Development of Fast-Cycling Superconducting Quadrupole and Corrector Magnets for the SIS300

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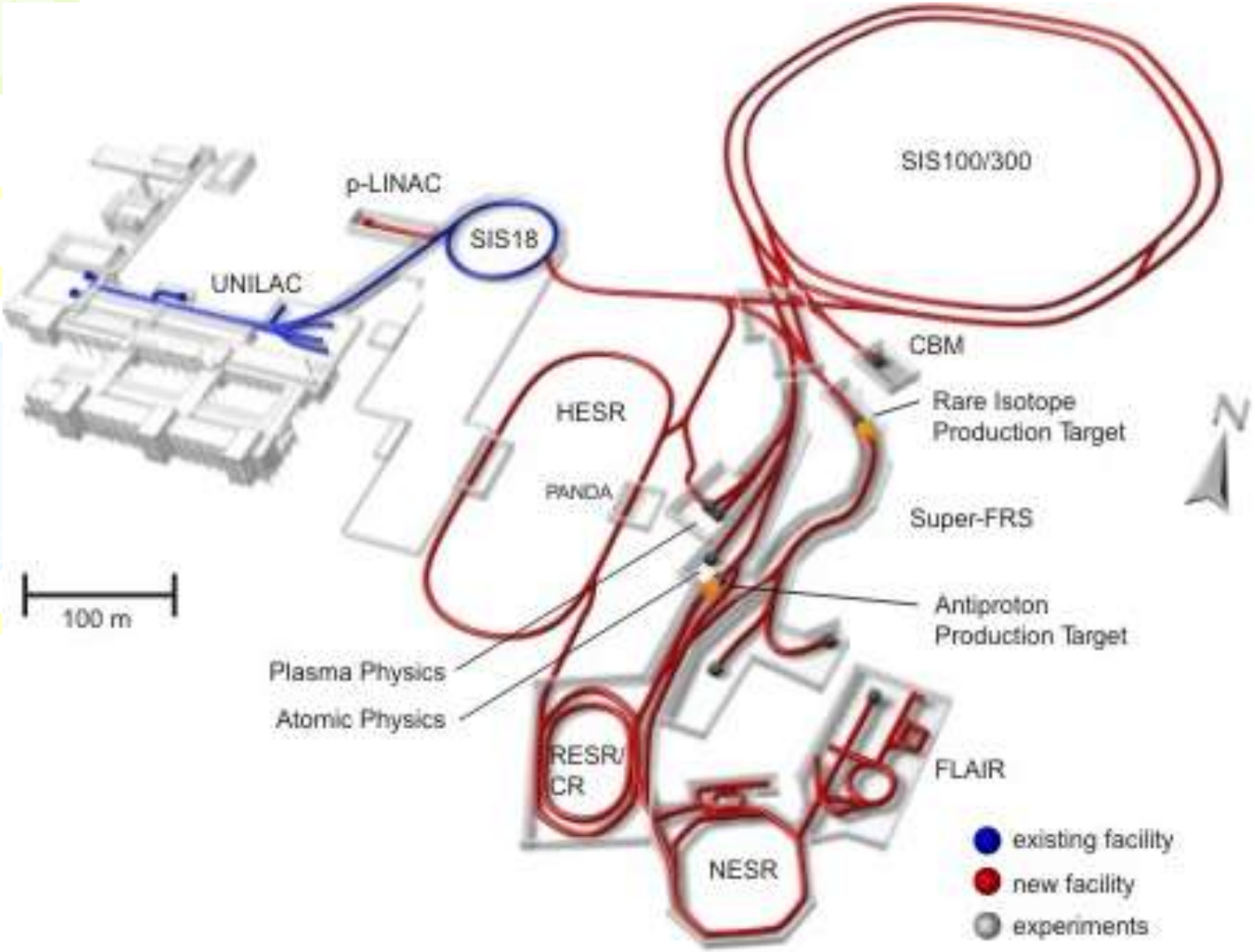
General view of the FAIR



Quadrupole Requirements

Central gradient	45 T/m
Coil ID	125 mm
ID of beam pipe	105 mm
“Good field” ID	80 mm
Effective length	1 m
Gradient of injection	10 T/m
Field ramp rate	10 T/m/c
Lower multipoles	$\lvert 2\times10^{-4}\rvert$
Temperature margin	> 1 K

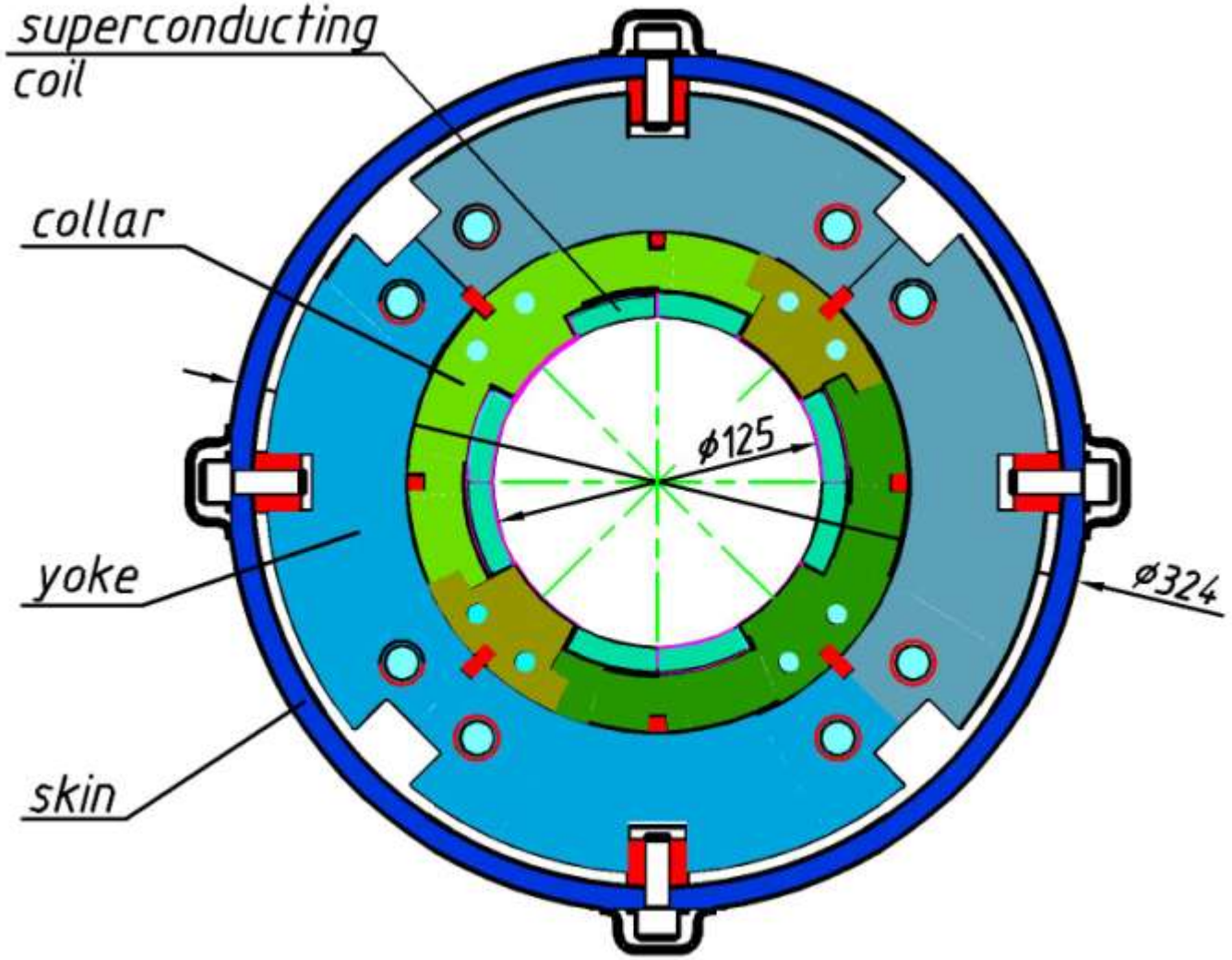
Superconducting wire

Strand diameter, mm	0.825
Filament diameter, μm	3.5
Filament twist pitch, mm	5
Cu/NbTi ratio	1.38
Resistive barriers	Yes
Strand coating	Staybrite
Critical current density, kA/mm^2 (5 T, 4.2 K)	2.7

Cable

Number of strands	19
Width with insulation, mm	8.5
Width without insulation, mm	8.25
Bare middle height, mm	1.447
Strand coating	Staybrite
Core	6 mm×25 μm
Transposition step	60 mm
Rutherford type	Fully keystone
Radial insulation, μm	125
Azimuth insulation, μm	98
R_c, mΩ	20
R_a, mΩ	0.02

