Magnets and Magnet R&D Status for SIS 100

E. Fischer[1], P. Schnizer[1], K. Sugita[1], P. Akishin[2], F. Klos[1], R. Kurnyshov[3]

A. Mierau[1], B. Schnizer[4], P. Shcherbakov[5],

MAC Meeting

March 2nd – 3rd 2009

at GSI Darmstadt

[1]Gesellschaft für Schwerionenforschung, Darmstadt, Germany

[2]Joint Institut for Nuclear Research, Dubna, Moscow Region, Russia

[3]Electroplant, Moscow, Russia

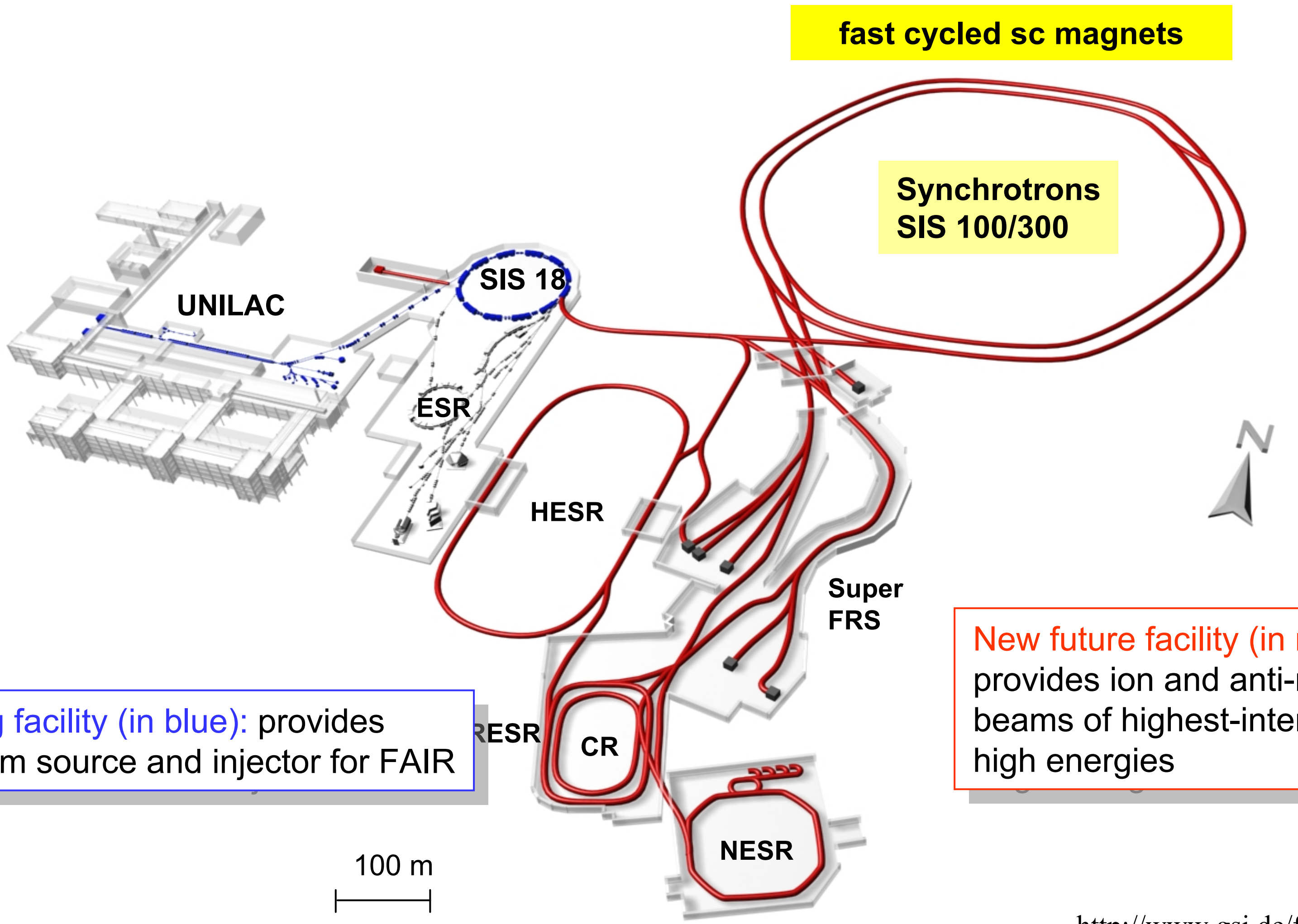
[4]Technische Universitat Graz, Austria

[5]Institut for High Energy Physics, Protvino, Moscow Region, Russia

SIS100 SC Magnets: Contents

- **SIS100 within FAIR**
- **Main R&D Results on Nuclotron based SC Magnets**
- **Corrector Magnets**
- **Magnetic field description**
- **Full size models: Design and Manufacturing**
  - Straight dipoles (BNG Wuerzburg, JINR Dubna)
  - Curved dipole (BINP Novosibirsk)
  - Quadrupole (JINR Dubna)
- **Measurement Results**
- **Additional Requirements and Critical Operation Parameters**
- **Conclusions toward the final design of the SIS100 Main Magnets**
  - **Design of the Curved SIS100 Dipole based on a Single Layer Coil**
  - **Main Operation Parameters of the CSL-Dipole**
- **Summary**

FAIR: Facility for Antiproton and Ion Research



Existing facility (in blue): provides ion-beam source and injector for FAIR

New future facility (in red): provides ion and anti-matter beams of highest-intensity and up to high energies

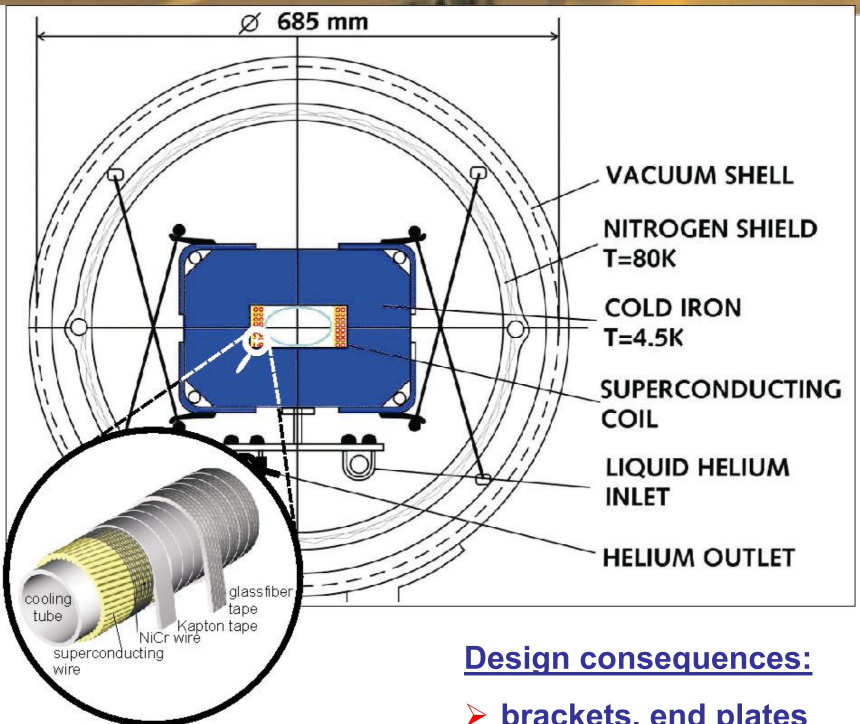
http://www.gsi.de/fair/

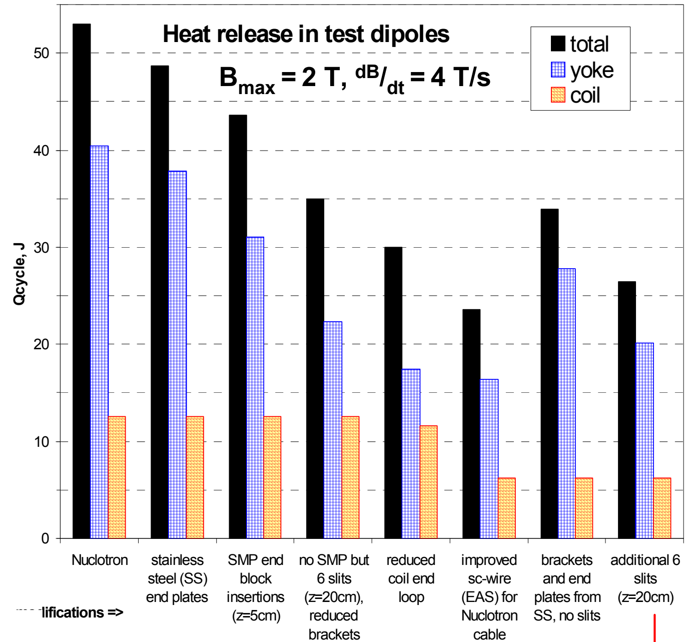
Basic Magnet Parameters of the SIS100

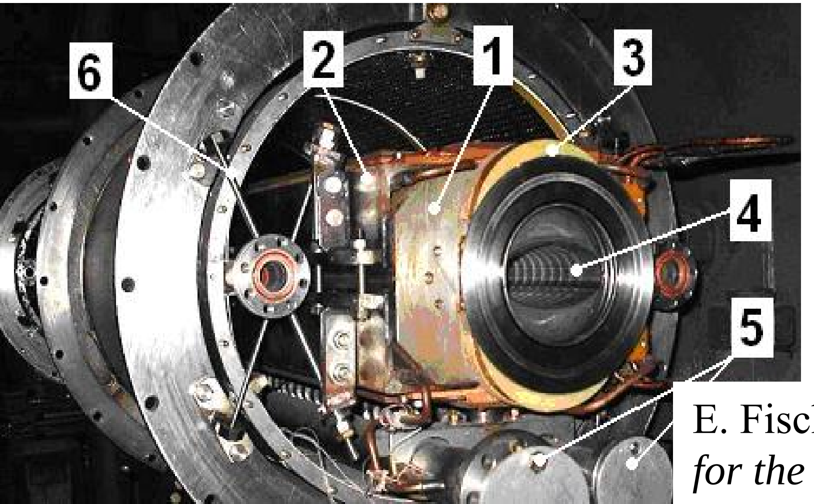
SIS100 Magnets	Number of magnets	nc/sc	Magnet design /type	Max. field (T), Gradient (T/m), etc.	Effective field length (m)	Bending angle(mrad) /radius (m)	*Useable horizontal / vertical aperture (mm)	Max. ramp rate (T/s,...)
Dipole	**108 + 1**	**sc**	**sf wf curved**	**1.9**	**3.062**	**58.18 / 52.632**	**115 / 60**	**4**
Quadrupole	**168 + 3**	**sc**	**superferric**	**27**	**1.3**		**135 / 65**	**57**
Quadrupole Inj./Extr.	**4**	**sc**	**superferric**	**27**	**1.3**		**135 / 65**	
Correction Magnets								
Error Comp. Quadrupoles**	**12**	**sc**	**cos-theta**	**0.75 T/m**	**0.75**		**150**	**5 T/m*s**
Chromat. Sextupoles	**48**	**sc**	**superferric**	**350 T/m2**	**0.5**		**135 / 65**	**2000 T/m2*s**
Error Comp. Sextupoles**	**12**	**sc**	**cos-theta**	**50 T/m2**	**0.75**		**150**	**210 T/m2*s**
Resonance Sextupoles	12	nc	6-fold	150 T/m2	0.74		150	2000 T/m2 *s
Error Comp. Octupoles**	**12**	**sc**	**cos-theta**	**2000 T/m3**	**0.75**		**150**	**8500 T/m3*s**
Fast quadrupole	1	nc	4-fold	12.5 T/m	0.54		125	125 T/m*s
Steering magnets								
Comb. h/v	**84**	**sc**	**cos-theta**	**0.3**	**0.5**	**1.5**	**135 / 65**	**1.5**
Extraction system steerer	**1**	**sc**	**cos-theta**	**0.3**	**0.5**	**1.5**	**135 / 65**	
Magnetic Septa								
Injection septum	1	nc	wf	0.82	1.5	h: 69	70 / 40	
Lambertson septum	1	nc	wf	0.6	1	v: 5.6/166.67	30 / 40	
Extraction septum 1	1	nc	wf	0.35	1.5	v: 5.1	60 / 30	
Extraction septum 2	1	nc	wf	1	1	v: 10	70 / 35	
Extraction septum 3***	1	nc	wf	v: 1.85 h: 0.25	2.2	V: 40.5 h: 5	80 / 45	
Transfer septum 1	1	nc	wf	0.8	0.5	v: 4	40 / 40	
Transfer septum 2	1	nc	wf	1.57	3	v: 47.2	40 / 40	

Main R&D Results: Short Test Models

Starting point Nuclotron dipole inside cryostat:
1 - yoke end plate
2 - brackets
3 - coil end loop
4 - beam pipe
5 - helium headers
6 - suspension
7 - laminated yoke

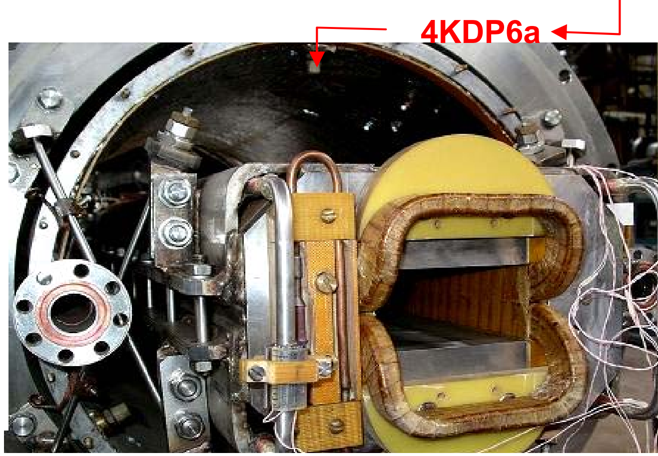






Design consequences:

- brackets, end plates made from SS
- laser cut lamination slits
- minimized coil ends
- optimized lamination geometry
- new coil package structure

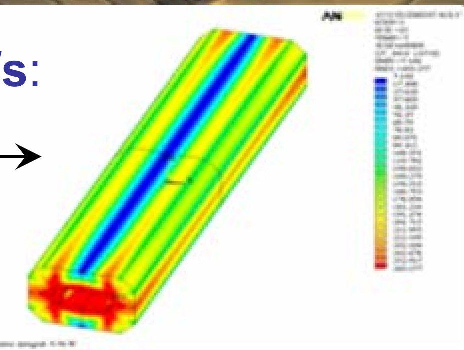


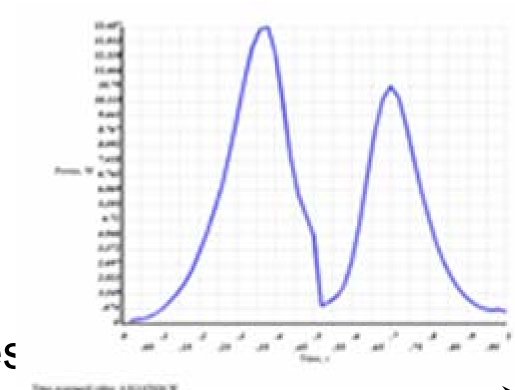
E. Fischer et al: *Fast Ramped Superferric Prototypes and Conclusions for the Final Design of the SIS 100 Main Magnets* ASC 2008

Main R&D Results: FEM Calculation of the AC Loss

4KDP6a results for the triangular cycle with B_{max}= 2 T, $^{dB}/_{dt}$=4 T/s:

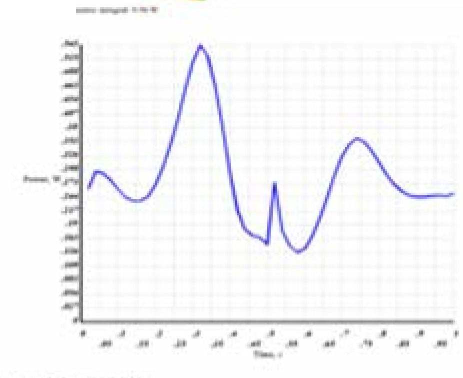
- Hysteresis loss in the laminated yoke
  = 9.56 J/cycle



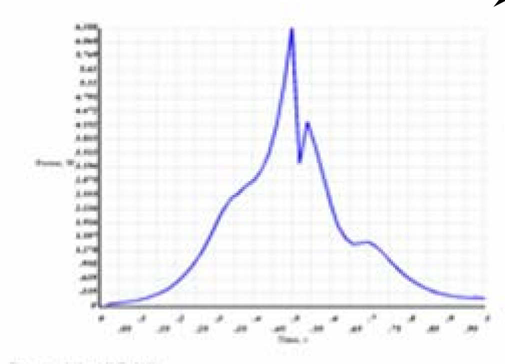


- Eddy current loss in the yoke ends
  = 4.81 J/cycle

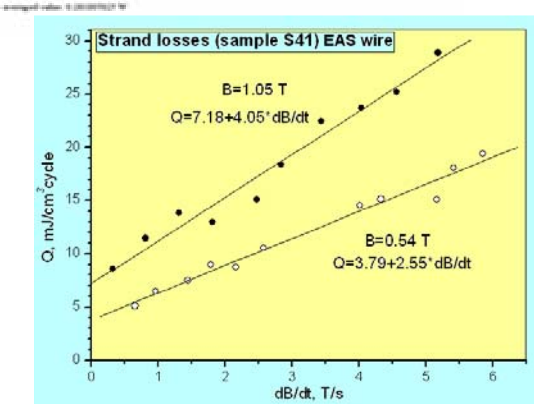
- Eddy current loss in the ss end plates
  = 0.28 J/cycle



- Eddy current loss in the ss brackets
  = 1.53 J/cycle



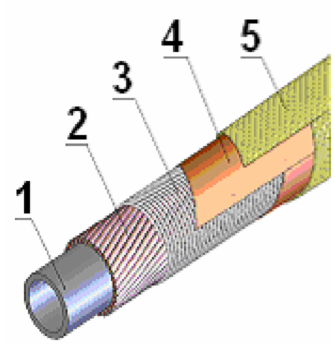
- AC loss in the superconducting coil
  = 6.4 J/cycle (from short sample measurements at JINR)



► **see also:** E. Fischer et al."Analysis of coupled electromagnetic-thermal effects in superconducting accelerator magnets", J. Phys.: Conf. Ser. 97 (2008) 012261

