Cross-talk Control between Q1BpF & Q1eF (Impact on Field Harmonics)

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BROOKHAVEN NATIONAL LABORATORY
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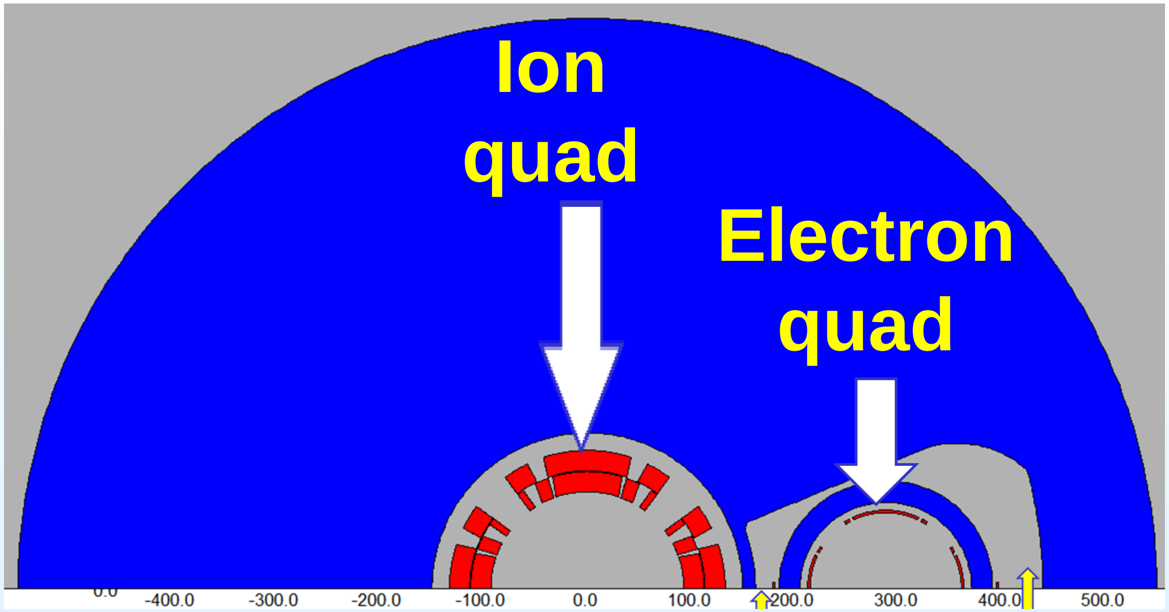
U.S. DEPARTMENT OF ENERGY

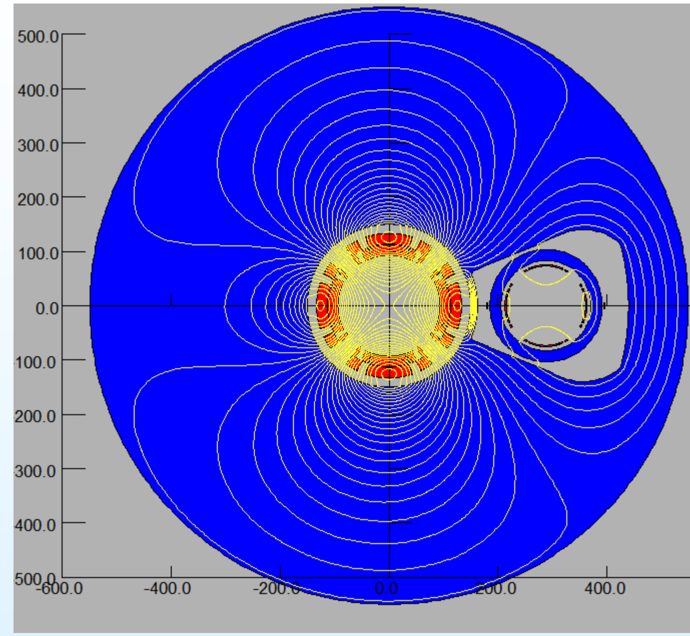
Overview

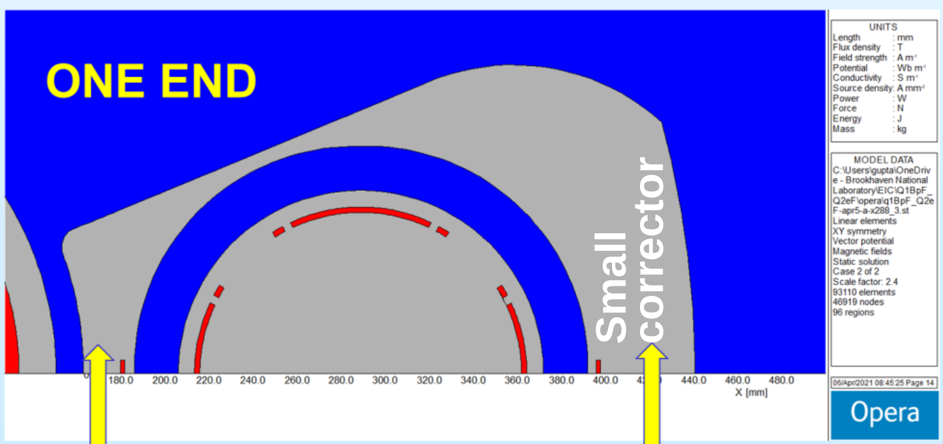
Study of field harmonics in electron quad (Q1eF) and in ion quad (Q1BpF) to evaluate cross-talk between the two

- Step by step approach
  1. Field harmonics in both quads at low fields
  2. Field harmonics in both quads as a function of current
  3. Field harmonics in both quad as separation changes
  4. Sensitivity of correctors on harmonic reduction
- The goal is that harmonics remain low in both quads
- To develop and optimize a good approach for reducing harmonics as quickly as possible, first proceed with 2-d analysis (although different locations gives a 3-d flavor)

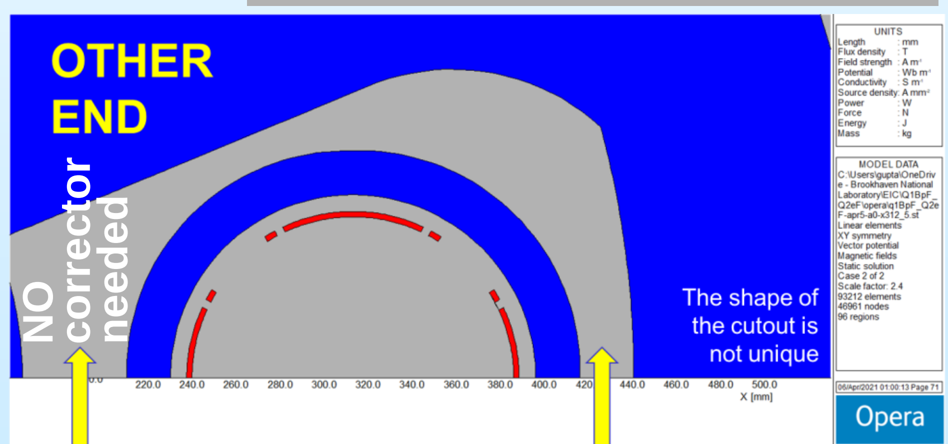
Basic Model to Demonstrate that Cross-talk in e-quad can be reduced







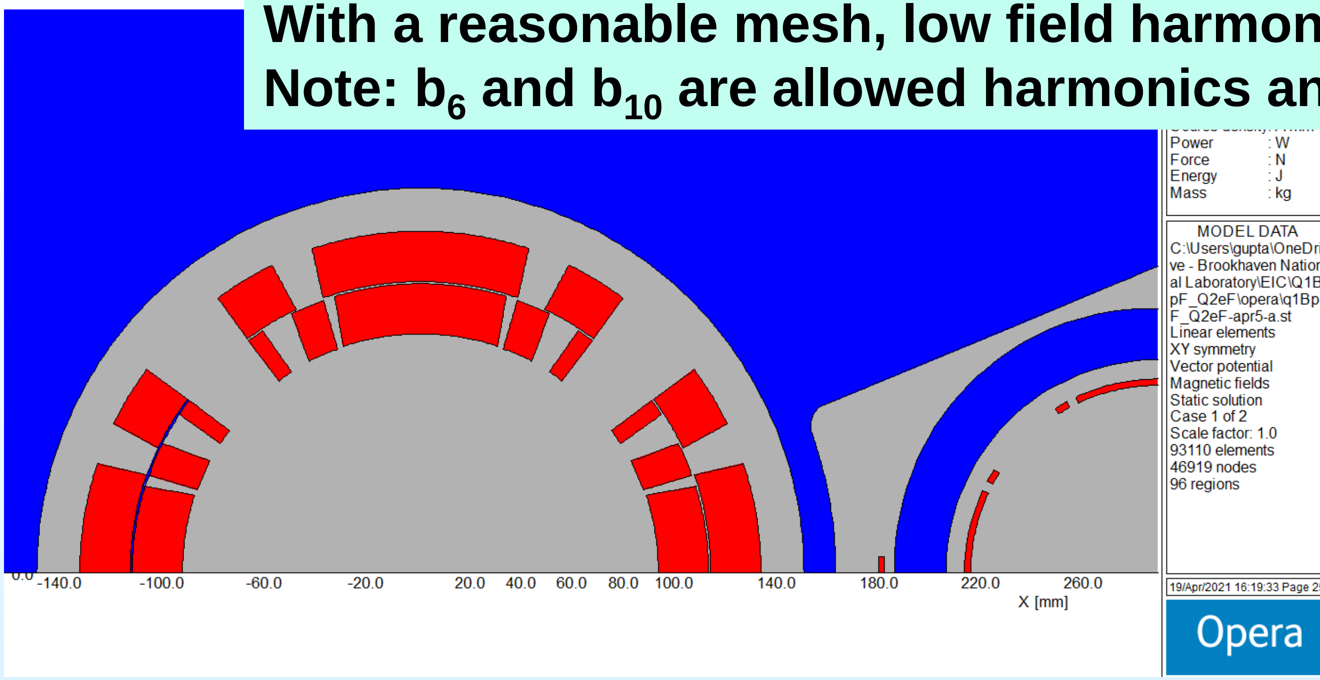
Cutout in the yoke where other hardware can be inserted (with rounded corners for the cutout)



Cutout in the yoke where other hardware can be inserted (with rounded corners for the cutout)

Field Harmonics at Low Excitation in Ion Quad

With a reasonable mesh, low field harmonics are close to zero.
Note: b_6 and b_{10} are allowed harmonics and they may be real

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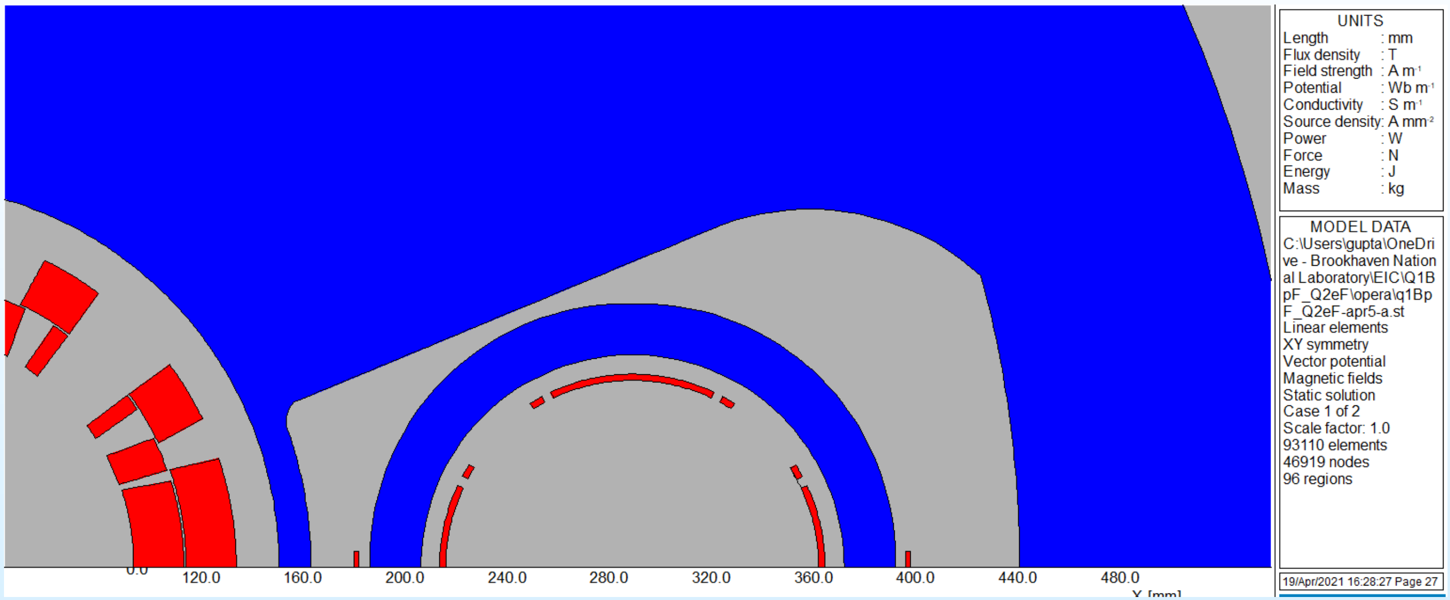
/ THIS SECTION IS TO DEFINE CONSTANT FOR HARMONIC CALCULATIONS
/
$CONS #RINT                              80.0
$CONS #R0                                60.0
$CONS #eRINT                             50.
$CONS #eR0                               30.
/$CONS #eX0                               288.3
$CONS #X0                                0.
$CONS #Y0                                0.
```

N	NORMAL(bn)
2	10000.000
3	0.207
4	-0.200
5	-0.141
6	-8.188
7	-0.002
8	-0.008
9	0.008
10	1.700
11	0.029
12	0.001
13	0.008
14	-0.167
15	-0.011
16	0.000

Field Harmonics at Low Excitation in electron Quad

With a reasonable mesh, low field harmonics are close to zero
b_6 and b_{10} are allowed harmonics and they may be real



N	NORMAL(bn)
2	10000.000
3	0.329
4	-0.242
5	0.013
6	7.606
7	0.003
8	-0.014
9	-0.006
10	-0.770
11	-0.008
12	-0.006
13	-0.006
14	0.004
15	-0.003
16	0.000
17	-0.001
18	0.000
19	0.000
20	0.000
21	0.000

