SUPERCONDUCTING MAGNETS AT FAIR

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Outline

Introduction

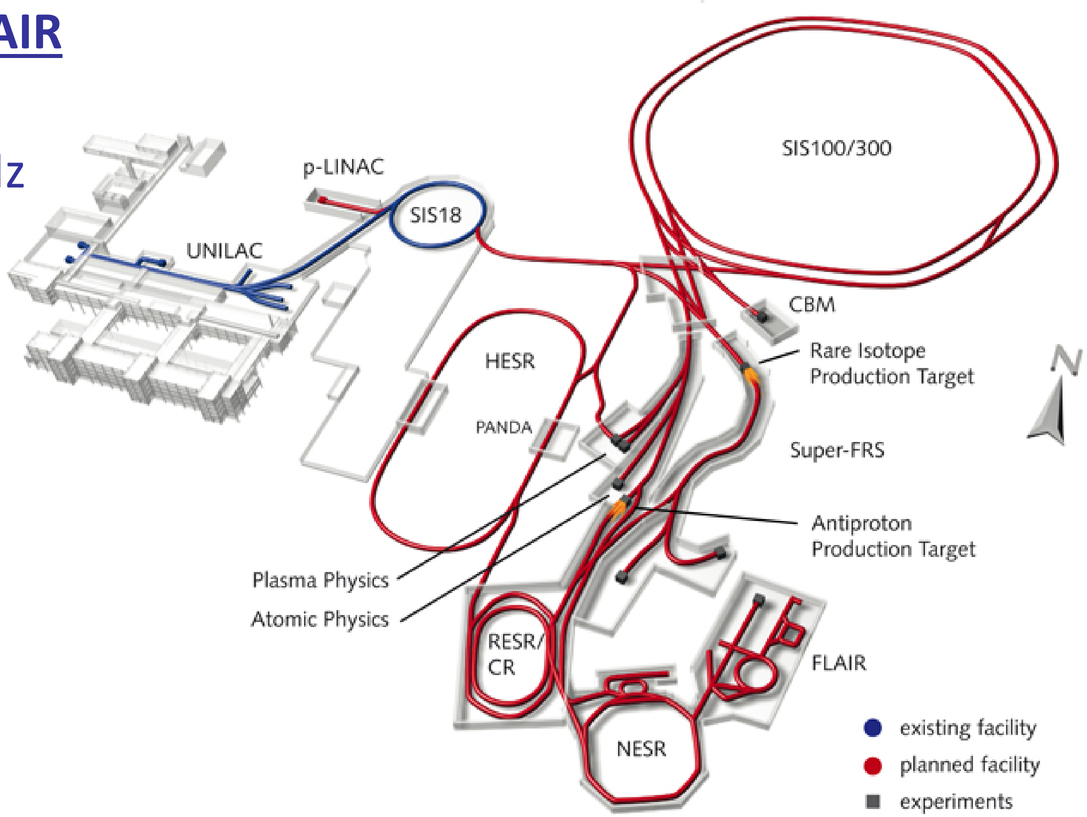
1. **Rapidly Cycling Magnets for SIS100**
   a) Main Dipoles
   b) Quadrupole Modules
   c) Magnet Test Facilities
2. **Large Aperture Magnets for Super-FRS**
   a) Multiplets
   b) Dipoles
   c) Preparation for Tests

Summary

Introduction: SC Magnets @ FAIR

- **SIS100 – the core component of FAIR**
- 100 Tm rigidity
- B_{max} = 1,9 T, ${}^{dB}/_{dt}$ = 4 T/s, f_{cycle} = 1 Hz
- 1100 m circumference
- sc dipoles: 108
- sc quadrupoles: 168
- sc correctors: 144
- cold beam pipe:
  vacuum quality critical for
  beam life time: < 10^{-12} mbar

- Super-Fragment Separator
- „mass spectrometer“
- large acceptance → large aperture
  400x200 mm^2
- sc dipoles / sc quadrupoles
  sc sextupoles / sc steerer



Special SC Magnets for:

APPA: High gradient quadrupole magnets for the final focusing system (FFS) of the HEDgeHOB experiment

CBM-Detector: Dipole (magnet gap 2500x1400x mm^2)

Introduction

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   a) Main Dipoles
   b) Quadrupole Modules
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2. Large Aperture Magnets for Super-FRS
a) Multiplets
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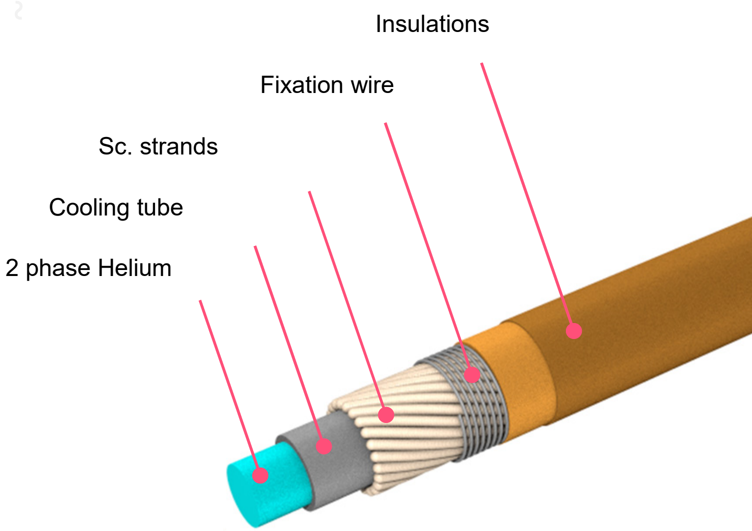
Summary

SIS100 Dipole: Basic Design

NUCLOTRON type magnet:

- superferric design
- hollow s.c. cable
- forced-flow two-phase He^4 cooling
- iron at 4 K



number of magnets	108 + 1 reference magnet
design	window-frame, laminated cold iron yoke, lamination thickness 1mm, one layer with 8 turns

number of magnets	108 + 1	
max. field B_{max}	1.9	T
min. field B_{min}	0.23	T
bending angle	3 1/3	Deg.
orbit curvature radius, R	52.632	m
effective magnetic length, L	3.062	m
good field region	$115 \cdot 60$	mm^2
field quality target	600	ppm
current at max. field	13093	A
inductance	0.55	mH
ramp rate	4	T/s

Successful R&D: Fast ramped sc magnets

- Based on the design and experience of the Nuclotron, operational at JINR since 1993.
- GSI & JINR through the last decade:
  - ✓ Improvement of design and manufacturing technology
  - ✓ adjustment with respect to the specific needs of the SIS100

SIS100	*Dipole*	
cable		
tube inner diameter	4.7	mm
number of strands	23	
critical current (at 2.5 T and 4.5 K)	19.8	kA
dipole		
field strength	1.9	T
field ramp rate	4	T/s
pole gap height	68	mm
magnet length	3.1	m
curvature radius	52.625	m
operation current	13.1	kA
inductance	0.55	mH
maximum AC loss	100	W

Activities

- AC Loss Reduction (exp. tests, FEM)
- Improvement of field quality (2D/3D Calculations)
- Mechanical Stress Analysis and Coil Restraint for ≥ $2 \cdot 10^8$ cycles (design, ANSYS)
- Experimental studies with modified Nuclotron magnets in JINR

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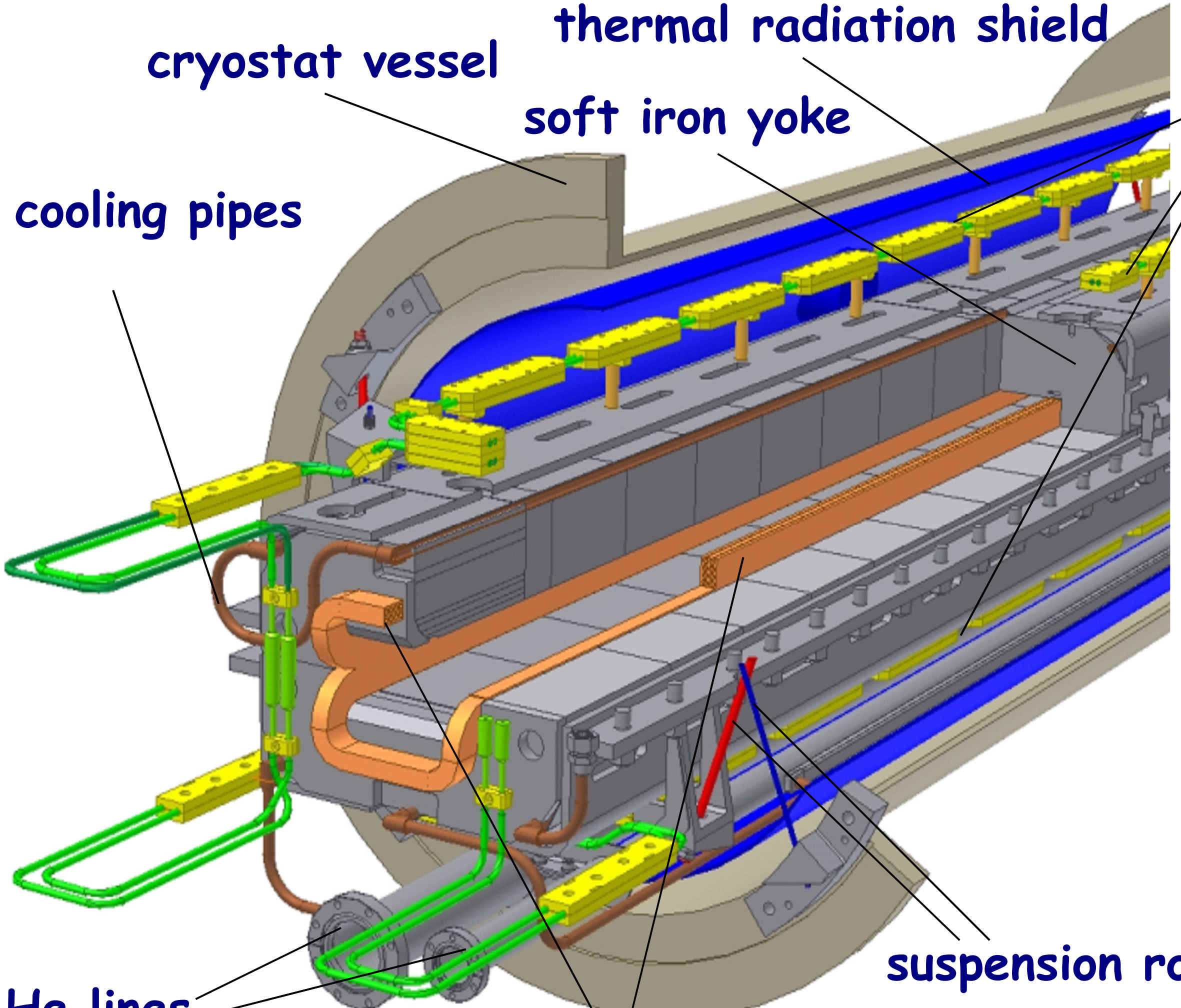
SIS100: Dipole Design



Wire & Cables

Main magnets and local cryogenics:
23 strands
diameter 0.8 mm

Corrector cable:
28 insulated strands
diameter 0.5 mm

Cable lengths needed:

Dipoles:	16 km
Quadrupoles:	11 km
Local Cryogenics:	4 km

Corrector magnets: 3.5 km

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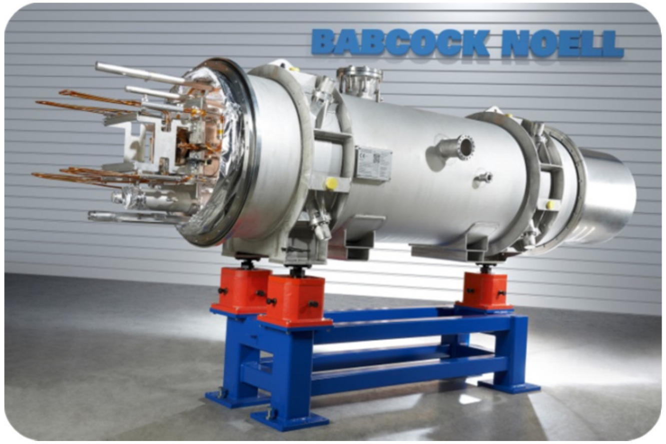
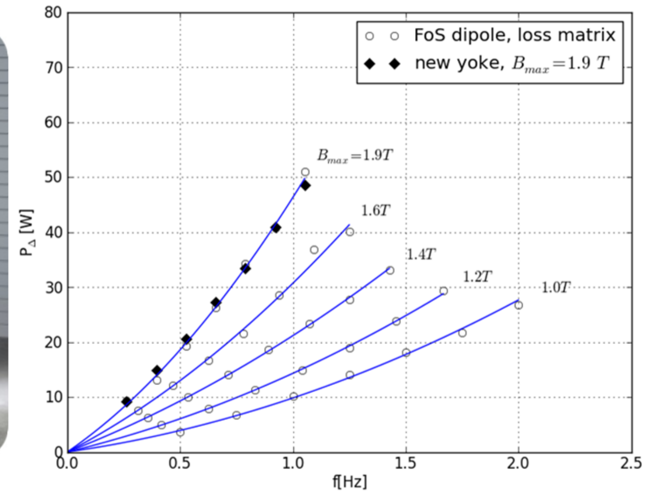
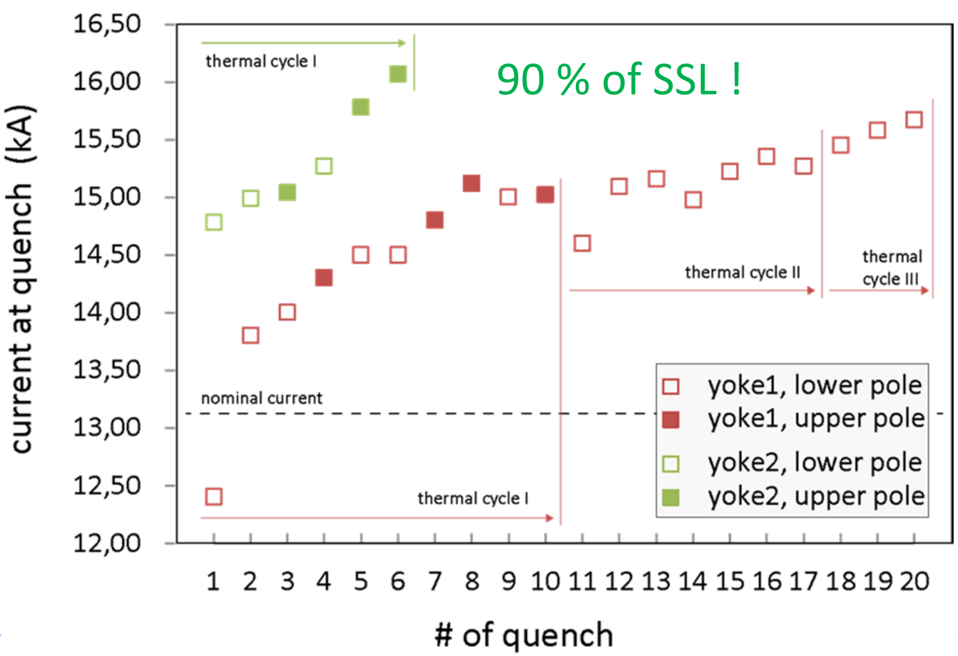
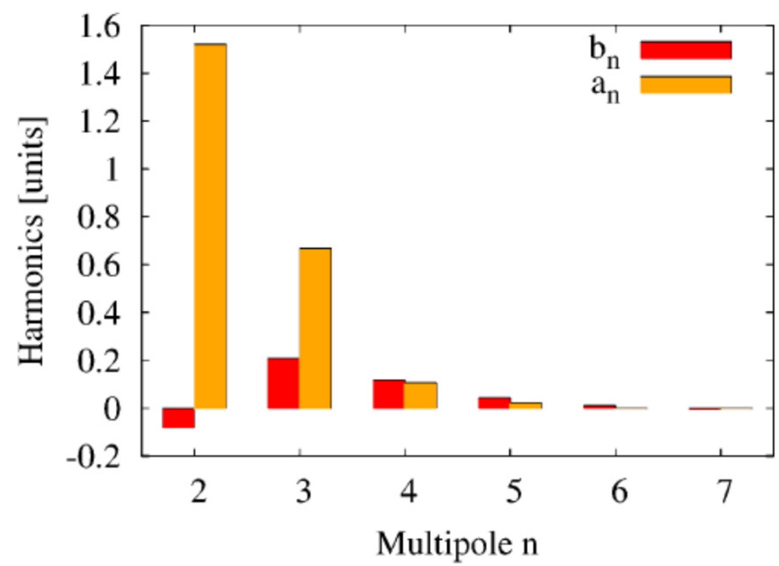
First SIS100 Dipole: Manufacturing & Tests



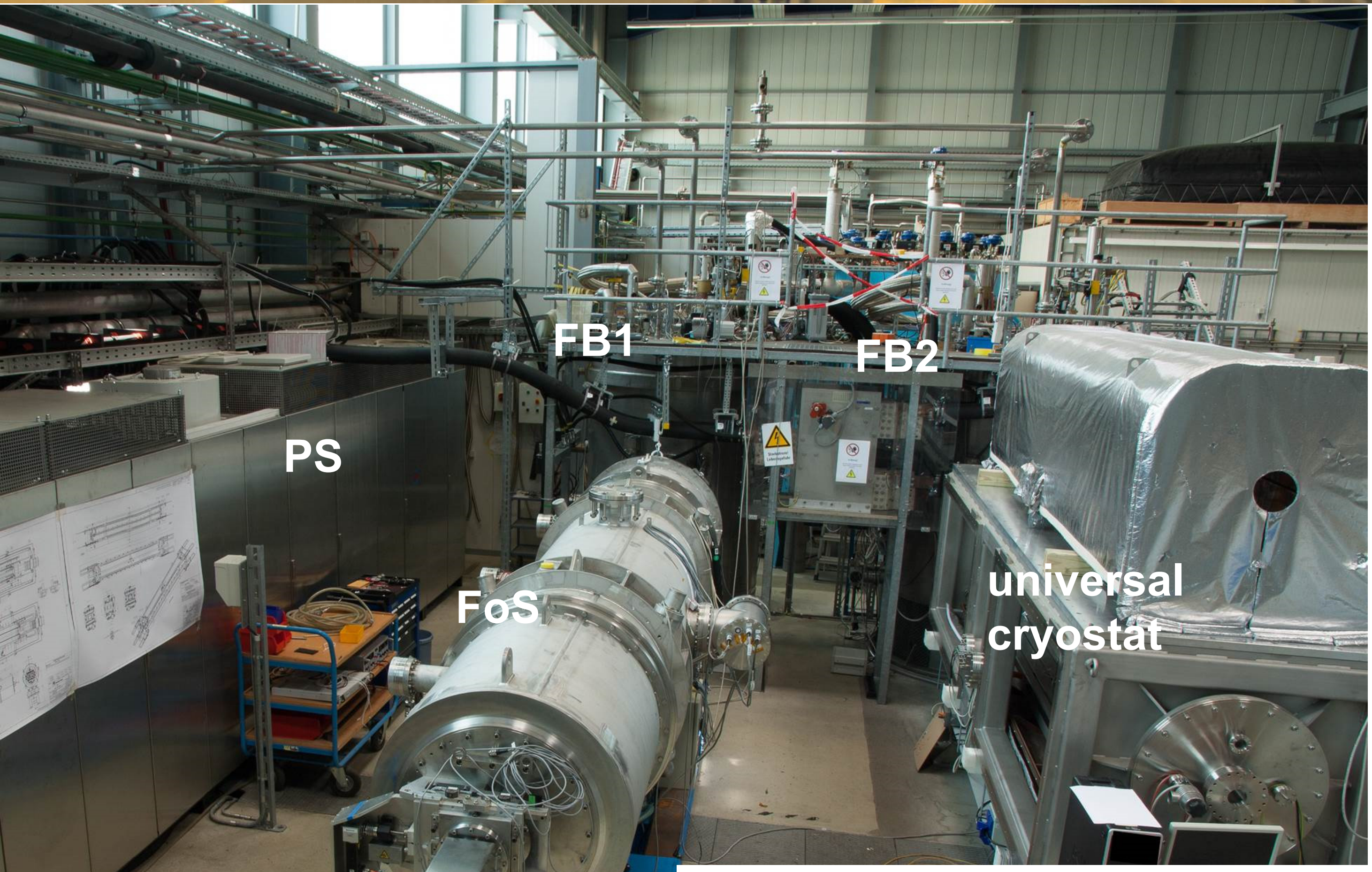




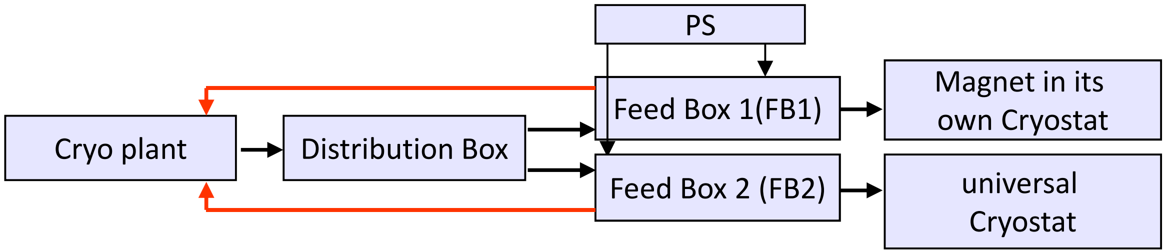


: Multipole spectrum of FoS2 at $I = 8$ kA.