Main R&D Results: Coil Mechanics

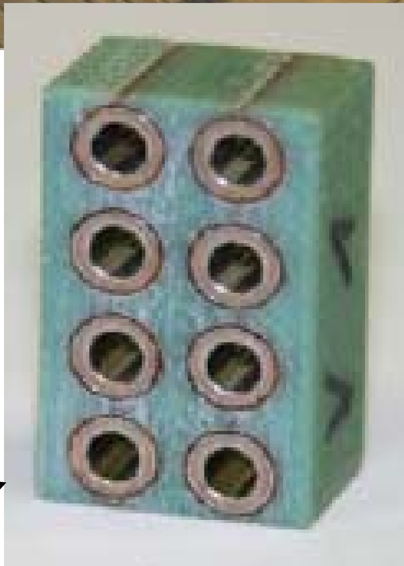
Nuclotron cable:



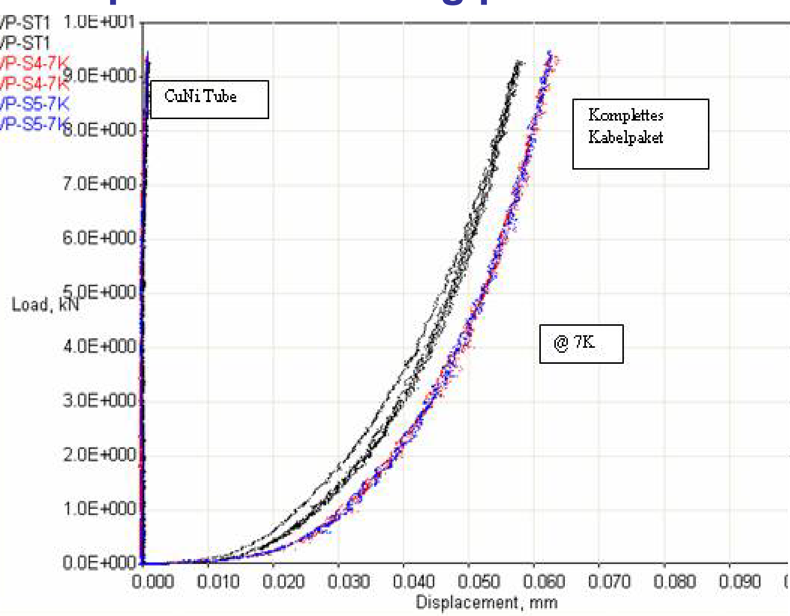
1 - Cooling tube
2 - SC wire
3 - CrNi wire
4 - Kapton tape
5 - Glasfiber tape

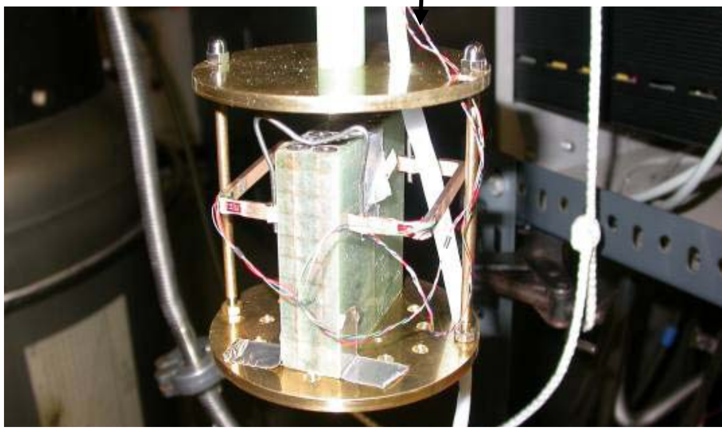
Analysis of:

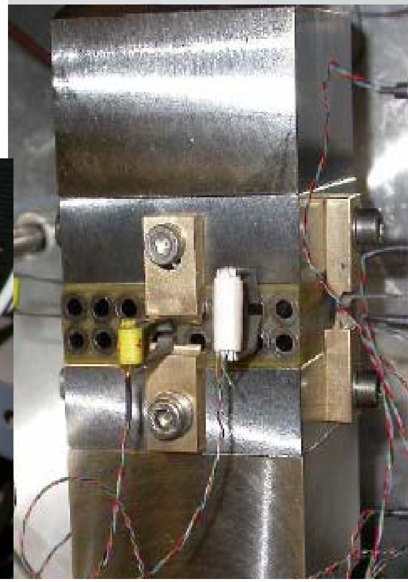
- wire and cable design
- Insulation concept
- Winding scheme
- Technological optimization
- ANSYS Models
- Substrate: comb or block
- Model coils production (BNG)
- Mechanical tests



stress strain load tests on the complete coil winding pack:







E. Fischer and et al. *Manufacturing of the first full size model of a SIS100 dipole magnet.* WAMSDO at CERN 2008

SIS100 Corrector Magnets: Requirements

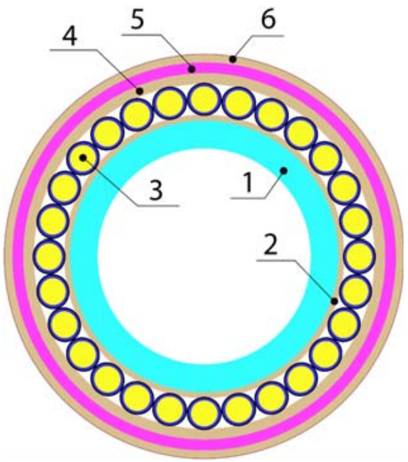
- Common cooling system: 2 phase helium forced flow,
- Nuclotron type cable: Effective cooling
- Low current < 300A: Minimize heat load from current leads.

	Multipole			Steerer		Chrom.
Num. of Mag.	12			84		48
	Quad.	Sext.	Oct.	H	V	
Cable length [m]	12	14	17	13	12	13
Num. of wires	10	22	19	28	28	20
Current [A]	249	245	251	260	268	255
Max. field [T]	0.5			0.5		1.2
dB/dt [T/s]	2.1			2.5		6.8

SIS100 Corrector Magnets: Cable Design

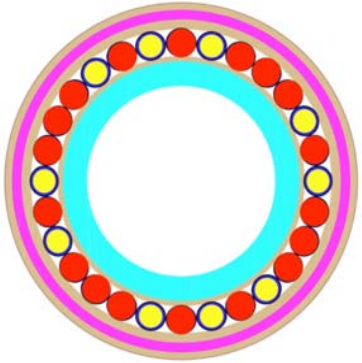
- **Nuclotron type cable with insulated wires**

– Connect wires in series
– By replacing sc. wire, operation current is adjustable.



1. CuNi tube
2. Kapton, t=0.05mm, 1 layer, 50% overlapped
3. Superconduting wire, 0.5mm diameter, with enamel
4. Kapton, t=0.05mm, 2 layers, 50% overlapped
5. CrNi wire, 0.2mm diameter
6. Kapton, t=0.07mm, 1 layer, 50% overlapped

Maximum 28 sc. wires

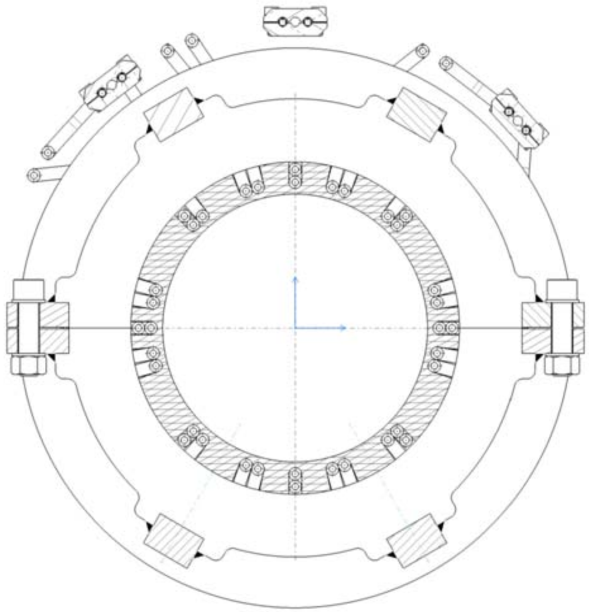


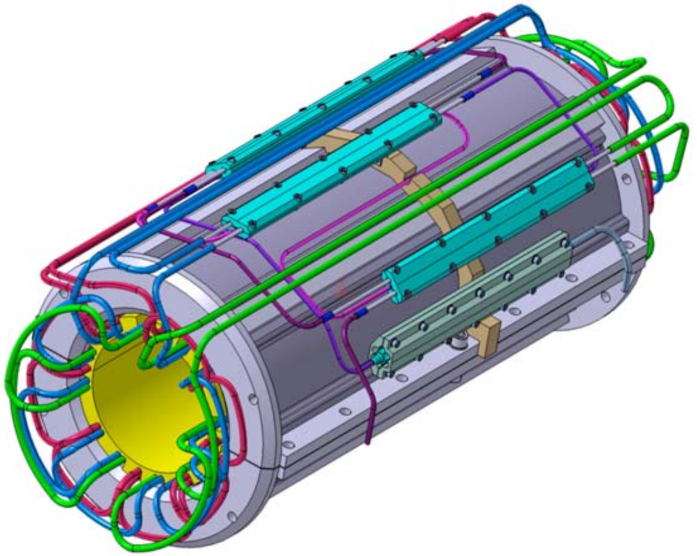
ex. 10 sc. wires cable for the quadrupole corrector

► **see also:** K. Sugita et al. "Design Study of Multipole Corrector Magnet for SIS 100", ASC 2008

SIS100 Corrector Magnets: Multipole

Error compensation multipole corrector
– Quadrupole, sextupole, and octupole are nested.

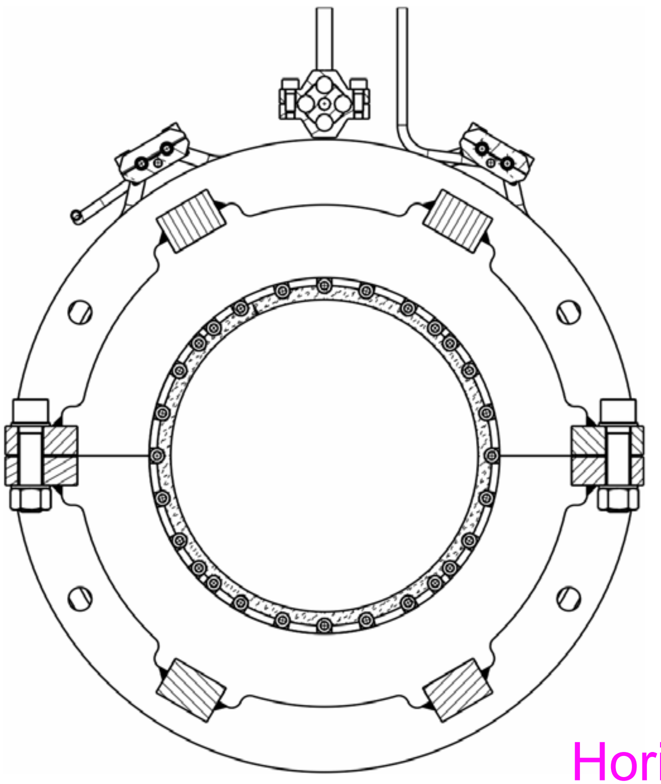


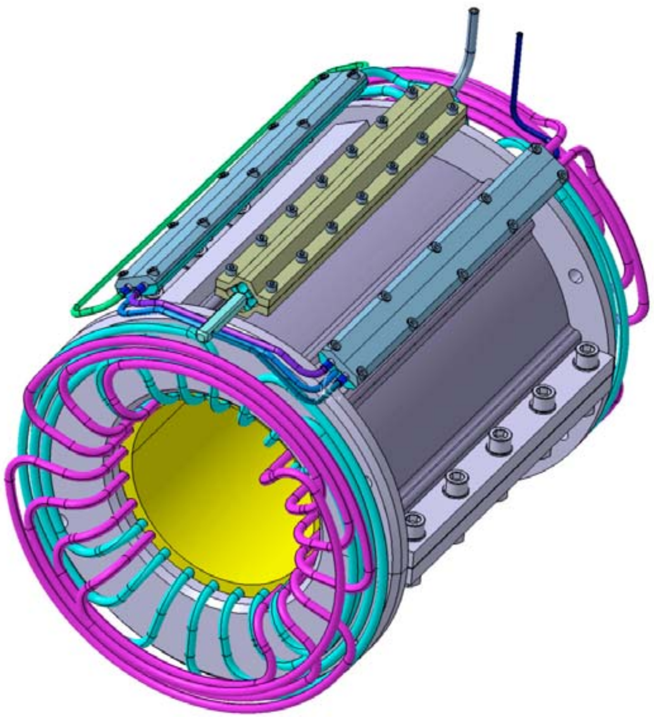


Quadrupole
Sextupole
Octupole

SIS100 Corrector Magnets: Steerer

Steerer magnet – Horizontal and vertical dipoles are nested.



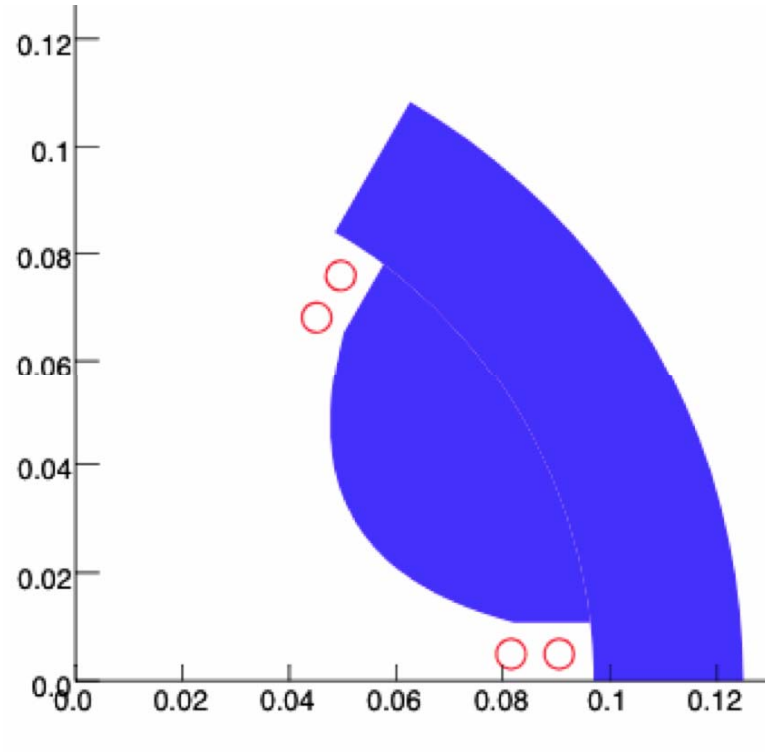


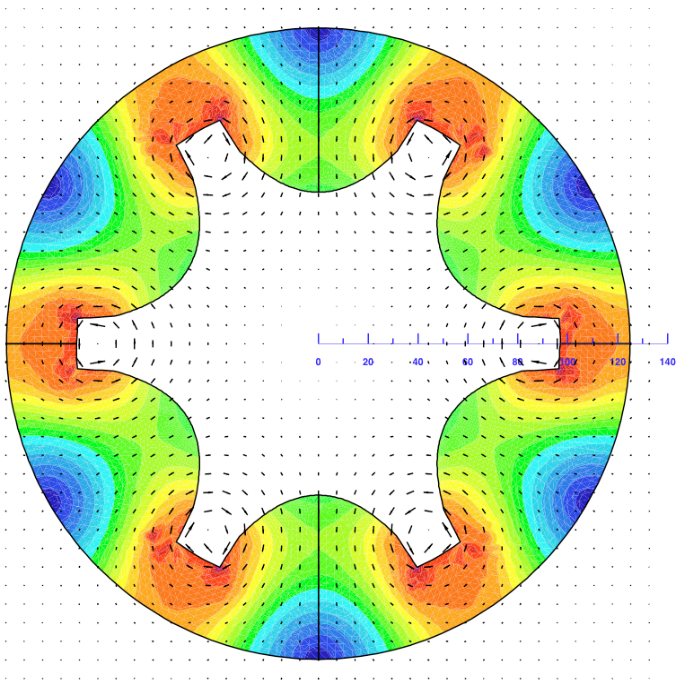
Horizontal (normal) dipole

Vertical (skew) dipole

SIS100 Corrector Magnets: Chromaticity Sextupole

Superferric type magnet





A. Kalimov: *Field Design for a SIS-100 chromaticity sextupole.* GSI Internal Report Feb. 2008

HELMHOLTZ GEMEINSCHAFT GSI FAIR

Magnetic Field Description: Circular Multipoles

Standard field description: Circular Multipoles

$$\mathbf{B}(\mathbf{z}) = B_y + iB_x = \sum_{m=0}^{\infty} \mathbf{C_m} \left(\frac{\mathbf{z}}{R_{ref}} \right)^m .$$

- convergent also outside R_{ref}
- satisfactory field description only for analytical data
- cofficients $\rightarrow$ FT on data on R_{ref} (FEM, measurement) $\rightarrow$ thus with artifacts

Magnetic Field Description: Elliptic Multipoles

Field expansion:

$$\mathbf{w} = \eta + i\psi$$

$$\mathbf{B}(\mathbf{w}) = \frac{\mathbf{e}_0}{2} + \sum_{n=1}^{\infty} \mathbf{e}_n \frac{\cosh[n(\eta + i\psi)]}{\cosh(n\eta_0)}$$

$\eta = const \ldots$ hyperbola $\qquad \psi = const \ldots$ ellipse

Expansion coefficients:

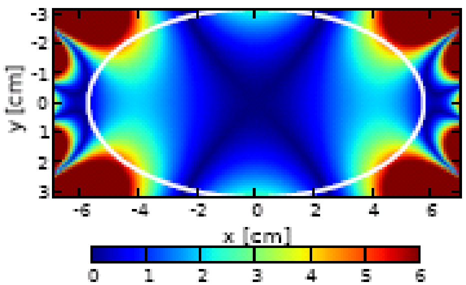
$$\mathbf{e}_n = \frac{1}{2\pi} \int_{-\pi}^{\pi} \mathbf{B}(\mathbf{w} = e \cosh(\eta_0 + i\psi)) \times \cos(n\psi)\, d\psi.$$

Linear Analytic Transformation to Circular Ones

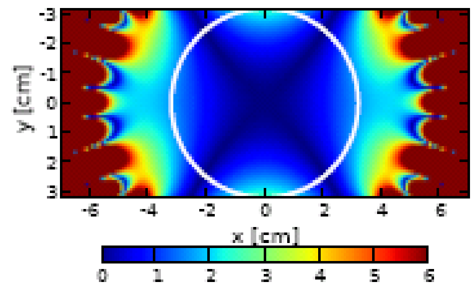
P. Schnizer, B. Schnizer, P. Akishin, and E. Fischer
Field representation for elliptic apertures. Technical report, Feb. 2007, Jan. 2008

