Jointly solving accelerator technology challenges at NICA and FAIR

Grigory Trubnikov
JINR, Dubna

Darmstadt, 16 November 2016

Joint workshop NICA-FAIR

Points of mutual interest and cooperation:

1) Superconducting magnets and superconducting components (together with GSI/FAIR).

2) Elements of the stochastic cooling system (SCS) for NICA collider (slot-coupler RF structures, based on FZJ design, developed for HESR).

3) Large power supplies/current transformers (250V, 12kA) for Storage rings (collider).

4) Helium satellite refrigerators + control systems (ILK, Dresden)

5) Development of the cryogenics test-bench and SC magnet testing (with GSI/FAIR)

6) SC p/i-linac, pulsed -> cw (together with GSI/FAIR and IAP Frankfurt)

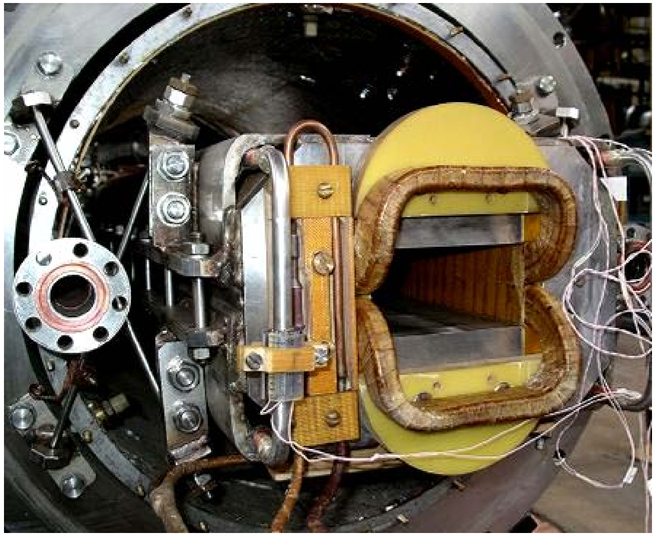
7) UHV beam chambers, thin walls, elliptic, curved (together with GSI/FAIR)

8) Different type of electronics (front-end electronics, analyzers, Software, microchips, …) for NICA MPD detector and accelerator complex.

…

Accelerator SC Magnet R&D

Fast cycling SC Magnets: super-ferric, B_field = 2T, ramp rate up to 4-8 T/sec.

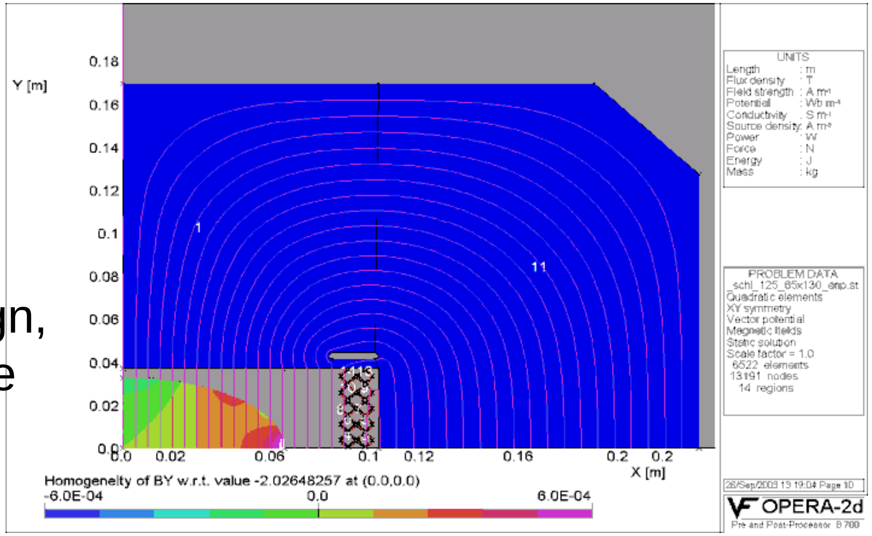


R&D Goals

- **Reduction of eddy / persistent current effects at 4K (3D field, AC loss)**
- **Improvement of DC/AC-field quality**
- **Guarantee of long term mechanical stability**
  ($\geq 2 \cdot 10^8$ cycles)

Activities

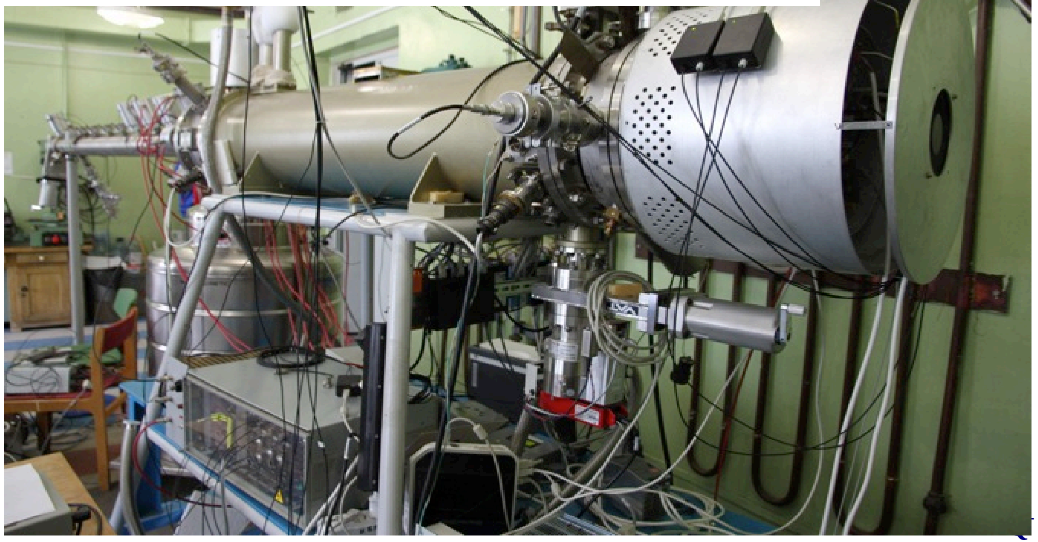
- AC Loss Reduction (exp. tests, FEM)
- 2D/3D Magnetic Field Calculations (OPERA, ANSYS, etc.)
- Mechanical Analysis and Coil Restraint (design, ANSYS) (>Fatigue of the conductor and precise positioning)



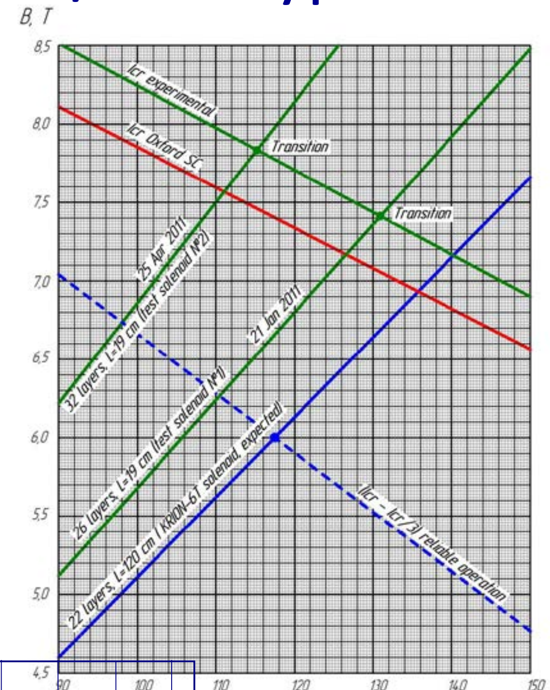
Experimental studies with modified Nuclotron magnets in JINR

Development of Heavy ion sources ESIS/EBIS type

JINR Krion-6T (ESIS) for NICA

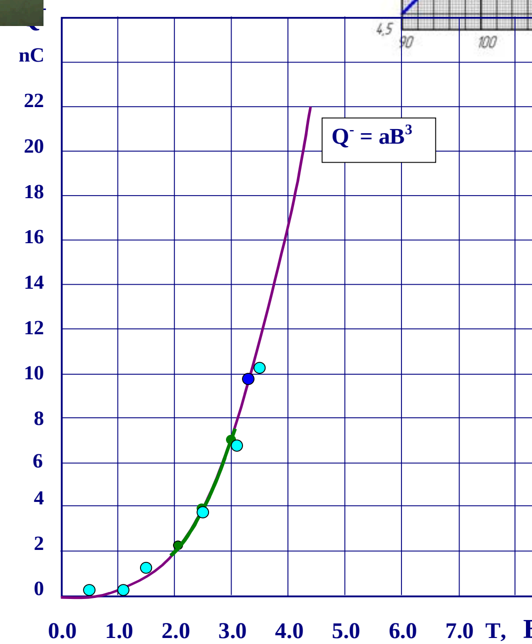


Leaders:
E.D.Donets
E.E.Donets



B = 6 (5.4) T
Ee = 25 (15) keV
J_el (design) = 1000 A/cm^2

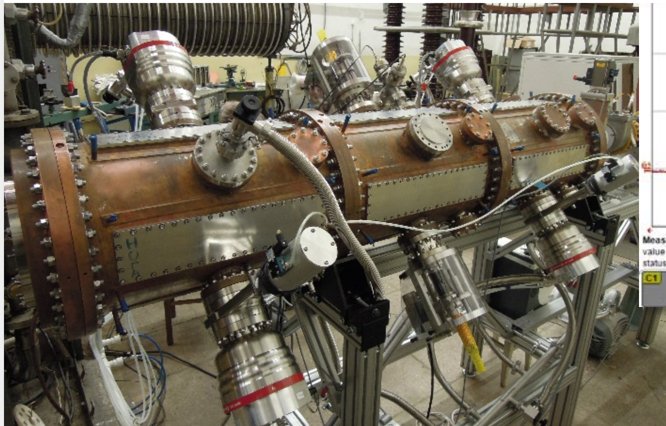
Au^{30+32+} : $6*10^8$ ppp,
t_{ion} = 20 ms @ 50 Hz.
Ion of $Au^{51+} \div Au^{54+}$ generated

