Indian Institute Fermi Lab Collaboration

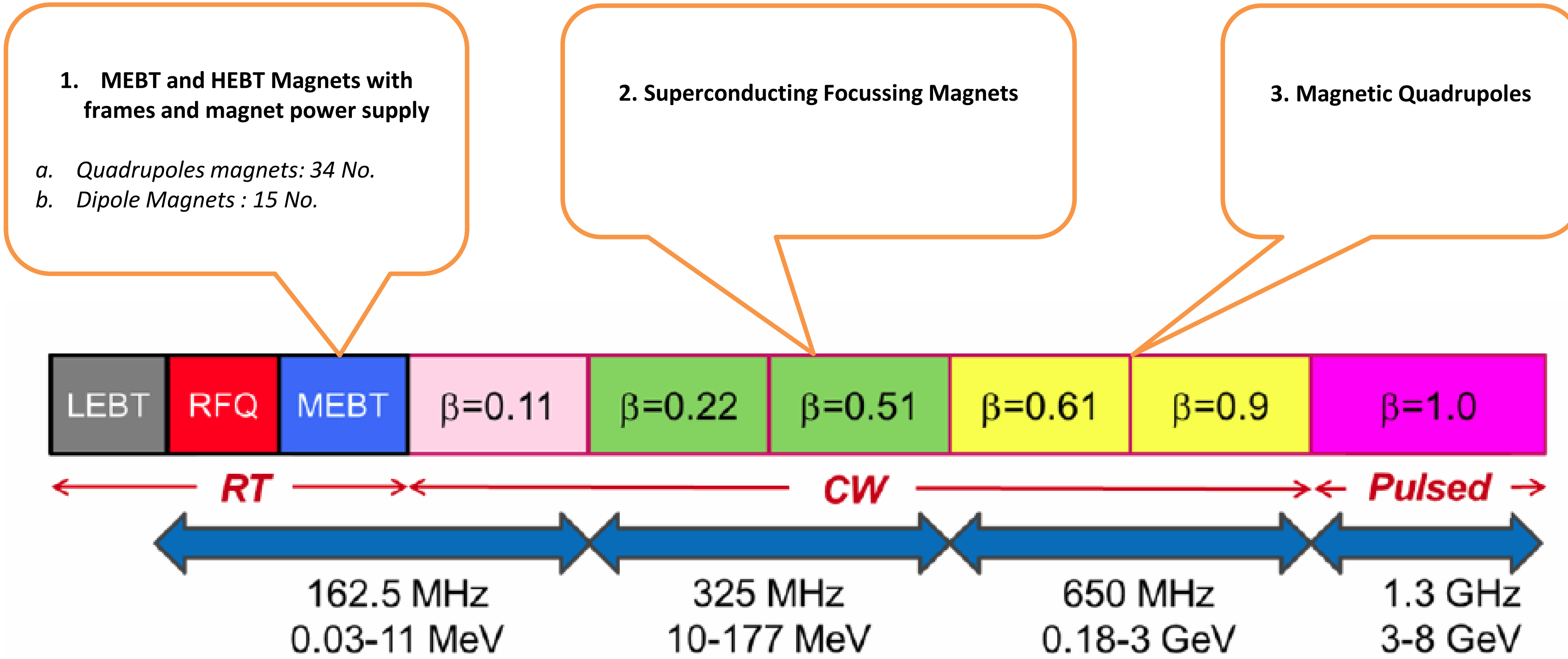
Status of development of Magnets for PIP-I and PIP-II

Electromagnetic Applications Section
Control Instrumentation Division
Bhabha Atomic Research Centre, Trombay, India

Outline of Presentation

1. Configuration of Project-X : layout of magnets
2. Status of MEBT and HEBT Magnets
    a. Quadrupole Magnets
    b. Dipole Correctors
3. Superconducting focusing lenses for SSR2
4. HB650 Quadrupole Magnets

Magnets layout in Project-X



Magnet configuration and specifications

The MEBT (Medium Energy Beam Transport) and HEBT consists of Following Quadrupole and Dipole Corrector Types.

- Quadrupole-F
- Quadrupole-D
- Dipole Corrector (DC)

Quadrupole-D along with Quadrupole-F forms part of triplets. MEBT consists of two doublet (F-F-DC) and seven triplets (D-F-D-DC). Combined corrector dipole coils are present after every doublet or triplet. Total number of Quadrupoles is as tabulated below.

Thus total of twenty five Quadrupoles and nine dipole correctors form part of PXIE MEBT. Following is the plan layout of MEBT for PXIE.

F-F-DC; F-F-DC; D-F-D-DC; D-F-D-DC; D-F-D-DC; D-F-D-DC; D-F-D-DC; D-F-D-DC; D-F-D-DC

SN	Magnet Type	Qty	Integrated magnetic field	Magnet Length (mm)	Radial Pole separation (mm)	Good Field Region	Integrated field uniformity	
			Required				Required	Obtained in design
1.	Quad-F	18	1.5 Tesla	140	34	23	<1%	0.38%
2.	Quad-D	16	0.85 Tesla	90	34	23	<1%	0.40%

Status of MEBT and HEBT Magnets as on February 25, ‘15

The development related to MEBT and HEBT magnets is underway in form of two major activities:

- Quadrupole Magnets and magnets frames
- Dipole Corrector magnets

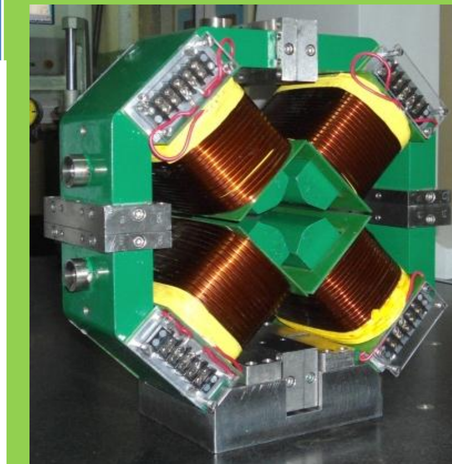
The present status of above activities is tabulated below.

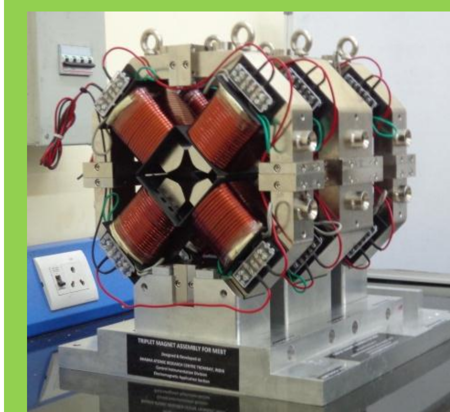
	Quadrupole Magnets and magnets frames	Dipole Corrector magnets
Deliverables	Quad-F : 18; Quad-D :16 Triplet frame : 8; Doublet frame: 3	15
Design	Complete	Complete
Prototyping	Complete	Complete
Qualification of prototypes at FNAL	Complete	Complete
Development of two number of Doublets with dipole correctors	Fabrication Complete, Magnetic measurements planned in first half of March 2015, Ready for shipment : March end/April 2015 beginning	Fabrication Complete, Magnetic measurements underway Ready for shipment : March end/April 2015 beginning
Series Production	• Quotations received from ECIL, recommendations for placement of PO done	• Tender floated • Purchase order recommended

Quadrupole magnets for MEBT and HEBT

DEVELOPMENT TILL DATE : QUADRUPOLE MAGNETS FOR MEBT & HEBT

SN	Milestones	Status
1.	Design, development, preliminary electrical and magnetic measurements and beam line qualifications of Quadrupole-F magnet at BARC	Complete
2.	Magnetic measurements on Quadrupole-F magnet at FNAL	Completed Met design requirements
3.	Development of Triplet Magnet Assembly	Development complete
4.	Development of Doublet Magnet Assembly	Development Complete
5.	Glass filled molded bobbins for Quadrupole-F and Quadrupole-D	Complete
6.	Setting up of Magnetic measurements set-ups at BARC	Tender raised
7.	Tender for series production of Quadrupole Magnets	Quotations received. Work order recommended

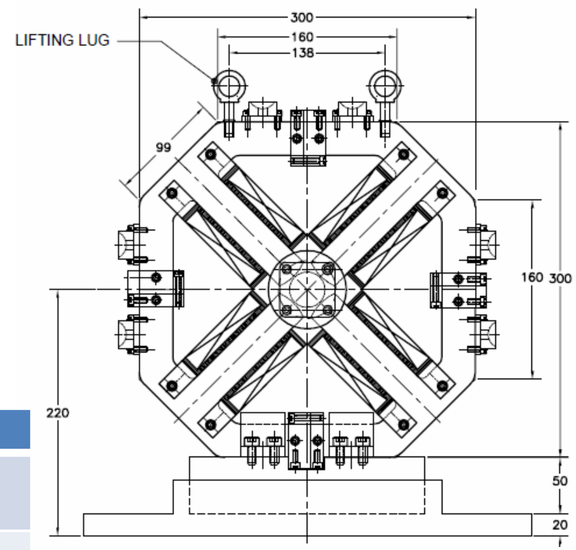




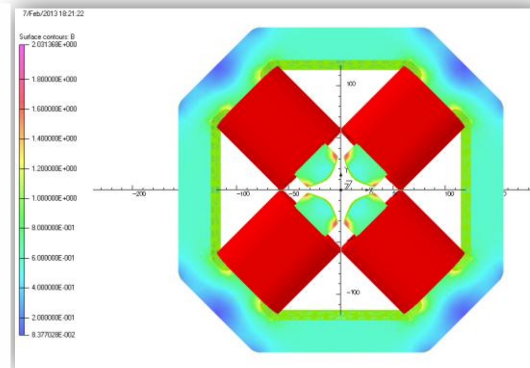
Electromagnetic design and salient features of Quadrupole

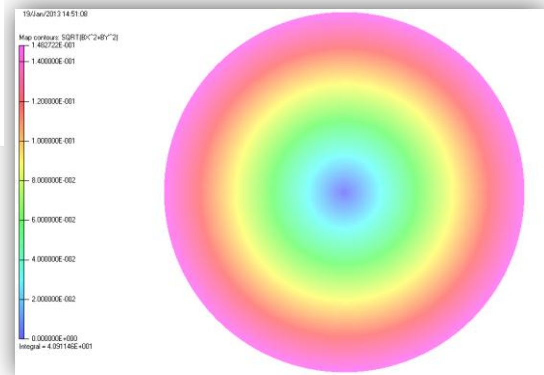
S	Parameter (Simulated values)	Value	Unit
1.	Integrated Magnetic field Gradient	1.54	T
2.	Integrated Magnetic field Gradient uniformity	0.15	%
3.	Magnetic Field gradient	12.89	T/m
4.	Magnetic length	119	mm
5	Magnetic Field linearity	0.88	%

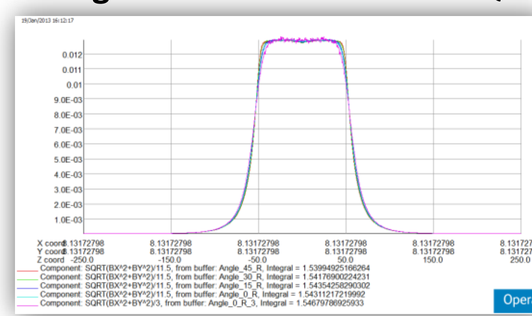
S	Parameter (Boundary conditions)	Value	Unit
1.	Maximum temperature rise	50	°C
2.	Transverse space	300 X 300	mm



Development drawing of Quadrupole


Magnetic field in Yoke and poles


Magnetic Flux in bore of EMQ



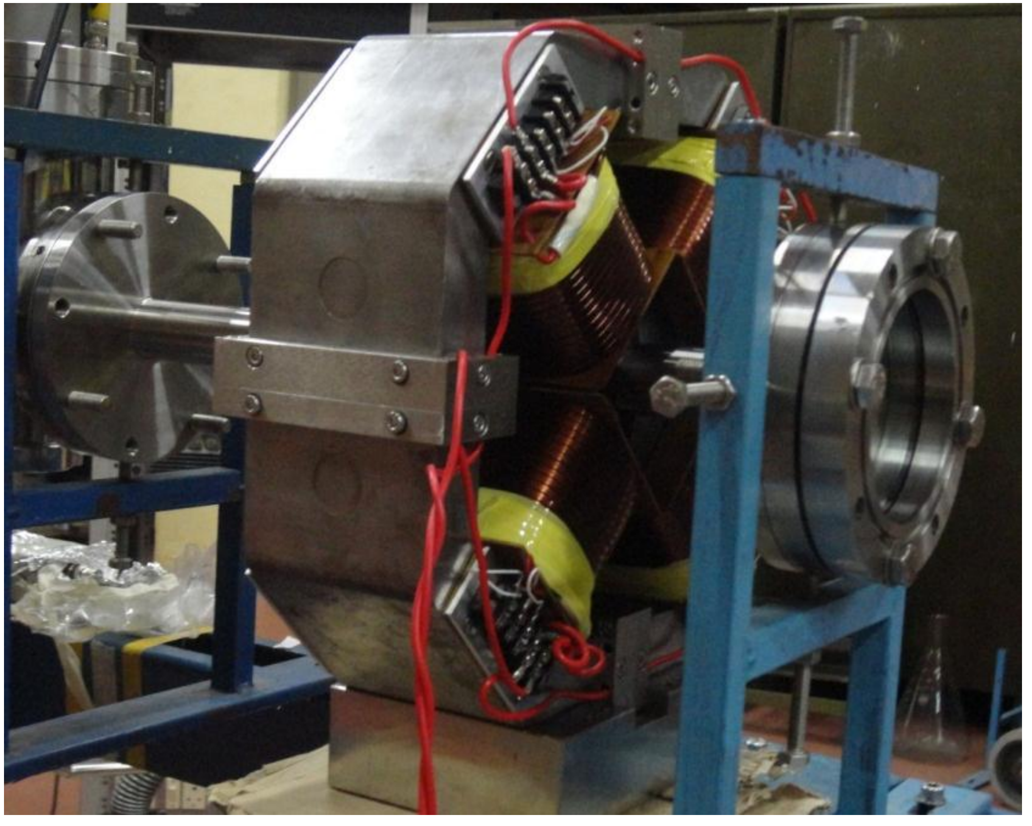
Transverse Magnetic Field in longitudinal direction

Salient features

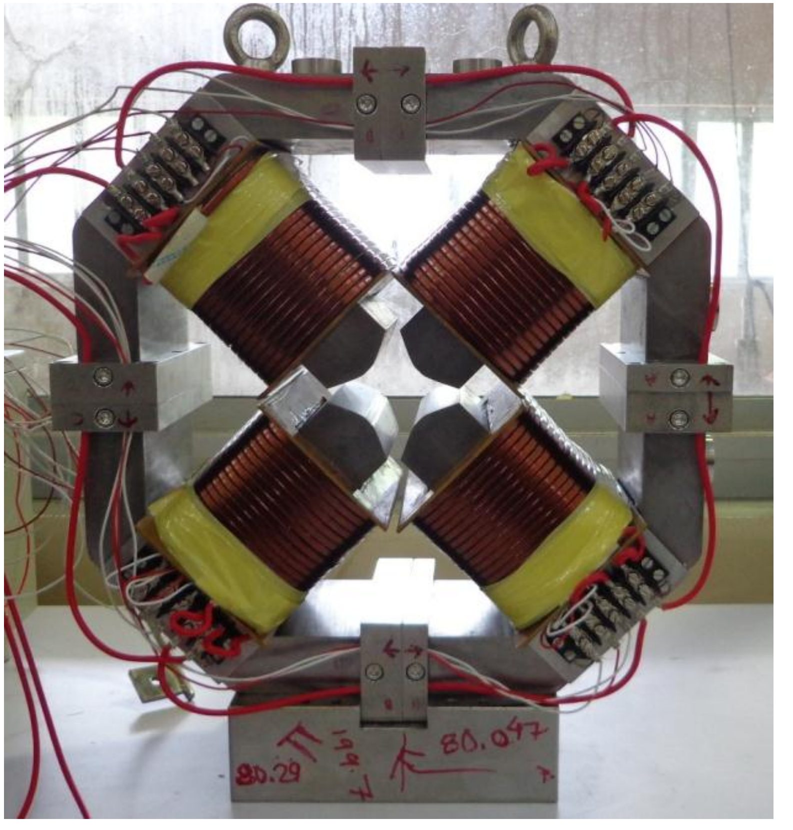
1. 3-D magnetic pole optimization for achieving required magnetic field uniformity and for limiting higher order multi-poles.
2. E-M design accomplished within the given boundary.
3. Design and thermal qualification of electrical coils; maximum temperature rise of 20 °C achieved with natural convection cooling.
4. Engineering design for ease of assembly and disassembly of magnets at site with repeatability of measurements.

