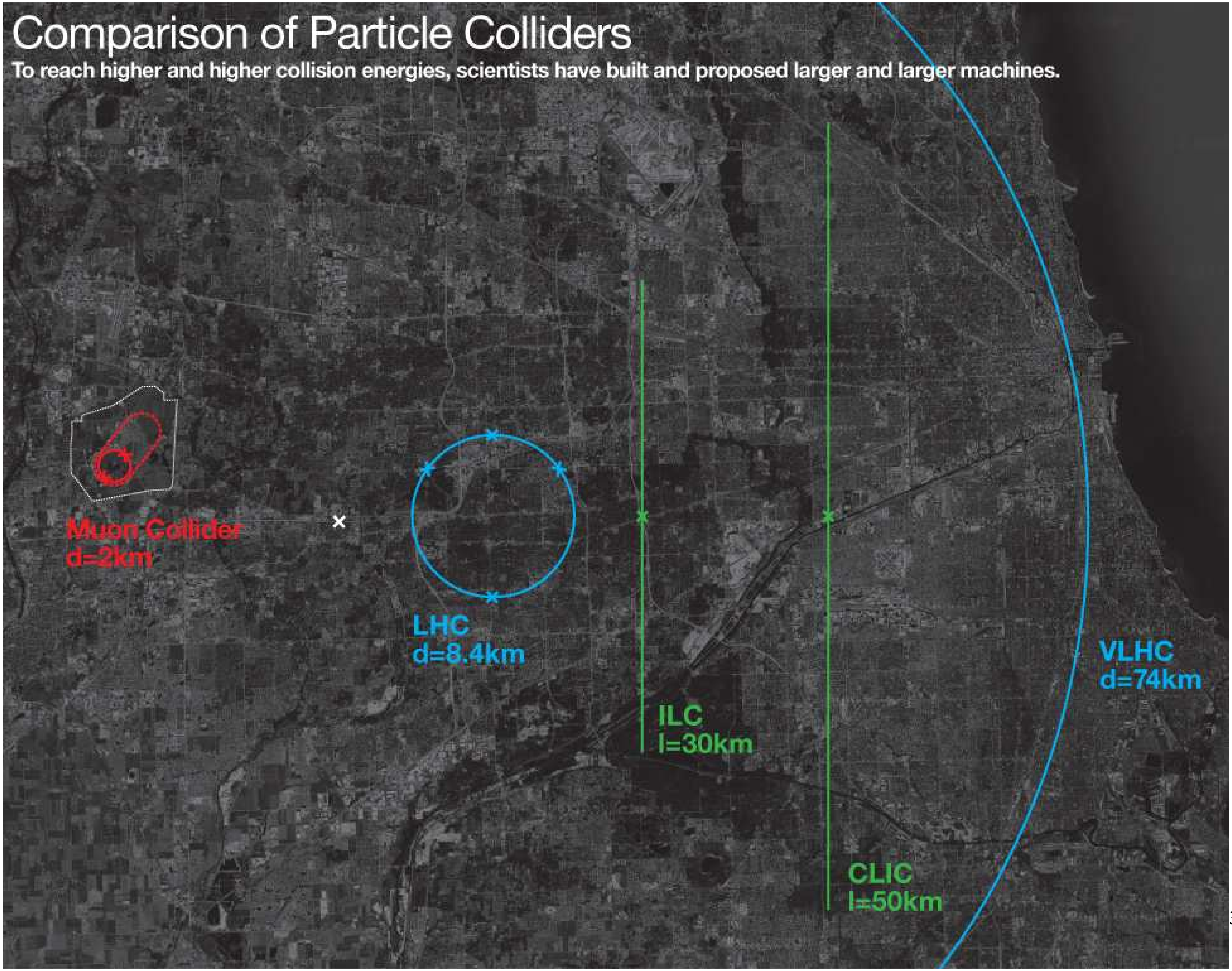
10
Unusual Designs

Mauricio Lopes – FNAL

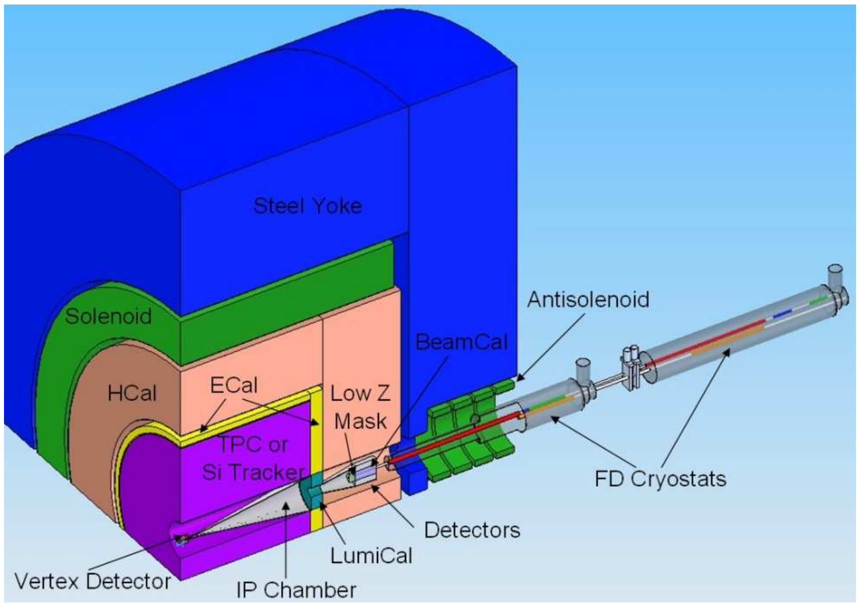
Outlook

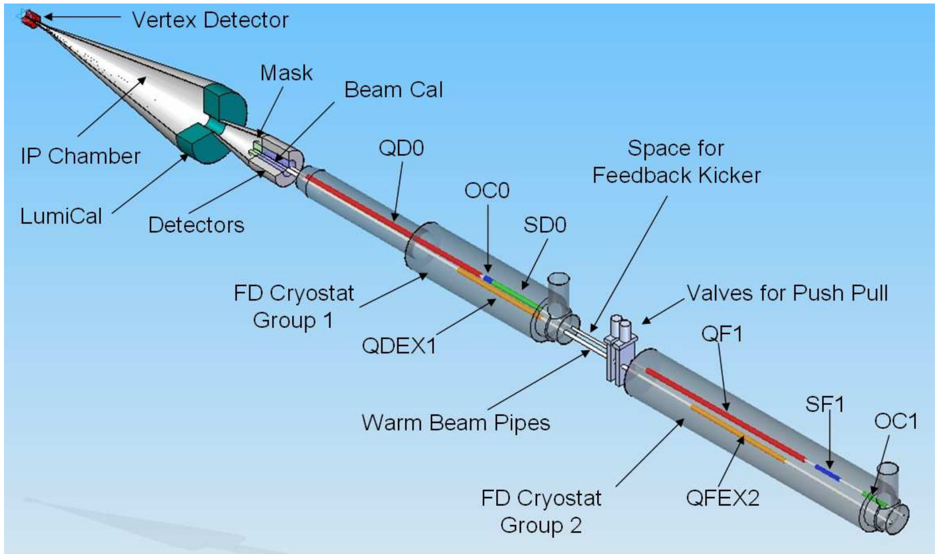
- ILC Interaction Region Quadrupoles
- Helical Solenoid
- Elliptical Dipoles for the Muon Collider SR
- Mu2e Transport Solenoid


Comparison of Particle Colliders
To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.
Muon Collider
d=2km
LHC
d=8.4km
ILC
l=30km
CLIC
l=50km
VLHC
d=74km

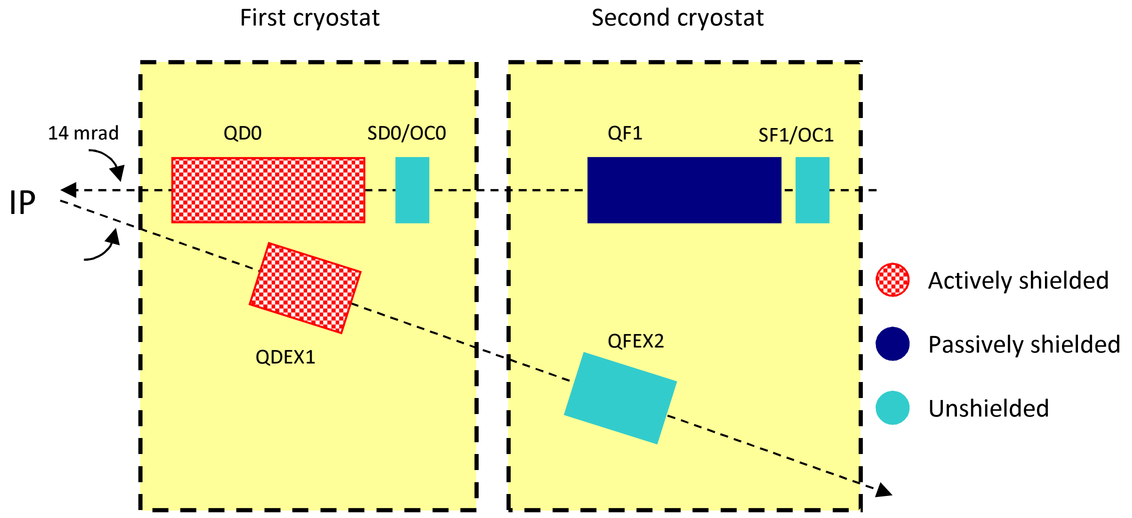
ILC – IR QUADS

ILC Interaction Region

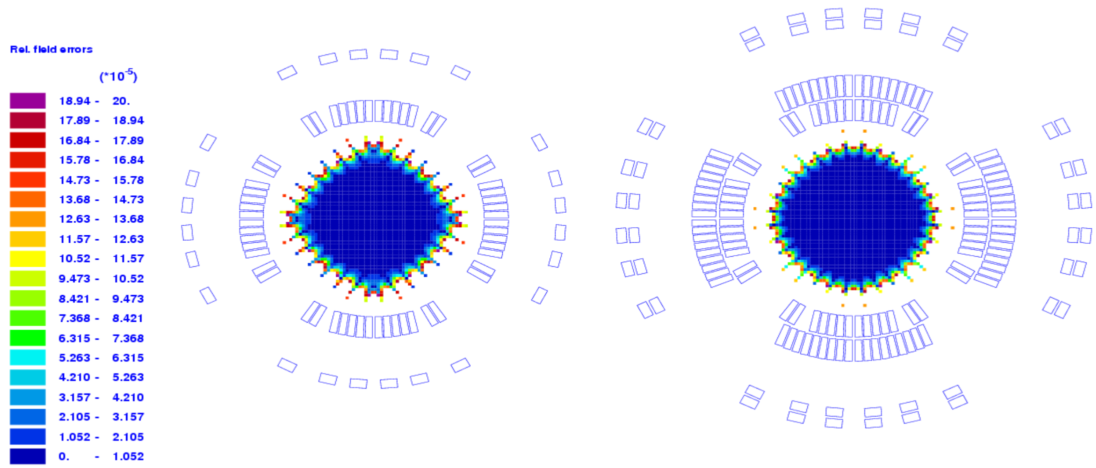




IR Quadrupoles for ILC



Tight space.
Compact design required.

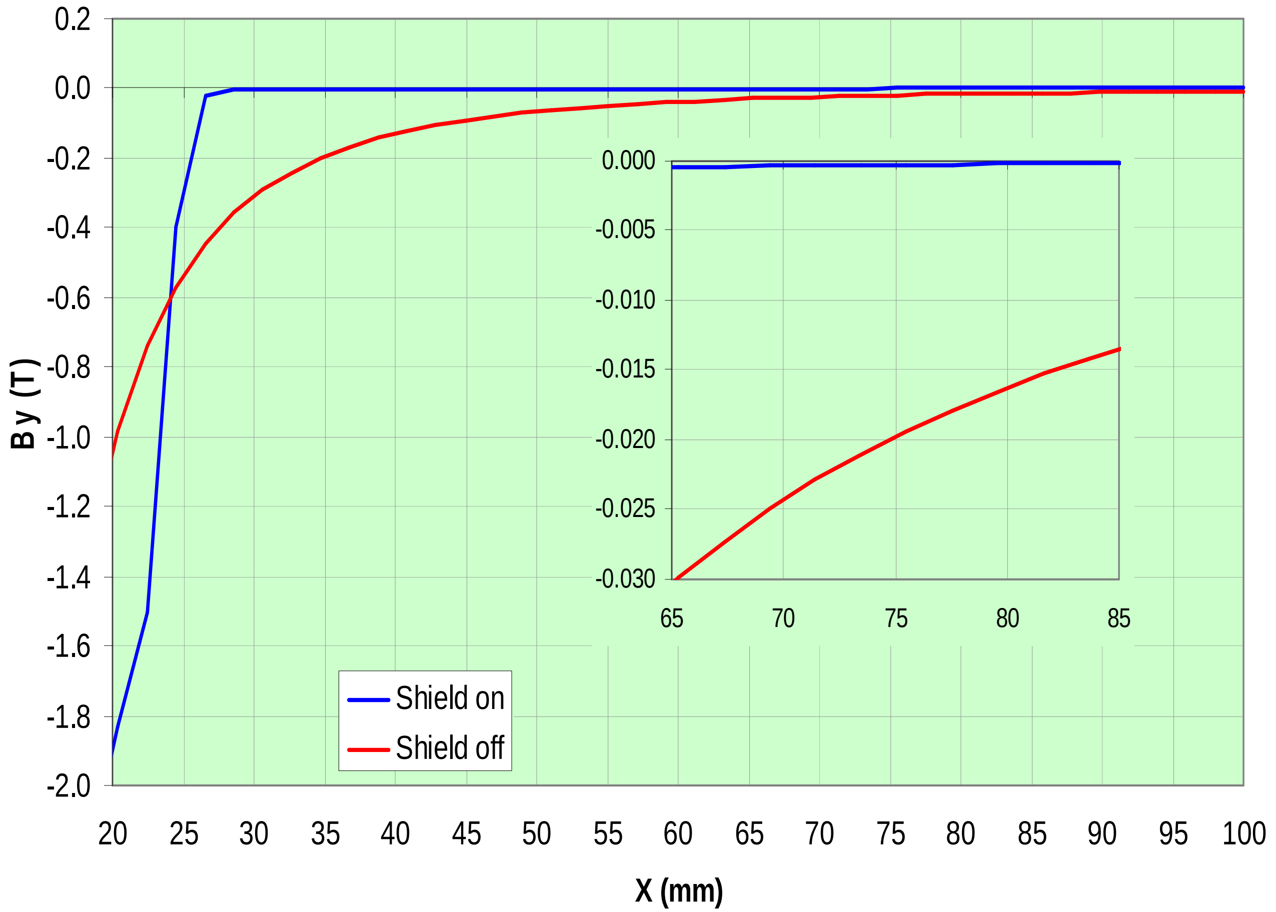


Single layer

Double layer

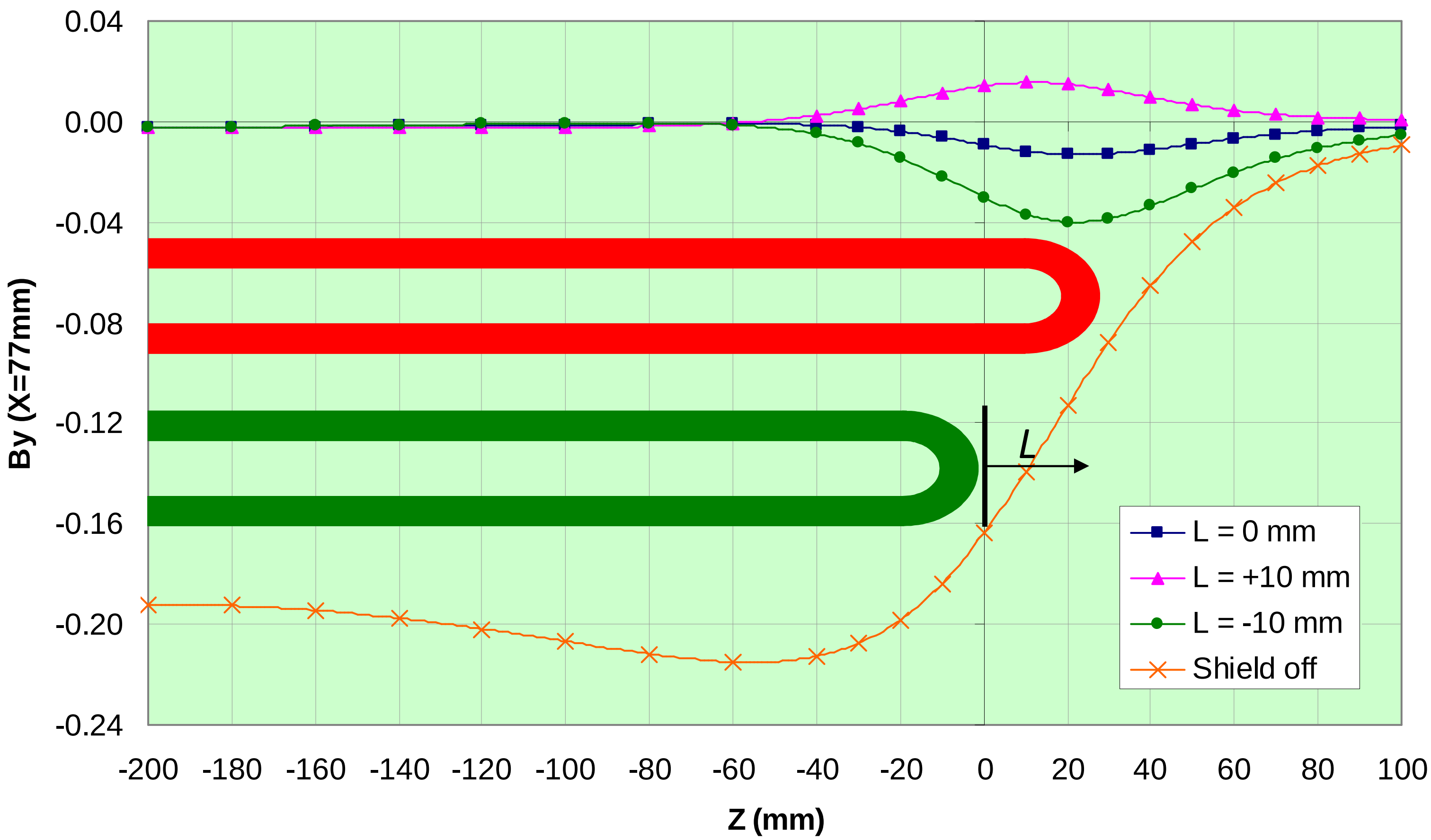
	QD0		QDEX1	
Number of layers	Single layer	Double layer	Single layer	Double layer
SC type	Nb_3Sn	NbTi	Nb_3Sn	NbTi
Operation temperature, K	4.2	1.9	4.2	1.9
Coil ID, mm	28		38	
Magnet OD, mm	49.4	61	61.4	76.8
Coil cross-section, mm^2	37.1	81.9	52.1	97.1
B_{peak}, T	5.8	4.9	6.0	5.0
Imax @ Bpeak, A	9971	4728	9617	4578
G_{max}, T/m	302.7	284.5	226.2	215.6
Gmax/Gnom	2.13	2.00	2.26	2.16
Inductance, mH/m	0.18	0.89	0.24	1.17
Stored energy at Gnom, kJ/m	1.9	2.4	2.2	2.6