MT20: Magnetic field analysis for superferric accelerator magnets using elliptic multipoles and its advantages. 3L06

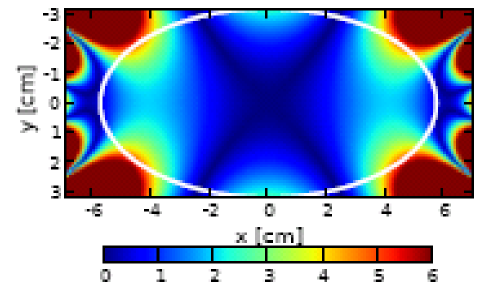
Magnetic Field Description: Elliptic Multipoles



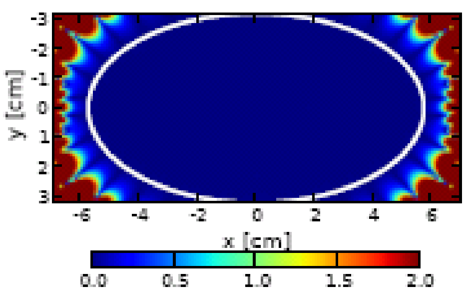
elliptic $\mathcal{C}_e$



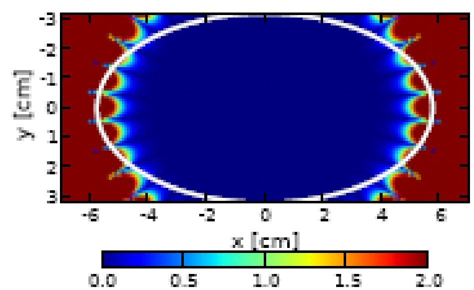
cyclic $\mathcal{C}$



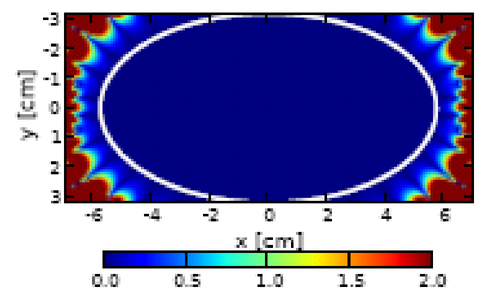
ell. $\longrightarrow$ cyclic in $\mathcal{C}_e$



Δ elliptic $\mathcal{C}_e$



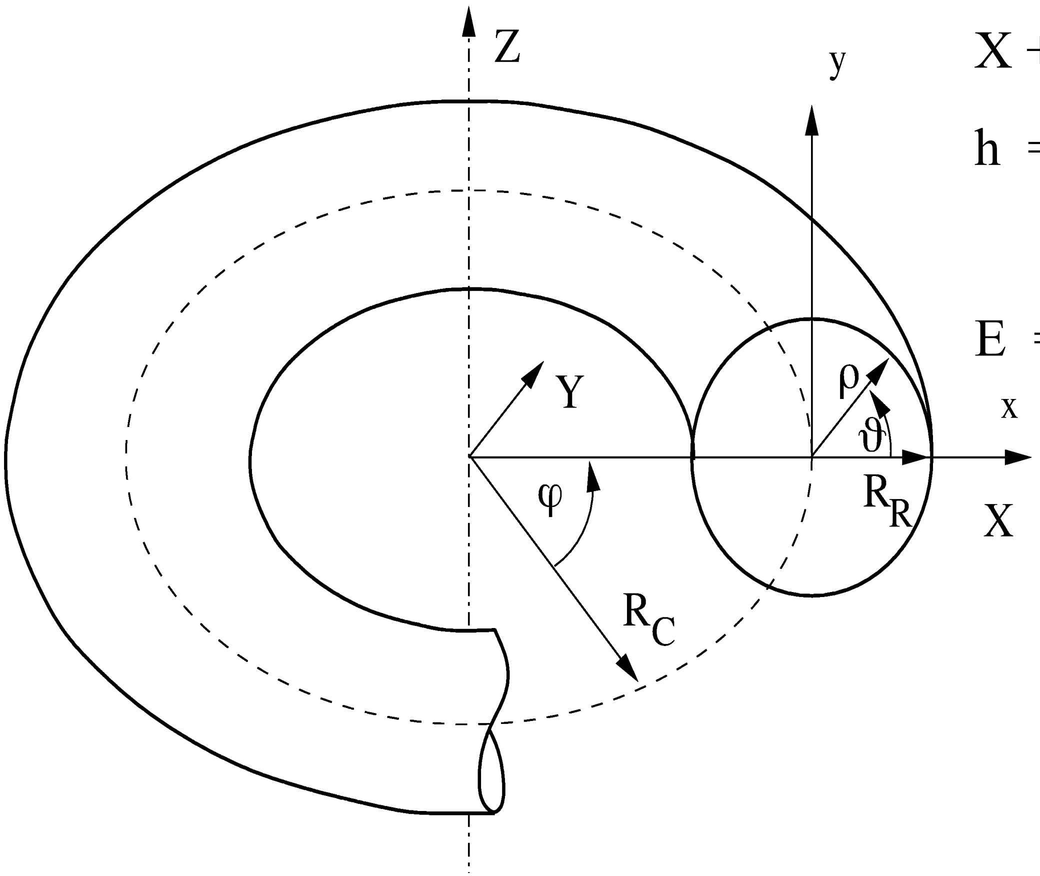
Δ cyclic $\mathcal{C}$



Δ ell. $\longrightarrow$ cyclic in $\mathcal{C}_e$

Illustrated for CSLD at Injection Field ($\approx 0.25\ T$)

Magnetic Field Description: Toroidal Multipoles



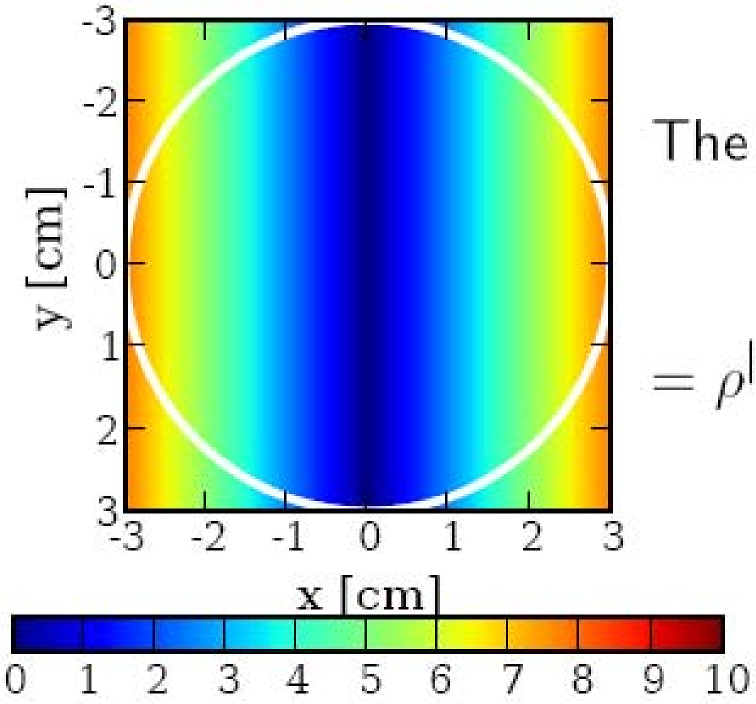
Local Toroidal Coordinates ρ, ϑ, ϕ

$X + iY = R_c\, h\, e^{i\phi}$

$h = 1 + \varepsilon\, \rho \sinh \vartheta$

$E = R_R / R_c \ll 1$

Magnetic Field Description: Toroidal Multipoles



The **toroidal multipoles** are:

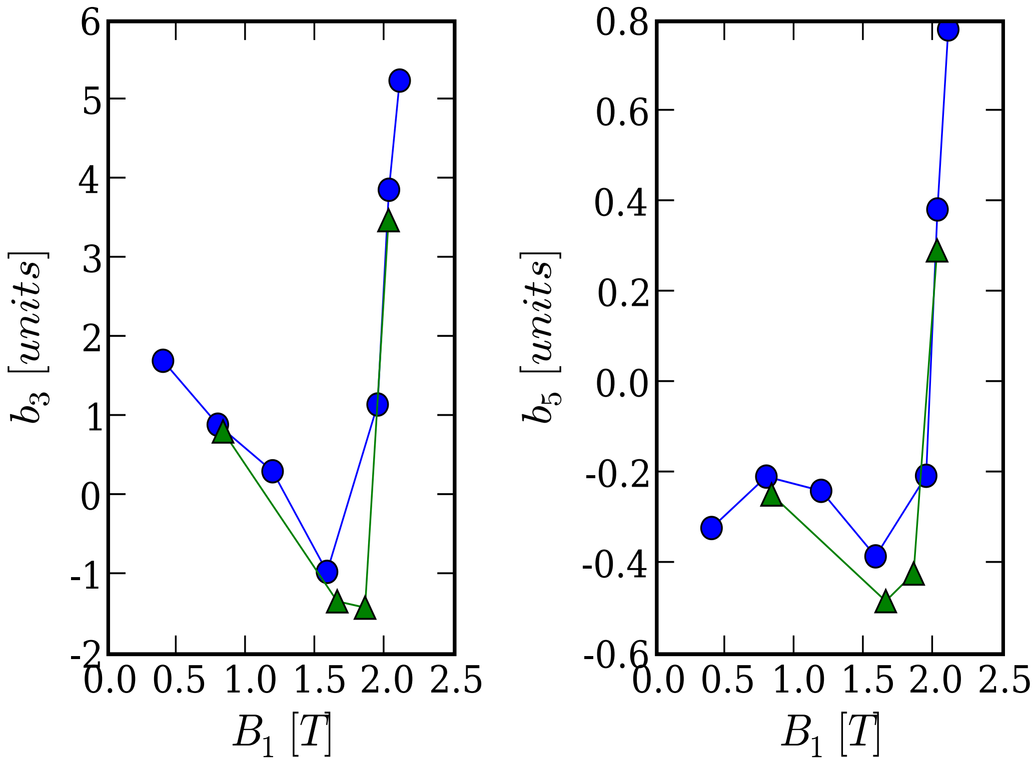
$$\Phi_m(\rho, \vartheta) = h^{1/2} \rho^{|m|}\ e^{im\vartheta} + O(\epsilon^2)$$

$$= \rho^{|m|}\ e^{im\vartheta} - \frac{\epsilon}{4} \rho^{|m|+1} \left(e^{i(m+1)\vartheta} + e^{i(m-1)\vartheta}\right).$$

P. Schnizer , B. Schnizer, P. Akishin and E. Fischer *Plane Elliptic or Toroidal Multipole Expansions within the Gap of Straight or Curved Accelerator Magnets* Accepted for Publication in COMPEL

Magnetic Field Description: Application

- multipoles of SIS 100 magnets
- comparison of different designs
  - straight dipole
  - curved dipole
- basis of beam dynamic calculations of SIS 100



P. Schnizer et. al *Magnetic Field Characteristics of a SIS 100 Full Size Dipole* EPAC 2008

P. Akishin, E. Fischer, P. Schnizer *3D Fields of the SIS 100 Magnets* Technical Report 2008

P. Akishin, E. Fischer, P. Schnizer, *Field quality of various designs of the SIS 100 magnets, A single layer dipole for SIS 100* Technical Reports 2007

Main R&D Results on Nuclotron based SC Magnets

- **The sources of the loss generation are understood, numerical calculations match the respective measurements**
- **Stainless steel end plates and brackets**
- **Minimized coil end loops**
- **Laminated and horizontally cut endblocks**
- **New wire with higher current density and lower losses**
- **More rigid coil structure**

- **Decision: design and build full size models** (contracts Dec. 2006)
  - **Two straight dipoles:** BNG Wuerzburg (Industry), JINR Dubna(Institute)
    → different manufacturing technologies and materials
  - **Quadrupole: JINR Dubna**
  - **Curved dipole: BINP Novosibirsk**
    → "no sagitta": significant benefits for lattice design and operation

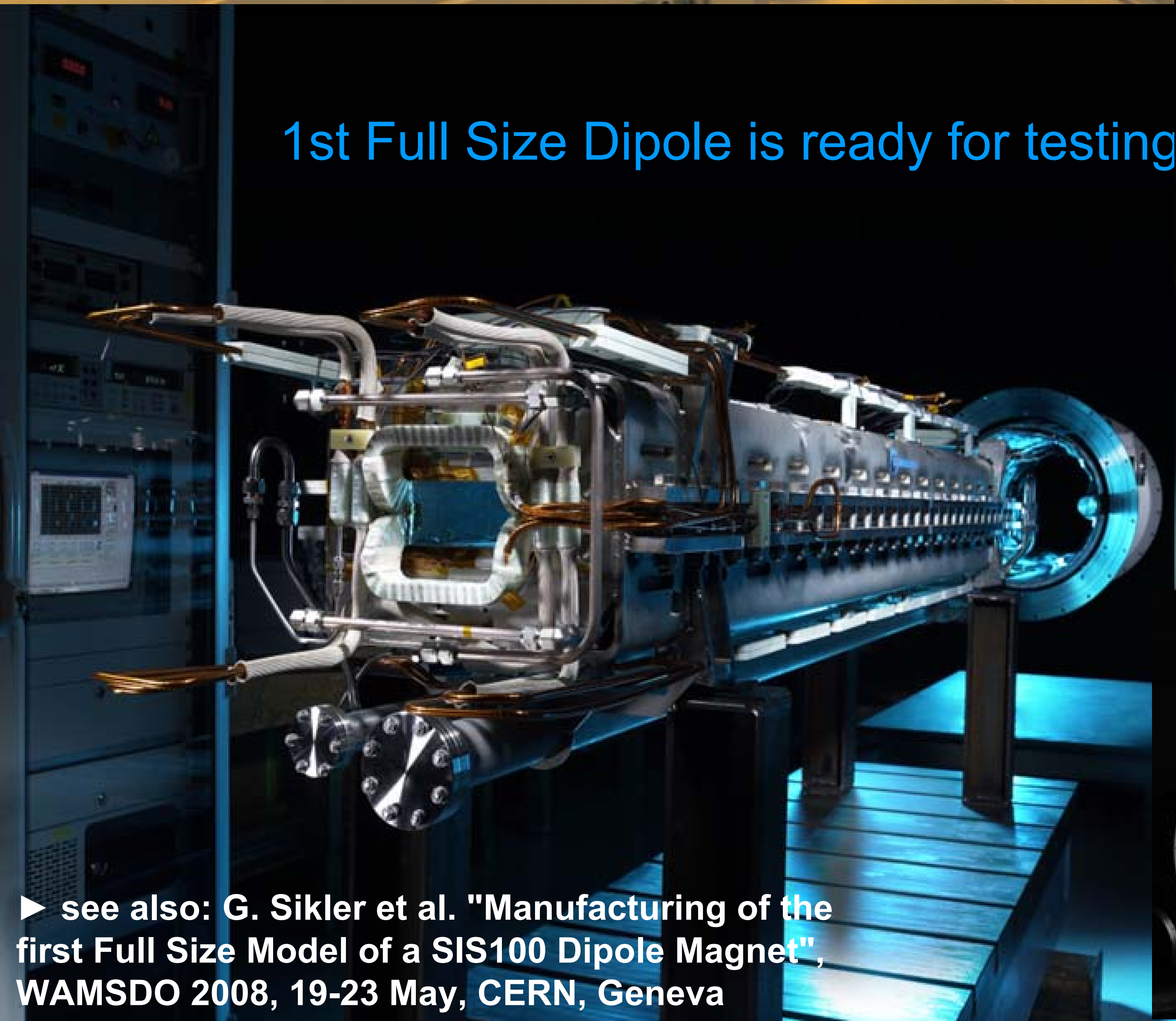
SIS 100 full Size Models: Design Parameters

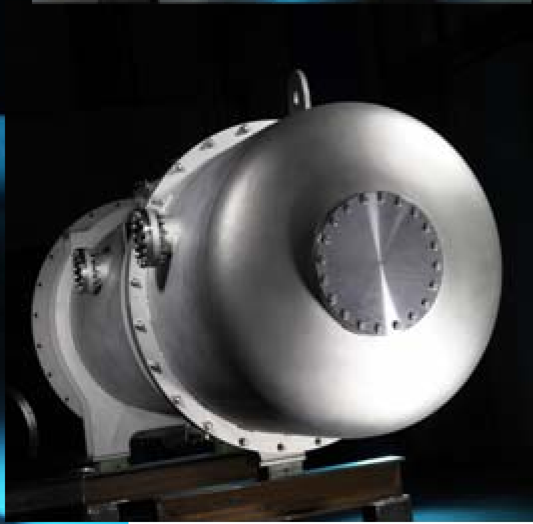
	Straight dipole FBTR (March 2006)	Curved dipole (Oct. 2006)
B x $L_{effective}$ [Tm]	5.818	5.818
B [T]	2.11	1.9
$L_{effective}$ [m]	2.756	3.062
Estimated L_{yoke} [m]	2.696	3.002
Bending angle [deg]	3 1/3	3 1/3
Radius of curvature [m]	47.368	52.632
Aperture (h x v) [mm]	130 x 60	115 x 60

	Quadrupole FBTR (March 2006)	Quadrupole Elongated(Oct.2006)
B' x $L_{effective}$ [T]	35	35
B' [T/m]	32	27
$L_{effective}$ [m]	1.1	1.3
Estimated L_{yoke} [m]	1	1.2
Aperture (h x v) [mm]	135 x 65	135 x 65

