The GSI cw-LINAC-project

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GSI, HIM

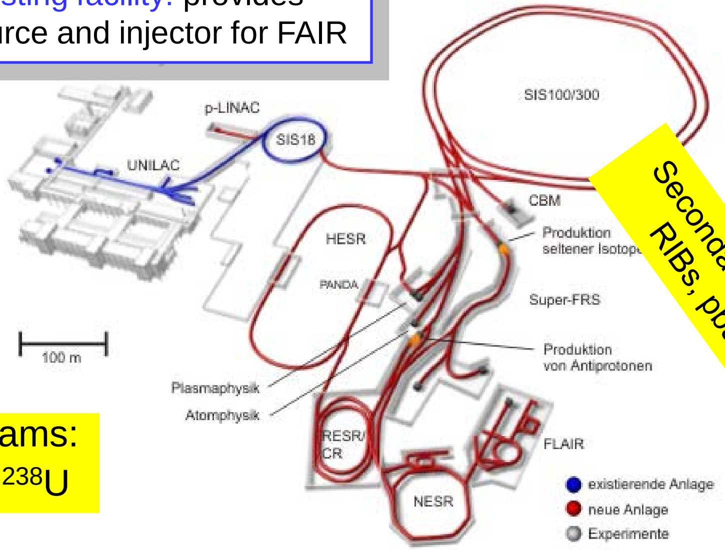
The GSI cw-LINAC-project

W. Barth, GSI - Darmstadt

1. **Existing GSI-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**

FAIR

Upgraded existing facility: provides ion-beam source and injector for FAIR



Secondary beams: RIBs, pbars

Primary beams: protons to ^{238}U

Preperation for civil construction, 2012

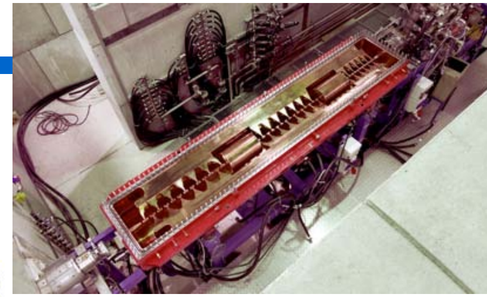
Accelerator Components & Key Characteristics

Ring/Device	Beam	Energy	Intensity
SIS 100 (100Tm)	protons	30 GeV	$4x10^{13}$
	^{238}U	1 GeV/u	$5x10^{11}$
	(intensity factor 100 over present)		
SIS 300 (300Tm)	^{40}Ar	45 GeV/u	$2x10^{9}$
	^{238}U	34 GeV/u	$2x10^{10}$
CR/RESR/NESR	ion and antiproton storage and experiment rings		
HESR	antiprotons	14 GeV	$\sim 10^{11}$
Super-FRS	rare isotope beams	1 GeV/u	$<10^{9}$

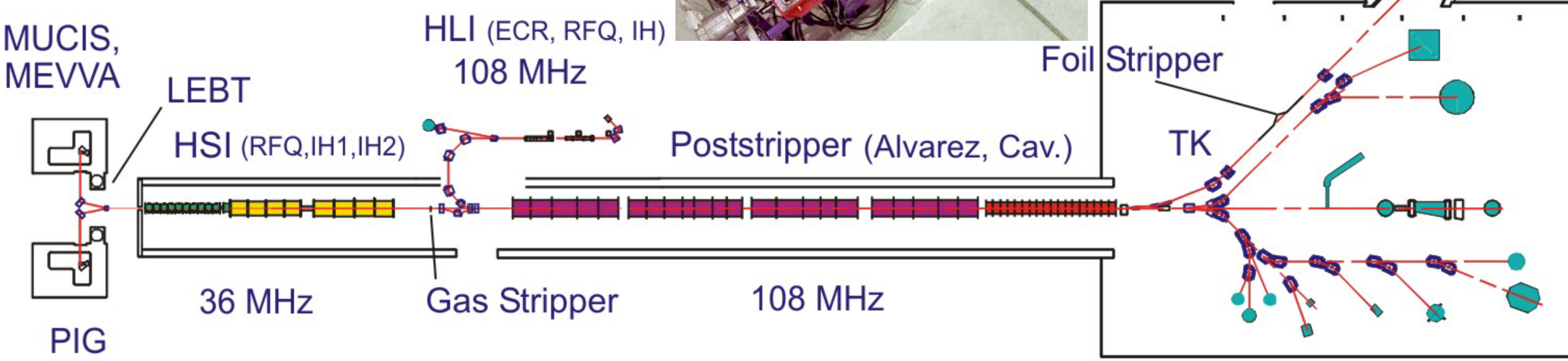
New future facility: provides ion and anti-matter beams of highest intensities and up to high energies

GSI UNIversal Linear ACcelerator

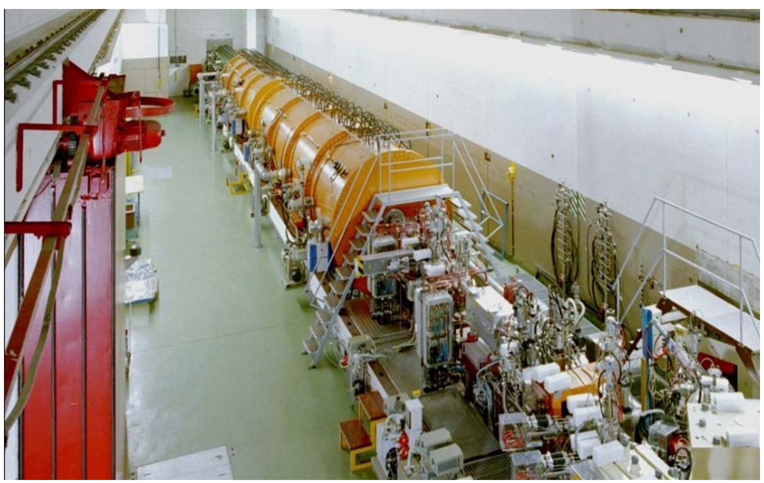
1 pμA, ^{48}Ca (from ECR)
1 pμA, ^{50}Ti (from PIG/ECR)
2.5 emA, ^{238}U (from MeVVa)



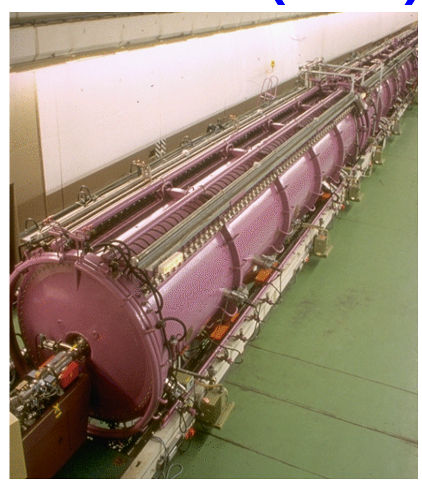
High Charge State Injector (1991)



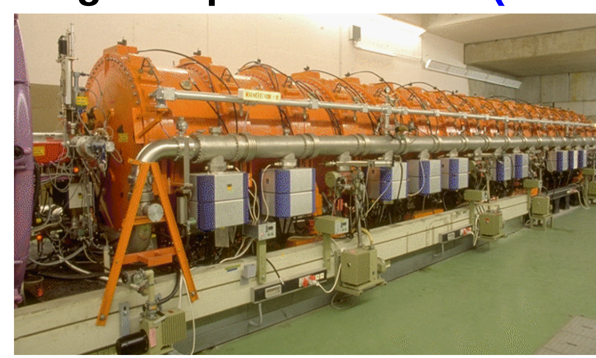
High Current Injector (1999)



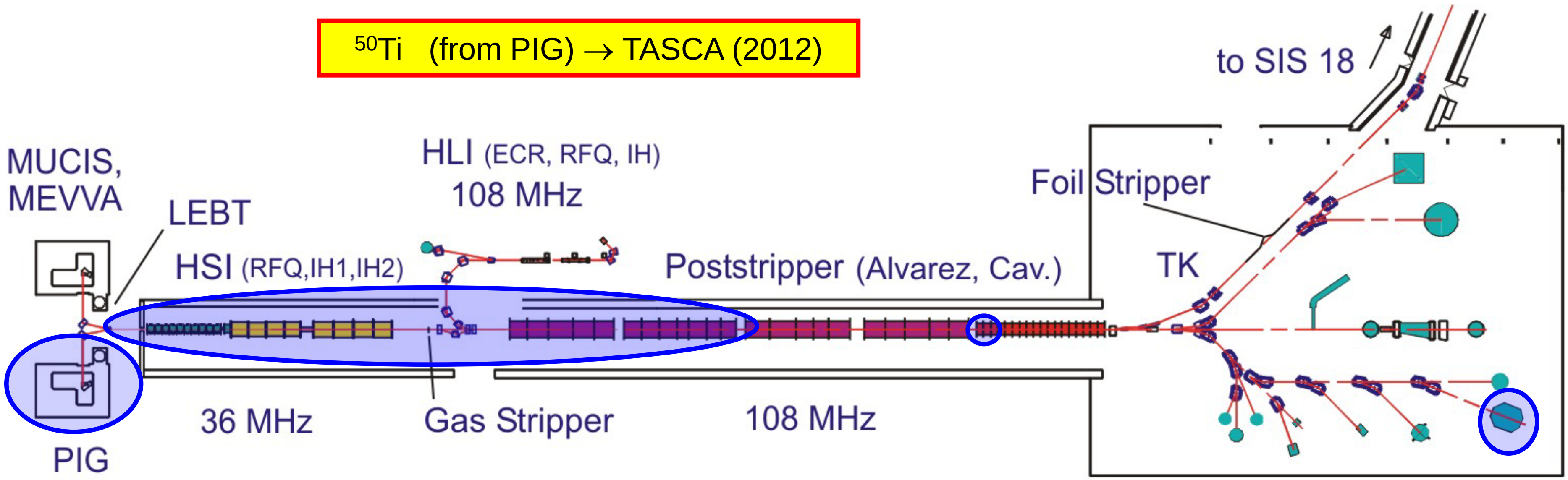
Alvarez (1975)



Single Gap Resonators (1975)



