Magnet development programme at DAE

Sanjay Malhotra
Bhabha Atomic Research Centre

Contributors

S. Sundar Rajan	*Prashant Kumar*
Kumud Singh	*U.G.P.S. Sachan*
Vikas Teotia	*Elina Mishra*
Praveen Trivedi	*Mahima*
Janvin Itteera	

Converging superconductivity and magnetism

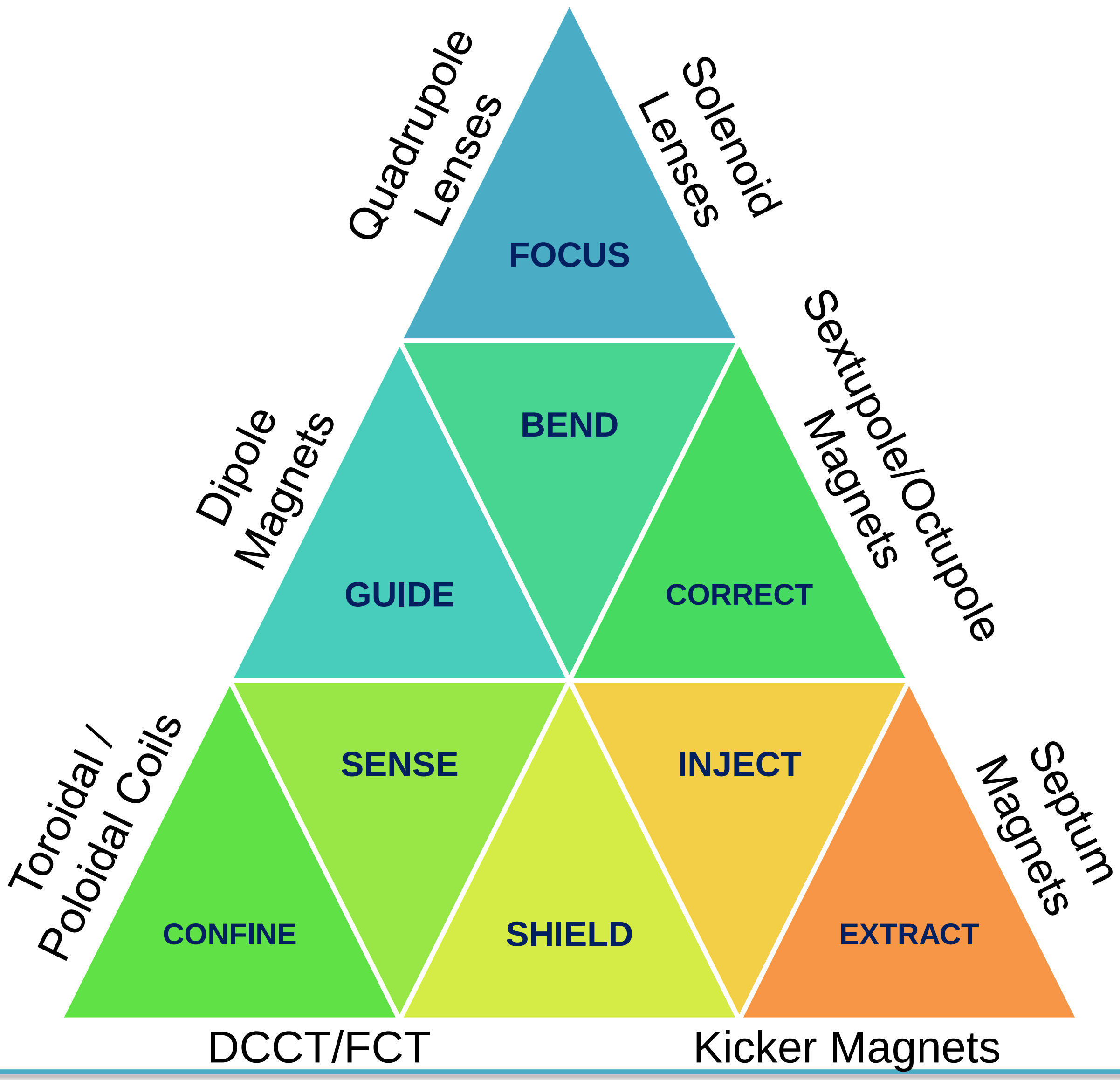
- **Introduction**

- **Accelerator beam line magnets**
  - *Drift tube Linac (10-20 MeV) & PMQs*
  - *Linac Magnets for PIP-II*
  - *Magnets for Delhi Light Source*
  - *Synchrotron beam line magnets*

- **Superconducting magnet technology**
  - *Liquid helium cooled superconducting magnet*
  - *Cryo-cooler based conduction cooled superconducting magnet*

- **LBNF and Dune Magnets**

Magnets: Omnipresent and benign



It is rare to find an application of charge particle beams where magnets don't find a role

Application Areas

Accelerator (Linear/Cyclotron/ Synchrotron)

Medical (MRI, NMR)

Fusion Experiments

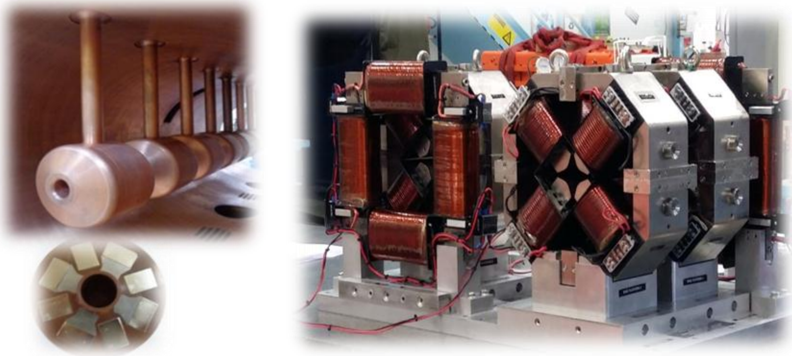
Mass spectrometers

RF Devices (Klystron, Gyrotron, BWO)

Agriculture

Sensors (SQUIDS/Fluxgates/ GMR/Faraday rotation)

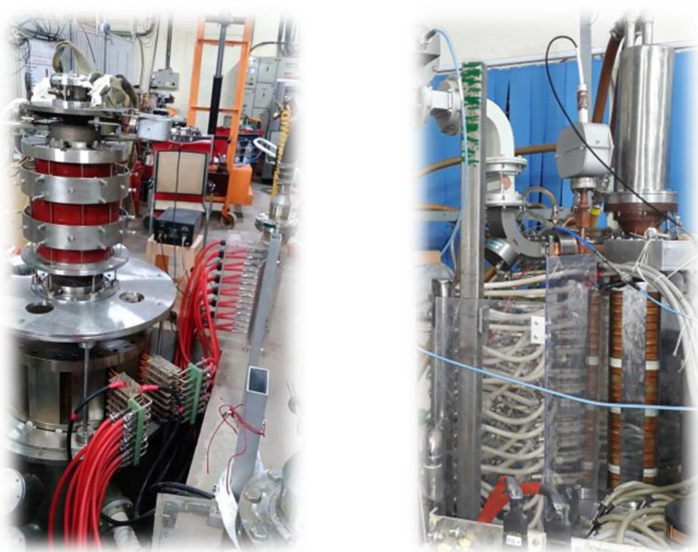
Contributing to an ever-expanding magnet compass



Accelerator Magnets
(Focusing & Steering Magnets)

Magnets for MHD Experiments

Bending Magnets

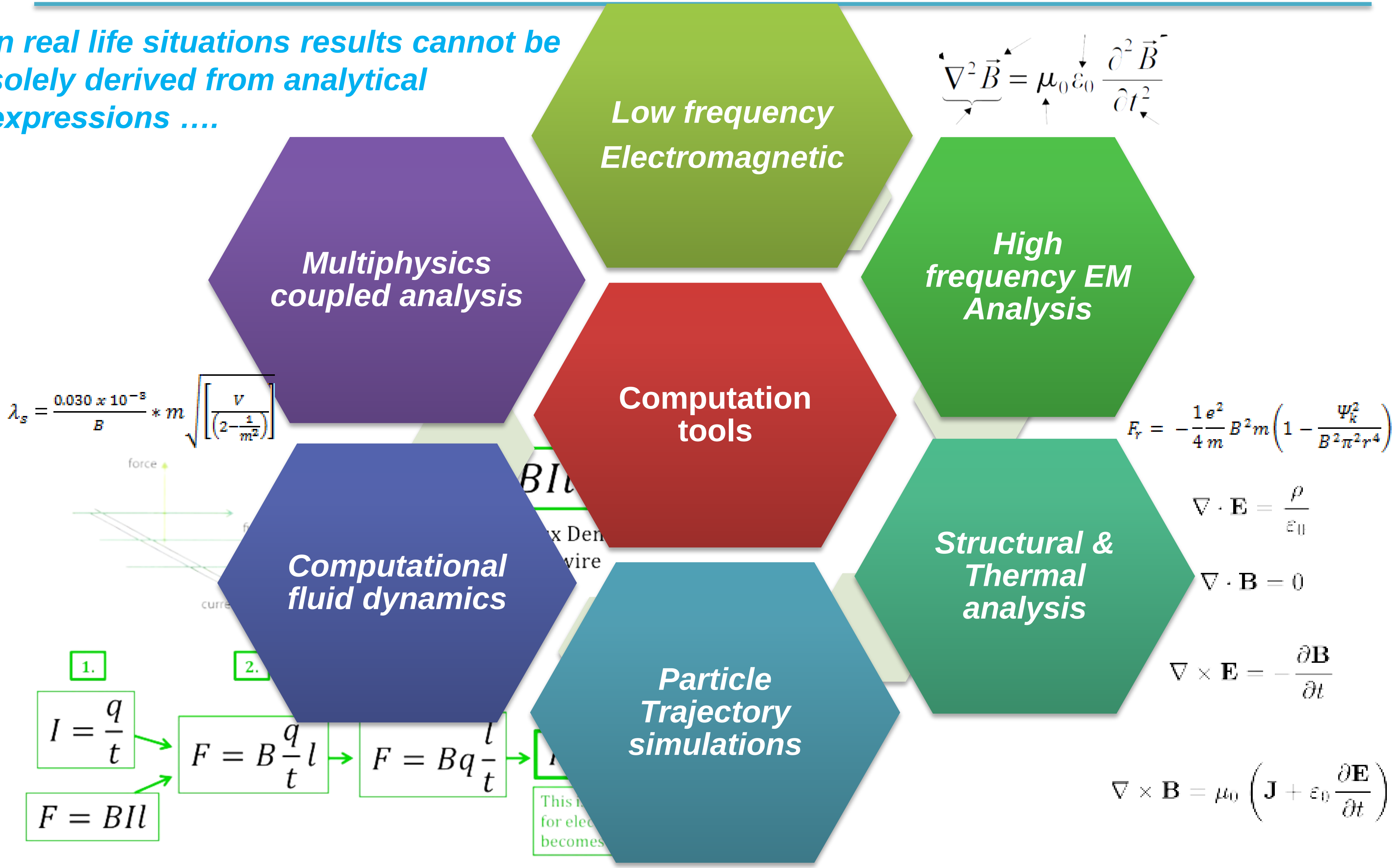


Focussing Lenses for
Vacuum tubes

Synchrotron Beam Line
Magnets

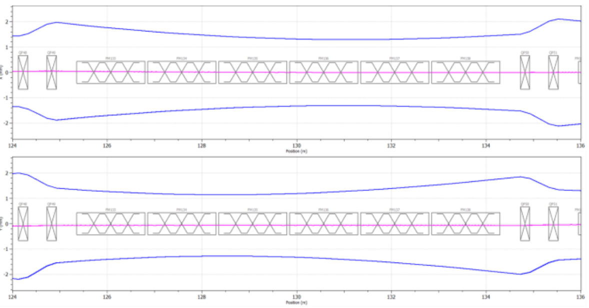
Design capabilities: Physics and Engineering goals

In real life situations results cannot be solely derived from analytical expressions ….



Typical development cycle of a magnet

1. Beam Dynamics Simulations



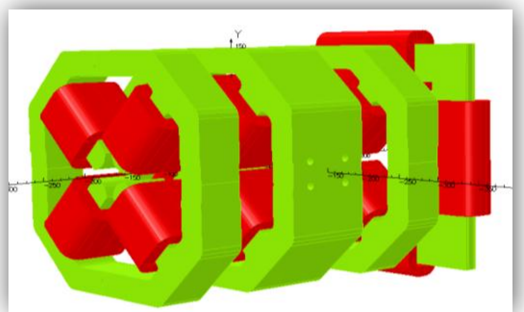
2. Functional Requirement

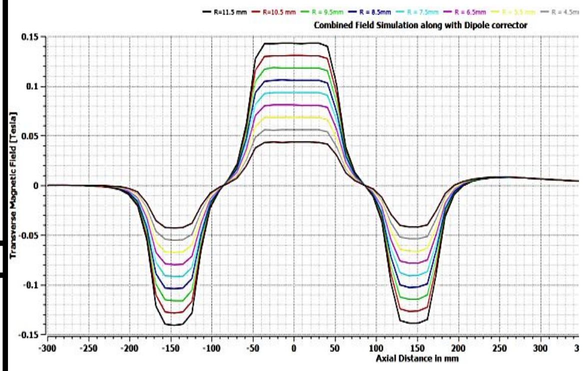
- Application
- Physics requirement

3. Engineering Requirements

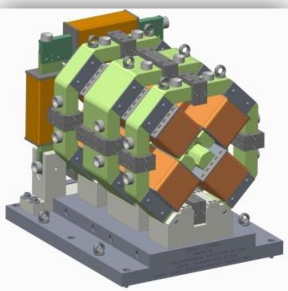
- Size/power consumption
- Seamless Interfaces
- QA & Acceptance

4. Electromagnetic design





5. Engineering design



6. Series Fabrication

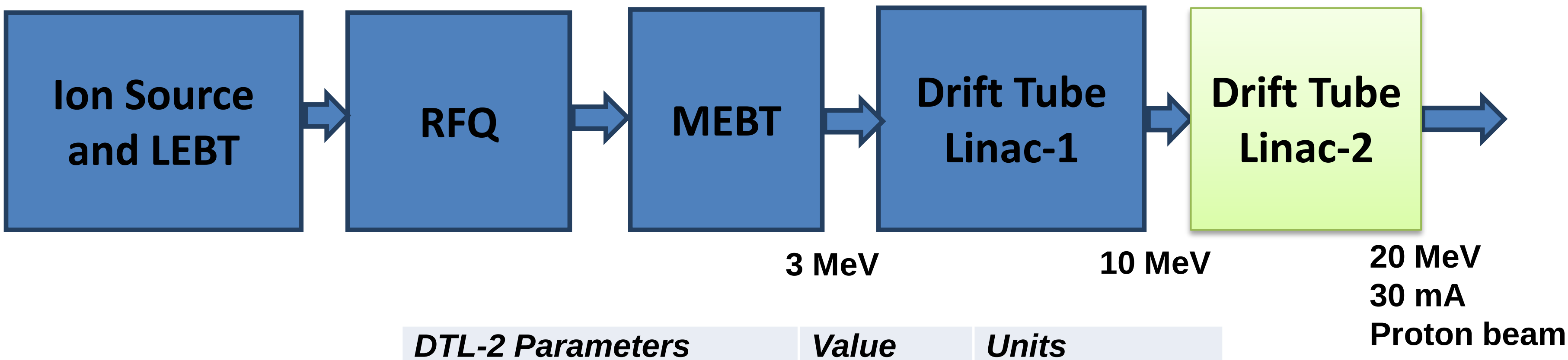
7. Qualification

8. Integration in beamlines

Accelerator beam line magnets

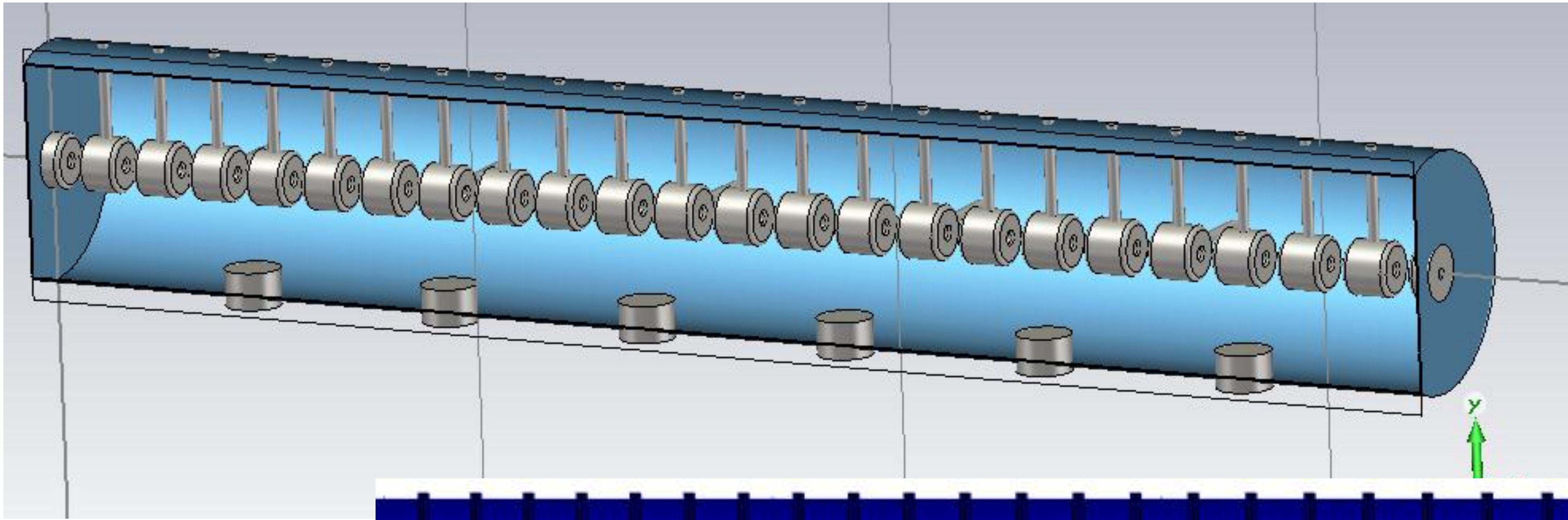
- Drift tube Linac (10-20 MeV) & PMQs (H^+ Beam)
- Linac Magnets for PIP-II (H^- Beam)
- Magnets for Delhi Light Source (e^- Beam)
- Synchrotron beam line magnets (e^- Beam)

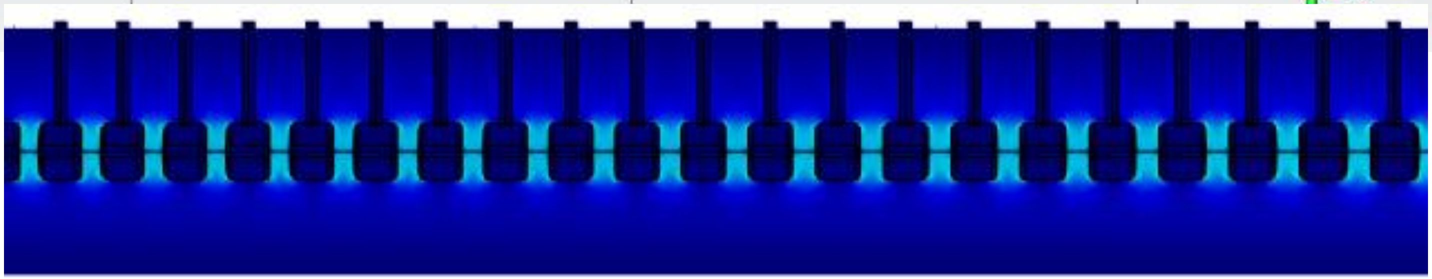
Typical configuration of a Proton Accelerator



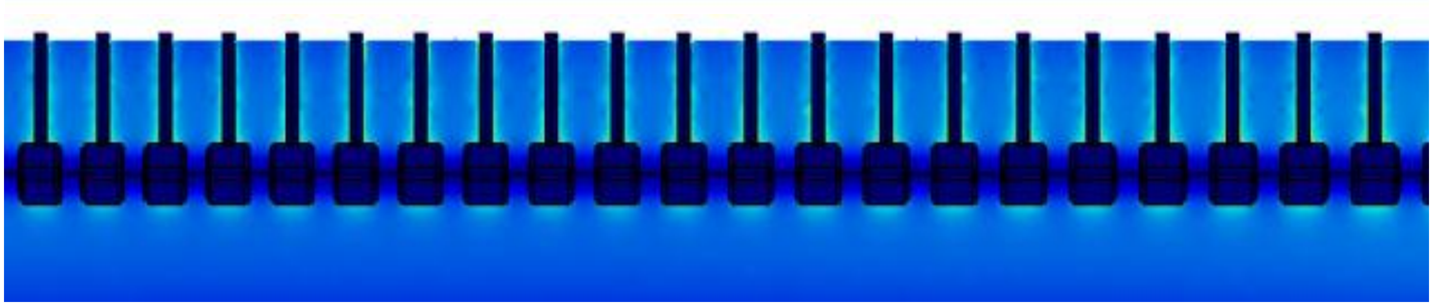
DTL-2 Parameters	***Value***	***Units***
I/O energy	10/20	MeV
Frequency	352.21	MHz
Current	30	mA
No. of Tanks	2	
Total length	~ 6	m
Total RF power	1	MW
Type of quadrupole	PMQ	
Focussing Lattice	FFDD	
Norm.RMS emittance	0.021	π cm-mrad

