BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

CONCEPTUAL MAGNETIC DESIGN OF THE LARGE APERTURE D2 DIPOLE FOR LHC UPGRADE*

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Abstract

As a part of the High Luminosity upgrade of the Large Hadron Collider (HL-LHC), the aperture of the D2 dipole is increased and spacing between the two apertures decreased without increasing the size of cryostat. This creates a significant challenge in keeping the saturation induced harmonics and the flux leakage low, particularly since the field in the two apertures is in the same direction. This paper presents an optimized magnetic design (with much effort made to optimize the yoke) to achieve the desired field quality in the magnets.

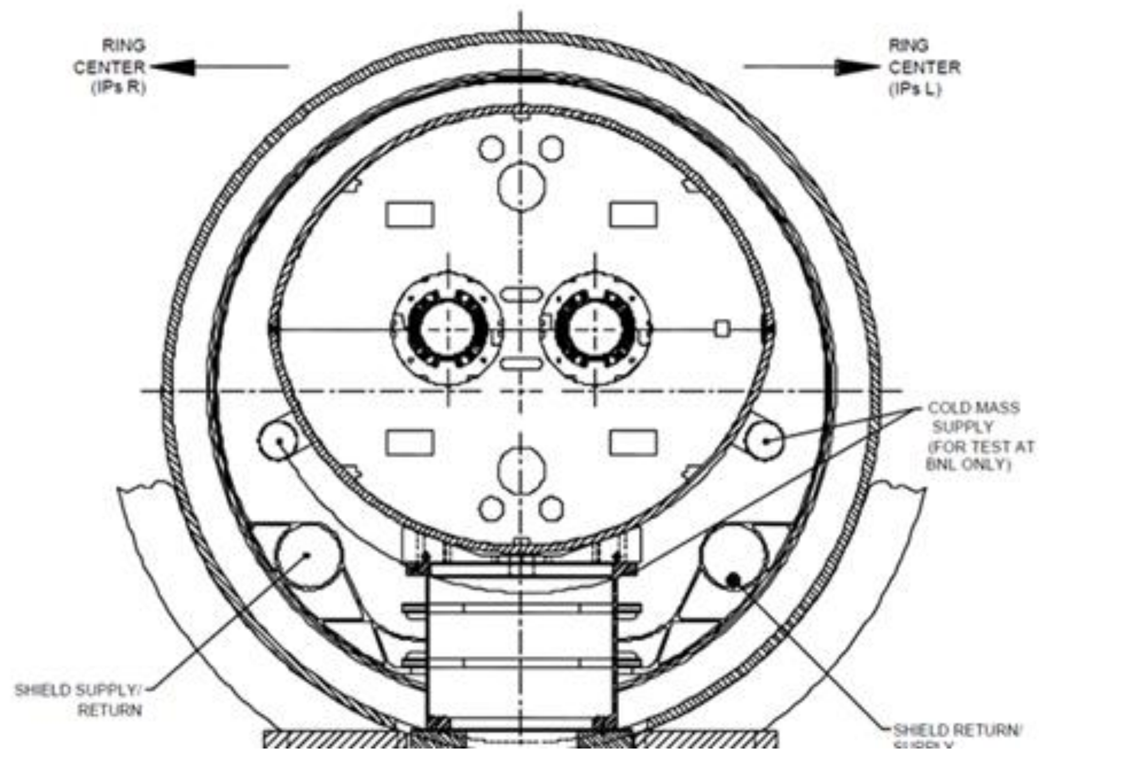
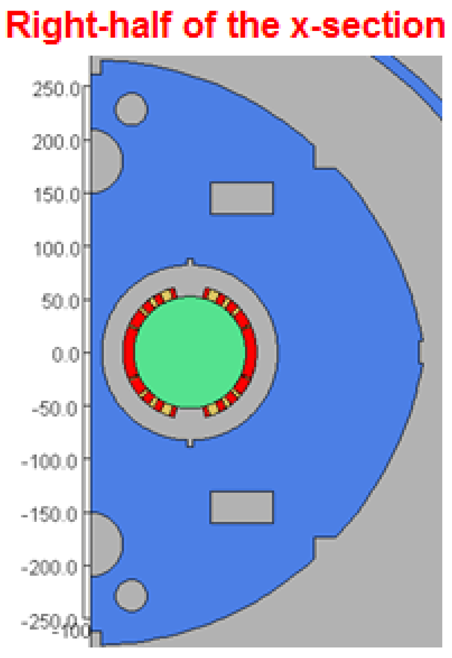


