Main Linac Superconducting Quadrupole

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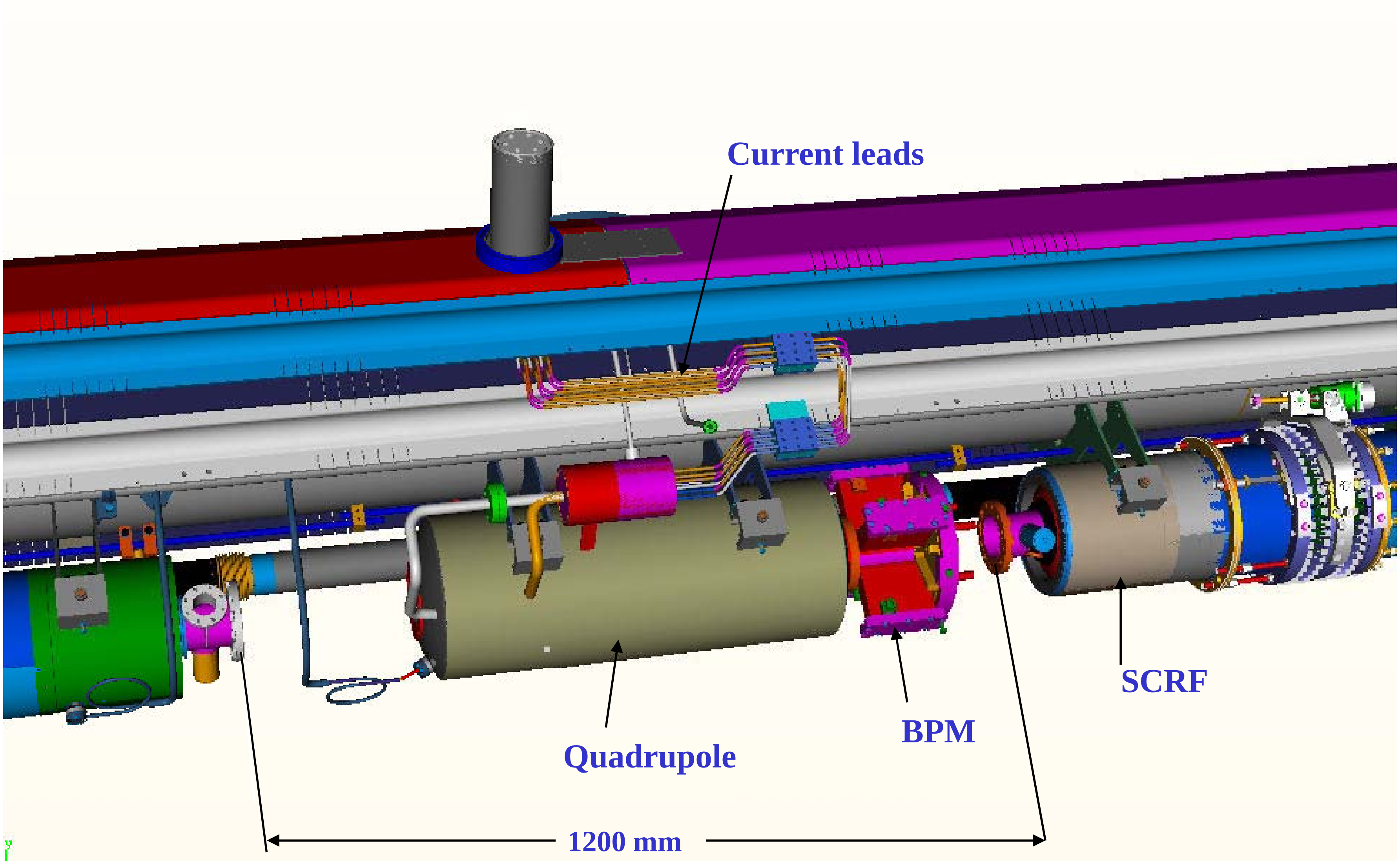
Outline

- Specification
- Quadrupole design
- Magnet fabrication
- Magnetic measurement methods
- Quadrupole test plan
- Summary

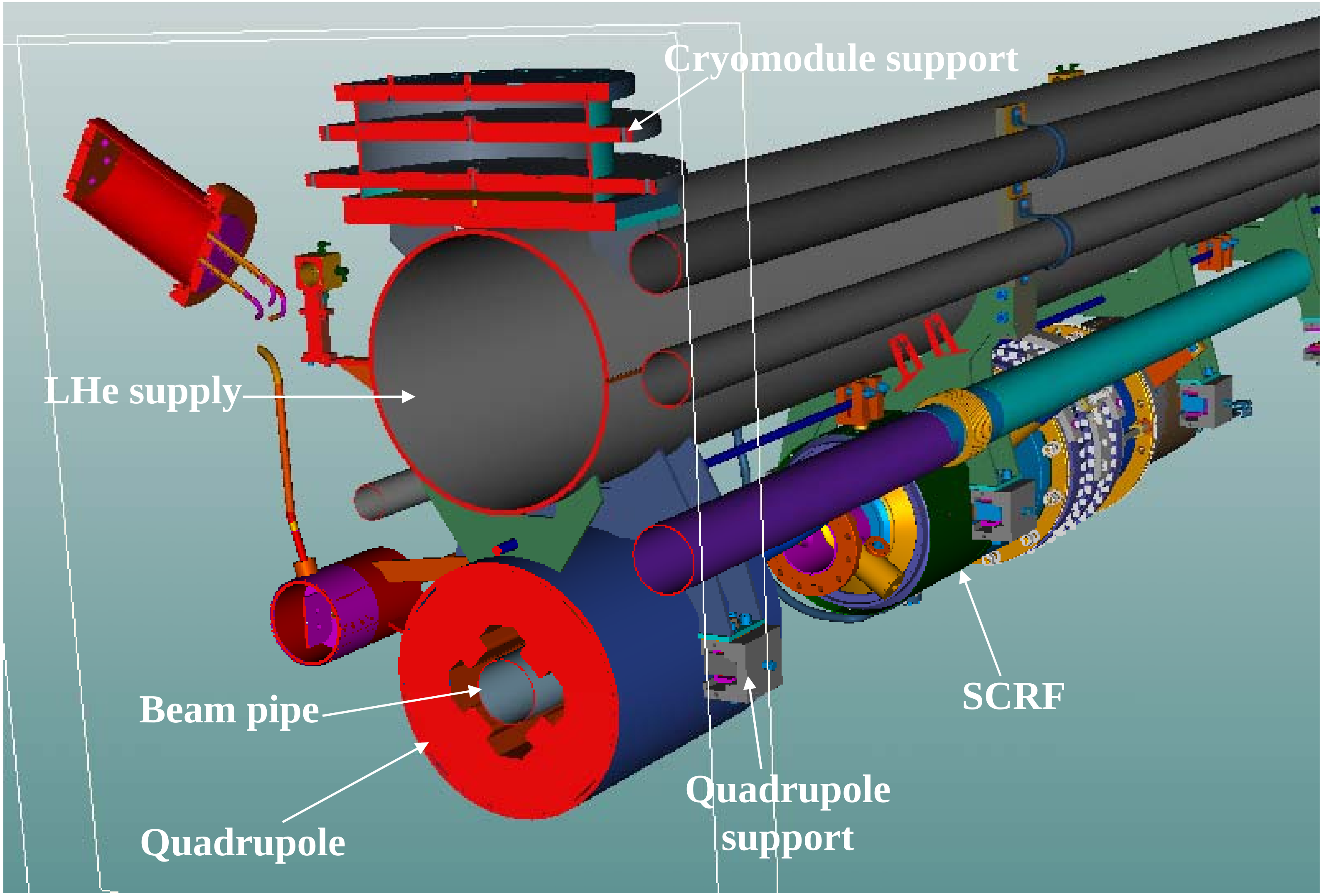
Quadrupole Specification

Integrated gradient, T	36
Aperture, mm	78
Effective length, mm	666
Peak gradient, T/m	54
Field non-linearity at 5 mm radius, %	0.05
Dipole trim coils	Vertical+Horizontal
Trim coils integrated strength, T-m	0.075
Quadrupole strength adjustment for BBA, %	-20
Magnetic center stability at BBA, um	5
Liquid Helium temperature, K	2
Quantity required	560