Cross section, general view



Collars

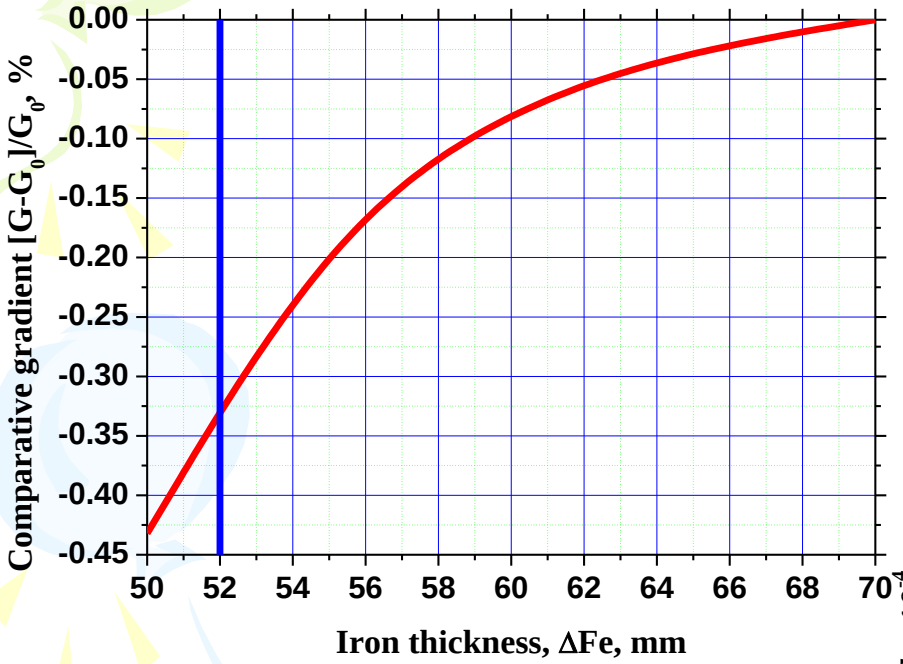
Ponderomotive forces, kN/m/octant

Horizontal magnetic force	124.2
Vertical magnetic force	-143.3
Total magnetic force	189.7

