Outline

Insertion devices built by ADC

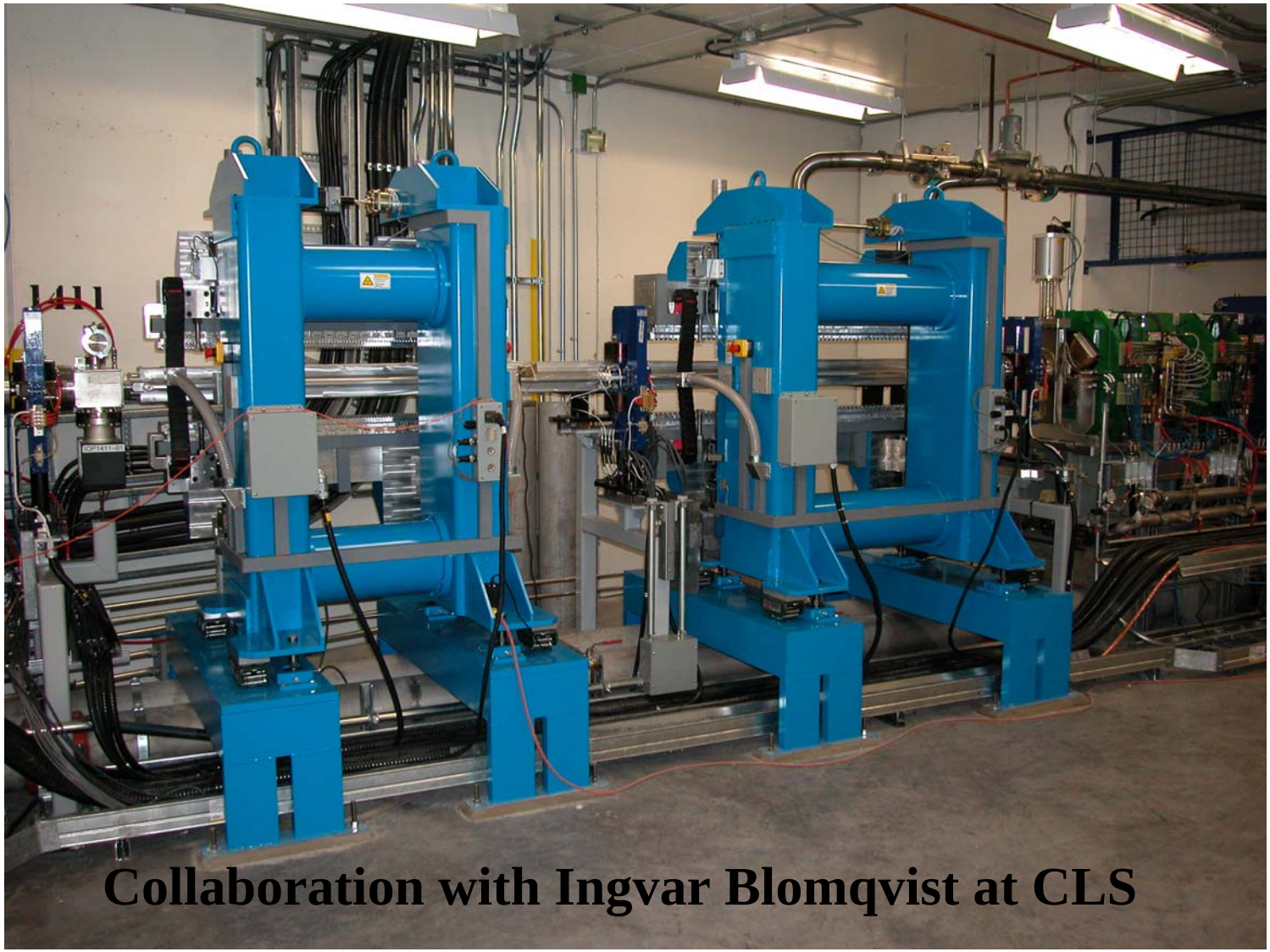
- magnetic performance

- design features

Mechanical and thermal analysis

Closing the loop on analysis

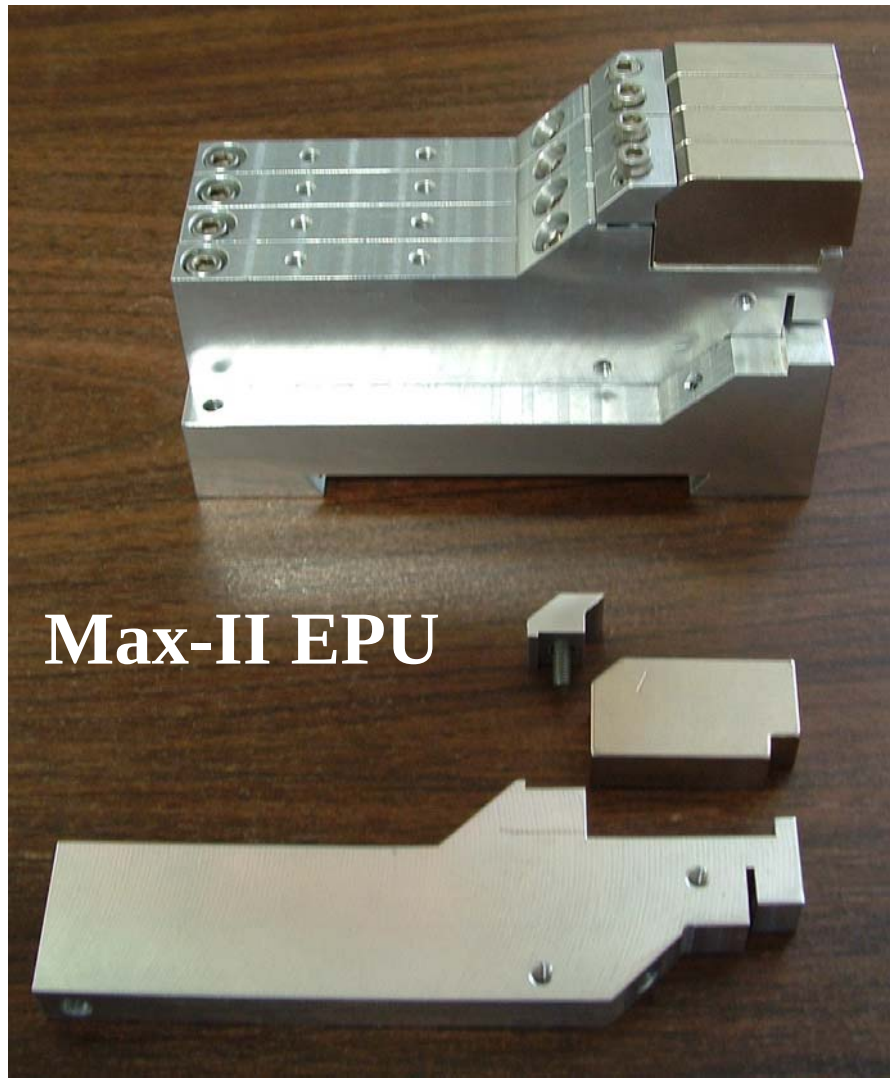
Early Devices for CHESS and CLS

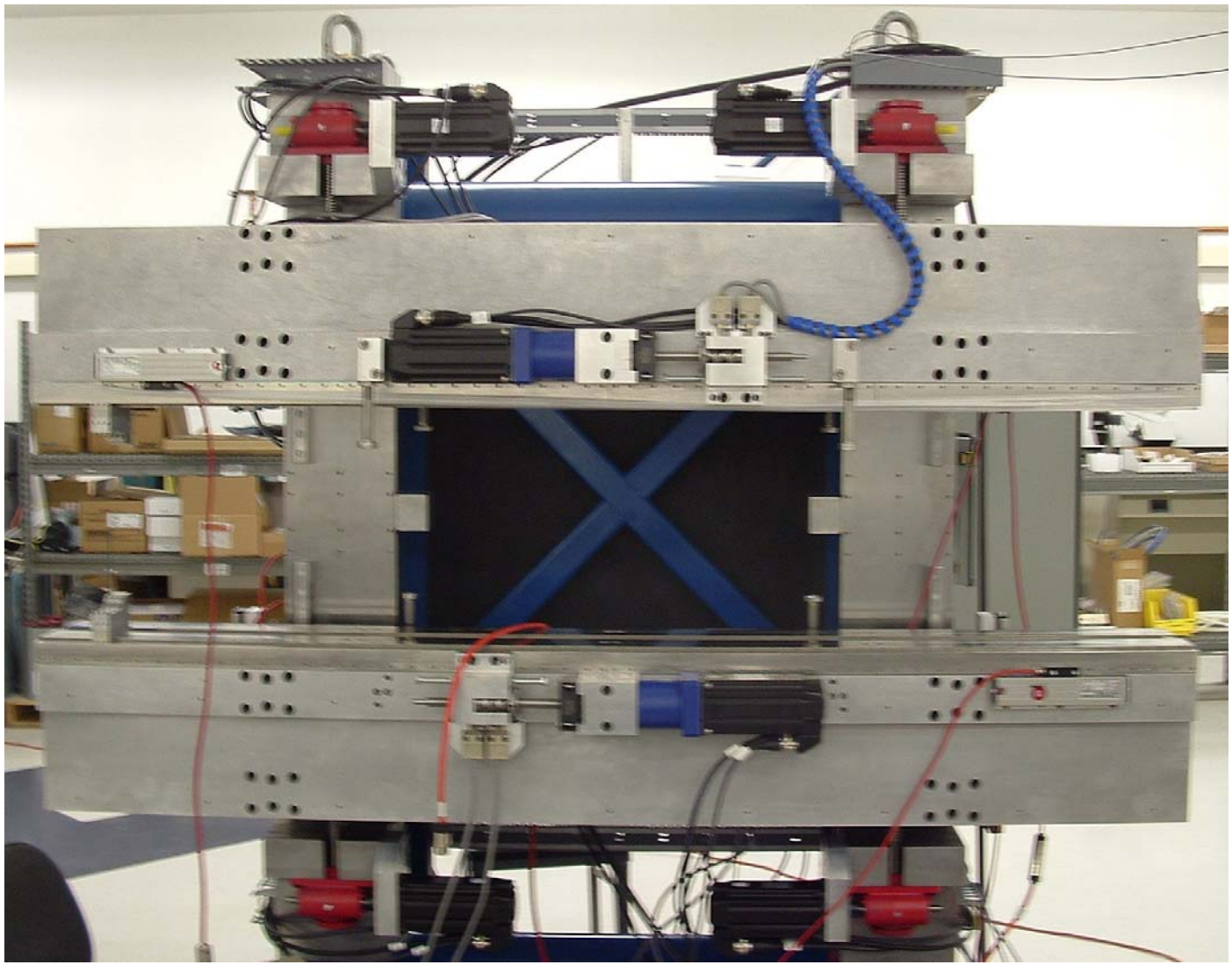


Collaboration with Ingvar Blomqvist at CLS

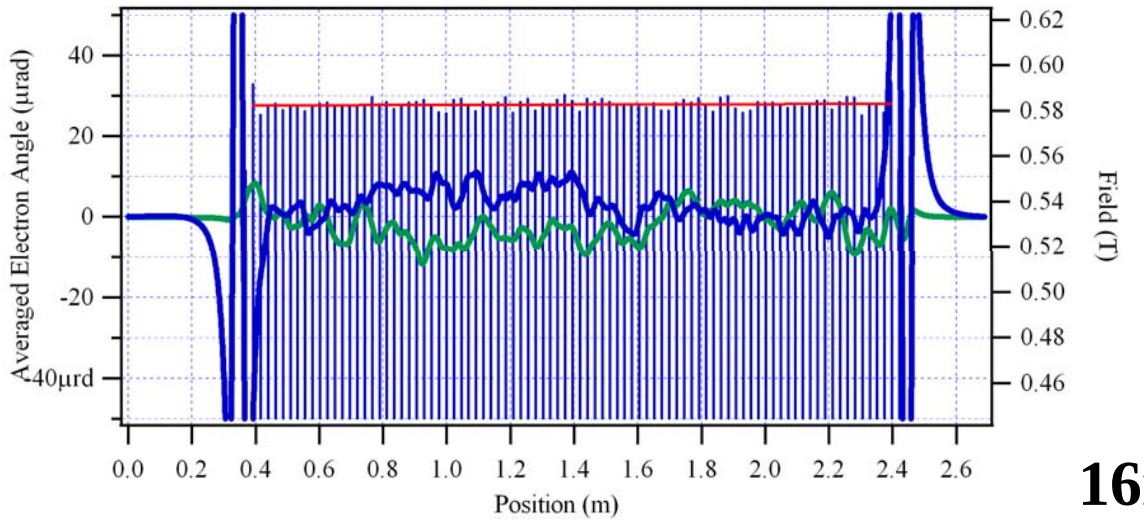
Shipped May 2005

- 92 full poles, PPM
- 46.6mm period, 2m length
- 14mm minimum gap
- 1st & 2nd integral coils
- Eight servo system
- Sectional girders
- ADC control system
- MaxLab control software (rewritten by ADC)

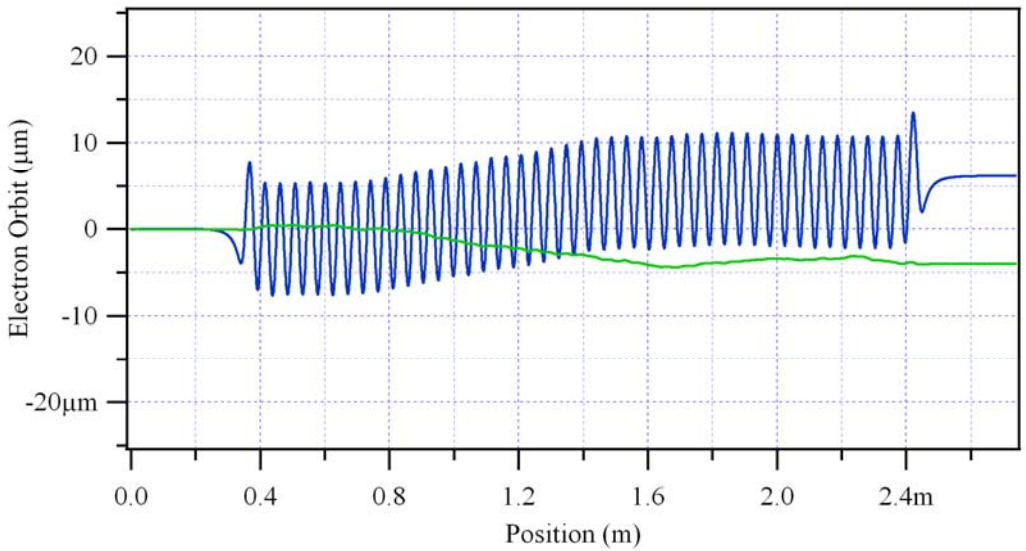


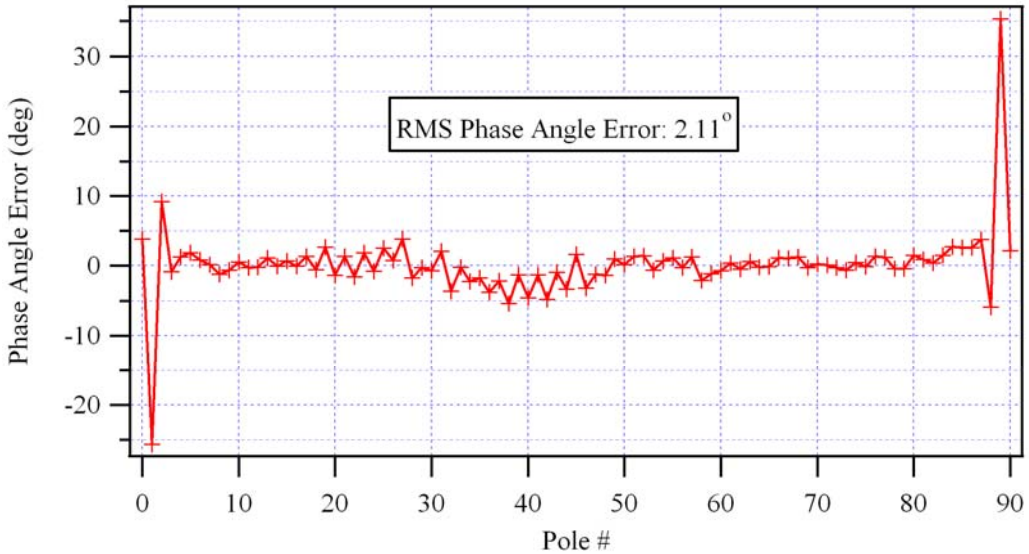


Planar mode							
Gap	$\int x$	$\int y$	$\int\int x$	$\int\int y$	B_y	Phase	Photon energy
(mm)	(Gcm)	(Gcm)	(Gcm^2)	(Gcm^2)	(T)	(deg)	(eV)
14.5	24	-21				2.1	
16	28	-28	1990	3080	0.583	2.1	108.1
18	29	-31	3130	1680	0.510	2.0	131.9
20	30	-33	1190	250	0.449	2.0	157.4
25	30	-32	-1410	1260	0.324	2.3	229.3
30	30	-33	-1840	2500	0.234	2.6	301.9
35	28	-32	-2570	3350	0.168	2.8	361.5
40	27	-29	-2070	3370	0.120	2.8	402.6
50	22	-26	-2250	3500	0.062	2.3	441.9