Figure: Cross-section of the 80 mm twin aperture D2 dipole that is currently installed in LHC using standard cryostat and support posts. Oblate shaped yoke provides extra iron needed at the midplane.

Major Difference Between LHC Main Dipole and D2 Dipole

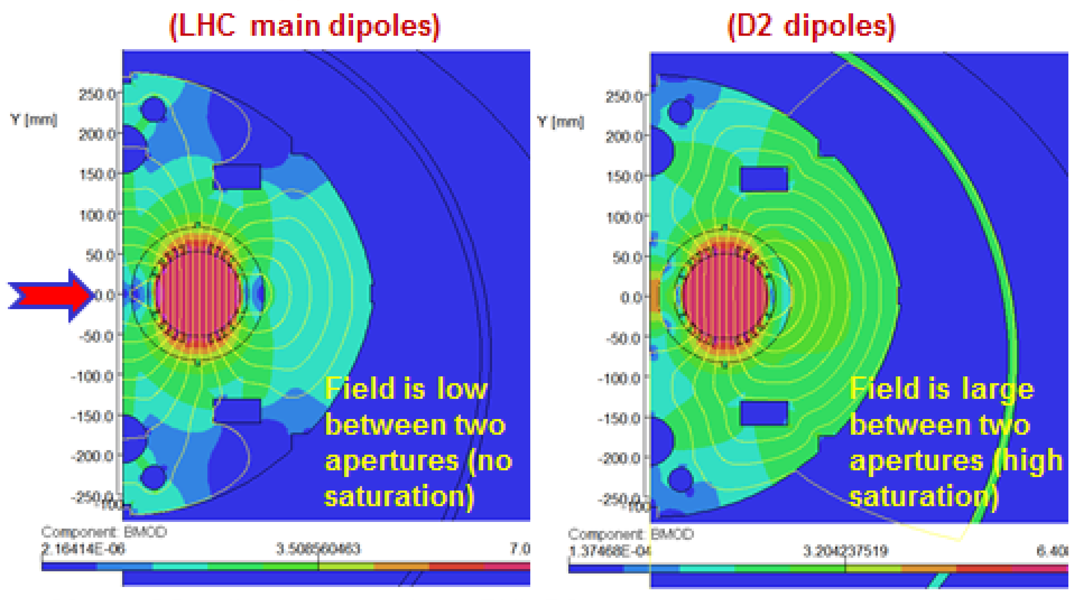
Right-half of the x-section



- Like LHC main dipole, LHC insertion D2 is also a 2-in-1 dipole.
- In main ring dipoles, however, the field in two apertures is in opposite direction allowing one side to provide return flux path to the other.
- This is not the case in D2 since the field is in the same direction. This means that the flux on one aperture must return on the same side.
- Reducing cross-talk due to proximity of two apertures (quadrupole harmonic, etc.) and other harmonics arising from the insufficient iron at midplane is the major challenge.
- In 80 mm D2 we were able to overcome this by the unique oblate yoke design developed at BNL which provided extra iron at the midplane.
- 105 mm D2 has more flux and less spacing.