```
/ THIS SECTION IS TO DEFINE CONSTANT FOR HARMONIC CALCULATIONS
/
$CONS #RINT                               80.0
$CONS #R0                                 60.0
$CONS #eRINT                              50.
$CONS #eR0                                30.
/$CONS #eX0                                288.3
$CONS #X0                                 0.
$CONS #Y0                                 0.
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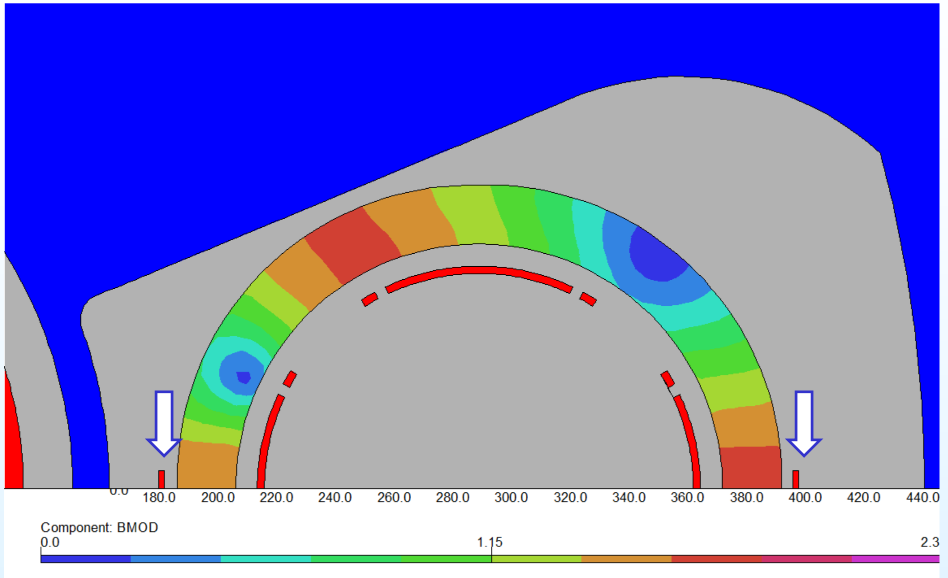
Harmonics as a function of Excitation in e-quad

Design gradients

- ion-quad (pGrad): 66.2 T/m
- e-quad (eGrad): 8 T/m (?)



Harmonics are reasonably small in a design optimized as a proof-of-principle design only **(with a corrector, as presented earlier)**

Can be reduced in a more optimized design

eCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.007	2.976	-0.338	0.115	-0.251	0.023	6.800	0.005	-0.029	-0.002
2	0.028	11.904	-1.353	0.115	-0.251	0.023	6.800	0.005	-0.029	-0.002
3	0.055	23.796	-2.707	0.087	-0.261	0.020	6.799	0.004	-0.029	-0.002
4	0.069	29.663	-3.383	0.059	-0.278	0.017	6.798	0.004	-0.029	-0.002
5	0.083	35.266	-4.060	0.054	-0.310	0.014	6.797	0.004	-0.029	-0.002
6	0.096	40.590	-4.736	0.061	-0.361	0.007	6.795	0.003	-0.029	-0.002
7	0.110	45.722	-5.411	0.031	-0.433	-0.010	6.791	0.002	-0.030	-0.002
8	0.124	50.722	-6.085	-0.011	-0.543	-0.046	6.786	-0.002	-0.031	-0.002
9	0.138	55.630	-6.756	-0.040	-0.765	-0.137	6.779	-0.009	-0.034	-0.003
10	0.151	60.477	-7.417	0.015	-1.299	-0.394	6.767	-0.026	-0.044	-0.004
11	0.165	65.282	-8.064	2.916	-2.711	-0.839	6.740	-0.022	-0.076	-0.001
12	0.179	70.046	-8.736	25.703	-7.524	-0.772	6.557	0.168	-0.177	0.021

Next design phase

- Harmonics along the length in both quads
  - Start with 2-d simulation along the length (faster and helps in developing strategies)
  - Then perform 3-d simulation and finer optimization
- Harmonics in p-quad as a function of excitation
  - Next few slides

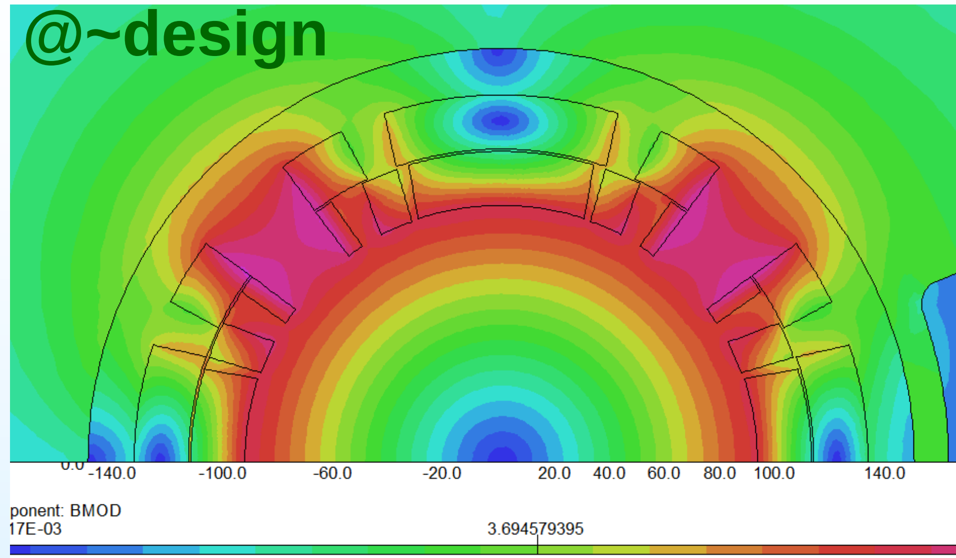
Harmonics as a function of Excitation in ion-quad (in an unoptimized design)

Design gradients

- ion-quad (pGrad): 66.2 T/m
- e-quad (eGrad): 8 T/m (?)

Harmonics become large due to uneven saturation (not surprising)

Needs to be controlled, as mentioned



F_Q2eF-apr5-a-x288_3-many-ep.BNS | q1BpF_Q2eF-apr14-a-x288_3-many-ep.BNS | q1BpF_Q2eF-apr14-a-x288_3-many-pe.BNS

pCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.007	2.976	-0.338	0.175	-0.223	-0.148	-8.178	-0.003	-0.008	0.008
2	0.028	11.904	-1.353	0.109	-0.251	-0.162	-8.184	-0.006	-0.009	0.008
3	0.055	23.796	-2.707	-0.637	-0.575	-0.285	-8.159	-0.020	-0.014	0.006
4	0.069	29.663	-3.383	-4.636	-2.357	-0.931	-7.892	-0.098	-0.043	-0.005
5	0.083	35.266	-4.060	-15.613	-7.185	-2.674	-6.446	-0.324	-0.127	-0.035
6	0.096	40.590	-4.736	-27.259	-12.116	-4.511	-4.582	-0.652	-0.248	-0.075
7	0.110	45.722	-5.411	-35.689	-15.346	-5.780	-3.192	-0.913	-0.340	-0.106
8	0.124	50.722	-6.085	-41.345	-17.298	-6.561	-2.380	-1.076	-0.390	-0.123
9	0.138	55.630	-6.756	-44.765	-18.339	-6.969	-2.006	-1.160	-0.409	-0.129
10	0.151	60.477	-7.417	-46.472	-18.698	-7.119	-1.921	-1.184	-0.409	-0.129
11	0.165	65.282	-8.064	-46.959	-18.637	-7.094	-2.015	-1.173	-0.397	-0.125
12	0.179	70.046	-8.736	-46.818	-18.347	-6.981	-2.223	-1.143	-0.380	-0.119

(+6)

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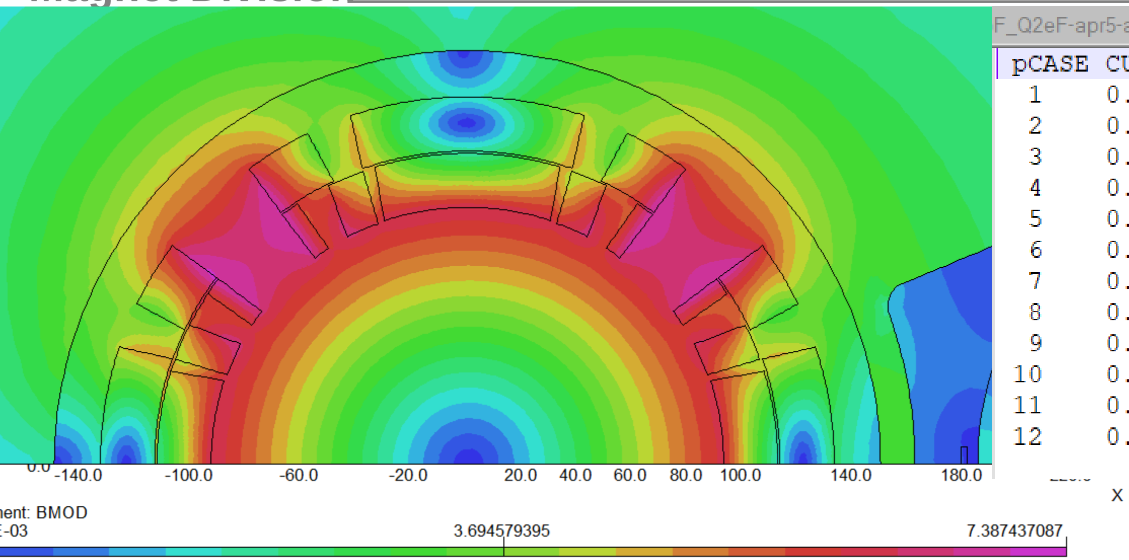
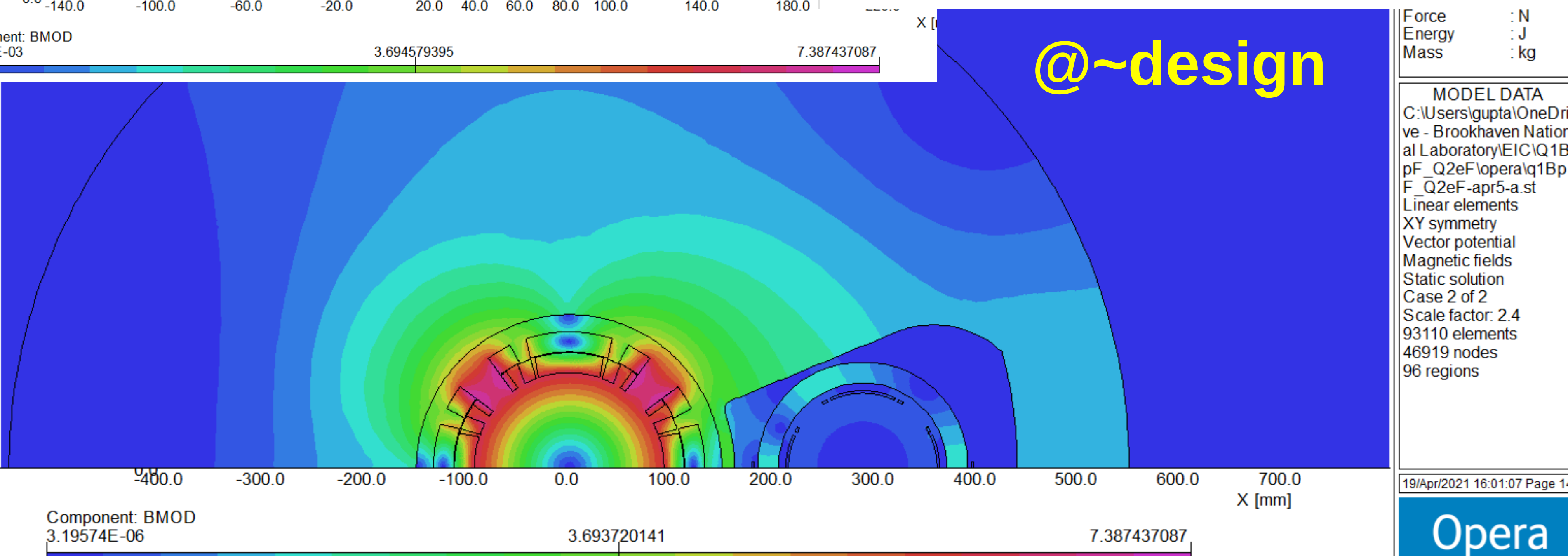
Non-uniform Saturation in Ion Quad (expect large saturation induced harmonics)



