HElmholtz LInear ACcelerator

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2nd Research Retreat, July 19-20, 2023

Introduction

The UNILAC will not be able to meet the high duty factor requirements in the future!

FAIR Requirements

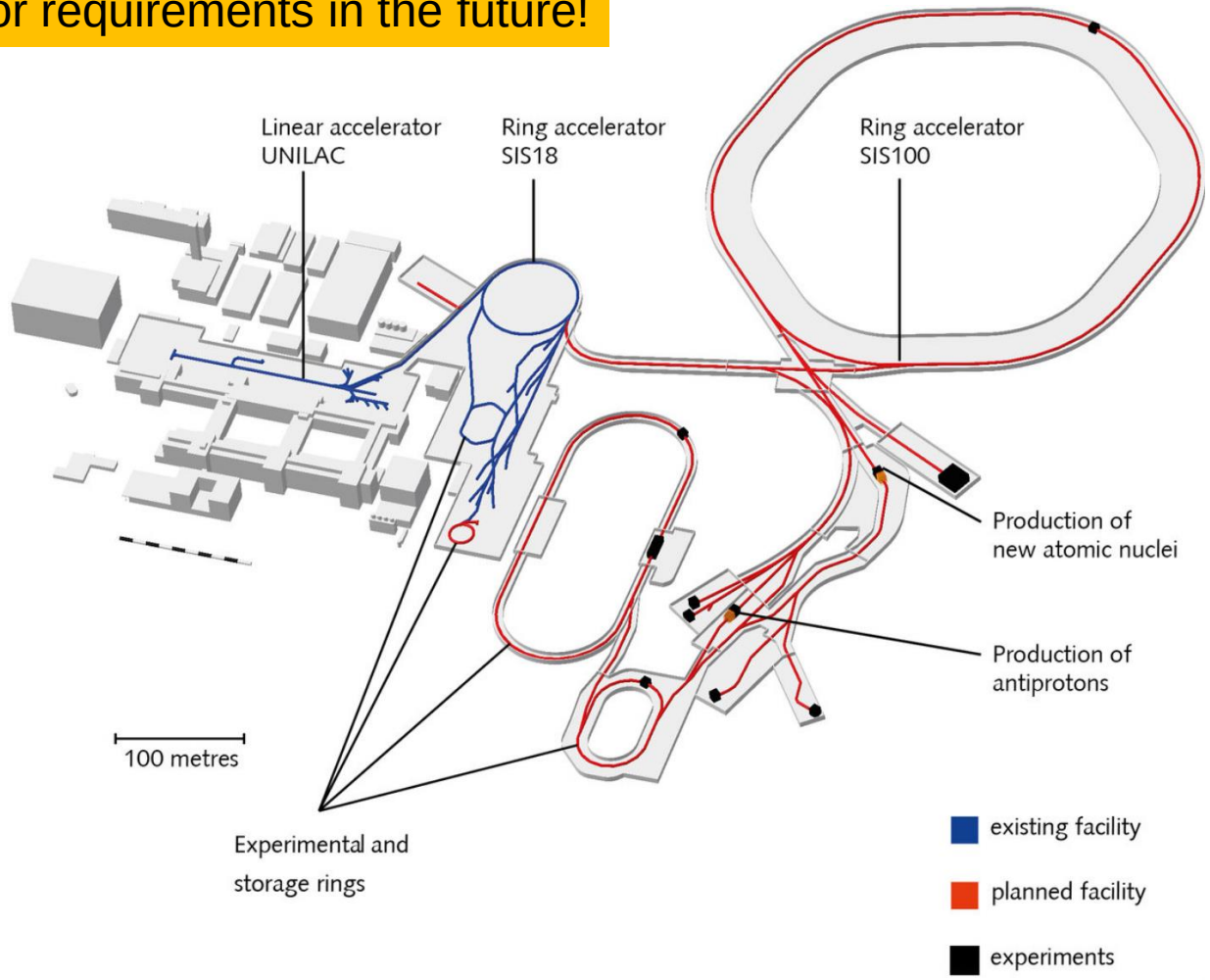
- high *peak* beam currents
- low duty factor (~0.1 %)
- → low repetition rate (max. 3 Hz)

UNILAC-Poststripper Upgrade

- optimised for FAIR requirements
- low duty factor / rep. rate

Super Heavy Element Requirements

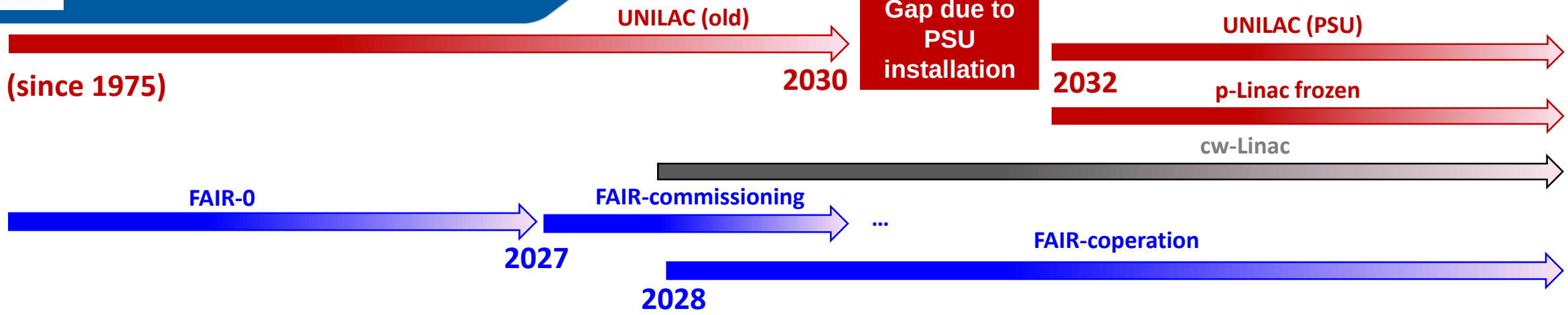
- high *average* beam currents
- high duty factor (~100 %)
- high repetition rate or just *c.w.*



Existing GSI facility and future FAIR complex

Injector Linac Schedule (preliminary)

HELIAC should become part of the FAIR injector strategy!



UNILAC, essentially as it is currently available (≤2030)

- no more high duty factor operation at UNILAC… after Poststripper-Rf-Upgrade for FAIR
- risk of substantial failure and therefore no FAIR injector operation!

→ HELIAC ≥2028

UNILAC, with replaced poststripper (≥2030?)

- no availability during installation and commissioning phase (≥15 months)

FAIR-p-Linac (≥2032) recently frozen?

- no availability during installation and commissioning phase

→ UNILAC as medium intensity injector Linac for proton beams

cw-Linac (≥2028)

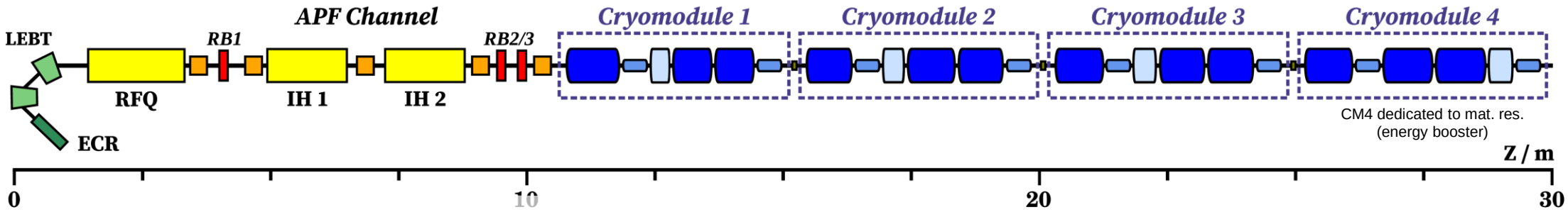
- no availability during installation and commissioning phase

→ UNILAC as high duty factor (25%) heavy ion Linac (FAIR-0)

Introduction

HELIAC has been optimized for the needs of the UNILAC users, in particular TASCA, SHIP & materials research and could be used as SIS18-injector for medium high intensities!

He**lmoltz**Li**near**Ac**celerator – **HELIAC



Source

Parameter	Unit
Type	ECR
Frequency	18 GHz

Normal-Conducting Injector

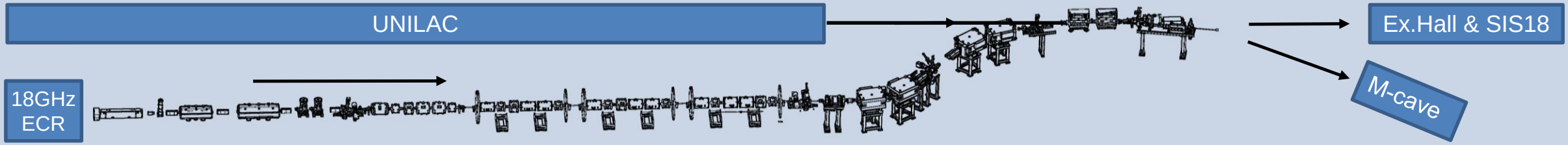
Parameter	Unit	Value
Output energy	MeV/u	1.4
RF Cavities		6
Operation mode		cw
A/Z		≤ 6

Superconducting Accelerator

Parameter	Unit	Value
Output energy	MeV/u	3.5 – 7.3
Beam current	mA	≤ 1
Operation mode		cw
A/Z		≤ 6
RF Cavities	#	12
RF Bunchers	#	4
Transversal Focussing	2 Solenoids per Cryom.	

HELIAC-Project Time Schedule

HELIAC operation from 2028 on requires start of bunker construction in 2025!