Impact of Relative Polarity (1)

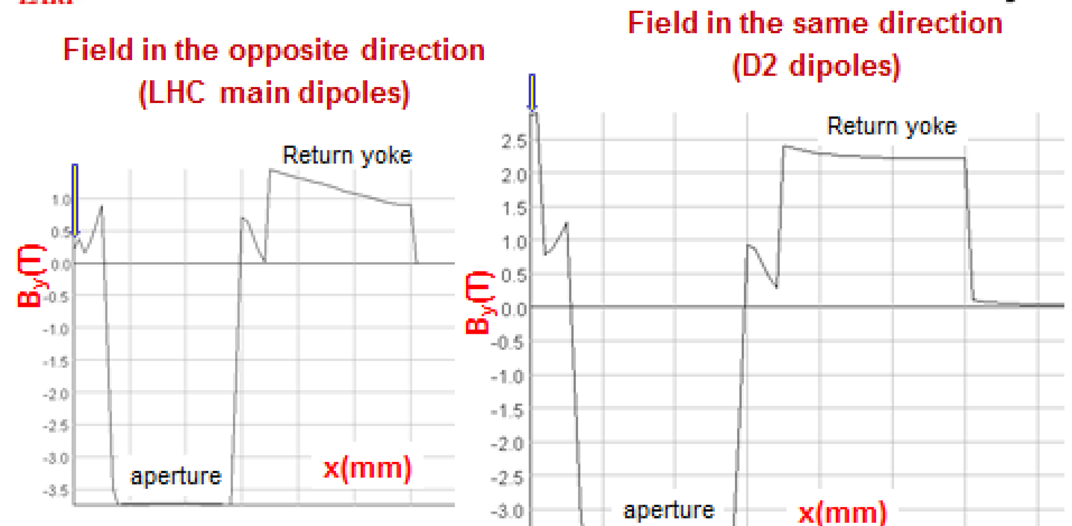
Field in the opposite direction (LHC main dipoles) | Field in the same direction (D2 dipoles)



20 mm SS collar (as in previous BNL D2)

Impact of Relative Polarity (2)

Field in the opposite direction (LHC main dipoles) | Field in the same direction (D2 dipoles)



Field is lower (~0.5 T) at the center of the magnet and in the return yoke (~1 T)

Field is higher (≥2.5 T) at the center of the magnet and also in the return yoke (≥2 T)

Design Specifications

- Aperture: 105 mm
  - Also examined:
    - 95 mm (produces a more conventional design)
    - 100 mm (RHIC insertion dipole - detailed proven coil design exists)
- Inter-beam distance: 186 mm
  - note this is smaller than 192 mm spacing in nominal LHC dipole
- Target operating point on load-line: 70%
- Integrated field: 35 T.m
- Magnetic length: below 10 m (means field 3.5 T or more)