GSI UNIversal Linear ACcelerator



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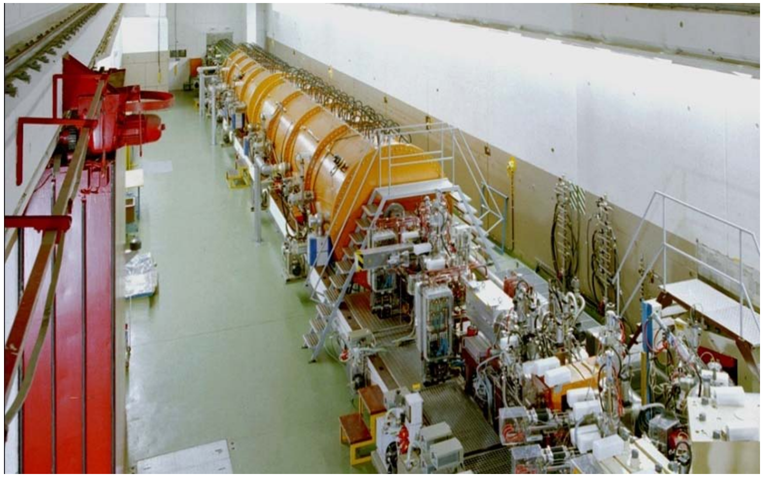
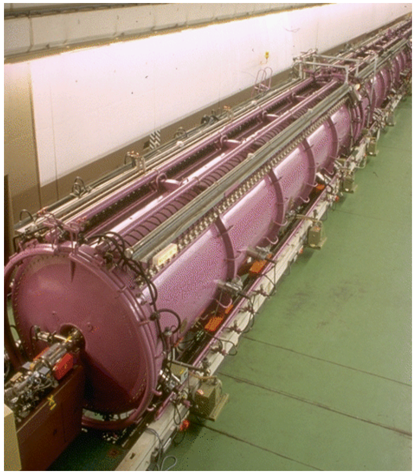


Alvarez (1975)

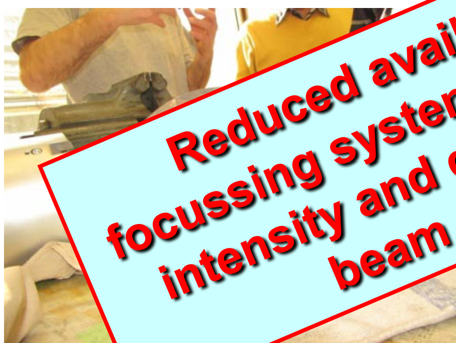


Single Gap Resonators (1975)

Active defects

178 tank-quadrupoles

(leak tightness/water/pre-vakuum, el. pre… …lts),
drift tubes + supports (wa…



Reduced availibility of the focussing system → limited beam intensity and quality, (no) multi beam operation !

Leak tightness of all tanks

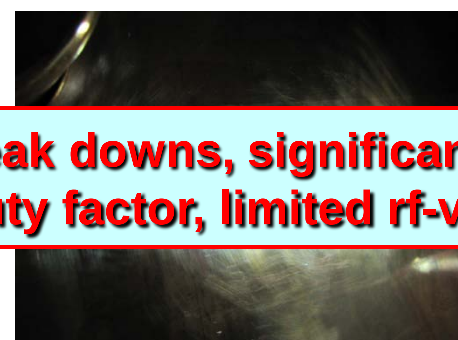
Regular and substantial repairing program for all tanks!

Drift tubes

massive sparkovers — beam induced surface defects

Copper surface quality

... inner tank blanket at different positions



High probality of long term-break downs, significant limitations during operation (reduced duty factor, limited rf-voltage, ...)

Future Requirements

Present Status Of UNILAC

- Most of the Alvarez-tank and all Single Gap Resonators in operation since 1975
- Issues on machine reliability and maintenance ⇒ substitution of the DTL cavities
- Operation of quadrupoles only in dc-mode
- Limited flexibility for multibeam operation
- Less effective for short pulse operation because of hi... ...gh duty factor operation
- max. duty factor of 25%

Main Requirements

- High intensity/bri... ...on linac as a synchrotron injector for FAIR
- High i... ...ghtness heavy ion linac as a synchrotron injector for FAIR
- Hig... ...ty factor, 7.5 MeV/u, variable beam energy, heavy ion linac for the SHE-program

MASSIVE INJECTOR-UPGRADE REQUIRED !

... plus

- heavy ions for material research, plasmaphysics, biophysics programmes, IRIS, ... (old exp. hall)
- High intensity rare isotope beams (from EZR) for FAIR
- entire multi beam operation

Requirements for FAIR and the SHE-program

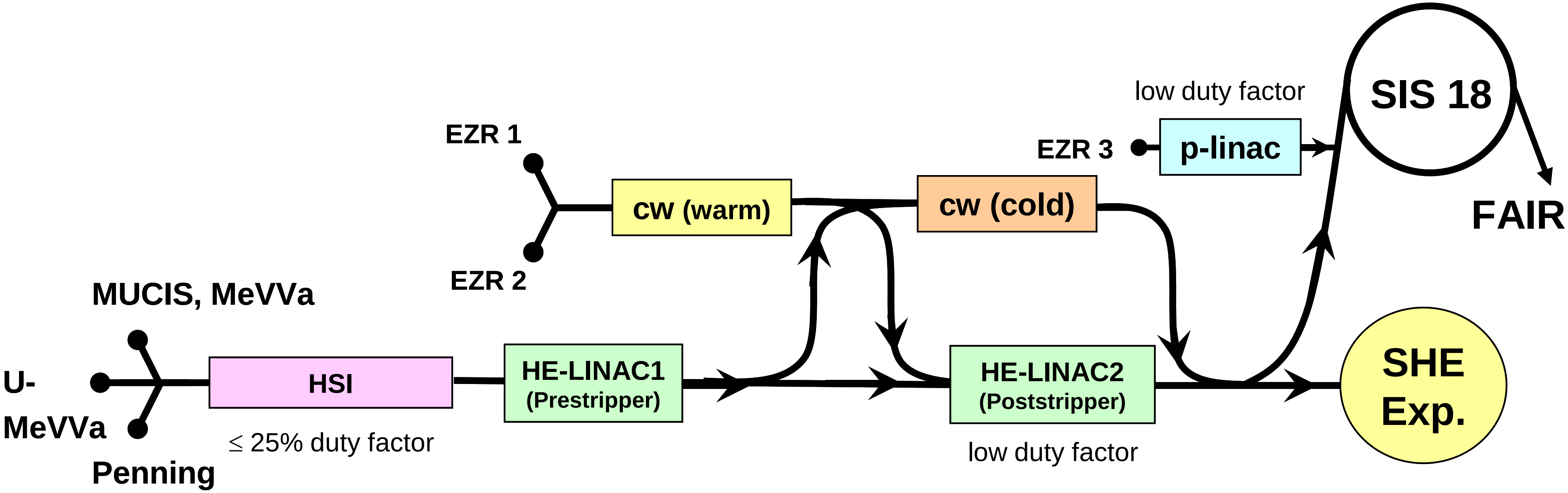
FAIR requirements:

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

SHE requirements:

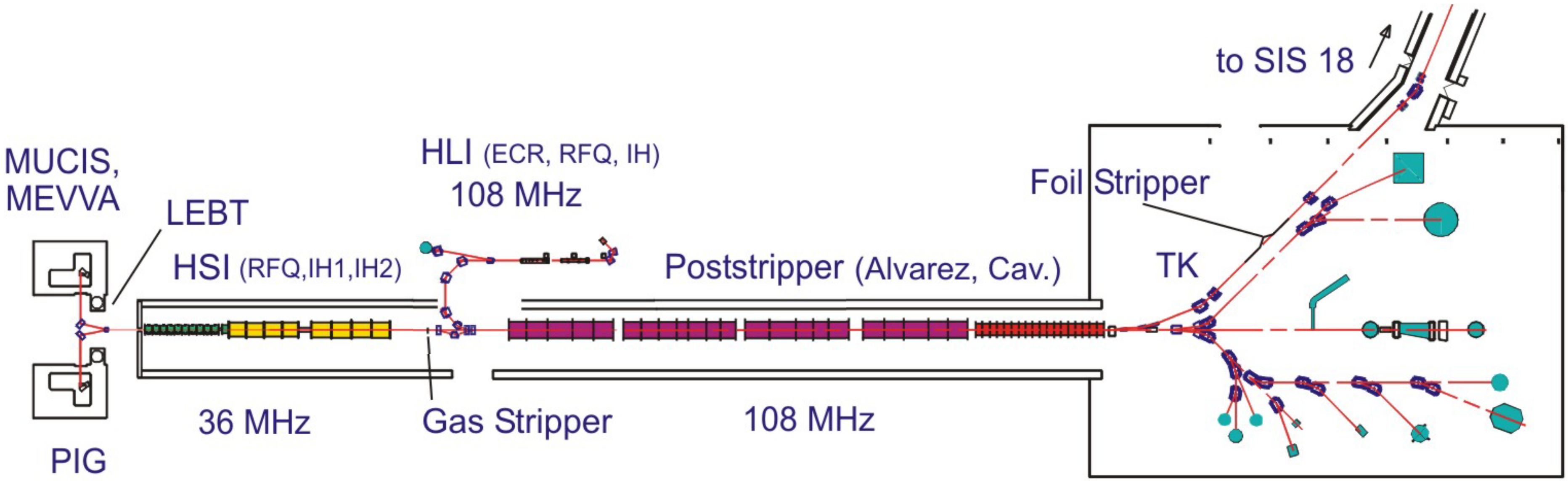
- relatively high pulse intensities
- high repetition rate (50 Hz)
- high duty factor (-> 100 %) (pulse length up to 20 ms)

GSI-Future Option



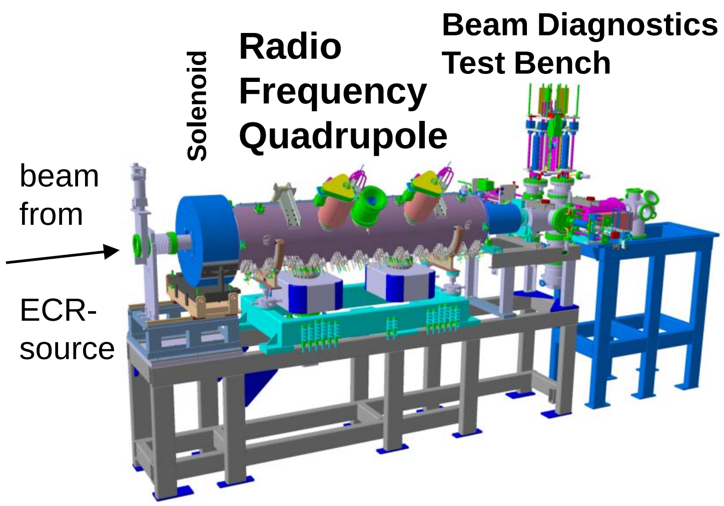
- **Proton linac-injector for FAIR (FAIR-pbar-physics)**
  - **70 MeV, 35 (70) mA, 325 MHz, 0.1% duty factor**
- **High Energy injector linac (replacement of Alvarez DTL)**
  - **Prestripper: 3 MeV/u, A/q = 60 (18 emA), 108 MHz, 1% duty factor**
  - **Poststripper: 11.4 MeV/u (max. 22 MeV/u), A/q = 6.3 (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



