JINR Experience in SC Magnets

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FCC Week, April 10-15, 2016, Roma, Italy

Outline

- Introductory remarks
- Fast-cycled SC magnets, Nuclotron, NICA
- SIS100 at GSI, improved Nuclotron design
- Fast-cycled 4-6 T SC magnets
- Pulsed 20-60 T single-turn dipole
- FCC design issues
- Summary

10 GeV proton synchrotron – “SYNCHROPHASOTRON”

- ***Weak focusing synchrotron***
- ***Put into operation – 1957***
- ***The magnet weight - 36 000 t***
- ***Supply power - 140 MBA***
- ***Perimeter -210 m***

The accelerator was modernized in the 70’s and used as relativistic light ion (up to sulphur) and polarized deuterons accelerator up to 2002.

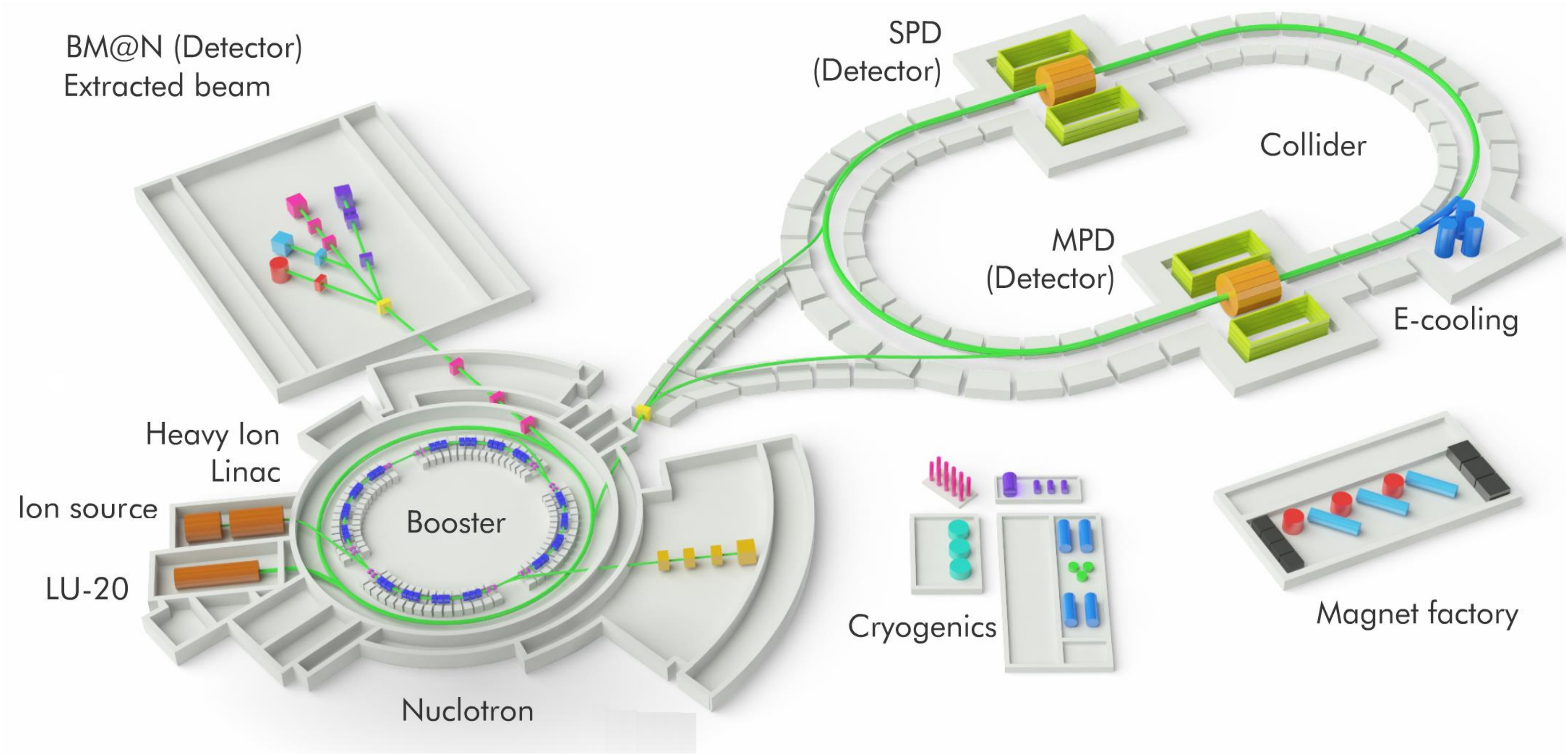
Nuclotron: view & some parameters

- ***Strong focusing synchrotron***
- ***Put into operation – 1993***
- ***Energy – 6 GeV/u for Z/A=1/2***

- Circumference – 251.5 m;
- 96 dipoles, 64 quadrupoles;
- Beam pipe: 55x110 mm;
- **SC slow extraction system**:

Beam species: **p** to **Xe**, polarized deuterons as well

NICA (Nuclotron based Ion Collider fAcility)



*Development of the Nuclotron facility and construction of collider of ions from p to Au, **polarized protons and deuterons** (up to $\sqrt{S_{NN}}$= **11** GeV (Au^{79+}) and =**27** GeV (p)*

Manufacturing plan

		2015				2016				2017				2018				2019				2020			
		I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Booster																									
dipoles	**40+3**																								
quadrupoles	**48+6**																								
multipole correctors	**40+4**																								
Collider																									
dipol																									
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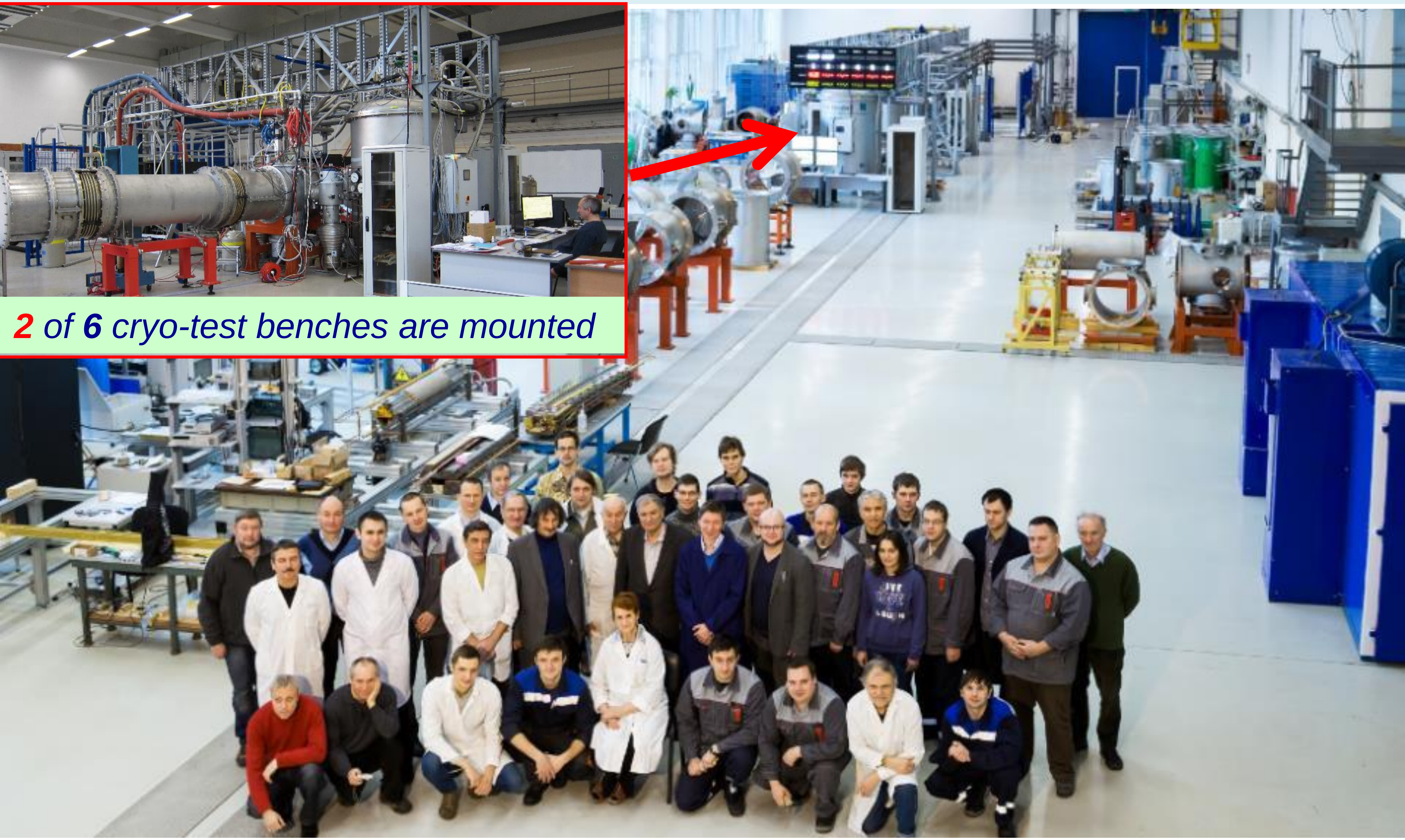
multipole correctors	**12**																								

