FCC-ee conceptual layout of a HTS superferric combined function quadrupole and sextupole magnet

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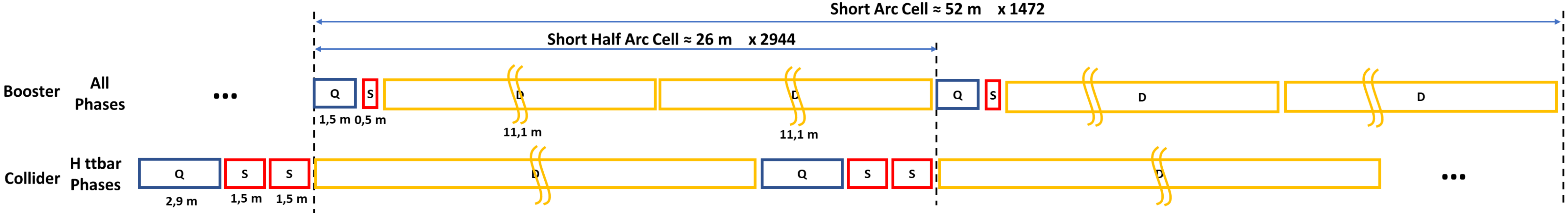
FCC-ee Lattice:



Regular arc half-cell layout

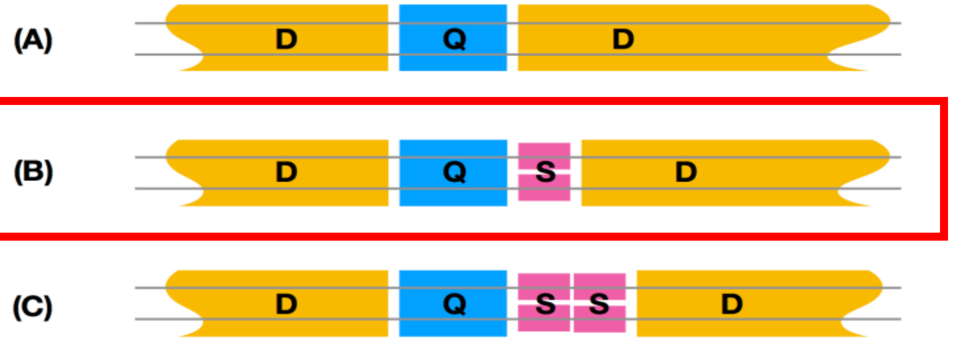
F. Carra & Arc half-cell WG

CDR: 2900 quads & 4700 sextupoles

Normal conducting, ~50 MW @ ttbar

3 different types of short straight sections

CDR arc lattice

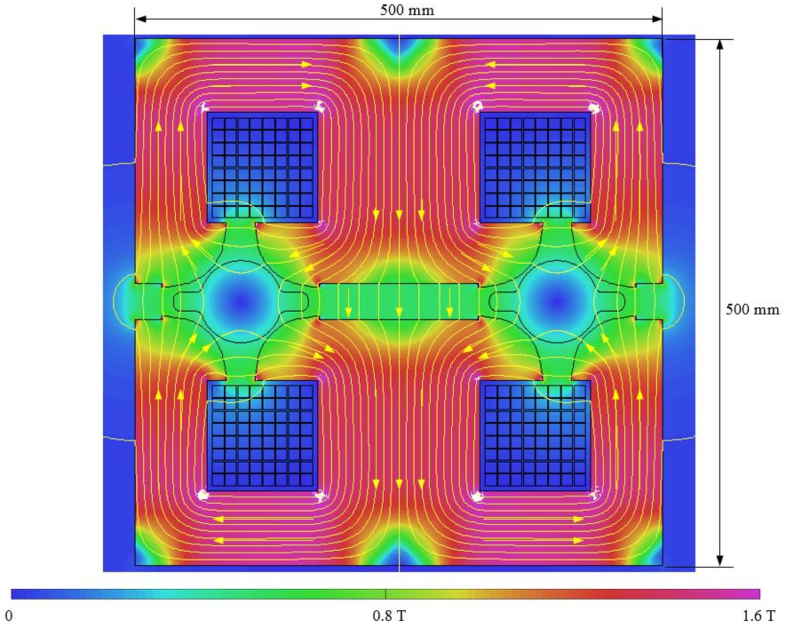


	Mag. Length [m]	Bore aperture (reduced) [mm]	Vacuum aperture (reduced) [mm]	Pole tip field [T]	Number of units (arcs)	Total magnetic length [km]	Ring filling factor (91 km) [%]
Dipole (S)	19.30				1128	21.77	
Dipole (M)	20.95	**37**	**30**	**0.061**	284	5.95	
Dipole (L)	22.65				1428	32.35	
Total					**2840**	**60.1**	**65.9**
Quadrupole	**2.9**	**37**	**30**	**0.438**	**2836**	**8.2**	**9.0**
Sextupole	**1.5**	**33**	**30**	**0.442**	**4672**	**7.0**	**7.7**

Arc magnet specifications from optics – May 2023 (K. Oide)

Resistive Sextupole and Quadrupole Design:

Quadrupole



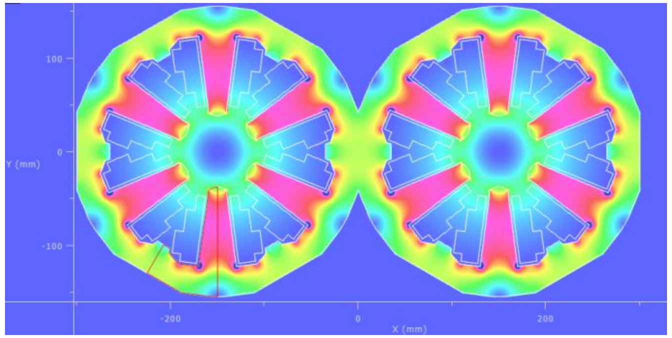
10 T design (CDR)

