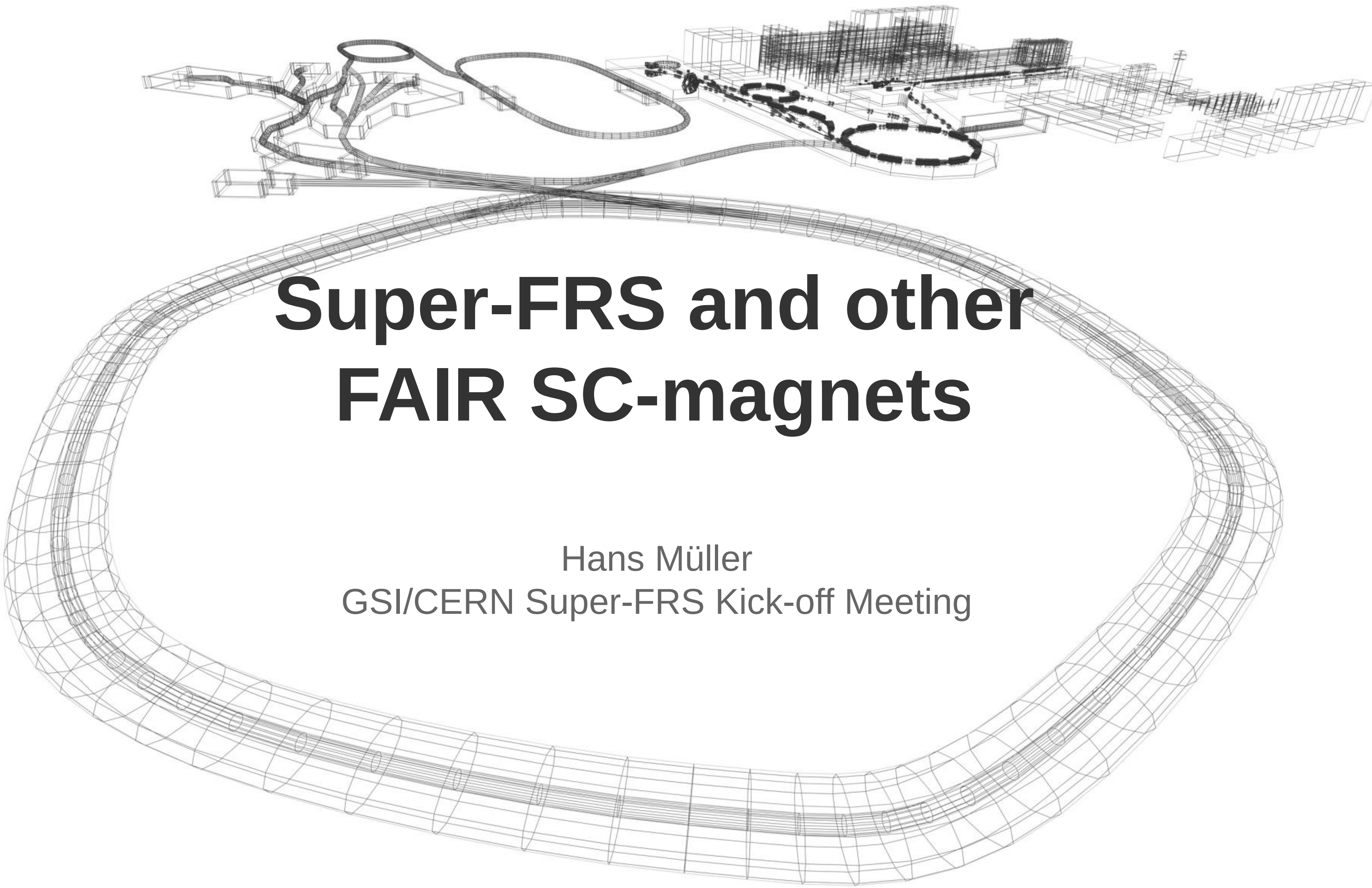


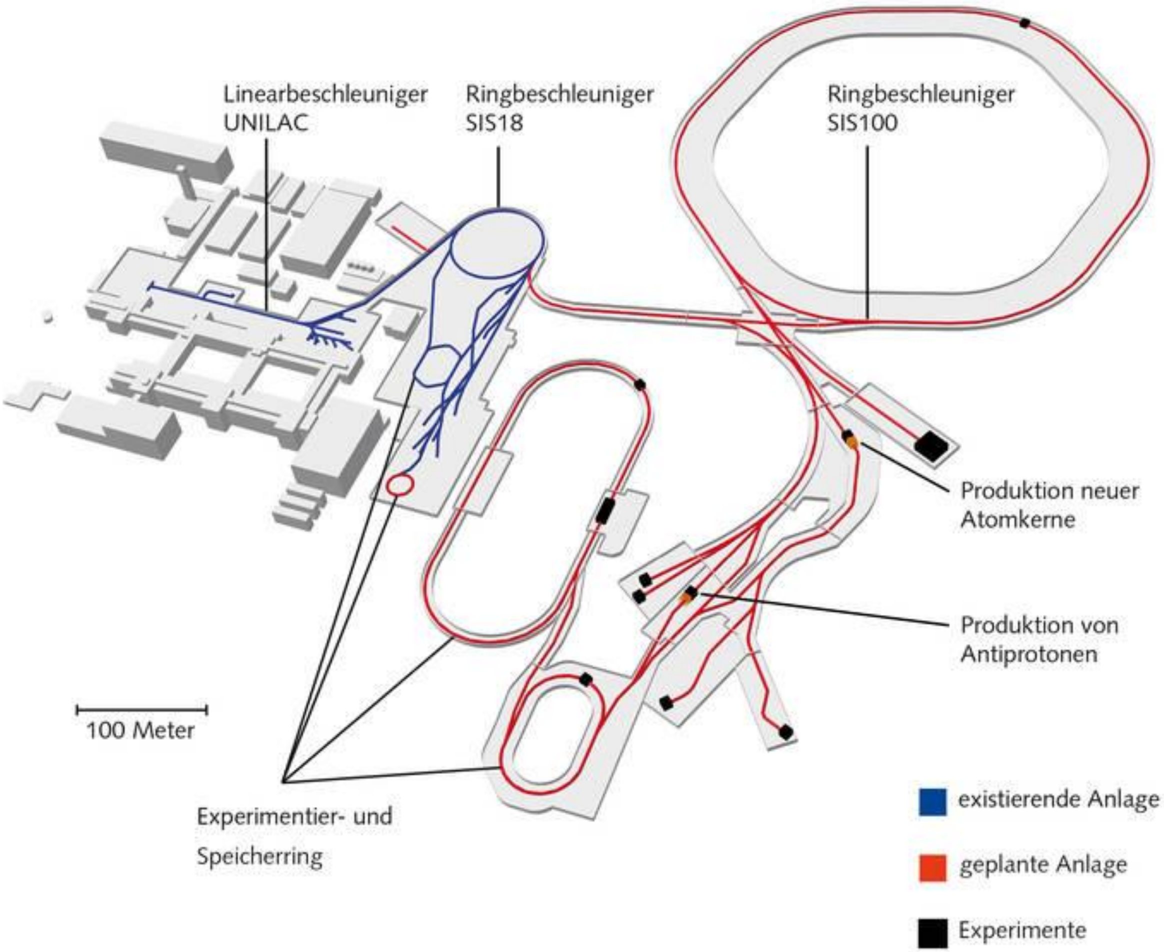
Super-FRS and other FAIR SC-magnets

Hans Müller

GSI/CERN Super-FRS Kick-off Meeting

Superconducting magnets at FAIR

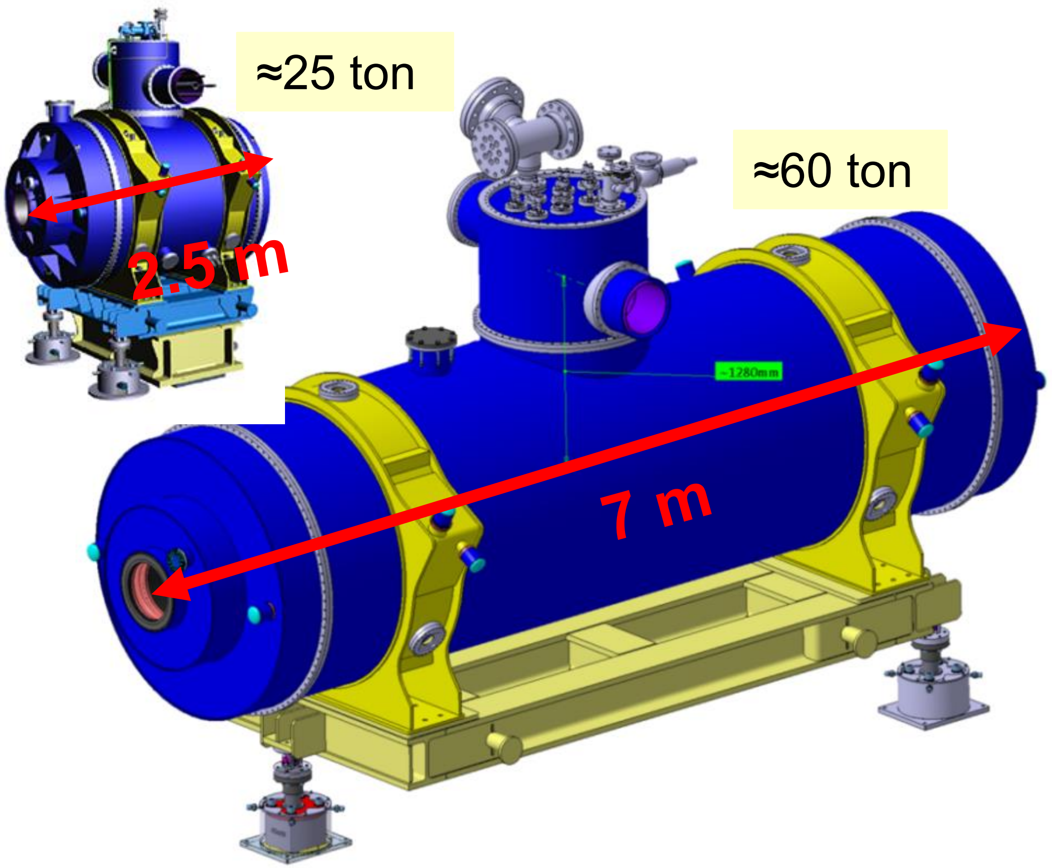
- **Accelerator**
  - Super-FRS
  - SIS 100
- **Experiments**
  - Nustar (Glad)
  - CBM
  - APPA
