Heavy Ion cw-linac as a future driver option for SHE Physics Experiments at GSI

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GSI, HIM

Heavy Ion cw-linac as a future driver option for SHE Physics Experiments at GSI

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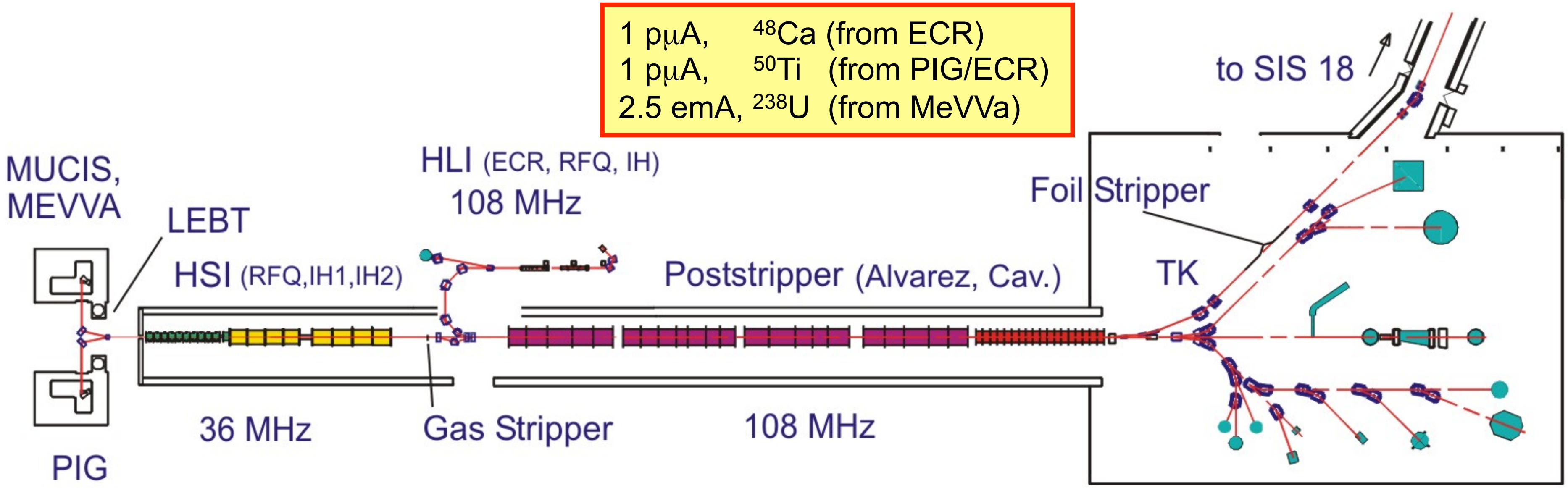
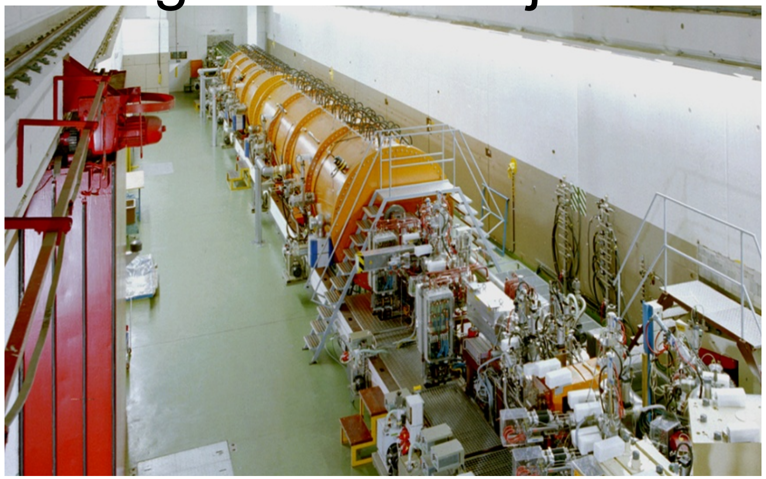
1. Existing UNILAC and future linac injectors@GSI
2. High duty factor upgrade
3. cw-linear accelerator concept
4. Multicell CH-cavity
5. CH-prototype and full performance test
6. Summary and Outlook