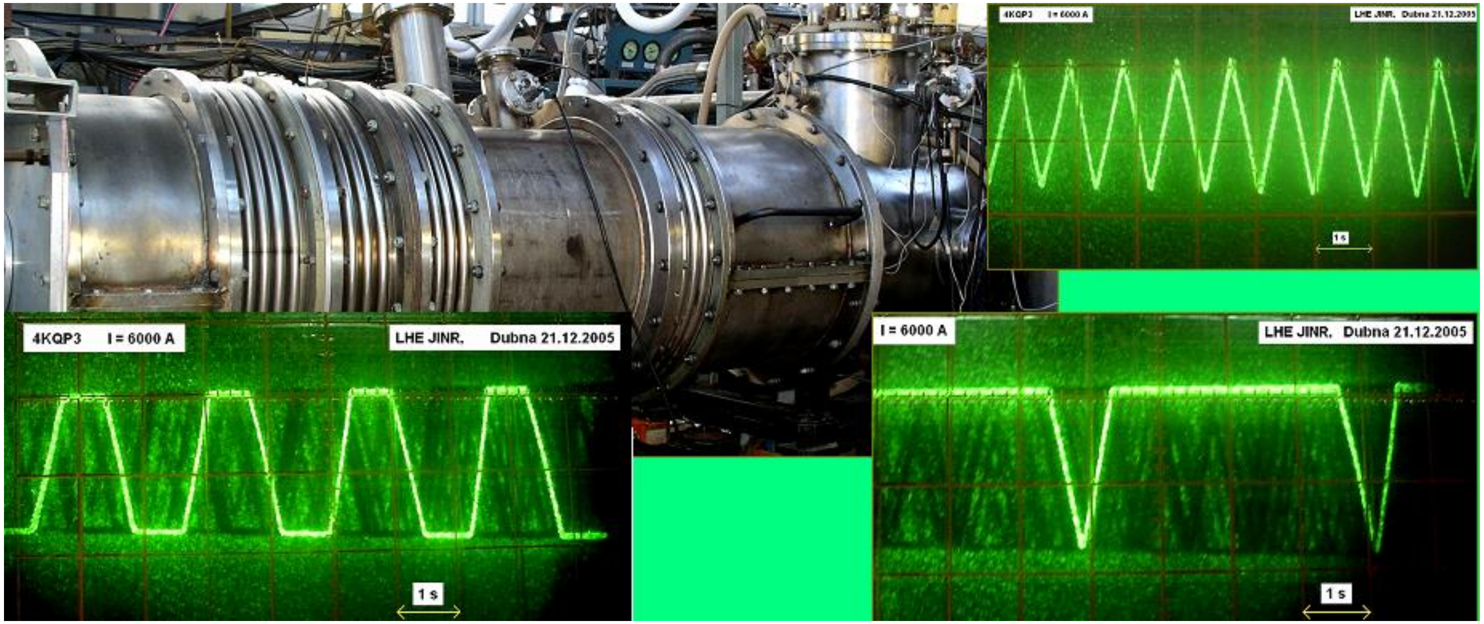
SC Magnets for Booster, Collider & SIS-100/FAIR workshop at VBLHEP JINR *(bld. 217)*



2 *of* ***6*** *cryo-test benches are mounted*

Nuclotron magnet operation modes

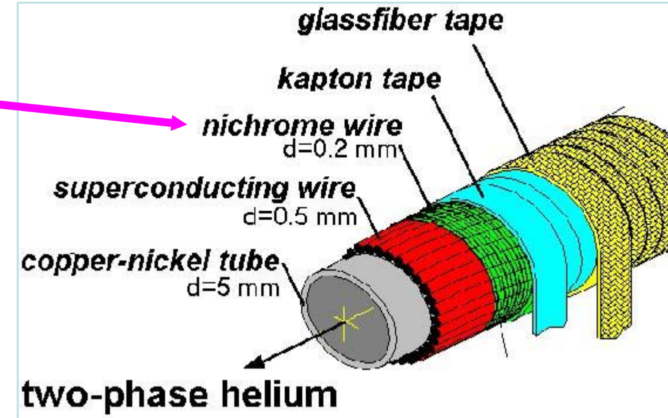
- Fast cycled and quasi- continues operation modes
- Multi flat tops at ramp up and ramp down as well

