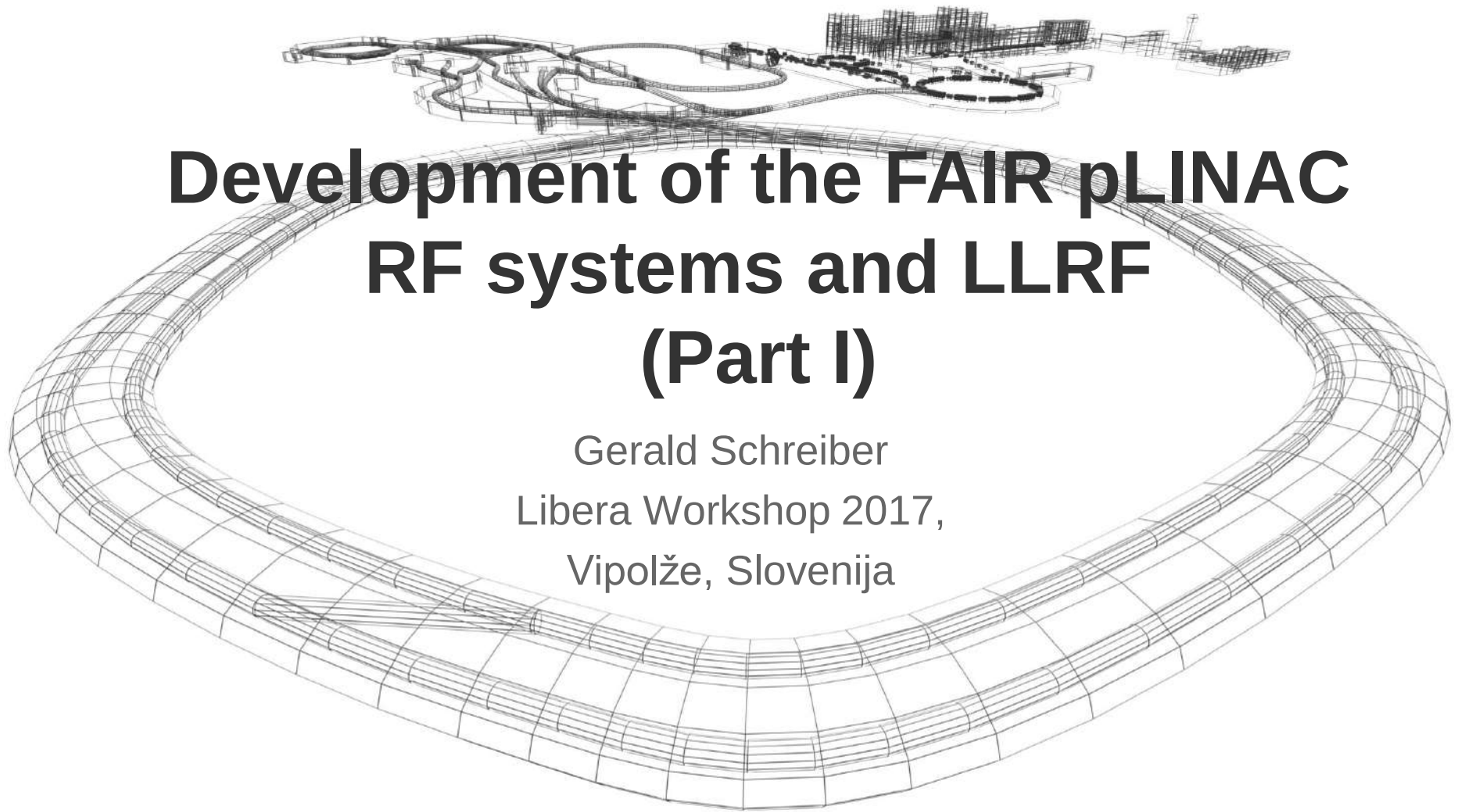


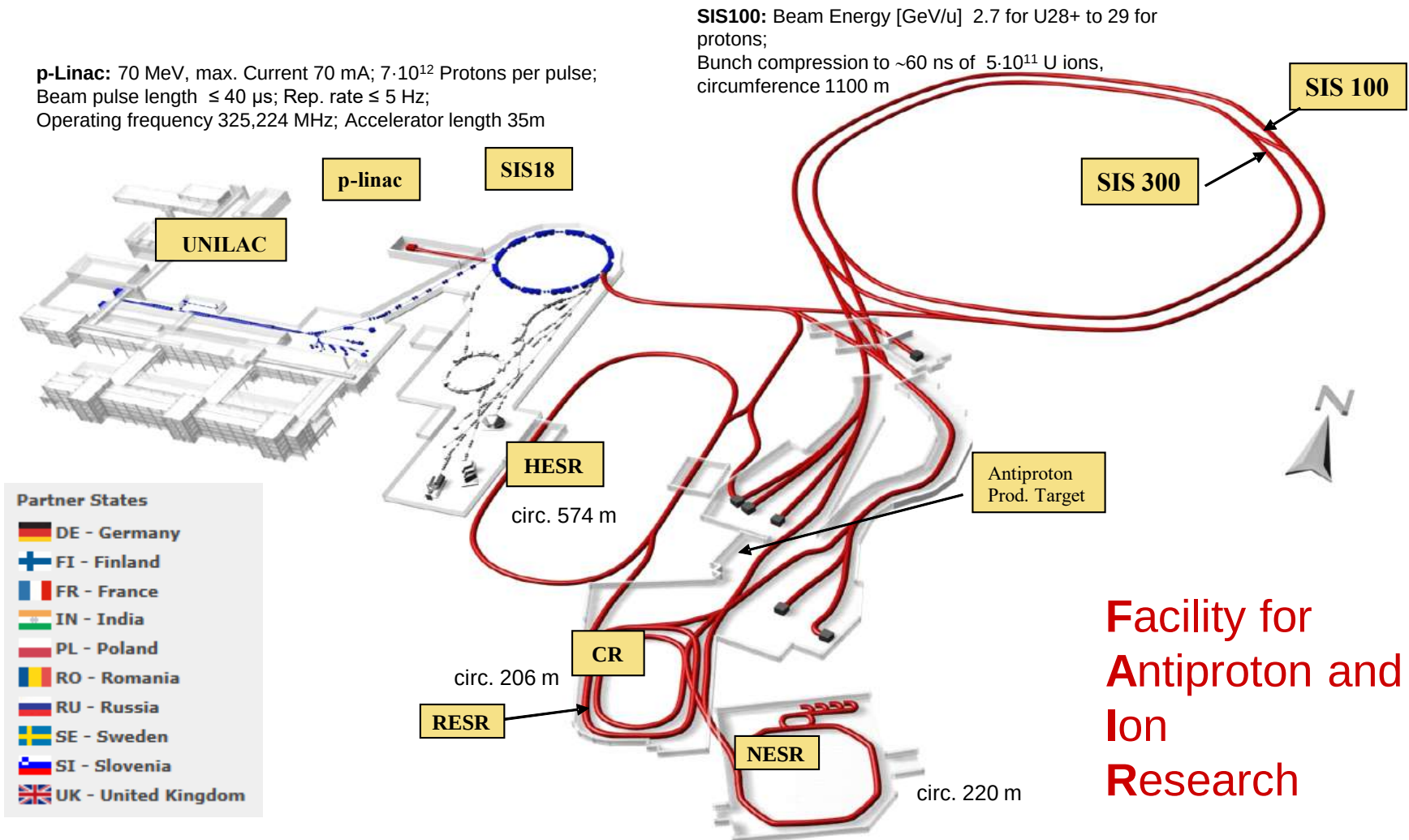
A 3D wireframe model of the FAIR pLINAC and LLRF systems. The model shows a large, curved, and segmented structure, likely representing the particle accelerator's components. In the background, there are smaller, more complex structures that appear to be part of the overall facility.

Development of the FAIR pLINAC RF systems and LLRF (Part I)

