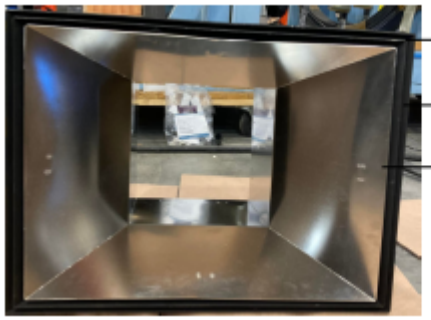
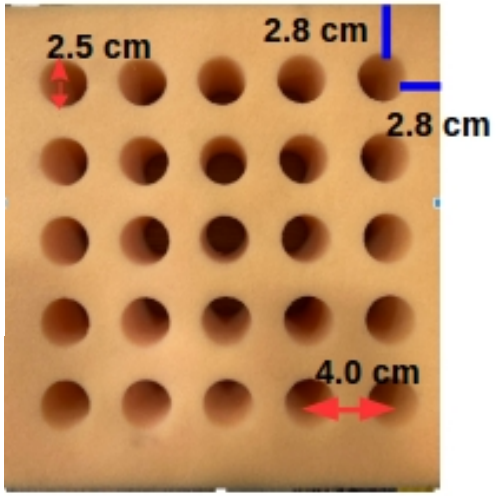
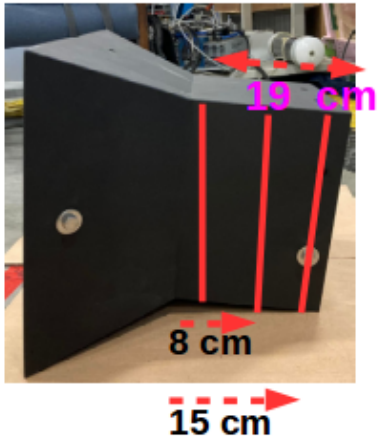
Magnetic shielding test

- External field of 90 G is applied using Helmholtz coil
- On each position (1, 2, and 3) both transverse and longitudinal field is measured

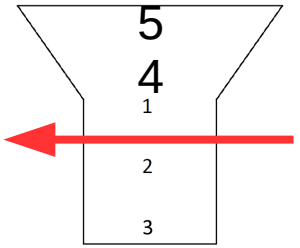


- 0.04”
- 0.08”

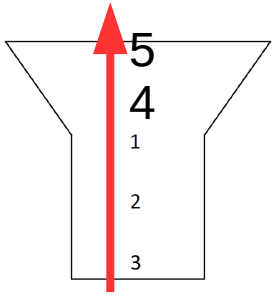




Transverse



Longitudinal



- Measurements are taken at position 1 , 2, 3 , 4, and 5
- PMT will be placed at position 1

Measurement done in two configuration of external field

- Transverse field, normal to side of PMT
- Longitudinal field, normal to face of PMT

Conclusion

Transverse field (at position where PMT seats)		
Measurement	Shielding	Comment
1	2 netic layer	Below 5 G
2	2 netic + 0.04 mu-metal	Below 3 G
3	1 netic + 0.08 mu-metal	Below 15 G
4	2 netic + 0.08 mu-metal	Below 2 G

Longitudinal field (at position where PMT seats)		
Measurement	Shielding	Comment
1	2 netic layer	Between 10-20 G
2	2 netic + 0.04'' mu-metal	Between 10-20 G
3	1 netic + 0.08'' mu-metal	Between 10-20 G
4	2 netic + 0.08'' mu-metal	Between 10-15 G