The GSI UNIversal Linear ACcelerator

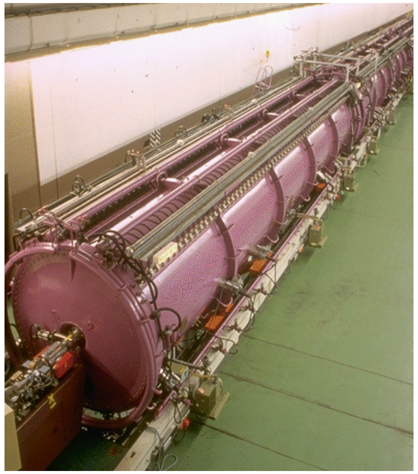
1 pμA,	^{48}Ca	(from ECR)
1 pμA,	^{50}Ti	(from PIG/ECR)
2.5 emA,	^{238}U	(from MeVVa)



High Current Injector



Alvarez



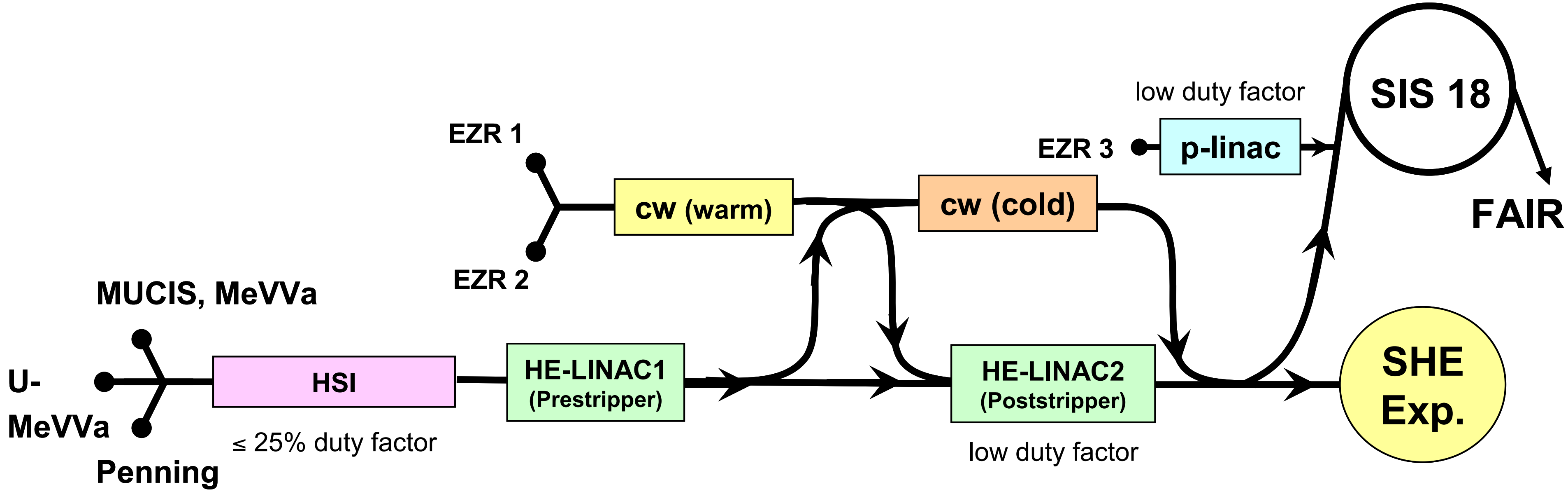
Single Gap Resonators

Requirements for FAIR and the SHE-program

FAIR requirements:
- extremely high pulse intensities
- low repetition rate (max. 3 Hz)
- low duty factor (0,1 %) (pulse length for SIS18 only 100 µs)