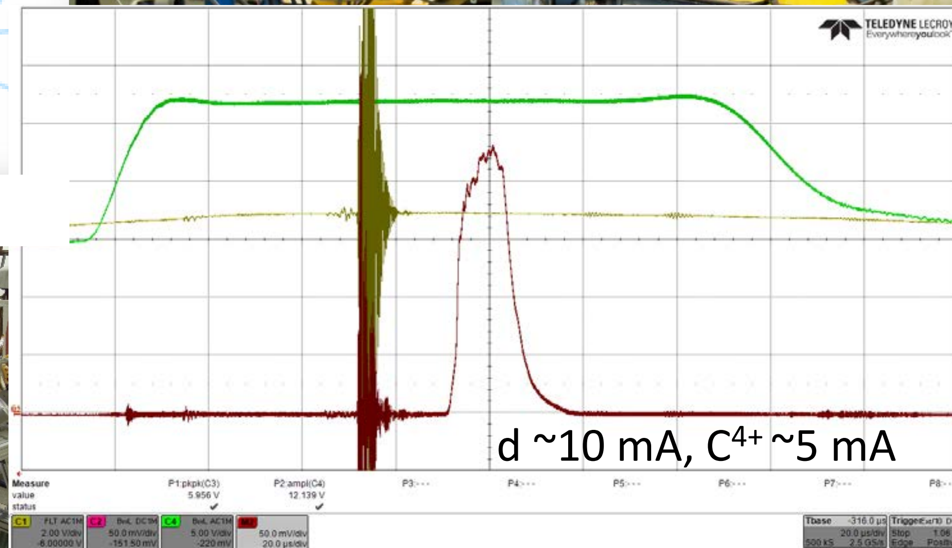


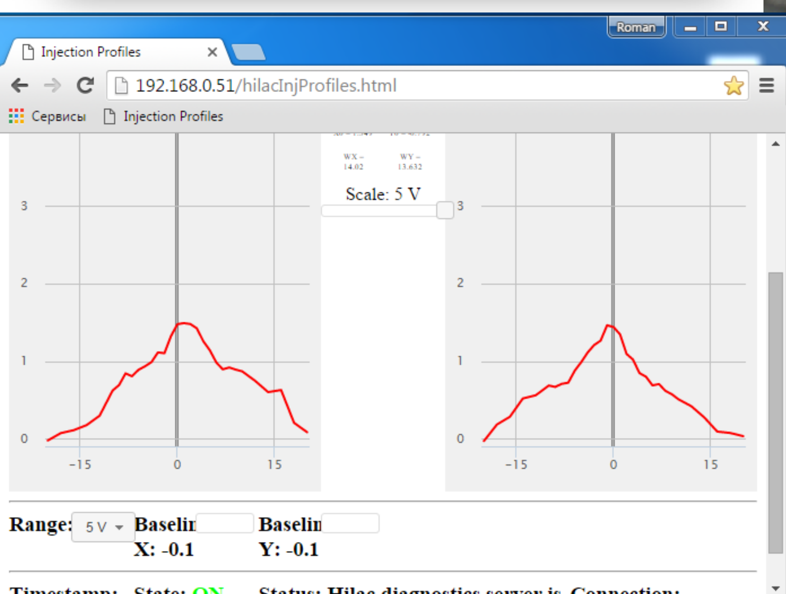
Dependency of a number of string electrons on

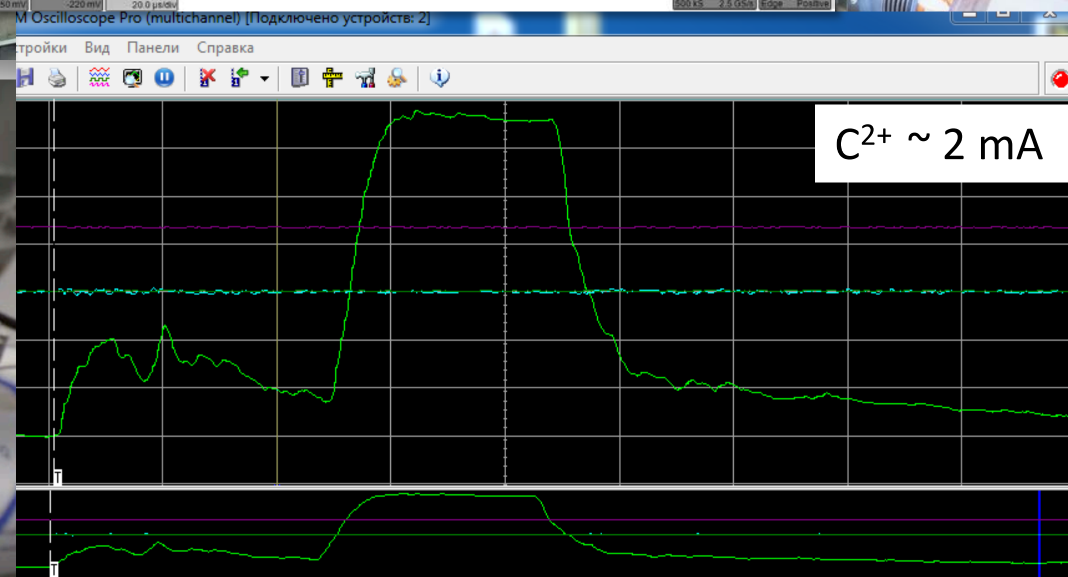
Injection complex: 2 linacs

JINR-ITEP-MEPhI-Snezhinsk







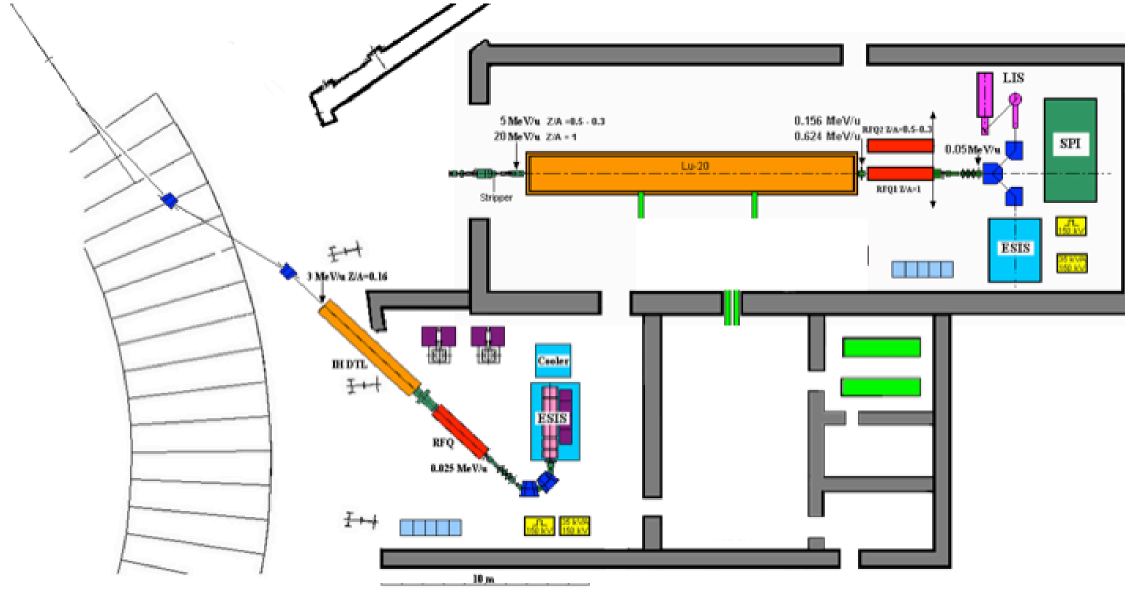


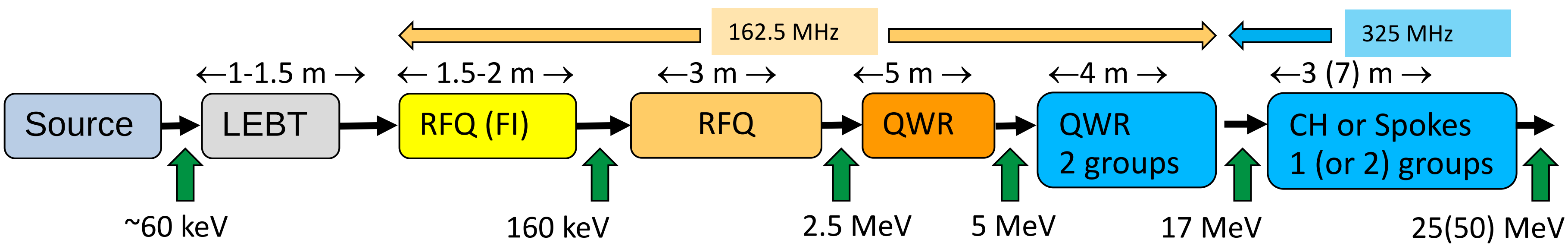
IAP, BEVATECH, JINR, ITEP

Parameters of SC linac

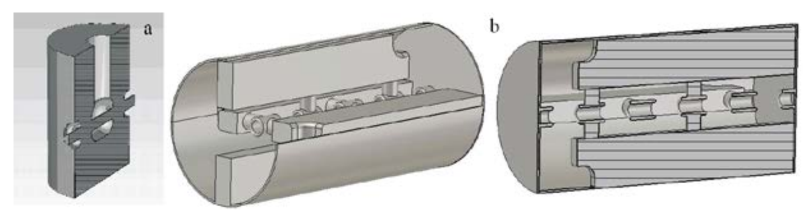
Cavities group	1	2	3	4
β_g	0.07	0.141	0.225	0.314
W_{in}, MeV	1.0	4.1	17.2	34.3
β_{in}	0.046	0.093	0.189	0.263
W_{out}, MeV	4.1	17.2	34.3	50
β_{out}	0.093	0.189	0.263	0.314
T, %	17.5	17.5	17.5	17.5
K_T, %	100	100	100	100
f, MHz	162	162	324	324
N_{gap}	2	4	4	4
φ, deg	−20	−20	−20	−20
L_{res}, m	0.13	0.26	0.416	0.58
E, MV/m	3.08	10	12	11.21
U_{res}, MV	0.4	2.6	5	6.5
B, T	1.6	2	2.6	2.8
L_{sol}, m	0.2	0.2	0.2	0.2
L_{gap}, m	0.1	0.1	0.1	0.1
L_{per}, m	0.53	0.66	0.816	0.98
N_{per}	8	6	4	4
L, m	4.24	3.96	3.264	3.92

