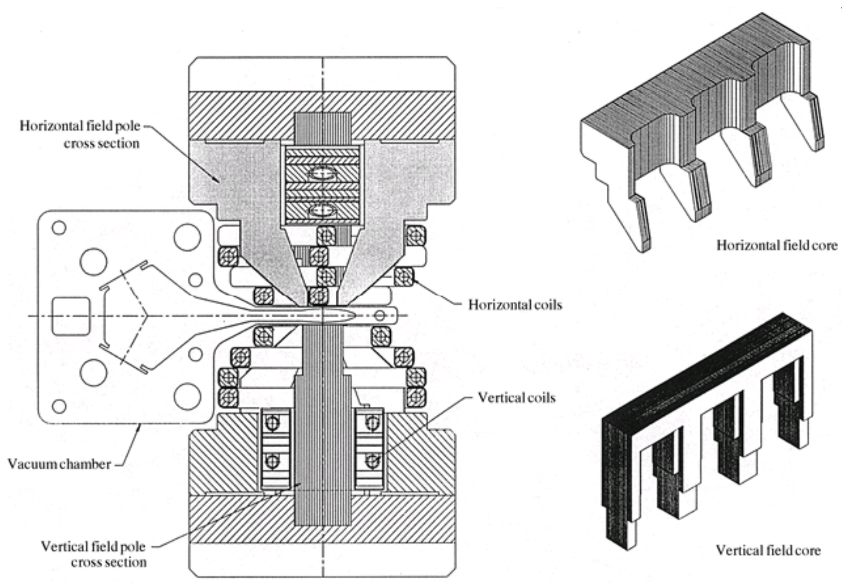
A Review of the IEX Undulator

Intermediate Energy X-ray

By Mark Jaski

History

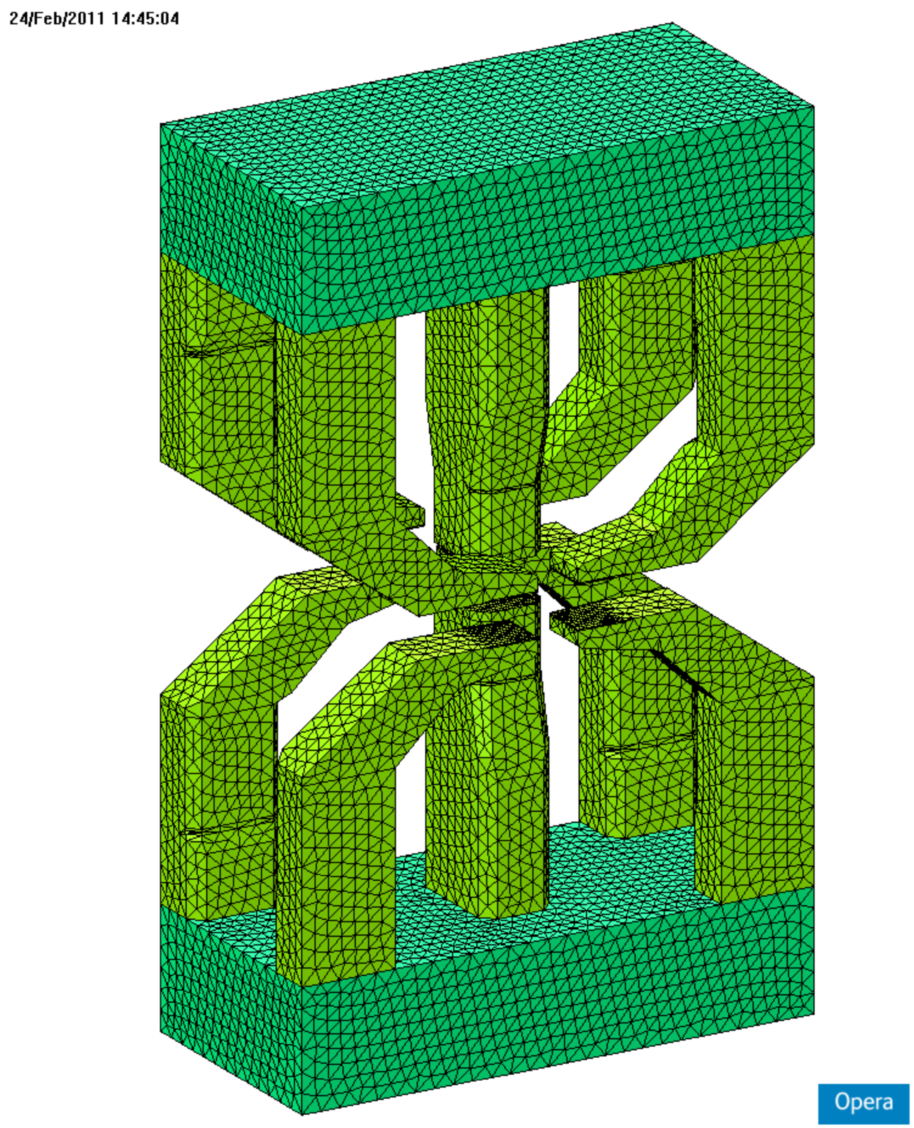


The CPU in Sector 4

- The project started with a request if we could do something similar to the circular polarizing undulator (CPU) that is installed in sector 4.
- Several possible undulator designs were discussed
  - Apple II (all permanent magnet)
  - Electromagnetic/Permanent magnet
  - Electromagnetic
- The device had to be quasiperiodic.

Optimization

- OPERA Optimizer was used to optimize the pole geometry
- Optimization was done on a ½ period model
- The currents were chosen such that the Bx and By coils were limited to 40 and 45 watts respectively. This constraint keeps the coil temperatures down.
- The geometry was modified, dimensions were changed, and the Bx and By effective fields were calculated.
- This process was repeated over and over again until the maximum Bx+By field was obtained.

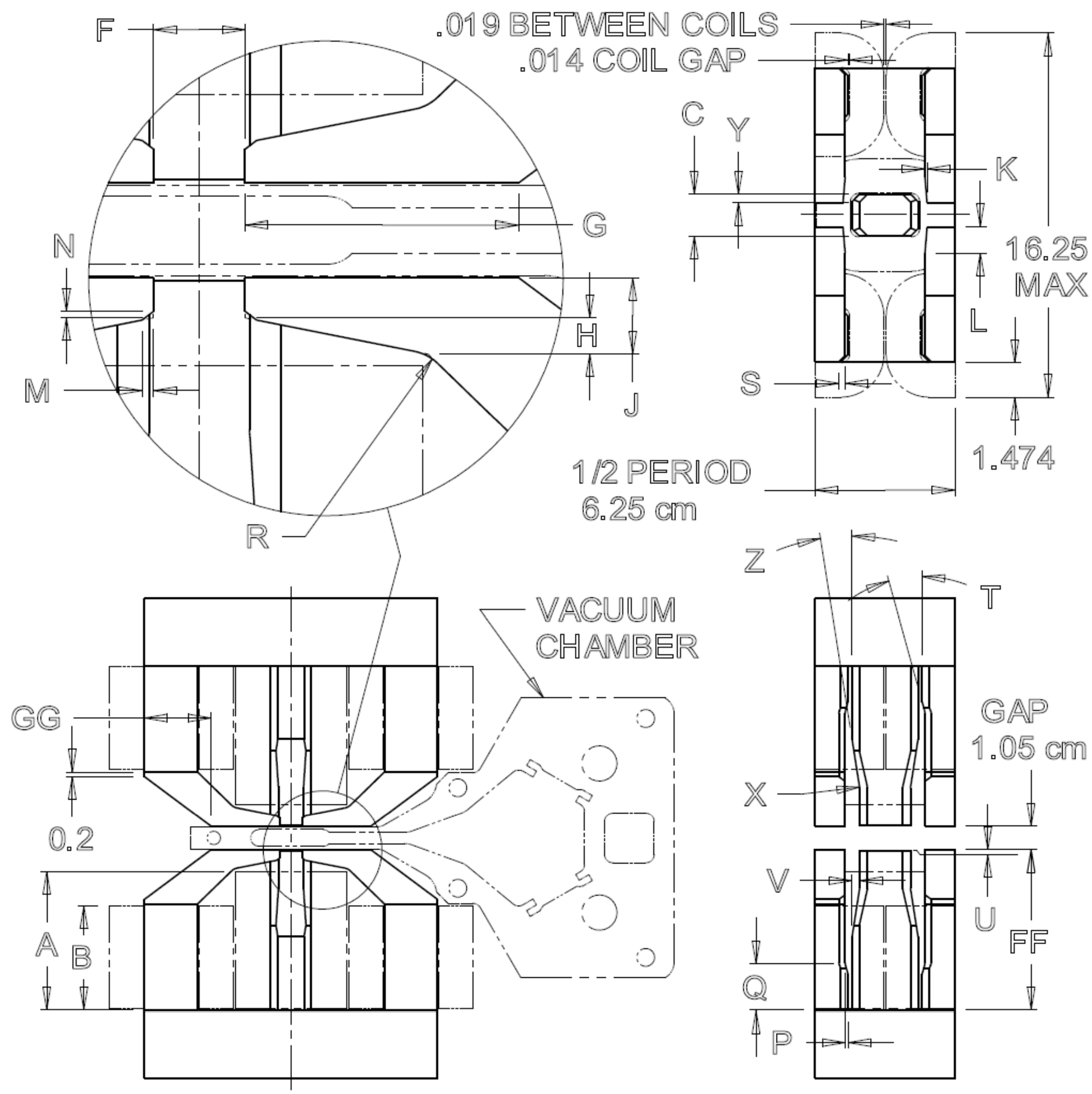


Optimization Model Dimensions

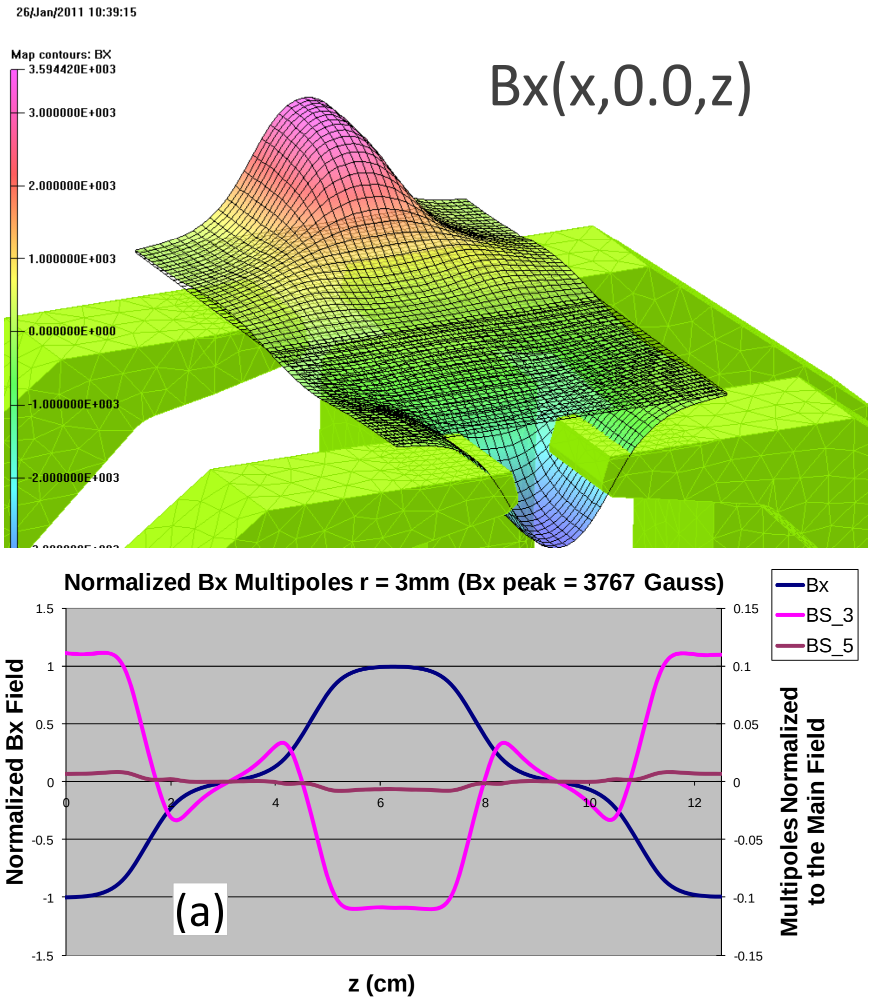
Table 3: Optimized dimensions.

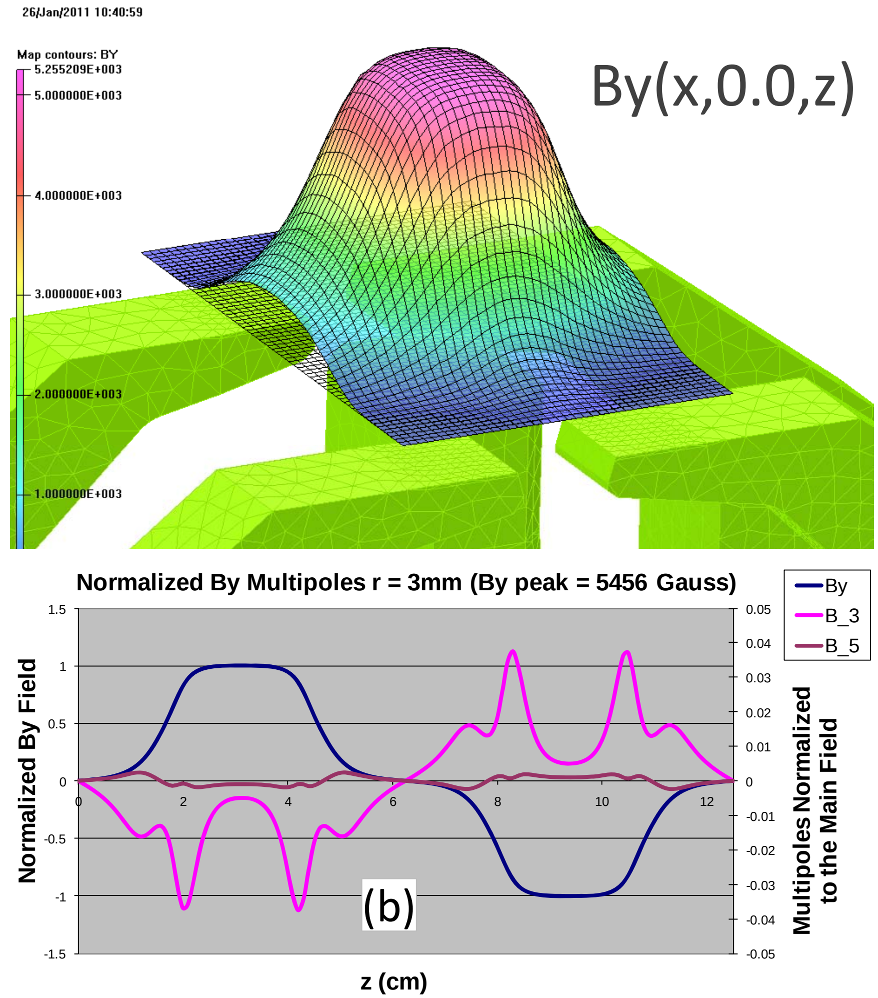
I.D.	Description	Optimal Value	unit
A	By coil height max	6.3	cm
B	Bx coil height max	5.034	cm
C	By pole width	1.823	cm
D*	Conductor size max	0.3264	cm
E*	Conductor size min	0.3231	cm
F	Bx pole gap	1.021	cm
G	Bx pole ball	3.561	cm
H	Bx toenail chamfer	0.404	cm
J	Bx pole toe	0.852	cm
K	Bx tip chamfer z	0.094	cm
L	Bx tip chamfer x	1.176	cm
M	Bx toe tip chamfer x	0.13	cm
N	Bx toe tip chamfer y	0.072	cm
P	Bx cut z	0.131	cm
Q	Bx base height	2.057	cm
R	Bx radius	0.5	cm
S	Bx chamfer	0.276	cm
T	Bx angle	15.5	°
U	By tip offset	0.037	cm
V	By cut z	0.341	cm
W	By base height	5.417	cm
X	By radius	0.5	cm
Y	By chamfer	0.351	cm
Z	By angle	9	°
AA*	Conductor radius	0.081	cm
BB*	Conductor insulation	0.049	cm
CC*	Inner coil fiberglass	0.046	cm
DD*	Outer coil fiberglass	0.036	cm
EE*	Conductor allowance	0.0076	cm
FF	Bx pole height	2.218	cm
GG	Bx pole heel width	2.973	cm

* Not shown in figure 2



Field Plots





Bx Field

By Field

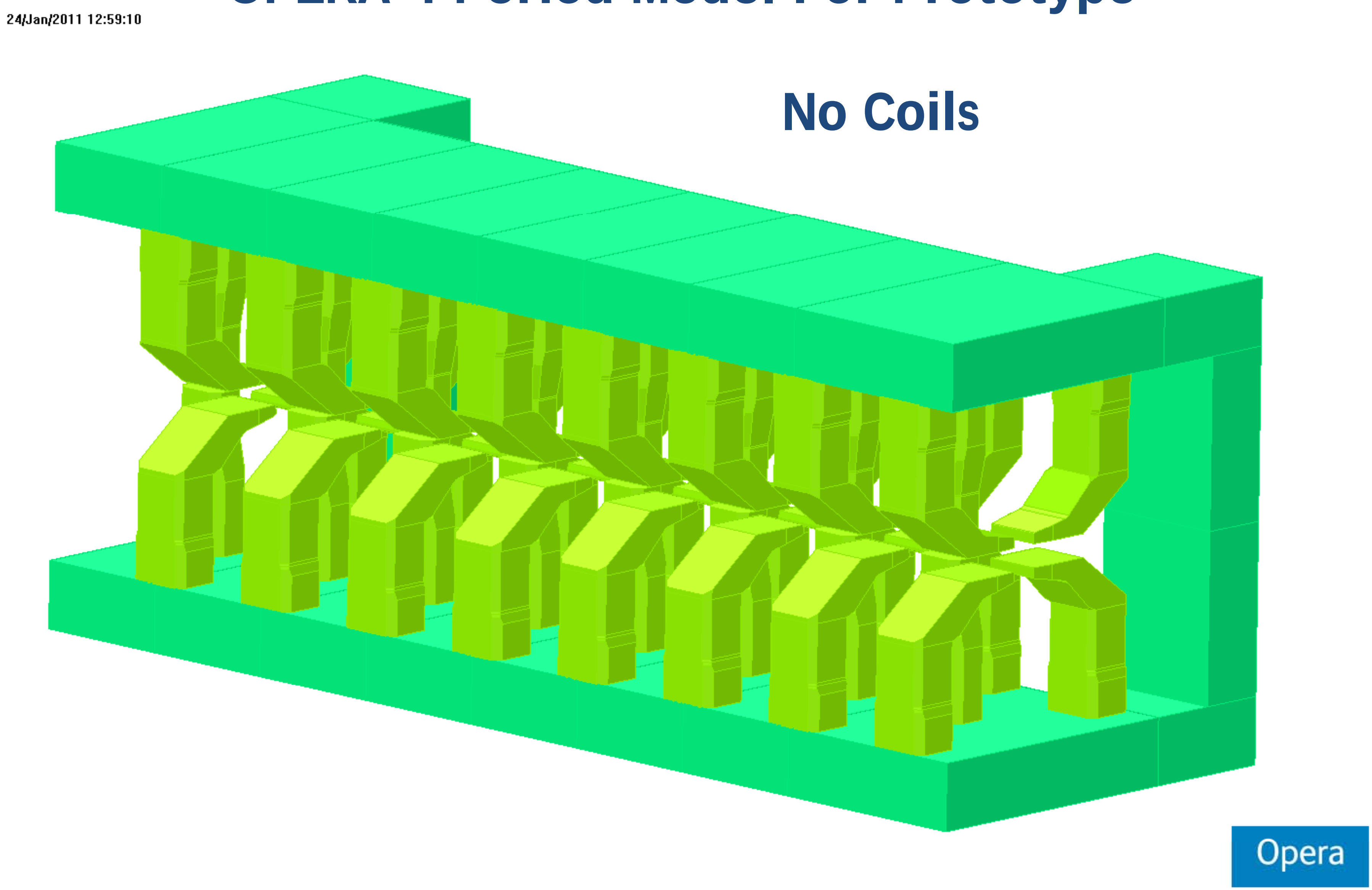
IEX Selected Parameters

General	Period	12.5	cm
	Gap	10.5	mm
	Periods per device (including end poles)	38	Periods
Horizontal Linear Polarization	Minimum Photon Energy	250	eV
	Required vertical effective field	4510	Gauss
	Current density in the copper conductor[2]	4.7	A/mm^2
	Current	47.6	A
	Turns per coil[1]	62	turns
	Ampere-turns[1, 2]	2951	Ampere-turns
	Watts per coil[1, 2]	44.9	Watts
	Total number of coils	152	Each
	Total power[2]	6630	Watts
	Maximum temperature of coils	100	°C
Vertical Linear Polarization	Minimum Photon Energy	440	eV
	Required horizontal effective field	3310	Gauss
	Current density in the copper conductor[2]	4.9	A/mm^2
	Current	50.3	A
	Turns per coil[1]	46	turns
	Ampere-turns[1, 2]	2314	Ampere-turns
	Watts per coil[1, 2]	40.2	Watts
	Total number of coils	304	Each
	Total power[2]	11,868	Watts
	Maximum temperature of coils	100	°C
Circular Polarization	Minimum Photon Energy	440	eV
	Required horizontal and vertical effective field	2340	Gauss
	Current at vertical effective field	20.7	A
	Current at horizontal effective field	34.2	A

