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A Proposal for the IAXO Magnet System

Riccardo Musenich, Stefania Farinon

INFN, Sezione di Genova, Via Dodecaneso 33, I-16146 Genova, Italy

Abstract

The note describes a proposal for a superconducting toroidal magnet for the IAXO axion helioscope obtained assembling several canted solenoid dipoles. Respect to toroids made with racetrack coils, having the same average field, it has lower stored energy, lower peak magnetic field at the conductor and lower cold mass.

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1 INTRODUCTION

The present report contains the proposal of a novel magnet system for the axion helioscope IAXO. The proposal is based on a previous design (racetrack toroid) reported by Shilon et al.[1] As a first step, it was decided to keep the same aperture, length and average magnetic field. In order to reduce the stray field, it was also chosen to keep the toroid-like configuration. The main difference is that the racetracks coils are replaced by coils with a $\cos\vartheta$ current distribution, where ϑ is the azimuthal angle in cylindrical coordinates.[2] A possible winding to obtain $\cos\vartheta$ current distribution is the canted solenoid. Such magnets, originally proposed in 1970[3], generate highly uniform dipole field obtained alternating solenoidal windings skewed in opposite direction as shown in Fig. 1. Recently, the idea reappeared[4),5)] and has found application in several projects.

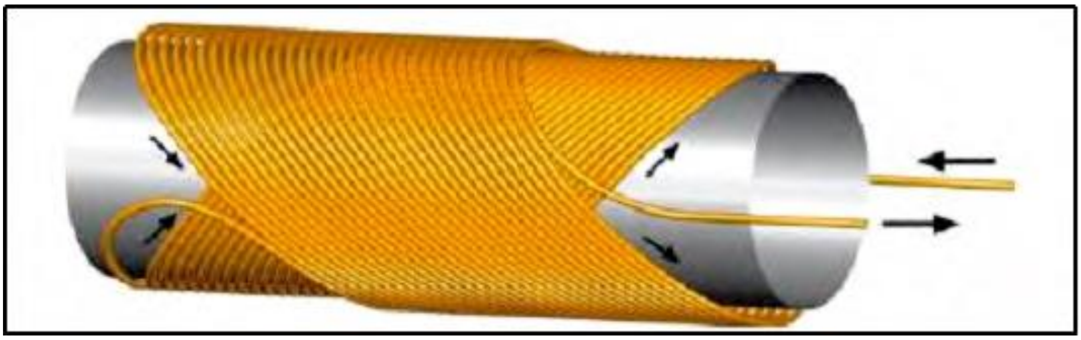

FIG. 1: Canted solenoid dipole.

If N dipoles are assembled in cylindrical symmetry in such a way that the i-th magnet is rotated along its axis by i/N π, a toroid-like field is obtained. This configuration was studied in the framework of the ARSSEM project[6] in order to design a radiation shield to protect spacecraft habitats (Fig. 2).

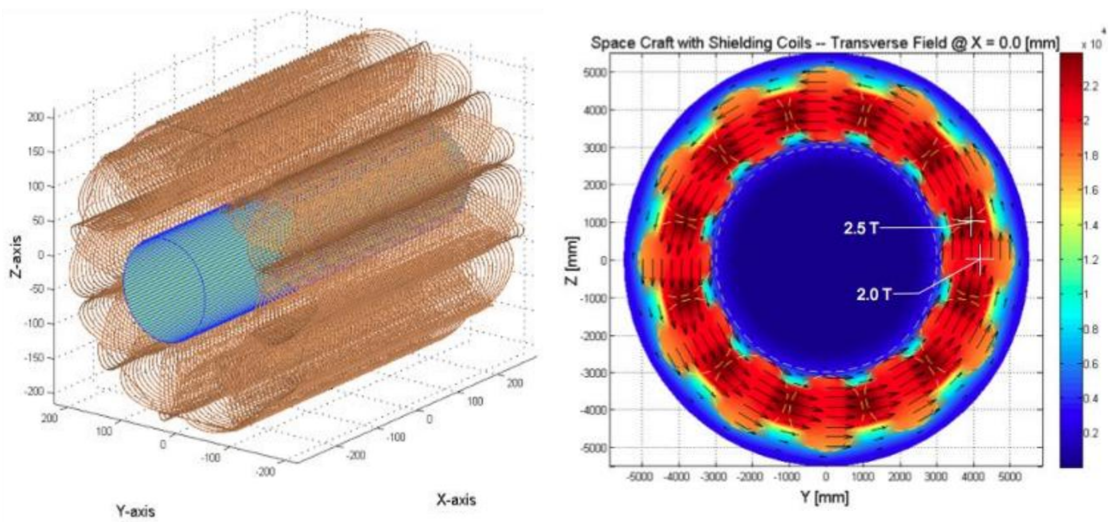

FIG. 2: Toroid obtained assembling canted solenoid dipoles[5].

