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Steps towards an Optimized Linac for SHE Production at GSI

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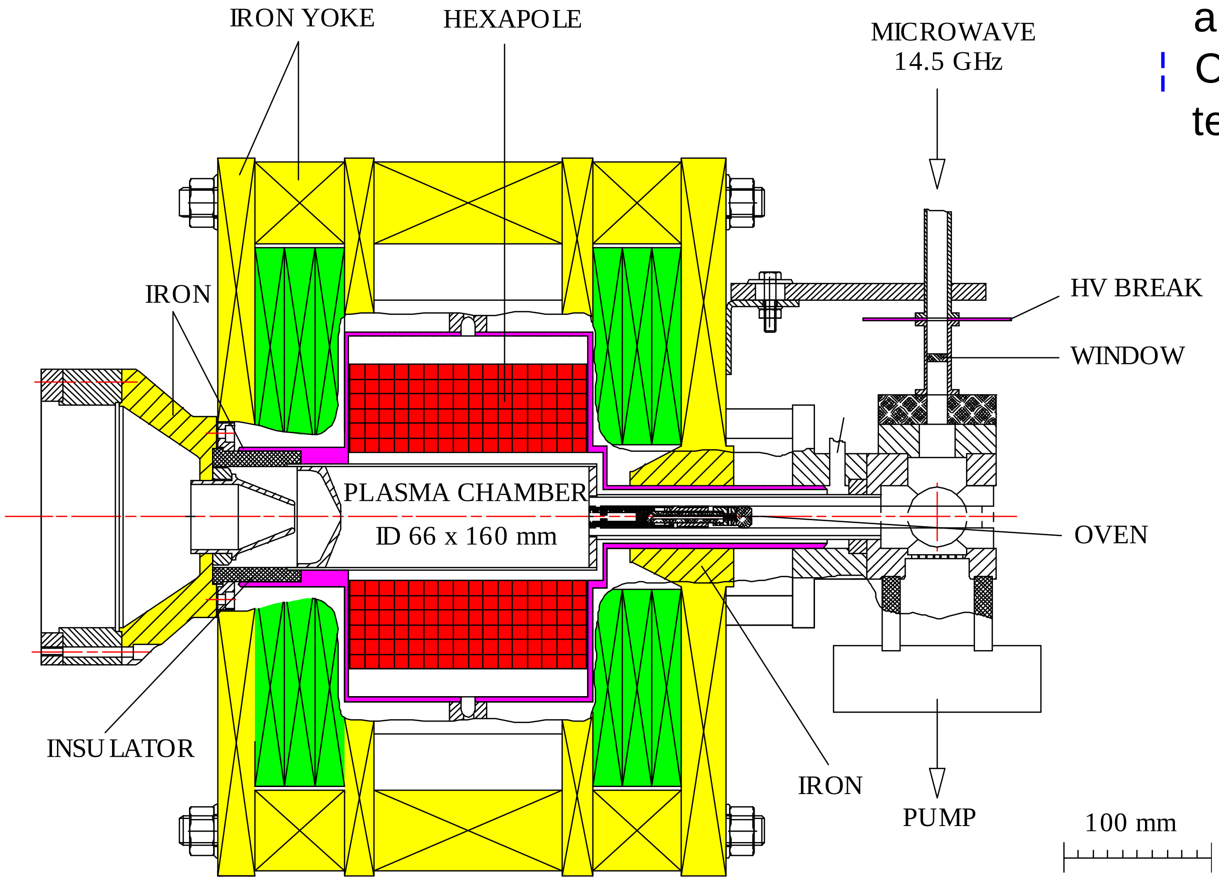
Workshop on the Future of Superheavy Element Research

February 17 - 18, 2004, GSI Darmstadt, Germany

- Improved ion source for high charge state production.
- Upgrade of the existing UNILAC.
- Two heavy ion linacs for different duties.
- Design of a cw superconducting linac.

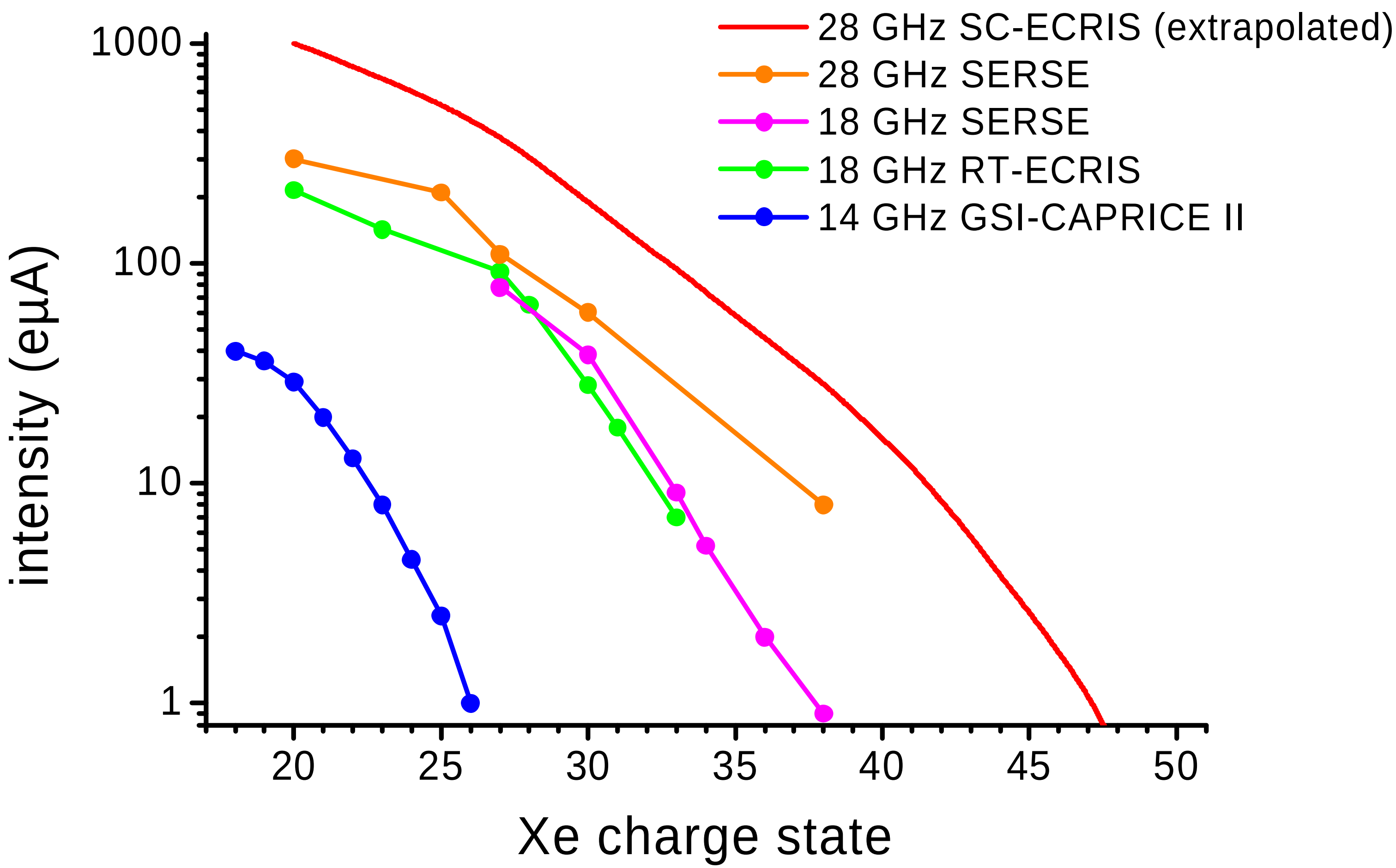
GSI-CAPRICE ECR Ion Source

- Technical standard of 1990 and status quo until now at GSI
- Continuously improved oven technology



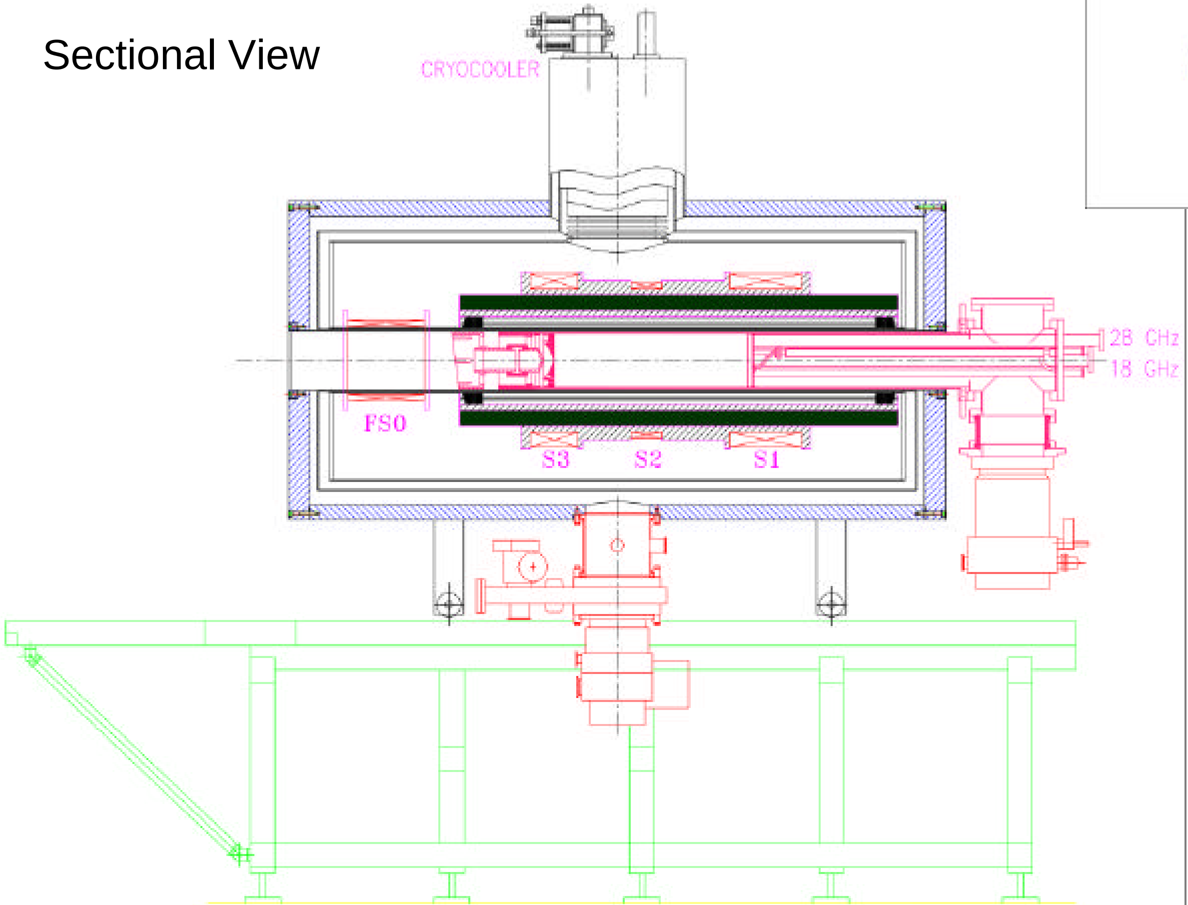
Ion Species	Intensity (eµA)
$^{26}Mg^{5+}$	80
$^{50}Cr^{8+}$	40
$^{58}Fe^{9+}$	50
$^{70}Zn^{10+}$	70

