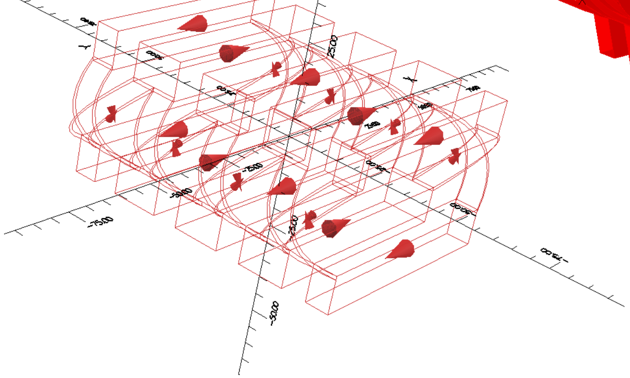
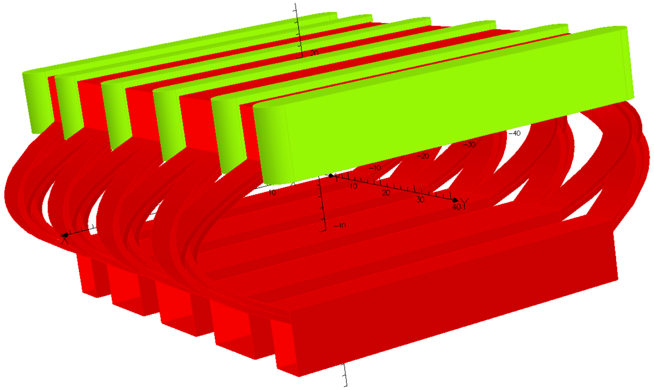
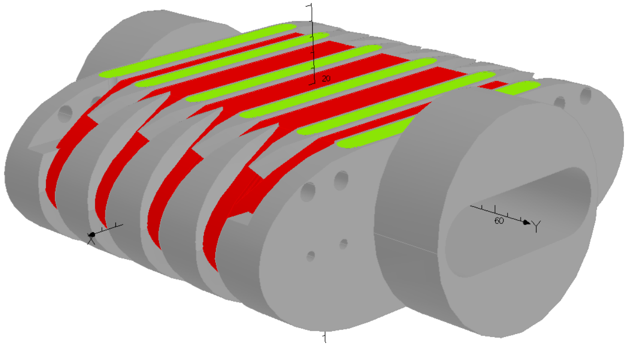
Wiggler modeling

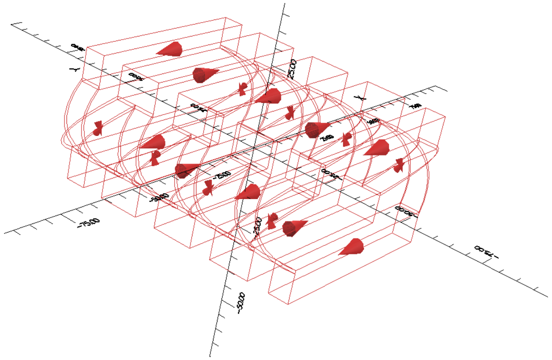
Double-helix like option

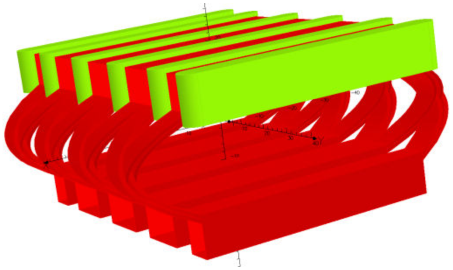
Simona Bettoni and Remo Maccaferri, CERN

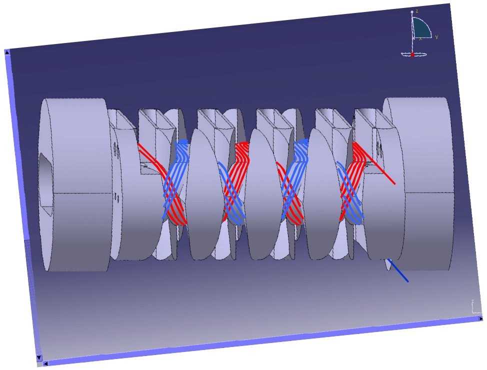




Outline

- Introduction
- The model
  - 2D (Poisson)
  - 3D (Opera Vector Fields-Tosca)
- The analysis tools
  - Field uniformity
  - Multipoles (on axis and trajectory)
  - Tracking studies
- The integrals of motion cancellation
  - Possible options
  - The final proposal
- The prototype analysis
- Conclusions

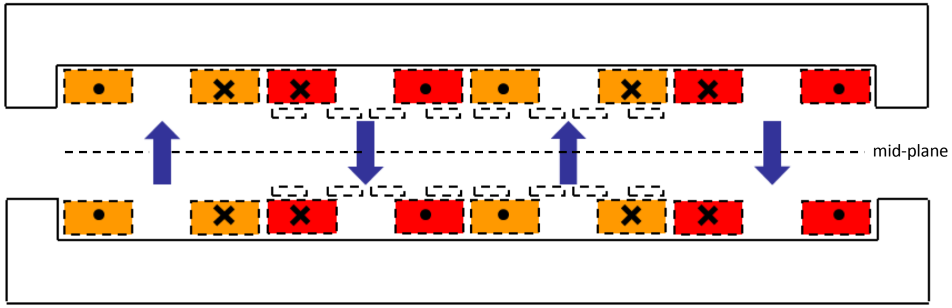


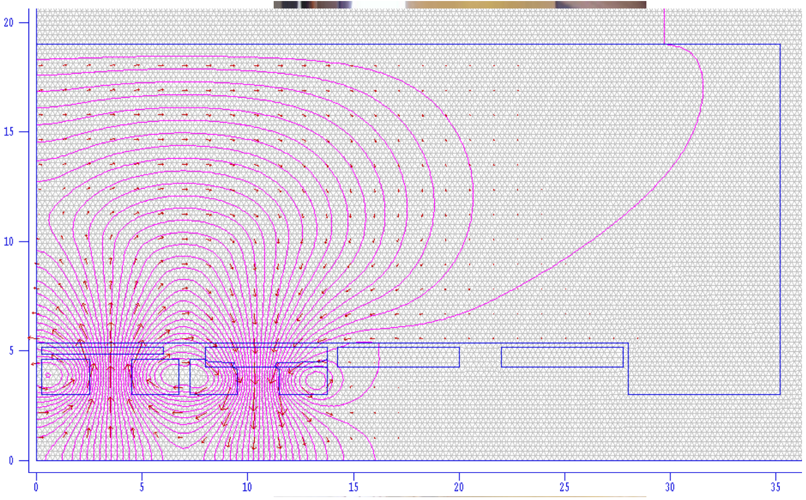




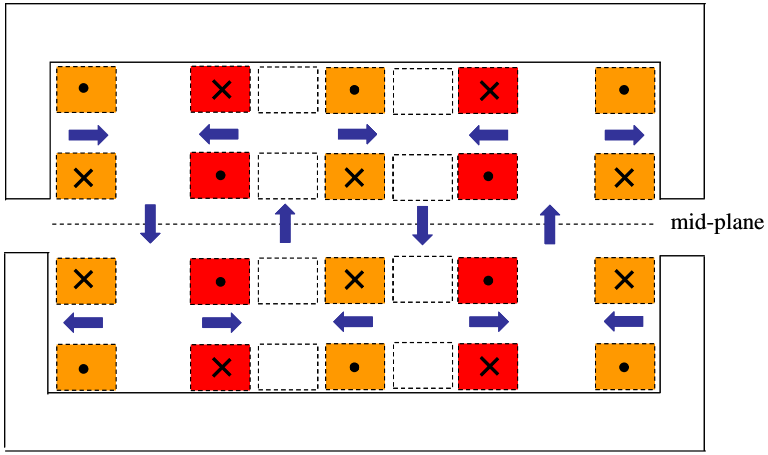
Wigglers/undulators model

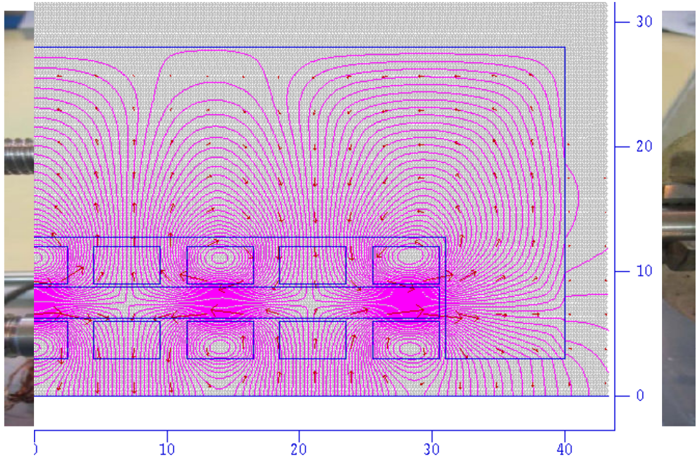
Large gap & long period



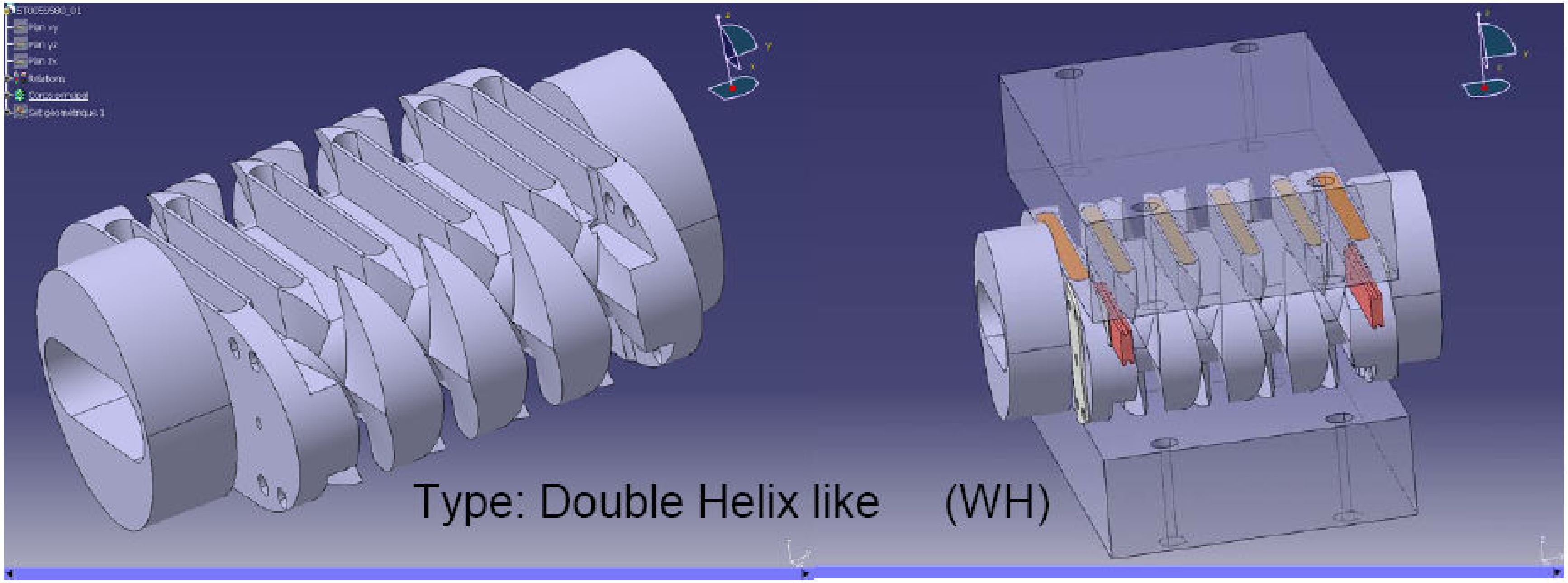


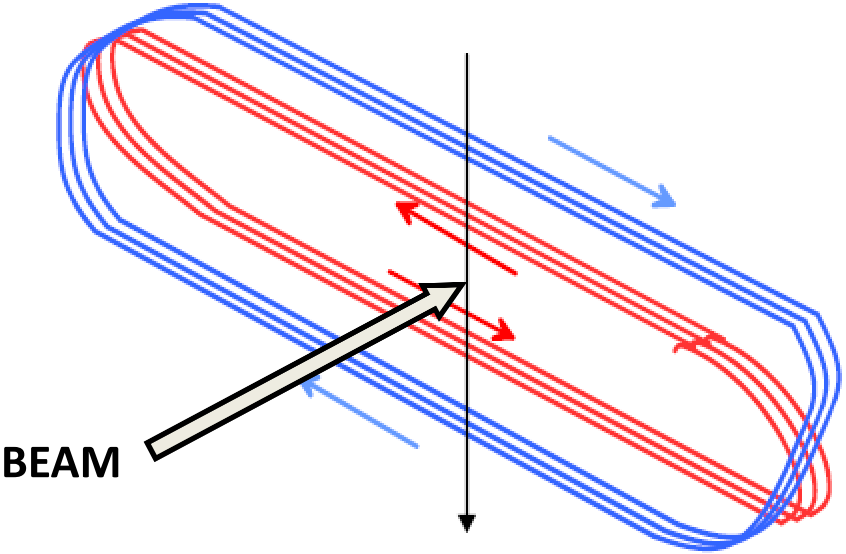
Small gap & short period

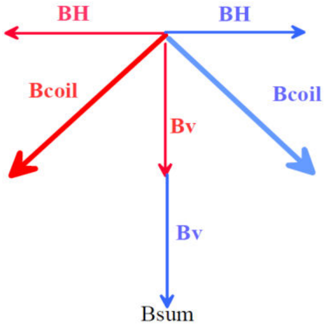




2D design (proposed by R. Maccaferri)


Type: Double Helix like (WH)

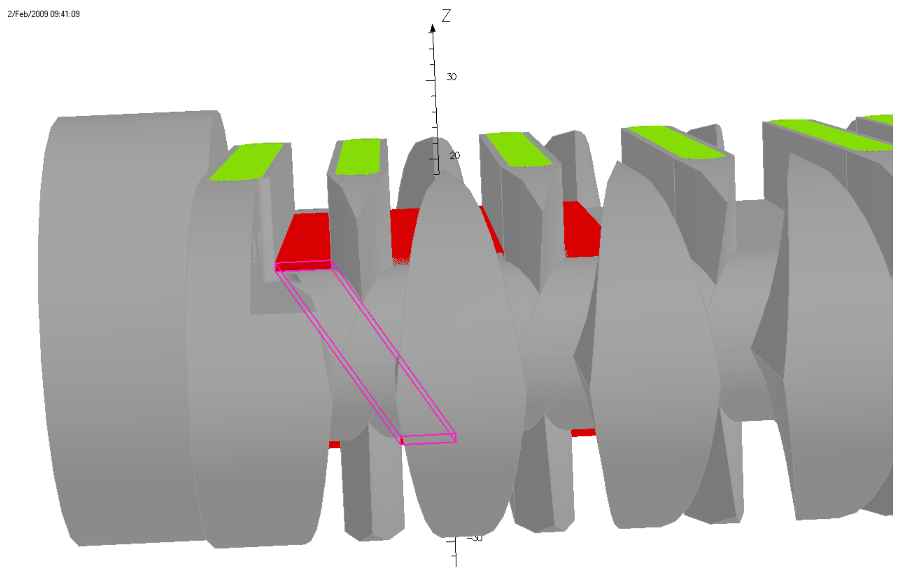


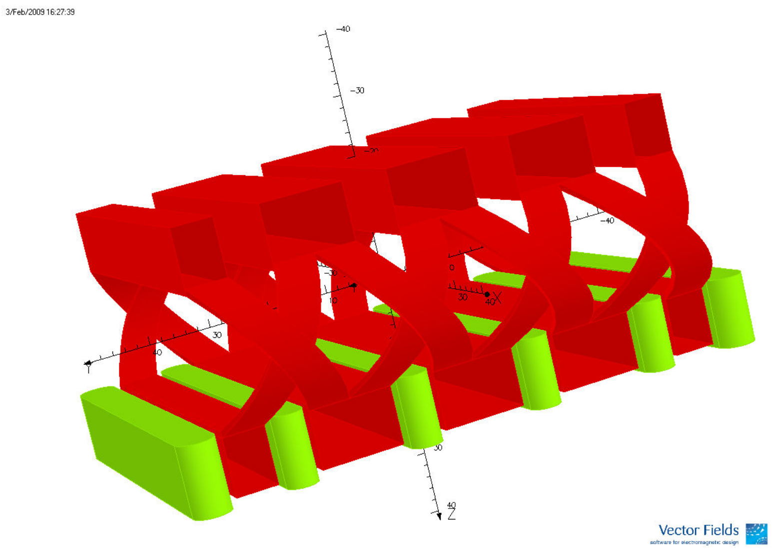


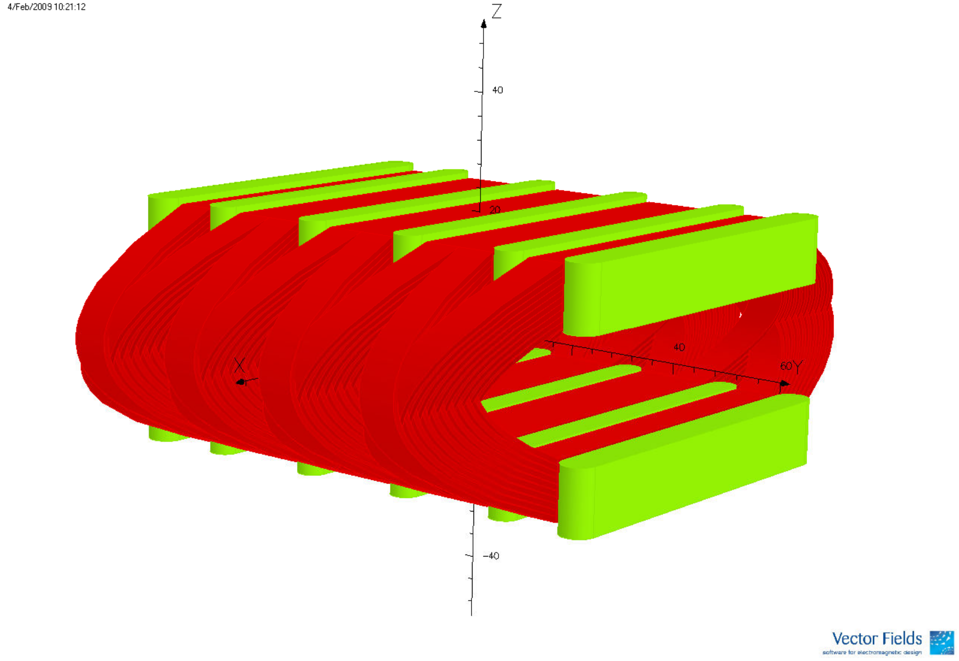
Advantages:

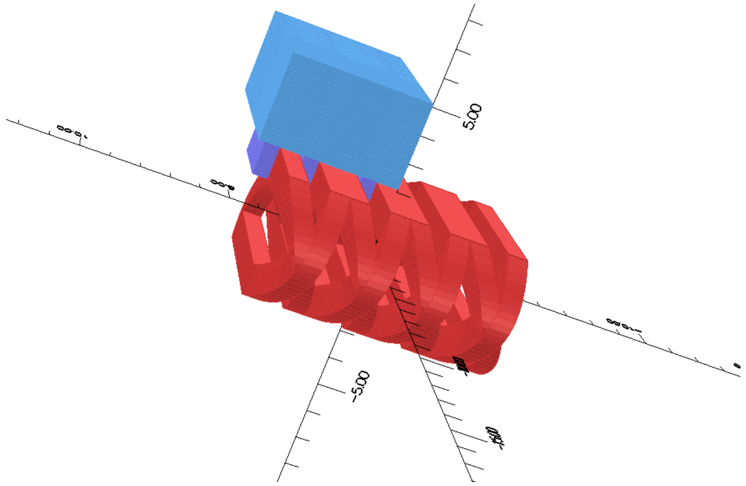
- ✓Save quantity of conductor
- ✓Small forces on the heads (curved part)

The 3D model

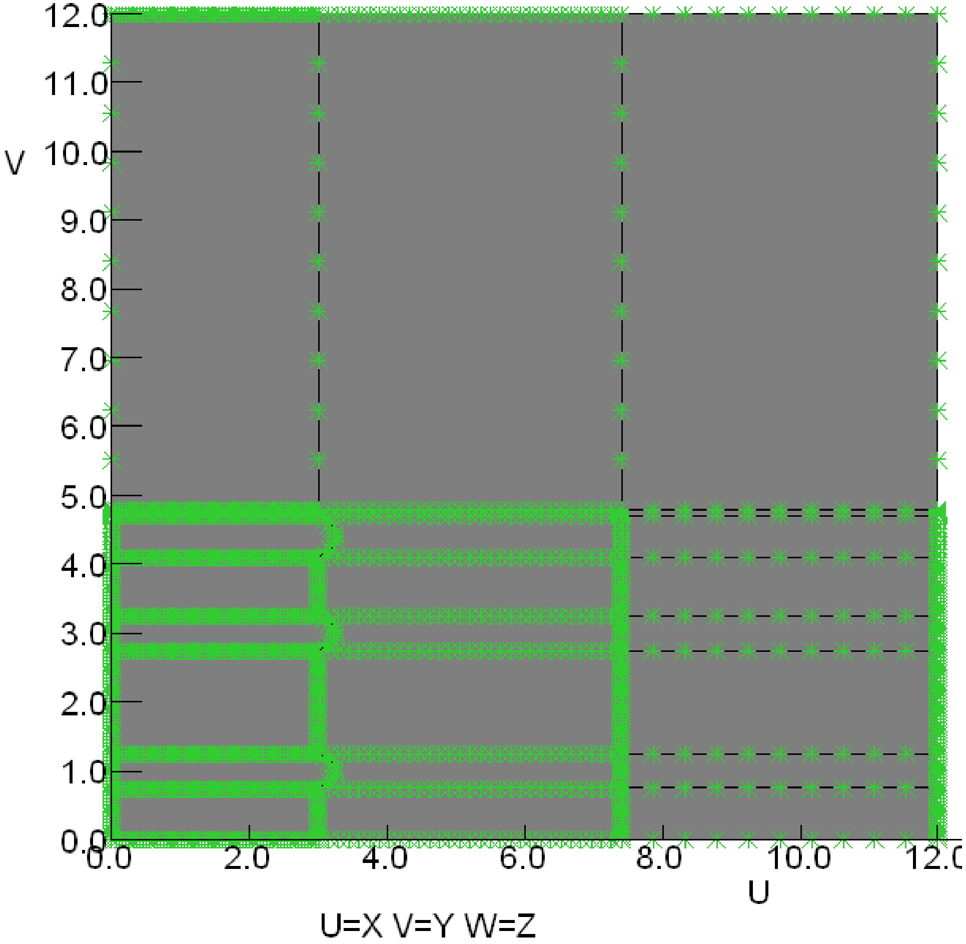

2/Feb/2009 09:41:09
Z
30
20
-30

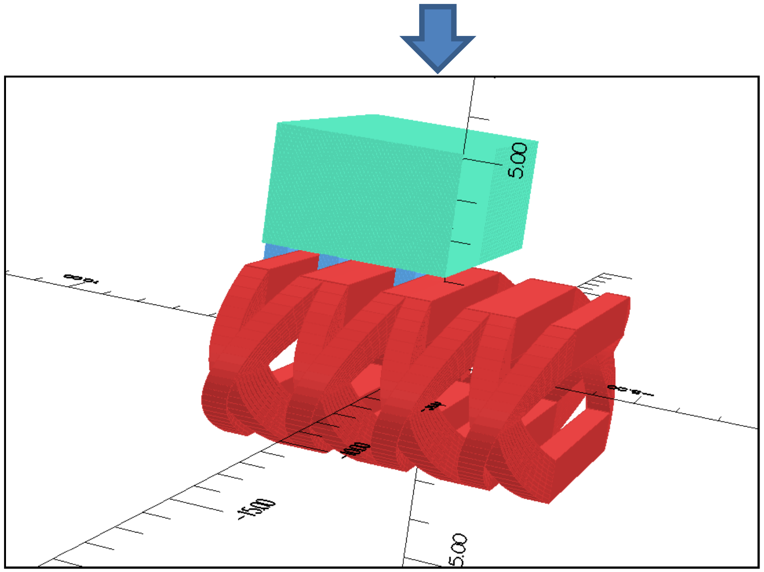

3/Feb/2009 16:27:39
-40
-30
-40
30
40
30
40
Y
X
Z
Vector Fields
software for electromagnetic design

