# Status of the cw-LINAC-project

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[3] Johannes Gutenberg-Universität Mainz, Mainz, Germany

1. Introduction
2. General Linac layout
3. RF-cavity development
4. R&D activities
5. First heavy ion beam acceleration
6. cw-Linac status
7. Outlook

# Introduction
# GSI UNIversal Linear ACcelerator

HELIAC GSI DARMSTADT

GSI HIM HELMHOLTZ Helmholtz Institute Mainz

## High Charge State Injector (1991)




## High Current Injector (1999)

## Alvarez (1975)

## Single Gap Resonators (1975)

# cw-Linac@GSI/Motivation

**FAIR:**

- high beam currents
- low repetition rate (max. 3 Hz)
- low duty factor (0.1 %, pulse length for SIS18 only 100 µs)

**“Super Heavy Element”:**

- relatively low beam currents
- high repetition rate (50 Hz)
- high duty factor (100 %, pulse length up to 20 ms)

**“Material Science”:**

- Heavy Ions (m ≥ 200)
- High Beam Energy (up to 10 MeV/u)
- high repetition rate (50 Hz)
- Continuous Beam Energy Variation (1.5 – 10 MeV/u)

# Poststripper Rf-upgrade for FAIR

**FAIR:**

- high beam currents
- low repetition rate (max. 3 Hz)
- low duty factor (0.1 %, pulse length for SIS18 only 100 µs)

~~**"Super Heavy Element":**~~

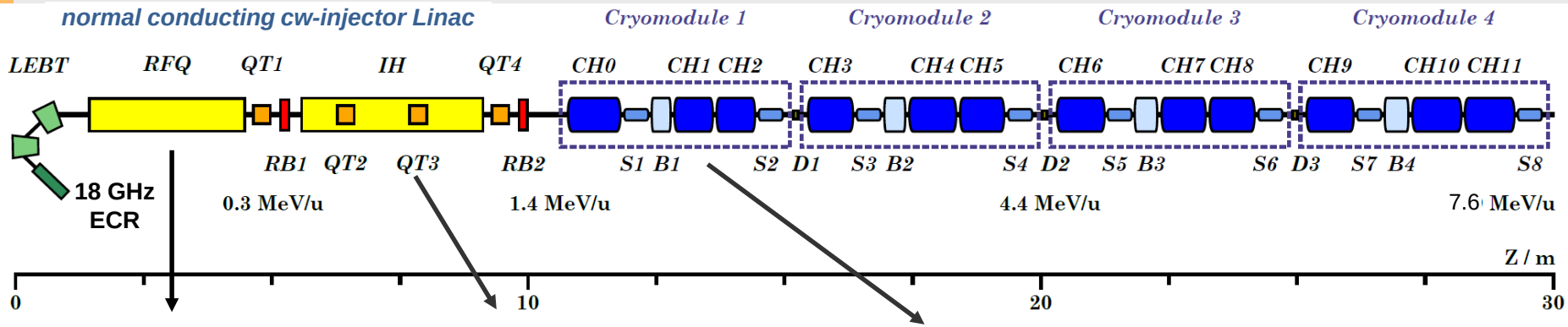
- relatively low beam currents
- ~~high repetition rate (50 Hz)~~
- ~~high duty factor (100 %, pulse length up to 20 ms)~~

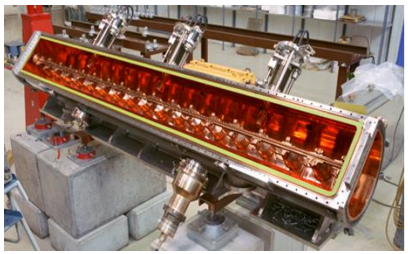
~~**"Material Science":**~~

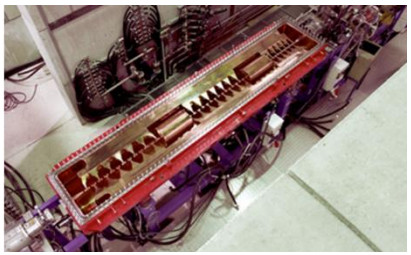
- Heavy Ions ($m \geq 200$)
- High Beam Energy (up to 10 MeV/u)
- ~~high repetition rate (50 Hz)~~
- ~~Continuous Beam Energy Variation (1.5 – 10 MeV/u)~~

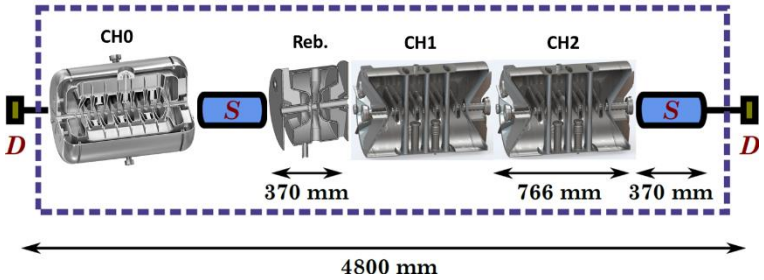
# Layout of the future superconducting cw HELIAC*

* HElmholz LInear ACcelerator








| Design parameters sc cw-LINAC | | |
|---|---|---|
| $A/q$ | | $\leq 6$ |
| Frequency | MHz | 216.816 |
| Beam current | mA | $\leq 1$ |
| Injection energy | MeV/u | 1.4 |
| Output energy | MeV/u | 3.5-7.6 |
| Length | m | 20 |
| CH cavities | # | 12 |
| Rebuncher | # | 4 |
| Solenoids | # | 8 |

**Layout properties**

- Short multigap CH cavities: length <1 m), transverse dimensions <0.5 m
- Modular construction: 4 cryomodules each with 3 CH, 1 buncher, 2 solenoids
- Compact Linac design ($E_a \geq 7.1$ MV/m)

**Maximum energy per CM**

| Cryo Module | Output energy (MeV/u | | | |
|---|---|---|---|---|
| | A/Z=8.5 | A/Z=6 | A/Z=3 | A/Z=1 |
| CM1 | 2.6 | 2.9 | 3.6 | 4.6 |
| CM2 | 3.5 | 4.2 | 5.5 | 7.7 |
| CM3 | 4.5 | 5.8 | 7.8 | 10.9 |
| CM4 | 5.55 | 7.6 | 10.5 | 14.6 |
| CM4 + CH12 | 6 | 8 | 11.4 | 15.6 |

