Status and Perspectives of the CW Upgrade of the UNILAC HLI at GSI

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- Introduction: History of the HLI
- Current Status, Issues and CW upgrade
- Perspectives: The future CW Linac

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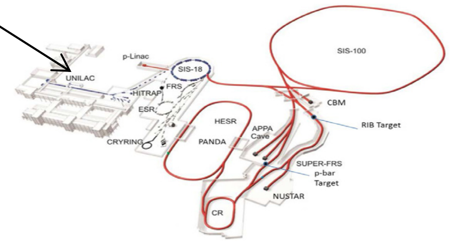
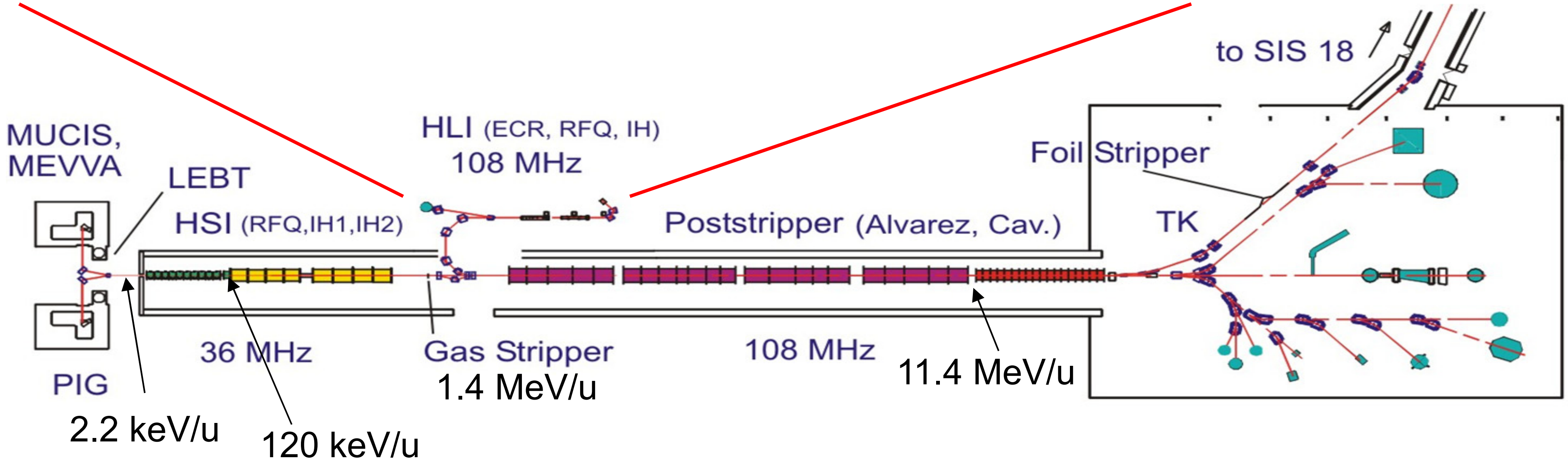
UNIversal Linear ACcelerator UNILAC



HLI design parameters

ion A/q for cw operation (pulsed)	≤ 6 (8.5), i.e. $^{12}C^{2+}$ ($^{238}U^{28+}$)	
beam current	5	emA
input beam energy	2.5	keV/u
output beam energy	1.4	MeV/u
normalized total output emittance, horizontal/vertical	1.5 / 1.5	mm mrad
beam pulse duration	cw (5.0)	ms
beam repetition rate	cw (≤ 50)	Hz
operating frequency	108.408	MHz
length	10.8	m



History: The original High Charge State Injector 1991

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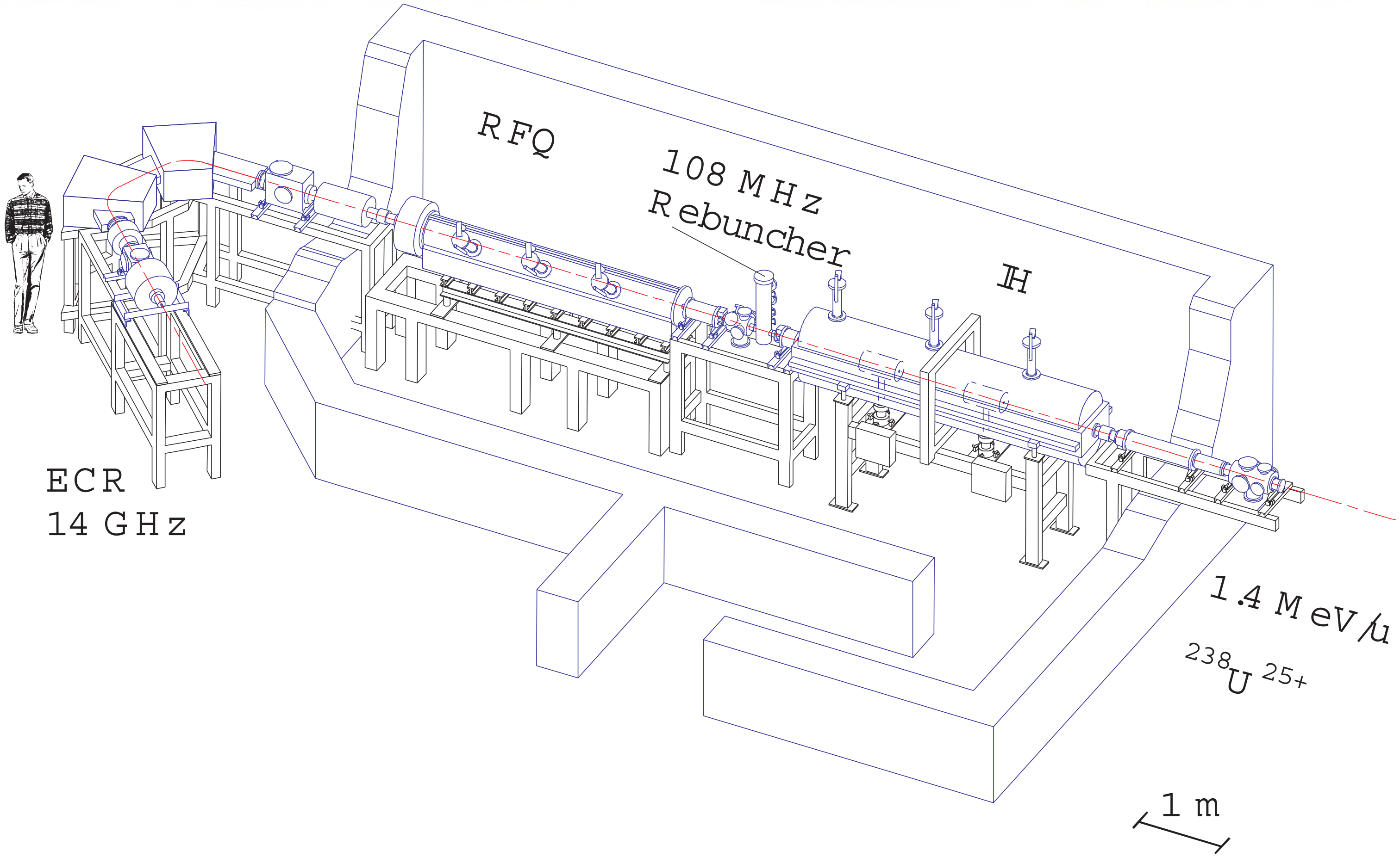

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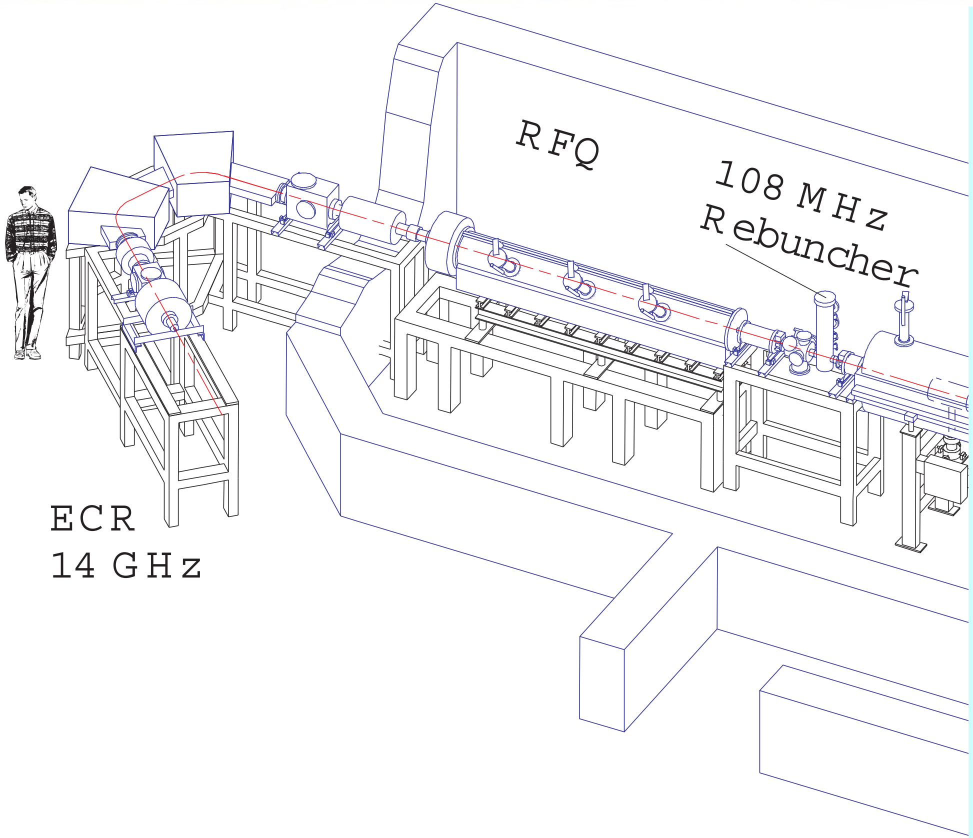

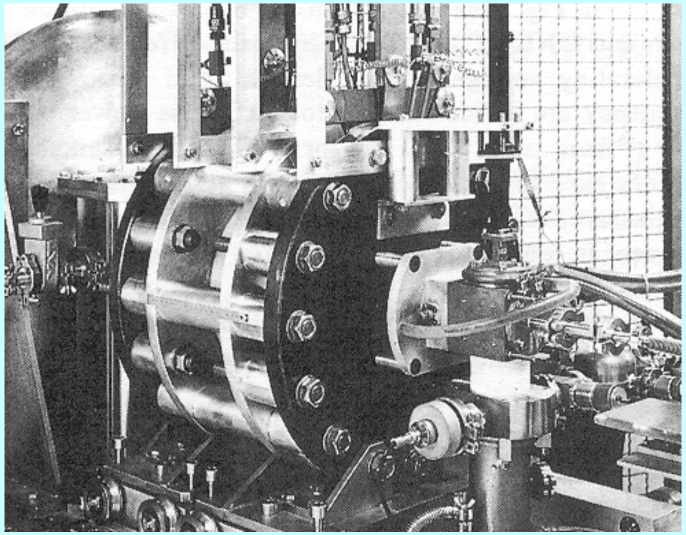

Ion Source	EZR (CAPRICE-Typ)
m/q	8.5
Extraction Voltage	2.5· (m/q) keV
Beam Energy	2.5 keV/u (β = 0.23 %)
Beam Emittance	0.46 π·mm·mrad (norm.) 200 π·mm·mrad (unnorm.)
Mass Resolution	$\Delta m/m = 3\cdot 10^3$

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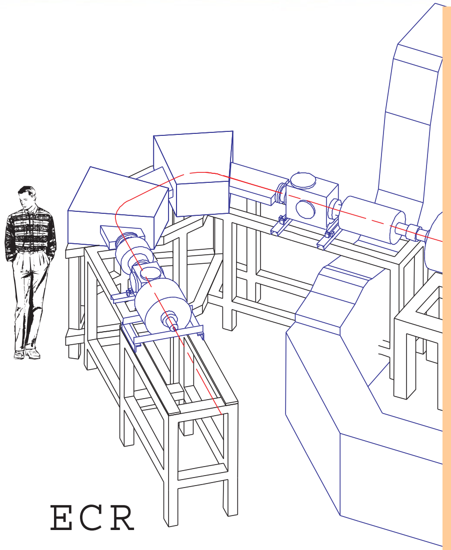
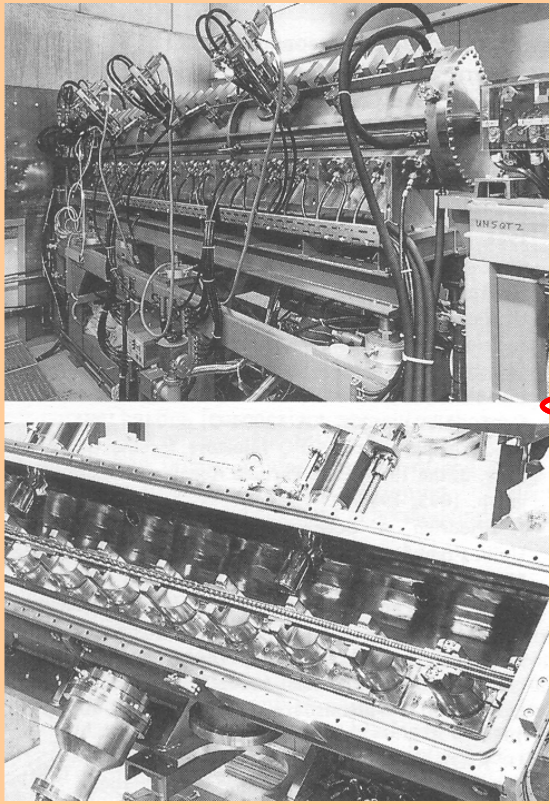


ECR
14 GHz



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.)	$\geq$ 0.8 π•mm•mrad
Longitud. emittance	30 π•keV/u•deg
Energy spread	± 1.0 %
Bunch width	± 0.3 ns (± 10 deg)

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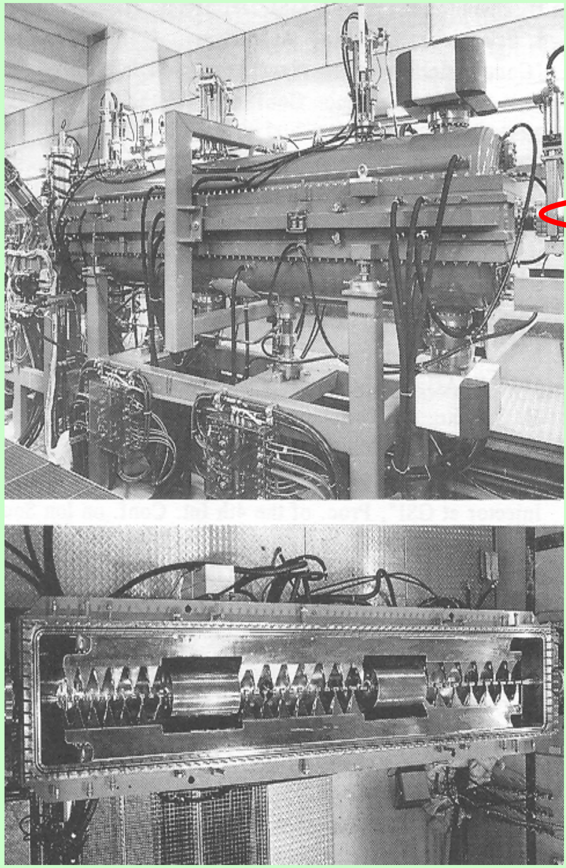
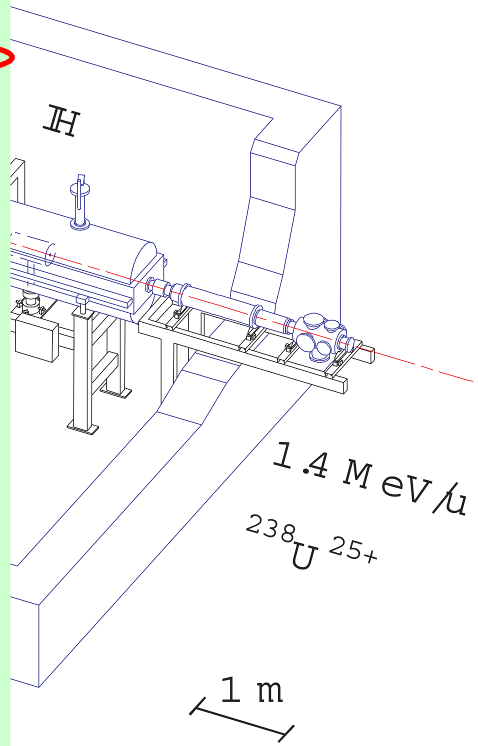
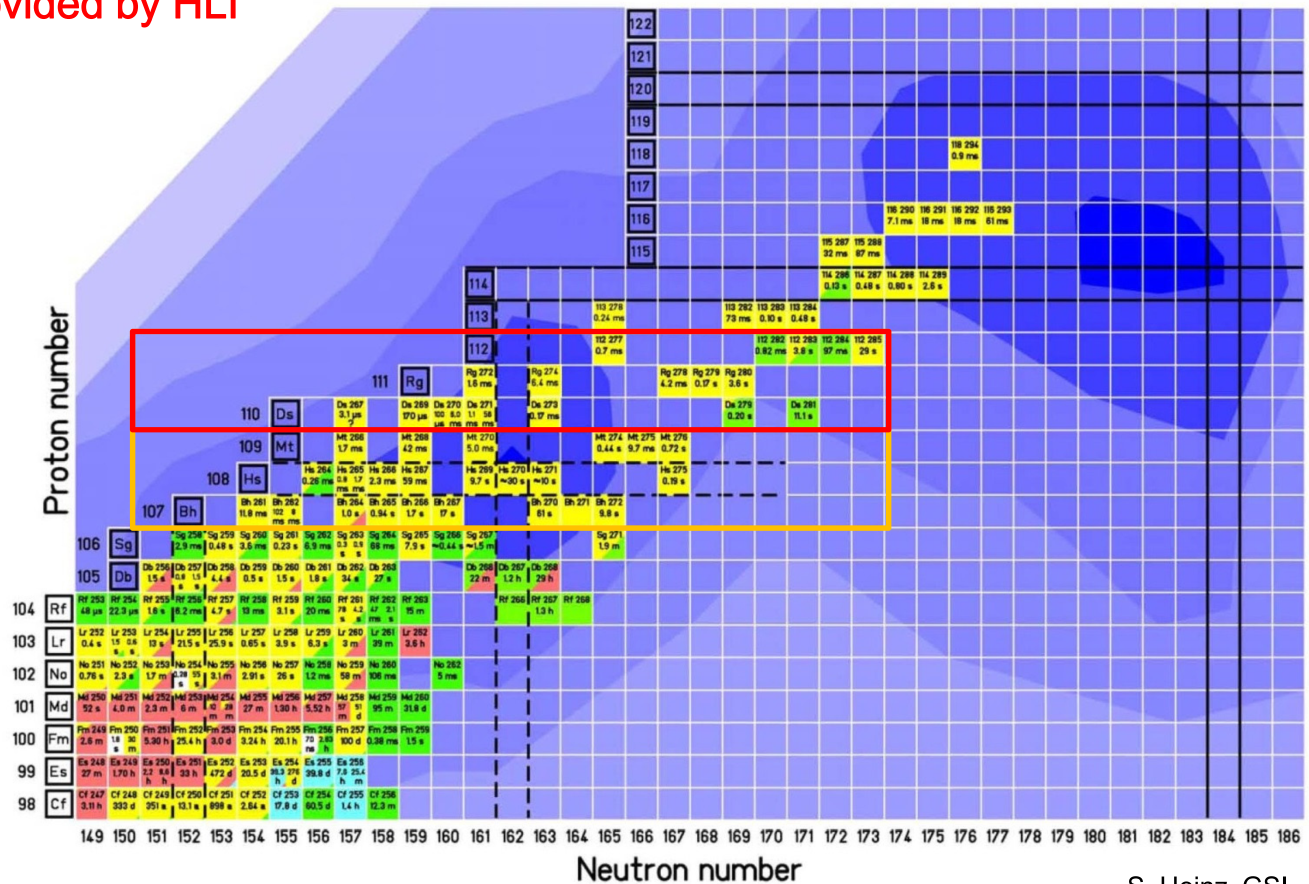


IH

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)



