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Numero DT *DT Number*	Data *Date*	Pagina *Page*
DT- MATN-2013-10-01	**October 16th, 2013**	**1 di 15**

Documento tipo / *Document type*

TECHNICAL NOTE (TN)

Titolo / *Title*

High Field Index Dipoles: a novel approach

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Parole chiave / *Keywords*

Tau-Charm, Dipole, Quadrupole, Magnet, Field Index

Riassunto / *Abstract*

Questa nota tecnica descrive una idea innovativa per il progetto di dipoli ad alto indice di campo, come richiesti dall'ottica di macchina, versione 55, del progetto Tau-Charm.

A novel approach to design high Filed Index dipoles is proposed in this technical note, as required in the lattice, version 55, of the Tau-Charm project.

Nome file / *Filename*	Versione / *Version*	Distribuzione / *Distribution*	Visibilità / *Access*
High Field Index Dipole TecNote.doc	**1**	**DT-DA**	**DESIGN**

Preparato / *Compiled*	Controllato / *Controlled*	Controllato / *Controlled*	Approvato / *Approved*
Claudio Sanelli	**Claudio Sanelli**		
16 Ottobre 2013	16 Ottobre 2013		

LISTA DI DISTRIBUZIONE / DISTRIBUTION LIST			
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ELENCO DELLE VARIAZIONI / HISTORY OF CHANGES			
Ver.	Data/Date	Pag.	Descrizione / Description
1	16-10-2013		Prima emissione

High Field Index Dipoles: a novel approach

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High Field Index Dipoles: a novel approach

1. Introduction

A novel approach to the design of dipoles with very high field index, as required in the tau/charm lattice version 55, has been investigated and 2D simulations with POISSON have been carried out. This study is very preliminary and more detailed calculations will be needed, even in 3D, if real magnets will have to be designed.

2. Design criteria

Instead to shape the pole profile of the dipole in such a way to resemble to a quadrupole pole profile, to introduce the requested quadrupolar Gradient, the new approach split the pole in two parts introducing a vertical slot where to put two additional coils, one for the right part of the pole and one for the left part of the pole, called “quadrupole coils”, that increase or decrease the magnetic flux between the right and left half of the pole so that a transition between two different magnetic dipole field is created. The transition must have the right slope corresponding to the requested quadrupolar Gradient or Field Index. The dipole field at the magnet centre can be controlled by the current value in the main coil (the big one in the magnet sketch), meanwhile the Gradient or Field Index can be controlled adjusting the currents in the so called quadrupole coils (the narrow ones in the sketch). So doing, one can change the dipole field and the quadrupole Gradient independently and the limitation due to the pole geometry is overcome.

3. Basic geometry

Figure 1 shows the geometry adopted in the Poisson simulations.

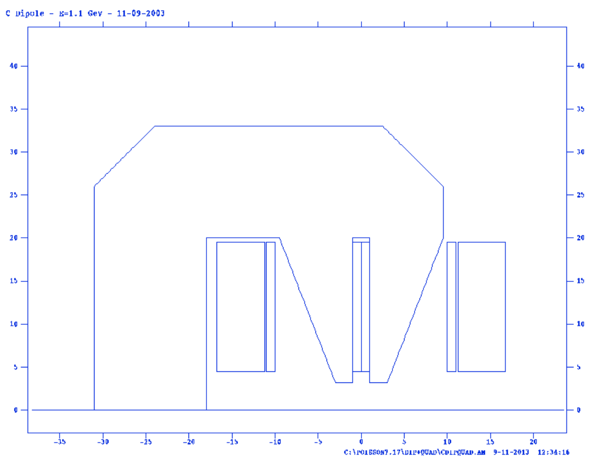

Figure 1: The basic geometry

4. Simulation in 2D – POISSON Code

In the following few examples are reported. Note that the currents in the quadrupole coils have the same value but, in principle, one can adopt different values affecting the magnetic field harmonic content. This option has not investigated in the following.

4.1 Example n. 1: Dipole Field 4457 Gauss; Gradient 377 Gauss/cm.

Figure 2 shows the magnetic flux lines in the dipole where a field index of 126.74 is requested as in BQDM. Figure 3 shows the magnetic field profile on the mid-plane. Figure 4 is a detail of figure 3 around the magnet centre.

