Super-Ferric Magnet R&D at Dubna and GSI

JLEIC Collaboration Meeting, March 29-31, 2016, Newport News, Virginia, USA

Outline

- Introductory remarks
- Dubna fast-cycled SC magnets
- Nuclotron - SC ion synchrotron
- SIS100/SIS300 at GSI in Darmstadt
- New facility NICA at Dubna
- Summary
- Future design issues

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 was used as relativistic light ion (up to sulphur) and polarized deuteron accelerator up to 2002.

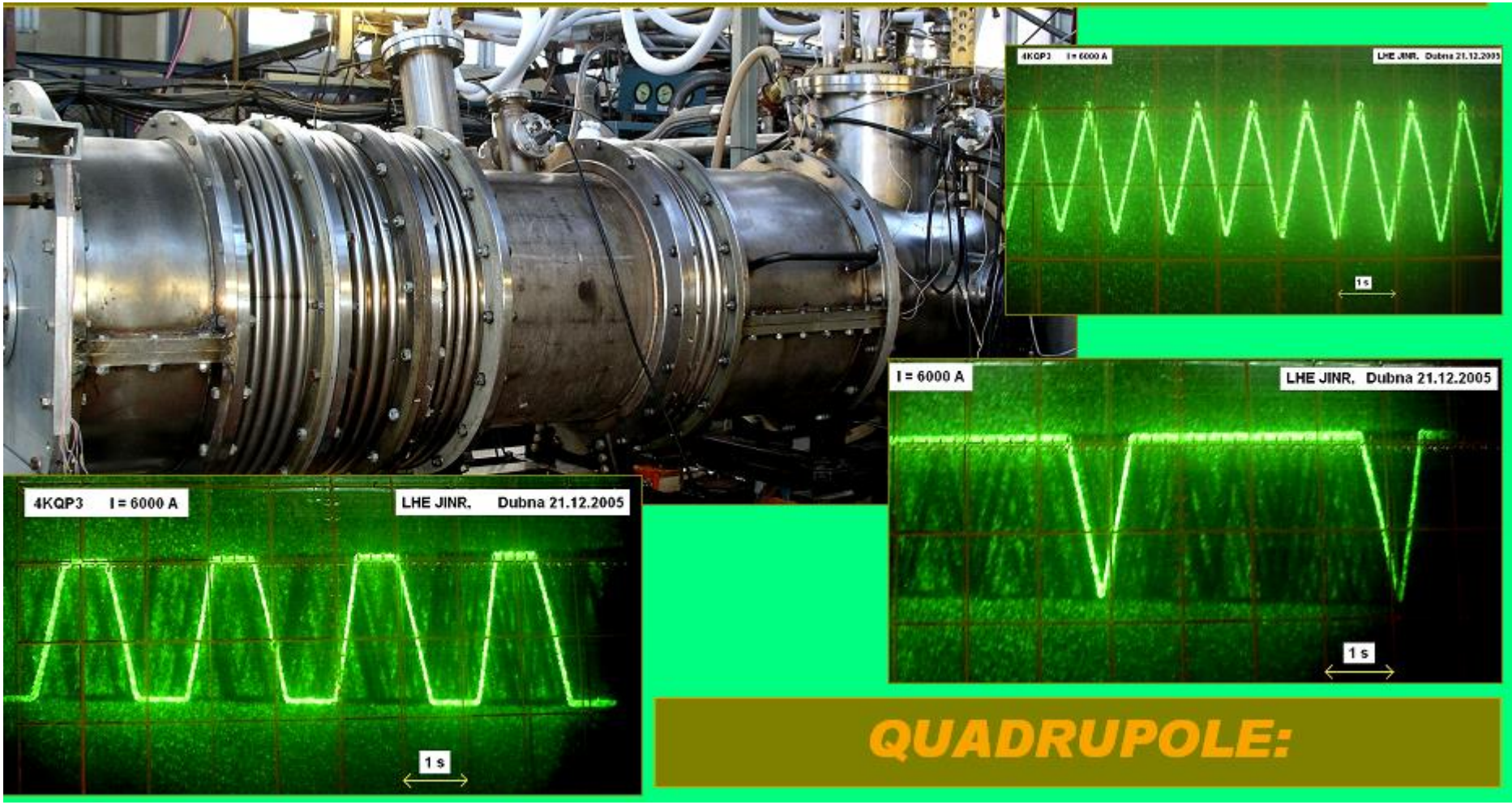
Nuclotron: view & some parameters

- ***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;
- Accelerated and extracted particles:

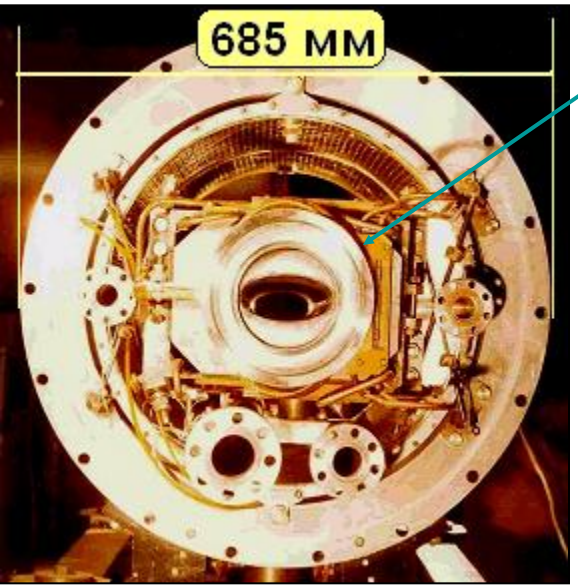
from **p** to **Xe, polarized deuterons as well**