Gerald Schreiber
Libera Workshop 2017,
Vipolže, Slovenija



Existing GSI facility



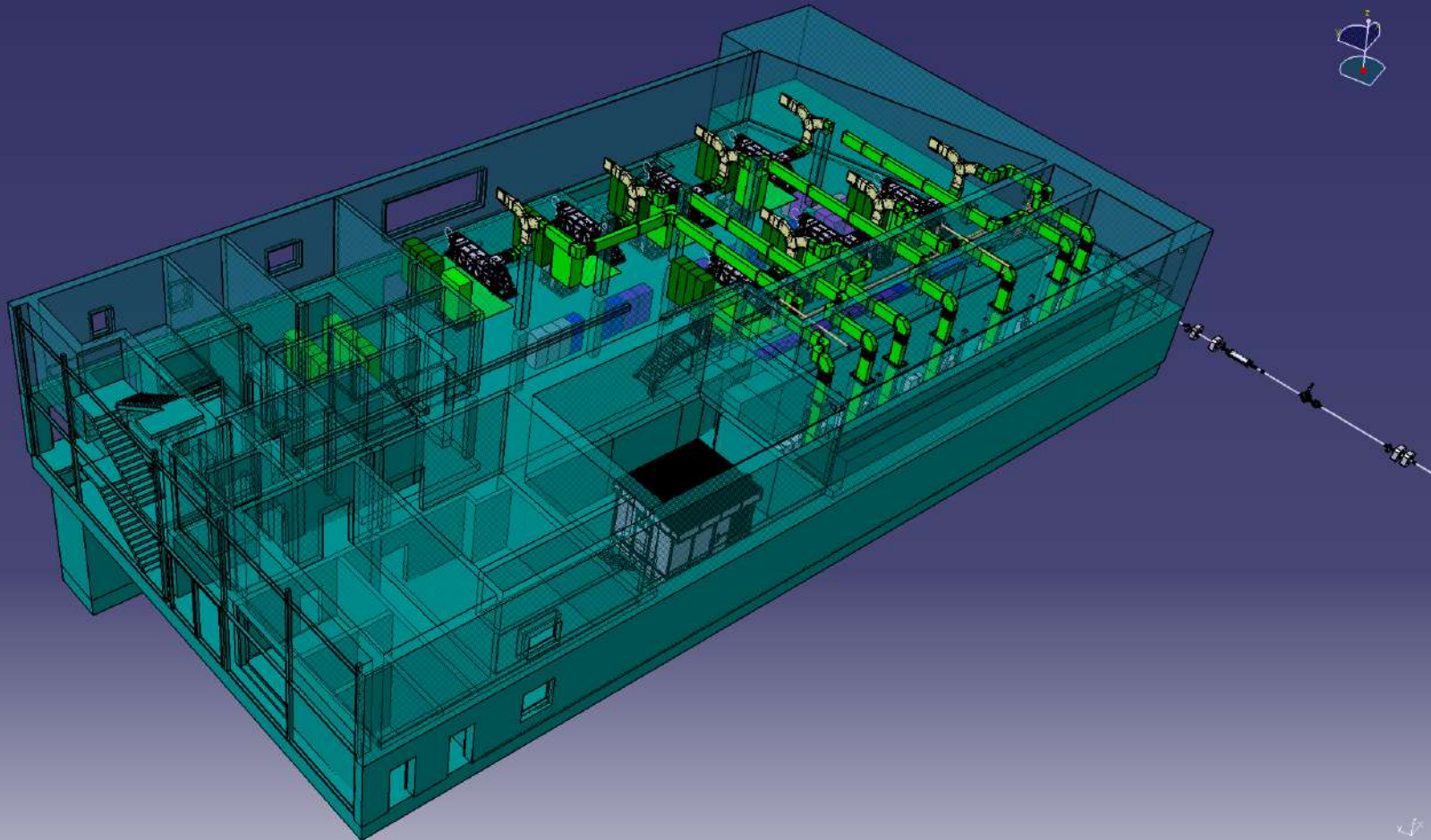


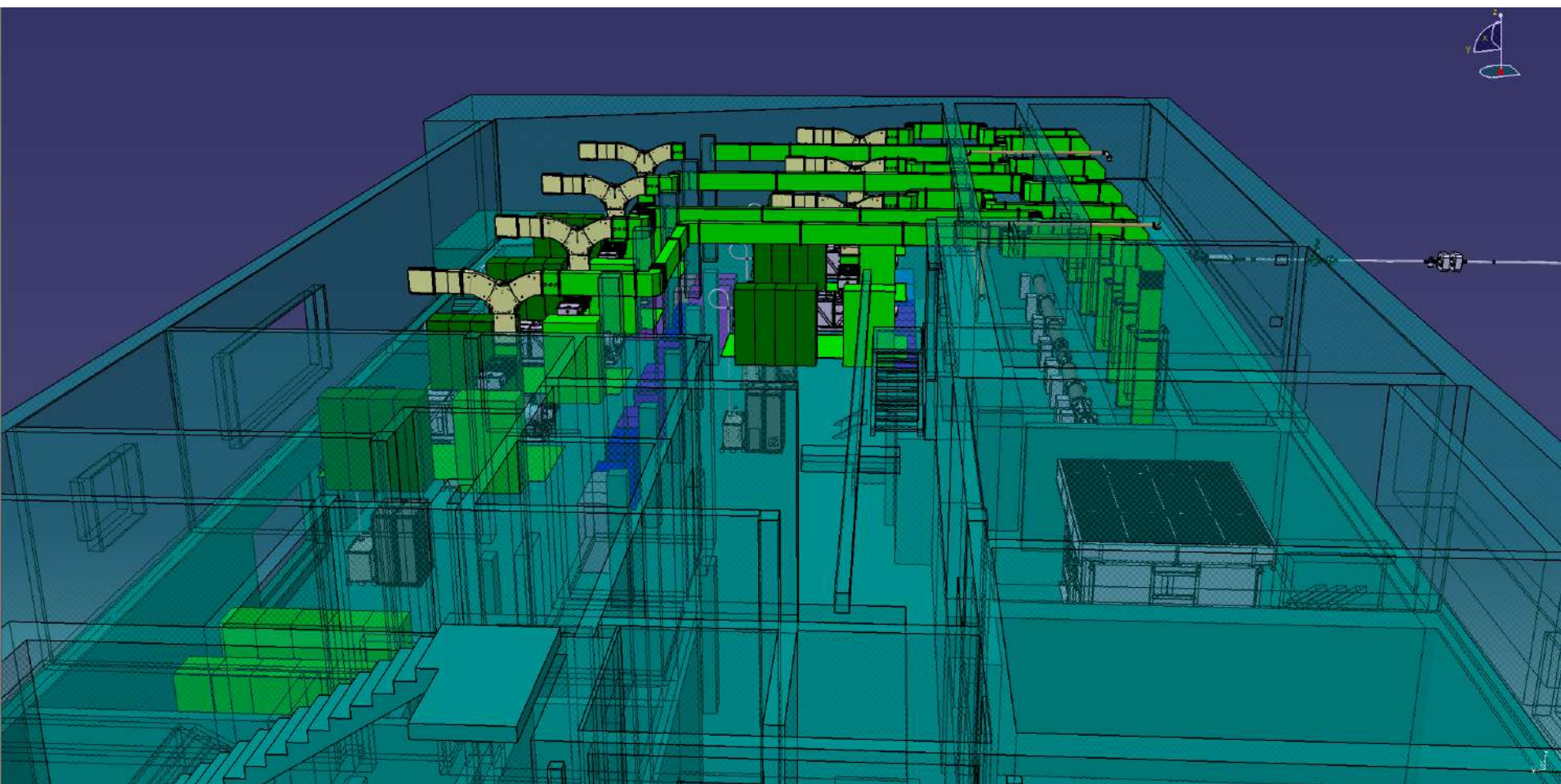


The future...

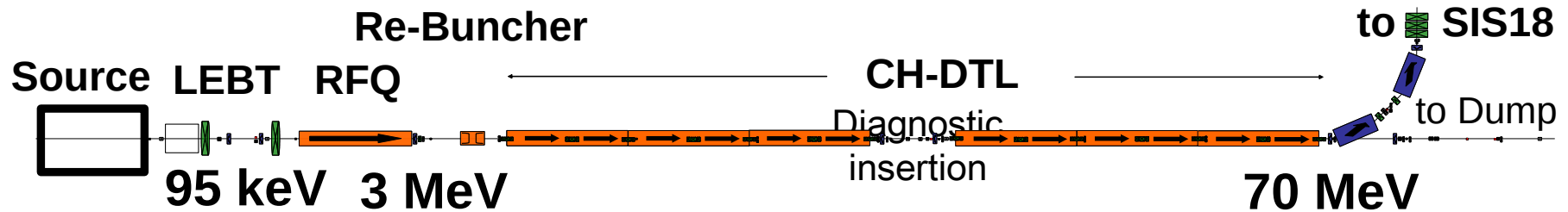


planned p-Linac Building





Inkind Contribution to the p-Linac RF Systems	Components
Germany (GSI)	Fast interlock system, PLC, RF Detectors, Cabling, Modulators, Circulators, Power Lines, Couplers, Main Control, <i>complete system integration</i>
France (CNRS)	Klystrons (Thales), RF Wave Guide Loads (AFT), 45 kW Amplifiers (Buncher)
Slovenia (Tehnodrom)	LLRF Digital Amplitude and Phase Control and Control System Integration (Instrumentation Technologies and Cosylab)



- ECR proton source & LEPT
- RFQ
 - 1 Klystron (~1.5 MW)
- 3 re-bunchers
 - 3 Solid State Amplifier (~45 kW)
- 6 * 2 accelerating cavities (CH-DTL)
 - 6 Klystrons (up to 2.5 MW)
- 2 dipoles, 45 quadrupoles, 7 steerers
- 10 turbo pumps, 34 ion pumps, 9 sector valves
- 41 beam diagnostic devices

Beam energy	70 MeV
Beam current (op.)	35 mA
<i>Beam current (des.)</i>	<i>70 mA</i>
Beam pulse length	36 μ s
Repetition rate	< 5 Hz
RF-frequency	325.224 MHz
Tot. hor emit (norm.)	2.1 / <u>4.2</u> μ m
Tot. mom. spread	$\leq \pm 10^{-3}$
Linac length	≈ 35 m

