EMF Shielding of One Set of Coils and Shielding with Installation Errors

Julanan Songwadhana (SUT)

with

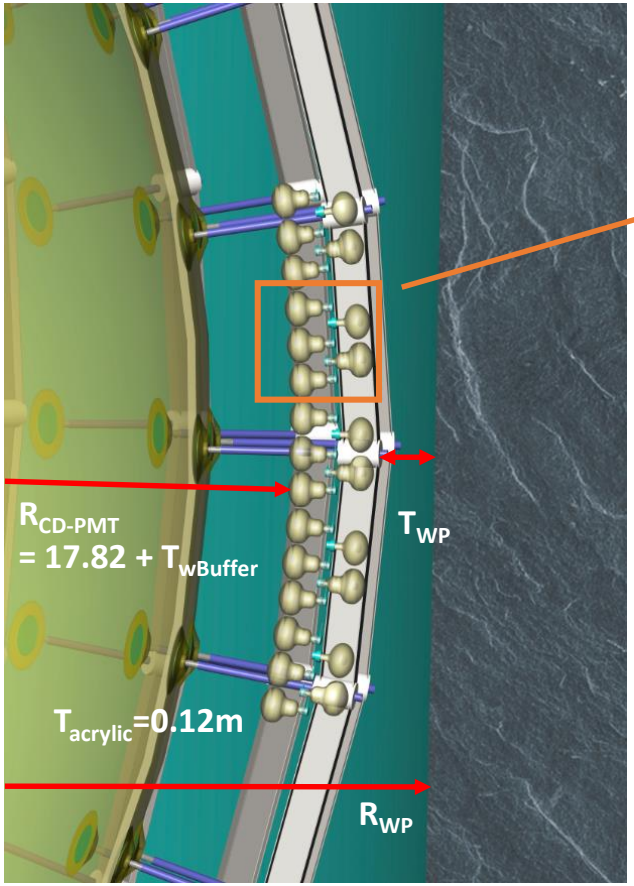
Thai-JUNO Consortium and IHEP EMF Shielding Group

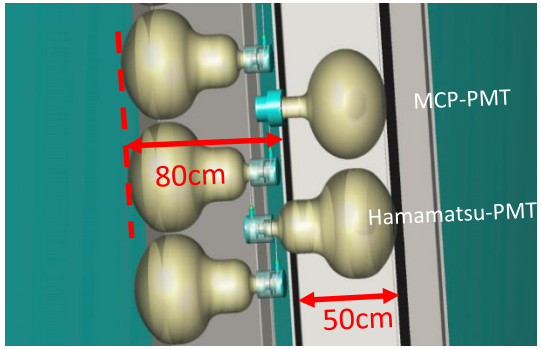
OVERVIEW

- **Introduction**
- **EMF Shielding with Perfect Coils**
  - Coil direction aligned to about 2° to the EMF direction
- **Coils outlined with almost the same interval**
- **Summary**

INTRODUCTION OF EMF SHIELDING

Parameters of Water Pool and PMT Locations





R_{LS} = 17.7m

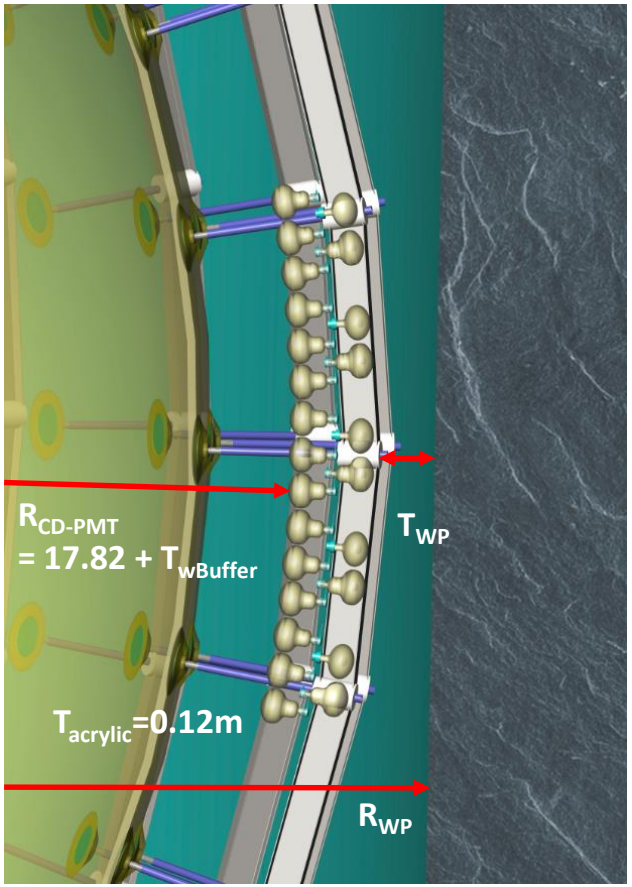
$T_{acrylic}$=0.12 m, $T_{wBuffer}$ = 1.43 m, T_{WP} = 1.2 m

Size of the water pool: 43.5 m

Radius to the faces of CD-PMTs: 19.25 m (Φ 38.5 m)

Radius to the faces of Veto PMTs: 20.55 m (Φ 41.1 m)

