

# Status of the Power Converters for the FAIR Project

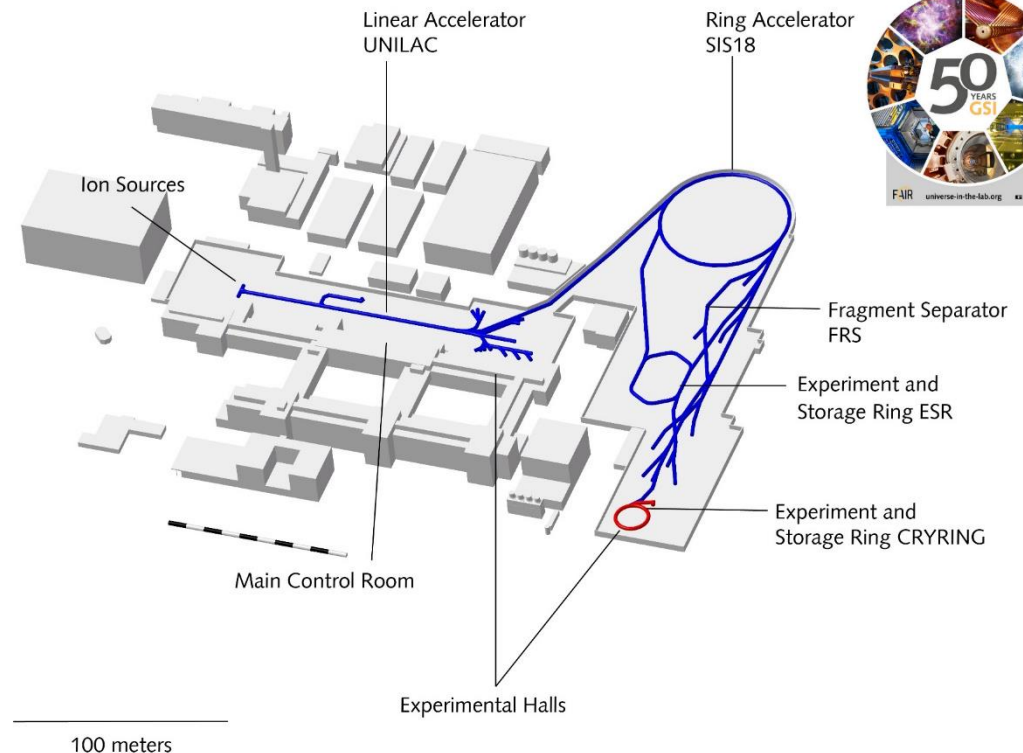
Horst Welker, GSI/EPS, POCPA7, 01.06.2023

- GSI Overview
- FAIR Overview
- Upgrade Projects at GSI for FAIR
- SIS100 Power Converters
- SFRS Power Converters
- HEBT Power Converters
- EPS Common Projects
- Status of the construction site
- Outlook

- Located in Darmstadt, Germany
- Foundation: 1969
- National Institute (Member of Helmholtz - Association)
- Associates: GER (90%), State of Hesse (8%), States of RP and Thüringen (each 1%)
- Employees approx. 1.600
- Visiting Scientists: approx. 1.200

➤ Research Areas:

- Nuclear and Particle Physics
- Atomic and Plasma Physics
- Biophysics and Medical Science
- Materials Research



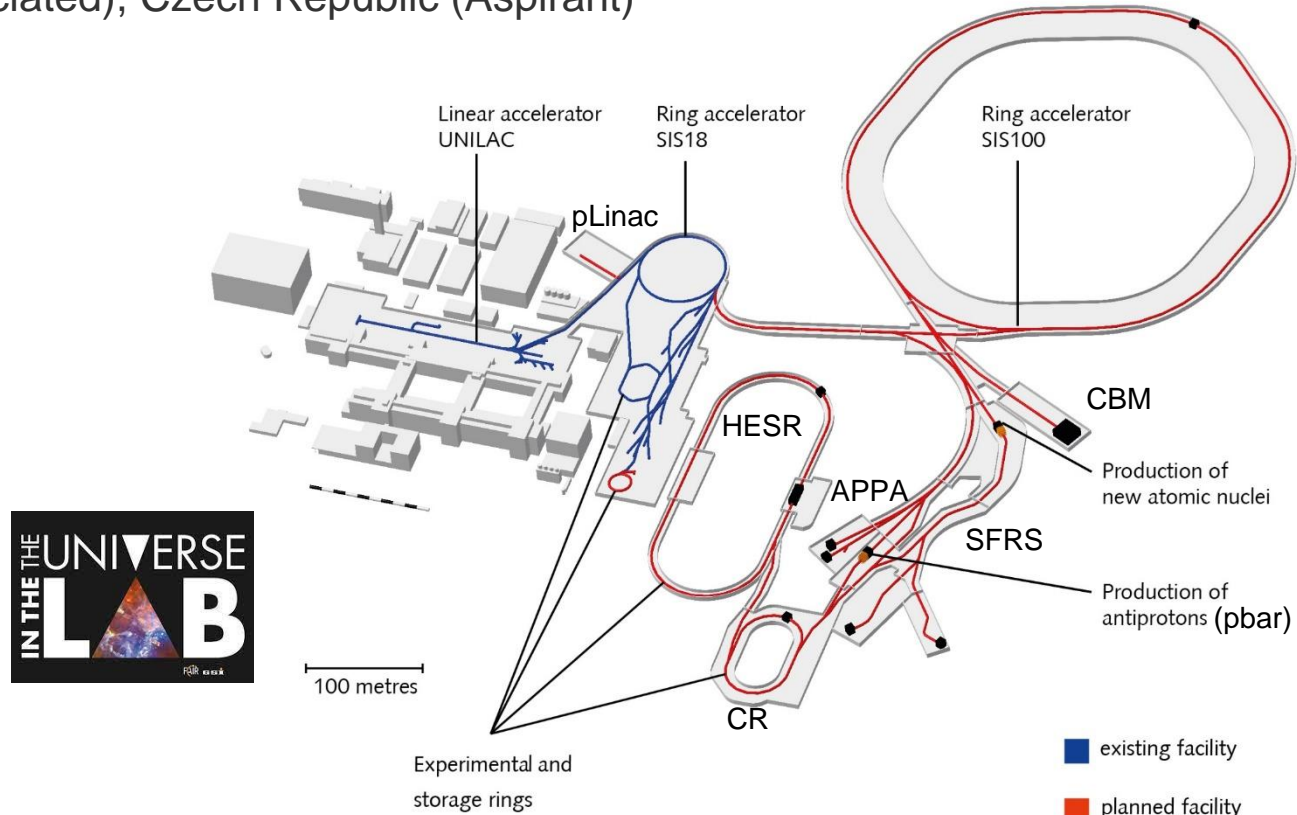
# FAIR Project Overview



- International Project
- Shareholders: Finland, France, Germany, India, Poland, Romania, Russia, Slovenia and Sweden. UK (Associated), Czech Republic (Aspirant)