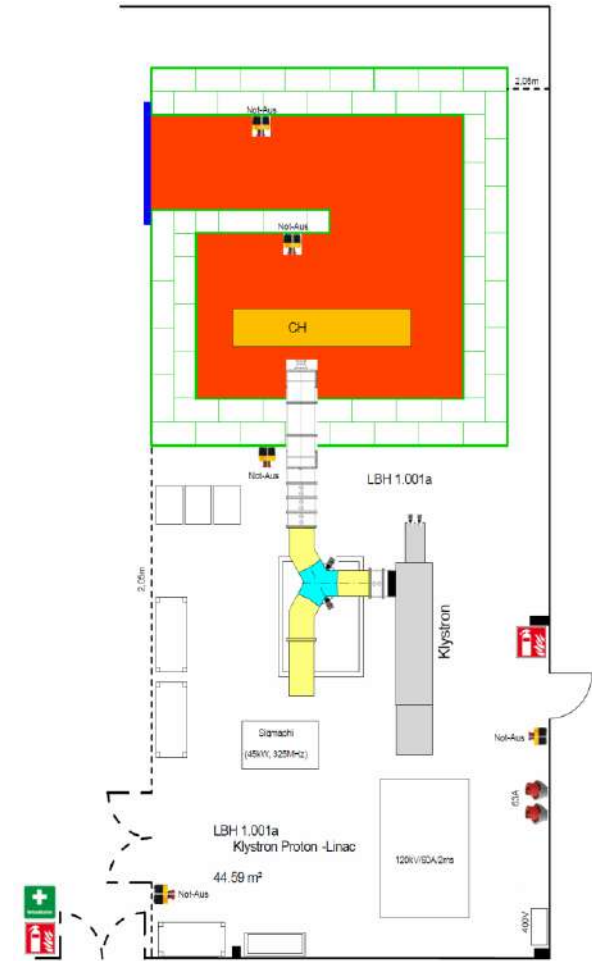
$\Rightarrow$ Total: 10 RF Systems



shielded
area for
cavities



RF amplifiers
and power
supplies





RF Test Stand with cavity bunker
Thales TH2181 klystron, Circulator, RF wave guide load (up to 3 MW pulsed), low-level control racks including fast interlock system, ARC detection system (AFT), slow-interlock system (PLC)

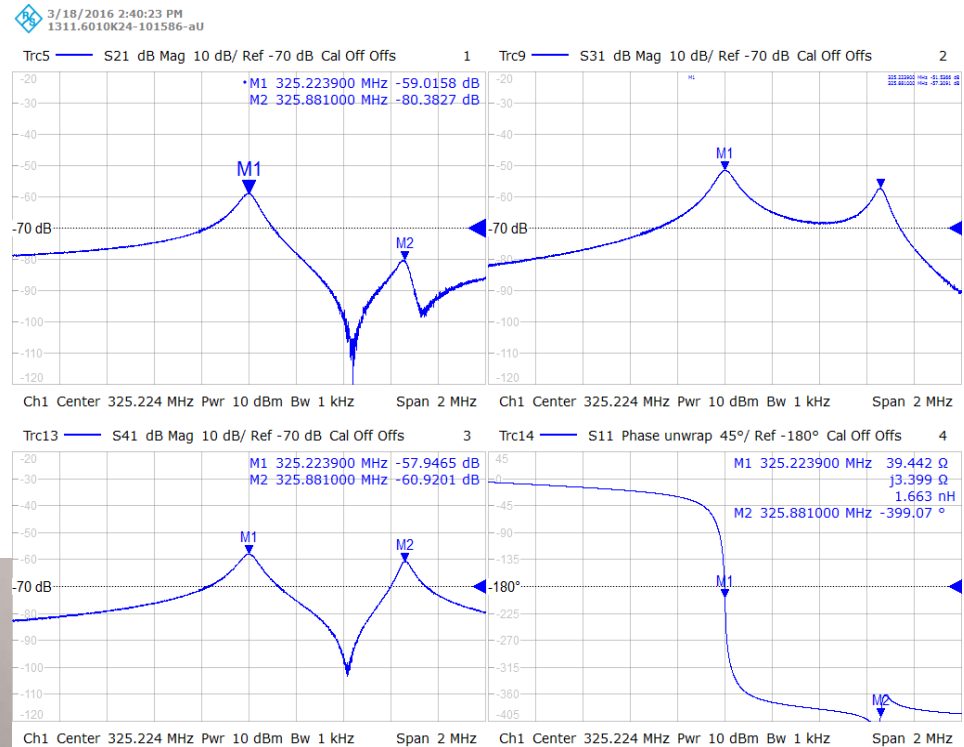
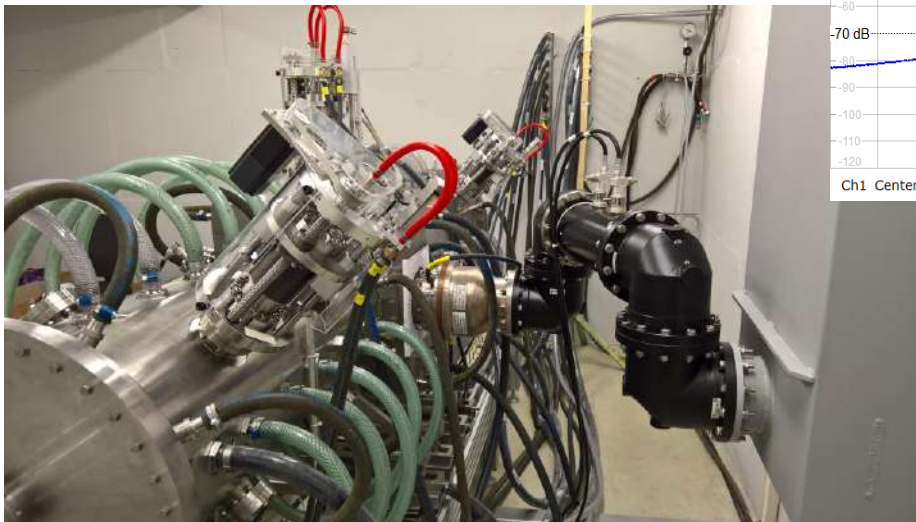
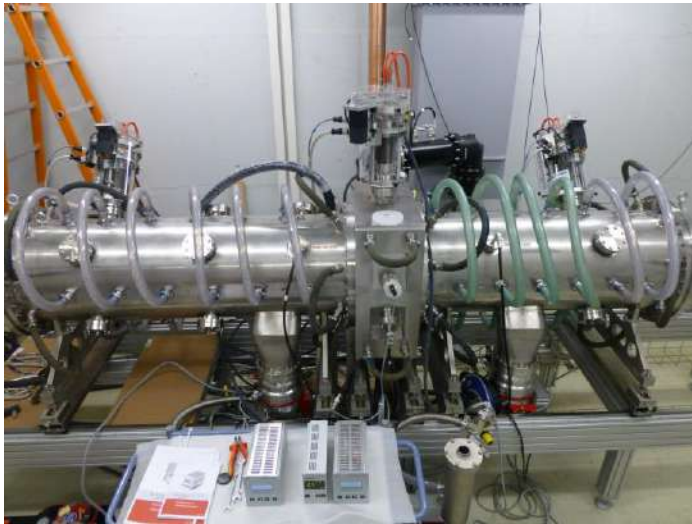