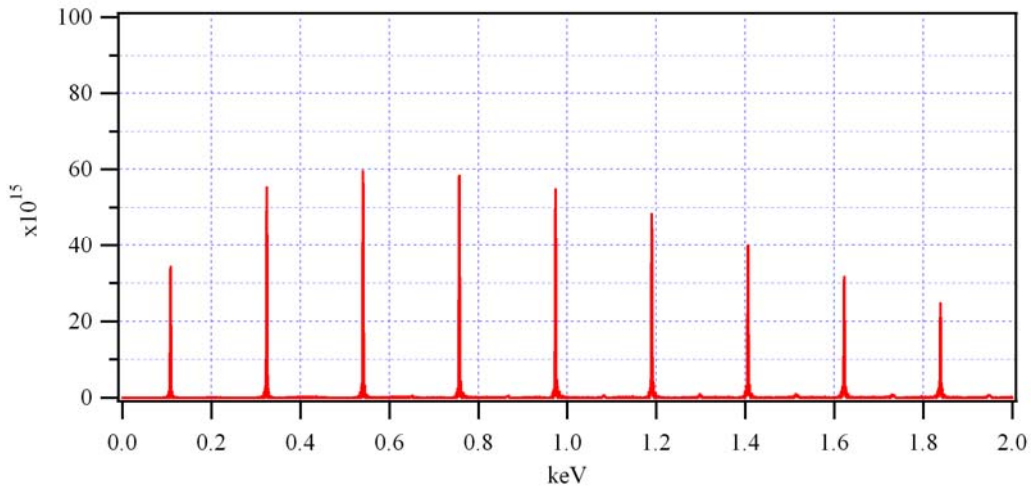


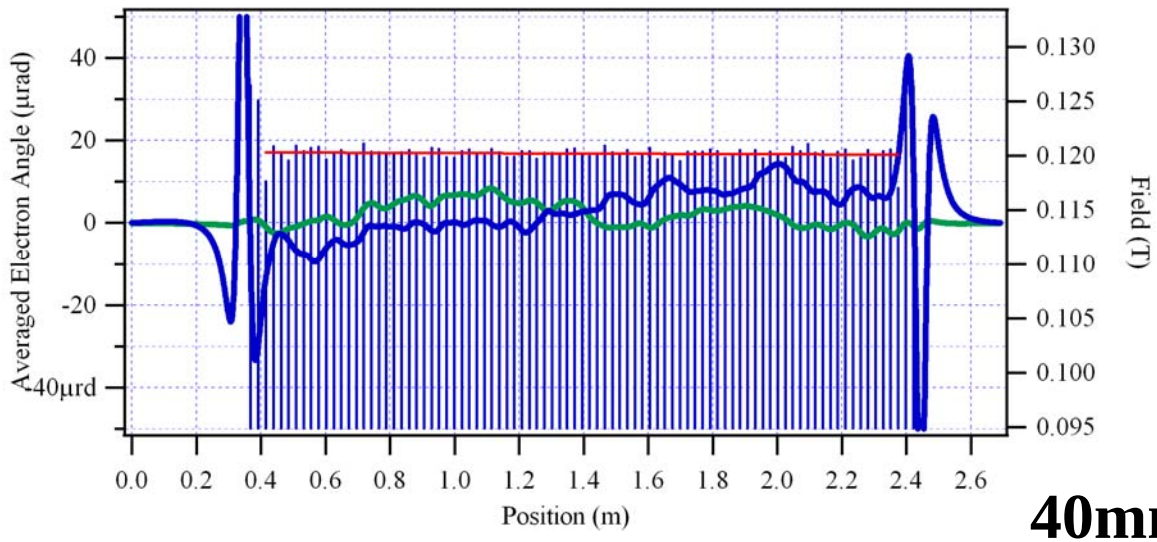
16mm, planar mode



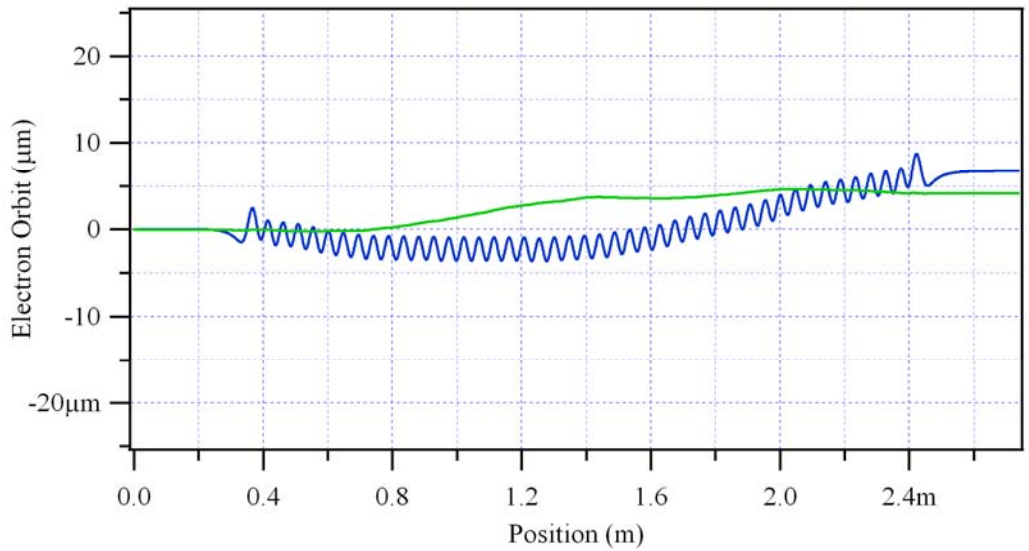


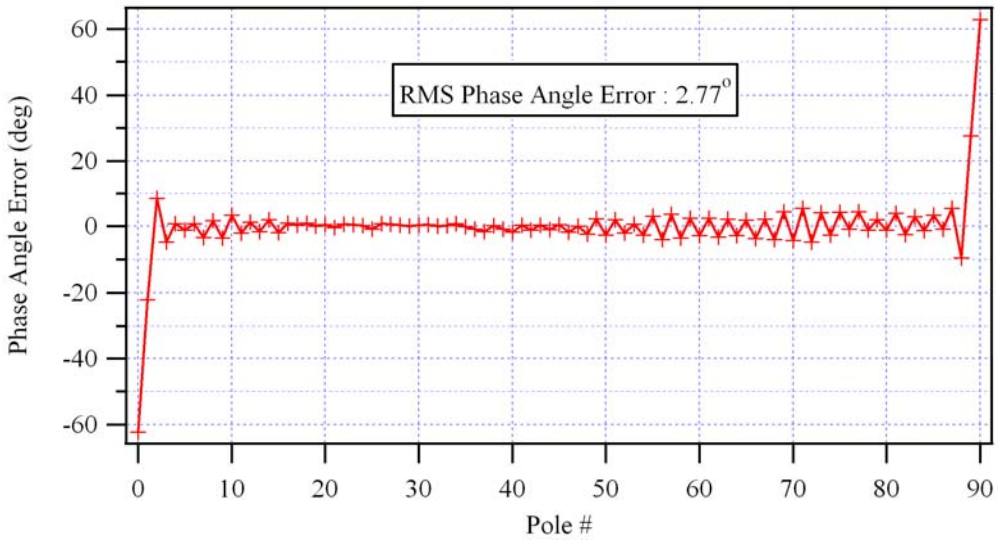
16mm, planar mode

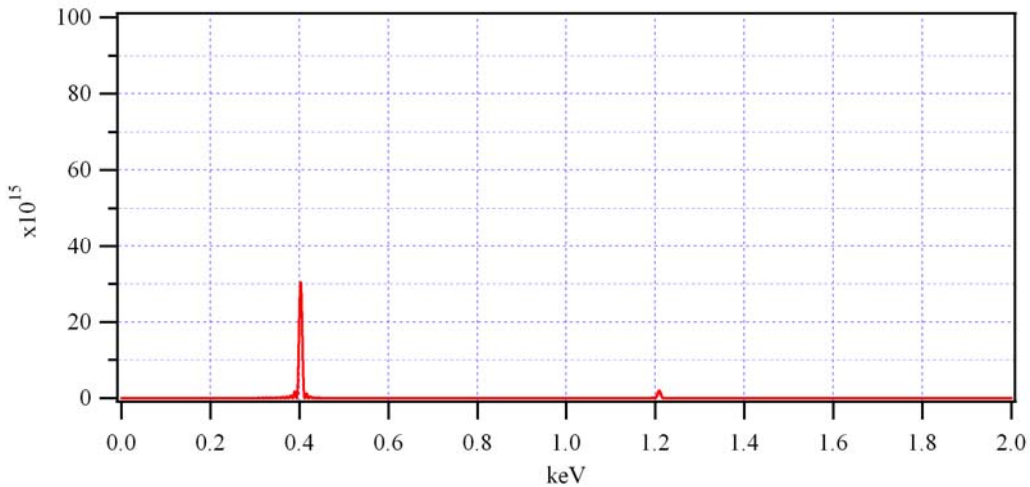




40mm, planar mode

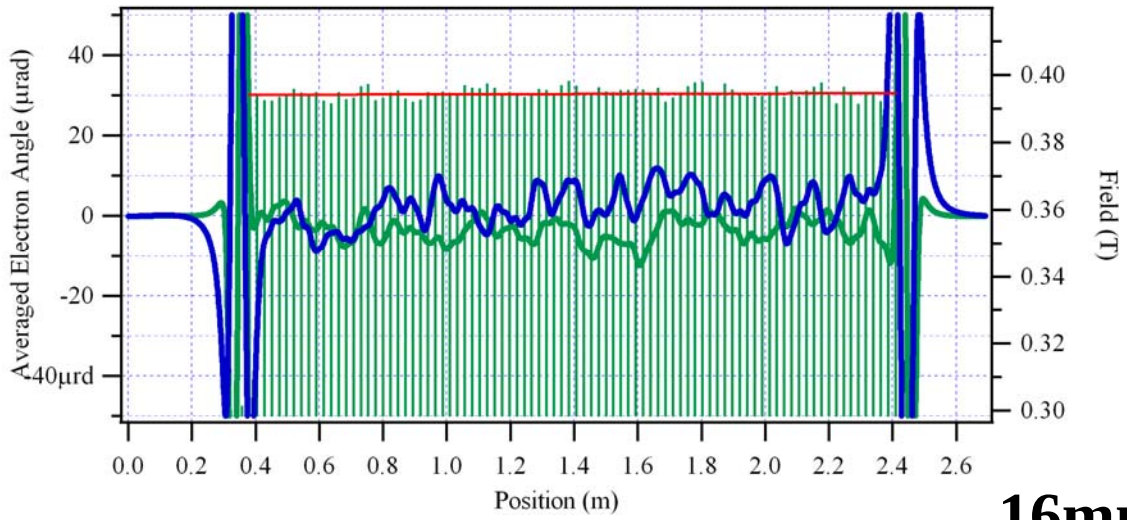




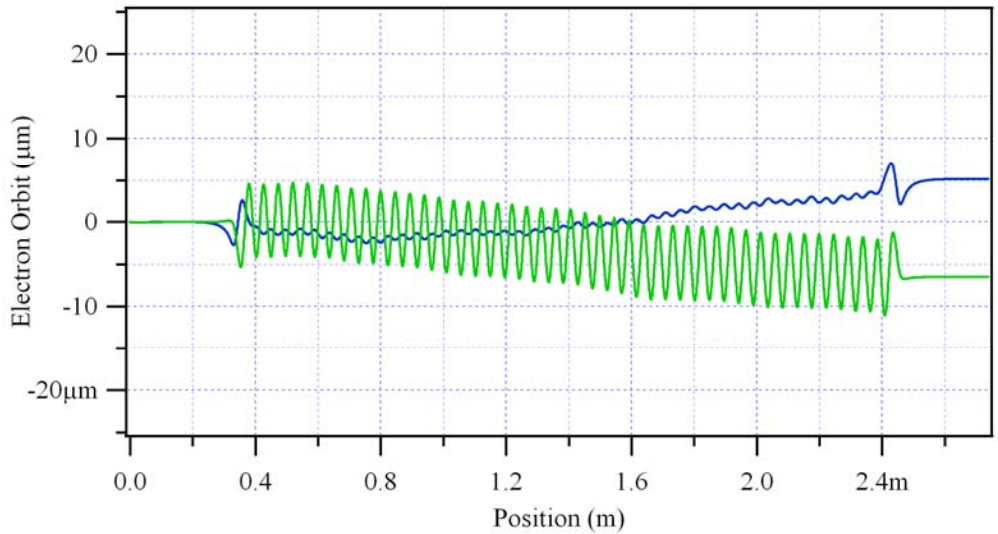


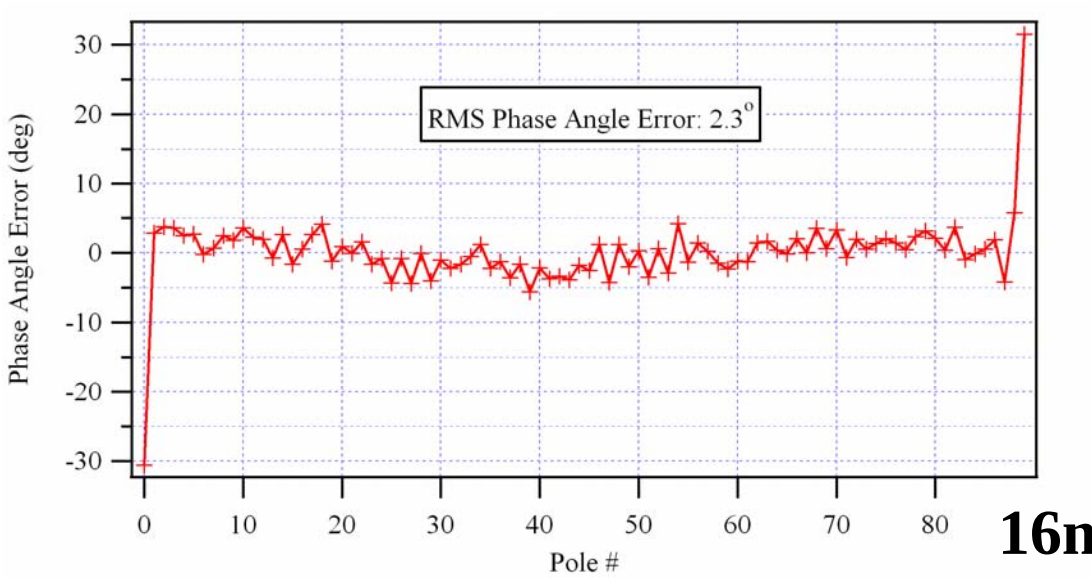
40mm, planar mode

Vertical mode							
Gap	$\int x$	$\int y$	$\int\int x$	$\int\int y$	B_y	Phase	Photon energy
(mm)	(Gcm)	(Gcm)	(Gcm^2)	(Gcm^2)	(T)	(deg)	(eV)
14.5	9	-50	-	-	-	2.6	-
16	19	-44	3240	2590	0.394	2.3	184.4
18	23	-42	690	2460	0.331	2.0	224.0
20	27	-38	0	2380	0.279	1.8	263.2
25	28	-35	-2780	2470	0.183	1.8	347.2
30	29	-30	-2270	2660	0.121	1.8	401.6
35	28	-28	-2830	3240	0.081	1.7	430.8
40	25	-26	-3610	3390	0.054	-	-
50	22	-23	-2670	3480	0.025	-	-

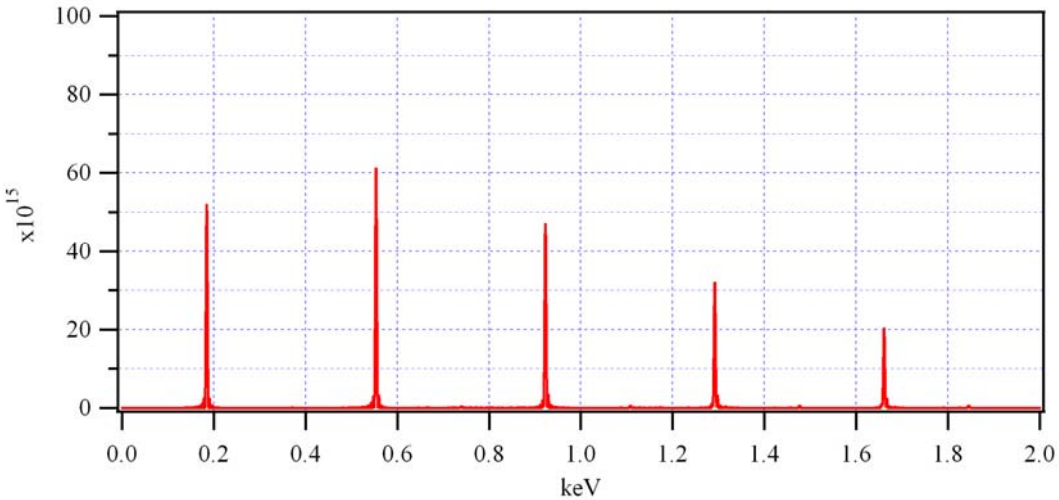


16mm, vertical mode

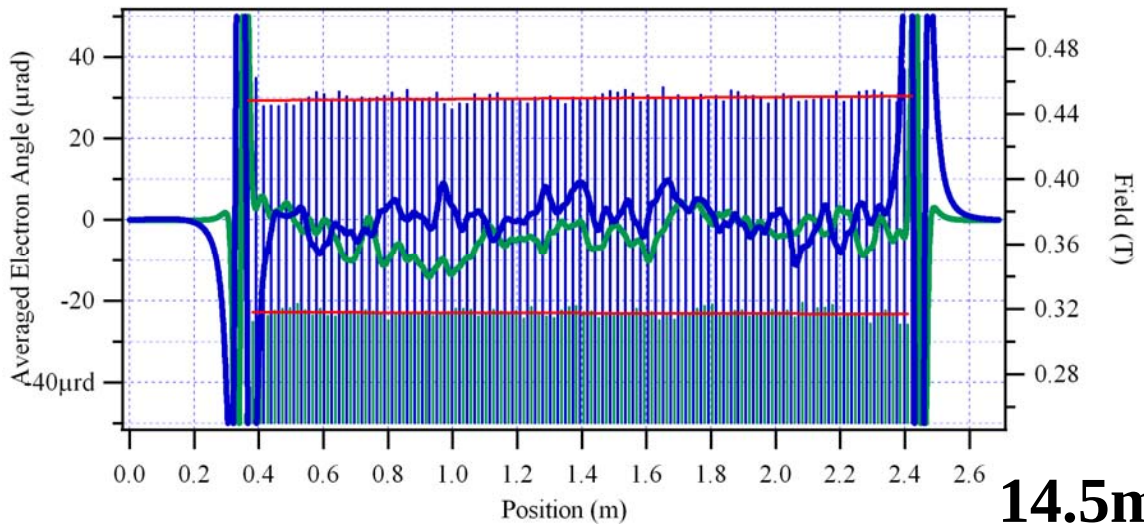




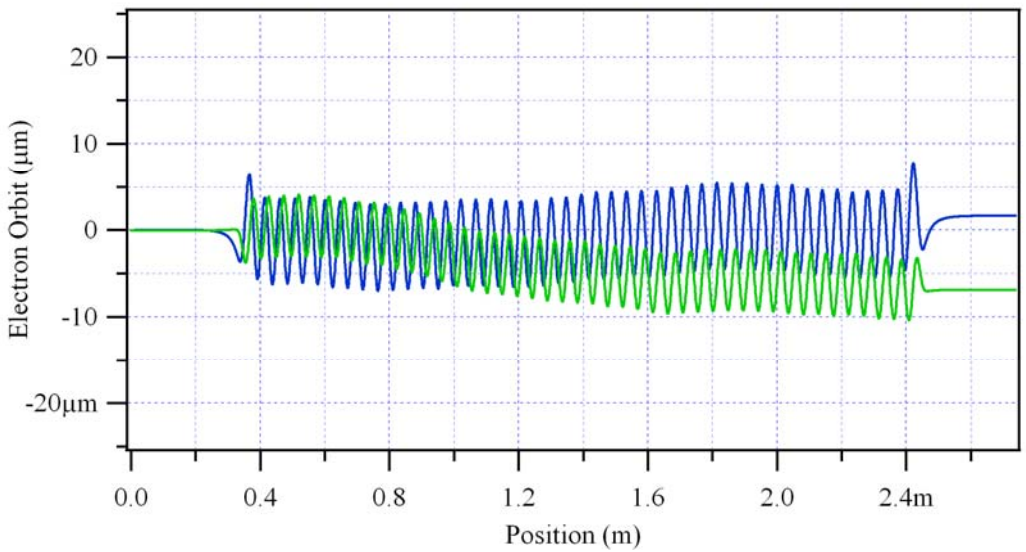
16mm, vertical mode

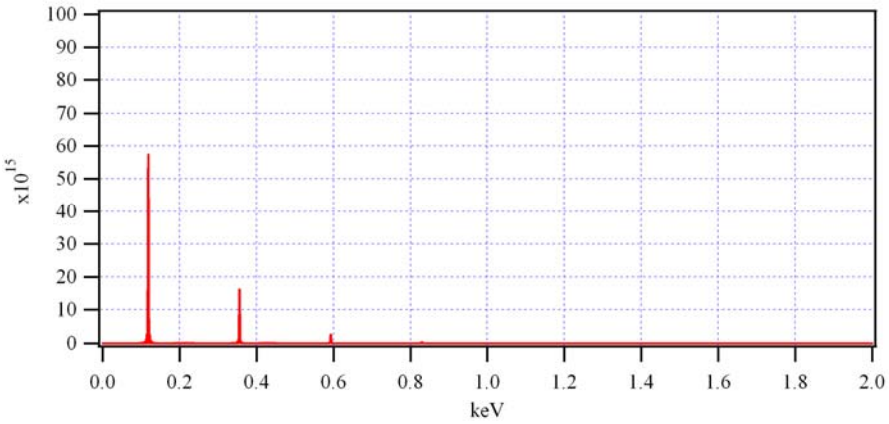


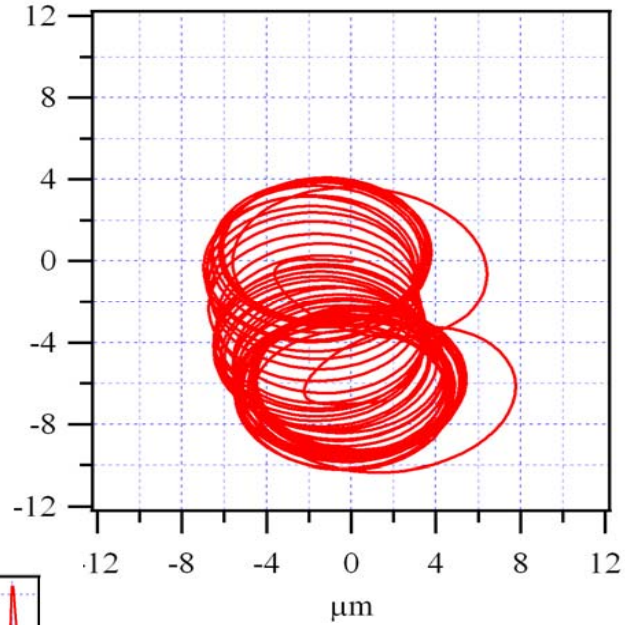
Helical mode							
Gap	$\int x$	$\int y$	$\int\int x$	$\int\int y$	B_x	B_y	Photon energy
(mm)	(Gcm)	(Gcm)	(Gcm^2)	(Gcm^2)	(T)	(T)	(eV)
14.5	-84	-82	3440	840	0.317	0.450	118.5
16	-45	-42	770	2550	0.278	0.409	138.4
18	-27	-38	170	2800	0.233	0.359	167.4
20	-16	-38	-1500	2720	0.196	0.316	198.4
25	2	-34	-1980	1920	0.129	0.228	277.7
30	10	-27	-2140	2830	0.086	0.164	345.8
35	11	-25	-2870	2850	0.057	0.118	394.0
40	15	-25	-2820	3180	0.038	0.084	423.3
50	15	-20	-2360	3310	0.018	0.043	448.5