SIS 100 Full Size Model: Dipole from Babcock Noell GmbH

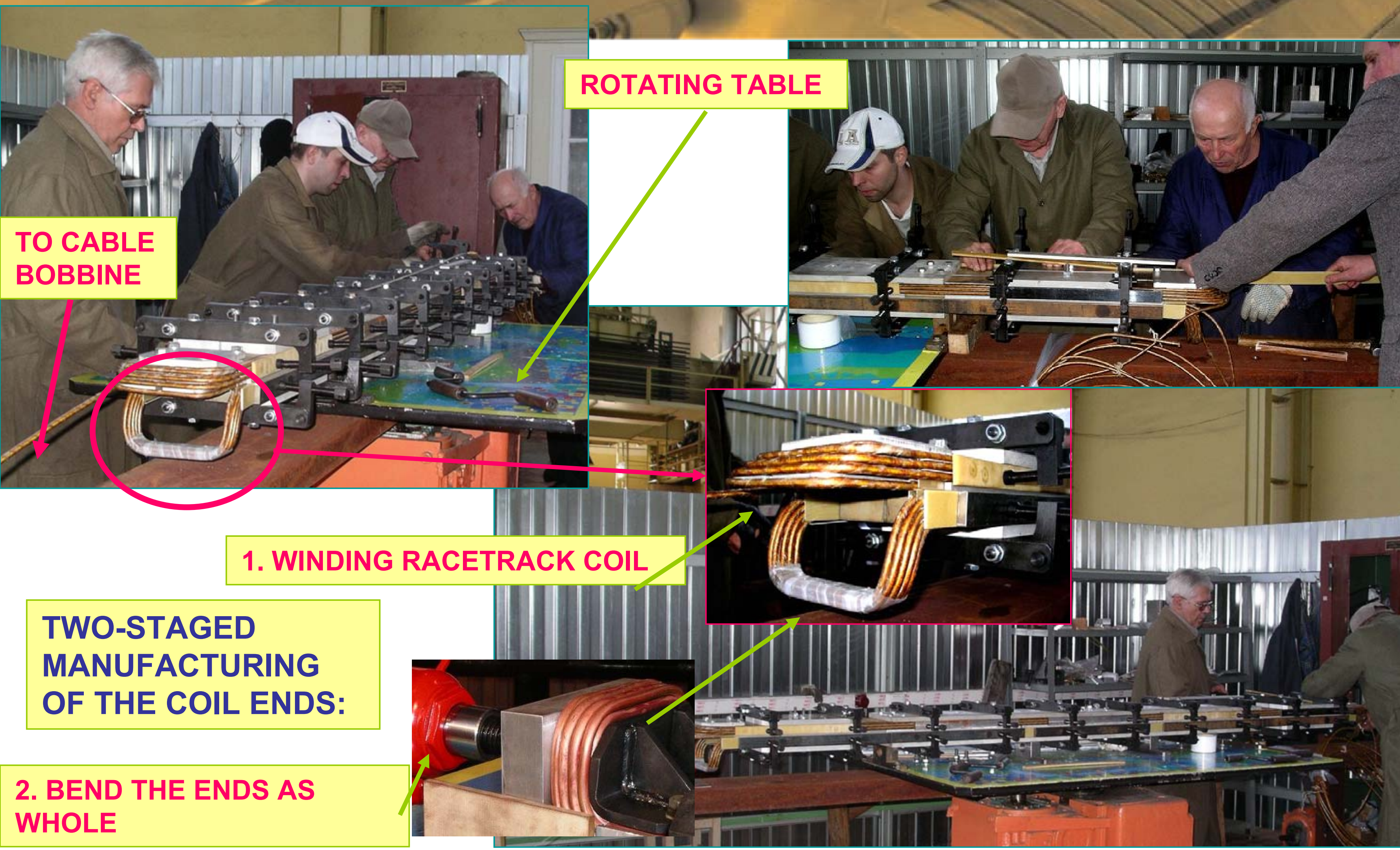
1st Full Size Dipole is ready for testing





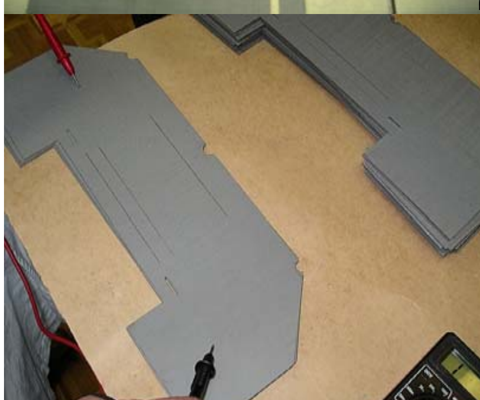
► see also: G. Sikler et al. "Manufacturing of the first Full Size Model of a SIS100 Dipole Magnet", WAMSDO 2008, 19-23 May, CERN, Geneva

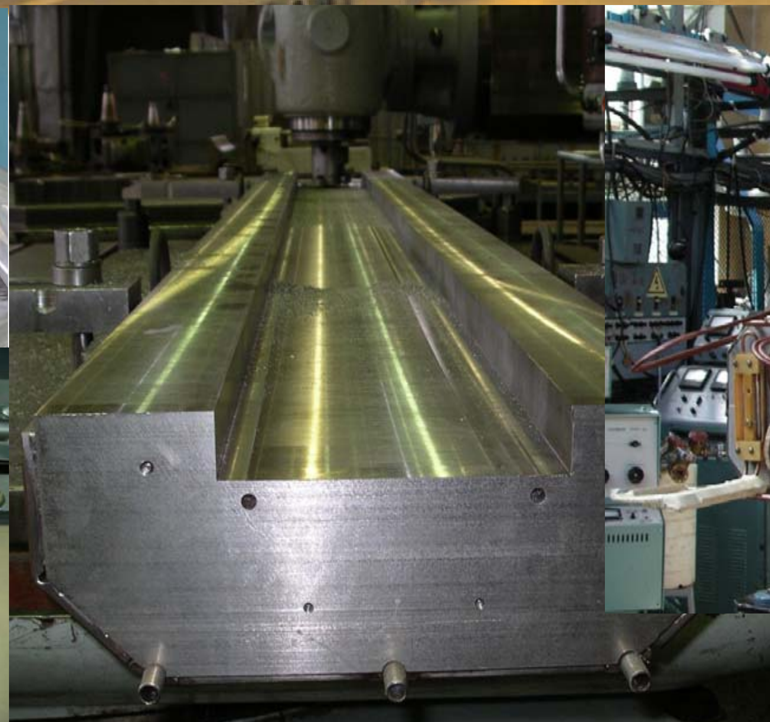
SIS 100 Full Size Model: Dipole Manufacuring at JINR



► see also: A.Kovalenko et. al "Full Size Magnets for Heavy Ion Superconducting Synchrotron SIS100 at GSI: Status of Manufacturing and Test at JINR", EPAC 2008, 23 to 27 June, Genova June, 2008, Genova

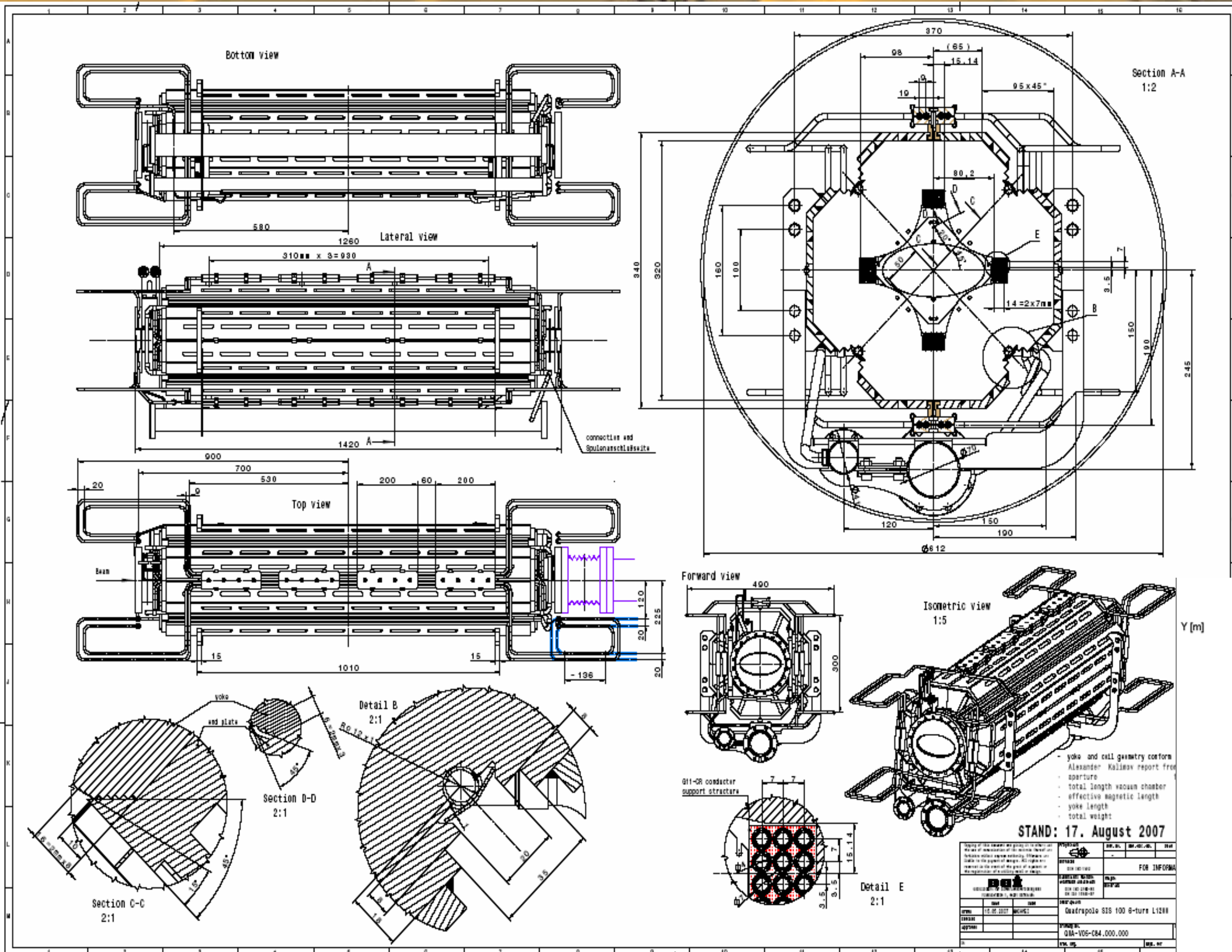
SIS 100 Full Size Model: Dipole Manufacuring at JINR





high quality and reproducible production of the lamination shape and the the iron yoke

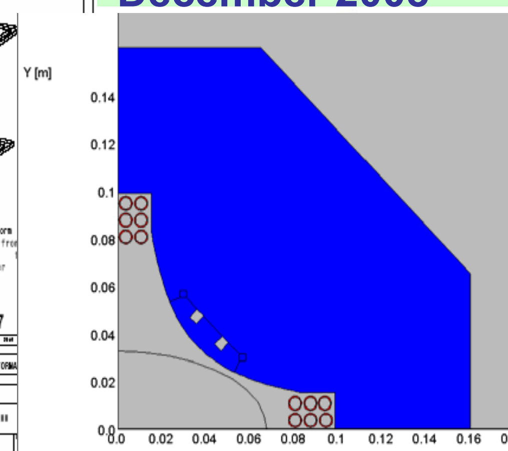
Full Size Model: Quadrupole Manufacturing at JINR



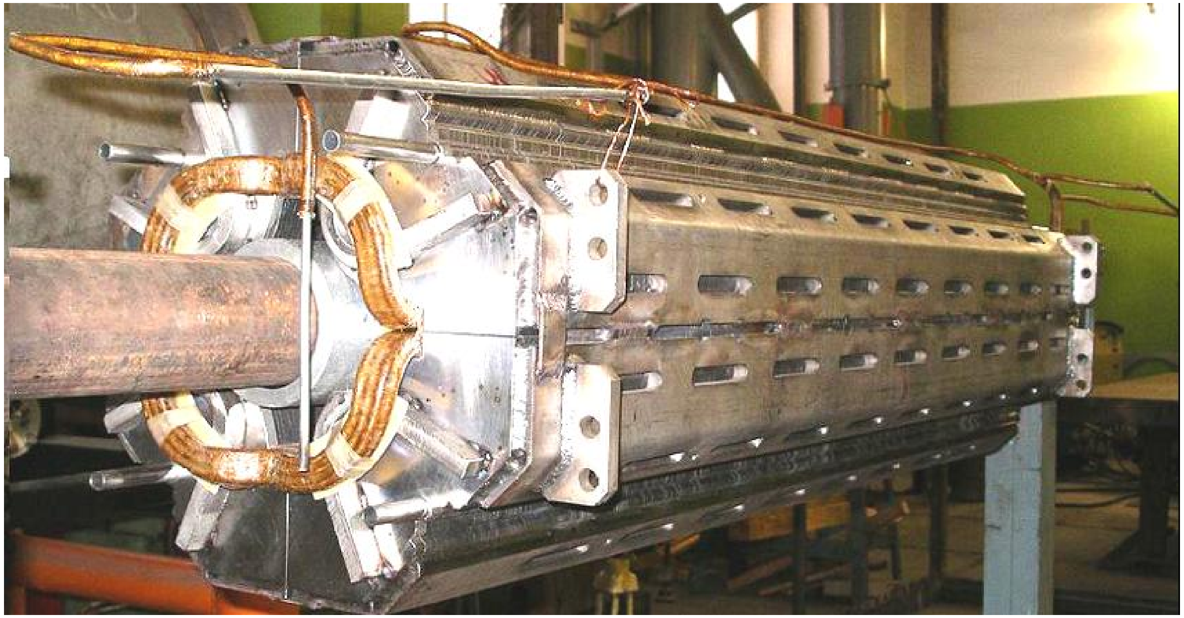
Completion of manufacturing and ready for tests **of full length main magnets produced at JINR Dubna:**

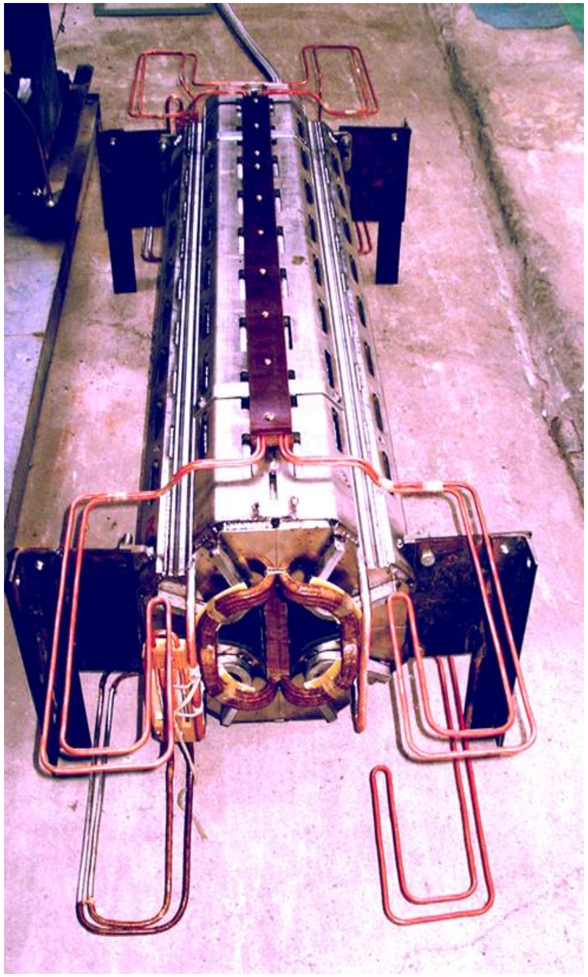
Dipole: September 2008:

Quadrupole: December 2008



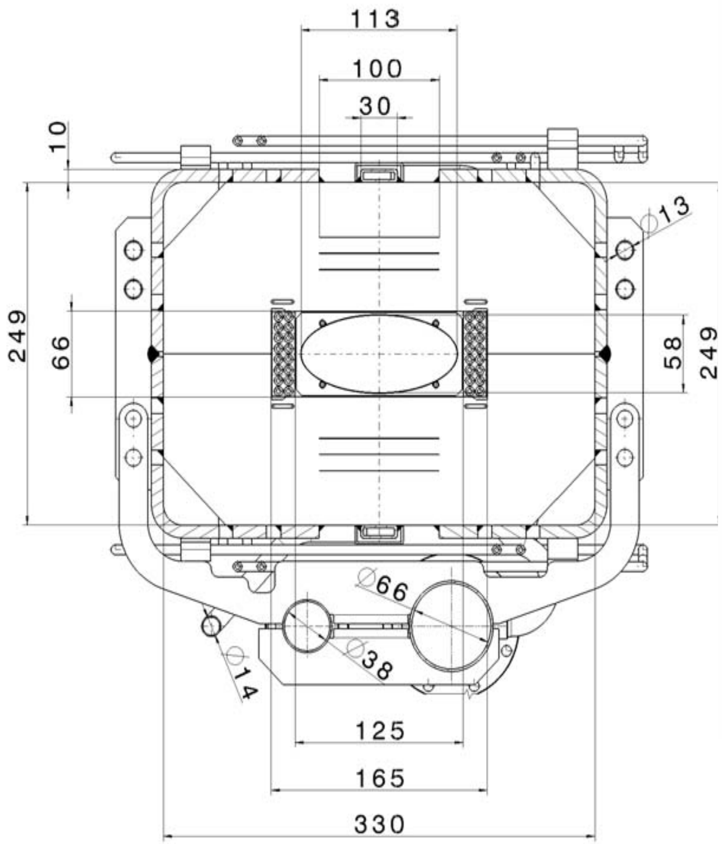
Full Size Model: Quadrupole Manufacturing at JINR