  - Panda

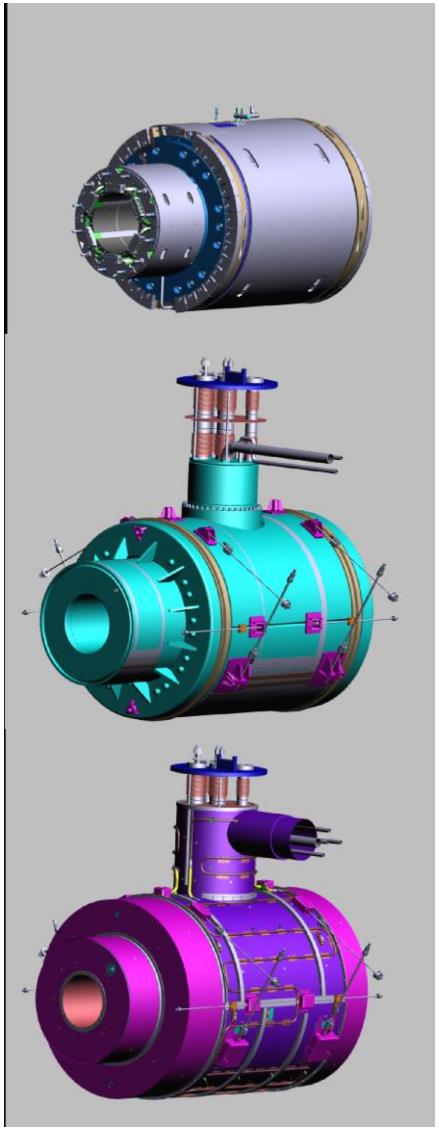


Super-FRS: Magnet design principles

- Large acceptance → large aperture
- Superferric (magnetic field shaped by iron yoke)
- Cooling by LHe bath (dipoles 60 l; Multiplets 1600 l)
- Individually powered magnets → max.operation current < 300 A
  → high inductivity
- Different setting should be adjustable in reasonable time
  → ability for 3 consecutive triangular cycles with t_r=120 sec.
- Common cryo-system with SIS100 and avoiding loss of Helium
  → 20 bar design pressure
- Quench Protection Scheme:
  - main dipoles and quads: energy extraction resistor
  - steering dipoles, sextupoles & octupoles: self-protecting
- Warm beam pipe