Active shield effect



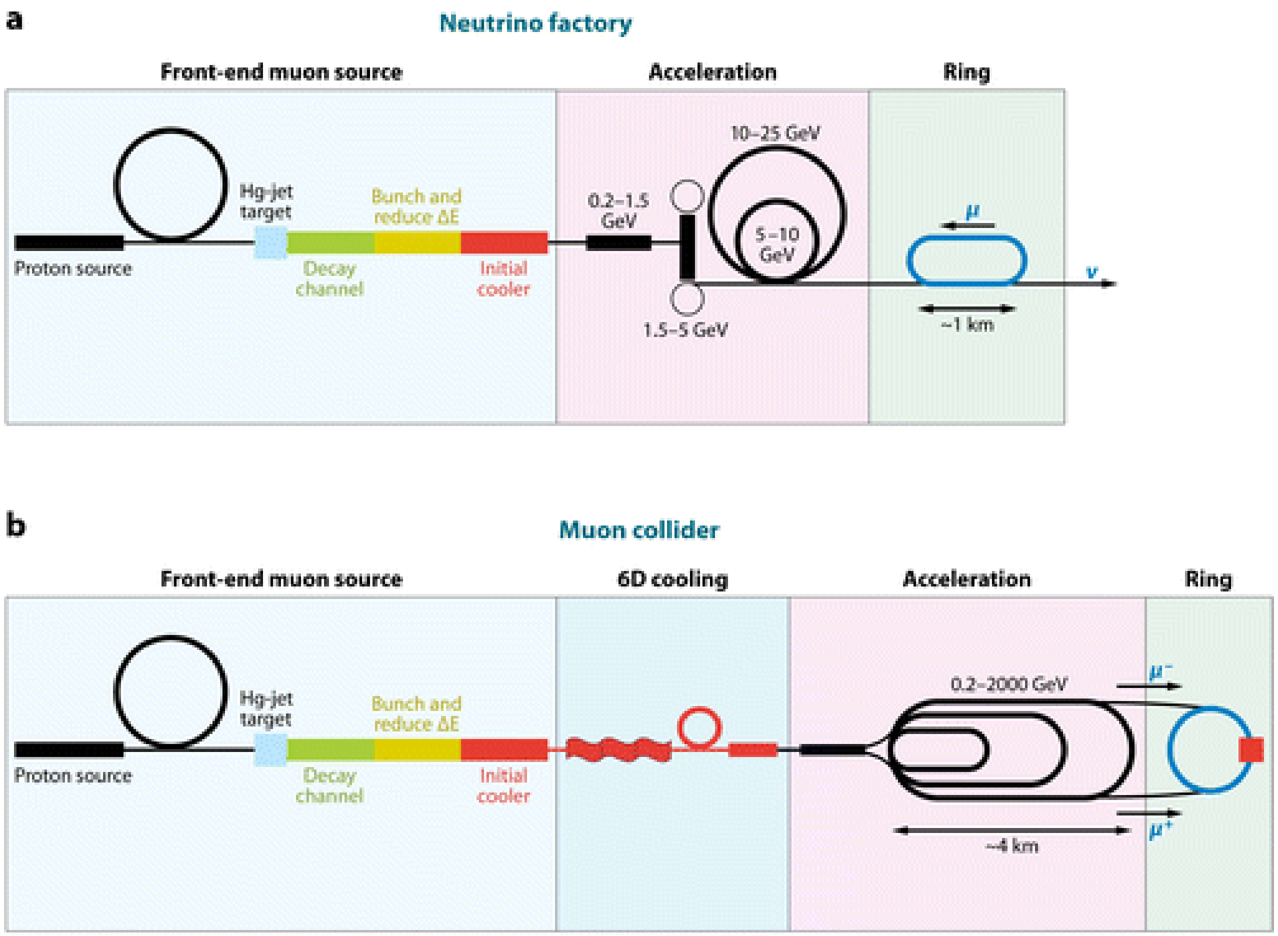
• M.L. Lopes, V.S. Kashikhin,V.V. Kashikhin,A.V. Zlobin; "Compact IR Quadrupoles for Linear Colliders Based on Rutherford-Type Cable", IEEE Transactions on Applied Superconductivity Volume 19, Issue 3, Part 2, June 2009 Pages:1158 – 1161

Coil end effects

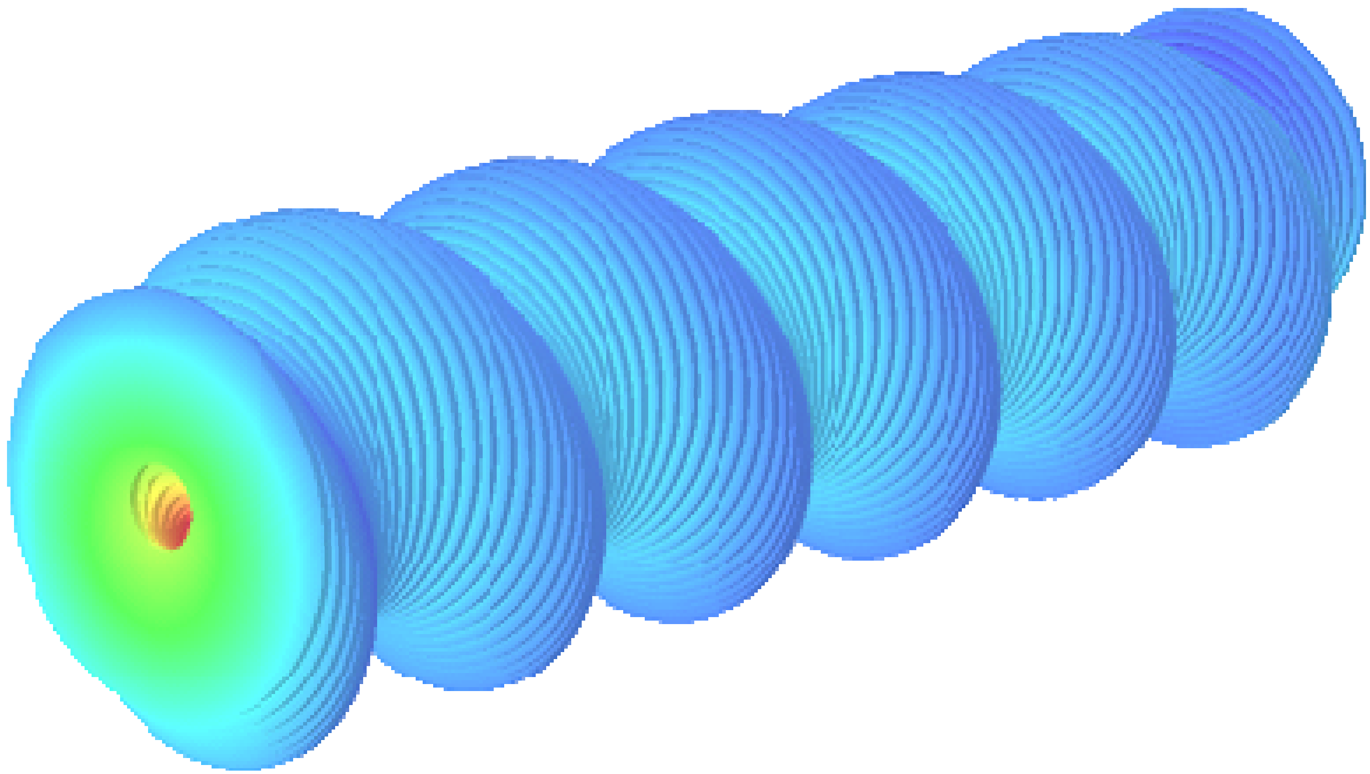


HELICAL SOLENOID

Muon Collider



Helical Solenoid



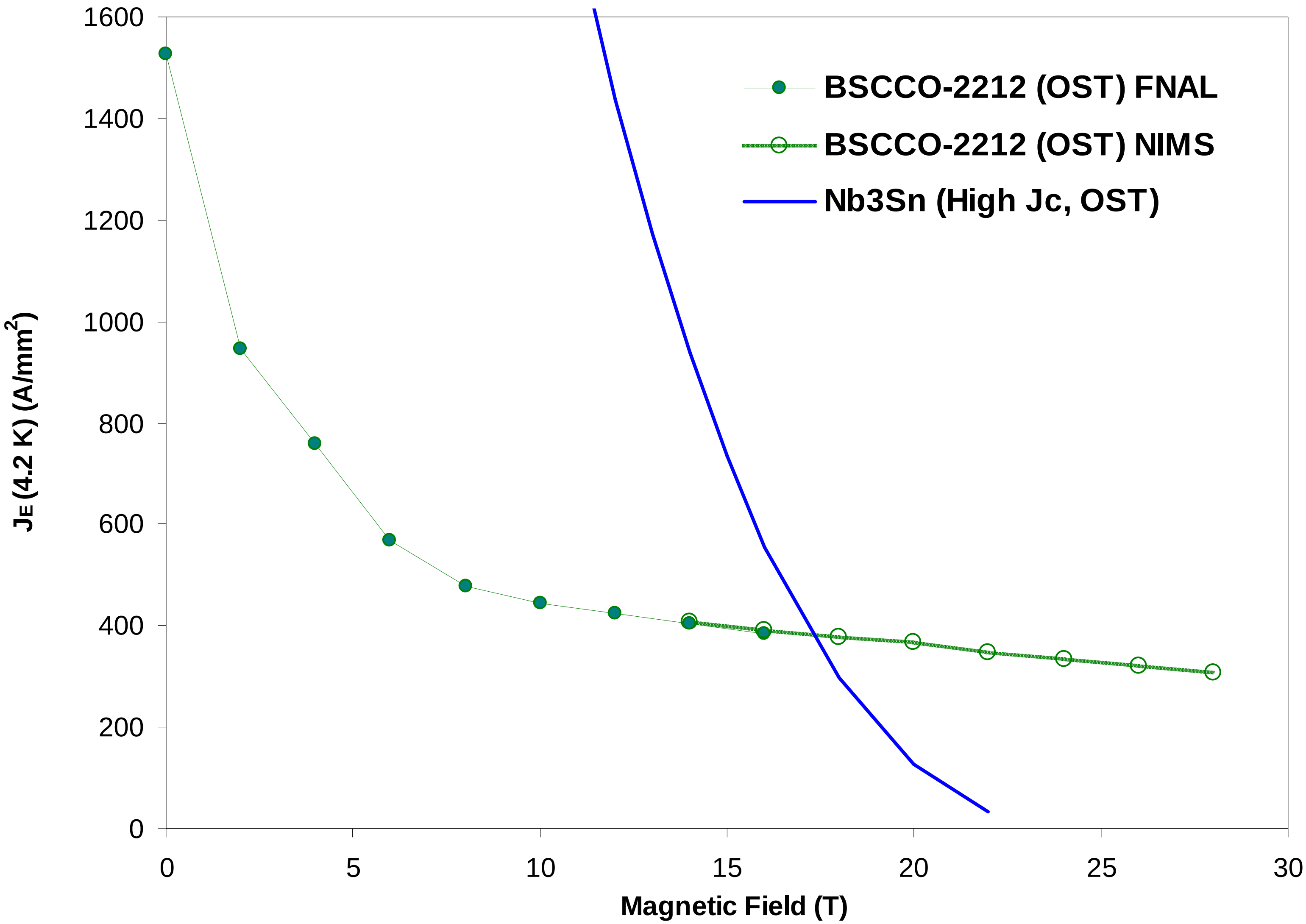
Helical cooling channel parameters*

Parameter			Section			
			1st	**2nd**	**3rd**	**4th**
Total length		m	50	40	30	40
Period		mm	1000	800	600	400
Orbit radius		mm	159	127	95	64
Solenoidal field	B_z	T	-6.95	-8.69	-11.6	-17.3
Helical dipole	B_t	T	1.62	2.03	2.71	4.06
Helical gradient	G	T/m	-0.7	-1.1	-2.0	-4.5