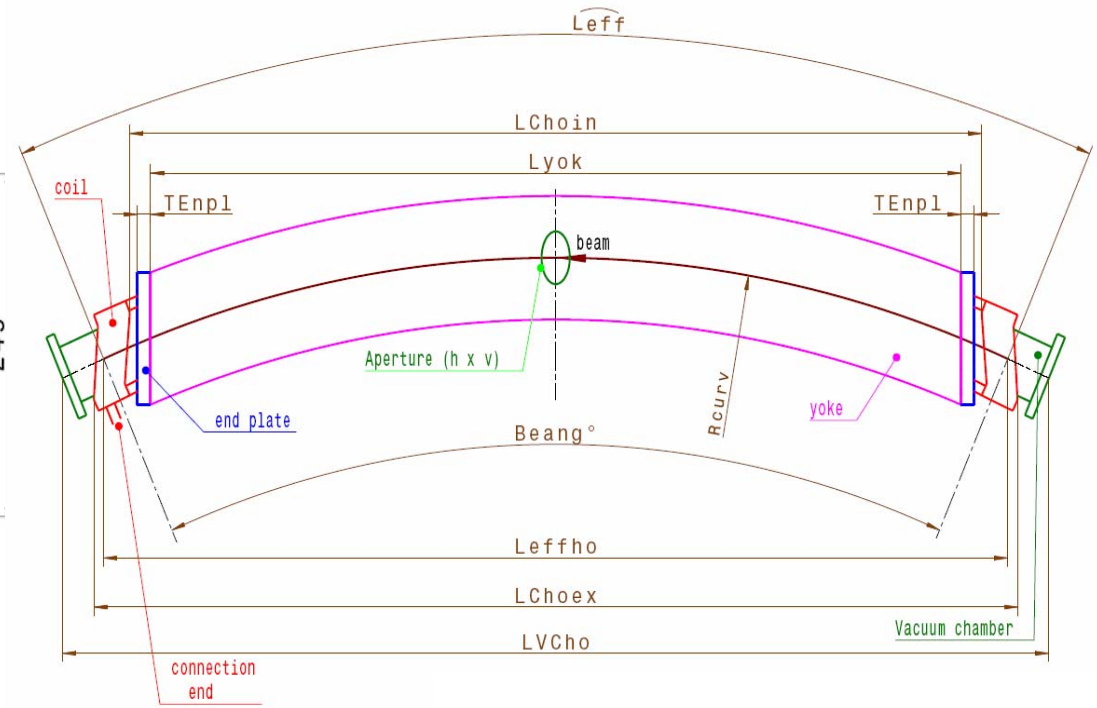




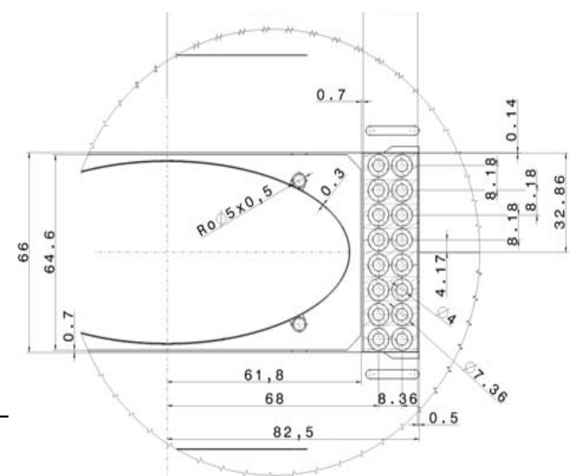
Photos of the manufactured quadrupole

Full Size Model: Curved Dipole Geometric Parameters

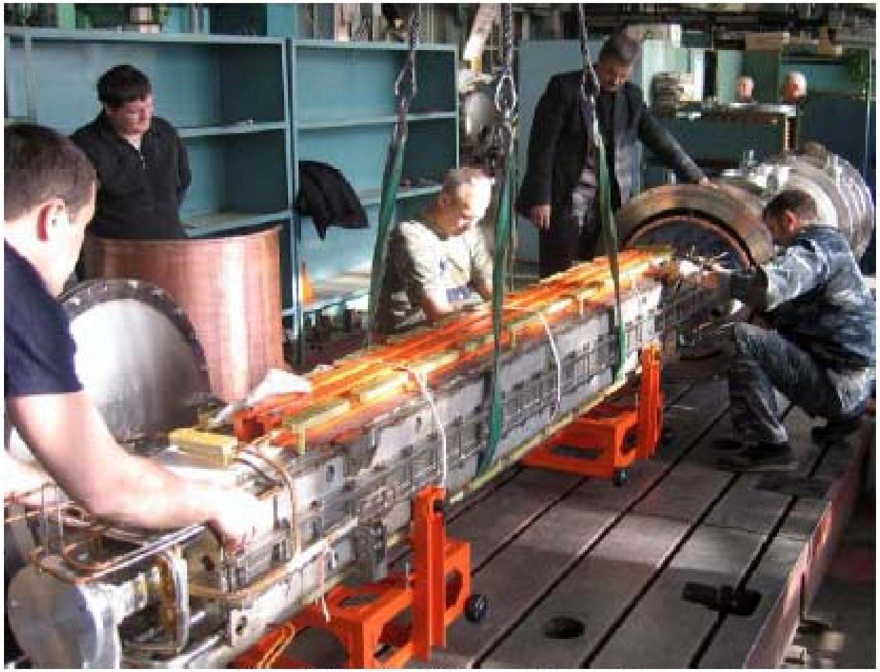




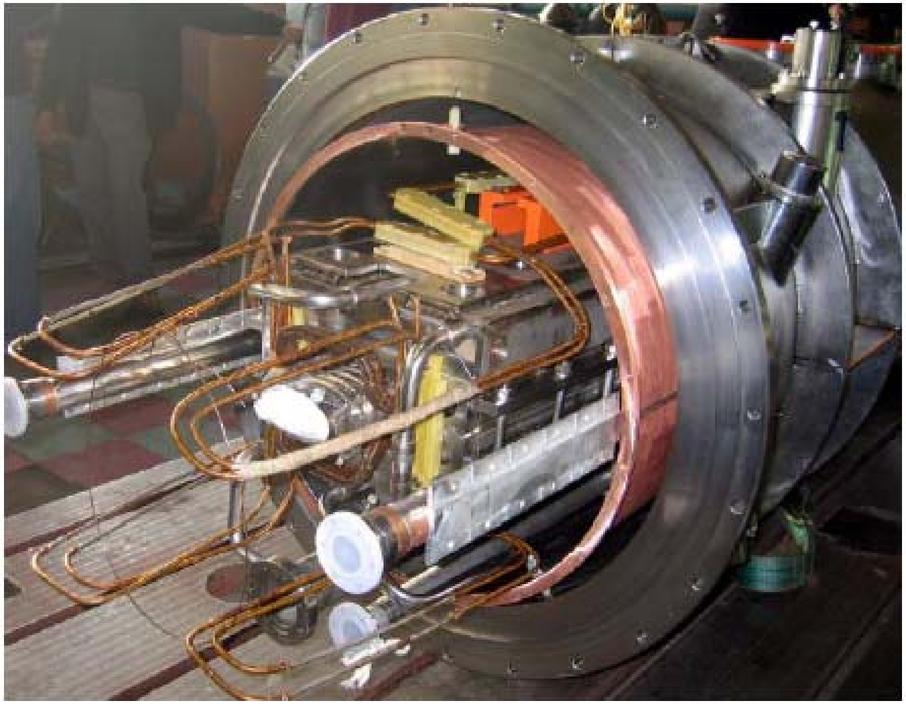
► **Geometrical details and dimensions**



Full Size Model: Curved Dipole from BINP



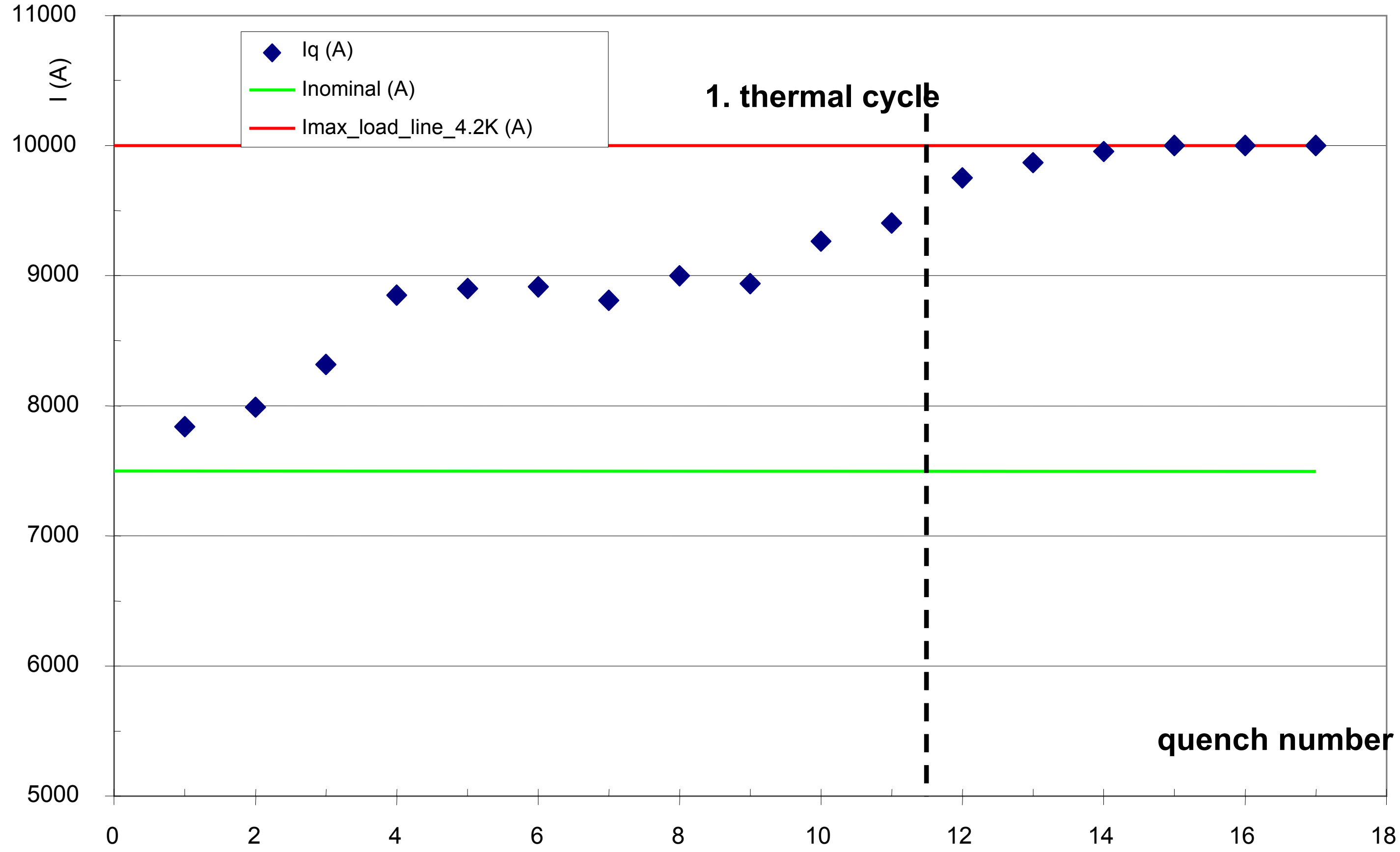
Inserting the dipole into the cryostat



Magnet in cryostat

- ► **Yoke and cryostat from BINP Novosibirsk**
- ► **SC coil produced at JINR Dubna**
- ► **completion for testing at GSI**

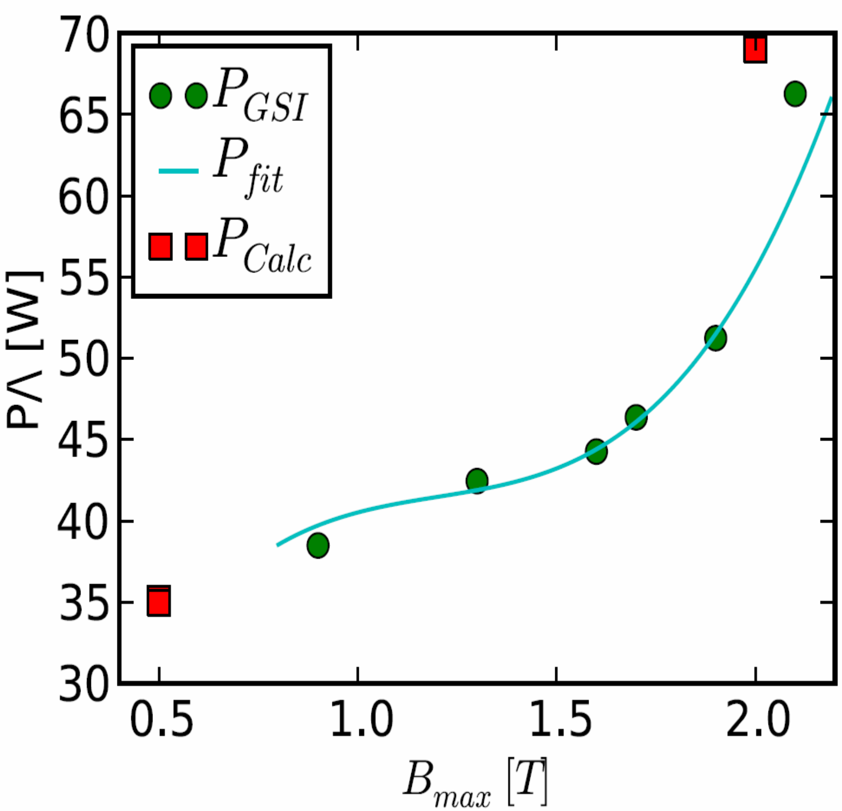
Measurement Results: Magnet Training

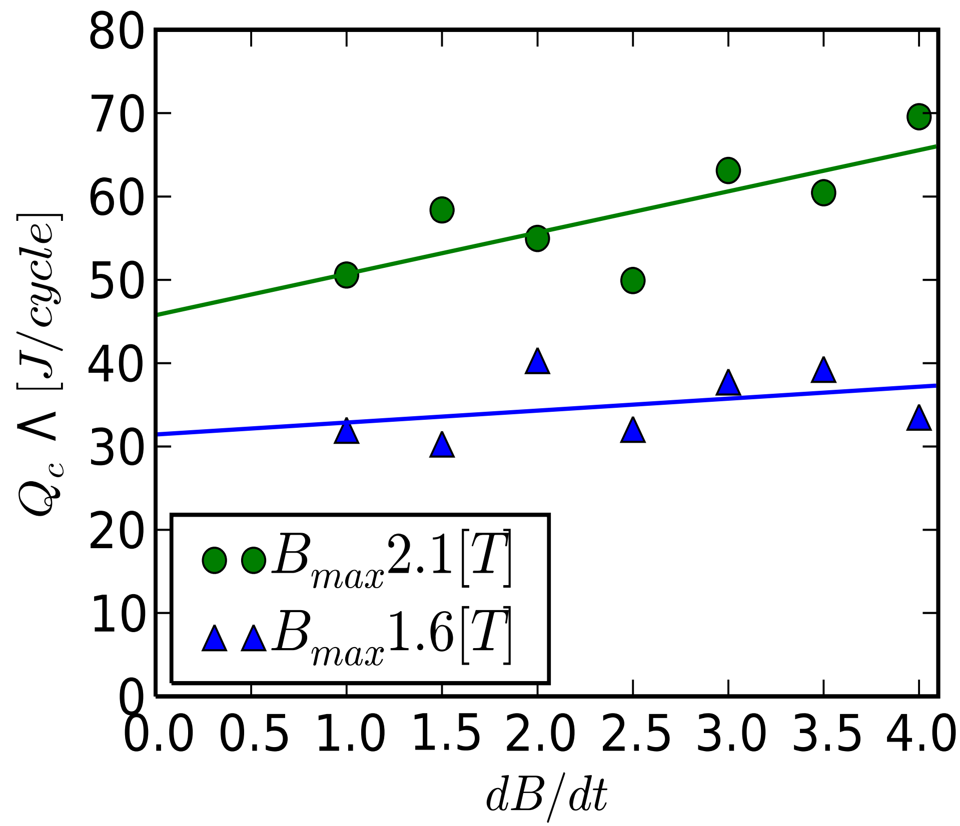


Last quenches at short sample limit (maximum limit of cable)
Quench over whole coil; no mechanical movement

HELMHOLTZ GEMEINSCHAFT GSI FAIR

Measurement Results: Magnet Losses

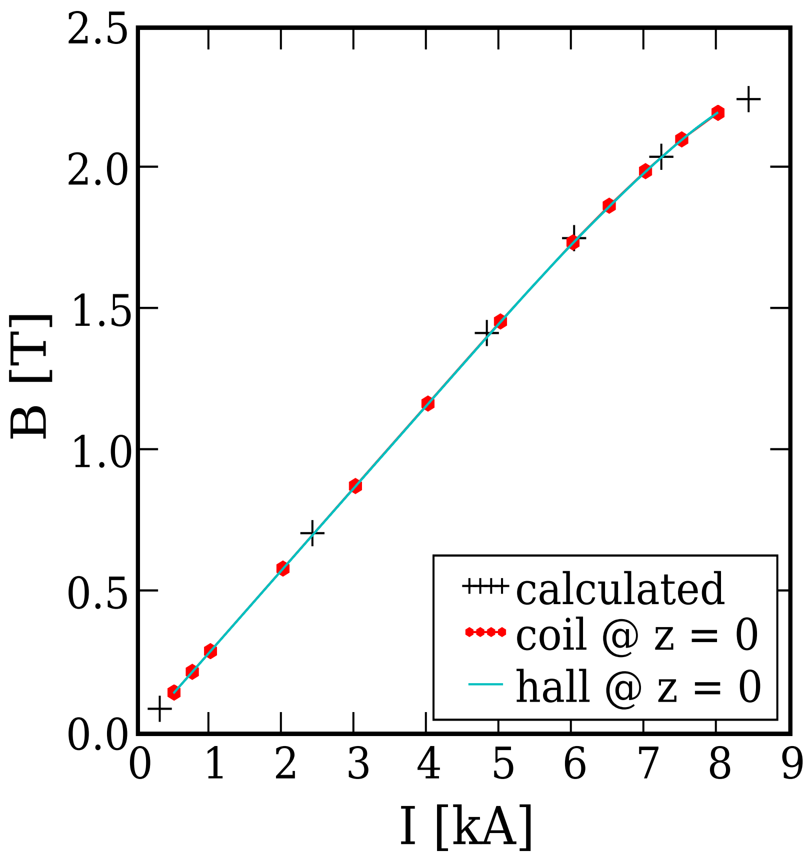




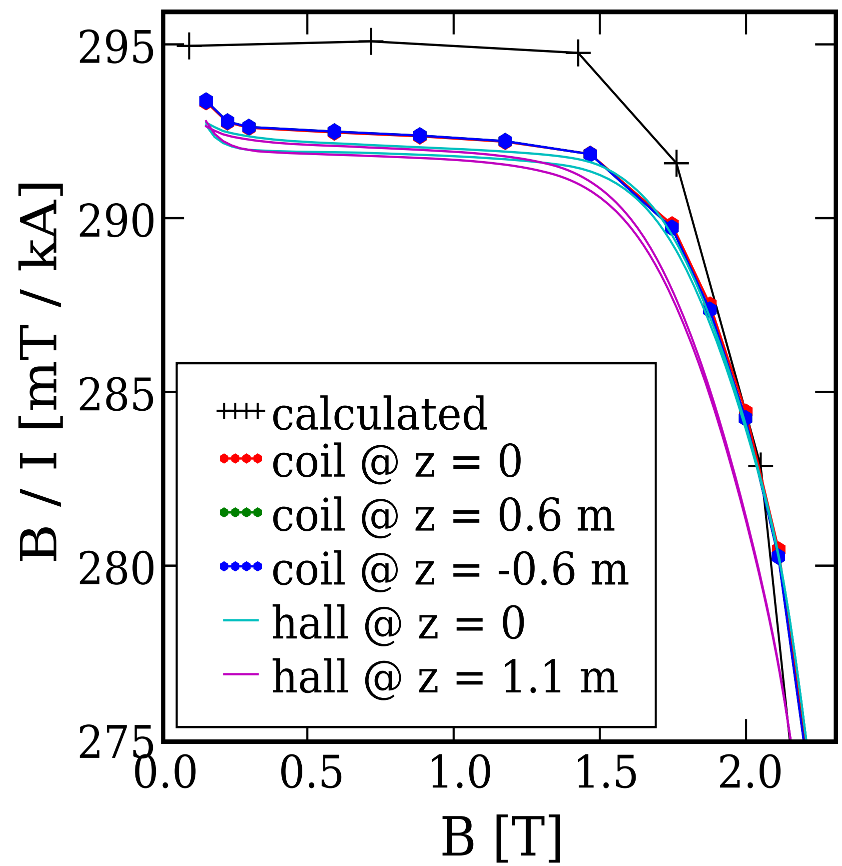
dB / dt = 4 T/s

Preliminary results within good agreement with calculations (ANSYS, and extrapolation from short model magnet measurements)