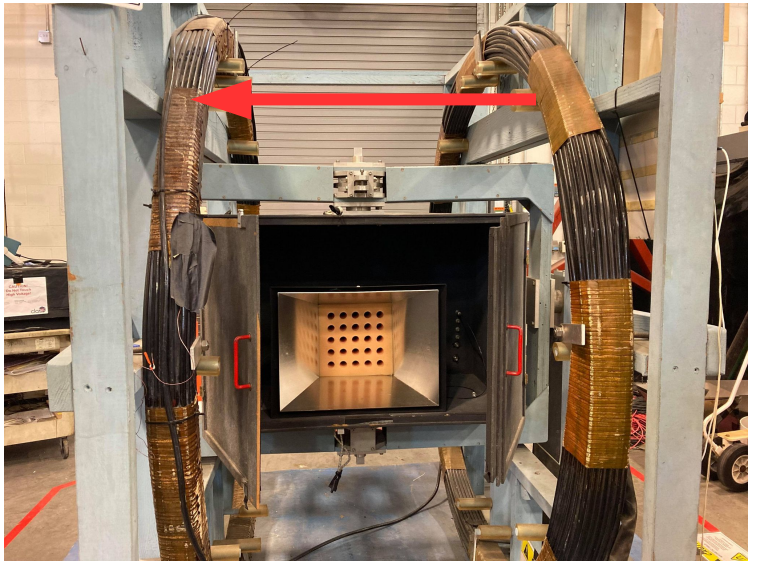
S.P Malace, B.D Sawatzky and H. Gao
https://arxiv.org/pdf/1306.6277.pdf

- Gain reduction in magnetic field for H8500C_03 PMT
  - 20 G transverse 2-5% reduction in gain central/edge pixel)
  - 20 G longitudinal 20 G 2-20% reduction in gain central/edge pixel
- Based on this study and assuming same gain reduction for HA12700-03 PMT the shielding reduces field to desired level

- Longitudinal filed is hard to shield
- Adding mumetal (0.04" or 0.08") along with two netic layer does not help much to reduce field

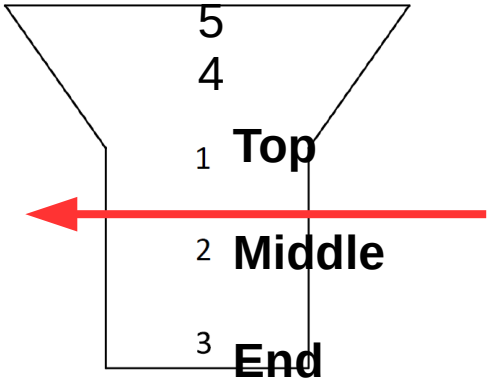
-1.6 1.2 17 4 3.2 3.5	-1.1 0.7 9.1 4.5 4.6 11	-0.2 -0.7 -0.5 4.7 5.0 714	0.5 -1.8 -12 4.3 4.2 11	0.9 -2.1 -21 3.8 1.6 2.5
-1.6 1.9 18 3.8 3.2 3.7	-1.1 1.5 10 4.8 5 13	-0.3 -0.7 -1.1 5.1 6 15	0.3 -12 -2.5 4.7 4.9 14	0.6 -2.6 -10.0 3.8 1.2 2.2
-1.9 1.7 8 4.1 3.2 2.8	-1.3 1.3 9.3 4.8 5 13	-0.4 -0.7 0.9 5.2 5.7 15	0.5 -2.7 12 4.9 4.9 12.4	1.0 -24 -3.1 3.8 1.1 2.6
-1.4 1.7 20 3.9 3.1 2.5	-1.1 1.4 8.9 4.6 4.8 11.5	-0.2 -0.6 -1.2 4.8 5.5 14	0.4 -2.6 13 4.7 4.4 13	1.0 -3.3 -27.0 3.9 2.2 2.3
-1.1 1.1 21 3.6 3.1 3.8	-0.6 0.7 10 4.1 4.2 8.9	-0.1 -0.4 1.5 4.3 4.5 9.6	0.3 -1.6 -13 3.9 3.8 7.9	0.8 -1.8 -25 3.6 2.4 1.7

