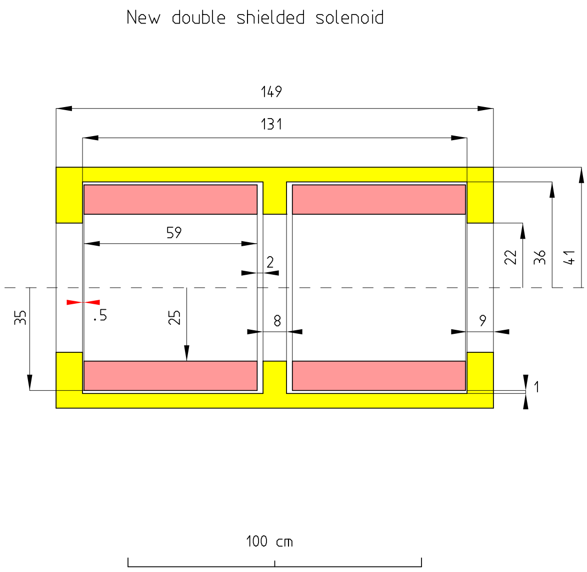
On the SWX1 and SWX2 solenoid

F Foroughi

PSI Aug 2001



1 Shielded solenoid

1.1 Presentation

Here is the geometry of the solenoid :

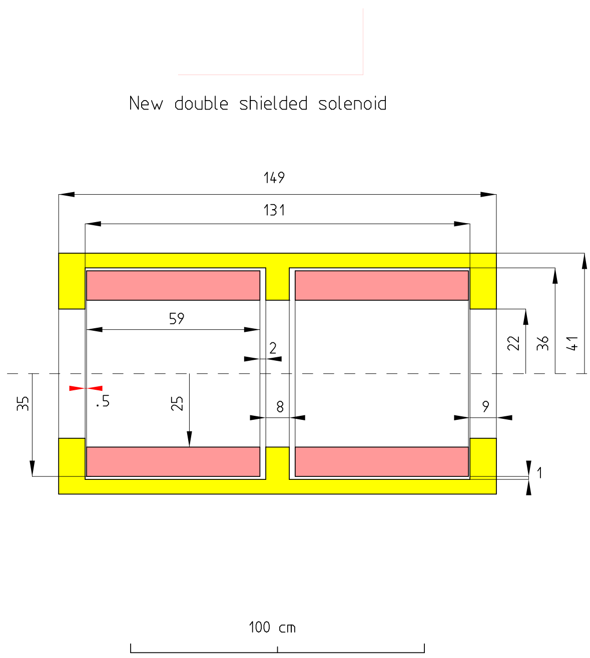


Figure 1:

In both side of the middle, there is room for coolers and connectors. The coils have been enlarge from 5 to 10 cm thickness, in order to be used with at most 500 A.

1.2 Field maps

Here is the input geometry for boundary element calculation :

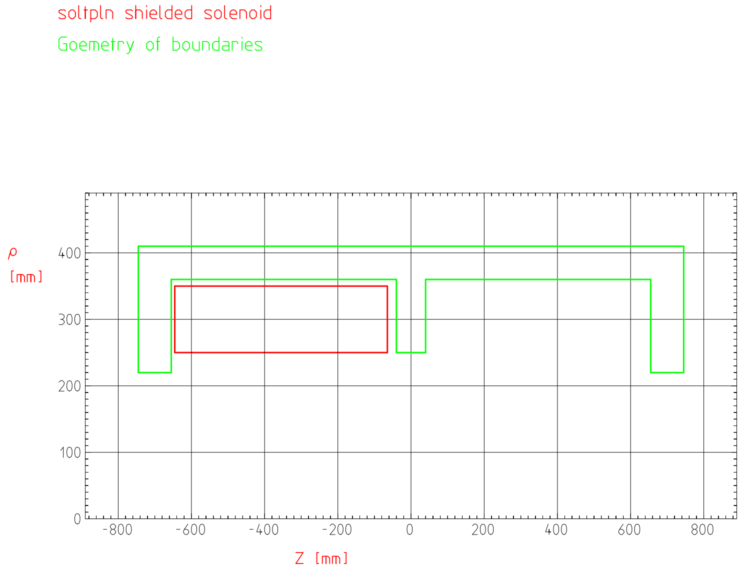


Figure 2:

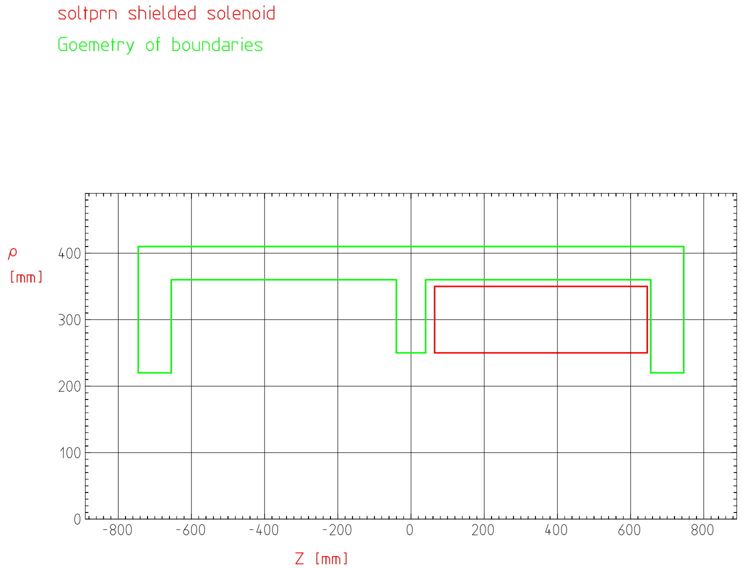


Figure 3:

Here is the corresponding **soltpln.don** files:

```
soltpln shielded solenoid
MAGNETIC
AXIS
NONSYMMAP

D
1.,+0.24e7
0.,0.,0.
C
-355.,300.,0.
-290.50,-50.,+290.50,-50.,+1,61
+290.50,-50.,+290.50,+50.,+1,21
+290.50,+50.,-290.50,+50.,+1,61
-290.50,+50.,-290.50,-50.,+1,21
F

D
2755.,0.
0.,0.,0.
C
0.,385.,0.
-745.,-165.,-655.,-165.,1,31
-655.,-165.,-655.,-25.0,1,31
-655.,-25.0,-40.0,-25.0,1,61
-40.0,-25.0,-40.0,-135.,1,31
-40.0,-135.,+40.0,-135.,1,31
+40.0,-135.,+40.0,-25.0,1,31
+40.0,-25.0,+655.,-25.0,1,61
+655.,-25.0,+655.,-165.,1,41
+655.,-165.,+745.,-165.,1,31
+745.,-165.,+745.,+25.0,1,31
+745.,+25.0,-745.,+25.0,1,31
-745.,+25.0,-745.,-165.,1,31
F

ZONE
G
0.,450.0,20.
-2000.,2000.,50.
2,2
```

and here is the corresponding **soltprn.don** files:

```
soltprn shielded solenoid
MAGNETIC
AXIS
NONSYMMAP

D
1.,+0.248e7
0.,0.,0.
C
+355.,300.,0.
-290.50,-50.,+290.50,-50.,+1,61
+290.50,-50.,+290.50,+50.,+1,21
+290.50,+50.,-290.50,+50.,+1,61
-290.50,+50.,-290.50,-50.,+1,21
F

D
2755.,0.
0.,0.,0.
C
0.,385.,0.
-745.,-165.,-655.,-165.,1,31
-655.,-165.,-655.,-25.0,1,31
-655.,-25.0,-40.0,-25.0,1,61
-40.0,-25.0,-40.0,-135.,1,31
-40.0,-135.,+40.0,-135.,1,31
+40.0,-135.,+40.0,-25.0,1,31
+40.0,-25.0,+655.,-25.0,1,61
+655.,-25.0,+655.,-165.,1,41
+655.,-165.,+745.,-165.,1,31
+745.,-165.,+745.,+25.0,1,31
+745.,+25.0,-745.,+25.0,1,31
-745.,+25.0,-745.,-165.,1,31
F

ZONE
G
0.,450.0,20.
-2000.,2000.,50.
2,2
```

In the two following figures are the "stability" for the vector potential A, solution of the boundary element (Q is the normal derivative of A) :

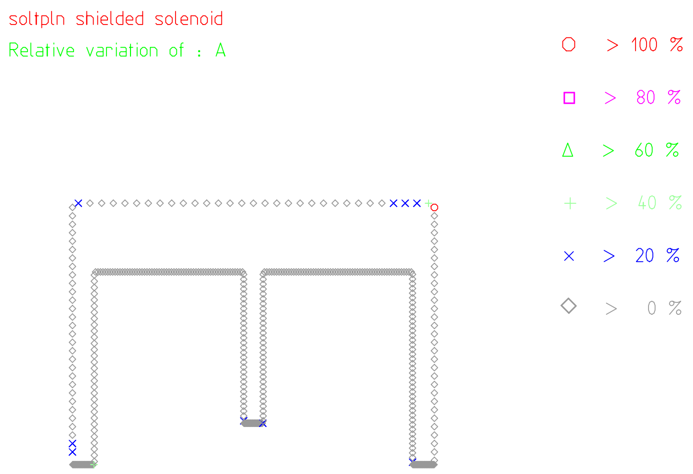


Figure 4:

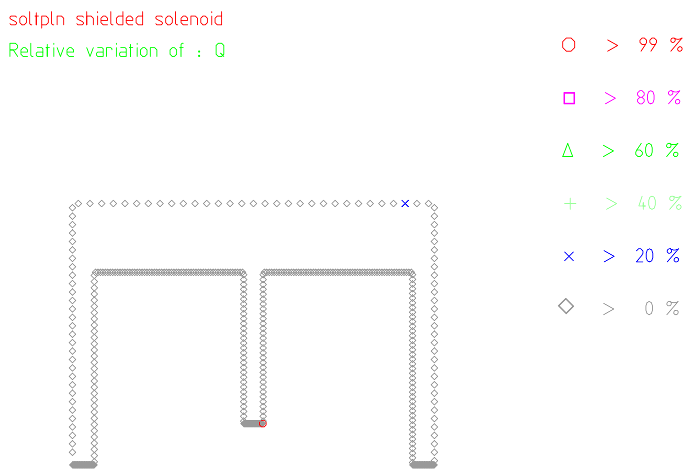


Figure 5:

1.3 Field and Ampere turn

Here is the **.set** file of left coil, for **Trajg** programme :

```
MAPINPUT
soltpln

ADJUST
 1     -1.000     0.0000      0.0000    135.0000      0.0000      0.0000

KINE
   28.000    0.000    0.000    0.000    0.000    0.500    1.892   105.658

STANDARD
  1  0.1000E-02  0.1000E-01   3500

FOCUS
      350.0000

WINDOW
 -150.0000    600.0000    -50.0000     50.0000    -50.0000     50.0000
 -150.0000    600.0000    -50.0000    600.0000    -50.0000     50.0000
 -150.0000   1800.0000   -150.0000    800.0000    -60.0000     60.0000

MATRICE
    0.5000     10.0000      0.5000     10.0000      1.0000  1

INTERPOL
Yes

CAPTION
             Left solenoid

MARGE
YES

OLD
YES

ZONE
```