# H-type Cavity developments

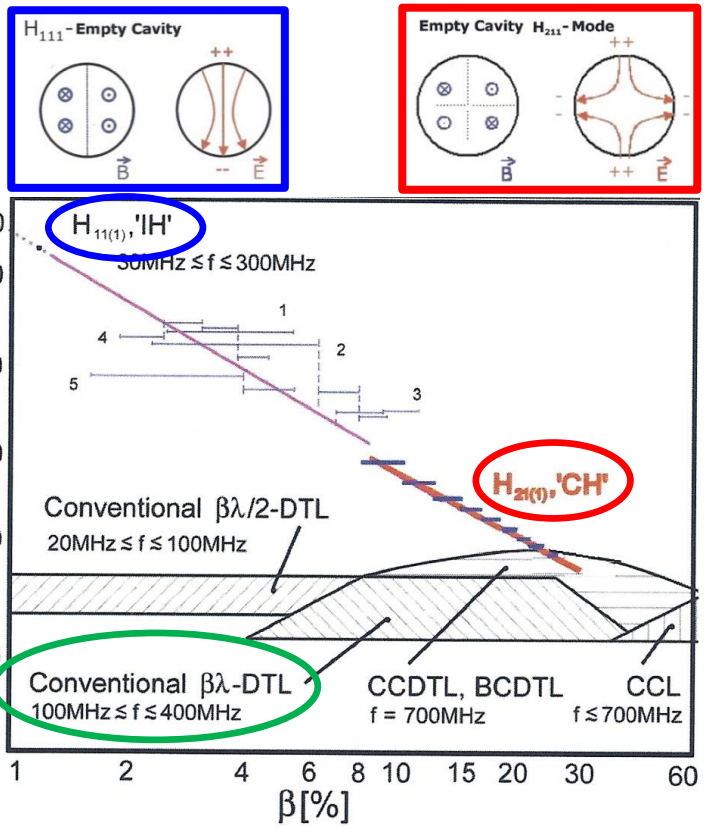
HELIAC GSI DARMSTADT

GSI HIM HELMHOLTZ Helmholtz Institute Mainz

HSI 36 MHz@gsi

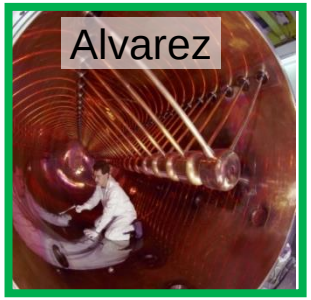
HLI 108 MHz@gsi

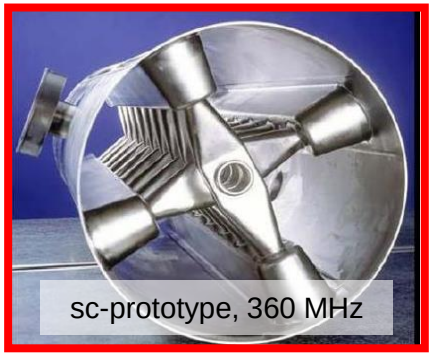
IH 216 MHz@HIT/Heidelberg




Wideröe

Alvarez

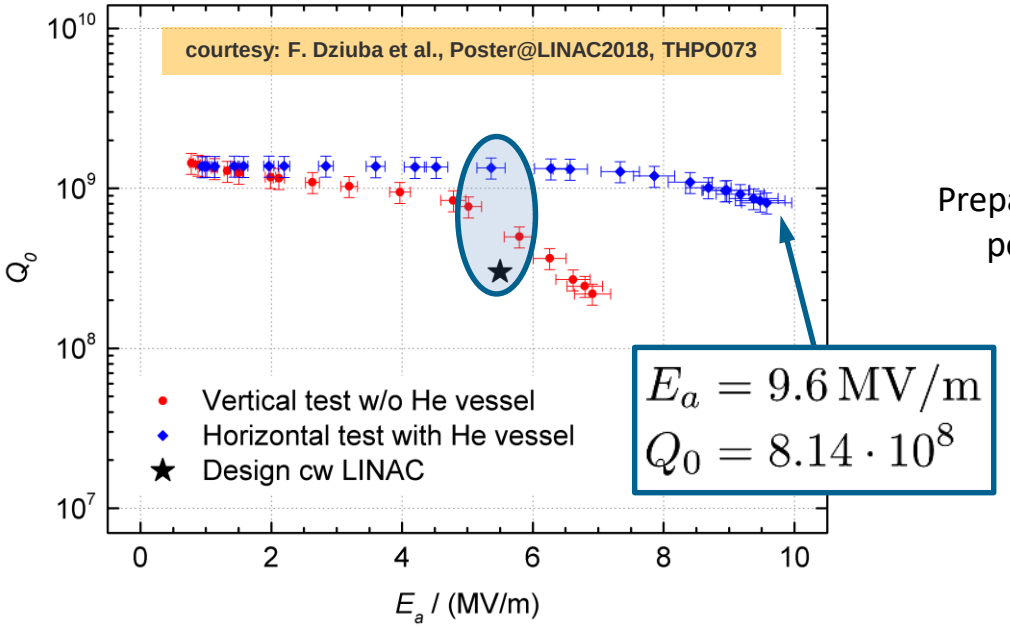


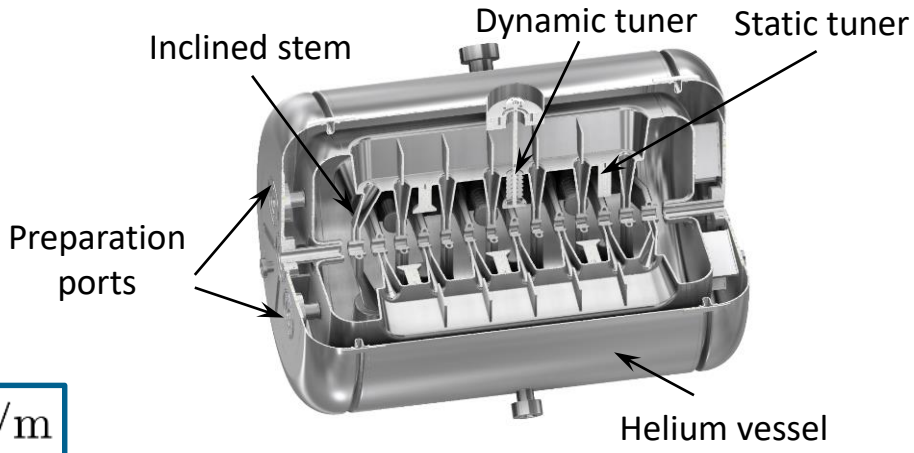




# RF Testing of the CH-Cavity (10/2016)

## RF test in a horizontal cryostat (@4.2°K)



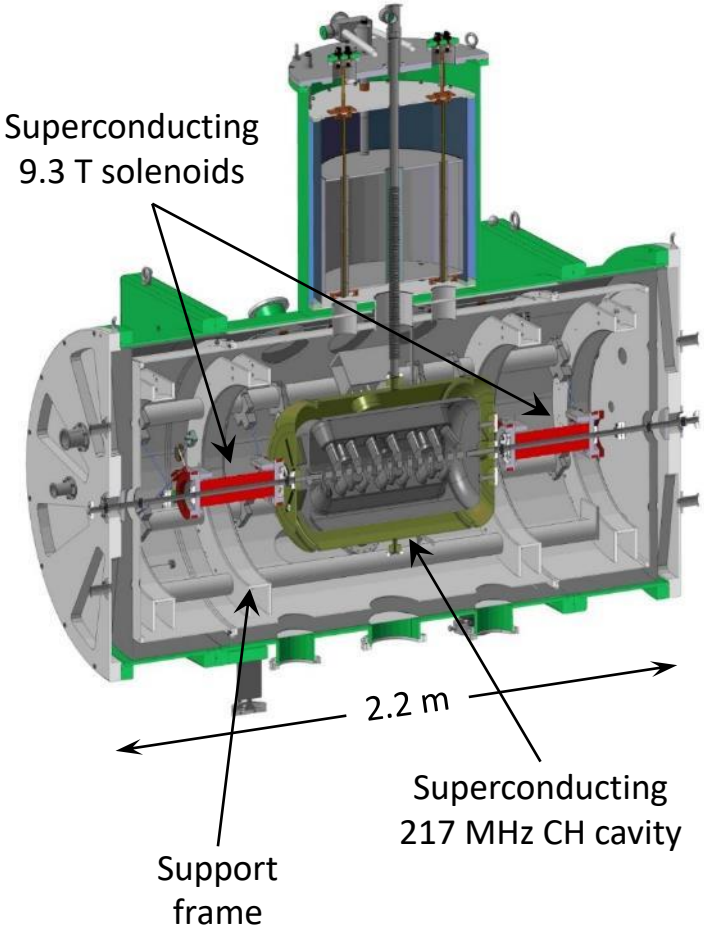




- Improved performance (add. HPR)
- Low field emission rate
- High field gradient
- Therm. quenching beyond 9.6 MV/m

