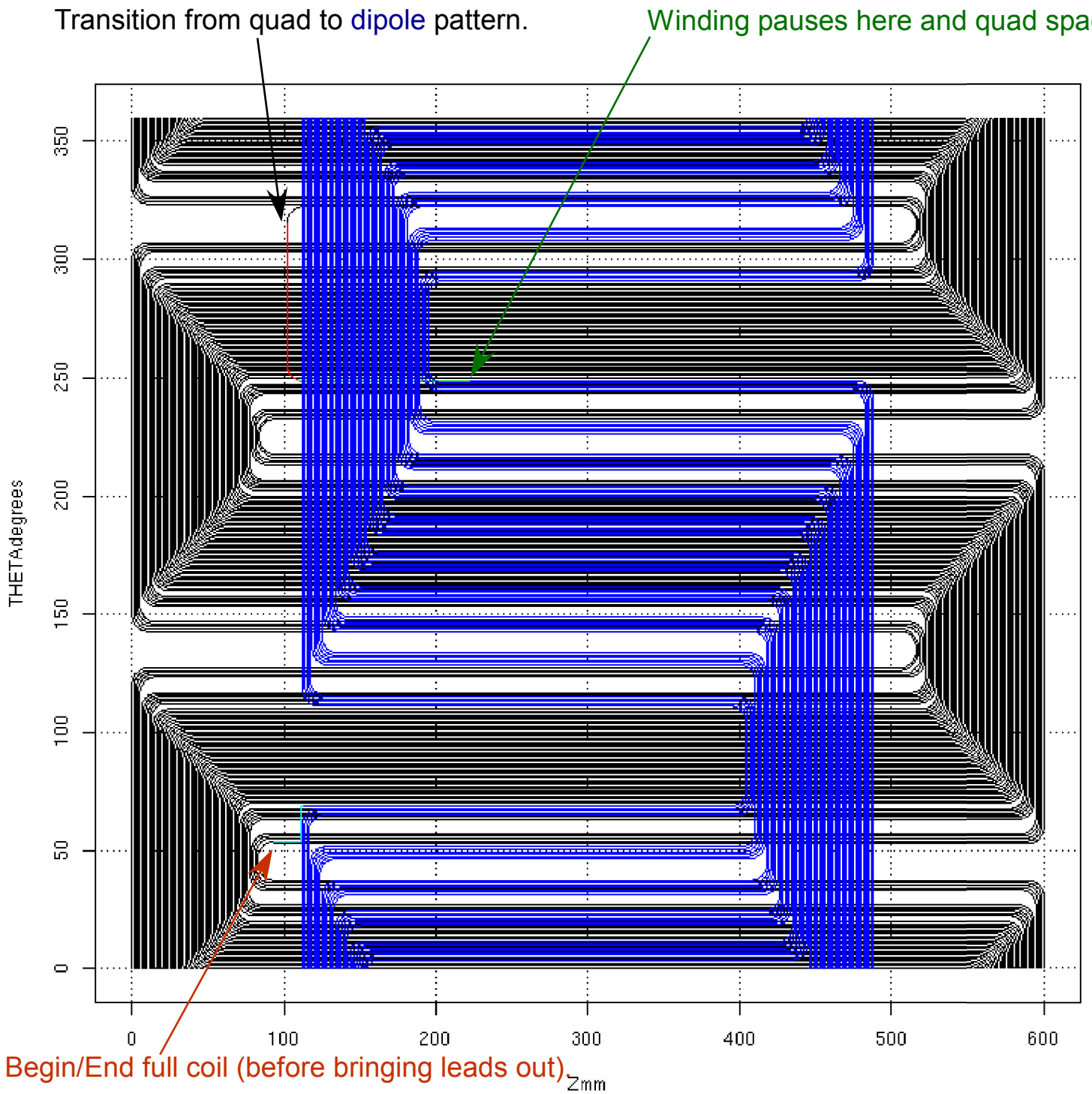
