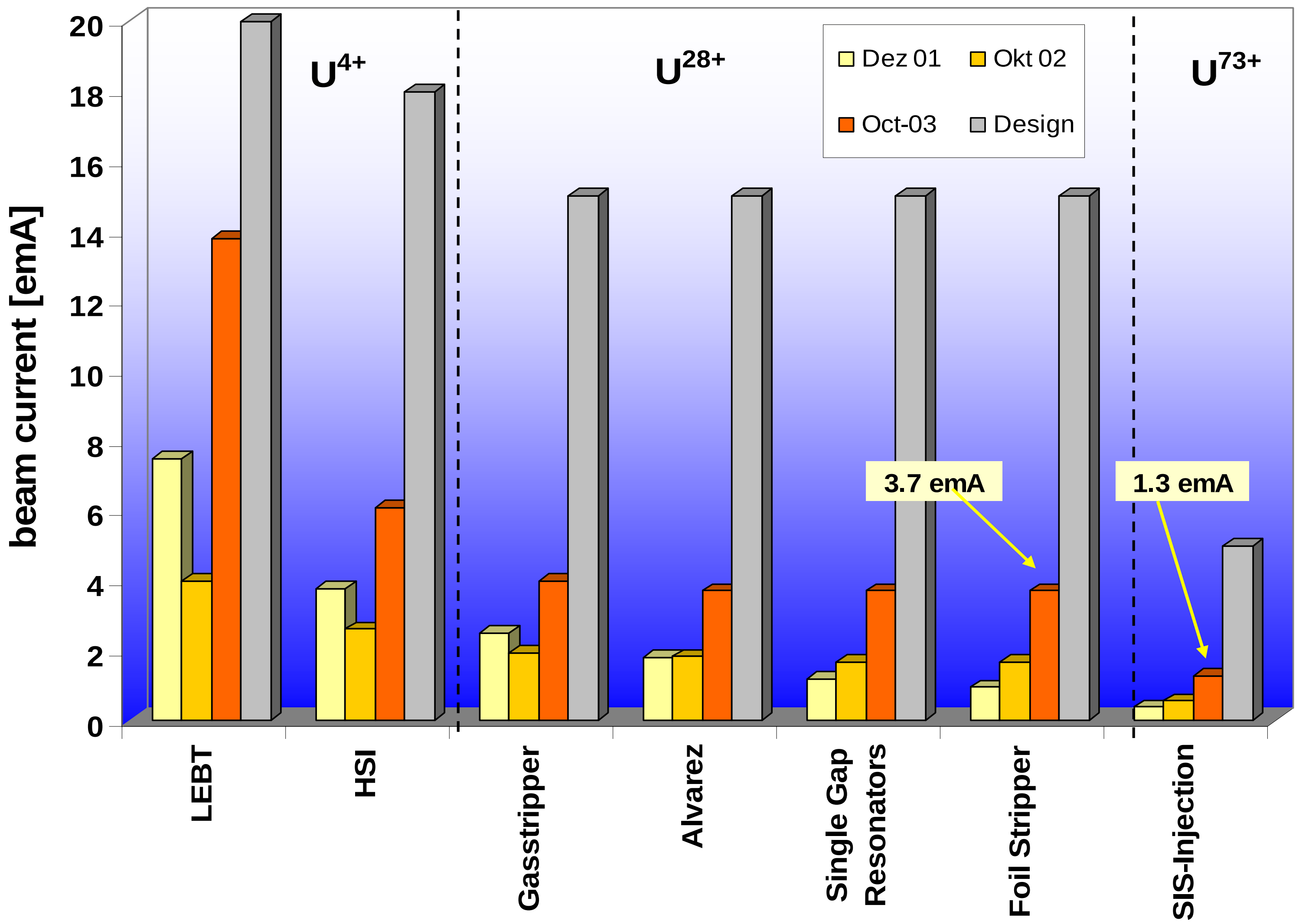
MUCIS
(Multi Cusp Ion Source)
(Emission Current Density ≤150 mA/cm²)



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

		HSI-INJECTION	DESIGN
MUCIS	H_3^+	1.0 mA	1.0 mA
	D_3^+	2.0 mA	2.0 mA
	$^{12}C^+$	7.0 mA	4.0 mA
	$^{14}N^+$	4.0 mA	4.8 mA
	$^{18}O^+$	5.0 mA	6.0 mA
	$^{20}Ne^+$	5.5 mA	6.8 mA
	CO^+	6.0 mA	10.1 mA
	$^{40}Ar^{1+}$	**19.0 mA**	**13.5 mA**
	$^{86}Kr^{2+}$	8.0 mA	14.5 mA
	$^{129}Xe^{2+}$	0.75 mA	21.2 mA
MEVVA	$^{12}C^+$	5.5 mA	4.0 mA
	$^{48}Ti^{1+}$	3.0 mA	16.1 mA
	$^{48}Ti^{2+}$	20.0 mA	7.5 mA
	$^{48}Ti^{3+}$	20.0 mA	5.4 mA
	$^{52}Cr^{1+}$	6.0 mA	17.5 mA
	$^{58}Ni^{1+}$	10.0 mA	19.5 mA
	$^{92}Mo^{2+}$	6.0 mA	15.5 mA
	$^{238}U^{4+}$	**16.0 mA**	**20.0 mA**

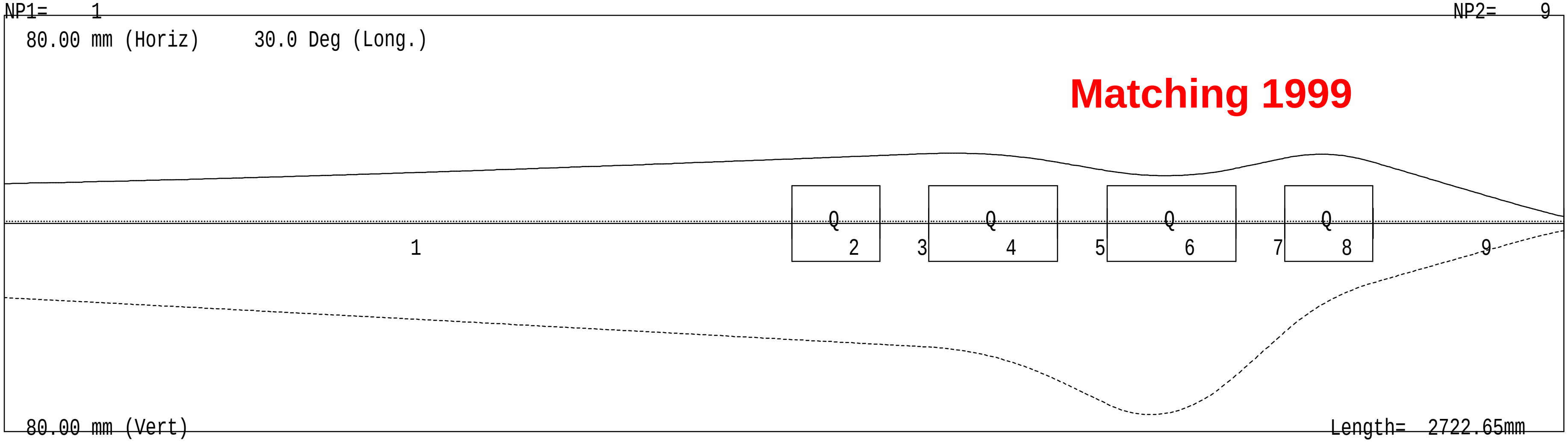
Status of Uranium intensity in 2003

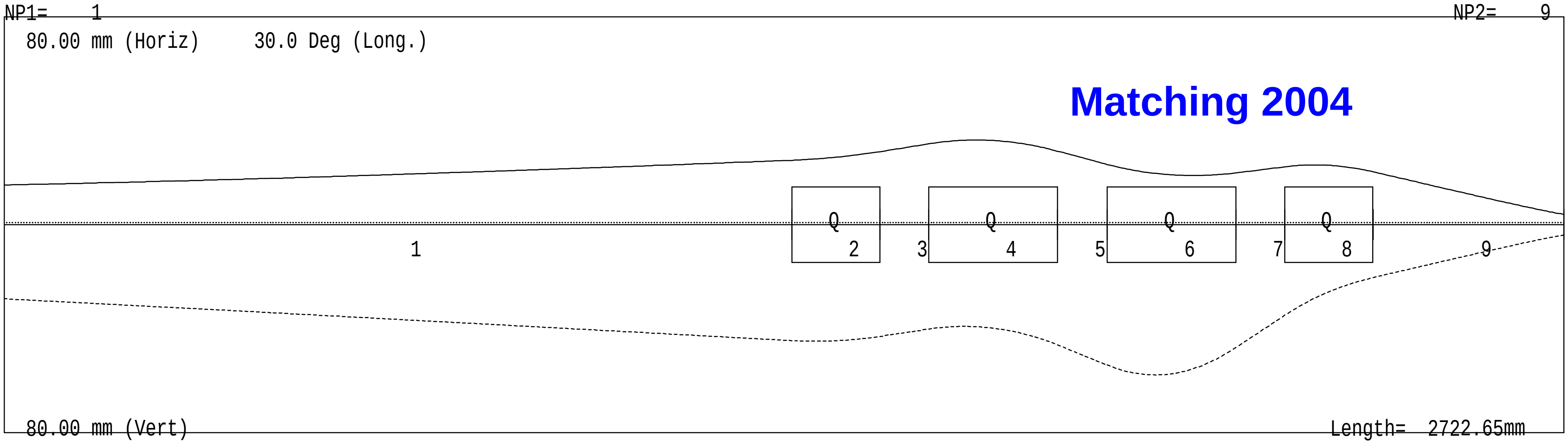


Unilac measures since 2003

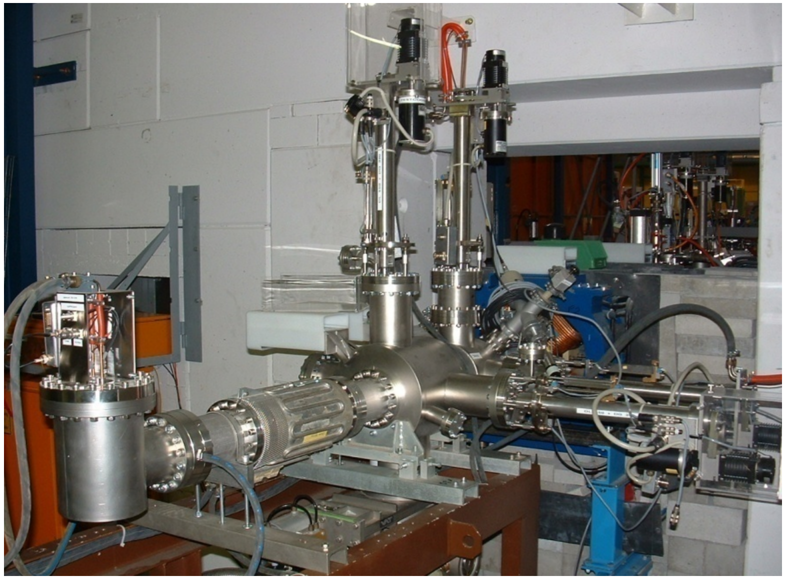
- **Improvement of the Mevva high current ion source**
- **RFQ-Upgrade: exchange of RFQ minivanes, modified IRM**
- **Increased stripper gas density**
- **Matching to the Alvarez DTL under space charge conditions**
- **Increase of Alvarez DTL transverse phase advance**
- **High current beam diagnostics, measurement of long. emittance**
- **Machine investigations: frontend, Alvarez matching, transfer line long. and transv. emittance measurements**
- ***New charge state separator in the transfer channel to SIS18 for U73+***

