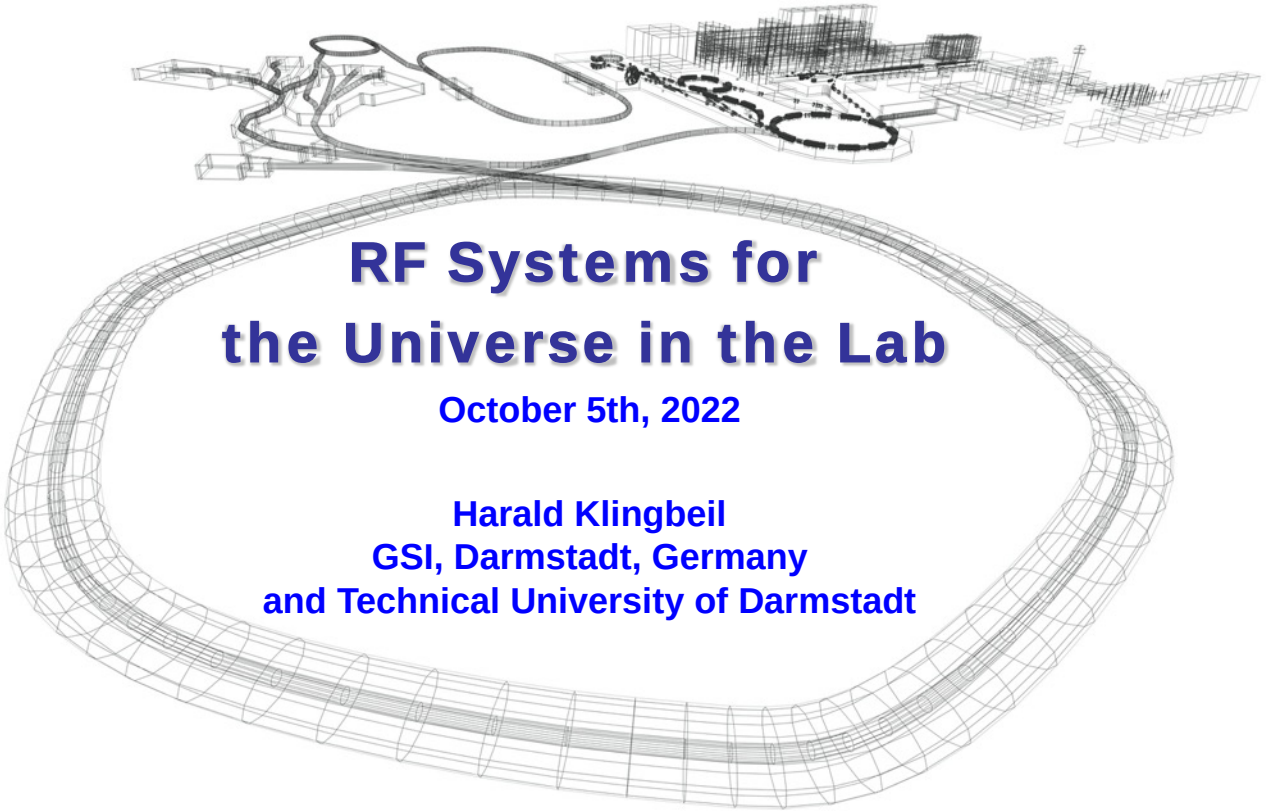
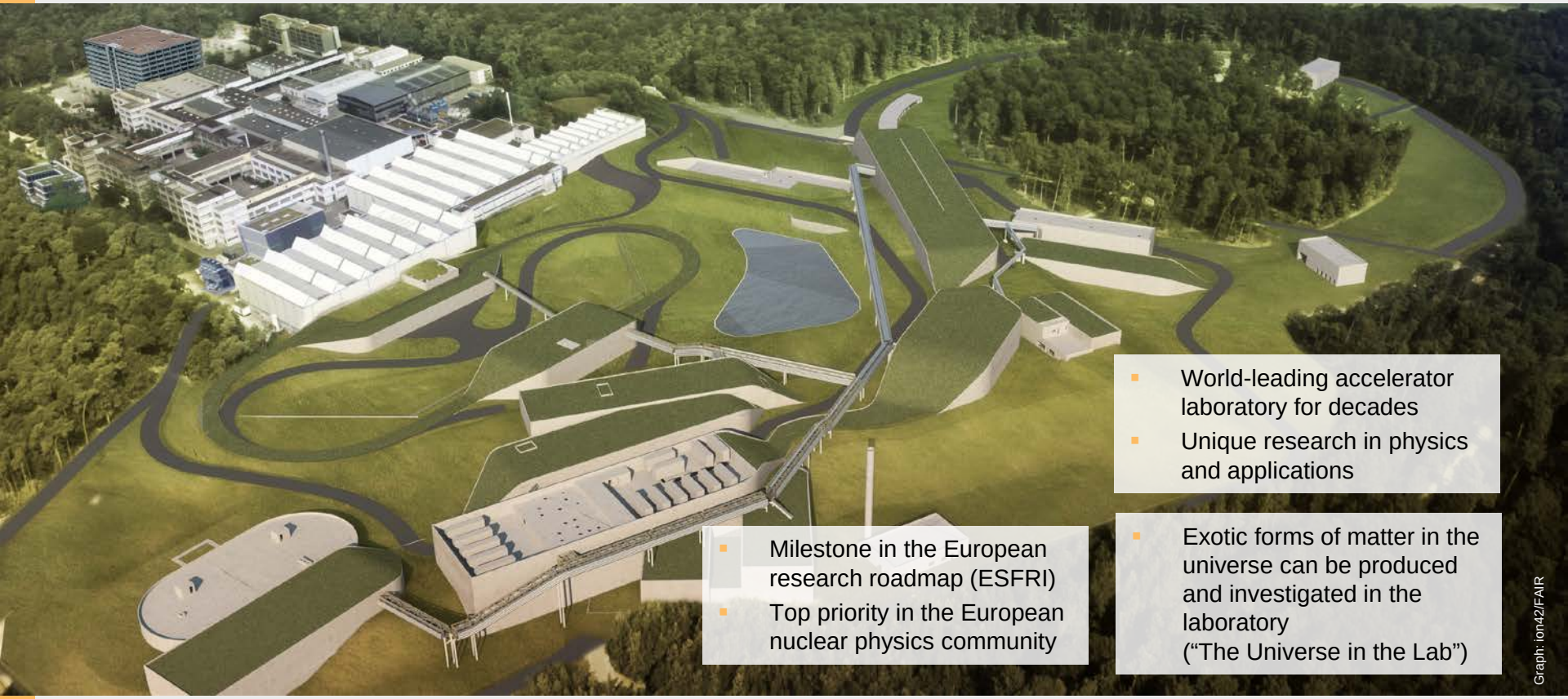


