The FAIR-NICA Collaboration for Production and Testing of Superconducting Accelerator Magnets

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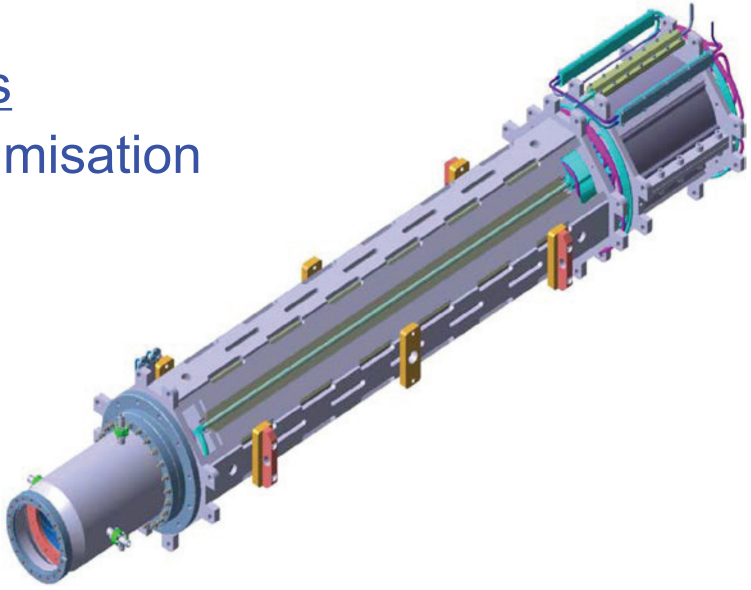
RuPAC 2016

November 21th - 25th
St. Petersburg, Russia

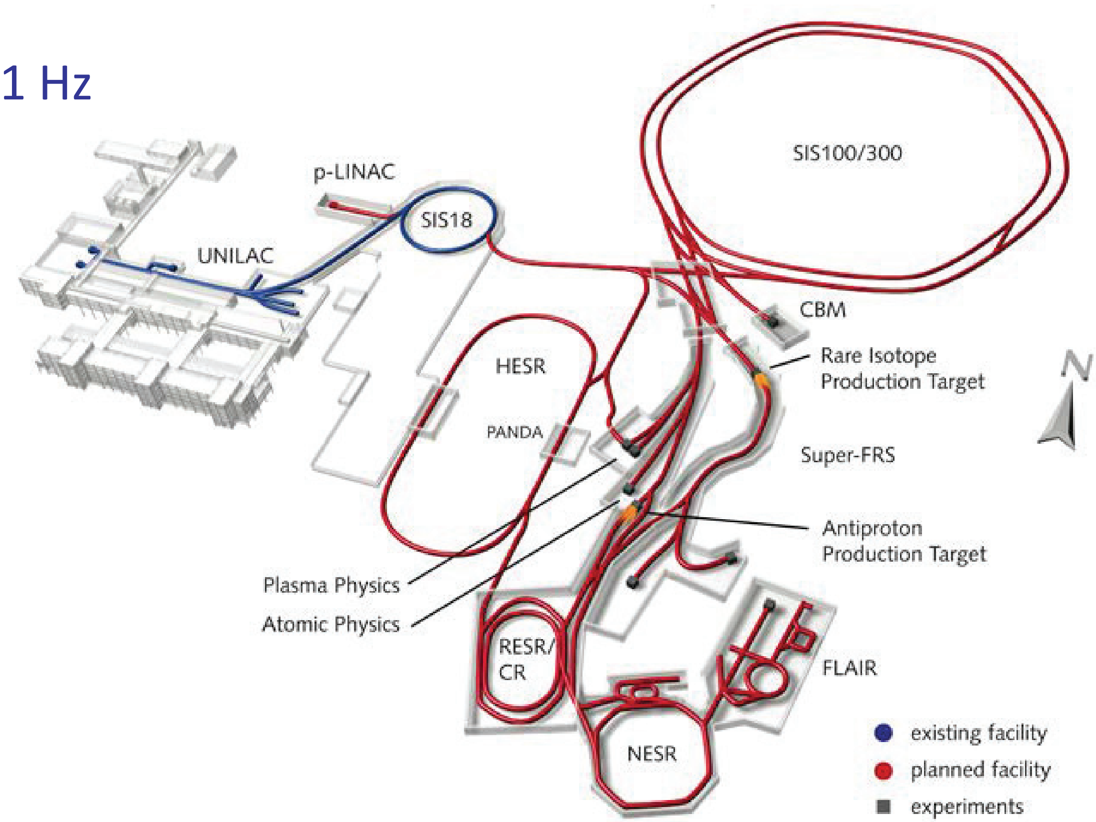
Contents



Introduction: The FAIR Project @ GSI

Heavy Ion Synchrotrons with superconducting magnets

- **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



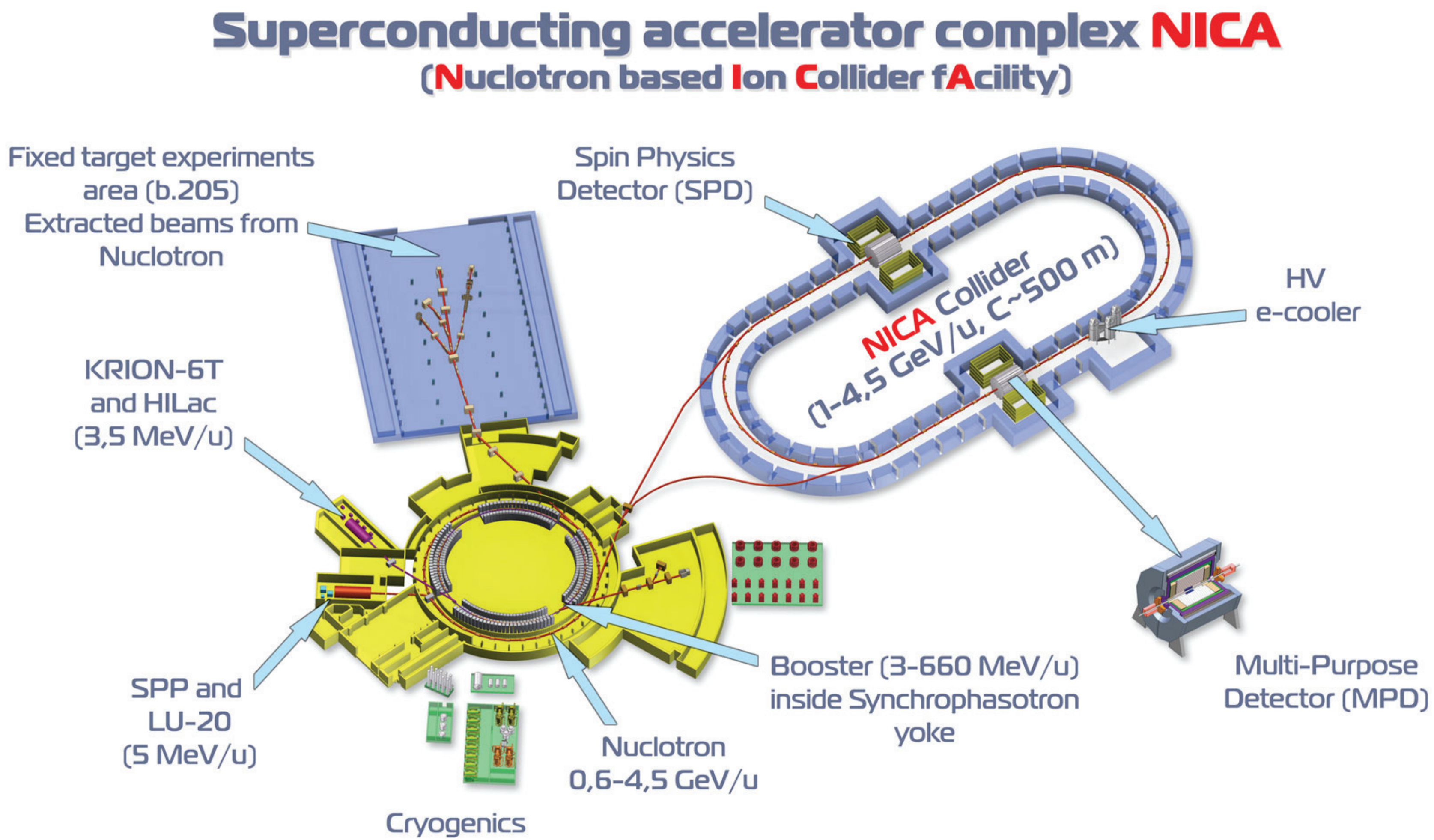
- **SIS300 – project phase B**
- 300 Tm rigidity
- B_{max} = 4,5 T, $^{dB}/_{dt}$ = 1 T/s
- sc dipoles
- sc quadrupoles
- sc correctors

Introduction: The FAIR Project @ GSI

- International collaboration

- Compare to GSI' existing facility
  - Primary beam intensities: ×100
  - Secondary beam intensities: ×10000
  - Primary beam energies: ×10
  - Antiproton production
- Start version: SIS100, Super-FRS, CBM/HADES, APPA, NuSTAR, PANDA

Introduction: The NICA Project @ JINR



Introduction: SC Magnets for FAIR @ NICA

Basic Technology:

“Nuclotron Type sc magnets”

Introduction: SC Magnets for FAIR @ NICA

Basic Technology:

“Nuclotron Type sc magnets”

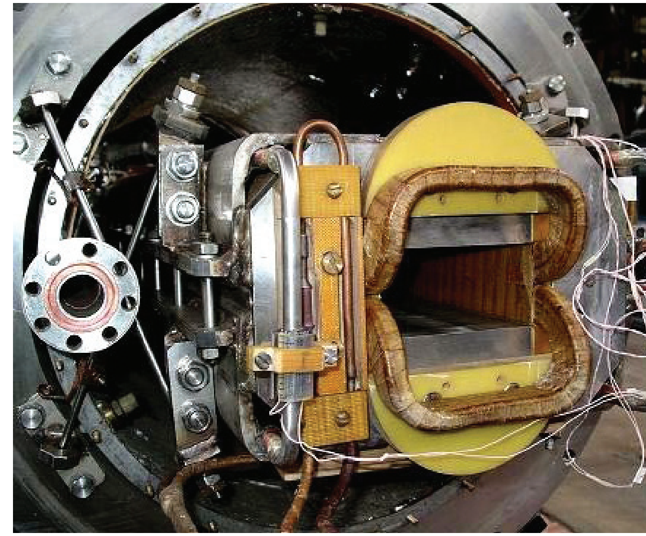
661 sc-magnets:

- 354 for NICA
- 307 for SIS100

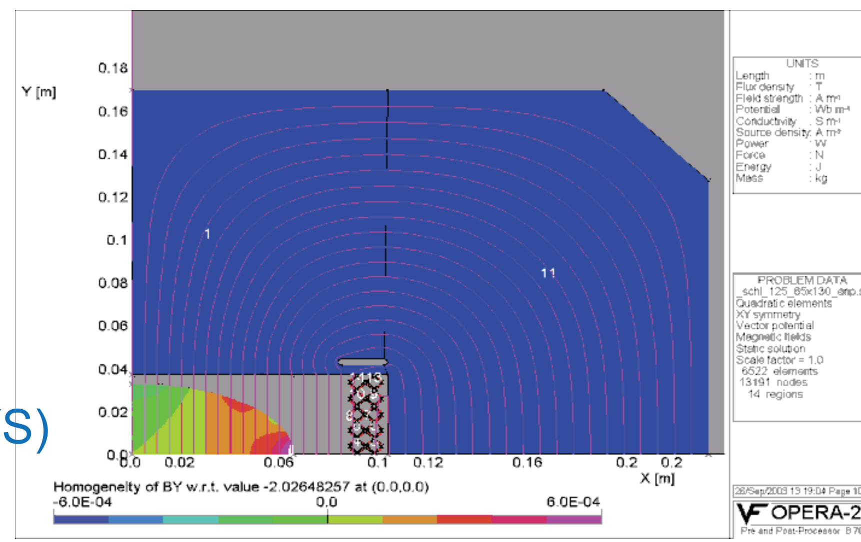
NICA FAIR

Common 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



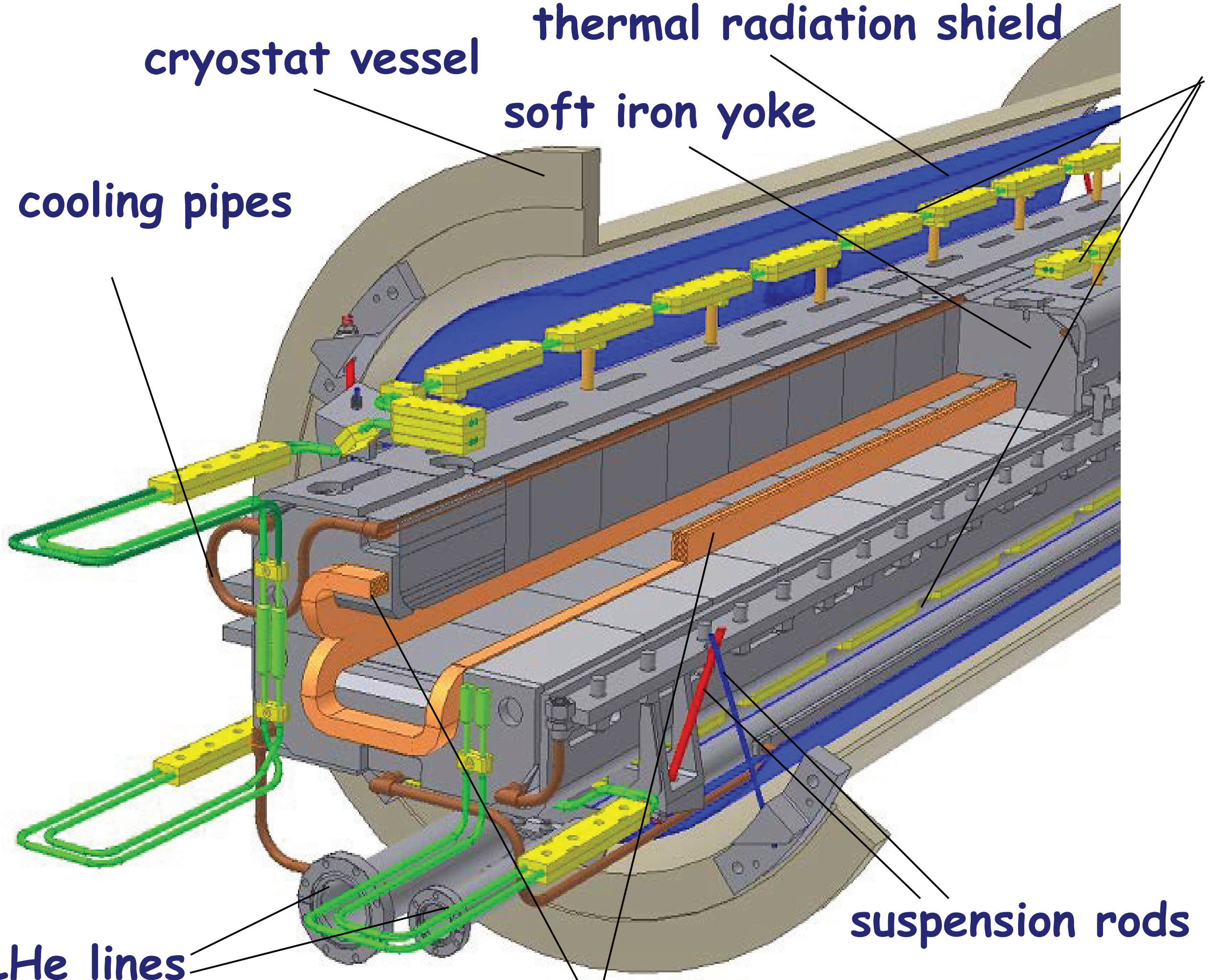
Accelerator SC Magnet R&D for
Fast cycling SC Magnets: super-ferric, B_{max} = 2 T, ramp rate up to 4-8 T/sec.