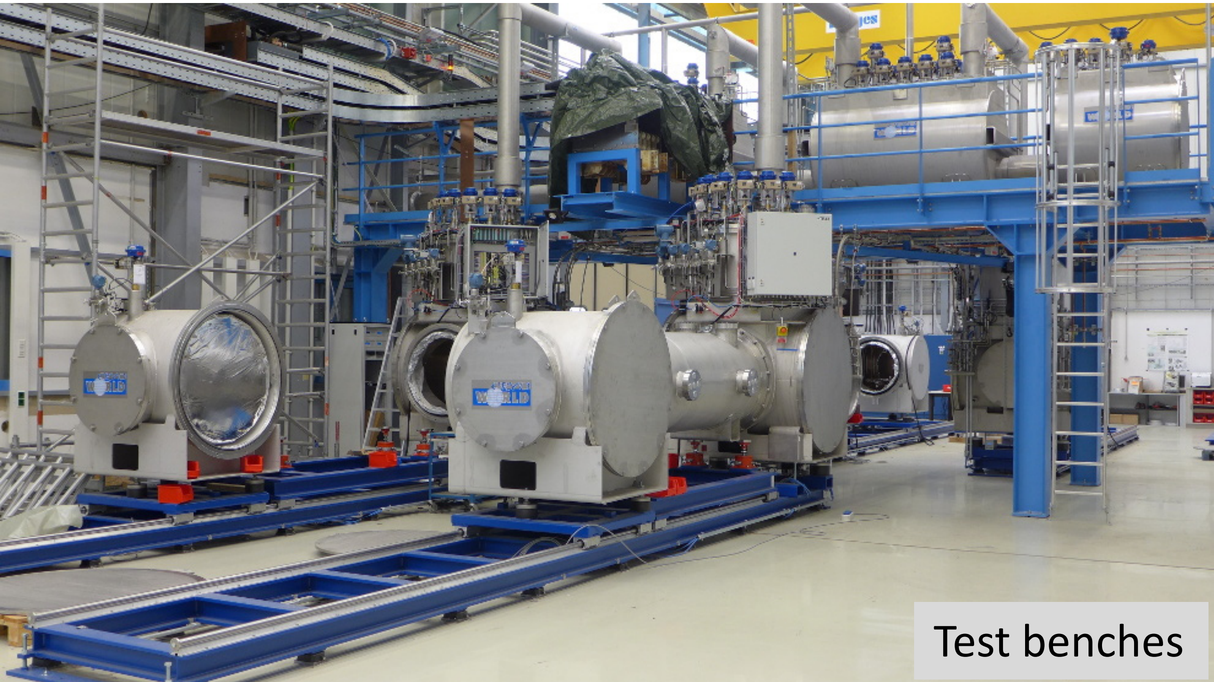
Testing the First SIS100 Dipole

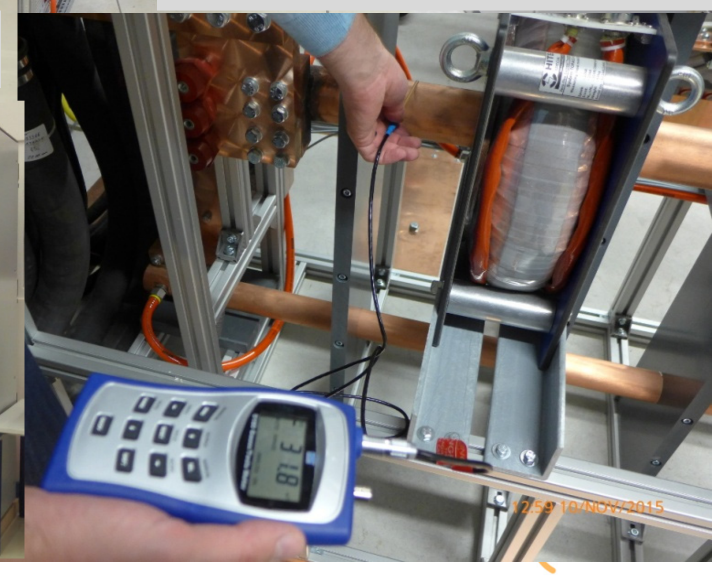


@ the GSI Prototype Test Facility



SIS100 Dipoles: Series Test Facility





SIS100 Quadrupoles and Correctors

Magnet Characteristics

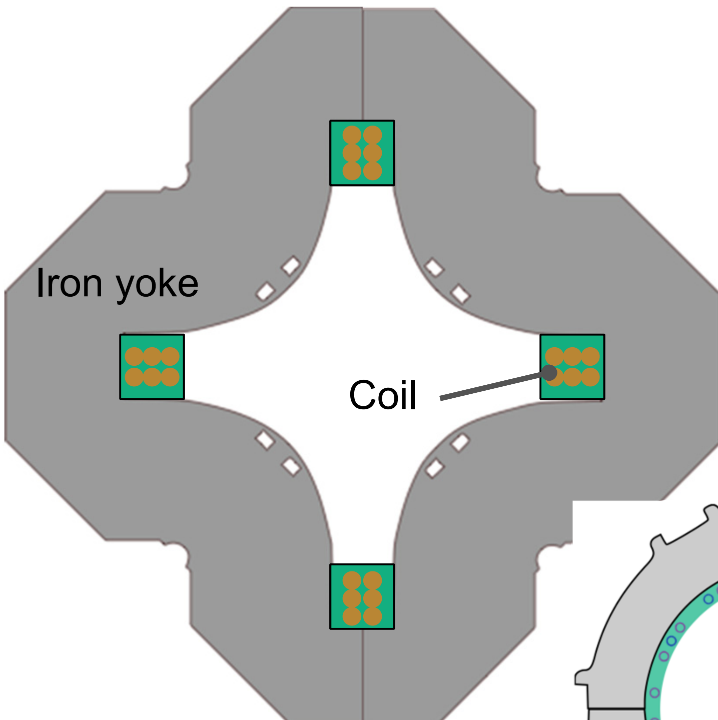
Characteristic	Lattice Quadrupole	Corrector magnet		
		Multipole (Q/S/O)	Steerer	Chrom. Sextupole
Number of magnets	166	12	84	42
Max. field strength, T/m^{n-1}	27.77	0.75/25/333,3	0.37	232
Effective magnetic length, m	1.264	0.75	0.403/0.41	0.383
Aperture diameter, mm	100	150	135	120
Operation current	10512	250/246/240	245/241	252
Magnet weight, kg	850	200	120	145

- Production at JINR Dubna
- Nuclotron-type design, cold, window-frame iron yoke
- coil made from hollow superconductor, i.e. Nuclotron type cable

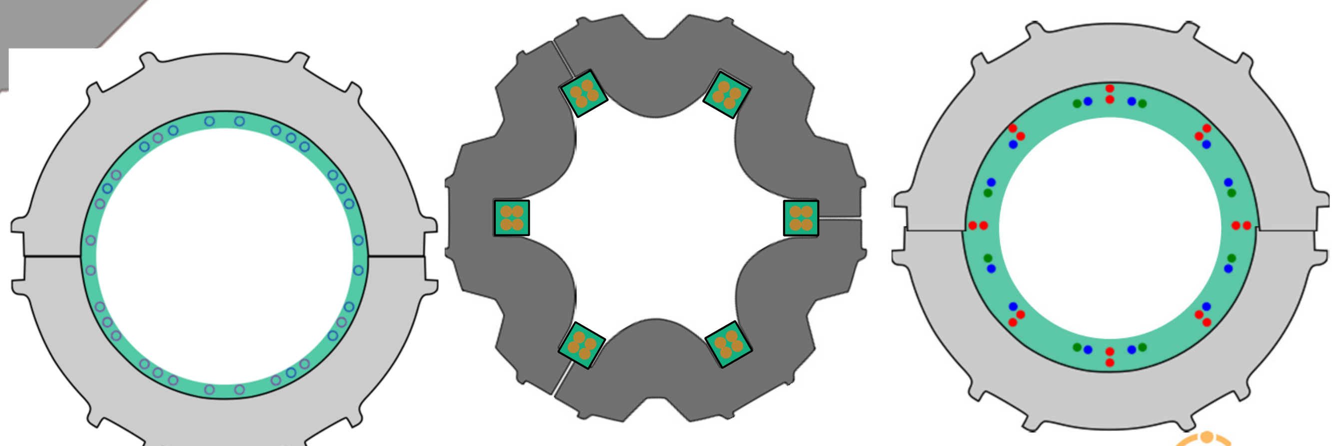
Low Current Magnets: Correctors

Quadrupole magnet

– 10 kA, 27.7 T/m



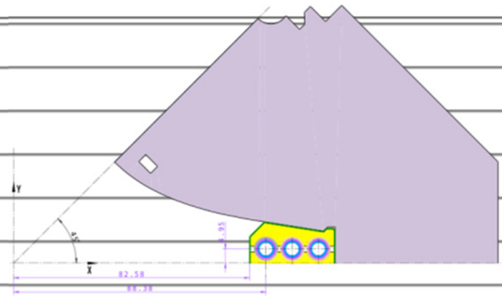
- Corrector magnets
  - ✓ Steering magnet (horizontal/vertical embedded)
  - ✓ Chromaticity sextupole magnet
  - ✓ Multipole corrector magnet (B2, A3, B4)
    - Nuclotron cable with insulated strands (250 A × 27 strands = 6.75 kA)

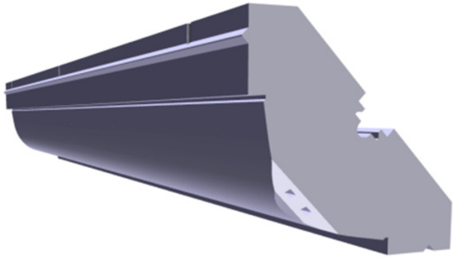


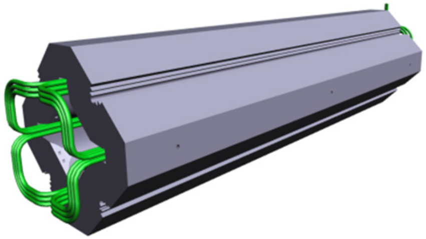
SIS100 Quadrupole Design

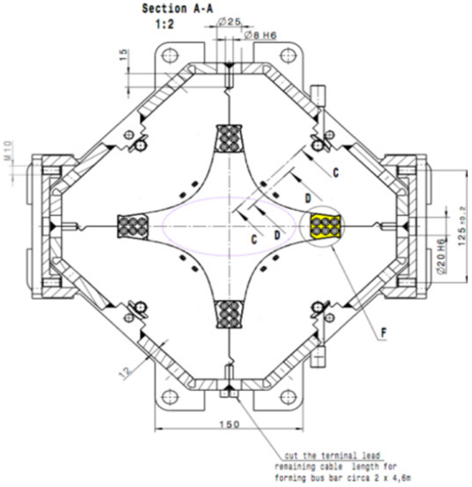
Quadrupole Parameters

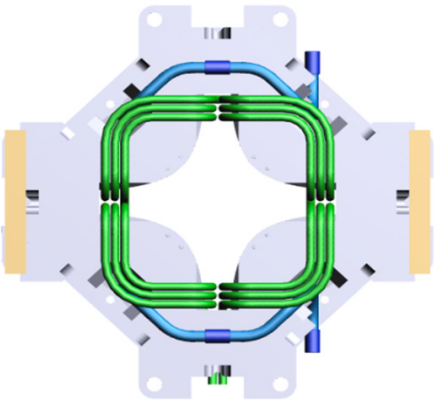
Parameter	Units	Value
Number of magnets		166+3
Design		Superferric
Maximum magnetic induction B_2	T/m	27
Effective magnetic length L_{eff}	m	1.3
Ramp rate dB/dt	(T/m)/s	57
Field quality		$\pm 6 \times 10^{-4}$
Good field region	mm^2	135×65
Overall magnet length (coil ends)	m	1.33