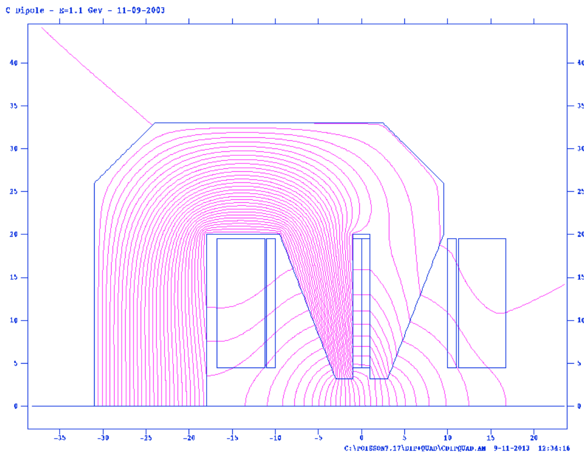

Figure 2: The magnetic flux lines in the example 1.

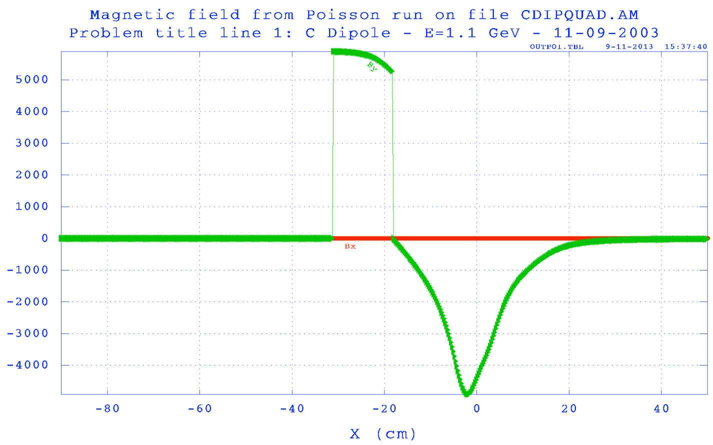

Figure 3: Magnetic field profile on the magnet mid-plane. The peak on the left corresponds to the backleg. The magnet centre is at x=0.0.

The width of the pole facing the mid-plane has been adjusted to minimize the Sextupole term in the harmonic content analysis.

Harmonic content analysis for different pole lengths.

In the following the different harmonic contents are reported for example 1 as function of the pole width (L). Figure 5 shows the variation of the Sextupole, Octupole and

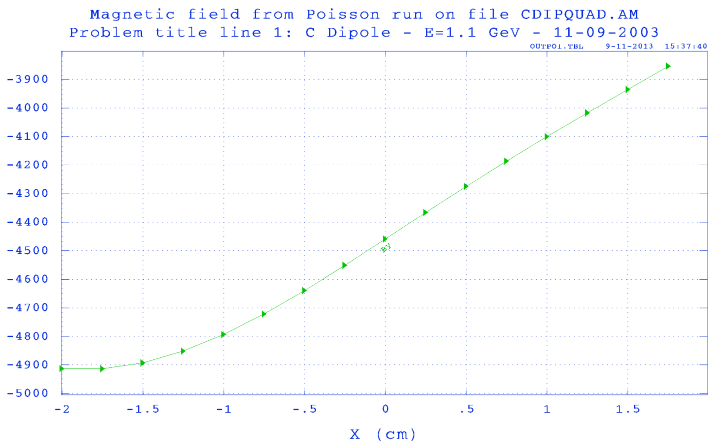

Figure 4: A zoom of the magnetic field around the magnet centre on the mid-plane of BQDM.

Harmonic content analysis for different pole lengths.

In the following the different harmonic contents are reported for example 1 as function of the pole width (L). Figure 5 shows the variation of the Sextupole, Octupole and Decapole terms as function of the pole width. As pole width I mean the width of the flat part of the right and left pole facing the mid-plane. The currents of the main coil and of the quadrupole coils are kept fixed. The pole width of L=3 cm is the one that vanishes the Sextupole term.