Super-FRS Multiplets





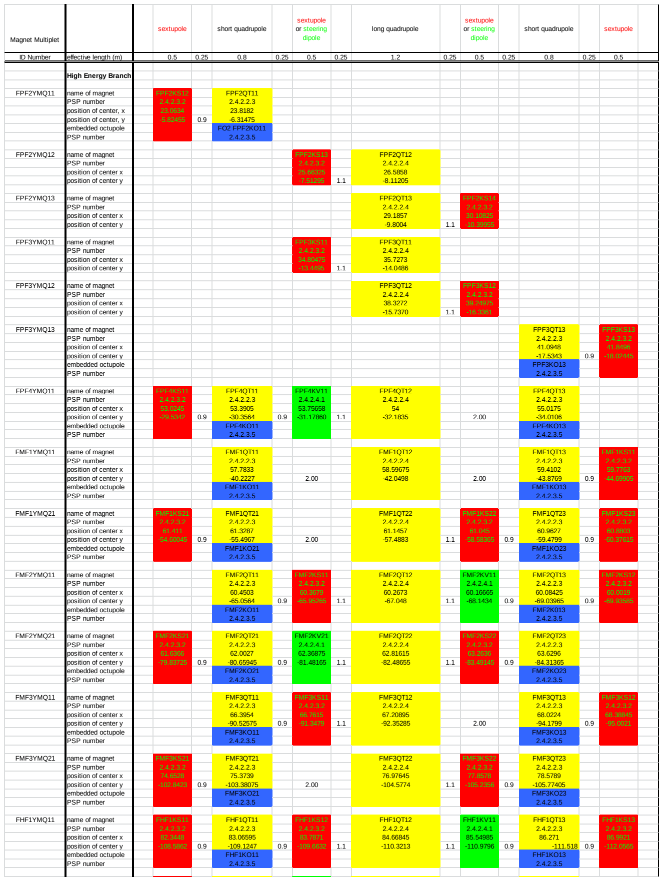
Super-FRS Multiplets: Magnet parameters

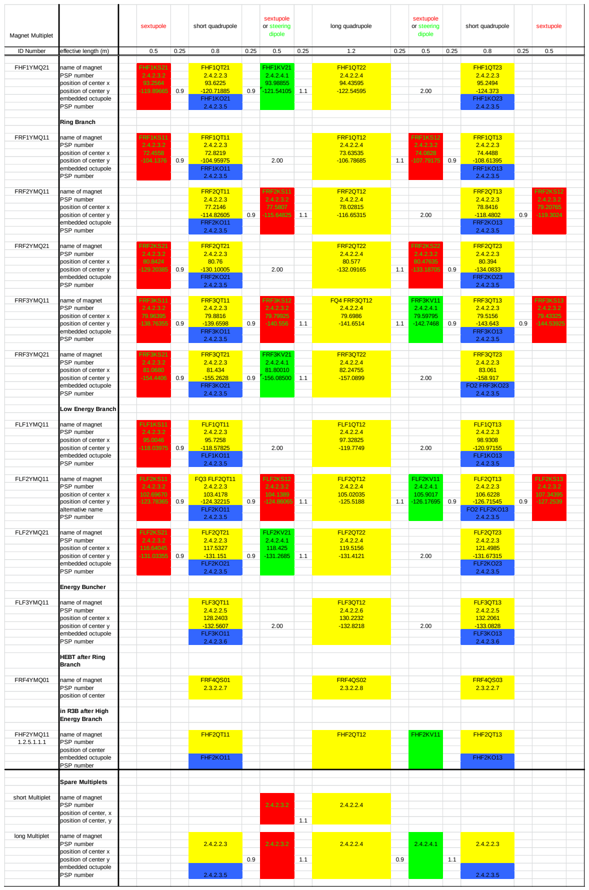
	Arranged in 32 Multiplets* (2-9 magnets)			
	Quadrupole Type 3	Quadrupole Type 4	Sextupole	Steerer
Number of Magnets	46	34	41	14 (13v/1h)
Effective length	0.8 m	1.2 m	0.5 m	0.5 m
Gradient/ Field Range	1.0-10 T/m	1.0-10 T/m	4-40 T/m2	0-0.2 T
Field Quality	(<0.8 gmax) $\pm 1 \cdot 10^{-3}$ (>0.8 gmax) $\pm 6 \cdot 10^{-3}$	$\pm 1 \cdot 10^{-3}$ $\pm 6 \cdot 10^{-3}$	$\pm 5 \cdot 10^{-3}$	
Usable aperture	Ø 380 mm	Ø 380 mm	Ø 380 mm	Ø 380 mm
Inductance	30 H	43 H	1.04 H	0.067 H
Nominal max, current	300 A	300 A	291 A	280 A
Stored Energy	670 kJ	950 kJ	37 kJ	2.6 kJ