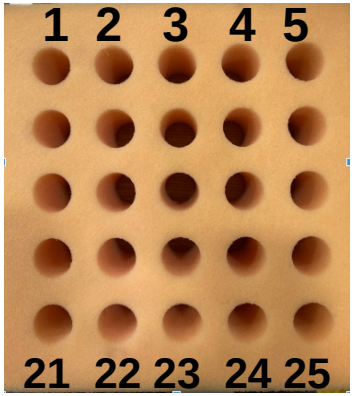
Two outer layer without mu metal



4: 0.2 12 **(field at 4)**

5: 0.5 28 **(field at 5)**





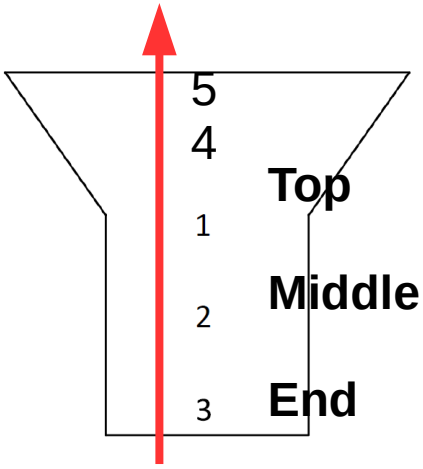
- 90 G external field from Helmoltz coil
- Longitudinal probe (top, middle, end)
- Transverse probe (top, middle, end)
- **At end position field is relatively high**

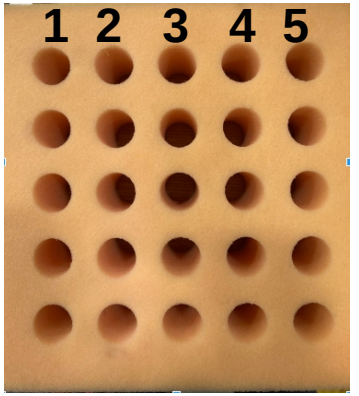
13 13 64 4.0 -14 -31	16 19 68 1.5 -5.1 -9.0	17 22 73 0.3 0.7 3.5	16 20 79 -3.2 5.2 15	13 13 70 -5.4 4.6 35
15 18 67 4.0 -8.1 -40	20 26 73 0.2 -9.0 -12	21 28 75 -1.1 -0.9 -3.3	20 25 82 -3.6 8.2 16	16 17 71 -7.1 19 46
16 18 69 4.3 -20 --42	20 27 74 1.1 -8.1 -15	22 29 77 0.6 -0.1 1.8	20 27 78 -3.7 9 14	16 17 75 -7.8 21 42
12 16 67 3.6 -17 -39	17 24 73 1.1 -8 -18	19 25 75 -0.2 -1.6 -4.2	17 23 79 -2.4 7.6 11	14 15 74 -5.8 16 39
8 9 50 2.6 -7 -24	10 13 54 1.1 -3.8 -12	11 15 63 -0.2 -2.6 -3.1	10 14 68 -1.2 1.9 -1.7	9 8 63 -3.1 7.8 18

Two outer layer without mu metal

4: 48 -4.0

5: 77 7.0

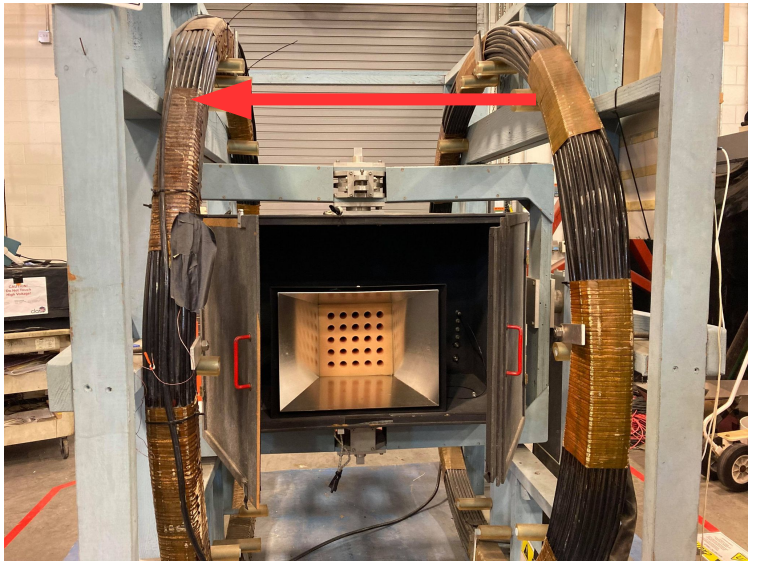




- 90 G external field (inside the plane)
- Longitudinal probe (top, middle, end)
- Transverse probe (top, middle, end)