Pole L= 5 cm

Field coefficients

Normalization radius = 1.00000

(Bx - iBy) = i[sum n*(An + iBn)/r * (z/r)**(n-1)]

n	n(An)/r	n(Bn)/r	Abs(n(Cn)/r)
1	4.5561E+03	0.0000E+00	4.5561E+03
2	-3.9702E+02	0.0000E+00	3.9702E+02
3	4.1504E+01	0.0000E+00	4.1504E+01
4	2.5538E+01	0.0000E+00	2.5538E+01
5	-8.4044E+00	0.0000E+00	8.4044E+00

Pole L= 4 cm

Field coefficients

Normalization radius = 1.00000

(Bx - iBy) = i[sum n*(An + iBn)/r * (z/r)**(n-1)]

n	n(An)/r	n(Bn)/r	Abs(n(Cn)/r)
1	4.5304E+03	0.0000E+00	4.5304E+03
2	-3.9140E+02	0.0000E+00	3.9140E+02
3	2.9115E+01	0.0000E+00	2.9115E+01
4	2.6172E+01	0.0000E+00	2.6172E+01
5	-9.0275E+00	0.0000E+00	9.0275E+00

Pole L= 3 cm

Field coefficients

Normalization radius = 1.00000

(Bx - iBy) = i[sum n*(An + iBn)/r * (z/r)**(n-1)]

n	n(An)/r	n(Bn)/r	Abs(n(Cn)/r)
1	4.4570E+03	0.0000E+00	4.4570E+03
2	-3.7715E+02	0.0000E+00	3.7715E+02
3	1.1947E-01	0.0000E+00	1.1947E-01
4	2.7616E+01	0.0000E+00	2.7616E+01
5	-1.0004E+01	0.0000E+00	1.0004E+01

Pole L=2 cm

Field coefficients

Normalization radius = 1.00000

(Bx - iBy) = i[sum n*(An + iBn)/r * (z/r)**(n-1)]

n	n(An)/r	n(Bn)/r	Abs(n(Cn)/r)
1	4.2547E+03	0.0000E+00	4.2547E+03
2	-3.3762E+02	0.0000E+00	3.3762E+02
3	-5.4447E+01	0.0000E+00	5.4447E+01
4	2.8855E+01	0.0000E+00	2.8855E+01
5	-9.0380E+00	0.0000E+00	9.0380E+00

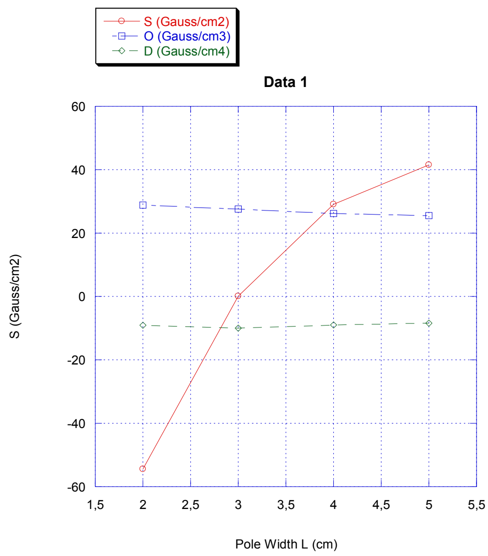

Figure 5: Plot of the Sextupole, Octupole and Decapole terms as function of the pole width (Excitation currents are kept fixed).

The following table report the numerical values plotted in figure 5.

L (cm)	Bo (Gauss)	G (Gauss/cm)	S (Gauss/cm2)	O (Gauss/cm3)	D (gauss/cm4)
2	4254.7	-337.60	-54.450	28.850	-9.0400
3	4457.0	-377.15	0.12000	27.610	-10.000
4	4530.4	-391.40	29.110	26.170	-9.0300
5	4556.1	-397.02	41.500	25.530	-8.4000

4.2 Example n. 2: Dipole Field 4457 Gauss; Gradient 323.4 Gauss/cm.

In this case the same geometry is adopted but the currents in the main winding and quadrupole coils are scaled to meet the requested dipolar magnetic field and quadrupolar gradient as in BQDMA. Figure 6 shows the magnetic field profile on the mid-plane around the magnet pole centre. Note that the horizontal scale is the same of fig. 4, with which it can be compared. Other graphs are not reported since they are very similar to that shown in figure 2 and 3.