[1]End coils are smaller

[2]At the required effective field

OPERA 4 Period Model For Prototype



OPERA 4 Period Model For Prototype

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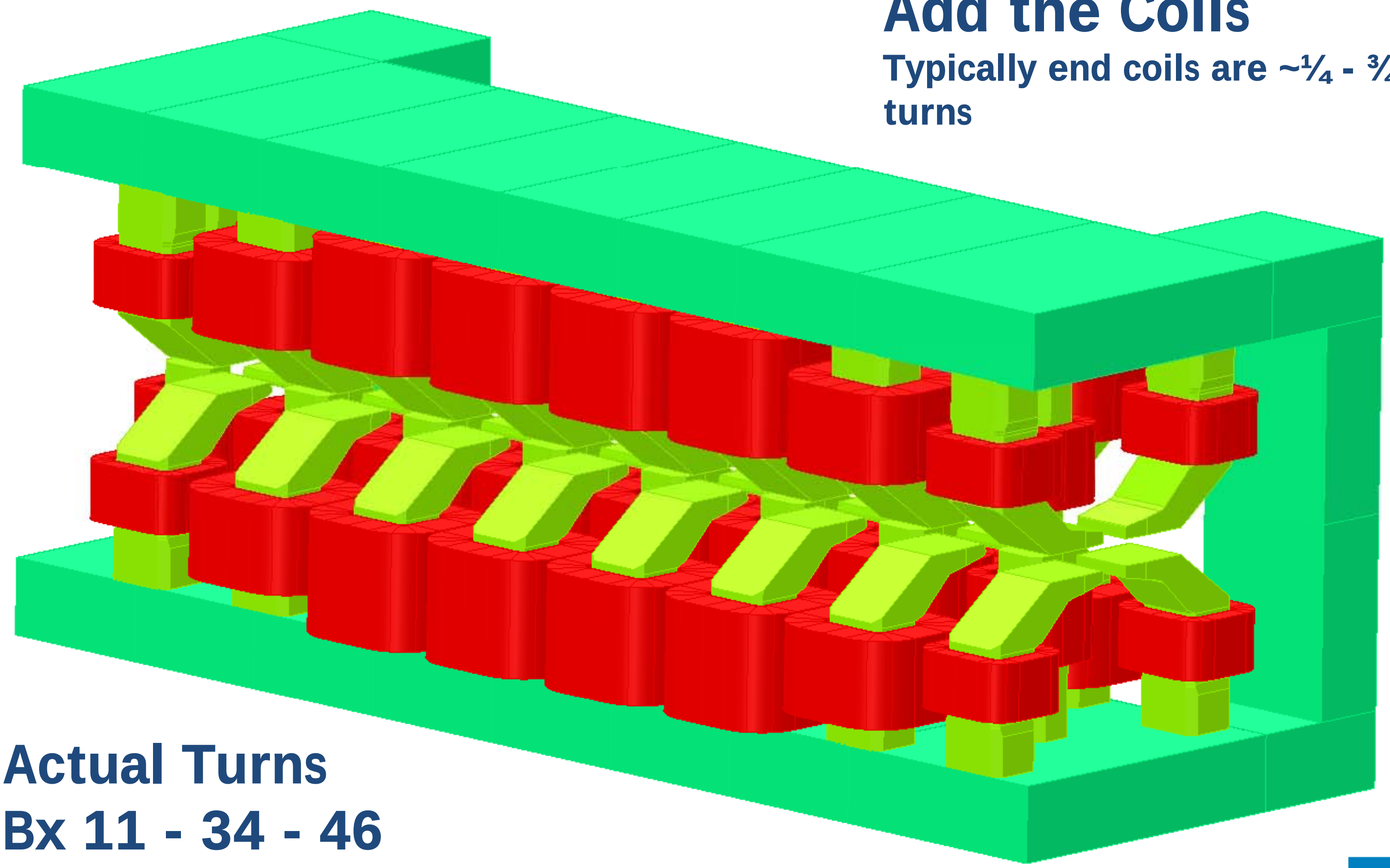

Add the Coils

Typically end coils are ~¼ - ¾ - 1 turns

Actual Turns
Bx 11 - 34 - 46
By 15 - 42 - 62

Opera

OPERA 4 Period Model For Prototype

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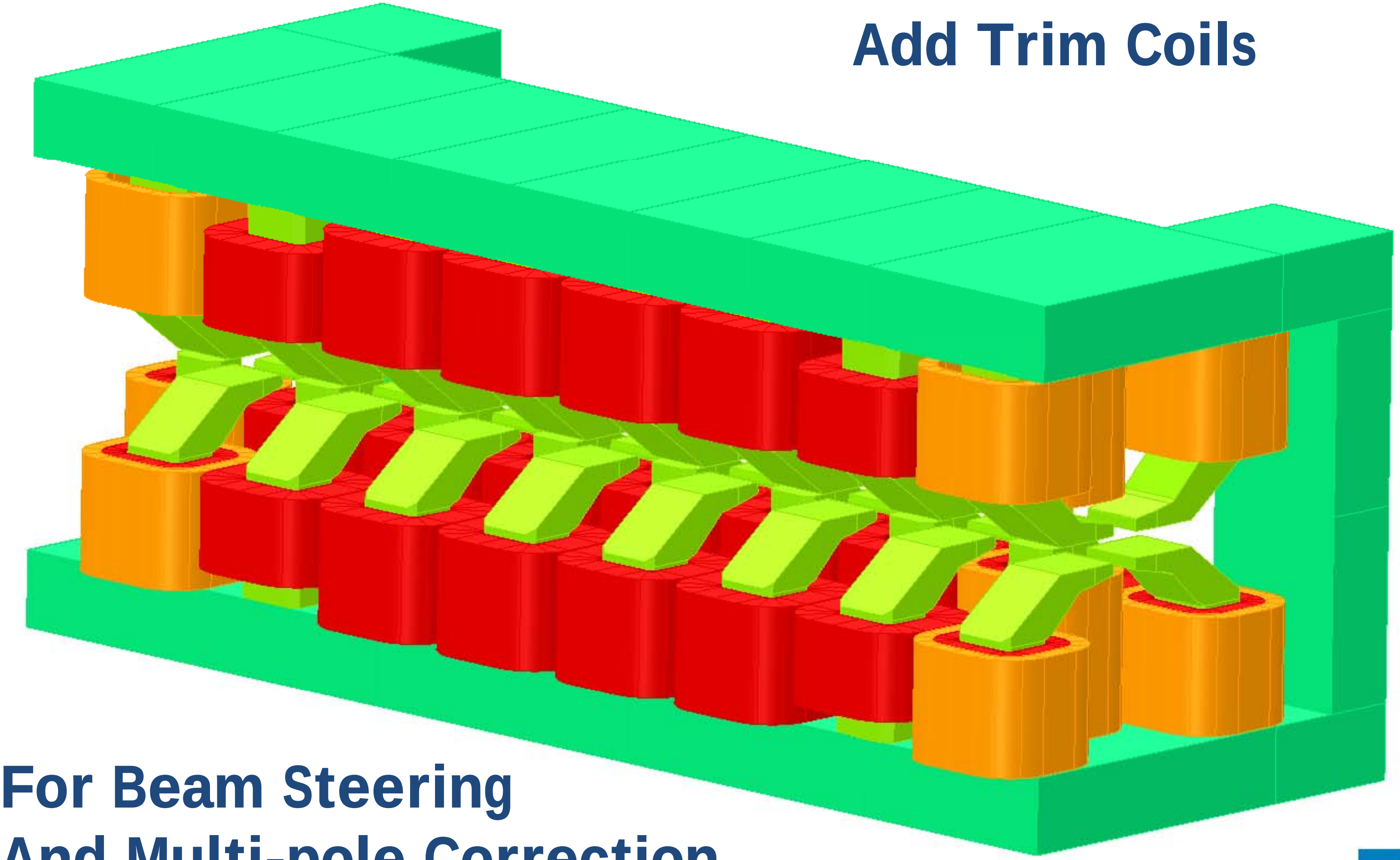


Add Trim Coils

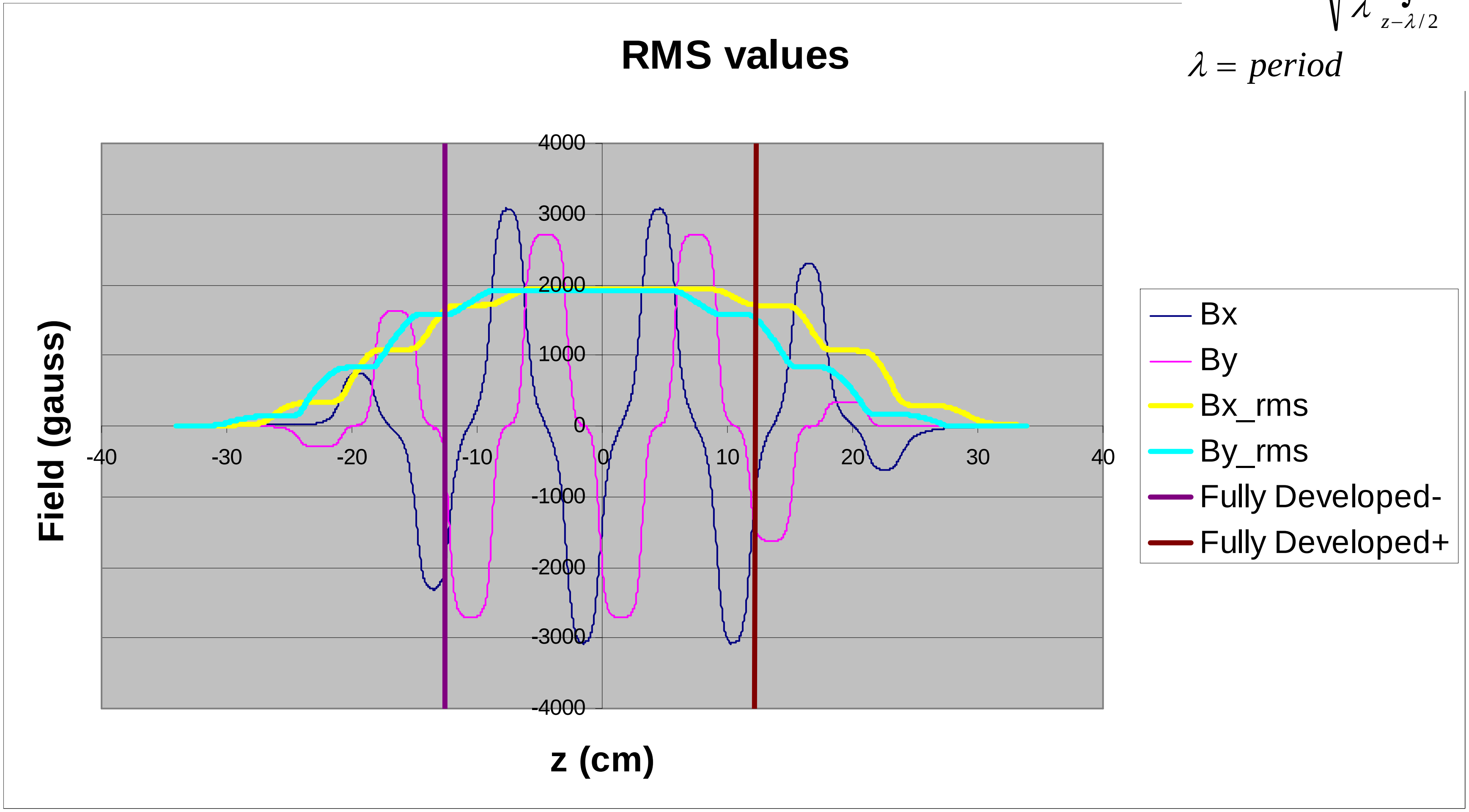
For Beam Steering
And Multi-pole Correction

Opera

4 Period Prototype. Why only 4 periods?

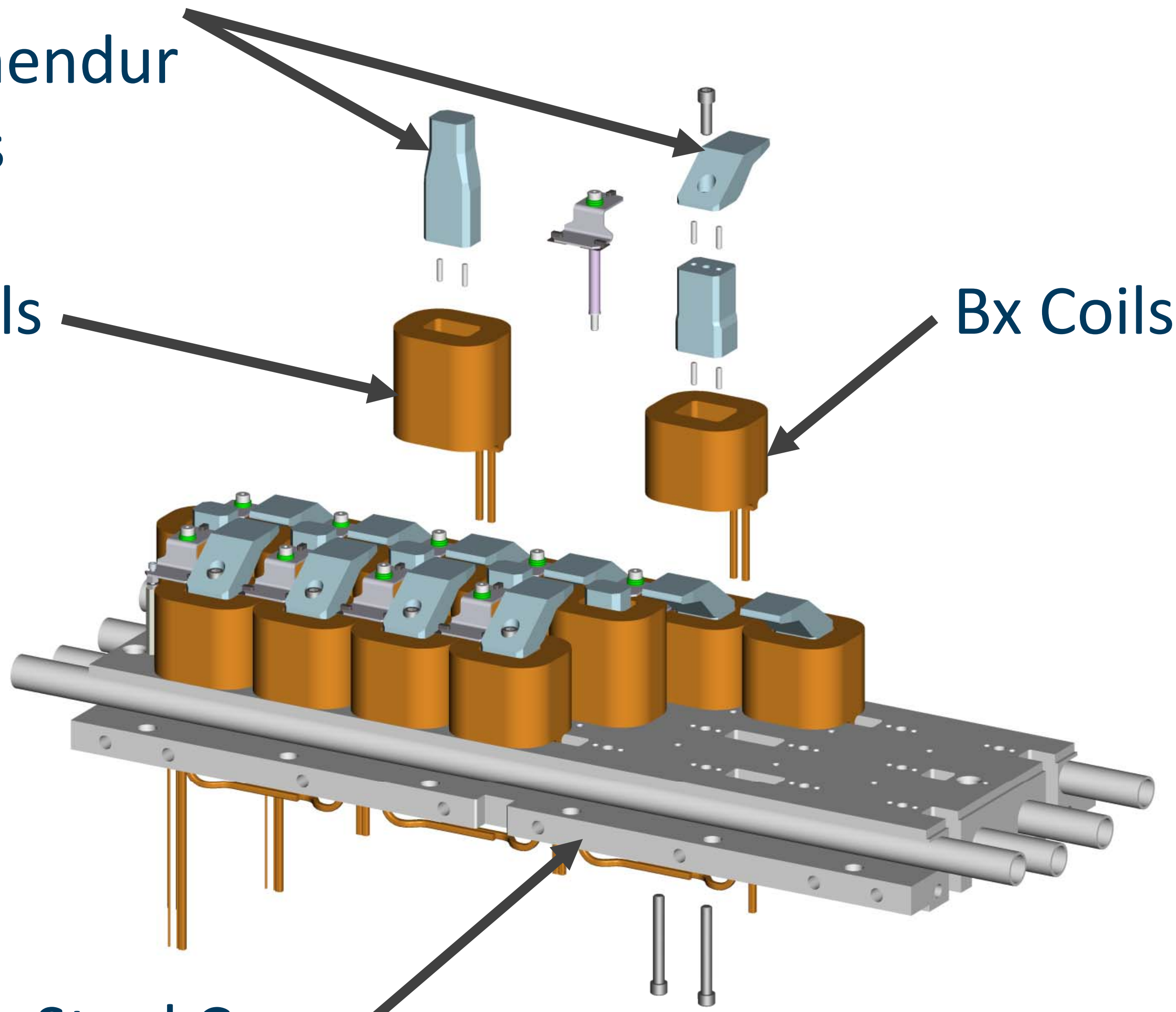
$$B_{rms}(z) = \sqrt{\frac{1}{\lambda}\int_{z-\lambda/2}^{z+\lambda/2} B^2 dz}$$