HELIAC-Basic Approach/Timeline

	2017	2018	2019	2020	2021	2022	**2023**	2024	2025	2026	2027	2028	2028+
Demonstrator Beam Test													
Cryo-Infrastr.&Test Area													
Adv. Dem. Cryostat Test													
CM1@HIM-Clean Room													
CM1-Beam Test@GSI													
CM1-Test Operation													
RFQ (old)-Recommissioning													
APF-IH-manufacturing + copper plating&RF-testing													
CM2-assembly @HIM													
CM2-test @GSI-test area													
CM3-assembly @HIM													
CM3-test @GSI-test area													
Setup of HELIAC-Bunker													
Start of HELIAC-commissioning/Ion source													
ECR + LEBT-commissioning													
normal conducting Injektor commissioning													
CM1&Link2UNILAC commissioning													
Start of HELIAC-operation													
Full scale expansion cw-capability/CM4 install													

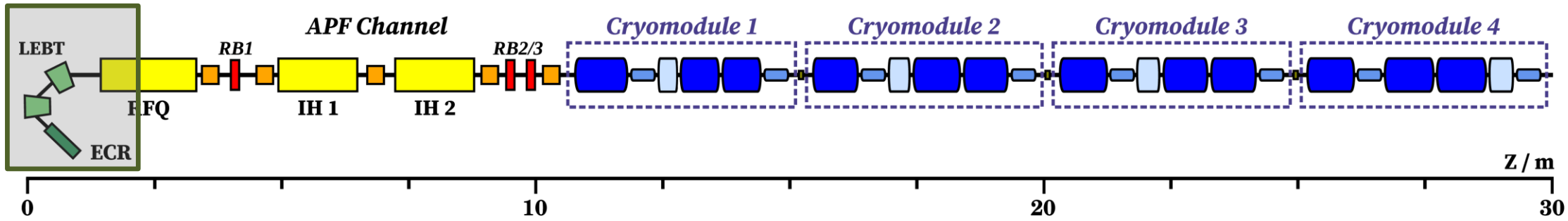
Advanced Demonstrator

Series procurement & assembly + tests

Bunker construction, step-by-step commissioning, link to UNILAC

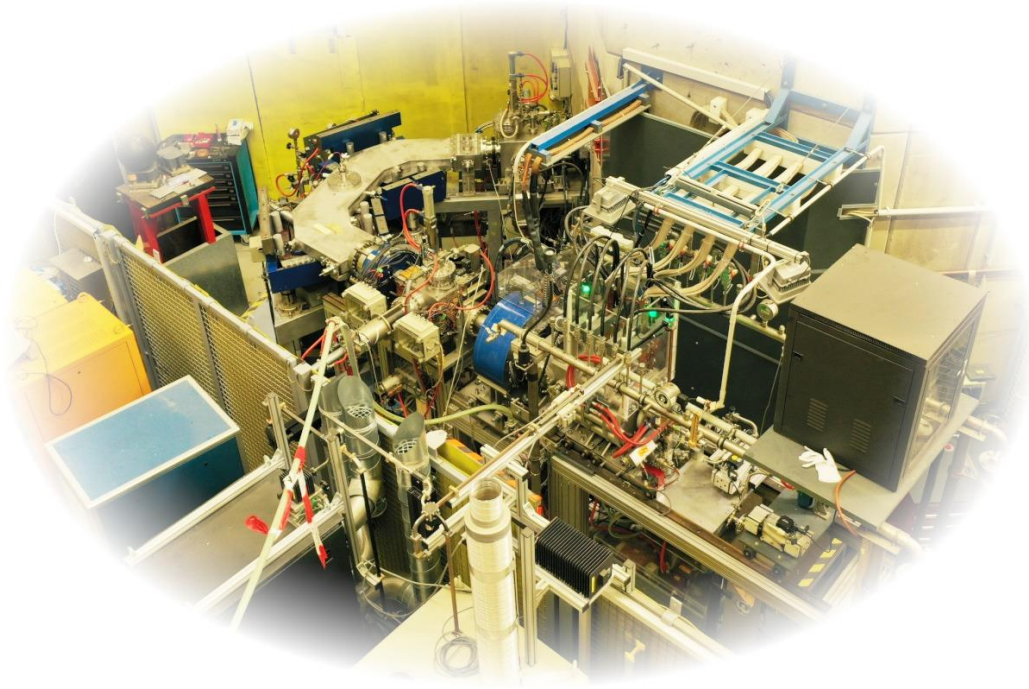
Status/Ion Source

Advanced ECR-ion source, will meet the user needs, 14 GHz caprice is available as startup version!



Ion Source

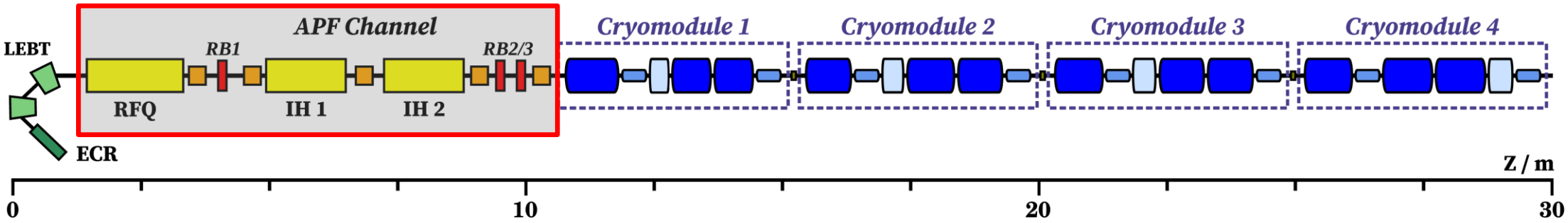
- **High charge states required**
  → 18-GHz-ECR (Jyväskylä design)
- **Low Energy Beam Transport**
  - Mass to charge-spectrometer
  - Transport/matching to RFQ
- **Start version: 14-GHz-CAPRICE-ECR @ GSI**
- **→ move 14 GHz-ECR+HLI-LEBT in 2025!**



CAPRICE14-GHz-Electron Cyclotron Resonance Ion Source @ GSI

Status/n.c. Injector Linac

Old HLI-RFQ is available for re-use, in perspective a cw-capable RFQ is needed!

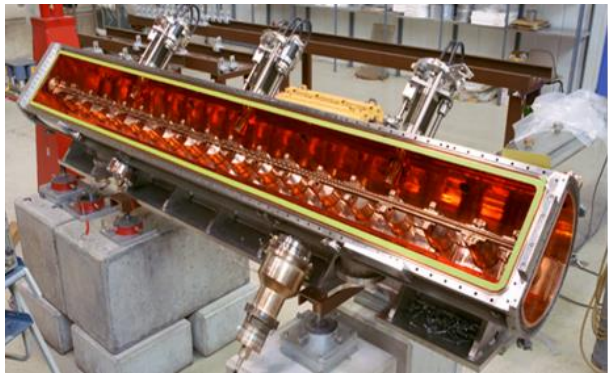


Ion Source

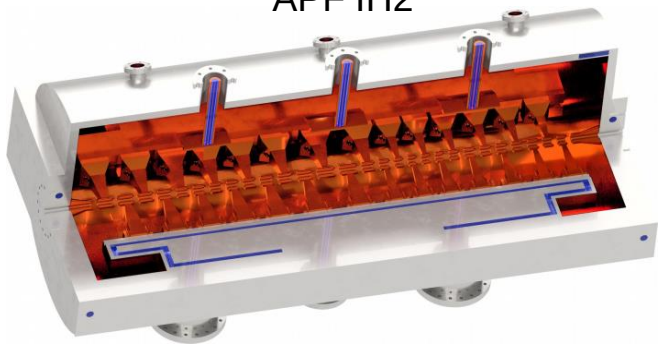
normal conducting Injector

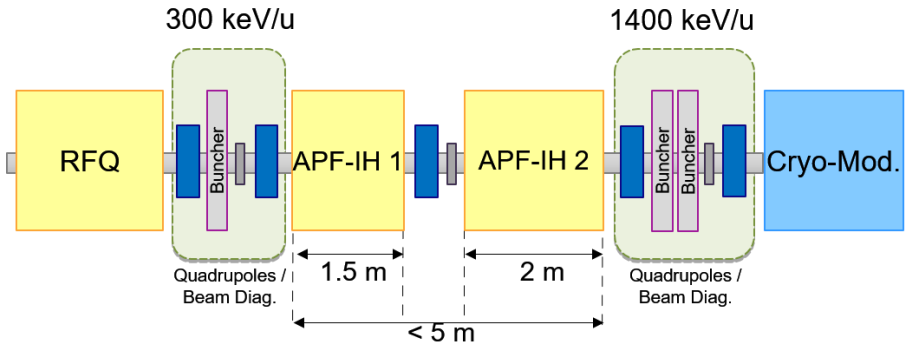
- Start version: Former HLI RFQ (1991)
  → 25% duty factor vs. 100 % (c.w.)
- APF IH-DTL with two-cavities (IH1&IH2)
  Alternating **P**hase **F**ocusing
  - APF DTL capable for 100% duty factor
  - Manufacturing started
  - 2024: ready for installation
- Start version: existing vacuum tube rf-amplifiers
  → 25% duty factor vs. 100 %

HLI-RFQ (1991)



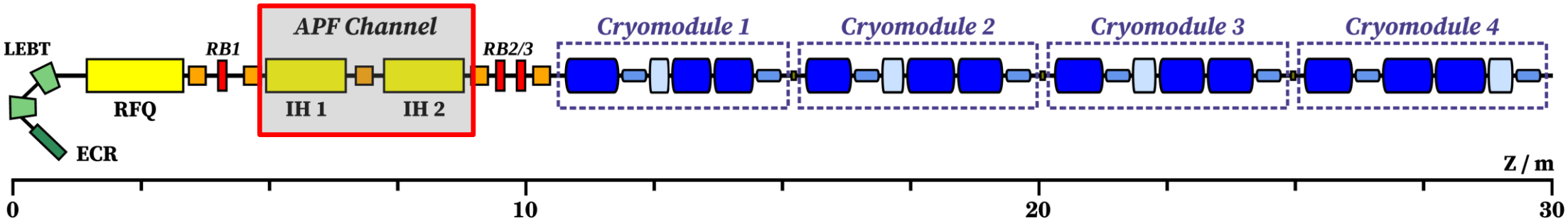
APF IH2





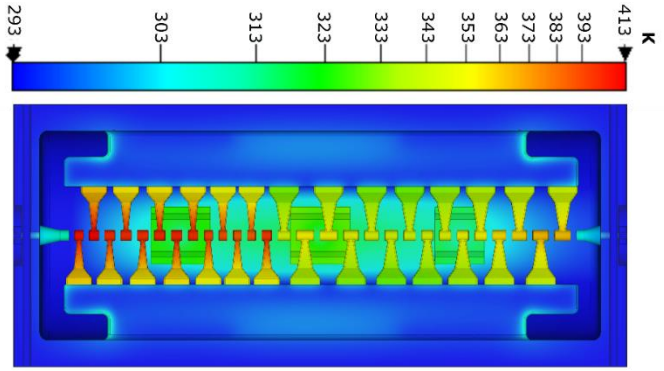
APF-IH-DTL for c.w. Operation

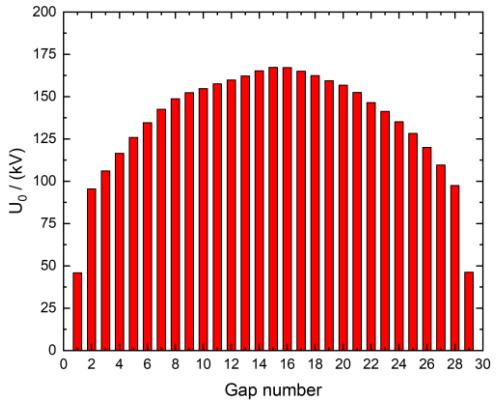
A cw-capable (nc) APF-IH-DTL was designed and ordered!