Comparison of Performances for Different ECR Ion Sources

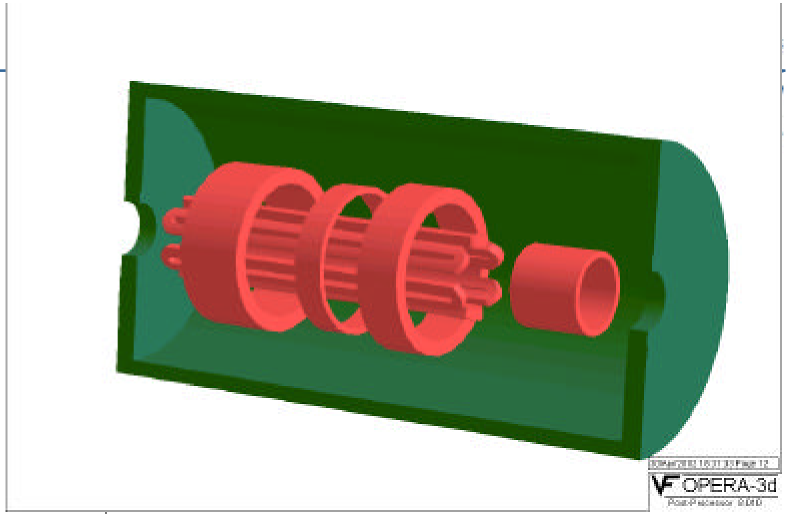


The GyroSerse Project

Sectional View



S. Gammino, private communication

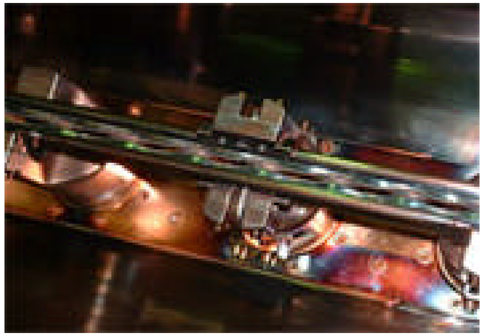


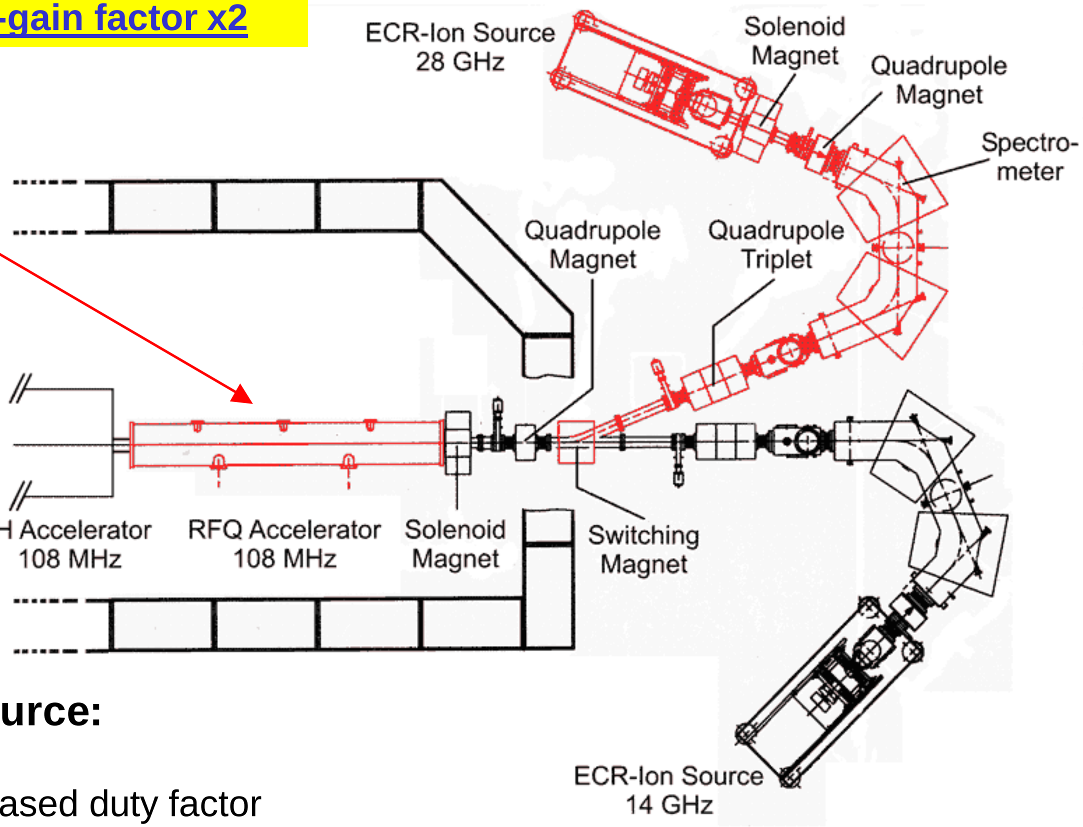
Magnetic System

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 → <u>intensity-gain factor x2</u>



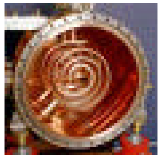
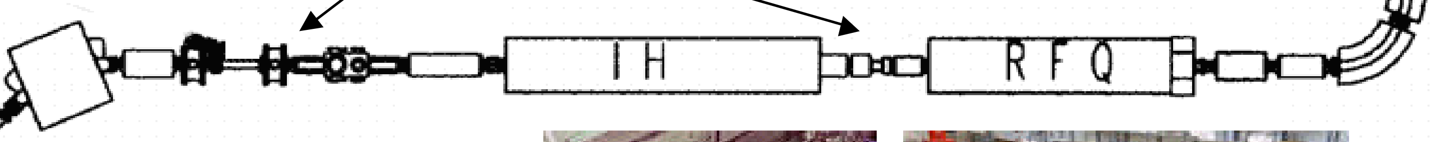
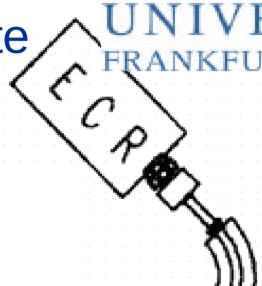


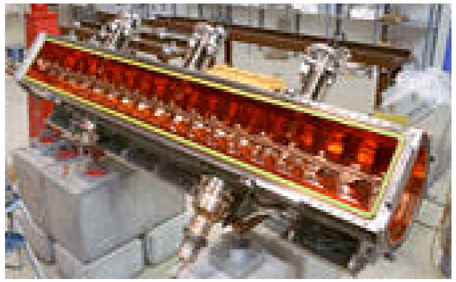
New RFQ-structure:
- gain of the duty factor
- higher injection energy
- increased acceptance

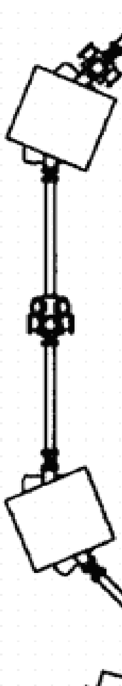
Additional 28 GHz-ion-source:
- intensity gain of factor two
- higher charge states for increased duty factor

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



Presently:

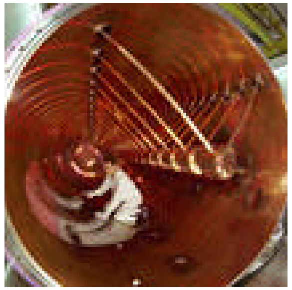
duty factor (beam)= 25 % (rf: 35 %), A/ξ ≤ 8

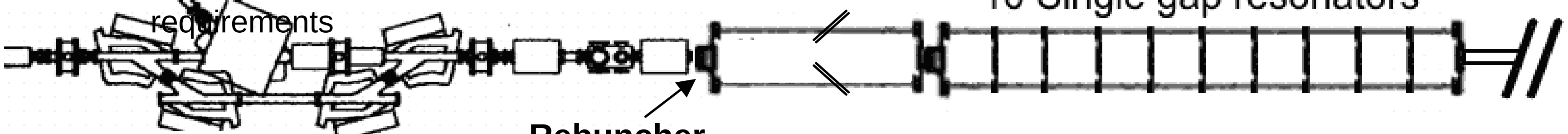
Upgrade:

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

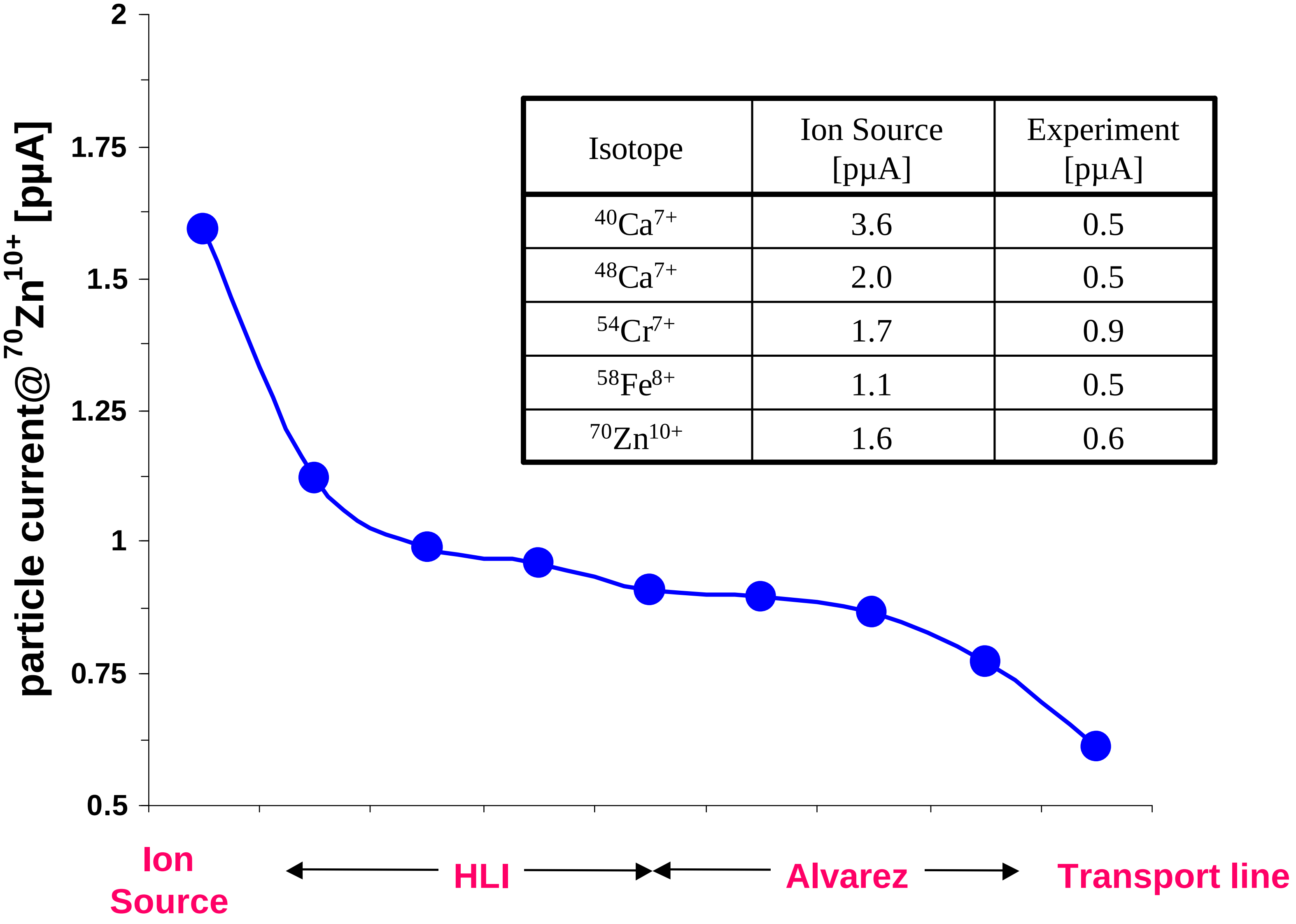
A/ξ ≤ 6.5, duty factor = 50 % (rf: 60 %)

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



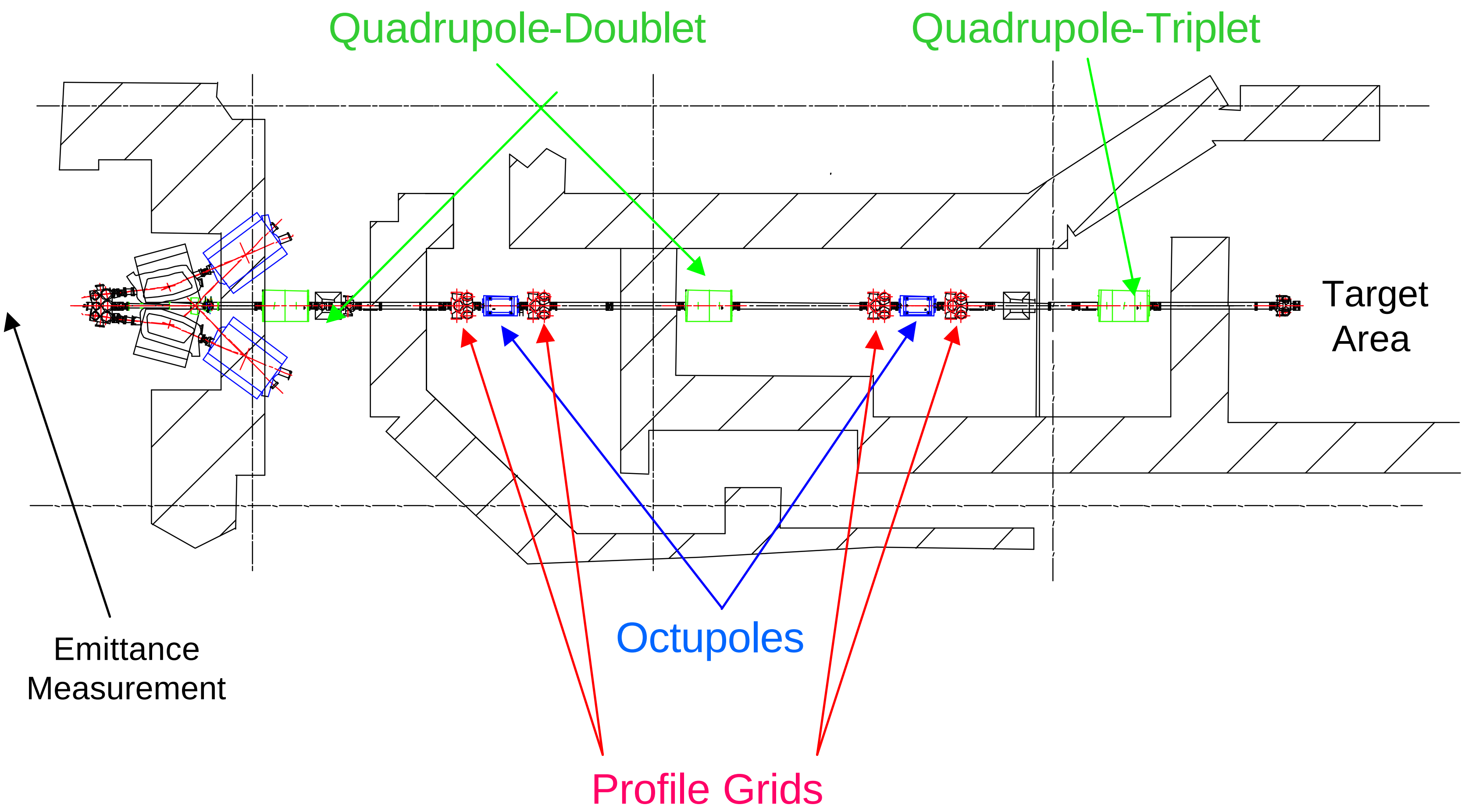



Particle Current in the GSI-Unilac (routine operation)

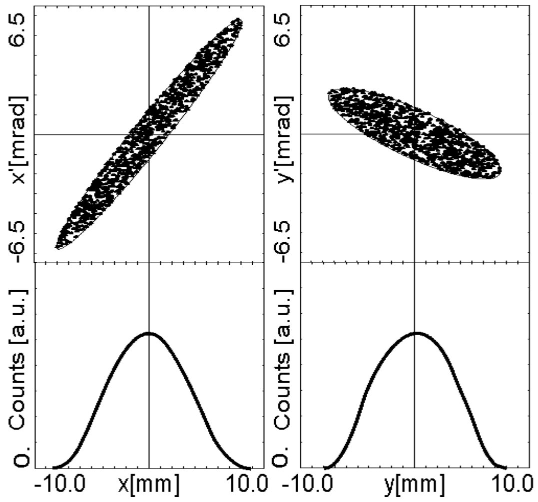


Isotope	Ion Source [pµA]	Experiment [pµA]
$^{40}Ca^{7+}$	3.6	0.5
$^{48}Ca^{7+}$	2.0	0.5
$^{54}Cr^{7+}$	1.7	0.9
$^{58}Fe^{8+}$	1.1	0.5
$^{70}Zn^{10+}$	1.6	0.6

Upgrade of the Beam Transport to the SHIP-Target



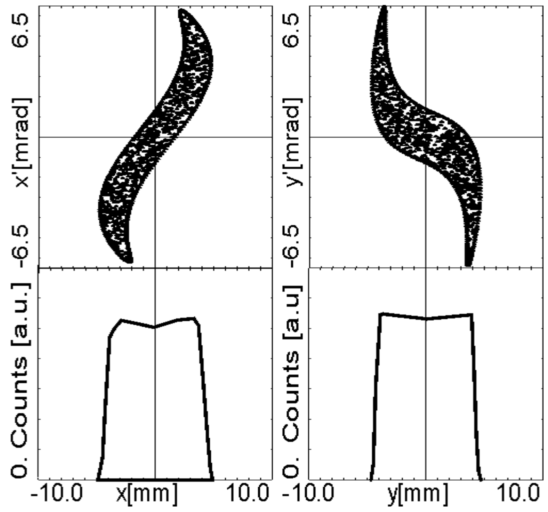
Transverse Beam Shaping with Octupole lenses



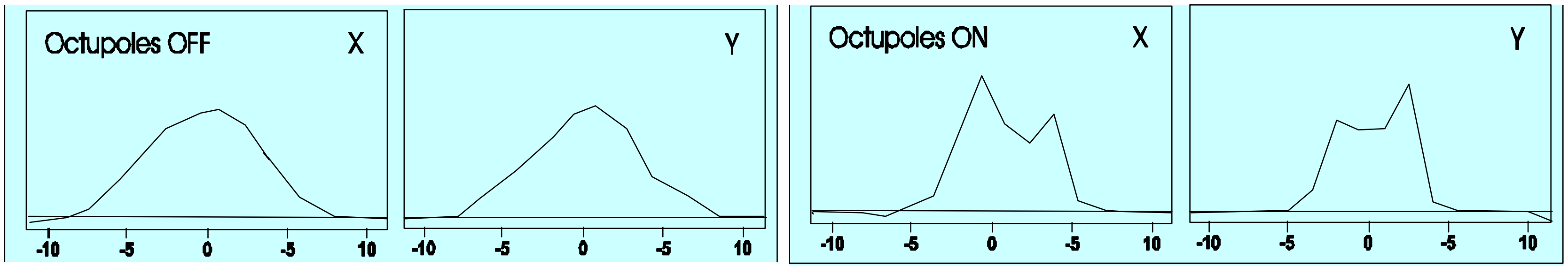
$B_x = G(y^3 - 3x^2y)$

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

G: pole tip field



Measured beam profiles at the target position



- Transmission losses of 30%
- Increase of underground noise by a factor of 1000

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.

⇒ Relaxed SIS 18 operation.

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

25 *A MeV* U^{28+} increases $N_{\mathrm{max,SIS18}}$ 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.