Sectional view of Drift Tube Linac



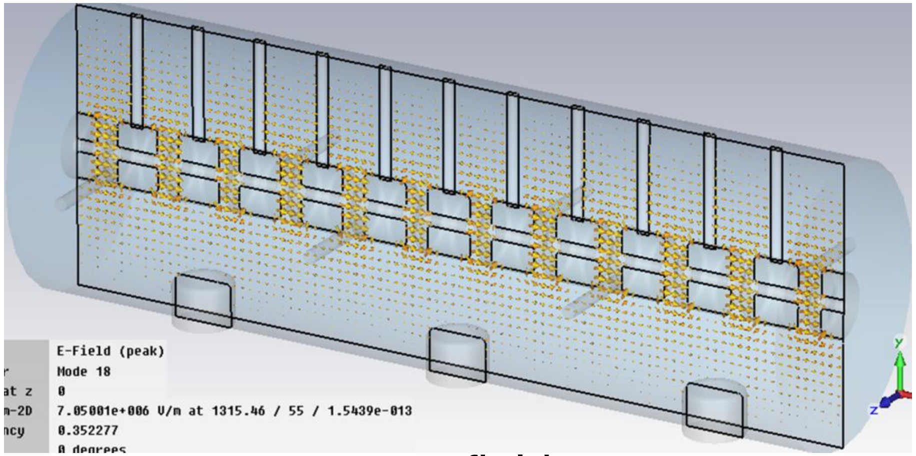


E-field distribution

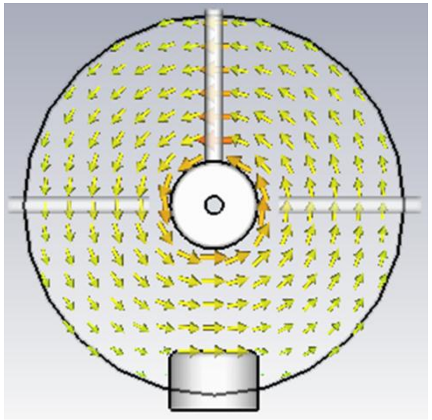


H-field distribution

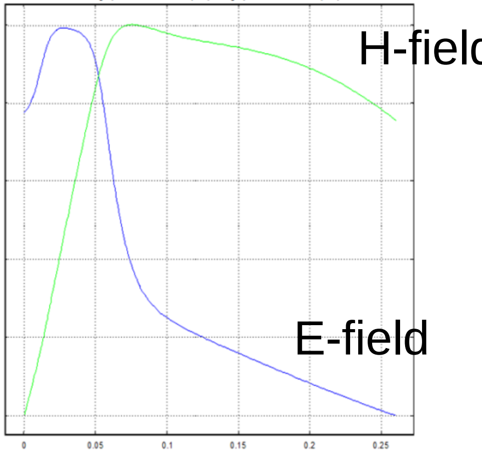
EM Field distribution in DTL

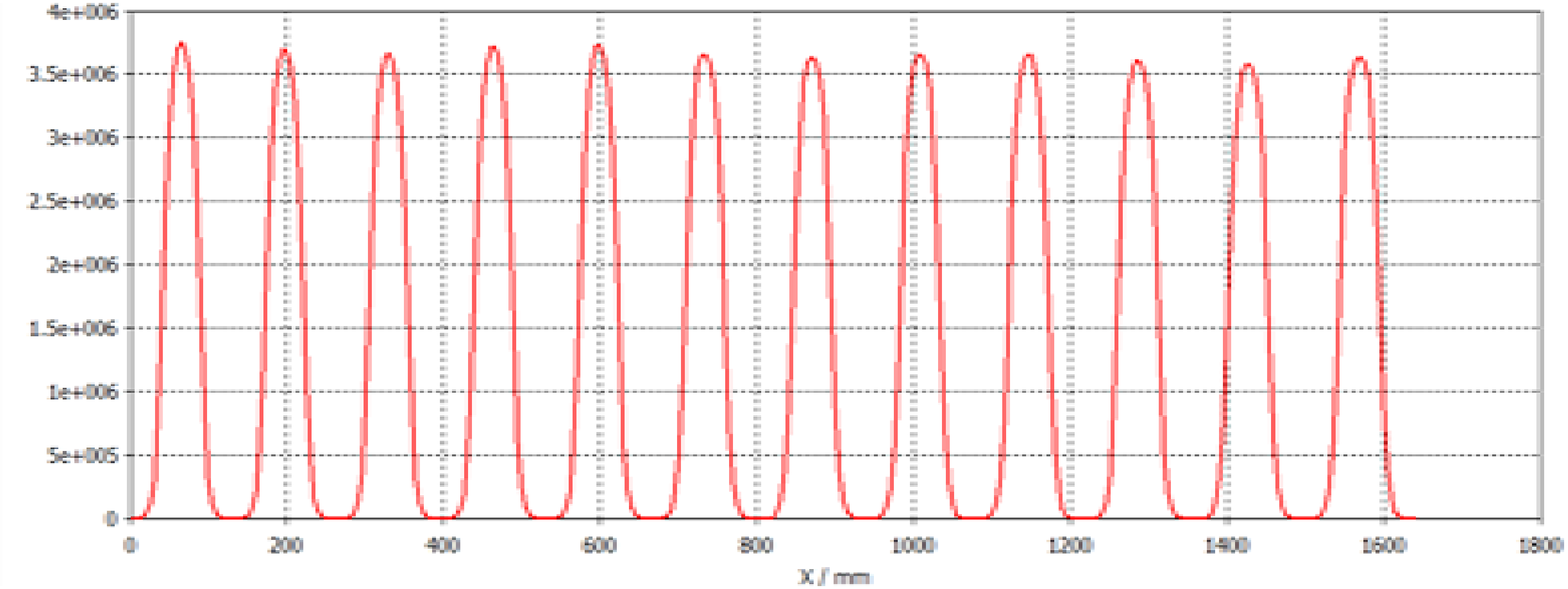


E-field



H-field



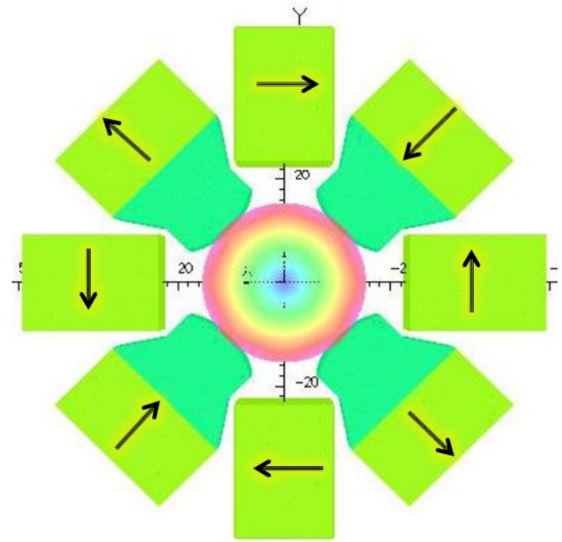


E-field profile along the beam axis

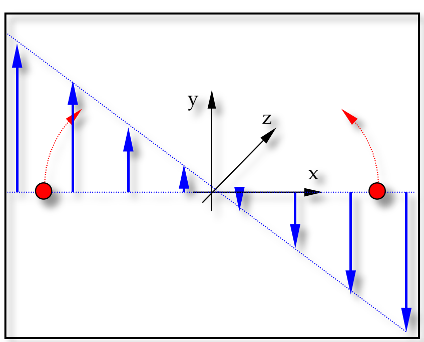
The Quadrupole configuration

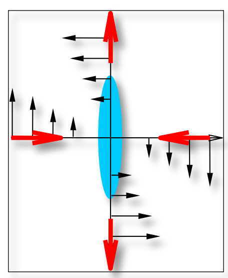
The Permanent magnet Quadrupoles

- Field Gradient in the aperture α 1/r^2
- Rare Earth Permanent magnets for high air gap flu density
- Smaller diameter leads to smaller drift tubes , henc higher shunt impedance
- Absence of Power supplies / high capacity coolin systems lead to greater reliability

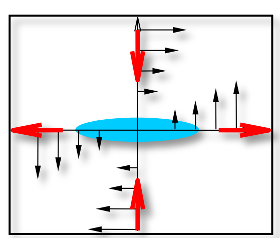


Gradient field (quadrupole)

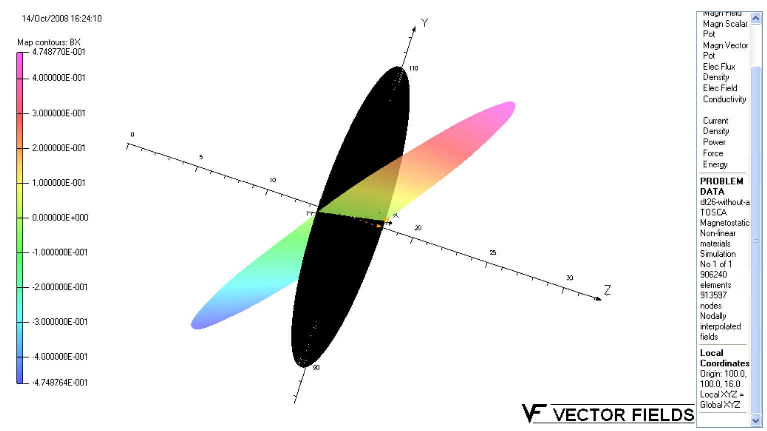




Focusing



De-focusing

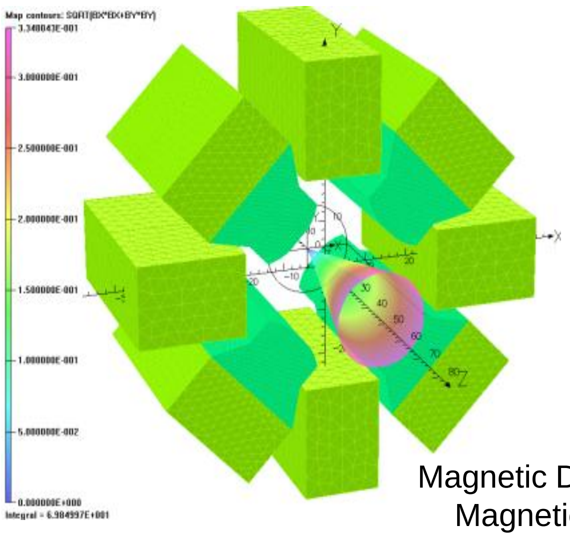


Field gradient in aperture

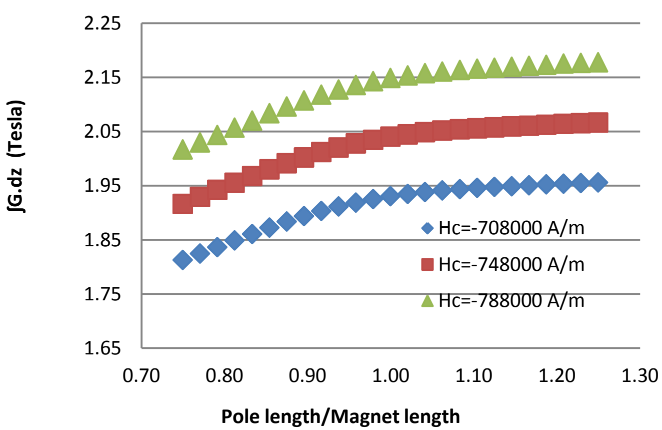
Magnetic Design of Permanent Magnet Quadrupoles

Independent measurements carried out at BARC, RRCAT and Danfysik using different measurement methods matched within 0.1%.

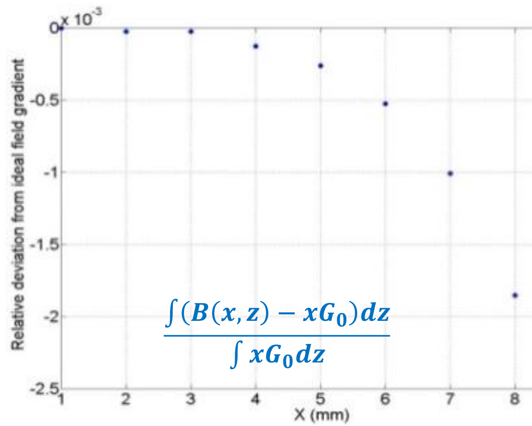
At BARC (Hall probe): 2.053 Tesla	At RRCAT, Indore (Rotating Coil) 2.051 Tesla
At BARC (Stretch Wire bench) 2.048 Tesla	



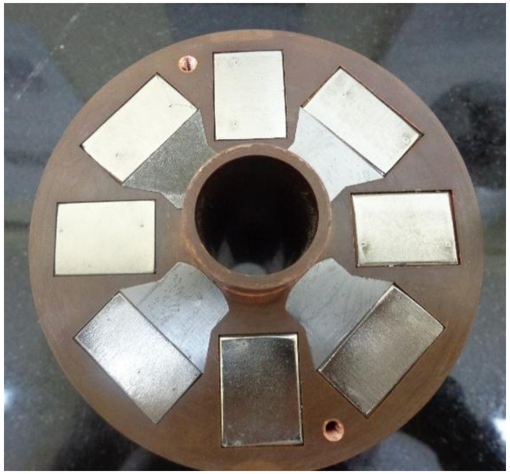
Magnetic Design of PMQ with Magnetic field histogram