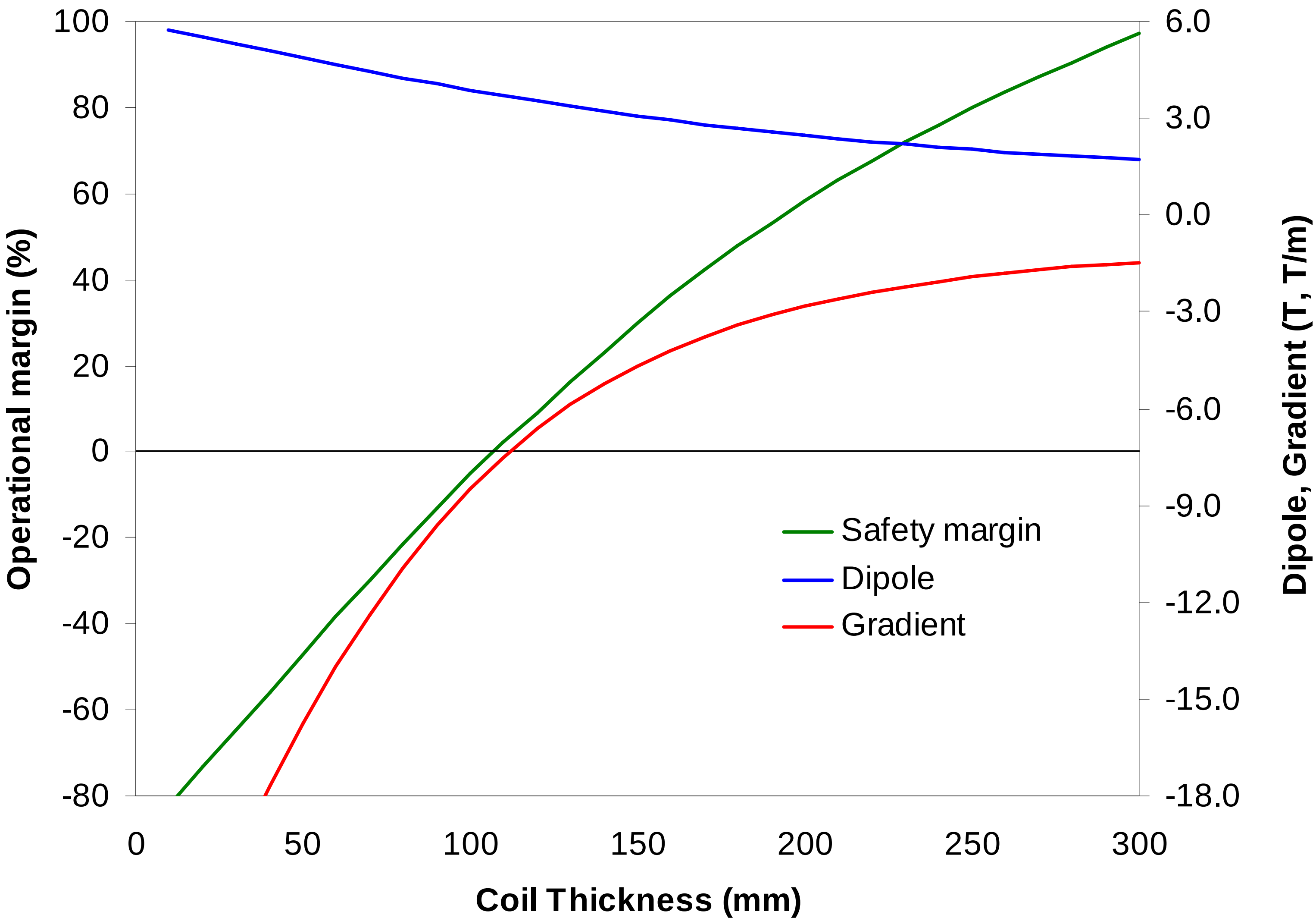
$B_{coil} \approx 21$ T

+ operation margin

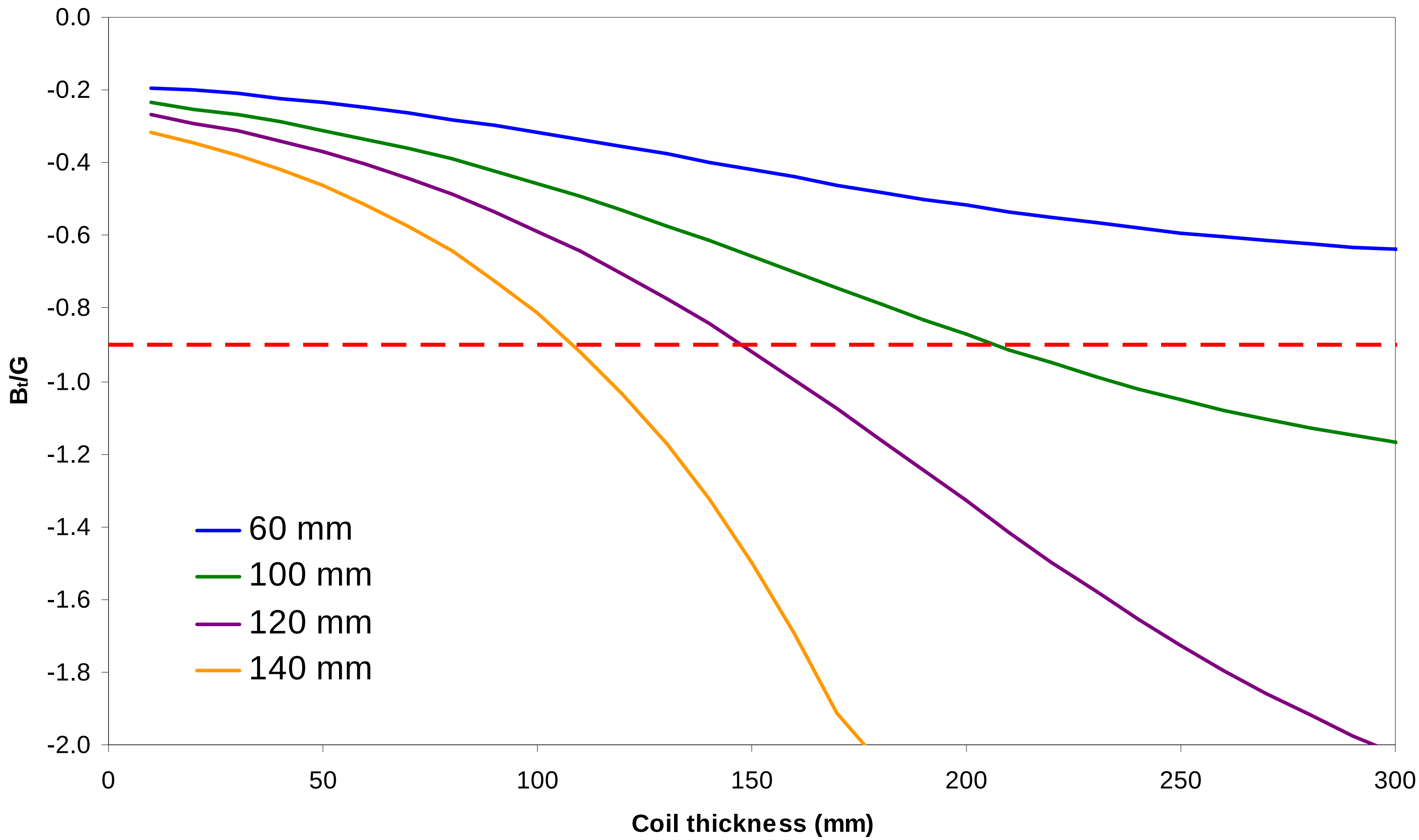
Superconductor choice



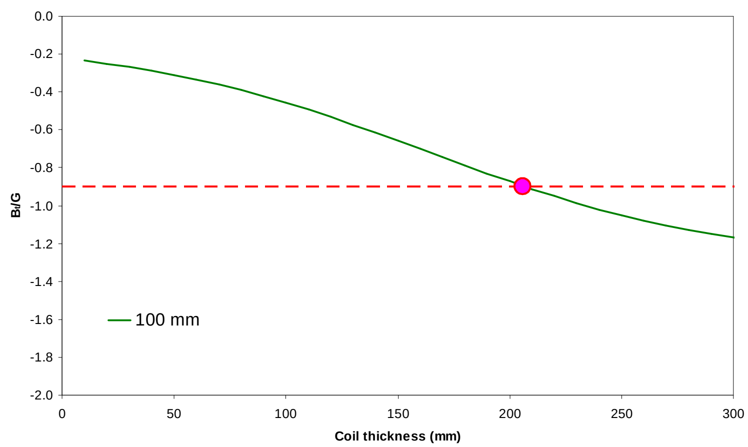
Geometry vs. Performance

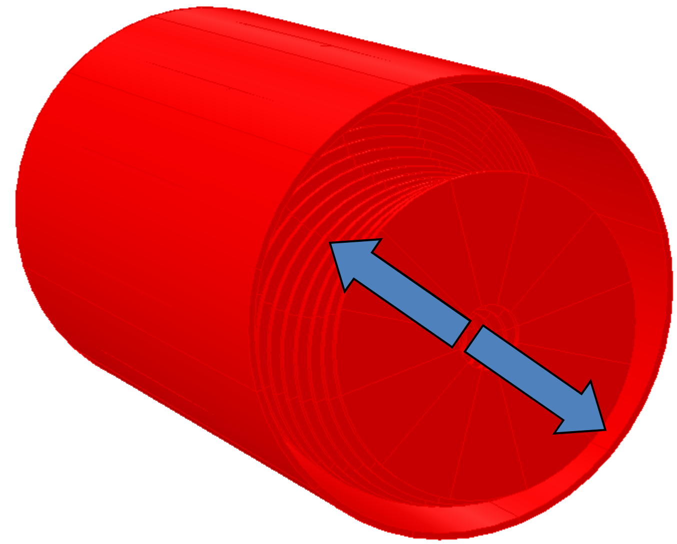


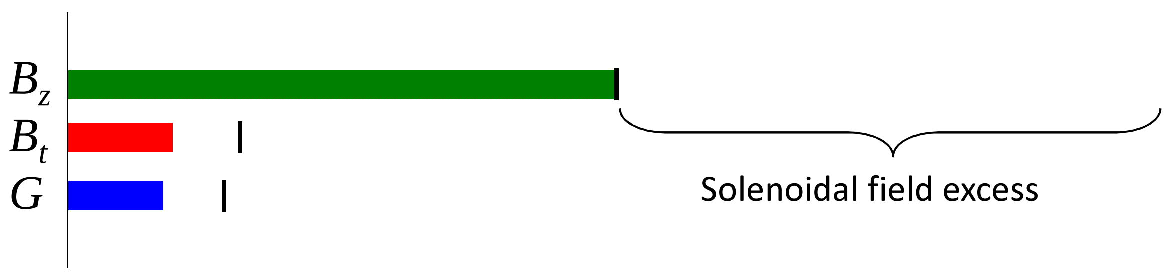
Geometry vs. Performance

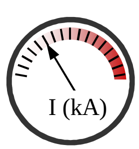


Correction system

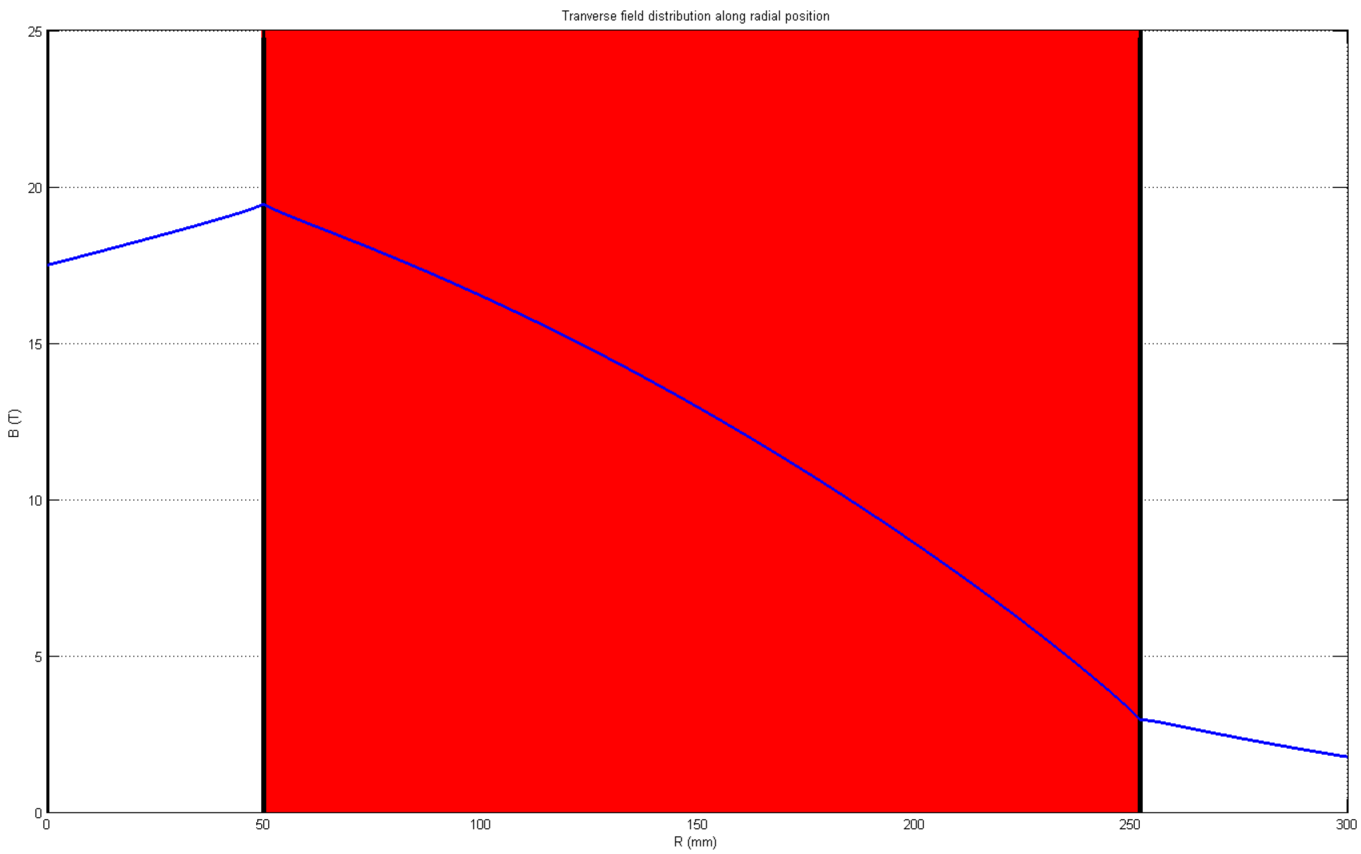








Coil grading



Coil grading

Thickness (mm) layer 1	layer 2	J1 (A/mm^2)	J2	Bz (T)	Bt (T)	G (T/m)	Peak field (T)	Operation margin Inner bore (%)	Operation margin (%)
200	-	298	-	-17.3	4.06	-4.65	20.97	12.9	12.9
100	100	298	298	-17.3	4.06	-4.65	20.97	12.9	12.9
100	90	294	327	-17.3	4.06	-4.56	20.97	13.9	13.9
100	80	290	362	-17.3	4.06	-4.48	20.97	15.1	15.1
100	70	285	407	-17.3	4.06	-4.40	20.97	16.3	4.4
100	60	281	468	-17.3	4.06	-4.35	20.97	17.6	-7.0
100	50	276	552	-17.3	4.06	-4.31	20.97	19.0	-18.9
100	40	271	678	-17.3	4.06	-4.30	20.97	20.5	-31.4
100	30	266	887	-17.3	4.06	-4.32	20.96	22.0	-43.8
100	20	261	1306	-17.3	4.06	-4.37	20.96	23.6	-56.3
100	10	256	2560	-17.3	4.06	-4.46	20.96	25.2	-71.2

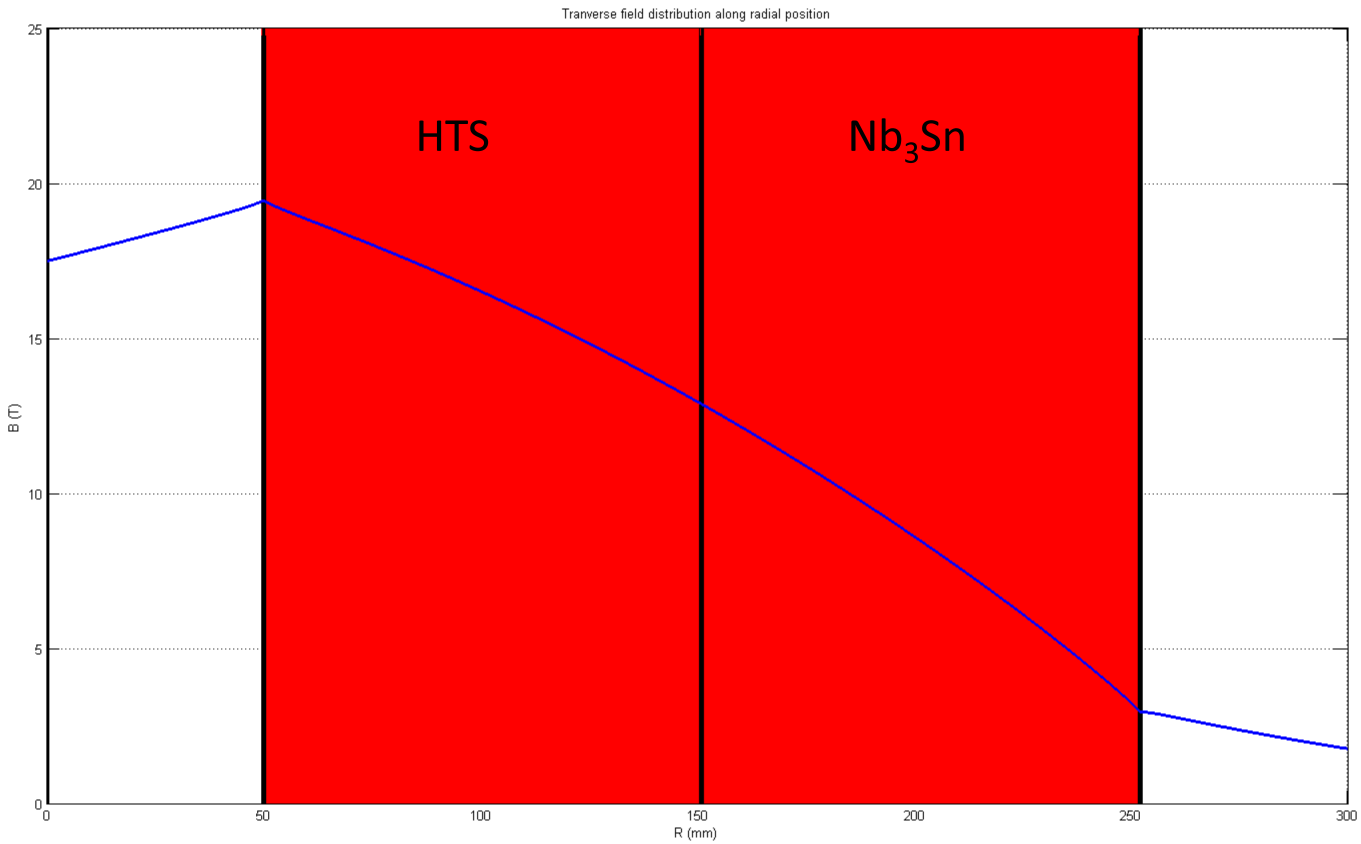
Coil grading

Thickness (mm) layer 1	layer 2	J1 (A/mm²)	J2	Bz (T)	Bt (T)	G (T/m)	Peak field (T)	Operation margin Inner bore (%)	Operation margin (%)
200	-	298	-	-17.3	4.06	-4.65	20.97	12.9	12.9
50	150	298	298	-17.3	4.06	-4.65	20.97	12.9	12.9
50	140	291	311	-17.3	4.06	-4.63	20.97	14.8	14.8
50	130	283	327	-17.3	4.06	-4.63	20.97	16.8	14.0
50	120	276	345	-17.3	4.06	-4.66	20.97	19.0	9.0
50	110	269	366	-17.3	4.06	-4.72	20.97	21.3	3.7
50	100	261	392	-17.3	4.06	-4.82	20.96	23.6	-2.0
50	90	254	423	-17.3	4.06	-4.97	20.96	25.9	-8.0
50	80	246	462	-17.3	4.06	-5.16	20.96	28.3	-14.3
50	70	239	512	-17.3	4.06	-5.40	20.96	30.8	-20.9
50	60	232	580	-17.3	4.06	-5.71	20.95	33.2	-28.5
50	50	225	675	-17.3	4.06	-6.07	20.95	35.7	-36.8
50	40	218	817	-17.3	4.06	-6.50	20.95	38.1	-45.8
50	30	211	1056	-17.3	4.06	-7.00	20.95	40.6	-55.7
50	20	205	1536	-17.3	4.06	-7.57	20.95	43.0	-65.6
50	10	199	2979	-17.3	4.06	-8.20	20.95	45.4	-76.6