Main Linac Cryomodule



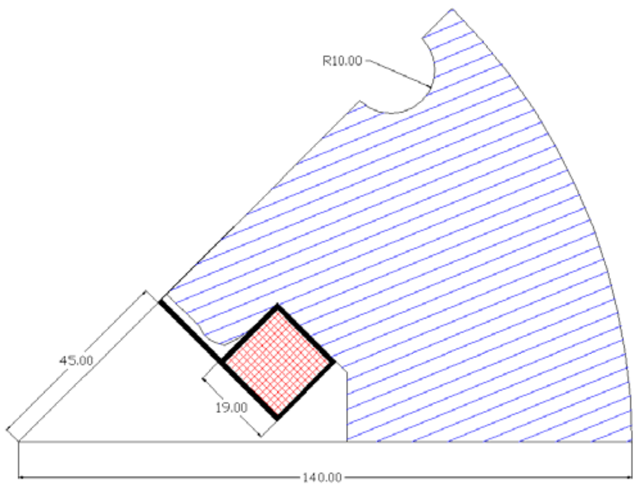
Cryomodule cross-section



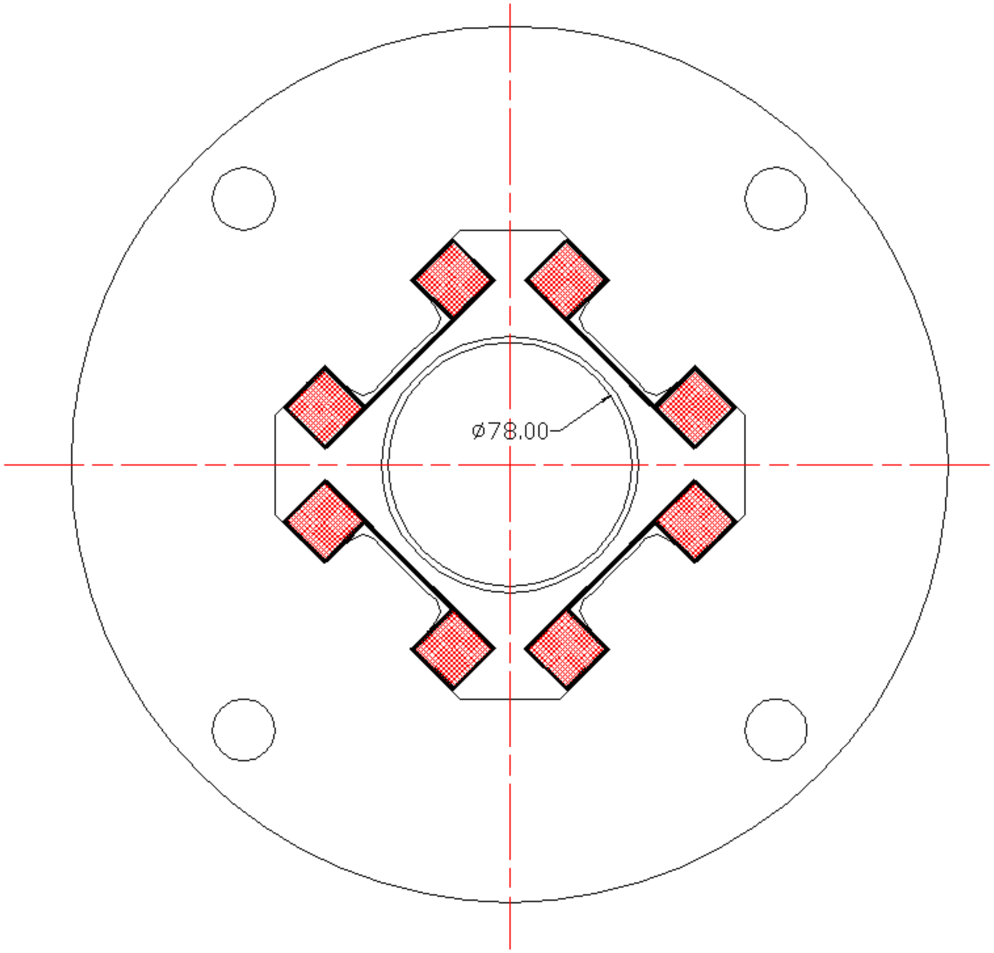
Quadrupole Model Goals

- Check quadrupole concept, magnetic and mechanical design
- Prove fabrication technology
- Measure the magnetic center stability at -20% gradient change with and without dipole shell type coils
- Investigate the acceptable (meet spec.) range of quadrupole integrated strength changes related to different beam energy levels
- Test quench protection system
- Test dipole correctors using trim coils
- Cold mass cost analysis

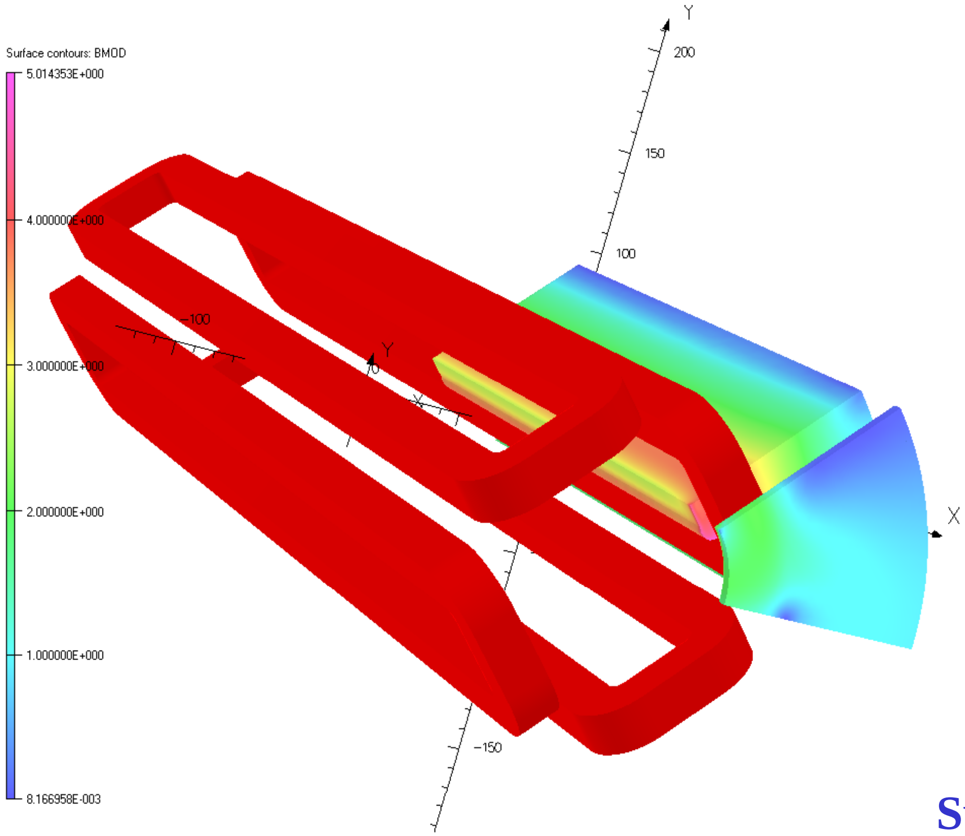
Quadrupole Cross-Section

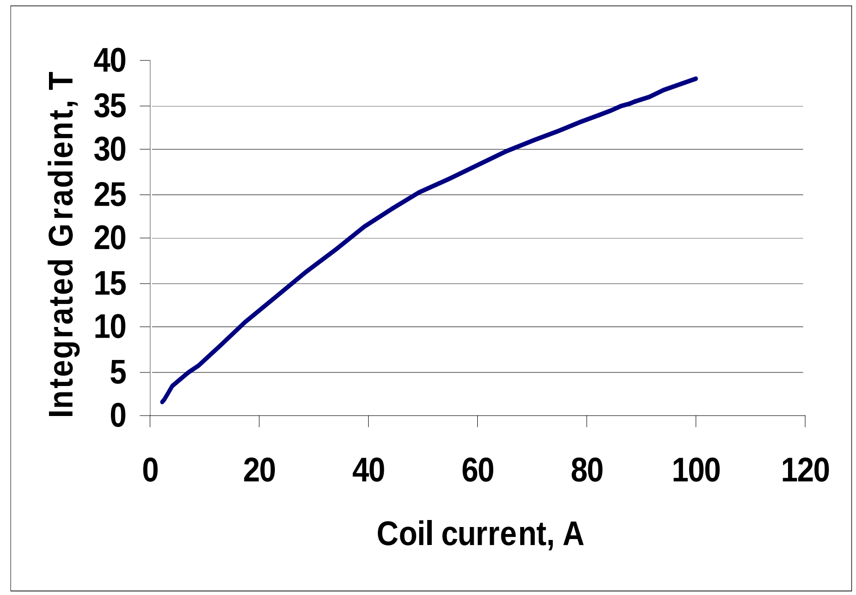


Cold mass diameter	**280 mm**
Cold mass length	**680 mm**
Pole length	**600 mm**
Peak current	**100 A**
Superconductor length	**5 km**
Yoke weight	**250 kg**