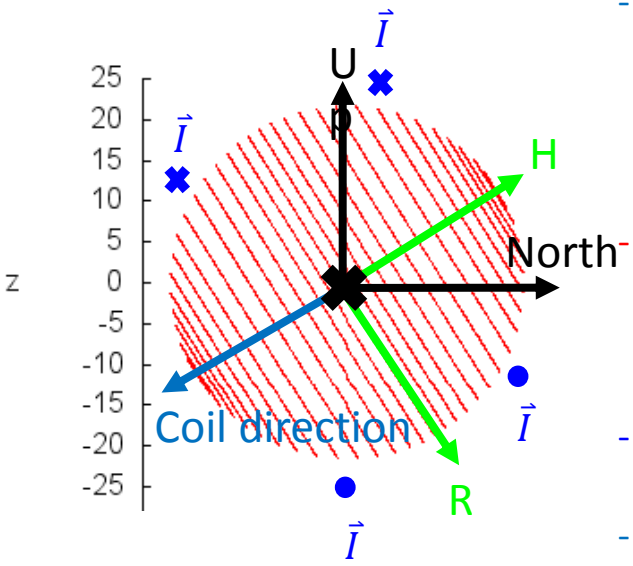
Parameters of Water Pool and PMT Locations



- In case Veto-PMT necks on Φ41 m.
- In case Veto-PMT necks on Φ41.5 m.

Residual field on Veto-PMT necks must be less than 15 %.

Directions of EMF and Coils



CIRCULAR COILS SET

- **EMF**: (0.37988, -0.01505, 0.23772) Gauss
  - North: 0.37988 Gauss
  - West: 0.01505 Gauss
  - Up: 0.23772 Gauss

  Resultant → 0.448382 Gauss

Location of coils described by the radius of coils (R) and the relative distance from the origin to the center of coils along coil direction (H).

- **Currents** ($\vec{I}$) flow in a counter-clockwise direction.

- **Coil direction:**
  - Coil direction is on North-Up plane
  - Coil direction is aligned to about 2° to the EMF

EMF Shielding with Perfect Coils

EMF Shielding with Perfect Coils

- Locations and currents of Coils for calculating magnetic fields

COIL	R(m)	H(m)	ΔH_{ij} (m)	I(A)
1	2.59	21.50	-	12.22
2	4.62	21.26	0.24	24.44
3	6.74	20.56	0.7	36.66
4	8.53	19.90	0.66	36.66
5	10.39	19.00	0.9	61.1
6	12.4	17.75	1.25	73.2
7	14.3	16.26	1.49	85.54
8	16.02	14.56	1.7	97.76

COIL	R(m)	H(m)	ΔH_{ij} (m)	I(A)
9	17.69	12.49	2.07	122.2
10	19.10	10.20	2.29	122.2
11	20.10	8.05	2.15	109.98
12	20.80	6.01	2.04	109.98
13	21.26	4.06	1.95	97.76
14	21.52	2.38	1.68	85.54
15	21.64	0.79	1.59	85.54

- $\Delta H_{ij} = H_i - H_j$; j = i + 1, and i and j stand for the ith and jth coils.

EMF Shielding with Perfect Coils

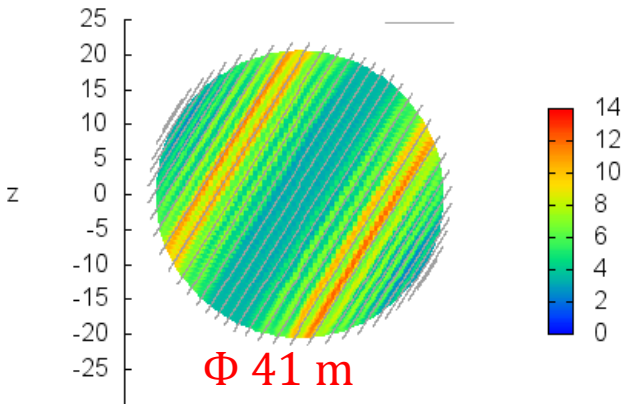
- PEAK-PEAK FIELD DEVIATION

$$B_p = \left(\frac{B_{max} - B_{min}}{B_{center}}\right) \times 100\ \%$$

Φ(m.)	Commercial program	Coding program
39	1.81	1.81
39.5	3.23	3.23
40	5.79	5.79
41	18.50	18.52

EMF Shielding with Perfect Coils

$$R = \left(\frac{\sqrt{(B_x - B_{EMFx})^2 + (B_y - B_{EMFy})^2 + (B_z - B_{EMFz})^2}}{B_{EMF}} \right) \times 100\%$$



SPHERICAL SURFACE PLOT FOR RESIDUAL FIELD

Φ(m.)	MAX OF RES.-TO-EMF DEV.(%)
39	4.57
39.5	5.26
40	6.46
41	13.18
41.5	21.74
41.8	30.94

EMF Shielding with Perfect Coils

Residual fields over 10%

Entries : 16111

Φ(m.)	MAX OF RES.-TO-EMF DEV.(%)	Top (3983 pts)		Bottom (3983 pts)		Central (8145 pts)	
		Sampling points	% on top	Sampling points	% on bottom	Sampling points	% on central
39	4.57	0	0.0	0	0.0	0	0.0
39.5	5.26	0	0.0	0	0.0	0	0.0
40	6.46	0	0.0	0	0.0	0	0.0
41	13.18	**441**	11.1	**440**	**11.0**	**647**	**7.9**
41.5	21.74	2462	61.8	**2462**	**61.8**	**3803**	**46.7**
41.8	30.94	**3268**	**82.1**	**3266**	**82.0**	**5985**	**73.5**