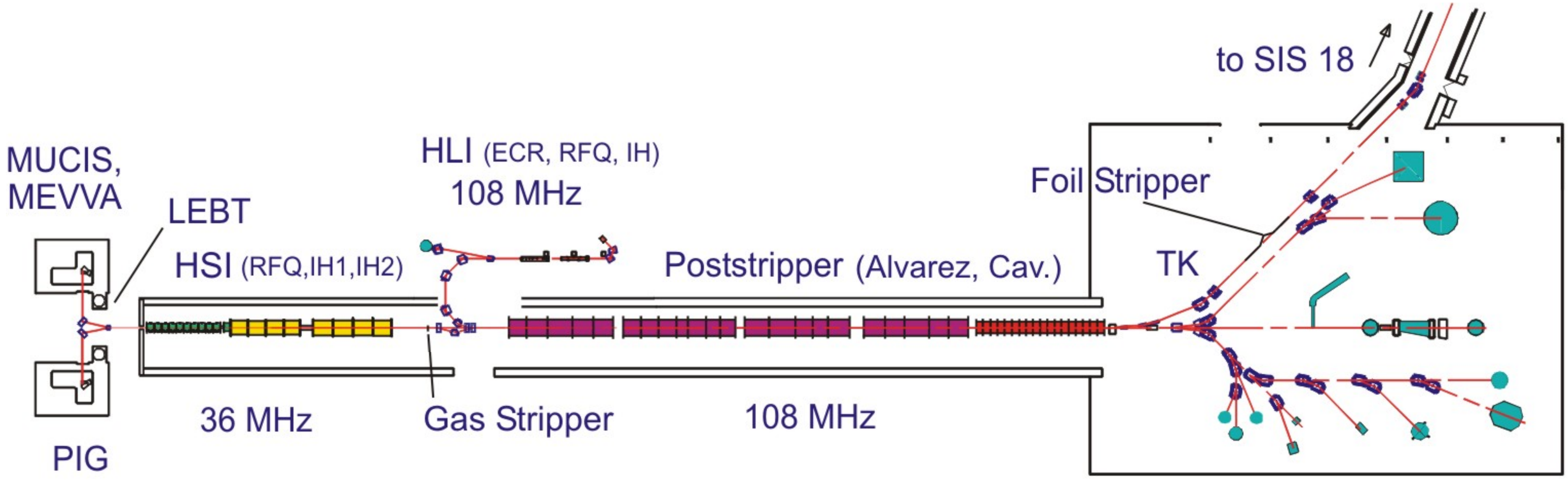
SHE requirements:
- relatively high pulse intensities
- high repetition rate (50 Hz)
- high duty factor (-> 100 %) (pulse length up to 20 ms)

GSI-Future Option



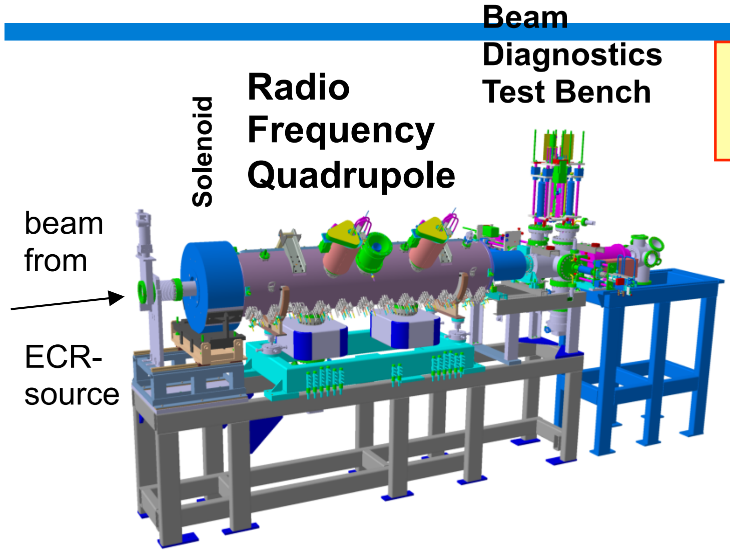
- **Proton linac-injector for FAIR (FAIR-pbar-physics)**
  - 70 MeV, 35 (70) mA, 325 MHz, 0.1% duty factor
- **High Energy injector linac (replacement of Alvarez DTL)**
  - Prestripper: 3 MeV/u, A/q = 60 (18 emA), 108 MHz, 1% duty factor
  - Poststripper: 11.4 MeV/u (max. 22 MeV/u), A/q = 6.3 (20 mA, 108/325 MHz, 1% duty Factor
- **sc-cw-linac (for Super Heavy Element program)**
  - 3.5 – 7.5 MeV/u, 1 mA, 217 MHz, 100 % duty cycle