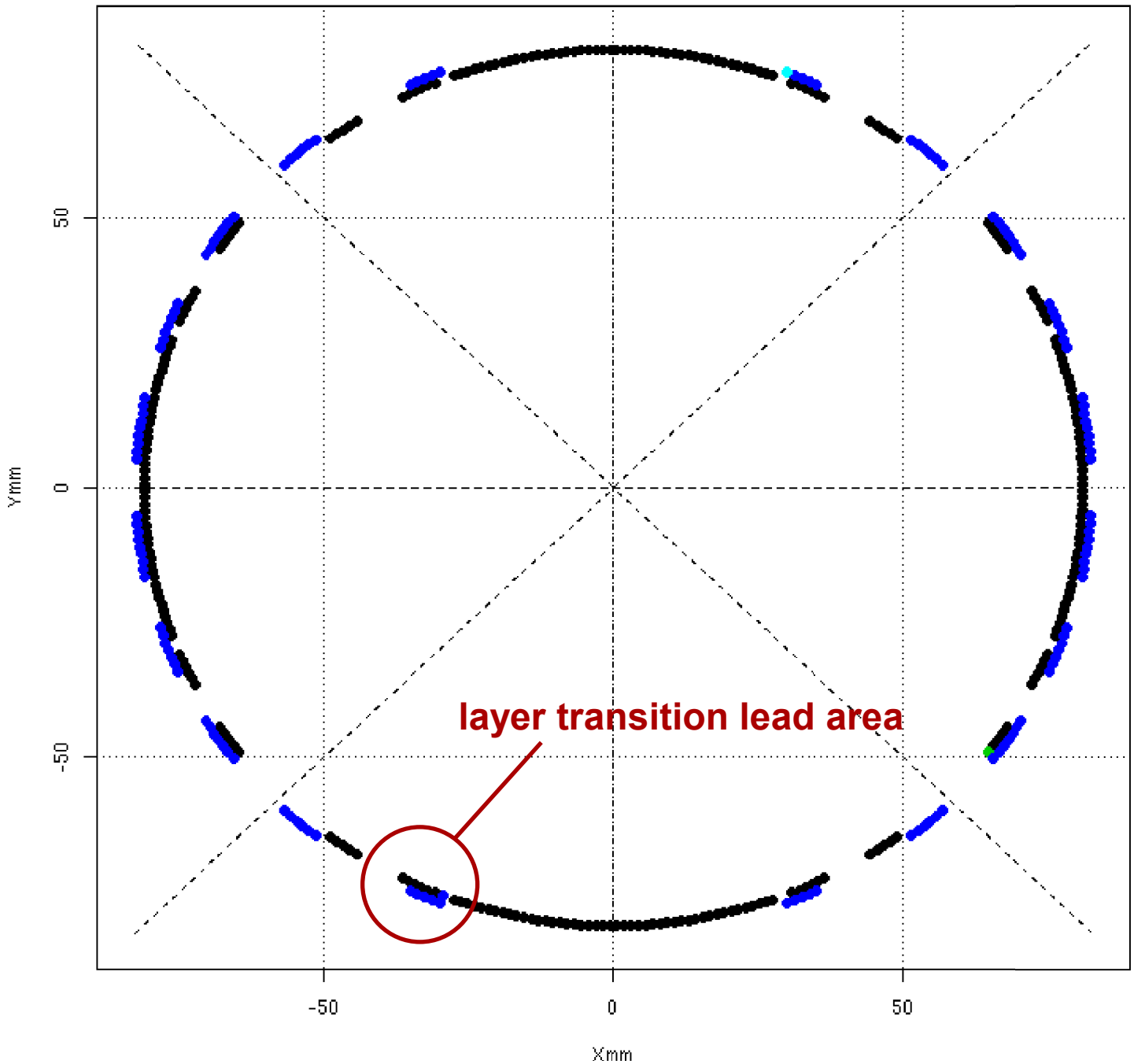