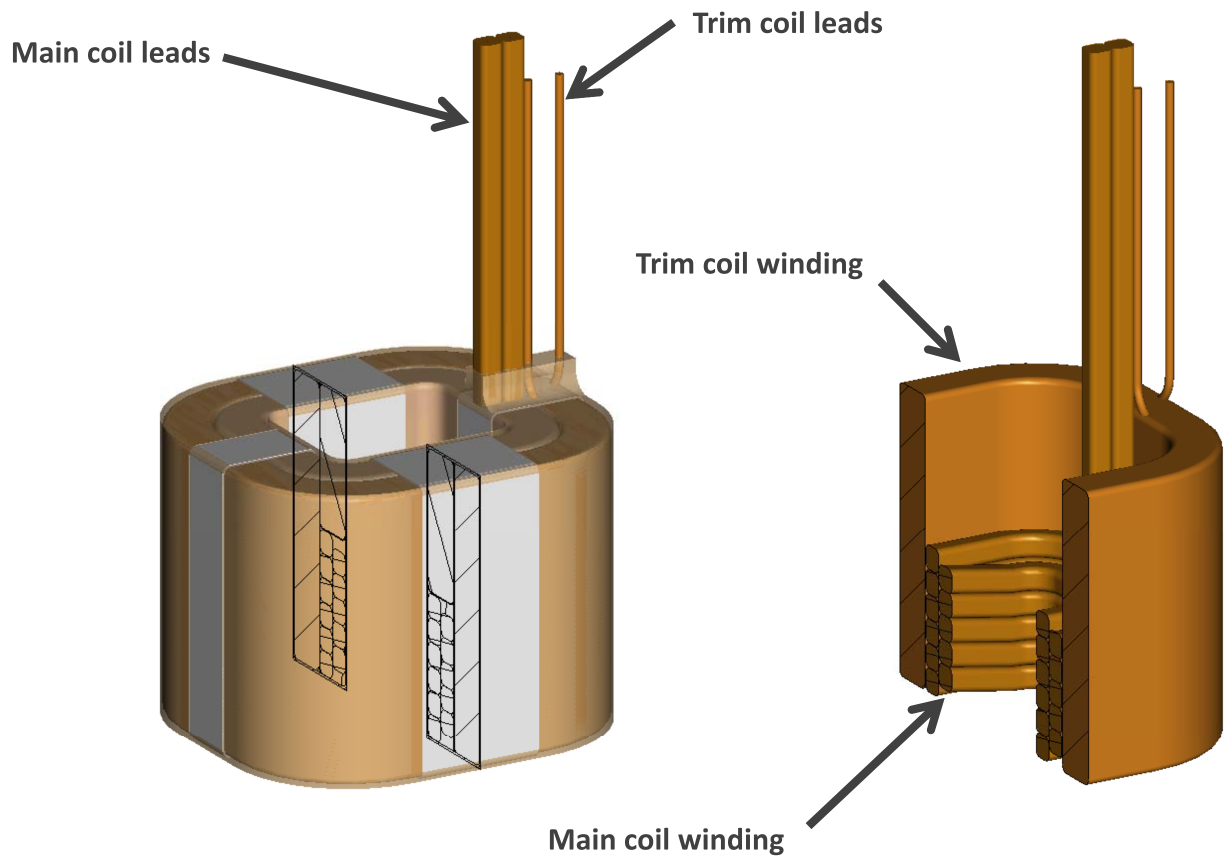
$$\lambda = period$$



~2 full Period of fully developed field

General Assembly Exploded View

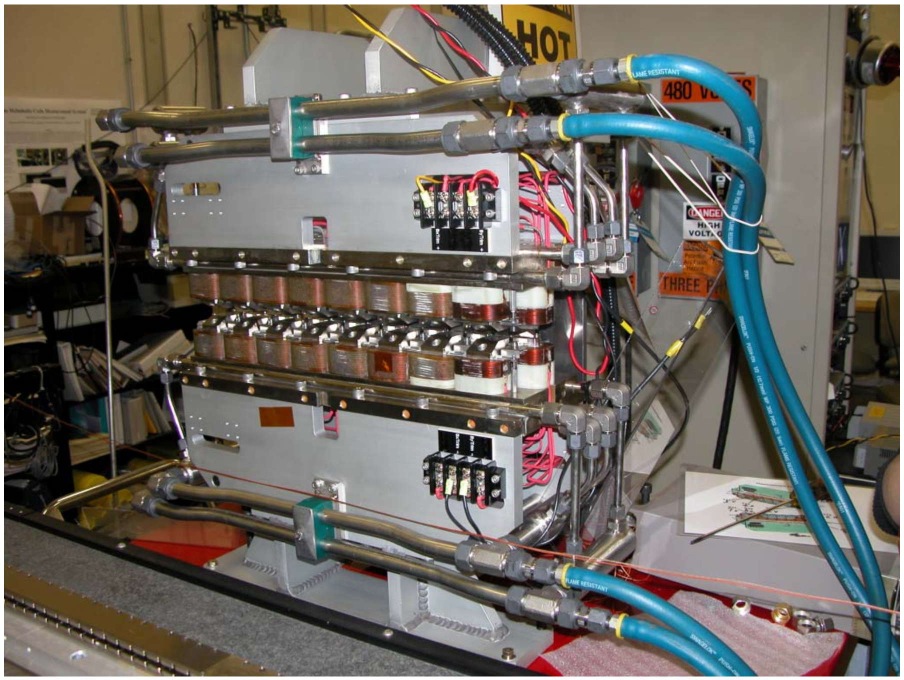




Trim Coils

- Two windings per coil
  - Main coil winding
  - Trim coil winding

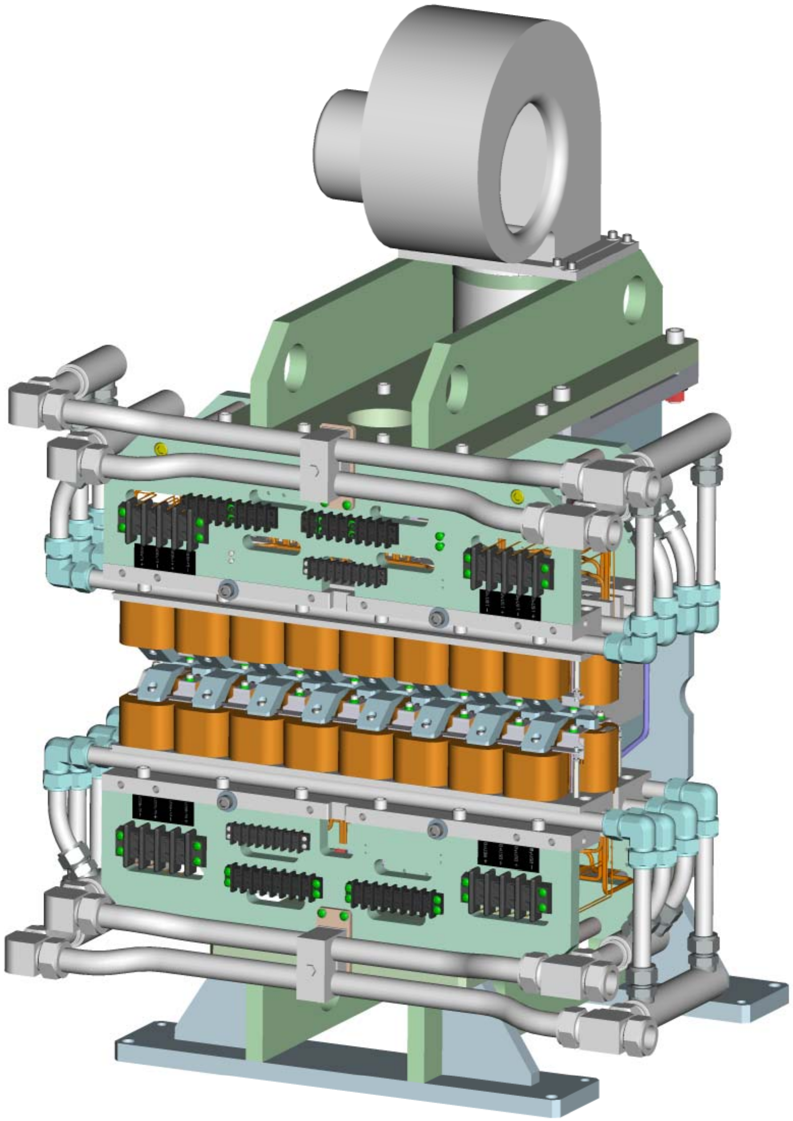
IEX Prototype 1 (4 periods)

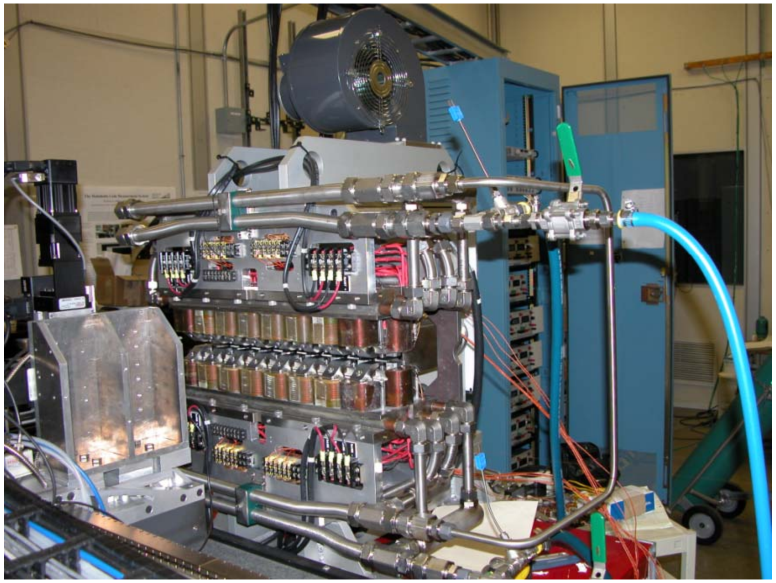


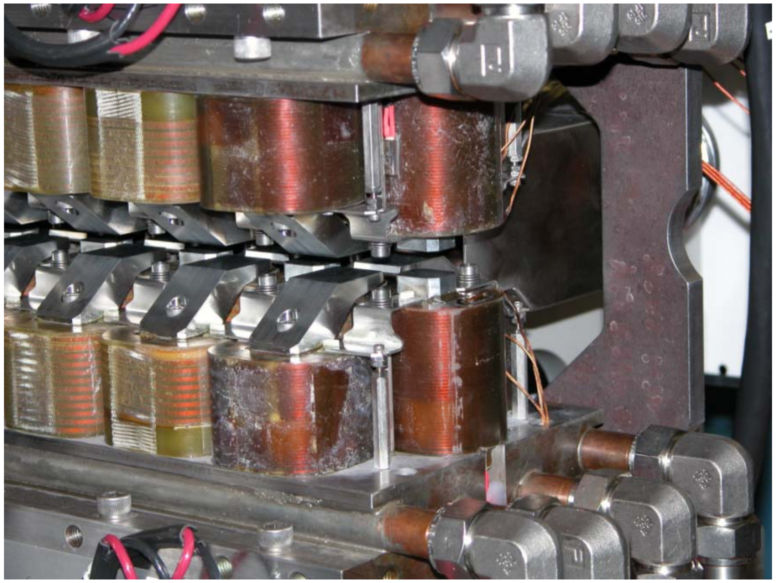
Major Changes

- Magnetic field roll off was too large for storage ring injection. The poles will be made wider.
- Plating reduced the field by ~1%. The poles are not plated.
- The gap was changed from 11.0 mm to 10.5 mm to lower the maximum current to lower the temperature rise.
- The period was changed from 12.0 cm to 12.5 cm to make the coils larger and lower the field requirements.

IEX Prototype 2

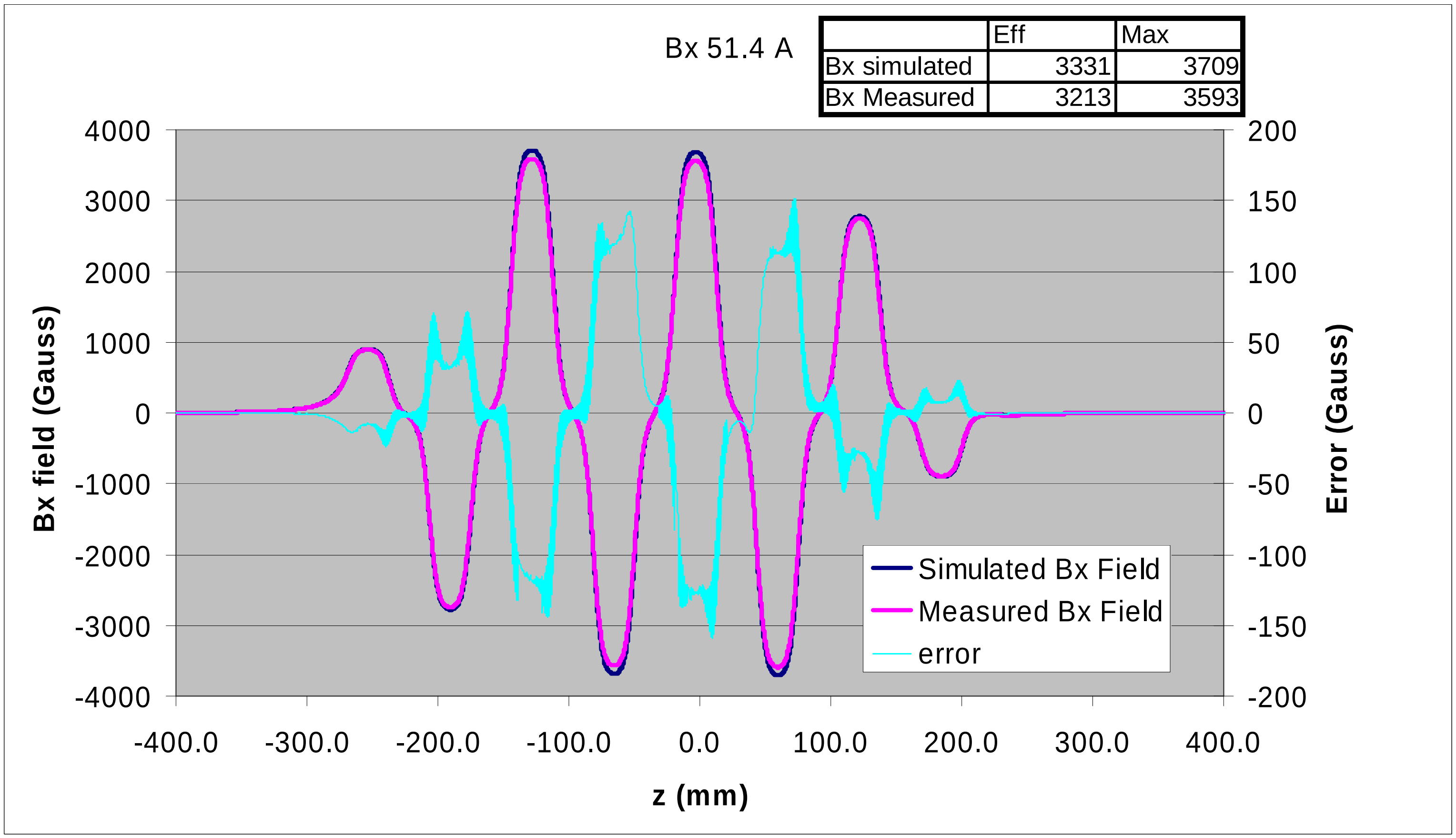






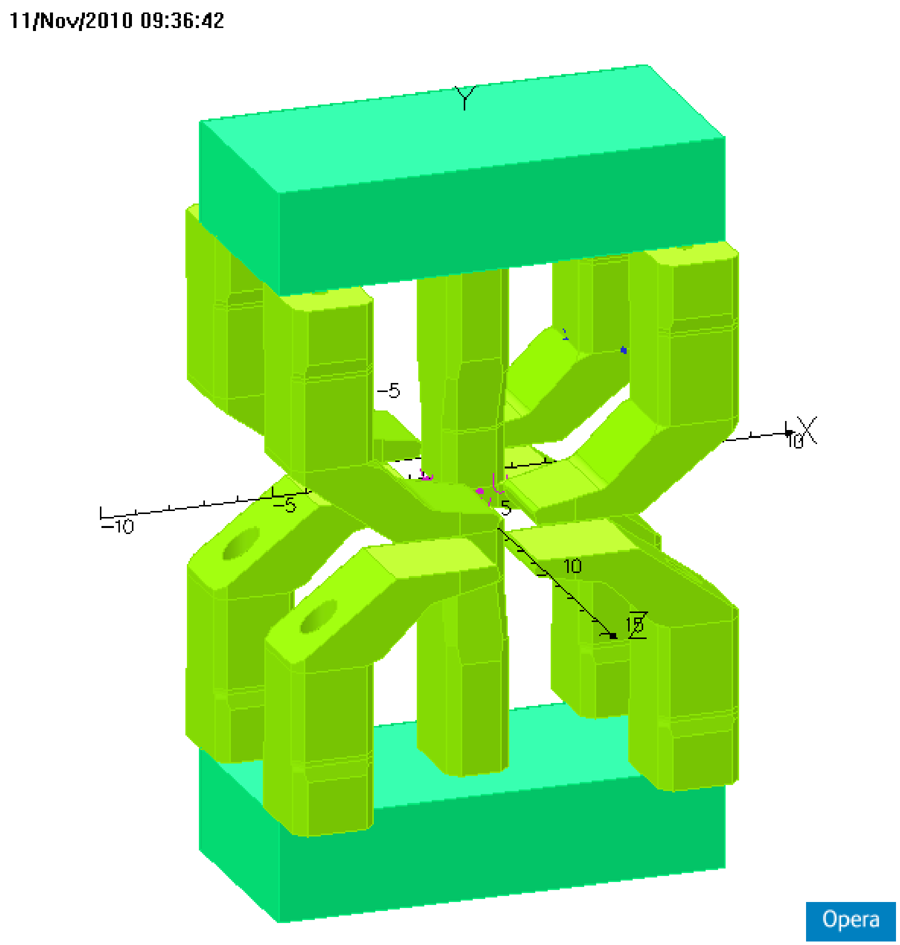
Compare Measured Bx Field To Simulated Bx Field

The measured Bx effective field is 3.5% lower than simulated.
The measured Bx Peak field is 3.1% lower than simulated.