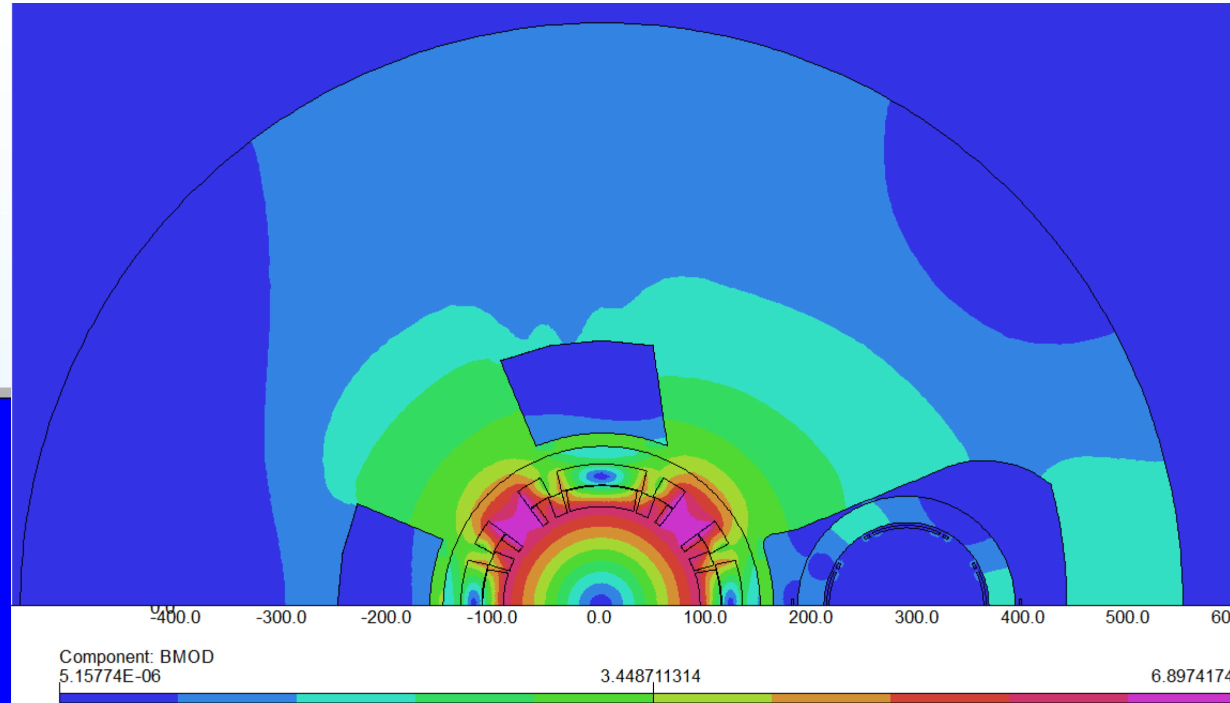
F_Q2eF-apr5-a-x288_3-many-ep.BNS | q1BpF_Q2eF-apr14-a-x288_3-many-ep.BNS

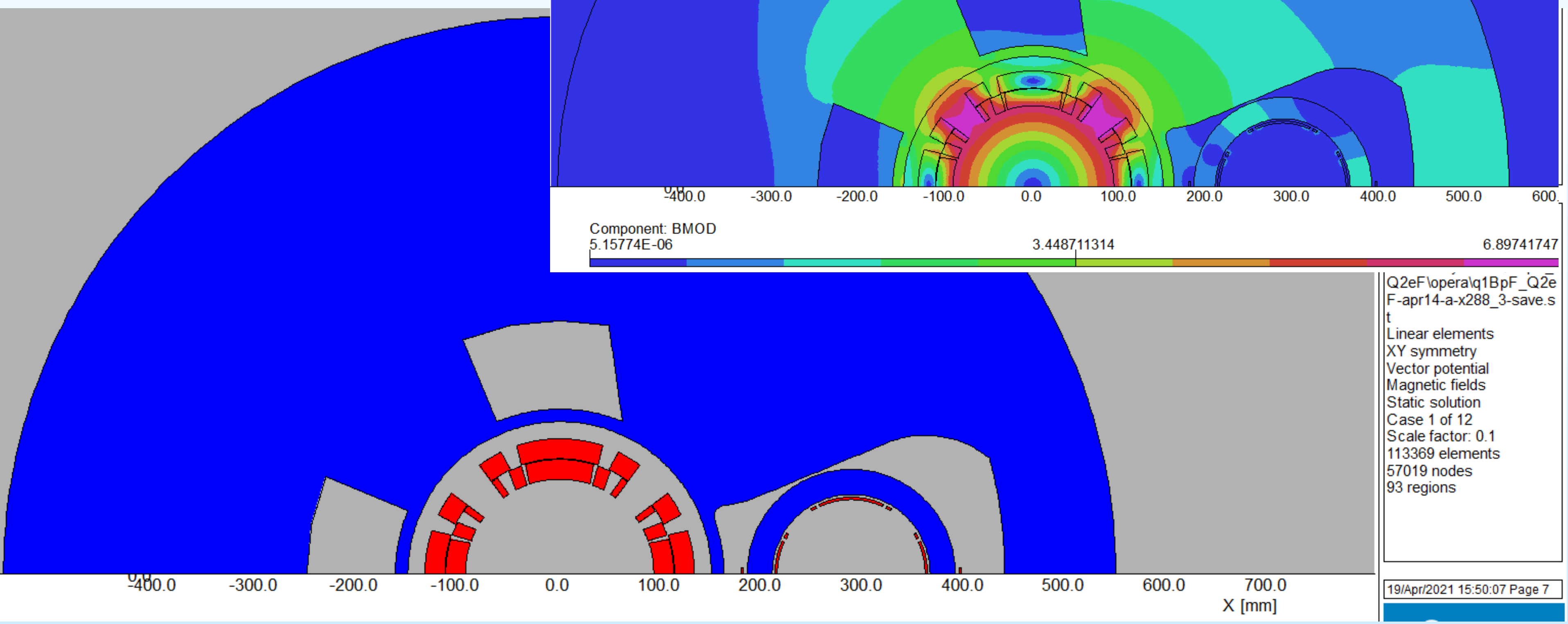
pCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5
1	0.007	2.976	-0.338	0.175	-0.223	-0.148
2	0.028	11.904	-1.353	0.109	-0.251	-0.162
3	0.055	23.796	-2.707	-0.637	-0.575	-0.285
4	0.069	29.663	-3.383	-4.636	-2.357	-0.931
5	0.083	35.266	-4.060	-15.613	-7.185	-2.674
6	0.096	40.590	-4.736	-27.259	-12.116	-4.511
7	0.110	45.722	-5.411	-35.689	-15.346	-5.780
8	0.124	50.722	-6.085	-41.345	-17.298	-6.561
9	0.138	55.630	-6.756	-44.765	-18.339	-6.969
10	0.151	60.477	-7.417	-46.472	-18.698	-7.119
11	0.165	65.282	-8.064	-46.959	-18.637	-7.094
12	0.179	70.046	-8.736	-46.818	-18.347	-6.981



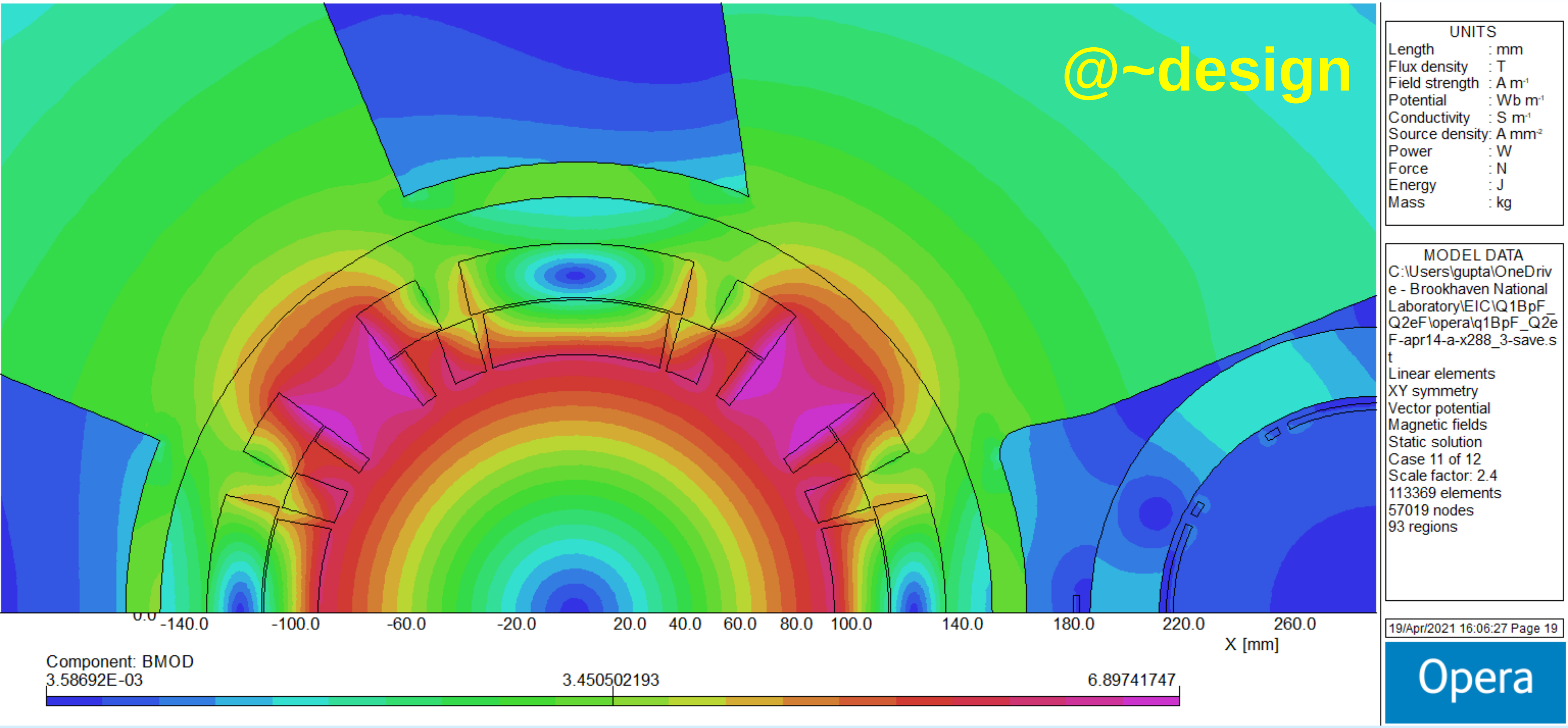
Modified Yoke to Force a More Uniform Saturation in Ion Quad