Magnetic measurement set-up at EMAS Lab

Quadrupole-F Prototype: Sent to FNAL

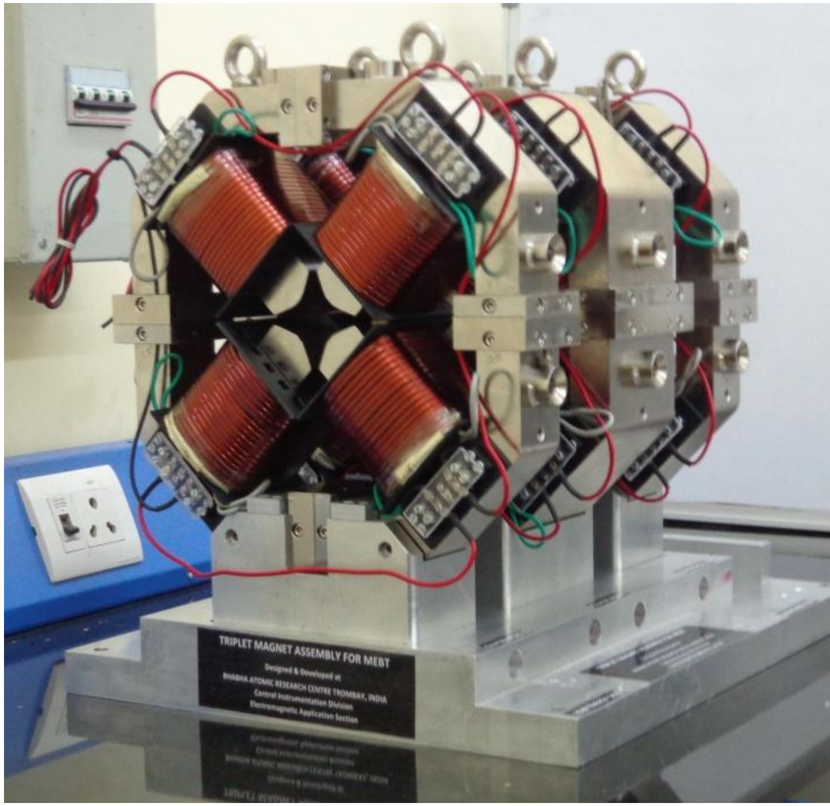


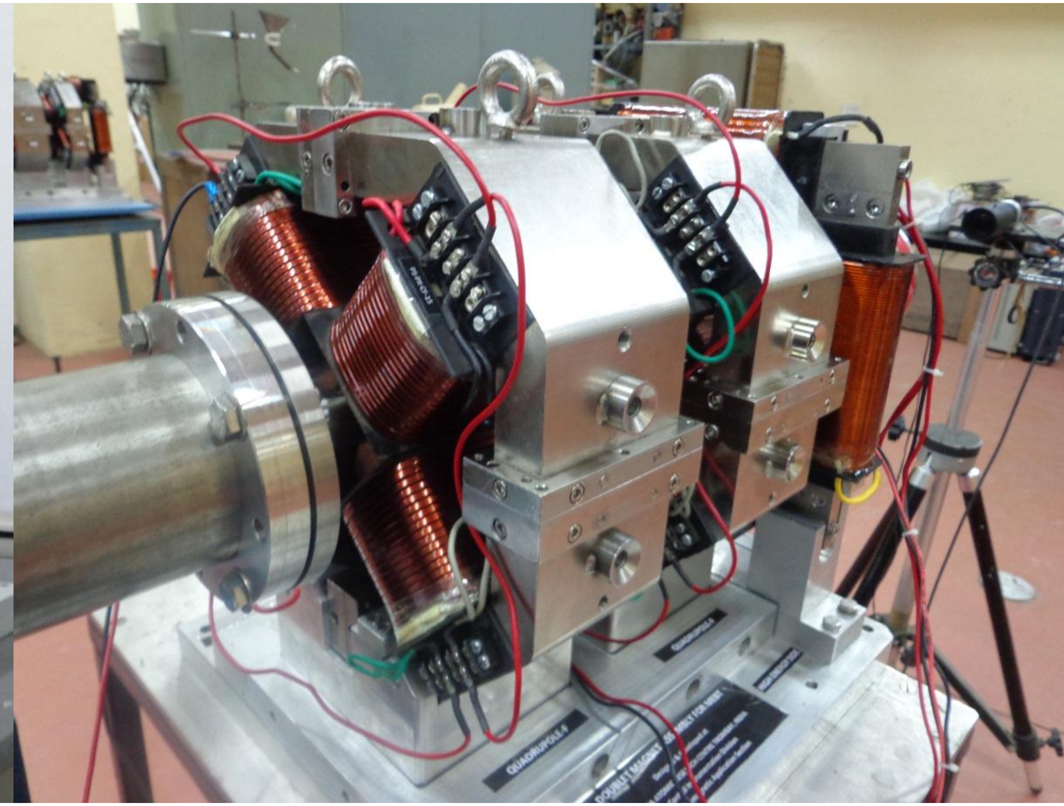
Quadrupole-F in Beam Line at FOTIA



Quad-F undergoing testing

Design and Development of Doublet and Triplet magnet assembly

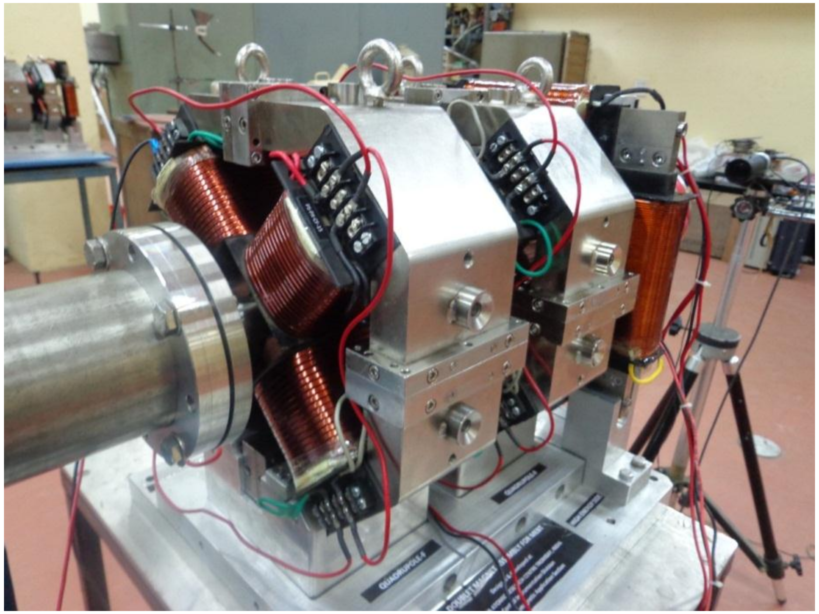




Triplet Quadrupole magnet assembly

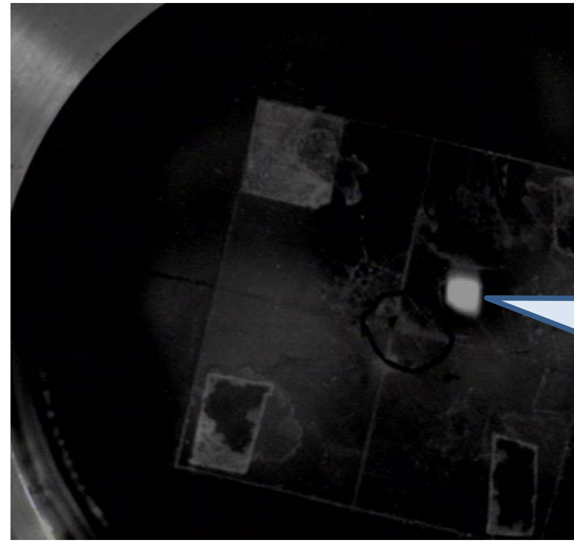
Doublet magnet assembly on FOTIA beam line

Beam Line Qualifications of Doublet Quad assembly at BARC



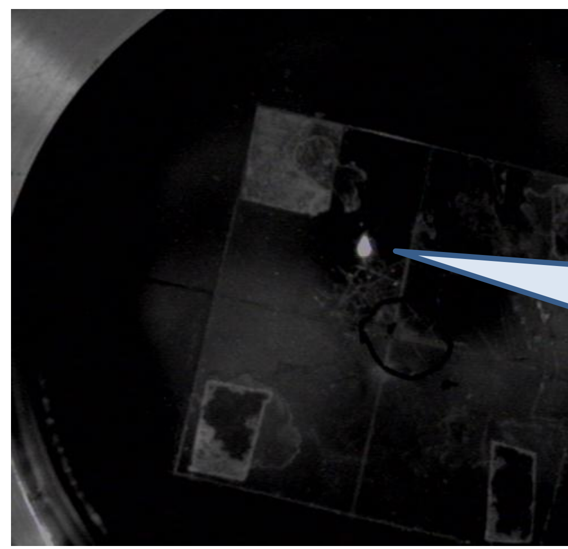
Doublet assembly at FOTIA beam line in BARC at 2.5 MeV Proton beam

Slight steering of beam due to offset between magnetic axis and beam axis



Magnets un-energized

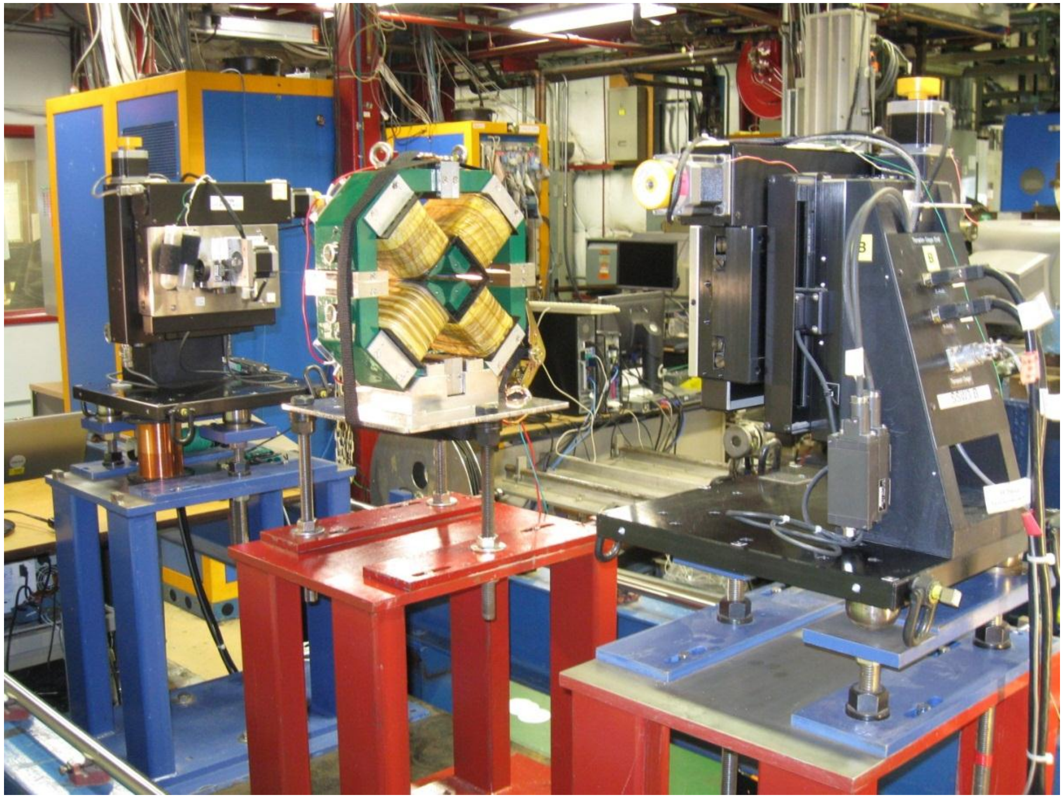
Unfocused beam



Doublet magnets energized

Focused beam

Magnetic Qualification on Quadrupole-F magnet at FNAL

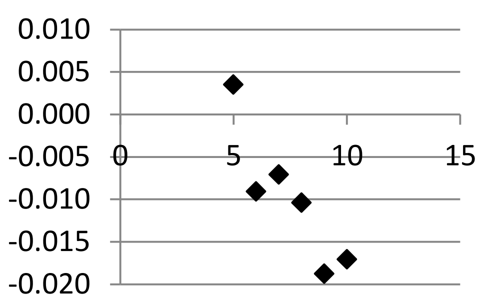


Quadrupole F mounted on Stretch wire bench at Fermi Lab

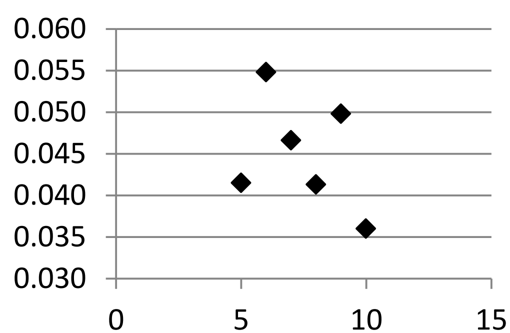
- Quad F Magnetic Requirements:
  - Center Stable to 0.1 mm (dis/re-assembly)
  - $\int G\,dl\,(I_{max}=10A)$ = 1.5 T (TF=150 T/kA)
  - 1% Field Homogeneity for R<11.5 mm
- Quad F Magnetic Measurements:
  - Single Stretched Wire Technique
  - Center Stability vs I, survey center reproducibility
  - Rotating Wire, Integral Strength and Harmonics
    - At good field radius R=11.5 mm