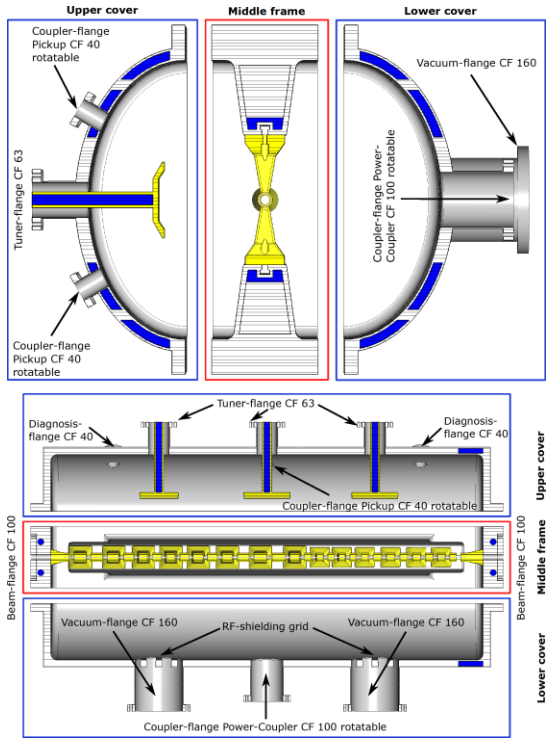


Extensive simulations performed:

- 3D e.m. field
- Thermal
- Multi-physics
- Beam dynamics & error studies
- Copper-plated steel structure
- Delivery expected in Q4 2023



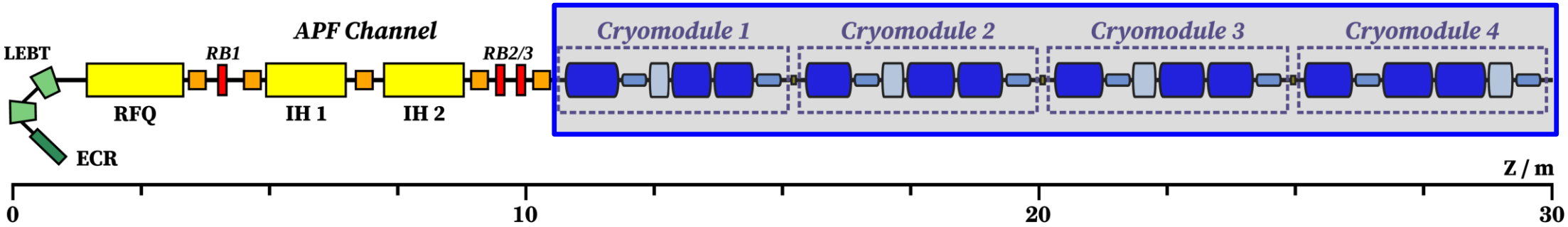




supported by HG-Innov. Pool

Status/s.c. Main Linac

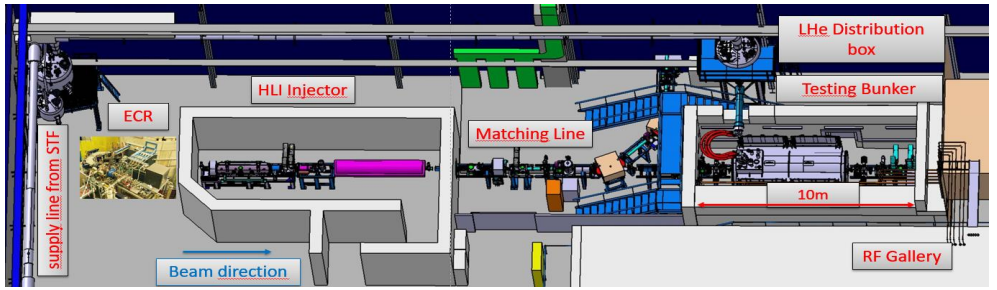
Multicell-CH-cavity and prototype CM(1) successfully tested, LHe-infrastucture built, HELIAC-technical layout completed!

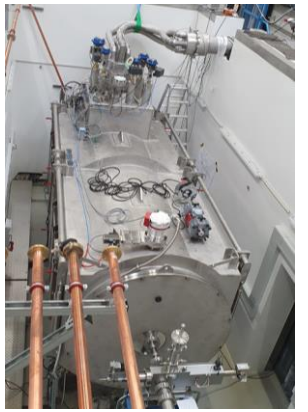


Ion Source

normal conducting Injector

superconducting Linac

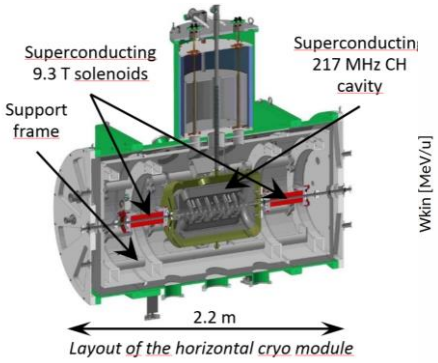




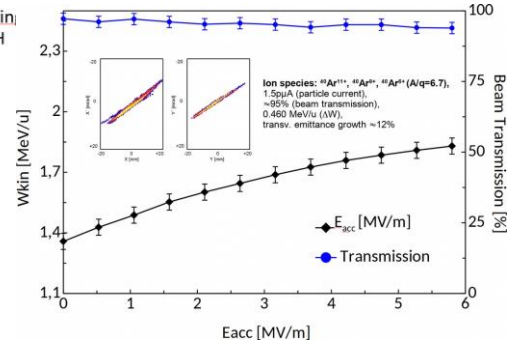
2021

Test of Cryostat & Solenoids

CH Cavity Qualification (2017)

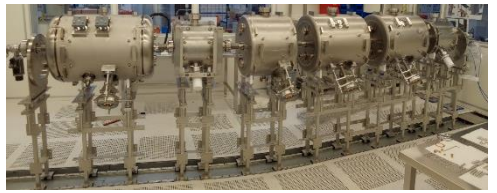


Layout of the horizontal cryo module



Helium & Test Infrastructure (2021)

Cryomodule (CM1) Qualification (2023)