Element	Magnetic component		Baseline Fields	
	Dipole	Quad	Dipole [T]	Quad [T/m]
Mian Dipoles	B1	- - -	0.0612	- - -
Quad F	Bf	QF	- - -	11.860
Quad D	B1	QD	- - -	-11.860

$t\bar{t}$

Via EPFL (Leon Van Riesen-Haupt , Cristobal Garcia) through PSI

Sextupole



Magnets for FCC-ee, J. Bauche et al.

Parameter	Unit	Value
Sextupole strength	T/m2	**880**
Current	A	**4250**
Number of turns per coil	-	14
Operation current	A	304
Conductor dimensions	mm^2	**8.5×8.5**
Cooling diameter	mm	4
Current density	A/mm^2	**5.1**
Voltage drop per magnet	V	23.4
Resistance per magnet	mΩ	78
Power per magnet	kW	**7.2**
Number of water circuits	-	**6**
Water temperature rise	°C	13.2
Cooling water speed	m/s	1.8
Pressure drop	bar	6
Reynolds no.	-	3530

WHY HTS Magnet?

Superconducting Magnet

- Increase Dipole Filling Factor, lower energy dispersion hence reducing the RF power consumption, can lead to an increased beam intensity
- Optics Flexibility

Higher Operating temperatures (20-50 K)

- Reduction of power consumption wtr LTS
- No need of LHe (cost reduction)

Parallel Synergies

- Detector Magnets
- Nuclear Fusion
- Medical Facilities

WHY Superferric Magnet?