Prototype Quad F : Results of Measurements from Fermi Lab

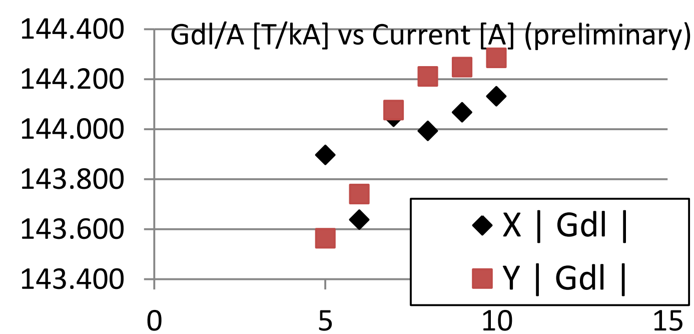
SN	Parameter	Measured Value	Designed for	Unit	Remarks
1.	∫ G.dl	1.44	1.44	Tesla	Meets Requirements
2.	Magnetic Centre (X axis)	45 to -30	Within ± 100	Microns	Meets Requirements
3.	Magnetic Centre (Y axis)	30 to -40	Within ± 100	Microns	Meets Requirements
4.	Integrated Magnetic field uniformity (up to n=10)	<0.5	< 1	%	Meets Requirements
5.	Magnetic centre as function of current	<20		Microns	Satisfactory
6.	Transfer function stability as function of input current	<0.5		%	Satisfactory
7.	Higher Order Multipoles	<0.3	< 1	%	Meets Requirements
8.	Skew Components	<0.1		%	Satisfactory



Magnetic centre (X-axis) as function of current



Magnetic centre (Y-axis) as function of current



Integral Gl as function of current

(1) Fabrication, integration and qualification of magnets will be carried out by supplier with guidance of BARC

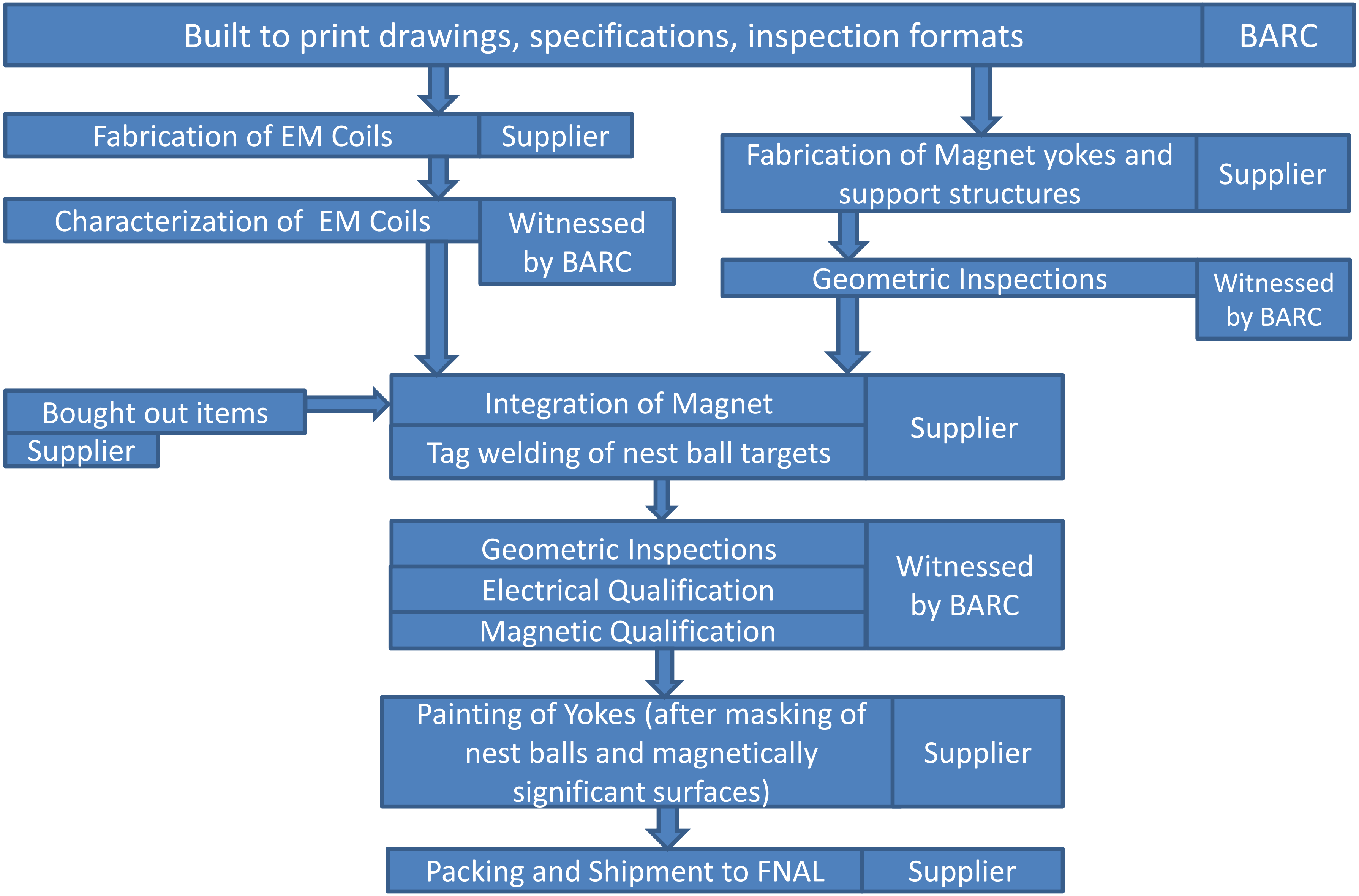
(2) Built to print drawings by BARC

(3) Inspection formats for all check points prepared and the same will be followed for all magnets

(4) Magnets will be shipped from Supplier to FNAL

(5) Supplier will maintain data base of all inspections and will fill traveller document for all components

WORK FLOW FOR EACH QUADRUPOLE MAGNET



QUADRUPOLE MAGNETS: MAJOR MILESTONES

Activity	End date	Remarks
Awarding the purchase order for series production	Week 0	
Preparation and approval of working document	Week 8	This information will be shared with FNAL before approval by BARC
Placement of PO for purchase of raw material by supplier	Week 10	
Delivery of FIM to the supplier	Week 16	
Receipt of raw material by supplier	Week 22	
Installation of Magnetic Measurement facilities	Week 22	By this stage the qualified quad-F (at present in FNAL) shall be returned . This will be used as reference magnet.
Bulk production and qualification stage I	Week 36	Three triplets assemblies
Bulk production and qualification stage II	Week 44	Three triplets assemblies
Bulk production and qualification stage III	Week 52	Two doublets assembly and one triplet assembly
Bulk production and qualification stage IV	Week 68	One doublet frame, one triplet frame, seven Quad-F, 6 Quad-D (These include magnets for HEBT and spares)

TIME LINES OF DELIVERY

SN	Stage	Deliverables	Quantity	Delivery date (from date of PO)	Proposed delivery dates (assuming placement of PO by last week of March 2015
1.	Stage 1	(a) Quadrupole F Magnets (b) Quadrupole D Magnets (c) Magnet Assembly D (d) Magnet Assembly T	4 Nos 8 Nos 0 Nos 4 Nos	Week 36	30 November, 2015
2.	Stage 2	(a) Quadrupole F Magnets (b) Quadrupole D Magnets (c) Magnet Assembly D (d) Magnet Assembly T	3 Nos 6 Nos 0 Nos 3 Nos	Week 44	29 February, 2016
3.	Stage 3	(a) Quadrupole F Magnets (b) Quadrupole D Magnets (c) Magnet Assembly D (d) Magnet Assembly T	4Nos 0 Nos 2 Nos 0 Nos	Week 52	31 May 2016
4.	Stage 4	(a) Quadrupole F Magnets (b) Quadrupole D Magnets (c) Magnet Assembly D (d) Magnet Assembly T	7 Nos 2 Nos 1 Nos 1 Nos	Week 68	31 August 2016

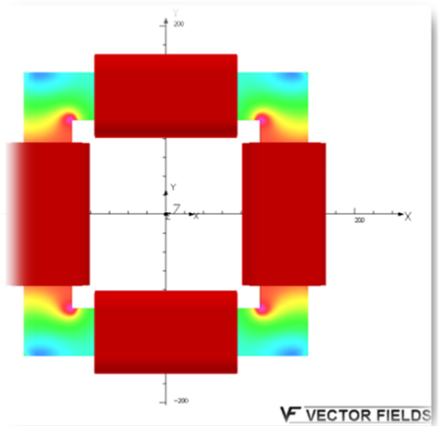
ACCEPTANCE CRITERIA : QUADS

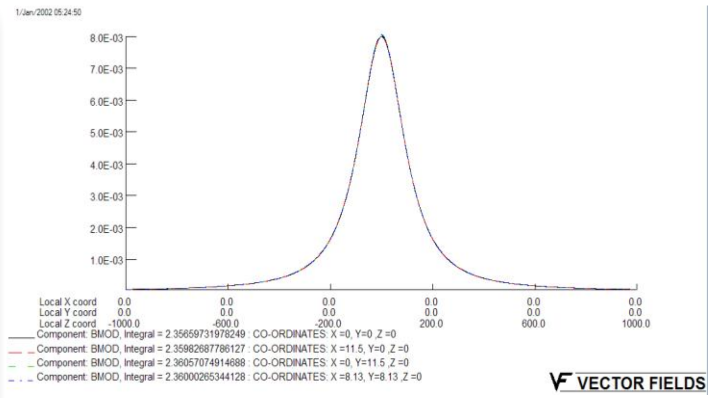
SN	Particulars	Acceptance criteria	Inspection Document
1.	**Qualifications on sub-components**	Following are applicable to each and every component. 1. Geometric tolerances of each and every component shall be strictly as per drawings. Inspection report for all shall be prepared and submitted. Sub-components are (a) Magnet Yokes (4 Nos per magnet) (b) Yoke Connector-I (4 Nos per magnet) (c) Yoke Connector-II (4 Nos per magnet) (d) Nest ball targets (6 nos per magnet) 2. The magnetic pole shall be scanned on CMM and deviation from the 2-D drawing shall be compared and reported. This deviation shall not be more than 20 microns.	 Format 1 (F1) Format 2 (F2) Format 2 (F2) Format 3 (F3) Format 8 (F8)
2.	**Qualifications on assembled magnet**	1. Pole tip to pole tip distance shall be measured on assembled magnet and reported. This shall not vary more than ± 20 microns of the true value. 2. Angle between poles shall be within ± 0.040°. 3. Repeatability of the assembly with values with in ± 20 microns. These measurements shall be done five times on each magnet.	Format 9 (F9)
3.	**Qualifications magnets assemble in the frame.**	1. Distance between yoke of consecutive magnets at three equal spaced locations in horizontal direction and two equal spaced locations in vertical direction. They shall not vary more than ± 50 microns of true value 2. Geometric inspection of frame and sub-components (a) Frame (b) Magnet Base Platform (c) Clamps	Format 13 (F13) (Triplet) Format 14 (F14) (Doublet) Format 5 (F5) Format 4 (F4) Format 7 (F7)
5.	**EM Coils**	1. Mechanical Qualifications The overall dimensional accuracy required is mentioned in drawings and are non-negotiable and shall be strictly complied with. The vendor shall carry out dimensional measurement with help of vernier calliper and shall report all the dimensions in table with following format. The dimensions shall be correct with 0.5 mm. 2. Electrical Qualifications i) Insulation Test using meger (Two electrode method) ii) Measurement of electrical resistance, inductance and Quality factor iii) Turn short test : the inter turn short will make the coil's rejection 1. Hi-pot test: The leakage current between coil and bobbin shall be less than 5 micro Ampere at 500 V (DC). 2. Thermal Qualification: Voltage across the coil after 8 hours shall not increase more than 10% at 10 A. 3. Measurement of electrical parameters as given in Format 8 (F8)	Format F8 (F8)
5.	**Visual Inspection**	All the poles will undergo visual inspection by the purchaser before and after nickel plating. IN case of dent or damage the given magnet yoke will be rejected and supplier shall replace the same.	

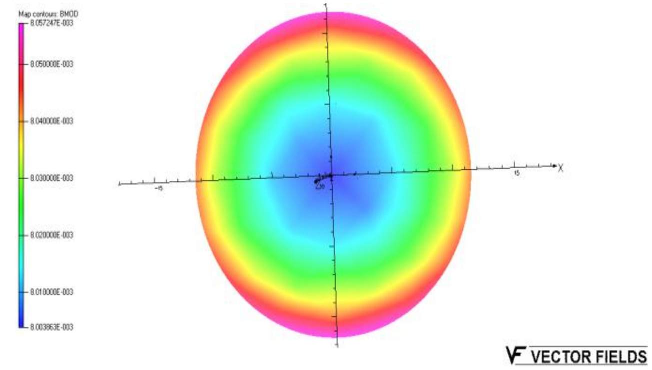
DIPOLE CORRECTOR MAGNETS

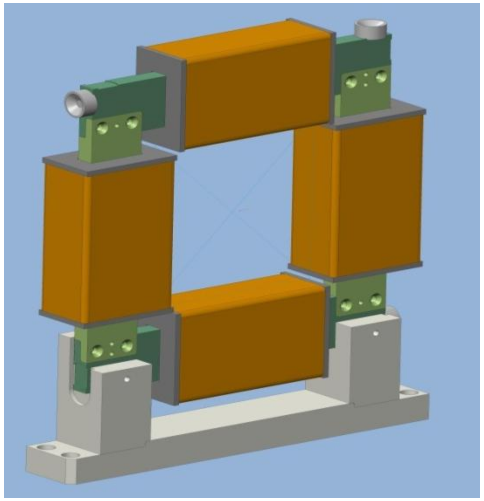
Dipole corrector- Electromagnetic Design

Dipole correctors are used for orbit correction by imparting horizontal and vertical kicks to the beam based on the feedback from BPMs.



