News on FF quad CCT design

MDI meeting

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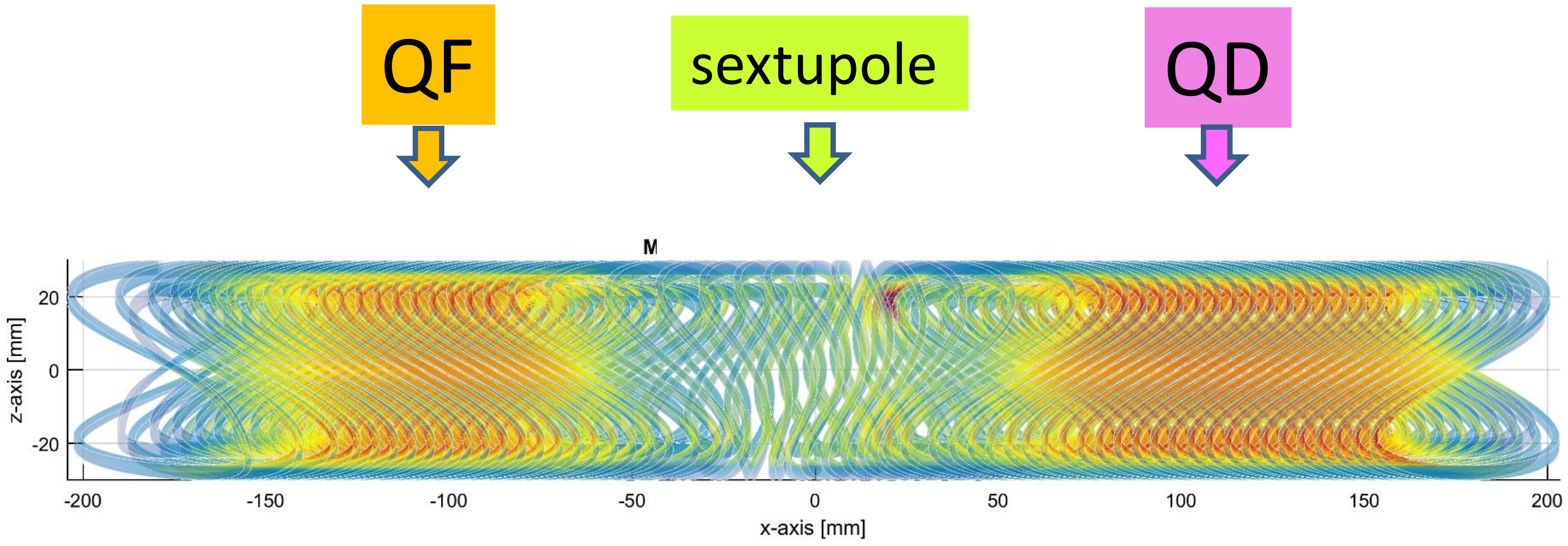
3/4/2017

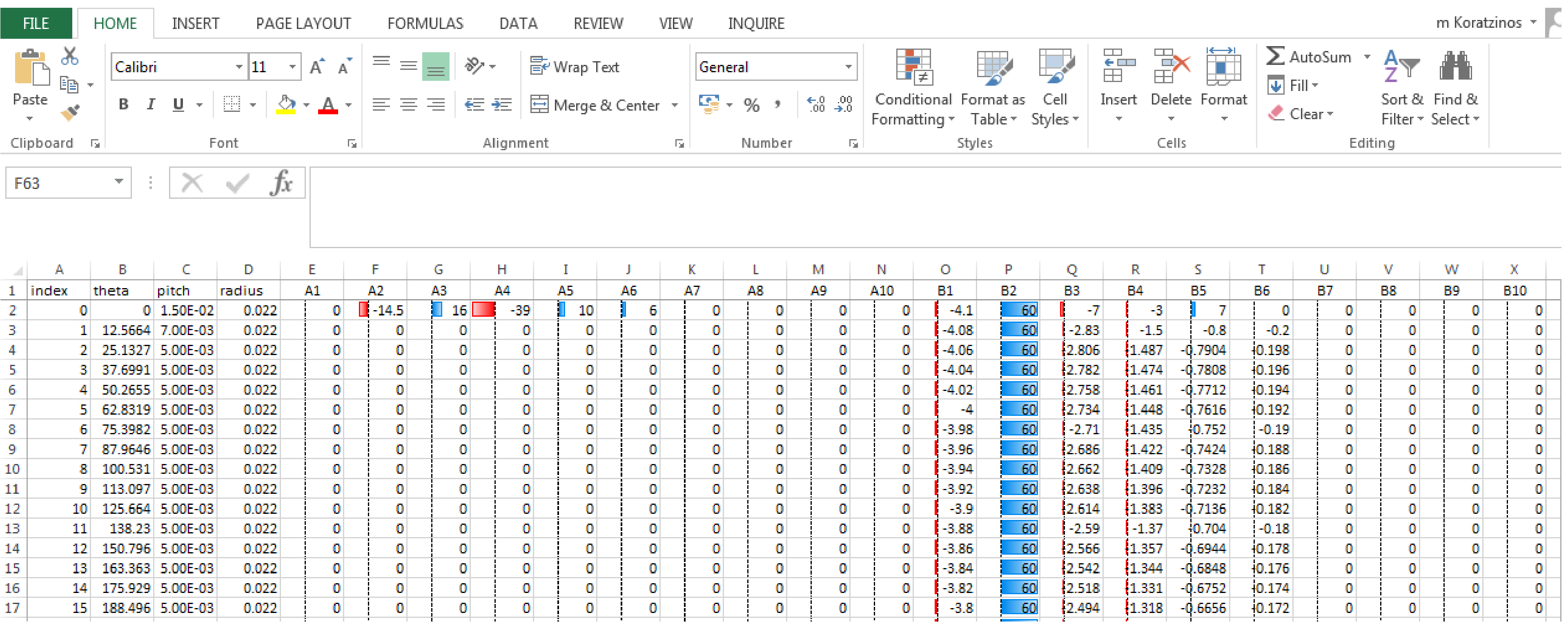
News

- The long-awaited customization possibility of CCT coils is now available, allowing limitless customization…
- (useless) example: QF/QD in one unit (with a bit of a sextupole in between)



Customized CCT

- One can define all multipole components for every turn of the cable via an excel file