- 4 Scientific pillars
  - NUSTAR (SFRS)
  - PANDA (HESR)
  - CBM
  - APPA

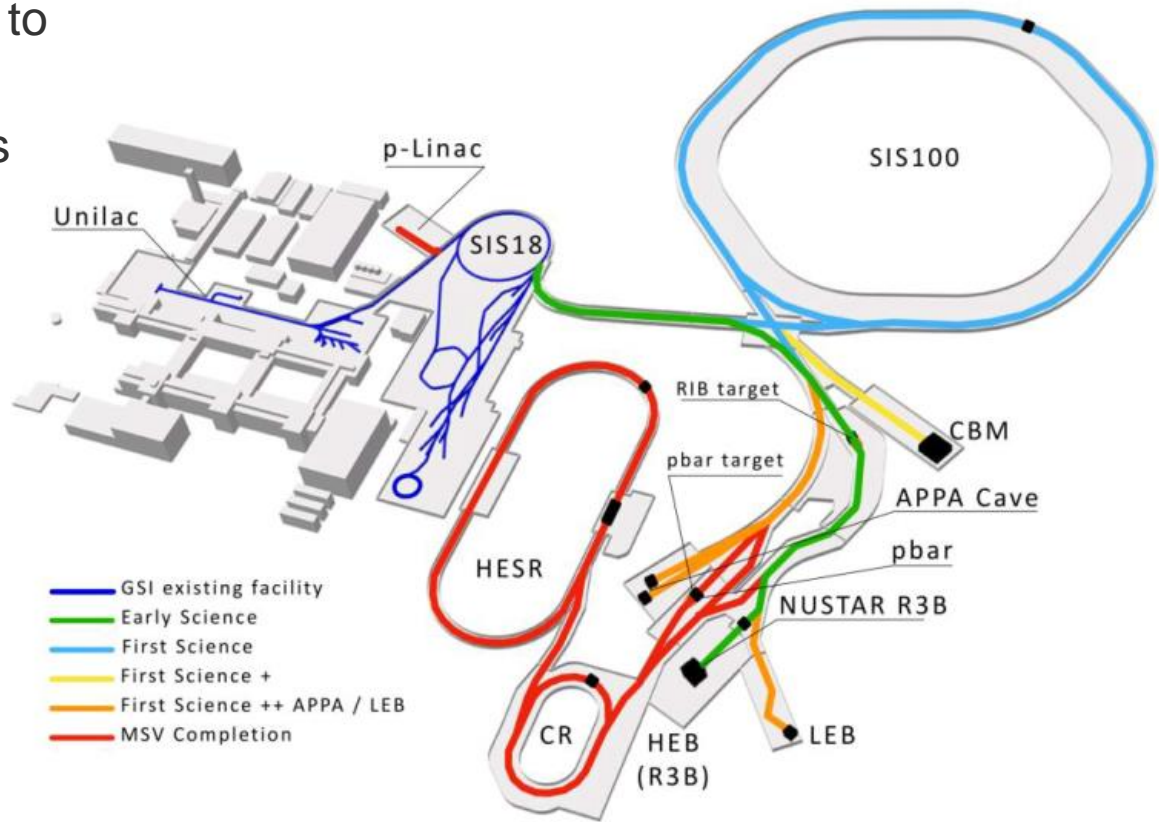
Machine	No of PCs
CR	90
HEBT	343
HESR	194
p-Bar	28
P-Linac	51
SIS100	252
Super FRS	229
<b>Total</b>	<b>1187</b>



- FAIR 2028:
  - Staging of the project due to the actual global situation
  - Focus on the first 3 stages (ES –FS+)

Stage	No of PCs
ES	199
FS	339
FS+	22
FS++	138
MSVc	489
	<b>1187</b>

**560**



## Overview

### UNILAC:

- 18 cover converters for Alvarez Quadrupoles: 210A ... 390A, 49V ... 543V, tr=1s (2008)

### SIS18:

- Dipole power converter to 3.500A, 19kA/s (before 2300A, 19kA/s) (2018)
- Power converter for Inflector Magnet: 2.100A DC, 24kA/s and 111V (2008)
- 10 power converters for additional horz. correctors:  $\pm 60$ A, 650A/s, 105V (2013)
- 3 power converters for the IPM system: 330A, 100V (2019)

### HEST:

- Fast divider magnet power converter ( $\pm 1250$ A/700V pulsed with 2.5Hz) (2019)

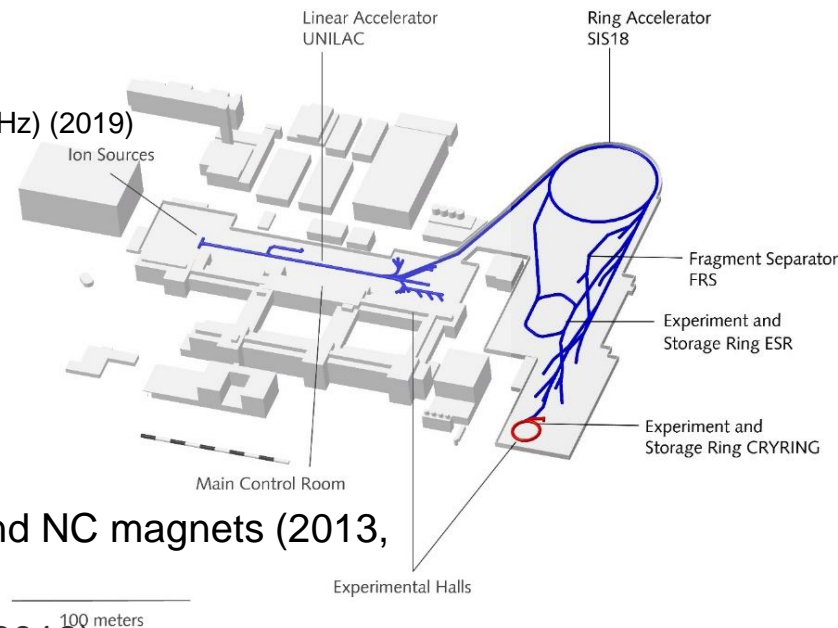
### Installation of CryRing, 60 PCs (2016)



- Dipole: 1.200A, 900V
- Quadrupoles: 200 ... 300A, 100V
- Inj. Septum 3.100A, 200kA/s
- 10kV switchgear and harmonic filter
- Step down transformer 2 MVA, 20kV/10kV

### Installation and upgrade of the Test Facilities for SC and NC magnets (2013, 2016, 2020)

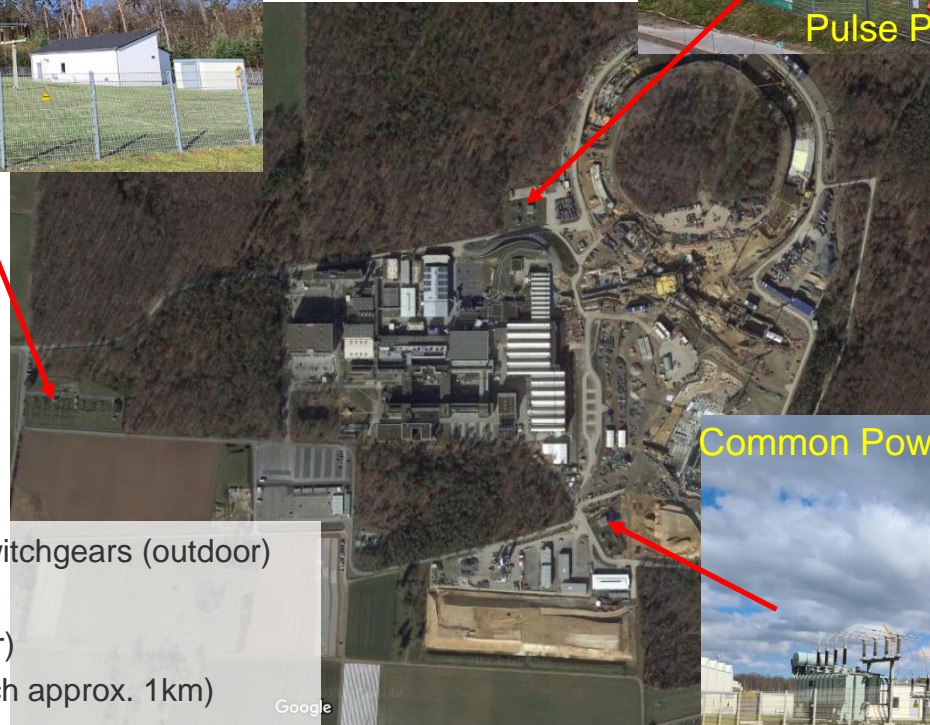
### Upgrade of the external Electrical Power Distribution (2019)