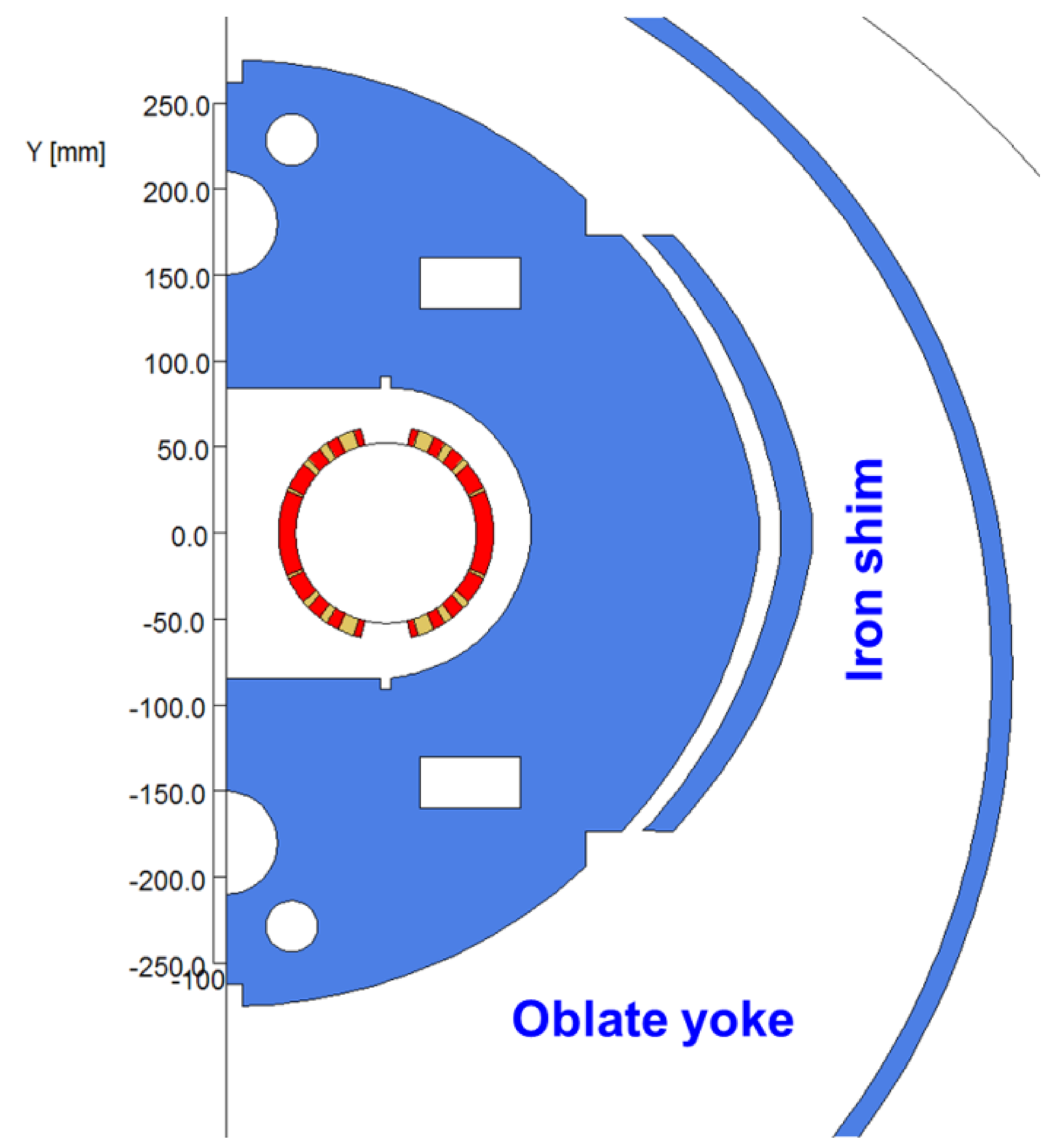


Figure: Computer model of a symmetric half (right half) of the optimized magnetic design.

