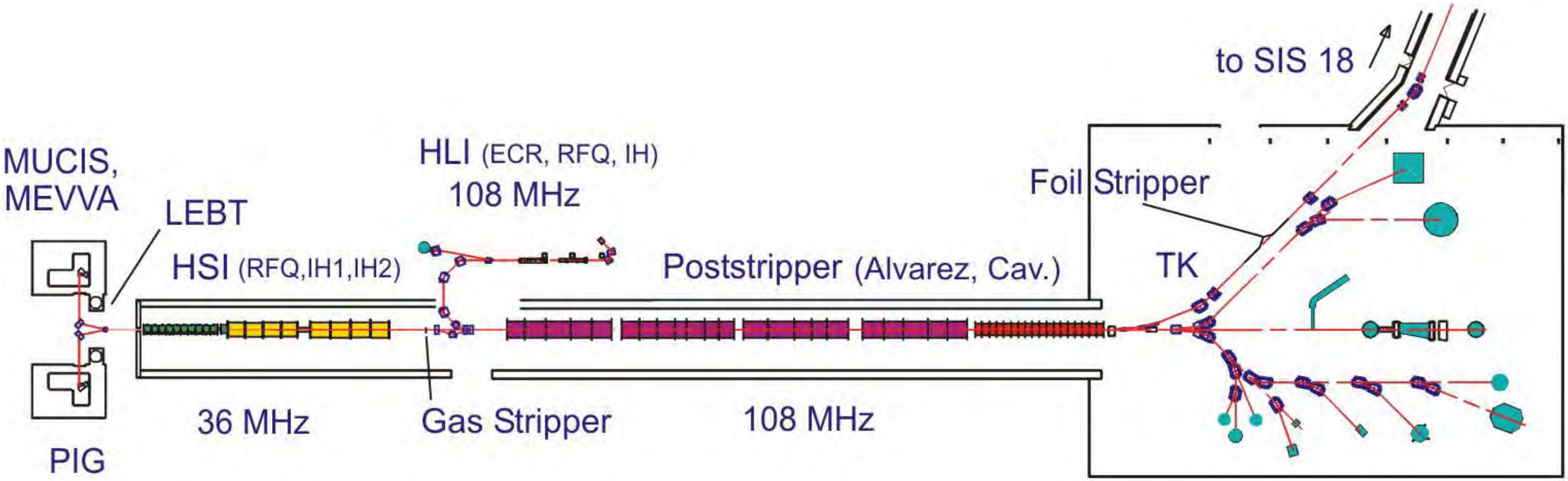
Present and future beams for SHE research at GSI

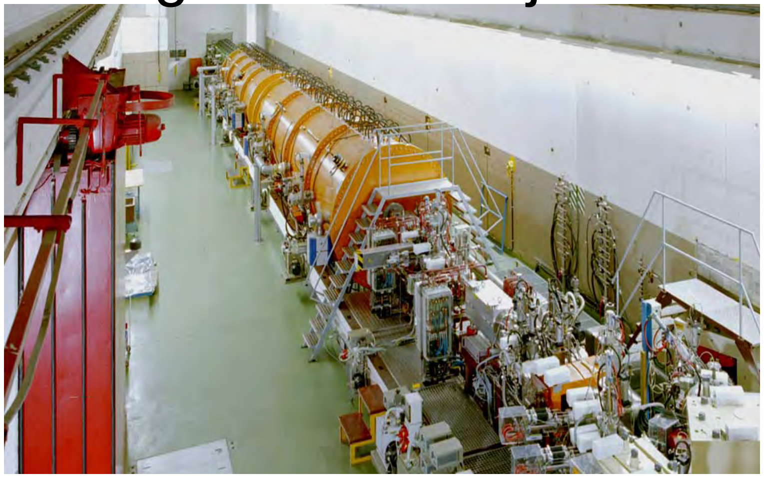
W. Barth, GSI - Darmstadt

1. Heavy Ion Linear Accelerator UNILAC
2. GSI Accelerator Facility – Injector for FAIR
3. Status Quo of the UNILAC-performance
4. Unilac Upgrade Measures
5. Design of a cw superconducting linac
6. Conclusion

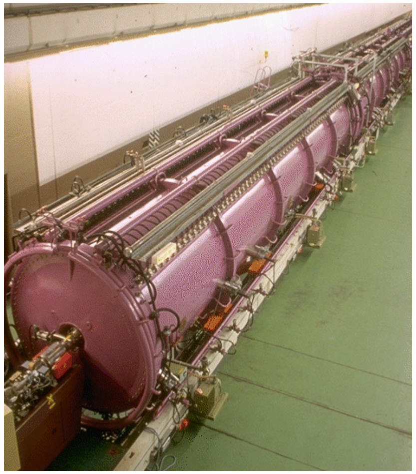
The GSI UNIversal Linear ACcelerator



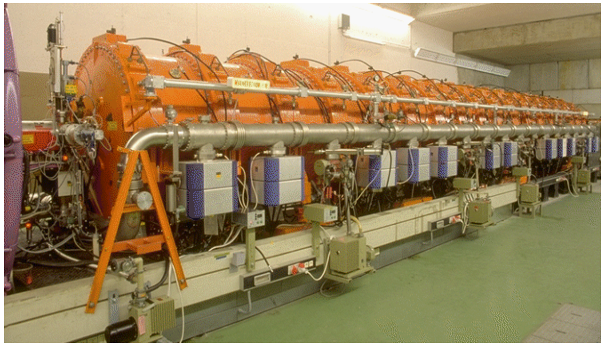
High Current Injector



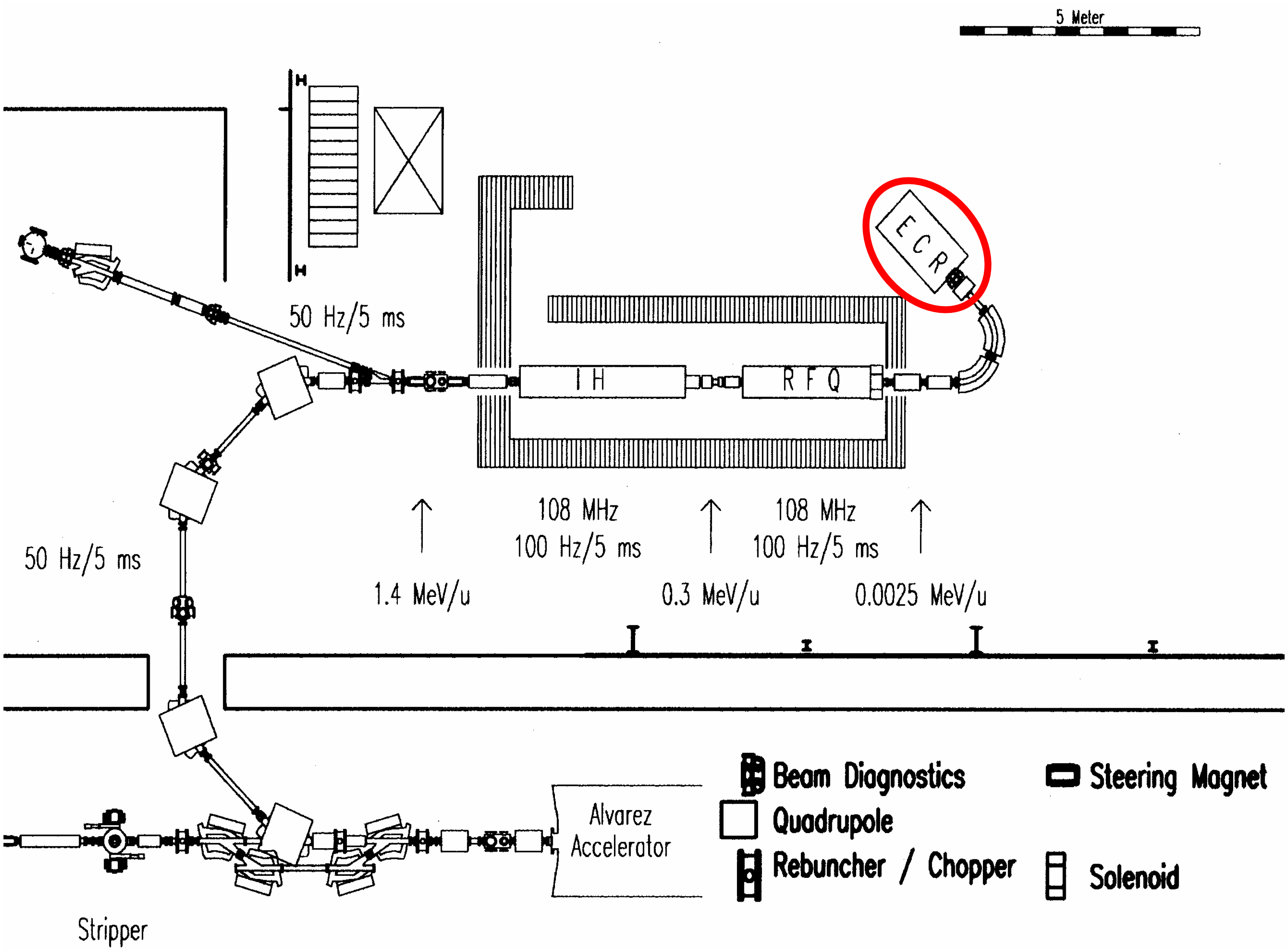
Alvarez



Single Gap Resonators



High Charge State Injector (HLI)