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	index	theta	pitch	radius	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
2	0	0	1.50E-02	0.022	0	-14.5	16	-39	10	6	0	0	0	0	-4.1	60	-7	-3	7	0	0	0	0	0
3	1	12.5664	7.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-4.08	60	-2.83	-1.5	-0.8	-0.2	0	0	0	0
4	2	25.1327	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-4.06	60	-2.806	-1.487	-0.7904	-0.198	0	0	0	0
5	3	37.6991	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-4.04	60	-2.782	-1.474	-0.7808	-0.196	0	0	0	0
6	4	50.2655	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-4.02	60	-2.758	-1.461	-0.7712	-0.194	0	0	0	0
7	5	62.8319	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-4	60	-2.734	-1.448	-0.7616	-0.192	0	0	0	0
8	6	75.3982	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.98	60	-2.71	-1.435	-0.752	-0.19	0	0	0	0
9	7	87.9646	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.96	60	-2.686	-1.422	-0.7424	-0.188	0	0	0	0
10	8	100.531	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.94	60	-2.662	-1.409	-0.7328	-0.186	0	0	0	0
11	9	113.097	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.92	60	-2.638	-1.396	-0.7232	-0.184	0	0	0	0
12	10	125.664	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.9	60	-2.614	-1.383	-0.7136	-0.182	0	0	0	0
13	11	138.23	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.88	60	-2.59	-1.37	-0.704	-0.18	0	0	0	0
14	12	150.796	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.86	60	-2.566	-1.357	-0.6944	-0.178	0	0	0	0
15	13	163.363	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.84	60	-2.542	-1.344	-0.6848	-0.176	0	0	0	0
16	14	175.929	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.82	60	-2.518	-1.331	-0.6752	-0.174	0	0	0	0
17	15	188.496	5.00E-03	0.022	0	0	0	0	0	0	0	0	0	0	-3.8	60	-2.494	-1.318	-0.6656	-0.172	0	0	0	0

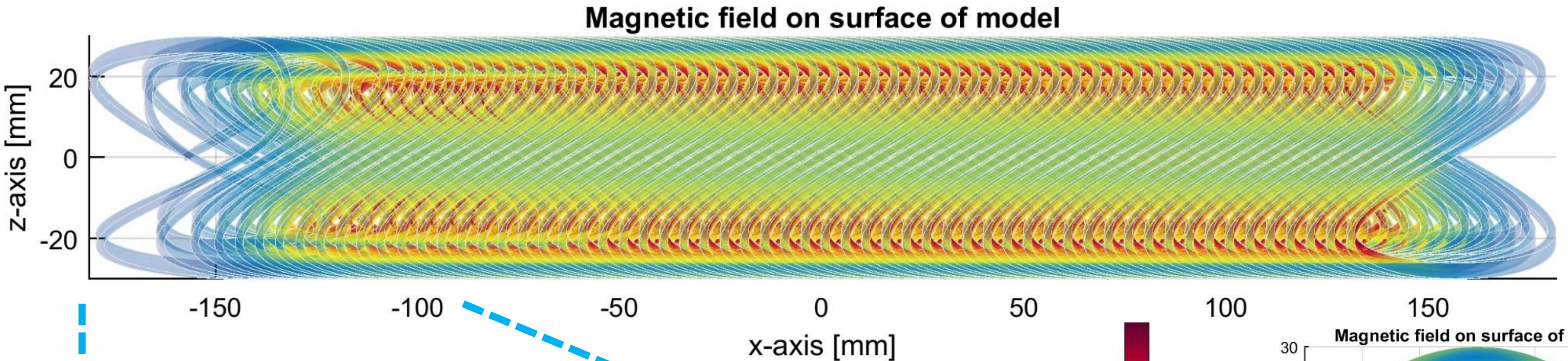
The problem (1)

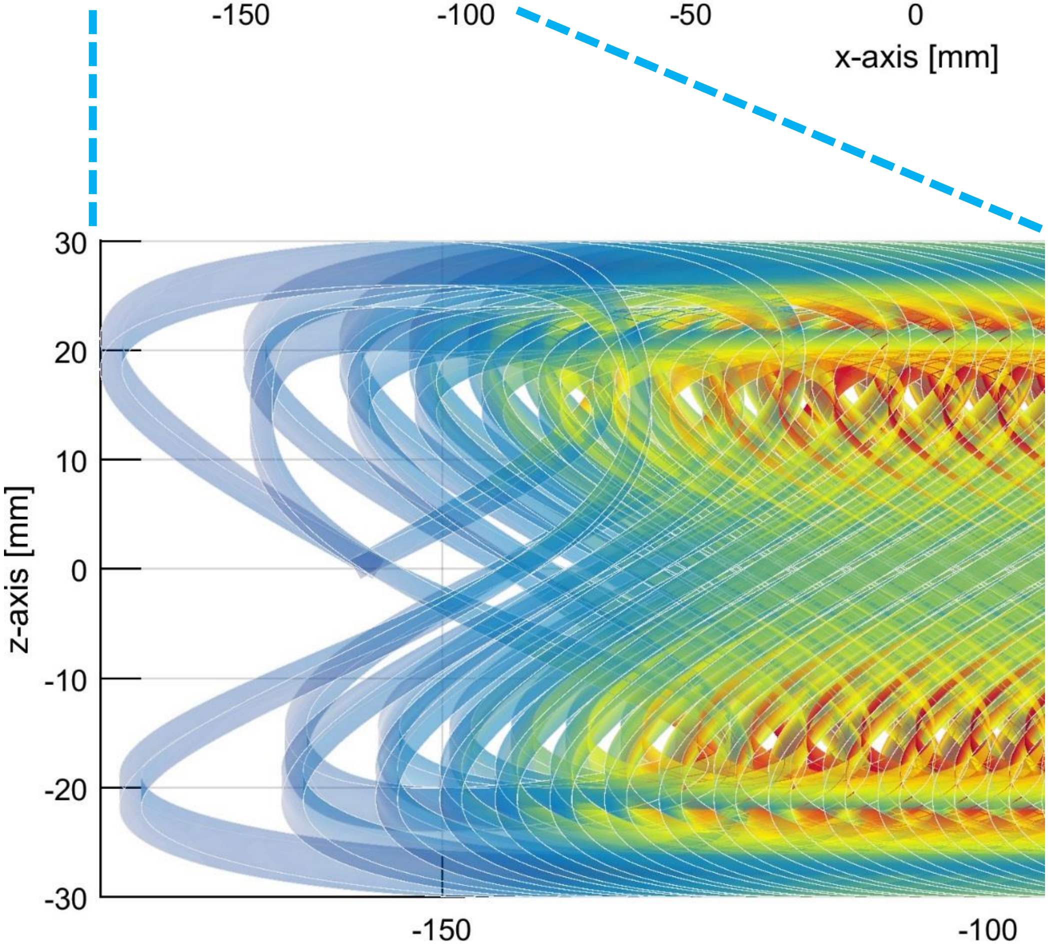
- The FF quads sit in an area of rapidly varying optics functions.
- This CCT design has excellent field quality when integrating over the whole length of the quadrupole. *This is not sufficient.*
- *Each side,* when treated separately, should have excellent field quality.
- The limit for multipoles has been loosely defined by Katsunobu to be less than 1 unit (10^{-4}). And the smaller the better.