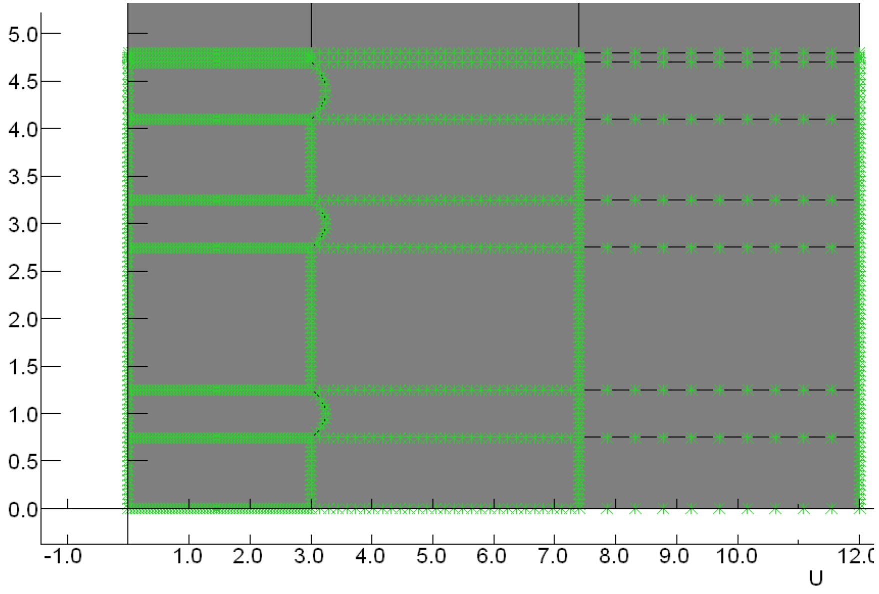

4/Feb/2009 10:21:12
Z
40
20
40
60Y
X
-40
Vector Fields
software for electromagnetic design


5.00
-5.00

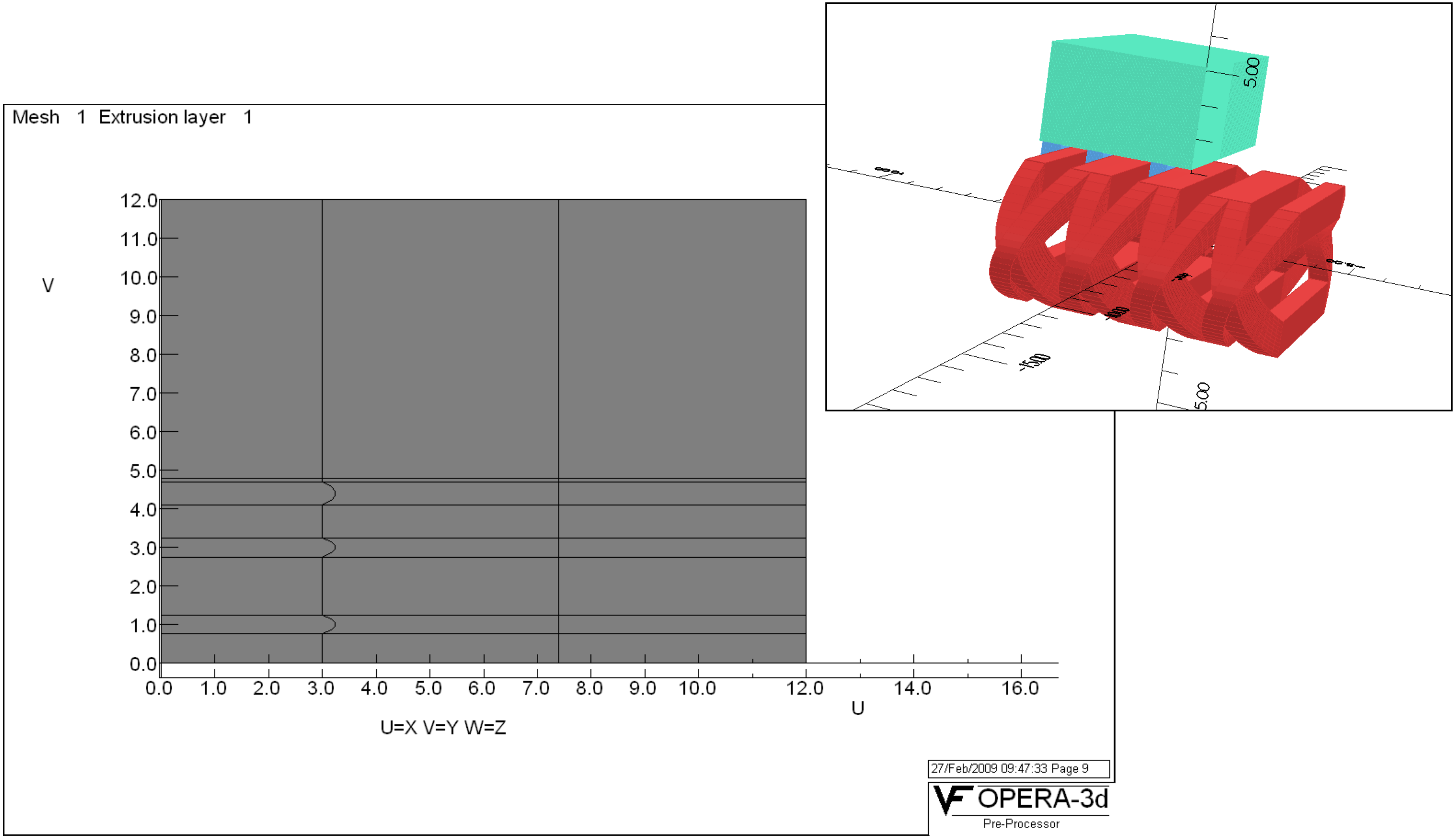
The 3D model (base plane)



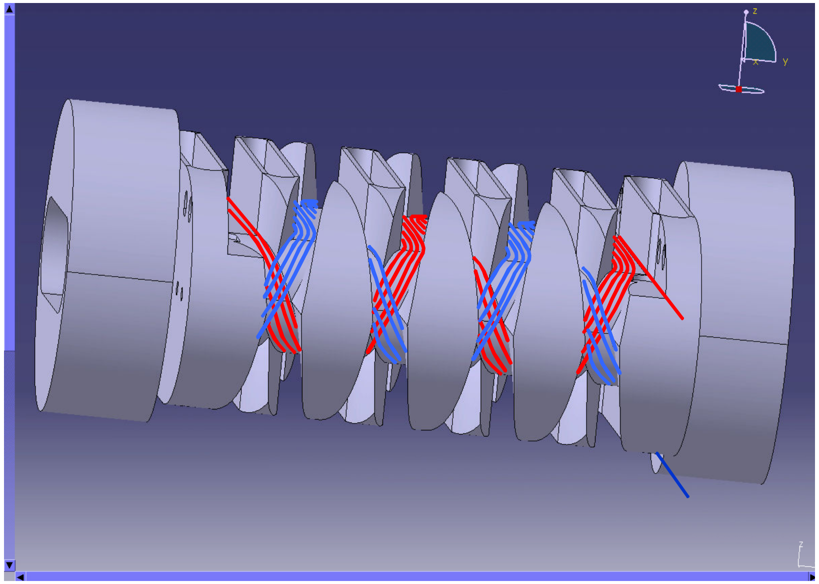




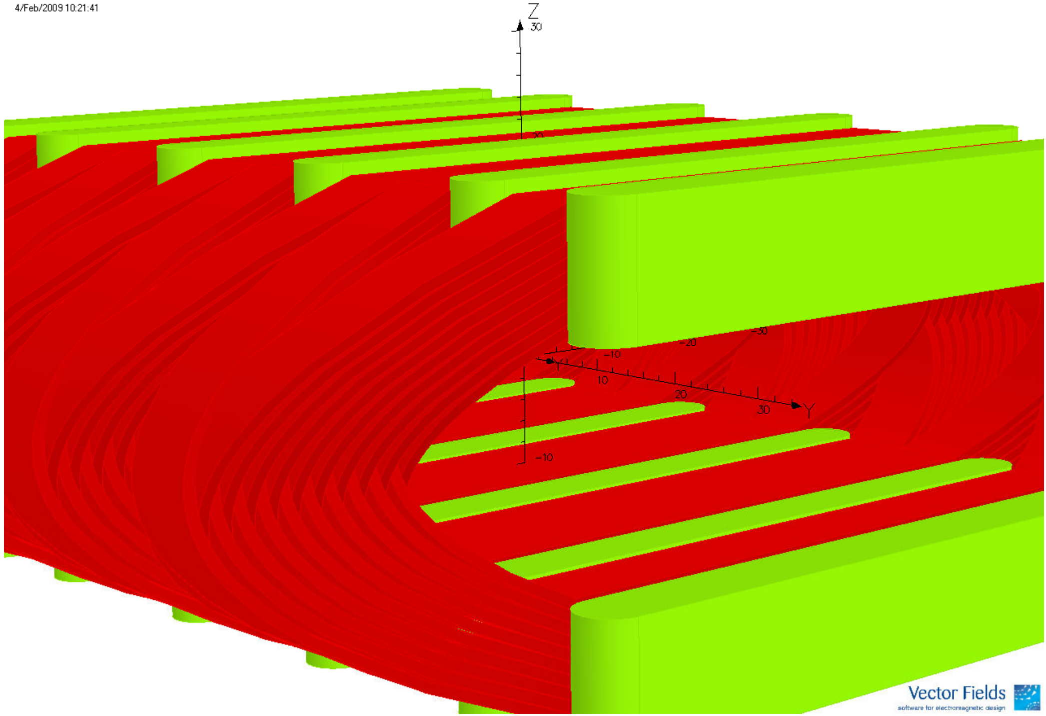
The 3D model (extrusions)



The 3D model (conductors)



Conductors generated using a Matlab script



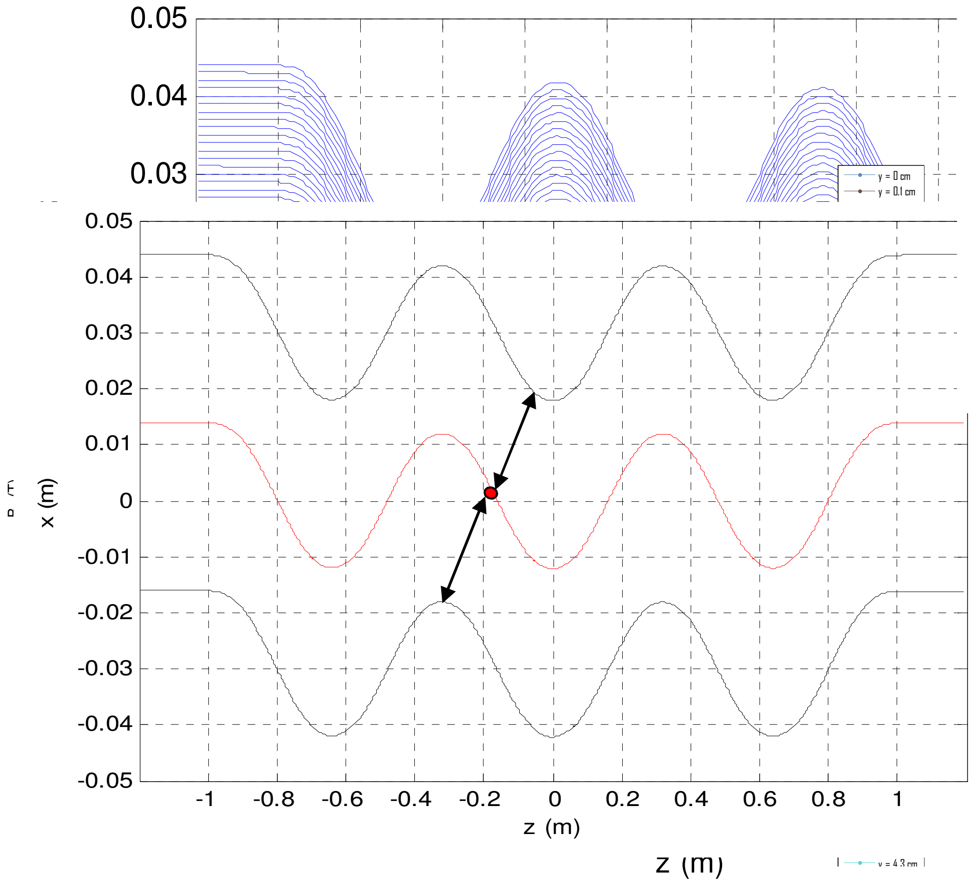
✓Conductors grouped to minimize the running time

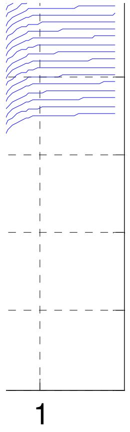
✓Parameters the script:

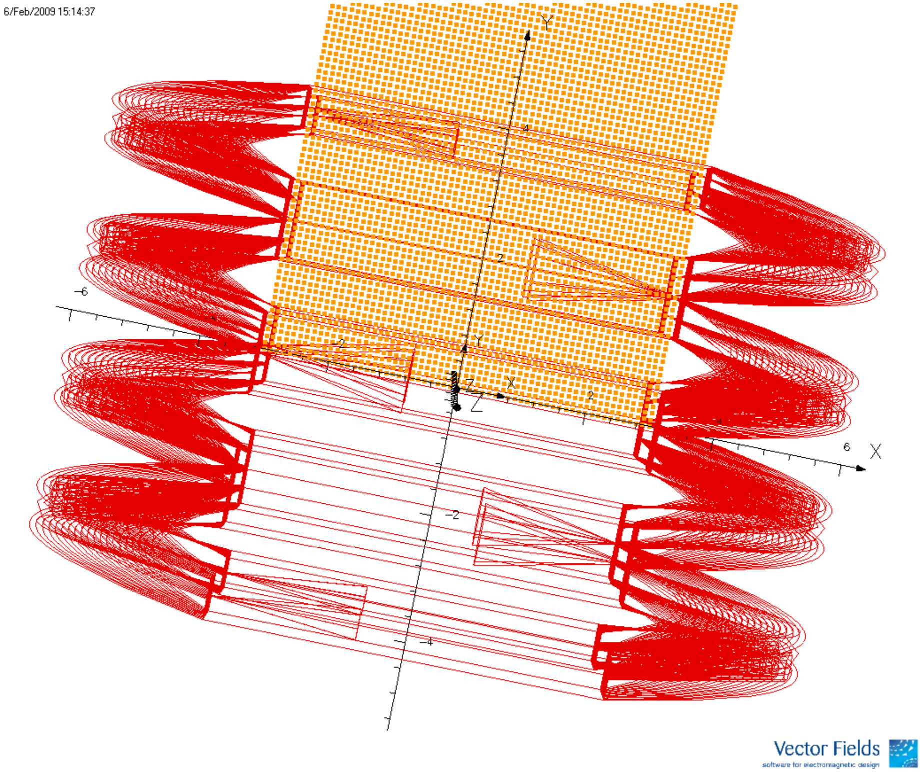
- ○ Wire geometry (l_h, l_v, l_trasv)
- ○ Winding “shape” (n_layers, crossing positions)

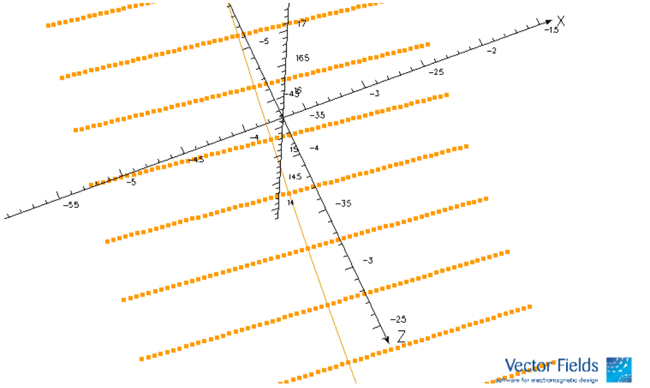
The analysis tools

- ○ Tracking analysis:
  - Single passage: ready/done
  - Multipassage: to be implemented
- ○ Field uniformity: ready/done
- ○ I

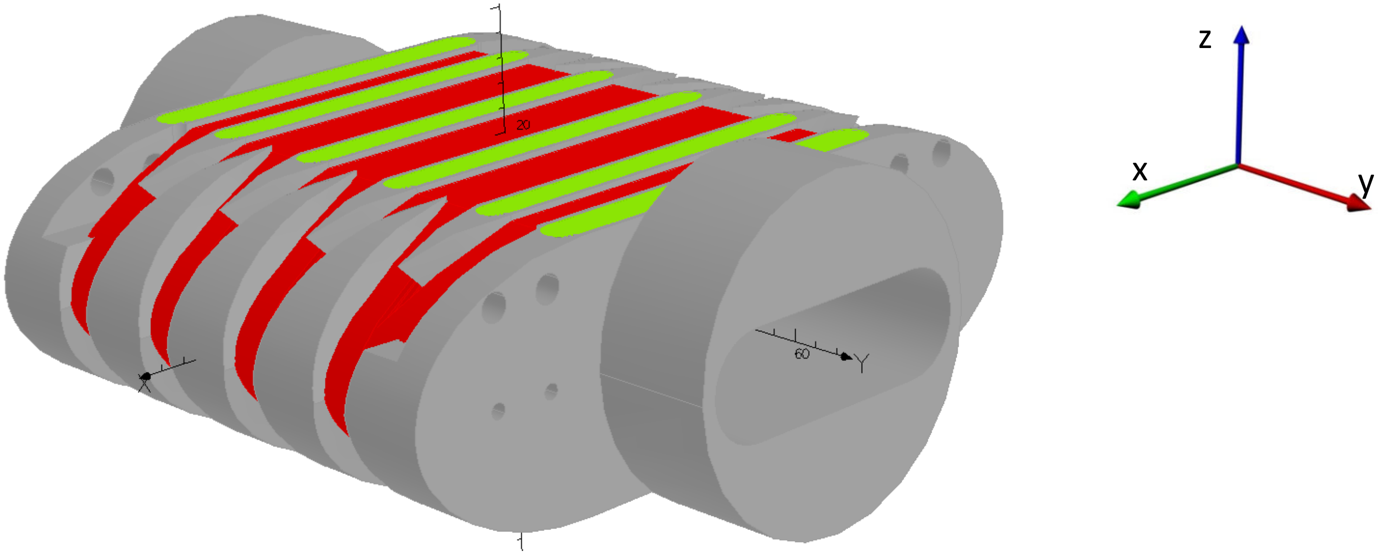








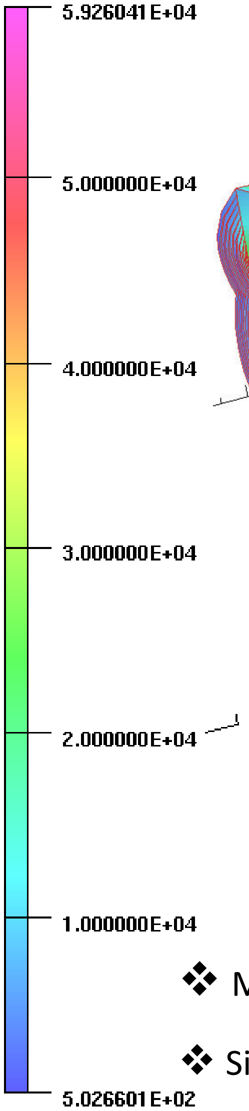
Prototype analysis

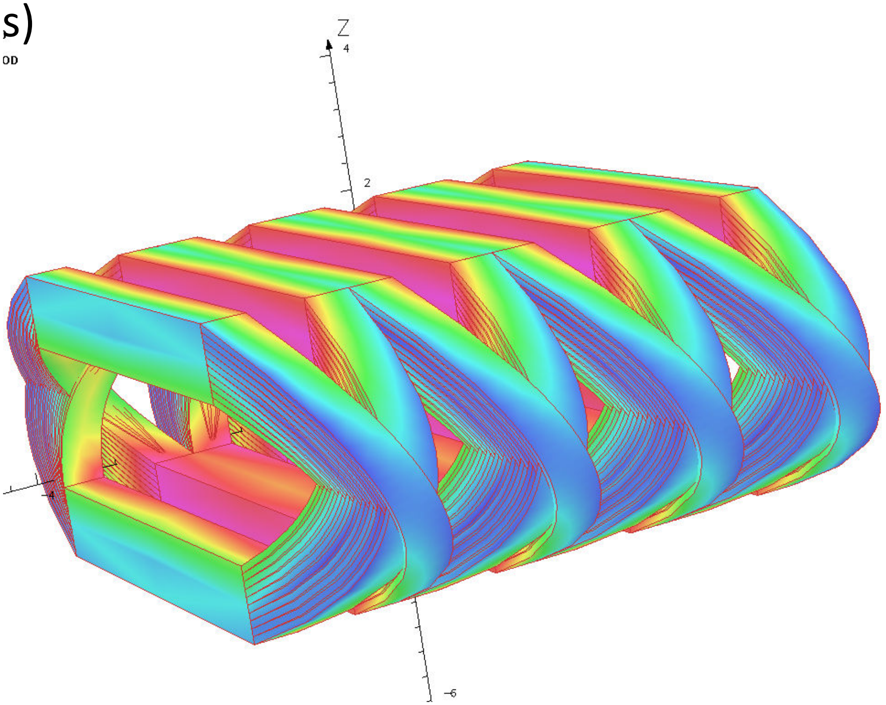


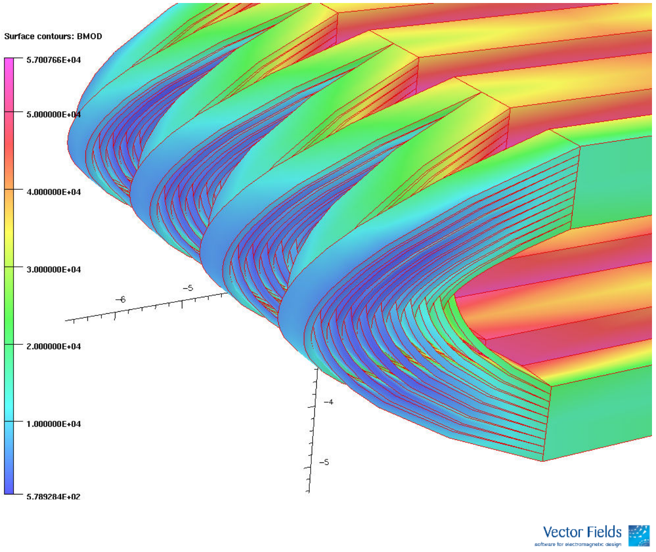
Period (mm)	Gap (mm)	Number of periods	Total length (cm)
40	20	2	9.4+flanges length

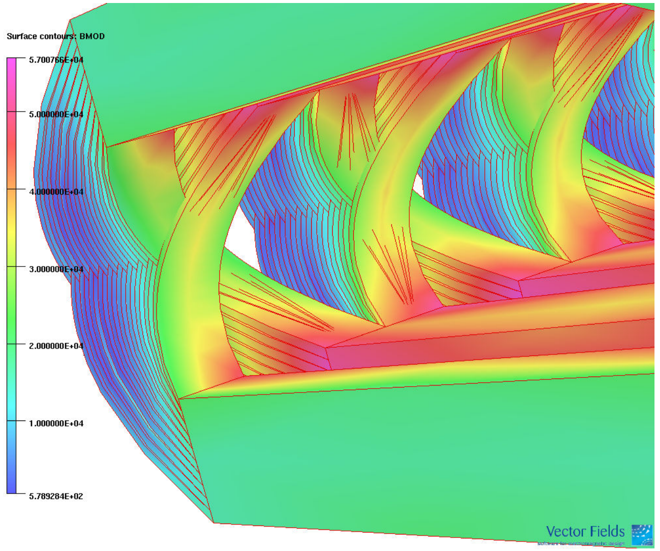
Field distribution on the conductors

B_{Mod} (Gauss)







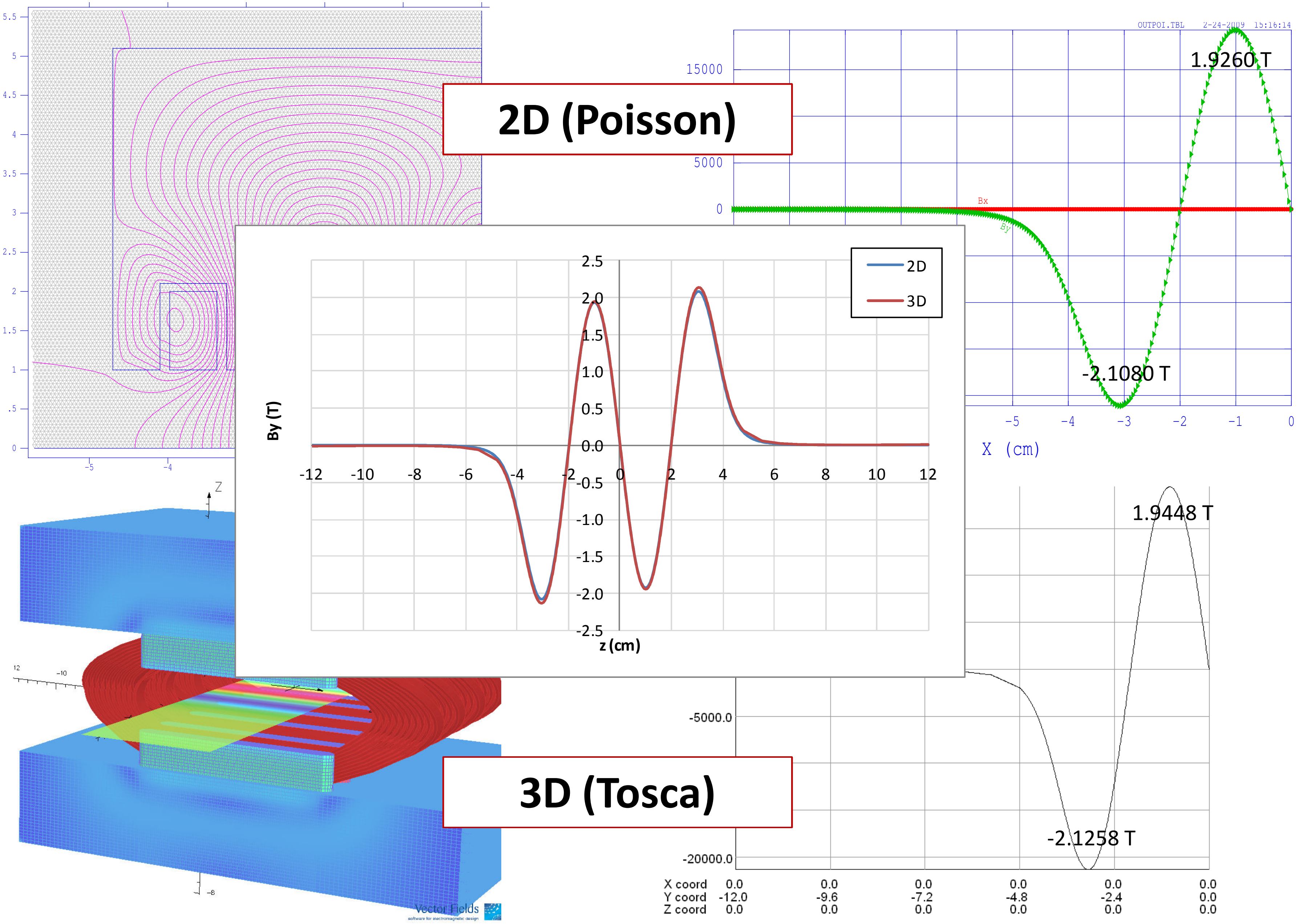


Maximum field and forces (P_{MAX} ~32 MPa)

on the **straight part**

- Manufacture: well below the limit of the maximum P for Nb_3Sn
- Simulation: quick to optimize the margin (2D)

