Status of Magnet Designs for the Implementation of an MBA Lattice at the APS

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DLSR Workshop

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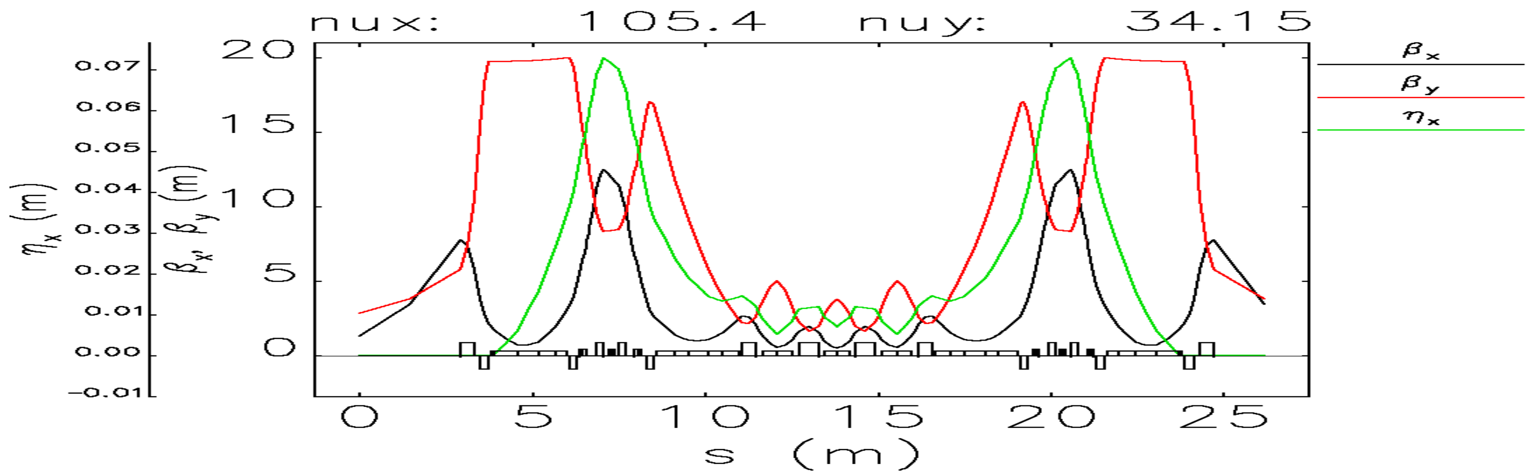
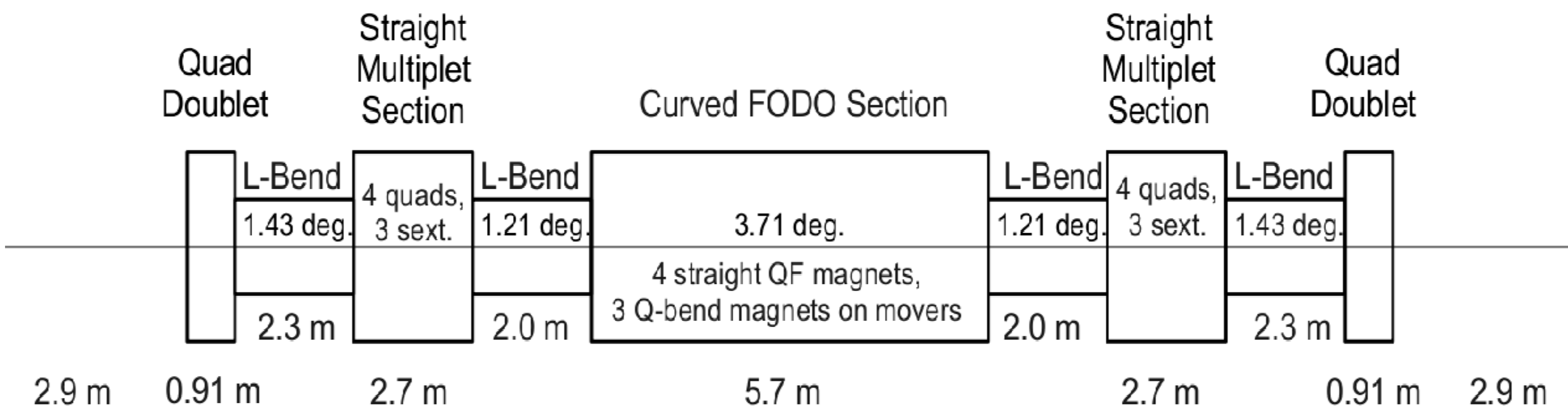
Accelerator Questions Needing Answers

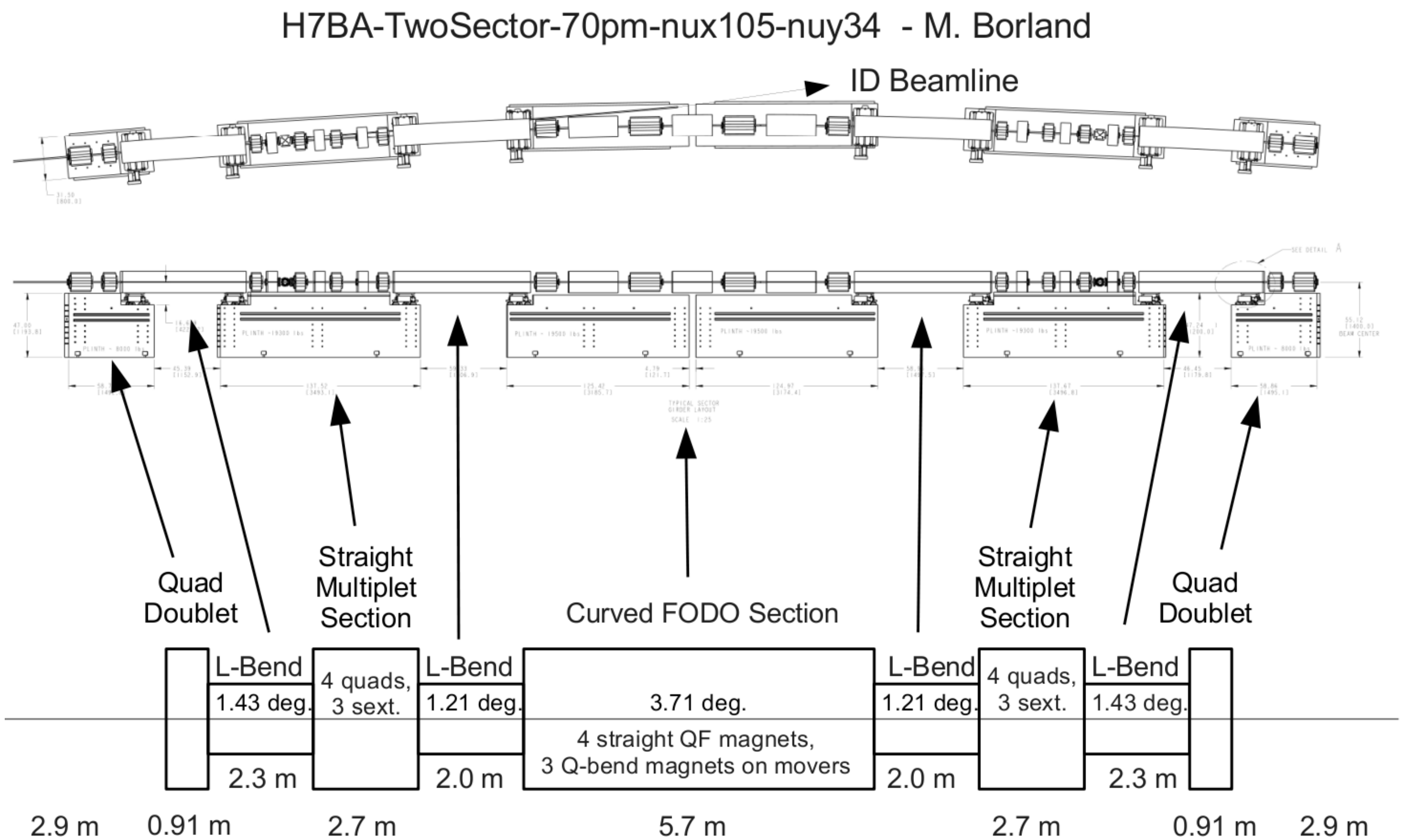
- What is the optimal magnet bore / chamber diameter?
- Magnets
  - Alignment, reproducibility, stability of magnet arrays
  - What is the impact of magnet-to-magnet crosstalk?
  - What limit is imposed by the use of steel vs. vanadium permendur?
  - What are the power supply requirements?