First wind lower layer quadrupole pattern (black) starting on the non-lead side of the coil pack (so we end up on the lead side). Winding proceeds as a normal serpentine until we are ready to wind second layer dipole pattern.

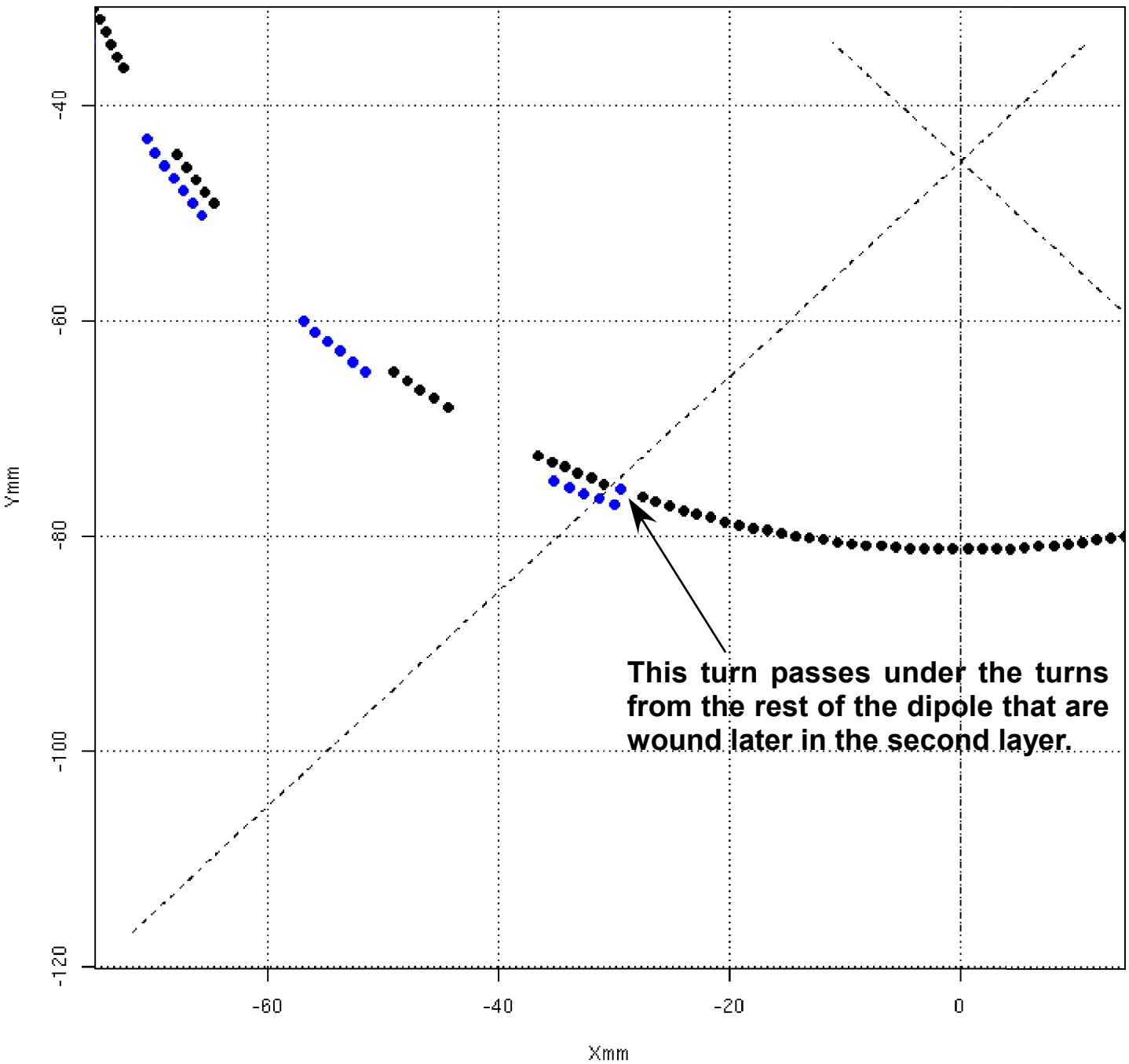
The dipole pattern (blue) has the same number of turns as the quadrupole pattern (in order not to generate integral solenoidal field). Its natural strength is a bit too high so we symmetrically shorten its pattern so as to generate the correct integral (4581 units, as per A. Jain). With the shortened dipole there are clear paths to get both the start lead and the leads from the skew dipole out.

The main complication comes from the fact that the quadrupole and dipole poles do not naturally line up and we want to avoid going to a third layer.