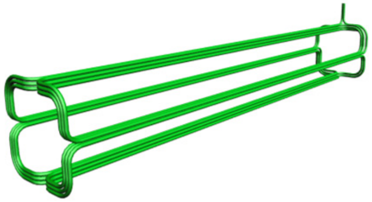


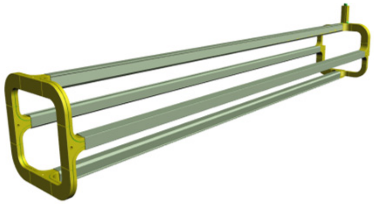


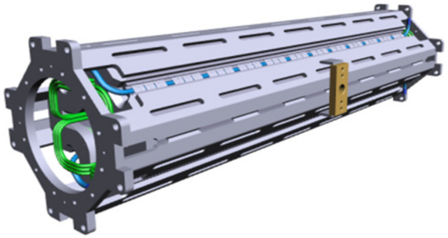




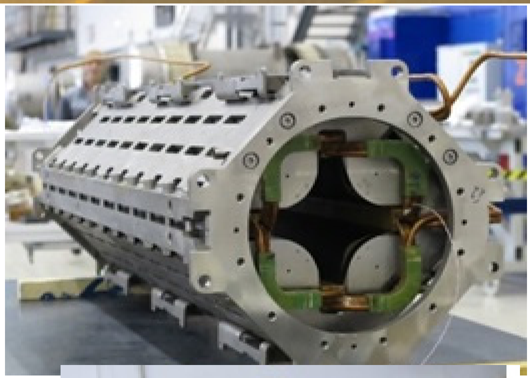


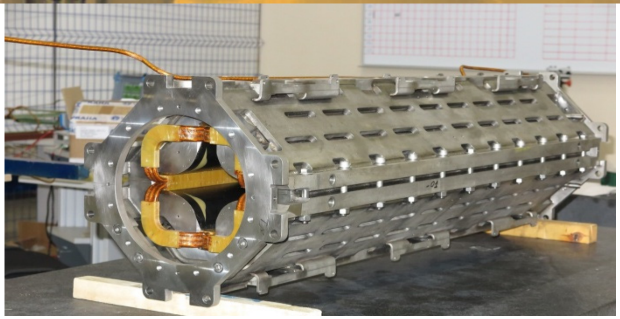


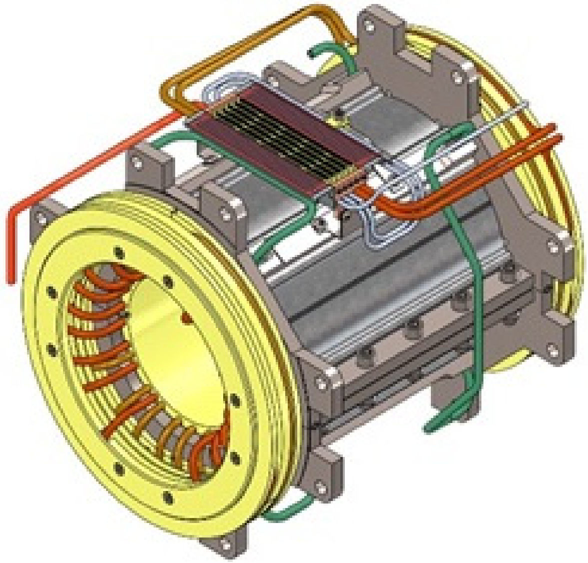


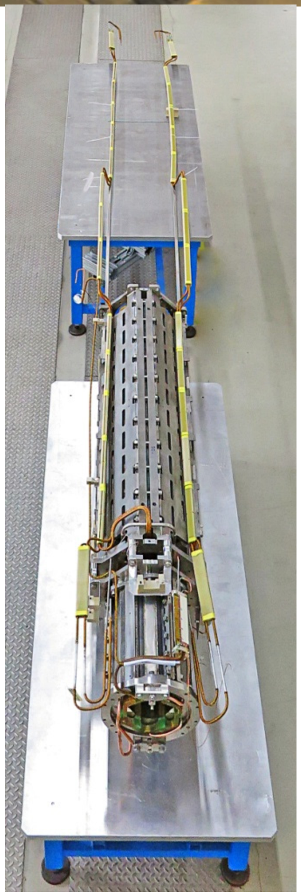


Production @ JINR: First Quadrupole Units



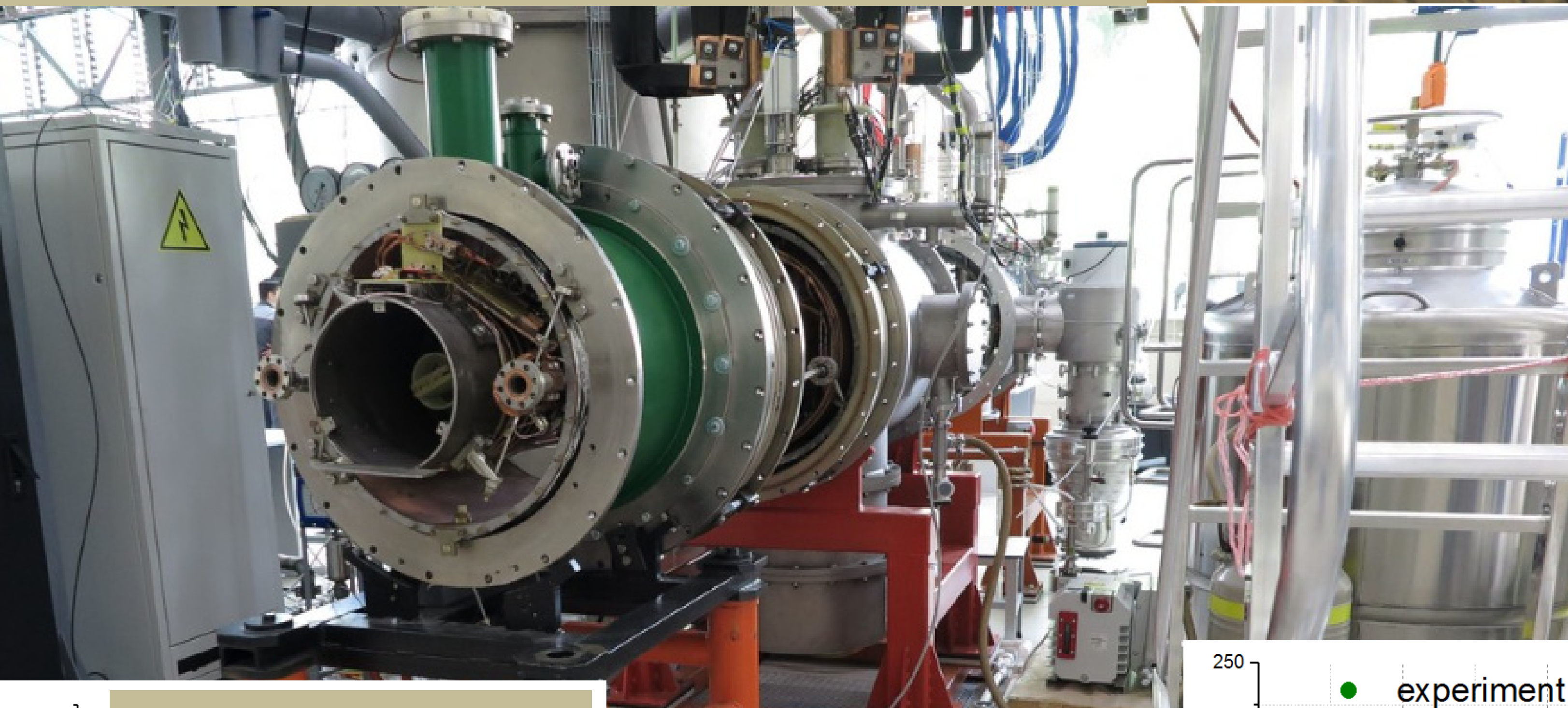


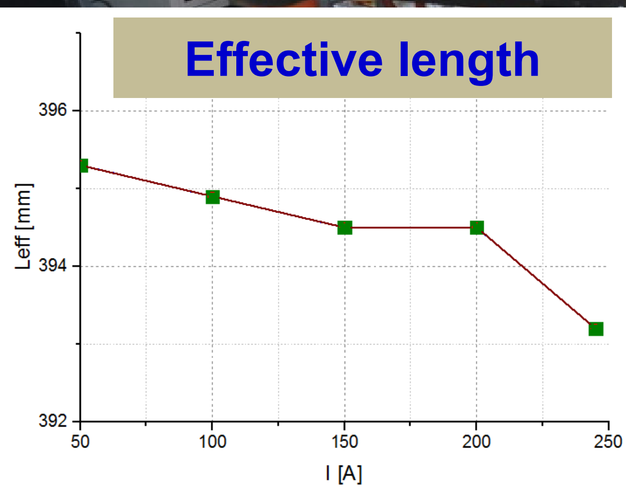




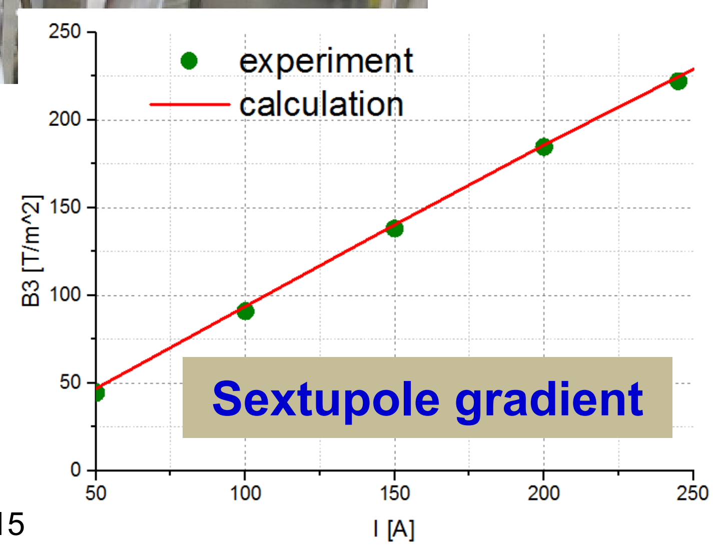
- A sextupole, a steerer and two quadrupole magnets were manufactured.
- Two FoS units of these magnets were assembled and prepared for cryogenic test.
- The beginning of the serial production of SC magnets for SIS100 in Dubna is scheduled for November 2017.

Testing @ JINR: Preseries SIS100 chrom. SP





First experimental verification for the design of fast ramped corrector magnets using Nuclotron Cable with insulated strands !



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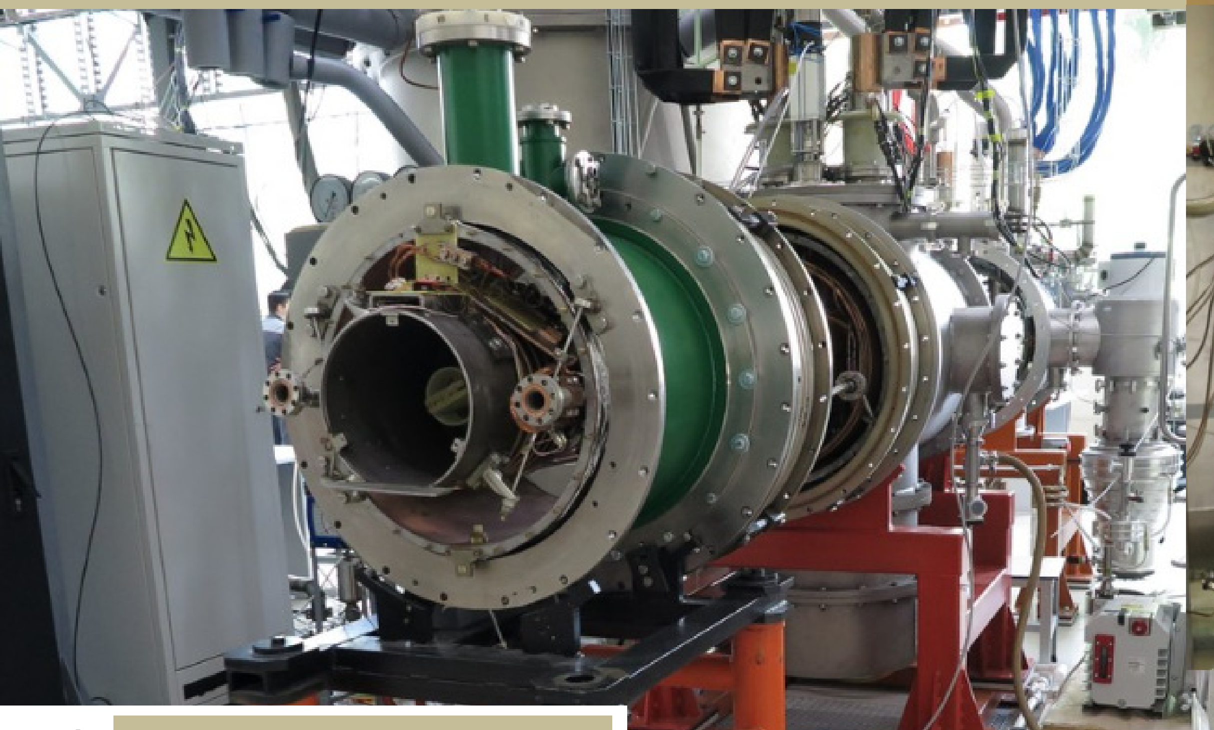