MBA Accelerator Design Development

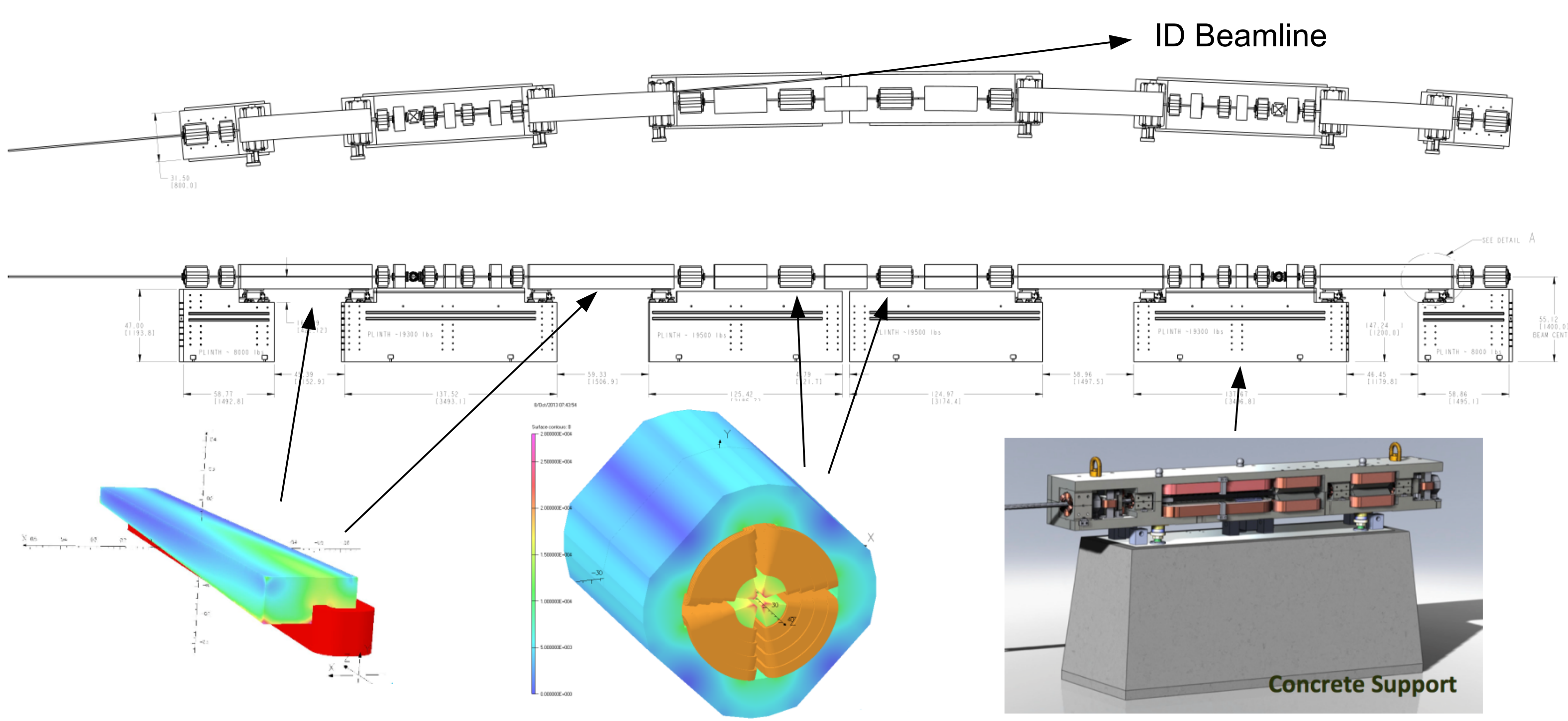




Accelerator Component Evolution



MBA Magnet Design Development



Longitudinal-gradient dipoles | Quadrupoles | Multi-Magnet Concept (MAX-IV)

MBA@APS Magnet Parameters

Table 2.5: Bending magnet parameters for H7BA-TwoSector-70pm-nux105-nuy34

Name	Length m	Angle deg	B_0 T	B' T/m	E_c keV	$P_{d,\text{integ}}$ W/mrad	P_d $W/mrad^2$
M1 (x80)							
M1.1	0.098	0.166	-0.589	-0.000	14.1	107.4	827.3
M1.2	0.862	0.754	-0.306	-0.000	7.3	55.7	429.5
M1.3	0.316	0.185	-0.205	-0.000	4.9	37.3	287.7
M1.4	0.769	0.201	-0.091	-0.000	2.2	16.7	128.4
M1.5	0.231	0.124	-0.188	-0.000	4.5	34.2	263.5
M2 (x80)							
M2.1	0.270	0.136	-0.175	-0.000	4.2	31.9	246.2
M2.2	0.328	0.178	-0.190	-0.000	4.5	34.6	266.4
M2.3	0.527	0.306	-0.203	-0.000	4.9	37.0	285.2
M2.4	0.383	0.235	-0.214	-0.000	5.1	39.1	301.3
M2.5	0.476	0.358	-0.262	-0.000	6.3	47.8	368.7
M3 (x80)							
M3.1	0.376	0.762	-0.707	44.798	16.9	128.9	993.4
M3.2	0.376	0.762	-0.707	44.798	16.9	128.9	993.4
M4 (x40)							
M4.1	0.329	0.333	-0.354	51.379	8.5	64.6	497.8
M4.2	0.329	0.333	-0.354	51.379	8.5	64.6	497.8

Table 2.6: Quadrupole data for H7BA-TwoSector-70pm-nux105-nuy34

Element Name	Length m	K_1 $1/m^2$	B' T/m	Count
Q1	0.437	2.890	-57.842	80
Q2	0.347	-2.685	53.742	80
Q3	0.233	-2.174	43.516	80
Q4	0.328	2.642	-52.885	80
Q5	0.162	1.959	-39.215	80
Q6	0.260	-2.294	45.912	80
Q7	0.484	3.356	-67.176	80
Q8	0.673	3.515	-70.350	80