# Upgrade Projects at GSI for FAIR

## Upgrade of external Electrical Power Distribution

Upgraded 110kV Substation Leonhardstanne



Common Power System (63/31,5 MVA)

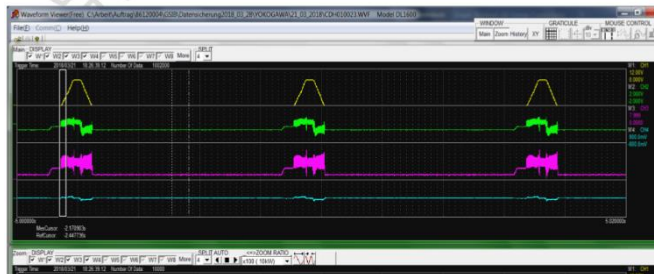


- Modification of existing 110kV switchgears (outdoor)
- 2x new 110kV substations
- 3x new 20kV switchgears (indoor)
- 4x 110kV cable connections (each approx. 1km)
- 3x new 63MVA transformers
- Relocation of 31,5MVA transformer

# Upgrade Projects at GSI for FAIR

## SIS18 Dipole Power Converter

- Upgrade of SIS18 dipole power converter to 3.500A, 12kV, 19kA/s, 2.5Hz,  $\pm 43$ MW pulse power (before mode1: 2.300A, 19kA/s, mode2: 3.500A, 10kA/s)
- SCR topology with parallel active filter
- 20kV switchgear (24 circuit breakers)
- Indoor harmonic filter (12MVA<sub>r</sub>) 5<sup>th</sup>, 7<sup>th</sup> and 11<sup>th</sup>
- 4 SCR power transformers ( $S_n = 4 \times 4140$ MVA)
- 4 smoothing inductors (3.500A, 10mH)





# (Upgrade) Projects at GSI for FAIR

## Test Facilities

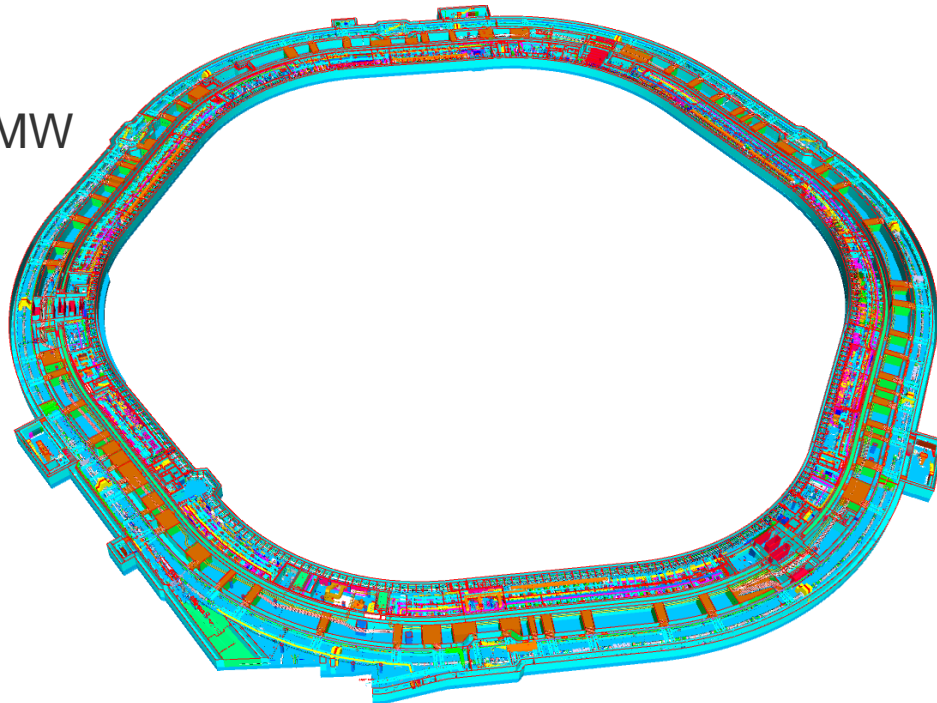
- SC-Prototype-TF (2003/2013): 20.000A, 70V/30V
  - DC circuit breaker <1ms opening time (IGBT+ fuses)
- SC-Series-TF (2016): 2x 20.000A, 70V/30V
  - DC circuit breaker <1ms opening time (IGBT+ fuses)
  - 2x 300A, 100V
  - 1x 450A, 200V
- NC-TF Upgrade (2020): 4.000A, 400V



## Overview

- Heavy Ion Synchrotron SIS100 (**S**chwer**I**onen**S**ynchrotron - SIS, 100Tm)
- Circumference – 1.100m
- approx. 15m underground
- Mainly superconducting magnets (main circuits: 108 dipoles, 2x83 quadrupoles)
- Ramped operation (500ms, 1Hz)
- Main dipole system: 13.2kA, 1.400V,  $\pm 18$ MW
- Main quadrupole systems:  
2x 8.5kA, 700V,  $\pm 6$ MW
- >200 Correctors: 300A, 50V

	<b>No of PCs</b>
Dipoles	1
Quadrupoles	15
Septa	6
Multipoles	14
Correctors	205
<b>Total</b>	<b>241</b>



# SIS100 Power Converters

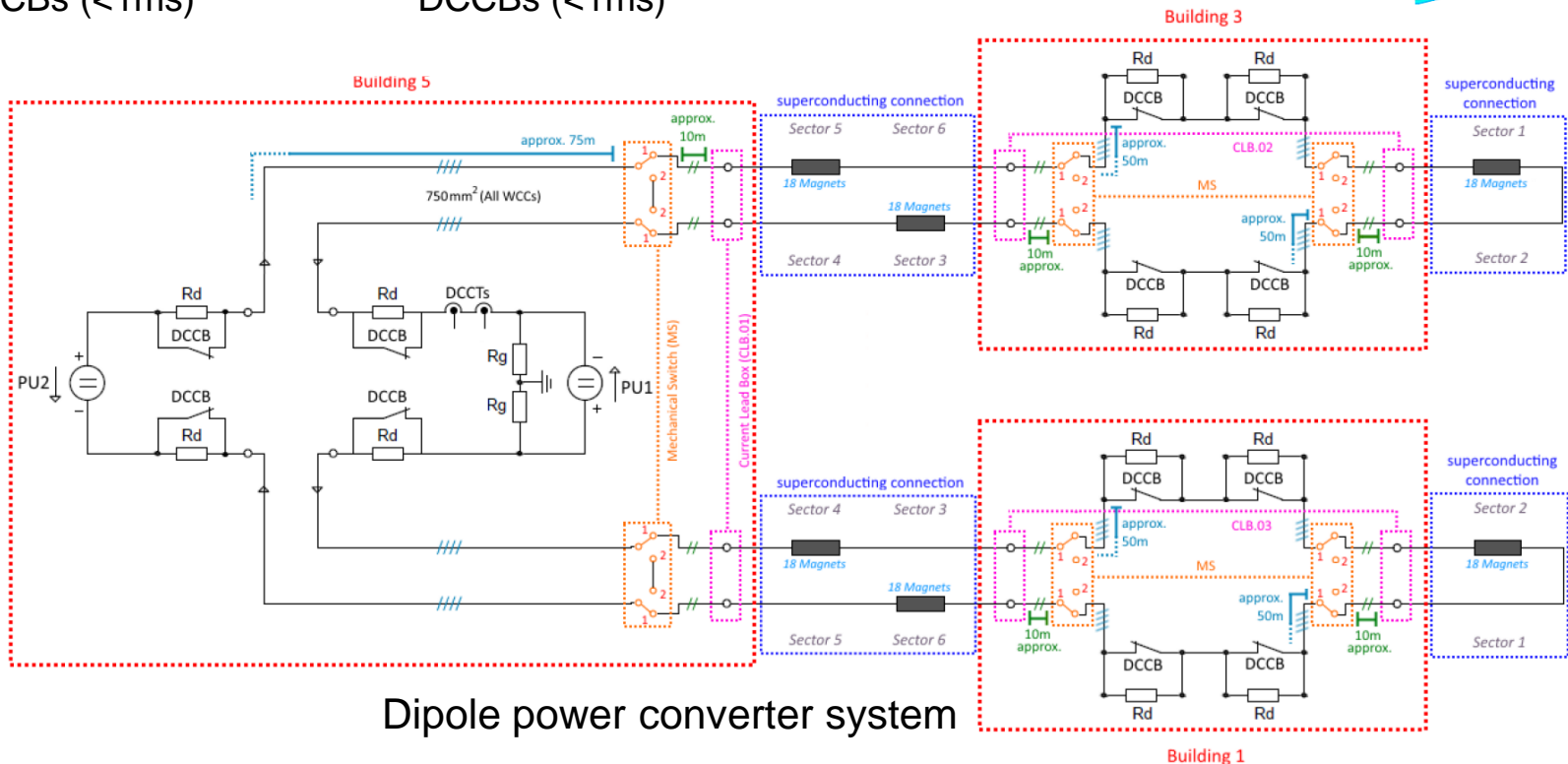
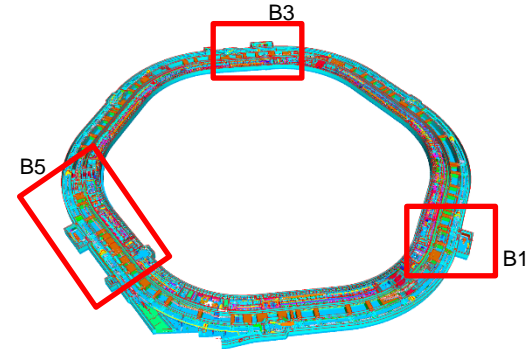
## Main Dipole and Quadrupole PCs (SC)