Important region for reducing saturation induced harmonics is yoke close to coil





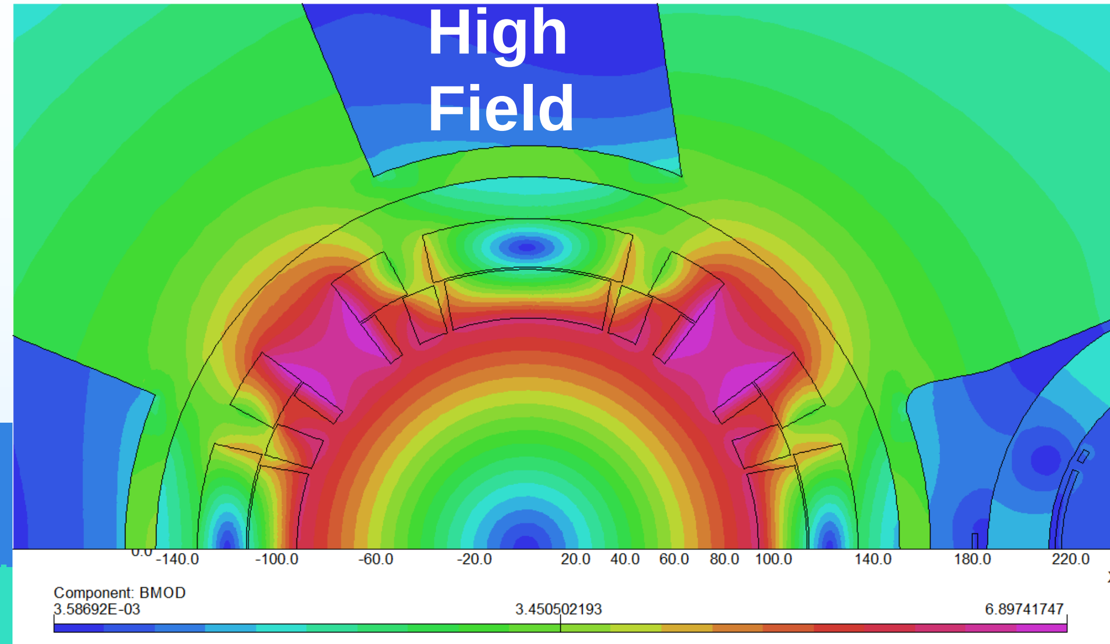
Field Contour in a yoke design with a More Uniform Saturation in Ion Quad

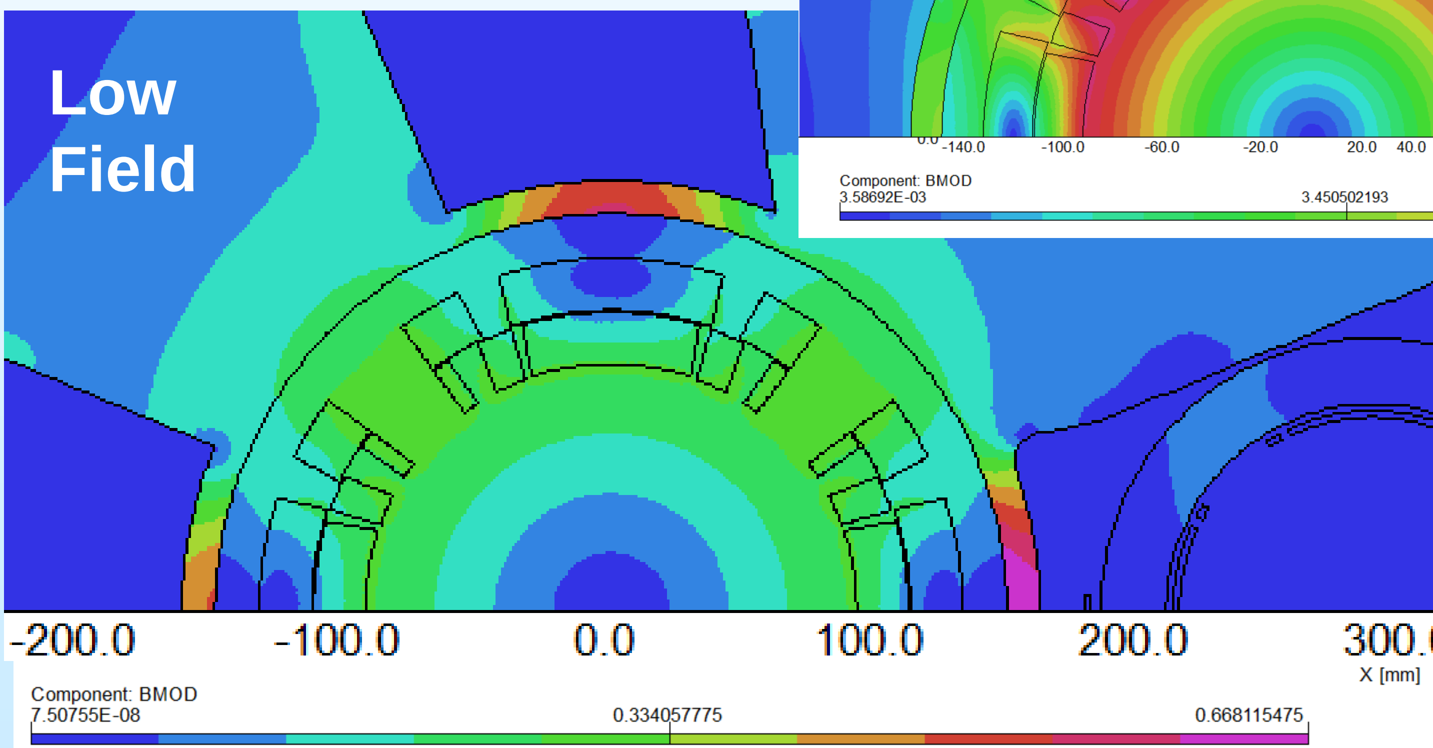


Important region for reducing saturation induced harmonics is the yoke close to coil

Field Distribution at the Low Field and at the Design (High) Field

Note: The field distribution around ion quad may look very different but if mu is high, it woudn't matter





Harmonics as a Function of Excitation in a Magnetically "Symmetrized" Yoke

Note: Change in harmonics small in both ion quad and electron quad (starting design; final optimization in 3-d)

Electron quad

q1BpF_Q2eF-apr14-a-x288_3-save-ep.BNS | q1BpF_Q2eF-apr14-a-x288_3-save-pe.BNS

eCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9	
1	0.007	2.976	-0.378	0.329	-0.242	0.013	7.606	0.003	-0.014	-0.006	
2	0.028	11.903	-1.511	0.329	-0.242	0.013	7.606	0.003	-0.014	-0.006	
3	0.055	23.790	-3.022	0.276	-0.261	0.007	7.604	0.002	-0.014	-0.006	
4	0.069	29.642	-3.777	0.265	-0.298	0.005	7.604	0.002	-0.014	-0.006	
5	0.083	35.218	-4.532	0.249	-0.360	0.000	7.602	0.001	-0.014	-0.006	
6	0.096	40.533	-5.286	0.217	-0.465	-0.018	7.599	-0.002	-0.015	-0.006	
7	0.110	45.673	-6.039	0.183	-0.623	-0.056	7.595	-0.008	-0.016	-0.006	
8	0.124	50.681	-6.790	0.194	-0.872	-0.137	7.594	-0.018	-0.019	-0.006	
9	0.138	55.597	-7.536	0.232	-1.302	-0.320	7.595	-0.038	-0.028	-0.006	
10	0.151	60.455	-8.271	0.356	-1.981	-0.684	7.607	-0.065	-0.045	-0.006	
11	0.165	65.272	-8.998	0.573	-2.748	-1.199	7.613	-0.084	-0.071	-0.006	
12	0.179	70.055	-9.727	4.695	-4.096	-1.611	7.574	-0.040	-0.119	0.000	

Ion quad (design 66.2 T/m)

(-3)

q1BpF_Q2eF-apr14-a-x288_3-save-ep.BNS | q1BpF_Q2eF-apr14-a-x288_3-save-pe.BNS

pCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9	
1	0.007	2.976	-0.378	0.207	-0.200	-0.141	-8.188	-0.002	-0.008	0.008	
2	0.028	11.903	-1.511	0.141	-0.209	-0.154	-8.210	-0.004	-0.008	0.008	
3	0.055	23.790	-3.022	0.265	-0.159	-0.114	-8.399	0.003	-0.006	0.009	
4	0.069	29.642	-3.777	0.553	-0.295	0.004	-9.077	0.032	-0.005	0.010	
5	0.083	35.218	-4.532	0.259	-1.293	0.071	-9.807	0.099	-0.015	0.010	
6	0.096	40.533	-5.286	0.422	-2.397	0.182	-10.403	0.169	-0.025	0.005	
7	0.110	45.673	-6.039	1.181	-3.067	0.309	-10.792	0.216	-0.028	0.000	
8	0.124	50.681	-6.790	1.899	-3.388	0.408	-11.097	0.246	-0.026	-0.002	
9	0.138	55.597	-7.536	2.516	-3.470	0.487	-11.319	0.262	-0.021	-0.003	
10	0.151	60.455	-8.271	3.169	-3.377	0.547	-11.461	0.275	-0.016	-0.003	
11	0.165	65.272	-8.998	3.793	-3.177	0.597	-11.541	0.284	-0.009	-0.002	
12	0.179	70.055	-9.727	4.349	-2.920	0.640	-11.578	0.290	-0.002	-0.002	

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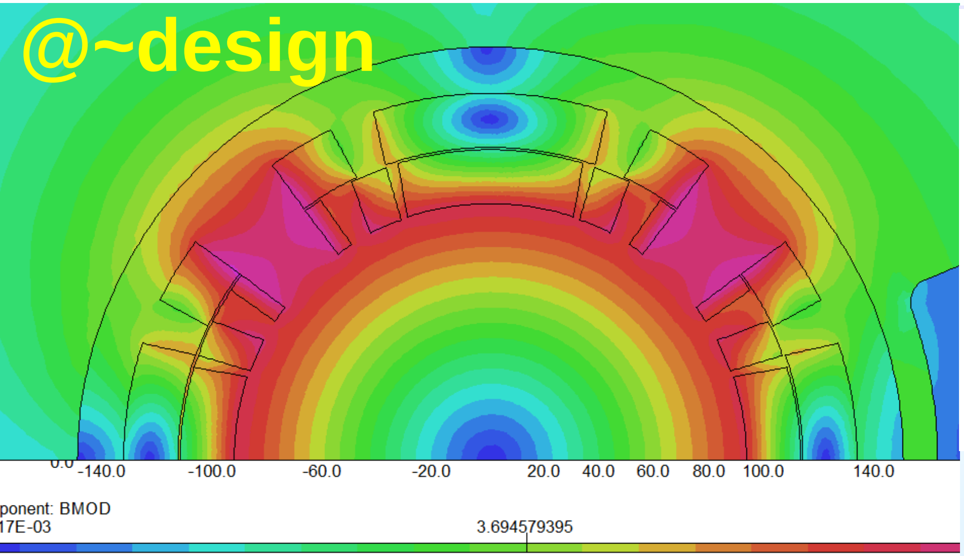
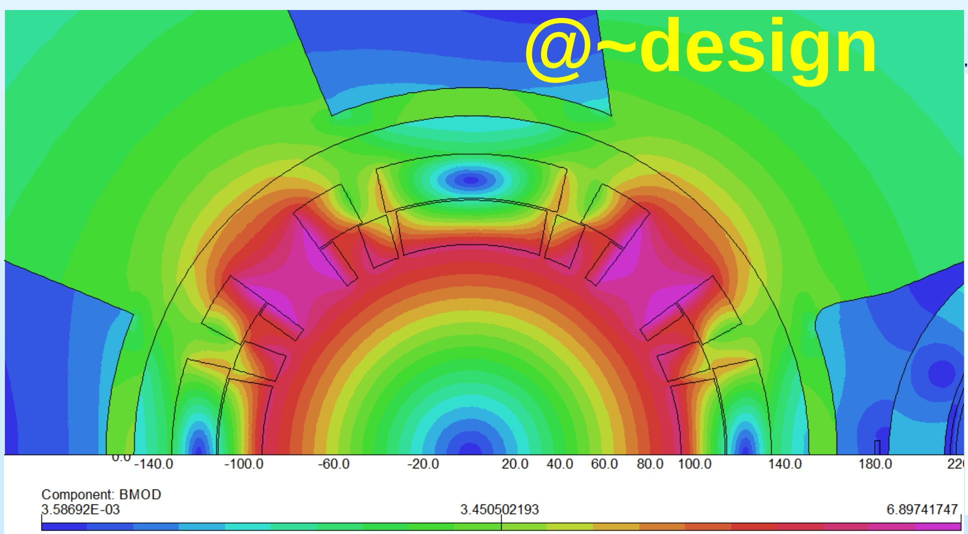
Recap – Yoke Optimization for ion-quad @"near end"



b3	b4	b5	b6	b7	b8
0.175	-0.223	-0.148	-8.178	-0.003	-0.008
0.109	-0.251	-0.162	-8.184	-0.006	-0.009
-0.637	-0.575	-0.285	-8.159	-0.020	-0.014
-4.636	-2.357	-0.931	-7.892	-0.098	-0.043
-15.613	-7.185	-2.674	-6.446	-0.324	-0.127
-27.259	-12.116	-4.511	-4.582	-0.652	-0.248
-35.689	-15.346	-5.780	-3.192	-0.913	-0.340
-41.345	-17.298	-6.561	-2.380	-1.076	-0.390
-44.765	-18.339	-6.969	-2.006	-1.160	-0.409
-46.472	-18.698	-7.119	-1.921	-1.184	-0.409
-46.959	-18.637	-7.094	-2.015	-1.173	-0.397
-46.818	-18.347	-6.981	-2.223	-1.143	-0.380