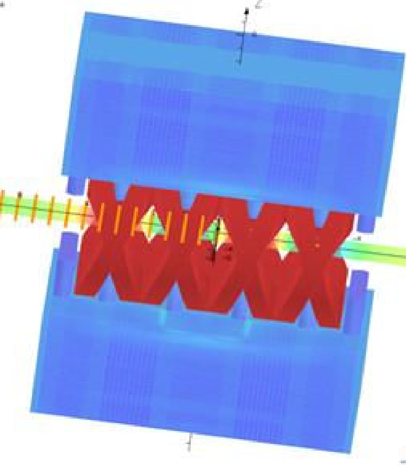
The 2D/3D comparison



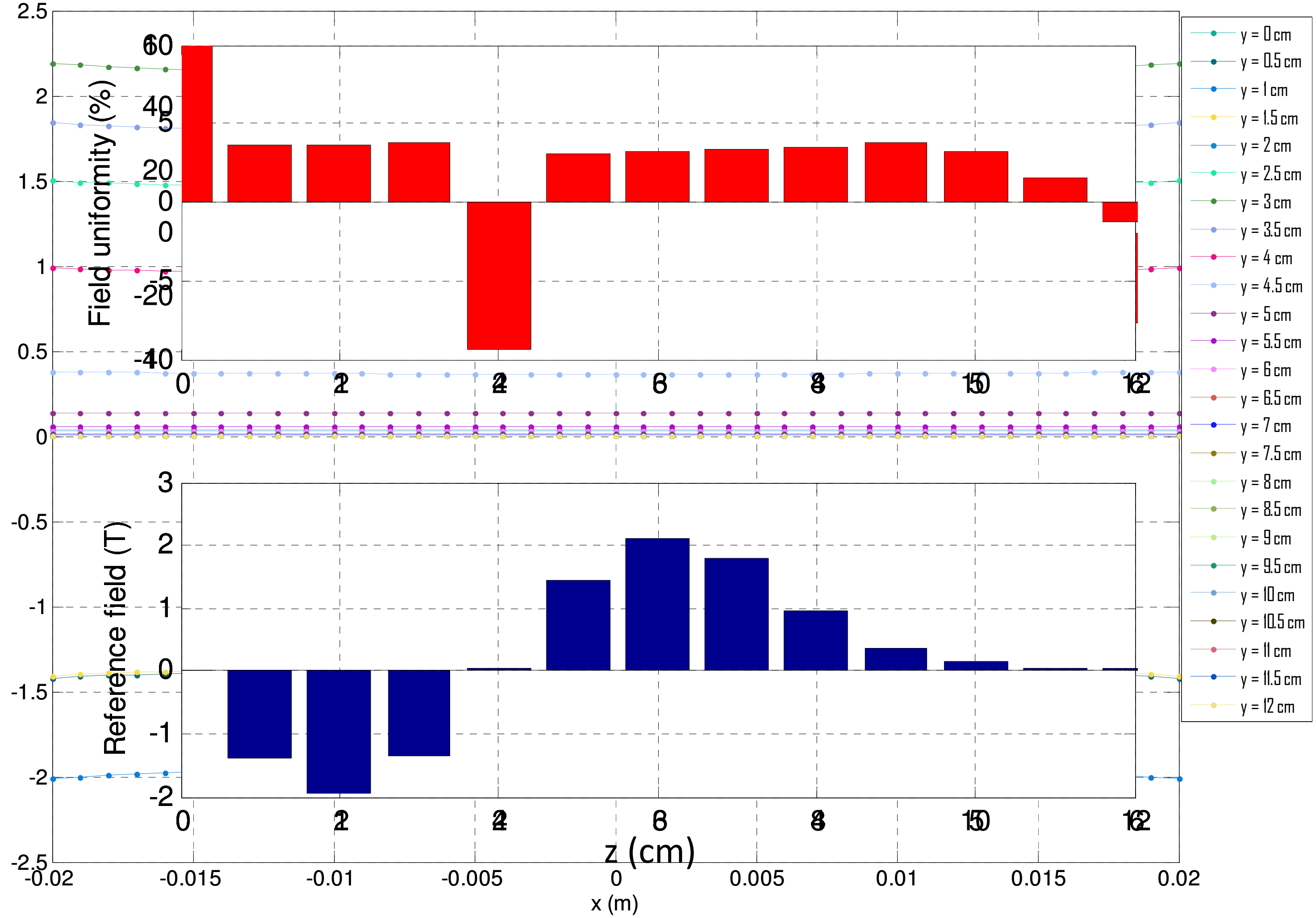
2D (Poisson)

3D (Tosca)

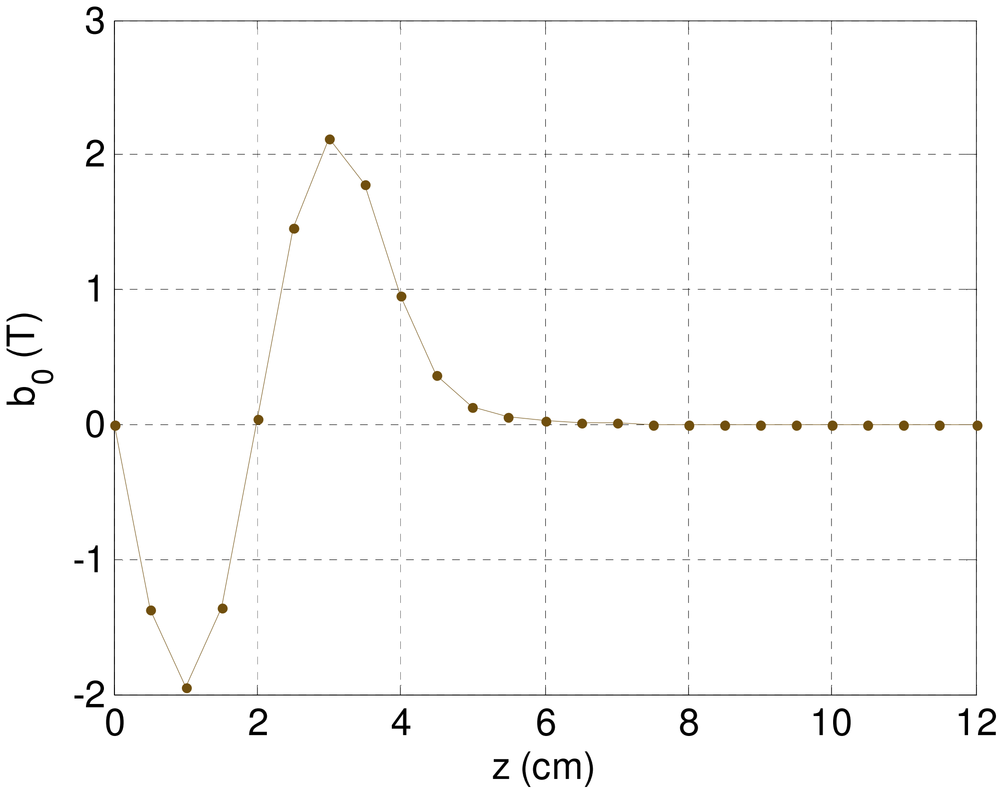
Field uniformity (x range = ±2 cm)



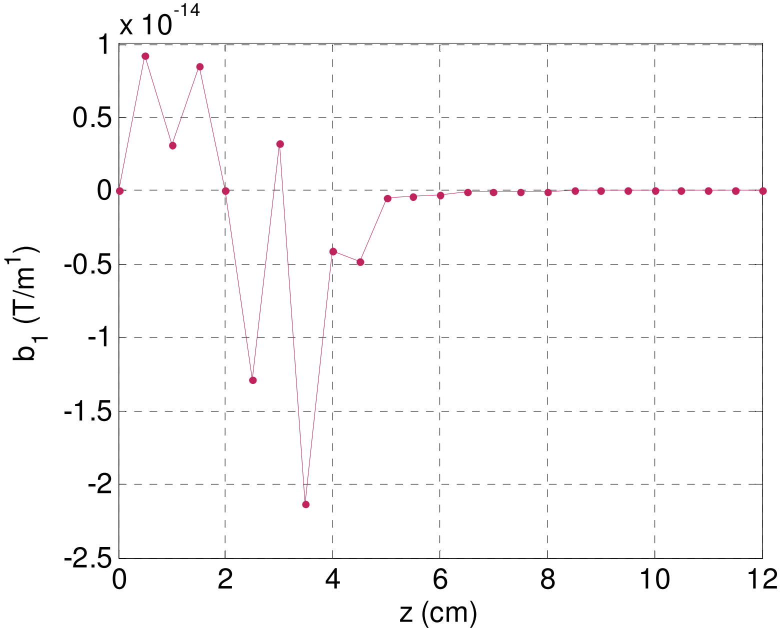
$$Field \quad uniformity\,(\%) \equiv \frac{B_z(x=2\ cm)-B_z(x=0\ cm)}{B_z(x=0\ cm)}\cdot 100$$



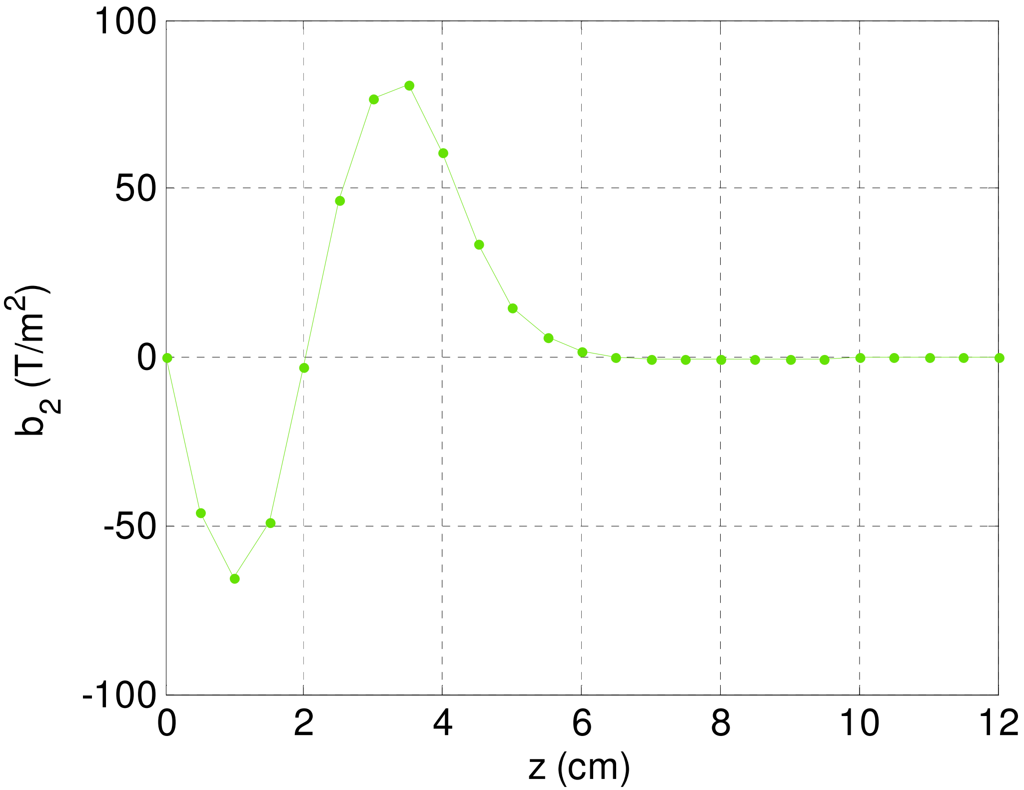
Multipolar analysis (x range = ±2 cm)



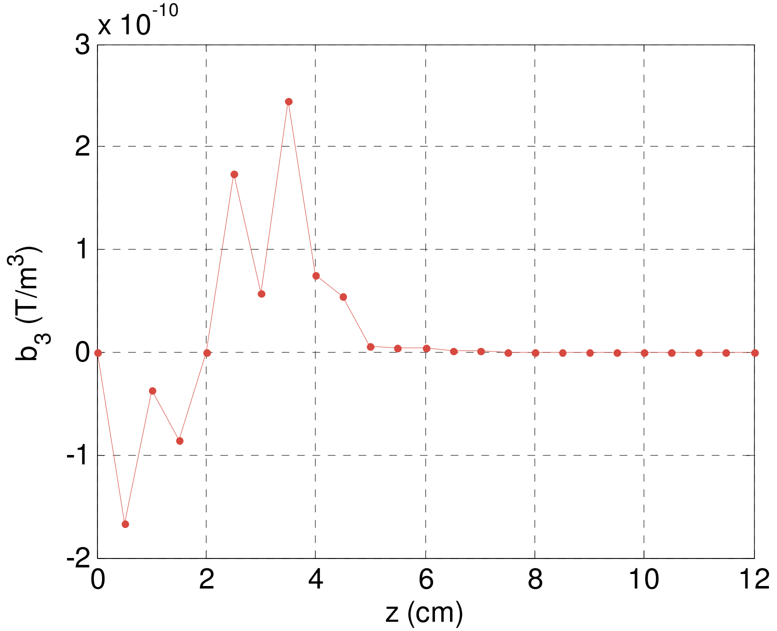
$$B_z(x) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4$$



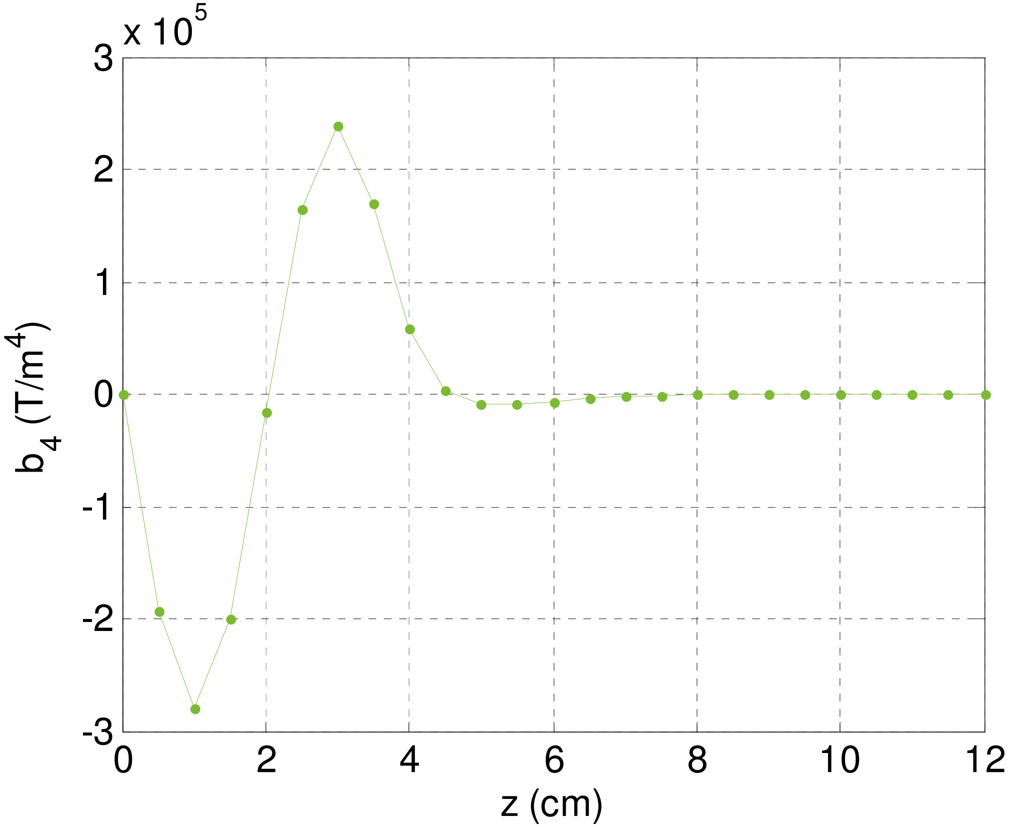
Multipolar analysis (x range = ±2 cm)



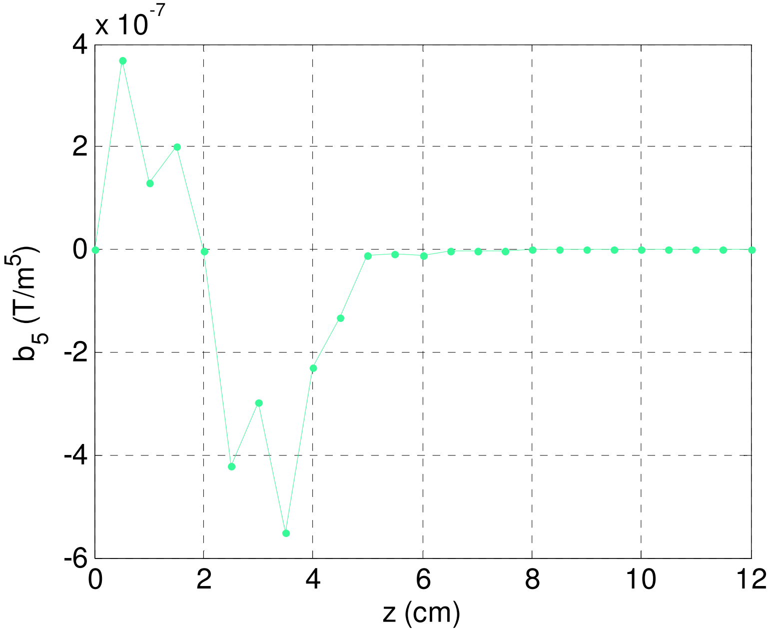
$$B_z(x) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4$$



Multipolar analysis (x range = ±2 cm)