EMF Shielding with Perfect Coils

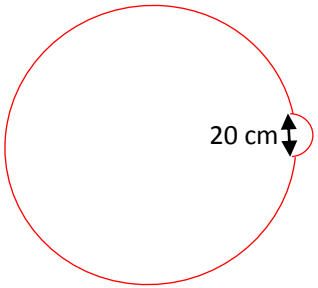
Residual fields over 15%

Entries : 16111

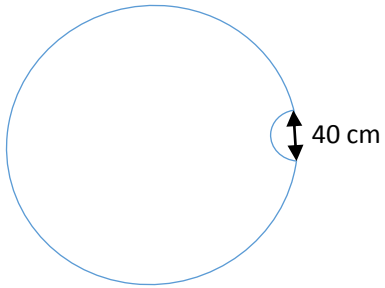
Φ(m.)	MAX OF RES.-TO-EMF DEV.(%)	Top (3983 pts)		Bottom (3983 pts)		Central (8145 pts)	
		Sampling points	% on top	Sampling points	% on bottom	Sampling points	% on central
39	4.57	0	0.0	0	0.0	0	0.0
39.5	5.26	0	0.0	0	0.0	0	0.0
40	6.46	0	0.0	0	0.0	0	0.0
41	13.18	0	0.0	0	0.0	0	0.0
41.5	21.74	890	22.3	890	22.3	1054	12.9
41.8	30.94	2418	60.7	2418	60.7	3739	45.9

Shielding with Slightly Distorted Coils

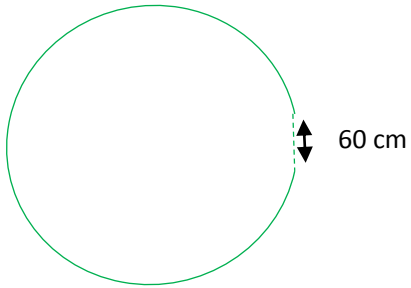
Small curves on circular coils of radius 16.02, 17.69, 19.1, and 20.1 meters.



Outer small curve, 10 cm



Inner small curve, 20 cm



Perpendicular small curve, 30 cm

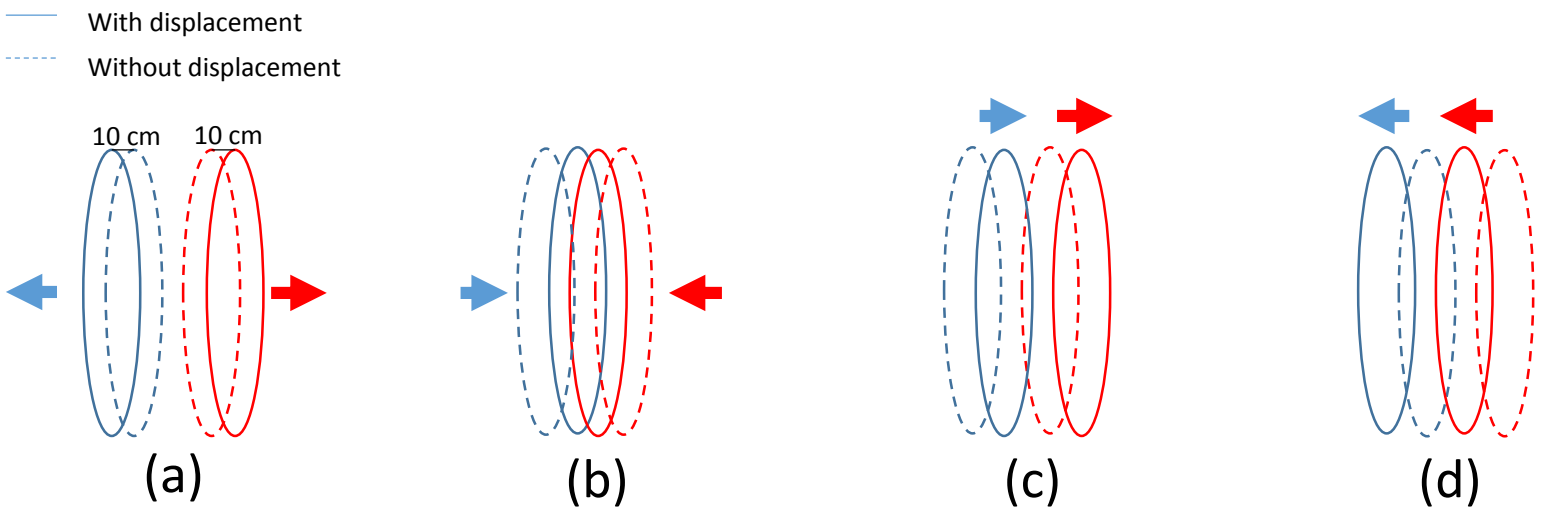
Shielding with Slightly Distorted Coils

- **COMPARISION OF RESIDUAL-TO-EMF FIELD DEVIATIONS**

$$R = \left(\frac{\sqrt{(B_x - B_{EMFx})^2 + \left(B_y - B_{EMFy}\right)^2 + (B_z - B_{EMFz})^2}}{B_{EMF}} \right) \times 100\%$$