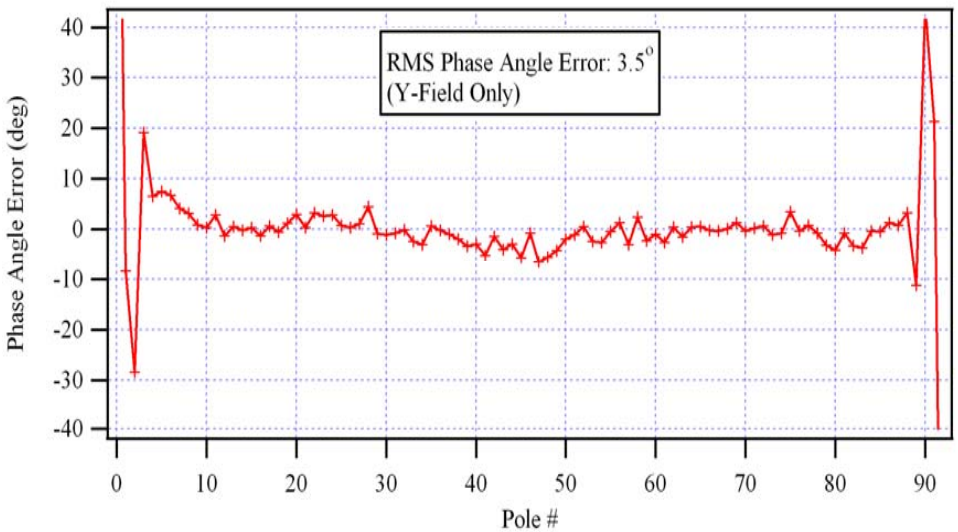
14.5mm, helical mode



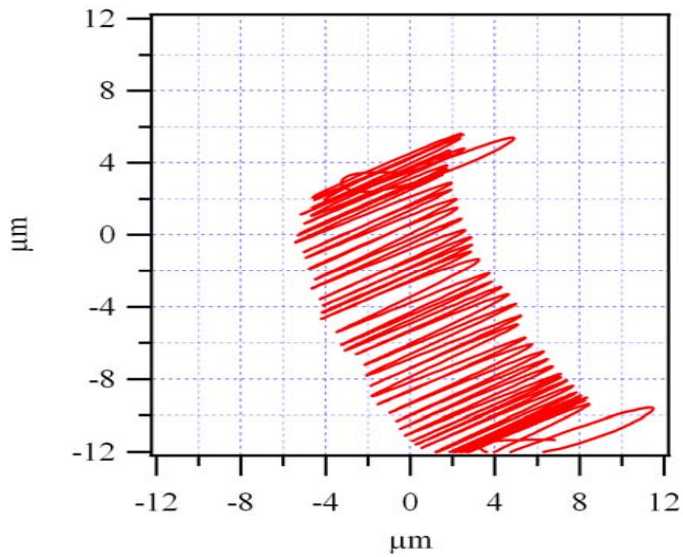


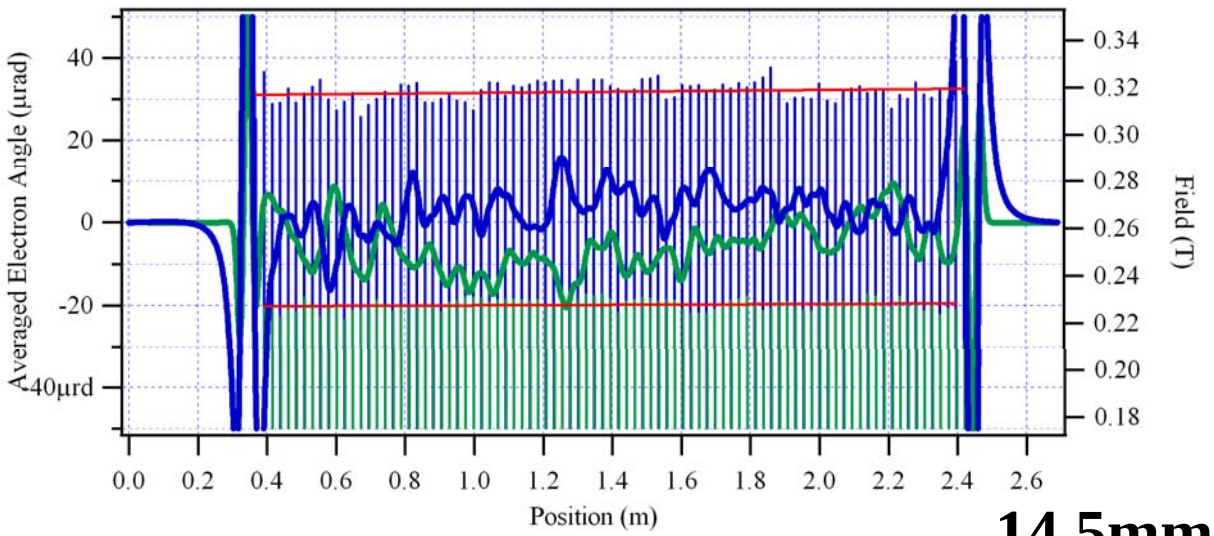


14.5mm, helical mode

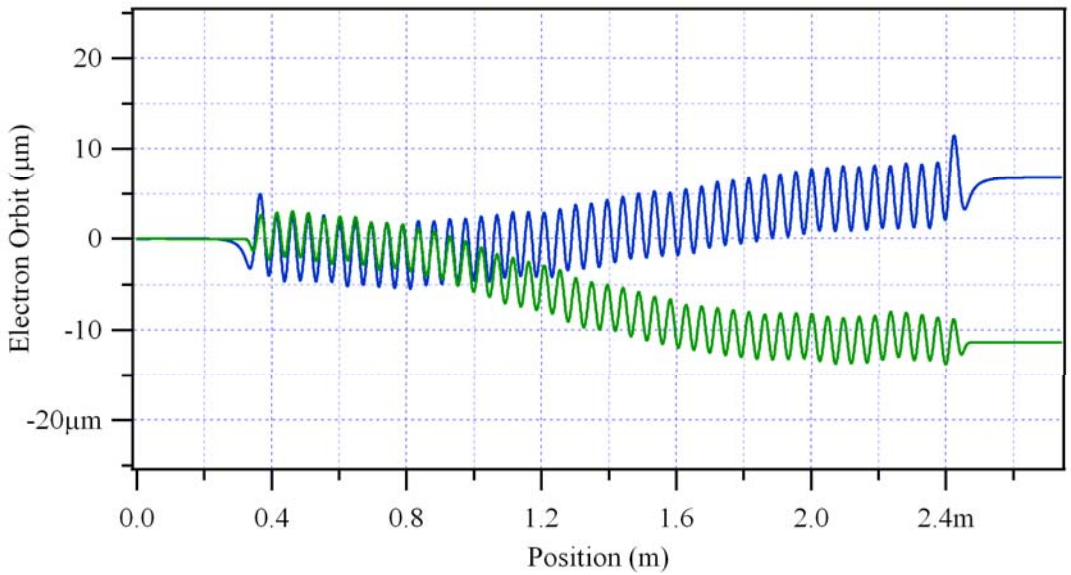


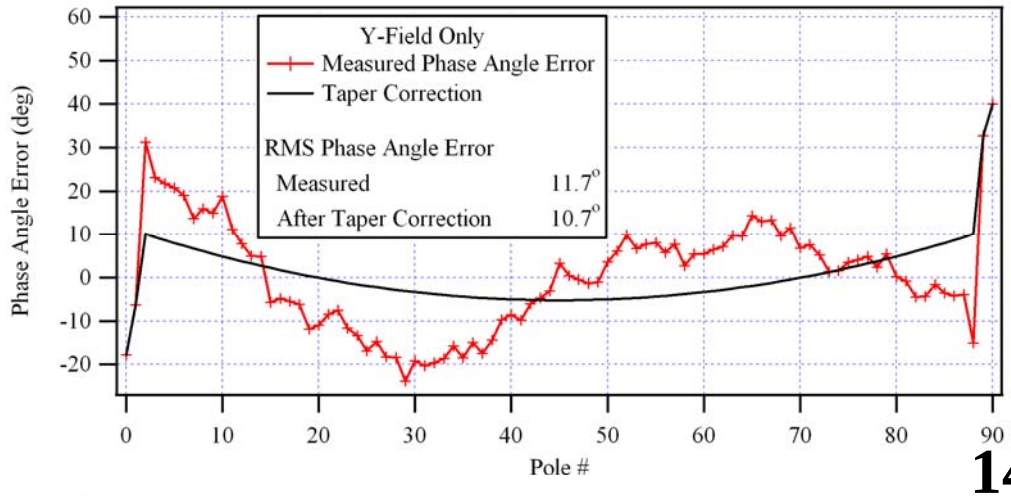
Inclined mode, 14.5mm gap							
Phase	$\int x$	$\int y$	$\int\int x$	$\int\int y$	B_x	B_y	Photon energy
(λ)	(Gcm)	(Gcm)	(Gcm^2)	(Gcm^2)	(T)	(T)	(eV)
-¼	20	-85	5690	3400	0.228	0.318	185.9
+ ¼	29	-53	2020	3790	0.216	0.328	183.6



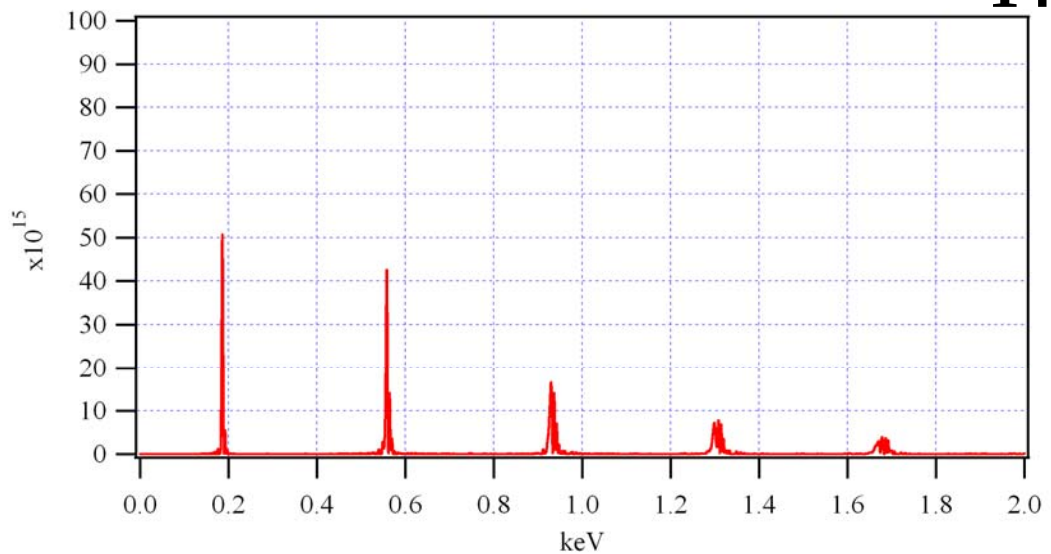


14.5mm, inclined mode





14.5mm, inclined mode



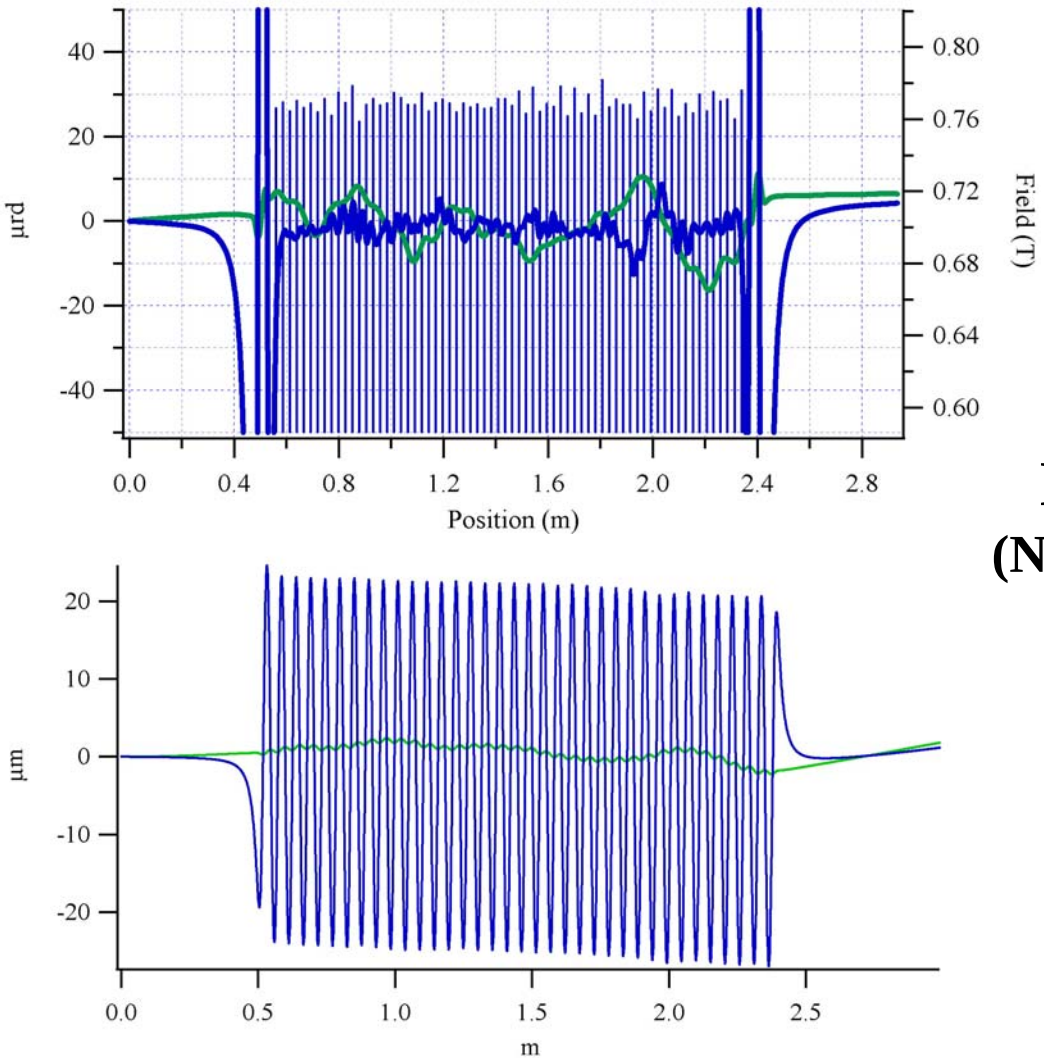
Phase		Normal Multipoles				Skew Multipoles			
		Dipole	Quad	Sext	Oct	Dipole	Quad	Sext	Oct
Planar		-51	49	44	55	-2	8	327	-197
Vertical	λ/2	-79	73	99	20	-10	38	358	-128
	- λ/2	-83	84	85	-6	-11	36	381	-126
Helical	λ/2	-79	121	114	-8	-86	14	537	-64
	- λ/2	-59	3	39	84	74	91	178	-226
Inclined Plane	λ/2	-53	-35	-2	123	31	65	280	-146
	- λ/2	-86	-42	94	155	20	71	337	-187

Max-III Planar

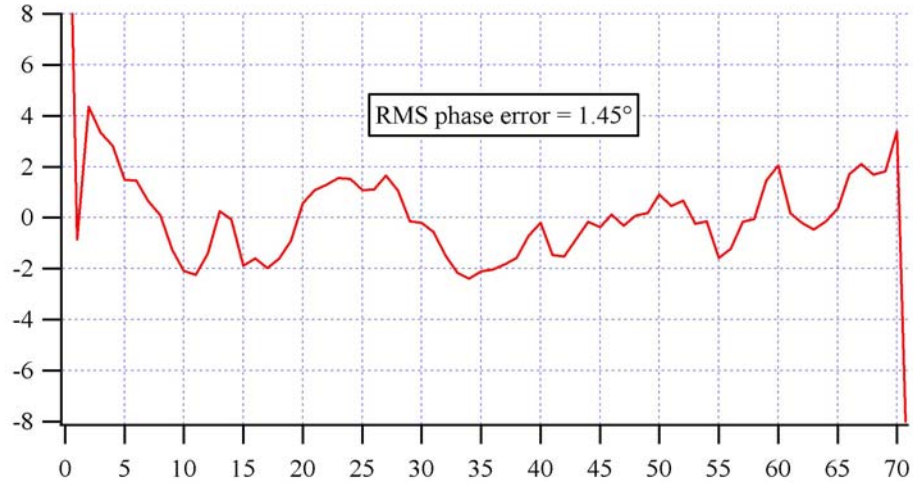
- Shipped September, 2005
- 70 full-sized poles, PPM
- 53.1mm period
- 16mm minimum gap
- Four servo-motor system
- No compensation springs
- 1st & 2nd integral correction coils
- ADC control system
- Control software by MaxLab
  (rewritten by ADC)

Max-III Planar

Summary of magnetic results.	Spec limit	Achieved
Electron energy at minimum gap	13.8 eV	10.9eV
RMS phase angle error, fundamental.	< 3°	< 1.45°
1st integral, vertical field	< 100 G-cm	17 G-cm
1st integral, horizontal field	< 100 G-cm	78 G-cm
Normal quadrupole	< 50 G	25.1
Skew quadrupole	<50 G	47.0
Normal sextupole	< 100 G/cm	10.6
Skew sextupole	< 100 G/cm	18.9
Normal octupole	< 150 G/cm^2	4.06
Skew octupole	< 150 G/cm^2	17.1

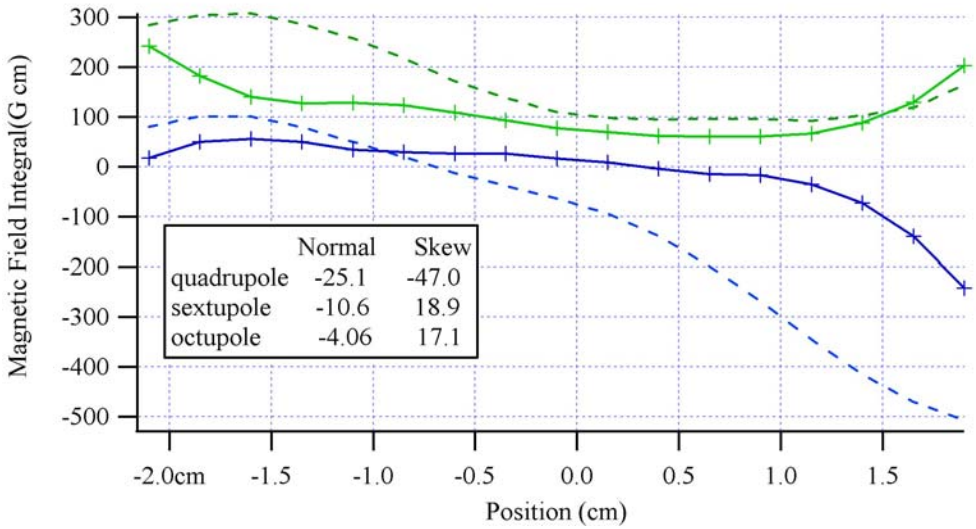


Max-III Planar
(No correction coils used)