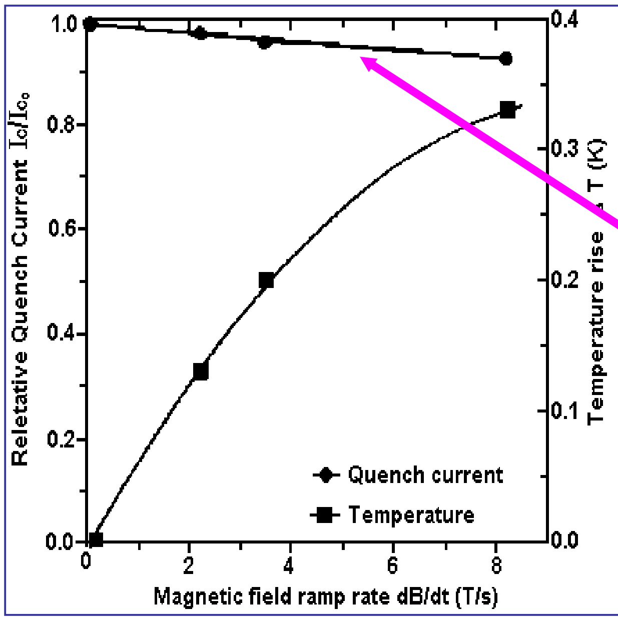


Beam duty factor can exceed 95%, if necessary

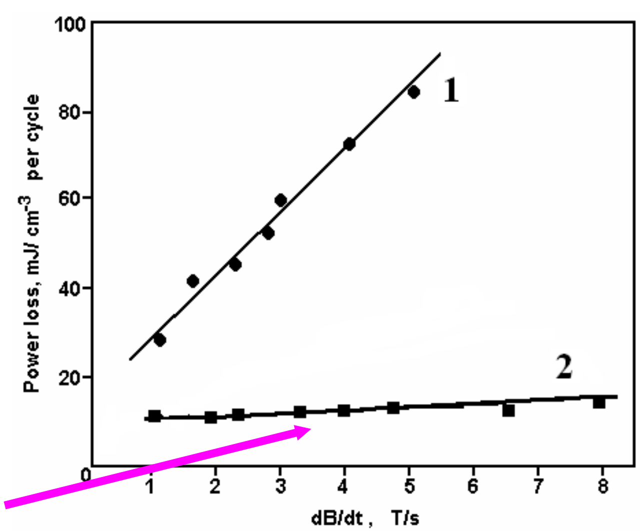
Dubna hollow SC cable

Basic idea: SC-strands pressed to cooling tube with wire wound.



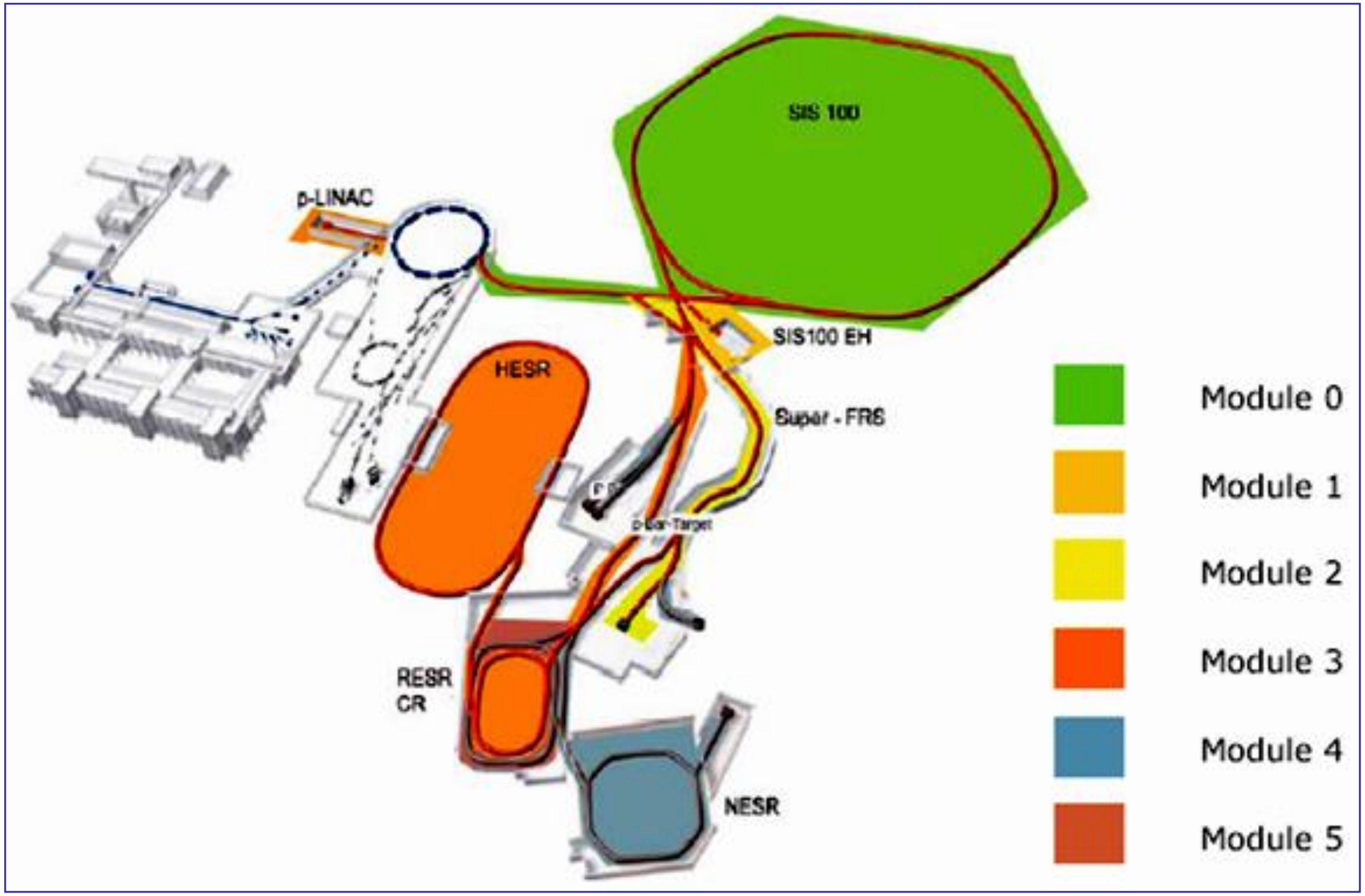


Weak degradation of critical current at fast ramp (~ 5 % @ dB/dt = 4 T/s)



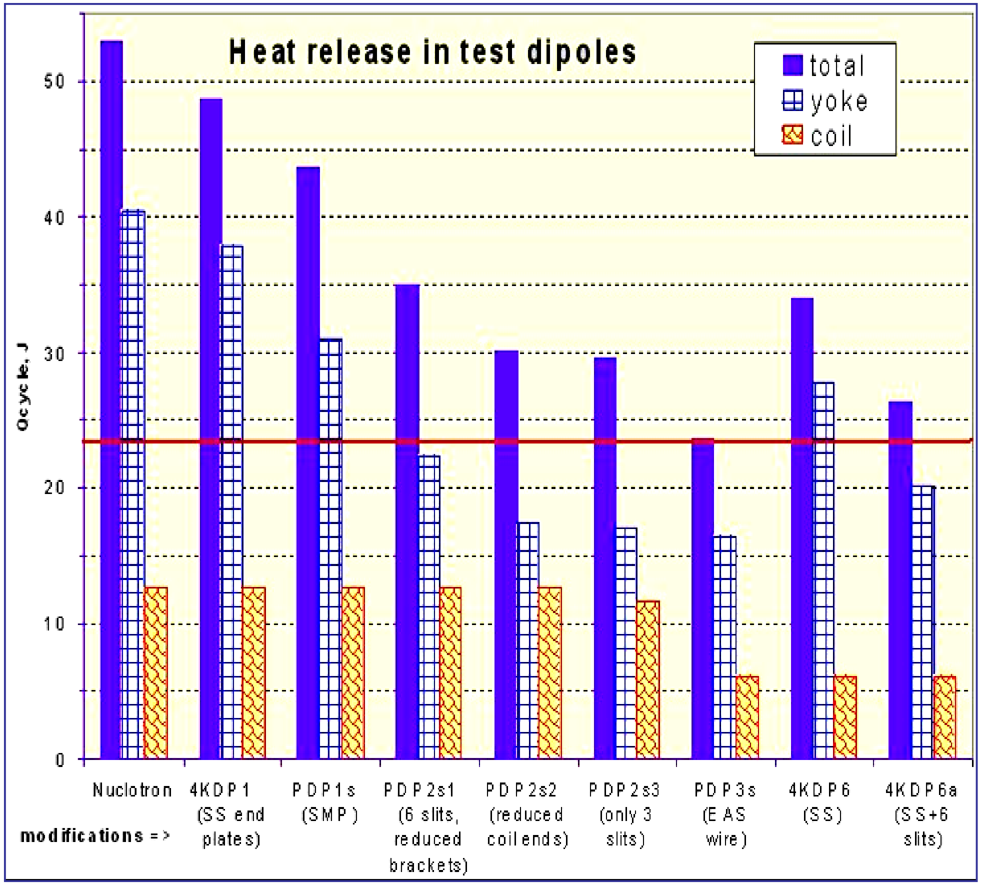
Weak dependence of the eddy current loss on the magnetic field ramp (2)