Overview/High duty factor upgrade

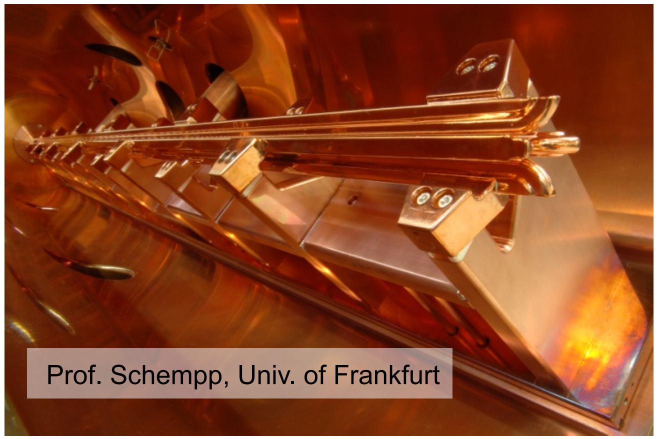


	Luminosity gain
• New RFQ: Duty cycle 25 -> 40%	x 1.6
• New MS-ECRIS: higher beam currents and	
• LEBT for new MS-ECRIS at HLI	x 5.0
• cw-linac	
– 100% duty cycle	x 2.5
– independent operation	x 2.0
	x 40

SHE-UNILAC-Upgrade



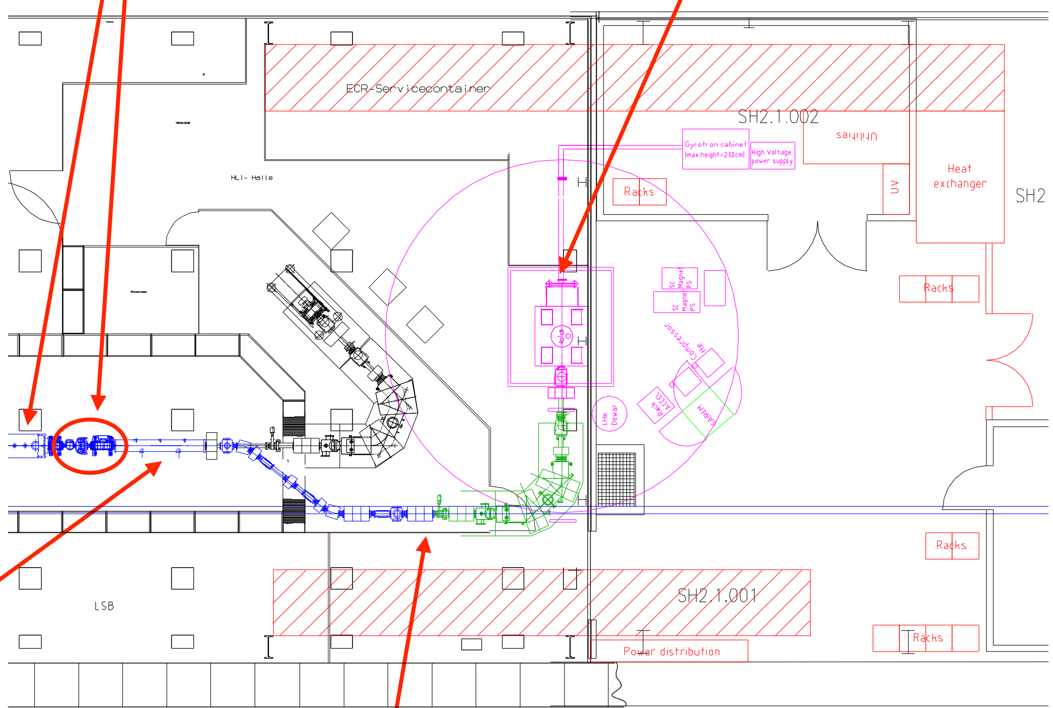
cw-RFQ-commissioning (2010)



