Magnet technologies and development at IMP

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OUTLINE

- Brief Introduction of IMP magnets
- Normal laminated magnets for CSR
- Super-ferric dipole prototype for FAIR
- Superconducting solenoids
- Summary

Brief introduction

Overview of IMP

HIRFL Layout

HIRFL: Heavy Ion Research Facility in Lanzhou

9.4 Tm, 129m

760 AMeV ($^{12}C^{6+}$)

500 AMeV U^{92+}

12.1 Tm, 161m

1.1 AGeV($^{12}C^{6+}$)

520 AMeV U^{72+}

2.8 GeV(p)

$^{12}C^{6+}$~10AMeV

ECRIS

$^{12}C^{6+}$~100AMeV

Magnets are very important parts or system of accelerators, IMP magnets' technologies developed more than 30 years for constructing and upgrading HIRFL (Heavy Ion Research Facility in Lanzhou) accelerator complex and experimental setup and for new scientific project requirement.

Developing to now, these technologies at IMP not only include calculation and design magnet but also manufacture it, not only massive iron and laminated steel normal magnets, but also super solenoid and super-ferric dipole superconducting magnets, not only Hall-probe points measurement but also long-coil integral measurement and rotating coil harmonic analysis and search coil for ramping field testing.

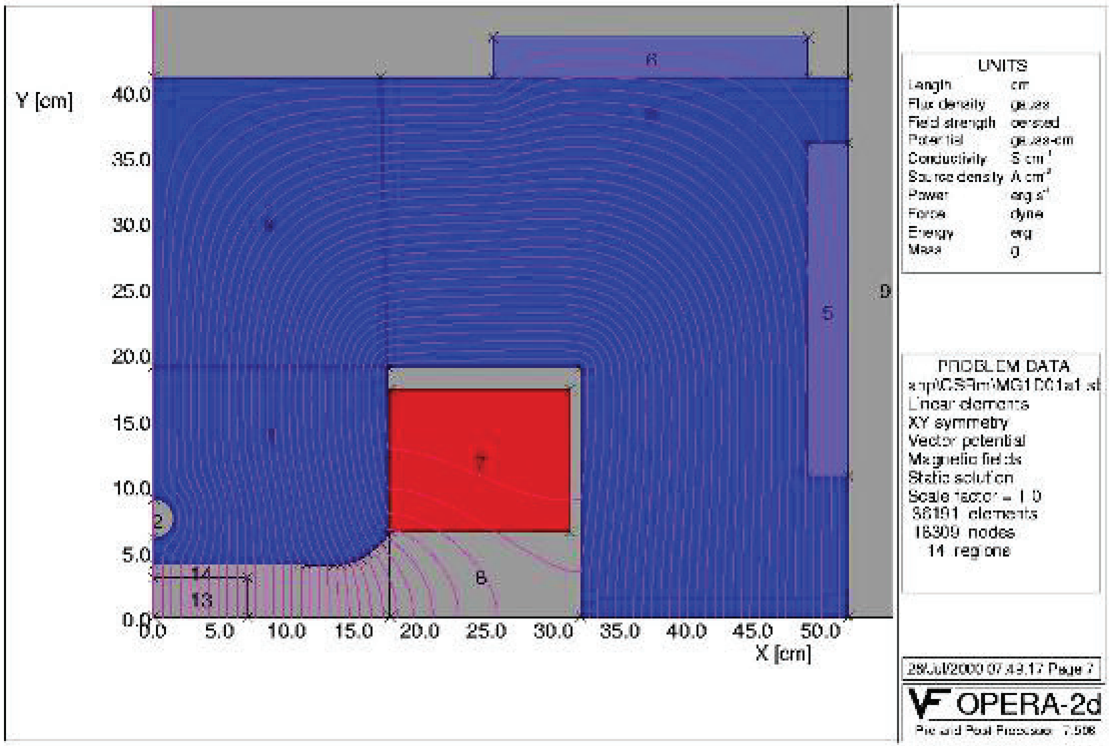
Normal laminated magnets for CSR project

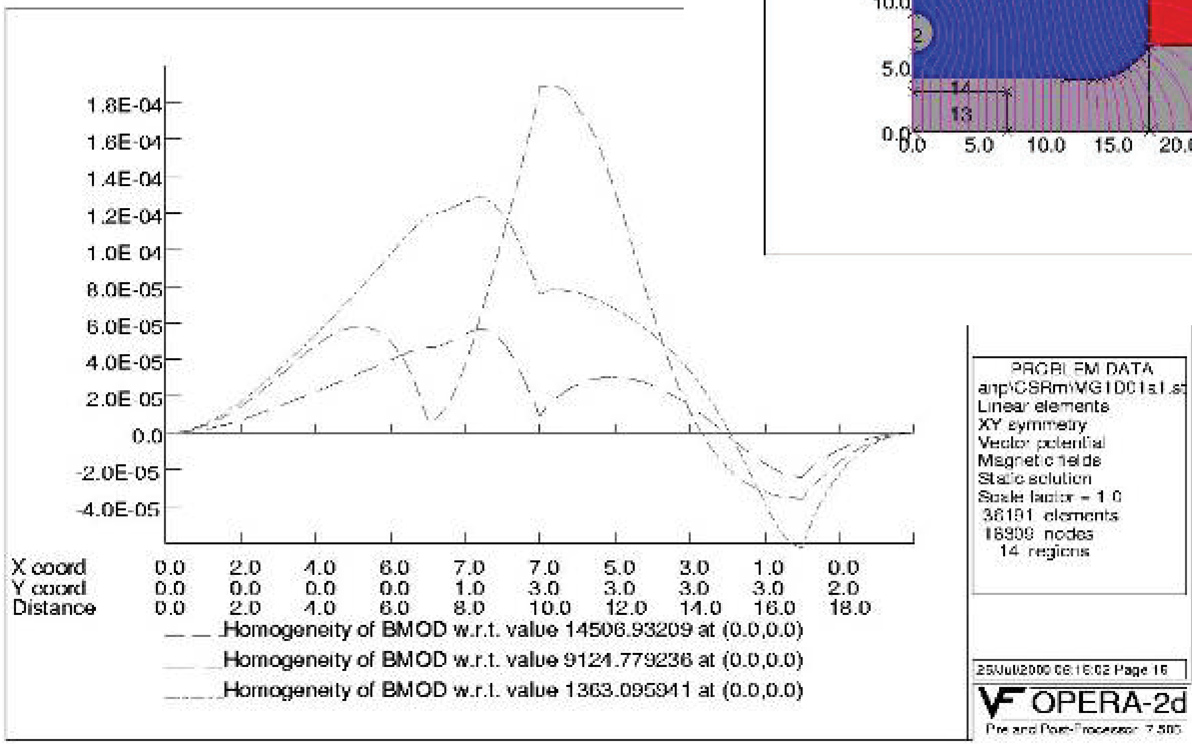
CSR magnets main parameters

	CSRm D	CSRm Q	CSRe D	CSRe Q
Number	16+1	18/12	16	20/2
Field range (T)	0.1--1.6		0.2--1.6	
Bending radius (m)	7.6		6.0	
Bending angle (degree)	22.5		22.5	
Gradient range (T/m)		0.3-10		0.1-7
Effective length (m)	2.965	0.5/0.65	2.341	0.65/0.75
Effective aperture (mm^2)	140×60	160×100	220×72	280×72
Gap or Aperture (mm)	80	170	84	240
Field uniformity	$\pm 2\times10^{-4}$	$\pm 2\times10^{-3}$	$\pm 2\times10^{-4}$	$\pm 2\times10^{-3}$
Magnets reproducibility	$\pm 2\times10^{-4}$	$\pm 5\times10^{-4}$	$\pm 2\times10^{-4}$	$\pm 5\times10^{-4}$
Coil turns/pole	20	48	48	78
Coil conductor (mm^2/mm)	25×25/ϕ11	12×12/ϕ6	18×18/ϕ10	12×12/ϕ6
Current (A)	3000	690	1350	580
Resistance (mΩ)	11.7	68.8/79.6	47.2	143/154.6
Magnet long (mm)	3240	616/766	2628	794/894
Magnet Wide (mm)	1046	948	1220	1220
Magnet High (mm)	820	912	1522	1180
Magnet weight (tons)	18.4	2.1/2.83	32	4.5/5.1

OPERA design and calculation

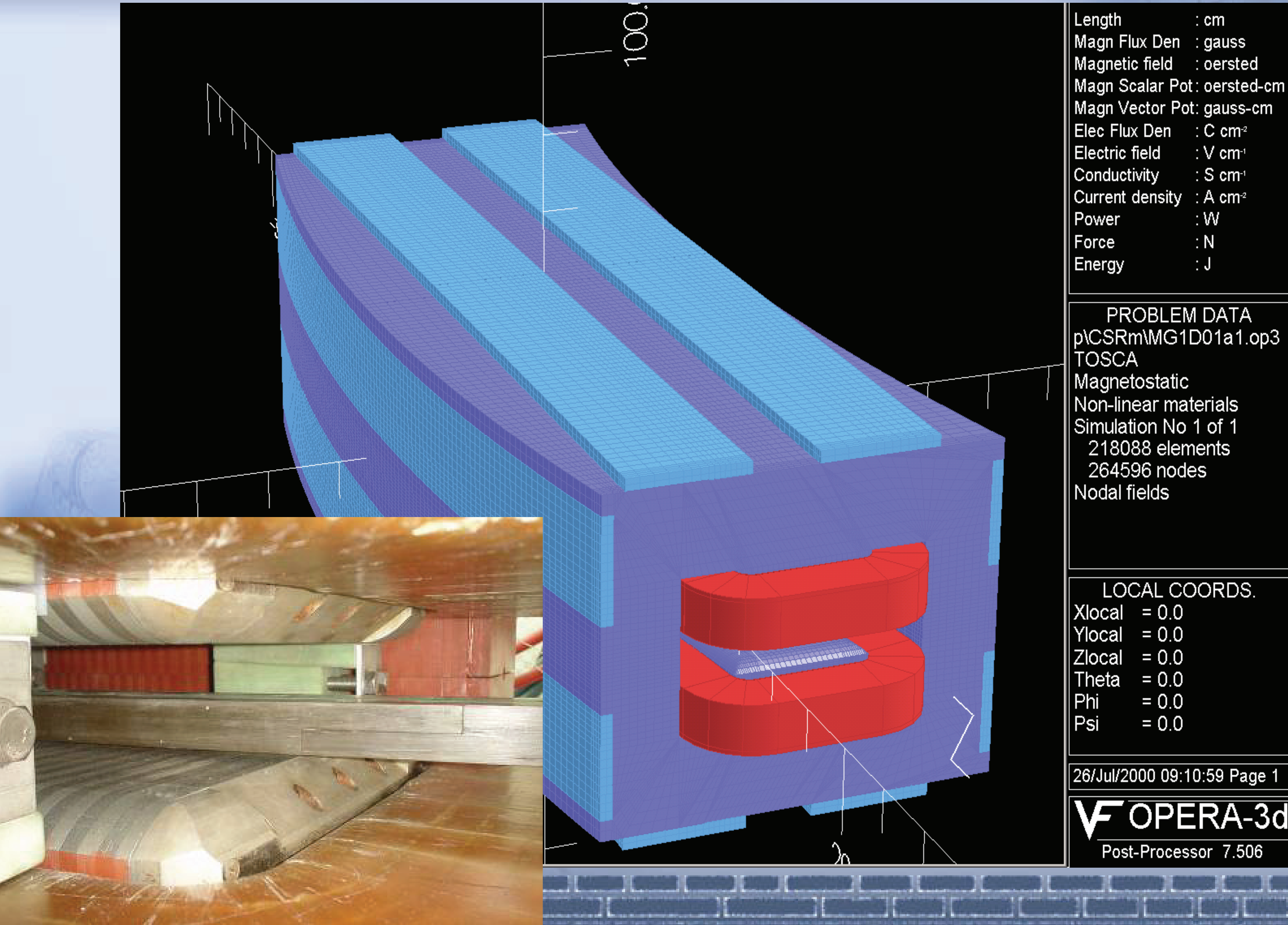
Magnet calculation is very important for magnet's design, that can define magnet's profile and pole shape with shim, normally we often use air slots or holes to improve magnetic filed distribution and reduce magnet's size, and its end chamfer shape.