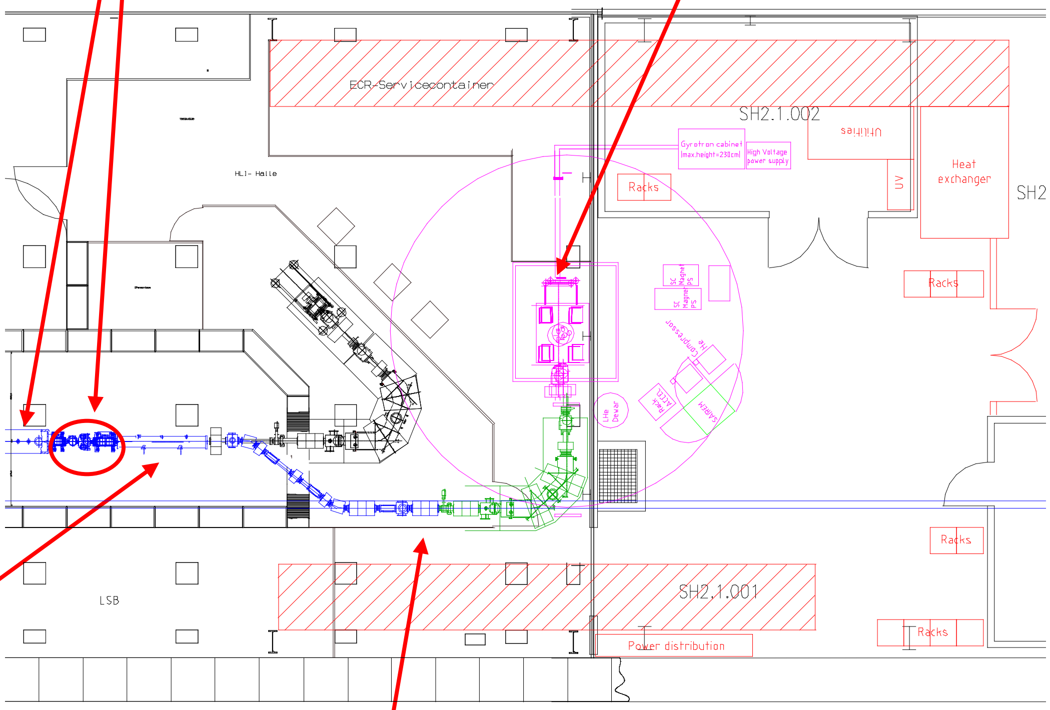
	Luminosity gain
• New RFQ: Duty cycle 25 -> 40%	x 1.6
• New MS-ECRIS: higher beam currents and	
• LEBT for new MS-ECRIS at HLI	x 5.0
• cw-linac	
– 100% duty cycle	x 2.5
– independent operation	x 2.0
	x 40

SHE-UNILAC-Upgrade

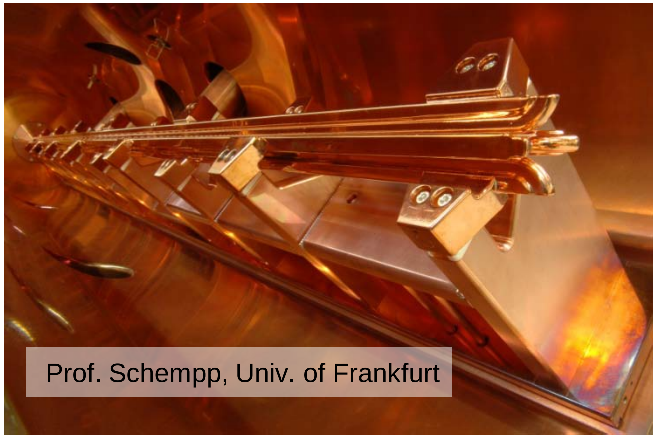


- cw-IH (upgrade defined)
- redesign rebuncher cavity

28 GHz-MS-ECRIS:
- redesign of magnetic system 2011
- testing 2012
- full performance beam tests@GSI (2013/2014)



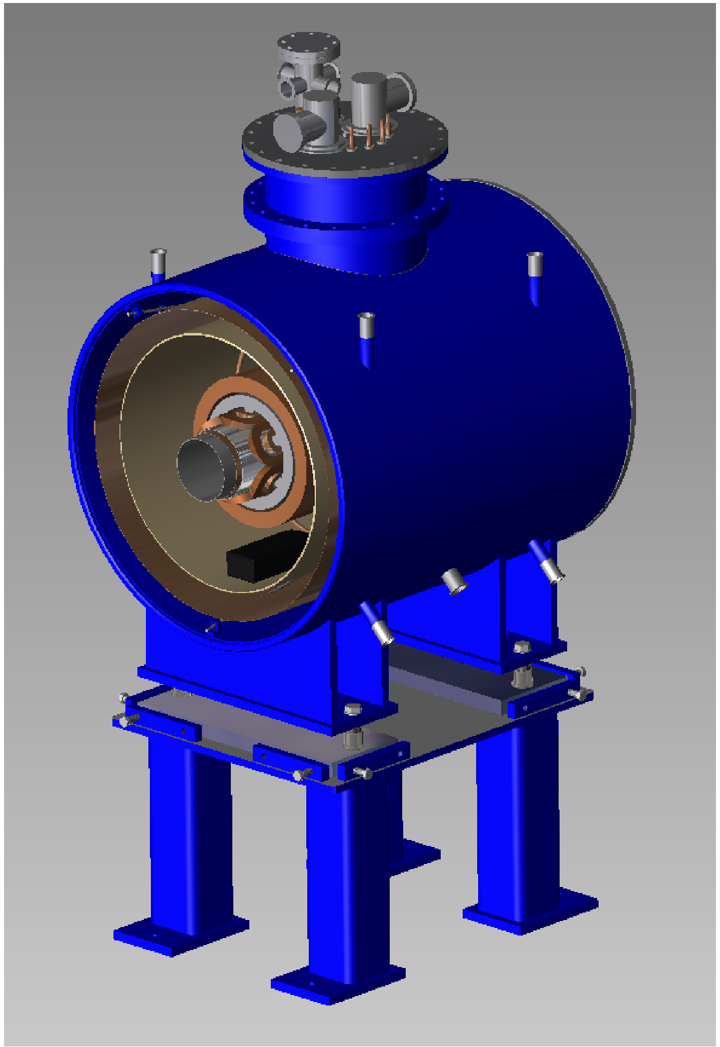
cw-RFQ-commissioning (2010)


Prof. Schempp, Univ. of Frankfurt

LEBT (status: conceptual design available)

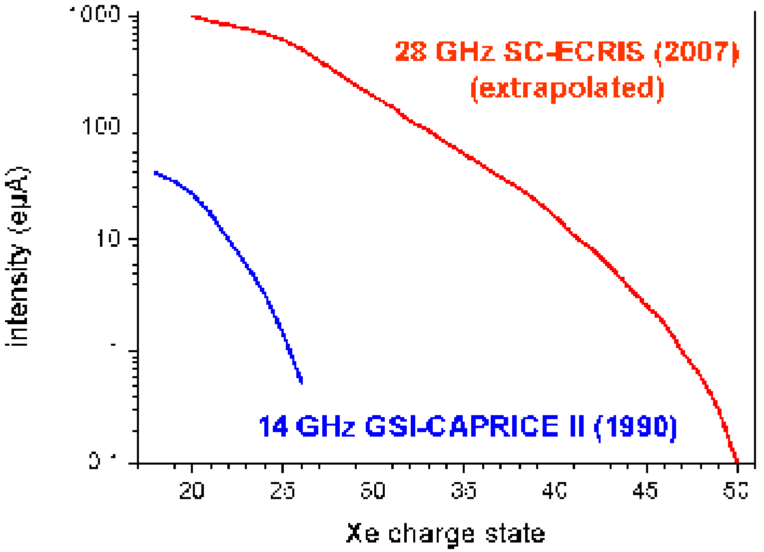
- beam diagnostics, low level rf, controls system (cw-capability)
- rf-power amplifier upgrade for cw-operation

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

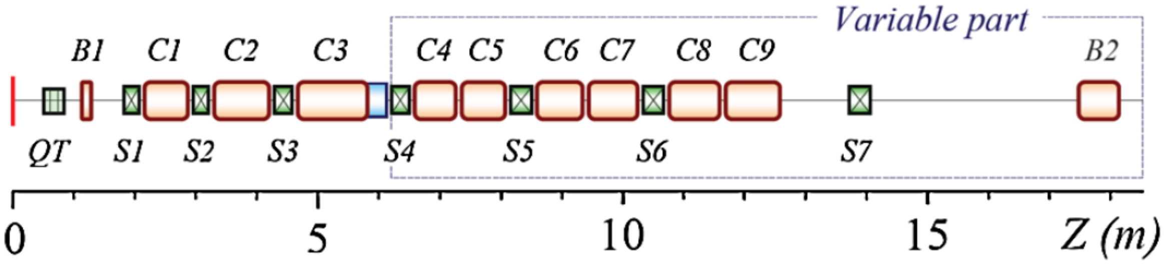
Multicell sc-CH-cavity

- 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...