Similar results for By

Bolt Holes



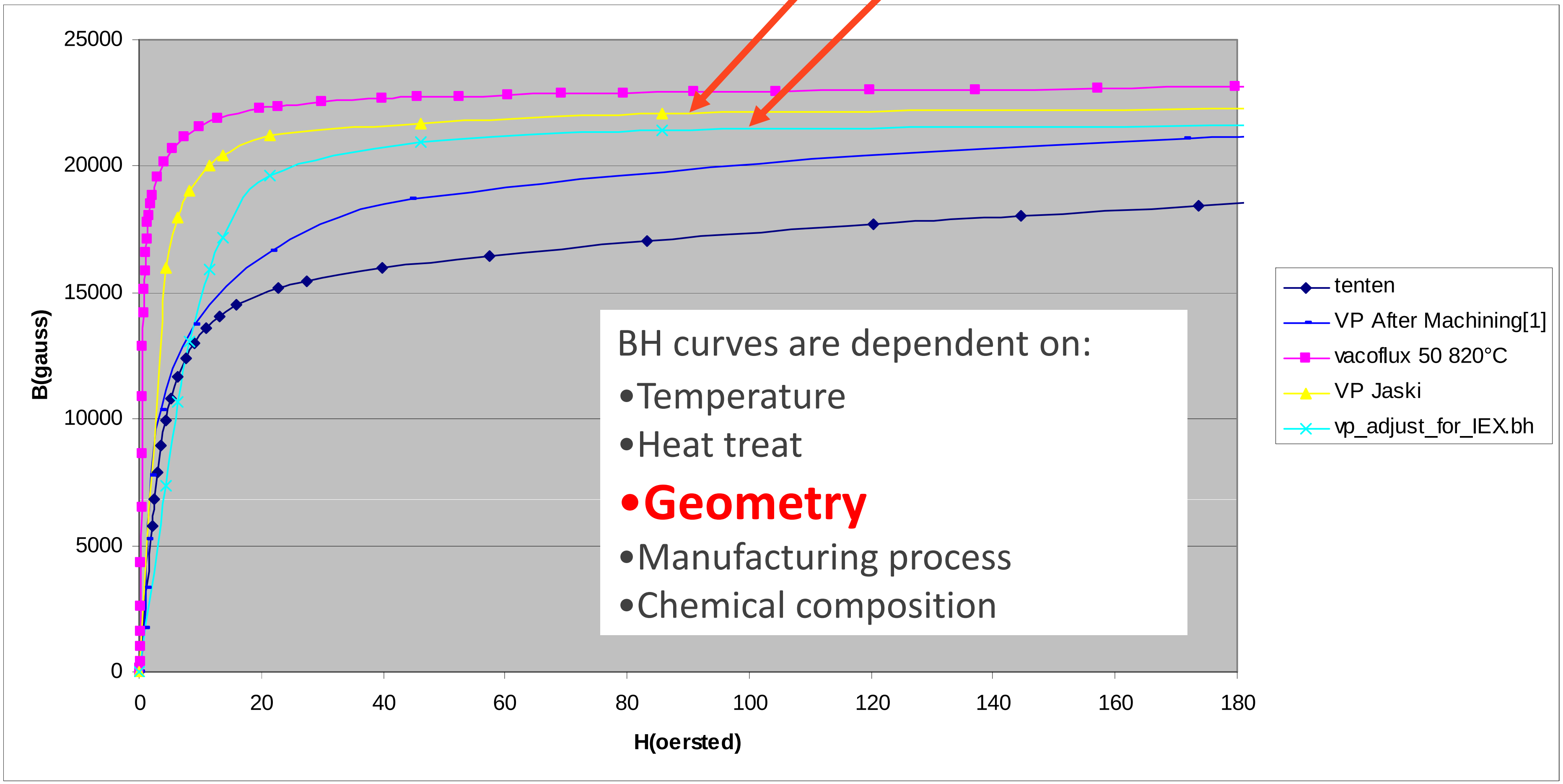
	Without bolt holes	With bolt holes	With bolt holes
	Gauss	Gauss	%
Bx max	3719	3690	-0.8
Bx eff	3360	3338	-0.7
By max	5388	5388	0.0
By eff	4590	4589	0.0

- Bolt holes do cause an 0.8% reduction in the Bx field.
- Bolt holes were not modeled because they add more computation time to the analyses.
- IEXP2 has SS bolts.
- Steel bolts can be used to slightly increase the Bx fields.
- Exchanging steel bolts with SS bolts could be used as a method for tuning.

Modify the VP BH Curve

Original BH Curve

Use This BH Curve

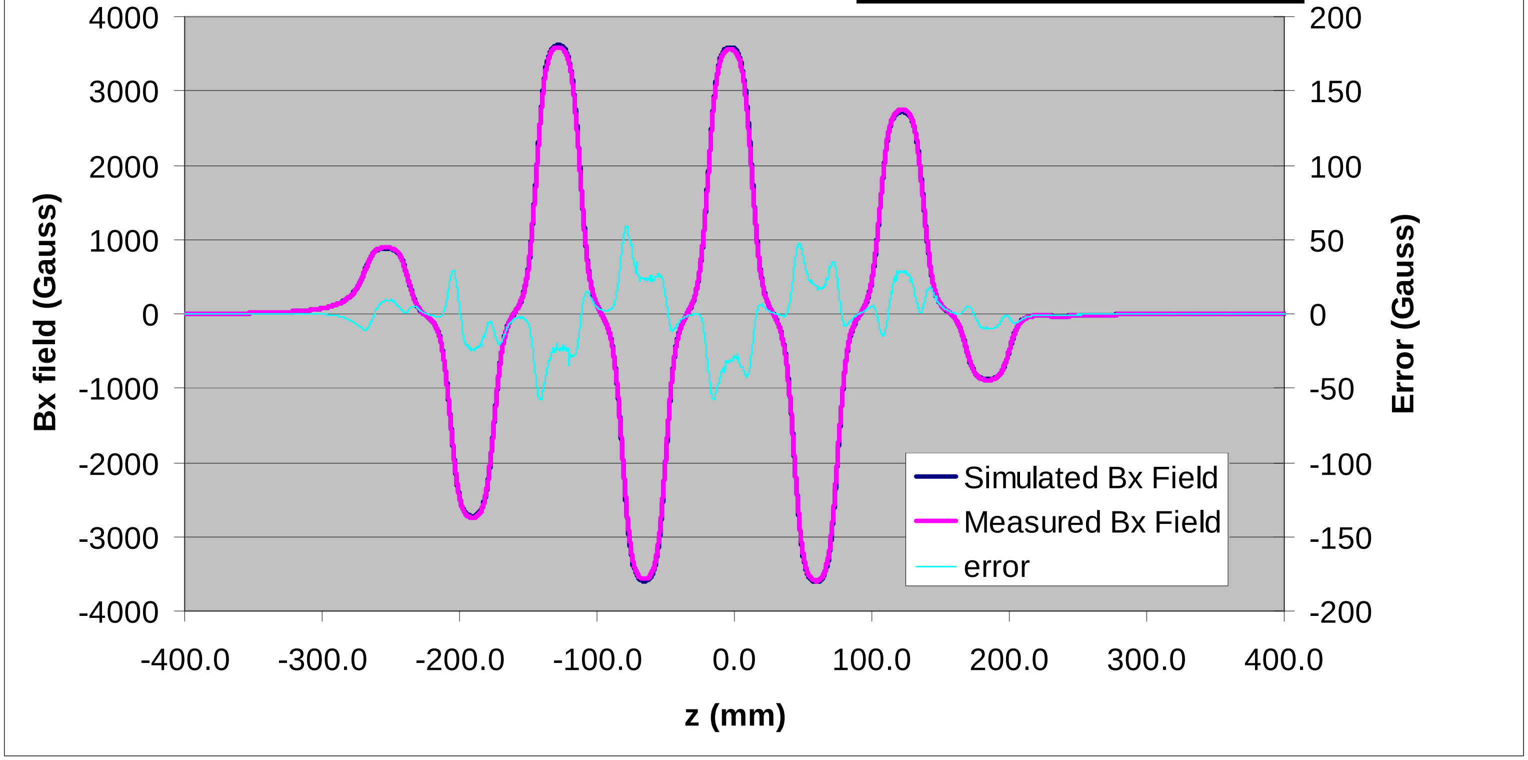


[1] "SOME INITIAL RESULTS FROM THE NEW SLAC PERMEAMETER"
J. K. Cobb and R. A. Early

Compare Measured Bx Field To Simulated Bx Field After Adjusted BH Curve

The measured Bx effective field is 1% lower than simulated.

The measured Bx Peak field is 0.6% lower than simulated.

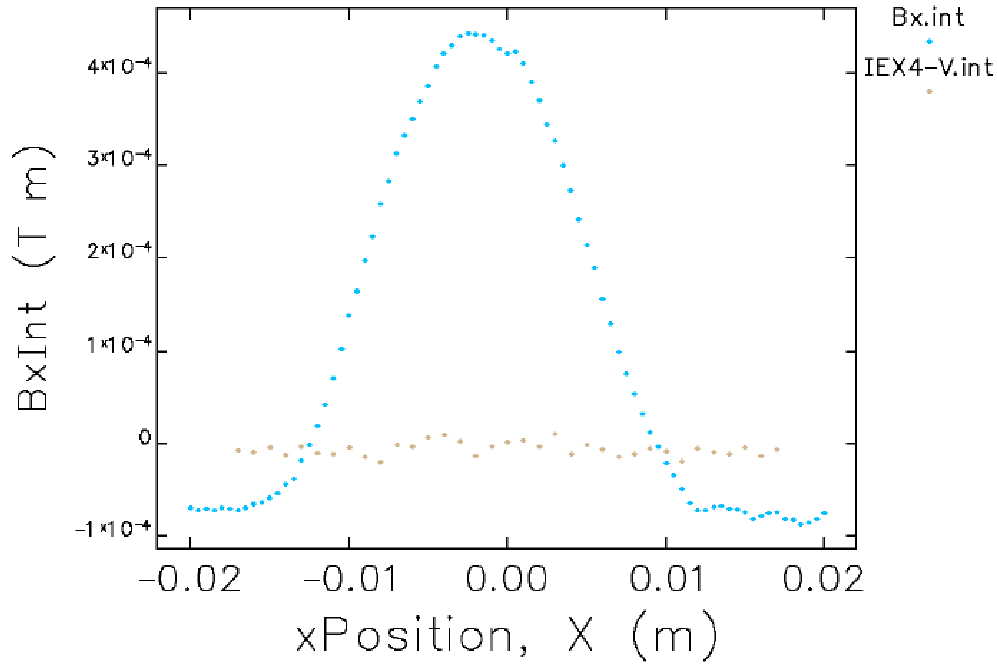


	Eff	Max
Bx simulated	3245	3614
Bx Measured	3213	3593

Simulated values will drop by ~0.8% if bolt holes are modeled

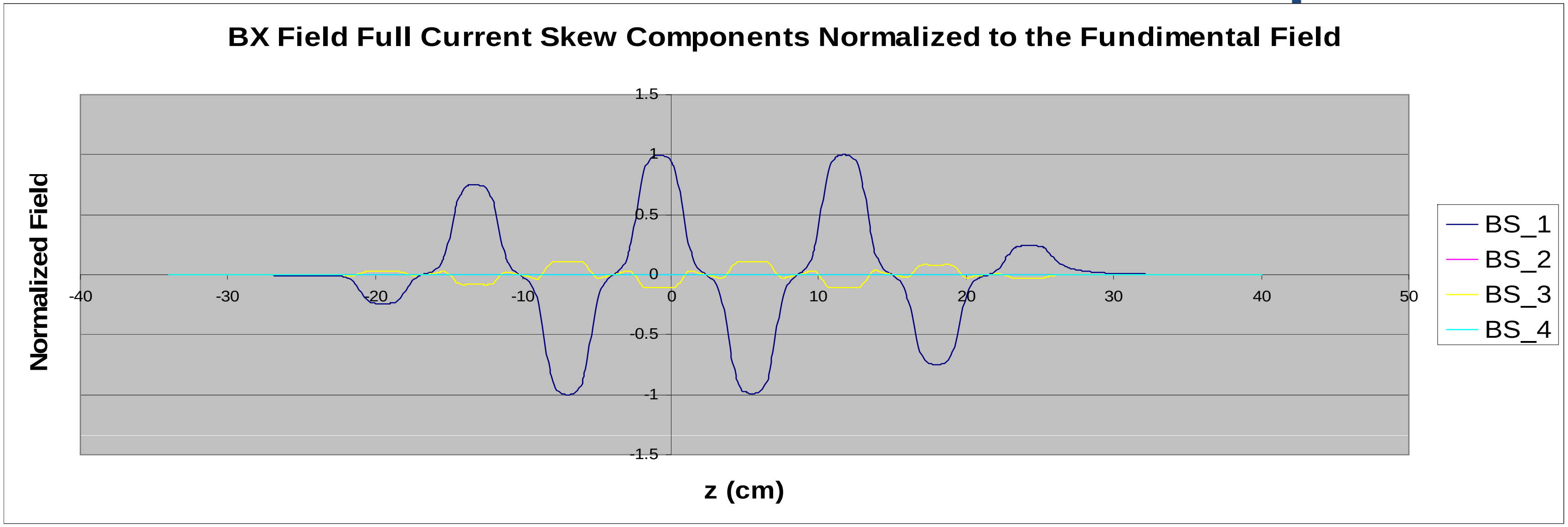
Measurements of IEXP2 Fix the Skew Sextupole

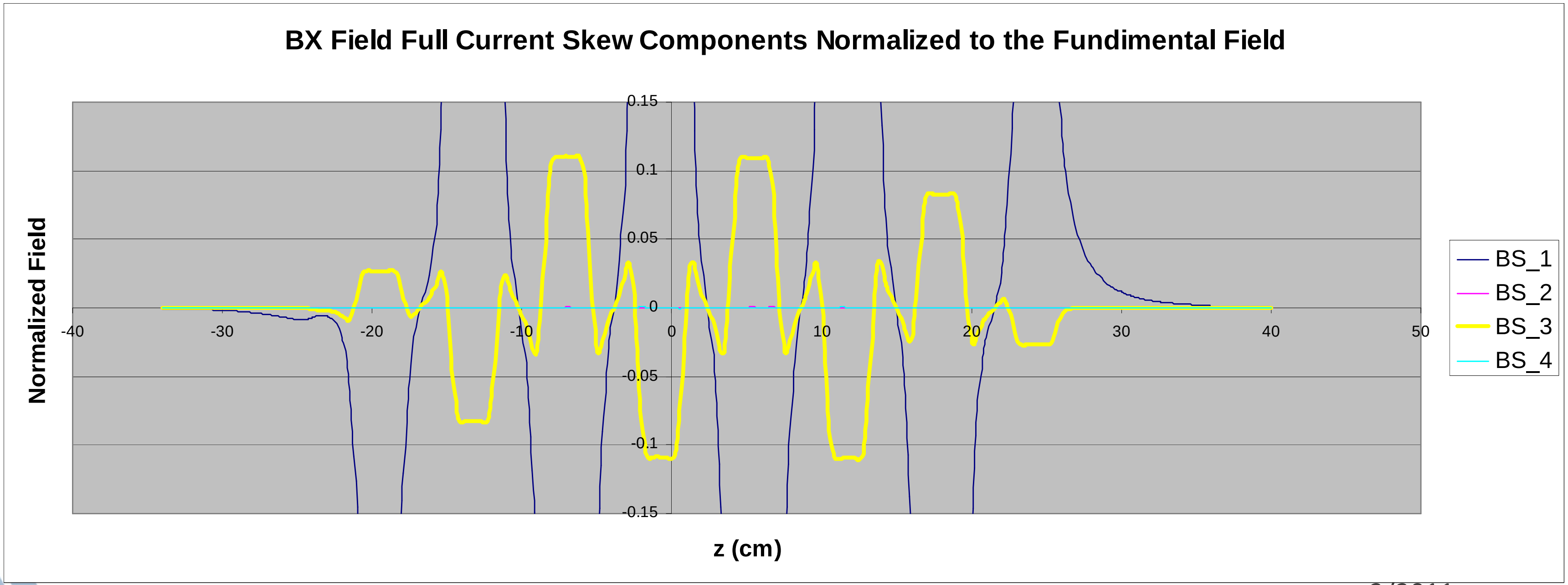
- Aimin X. pointed out a skew sextupole component.
- Yes it can be fixed.
- Not an active fix.



1st integral (y=0) – Very different..
But at same level of By field.
Is this a problem? Can it be fixed?

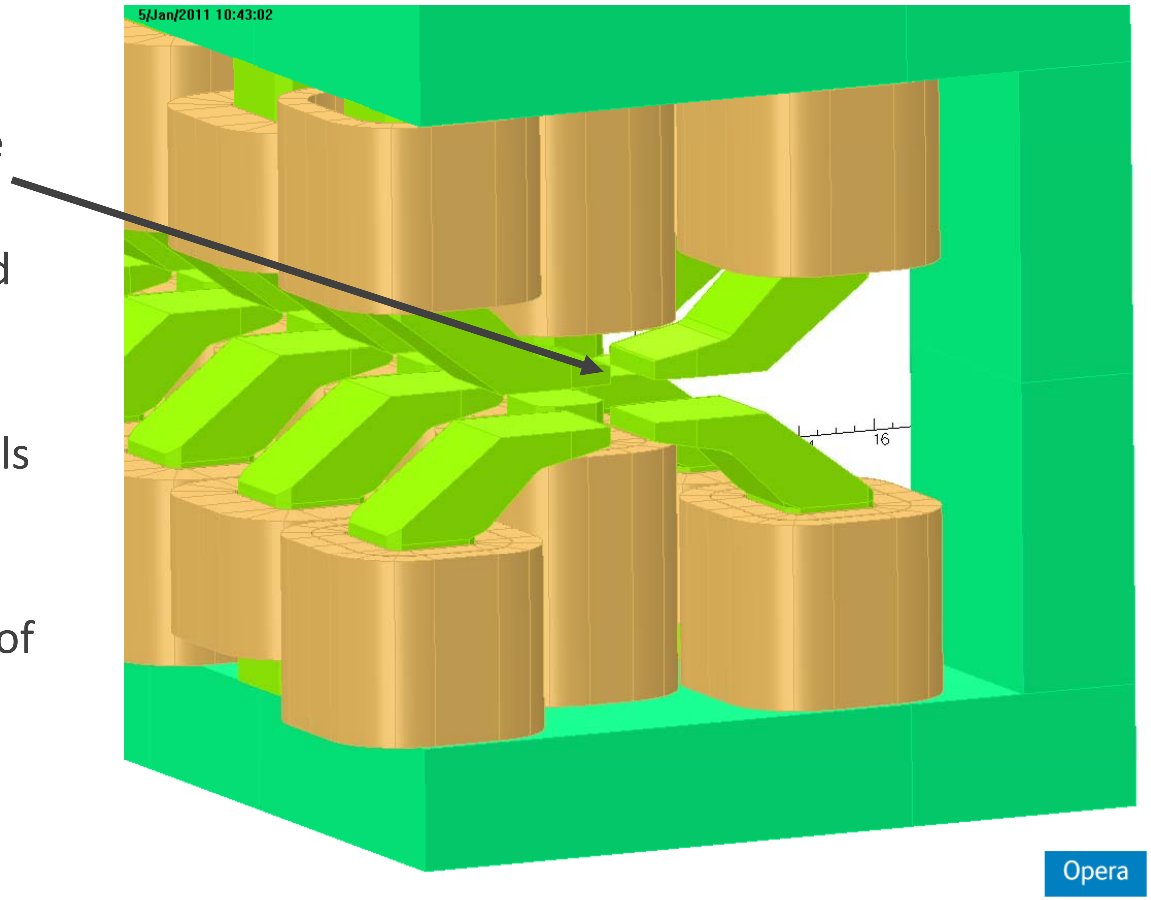
Measurements of IEXP2 Fix the Skew Sextupole