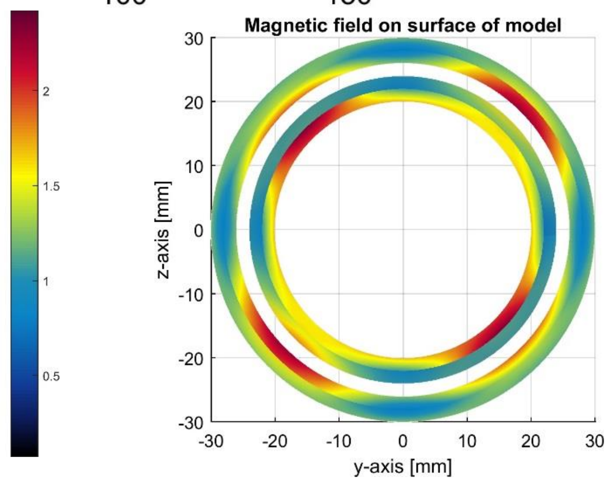
Solving this problem

- The new option in the design of the CCT quadrupole can introduce the appropriate multipole components only at the edge of the quadrupole.
- Minimization done empirically, but a reduction of the multipole components at the edge by an order of magnitude is possible.
- To demonstrate: standalone FF magnet (one aperture). Correcting only one side (l.h.s.) and comparing with the other side

The FF quadrupole





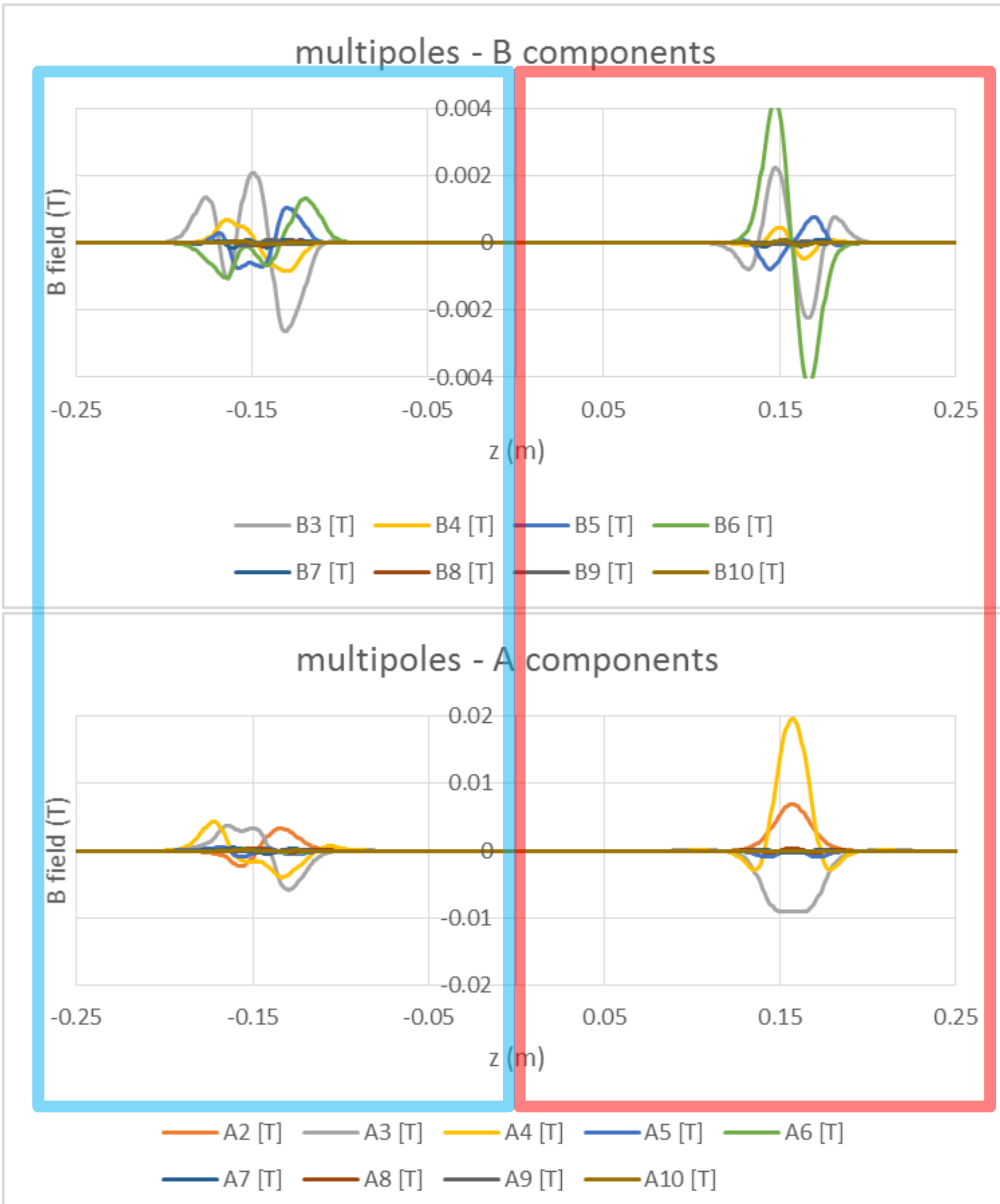


The first two turns of the quadrupole contain, apart from the B2 component, all the necessary components to nullify the edge effects.

Only one side corrected (for demonstration)