RF Systems for the Universe in the Lab

October 5th, 2022

Harald Klingbeil
GSI, Darmstadt, Germany
and Technical University of Darmstadt

FAIR – Facility for Antiproton and Ion Research



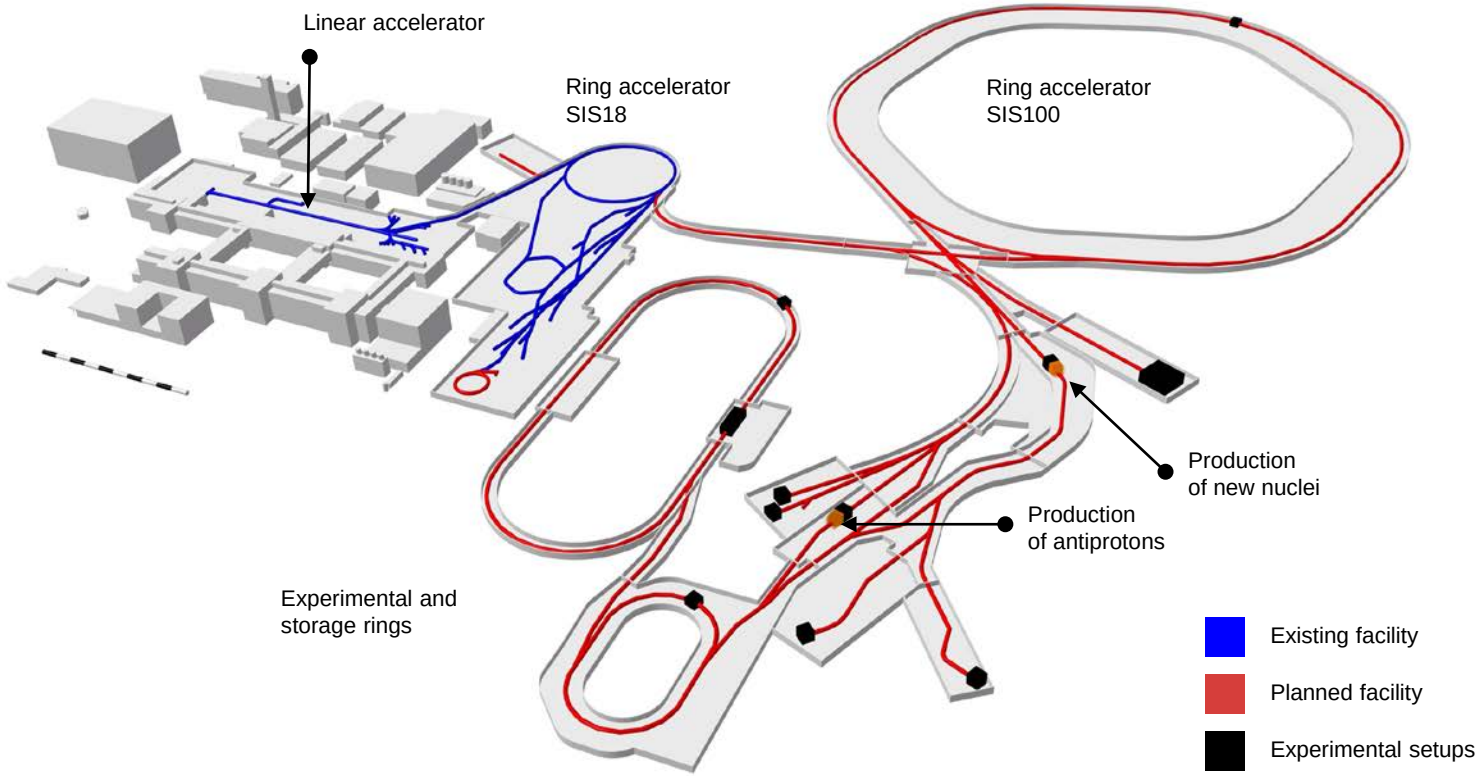
- World-leading accelerator laboratory for decades
- Unique research in physics and applications