Φ(m.)	PERFECT	SC 10 CM	SC 20 CM	SC 30 CM
39	4.57	4.59	4.58	4.57
39.5	5.26	5.27	5.26	5.26
40	6.46	6.46	6.48	6.47
41	13.18	13.18	13.18	13.18
41.5	21.74	21.74	21.74	21.74
41.8	30.94	30.94	30.94	30.94

Shielding with Slightly Displaced Coils



Shielding with Slightly Displaced Coils

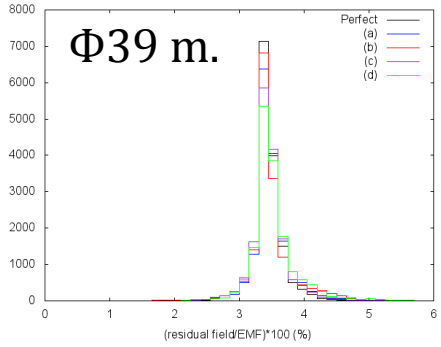
- Coil 9 (17.69 m radius) and Coil 10 (19.1 m radius) displaced 10 cm.

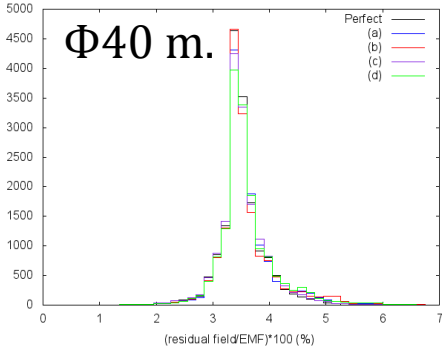
(R,H)	Without displacement	With Displacement							
		(a)		(b)		(c)		(d)	
		Coil 9	Coil 10	Coil 9	Coil 10	Coil 9	Coil 10	Coil 9	Coil 10
R	(17.69,19.1)	17.62	19.16	17.76	19.05	17.62	19.05	17.76	19.16
H	(12.49,10.1)	12.59	10.1	12.39	10.3	12.59	10.3	12.39	10.1

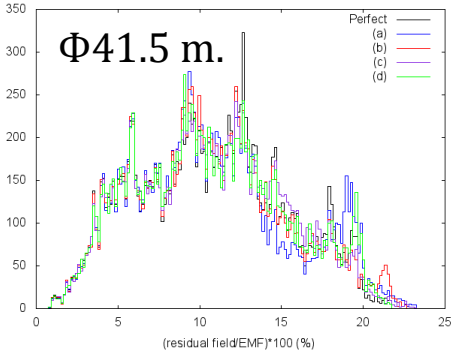
Shielding with Slightly Displaced Coils

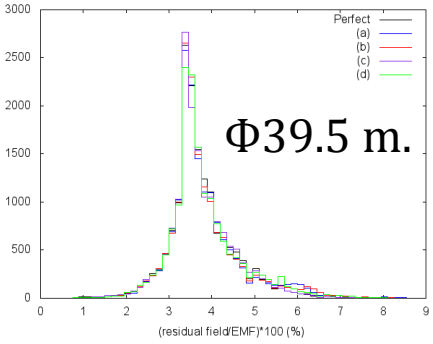
HISTOGRAM PLOT FOR RESIDUAL FIELD

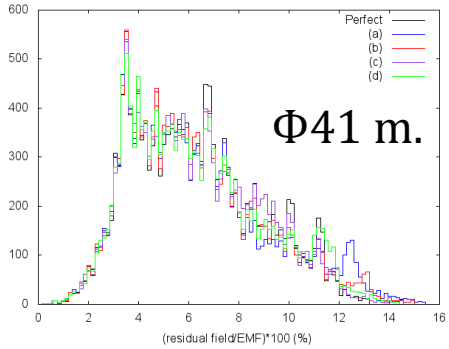
Perfect
(a)
(b)
(c)
(d)

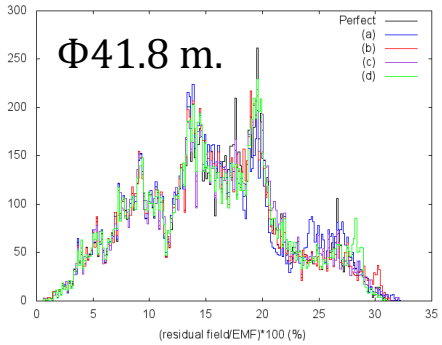












Shielding with Slightly Displaced Coils

- **COMPARATION of MAX OF RESIDUAL-TO-EMF FIELD DEVIATIONS**

$$R = \left(\frac{\sqrt{(B_x - B_{EMFx})^2 + (B_y - B_{EMFy})^2 + (B_z - B_{EMFz})^2}}{B_{EMF}} \right) \times 100\%$$