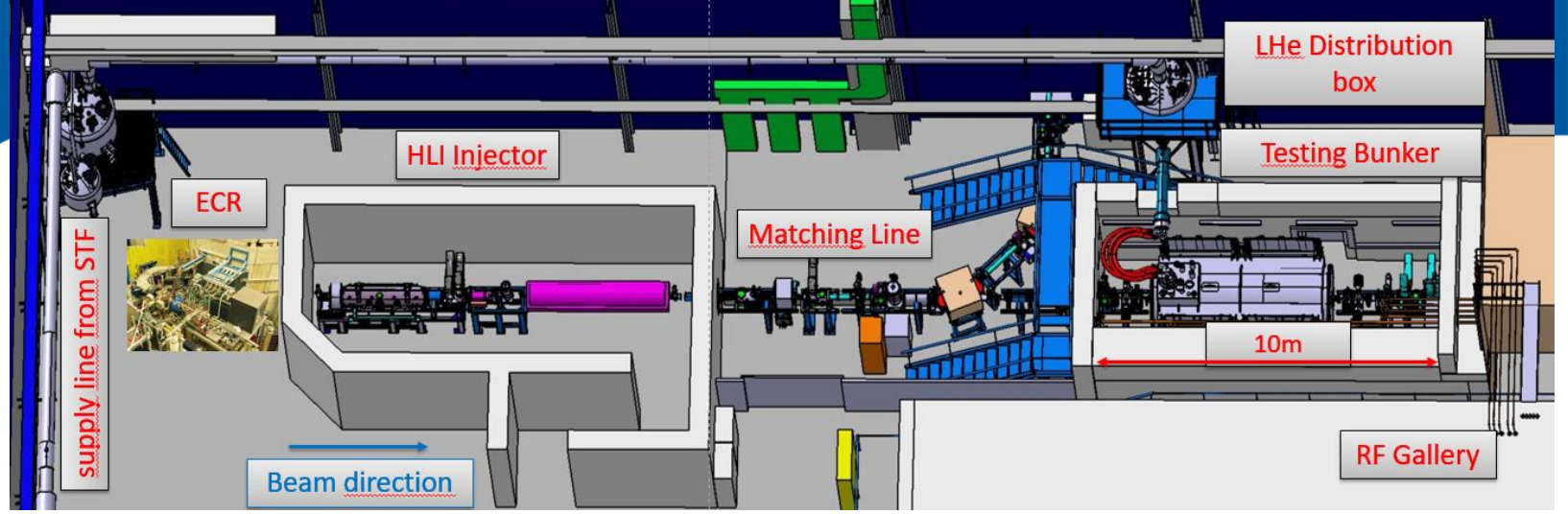


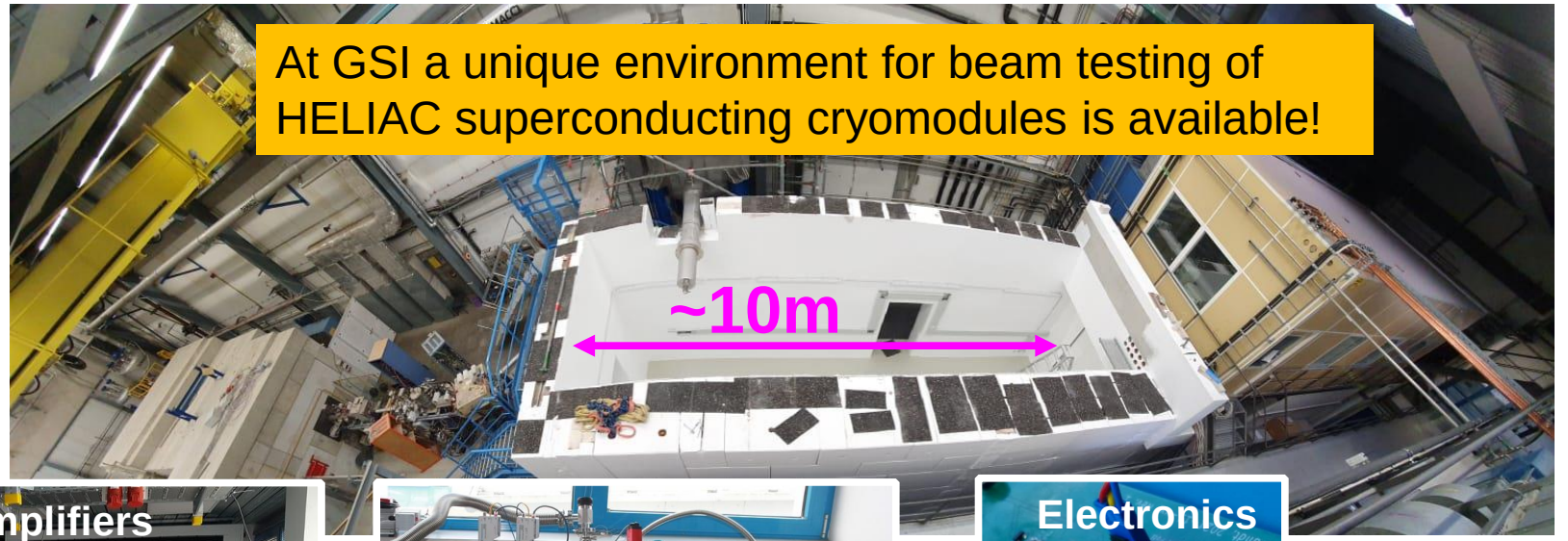
Entire HELIAC Setup

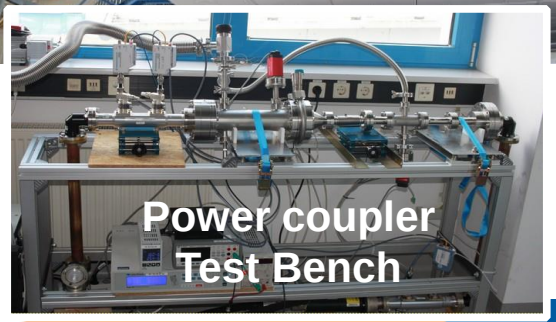
Test Site @ GSI

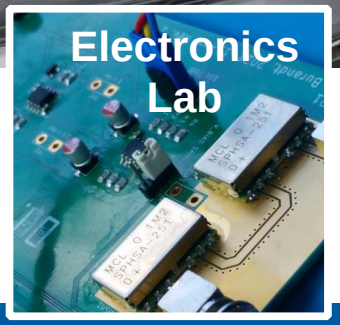
Setup of Advanced Dem. test site @ GSI

- ✓ Radiation cave behind HLI injector
- ✓ Control room
- ✓ RF supply room
- ✓ Test bench for high power couplers
- ✓ Electronic lab
- ✓ Beam line to GSI‘s HLI as injector
- ✓ Link to cryo plant
- ✓ Advanced Demonstrator setup allows first user experiments
- ✓ Test site allows qualification of CM1-CM4









Test Site @ GSI

CM1-cryostat was successfully tested under cryogenic conditions with beam!

CM1 with dummy cavities

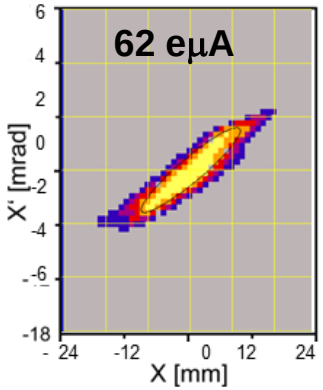
2021

- Int
1.0
5
10
20
40

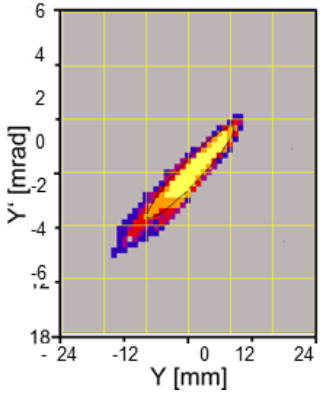
($^{40}Ar^{8+}$ ion beam)

w/o solenoid

5.4 mm mrad

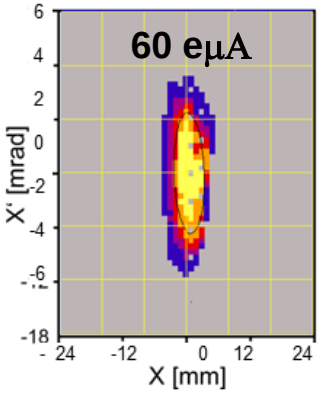


4.72 mm mrad

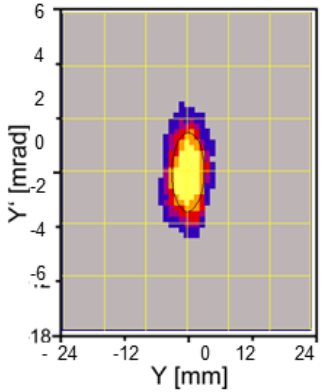


Focus
I_{Sol2} = 25A

6.44 mm mrad



4.69 mm mrad



s.c. Solenoid beam-com-missioning

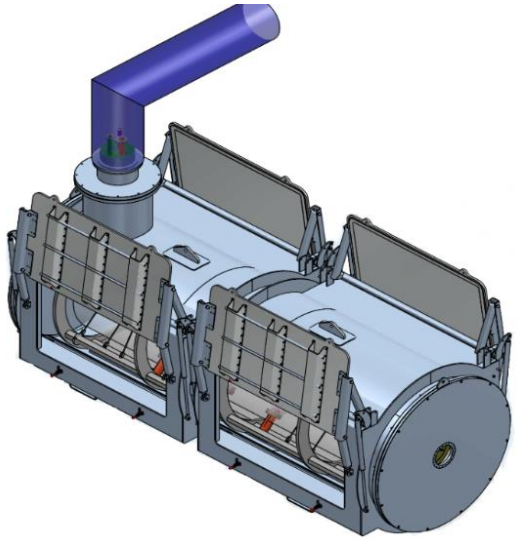
Cryomodule Qualification

A standard cryomodule (3 CHs + 1 Buncher) has been designed, technically laid out and built (CM1)!

HELIAC-CM1

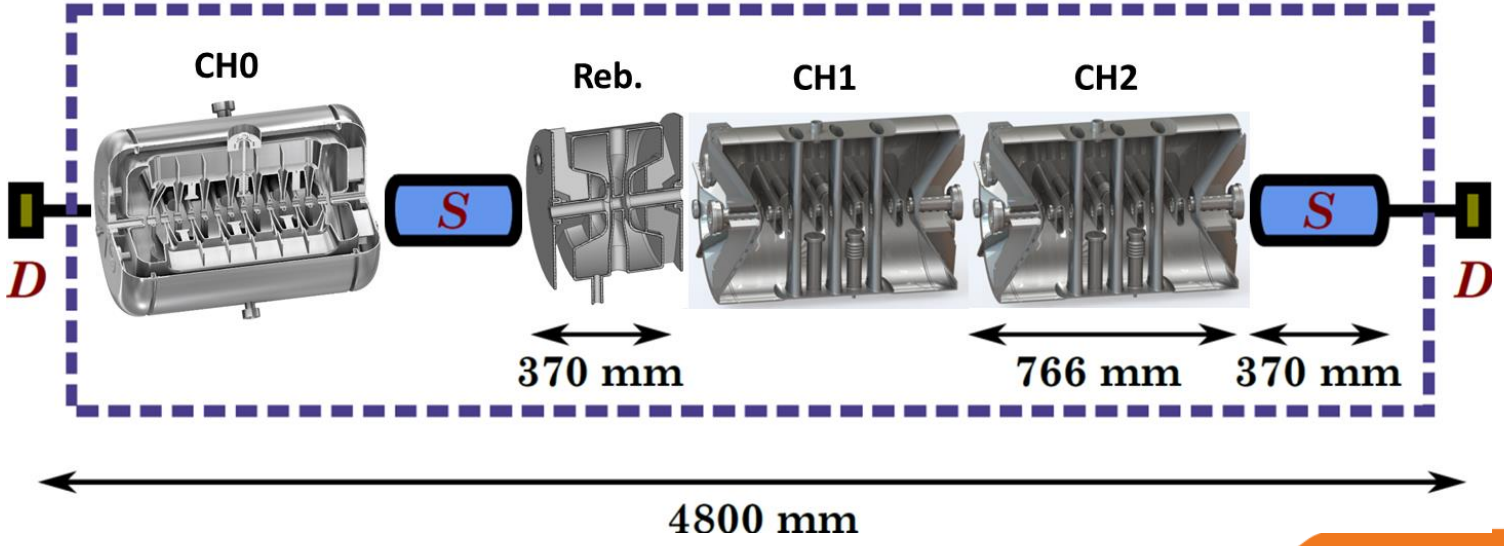
(HGF-PoF4 – MatterTechnologies ARD)

- 3 Crossbar H-Mode RF-cavities
- 1 Crossbar H-Mode Rebuncher cavity
- 2 superconducting 10T-Solenoids



Cryomodule 1

Standard Cryomodule Layout

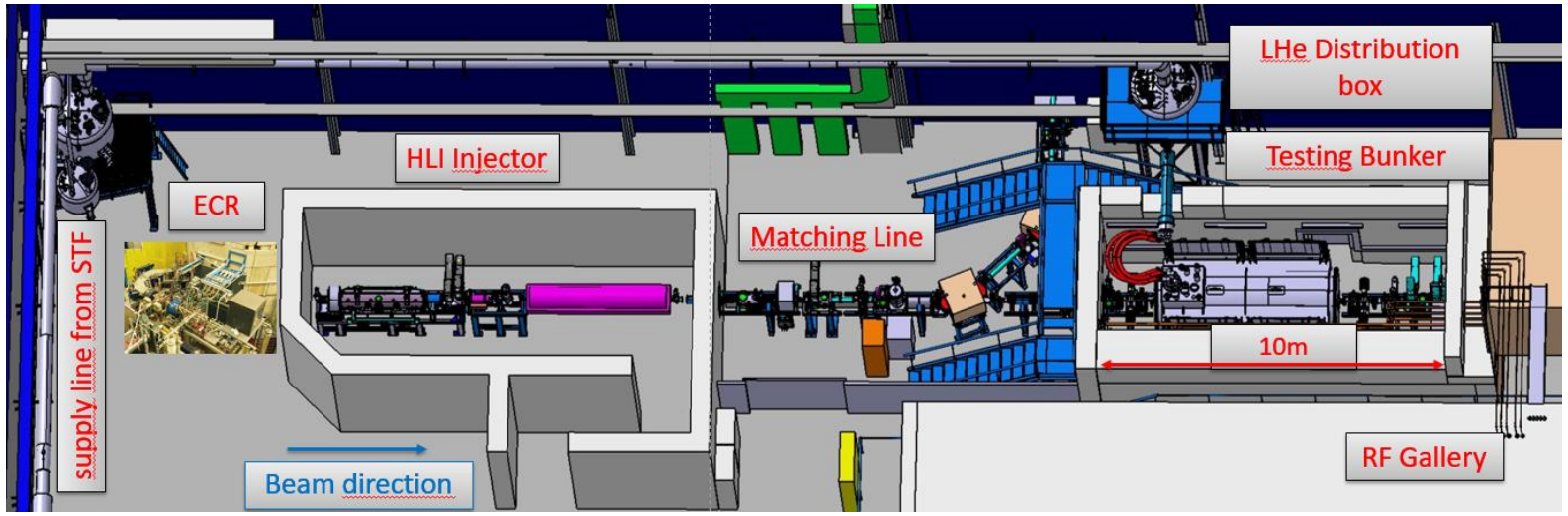


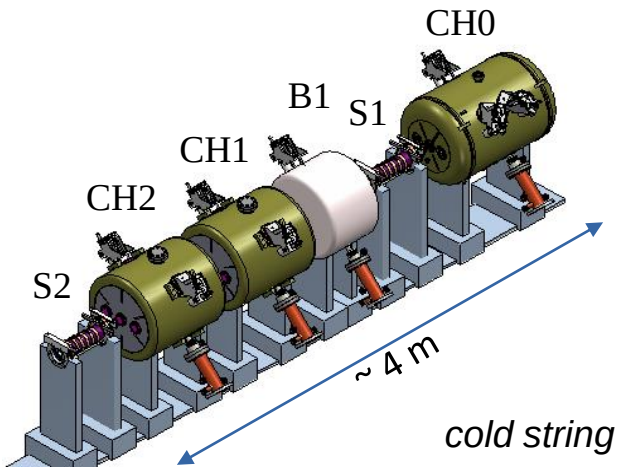
Cryomodule Qualification

ALL key components of the first fully equipped HELIAC cryo module are available in full function!