Nuclotron magnets operation modes

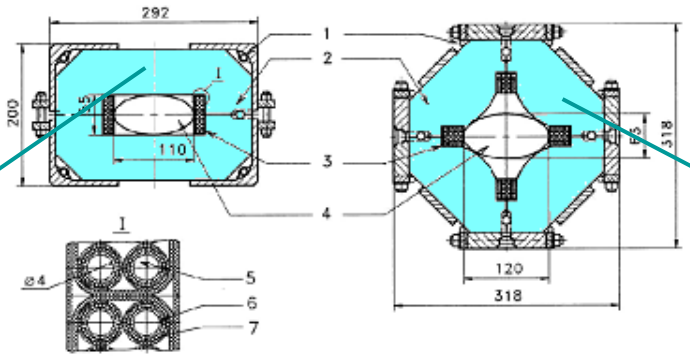


Beam duty factor can exceed 95%, if necessary

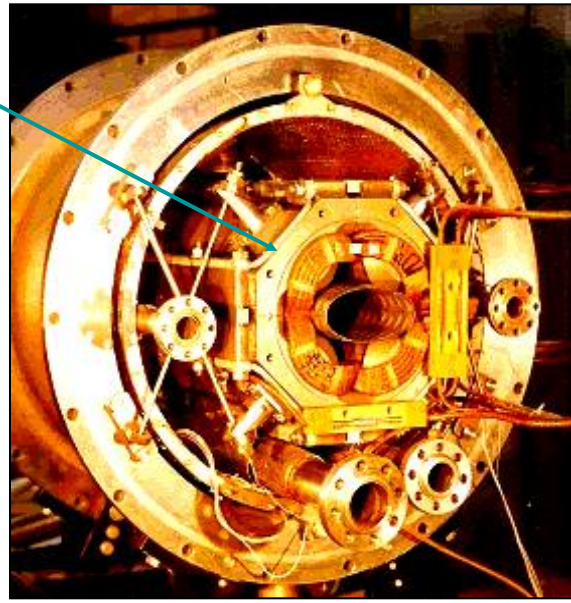
Nuclotron Superferric Magnets



2 T, 4 T/s, 1 Hz dipole



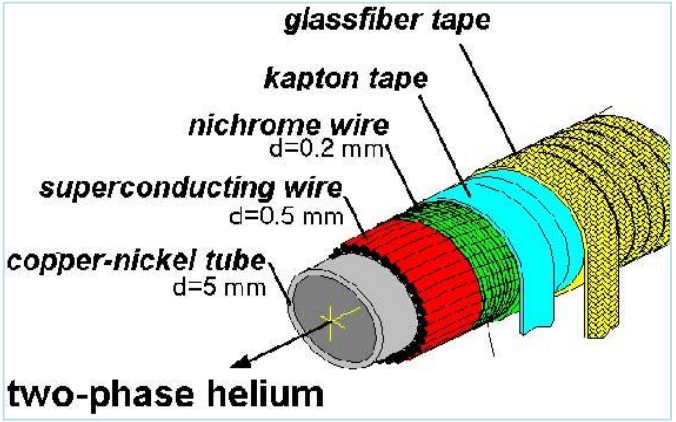
- **Cold iron (T = 4.5 K)**
- **Hollow SC cable**
- **Two-phase helium**



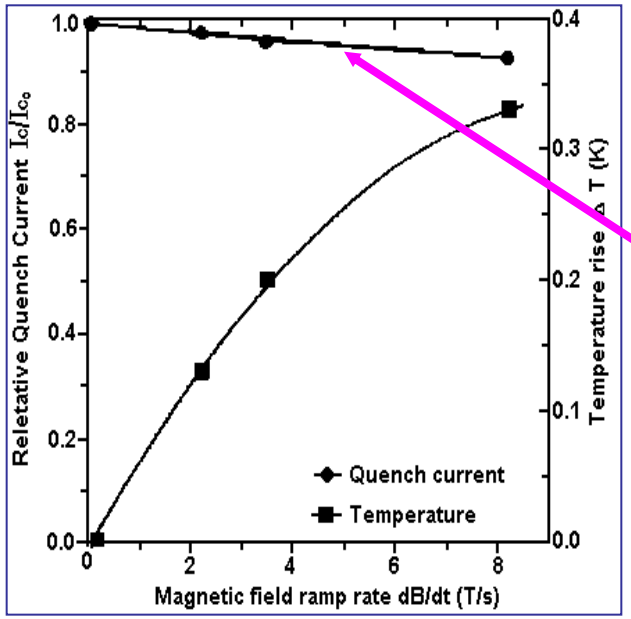
34 T/m, 68 T/m s, quad

Dubna hollow SC cable

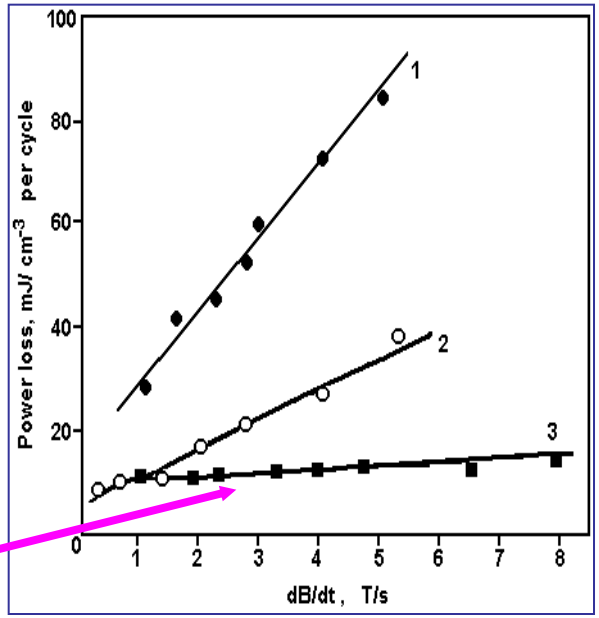
Basic idea: SC-strands don't soldered to the tube but pressed with wire wound.