Iron Dominated Magnet

- Well Know design, like a resistive magnet
- Better control on the field quality
- No need of complicated geometries for the coils, HTS materials are fragile.
- Small amount of HTS (lower material costs)

Combined Magnet

- Low number of power supplier
- Reduce total number of magnets

MAIN GOAL of the proposal:

Combined Sextupole and Quadrupole Superferric HTS magnet

LASA-proposal:

Requirements:

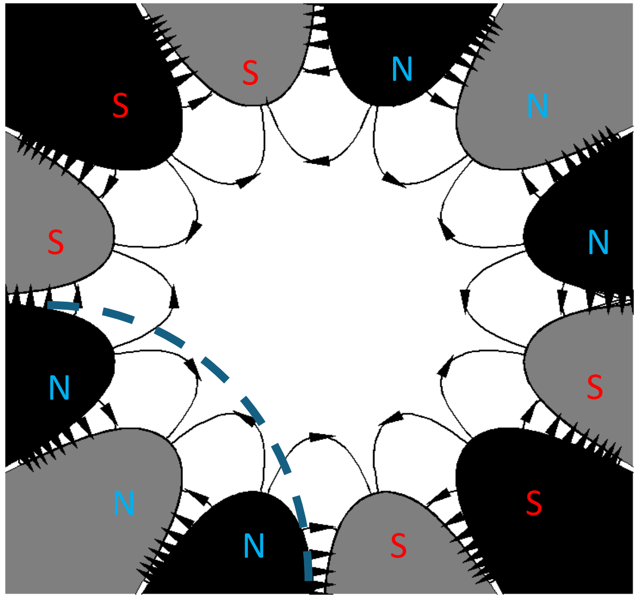
- Independent Quadrupole and Sextupole, have to work only as either a quadrupole or sextupole
- Minimum number of power supplier to lower energy consumption
- High field quality in the bore @Rref = 10mm
- Bore Dimension : 35 mm
- Quadrupole can not be shorter due to quadrupole synchrotron radiation (Open Challenge)

Solution:

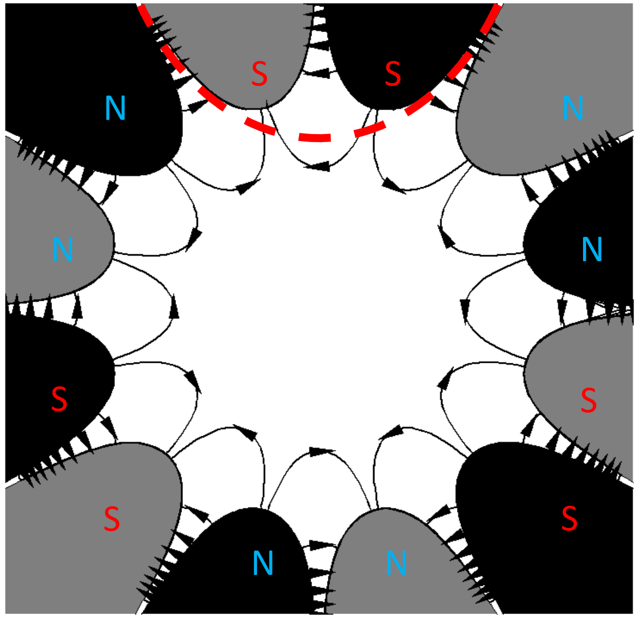
- Dodecapole iron structure
- Two Independent power supplier

Property	**CDR**	**LASA - HTS**
Magnetic Length	2.9 + 1.5	2.9
Max Quad Gradient [T/m]	11.86	11.86
Max Sextupole Strength [T/m^2]	880	455
Integrated Sextupole Field [T m]	0.132	0.13195