Test of fully equipped standard Cryomodule

- **Delivery of key components**
  - RF-Cavities
  - Solenoids
  - Power couplers
  - RF amplifiers
  - LLRF
  - Cryostat
- **Clean and precise assembly**
- **Many „firsts“**
  - Assembly procedures
  - Auxiliary constructions
  - Transport HIM ↔ GSI
- **Test site + infrastructure**



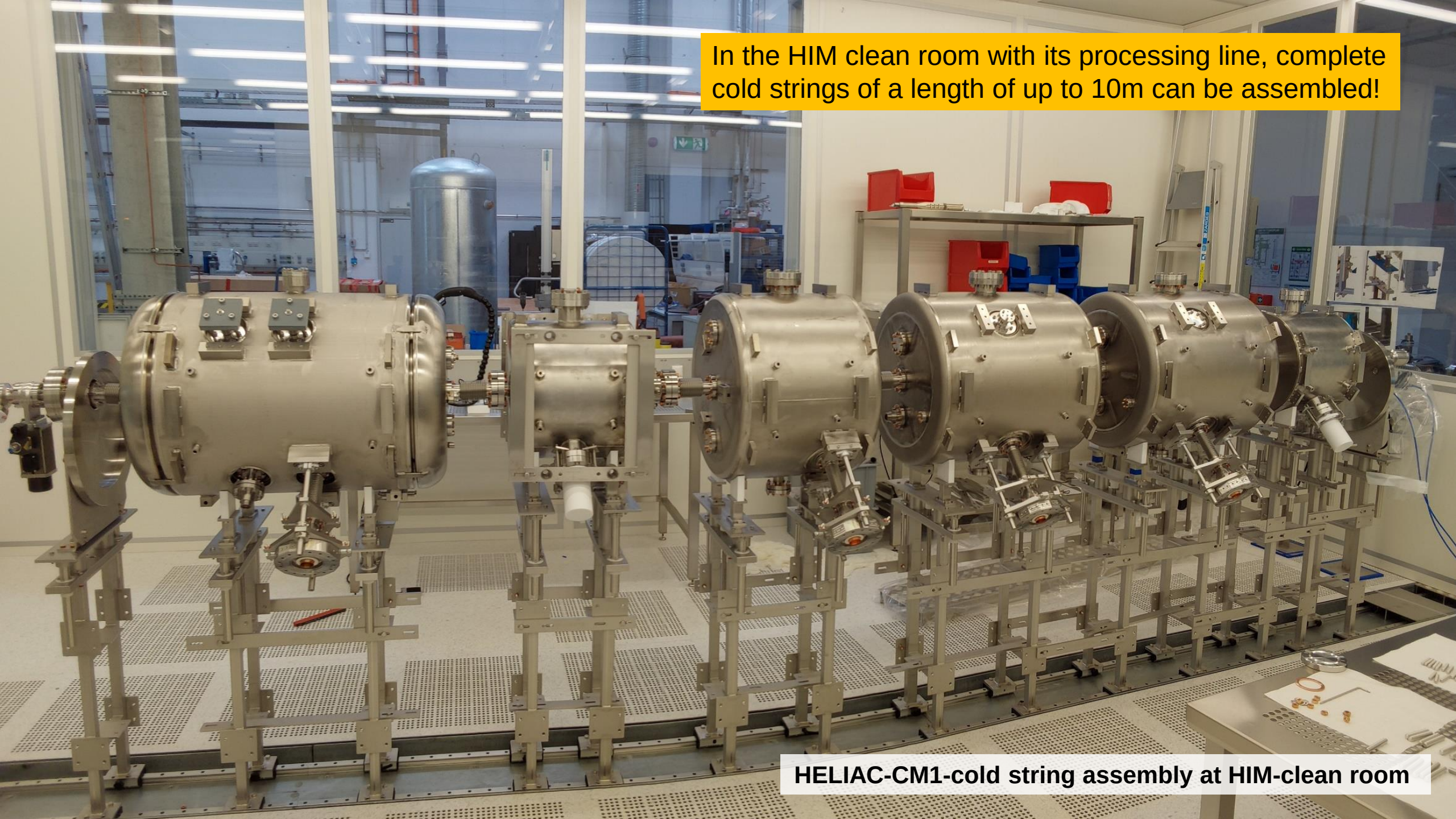


cold string

Rf-amplifiers

power coupler

cryostat



HELIAC-CM1-cold string assembly at HIM-clean room

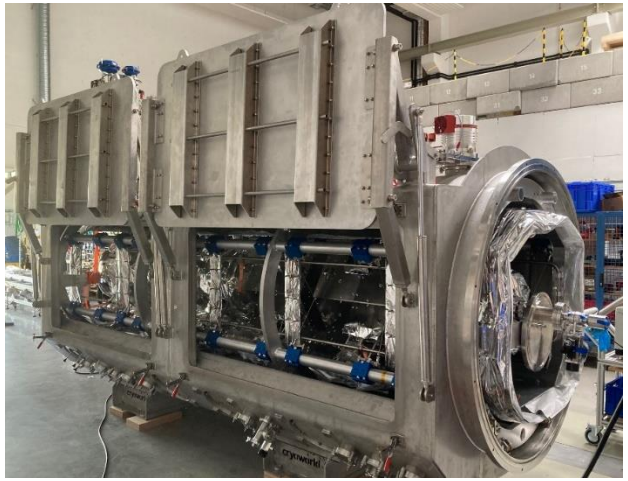
Accelerator String Integration

Cold string integration at HELIAC-CM1!

Acceleration string mounted on individual trolleys

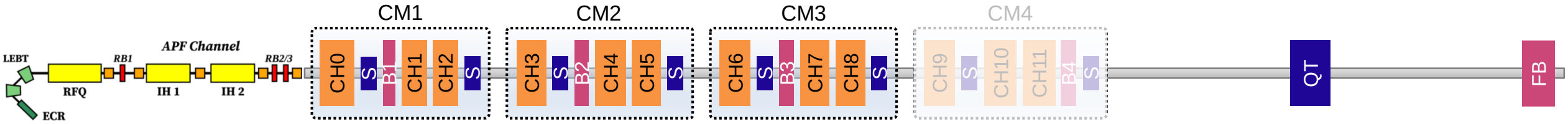
empty cryostat

Acceleration string mounted inside transport frame



…integrated inside cryostat

Basic Approach and Link to UNILAC



- HELIAC to be realized in a step-wise approach
- 2023: Finalizing R&D-phase with installation and commissioning of CM1
- ECR-ion source and nc-injector linac at new HELIAC radiation protection shelter
- Basic version comprises CM1 – CM3 (long)
- CM3 is equipped with a basic set up of 3 CH-cavities, 1 rebuncher and 2 solenoids
- Energy spread can be transformed with the FB to ±3 keV/u.
- For CH8 output energy (5.93 MeV/u), no CM3-buncher cavity required
- In a first step HELIAC operation is restricted to 25% beam duty factor

A HELIAC starter version has been defined that can provide heavy ion beam for FAIR as well as allow the SHE program to continue!

Sustainability

Save Energy, build HELIAC!

Power consumption
UNILAC vs. HELIAC
for identical particle number on target)

HELIAC (sc): A/Z= 6, 7.5 MeV/u, **cw-operation**

UNILAC (nc): A/Z 26 (HSI), A/Z = 6 (poststripper), 7.5 MeV/u (A3-intermediate energy/7.1 MeV/u +3xERs), **30% RF-duty factor**

For typical beam time:

>90% less power consumption

(Energy savings for 6 months of operation (HELIAC vs. UNILAC) ≈ 16.4 GWh)

Energy savings for 6 months UNILAC-experiment (vs. 1.5 months/HELIAC)≈ 20 GWh

Summary: achievements

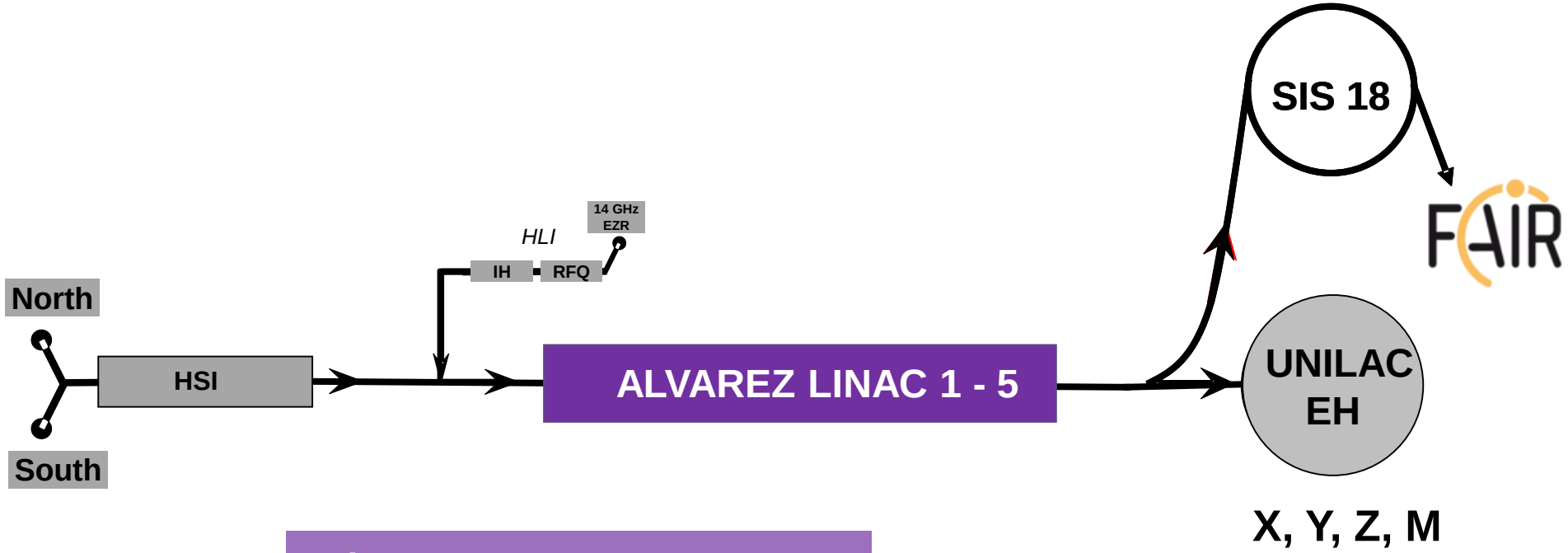
- The unique HIM infrastructure is used to process superconducting RF cavities and assemble complete accelerator strings.
- Cavity (CH0) successfully tested under cryogenic conditions with beam at GSI in 2017.
- Cryostat (CM1 equipped with the original sc solenoids) successfully tested with beam at GSI in 2020.
- At GSI a unique environment for beam testing of HELIAC superconducting cryomodules is available.
- Cryogenic supply system for future HELIAC operation is available from the STF.
- ALL key components of the first fully equipped HELIAC cryomodule are available in full function

HELIAC could be ready in 2028!