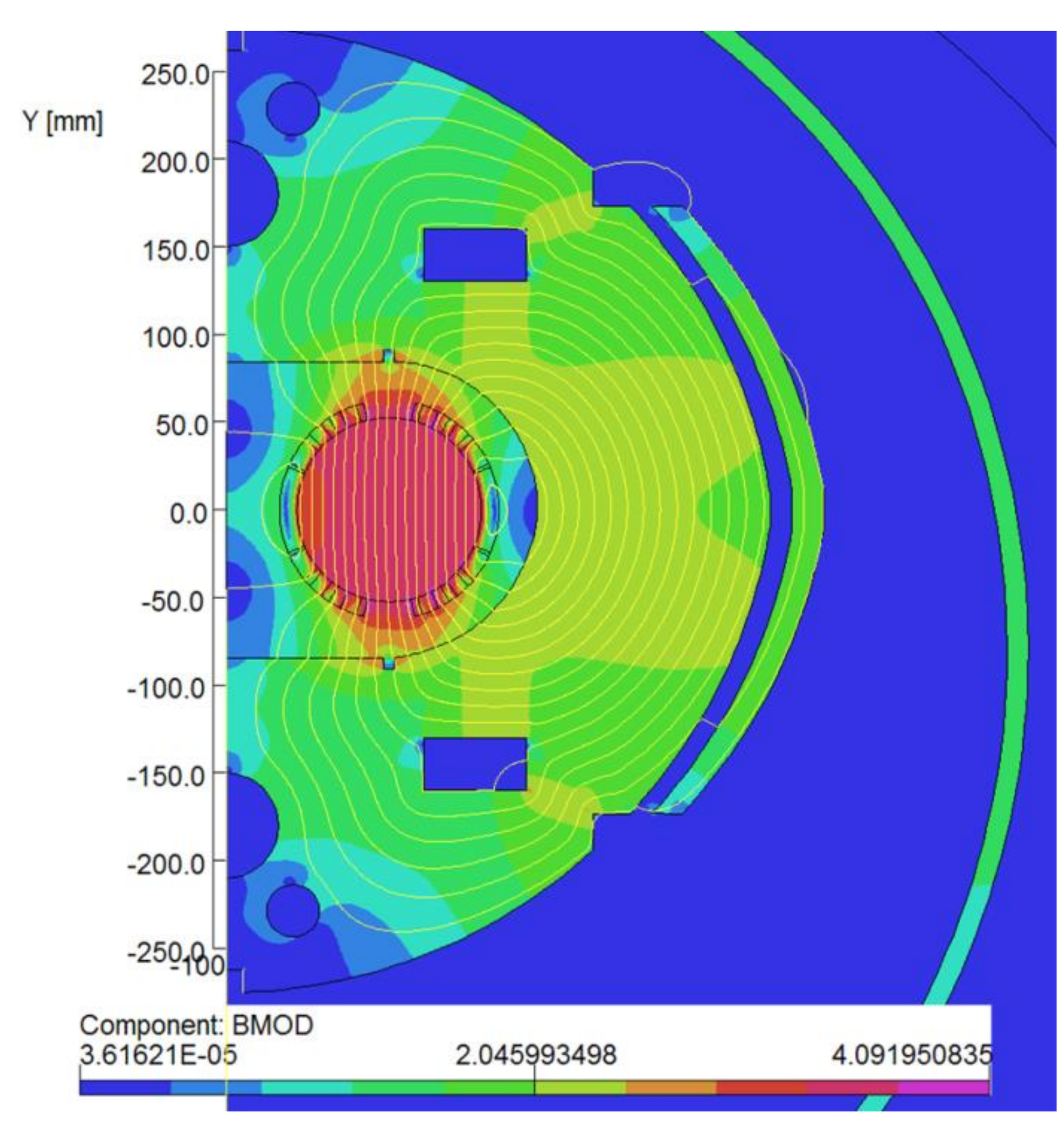


Figure: Field contours and field lines at the design field.