22-mm collar thickness is chosen from technological reason

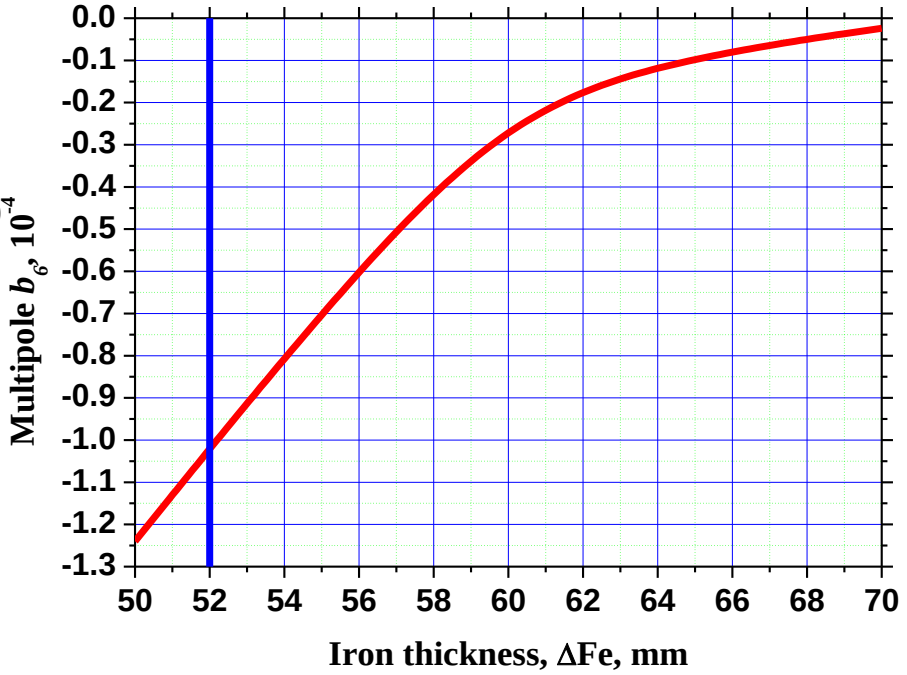
Material Nitronic 40

Iron thickness, quadrupole normalization



Material 2212

Bus bars = 17×40 mm^2



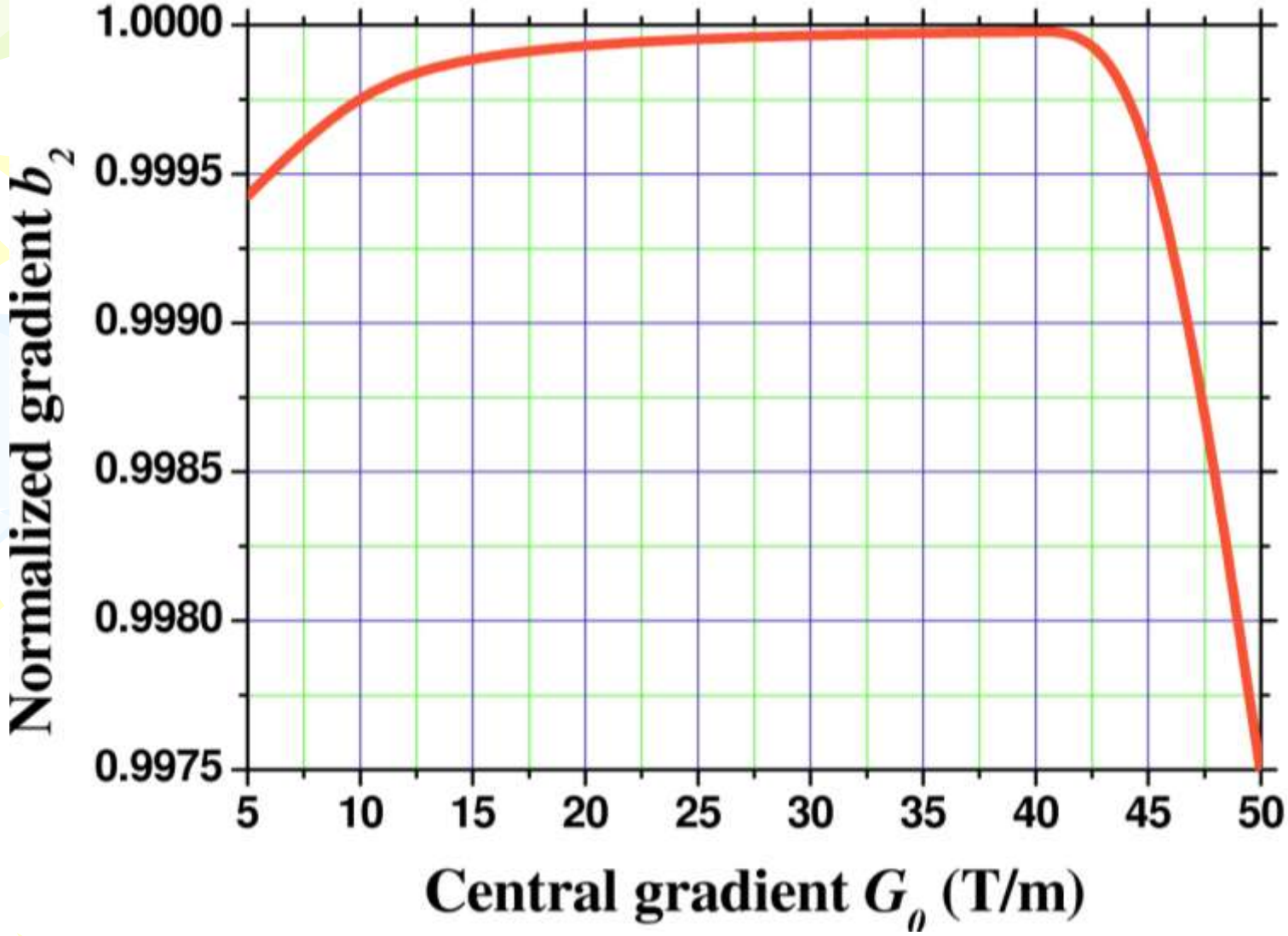
Iron thickness = 52 mm

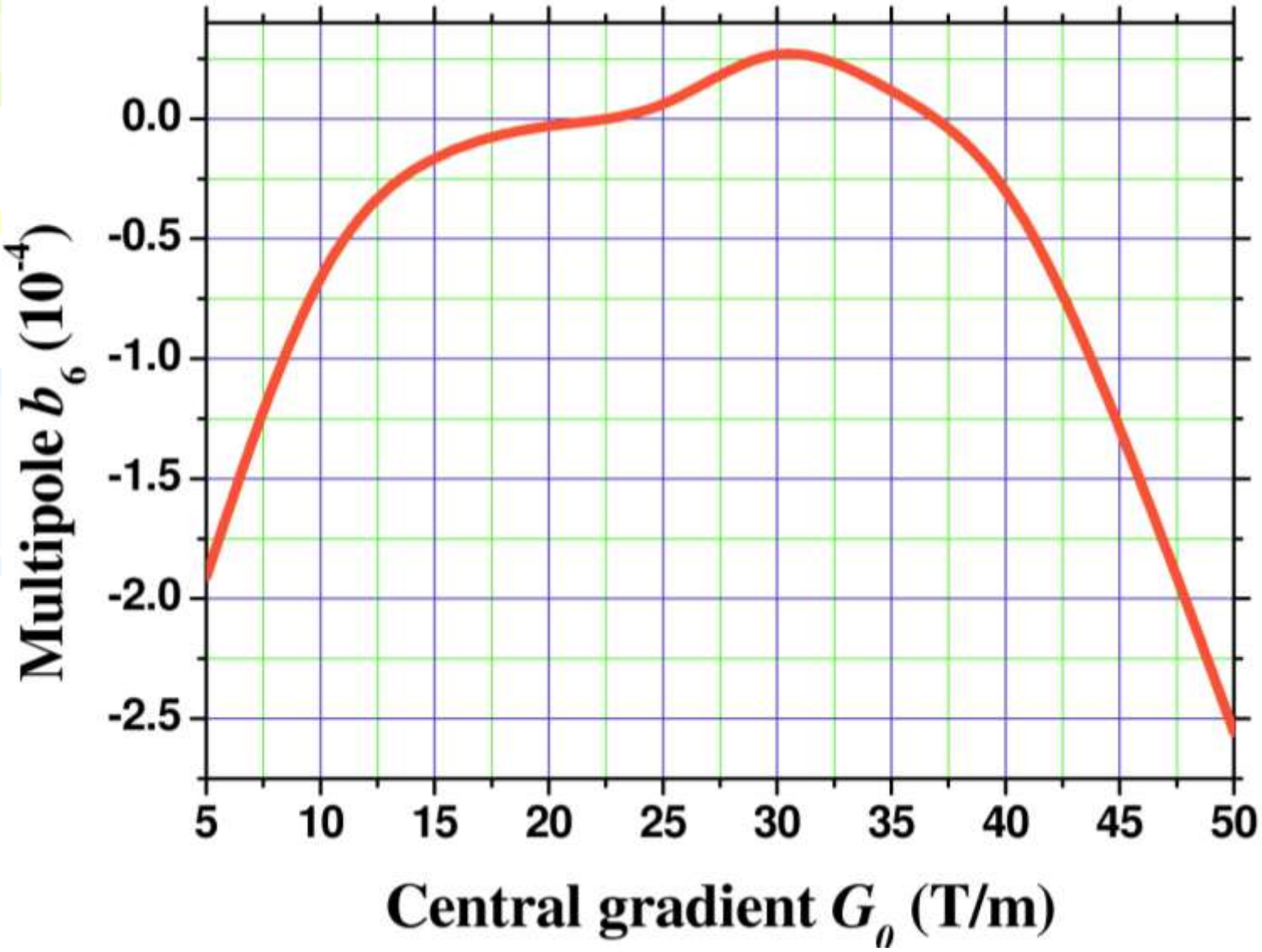
Lamination thickness = 0.5 mm

Main parameters

Turn number/octant	8 + 7 + 5 = 20
Initial angle, deg.	0.131; 11.959; 26.604
Final angle, deg.	11.413; 21.831; 33.656
Operating current, kA	6.262
Maximal field in cross section, T	3.51
Radius of maximal field, mm	65.33
Critical temperature, K	7.22
Temperature margin, K (2D)	1.4
Iron thickness, mm	52
Stored energy, kJ/m	38
Inductance, mH/m	1.94

Field quality

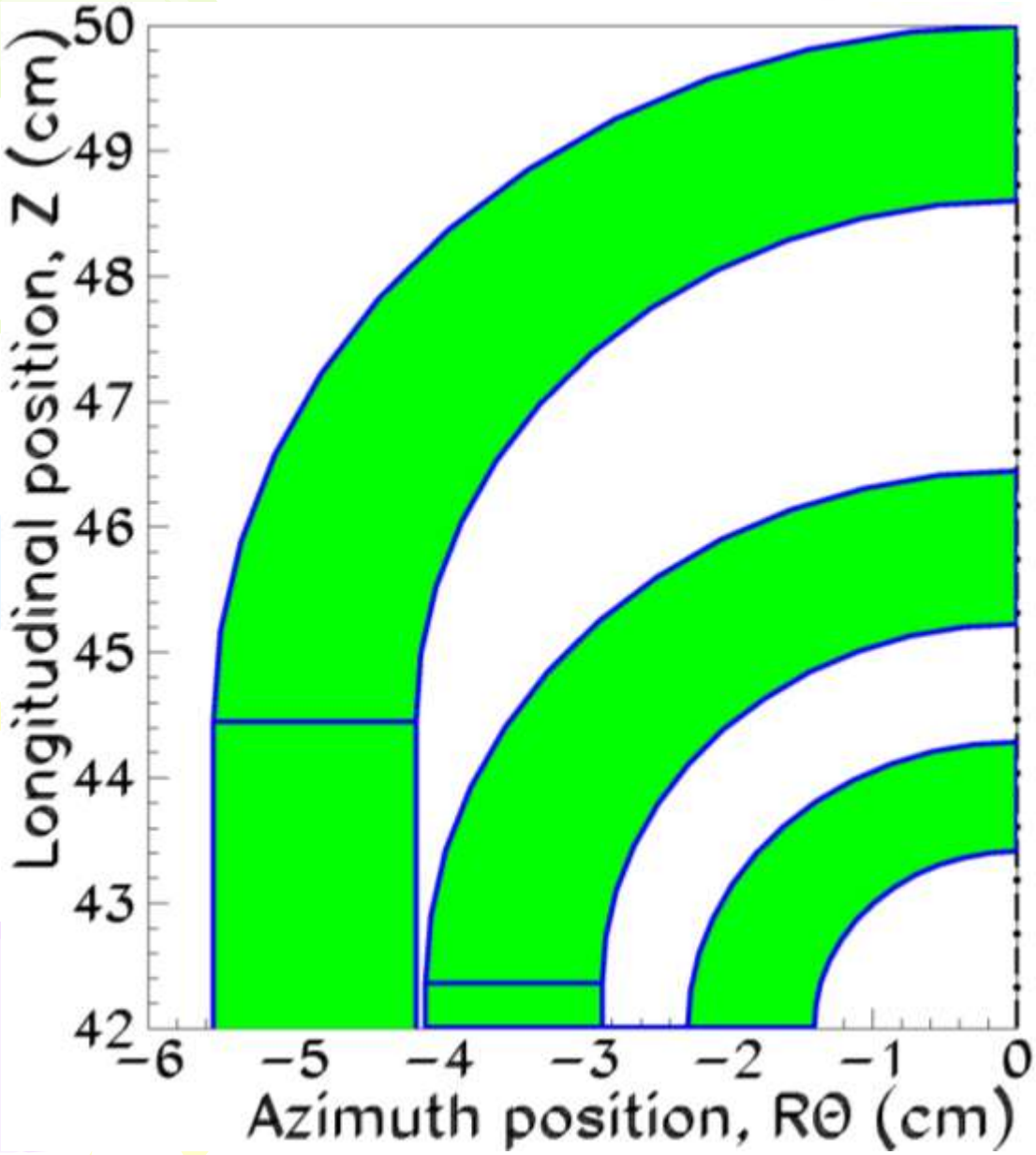



0.0
-0.5
-1.0
-1.5
-2.0
-2.5
Multipole b_6 (10^{-4})
5
10
15
20
25
30
35
40
45
50
Central gradient G_0 (T/m)

Losses, J/m, field cycle 10 - 45 T/m, time 3.5 sec

Hysteresis	9.4
Matrix	3.0
Cable	0.3
Total in coil	12.7
Hysteresis in iron	5.0
Total in magnet	17.7