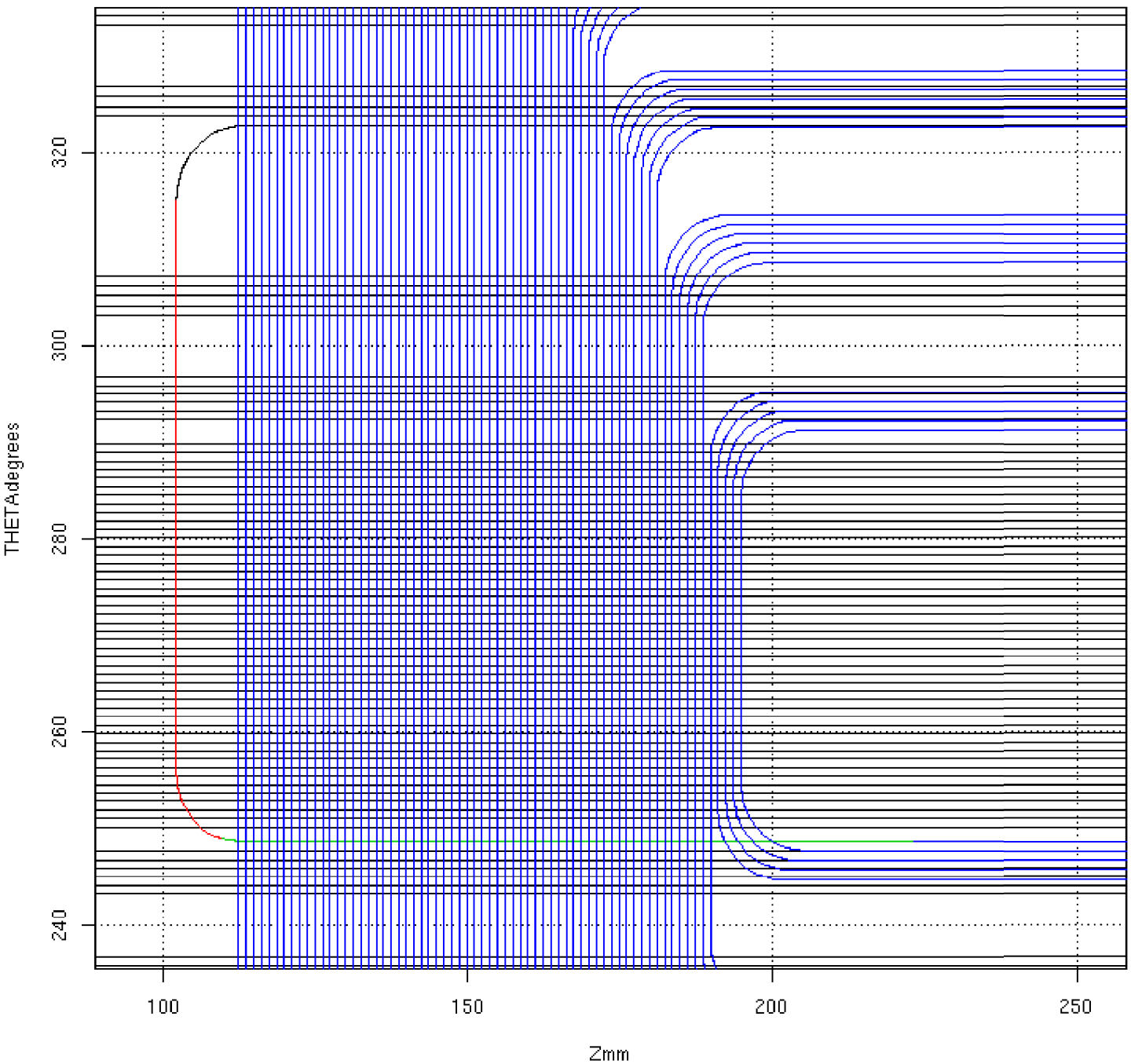
As will be illustrated later a small spacer is introduced in the quadrupole pattern that is used to allow wiring to start on the non-lead side of the dipole pack in order that the return lead from the dipole can be brought out simply.



2D cross section showing quadrupole pattern on bottom and dipole pattern on top. Next viewgraph has a blowup at the indicated spot showing how the first first turn of the dipole is lined up with a spacer in the quadupole pattern.



The indicated gap is used to bring the wire under the area where the lead end turns will be wound later. this allow winding to start on the non-lead side of the pack so that the dipole winding ends up on the lead side.