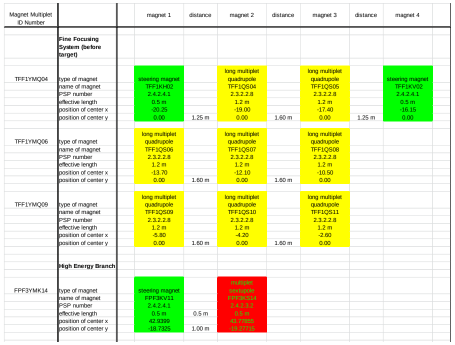
In quadrupoles type 3 an octupole magnet with gradient 105 T/m³ is embedded

* including 2 spares

Super-FRS Multiplets: Configurations





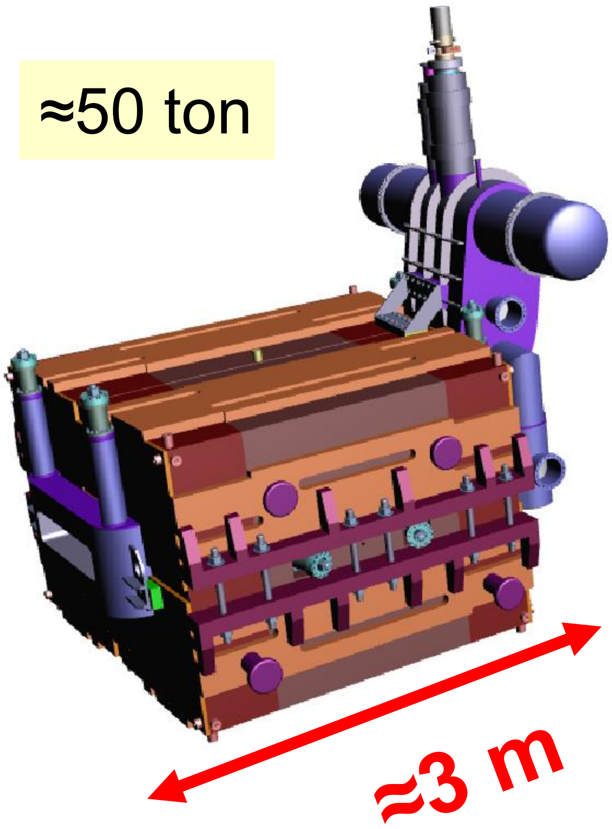


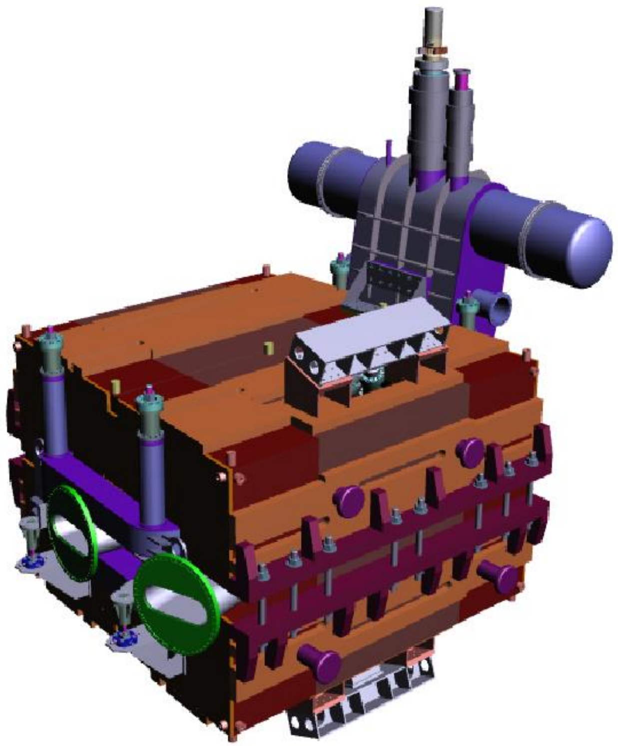
Yellow: Quadrupole
red: Sextupole
green: Steering dipole
blue: octupole (embedded)

Super-FRS Multiplets: Status

- Contract awarded to ASG, Genova
- First of Series short multiplet succesfully warm tested at factory in January 2019
- Installed at CERN test bench ready for cool down
- Factory acceptance test for long FoS-multiplet expected for January 2020