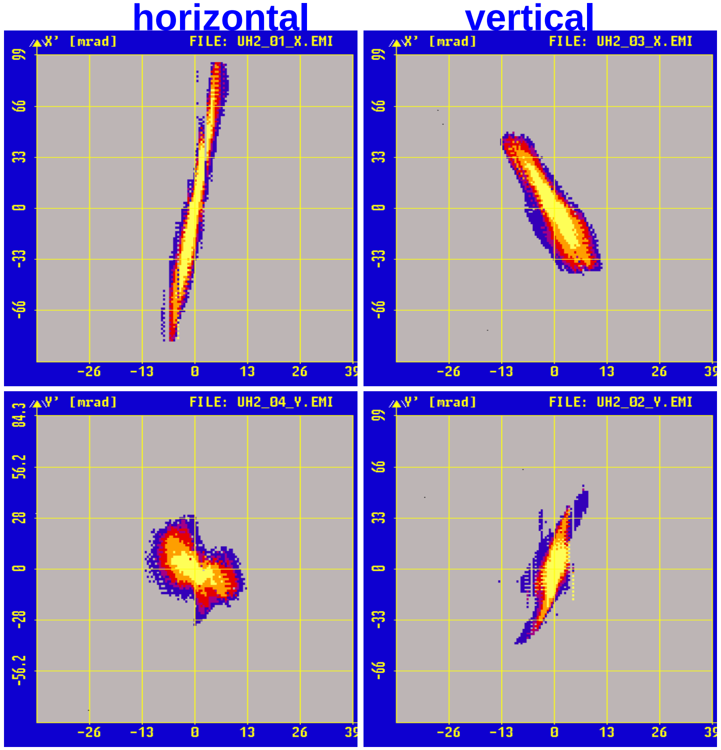
RFQ-Upgrade: Modified Input Radial Matcher





LEBT emittance measurements with U^{4+} beam of 8 emA

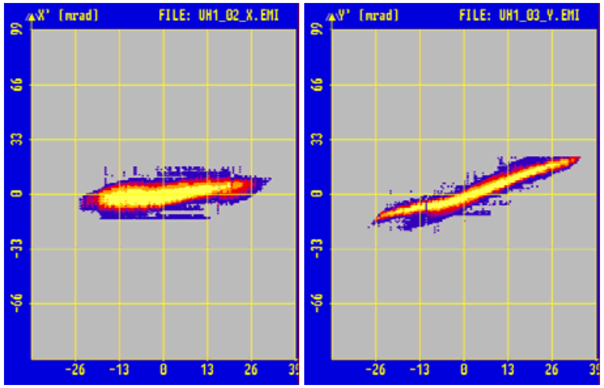




1999

2004

before Quadrupole Quartet



Emittance Growth: -19 % (3 %)

Transmission: 70 % (84 %)

2006: Mevva ion source: 37 emA of U^{4+} and 18 emA of U^{3+} beam

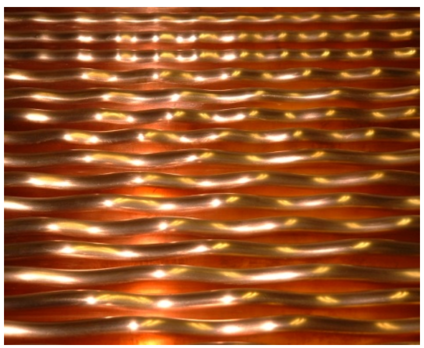
RFQ-upgrade: new RFQ-rods in 2004

Two reasons: improved input matching (Stepan Yaramishev)