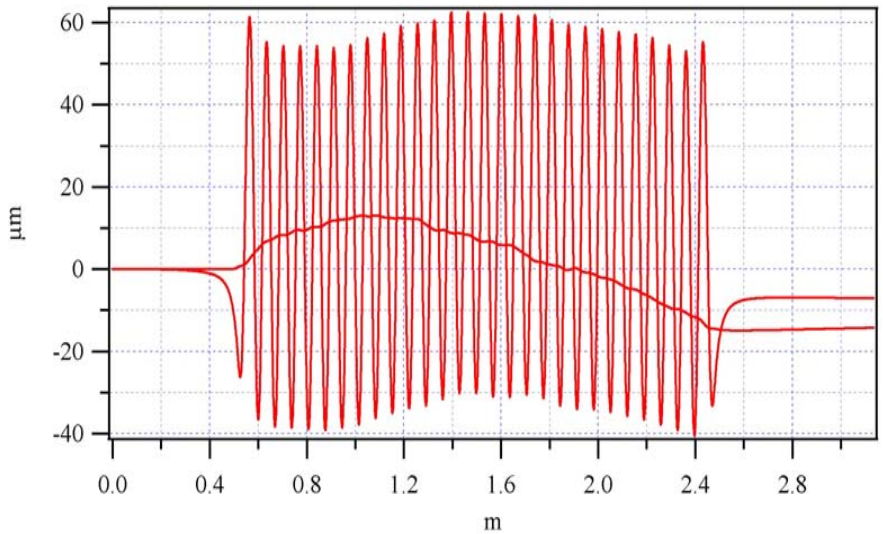
Max-III Planar

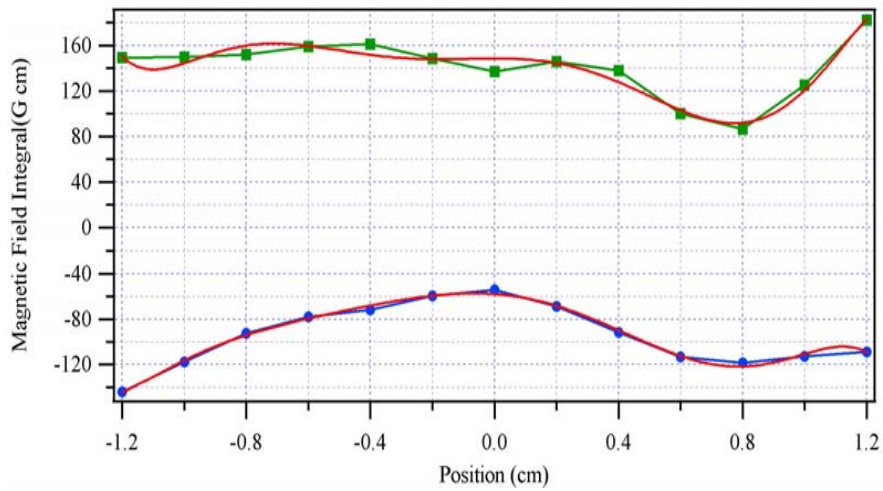
(No correction coils used)



Max-III EPU

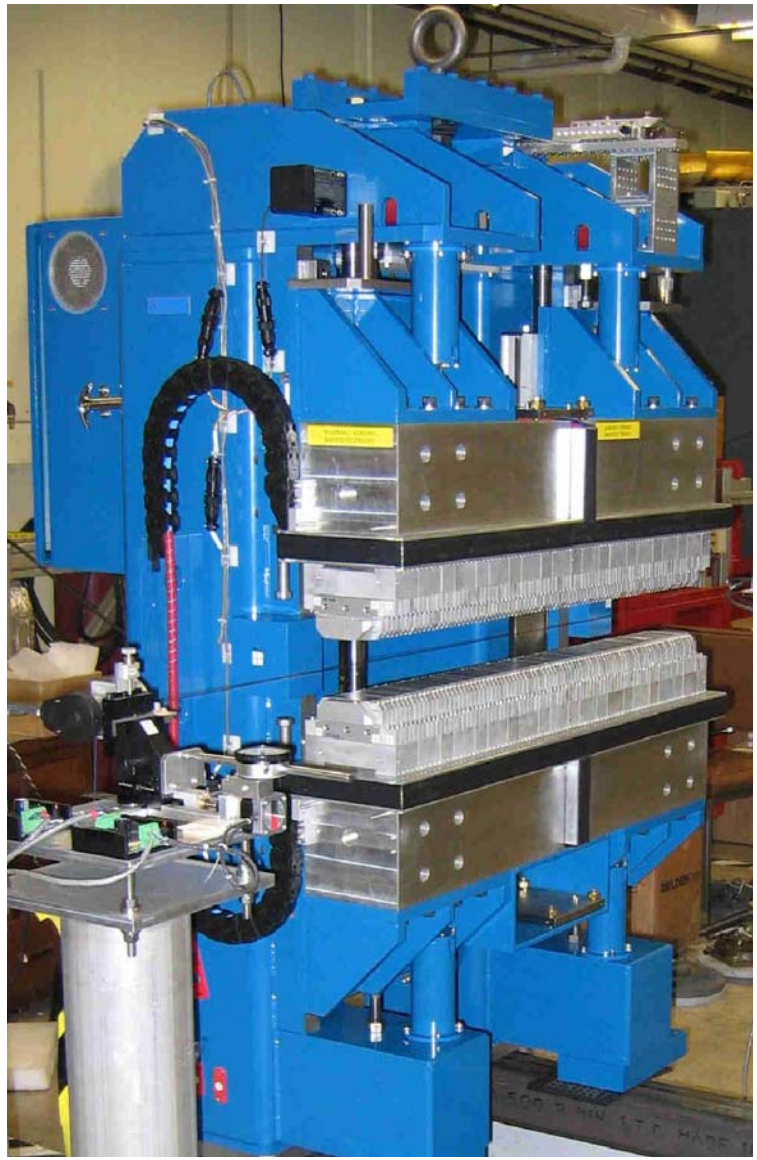
- Shipped October 2006
- 92 full-sized poles, PPM
- 46.6mm period, 2m length
- 16 mm minimum gaps
- Six servo-motor system
- no compensation springs
- Sectional girders
- Shims
- Glued this time





SRC Planar

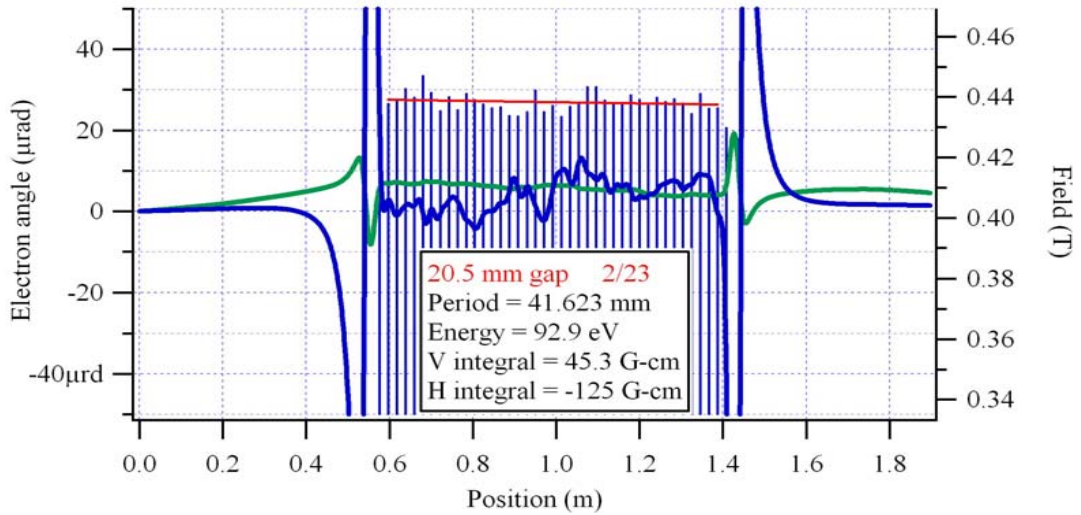
- **Shipped March 2005**
- **41 full-sized poles, PPM**
- **41.6mm period, 0.9m length**
- **20.5mm minimum gap**
- **Single stepper motor**
- **Manual phase adjuster**
- **Compensation springs**
- **1st integral skew quad and normal 2nd integral coils**

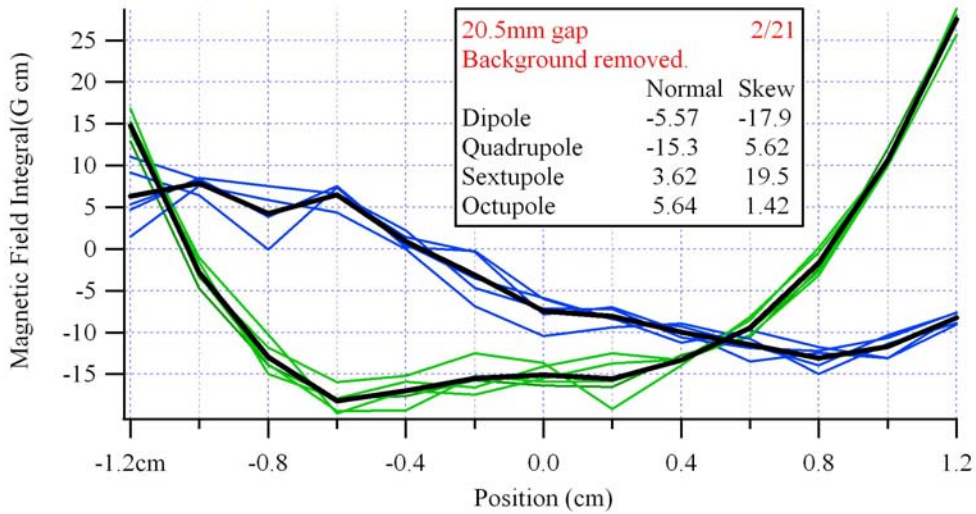


Gap		Normal terms				Skew terms			
		Di	Quad	Sex	Oct	Di	Quad	Sex	Oct
20.5	Closing	-5.57	-15.3	3.62	5.64	-17.9	5.62	19.5	1.42
21	Open	-4.27	-15.7	1.05	7.01	-18.1	7.64	22.3	-1.63
21	Closing	-1.66	-17.1	3.25	6.92	-15.1	5.51	20.0	1.41
22.7	Open	-6.57	-13.4	2.79	6.53	-9.83	7.39	25.2	-5.11
25.1	Open	-7.70	-10.6	3.72	6.69	1.82	5.51	26.3	-6.66
28.7	Open	-9.84	-5.49	4.44	4.01	18.3	1.44	27.1	-6.79
28.7	Closing	-6.96	-7.69	4.26	5.43	19.0	-2.55	25.9	-2.57
37.5	Open	-13.9	-2.56	4.20	3.43	51.3	-6.30	21.7	-4.84
80	Open	-49.6	2.83	-1.39	-0.44	118	-7.33	4.12	0.18
Spec limit		50	25	20	25	15	5	20	25

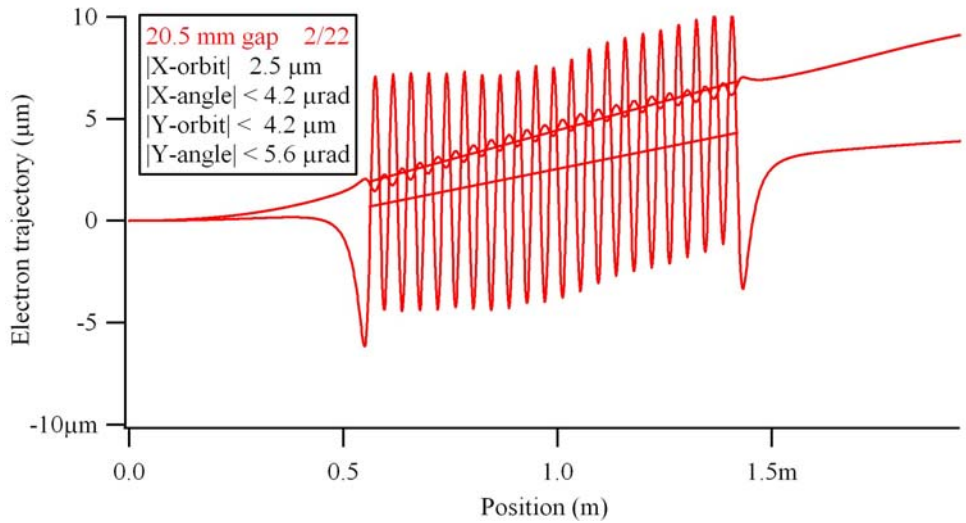
SRC Planar - Multipoles with the background fields removed.

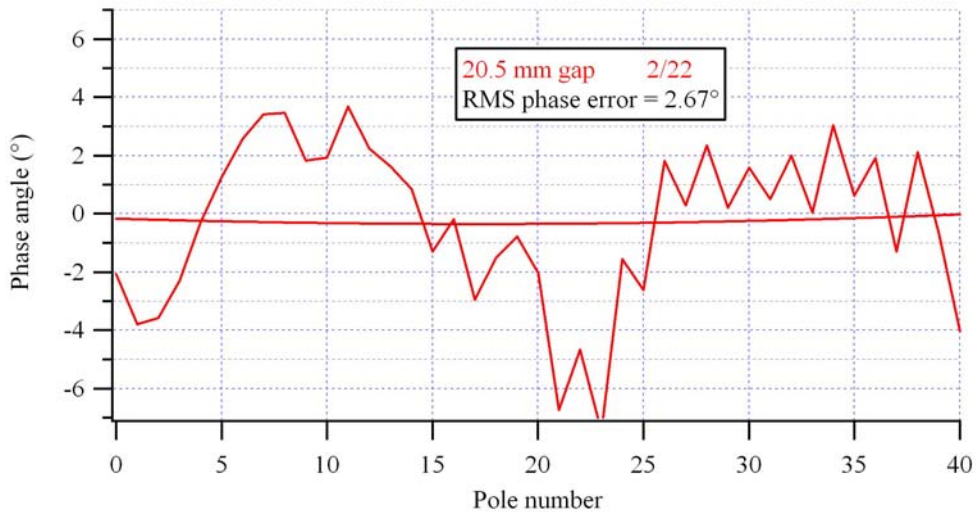
SRC Planar


Electron angle (µrad)
Field (T)
Position (m)
20.5 mm gap 2/23
Period = 41.623 mm
Energy = 92.9 eV
V integral = 45.3 G-cm
H integral = -125 G-cm


Magnetic Field Integral(G cm)
Position (cm)
20.5mm gap 2/21
Background removed.
Normal Skew
Dipole -5.57 -17.9
Quadrupole -15.3 5.62
Sextupole 3.62 19.5
Octupole 5.64 1.42

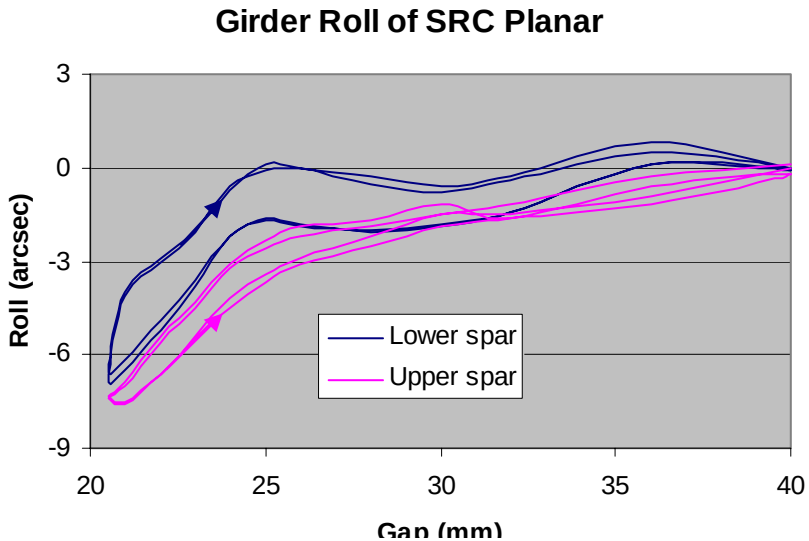
SRC Planar

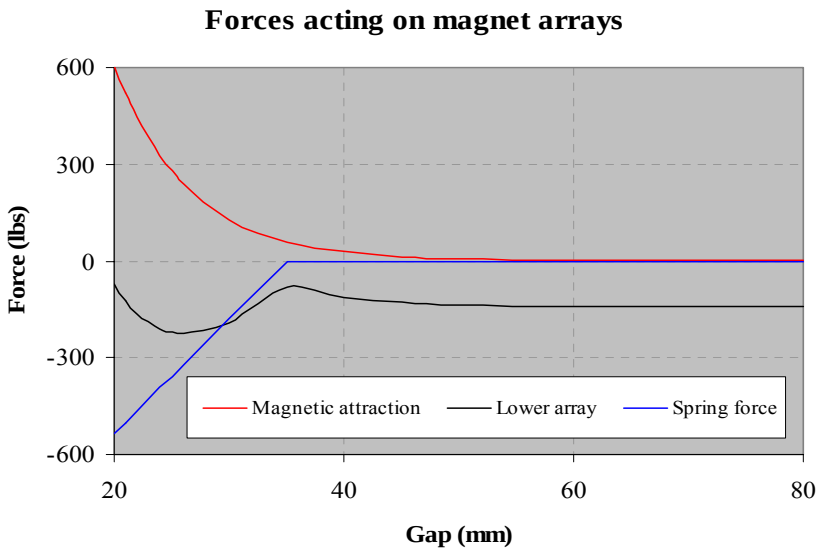

20.5 mm gap 2/22
|X-orbit| 2.5 µm
|X-angle| < 4.2 µrad
|Y-orbit| < 4.2 µm
|Y-angle| < 5.6 µrad
Electron trajectory (µm)
10
5
0
-5
-10µm
0.0
0.5
1.0
1.5m
Position (m)

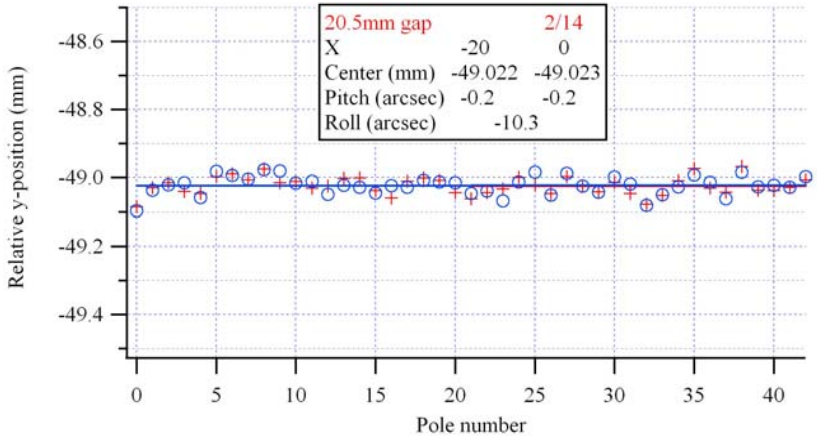

20.5 mm gap 2/22
RMS phase error = 2.67°
Phase angle (°)
6
4
2
0
-2
-4
-6
0
5
10
15
20
25
30
35
40
Pole number

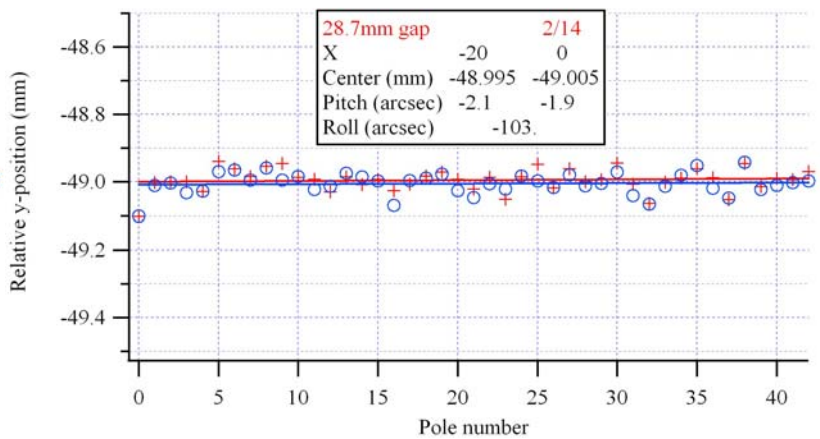
Gap (mm)	Energy (eV)	Phase Error	X_{orb} (μm)	X_{ang} (μrad)	Y_{orb} (μm)	Y_{ang} (μrad)	$\Integral_{hor}$ (G-cm)	$\Integral_{vert}$ (G-cm)	$\Integral\Integral_{hor}$ (G-cm^2)	$\Integral\Integral_{vert}$ (G-cm^2)
20.5	92.9	2.67	2.5	4.2	4.2	5.6	-15	4.2	-1400	420
21	97.1	2.49	0	-0.6	-0.8	-1.4	-12	0.4	-1200	-39
22.7	112	2.12	0.7	0.2	1.7	3.4	-4	-5.0	-350	-499
25.1	132	1.86	-0.1	-3.0	-1.4	-3.1	7	-6.7	728	-671
28.7	161	1.63	0.9	0.9	-1.9	1.4	22	-9.0	2260	-900
37.5	206	2.77	-0.3	-6.6	0.6	-3.6	54	-15	5420	-1500
80			-7.7	-12.3	-4.1	-5.7	120	-46.6	11,800	-5,030
Limit		7	50	40	10	10	50	15	2500	7500

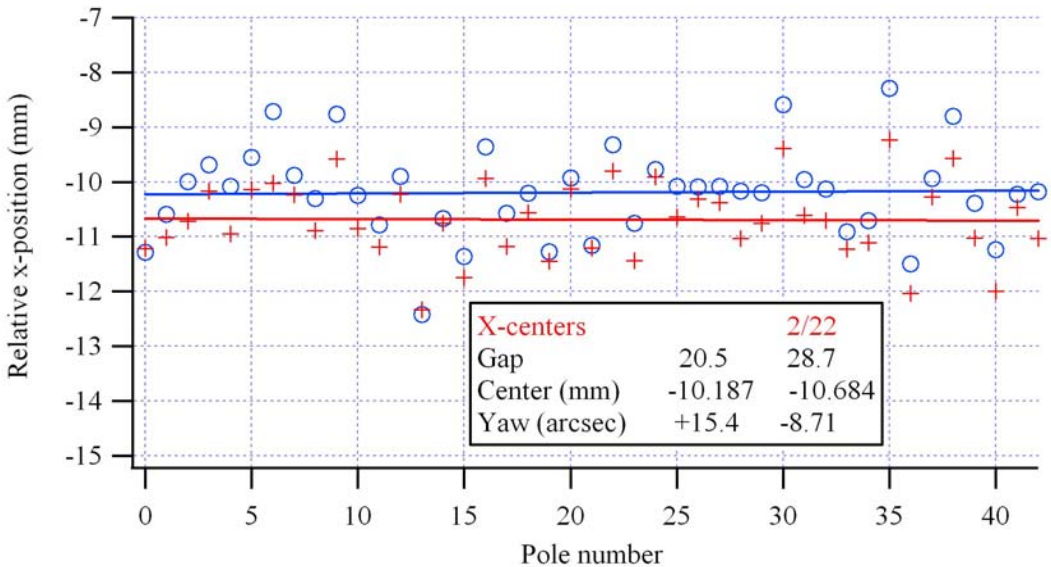
Summary of SRC planar undulator performance. No correction coils used.