3D



$S_1 = 21.56$ mm

$S_2 = 9.42$ mm

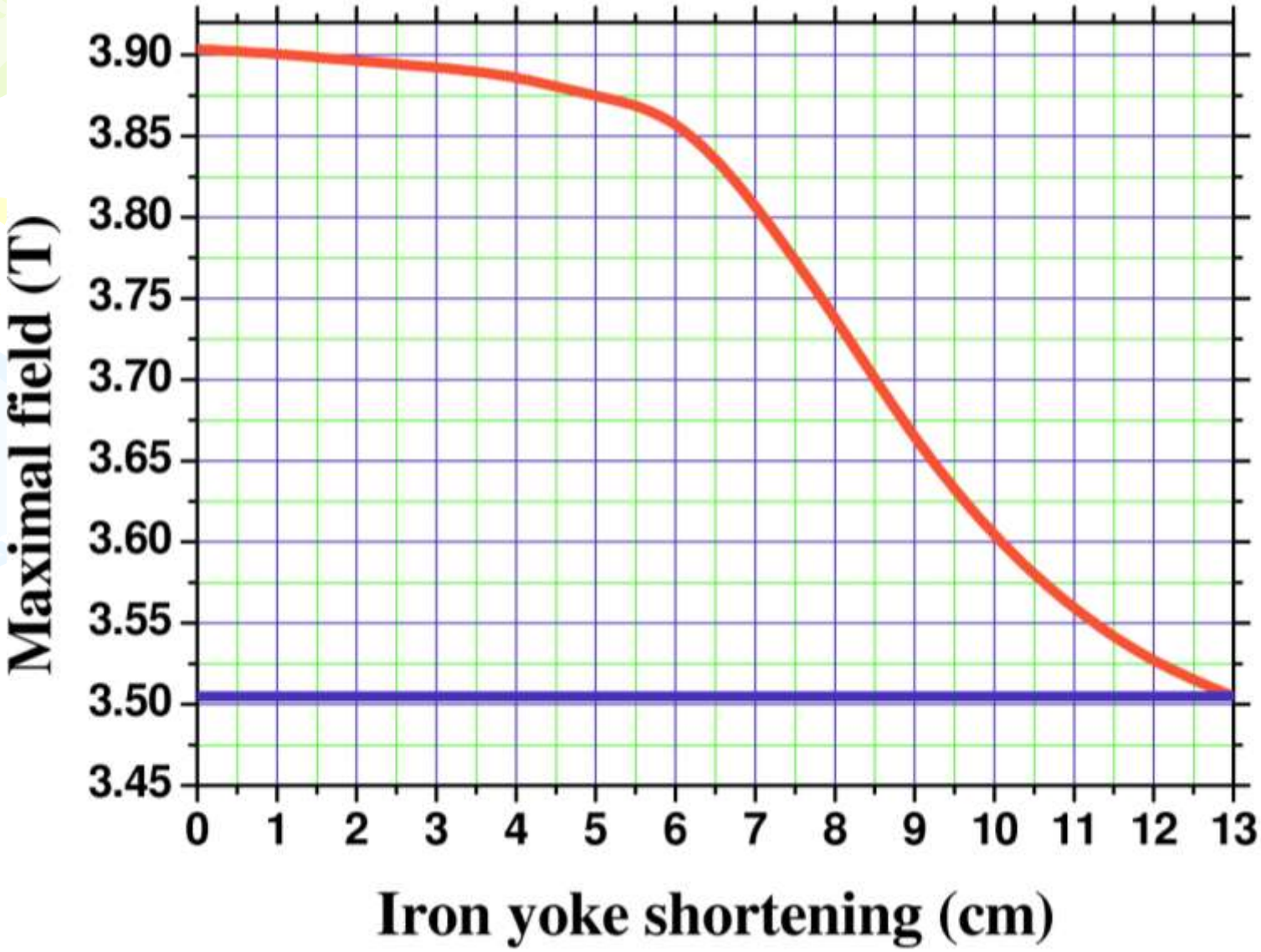
$\mu = \infty$

$L_{iron} = L_{coil}$

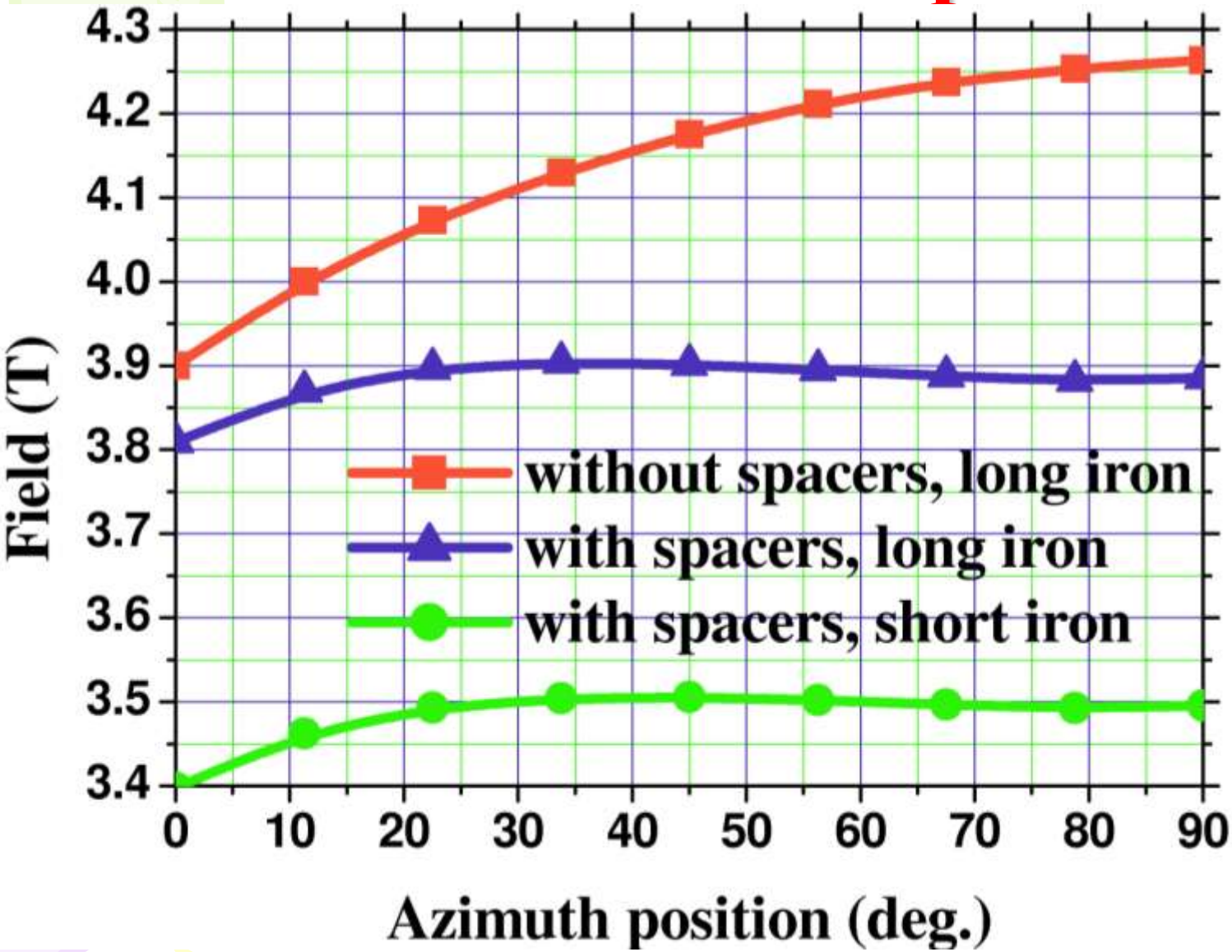
$L_{Geom} = 1000$ mm

$L_{eff} = 948.8$ mm

Iron shortening



Field in end parts



B_{max}, T

4.263

3.904

3.505

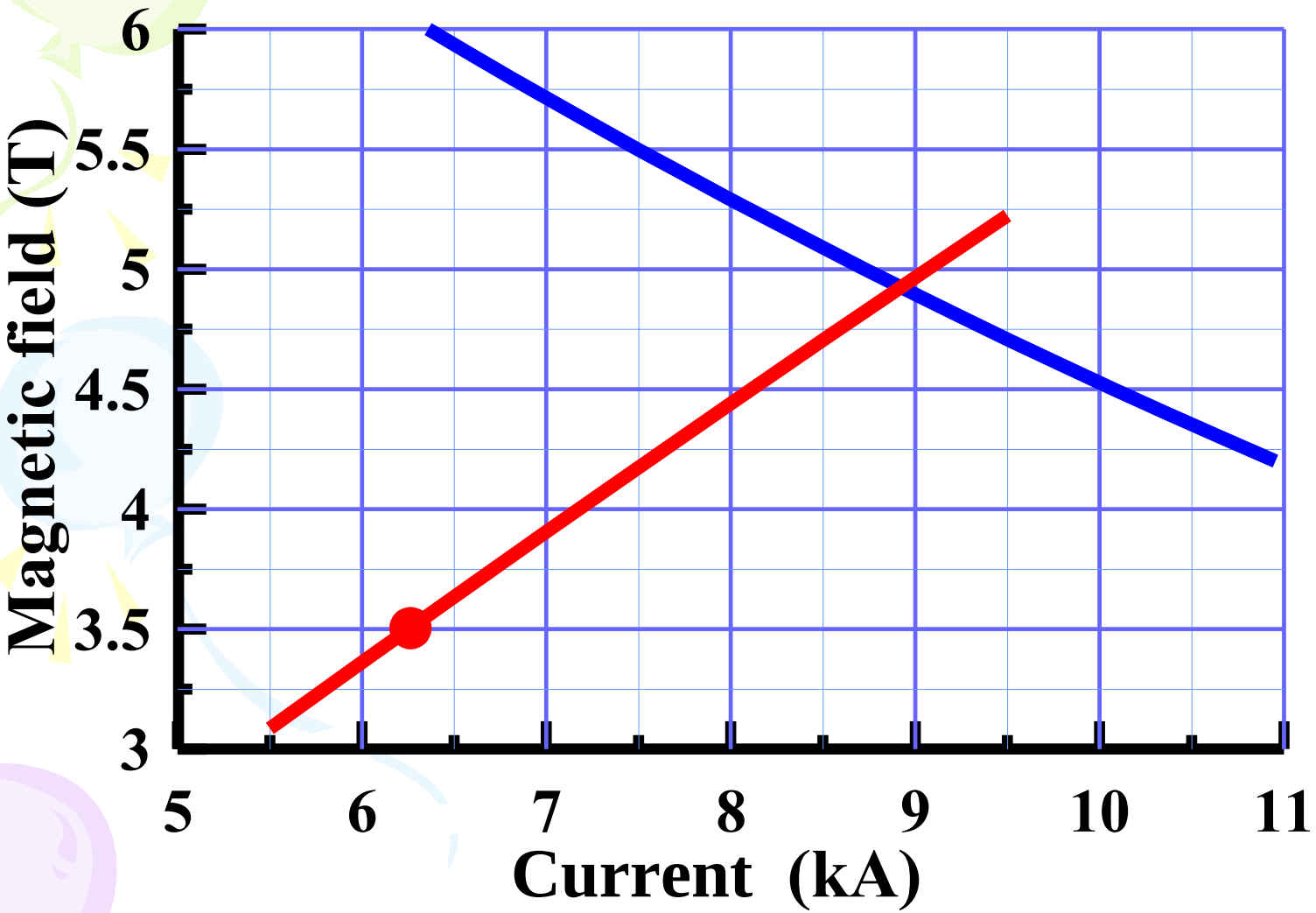
L_{eff}, mm

948.8

927.0

902.1

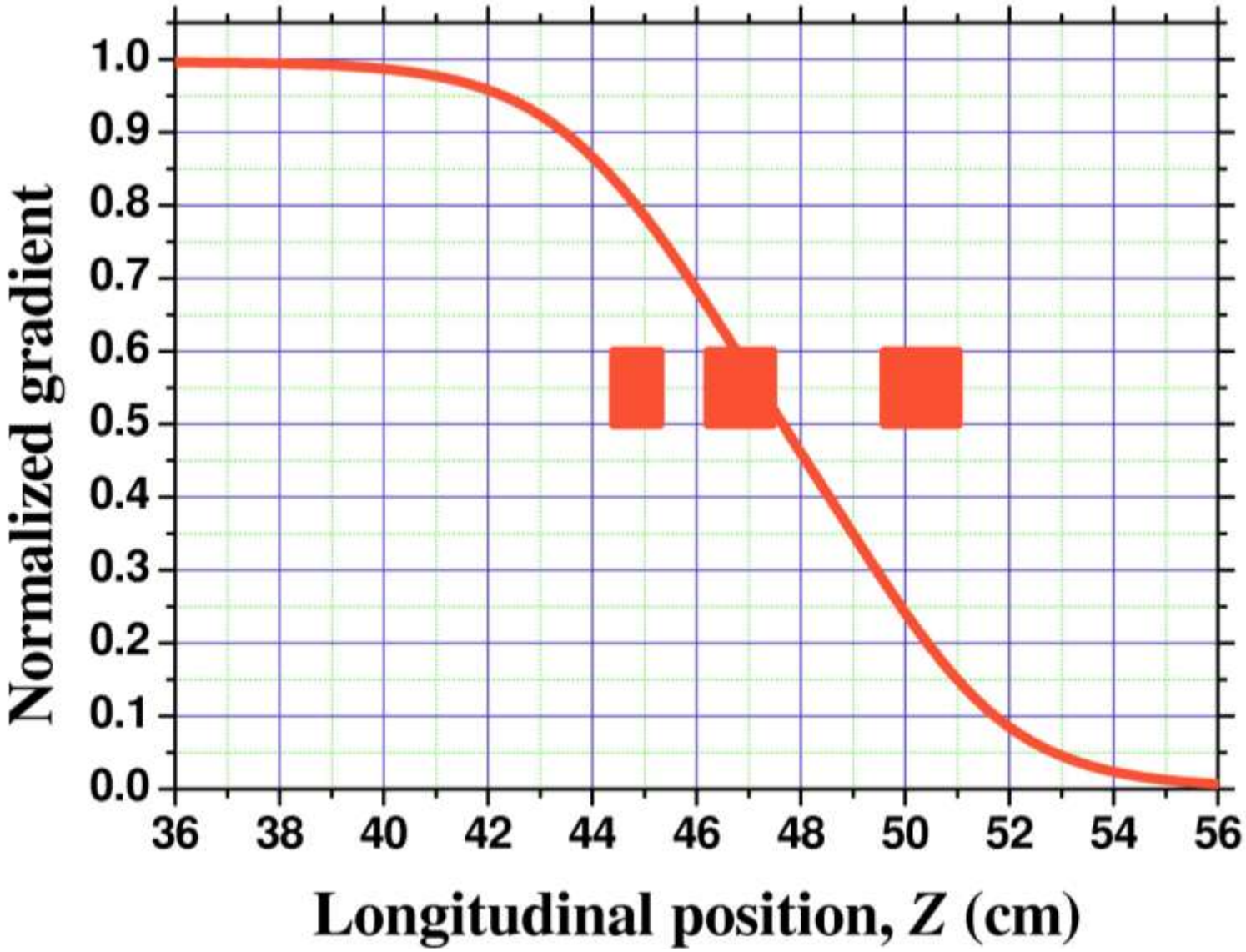
Load line



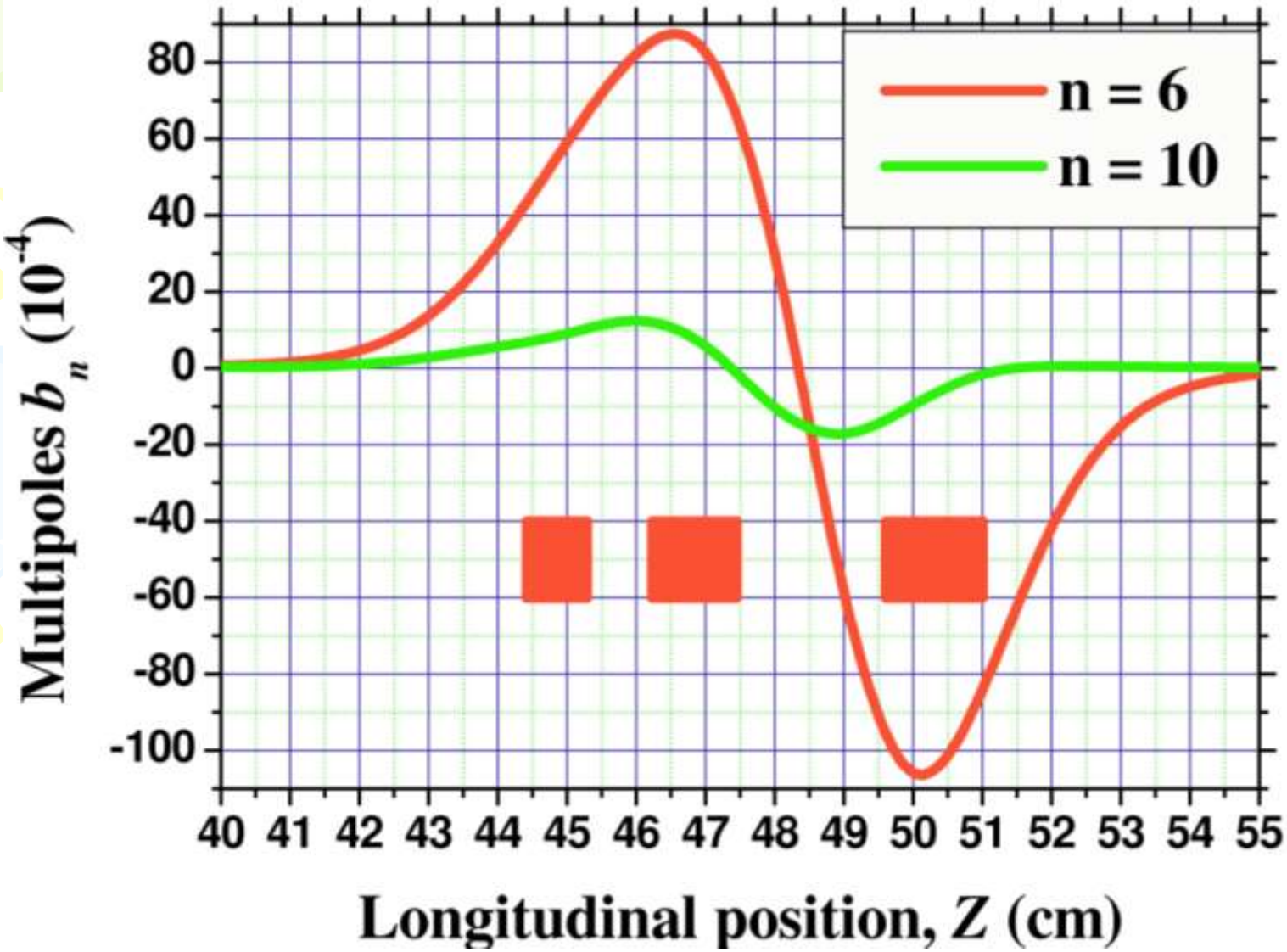
$\Delta I = 44\%$

$I/I_C = 0.7$