inventor
A.Smirnov

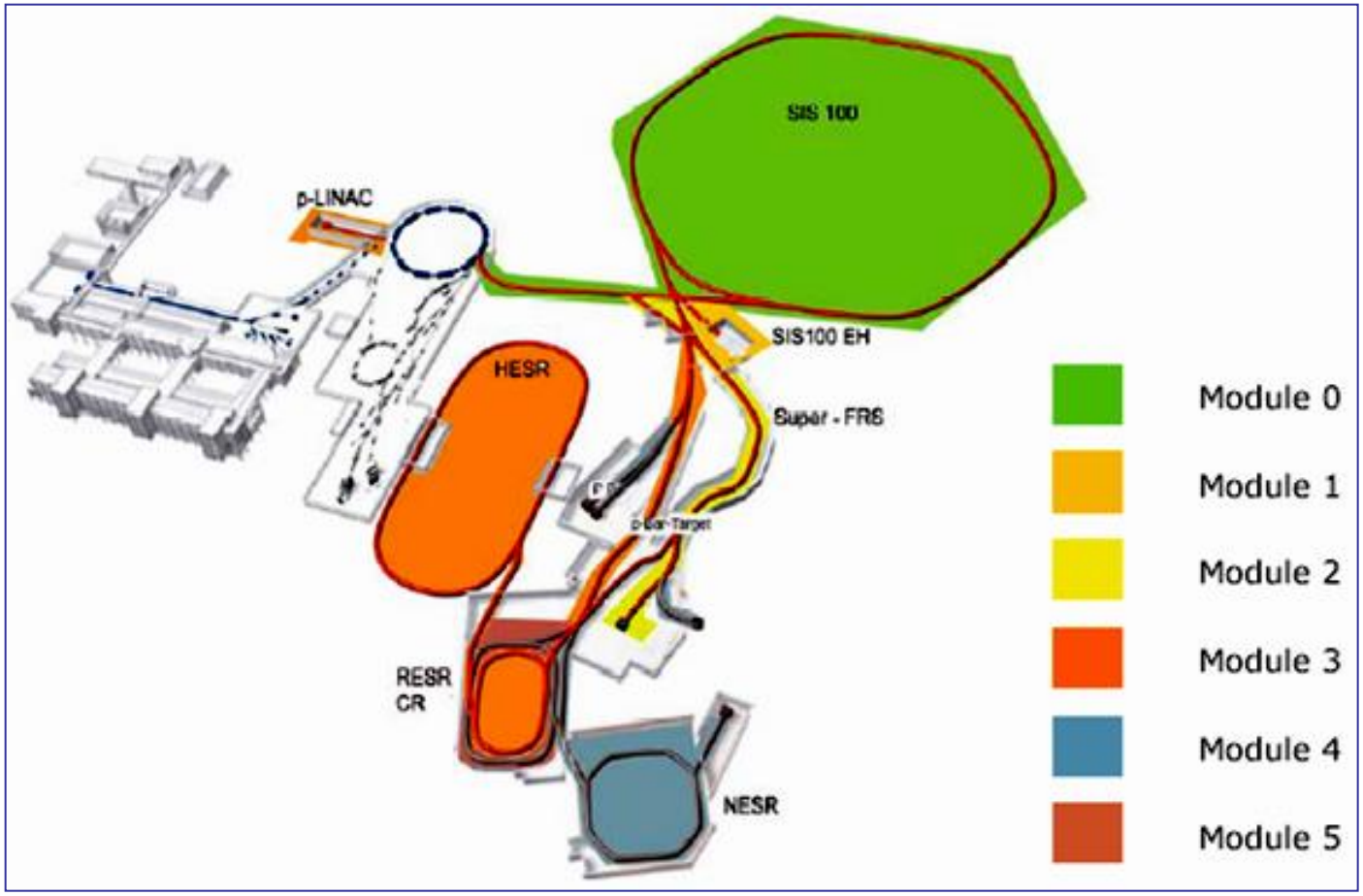


Weak degradation of critical current at fast ramp (~ 5 % @ dB/dt = 4 T/s)



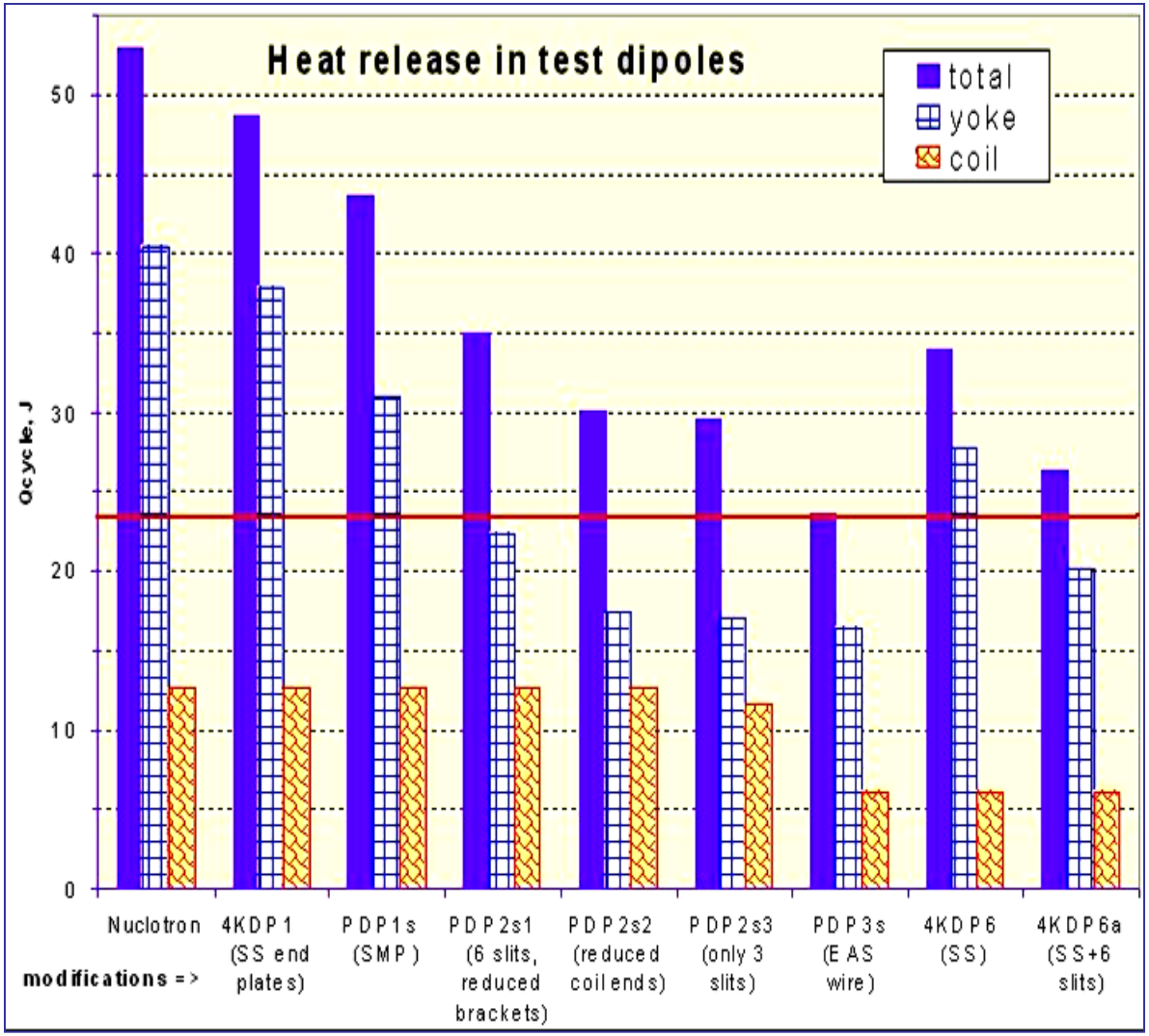
Weak dependence of the eddy current loss on the magnetic field ramp (3)