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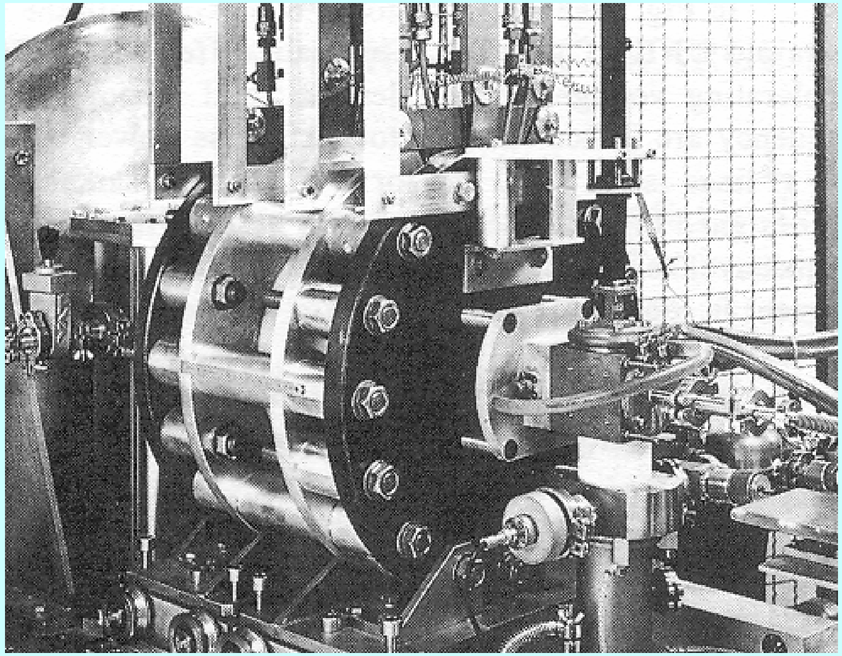
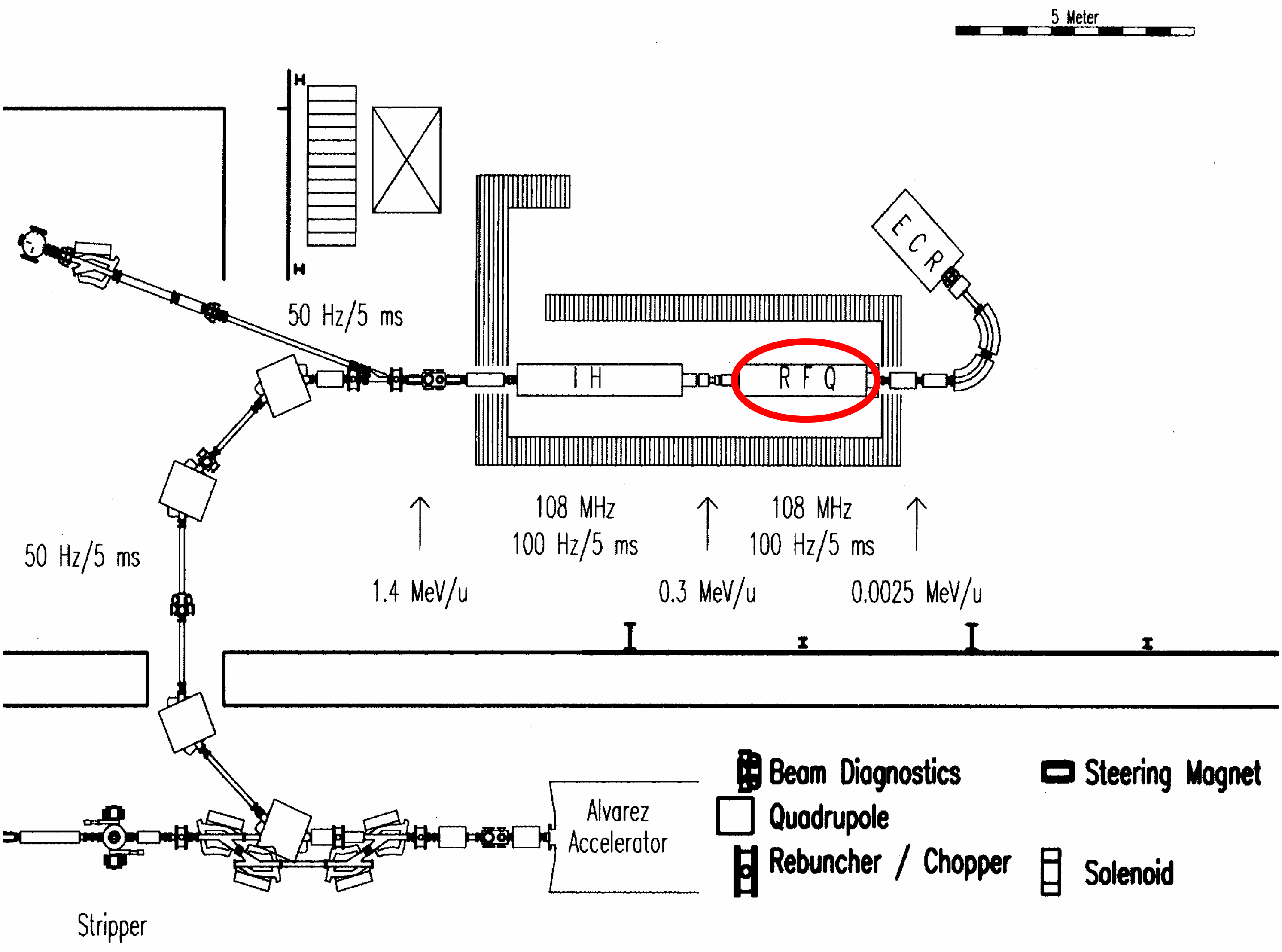


Ion Source	EZR (CAPRICE-Typ)
m/q	8.5
Extraction Voltage	2.5· (m/q)
Beam Energy	2.5 keV/u (β = 0.23 %)
Beam Emittance	0.46 π·mm·mrad (norm.) 200 π·mm·mrad (unnorm.)
Mass Resolution	$\Delta m/m = 3 \cdot 10^3$

High Charge State Injector (HLI)



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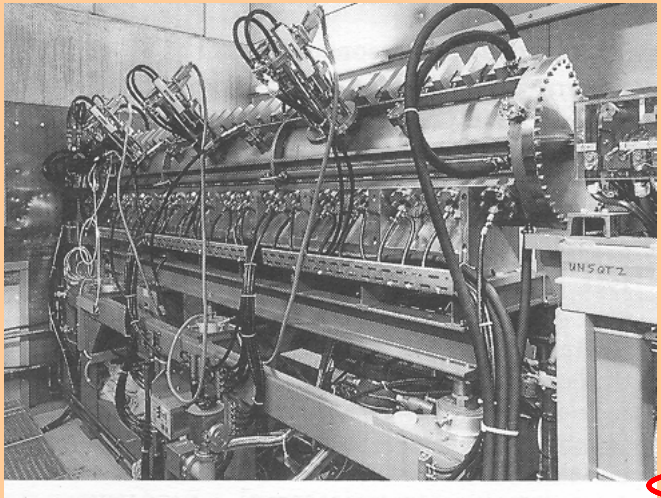
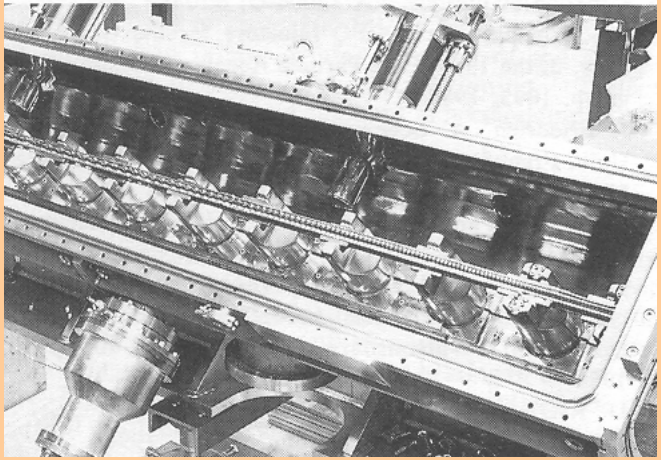
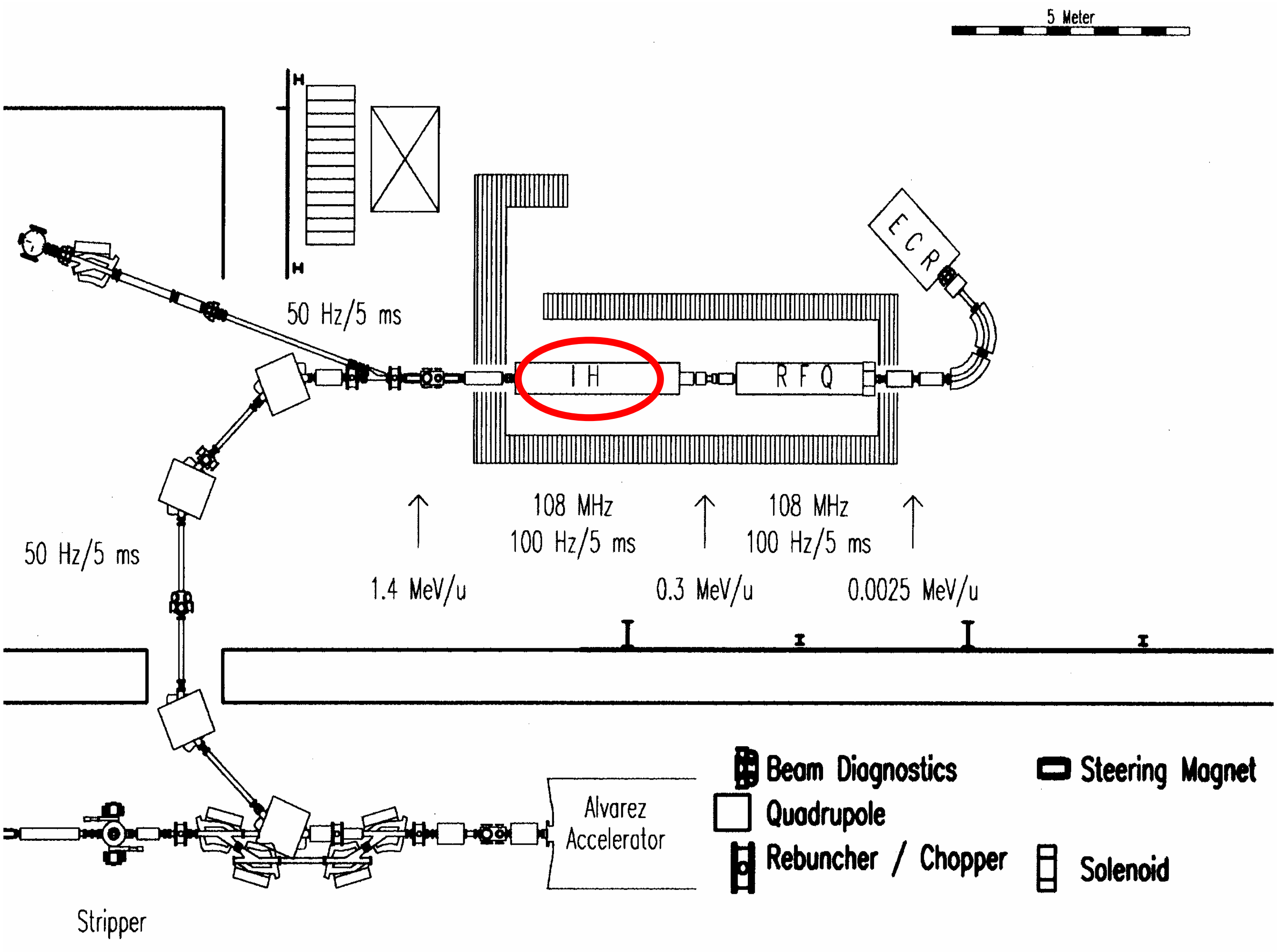