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

Common R&D: 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

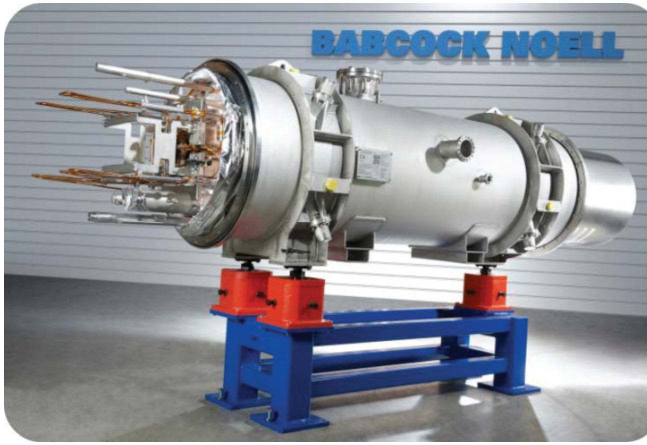
Common R&D: SIS100 Dipole Parameters

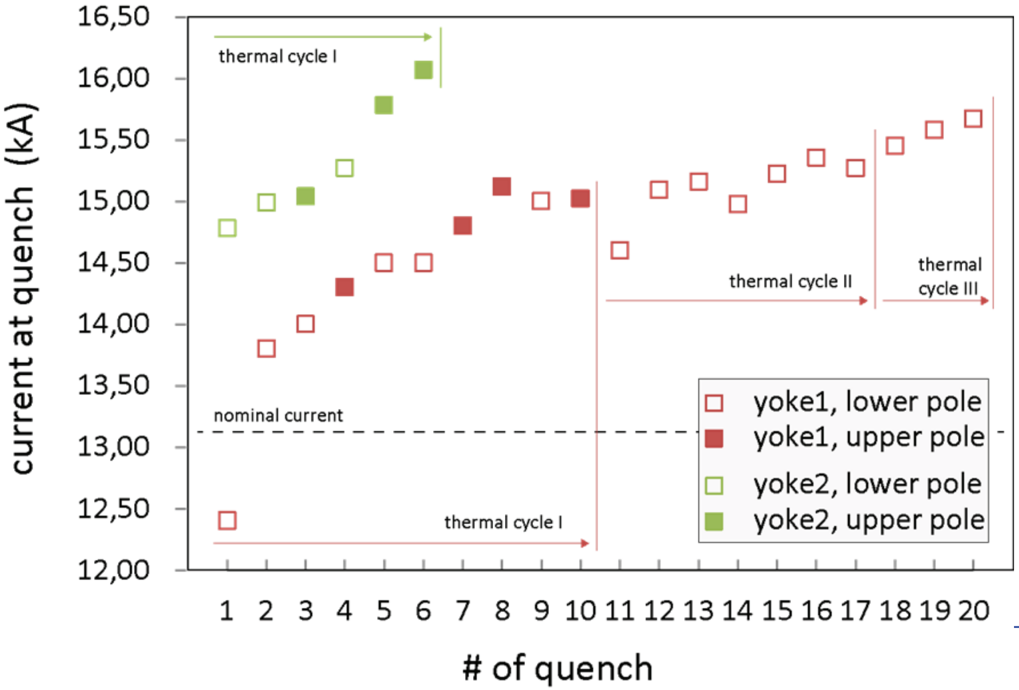
number of magnets	108 + 1 reference magnet	
design	window-frame, laminated cold iron , curved yoke, lamination thickness 1mm, one layer with 8 turns	
number of magnets	108 + 1	
max. field B_{max}	1.9	T
min. field B_{min}	0.23	T
bending angle	3 1/3	Deg.
orbit curvature radius, R	52.632	m
effective magnetic 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

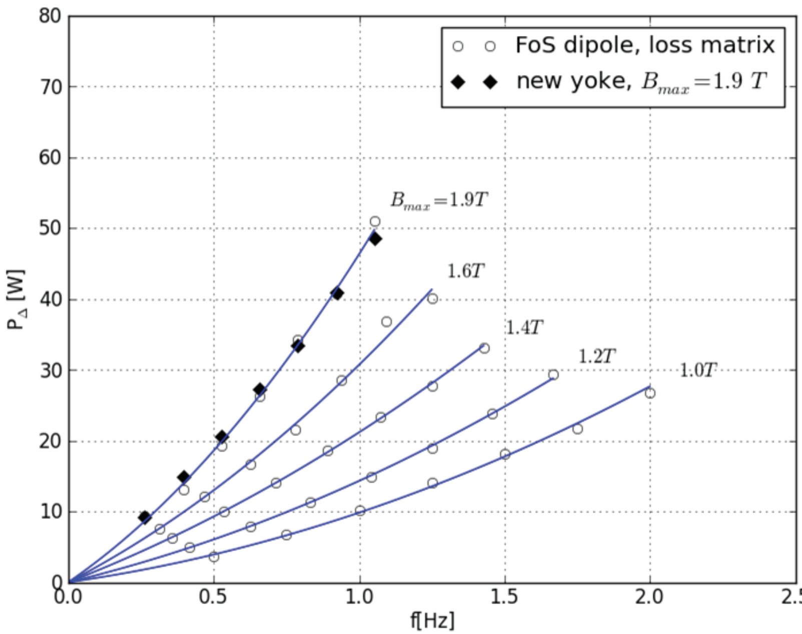
other components:

- 168 quadrupole magnets
- 144 corrector magnets
- cold vacum chamber
- cryo collimators

First SIS100 Dipole: Manufacturing @ Tests





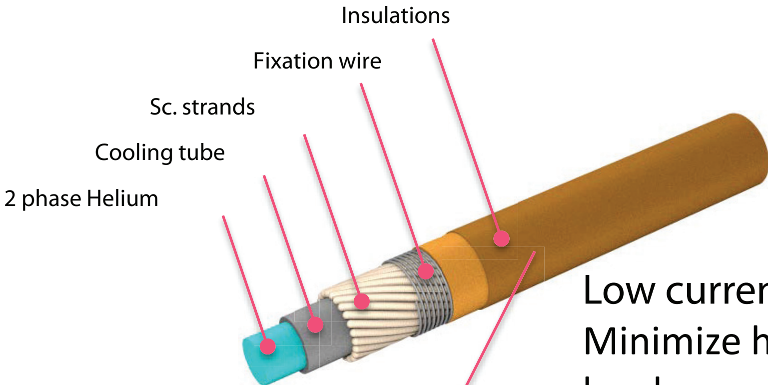


Common R&D: Comparison of Main Dipoles

	GSI	NICA	NICA	
	SIS100	*Booster*	*Collider*	
cable				
tube inner diameter	4.7	3	3	mm
number of strands	21	18	16	
critical current (at 2.5 T and 4.5 K)	19.8	14.2	16.8	kA
dipole				
field strength	1.9	1.8	1.8	T
→ field ramp rate	4	1.2	≤ 0.5	T/s
pole gap height	68	64	70	mm
→ magnet length	3.1	2.2	1.94	m
curvature radius	52.625	14.090		m
operation current	13.1	9.68	10.4	kA
inductance	0.55	0.63	0.45	mH
→ maximum AC loss	100	8.4	8	W

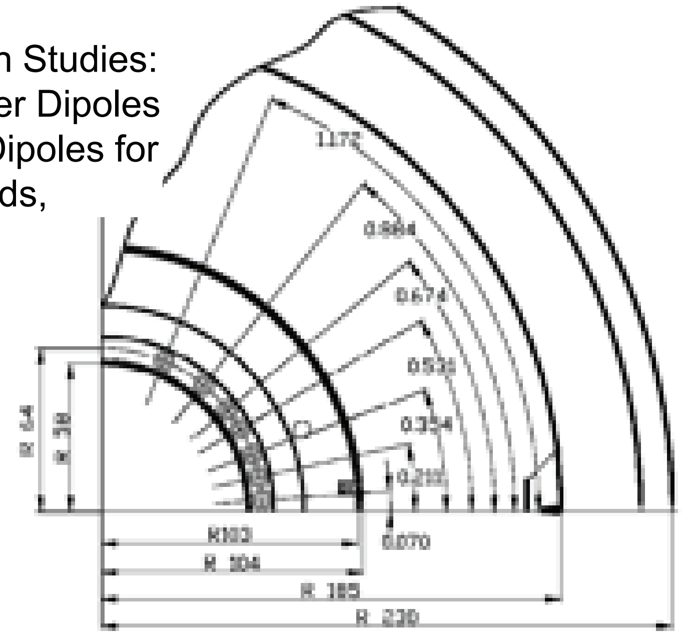
Common R&D: New Design Applications

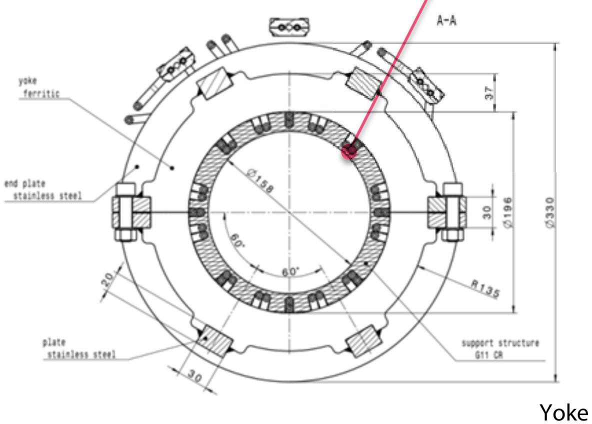
Further Options with Nuclotron type cables



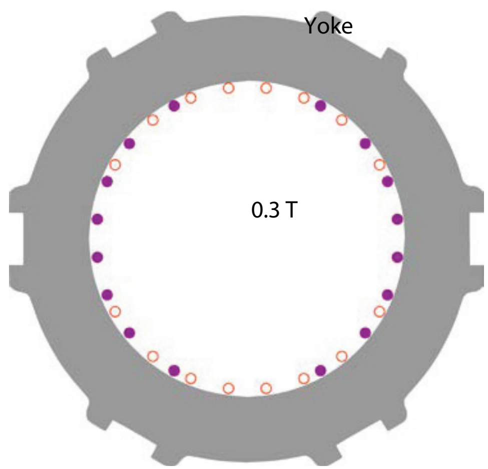
Low current < 300 A:
Minimize heat load from
local current leads
=> insulated strands

GSI-JINR Design Studies:
4.0 T Single Layer Dipoles
and Two layer Dipoles for
higher fields,





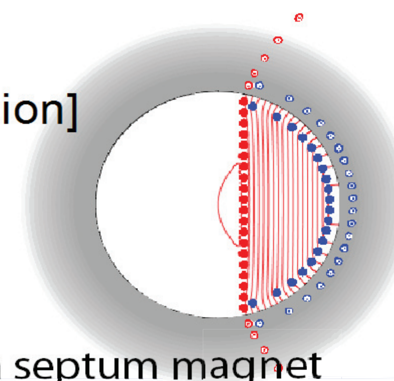
SIS100 Multipole corrector
Cosine-theta type (nested)



SIS100 Steering Magnet
Cosine-theta type (H/V nested)

[Design Option]

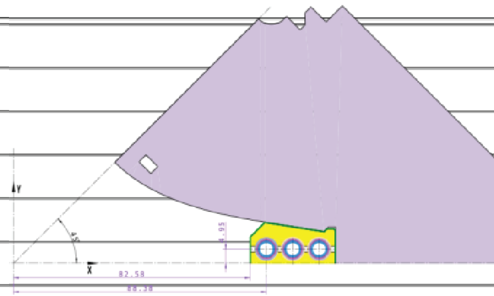
Fast-Ramp,
Truncated,
Iron-yoked,
cosine-theta septum magnet

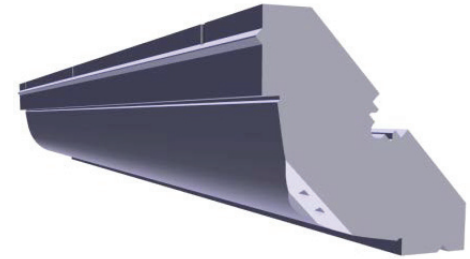


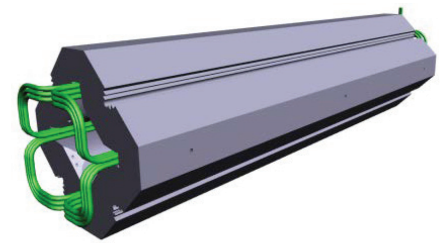
SIS100 QP-Units: Magnet Design

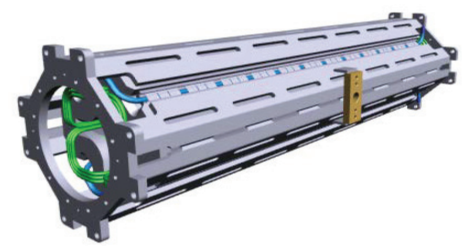
Quadrupole Parameters

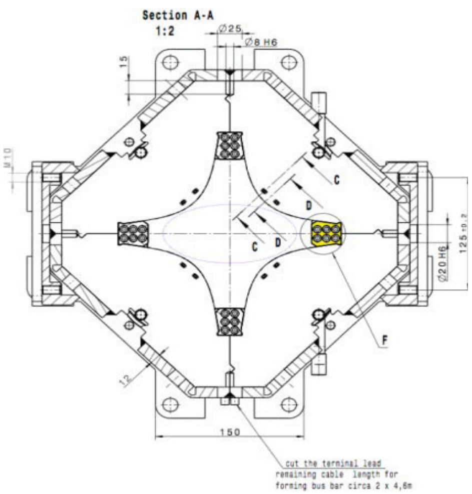
Parameter	Units	Value
Number of magnets		166+3
Design		Superferric
Maximum magnetic induction B_2	T/m	27
Effective magnetic length L_{eff}	m	1.3
Ramp rate dB/dt	(T/m)/s	57
Field quality		$\pm 6 \times 10^{-4}$
Good field region	mm^2	135×65
Overall magnet length (coil ends)	m	1.33

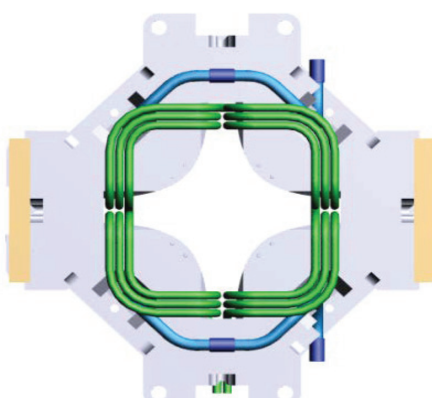


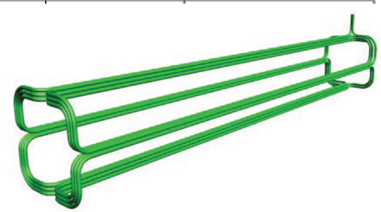








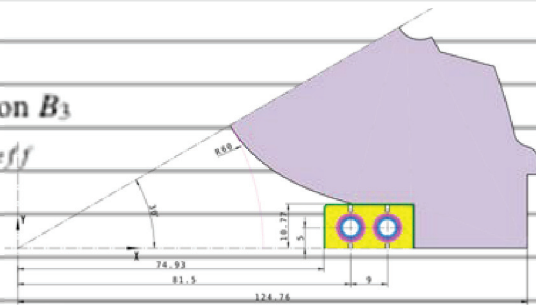


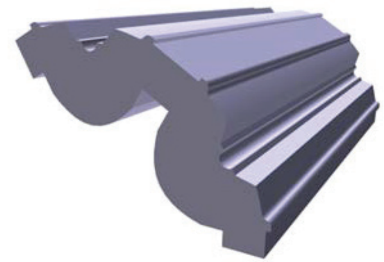


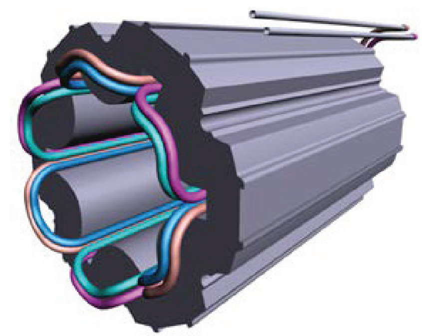
SIS100 QP-Units: Magnet Design

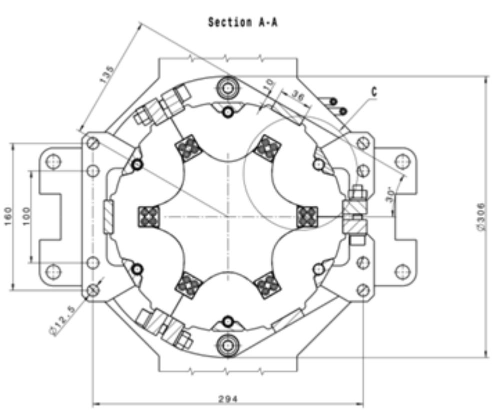
Chromaticity Sextupole

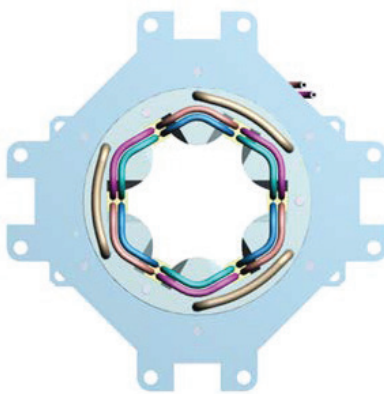
Parameter	Units	Value
Number of magnets		42
Design		Superferric
Maximum magnetic induction B_3	T/m^2	175
Effective magnetic length L_{eff}	m	0.383
Ramp rate dB/dt	$(T/m^2)/s$	1000
Field quality		$\pm 6 \times 10^{-4}$
Good field region	mm^2	135×65
Overall magnet length (coil ends)	m	0.426