### Dipole:

$I_{out} = 13.200\text{ A}$   
 $di/dt = 19\text{ kA/s}$   
 $V_{out} = \pm 1.400\text{ V}$   
 $P_{max} = \pm 18,5\text{ MW}$   
 $S_n = 12\text{ MVA}$   
 DCCBs ( $< 1\text{ ms}$ )

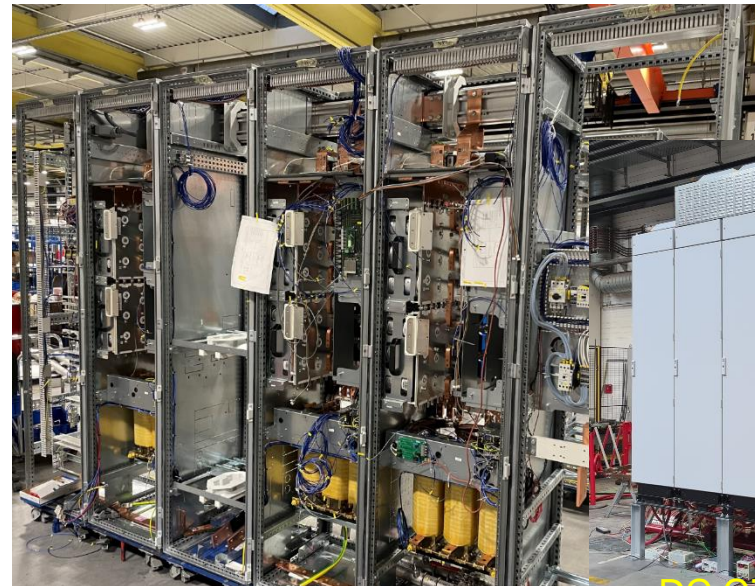
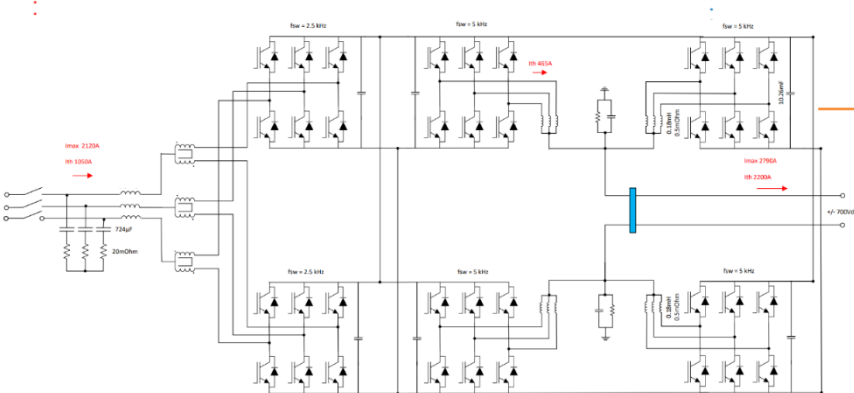
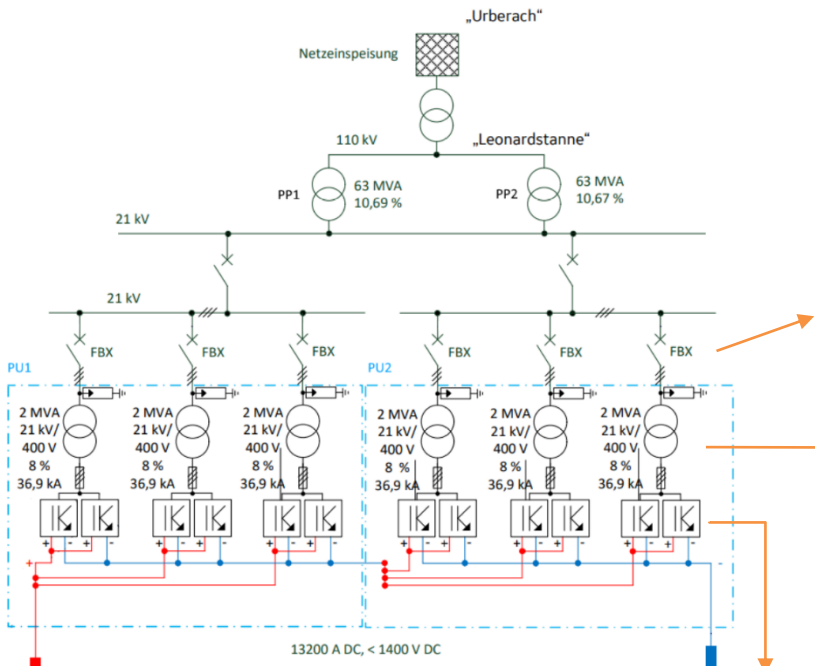
### Quadrupoles:

$I_{out} = 8.500\text{ A}$   
 $di/dt = 15\text{ kA/s}$   
 $V_{out} = \pm 700\text{ V}$   
 $P_{max} = \pm 6\text{ MW}$   
 $S_n = 4\text{ MVA}$   
 DCCBs ( $< 1\text{ ms}$ )