3D Quadrupole Magnetic Design

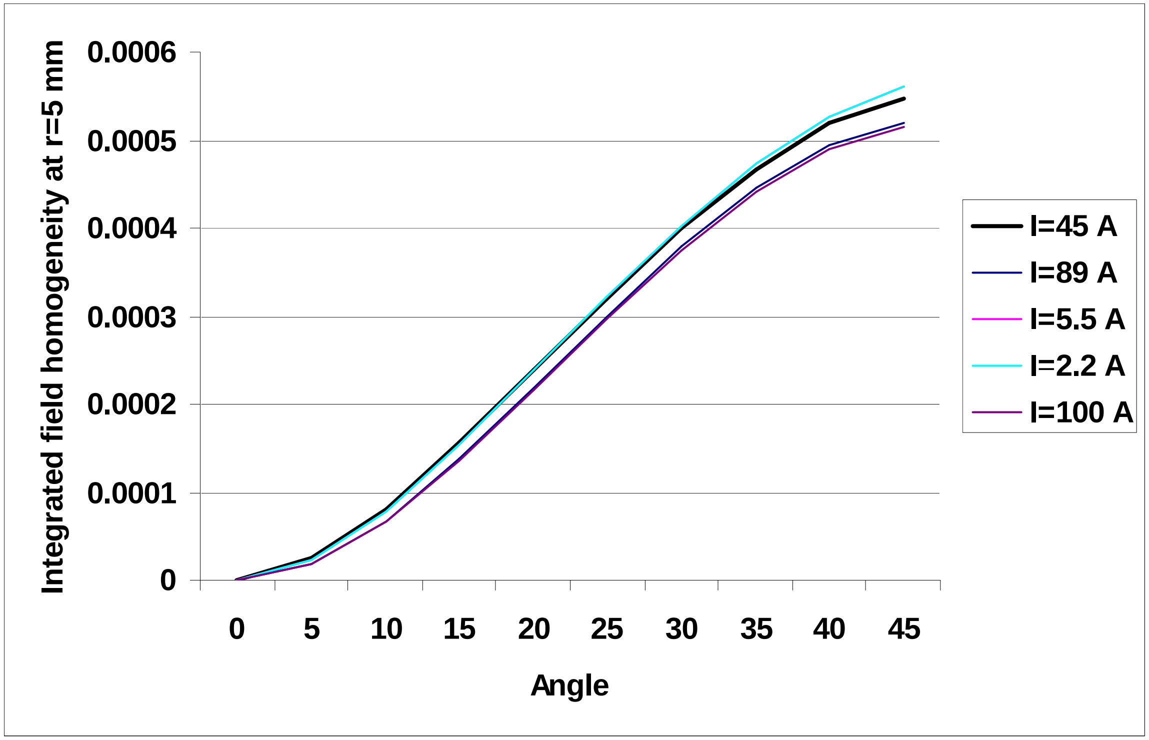




Specified peak integrated gradient 36 T at 93 A of total current/coil

Maximum flux density 5 T at pole ends and 100 A current

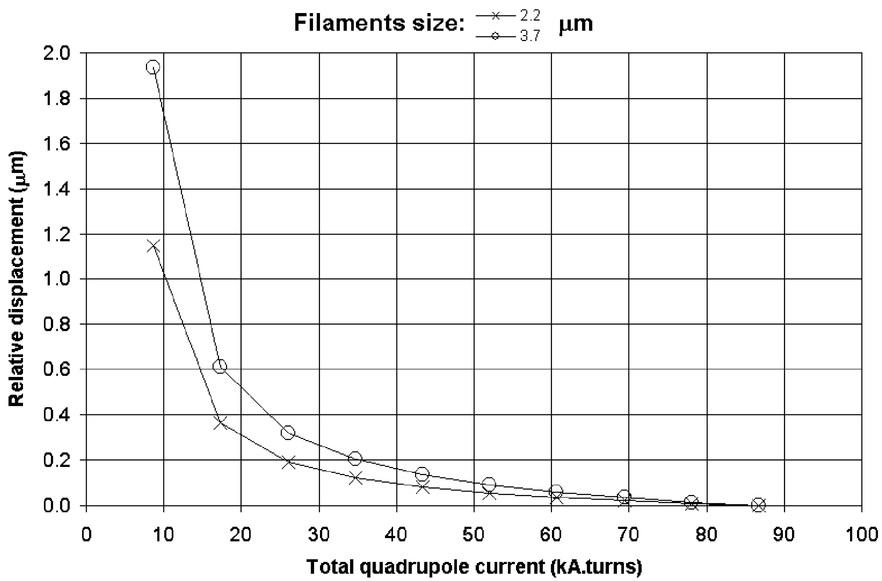
3D Integrated Field Quality

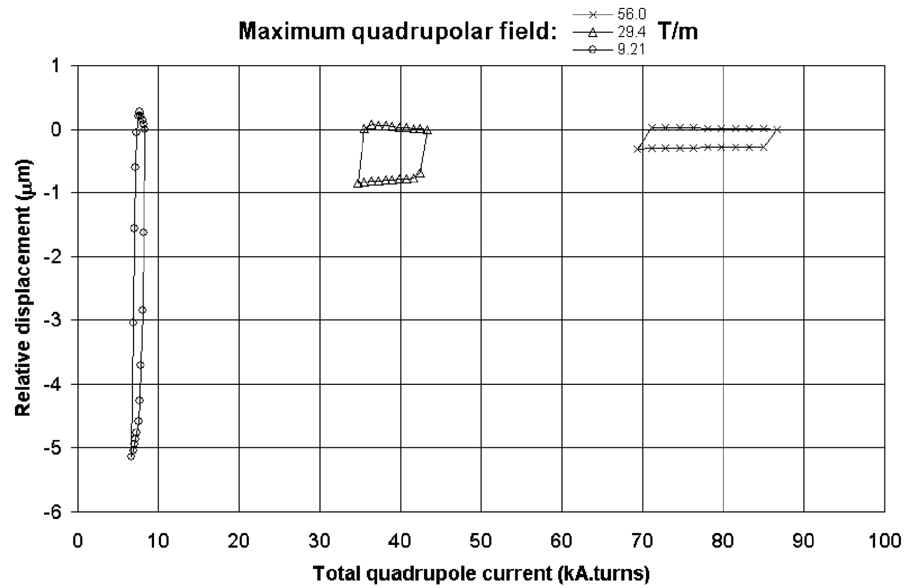


1. There are less than 1 unit changes in integrated field homogeneity at radius 5 mm because of iron saturation effects.

2. Total allowed high order harmonics less than 5.5 units at R=5mm and caused by magnet ends.

Superconductor magnetization effects





Magnetic center displacement at zero shell corrector current

Magnetic center displacement at zero shell corrector current and -20% gradient change