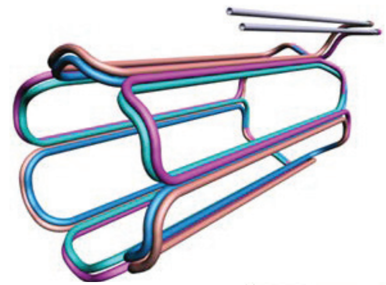


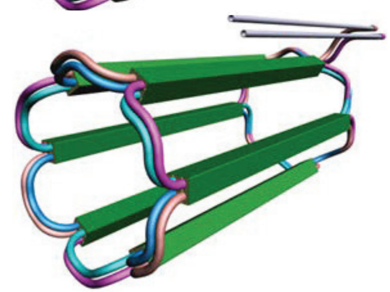


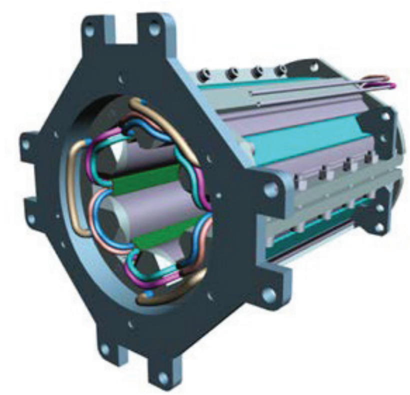








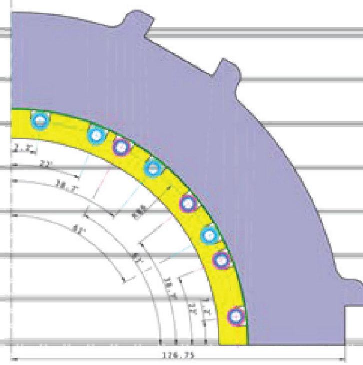


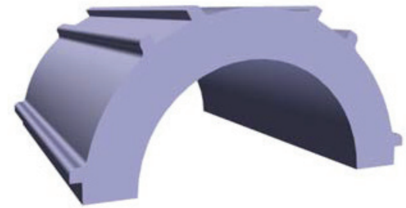


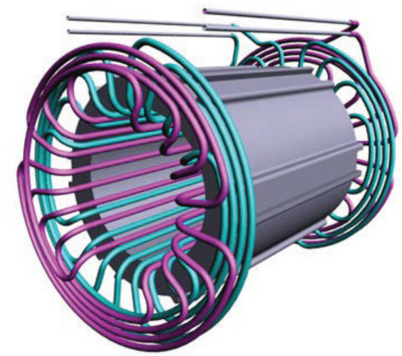
SIS100 QP-Units: Magnet Design

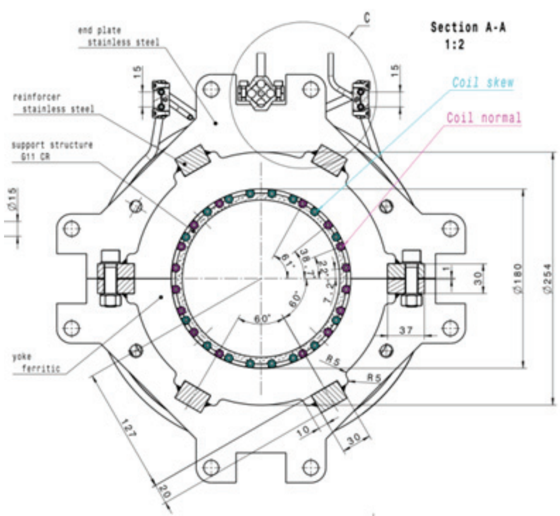
Steering Magnet

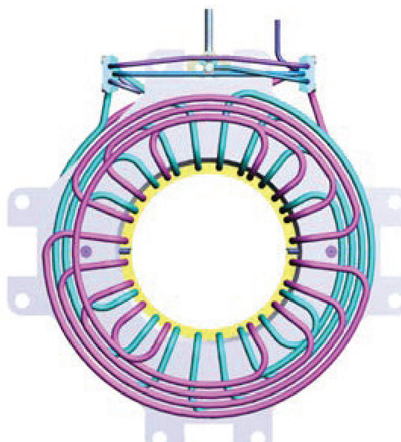
Parameter	Units	Value
Number of magnets		84
Design		Cosine-theta
Maximum magnetic induction B_1, A_1	T	0.3
Effective magnetic length L_{eff}	m	0.402, 0.410
Ramp rate dB/dt	T/s	1.5
Field quality		$\pm 6 \times 10^{-3}$
Good field region	mm^2	135 × 65
Overall magnet length (coil ends)	m	0.440

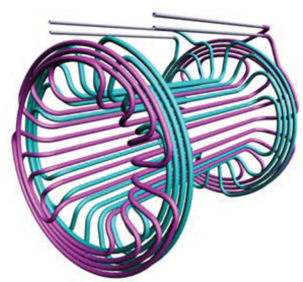


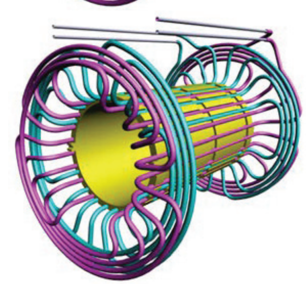


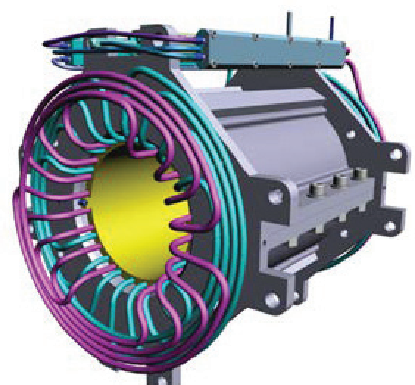








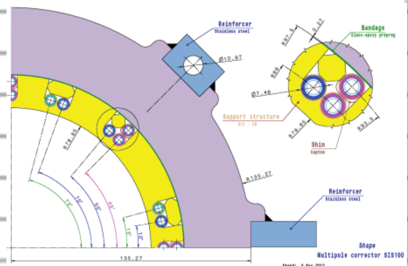


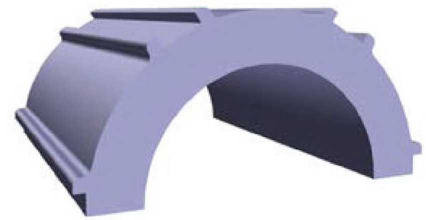


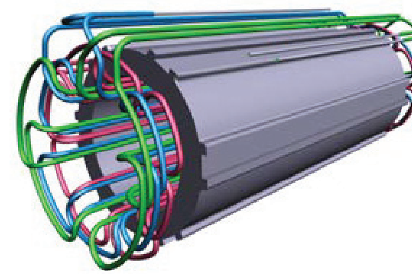
SIS100 QP-Units: Magnet Design

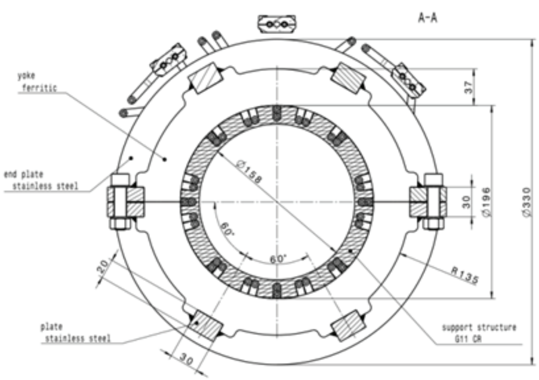
Multipole Corrector

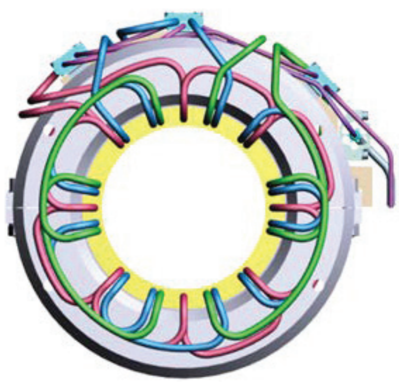
Parameter	Units	Value
Number of magnets		12
Design		Cosine-theta
Maximum magnetic induction B_2, B_3, B_4	T/m^{n-1}	0.75, 25, 333.3
Effective magnetic length L_{eff}	m	0.75, 0.73, 0.70
Ramp rate dB/dt	$T/m^{n-1}/s$	5, 104, 1388
Field quality		$\pm 6 \times 10^{-3}$
Good field region	mm^2	135×65
Overall magnet length (coil ends)	m	0.700

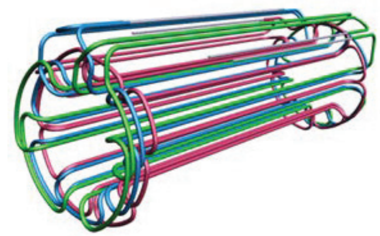


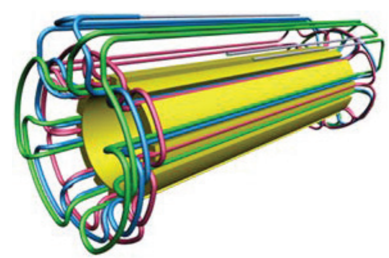


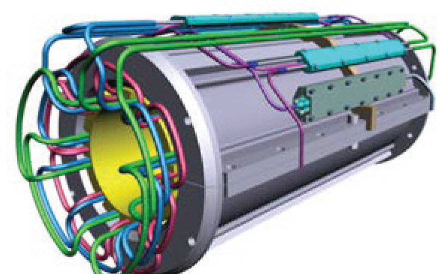












SIS100 QP-Units: Components

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	

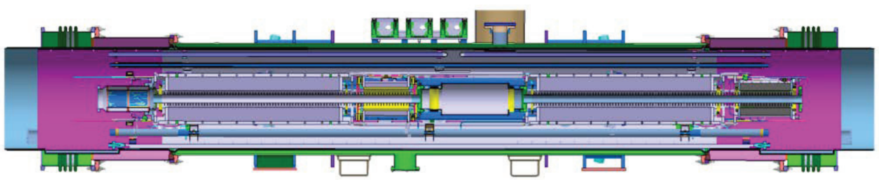
- Focusing quadrupole F1 and F2 have different bus bar configuration.
- Horizontal/Vertical Focusing Chromaticity Sextupole (CH/CV) is identical within the cryostat.
  - But the joints between the power cable and the current lead (at warm) is opposite polarity.

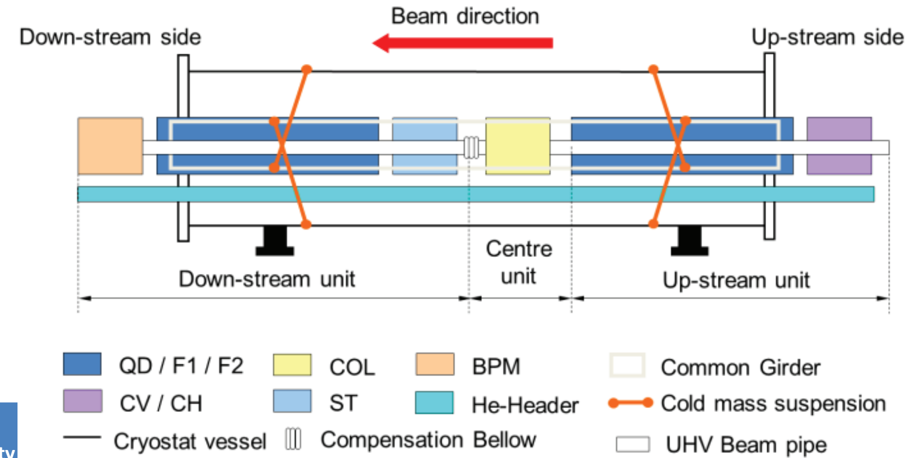
SIS100 QP-Units: Assembly Types

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: Cryogenic Doublet Modules





11 Configurations of SIS100-QDM

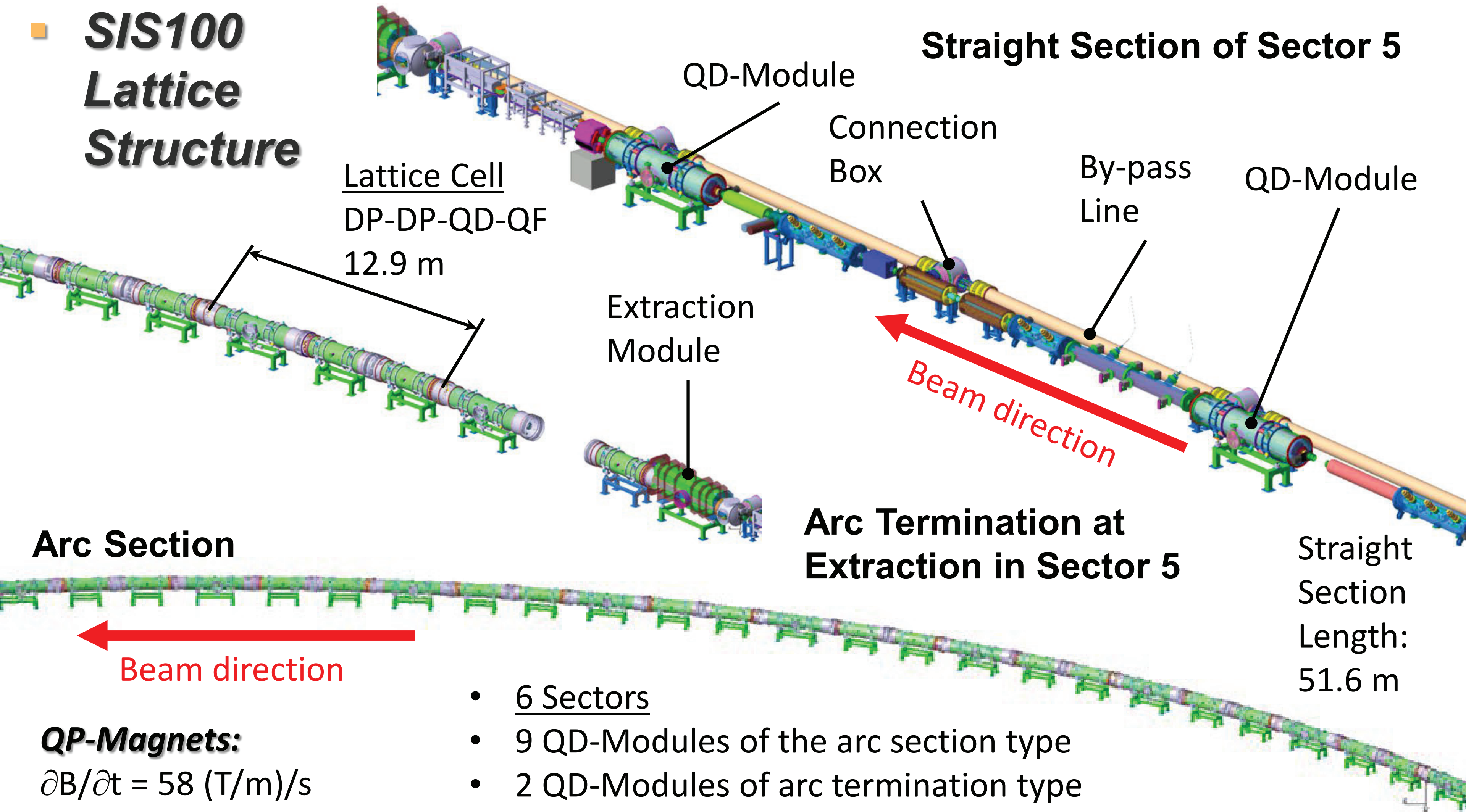
Module Family	Up-stream unit	Centre unit	Down-stream unit	IOL cell	Short name	Quantity
Straight section	QD*B	TRP	SF2*	1, 2, 3	**2.123**	14
	QD*Bs	TRP	SF2*s	1, 3	**2.13s**	3
Arc start	QDBb	T	SF2Mb	4	**2.4**	5
Extraction	QDBx	T	SF2Mx	4	**2.4x**	1
	LD	P	LF			
Arc section	VQD	CR	SF2B	5	**2.5**	6
	BQD	C	SF1H	6, 10	**1.6A**	12
	VQD	CR	SF1B	7, 11	**1.7B**	12
	BQD	C	SF2H	8, 12	**2.8C**	12
	BQD	CR	SF2J	9, 13	**2.9D**	12
Arc end	MQDb	C	SF1Bb	14	**1.E**	5
Injection	MQDi	C	SF1Bi	14	**1.Ei**	1
	LD	P	LF			