PLC Rack

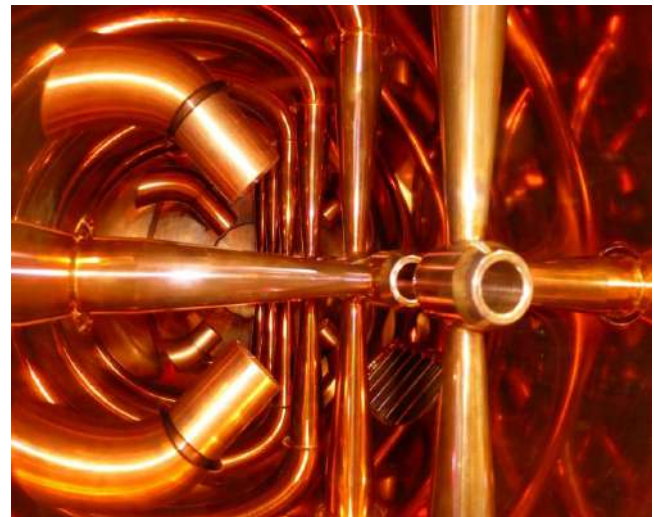
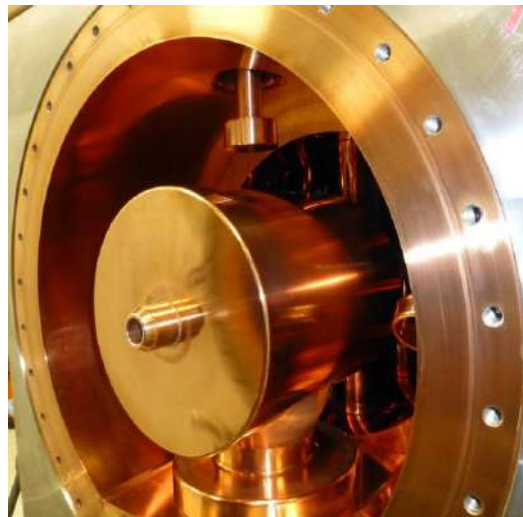
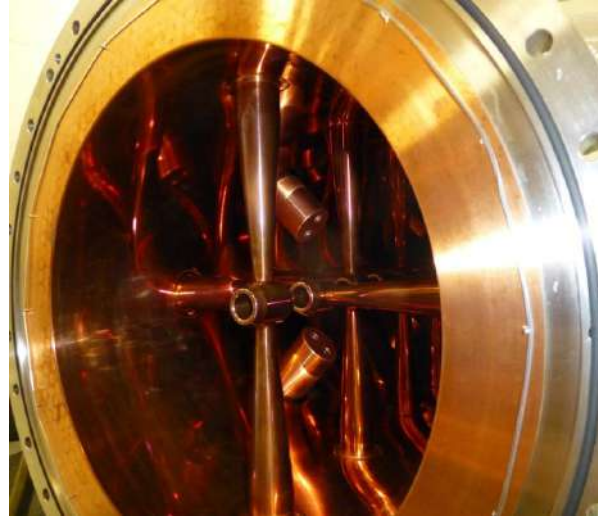