From Andrzej Wolski, CAS



Quadrupole configuration

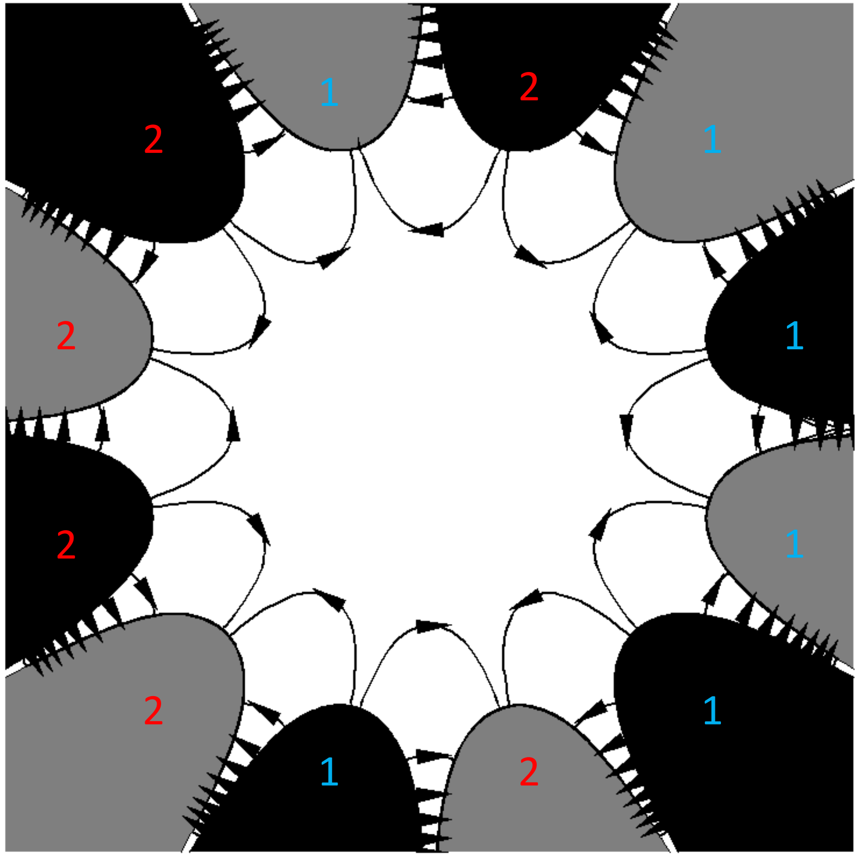


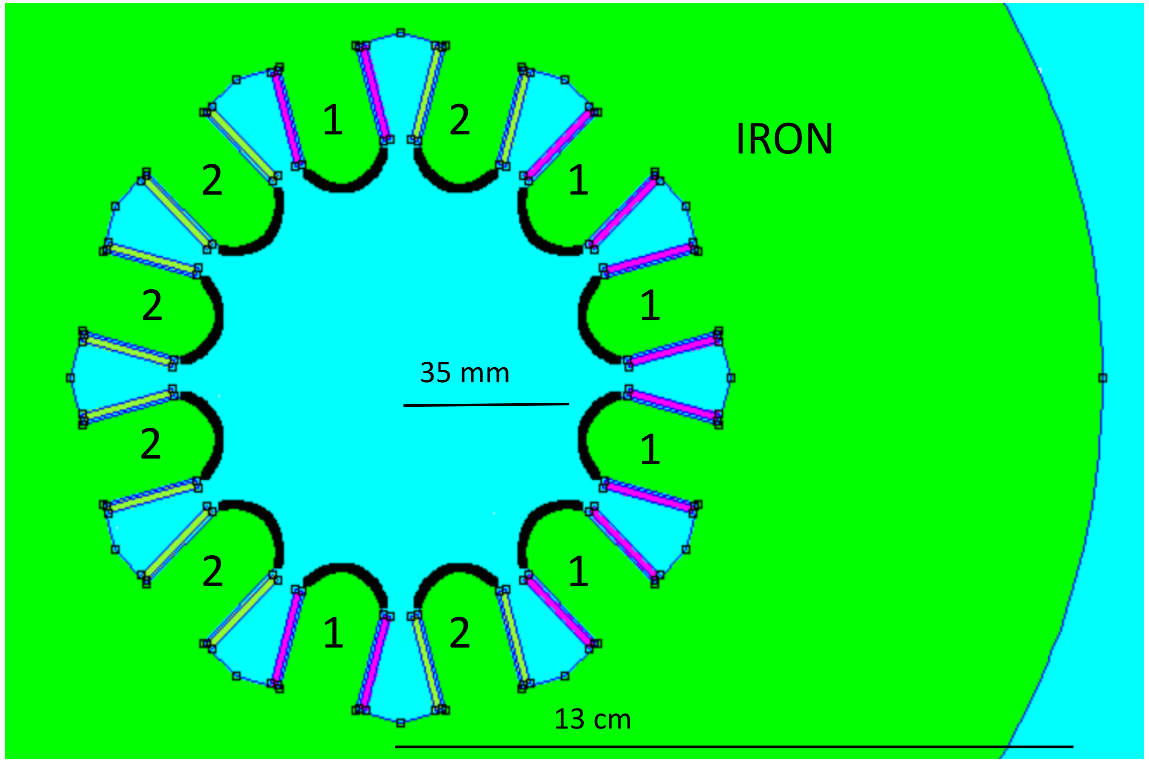
Sextupole configuration

Coil Configuration

- Use 2 different power supply, one for group 1 and one for group 2.
- Be able to obtain, only quadrupole, only