Differently from the racetrack toroid, the dipole assembly allows concentrating the magnetic flux lines within the helioscope tubes producing a more homogeneous field and reducing the stored energy. Moreover, the peak magnetic field at the magnet conductor is lower respect to the racetrack toroid. A lower peak field means that there is margin to increase the magnetic field inside the tubes.
The following configurations are referred to toroid-like magnets obtained by assembling 8 and 3 canted solenoid dipoles, respectively. Of course, it is possible to assembly different number of coils. The cold masses reported in the tables are only a rough estimation. More accurate values require calculation of the mechanical structures.
The coils are supposed to be wound with an aluminum stabilized NbTi wire.

2 8-COIL TOROIDAL MAGNET

The first configuration we considered is the assembly of 8 coils, in order to have a comparison with the magnet proposed in (1).

TAB. 1: Characteristics of the 8-coil toroidal magnet.

Parameter	Value
Tube inner diameter	0.6 m
Total aperture	2.26 m^2
Length	22 m
Average field in the tube	2.5 T
Peak magnetic field	3.1 T
Current density	147 MA/m^2
Stored magnetic energy	160 MJ
Cold mass (estimated)	40 tons
Stray field (40 G)	< 3 m

If the winding skew is 15° and the metal/superconductor ratio is 14, the current density in NbTi is 2130 A/mm^2, i.e. about 60% of the critical current density at the operating conditions (4.5 K and 3.1 T). As the overall current density is quite high, in order to protect the magnet against quenches, the winding can be done with no-insulation or with partial insulation. The no-insulation technique affects the charging and discharging time, therefore the operating current and consequently the cable must be chosen in such a way to limit the inductance.