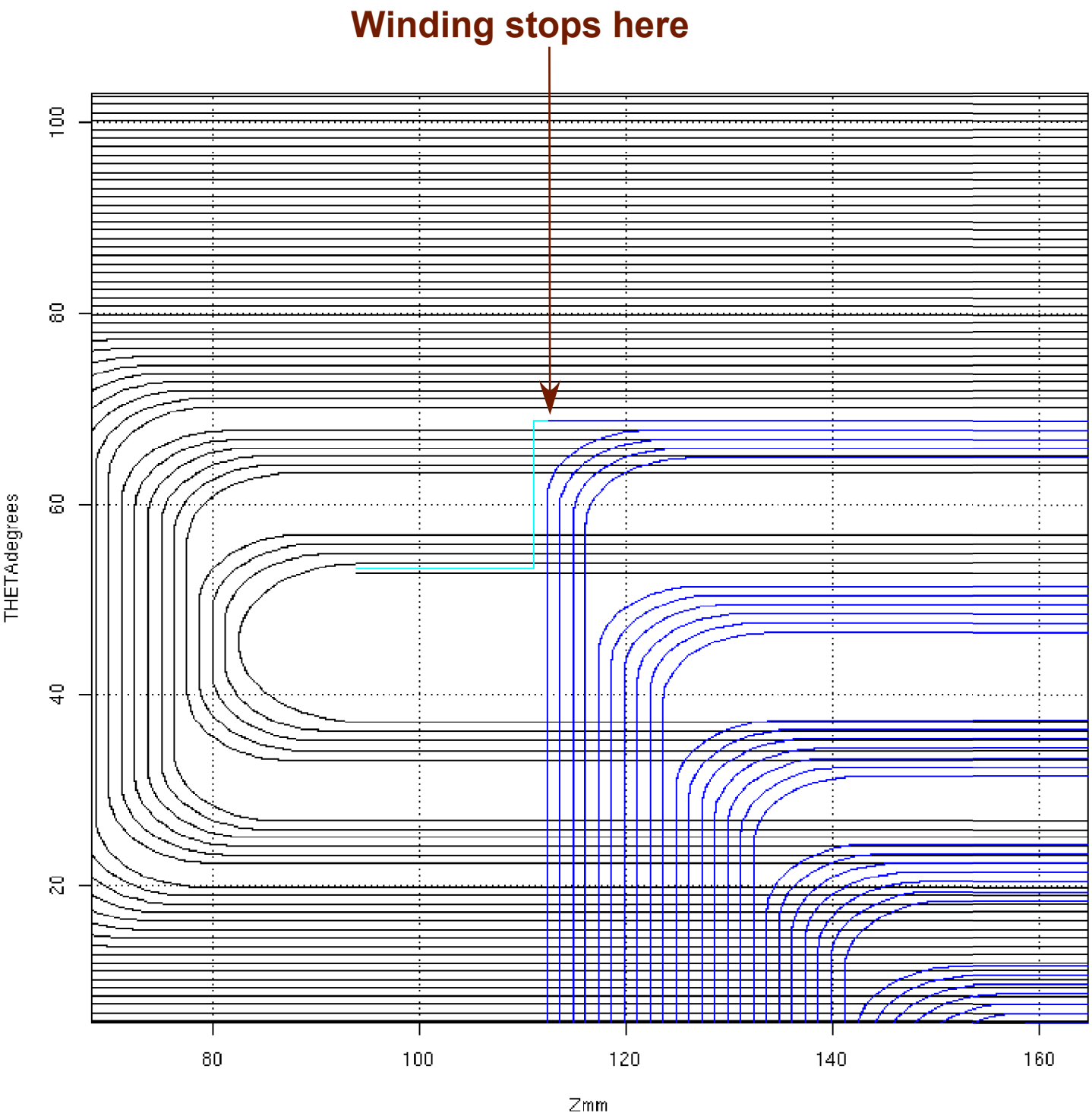


Winding of the bottom quadrupole (black) proceeds past the area where the dipole (blue) end turns will cross later. Once we have turned enough to be normal the the coil pack we climb up and over (red) the existing quadrupole turns in a region that will be clear later.

Then we turn and slide down into a gap in the quadrupole pattern that lines up with the first turn of the dipole. Winding proceeds back in the first layer until we have passed far enough (green) that we are past the place where the second layer dipole turns (blue) go later on.

Now we can stop and fill in the bottom layer gaps with G10 and matched expansion epoxy. At this time the skew dipole leads can also be brought into the open end of the quadrupole pattern and brought past where the dipole will go.