sextupole or both, depending on the current given by the two generators.

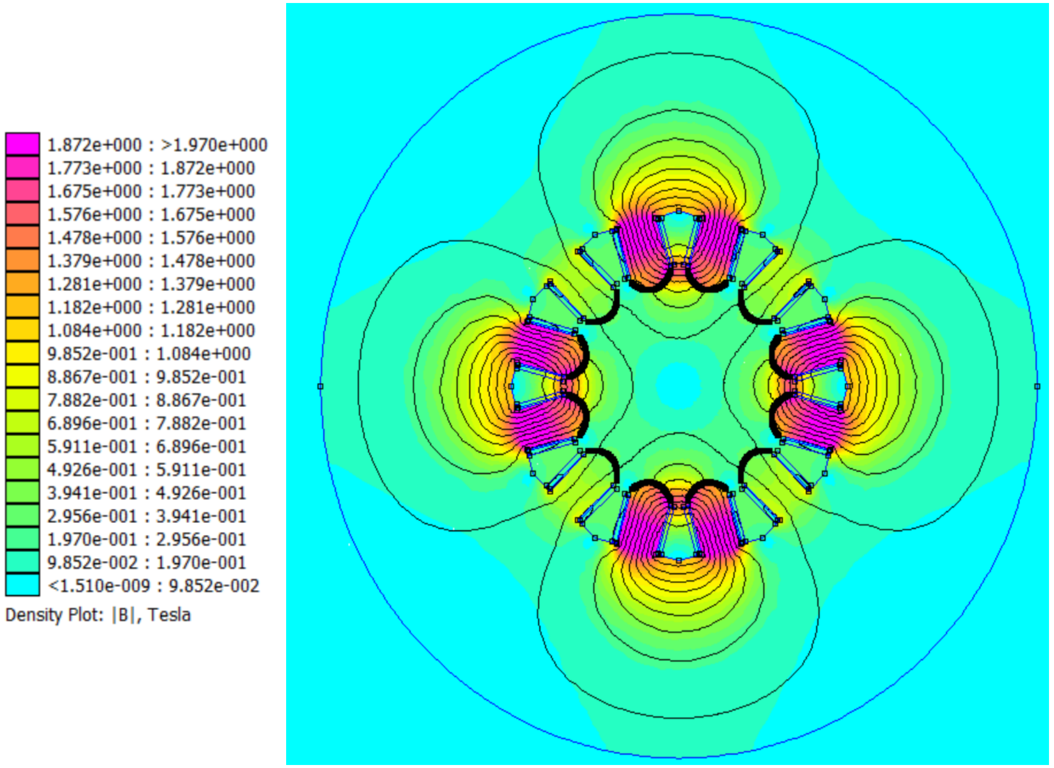
Parameter	Value
Radius of the bore (r0) [mm]	35
Radius of cut for the iron pole (rc) [mm]	41
N° of 4 mm tapes per coil	20
Tape bending radius [mm]	9
Total tape length per coil [m]	117