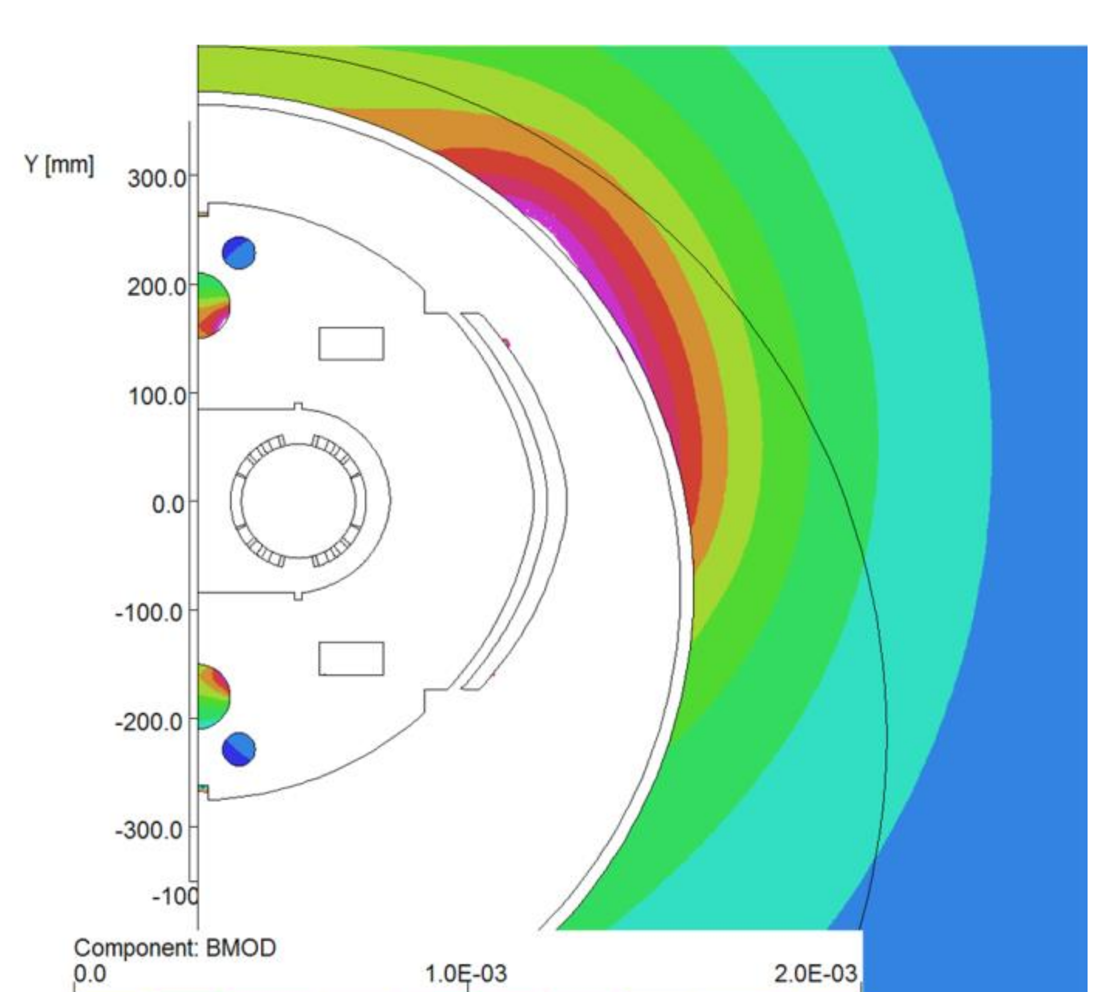


Figure: Fringe field outside the cryostat at the design field.