Girder Roll of SRC Planar
Roll (arcsec)
3
0
-3
-6
-9
20
25
30
35
40
Gap (mm)
Lower spar
Upper spar

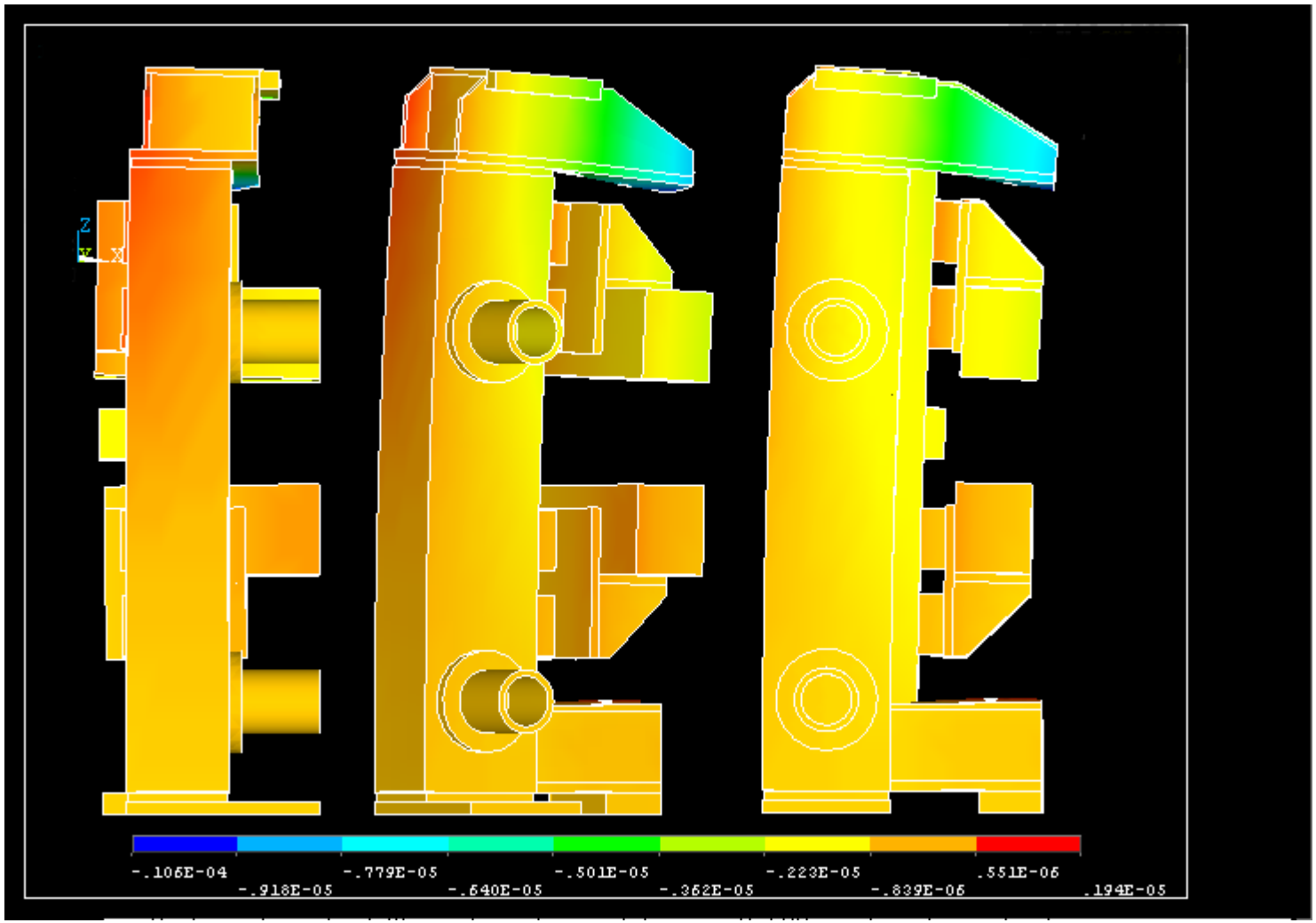

Forces acting on magnet arrays
Force (lbs)
600
300
0
-300
-600
20
40
60
80
Gap (mm)
Magnetic attraction
Lower array
Spring force





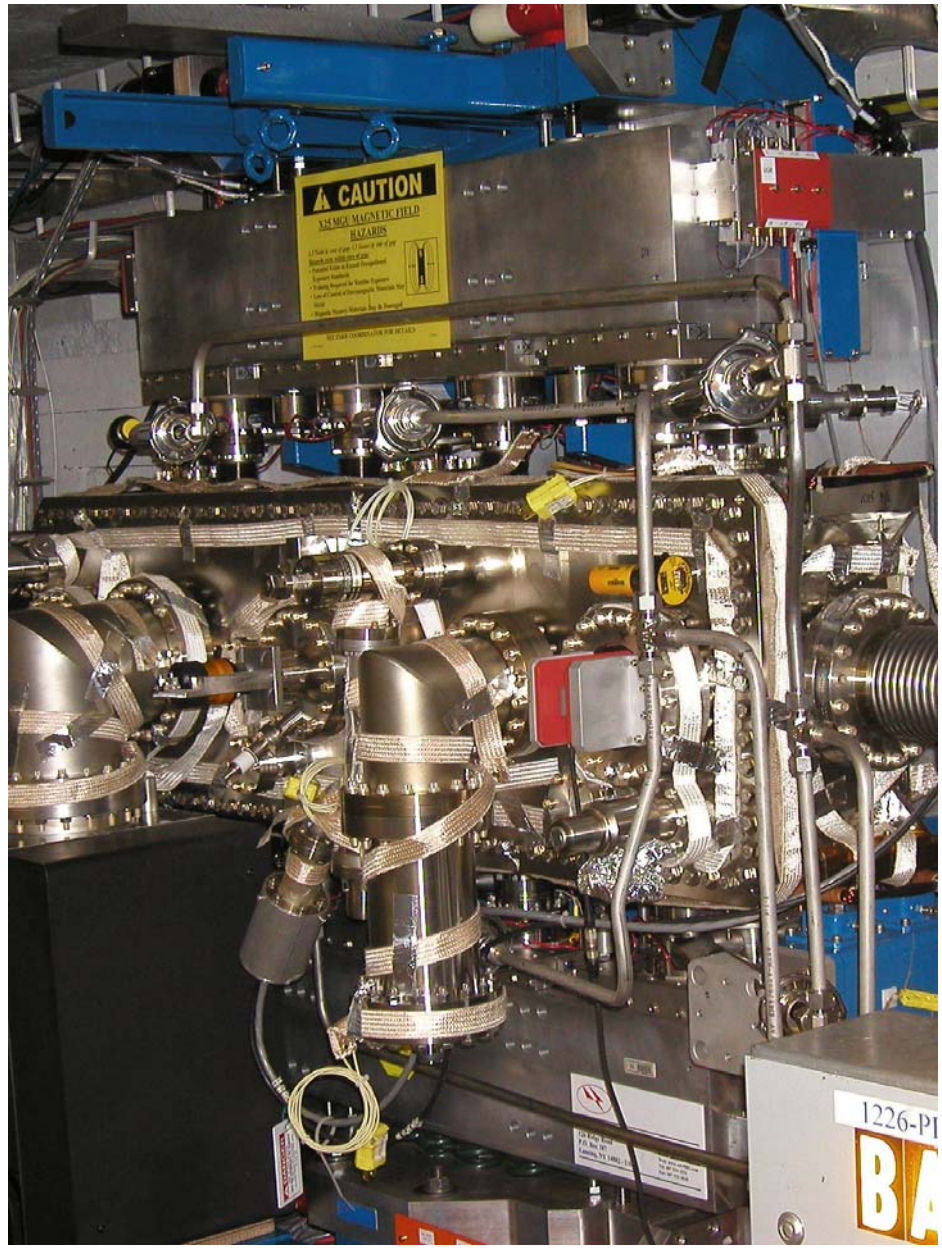


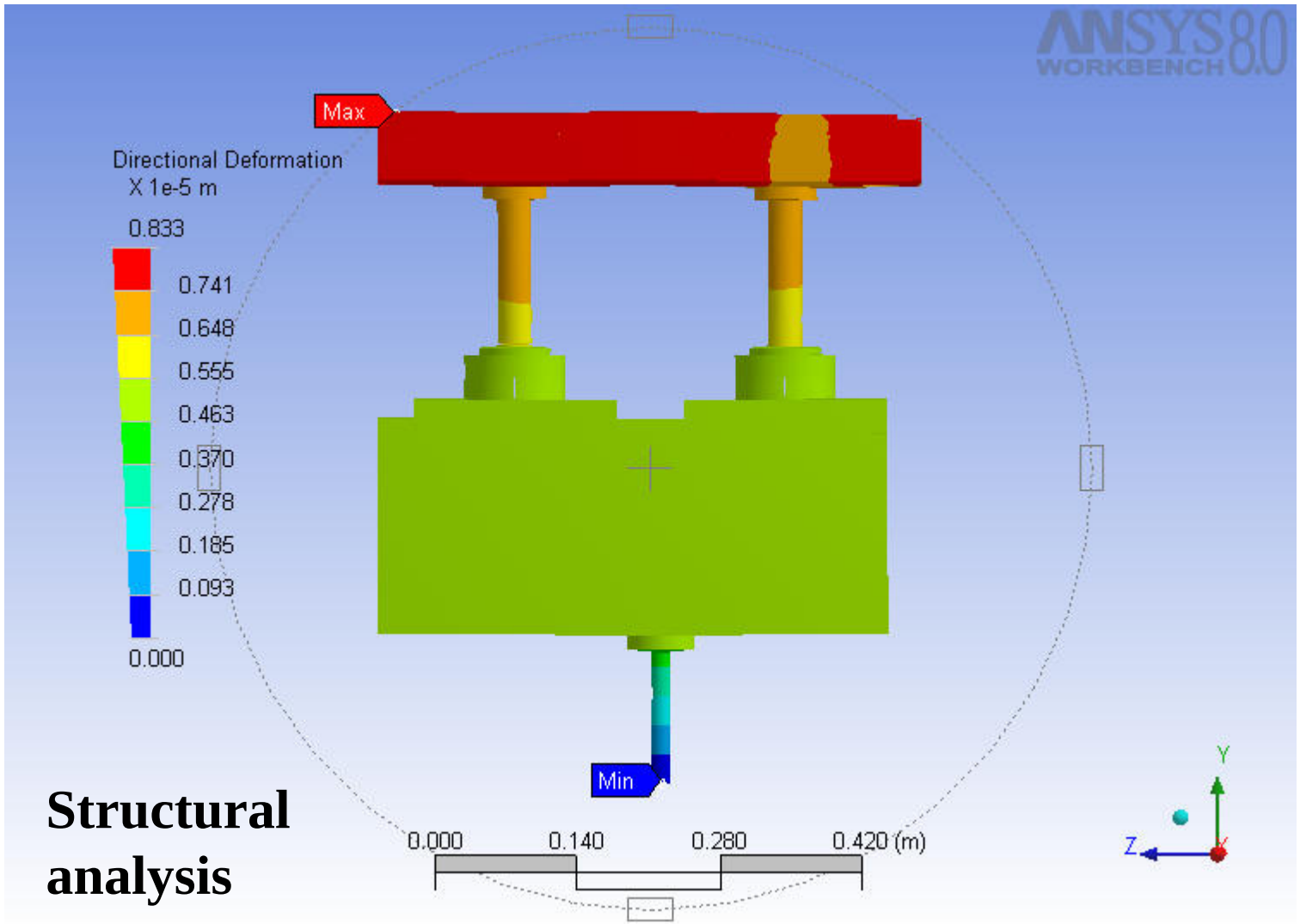
Little change in Y
Bigger change in X


Z
Y
X
-.106E-04
-.918E-05
-.779E-05
-.640E-05
-.501E-05
-.362E-05
-.223E-05
-.839E-06
.551E-06
.194E-05

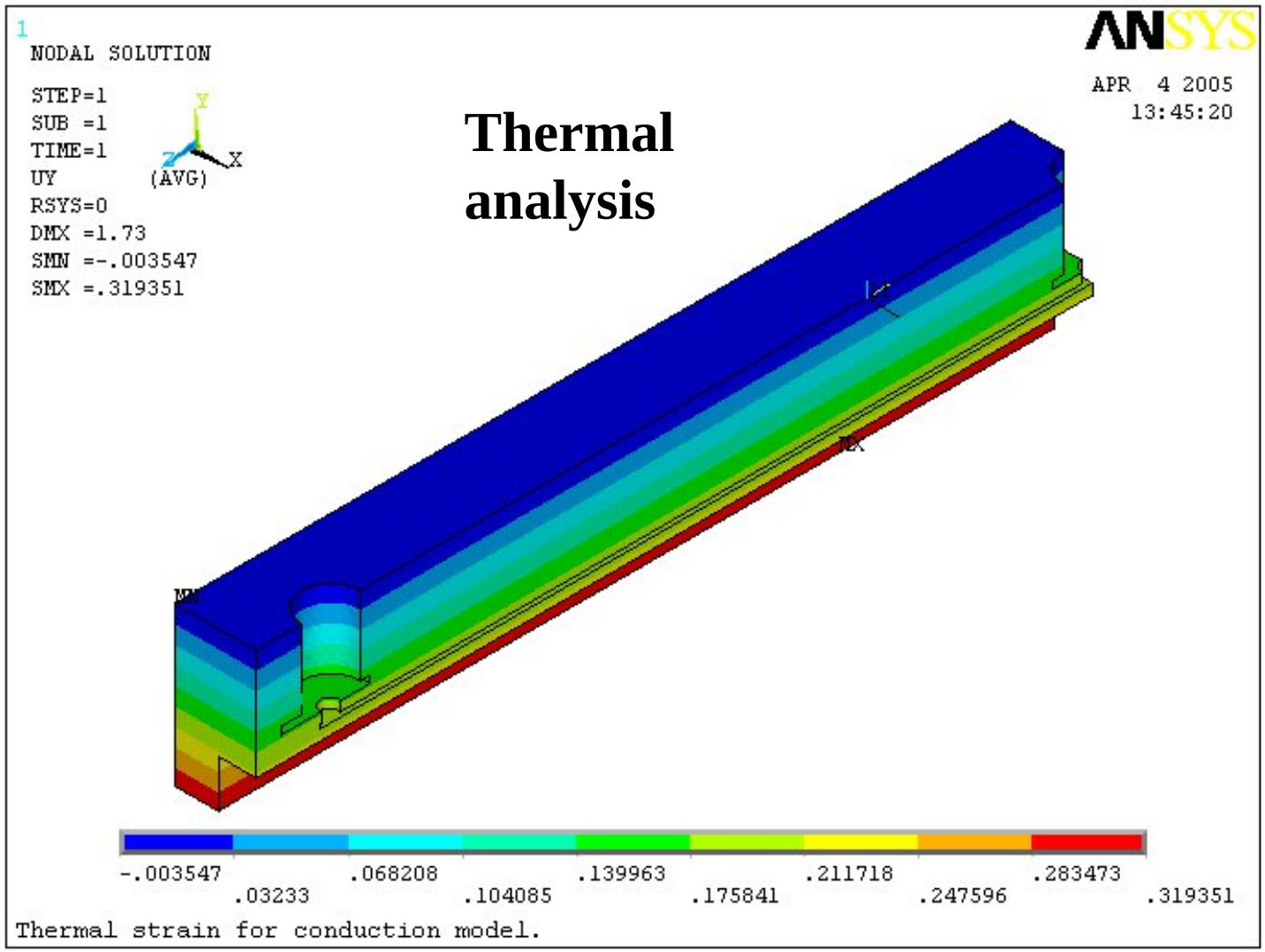
BNL In-vacuum Hybrid

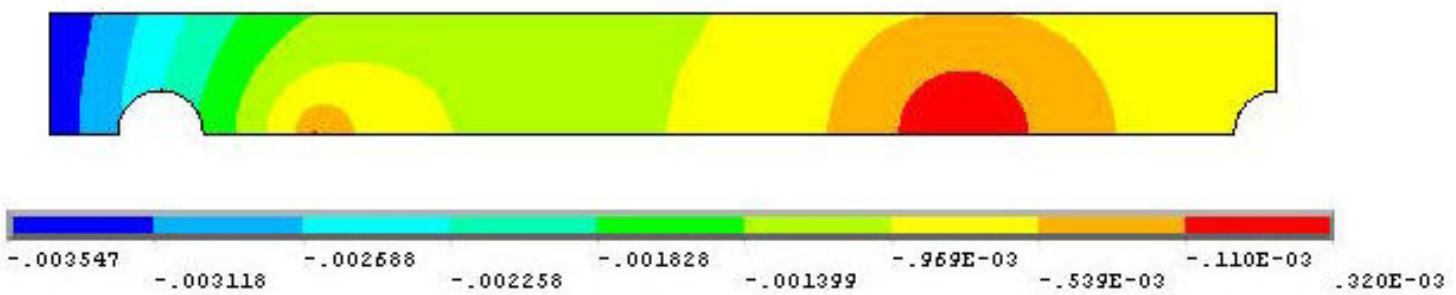
- **Shipped October 2005**
- **Magnets installed by BNL**
- **In-situ shimming**
- **Cryo-capable**
- **Thermal compensation**
- **5 mm minimum gap**
- **Four stepper motors**
- **0.5 µm accuracy**
- **Optical gap control**



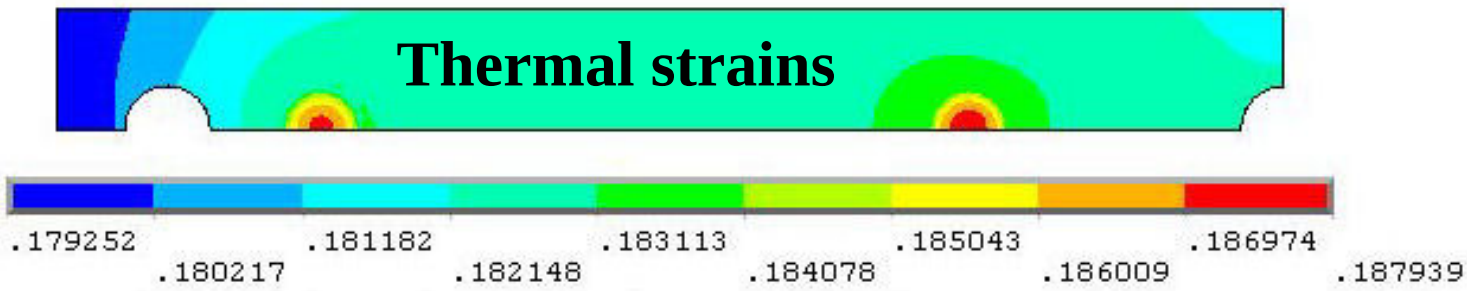


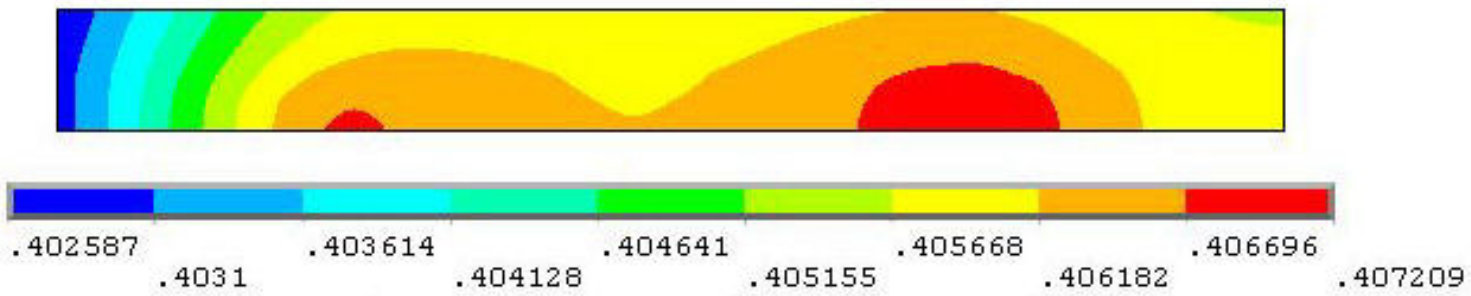
Structural analysis


1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UY (AVG)
RSYS=0
DMX =1.73
SMN =-.003547
SMX =.319351
ANSYS
APR 4 2005
13:45:20
Thermal analysis
-.003547
.03233
.068208
.104085
.139963
.175841
.211718
.247596
.283473
.319351
Thermal strain for conduction model.