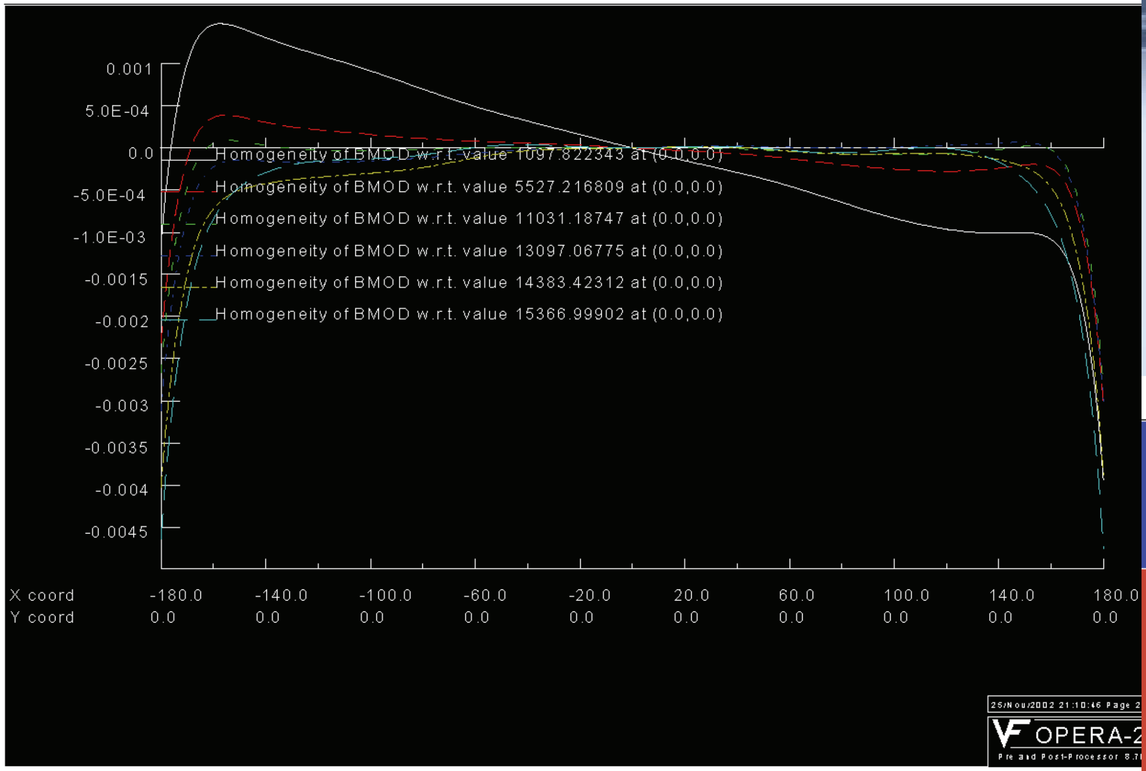


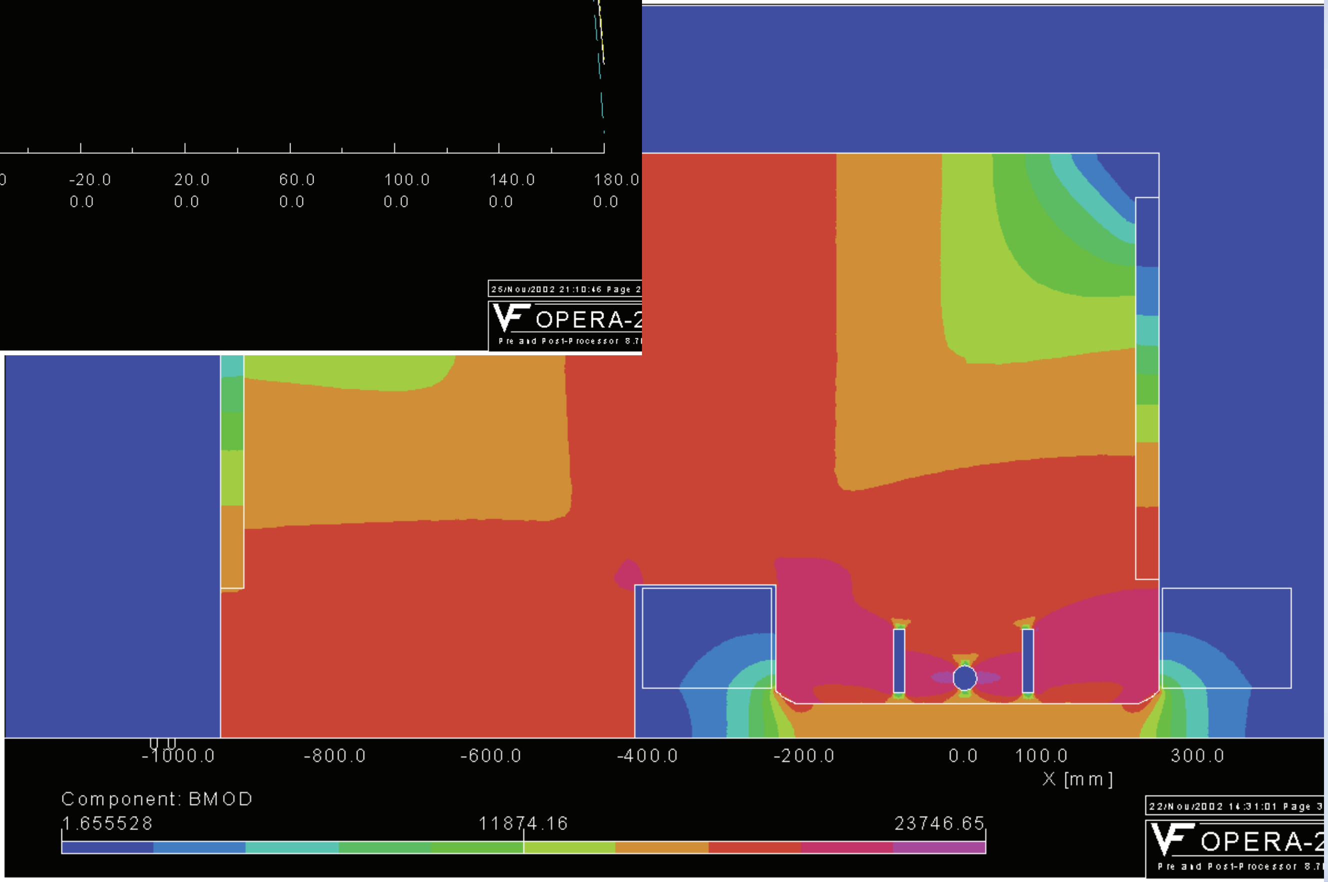


CSRm dipole flux plot and field homogeneity distribution

CSRm dipole 3D mesh model and ends chamfer

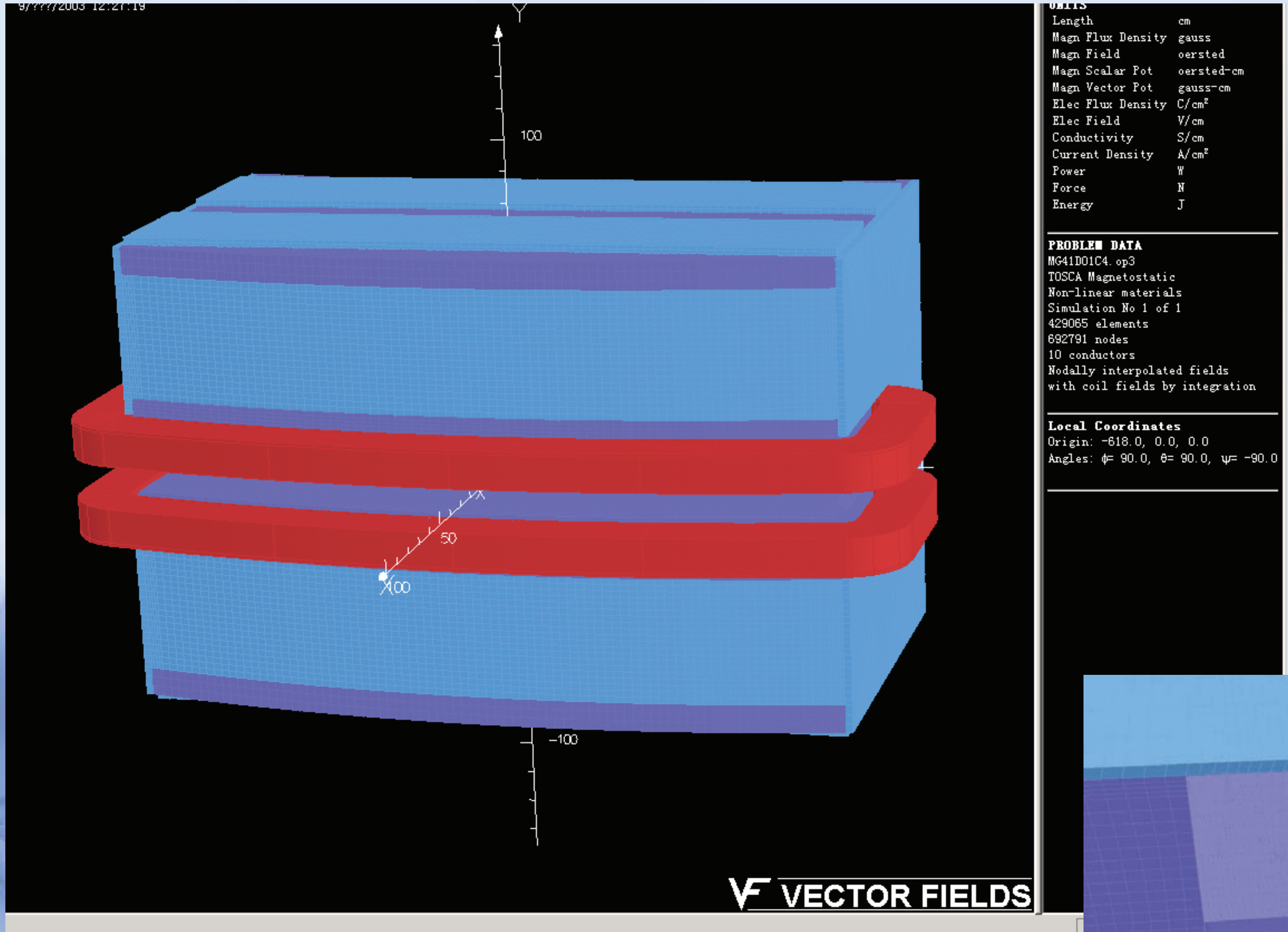


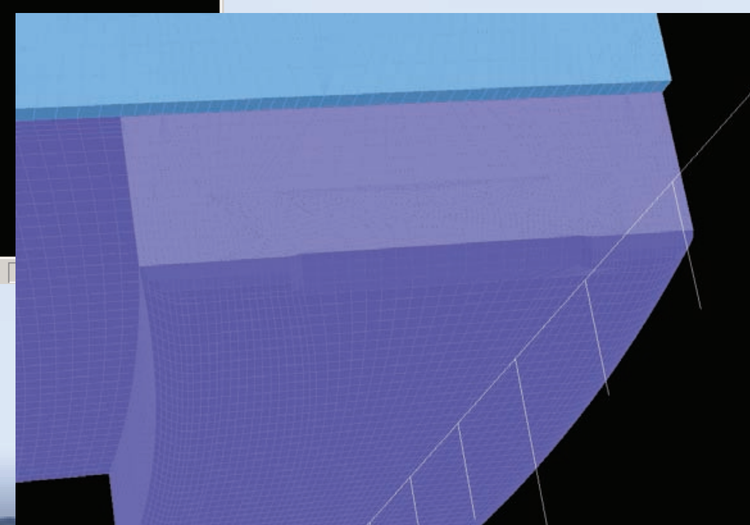




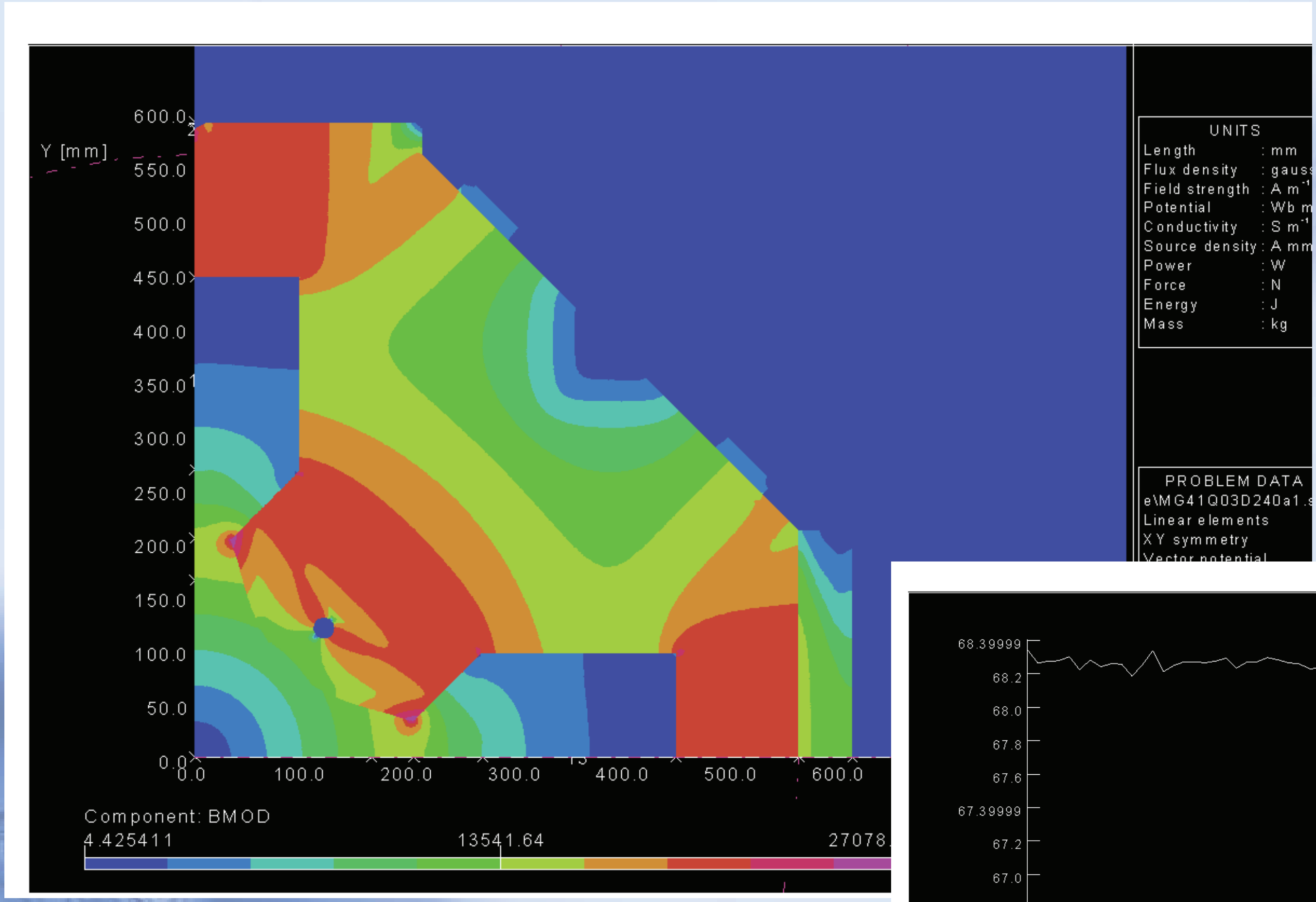
CSRe dipole B contour and field homogeneity distribution

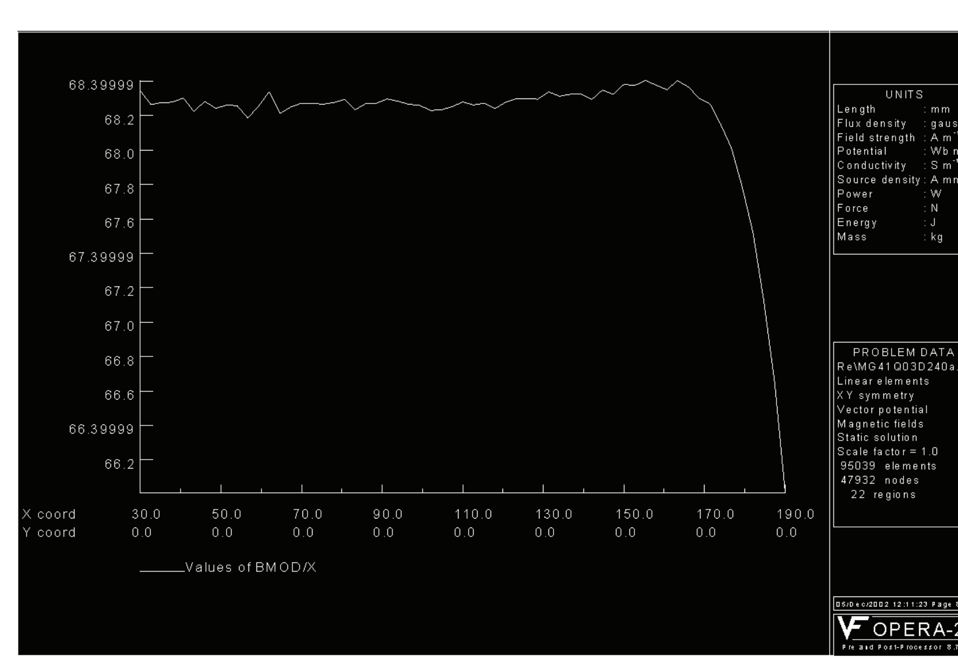
CSRe dipole 3D mesh model and ends chamfer