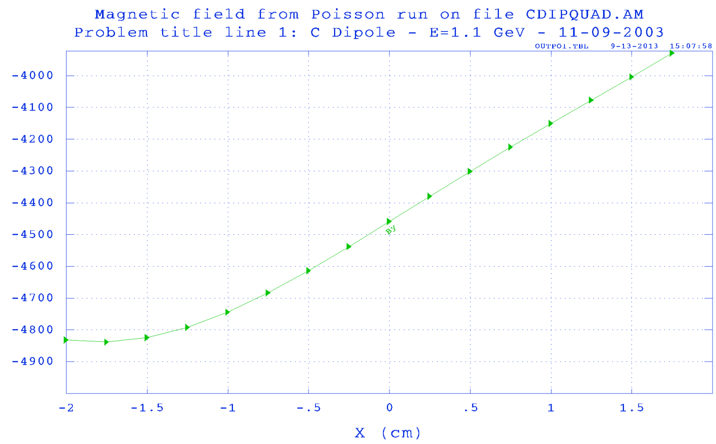

Figure 6: The magnetic field around the magnet centre on the mid-plane of BQDMA

4.3 Example n. 3: Dipole Field 4457 Gauss; Gradient ≈ 0.0 Gauss/cm.

In this example, the same geometry is used but the current in quadrupole coils is near zero to vanish the quadrupole gradient to have zero Field Index, like in BSUP. In other words only the dipolar magnetic field. Figure 7 shows the magnetic flux lines in the proposed geometry, figure 8 the magnetic field profile on the mid-plane and finally figure 9 a zoom of figure 8 in the same horizontal scale of figure 4 and 6.

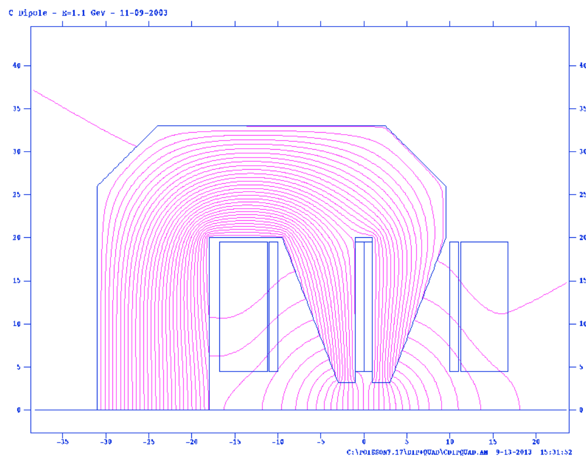

Figure 7: The magnetic flux lines in the example 3.

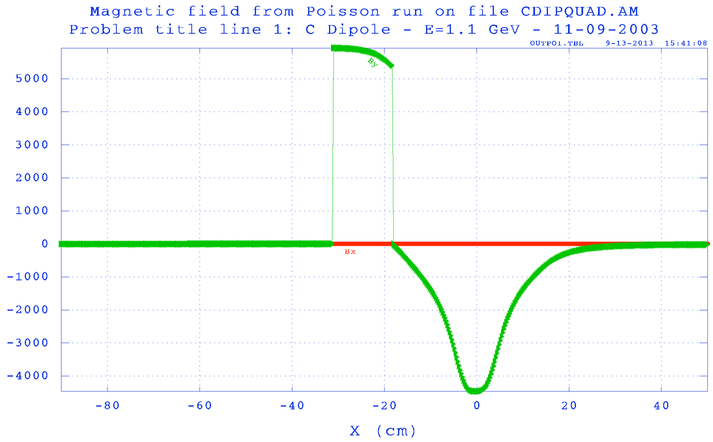

Figure 8: Magnetic field profile on the magnet mid-plane. The peak on the left corresponds to the backleg. The magnet centre is at x=0.0.