Development of new injector @ VBLHEP JINR





Electrodynamics models of QWR cavities were designed for β =0.07, 0.105, 0.12 (and 0.150 as reserve) and resonant frequency of f=162 MHz. As an example, optimal QWR characteristics for f=162 MHz and β =0.07 are the following: cavity height 480 mm, central conductor length 439 mm, central conductor radius 18 mm, cavity internal radius 67 mm, central drift tube length 118 mm, gaps length 24 mm



As a flag for the future, a cw-linac is highly desired for JINR: a 50 MeV (pulsed at 1st stage) SC LINAC as ring injector.

The design, development and construction of superconducting cavities, rf-supply- as well as cryo support systems are the main possible topics of future collaboration. Besides the beam dynamics design (also for smooth energy adaption) and the design and upgrade of the normal conducting cw-frontend (ECR ion source, LEBT, RFQ and IH-DTL or something adequate) are of high common interest.

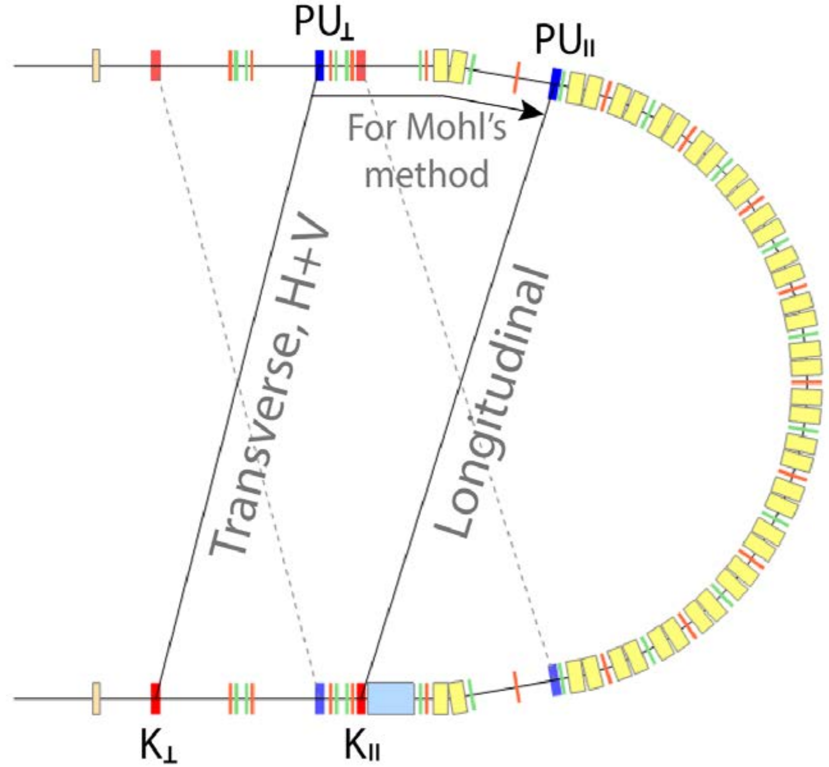
Superconducting cavity design, prototyping, measuring, serial production

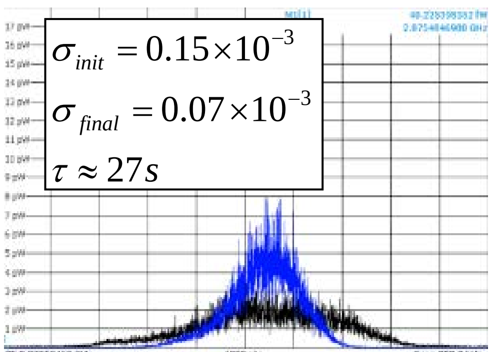
W.Barth, S.Yaramyshev (GSI)
H.Podlech, H.Holtermann, U.Ratzinger, A.Schempp(IAP, Frankfurt)

Stochastic Cooling System for NICA

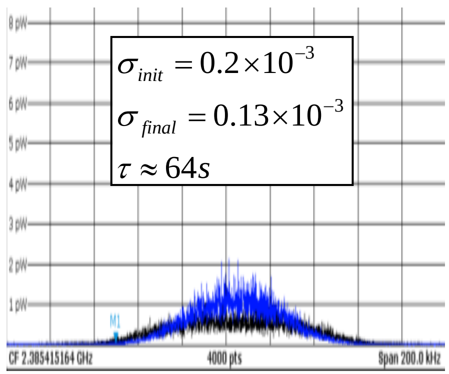
Stochastic Cooling System installed at Nuclotron - prototype for the NICA Collider:
W=2-4 HGz,
P = up to 60 W
Collaboration:
with IKP FZ Juelich

Ring slot-coupler RF structure (design FZJ)





Coasting beam



Bunched beam

C^{6+} beam, E = 2.5 - 4 GeV/u

Concept for collider: Max.power ~ 500W
Filter cooling only for E > 3.9 GeV/u
Palmer cooling will be OK at
2.5 < E < 4.5 (t_{cool}: from 250 to 500 s)

Rolf Stassen, Dieter Prasuhn, Nikolay Shurkhno, Ivan Gorelyshev, Anatoly Sidorin, GT

PROPOSAL for cooperation between JINR (Dubna) and FZ Juelich on design, construction and delivery of the STOCHASTIC COOLING SYSTEM (SCS) ELEMENTS FOR the NICA COLLIDER.

Rolf Stassen, Mei Bai (IKP-4) + ZEA1 (Frank Martin Esser, Ralf Greven)

We propose participation of JINR team (2-3 FTE) in:

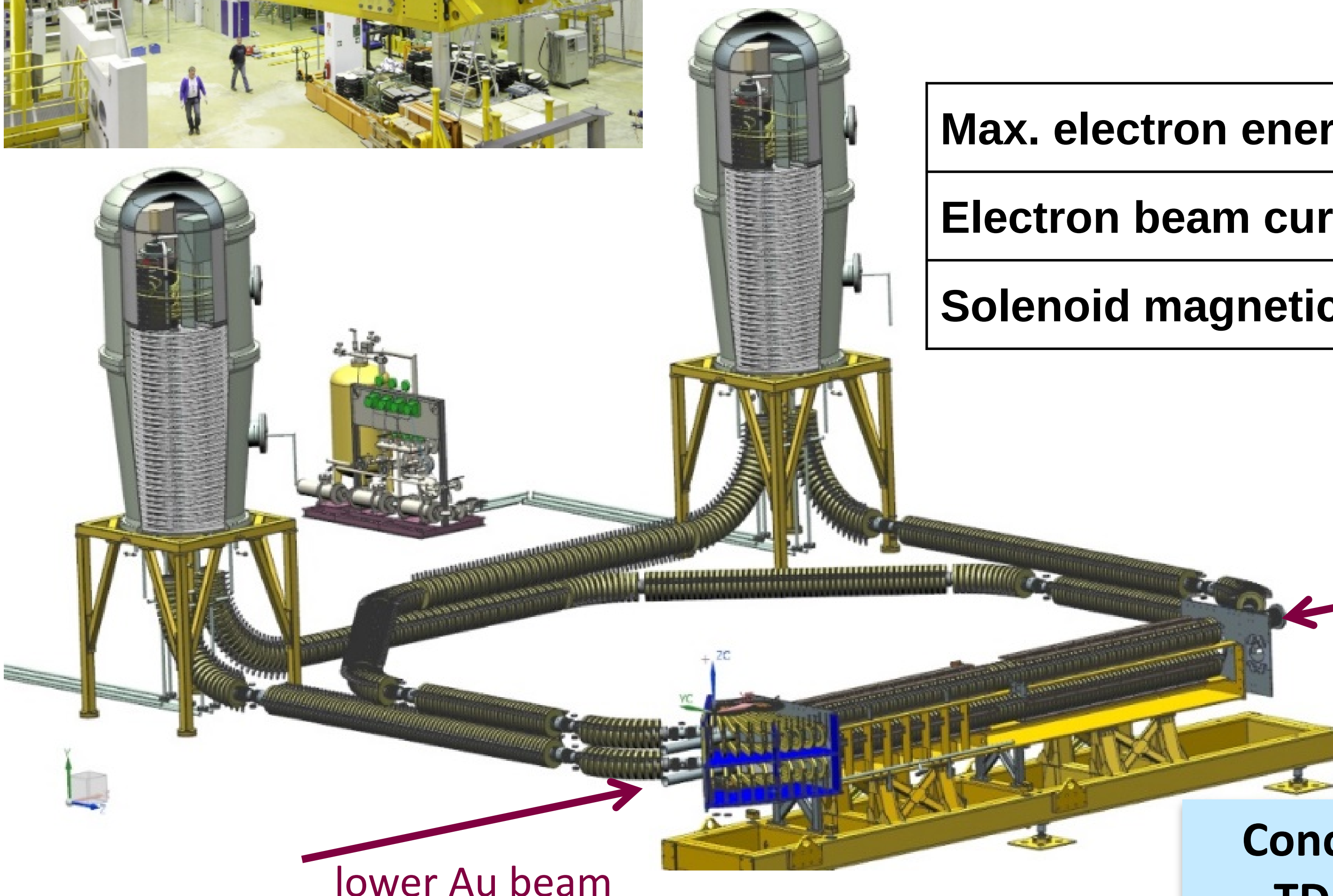
- design structures, cryostat, joints and connections.
- Assembly and testing of HESR structures at FZJ
- Assembly and testing of NICA structures at FZJ later

NICA Stochastic Cooling system has following configuration: 4 Kickers (2 per each collider ring) and 6 pickups (3 per each collider ring). Each structure (Ring Slot Coupler) consists of 16 rings and 8 combiner boards (16 x 1). Each Pickup for NICA SCS consists of 2 Structures. Each Kicker consist of 4 structures. In total 30 RF structures.