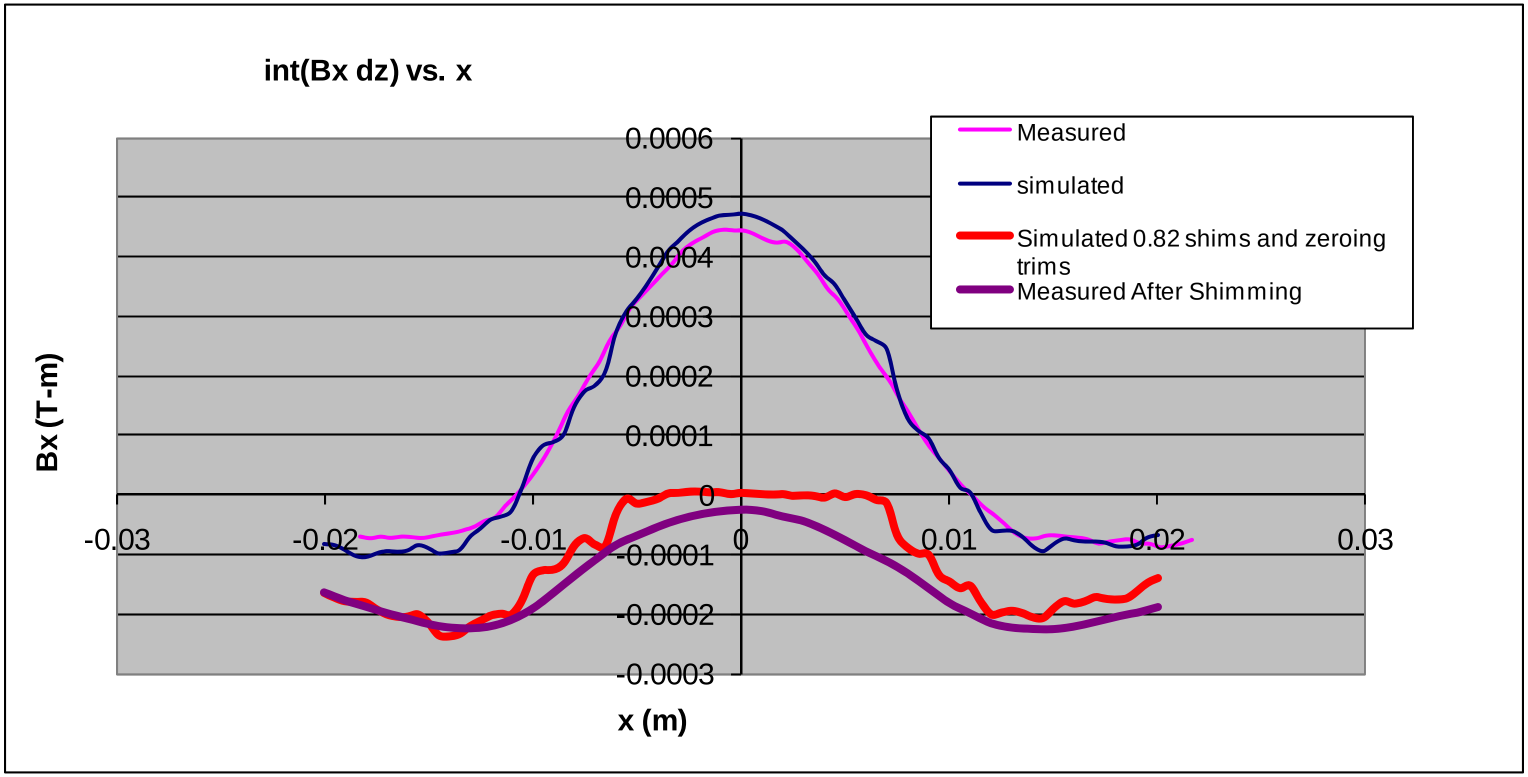


Measurements of IEXP2 Fix the Skew Sextupole

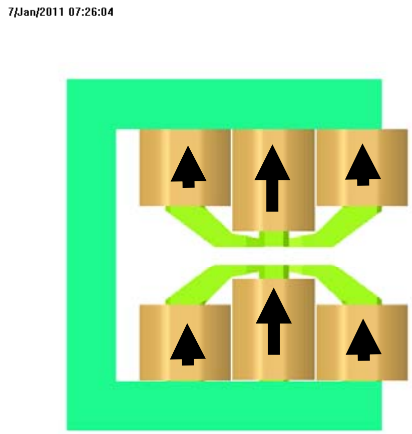
- Grinding these four downstream pole tips reduces the skew sextupole component.
- This was tested and showed this on the prototype.
- The trim coils will be set so the first and second integrals are zero.
- The skew sextupole will be measured and the amount of grinding will be calculated.
- Extra pole tips have been ordered.
- Provisions for easy replacement of these pole tips are provided.



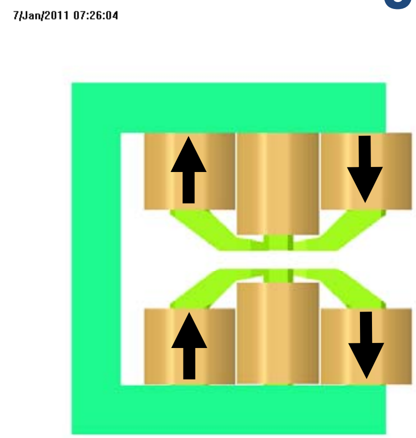
Measurements of IEXP2 Fix the Skew Sextupole



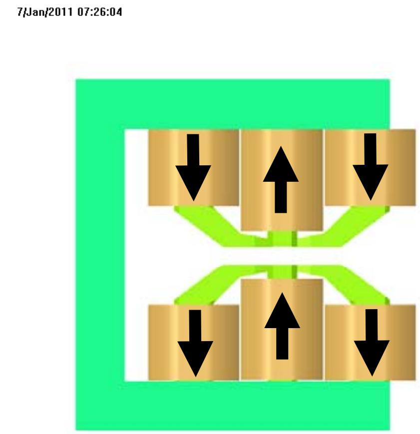
End Coil Multi-pole Field Configurations



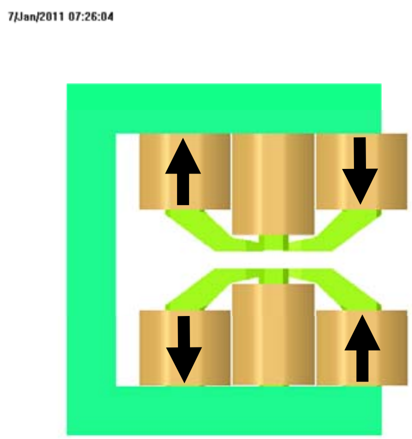
Normal Dipole



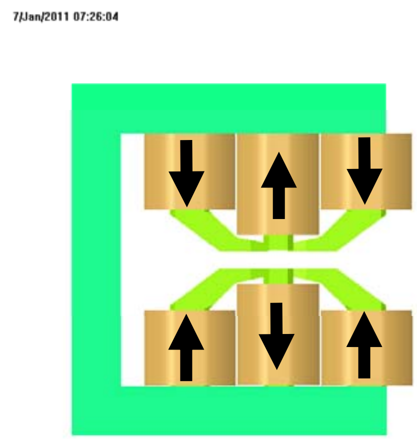
Normal Quadrupole



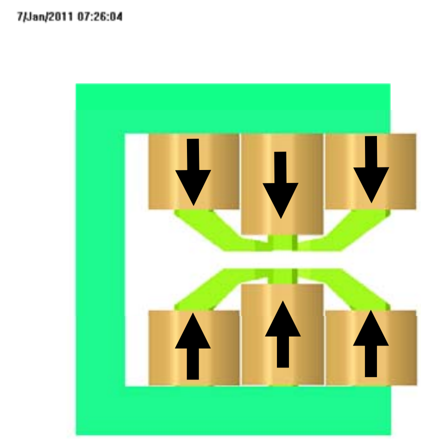
Normal Sextupole



Skew Dipole

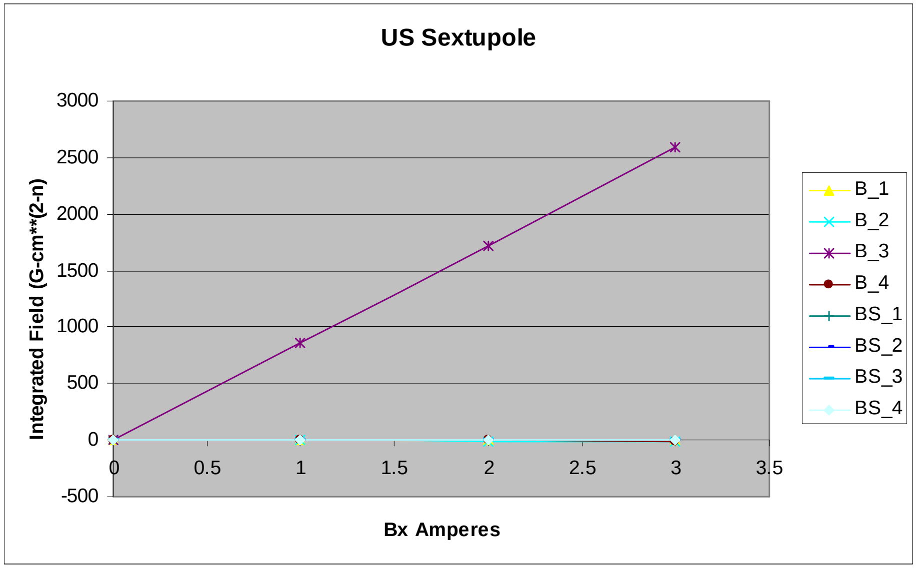


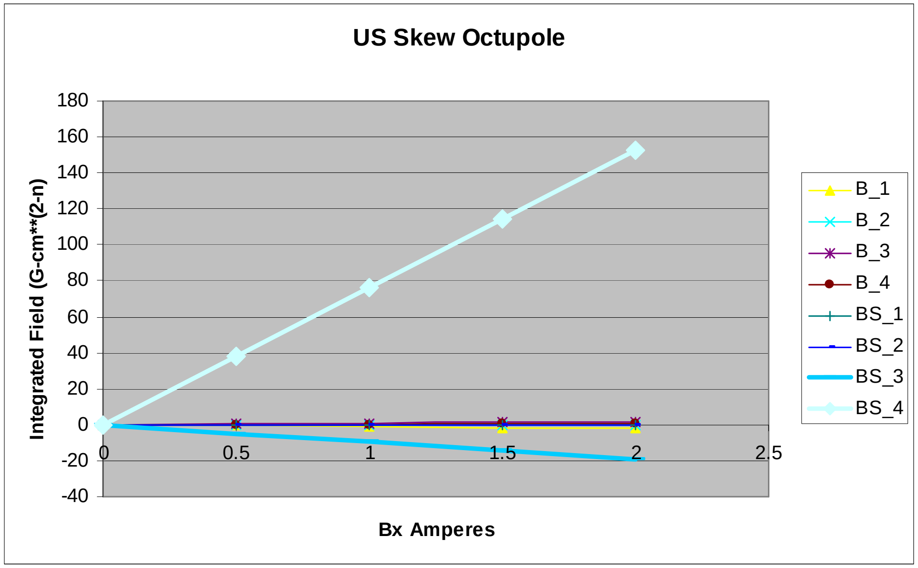
Skew Quadrupole

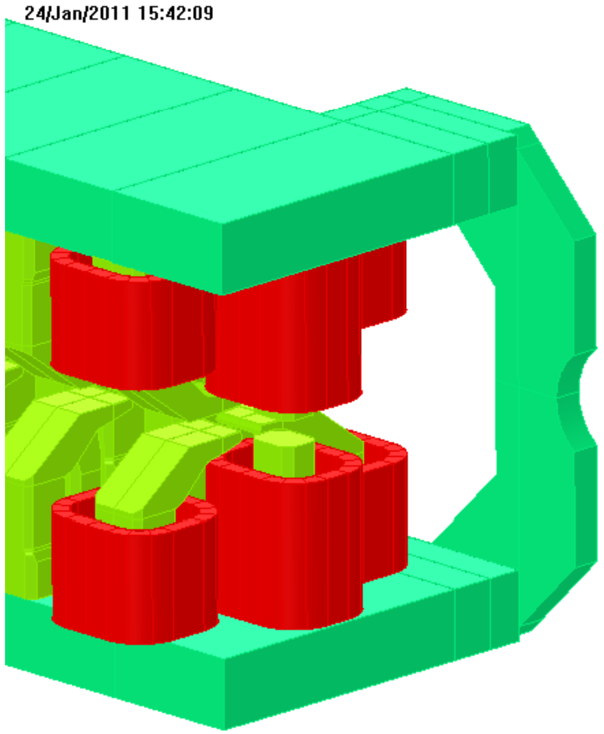


Skew Octupole

Preliminary Results

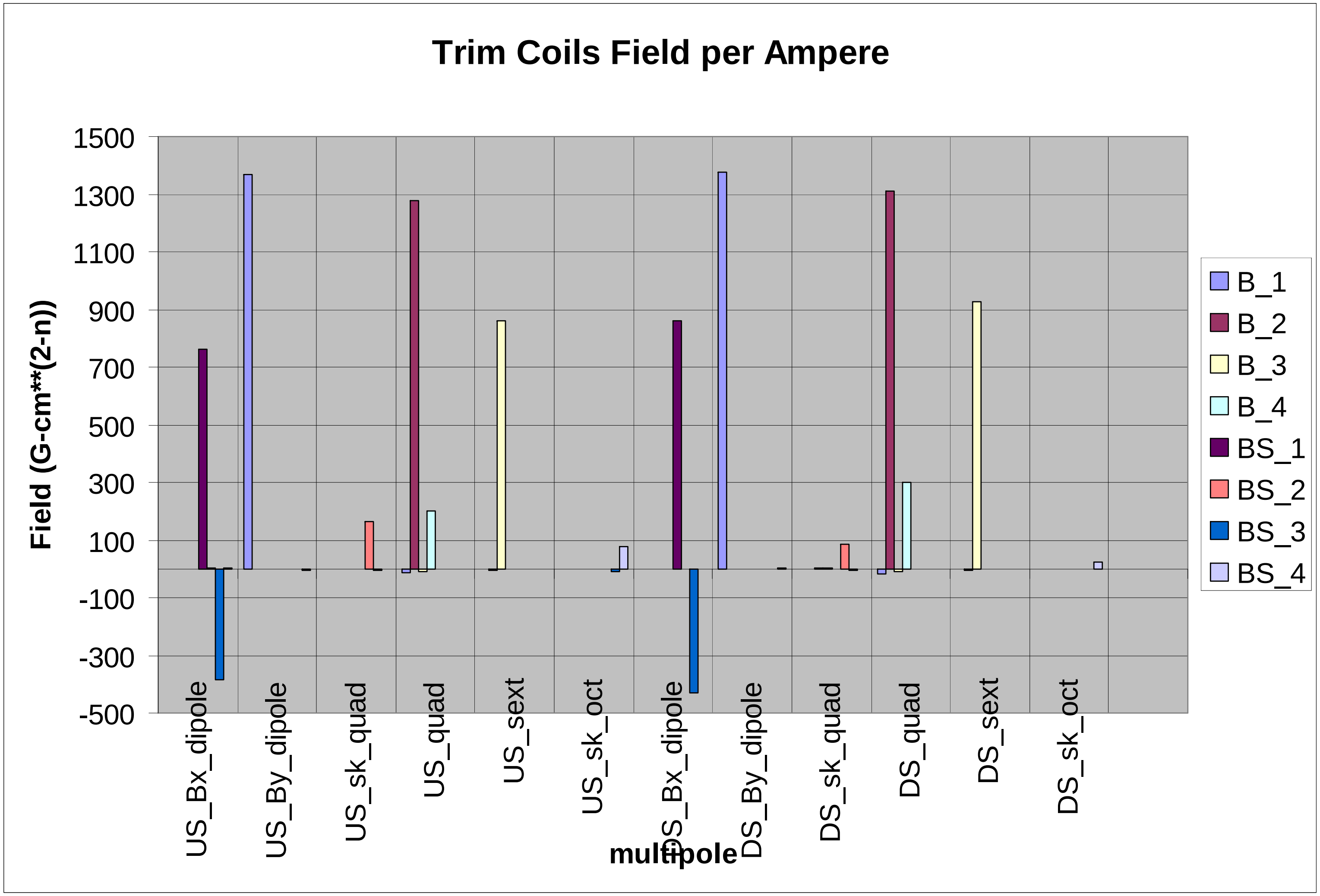




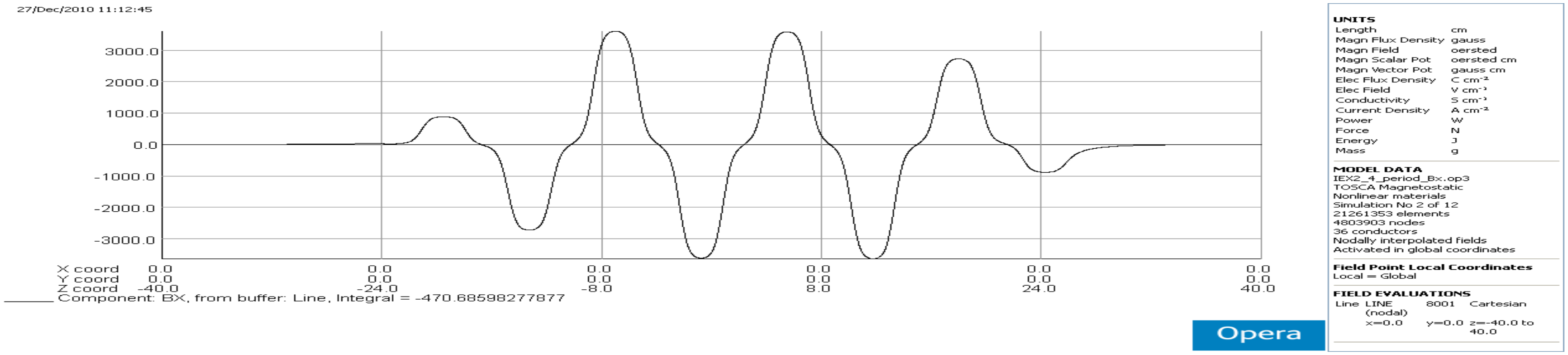


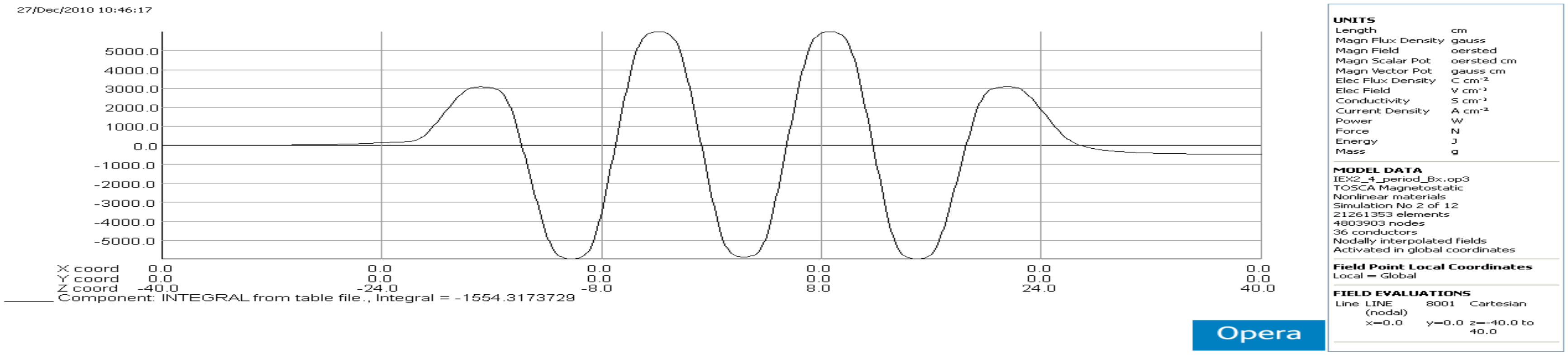
- US sextupole is clean with no other multipoles.
- US skew octupole also has a skew sextupole.
- The flux bridge appears to play a roll in additional multipoles.