Coil grading

Number of grading layers	Layer size (mm)				Coil radial thickness (mm)	Norm coil volume	G (T/m)	Operation margin (%)	SS field (T)
	1st	2nd	3rd	4th					
1	200	-	-	-	200	1.00	-4.65	12.9	11.2
2	50	130	-	-	180	0.84	-4.63	14.0	9.6
3	50	40	80	-	170	0.77	-4.57	13.8	9.1
4	50	40	30	30	150	0.63	-5.16	11.5	7.1
4	50	40	30	20	140	0.56	-5.50	9.6	6.2

Hybrid

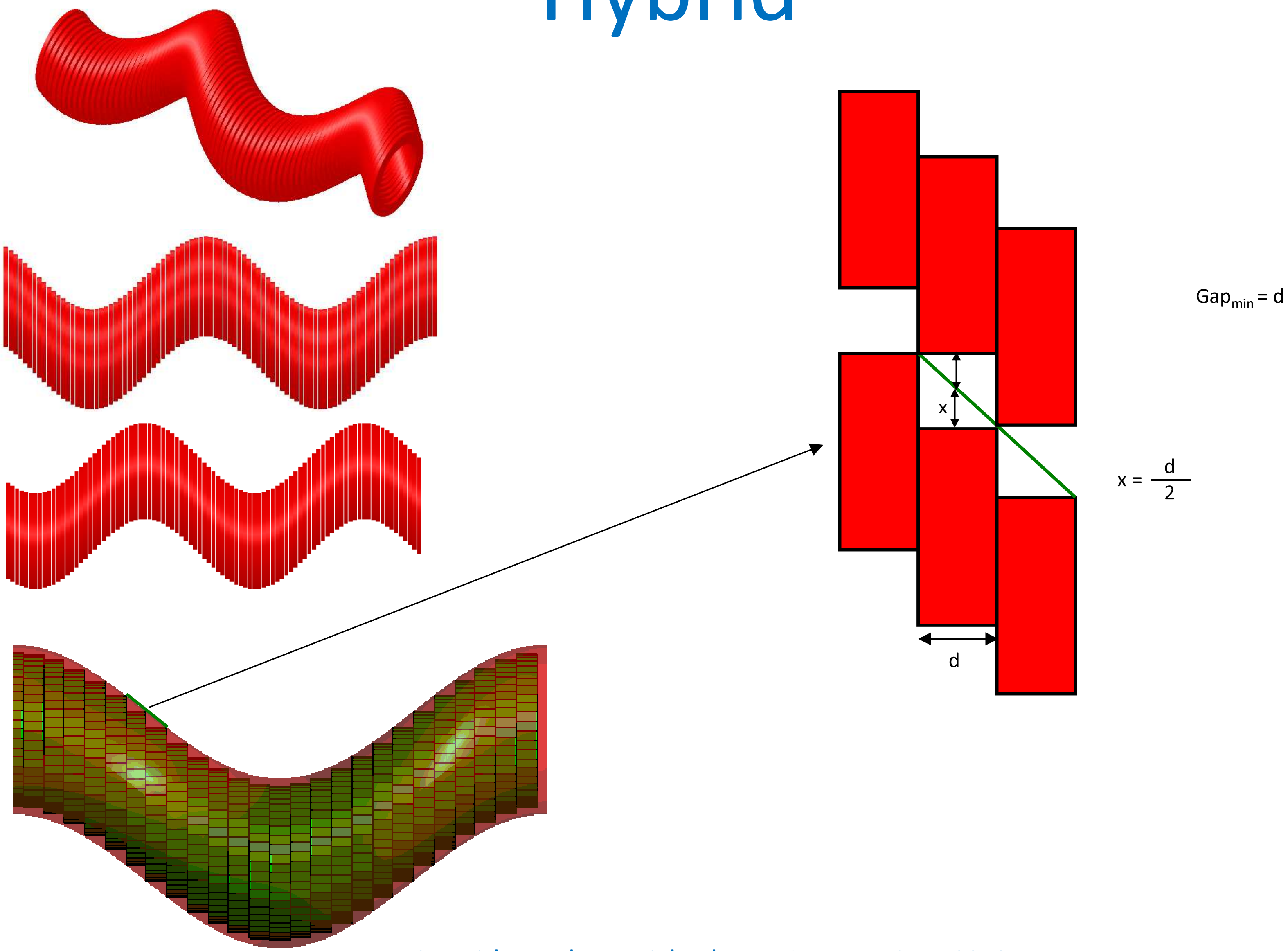


Tranverse field distribution along radial position
HTS
Nb3Sn
B (T)
R (mm)
0
5
10
15
20
25
0
50
100
150
200
250
300

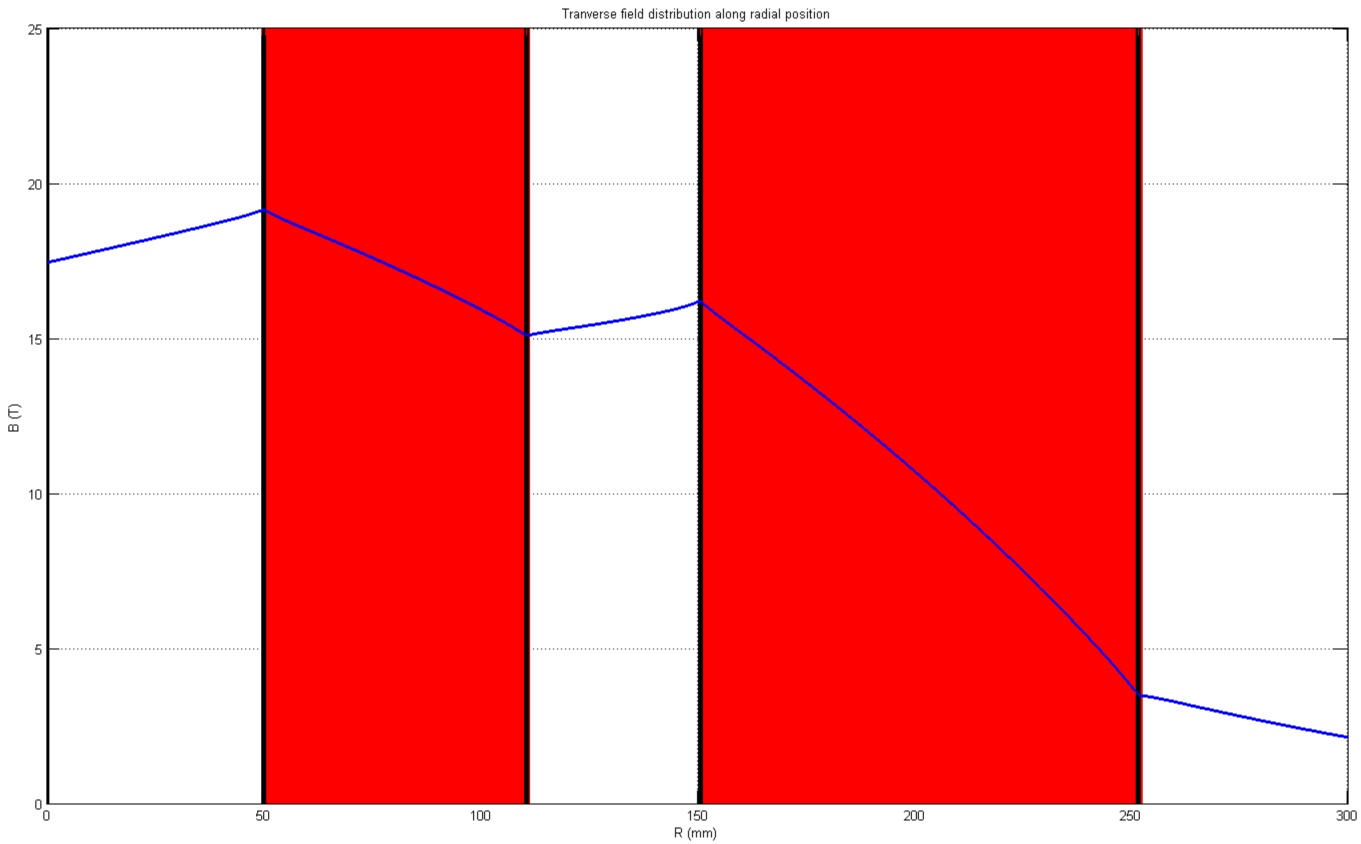
Hybrid

Material	BSCCO Cable	YBCO Tape	Nb_3Sn Cable
Coil fabrication method	Wind & React	React* & Wind	Wind & React
Wind technique	Easy or hard bend	Easy bend	Easy or hard bend
Reaction Conditions	~ 890°C in pure O_2	*Reacted YBCO tape provided by the vendor	~ 650°C in Ar/Vacuum

Hybrid



Hybrid



Tranverse field distribution along radial position
B (T)
R (mm)
0
5
10
15
20
25
0
50
100
150
200
250
300

Hybrid coil grading

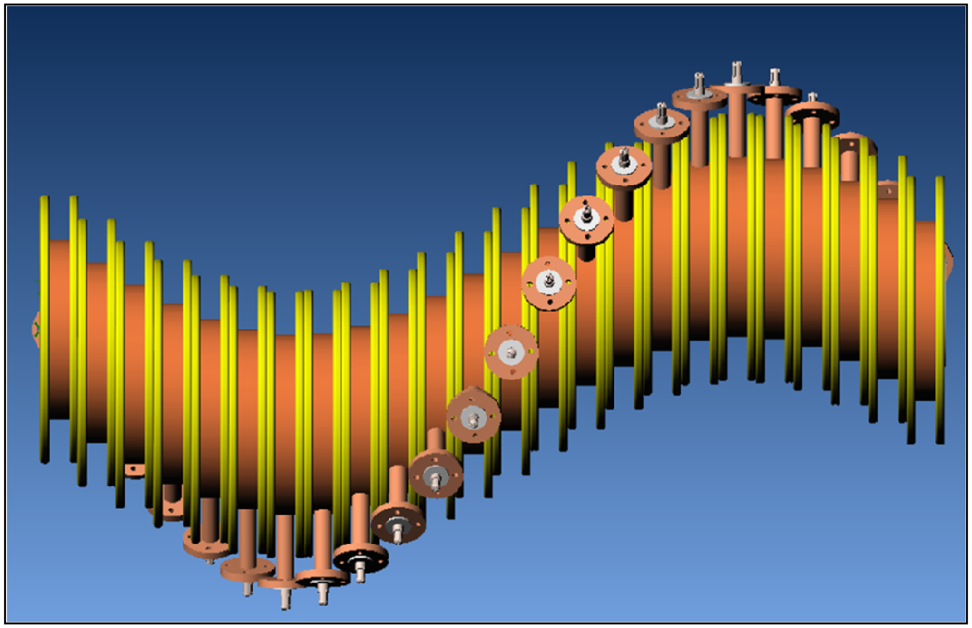
Layers configuration*	Coil radial thickness (mm)	Norm. HTS coil volume	Norm. total cond. volume	G (T/m)	Safety margin HTS (%)	Safety margin Nb_3Sn (%)	SS field (T)
200 g 0	200	1.00	1.00	-4.65	12.9	-	11.2
110 g 20	170	0.39	0.53	-4.63	11.2	18.9	11.9
100 g 30	170	0.33	0.54	-4.55	10.8	18.3	12.0
70 g 70	180	0.20	0.65	-4.13	7.7	9.3	13.5
60 g 90	190	0.16	0.75	-3.92	5.3	6.8	14.6
50 g 110	200	0.13	0.84	-3.59	2.6	3.1	16.0

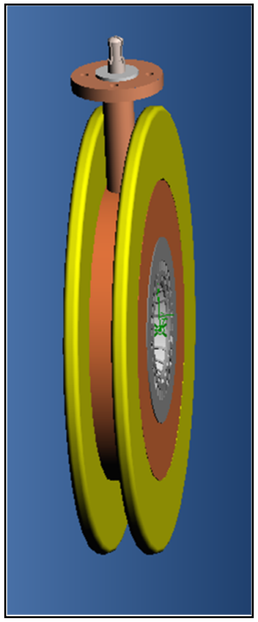
*g represents a 40 mm gap

• V.V. Kashikhin, , V.S. Kashikhin,M. Lamm, M.L. Lopes, A.V. Zlobin, M. Alsharo'a, R. P. Johnson, S. Kahn, "Design Studies of Magnet Systems for Muon Helical Cooling Channels", Proceedings of the European Particle Accelerator Conference 2008, Genoa, Italy

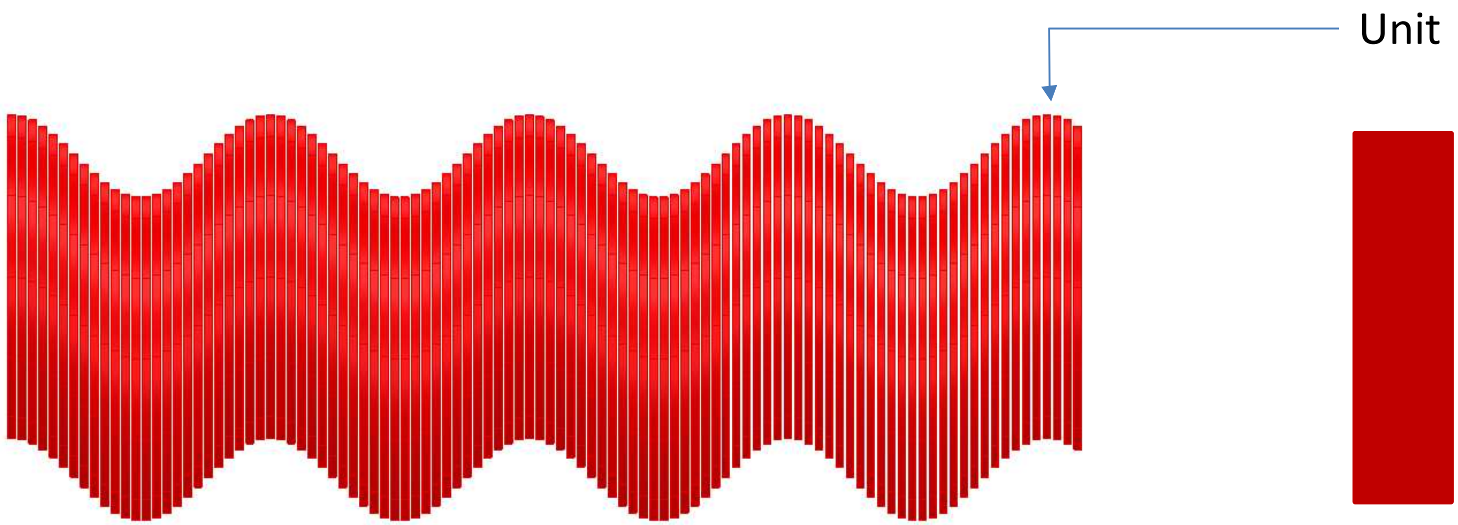
• M.L. Lopes, V.S. Kashikhin, A.V. Zlobin, R. Johnson, S. Kahn, "Studies of the High - Field Section for a Muon Helical Cooling Channel", Proceedings of the Particle Accelerator Conference 2009, Vancouver British Columbia, Canada