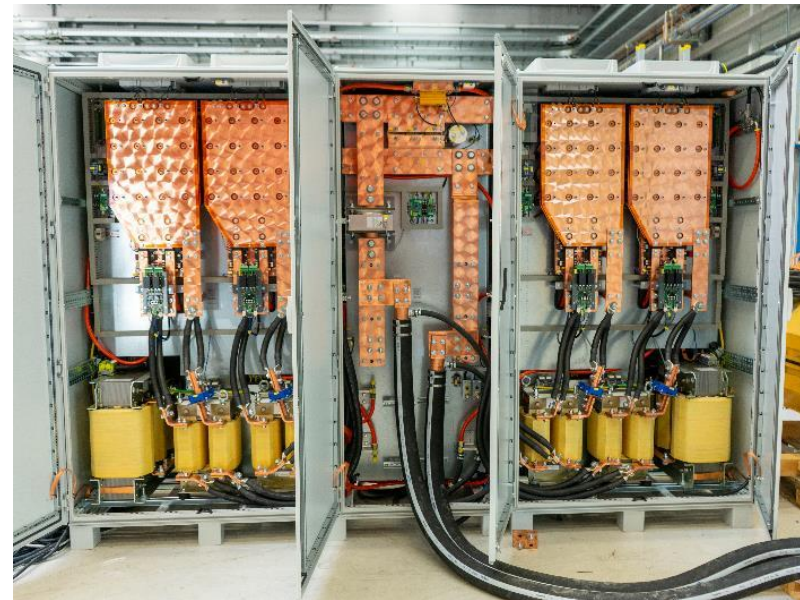
# SIS100 Power Converters

## Main Dipole and Quadrupole PCs (SC)



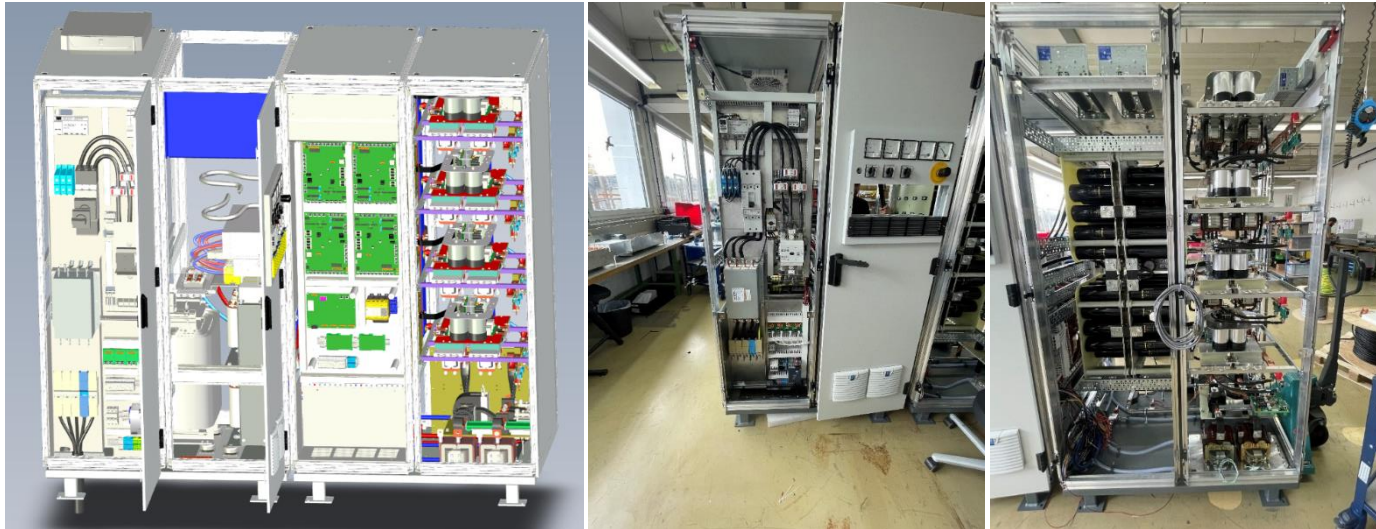
## Sub-project Status

- Delivered (207):
  - 1 IPM Diagnostic and 2 Correctors (NC) – 300A / 140V, 175A / 60V – Jäger Elektrotechnik
  - 2 Injection Septa (NC) – 4.500A / 25V, 2.000A / 20V – Jäger Elektrotechnik
  - 202 Multipole Correctors (SC) – 300A / 50V – ECIL (Electronics Corporation of India Limited, Hyderabad - In-kind contribution India)



## Sub-project Status

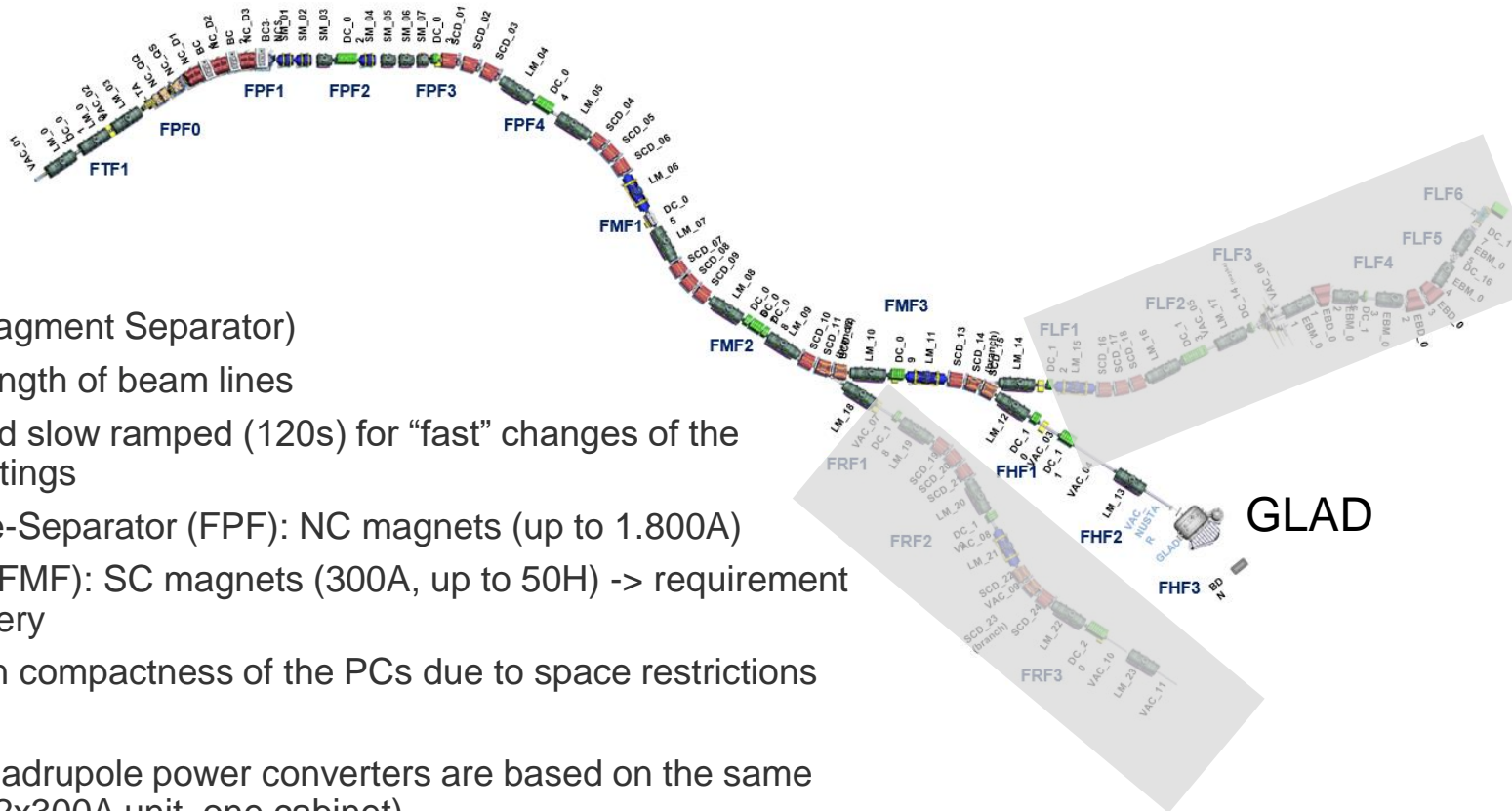
- In production (9):
  - 6 Resonance Sextupoles (NC) – 775 A / 400V – Heinzinger
  - 1 Main Dipole and 2 Main Quadrupoles (SC) – GE Power Conversion