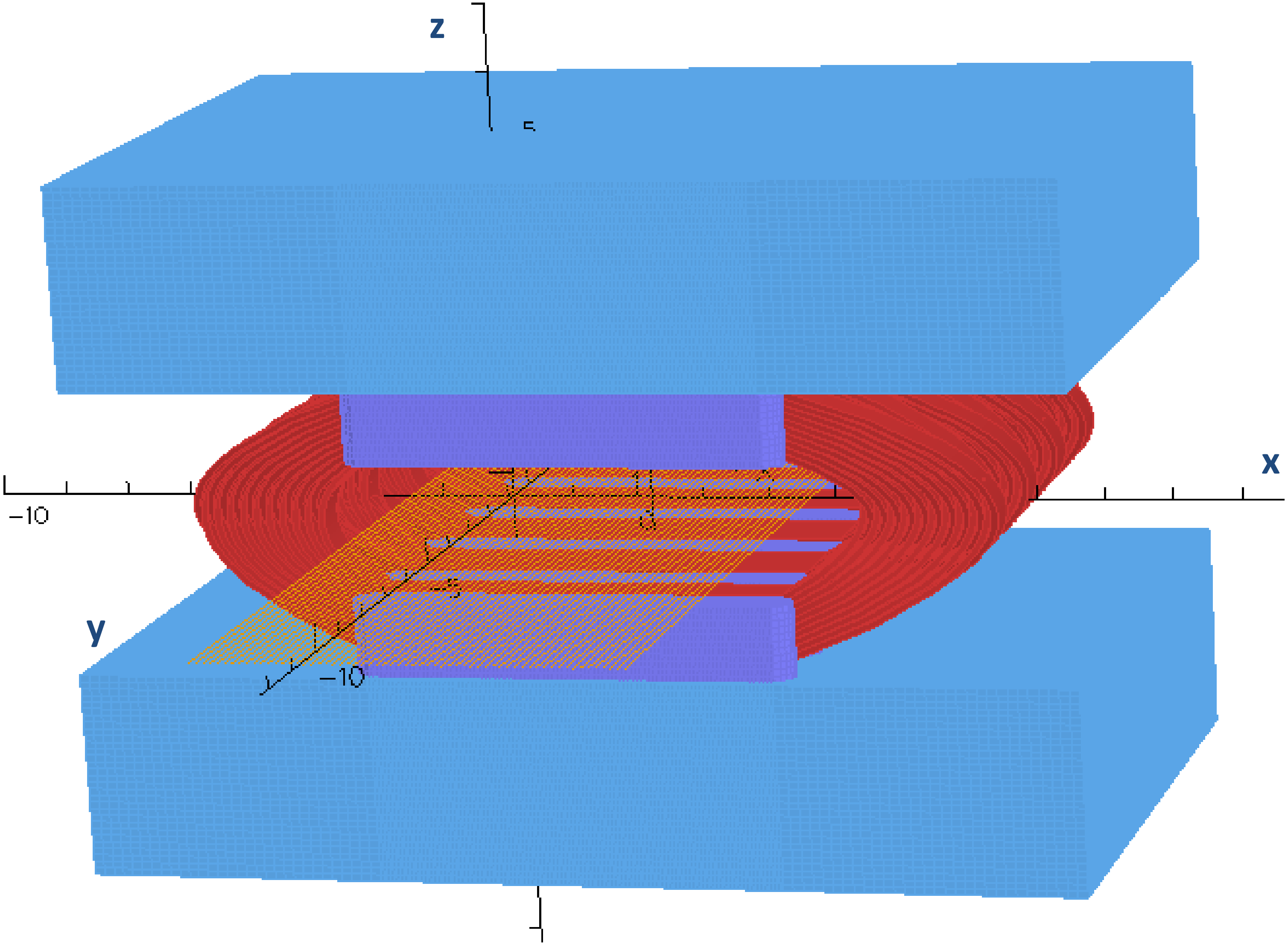


$$B_z(x) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4$$

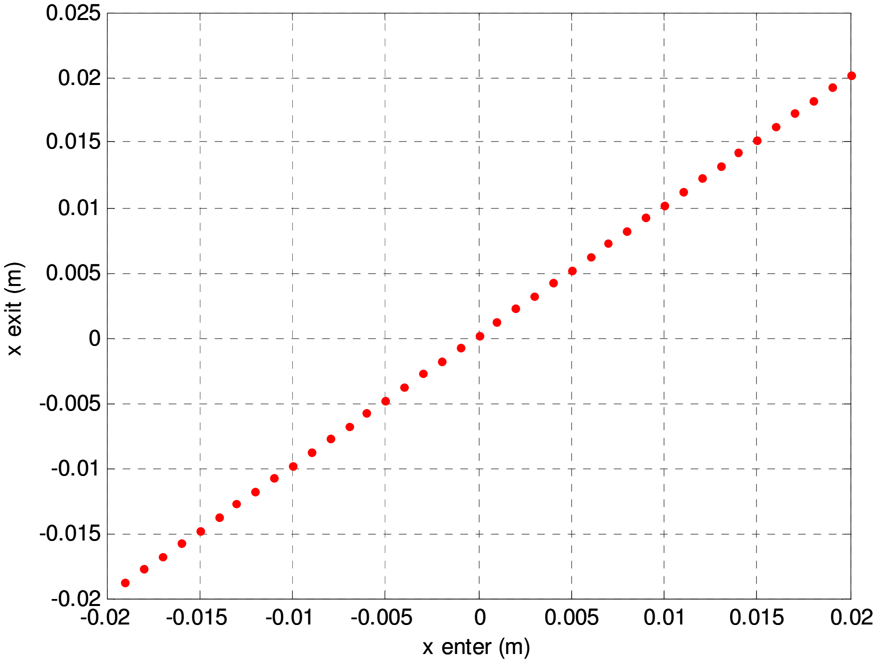


Tracking studies

Trajectory x-shift at the entrance = ± 3 cm



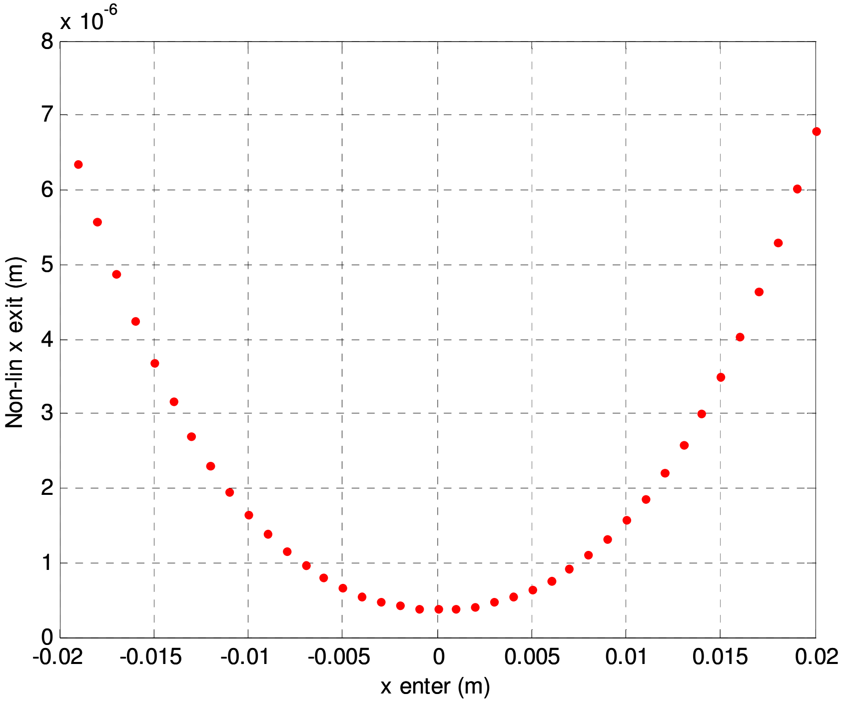
Tracking studies: the exit position



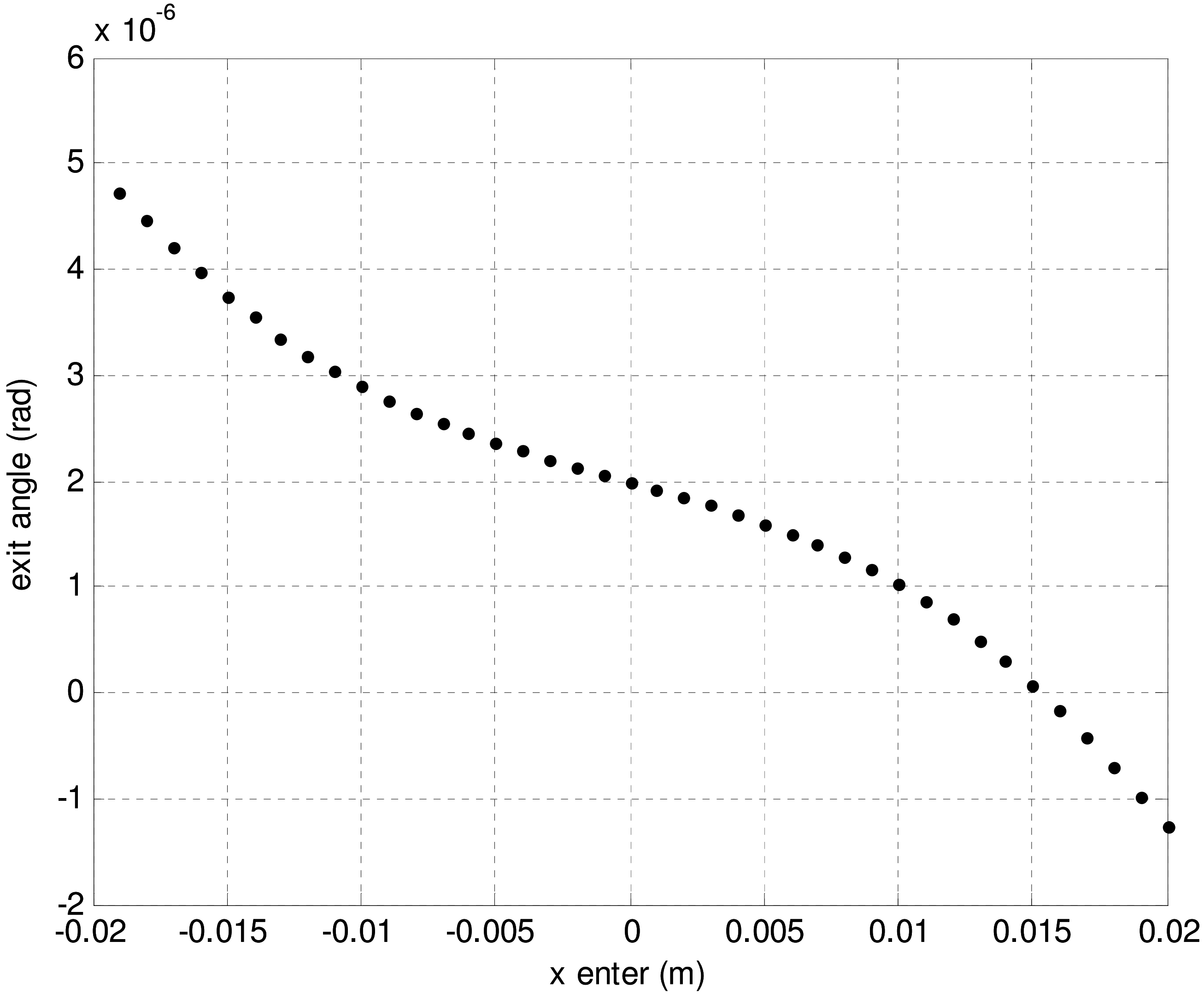
$$x_{Exit} = a_0 + a_1 \cdot x_{Entr} + a_2 \cdot x_{Entr}{}^2 + a_3 \cdot x_{Entr}{}^3 + a_4 \cdot x_{Entr}{}^4 + a_5 \cdot x_{Entr}{}^5$$

Subtracting the
linear part

$$x_{Exit} = a_2 \cdot x_{Entr}{}^2 + a_3 \cdot x_{Entr}{}^3 + a_4 \cdot x_{Entr}{}^4 + a_5 \cdot x_{Entr}{}^5$$



Tracking studies: the exit angle

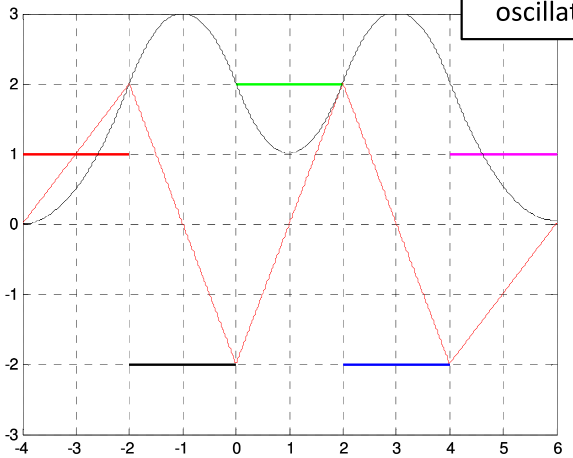


Integrals of motion

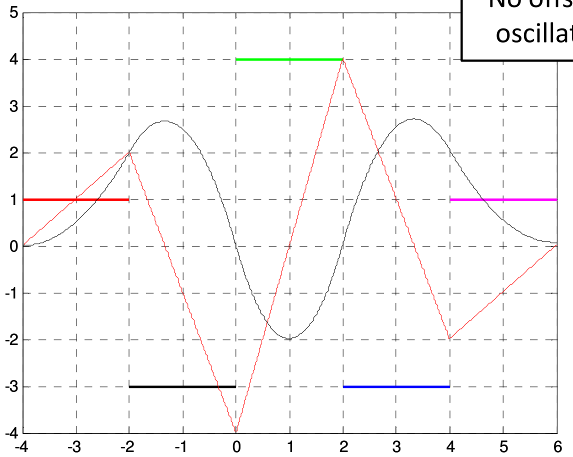
1st integral → $x'(s) = \frac{e}{\gamma mc}\int_{-\infty}^{s} ds'\ B_z(s')$ **= 0 for anti-symmetry**

2nd integral → $x(s) = \frac{e}{\gamma mc}\int_{-\infty}^{s} ds' \int_{-\infty}^{s'} ds''\ B_z(s'')$

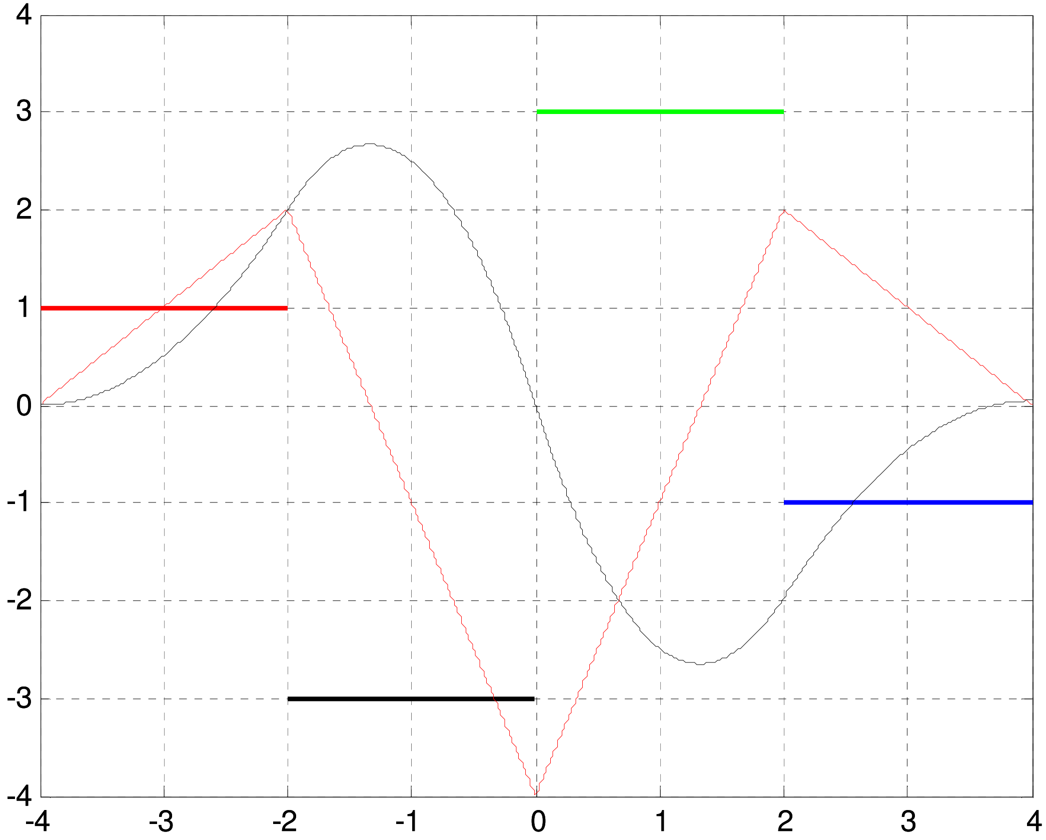
Offset of the oscillation axis



No offset of the oscillation axis



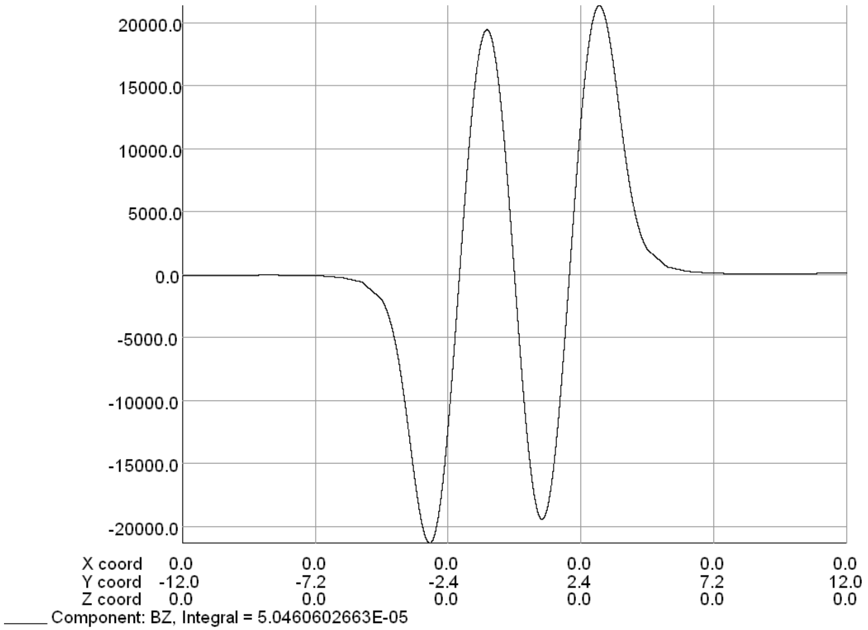
CLIC case: even number of poles (anti-symmetric)

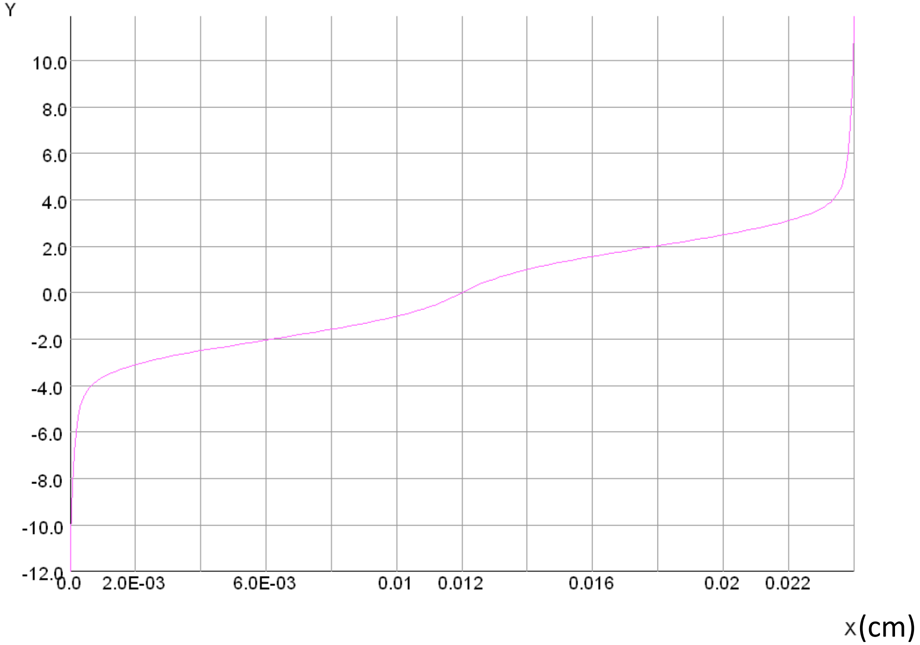


Integrals of motion: the starting point

1st integral $x'(s) = \frac{e}{\gamma m c}\int_{-\infty}^{s} ds'\; B_z(s')$ **= 0 for anti-symmetry**

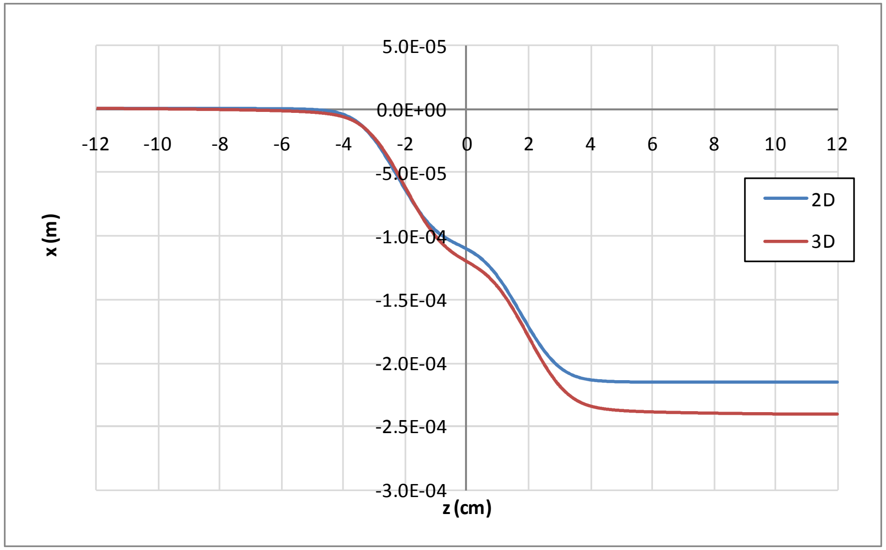
2nd integral $x(s) = \frac{e}{\gamma m c}\int_{-\infty}^{s} ds' \int_{-\infty}^{s'} ds''\; B_z(s'')$



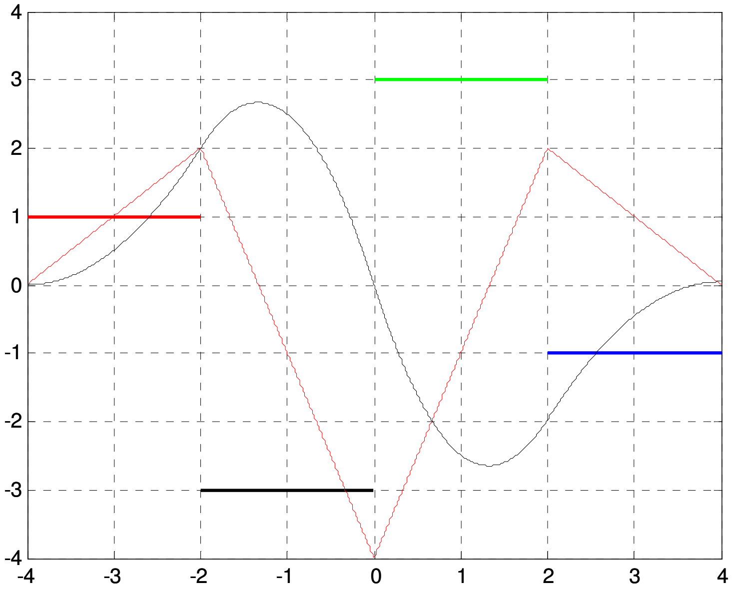


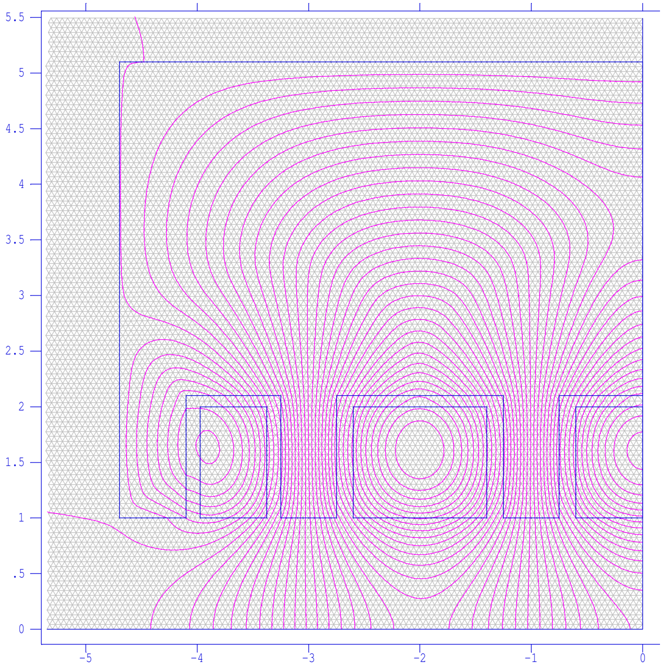
First integral Bz * dy	Second integral Bz * dy
5e-5 Gauss*cm	-1.94e5 Gauss*cm^2
5e-11 T*m	-1.94e-3 T*m^2

Lowering the 2nd integral: what do we have to do?

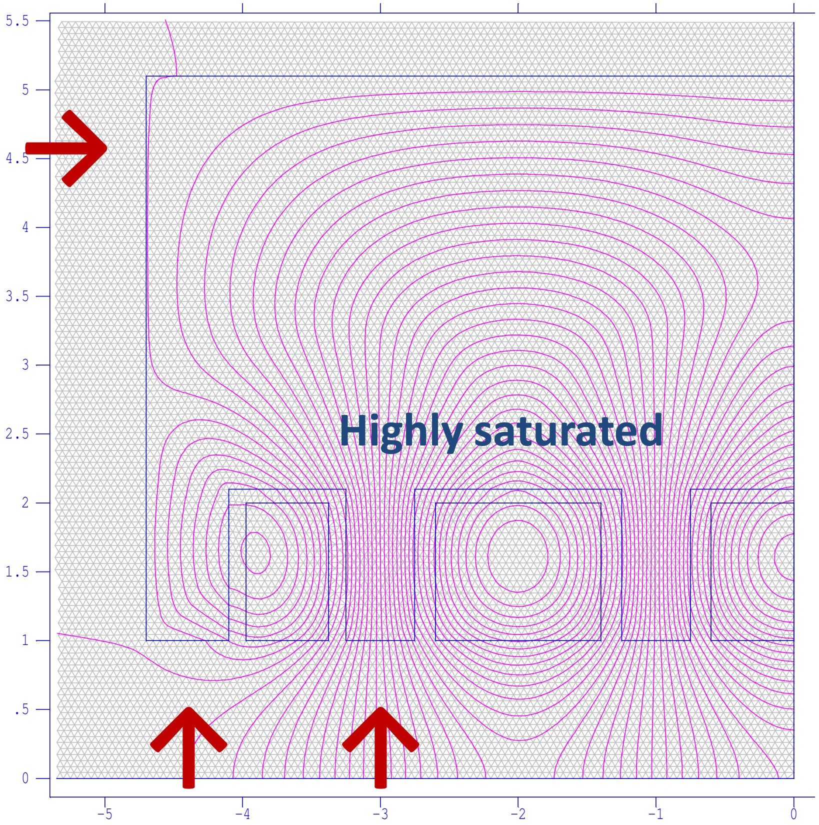


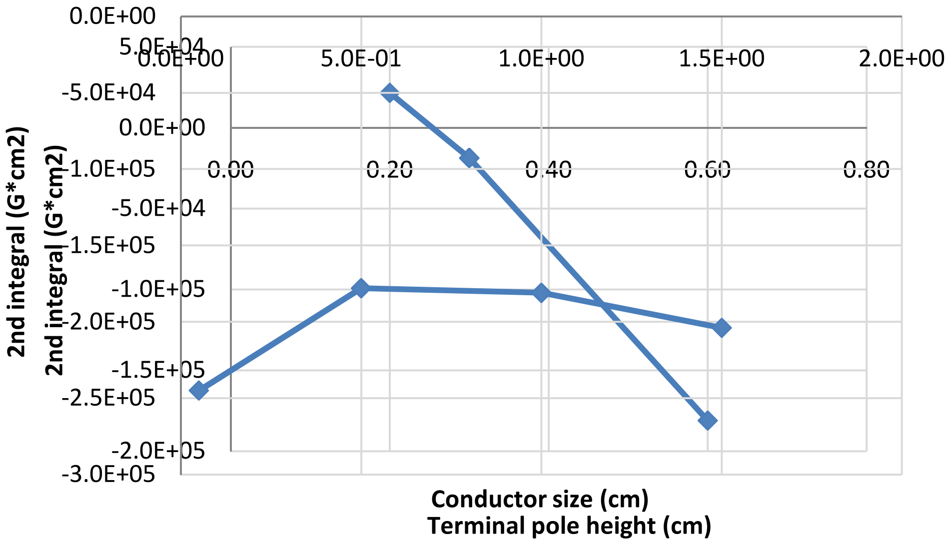
To save time we can do tracking studies in 2D up to a precision of the order of the difference in the trajectory corresponding to the 2D/3D one (~25 μm) and only after refine in 3D.





Lowering the 2nd integral: how can we do?