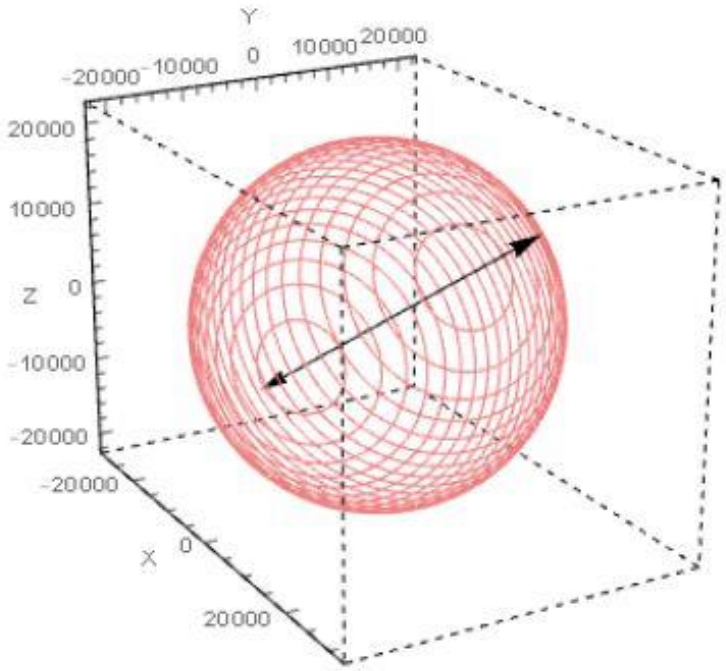
Φ(m.)	(a)		(b)		(c)		(d)	
	R(%)	Ratio	R(%)	Ratio	R(%)	Ratio	R(%)	Ratio
39	5.78	1.26	5.75	1.26	5.34	1.17	5.77	1.26
39.5	6.81	1.29	6.72	1.28	6.18	1.17	6.63	1.26
40	8.46	1.31	8.27	1.28	7.6	1.18	8.03	1.24
41	15.41	1.17	14.97	1.13	14.53	1.1	14.36	1.09
41.5	23.24	1.07	22.55	1.04	23.12	1.06	21.75	1.0
41.8	32.1	1.04	31.19	1.01	32.06	1.04	30.96	1.0

*Ratio = Ratio of maximum residual of each case to the maximum residual from perfect coils

26 Coils outlined with the interval 1.67 m

From…

Chulalongkorn's model

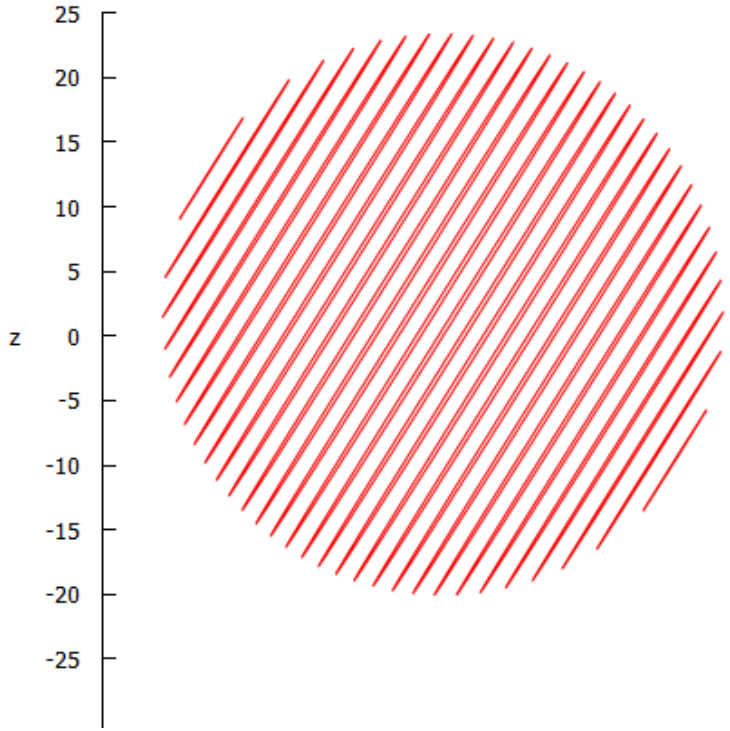


H	R	I
20.91	5.97	71.21
19.24	10.14	93.67
17.57	12.82	88.31
15.89	14.85	90.10
14.22	16.46	89.34
12.55	17.77	89.64
10.88	18.84	89.49
9.20	19.71	89.61
7.53	20.41	89.51
5.86	20.95	89.57
4.18	21.34	89.54
2.51	21.60	89.56
0.84	21.73	89.55
-0.84	21.73	89.55
-2.51	21.60	89.55
-4.18	21.34	89.55
-5.86	20.95	89.55
-7.53	20.41	89.54
-9.20	19.71	89.57
-10.88	18.84	89.50
-12.55	17.77	89.67
-14.22	16.46	89.31
-15.89	14.85	90.11
-17.57	12.82	88.30
-19.24	10.14	93.67
-20.91	5.97	71.21

similar

30 Coils outlined with the interval 1.46 m

Tried…



H	R	I
4.56	21.17	49.198
8.97	19.71	76.18
11.66	18.25	77.91
13.68	16.79	78.064
15.3	15.33	78.104
16.63	13.87	78.102
17.75	12.41	78.083
18.68	10.95	78.041
19.46	9.49	78.156
20.11	8.03	78.096
20.63	6.57	78.118
21.04	5.11	78.109
21.35	3.65	78.112
21.54	2.19	78.112
21.64	0.73	78.112
21.64	-0.73	78.112
21.54	-2.19	78.112
21.35	-3.65	78.112
21.04	-5.11	78.109
20.63	-6.57	78.118
20.11	-8.03	78.096
19.46	-9.49	78.156
18.68	-10.95	78.041
17.75	-12.41	78.083
16.63	-13.87	78.102
15.3	-15.33	78.104
13.68	-16.79	78.064
11.66	-18.25	77.91
8.97	-19.71	76.18
4.56	-21.17	49.198

← similar

But…It doesn’t work !!!