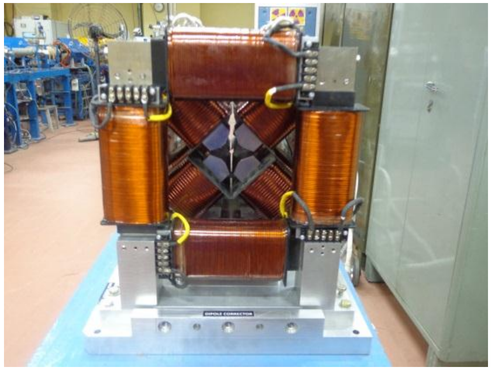




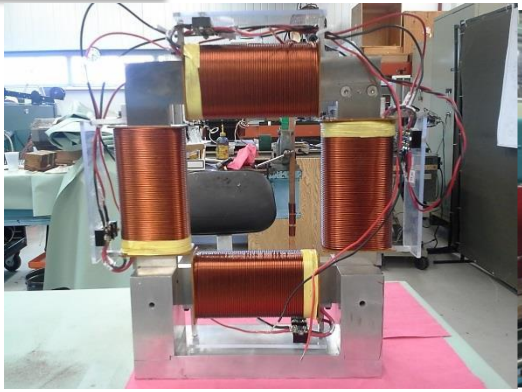


Sr. No	Parameter	Value	Unit
1.	Integral B field	2.4	mT-m
2.	Peak B field	9.5	mT
3.	Current density	1.2	A/mm^2
4.	Clear Aperture	150 x 150	mm^2
5.	Ampere turns	2400	AT
6.	Good Field region	ø25	mm
7.	Field uniformity	1	%

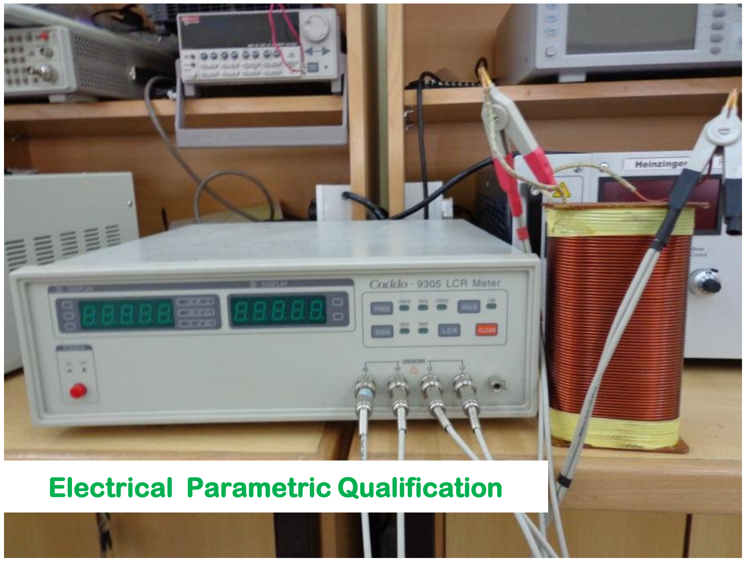
Dipole corrector- Summary of the development till date



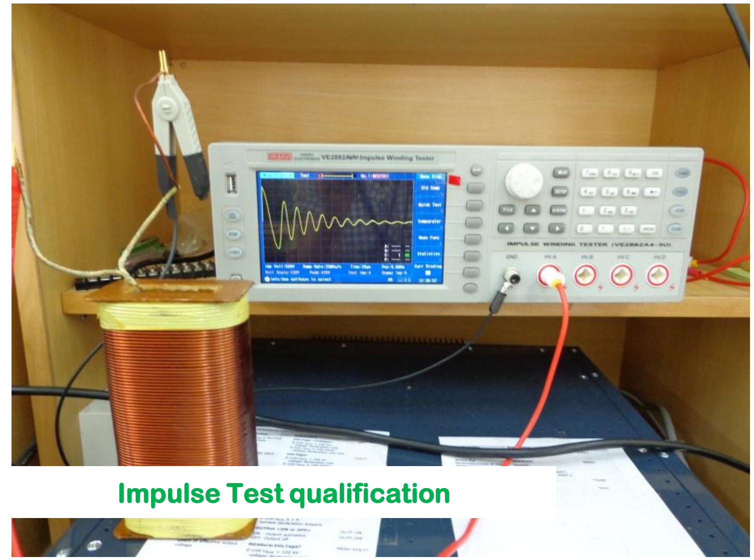
- FRS and TRS received for MEBT magnets – Feb'2013
- Electromagnetic and thermal design – April'2013
- Fabrication of initial prototype initiated- June 2013
- Completion of magnet yoke and coil fabrication – Dec'2013
- Completion of prototype Magnet qualification at BARC – April'2014
- Prototype magnets shipped to FNAL – July'2014
- Completion of prototype Magnet qualification at FNAL – October'2014
- Tender initiated for series magnet fabrication – Dec'2014



Electrical qualification of Dipole corrector coil windings

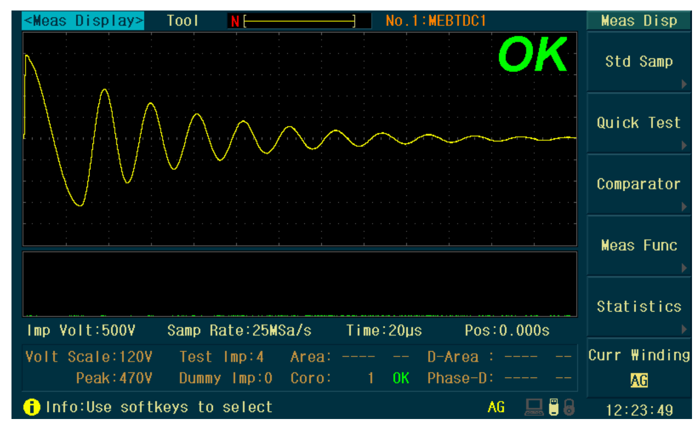


Electrical Parametric Qualification

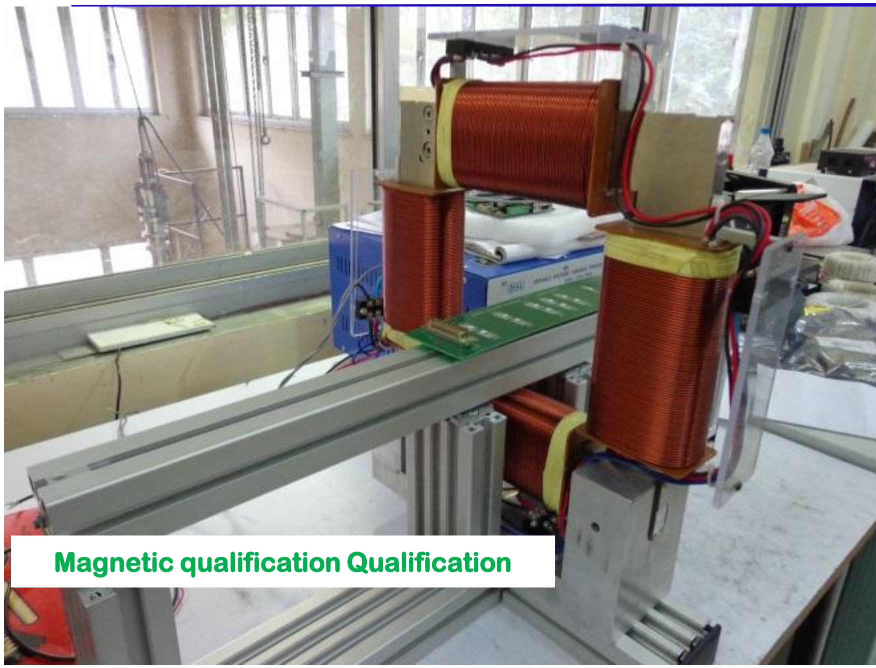


Impulse Test qualification

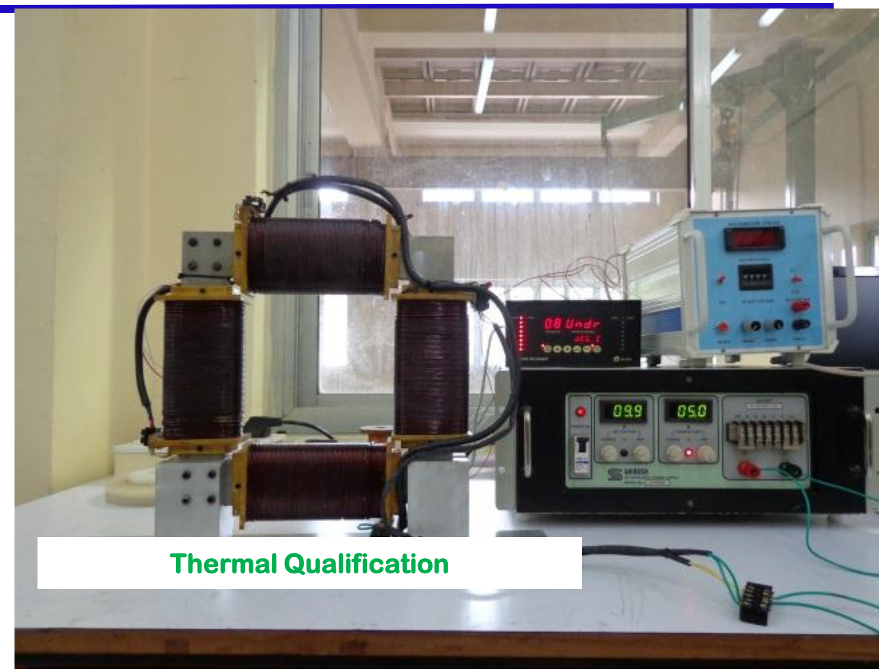
	COIL A	COIL B	COIL C	COIL D	COIL E
R @ 25^{0}C (Ohms)	0.790	0.794	0.791	0.788	0.791
L @100Hz (mH)	5.77	5.85	5.73	5.75	5.73
Q@100Hz	4.49	4.47	4.35	4.43	3.89
L@1KHz (mH)	5.761	5.83	5.72	5.756	5.72
Q@1KHz	22.4	22.5	22.2	22.4	20.8



Thermal/Magnetic Qualification tests



Magnetic qualification Qualification

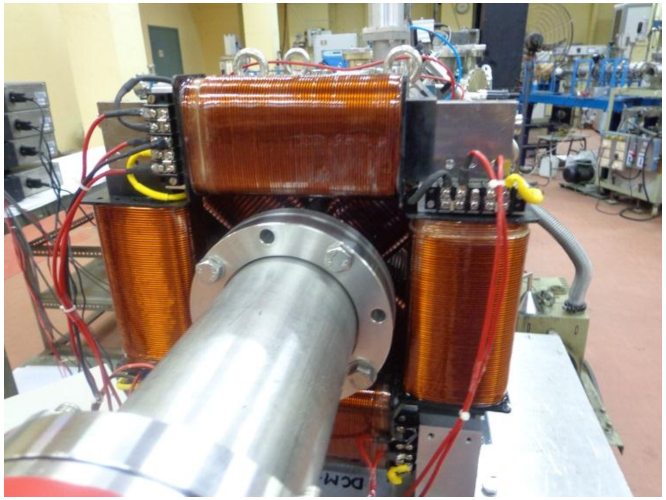


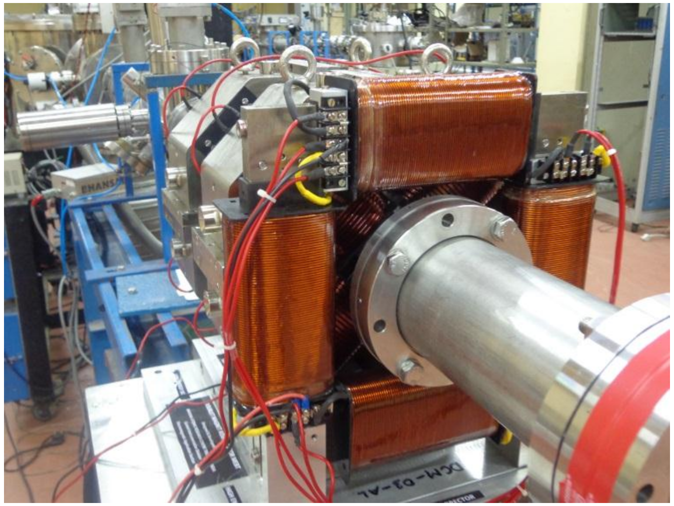
Thermal Qualification

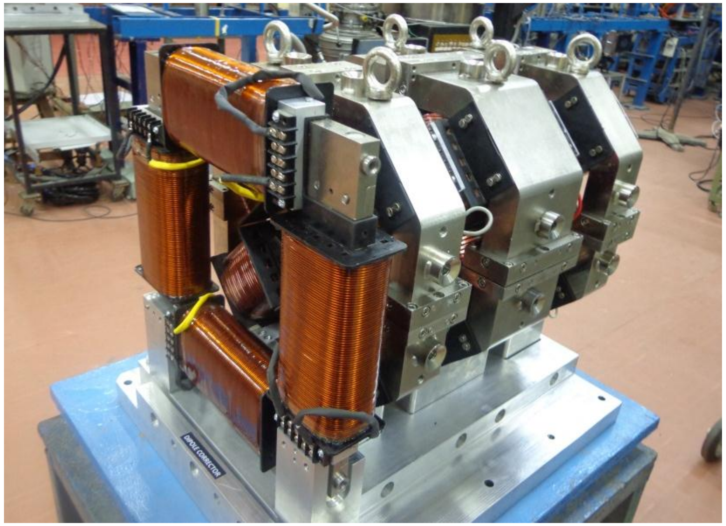
Sr. No	Parameter	Value
1.	Integral B field at I = 4A	2.4mT-m @4A 2.1mT-m @3.5A
2.	B field in the center of GFR	95 Gauss@4A 82 Gauss@3.5A
3.	Integral field uniformity	1.5%

Sr. No	Parameter	Value
1.	Initial voltage for HD/VD @ 4A	6.4 V
2.	Stabilised voltage	7.0 V
3.	Temperature Rise	~23^0C

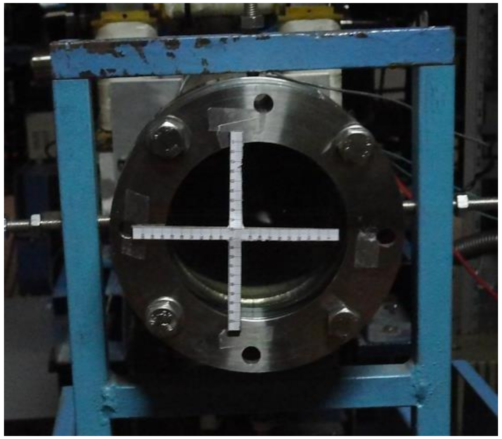
Dipole Corrector magnets mounted in doublet and triplet lattice arrangement