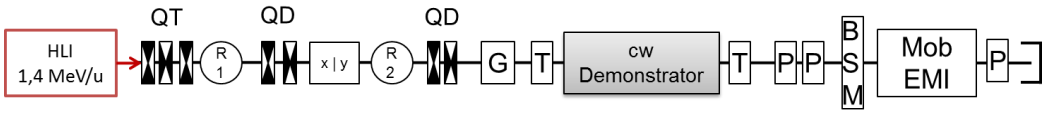
| | | Vertical test w/o He vessel | Horizontal test with He vessel |
|---|---|---|---|
| $Q_0^{\mathrm{low}}$ | | $1.44 \cdot 10^9$ | $1.37 \cdot 10^9$ |
| $R_S$ | nΩ | 36 | 38 |
| $R_{BCS}$ | nΩ | 15 | 15 |
| $R_{mag}$ | nΩ | 9 | 12 |
| $R_0$ | nΩ | 12 | 11 |
| $E_a$ | MV/m | 6.9 | 9.6 |
| $Q_0$ | | $2.19 \cdot 10^8$ | $8.14 \cdot 10^8$ |
| $V_a$ | MV | 4.2 | 5.9 |
| $E_p$ | MV/m | 43 | 60 |
| $B_p$ | mT | 39 | 55 |

# Experimental setup of the demonstrator at GSI

## Layout of the horizontal cryomodule

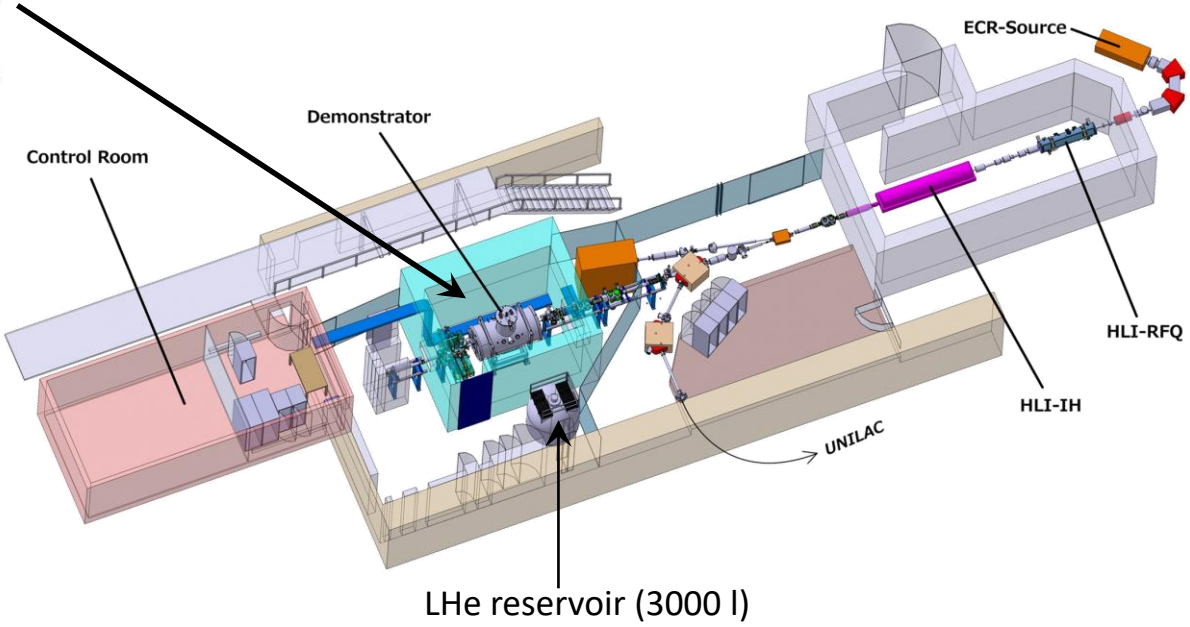



## Matching line - demonstrator – test bench

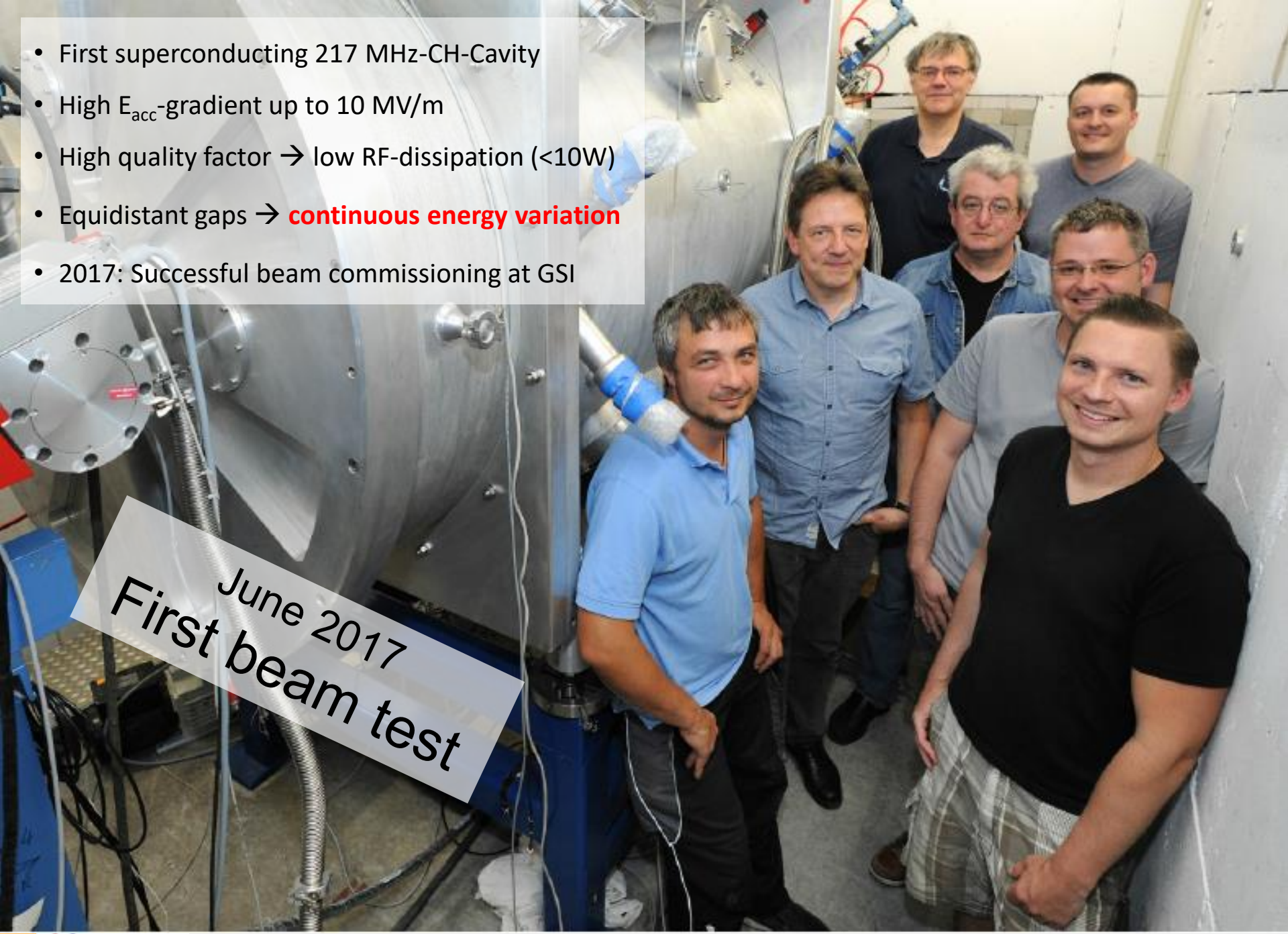



- Steering magnets
- Rebuncher
- Quadrupole doublet
- Profile grids
- Phase probes for TOF measurement
- Beam current transformers
- Bunch shape monitor (Feschenko)
- Emittance measurement