It produce the following B_z field on the axis :

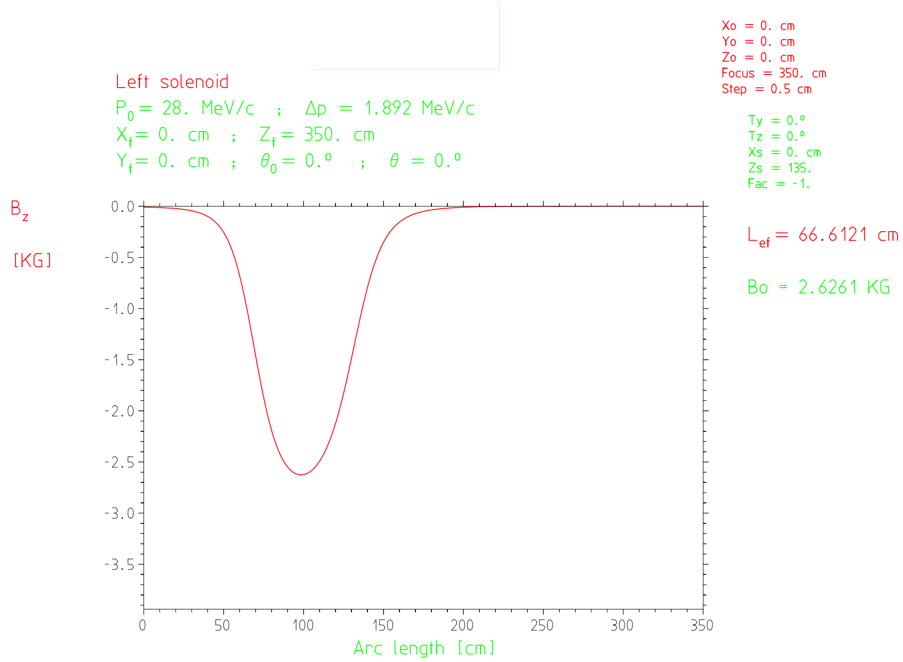


Figure 6:

The corresponding Ampere-turn is for 28 MeV/c

$$\frac{0.262 \times 0.666}{4\pi\, 10^{-7}} \;=\; 1.38\, 10^5 \;\; \text{A turn}$$

giving for 40 MeV/c : $1.98\, 10^5$ A turn.

Assuming conductor with 1 cm^2 surface, we have

$$59 \times 10 \;=\; 590 \;\; \text{turns}$$

Therefore for 40 MeV/c we need at least

$$\frac{1.98\, 10^5}{590} \;=\; 336 \;\; \text{A}$$

With the new normalization we have

$$\boxed{\text{Fac} \;=\; 1 \;\; \Longrightarrow \;\; 2.6261\, \text{KG}}$$

The remaining magnetic field B_z at target E, is :

P [MeV/c]	B_z [G]
28	7
40	10

Here are the first order matrix elements :

```
Left solenoid
*************

Po =    28.0000 MeV/c    dP =     1.8920 MeV/c

n    Fac          Xs [cm]     Ys [cm]    Zs [cm]     Ty []       Tz []
1       -1.0000      0.0000      0.0000    135.0000      0.0000      0.0000

xm              ym             xpm             ypm           dpm [MeV/c]
0.5000          0.5000         10.0000         10.0000         1.0000

Xo =     0.00 cm    Yo =   0.00 cm   Zo =    0.00
Xa =     0.0000 cm  Ya =   0.00 cm   Za =  135.0000 cm

Foc =   200.0000 cm    Step =     0.50 cm  Eps = 0.1000E-02

Determinant = 0.1000E+01

QUADRATIC Interpolation

                       *TRANSFORM* 1

        0.04721   0.06588  -0.07425  -0.08939   0.00000
       -5.30243   0.06059   7.18560  -0.07419   0.00000
        0.07425   0.08939   0.04721   0.06588   0.00000
       -7.18560   0.07419  -5.30242   0.06059   0.00000
        0.00000   0.00000   0.00000   0.00000   1.00000
```

The corresponding "rotation" is :