- cw-IH (upgrade defined)
- redesign rebuncher cavity

28 GHz-MS-ECRIS:

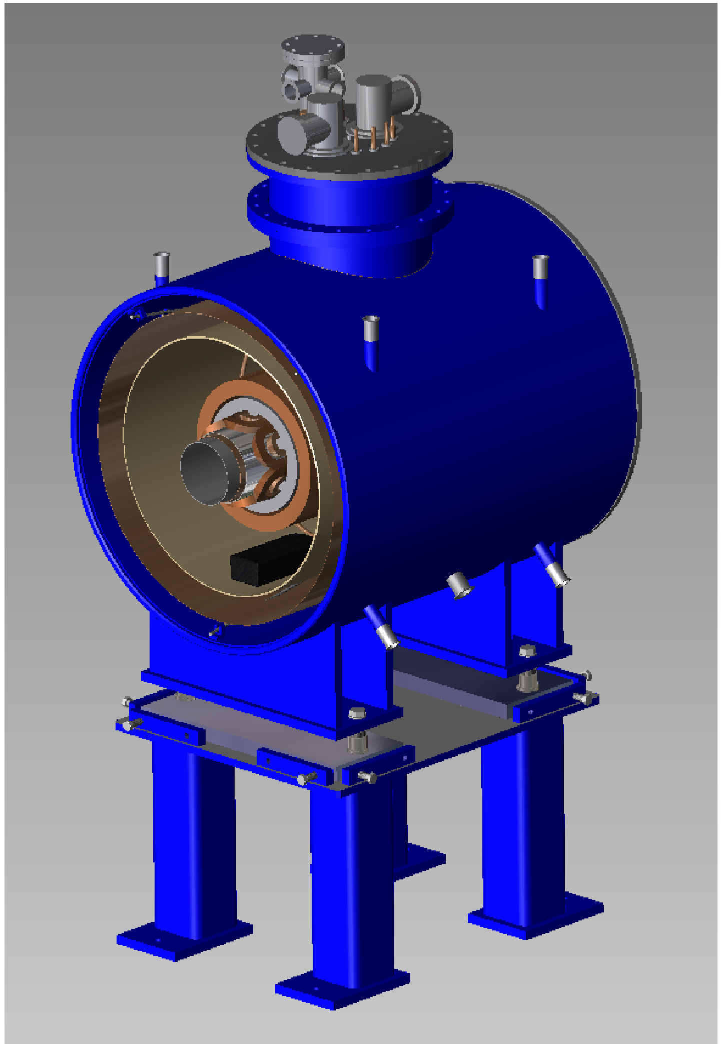
- redesign of magnetic system 2011
- testing 2012
- full performance beam tests@GSI (2013/2014)



LEBT (status: conceptual design available)

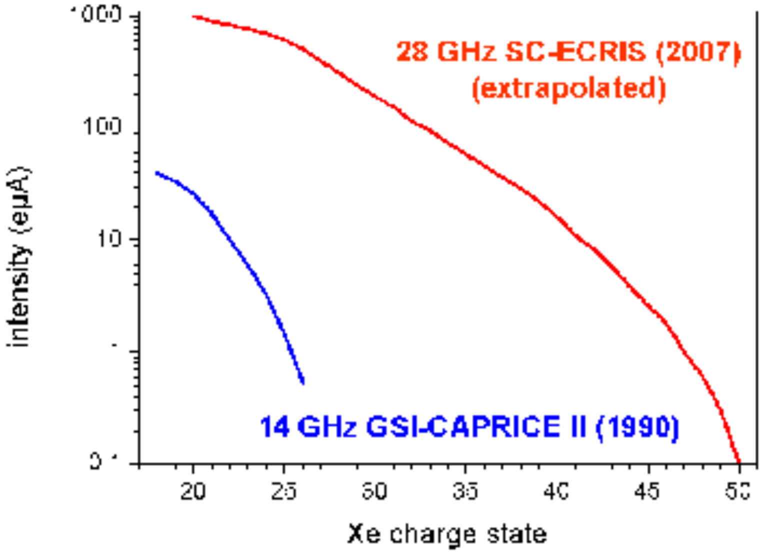
- beam diagnostics, low level rf, controls system (cw-capability)
- rf-power amplifier upgrade for cw-operation

28 GHz- ECR ion source/Status Quo



Major steps:

- Completion of sc magnet system and cryostat
- Delivery to GSI/IQ
- Completion of ion source
- Commissioning on test bench
- Installation and commissioning at HLI