Ion beams provided by HLI

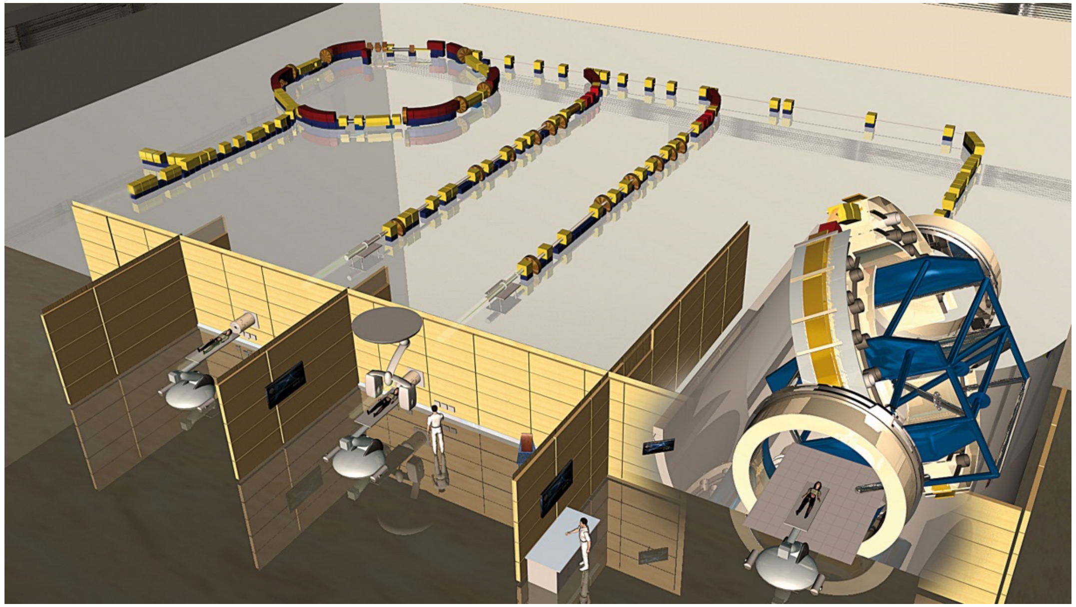


S. Heinz, GSI

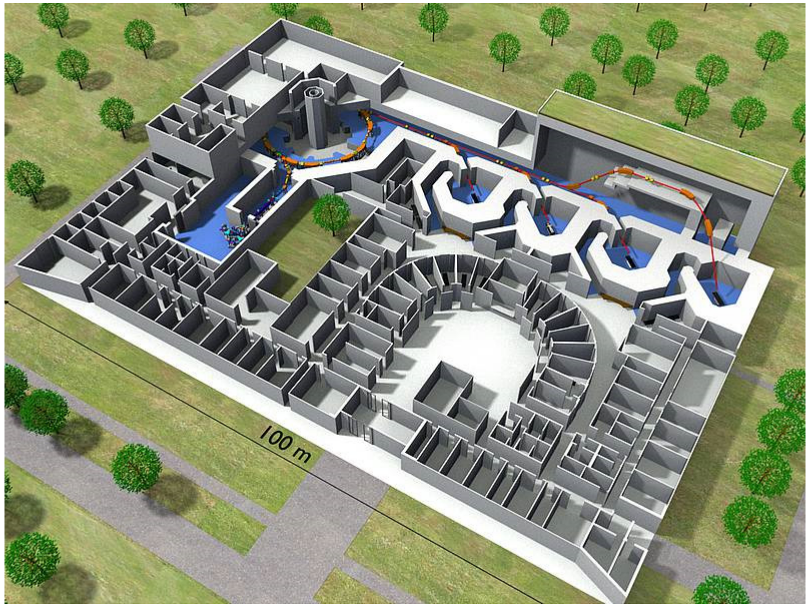
History: Heavy Ion Cancer Therapy

Developed at GSI with Carbon ions provided by the ECR/HLI

HIT @ Heidelberg



MIT @ Marburg



S. Heinz, GSI

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Current Status of HLI

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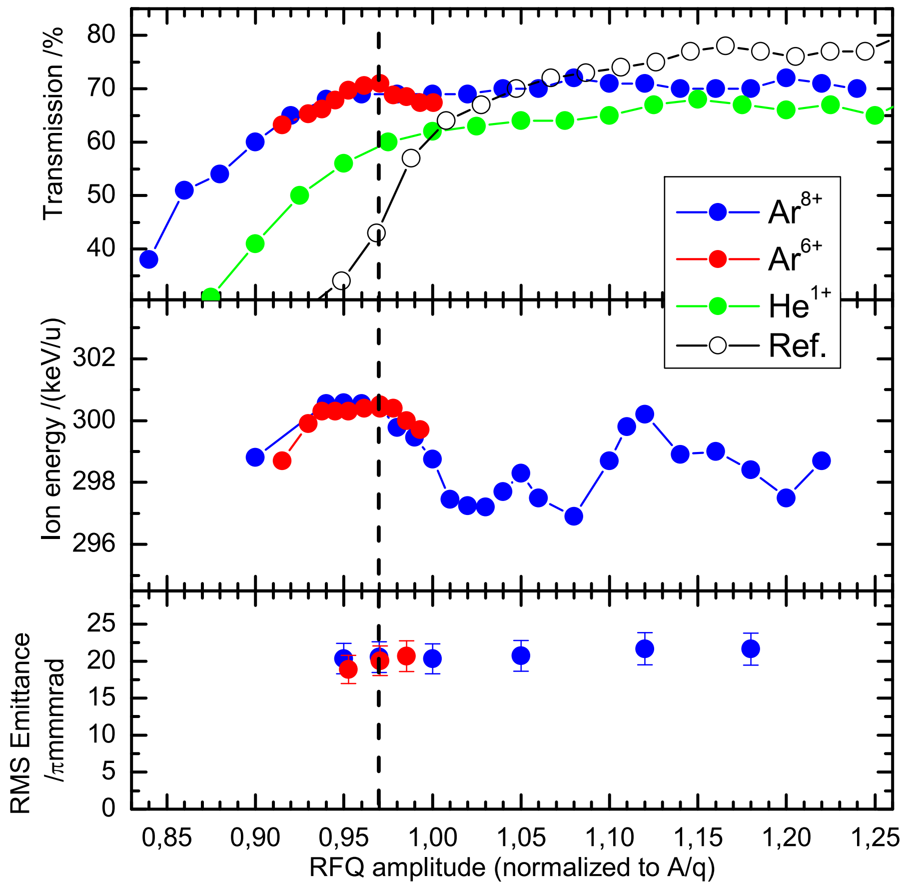
Advantages:

+ Work horse for long beam times with high duty cycle beams of medium heavy, rare isotope ions like $^{48}Ca^{10+}$, $^{12}C^{2+}$, $^{22}Ne^{4+}$, $^{64}Ni^{9+}$
+ ECR ion source has long life time for metallic ions (up to 4 weeks) between services
+ High availability and reliability when set up correctly
+ Low power consumption
+ High average beam current up to 1 pnA (experiment limit)

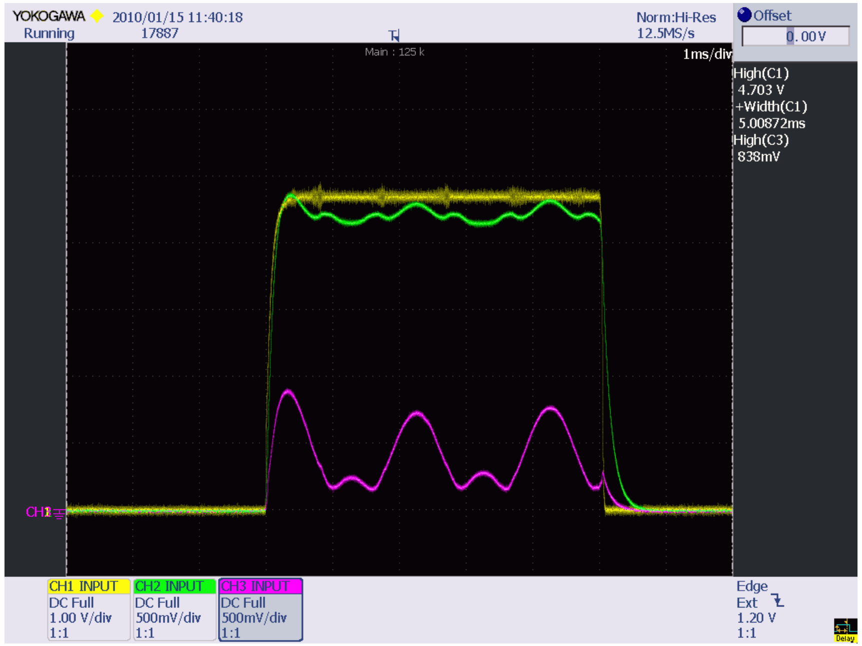
Drawbacks:

- Effectively restricted to A/q=6.5, full duty cycle (25%) up to A/q=5.5
- Transmission less than 60% (analysed beam to UNILAC injection)
- Beam setup is delicate and needs experience, endurance
- New RFQ (2009) mechanically unstable, deteriotated beam quality

2009: New CW 4-rod Radio Frequency Quadrupole



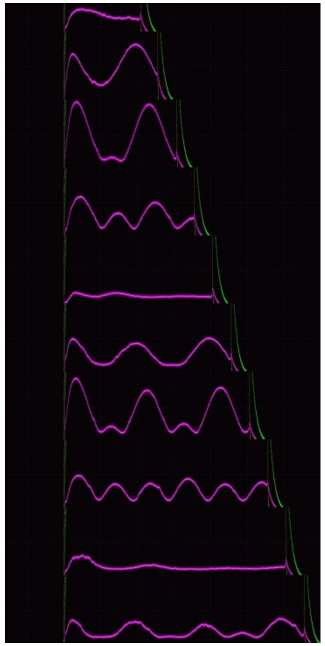
Rod vibrations: RF Measurements

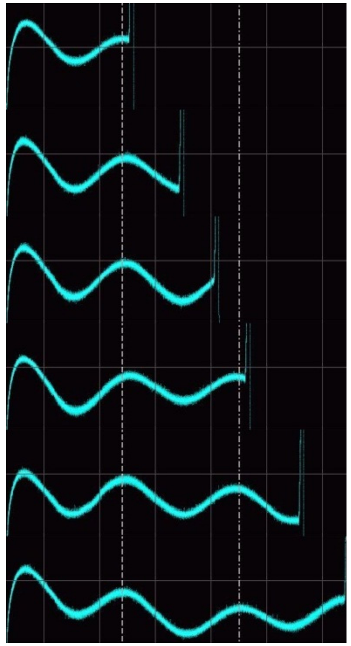


Tank signal

Forward rf

Reflected rf





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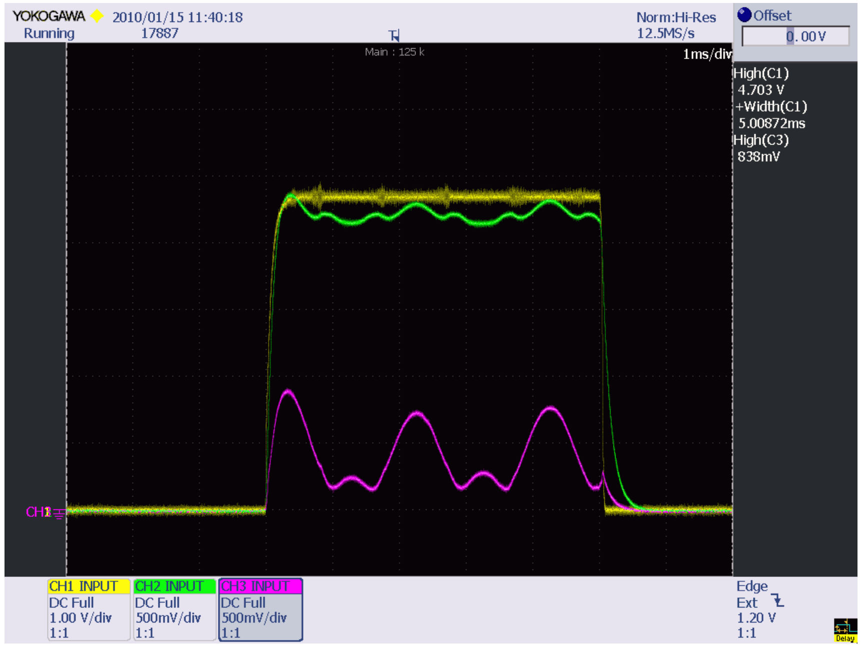

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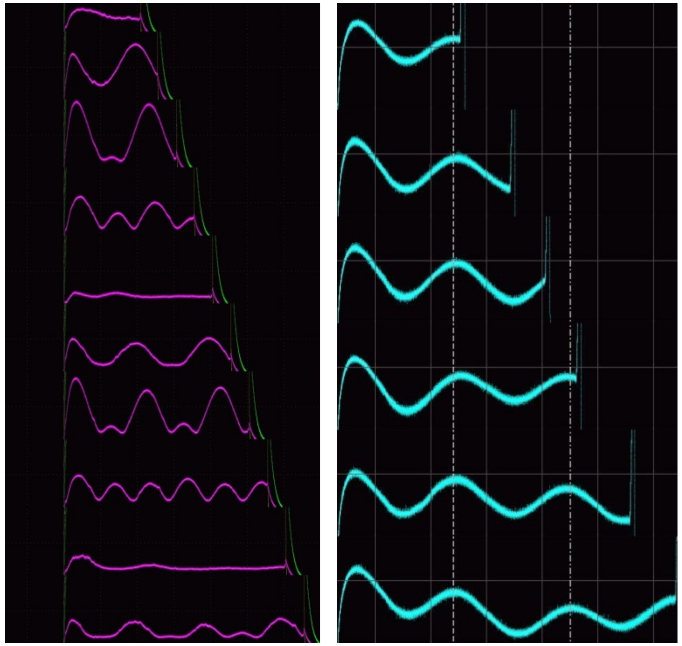
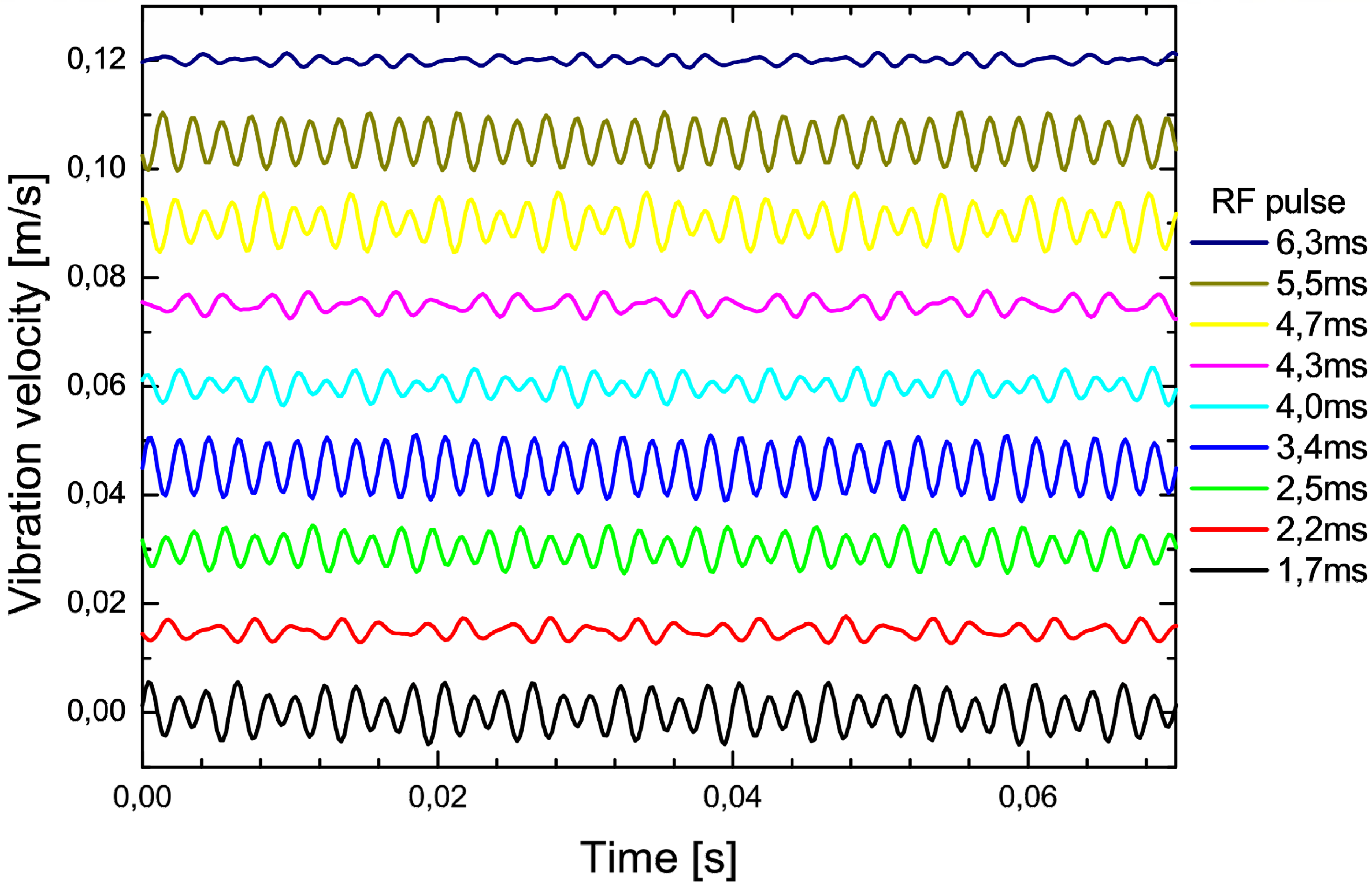


→ Detailed investigation of rod vibrations: Laser Vibrometer Measurements

Rod vibrations: Standard Operation, seen with Laser Vibrometer



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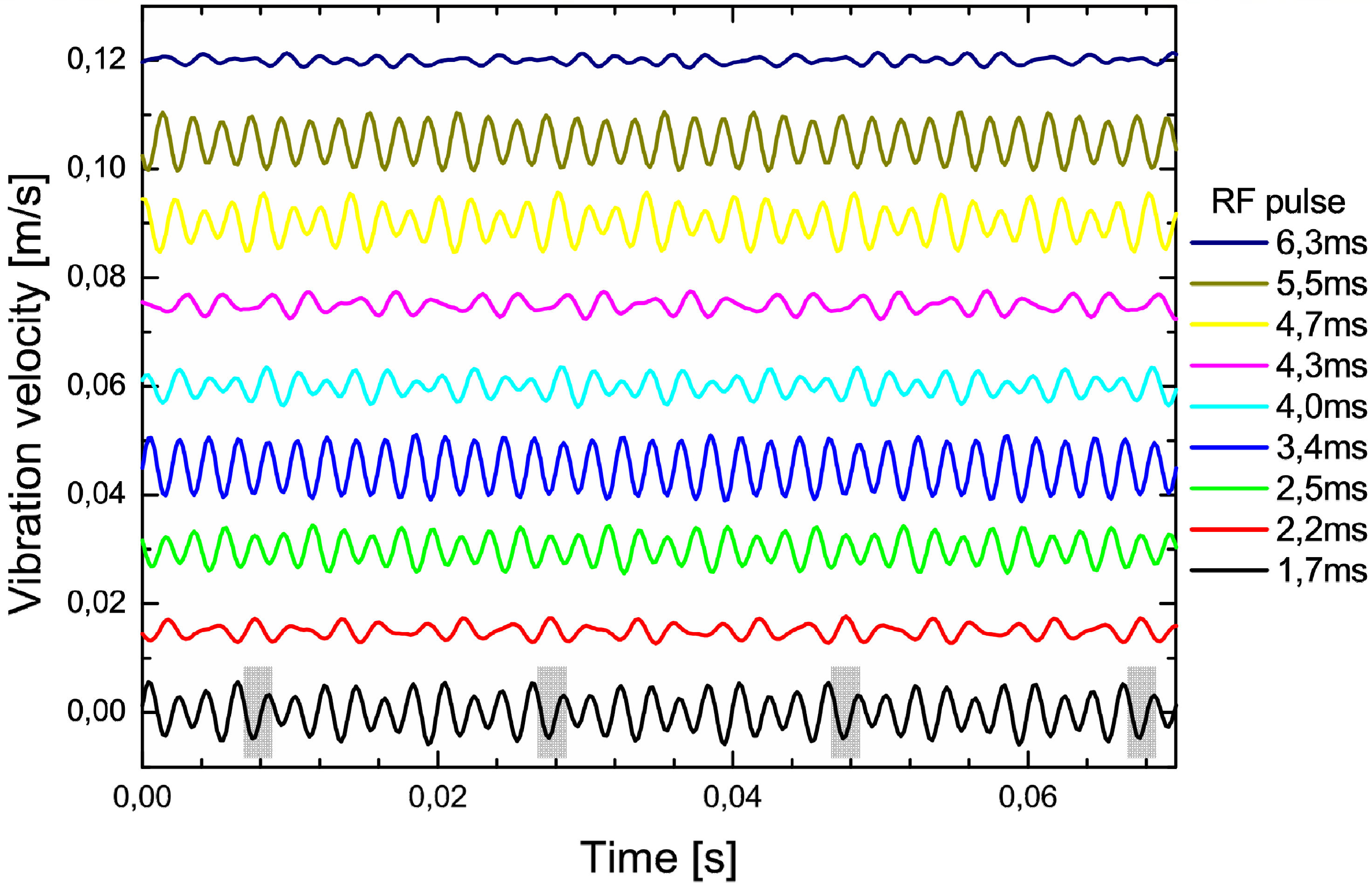

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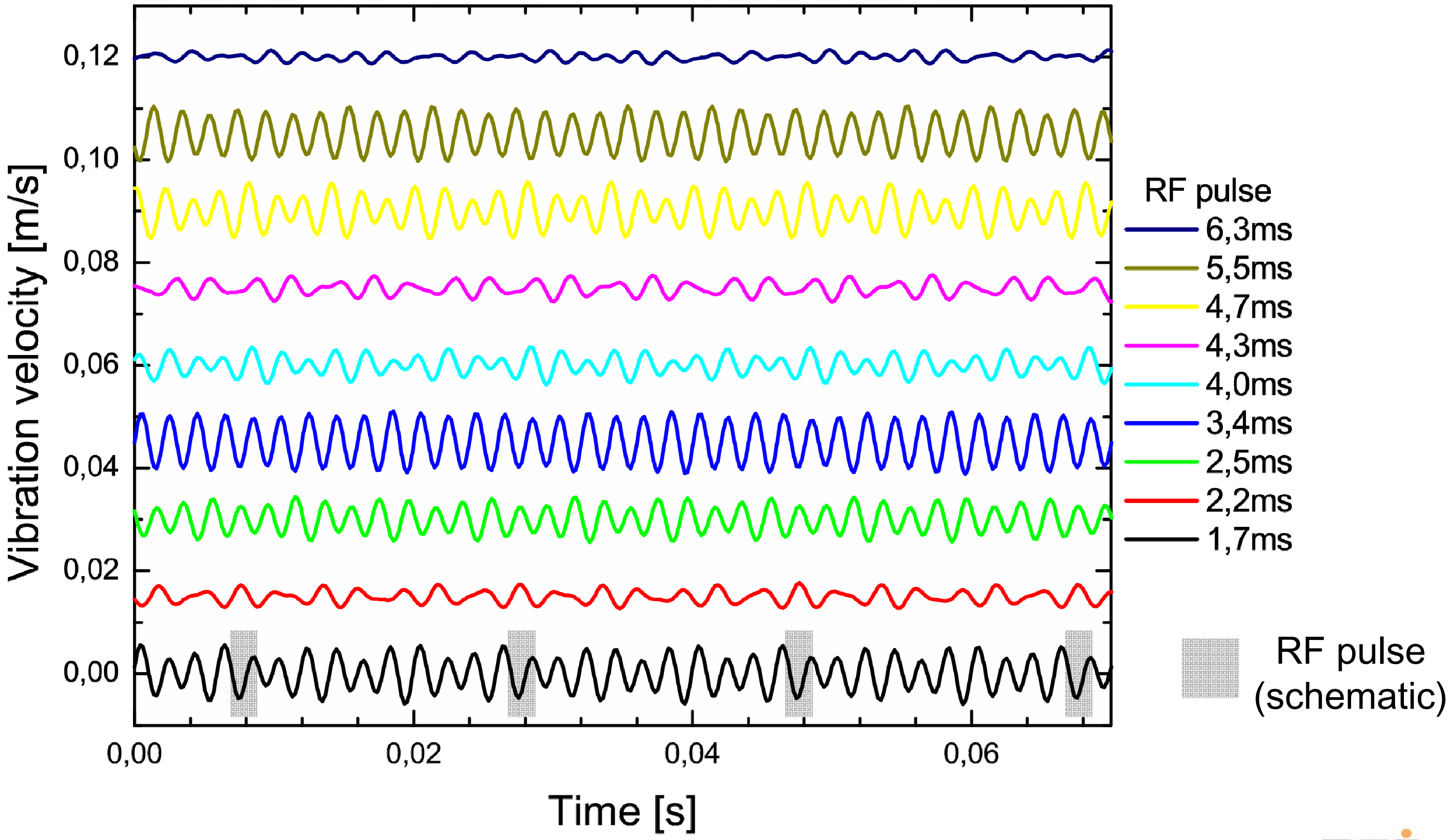