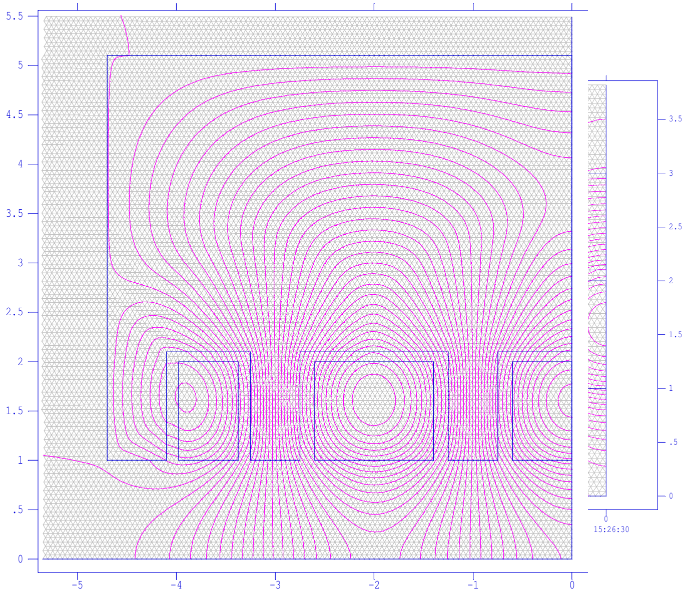


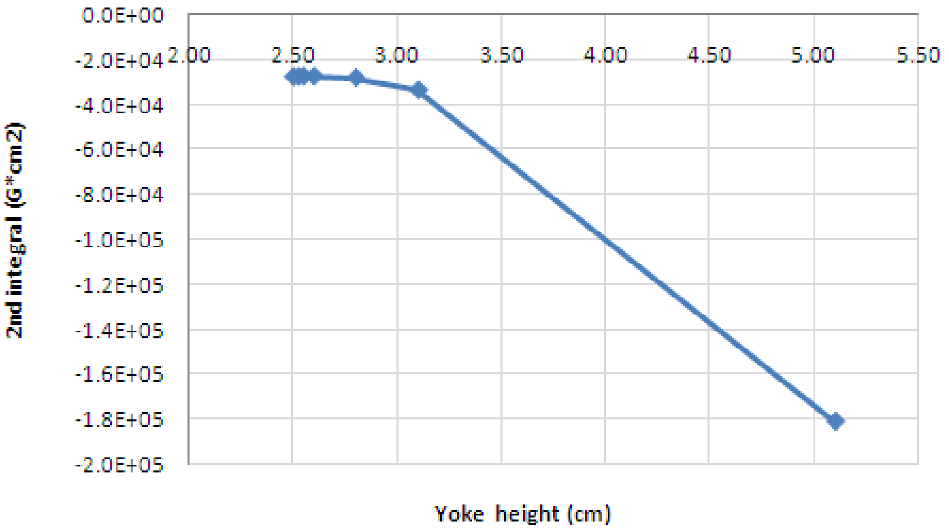


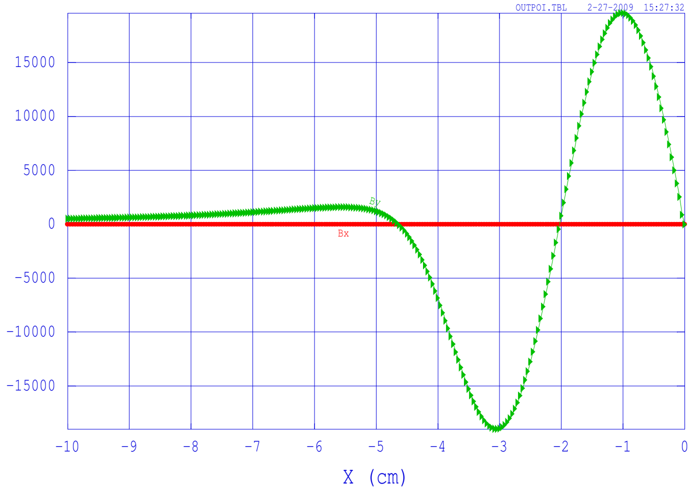
What we can use:

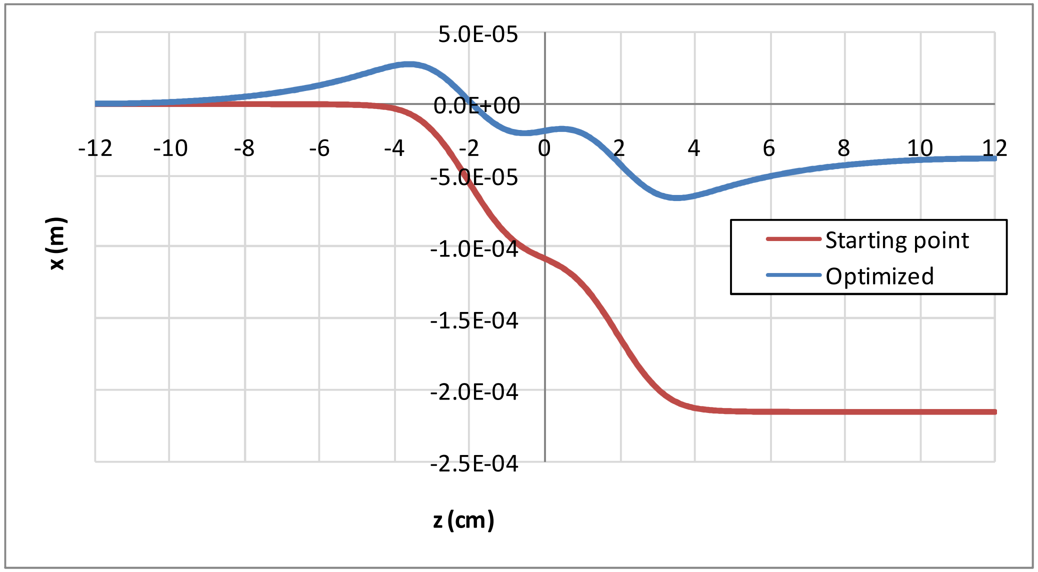
- End of the yoke length/height
- Height of the yoke
- Terminal pole height (|B| > 5 T)
- Effectiveness of the conductors

Lowering the 2nd integral: option 1





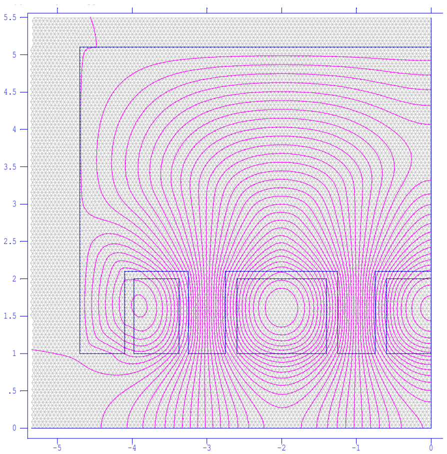




The multipoles of the option 1

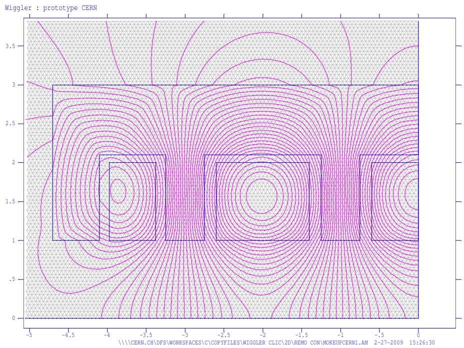
Starting configuration

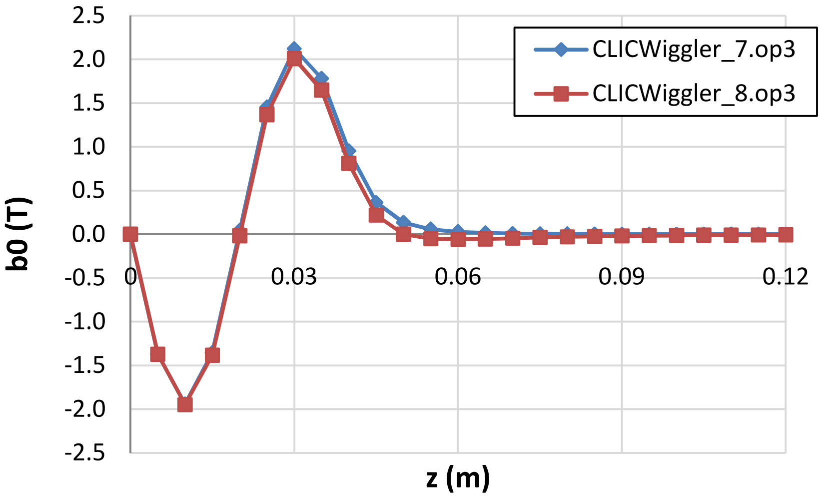
(CLICWiggler_7)

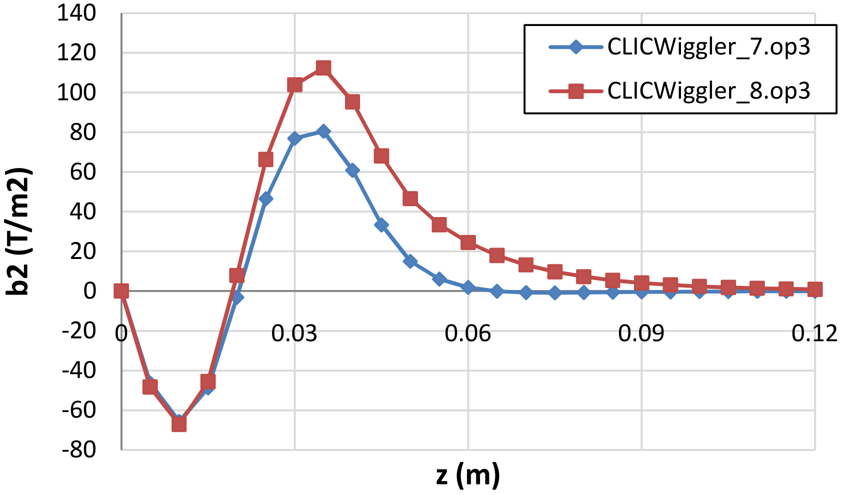


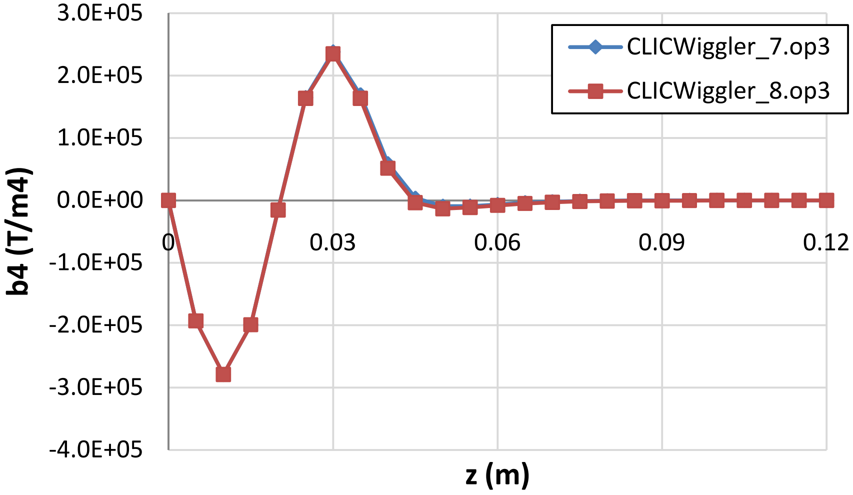
Modified (option 1)

(CLICWiggler_8)

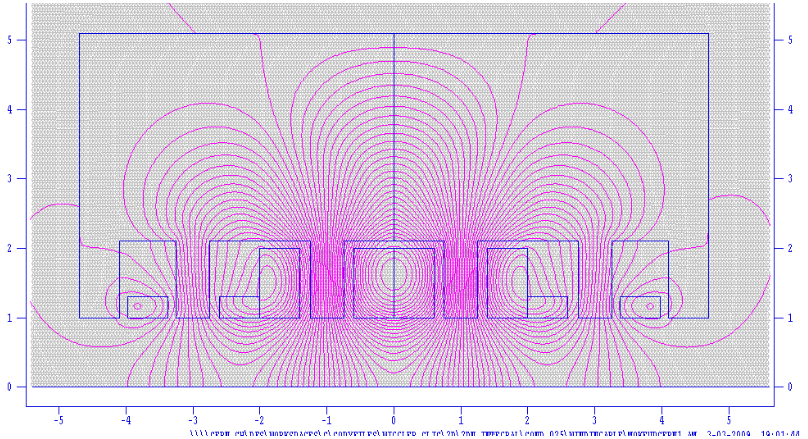


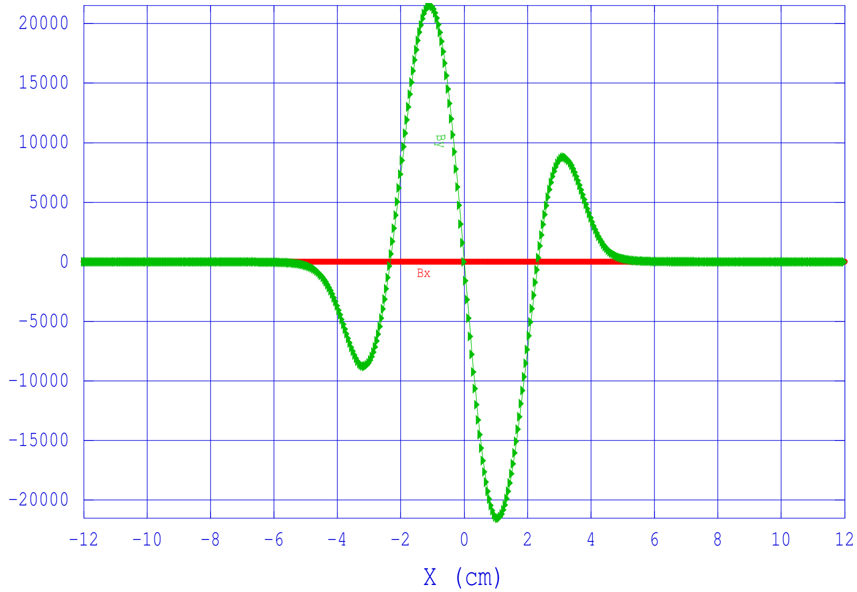


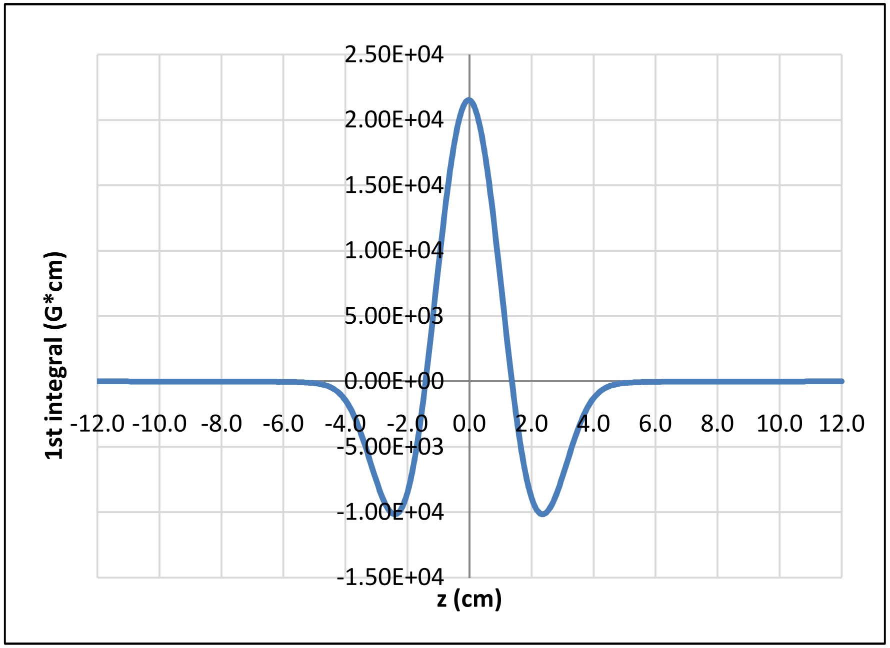


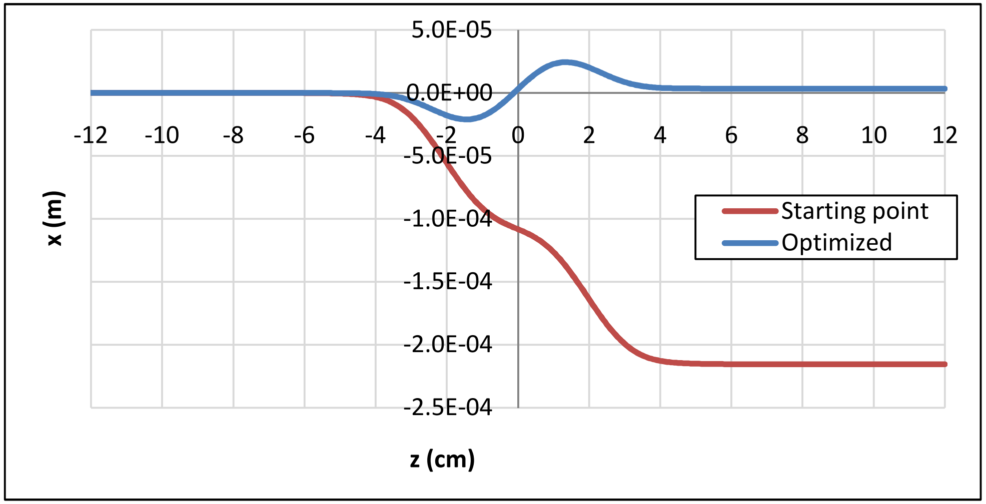


Lowering the 2nd integral: option 2 (2D)









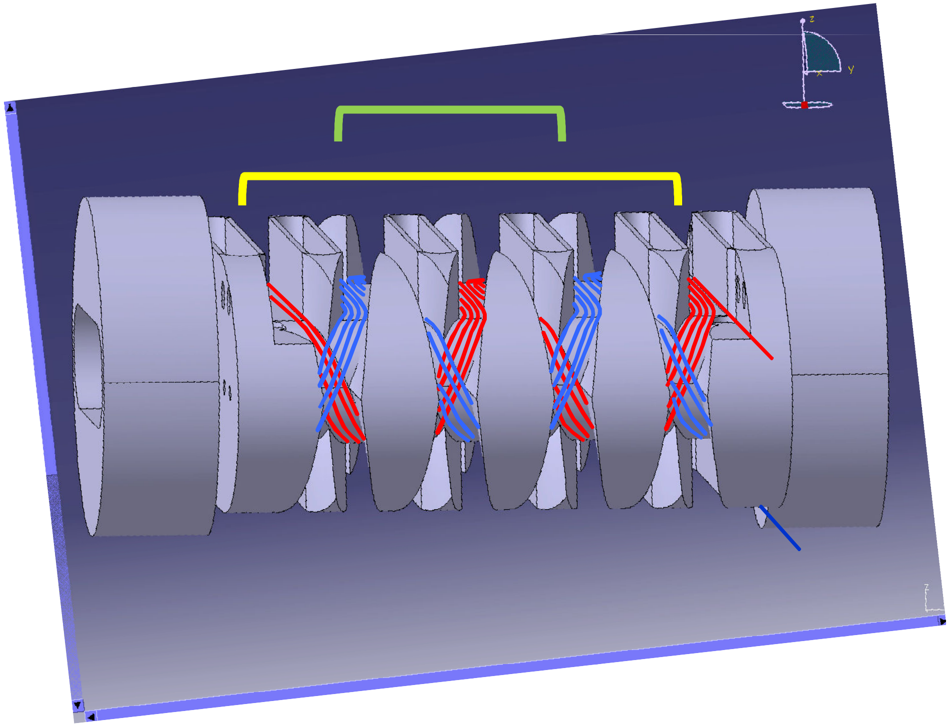
Option 1 vs option 2

The “advantage” of the option 2:

- Perfect cancellation of the 2nd integral
- Field well confined in the yoke
- Possibility to use only one IN and one OUT (prototype)

The “disadvantage” of the option 2:

- Comments?

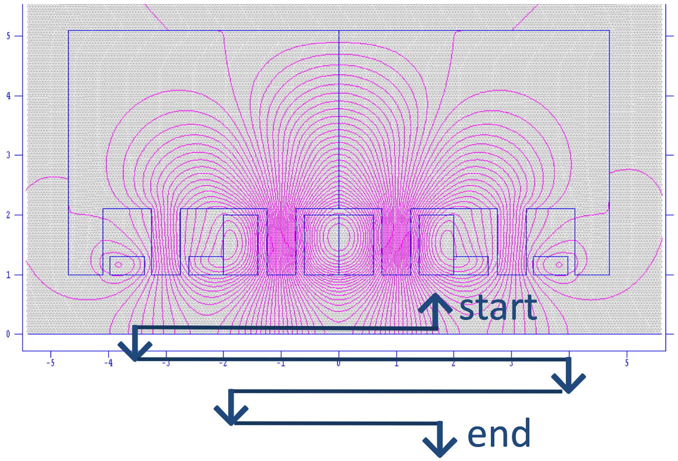


The “advantage” of the option 1:

- Quick to be done

The “disadvantage” of the option 1:

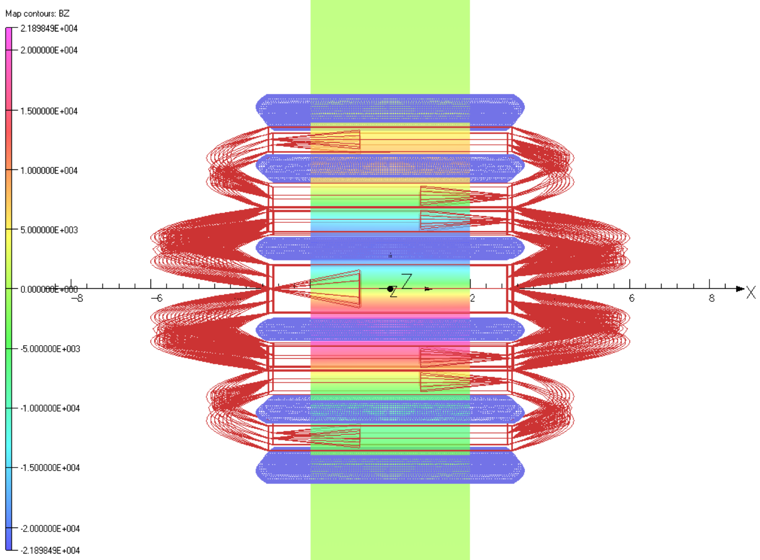
- Not perfect cancellation of the 2nd integral
- Field not completely confined in the yoke
- Multipoles get worse

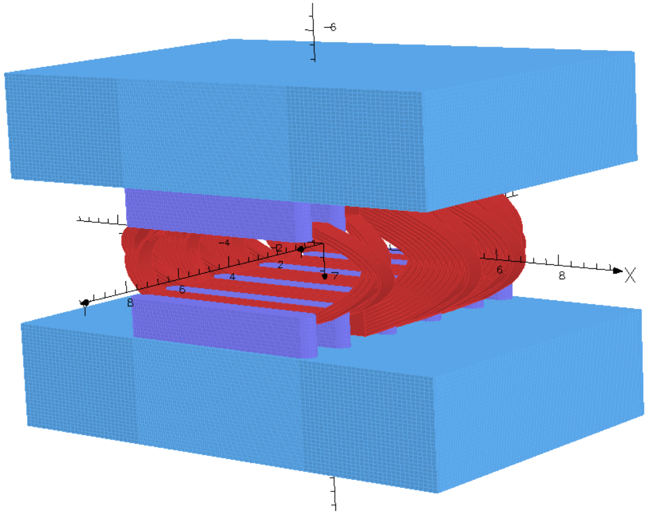


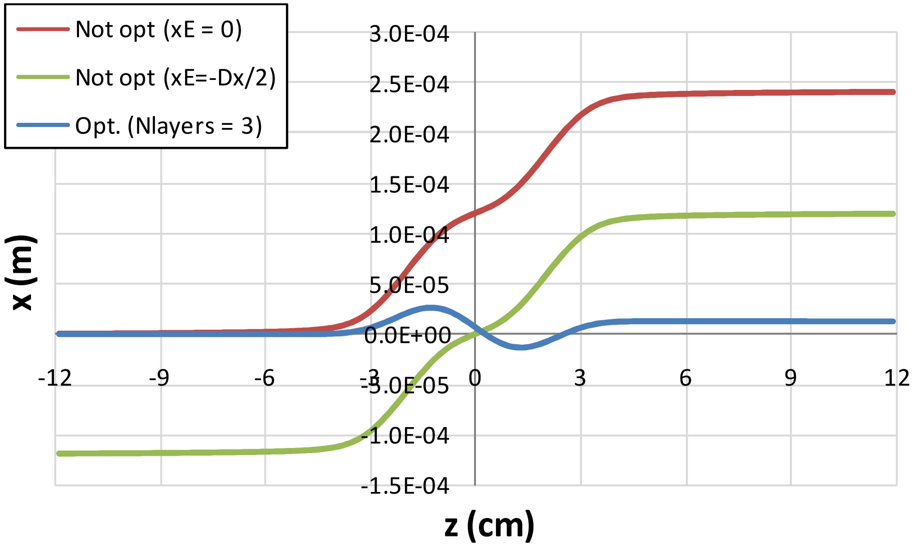
1st layers (~1/3 A*spire equivalent)

All the rest

Lowering the 2nd integral: option 2 (3D)