Space for the RF feed/Cavity

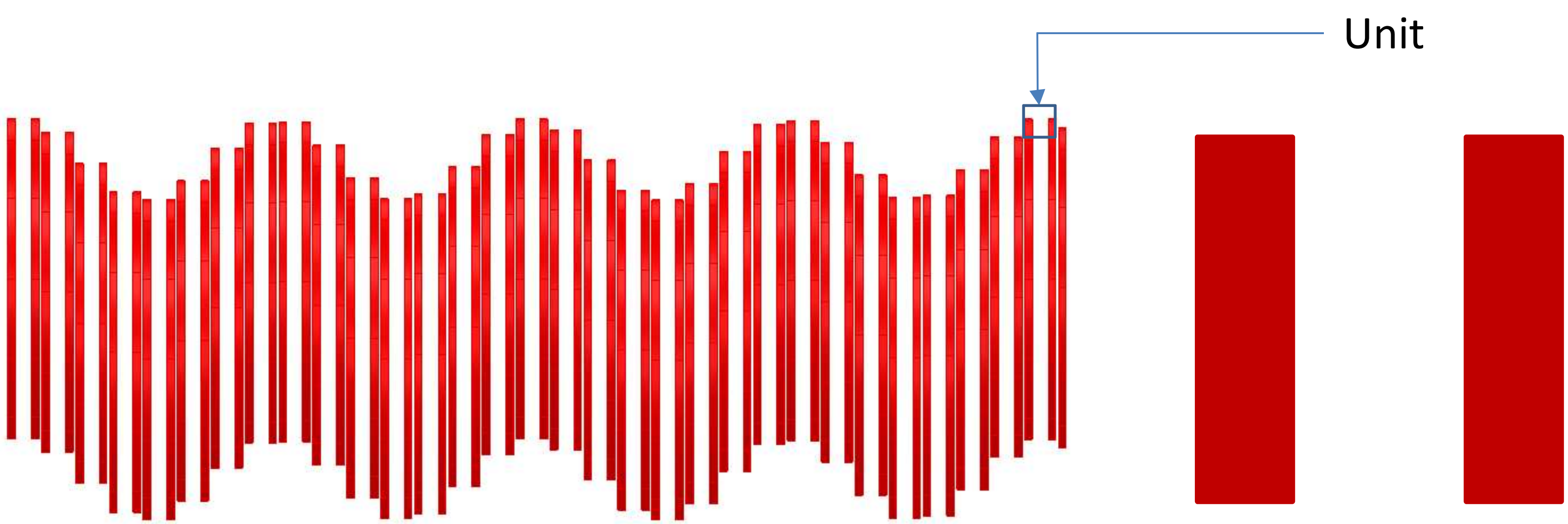




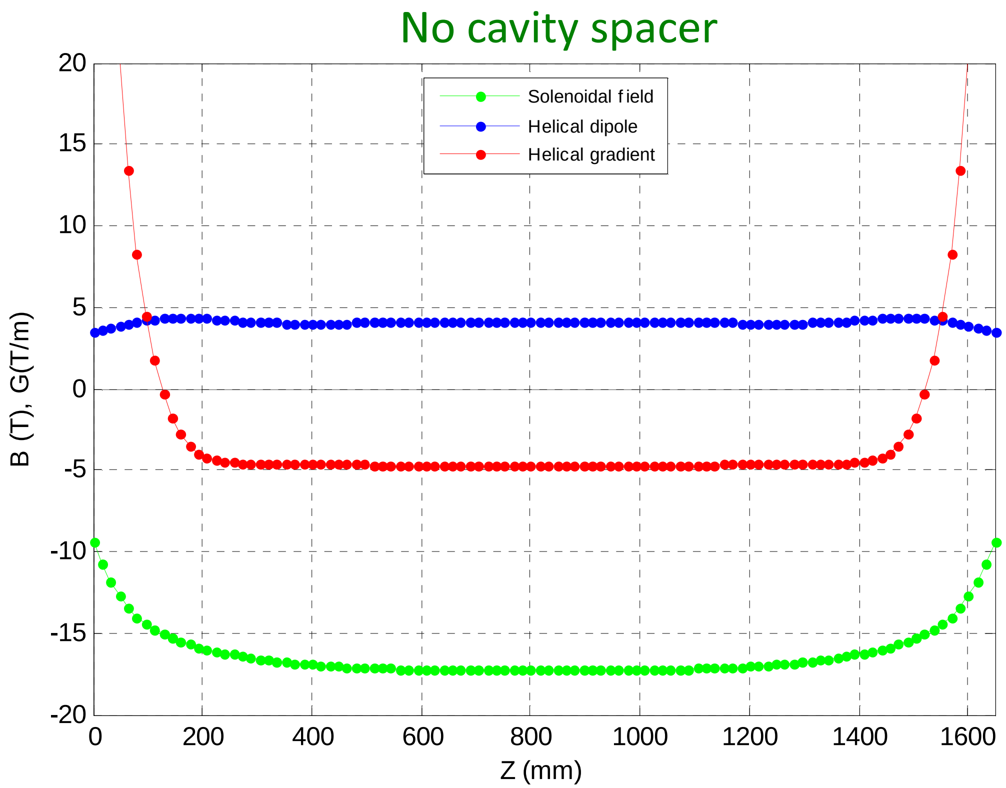
Modeling



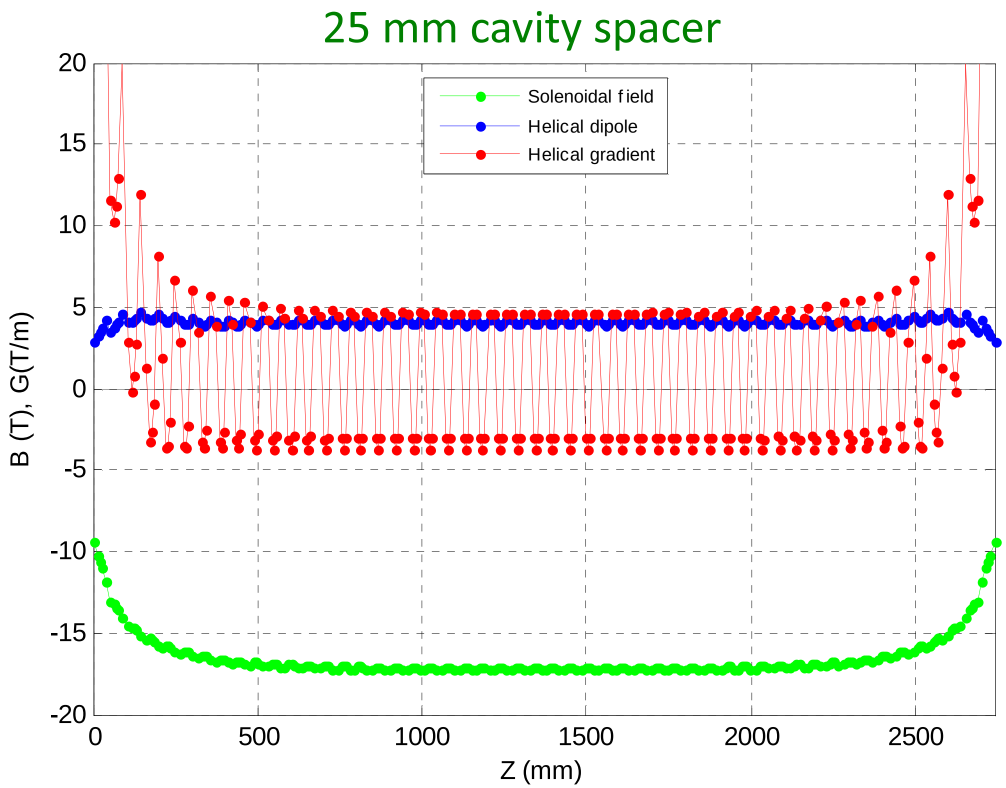
Modeling



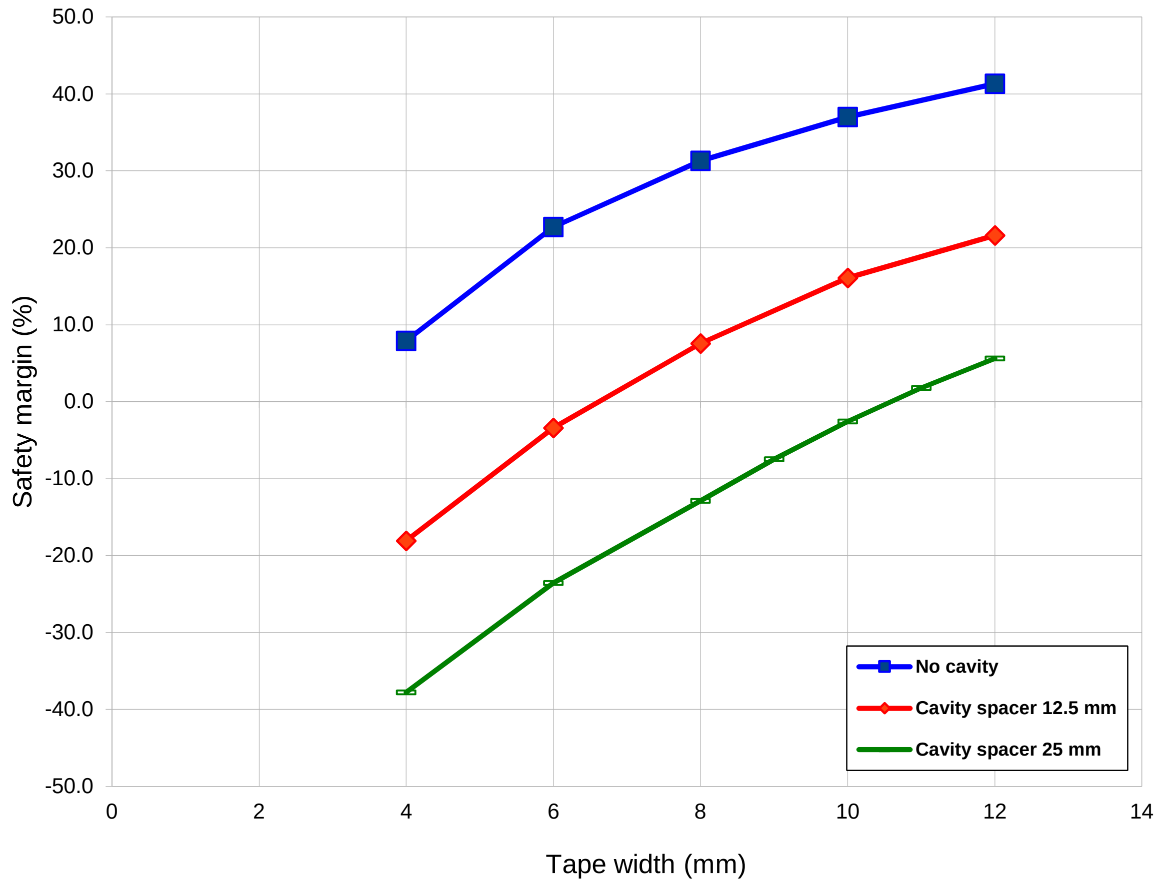
Field Performance



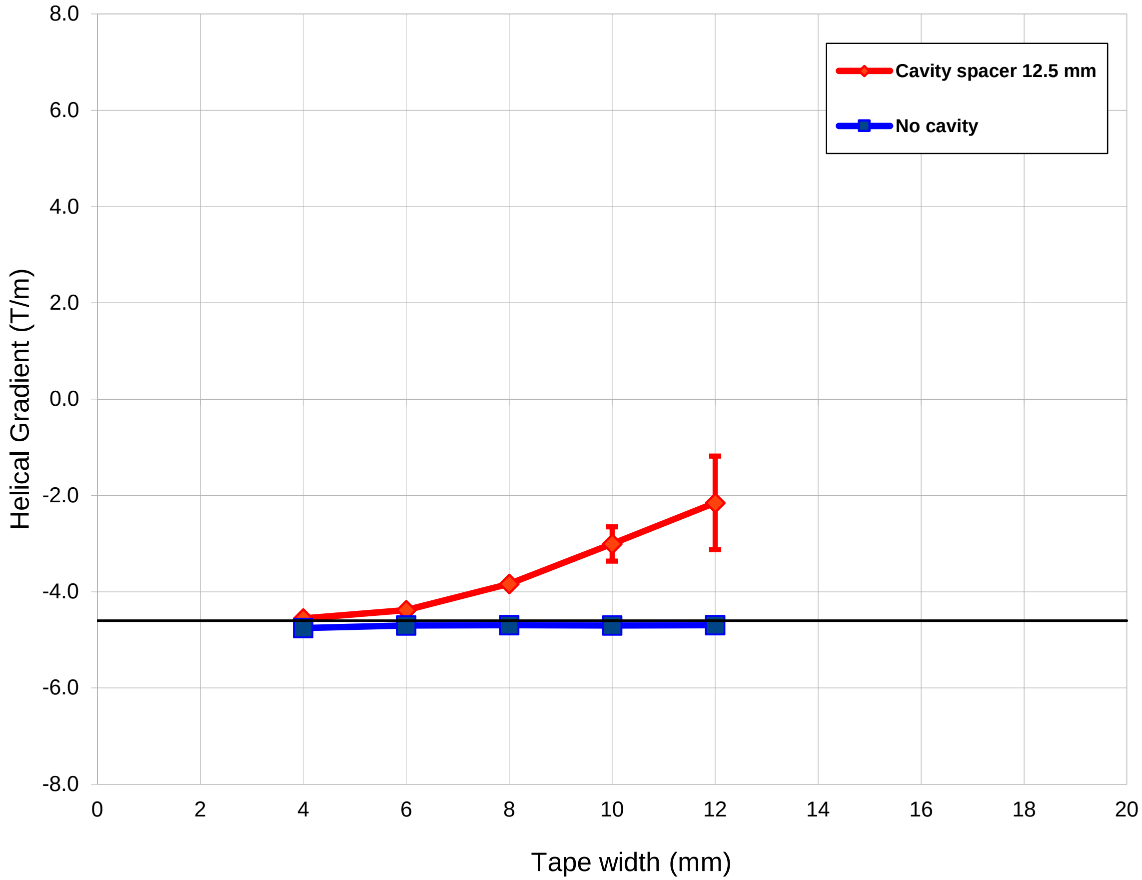
Field Performance



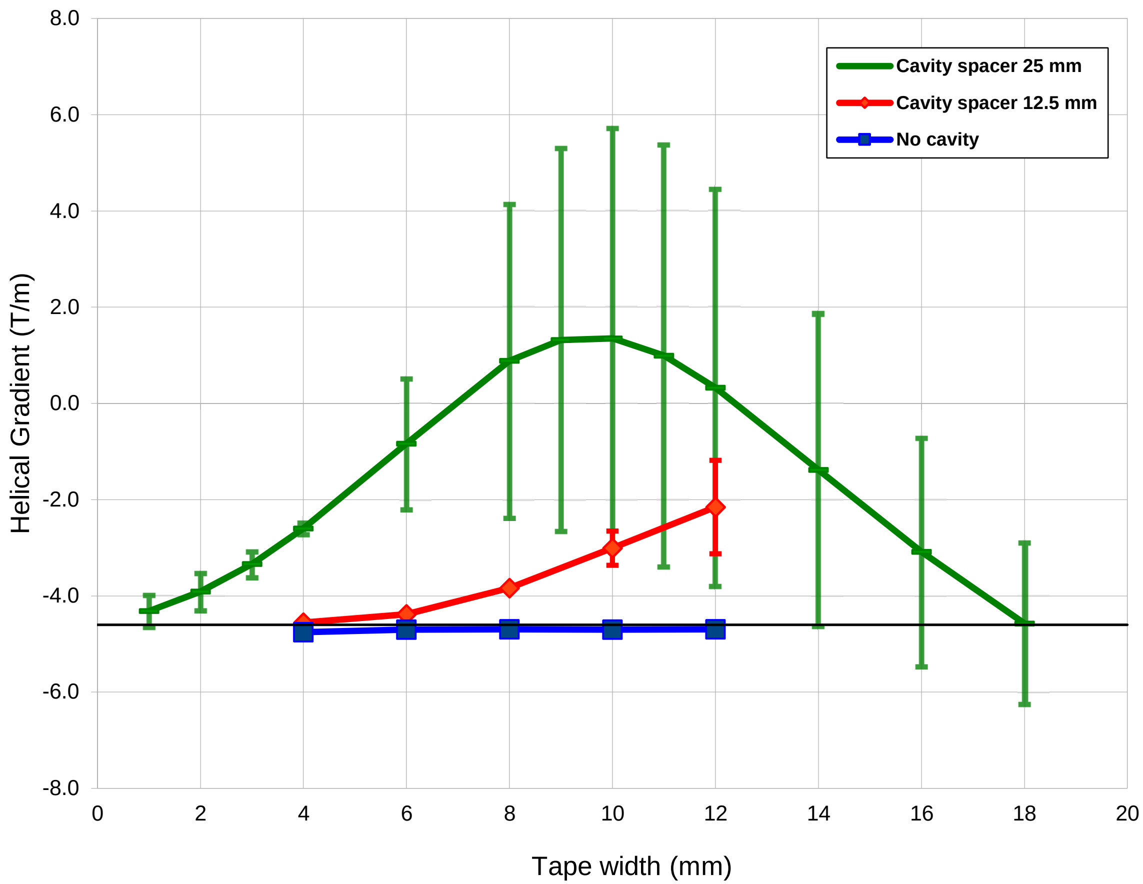
Operational margin



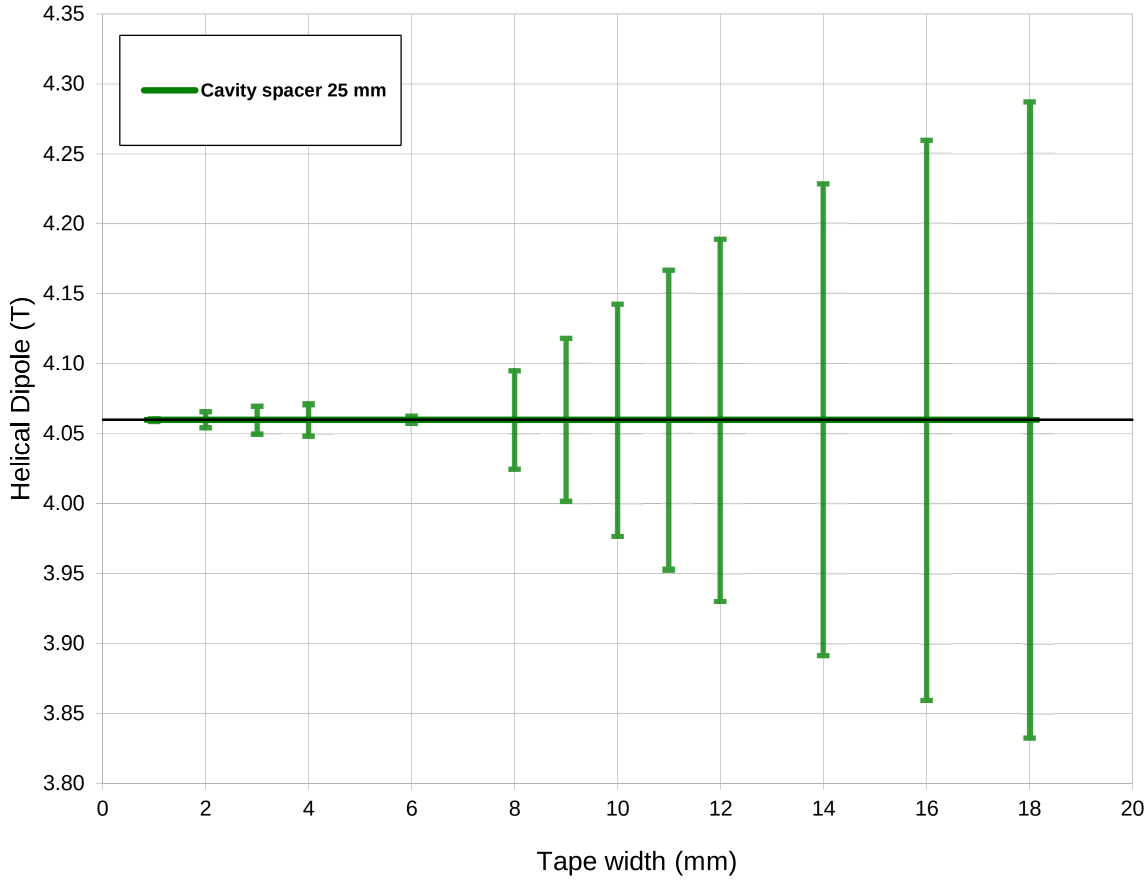
Tune limitations