Racetrack corrector has low 2D magnetization effects

3D effects (end effects) should be investigated

Mechanical Stress Analysis

Stainless steel coil support structure

Lorentz forces at 100 A : **Fx=133 kN/m**

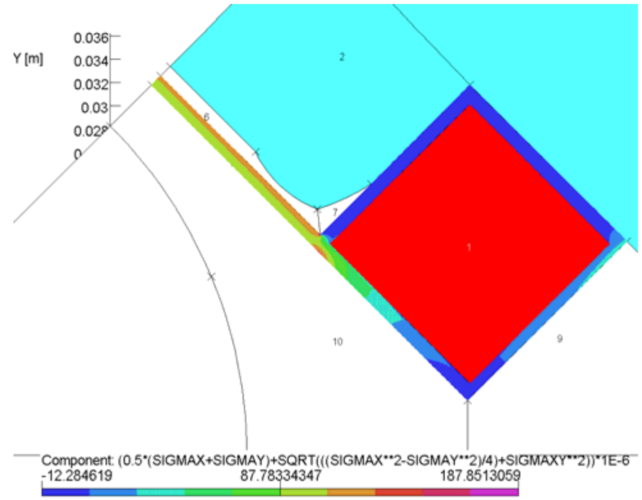
Fy=-34.4 kN/m

Support structure max stress 120 MPa

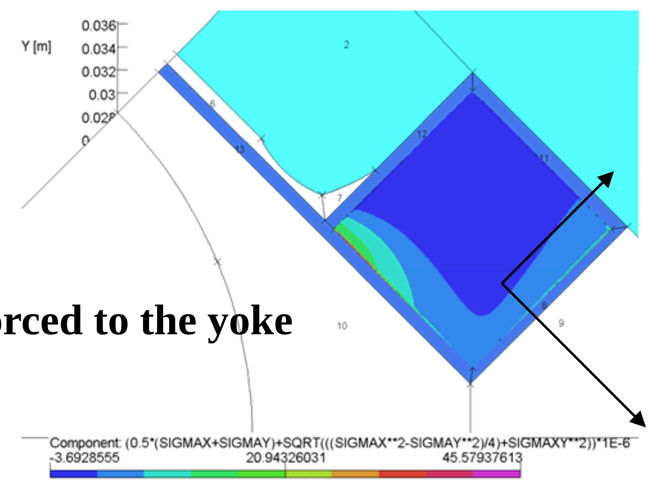
Coil max stress **45 MPa**

Coil displacements **11-19 um**

Coil Young modulus **40 GPa**

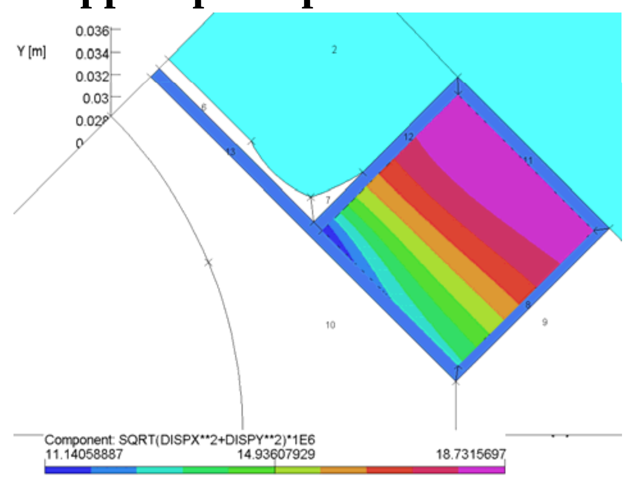


Support principal stresses



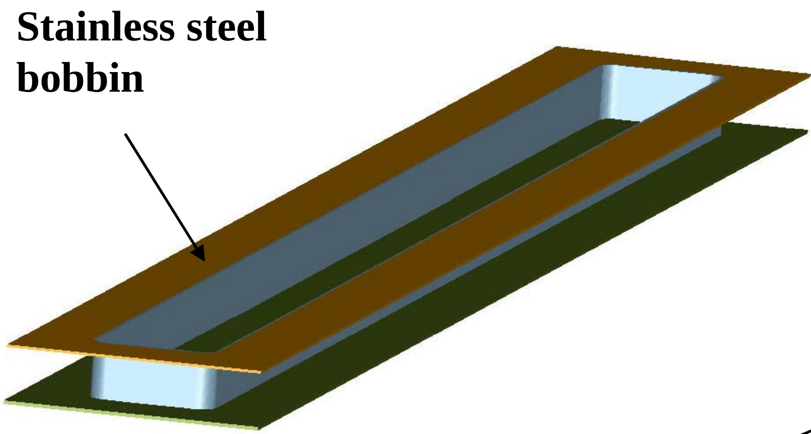
Coil forced to the yoke

Coil principal stresses

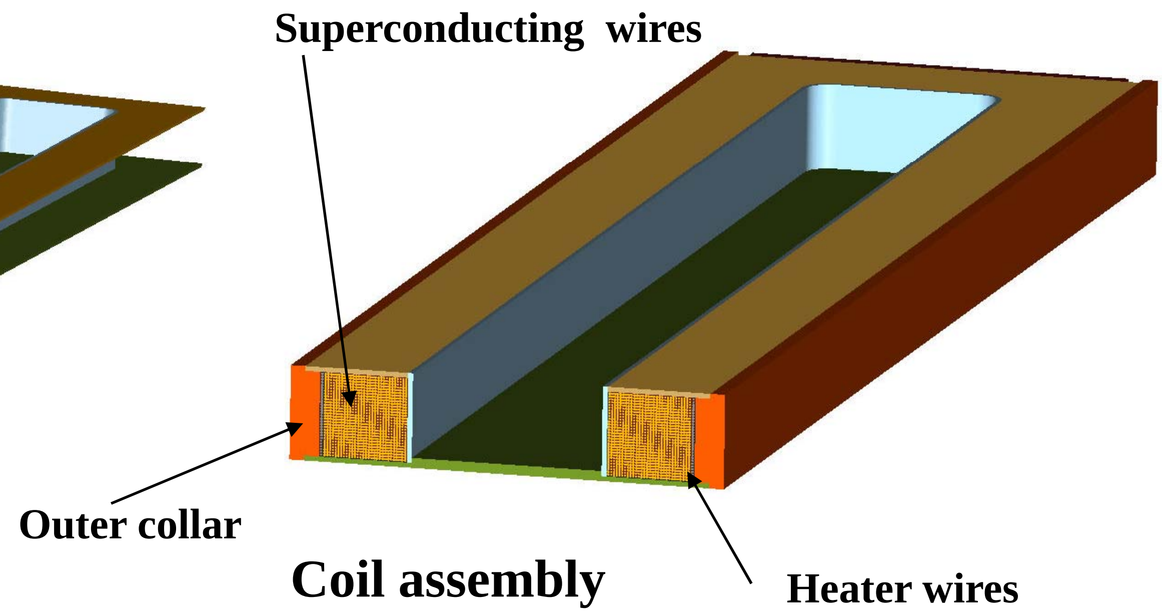


Coil displacements

Quadrupole Coil Design



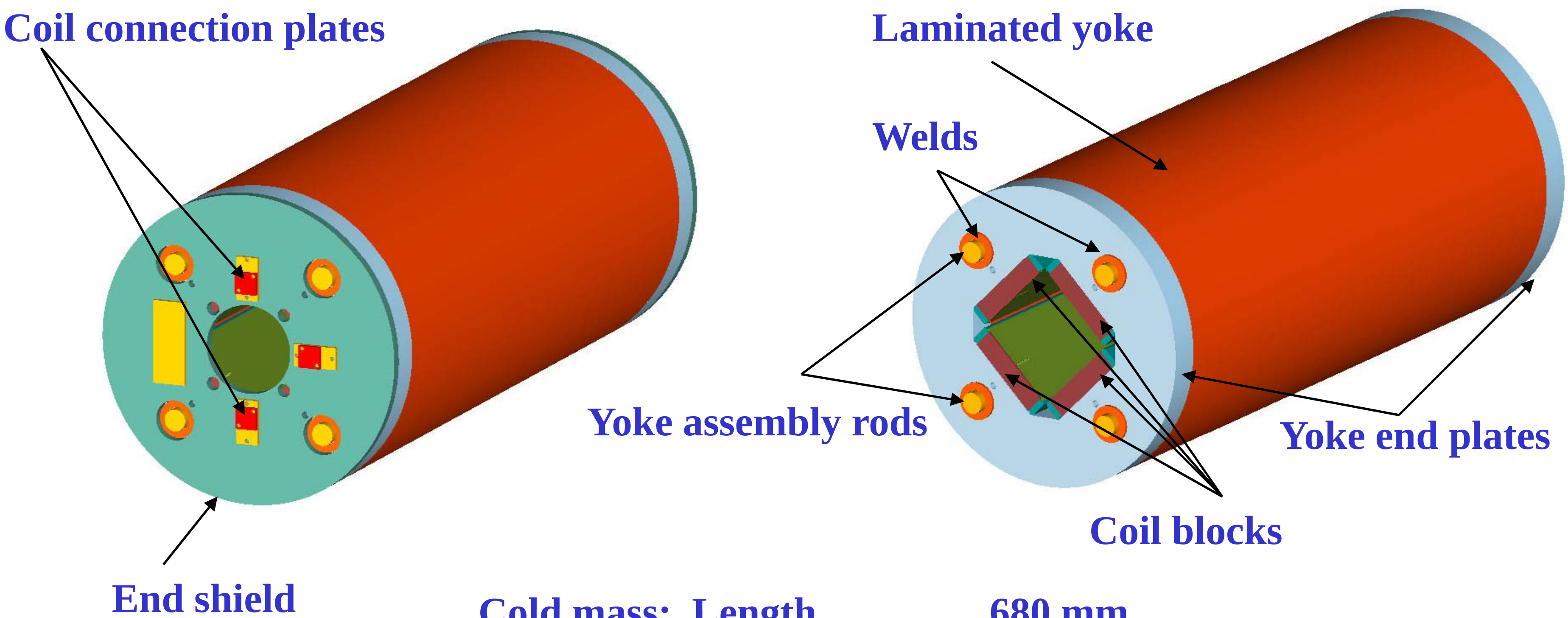
Coil bobbin



Coil assembly

- Coil bobbin used as mandrel for superconducting coil winding
- Kapton film used as ground insulation between bobbin and wires
- Bobbin and outer collar structure forms closed mold for epoxy vacuum impregnation
- Easy assemble coil structure with an iron yoke
- Coil attached to the pole on both ends

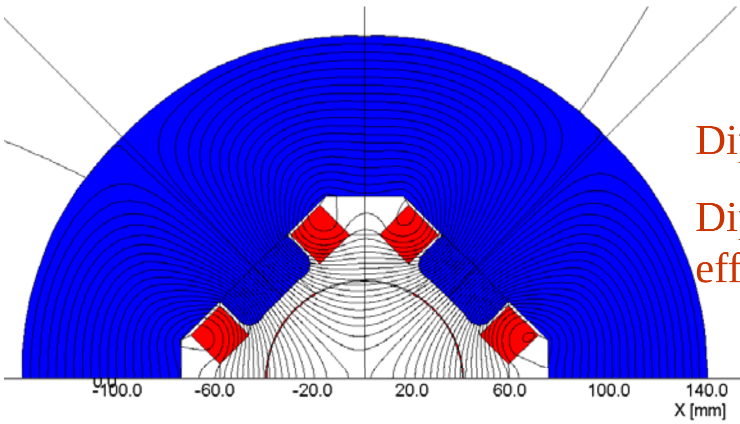
Quadrupole cold mass



Cold mass: Length 680 mm

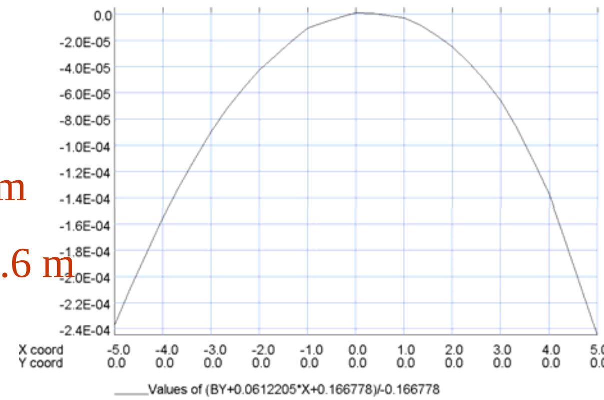
Outer diameter 280 mm

Dipole Correctors



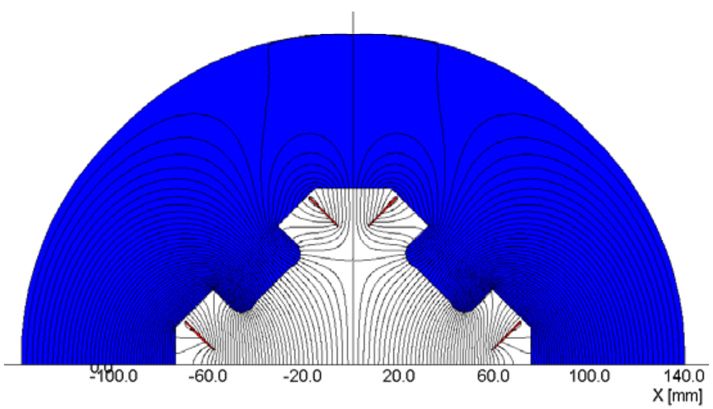
Dipole integrated field 0.075T-m

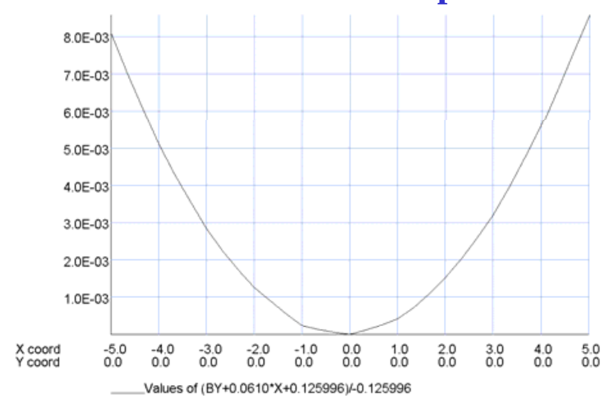
Dipole center field 0.125T at 0.6 m effective length



Shell type dipole field homogeneity at 61 T/m gradient and 0.166 T vertical dipole field