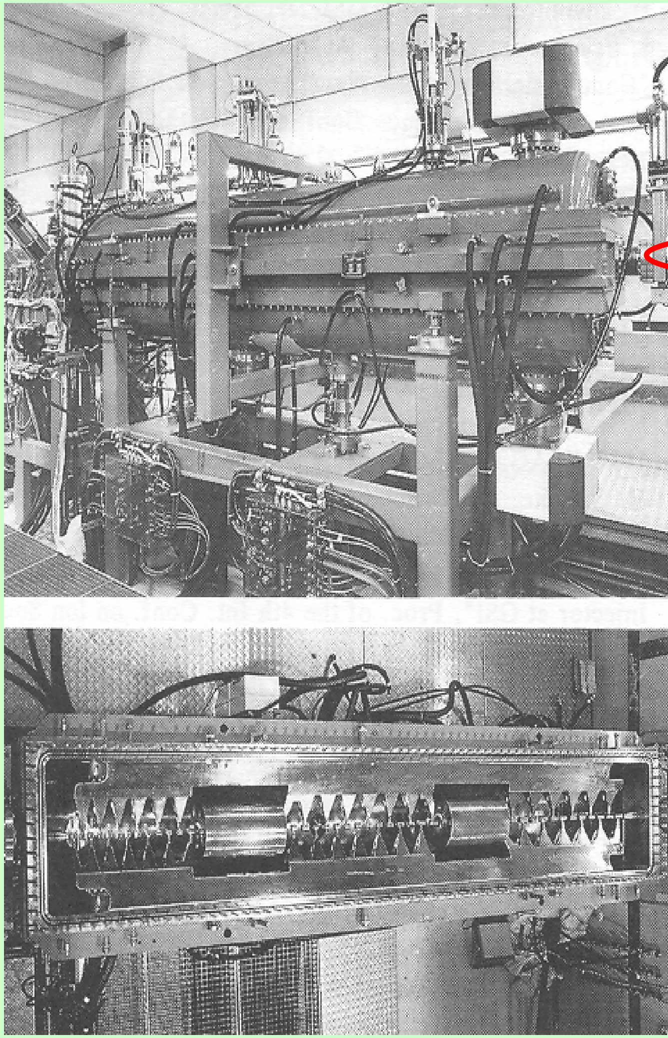
RFQ

Structure type	four-rod
Input energy	2.5 keV/u ($\beta = 0.0023$)
Output energy	300 keV/u ($\beta = 0.025$)
Radio frequency	108 MHz
Repetition frequency	100 Hz
Duty cycle	50 %
Max. RF power(U^{25+})	125 kW
Max. voltage	90 kV
Length	3 m
Tank diameter	0.5 m
Radial acceptance (norm.)	≥ 0.8 π•mm•mrad
Longitud. emittance	30 π•keV/u•deg
Energy spread	± 1.0 %
Bunch width	± 0.3 ns (± 10 deg)

High Charge State Injector (HLI)



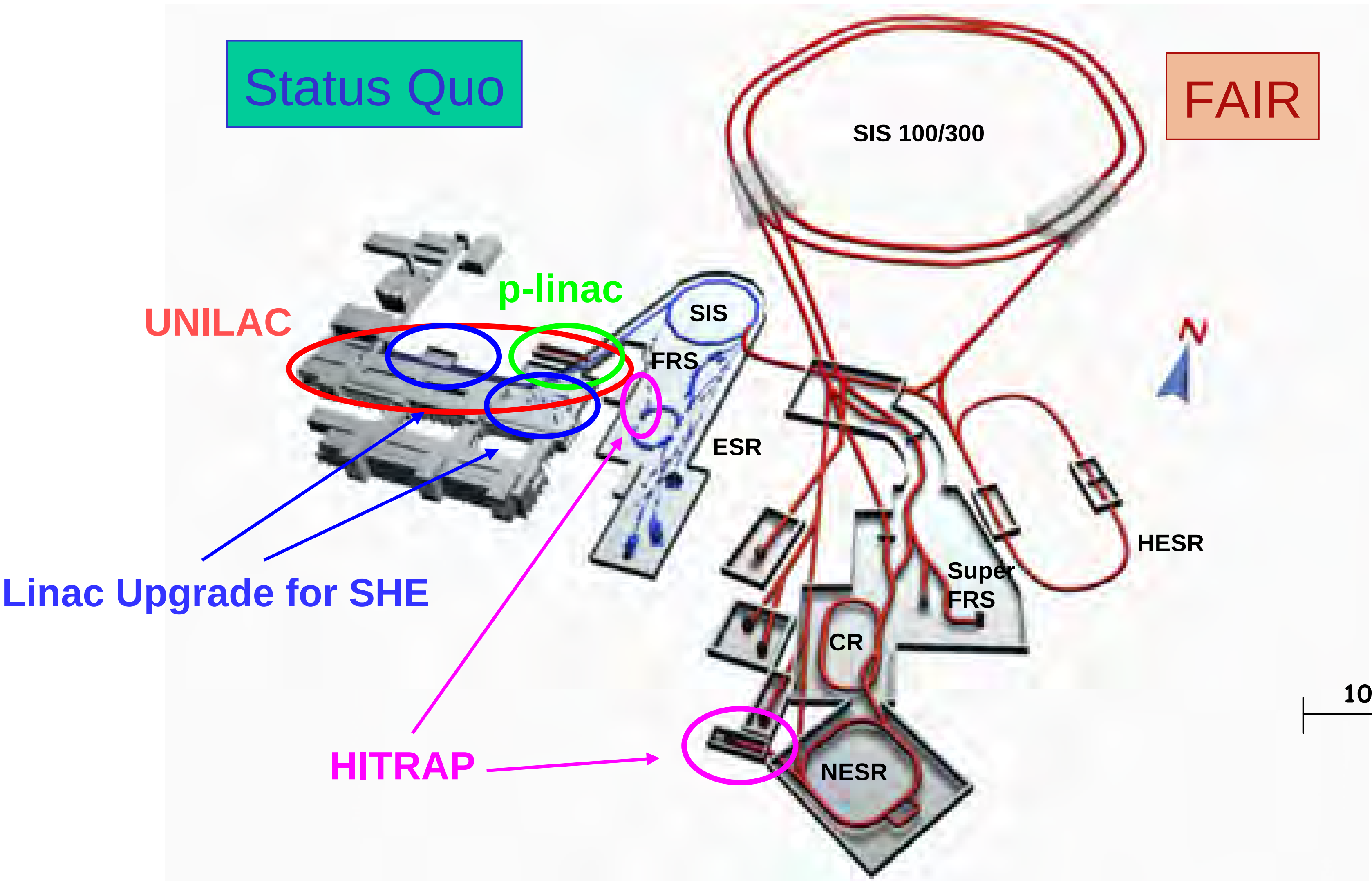
High Charge State Injector (HLI)