GSI sc-cw-LINAC-project

Motivation:

Element 120, <0.1 pb (1pb <-> 1 event/week)

	GSI-UNILAC	cw-LINAC
Beam Intensity (particles/sec) *(S. Hofmann et al, EXON 2004)*	3 $*10^{12}$	6 $*10^{13}$
Beam on target	10 weeks	4 days

UNILAC is not dedicated to SHE, nearly not obtainable to keep SHE @ GSI competetive: Increase of Beam Intensity and Detection Efficiency

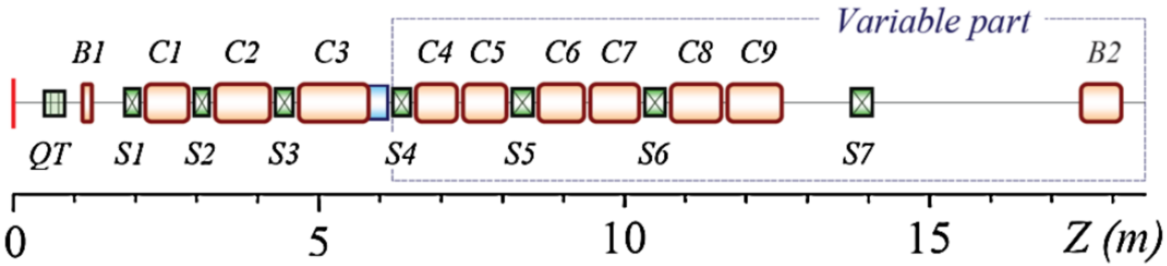
Multicell sc-CH-cavity

- Small number of rf cavities (gap numbers from 10 to 20)
- acc. gradient of 5 MV/m → compact linac design
- Cold solenoids in the inter-tank sections
- Several cavities, solenoids per cryostat
- Cavity lengths range up to around 1 m
- Cylindrical cryostats is typically <6 m long
- At a given frequency: CH-type cavities has very small transverse dimensions

General parameters

Mass/Charge		1/6
Frequency	MHz	217
max. beam current	mA	1
Injection Energy	MeV/u	1.4
Output energy	MeV/u	3.5 – 7.5
Output energy spread	keV/u	+- 3
Length of acceleration	m	12.7
Sc CH-cavities		9
Sc solenoids		7

Conceptual layout of the cw-LINAC



CH-cavities

So far...

- sc energy variable linacs: 2 gap or 3 gap-cavities (spiral-, $\lambda/4$- $\lambda/2$-type, spoke-, ...)
- High flexibility in beam energies and q/m-ratios → altering rf-phase relations between cavities and matching the voltage amplitudes
- But: Relatively long lengths between accelerating sections and high total number of cavities including couplers, tuners, controls, and RF power amplifiers
- R.T. focusing elements → high number of separated cryostats accompanied by many cold-warm transitions

Multicell CH-cavities:

- 10 - 20 cell cavities + cold lenses (cryostat with several cavities and lenses)
- cavity length ≤ 1 m, cryostat length ≈ 5 m in length
- H-type cavities: Small transverse dimensions (at a certain frequency)
- A 19-cell 360 MHz prototype successfully developed and operated at Univ. of Frankfurt
- EQUidistant mUlti-gap Structure (EQUUS) + external focusing lenses → Negative initial and final rf-phases; acceleration around the crest of the wave along the middle part. → maximum in accelerating voltage between two neighboring focusing lenses
- EQUUS → eased manufacturing and rf-tuning (importance for sc structures)
- Comfortable beam dynamics layout