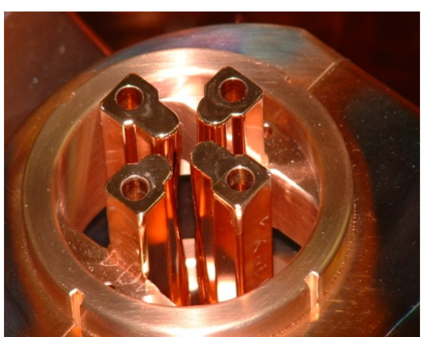
high power consumption , dark currents

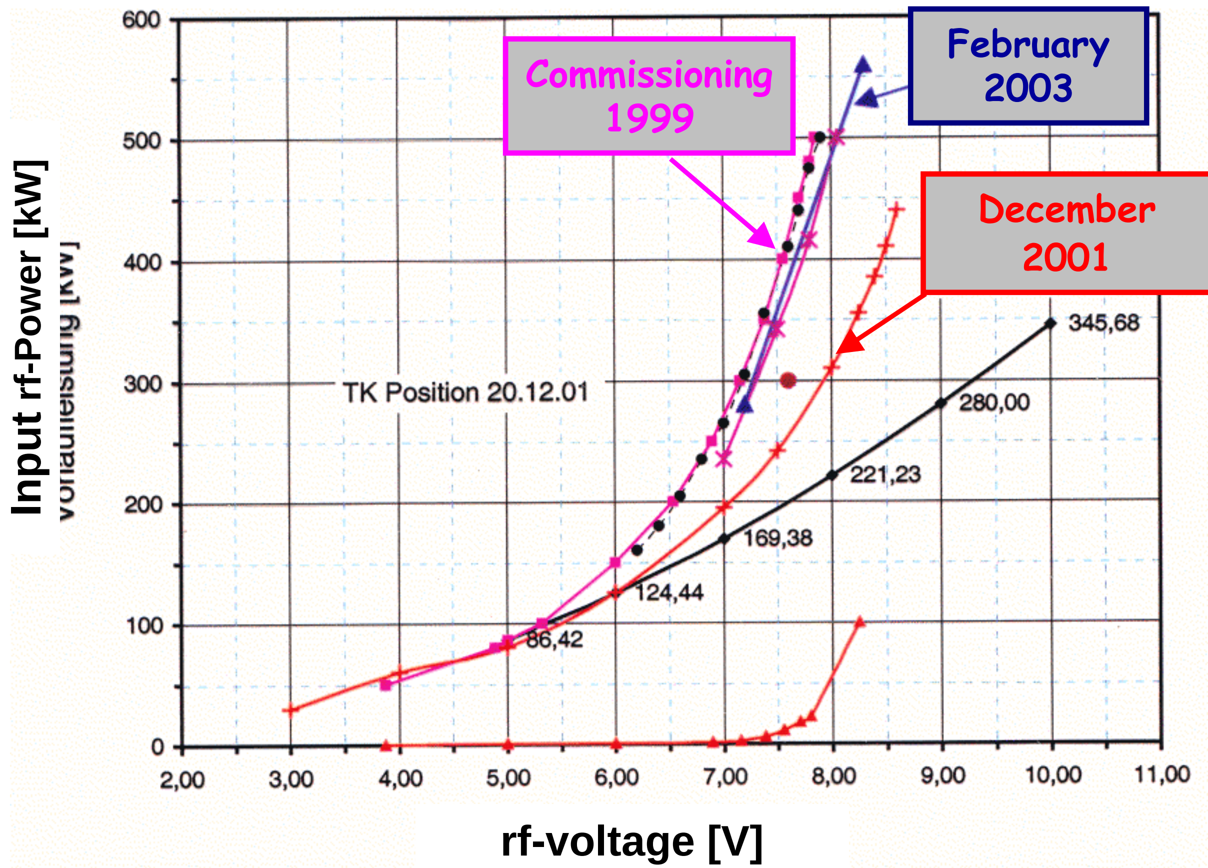
After
5 years of
operation

New
RFQ-rods

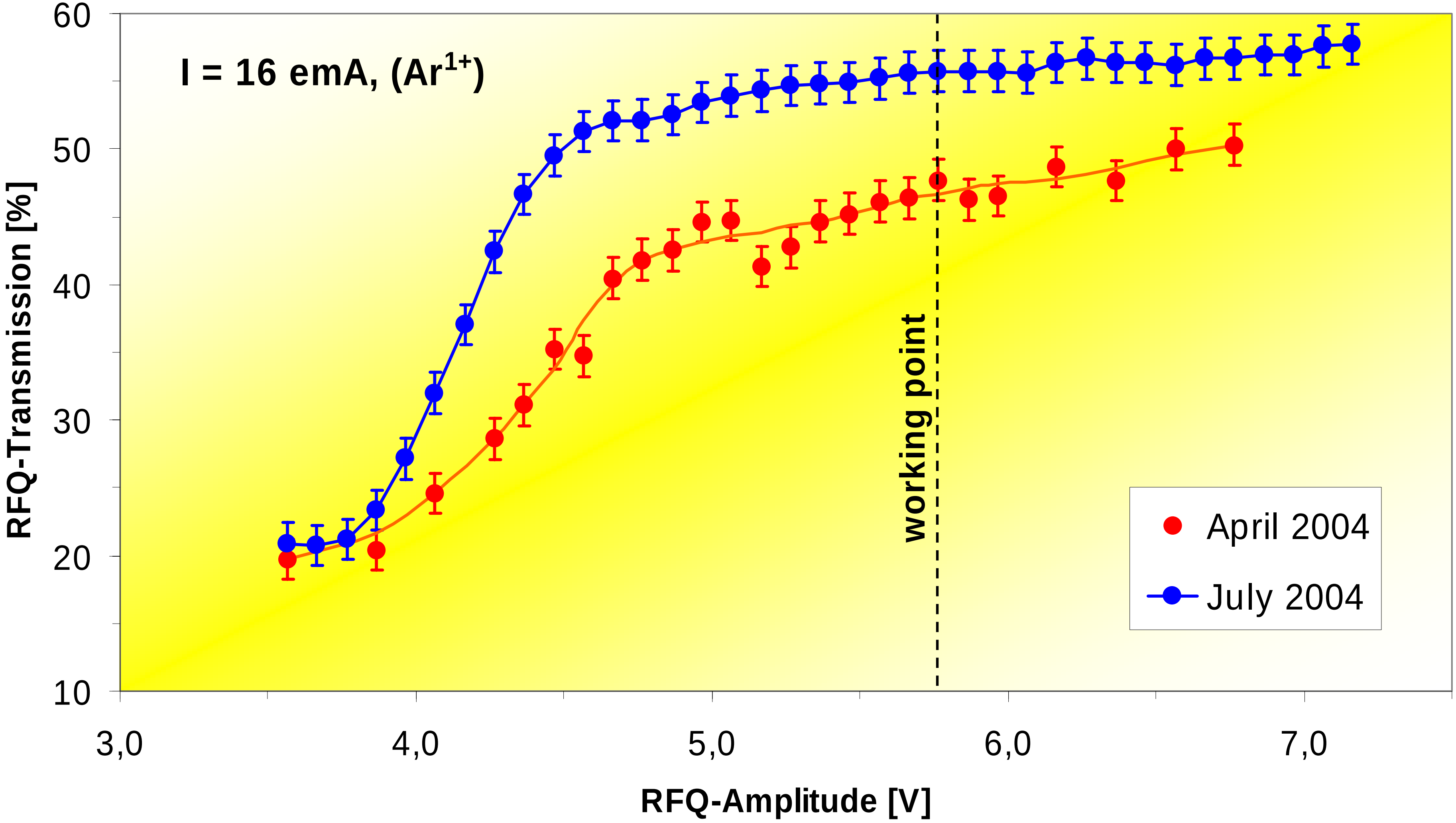


After
copper-
plating

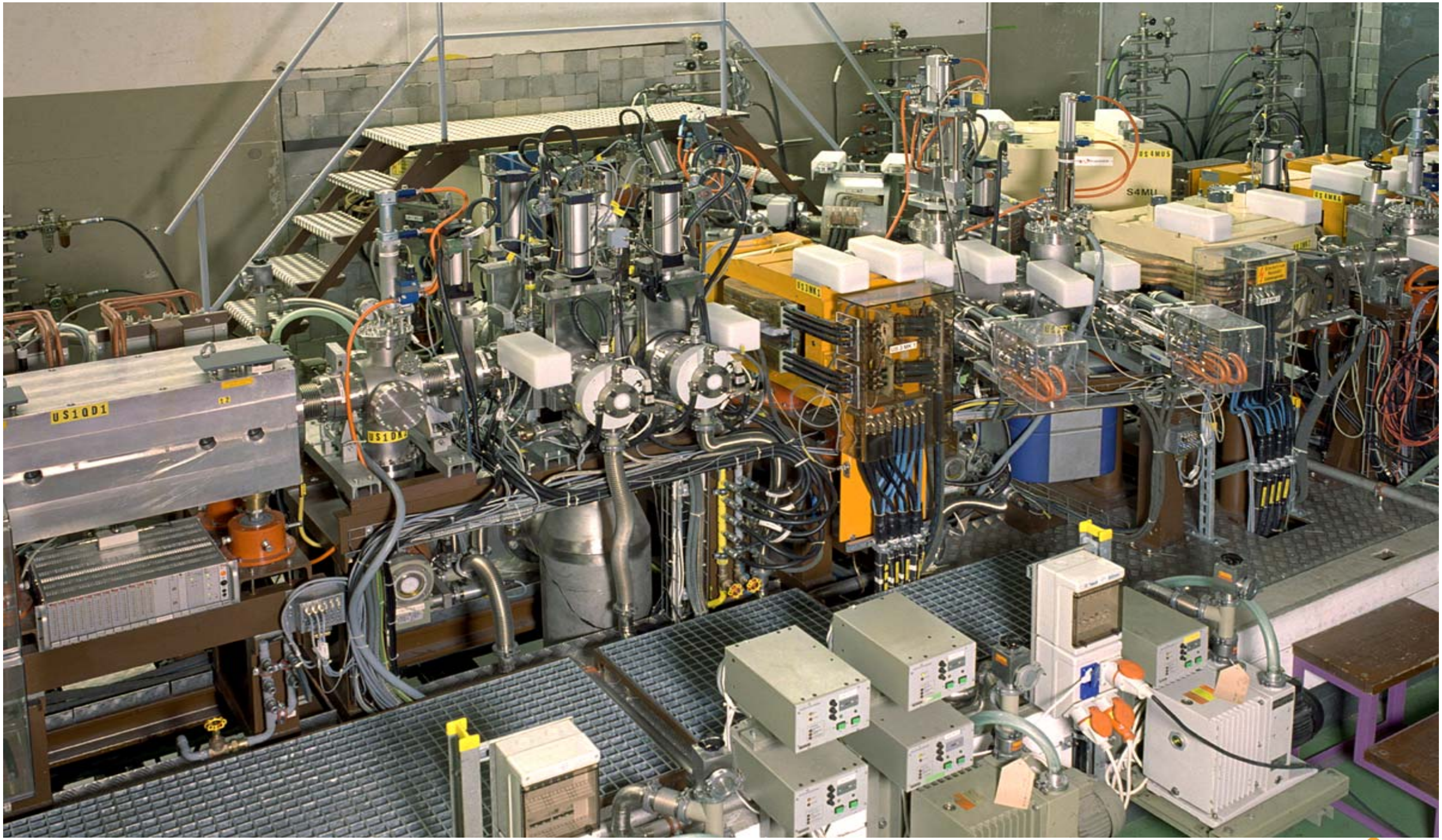




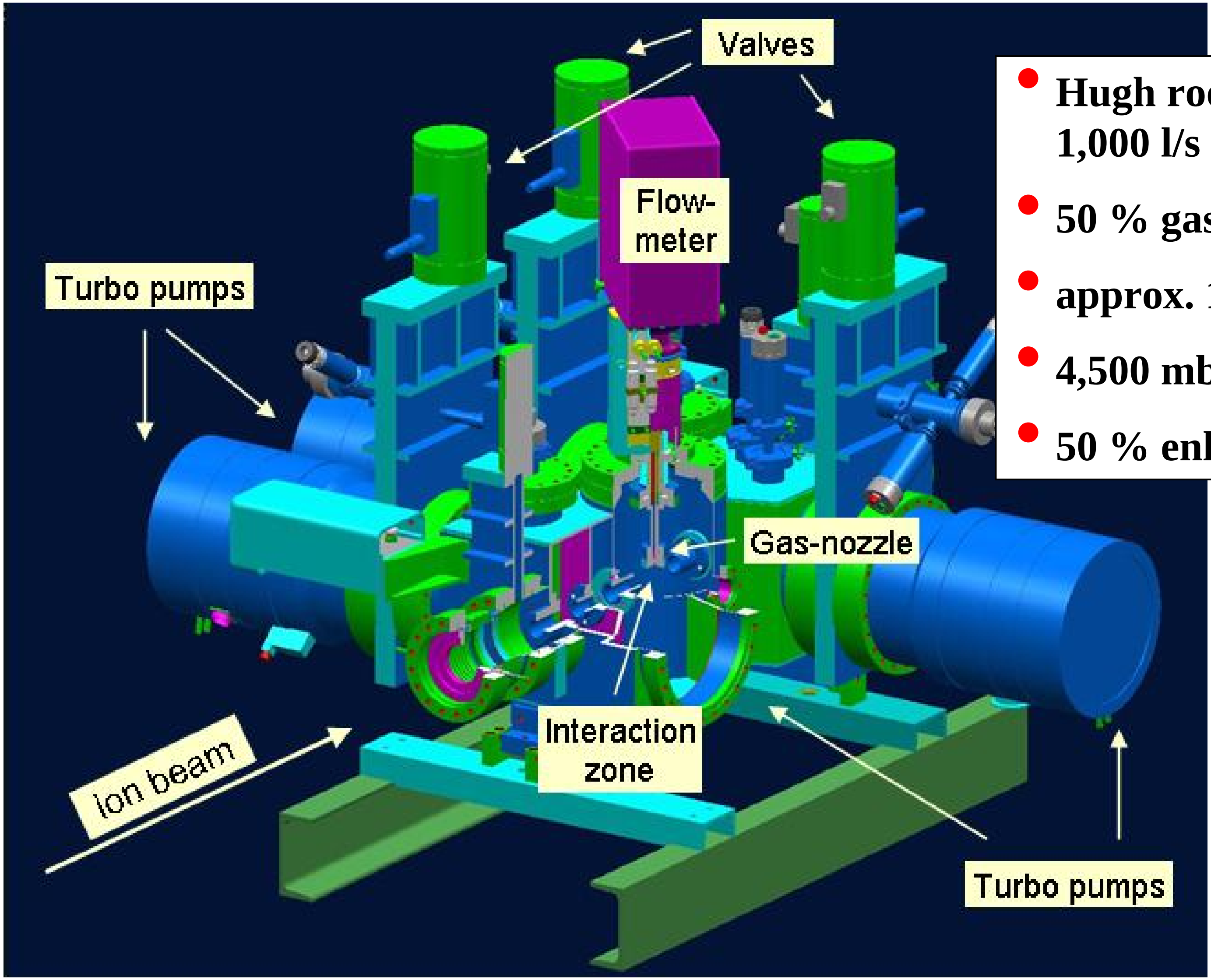
HSI RFQ commissioning (7/2004)