QD	Defocusing quadrupole
LD	Low current defocusing quadrupole
LF	Low current focusing quadrupole
F1	Focusing quad. type 1
F2	Focusing quad. type 2
J	γ_t - jump quadrupole
B	Beam position monitor
V	Vertical chromaticity sextupole
H	Horizontal chromaticity sextupole
S	Steering magnet
M	Multipole corrector magnet
C	Cryo-Collimator
T	Drift tube
P	Cryo-sorption-pump
R	Roughing pump with CWT
s	Star shape chamber
b	extended bus bars
*	modified bus bars
i	injection Y cryostat
x	extraction Y cryostat

FAIR

SIS100 Quadrupole Doublet Modules

- ***SIS100 Lattice Structure***



QP-Magnets:
$\partial B/\partial t$ = 58 (T/m)/s
grad(B_{max}) = 27,8 T/m

- <u>6 Sectors</u>
- 9 QD-Modules of the arc section type
- 2 QD-Modules of arc termination type
- 18 DP-Modules

Production @ JINR: Procurement Strategy

Common work for the QP Units

- Share the work load between JINR and GSI.
- GSI and JINR will interact for the Delivery and Testing of SIS100 Quadrupole Units as German and Russian In-Kind-contributions to FAIR
- The collaboration between the JINR and GSI focuses on the SIS100 Quadrupole units.
- GSI will deliver the final design, specifications and blueprints for all quadrupole units.

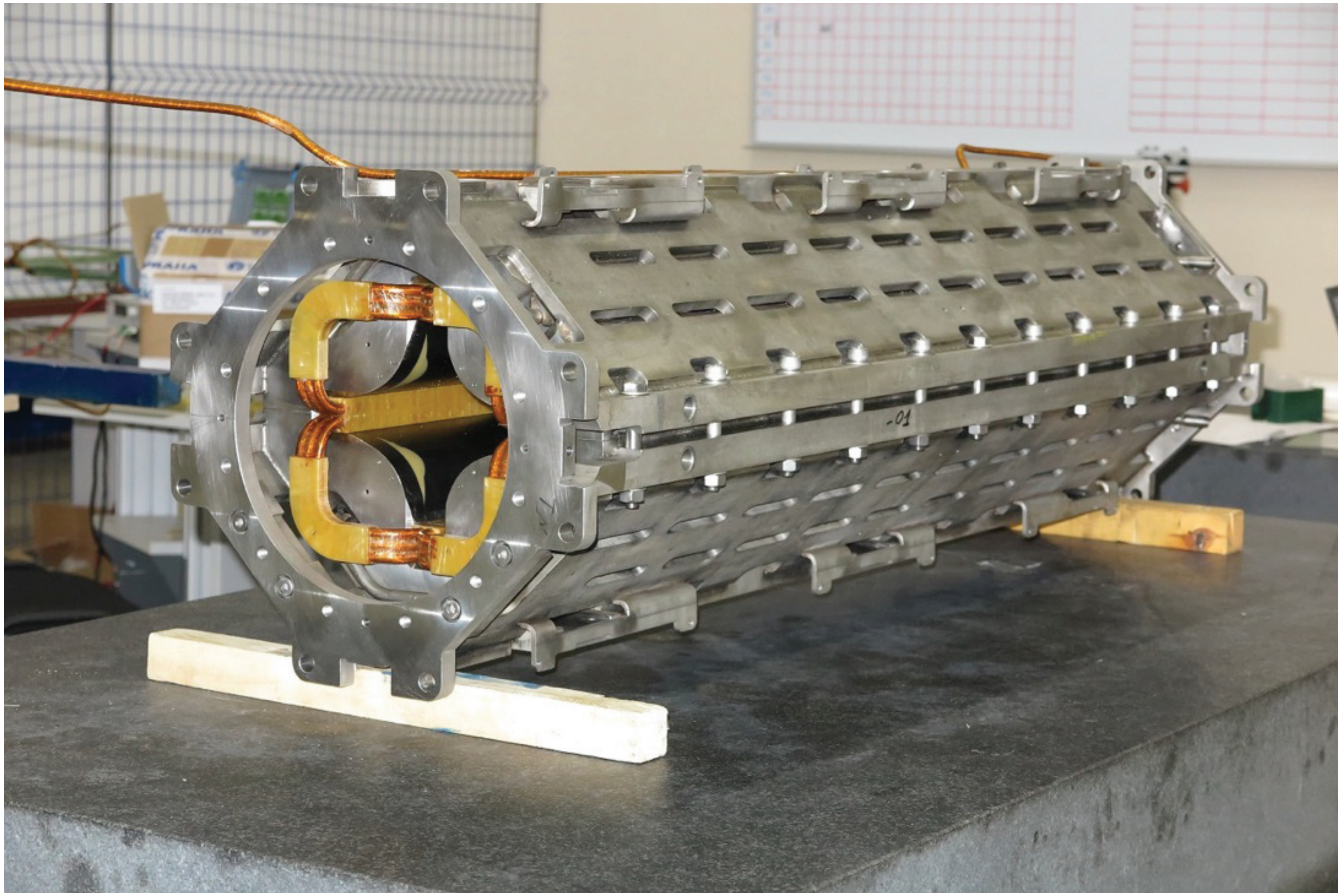
Production @ JINR: SIS100 Quadrupole

Manufacturing of the SIS100 quadrupole coil

Production @ JINR: SIS100 Quadrupole

The SIS 100 quadrupole coil prepared for heat treatment in oven

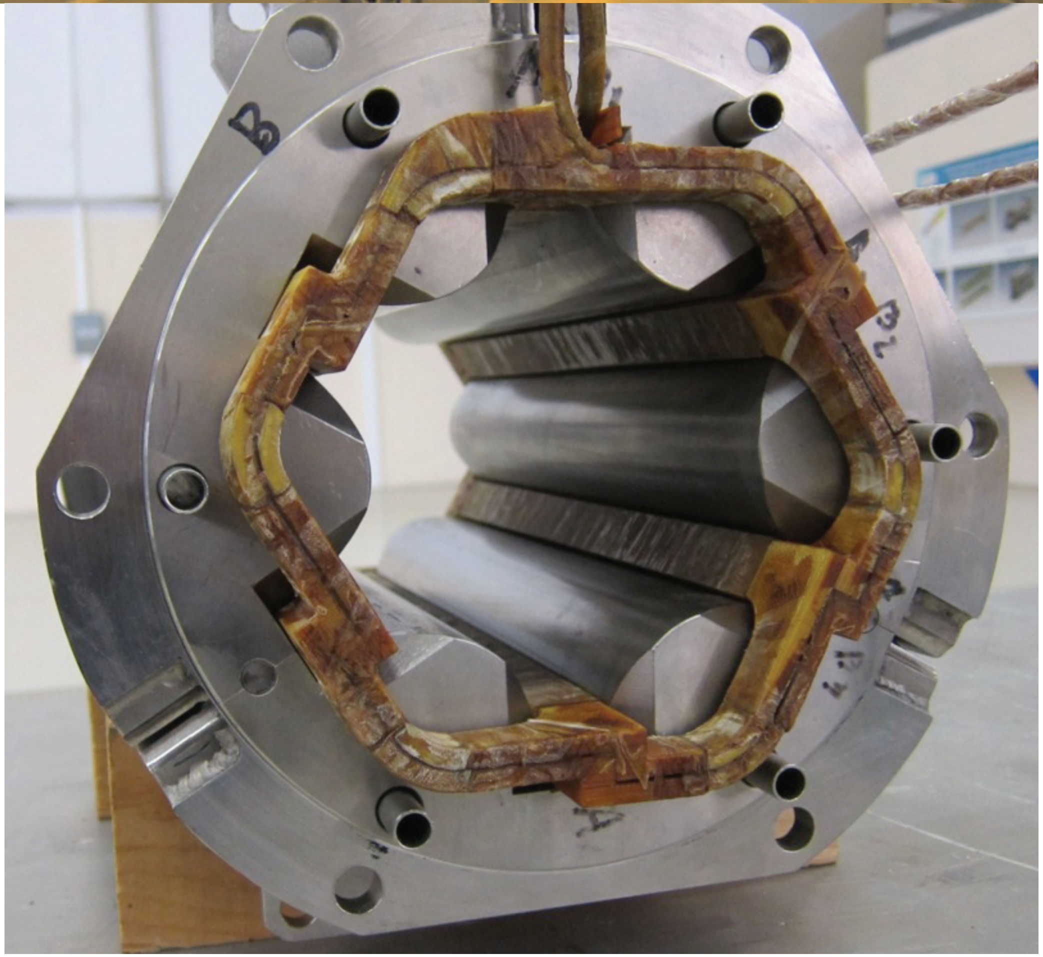
Production @ JINR: First SIS100 Quadrupole



First of Series SIS100 quadrupole magnet.

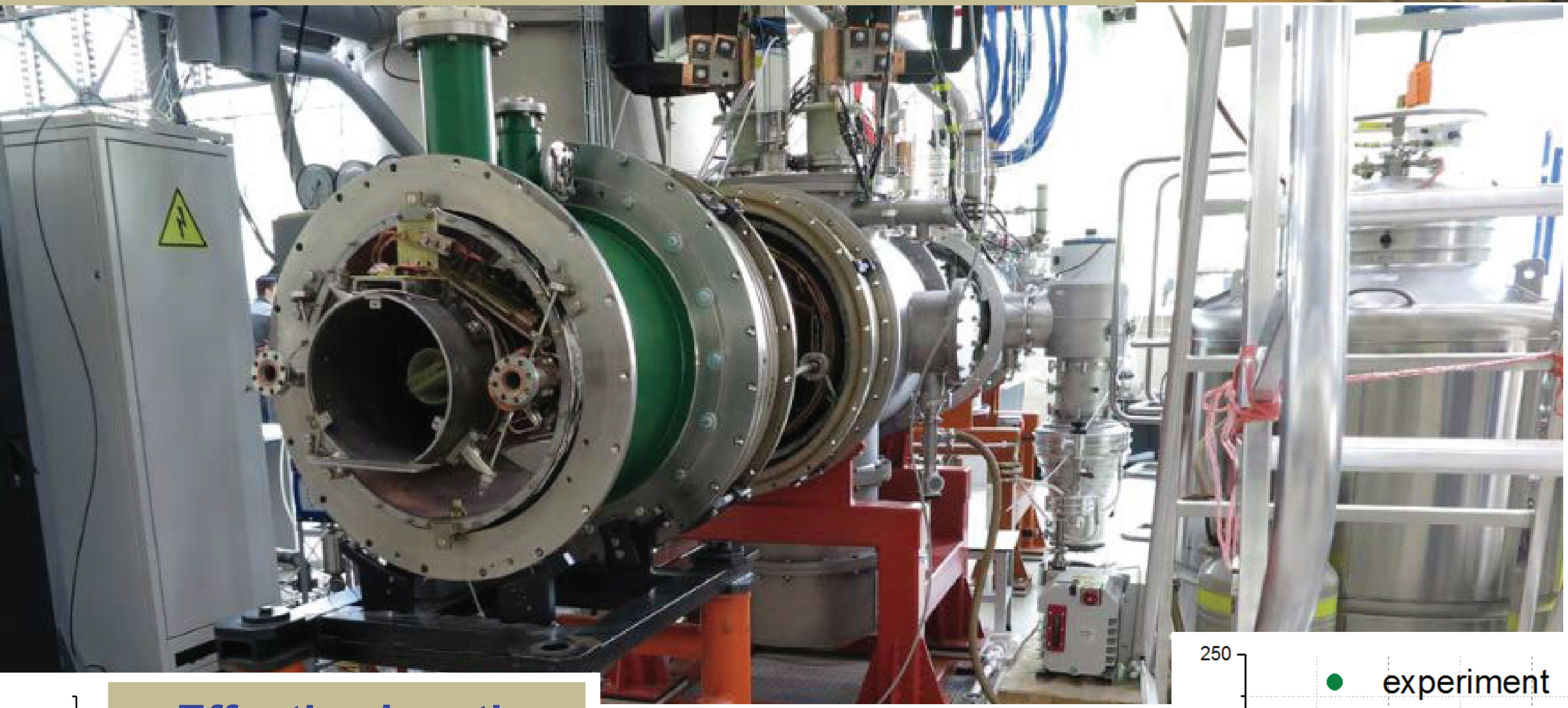
Second magnet will be done in December 2016

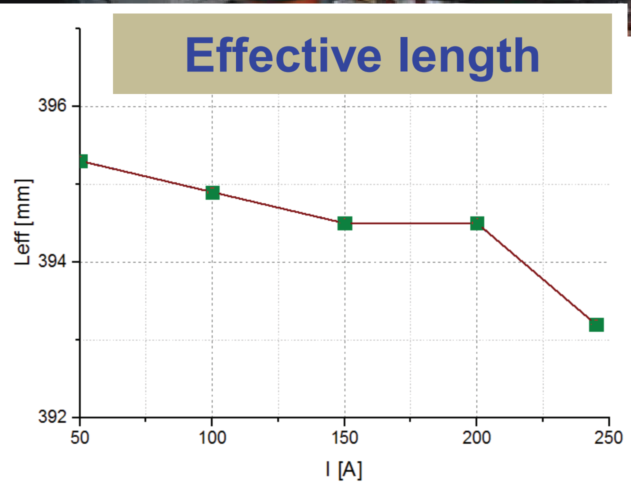
Production @ JINR: SIS100 chrom. SP



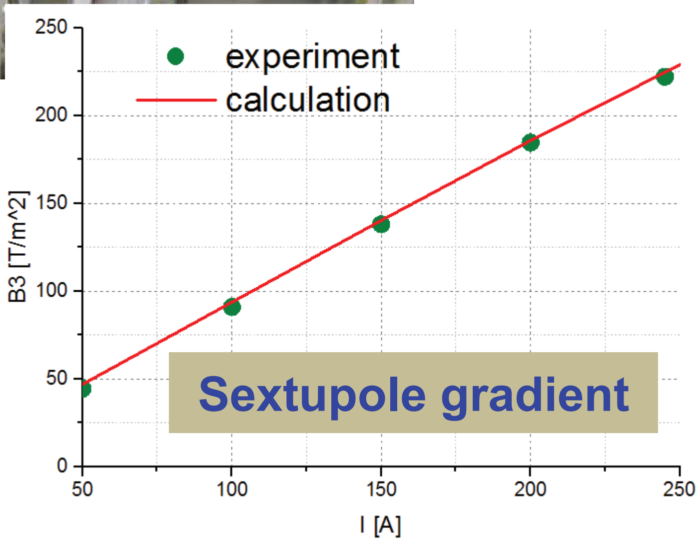
The SIS100 chromaticity sextupole magnet.
Completion scheduled on December 2016