Thermal strains





ASP Wiggler

Shipped November, 2006

40 poles, 100 mm period

14 mm minimum gap

11.55 keV critical energy

Single stepper system

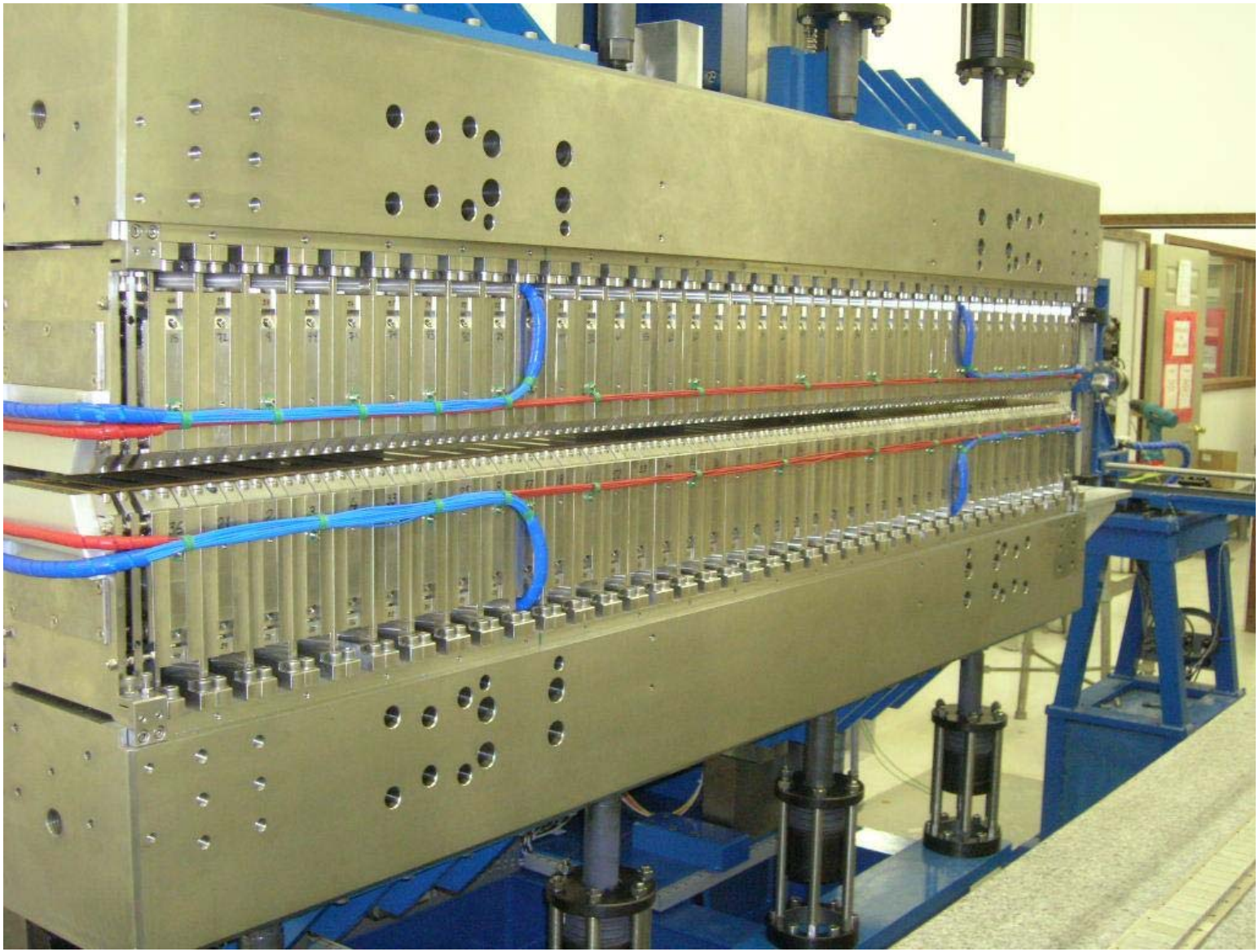
Manual phase adjuster

1st and 2nd integral coils

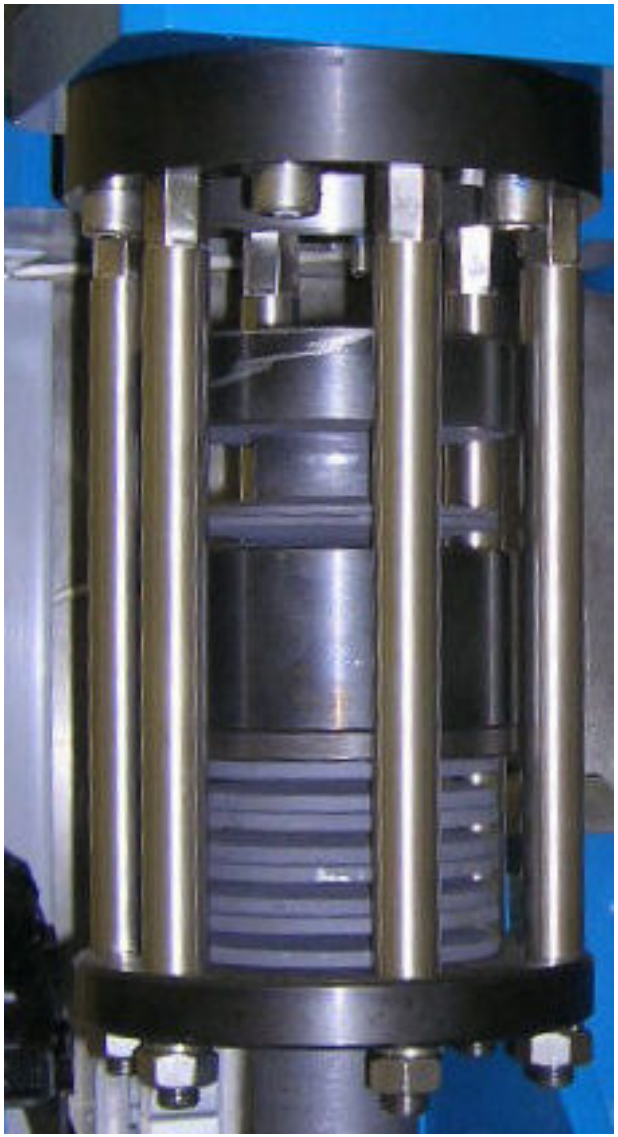
Bi-linear springs

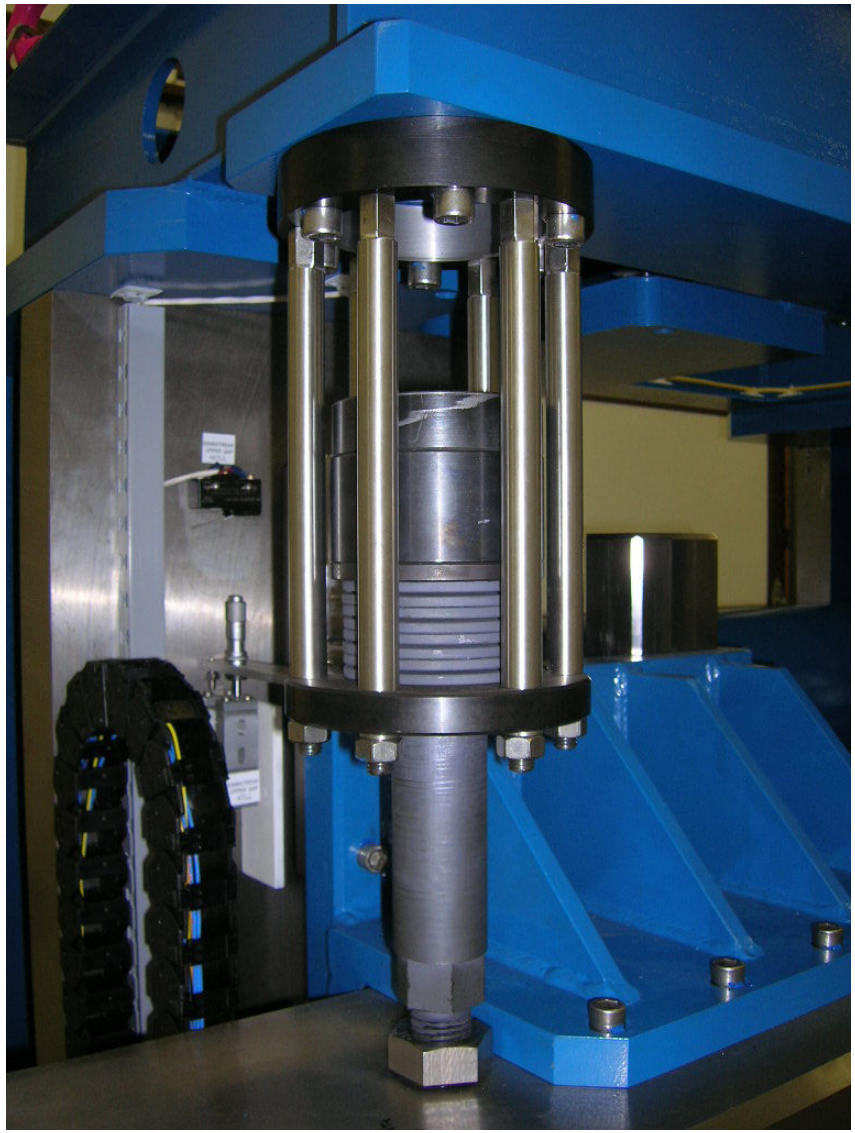
Decoupled base

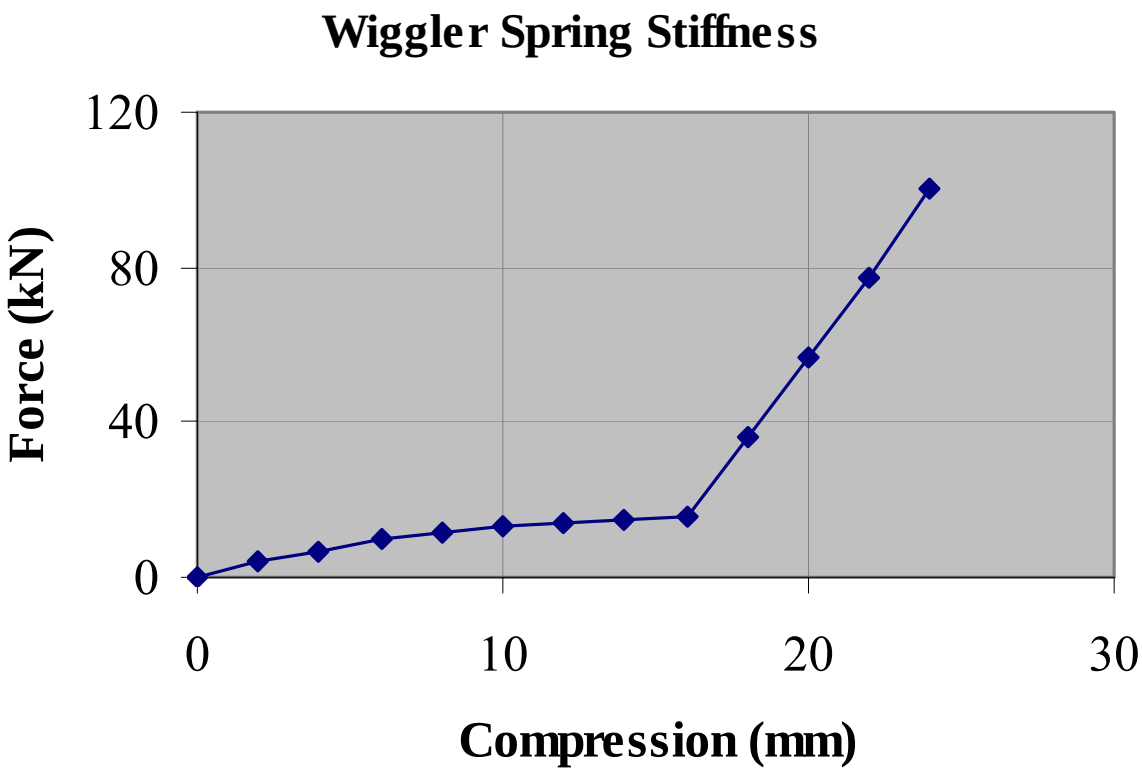
Adjustment without shims

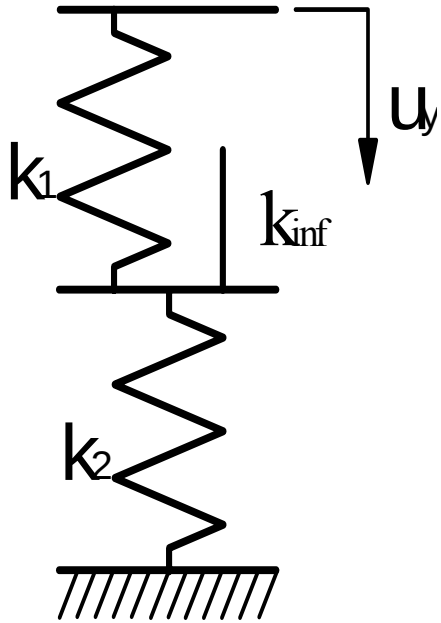


	Normal				Skew			
gap	dipole	quad	sext	oct	dipole	quad	sext	oct
14	5	18	5	23	-7	-43	-31	11
16	-18	19	-21	20	33	-15	1	24
18.16	-1	21	-8	4	-5	-4	1	-10
20	5	23	-8	2	25	4	7	-13
24	0	8	-18	11	7	21	-3	-1
30	35	27	23	6	-27	42	-19	17
40	17	-26	6	7	8	-10	32	7
206	-1	7	2	-5	-11	0	5	-3
Summary of ASP wiggler performance. No correction coils used.								

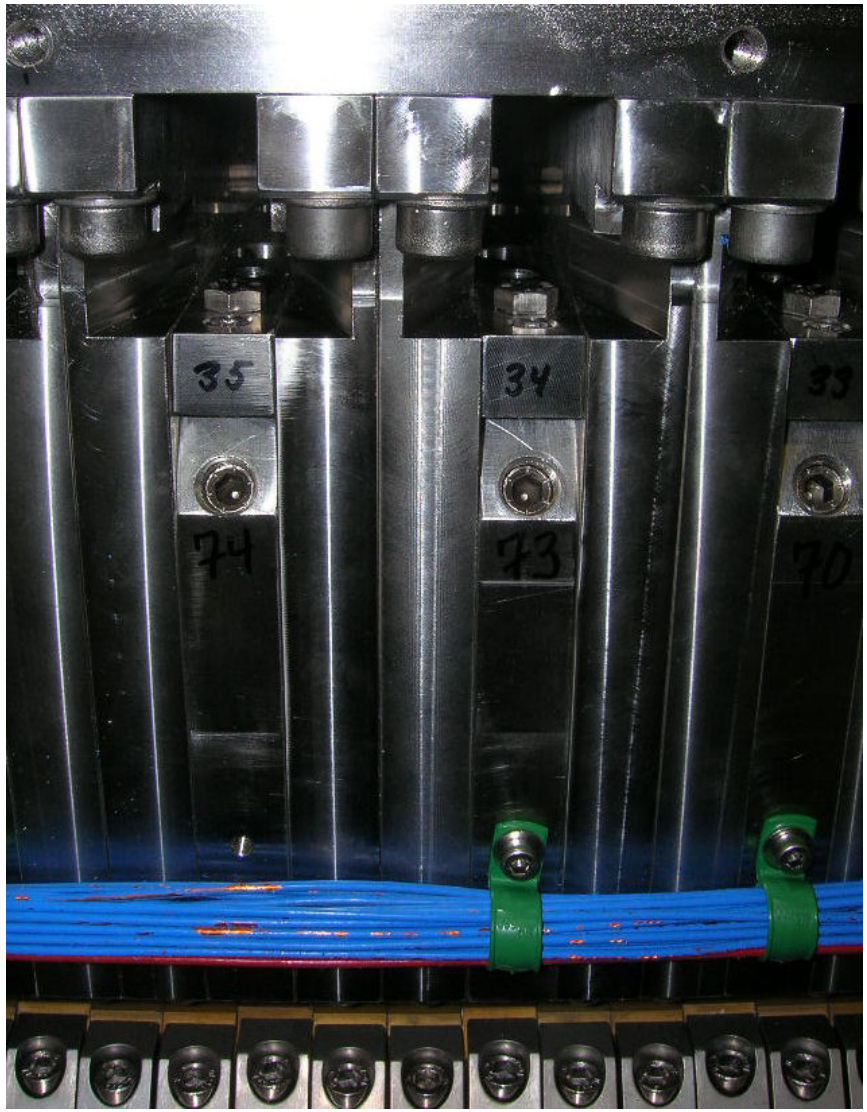




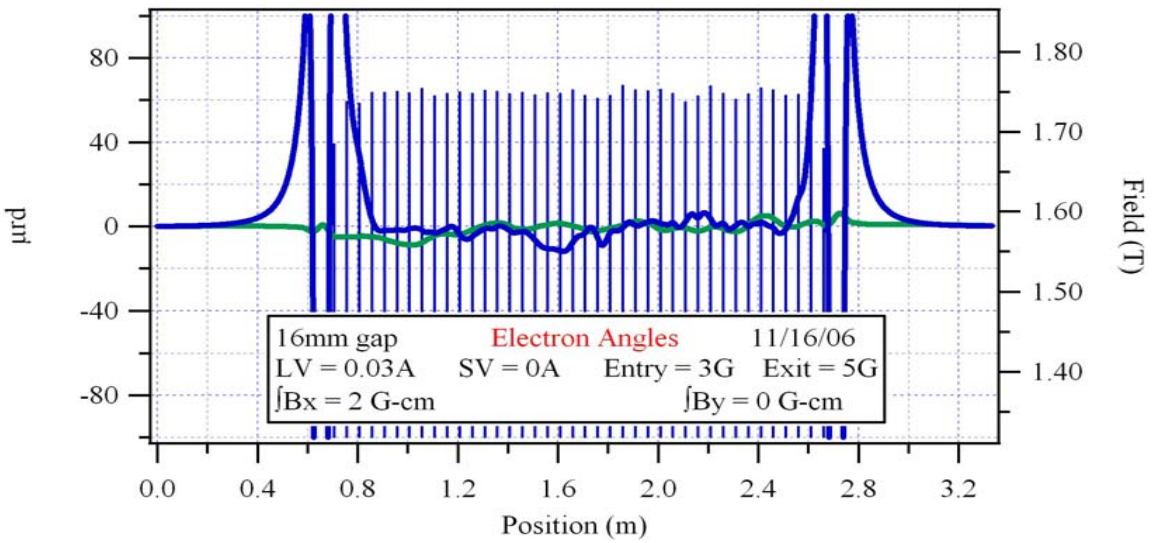

Wiggler Spring Stiffness
120
80
40
0
Force (kN)
0
10
20
30
Compression (mm)