GSI Nitrogen gas stripper section at 1.4 MeV/u



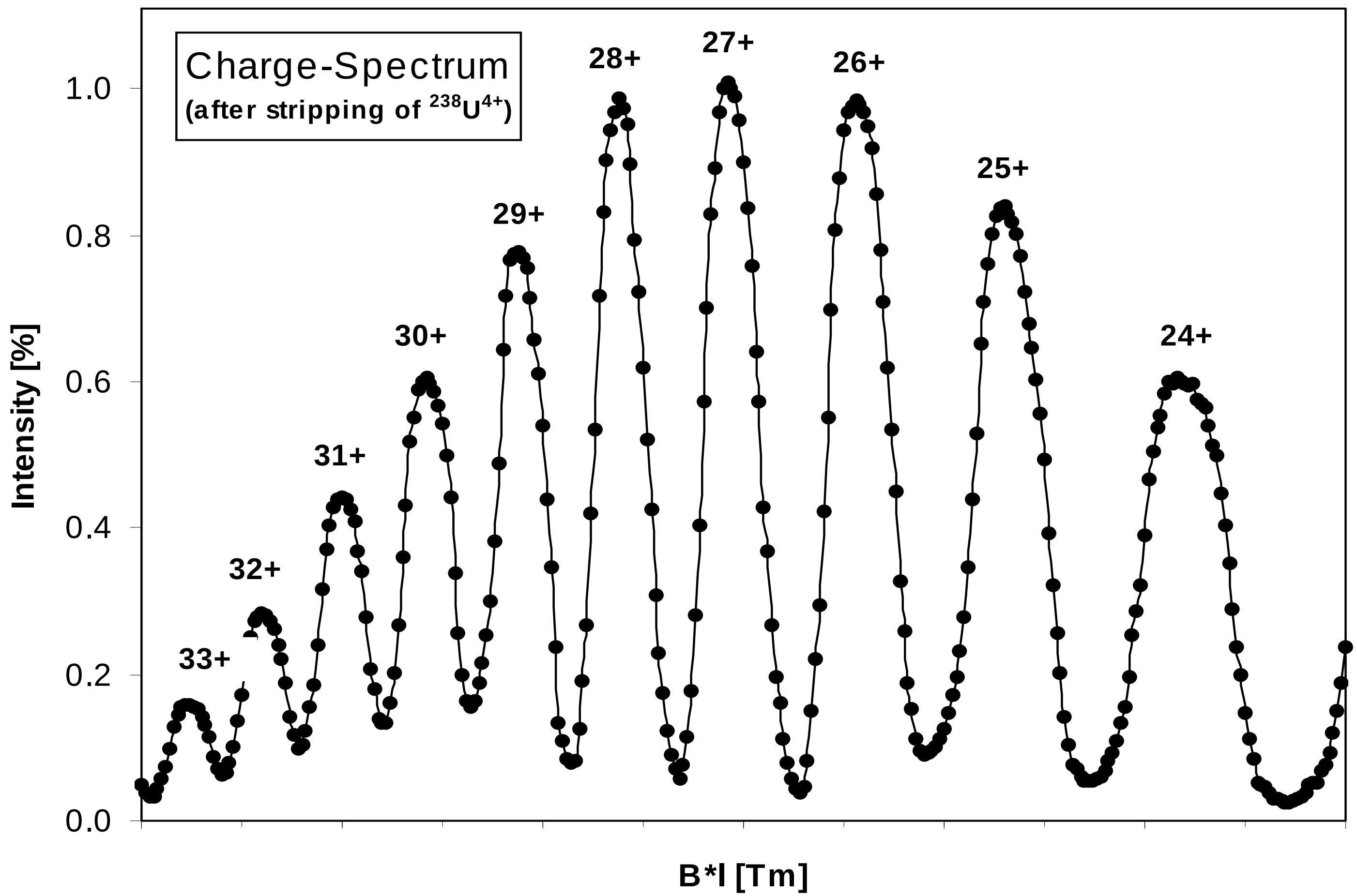
Increase of pressure and pumping capacity



- **Hugh roots pump and four 1,000 l/s turbo pumps**
- **50 % gas density increase**
- **approx. 1 µg/cm^2 gas density**
- **4,500 mbar at nozzle**
- **50 % enlarged beam aperture**

Charge state spectrum of an Uranium beam

14 % of particles within charge state 28+



Alvarez-Matching

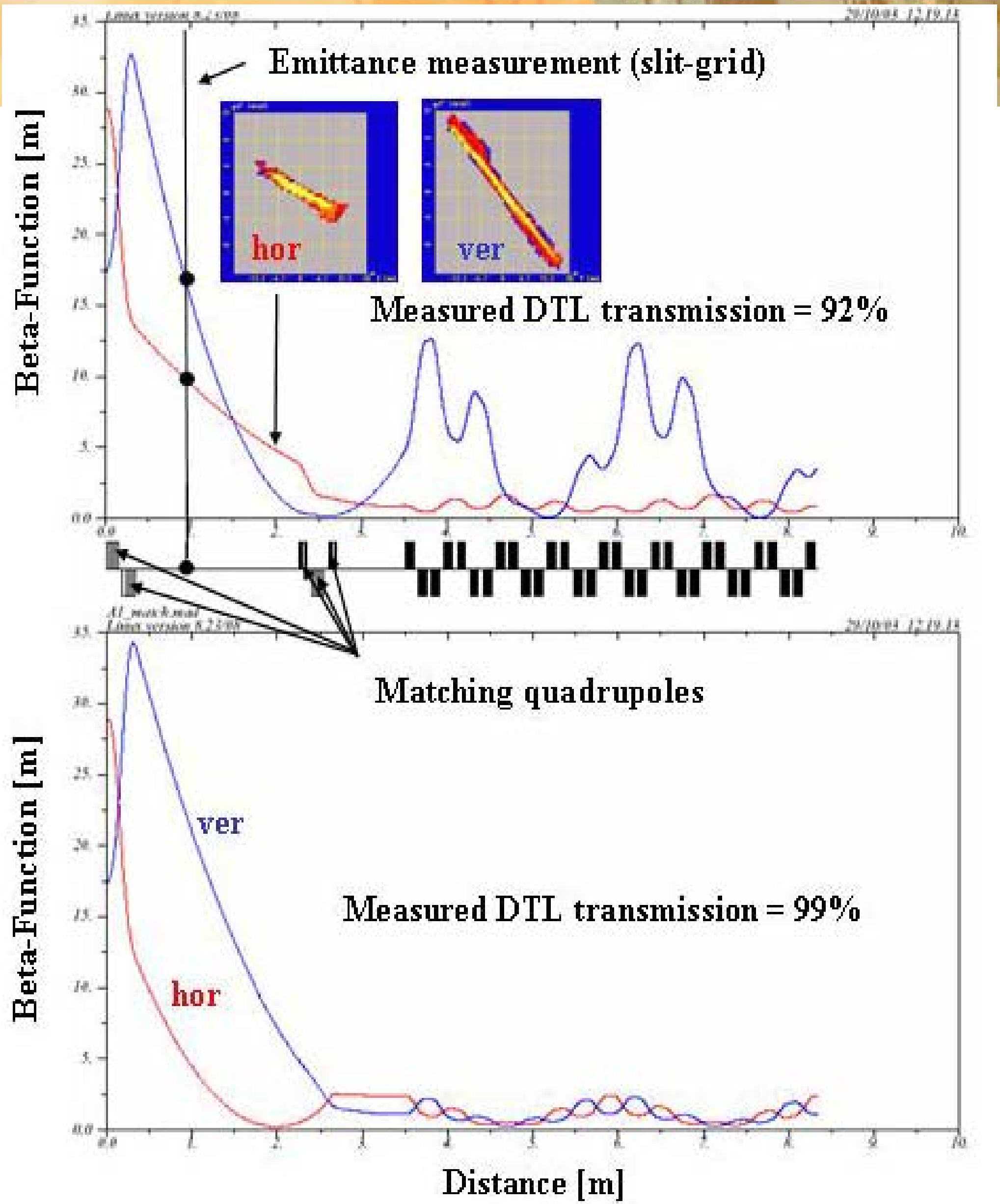
Periodicity FDDF, interrupted by the intertank sections

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

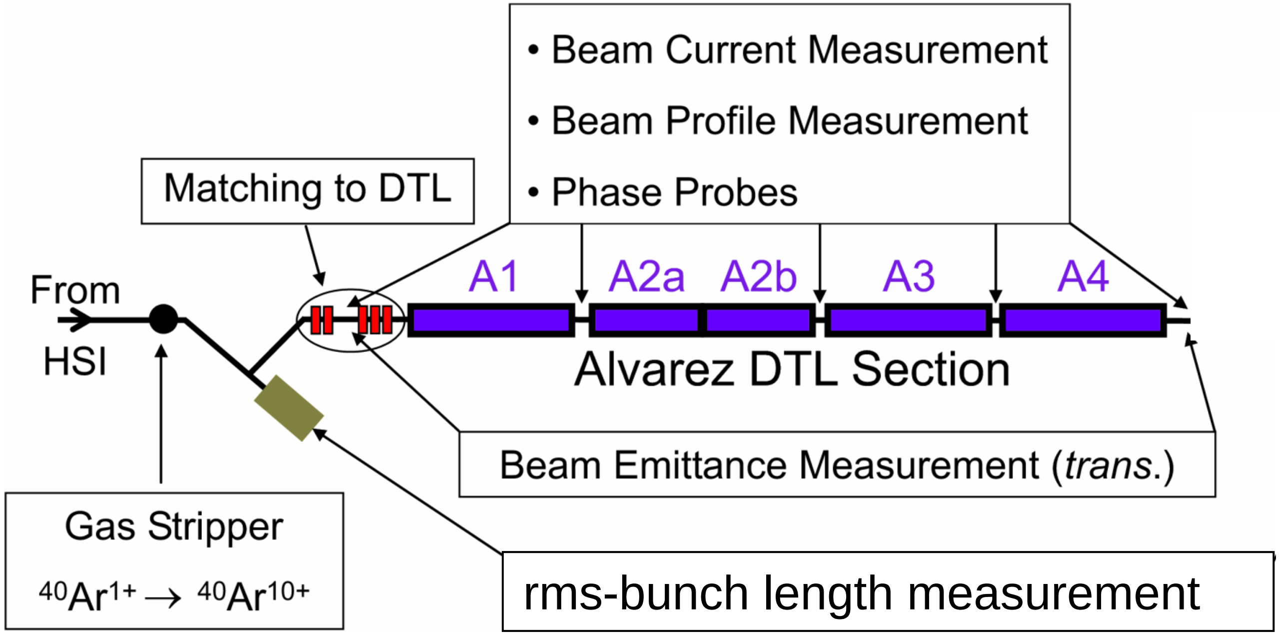
Betafunction (before Matching)

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

Betafunction (afterMatching)