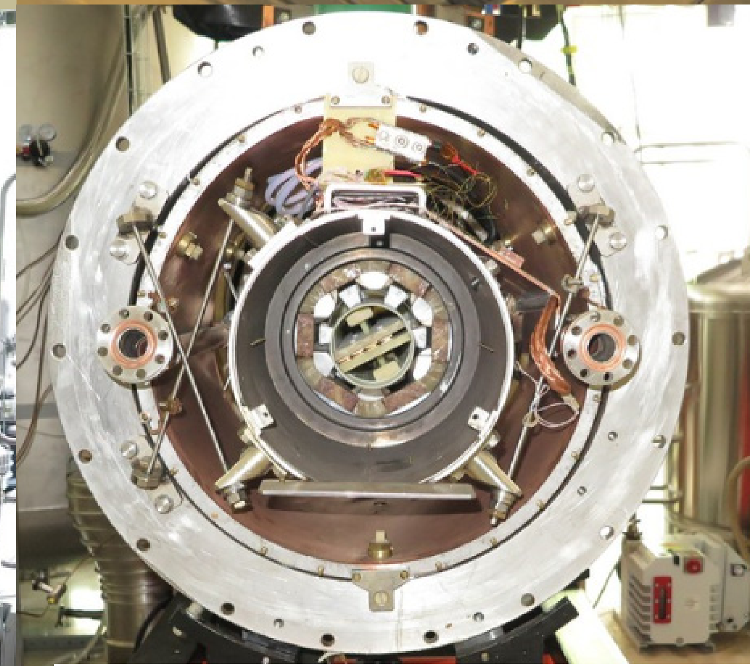

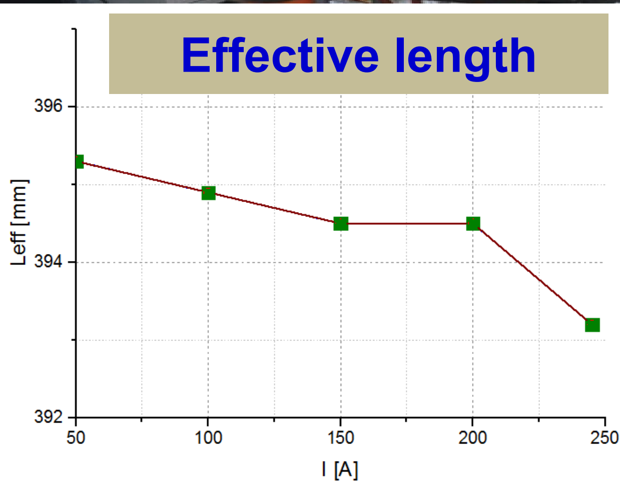

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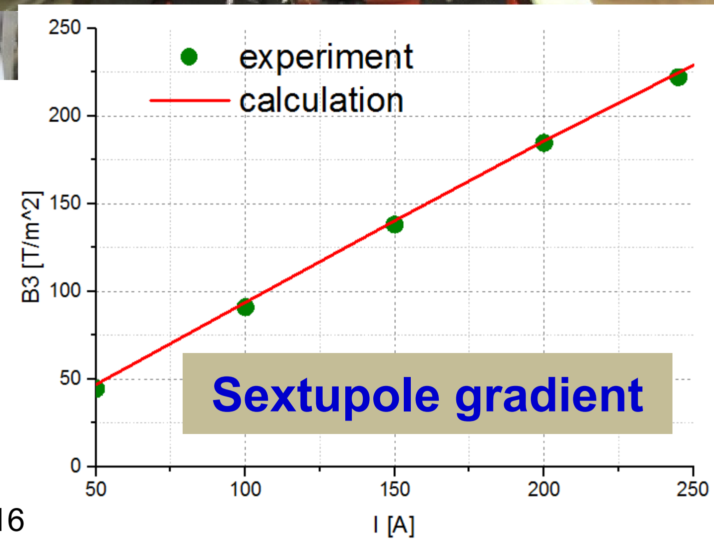
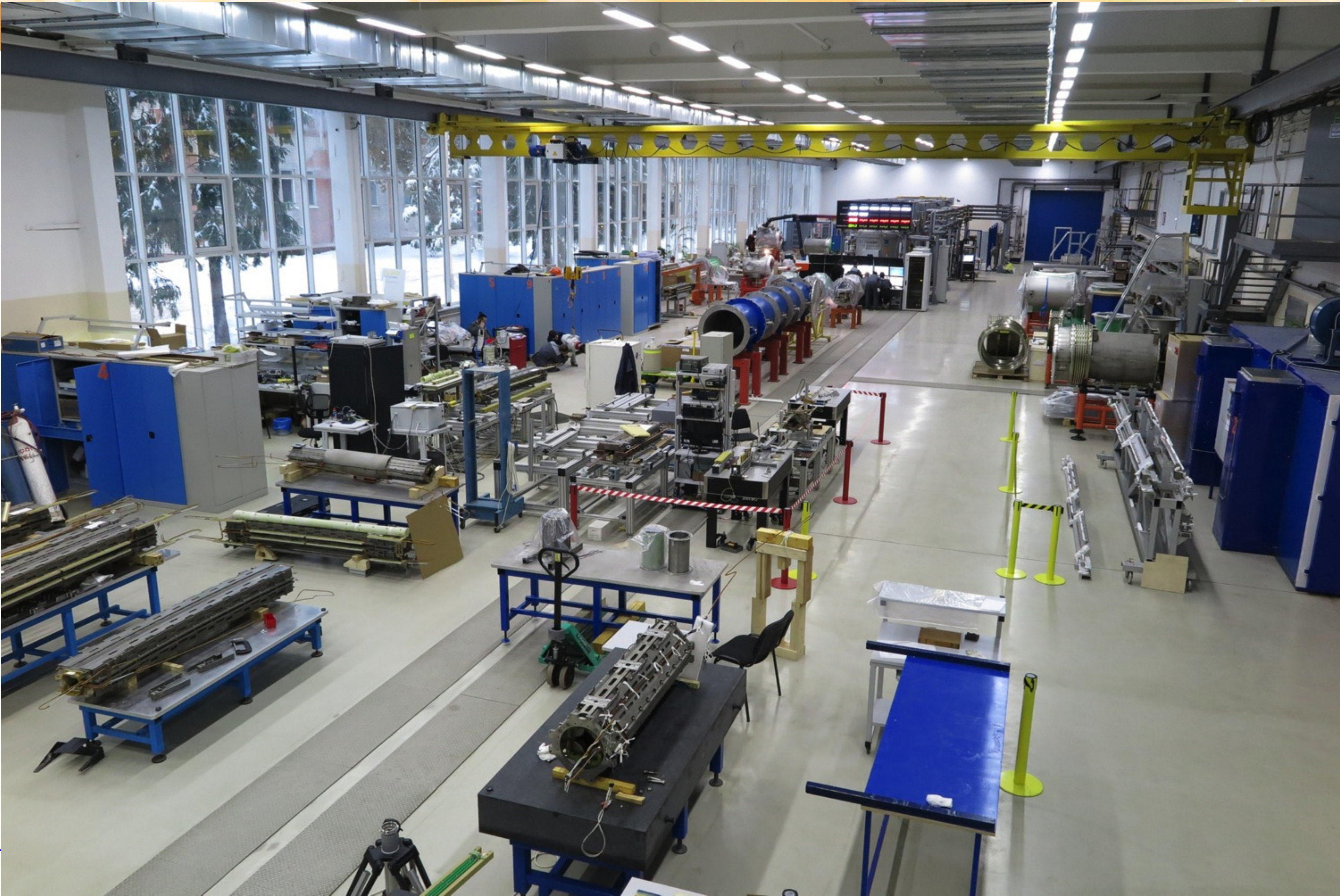


SIS100 QP-Units: Components

Magnet	Name	Nomenclature	Quantity	Comments
Quadrupole	Focusing Quadrupole 1	F1	36	
	Focusing Quadrupole 2	F2	47	
	Defocusing Quadrupole	QD	83	
Sextupole	Horizontal Focusing Chromaticity Sextupole	CH	24	
	Vertical Focusing Chromaticity Sextupole	CV	24	
Steerer	Horizontal/Vertical Steerer	ST	83	Combined magnet
Multipole	Multipole Corrector	MC	12	Combined magnet
Others		Nomenclature	Quantity	Comments
Beam Position Monitor		BPM	83	
Ion Catcher (Collimator)		COL	60	

- Focusing quadrupole F1 and F2 have different bus bar configuration.
- Horizontal/Vertical Focusing Chromaticity Sextupole (CH/CV) is identical within the cryostat.
  - But the joints between the power cable and the current lead (at warm) is opposite polarity.

QP-Units: Test Facility for NICA & FAIR @ JINR



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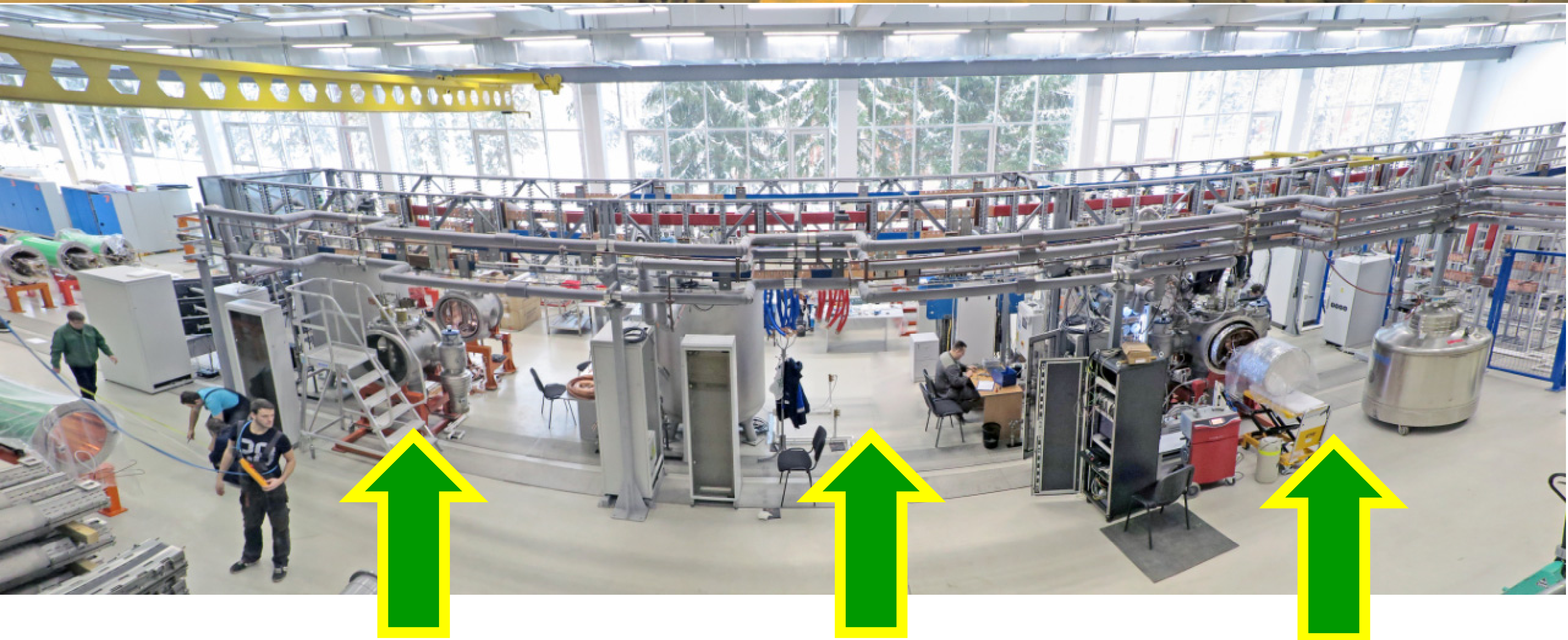


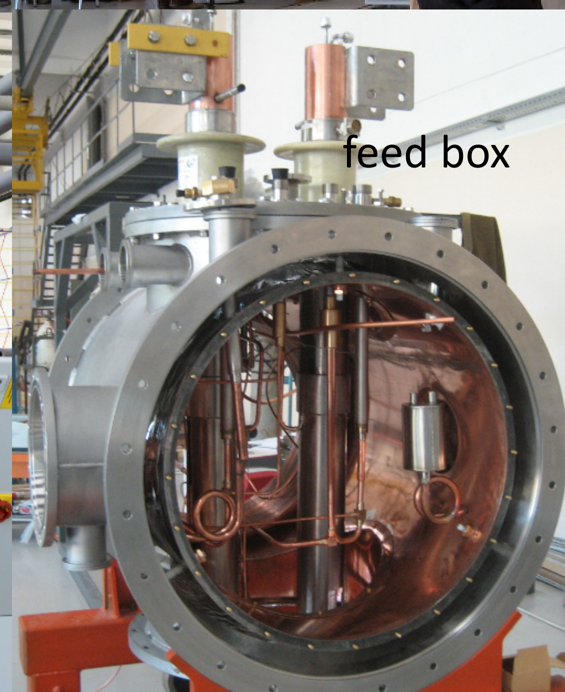
3 of 6 tests benches => for SIS100 units tests