Coils outlined with almost the same interval

EMF Shielding with 32 of Perfect Coil

- Locations and currents of Coils for calculating magnetic fields

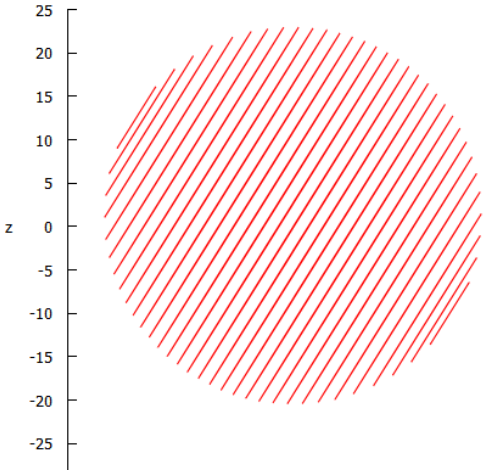
COIL	R(m)	H(m)	ΔH_{ij} (m)
1	4.17	21.25	-
2	7.04	20.48	0.77
3	9.46	19.48	1
4	11.66	18.25	1.23
5	13.68	16.79	1.46
6	15.29	15.33	1.46
7	16.63	13.87	1.46
8	17.75	12.41	1.46

0.23

0.23

0.23

COIL	R(m)	H(m)	ΔH_{ij} (m)
9	18.68	10.95	1.46
10	19.46	9.49	1.46
11	20.11	8.03	1.46
12	20.63	6.57	1.46
13	21.04	5.11	1.46
14	21.35	3.65	1.46
15	21.54	2.19	1.46
16	21.64	0.73	1.46



- $\Delta H_{ij} = H_i - H_j$; j = i + 1, and i and j stand for the ith and jth coils.

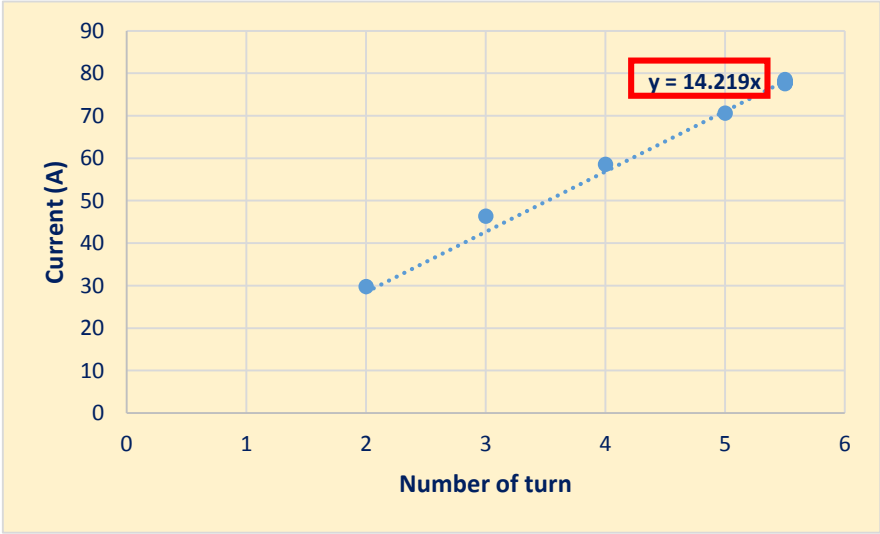
EMF Shielding with 32 of Perfect Coil

From BVLS

I(A)
29.96
46.07
58.35
71.25
77.5
77.86
77.74
77.99
78
77.99
78.02
78.05
77.83
78.2
78.01
78.16

Optimized on
Φ 41.5 m.

Using linear regression to find the slope

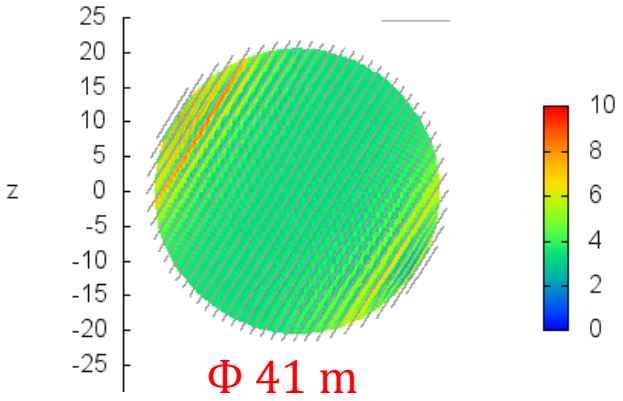


I/Turn = 14.22 A

Turn
2
3
4
5
5.5
5.5
5.5
5.5
5.5
5.5
5.5
5.5
5.5
5.5
5.5
5.5

EMF Shielding with 32 of Perfect Coils

$$R = \left(\frac{\sqrt{(B_x - B_{EMFx})^2 + (B_y - B_{EMFy})^2 + (B_z - B_{EMFz})^2}}{B_{EMF}} \right) \times 100\%$$