Tuning curves for different magnet strength

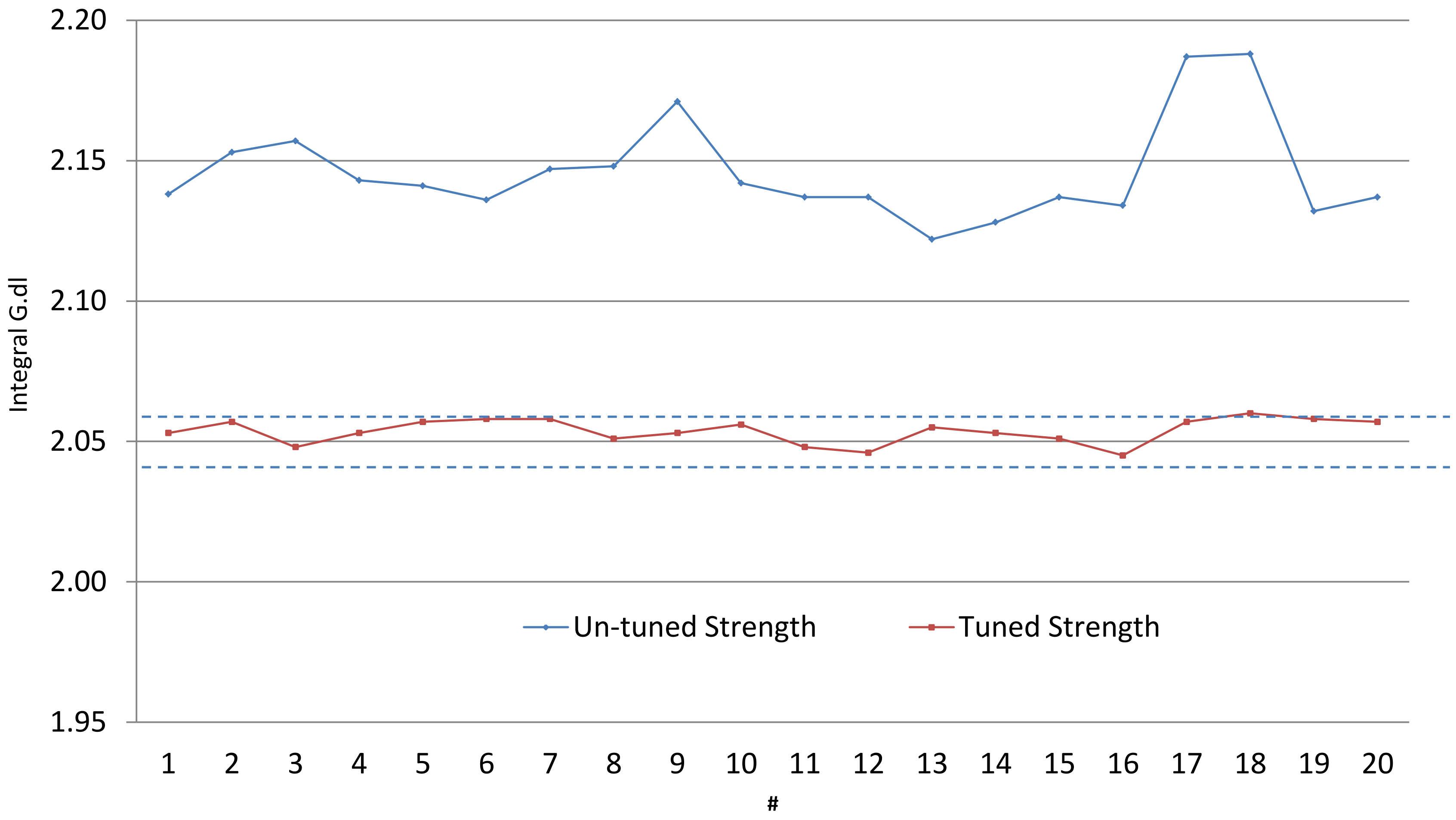


Uniformity of ∫G.dl



PMQ Assembly

Tuning of Permanent Magnet Quadrupoles

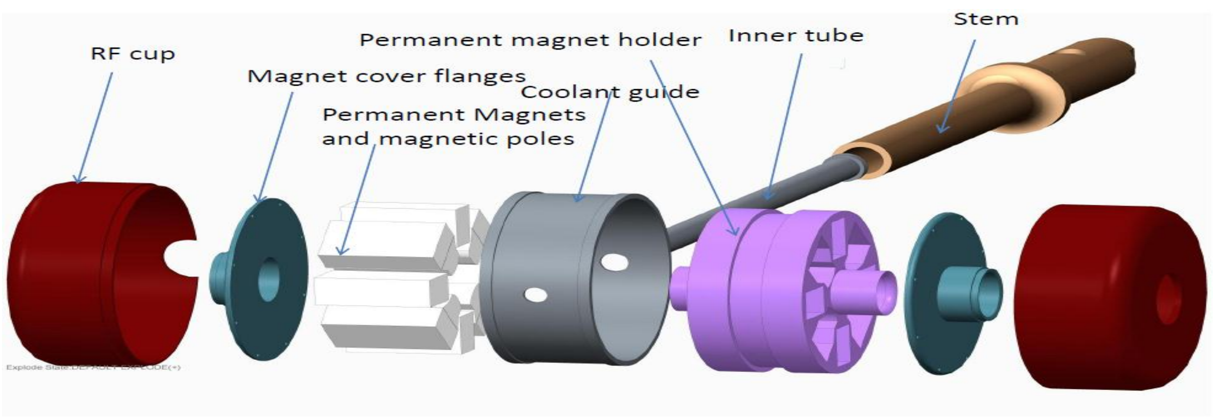


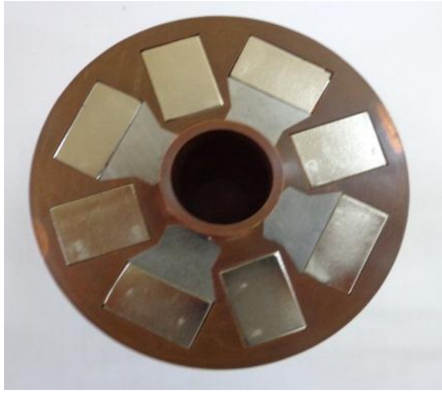
Alvarez Drift Tube Linac

Developed Drift Tubes Linac cavity with assembled Drift Tubes

Drift Tubes aligned concentrically along the DTL cavity axis

Drift Tube

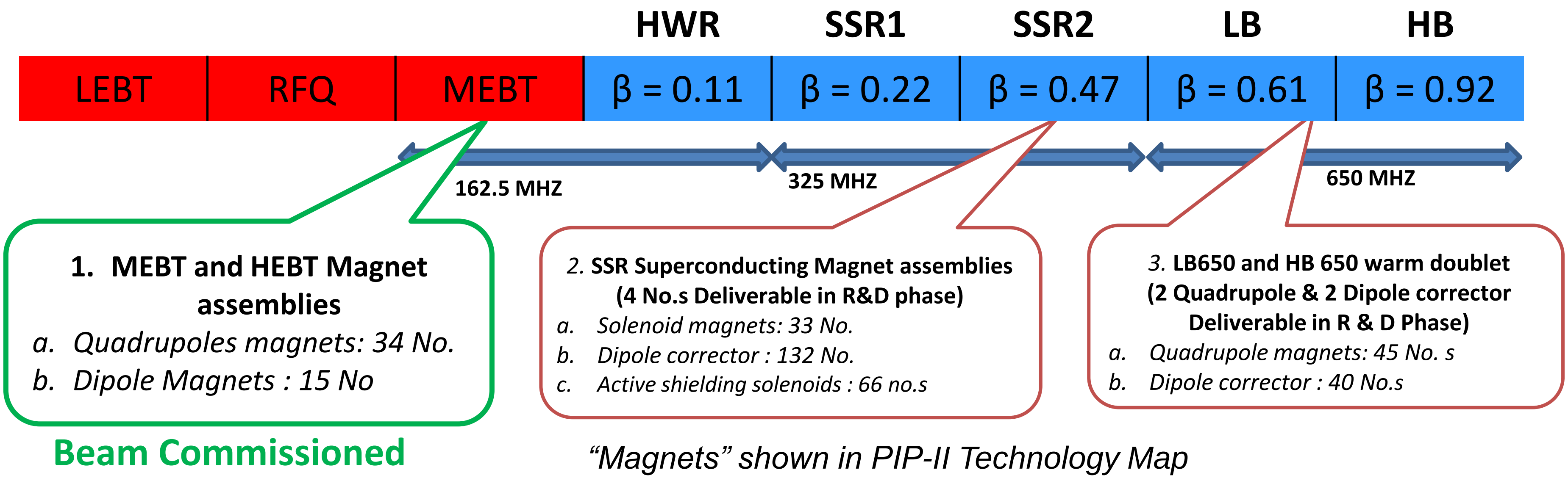




Permanent Magnet Quadrupole

20 MeV Alvarez DTL developed at BARC

LINAC magnets for PIP-II



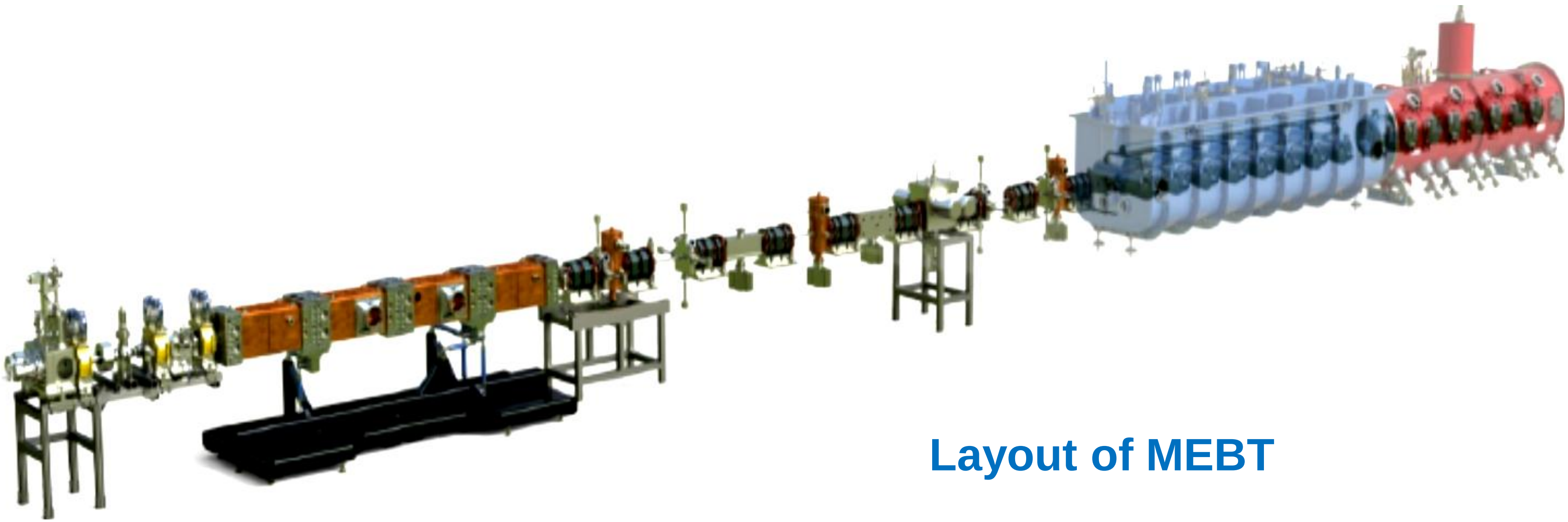
"Magnets" shown in PIP-II Technology Map

- 49 Nos of BARC developed MEBT magnets (34 Quads + 15 H/V Dipole corrector) commissioned in PIP2IT beamline, FNAL.
- Design and engineering development of bath cooled superconducting focussing lenses. Cryogenic Qualifications @ 2.1K proves efficacy of BARC design to meet beam optics and engineering requirements.
- Design and Engineering development of LB/HB650 warm doublet (Quads and Dipole corrector).

MEBT Quadrupole Doublet & Triplet and Dipole Correctors for PIP2 Injector under IIFC

- *MEBT quadrupole focussing magnets and dipole correctors designed at BARC*
- *Magnets designed, developed and sent to FNAL after magnetic, electric & thermal characterization at BARC*
- *Magnets beam commissioned at FNAL*

Magnets	Number
Quad-F	18
Quad-D	16
Dipole Corrector	15
Triplet Frames	8
Doublet Frames	5

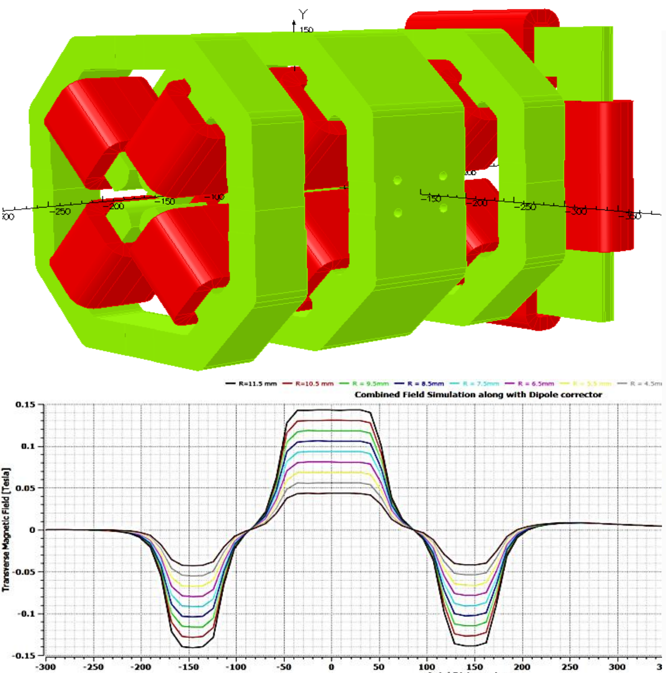


Layout of MEBT

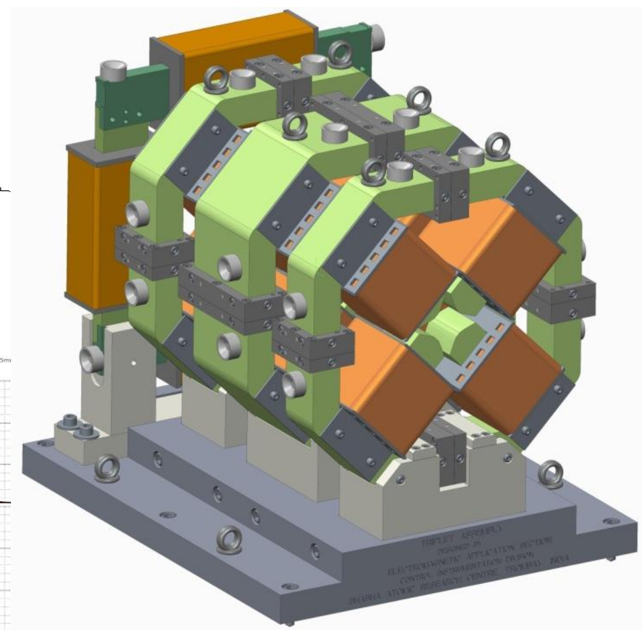
Design and Development of Focusing lenses for MEBT

Stages of development at BARC:

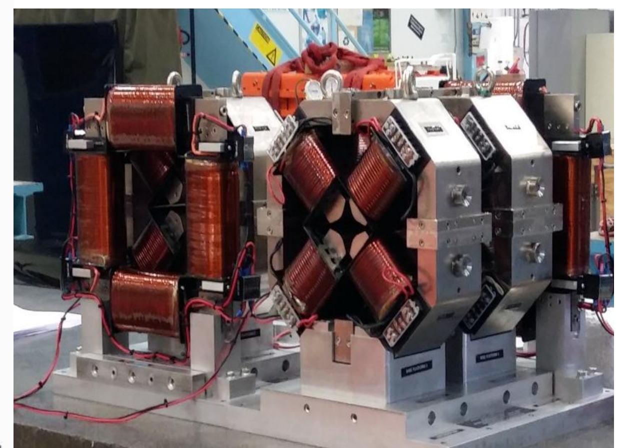
1. Electromagnetic design of lenses - Quadrupole Focussing Magnets and dipole correctors
2. Engineering design
3. Development drawings
4. Fabrication and Geometrical inspection
5. Magnetic measurements (integral fields)
6. Quality checks and traveller
7. Qualification tests with H^+ beam at 2.5 MeV



Electromagnetic Simulation

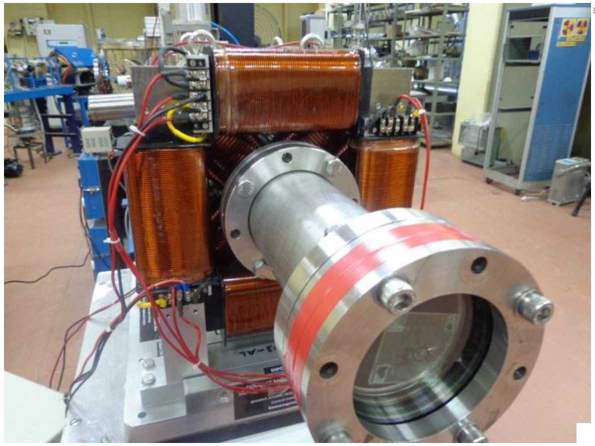


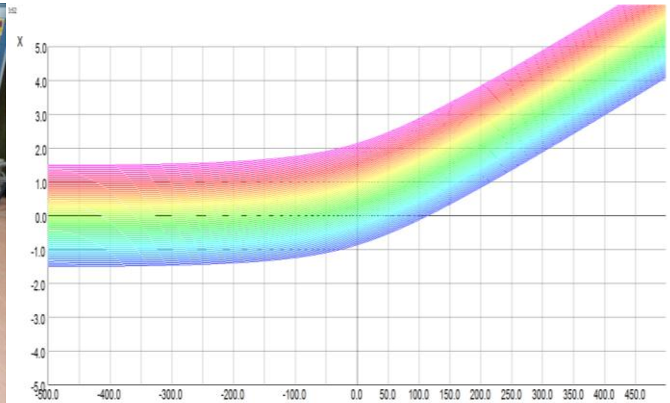
Mechanical Design

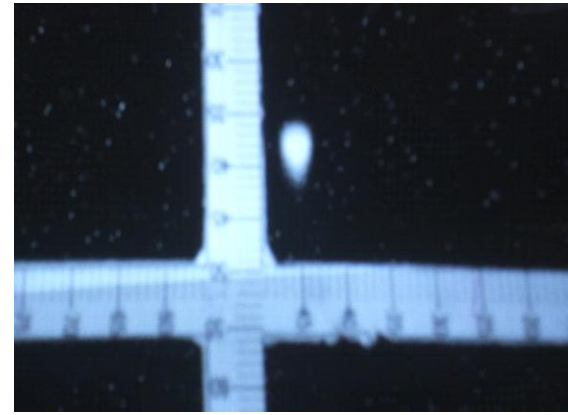


Developed Magnets

Qualification with H^+ beam at FOTIA

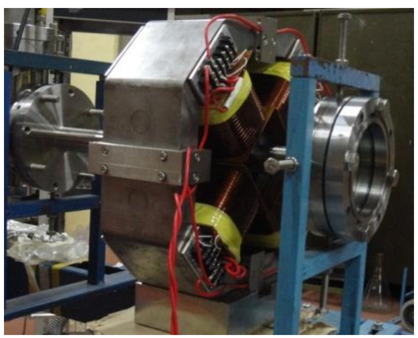


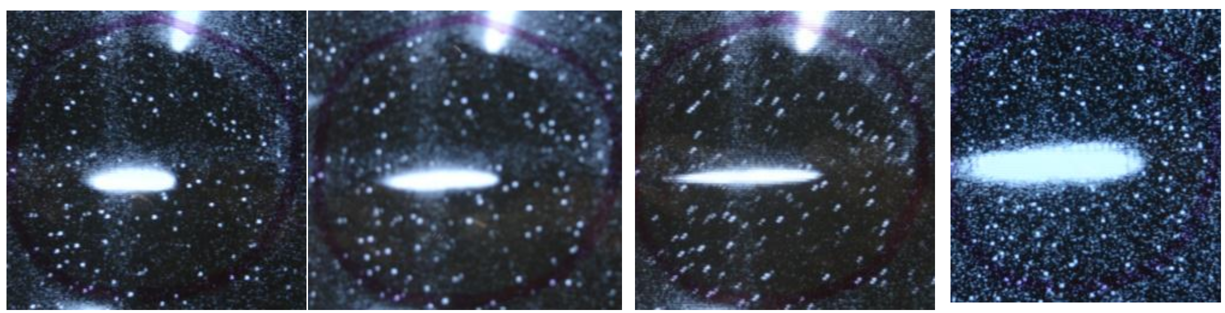




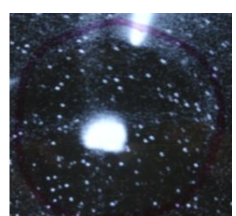
Beam line qualification of DC magnets @FOTIA facility

H^+ Beam Current 10nA; Beam Energy 2.5MeV; Angular kick 10mRad





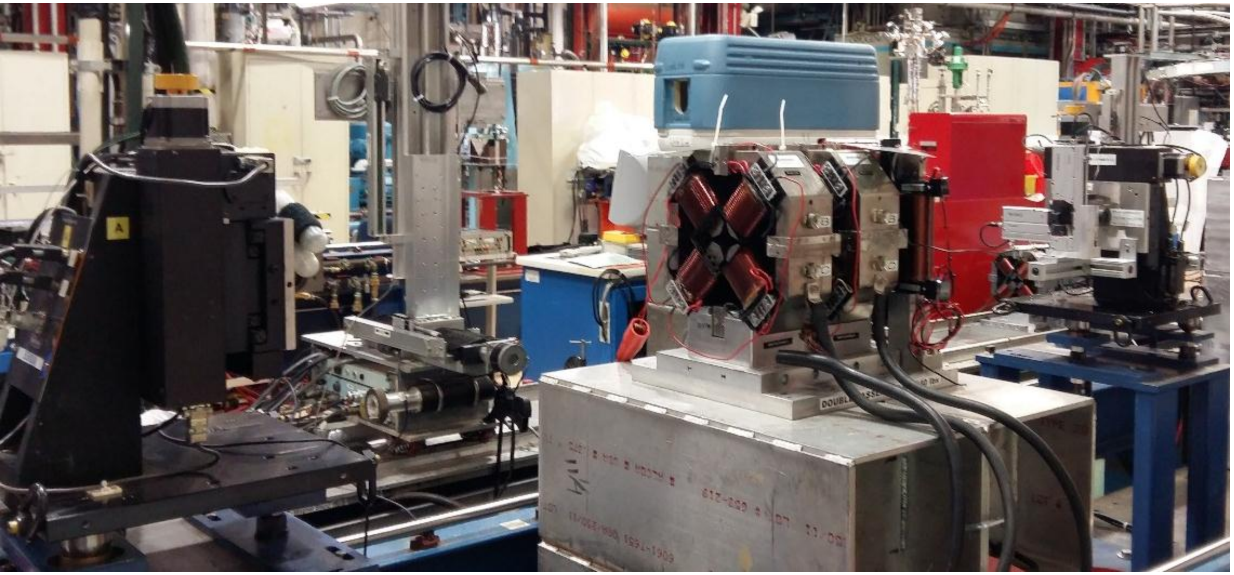
Focusing snap shots at different currents, Beam focuses as current of Quad increases, and it tends to de-focus when focused beyond focal point



Beam snap shot (Quadrupole off)

Beam snap shots (Quadrupole on)

Measurements on Quadrupole Magnets (July 2015)



Doublet assembly mounted on Single Stretch Wire Magnetometer

Magnet	Transfer Function (T/kA)
PXQF002	142.24
PXQF003	142.41
PXQF004	142.27

Mechanical center agreed with magnetic center within (~0.05mm)
Angles (yaw and pitch) agreed with mechanical to within (5-10mrad)
Roll angles were small (< 0.5mrad)

Harmonics after centering corrections

	an	bn	cn
1	0.000	0.000	0.000
2	6.450	-10000.221	10000.223
3	-26.245	-16.418	30.957
4	-28.146	25.091	37.706
5	1.256	-22.307	22.343
6	-14.749	26.816	30.605

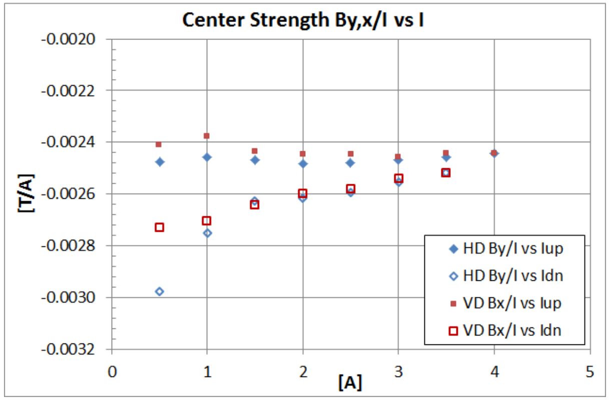
Harmonics after centering corrections

	an	bn	cn
1	-0.250	-0.214	0.329
2	5.860	10002.876	10002.878
3	-12.690	-10.088	16.212
4	1.703	5.622	5.874
5	-16.412	-9.326	18.877
6	24.345	-8.194	25.687

Harmonics after centering corrections

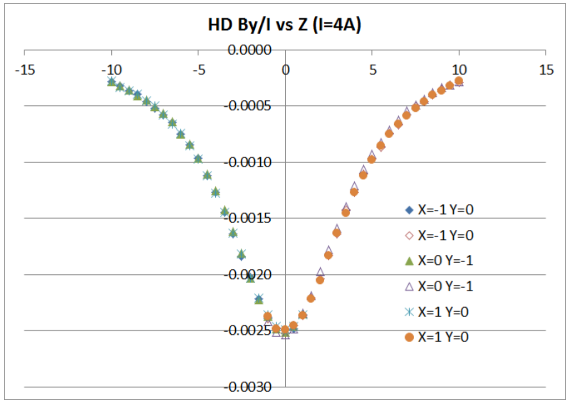
	an	bn	cn
1	-0.000	0.000	0.000
2	-0.328	-10000.006	10000.006
3	-5.297	2.231	5.747
4	-0.418	-46.679	46.681
5	19.158	-21.341	28.679
6	2.780	22.129	22.303

Magnetic Measurements on dipole correctors



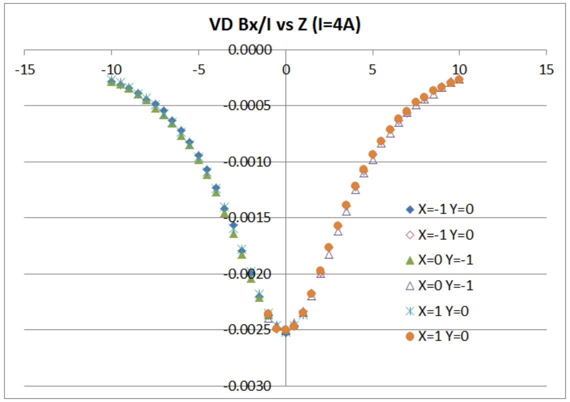
Graph 1

Normalized center field strength [B field / nominal Current (4A)] vs various excitation current.



Graph 2

Normalized Magnetic field and uniformity of the normalized magnetic field in the good field region aperture (GFR) of horizontal dipole corrector.



Graph 3

Normalized Magnetic field and uniformity of the normalized magnetic field in the good field region aperture (GFR) of vertical dipole corrector.