Testing @ JINR: Preseries SIS100 chrom. SP

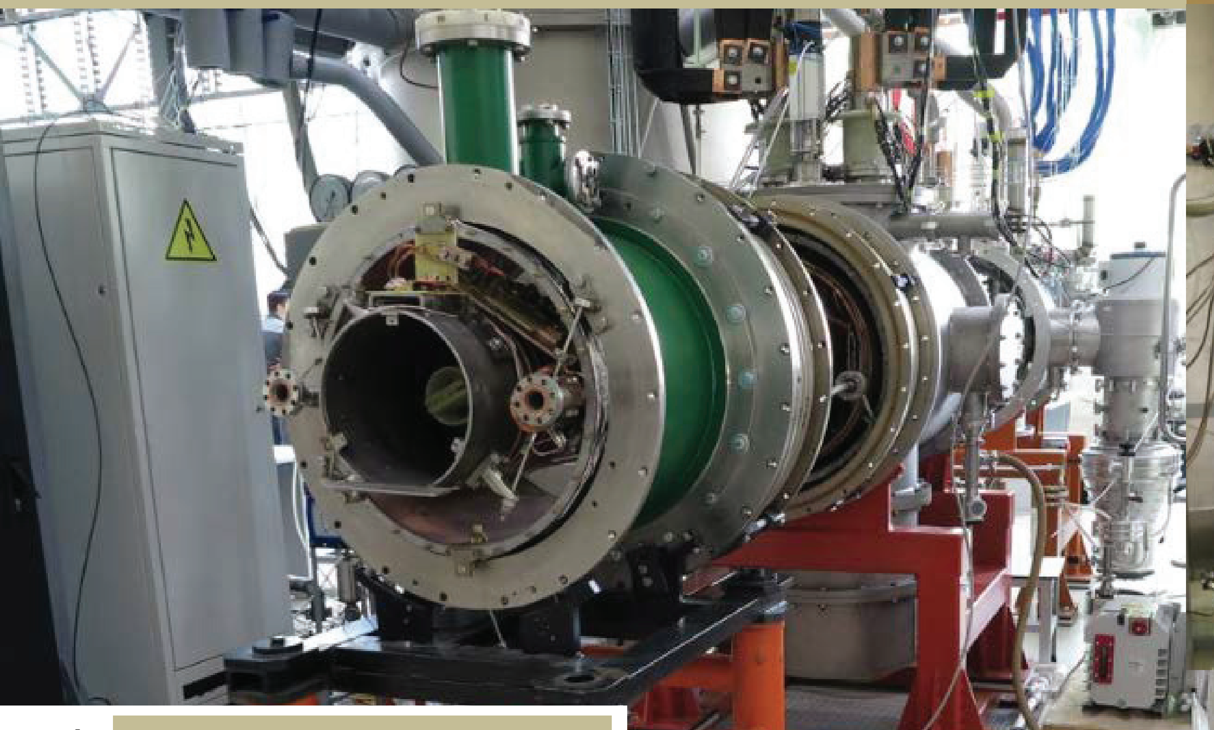


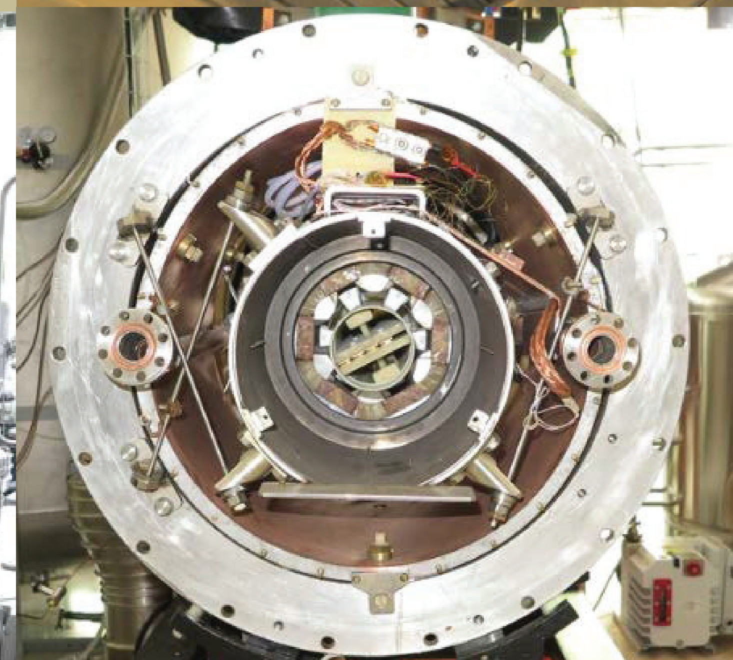


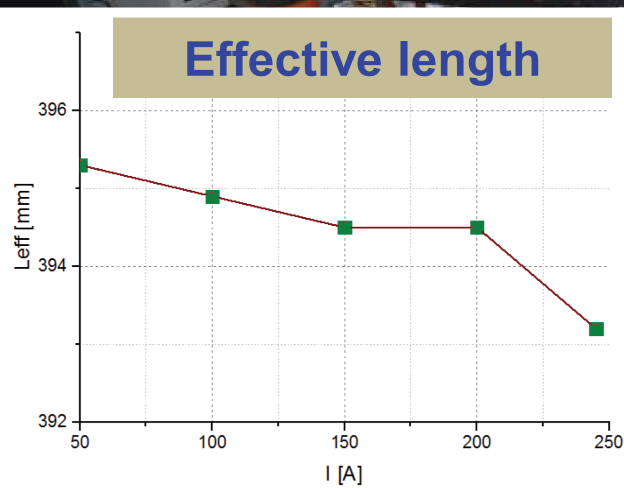
First experimental verification for the design of fast ramped corrector magnets using Nuclotron Cable with insulated strands !



Testing @ JINR: Preseries SIS100 chrom. SP







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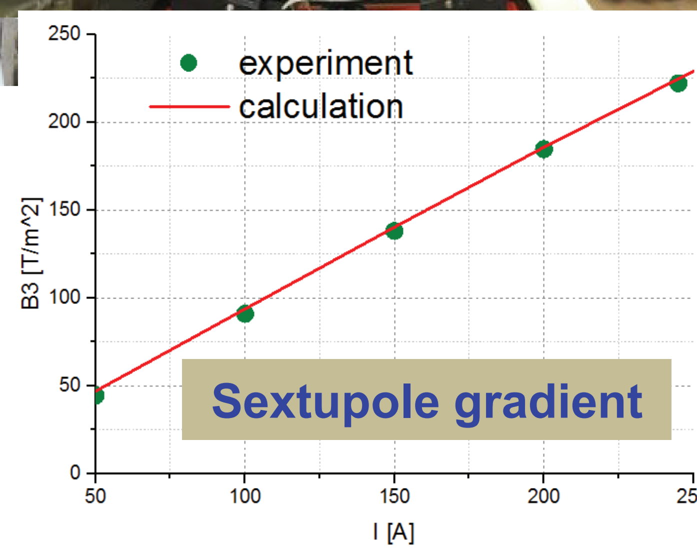


New Facility for SC magnets assembly & test

Requirements

The facility is designed for 24-hours mode assembly and cryogenic testing of Nuclotron-type SC magnets. The following magnets will be assembled and tested at the facility:

- **40** dipole magnets for the NICA booster;
- **24** quadrupole doublets with multipole correctors for the NICA booster;
- **171 quadrupole magnets with multipole correctors for the SIS100 synchrotron (FAIR project);**
- **80** dipole magnets for the NICA collider;
- **86** quadrupole magnets with multipole correctors for the NICA collider.

SC Magnet Tests for NICA @ FAIR

Test facility at JINR

Schema of the new SC-magnet test facility at JINR Dubna

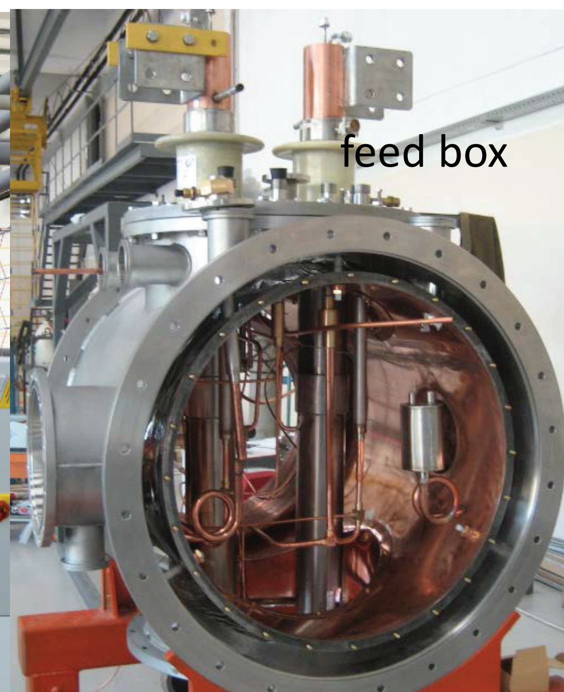
1600 m^2 main hall

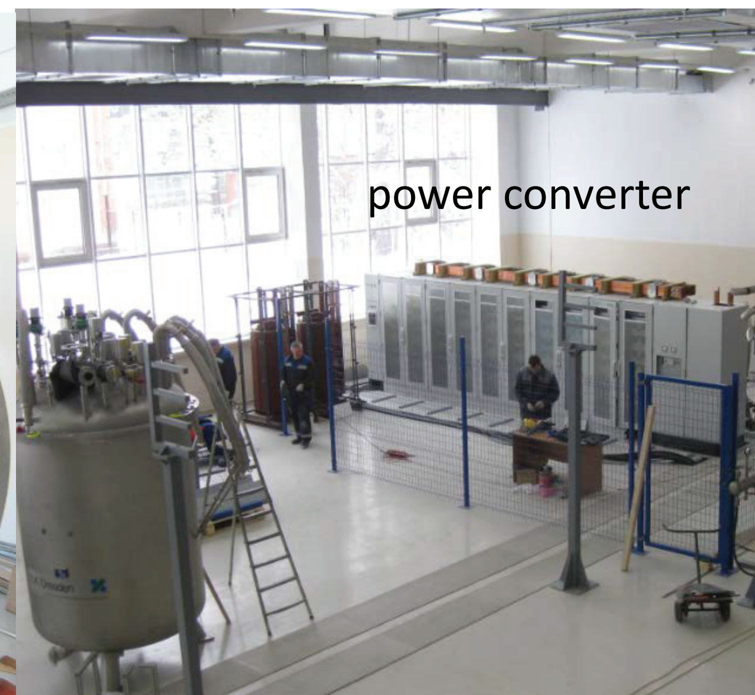
700 m^2 auxiliary facilities

SC Magnet Tests for NICA @ FAIR

SC Magnet Tests for NICA @ FAIR

satellite refrigerator





SC Magnet Tests for NICA @ FAIR

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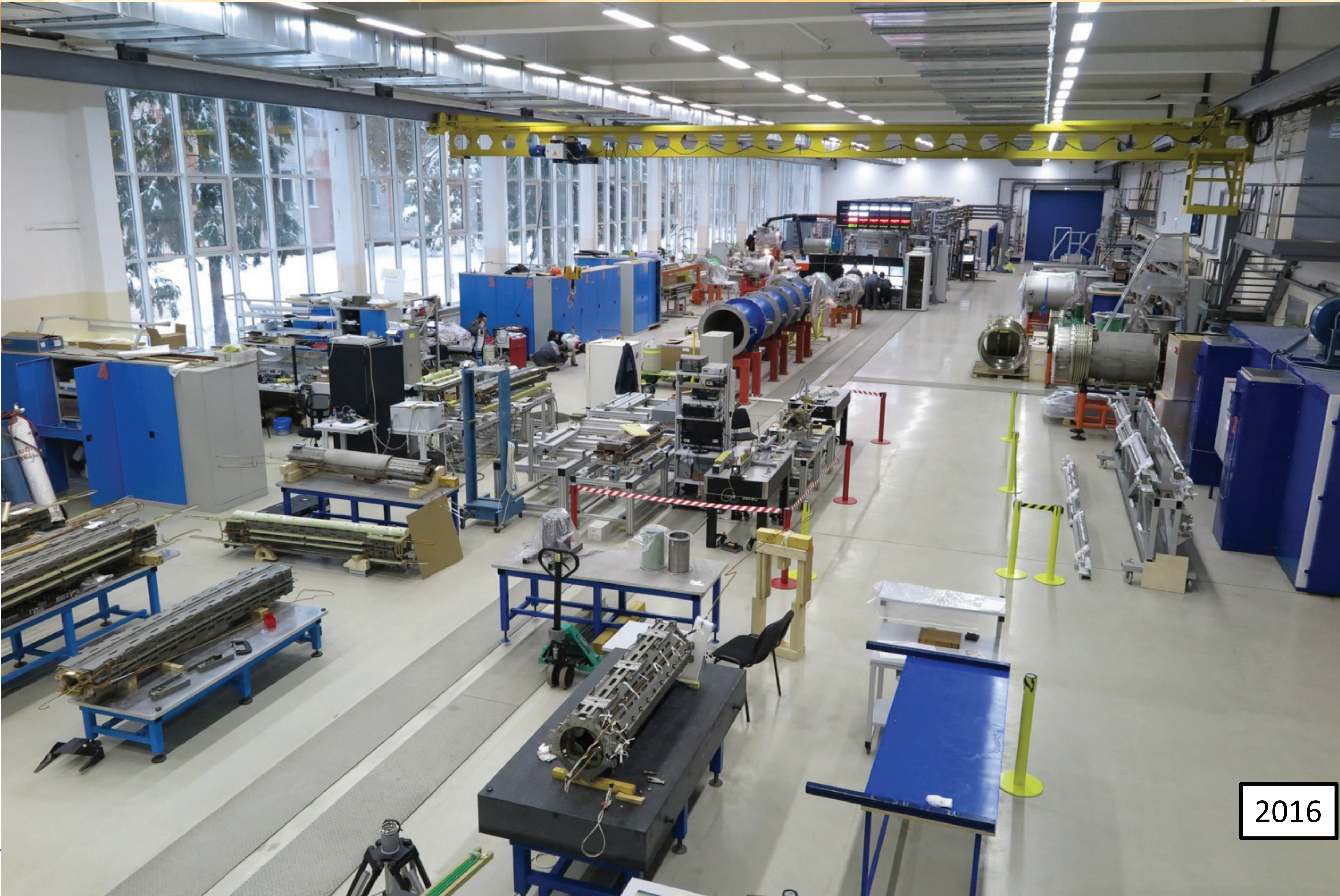


2016

SC Magnet Tests for NICA @ FAIR

3 of 6 tests benches => for SIS100 units tests

Official launch 28.11.16

SC Magnet Tests for NICA @ FAIR

Cryogenic tests hall

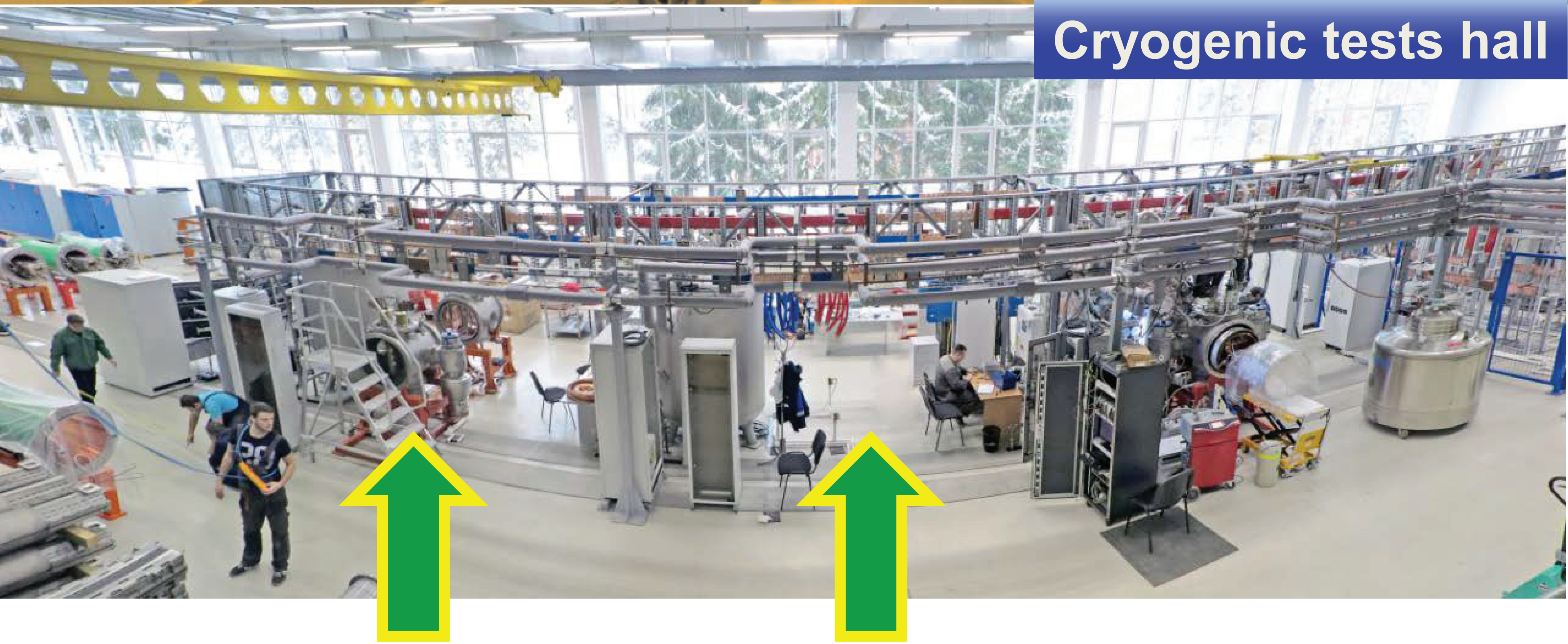
3 of 6 tests benches => for SIS100 units tests