Inner bore: 40mm diameter; 100T/m B2 field

Multipoles – before and after



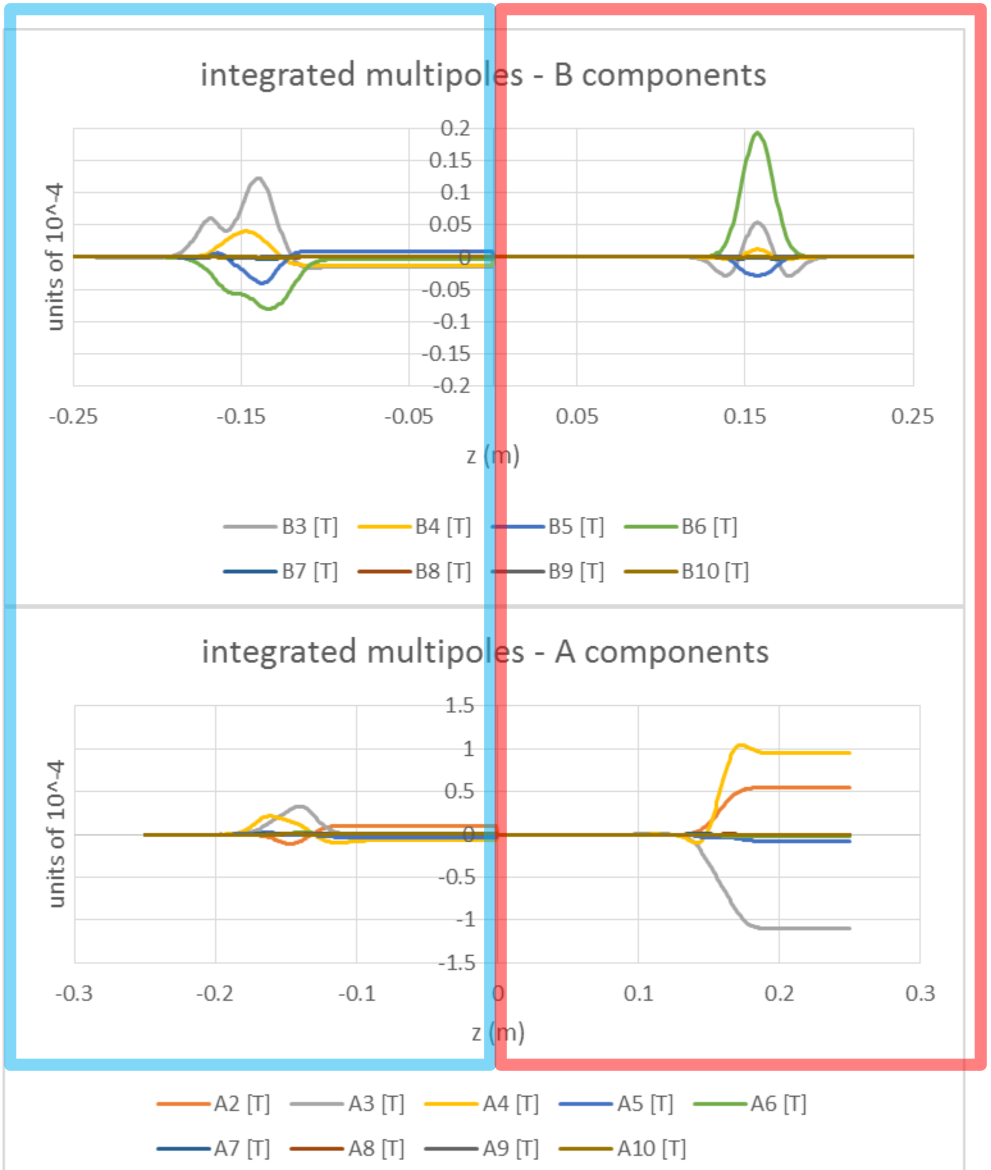
Multipoles at 2/3 aperture. (10mm radius)

Right: uncorrected edges. Note that in this configuration, the B components integrate to zero per side, but the A components integrate to zero only over the whole length of the magnet.

The B1, B2 and A1 components have been removed for clarity.

Left: the corrected side (see also next slides)

Integrated multipoles



Now normalised to the B2 component over the whole length of the quadrupole: we are at a radius of 10mm, so integrated B component is 3.2Tm (100T/m gradient, 3.2m long)

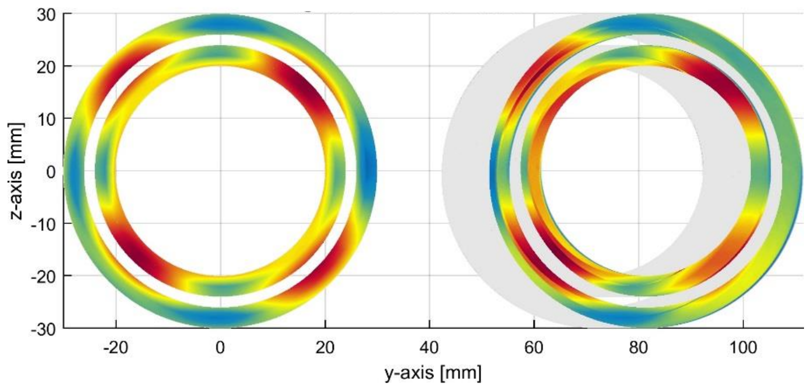
After correction: less than 0.1 unit. Before correction: A components as big as 1.1 units