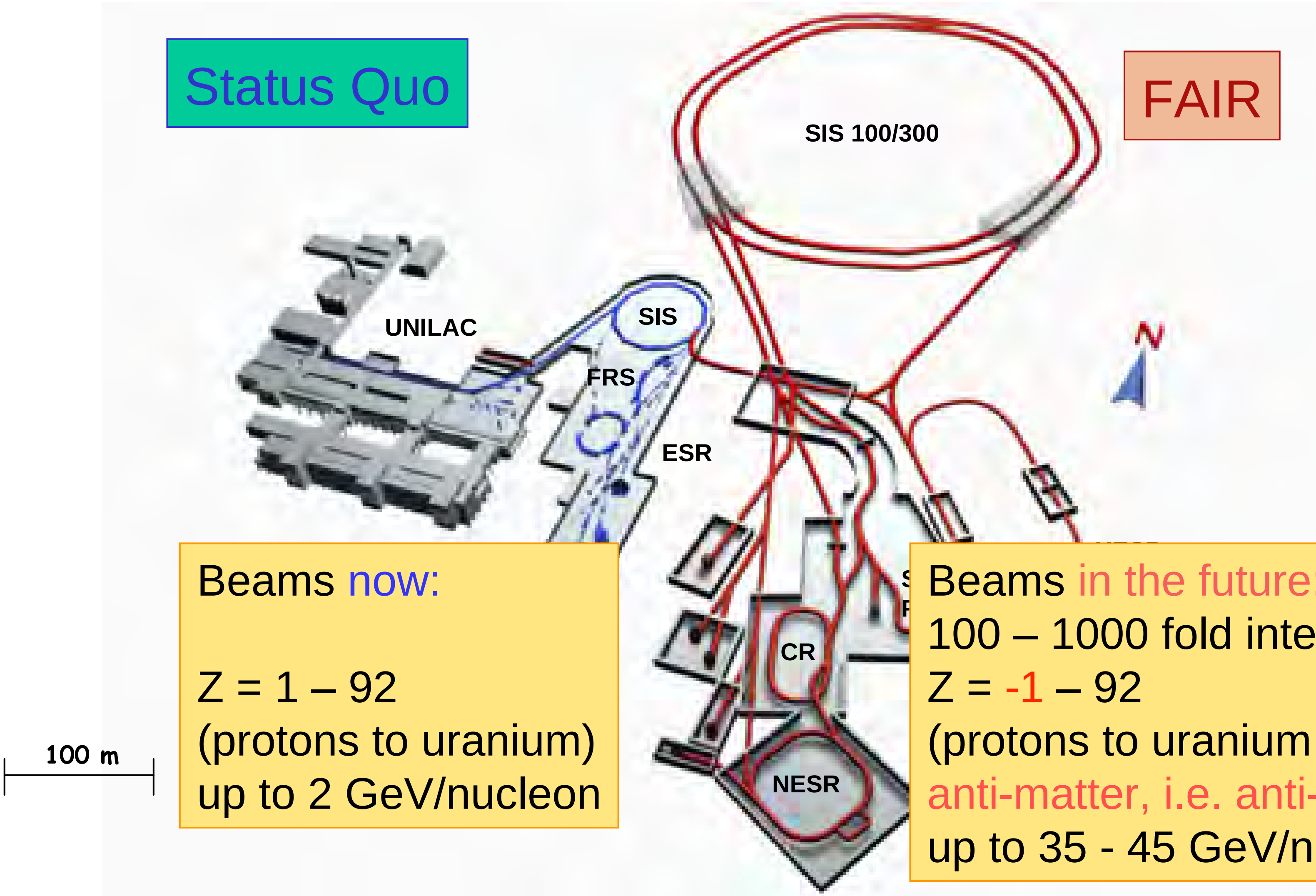
IH

Input energy	300 keV/u (β=0.025)
Output energy	1.4 MeV/u (β=0.055)
Radio frequency	108 MHz
Repetition frequency	100 Hz
Duty cycle	50 %
Max. RF power(U^{25+})	100 kW
Max. field strength	150 kV/cm
Length	3.55 m
Shunt impedance	310 MΩ/m
Radial acceptance	
(norm.)	1.5 π•mm•mrad
(unnorm.)	60 π•mm•mrad
Longitudinal	
acceptance	150 π•keV/u•deg
emittance	70 π•keV/u•deg
Energy spread	± 0.5 %
Bunch width	± 0.3 ns (± 10 deg)

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)

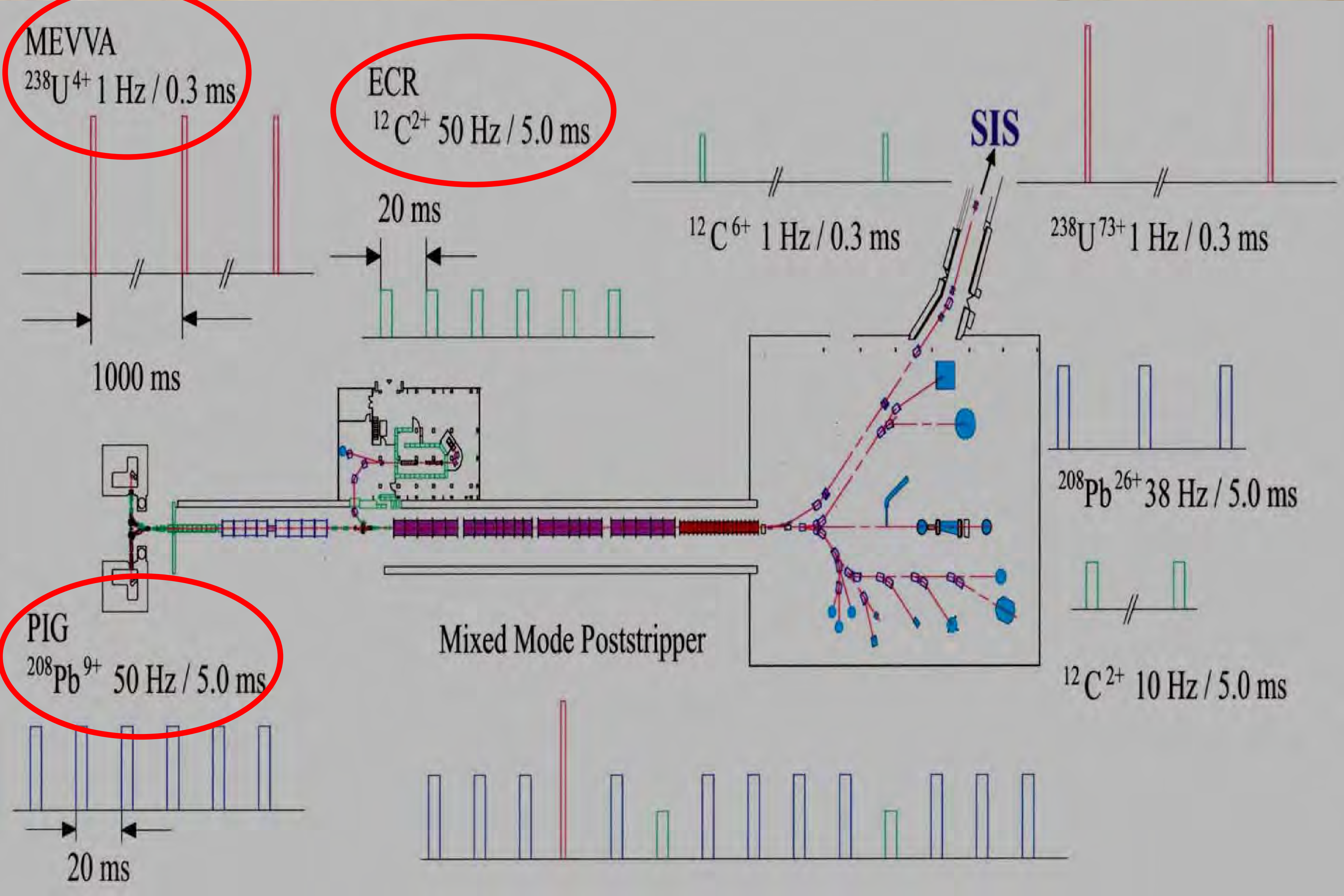


Beams now:

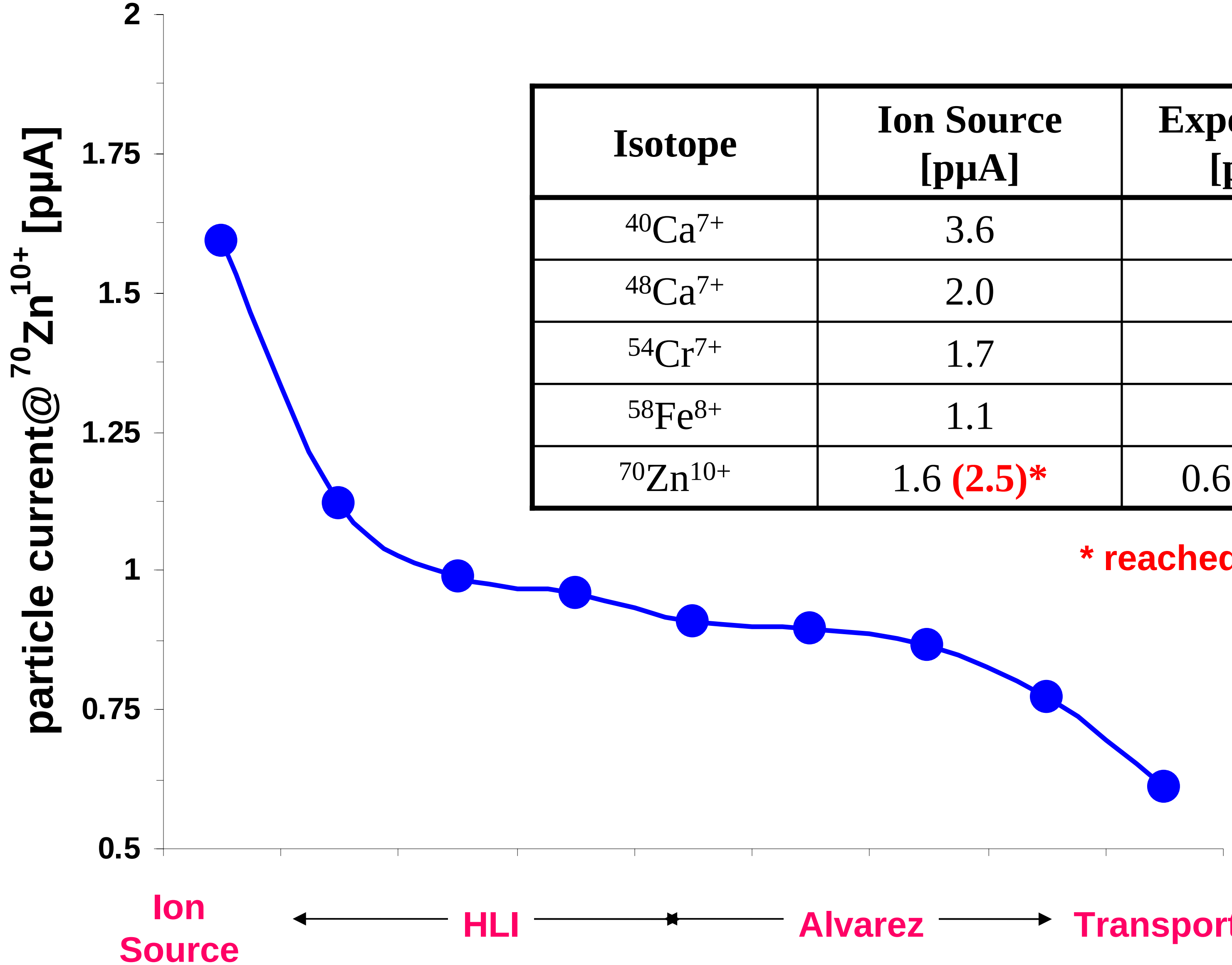
Z = 1 – 92
(protons to uranium)
up to 2 GeV/nucleon