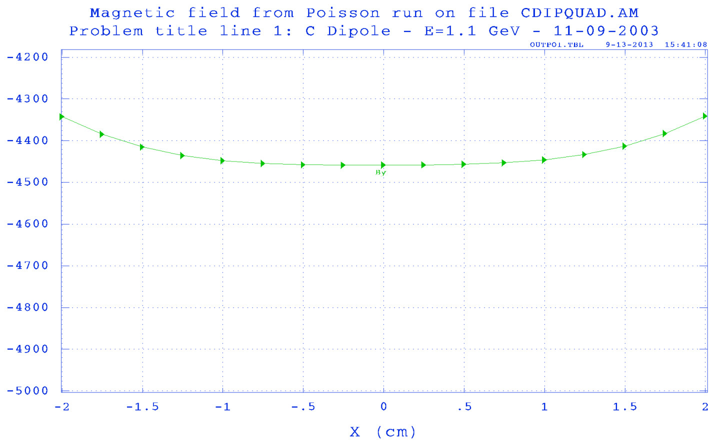

Figure 9: A zoom of the magnetic field around the magnet centre on the mid-plane of BSUP.

The following table collect the coefficients of the harmonic analysis of the magnetic field around the magnet centre (Point 0,0) on a circle having radius 1 cm, POISSON results, for the different dipoles foreseen in the lattice version 55.

Name	Bo	Gradient	Sextupole	Octupole	Decapole	Imain	Iquad
	Gauss	Gauss/cm	Gauss/cm^2	Gauss/cm^3	Gauss/cm^4	A	A
BQDM	4457	377	0.12	27.6	-10.0	12241	2273
BQDMA	4457	323.4	0.106	23.9	-10	12236	1945
BSUP/BARC	4457	0.014	0.067	1.67	-10.2	12225	0.9
B1	2772	-0.023	0.042	1.044	-6.35	7606.3	0.0
B3	3680	0.071	0.056	1.379	-8.425	10093.4	0.0
B2/B4/B5	4440	0.078	0.0674	1.665	-10.165	12177.9	0.5
BSB1	130	-0.0068	0.0021	0.049	-0.297	358.7	0.0

5. Simulation in 3D – OPERA Code

To validate the 2D simulations a 3D model, having the same cross-section simulated in 2D, has been developed. For simplicity the magnet is straight with a mechanical length of 0,5 m, even if the dipoles requested by the lattice, version 55, are specified to have bending radius of the order of 15 m or more and lengths in the range of 1,5 – 3 m. The aim of the simulation is the validation of the scheme and the evaluation of the differences between the 2d and the 3D calculation. Two examples have been considered, the first one refers to the one reported in chapter 4.1 and the second one to the one reported in 4.3.

Figure 10 shows the full model in the configuration considered in 4.1 where the currents in the coils are the same adopted in the 2D model. The colour in the two half poles is different due to the different value of the magnetic field in the iron.