Summary of magnetic measurements at FNAL

Quadrupole

SN	Parameter	Requirement	Designed for	Measured	Unit	Remarks
1.	∫ G.dl	1.44	1.44	1.44	T	Meets Req.
2.	Magnetic Centre (X axis)	Within ± 100	0	45 to -30	um	Meets Req.
3.	Magnetic Centre (Y axis)	Within ± 100	0	30 to -40	um	Meets Req.
4.	Integrated Magnetic field uniformity (up to n=10)	<1	0.30	<0.5	%	Meets Req.
5.	Magnetic centre as function of current	50	0	<20	um	Meets Req.
6.	Transfer function stab.	0.30	0.20	<0.5	%	Meets Req.
7.	Higher Order Multipoles	<1	0.20	<0.3	%	Meets Req.
8.	Skew Components	0.2	0.05	<0.1	%	Meets Req.

Dipole Corrector

S. No	Parameter	Specified	Achieved	Remarks
1.	Magnetic field integral	2.1 mT-m	2.4mT-m	Meets requirements
2.	Field tilt -Deviation of X and Y field from perpendicular	$<3^0$	Negligible	No evidence of tilt in the orthogonal field
3.	Integrated field uniformity	5%	Highly uniform	Acceptable even at 25mm radius, well beyond requirement level

Memo generated by FNAL after magnetic qualifications of pre-series magnets

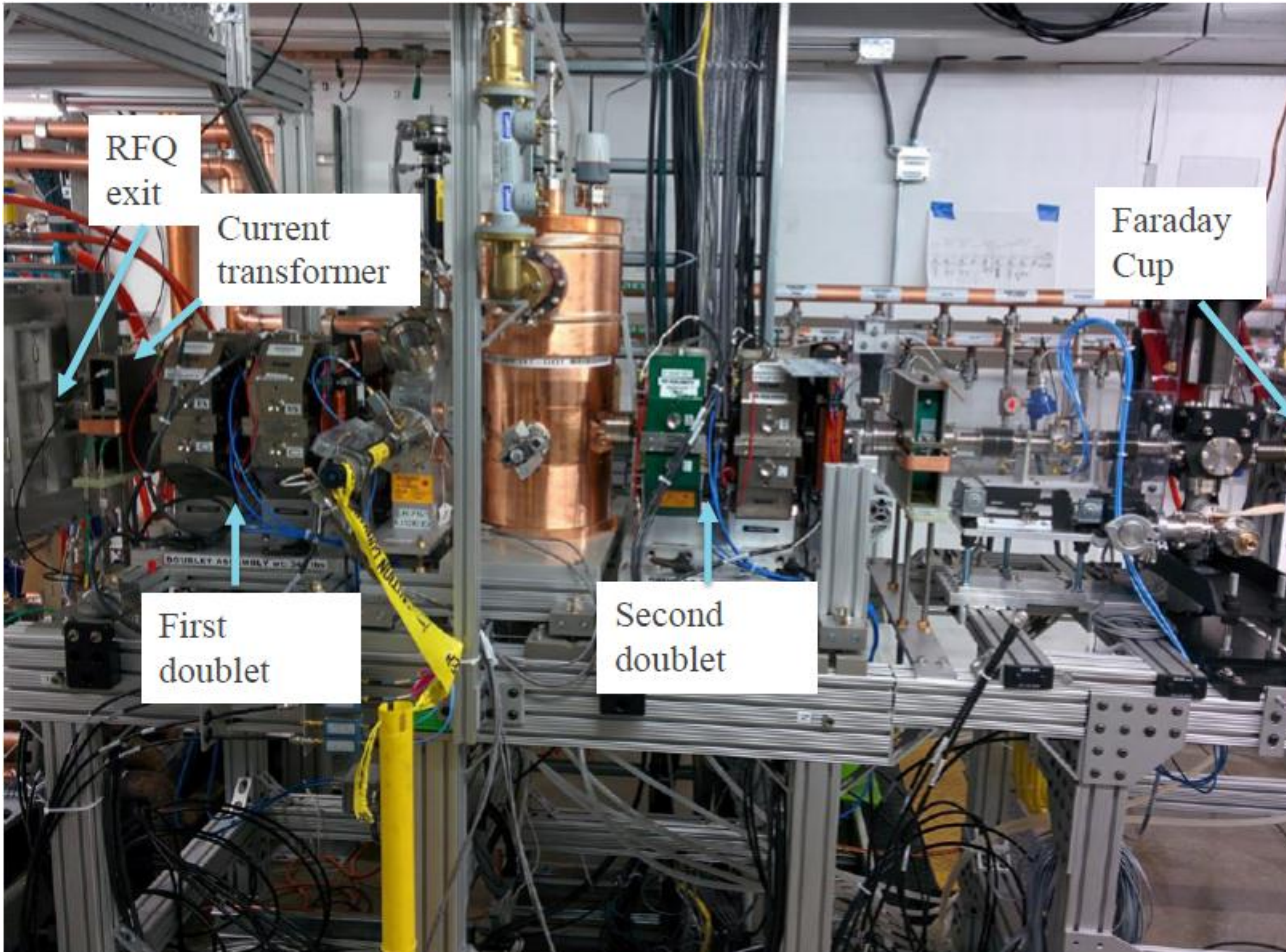
To:	Dr. Shekhar Mishra
From:	Dr. Michael Tartaglia, PXIE Magnet SPM, Tech. Division Test & Instrumentation Department Head
Subject:	Qualification of PXIE MEBT Pre-series Magnets from BARC

As part of the Indian Institutions and Fermilab Collaboration, the Electromagnetic Applications Section at the Bhabha Atomic Research Centre (BARC) has delivered to Fermilab a set of pre-series magnets suitable for use in the MEBT section of the PXIE beamline. The deliverables included three F-Quadrupoles (PXQF), two Corrector Dipoles (PXD), and two "doublet" frames, used for mounting two PXQF and one PXD into one "doublet" assembly. No design changes have occurred in the PXQF magnets, and some minor changes were introduced for the PXD magnets, since the first two prototype magnets were accepted one year ago. These BARC-designed magnets were built by industry in India according to drawings provided by BARC, and came complete with travelers documenting the components, fabrication and tests.

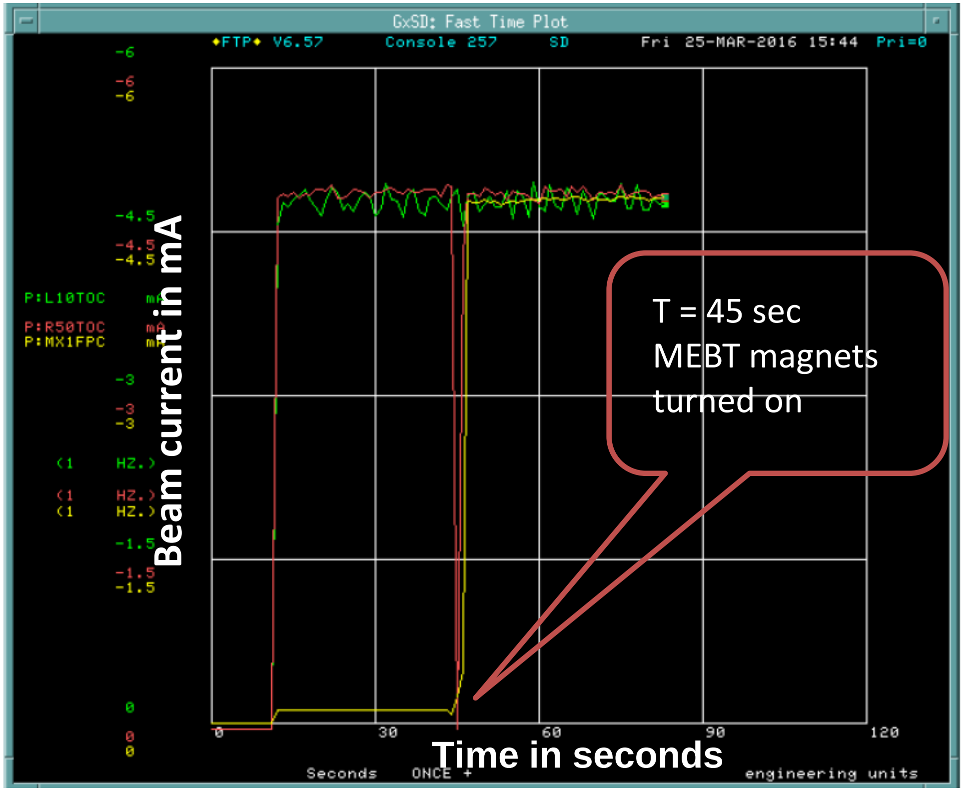
Upon delivery the magnets were electrically inspected and measured at the Fermilab Magnet Test Facility to verify that they achieved the required magnetic performance as documented in the Technical Requirement Specifications (Teamcenter ED0003467). The results of these measurements have been reviewed by Dr. A. Shemyakin (PXIE Warm Front End Manager), C. Baffes (PXIE Warm Front End Engineer), and me. I am pleased to say that these magnets meet the required performance in terms of physical aperture and length, maximum operating current, integrated magnetic strength, field uniformity, stability of the quad magnetic center, and dipole field angle perpendicularity. These pre-series magnets are ready for integration into the PXIE beam line. Based upon the successful fabrication and test performance of these pre-series magnets it is recommended that approval be given to BARC to proceed as soon as possible with fabrication of production quantities of the PXQF, PXQD, and PXD magnets.

BARC developed beam-handling components on Fermilab Magnetic measurement bench (July 2014)

PXIE Beam line integration of MEBT (2 Doublets) (Feb' 2016)



Transport through the MEBT 1.1 line



The MEBT magnets were turned on at T=45 sec.

Green - beam current at the entrance of RFQ.

Red - beam current at the exit of RFQ.

Yellow - beam current in the Faraday Cup.

Vertical axis –beam current, 1.5 mA/div.

Horizontal axis –time, 30 sec/div.

5 mA, 20 μs, 10 Hz

With quadrupoles and dipole correctors tuned, most of the beam goes into the Faraday Cup at the end of the beam line at the nominal current of 5 mA.

Mail from Steve Holmes on BARC magnets performance

From: owner-iifc@listserv.fnal.gov [mailto:owner-iifc@listserv.fnal.gov]
On Behalf Of Stephen D Holmes Sent: Wednesday, March 23, 2016 4:45 PM

To: iifc <iifc@fnal.gov> Cc: Nigel S. Lockyer <lockyer@fnal.gov>

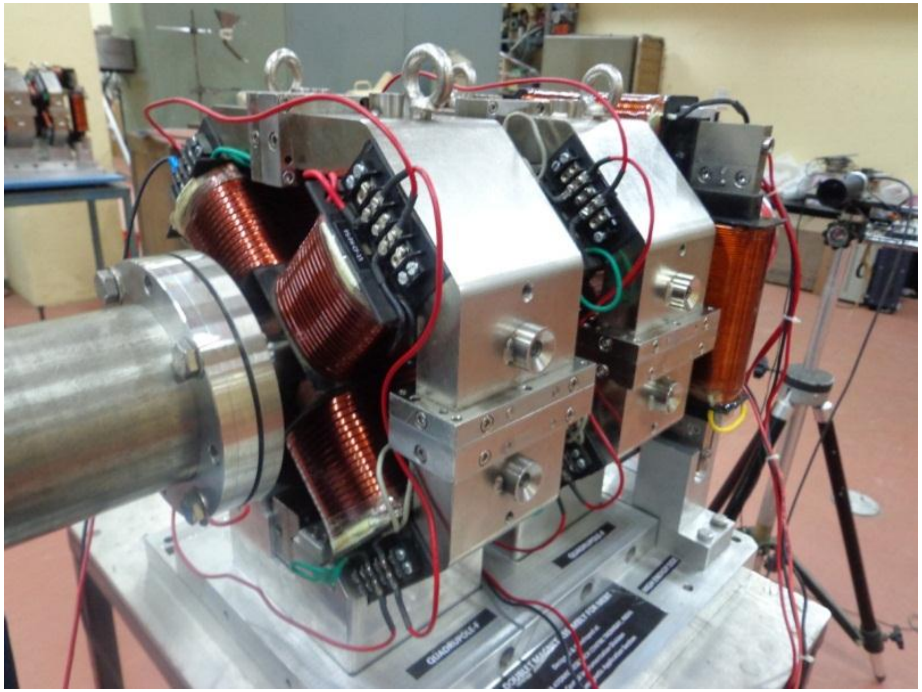
Subject: Beam through the PXIE RFQ

Dear Colleagues,
It is a pleasure to tell you that today we successfully accelerated beam through the RFQ at PXIE. **Following the exit of the linac are four quadrupoles and two correction dipoles manufactured at BARC. Once the quadrupoles were energized beam transmission to the Faraday Cup downstream of the magnets approached 100%.**

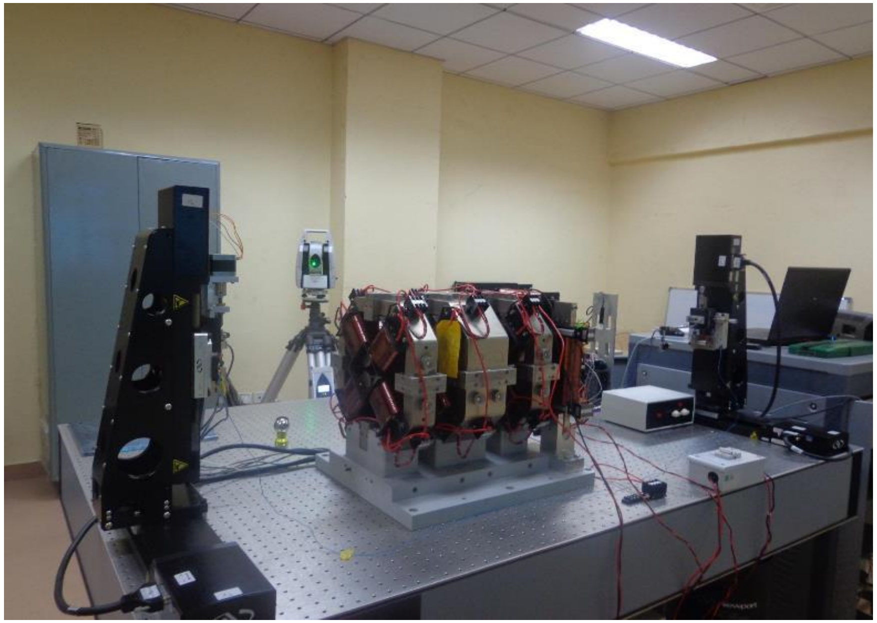
For those of you at Fermilab we will be congregating at the Users Center tomorrow (Thursday) at 5:00 for a little celebration.

Best Regards,
Steve

MEBT Quadrupole Triplets & Doublets for PIP2-IT (IIFC)



Design, development and characterization of Single Stretch Wire bench

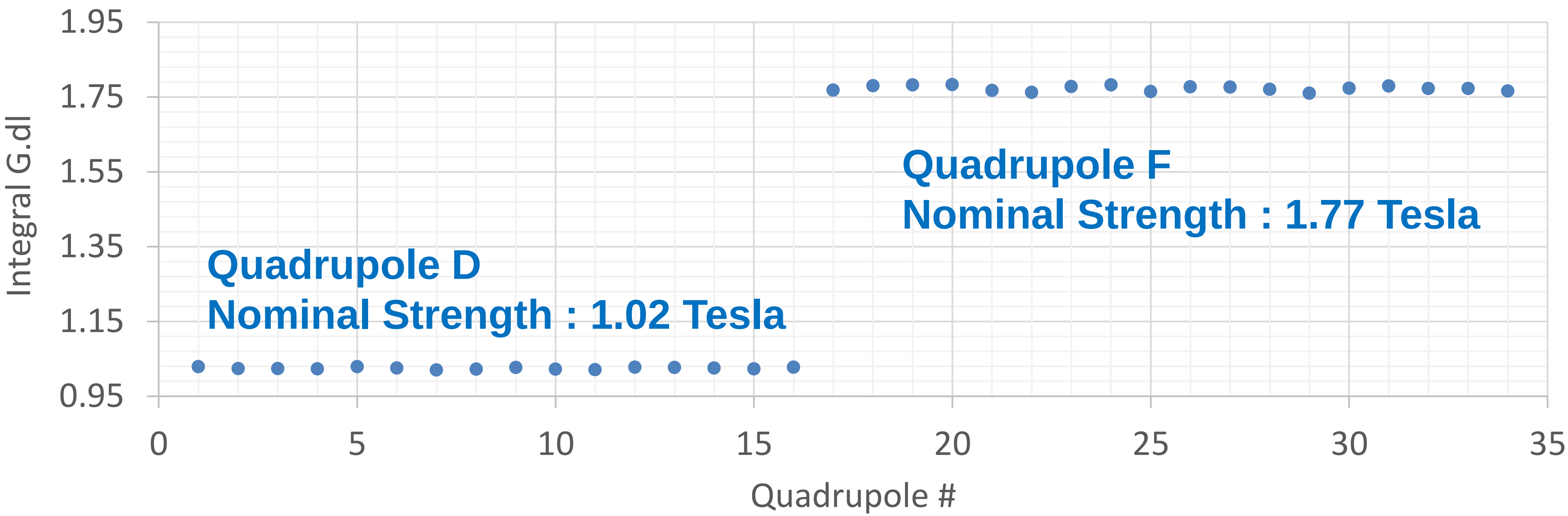


Magnetic Parameter measured

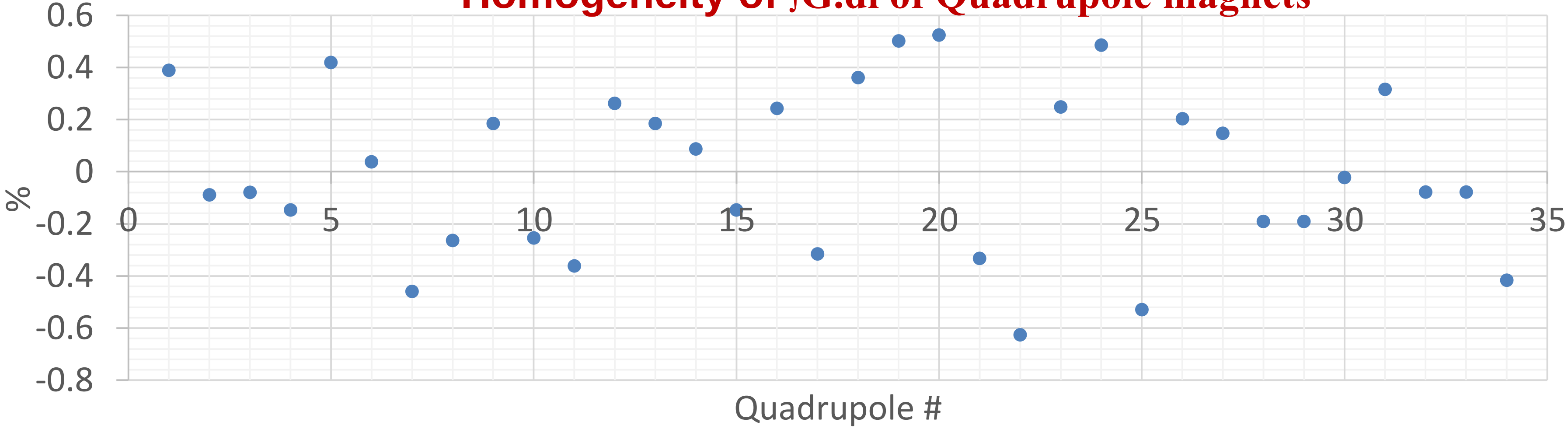
- Magnetic field transfer function
- Offset between geometric and magnetic center
- Uniformity of ∫G.dl
- Higher Order Multi-poles
- Roll, Yaw and pitch angles
- Magnetic alignment using laser tracker

1. ***The two opposite orthogonal stage pairs are portable and can be placed as per requirement of the magnet being measured.***
2. *Long Magnets can be measured using the set-up. In this case the magnet will be placed on independent heavy duty platform between the stages.*
3. *Sag compensation can be carried out during measurements*

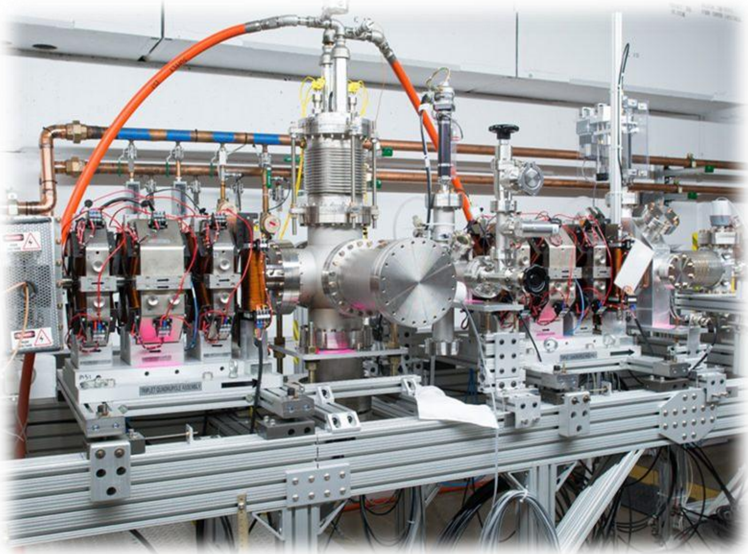
Integral Magnetic Field Gradient of series Quadrupole Magnets