- To be tendered (25):
  - 4 Septum PCs (NC): 500 ...13kA, 20 ...1.200kVA
  - 8 Multipole PCs (SC): 250 ...1.200A, 50 ...140kVA
  - 13 Quadrupole PCs (NC): 150 ...1.500A, 10 ...430kVA

## Overview

	No of PCs
Dipoles	18 (12)
Quadrupoles	49 (42)
Correctors	55 (53)
(non FS+)	122 (229)

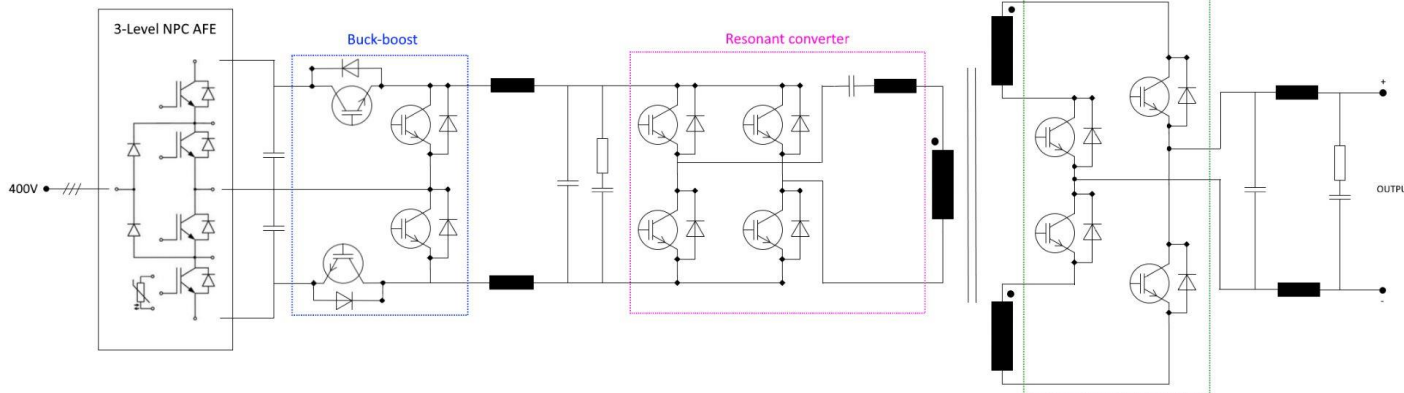


- SFRS (Super Fragment Separator)
- Approx. 250m length of beam lines
- DC operation and slow ramped (120s) for “fast” changes of the experimental settings
- First stage of pre-Separator (FPF): NC magnets (up to 1.800A)
- Main separator (FMF): SC magnets (300A, up to 50H) -> requirement for energy recovery
- Requirements on compactness of the PCs due to space restrictions
- All dipole and quadrupole power converters are based on the same general design (2x300A unit, one cabinet).
- Power converters for NC magnets are parallel connections of these units
- Correctors using the SIS100 corrector design
- R3B Experiment (GLAD) already in operation at the existing facility

# SFRS Power Converters

## Dipole and Quad. Power Converters

- In-house design:
  - 2 x bipolar 320A/220V,70kVA power converters per cabinet
  - AFE input stage for energy recovery
  - Intermediate stage: Buck-boost, Resonant converter, Medium frequency transformer
  - Quench protection for SC magnets
  - up to 3 parallel cabinets (6 units) for NC magnets
- Actual status:
  - Prototype converter was tested with NC load @ GSI
  - Production of power converters for NC magnets is tendered
  - Tendering of production for SC PCs in 2023

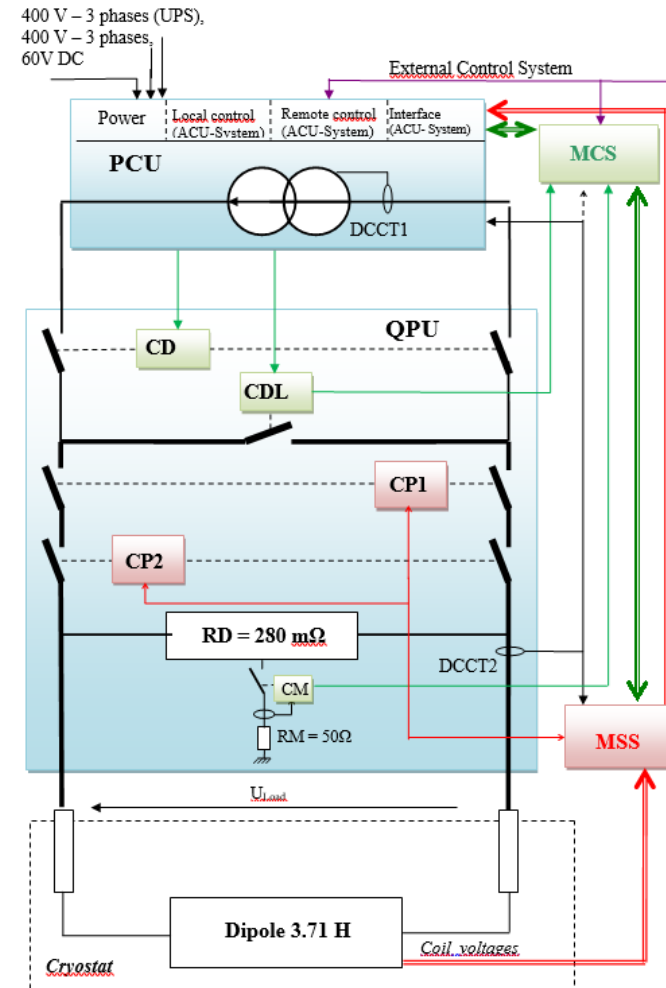
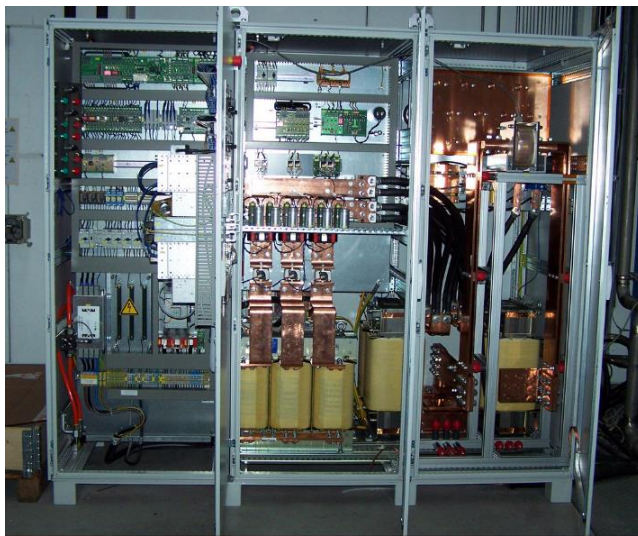