- Milestone in the European research roadmap (ESFRI)
- Top priority in the European nuclear physics community

- Exotic forms of matter in the universe can be produced and investigated in the laboratory ("The Universe in the Lab")

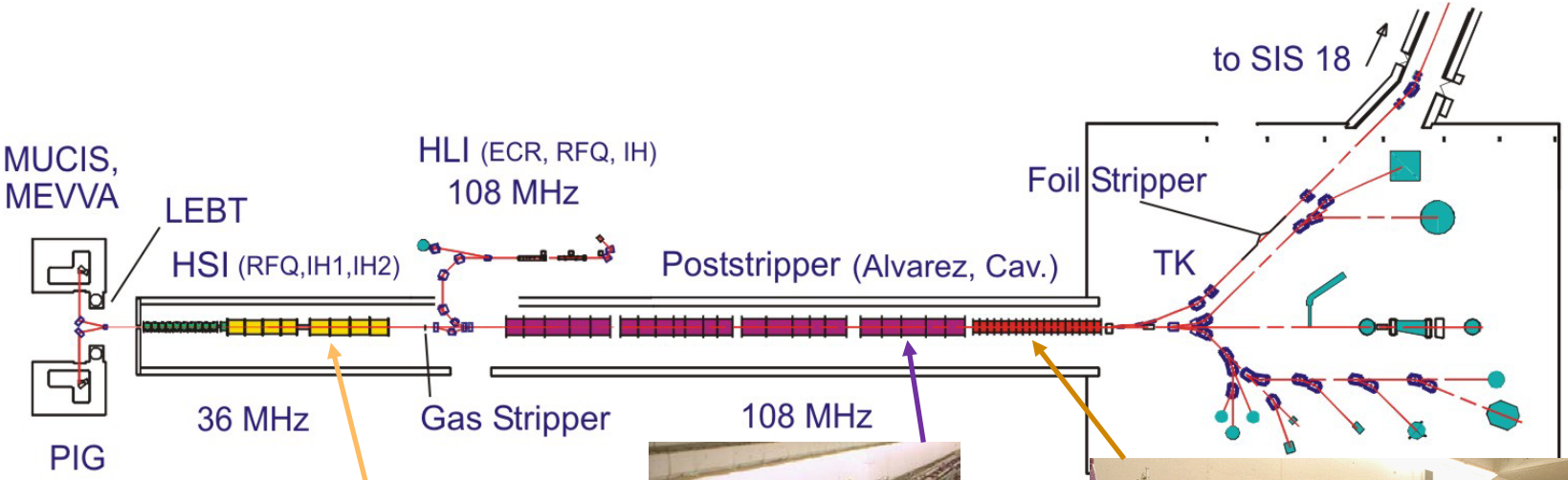
Graph: ion42/FAIR

FAIR

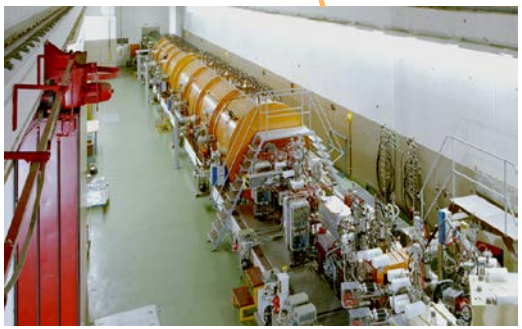


Graph: GSI/FAIR

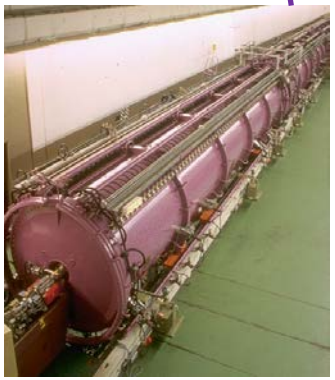
LINAC RF Structures



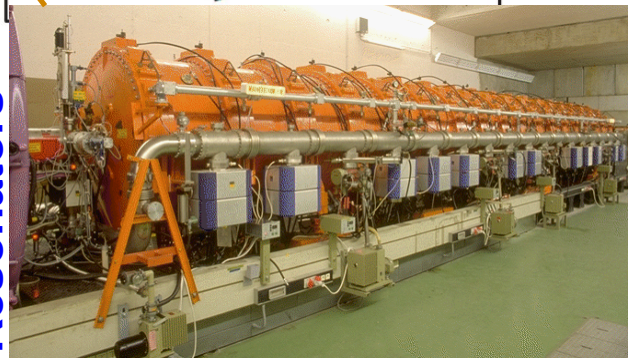
High Current Injector



Alvarez



Single Gap Resonators



Ring RF Cavities for FAIR
Example: SIS18 h=2 System

SIS18 h=2 cavities
(tetrode power amplifiers on top)

Platform for SIS18 h=2 power supplies (2nd floor),
mains distribution (1st floor),
and oil cooling system (ground floor)

Ring RF Cavities for FAIR

Ring	RF System	Frequency Range [MHz]	Voltage per Cavity [kV]	Duty Cycle	Length	Qty
SIS18 Upgrade	Ferrite cavities, h=4 Accel. h=2 Bunch Compression	0.85 ... 5.5 0.43 ... 2.8 0.8 ... 1.2	16 13.3 40	100% 100% 0.05%	3 m 1.2 m ≈1 m	2 3 1
SIS100 **2.8.4**	Accel. h=10 (Ferrite) Bunch Compression Barrier Bucket Long. Feedback	1.1 ... 3.2 0.310 ... 0.560 broadband broadband	20 40 2 x 15 12...15	100% 0.05% 20% 100%	3.0 m 1.2 m 1.3 m 1.3 m	14 9 2 2
