Status and plans of magnetic analysis for 2nd generation IR quadrupoles

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Outline

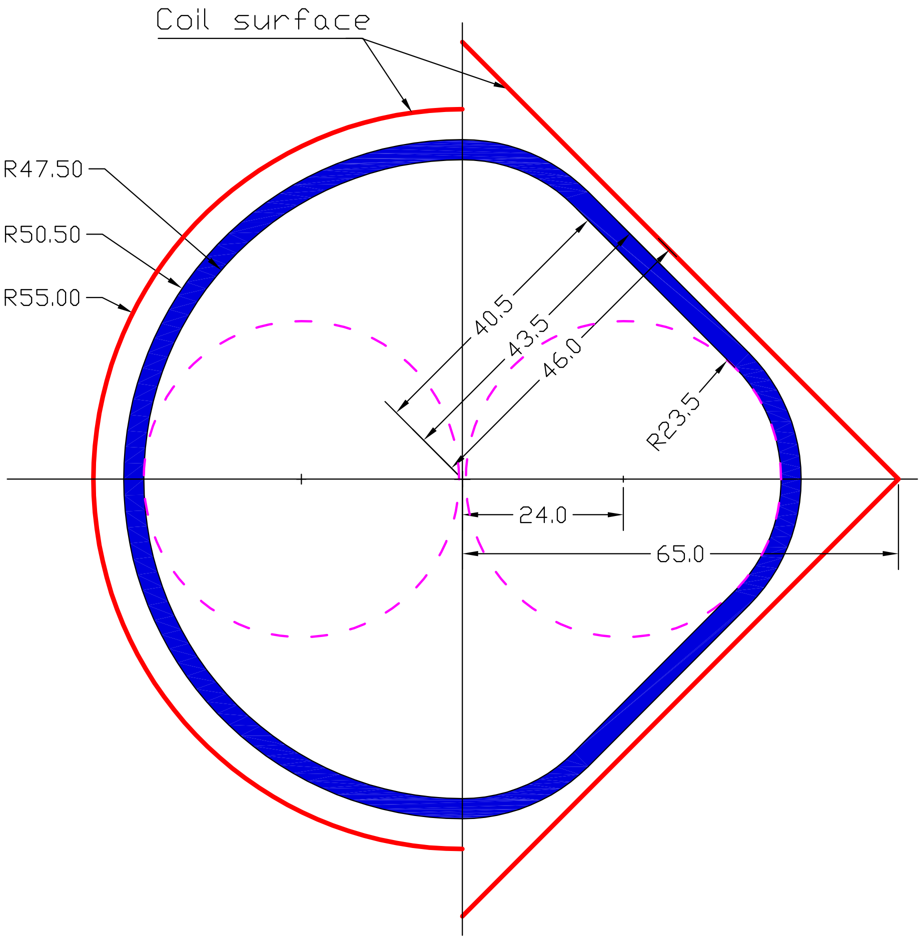
Comparison of the shell and racetrack based magnets:

- aperture issues;
- possible coil cross-sections;
- field quality;
- forces;
- conductor area;
- efficiency;

Next steps

Aperture issues

What is the equivalent aperture of racetrack quadrupole?



Equivalence criterion – the same space for beams as in 110-mm shell type magnet.

Constrains:

- **the same thickness of beam tubes;**
- **the same area of the cooling channels.**