Electron cooling system for NICA: 2.5 MeV

Main base: COSY e-cooler (2 MeV)

Max. electron energy, MeV	0.5 - 2.5
Electron beam current, A	0.1 – 1.0
Solenoid magnetic field, T	0.2



Concept by Budker INP.
TDR started in 2016.

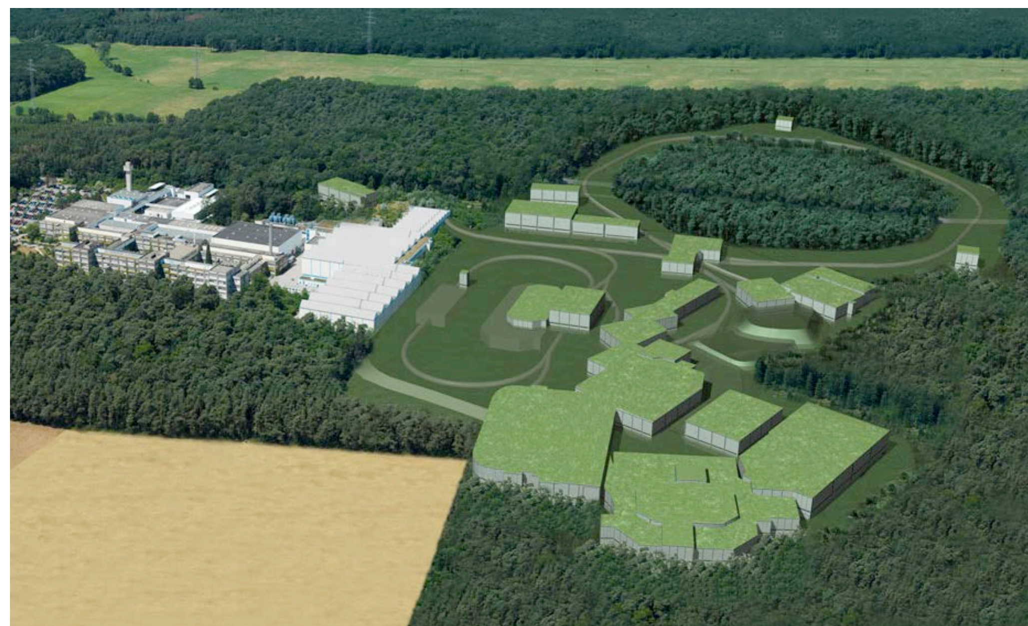
NICA @ Dubna

Technology

“Nuclotron magnet”

Leaders:
H.Khodzhibagiyan, S.Kostromin, GT
E.Fischer, P.Spiller

FAIR @ Darmstadt



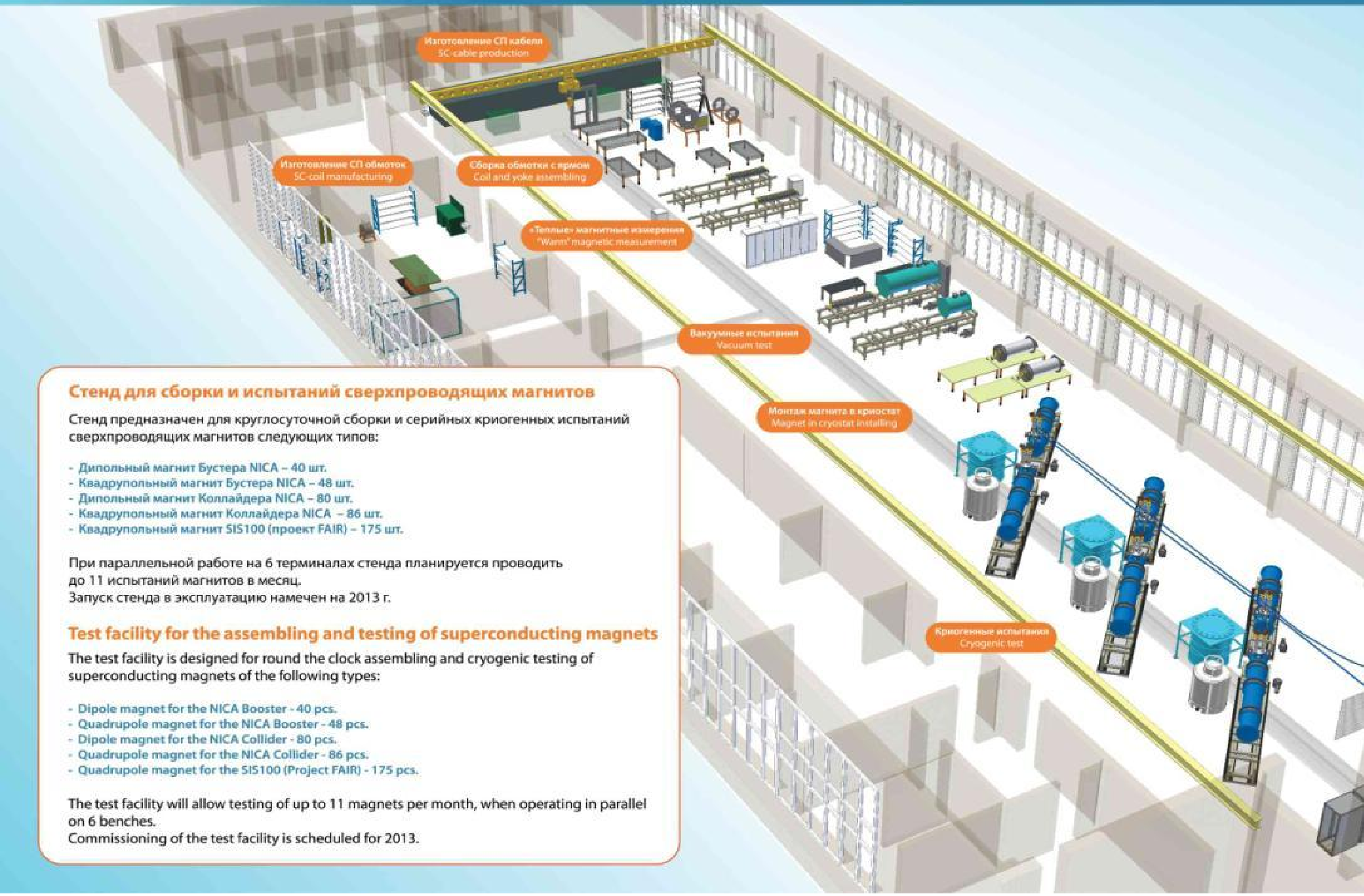
633 SC-magnets:
- **326 for NICA**
- **307 for FAIR**

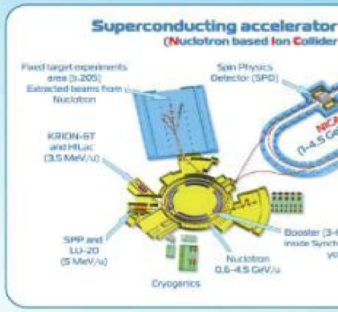
Facility for SC magnets assembling & test

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.

СТЕНД ДЛЯ СБОРКИ И ИСПЫТАНИЙ СВЕРХПРОВОДЯЩИХ МАГНИТОВ
TEST FACILITY FOR THE ASSEMBLING AND TESTING OF SUPERCONDUCTING MAGNETS





Стенд для сборки и испытаний сверхпроводящих магнитов

Стенд предназначен для круглосуточной сборки и серийных криогенных испытаний сверхпроводящих магнитов следующих типов:

- Дипольный магнит Бустера NICA – 40 шт.
- Квадрупольный магнит Бустера NICA – 48 шт.
- Дипольный магнит Коллайдера NICA – 80 шт.
- Квадрупольный магнит Коллайдера NICA – 86 шт.
- Квадрупольный магнит SIS100 (проект FAIR) – 175 шт.

При параллельной работе на 6 терминалах стенда планируется проводить до 11 испытаний магнитов в месяц.
Запуск стенда в эксплуатацию намечен на 2013 г.