Table 2.7: Sextupole data for H7BA-TwoSector-70pm-nux105-nuy34

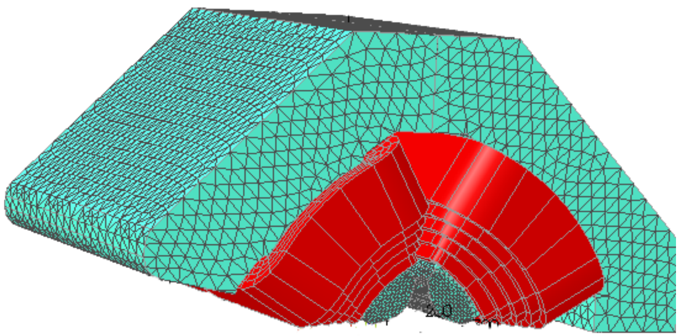
Element Name	Length m	K_2 $1/m^3$	B'' T/m^2	Count
S01A:S1	0.241	-170.500	3412.361	20
S01A:S2	0.368	190.610	-3814.830	20
S01A:S3	0.284	-193.441	3871.500	20
S01B:S3	0.284	-181.530	3633.113	20
S01B:S2	0.368	190.244	-3807.514	20
S01B:S1	0.241	-169.274	3387.824	20
S02A:S1	0.241	-175.549	3513.411	20
S02A:S2	0.368	192.636	-3855.387	20
S02A:S3	0.284	-177.450	3551.457	20
S02B:S3	0.284	-176.105	3524.538	20
S02B:S2	0.368	190.233	-3807.294	20
S02B:S1	0.241	-169.579	3393.928	20

MBA@APS Magnet Field Quality Requirements

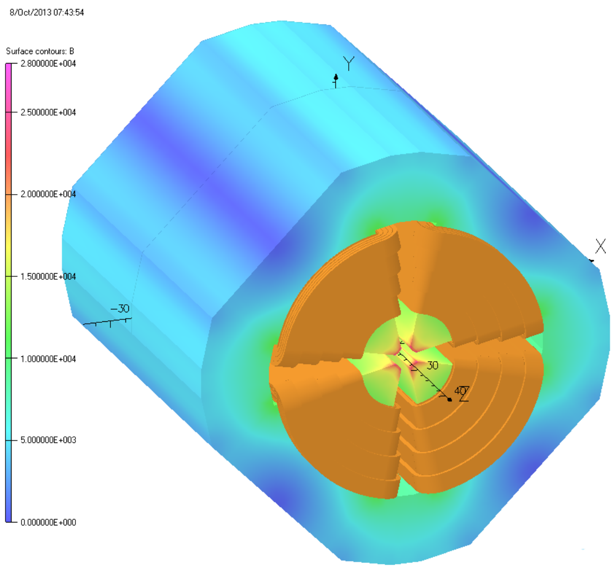
Main field type	m	n	Normal % error at $R = 1$ cm	Skew % error at $R = 1$ cm
dipole	0	-	TBD	TBD
quadrupole	1	5, 9, 13, 17	1 each	TBD
sextupole	2	8, 14, 20	1 each	TBD

APS-U Magnet Counts and Concepts

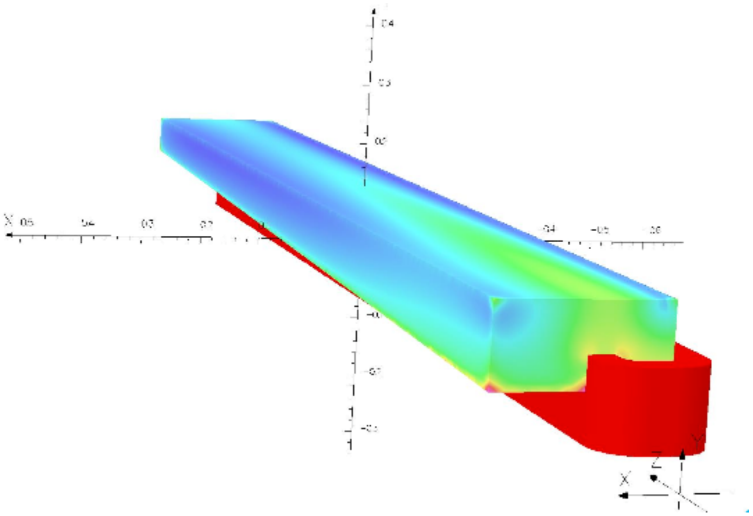
- Magnets
  - Long. Grad. dipoles 160
  - Trans. Grad. dipoles 120
  - Quadrupolesq 640
  - Sextupoles 240
  - Fast correctors 160