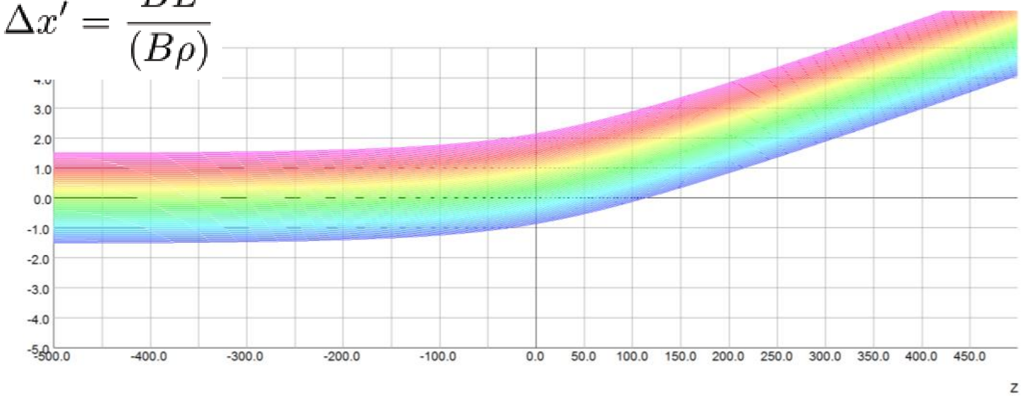




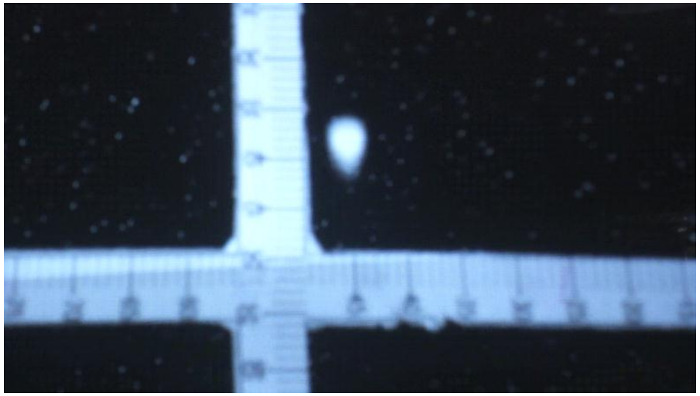
Beam line qualification tests at FOTIA facility BARC



$$\Delta x' = \frac{BL}{(B\rho)}$$



Particle Trajectory simulations



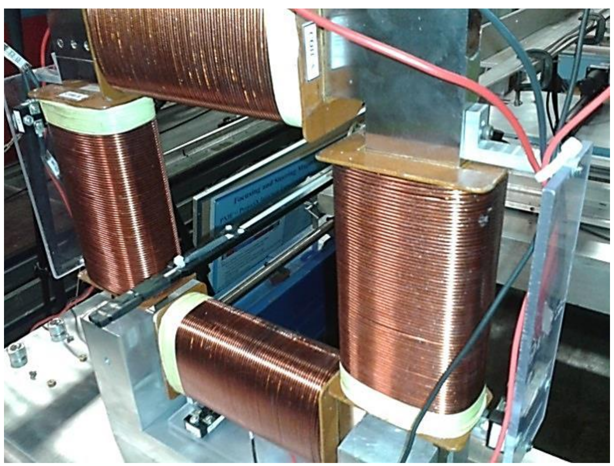
Proton Beam scan in first quadrant of HD/VD dipole corrector

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

Magnetic Measurements carried out at Fermi Lab on Combined H and V Dipole Steerer

Magnetic measurement was carried out at FNAL on Dipole steerer magnet using Hall probe scanning method.

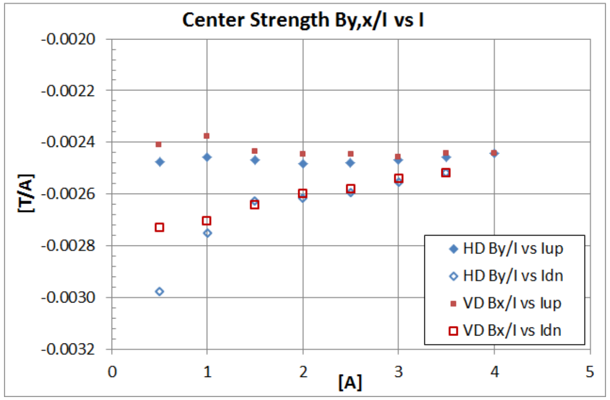
S. No	Parameter	Specified	Achieved
1.	Magnetic field integral	2.1 mT-m	2.4mT-m
2.	Field tilt -Deviation of X and Y field from perpendicular	$<3^0$	Negligible
3.	Integrated field uniformity	5%	Highly uniform



Comments from Dr. Mike Tartaglia – Fermilab (telcon meeting):

- The transfer functions and field profiles, are insensitive to the X,Y position (good).
- The calculated field integrals at 4A are BdL(VD)=0.00245 T-m, BdL(HD)=0.00242 T-m (requirement is .0021 T-m).
- Field integral meets requirements
- Field quality is acceptable even at 25mm radius, well beyond requirement level
- No evidence of tilt in the orthogonal field components.

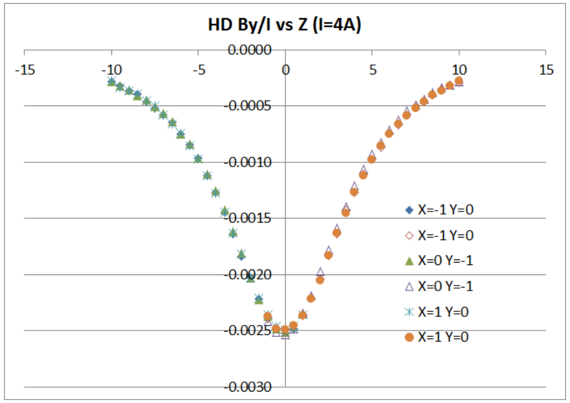
Magnetic Measurements result



Graph 1

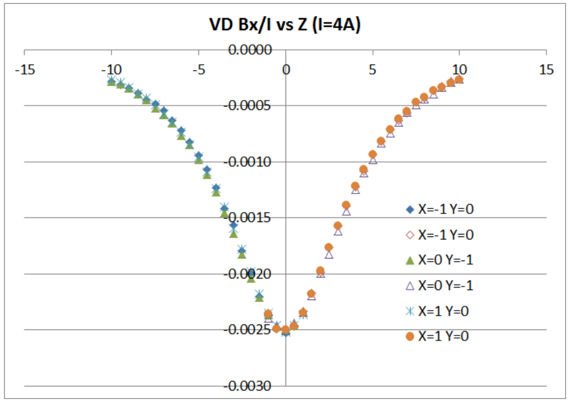
Normalized center field strength [B field / nominal Current (4A)] vs various excitation current.

This graph is will facilitate to create a look up table in order to estimate the centre field of the magnet in the operating region while ramping up (and down) of the magnet power supply.



Graph 2

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

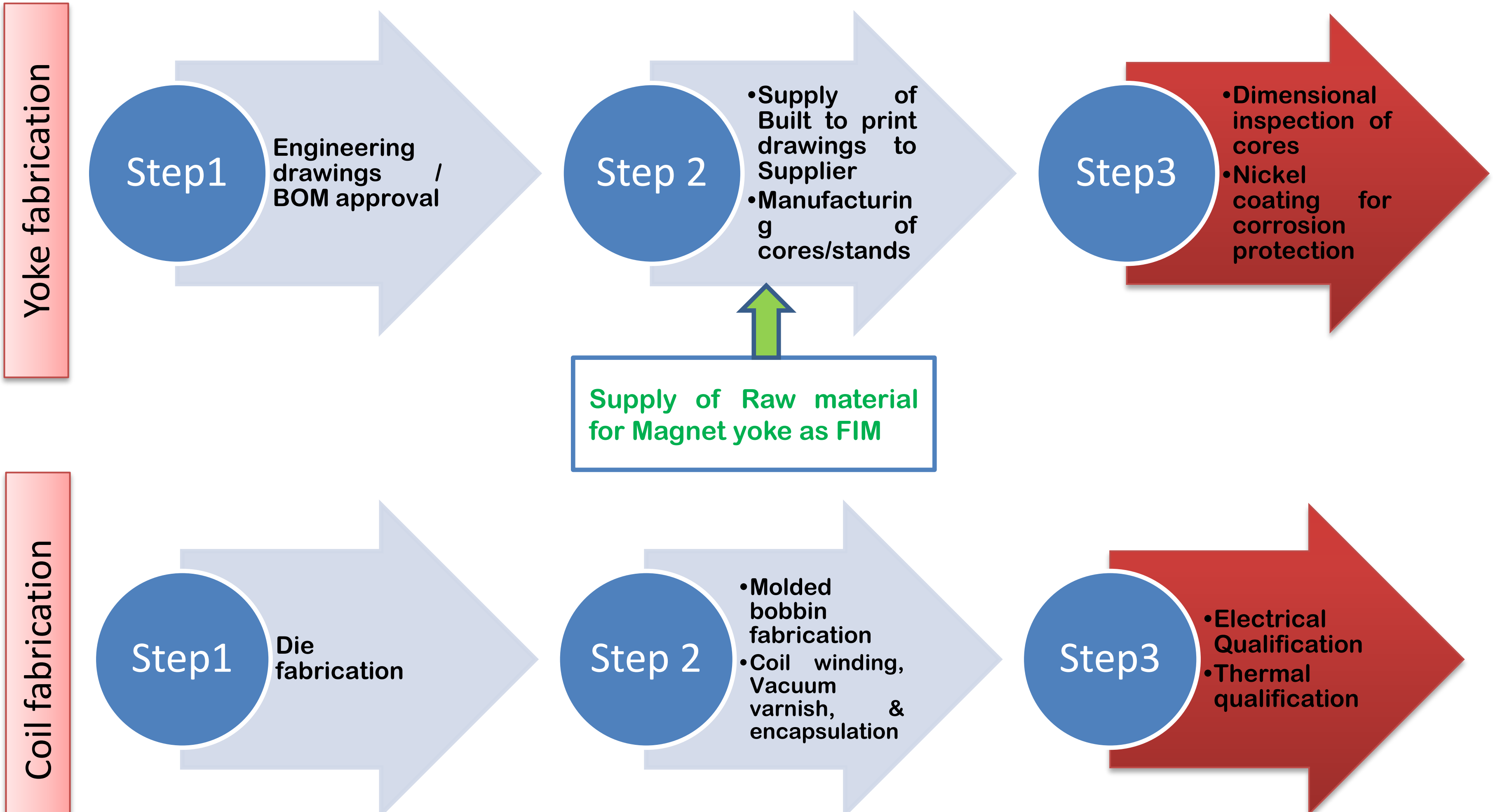


Graph 3

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

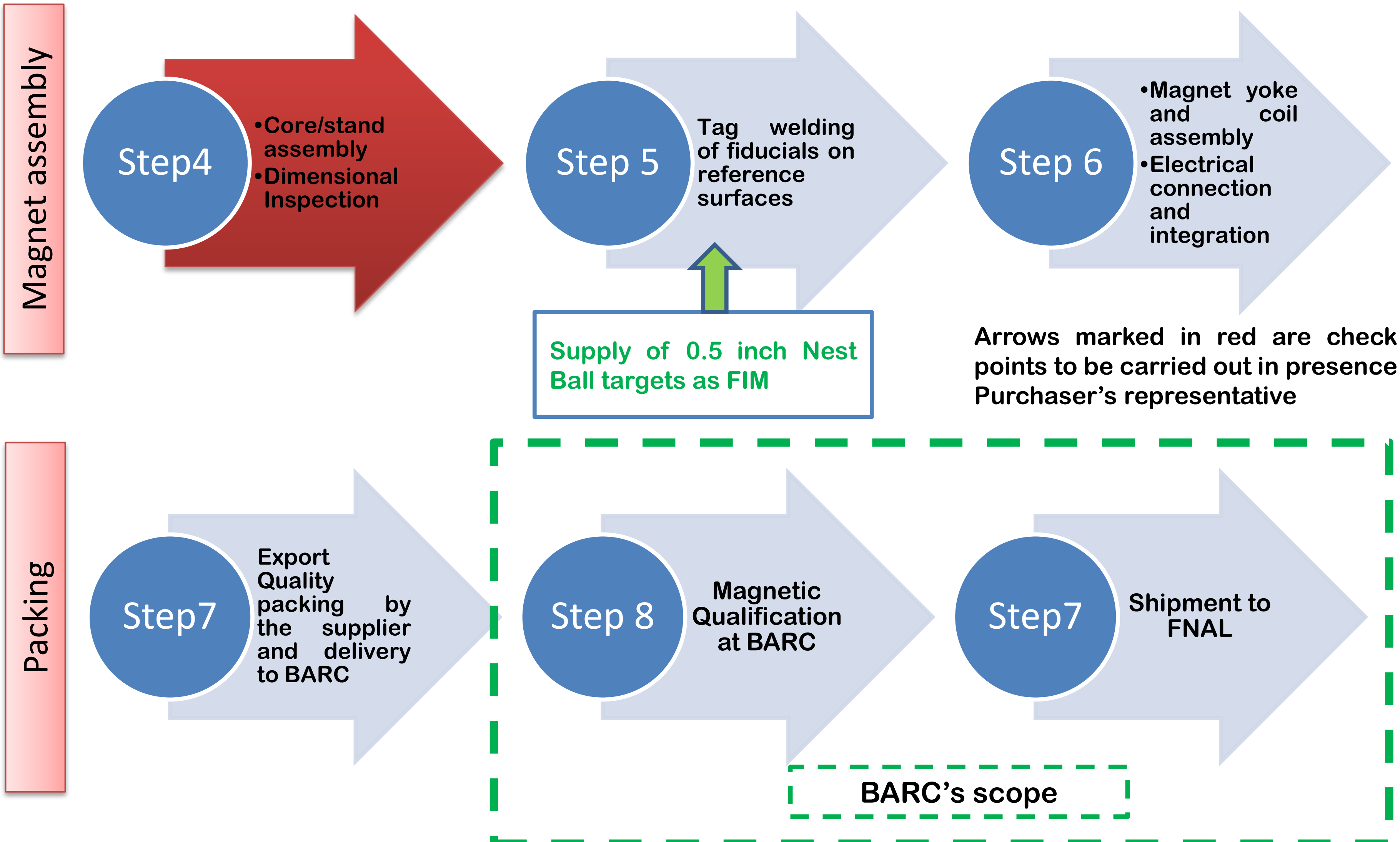
Here the GFR aperture scanned is 25 mm diameter. From the plot, it is observed that integral field is independent of x and y position, hence the field is uniform

Dipole corrector- Plan for series production



Arrows marked in red are check points to be carried out in presence Purchaser's representative

Dipole corrector- Plan for series production



Acceptance criteria

Dimensional Inspection			
Sr. no	**Qualification**	**Acceptance criteria**	**Scope**
1.	Visual inspection	Visual signs of damage, deterioration and oxidation shall not be present on any component of the assembly, Loose terminal connection or wiring shall not be present	Purchaser Representative shall inspect the magnet assembly at suppliers premises
2.	Geometrical Inspection	Each complete magnet shall undergo a geometrical control, to ensure compliance with the dimensional tolerances. Geometrical Inspection Template will be provided to supplier Major acceptance criteria is as given below:	

Parameter	Value
Angle θ (θ1,θ2,θ3,θ4) as per DC-006	*$90^0 \pm 0.05^0$ (tolerance is inclusive of repeatability of angular measurements after dis-assembly and assembly of magnets multiple times)*
Transverse dimensions of the assembled magnet with dowels	300mm $^{-0.05/+0}$ mm , 50$^{-0.05/+0}$ mm
Longitudinal dimensions of the assembled magnet	16 mm $^{-0.05/+0}$ mm
All other dimensions and tolerances as per drawing	
Surface finish on all surfaces 0.8 microns or better	

Acceptance criteria - continued

Electrical Qualification of coils

Parameter	Value
Resistance	0.8 Ω ± 0.01 Ω
Inductance	5.7mH ± 0.1mH
Q factor @ 100Hz @ 1KHz	 4.7±0.5 22±0.5
Leakage current between coil and core (Hipot test @500V)	<5µA
Ring test	All the coils shall pass the ring test @100V by differential area method within 2% band.