FAIR at GSI – new facility for antiproton and ion research

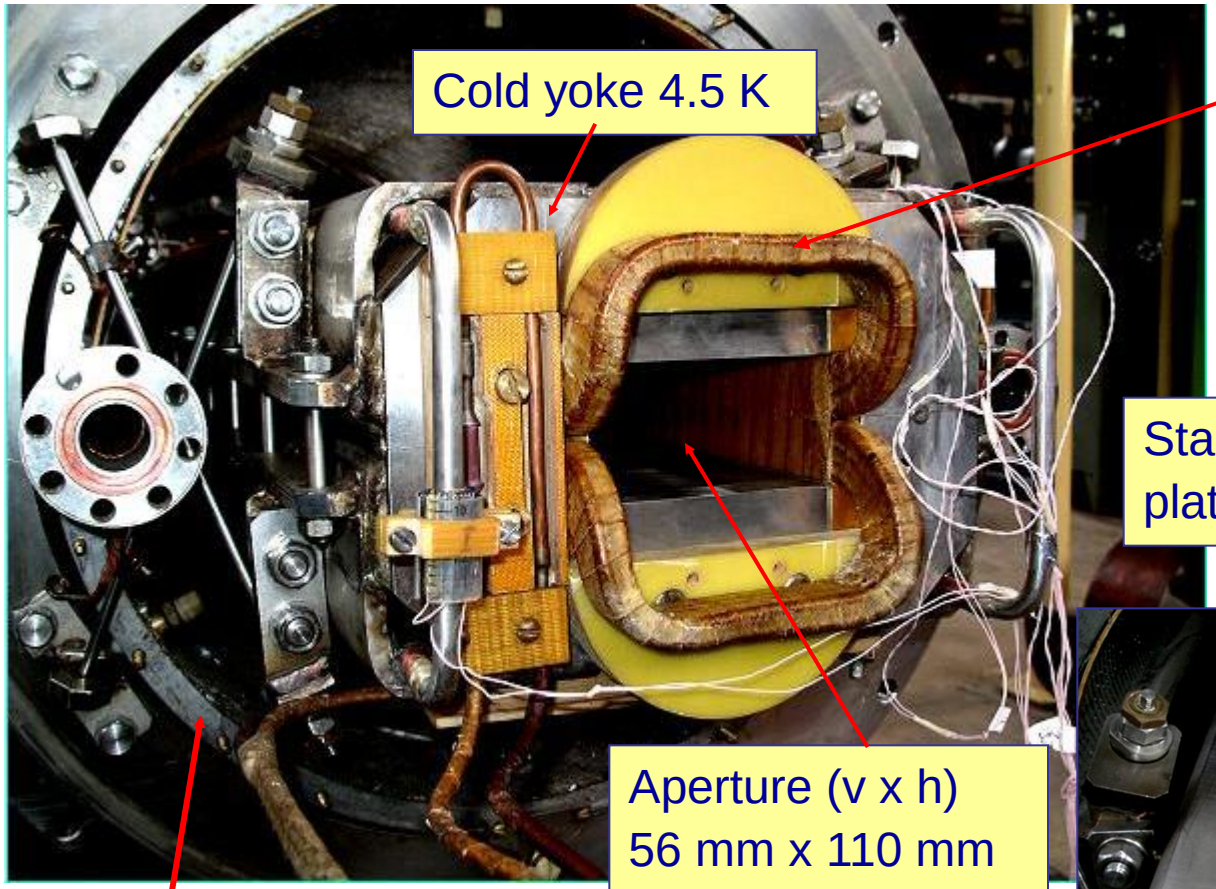


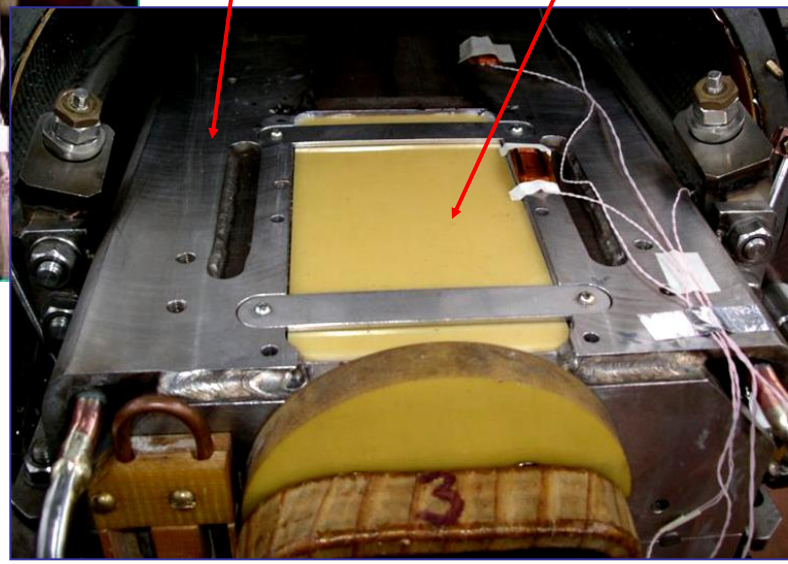
Improvement of original Nuclotron magnets

JINR/GSI: SIS100
(Y2000/2010):
2T, 4 T/s, 1 Hz,
larger sizes,
less AC losses,
better stability



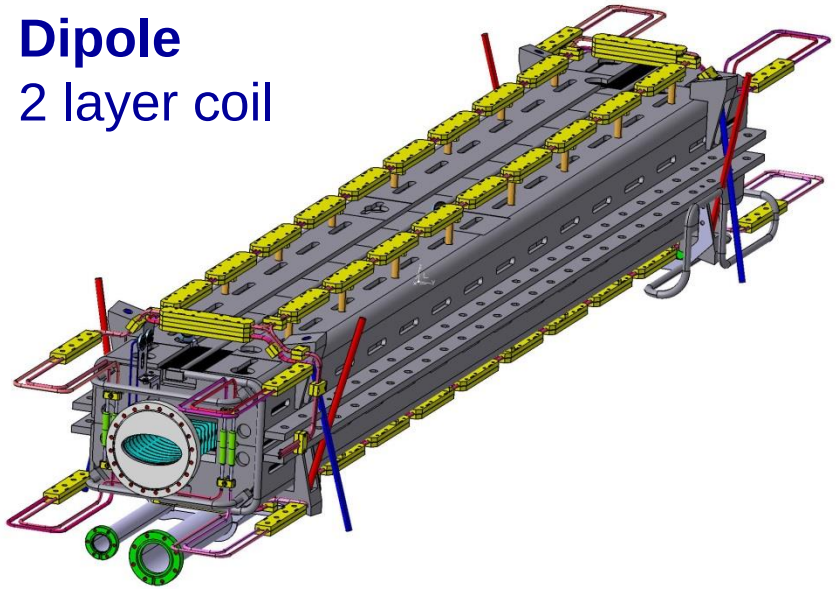
SIS100 model dipole





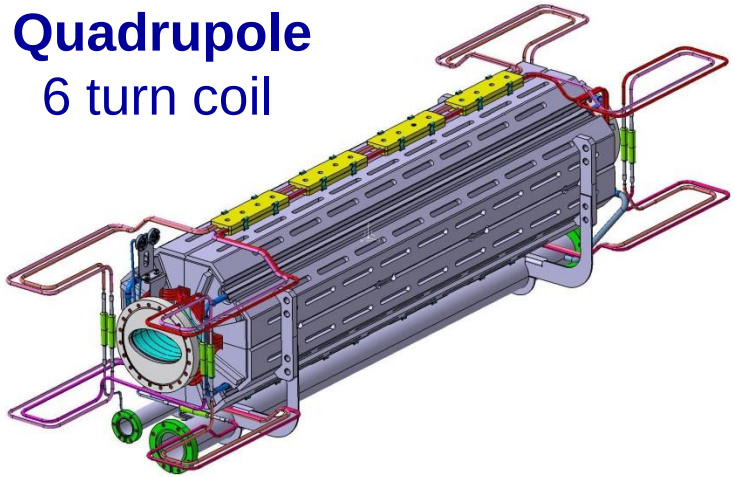
SIS100 full size prototypes

Dipole
2 layer coil



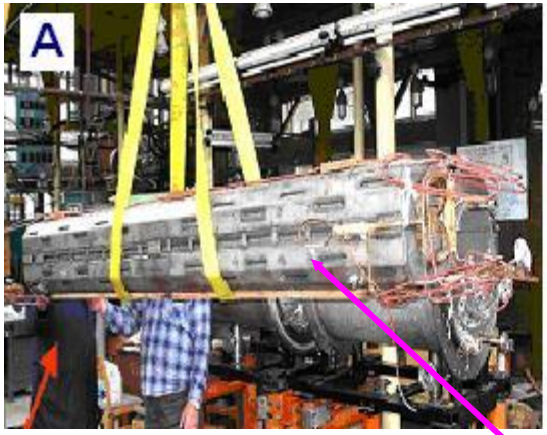
Straight dipole		FBTR design
B x $L_{effective}$	[Tm]	5.818
B	[T]	2.11
$L_{effective}$	[m]	2.756
L_{yoke}	[m]	2.696
Bending angle	[deg]	3 ?
Rad.of curvature	[m]	47.368
Aperture (h x v)	[mm]	130 x 60