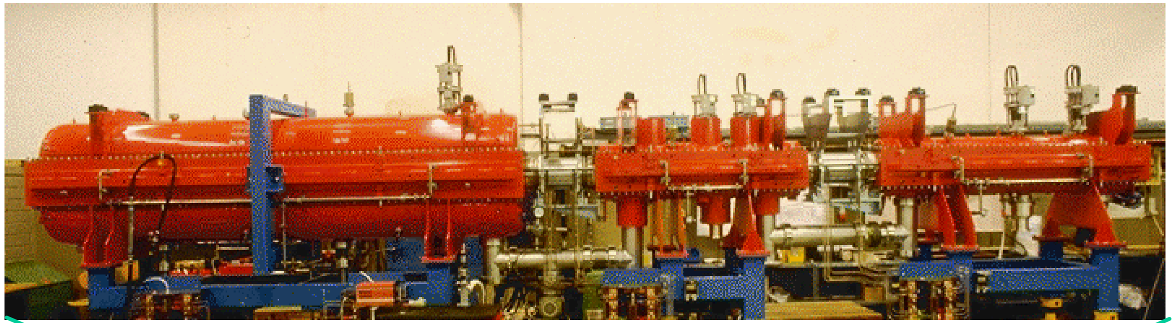
- Optimum beam matching to the target wheel; highest counting rates.

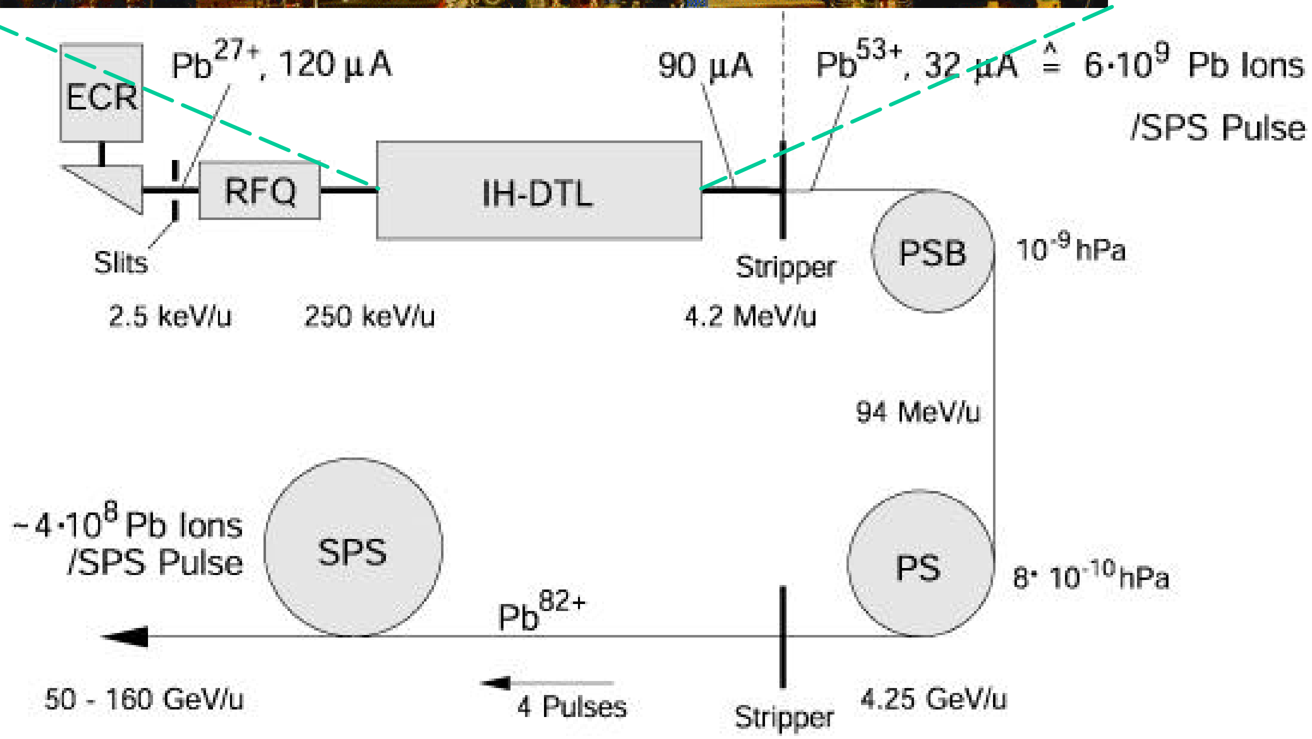
Small and Fast Solution

- Room temperature linac :
  HLI (1.4 *AMeV*) & 217 MHz DTL (IH section, 4 tanks
  $P_{rf} \lesssim 100$ *kW* each).
  $A / q \lesssim 5$; $W \lesssim 6$ *AMeV* ;
  $\overline{Z}_{eff} \simeq 140$ *MW/m*; $L_{tot} \simeq 20$ *m* ;
  $P_{tot,rf} \simeq 320$ *kW* ;
  $P_{plug} \simeq 700$ *kW*, for 217 *MHz* cavities !

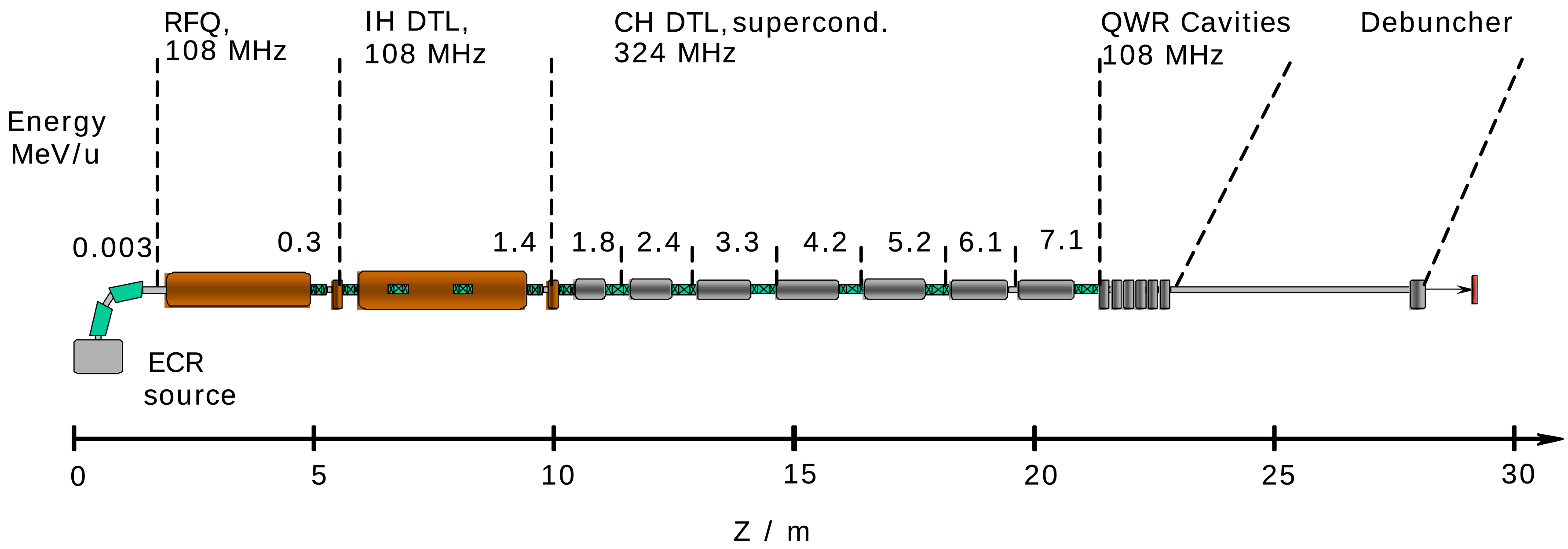
- $4 \times \lambda/4$, 108 MHz, 2 gap cavities for energy variation, superconducting (two cryostats).

Lead Acceleration at CERN





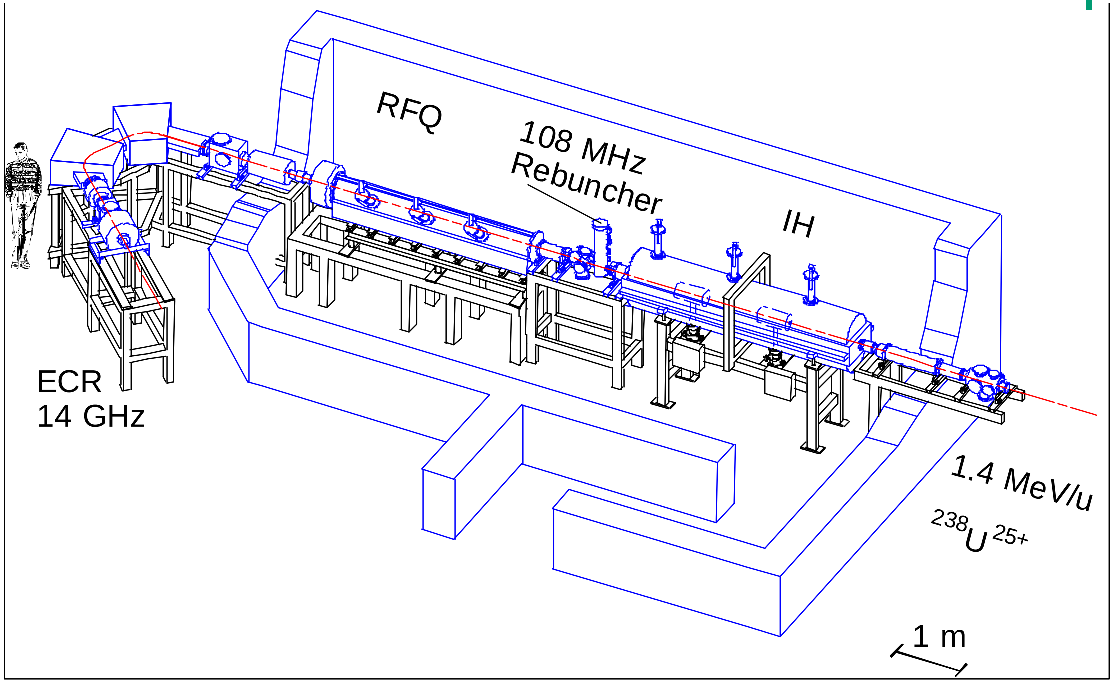
Layout of the Proposed cw Superconducting Linac