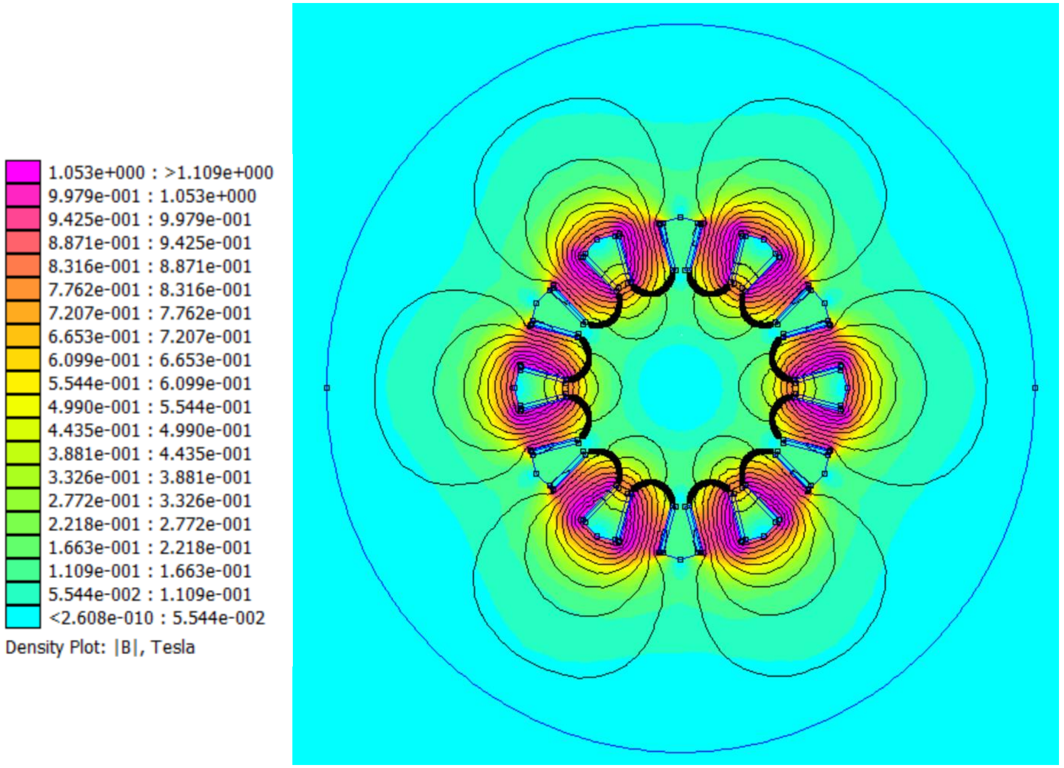
Single Mode

Quadrupole Configuration