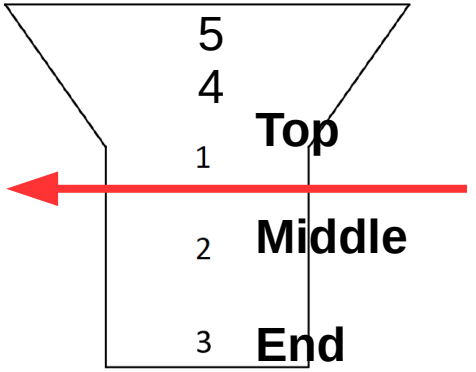
-0.9 0.9 9.5 2.0 1.7 -1.0	-0.6 1.0 6.6 2.9 2.7 5.6	-0.1 -0.1 0.1 3.2 3.2 7.2	0.6 -1.1 -5.7 2.9 2.7 5.2	0.9 -1.0 -8.0 2.1 1.5 -0.2
-0.9 1.5 10.5 1.9 1.5 -1.4	-0.8 1.5 7.5 2.9 2.9 6.3	-0.1 0.1 -0.5 3.3 3.9 8.7	0.6 -1.5 -6.2 3.2 3.2 6.9	0.9 -1.6 -10.0 2.2 1.5 -0.2
-1.2 1.8 11.6 2.1 1.5 -1.3	-0.8 1.6 8.3 3.0 2.9 7.1	-0.1 -0.1 0.9 3.3 3.8 9.4	0.5 -1.5 -6.9 2.9 3.0 6.9	0.9 -1.7 -10.1 2.2 1.3 0.5
-0.8 1.6 10 1.9 1.5 -1.3	-0.5 1.5 7.0 2.9 2.9 6.0	-0.1 0 1.1 3.1 3.7 8.4	0.3 -1.5 -6.5 2.9 2.9 6.5	0.7 -1.7 -12.0 2.1 1.6 -0.2
-0.7 0.9 7.3 1.9 1.5 -0.9	-0.5 0.7 5.1 2.6 2.6 4.2	-0.2 -0.1 0.8 3.0 2.9 5.5	0.1 -0.7 -4.4 2.7 2.4 4.8	0.4 -0.8 -8.7 1.9 1.6 0.4