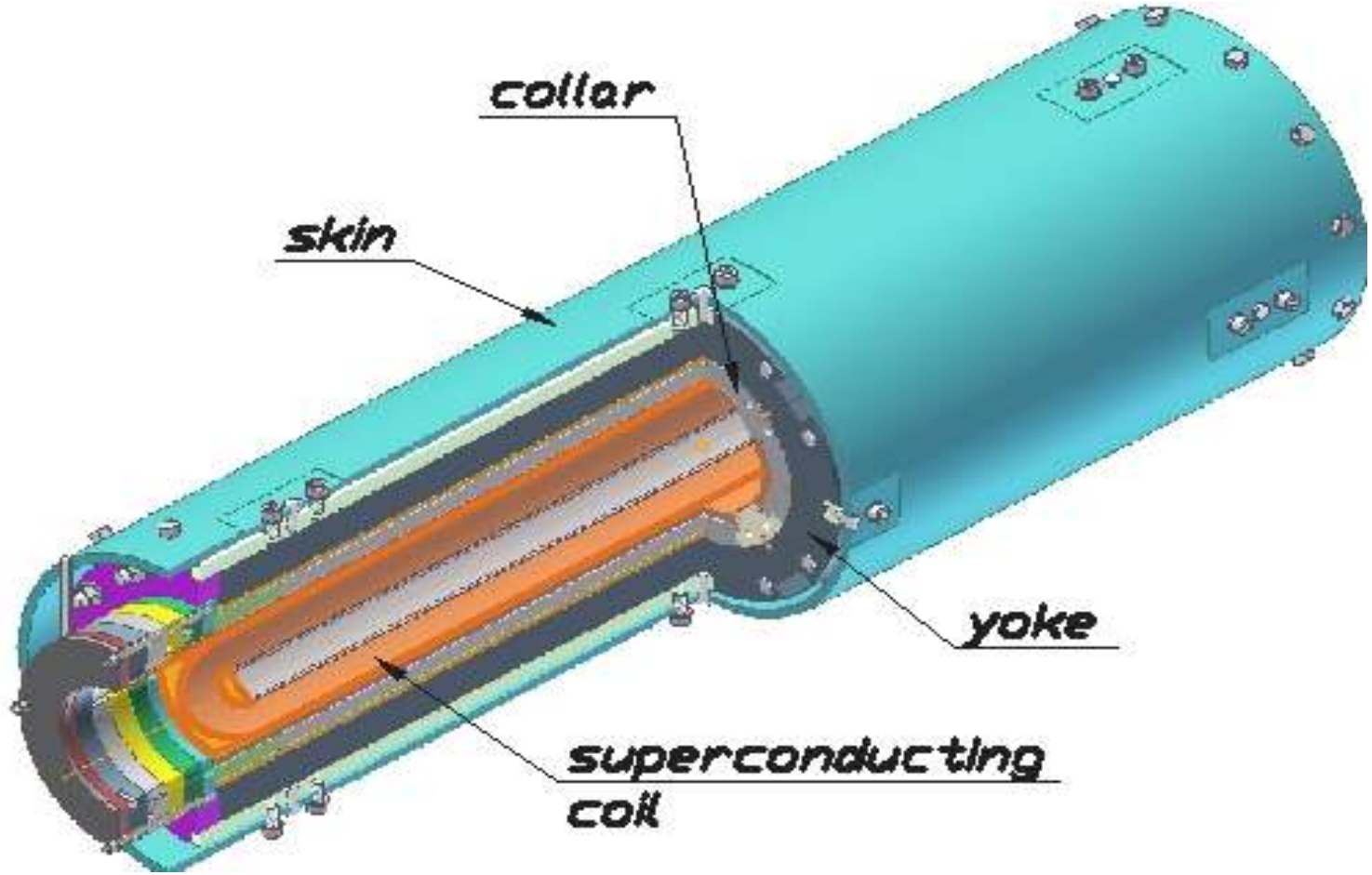
End field


Normalized gradient
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
36
38
40
42
44
46
48
50
52
54
56
Longitudinal position, Z (cm)

End multipoles



General view of quadrupole



Correctors: Main requirements

$$B_y + iB_x = B_0 \sum_{n=1}^{\infty} W_n(z) \left(\frac{r}{r_0} e^{i\varphi} \right)^{n-1}, W_n(z) = b_n + ia_n$$

	Strength	L_{eff}, m	t, s	N
Comp. Quadrupole MQ	1.8 T/m	0.65	2.25	12
Comp.Sextupole MS	60 T/m^2	0.65	2.18	12