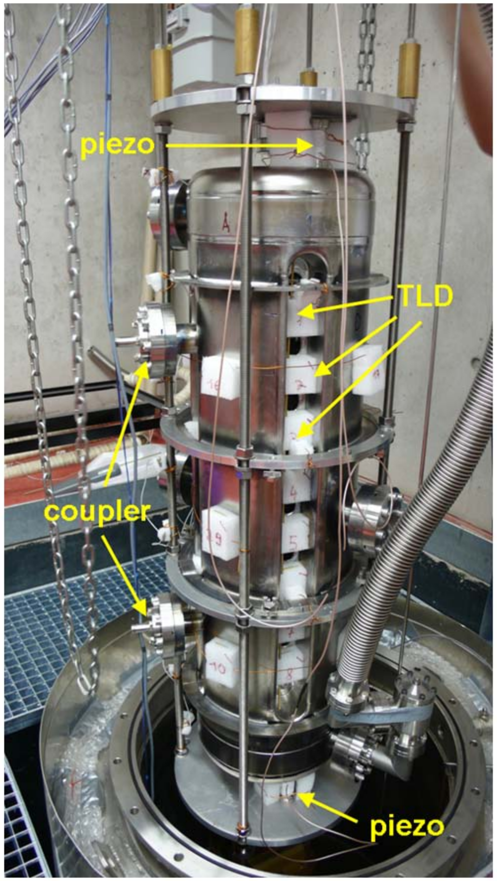
- sc energy variable linacs: 2 gap or 3 gap-cavities (spiral-, $\lambda/4$- $\lambda/2$-type, spoke-, ...)
- High flexibility in beam energies and q/m-ratios $\rightarrow$ altering rf-phase relations between cavities and matching the voltage amplitudes
- But: Relatively long lengths between accelerating sections and high total number of cavities including couplers, tuners, controls, and RF power amplifiers
- R.T. focusing elements $\rightarrow$ 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 $\leq$ 1 m, cryostat length $\approx$ 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 $\rightarrow$ Negative initial and final rf-phases; acceleration around the crest of the wave along the middle part. $\rightarrow$ maximum in accelerating voltage between two neighbo^^ring focusing lenses
- EQUUS $\rightarrow$ eased manufacturing and rf-tuning (importance for sc structures)
- Comfortable beam dynamics layout

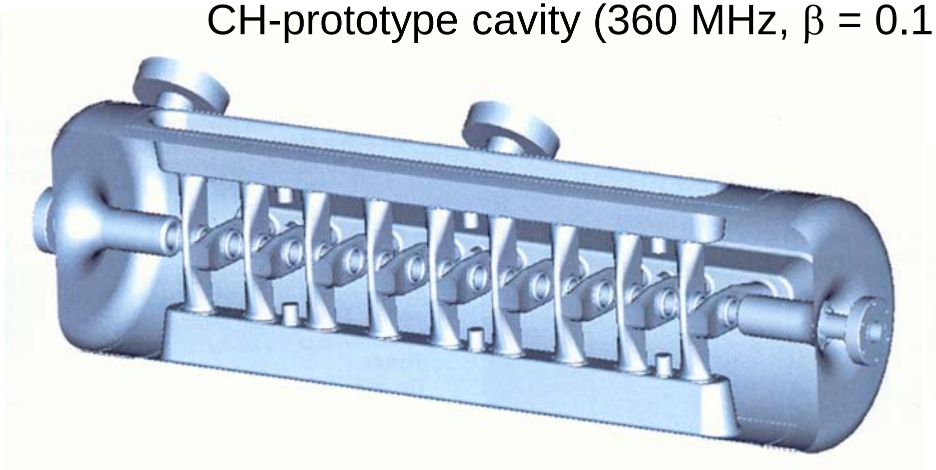
CH-cavities

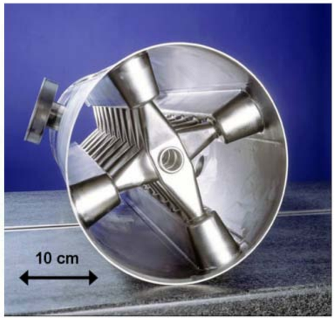
Vertical test setup of the sc-CH-prototype cavity



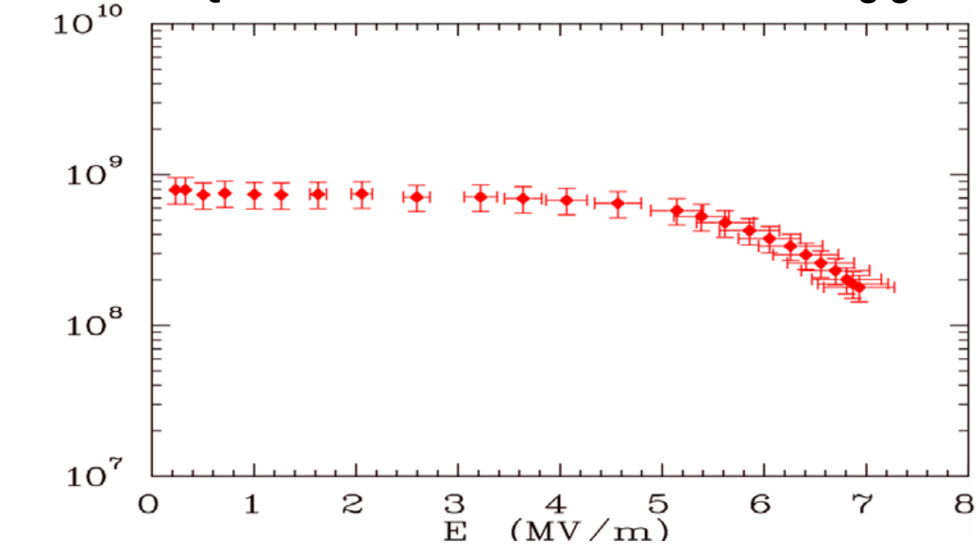
U. Ratzinger, H. Podlech (Univ. of Frankfurt)

CH-prototype cavity (360 MHz, β = 0.1, 19 cells)





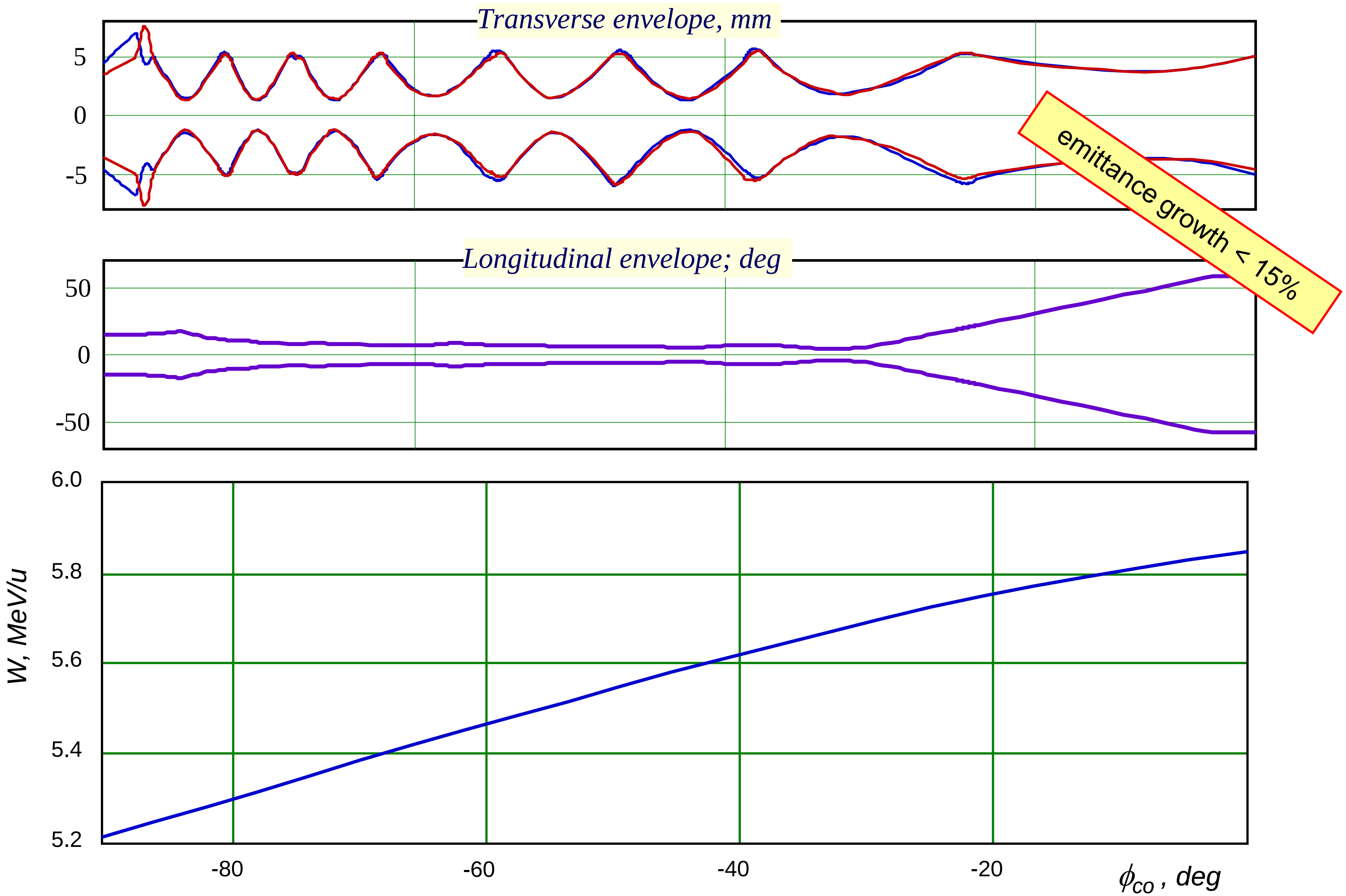
Measured Q-value as function of the accelerating gradient