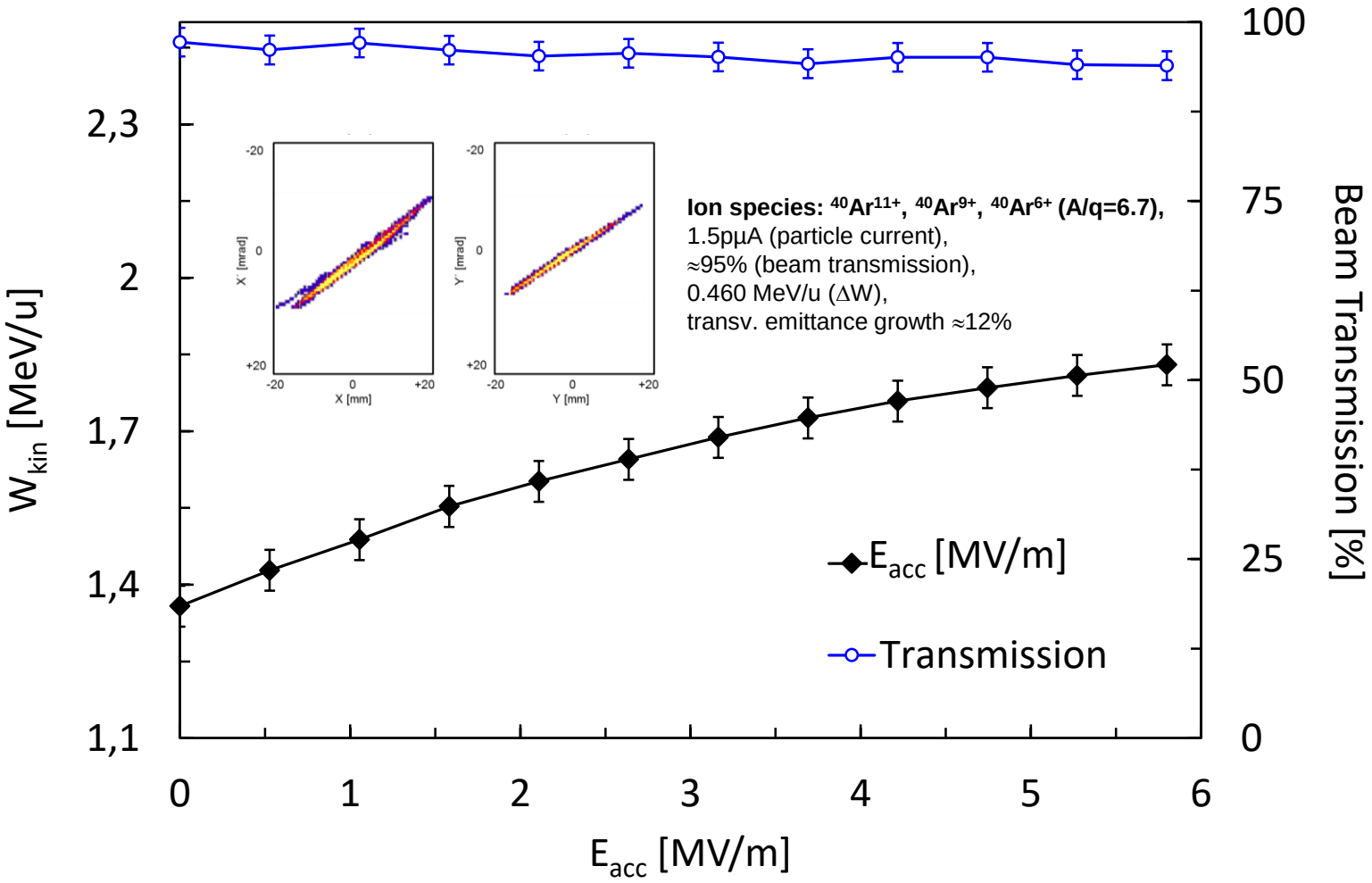
## Demonstrator at GSI-High Charge State Injector (HLI)



- First superconducting 217 MHz-CH-Cavity
- High $E_{acc}$-gradient up to 10 MV/m
- High quality factor → low RF-dissipation (<10W)
- Equidistant gaps → **continuous energy variation**
- 2017: Successful beam commissioning at GSI

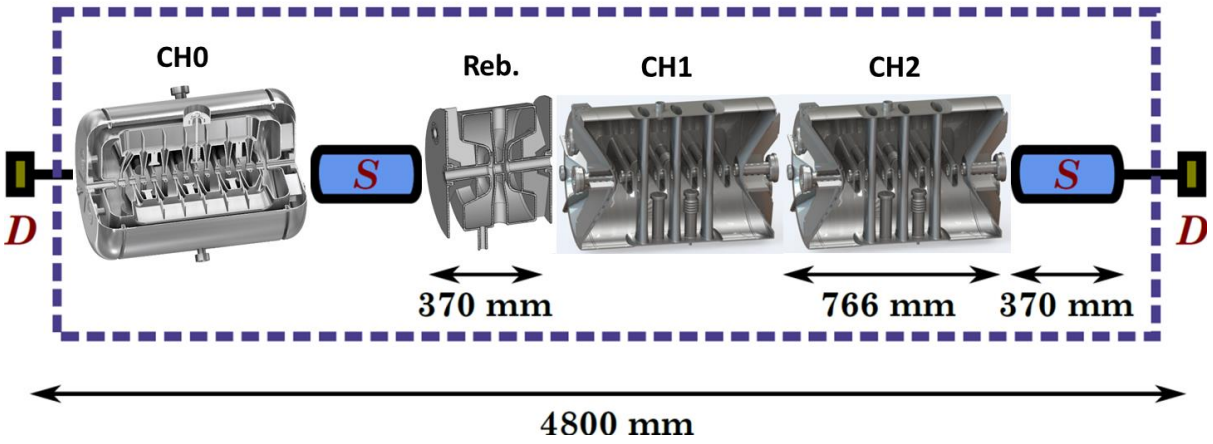


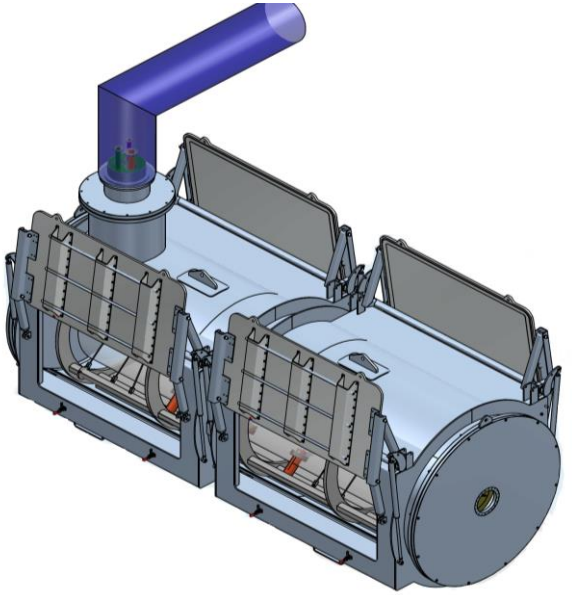
# Rf-amplitude-scan



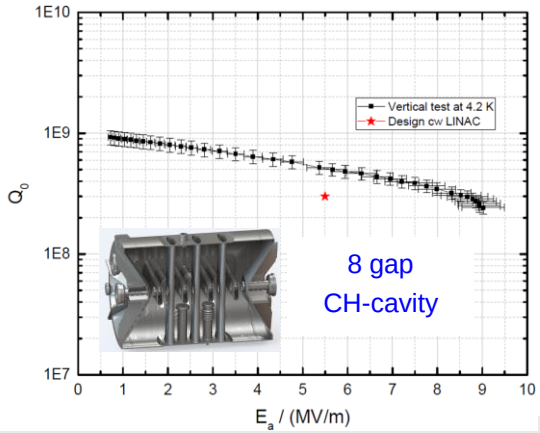
# cw-Linac-Prototyping: Advanced Demonstrator