CR **2.5.4**	Debuncher (RIB, anti-protons, incl. Bucket Generation)	1.10...1.25 (1.50) (pbar)	Pulsed: 40 (21) CW: 2 (1.35) (pbar)	0.06%	1.125 m	5
CRYRING	Existing Swedish system	0.135...2.4	0.15...0.35	100%	≈3 m	1
ESR	Ferrite cavity, h=2 Barrier bucket cavity	0.85 ... 5.5 broadband	5 0.6 (2 pulses)	100% 50%	1.68 1.13	1 2 in 1

Ring RF Cavities for FAIR

SIS100 Acceleration
(RI Research Instruments GmbH)

SIS100 Bunch Compression
(Aurion Anlagentechnik GmbH)

CR Debuncher
(RI Research Instruments GmbH)

General Statements

LINAC RF Systems

- Fixed frequency (36 MHz, 108 MHz, 216 MHz, 325 MHz)
- Mixed pulse operation (different shapes of subsequent pulses)
- 50 Ω impedance matching, long (up to 80 m) coaxial lines (up to 9 3/16 inches diameter for pLINAC) from power amplifier to cavity/RF structure

Ring RF Systems

- Ramped frequency, ramped amplitude, ramped phase
- Power amplifier as part of the cavity, no 50 Ω impedance matching between power amplifier and cavity (only from driver amplifier to power amplifier)
- Cavities loaded with ferrite or magnetic alloy ring cores