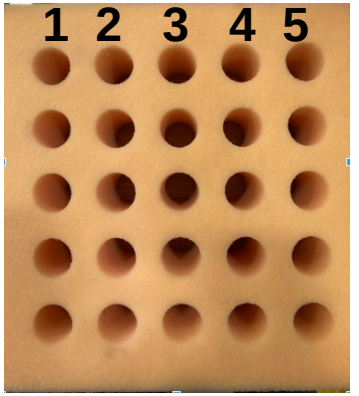
Two outer layer + 0.04” mu metal



4: 2.5 10

5: 0.3 23



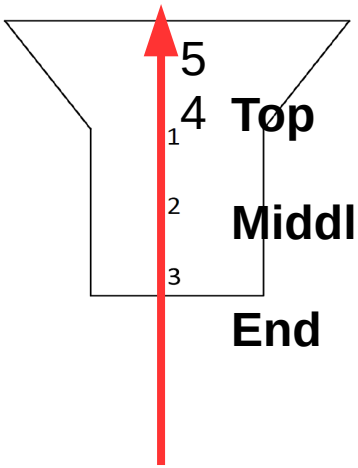


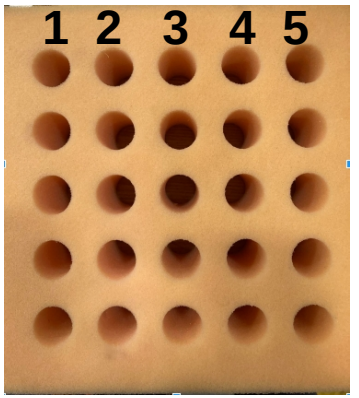
- 90 G external field from Helmoltz coil
- Longitudinal probe (top, middle, end)
- Transverse probe (top, middle, end)
- **At end position field is relatively high**

12 19 83 3.5 -10 -38	15 26 86 1.9 -4.7 -12	16 27 85 0.4 0.5 3.4	15 23 87 -2.0 7.1 11	13 14 75 -4.8 13.2 41
15 23 84 6.0 -17 -50	18 33 88 3.0 -12.3 -23	19 37 87 -1.7 -2.4 -4	18 29 86 -3.0 7.5 15	14 18 87 -6.0 16.4 49
15 26 82 5.7 -16.4 --50	19 35 87 2.6 -6.1 -14	20 36 87 1.6 -3.3 5.0	18 32 85 -3.6 6.1 23	14 18 85 -6.2 17 50
13 20. 77 5.2 -13.4 -52.0	16 29 82 2.2 -7.9 -21	17 30 86 -1.9 -0.8 -4.0	16 26 86 -2.9 5.1 12.2	13 17 90 -5.2 13.1 44.1
10 12 71 2.1 -7.1 -28	11 15 78 0.5 -2.3 -7.4	11 16 73 0.3 1.4 10	11 15 83 -0.2 4.9 12	9 10 80 -3.0 6.9 34

Two outer layer + 0.04” mu metal

4: 47	-3
5: 75	-4

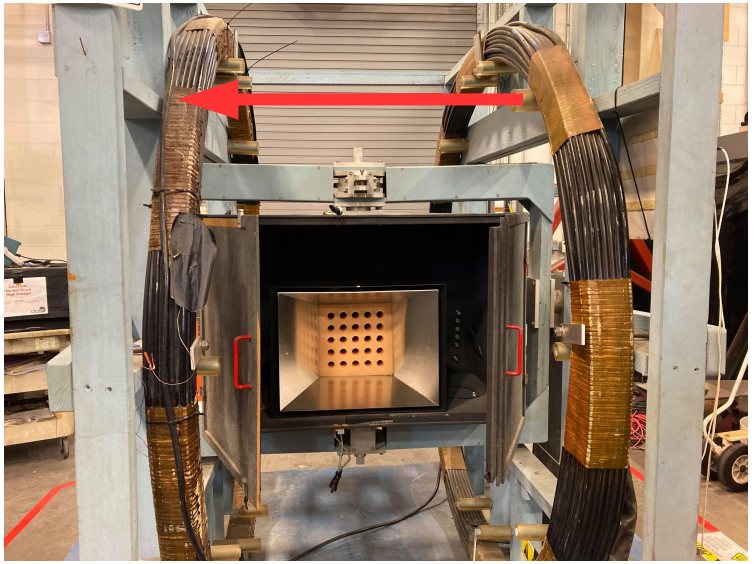




- 90 G external field (inside the plane)
- Longitudinal probe (top, middle, end)
- Transverse probe (top, middle, end)