Test facility for the assembling and testing of superconducting magnets

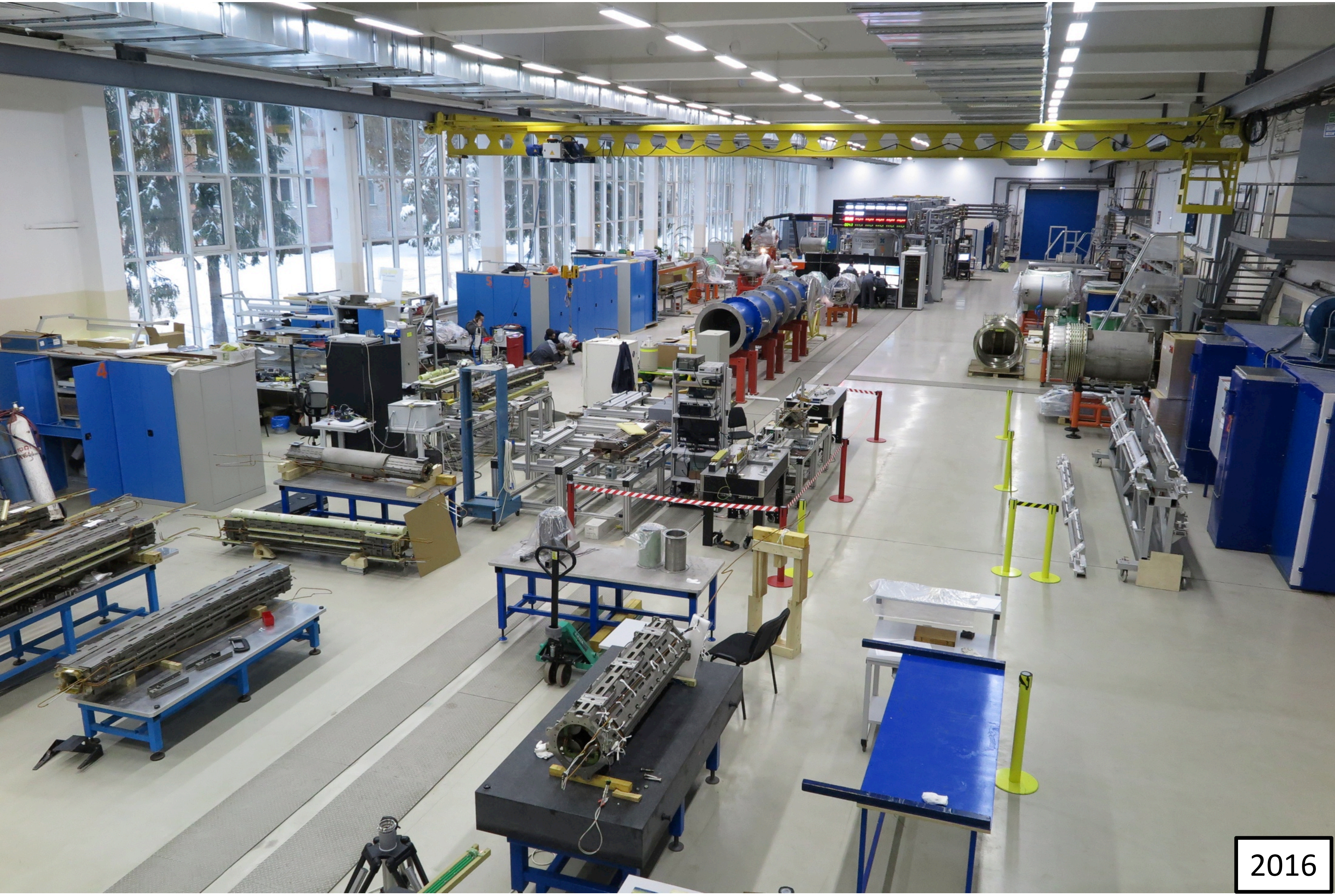
The test facility is designed for round the clock assembling and cryogenic testing of superconducting magnets of the following types:

- Dipole magnet for the NICA Booster - 40 pcs.
- Quadrupole magnet for the NICA Booster - 48 pcs.
- Dipole magnet for the NICA Collider - 80 pcs.
- Quadrupole magnet for the NICA Collider - 86 pcs.
- Quadrupole magnet for the SIS100 (Project FAIR) - 175 pcs.

The test facility will allow testing of up to 11 magnets per month, when operating in parallel on 6 benches.
Commissioning of the test facility is scheduled for 2013.

New SC-magnet test facility - under completion (phase-I for NICA)


2014



2016

Facility for SC magnets assembling & test

Cryogenic tests hall

3 of 6 tests benches => for SIS100 units tests

Official launch 28.11.16

Main challenge:

“Good” magnets ⇒ **Facility rings** **…on time**

Objectives:

- Assembly and testing workflow:
  - well developed procedures
  - repeatability of all processes
  - protocols for tests and checks
  - correction actions if needed

⇒ **Quality assurance**

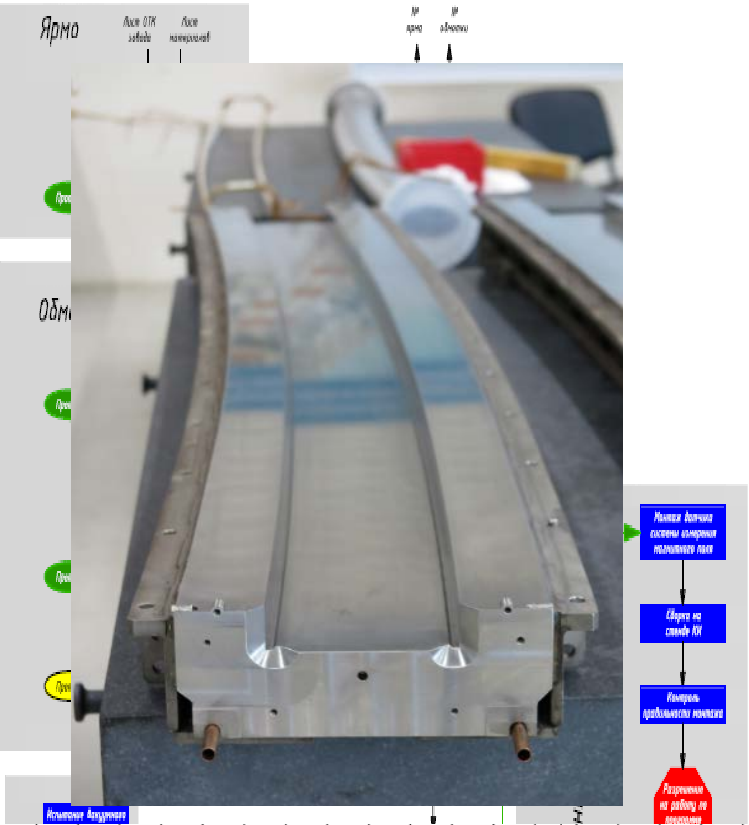
- SC-magnet tests => physics parameters check
  - Leakage tests
  - sc-magnet training
  - magnetic measurements
  - ac-losses + static heat leak check
  - Hydraulic resistance measurements

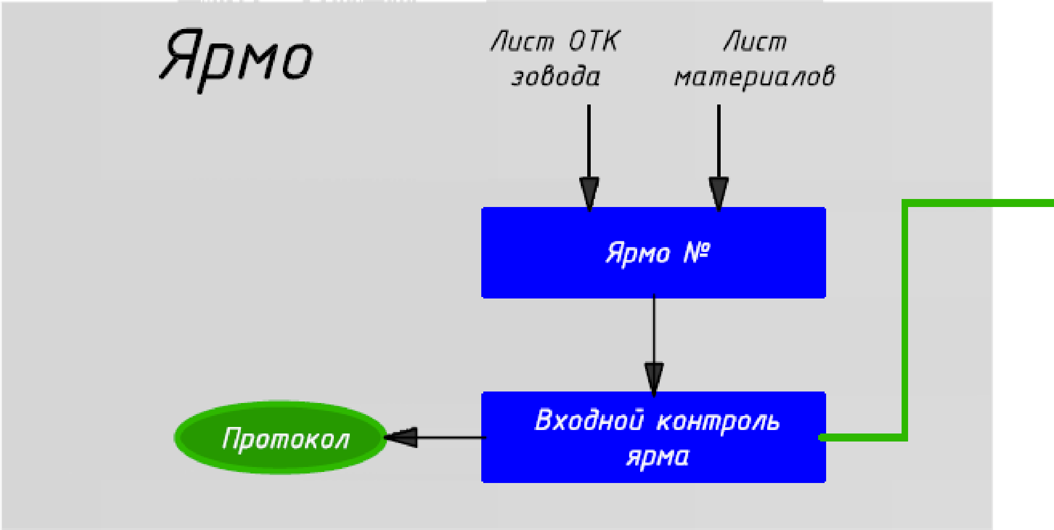
+ communicate accelerator physicists and magnets design engineers)