Transverse-gradient dipole

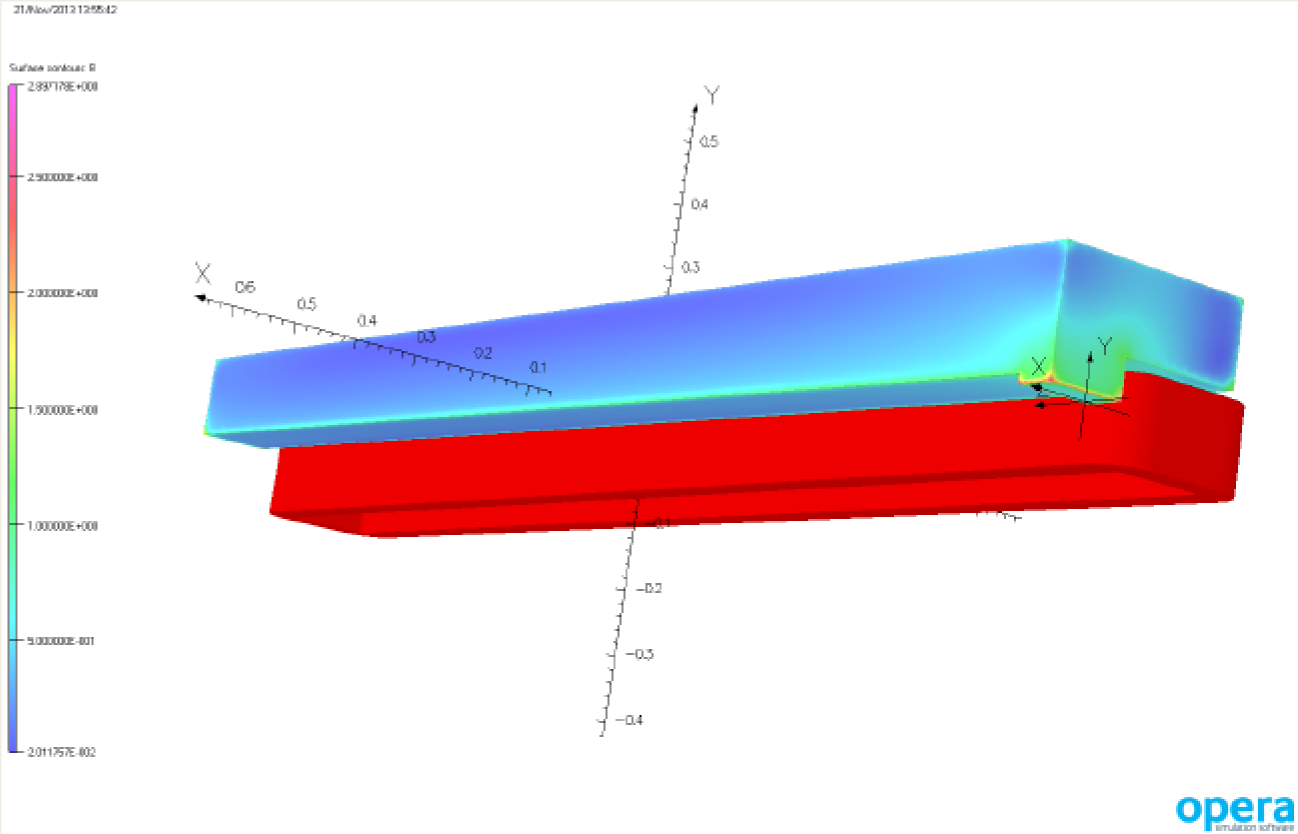


Quadrupole



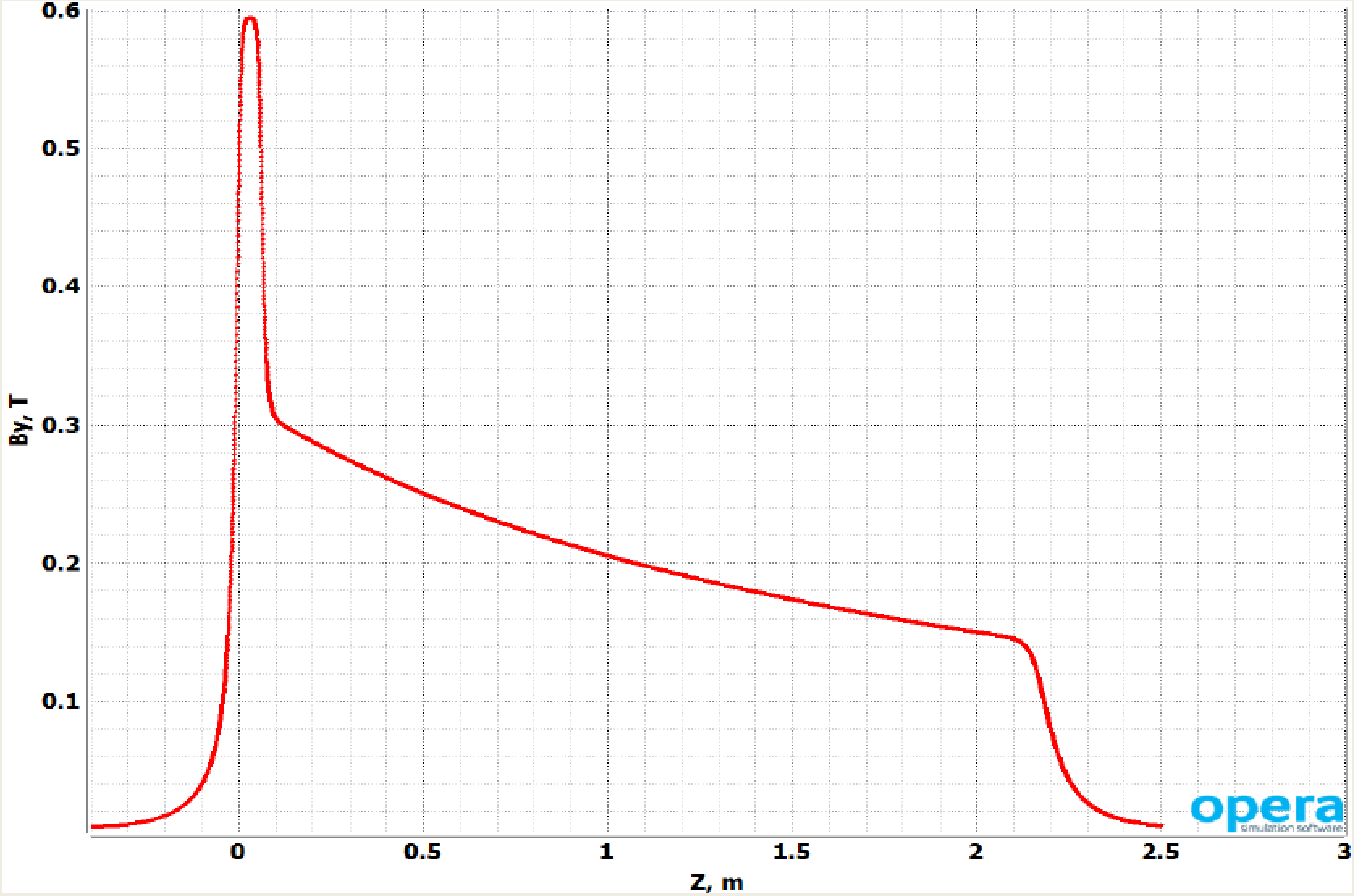
Longitudinal-gradient dipole

Longitudinal-Gradient Dipole M1 – Pre-prototype



The dipole magnet designed for the homogenous field in the transverse direction. M1 total length 2.163 m. Pole length=Coil length=Yoke length, Current 130 A, power losses 6 kW, water temperature rise 19 °C at 5 atm of water pressure drop, yoke weight 1700 kg.

M1 Magnet By(z) Field at x=0



Dipoles M3 and M4 – Transverse Gradient

- Exploring designs where requirements are achieved through either mechanical motions or additional electrical windings

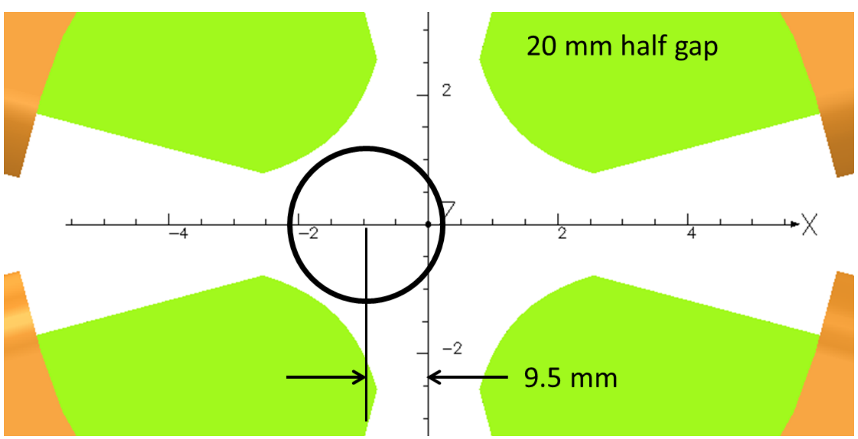


Table 3.3: Transverse-gradient dipole design parameters **

	Dipole type		
	M3	M4	units
Transverse position (max)	28	19	mm
Integrated dipole Field*	0.224	0.146	T-m
Integrated quadrupole Field*	16.442	16.666	T
Power*			W
Current (max)			A
Insertion length	0.54	0.508	m
Core length	0.43	0.348	m
Effective Length			m
Gap			mm
Vertical gap at transverse position (max)	26	26	mm
Central Dipole Field*	0.522	0.419	T
Central Quadrupole Field*	38.239	-47.892	T/m
Inductance			mH