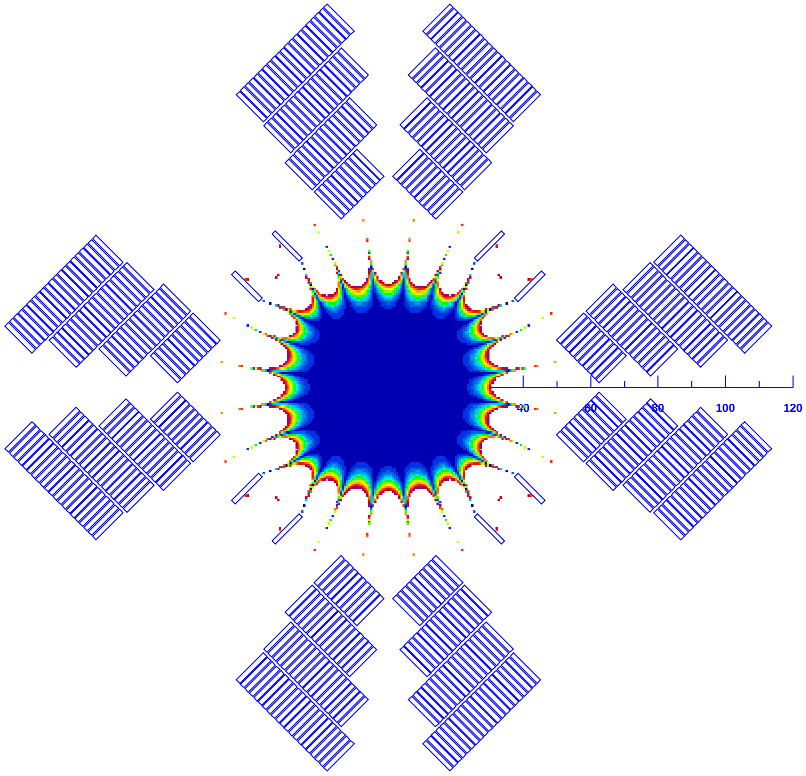
110-mm shell ≡ 92-mm racetrack (in the pole plane).

Optimization constrains

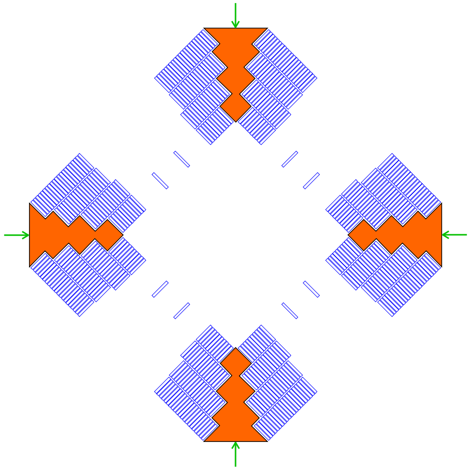
The racetrack quadrupole magnets were optimized with the following basic constrains, used also during the shell type magnet optimization:

- **$J_{non\text{-}Cu}$(12T,4.2K) = 3000 A/mm^2;**
- **Cu/nonCu = 1.3;**
- **Round iron yoke, μ = 1000;**
- **Coil-yoke space in the midplane = 15 mm;**
- **One spacer/octant for the field quality correction.**

90-mm racetrack quadrupole with midplane spacer



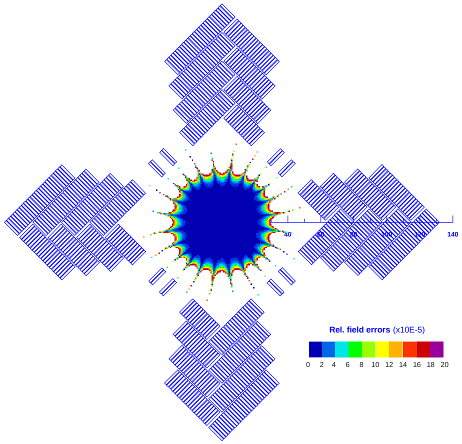
- G_{max} = 215 T/m (can be increased up to ~225 T/m by the coil width);
- Harmonics < 10^{-4} at 2/3 aperture;
- 2 types of coils (double-pancakes) are needed;
- Prestress – how to provide it in this configuration?