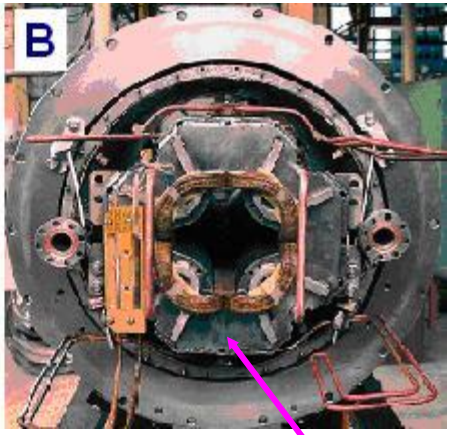
Quadrupole
6 turn coil



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

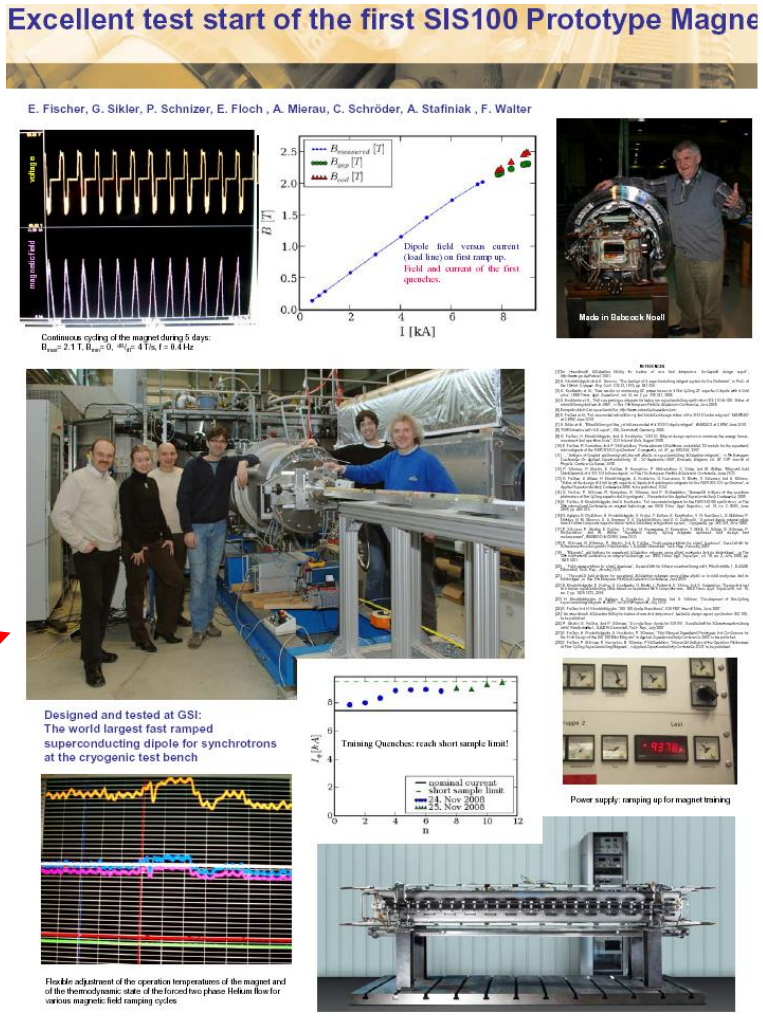




Full size SIS100 Dipole (A) and Quad (B) Manufactured and tested at JINR.

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

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



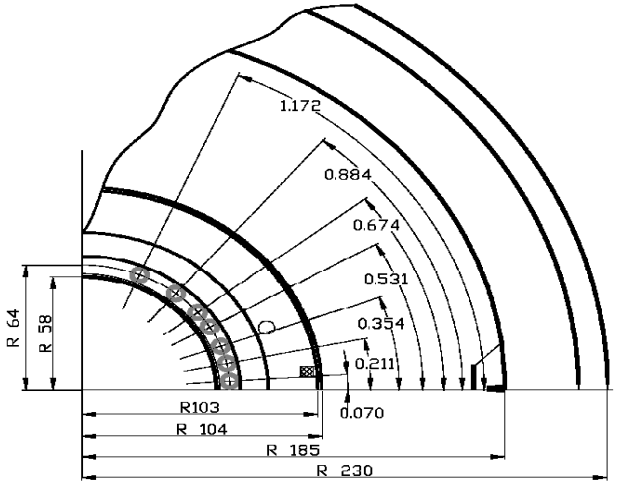
FAST RAMPED 4-6 T FIELD DIPOLE

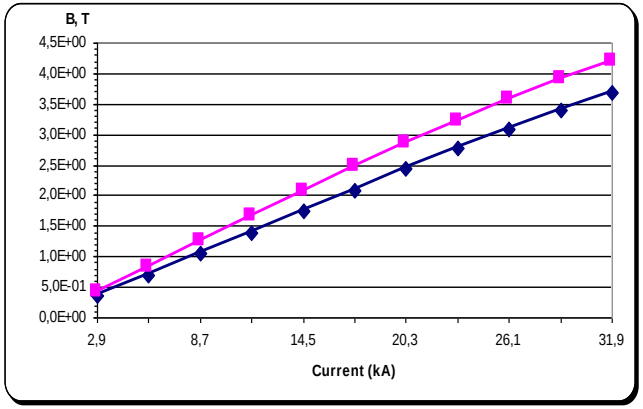
General remark:

- **hollow superconducting cable can be applied to the design and construction of a fast-ramped 4...6 T dipoles of the future synchrotrons.**
- **“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

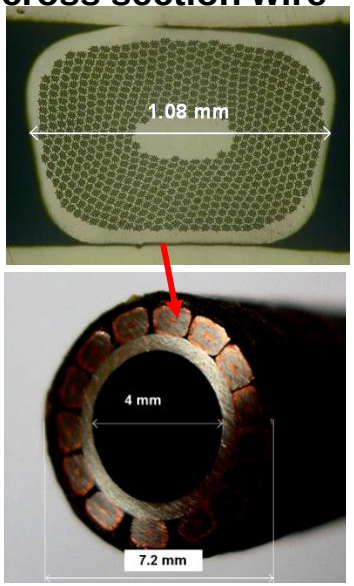




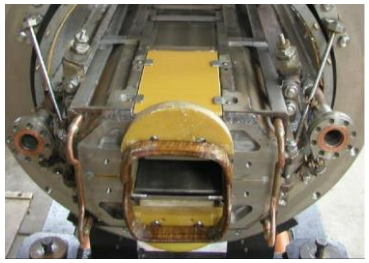
- **APERTURE: 100-110 mm;**
- **SINGLE LAYER COIL (12-14 turns)**
- **HOLLOW NbTi CABLE MADE of KEYSTONE WIRES;**
- **THE COLD MASS LIMITED TO THE COIL AND COLLAR;**
- **THE YOKE at T = 50- 80 K;**
- **TWO-PHASE HELIUM FLOW (mass flow rate of 2 g/s);**
- **OPERATING CURRENT OF 30 kA;**
- **THE FIELD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