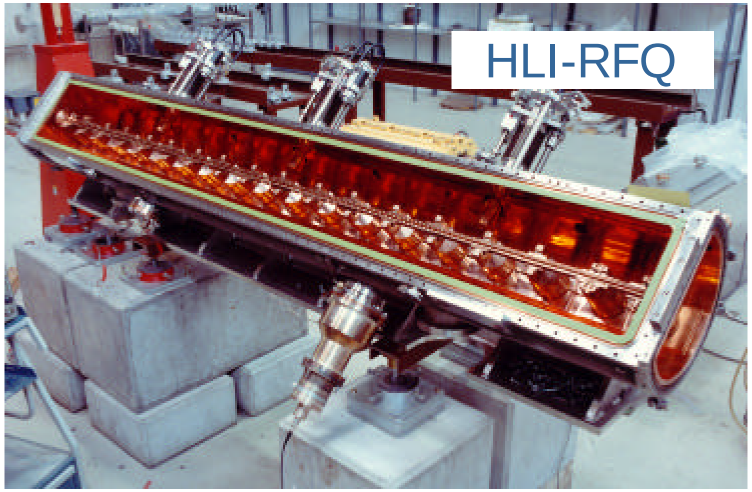


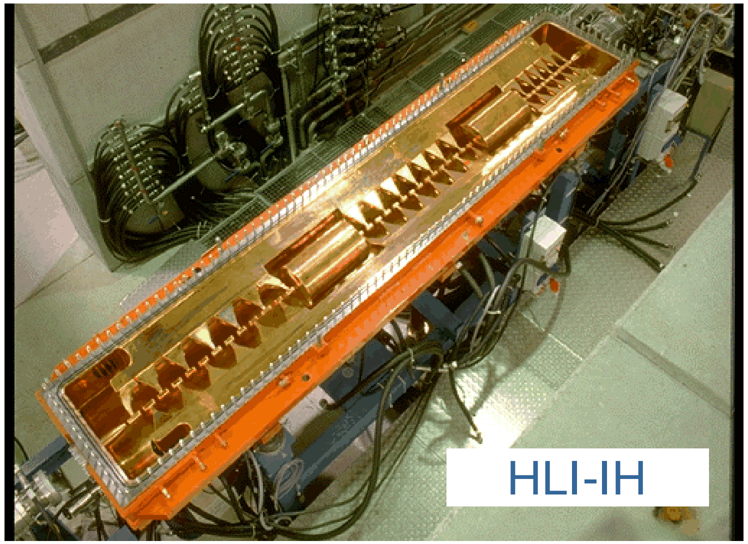
Main components:

- 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.

Radio Frequency Quadrupole (RFQ) accelerator

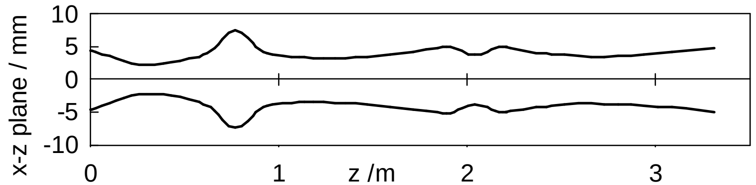
GSI cw-RFQ	GSI HLI-RFQ
A/q = 7 (A < 150)	A/q = 8.5 (U^{28+})
W = 3 – 300 keV/u	W = 2.5 – 300 keV/u
f = 108.48 MHz	f = 108.48 MHz
L ≈ 3m	L ≈ 3m
U_{el} = 60 kV	U_{el} = 80 kV
a = 3.2 – 2.5 mm	a = 4 – 3 mm
P = 70 kW cw	P = 125 kW 25%

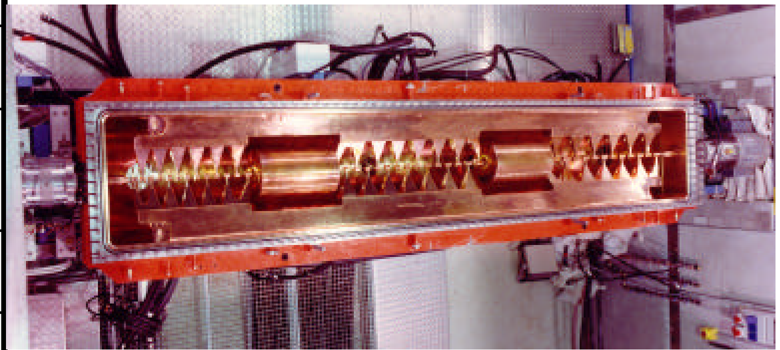
At 108 MHz the 4-rod-RFQ type is preferred

Interdigital H-Type (IH) - DTL

Resonator parameters	
Accel. sections	3
Magn. quad. lenses	2
No. Of gaps	44
Total length /m	3.5
Max. eff. gap volt. /kV	231
Avg. accel. gradient / MV/m	2.3
Avg. power loss / kW/m	26
Beam parameters	
$\varepsilon_{n,transv,input}$ /mm mrad	0.8
$\varepsilon_{n,long,input}$ /keV/u*ns	1.7

Beam dynamics for the IH – DTL (transverse envelopes) :



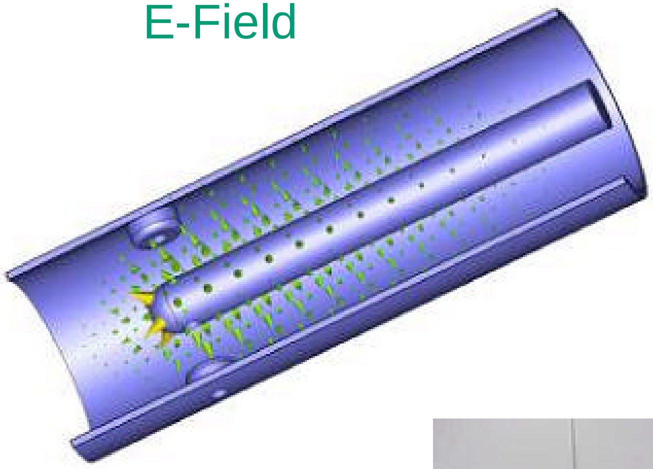


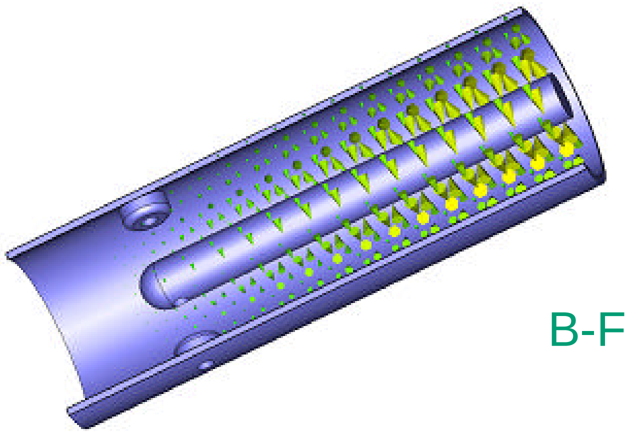
Cavity Options for the S.C. DTL

SC Splitring resonators for ATLAS (f = 115 MHz)