Comp. Octupole MO	767 T/m^3	0.65	2.24	12
Chromat. Sextupole CS	130 T/m^2	0.78	0.208	24
Resonance Sextupole RS	325 T/m^2	1	0.5	12
Steering dipole h/v SD	0.5 T	0.65	2.27	78

Beam ID 105 mm; coil ID 125 mm;
"Good field" ID 80 mm

Superconducting wire

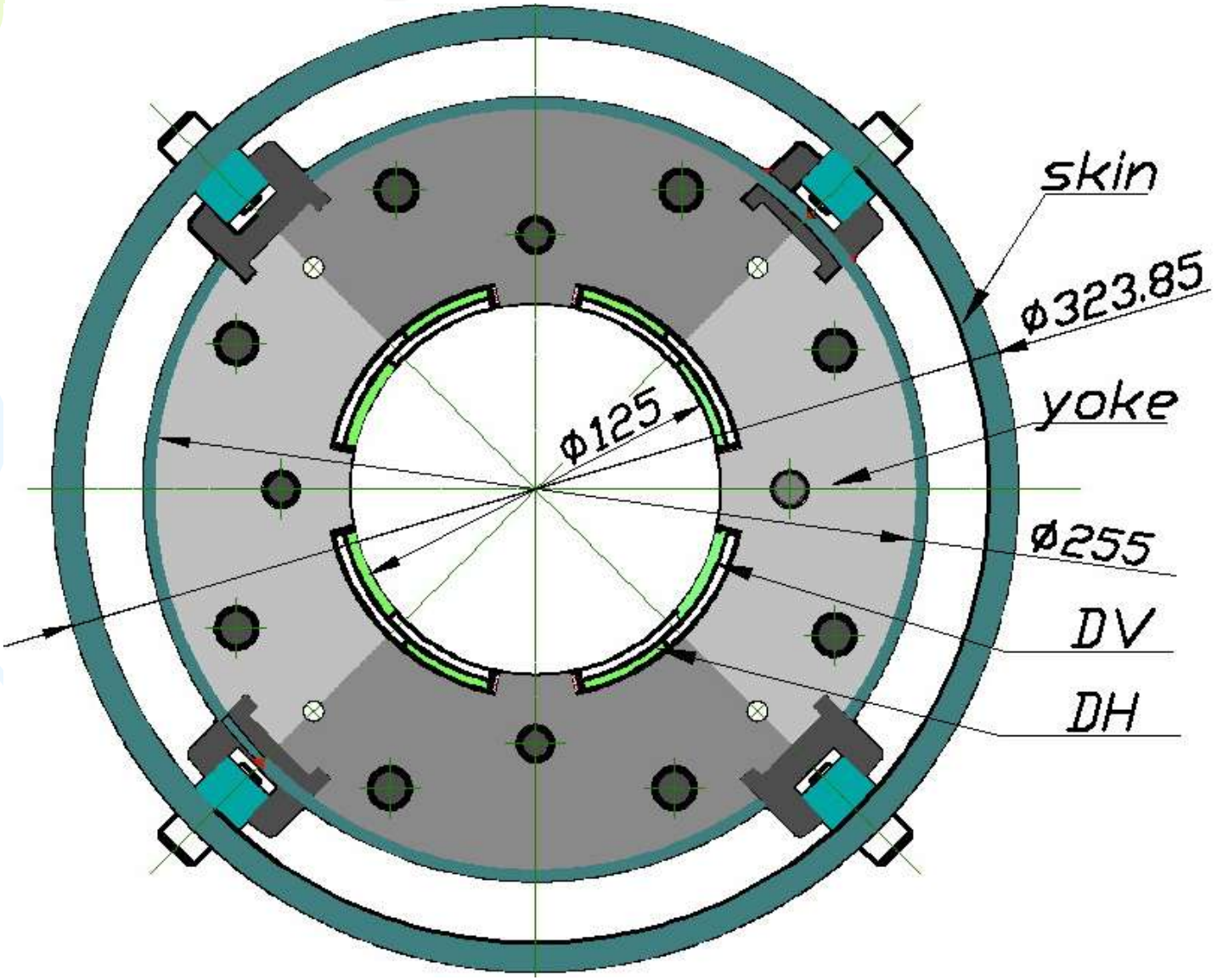
Superconductor	NbTi
Strand diameter, mm	0.3
Filament diameter, μm	3.5
Twist pitch, mm	<5
Cu/superconductor ratio	1.5
RRR	>70
Current density, kA/mm^2 (at 5 T, 4.2 K)	2.7
Coating	Oxide