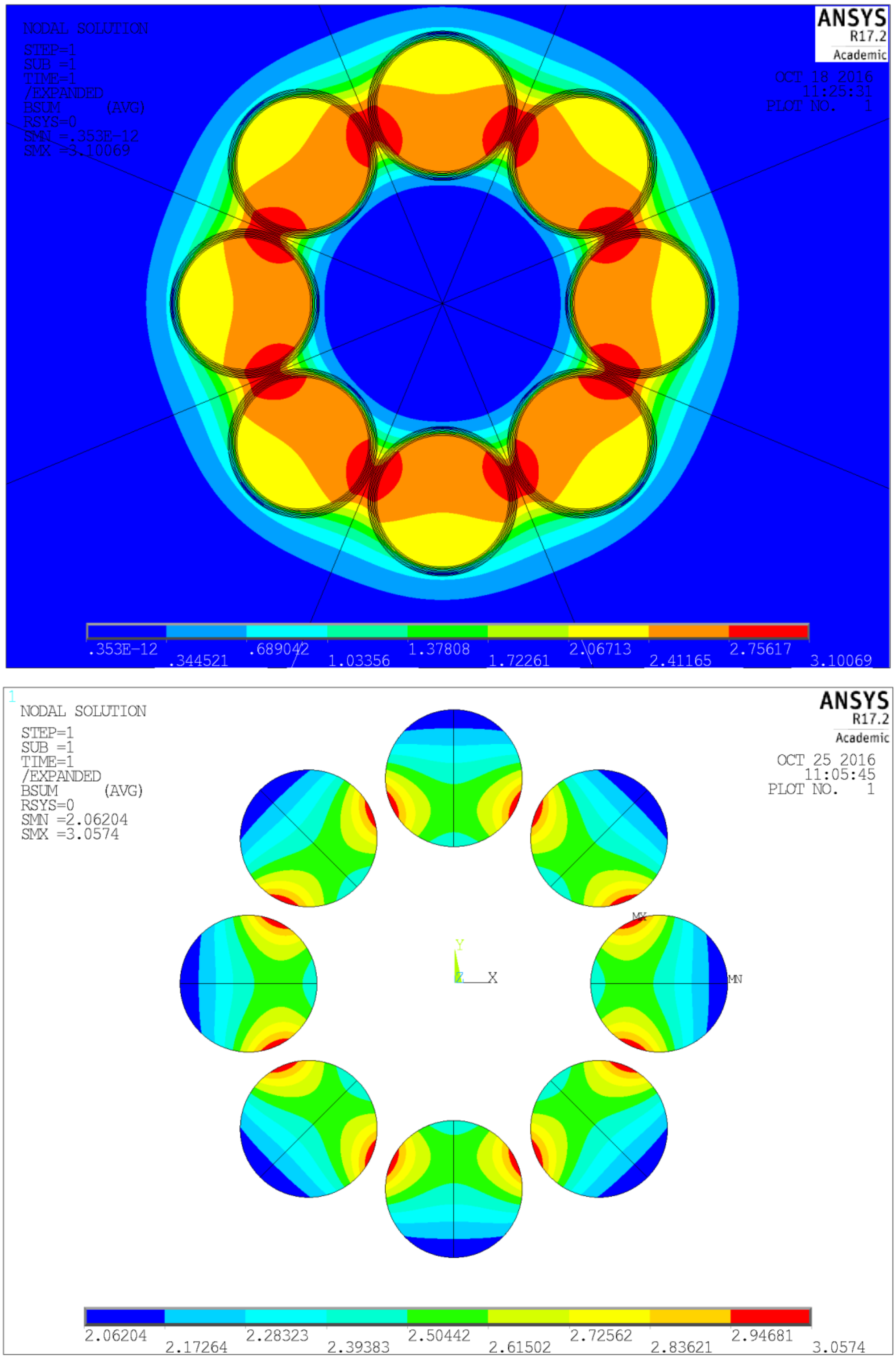

FIG. 3: Magnetic field map (T) of the whole system (up) and within the aperture (down).

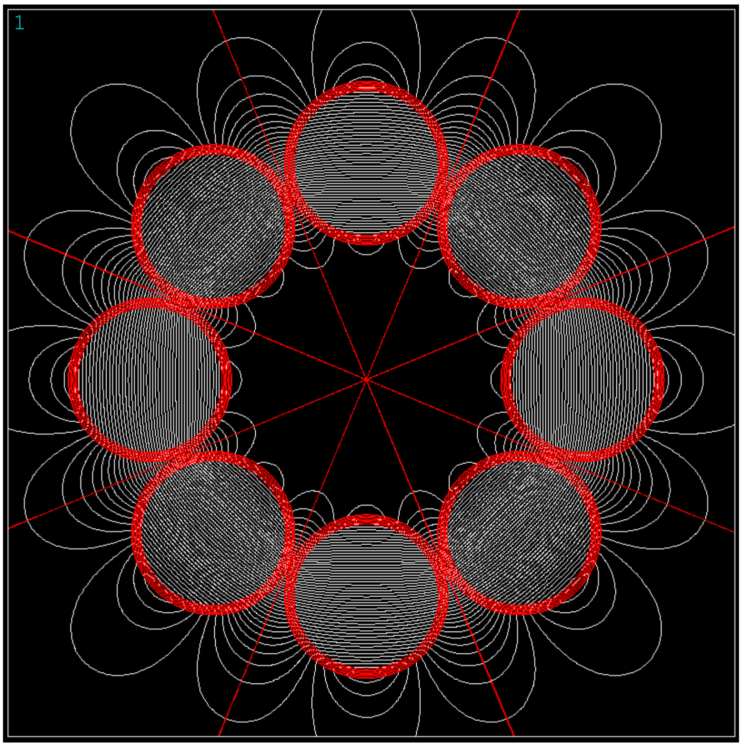

FIG. 4: Flux lines.