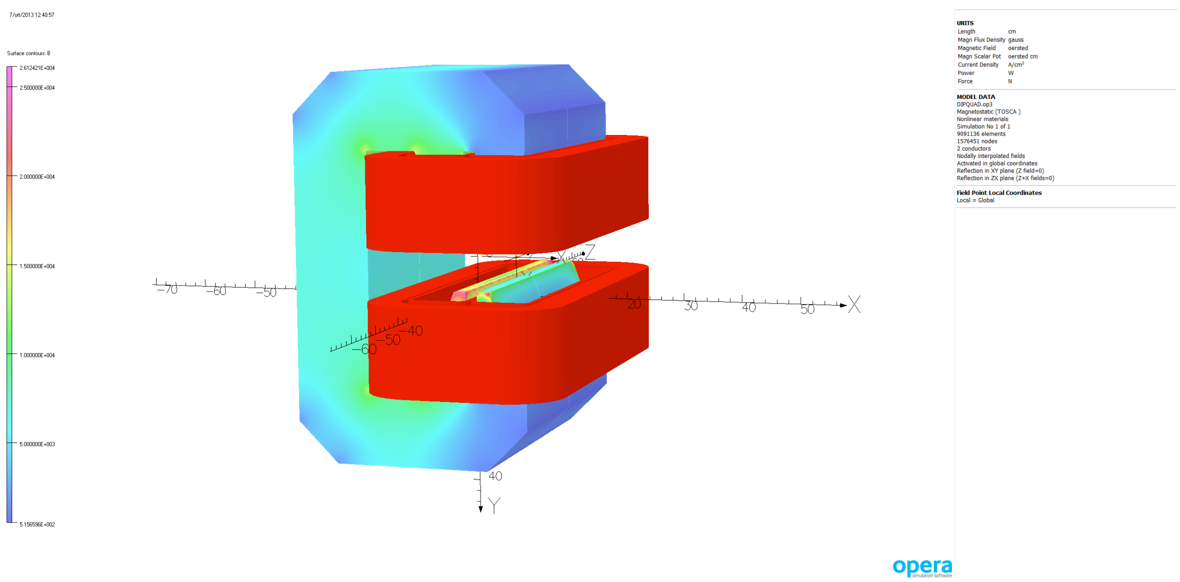

Figure 10: 3D full model of the geometry of example 4.1.

In figure 12 the comparison among the Poisson and OPERA results are reported. The POISSON results are the same shown in figure 4. The OPERA results are a little higher than the POISSON results with an offset of about 50 Gauss on the dipole term and a gradient term a little more stronger (394 against 377 Gauss/cm), even if the same iron magnetization curve (steel 1010) has been used in both cases. In principle this is not a problem since the currents in the main coils and in the quadrupole coils can be adjusted independently.

Also the example reported in 4.3 was simulated in 3D by OPERA using the same currents as in the 2D case. Figure 13, showing the magnetic field values on the mid-plane, is the equivalent of figure 8 but simulated by OPERA. The peak on the left side shows the magnetic field value in the backleg meanwhile on the right side the magnetic field value under the poles, on the mid-plane, is shown.

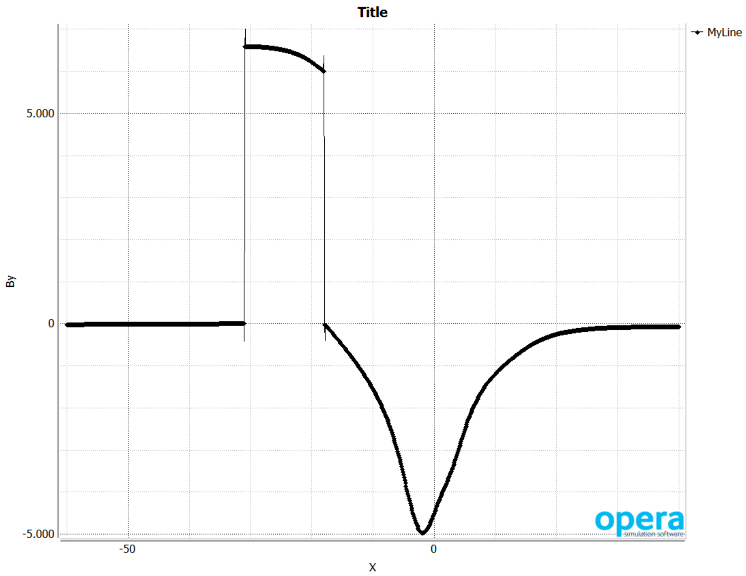

Figure 11: Magnetic field profile on the magnet mid-plane at the magnet centre. The peak on the left corresponds to the backleg. The magnet centre is at x=0.0. OPERA Code.

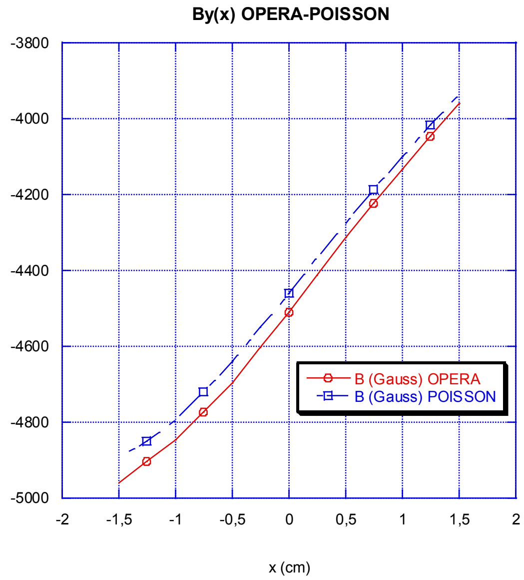

Figure 12: Comparison between POISSON (blue line) and OPERA (red line) of the magnetic field around the magnet centre on the mid-plane of BQDM.