Super-FRS Dipoles



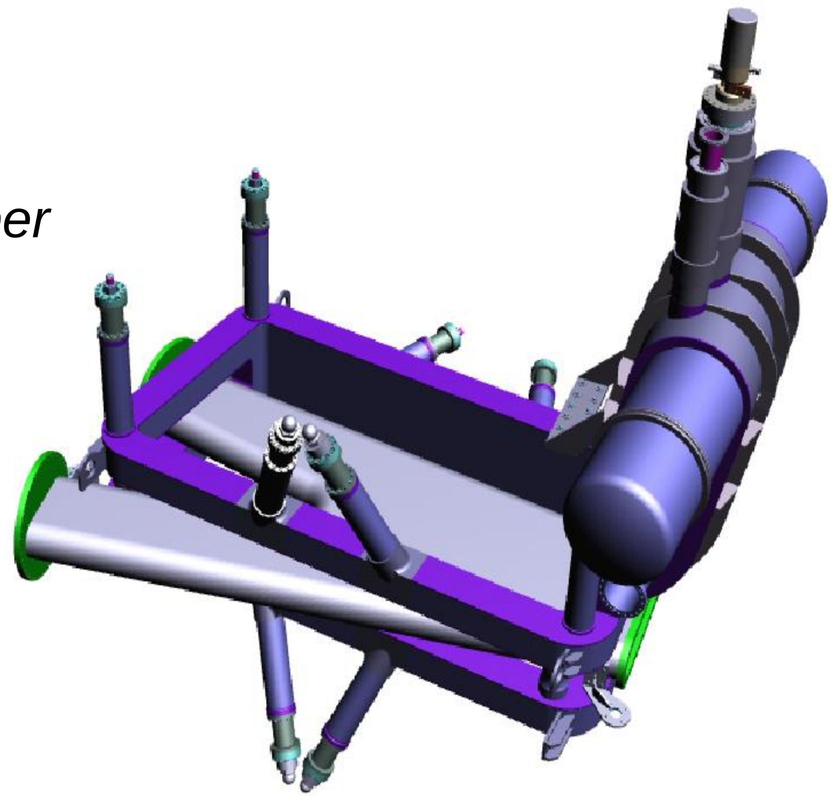


Super-FRS Dipoles: Parameters

	Type 2	Type 3	Type 3Y
Number of magnets	3	18	3
Dipole field [T]	0.15-1.6	0.15-1.6	0.15-1.6
Bending angle [°]	12,5	9,75	9,75
Curvature radius [m]	12,5	12,5	12,5
Effective straight length [m]	2,4	2,13	2,13
Good field region [mm]	±190	±190	±190
Pole gap height [mm]	170	170	170
Integral field quality (relative)	±3*10-4	±3*10-4	±3*10-4
Inductance	18.2 H	15 H	14 H
Nominal max. current	246 A	246 A	279 A
Stored Energy	550 kJ	454 kJ	563 kJ

Super-FRS Branched Dipole

C-shaped cryostat
to allow insertion of
Y-shaped vacuum chamber



inclined cold to warm supports to
cope with magnetic forces

Super-FRS Dipoles: Status

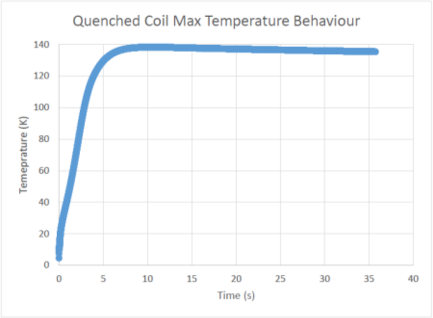
- **Standard dipoles:**
  - Conceptual design by CEA, Saclay
  - Contract awarded to Elytt Energy, Madrid
  - Design phase finished
  - Preliminary mock-up activities ongoing
  - FAT for FoS dipole expected in Spring 2020
- **Branching dipoles:**
  - Conceptual design by CEA completed
  - Tender about to start in Q2/2019