HOLLOW SC CABLE & SINGLE-LAYER SC DIPOLE

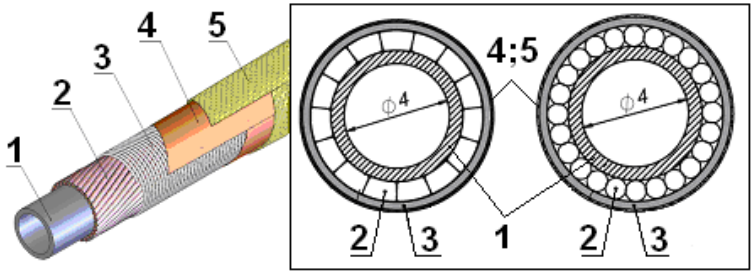
NbTi composite KEYSTONE cross section wire



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

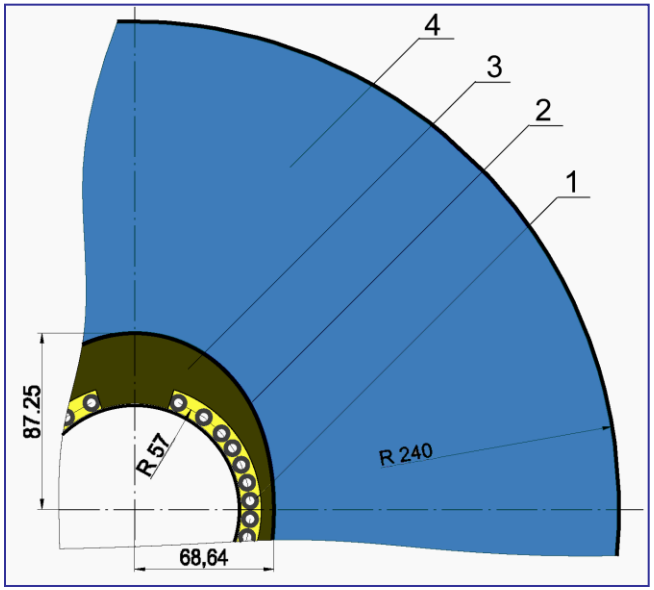


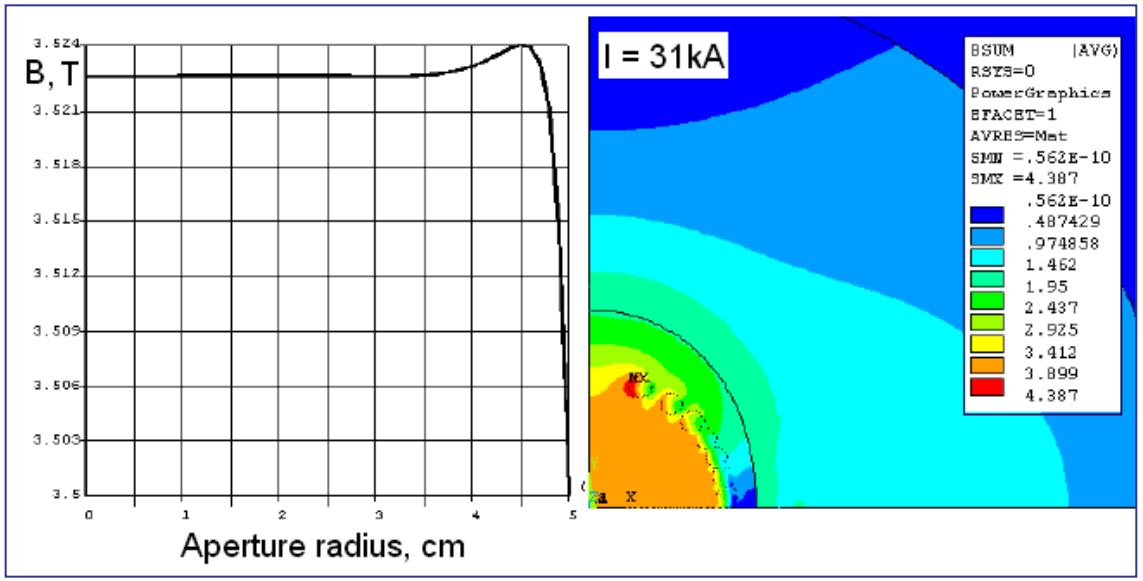
SINGLE LAYER COIL DIPOLE

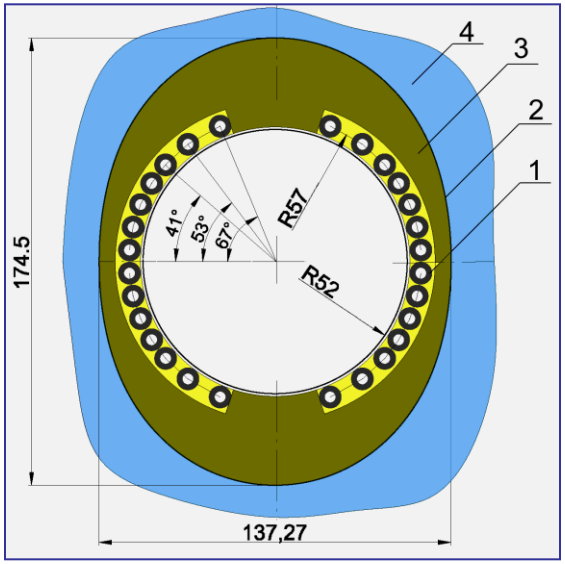


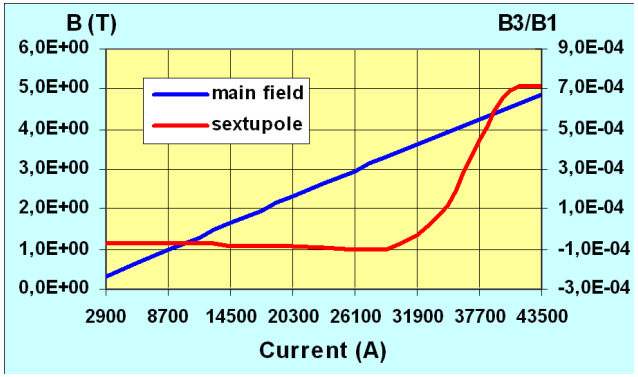
presented at ASC2004, Jacksonville, USA

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









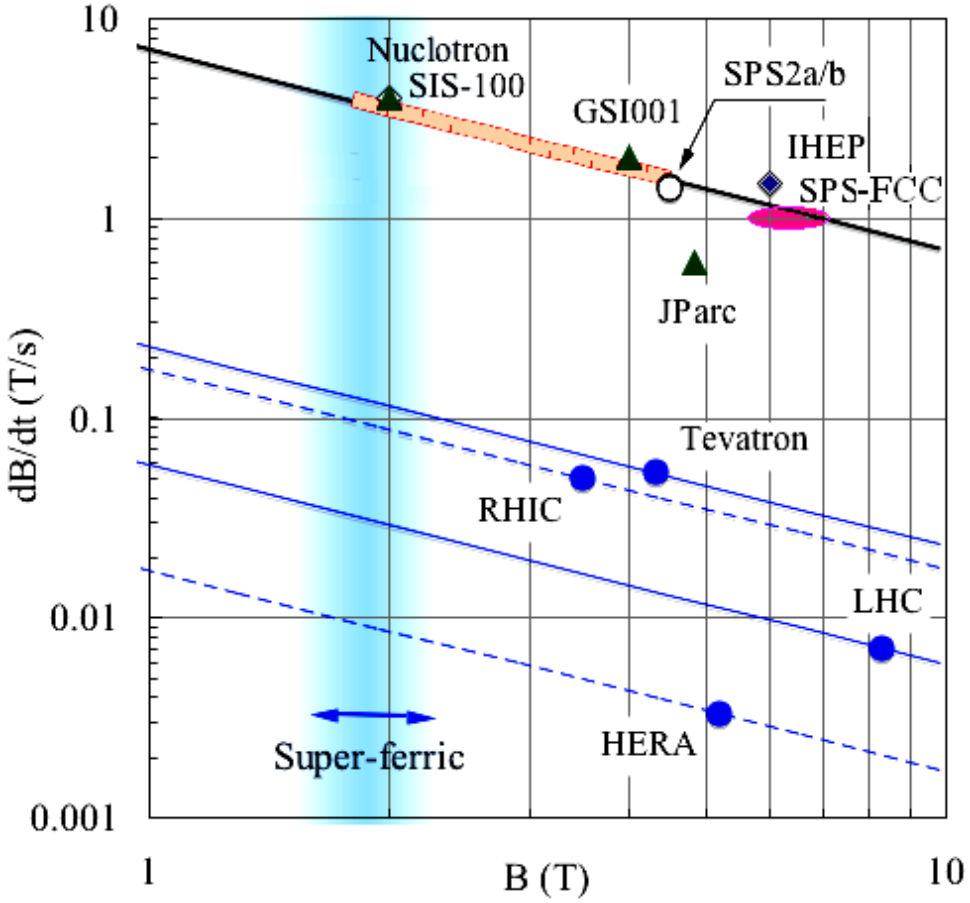
Improvement of the field quality by means of the yoke boundary profile and the coil turns azimuth position

FAST RAMPED 6 - 6.5 T DIPOLE

General remark:

- **Seems, it will be necessary to use double-layer coil consisted of a hollow cable (inner layer) and the Rutherford one (outer layer) exited with different ramps.**
- **More careful analysis and R&D work including optimization of different aspects (lattice, magnet sizes, power supply, cooling scheme, etc.) are needed.**

WHERE IS JLEIC MAGNETS?