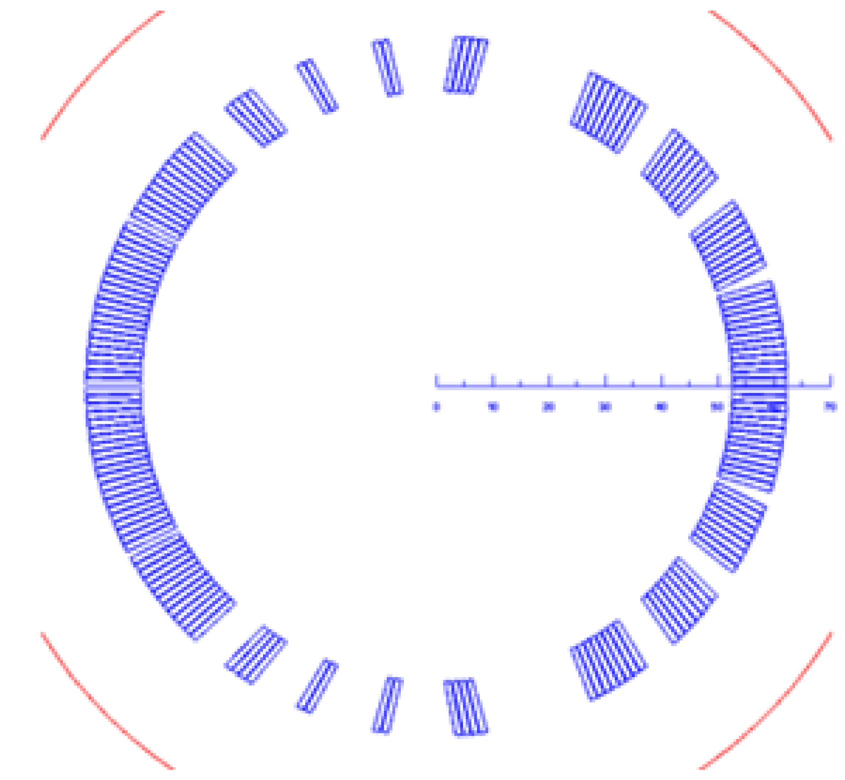


Figure: Coil design with ROXIE to compensate the harmonics arising due to a non-circular yoke aperture.

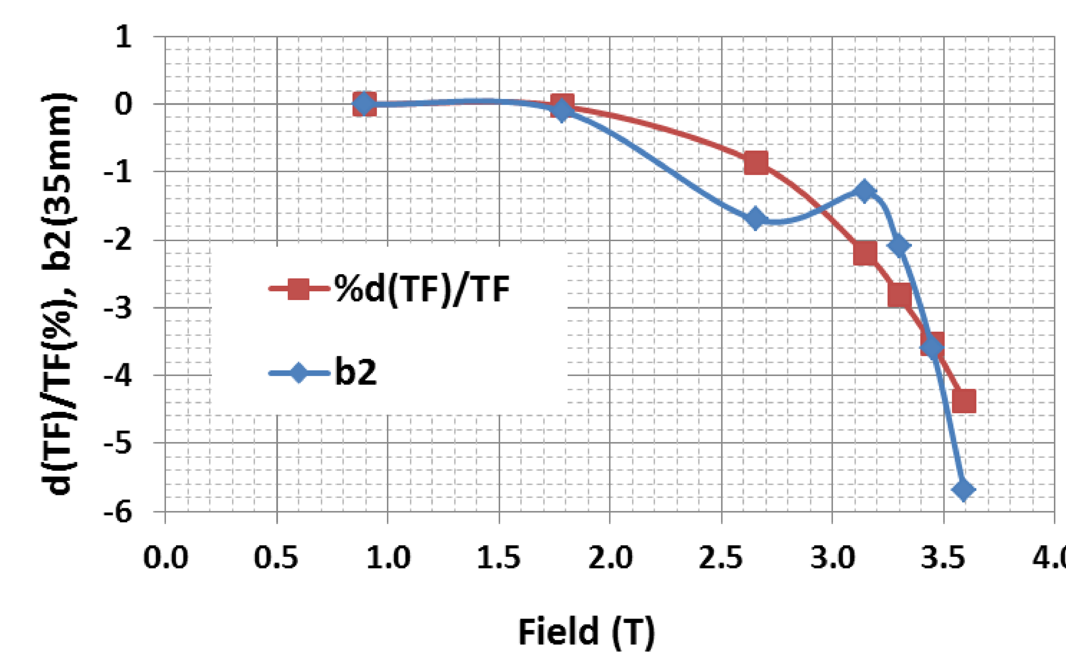


Figure : Relative change in transfer function (in percentage) and field harmonics as a function of current.