Resonant Frequency Control with stepper motor controllers, ARC detection system, fast interlock system and measurement, master oscillator, power meters and 300 W klystron driver

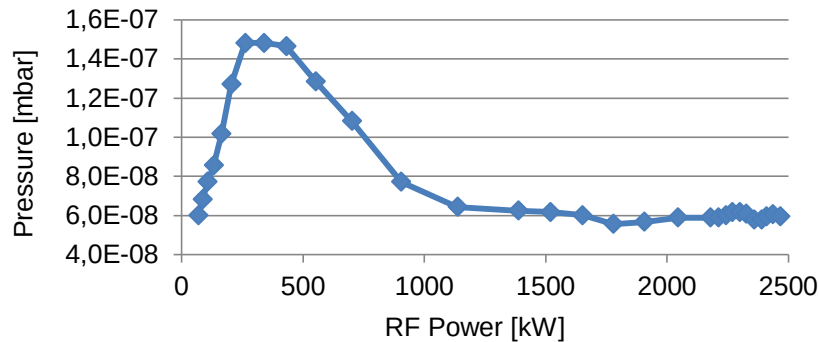


Coupled CH Cavity Prototype Cavity by IAP
University of Frankfurt

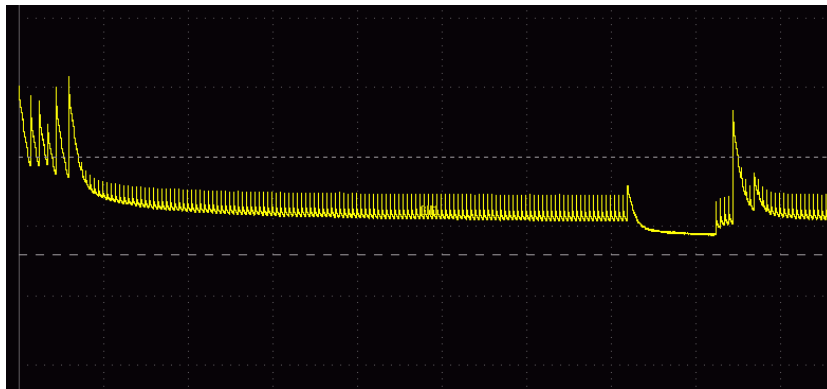
Calc. RF power for design field: 1.35 MW
Calc. RF power for beam load: 885 kW



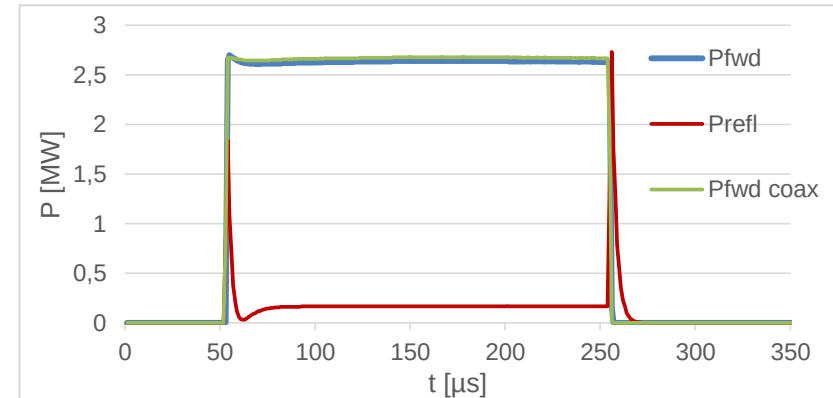
CH Cavity after copper plating at GSI (in-house)