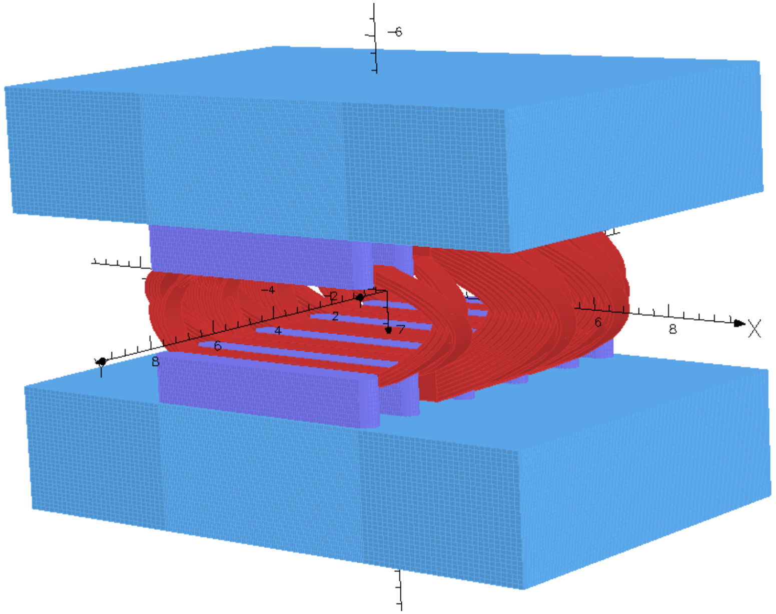




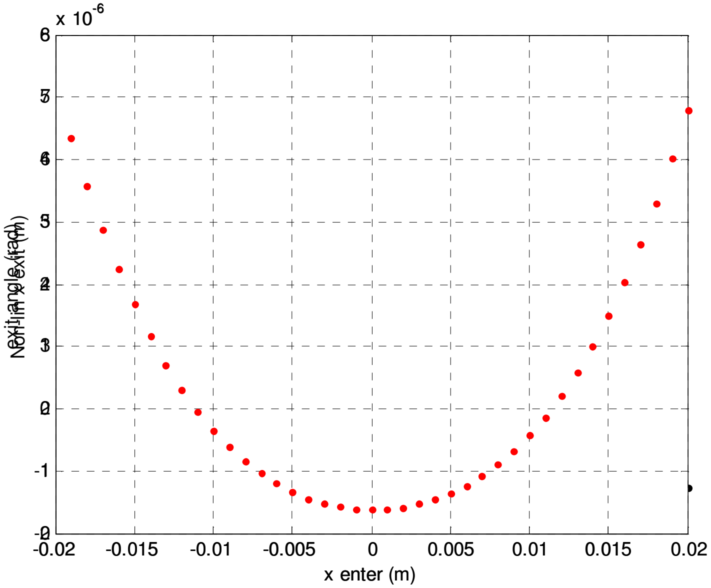


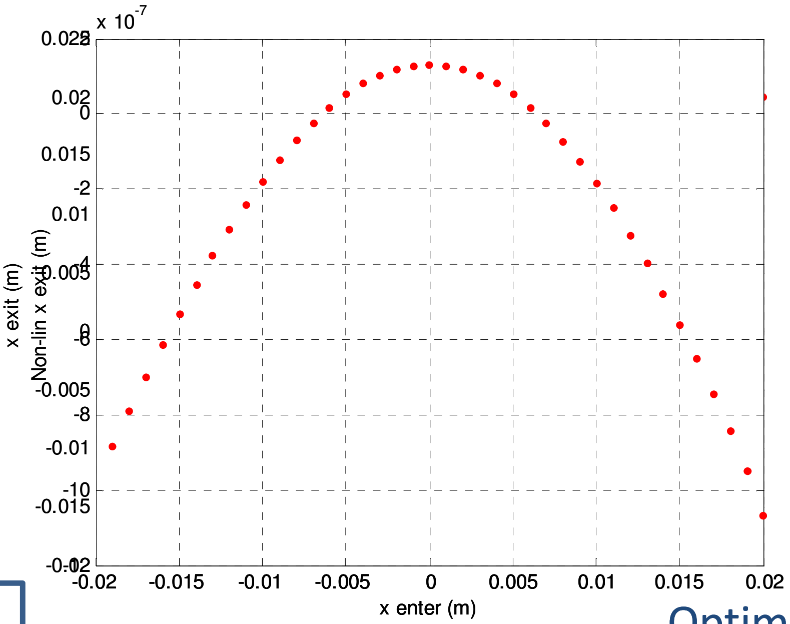
If only one IN and one OUT → discrete tuning in the prototype model

Tracking studies (optimized configuration)

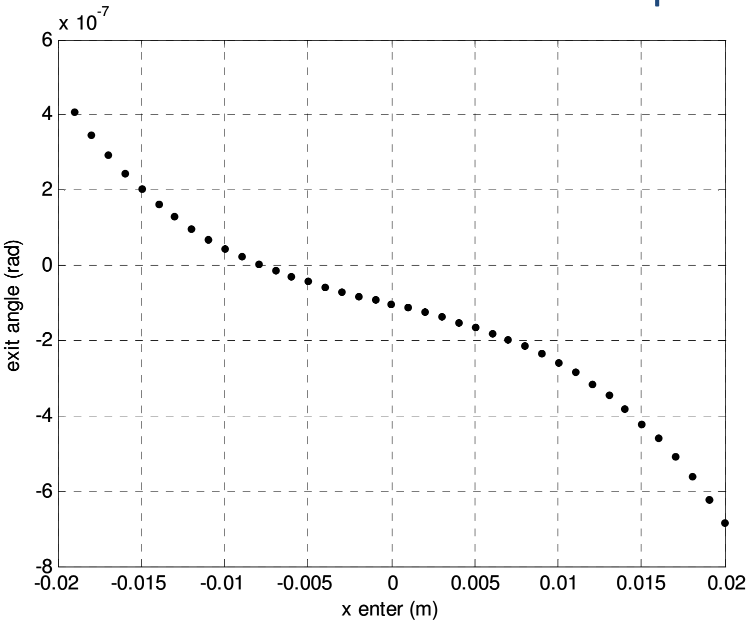


Not optimized





Optimized



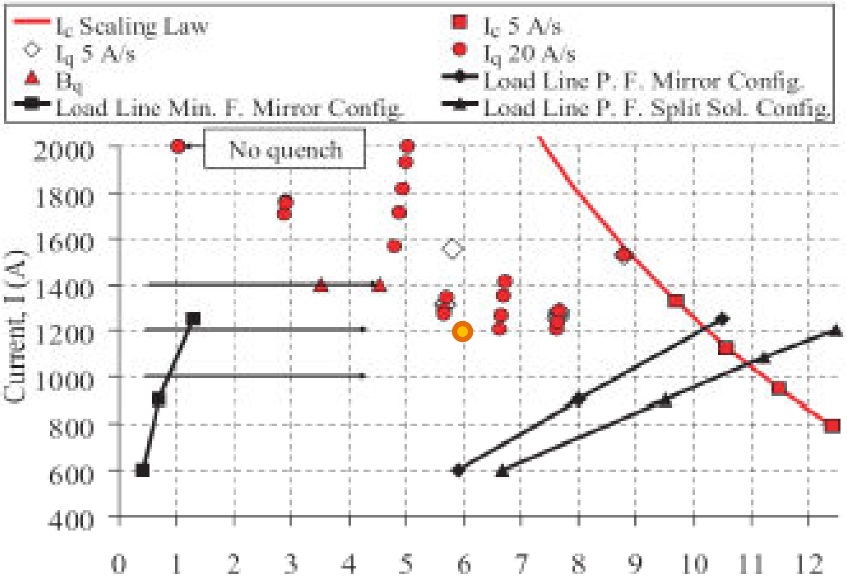
Working point: Nb_3Sn & NbTi

Non-Cu fraction = 0.53

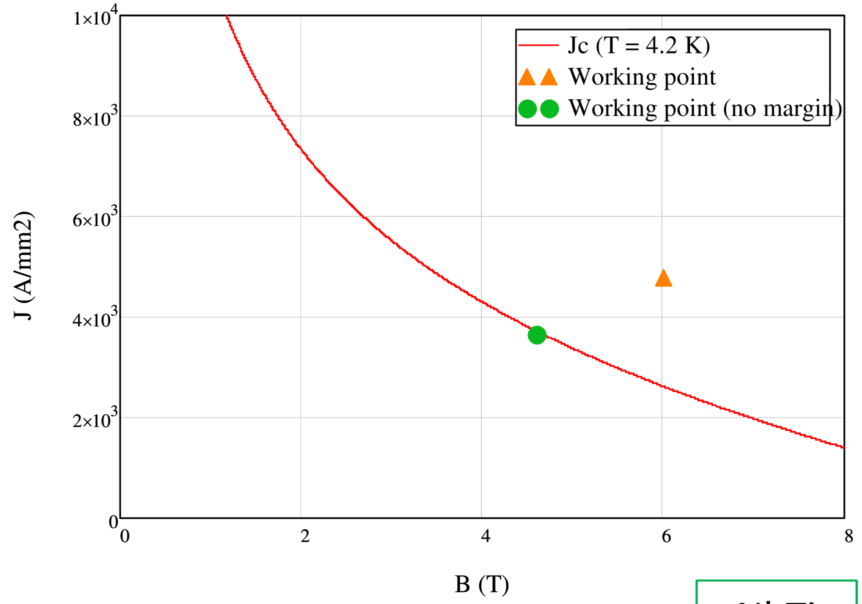
Wire diameter (insulated) = 1 mm
Wire diameter (bare) = 0.8 mm

Cu/SC ratio = 1

*



Nb_3Sn



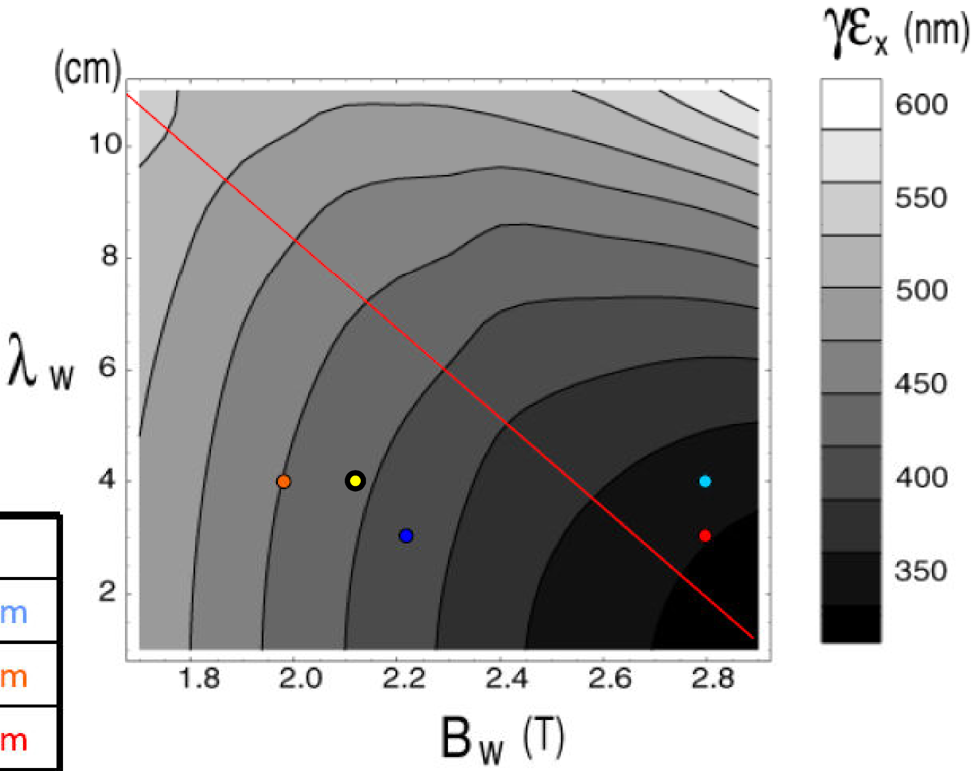
NbTi

	I (A)	Max|B| (T)	By peak (T)
Nb_3Sn	**1200**	**6.0**	**2.1**
	1100	5.5	1.9
NbTi	920	4.6	1.6

*__MANUFACTURE AND TEST OF A SMALL CERAMIC-INSULATED Nb3Sn SPLIT SOLENOID__, B. Bordini et al., EPAC'08 Proceedings.

Possible configurations

Wigglers working points



Possible to increase the peak field of 0.5 T using holmium

Type	Bmax	Period	Gap
Nb_3Sn	2.8 T	40 mm	16 mm
NbTi	2.0 T	40 mm	16 mm
Nb_3Sn	2.8 T	30 mm	10 mm
NbTi	2.2 T	30 mm	10 mm
Nb_3Sn	**2.1 T**	**40 mm**	**20 mm**

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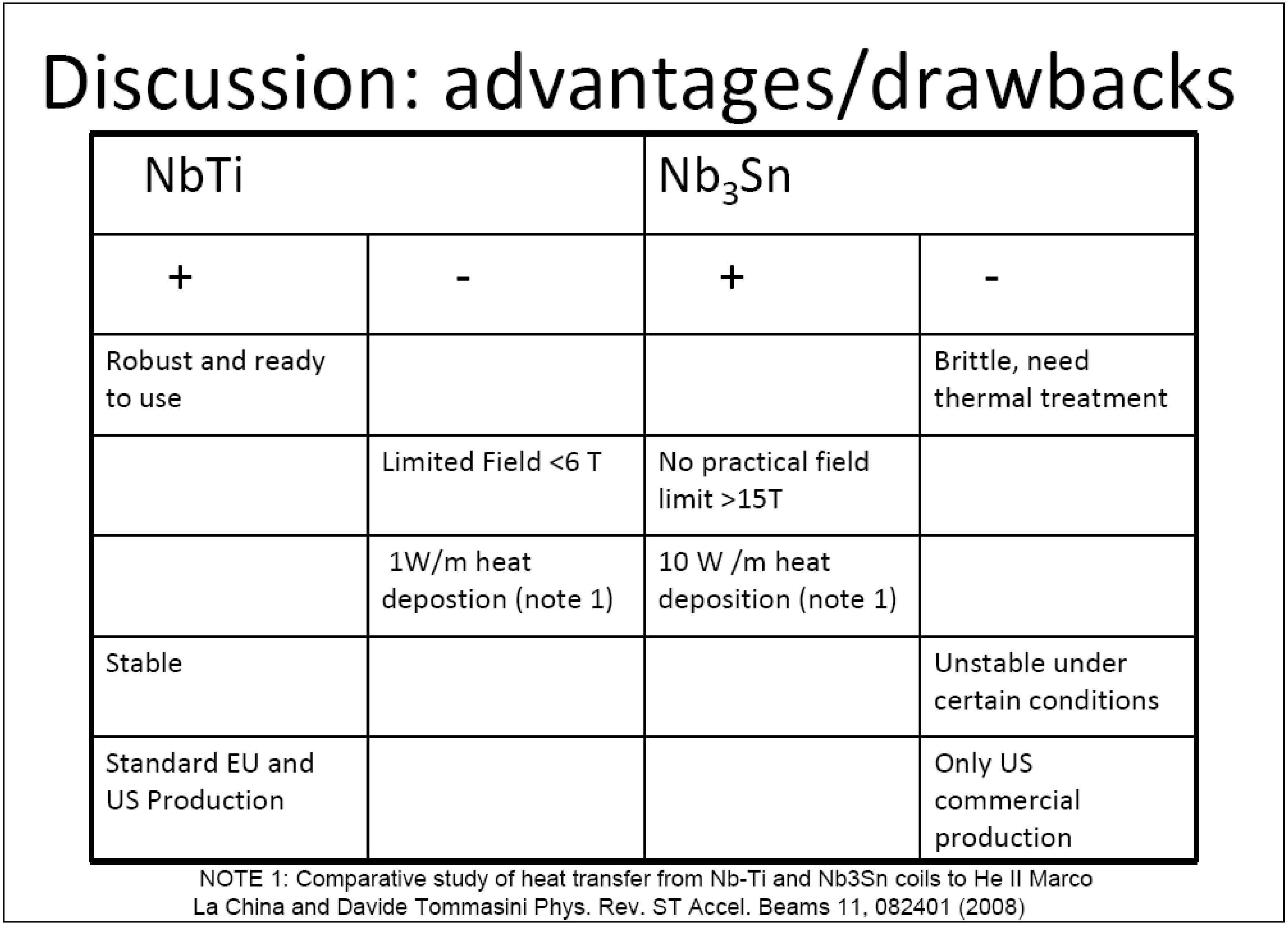
Working point: comparison

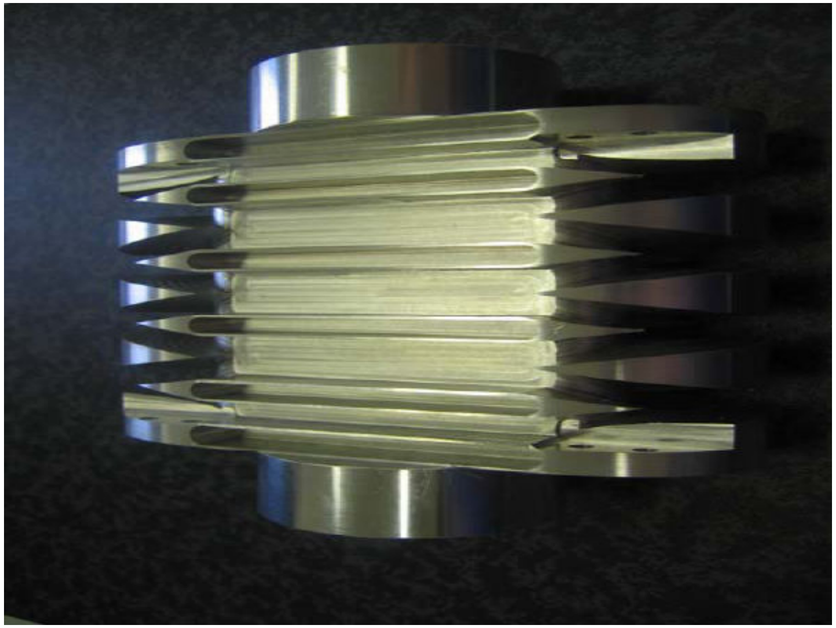


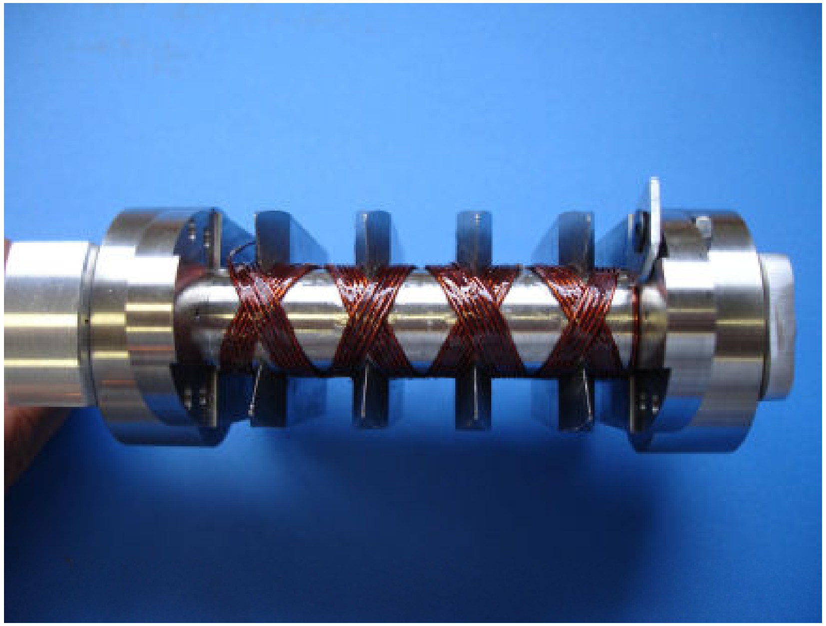
Discussion: advantages/drawbacks

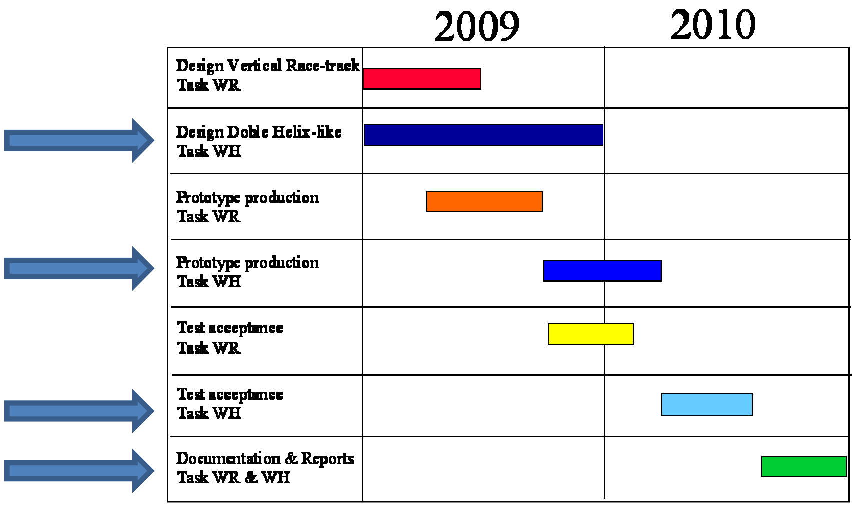
NbTi		Nb_3Sn	
+	-	+	-
Robust and ready to use			Brittle, need thermal treatment
	Limited Field <6 T	No practical field limit >15T	
	1W/m heat depostion (note 1)	10 W /m heat deposition (note 1)	
Stable			Unstable under certain conditions
Standard EU and US Production			Only US commercial production

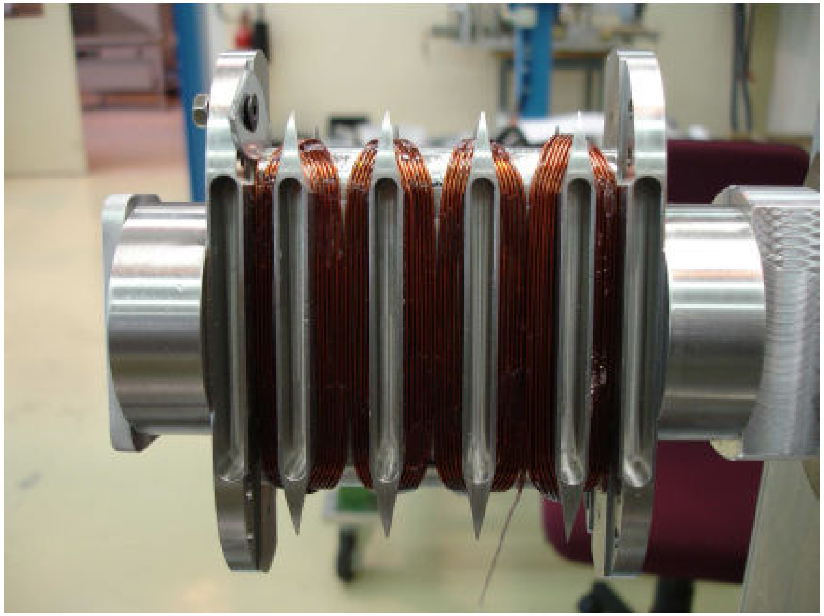
NOTE 1: Comparative study of heat transfer from Nb-Ti and Nb3Sn coils to He II Marco La China and Davide Tommasini Phys. Rev. ST Accel. Beams 11, 082401 (2008)

Short prototype status & scheduling









Conclusions

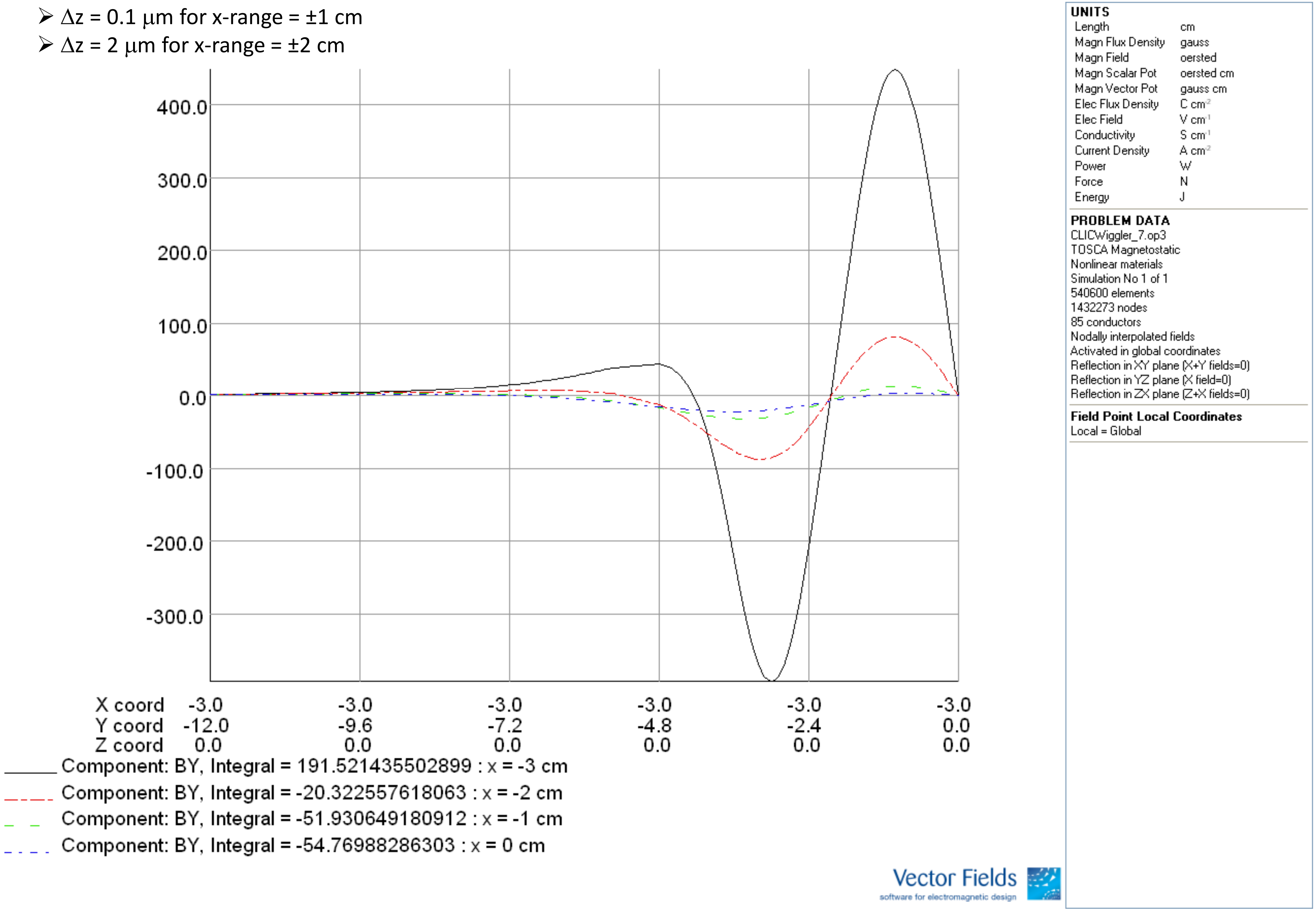
- A novel design for the CLIC damping ring has been analyzed (2D & 3D)
  - Advantages:
    - Less quantity of conductor needed
    - Small forces on the heads
  - Analysis on the prototype:
    - Maximum force
    - Multipolar analysis
    - Tracking studies
    - Zeroing the integrals of motion
- Future plans
  - Optimization of the complete wiggler model (work in progress):
    - Best working point definition
    - Modeling of the long wiggler
    - 2nd integral optimization for the long model
    - Same analysis tools applied to the prototype model (forces, multipoles axis/trajectory, tracking)
    - Minimization of the integrated multipoles