Φ 41 m

SPHERICAL SURFACE PLOT FOR RESIDUAL FIELD

Φ(m.)	MAX OF RES.-TO-EMF DEV.(%)
39	5.49
39.5	5.86
40	6.32
41	9.09
41.5	12.92
41.8	16.88

EMF Shielding with 32 of Perfect Coil

Residual fields over 10%

Entries : 16111

Φ(m.)	MAX OF RES.-TO-EMF DEV.(%)	Top (3983 pts)		Bottom (3983 pts)		Central (8145 pts)	
		Sampling points	% on top	Sampling points	% on bottom	Sampling points	% on central
39	5.49	0	0.0	0	0.0	0	0.0
39.5	5.86	0	0.0	0	0.0	0	0.0
40	6.32	0	0.0	0	0.0	0	0.0
41	9.09	0	0.0	0	0.0	0	0.0
41.5	12.92	117	2.9	115	2.9	464	5.7
41.8	16.88	1124	28.2	1109	27.8	2473	30.4

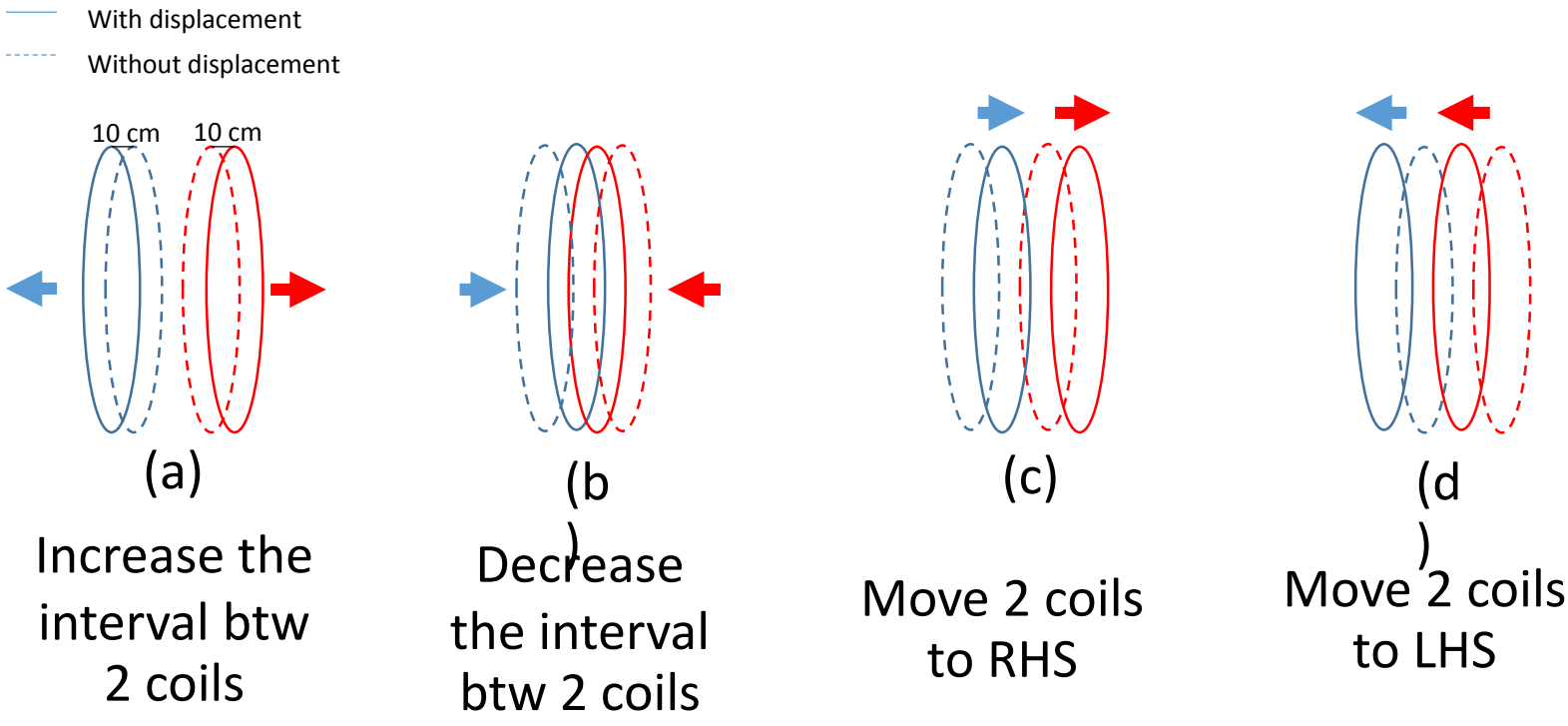
EMF Shielding with 32 of Perfect Coil

Residual fields over 15%

Entries : 16111

Φ(m.)	MAX OF RES.-TO-EMF DEV.(%)	Top (3983 pts)		Bottom (3983 pts)		Central (8145 pts)	
		Sampling points	% on top	Sampling points	% on bottom	Sampling points	% on central
39	5.49	0	0.0	0	0.0	0	0.0
39.5	5.86	0	0.0	0	0.0	0	0.0
40	6.32	0	0.0	0	0.0	0	0.0
41	9.09	0	0.0	0	0.0	0	0.0
41.5	12.92	0	0.0	0	0.0	0	0.0
41.8	16.88	44	1.1	44	1.1	186	2.3

Shielding with Slightly Displaced Coils



Shielding with Slightly Displaced Coils

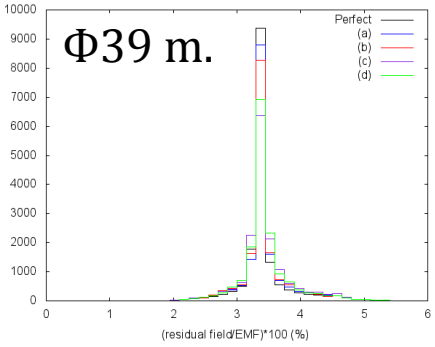
- Coil 8 (17.75 m radius) and Coil 9 (18.68 m radius) displaced 10 cm.