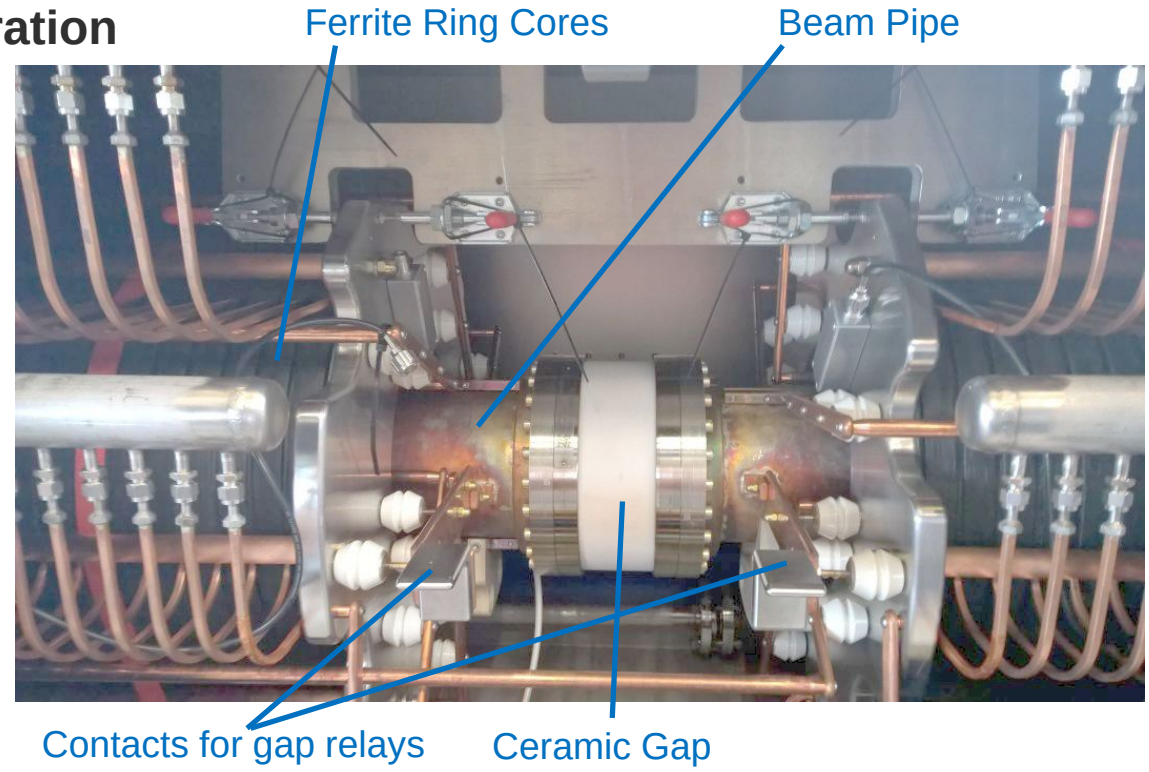
General Aspects

- Typically, tetrode power amplifiers are used due to power and frequency range (and radiation hardness for Ring RF cavities)
- Driver amplifier stages needed to feed power amplifiers

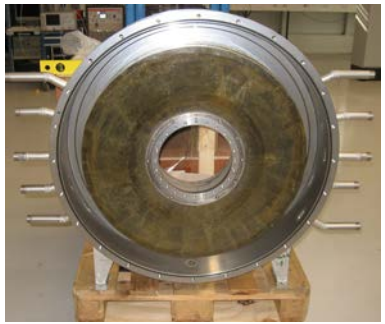
Components: Cavity

Example: SIS100 Acceleration

- 1.1 to 3.2 MHz
- 20 kV gap voltage



Example: MA Ring core for SIS18 h=2 cavity



Components: Tetrode Amplifiers

Tetrode Amplifiers

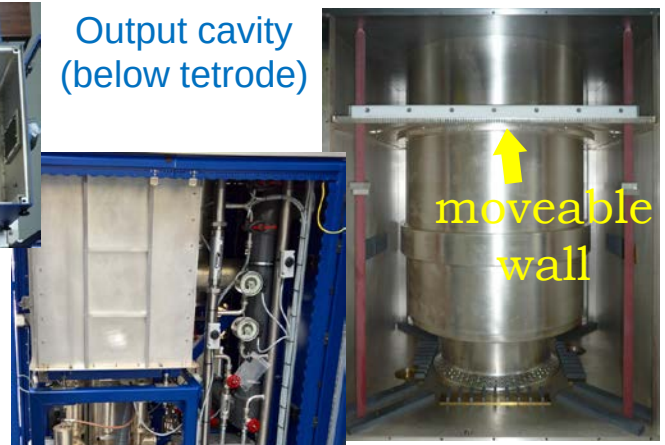
- **LINAC RF:**
  - 10 kW (50 Hz pulse repetition rate, 400 V mains)
  - 150 kW (pulsed 30%=6 ms pulse length, 400 V mains) → in future solid-state amplifiers
  - new final amplifier: 1.8 MW, 108 MHz (Alvarez, 2 ms pulse length, 10 Hz repetition rate, 20 kV mains)
- **Ring RF:**
  - up to 600 kW (up to 3 Hz machine cycle repetition rate, 400 V mains)
  - Quick change of working point for pulsed systems

Klystrons

- **LINAC RF:**
  - 325 MHz, 2.5 MW (for pLINAC), pulsed <5 Hz, 0.1 % duty cycle

Tetrode (anode)

Output cavity (below tetrode)