Extra slides

Longitudinal field (By = f(y), several x)

Scan varying the entering position in horizontal, variation in vertical:

- $\Delta z = 0.1\ \mu m$ for x-range = ±1 cm
- $\Delta z = 2\ \mu m$ for x-range = ±2 cm



Component: BY, Integral = 191.521435502899 : x = -3 cm

Component: BY, Integral = -20.322557618063 : x = -2 cm

Component: BY, Integral = -51.930649180912 : x = -1 cm

Component: BY, Integral = -54.76988286303 : x = 0 cm

UNITS

Length	cm
Magn Flux Density	gauss
Magn Field	oersted
Magn Scalar Pot	oersted cm
Magn Vector Pot	gauss cm
Elec Flux Density	C cm^{-2}
Elec Field	V cm^{-1}
Conductivity	S cm^{-1}
Current Density	A cm^{-2}
Power	W
Force	N
Energy	J

PROBLEM DATA

CLICWiggler_7.op3
TOSCA Magnetostatic
Nonlinear materials
Simulation No 1 of 1
540600 elements
1432273 nodes
85 conductors
Nodally interpolated fields
Activated in global coordinates
Reflection in XY plane (X+Y fields=0)
Reflection in YZ plane (X field=0)
Reflection in ZX plane (Z+X fields=0)

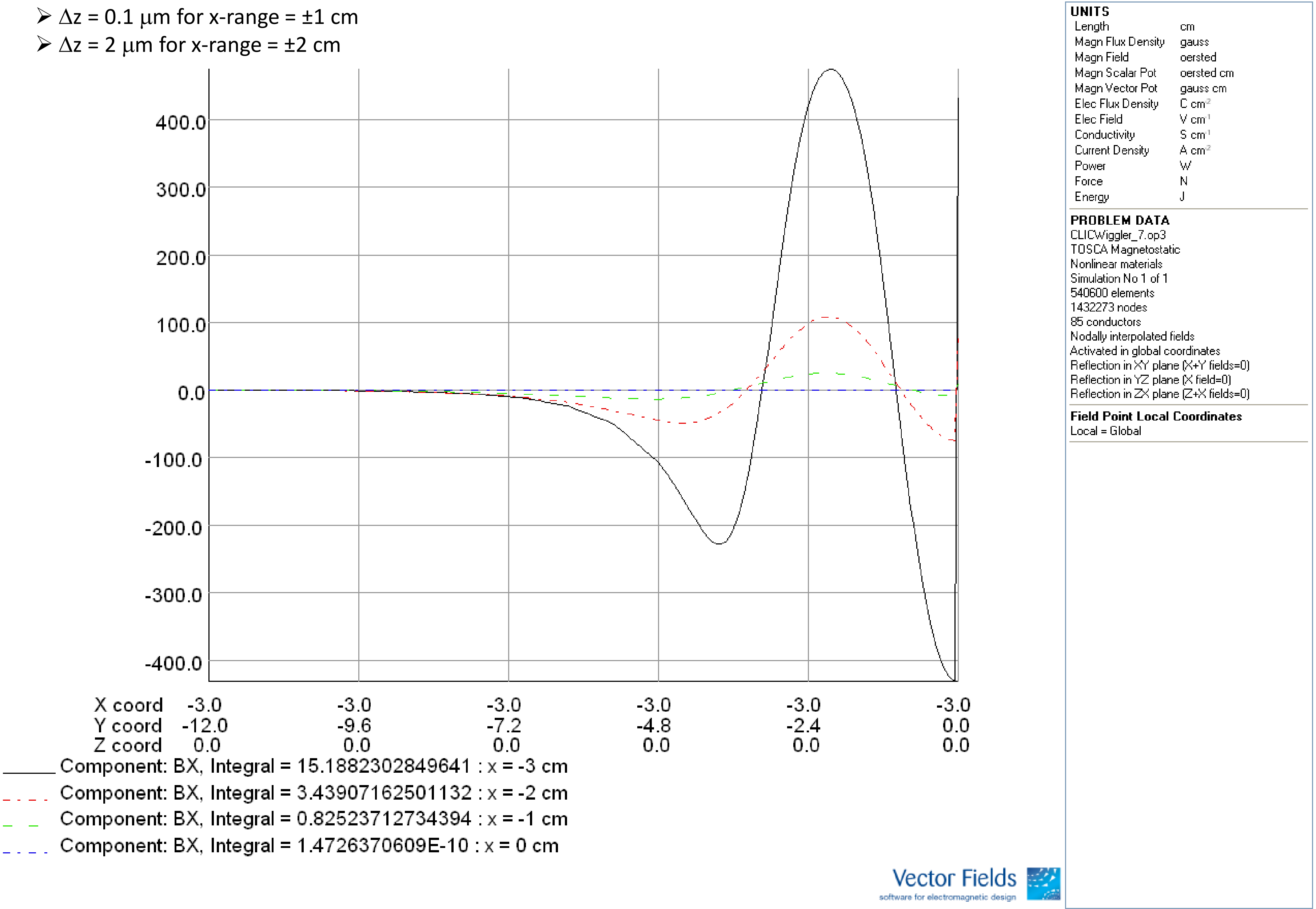
Field Point Local Coordinates

Local = Global

Horizontal transverse field (Bx = f(y), several x)

Scan varying the entering position in horizontal, variation in vertical:

- Δz = 0.1 μm for x-range = ±1 cm
- Δz = 2 μm for x-range = ±2 cm



Component: BX, Integral = 15.1882302849641 : x = -3 cm

Component: BX, Integral = 3.43907162501132 : x = -2 cm

Component: BX, Integral = 0.82523712734394 : x = -1 cm

Component: BX, Integral = 1.4726370609E-10 : x = 0 cm

UNITS

Length	cm
Magn Flux Density	gauss
Magn Field	oersted
Magn Scalar Pot	oersted cm
Magn Vector Pot	gauss cm
Elec Flux Density	C cm^{-2}
Elec Field	V cm^{-1}
Conductivity	S cm^{-1}
Current Density	A cm^{-2}
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Force	N
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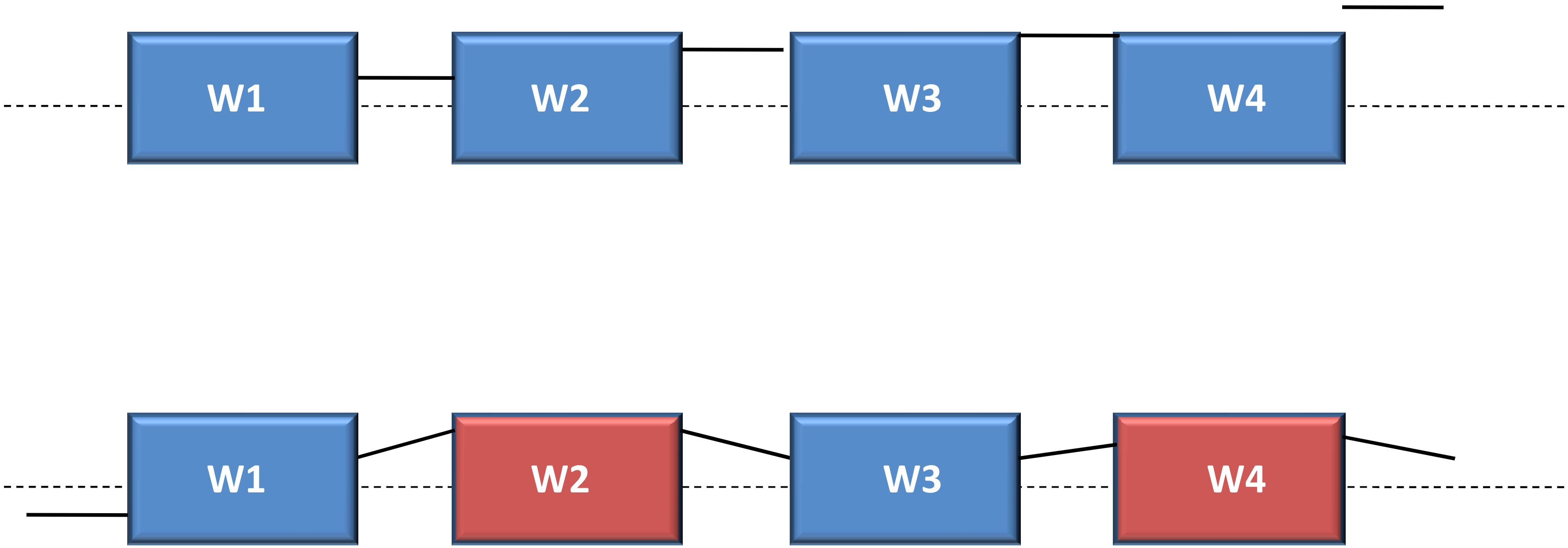
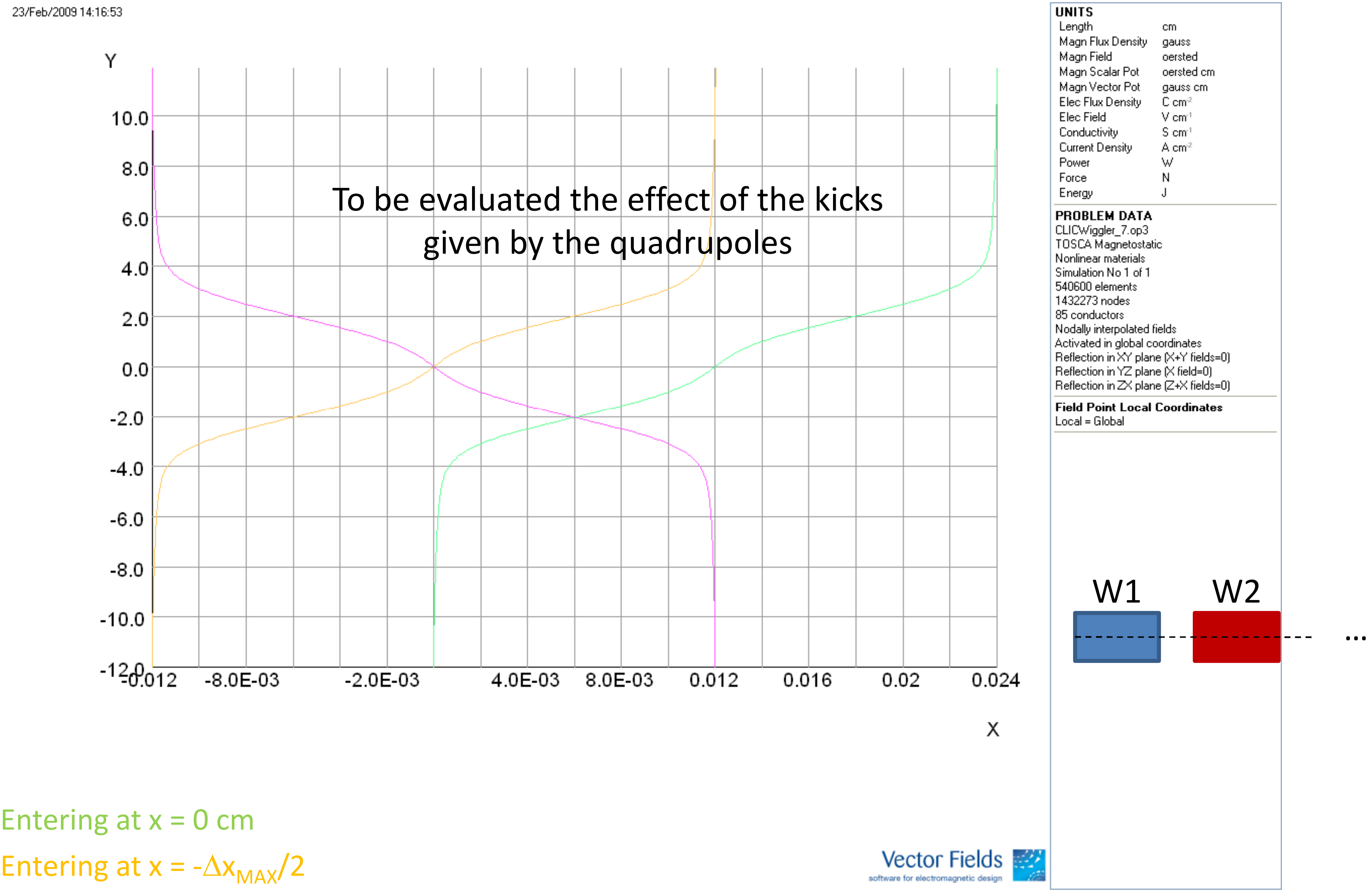
Field Point Local Coordinates
Local = Global

Controlling the y-shift: cancel the residuals



2 μm in 10 cm -> 20*2 = 40 μm in 2 m

Controlling the x-shift: cancel the residuals (during the operation)



To be evaluated the effect of the kicks given by the quadrupoles

UNITS

Length	cm
Magn Flux Density	gauss
Magn Field	oersted
Magn Scalar Pot	oersted cm
Magn Vector Pot	gauss cm
Elec Flux Density	C cm^{-2}
Elec Field	V cm^{-1}
Conductivity	S cm^{-1}
Current Density	A cm^{-2}
Power	W
Force	N
Energy	J

PROBLEM DATA

CLICWiggler_7.op3
TOSCA Magnetostatic
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85 conductors
Nodally interpolated fields
Activated in global coordinates
Reflection in XY plane (X+Y fields=0)
Reflection in YZ plane (X field=0)
Reflection in ZX plane (Z+X fields=0)

Field Point Local Coordinates

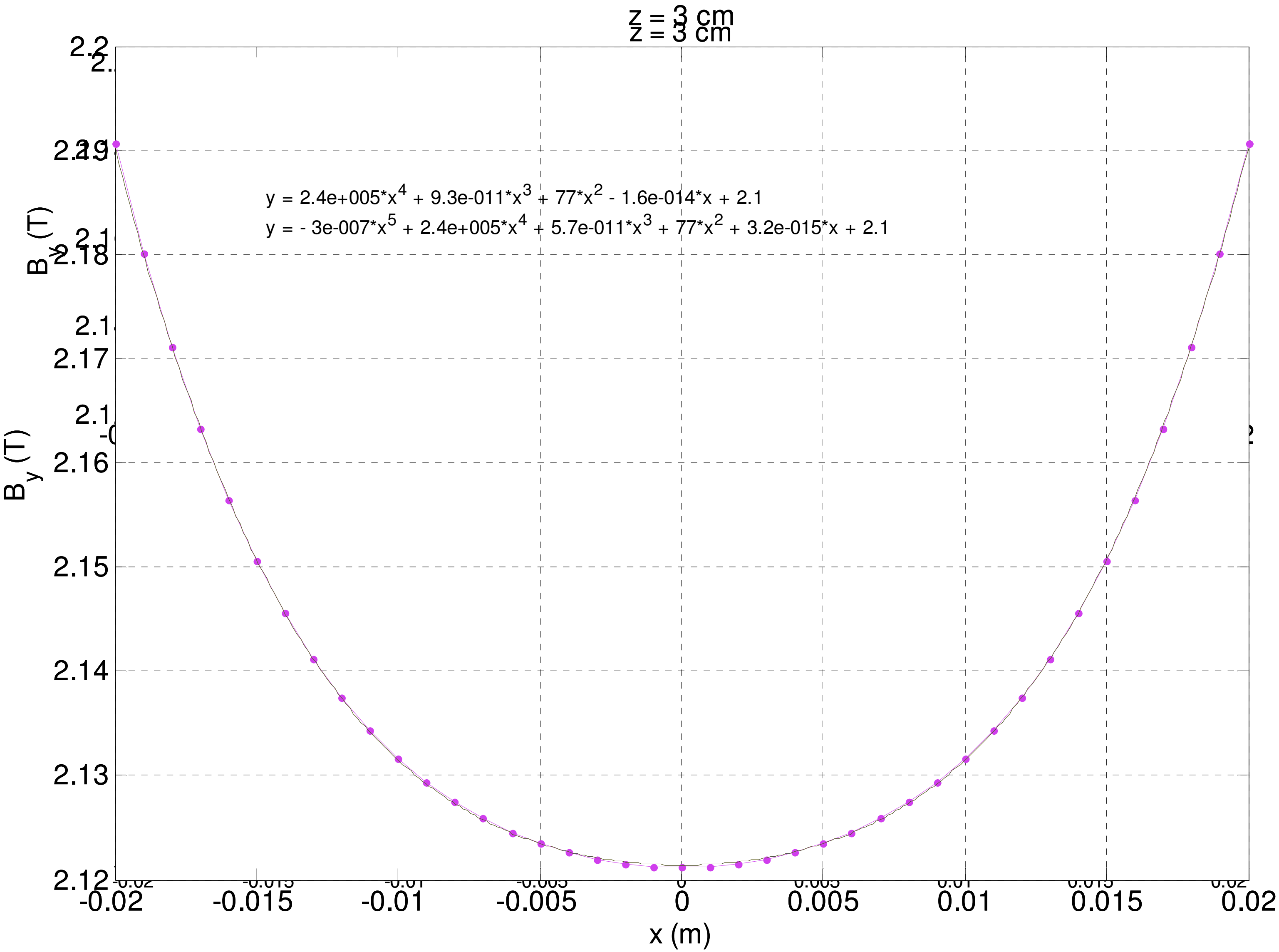
Local = Global

Entering at x = 0 cm

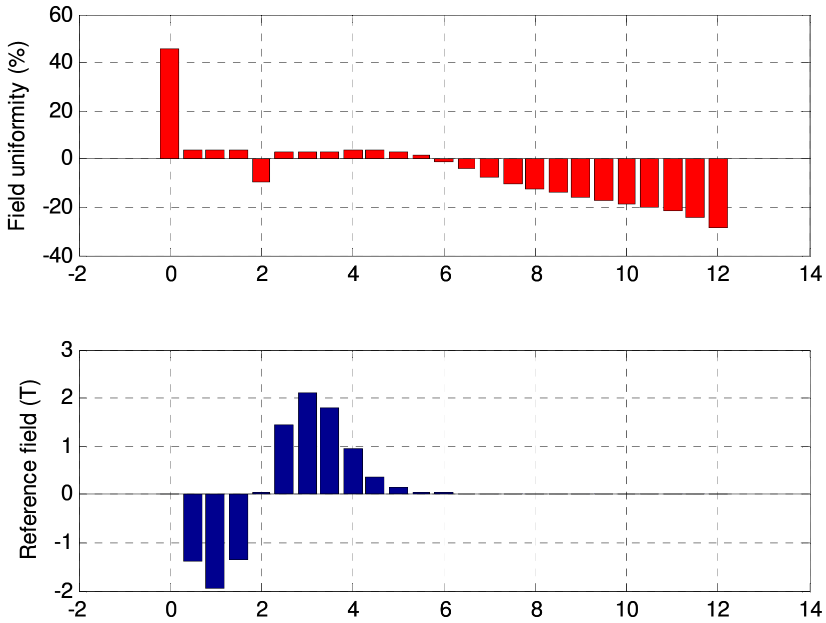
Entering at x = -$\Delta x_{MAX}/2$

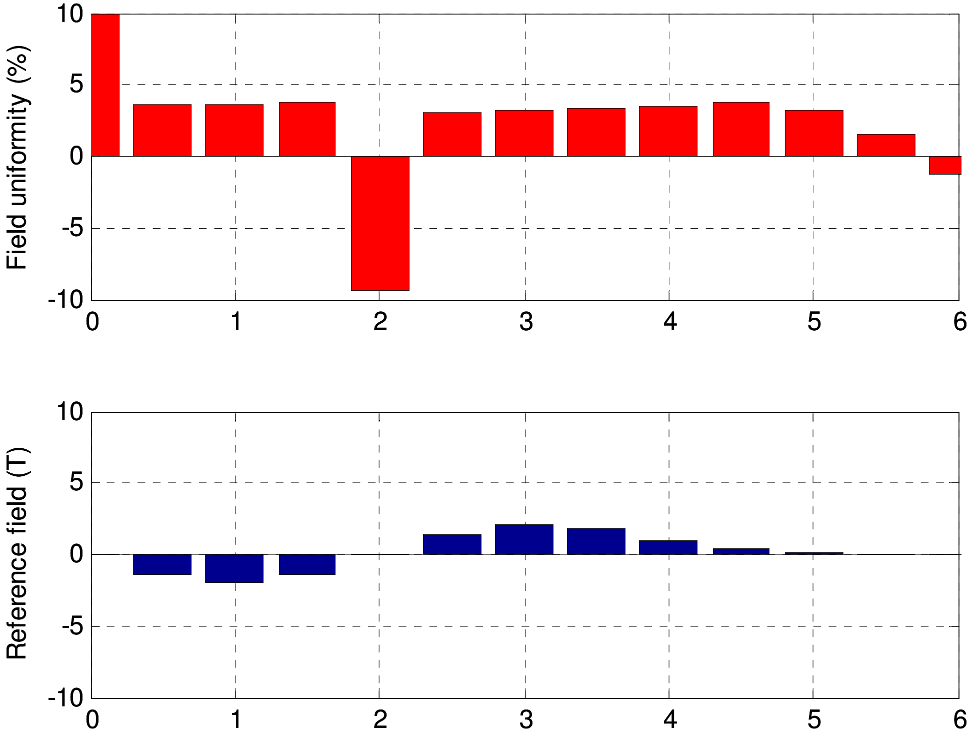
Entering at x = +$\Delta x_{MAX}/2$ (opposite I wiggler … positron used for trick)

The fit accuracy: an example



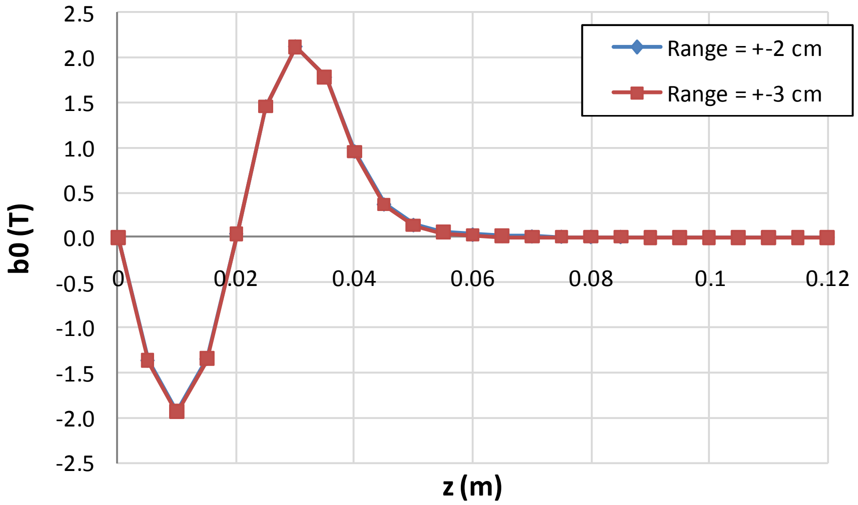
Field uniformity (x-range = ±3 cm)

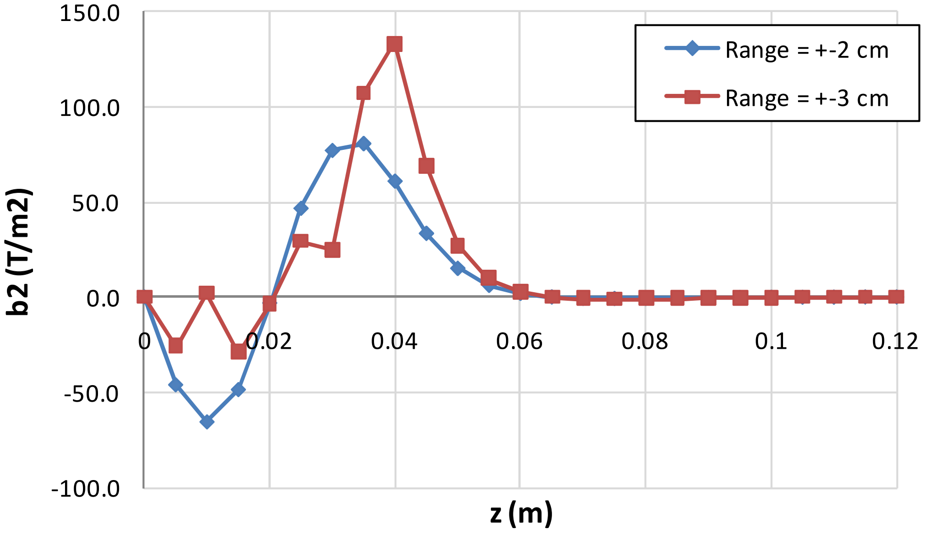


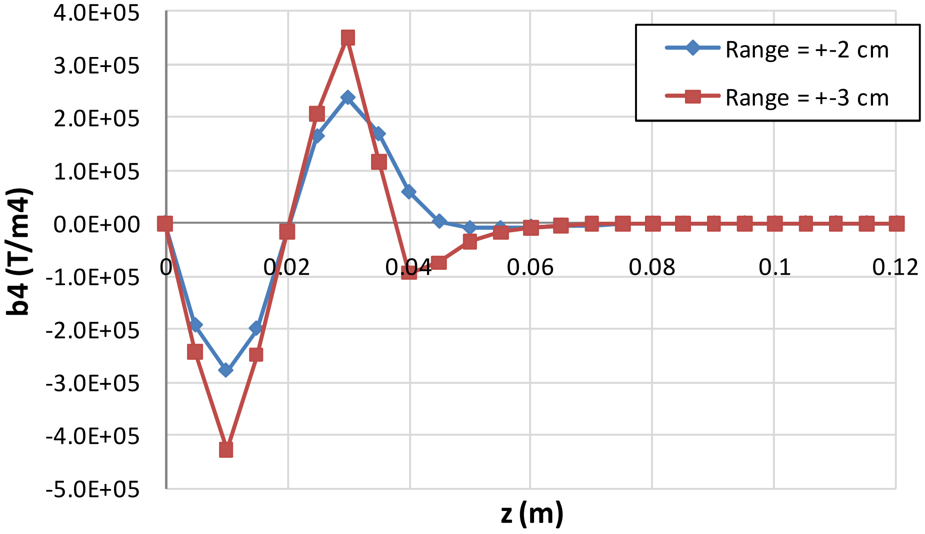


Multipolar analysis (x-range = ±3 cm)