FAIR at GSI – new facility for antiproton and ion research



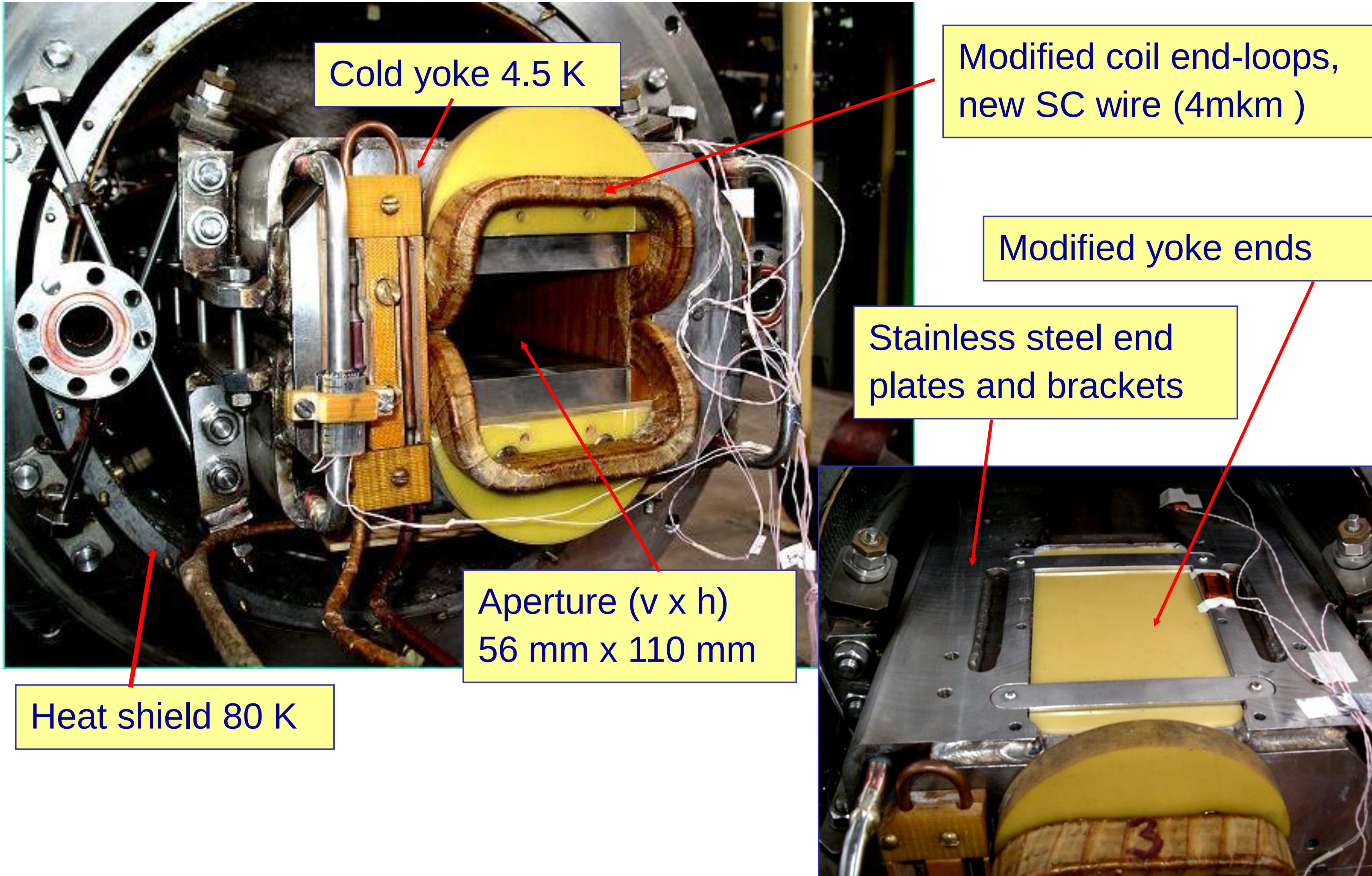
Improvement of original Nuclotron magnets

JINR/GSI: SIS100 (Y2000/2010): 2T, 4 T/s, 1 Hz,
larger sizes, less AC losses, better mechanical stability especially important at cycled operation for a long time



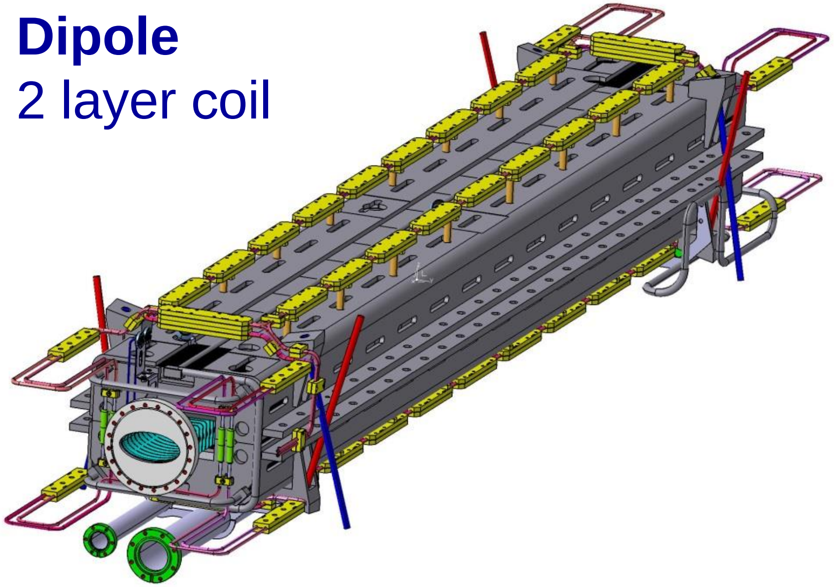
Alexander D. Kovalenko, FCC Week, Roma 11-16 April, 2016