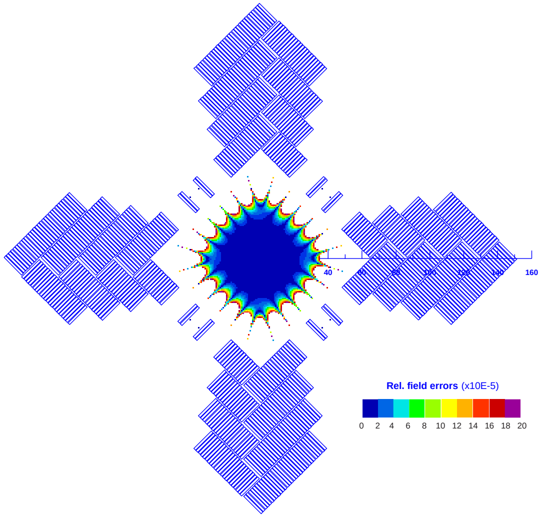
Coil designs

90-100 mm racetrack quadrupoles with interleaving coils

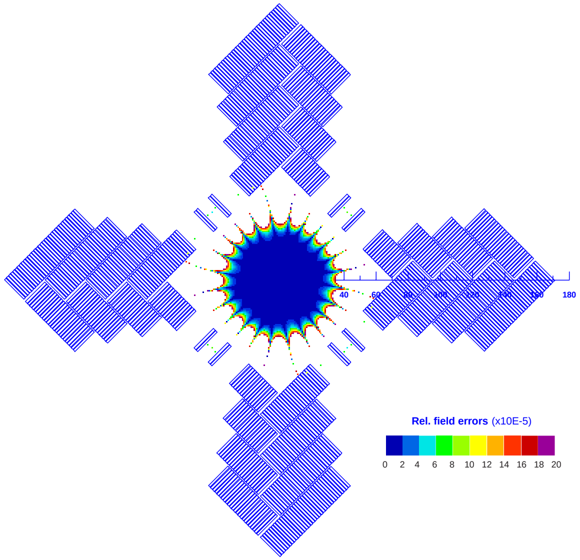
90-mm



92-mm



100-mm



Assume the mechanical challenges can be addressed. Then…

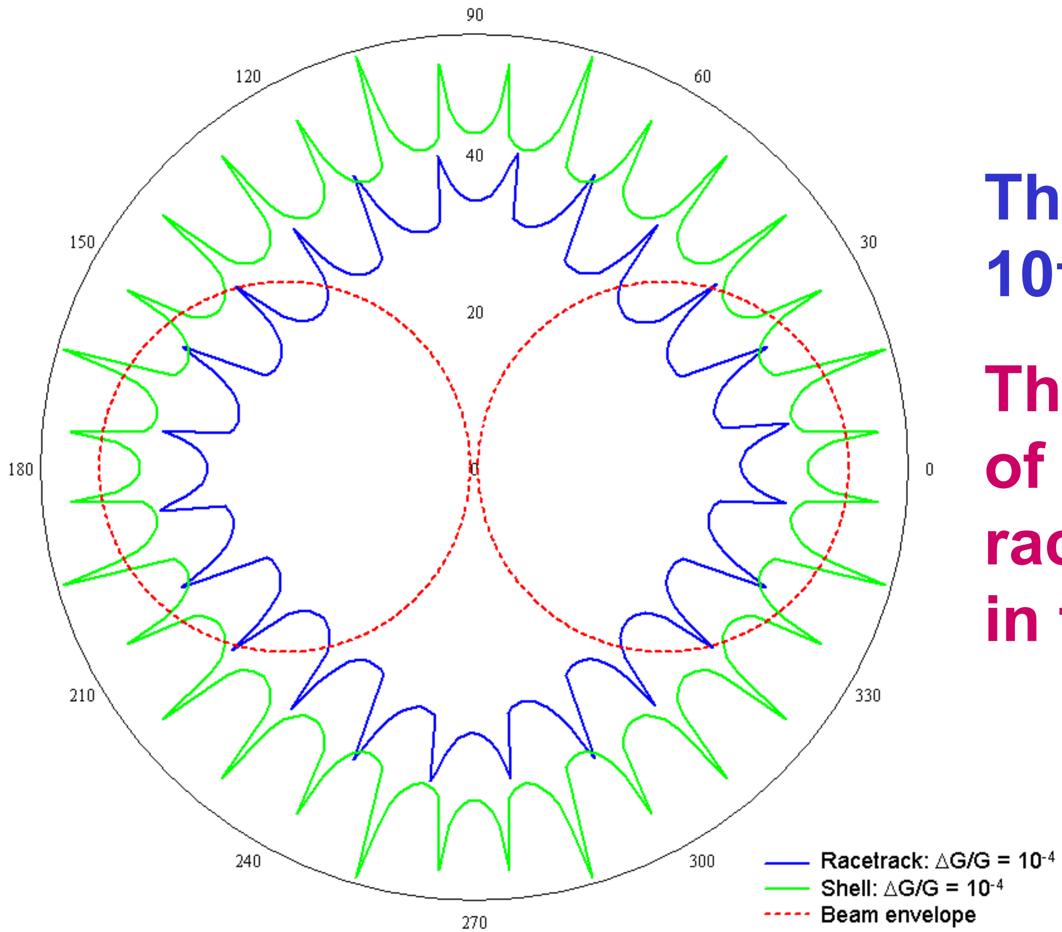
Field quality

Harmonics at half-bore radius

Harmonic	Racetrack			Shell		
	90 mm	**92 mm**	100 mm	90 mm	100 mm	**110 mm**
b_6	-0.0008	**0.0004**	-0.0001	0.0006	0.0005	**0.0002**
b_{10}	-0.0797	**0.1484**	0.0055	0.0045	0.0029	**0.0033**
b_{14}	-0.0529	**-0.0490**	-0.0447	0.0069	0.0046	**0.0118**
b_{18}	0.0025	**0.0016**	0.0017	-0.0047	-0.0036	**-0.0032**
a_4	0.0035	**-0.0041**	0.0039	-	-	-
a_8	0.0051	**0.0245**	0.0508	-	-	-
a_{12}	0.0040	**0.0015**	0.0027	-	-	-
a_{16}	0.0000	**0.0000**	0.0000	-	-	-

The limiting harmonic is b_{14}: a factor of 5 larger in the racetrack magnets.