* at maximum current and transverse position

**Note parameter fluidity

Quadrupoles

- Vanadium Permendur assumed for Q7 and Q8 pole tips
- Chromaticity Section must accommodate photon extraction
- Iterating to minimize number of magnet families
- Q1 and Q2 may become 'fast' magnets

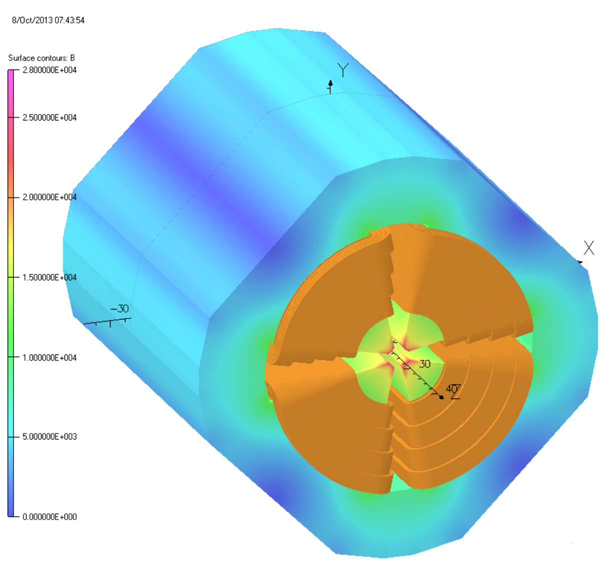


Table 3.4: Quadrupole design parameters

	Quadrupole type				
	0.569	0.401	0.259	0.213	units
Main magnet					
Integrated quadrupole Field*	49.5	34.8	20.1	15.7	T
Power *	5517	4570	3102	2737	W
Current (max)	146	153	147	147	A
Insertion length	0.569	0.401	0.259	0.213	m
Core length	0.511	0.343	0.201	0.155	m
Effective Length					m
Gap	26	26	26	26	mm
Vertical gap	10	10	10	10	mm
Central quadrupole field*	95	98.7	95.1	94.6	T/m
Inductance	95.3	65.8	41.2	33.4	mH
Vertical dipole winding					
Integrated field**					T-m
Power**					W
Current (max)					A
Central field**					T
Inductance					mH
Horizontal dipole winding					
Integrated field***					T-m
Power***					W
Current (max)					A
Central field***					T
Inductance					mH

* at maximum quadrupole current

** at maximum vertical dipole current

*** at maximum horizontal dipole current

Sextupoles

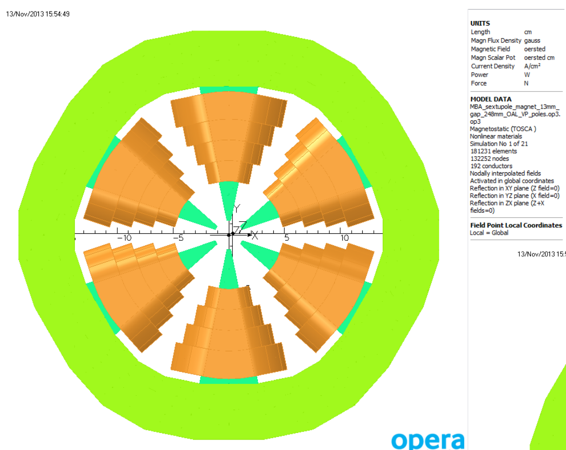
- Chromaticity Section must accommodate photon extraction
- Iterating to minimize number of magnet families
- Trading length for strength to make room for instrumentation, etc

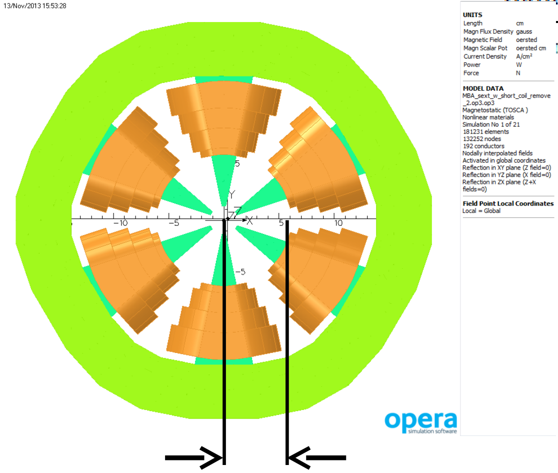
Table 3.5: Sextupole design parameters

	Sextupole type		
	0.186	0.248	units
Main magnet			
Integrated sextupole field (B'')*	898	1348	T/m
Power *	379	519	W
Current (max)	71	72	A
Insertion length	0.186	0.248	m
Core length	0.125	0.187	m
Effective Length			m
Gap	26	26	mm
Vertical gap	10	10	mm
Central sextupole field*	6796	6992	T/m**2
Skew-quadrupole winding			
Integrated field**			T
Power**			W
Current (max)			A
Central field**			T/m
Inductance			mH