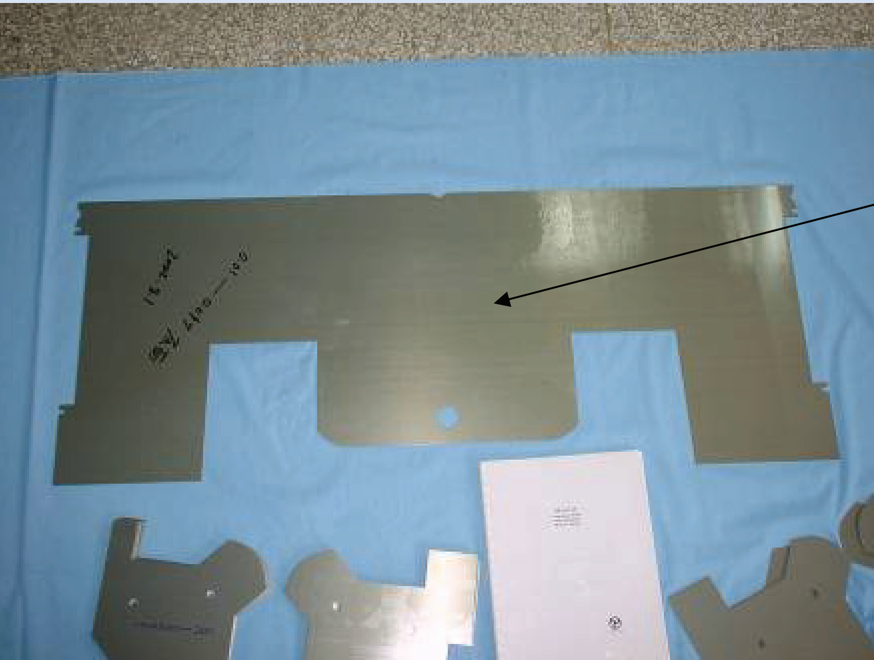


Quadrupole design and calculation





Stacking tables and devices



~ μm thickness glue

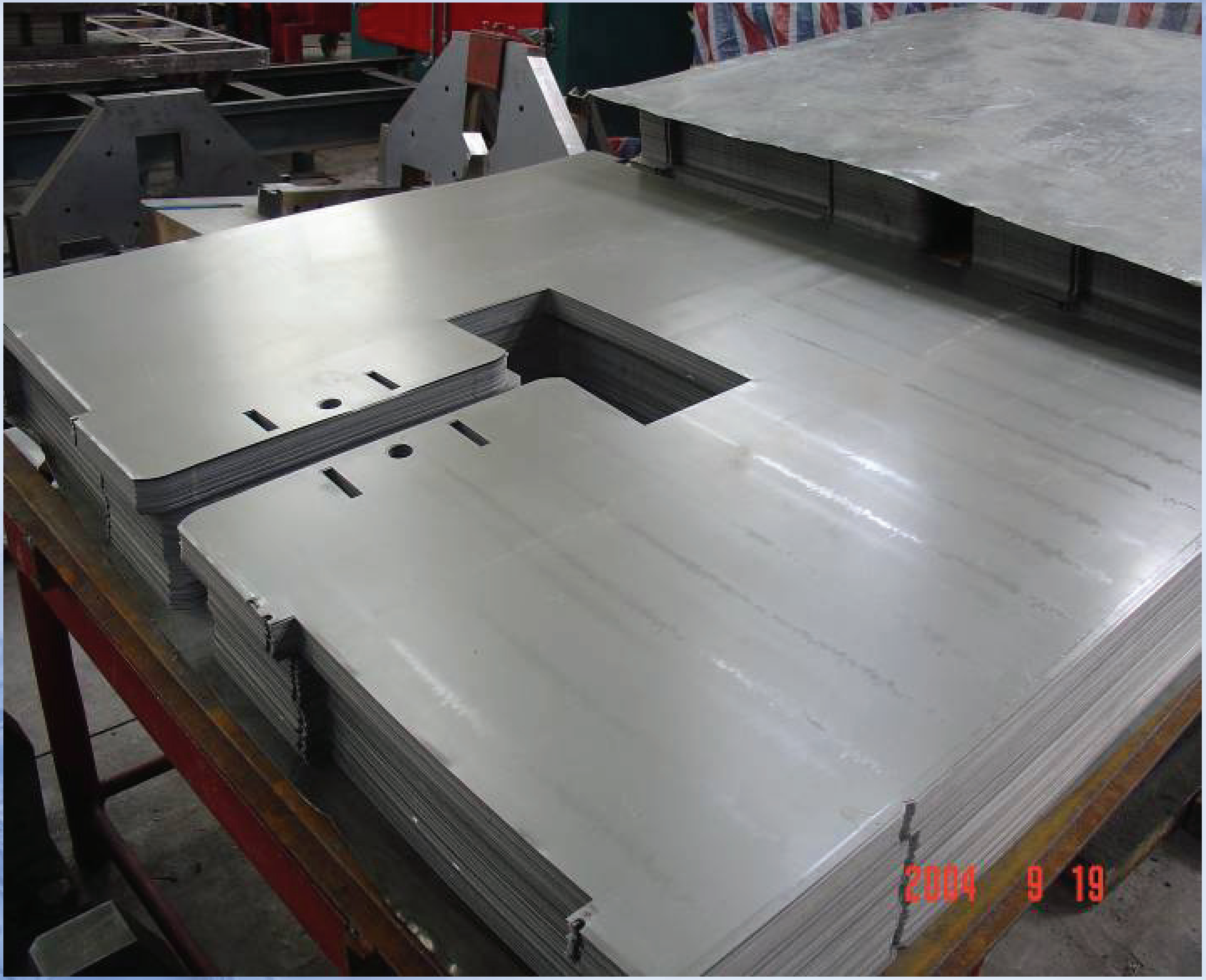
Laminates and epoxy glue coating machine

Laminating sheets punching after mixing

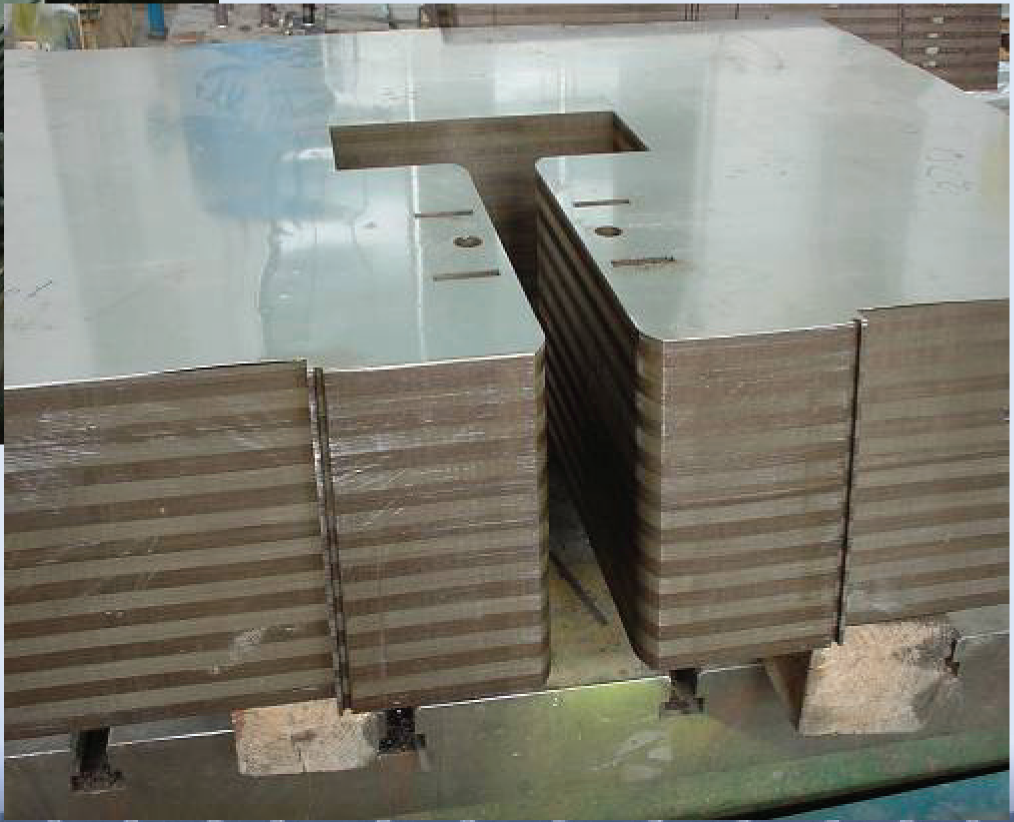
CSRm dipoles, 18tons and 3m length

CSRe dipole punching sheets

1.



CSRe dipole endplates stacking and glued



Endplates fabricating and dipole stacking

Dipole iron body welding with pressing plates

Dipole coils winding and insulating

CSRe dipole magnets

1.

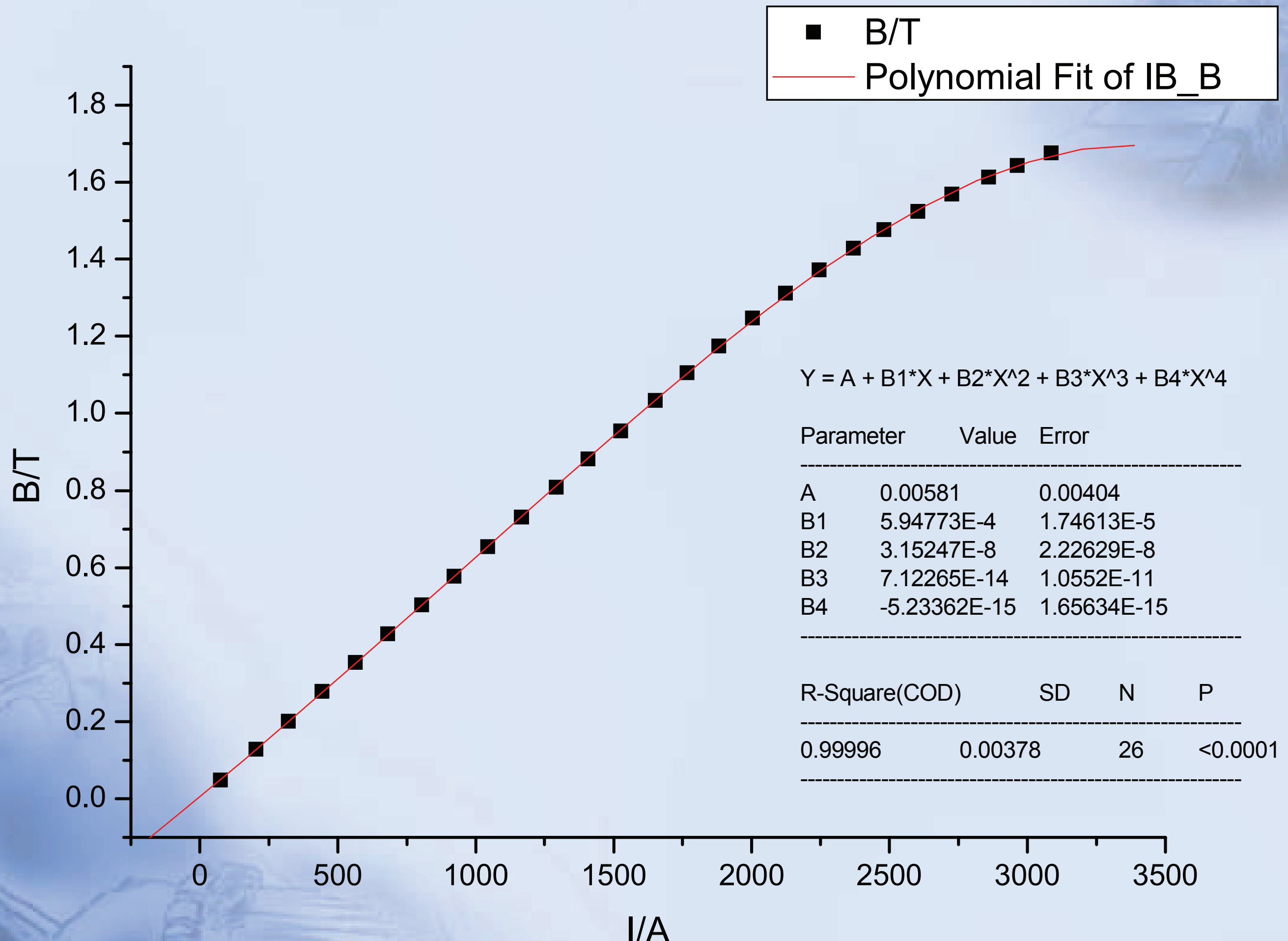
Length	2.6m
E.angle	22.5 °
Gap	84mm
M.field	1.6T
Current	1250A
Volt(DC)	66V
Weight	32tons
W.P.	1.0MP
ΔT	35° C

CSRm ϕ170mm
quadrupoles

兰州科近泰基新技术有限责任公司 (KjTj)