$$\frac{7.185}{5.302} = 1.35 \implies \phi = 53.57^0$$

Here are the levels in the X-Z plane

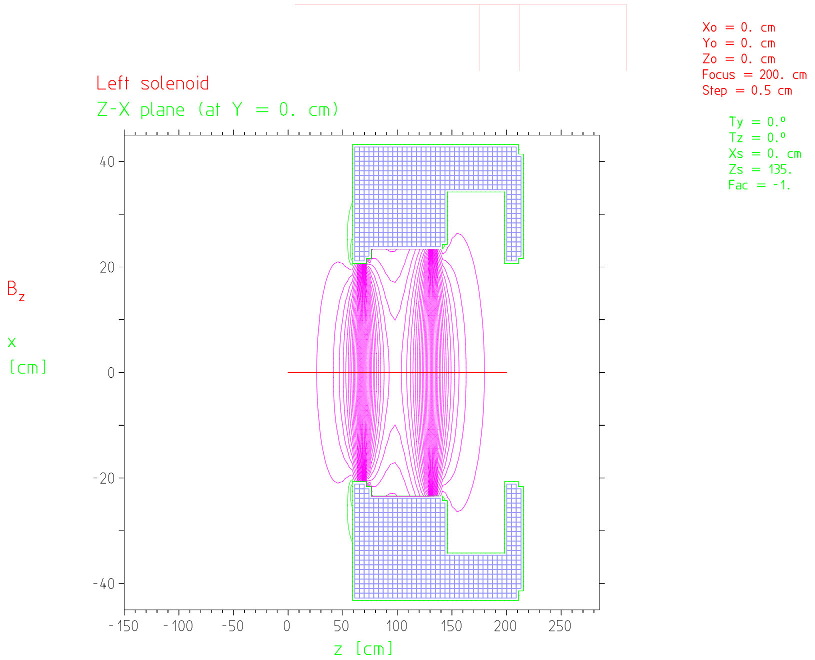


Figure 7:

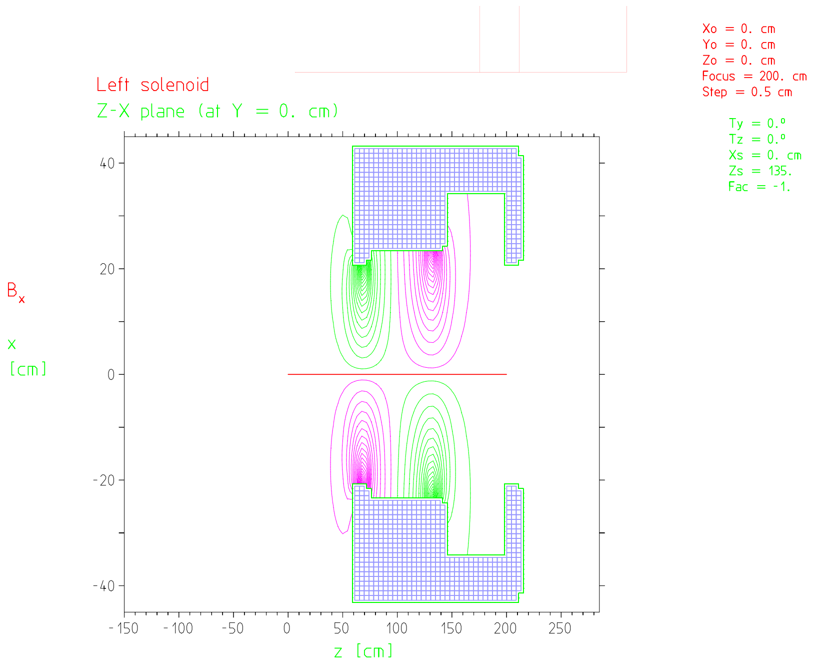


Figure 8:

Here is the divergence and rotational of the calculated field, for $\rho = 5$ cm :

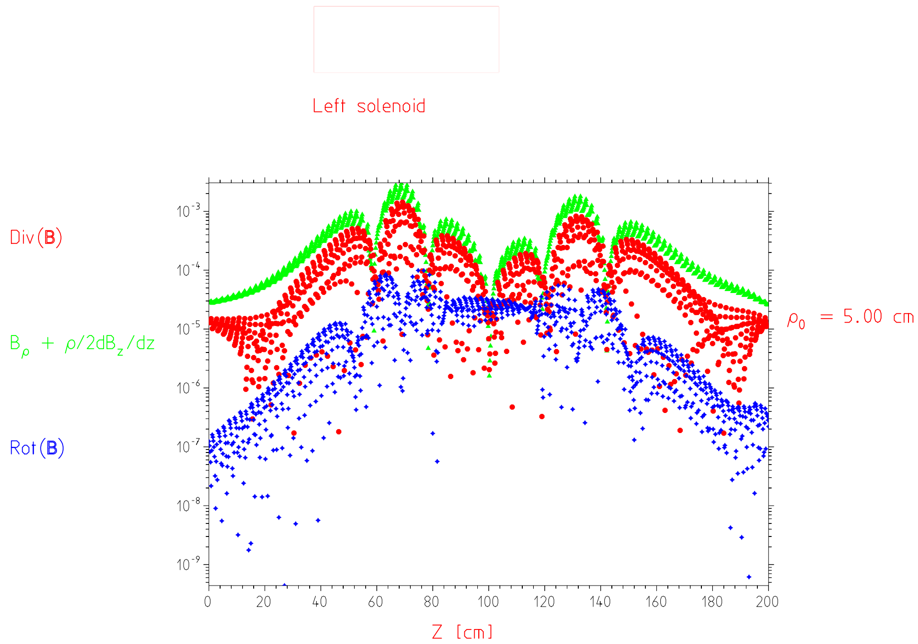


Figure 9:

1.4 Discussion

The effective length of a "coil" is ; 66.6 cm, and for the previous solenoids we had 68.5 cm. One coil has a cross section area of 59×10 cm^2, the bore radius being 25 cm and the outer one 30 cm, this give for the length of a conductor of 1 cm^2 cross section area

$$L_c \;=\; 2\pi\,(\,10\,r + 45\,)\,59 \;=\; 2\,\pi \;\overbrace{590}^{\text{nb of turn}}\; \underbrace{(\,r\,+\,4.5\,)}_{<\,r\,>}$$

here $r \;=\; 25.5$ cm. Hence

$$L_c \;=\; 2\,\pi \times 590 \times 30 \;=\; 11.12\,10^4\,\text{cm} \;=\; 1112\,\text{m}$$

The conductor being made of copper, with a resistivity of $\rho \;=\; 0.17\,10^{-7}$ Ω m, the resistor of the coil is

$$R_c \;=\; \rho\,\frac{L_c}{s} \;=\; 0.17\,10^{-7} \times \frac{1120}{10^{-4}} \;=\; 0.189\,\Omega$$

we have assumed a cross section area of 1 cm^2 for the conductor.