$$I_C = 133.33 - 13.33\ B\ [A]$$

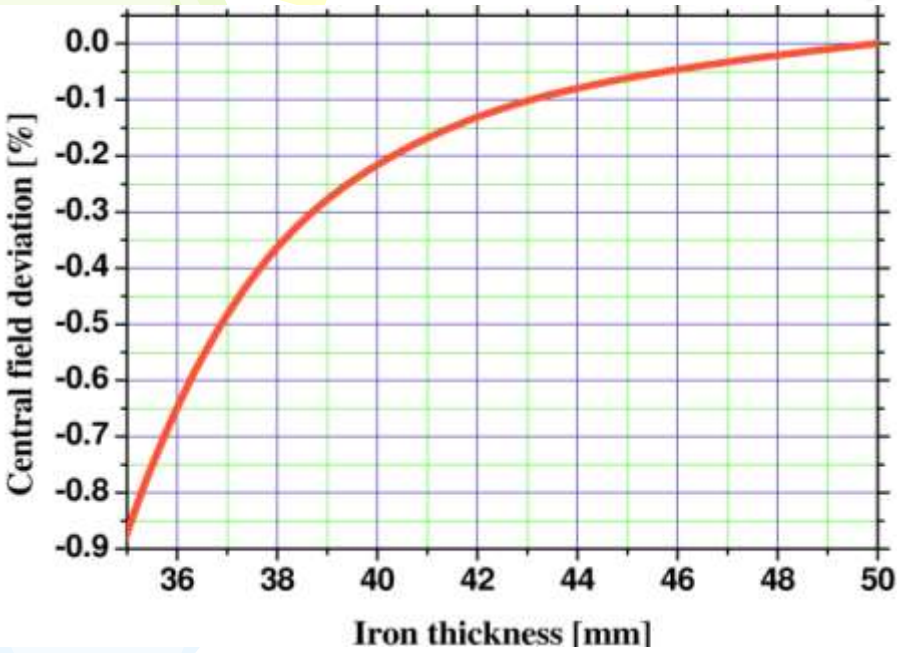
Cable

Strand number	8
Cross section	Rectangular
Transposition step, mm	11.9
Transverse dimension, mm^2	0.6×1.63
Polyimide insulation, μm	3×25
R_c, R_a, mΩ	2