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

Example of UNILAC 3-Beam Operation



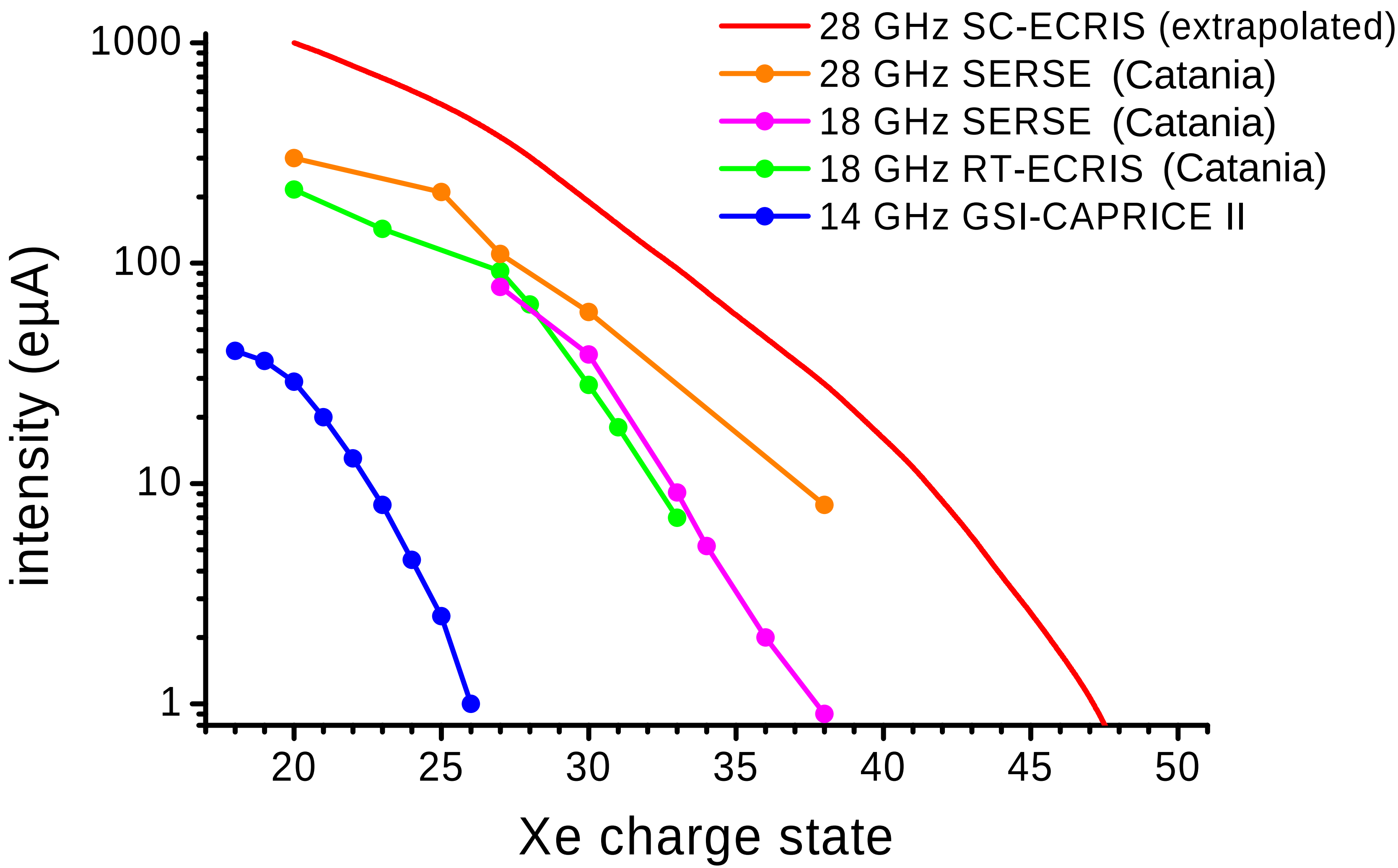
Particle Current in the GSI-Unilac (routine operation)



Isotope	Ion Source [pμA]	Experiment [pμA]
$^{40}Ca^{7+}$	3.6	0.5
$^{48}Ca^{7+}$	2.0	0.5
$^{54}Cr^{7+}$	1.7	0.9
$^{58}Fe^{8+}$	1.1	0.5
$^{70}Zn^{10+}$	1.6 **(2.5)***	0.6 **(0.9)***

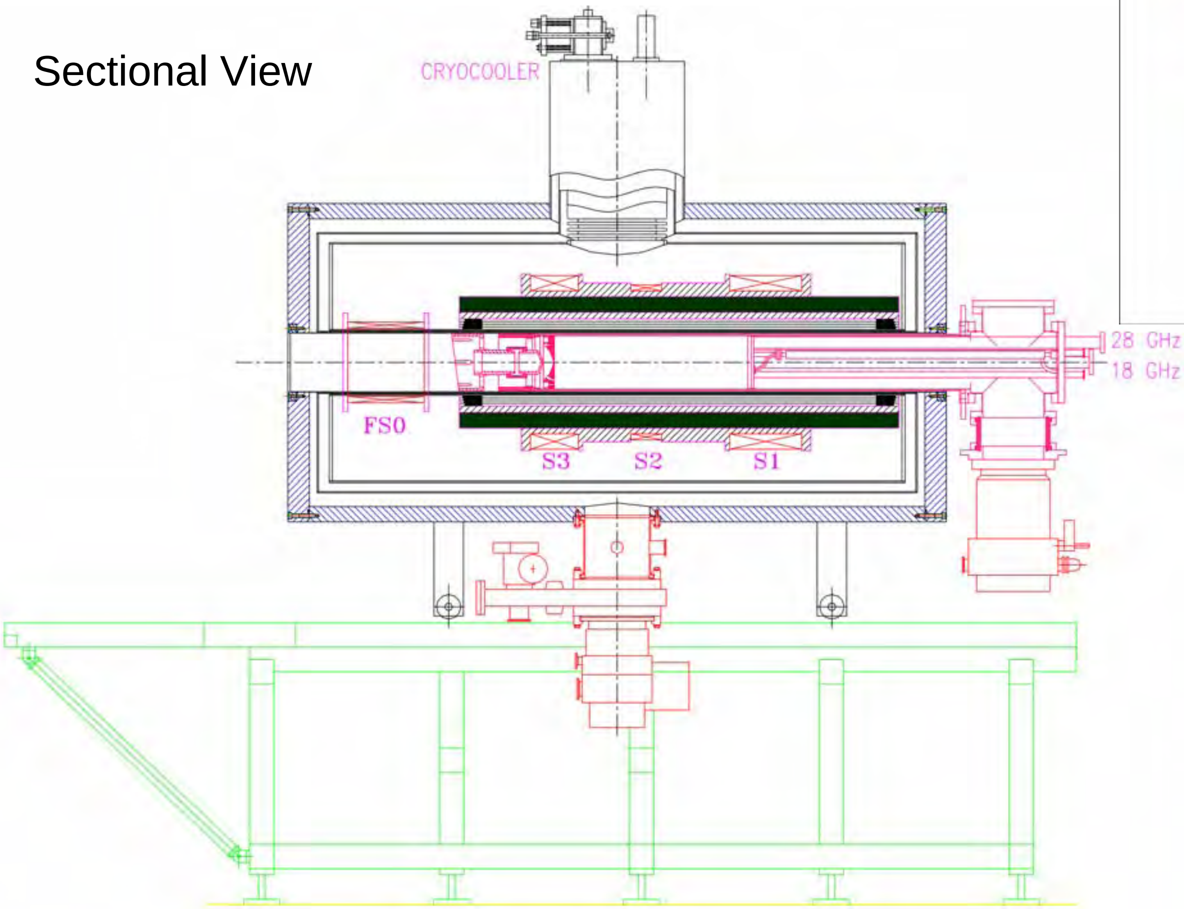
*** reached in 8/2004**

Comparison of Performances for Different ECR Ion Sources

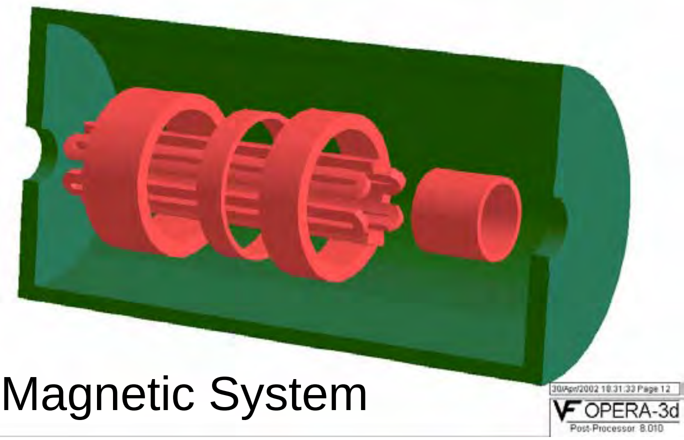


The GyroSerse Project

Sectional View



S. Gammino, private communication

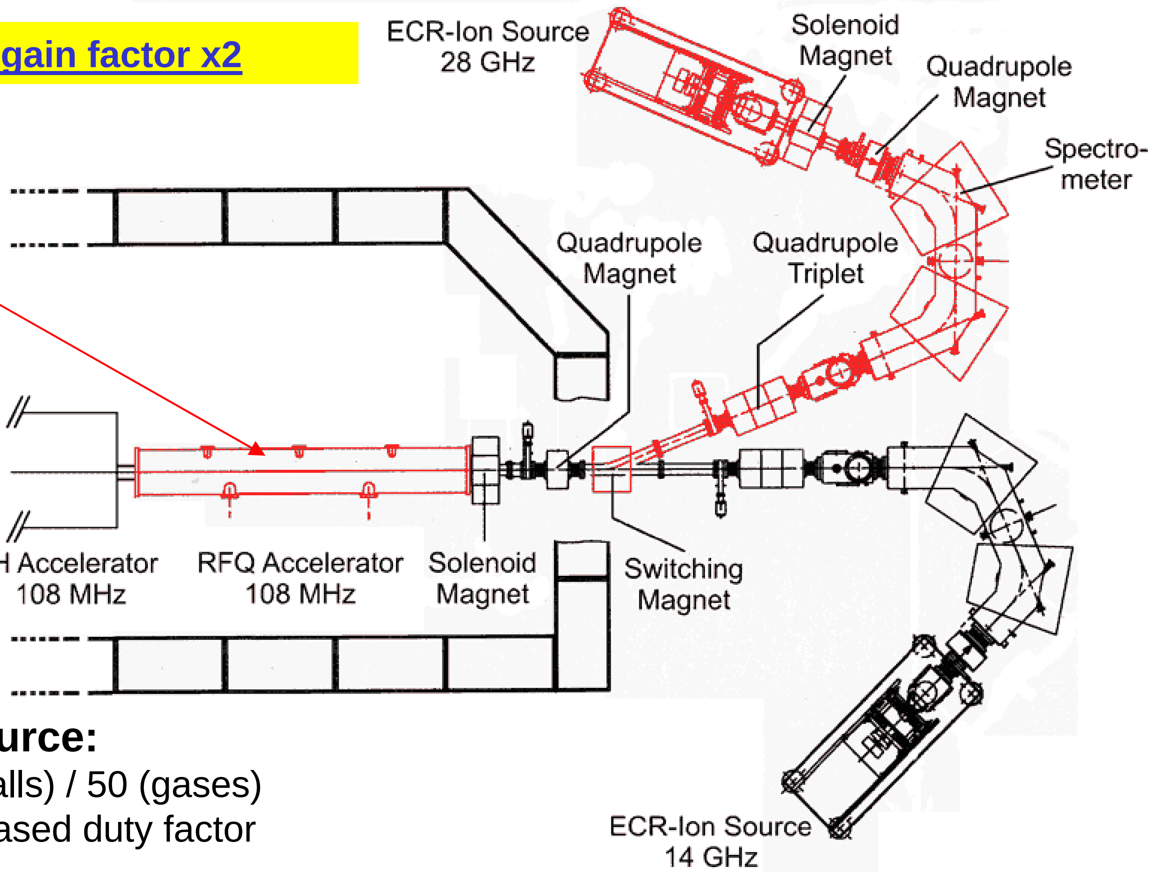


Magnetic System

Frequency	28-37 GHz
Max. RF power	10 kW
B_{radial}	3 T
B_1 (injection)	4.5 T
B_2(extraction)	3.5 T
$\phi_{chamber}$	180 mm
$L_{chamber}$	700 mm
$\phi_{cryostat}$	1000 mm
$L_{cryostat}$	2150 mm