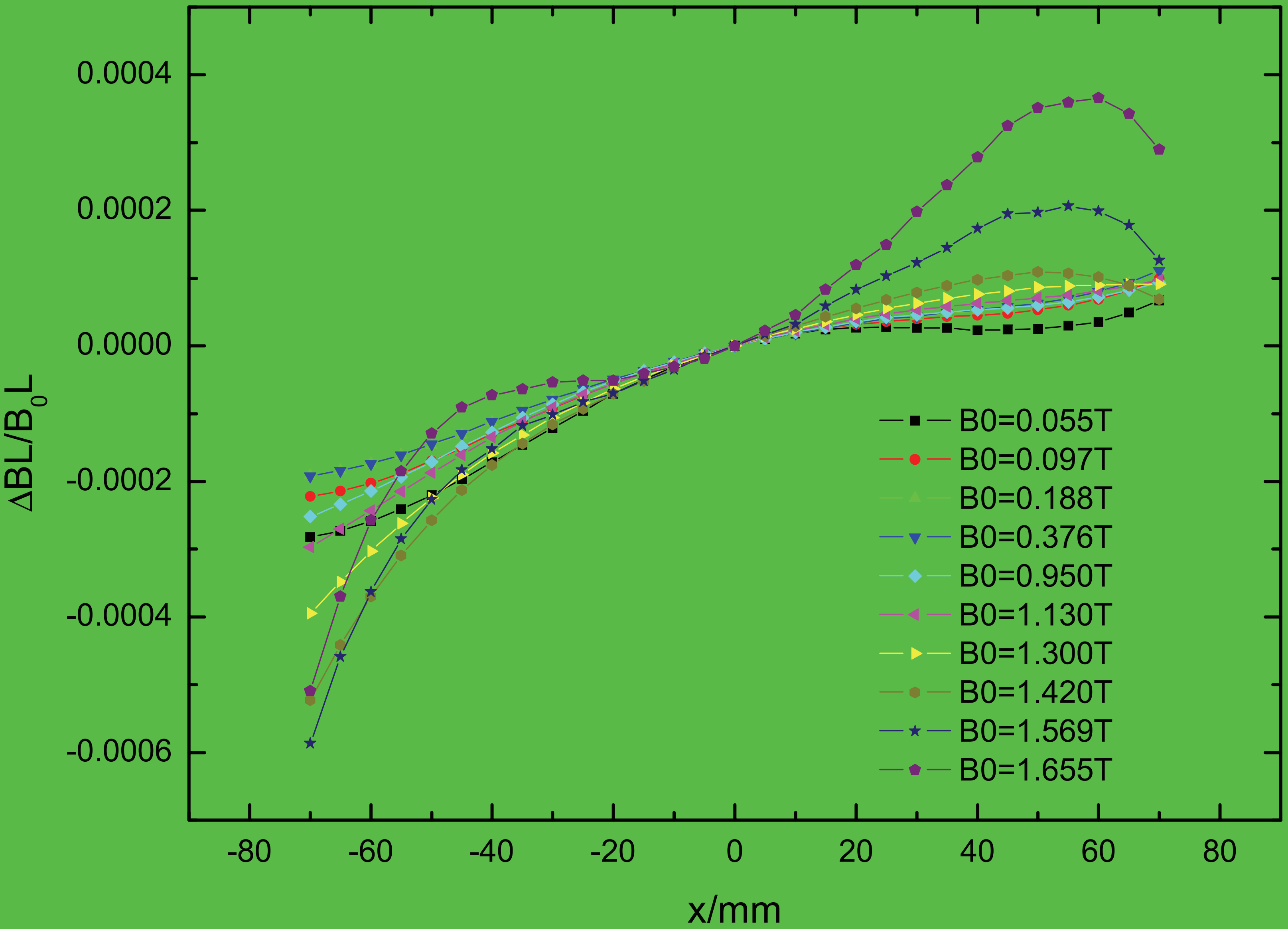
CSRe ϕ240mm quadrupoles

CSRm dipole B-I actuating curve

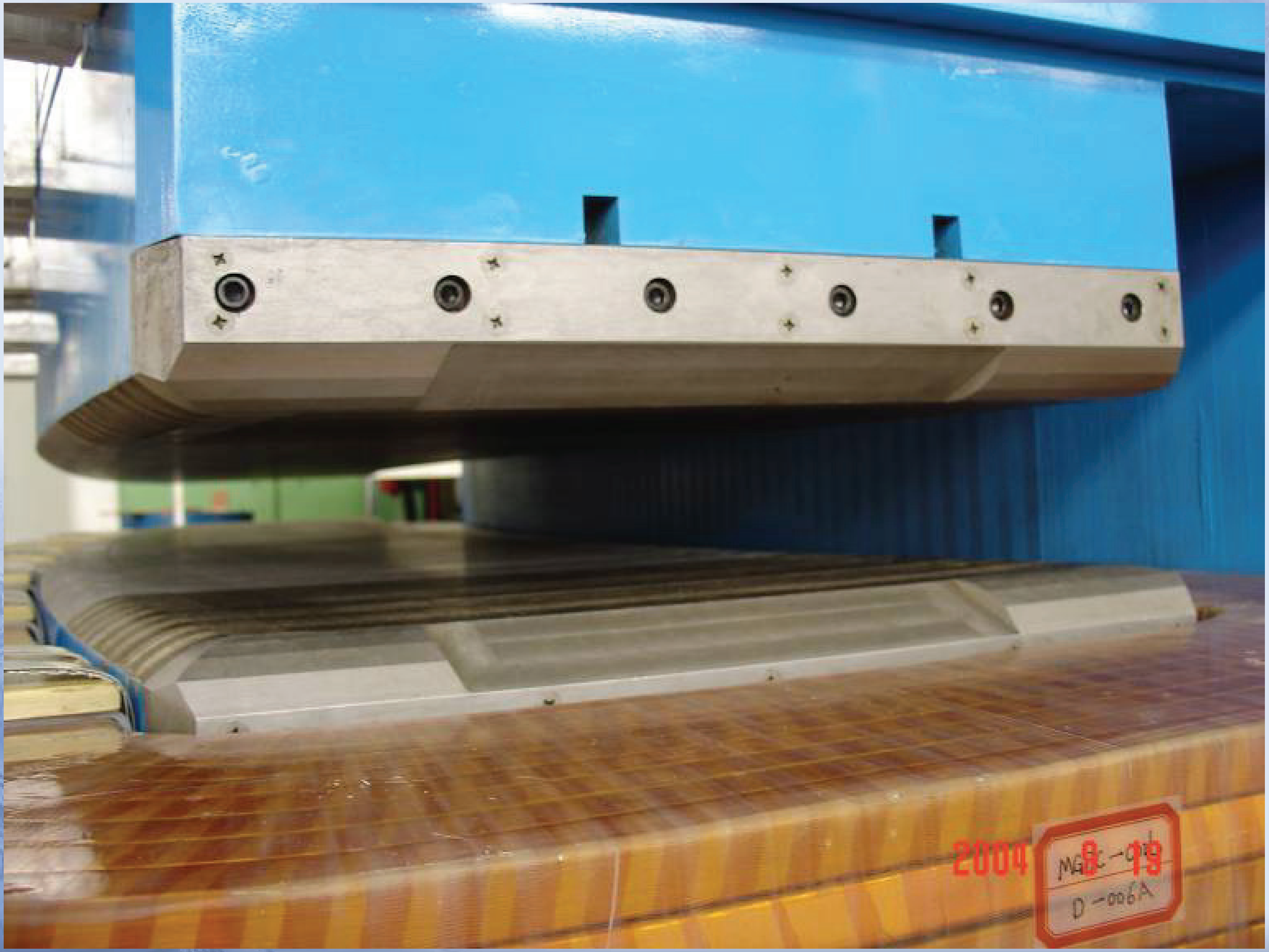


CSRm Dipole Magnet 01 2003-08-13

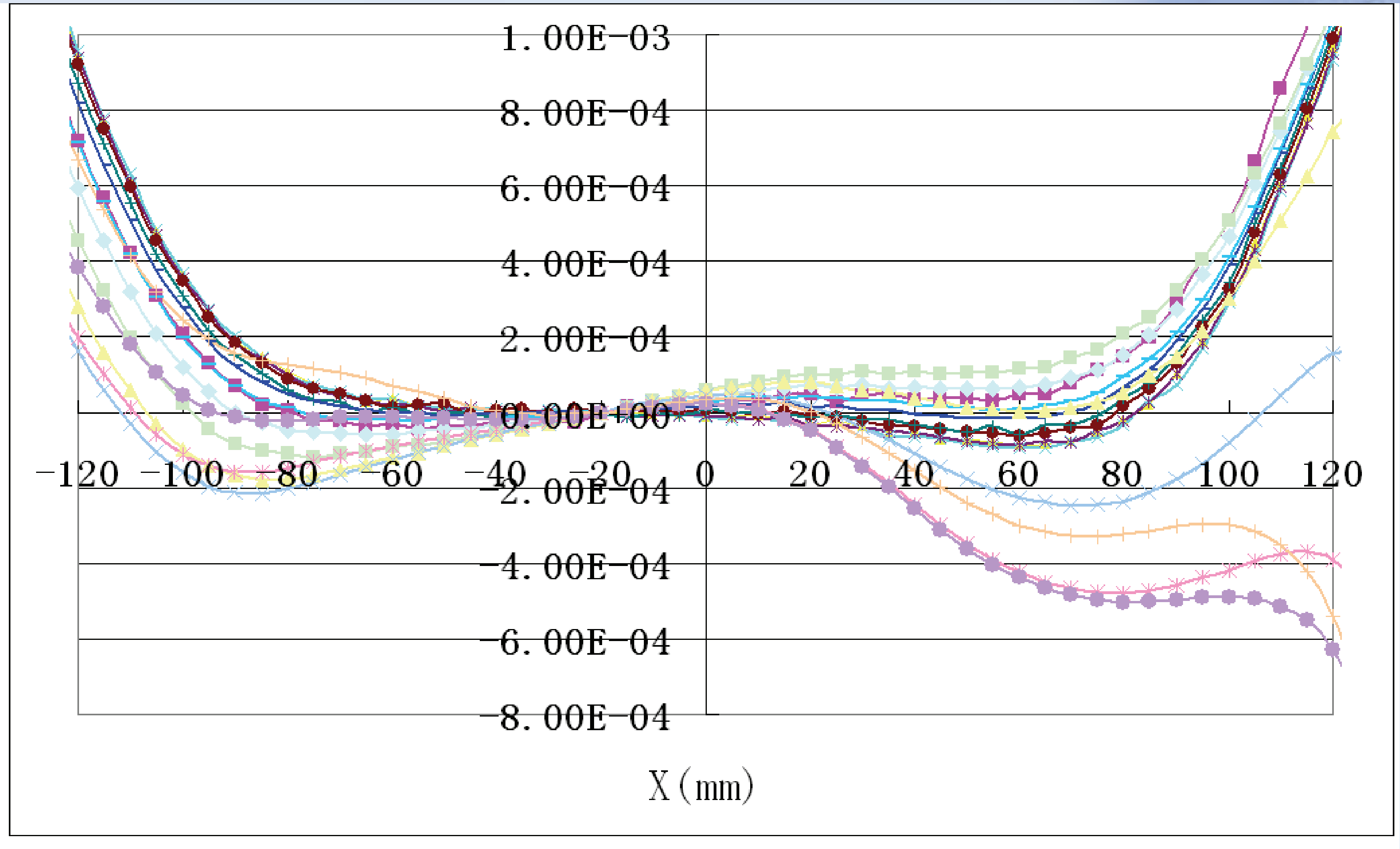
Integral distribution of CSRm dipole



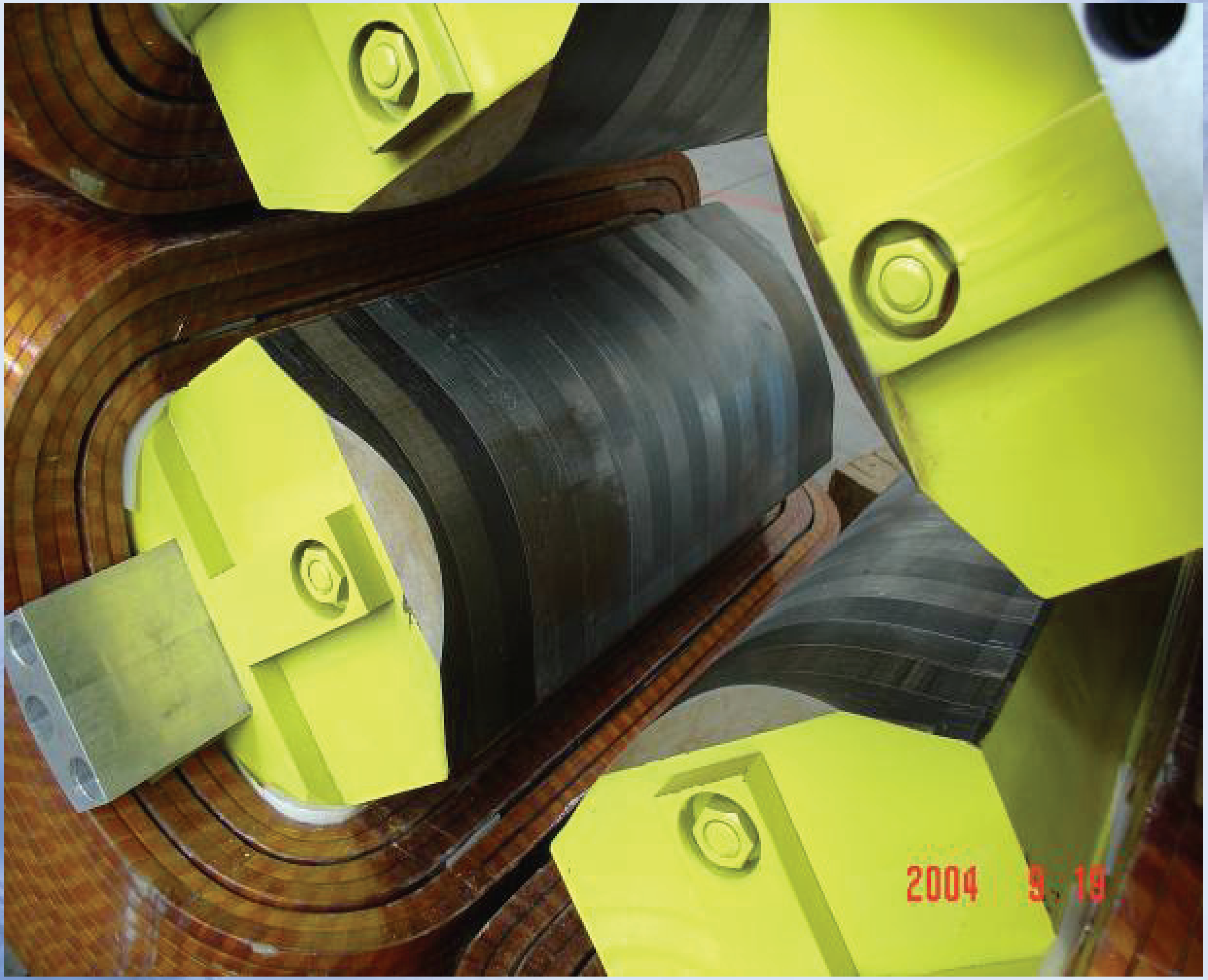
CSRe dipole pole ends chamfer



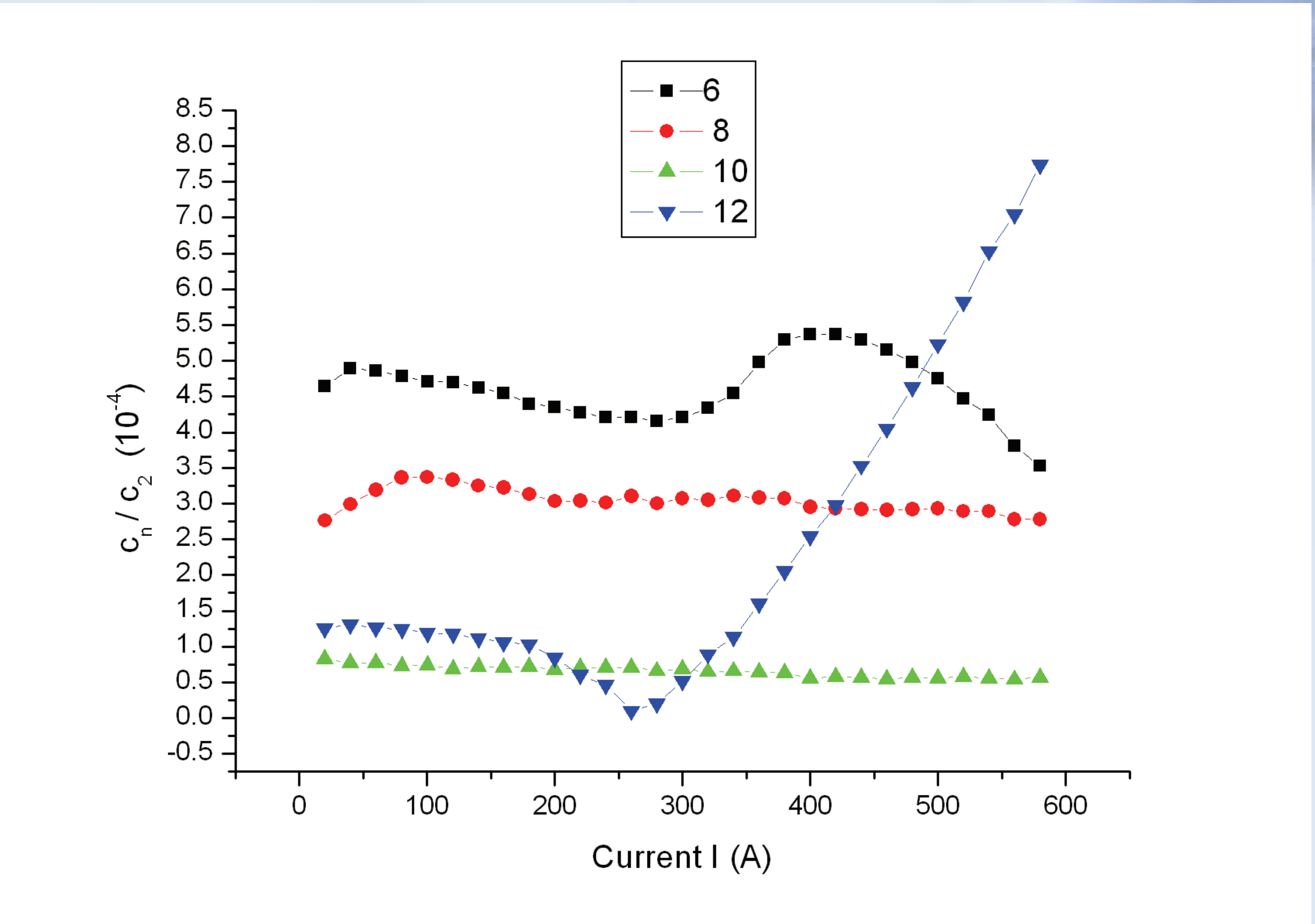
Integral distribution of CSRe dipole



CSRe quadrupole pole ends chamfer



Some harmonic components variation with actuating current



Super-ferric dipole prototype for FAIR

The super-ferric dipole prototype is being made by FCG (FAIR China Group) in cooperation with GSI for FAIR Super-FRS.

FCG firstly consist of the Institute of Modern Physics (IMP Lanzhou), the Institute of Plasma Physics (IPP, Hefei) and the Institute of Electric Engineering (IEE, Beijing).

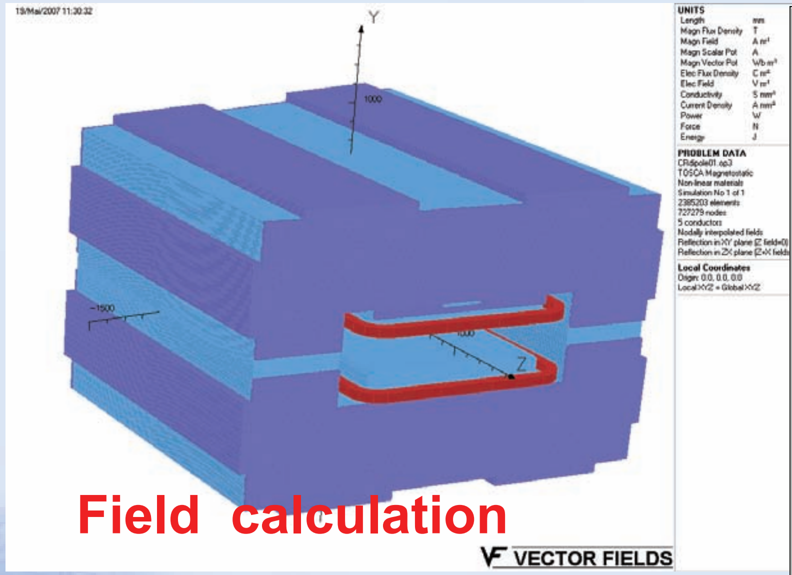
Main parameters for CR/Super-FRS prototype

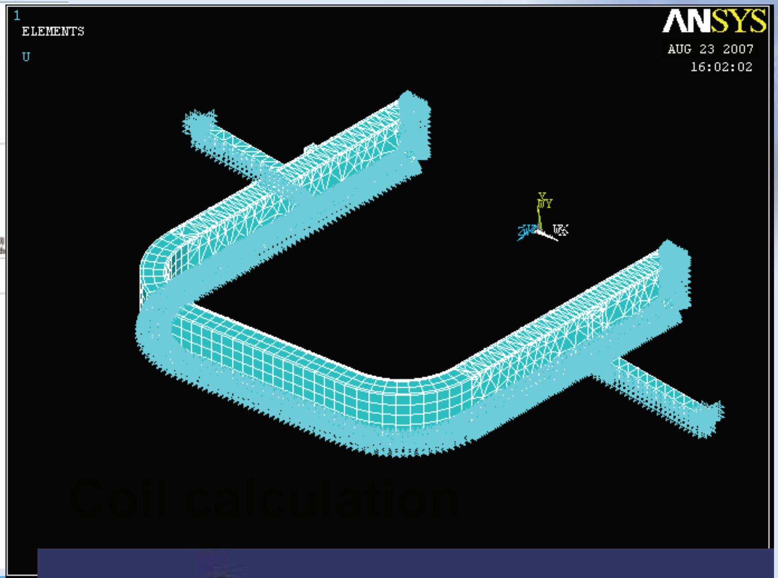
Dipole field	T	0.15-1.6 ±0.02
Bending angle	Degree	15
Curvature radius, R	mm	8125