Parameters of the sc multi-gap accelerating cavities

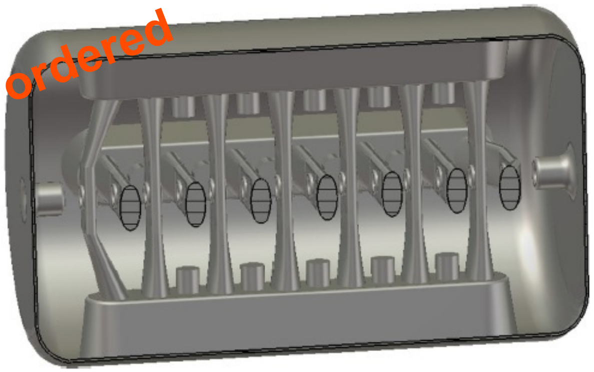
Parameter	*unit*	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*
Gap number		15	17	19	10	10	10	10	10	10
Total length	mm	613	811	1054	636	642	726	726	813	862
Cell length,	mm	40.8	47.7	55.5	63.6	64.2	72.6	72.6	81.3	86.2
Synch. velocity		0.059	0.069	0.080	0.092	0.093	0.105	0.105	0.118	0.125
Aperture diameter	mm	20	22	24	26	28	30	32	34	36
Eff. gap voltage	kV	225	274	317	356	362	408	411	459	538
Voltage gain	MV	3.13	4.14	5.42	3.27	3.30	3.73	3.73	4.18	4.43
Phase Factor*		0.93	0.89	0.90	0.92	0.91	0.92	0.91	0.91	0.82
Accelerating rate	MV/m	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1

* The parameter named "phase factor" characterizes the accelerating efficiency with respect to the phase sliding along the section.

sc-216 MHz-CH-Protype

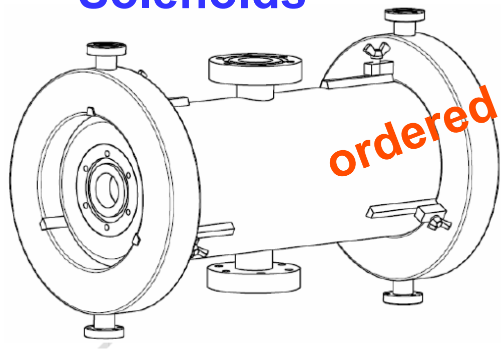
216 MHz-CH-cavity

(Goethe Univ. Frankfurt)



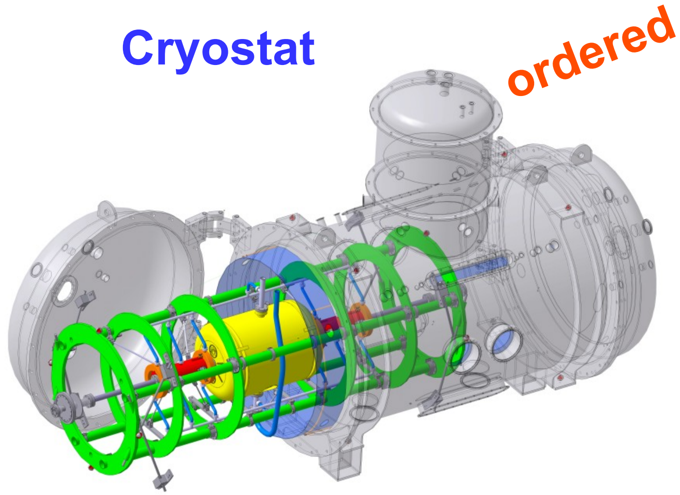
Parameter	Unit	CH-1
Beta		0.059
Frequency	MHz	217
Gap number		15
Total length	mm	690
Cavity diameter	mm	420
Cell length	mm	40.82
Aperture	mm	20
Effective gap voltage	kV	225
Voltage gain	MV	3.13
Accelerating gradient	MV/ m	5.1
E_p/ E_a		6.5
B_p/ E_a	mT/ (MV/m)	5.9
R/ Q	Ω	3540
Static tuner		9
Dynamic bellow tuner		3