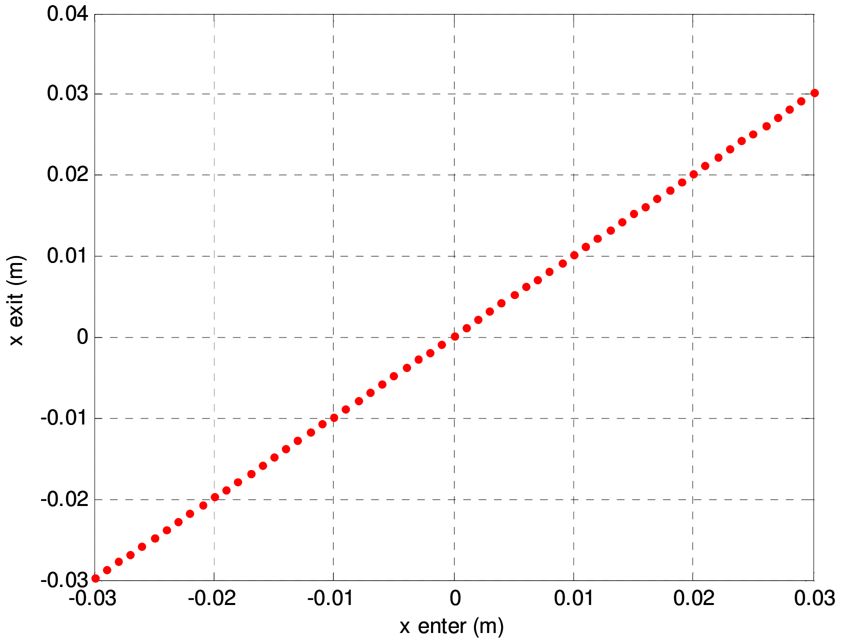
$$B_z(x) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4$$







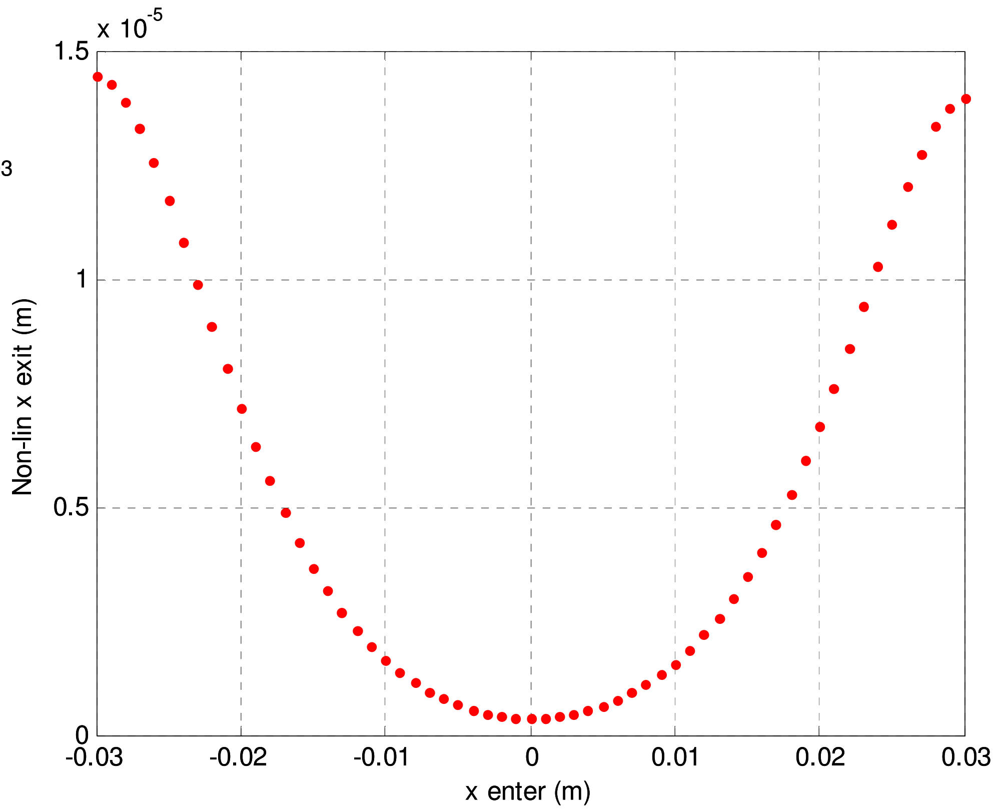
Tracking at x-range = ±3 cm: exit position



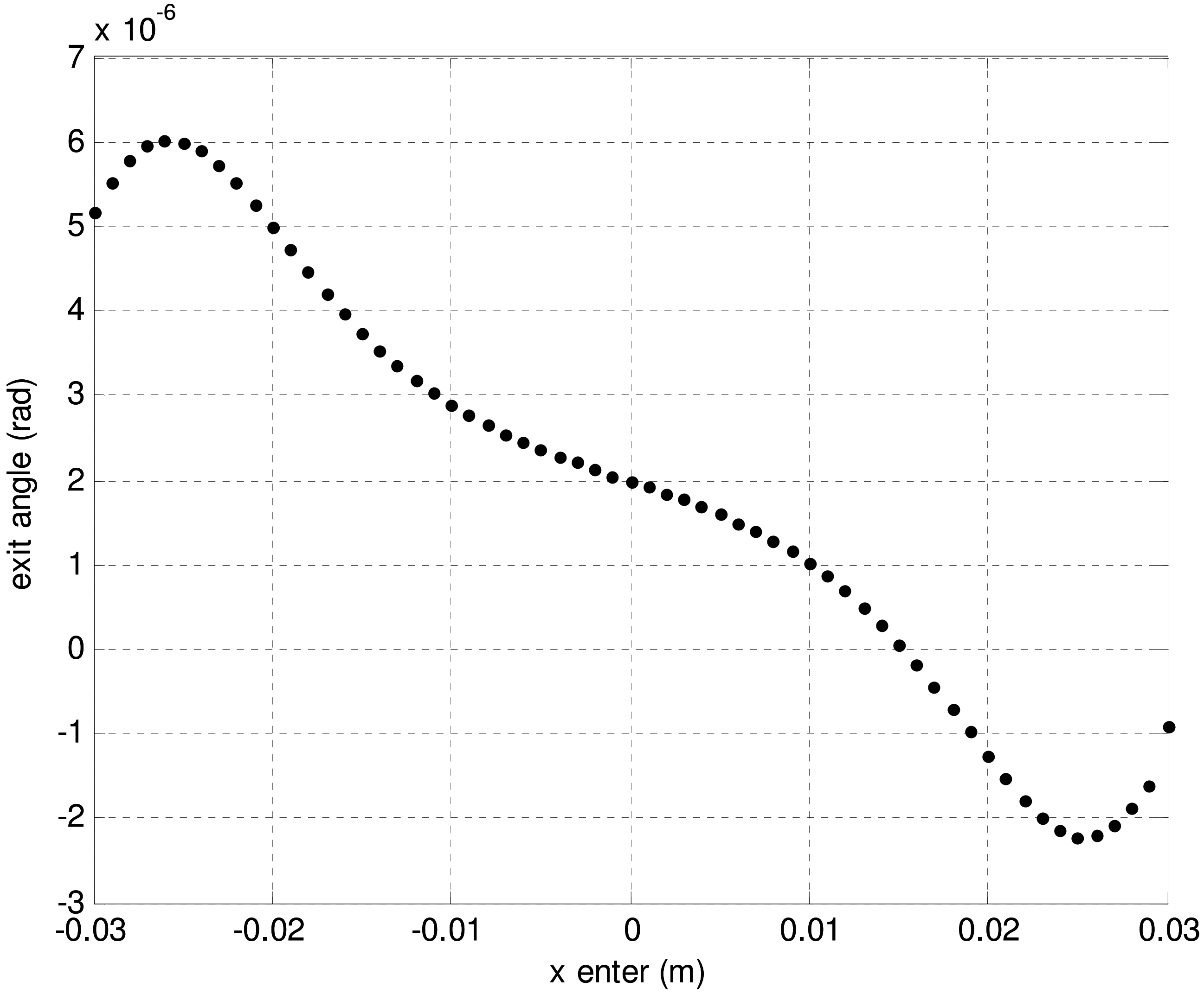
$$x_{Exit} = a_0 + a_1 \cdot x_{Entr} + a_2 \cdot x_{Entr}{}^2 + a_3 \cdot x_{Entr}{}^3 + a_4 \cdot x_{Entr}{}^4 + a_5 \cdot x_{Entr}{}^5$$

Subctracting the linear part

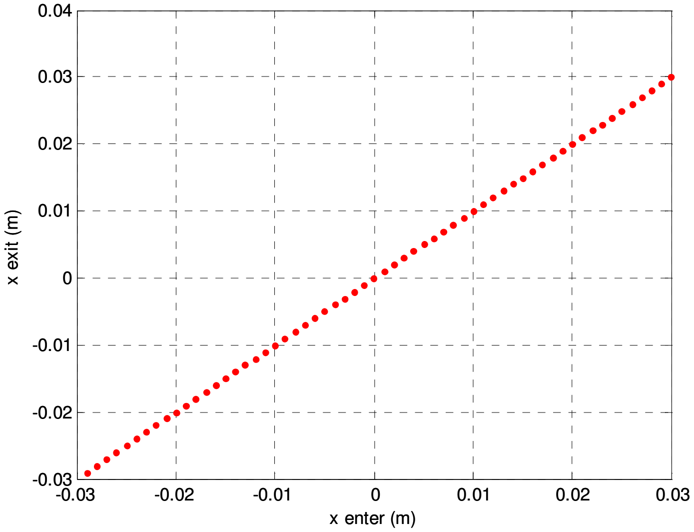
$$x_{Exit} = a_2 \cdot x_{Entr}{}^2 + a_3 \cdot x_{Entr}{}^3 + a_4 \cdot x_{Entr}{}^4 + a_5 \cdot x_{Entr}{}^5$$

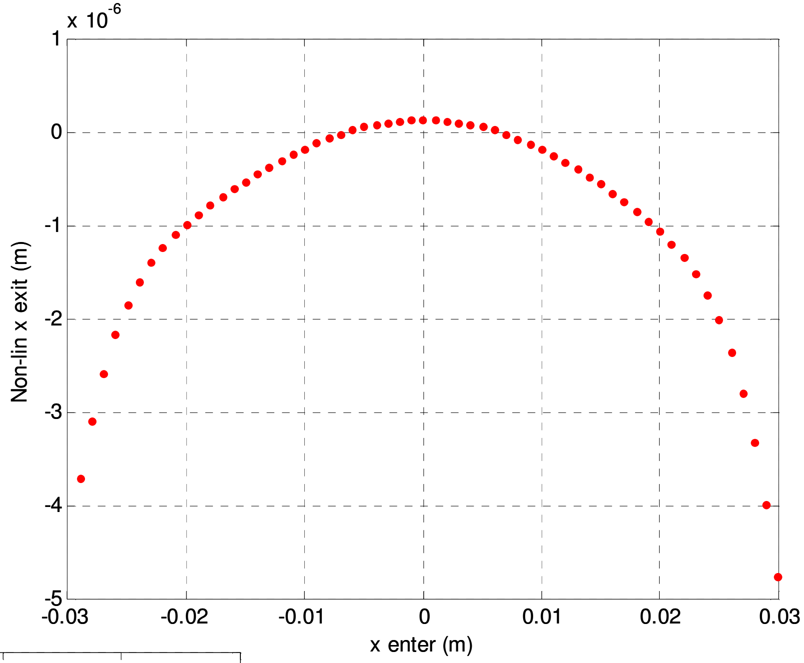


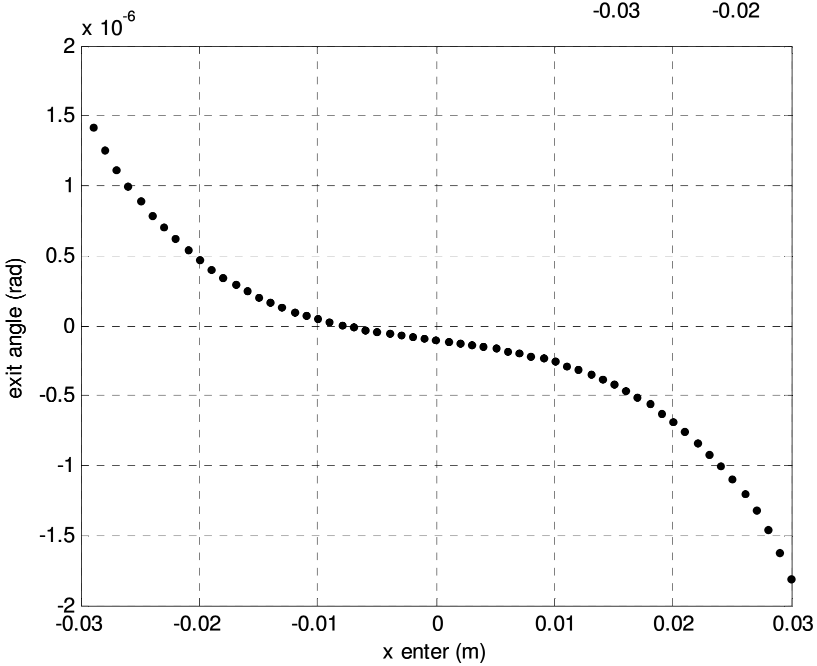
Tracking at x-range = ±3 cm: exit angle



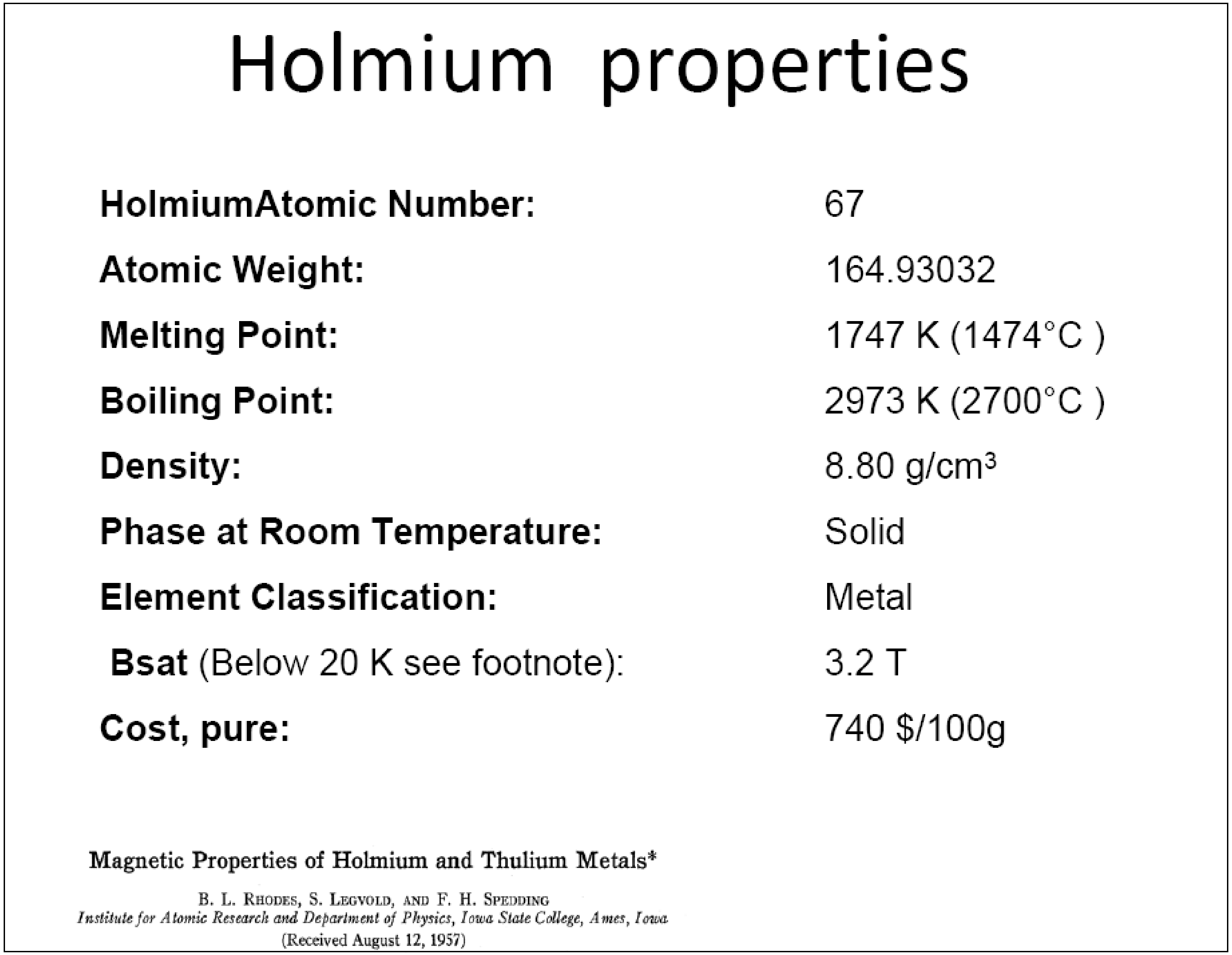
Tracking optimized (x-range = ±3 cm)







Holmium option



Holmium properties

HolmiumAtomic Number:	67
Atomic Weight:	164.93032
Melting Point:	1747 K (1474°C)
Boiling Point:	2973 K (2700°C)
Density:	8.80 g/cm^3
Phase at Room Temperature:	Solid
Element Classification:	Metal
Bsat (Below 20 K see footnote):	3.2 T
Cost, pure:	740 $/100g

Magnetic Properties of Holmium and Thulium Metals*

B. L. Rhodes, S. Legvold, and F. H. Spedding
Institute for Atomic Research and Department of Physics, Iowa State College, Ames, Iowa
(Received August 12, 1957)

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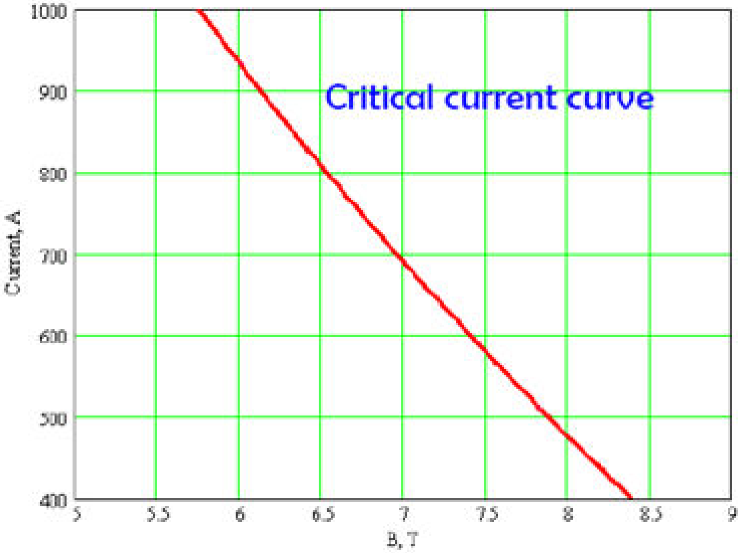
BINP wire

Superconductor

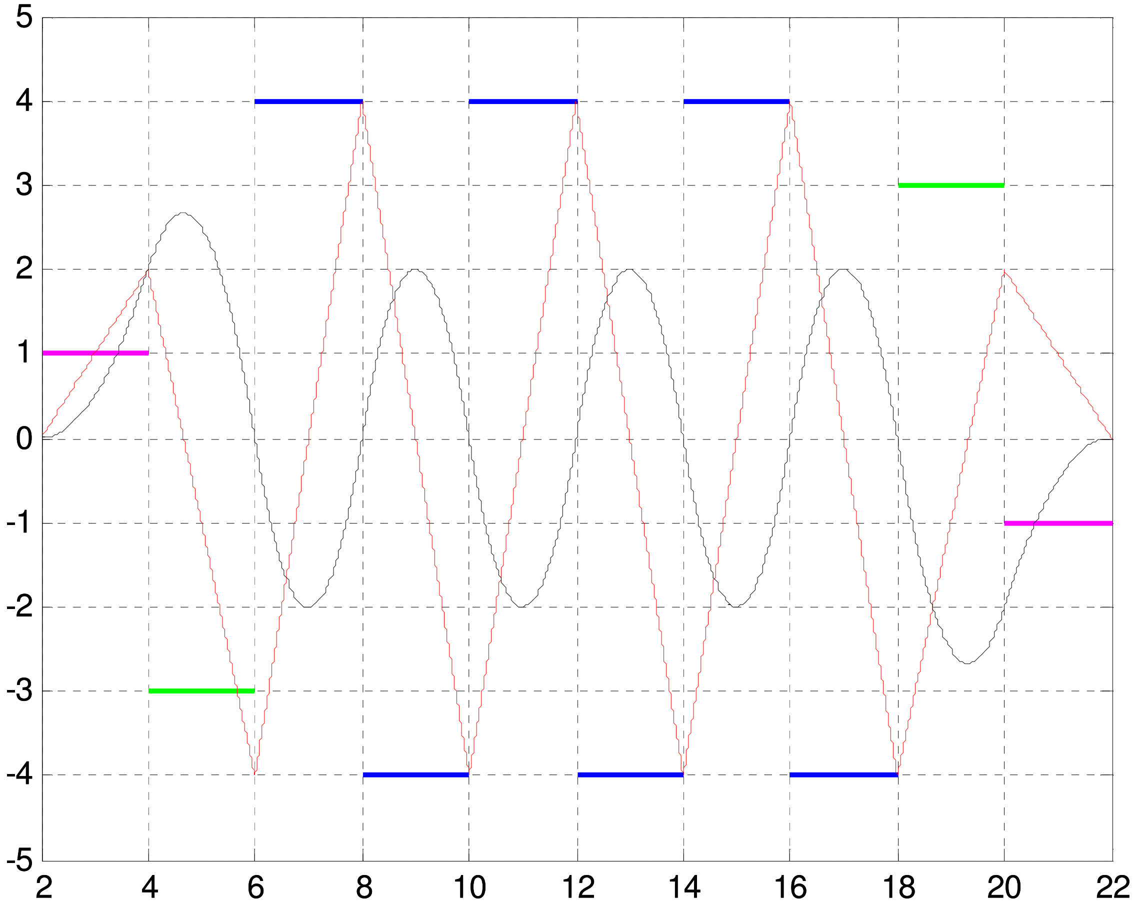
For many years Bochvar Institute in Moscow produces special NbTi SC wire for BINP with the following parameters:

Single wire length (0.5 m)	– ~2.0 km
SC packing factor	– 67.5 %
Critical current	for 7 T – 700 A for 8 T – 450 A
Wire diameter	– 0.9 mm
SC strand thickness	– 30 um

In our case the current density in the SC wire is 1250 A/mm2



2nd integral optimization (long model)

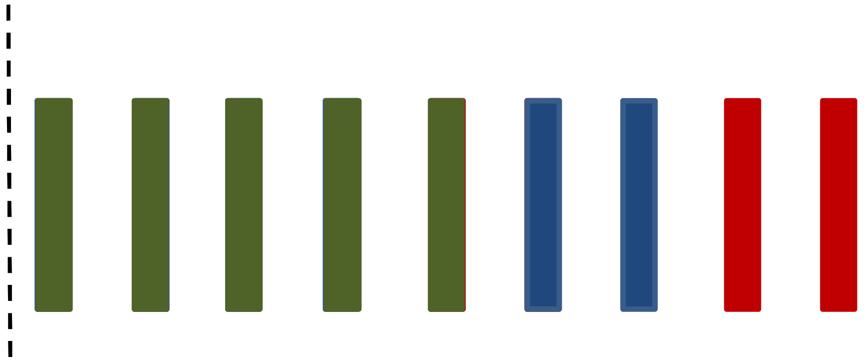


Long wiggler modeling

Problem: very long running time (3D) because of the large number of conductors in the model

Solution:

- Build 2D models increasing number of periods until the field distribution of the first two poles from the center give the same field distribution (Np)
- Build 3D model with a number of poles Np
- “Build” the magnetic map from this



Damping ring layout