Once the pre-series coil winding is completed the parameters may differ slightly. Series coils will be compared against first standard coil. Following parameters shall be controlled to avoid variations in electrical parameters of the coil:

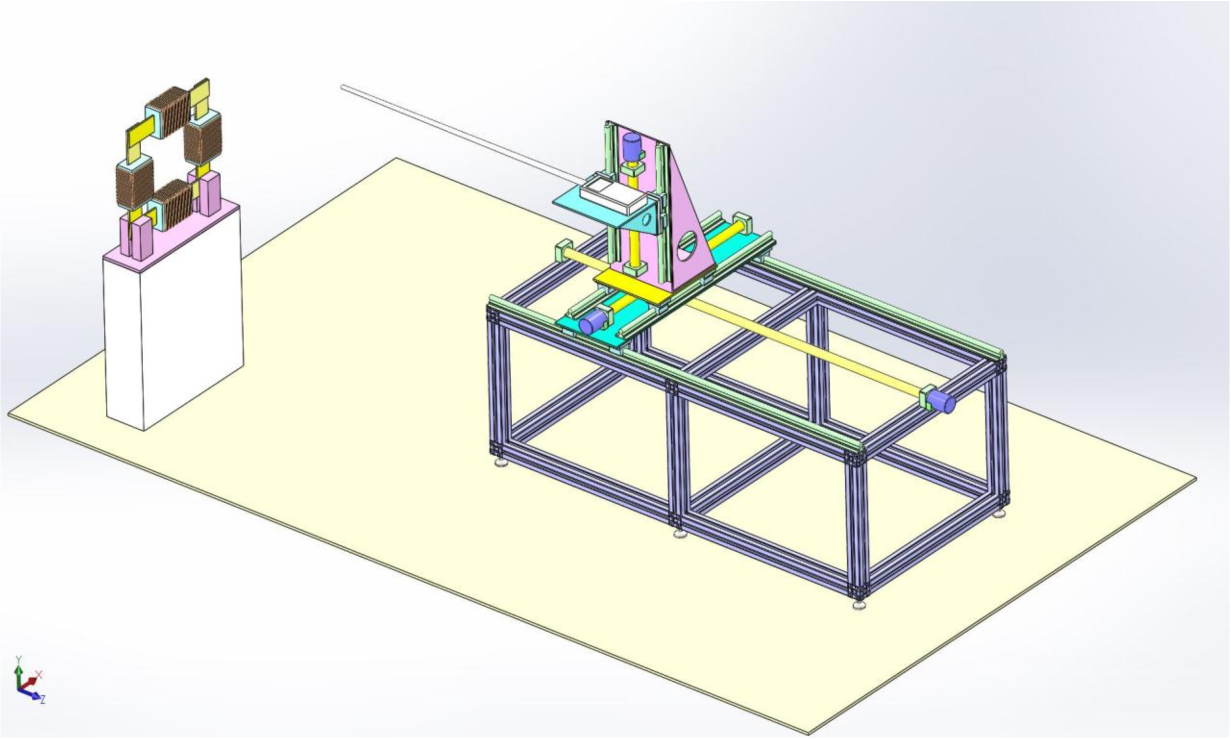
Parameter	Value
Total number of turns	608 ± 1 turn
Min number of turn /layer	76
Max number of turn/layer	77
Number of layers	8

Magnetic Qualification of Dipole Steerer

Magnetic Qualification of the dipole steerer will be carried out at BARC before shipment to FNAL:

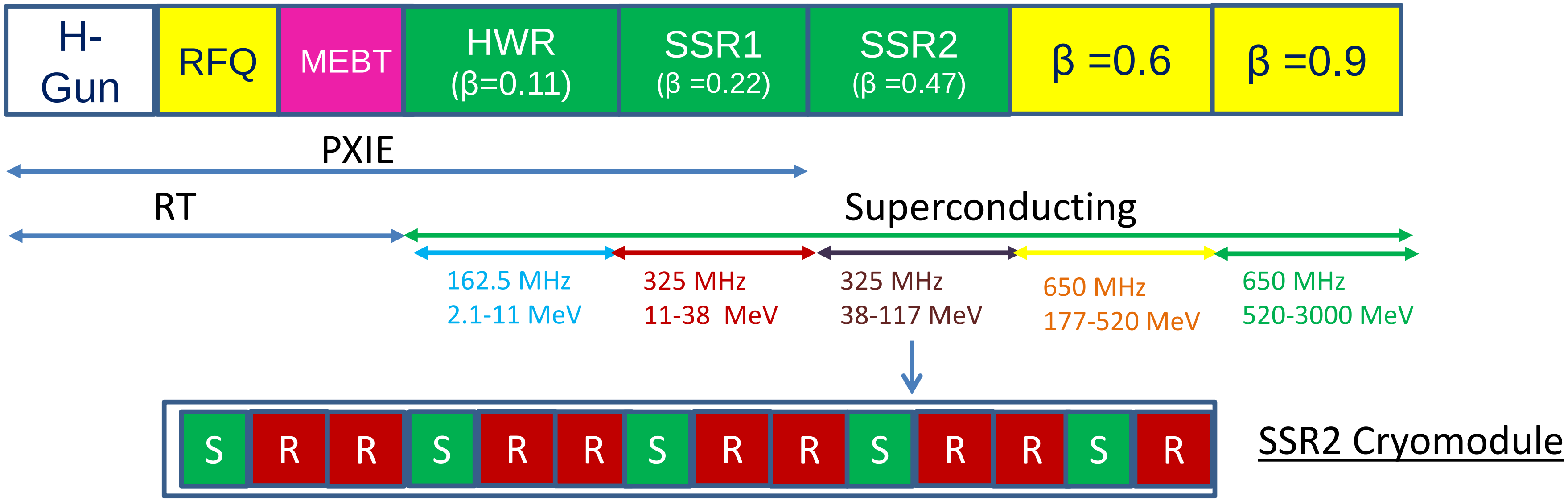
Following parameters will be measured (Magnetic Measurement bench under development, will be ready by April'2014):

i. **Field integral vs excitation current (during ramp up and down)**
ii. **Field integral uniformity for horizontal and vertical dipole corrector**
iii. **Tilt in orthogonal field components**



Superconducting focusing lenses for SSR2

SSR2 Focusing lens Location in Project-X Beam Lattice



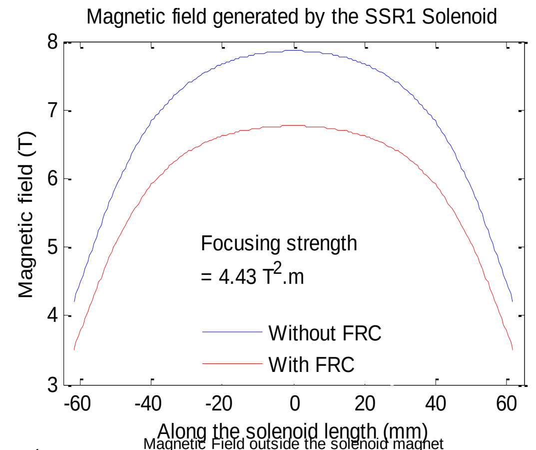
- 1 Cryomodule consists of 9 cavities & 5 magnets
- Four such SSR2 cryomodules- **Total 20 Magnets and its cold mass and its current leads**
- Cavity and focusing elements are grouped and placed in SR^2

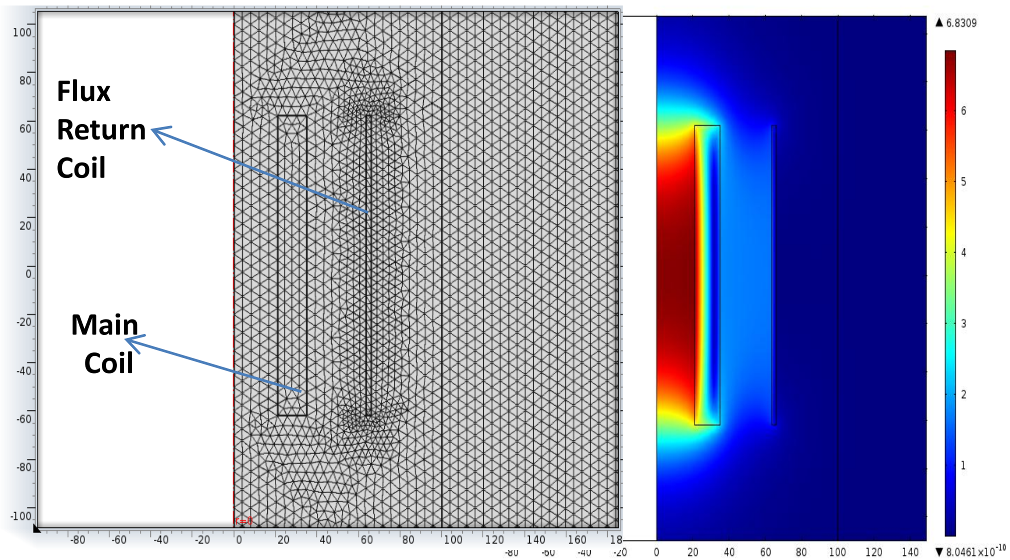
Beam Optics requirements for SC focusing lenses

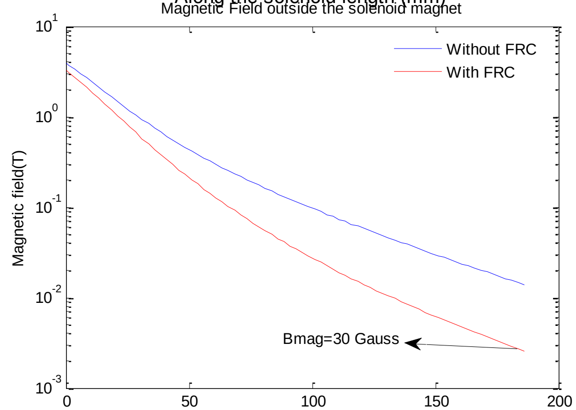
- Integrated focusing strength ≥ **5 T^2m**
- Integrated dipole correctors- 2 Nos – Each with bending strength **≥ 0.003 T-m**
- Cold mass clear aperture **= 45 mm**
- Uncertainty of location of effective magnetic axis in the focusing solenoid of lens relative to fiducials on the outer surface of cold mass – **Better than 0.5 mm RMS**
- Precision of angular alignment must be better than - **1 mrad RMS**

Design of solenoid focusing lens

- Solenoid current : ≤ 100 A
- Dipole current : ≤ 50 A
- Each lens must be quench protected
- Maximum magnetic field generated by the lenses on the surface of SSR2 cavities must be limited to 100 G

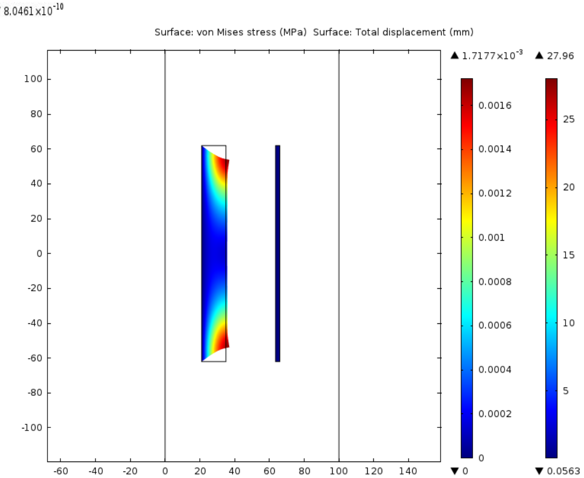






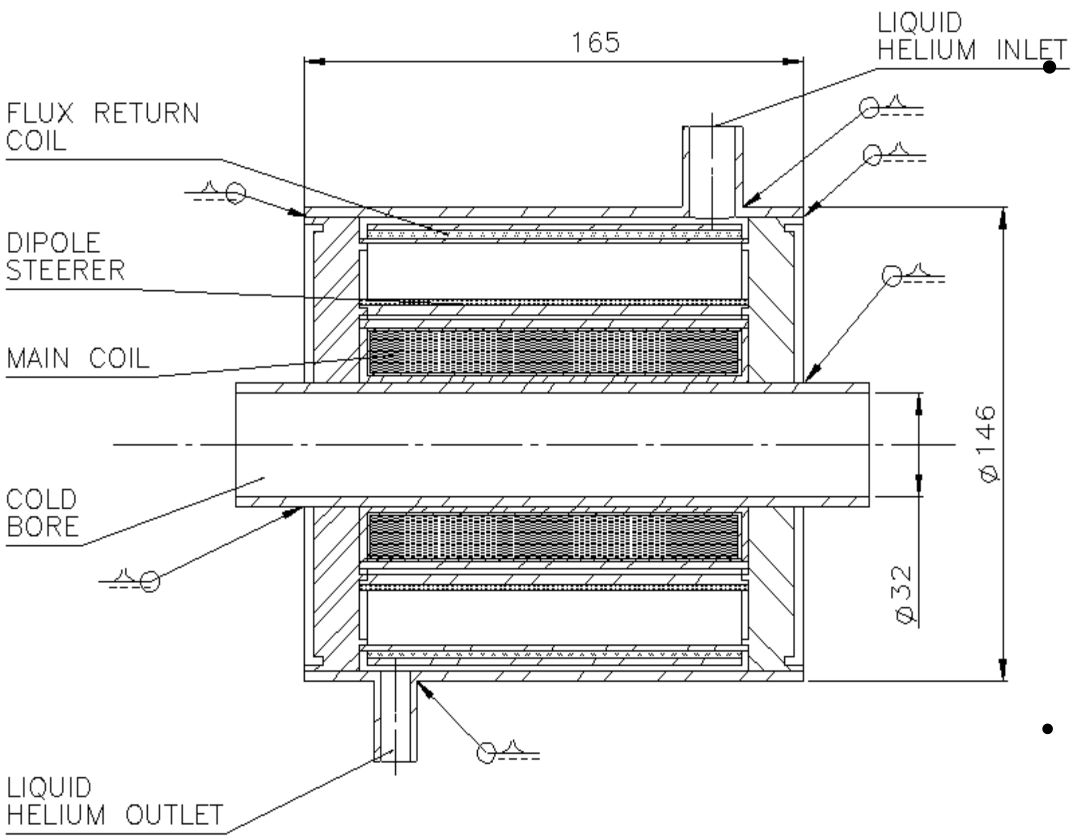
Stresses with wire pre tension of 10 N

Max Von Mises stress : 28 MPa



Magnet design and analysis – Reference inputs from TD-12-010

Cold Mass With Focusing Lens



MAIN COIL & Flux return coil

– 0.438 mm diameter NbTi wire with 54 filaments (M/s Luvata make),(0.4 bare diameter)
– Formvar insulation (class 105).
– Winding tension – 10 N .
– Vacuum epoxy impregnation
– Banding using SS 316L
– Number of turns/layer : 282 ± 1
– Number of layers : 31
– Stored energy : 6.5 KJ at 100A