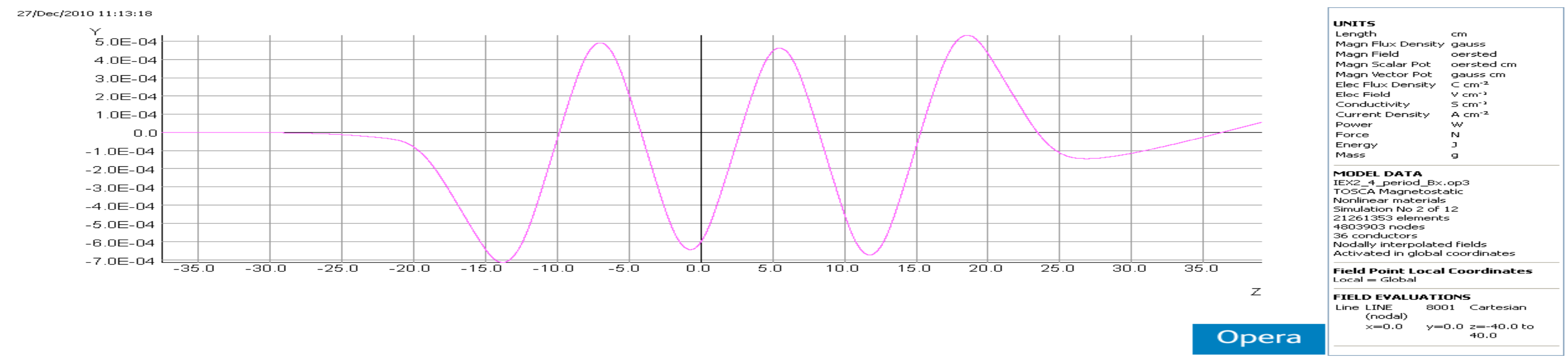
Possible Multi-pole Fields With Trim Coils



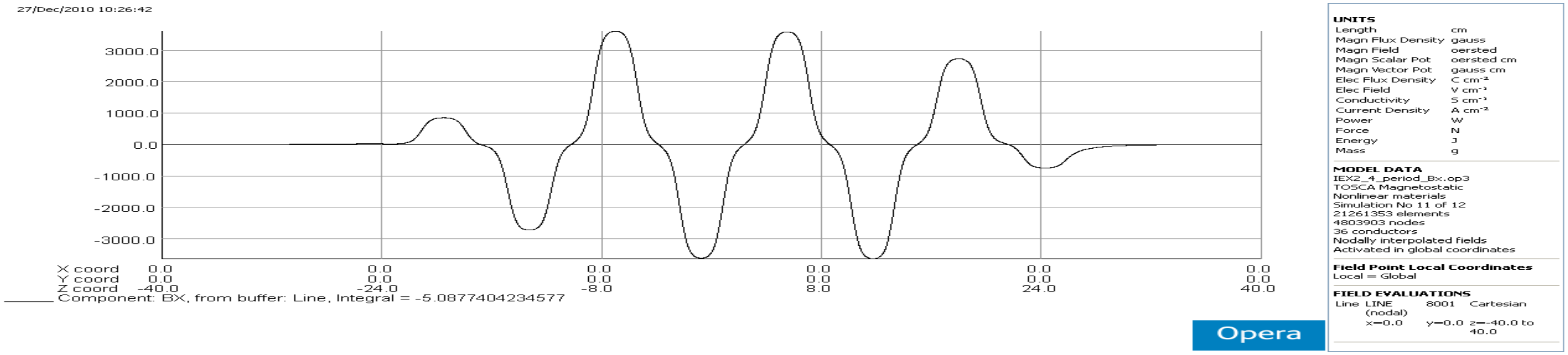
Bx, 1st integral, and Beam Trajectory No Trim Coils

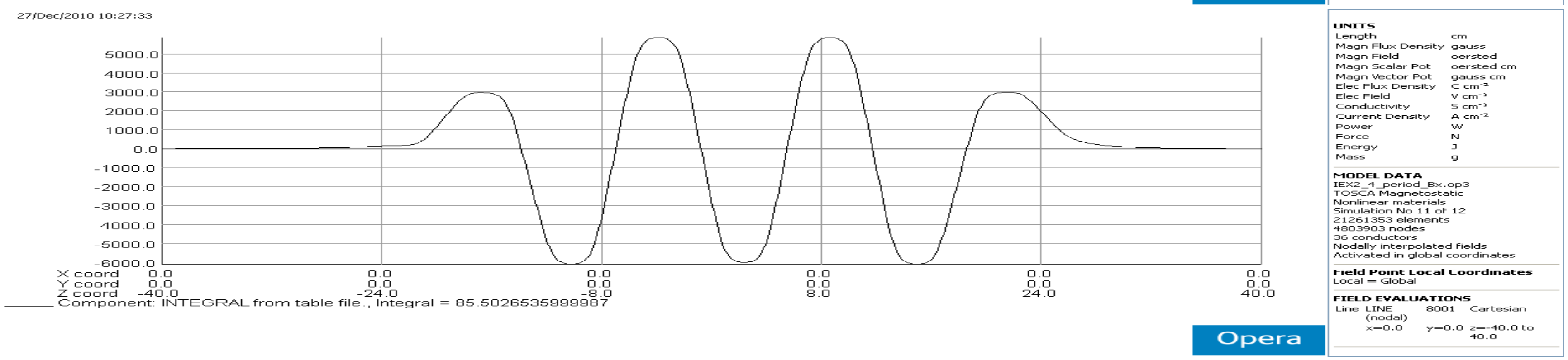


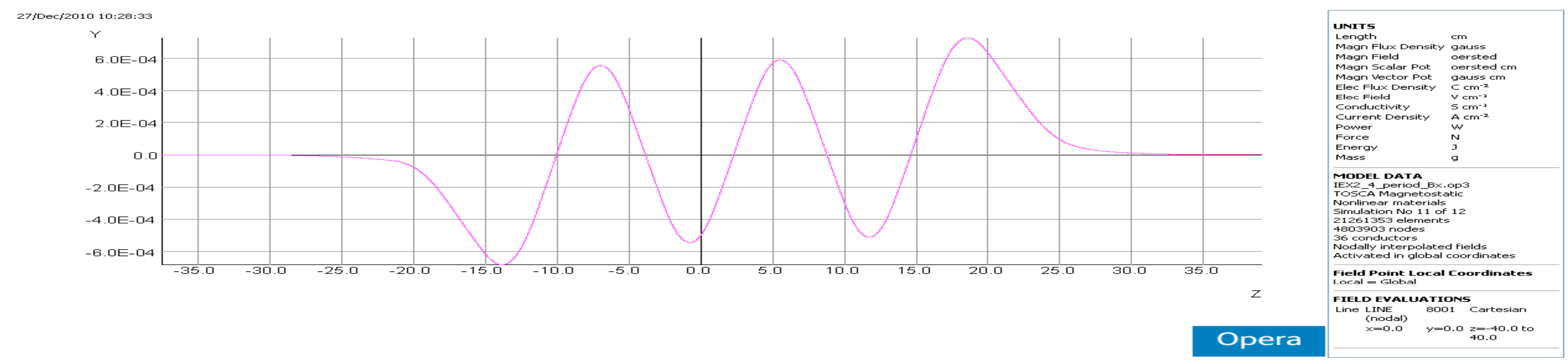




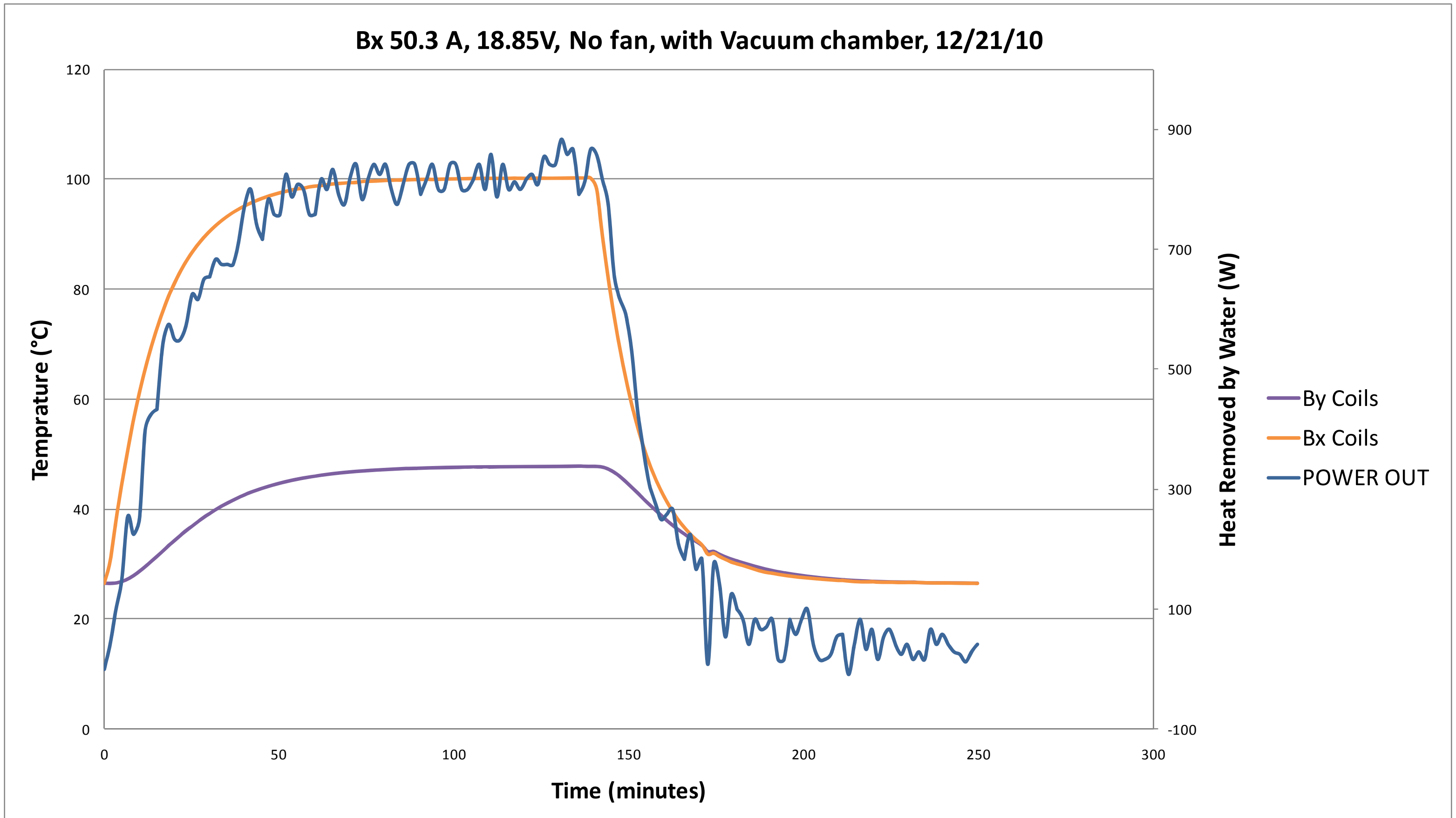
Bx, 1st integral, and Beam Trajectory With Trim Coils







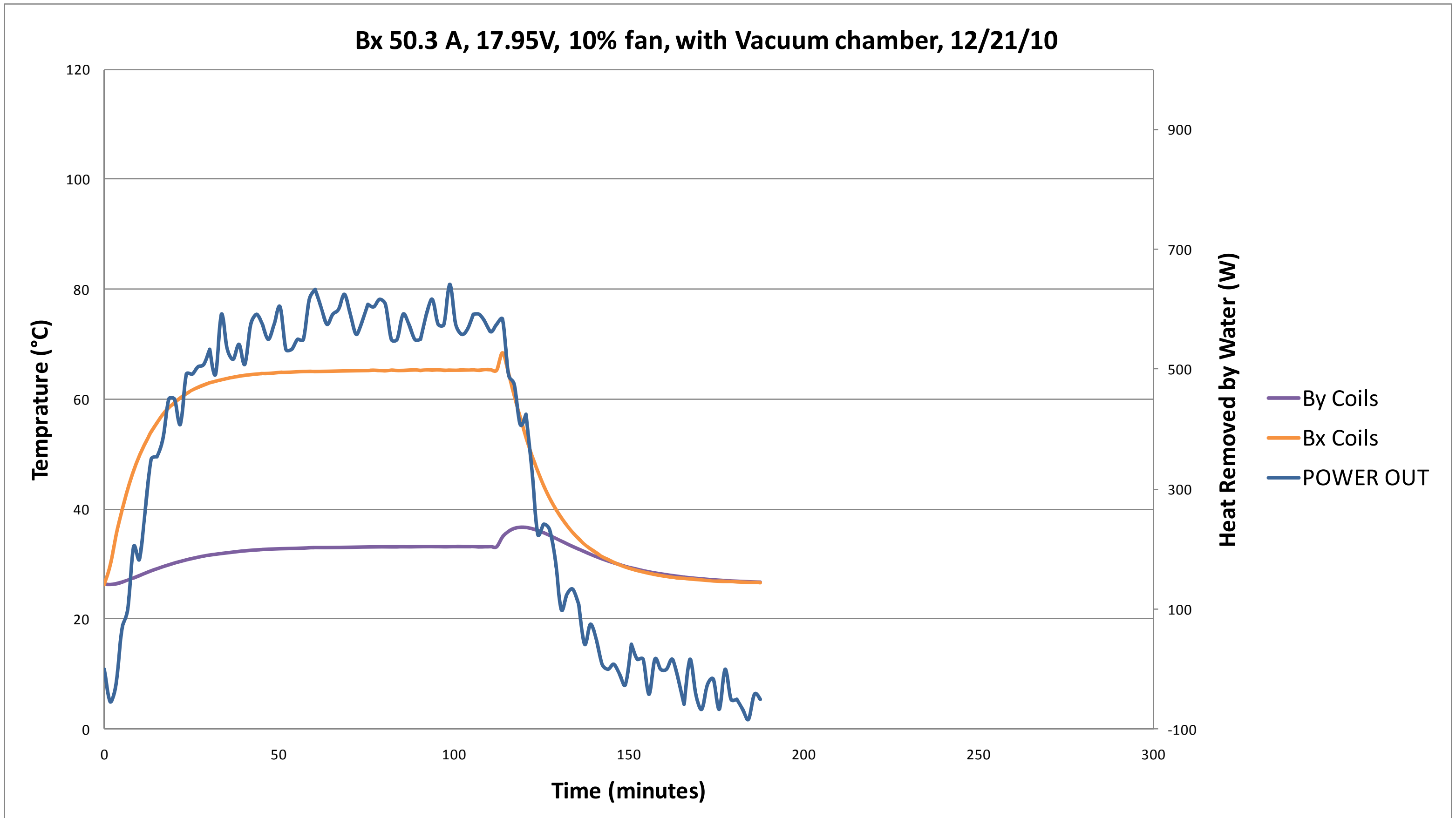
Thermal Test (with help from Jeff C.)



With Vacuum Chamber
Bx 50.3 Amps
18.85 V
No fan
949 Watts total in
until 137 minute mark
then power off

827 W removed by water
87% removed by water

Thermal Test (with help from Jeff C.)



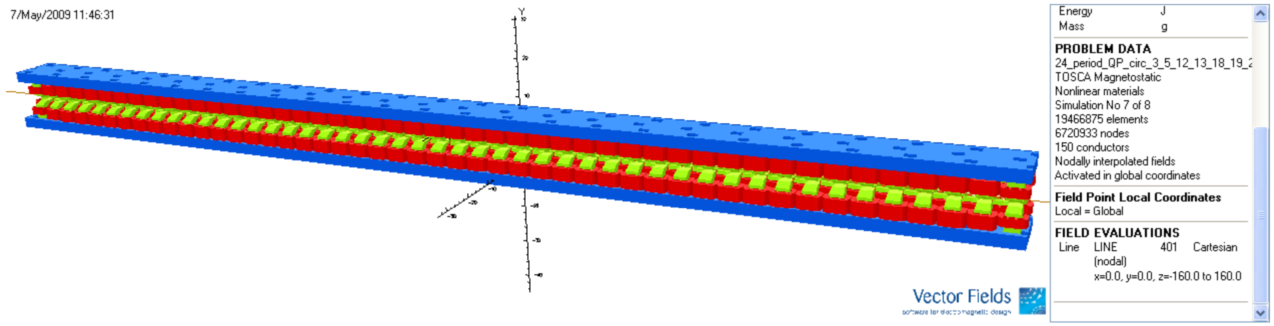
With Vacuum Chamber
Bx 50.3 Amps
17.95 V
10% fan
903 Watts total in
until 111 minute mark
then power off and fan off

578 W removed by water
64% removed by water

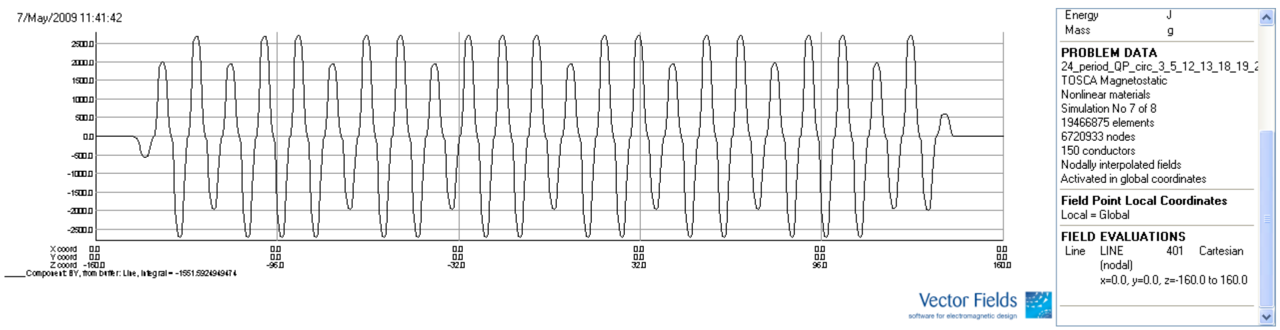
Tunnel Heating

- Without the fan turned on ~1500 W of heat will leak into the tunnel at full current.
- With the fan turned on ~3500 W of heat will leak into the tunnel at full current.
- Sometimes the device is on full current. Sometimes the device is off. Sometimes the device operates somewhere in-between.
- The heat into the tunnel is not constant. This make the tunnel temperature difficult to control.
- Reversing the fan and sucking the heat from the device into the tunnel air handling system eases controlling the tunnel temperature
  - Suggested by Marvin K.
- This minimizes the heat leaking into the tunnel.
- A smoke test with a reversed fan showed adequate good air flow.
- A thermal test showed similar coil cooling.