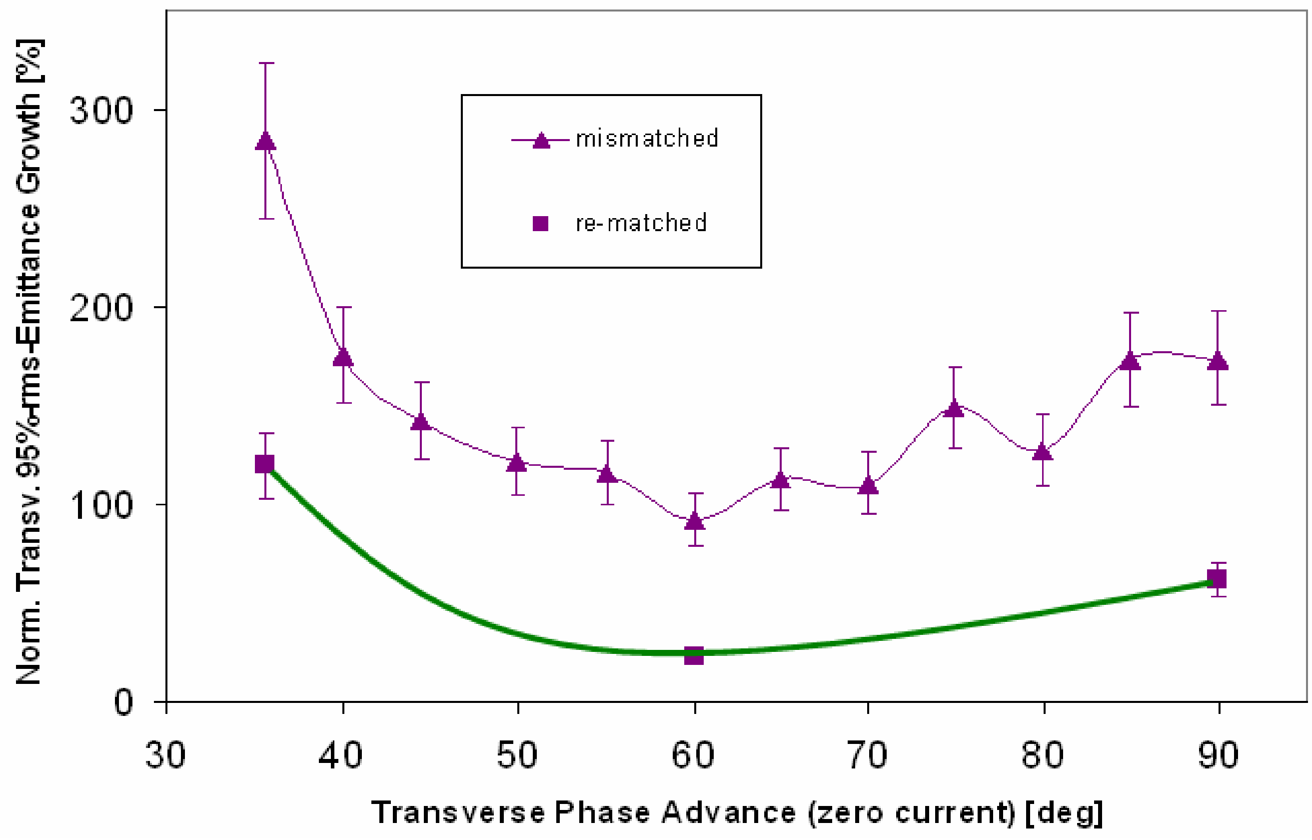
Experimental Set-up for Alvarez DTL matching



- set beam current to 7.1 mA of $^{40}Ar^{10+}$ (equiv. to FAIR design of 15 mA of $^{238}U^{28+}$)
- measure hor., ver. emittance and long. rms-bunch length at DTL entrance
- set DTL transverse phase advance to values from 35° to 90°
  - tune depression varied from 21% (90°) to 43% (35°)
- measure transmission, hor., and ver. rms-emittance at DTL exit

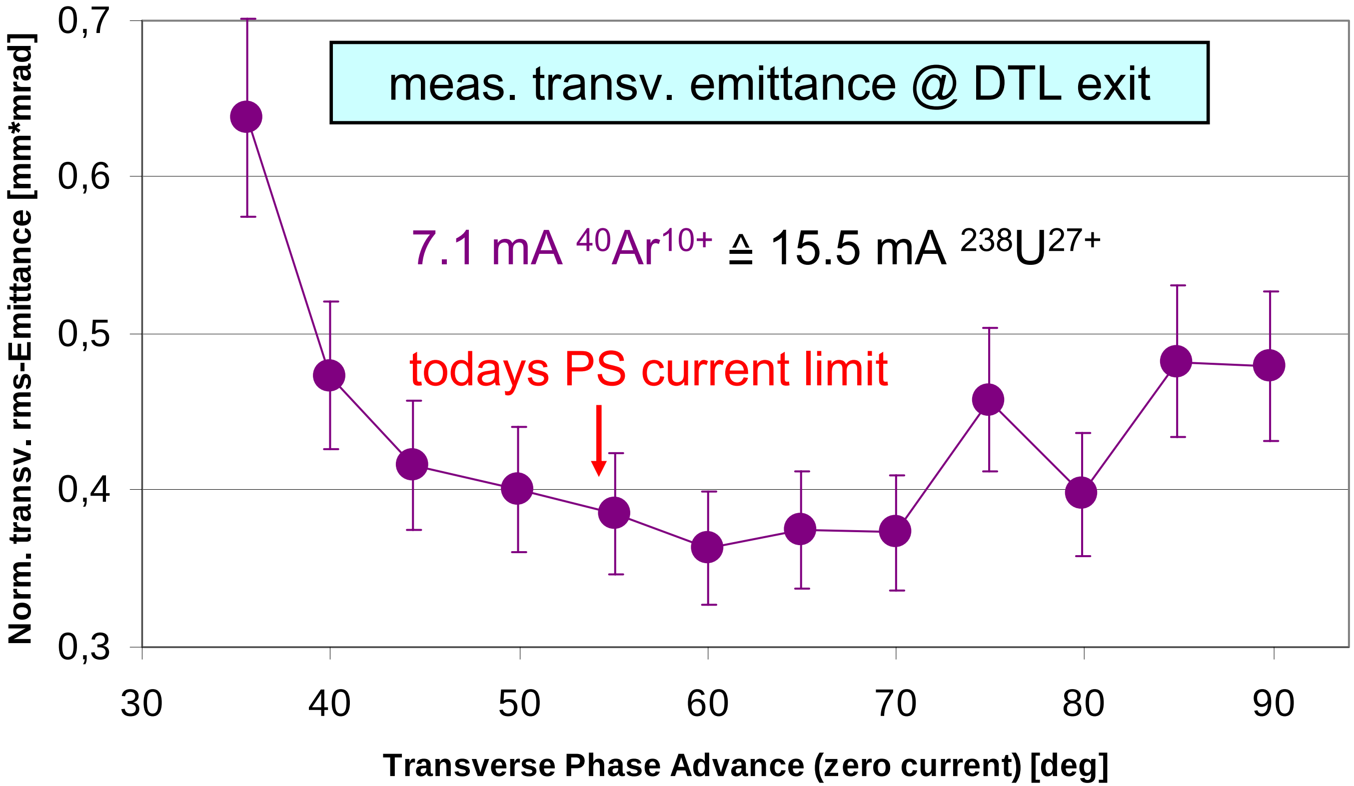
Transverse emittance growth in Alvarez DTL