Effective straight length, $L_{effe.}$	mm	2126
Good field region (H×V)	mm^2	(±190±35)×(±70)
Pole gap height	mm	170
Integral field quality (relative)		B=0.15 to 1.2 T: $\pm 3\times10^{-4}$ B=1.2 to 1.6T:$\pm 1\times10^{-4}$
Laminated iron length, L_{iron}	mm	2020
Current, I	A	246
Inductance, L	H	16.8 at B=1.57T
Weight of iron body	Tons	50

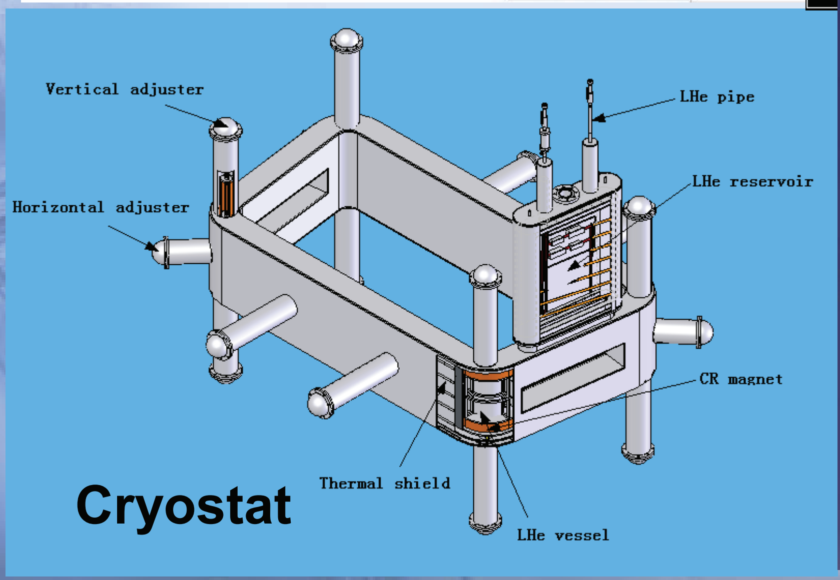
Superconducting conductor and coil main parameters

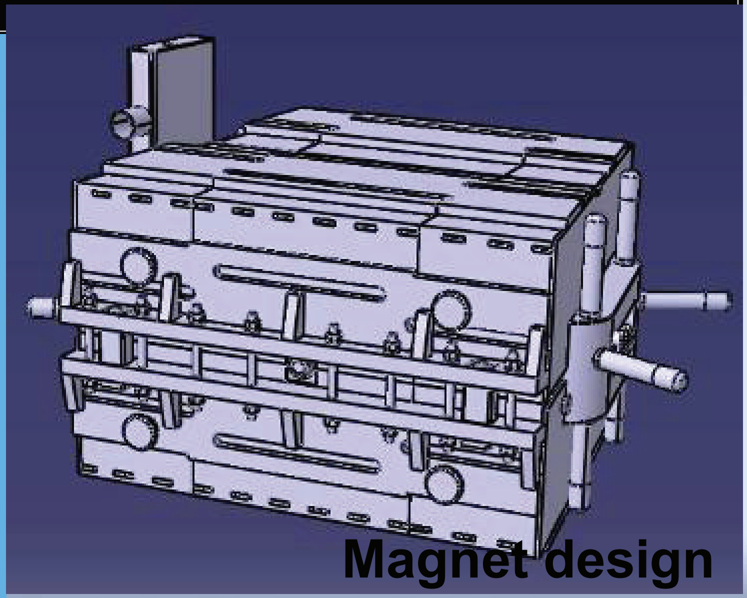
Item	Parameters	Unit
Superconducting strands	NbTi	Oxford
Dimension of conductor	1.43×2.23	mm
Filament diameter d_f	66	µm
Number of Sc filaments	55	
Ratio of Cu and no Cu	10.7	
RRR of Cu in core wire	133	
Operating current I_{op}	246	A
Number of the turns	28×20=560	Turn
Section size of coil	52.1×48.8	Mm
Cooling cubic capacity	Pool 0.05	M^3
Weight of coil and cryostat	1744	Kg

Super-FRS Super-ferric dipole calculation and design









Punching die and sheets: IMP

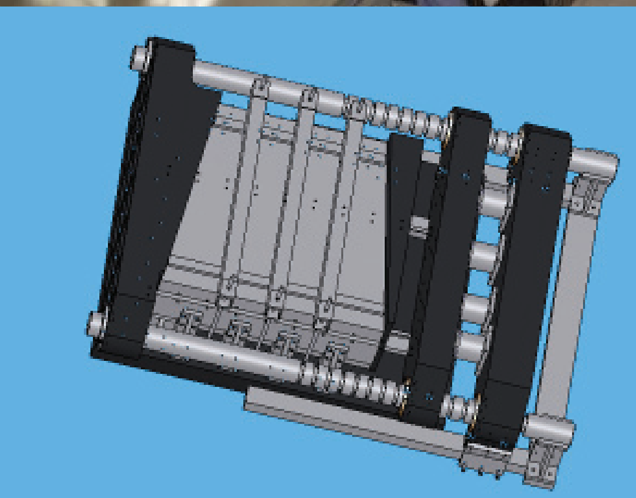
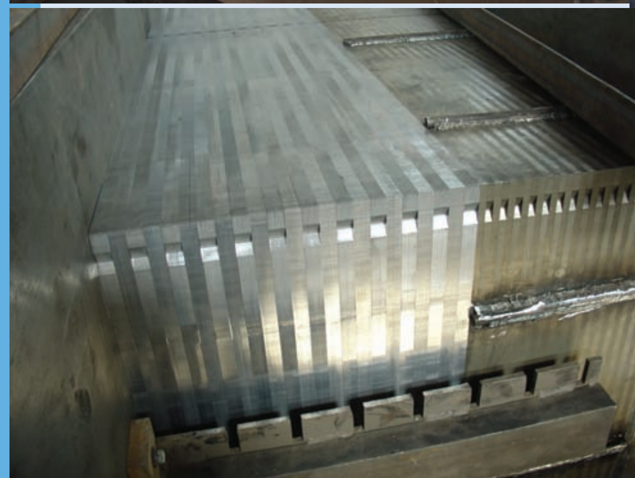
The assembly for the punching die