Outlook

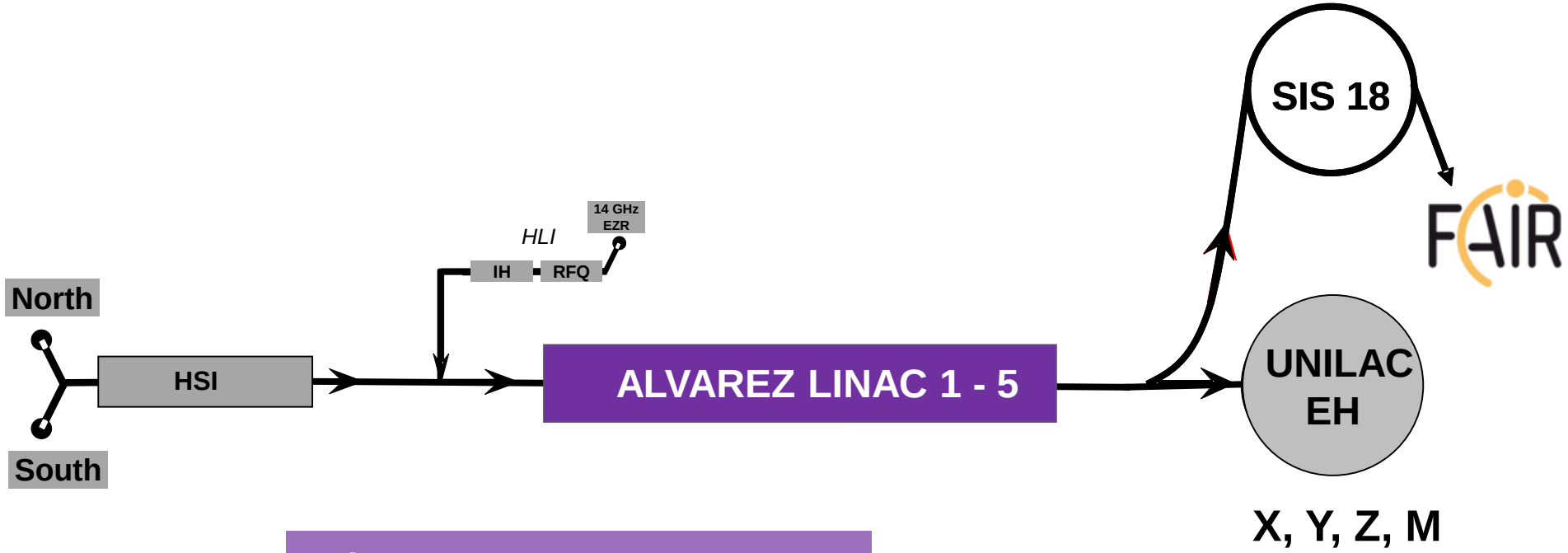
- HELIAC has been optimized for the needs of the low-energy users within NUSTAR (e.g. superheavy elements) and APPA (e.g. materials science and biophysics).
- HELIAC operation can start in 2028, if civil construction starts in 2025.
- A HELIAC starter version has been defined, that can provide heavy ion beam for FAIR as well as allow the SHE program to continue.
- Save Energy, build HELIAC to reduce operating costs!
- HELIAC should become part of the FAIR injector strategy to…
  - mitigate the gap induced by the PSU installation
  - mitigate the risk of UNILAC failure
  - serve the low-energy of NUSTAR and APPA in a sustainable way

UNILAC (2023)



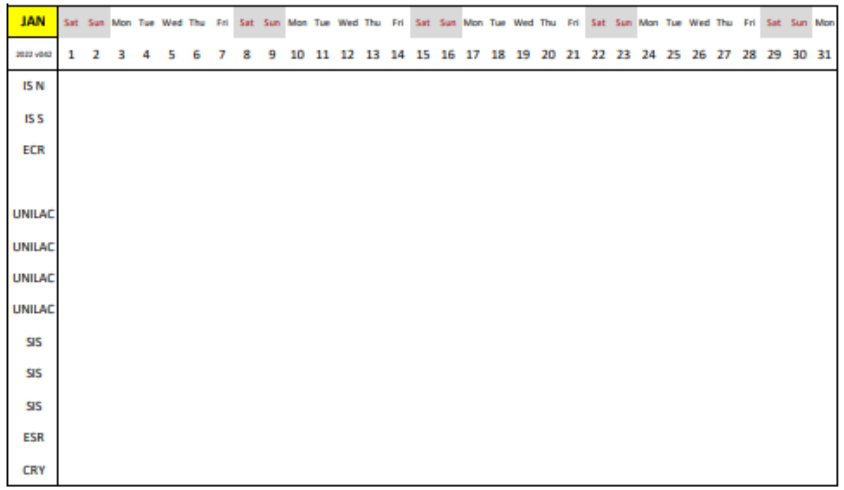
A/q ≤ 8.5, 50 Hz, 5 ms
W_{kin} = 3.6 - 12.5 MeV/u

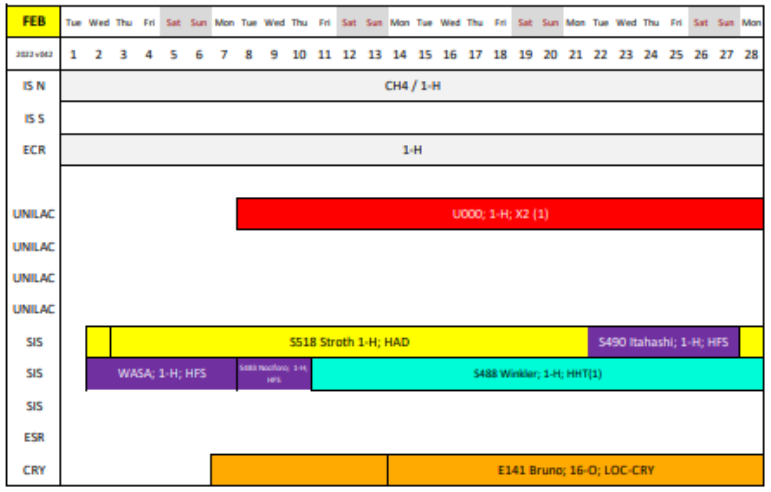
UNILAC (2028)



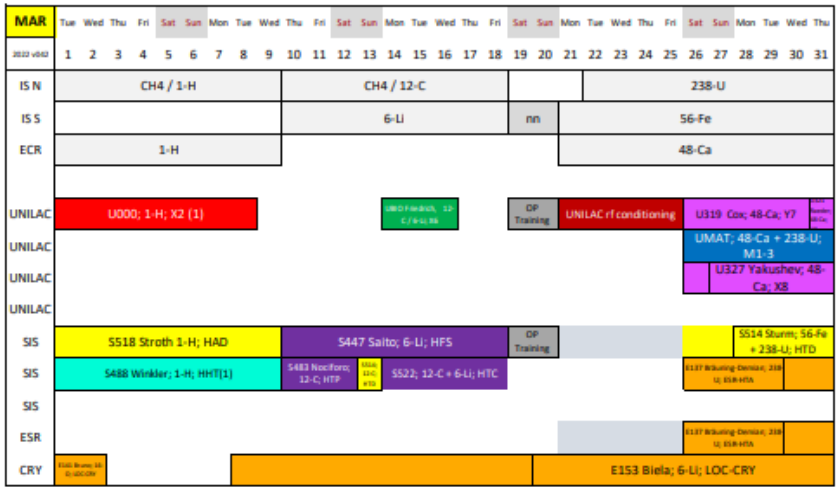
A/q ≤ 8.5, 5 Hz, 1 ms
W_{kin} = 3.6 - 12.5 MeV/u