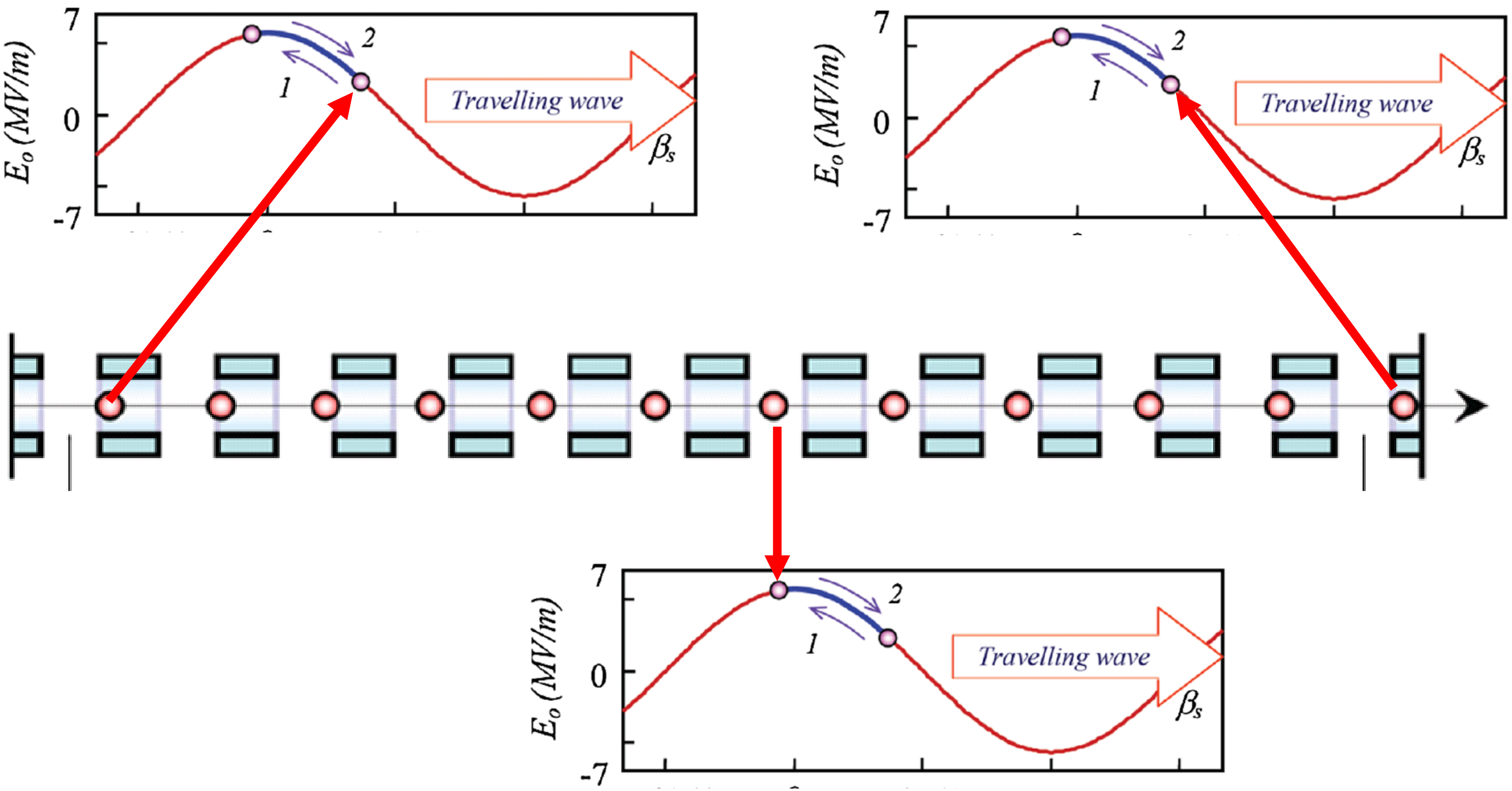
beam optics design

Transverse and longitudinal beam envelopes

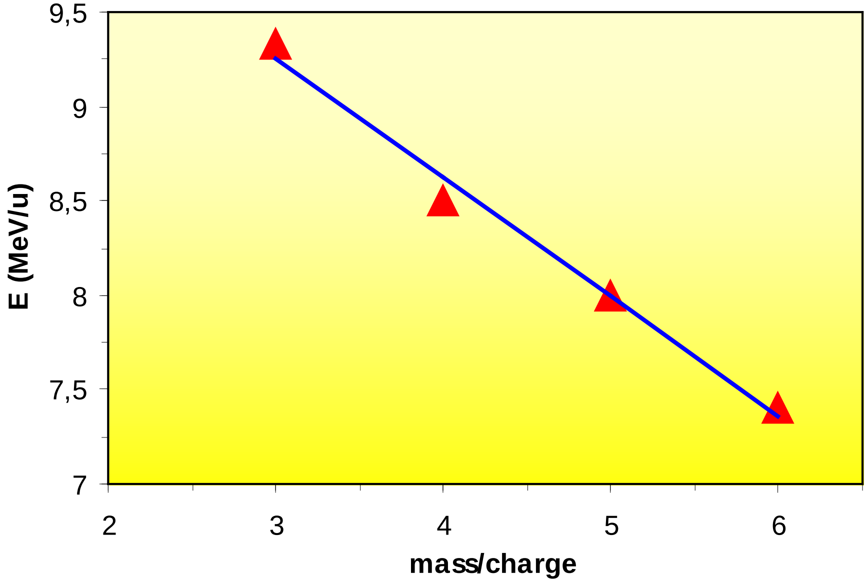
Beam energy against initial phase of the bunch center for 7-th section

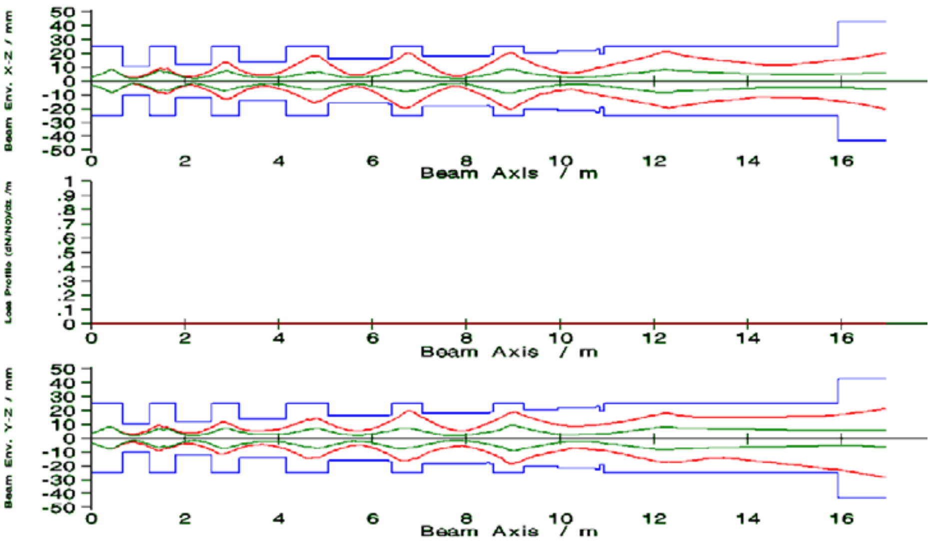


EQUUS (EQUidistant mUltigap Structure)



Advanced cw-linac beam dynamics layout





Beam Energies above the LINAC-design (7.5 MeV/u):

- Request by user communities
- Fixed beta profile applying EQUUS beam dynamics approach → ≤ 10 MeV/u (A/q<<6)

Influences of statistical errors:

- 300 LORASR-simulation runs
- Statistical distribution of horizontal and vertical shift of beam line components (±300 µm)
- Statistical tilt error (±1.7 mrad)

Parameters of the sc multi-gap accelerating cavities

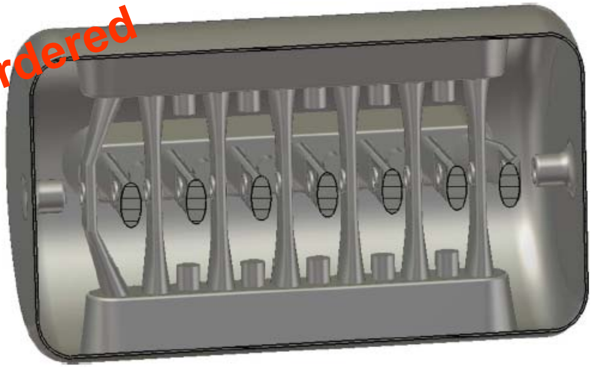
Parameter	***unit***	***C1***	***C2***	***C3***	***C4***	***C5***	***C6***	***C7***	***C8***	***C9***
Gap number		15	17	19	10	10	10	10	10	10
Total length	mm	613	811	1054	636	642	726	726	813	862
Cell length,	mm	40.8	47.7	55.5	63.6	64.2	72.6	72.6	81.3	86.2
Synch. velocity		0.059	0.069	0.080	0.092	0.093	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

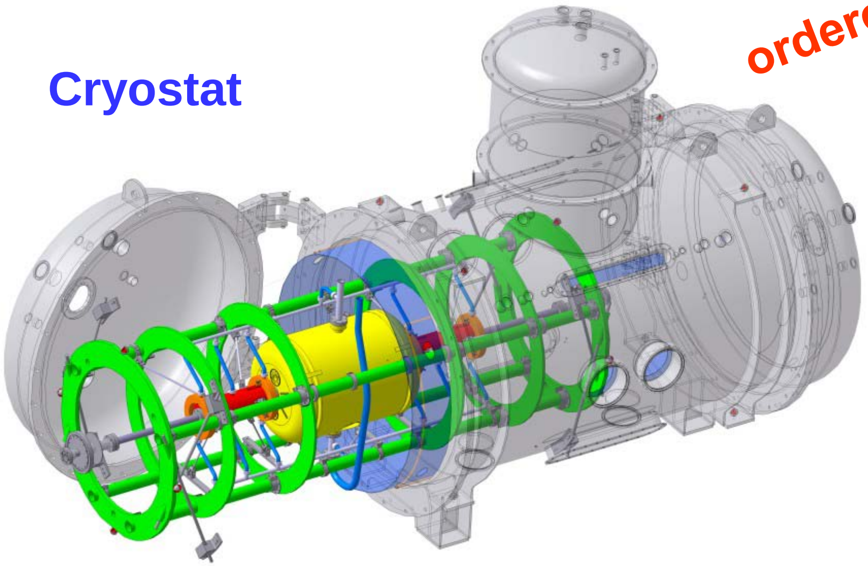
216 MHz-CH-cavity

(Goethe Univ. Frankfurt)



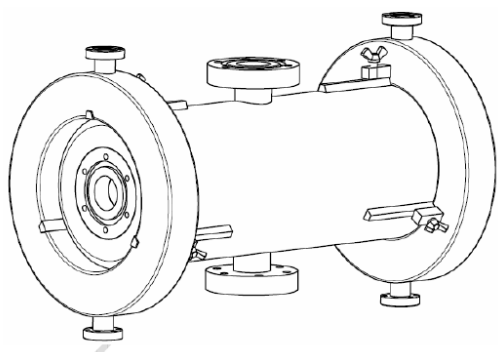
Parameter	Unit	CH-1
Beta		0.059
Frequency	MHz	217
Gap number		15
Total length	mm	690
Cavity diameter	mm	420
Cell length	mm	40.82
Aperture	mm	20
Effective gap voltage	kV	225
Voltage gain	MV	3.13
Accelerating gradient	MV/ m	5.1
E_p/ E_a		6.5
B_p/ E_a	mT/ (MV/m)	5.9
R/ Q	Ω	3540
Static tuner		9
Dynamic bellow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