Shell type dipole field homogeneity

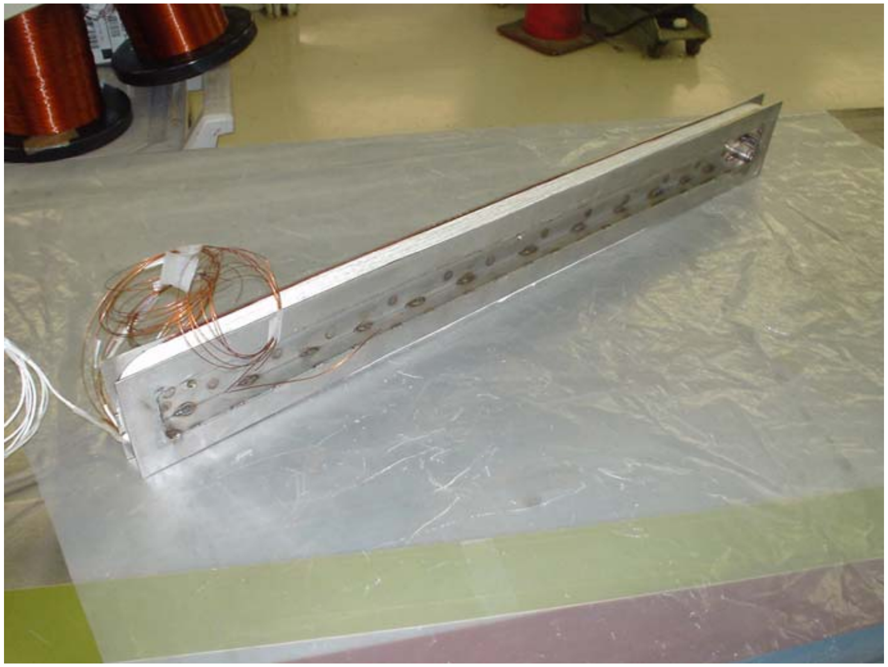




Racetrack type dipole field homogeneity at 61 T/m gradient and 0.125 T vertical dipole field

Racetrack type dipole field at zero quadrupole field

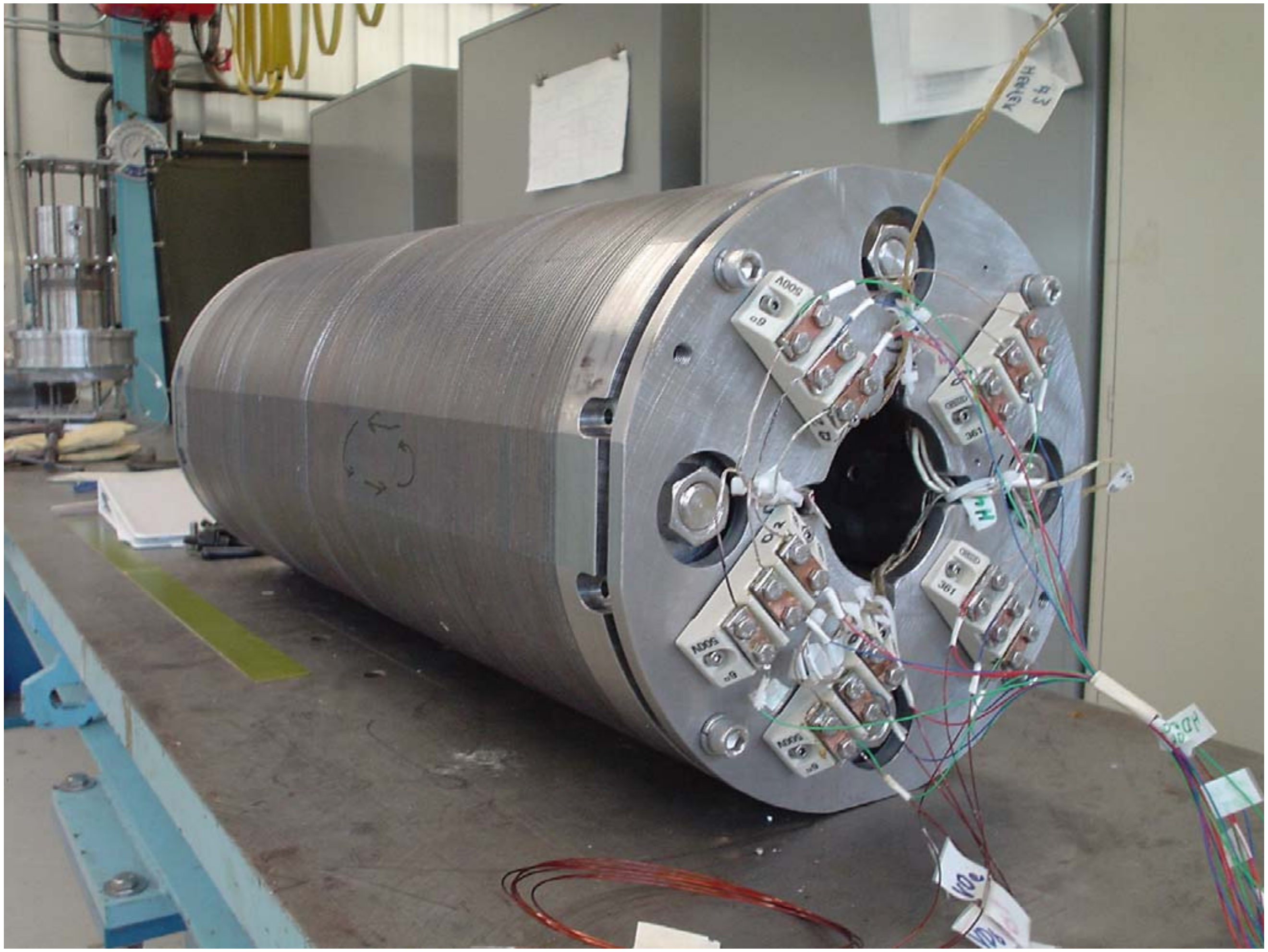
Superconducting coil fabrication



SC Coil after winding

SC Coil after collar welding and epoxy impregnation (ready to install)

ILC Quadrupole Model HGQ01



Quadrupole is ready for the test

Magnet Tests

1. Quadrupole test using FNAL VMTF. Stand upgrade is in progress (new power supplies, electronics, and two pairs of 150 A current leads).
2. Field measurements by rotational coils by G. Velev. All probes and measurement systems exist and used for HFM and LARP program tests.
3. Quadrupole test using AC flat board technique by J. DiMarco. At the moment this new technique was verified during FNAL Booster Correctors measurements at 15 Hz.

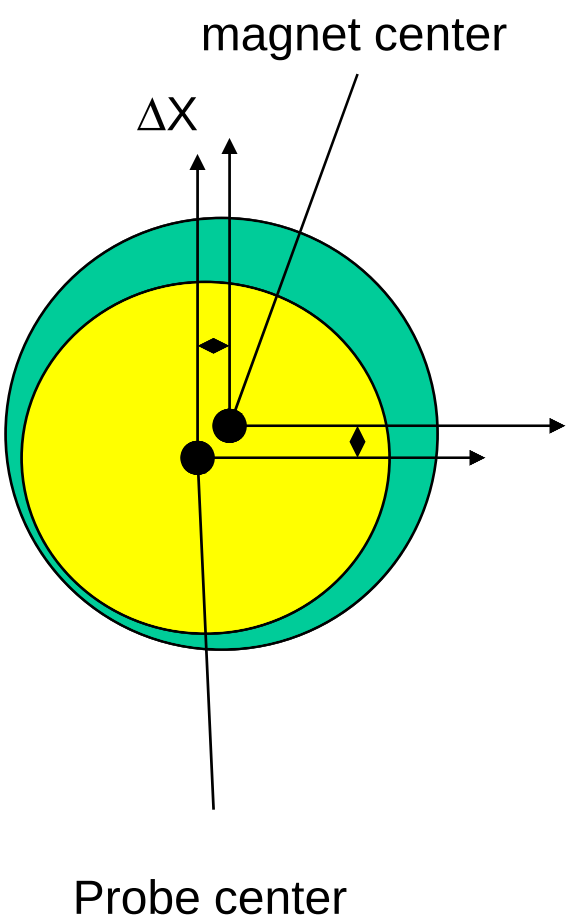
Questions for Magnet Tests

1. Quadrupole magnetic center stability during -20% gradient decrease. Should be measured at different gradient levels in range of gradients of 2-100%.
2. Magnetic center stability as in 1. at different trim coils currents.
3. Long term magnetic center stability at DC current for different field levels.
4. Field quality at 5 mm reference radius for strait section and whole length at different quadrupole and trim coils currents.
5. Fringing field at some distance (~100mm) from magnet end
6. Peak current at quench.
7. Efficiency of quench protection system.
8. Coil maximum temperature after the quench.
9. Quadrupole cooling down time and time recovery after the quench.
10. Effective RRR.
11. Residual magnetic field at zero currents.

Rotational coil measurement, G. Velev

- **In the center of the pure quadrupole field all field harmonics are zero**
- **If we offset ΔX and ΔY from the center, the measurement probe will see a dipole field - a feed down from the quadrupole**
- **Magnetic center shift is equal the change of the dipole magnetic field component**
- **Assuming that probe vibrations produce (random) errors in the quad center measurements and assuming that the dynamic field changes are slow**
  - we can measure the quadrupole center N times
  - determine the mean of the ΔX and ΔY distributions:

$$\delta\ (\text{mean}(\Delta(X,Y))) = \text{sigma}(\Delta(X,Y)/\text{sqrt}(N)$$



Rotation probe measurement tower

Probes, cont.