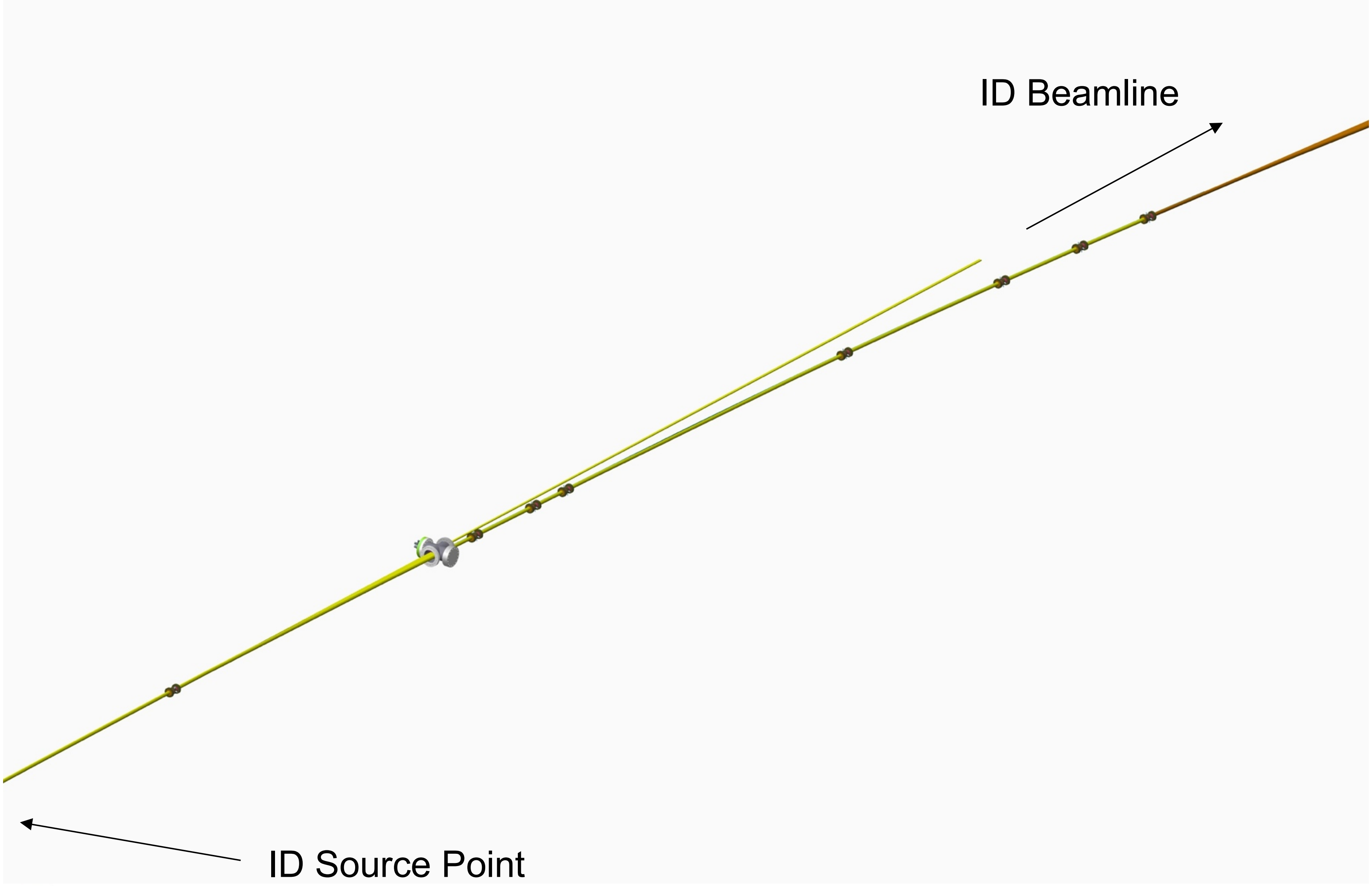
maximum sextupole current

maximum skew quadrupole current

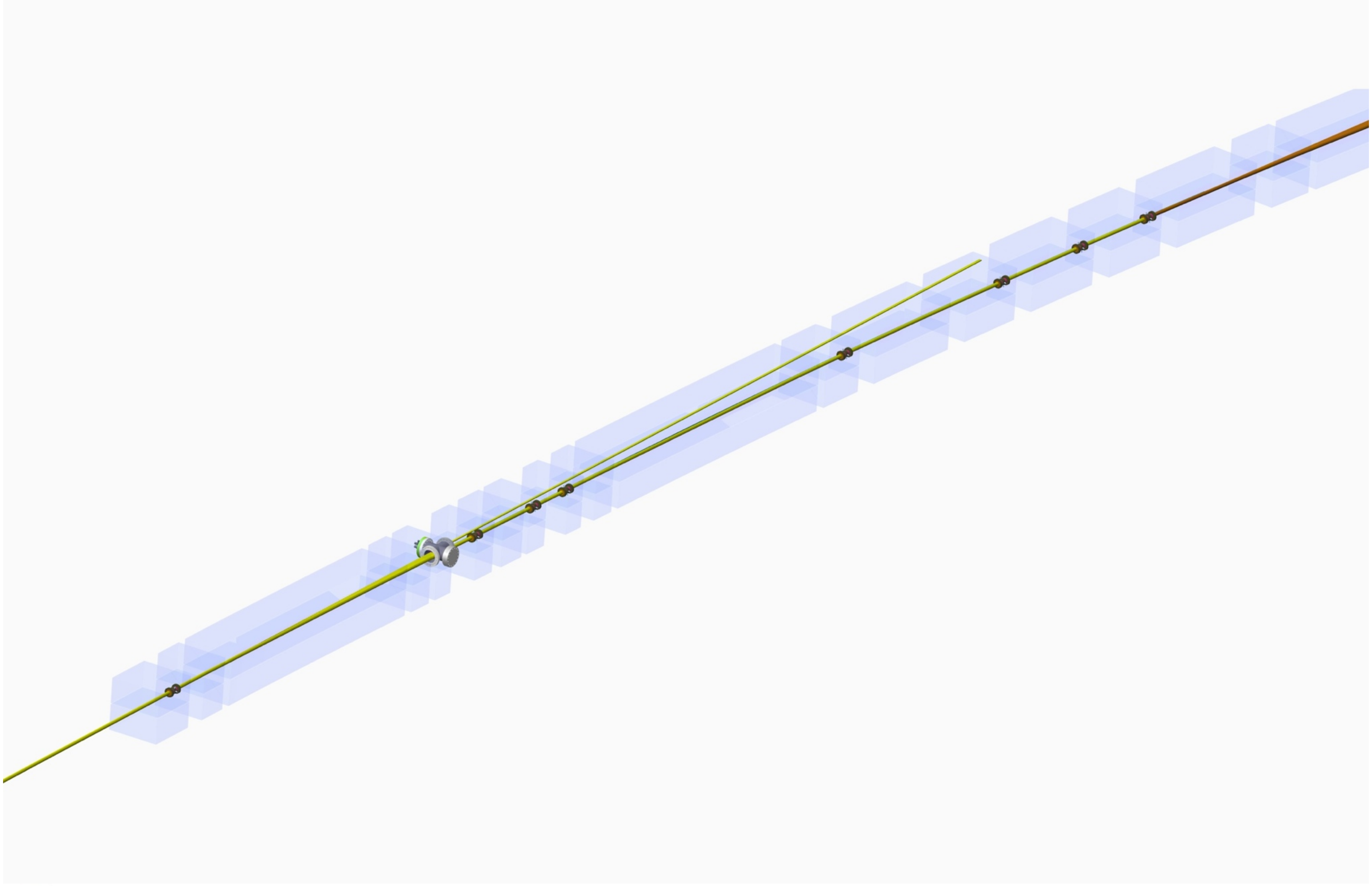




APS MBA Design Development



APS MBA Design Development



APS MBA Design Development

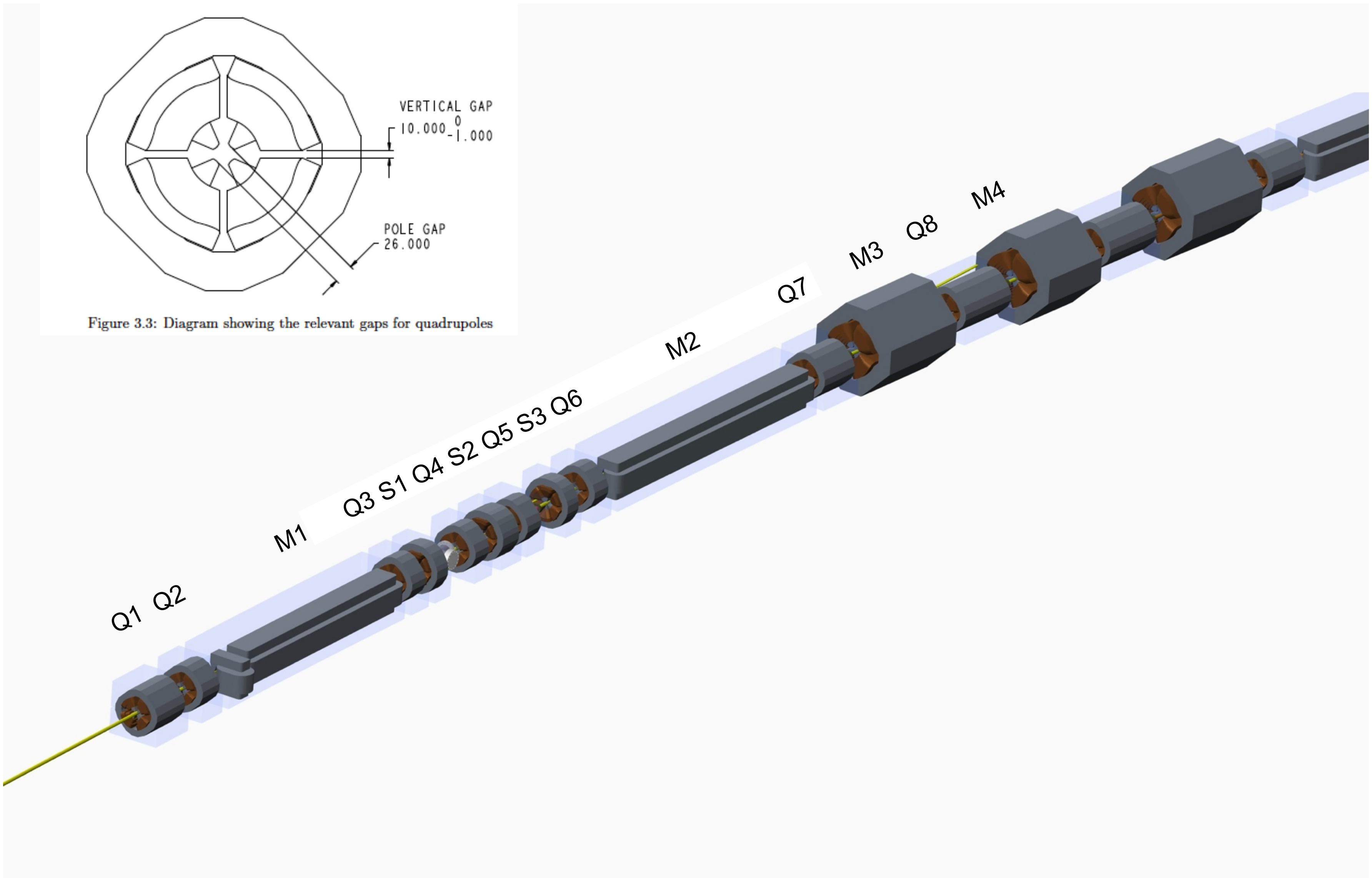


Figure 3.3: Diagram showing the relevant gaps for quadrupoles

Summary

The Advanced Photon Source is studying the implementation of an MBA Lattice to replace the existing APS storage ring

Lattice includes 33 magnets / sector in 40 sectors:

- 4 longitudinal-gradient dipoles