Measurement Results: Loadline



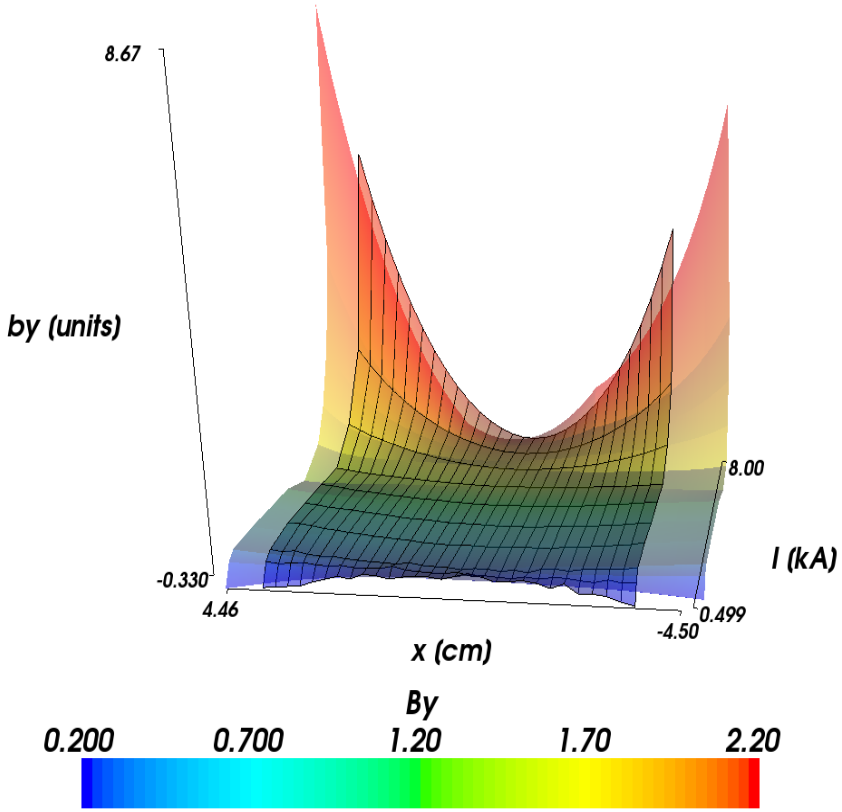
Load Line

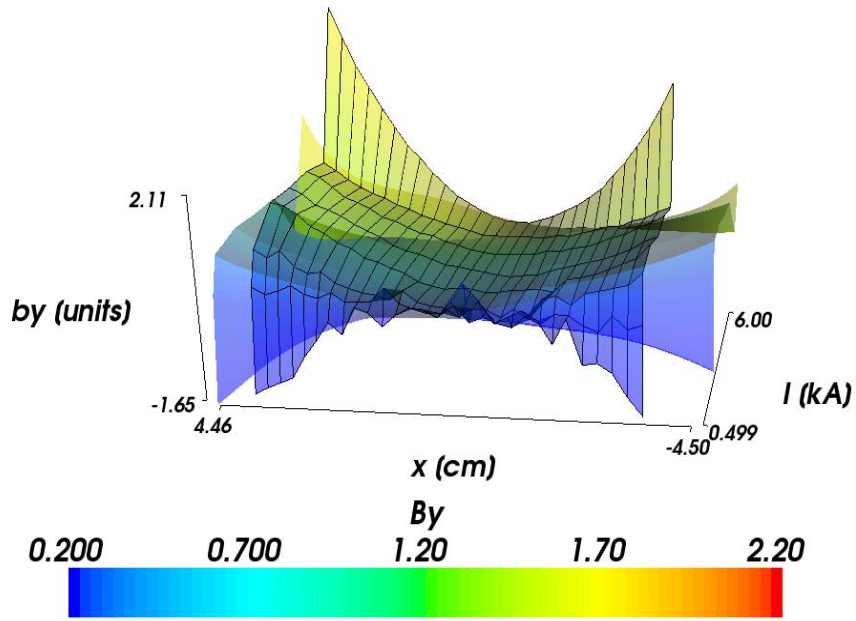


Transfer function

Measurements in good agreement with calculation (only catalog data at 50 / 60 Hz)

Measurement Results: Field Homogeneity





Field deviation in an area +/- 45 mm less than 2 units up to 1.75 T

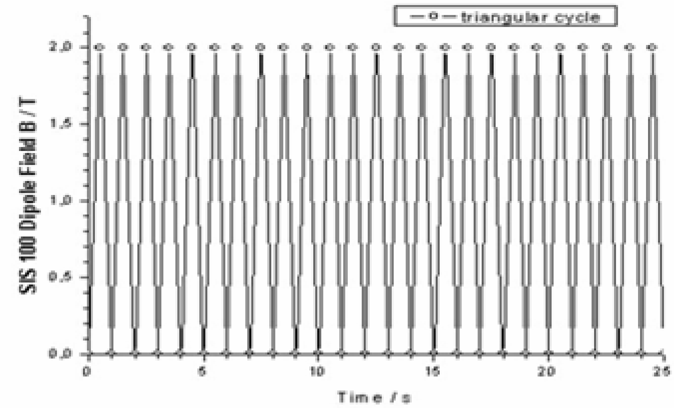
Coil probe (centre) agree well with Hall Probes @ (~1m)

Measurements in good agreement with calculation (only material sheet at 50 / 60 Hz)

Additional Operation Requirements

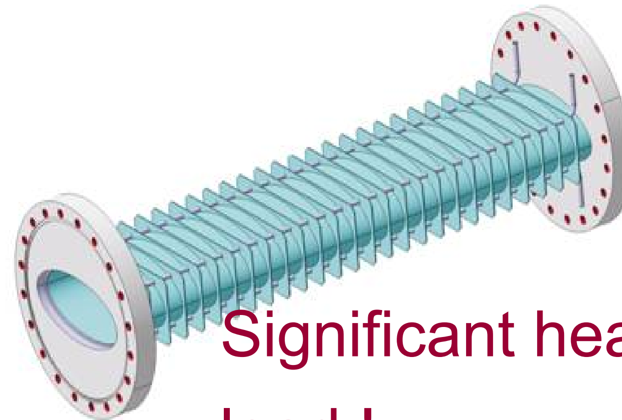
FAIR Supercycles for Parallel Operation

- Purpose: Standard scenario for layout of magnets, cryogenics, power supplies etc.
- Each cycle may run for several hours (... days)
- Different extraction energies may be used, but for the standard supercycles, for each experiment, a typical energy was chosen.
- For the calculation of a mean energy consumption of the accelerator complex, a percentage of the annual beam time is assigned to each cycle.
- During commissioning of experiments, many other operation modes may occur.
  - ➢ March 2007: Additional requirements from beam dynamics:
    continously triangular cycle must be provided,
    i.e. B_{max} = 2T, $^{dB}/_{dt}$ = 4 T/s, f = 1 Hz!

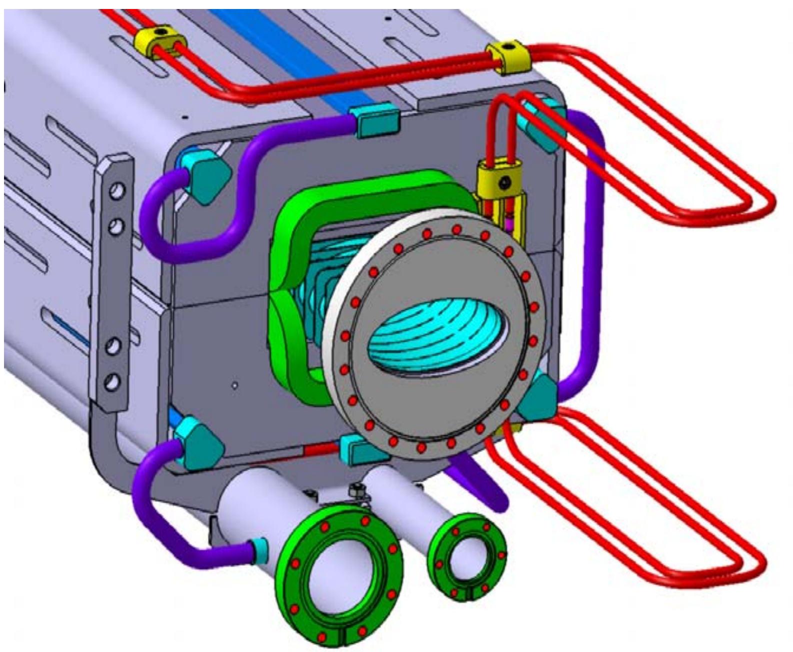


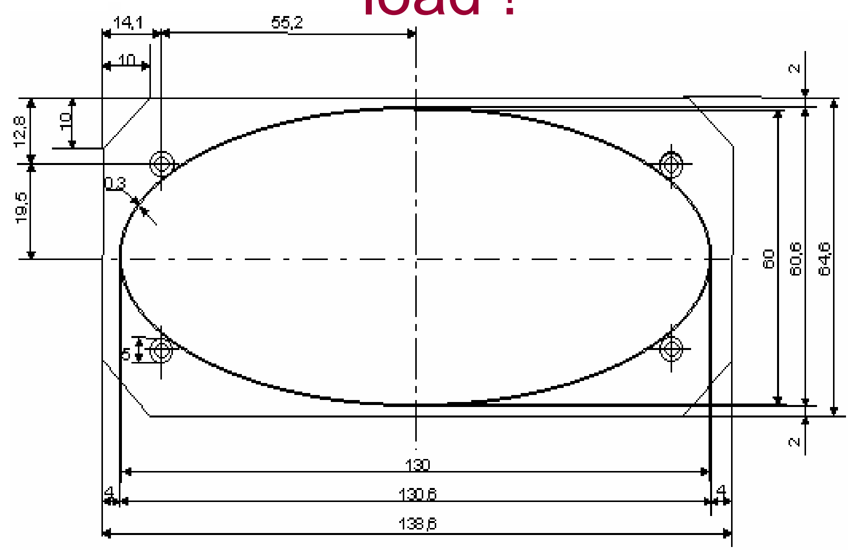
Additional Requirements: Beam Pipe as Cryopump

- **elliptical cross section**
- **wall thickness: 0.3 mm (minimize AC-losses!)**
- **strengthening of chamber by ribs**
- **T_{max} < 15 K (to be cooled by forced flow or yoke)**



Significant heat load !

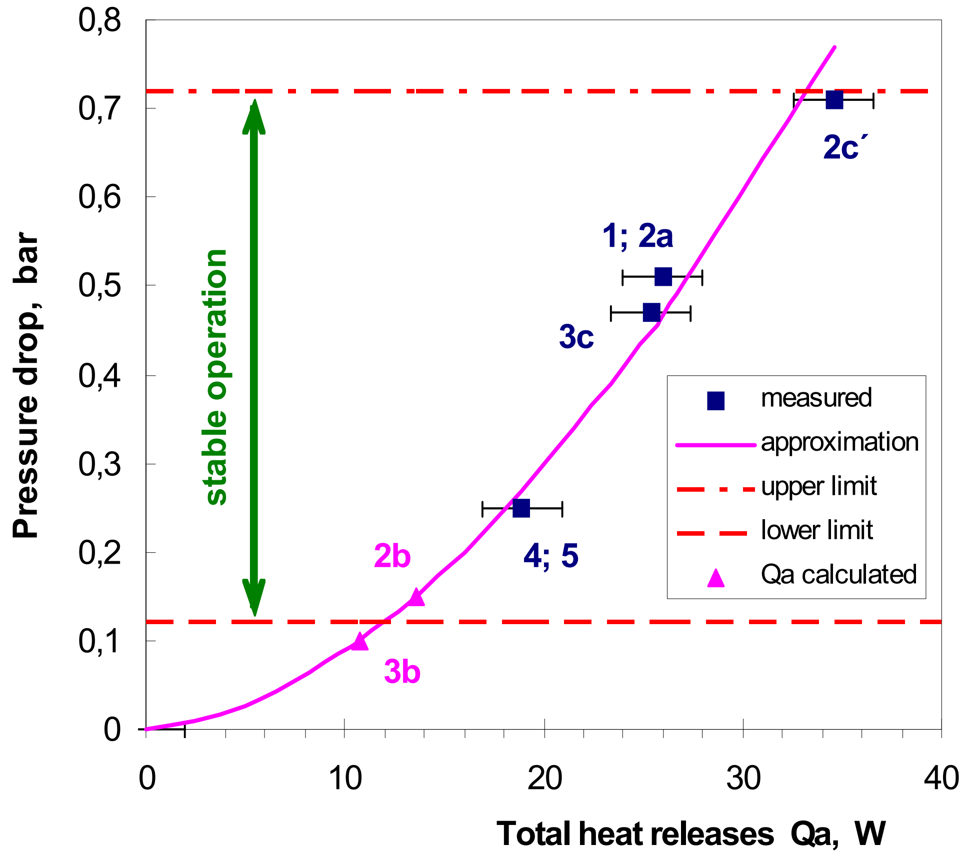


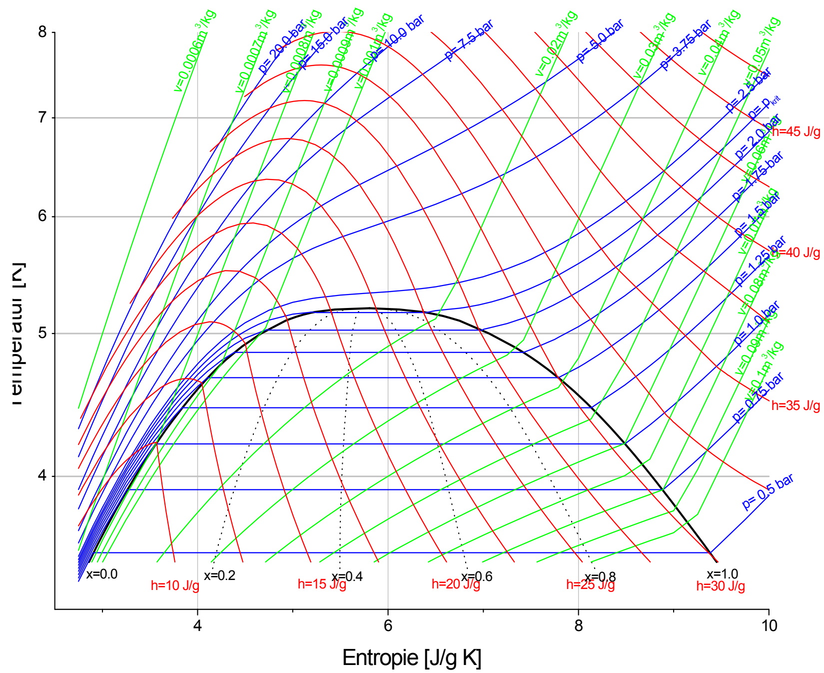


Schematic drawing of cross section of the dipole vacuum chamber

Operation Performance: Full Length Composite Dipole

The hydraulic restistance of the coil limits the feasibility of the

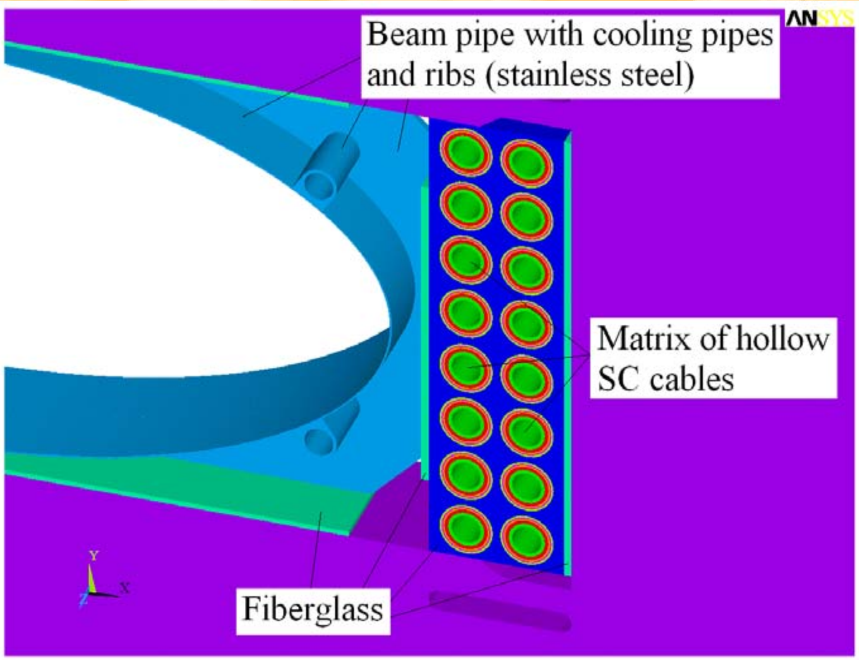


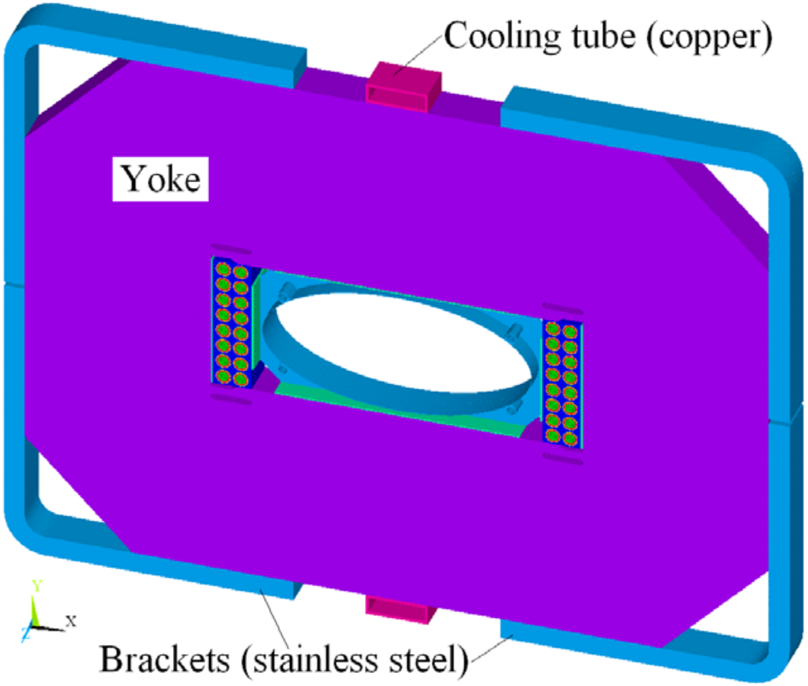


Confirmed by the Measurements on the Full Size Straight Dipole (BNG)