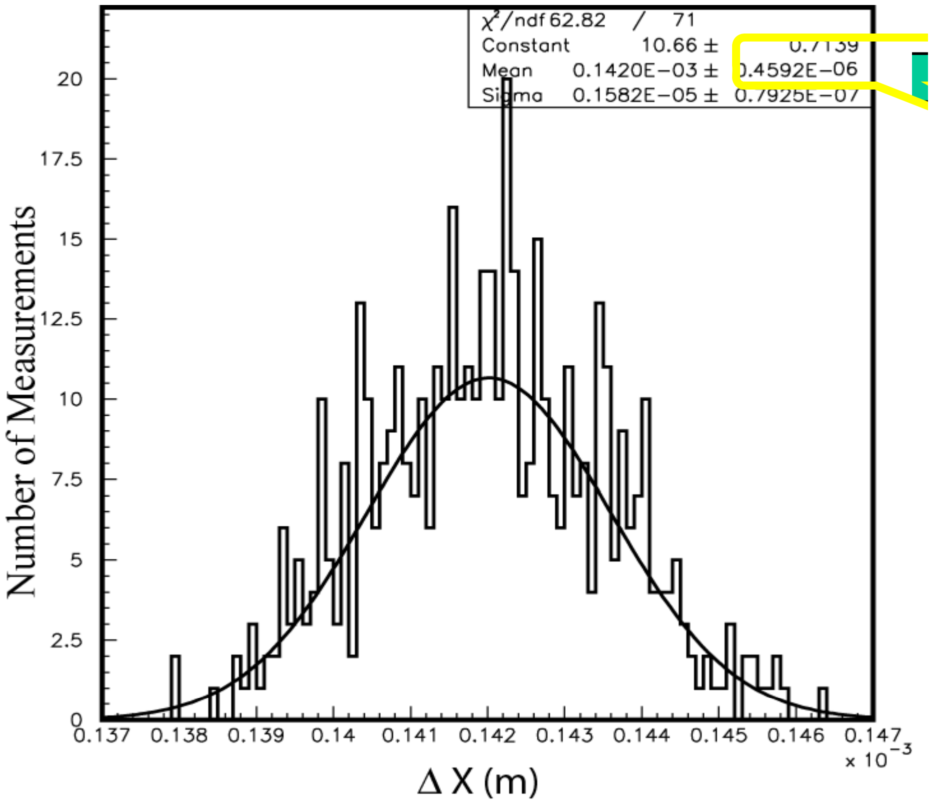
- 1 m long LHC/Tevatron probe of 4 cm diameter
- Best candidate for 67 + 5*7.5 cm end fields cm magnet
- To decrease the vibrations – It might need additional support (Vespel) in several places
- May Need extra calibration

100 cm Tevatron probe,
∅ = 4.0 cm

TQC02 LARP Quadrupole measurements

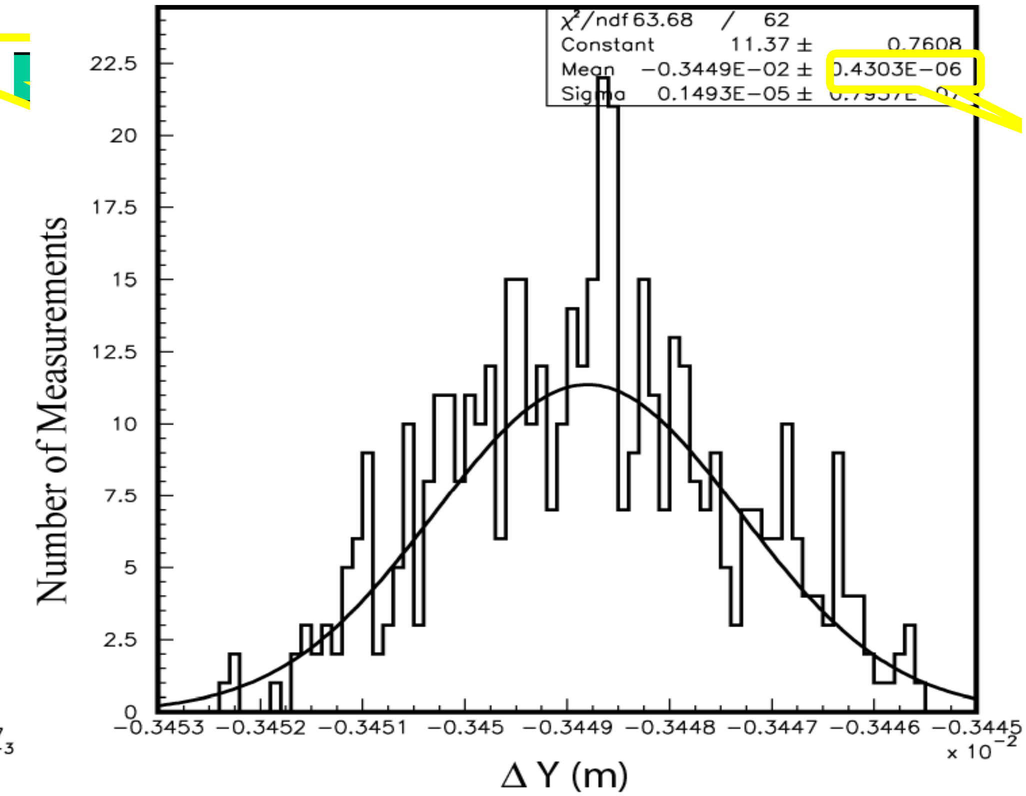
Delta X

Uncertainty
on the mean



Delta Y

Uncertainty
on the mean



Magnetic center position uncertainty 0.5-0.7 micron

Rotational Coil Measurement Summary

- Proposed a method to measure the stability of quadrupole magnetic center for ILC Quadrupole.
- For these measurements was used FNAL standard magnetic measurement equipment, the same exploited in the HFM and LARP programs.
- The preliminary test shows that we can achieve a resolution of 0.5-0.7 μm – only statistical power after accumulating of ~90 s data.
- Systematical uncertainty, due to the measurement system, seems to be not a problem – it is a differential measurement
- Systematical uncertainty which are time dependent were tested on TQC02 – seems not a problem, we can calibrate the system before any measurements

Fixed coil probe measurements, J. DiMarco

- **28 Layer circuit board design**
  1152 turns of 'dipole sensitive' winding
  48 turns of 'quad sensitive' winding
- **Measure quad and dipole change during ramp to determine and monitor center offset of probe wrt magnet.**
- **Used vertically or horizontally**
- **Could attach vibration measurement instrumentation**
- **Mount probe on supports which isolate it from vibrations**
- **Other environmental control (?) (temperatures, …)**

Flat coil sensitivity

- Quadrupole:
  - 0.66m effective length
  - 54 T/m max.
  - 3.2 T/m at front Linac end
- Check center stability during 20% gradient change:
  Most difficult at injection
  → 20% field change is 0.64T/m or 0.64 μT/μm
  For centered probe, expected flux change for 1μm shift is

$$\Delta\phi = \Delta g * \delta * 2 * N_{turns} * L * \overline{D}$$

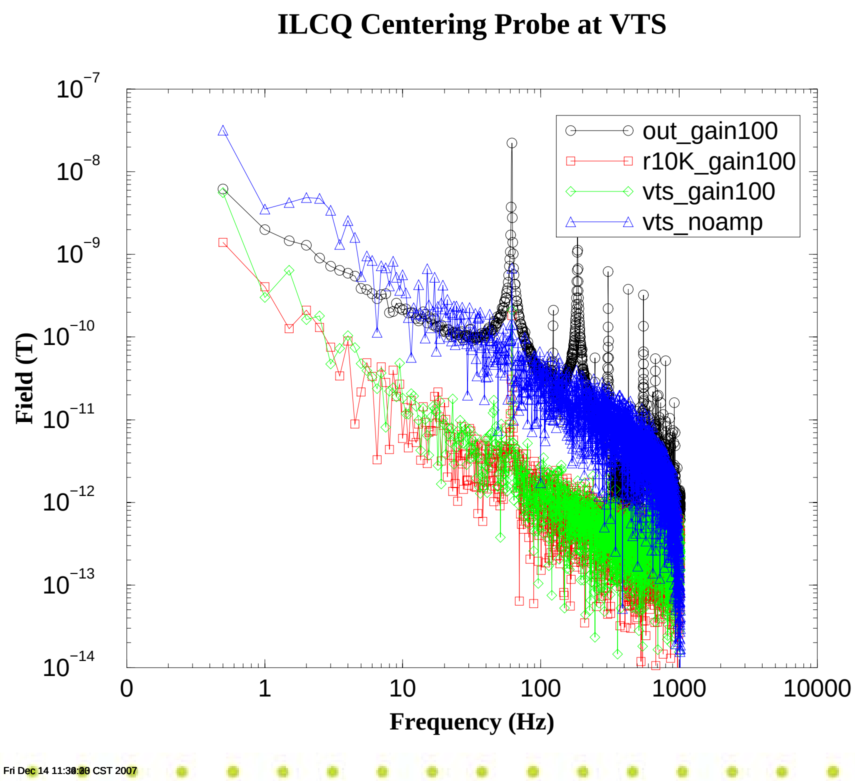
$$= 20 \mu Vs$$

- where g is gradient, δ is the change in offset, L is probe/magnet length, and D is the half-width of the loop (about 0.02m).
- If 20% field change ramp takes 10s (→ 0.064T/m/s) then expected signal is 2μV during ramp.
- Resolution of electronics is about 0.5μV → should be ok.
- Pre-amplifier can be added to input signals if needed.