## Standard cryomodule layout

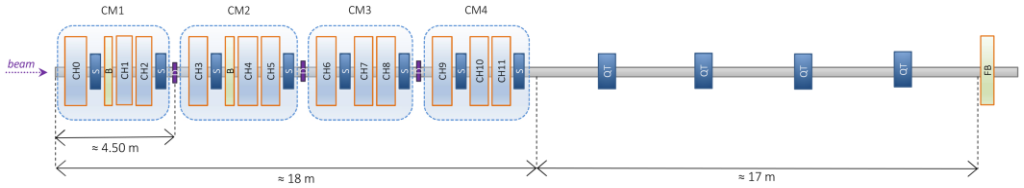


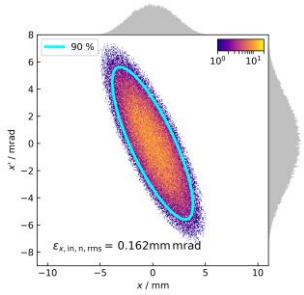



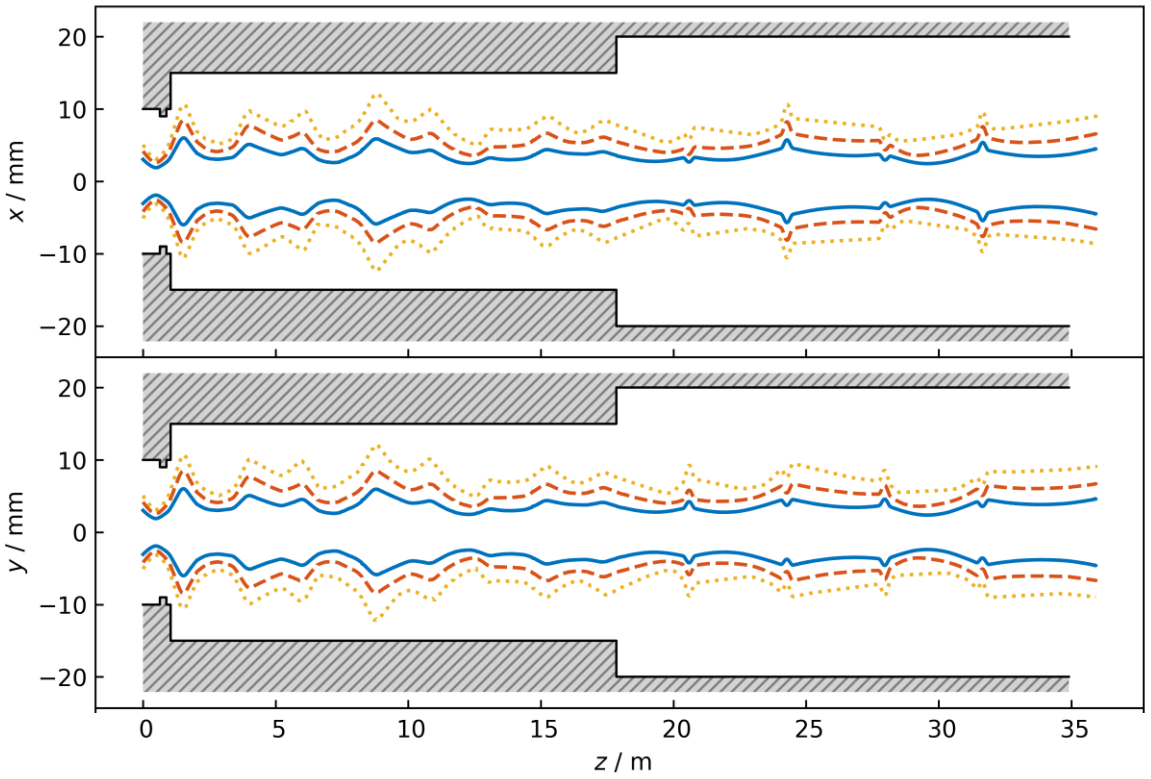
- New cryo module layout containing demonstrator CH cavity, 2 short CH cavities, 1 buncher and 2 solenoids
- Simplified cavity design (easier manufacturing & surface processing
- CH1 & CH2 are already produce and tested
- cryostat delivery Q2/2021 ✓
- compact linac design for or higher A/q (=8.5)

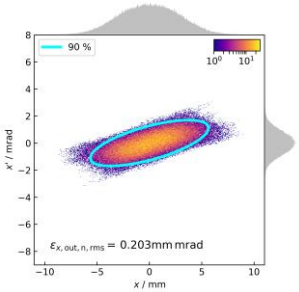


# Transversal beam dynamics cw-Linac layout



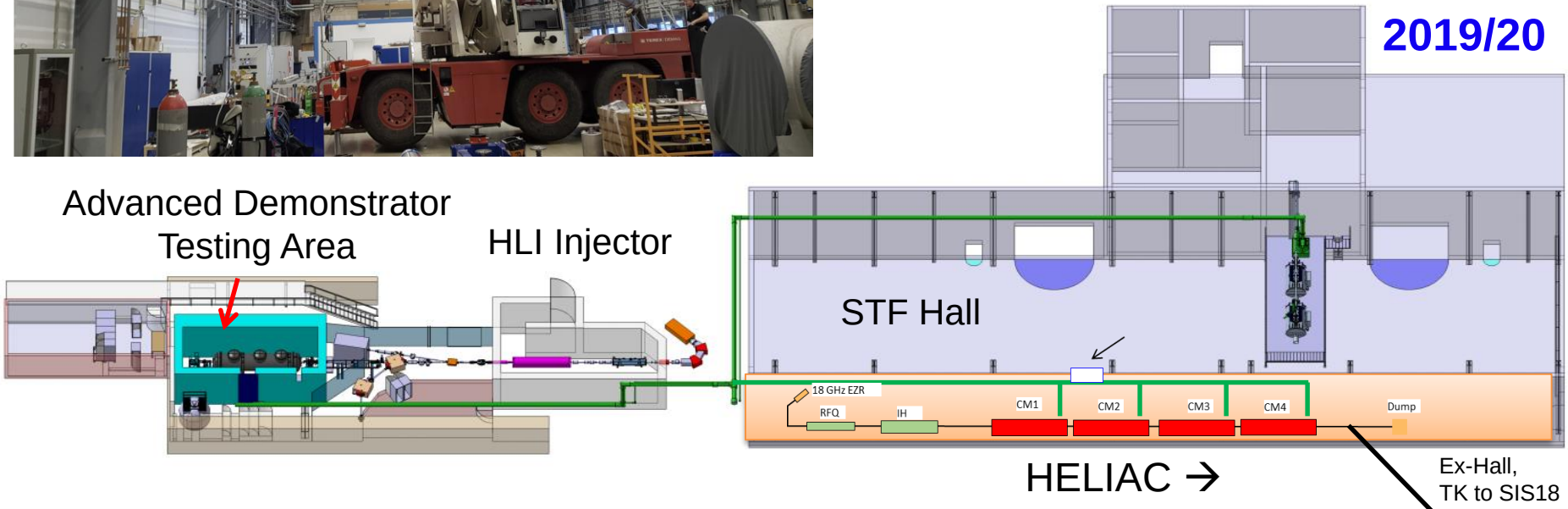




**courtesy:**
**M. Schwarz, et al.**

# 4K He-supply infrastructure@GSI

**Link to STF (Series Test Facility)**

**2019/20**



# SRF-test activities

- CH0: SRF-test at HI-Mainz Lab
- CH1: SRF-test at HI-Mainz Lab
- CH2: SRF-test at vertical cryostat (GU-Frankfurt)
- Set up of a new HELIAC-test area at GSI-Darmstadt
- Universal test kryostat for horizontal tests of „undressed“ CH-cavities

Universal Test Cryostat at GSI-Darmstadt

CH2 at GU-Frankfurt

# Cleanroom Operation at HI-Mainz

### Main features

- Aluminum double floor (5 tons/m$^3$)
- **Heavy duty rail system**
- Ultra high purity water supply (0.055 µS/cm, 2500 l/h, 5000 l storage)
- High pressure washer
- **High pressure rinse (HPR)**
- **Ultrasonic bath and conductance rinse**
- **160°C vacuum oven**