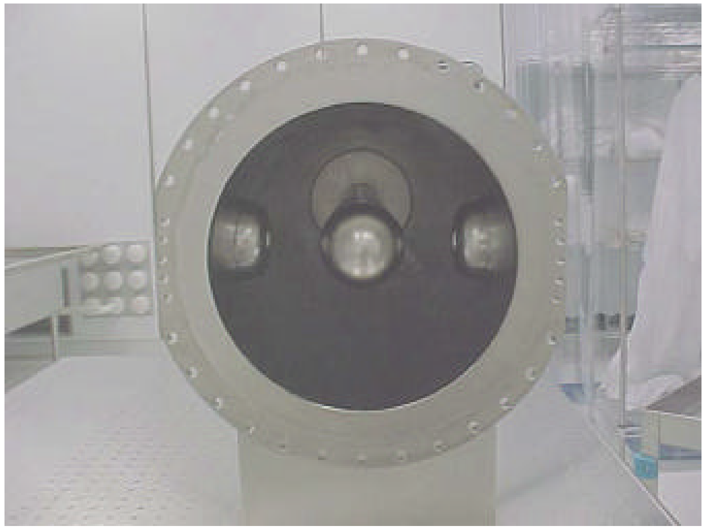
Quarter Wave Resonators

E-Field

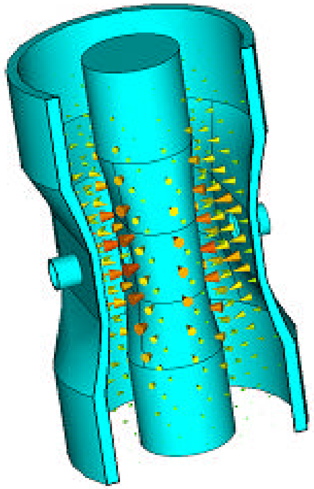




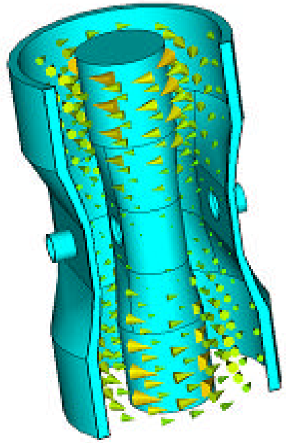
B-Field



Half Wave Resonators

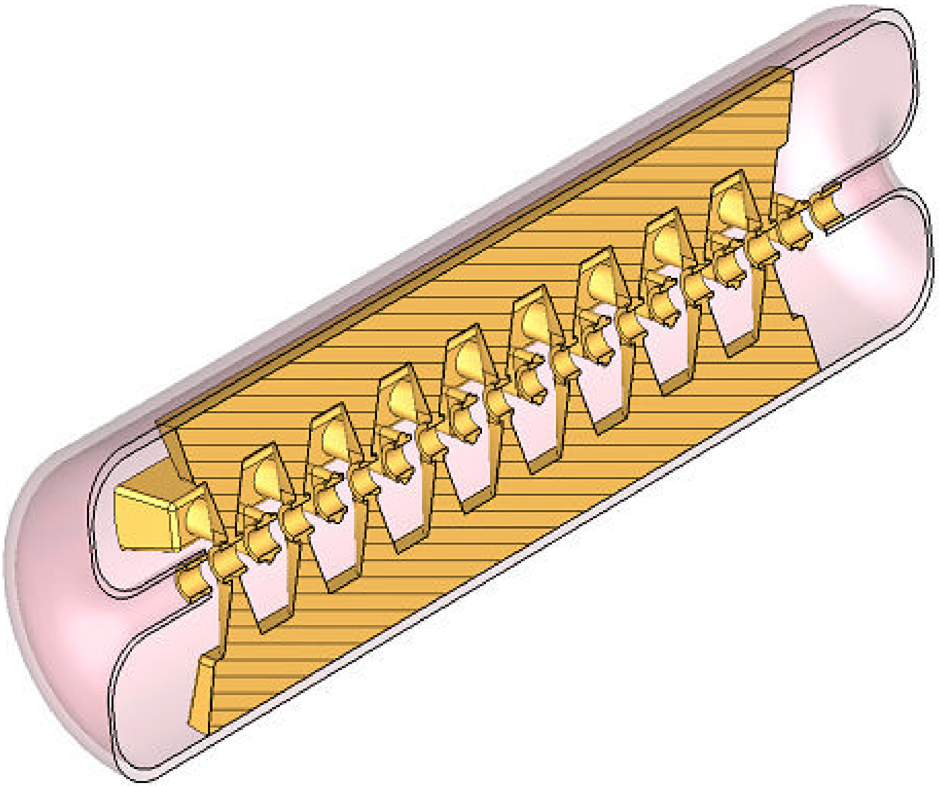


E-Field



B-Field

Superconducting CH-prototype
Microvawe Studio™ Design and Parameter List



Gap number	**19**
Length (m)	**1.05**
Frequency (MHz)	**352**
b	**0.1**
Material	**bulk Niobium**
E_0 (MV/m)	**4**
E_a=ET (MV/m)	**3.2**
E_p (MV/m) at 3.2 MV/m	**21.0**
B_p (mT) at 3.2 MV/m	**23.3**
G=R_sQ_0 (W)	**56**
R_a/Q (W) (T incl.)	**3220**
(R_a/Q)G (W^2)	**180000**
Q_0 (BCS, 4K, 352 MHz)	**1.5x10^9**
Q_0 (total R_s=150 nW)	**3.7x10^8**
W (mJ/(MV/m)^2)	**155**
W at 3.2 MV/m (J)	**1.58**
P at 3.2 MV/m and R_s=150 nW =(W)	**9.5**

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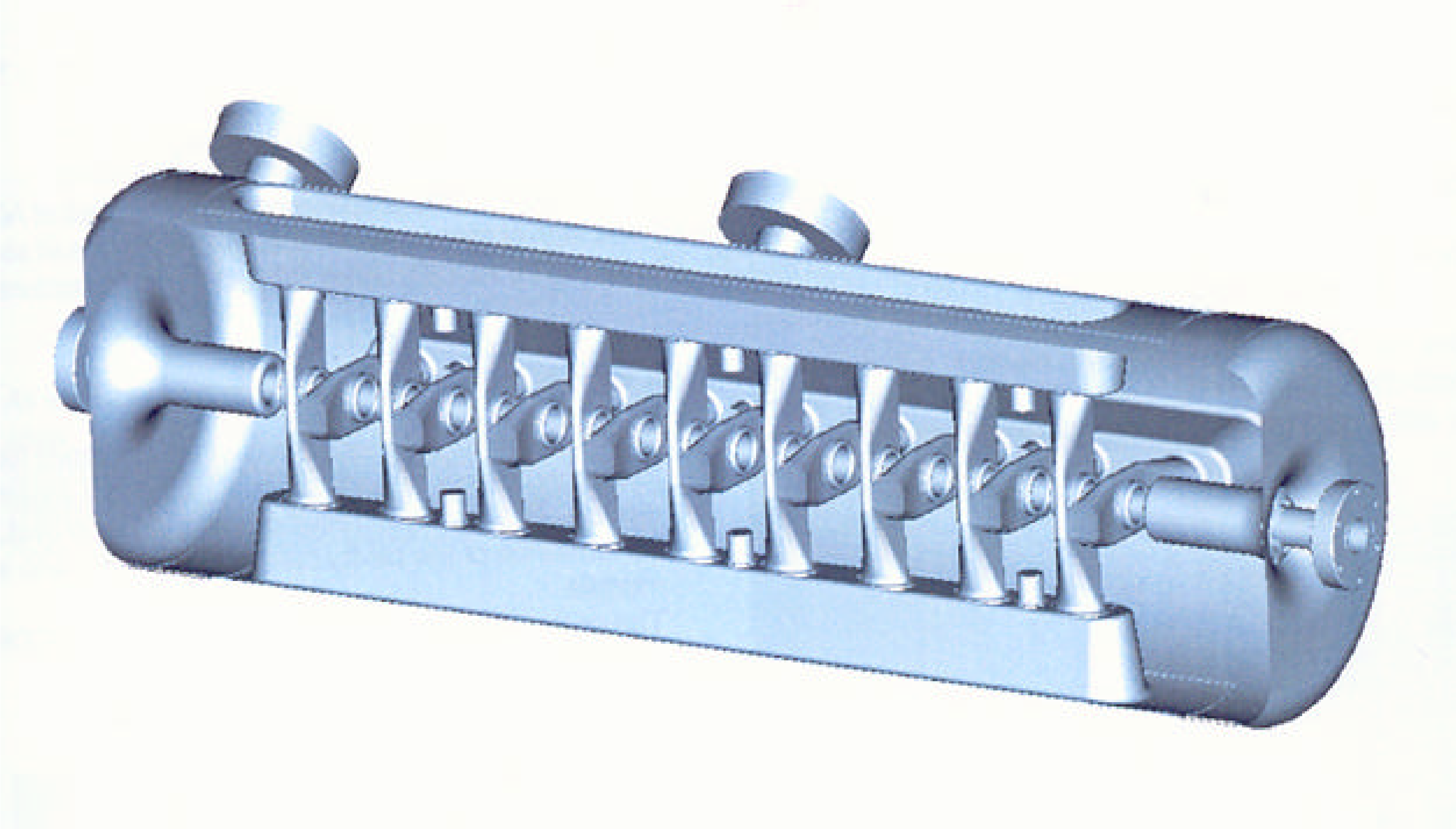
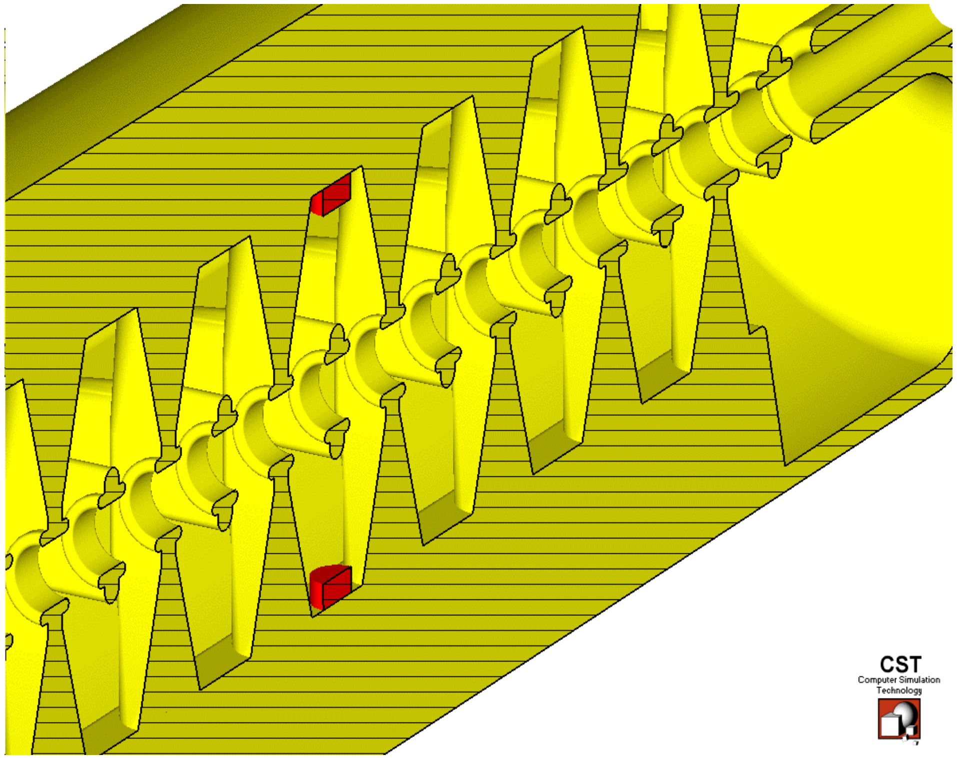
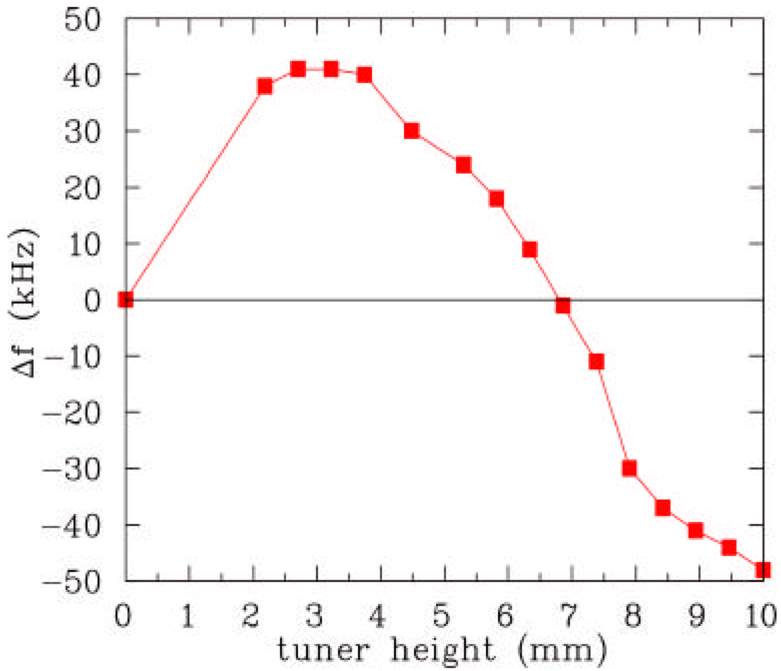
Superconducting CH-prototype :
19-cell, 352 MHz SC CH-structure to be built by an industrial manufacturer