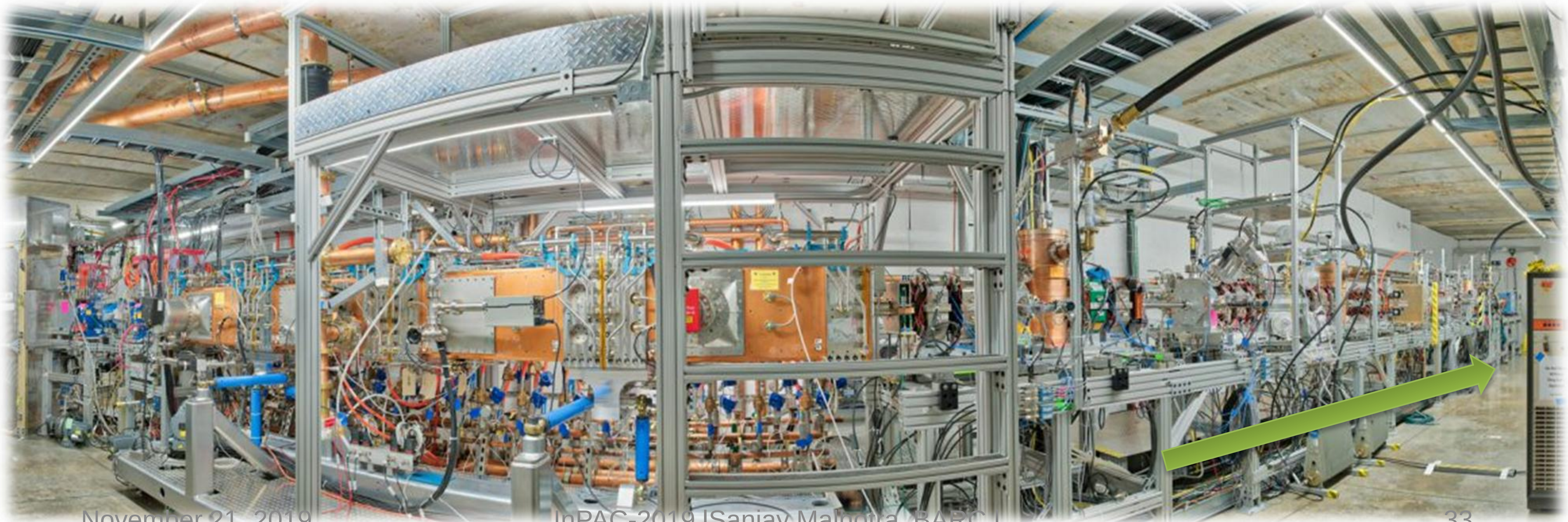


Homogeneity of ∫G.dl of Quadrupole magnets



Magnets Commissioned in P2IT beam line at FNAL



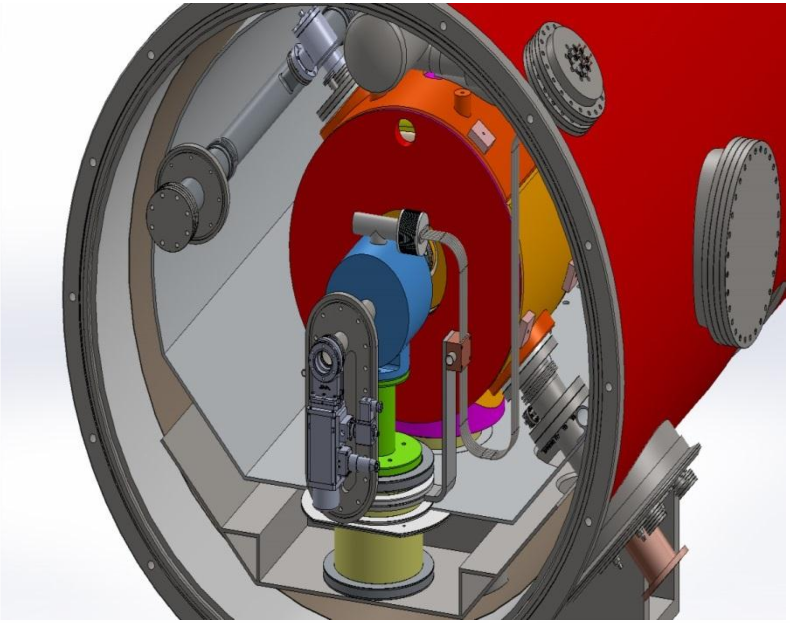


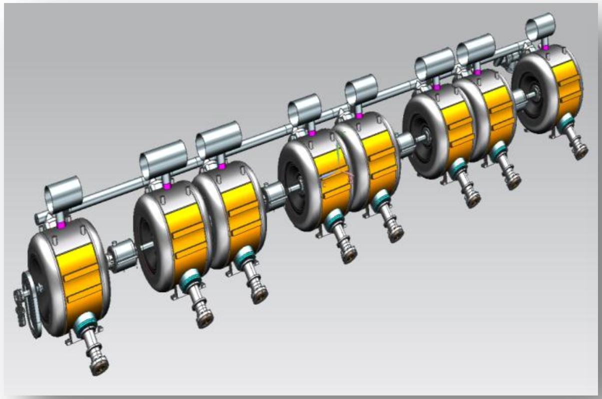
SOLENOIDS FOR SUPERCONDUCTING CRYOMODULES FOR PIP-II

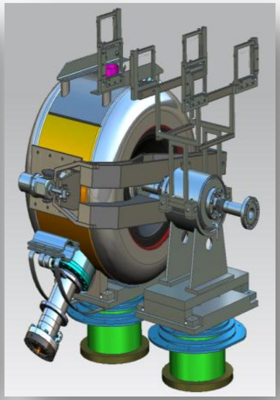
The optical design of the PIP-II accelerator front end requires using superconducting solenoids inside the HWR, SSR1, and SSR2 cryo-modules as transverse focusing elements.

Major design criteria for superconducting focusing lenses:

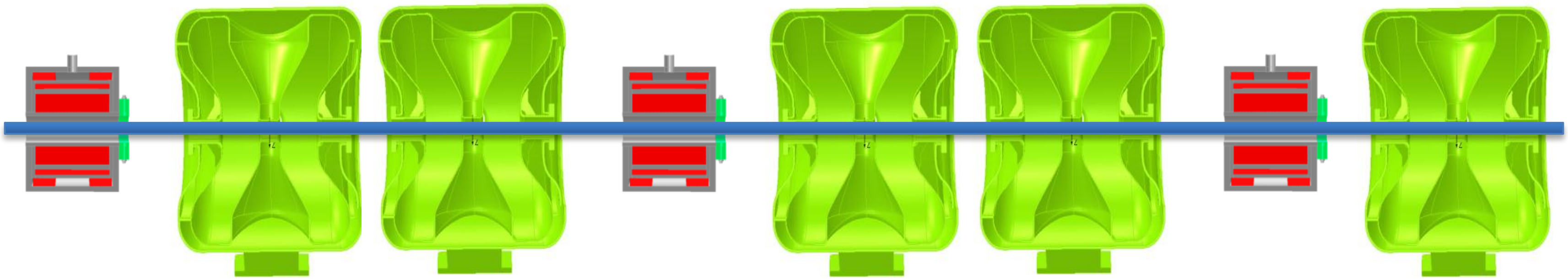
- To meet the focusing and correction strength requirements as derived from beam dynamics simulation.
- To meet the fringe field requirements on the neighboring cavity surface to minimize Q degradation due to trapped flux in cavity walls.







SSR SUPERCONDUCTING MAGNET ASSEMBLIES (IIFC)

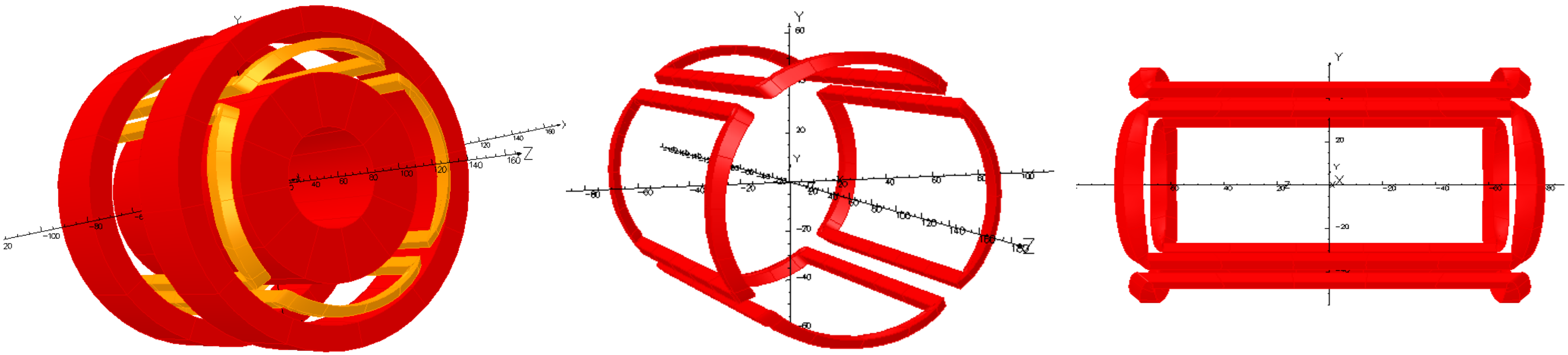


Magnet Cavity string arrangement for SSR2 cryomodule for PIP-II

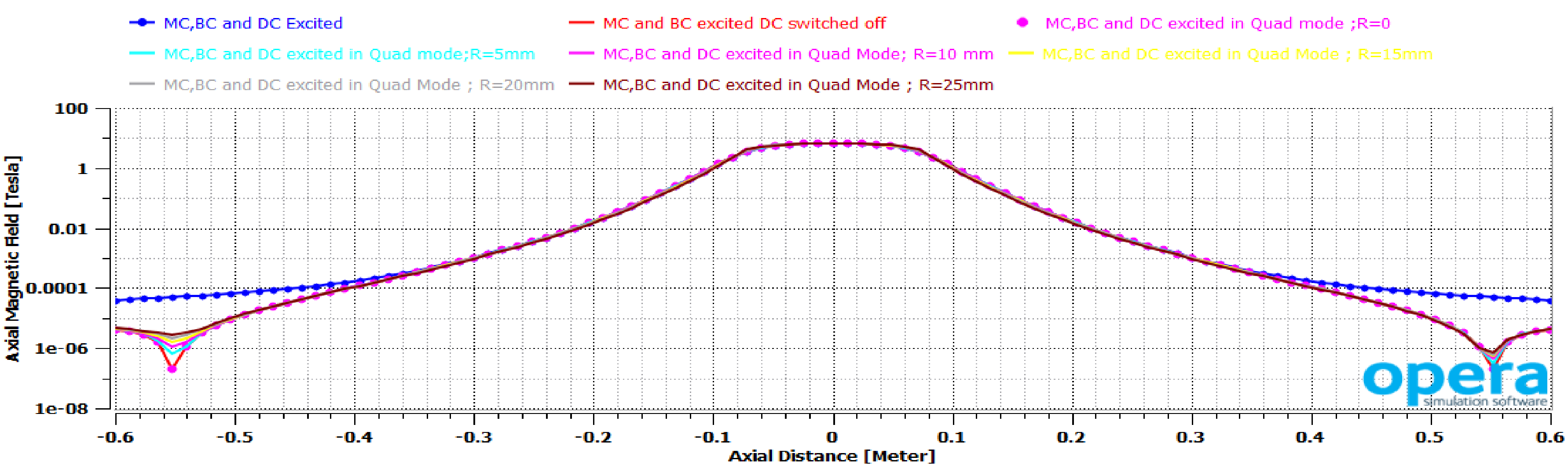
Parameters	Requirements
Focusing Strength	5 T^2m
Bending strength of Dipole correctors	5 mT-m
Beam pipe aperture	40 mm
Transverse and angular alignment	<0.1mm RMS & <0.5 mrad RMS
Effective length of solenoid (FWHM)	<15 cm
Active magnetic shielding requirements	$0.5Q_0$ criterion
Maximum current in the solenoid	100A
Maximum current in the dipole correctors	50 A

Functional requirement Specifications

SSR SUPERCONDUCTING MAGNET ASSEMBLIES (IIFC)

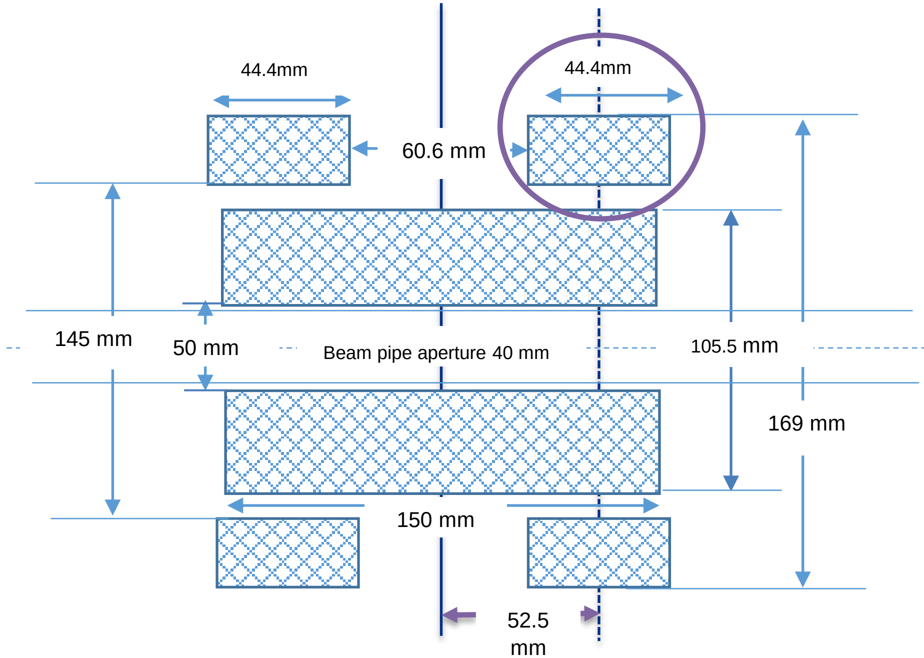


Main Solenoid, Dipole Corrector and Bucking coils Design for SSR2 magnet Assembly



EM DESIGN

Sr. no	Parameter	Value	Unit
1.	Designed value of focusing strength	5.33	T^2m
2.	Magnetic Field Integral	1.01	T-m
3.	Peak transverse Magnetic field in the lens aperture	6.22	T
4.	Peak Magnetic field on the wire strand	6.878	T
5.	Nominal current	77.4	A
6.	Nominal Current Density	260	A/mm^2
7.	B max at the cavity Surface	0.179	Gauss
8.	Field Integral (along the radial line 0 to 0.3m) at axial Distance of 0.5 mm	3.9	G-cm



Objective function :

$\int B_z^2 . dz \geq 5$ T^2m

Minimize $\int_{r=0}^{r=0.3} B.dl$ at z= 0

Constraints:

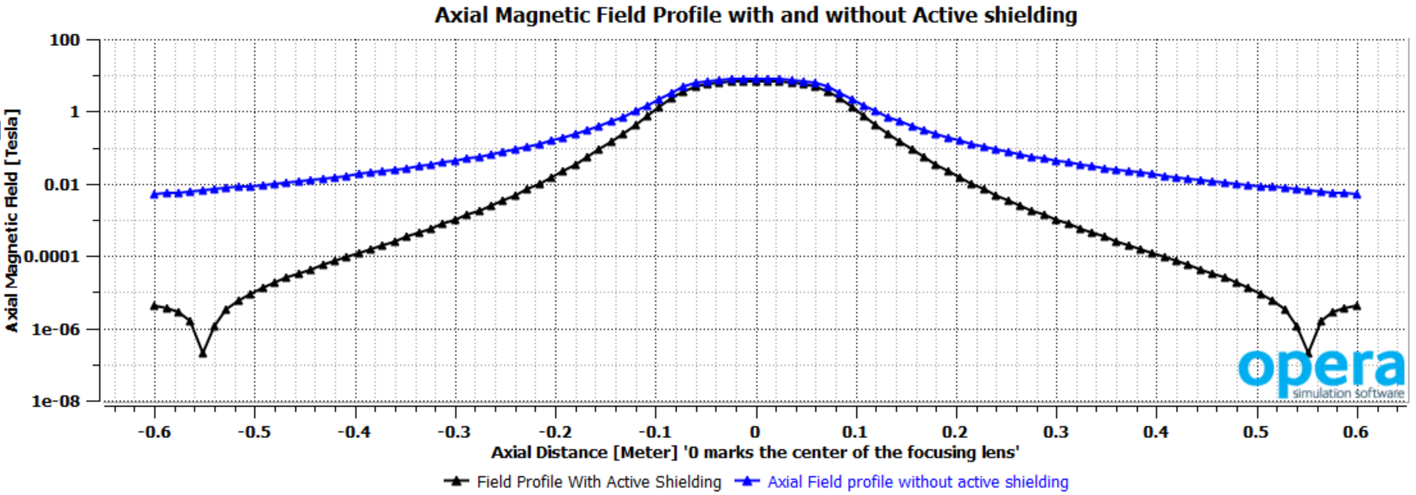
$\frac{\int (B_z * dz)}{B_0} \leq 150$ cm

$I_{exc} < 100A$

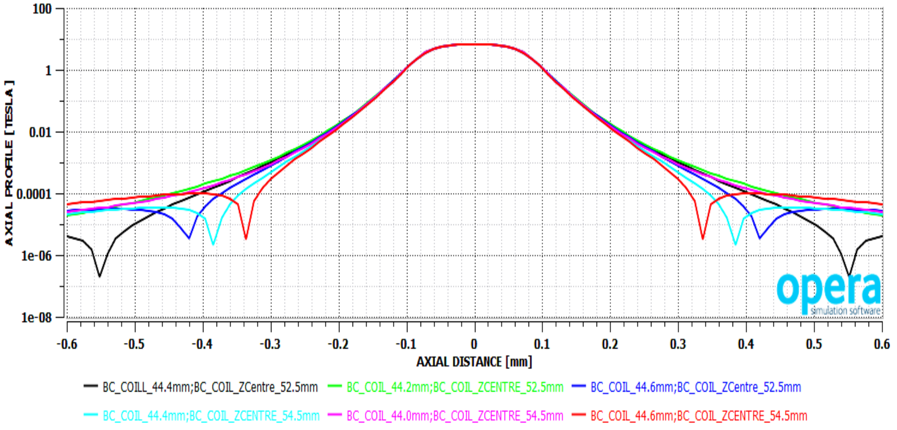
Optimization Parameters:

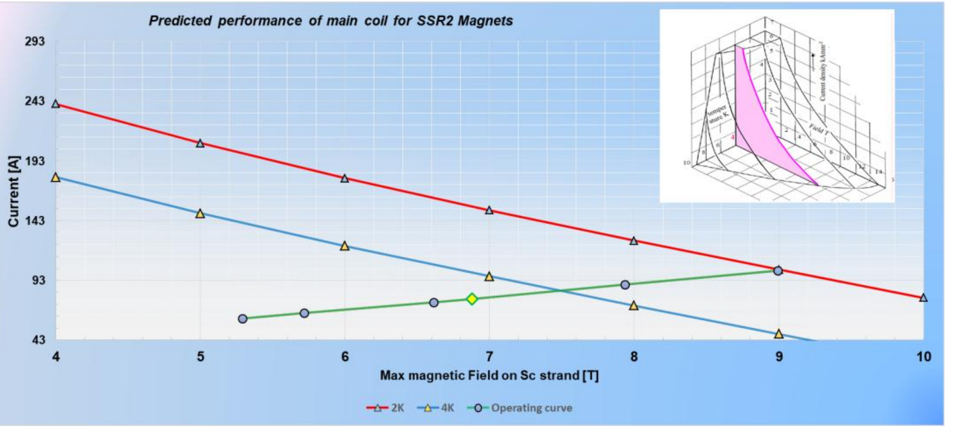
N_{main}, L_{main}, R_{main}

N_{BC}, L_{MC}, R_{MC}, $Z_{center-BC}$



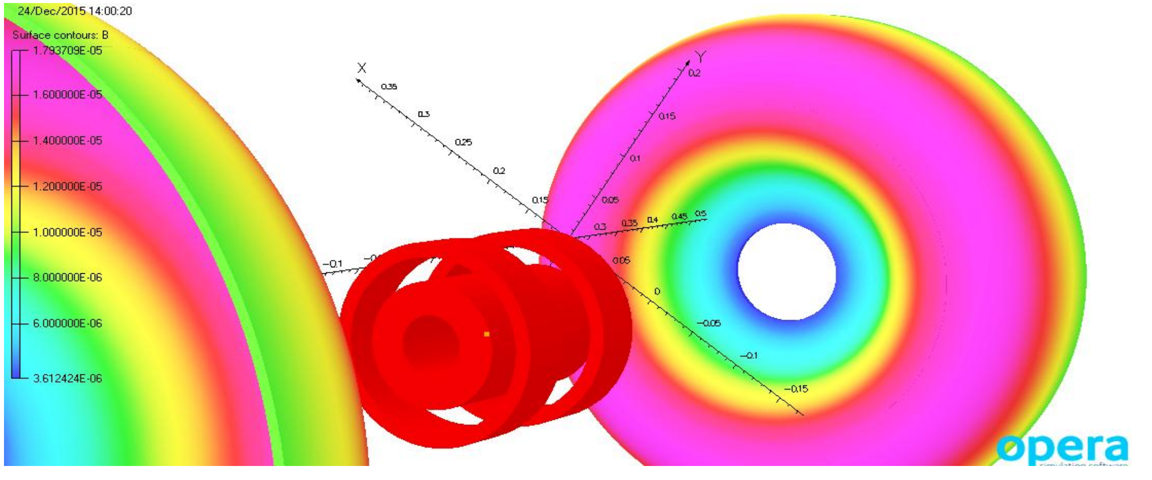
Tolerance and Fringe field analysis





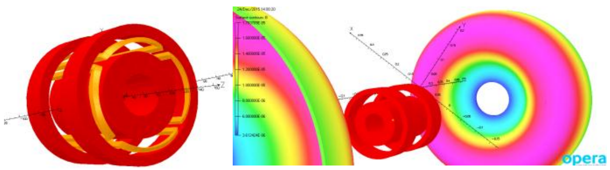
Bucking Coil optimization studies

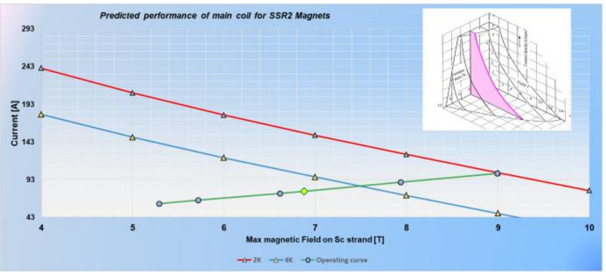
Magnet Load Line



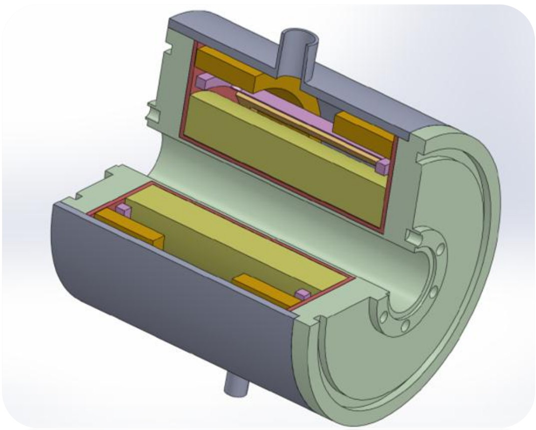
$$R_{surf} = R_{BCS}\ (\nu, T) + R_{res} + R_{mag}\ (H_{ext})$$

SSR superconducting magnet assemblies

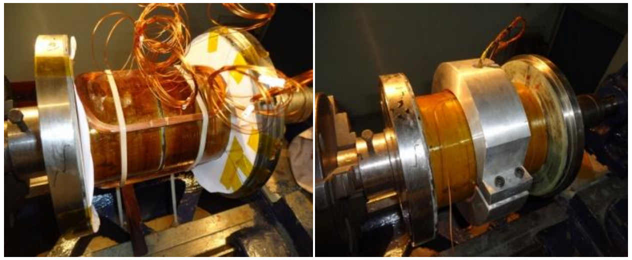


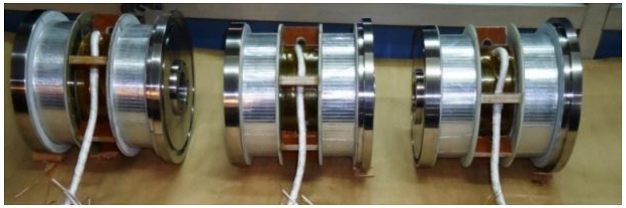


Electromagnetic & Thermal (Quench Design)

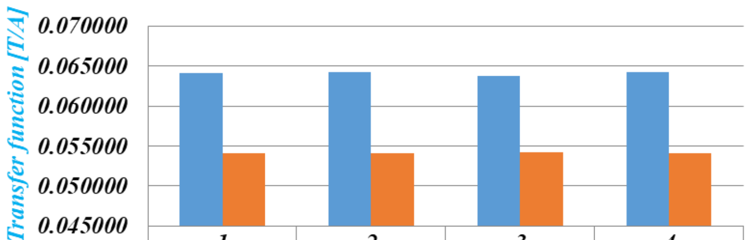


Engineering Design



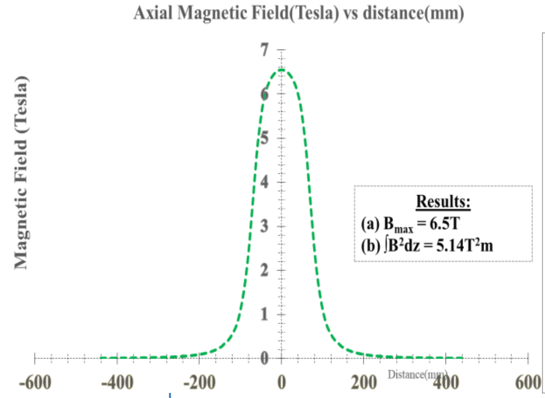


Engineering Development

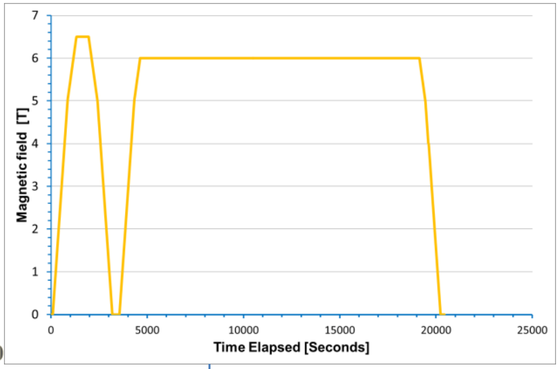


	1	2	3	4
MC	0.064155	0.064227	0.063746	0.064250
MC+BC	0.054070	0.054104	0.054173	0.054141

Warm Magnetic Qualifications



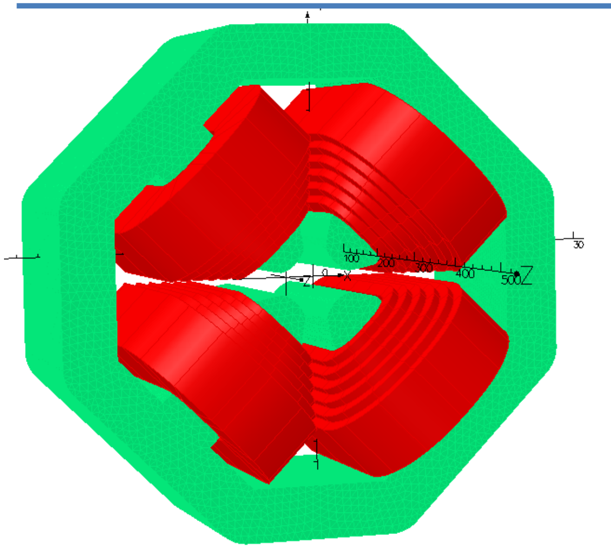
Axial field mapping at 4.2K



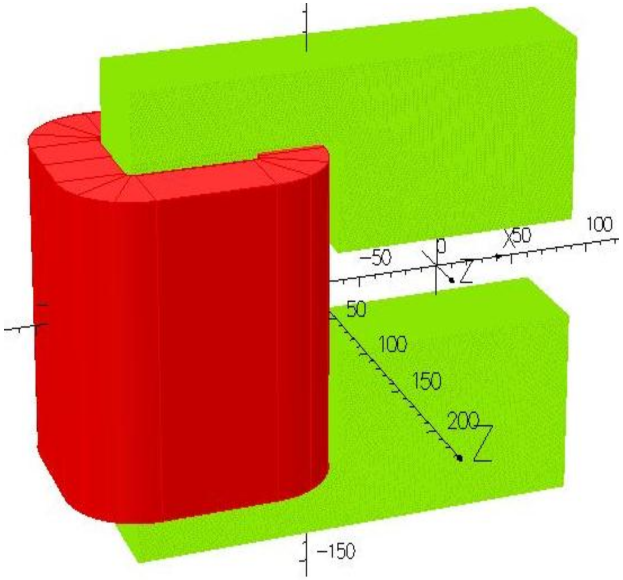
Power Tests & Quench Qualifications

Cold Magnetic Qualifications

Quadrupole Magnets for LB/HB 650 PIP-II

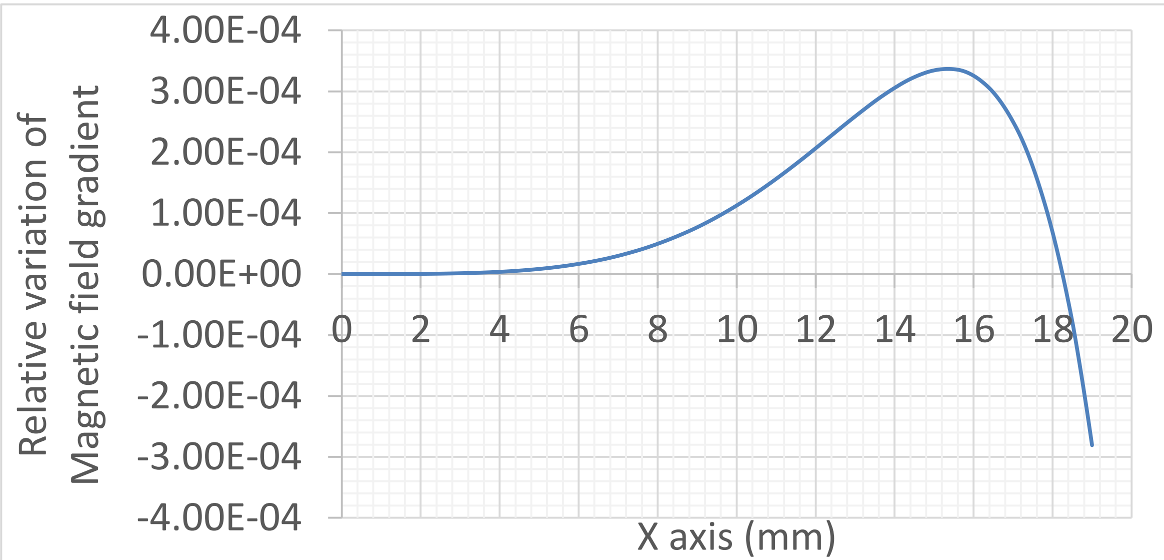


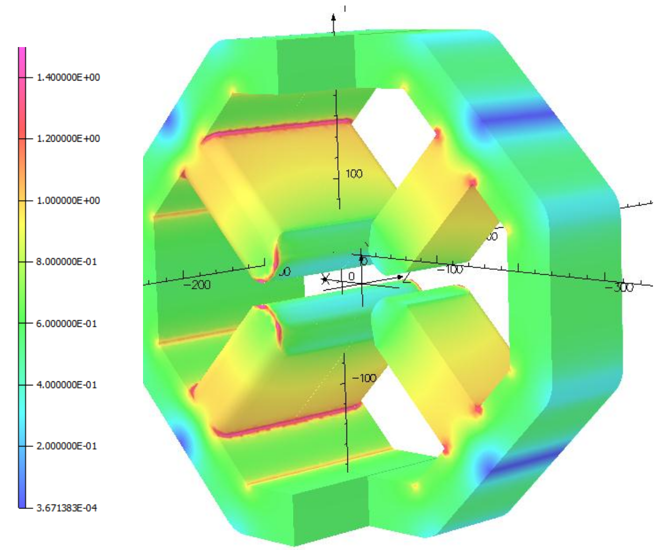
Parameters	Required	Achieved in design	Unit
Integral magnetic field gradient (∫G.dl)	3.0	3.0	(T/m).m
MMF	3600	3555	At
Magnetic field gradient	13.5	12.8	T/m
Aperture	52	52	mm
Good field region aperture	26	26	mm
Uniformity of ∫G.dz in GFR	0.100	0.007	%
Physical length	200	200	mm
Maximum transverse dimensions	600	425	mm

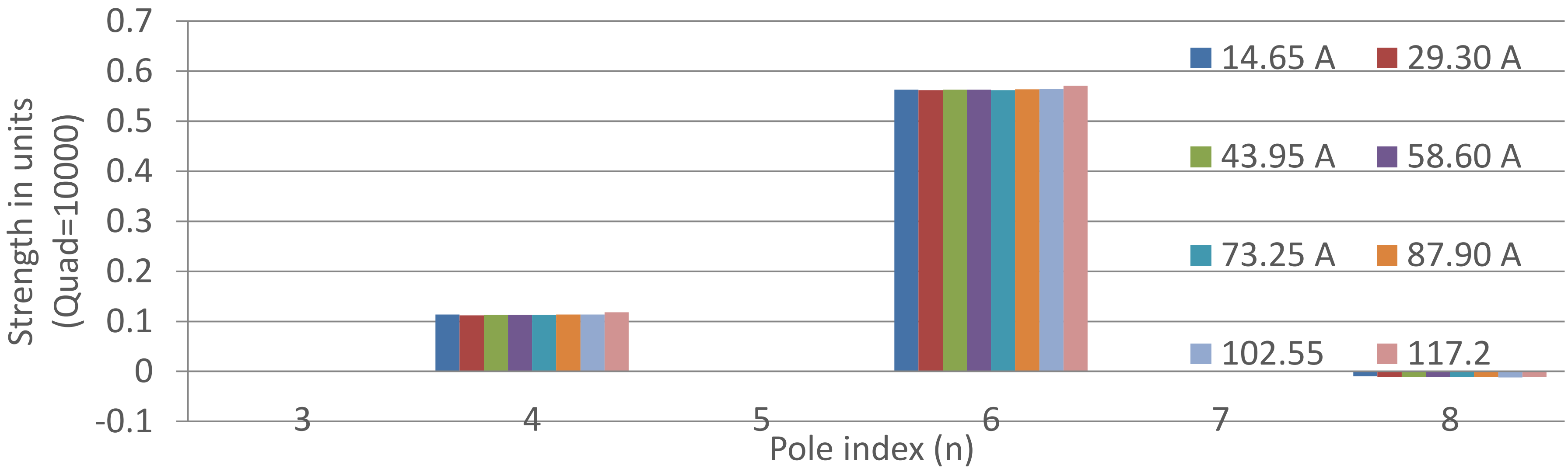


Parameter	Required	Achieved in design	Units
Integral Magnetic field	10	10	mT.m
Pole tip to pole tip gap	52	52	mm
Good Field region	Ø 26	Ø 26	mm
Uniformity in GFR	1	0.58	%
Maximum transverse dimensions	600	275	mm
Maximum longitudinal dimensions	180	130	mm
Power supply preference (I)	<15	9.2	A
Power supply preference (V)	<30	2.5	V

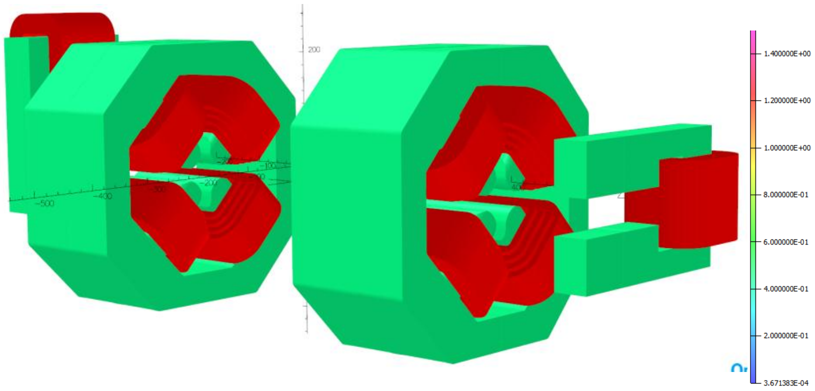
Magnetic design of Quadrupole Magnets for LB/HB650



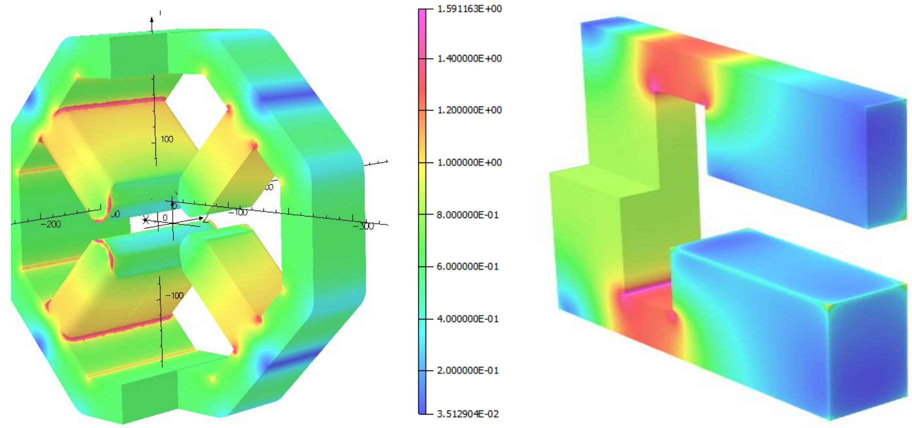




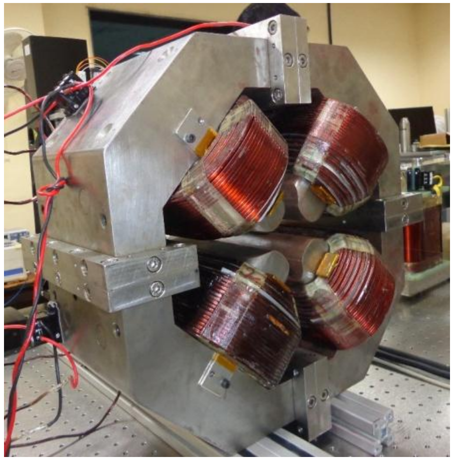
Doublets for LB/HB 650 MHz section of PIP-II