Official launch 28.11.16

NICA

FAIR

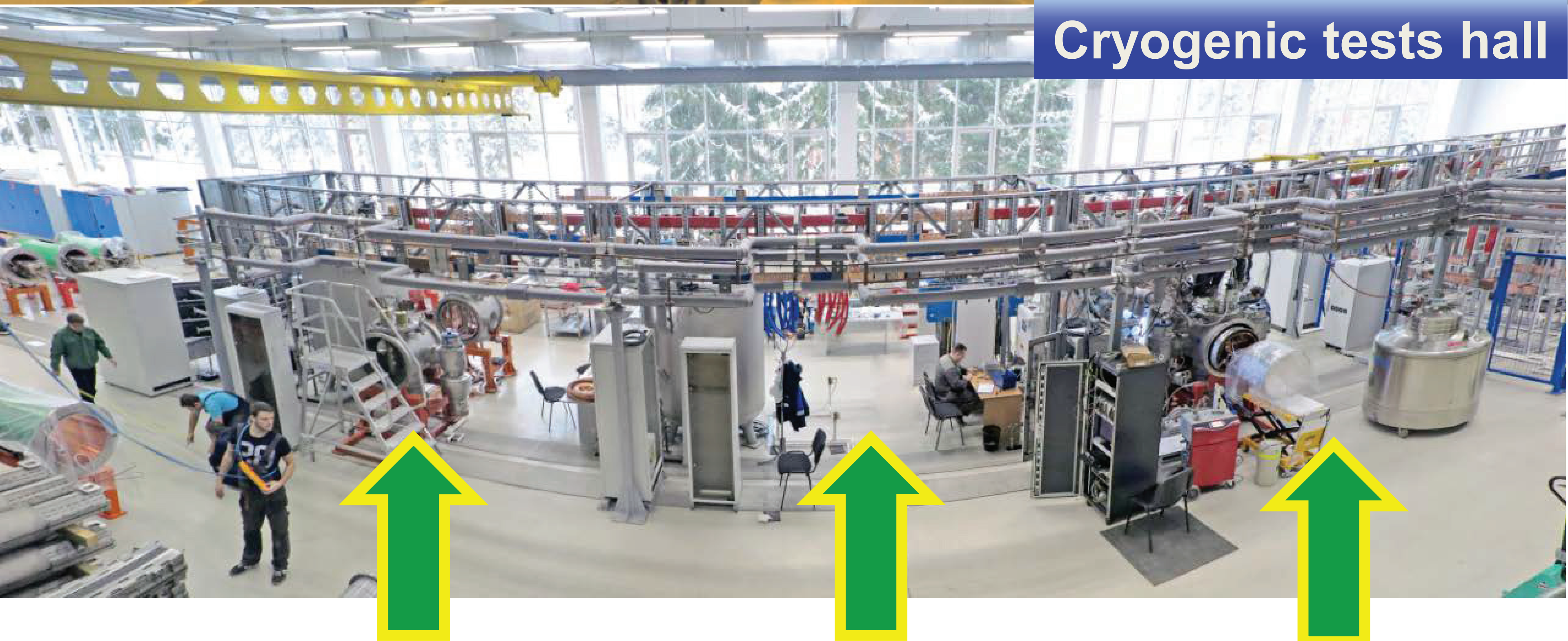
SC Magnet Tests for NICA @ FAIR



3 of 6 tests benches => for SIS100 units tests

Official launch 28.11.16

SC Magnet Tests for NICA @ FAIR



Cryogenic tests hall

3 of 6 tests benches => for SIS100 units tests

Official launch 28.11.16

NICA

FAIR

Production and test schedule of first QP-units

Ид.	Название задачи	Длительность
1	**SIS100 Quad Uints production**	**18 мес**
2		
3	General schedule aproval	0 мес
4	**FoS Quad Units production**	**18 мес**
5	**2FoS Quad manufacturing**	**10 мес**
6	Production of toolings	5 мес
7	Delivery of SC-wires, V-brackers, T-sensors, Heaters	0 мес
8	Production of Quad Coils & Checks	3 мес
9	Choosing the subcontractor, contracting the quads yokes production, release prepayment	1 мес
10	Production of quad ykoes + FAT	6 мес
11	Get produced quad yokes	0 мес
12	SAT	0,5 мес
13	Assembly Coils and Yokes & "warm" tests	1 мес
14	2FoS Quad ready	0 мес
15		
16	**FoS Steerer manufacturing**	**14 мес**
17	Production of toolings	3 мес
18	Production of steerer coils & Checks	3 мес
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20	Production of steerer yoke + FAT	6 мес
21	Get produced steerer yoke	0 мес
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23	Assembly Coils and Yokes & "warm" tests	1 мес
24	Steerer ready	0 мес
25		
26	**FoS Sextupole manufacturing**	**10 мес**
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28	Production of Sextupole Coils & Checks	4 мес
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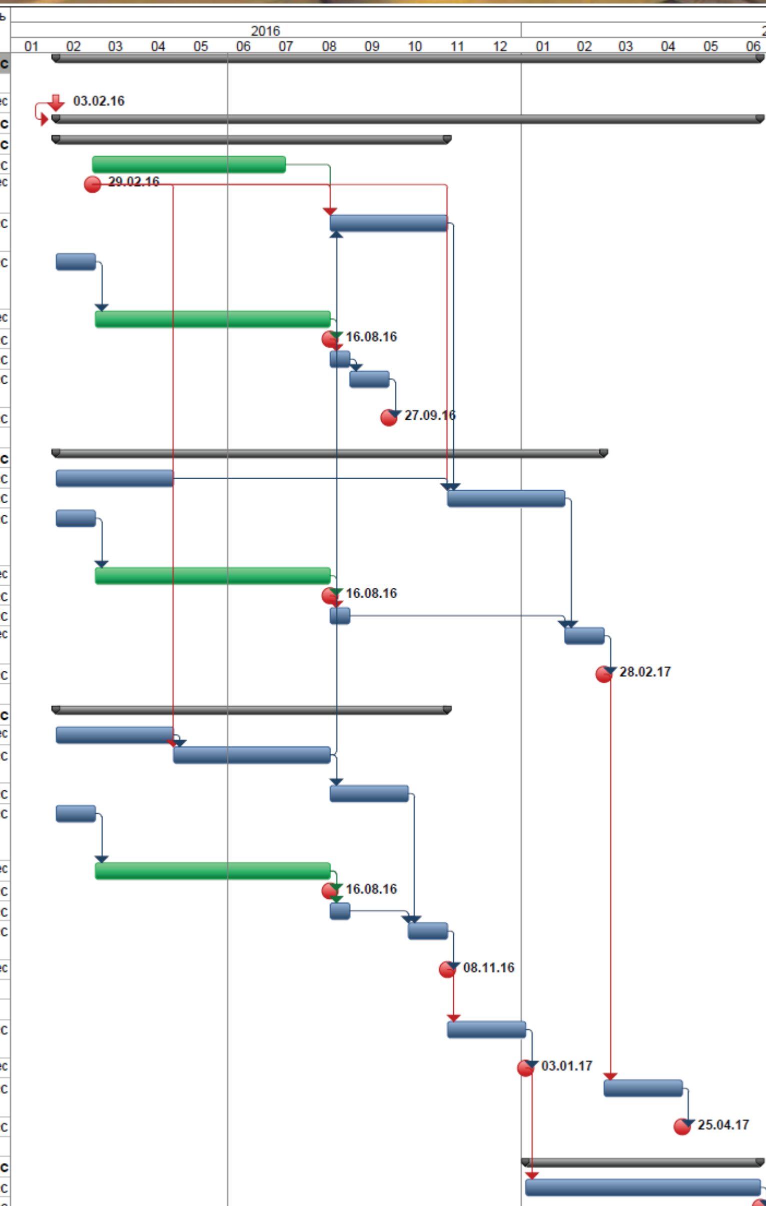
42		
	yo-tests of FoS Units	**6 мес**
	Cryo-tests of FoS Units	6 мес
	Units ready FAT passed	0 мес



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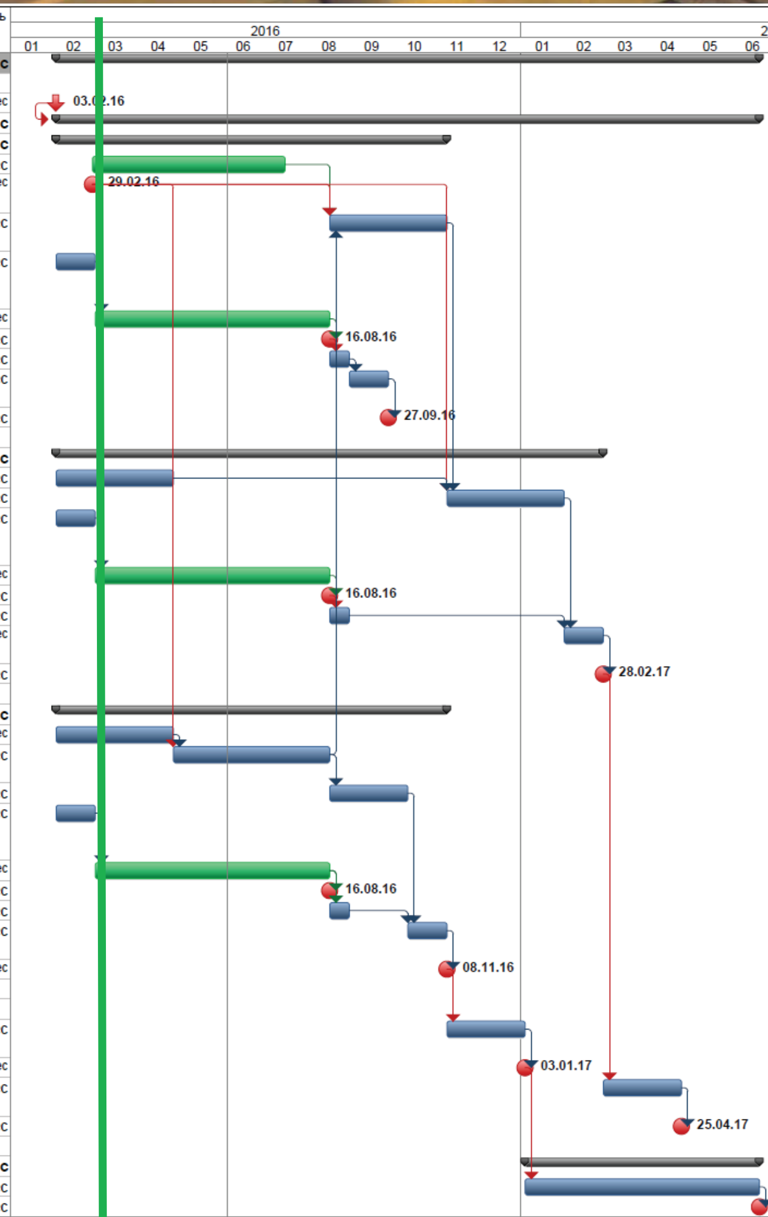

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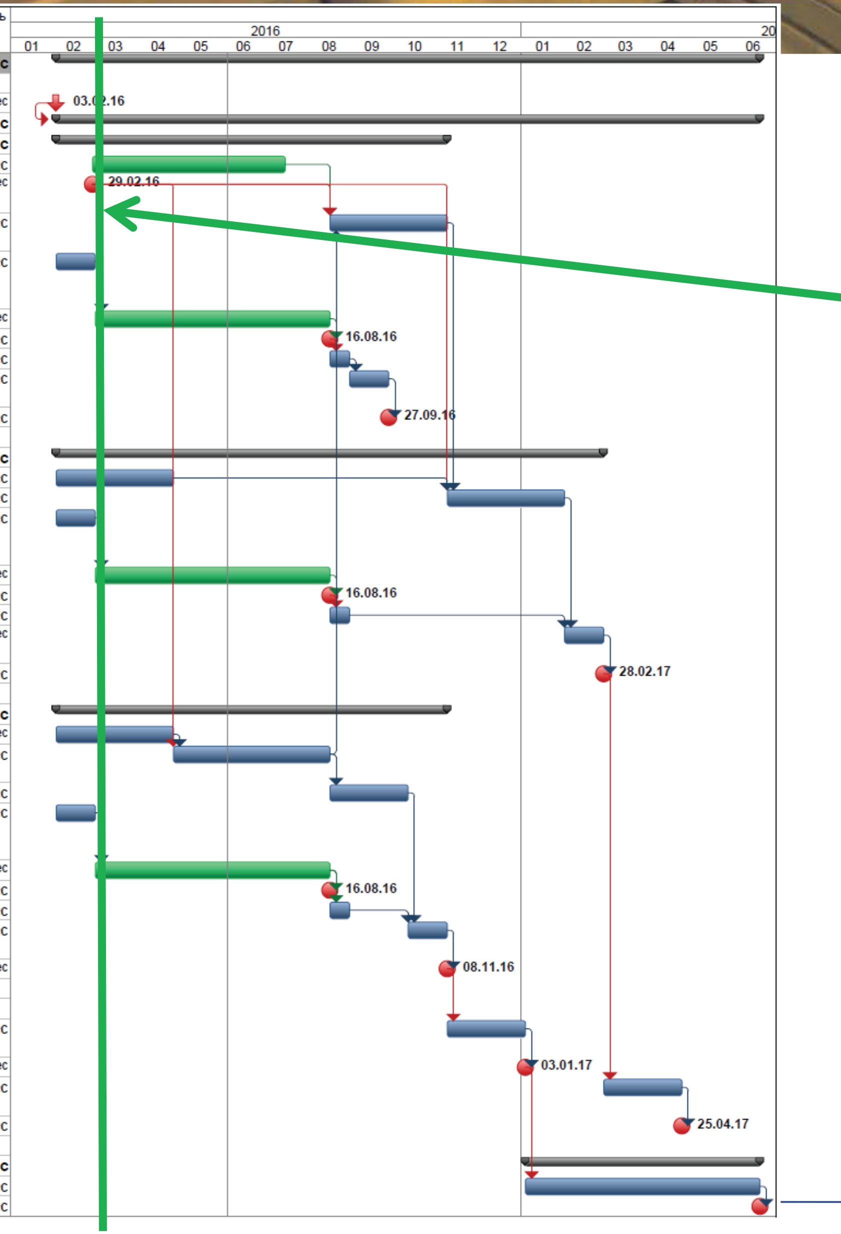