Beam Time 2022

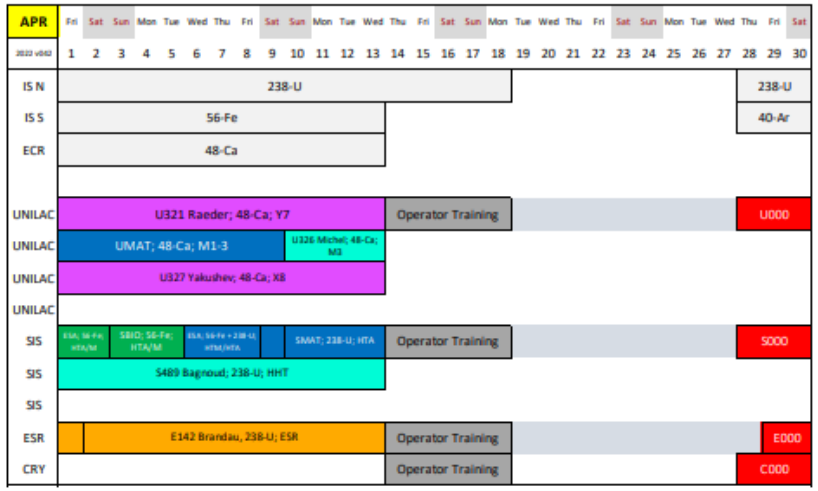


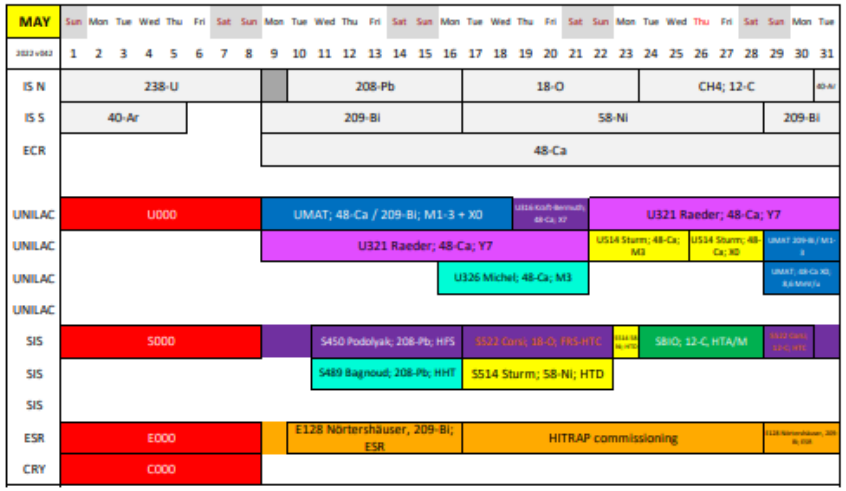


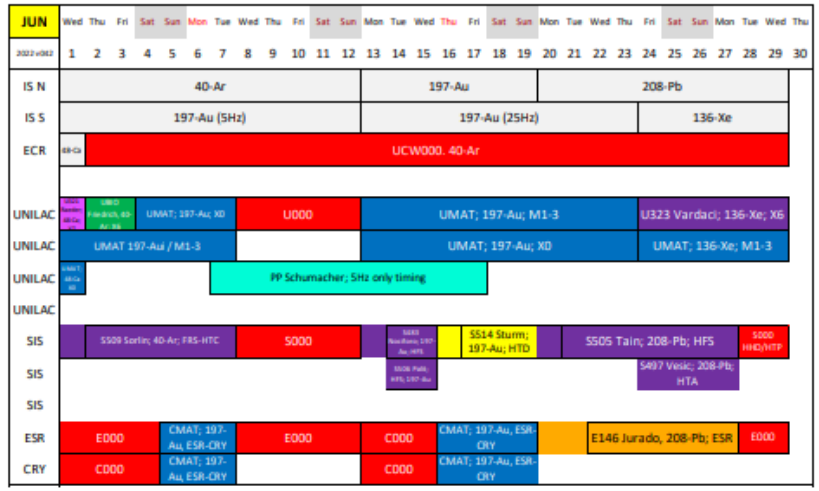
(1) only if parallel operation possible /// (2) only block mode



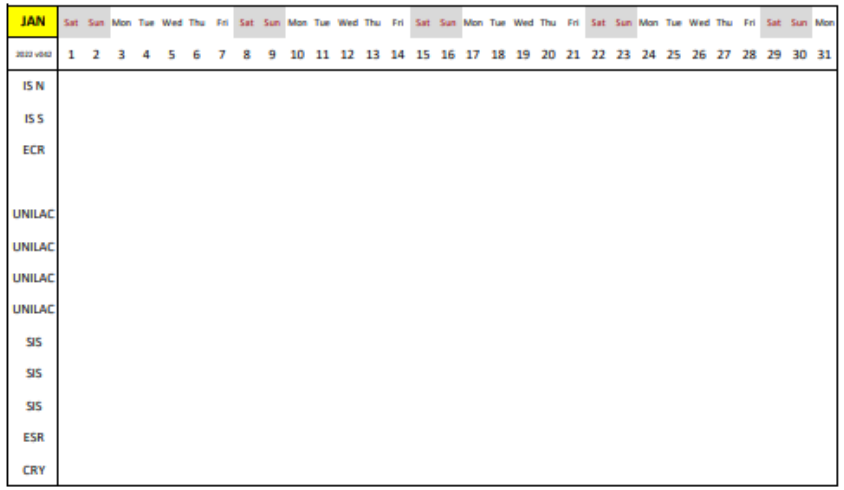
(1) only if parallel operation possible /// (2) only block mode

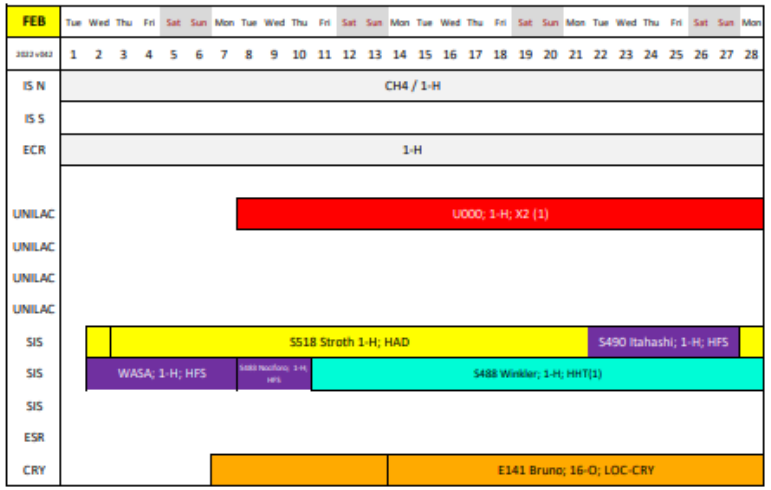




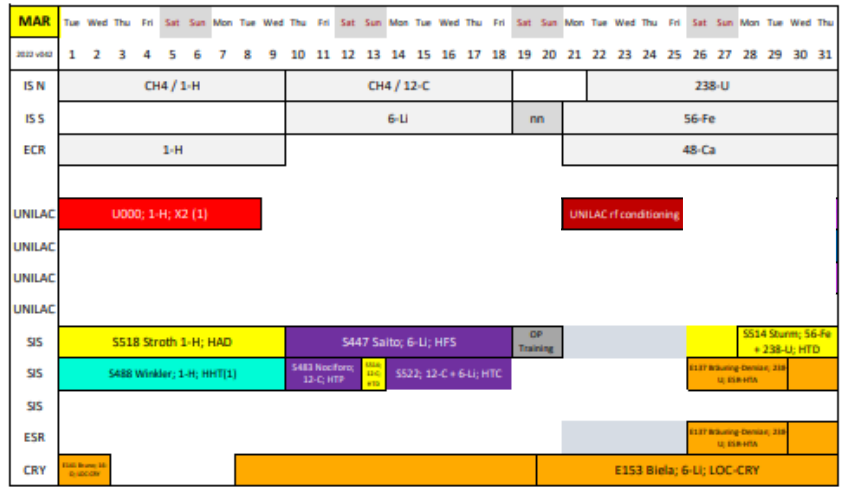


Beam Time 2022

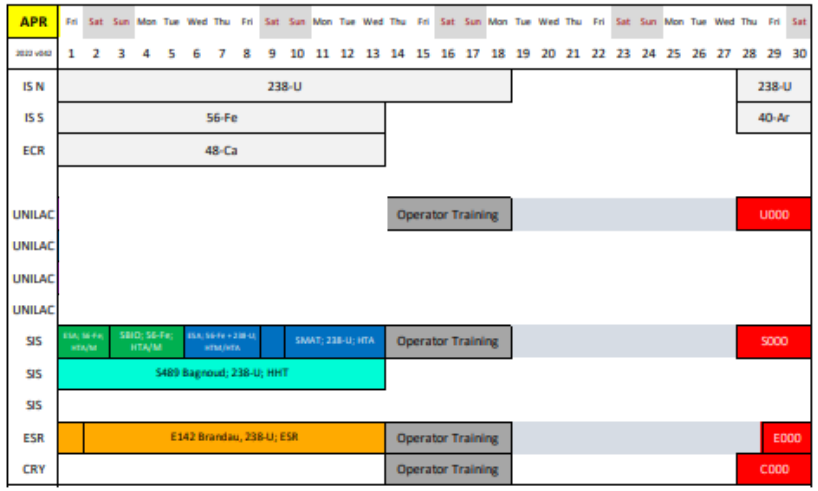


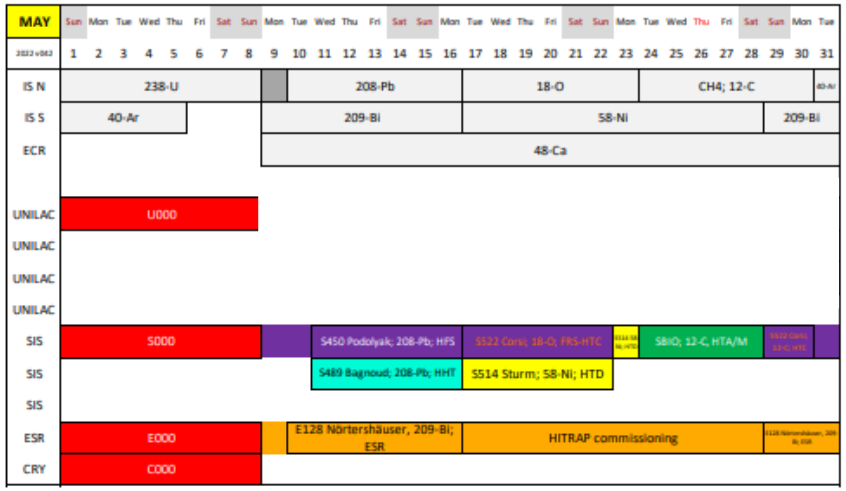


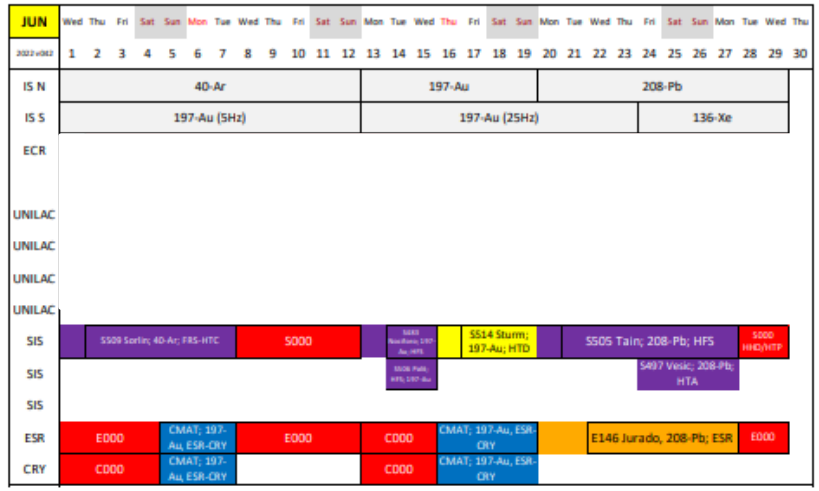
(1) only if parallel operation possible /// (2) only block mode