The Punching die assembly

The Punching die installation

The punching sheets

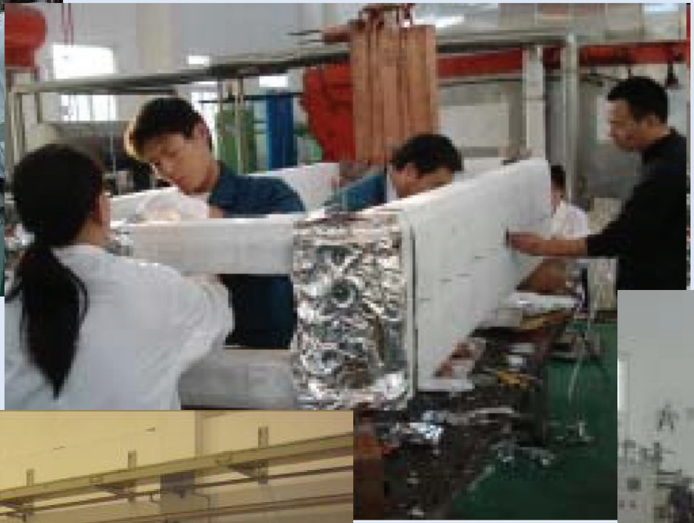


50 tons laminated iron yokes fabrication

Superconducting coils and Cryostat: IPP

Coil fabricating

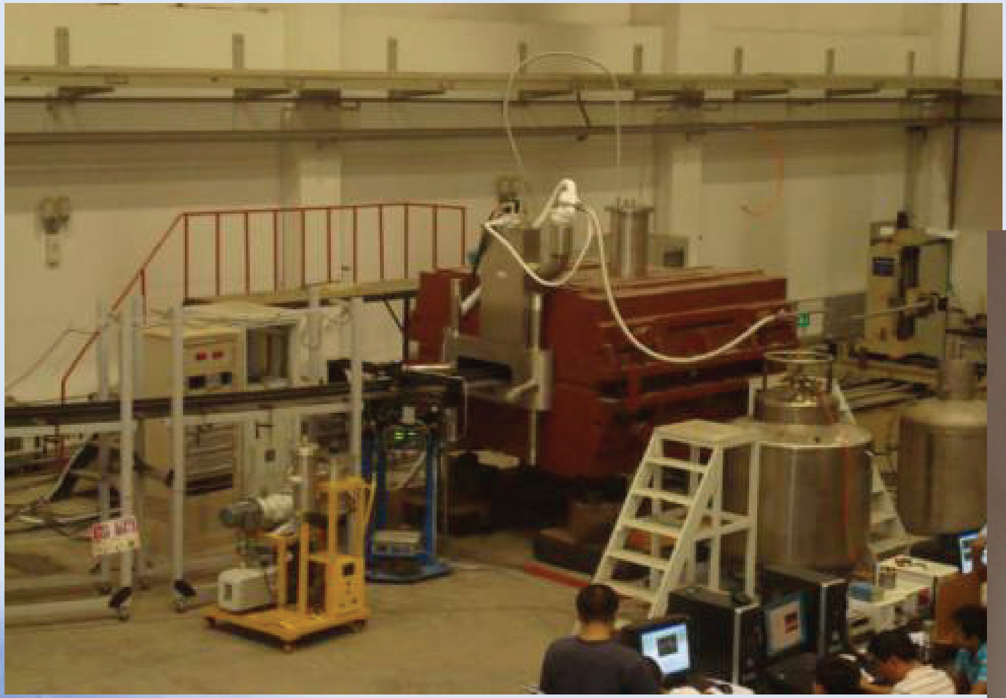


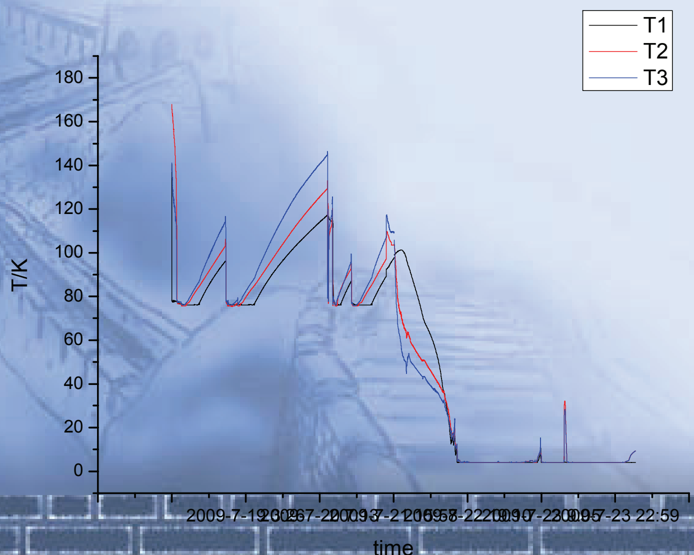
Thermal shielding

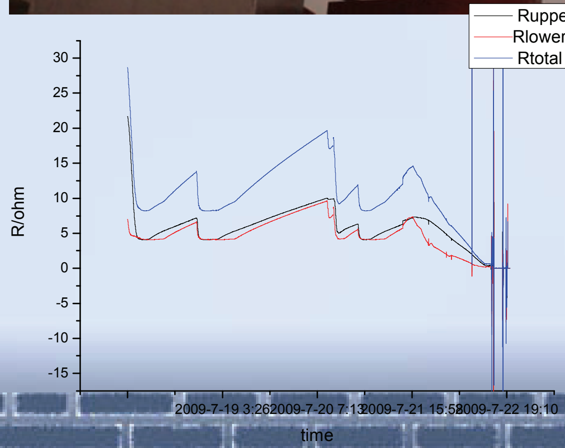
Cryostat fabricating

Cryostat

Tests of the superconducting dipole prototype

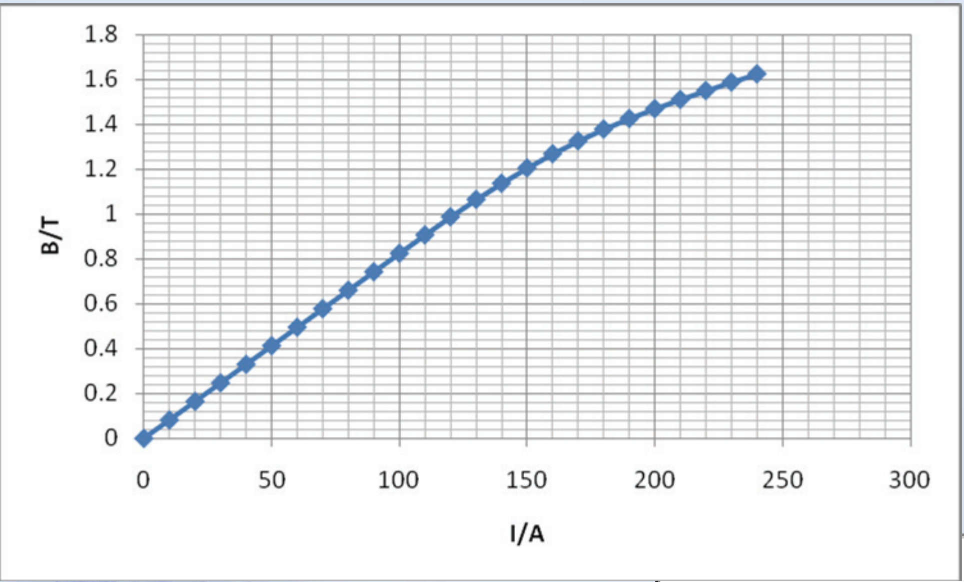


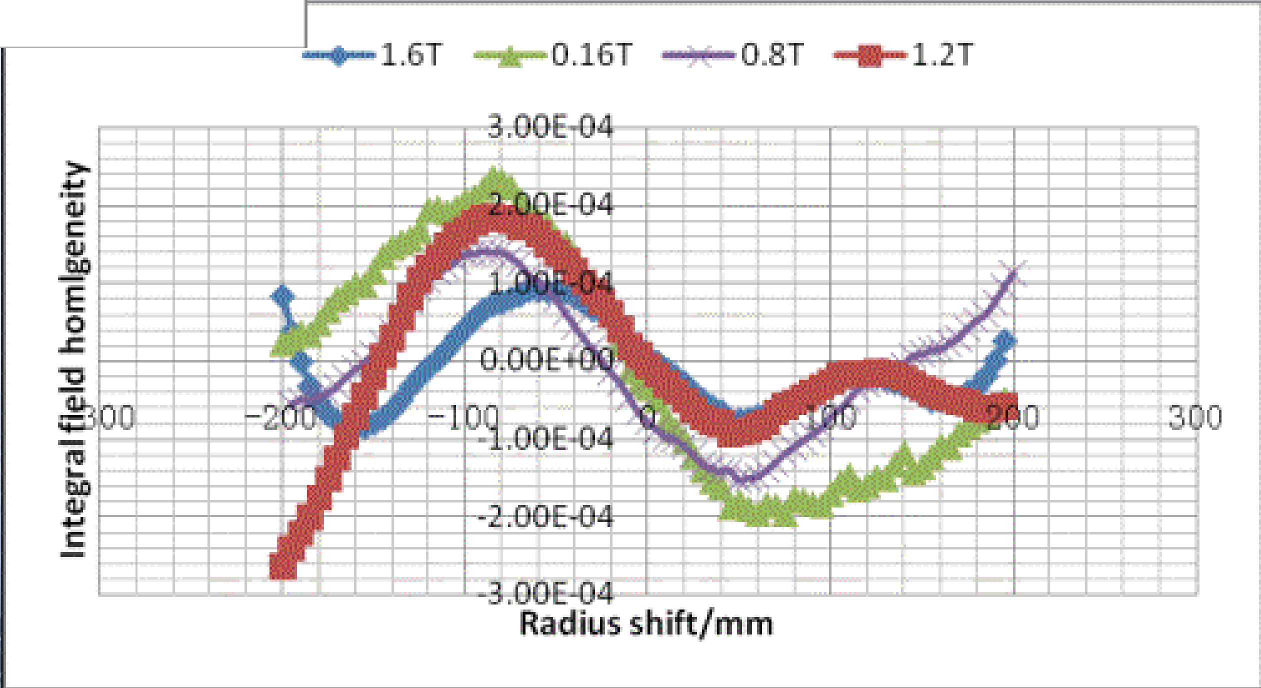




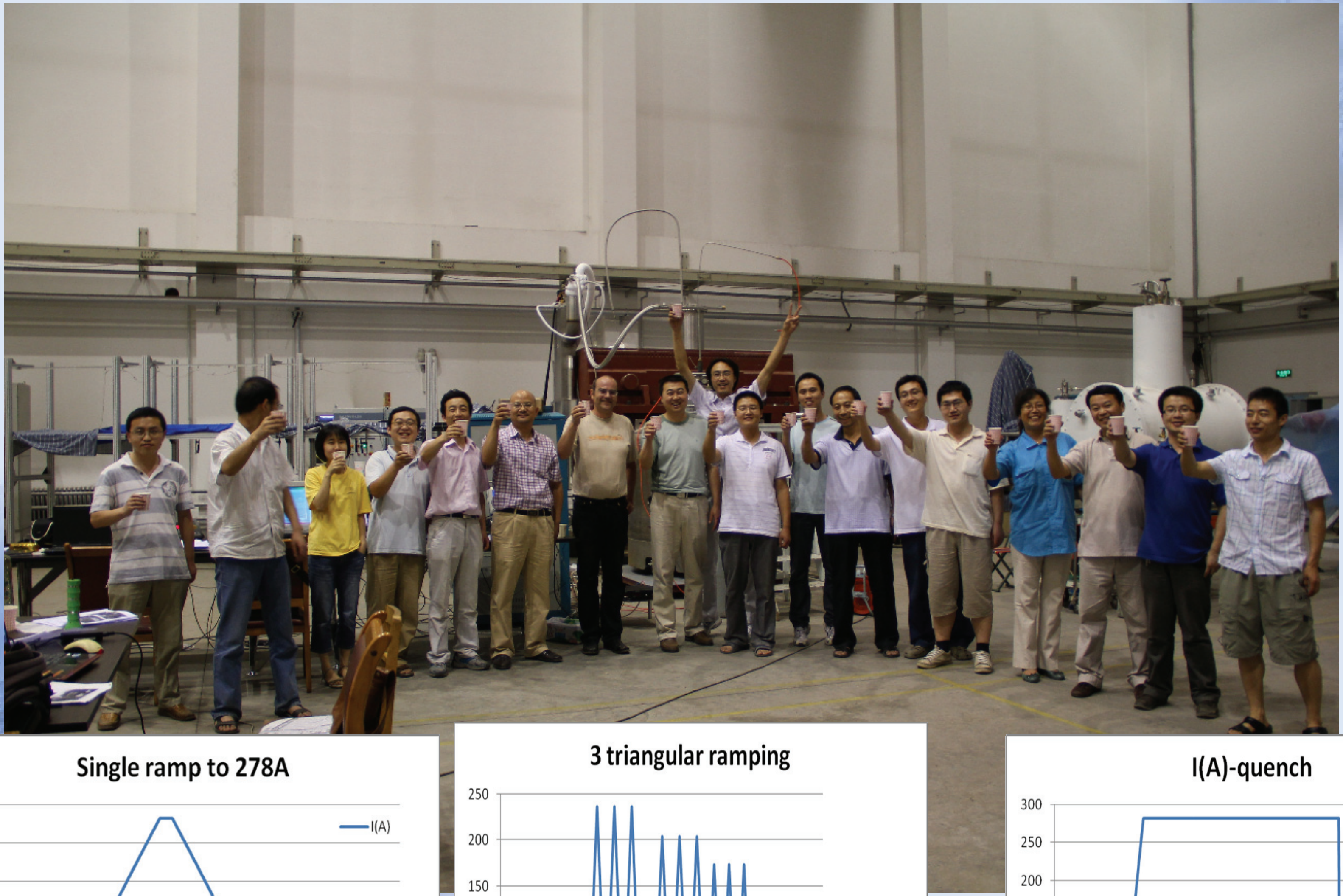
The system of magnetic field measurement

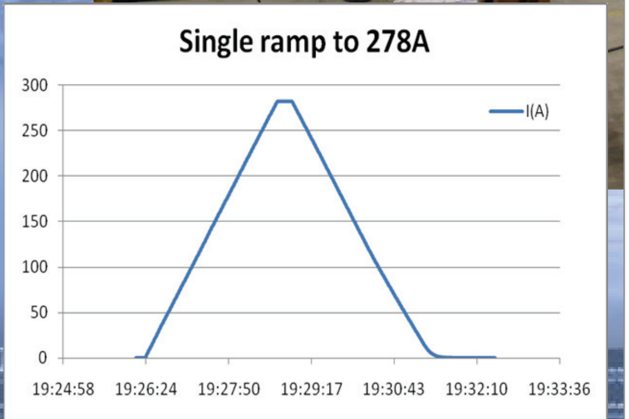
The magnetic field actuating curve and static integral field distribution in the good field region