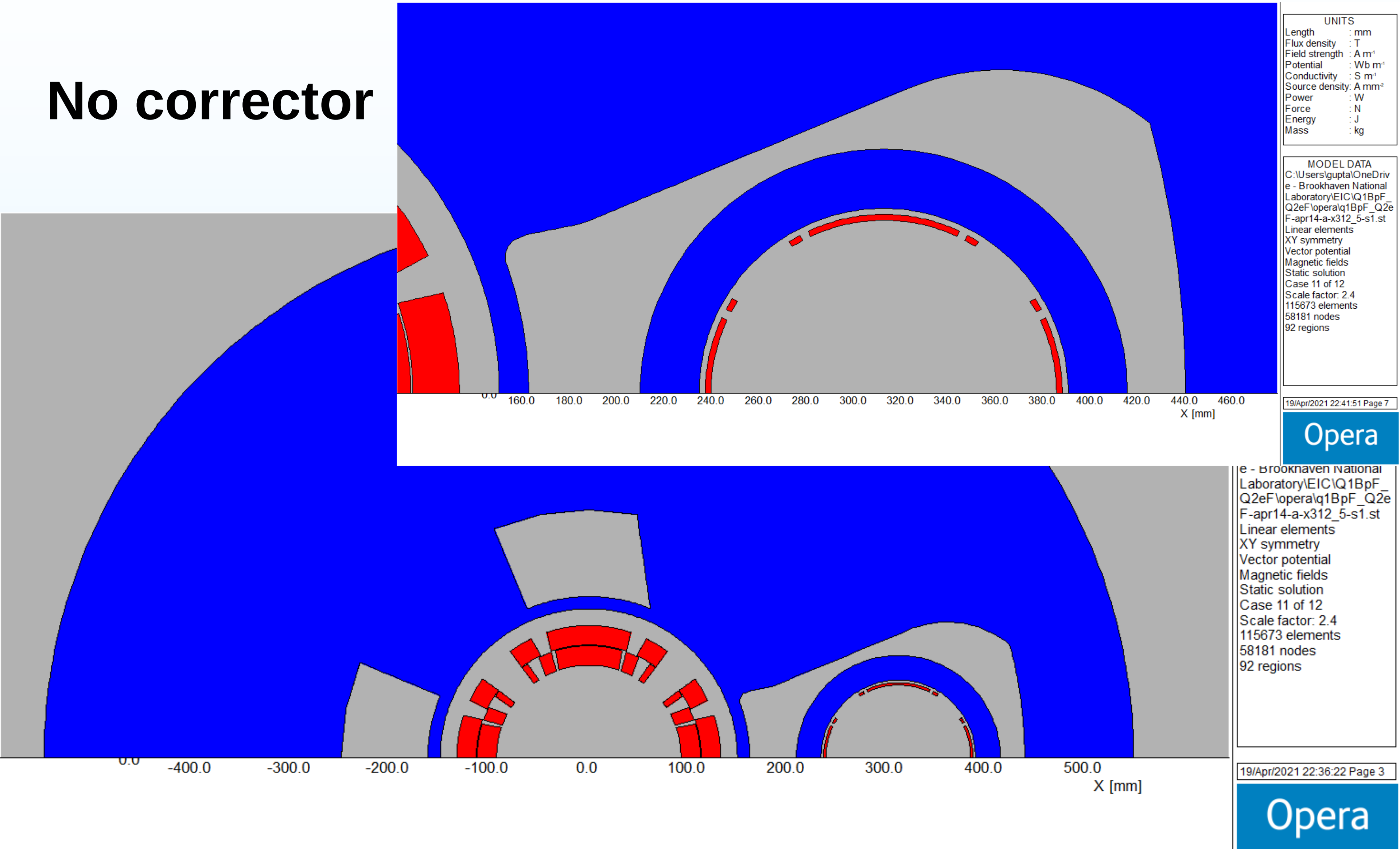
Note: A big difference in change in harmonics



b3	b4	b5	b6	b7	b8
0.207	-0.200	-0.141	-8.188	-0.002	-0.008
0.141	-0.209	-0.154	-8.210	-0.004	-0.008
0.265	-0.159	-0.114	-8.399	0.003	-0.006
0.553	-0.295	0.004	-9.077	0.032	-0.005
0.259	-1.293	0.071	-9.807	0.099	-0.015
0.422	-2.397	0.182	-10.403	0.169	-0.025
1.181	-3.067	0.309	-10.792	0.216	-0.028
1.899	-3.388	0.408	-11.097	0.246	-0.026
2.516	-3.470	0.487	-11.319	0.262	-0.021
3.169	-3.377	0.547	-11.461	0.275	-0.016
3.793	-3.177	0.597	-11.541	0.284	-0.009
4.349	-2.920	0.640	-11.578	0.290	-0.002

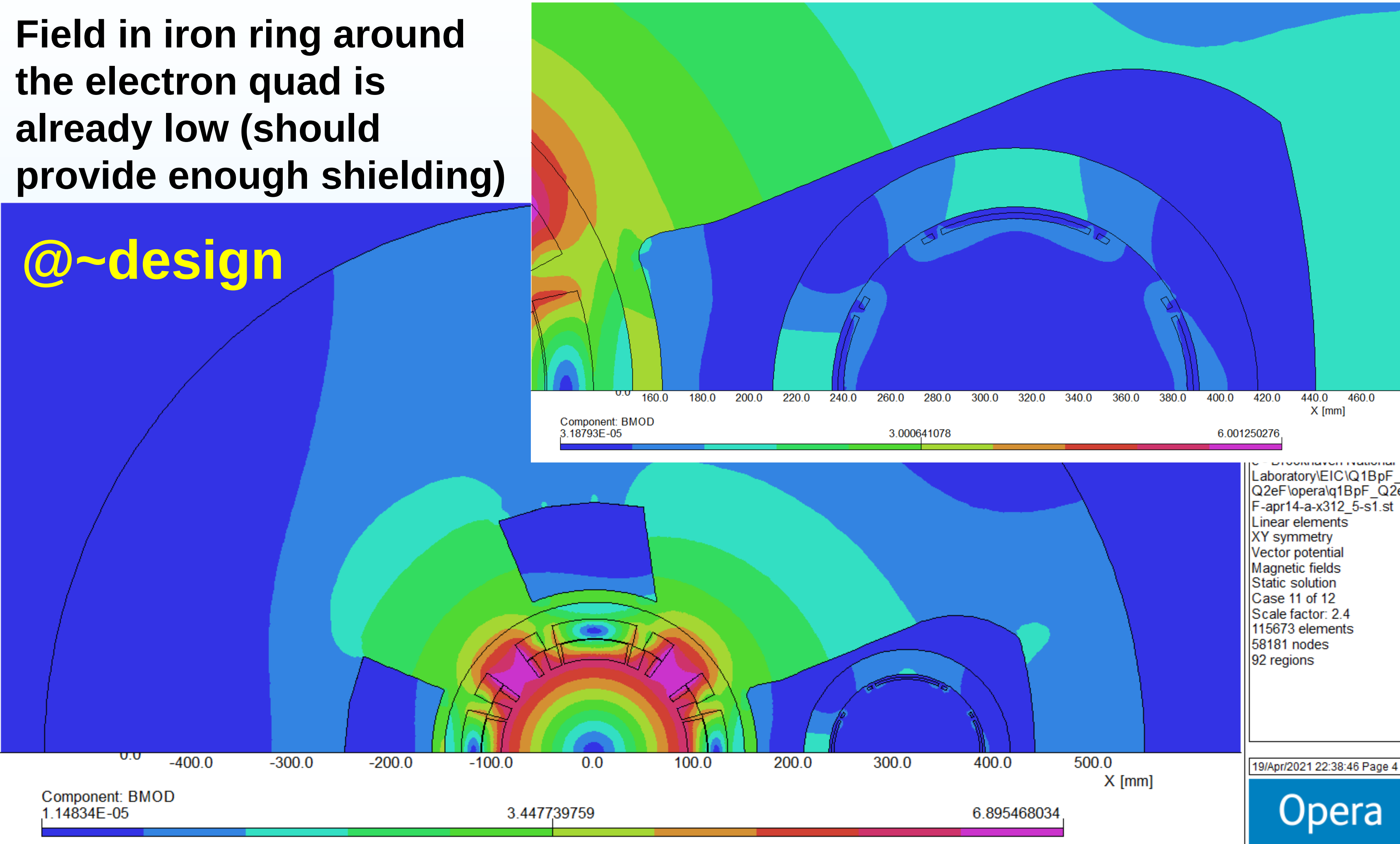
Far Side with the Maximum Separation between e-quad and ion quad (no corrector)

No corrector



Far Side with the Maximum Separation between e-quad and ion quad (no corrector)

Field in iron ring around the electron quad is already low (should provide enough shielding)



Far Side with the Maximum Separation between e-quad and ion quad (no corrector)

e-quad: very little change despite no correction

q1BpF_Q2eF-apr14-a-x312_5-s1-ep.BNS | q1BpF_Q2eF-apr14-a-x312_5-s1-pe.BNS

eCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.069	29.650	-3.770	-0.050	-0.179	0.012	7.577	-0.012	-0.037	0.013
2	0.007	2.976	-0.377	-0.055	-0.178	0.012	7.577	-0.012	-0.037	0.013
3	0.028	11.903	-1.508	-0.055	-0.178	0.012	7.577	-0.012	-0.037	0.013
4	0.055	23.793	-3.016	-0.054	-0.178	0.012	7.577	-0.012	-0.037	0.013
5	0.083	35.233	-4.524	-0.037	-0.183	0.013	7.577	-0.012	-0.037	0.013
6	0.096	40.546	-5.278	-0.014	-0.189	0.015	7.576	-0.012	-0.037	0.013
7	0.110	45.683	-6.032	0.022	-0.196	0.018	7.575	-0.012	-0.037	0.013
8	0.124	50.683	-6.786	0.073	-0.206	0.023	7.572	-0.012	-0.037	0.013
9	0.138	55.583	-7.541	0.179	-0.230	0.035	7.568	-0.010	-0.037	0.013
10	0.151	60.416	-8.296	0.444	-0.292	0.069	7.554	-0.006	-0.038	0.013
11	0.165	65.202	-9.052	1.155	-0.417	0.167	7.509	0.006	-0.042	0.015
12	0.179	69.949	-9.815	3.892	-0.617	0.553	7.289	0.055	-0.050	0.021