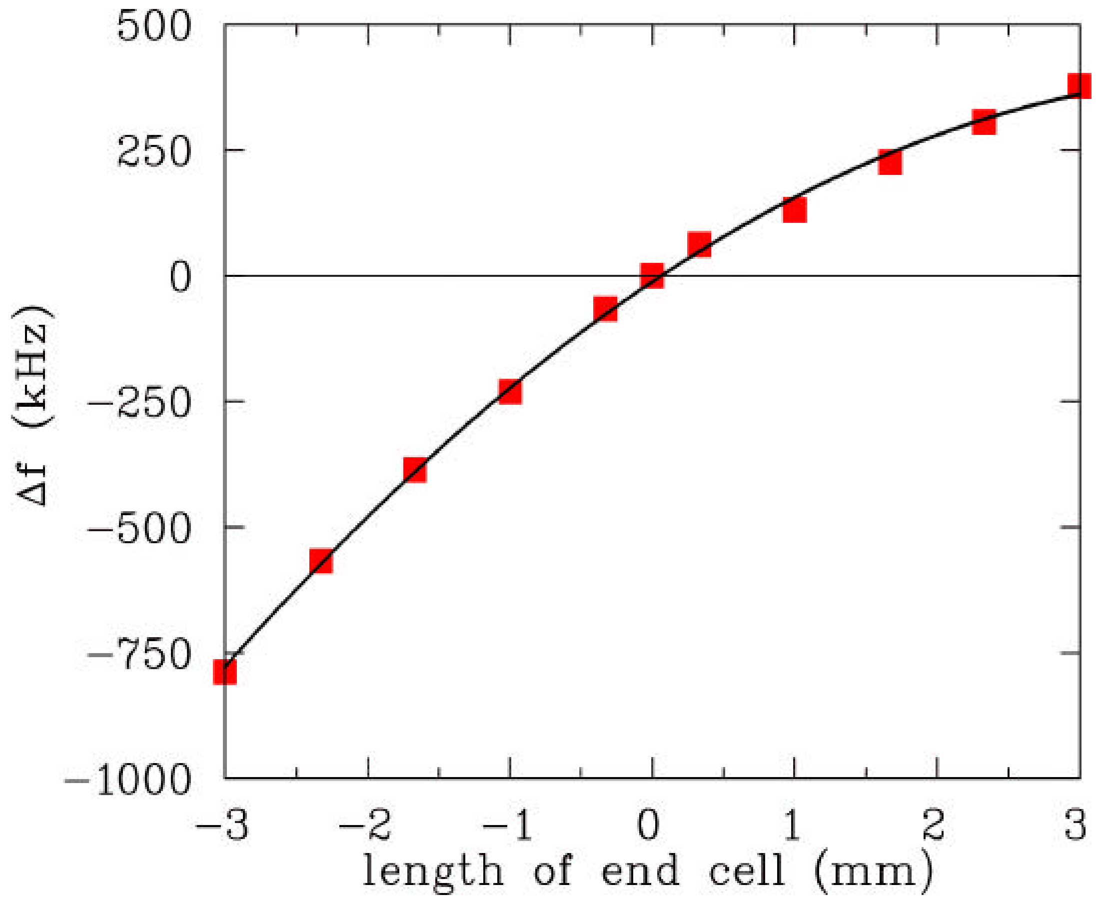


Tuning of CH-cavities

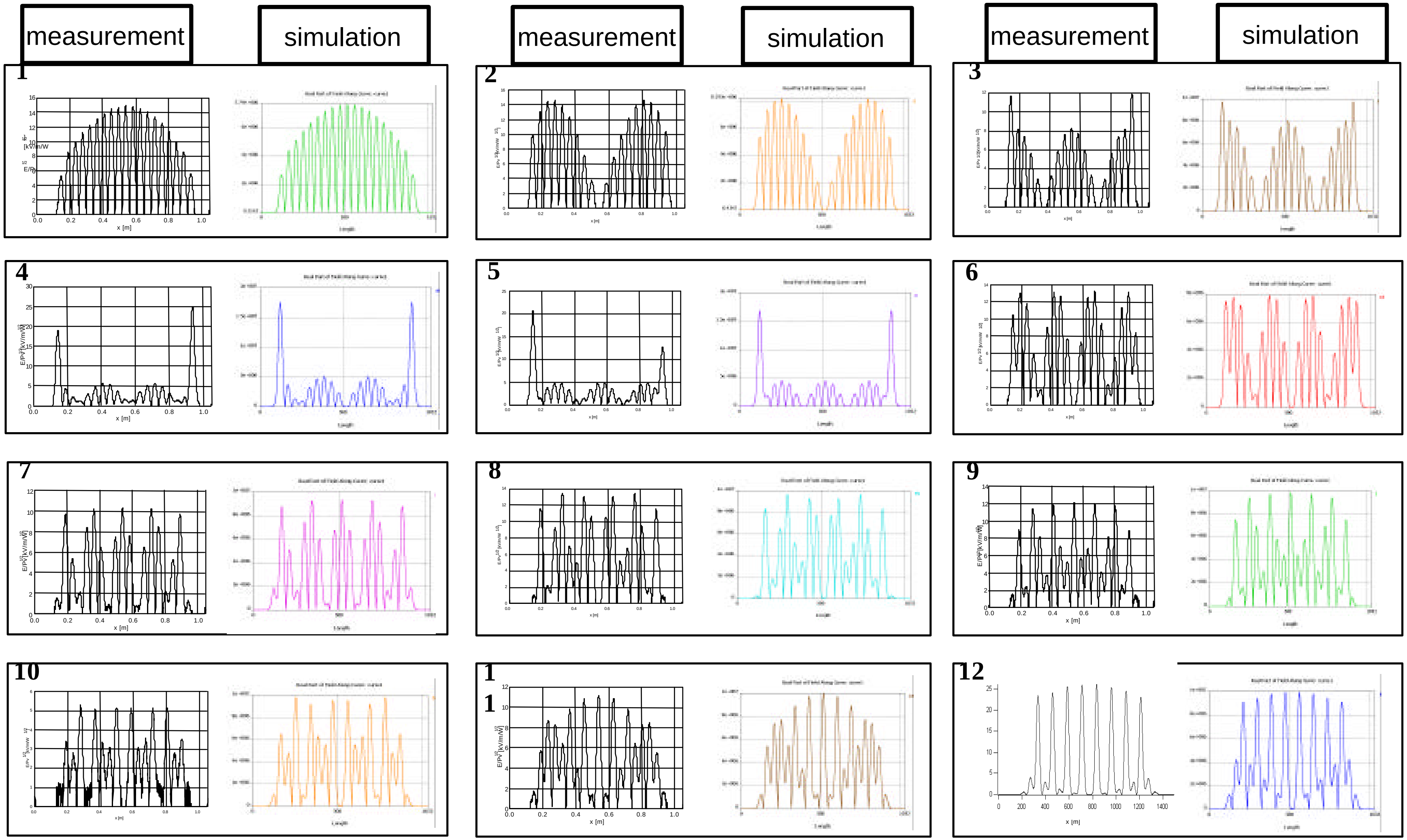




Tuning of CH-cavities : Changing the Length of the End Cells



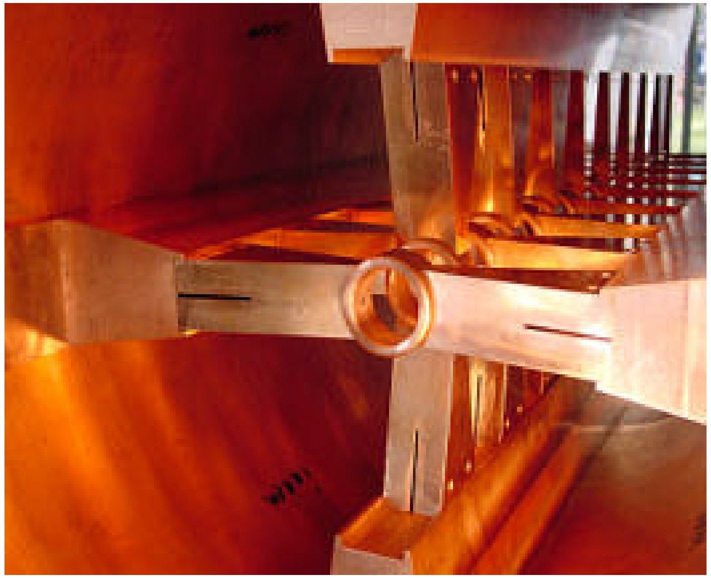
Higher Order Modes in the CH-Structure

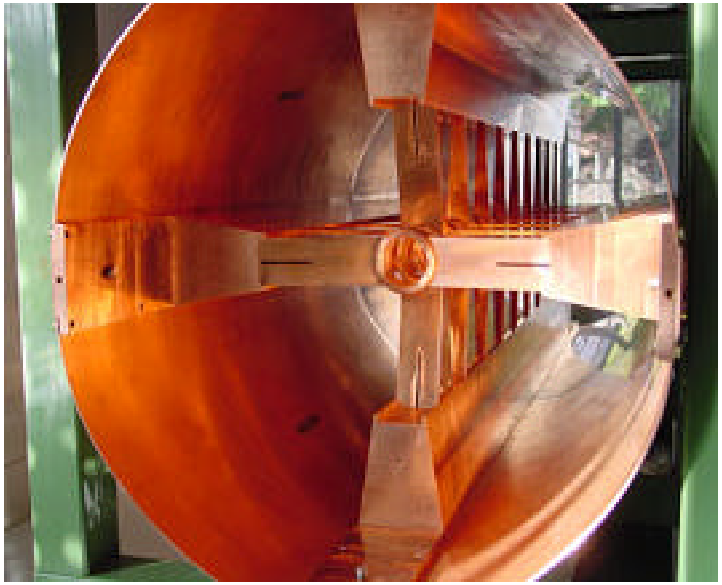


Room temperature CH-model (copper)

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

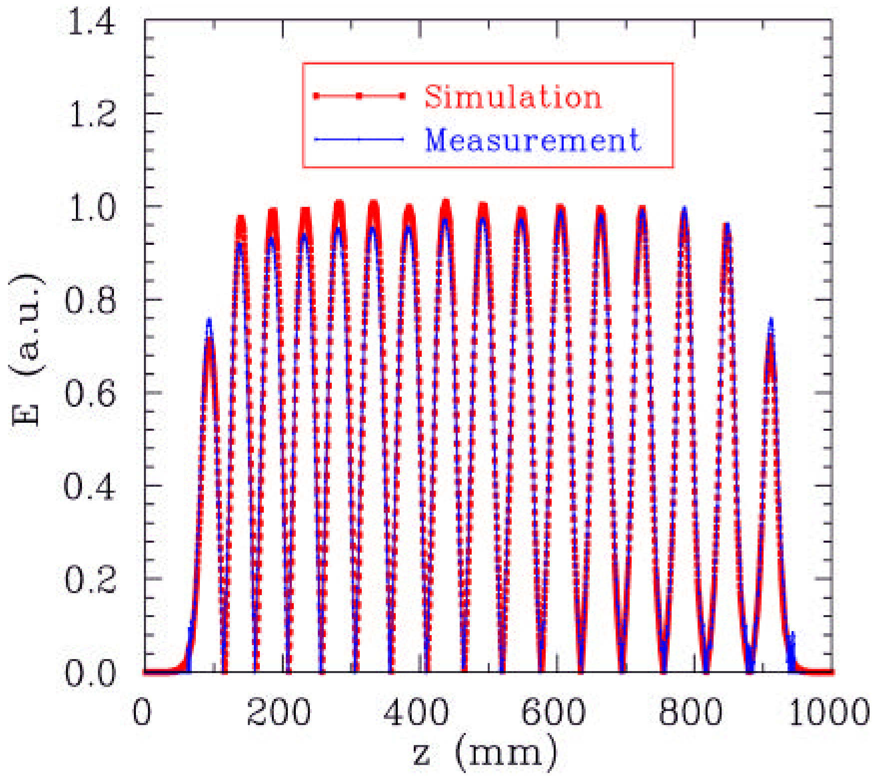
- Validation of the simulatios
- Tuning (Frequency- and field distribution)
- Higher Order Modes (HOM)