- 3 transverse-gradient dipoles
- 16 quadrupoles with h/v trim windings
- 6 sextupoles with skew quad windings
- 4 fast h/v steering corrector magnets

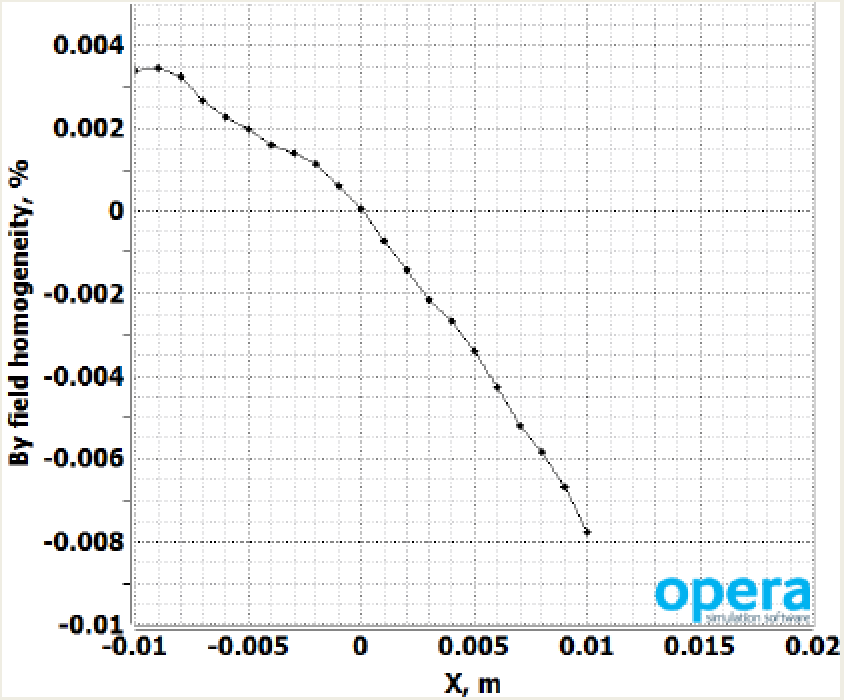
Prototypes for longitudinal gradient dipole and straight multiple-magnet arrays are being pursued in FY13.

On-axis swap-out injection scheme allows relaxed field quality requirements.

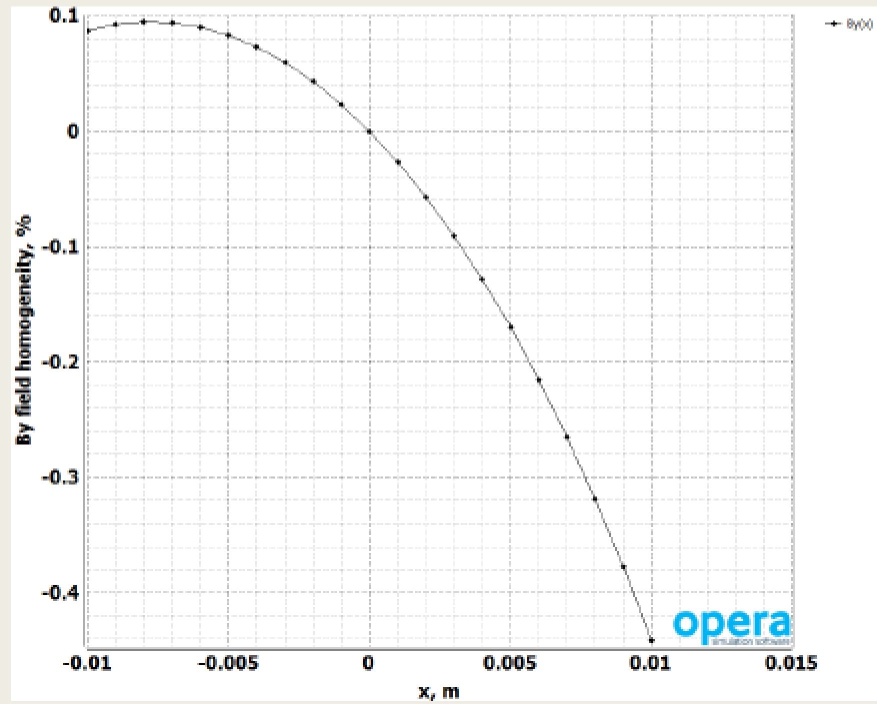
Primary challenges are high gradients, small apertures, alignment, integration with vacuum, and accelerated installation.