E. Fischer et al: *Fast Ramped Superferric Prototypes and Conclusions for the Final Design of the SIS 100 Main Magnets* ASC 2008

Vacuum Chamber Issues





Vacuum chamber:

ribs & cooling pipes

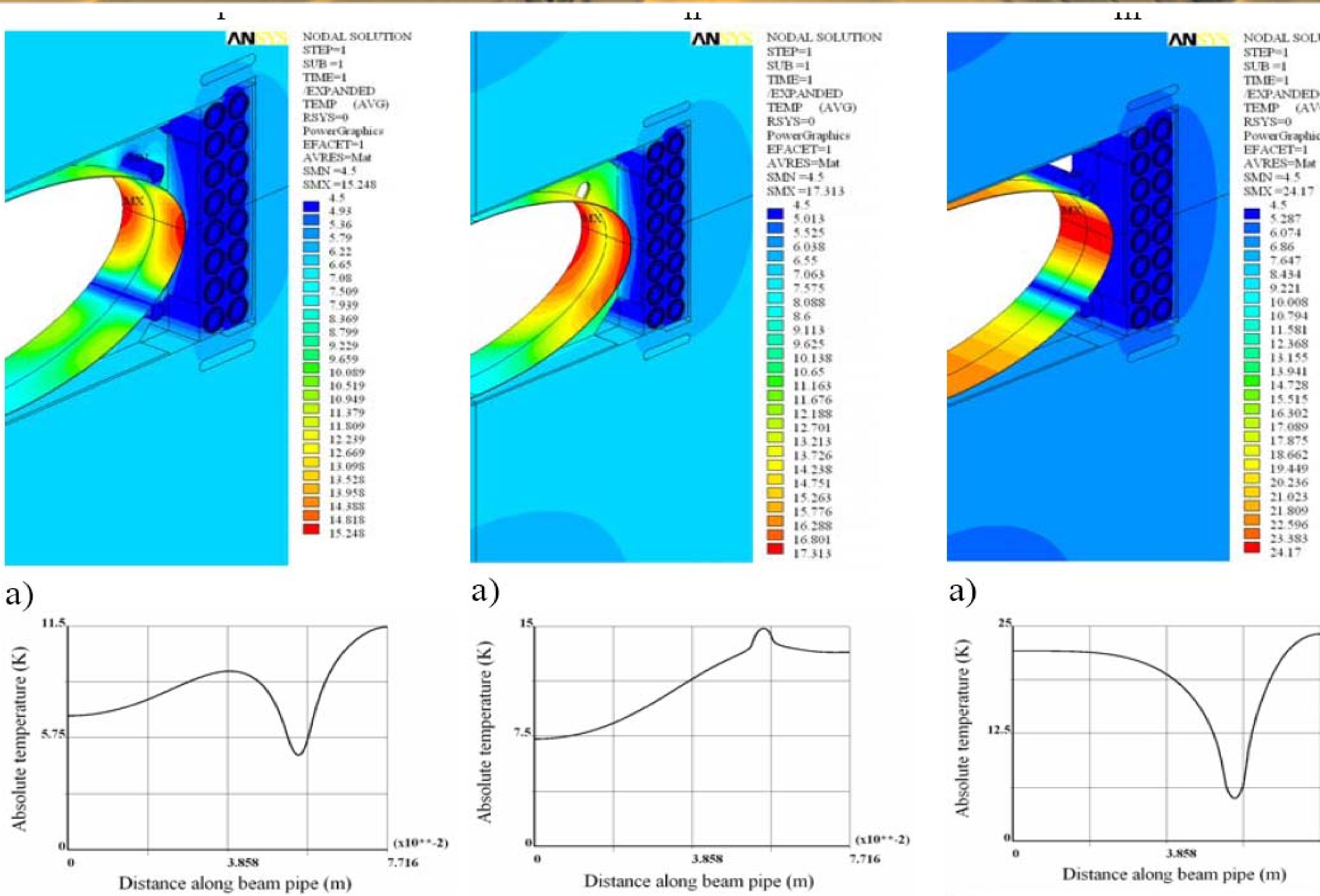
Additional 25 W heat load (= 1/3 of the magnet)

E. Fischer, R. Kurnyshov, and P. Shcherbakov, "*Analysis of coupled electromagnetic-thermal effects in superconducting accelerator magnets*", EUCAS *2007*

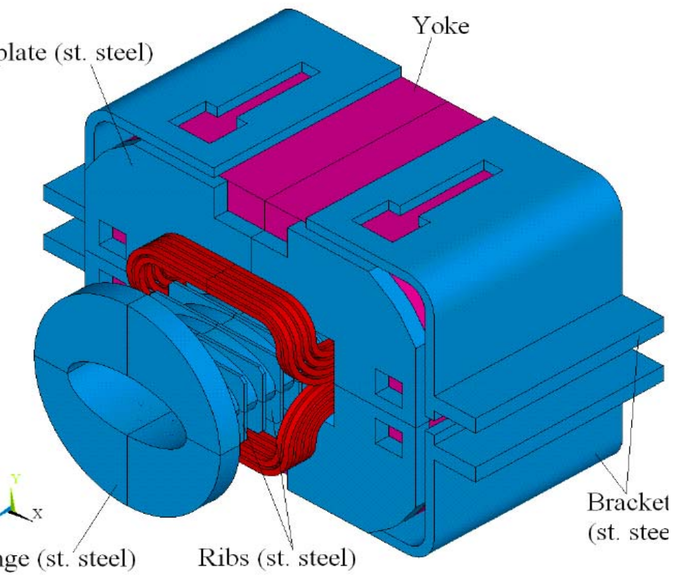
Vacuum Chamber: Calculation Procedure

- vacuum chamber in defined contact with yoke and coil (using G10 inserts)
- transient analysis steady state after 60 cycles
- used steady state mode for thermal calculations
- Different options studied
  - design as built by BNG
  - without cooling tubes
  - without ribs
- First steps started

Vacuum Chamber: Temperature Profile



Vacuum Chamber Issues: Heat Loads

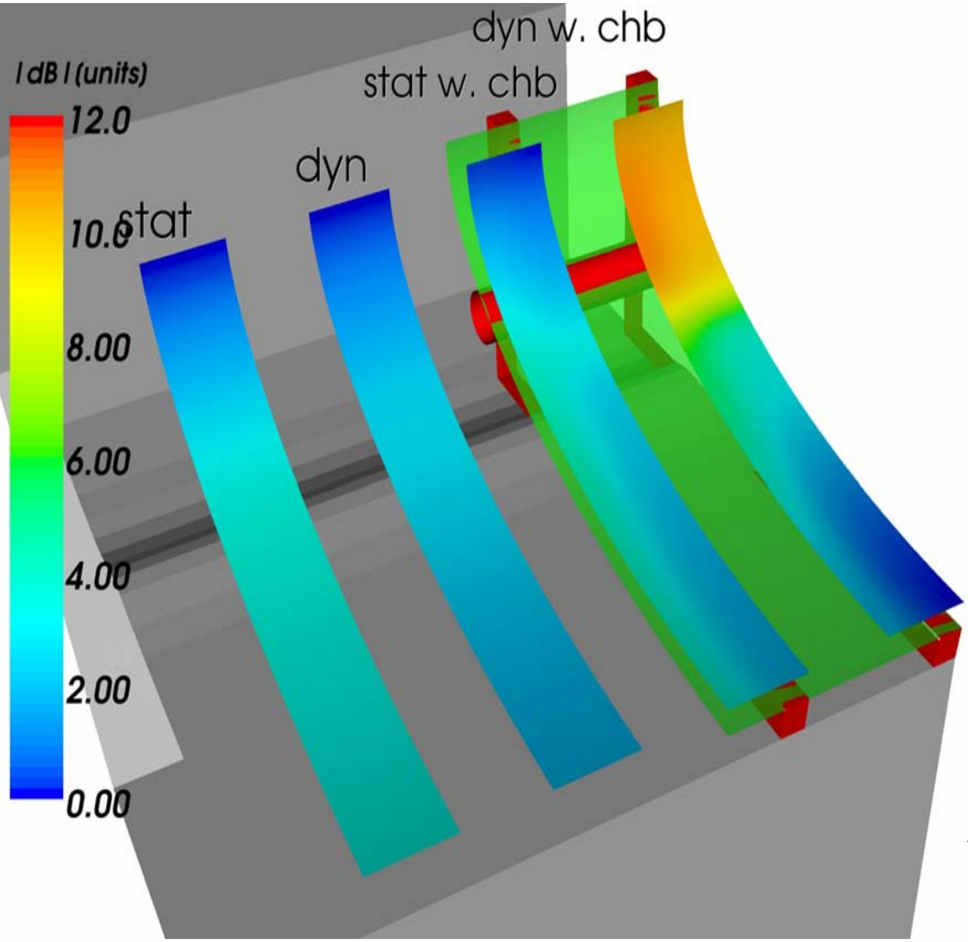


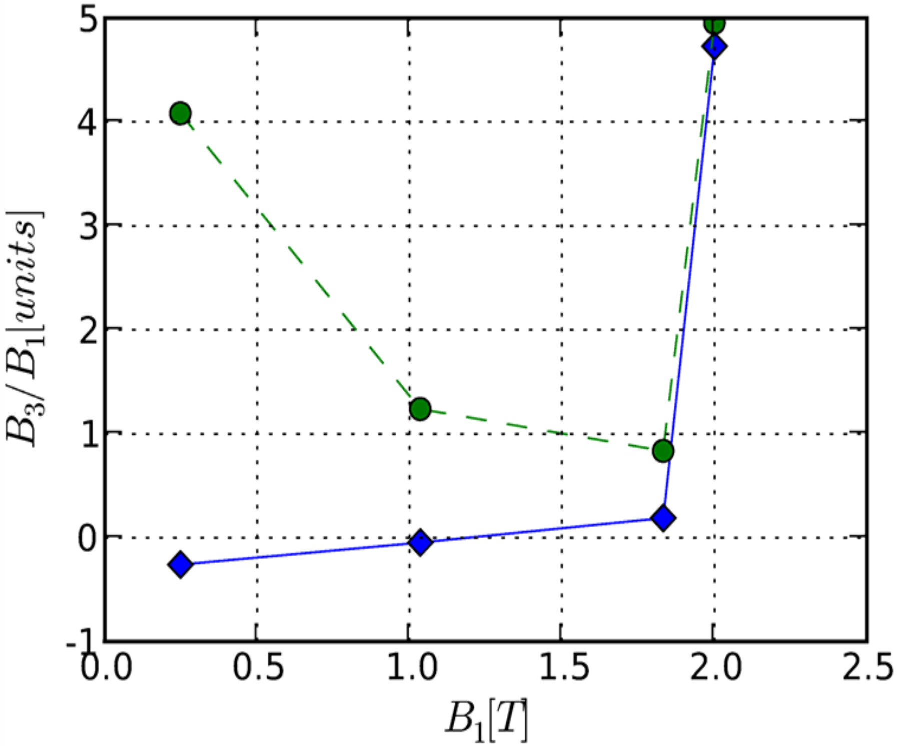
E. Fischer, et al. "*Numerical Analysis of the Operation Parameters of Fast Cycling Superconducting Magnets*" 2LPK07 ASC 2008

cycle	2a H	2a E	2b H	2b E	2c H	2c E	∧ H	∧ E
				magnet central part				
yoke	0.6	0.1	3.6		11.8	0.3	23.7	0.6
				magnet end part				
brackets				0.4		0.7		1.2
endplates		1.1		3.3		3.8		8.0
yoke		0.4	0.8	1.5	2.2	3.0	4.0	5.3
				beam pipe central part				
pipe		1.7		4.7		6.7		13.9
tubes		0.7		1.9		2.7		5.6
ribs		0.1		0.2		0.3		0.6
				beam pipe end part				
pipe		0.3		0.7		0.9		1.9

Total	2a	2b	2c	∧
magnet				
centre	0.7	3.9	12.2	24.5
end	1.8	6.0	9.7	18.5
coil	8	2	11	22
total	10.5	11.8	32.9	65.0
vacuum chamber	2.8	7.6	10.6	22.2
total load	13.2	19.4	43.5	87.1

Vacuum Chamber Issues: Field Quality





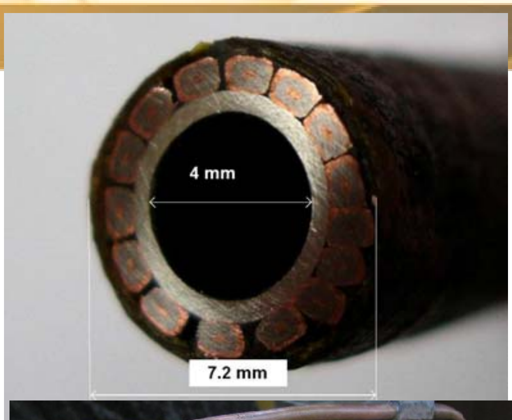
Vacuum chamber: ribs & cooling pipes eddy currents large field deviation at injection

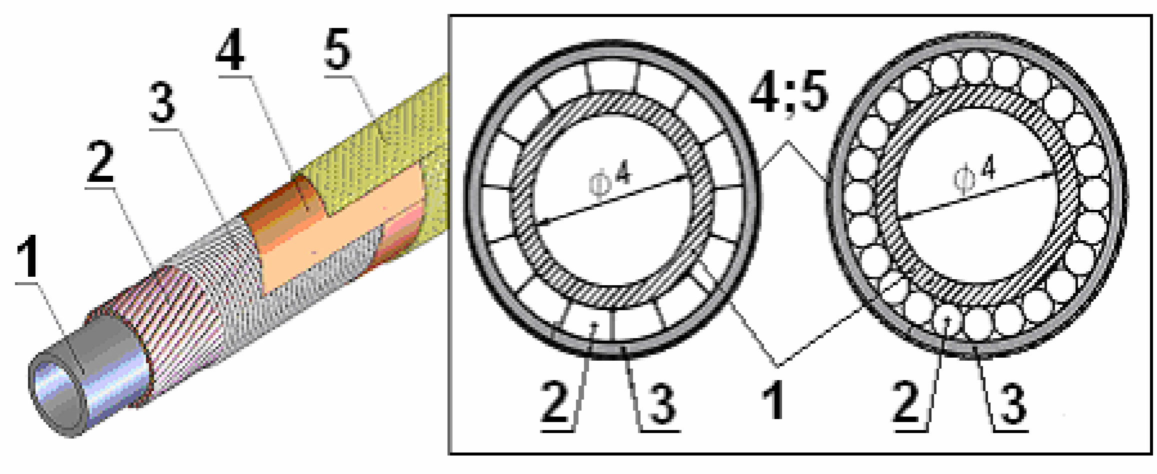
see also E. Fischer et al, *Numerical Analysis of the Operation Parameters of Fast Cycling Superconducting Magnets* ASC08

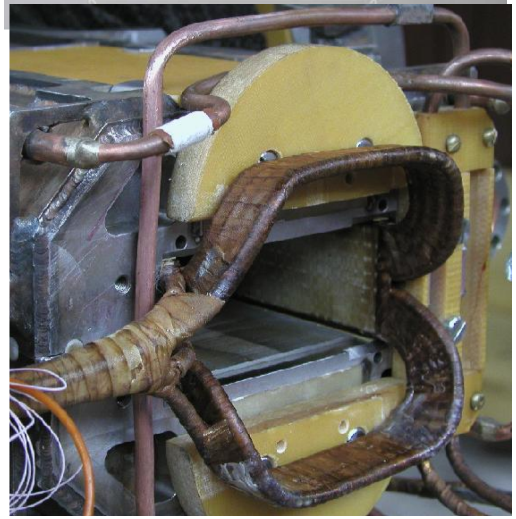
Conclusions toward the Final Dipole Design

- **The estimated limits of the actual full size models are not sufficient for the recently changed requirements of the SIS100 machine (also a significant operation margin has to be provided).**
- **Redesign options to satisfy the updated operation parameters:**
  - **new cable design (with lower hydraulic resistance)**
  - **shorter coil length**
  - **CSLD (curved single layer dipole)**

Magnet Design Options: new cable and single layer coil





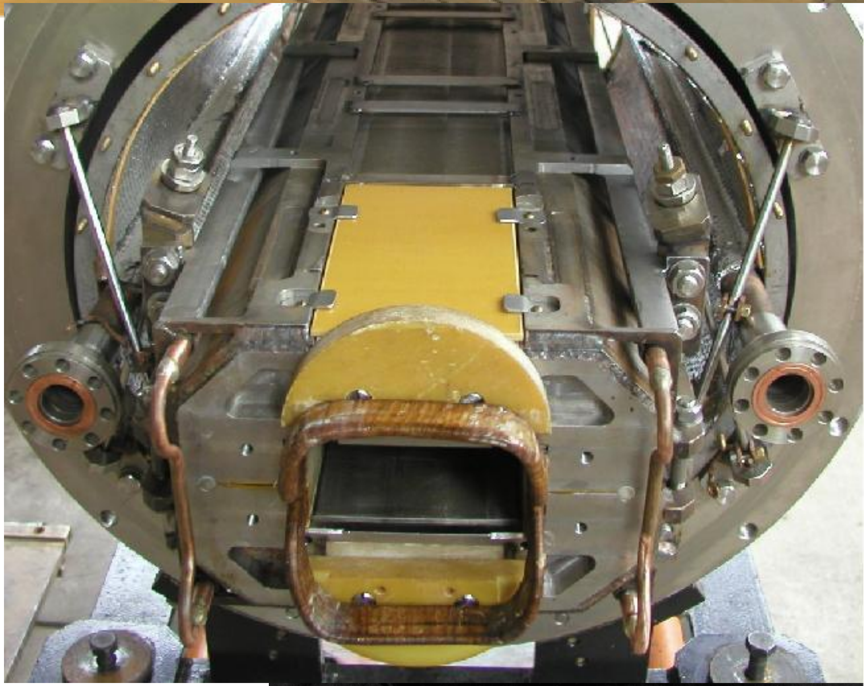


"DESIGN AND TEST OF A HOLLOW SUPERCONDUCTING CABLE BASED ON KEYSTONED NbTi COMPOSITE WIRES", ASC 2004, October 2004, Jacksonville, USA H. G. Khozhibagiyan et al., ASC2004, Jacksonville, Florida, USA, IEEE Trans. on Supercond., Vol. 15, No. 3, Part II, pp. 1529-1532, June 2005