Cryogenic test hall

QP-Units: Test Facility for NICA & FAIR @ JINR

Official launch 28.11.16

QP-Units: Test Facility for NICA & FAIR @ JINR

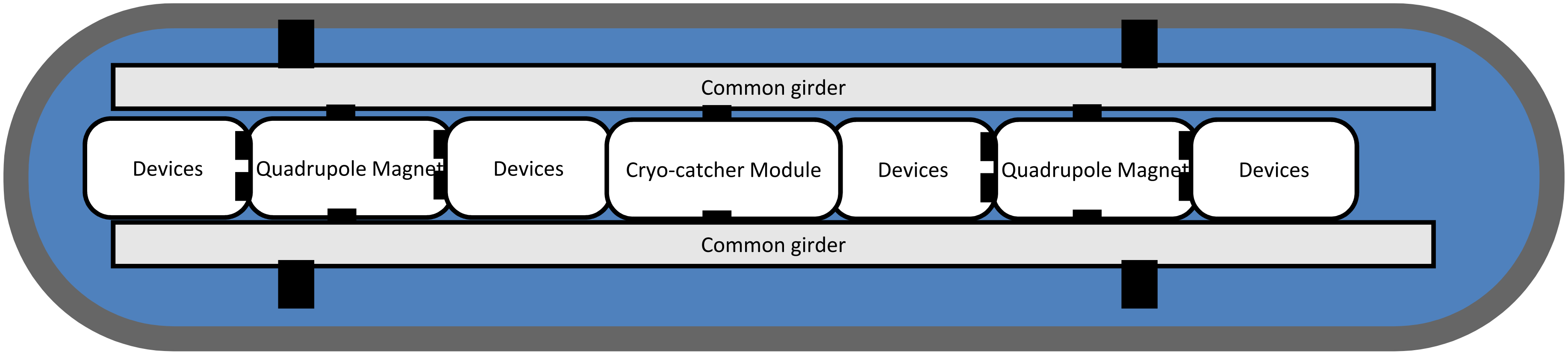


SIS100 QP Modules: Overview

Unit: Mechanical assembly of one quadrupole and other devices (corrector magnets, BPM)

Doublet: Two Units on Common Girder System (w/wo Cryo-Catcher Module)

The girder is suspended by rods in the cryostat.



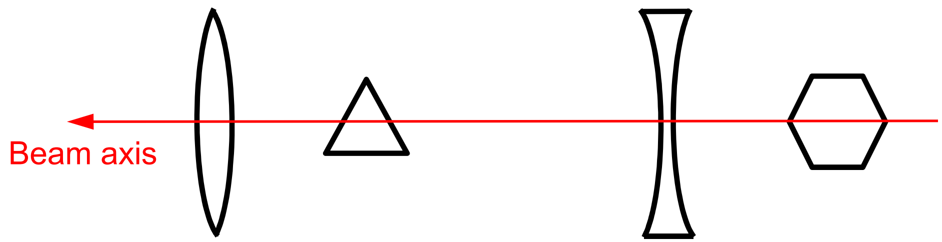
SIS100 QP-Units: Assembly Types

Type of the quadrupole unit

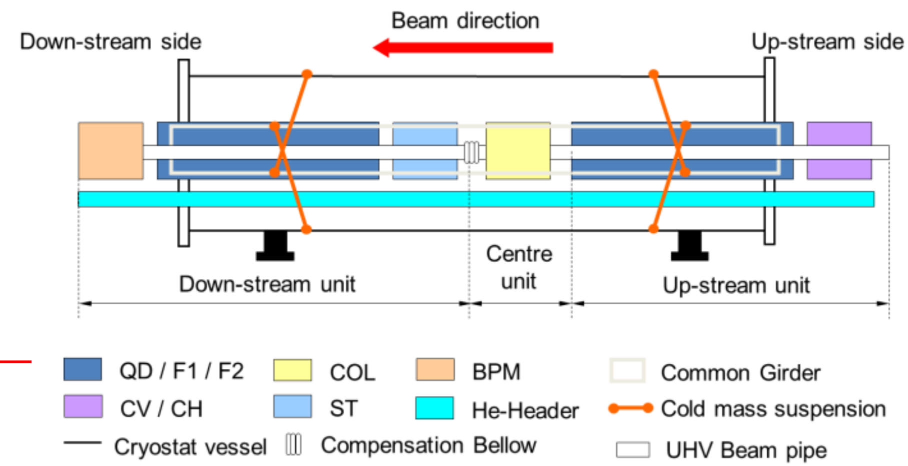
Type	1	2	3	4	5	6	7	8	9	10
Contents	QD	QD BPM	BPM QD	CV QD	ST F1	ST F2	ST F1 BPM	ST F2 BPM	ST F1 CH	ST F2 CH
Quantity	12	23	24	24	6	17	18	18	12	12
Position in doublet	upstream				downstream					

SIS100 QP-Units: Cryomagnetic Doublets

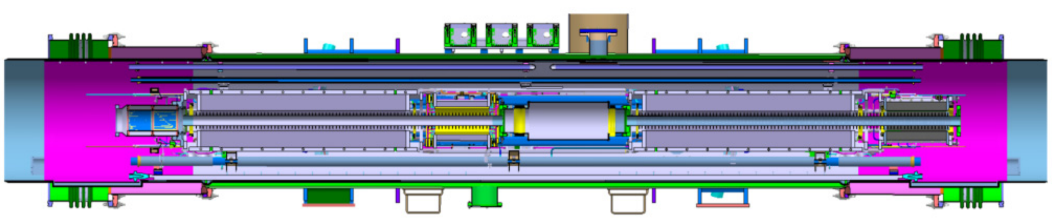
Basic ion-optical configuration of a typical SIS100-QDM



Quadrupole-magnet, horizontally focusing	Steering-magnet, horizontal & vertical	Quadrupole-magnet, horizontally defocusing	Sextupole-magnet, chromaticity correction



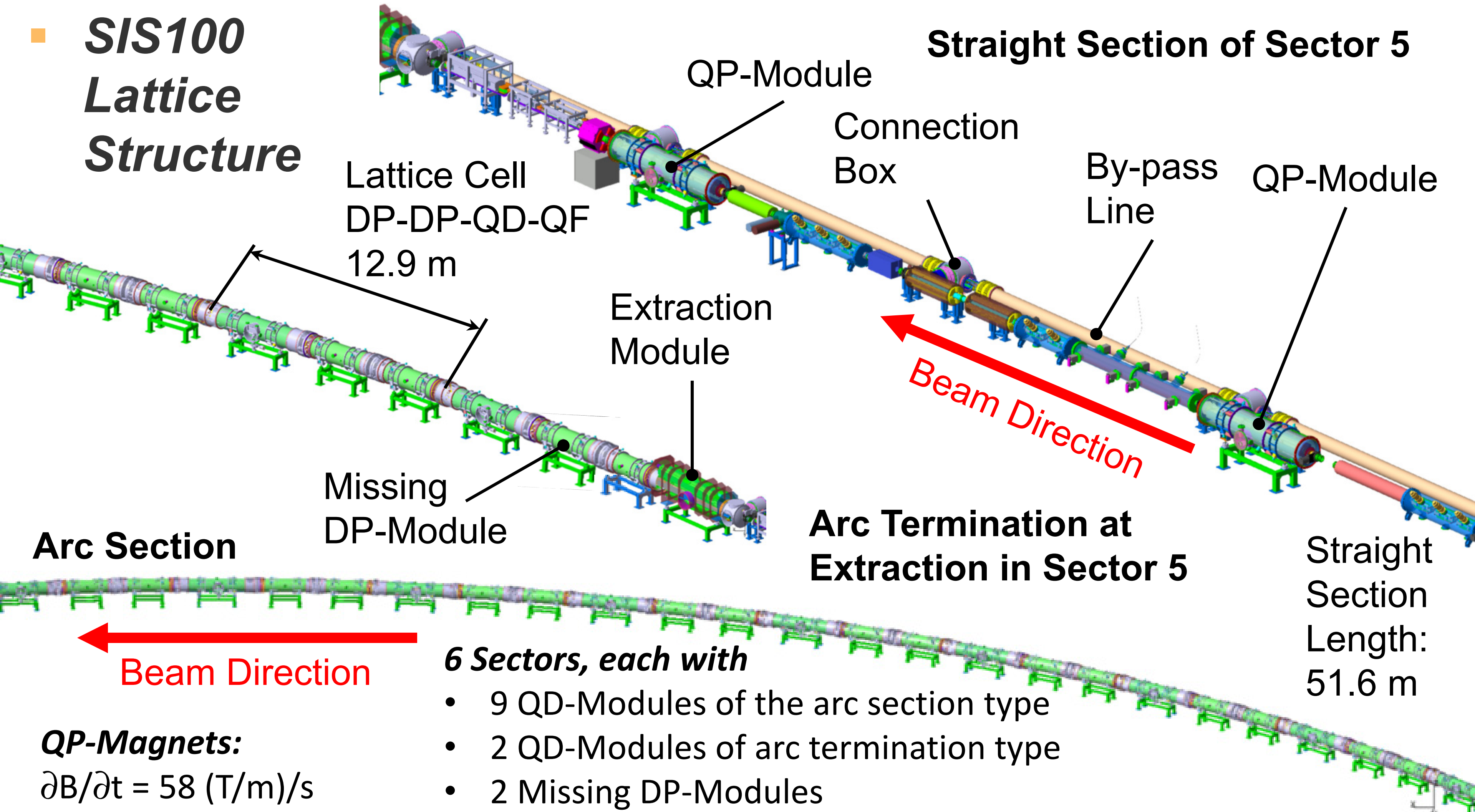
QD	Defocusing quadrupole
F1	Focusing quad. type 1
F2	Focusing quad. type 2
BPM	Beam position monitor
V	Vertical chromaticity sextupole
H	Horizontal chromaticity sextupole
ST	Steering magnet
COL	Cryo-Collimator



11 Configurations of SIS100-QDM

SIS100 Quadrupole Doublet Modules

- ***SIS100 Lattice Structure***



6 Sectors, each with

- 9 QD-Modules of the arc section type
- 2 QD-Modules of arc termination type
- 2 Missing DP-Modules
- 18 DP-Modules

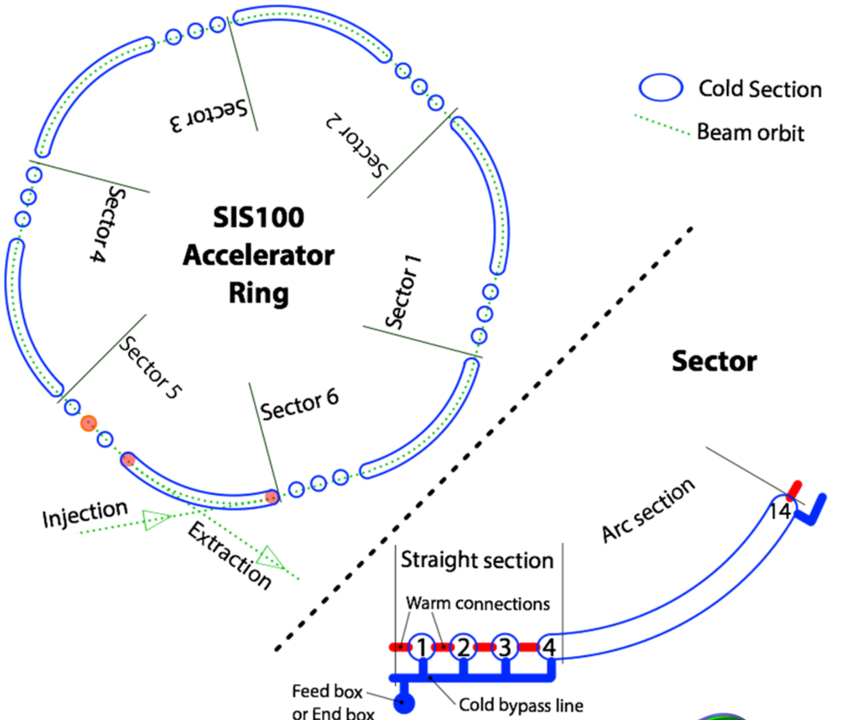
QP-Magnets:

$\partial B/\partial t = 58$ (T/m)/s

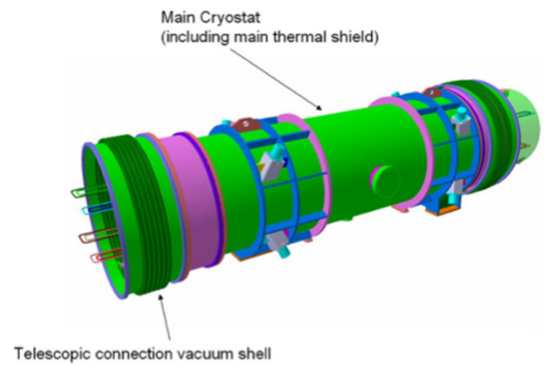
grad(B_{max}) = 27,8 T

SIS100 Cryomagnetic Doublet Modules

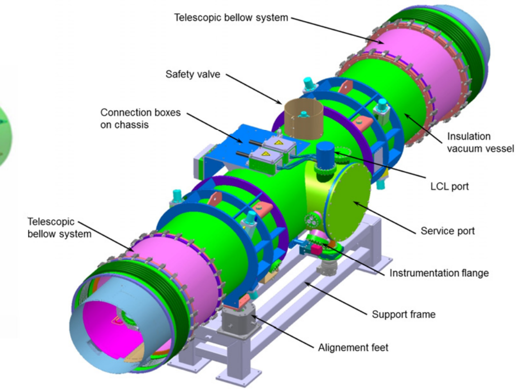
Structure



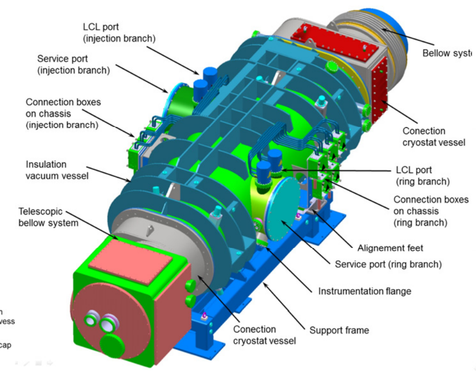
Cell 5 to 13 Dipole module



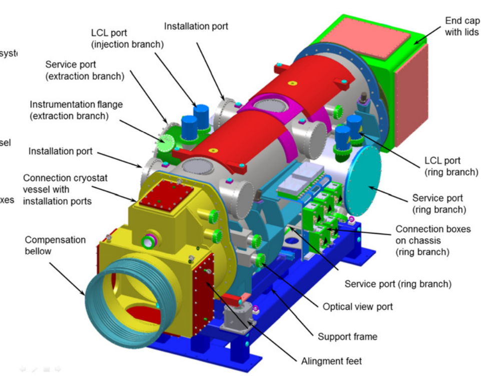
Quadrupole doublet module



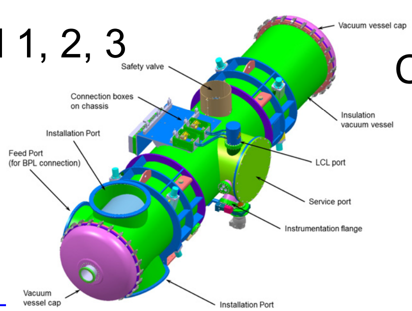
Injection



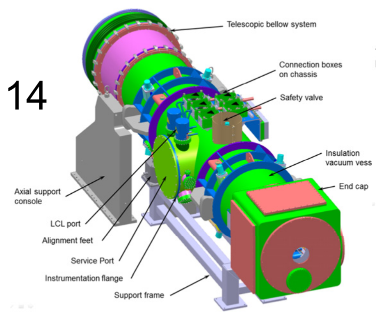
Extraction



Cell 1, 2, 3



Cell 4, 14



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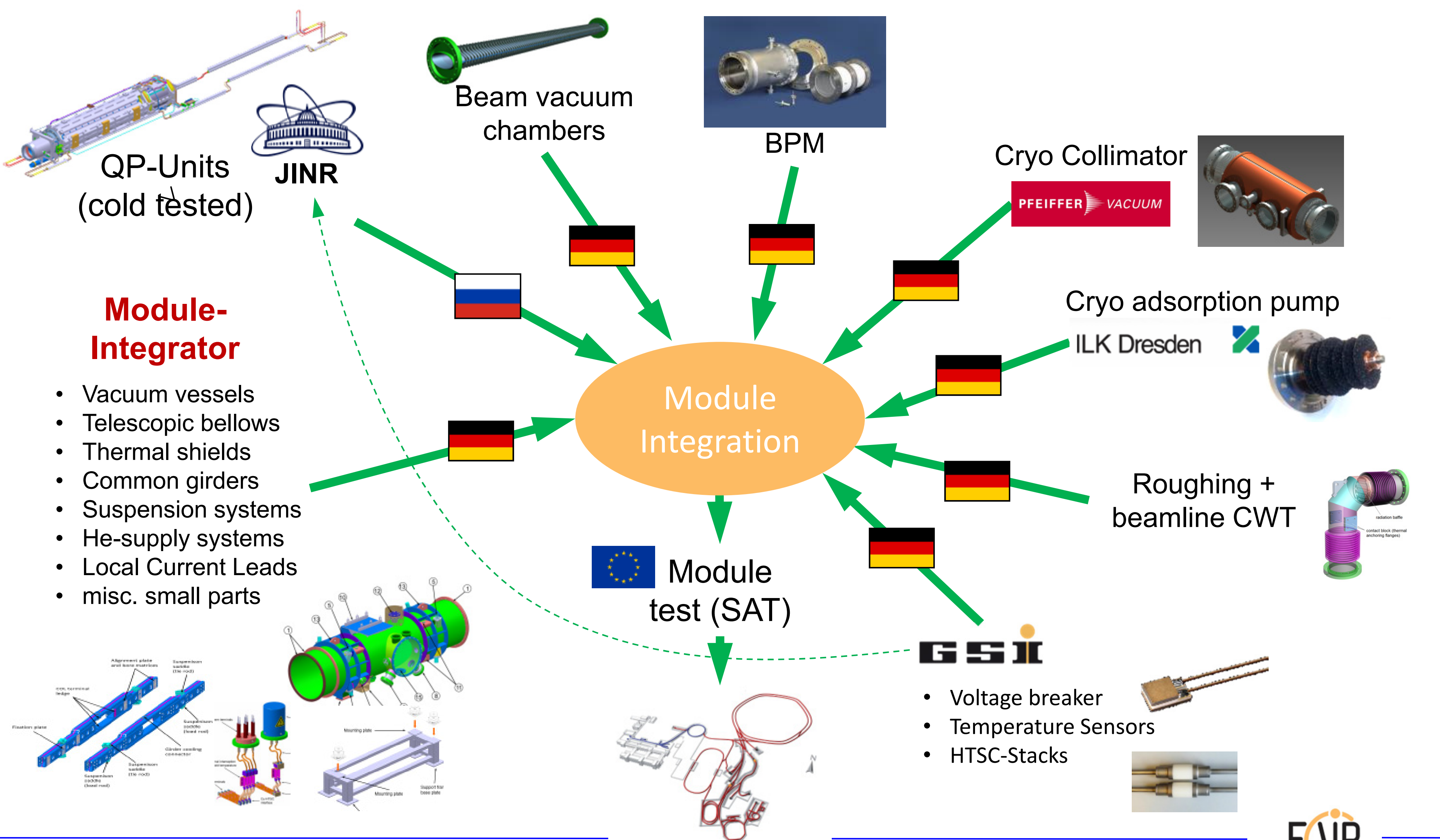
Procurement Structure for QDM-Integration



FAIR

Introduction

1. Rapidly Cycling Magnets for SIS100
   a) Main Dipoles
   b) Quadrupole Modules
   c) Magnet Test Facilities

2. **Large Aperture Magnets for Super-FRS**
   a) Multiplets
   b) Dipoles
   c) Preparation for Tests

Summary

Super-FRS: Layout

Design Parameters:

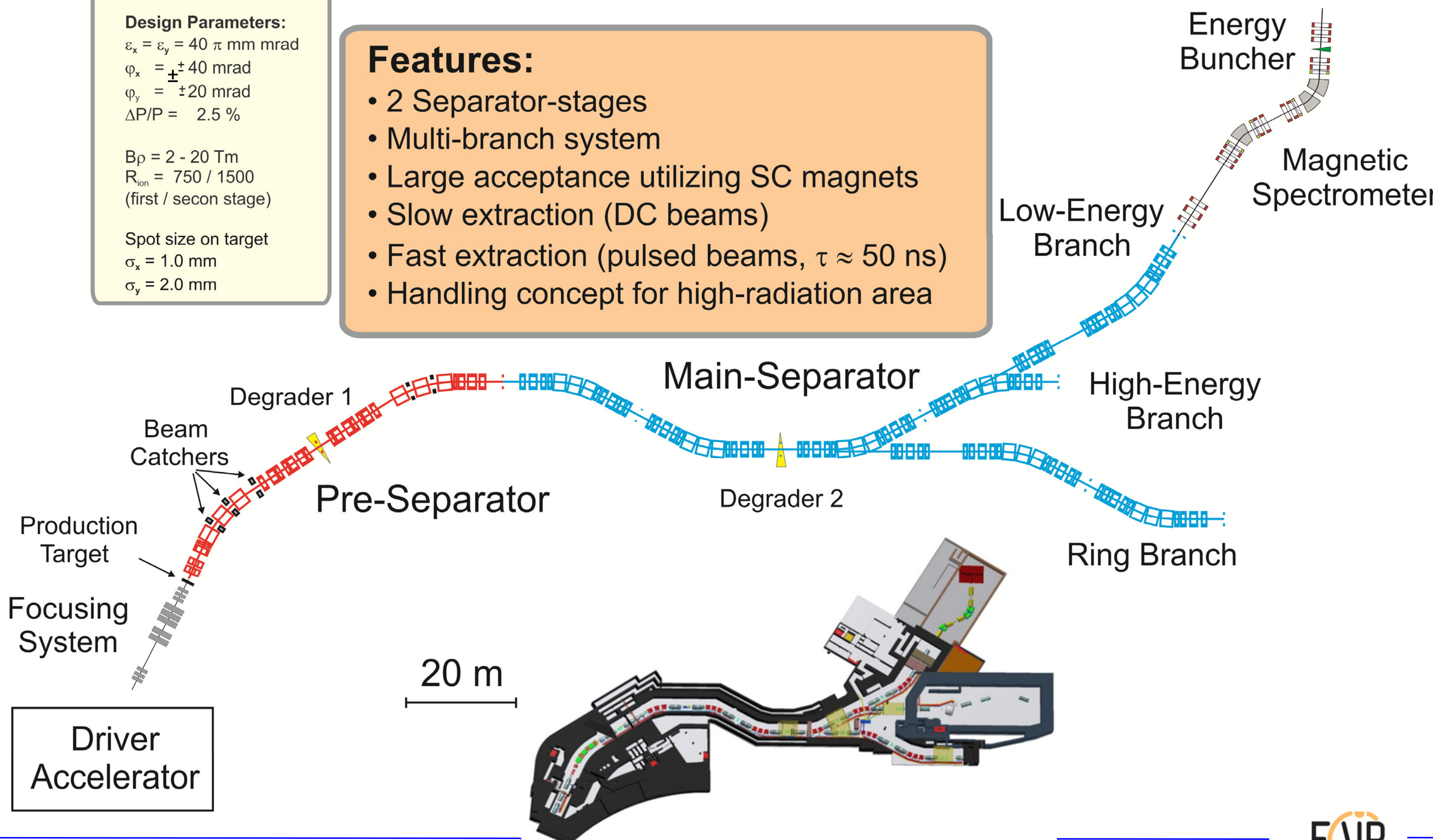
$\varepsilon_x = \varepsilon_y = 40\ \pi$ mm mrad
$\varphi_x = \pm 40$ mrad
$\varphi_y = \pm 20$ mrad
$\Delta P/P = 2.5$ %