(1) only if parallel operation possible /// (2) only block mode

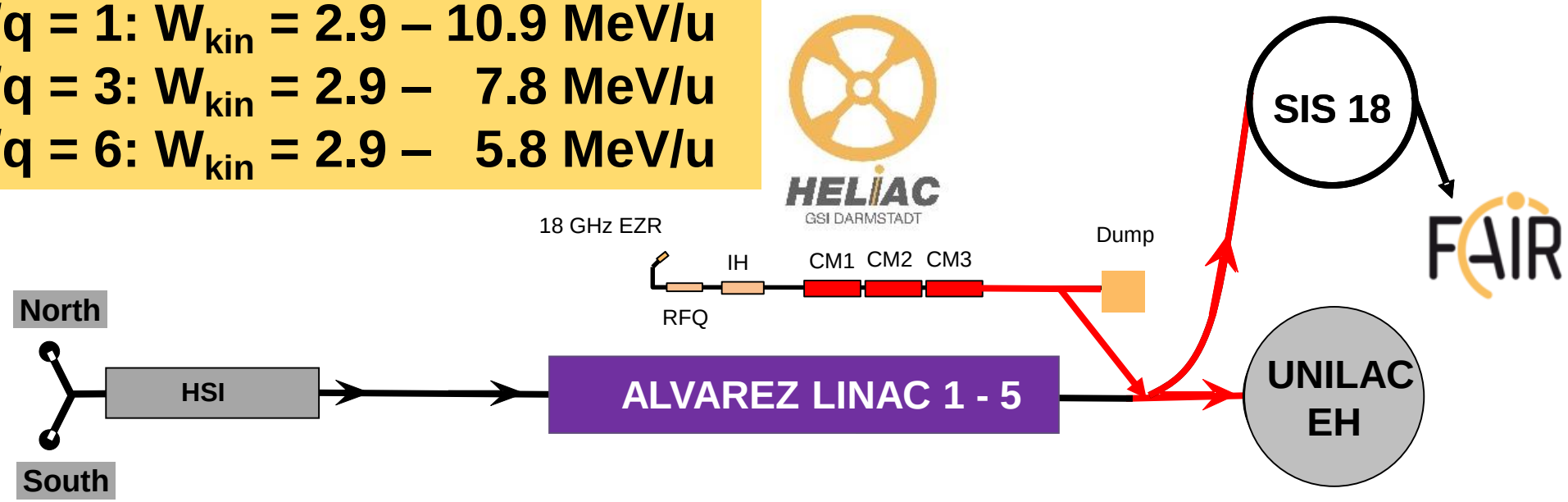






cw-Linac@SH2/3 (>2028)

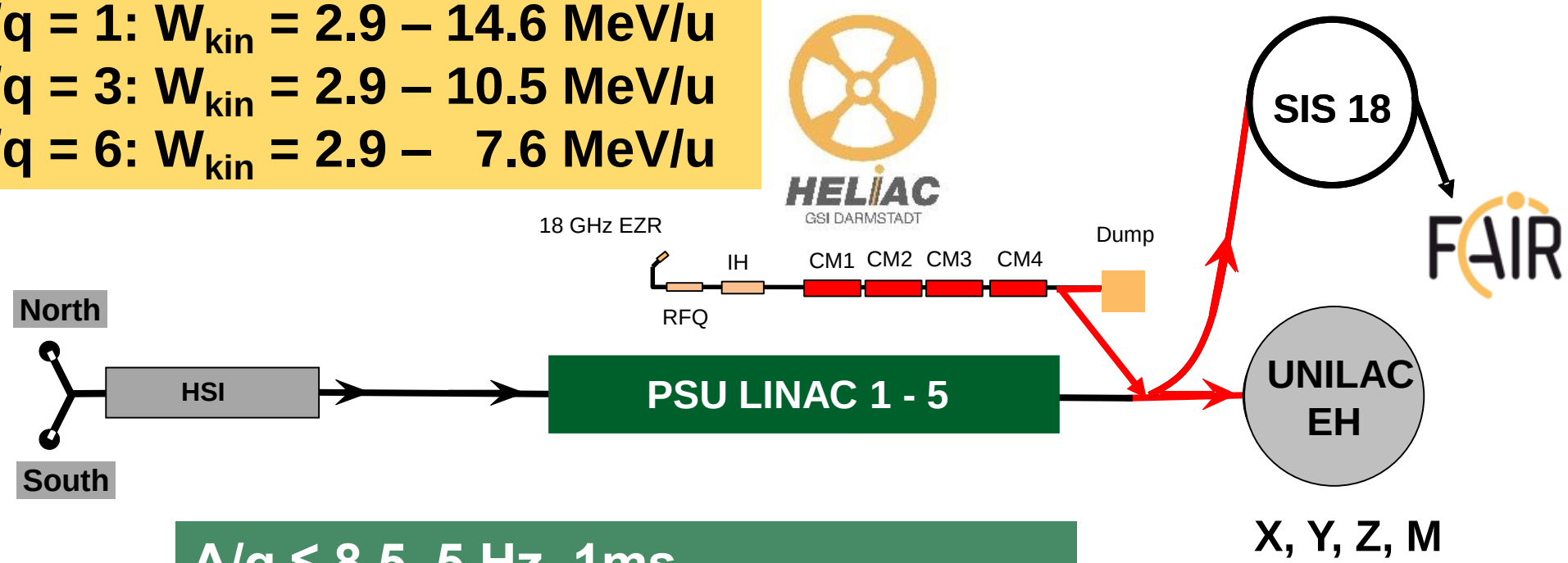
50 Hz, 5ms
A/q = 1: W_{kin} = 2.9 – 10.9 MeV/u
A/q = 3: W_{kin} = 2.9 – 7.8 MeV/u
A/q = 6: W_{kin} = 2.9 – 5.8 MeV/u



A/q ≤ 8.5, 5 Hz, 1ms
W_{kin} = 3.6, 4.8, 5.9, 8.6, 11.4 MeV/u

cw-Linac@SH2/3 (>2030)

50 Hz, 20ms (c.w.)
A/q = 1: W_{kin} = 2.9 – 14.6 MeV/u
A/q = 3: W_{kin} = 2.9 – 10.5 MeV/u
A/q = 6: W_{kin} = 2.9 – 7.6 MeV/u



A/q ≤ 8.5, 5 Hz, 1ms
W_{kin} = 3.6, 4.8, 5.9, 8.6, 11.4 MeV/u

Thank you for attention!

Attachments

Conclusions of the Retreat of FAIR/GSI Research

19-21 Jan 2021

Input to the discussion on linear accelerators

The GSI/FAIR research division is concerned about the situation that may occur after the end of operation of the UNILAC linear accelerator according to current planning. On the one hand, at times where SIS100 is in full operation and commissioning of the FAIR facilities and first FAIR experiments with SIS100 are in full swing, an upgrade of the UNILAC will interrupt further beam operation for an extended period of up to two years. On the other hand, this will end the various, highly visible programs that use the long-duty cycle beams in superheavy element research and a significant part of the materials research activities. **Both problems are best mitigated by the timely installation of a minimal configuration of a cw-linac (HELIAC) delivering long-duty cycle beams in a configuration that comprises a new (18 GHz) ECR ion source and Low Energy Beam Transport Line, the existing 25%-duty-cycle injector and three accelerator cryomodules and its link to the existing beam transport system behind UNILAC. This configuration will provide heavy ion beams of sufficient energy and duty cycle that can be injected into SIS18 and serve a compelling science program in superheavy element research, except for new element search, and a significant part of the materials research program.** A cw-linac configuration with two cryomodules is not a viable option as the resulting beam energy is too low. The minimum configuration cw-linac would not only provide a second heavy-ion injector to increase the operational flexibility but could also serve as backup injector for FAIR commissioning/operation during the installation of the post-stripper upgrade, currently foreseen to start in 2028. Without this three-module based cw-linac, the FAIR experiments cannot be served with heavy-ion beams for about two years limiting experiments in the planned FAIR Phase-1. A fourth module and/or a pre-accelerator would further enhance the capability significantly.

Clean Room Infrastructure @ HIM

The unique HIM infrastructure is used to process superconducting RF cavities and assemble complete accelerator strings!

Unique infrastructure for SRF R&D@HI-Mainz

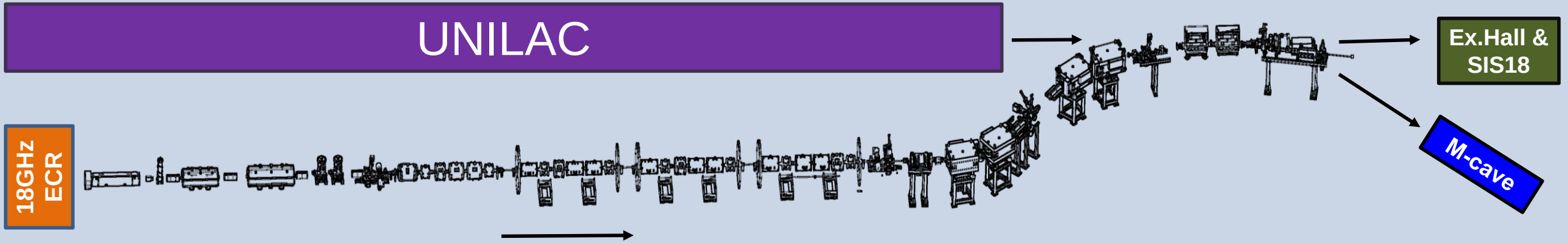
- 2 interconnected clean rooms: 42m^2 (ISO6)+42m^2 (ISO4)
- Ultra high purity water supply (18MΩ/cm)
- Ultrasonic bath and conductance rinse (outer surfaces preparation)
- High Pressure Rinse (HPR) applying 100 bar-removal of particulates & contamination from inner surfaces of vacuum bellows, cavities, solenoids …..
- Weekly cleaning by external company
- Ready for cryomodule assembly!

ISO 6 Clean Room

ISO 4 Clean Room

Funding/Basic approach

Funding for major parts of HELIAC secured via HIM and third-party funding. Funding for ECR, transport beamlines and civil construction of tunnel lacking, Manpower required!



- HELIAC designed to fit into existing SH2/SH3 → available
- Feasibility study for civil → construction/tunnel?
- STF cryogenic plant for supply of HELIAC → *available*
- *ECR 14GHz+LEBT → from existing GSI-HLI*
- RFQ → old HLI RFQ (25% duty) → on stock
- IH1/IH2 in manufacturing → HGF-Innov. Pool
- CM1 is in assembly/testing → HGF-PoF3 (ARD)
- CM2 is in manufacturing → HGF-PoF4 (ARD)
- CH-Cavities for CM3 are in manufacturing → BMBF
- CM3-remaining components → EFRE-EU/Hessen?
- Bending magnets from GSI-stock, power supplies to be ordered
- Most of beam line magnets on GSI-stock, most of power supplies to be ordered
- For „basic approach“ (25% duty) reuse of existing high power rf-amplifiers
- Requires the planning i.e. manpower now!