R = B·(dB/dt)·f, (T/s)^2

B – magnetic field ,

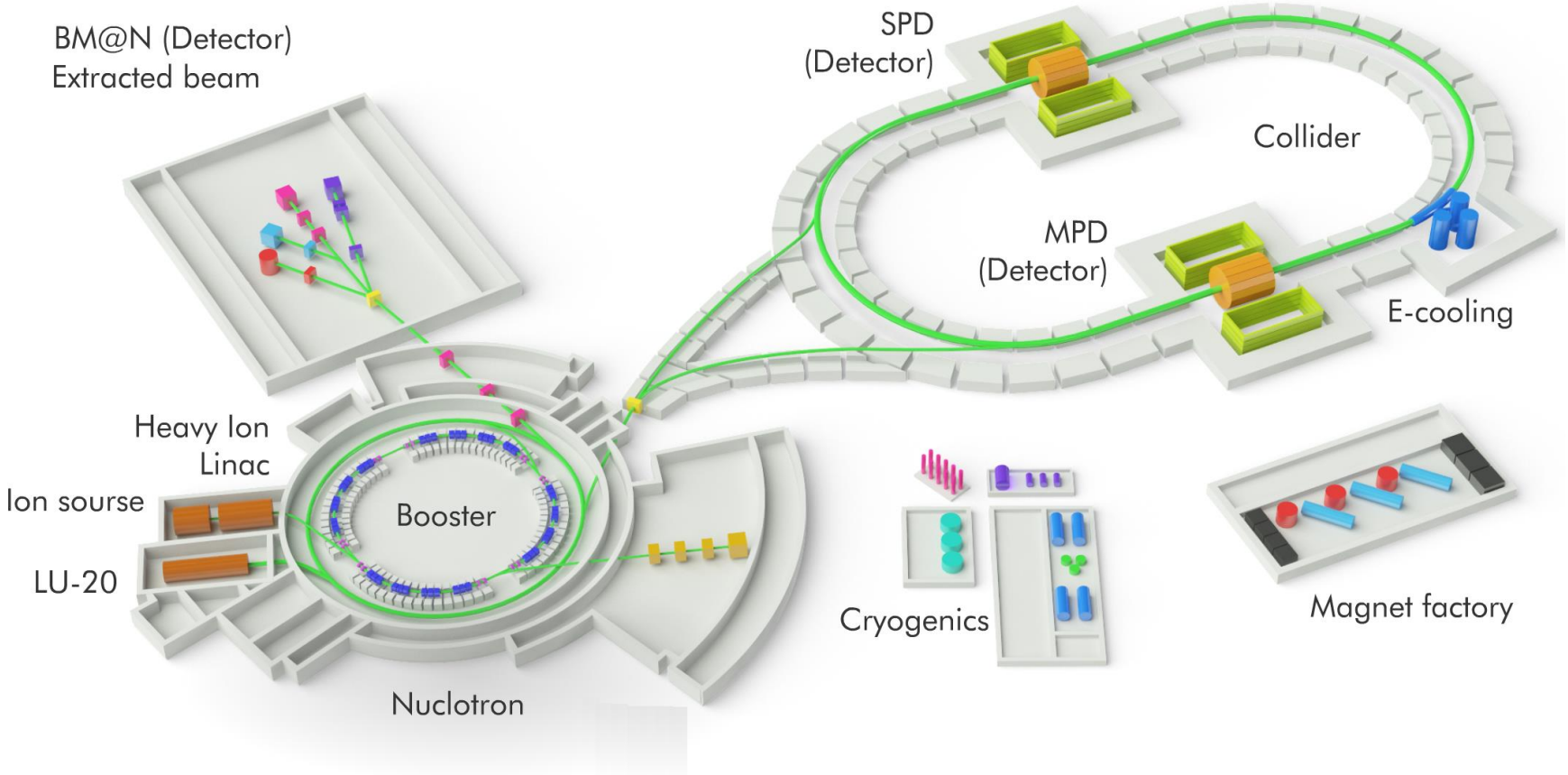
dB/dt – the field ramp

f – pulse repetition rate,

Nuclotron-type magnet

R > 8

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)*

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

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

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																									
quad																									
multi																									
nons																									
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quad																									
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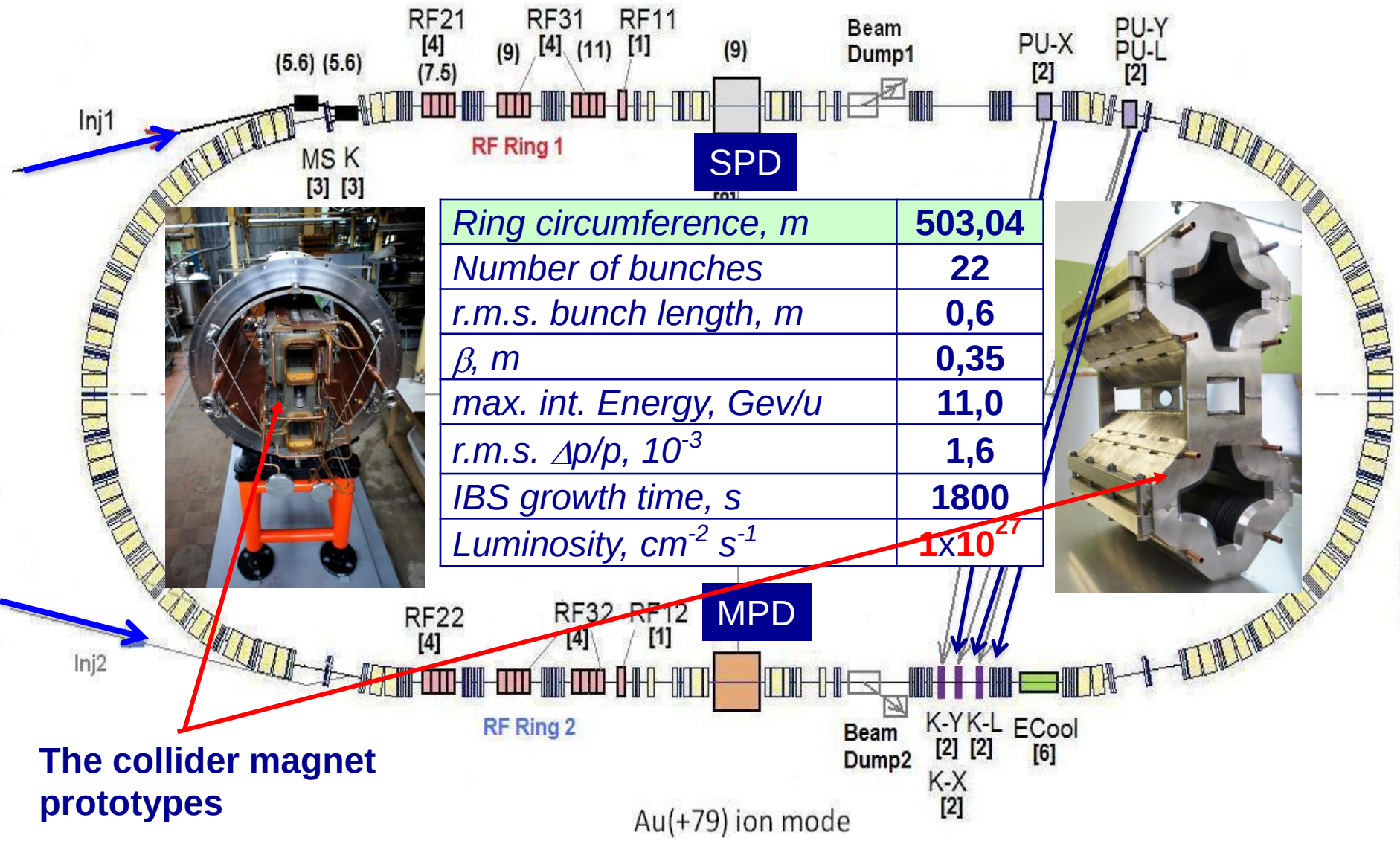
multipole correctors	**12**																								

The Collider: 45 T*m, *(4.5 GeV/u for Au79+)*



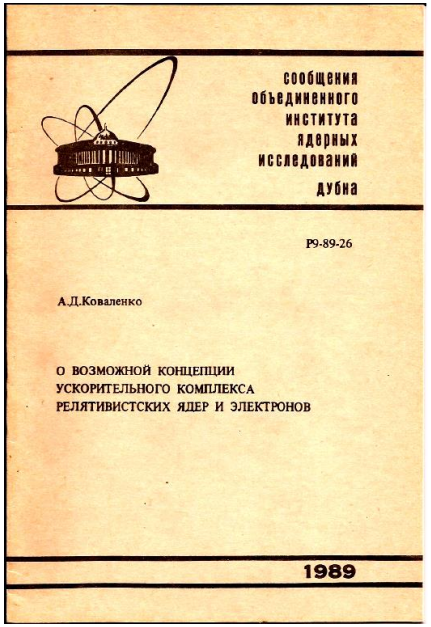
Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. $\Delta p/p$, 10^{-3}	**1,6**
IBS growth time, s	**1800**
Luminosity, cm^{-2} s^{-1}	**1×10^{27}**

The collider magnet prototypes

the area is prepared for the construction

Future design issues

The idea of electron-nuclear collider consisting of the CEBAF-type electron linac and Nuclotron-type 60 AGeV ion synchrotron/storage ring came to my mind also. So, it's my great pleasure to participate in this meeting discussing different magnet options.