$B\rho = 2 - 20$ Tm
$R_{ion} = 750 / 1500$
(first / secon stage)

Spot size on target
$\sigma_x = 1.0$ mm
$\sigma_y = 2.0$ mm

Features:

- 2 Separator-stages
- Multi-branch system
- Large acceptance utilizing SC magnets
- Slow extraction (DC beams)
- Fast extraction (pulsed beams, $\tau \approx 50$ ns)
- Handling concept for high-radiation area



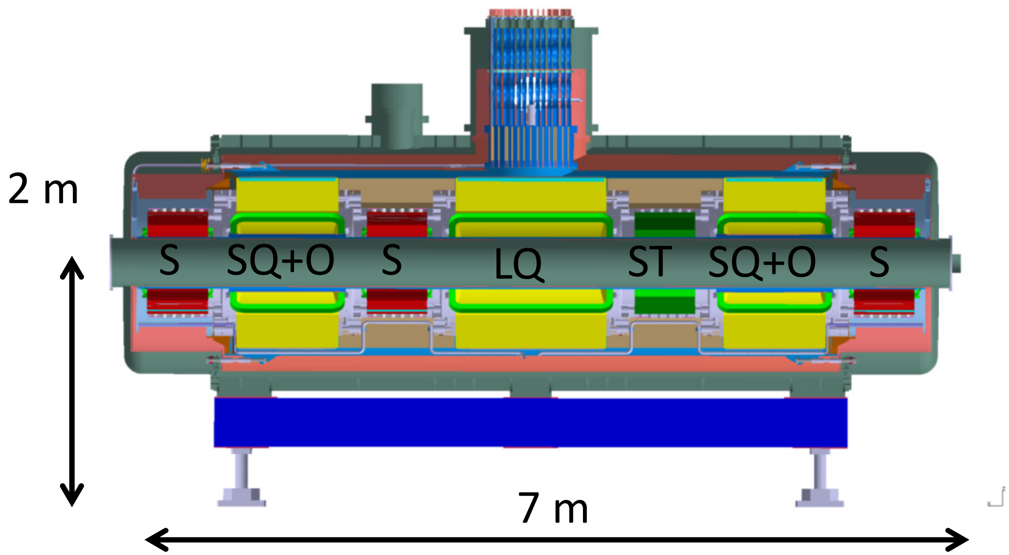
Super-FRS: Multiplet components

	Arranged in 33 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	$\pm 1 \cdot 10^{-3}$	$\pm 1 \cdot 10^{-3}$	$\pm 5 \cdot 10^{-3}$	
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/m^3 is embedded

Super-FRS: Multiplet structure

- 25 long multiplets + 8 short multiplets
- Cold, laminated iron yoke (> 40 tons)
- Common helium bath (~ 1200 liter helium)
- 1 pair of current leads per magnet
- max. current < 300 A for all magnets



longest multiplet system

- ~ 7 m long, > 60 tons
- 1 x long quadrupol (LQ)
- 2 x short quadrupol (SQ) equipped with octupol (O) coil
- 3 x sextupole (S)
- 1 x steering dipole (ST)

Contract awarded to ASG, Genoa

Super-FRS Multiplets: Procurement schedule

• Preliminary Design Review:	26.07.2016
• Final Design Review:	14.12.2016
• Production readiness review (short multiplet):	8.6.2017
• Production readiness review (long multiplet):	September 2017
• FAT short multiplet:	March 2018
• FAT long multiplet:	October 2018
• First series multiplet:	August 2019
• End of series production and testing:	2023

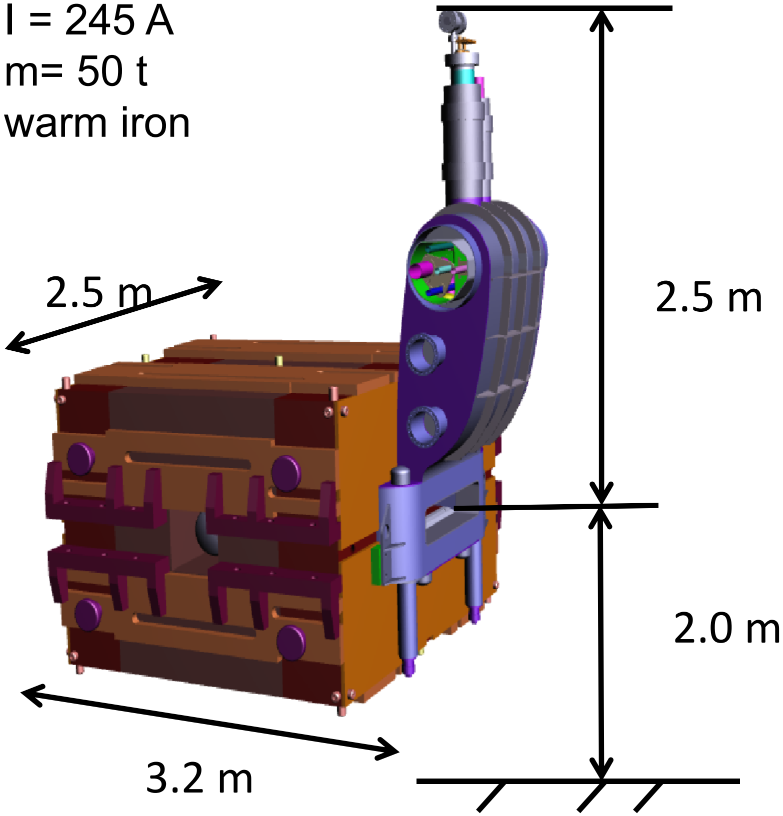
Super-FRS Dipoles

	Arranged in groups of 3	
	Dipole Type 2	Dipole Type3
Number of Magnets	3	21
Effective length	2.40 m	2.13 m
Field Range	0.15-1.6 T	0.15-1.6 T
Field Quality	$\pm 3\times 10^{-4}$	$\pm 3\times 10^{-4}$
Usable aperture	380x140 mm	380x140 mm

3 of the dipoles of type 3 are branching dipoles with an additional straight exit.

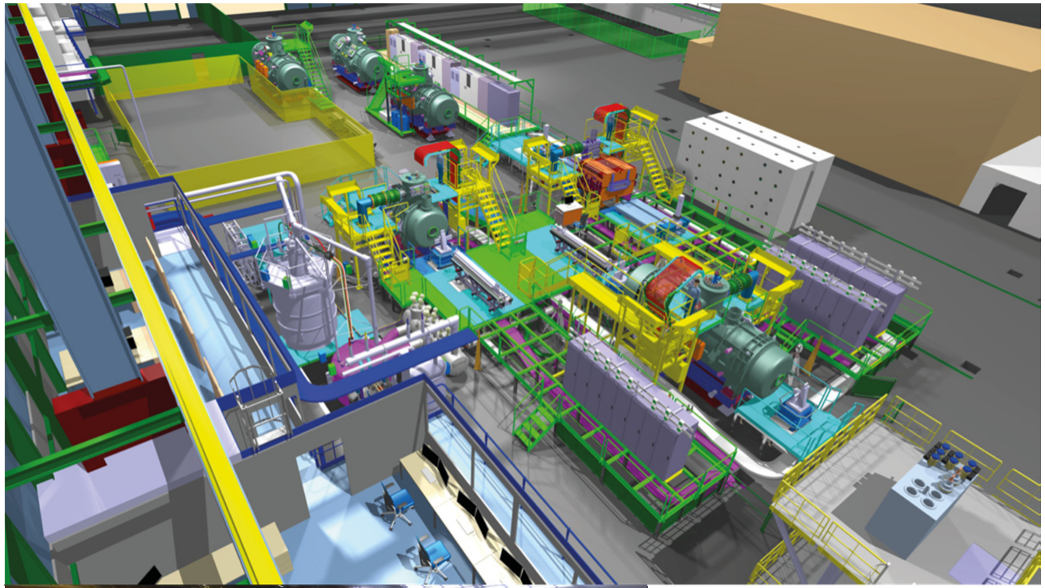
Super-FRS Dipoles: Design concept by CEA

Dipole (9.75°)
E=450 kJ
L=15.4 H
I = 245 A
m= 50 t
warm iron



- **Tender started with bidder pre-qualification: 12.4.2017**
- Contract signature: December 2017
- Final Design Review: June 2018
- FAT pre-series: March 2019
- SAT pre-series September 2019
- First series dipole: March 2020
- Last series dipole: 2023

Super-FRS Magnets: Testing at CERN



Collaboration between CERN and GSI for cold (4K) testing of the superconducting dipoles and multiplets of the Super-FRS:

- ✓ **CERN Building 180: 3 test benches, incl. magnetic field measurements**
- ✓ **Pre-series short multiplet testing is planned in 2018**

Summary

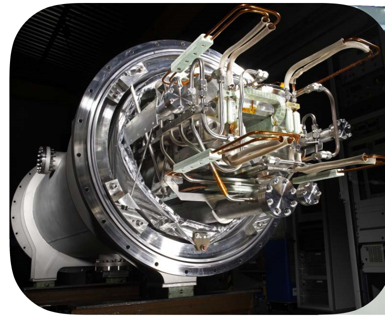
Fast ramped sc magnets SIS100

Main dipole magnets

Series production started now.
Series Test Facility at GSI is commissioned
Series testing will start in Autumn 2017

Quadrupole doublet modules

Production for the First of series units
(Q+Sextupole, Q+Steerer) was startet.
Units tests begin end of May 2017 in JINR, Dubna.



Large aperture super-ferric magnets for Super-FRS

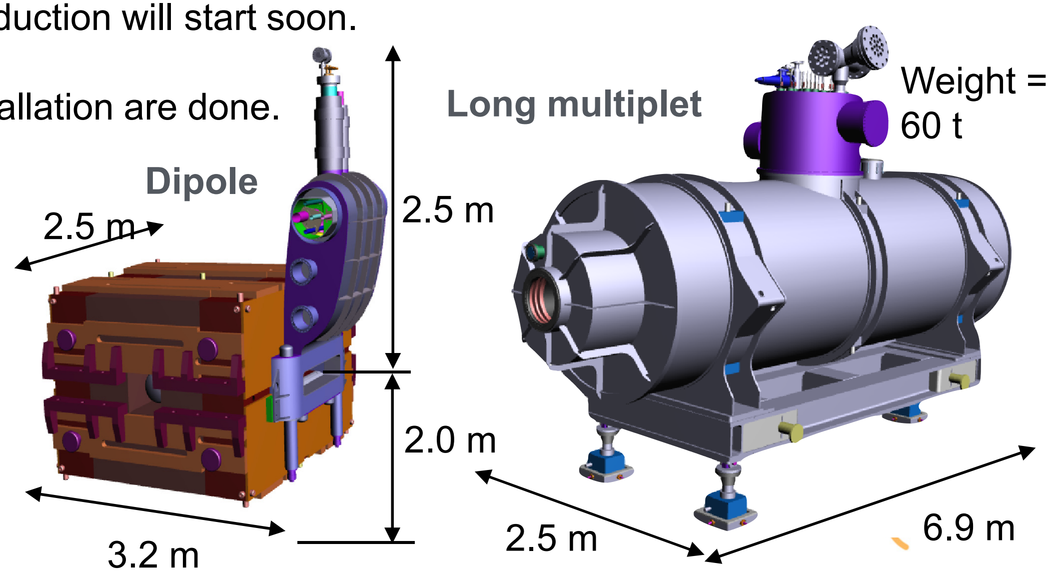
Dipole magnets Tendering process started.

Multiplets Pre-series short multiplet production will start soon.

Testing at CERN Building 180

Refurbishment and new infrastructure installation are done.
Commissioning of the cryo-plant started.

Test facility at CERN B.180



FAIR/GSI: construction site

Thank you for your attention !