Backujp Slides

M1 Magnet By(x) Field



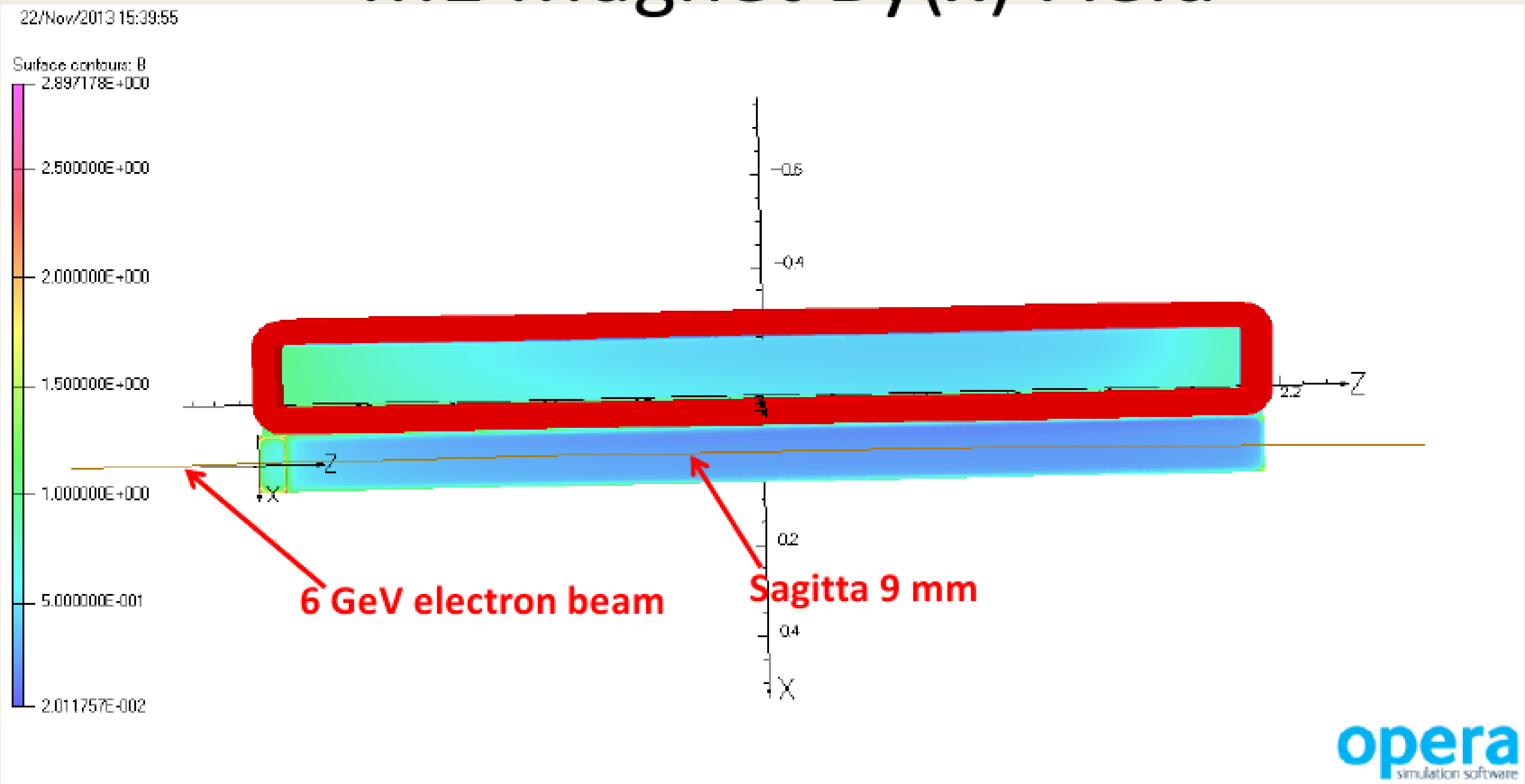
Front end at z=0.0295 m



Far end at z=2.1 m

At 130 A coil current, pole width 0.12 m, pole length 2.163 m :
Total integrated field at x=0 is 0.500744 T-m (Spec. 0.49968 T-m)
Integrated field for the first front section is 0.0574 T-m (Spec. 0.0577 T-m)
Integrated field homogeneity at x=-0.01 m is +0.1%, at x=0.01 m is -0.2 % (Spec. 0.3%)
Peak field is 0.5948 T (Spec. 0.589 T)
No shims added.

M1 Magnet By(x) Field



The magnet rotated -0.715° around y-axis to provide the beam path closer to the beam pipe central axis. Center of the beam shift at the front end dx=-0.012 mm, at the far end dx= -0.28 mm. Max dx= - 9 mm at z= 0.809 m.

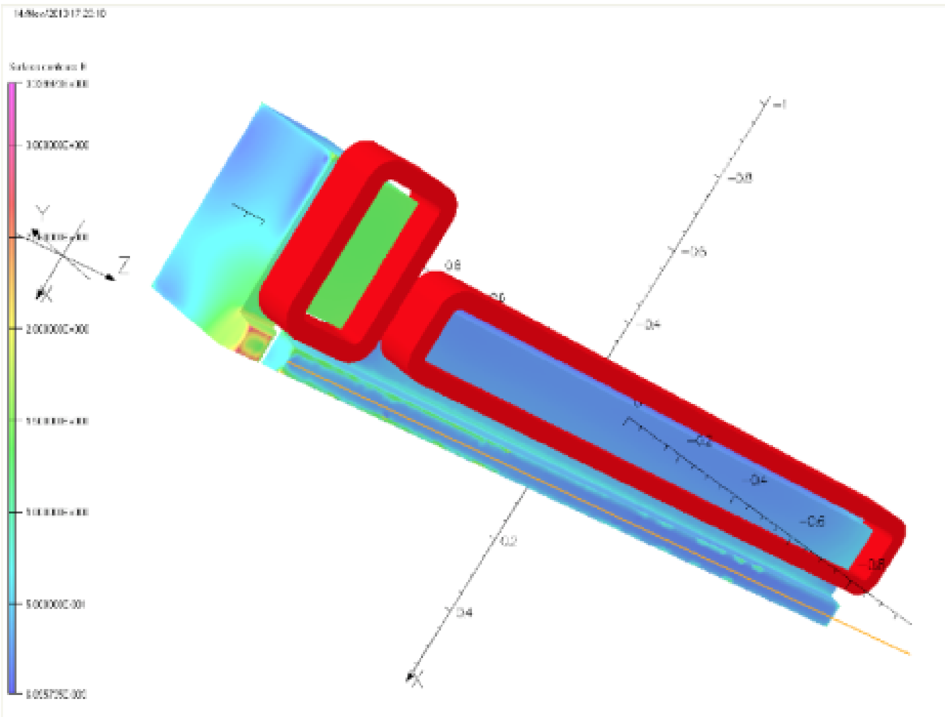
Dipoles M1 and M2 – Longitudinal Gradient

- Exploring C-Magnet designs, with field gradient determined by machining of iron pole along length
  - Possibility of some sextupole in design as well
  - Pursuing a Pre-Production Prototype in 2014 to better understand manufacturing, measurements, and tolerances

Table 3.2: Longitudinal-gradient dipole design parameters

	Dipole type		
	M1	M2	units
Integrated Field*	0.506	0.46	T-m
Power *	4030	2680	W
Current (max)	120	120	A
Insertion length	2.3	2.35	m
Core length	2.168	2.35	m
Minimum gap	26	26	mm
Maximum gap	65	47	mm
Field at minimum gap*	0.68	0.26	T
Field at maximum gap*	0.13	0.14	T
Inductance			mH

* at maximum current



Early 1-T Prototype Concept