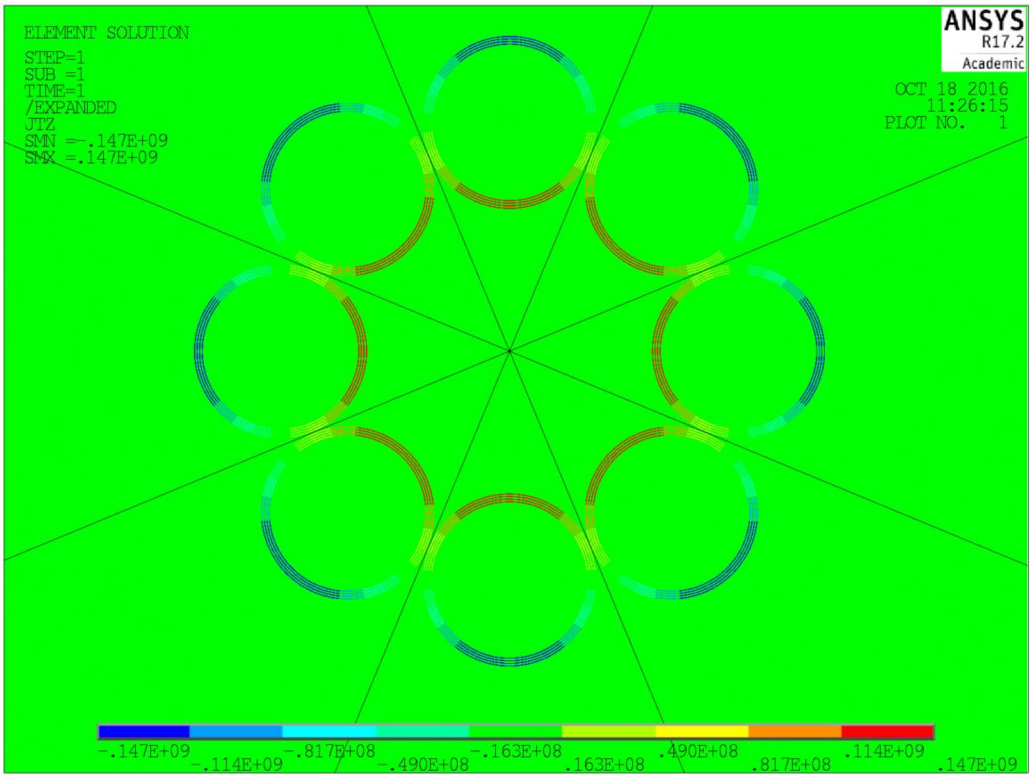

FIG. 5: Current density (A/m^2).

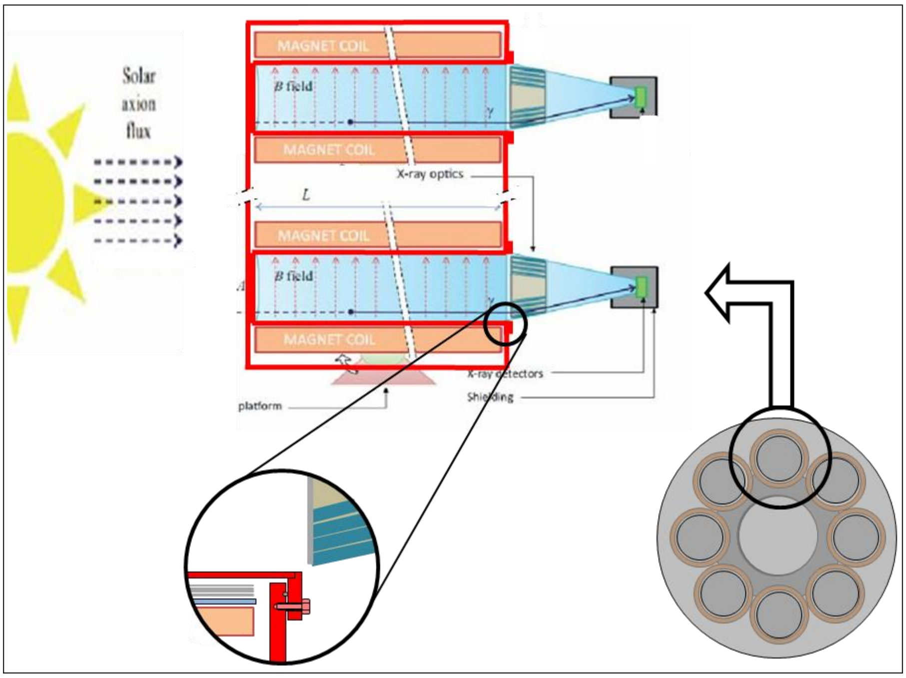

FIG. 6: Schematic view of magnets integrated in the helioscope cryostat.

The proposed configuration is intrinsically modular allowing the assembly of toroids with various numbers of coils. Fig. 7 shows some examples of different assemblies. Therefore, the helioscope can be constructed and operated with the available coils. In principle this can be done by only adapting the inner mechanical support and the cryostat flange. The following section shows a study of assembly of three coils.