u_y
k_1
k_{inf}
k_2

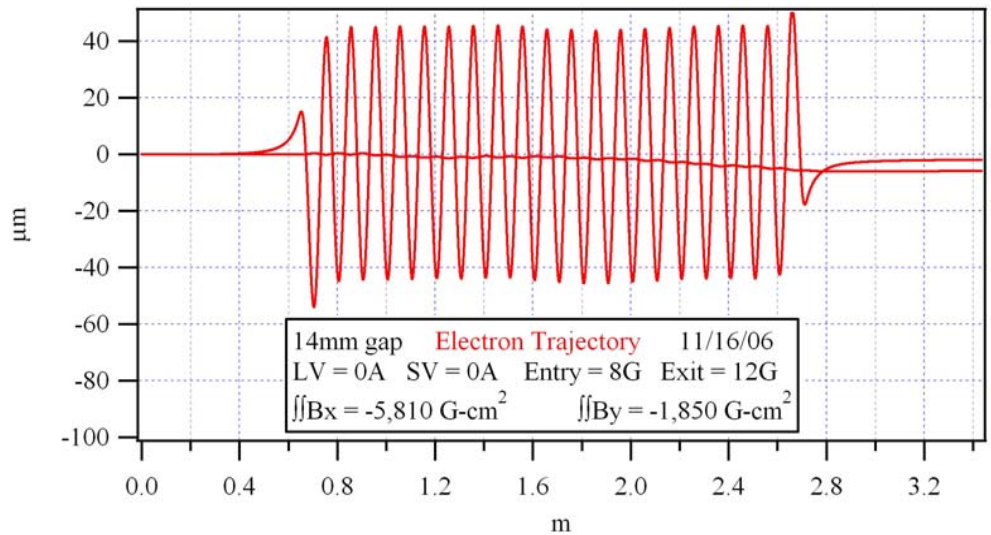

ASP Wiggler

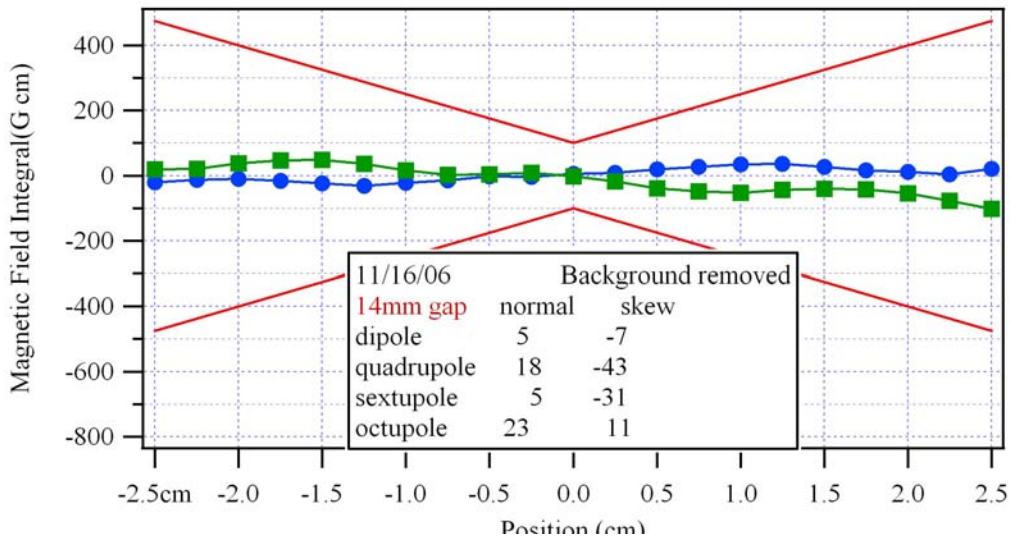


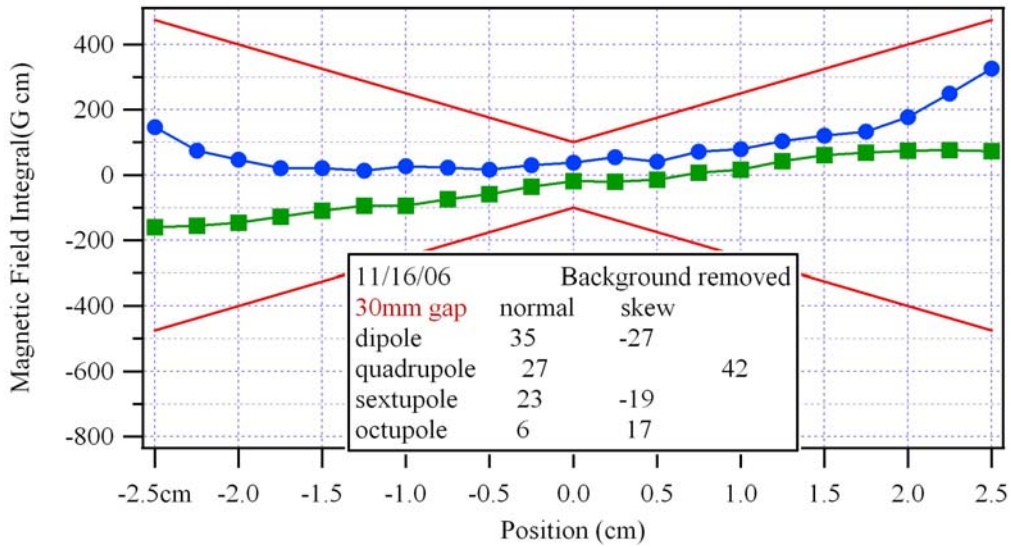
ASP Wiggler
Shimming


80
40
0
-40
-80
µrd
1.80
1.70
1.60
1.50
1.40
Field (T)
16mm gap Electron Angles 11/16/06
LV = 0.03A SV = 0A Entry = 3G Exit = 5G
∫Bx = 2 G-cm ∫By = 0 G-cm
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2
Position (m)

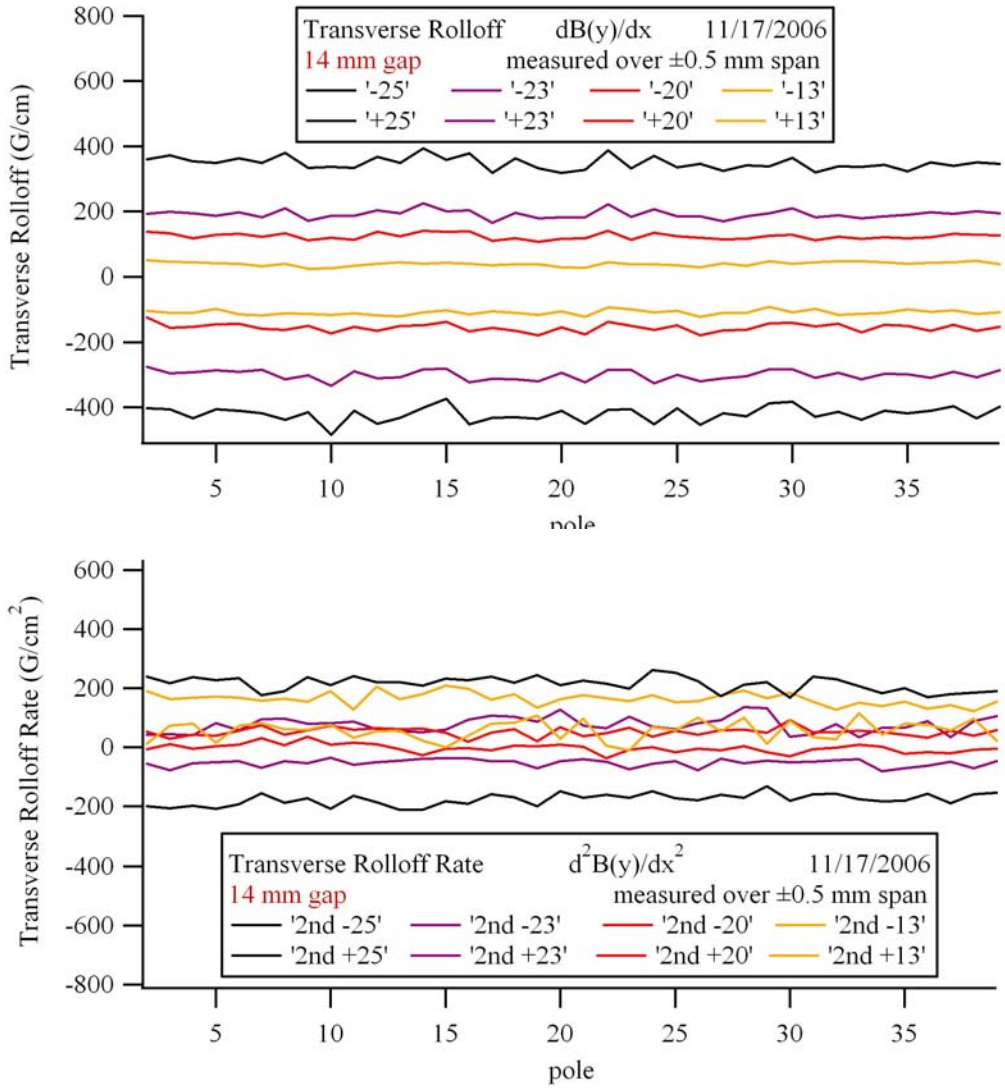
ASP Wiggler


40
20
0
-20
-40
-60
-80
-100
µm
14mm gap Electron Trajectory 11/16/06
LV = 0A SV = 0A Entry = 8G Exit = 12G
∫∫Bx = -5,810 G-cm^2 ∫∫By = -1,850 G-cm^2
0.0 0.4 0.8 1.2 1.6 2.0 2.4 2.8 3.2
m


Magnetic Field Integral(G cm)
400
200
0
-200
-400
-600
-800
-2.5cm -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5
Position (cm)
11/16/06 Background removed
14mm gap normal skew
dipole 5 -7
quadrupole 18 -43
sextupole 5 -31
octupole 23 11


Magnetic Field Integral(G cm)
400
200
0
-200
-400
-600
-800
-2.5cm -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5
Position (cm)
11/16/06 Background removed
30mm gap normal skew
dipole 35 -27
quadrupole 27 42
sextupole 23 -19
octupole 6 17

ASP Wiggler

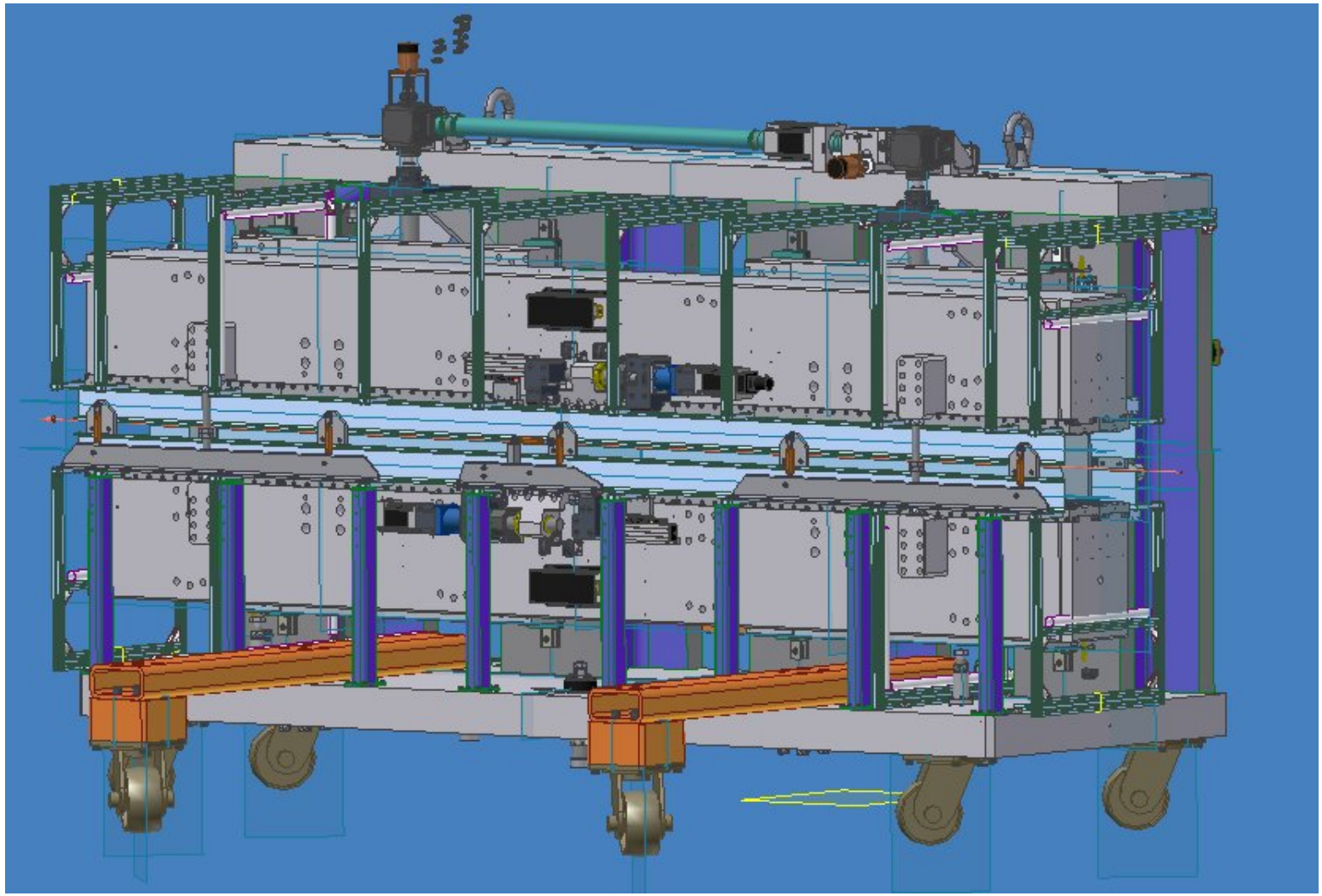

Transverse Rolloff dB(y)/dx 11/17/2006
14 mm gap measured over ±0.5 mm span
'-25' '-23' '-20' '-13'
'+25' '+23' '+20' '+13'
Transverse Rolloff (G/cm)
800
600
400
200
0
-200
-400
5
10
15
20
25
30
35
pole
Transverse Rolloff Rate (G/cm²)
600
400
200
0
-200
-400
-600
-800
Transverse Rolloff Rate d²B(y)/dx² 11/17/2006
14 mm gap measured over ±0.5 mm span
'2nd -25' '2nd -23' '2nd -20' '2nd -13'
'2nd +25' '2nd +23' '2nd +20' '2nd +13'
5
10
15
20
25
30
35
pole

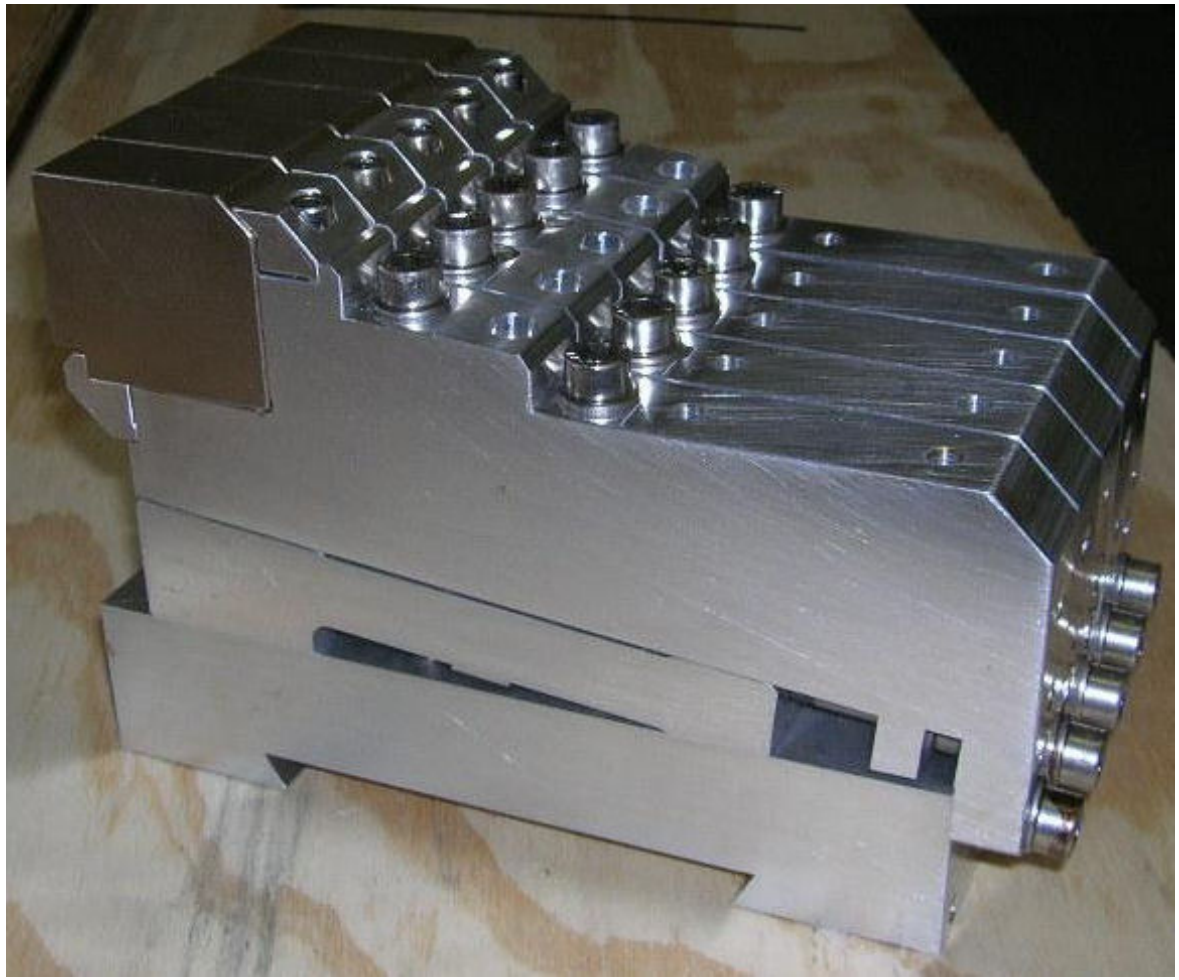
ASP Wiggler

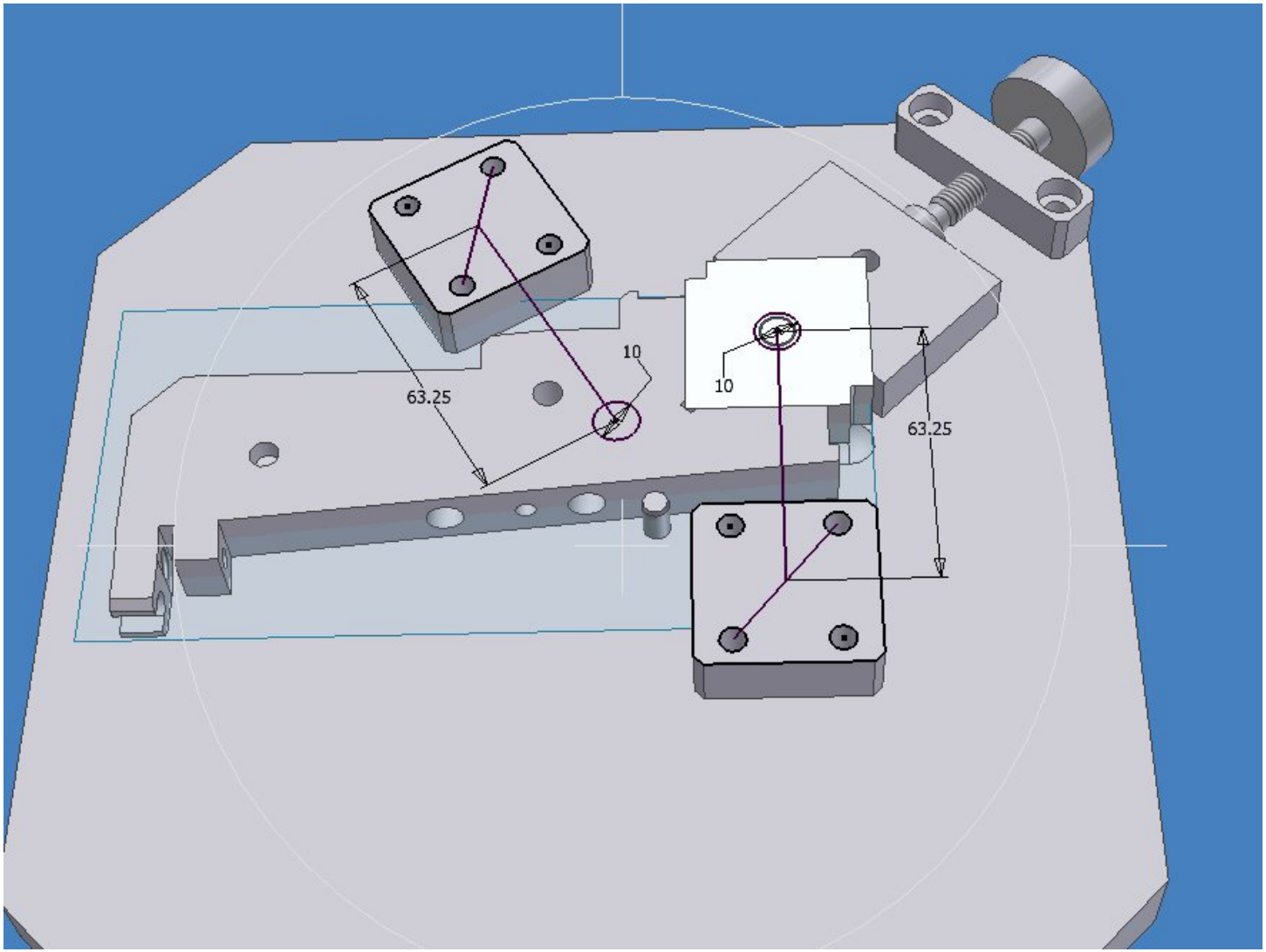
What next?