NICA FAIR

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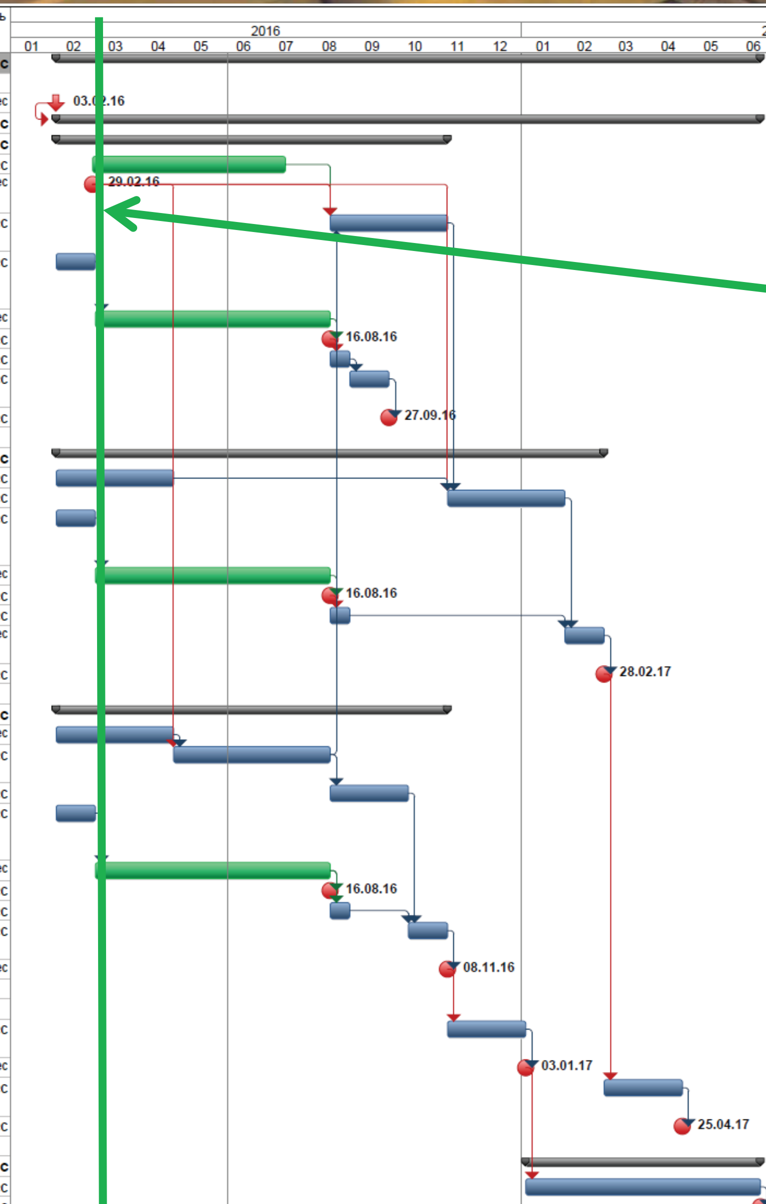

March 2016
Production start

NICA

FAIR

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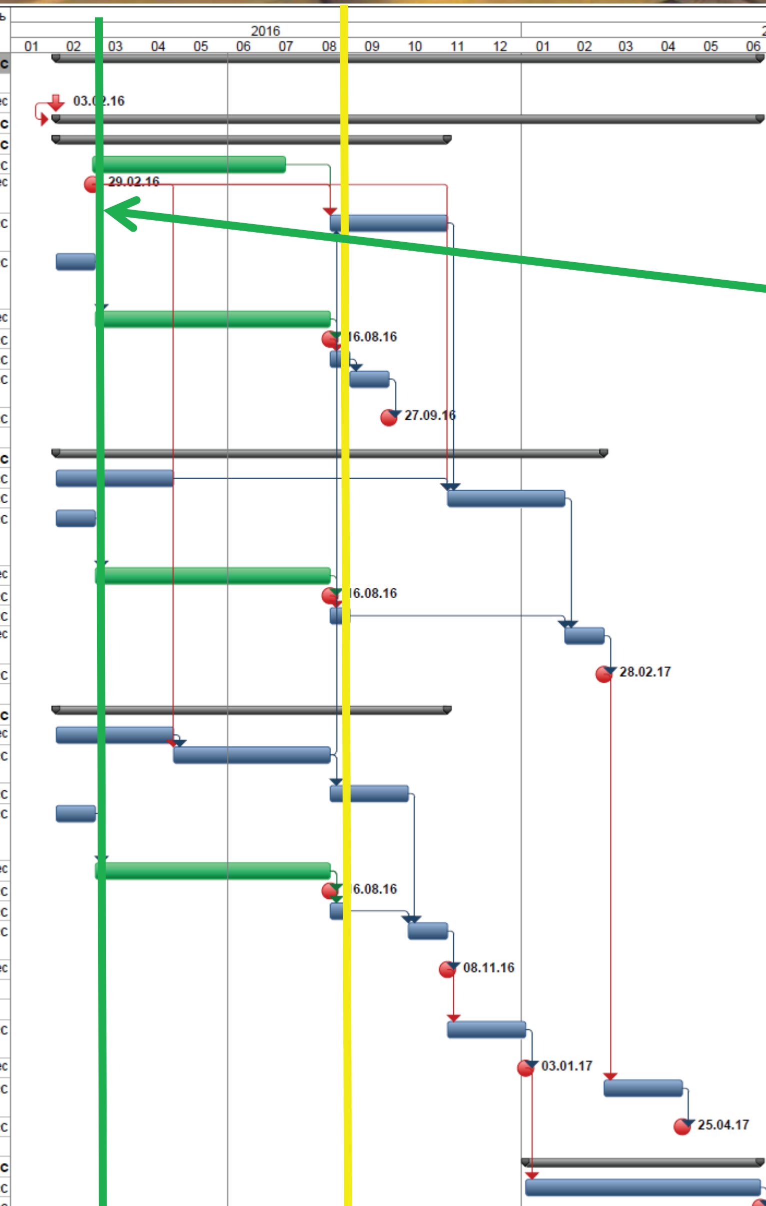

March 2016 Production start

Production and test schedule of first QP-units

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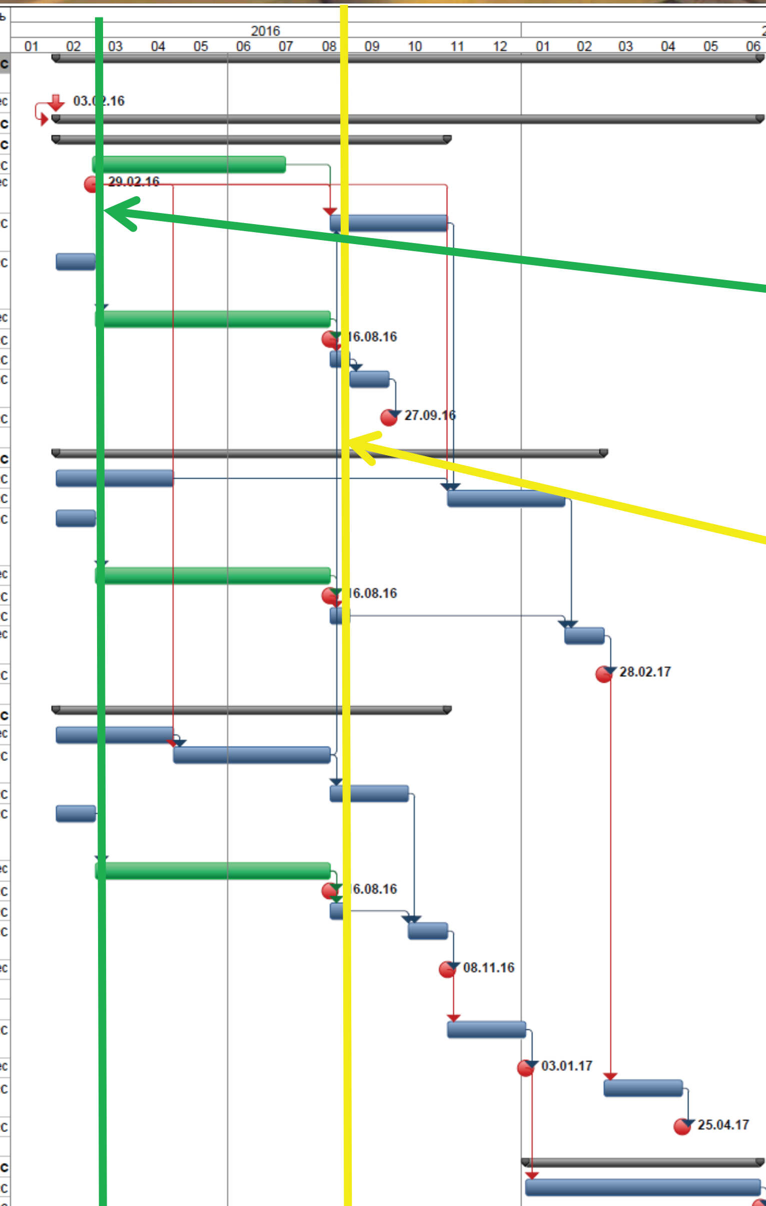

March 2016 Production start

NICA

FAIR

Production and test schedule of first QP-units

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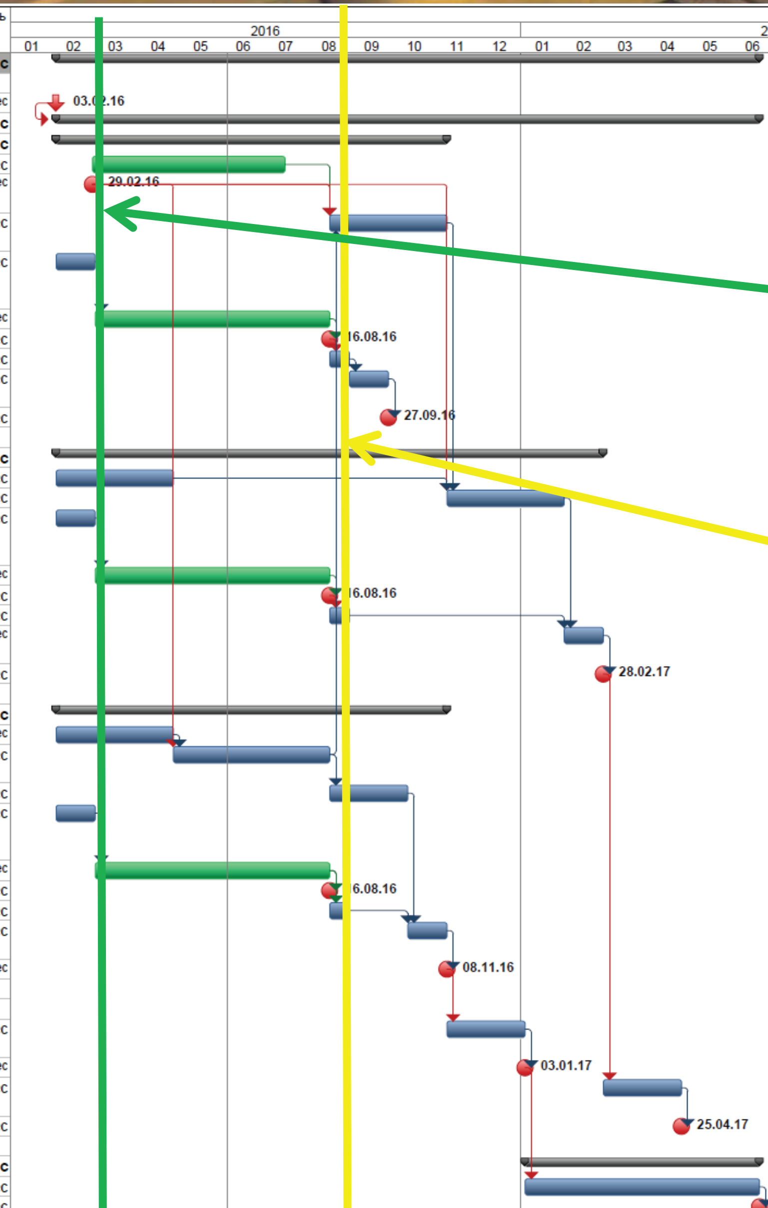

March 2016
Production start

Aug. 2016
Yoke & tooling complete

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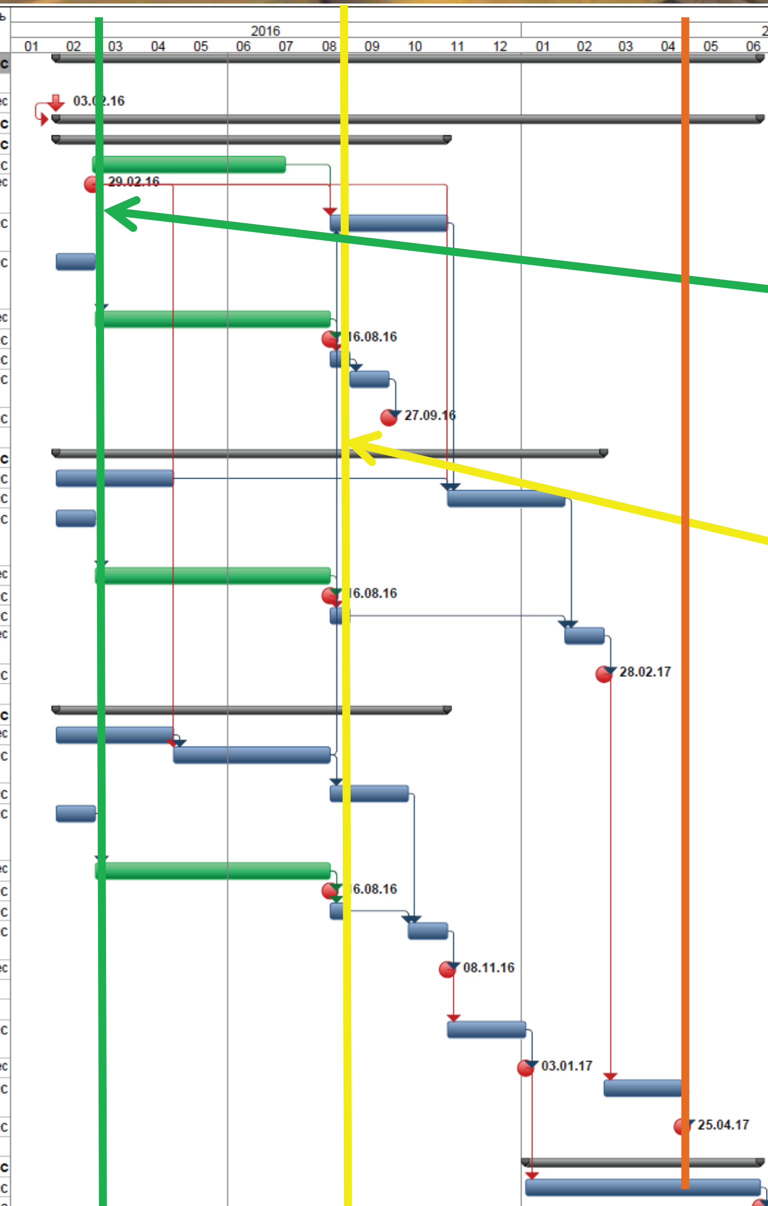
10	Production of quad ykoes + FAT	6 мес
11	Get produced quad yokes	0 мес
12	SAT	0,5 мес
13	Assembly Coils and Yokes & "warm" tests	1 мес
14	2FoS Quad ready	0 мес
15		
16	**FoS Steerer manufacturing**	**14 мес**
17	Production of toolings	3 мес
18	Production of steerer coils & Checks	3 мес
19	Choosing the subcontractor, contracting the quads yokes production, release prepayment	1 мес
20	Production of steerer yoke + FAT	6 мес
21	Get produced steerer yoke	0 мес
22	SAT	0,5 мес
23	Assembly Coils and Yokes & "warm" tests	1 мес
24	Steerer ready	0 мес
25		
26	**FoS Sextupole manufacturing**	**10 мес**
27	Refinment of tooling	3 мес
28	Production of Sextupole Coils & Checks	4 мес
29	Produced coils check	2 мес
30	Choosing the subcontractor, contracting the quads yokes production, release prepayment	1 мес
31	Production of sextupole yoke + FAT	6 мес
32	Get produced sextupole yoke	0 мес
33	SAT	0,5 мес
34	Assembly Coils and Yokes & "warm" tests	1 мес
35	Sextupole ready	0 мес
36		
37		
38	Assembly of 1st FoS unit + "warm" tests	2 мес
39	1st FoS QP Unit ready for cryo tests	0 мес
40	Assembly of 2nd FoS unit + "warm" tests	2 мес
41	2nd FoS QP Unit ready for cryo tests	0 мес
42		
	...yo-tests of FoS Units	**6 мес**
	Cryo-tests of FoS Units	6 мес
	...nits ready FAT passed	0 мес