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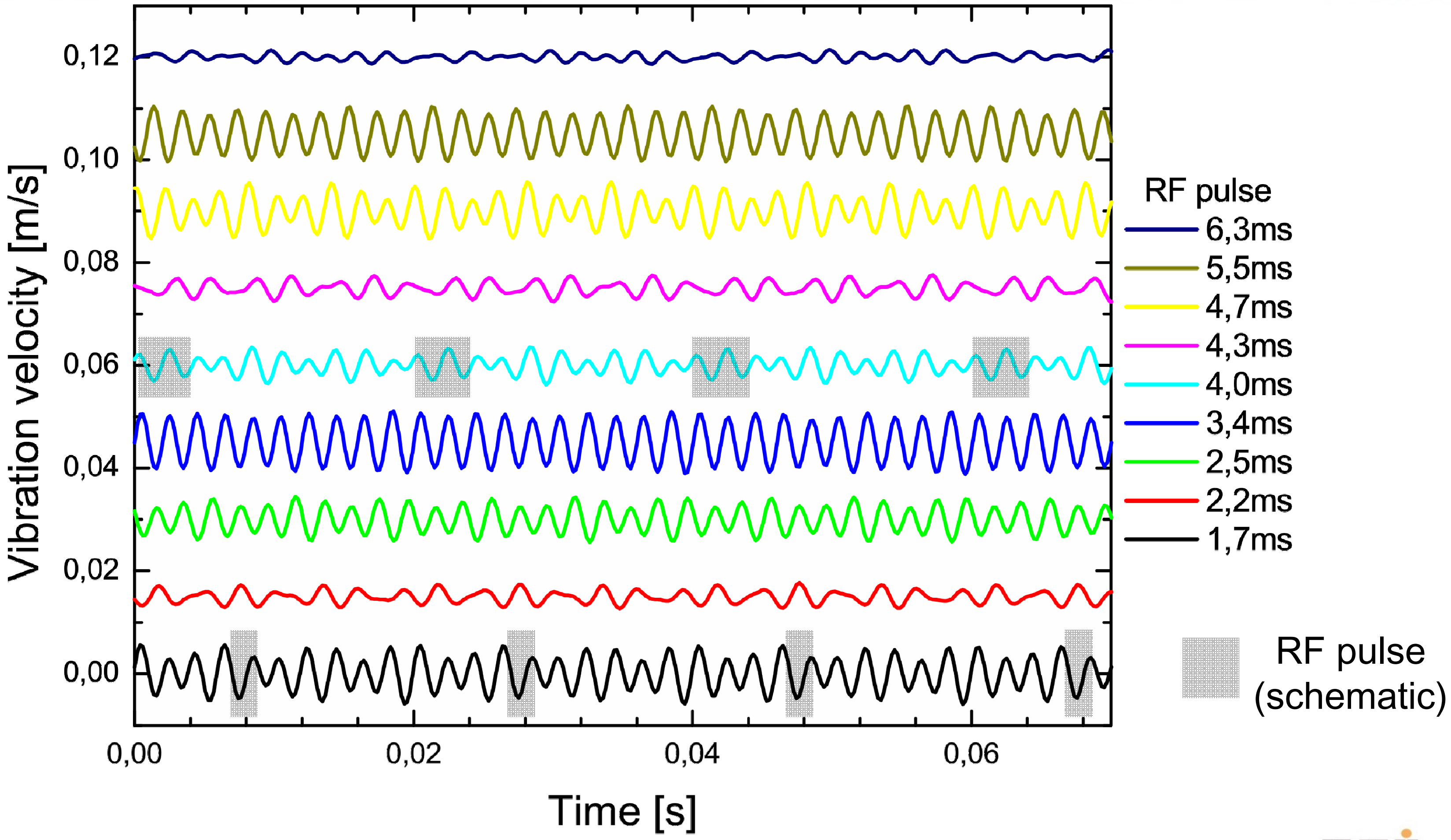

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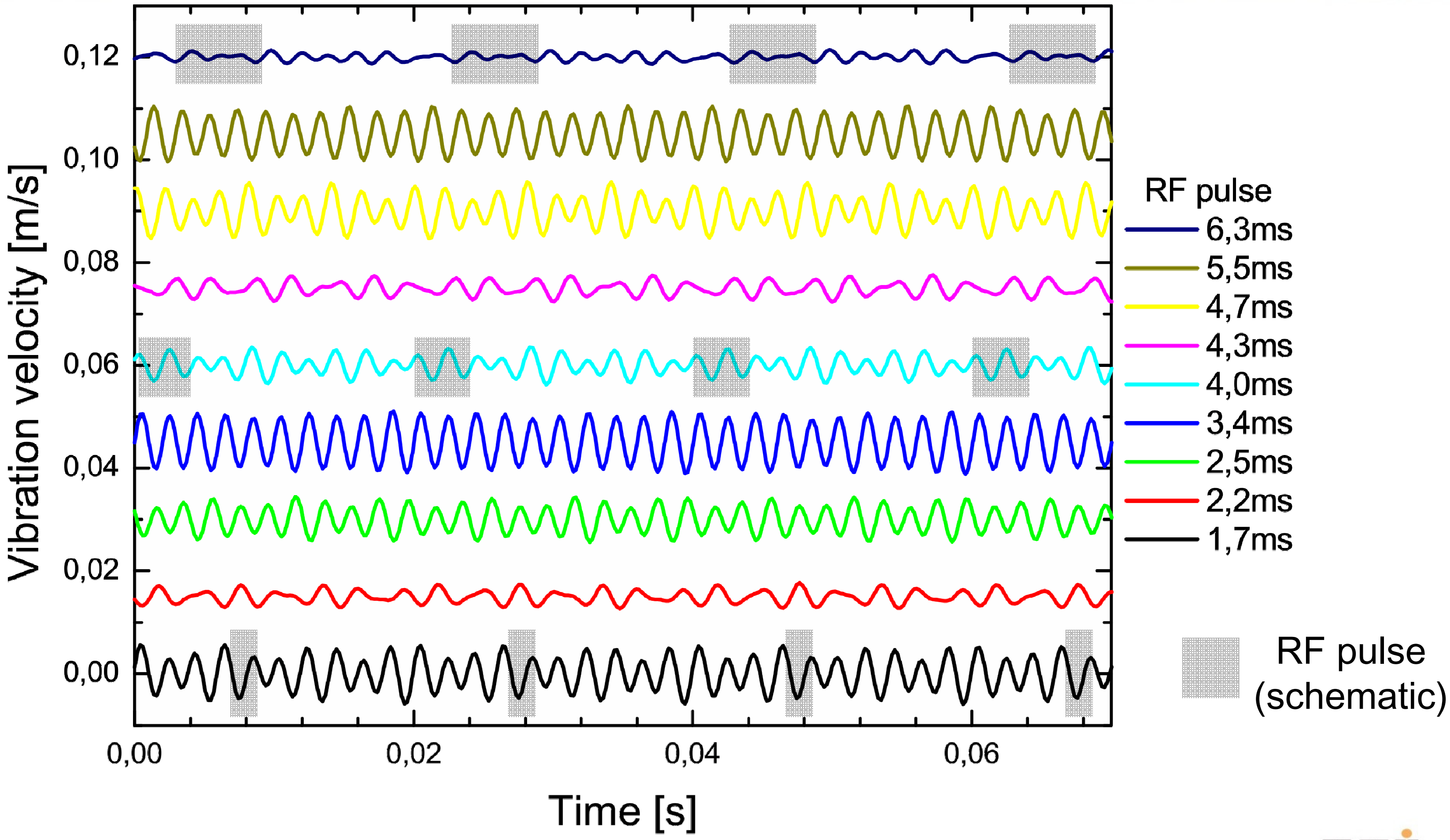
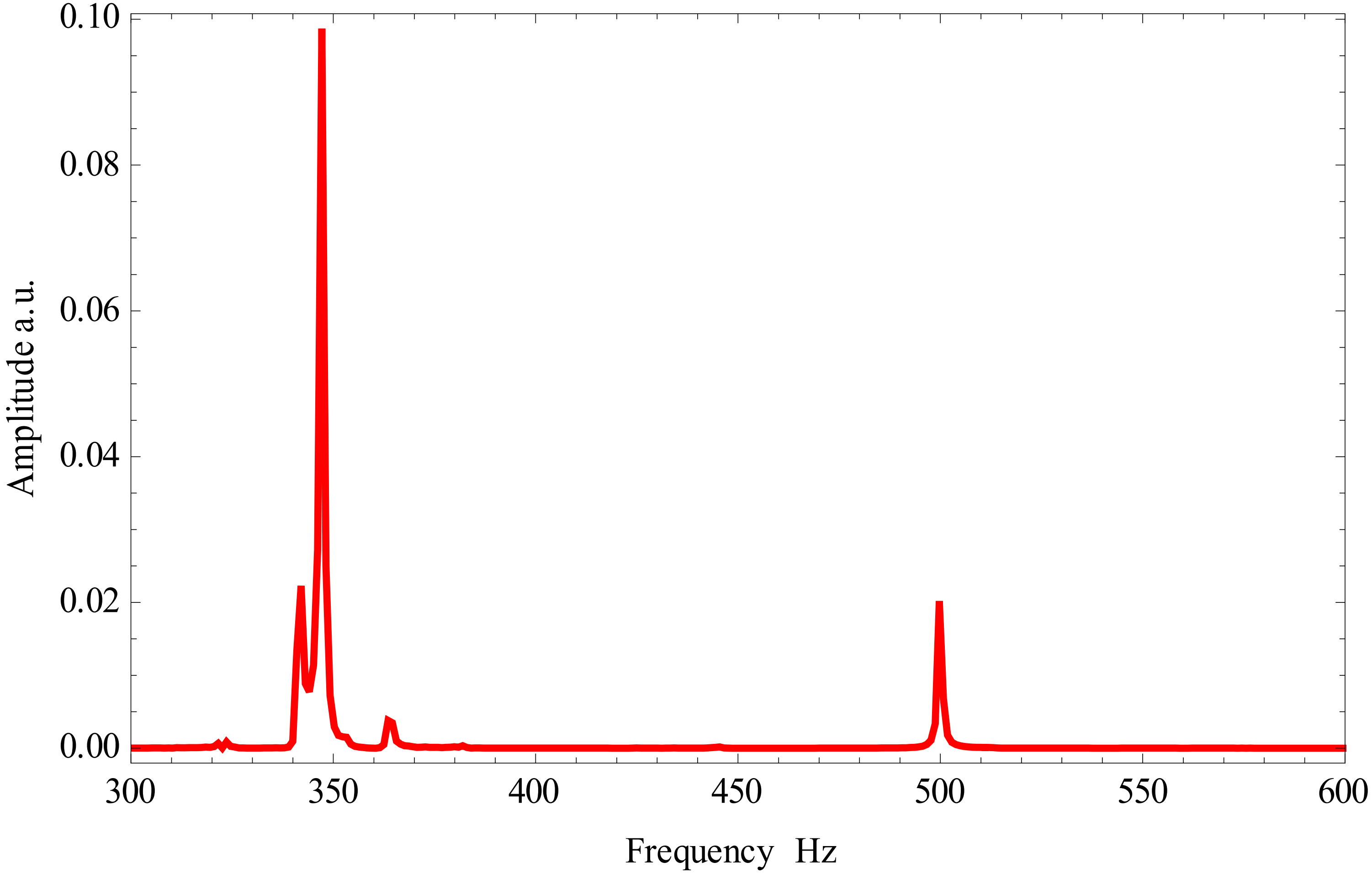


Rod vibrations: Ringdown Spectrum



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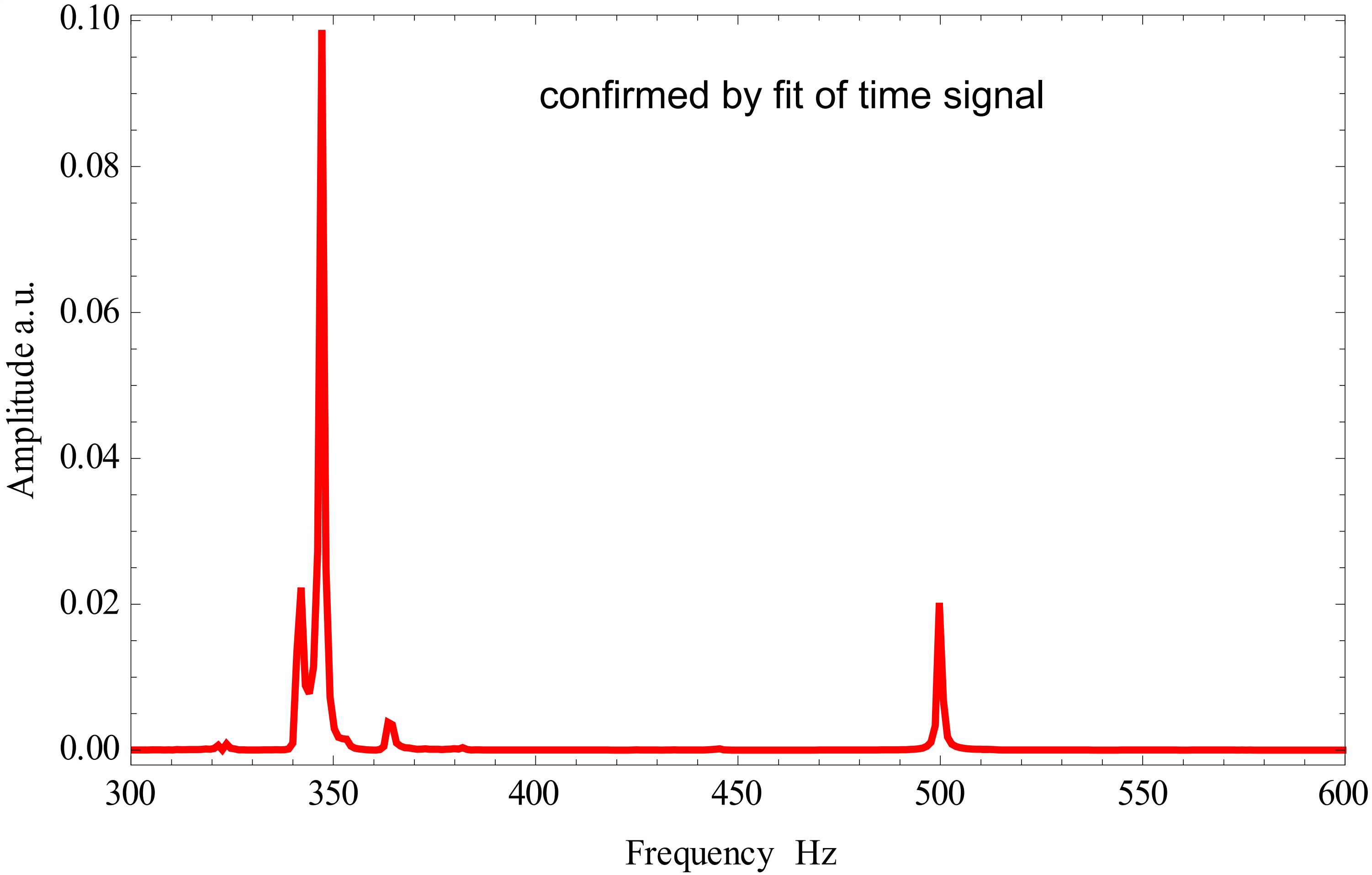

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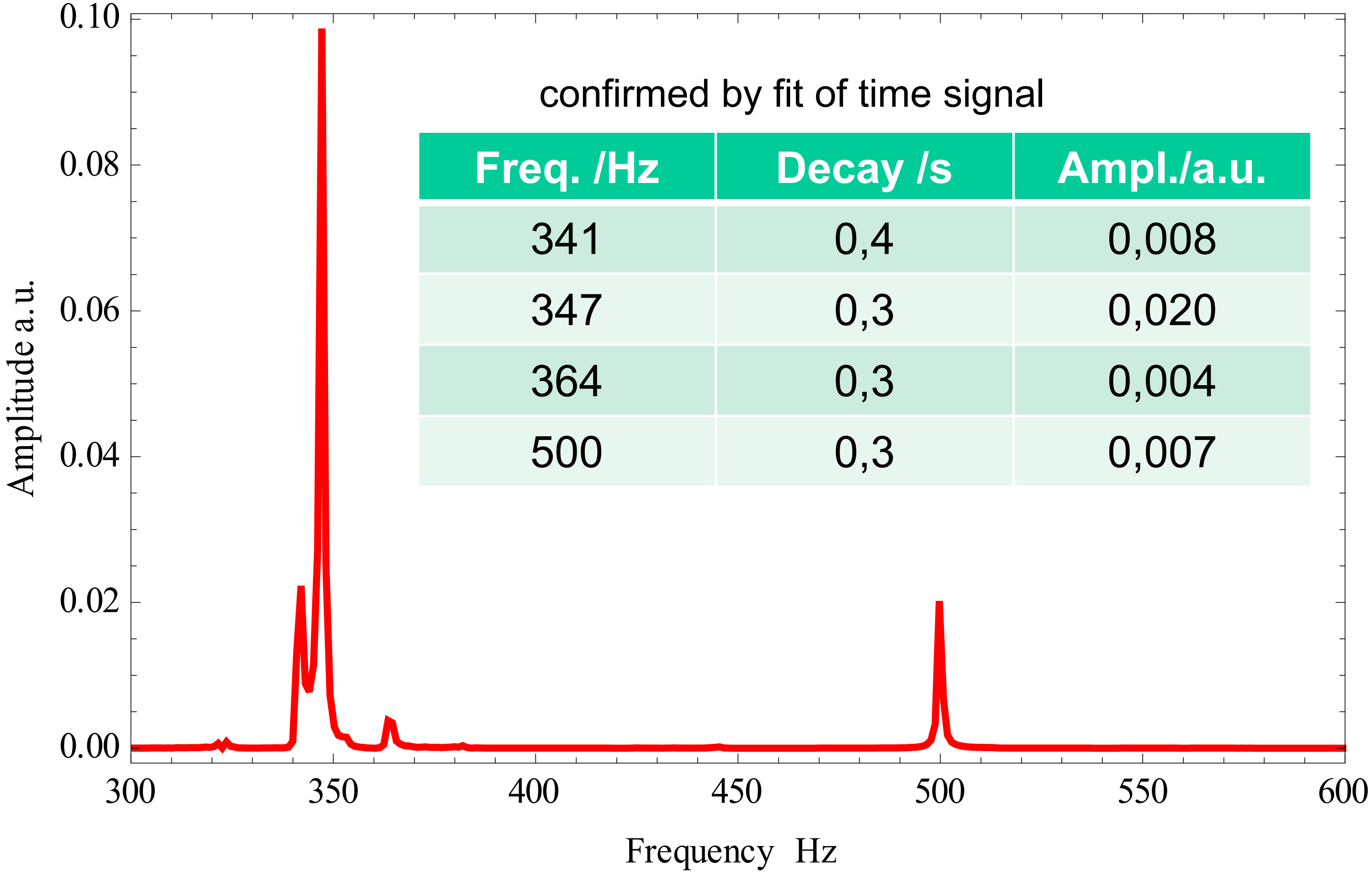
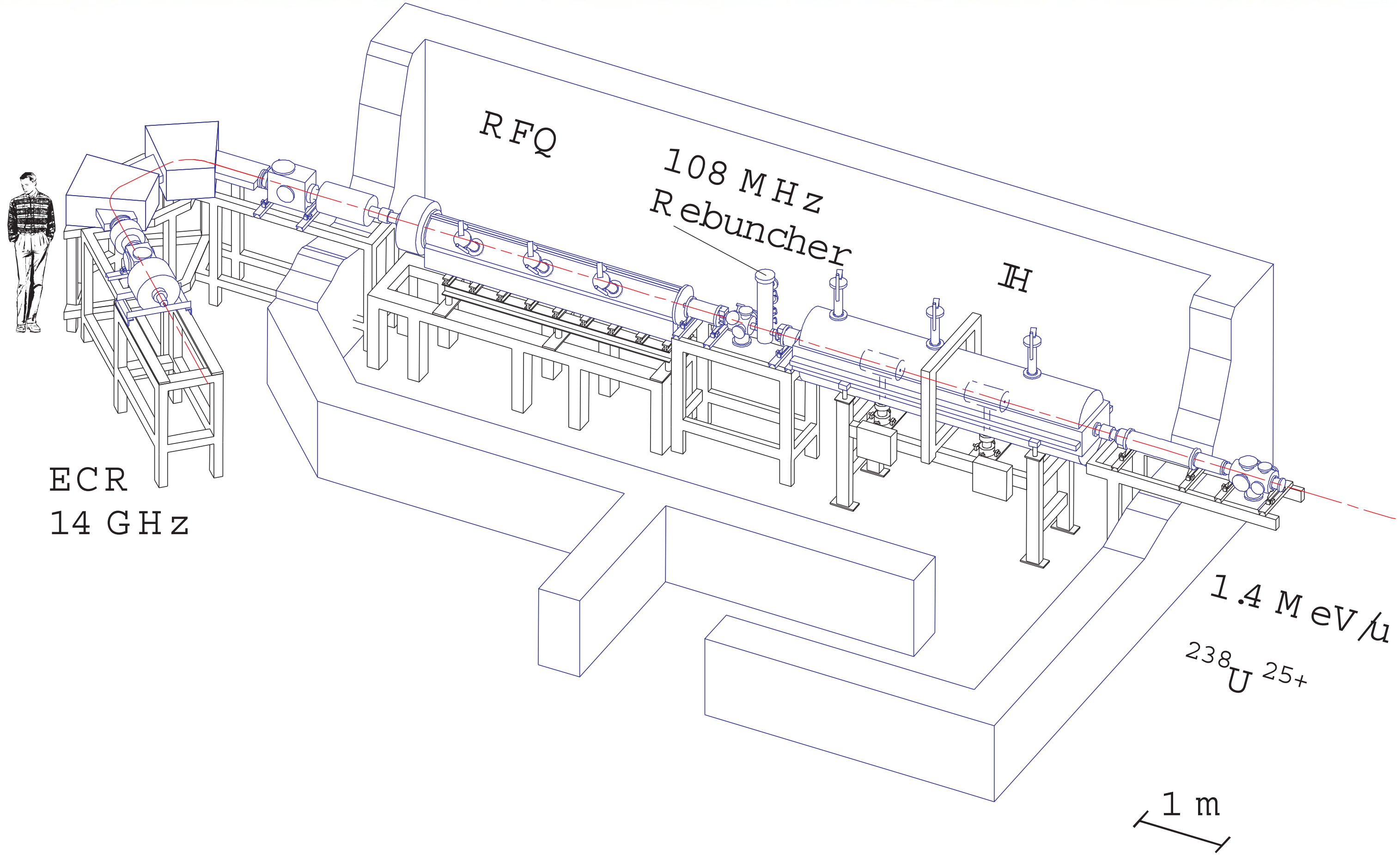


confirmed by fit of time signal

Freq. /Hz	Decay /s	Ampl./a.u.
341	0,4	0,008
347	0,3	0,020
364	0,3	0,004
500	0,3	0,007