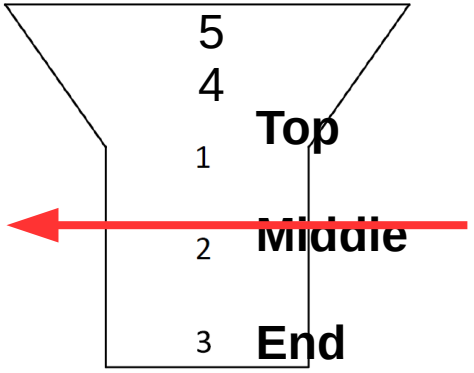
0.1 2.4 11.5 11 1.0 9.6	0.2 2.3 7.7 13 13 20	0.1 0.9 -0.4 14 14 21	0 -0.5 -8.3 13 14 19	-0.3 -1.1 -13 11 1.1 8.3
0.1 3.1 14.0 1.1 1.5 10	0.1 3.0 8.4 13 13 20	0.1 1.2 -0.5 13 15 24	0.0 -0.5 -9.1 13 13 18	0.2 -1.5 -15 12 11 8.1
0 3.1 15 11 11 10	-0.3 2.8 8.3 13 14 21	-0.1 1.1 -1.2 13 13 24	0.2 -0.5 -9.6 14 14.0 20	0.2 -1.4 -16 12 11 6.7
-0.2 2.0 21 12 1.1 9.6	-0.1 1.9 11 13 13 20	-0.2 -0.4 -0.9 14 15 22	0.2 -0.8 -9.6 13 13 18	-0.1 -1.3 -17 12 1.1 7.3
-0.2 1.3 19 11 1.1 10	-0.6 1.4 8.4 14 14 19	0 0.5 1.3 15 15 21	-0.1 -0.4 -6.3 14 14 18	-0.5 -0.7 -13 10 9.4 8

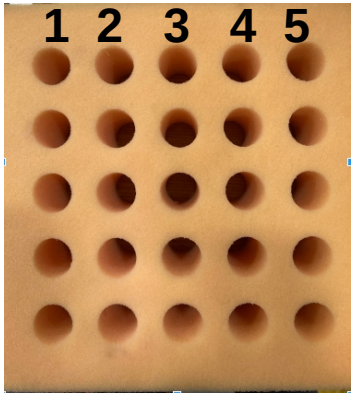
One outer layer + 0.08” mu metal



4: x x

5: x x





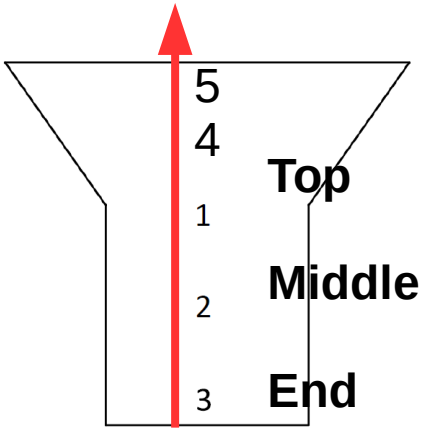
- 90 G external field from Helmoltz coil
- Longitudinal probe (top, middle, end)
- Transverse probe (top, middle, end)

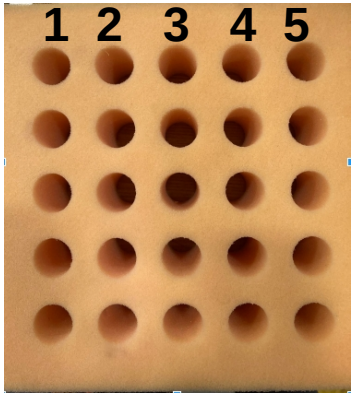
12 13 91 4.2 -7.8 -33	15 18 86 4.0 -3.6 -11	16 19 90 -0.9 -0.1 0.5	15 19 89 -3.2 3.7 13	13 11 92 -5.2 7.1 37
15 17 89 5.3 -10.2 -45	18 25 88 2.1 -4.4 -15	19 27 88 -1.6 -1.1 -4.6	18 24 87 -3.7 4.5 15	15 16 93 -7.2 9.2 44
16 18 86 5.7 -11 --48	19 26 89 2.6 -5.1 -14	20 28 86 1.3 -0.8 -5.6	19 26 89 -3.8 3.8 13	16 16 91 -7.3 9.4 42
14 14 86 4.8 -8.4 -40	17 22 92 2.2 -4.3 -11	17 23 87 -1.3 -1.9 -8.6	16 20 88 -2.5 2.5 9.7	13 14 89 -5.7 7.1 35
11 7.6 74 2.6 -3.7 -24	12 12 85 1.2 -2.3 -2.1	13 12 78 -0.7 -2.2 -5.4	11 15 81 -1.2 1.5 5.4	6.9 10 72 -2.5 3.1 20