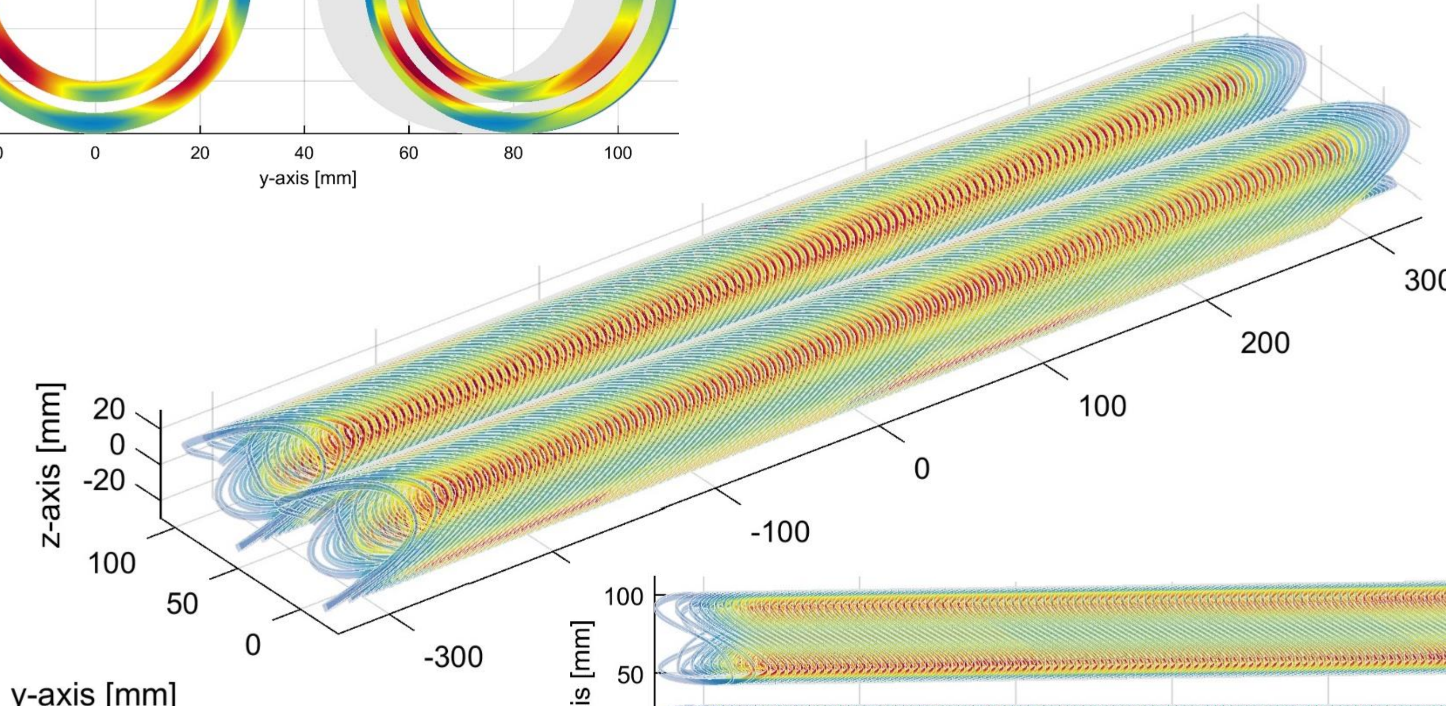
Single magnet edge correction

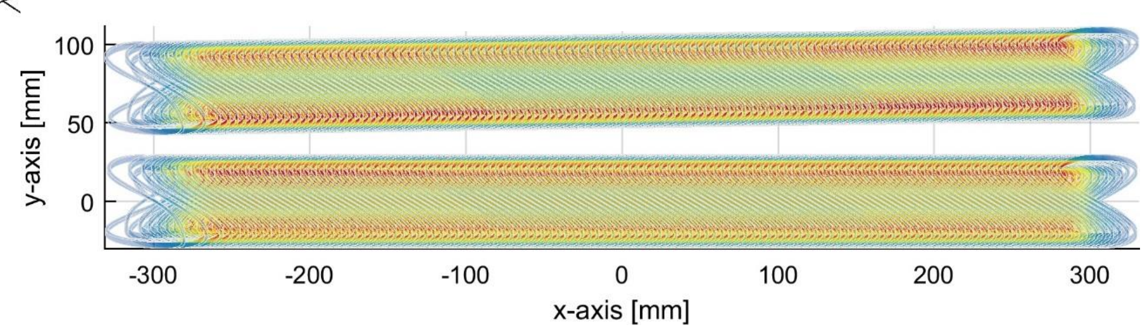
- “proof of principle” works beautifully; not clear where the limits of this method are. Multipoles can be kept to below 0.1 units (and can be reduced to an arbitrarily small number).
- Correcting one component does not spoil other components; the process converges rather fast.
- Multipole components added only to the first two turns of the cable
- Next step: correct also crosstalk between adjacent apertures

The problem (2): crosstalk compensation

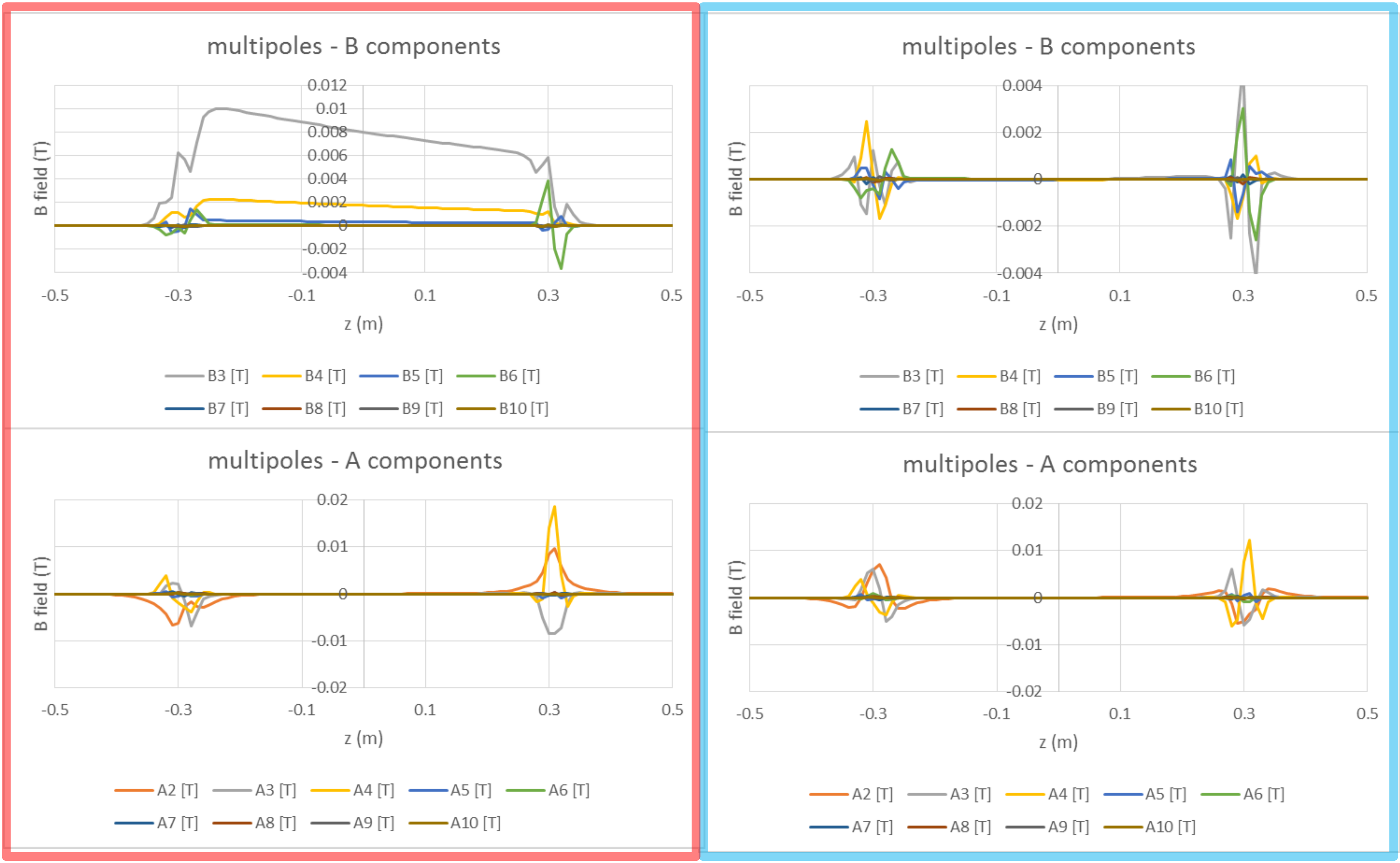
This the part of the FF quadrupole closest to the IP, length = 720mm distance at tip: 66mm, angle 30mrad