CW upgrade: General



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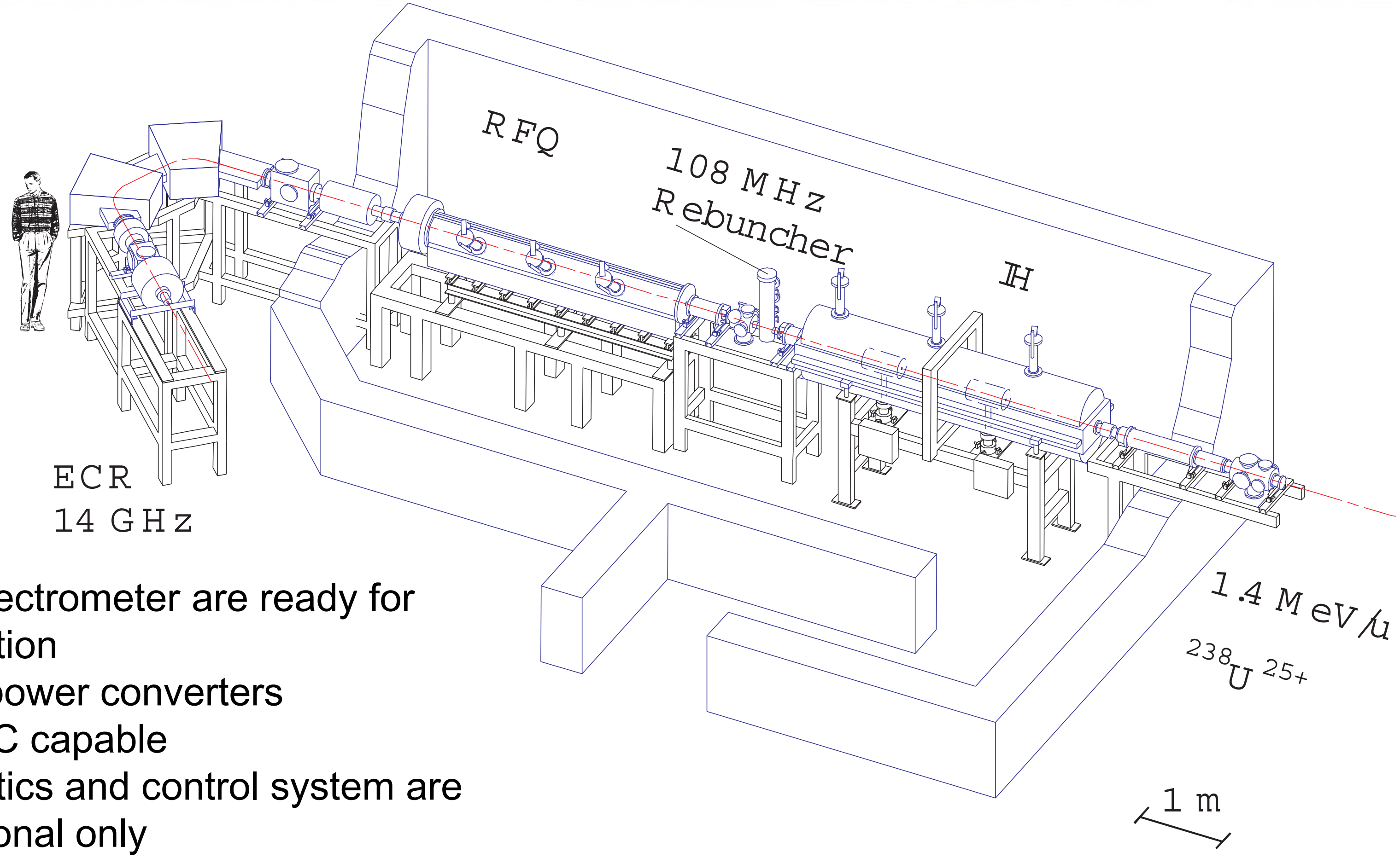
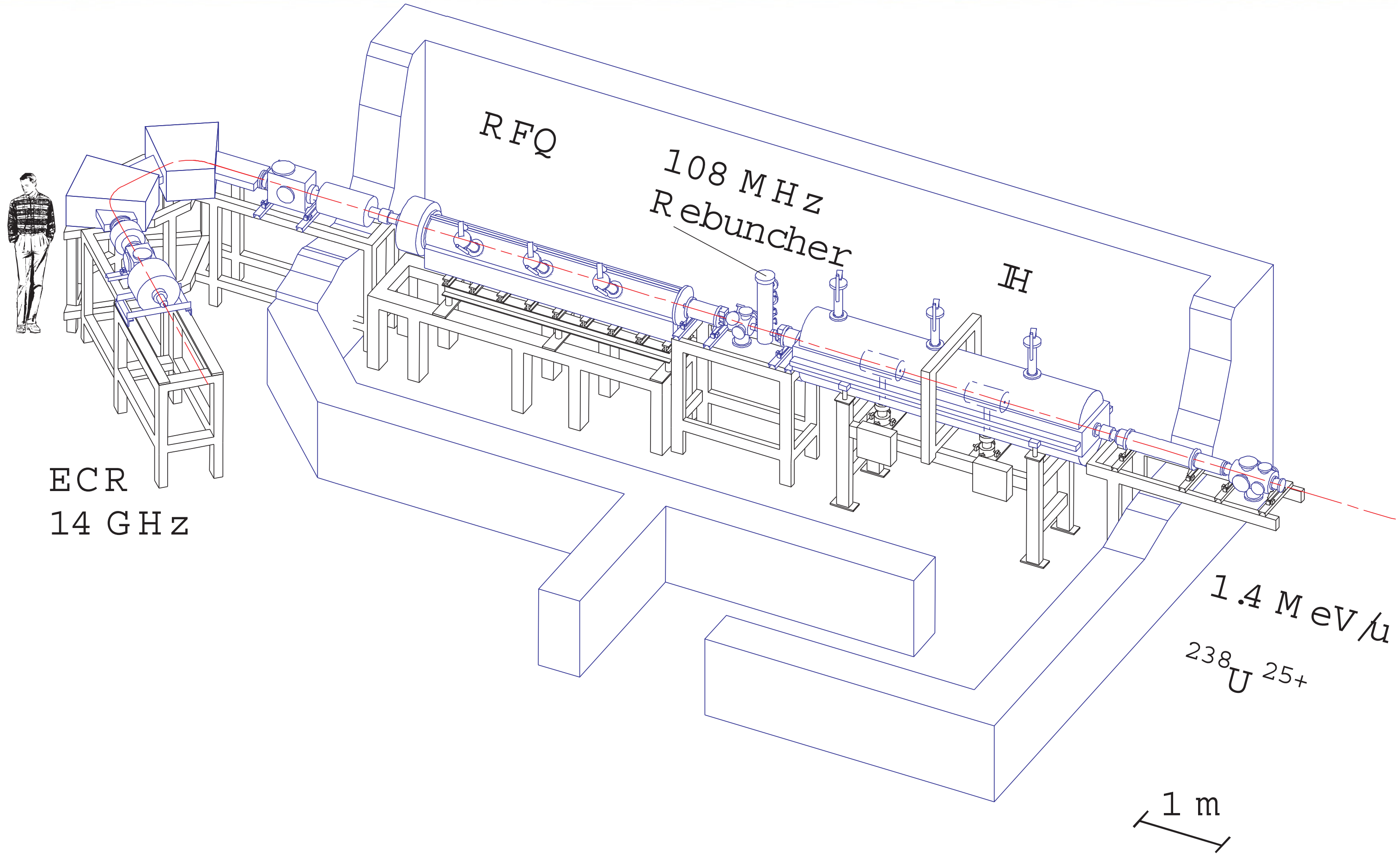


- ECRIS and spectrometer are ready for cw linac operation
- Magnets and power converters are (mostly) DC capable
- Beam diagnostics and control system are pulsed operational only

CW upgrade: Ion Source



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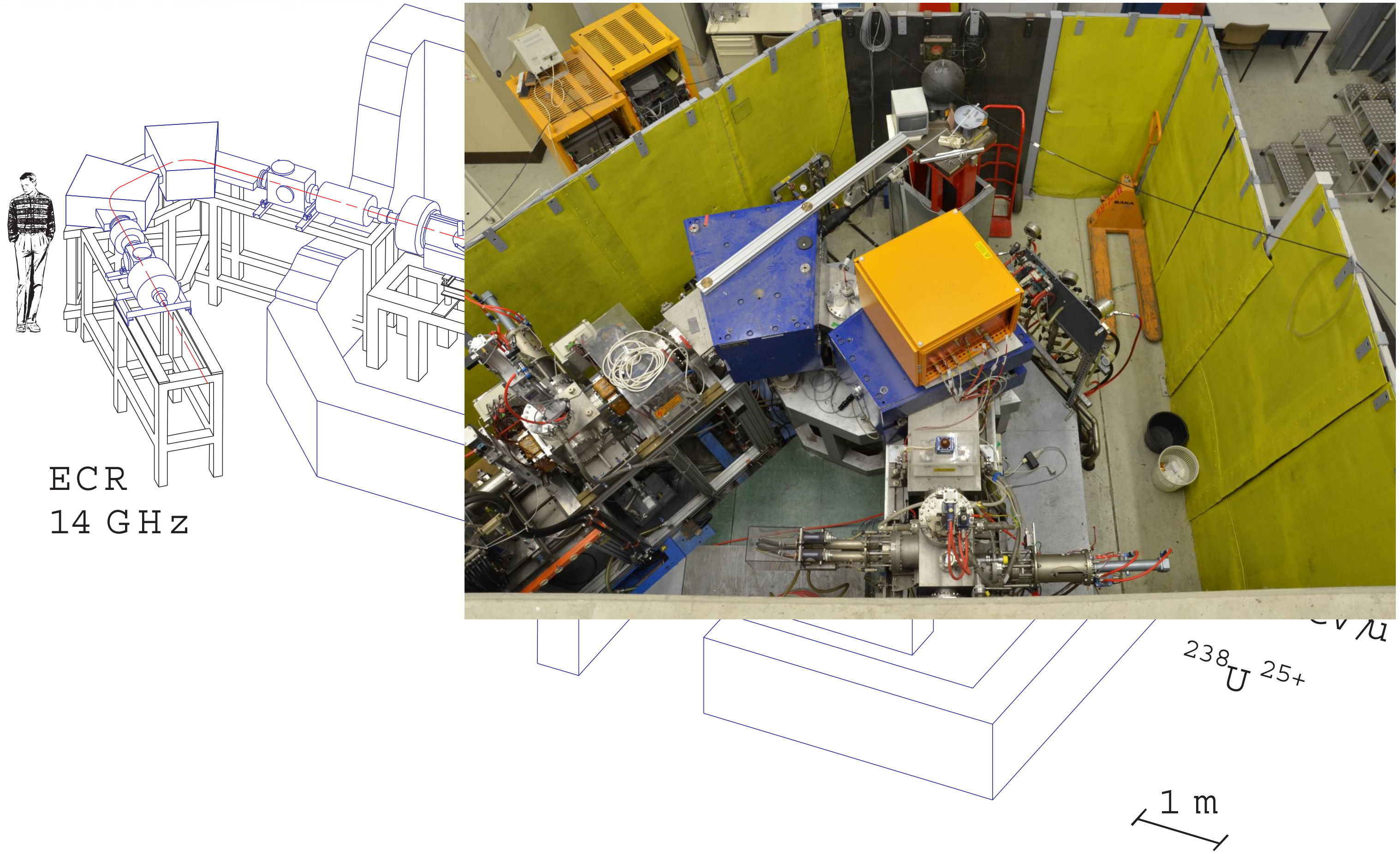

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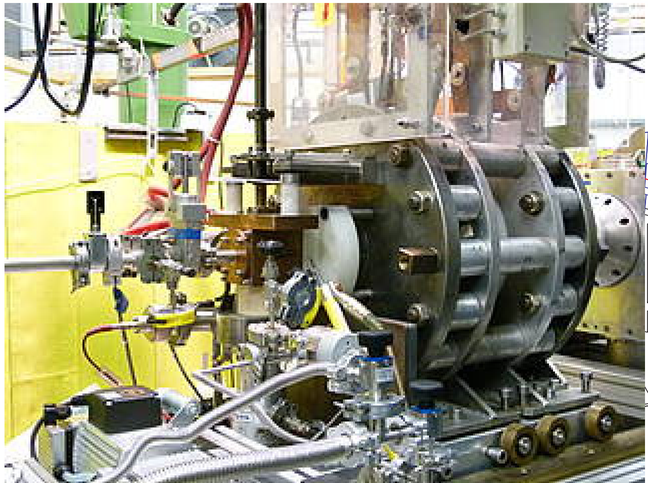

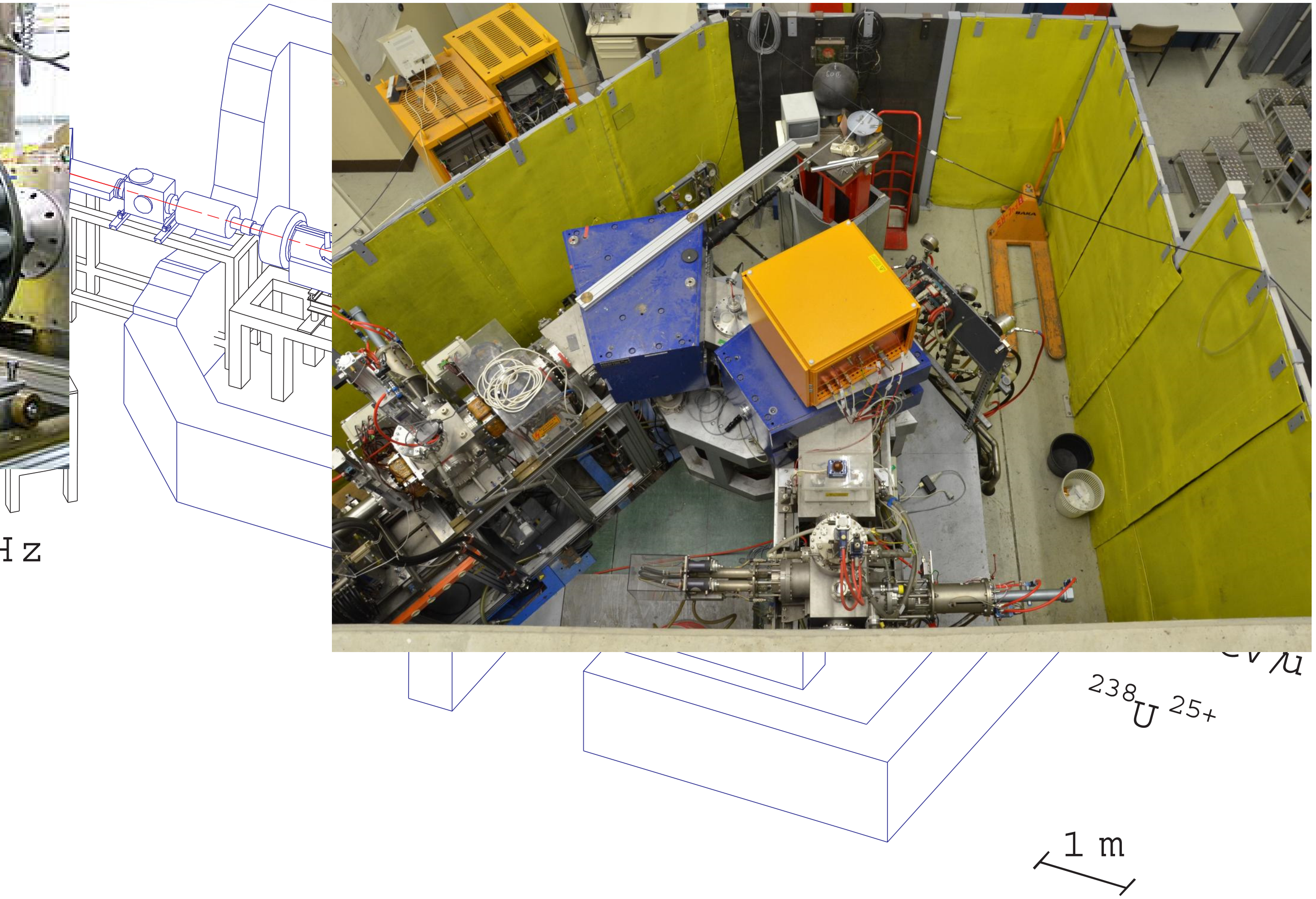

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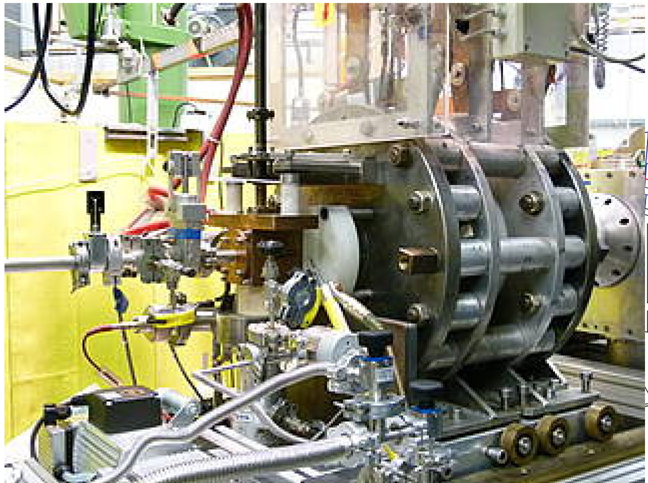
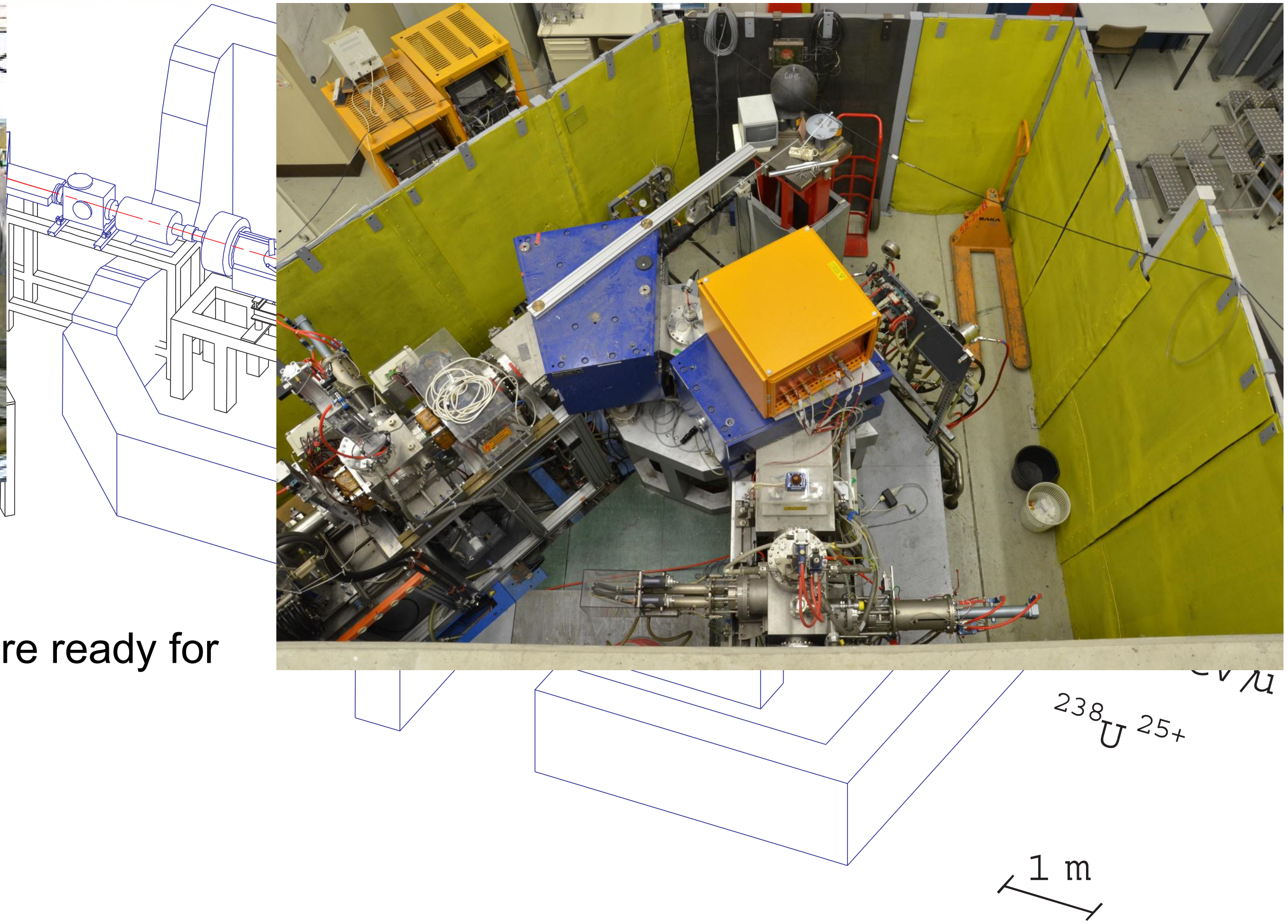