Cryostat



ordered

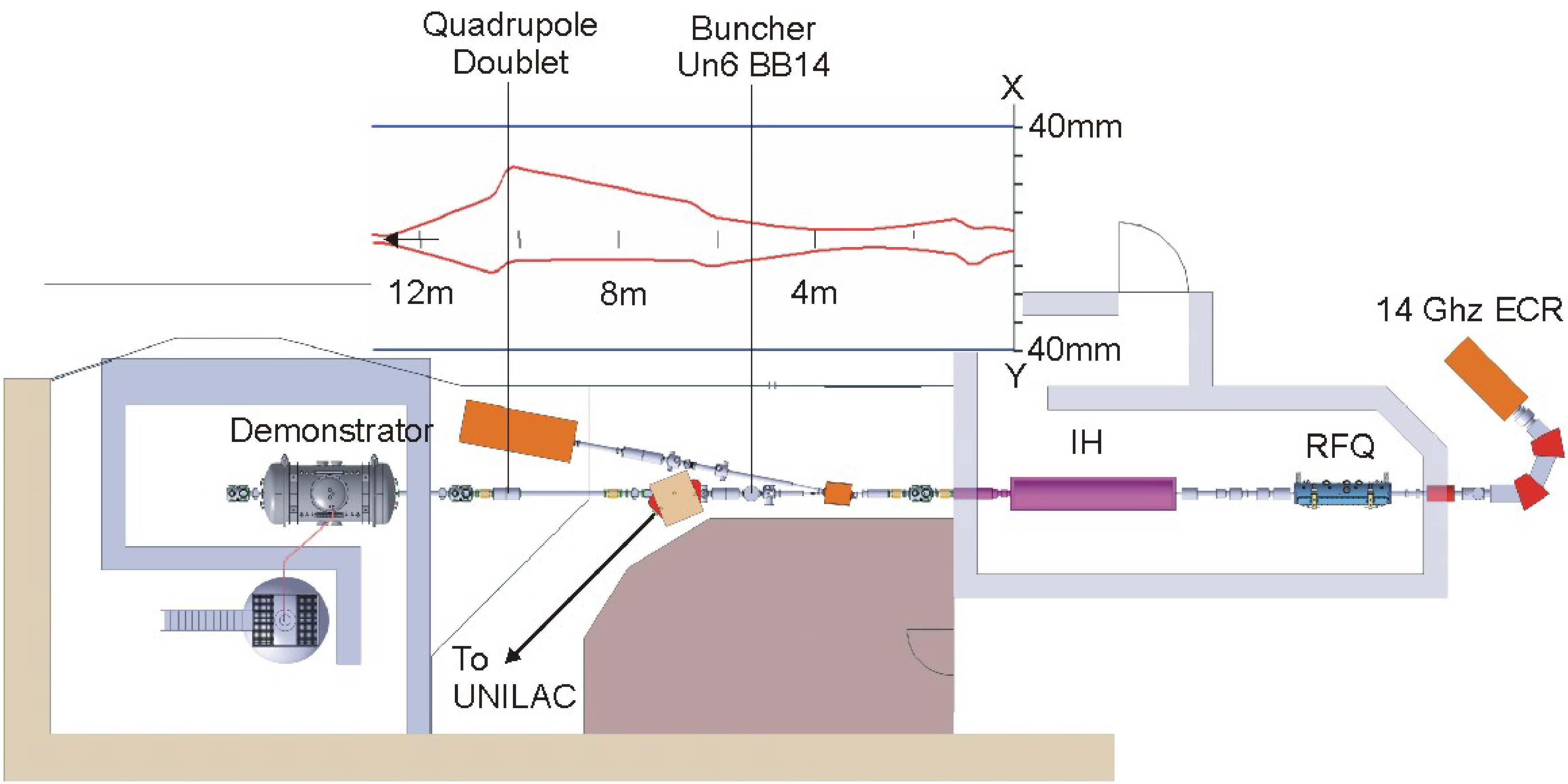
Solenoids



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

ordered

Demonstrator Project (HIM, GSI)



High Charge State Injector

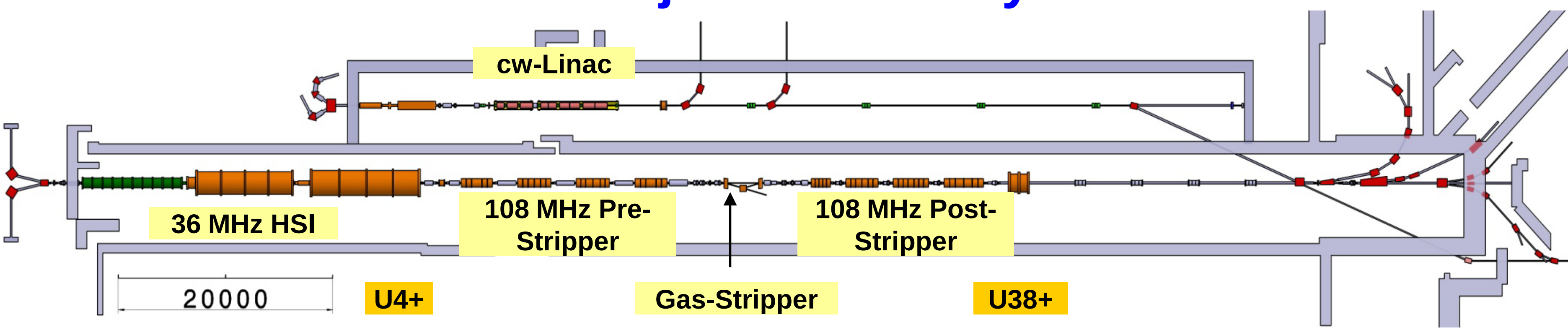
Summary

- FAIR high current requirements should be reached by the upgrade of the 35 years old GSI-UNILAC (not compatible with SHE-requirements)
- A high duty factor upgrade of the GSI High Charge State Injector 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-beam dynamics design
  - Cold Solenoids (< 10T)
  - Error studies
- The cw-linac R&D (CH-Demonstrator project) is on the way
  - 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

Addendum

General Approach

A Modern High Power Injector...

should be...

- compact
- high efficient (rf-power consumption)
- cost saving in production and operation

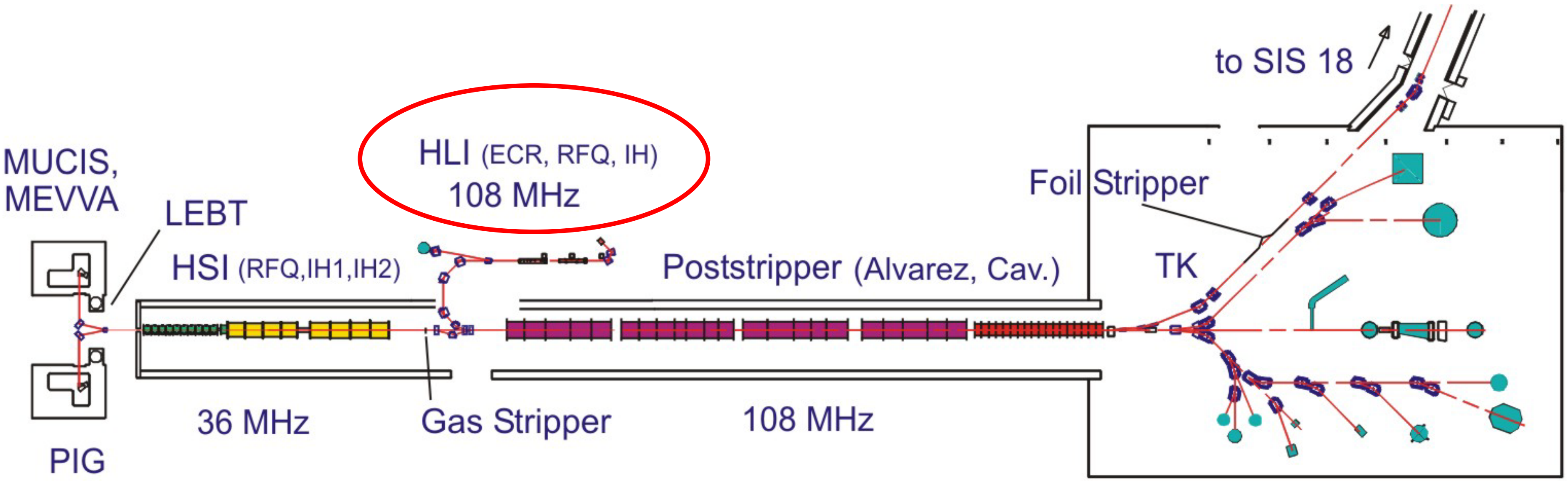
should provide beam of...