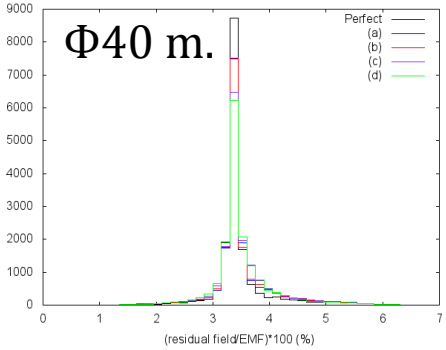
(R,H)	Without displacement	With Displacement							
		(a)		(b)		(c)		(d)	
		Coil 8	Coil 9	Coil 8	Coil 9	Coil 8	Coil 9	Coil 8	Coil 9
R	(17.75,18.68)	17.68	18.74	17.81	18.62	17.81	18.74	17.68	18.62
H	(12.41,10.95)	12.51	10.85	12.31	11.05	12.31	10.85	12.51	11.05

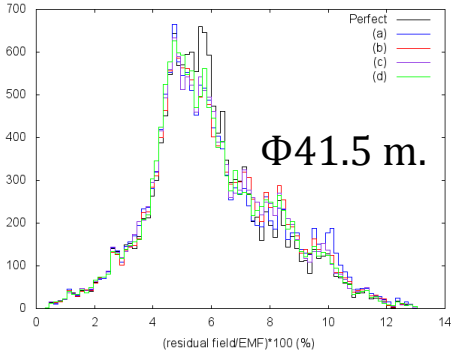
Shielding with Slightly Displaced Coils

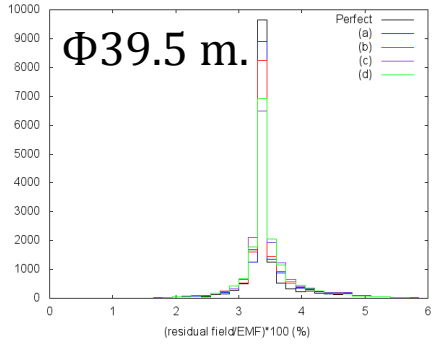
HISTOGRAM PLOT FOR RESIDUAL FIELD

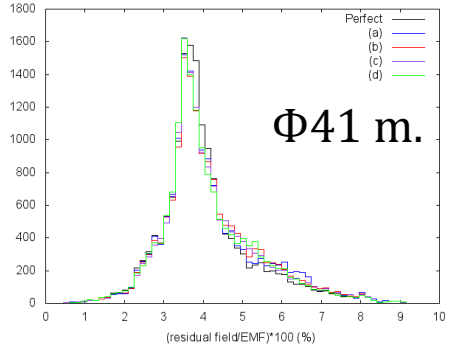
Perfect
(a)
(b)
(c)
(d)

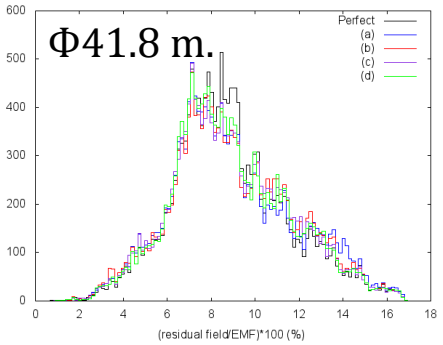












Shielding with Slightly Displaced Coils

- **COMPARATION of MAX OF RESIDUAL-TO-EMF FIELD DEVIATIONS**

$$R = \left(\frac{\sqrt{(B_x - B_{EMFx})^2 + \left(B_y - B_{EMFy}\right)^2 + (B_z - B_{EMFz})^2}}{B_{EMF}} \right) \times 100\%$$

Φ(m.)	(a)		(b)		(c)		(d)	
	R(%)	Ratio	R(%)	Ratio	R(%)	Ratio	R(%)	Ratio
39	5.49	1.0	5.49	1.0	5.5	1.0	5.53	1.01
39.5	5.86	1.0	5.86	1.0	5.87	1.0	5.91	1.01
40	6.32	1.0	6.32	1.0	6.33	1.0	6.37	1.01
41	9.09	1.0	9.09	1.0	9.12	1.0	9.09	1.0
41.5	12.94	1.0	12.92	1.0	13.01	1.01	12.93	1.0
41.8	16.88	1.0	16.89	1.0	16.89	1.0	16.93	1.0

*Ratio = Ratio of maximum residual of each case to the maximum residual from perfect coils

SUMMARY

- Small distortions and displacements (possible installation errors) to the circular coils lead to negligible effects.
- The model of 16 pairs circular coils uses a total current ~1137.6 A while the model of IHEP 15 pairs uses about ~2321 A.
- The current distribution of the 16 pairs of circular coils is very uniform, around 78 A in each coil.
- The model of 16 pair circular coils shield the Veto PMT much better than the IHEP 15 pairs. Maximum residue fields below 10% in both the CD-PMT and Veto-PMT regions (in case Veto-PMT on Φ41m.) and below 15% in both the CD-PMT and Veto-PMT regions (in case Veto-PMT on Φ41.5m.).

Thank you for your attention !