SIS100 model dipole



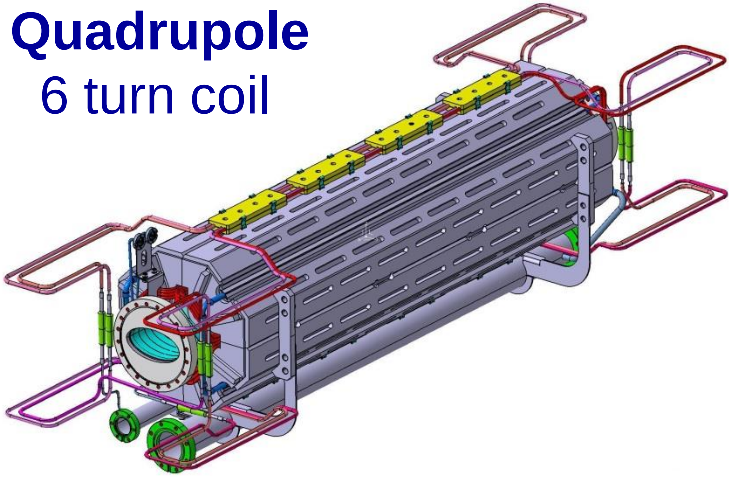
SIS100 full size prototypes

Dipole
2 layer coil



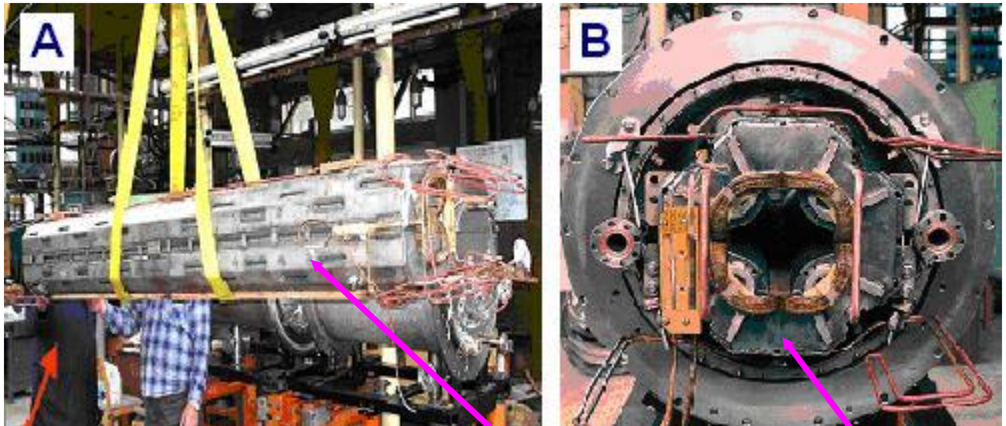
Straight dipole	FBTR design
B x $L_{effective}$ [Tm]	5.818
B [T]	2.11
$L_{effective}$ [m]	2.756
L_{yoke} [m]	2.696
Bending angle [deg]	3 ?
Rad.of curvature [m]	47.368
Aperture (h x v) [mm]	130 x 60

Quadrupole
6 turn coil



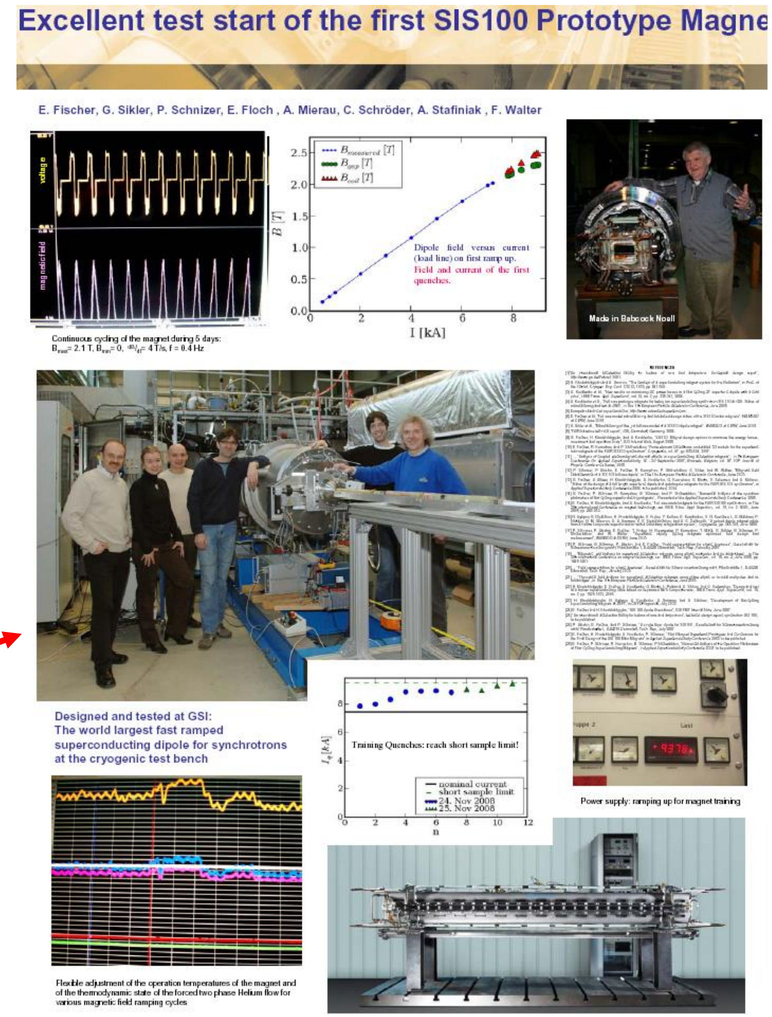
Quadrupole	FBTR design
B' x $L_{effective}$ [T]	35
B' [T/m]	32
$L_{effective}$ [m]	1.1
Estimated L_{yoke} [m]	1
Aperture (h x v) [mm]	135 x 65

Pilot Full Size SIS100 Dipoles and Quad



Full size SIS100 Dipole (A) and Quad (B) Manufactured and tested at JINR.

Full size SIS100 Dipole was in parallel manufactured BNG was tested at GSI



The Collaboration is continuing: SIS100 quadrupole modules will be manufactured at Dubna magnet facility

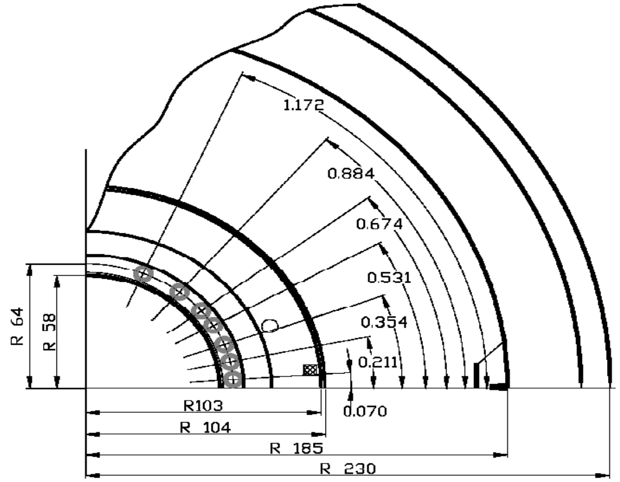
FAST RAMPED 4-6 T FIELD DIPOLE

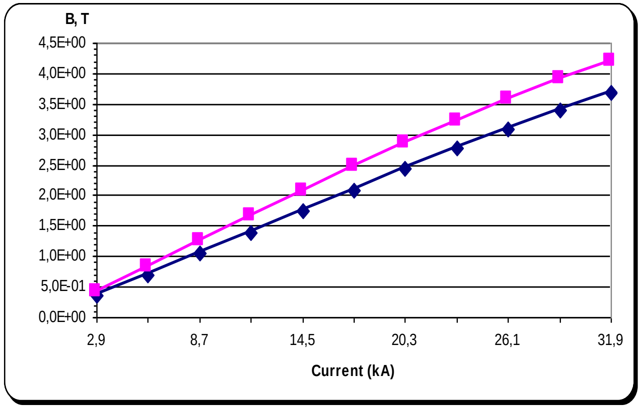
General remarks:

- **hollow superconducting cable can be applied to the design and construction of a fast-ramped 4...6 T dipoles.**
- **"cosineΘ" style of the magnets (dipoles and quadrupoles) should be used in this case.**

"Cable Design and Related Issues in a Fast-Cycling Superconducting Magnets", Workshop on Accelerator Magnet Superconductors, WAMS2004, Archamps, March 22-24, 2004.