One outer layer + 0.08” mu metal

4: x x

5: x x

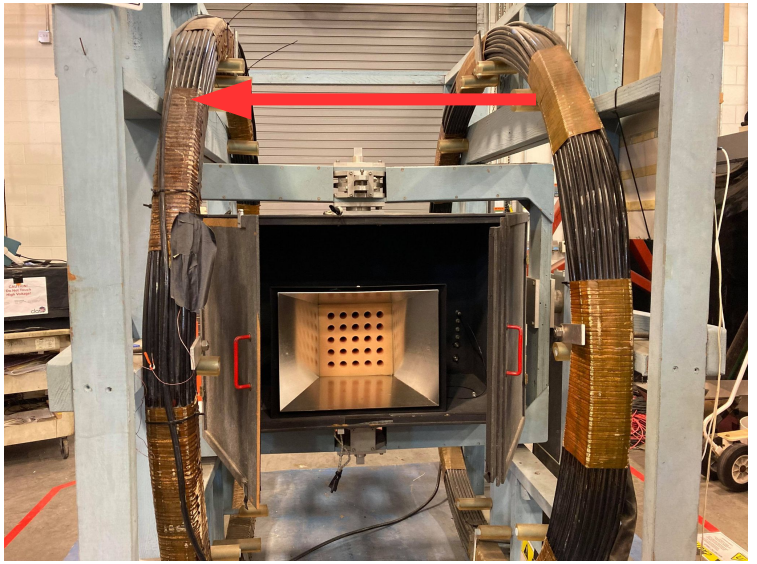




- 90 G external field (inside the plane)
- Longitudinal probe (top, middle, end)
- Transverse probe (top, middle, end)

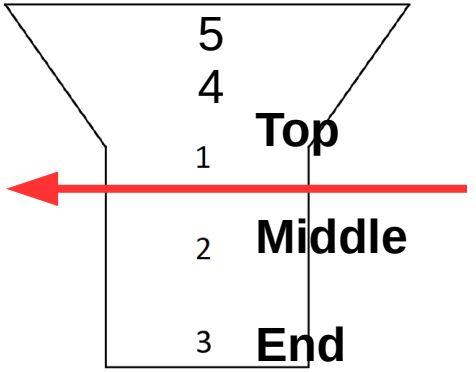
0.0 2.0 17.5 0.6 -1.1 -4.0	0.5 2.4 11.9 1.1 0.8 6.0	0.9 1.4 4.3 1.3 1.8 6.7	1.4 0.1 -3.3 1.0 1.5 5.8	1.4 -0.3 -9.7 0.1 0.6 0.1
0.1 2.8 18.0 0.6 -1.6 -6.0	0.6 3.3 13.6 1.4 1.0 5.0	1..3 2.0 5.3 1.6 2.5 8.5	1.8 0.3 -3.0 1.1 2.0 7.7	1.9 -0.5 -9.3 -0.1 0.7 0.2
0.1 2.8 18.5 0.6 -1.8 -7.0	1.1 3.6 13.1 1.4 0.9 5.4	2.1 2.1 4.8 1.6 2.3 9.0	3.1 0.2 -3.6 1.0 2.1 7.7	4.1 -0.5 -9.3 -0.2 0.6 0.1
0.1 2.4 17.3 0.6 -1.2 -5.7	0.6 3.0 13.4 1.2 1.0 5.3	1.2 1.8 4.9 1.4 2.2 8.6	1.7 0.2 -3.7 1.0 1.8 7.4	1.7 -0.4 -10.0 0.0 0.5 0.3
0.0 1..2 13.7 0.6 -0.2 -3.3	0.3 1.7 10.5 0.9 0.6 4.0	0.7 1.0 3.7 1.0 1.2 5.1	1.0 0.2 -3.3 0.7 1.0 4.5	1.0 -0.2 -7.8 0.1 0.5 0.1