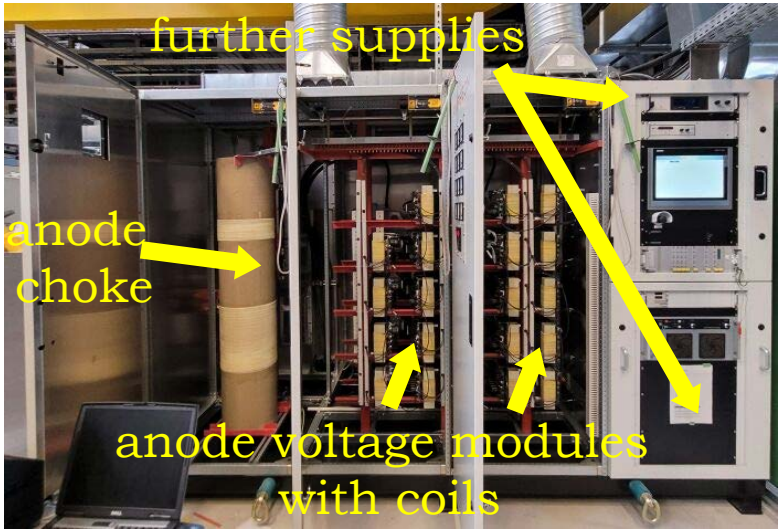


CR debuncher tetrodes (anode)

Components: Power Supply Units

Example for LINAC RF: Alvarez PSU, Anode voltage power supply

- 20 kV mains, up to 24 kV DC
- classical transformer/rectifier principle
- ignitron crowbar for tube protection
- capacitor bank ~ 880 µF
  (250 kJ @ 24 kV)
- 8 m x 2 m x 3 m
- central PLC with 4 local subunits



Example for Ring RF: PSU for SIS100 Acceleration system

- 400 V mains, 220 kW
- transformer + SMPS principle
- up to 15 kV DC anode voltage
- up to 200 A bias current

Components: Solid-State Power Amplifiers

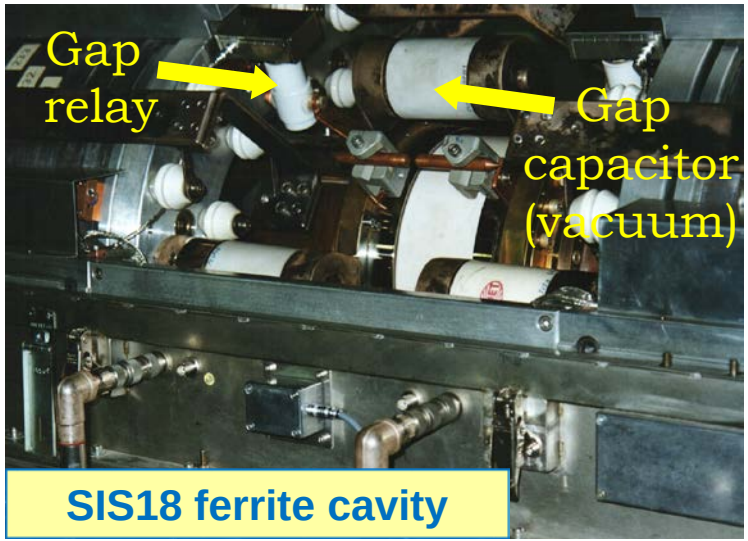
Example for Ring RF: Modular Power Amplifier

- Delivered by barthel HF-Technik GmbH
- 500 W per module
- 300 kHz … 6 MHz
- CW
- RF combiner allows combination of 2 or 4 modules