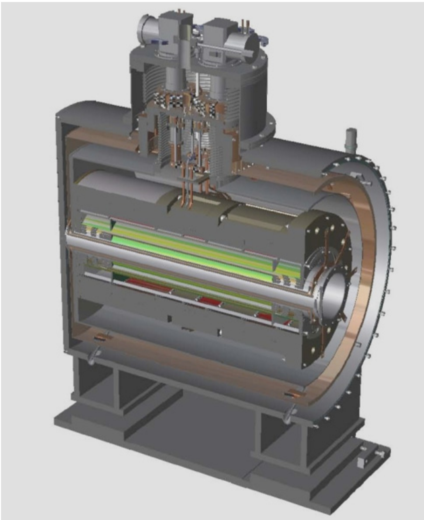


- ECRIS and spectrometer are ready for cw linac operation

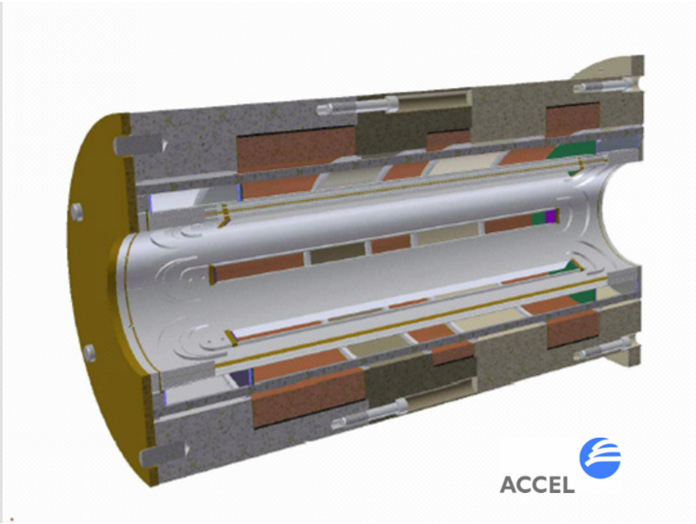
→ Upgrade: MS-ECRIS

CW upgrade: MS-ECRIS project

Cryostat



SC magnet system



CW upgrade: MS-ECRIS project

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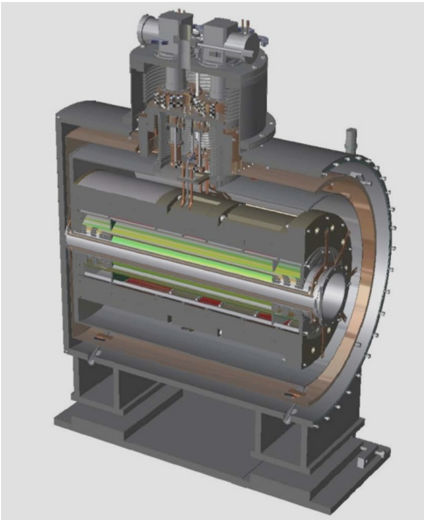

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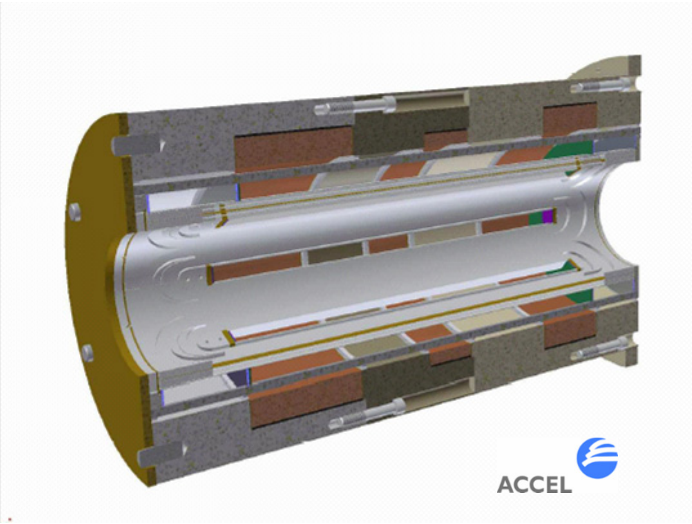


Key features:

- SC magnet system 4.5 T
- 28GHz microwave frequency
- 10x increased beam current
- higher charge states

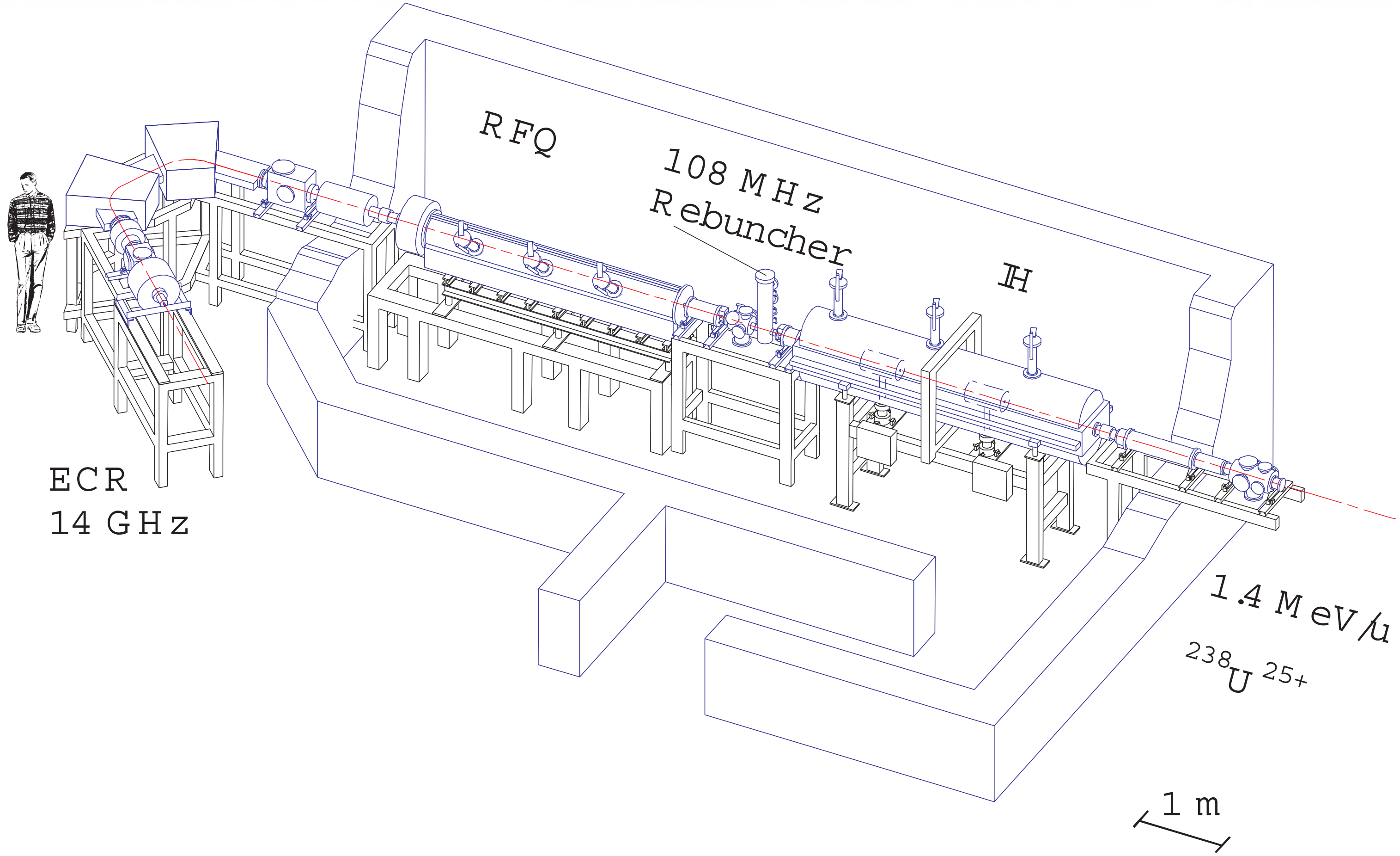
Too ambitious:

- Construction of magnet system failed
- Magnet quench at 50%
- Several attempts, finally stopped

Current status:

- Alternative sources are evaluated

CW upgrade: RF Cavities - RFQ



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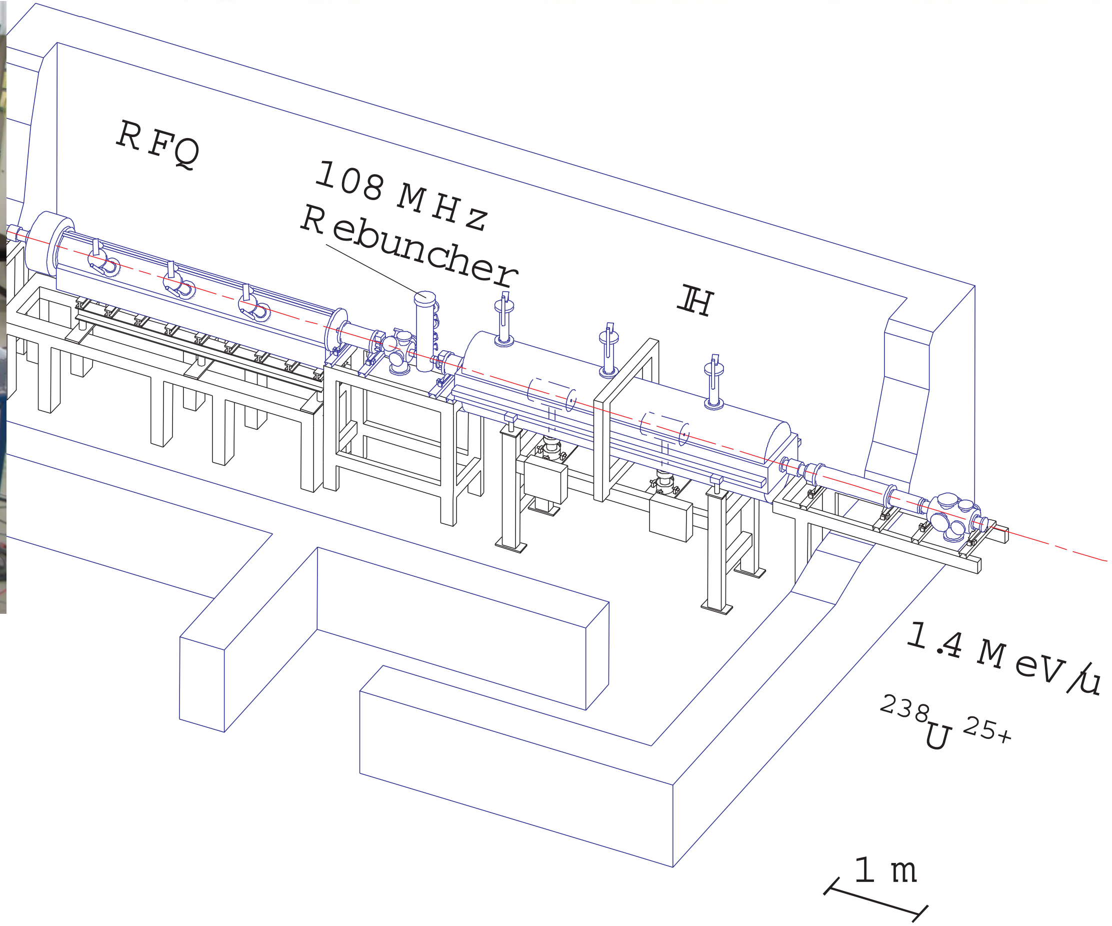

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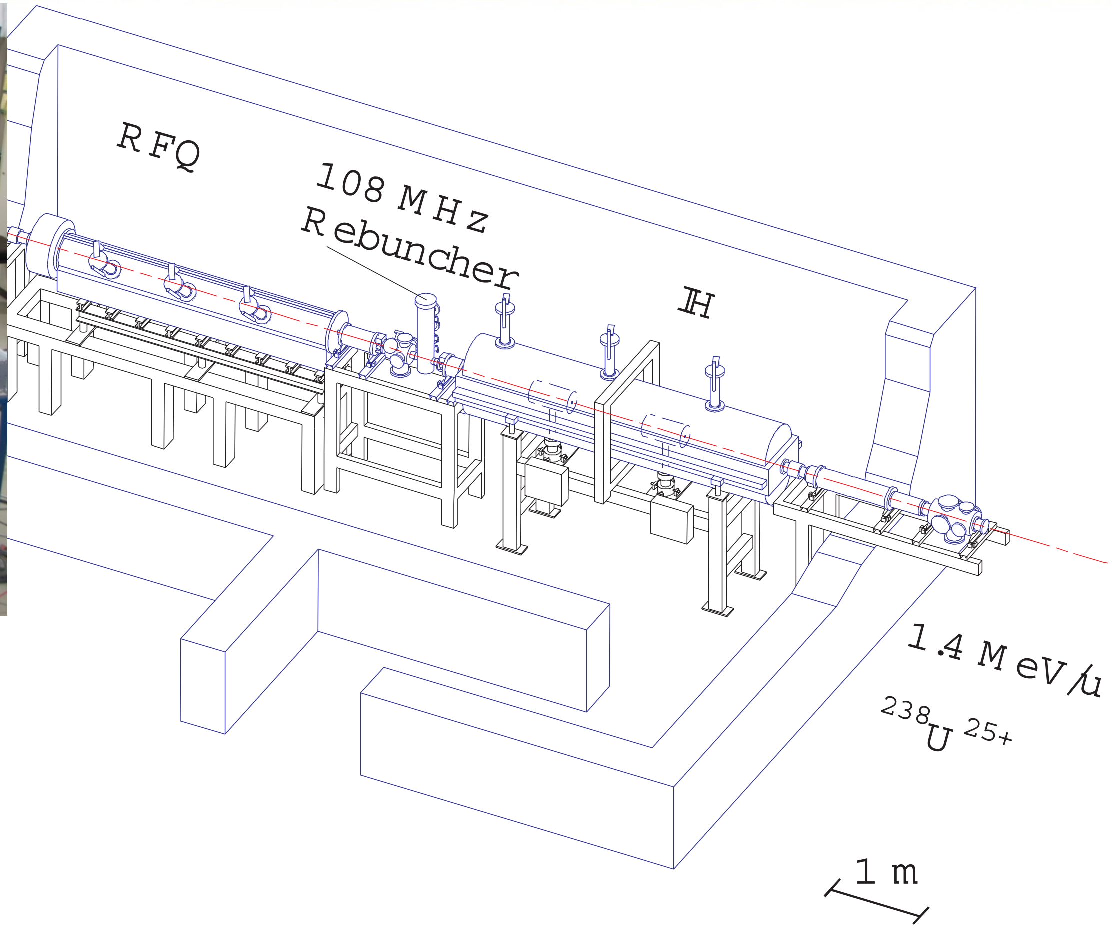
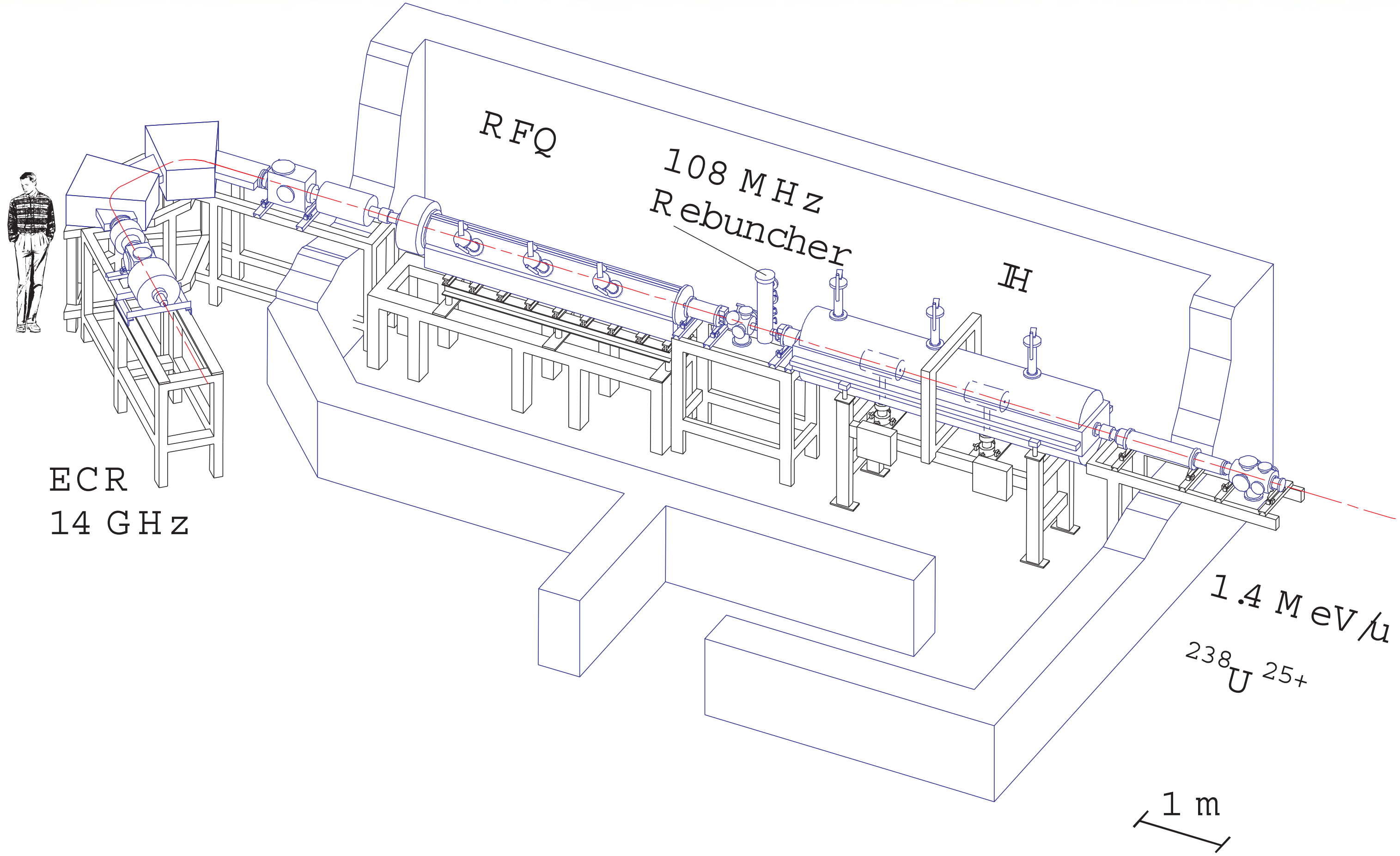


- RFQ: CW operation failed
- New RFQ needed
- Enhanced mechanical stability and better cooling
- Optimized beam dynamics

CW upgrade: RF Cavities - IH



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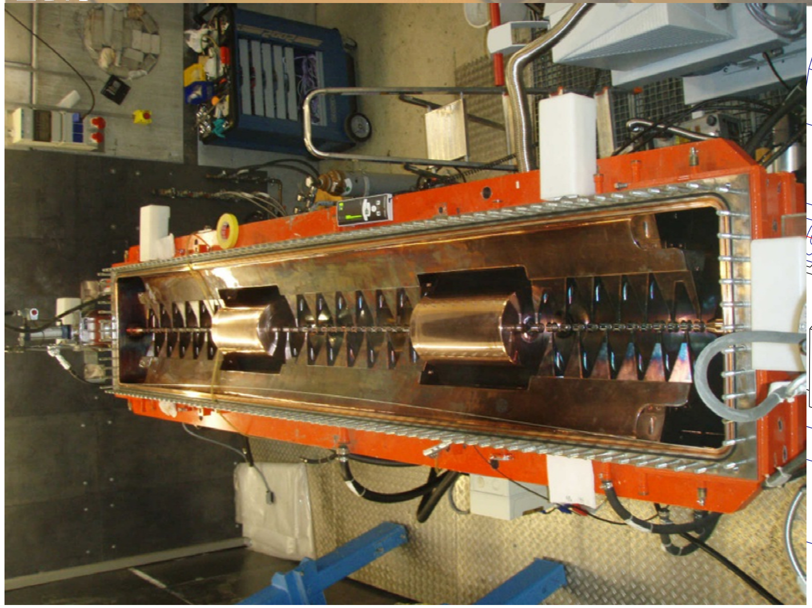