FAST RAMPED 4T DIPOLE

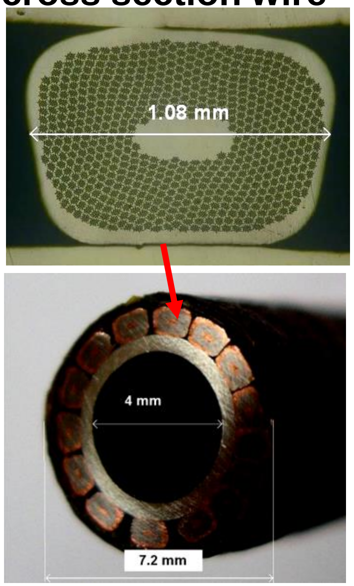




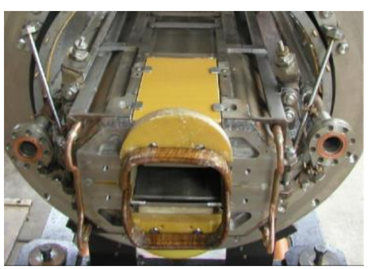
- APERTURE: 100-110 mm;
- SINGLE LAYER COIL (12-14 turns)
- HOLLOW NbTi CABLE MADE of KEYSTONE WIRES;
- THE COLD MASS LIMITED TO THE COIL AND COLLAR;
- THE YOKE at T = 50- 80 K;
- TWO-PHASE HELIUM FLOW (mass flow rate of 2 g/s);
- OPERATING CURRENT OF 30 kA;
- THE FIELD RAMP OF 4 T/s;

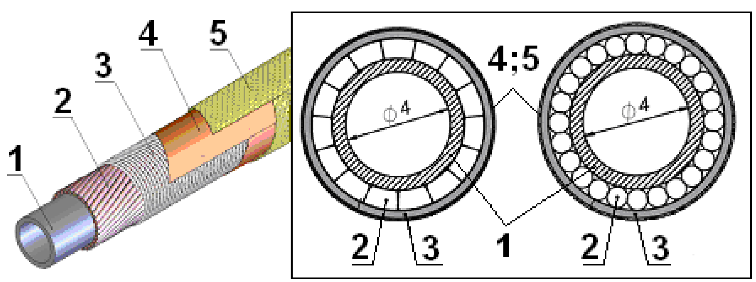
HOLLOW SC CABLE & SINGLE-LAYER SC DIPOLE

NbTi composite
KEYSTONE
cross section wire



Characteristics	Units	Nuclotron	Keystoned
CABLE			
Cooling channel diameter	mm	4	4
Cu-Ni tube diameter	mm	5	5
Number of strands		31	15
Twist pitch of strands	mm	47	65
Ni-Cr wire diameter	mm	0.2	0.3
Ni-Cr wire binding pitch	mm	0.4	0.4
Cable diameter with insulation	mm	7	7.34
Current density in the winding	A/mm^2	122.4	219.1