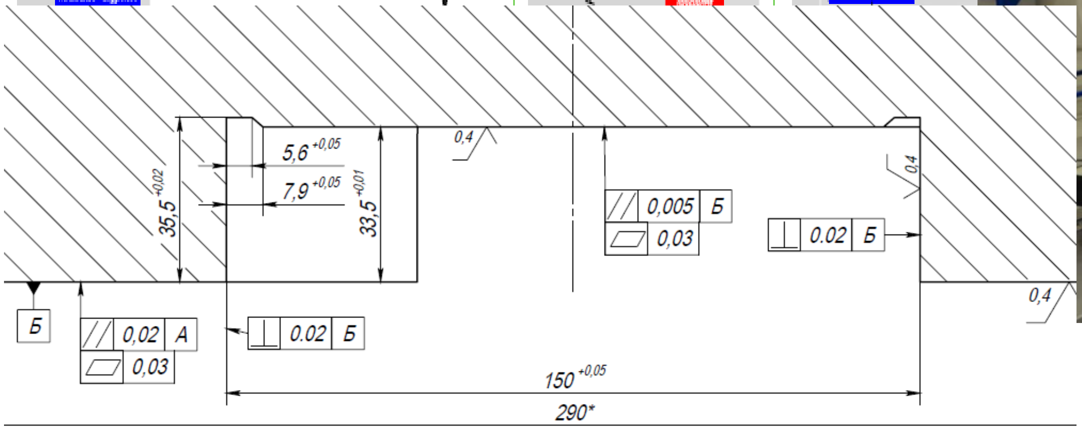
SC-magnet assembly & testing workflow

Yoke

geometry check

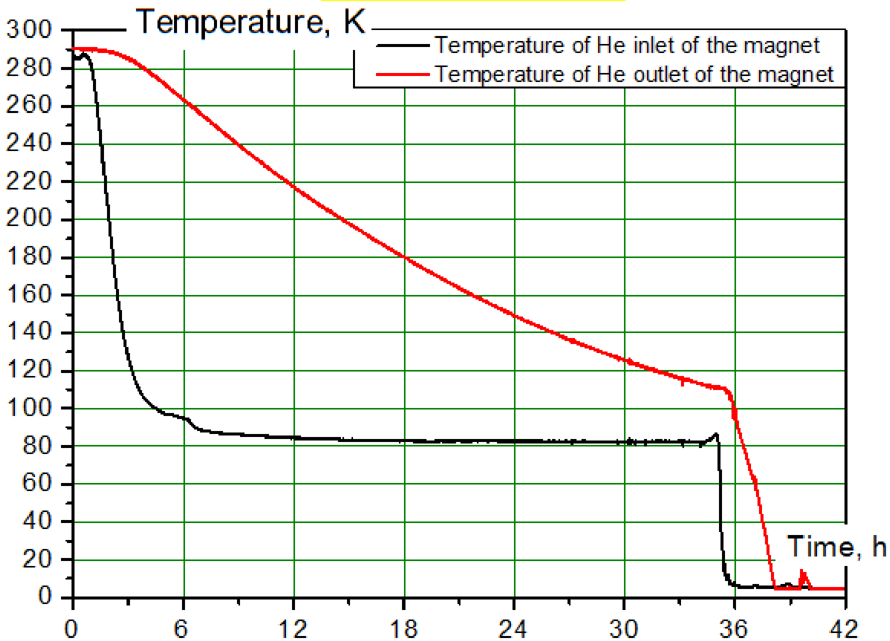




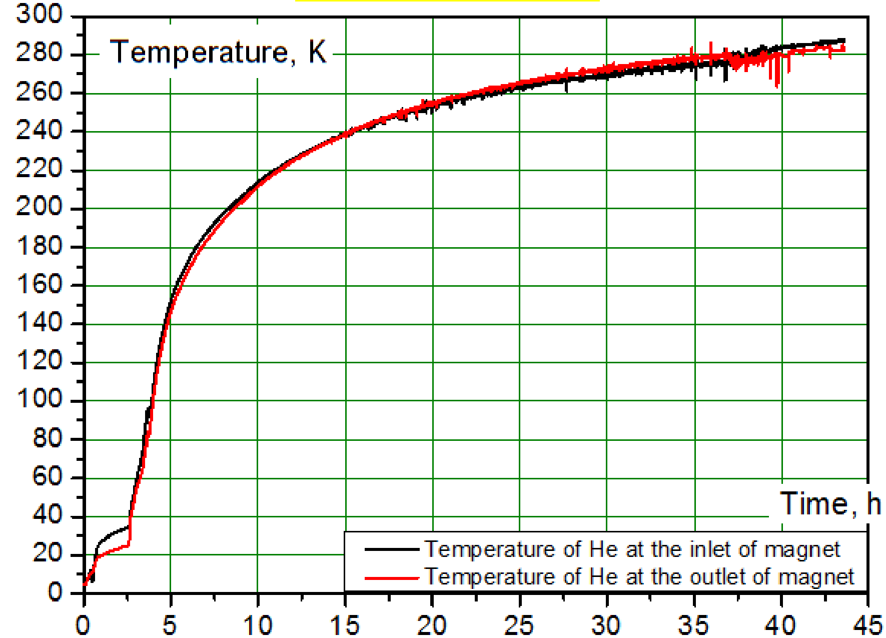


Cryogenic tests: NICA Booster dipole M05

Cooldown



Warm up



	Booster Dipole MO5		
	Calculation	Experimental data (calorimetric method)	Experimental data (electrical method)
Dynamic heat releases, W	**8.4**	**7.1**	**7.8**
Static heat leak, W	**4.4**	**3.7**	**–**

SIS 100 magnets

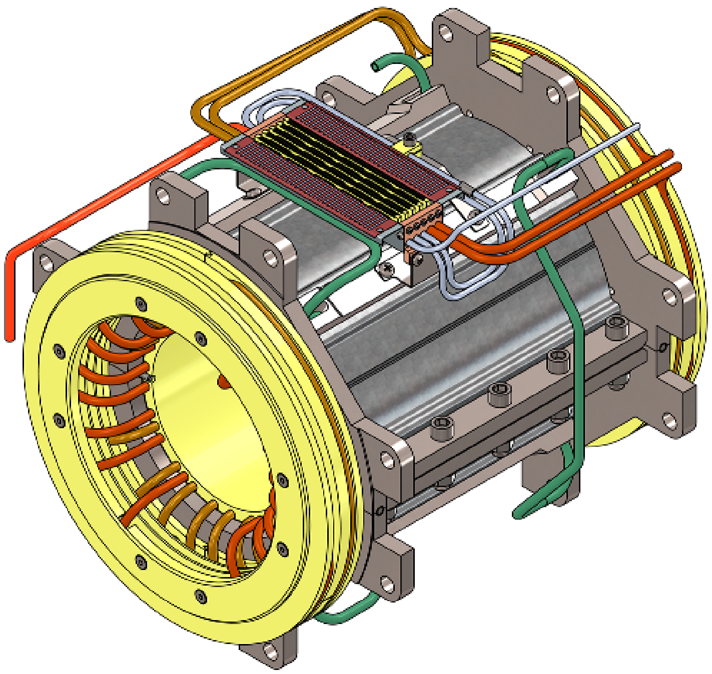
First of Serial SIS100 Quadrupole Units

- SF2B – F2: Quadrupole + Steerer Magnet

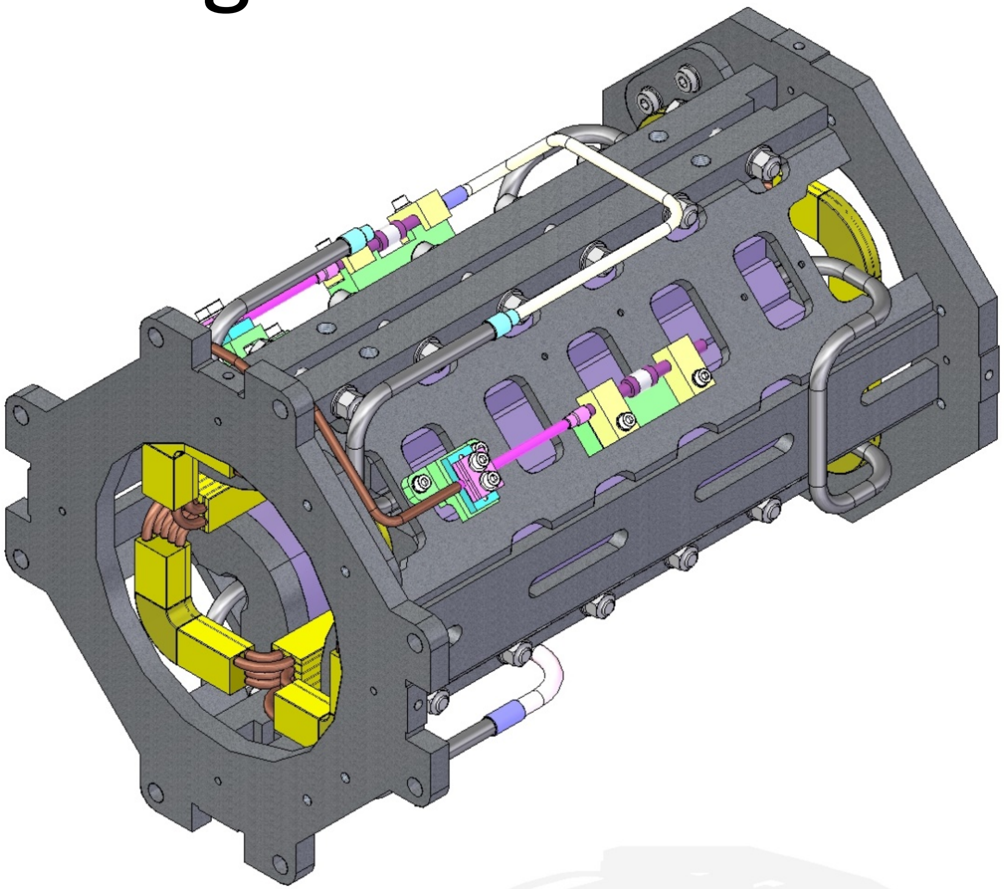
- VQD – D: Quadrupole + Chromaticity Sextupole Magnet

Sending of finished FoS SIS100 QP units from JINR to GSI is scheduled for the end of April 2017.

SIS 100 magnets



The SIS100 Steerer magnet.
Completion scheduled on Jan’2017



The SIS100 gamma transition jump quadrupole magnet.
Completion scheduled on Dec‘2016.