Waveguides and Additional Components

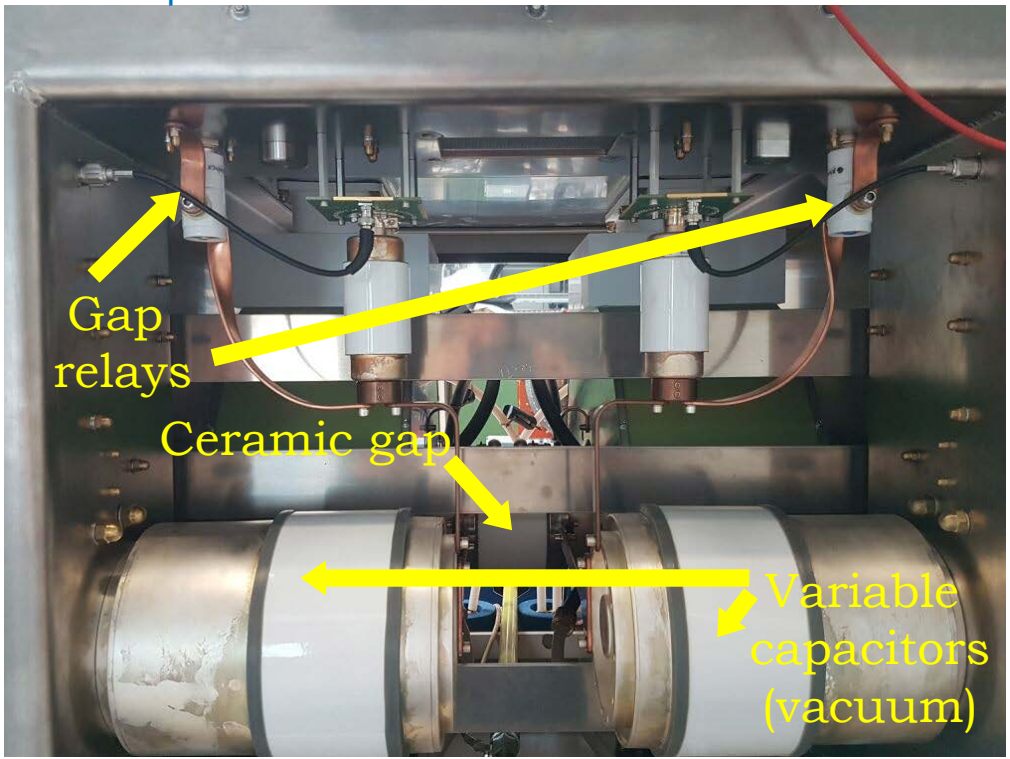
Waveguides, Transmission Lines

- **LINAC RF:**
  - Coaxial lines and rectangular waveguides
- **Ring RF:**
  - Semi-rigid coaxial cables for long distances



Additional Components

Example: CR Debuncher



Example: Circulator for pLINAC RF systems, directional couplers, and RF load (partly visible)

Outlook to Future Needs

- **Technology will be similar**
- **Commercial off-the-shelf components *and* industrial partners for joint developments**
- **Next systems to be realized**
  - pLINAC and CW LINAC RF systems → see next slide
  - Upgrade of amplifiers for Alvarez structures (call for tenders running for 150kW driver amplifiers)
  - SIS100 Barrier Bucket system, SIS100 Longitudinal Feedback system (4 identical cavities)
- **Challenges**
  - Reliability (6000 operating hours per year, 24/7)
  - Maintenance (must be simple in order to reduce presence in radiation-controlled area and to reduce repair time, must be possible by GSI/FAIR staff)
  - In most cases customer-specific development required
  - Long-term availability of spare parts (at least 8 years, 30 years of operation not unusual) – commercial product life cycles are often too short for us.
  - EMC
  - Radiation hardness
  - More automation (measurement technology, data acquisition – also post-mortem, calibration, etc.)
  - Control system integration (FESA, PLC, etc.)

Outlook to Future Needs

- **CW LINAC Components**
  - 3 kW solid-state amplifiers
    - 216 MHz
    - both, CW & pulsed operation
    - about 10 pieces required for series
  - CW LINAC RF system control (digital) and infrastructure
- **pLINAC Components**
  - Klystron auxiliary power supplies (DC only, for klystron solenoids) for 7 klystrons
    - 2 pieces 1 kW (about 15 A) per klystron
    - 1 piece 3 kW (about 15 A) per klystron
  - Circulators for 7 klystrons
    - 325 MHz
    - 3 MW pulse, pulsed <5 Hz, 0.1 % duty cycle
  - Rectangular waveguides WR 2300 full height (about 100 m in total)
  - Auxiliary components, e.g. low-power measurement transitions from WR 2300 to coaxial type N

FAIR's Procurement Opportunities

Technology	Estimated expenditure (M€)
Cryogenics, vacuum and leak detection technologies	55
Diagnostics and detectors, sensors, optics and instruments	35
Electrical, power electronics, electromechanical and RF systems	43
High precision and large mechanical components	10
Instrumentation, control and CODAC	34
Superconductivity and superconducting magnets	25
Normal conducting magnets	30
Remote handling	7

Current procurements

(Taken from the slides of the presentation
"FAIR - the Facility for Antiproton and Ion Research in Europe: The Universe in the Laboratory"
by Jörg Blaurock in Plenary Session I)