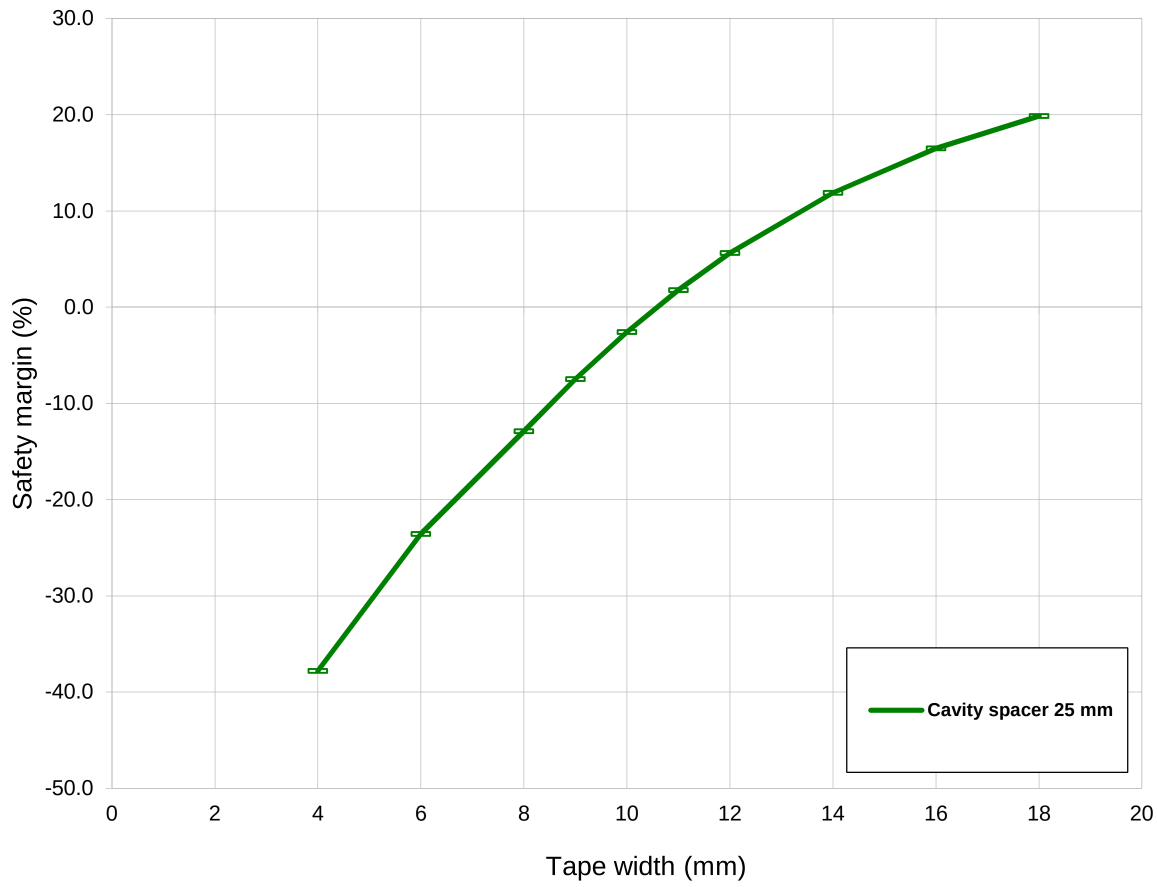
Tune limitations



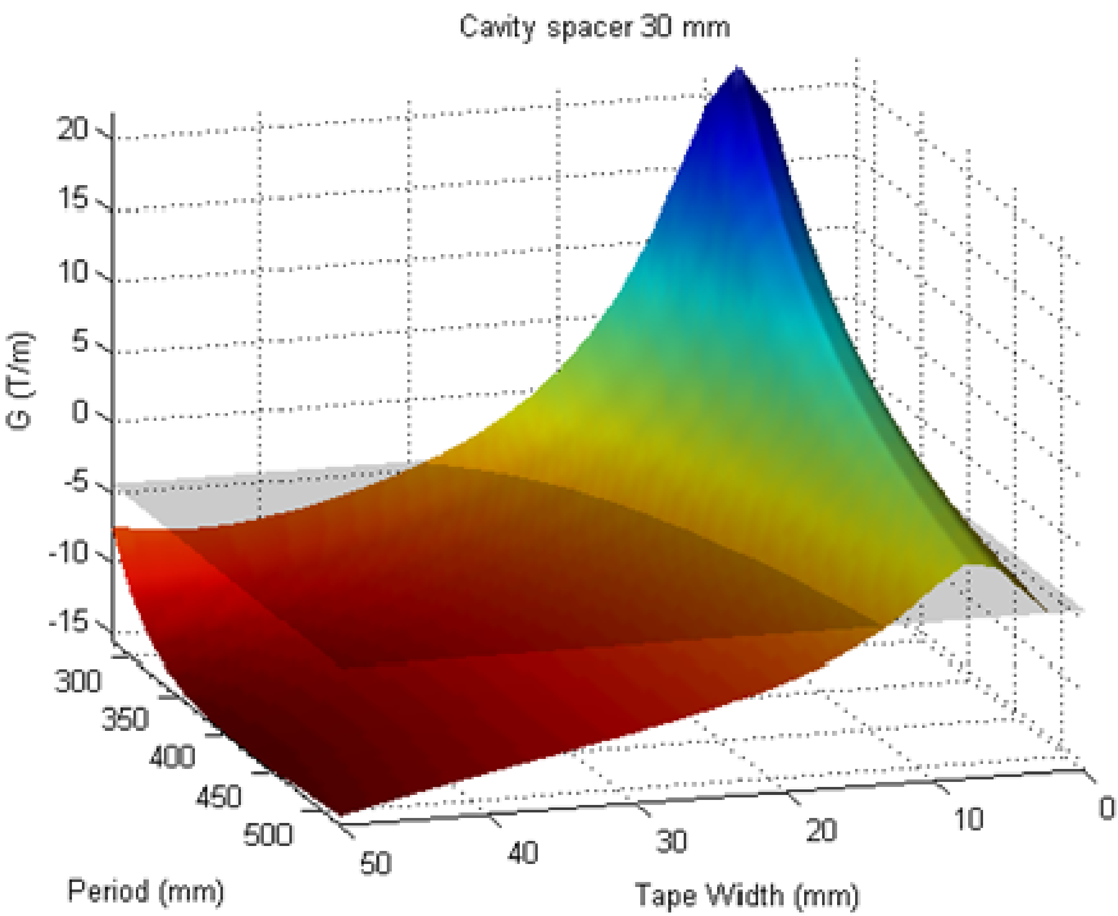
Tune limitations



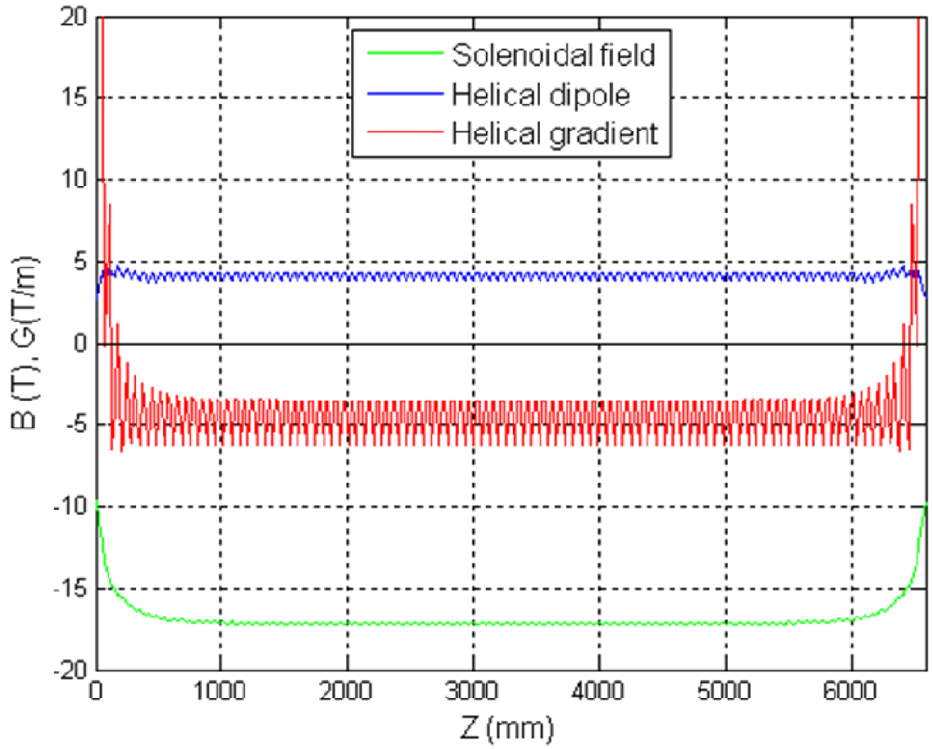
Operational margin



Multi-parameter tuning



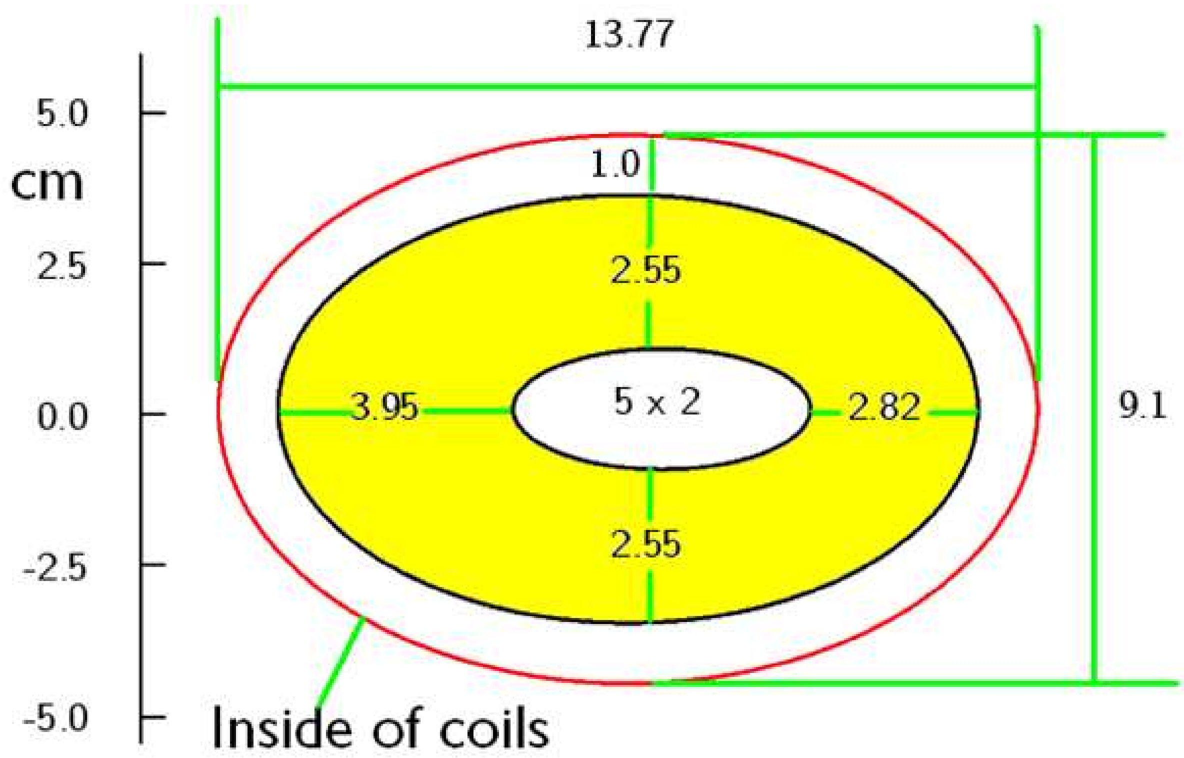
Results



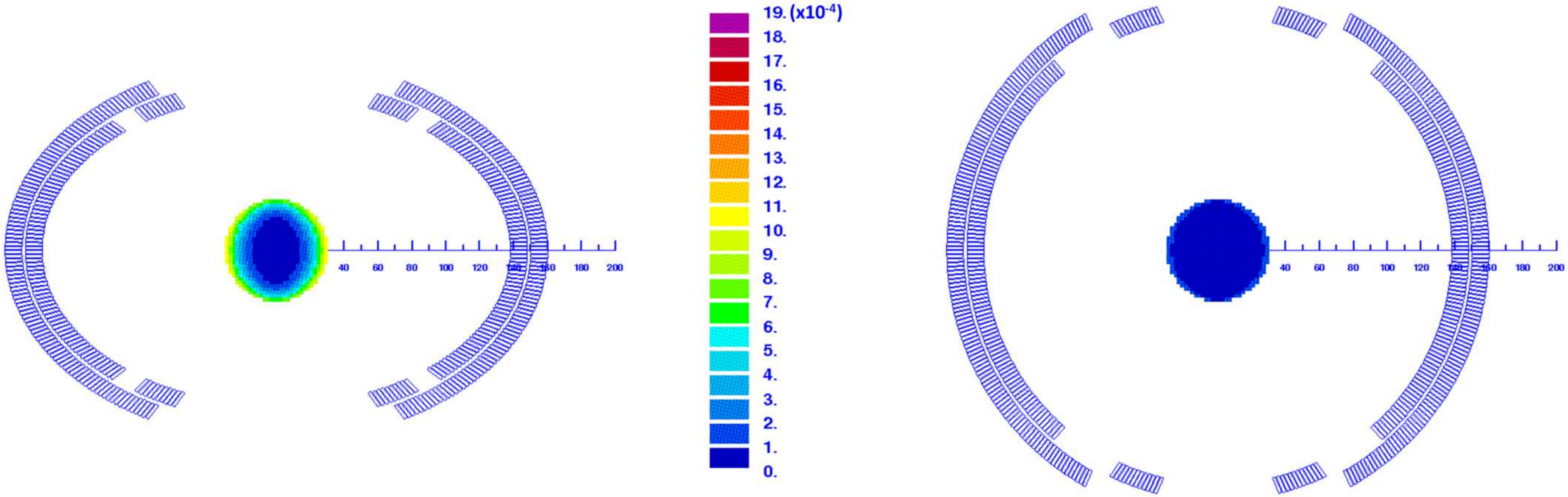
Solenoidal field
Helical dipole
Helical gradient
B (T), G(T/m)
Z (mm)
20
15
10
5
0
-5
-10
-15
-20
0
1000
2000
3000
4000
5000
6000