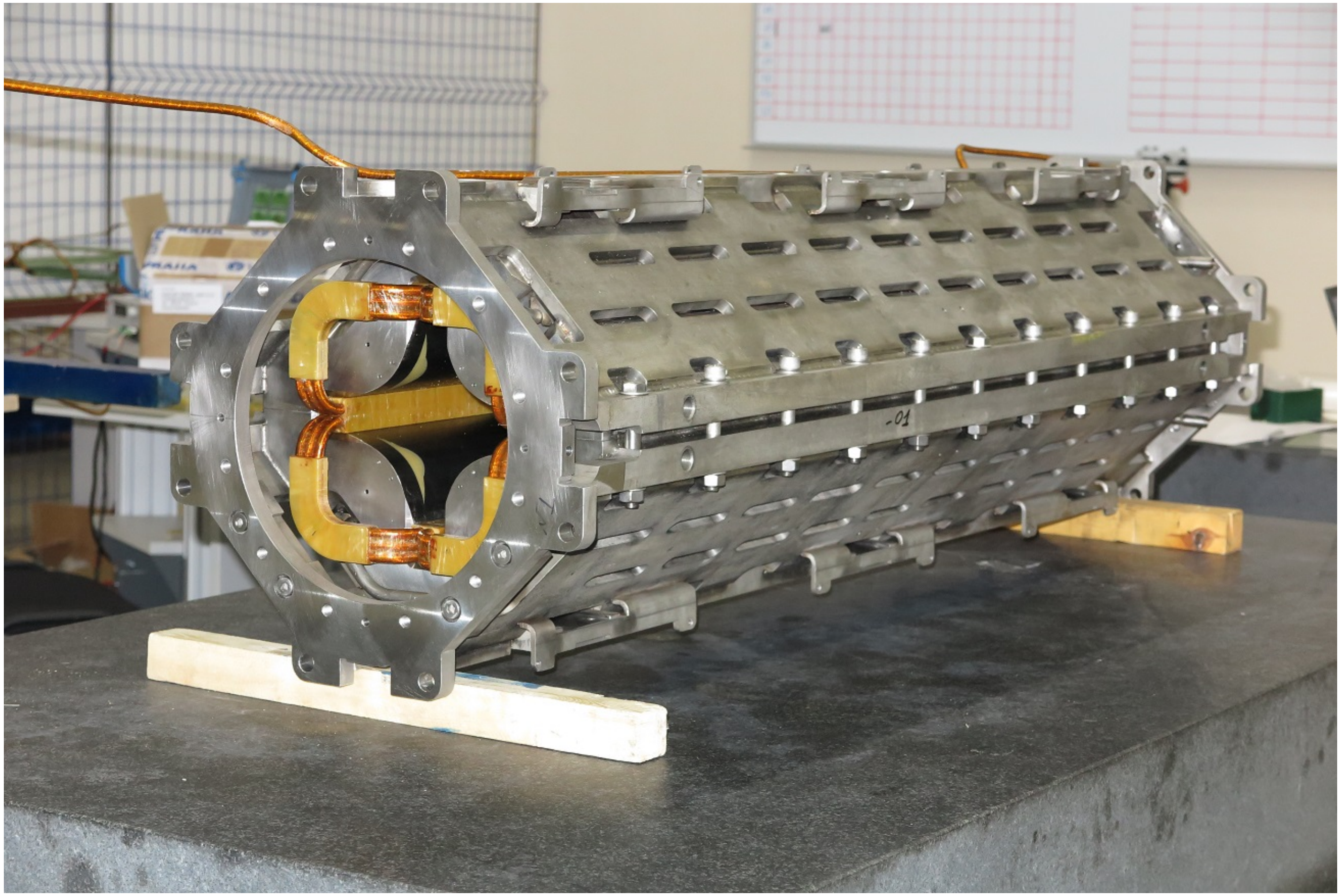
SIS 100 magnets

Manufacturing of the SIS 100 quadrupole coil

SIS 100 magnets

The SIS 100 quadrupole coil prepared to heat treatment in oven

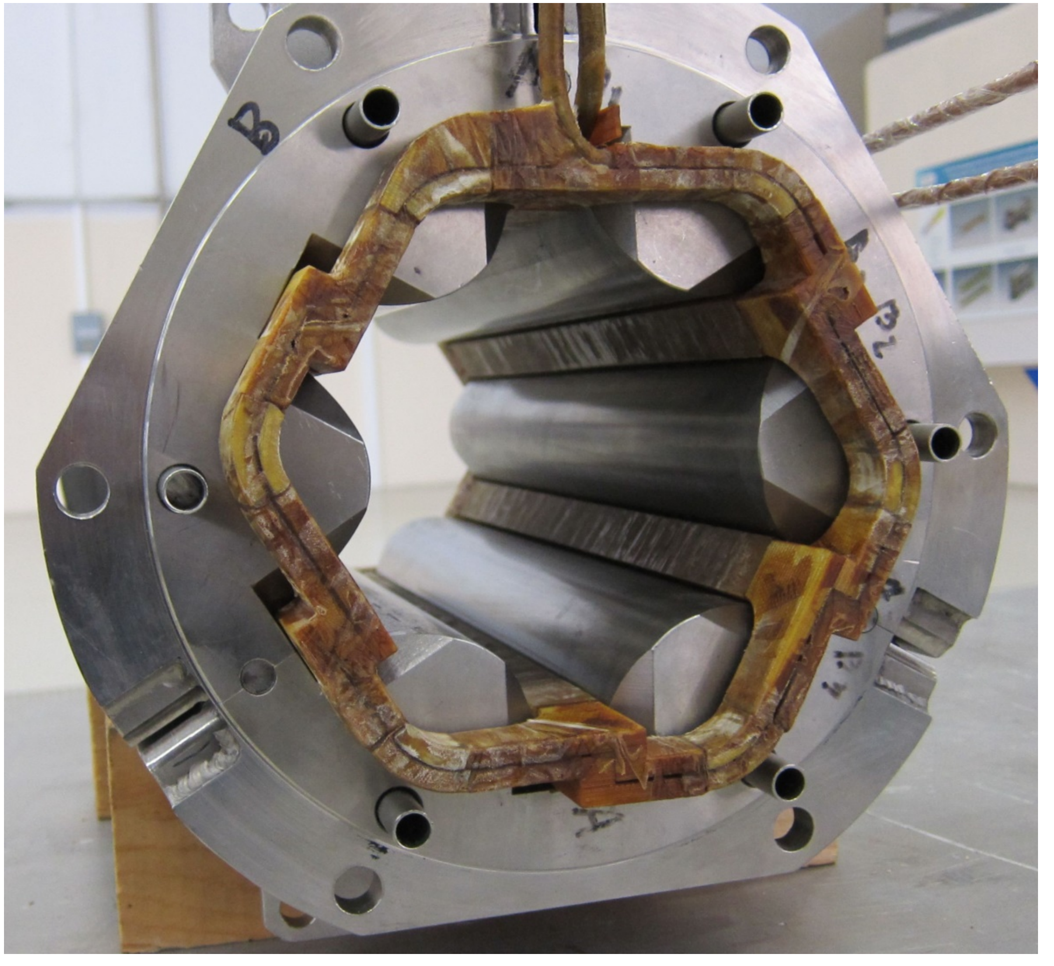
SIS 100 magnets



FoS SIS-100 quadrupole magnet.

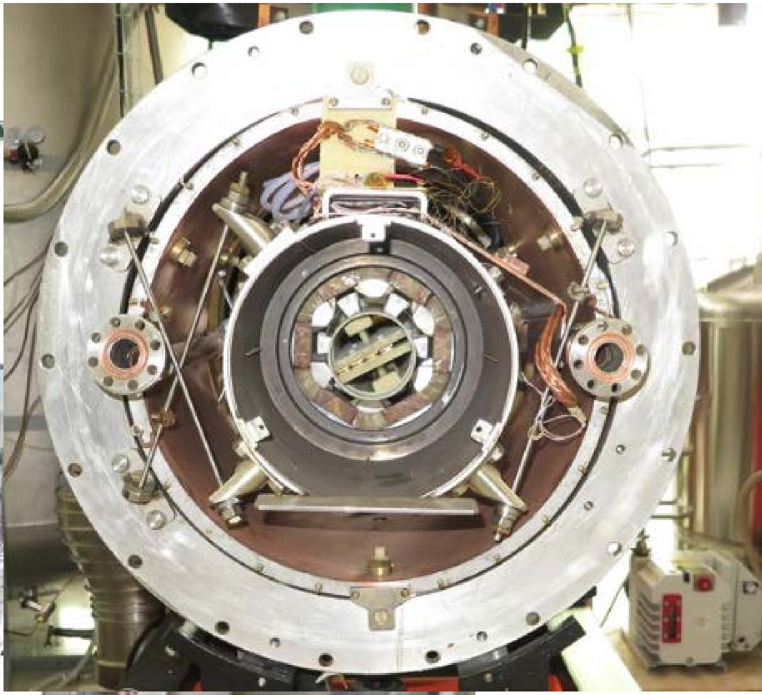
Second magnet will be done in December 2016