- **Flux return Coil**

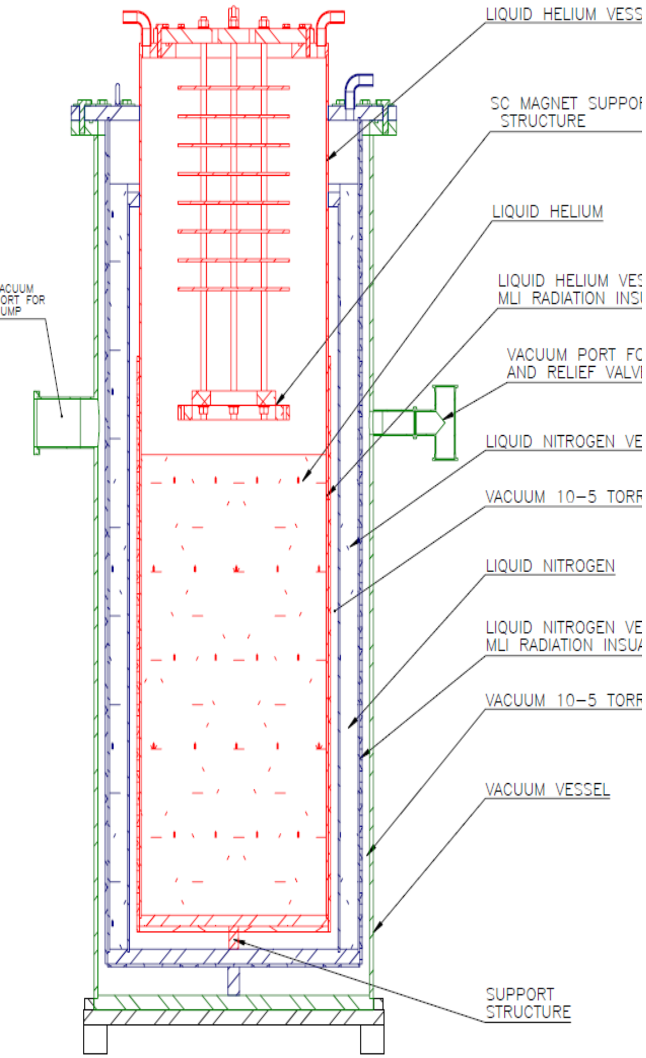
– Number of turns/layer : 282± 1
– Number of layers : 6
– Stored energy : 1.2 KJ at 100A

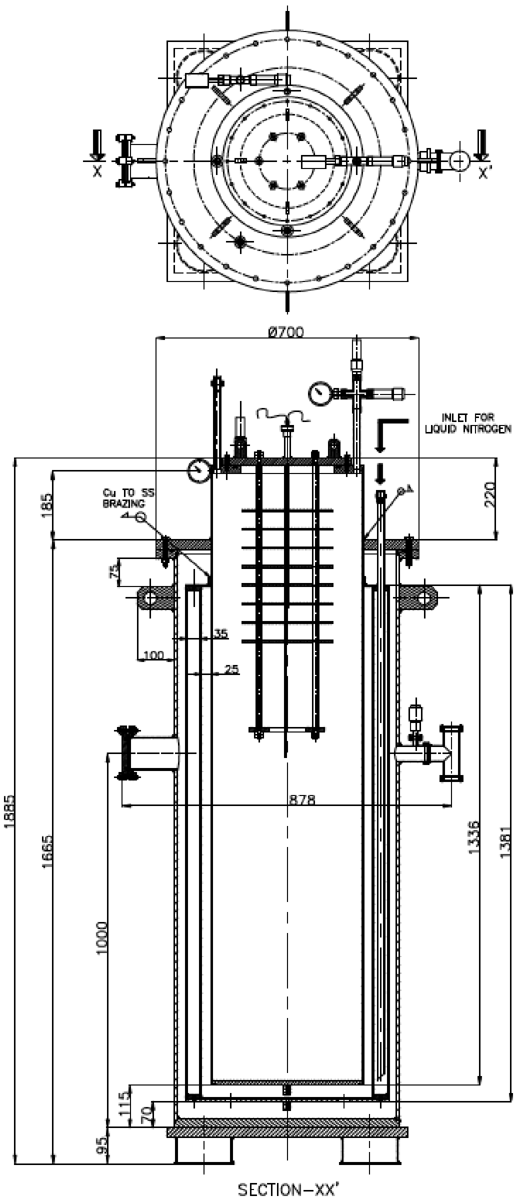
Steering Dipole
Includes : Horizontal and vertical steering

- Rectangle area : 5 x 5 mm^2
- Number of turns : 100 turns
- 0.438 mm diameter NbTi wire with 54 filaments.
- Formvar insulation (class 105).

Requirement of NbTi strand/magnet = 2 Km

Vertical Cryostat for SC Magnet testing





- Liquid nitrogen cooled Low loss liquid helium cryostat.
- Specifications:

– Bore diameter : 250 mm (clear access)

– Liquid helium volume : 100 lts.

– Helium Evaporation rate : < 2 lph

- Purpose:

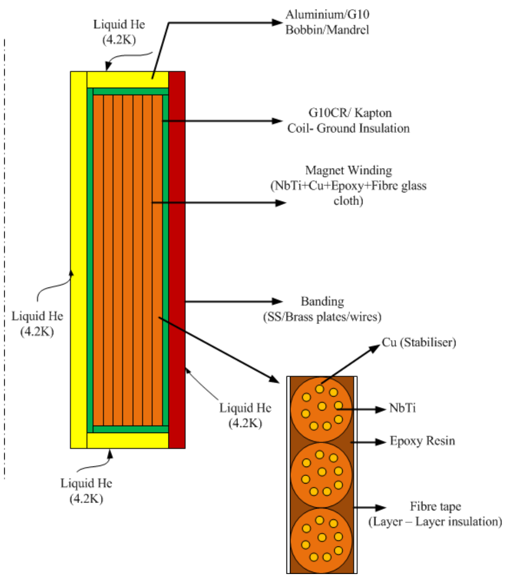
– Cold bore Magnetic field measurement of SC Magnet.

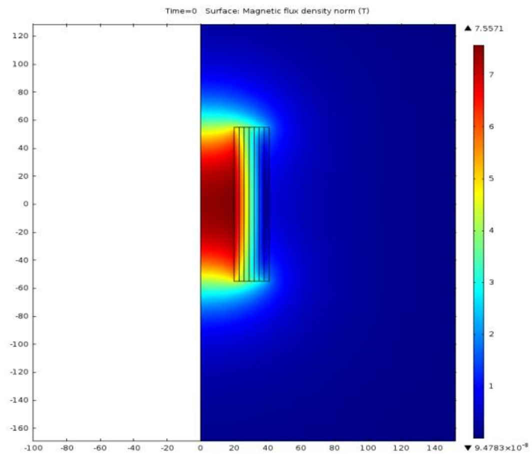
– Quench characterisation of SC Magnet.

<u>Expected to be installed inside BARC before March 2015</u>.

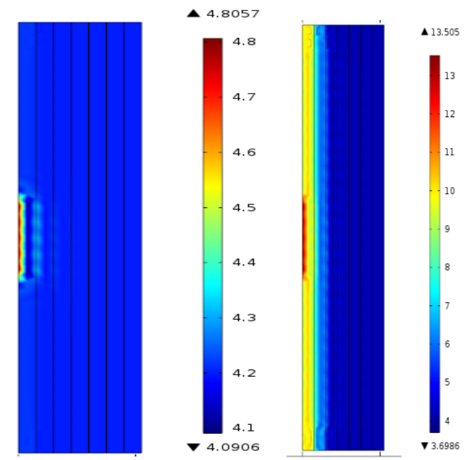
Quench Simulation

- COMSOL based quench analysis program has been developed.
- The basis of this program is “Propagation of Normal Zone in quenching superconducting solenoid modeling using COMSOL”- I.Trechkine – TD-14-003

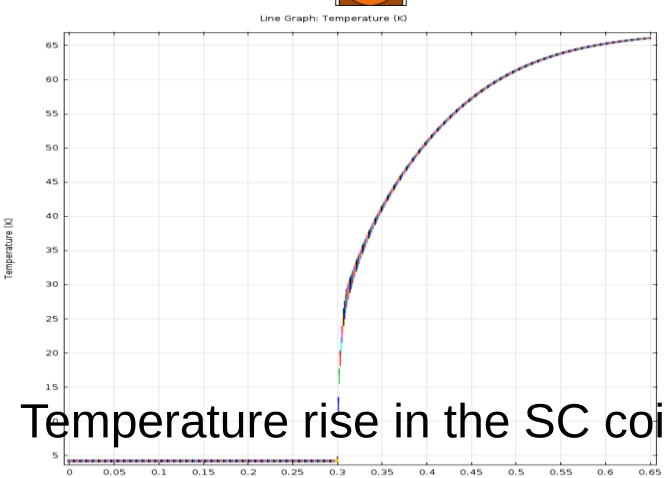




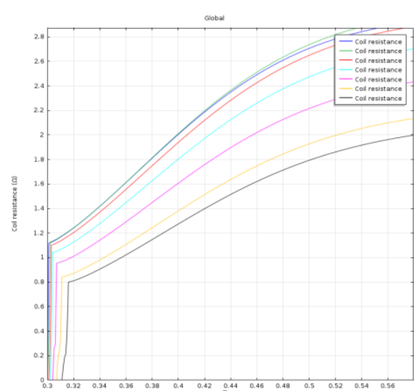
Magnetic field



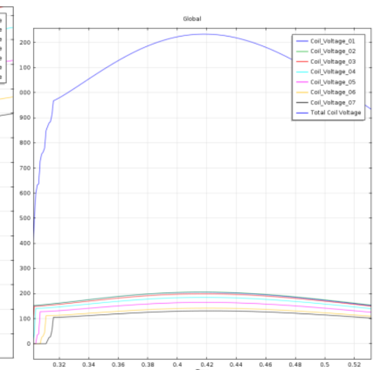
Normal Zone propagation



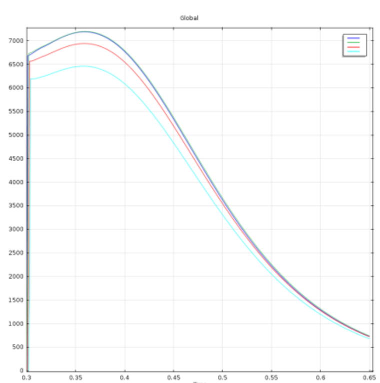
Temperature rise in the SC coil



Resistance growth



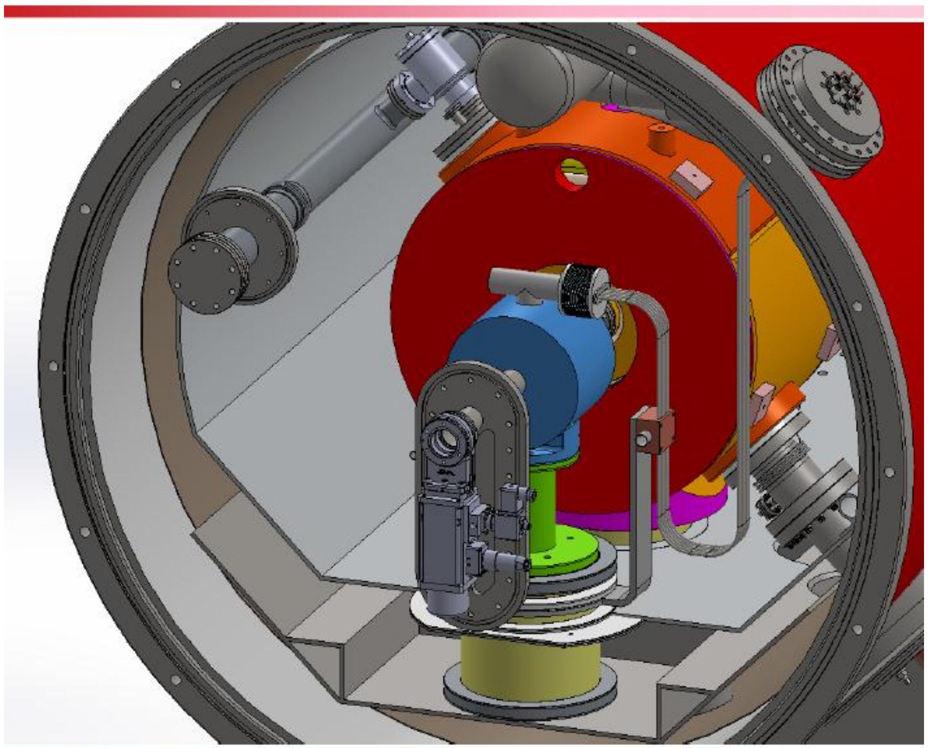
Voltage developed (Rdump=250 mΩ)

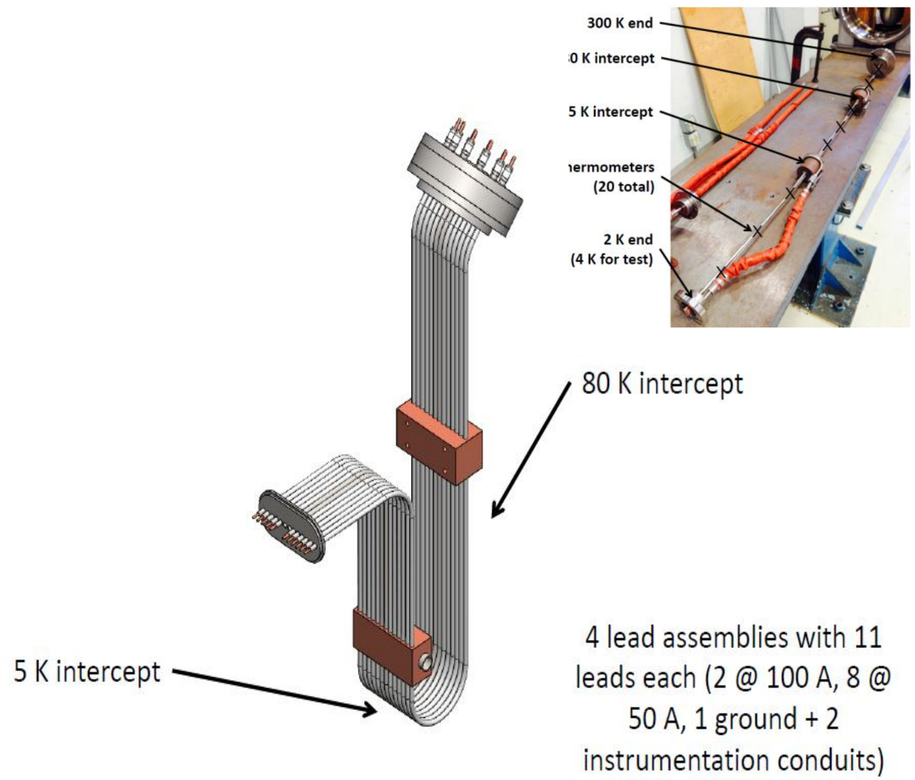


Power dissipated inside SC coil

Conduction cooled Current leads

- Current leads contribute to major heat load on the cryomodule.
- Conduction cooled current leads with thermalisation blocks to reduce heat load on liquid helium.