ELLIPTICAL DIPOLE

Elliptical Dipoles for the SR of the Muon Collider



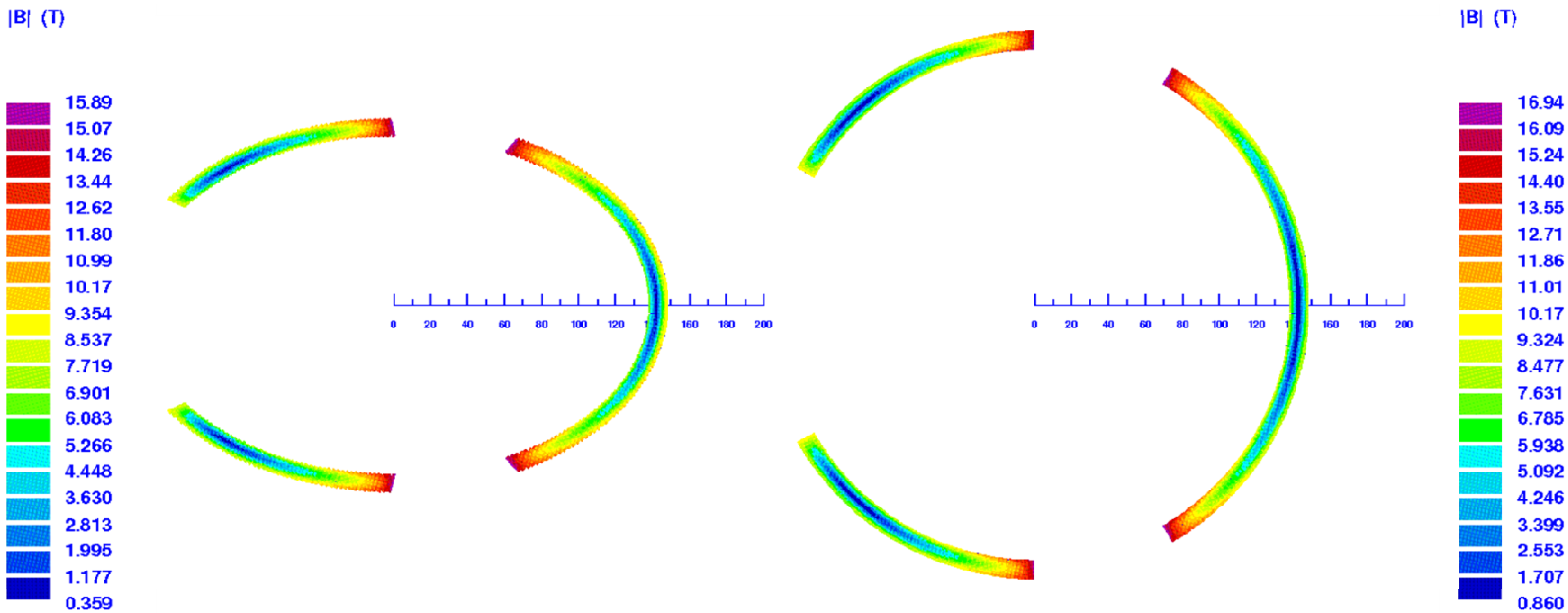
Elliptical Dipoles



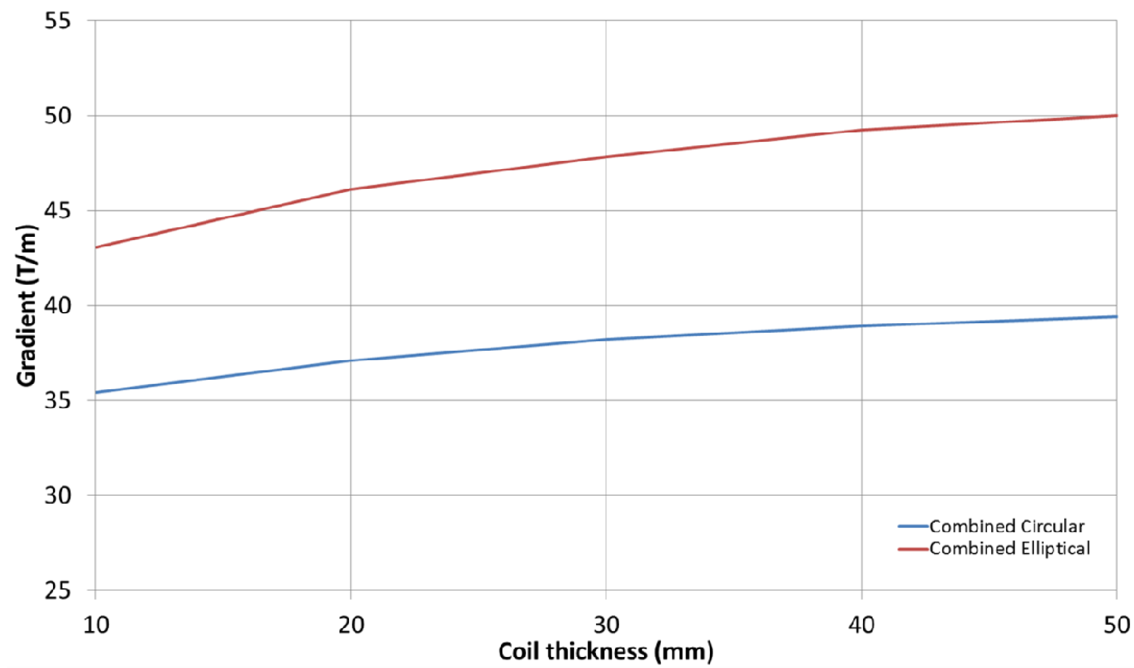
Parameters

Parameter	Value
Nominal dipole field (T)	8
Nominal gradient (T/m)	80
Operation Temperature (K)	4.5
Coil Aperture (mm)	138
Apertures ratio – (elliptical case only)	0.66

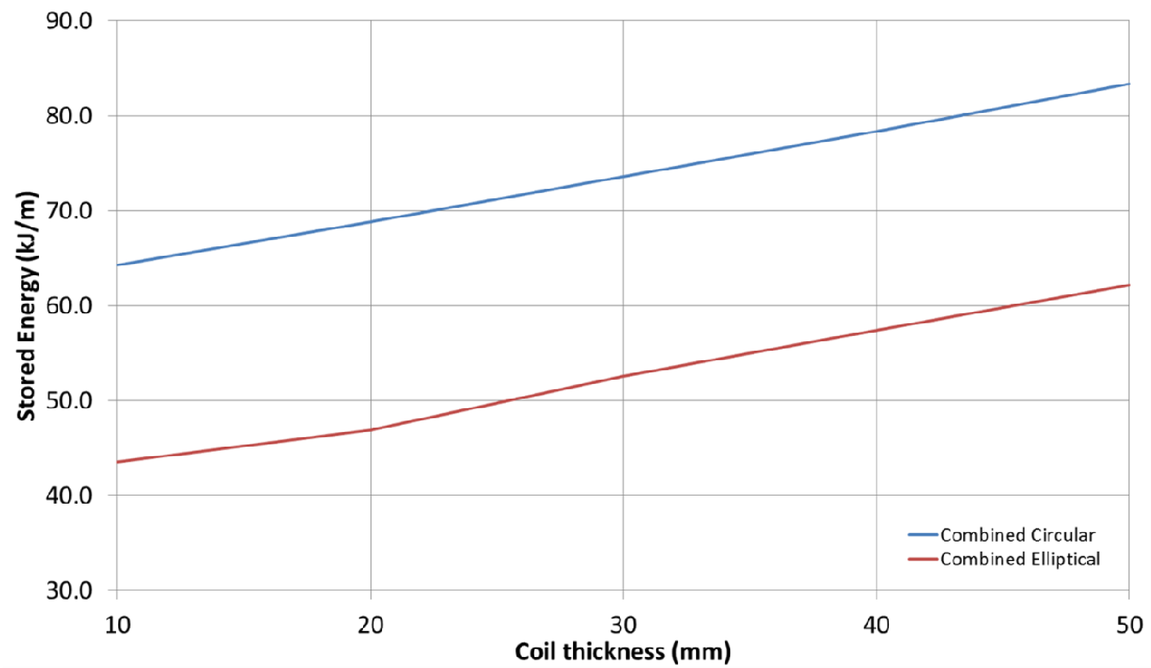
Combined Function Dipole



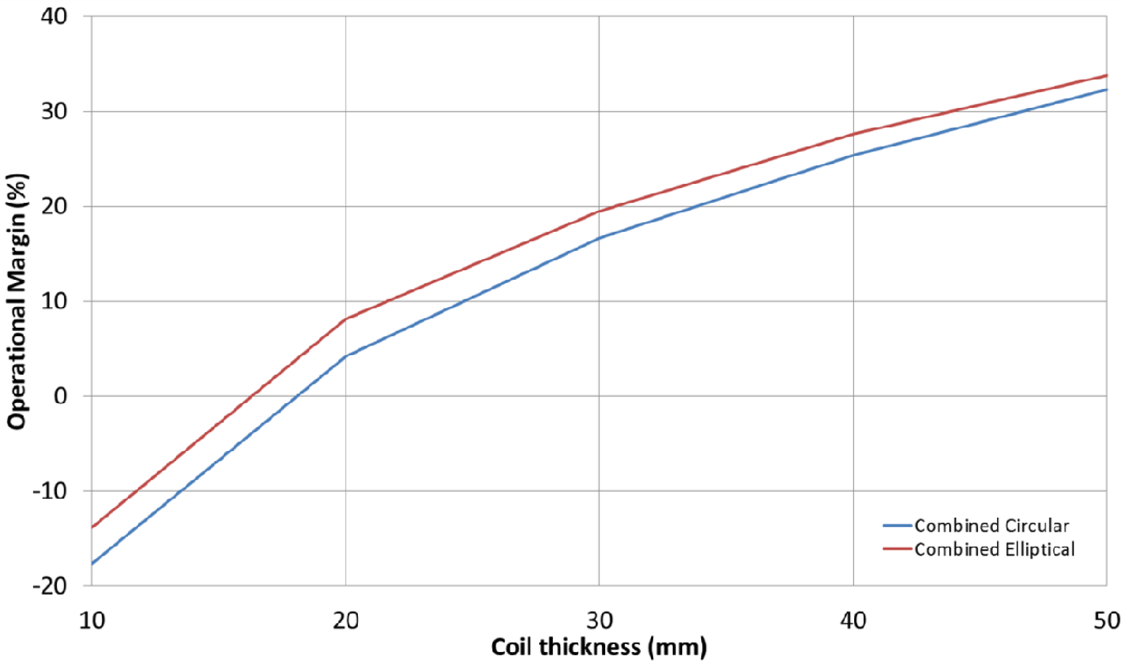
Gradient vs. Coil thickness



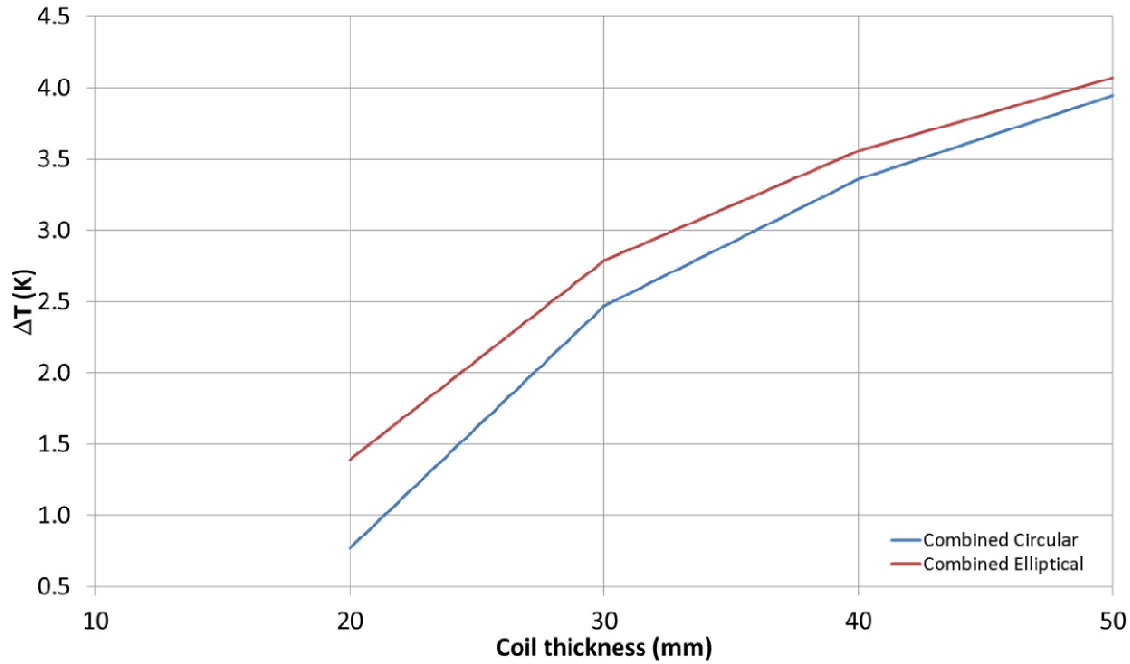
Stored Energy vs. Coil thickness



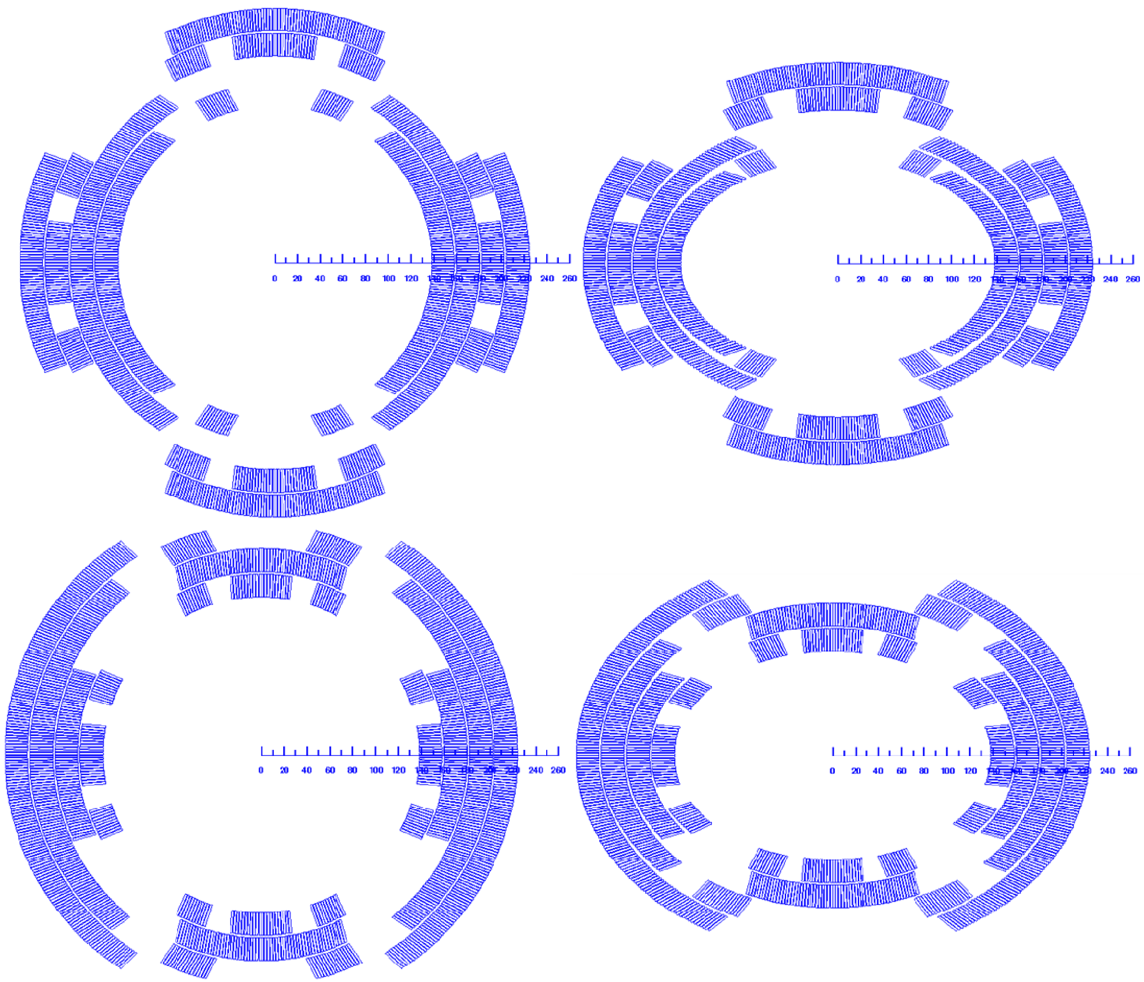
Op. Margin vs. Coil thickness



Temperature Margin vs. Coil thickness



Nested Magnets



Harmonics

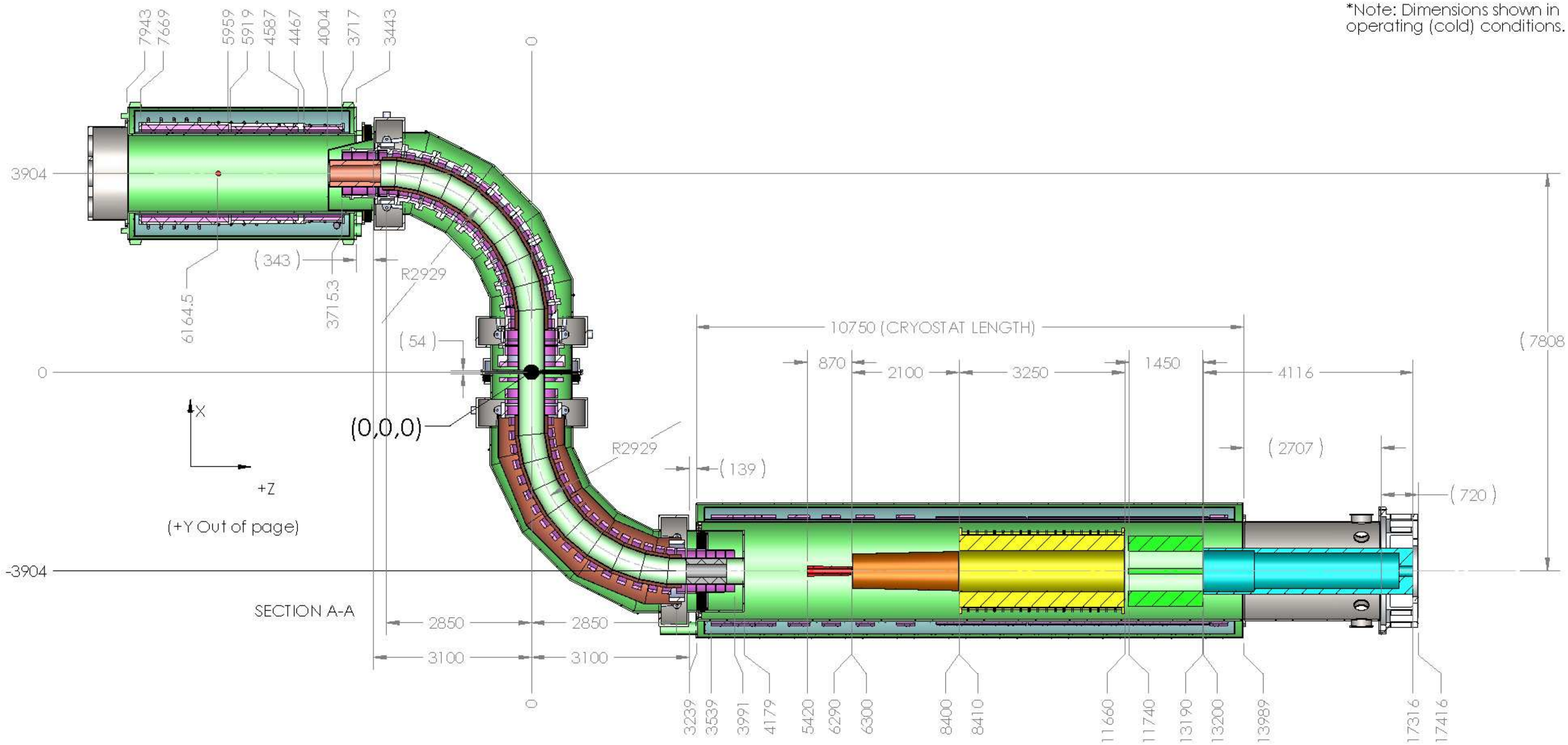
Elliptical				
(Bn/B1)*10^4	**Dipole**	**Combined function**	**Nested D+Q**	**Nested Q+D**
B2	0.0	1771.7	2104.3	2746.8
B3	-2.4	-323.1	5.1	-1.0
B4	0.0	-9.1	-5.8	-24.7
B5	-9.4	5.0	-7.2	-1.3
B6	0.0	-0.7	0.0	-0.1
B7	0.5	-0.5	0.4	0.1
B8	0.0	0.0	0.0	0.1
B9	0.0	0.1	0.0	0.0