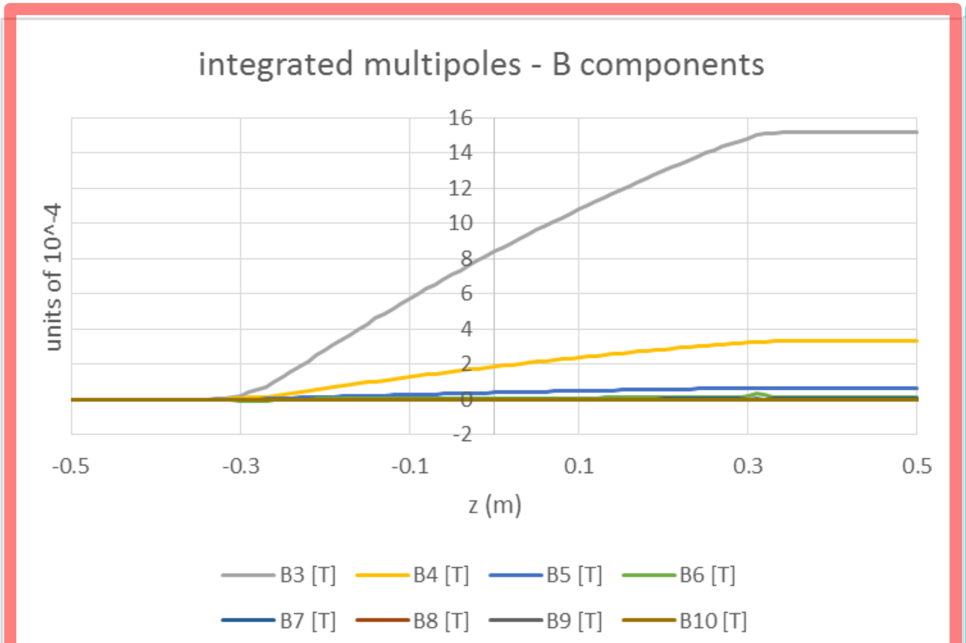
Multipoles – before and after

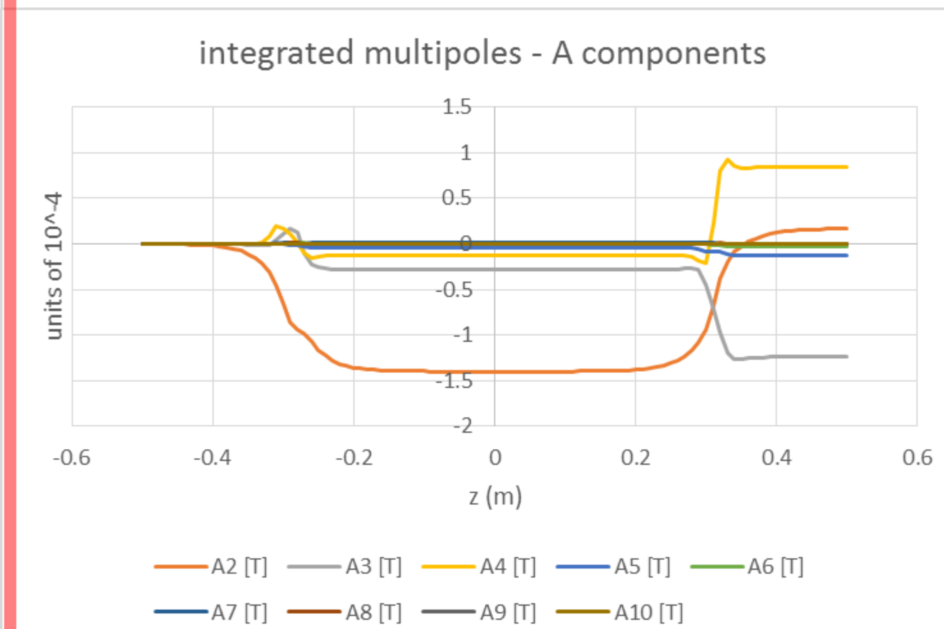


Before /after picture: not different scales

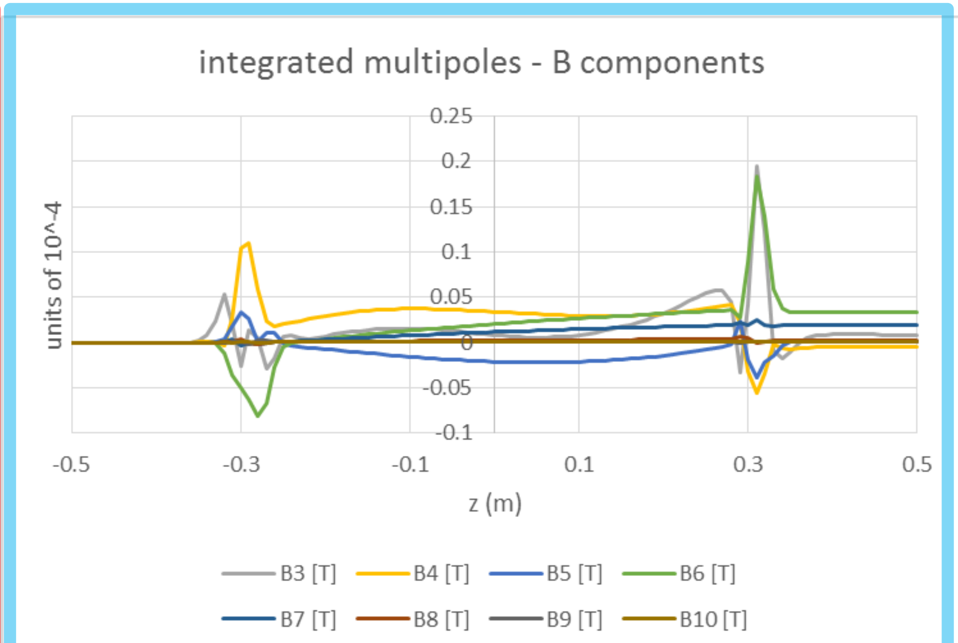
Integrated multipoles

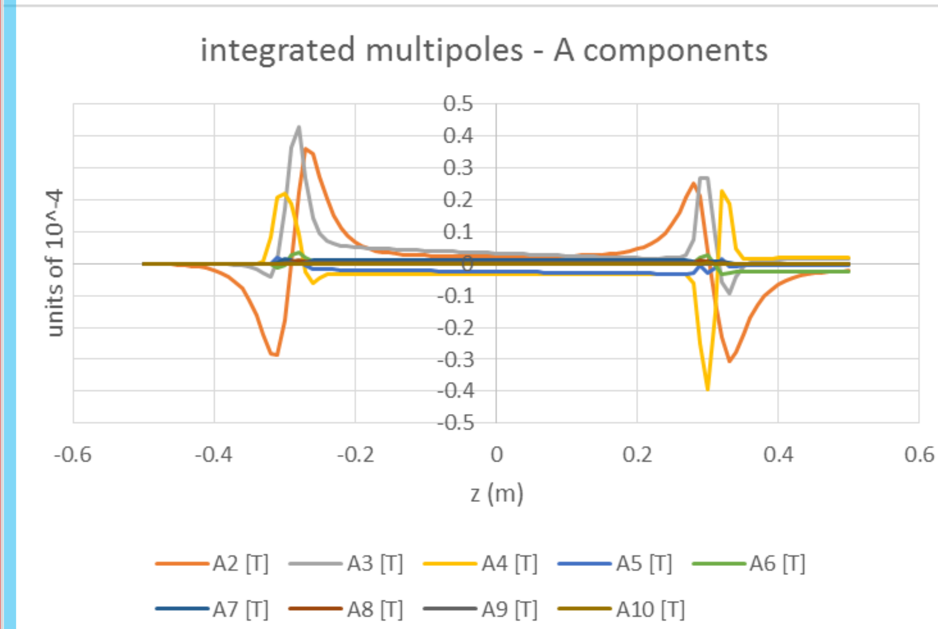
before





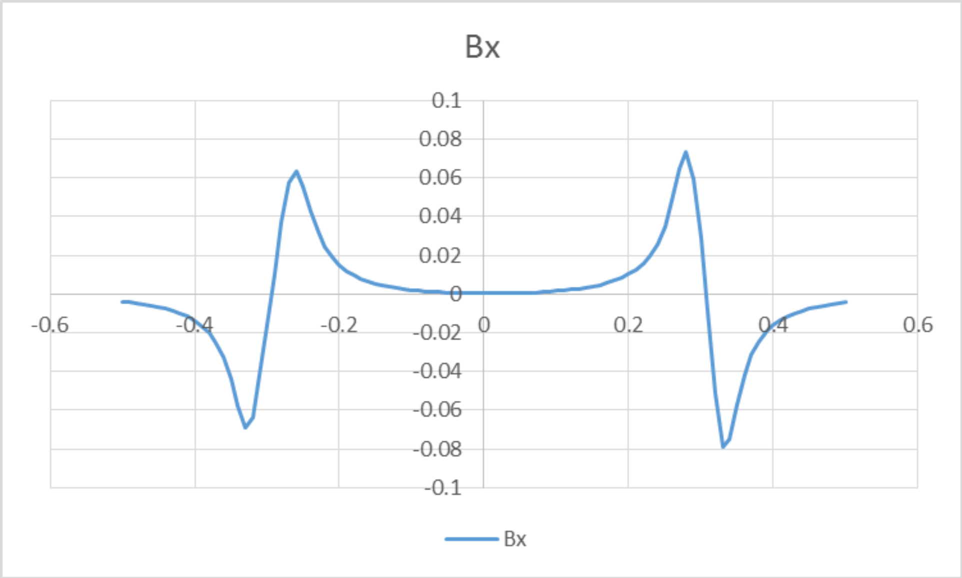
after





Longitudinal field