New Front-end for the High Charge State Injector

50% duty factor → intensity-gain factor x2

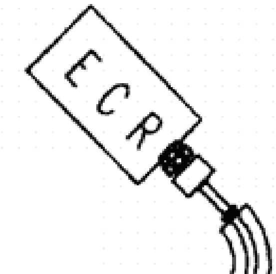


New RFQ-structure:
- gain of the duty factor
- higher injection energy
- increased acceptance

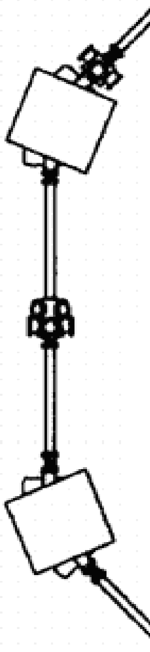
Additional 28 GHz-ion-source:
- intensity gain of factor 5 (metalls) / 50 (gases)
- higher charge states for increased duty factor

LEBT – Laminated magnets:
- redundance for ion sources
- preparation for future pulse to pulse operation with different ion-species

High Duty Cycle RF-Operation of the GSI-High Charge State Injector (HLI) and the Alvarez-accelerator



Rebuncher



Presently:

duty factor (beam)= 25 %
(rf: 35 %), A/ξ ≤ 8

Upgrade:

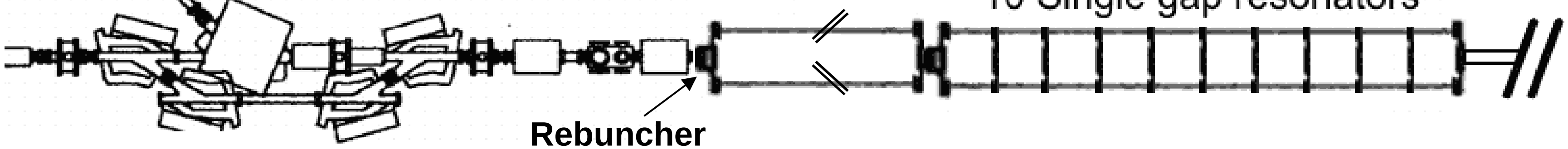
(new RFQ-structure, higher charge state from 28 GHz-ECR)

A/ξ ≤ 6.5, duty factor = 50 % (rf: 60 %)

Performance of all rf-tube-amplifiers (Alvarez@1.5 MW, IH+RFQ+Single Gap@200 kW, Rebuncher@ 4 kW) is sufficient to meet the requirements

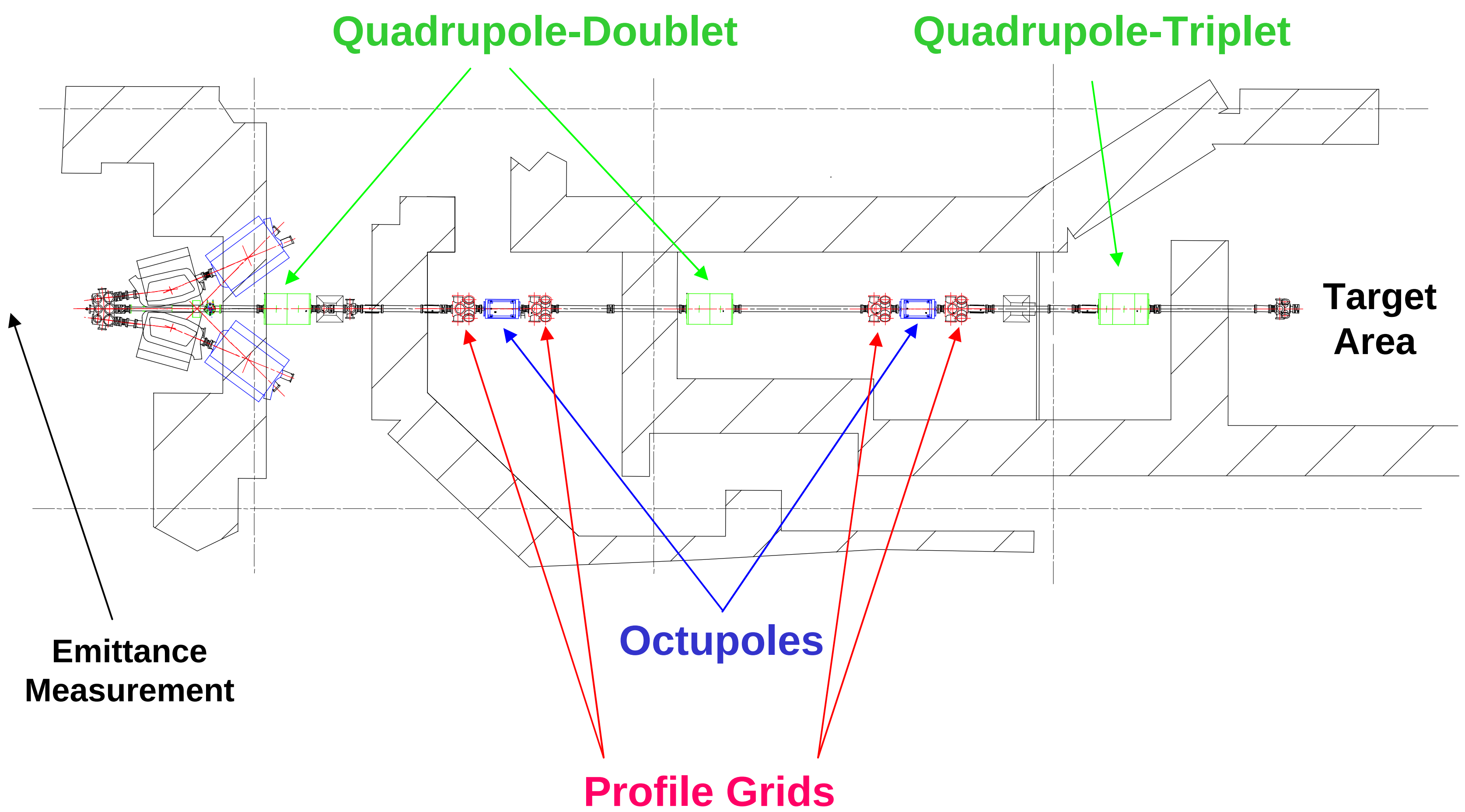
Alvarez

10 Single gap resonators

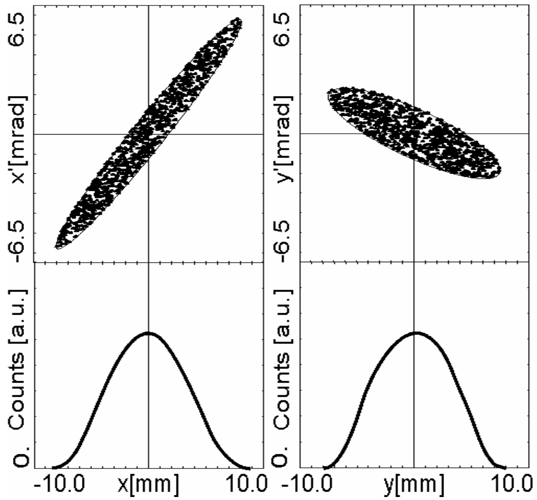


Rebuncher

Upgrade of the Beam Transport to the SHIP-Target (2004)



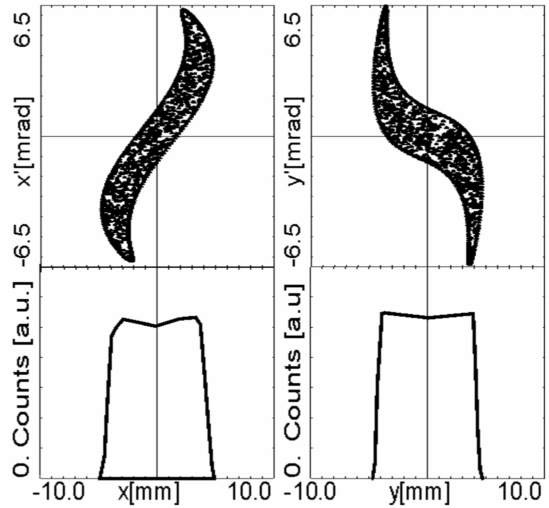
Transverse Beam Shaping with Octupole lenses



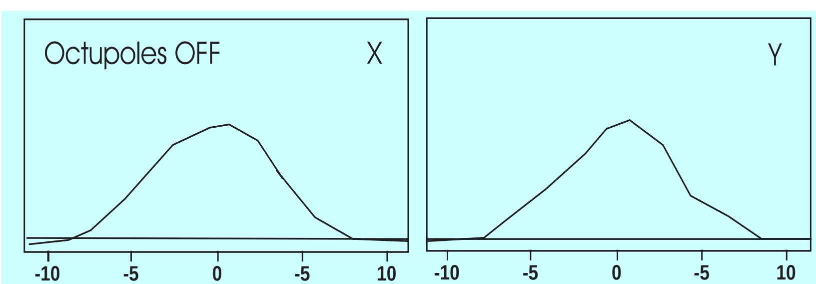
$B_x = G(y^3 - 3x^2y)$

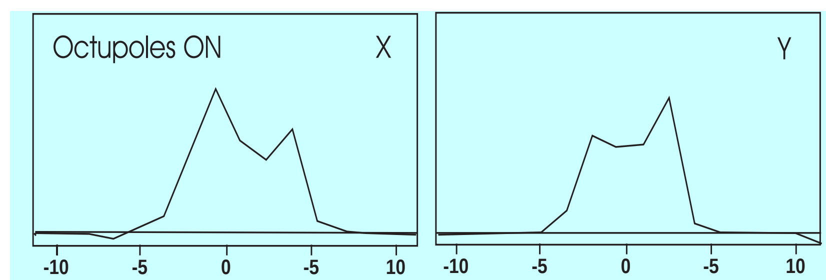
$B_y = G(3y^2x - x^3)$

G: pole tip field



Measured beam profiles at the target position





- Transmission losses of 30% (first tests: 2003)
- Increase of underground noise by a factor of 1000 (first tests: 2003)

Two Heavy Ion Linacs for Different Duties...