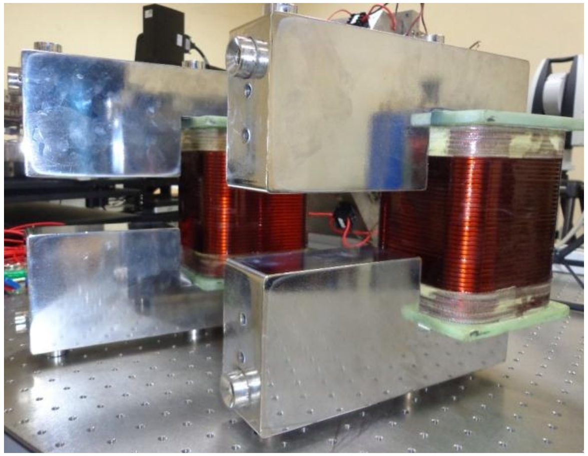


3D Model for LB/HB650 Warm doublet

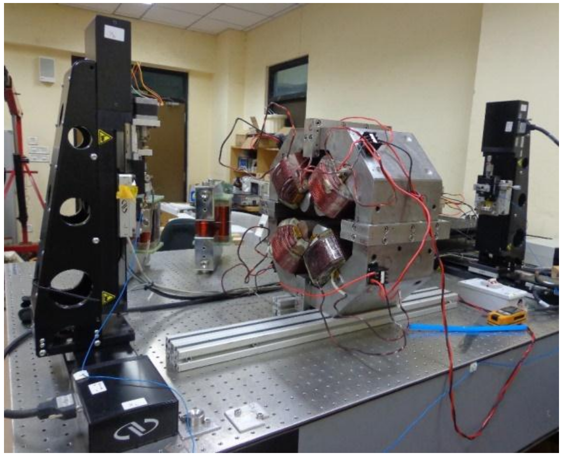


Electromagnetic Design





Developed Quadrupole & Dipole Magnet Assemblies



Magnetic Qualification bench

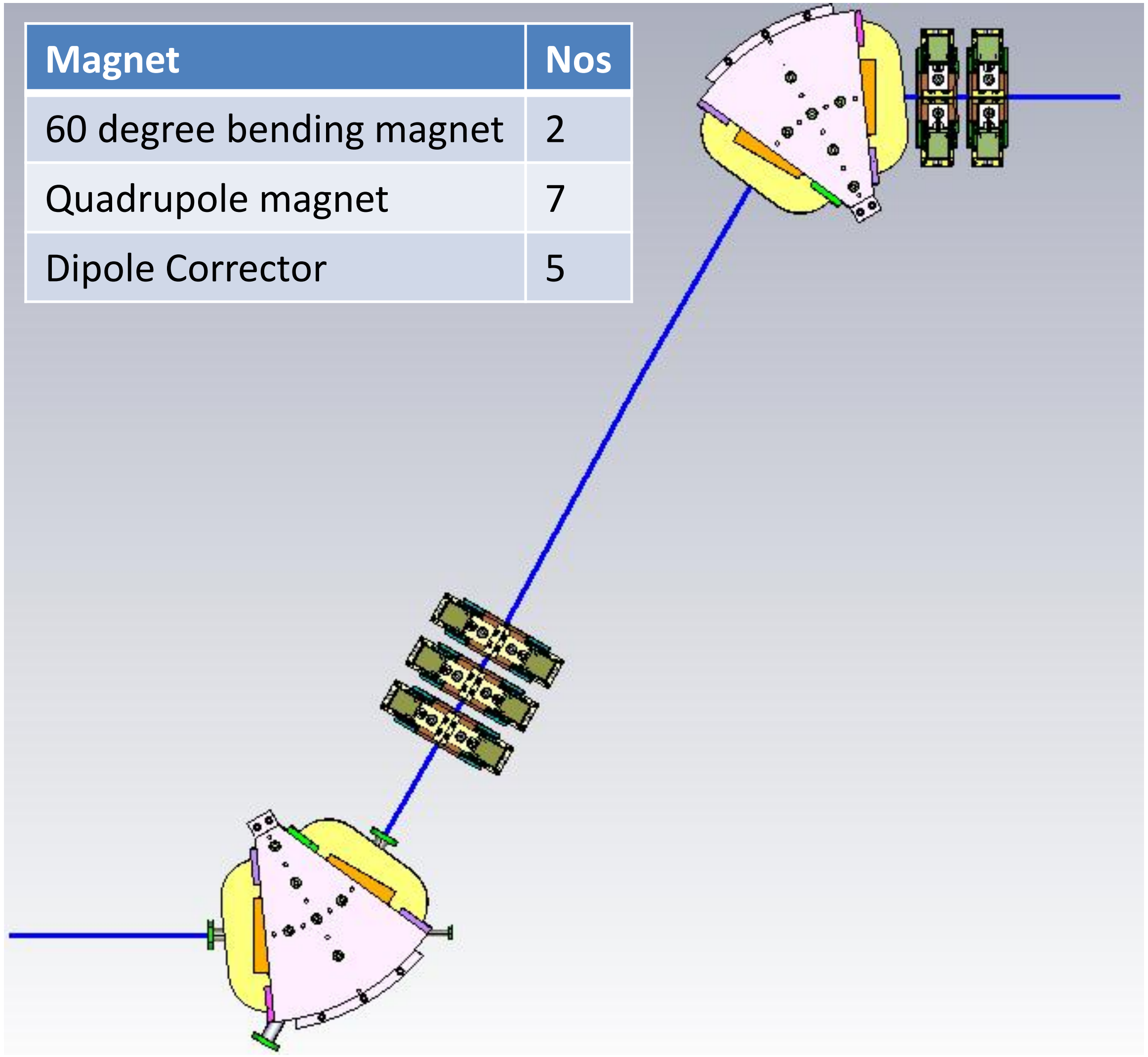
Magnets for Delhi Light Source (DLS) (Electron beam)

Magnet layout and specifications

Bending Magnet

SN	Parameter	Value	Unit
1.	θ	60 ± 0.5^o	o
2.	R	300 ± 1	mm
3.	Pole gap	40 ± 0.1	mm
4.	B_0	1200	G
5.	Entry and exit angle	6 ± 0.1^o	o
6.	Homogeneity of B field	500	ppm
7.	Good field region	± 16 (Z) ± 40 (R)	mm

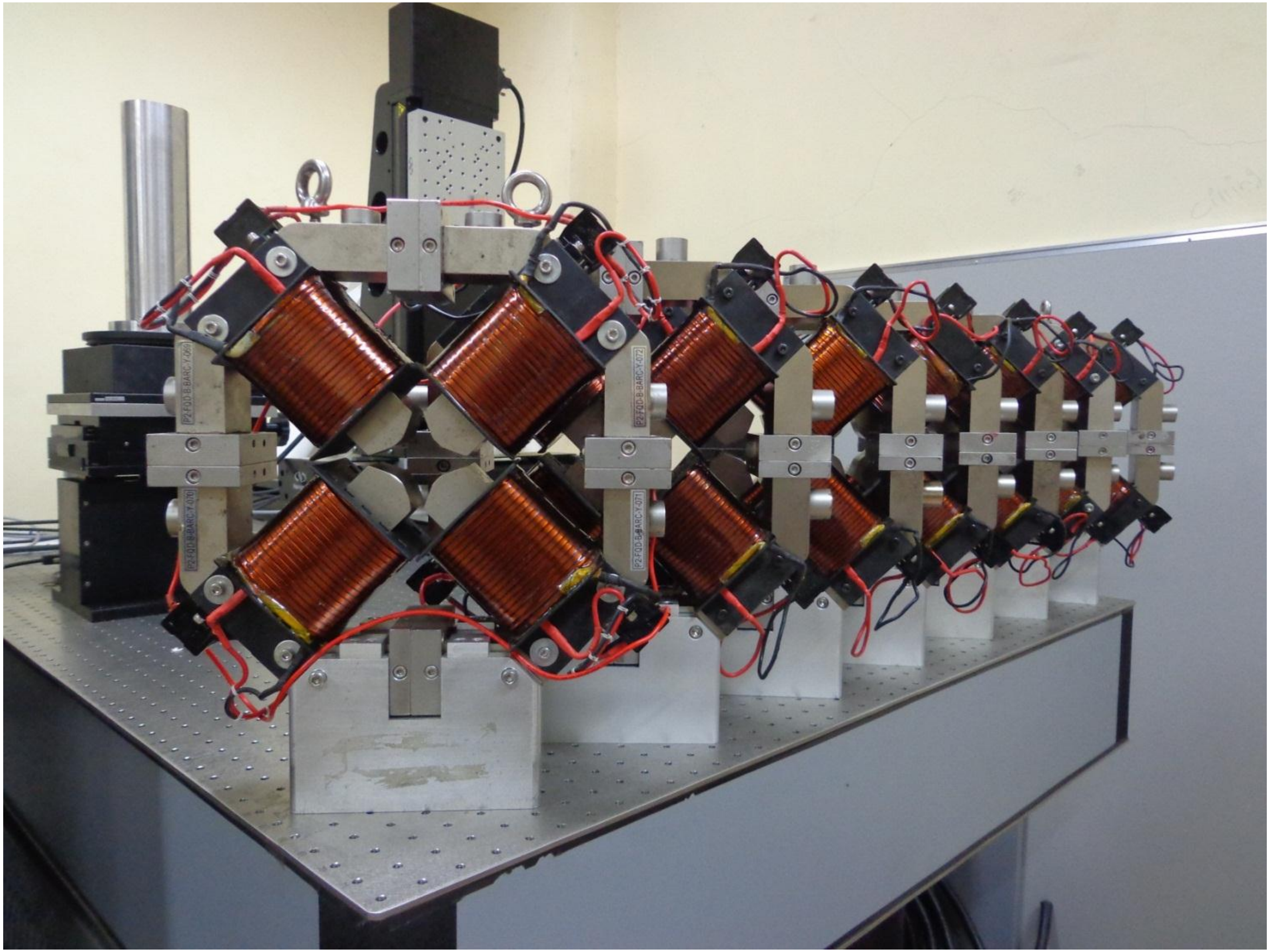
Magnet	Nos
60 degree bending magnet	2
Quadrupole magnet	7
Dipole Corrector	5



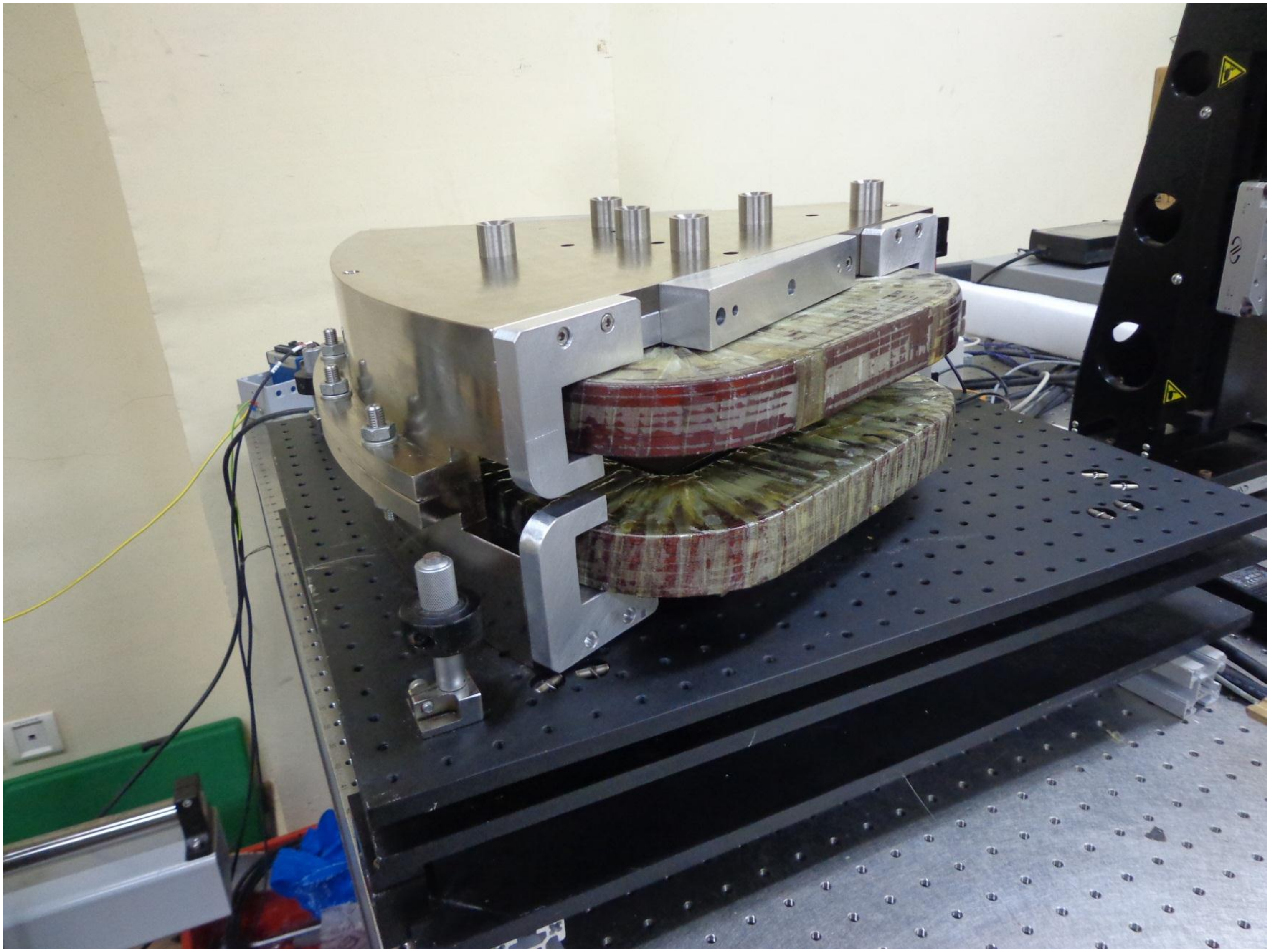
Quadrupole Magnet

SN	Parameter	Value	Unit
1.	G	11.5	T/m
2.	Aperture	34	mm
3.	GFR	23	mm
4.	Homogeneity in GFR	<0.5	%
5.	Effective length	71	mm
6.	Roll angle	<3 mrad	ppm

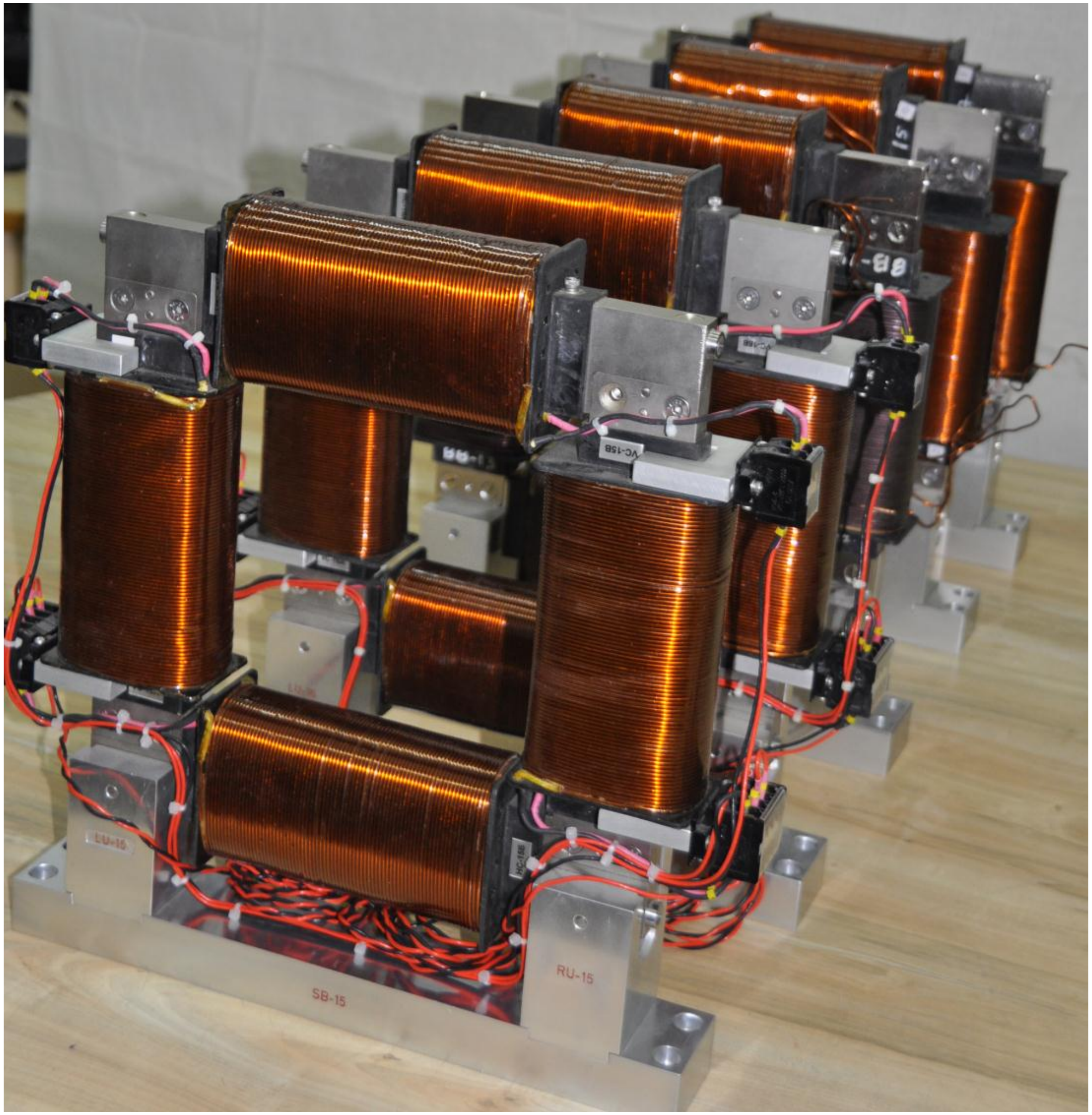
Magnets for DLS - Quadrupole lenses (7 nos.)



Magnets for DLS - 60 degree bending magnet (2 nos.)



Magnets for DLS - Dipole Steering Magnets (5 nos.)

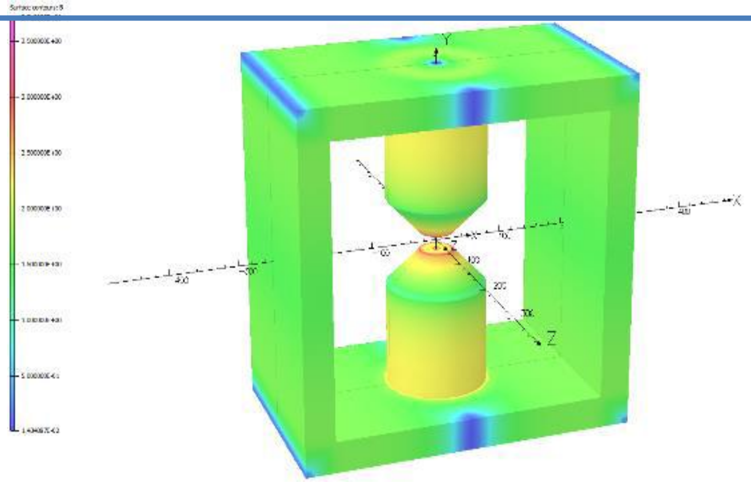


Synchrotron Beamline Magnets

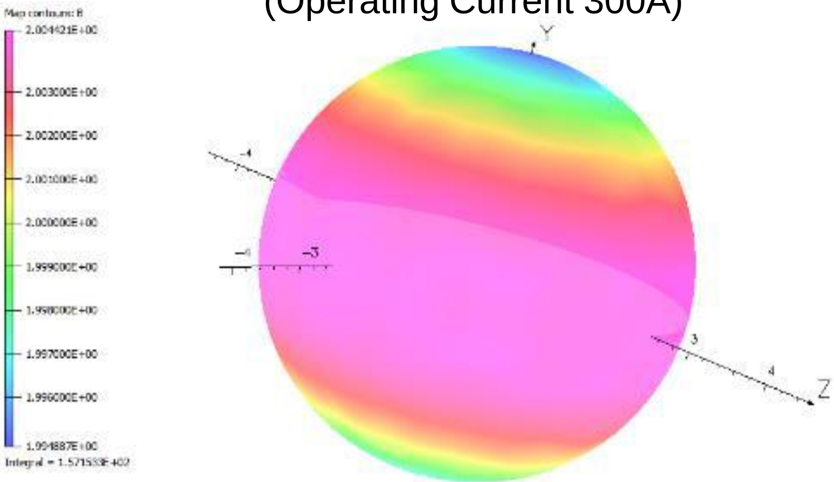
Dipole Magnet for XMCD Measurements (BL-08)

Technical specification of the Electromagnet for XMCD measurements

Parameter	Values
Central Magnetic field	2 Tesla
Pole Air gap	25 mm
Max Sample size Area	5 mm × 5 mm
DSV	5 mm
Magnetic field uniformity	100 ppm
Magnet Shape	H Dipole
Magnet outer dimensions Restrictions	500 mm×500 mm ×400 mm
10 mm diameter central hole through the magnet for the X-ray beam to pass through	



EM Design of the electromagnet (Operating Current 300A)



Central Magnetic Field (2 Tesla)

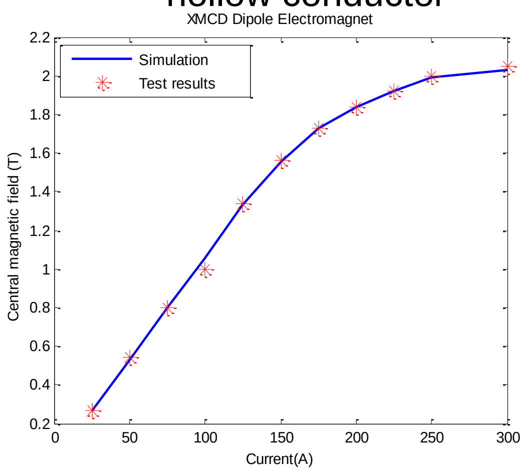
Magnetic field uniformity (DSV: 5 mm) (Better than 100 ppm)

XMCD Magnet measurements

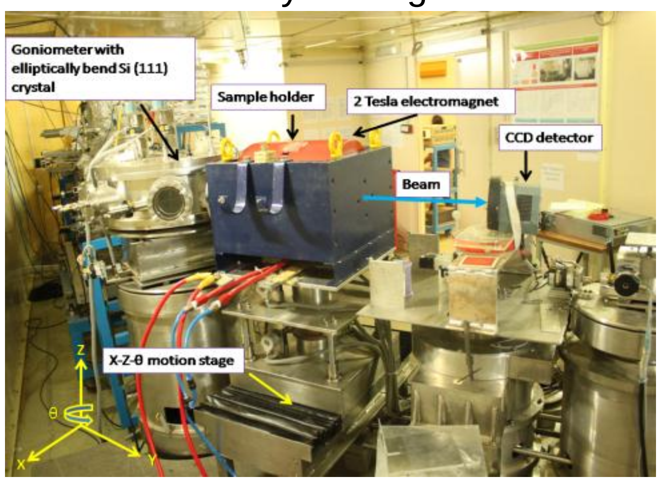
Jig for winding 12mm × 12mm hollow conductor