### Additional equipment

- Ionized nitrogen guns
- Particle counters
- Smaller US-baths
- Dish washer
- Lift trolleys (200 kg)
- Wet/Dry vacuum cleaners

### Preparation for PoF4-activities

- Cleanroom succesfully modified with new installations
- Cleanroom re-classified
- Particle concentrations even lower due to weekly cleaning
- On-going testing of equipment in operation

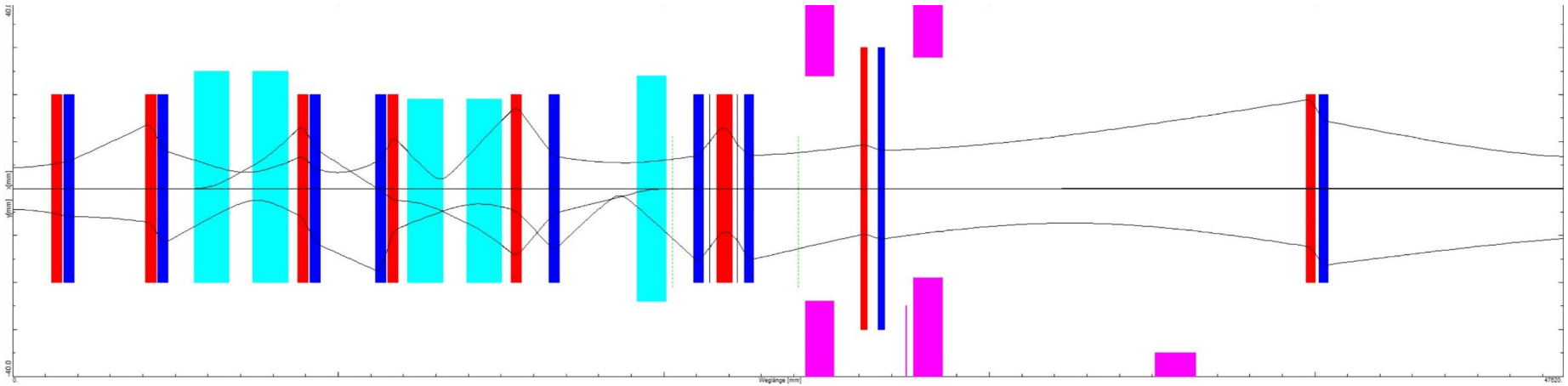
**Industry partnership (planned): Shared clean room for SRF-cavity preparation and installation projects**

# HELIAC@LINAC tunnel & Link2UNILAC

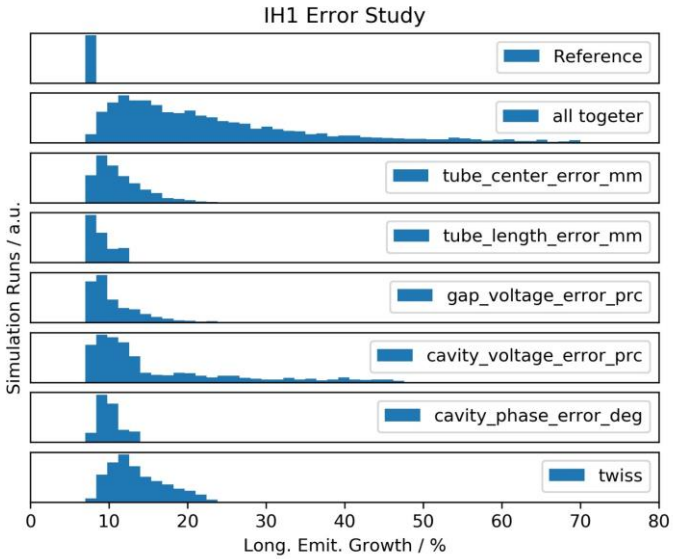
## HEBT to UNILAC

4x

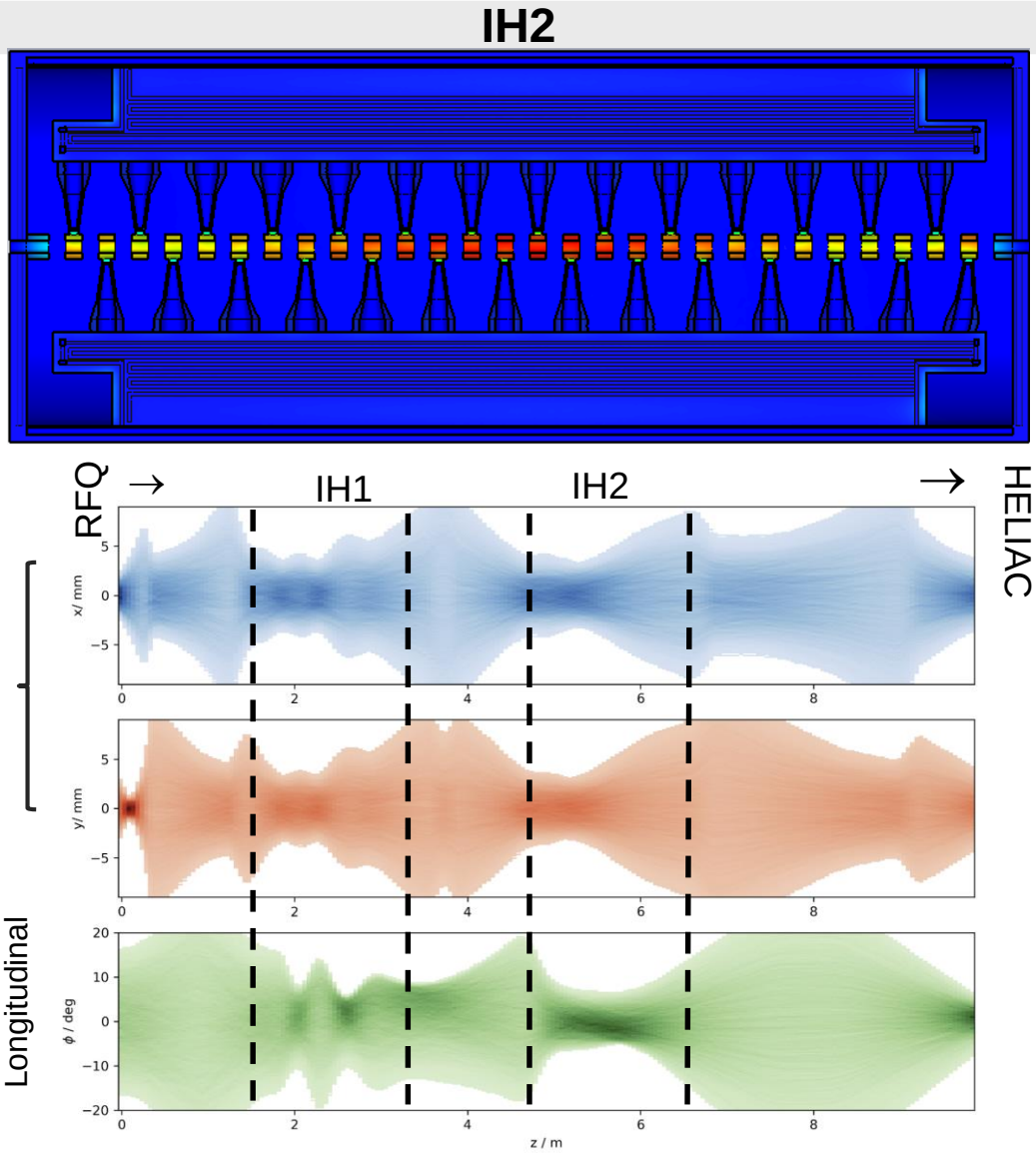


# cw-Injector: nc-IH-APF-Drift Tube LINAC IH1&IH2



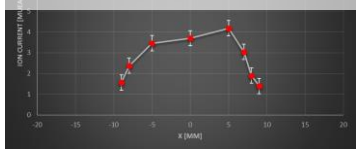

| Variable | Value |
|---|---|
| Tube center | ±0.2 mm |
| Tube length | ±0.1 mm |
| Gap Voltage | ±2 % |
| Cavity Voltage | ±1 % |
| Cavity Phase | ±1° |