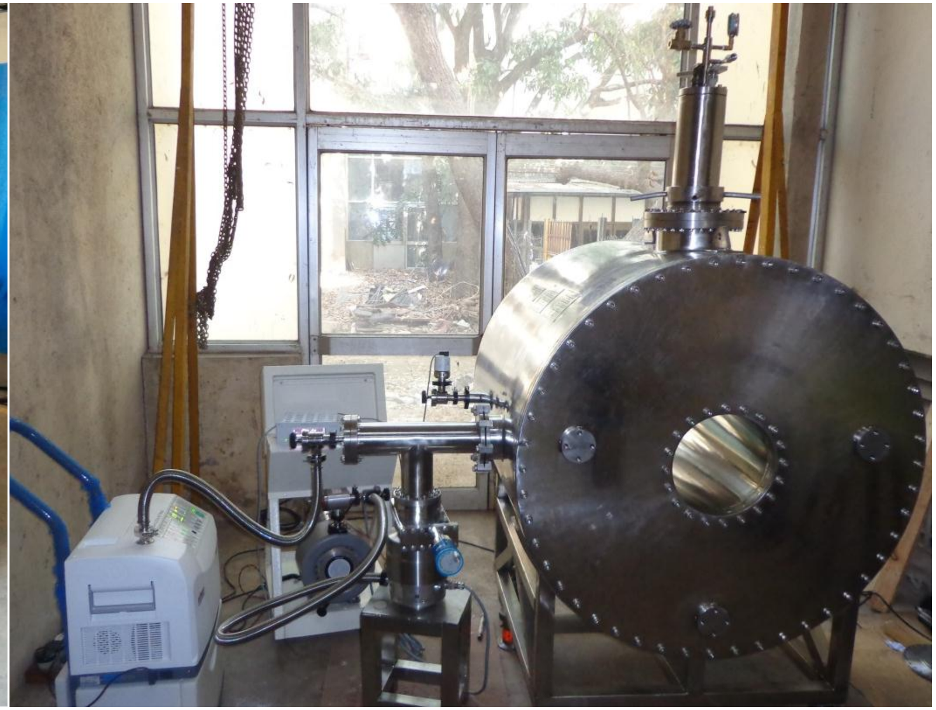


T.Nicol , PIP-II Meeting, Sept 2014

- Two different lengths of copper electrodeposited over brass wire.
- SS Enclosure welded to connecting blocks.
- Kapton , Epoxy impregnated G10 for electrical insulation.

Our capabilities

Room temperature bore cryostat



Cryostat Vacuum testing

TUV ASME 'U' Stamping on vessel

Liquid Nitrogen testing (9.4×10^{-6} Torr)

Four quadrant Programmable power supply (400A , 10V)

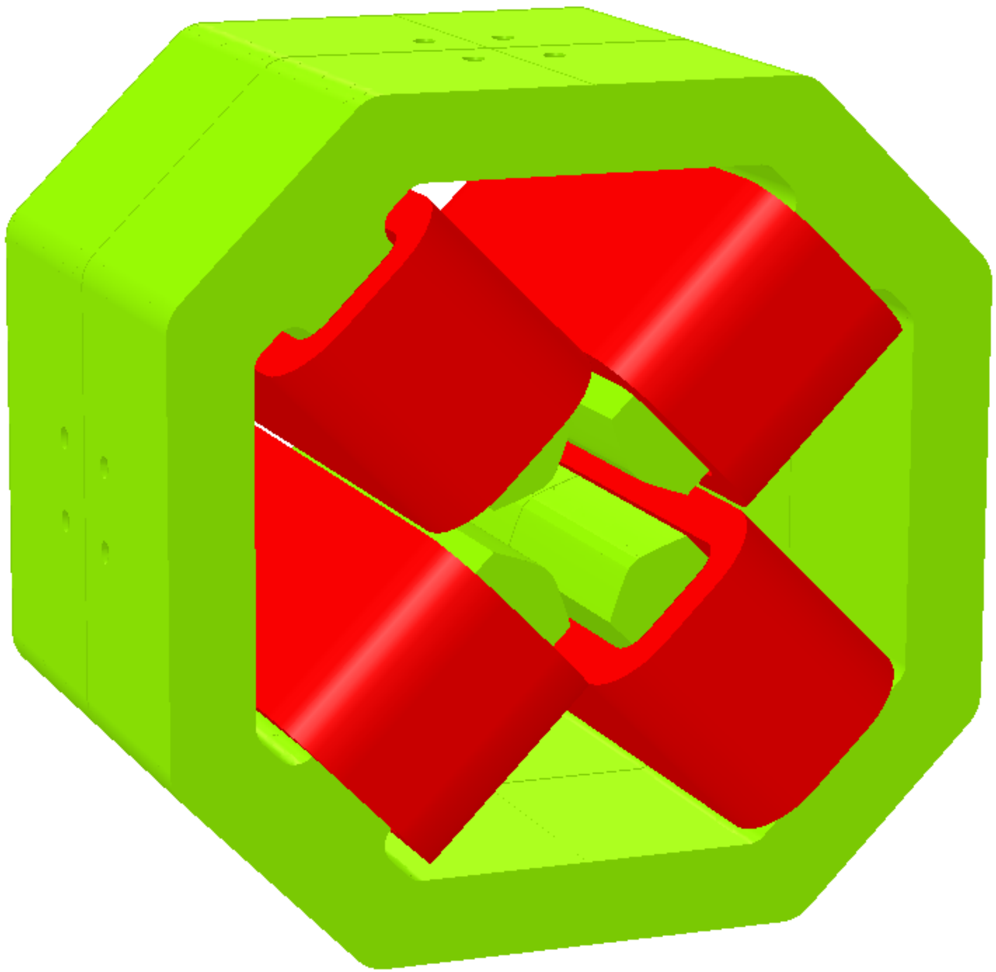
HB650 Quadrupole Magnets

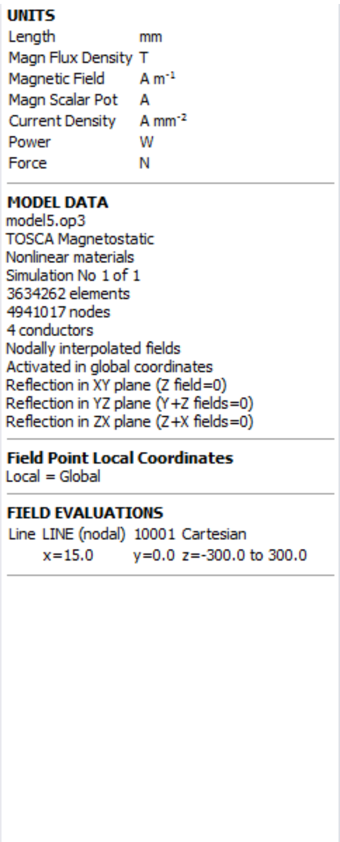
Optics requirements of HB650

SN	Parameter	Value	Unit
1.	Integral Magnetic Field gradient	~ 3 @ 1 GeV	Tesla
2.	Magnetic Field gradient (G_0)	15 @ 1 GeV	Tesla/m
3.	Pole tip to Pole tip distance	22	mm
4.	Good field region (Diameter)	30	mm
5.	Uniformity of integral magnetic field gradient in Good Field region	1	%
6.	Permissible Higher order multipoles strength as percentage of quadrupolar component (upto n= ??)	1	%
7.	Energy of the beam	1000	MeV
8.	Lattice configuration	FD-CCCCCC-FD	-
9.	Magnetic Effective Length	200	mm
10.	Transverse aperture Limitation (Radius)	22	mm
11.	Separation b/w two quads (center to center)	600	mm

Required MMF per Coil : 2,800 AT

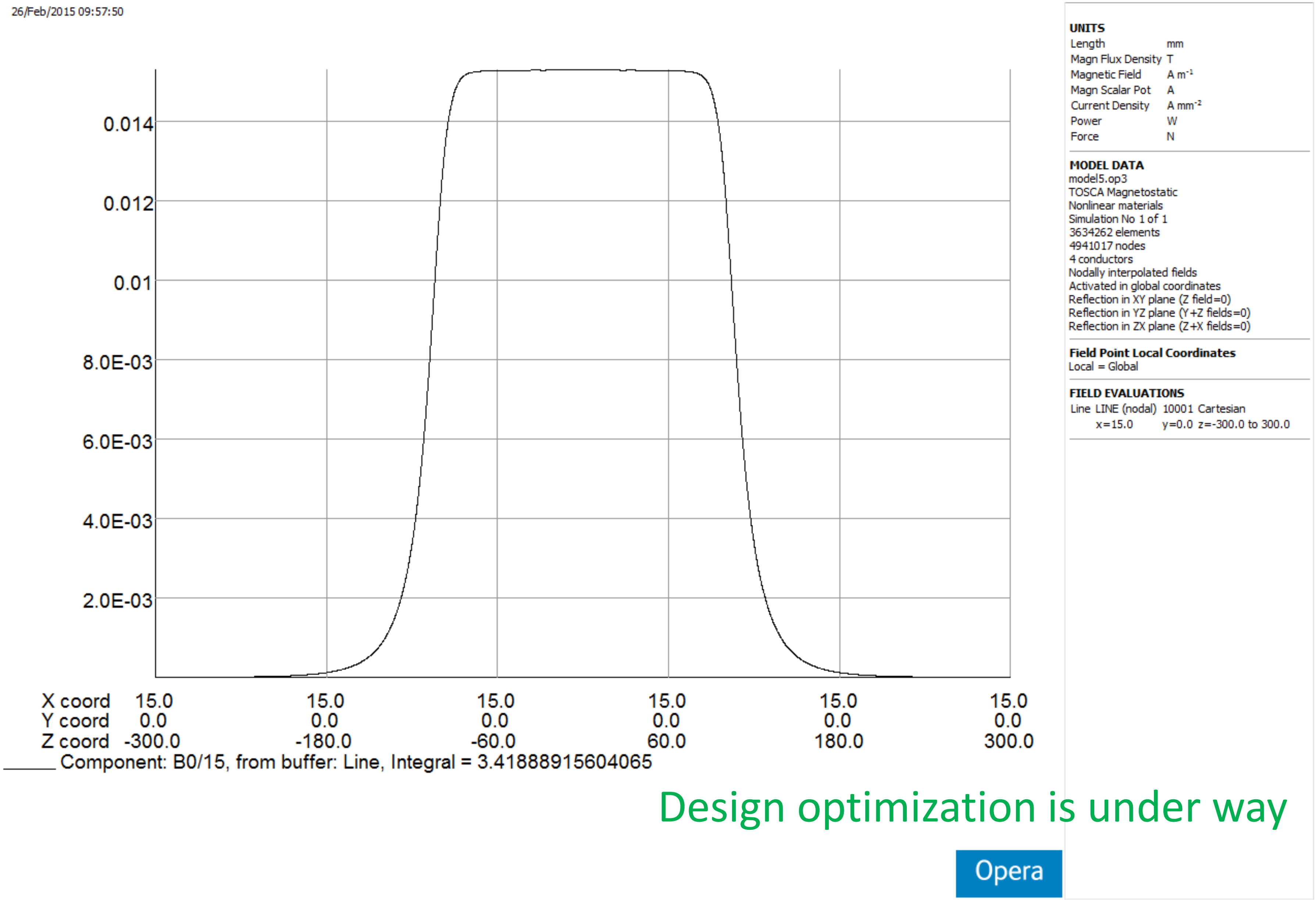
3D Simulation Model of HB650 Quad





Longitudinal length	200	mm
Transverse dimensions	250 X 250	mm
Pole tip to Pole Tip distance	44	mm
MMF	2800	AT

Axial Magnetic field profile



Design optimization is under way

Thanks for your kind attention!

Cryomodule Interface and electrical inputs requirements – Back up slide

- Solenoid current : ≤ 100 A
- Dipole current : ≤ 50 A
- Each lens must be quench protected
- Maximum magnetic field generated by the lenses on the surface of SSR2 cavities must be limited to 100 G
- The solenoid must be integrated inside a LHe Vessel along with the beam pipe.
- Beam pipe must have
  - provision for mounting BPMs
  - bellow for alignment of cold mass in the cryomodule.
- Location of magnetic axis must be referred to optical fiducials installed on extension beams.
- Each focusing lens is to be installed on an individual alignment fixture and individual thermal insulating post.
- Each focusing lens must be mechanically and vacuum-tight connected to the beam pipe and Beam Position Monitor.
- Current is delivered to the focusing solenoid and the correctors of the lens by three pairs of current leads connected to power supplies located outside the cryomodule.
- Each focusing lens will be equipped with extension beams where optical fiducials used for the lens alignment are fixed.
- Each focusing lens must be equipped with gauges and voltage taps required by a quench-protection system.