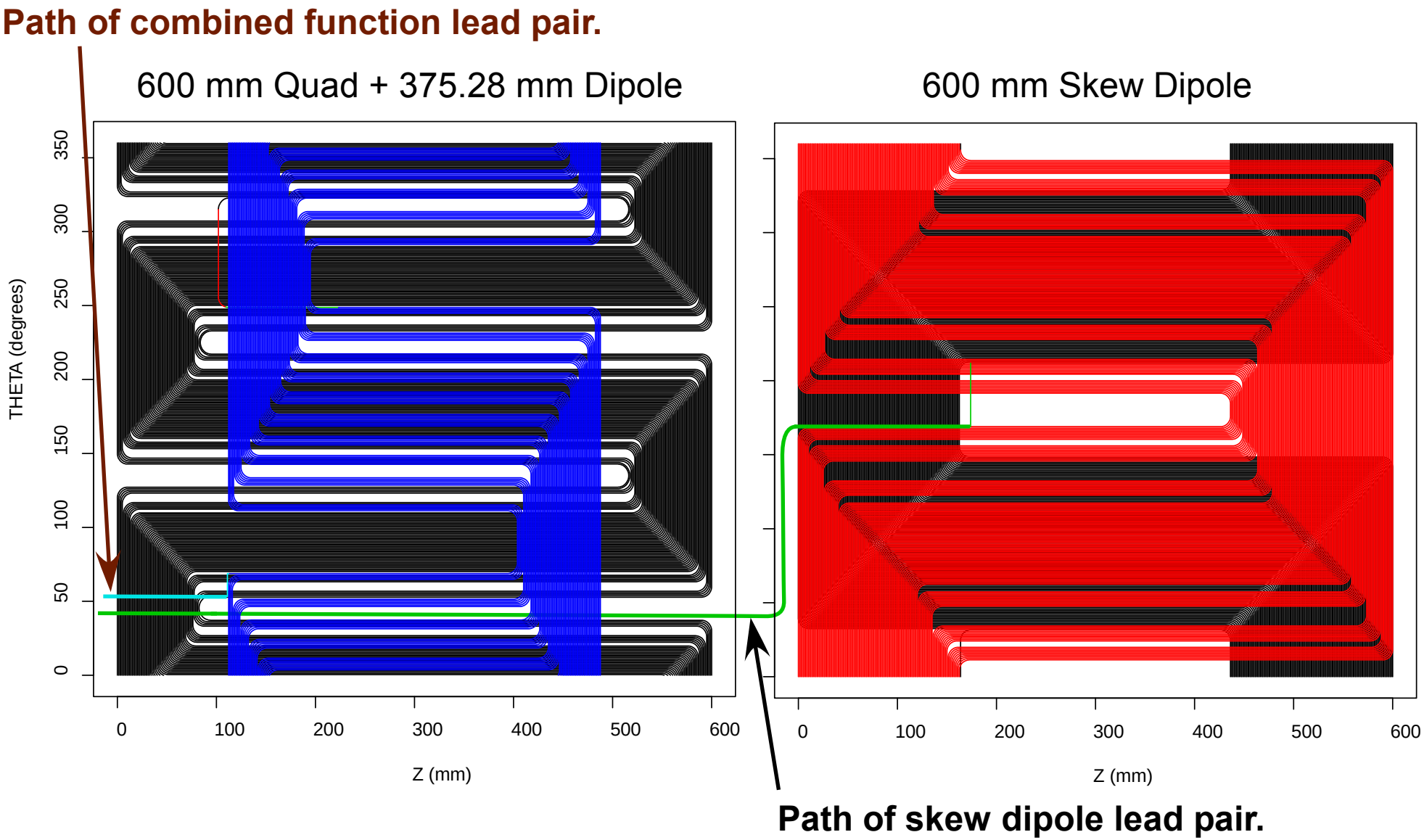
Finally we wrap with fresh substrate and proceed with winding on the second layer.



Winding the dipole finishes on the lead side of the pack close to the start lead (cyan). The return lead is then brought next to the start lead and they are both brought out over the end turns from the first layer.

Note the winding machine stops at the end of the dark blue track and the rest (lead work) is done by hand using reasonable bends. The cyan path is an approximation (given in another file not used for winding) that is used only for calculating harmonics and flux coupling etc.