# SFRS Power Converters

## Power Converter for GLAD

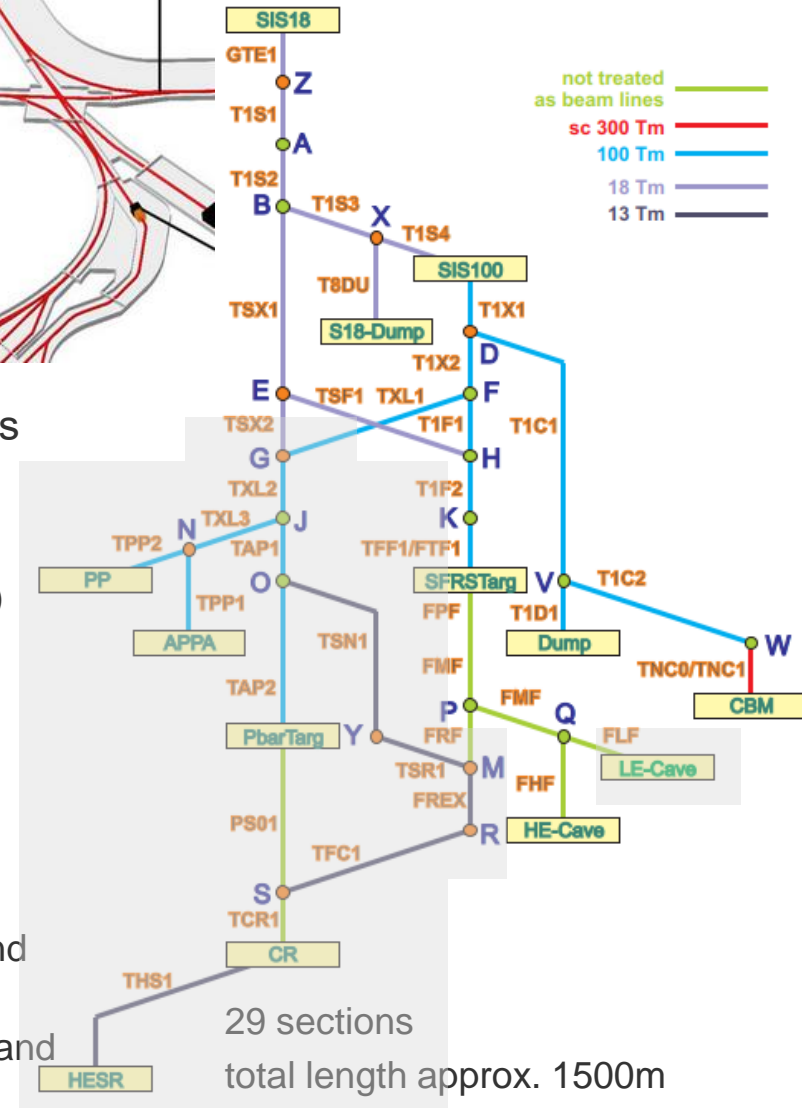
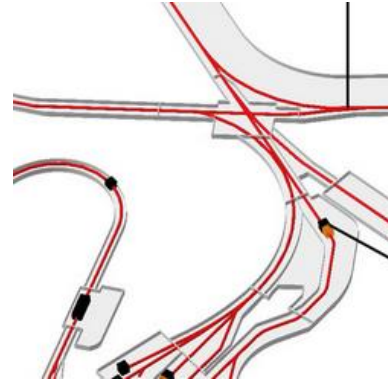
- 3.800A, 10V
- SC magnet 3.7H, 27MJ stored energy
- 12-pulse SCR topology
- Quench protection unit with mechanical circuit breakers
- Installation and commissioning in 2016
- Experimental usage since 2019



# HEBT Power Converters

## Overview

Stage		No of PCs
ES-FS+	Dipoles	28
	Quadrupoles	95
	Steerers	59 182
FS++/MSVc	Dipoles	27
	Quadrupoles	83
	Steerers	44 154

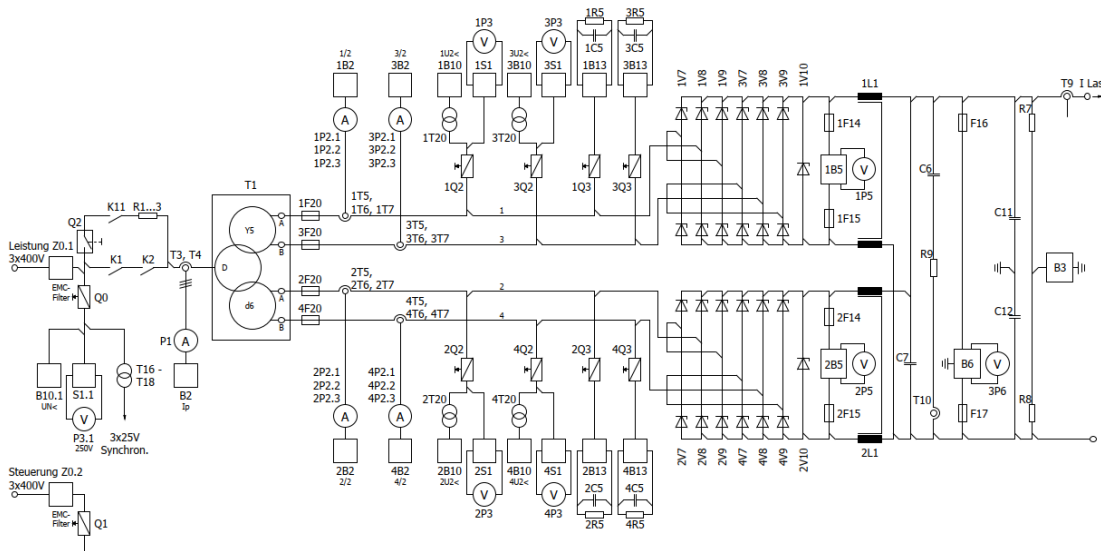


- HEBT (High Energy Beam Transfer)
- Pulsed (500...800ms) and DC operation of beam lines
- Dipoles: 550A, 1500A, 2500A (70 ... 1000kVA)
  - supplied by 400V/20 kV supply system
  - special requirements for PAS (personal access system)
  - zero field control, field control
- Quads: 300A, 500A, 900A, 1500A (20 ... 250kVA)
- Steerers: 100A, 400A (5 ... 30kVA)
- Providers:
  - Quadrupoles (up to 500A) and Steeres are Indian in-kind contribution, provided by ECIL
  - Dipoles and Quadrupoles (900A/1.500A) are tendered and provided by company Jäger Elektrotechnik

# HEBT Power Converters

## Dipole Power Converters

- 550 - 900A: IGBT 2/4 Quadrant Topology
- 1200 - 2500A: 12-pulse SCR topology (2 stages: DC/pulsed)



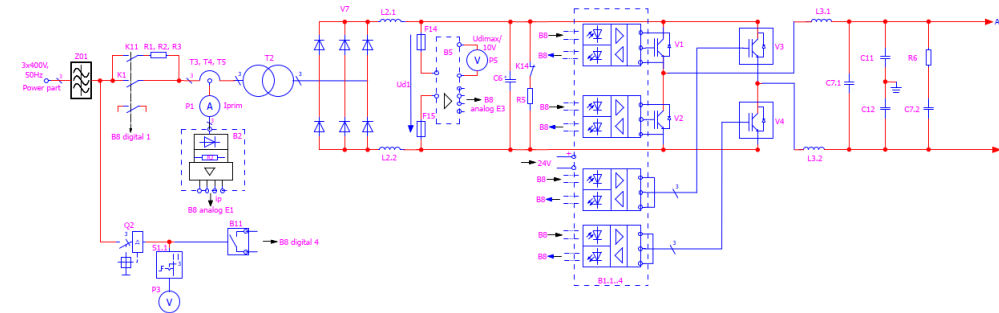
- Actual status:
  - 21 PCs delivered
  - 32 PCs until end of 2023
  - 8 PCs until 02.24



# HEBT Power Converters

## Quadrupole / Steerer Power Converters

- 6 types of quadrupole PCs, 2 types of steerer PCs
- All types using 1, 2 or 4 quadrant IGBT topologies
- Standardisation of components over different types

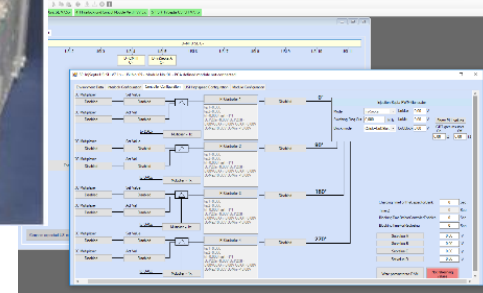


- Actual status:
  - 180 PCs delivered
  - 72 until end of 2023



## Power Converter Control Electronics

- Hardware development and procurement
- Software/firmware development



## Current measurement systems (DCCT)

- 3 classes (100ppm, 50ppm, 10ppm)
- Specification and procurement
- Development of ADC electronics
- Set-up of calibration and testing lab @ GSI