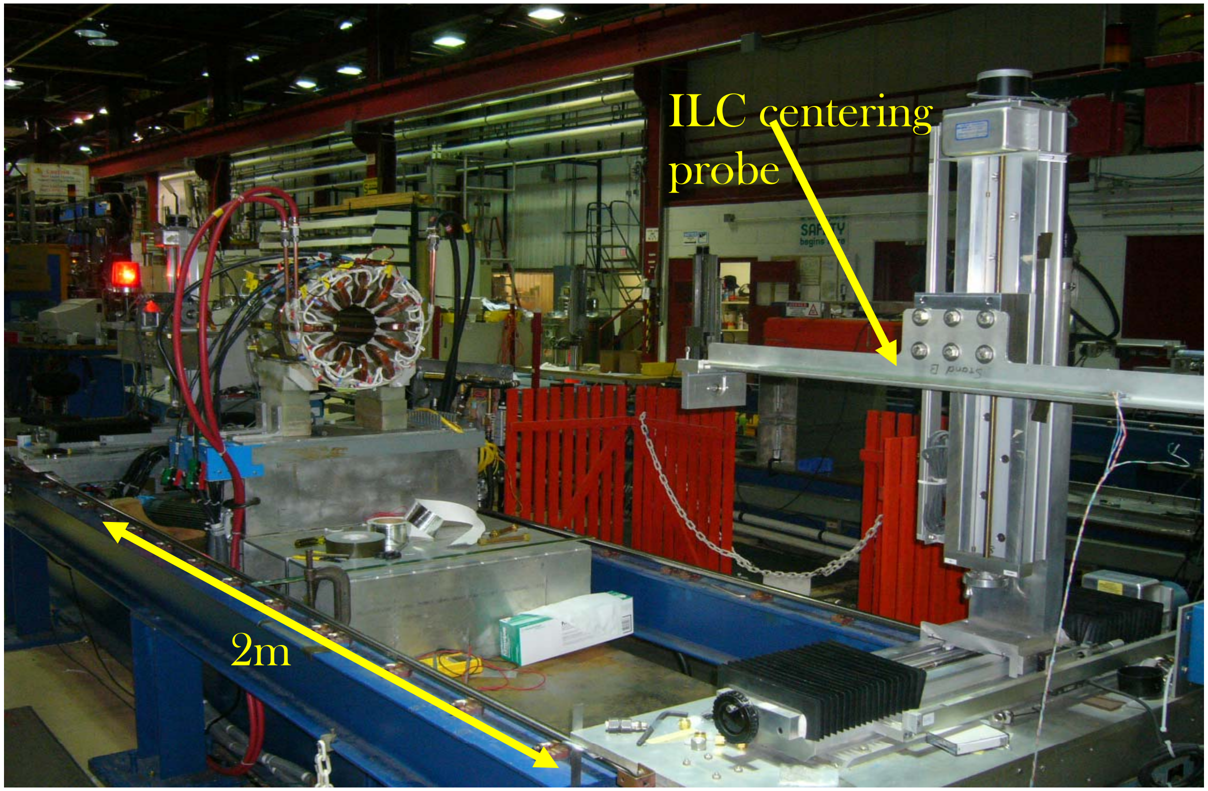
Another look at sensitivity…

- **Probe has been used to study stray fields.**
- **For low frequencies, expect field sensitivity of few* 0.1μT (see plot below)**

→ Should be able to resolve at the level of 1μm (since expect <u>0.64 μT/μm)</u>



Stray Field Test with ILCQ Centering Probe



Used the multi-turn fixed coil for these measurements Tested the centering probe sensitivity to stray fields by placing it 2m outside the 0.1T-m/m fringe field of the Booster corrector magnet. Measured fields seen on probe with 50A DC on magnet, 15Hz AC cycle on magnet

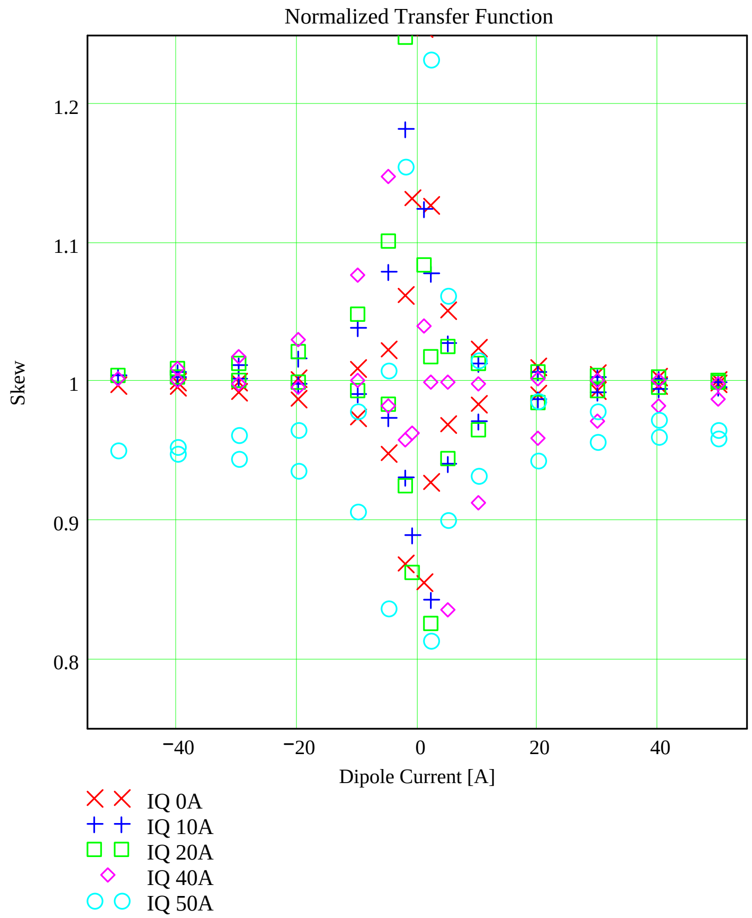
Probe for HGQ01 measurements

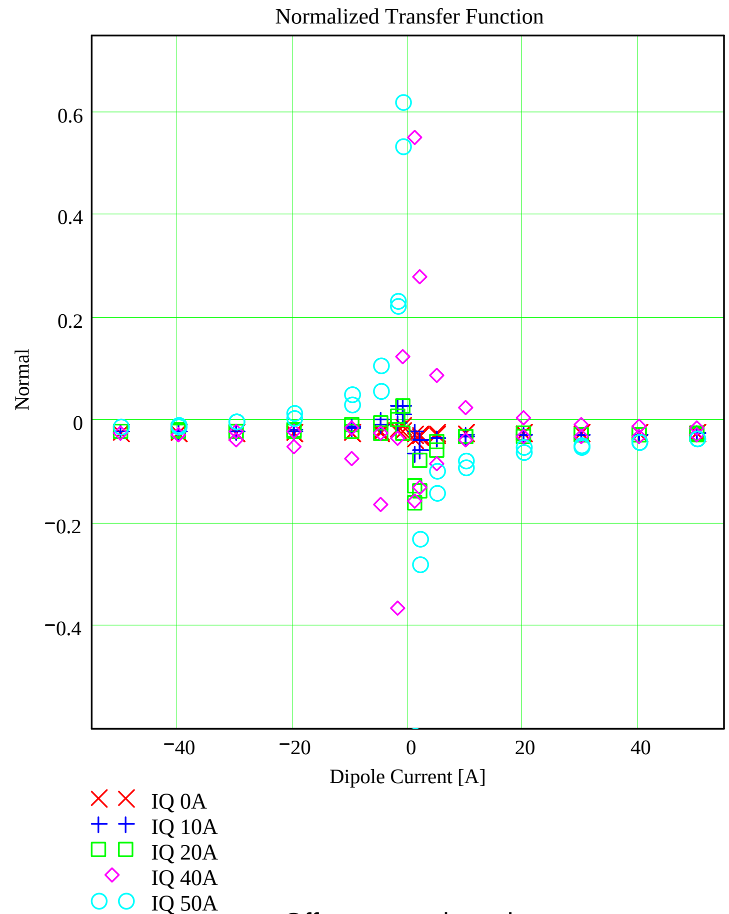
Quad centering probe ready to be inserted into VMTF (with “safety harness” attached)

Summary

- The first FNAL ILC Main Linac Quadrupole is ready for tests
- The VMTF Test Stand upgrade is in progress
- The rotational probe measurement system tested and showed 0.5-0.7 micron accuracy of quadrupole magnetic center measurement
- The flat board technique is tested and showed good AC fields measurement results
- The magnet test is scheduled for the summer of 2008

XFEL Quadrupole test results, news from T. Fernando, CIEMAT



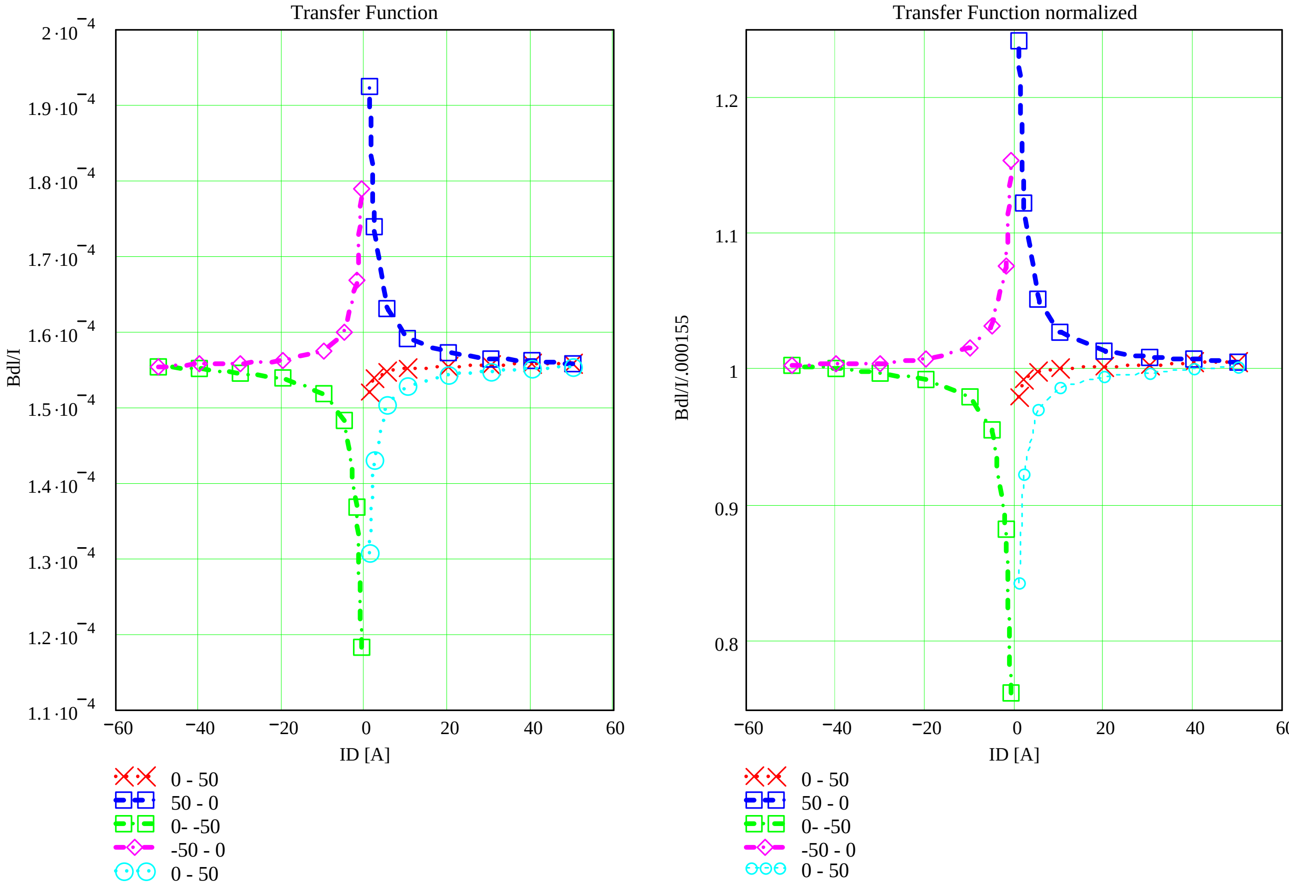


Dipole at various quadrupole currents at 4.3K

Offset corrections done
At IQ 50A saturation , ~3% seen also in dipole strength
At lower ID large effects show up in
strength
angle (skew/normal)