March 2016
Production start

Aug. 2016
Yoke & tooling complete

Production and test schedule of first QP-units

Ид.	Название задачи	Длительность
1	**SIS100 Quad Uints production**	**18 мес**
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3	General schedule aproval	0 мес
4	**FoS Quad Units production**	**18 мес**
5	**2FoS Quad manufacturing**	**10 мес**
6	Production of toolings	5 мес
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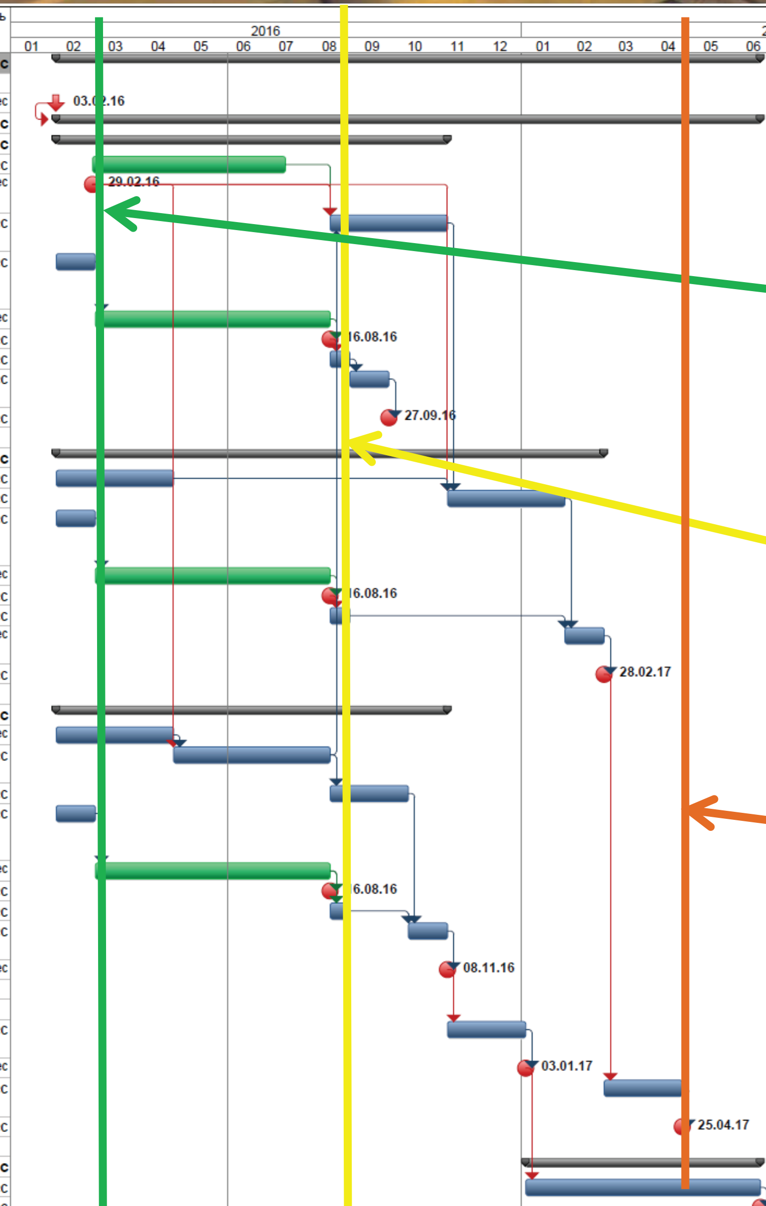

March 2016 Production start

Aug. 2016 Yoke & tooling complete

NICA

FAIR

Production and test schedule of first QP-units

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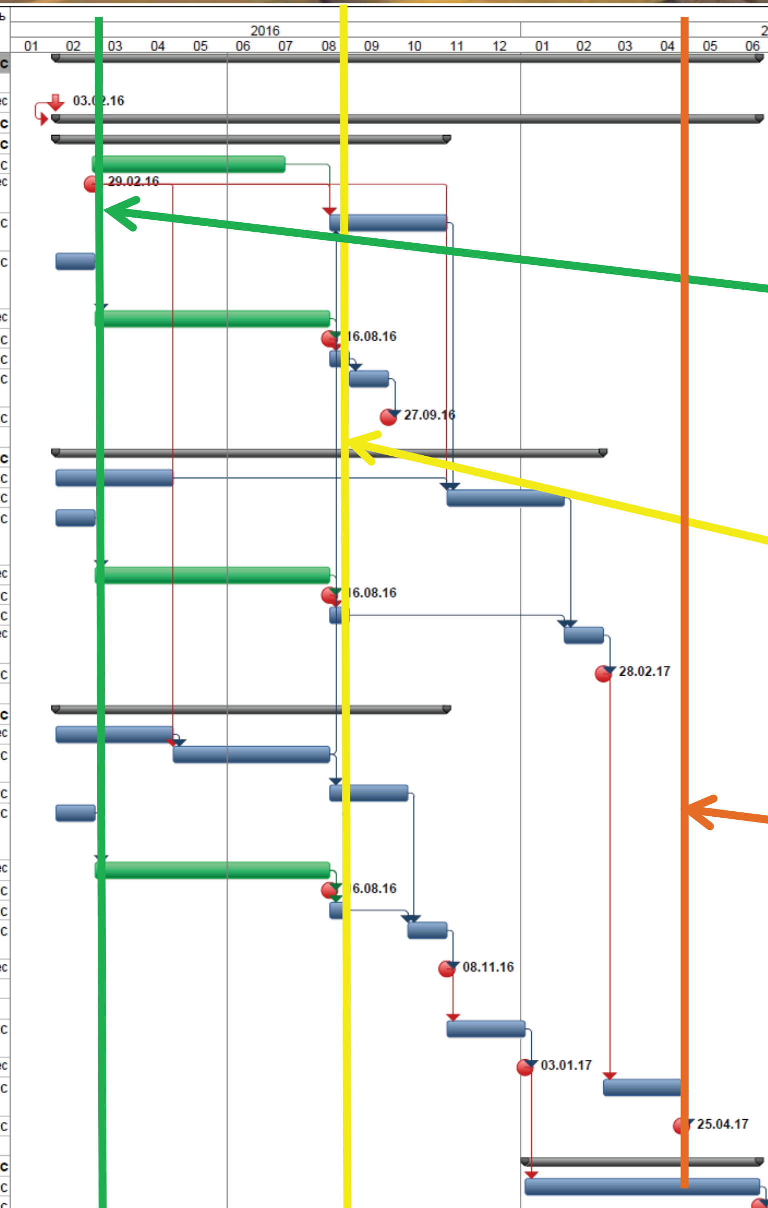

March 2016
Production start

Aug. 2016
Yoke & tooling complete

Apr. 2017
2 FoS QP Units fabricated

NICA

FAIR

Production and test schedule of first QP-units

Ид.	Название задачи	Длительность
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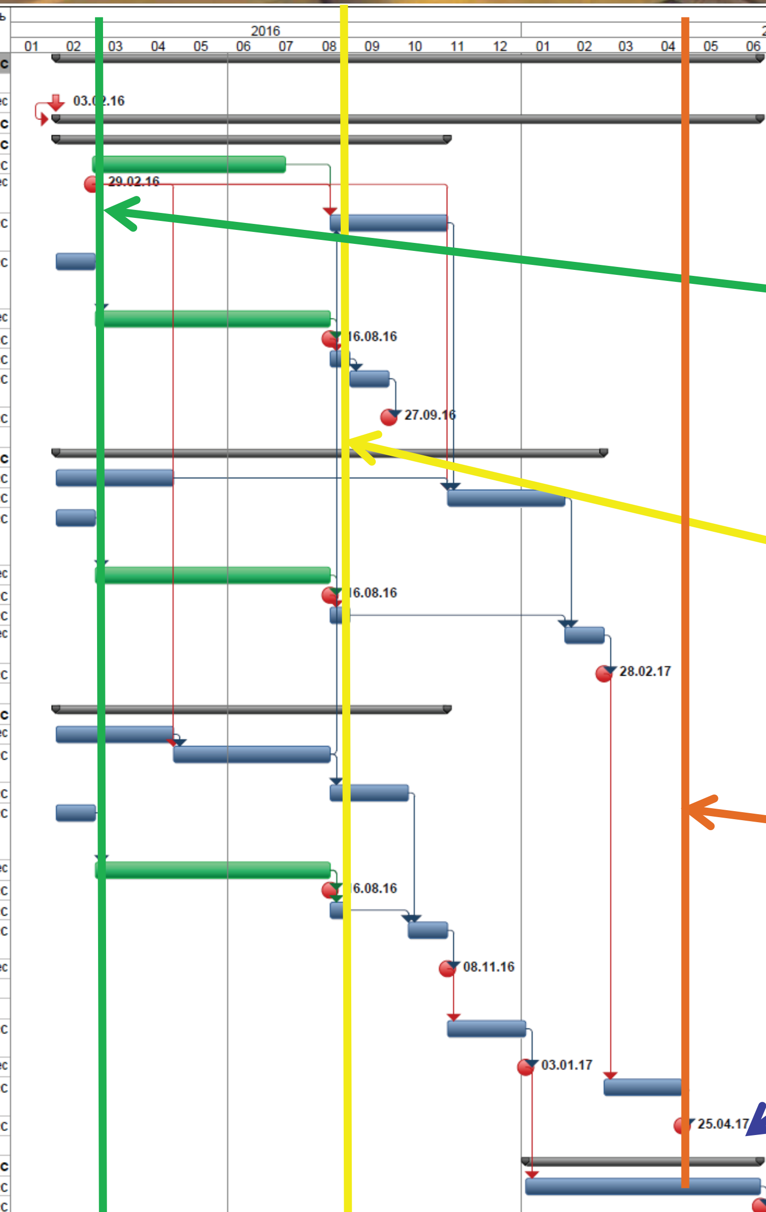

March 2016
Production start

Aug. 2016
Yoke & tooling complete

Apr. 2017
2 FoS QP Units fabricated

NICA

FAIR

Production and test schedule of first QP-units

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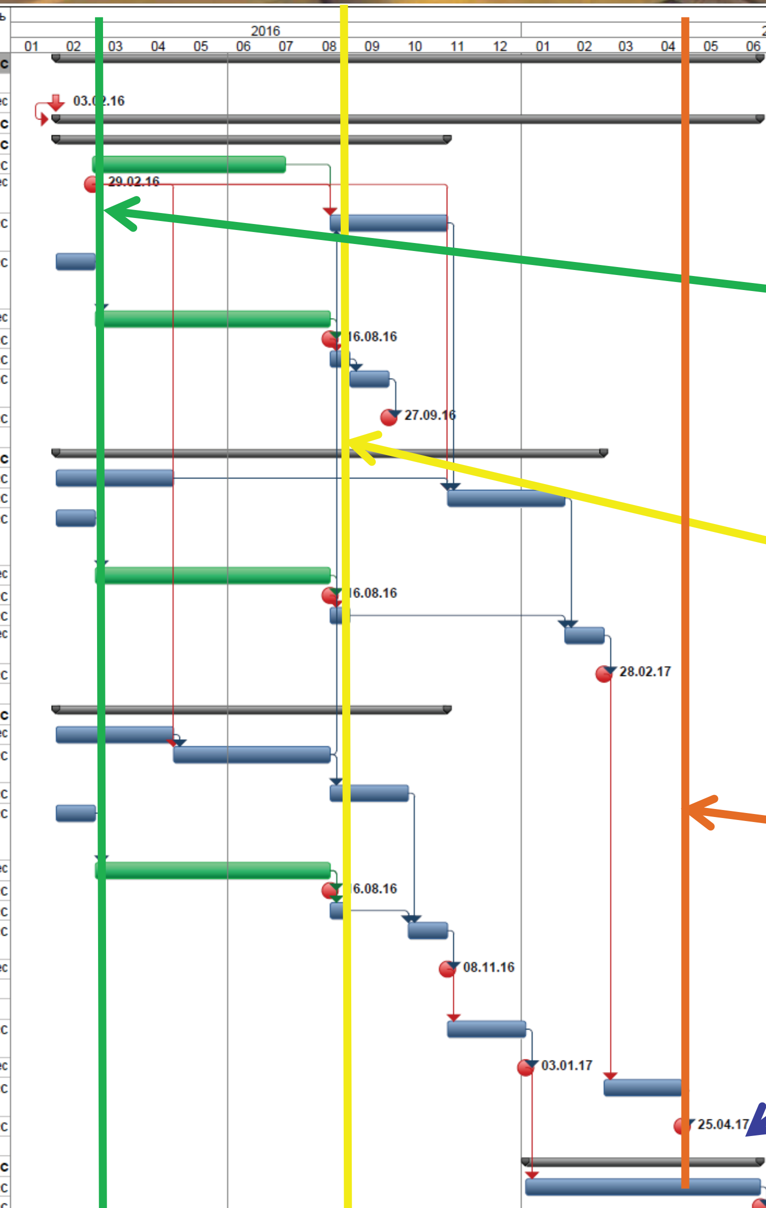


March 2016 Production start

Aug. 2016 Yoke & tooling complete

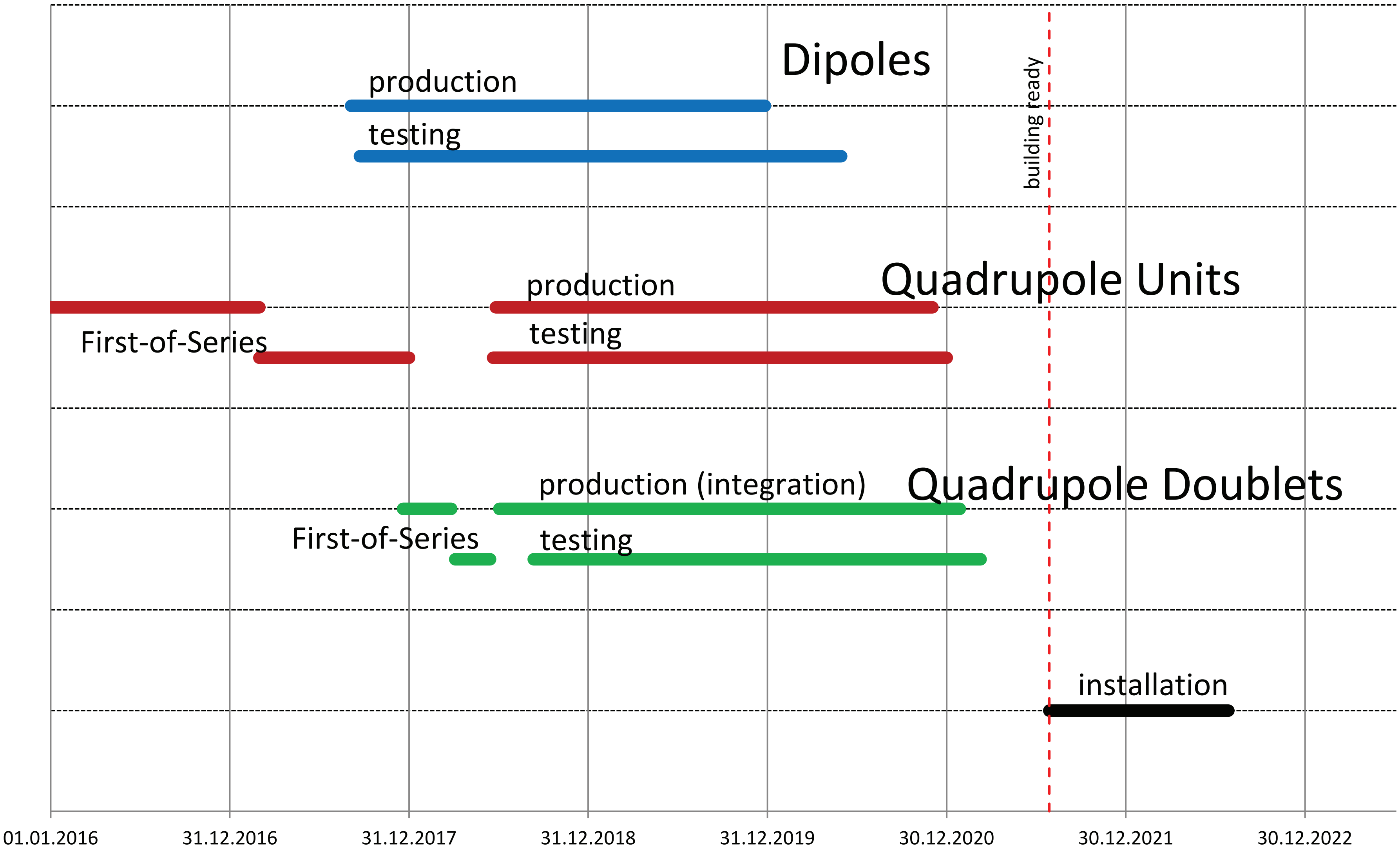
Apr. 2017 2 FoS QP Units fabricated

Cold tests

NICA

FAIR

Production & Installation Schedule for SIS100



NICA FAIR

FAIR/GSI: construction site

NICA: construction site

Conclusions

- Production of SC magnets for SIS100 and NICA is on the way and the cooperation is very fruitful.
- It gives absolute synergy to both the NICA and FAIR projects.
- Together we are creating the Common European Research infrastructure for Heavy Ion Physics: FAIR & NICA