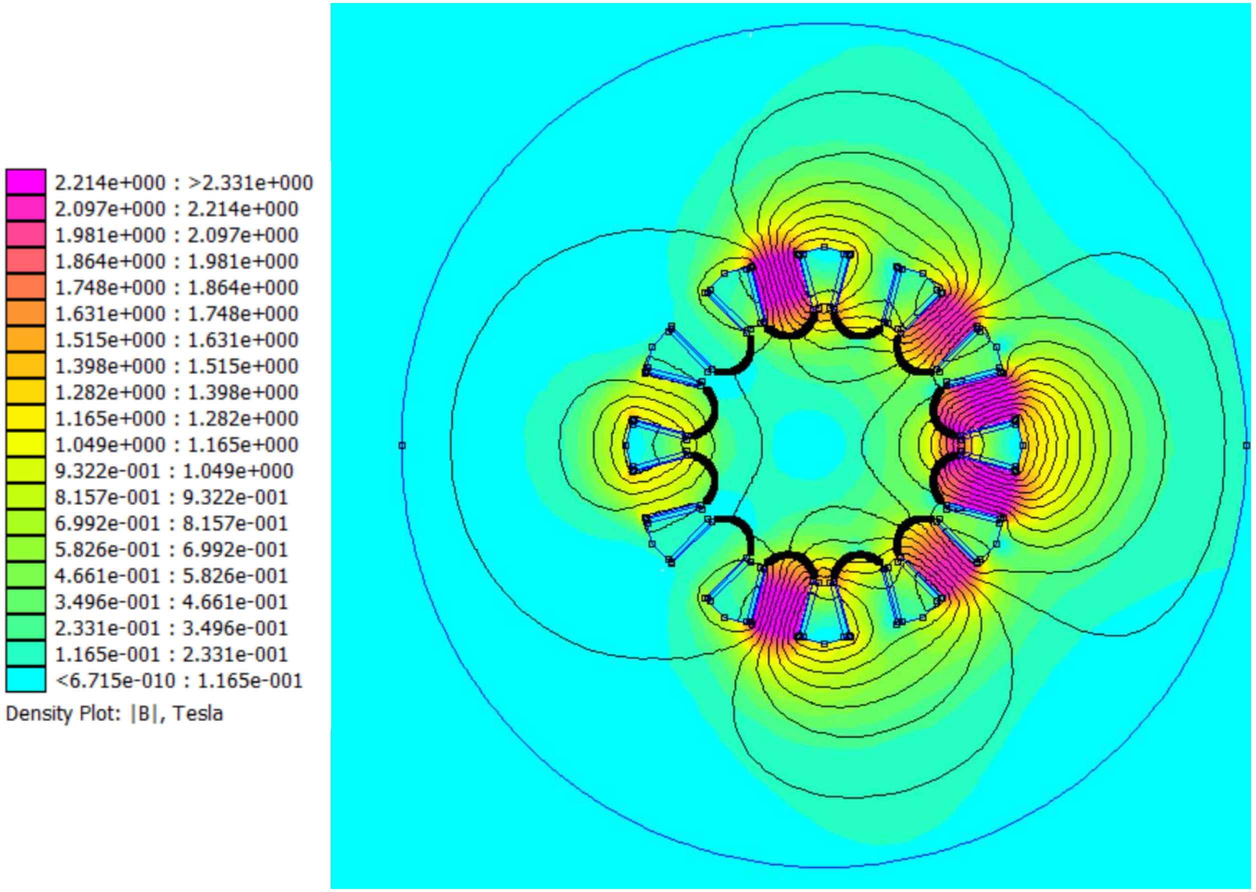
Peak Field on the tape: 1.84 T
Current in each tape: 257 A