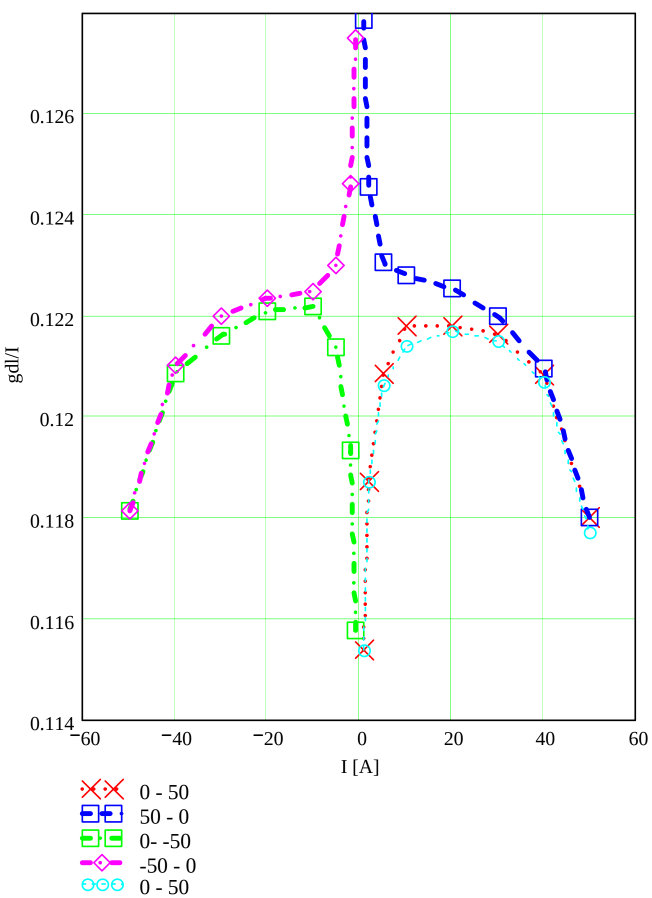
Dipole, Quadrupole off

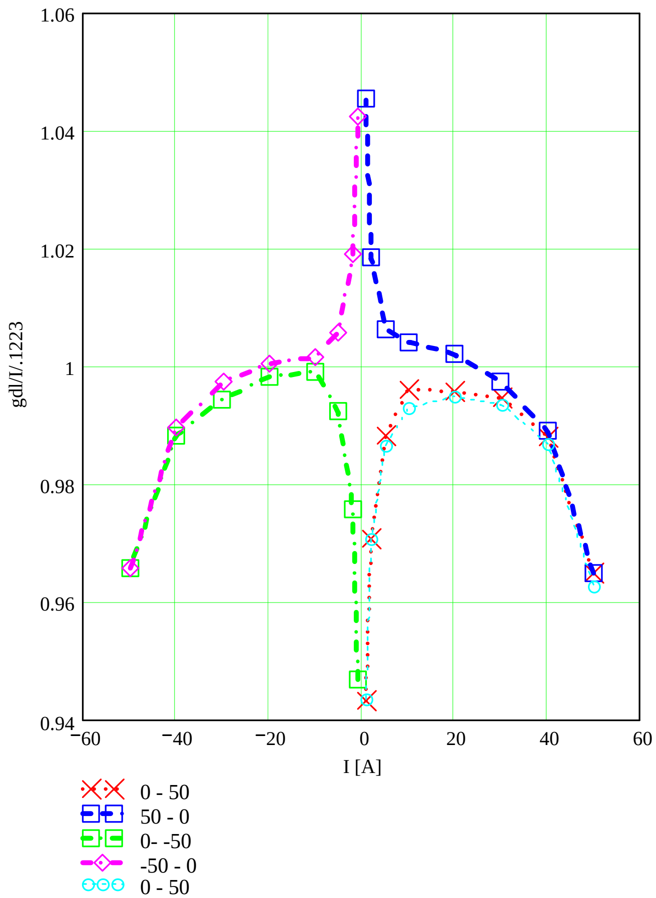
fname = "HH_10052007_1242"



Quad Cold 4.2K after Massage

fname = "HH_10052007_0949"





Massage:

Quad 0 - 50

D1, D2 0 - 50

D1, D2 50 - 0

Quad 50 - 0

Quad 0 - -50

D1, D2 0 - -50

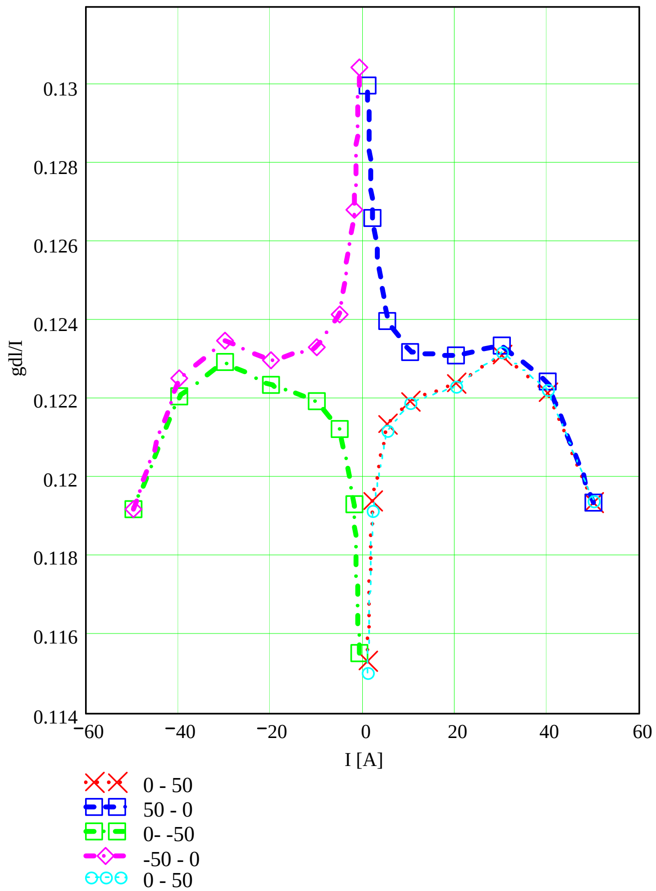
D1, D2 -50 - 0

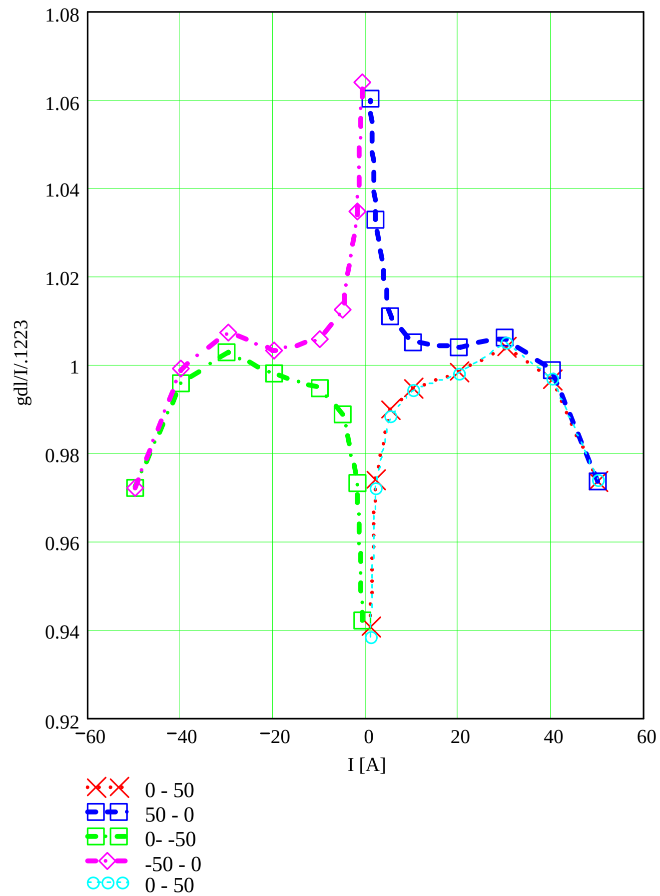
Quad -50 - 0

No absolute calibration!!

Quad Cold 2K after Massage

fname = "HH_11052007_1137"





Massage:

Quad 0 - 50

D1, D2 0 - 50

D1, D2 50 - 0

Quad 50 - 0

Quad 0 - -50

D1, D2 0 - -50

D1, D2 -50 - 0

Quad -50 - 0

No absolute calibration!!