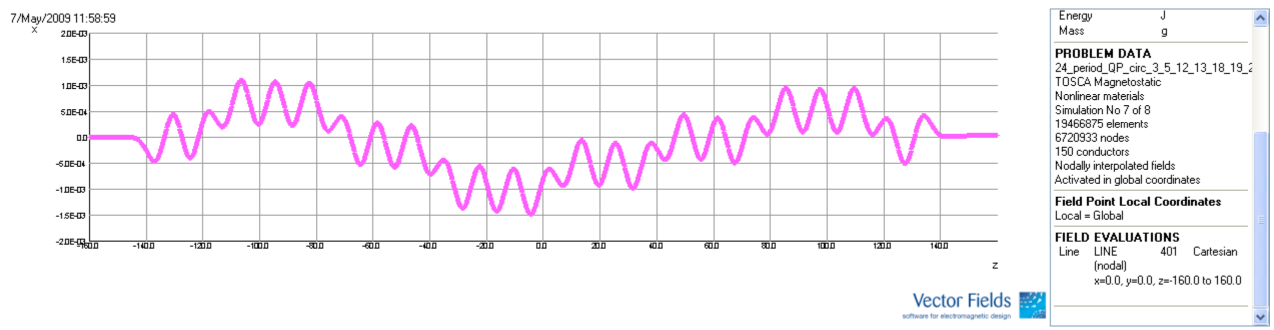
Quasi-periodicity with an Electromagnet Device



24 Period Model Shown

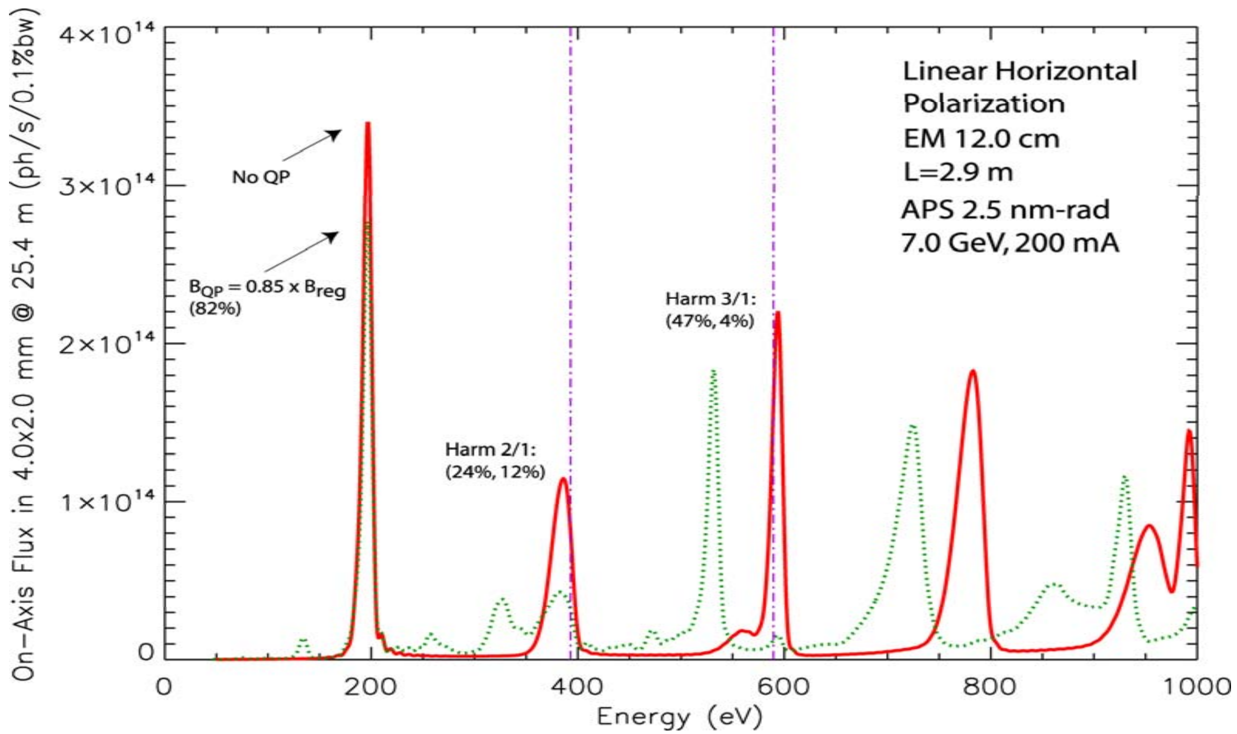


Quasiperiodic By Field



Quasiperiodic Electron Trajectory

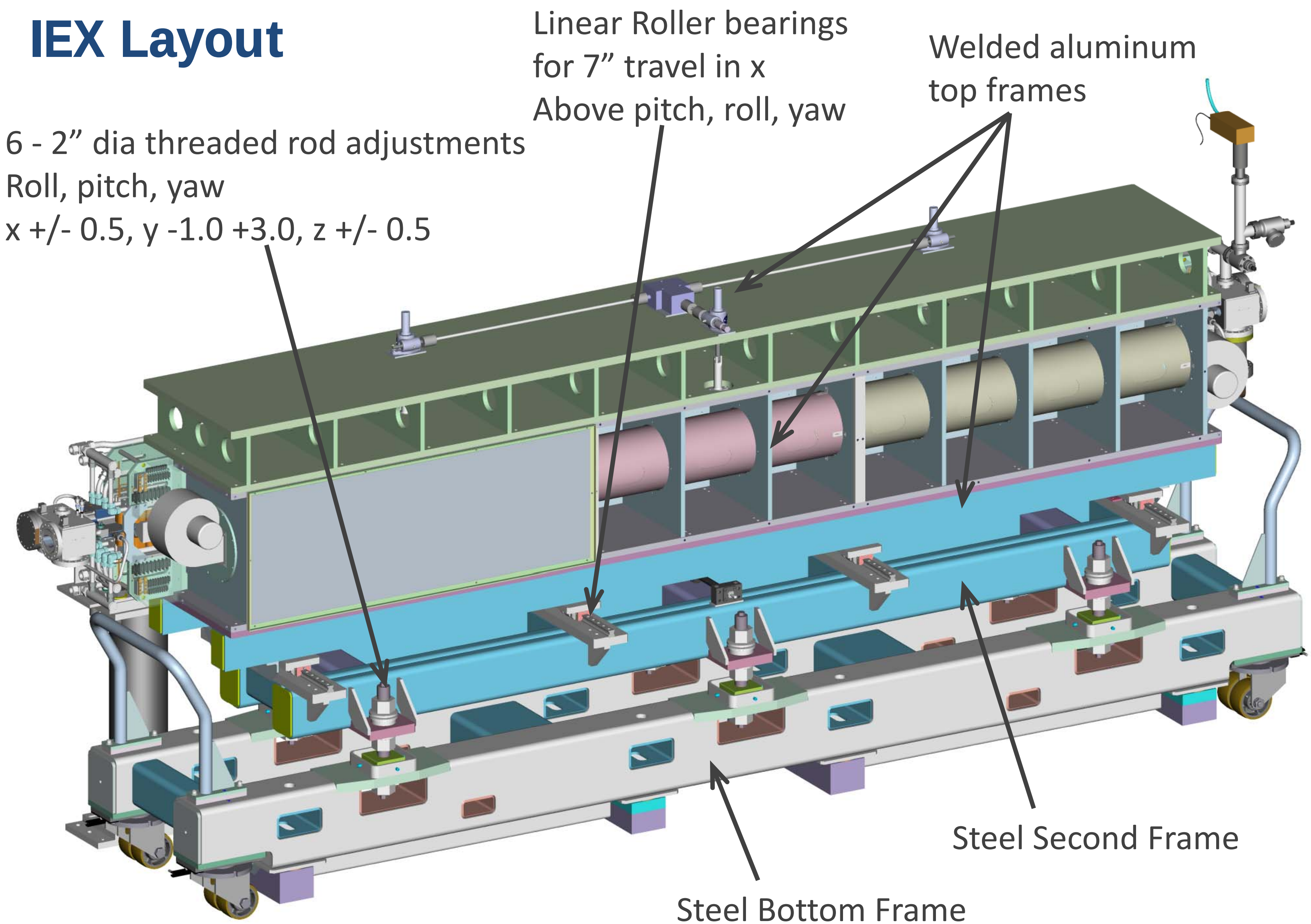
Quasi-periodicity Suppresses the Higher Harmonics



Flux with and without quasi-periodicity turned to a 15% field-strength reduction at the QP poles for the EM. The 3rd harmonic is reduced by over 90% while the first harmonic is reduced by ~18%.

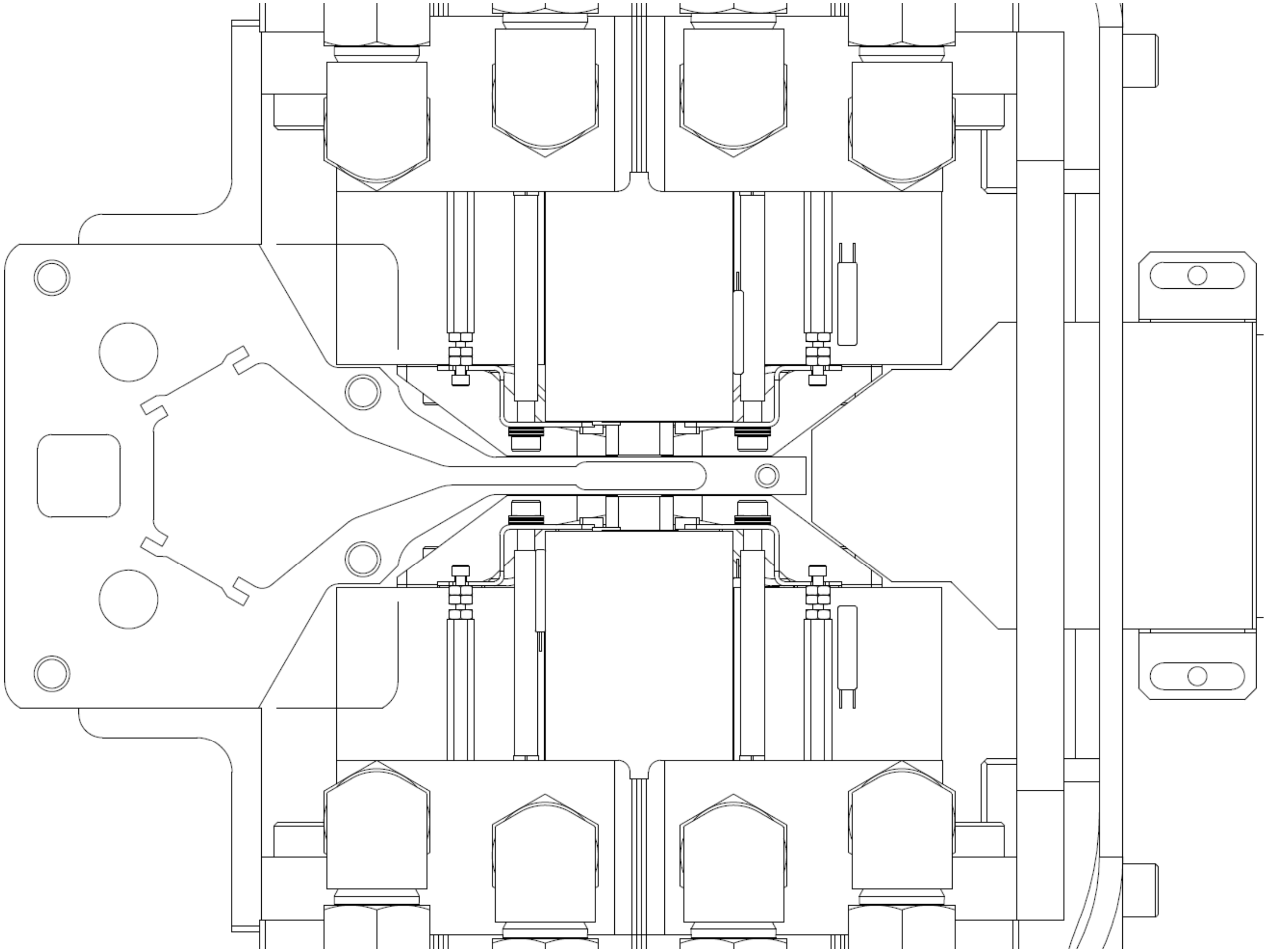
R. Dejus et al., Spectral Performance Of Circular Polarizing Quasi-periodic Undulators For Soft X-rays At The Advanced Photon Source, PAC09

IEX Layout

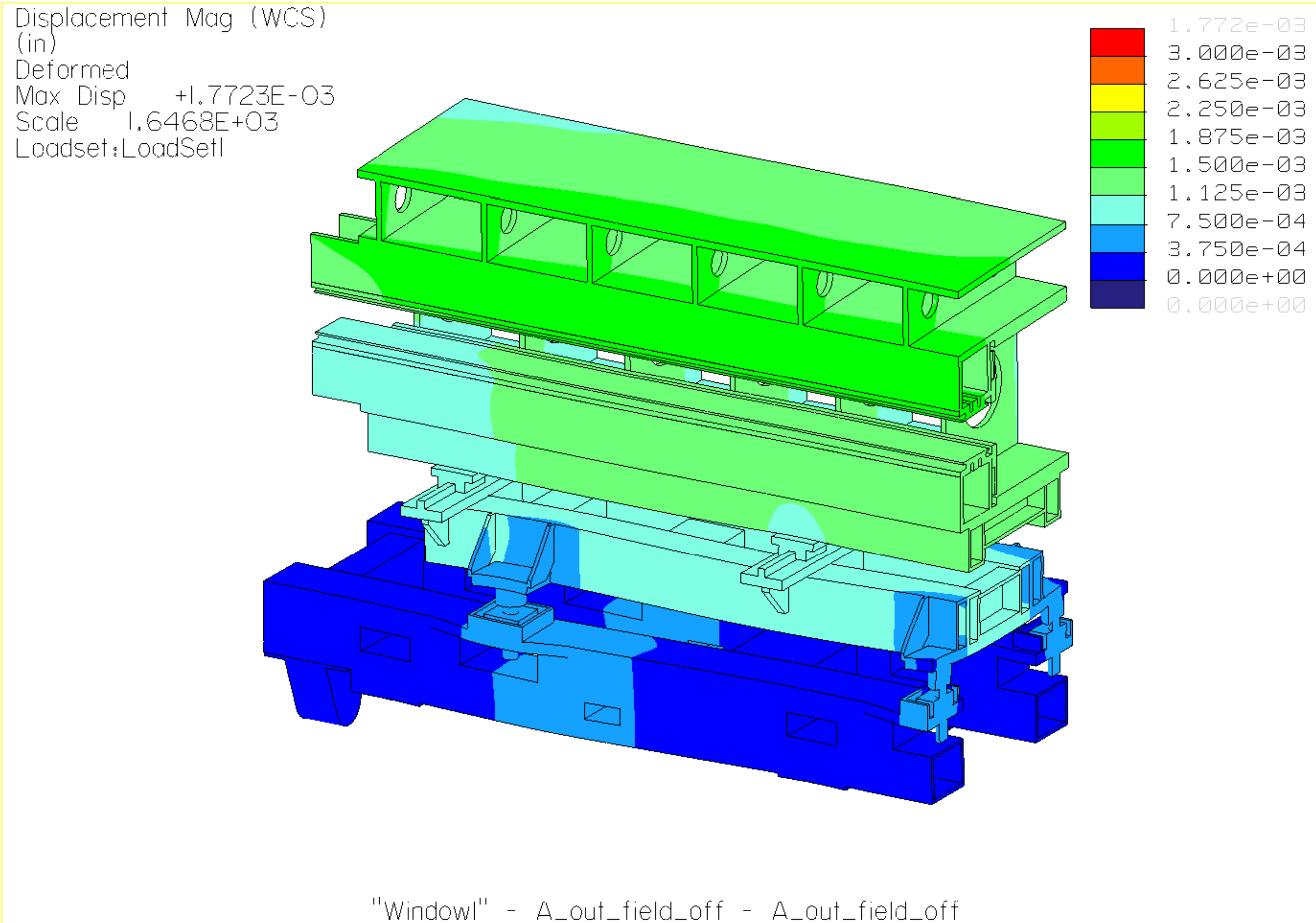


Linear Roller bearings
for 7” travel in x
Above pitch, roll, yaw
Welded aluminum
top frames
6 - 2” dia threaded rod adjustments
Roll, pitch, yaw
x +/- 0.5, y -1.0 +3.0, z +/- 0.5
Steel Second Frame
Steel Bottom Frame