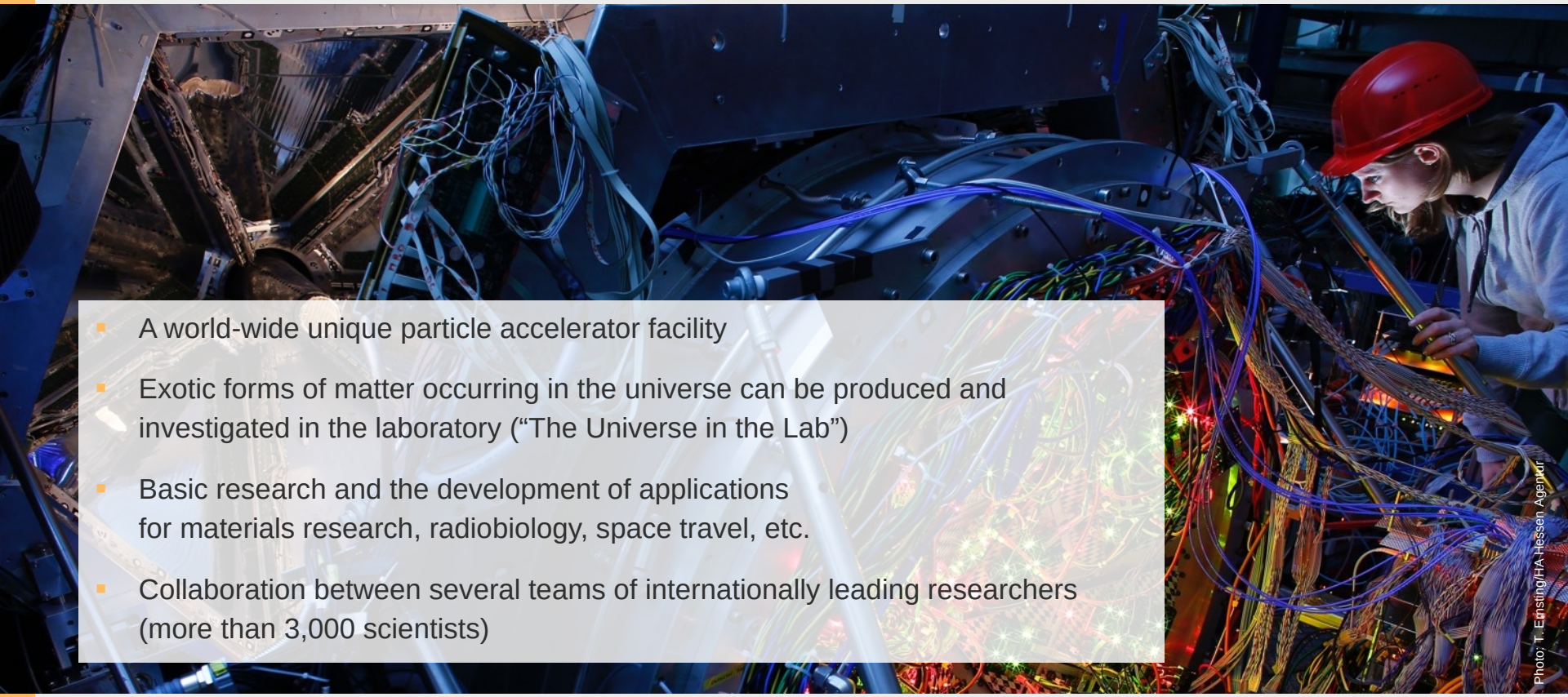
Thank you for your attention!

Acknowledgements: Thanks to Dr. Gerald Schreiber and Dr. Alexander Schnase
for the input concerning the LINAC RF systems!
And thanks to Robert Balß and Dr. Ulrich Laier for the contributions concerning the Ring RF systems!

Graph: ion42/FAIR

Appendix

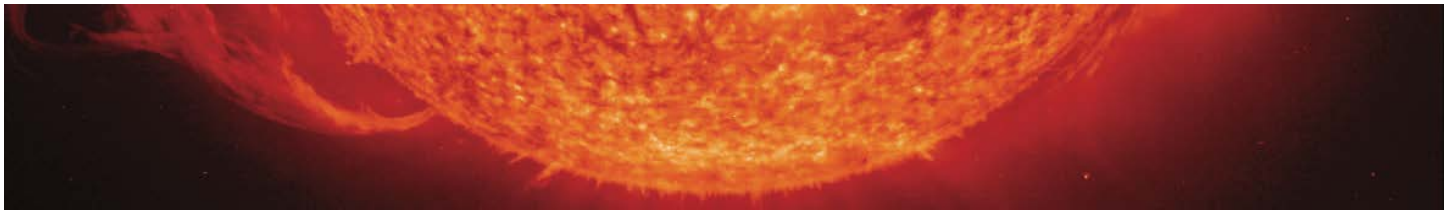
FAIR – Facility for Antiproton and Ion Research



- A world-wide unique particle accelerator facility
- Exotic forms of matter occurring in the universe can be produced and investigated in the laboratory (“The Universe in the Lab”)
- Basic research and the development of applications for materials research, radiobiology, space travel, etc.
- Collaboration between several teams of internationally leading researchers (more than 3,000 scientists)

Photo: T. Ernsting/HA Hessen Agentur

The four scientific pillars at FAIR



NUSTAR
Nuclear Structure, Astrophysics and Reactions: Stars and nuclei
(850 scientists)

CBM
Compressed Baryonic Matter:
Inside a neutron star
(500 scientists)

PANDA
Antiproton-Annihilation at Darmstadt:
Antimatter research
(500 scientists)

APPA
Atomic, Plasma Physics and Applications:
From atoms to planets to cancer research
(720 scientists)