$^{40}Ar^{10+}$ beam, 7.1 emA, equivalent to 15 emA U^{28+} beam

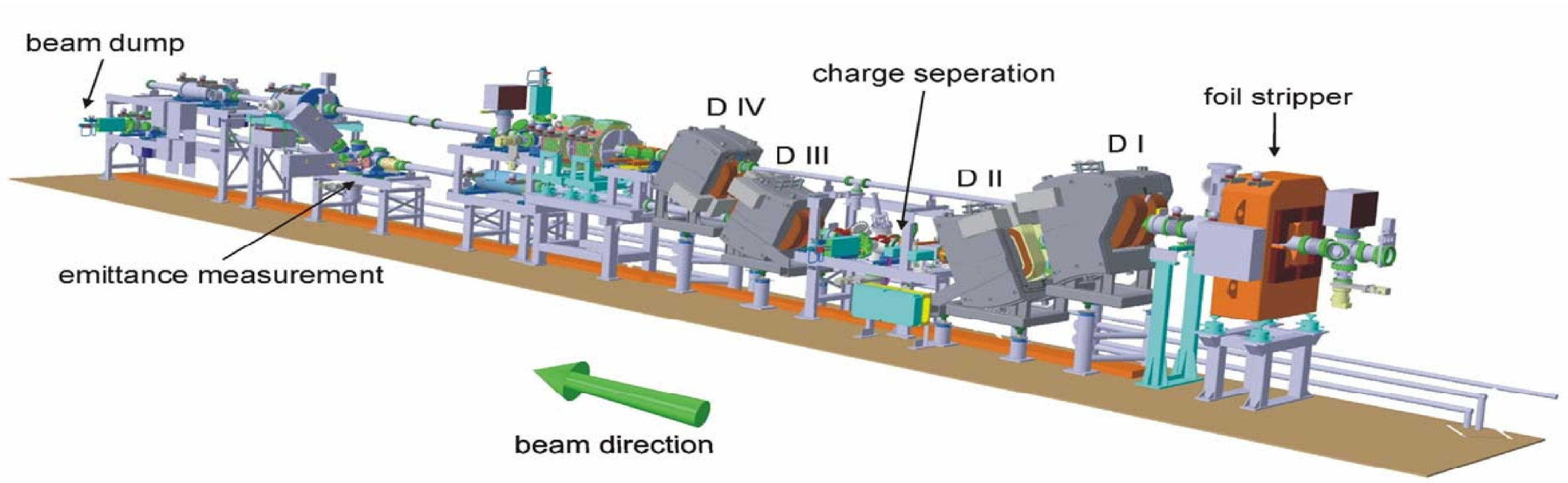


New Power Supplies for the Alvarez dc-Magnets

- 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

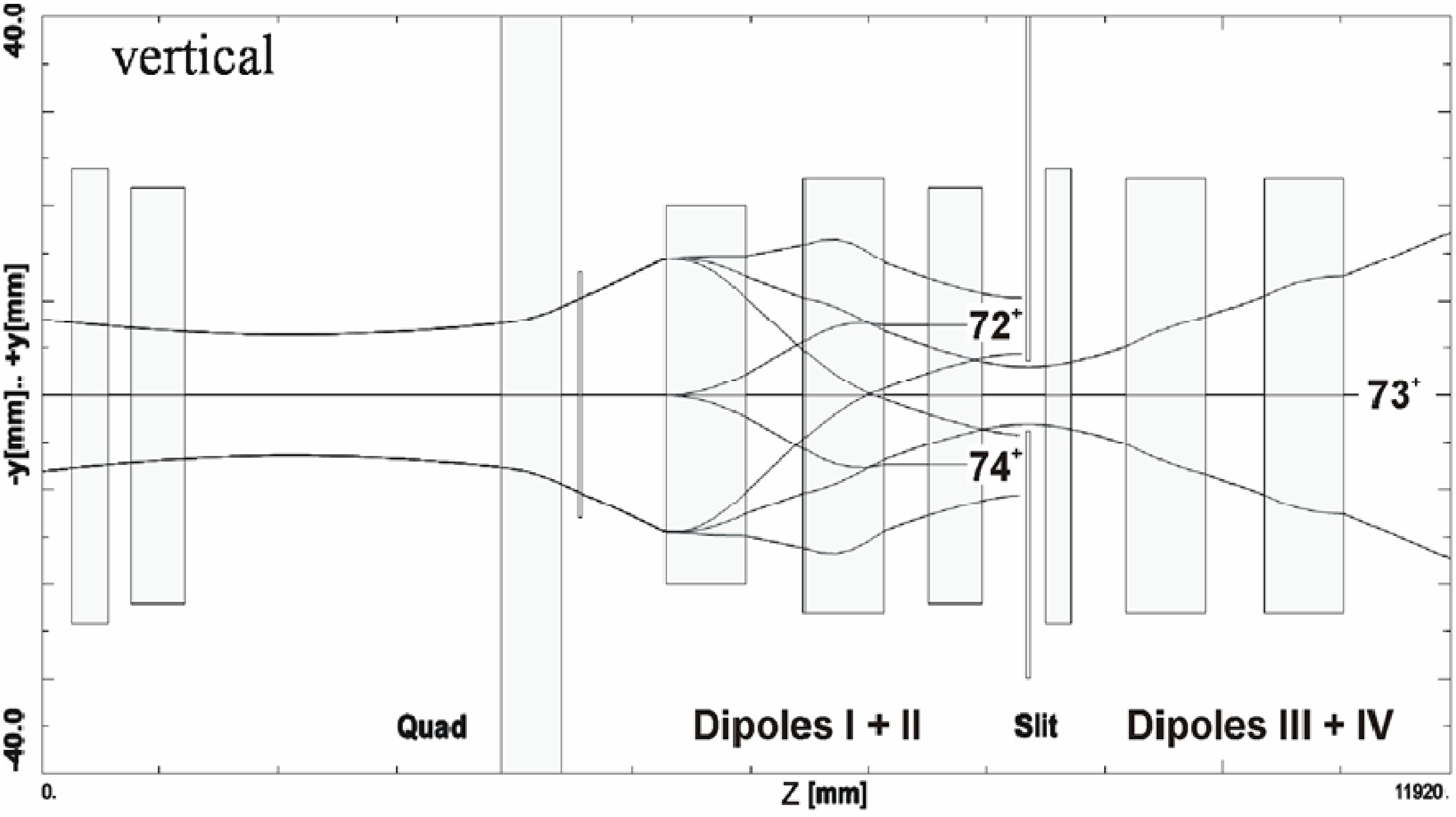


New charge state separator behind foil stripper

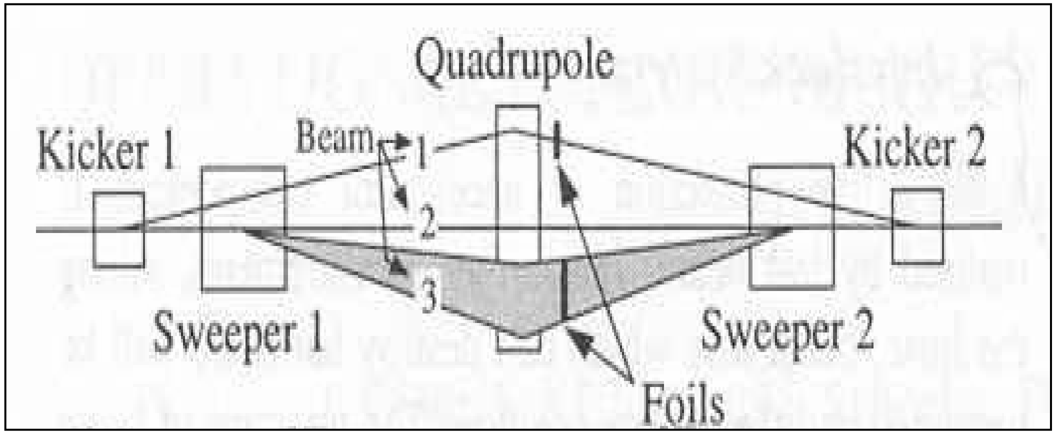


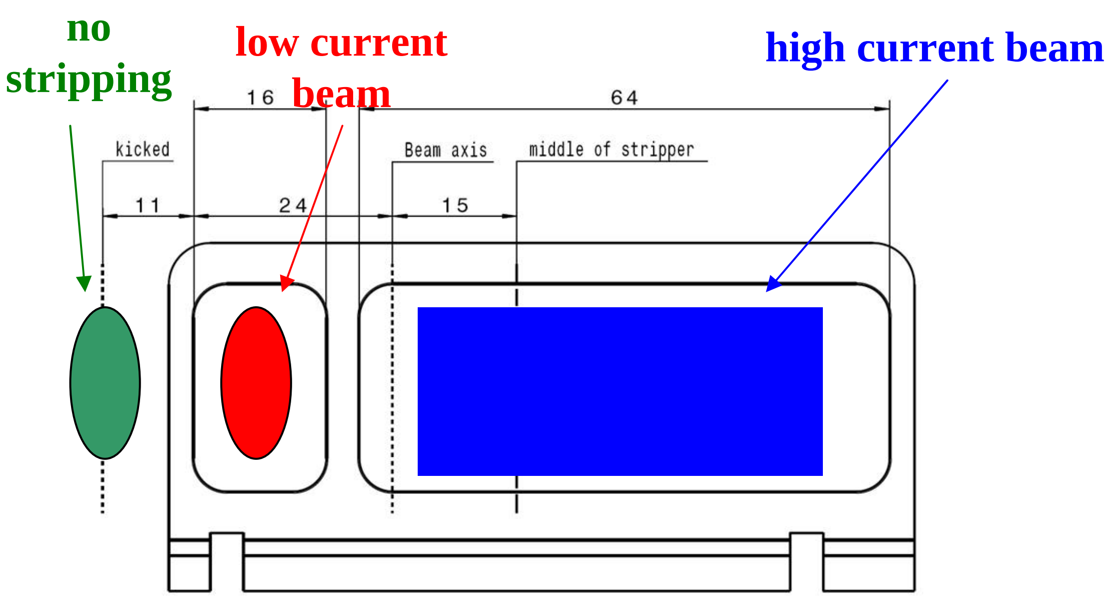
Beam Energy 11.4 MeV/u

Beam dynamics

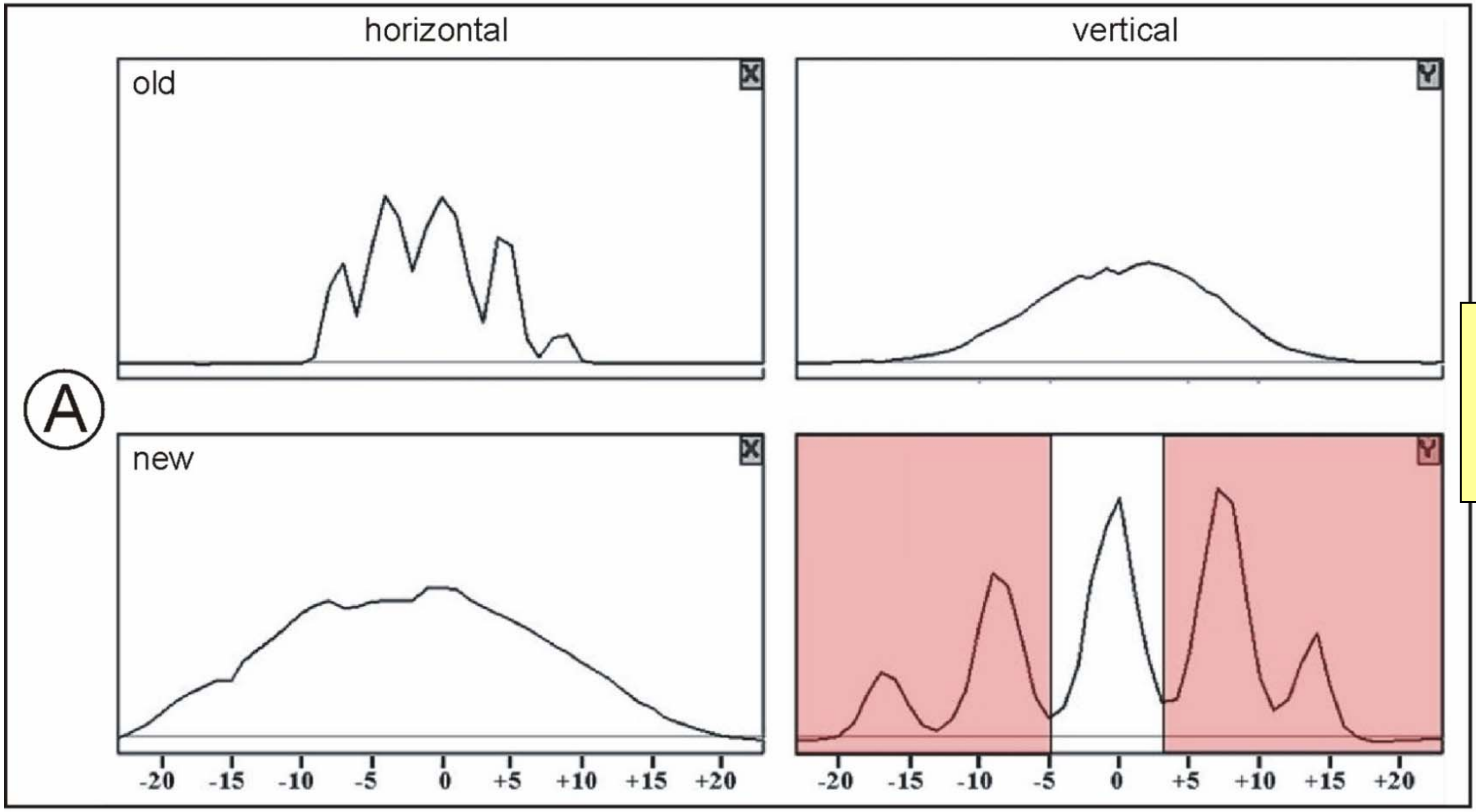


Foil stripping modes





Commissioning with Uranium beam

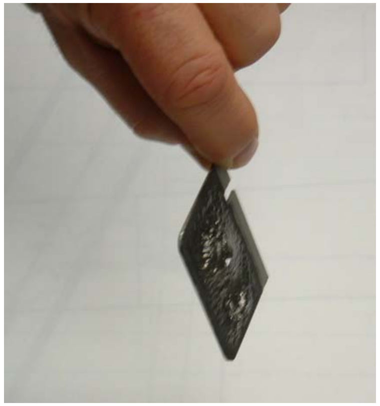


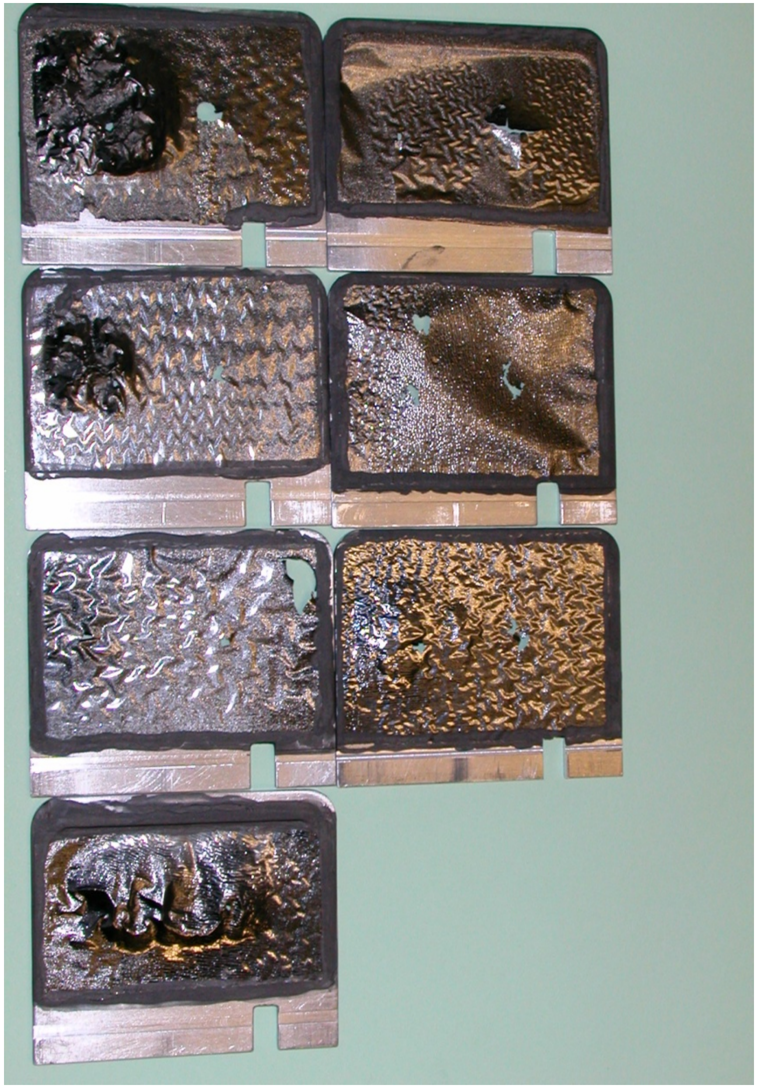
Uranium charge states

71 - 75+

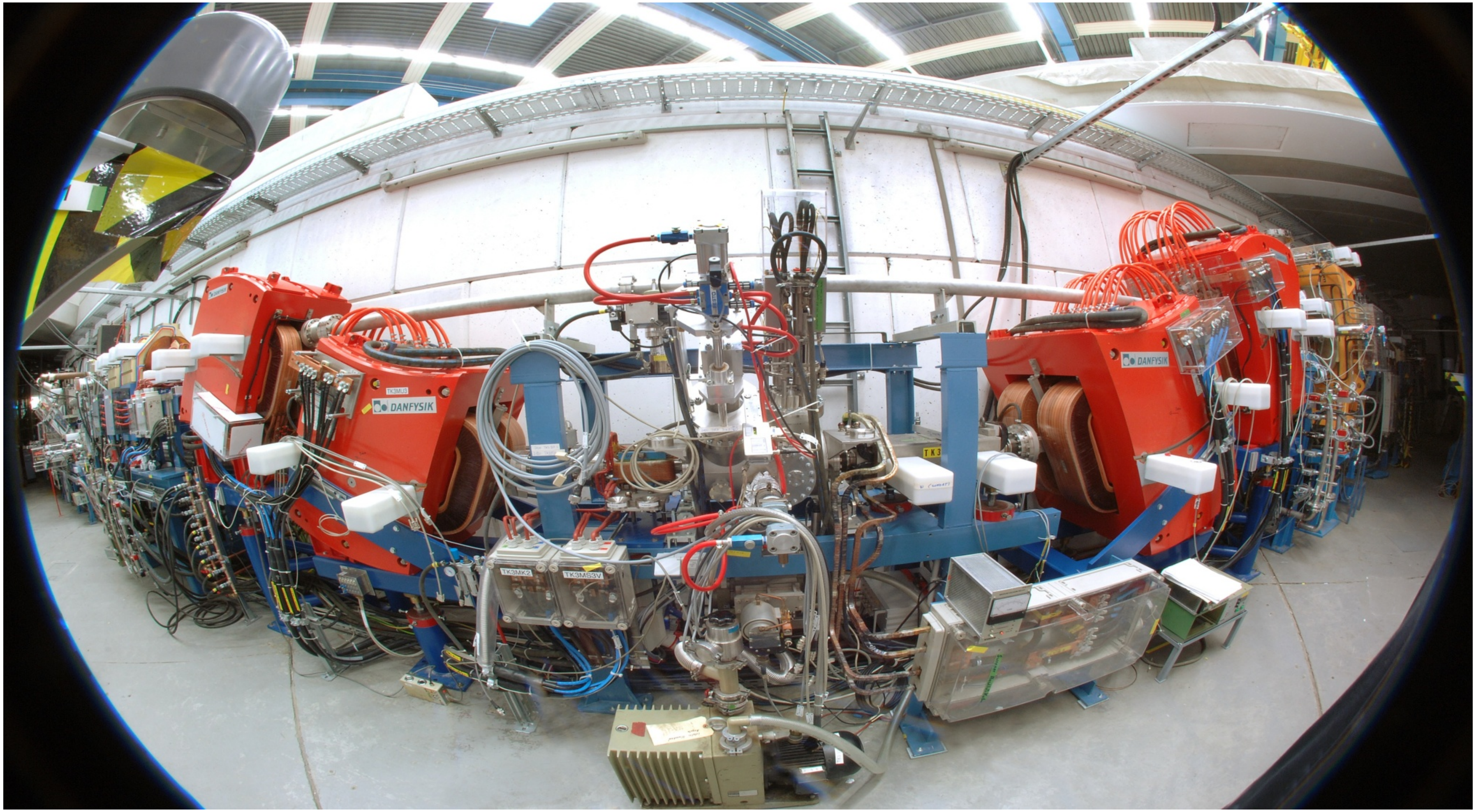
horizontal **vertical**

Carbon foils 200 – 600 μg/cm²

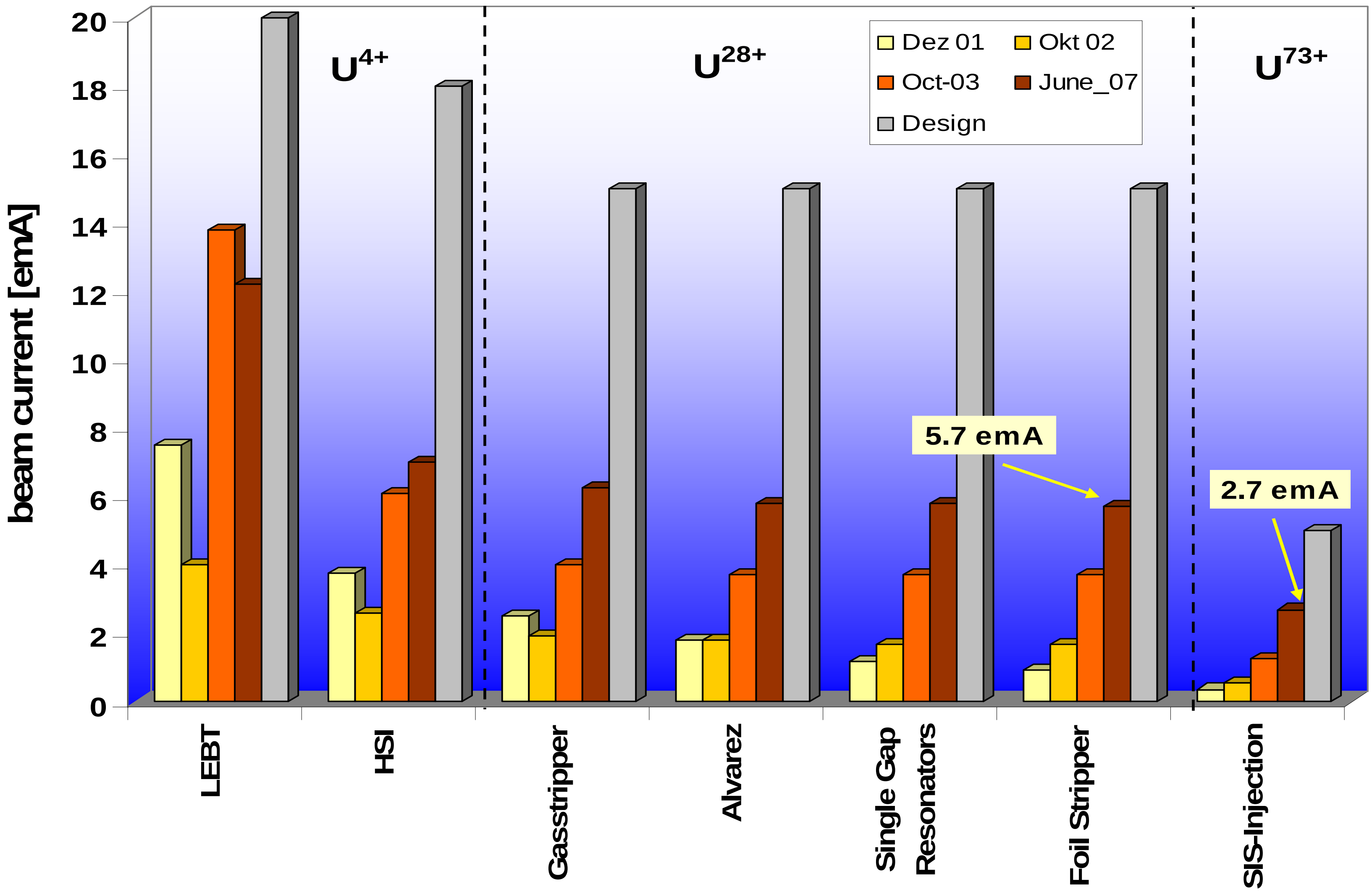




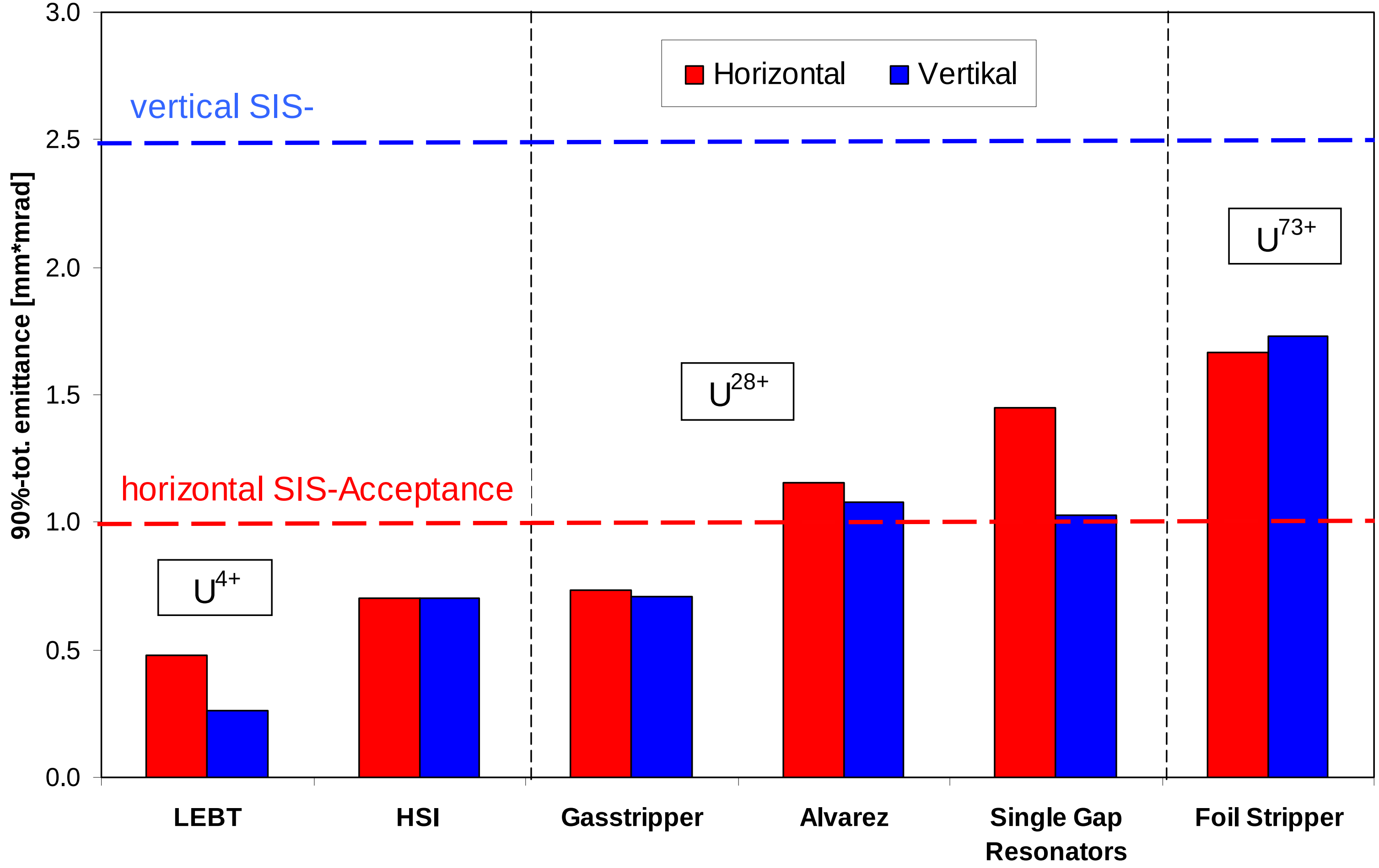
Fish eye view of the charge state separator



Present Uranium beam intensity



Normalized emittances along the UNILAC



Front-end upgrade (2009-2011)

- **Test bench for the investigation of high current ion sources and acceleration gap.**