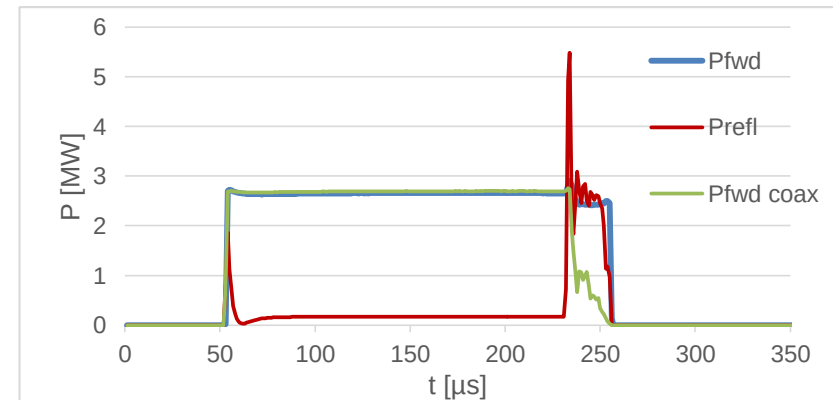
Minimum measured cavity vacuum pressure depending on the RF power shows a typical increase at lower cavity fields (might be improved with longer conditioning time).



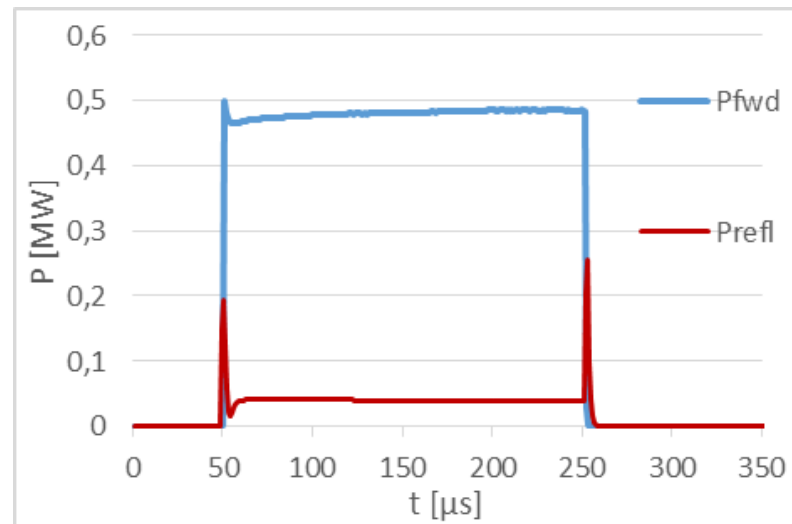
Vacuum signal during conditioning (10 s/div), fast interlock threshold at $5 \cdot 10^{-7}$ mbar



RF pulse after conditioning: forward and reflected power at the waveguide directional couplers (blue/red), forward signal at the coaxial directional coupler (green).



Cavity arcing short before the end of the RF pulse, the coaxial coupler is located near the cavity input coupler (green), forward and reflected signal in the wave guides (blue/red) between circulator and cavity.



A proposal for a possible FAIR p-Linac ladder RFQ by IAP University of Frankfurt. 0.8m prototype RFQ section with coaxial RF power line and with movable tuner tested in the GSI test stand bunker.

Power losses for the design field strength are calculated with 94 kW. Careful conditioning lead to a maximum power of 485 kW but showed some arcing in operation over several hours which did not vanish. After initial conditioning a stable operation in the order of 260 kW without arcing was possible.

Slovenian In-kind Contribution "LLRF":

- Amplitude, phase and resonance frequency control
- Control system interface (Data / Timing), FESA and White Rabbit



Parameter	value
Amplitude stability	$< \pm 0.15 \%$ (0.1 % RMS)
Phase stability	$< \pm 0.5^\circ$ (0.33 $^\circ$ RMS)
Latency from RF input to output	$< 1 \mu\text{s}$
RF pulse repetition rate	max. 5 Hz (nominal ~ 4 Hz)

Cavity start-up process	Untuned cavity state: reduced set values to avoid high reflected power Reaching tuned state: the output level is increased by a defined rate per pulse
RF pulse shaping	Configurable RF pulse rise time / pulse shape avoiding power overshoots
“Multi pulse operation”	Variation of amplitude and phase from pulse to pulse, “beam processes” / “virtual accelerators”
Local / Remote operation	Manual set values by a local graphical user interface (GUI)
Expert GUI	Parallel to remote control by FAIR central control system
LLRF internal monitoring & interlock	Monitor & interlock the integral output power, maximum forward and reflected power
External interlock	Fast suppression of RF output pulses by a fast external RF interlock (reaction time < 5µs)
Feed forward implementation	Heavy beam load expected
Timing / Pulse Generation	Integration of the FAIR timing receiver (FTRN)

Part II

Borut Baričević,
Instrumentation Technologies