Good field region in 92-mm racetrack and 110-mm shell type magnets

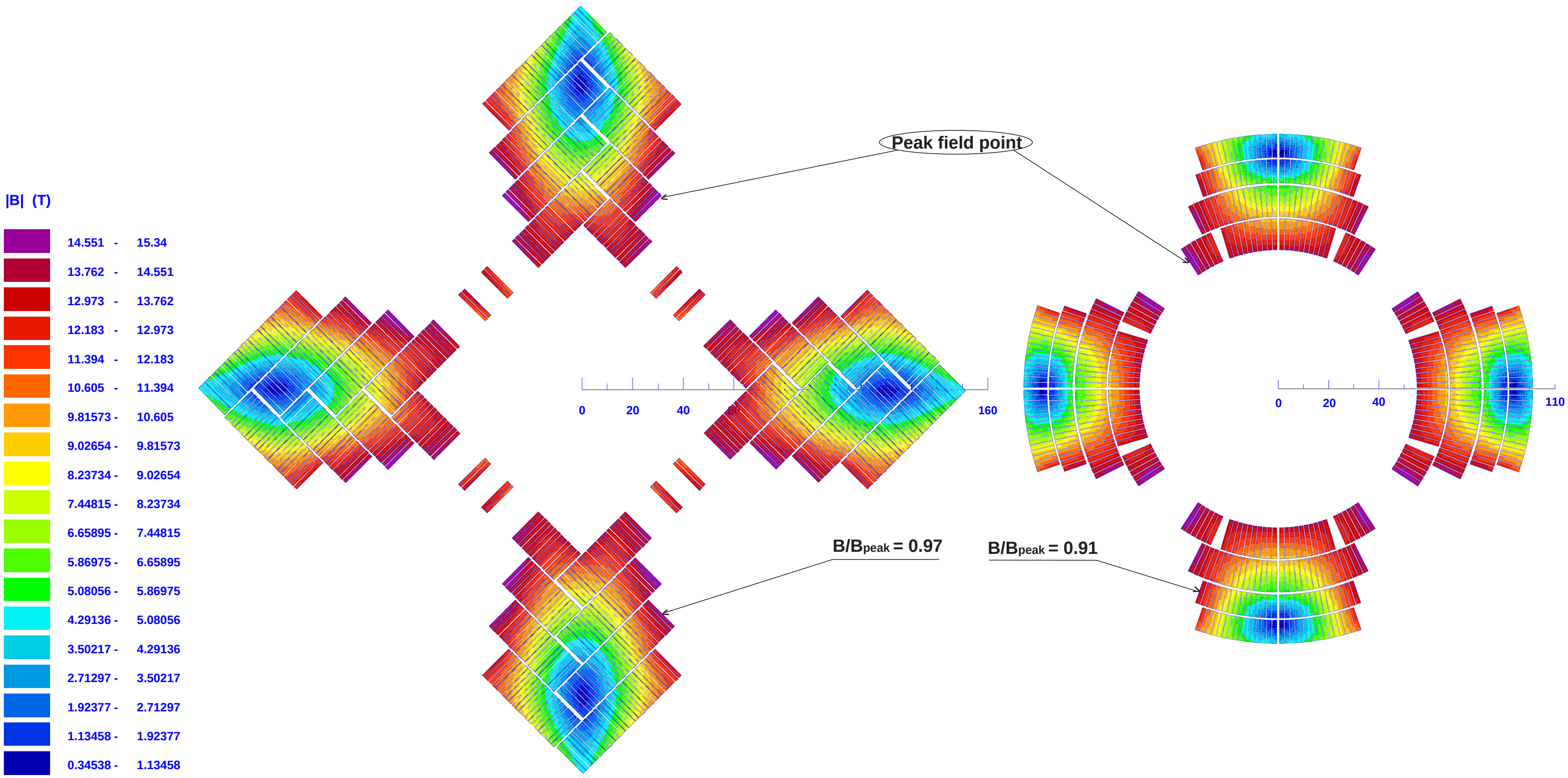


The plot shows contours of 10^{-4} field uniformity.

The good field region is 70% of the beam envelope in the racetrack magnet, and 90% in the shell type magnet.

Peak field

92-mm racetrack 110-mm shell



Cable grading in the racetrack magnet is ineffective.

Magnet parameters

Parameter		Unit	Racetrack			Shell		
			90mm	**92mm**	100mm	90mm	100mm	**110mm**
N of layers			4	**4**	4	2	4	**4**
N of turns			332	**368**	388	144	228	**248**
Coil area (Cu + nonCu)		**cm^2**	96.53	**133.08**	169.22	48.09	59.31	**84.88**
NonCu Jc at 12 T, 4.5 K		**A/mm^2**	3000	**3000**	3000	3000	3000	**3000**
Quench gradient		**T/m**	240.8	**240.4**	226.4	260.6	258.2	**248.9**
Quench current		**kA**	11.87	**13.70**	14.52	17.64	12.31	**14.13**
Peak field in the coil		**T**	14.9	**15.3**	15.7	13.5	14.5	**15.3**
Inductance		**mH/m**	30.86	**33.44**	39.94	4.86	14.71	**17.46**
Stored energy @ 205 T/m		**kJ/m**	1575.6	**2282.0**	3452.0	468.2	702.9	**1181.4**
Forces/octant at 205 T/m	Fx	**MN/m**	3.67	**4.42**	6.10	1.50	2.38	**3.44**
	Fy	**MN/m**	-3.78	**-4.83**	-3.18	-1.92	-2.39	**-3.42**

92-mm racetrack quadrupole has lower efficiency than 110-mm shell type magnet: coil area is larger by 57%, stored energy – by 93% and forces – by 41%.

Summary

- The equivalent of 110-mm round aperture is 92 mm in the pole plane.
- The design with open midplane does not provide necessary gradient even with 90 mm aperture. In order to receive 240-250 T/m, the aperture has to be reduced to ~80 mm.
- Racetrack quadrupole with 92-mm aperture is less effective than the shell type design with 110-mm aperture by all the major parameters.
- The design with interleaving coils has essentially larger gradient at the same bore size. For 240 T/m, it appears to be the aperture limit of ~95 mm in the pole plane. Mechanics of this design needs to be understood.
- The racetrack design is even less effective for 2-in-1 configuration.

Next steps

Analysis of 2-in-1 quadrupole magnet

Questions to address:

- aperture limit with LHC beam separation;
- field quality;
- "cold" vs. "warm" yoke design;
- symmetric vs. asymmetric coil.