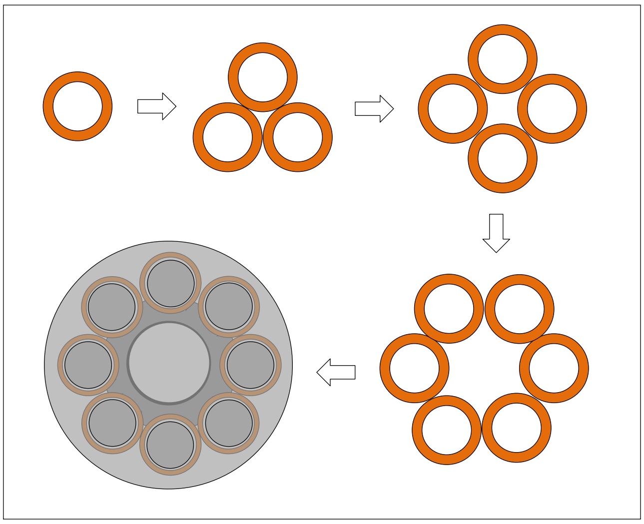

FIG. 7: Assembling of various numbers of coils (1, 3, 4, 6 and 8).

3 3-COIL MAGNET

The 3 coil assembly leads to a more compact configuration. The drawback is related to the lower field uniformity (comparable to the racetrack toroid) and to the higher stray field (the 40 gauss line moves from 3 to about 8 m.). If the winding skew is 15° and the metal/superconductor ratio is 14, the current density in NbTi is 2430 A/mm^2, i.e. about 80% of the critical current density at the operating conditions (4.5 K and 3.3 T).

TAB. 2: Characteristics of the 3-coil toroidal magnet.

Parameter	Value
Tube inner diameter	0.98 m
Total aperture	2.26 m^2
Length	22 m
Average field in the tube	2.5 T
Peak magnetic field	3.3 T
Current density	168 MA/m^2
Stored magnetic energy	170 MJ
Cold mass (estimated)	20 tons
Stray field (40 G)	< 8 m

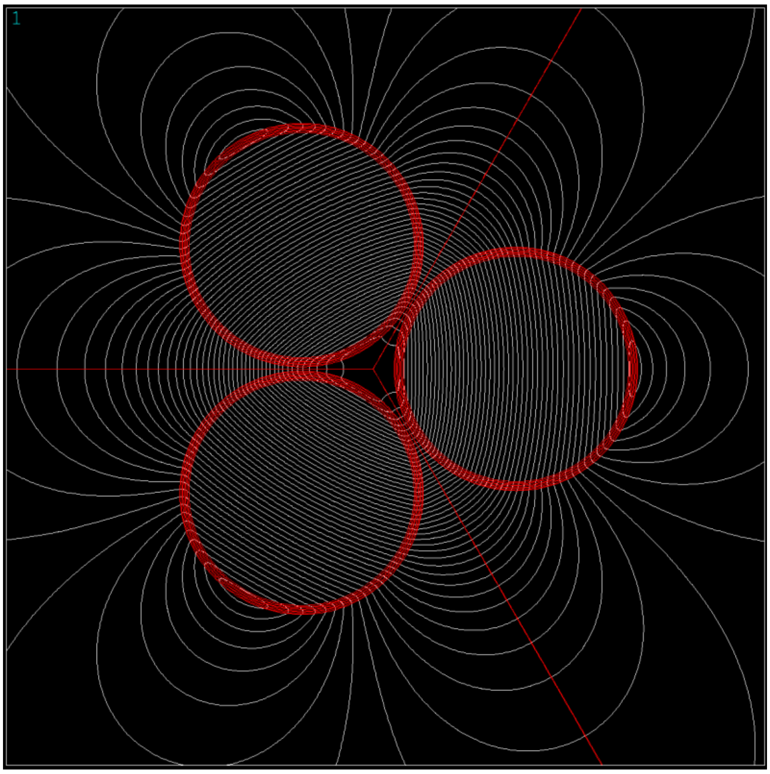

FIG. 8: Flux lines.