Synchrotron Injector

- Poststripper section in operation since 30 years.
  - Alvarez structure operation among the highest duty factors worldwide.
  - Drift tubes with internal quadrupoles.
  - 108 MHz rf power amplifiers in use from the beginning.

Option

- Rebuilt of the Poststripper section.
  - Low duty cycle.
  - High voltage gain.
  - Emittance growth reduction.
  - New operating rf frequency.
  - New beam inflector into SIS 18.

$\Rightarrow$ Relaxed SIS 18 operation.

$$N_{\max} \propto \beta_i^2 \gamma_i^3 \frac{A}{q^2}$$

25 A MeV U^{28+} increases N_{max}, SIS18 by a factor of 2.

A Dedicated cw Linac for SHE Production

- No interference with synchrotron operation.
- Significant increase in available time and in flexibility for tests and for experiments.
- Optimum beam matching to the target wheel; highest counting rates.

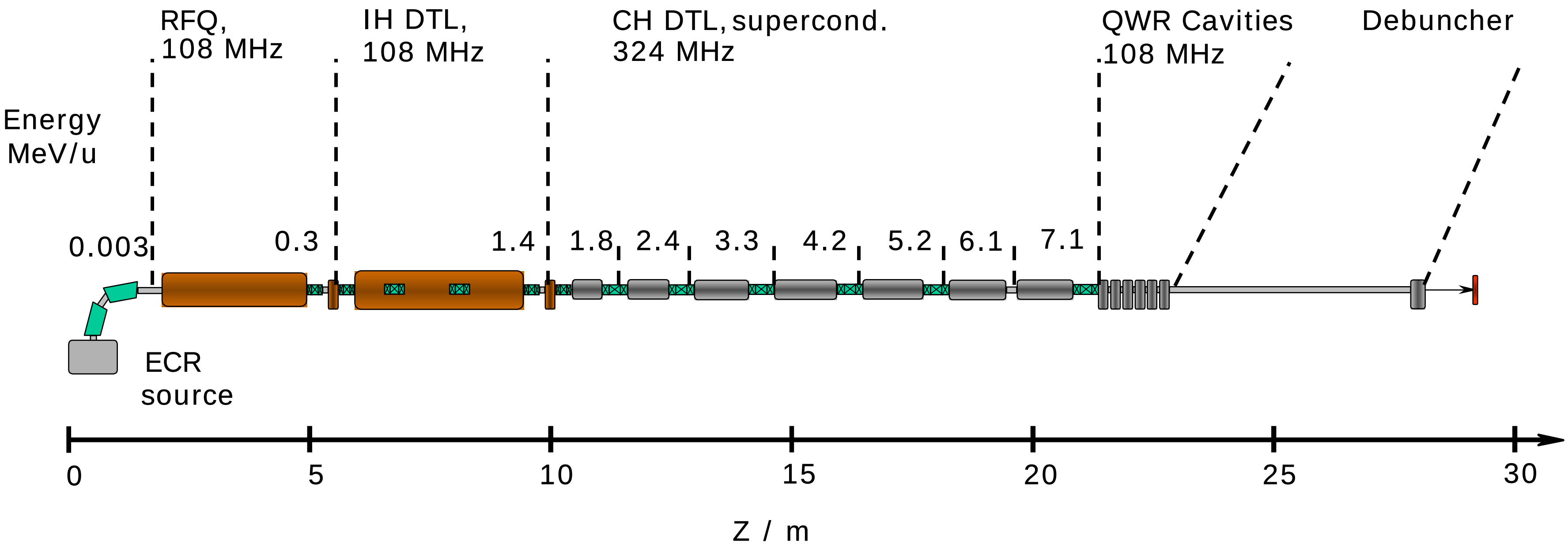
Small and fast Solution

- **Room temperature linac :**
  - HLI (1.4 *AMeV*)
  - 217 MHz DTL

    (IH section, 4 tanks P_{rf} < 100 *kW* each).
  - A / q < 5 ; W < 6 *AMeV*; L_{tot} ~ 20 *m*

    (*Z_{eff} ~ 140 MW/m; $P_{tot,rf}$ ~ 320 kW ; P_{plug} ~ 700 kW, for 217 MHz cavities*)
- **4 × λ/4, 108 MHz, 2 gap cavities for energy variation, superconducting (two cryostats).**

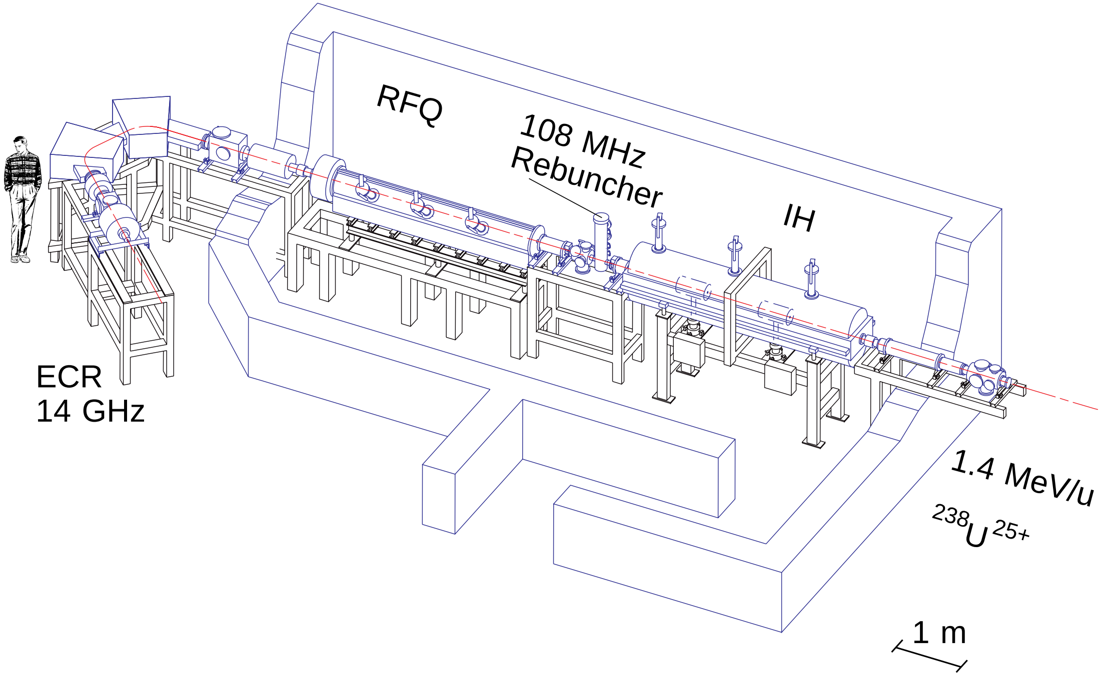
Layout of the Proposed cw Superconducting Linac

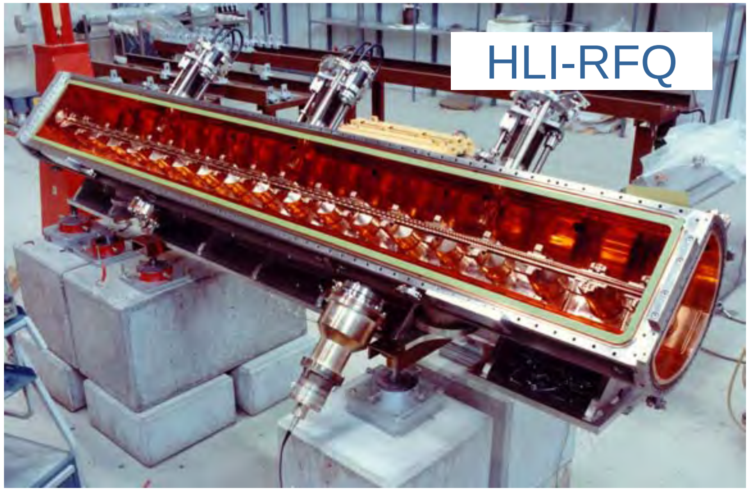


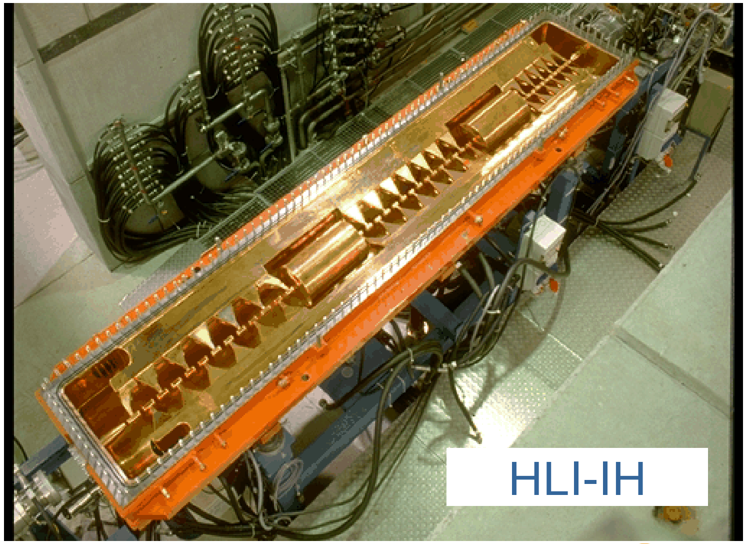
Main components:

- Room temperature RFQ and IH-DTL at 108 MHz
- Superconducting CH-DTL (324 MHz) and QWR (108 MHz)

cw Linac – Room Temperature Part







Rebuilt of the HLI with small modifications :

- Improved mechanical design with respect to cooling, especially:
- Cooling of the IH drift tubes.
- Cooling of the RFQ mini vanes.
- Improvement of longitudinal beam dynamics.