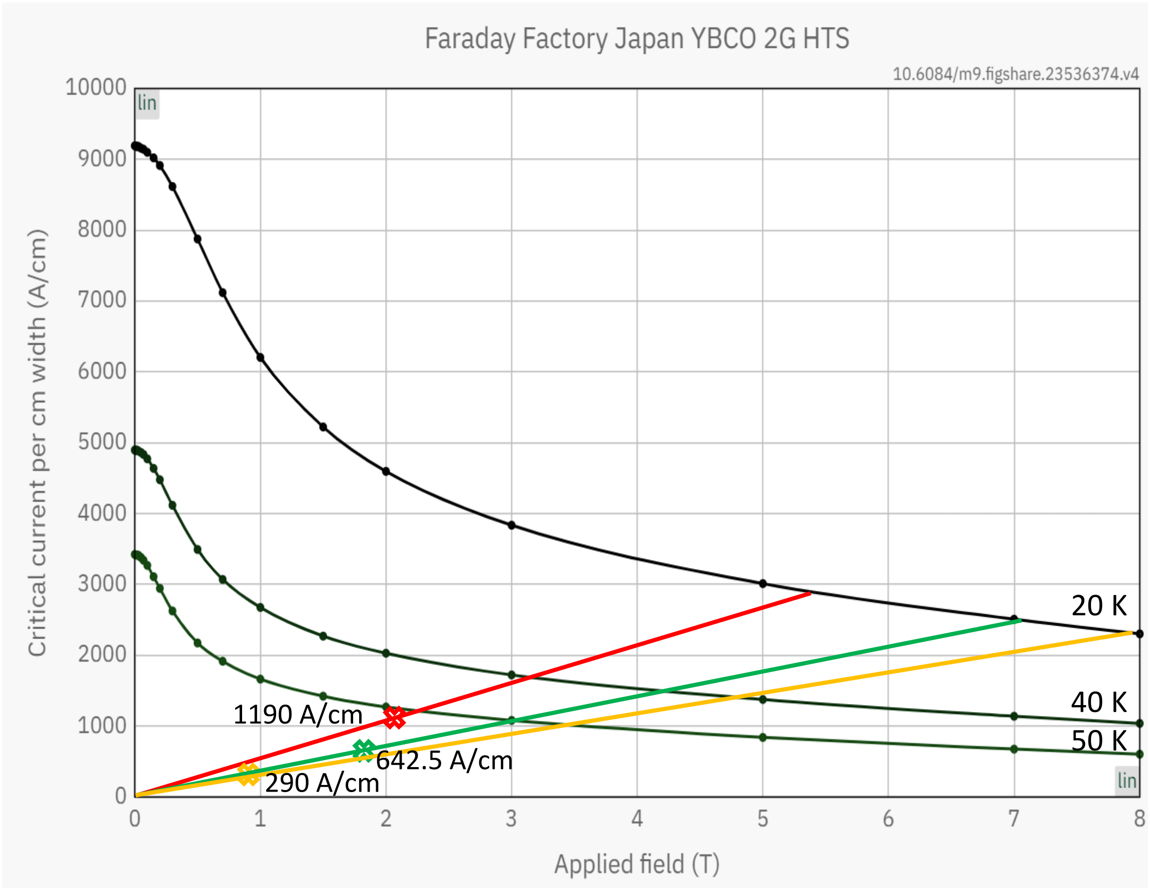
Sextupole Configuration



Peak Field on the tape: 0.91 T
Current in each tape: 116 A

Combined Mode





Peak Field on the tape: 2.02 T
Current in each tape: 476 A
Inductance: 0.216 mH

Loadline using Faraday Factory Japan tape

Field Quality of the magnet

Mode	Target Value	NI group 1	NI group 2	Dipole Field [T]	G [T/m]	S [T/m^2]	b4 [units]	b5 [units]	b6 [units]	a2 [units]
Quadrupole	11.8 T/m	5140	5140	-1.96E-05	-11.86	0.9488	-1.6359	2.2698	46.2834	-6.4341
Sextupole	455 T/m^2	2320	-2320	4.96E-07	-4.29E-05	-455.15	-1.8481	-3.4769	2.8898	-1.4357
Combined	11.8 T/m 455 T/m^2	9513	2441	-0.024	-11.86	-455.07	44.22	-16.35	32.48	5.95

Open Points and Next Steps

Open Points

Field Quality and Magnet optimization

- Possibile use of the combined magnet also as a dipole
- Is the quality maintained for each combination of quadrupole and sextupole?
- Possible coupling between the two beam lines

Coil Construction

- Is it possible to have such a narrow coil?
- Insulated or Non insulated
- Junction and winding

→ ESMA project @ LASA plans to answer this questions

Next Steps

Energy Losses and Cryogenics

- Quench Analysis
- Cryocooling, Liquid N line?
- Cooling methods and thermal isolation, Iron mass is cold?

Mechanical structure and Assembly

- Supports, position of the walls and how to assemble it
- Lorentz forces analysis ad effect on the HTS material

Demostrator @ LASA
~ 0.5 m for second half 2025

INFN LASA