- High Intensity (minimum particle loss)
- High Brilliance

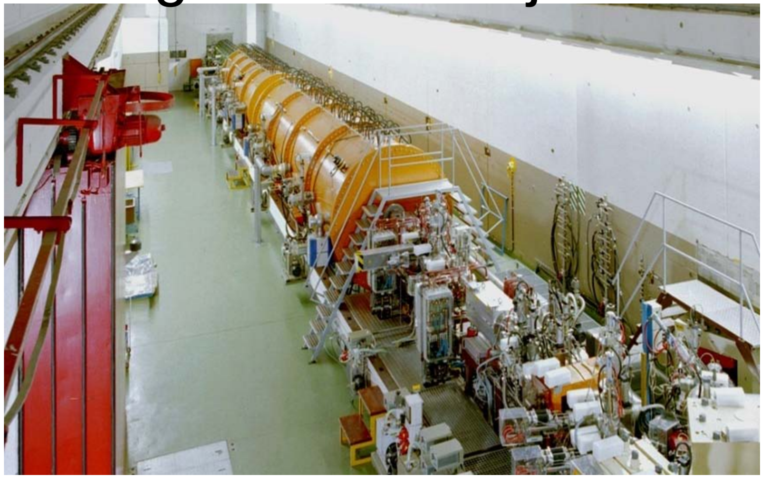
LINAC parameters (e.g. final beam energy, beam current and charge) should be fixed with respect to the synchrotron design limits

- Tune Shift
- Life Time
- Space charge limit

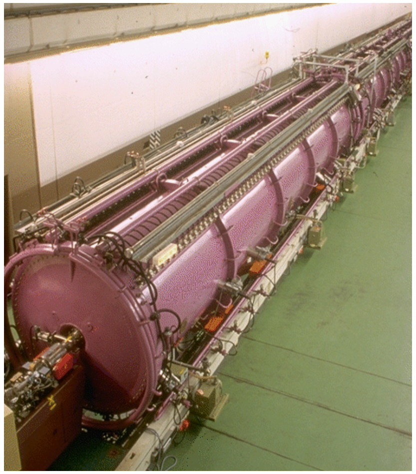
The GSI UNIversal Linear ACcelerator



High Current Injector

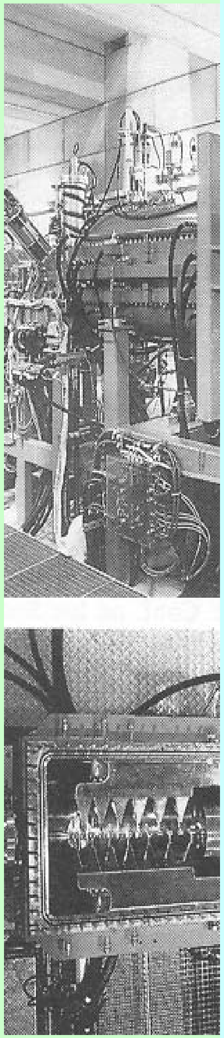


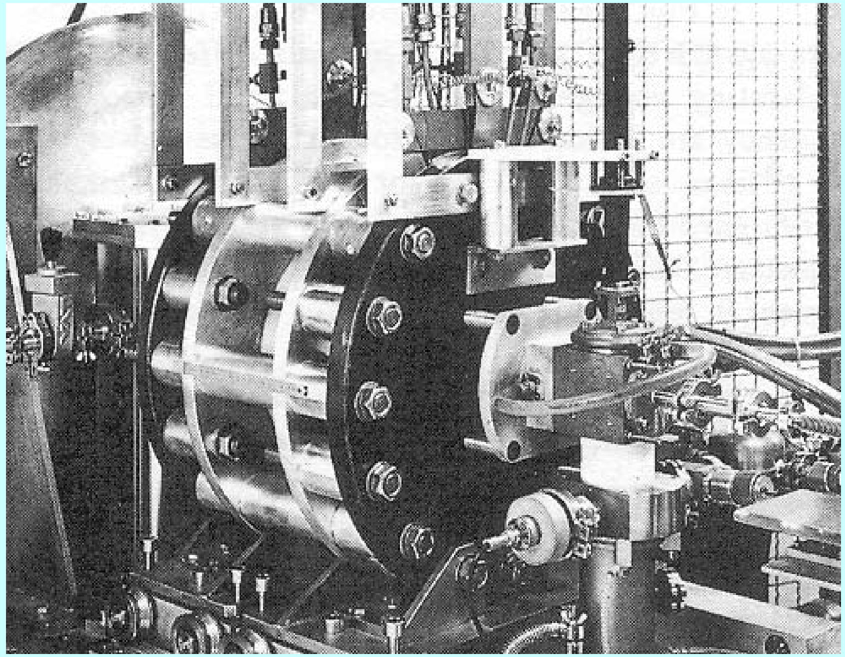
Alvarez



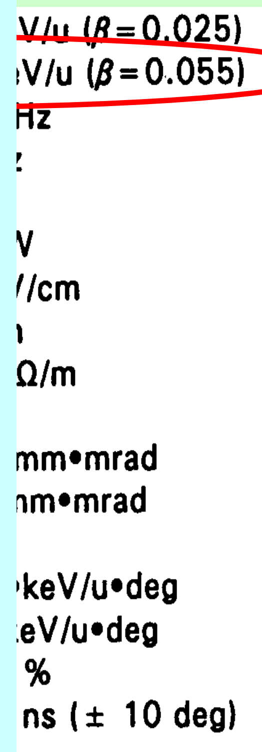
Single Gap Resonators

High Charge State Injector (HLI)

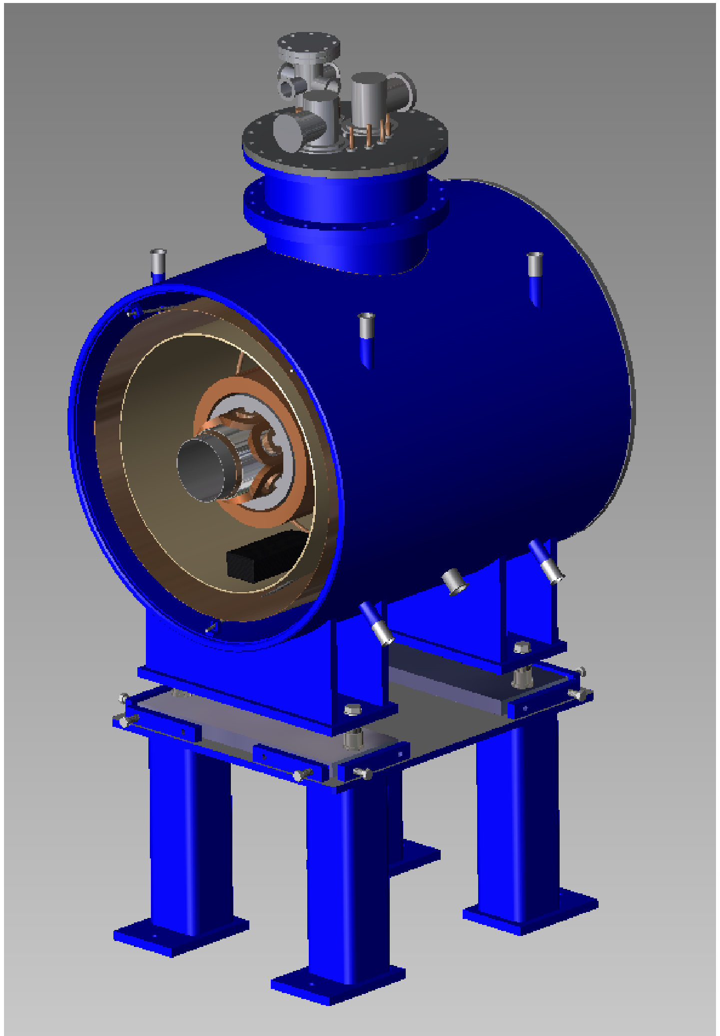




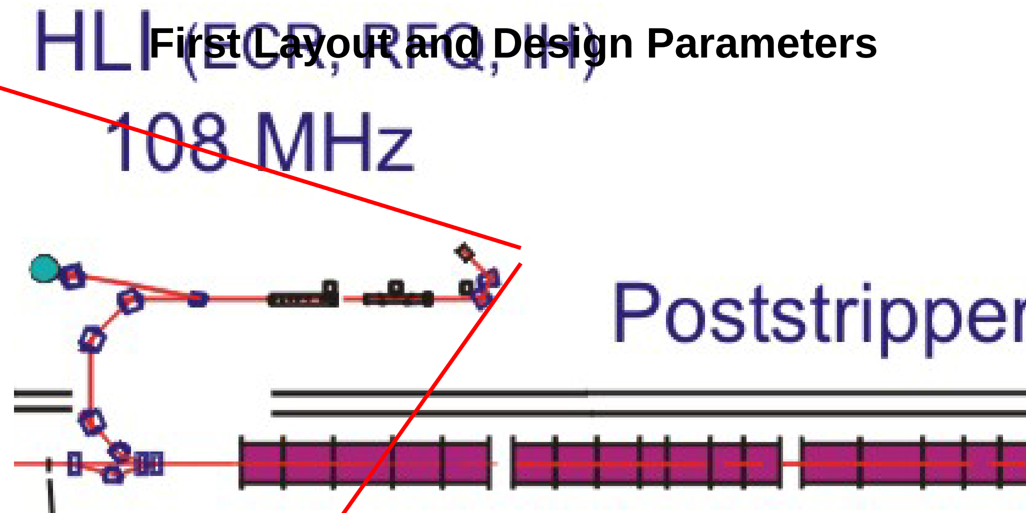
Ion Source	EZR (CAPRICE-Typ)
m/q	8.5
Extraction Voltage	2.5· (m/q)
Beam Energy	2.5 keV/u (β = 0.23 %)
Beam Emittance	0.46 π·mm·mrad (norm.) 200 π·mm·mrad (unnorm.)
Mass Resolution	$\Delta m/m = 3\cdot10^3$