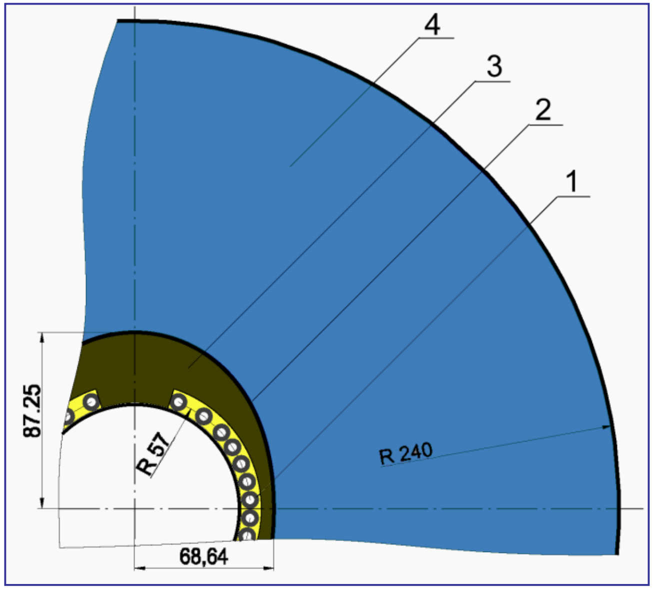


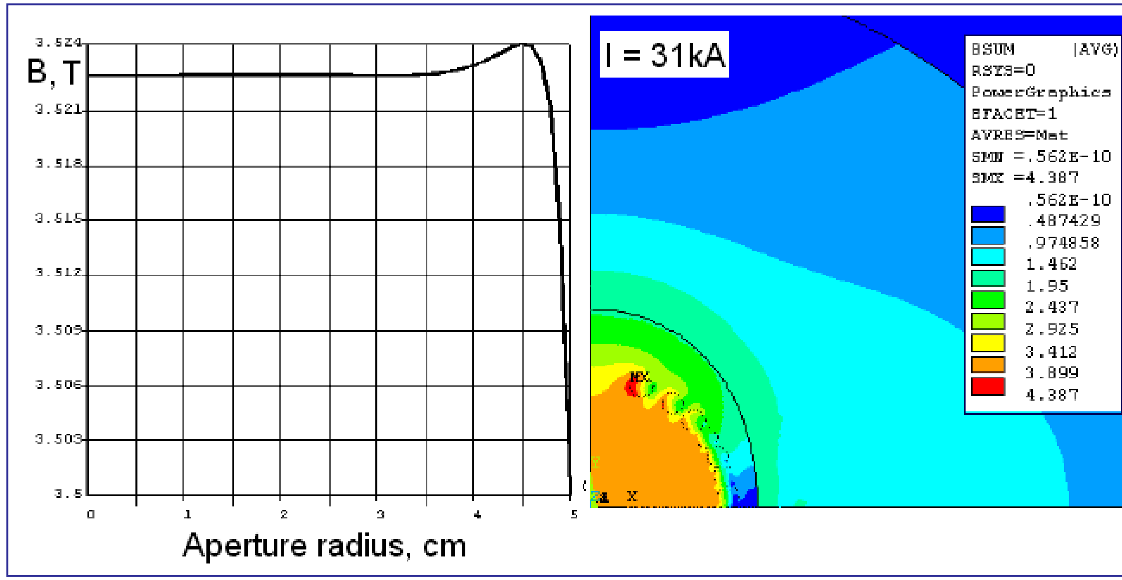


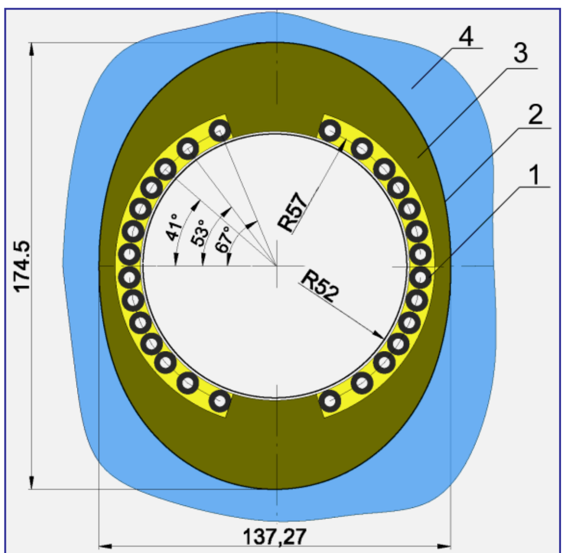
presented at ASC2004, Jacksonville, USA

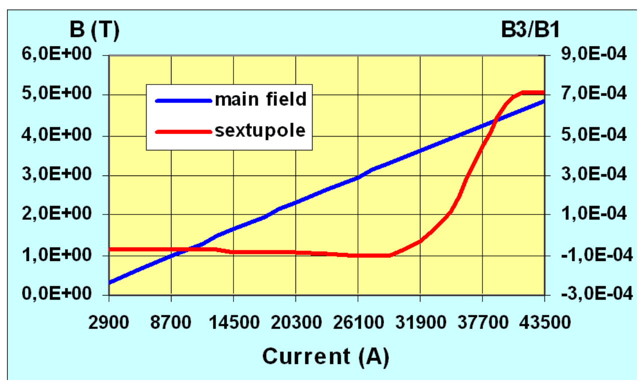
SINGLE LAYER COIL DIPOLE

4 T, 2-4 T/s Cos(theta)-style dipole







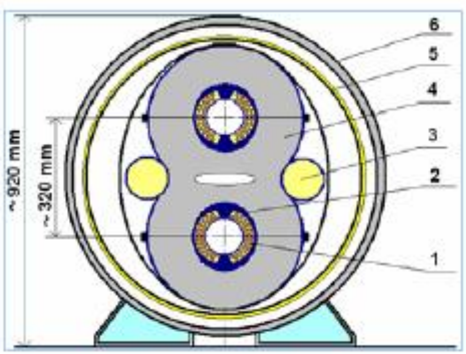


Improvement of the field quality by means of the yoke boundary profile and the coil turns azimuth position

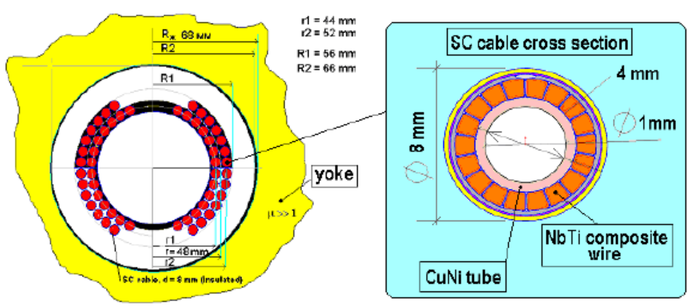
Design of a Twin-Aperture 4 T Curved Dipole Based on High Current Hollow Superconducting Cables for the NICA Collider at JINR

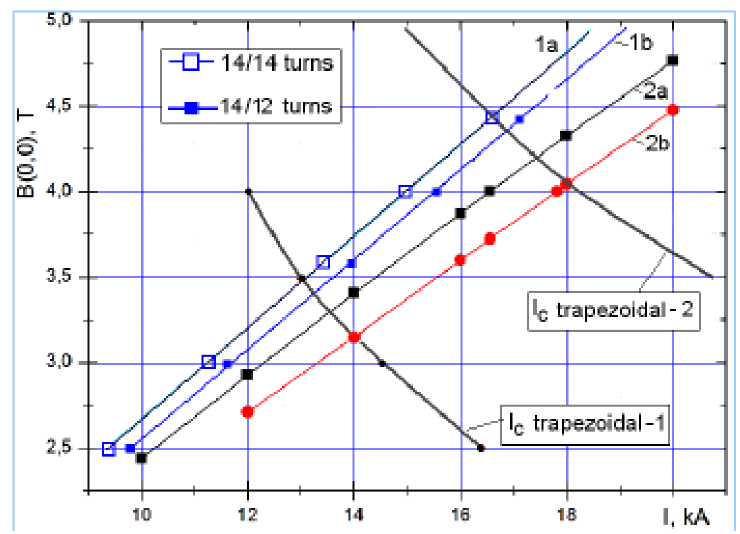
9th European Conference on Applied Superconductivity (EUCAS 09) IOP Publishing
Journal of Physics: Conference Series **234** (2010) 032033 doi:10.1088/1742-6596/234/3/032033

A Kovalenko[1], A. Bychkov[1], A. Gromov[1], E. Fischer[2], H. Khodzhibagiyan[1], A. Shabunov[1], P. Schnizer[2], A. Starikov[1], G. Titova[1]



- ❖ Two top-on-top dipoles, double-layer coil made of a hollow cable operating at 4.5 K, supply current up to 17 kA, the field ramp up to 1 T/s

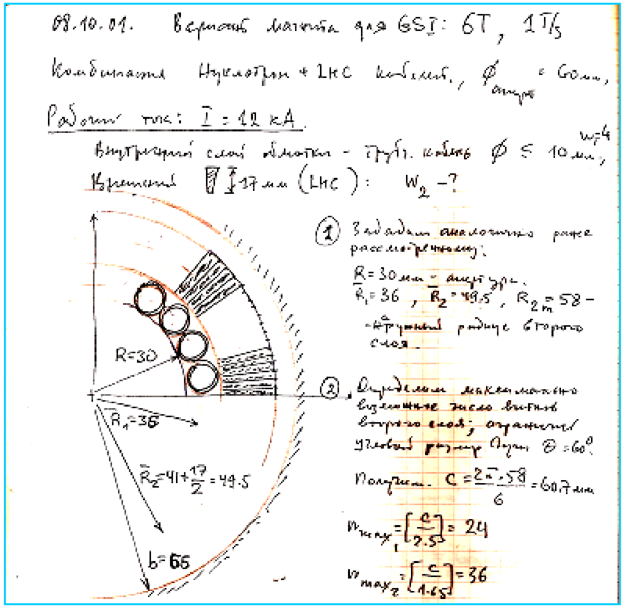




- ❖ The cable made of a wire of trapezoidal cross section

FAST RAMPED DIPOLE: B > 7 T

Aimed at the SPS or NICA future upgrade

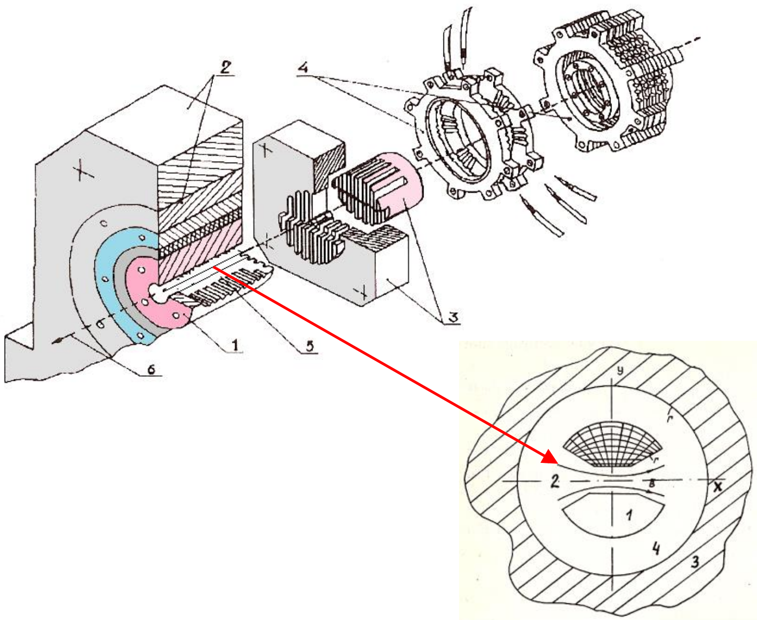


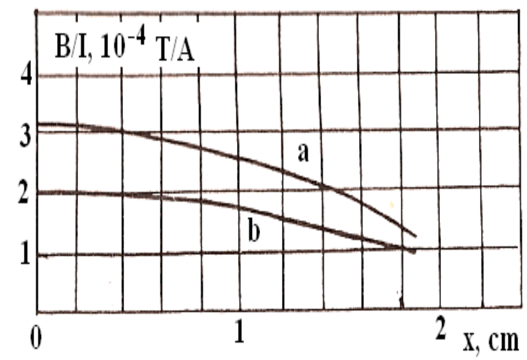
- ❖ double-layer coil consisted of a hollow cable (inner layer) and the Rutherford one (outer layer) exited with different ramps.
- ❖ R&D work on optimization of different aspects (lattice, magnet sizes, power supply, cooling scheme, etc.) are needed.