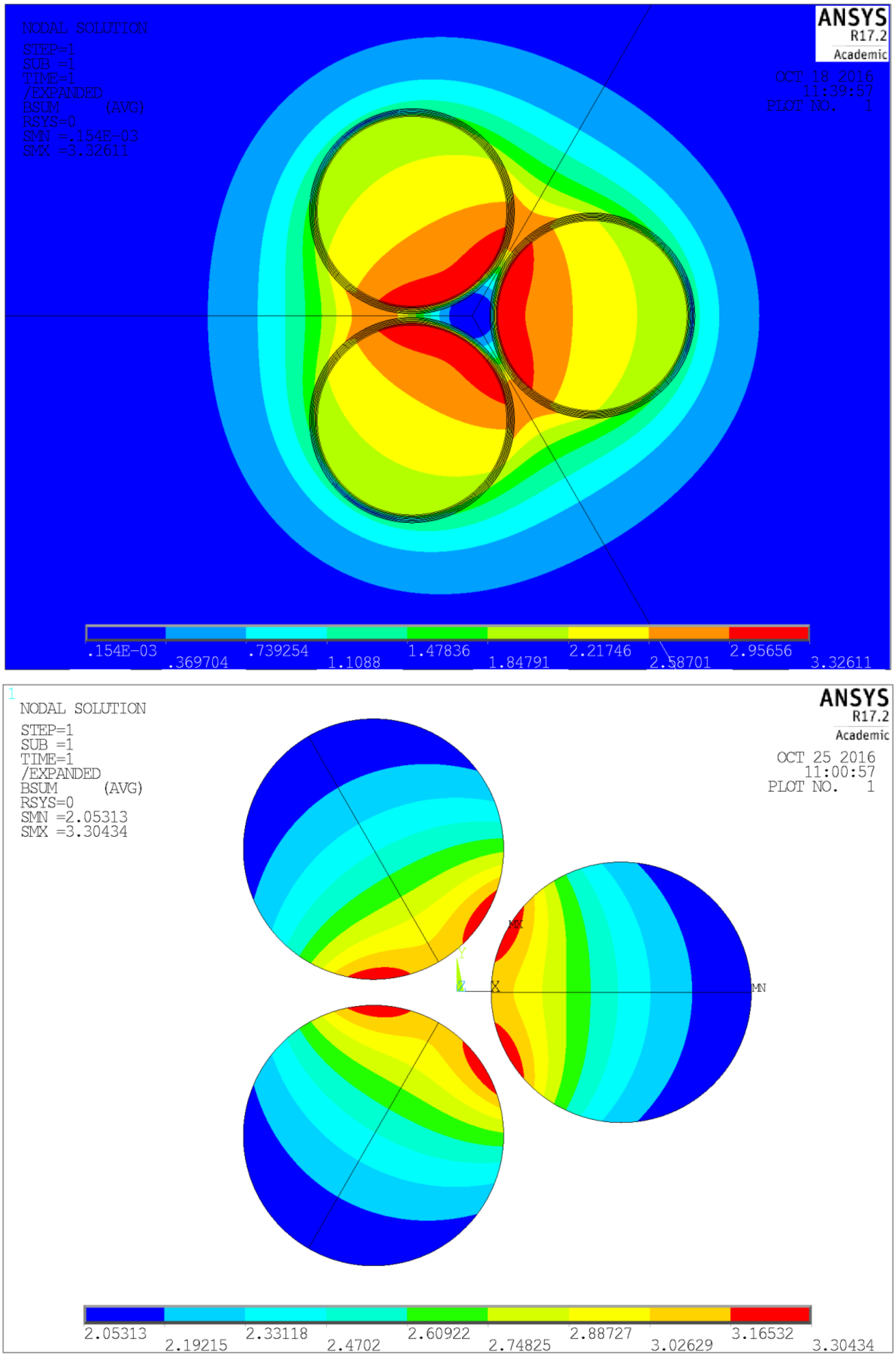

FIG. 9: Magnetic field map (T) of the whole system (up) and within the aperture (down).