# Advanced Demonstrator/Status: 06/2021

New Testbunker with test bench (2020)

beam meas. 2020



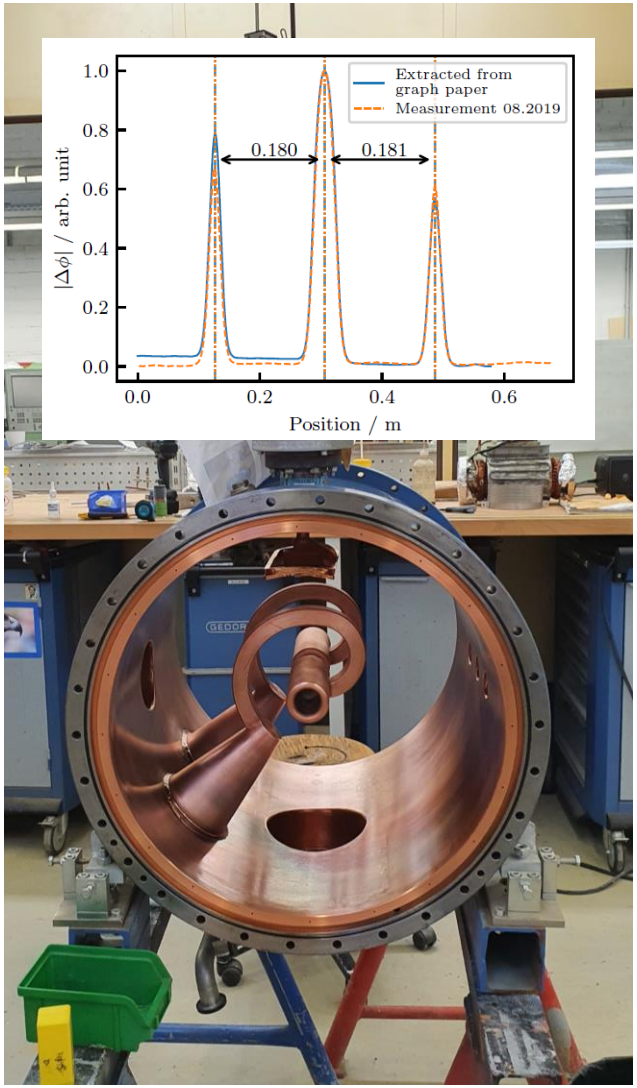
Installation of Matching Line (2020)

CM1-Advanced Demonstrator (2021)

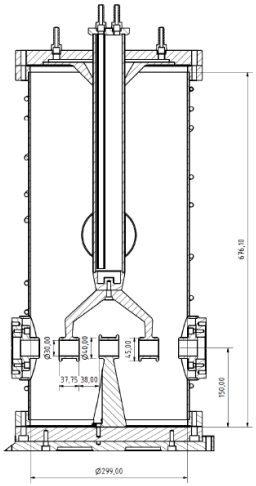
CM1 at Test Bunker (2021)

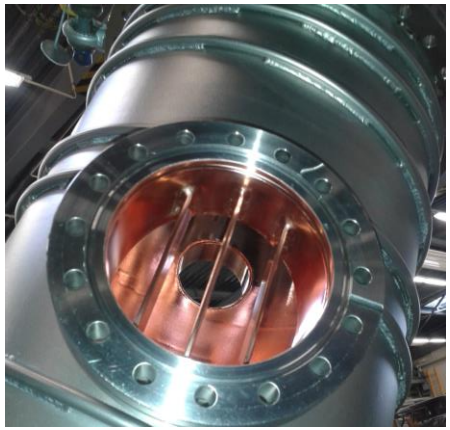
# Normal conducting cw-rebuncher cavities

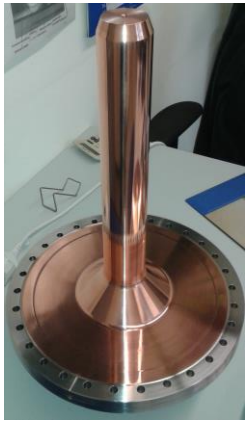
## Debuncher Cavity (β=0.1)




## Rebuncher Cavity (β=0.054)

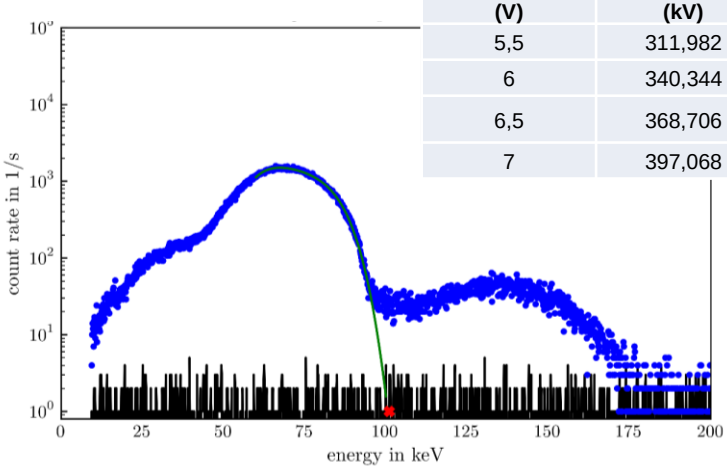




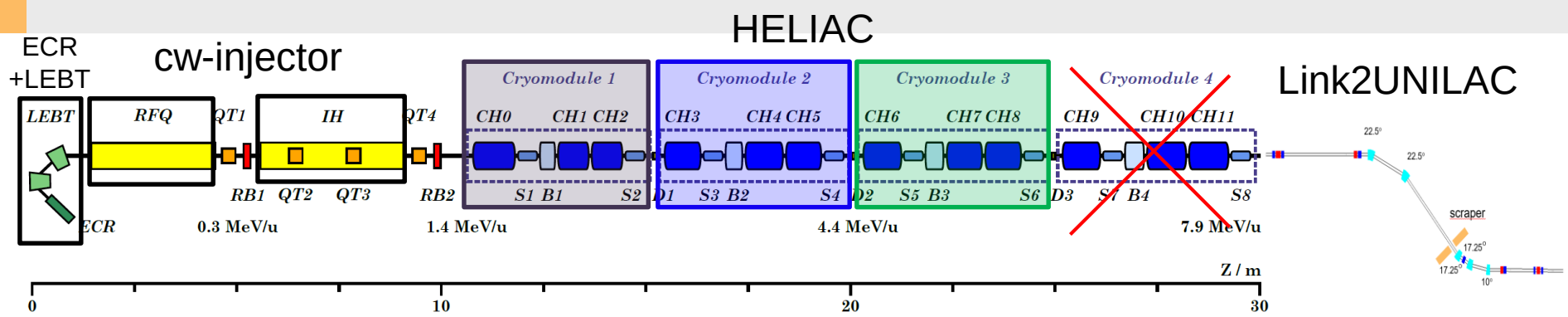


## Measured Roentgen-spectrum

| Rel. RF-Voltage (V) | Tot. TF-voltage (kV) | Gap-Voltage (kV) |
|---|---|---|
| 5,5 | 311,982 | 77,995 |
| 6 | 340,344 | 85,086 |
| 6,5 | 368,706 | 92,176 |
| 7 | 397,068 | 99,267 |