  Optimization of extraction and gap geometry for highest beam brilliance.

- **New RFQ minivane design for enlarged acceptance and higher beam brilliance.**

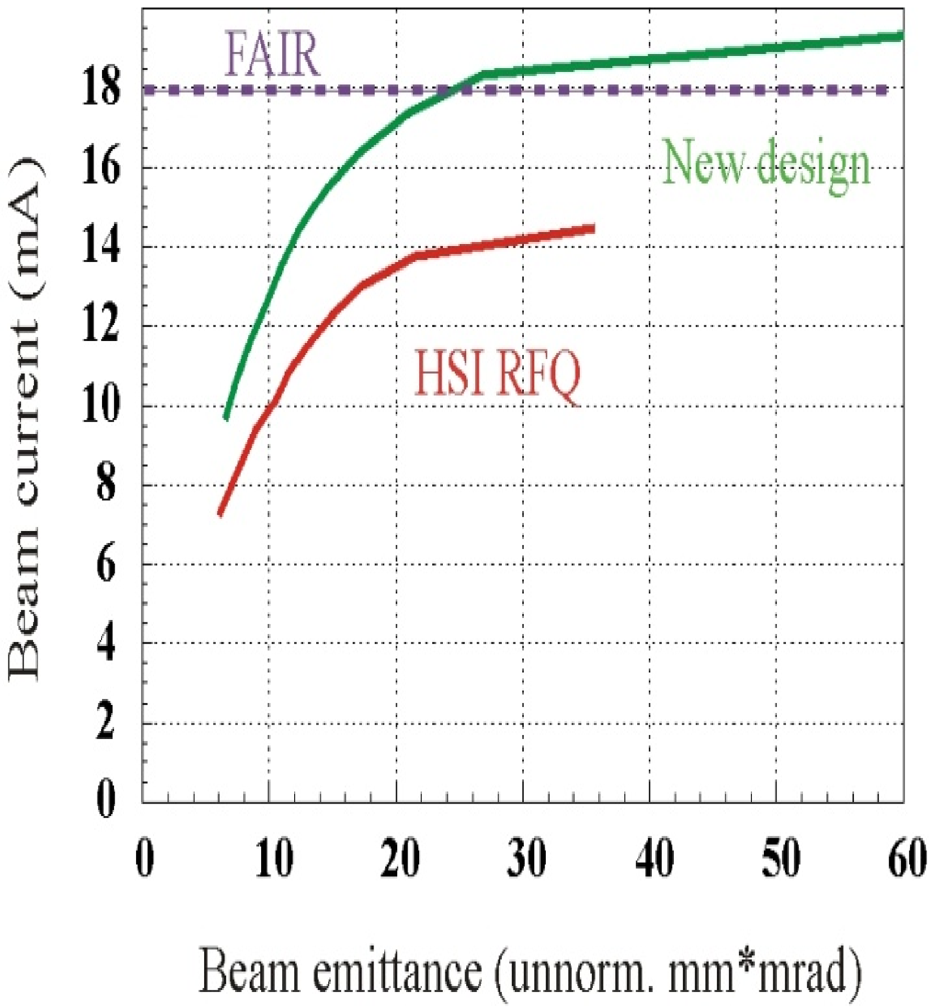
- **Dedicated high intensity beam LEBT (Compact LEBT) to transport 37 emA of U4+ beam into the RFQ.**

Old and new design of RFQ minivanes

	New Design	Existing Design
Voltage, kV	155.0	125.0
Average radius, cm	0.6	0.52-0.77
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 to -28	-90 to -34
Aperture, cm	0.41	0.38
Min. transverse phase advance, rad	0.56	0.45
Norm. transverse acceptance, cm mrad	0.086	0.73
Output energy, MeV/u	0.120	
Electrode length, mm	9208.4	

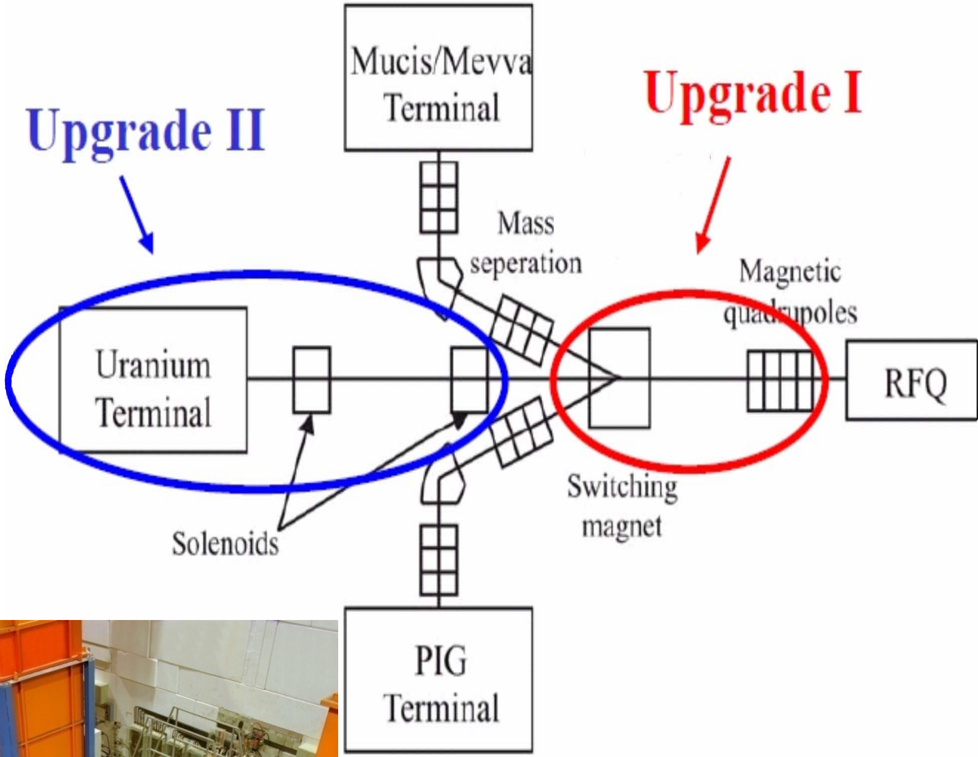
Designed by
Andrej Kolomiets

Advantages of new RFQ minivanes



- Higher transverse acceptance and phase advance
- 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

Compact LEBT



Pre investigations

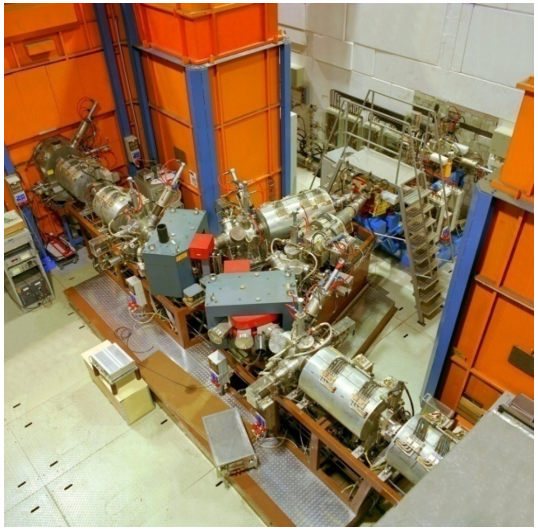
- High current test bench measurements

Upgrade I

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

Upgrade II (Compact LEBT)

- sc solenoids for straight line injection of **37 emA of U4+ beam** into the RFQ



HSI-LEBT

Summary

- An extended upgrade program at the UNILAC 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 measures: improved ion source performance, increase of stripper gas density, improved Alvarez-DTL-matching, increased phase advance in the DTL, compact charge state separator behind the foil stripper.
- The UNILAC-upgrade will be continued with a new front end comprising a compact LEBT, a new RFQ minivane design, and beam diagnostics devices, sufficient for the operation with megawatt heavy ion beams (until 2011). Thus the FAIR requirements will be approached.
- **BUT:** The UNILAC is in operation since 35 years. In long term perspective the substitution of the Alvarez DTL by more efficient high current heavy ion accelerators for low frequent beam pulses for FAIR injection is necessary.
- **AND:** The UNILAC experimental program should be decoupled from the FAIR injection linac by a new independent sc cw-linac up to 7.5 MeV/u.

co-workers

LINAC group of the GSI accelerator division:

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