If we use a current of 500 A, then :

$$V \;=\; 0.189 \times 500 \;=\; 93.5\,V$$

and

$$W \;=\; 0.189 \times (500)^2 \;=\; 47.25 \text{ kW}$$

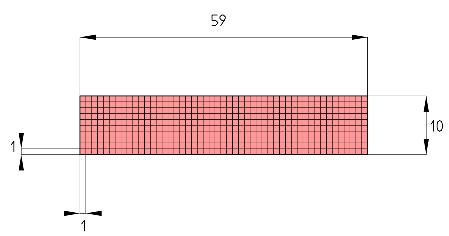


Figure 10:

In fact we will use 4 packages for the coil, with cooling in between (see figure where only 1 cm along the length is shown). Assuming 0.5 cm for the cooler, we have for the package i :

$$L_c^i = 2\,\pi \times 59 \times 2\,(< r_i > + 0.5) \;\; ; \;\; i = 1,..,4$$

with (in cm)

$$< r_i > \;\; = \;\; 26 \;\; ; \;\; 28.5 \;\; ; \;\; 31 \;\; ; \;\; 33.5$$

This yields ($< r_i >$ in cm)

$$L_c^i = 3.71 + 7.71 < r_i > \; ; \; [L_c^i] = \mathrm{m}$$

or

i	L_c^i [m]
1	204
2	223
3	243
4	262

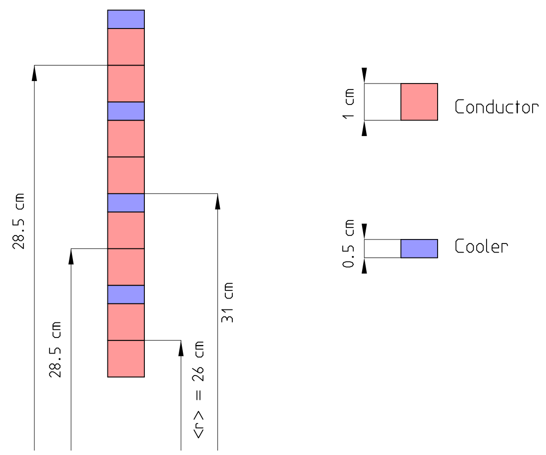


Figure 11:

1.5 Summary of some properties

For the most exited coil , we have

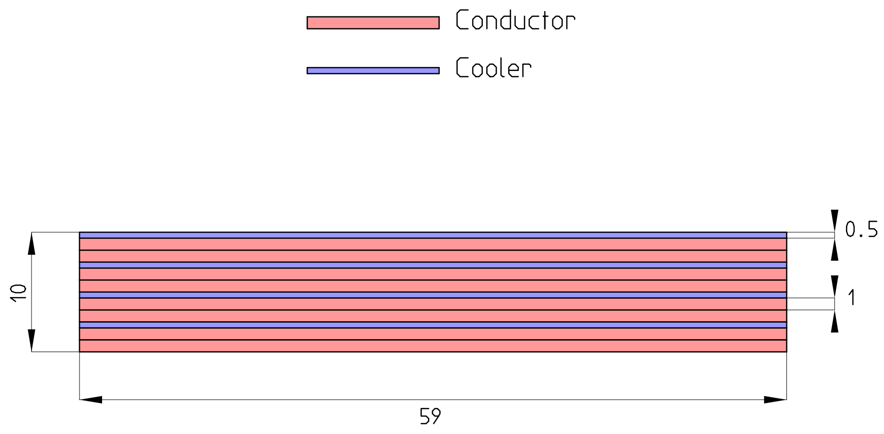
L a b L_{eff}	59.0 cm 25.0 cm 30.0 cm 66.6 cm
Ampere-turn	$1.38\,10^5$ (28 MeV/c) $1.98\,10^5$ (40 MeV/c)
L_c R_c	1120 m 0.189 Ω
L_c^1 R_c^1 L_c^2 R_c^2 L_c^3 R_c^3 L_c^4 R_c^4	204 m 0.035 Ω 223 m 0.038 Ω 243 m 0.041 Ω 262 m 0.045 Ω

Here a is the bore radius and b the outer radius.

The density of copper being 8.92 g/cm^3, we have

$$1120 \times 10^2 \times 8.92 = 999\,10^3 \text{ g} \Longrightarrow 999\,\text{kg}$$

$$932 \times 10^2 \times 8.92 = 835\,10^3 \text{ g} \Longrightarrow 835\,\text{kg}$$



Scheme of the cross section area of a coil

Figure 12:

In the above figure is a scheme of the coil's structure.