Lead Path Schematic



Same total coil but analyzed two different ways

```
cf14jan04_jparc_shf  FFT-FieldMap Harmonics
  B2(T,meter) at this point =0.00649674
rRef =  50.000 mm B2 =   6.4967e-03
   m          bm          am
    1      8745.459        2.250
    2     10000.000        0.115
    3        -1.624        0.158
    4        -0.027       -0.342
    5         0.343        0.075
    6         0.074        0.151
    7         1.002       -0.115
    8         0.091       -0.016
    9        -3.503        0.061
   10        -0.964       -0.023
   11         4.469       -0.016
   12         0.005        0.018
   13        -2.429       -0.001
   14        -2.559       -0.007
   15         0.623        0.004
   16        -0.003        0.001
   17        -0.177       -0.002
   18         0.212        0.001
   19        -0.267        0.001
```

As quad:

Lpattern = 600 mm

Lmag = 515 mm

ITF: 1 A => 3.35e-3 T

```
cf14jan04_jparc_shf  Integral Cylindrical Harmonics
  B2(T,meter) at this point =0.0033487
rRef =  50.000 mm B2 =   3.3487e-03
   m          bm          am
    1      4581.006      -25.161
    2     10000.000       -5.284
    3        -1.534       -3.553
    4         2.696       -4.904
    5         4.402        1.255
    6         0.744        2.157
    7         0.495        0.098
    8         0.305        0.283
    9        -2.339        0.392
   10        -1.329       -0.151
   11         2.500       -0.143
   12         0.007        0.017
   13        -1.378       -0.038
   14        -2.509       -0.038
   15         0.377        0.014
   16        -0.005        0.010
   17        -0.100       -0.001
   18         0.210        0.006
   19        -0.153        0.003
```

```
cf14jan04_jparc_shf  FFT-FieldMap Harmonics
  B1(T,meter) at this point =0.000284085
rRef =  50.000 mm B1 =   2.8408e-04
   m          bm          am
    1     10000.000        2.572
    2     11434.505        0.132
    3        -1.857        0.181
    4        -0.031       -0.391
    5         0.392        0.085
    6         0.084        0.173
    7         1.146       -0.131
    8         0.104       -0.018
    9        -4.005        0.070
   10        -1.102       -0.026
   11         5.110       -0.019
   12         0.005        0.020
   13        -2.777       -0.002
   14        -2.926       -0.008
   15         0.713        0.004
   16        -0.004        0.001
   17        -0.202       -0.002
   18         0.243        0.001
   19        -0.305        0.001
```

As dipole:

Lpattern = 375.28 mm

Lmag = 270 mm

ITF: 1 A => 7.67e-5 T·m

```
cf14jan04_jparc_shf  Integral Cylindrical Harmonics
  B1(T,meter) at this point =7.6702e-05
rRef =  50.000 mm B1 =   7.6702e-05
   m          bm          am
    1     10000.000      -54.924
    2     21829.267      -11.535
    3        -3.348       -7.756
    4         5.885      -10.705
    5         9.608        2.739
    6         1.623        4.709
    7         1.081        0.215
    8         0.667        0.618
    9        -5.106        0.856
   10        -2.902       -0.330
   11         5.458       -0.313
   12         0.015        0.037
   13        -3.007       -0.082
   14        -5.478       -0.083
   15         0.823        0.031
   16        -0.011        0.021
   17        -0.218       -0.002
   18         0.459        0.012
   19        -0.333        0.007
```

Some final comments

Because the dipole component changes sign under a 180° rotation but the quadrupole does not the degree of coupling depends upon the orientation of the final corrector pattern inside the JPARC magnet. For one orientation the coupling is doubled (total flux 13.58, so single coil = 6.8) and the other the flux coupling is almost completely canceled (final is 1.2e-3) for an effective suppression ratio of factor 5700.

Of course this depends upon the main dipole field being 2.5863 T and the main quad being 0.931 T at 50 mm (18.62 T/m). If these numbers have changed we can fairly easily retune.

However John Escallier is now ready to wind. He will cut and spool wire to the machine and start winding as soon as I give him the go ahead that this is the pattern we really want to wind.

I'd like to tell him what to do as soon as our videoconference is over. Thank you for your patience. - B. Parker 20-Jan-2004