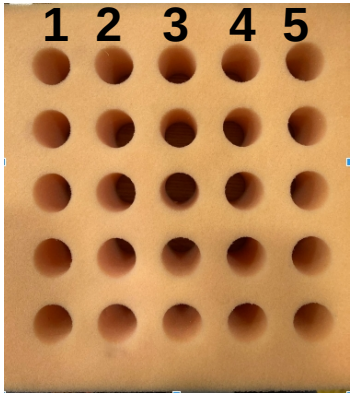
Two outer layer + 0.08” mu metal



4: 1.8 5.8

5: 3.2 15





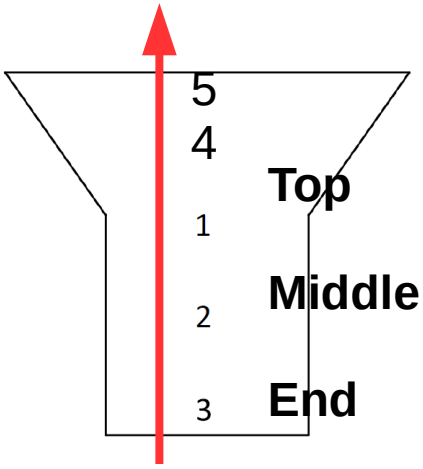
- 90 G external field from Helmoltz coil
- Longitudinal probe (top, middle, end)
- Transverse probe (top, middle, end)
- **At end position field is relatively high**

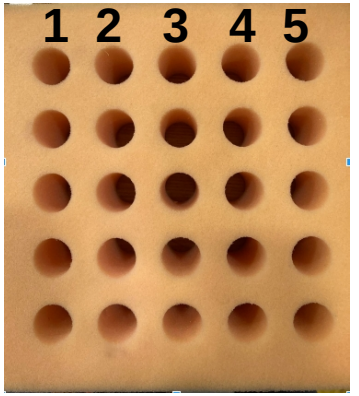
8.6 11.0 34.0 4.5 -8.6 -28.0	11.9 16.8 42.9 2.8 -3.3 -9.0	13.1 18.5 40.0 1.5 1.2 2.3	12.6 15.9 36.2 -0.2 6.7 15.2	10.2 8.5 23.1 -3.0 10.5 28.6
10.9 14.2 36.7 7.0 -13.8 36.0	15.1 23.8 50.4 3.4 -6.4 -14.6	16.6 26.4 53.0 1.8 1.7 0..5	15.8 23.5 48.8 -0.1 9.1 20.0	12.6 12.2 29.4 -4.0 15.0 35.0
11.1 15.7 38.4 6.7 -14.8 -38.0	15.6 25.2 52.8 3.3 -6.0 -13.0	17.1 28.0 55.4 1.1 2.0 3.5	16.2 24.7 50.7 -0.6 9.8 19.6	13.0 14.0 32.3 -3.6 17.0 37.0
9.7 13.9 37.4 5.8 -13.0 -28.0	13.3 21.2 50.0 2.6 -4.7 -9.6	14.6 23.4 51.5 1.1 1.3 2.0	13.6 20.5 48.0 -0.7 6.7 16.2	10.7 11.2 30.5 -3.4 12.9 30.3
5.6 7.4 23.0 3.1 -6.0 -13.0	7.7 11.3 30.2 1.6 -3.5 -5.2	8.4 12.6 30.7 1.0 -0.7 0.8	8.2 10.4 29.3 0.0 2.6 7.5	6.6 5.8 18.4 -1.7 6.4 15.3

Two outer layer + 0.08” mu metal

4: 28 **2.5**

5: 59 **3.6**





- 90 G external field (inside the plane)
- Longitudinal probe (top, middle, end)
- Transverse probe (top, middle, end)