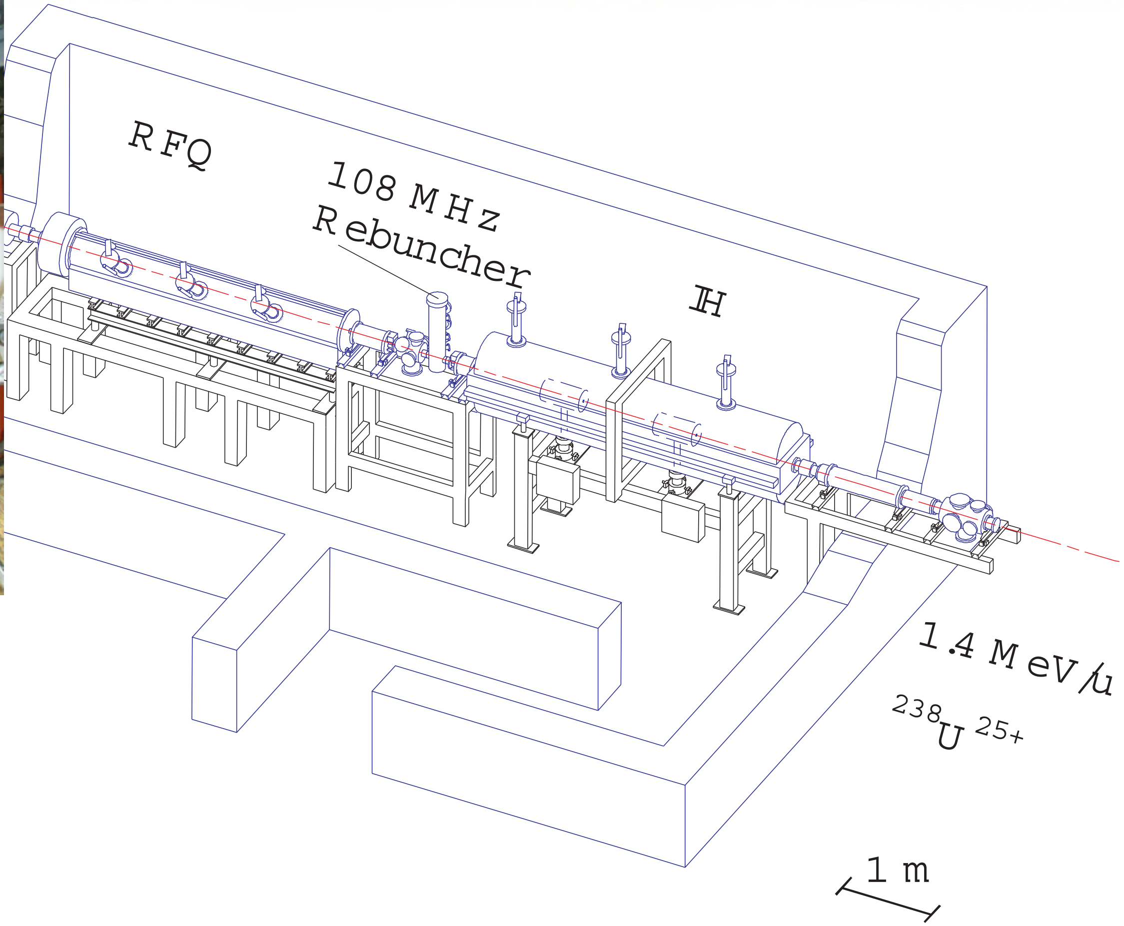

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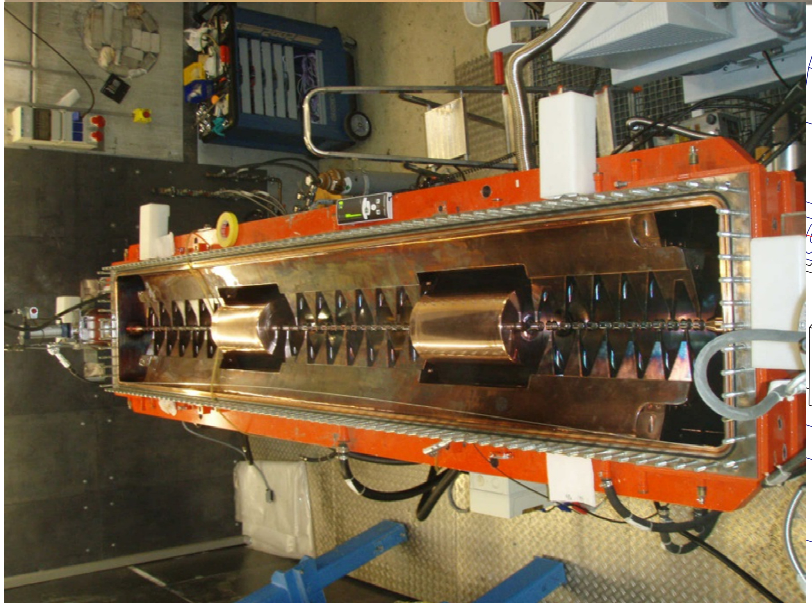
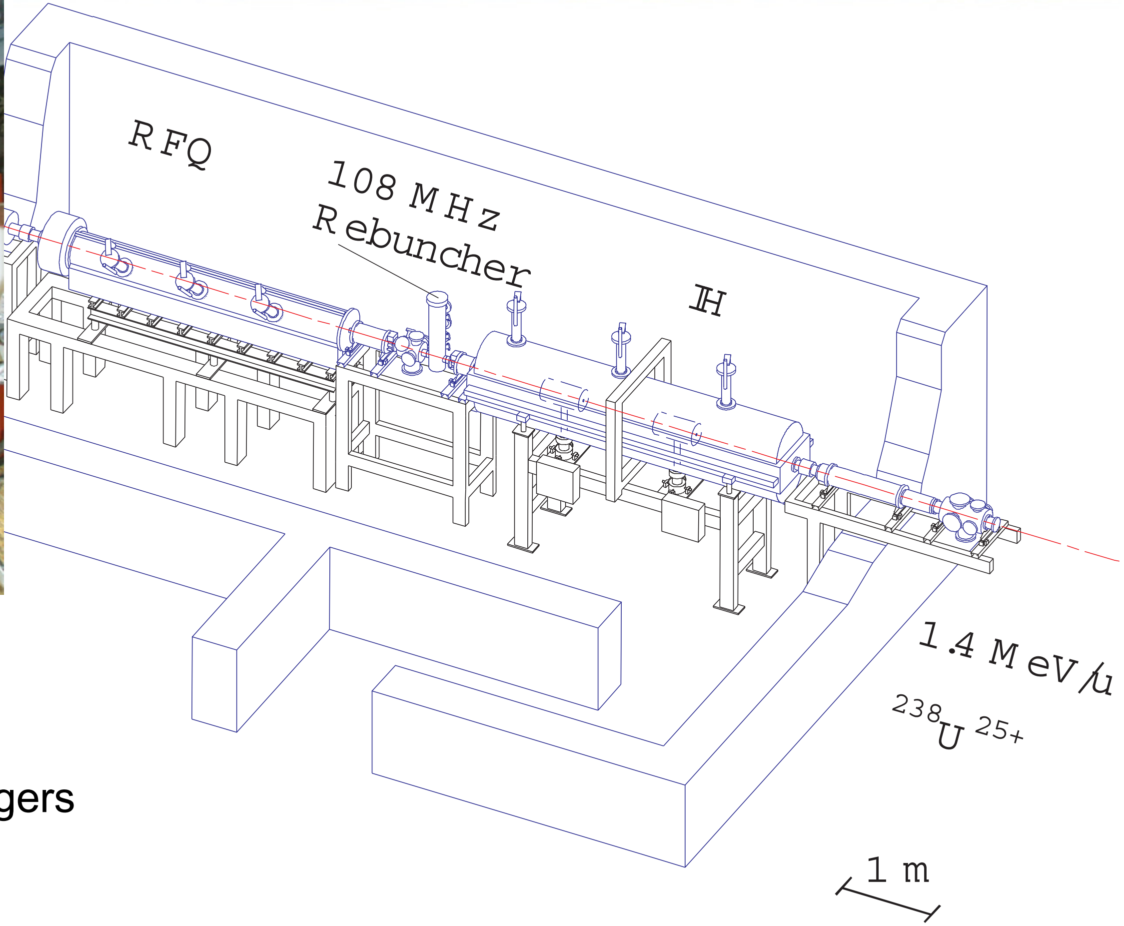
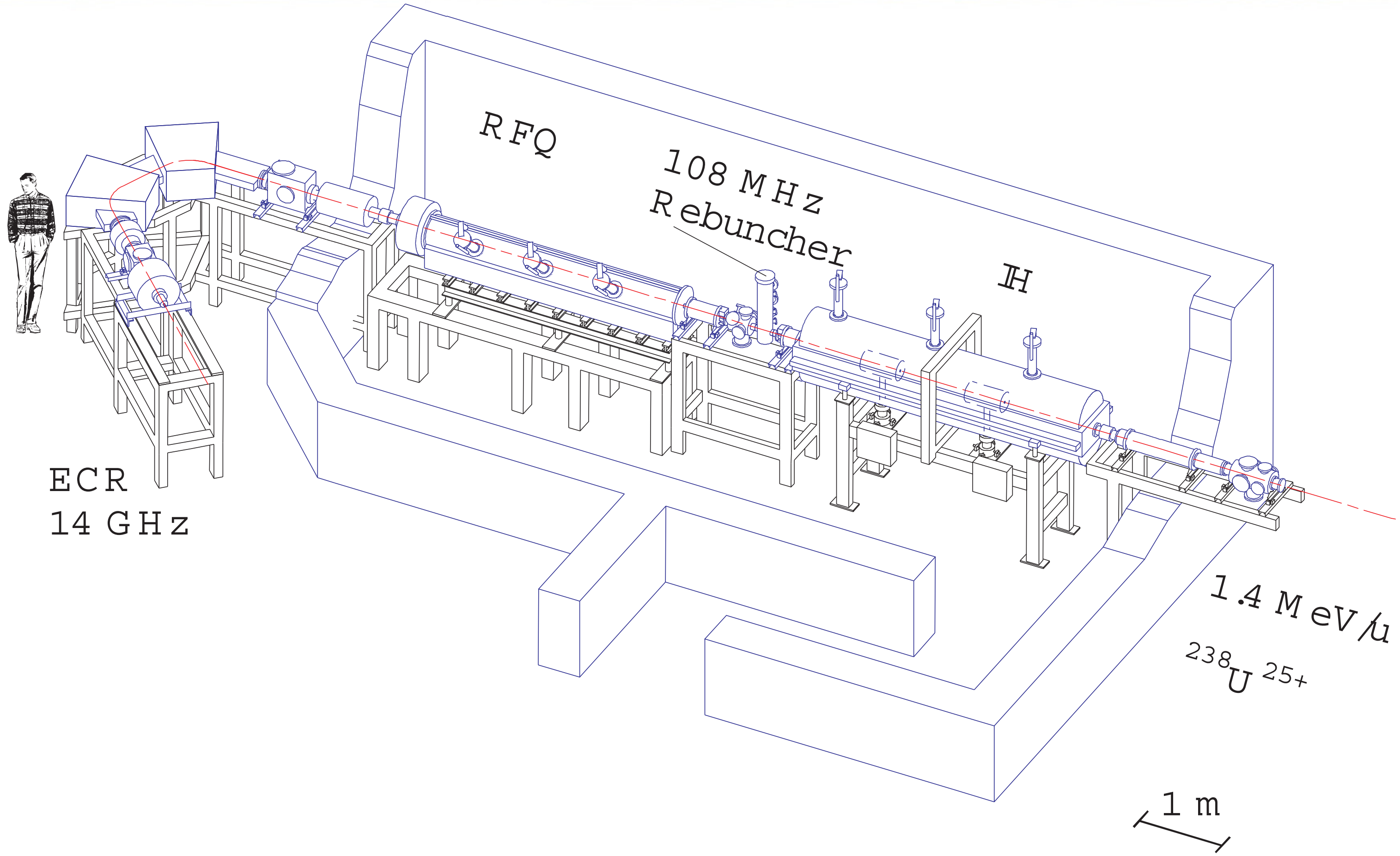




- Running well
- Has problems at high avg. power
- Field distribution critical due to plungers
- Cooling of plungers limited
- New top shell proposed

CW upgrade: RF Cavities - Bunchers



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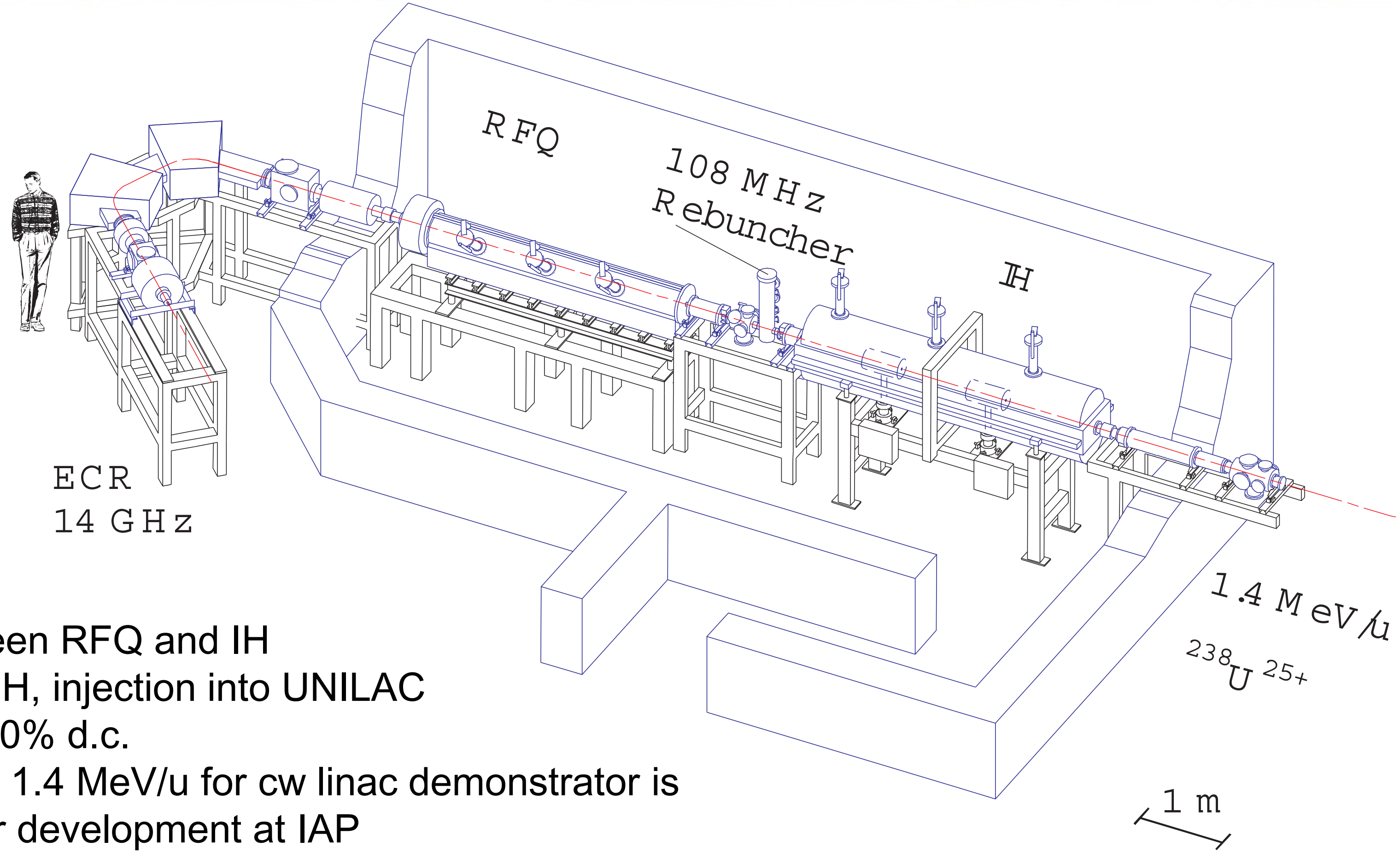

- Buncher between RFQ and IH
- Buncher after IH, injection into UNILAC
- Designed for 50% d.c.
- New design @ 1.4 MeV/u for cw linac demonstrator is currently under development at IAP

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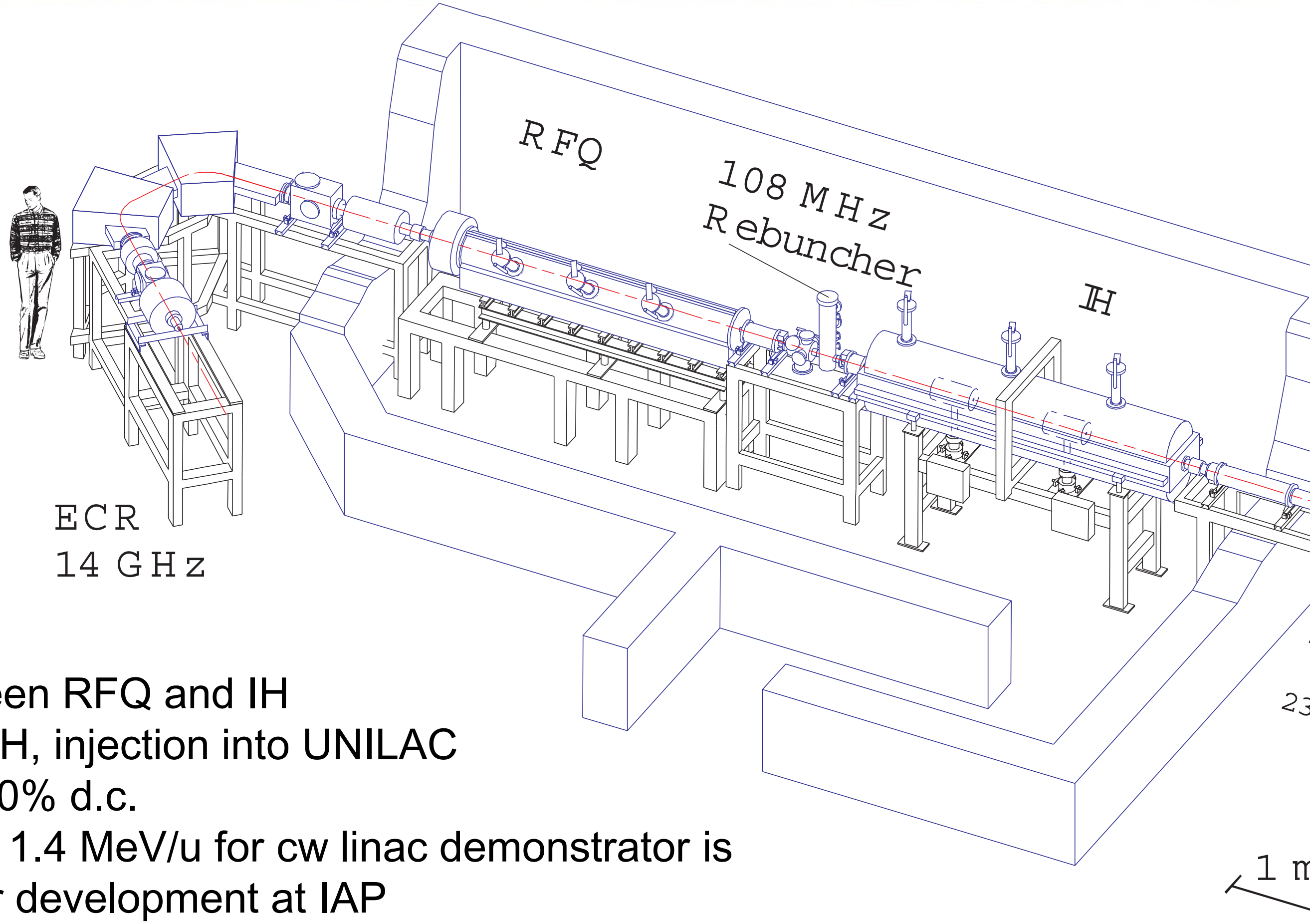

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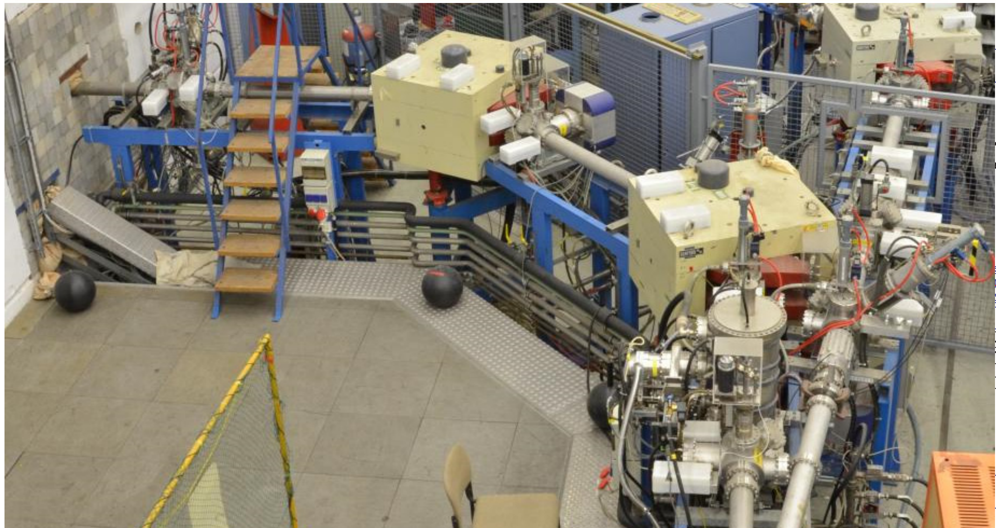

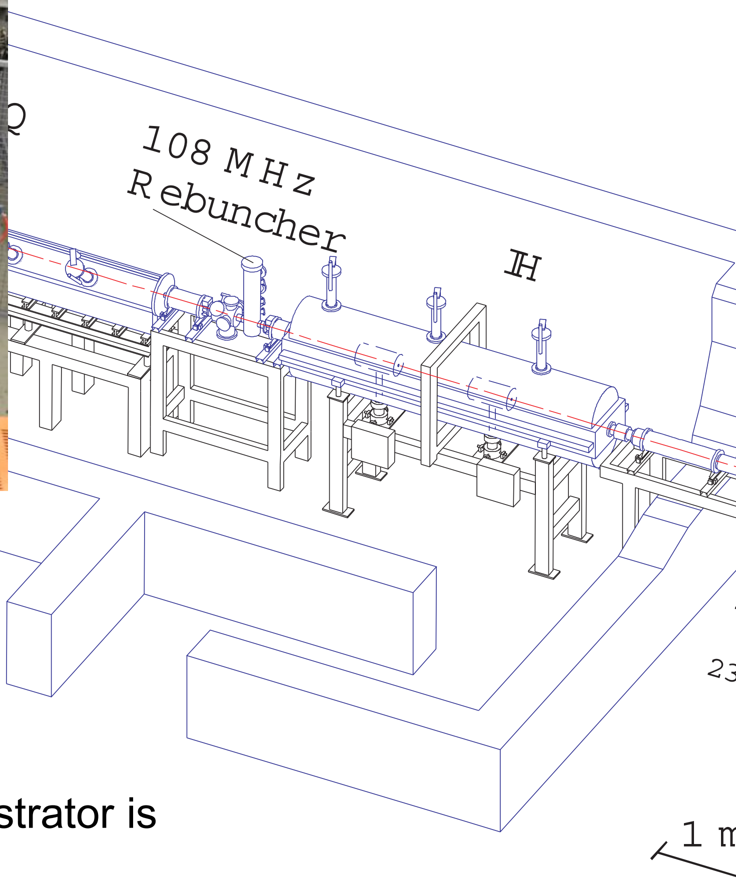

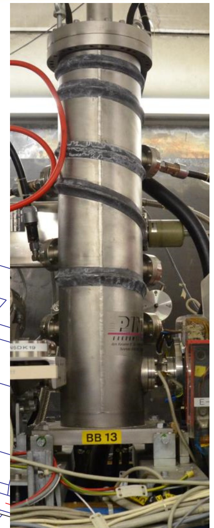

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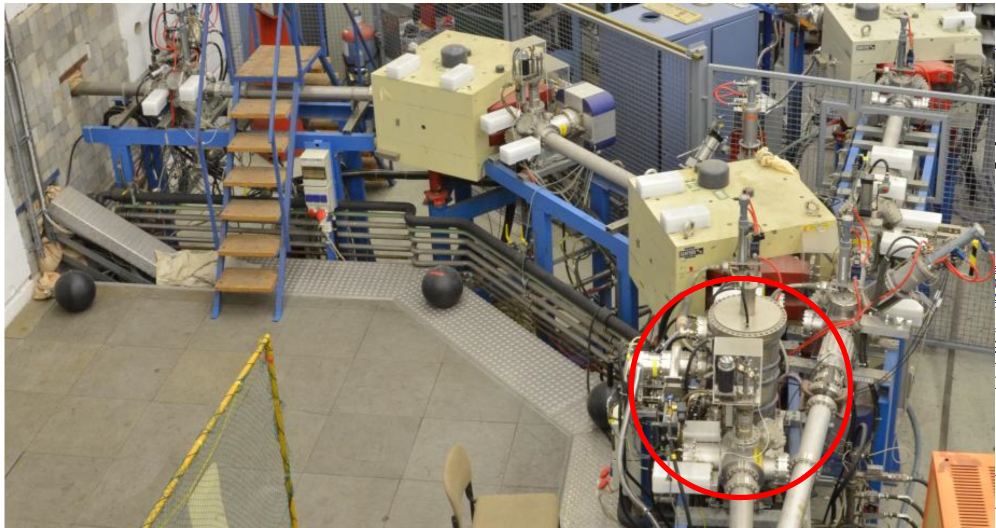