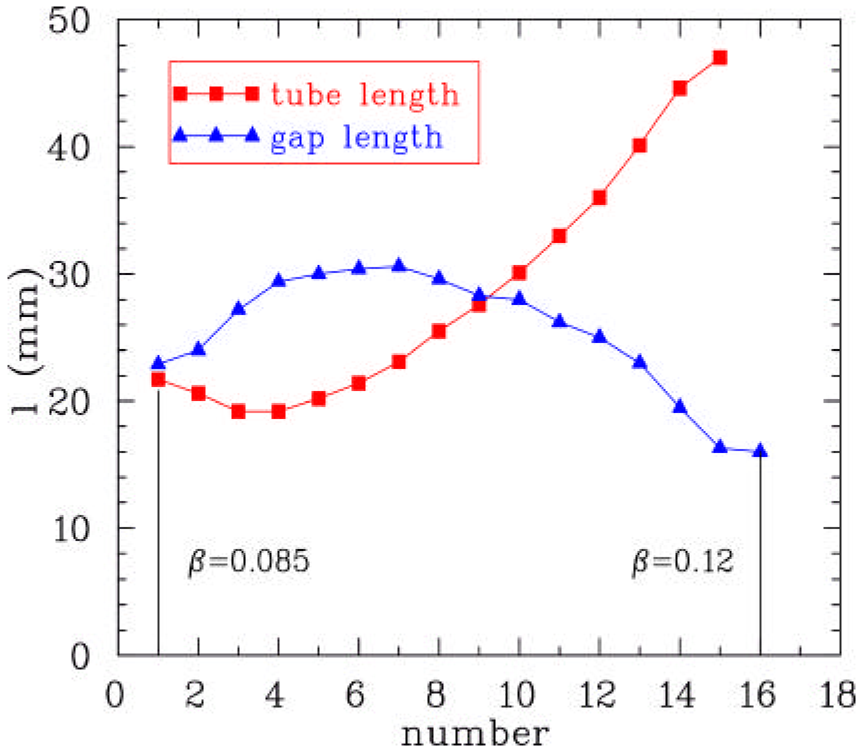


Flatness in a CH-DTL With β-Profile

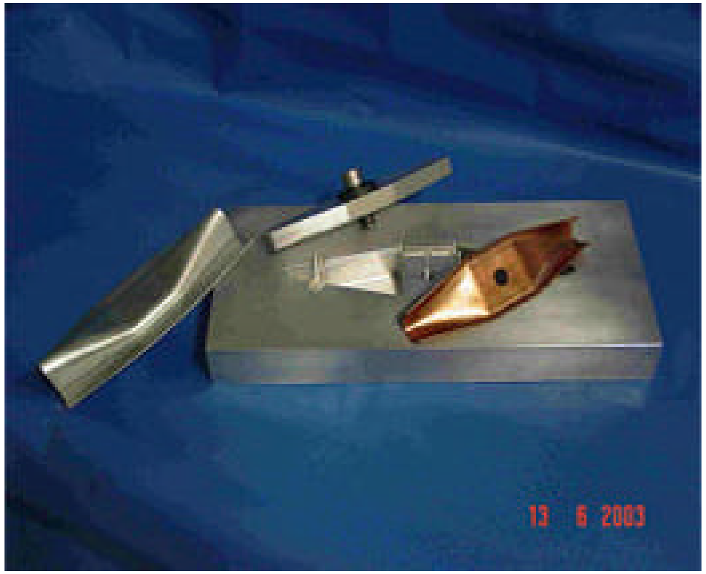
Field distribution with beta profile

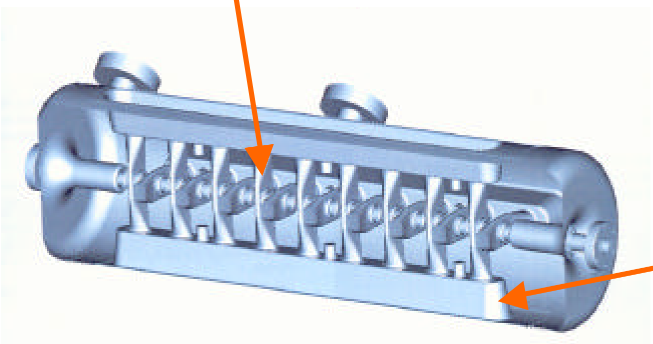


Required tube and gap length



Manufacturing of Prototype Components at ACCEL Company





Status : Components ready for e^{-} - beam welding

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

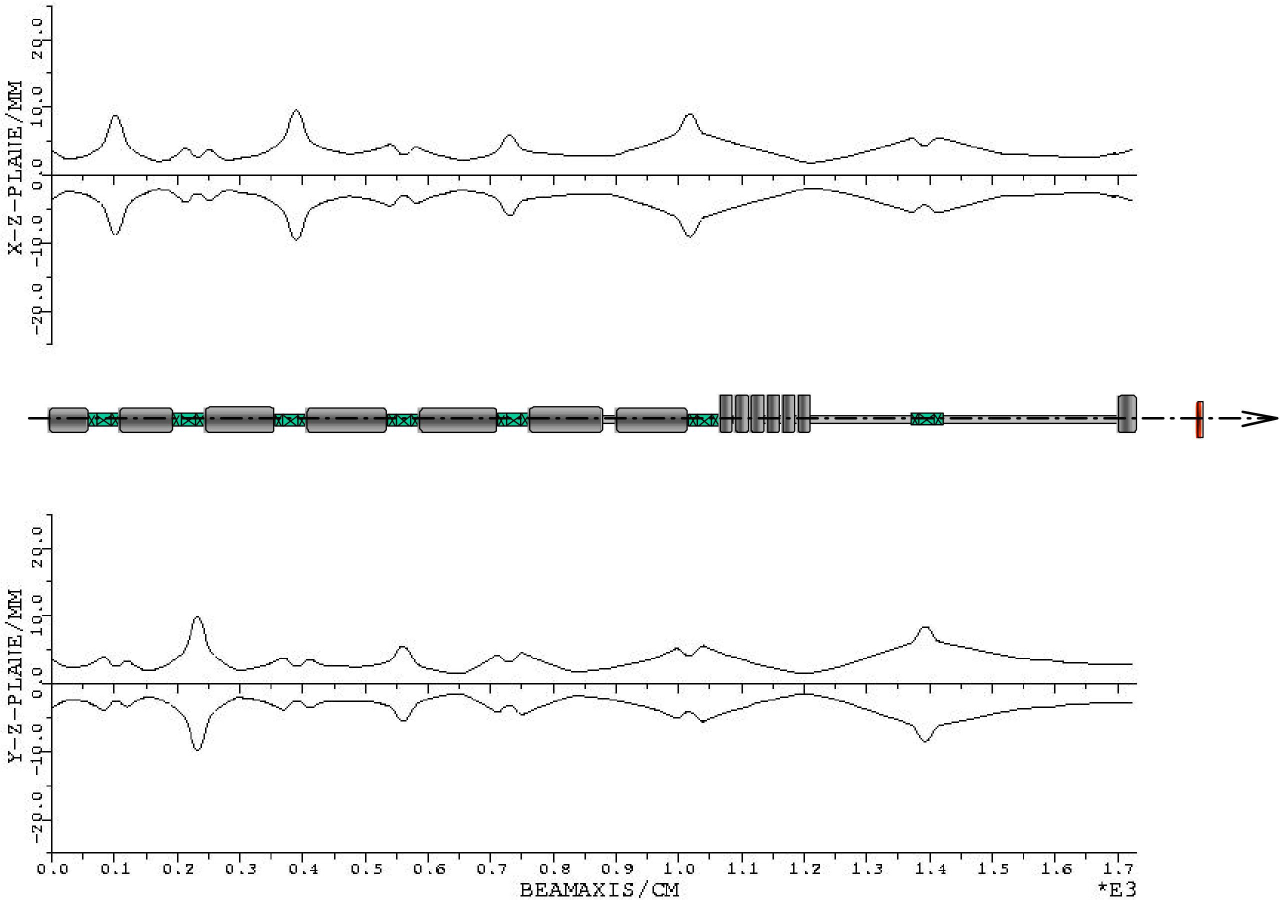
-> 5.25 MeV/u	-> 6.15 MeV/u	-> 7.15 MeV/u

- 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.

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



Parameters of the CH-DTL Section

Resonator	Gaps	Res. Length	E_{acc}
CH 1	24	625 mm	5.0 MV/m
CH 2	28	850 mm	5.4 MV/m
CH 3	32	1130 mm	5.3 MV/m
CH 4	32	1290 mm	5.0 MV/m
CH 5	28	1260 mm	5.4 MV/m
CH 6	24	1180 mm	5.2 MV/m
CH 7	22	1150 mm	5.6 MV/m
QWR 1-6	2	E_{syn}=5.6 MeV/u	
Debuncher (RT)	4	E_{syn}=5.6 MeV/u	

Parameters of the SC Quadrupole Lenses

Quadrupole-triplet	Aperture	Gradient		eff. Length	
		Q1 & Q3	Q2	Q1 & Q3	Q2
QT 1	30 mm	59 T/m	56 T/m	120 mm	200 mm
QT 2	30 mm	70 T/m	66 T/m	120 mm	200 mm
QT 3	30 mm	70 T/m	68 T/m	120 mm	200 mm
QT 4	30 mm	64 T/m	70 T/m	120 mm	200 mm
QT 5	30 mm	73 T/m	73 T/m	120 mm	200 mm
QT 6	30 mm	56 T/m	62 T/m	120 mm	200 mm
QT 7 (RT)	30 mm	52 T/m	59 T/m	120 mm	200 mm

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, $\lambda/4$).