Layout of the superconducting CH – DTL section

Due to the following experimental requirements :

- Variation of the output energy, 3.8 – 7.5 MeV/u
- Final energy spread < ± 3 keV/u

the following layout resulted :

- 7 CH tanks

1.4-1.85 MeV/u	-> 2.5 MeV/u	->3.35 MeV/u	-> 4.25 MeV/u

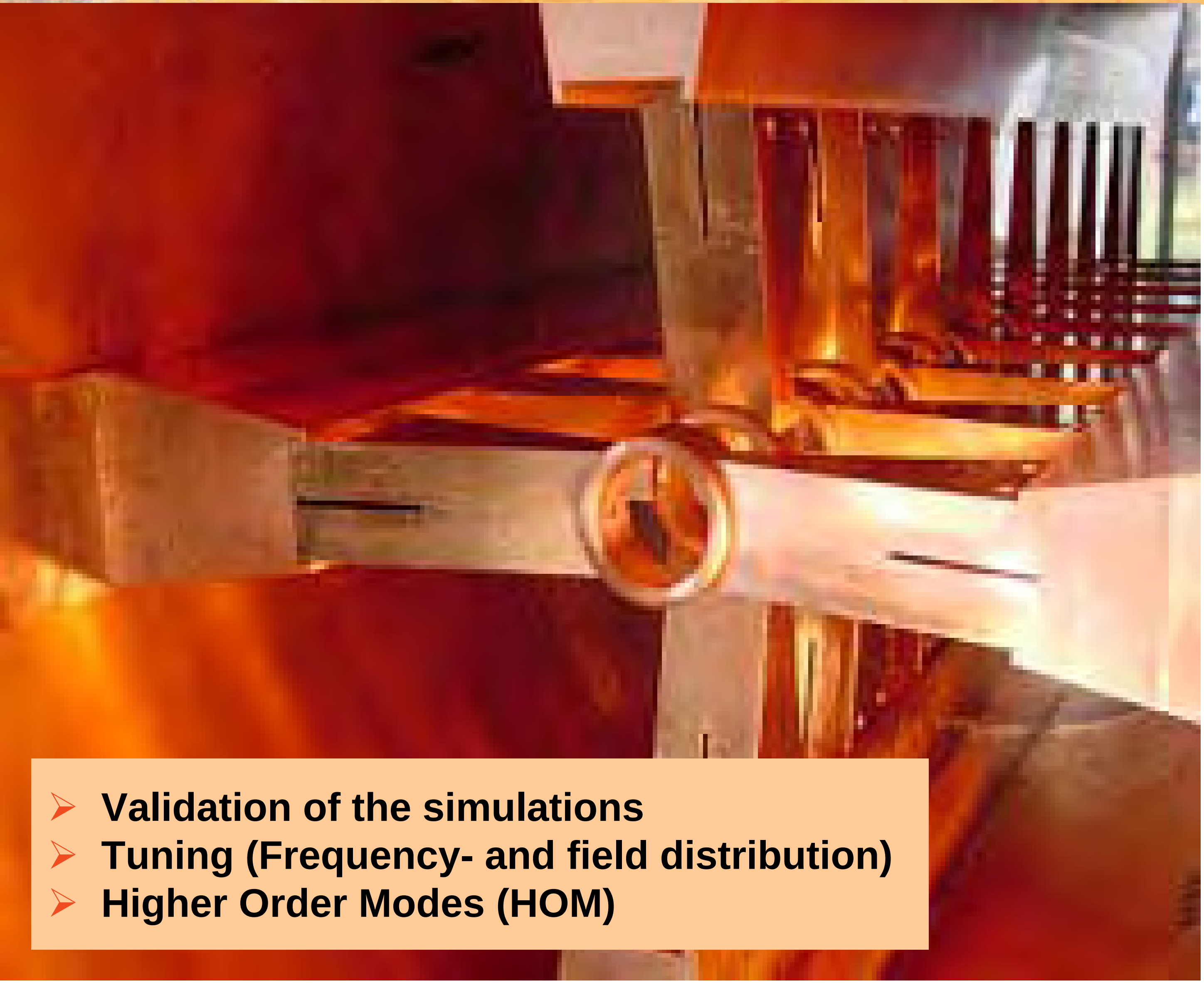
-> 5.25 MeV/u	-> 6.15 MeV/u	-> 7.15 MeV/u

- An ‘energy modulator’ (2 gap resonators)

+/- 0.5 MeV/u

- A 4 gap debuncher cavity (after a 5 m drift space) for the final longitudinal beam shaping.

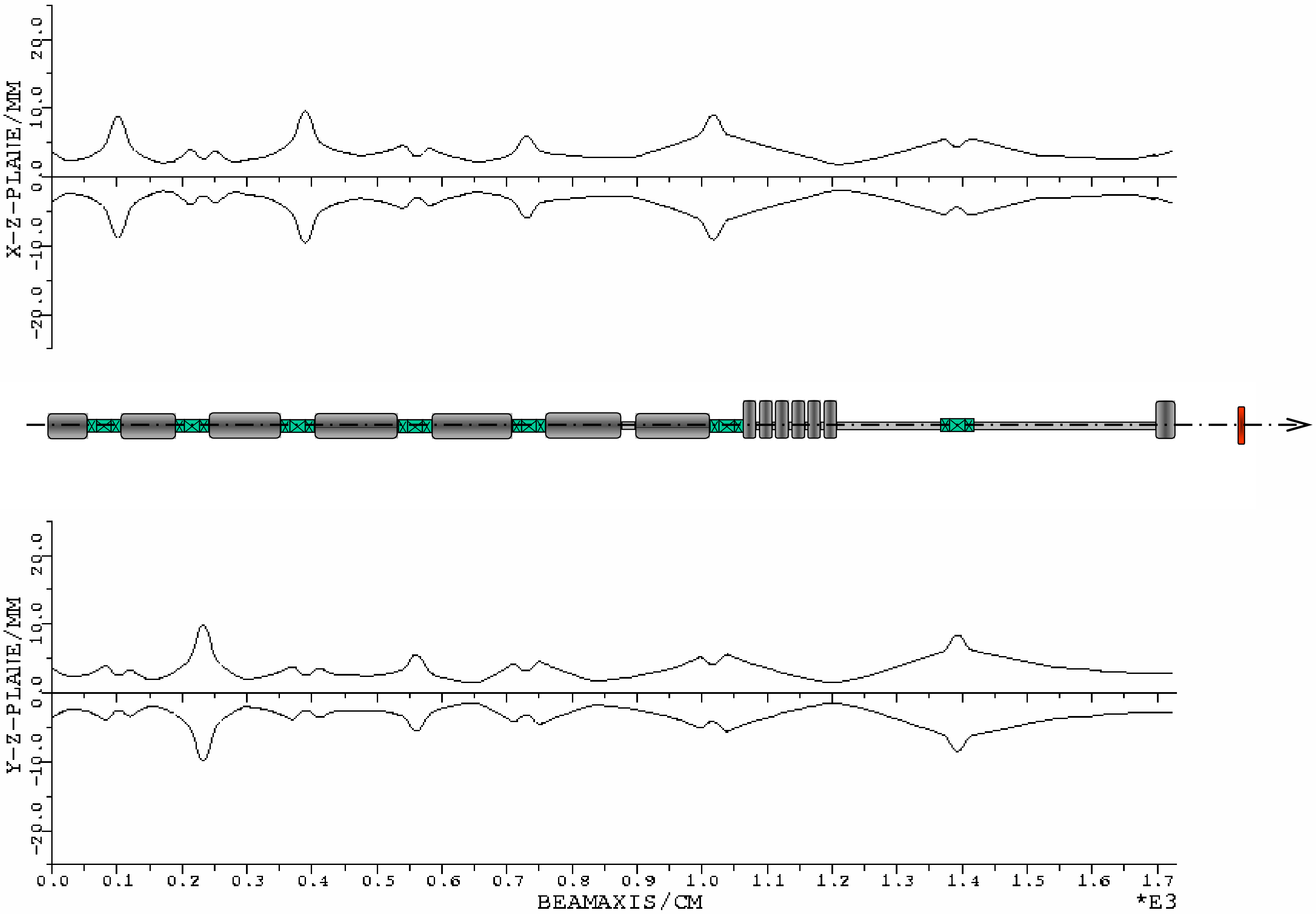
Room temperature CH-model (copper)



- Validation of the simulations
- Tuning (Frequency- and field distribution)
- Higher Order Modes (HOM)

- 19 gaps
- β=0.08
- L=105 cm
- Ø 34 cm

Beam dynamics for the CH – DTL (transverse beam envelopes)



Conclusions

- Improvements of beam intensities from Unilac by factors 10 (metals) to 100 (gases) for SHIP seem feasible:
  - 28 GHz ECR source.
  - Duty factor upgrade to 50 %.

- An optimized synchrotron injector Unilac together with a new cw linac offer attractive long term capabilities:
  - Rebuilt of the Unilac post stripper section as a pulsed high current linac (emittance growth reduction, higher beam energy and SIS current limit, factors ~ 2).
  - New cw linac with independent beam time schedule.

- Two main options for the cw linac:
  - Small solution $A/q \leq 5$, $3.8 < W < 6$ *AMeV*, room temperature IH linac with 4 s.c. quarter wave cavities (two cryostats) for energy variation.
  - Big solution $A/q \leq 7$, $3.8 < W < 7.5$ *AMeV*, 108 *MHz* HLI (1.4 *AMeV*) & s.c. 324 *MHz* CH linac & energy modulator (2 gap, $\lambda/4$).