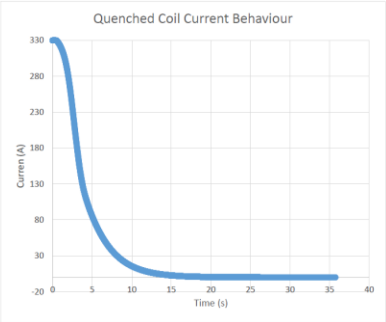
Super-FRS magnets: Quench analysis

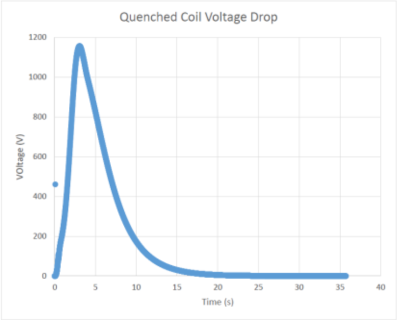
Magnet	Rd [Ω]	Rqmax [Ω]	Vqmax [V]	Tmax [T]	Vmax-coil to ground (ground in the middle) [V]
Dipole	0	5.2	441	105	220
	2.8	1.1	90	53	± 360
Long quadrupole	0	17.8	2130	180	1200
	2.8	11.3	1110	137	± 950

only dipoles and quadrupoles have dump resistors for energy extraction

example:
long quadrupole
without dump resistor







Super-FRS magnet cryogenics

- **Vapour cooled cooled current leads**
  - Temperature sensors on 90% of length (for valve regulation)
  - Temperature sensors on warm terminal
  - Heaters on warm terminal (to prevent icing)
  - Testing of FoS shall establish proper regualtion scheme and allow optimization of number of valves
- **Dipole cooling by thermosiphon**
  - 2 independent thermosiphon cooling loops for upper and lower coil
  - Heaters (about 2 W) required to get constant flow

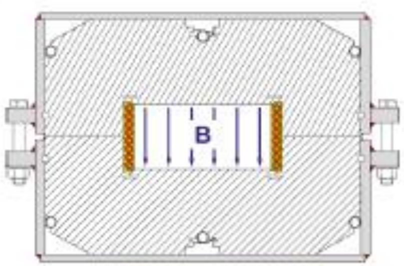
SIS 100 Dipole design features

NUCLOTRON type

- superferric magnet
  - superconducting coil
  - iron-dominated
- Nuclotron cable
  - NbTi wire wrapped around cooling tube
  - two-phase He cooling (forced flow)
- cold iron

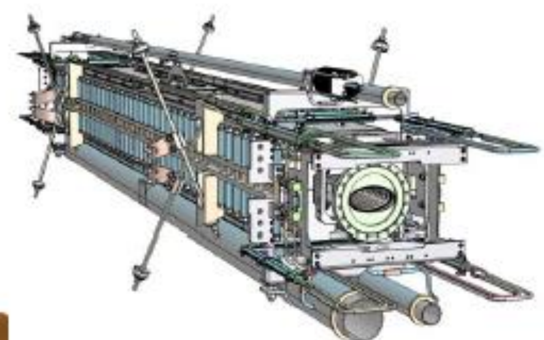
featuring

- B_{max} = 1.9 T
- high ramp rate of 4 T/s (@1 Hz)
- cold environment for beam chamber
- low space requirements
- low ac losses