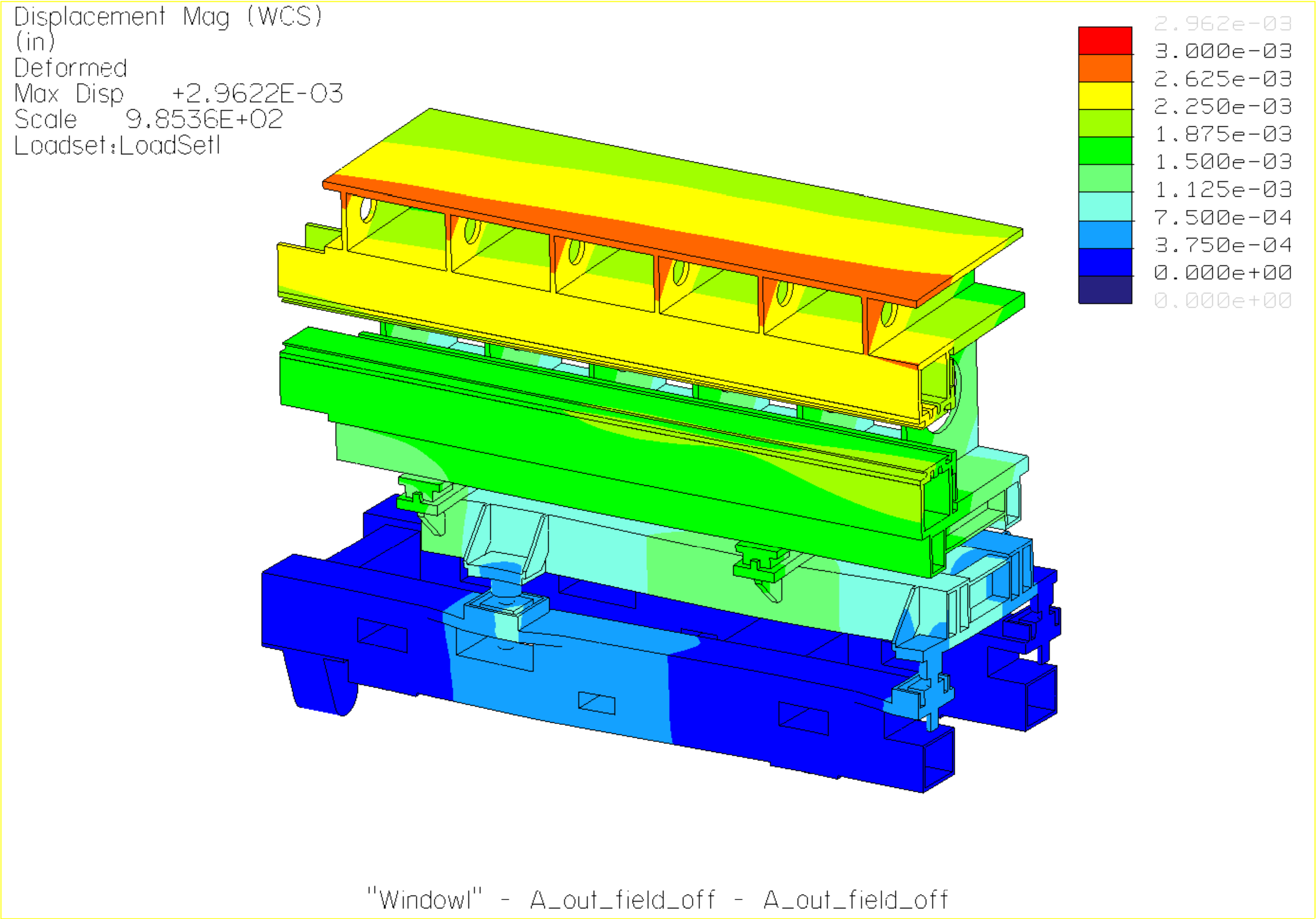
Modified Vacuum Chamber



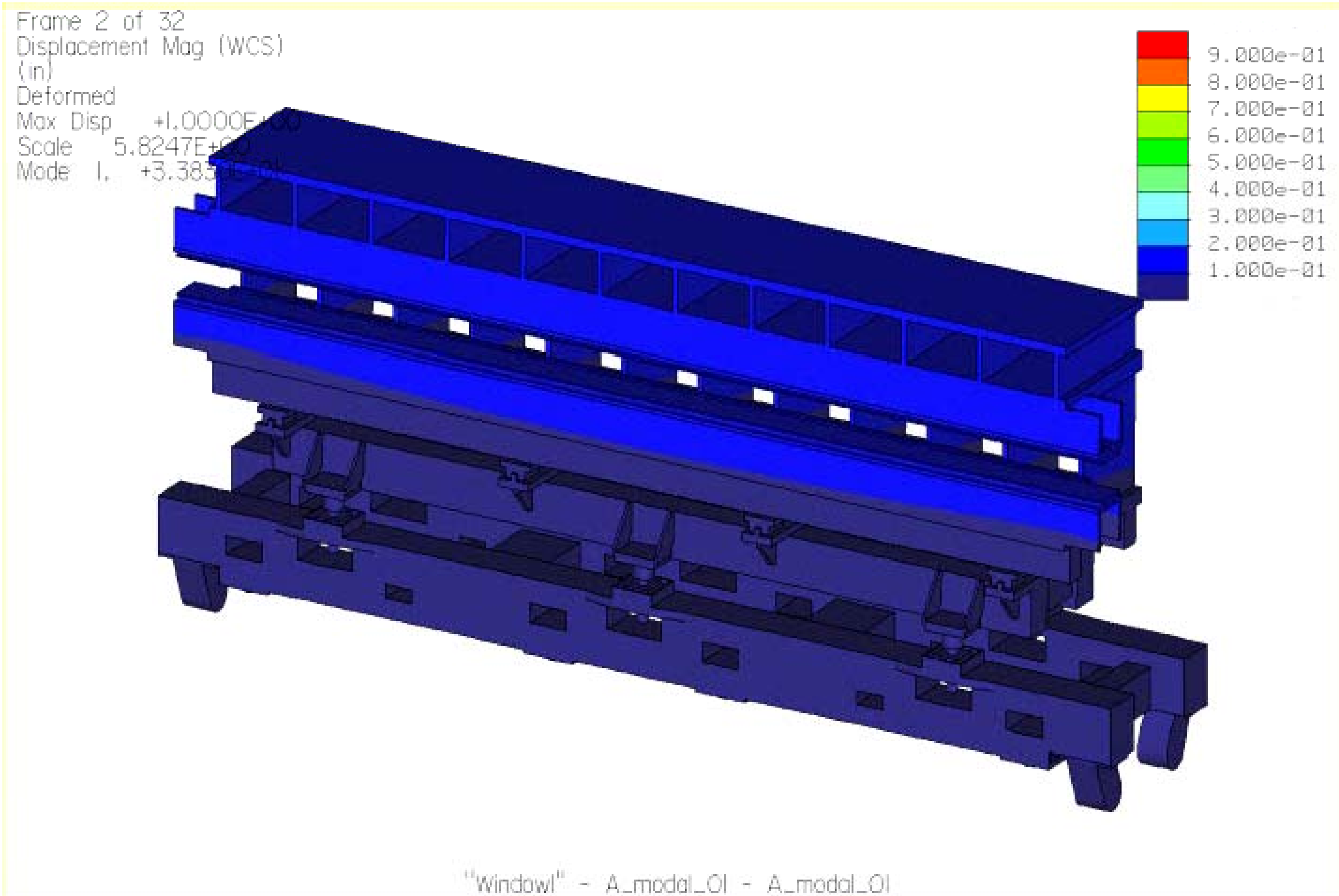
Assembled Position (out position)



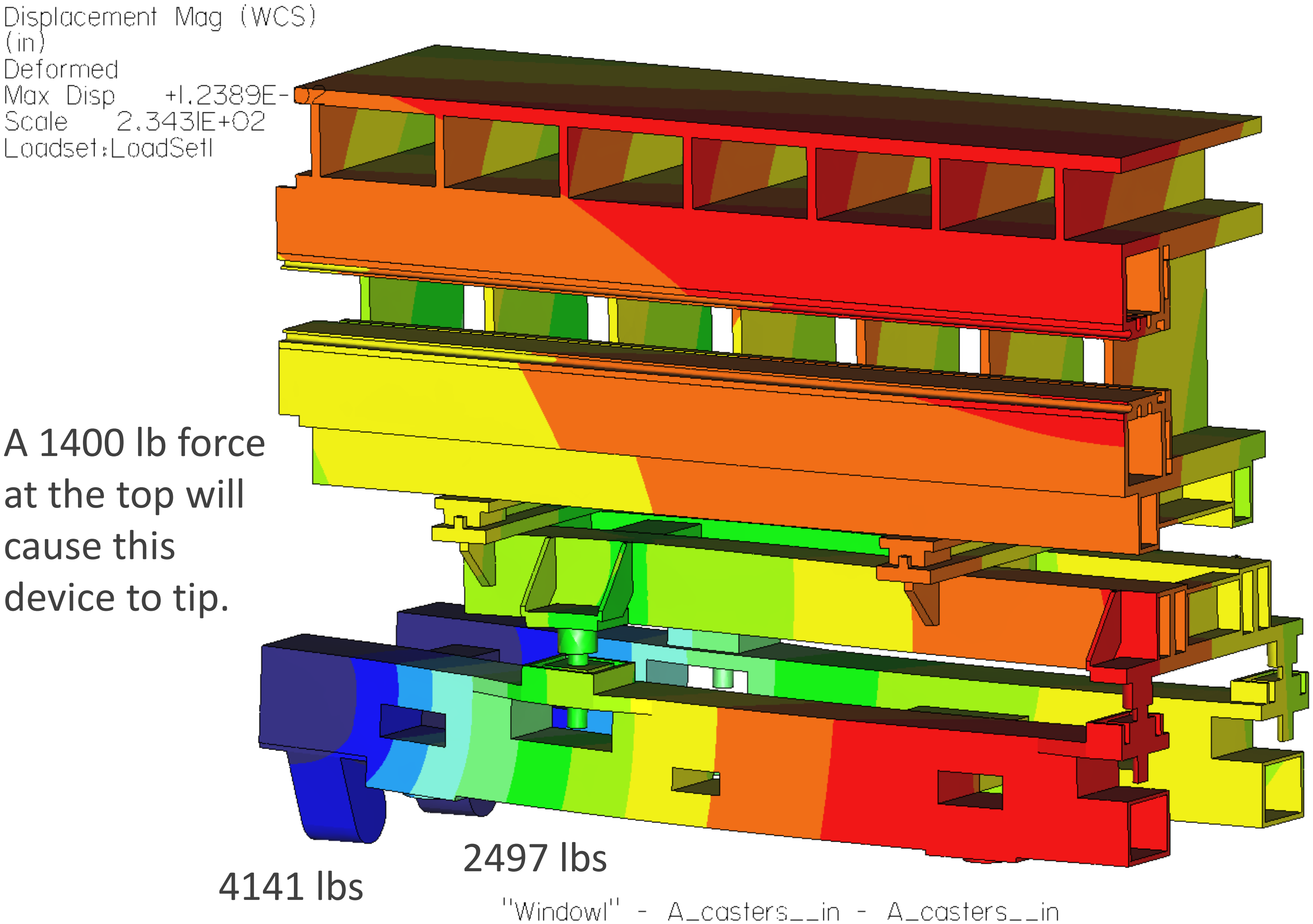
Jaw drops 10 microns (0.00040”) from out to in.



Fundamental Harmonic 33.8 Hz.



Load on casters (in position)

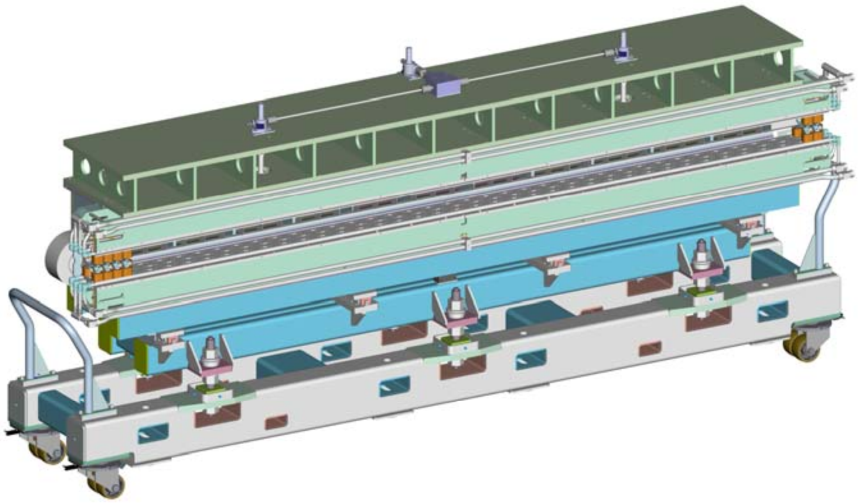


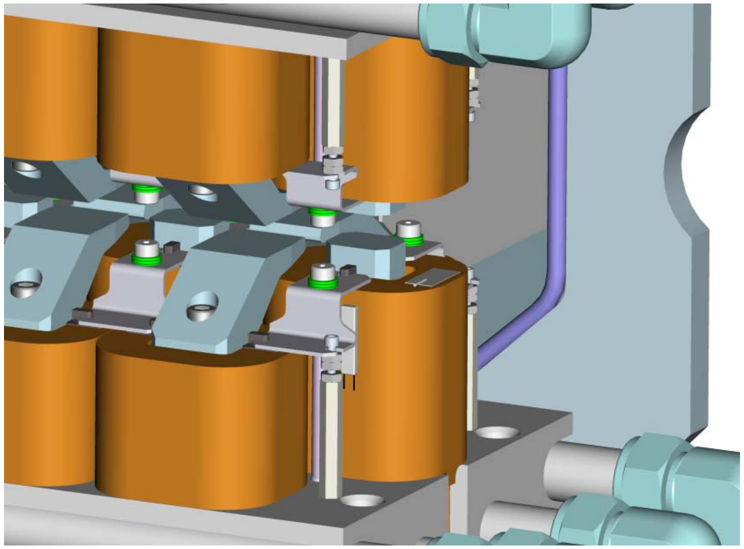
A 1400 lb force at the top will cause this device to tip.

A double wheel caster with a 5,000 lb rating will be used.

Selected Features

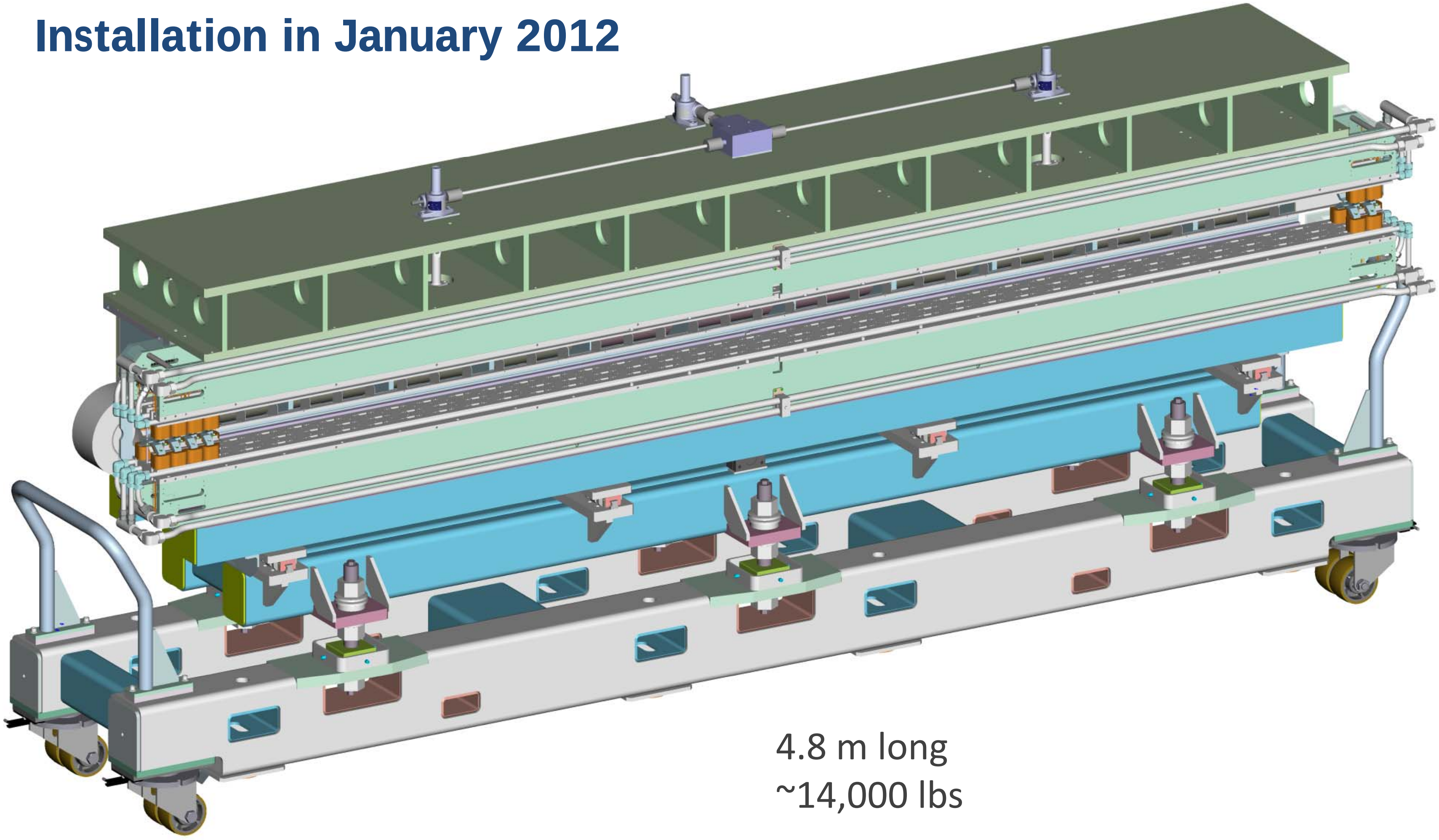
- ~200 lbs to push to get rolling on casters.
- 34” wide, 194” long, 57.2” tall on casters.
- An acme screw will be provided to move the jaws in or out of operating position.
- 456 coils and 16 power supplies.





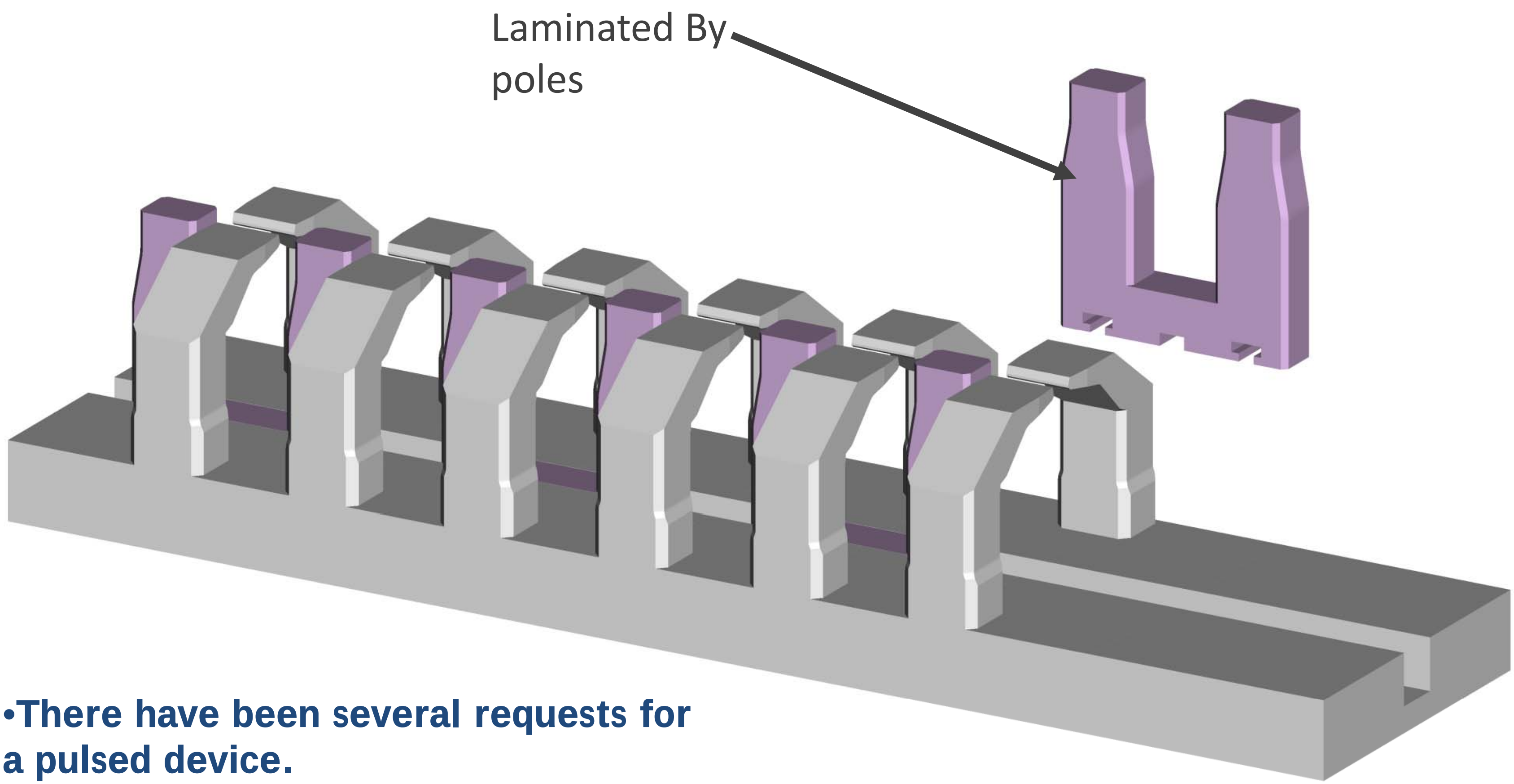
IEX Device

Installation in January 2012



4.8 m long
~14,000 lbs

Laminated Assembly Proposal



- There have been several requests for a pulsed device.

Thank You