Kovalenko A.D. P9-89-26

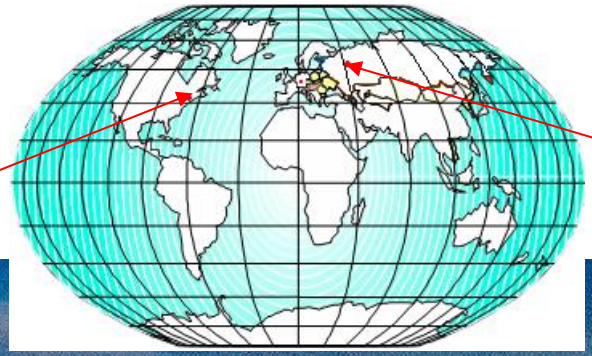
On a Possible Conception of a Relativistic Nucleus and Electron Beams Facility

The problems are considered of combining in a common accelerating complex of a superconducting synchrotron of 60-70 GeV/nucl. relativistic nuclei and a continuous electron beam superconducting linear accelerator for the energy above 4 GeV and average current of 150-200 μA. It is pointed out the possibility of using traveling-wave linac for the acceleration and bunching of heavy relativistic particles (protons, nuclei). Such accelerating complex could provide one with ample opportunities for investigation of modern nuclear physics fundumental problems, for running experiments both on fixed target and nucleus- and electron-nucleus colliding beams, and for some applied purposes.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1989

Nevertheless, the other problems of common interest are exist also – problem of the EDM, for example. NICA storage rings could provide the unique possibility to study that with polarized deuteron beam.



THANK YOU
FOR YOUR ATTANTION

Alexander D. Kovalenko, Newport News, Virginia USA, 29-31 March, 2016