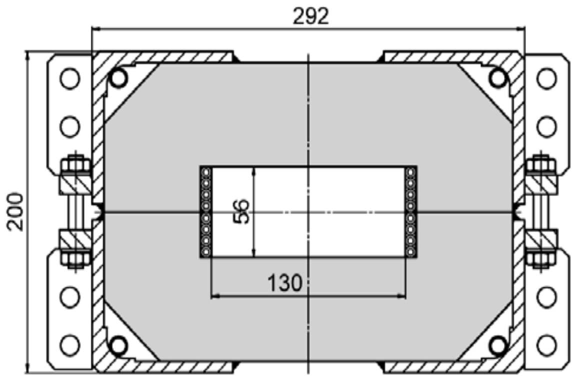
➢ **cycle limit estimations for a round wire cable CSLD with 8 turns (detailed specification in MT-INT-EF-2007-002, GSI):**

Dynamical heat release (cycle 2c)	W	≈ 31
Pressure drop for cycle 2c	bar	≈ 0.42
Maximal temperature of helium in the coil (2c)	K	4.7
Dynamical heat release (B_{max} = 1.9 T, f = 1 Hz)	W	≈ 54
Pressure drop (B_{max} = 1.9 T, f = 1 Hz)	bar	≈ 0.7
Maximal temperature of helium in the coil (triangular cycle with B_m = 1.9 T, f = 1 Hz)	K	4.8

Design and Test of a Single Layer Coil Model



- advantages of a high current cable:
  - single layer coil
  - allows reducing the <u>aperture</u> and AC loss
  - <u>simplifies cooling</u>
  - simpler coil mechanics



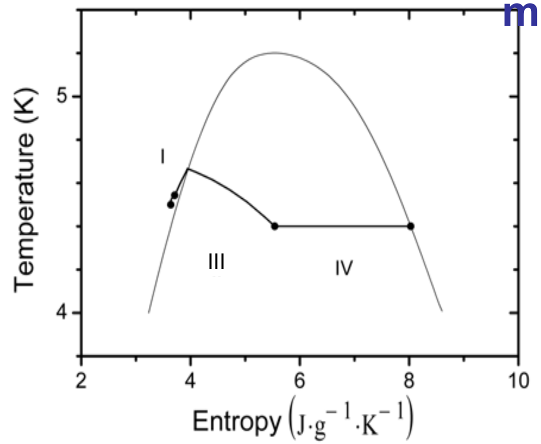
model dipole with a single layer coil, tested at JINR Dubna in 2004 and quadrupole in 2006

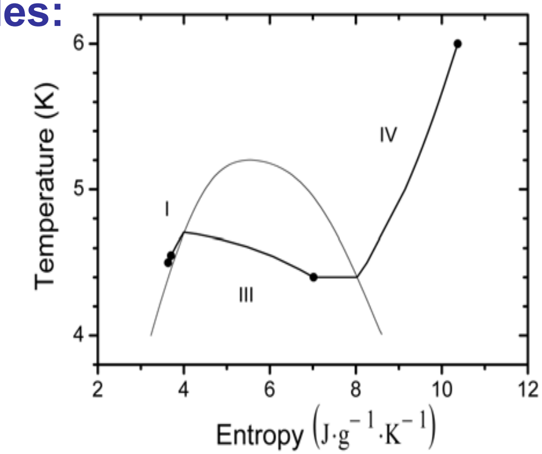
Main Operation Parameters of the CSL-Dipole

Parameter \ Version	**straight**	**curved**	**C2LD-a**	**CSLD**
Maximum field, T	2.11	1.9	1.9	1.9
Magnetic length, Tm	2.756	3.062	3.062	3.062
Turns per coil	**16**	**16**	**16**	**8**
Usable aperture, mm^2	130 · 60	115 · 60	115 · 60	140 · 60
Cables				
Number of strands	**31**	**31**	**38**	**23**
Outer diameter, mm	7.36	7.36	7.5	8.25
Cooling tube inner diameter, mm	**4**	**4**	**4.7**	**4.7**
Length of the cable in the coil, m	110	110	110	57
Bus bars length, m	37	39	39	39
Operating current	**7163**	**6500**	**6500**	**13000**
Critical current @ 2.1 T, 4.7 K	11900	11900	11900	19840
Wires				
Strand diameter, mm	**0.5**	**0.5**	**0,46**	**0.8**
Filament diameter, µm	2.5 - 4	2.5 - 4	2.5 - 4	3.5 - 4
Filament twist pitch, mm	4 – 5	4 – 5	4 - 5	5 - 8
loss and hydraulic				
Static heat flow, W	7	7	7	7
Heat load to bus bars, W	0.5	0.5	0.5	0.5
cycle 2c				
AC losses, W	36.3	35.4	35.4	35.7
Pressure drop, bar	1.10	1.15	0.604	0.389
T_{max} of *He* in the coil (for $x_6 \approx 1$), K	4.94	4.95	4.78	4.64
triangular cycle [dB/dt = 4 T/s, $t_{cycle} = 2 \cdot B_{max} / (dB/dt)$]				
AC losses, W	75.1	74.0	74.0	74.6
Pressure drop, bar	**1.14**	**1.20**	**0.657**	**0.486**
T_{max} of *He* in the coil, K	5.08 at T_6=8K	5.10 at T_6=8K	4.86 at T_6=8K	4.72 at T_6=7K

for details see →

Curved Single Layer Dipole at intensive ramping modes:





T – S diagrams for the CSLD operation

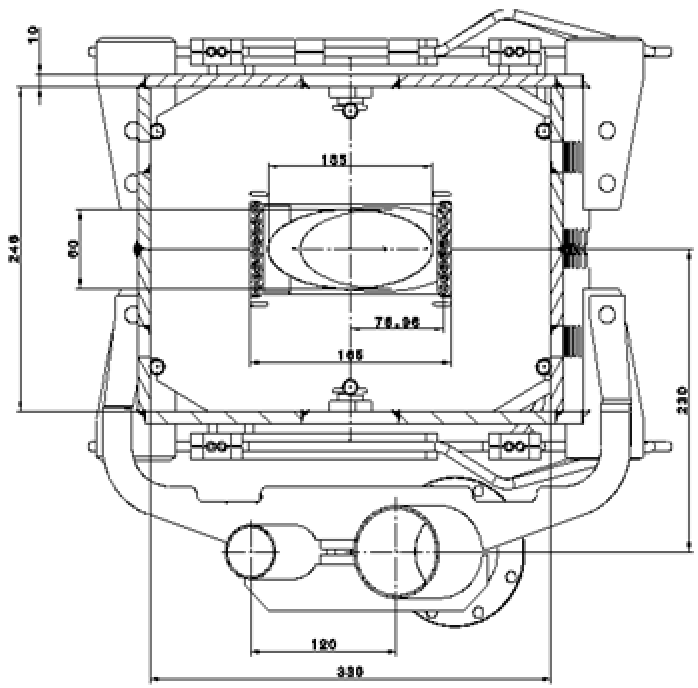
Helium flow trough the bus bars I, the coil III and the iron yoke IV at cycles - 2c (left) and triangular (right)

Single Layer Dipole:
"Minimization of AC Power Losses in Fast Cycling Window Frame 2T Superferric Magnets with the Yoke at T=4.5K",E.Fischer et al., ASC 2004, 3LR04; Internal Note GSI: MT-INT-EF-2004-09

Curved Single Layer Dipole:
"Full Size Model Magnets for the FAIR SIS100 Synchrotron"; Egbert Fischer, Hamlet Khodzhibagiyan, Alexander Kovalenko; MT-20; 4V07; 2007; Internal Note GSI: MT-INT-EF-2007-03

Dipole Redesign: Magnet Parameters (TDR)

Name of the magnet		SIS 100 Main Ring Dipole
Number of magnets		108 + 1 reference magnet
Design		Window-frame, laminated cold iron yoke, lamination thickness 1mm, **one layer coil with 8 turns**
Max. Field	T	1.9
Min. Field	T	0.23
Bending angle	Deg.	3.33
Edge angles (entrance / exit)	Deg.	1.665 / -1.665
Orbit curvature radius, R	m	52.632
Effective magnetic length, L	m	3.062
Coil aperture	mm	165 · 68
Useable aperture (good field region):	mm	135 · 60
Field quality (goal)		$\pm 6 \cdot 10^{-4}$
Overall magnet length (slot length)	m	3.354
Overall width (cryostat)	m	1.0
Overall height (cryostat)	m	1.0
Overall weight	kg	1850
Current at max. field	A	12745
Inductance	mH	0.55
Ramp rate	T/s	4
High field flat top duration	s	0.1
Low field flat top duration	s	0.8
Cycle length	s	1.82
Total AC loss per cycle @4.2K per magnet (cycle number 2c)	J	18.9



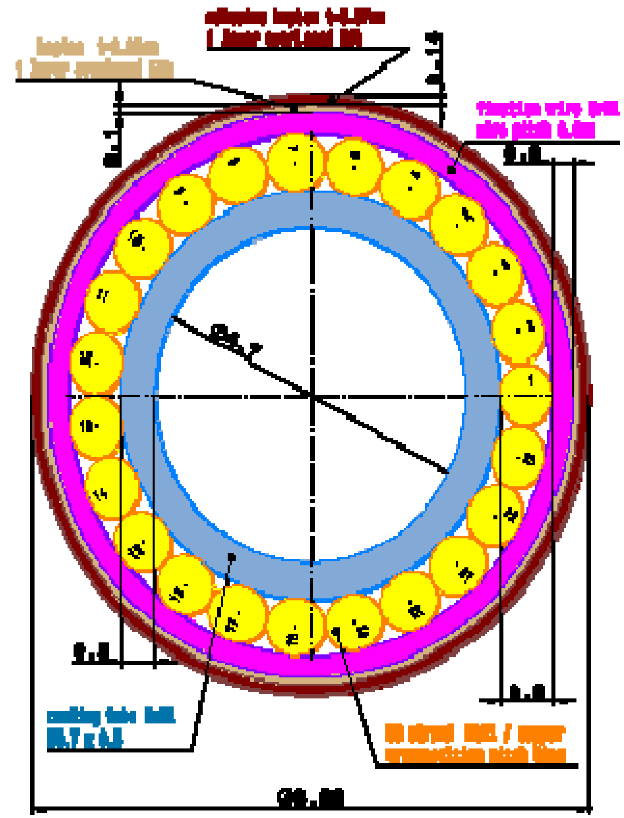
curved single layer dipole (CSLD)

(details: see Technical Design Report,

GSI Darmstadt, 2008)

Dipole Redesign: Cable Parameters (TDR)

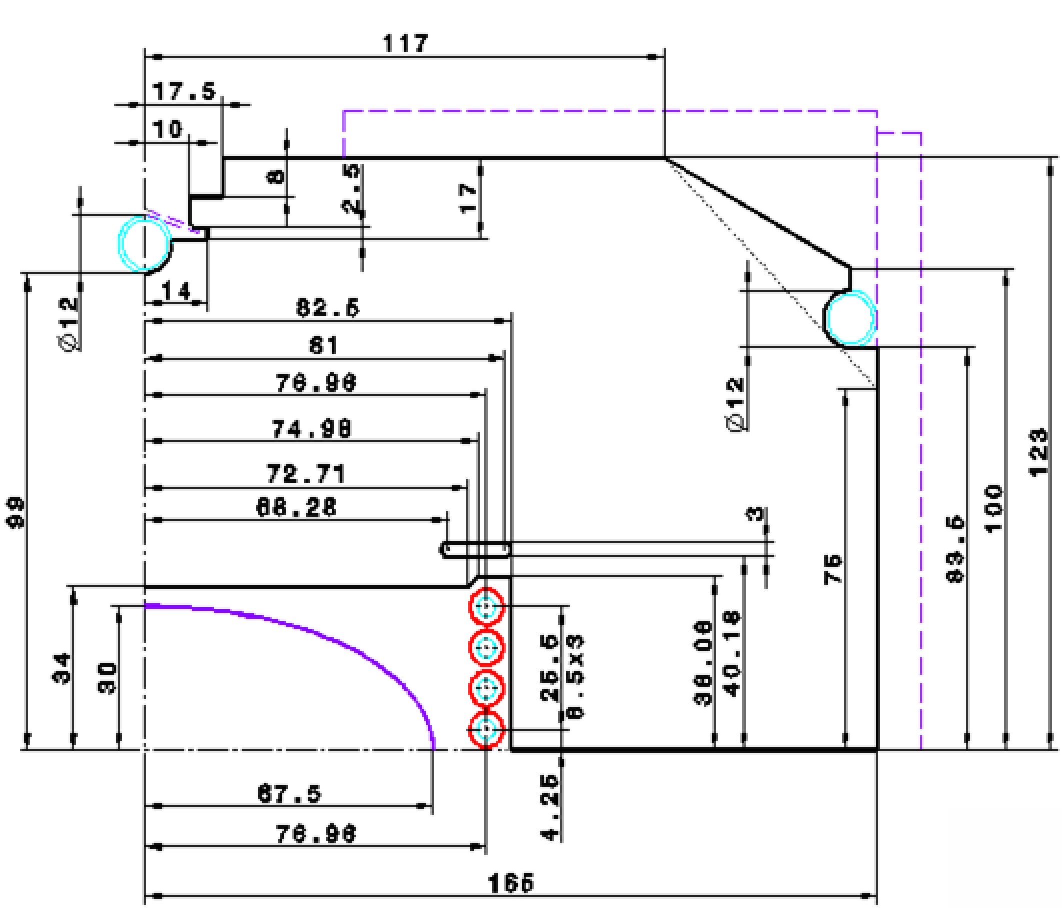
Number of strands			23	
Transposition pitch			50	mm
Cooling tube material			Cu-Ni	
Cooling tube outer diameter			5.7	mm
Cooling tube wall thickness			0.5	mm
Critical current @ 2.1 T, 4.2 K			19840	A
1st insulating layer	with epoxy impregnation			
material	kapton	tape	2	layers
thickness/layer			50	microns
2nd insulating layer	with epoxy impregnation			
material			2	layers
thickness	kapton	tape	70	microns
Wire				
Strand diameter			0.825	mm
Filament diameter			3.5	microns
Number of filaments			18144	
Filament twist pitch			5-8	mm
Superconducting material			NbTi	
Copper to superconductor ratio			1.5	
Copper RRR			196	
Transverse resistivity				Ωm
Fixation of the strands	CrNi-wire	D=0.2	transp. = 0.4	mm
Coating	epoxy compound			



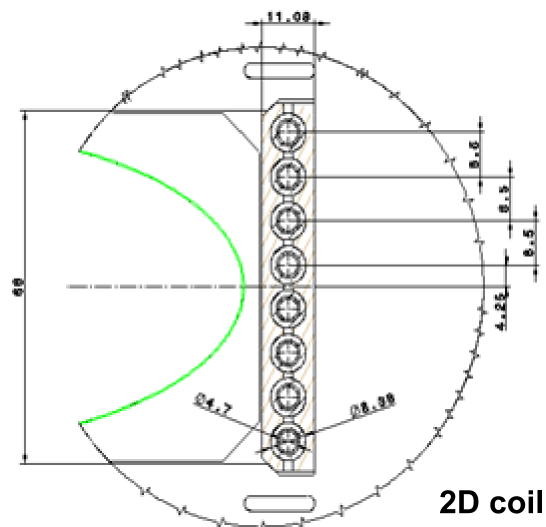
Cross section of the cable adopted for the SIS100 dipole coils (Nuclotron-type cable).

E. Fischer et al: *Fast Ramped Superferric Prototypes and Conclusions for the Final Design of the SIS 100 Main Magnets* ASC 2008

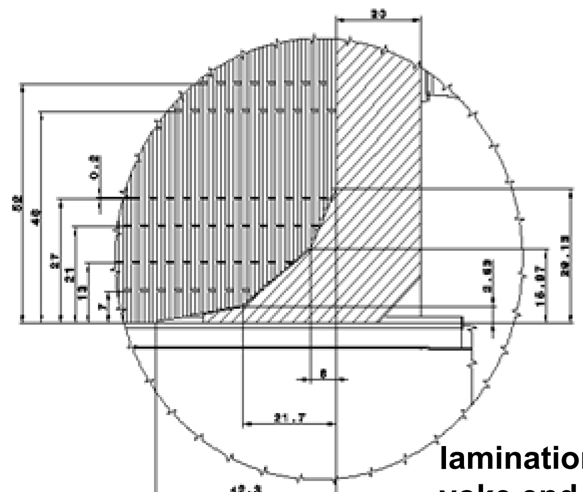
Dipole Redesign: Geometric Details (TDR)



lamination geometry



2D coil structure



lamination slits near yoke end

Summary

- The main R&D goals for the SIS100 magnets have been reached and were used to specify the design of the first full length model magnets for industrial production.
- The first full size dipole is being testing at GSI, a second dipole, a quadrupole and a curved dipole will be tested at GSI and JINR in 2009.
- The first test results (BNG dipole) confirm our R&D results and calculations of AC loss behaviour; magnetic field quality and stable coil mechanics.
- The comprehensive test of these models will give us important information required to optimize the final design and to specify the pre-series magnets.
- The redesign toward an optimized curved dipole with a single layer coil can fulfill the recently updated operation requirements of the FAIR SIS100 accelerator.
- We are sure that we are able to produce the superconducting magnets fulfilling the requirements and operation parameters of SIS 100.

The authors thank all those who contributed to this work, especially all colleagues from the participating laboratories; in particular from JINR Dubna, GSI Darmstadt, BNG Würzburg, BINP Novosibirsk and FZ Karlsruhe.