ion-quad: very little change

q1BpF_Q2eF-apr14-a-x312_5-s1-ep.BNS | q1BpF_Q2eF-apr14-a-x312_5-s1-pe.BNS

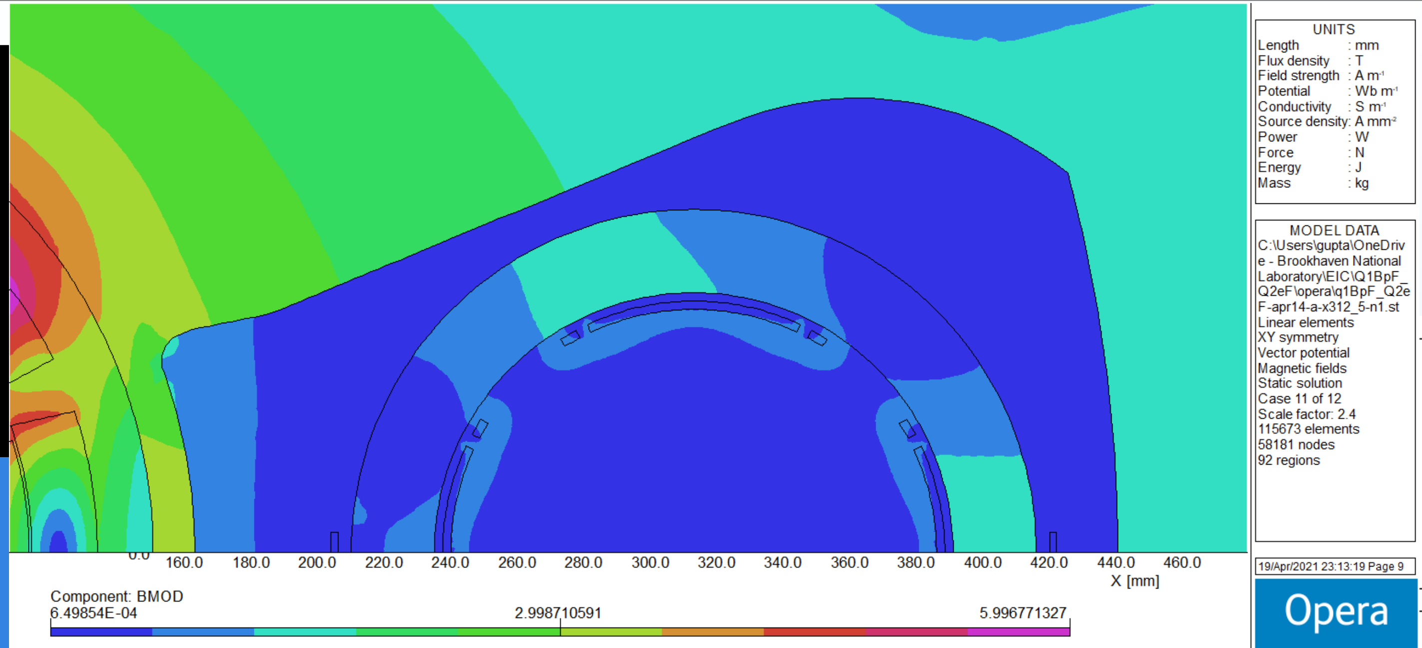
pCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.069	29.650	-3.770	0.986	-0.120	0.084	-9.046	0.042	-0.003	0.012
2	0.007	2.976	-0.377	0.228	-0.197	-0.139	-8.187	-0.002	-0.008	0.008
3	0.028	11.903	-1.508	0.185	-0.203	-0.148	-8.208	-0.003	-0.008	0.008
4	0.055	23.793	-3.016	0.406	-0.112	-0.089	-8.389	0.006	-0.005	0.009
5	0.083	35.233	-4.524	0.944	-1.016	0.190	-9.760	0.113	-0.011	0.012
6	0.096	40.546	-5.278	0.826	-2.273	0.242	-10.375	0.179	-0.023	0.006
7	0.110	45.683	-6.032	1.258	-3.120	0.298	-10.789	0.215	-0.029	0.000
8	0.124	50.683	-6.786	1.554	-3.639	0.317	-11.127	0.232	-0.032	-0.005
9	0.138	55.583	-7.541	1.624	-3.943	0.307	-11.387	0.234	-0.033	-0.007
10	0.151	60.416	-8.296	1.647	-4.085	0.273	-11.569	0.233	-0.032	-0.009
11	0.165	65.202	-9.052	1.607	-4.120	0.232	-11.689	0.228	-0.030	-0.010
12	0.179	69.949	-9.815	1.512	-4.086	0.190	-11.762	0.221	-0.028	-0.011

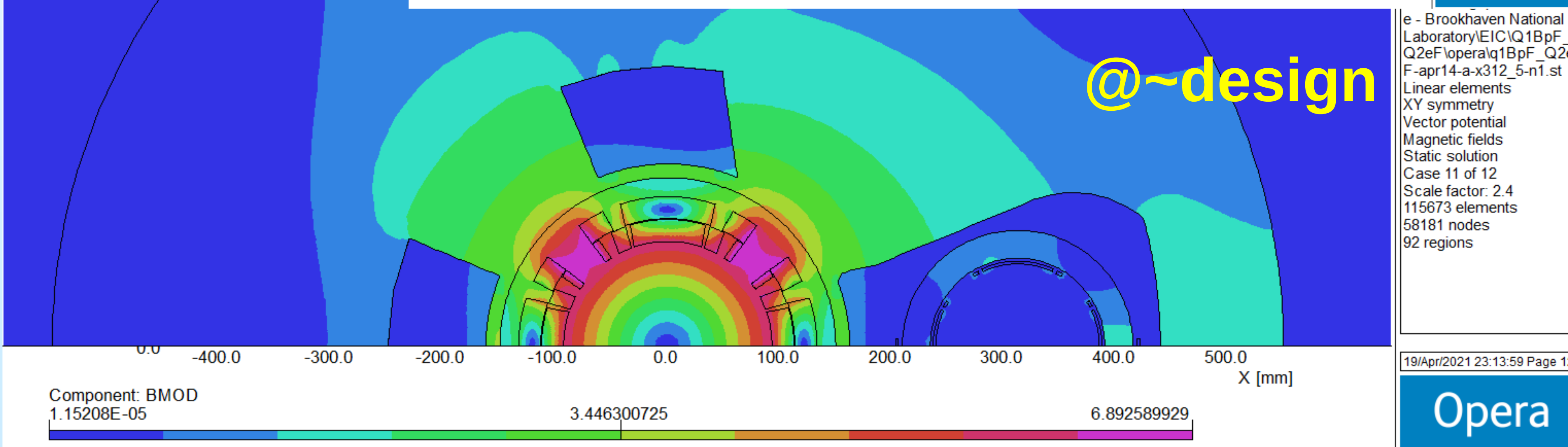
Far Side with the Maximum Separation between e-quad and ion quad

- Since there is a little change in e-quad harmonics without corrector, no corrector is needed
- But how about if we energize the full-strength corrector? That will examine the sensitivity. Low harmonics in both cases means low sensitivity
- Remember that this is a different type of corrector. They are not used to correct the field errors. They are used to control the iron saturation. If “mu” remains somewhat high, it would provide shielding irrespective of anything.

Far Side with the Maximum Separation between e-quad and ion quad (full corrector)

Full-strength correctors (Note: low field in yoke around e-quad)





Far Side with the Maximum Separation between e-quad and ion quad (full corrector)

e-quad: very little change despite full-strength corrector

q1BpF_Q2eF-apr14-a-x312_5-n1-ep.BNS | q1BpF_Q2eF-apr14-a-x312_5-n1-pe.BNS

eCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.069	29.647	-3.768	-0.113	-0.208	0.006	7.576	-0.013	-0.037	0.013
2	0.007	2.976	-0.377	-0.090	-0.196	0.009	7.577	-0.013	-0.037	0.013
3	0.028	11.903	-1.507	-0.090	-0.196	0.009	7.577	-0.013	-0.037	0.013
4	0.055	23.792	-3.014	-0.092	-0.198	0.008	7.577	-0.013	-0.037	0.013
5	0.083	35.225	-4.521	-0.130	-0.220	0.004	7.575	-0.013	-0.037	0.013
6	0.096	40.533	-5.274	-0.148	-0.237	0.000	7.574	-0.013	-0.037	0.013
7	0.110	45.664	-6.027	-0.172	-0.257	-0.008	7.572	-0.014	-0.037	0.013
8	0.124	50.656	-6.780	-0.216	-0.288	-0.022	7.569	-0.015	-0.038	0.012
9	0.138	55.546	-7.532	-0.288	-0.332	-0.043	7.563	-0.017	-0.038	0.012
10	0.151	60.369	-8.283	-0.386	-0.391	-0.079	7.554	-0.019	-0.040	0.012
11	0.165	65.143	-9.032	-0.536	-0.481	-0.154	7.538	-0.023	-0.043	0.011
12	0.179	69.880	-9.774	-0.815	-0.652	-0.343	7.499	-0.029	-0.050	0.008

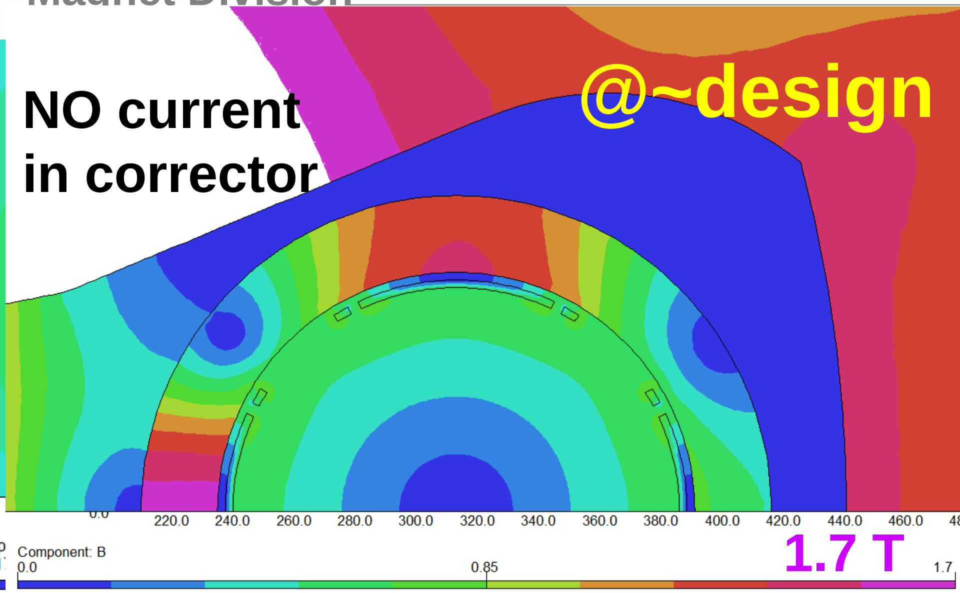
Means: works well whether correctors are present or not

ion-quad: very little change

q1BpF_Q2eF-apr14-a-x312_5-n1-ep.BNS | q1BpF_Q2eF-apr14-a-x312_5-n1-pe.BNS

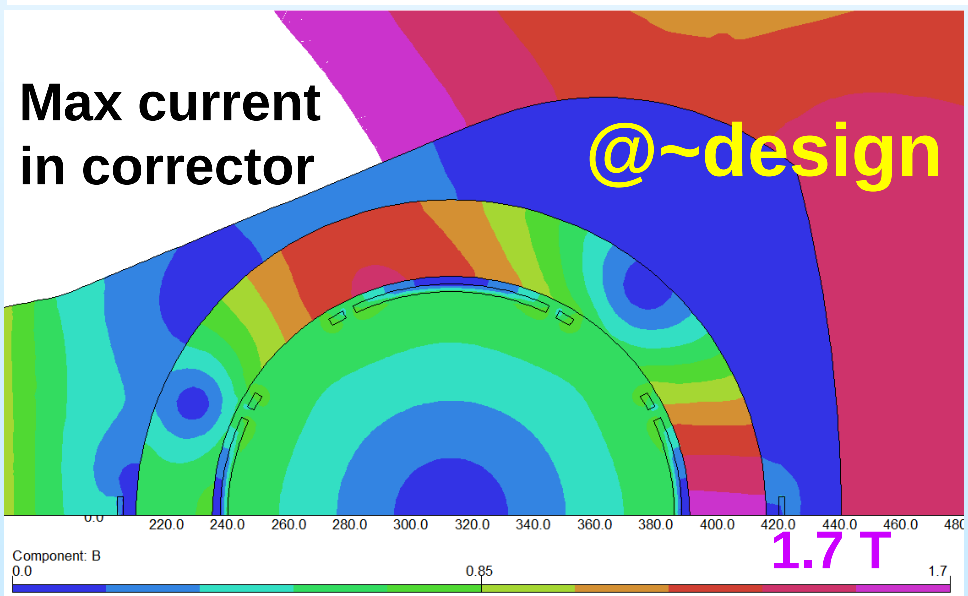
pCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.069	29.647	-3.768	0.818	-0.187	0.053	-9.058	0.038	-0.004	0.011
2	0.007	2.976	-0.377	0.219	-0.199	-0.140	-8.187	-0.002	-0.008	0.008
3	0.028	11.903	-1.507	0.167	-0.205	-0.150	-8.209	-0.004	-0.008	0.008
4	0.055	23.792	-3.014	0.355	-0.128	-0.097	-8.393	0.005	-0.006	0.009
5	0.083	35.225	-4.521	0.524	-1.192	0.117	-9.788	0.105	-0.013	0.011
6	0.096	40.533	-5.274	0.299	-2.485	0.153	-10.411	0.166	-0.027	0.005
7	0.110	45.664	-6.027	0.620	-3.359	0.197	-10.833	0.200	-0.035	-0.002
8	0.124	50.656	-6.780	0.773	-3.911	0.203	-11.178	0.214	-0.038	-0.007
9	0.138	55.546	-7.532	0.697	-4.247	0.182	-11.444	0.214	-0.040	-0.010
10	0.151	60.369	-8.283	0.586	-4.418	0.138	-11.631	0.211	-0.039	-0.012
11	0.165	65.143	-9.032	0.427	-4.478	0.089	-11.754	0.205	-0.037	-0.013