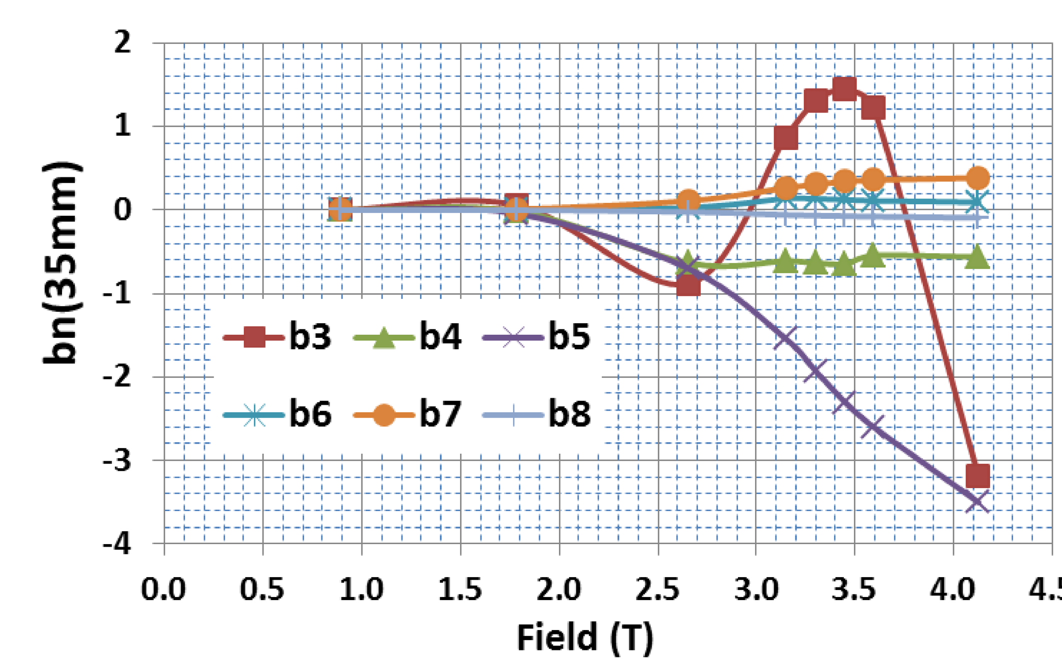


Figure: Computed change in field harmonics (b_3 to b_8) as a function of current.

Table 1. Relative change in transfer function (in percentage) and field harmonics (at 35 mm radius) as a function of field.

Bo	d(TF)/TF,%	b_2	b_3	b_4	b_5	b_6	b_7	b_8
0.89	0.00	0	0	0	0	0	0	0
1.79	-0.03	-0.1	0.06	-0.02	-0.05	0.00	0.01	0.00
2.66	-0.86	-1.7	-0.88	-0.63	-0.70	0.03	0.11	-0.03
3.15	-2.19	-1.3	0.86	-0.61	-1.54	0.14	0.26	-0.06
3.30	-2.82	-2.1	1.31	-0.63	-1.93	0.13	0.31	-0.07
3.45	-3.54	-3.6	1.44	-0.65	-2.31	0.12	0.34	-0.07
3.59	-4.37	-5.7	1.22	-0.55	-2.60	0.11	0.36	-0.08
4.13	-8.24	-18.	-3.19	-0.56	-3.50	0.09	0.38	-0.09

Table 2. The expected "systematic", "uncertainty" and "random" normal (b_n) harmonics in HL-LHC D2 dipole at a reference radius of 35 mm (updated from Todesco).

	Systematic					Uncertainty		Random	
b_n n=	Geom-etric	Satu-ration	Persis-tent	Injec-tion	High Field	Injec-tion	High Field	Injec-tion	High Field
2	6.0	-6	0	6	0	3	3	3	3
3	0	0	-14.2	0	1	2	2	2	2
4	-0.6	0	0	-0.6	0	1	1	1	1
5	3	-3	-1	3	0	2	2	1	1
6	0	0	0	0	0	0.1	0.1	0.1	0.1
7	0	0.4	-0.7	-0.4	0	0.2	0.2	0.2	0.2
8	0	-0.1	0	0.1	0	0.1	0.1	0.1	0.1

CONCLUSION

With special shaping of iron, it is possible to design 105 mm aperture D2 dipole for HL-LHC with the desired field quality and low fringe field outside the yoke despite the field in the two apertures being in the same direction. Expected field errors are now comparable to those that are expected in a typical accelerator magnet.

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