# cw-LINAC „basic approach“




2026

## normal conducting 25%-injector Linac

- **ECR + LEBT**
  - 18 GHZ-ECR
  - LEBT (prelim. layout)
- **cw-RFQ**
  - former HLI-RFQ
- **cw-IH-DTL (tendering: Q1 2021)**
- **transport sections, etc.**
  - MEBT, Matching Line, HEBT (Quads, Dipole)
  - cw-Rebuncher, debuncher
- **High power Rf-ampl.** (RFQ, IH, buncher) (reused)
- **Other supply systems**
  - Power supplies (LEBT, MEBT, HEBT)
  - beam diagnostics, vacuum system, controls

## superconducting cw-Linac

- **CM1 (PoF3)**
  - CH1 tested & CH2 tested
  - Rebuncher cavity ordered
  - Cryostat ordered
  - Solenoids ordered
  - 4 rf amplifiers ordered
  - aux. comp. (couplers, tuner, BPM, LLRf)
- **CM2 (PoF4)**
  - CH3-5 specified, ordering (tendering/Q3 2021)
  - Re-buncher cavity ordered
  - Cryostat ordered
  - Solenoids, rf Amplifiers, aux. components
- **CM3 (BmBF)**
  - CH6-8 specified, ordering (tendering/Q2 2021)
  - Re-buncher, Cryostat, Rf Amplifiers, …
  - Solenoids

# cw-Linac “basic approach”-timeline

| | |
|---|---|
| **Q4/2022** | CM1 (Advanced Demonstrator) beam test at Test Area |
| **Q2/2024** | **Linac-Tunnel (@SH2/3) ready for installation of components** |
| **Q3&4/2024** | ECR and LEBT commissioning @ Linac-tunnel |
| **Q4/2024** | CM2 beam test at Test Area |
| **Q1/2025** | RFQ commissioning @ Linac tunnel |
| **Q2/2025** | cw-IH-DTL commissioning @ Linac tunnel |
| **Q3/2025** | Matching Line & CM1 commissioning |
| **Q4/2025** | CM2 commissioning (and CM3 beam at Test Area) |
| **Q1/2026** | **CM3 & HEBT to UNILAC commissioning** |

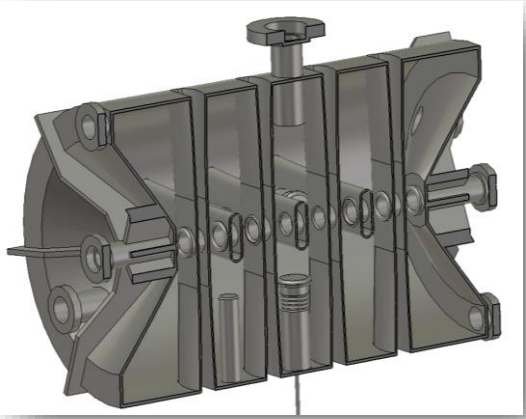
**@Additional schedule for test activities at HI-Mainz**

# Summary&Outlook

- Demonstrator beam commissioning was a major milestone paving the way to the GSI/HIM-cw-Linac
- Design acceleration gain was achieved with heavy ion beams even above the design mass to charge ratio at full transmission and maximum available beam intensity
- Beam quality was measured as excellent in a wide range of different beam energies, confirming EQUUS beam dynamics design
- Advanced cw-Linac layout based on four cryomodules, each equipped with three CH-cavities and a sc-rebuncher demonstrates the high capabilities due to energy variation preserving the beam quality
- New design could provide beam acceleration for a wide range of different ions (protons to uranium) above the design beam energy, featuring the ambitious GSI-user program, while the GSI-UNILAC is upgraded for short pulse high current FAIR-operation
- A basic cw-Linac approach (3 CM, 25% duty factor) is envisaged to be built and commissioned until 2026

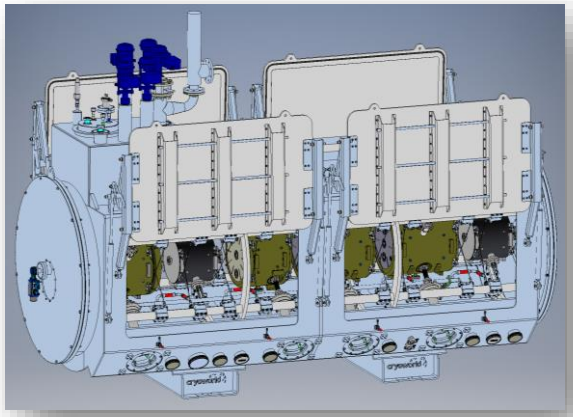
# Further HELIAC-activities

## CH3-CH5 Design



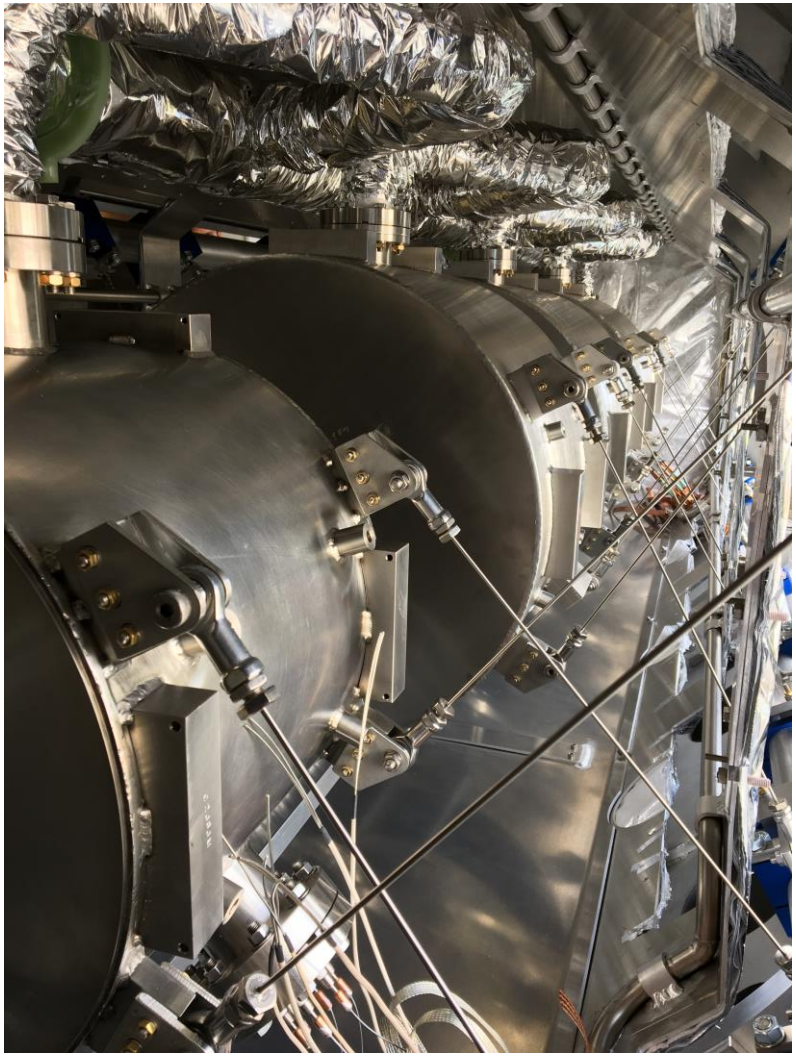
- Design of CH3-CH5 for CM2
- Unified design of elements for 6 cavities:
  - stems
  - end cups
  - dynamic tuners
  - reduction of the costs
- Tender for manufacturing is in preparation
- HPR treatment at HIM-clean room
- Design, layout, manufacturing CM2-key components
  - cryostat
  - sc CH-rebuncher
  - sc-solenoids
  - rf-power coupler
  - fast and slow rf-tuning system
  - rf-amplifier-system
- Cryomodule assembly & rf-test at HIM
- CM2 beam test at advanced test area

## Cryomudule 2



## High power Rf-coupler

## sc-CH-rebuncher



*June 2021:* ***Delivery of CM1***

# *Thank You for Your attention!*