Harmonics

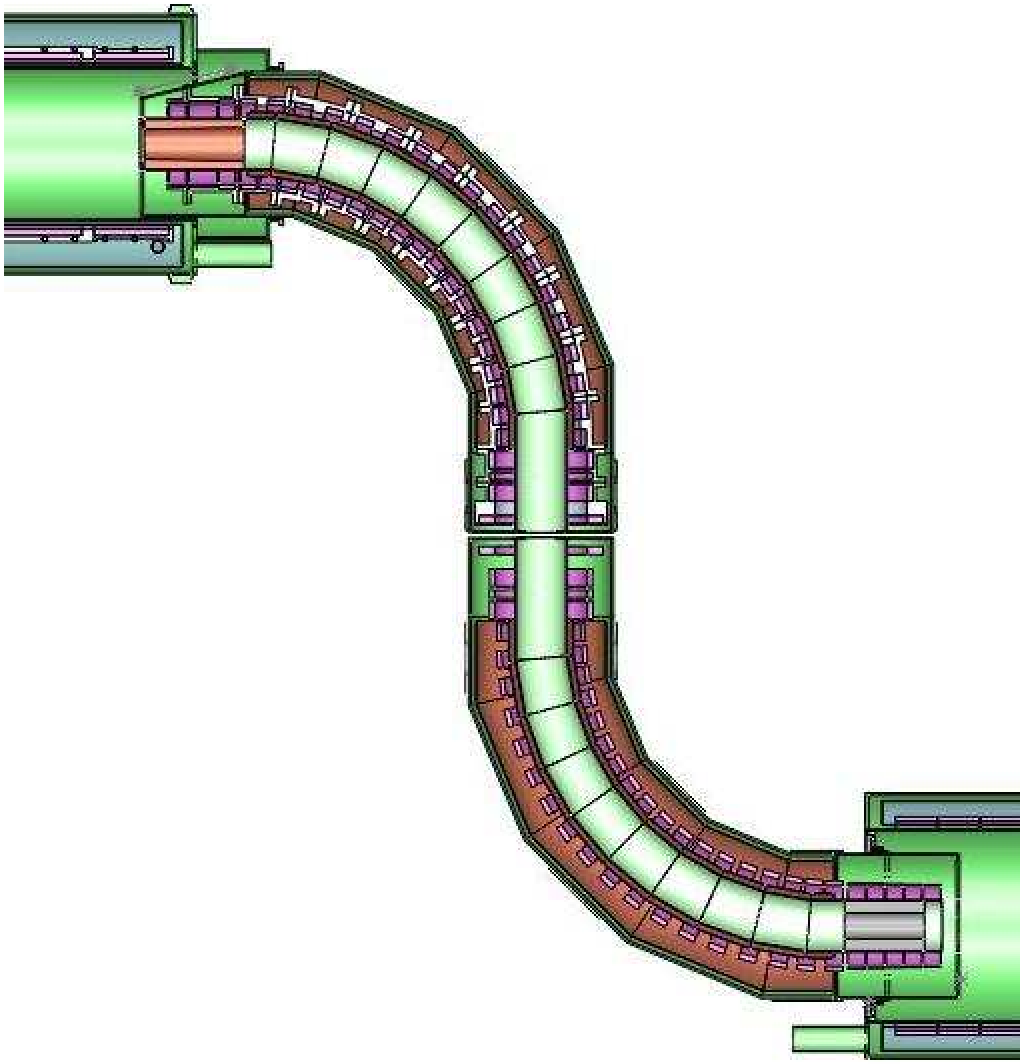
Circular				
(Bn/B1)*10 4	**Dipole**	**Combined function**	**Nested D+Q**	**Nested Q+D**
B2	0.0	1418.1	1891.9	2343.5
B3	-0.1	-178.2	18.0	4.0
B4	0.0	-0.1	0.0	0.0
B5	-1.3	-0.4	-0.9	-0.4
B6	0.0	-0.2	0.1	0.4
B7	0.0	0.0	-0.1	0.0
B8	0.0	0.0	0.0	0.0
B9	0.0	0.0	0.0	0.0

MU2E

Mu2e Magnet System

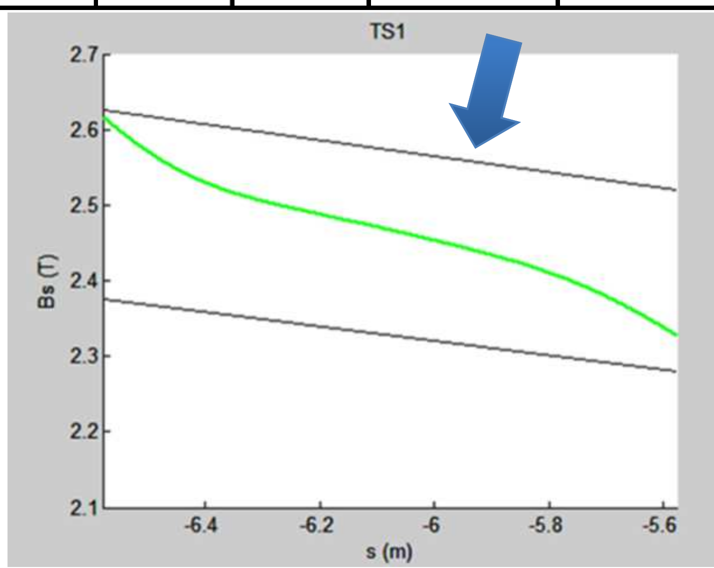


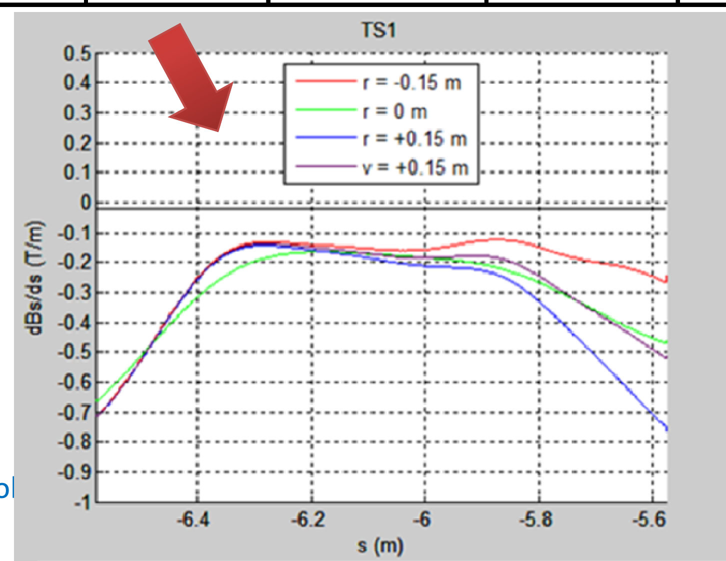
Transport Solenoid



Magnetic Field Requirements

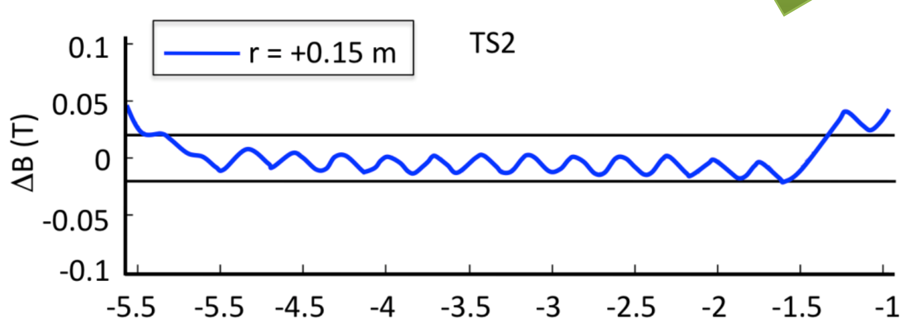
regions	s_{intial} (m)	s_{final} (m)	$B_{initial}$ (T) ±5 %	B_{final} (T) ±5 %	R_{max} (m)	dB_s/ds (T/m)	dB_s/dr (T/m)	Ripple (T)	where
TS1	-6.58	-5.58	2.50	2.40	0.15	< -0.02	na	na	r=0, r = Rmax
TS2	-5.58	-0.98	na	na	0.15	na	> 0.275	±0.02	r < Rmax
TS3	-0.98	0.98	2.4	2.1	0.15	< -0.02	na	na	na
TS4	0.98	5.58	na	na	0.15	na	> 0.275	±0.02	r < Rmax
TS5	5.58	6.58	2.10	2.00	0.15	< -0.02	na	na	r=0, r = Rmax



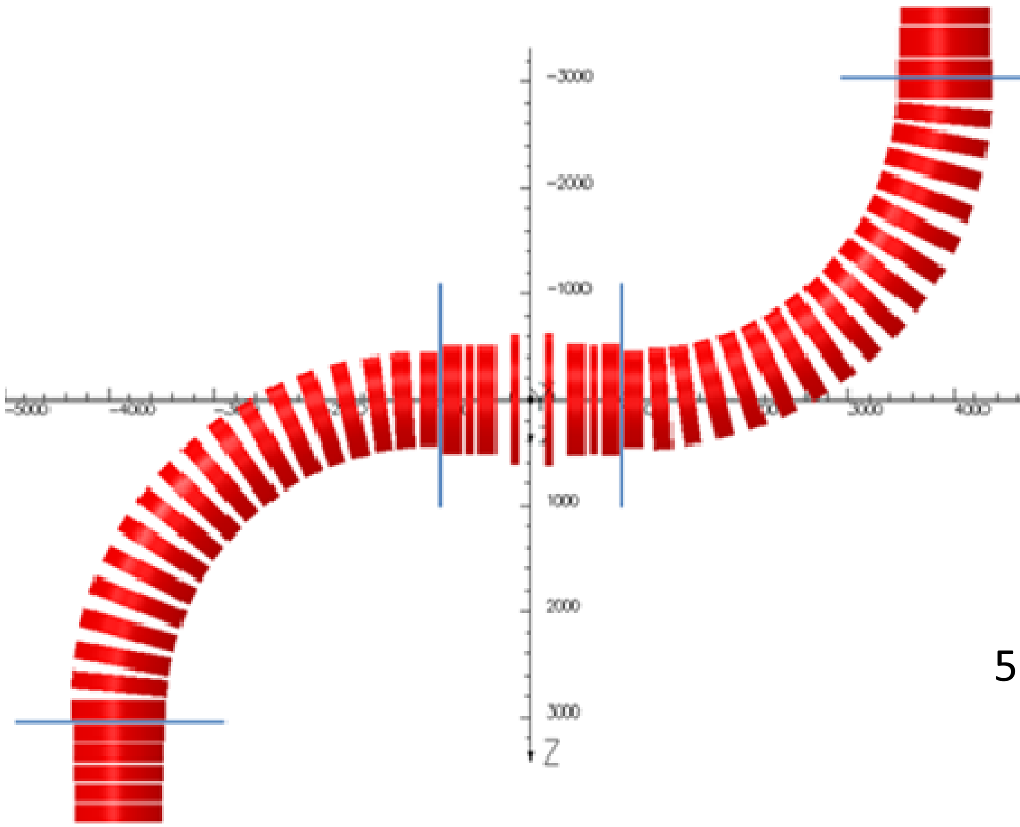


Magnetic Field Requirements

regions	S_{intial} (m)	S_{final} (m)	$B_{initial}$ (T) ±5 %	B_{final} (T) ±5 %	R_{max} (m)	dB_s/ds (T/m)	dB_s/dr (T/m)	Ripple (T)	where
TS1	-6.58	-5.58	2.50	2.40	0.15	< -0.02	na	na	r=0, r = Rmax
TS2	-5.58	-0.98	na	na	0.15	na	> 0.275	±0.02	r < Rmax
TS3	-0.98	0.98	2.4	2.1	0.15	< -0.02	na	na	na
TS4	0.98	5.58	na	na	0.15	na	> 0.275	±0.02	r < Rmax
TS5	5.58	6.58	2.10	2.00	0.15	< -0.02	na	na	r=0, r = Rmax

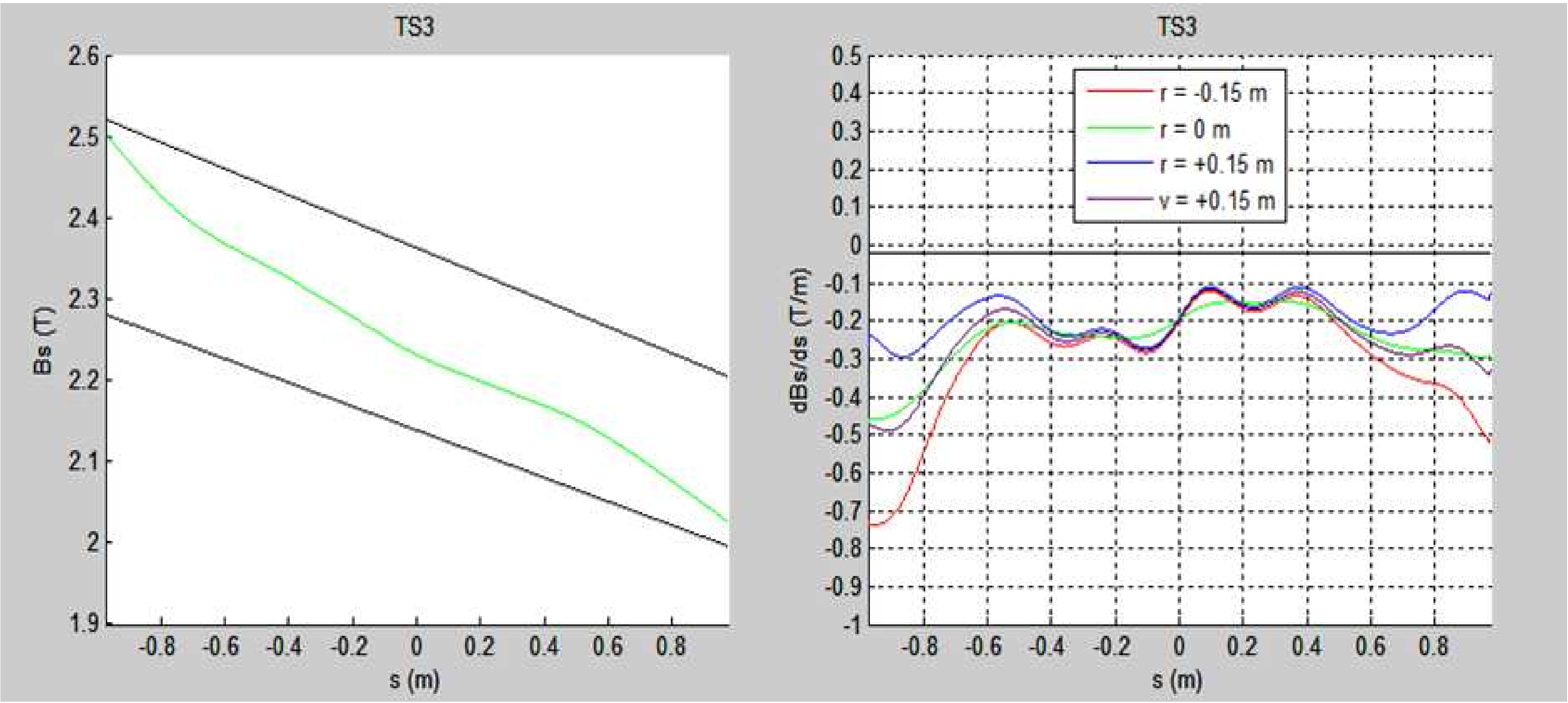


TS Coils



52 Coils

TS3 Field Profile



THE END