- Multipole analysis does not deal with longitudinal fields – what is their magnitude?



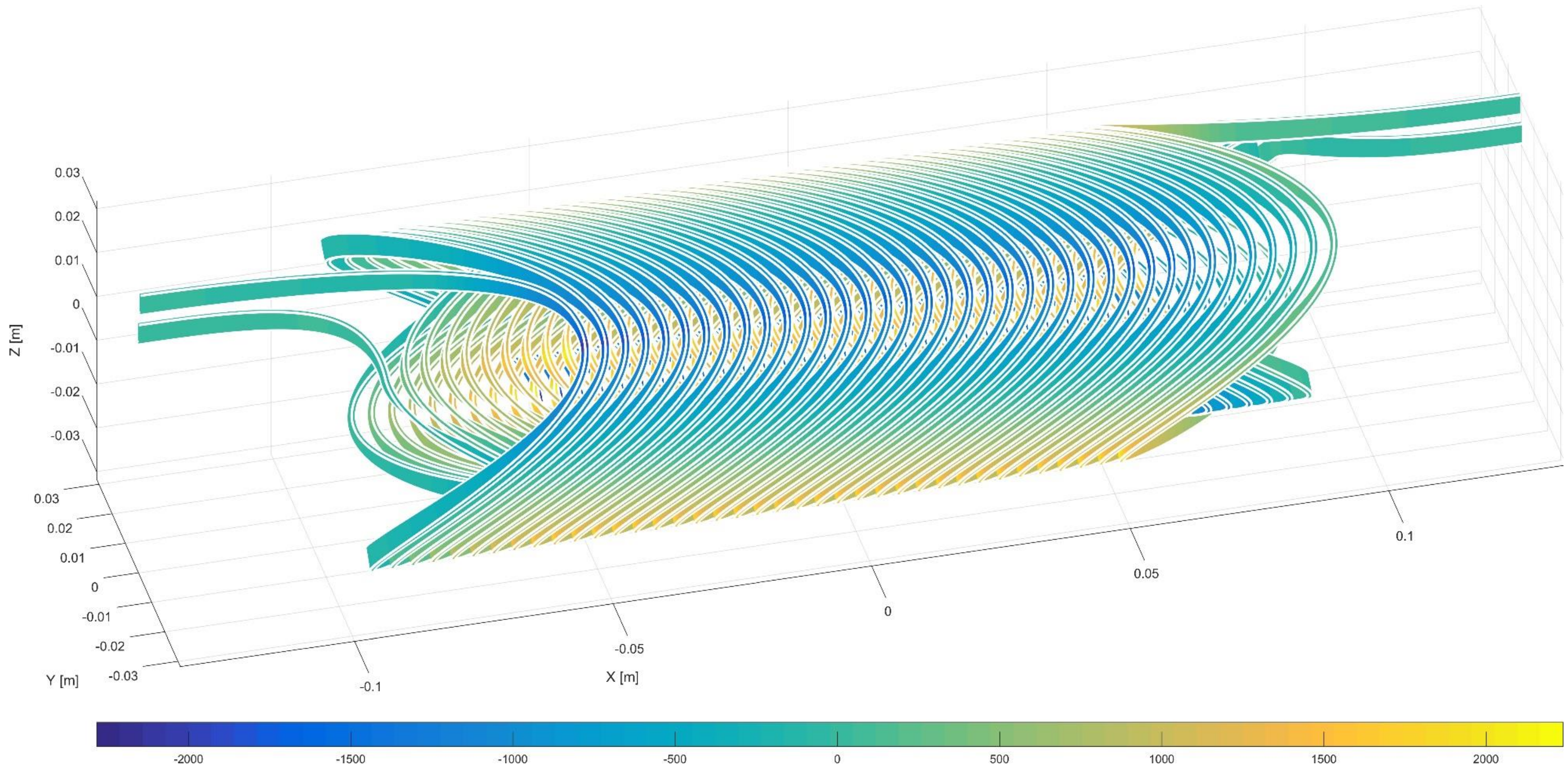
Longitudinal field integrates out to zero per side

After correction, and with a small asymmetry to the currents of the two layers – by 0.3%. Without the asymmetry, there is a residual field of 4mT