Here is the corresponding *.set file (**dsol.set**)

```
MAPINPUT
soltpln
soltprn

ADJUST
 1     -0.99238     0.0000      0.0000    135.0000      0.0000      0.0000
 2     -0.52050     0.0000      0.0000    135.0000      0.0000      0.0000

KINE
   28.000    0.000    0.000    0.000    0.000    0.200    1.892    105.658

STANDARD
  1  0.1000E-02  0.1000E-01   3500

FOCUS
      300.0000

WINDOW
 -150.0000    600.0000    -50.0000     50.0000    -50.0000     50.0000
 -150.0000    600.0000    -50.0000    600.0000    -50.0000     50.0000
 -150.0000   1800.0000   -150.0000    800.0000    -60.0000     60.0000

MATRICE
    0.5000     10.0000      0.5000     10.0000      1.0000  1

INTERPOL
Yes

CAPTION
      Two asymmetric shielded solenoids (thicker coils)

MARGE
YES

OLD
YES

ZONE
```

and the correspond field B_z on axis :

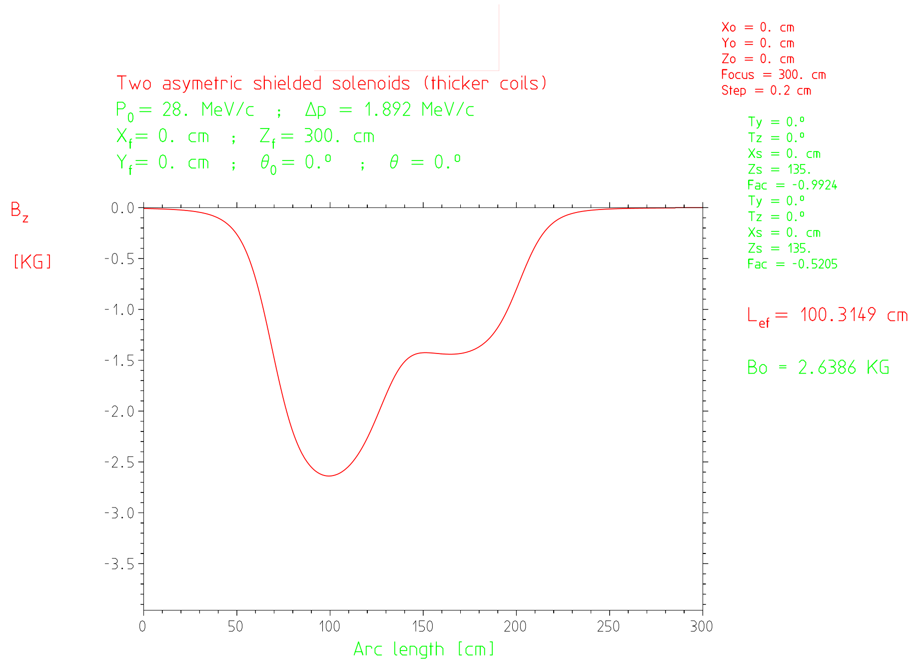


Figure 13:

The effective length being now shorter, at position of the right coil, the field is smaller by about 100 G, than for the previous design !

Here are the first order matrix elements :

```
Two asymmetric shielded solenoids (thicker coils)
************************************************

Po =    28.0000 MeV/c    dP =     1.4000 MeV/c

n    Fac       Xs [cm]     Ys [cm]     Zs [cm]     Ty []       Tz []
1       -0.9924      0.0000      0.0000    135.0000      0.0000      0.0000
2       -0.5205      0.0000      0.0000    135.0000      0.0000      0.0000

xm             ym            xpm            ypm           dpm [MeV/c]
0.5000         0.5000        10.0000        10.0000         1.0000

Xo =     0.00 cm  Yo =     0.00 cm  Zo =     0.00

Xa =     0.0000 cm  Ya =     0.0000 cm   Za =   135.0000 cm

Foc =   300.0000 cm    Step =     0.20 cm  Eps = 0.1000E-02

Detx = 0.2329E-01    Dety = 0.2329E-01

QUADRATIC Interpolation

           Determinant = 0.1000E+01

                 *TRANSFORM* 1

 -0.17746   0.01038   1.04299  -0.06244   0.00000
 -1.67238  -0.03339  10.44939   0.31059   0.00000
 -1.04299   0.06244  -0.17746   0.01038   0.00000
-10.44939  -0.31059  -1.67238  -0.03339   0.00000
  0.00000   0.00000   0.00000   0.00000   1.00000
```

1.6 Some rays through the solenoid

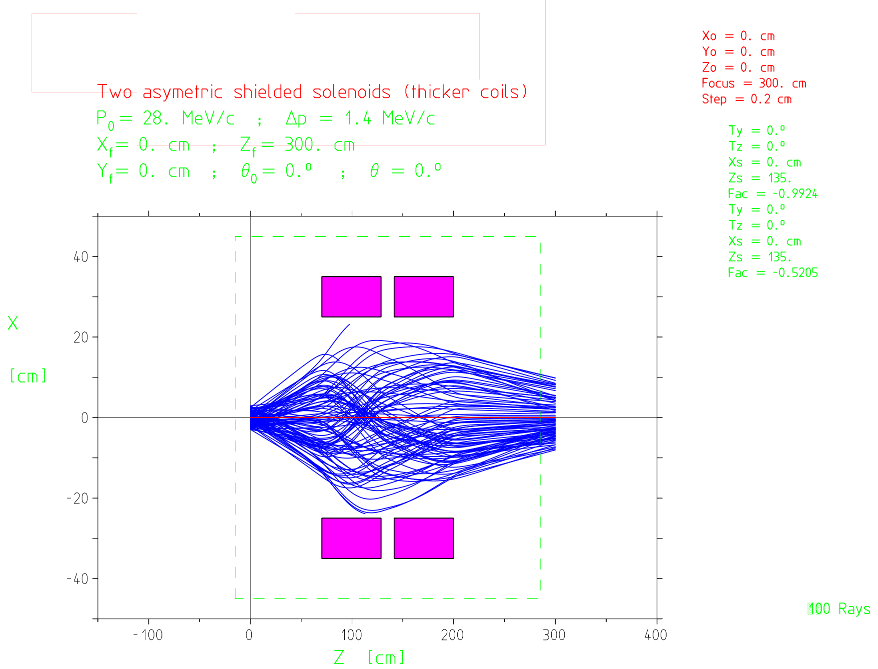


Figure 14:

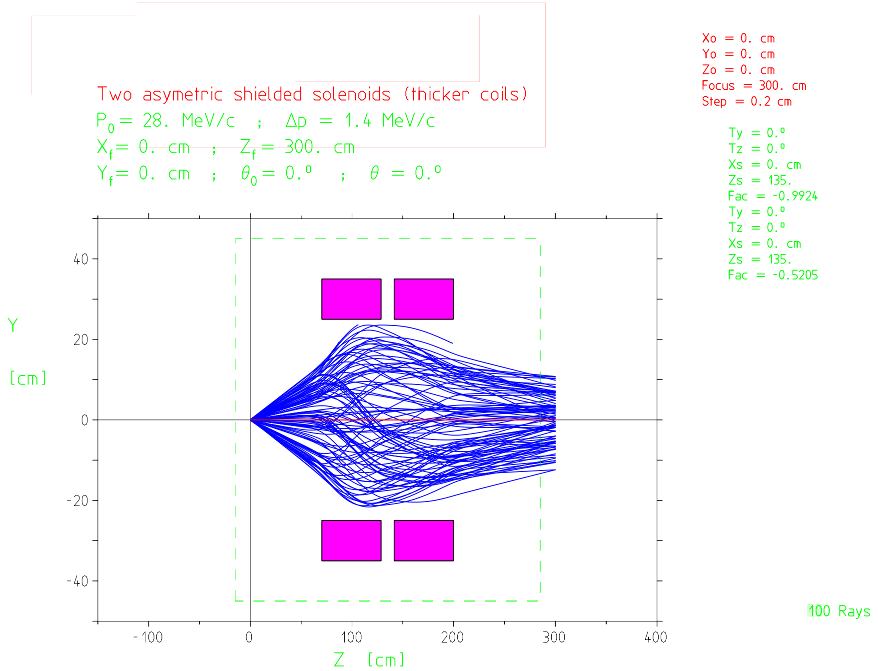


Figure 15:

The input phase space is the same as for the whole beam line namely :

```
The name of the file is :        ro.dot
 The number of rays is :         100

         Xmax [cm] is :          3.000
        X'max [mr] is :          200.0
         Ymax [cm] is :         0.1500
        Y'max [mr] is :          200.0
            Dp [%] is :          5.000
```

and here the same rays with the ASK61 at its position :

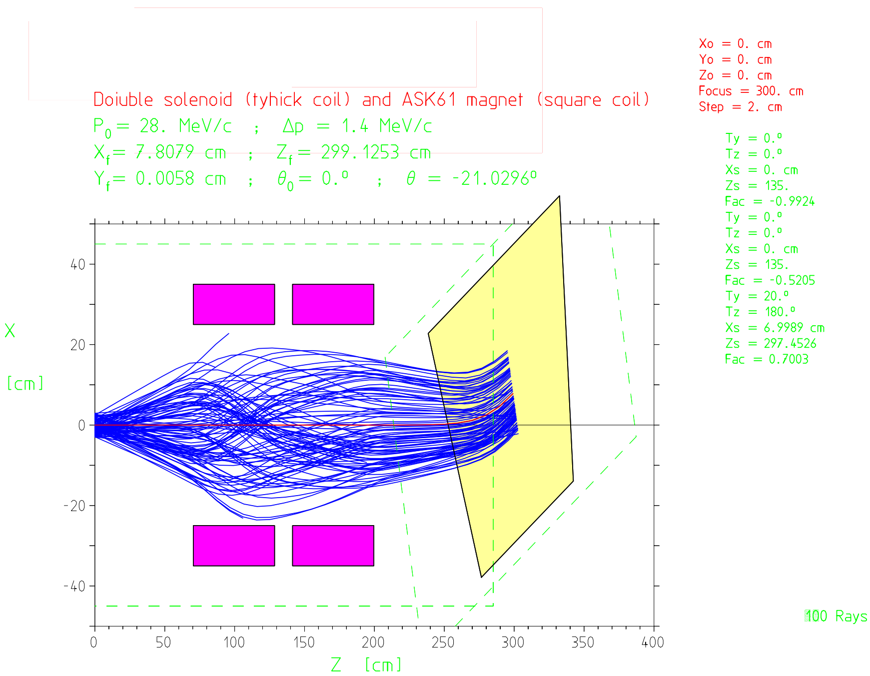


Figure 16:

1.7 Levels of the whole solenoid

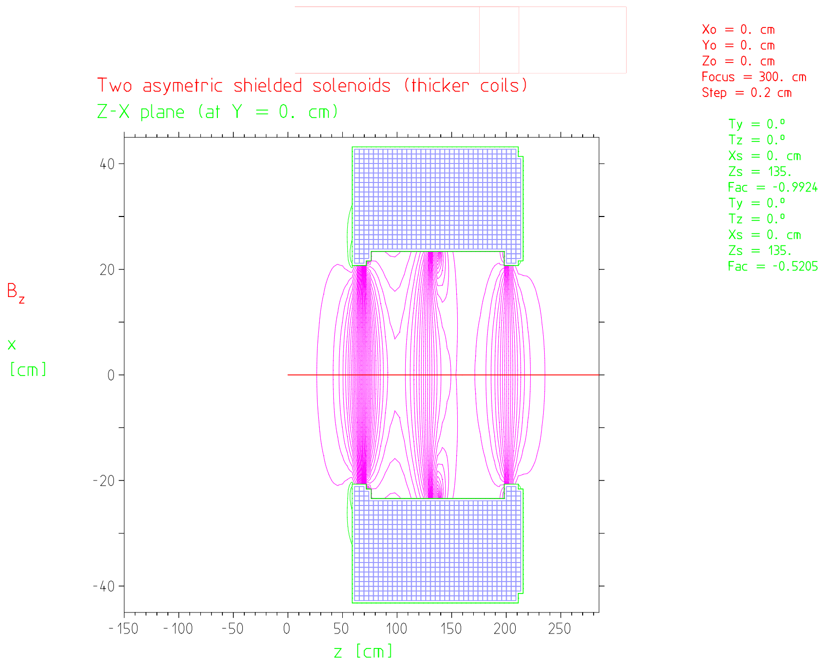


Figure 17:

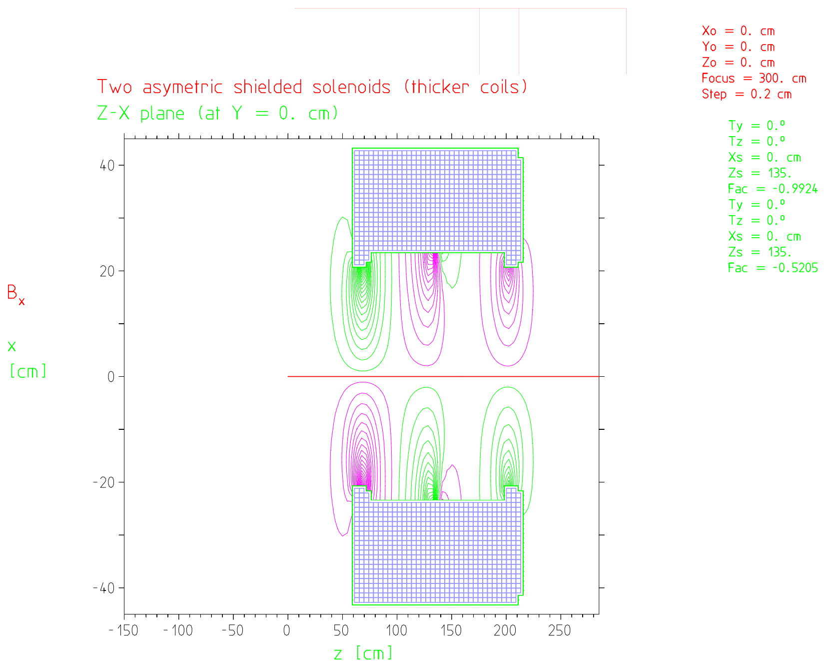


Figure 18:

1.8 Output from TRANS programme

Here is the *.set file (**trans.sol**)

```
 Double shielded solenoid (Thick coil)
 50.   50.    3.
 3. 200. .15  200. 5.  28.
 D  0.600
 S  2.5336  0.800 .25 Sol61
 S  0.6500  0.894 .25 Sol62
 D 0.706
 ZONE
```

and the corresponding first order matrix elements :

```
Double shielded solenoid (Thick coil)

3.0000      200.0000        0.1500      200.0000        5.0000        28.0000

Focus = 3.000 m

               First order matrix

 +0.2462     -0.0016     -1.4277     +0.0091     +0.0000
 +1.9689     +0.1048    -11.4192     -0.6077     +0.0000
 +1.4277     -0.0091     +0.2462     -0.0016     +0.0000
+11.4192     +0.6077     +1.9689     +0.1048     +0.0000
 +0.0000     +0.0000     +0.0000     +0.0000     +1.0000

Detx  = +0.0289 ; Dety = +0.0289

               Det  = 1.0000
```

And here the envelop :

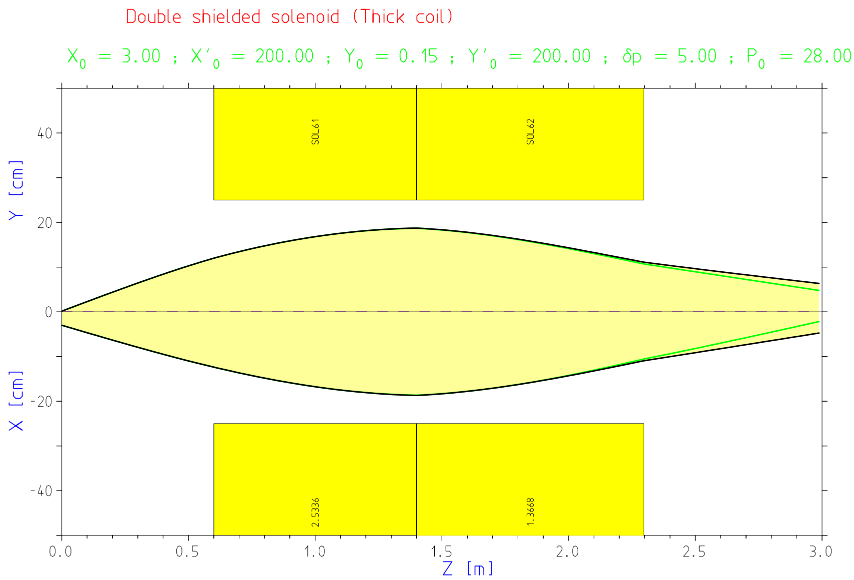


Figure 19:

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