Superconducting ECR ion source



First Layout and Design Parameters

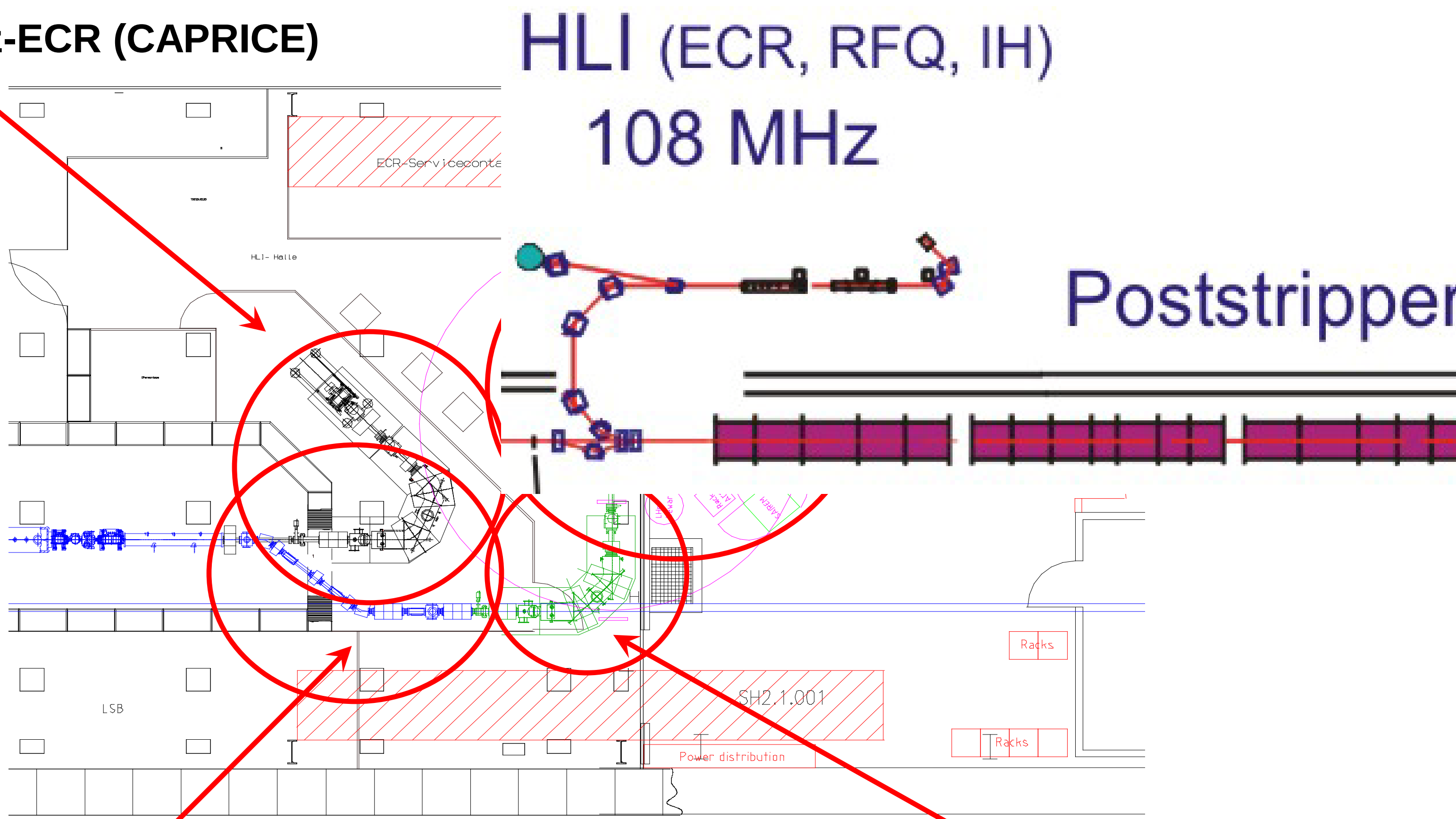


Diameter of Plasma chamber	180 mm
Diameter of Cryostat	1200 mm
Length of Cryostat	1350 mm
Extraction Voltage	up to 40 kV
LHe consumption	0

New LEBT for MS-ECRIS

Existing 14 GHz-ECR (CAPRICE)

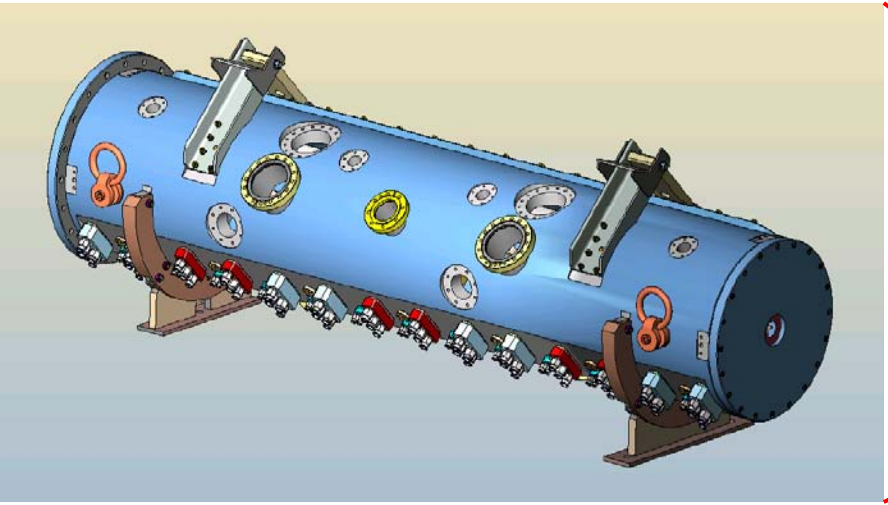
HLI linac

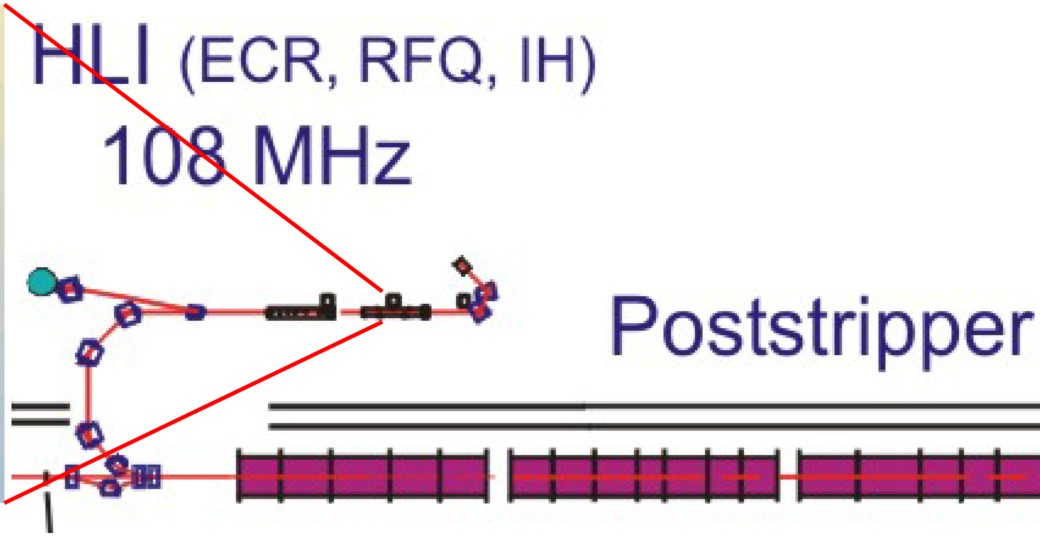


Analyzing system

New Low Energy Beam Transport Line

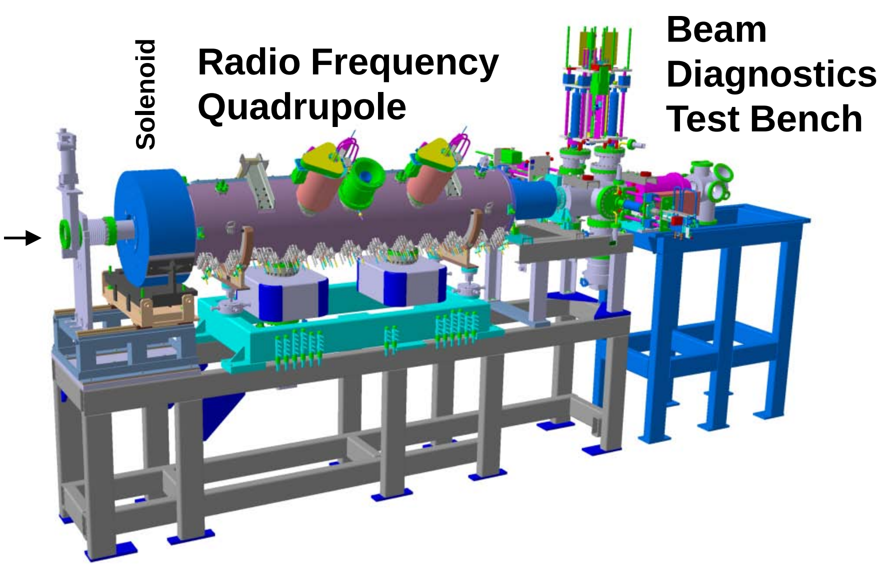
RFQ upgrade



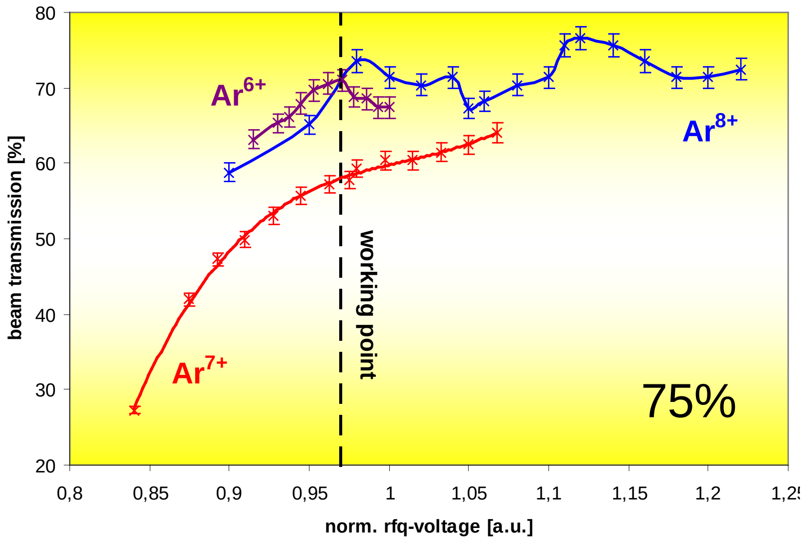


- **Status quo: Same RFQ in operation since 1991, first RFQ-IH-LINAC, RFQ with longest operation time in the world**
- **Design parameters: W_{out}/300 keV/u, operating frequency: 108 MHz, duty cycle 25-50%, rep. rate 50-100 Hz, electrode voltage: 80 kV, tank length: 3 m**
- **Problems: Reduced transmission and poor reliability, limited duty cycle (25%)**
- **New RFQ: 100% duty cycle, increased acceptance, improved beam transmission, revised construction for stable operation; compact design (2 m), reduced electrode voltage (55 kV), keeping the max. average rf power (remaining rf power amplifier)**

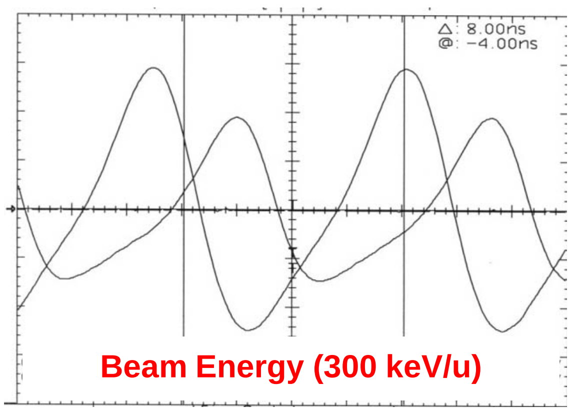
RFQ-Commissioning (October - April 2010)



Beam Transmission



Phase Probe Signals (TOF)



Emittance Measurement (RFQ_{out})