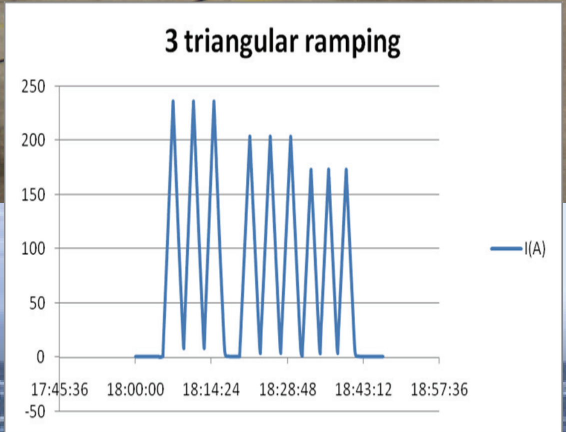


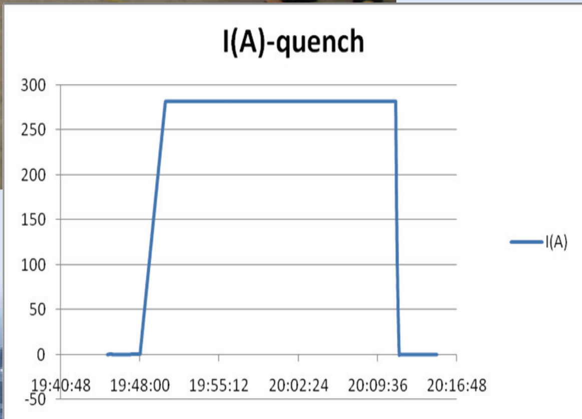


Ramping magnetic field and quench testing









3T and 7T superconducting solenoid

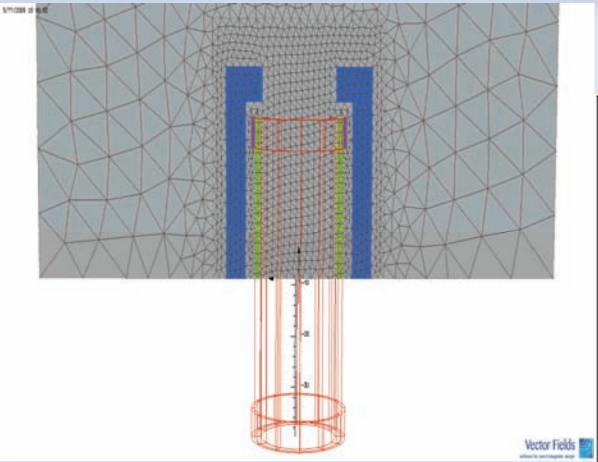
TABLE 1 dimension parameters of the magnet

	Unit	Inner coil	Outer coil (×2)	Inner yoke	end yoke (×2)
Inner diameter	mm	172	199.8	246	172
Outer diameter	mm	199.8	213	340	340
length	mm	480	44	546	55

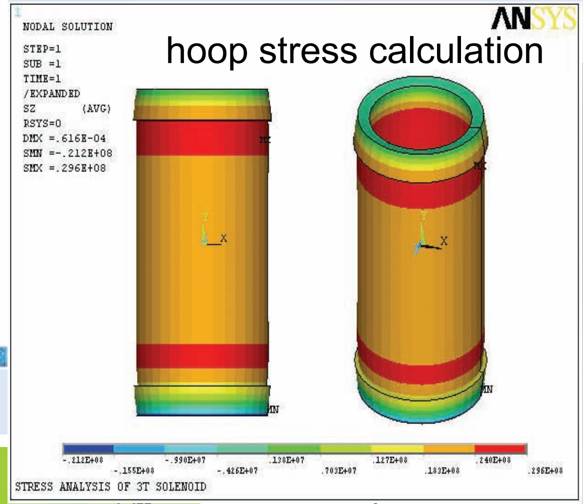
TABLE 2 electrical parameters of the magnet

	Unit	Magnet system
Central field	T	3.0
Current	A	270
Iopc/Ic *100%		45%
Inductance	H	1.5
Stored energy	KJ	47

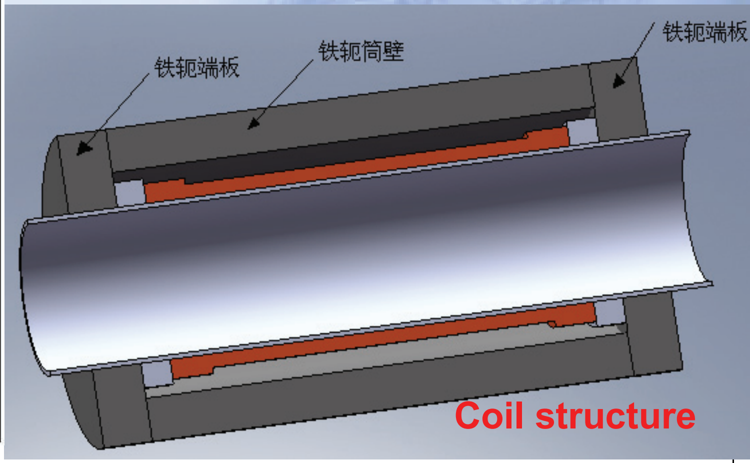
A 3T superconducting solenoid calculation and design



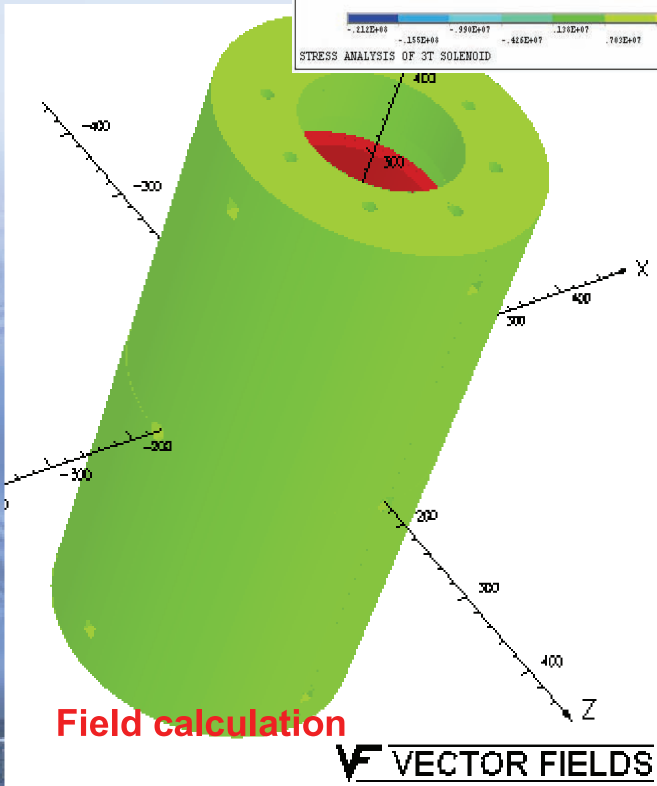
quench calculation



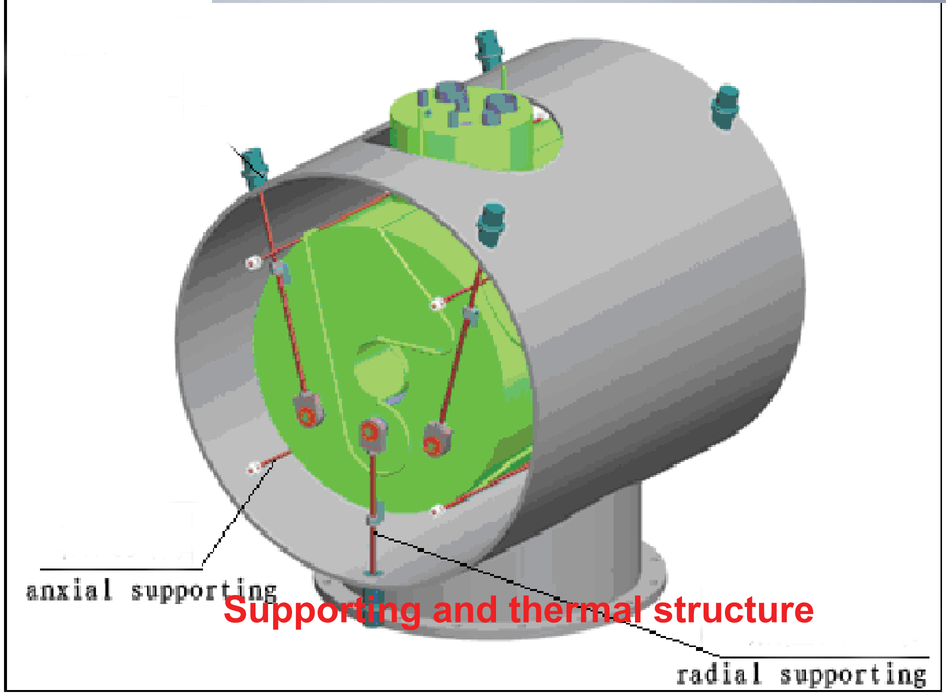
hoop stress calculation



Coil structure

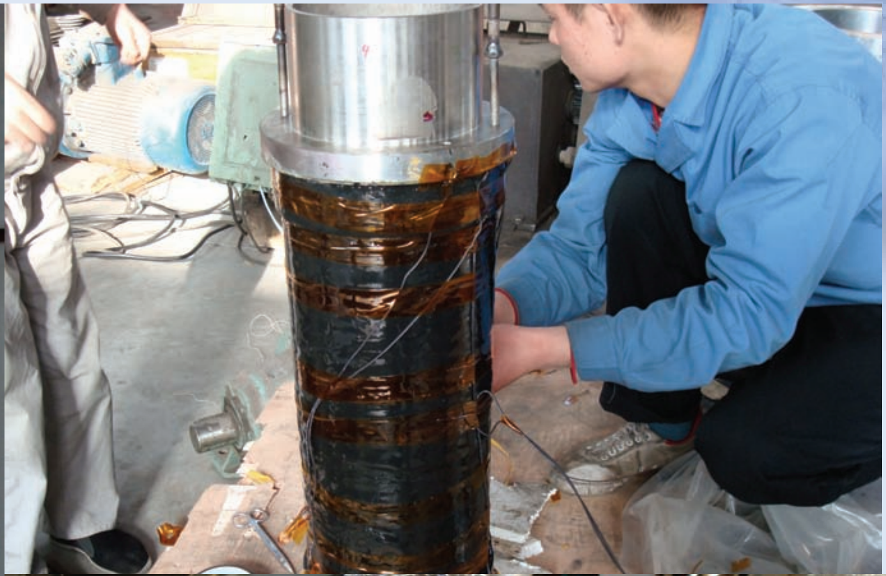


Field calculation

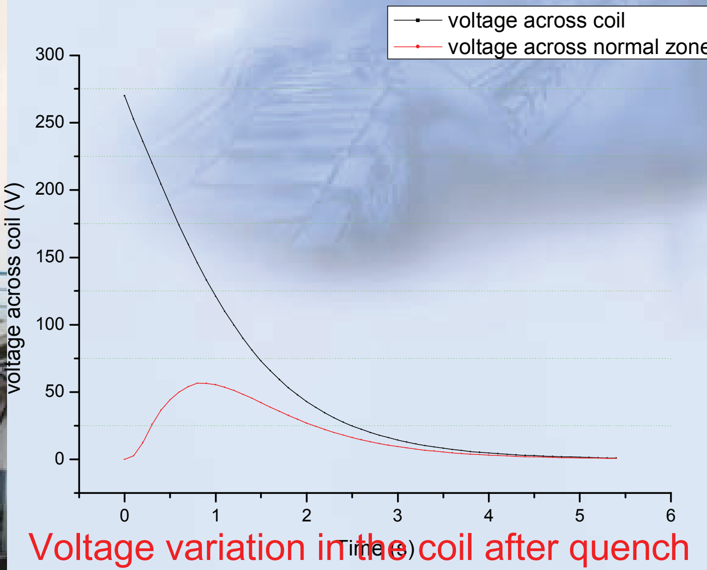


Supporting and thermal structure

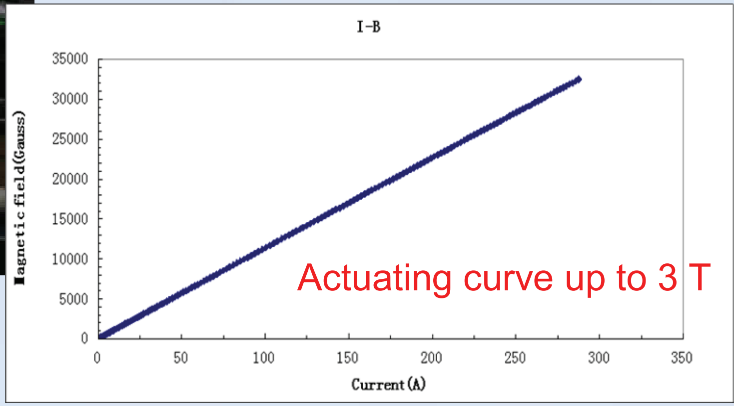
A 3T superconducting solenoid fabrication



The 3T solenoid, cryostat tests and measurement



Voltage variation in the coil after quench



Actuating curve up to 3 T

The field homogeneity in ϕ30mm×30mm central region reached to $\pm 4.95\times 10^{-5}$, better than the design.