Recap – There is sufficient shielding irrespective of the strength of corrector



/m b3	b4	b5	b6	b7	b8
-0.050	-0.179	0.012	7.577	-0.012	-0.037
-0.055	-0.178	0.012	7.577	-0.012	-0.037
-0.055	-0.178	0.012	7.577	-0.012	-0.037
-0.054	-0.178	0.012	7.577	-0.012	-0.037
-0.037	-0.183	0.013	7.577	-0.012	-0.037
-0.014	-0.189	0.015	7.576	-0.012	-0.037
0.022	-0.196	0.018	7.575	-0.012	-0.037
0.073	-0.206	0.023	7.572	-0.012	-0.037
0.179	-0.230	0.035	7.568	-0.010	-0.037
0.444	-0.292	0.069	7.554	-0.006	-0.038
1.155	-0.417	0.167	7.509	0.006	-0.042
3.892	-0.617	0.553	7.289	0.055	-0.050

Note: A big difference in the appearance of iron magnetization but remains below 1.7 T, providing sufficient shielding

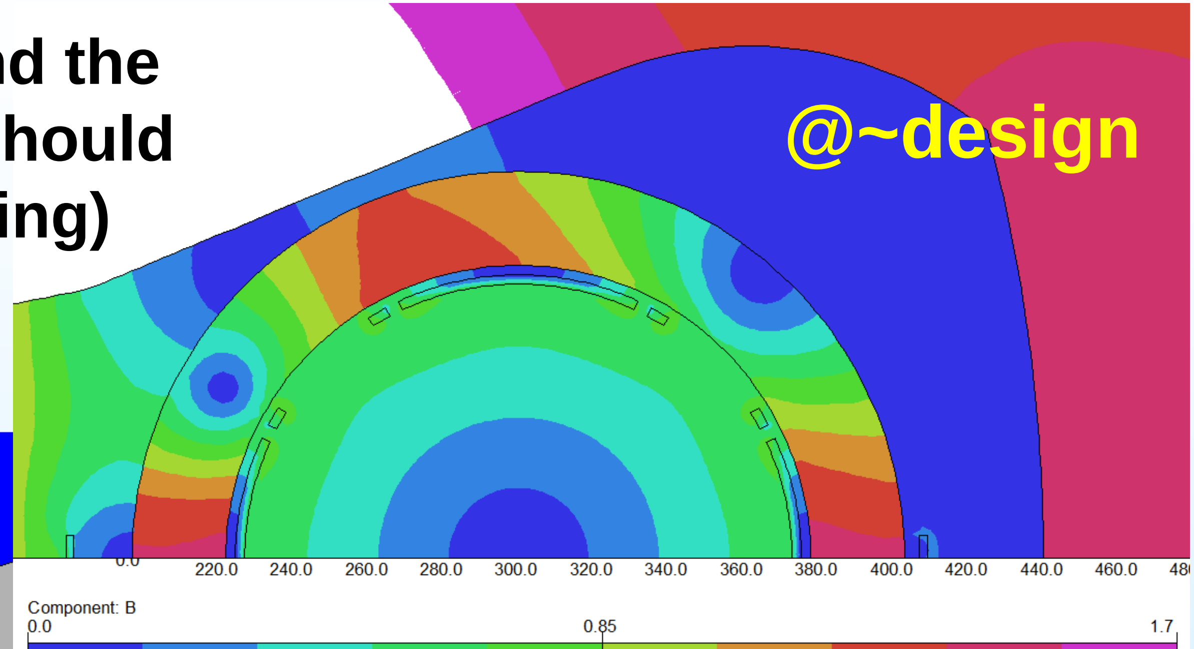


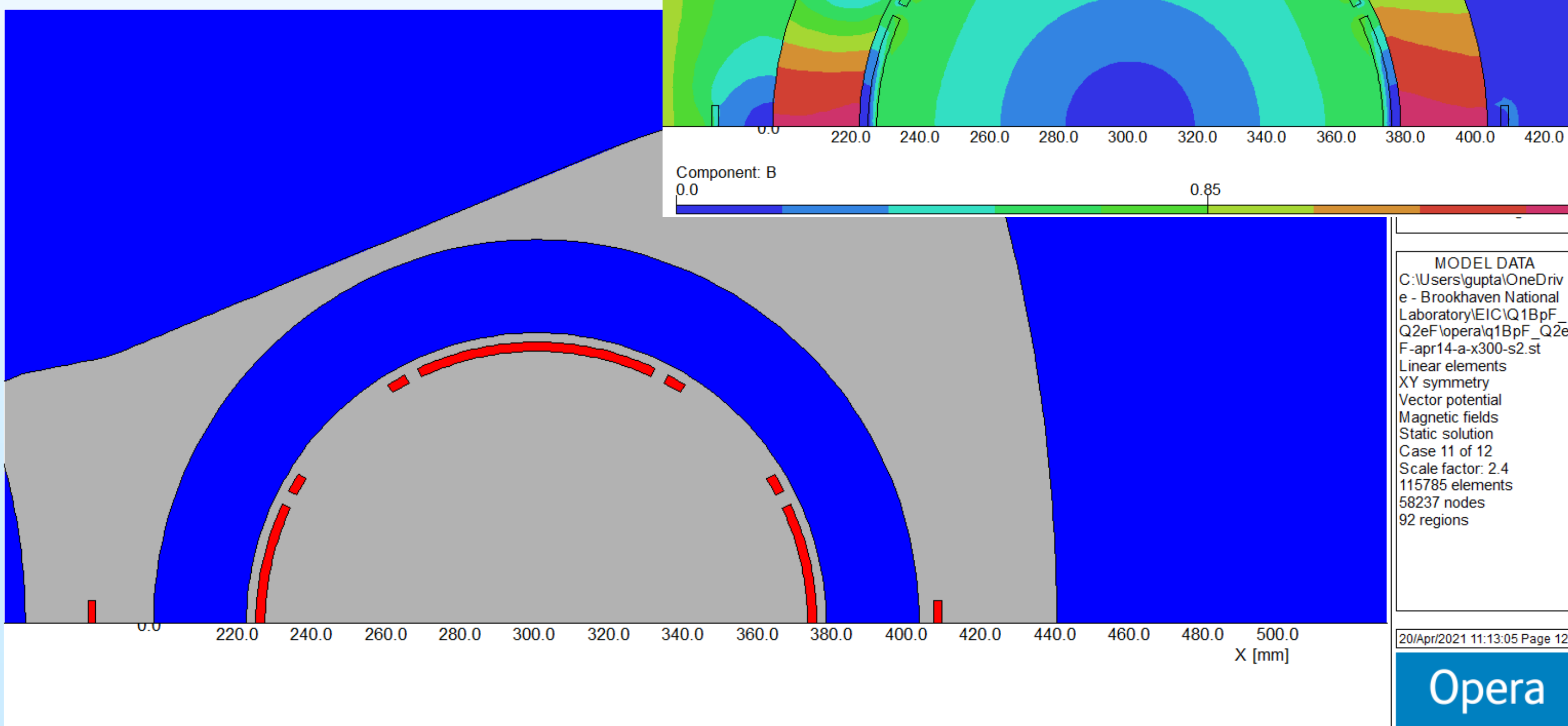
/m b3	b4	b5	b6	b7	b8
-0.113	-0.208	0.006	7.576	-0.013	-0.037
-0.090	-0.196	0.009	7.577	-0.013	-0.037
-0.090	-0.196	0.009	7.577	-0.013	-0.037
-0.092	-0.198	0.008	7.577	-0.013	-0.037
-0.130	-0.220	0.004	7.575	-0.013	-0.037
-0.148	-0.237	0.000	7.574	-0.013	-0.037
-0.172	-0.257	-0.008	7.572	-0.014	-0.037
-0.216	-0.288	-0.022	7.569	-0.015	-0.038
-0.288	-0.332	-0.043	7.563	-0.017	-0.038
-0.386	-0.391	-0.079	7.554	-0.019	-0.040
-0.536	-0.481	-0.154	7.538	-0.023	-0.043
-0.815	-0.652	-0.343	7.499	-0.029	-0.050

e-quad and ion quad halfway through the magnet (corrector strength 70%)

Field in iron ring around the electron quad is low (should provide enough shielding)

@~design





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Superconducting Magnet Division

e-quad and ion quad halfway through the magnet (corrector strength 70%)

Note: Change in harmonics small in both quads

Electron quad

q1BpF_Q2eF-apr14-a-x300-s2-ep.BNS | q1BpF_Q2eF-apr14-a-x300-s2-pe.BNS

eCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.069	29.646	-3.768	-0.056	-0.206	0.010	7.577	-0.013	-0.037	0.013
2	0.007	2.976	-0.377	-0.052	-0.199	0.011	7.577	-0.013	-0.037	0.013
3	0.028	11.903	-1.507	-0.052	-0.199	0.011	7.577	-0.013	-0.037	0.013
4	0.055	23.792	-3.014	-0.051	-0.200	0.011	7.577	-0.013	-0.037	0.013
5	0.083	35.225	-4.521	-0.057	-0.219	0.009	7.576	-0.013	-0.037	0.013
6	0.096	40.536	-5.275	-0.050	-0.233	0.008	7.575	-0.013	-0.037	0.013
7	0.110	45.673	-6.028	-0.040	-0.246	0.005	7.574	-0.013	-0.037	0.013
8	0.124	50.673	-6.782	-0.027	-0.261	-0.001	7.573	-0.013	-0.037	0.013
9	0.138	55.576	-7.535	-0.005	-0.280	-0.007	7.571	-0.013	-0.037	0.013
10	0.151	60.416	-8.289	0.044	-0.305	-0.015	7.567	-0.013	-0.038	0.013
11	0.165	65.209	-9.042	0.263	-0.354	-0.015	7.557	-0.010	-0.039	0.013
12	0.179	69.968	-9.799	1.893	-0.583	0.057	7.506	0.019	-0.048	0.015

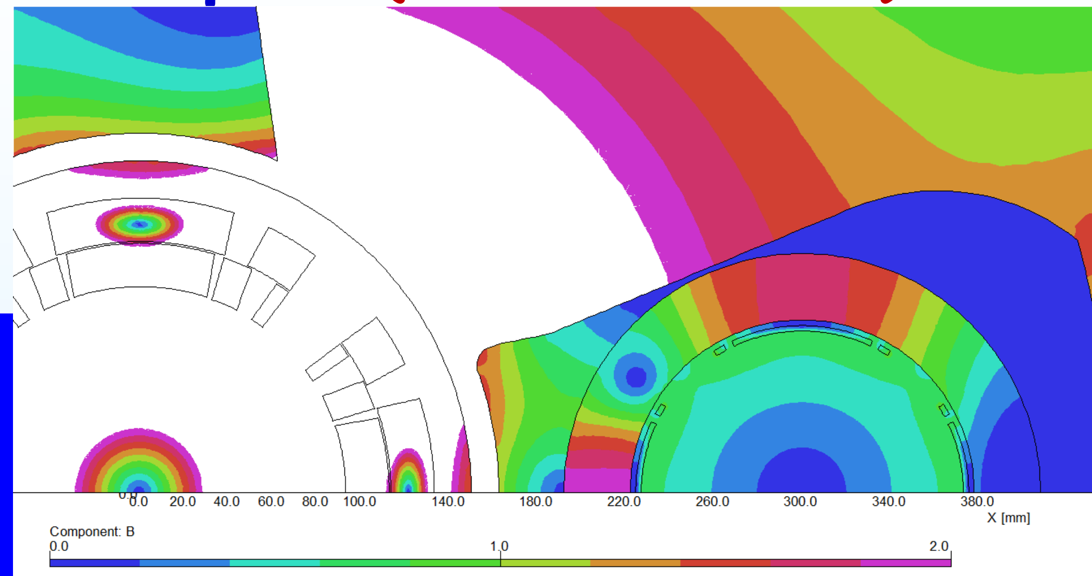
Ion quad (design 66.2 T/m)