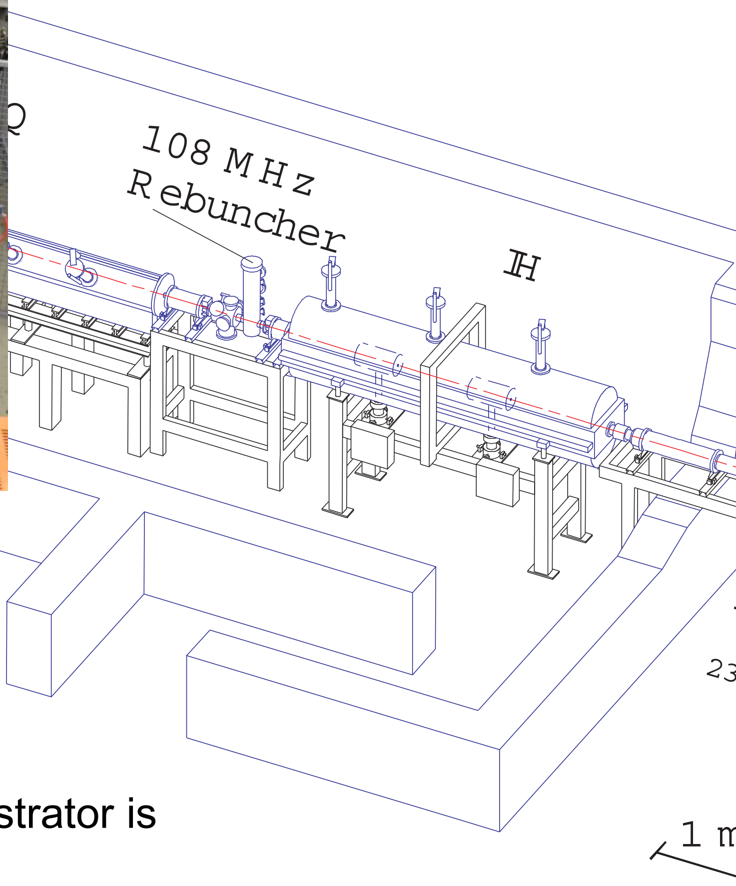

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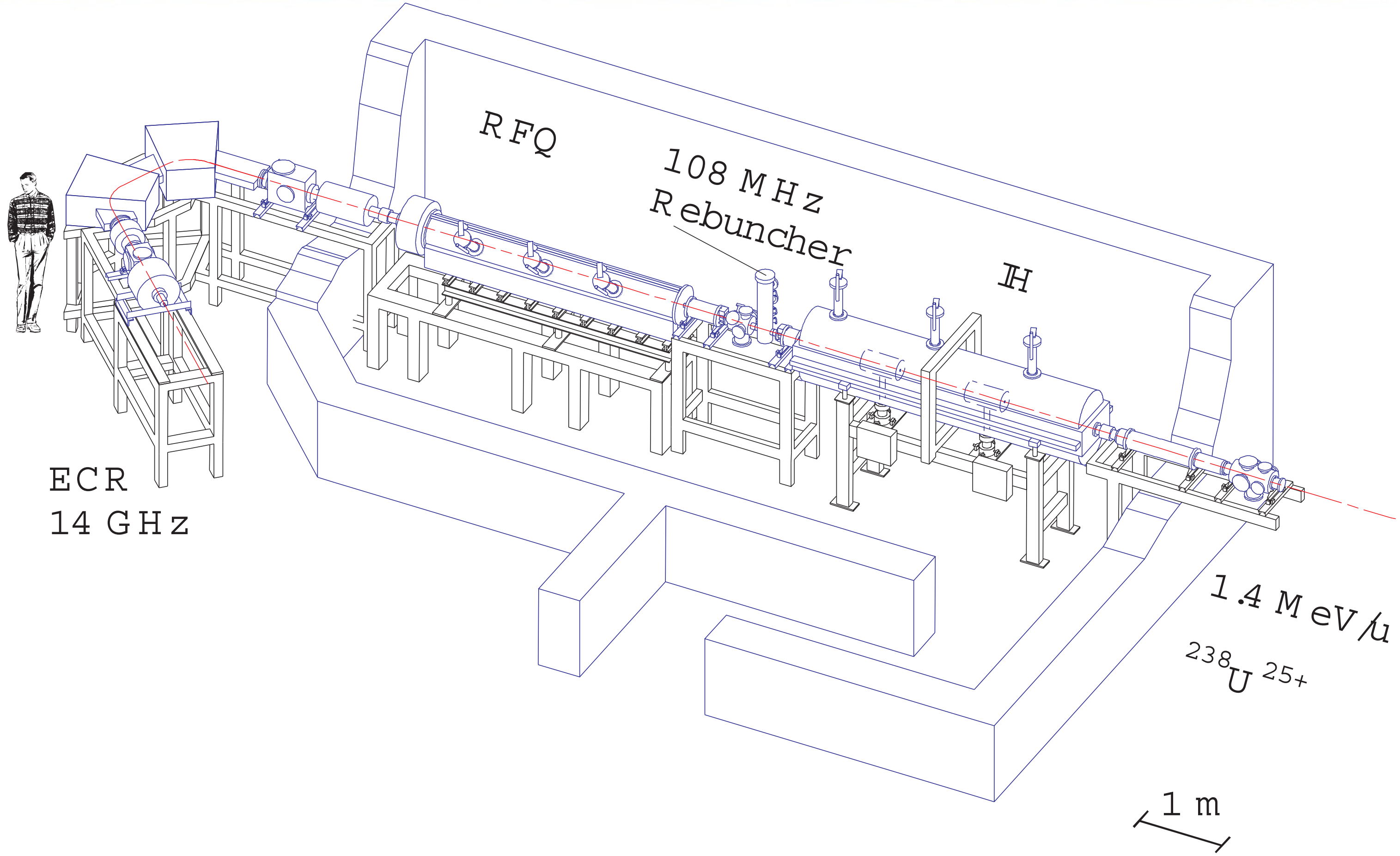
CW upgrade: RF Systems



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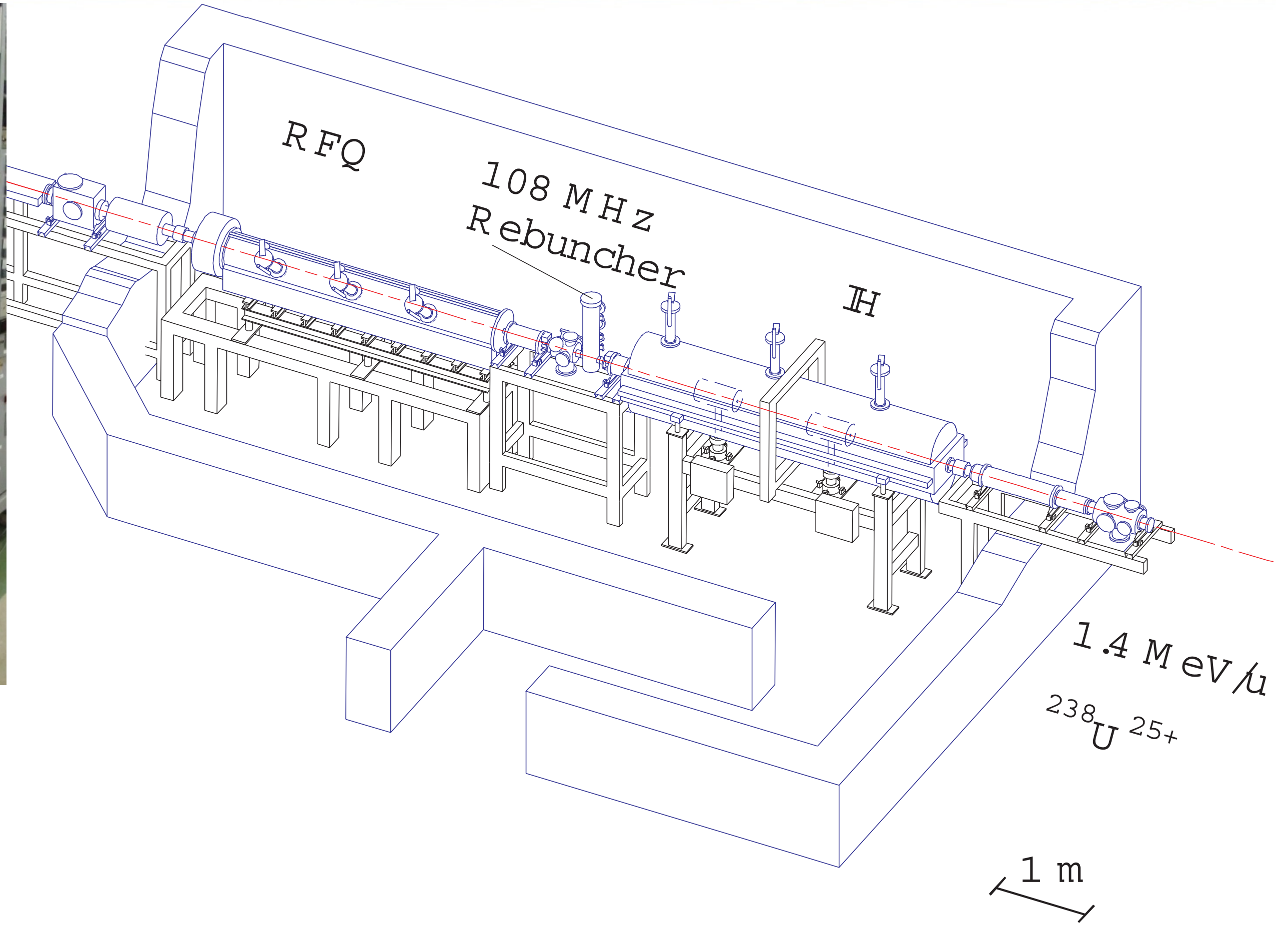

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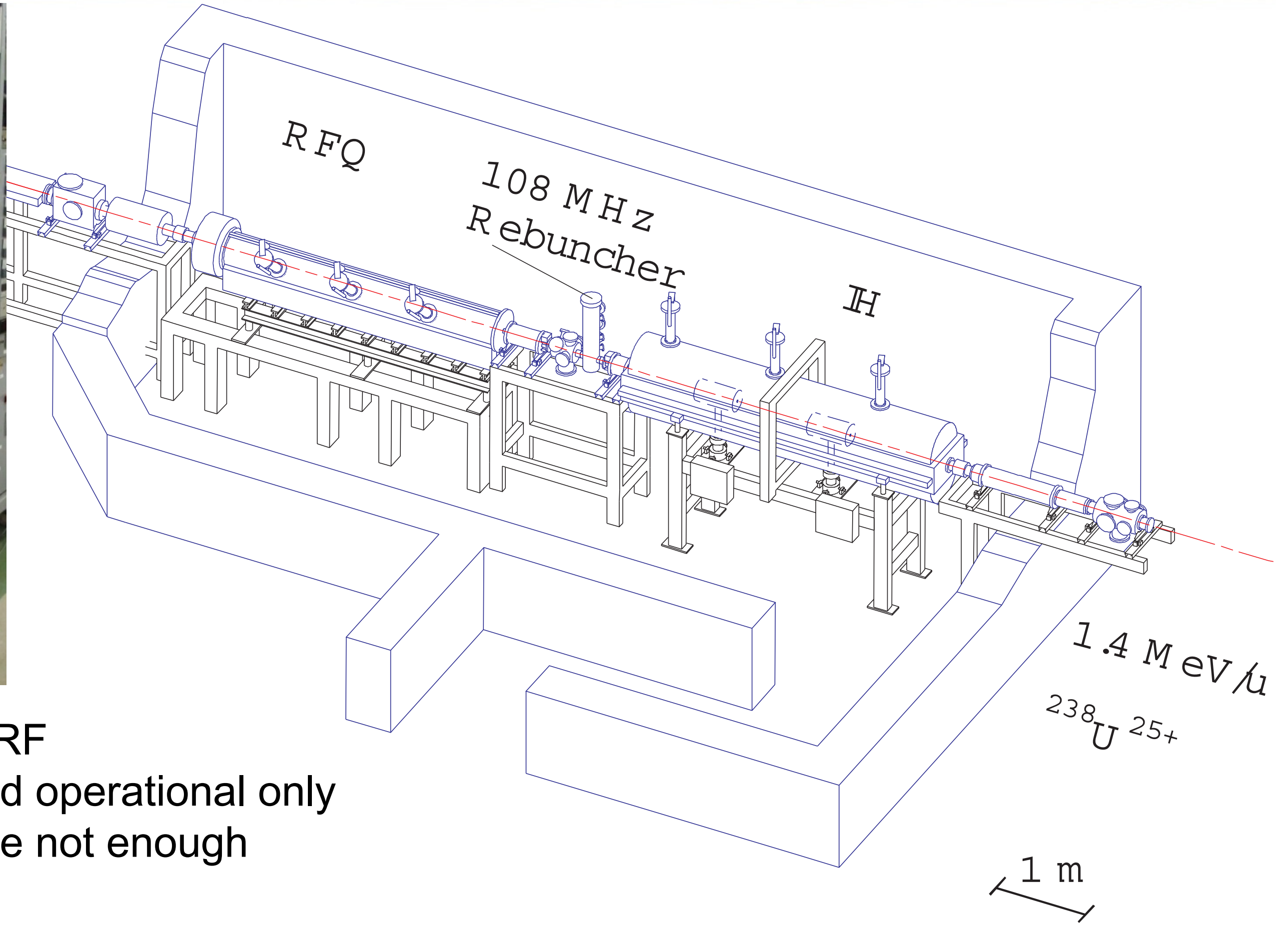

- Old fashioned, tube based RF
- All LLRF systems are pulsed operational only
- All RF power amplifiers have not enough power for cw operation

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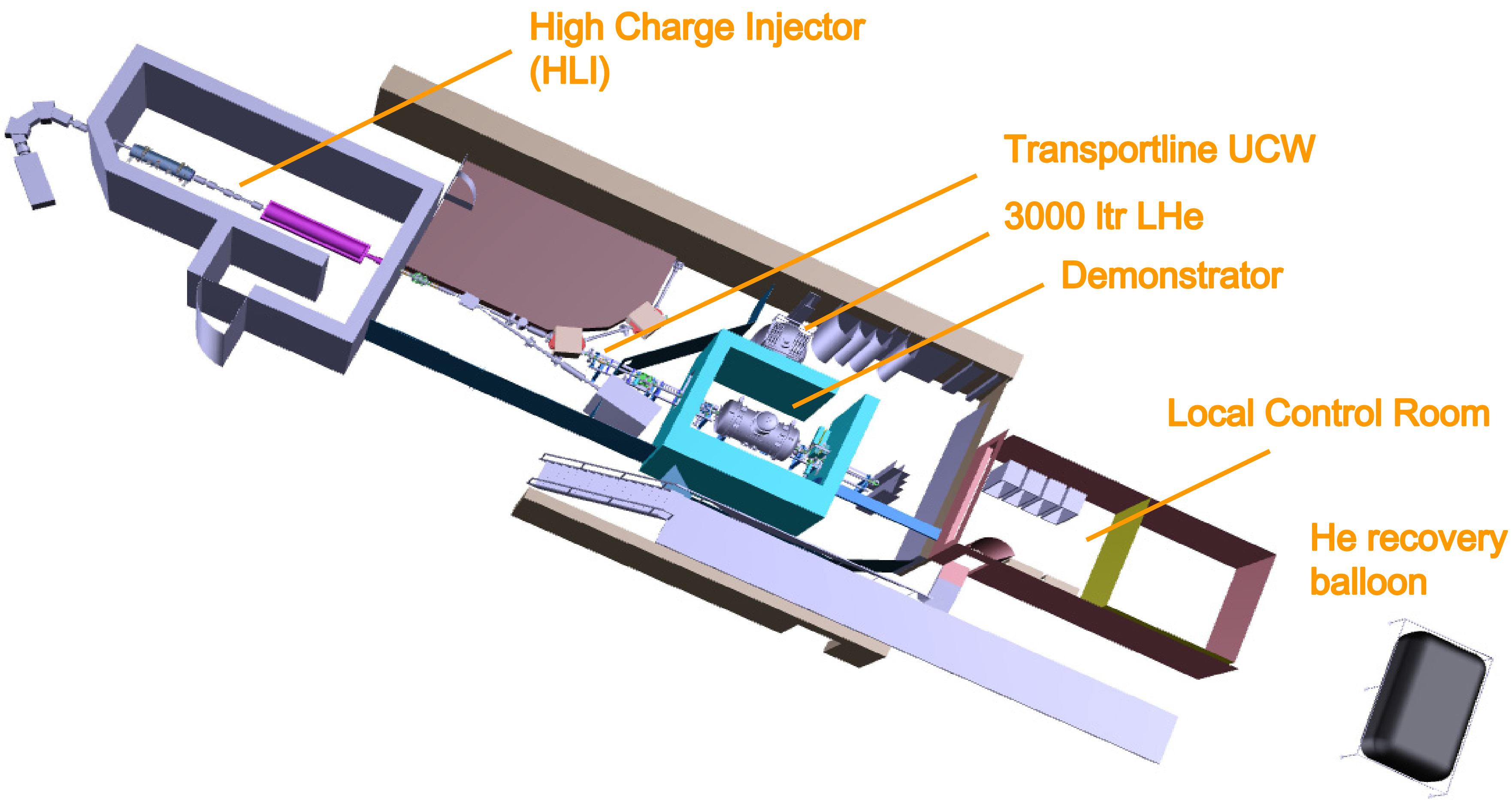
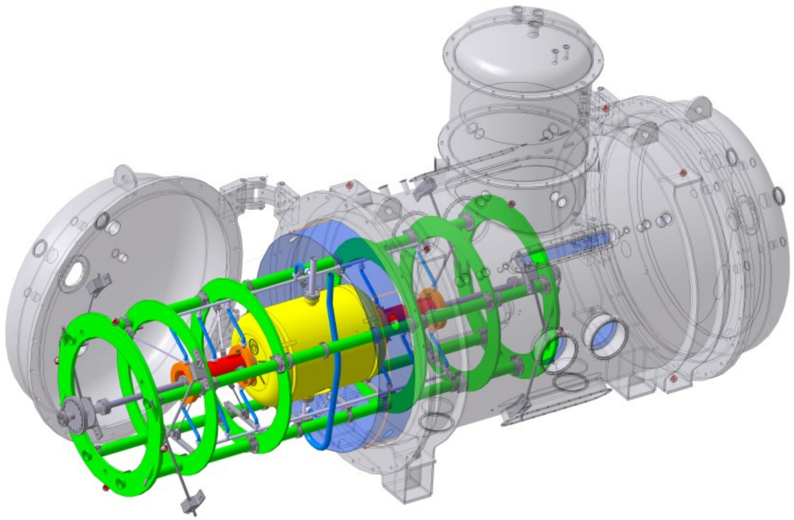
- Perspectives: The future CW Linac

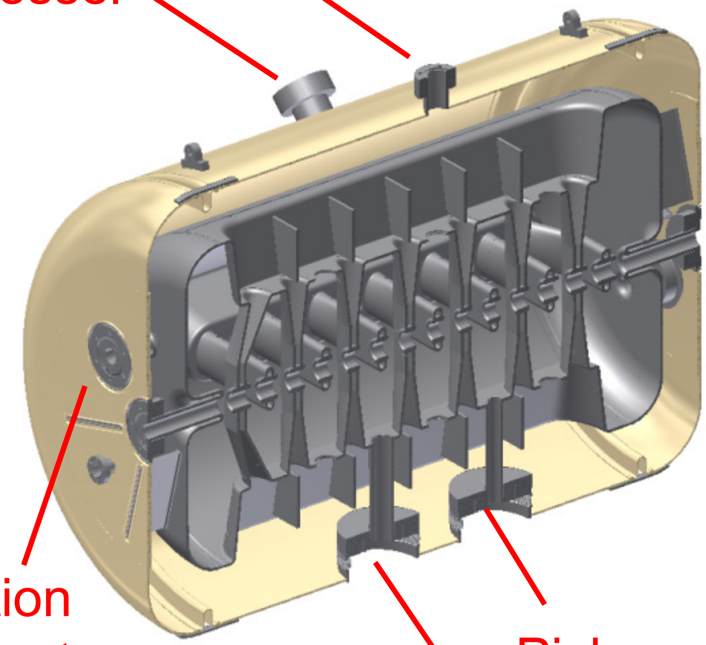
Current Status: The SC CW-Linac Demonstrator