SIS 100 magnets



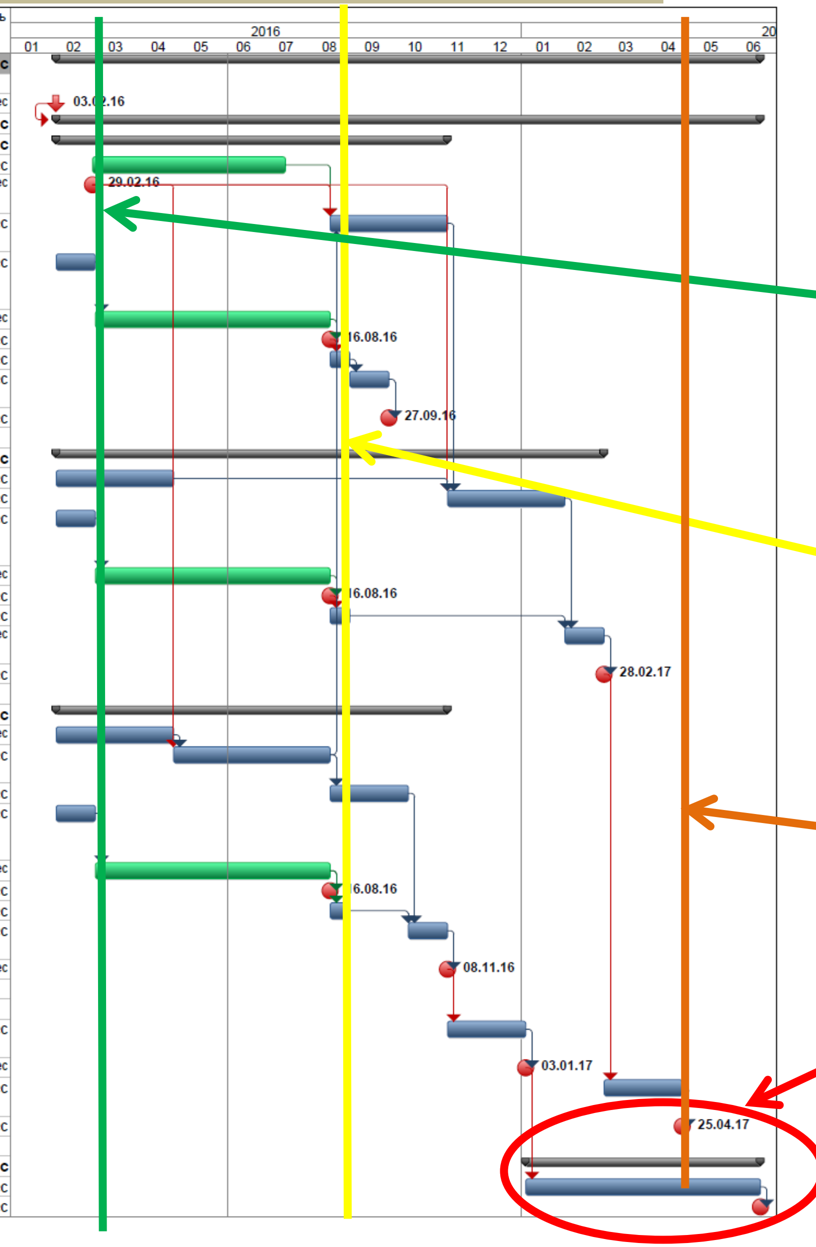
The SIS100 chromaticity sextupole magnet.
Completion scheduled on December 2016

Cold magnetic measurements of SIS100 sextupole



Production and test of FoS 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
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		
43	**Cryo-tests of FoS Units**	**6 мес**
44	Cryo-tests of FoS Units	6 мес
45	FoS Units ready FAT passed	0 мес



March 2016 Production start

Aug. 2016 Yoke & tooling complete

Apr. 2017 2 FoS QP Units fabricated

Cold tests scheduled (formally not yet agreed)

2016

Work packages

Phase	Validation criteria (Milestones given in Table 5Table 5 in Annex2)	Expected Delivery Date
Contract Conclusion	Exchange of signed Contract (M4)	Nov 2014 Mar 2015
Plan Review	Passed Plan Review Approval of detailed time schedule	Mar 2015 Nov 2015
First of Series (FoS)	Development of general views (M6) and FOS manufacturing drawings(M7) Approval of general views (M6) and FOS manufacturing drawings(M7)	Feb 2015 Nov 2015
First of Series (FoS)	FOS units shipment SAT Aa acceptance passed (M9)	July 2016 Apr 2017
Two units of series delivery	Factory Acceptance Test (FAT) passed (M9) Delivery and acceptance (SAT Aa passed)	Aug 2017 May 2018
Delivery of all units	FAT passed (M9) Delivery and acceptance (SAT Ab passed) of series units and spare parts (M10)	Start Aug 17 End Feb 20 Start May 18 End Jul 21
After warranty expiry	Free of functional faults	Delivery + 2 year

Nov 2015 → **Mar 2016**

Apr 2017 → **July 2017**

pre-scheduled date

actual execution time

planned execution time

Cold testing of magnets – must be contracted asap

SIS 100 magnets

- All the tooling for the production of the FOS SIS100 magnets yokes and coils was manufactured.
- Defocusing SIS100 FoS quadrupole magnet is made.
- The coil of the focusing SIS100 FoS quadrupole magnet and 90% of it yoke are made.
- In the final stage of manufacture are the yoke of the sextupole magnet 80% and the yoke of the steerer magnet 75%.
- Completion of the production of both FoS units is expected in April 2017, which corresponds to the scheduled date.
- Start of serial production of the SIS100 units will be given by FAIR / GSI after measuring the characteristics of the doublet, assembled from two FoS units.
- Test facility for cryogenic test of SC magnets ready for operation.
- Mass production and cold testing of all 166 units scheduled to run for 3 years.

To ensure compliance with such a busy schedule it is necessary to minimize the loss of time on the preparation of contracts between JINR and FAIR / GSI.

NICA booster magnets

SC Magnets for the NICA booster synchrotron:

- 40 Dipole Magnets
- 24 Doublet of the Quadrupole Lenses
- 32 Corrector Magnets

Completion of serial production and cryogenic tests of the magnets is scheduled on end of 2017.

NICA booster magnets

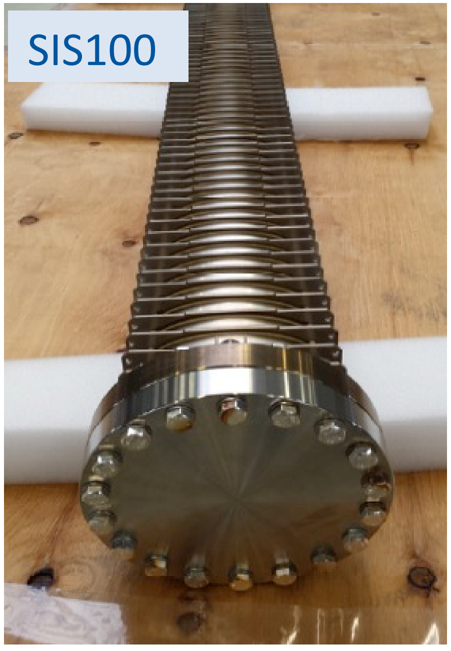
Status of Magnets production:

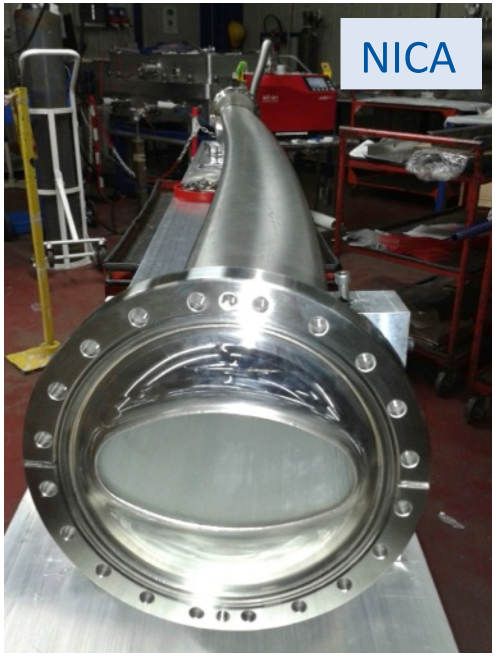
- Yoke of the Dipole Magnets – 24 or 60%
  Coil of the Dipole Magnets - 16 or 40%
- Yoke of the Quadrupole Magnets – 48 or 100%
  Coil of the Quadrupole Magnets - 38 or 79%
- Yoke of the Corrector Magnets – 8 or 25%
  Coil of the Corrector Magnets - 2 or 6%

Vacuum chambers for NICA, FAIR, HIAF:

Due to high B ramping rates (< 4-8 T/s), thin wall vacuum chambers are needed for all magnets to keep eddy currents at a tolerable level.
To withstand the atmospheric pressure the walls are supported:
- by ribs parallel to mag. fields lines (SIS, HIAF)
- by iron yoke inner surface (NICA)

Max.surface ➔ ideal mechanical contact for strength and heat contact for cooling





Elliptical curved (!) curvature radius 14m, 1mm wall, shape accuracy – μm's.
Cooled by the yoke, no LHe bath

NICA collider magnets

Two aperture SC Magnets for the NICA collider:

- 80 + 8 Dipole Magnets
- 86 + 12 Quadrupole Lenses
- 88 Corrector Magnets

Start of serial production and cryogenic tests of the magnets is scheduled for 2017.

- Production of SC magnets for SIS100 and NICA is on the way and cooperation is very fruitful. This is a huge deal for both.
- GSI/FAIR and FZJ (Group of Rolf Stassen + ZEA1) – our reliable partners. Prepared proposals for production of the RF structures for NICA SC, hope it will start very soon in frames of Protocol of scientific collaboration between JINR and FZJ.
- Collaboration on SC linac is very perspective and promising

We consider that participation of Germany (FAIR, FZJ, IAP, ILK, Industry) gives absolute synergy to both NICA and FAIR projects. All equipment will be ordered in Germany (or EU) and could be contributed as in-kind to NICA.

We together are creating Common European Research infrastructure for Heavy Ion Physics: FAIR & NICA

Thank you very much

Our success is inevitable!