- ❖ Co-existence of the two independent coils could be useful in the case of organization of successive excitation of a double aperture magnet used for different particles.

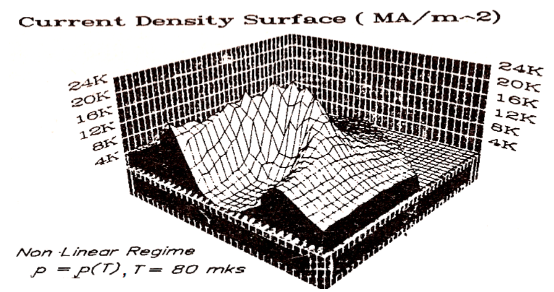
20-70 T, pulsed single-turn dipole

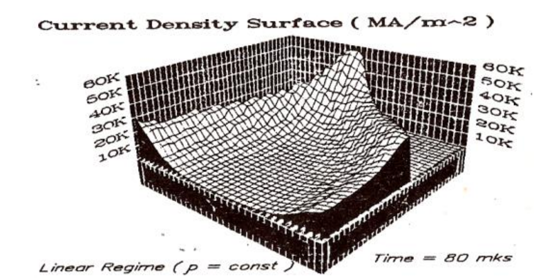
Was designed in the 80’s to expose nuclear emulsion stacks to particle beam at external magnetic field that gives better accuracy of the momentum measurements. SLON-setup was constructed and tested.





Effect of nonlinear difusion of the magnetic field (B ≳ 70 T): a. t = 40 mks; b. t = 80 mks

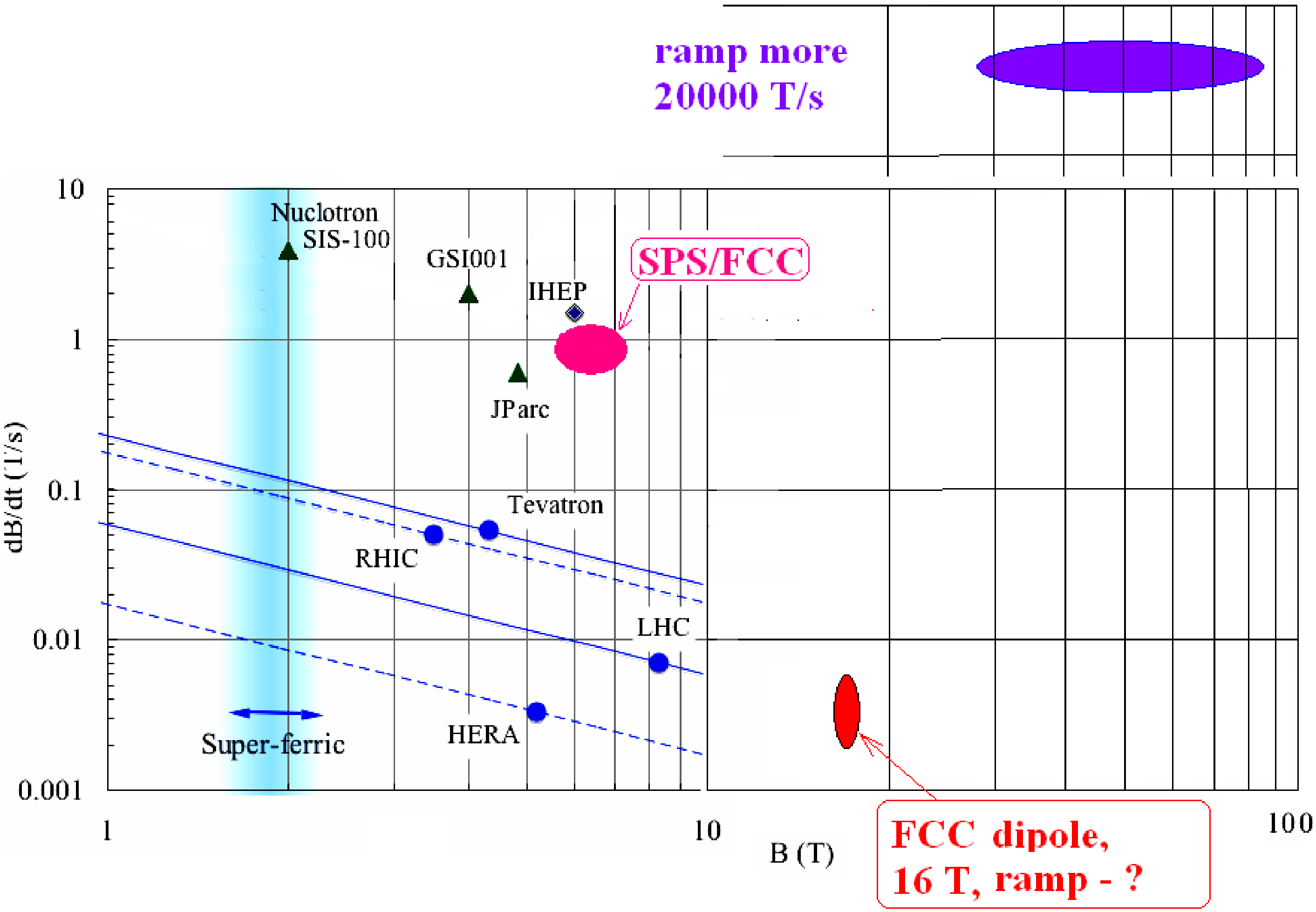




The field and stress analysis were performed. Long term stability of the design approach at the field level of 55-60 T was calculated.

Possible use: beam kicker system, beam deflector at the transfer lines. Design parameters: Bl ~ 50 Tm/m

Magnet design areas



Summary

- R&D work on superconducting proton and ion synchrotrons is continuing at the Laboratory since 1970.
- Several options of SC magnets covering the parameters range of B = (1.5 – 4.5 T), dB/dt = (1 – 4 T)/s, pulse repetition rate f = 0.5 – 5 Hz were proposed and studied.
- The 6 AGeV ion synchrotron based on a fast - cycled SC magnets was constructed, it operates since March 1993.
- The Nuclotron SC systems are based on technological advances.
- Pulsed 20-70 T single-turn dipole was design and tested.
- We analyze some new solutions that could be used in the FCC, in particular: design of a curved 5-7 T dipoles ramped at least at 0.5 T/s, consideration of a 1.5 -3TeV proton bunch extraction schemes, some aspects of a beam transportation to the main FCC ring.


THANK YOU
FOR YOUR ATTANTION