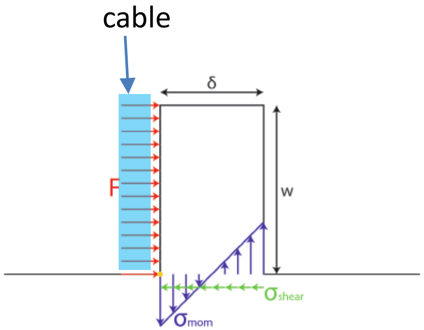
Dual aperture crosstalk compensation

- …also works beautifully.
- The multipole components added are small (order of a few percent or less) and to the naked eye a compensated and uncompensated quad looks the same

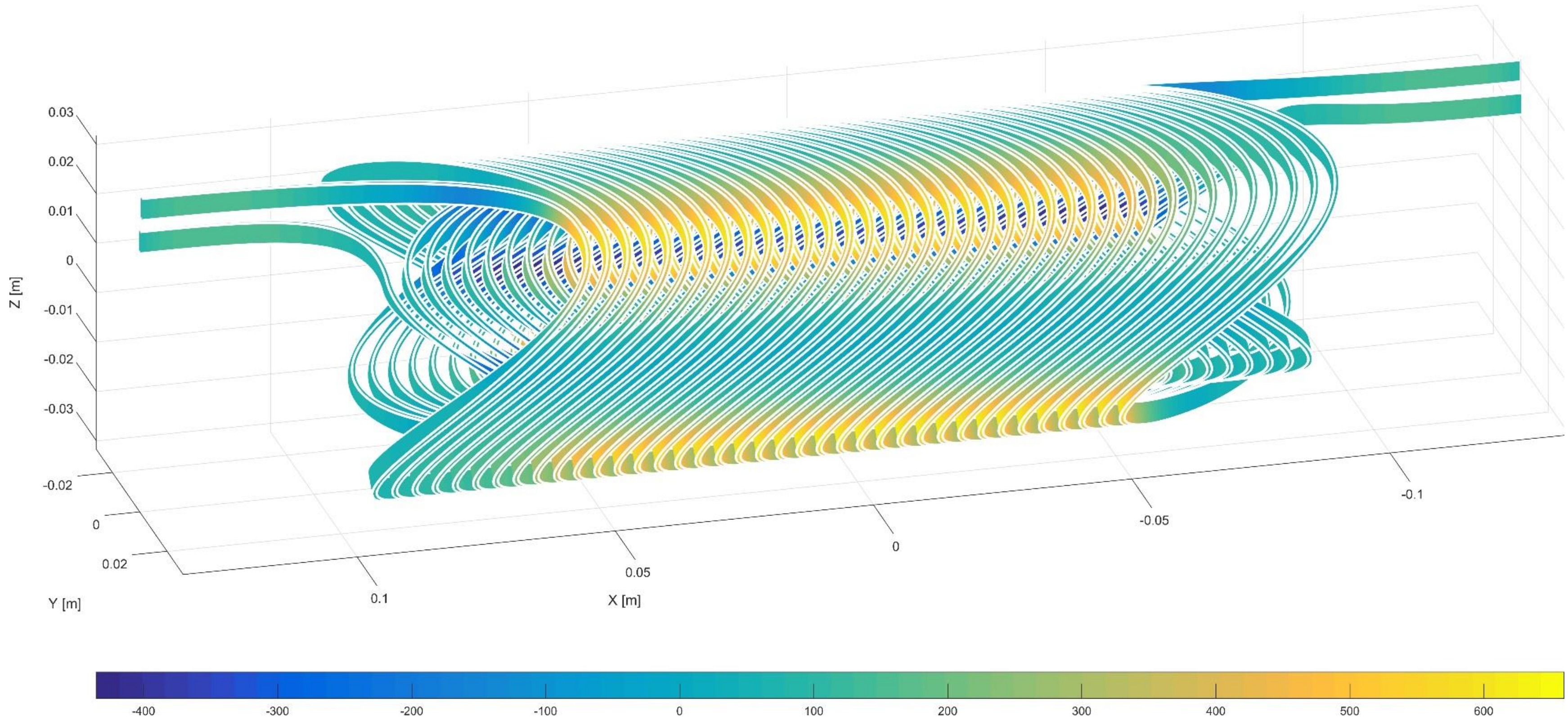
Forces and pressure - longitudinal



Here the longitudinal force is taken by the material between successive grooves – there the force is highest, groove distance is maximum.
We get 8000N/m, so for 2 cm the force is 160N, and the pressure is applied in an area of 4mmX2cm => 2MPa or pressure where the material is ~3mm thick



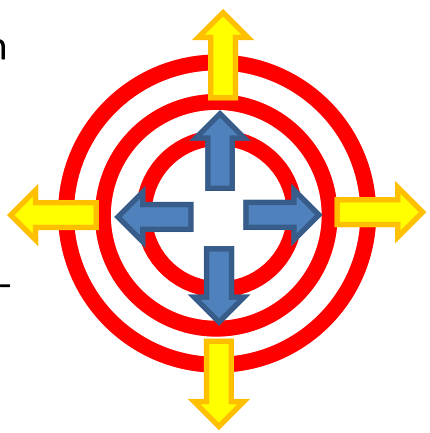
Forces and pressure - radial



Above is a test quadrupole with 50T/m. Multiply all forces by a factor 4! Maximum radial force is 2500N/m – "trying to make the circle a square".

Force exerted in ~20mm strip along the magnet (20cm long, 30 windings) is 1500 N for 4000 mm2 or ~0.4MPa

Force is exerted on support tubes (in red). Note that since the force is quadrupole-like, any deformation does not affect the field quality!!



Conferences

MT25 – abstract submitted on edge correction

A novel method for greatly reduced edge effects design in CCT magnets

Authors: *m Koratzinos, Glyn Kirby, Jeroen Van Nugteren, Erwin Roland Bielert*

Iron-free CCT magnet design offers many advantages, one being the excellent field quality and the absence of multipole components. However, edge effects are present, although they tend to integrate out over the length of the magnet. Many modern accelerator applications, however, require that these magnets are placed in an area of rapidly varying optics parameters, so magnets with greatly reduced edge effects have an advantage. We have designed such a magnet (a quadrupole) by adding multipole components of the opposite sign to the edge of the magnet, effectively resulting in a combined function magnet with multipole components that vary along its length. A possible application could be the final focus magnets of the FCC-ee, where beam sizes at the entry and exit point of the magnets vary by large factors.

EUCAS 2017 – abstract to be submitted on compensation

Conclusions

- Both the edge effects correction and the crosstalk correction work very well with the CCT design.
- The limit in precision of such a magnet is probably not in how well one can compensate, but rather it would depend on misalignment errors, calculated to be small a year ago. I would need to revisit this analysis.
- (one of the main advantages of the CCT design is that the cable misalignment errors are small)
- For FCC-ee to be able to decide on a baseline solution for the FF quadrupoles, we need to know the edge effect errors and the crosstalk errors of the Panofski-type quadrupole. News from BINP: analysis underway

Thank you