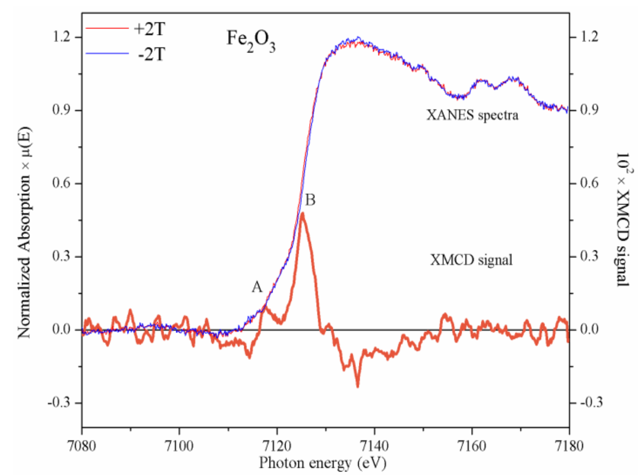
X-Z-θ motion stages which can carry 500 Kg max load

Electromagnet with hydraulic and Electrical connections



Simulated and measured B-Field in center of air-gap

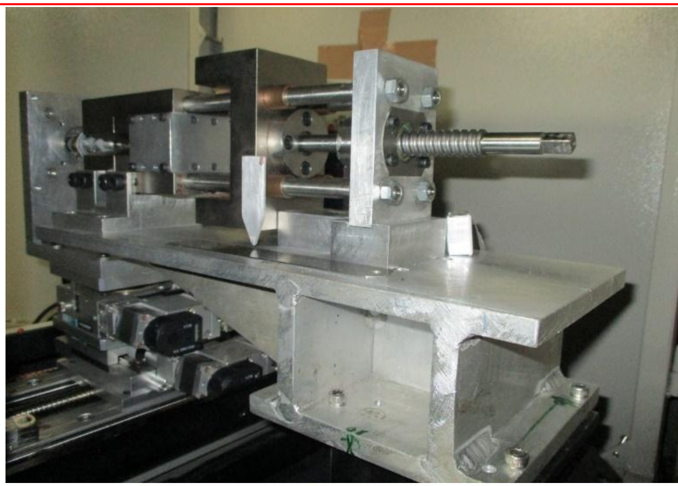




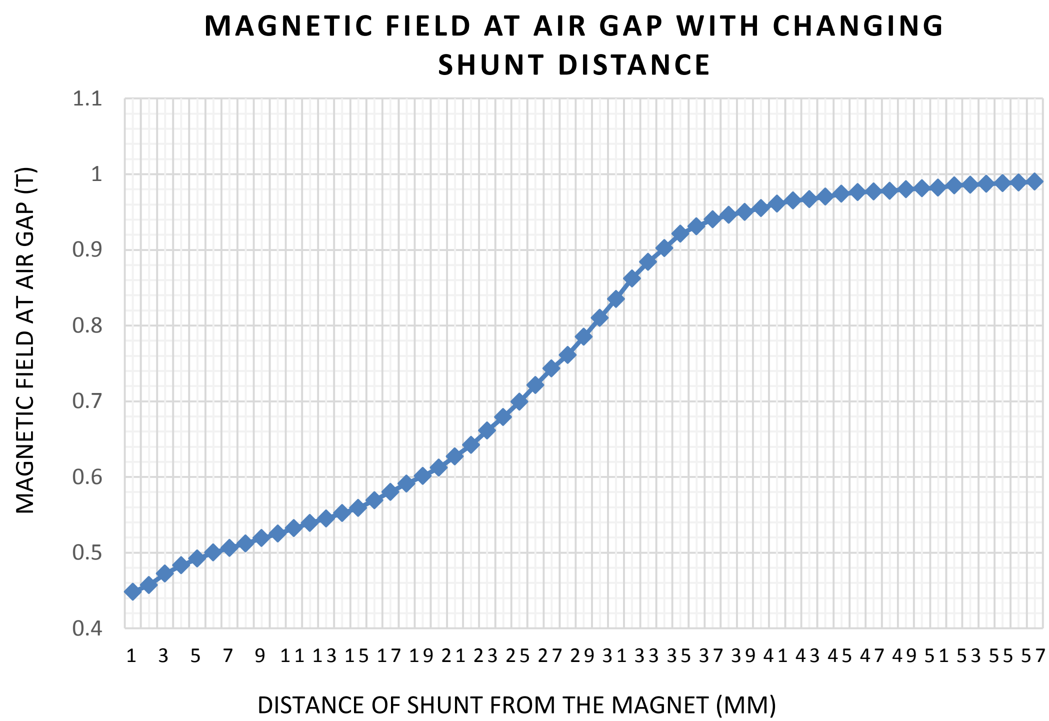
Photograph of the Energy Dispersive EXAFS beamline along with the magnet in BL-08 at Indus-2 Synchrotron

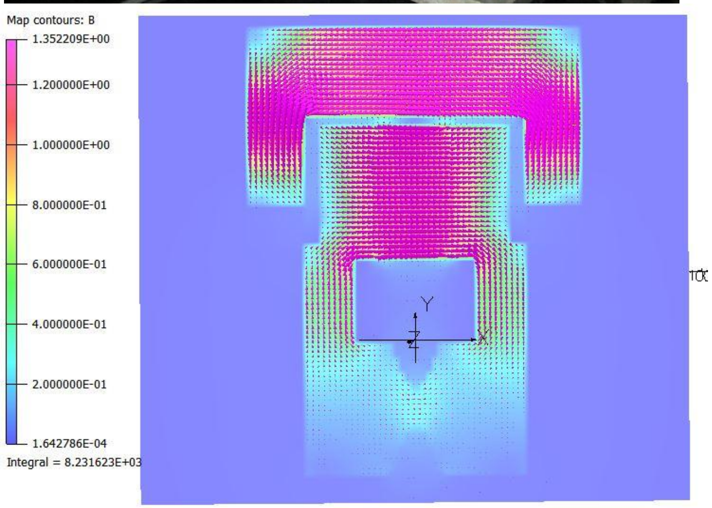
Variable field Permanent Magnet Dipole

- To understand the magneto-structural transitions in magneto-caloric materials at room temperature, x-ray diffraction studies have to be done in the presence of magnetic field.
- These studies are done at Beamline-11 of INDUS-II at RRCAT, Indore
- 1 T tunable permanent magnet based dipole was developed. Tuning of the magnetic field was achieved using a shunt soft iron plate.



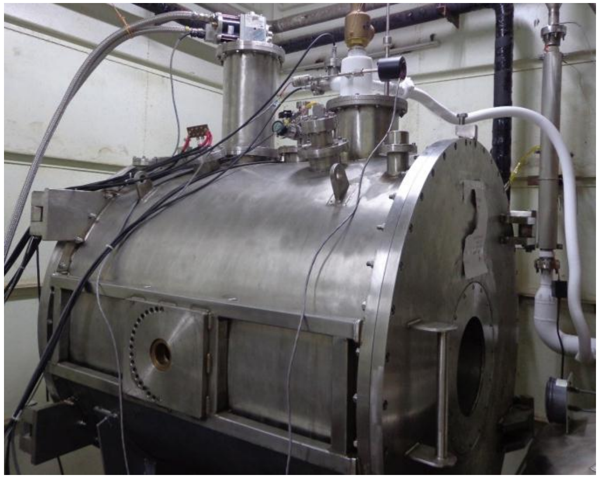
Magnet installed at BL-11, INDUS-II





Magnetic flux being shunted by soft iron plate

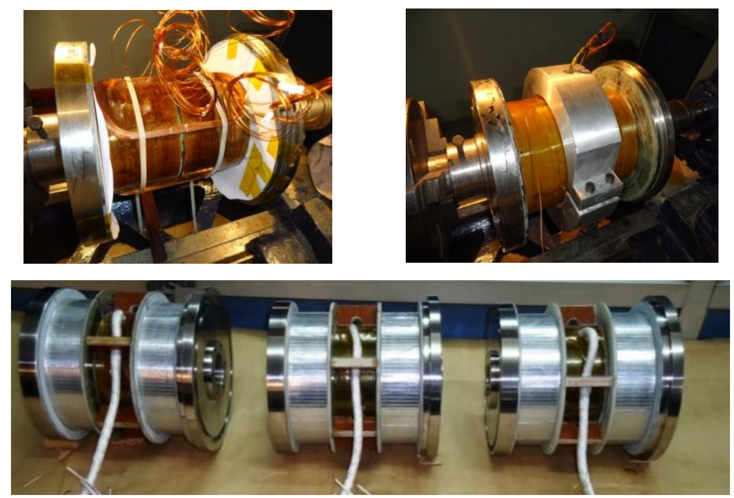
Superconducting Magnet Technology



300mm LHe cooled SC magnet for MHD experiments

130 mm warm bore cryogen free SC magnet for High Frequency RF device

300mm cryogen free SC magnet for MHD experiments

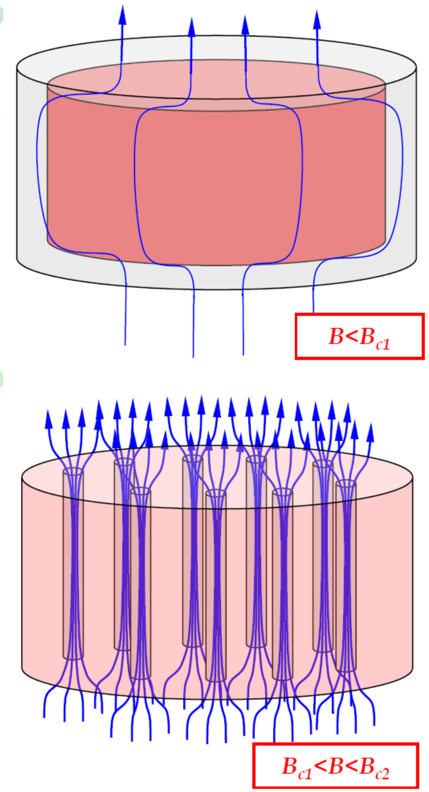


Cold bore SC magnet for SSR Cryomodule under IIFC

Superconducting magnet development-Truly multidisciplinary

Superconducting magnet design is a multidisciplinary field:

Material Science	Superconducting material
Quantum Physics	Key mechanism of superconductivity
Classical Electrodynamics	Magnet Design
Mechanical Engineering	Support Structures
Electrical Engineering	Powering & Quench protection
Cryogenic & Thermal	To maintain cryogenic temperatures



Flux Pinning in Type II SC magnets

Quench Phenomenon in SC magnets

Conductor limited quench

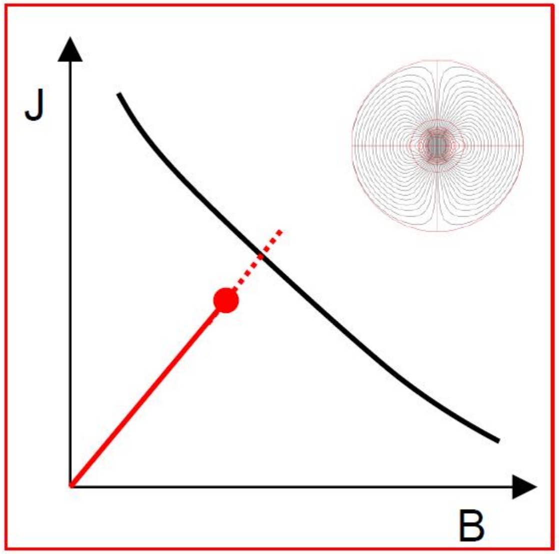
Critical surface is crossed due to an increase in I (or B)

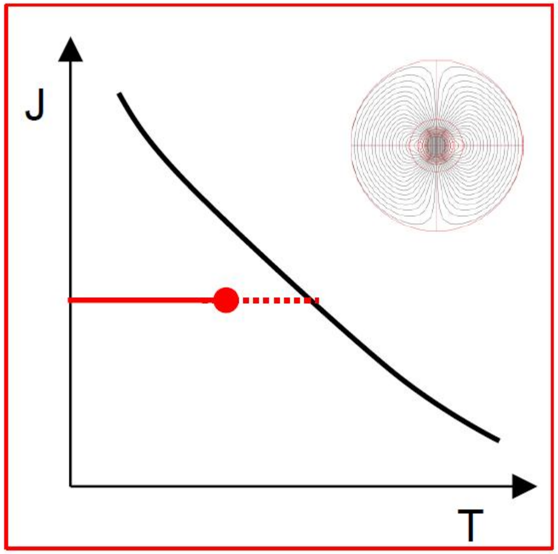
Taken care in magnet design by choosing the load line of the magnet so as to operate at nearly 80% of the critical current

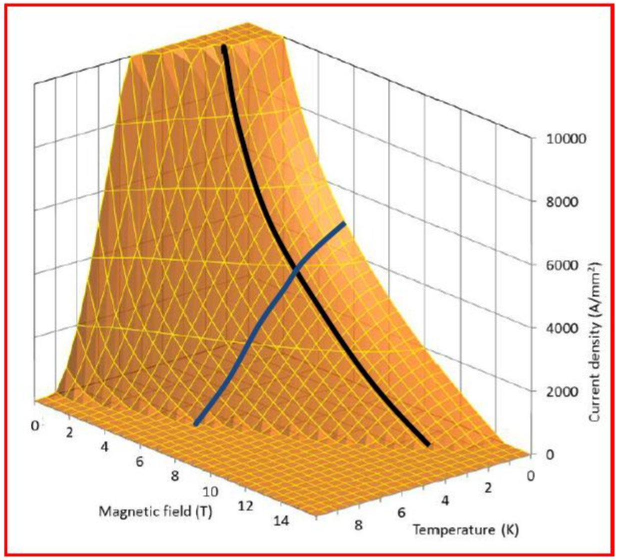
Energy- deposited or premature Quenches

Critical surface is crossed due to an increase in T

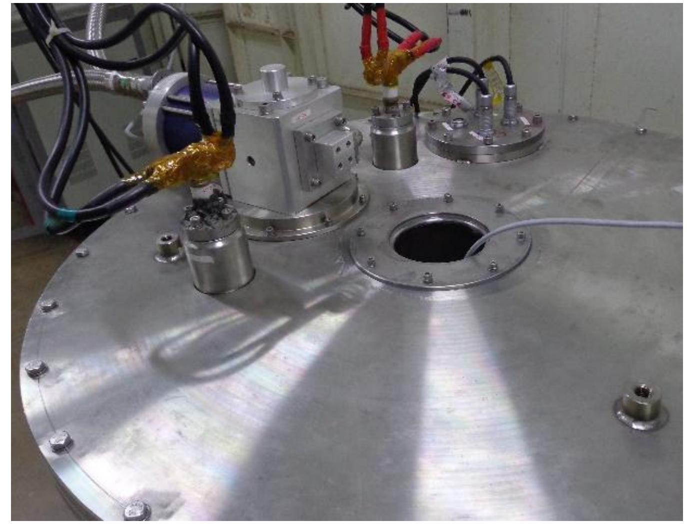
Taken care in magnet thermal design & magnet fabrication by pre-stress to avoid epoxy cracks during powering of the magnet



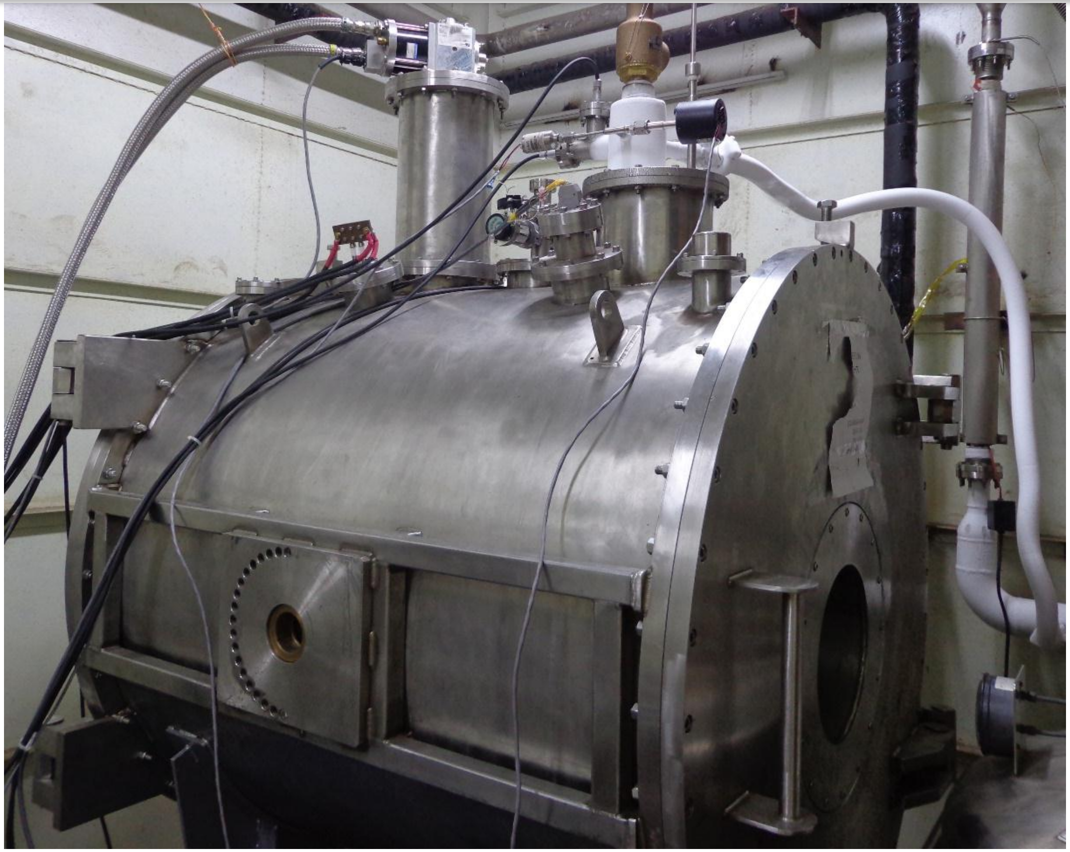




4-Tesla warm bore, Cryocooled magnet

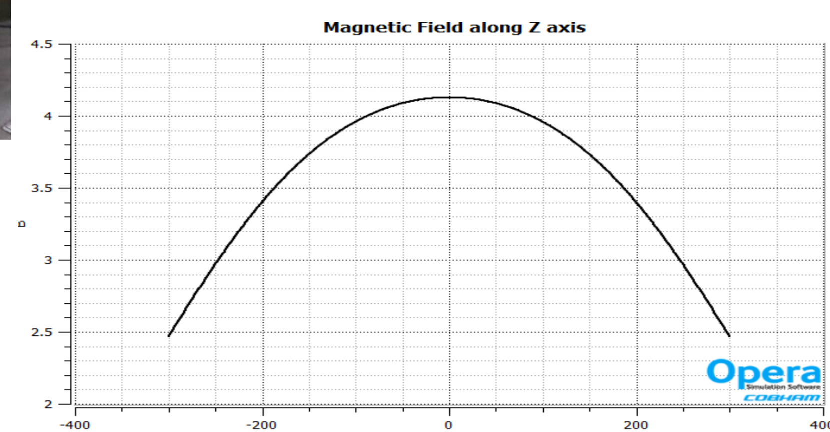


Warm Bore LHe cooled SC Solenoid magnet for MHD experimental Studies



Liquid Helium Cooled 4 Tesla 300mm diameter room temperature bore Superconducting Solenoid magnet

Technical specifications	
Central Magnetic field	4 Tesla
Operating current	300 A
Magnet stored energy	930 KJ
Room Temperature Bore	300mm
Thermal shield	50K
Cooled by Closed Cycle GM Cryocooler	
Operating Vacuum level	10^{-6} Torr
Helium evaporation rate	< 1 LPH



Warm Bore Conduction cooled SC Solenoid magnet for MHD induced experimental corrosion studies

Technical specifications	
Central Magnetic field	4 Tesla
Operating current	200 A
Magnet stored energy	1025 KJ
Room Temperature Bore	300mm
Thermal shield	50K
Cooled by Closed Cycle GM Cryocooler	
Operating Vacuum level	10^{-6} Torr


P2-FQD-B-BARC-Y-069
P2-FQD-B-BARC-Y-072
P2-FQD-B-BARC-Y-070
P2-FQD-B-BARC-Y-071
Thank you for your kind attention