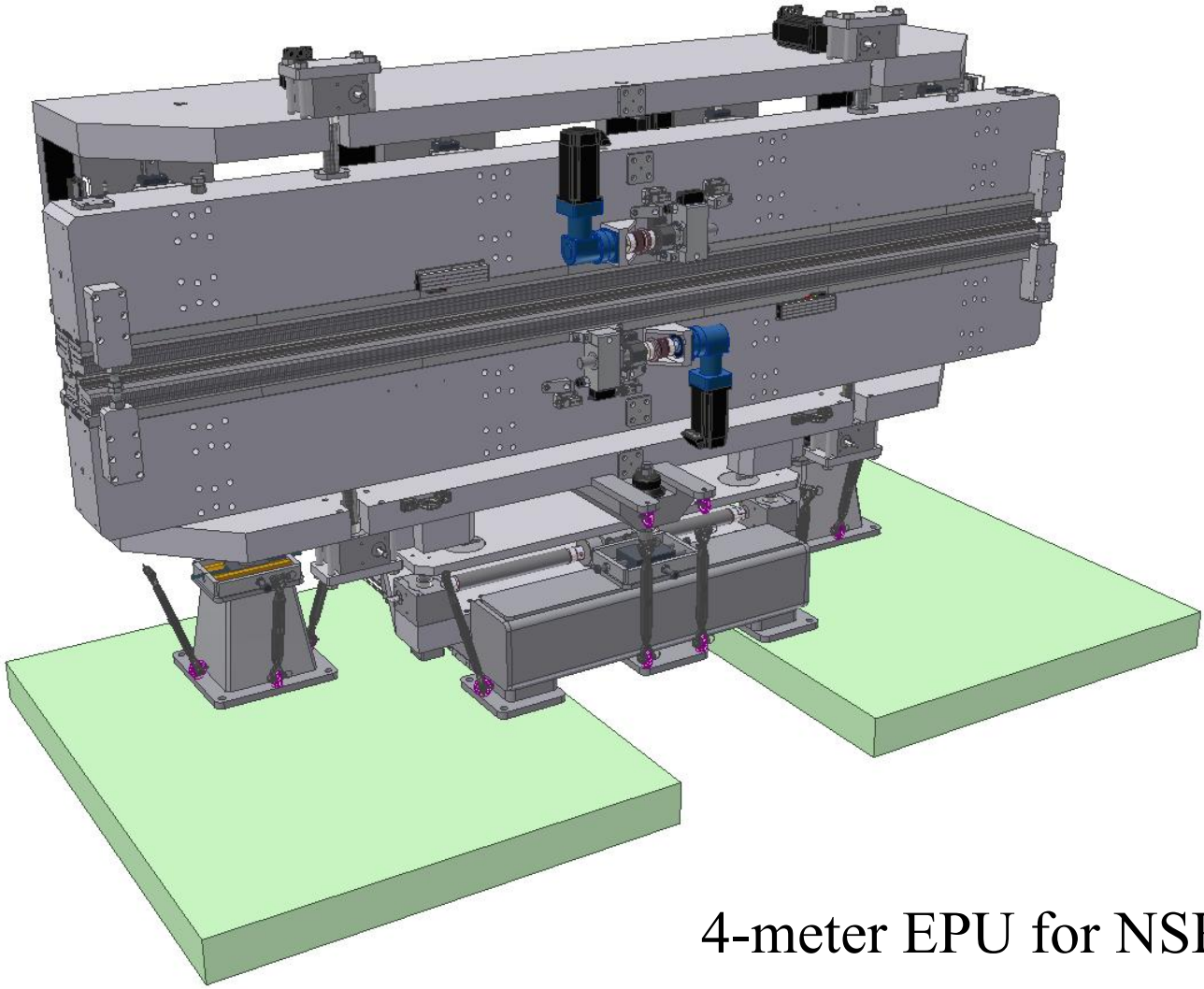
4-meter EPU for SLAC

- SmCo magnets
- Single motor drive with phase motor

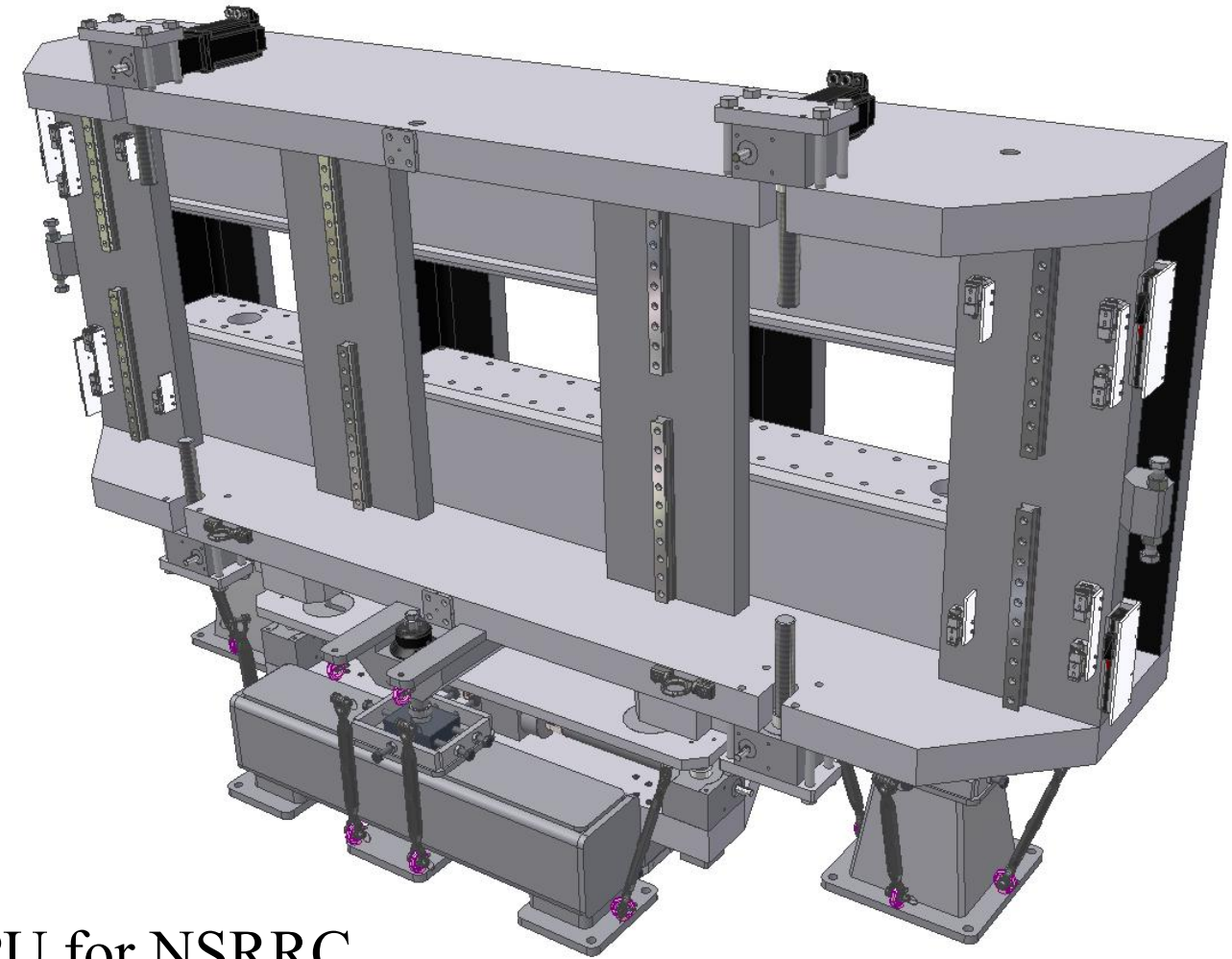




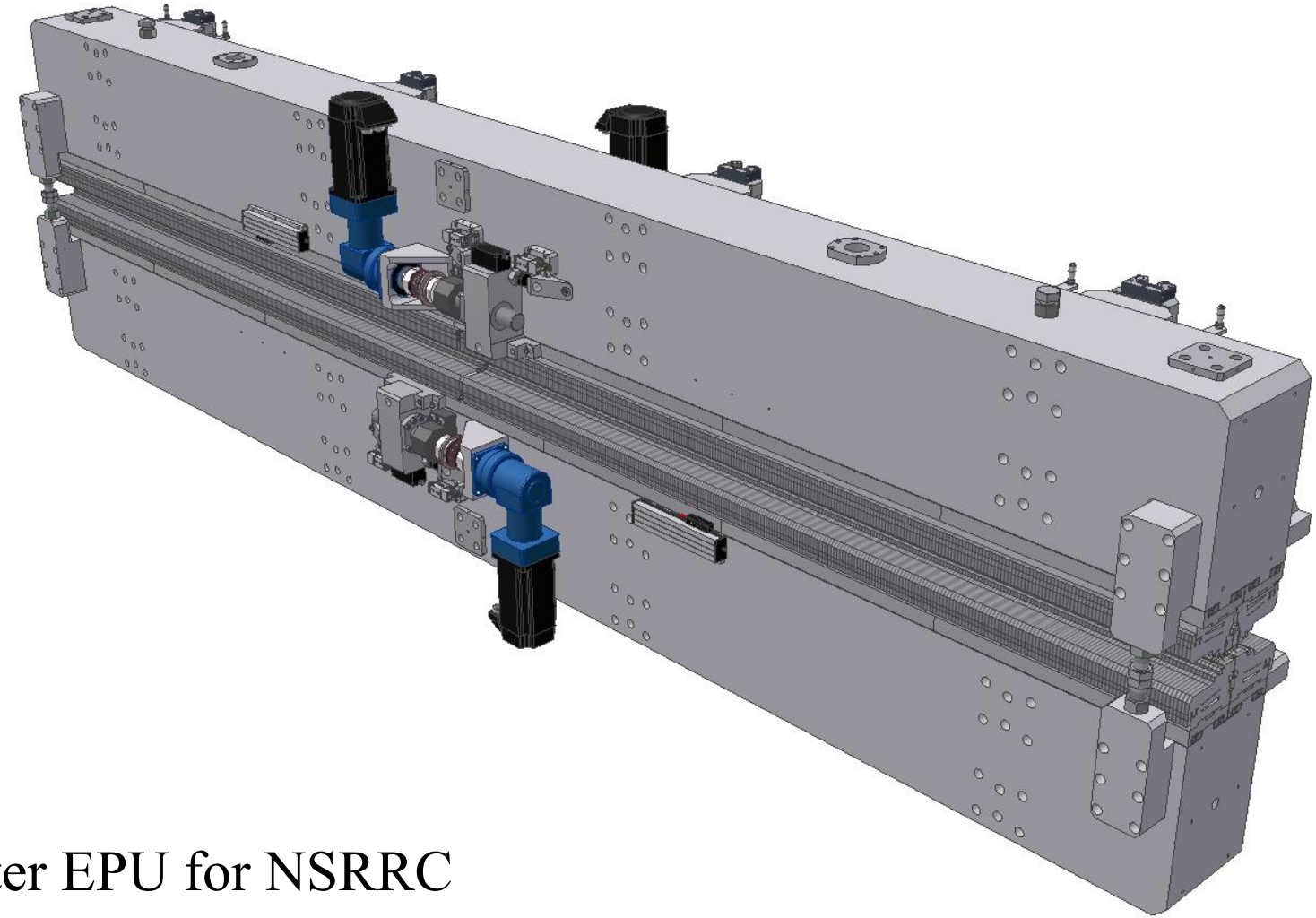

10
63.25
10
63.25



4-meter EPU for NSRRC

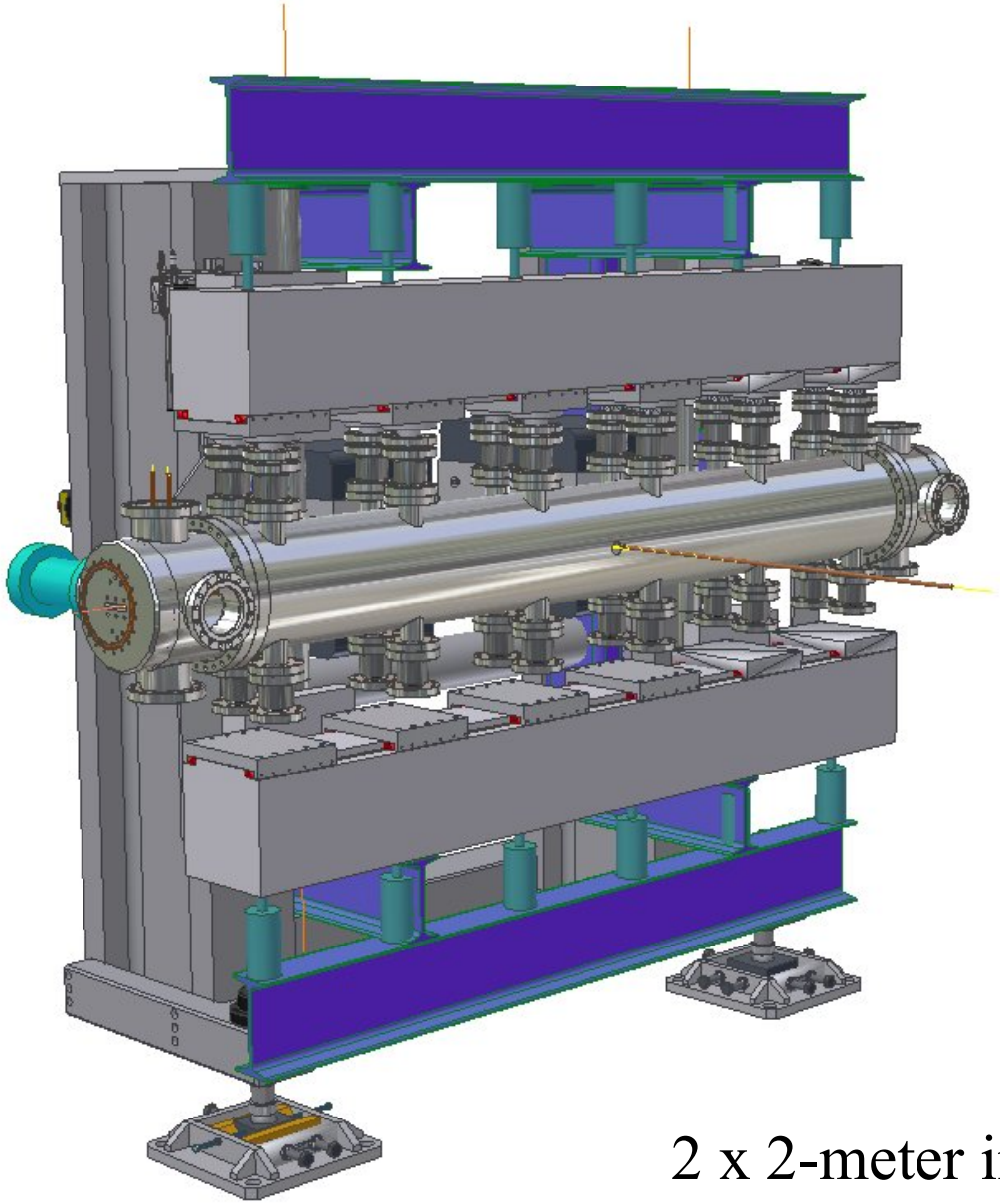


4-meter EPU for NSRRC



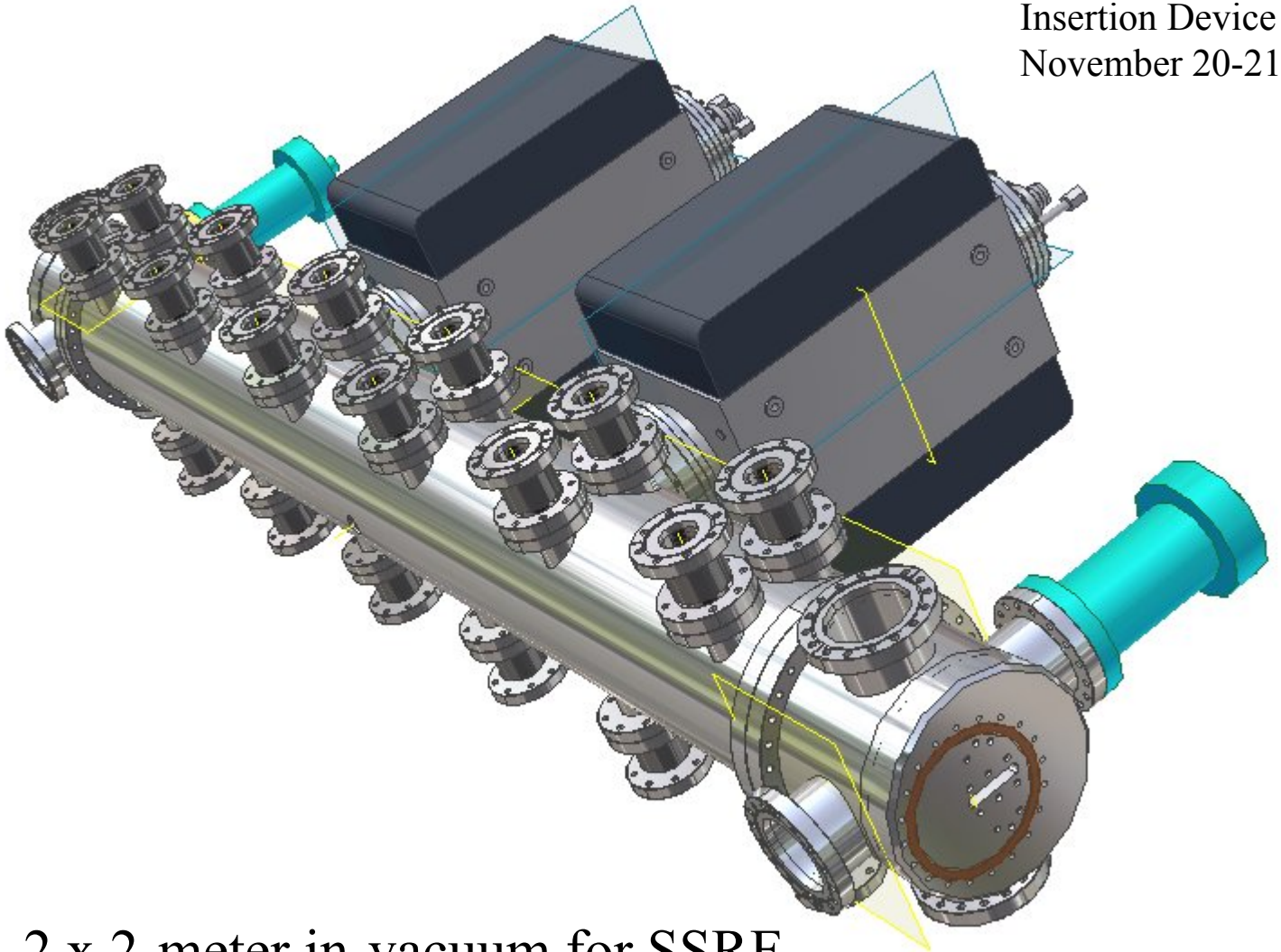
4-meter EPU for NSRRC

Advanced Design Consulting
Insertion Device Workshop
November 20-21, 2006



2 x 2-meter in-vacuum for SSRF

Advanced Design Consulting
Insertion Device Workshop
November 20-21, 2006



2 x 2-meter in-vacuum for SSRF

Closing the loop on structural analysis

- component testing
  - springs
  - ball-nuts
  - bearing blocks
- deflections
  - optical measurements
  - frame deflections
  - magnet displacements
-
- temperatures
  - IR using cryo-cooled bolometer
- *set realistic limits on each based on ID performance.*