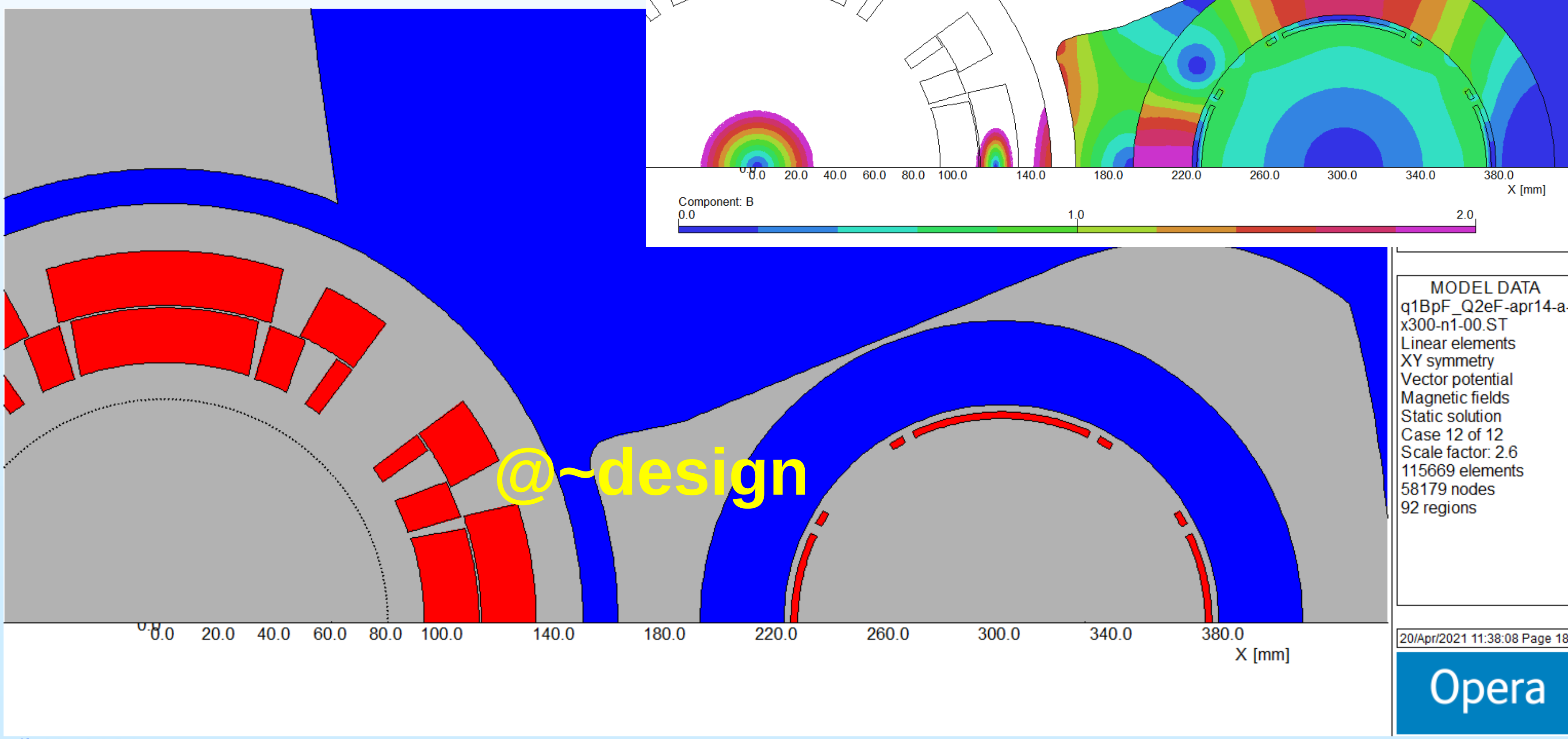
q1BpF_Q2eF-apr14-a-x300-s2-ep.BNS | q1BpF_Q2eF-apr14-a-x300-s2-pe.BNS

pCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.069	29.646	-3.768	0.772	-0.209	0.044	-9.061	0.037	-0.004	0.011
2	0.007	2.976	-0.377	0.220	-0.199	-0.140	-8.187	-0.002	-0.008	0.008
3	0.028	11.903	-1.507	0.167	-0.205	-0.150	-8.209	-0.004	-0.008	0.008
4	0.055	23.792	-3.014	0.342	-0.134	-0.100	-8.394	0.005	-0.006	0.009
5	0.083	35.225	-4.521	0.511	-1.200	0.113	-9.789	0.104	-0.014	0.011
6	0.096	40.536	-5.275	0.436	-2.430	0.174	-10.403	0.169	-0.026	0.005
7	0.110	45.673	-6.028	0.941	-3.234	0.248	-10.812	0.207	-0.032	-0.001
8	0.124	50.673	-6.782	1.337	-3.701	0.287	-11.143	0.227	-0.034	-0.005
9	0.138	55.576	-7.535	1.553	-3.941	0.302	-11.392	0.233	-0.033	-0.008
10	0.151	60.416	-8.289	1.763	-4.009	0.297	-11.562	0.236	-0.031	-0.009
11	0.165	65.209	-9.042	1.937	-3.966	0.287	-11.669	0.236	-0.027	-0.009
12	0.179	69.968	-9.799	2.075	-3.850	0.275	-11.729	0.233	-0.023	-0.009

e-quad and ion quad halfway through the magnet with thicker iron ring around e-quad (No corrector)

Field in iron ring around the electron quad is ~2T. We may NOT have enough shielding, but shouldn't be terrible either





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e-quad and ion quad halfway through the magnet with thicker iron ring around e-quad (No corrector)

Note: Change in harmonics are moderate. Maybe we can make it work with a few iteration.

Electron quad

q1BpF_Q2eF-apr14-a-x300-n1-ep.BNS | q1BpF_Q2eF-apr14-a-x300-n1-pe.BNS | q1BpF_Q2eF-harm-apr14-a-x300-n1-00.comi | q1BpF_Q2eF-apr1

eCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.069	29.651	-3.770	-0.049	-0.178	0.012	7.577	-0.012	-0.037	0.013
2	0.007	2.976	-0.377	-0.056	-0.177	0.011	7.577	-0.012	-0.037	0.013
3	0.028	11.903	-1.508	-0.057	-0.176	0.011	7.577	-0.012	-0.037	0.013
4	0.055	23.793	-3.016	-0.056	-0.176	0.011	7.577	-0.012	-0.037	0.013
5	0.083	35.238	-4.524	-0.030	-0.183	0.013	7.577	-0.012	-0.037	0.013
6	0.096	40.558	-5.278	0.005	-0.194	0.017	7.576	-0.012	-0.037	0.013
7	0.110	45.705	-6.032	0.058	-0.207	0.021	7.574	-0.012	-0.037	0.013
8	0.124	50.721	-6.787	0.148	-0.228	0.031	7.571	-0.011	-0.037	0.013
9	0.138	55.643	-7.542	0.368	-0.287	0.057	7.561	-0.008	-0.038	0.013
10	0.151	60.503	-8.298	0.911	-0.427	0.132	7.532	0.002	-0.041	0.014
11	0.165	65.319	-9.058	2.675	-0.683	0.394	7.404	0.034	-0.050	0.019
12	0.179	70.098	-9.832	9.213	-1.041	1.278	6.885	0.147	-0.068	0.033

Ion quad (design 66.2 T/m)

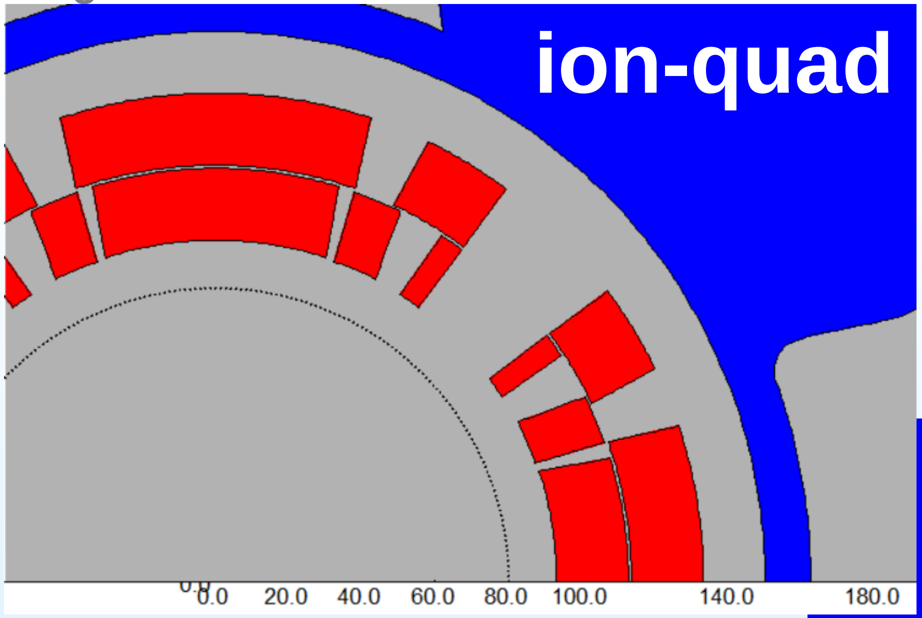
q1BpF_Q2eF-apr14-a-x300-n1-pe.BNS | q1BpF_Q2eF-apr14-a-x300-n1-00-ep.BNS | q1BpF_Q2eF-apr14-a-x300-n1-00-pe.BNS

pCASE	CUR(A)	pGrad(T/m)	eGrad(T/m	b3	b4	b5	b6	b7	b8	b9
1	0.069	29.651	-3.770	1.018	-0.106	0.090	-9.044	0.042	-0.002	0.012
2	0.007	2.976	-0.377	0.228	-0.197	-0.139	-8.187	-0.002	-0.008	0.008
3	0.028	11.903	-1.508	0.186	-0.202	-0.148	-8.208	-0.003	-0.008	0.008
4	0.055	23.793	-3.016	0.409	-0.111	-0.088	-8.389	0.006	-0.005	0.009
5	0.083	35.238	-4.524	1.191	-0.907	0.235	-9.743	0.118	-0.009	0.012
6	0.096	40.558	-5.278	1.360	-2.044	0.337	-10.337	0.192	-0.018	0.008
7	0.110	45.705	-6.032	2.114	-2.768	0.445	-10.727	0.238	-0.021	0.003
8	0.124	50.721	-6.787	2.820	-3.144	0.520	-11.039	0.265	-0.021	0.000
9	0.138	55.643	-7.542	3.369	-3.287	0.573	-11.271	0.278	-0.018	-0.002
10	0.151	60.503	-8.298	3.905	-3.260	0.604	-11.425	0.286	-0.014	-0.002
11	0.165	65.319	-9.058	4.373	-3.133	0.623	-11.518	0.290	-0.009	-0.002
12	0.179	70.098	-9.832	4.730	-2.956	0.632	-11.570	0.290	-0.004	-0.002

Summary

- **A novel technique is being developed to reduced cross-talk between two quads in a single yoke, placed in tight space. Iron saturation is controlled with proper cutouts and small coils.**
- **It is based on controlling the yoke saturation (experience from RHIC magnets - now standard around the world), where we reduced saturation from 40+ unit of sextupole to just a few units.**
- **Even though the solutions are not yet fully optimized, the harmonics remain small both in electron quad and proton quad at different level of excitation and at different axial locations (based on 2-d) analysis.**
- **The corrector strength doesn't have to be controlled too well.**
- **Next step: verification with the 3-d modelling but all signs are promising.**

Harmonic Analysis

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/Center of electron
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$CONS #eX0                          300.0
/
/ NUMBER OF CASES
/
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$CONS #Y0                           0.
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