Lanzhou Penning Trap (LPT)

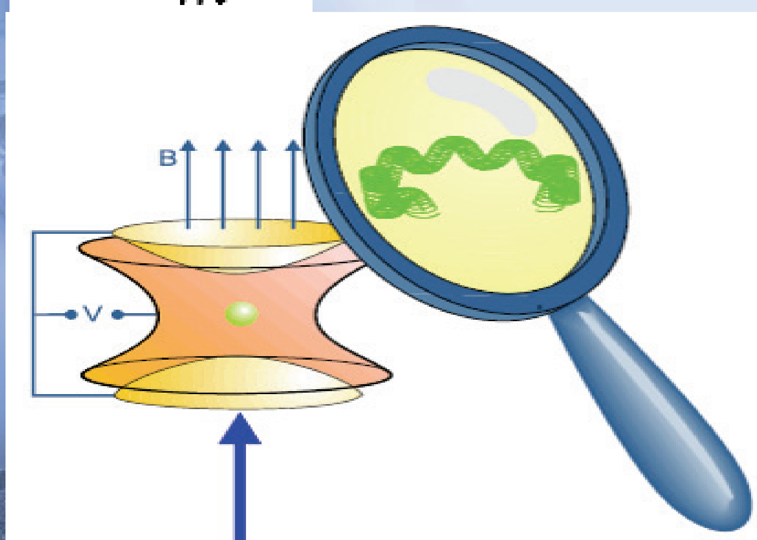
Main Objective:

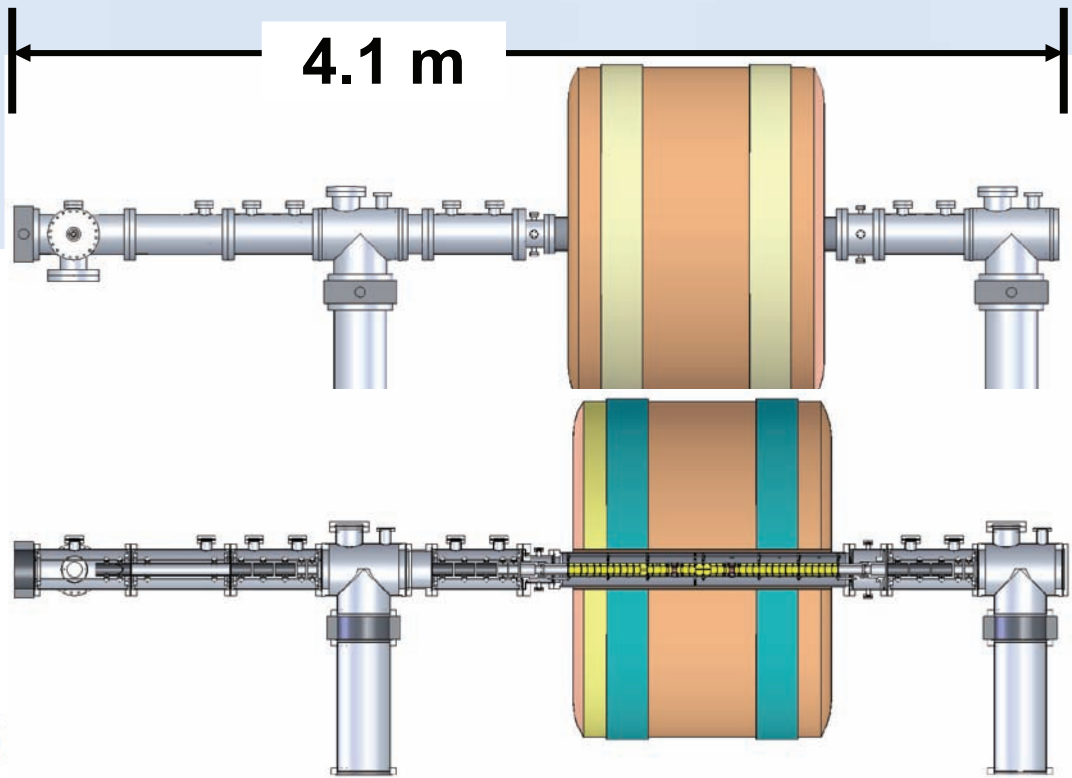
to perform direct mass measurement of the fusion-evaporation residues and if possible for the heavy isotopes.

high precision mass measurement setup

Need: high field(7T), high homogeneity(10^{-7})

$$\omega_c = \frac{q}{m} B$$





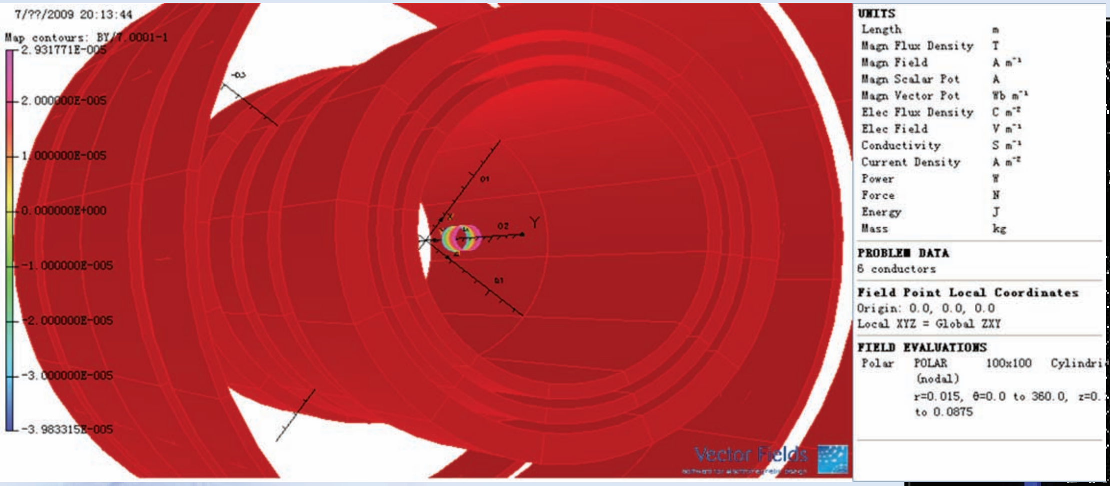
The LPT magnet design goals

Items	Value
Central field	7T
Homogeneity	3×10^{-7} within $1cm^3$
Stray field(5×10^{-4}T lines)	2m away from the center
Warm bore	Φ156mm
Field stability	10^{-8}/hour

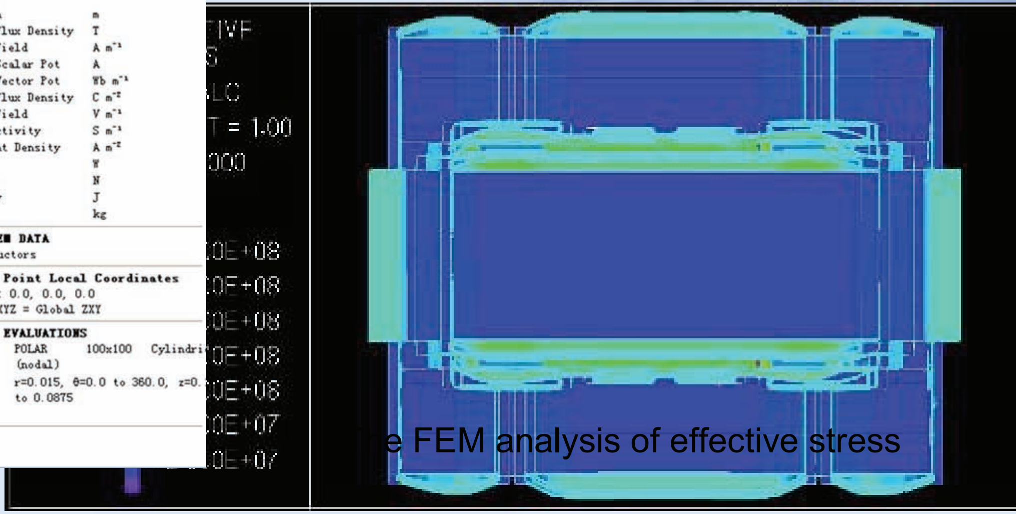
So a superconducting magnet which provides a highly homogeneous magnetic field is the key component of the penning trap.

The central field is 7T with a uniformity of 3×10^{-7} in the two regions of interest. The warm bore is ϕ156 mm. However, due to the manufacturing and winding tolerances, it is impractical to achieve such a high homogeneity only with the main coils. So we firstly design the main coils with a lower homogeneous field (10^{-5}) and then the superconducting shim coils and passive shim pieces are used to reach the required homogeneity.

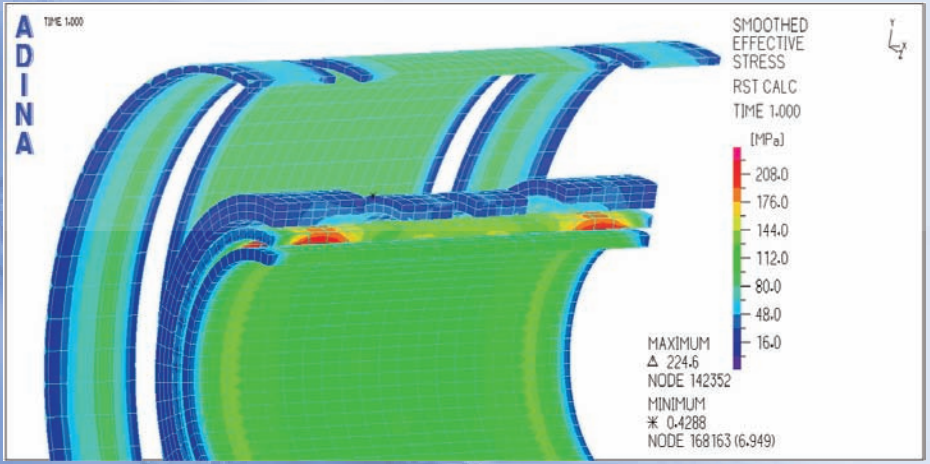
The design of 7T superconducting homogenous solenoid for LTP



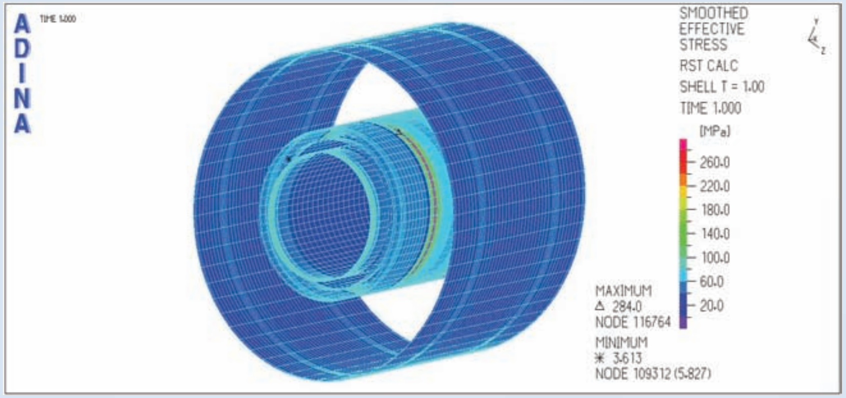
The field homogeneity of the main coil



e FEM analysis of effective stress

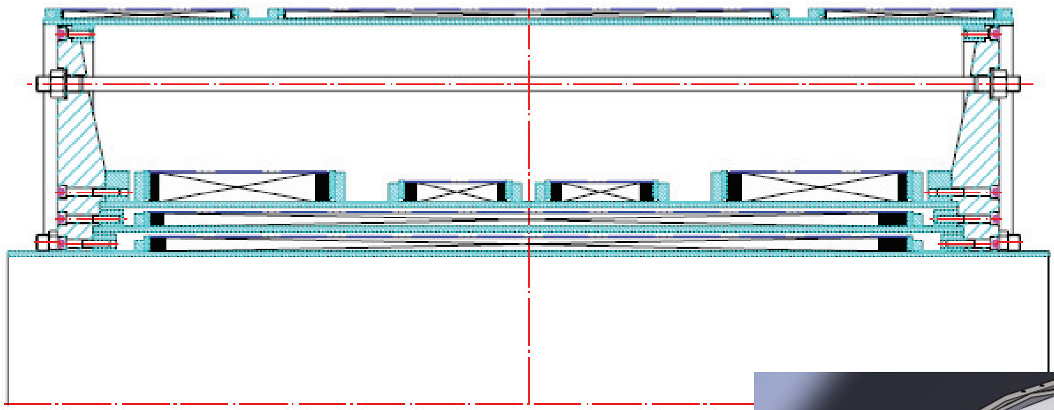


The effective stress distribution of the LPT winding

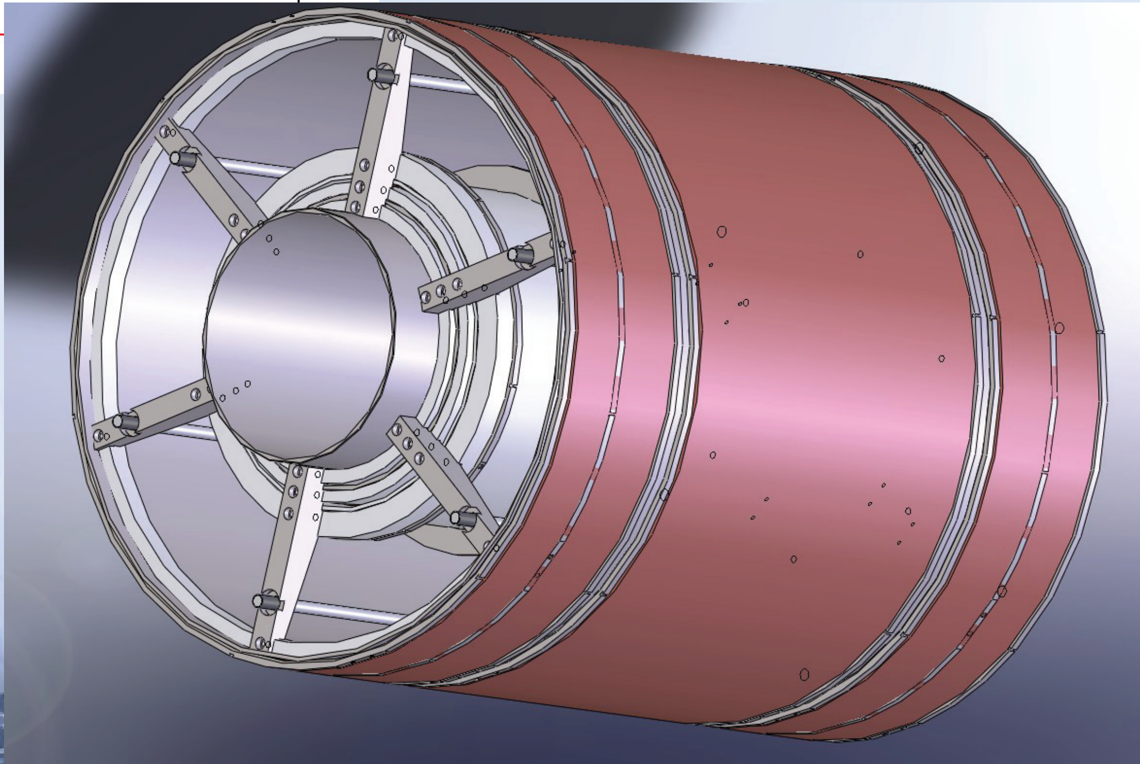


The effective stress distribution of the winding bobbin

The design of 7T superconducting homogenous solenoid for LTP



Coil structural layouts



Summary

- Magnets at IMP development was from massive iron normal magnets to laminated steel normal magnets to superconducting magnets, meanwhile the magnetic field measurement technologies also developed from points measurement to integral field measurement and harmonic analysis to ramping field measurement and tracking.
- LPT 7T superconducting solenoid is constructing.
- What's next step?

  high field, high homogeneity, fast ramping, big size, superconducting magnets will be needed and developed in the future.

Thank you

for your attention!!!