## Cable Management

- Coordination of 50.000 cables with more than 4.000 km length
- Cable specs and requirements collected & maintained in a cable database
- Design of machine cable trays
- Coordination of:
  - Cable routing
  - Cable procurement & laying
  - Confectioning and connection
  - Grounding system





Status April 2023

■ **2 million cubic meters of earth**  
...to be excavated — as much as for 5,000 single-family homes



■ **600,000 cubic meters of concrete**  
...to be used — as much as for eight Frankfurt soccer stadiums

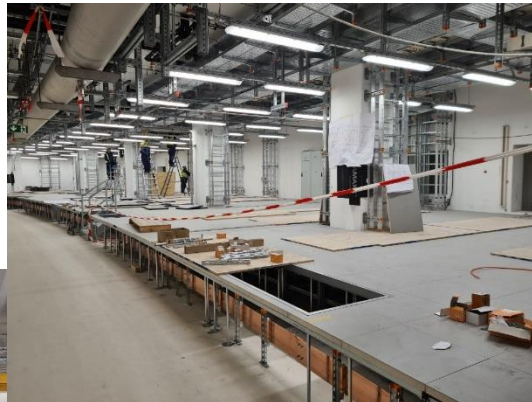
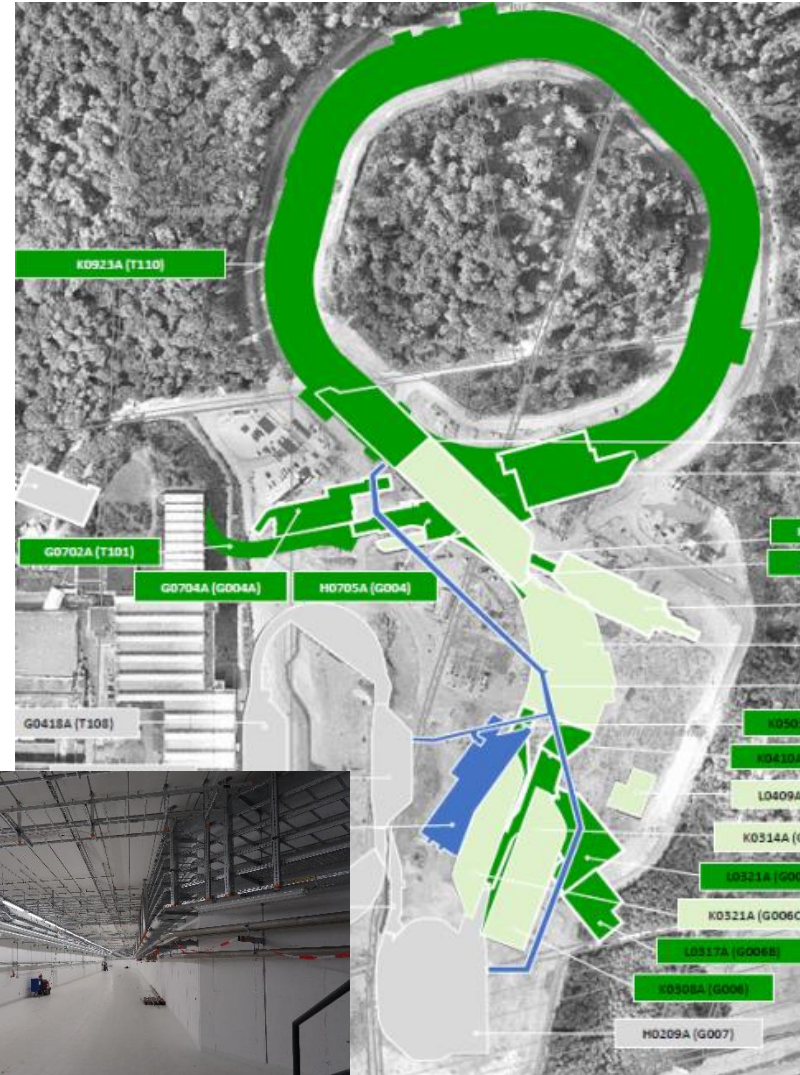


■ **65,000 tons of steel**  
...to be utilized — as much as for nine Eiffel Towers

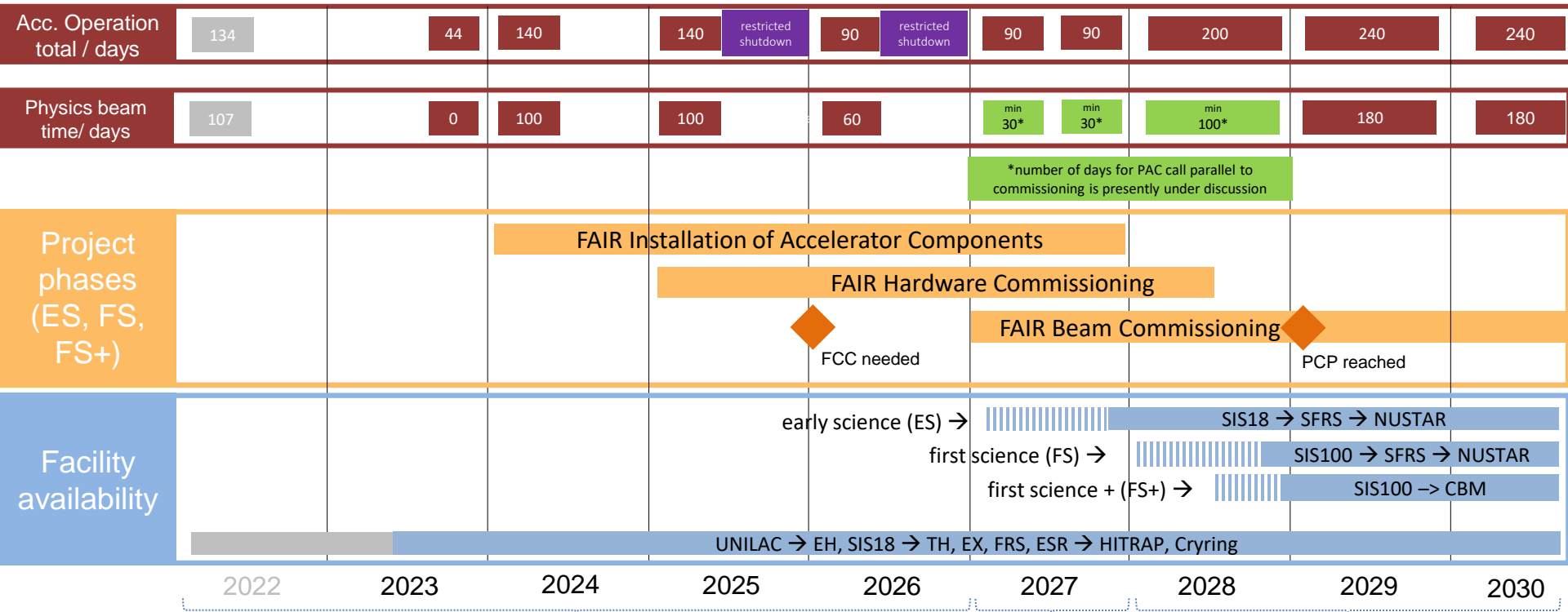


# Status of the construction site

- Shell construction finished in 2023/24
- Technical infrastructure started in 2022
- Laying of the accelerator cables - Q3/2023
- Installation of the accelerator components (incl. supply areas) - Q1/2024



# Outlook



2022      2023      2024      2025      2026      2027      2028      2029      2030

FAIR Phase 0

Early Science

Early Science & First Science+



Thank You!