The SC CW-Linac Demonstrator: Cryostat

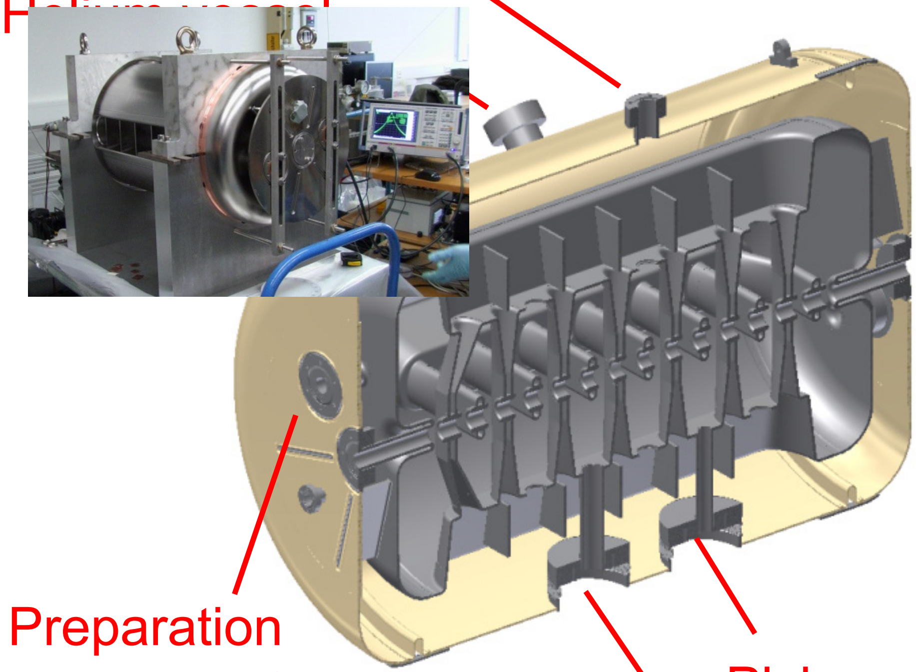
Inner length (mm)	2200
Inner diameter (mm)	1120
Material tank	Al
Isolation vacuum (mbar)	<1*10^-5
Total leak rate (mbar*l/s)	10^-9
Max. operation pressure (bar)	<0,5
Operation temperature (K)	4,4
Temperature nydrogen shield (K)	77
Material magnetic shielding	µ-Metall (2 mm)
Max. static losses in stand-by operation (W)	<10
Cold-warm-transition (beam-pipe) - gradient (K/cm)	10





Parameter	Unit	
Beta		0.059
Frequency	MHz	216.816
Gap number		15
Total length	mm	687
Cavity diameter	mm	409
Cell length	mm	40.82
Aperture	mm	20
Energy gain	MeV	2.97
Accelerating gradient	MV/ m	5.1
Static tuner		9
Dynamic bellow tuner		3

The SC CW-Linac Demonstrator: SC CH-Cavity



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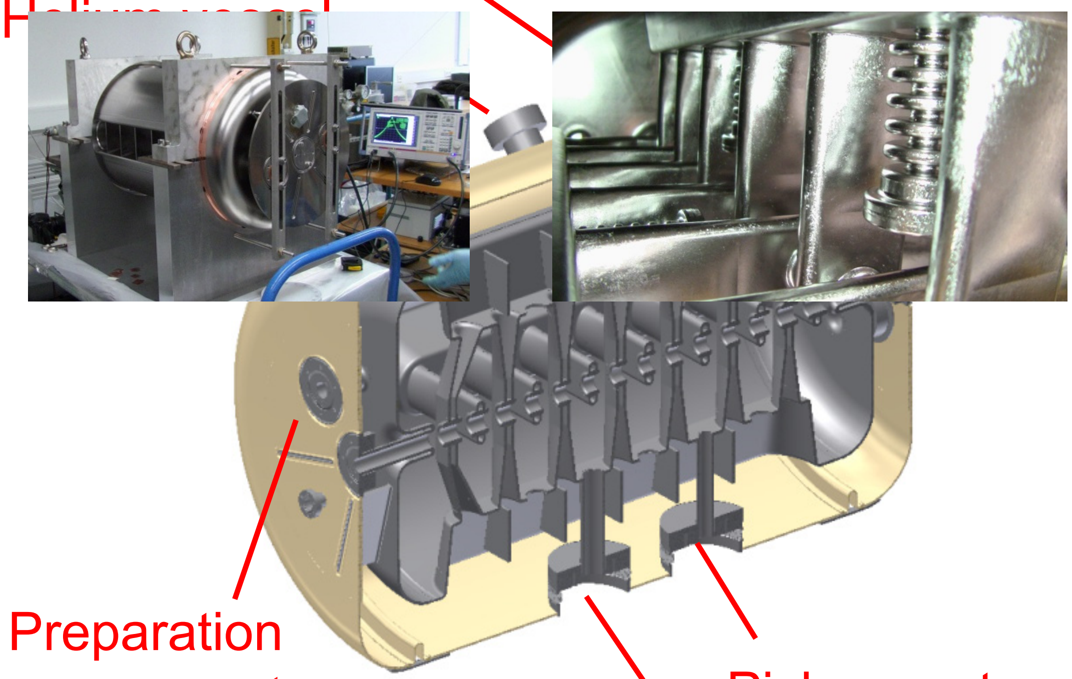

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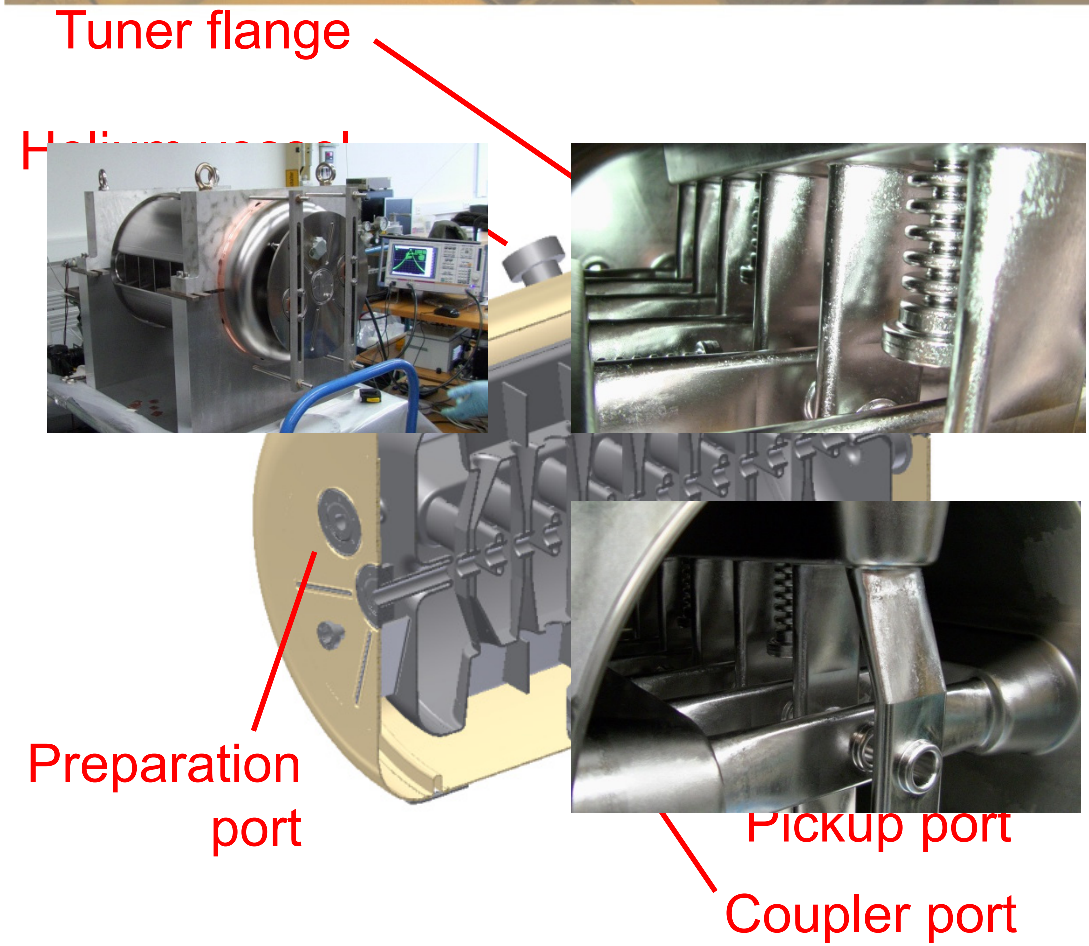

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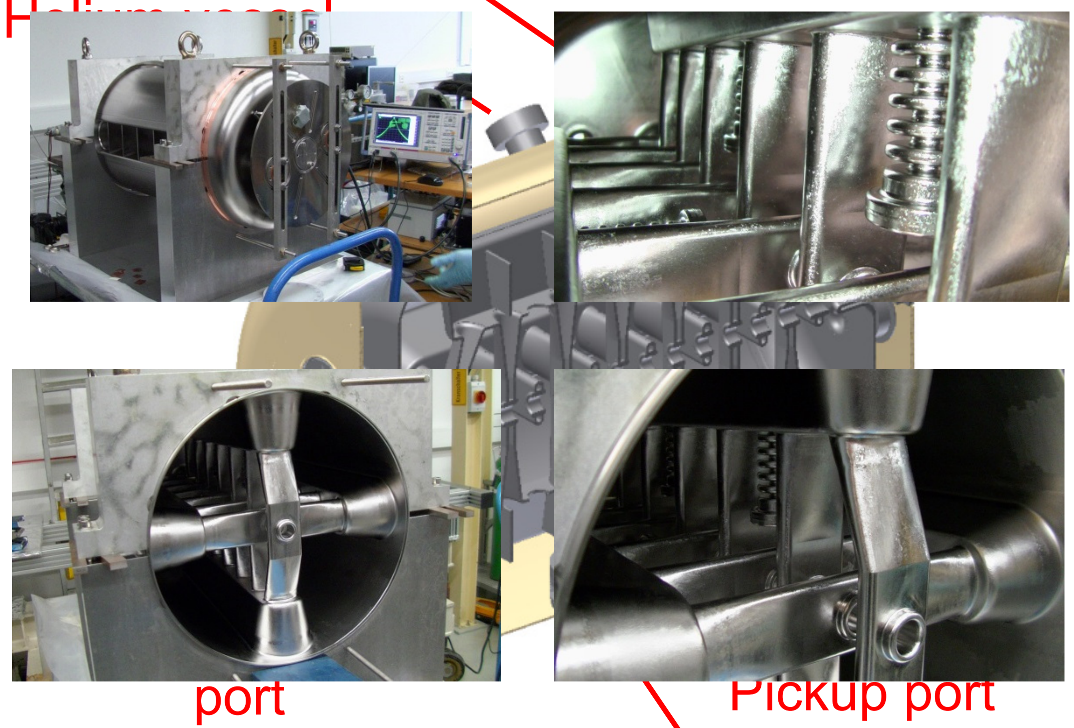

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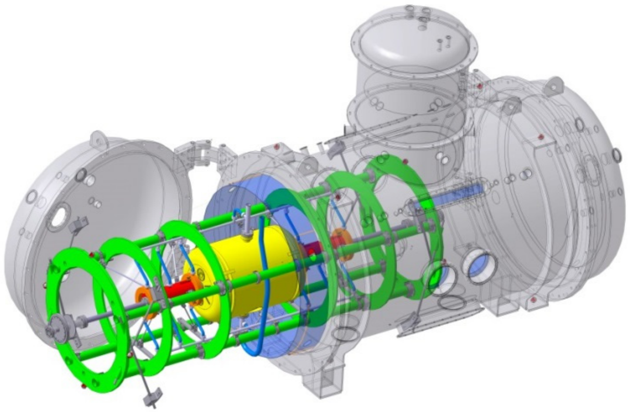
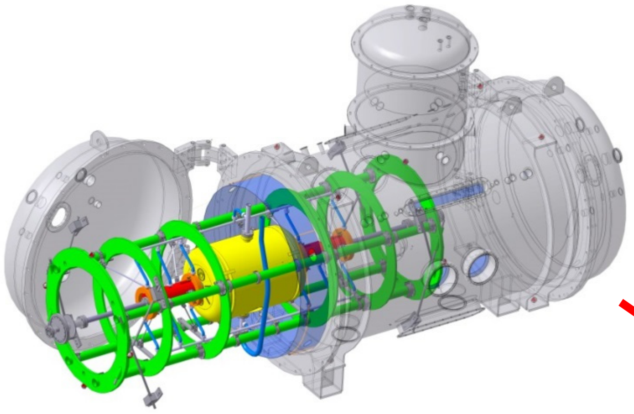
The SC CW-Linac: Integration at GSI UNILAC





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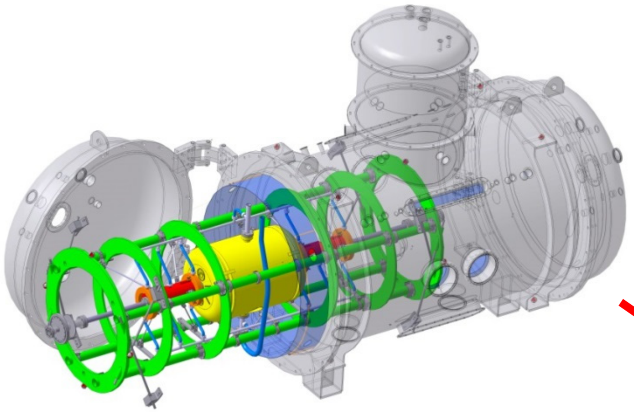

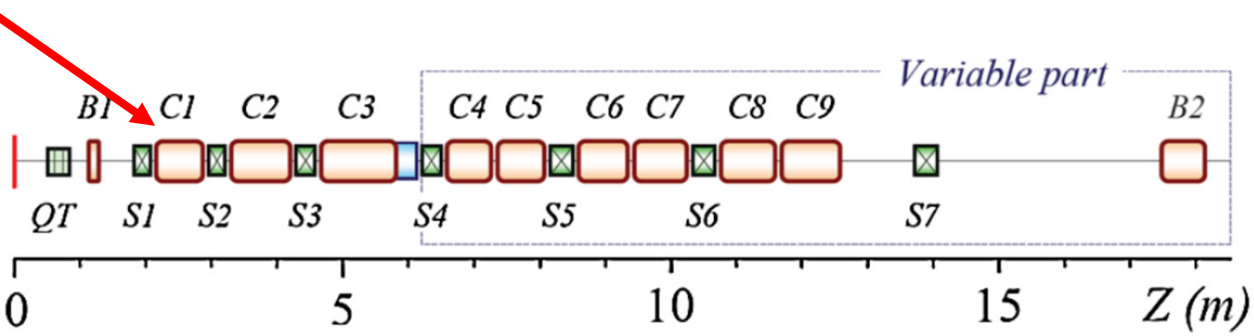

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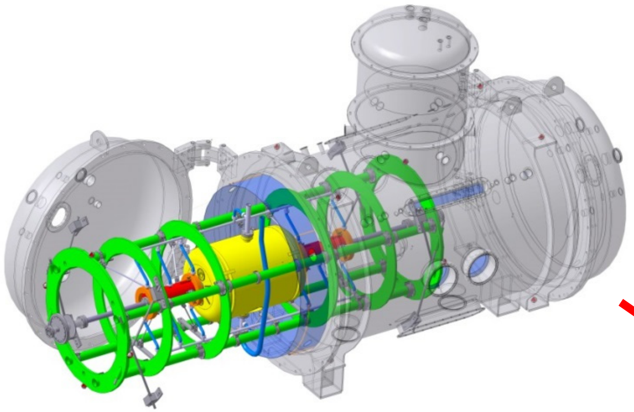

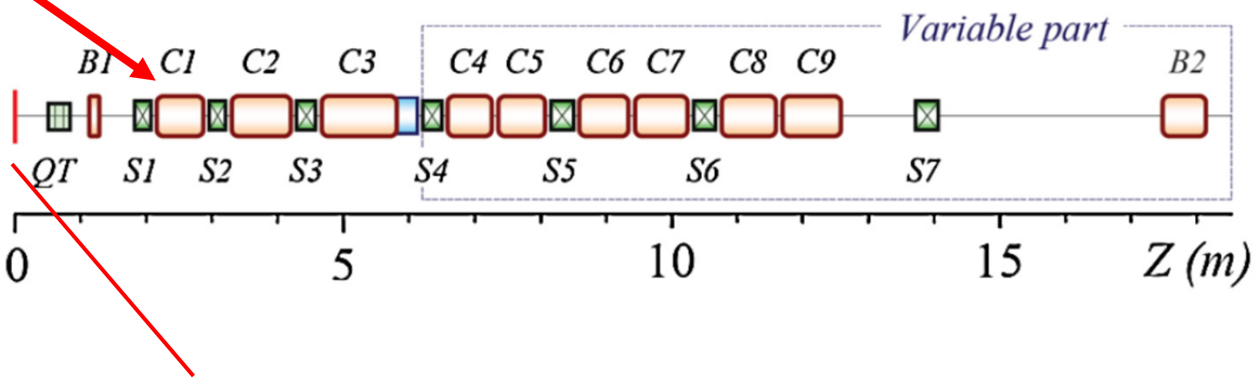

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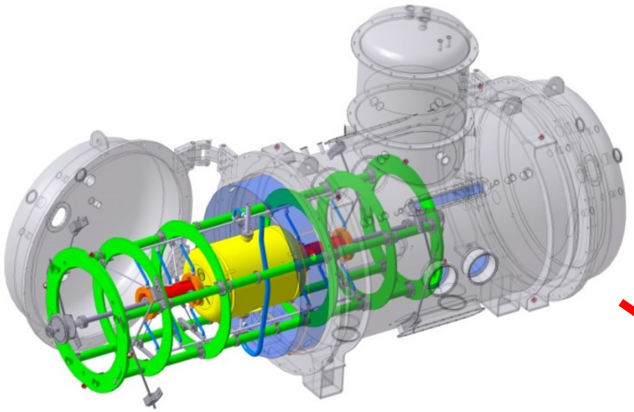

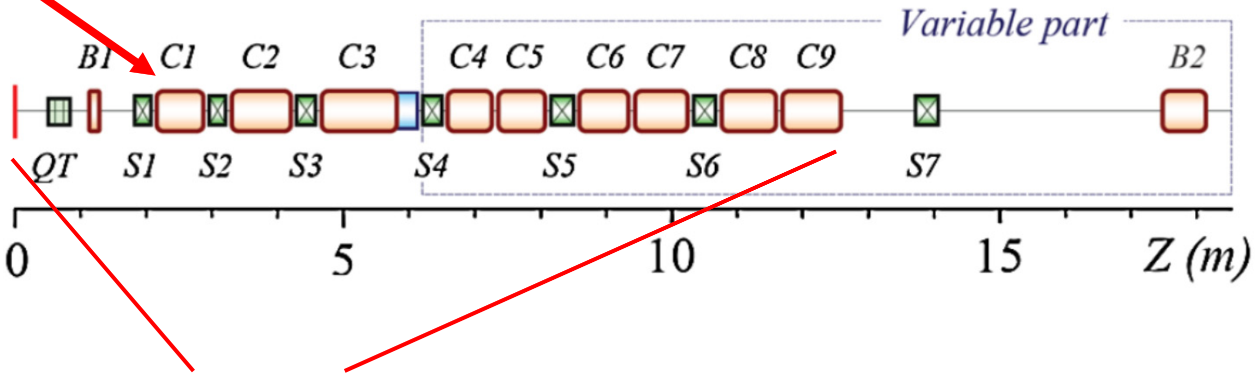

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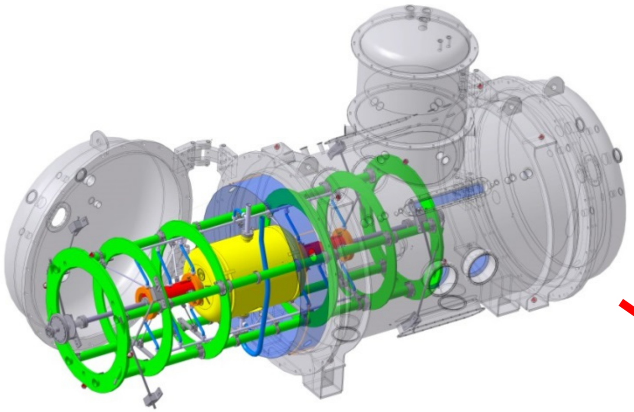

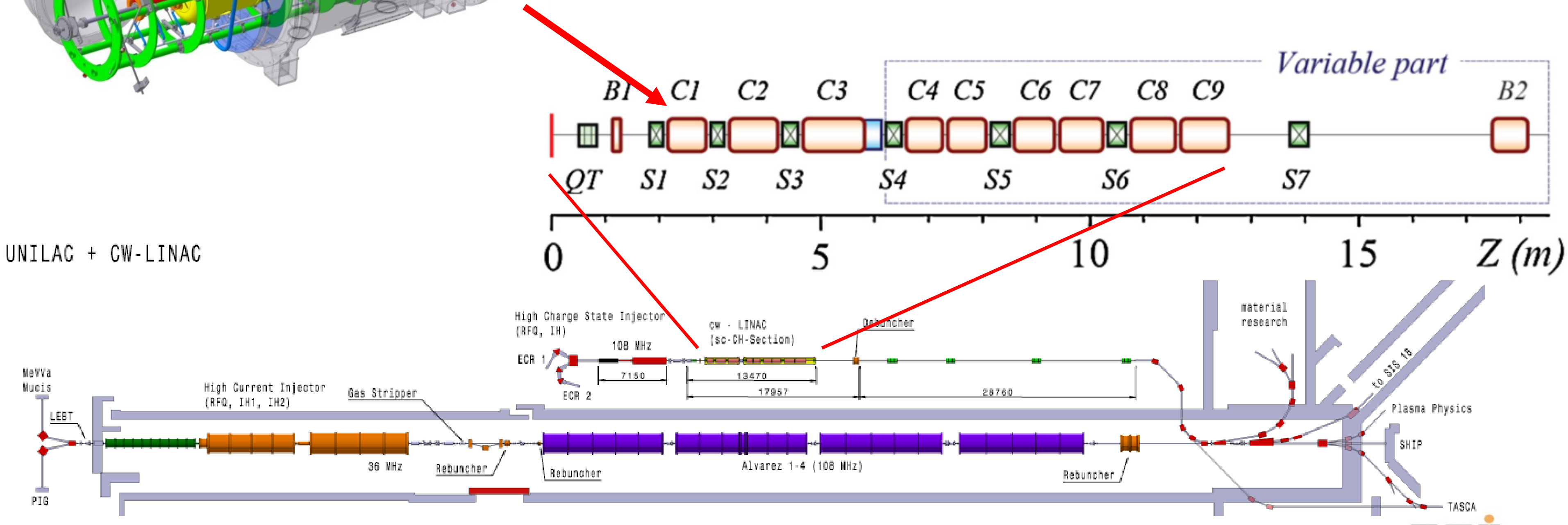

Summary

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- HLI is operational for limited, pulsed operation
- Ion source upgrade: MS-ECRIS is canceled, existing source can be used
- Magnets and power converters can be kept
- Upgrade measures for rf cavities are defined, but on hold
- Upgrade of LLRF and RF power amplifiers are defined, but on hold
- Upgrade of beam diagnostics and control system required,
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→ **CW linac demonstrator is key project:**
Demonstration of availability of SC CH-cavity technology is essential

→ Further CW upgrade actions will start only after successful demonstration

→ Integration of CW linac at GSI is subject to change

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Thank you!