Figure 14 shows the comparison between the POISSON and OPERA result when the quadrupole coils are switched off. The example corresponds to the BSUP/BARC case. The Poisson data are the same shown in figure 9. As in the previous example, there is an offset of about 50 Gauss between the two codes.

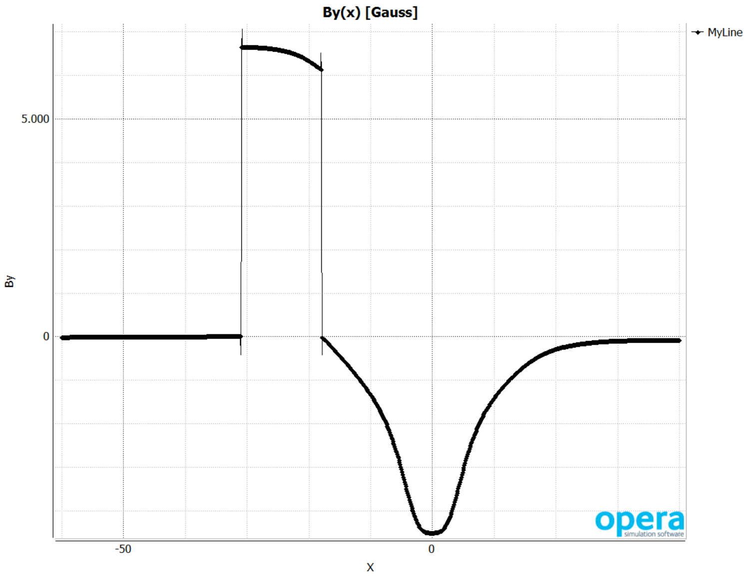

Figure 13: Magnetic field profile on the magnet mid-plane. The peak on the left corresponds to the backleg. The magnet centre is at x=0.0. OPERA Code.

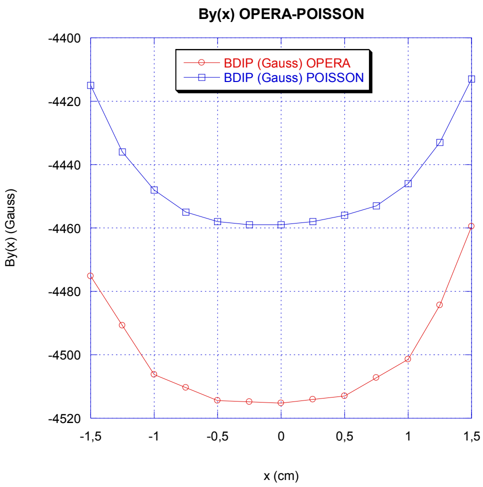

Figure 14: A zoom of the magnetic field around the magnet centre on the mid-plane of BSUP. POISSON and OPERA comparison.

6. Conclusions

The found magnet geometry and coil configuration allow to adopt the same iron lamination cross-section for all the magnet foreseen for the tau-charm storage rings.

Tuning properly the current value in the “quadrupole coils” it seems possible to obtain the desired Field Index or quadrupole gradient, giving a lot of flexibility. Even the zero Field Index dipoles can be obtained switching off, or near switching off, the “quadrupole coils”.

The sextupole terms seems to be very sensitive to the flat length of the pole facing the mid-plane but a solution with near zero sextupole term seems to be reachable. Other terms probably are not so small as desirable but with more fine optimization, may be, they can be lowered.

Obviously, different magnetic length and different curvature radius can be obtained mechanically during the packing of the laminations on suitable moulds.

It should be very useful if a prototype of such kind of magnet, after a more detailed simulations and optimization, should be realized.