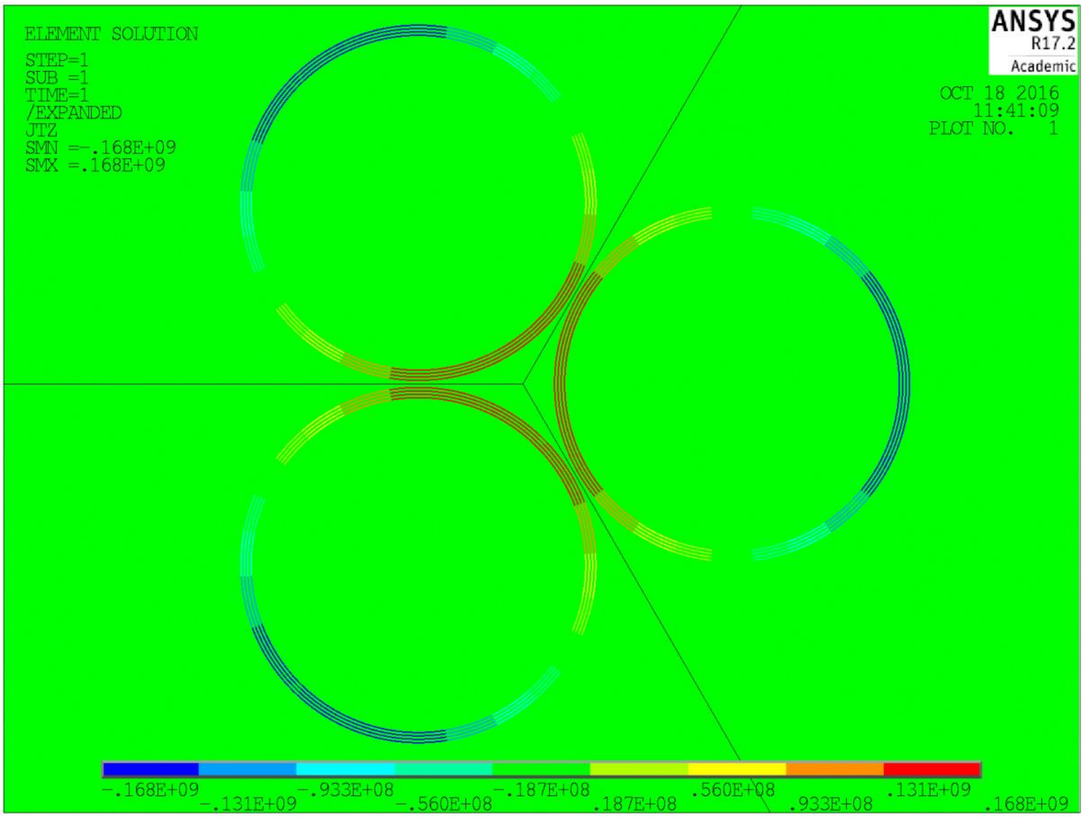

FIG. 10: Current density (A/m^2).

4 COMPARISON WITH RACETRACK TOROID

The following table compares the characteristics of a racetrack toroid and the two canted solenoid configurations having the same aperture and average magnetic field. The canted solenoid configurations have lower stored magnetic energy, are more compact and lighter. Moreover, as they have a lower peak field at the conductor, there is margin to increase the total current and consequently the helioscope performance (in principle, doubling it).

TAB. 3: Comparison between the three configurations.

	Racetrack toroid	8 c.s.d. toroid	3 c.s.d. toroid
<B> [T]	2.5	2.5	2.5
Total aperture [m^2]	2.26	2.26	2.26
Cold mass [tons]	130	40	20
$\iint B^2 dxdy$ [T^2m^2]	14.3	14.1	14.1
Stored energy [MJ]	660	160	170
B_{peak}[T]	5.7	3.1	3.3

8 REFERENCES

(1) I. Shilon, A. Dudarev, H. Silva, U. Wagner, H. H. J. ten Kate, “New Superconducting Toroidal Magnet System for IAXO, the International Axion Observatory”, arXiv:1308.2526v1, 2013.

(2) M.N. Wilson, “Superconducting Magnets”, pp. 28-32, Oxford Science Publ., 1983.

(3) D. I. Meyer and R. Flasck, “A new configuration for a dipole magnet for use in high energy physics applications,” Nucl. Instrum. Meth., **80** (2), 1970.

(4) A.V. Gavrilin, M.D. Bird, S.T. Bole, Y.M. Eyssa, “Conceptual Design of High Transverse Field Magnets at the NHMFL”, IEEE Trans. Appl. Supercond., **12** (1), 2002.

(5) R.B.Meinke, M.J.Ball, and C.L.Goodzeit, “The double-helix dipole—A novel approach to accelerator magnet design,” IEEE Trans. Appl. Supercond., **13** (2), 2003.

(6) R. Battiston, W.J. Burger , V.Calvelli, R.Musenich, V.Choutko, V.I.Datskov, A.Della Torre, F.Venditti, C.Gargiulo, G.Laurenti, S.Lucidi, S.Harrison, R. Meinke, “Active Radiation Shield for Space Exploration Missions”, arXiv:1209.1907, 2012.