Solenoids

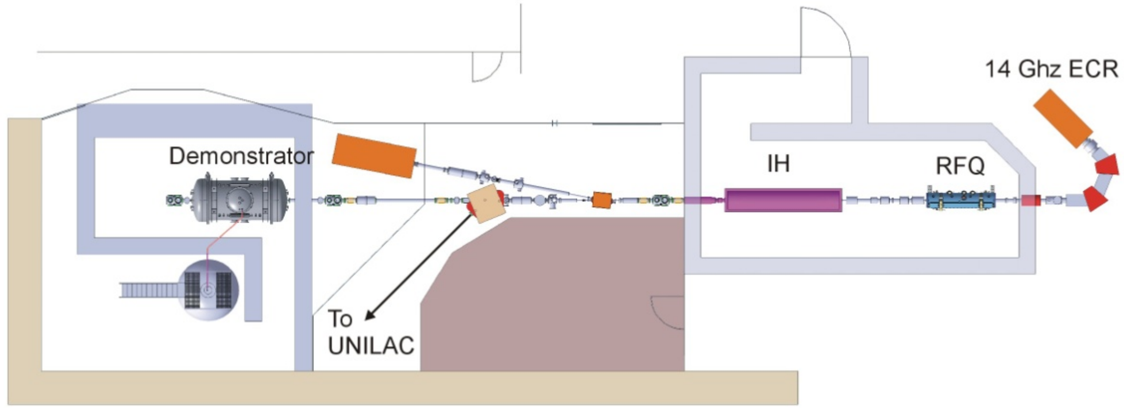


Bmax	9,323T
B*L	2,635 Tm
L	0,28 m
Aperture	30 mm

Cryostat



Demonstrator Project (HIM, GSI)



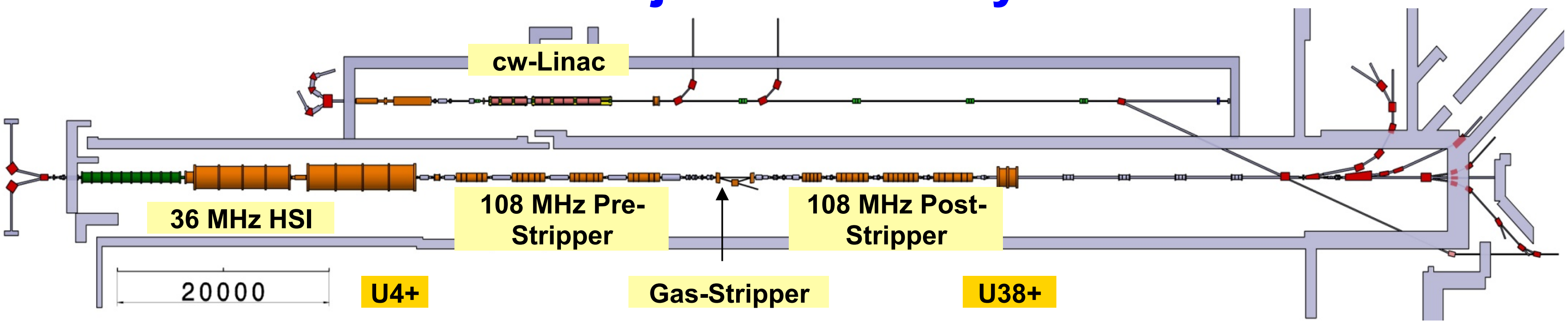
Summary

- FAIR high current requirements should be reached by the upgrade of the 35 years old UNILAC (not compatible with SHE-requirements).
- A high duty factor upgrade of the HLI is still ongoing:
  - cw-RFQ (commisioning)
  - 28 GHz ECR (R&D)
  - Low Energy Beam Transport (layout)
- A conceptual layout of a separate cw-LINAC for the SHE experimental program is well prepared
  - Choice of acc. structure (multicell CH)
  - EQUUS-design
  - Cold Solenoids (< 10T)
  - Basic Beam dynamics layout
  - Error studies
- CH-Demonstrator
  - CH-cavity, sc-solenoids, cryostat, rf-amplifier still ordered
  - rf-testing@GUF scheduled (2013)
  - test environment in preparation
  - full performance beam test scheduled (2013/14)

Schedule

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Heavy Ion-LINAC-Injector for FAIR-commissioning/-operation							UNILAC			cw-LINAC		HE-LINAC			
p-LINAC as FAIR-injector									FAIR-proton-LINAC						
UNILAC-Upgrade "Campus Development"															
FAIR-UNILAC-Upgrade															
SHE-UNILAC-Upgrade															
FAIR-Protonen-LINAC	Techn. Design						Mounting& Commissioning								
cw-CH-LINAC-Demonstrator			beam test												
sc-cw-LINAC	Designphase							Mounting& Commissioning							
HE-LINAC (Step 1)		Designphase								Mounting& Commissioning					
HE-LINAC (Step 2)						Designphase								Mounting& Commissioning	

Advanced injector linac layout



HE-LINAC 1