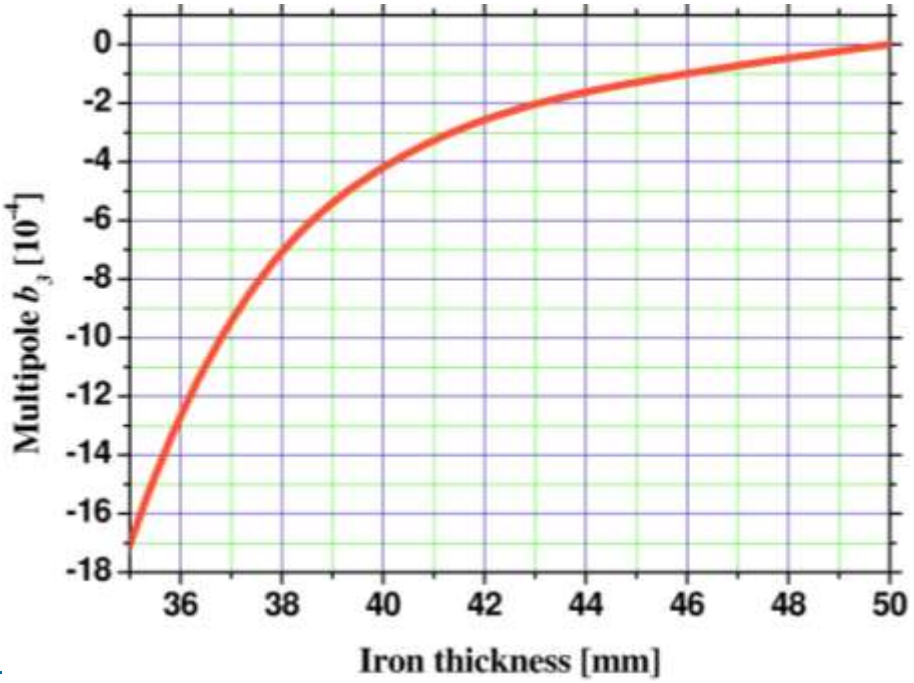
Dipole corrector



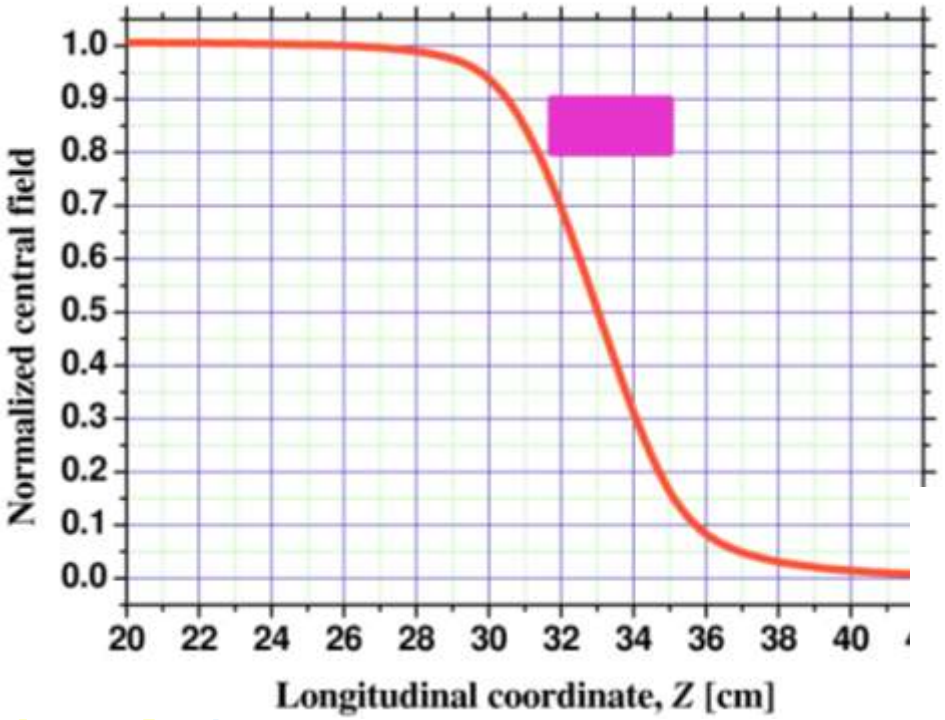
Iron thickness, dipole corrector

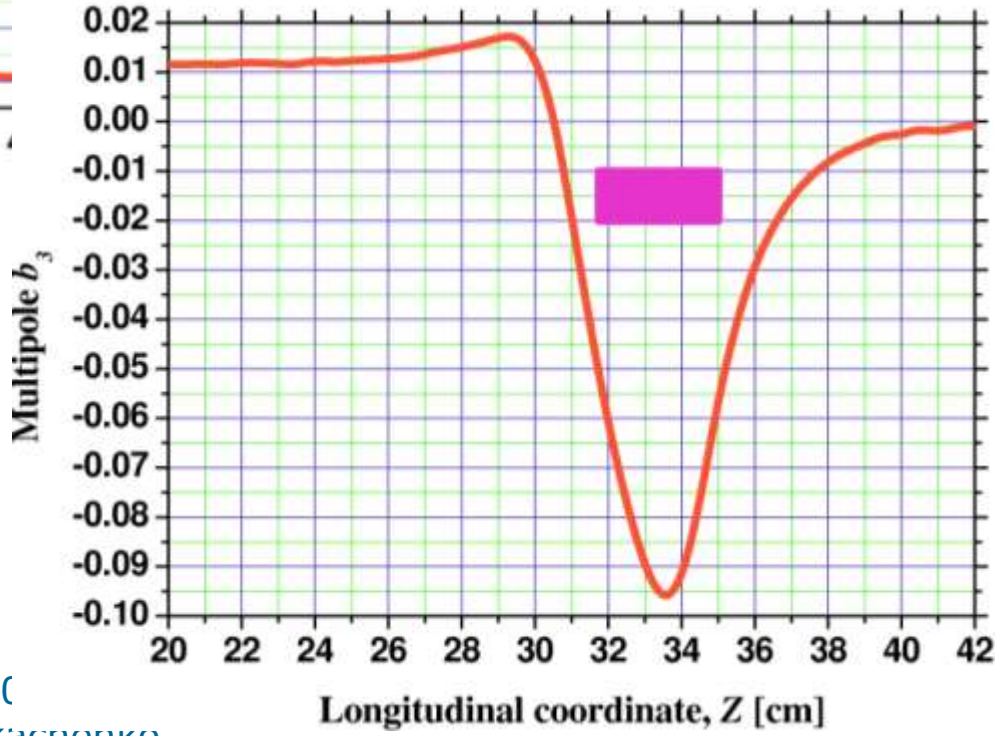


ΔR_{Fe} = 50 mm



Field quality, vert. dipole

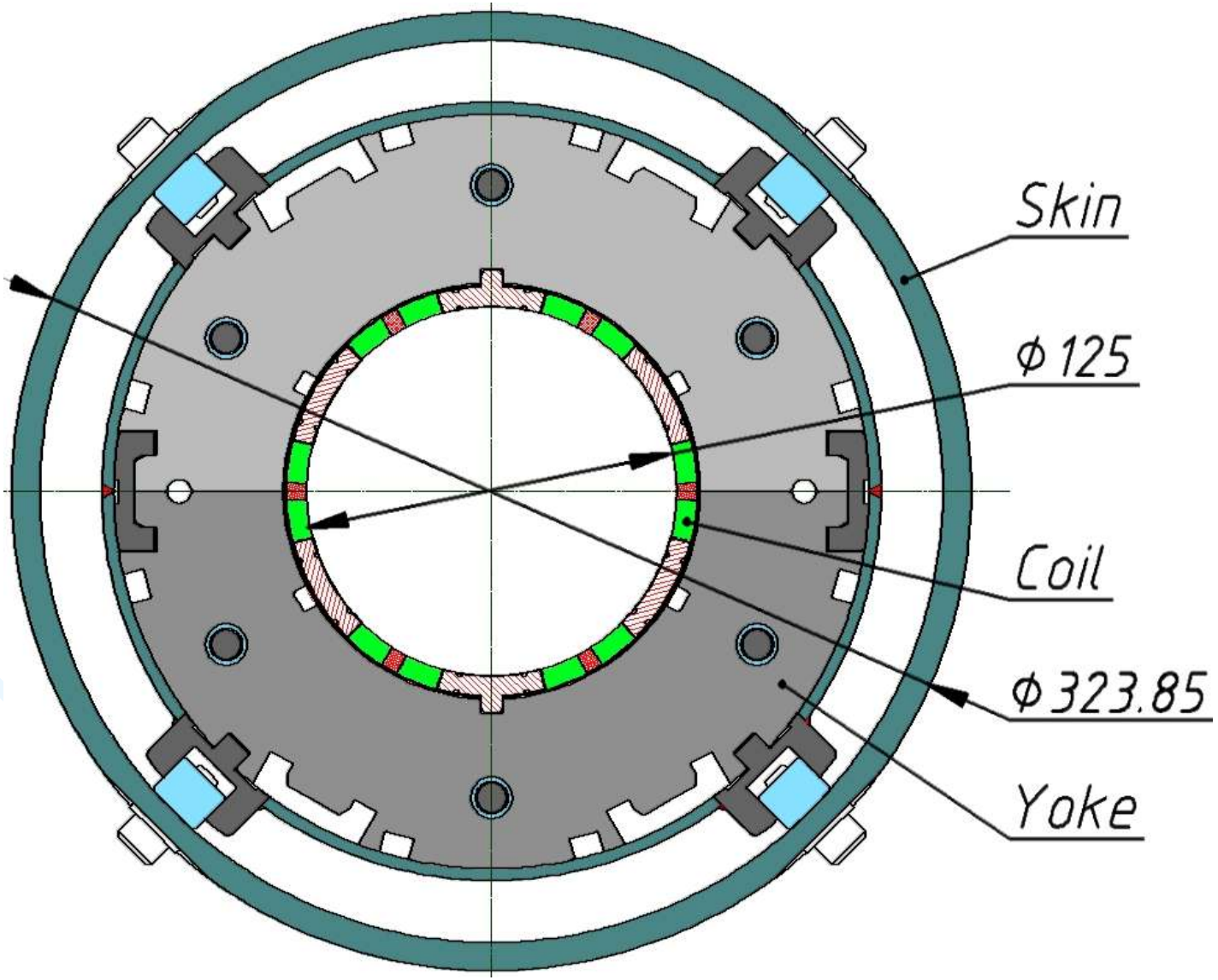




Dipoles

	V	H
φ	12.954	13.425
α	41.310	40.263
N_w	2×53	2×53
R_F, mm	71	71
I_{op}, A	230	231
L_{geom}, mm	700	700
S, mm	611.2	610.2
L_{ef0}, mm	650	650
L_{ef}, mm	666.8	668.3
B_{max}, T	1.15/1.42	1.24/1.42
E, J	1033	1126
L, mH	39.1	42.2
F_x, kN/m	9.2	0.3
F_y, kN/m	-0.8	11.0
$\|F\|$, kN/m	9.2	11.0

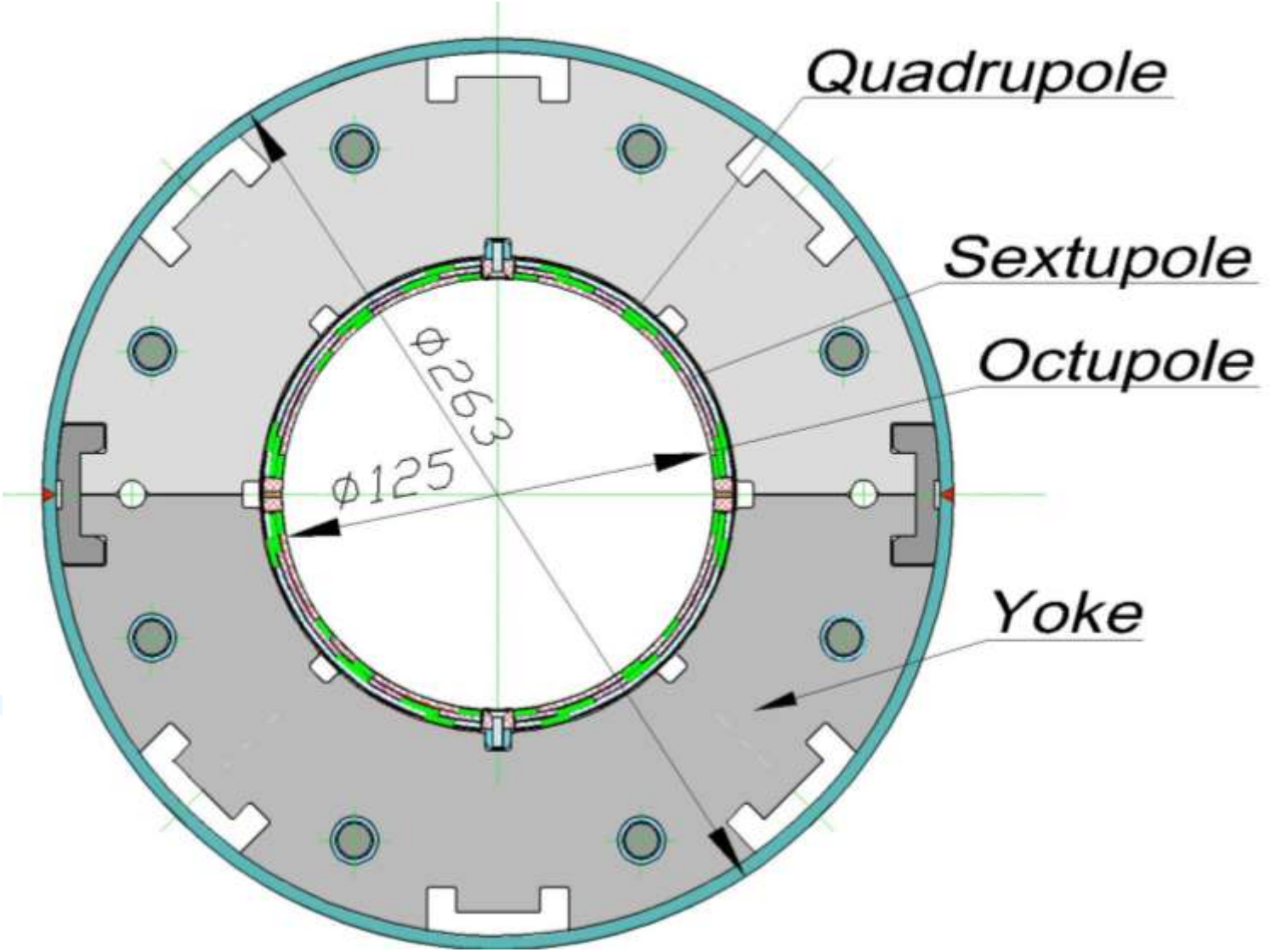
Sextupole correctors



Main parameters, sextupoles

	Chrom.	Res.	
φ	4.485	2.320	2.466
α	15.186	17.424	14.444
N_w	2×20	4×29	4×23
R_F, mm	67.365	71.0	71.0
I_{op}, A	234	235	236
L_{geom}, mm	800	1030	1040
S, mm	741.2	962.8	973.2
L_{ef0}, mm	780	1000	1000
L_{ef}, mm	780.4	1004.8	1008.6
B_{max}, T	0.82/0.89	1.65/1.49	1.69/1.53
E, J	582	4173	4358
L, mH	21.3	151.1	156.5
F_x, kN/m	2.8	18.0	17.6
F_y, kN/m	-1.5	-12.9	-13.4
$\|F\|$, kN/m	3.2	22.1	22.0

Multipole



Multipoles

	Oct	Sext	Quad
φ	4.424	4.808	10.916
α	10.396	14.826	18.089
R_{in}, mm	62.50	64.38	66.26
N_w	11	19	14
R_F, mm	70.52	70.52	70.52
I_{op}, A	232/236	234/239	228/235
L_{geom}, mm	800	725	650
S, mm	759.6	667.0	569.3
L_{ef}, mm	787.8	706.1	629.2
B_{max}, T	0.32	0.42	0.35
E, J	48.9	122.7	55.4
L, mH	1.82	4.49	2.13
F_x, kN/m	0.14	0.46	0.30
F_y, kN/m	-0.14	-0.33	-0.07
$\|F\|$, kN/m	0.19	0.57	0.31

The nearest plans:

- **Production of prototype of the quadrupole magnet – this year;**
- **Test of the quadrupole prototype – 2011 year;**
- **Production of prototype of the steering dipole magnet – 2011 year.**

Thank you for attention!