yoke cross section with coil

cable



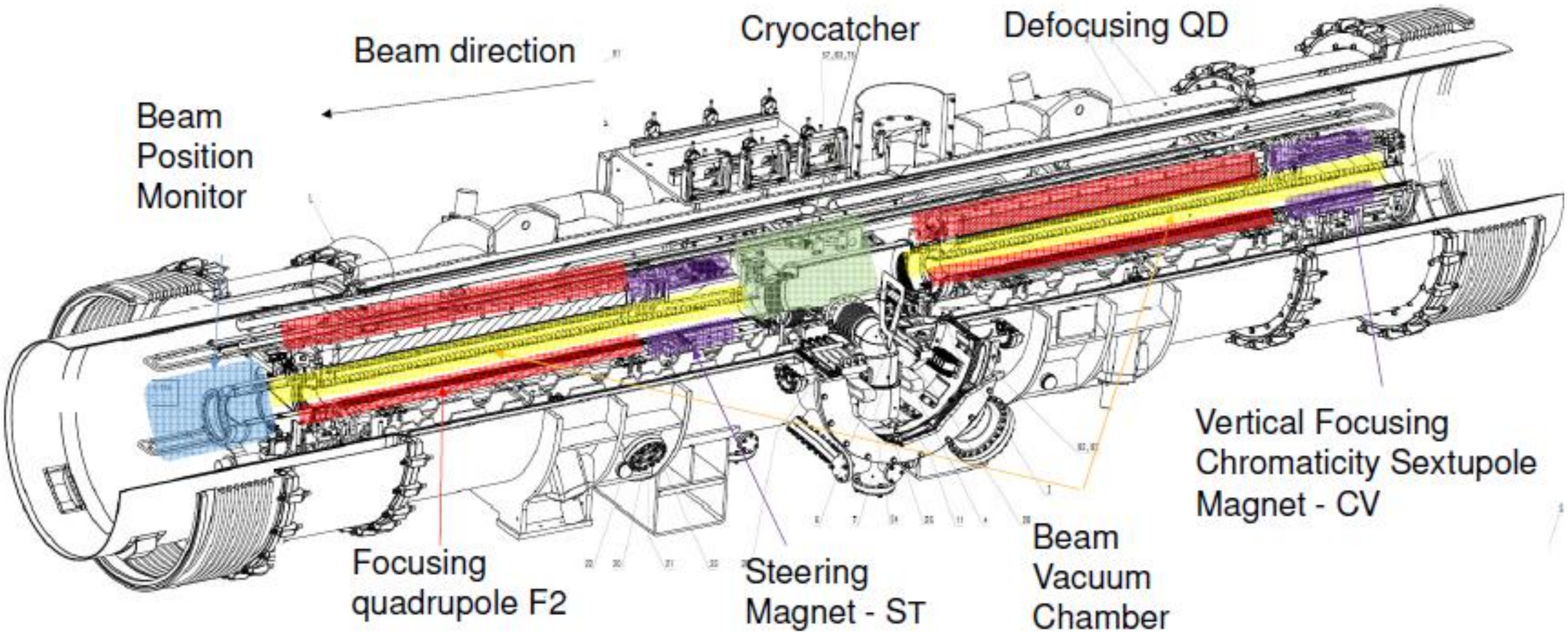
cold mass with beam chamber

module

SIS 100 Dipole status

- Production of 109 series dipoles is ongoing at Bilfinger Noell
- Series testing at GSI STF
- good reproducibility between magnets
- good field quality

SIS100 Quadrupole modules



Unit Production

JINR

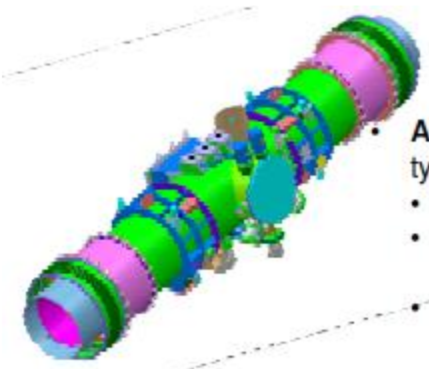
Integration

BiLFINGER

Testing

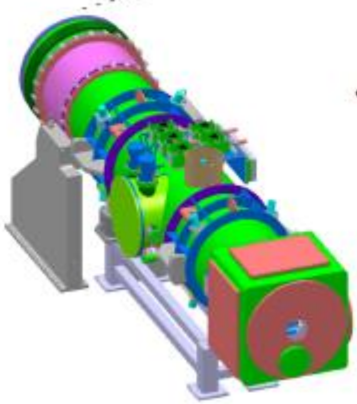
INFN Istituto Nazionale di Fisica Nucleare

SIS 100 Quadrupole modules

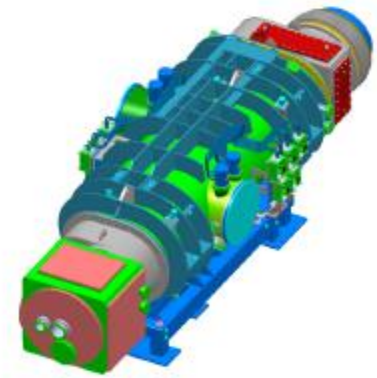


- **Arc section modules**
  types 2.5 to 2.9D
  - **54 modules**
  - Arc section module type incline of the arc-section
  - Cryogenic supply in line of the arc section

- **Straight section modules**
  types 2.123 and 2.13s
  - **17 modules**
  - Stand-alone module types are in between two warm sections
  - Cryogenic supply through attached by-pass line



- **Arc termination modules**
  types 2.4 and 1.E
  - **10 modules**
  - US- and DS-termination of the arc section of SIS100
  - Cryogenic supply by attached by-pass line
  - Additional support for vacuum forces



- **Special modules**
  types 2.4x and 1.Ei
  - **2 modules**
  - US- and DS-terminations of sector 5 in SIS100
  - Additional Injection- and extraction QP-doublets separately supported
  - Cryogenic supply by attached by-pass line

Experiments