Recent work on insertion devices at MAX-lab

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"New Frontiers in Insertion Devices"
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I.C.T.P. - Main building hall
Strada Costiera, 11 - TRIESTE

The recent work on IDs at MAX-lab includes:

- Installation of NEG coated AL chambers in the 1.5 GeV MAX II ring.
- 1 EPU has been installed in the 1.5 GeV MAX II ring*.
- 1 EPU and 1 PPM undulator have been purchased for the 0.7 GeV MAX III ring*.
- A magnetic measurement bench for IDs has been installed*.
- Small scale prototyping of superconducting undulators.

In addition to the activities listed above, different schemes for the insertion devices for the future MAX IV light source have been evaluated.

MAX-lab is interested in the development of superconducting undulators in order to install them on the future MAX IV 3 GeV storage ring.

The planned first set of beam lines on MAX IV do however rely on today's state of the art technique with in vacuum undulators.

* Equipment bought from the company ADC: Advanced Design Consulting USA, Inc. 126 Ridge Road, Lansing, NY 14853, USA; www.adc9001.com

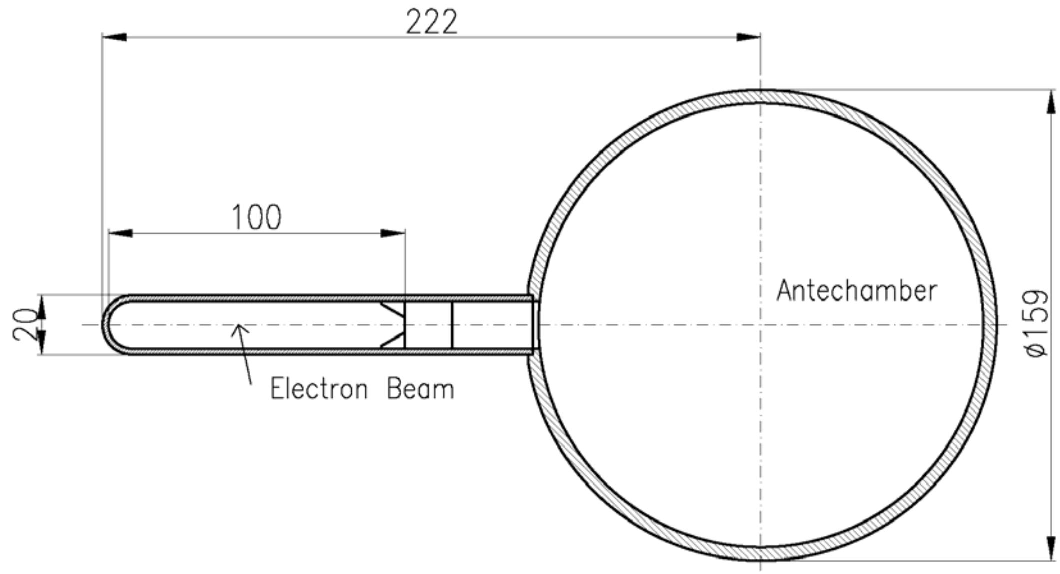
2 vacuum chambers of NEG Coated extruded Al have been installed on the 1.5 GeV MAX II ring.

The outer/inner vertical apertures are 15/11 and 13/9.

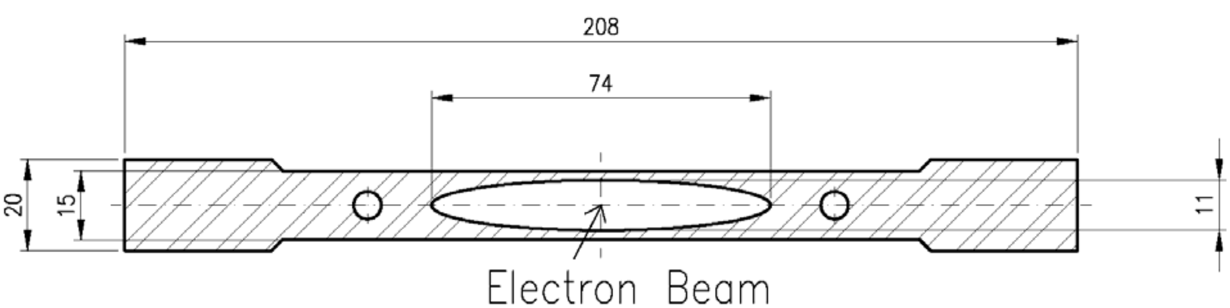
The existing IDs can be run with smaller gap with Al chamber.

The Al chambers works well and 2 more will be installed on the MAX II ring.

Old vacuum chamber made of stainless steel.



New vacuum chamber of NEG coated extruded Al.



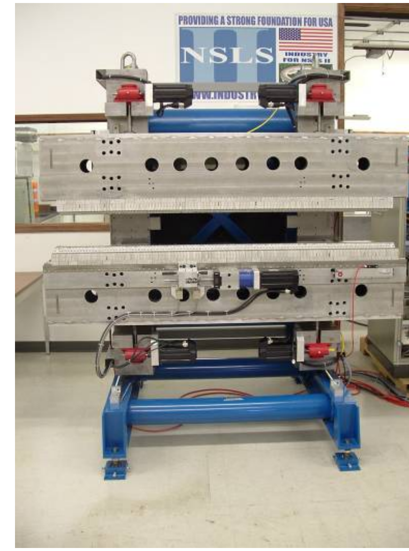
MAX II EPU

Period Length	46.1 mm
Number of Poles	92
Min. Gap	14 mm
B_x	0.51 T
B_y	0.71 T
Length	2.1 m
Beam Energy	1.5 GeV

MAX III Planar

Period Length	53.1 mm
Number of Poles	72
Min. Gap	16 mm
B_x	
B_y	0.77 T
Length	1.91 m
Beam Energy	0.7 GeV

MAX III EPU



Period Length	69.1 mm
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Min. Gap	15 mm
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The MAX II EPU has recently been installed on the 1.5 GeV MAX II ring.

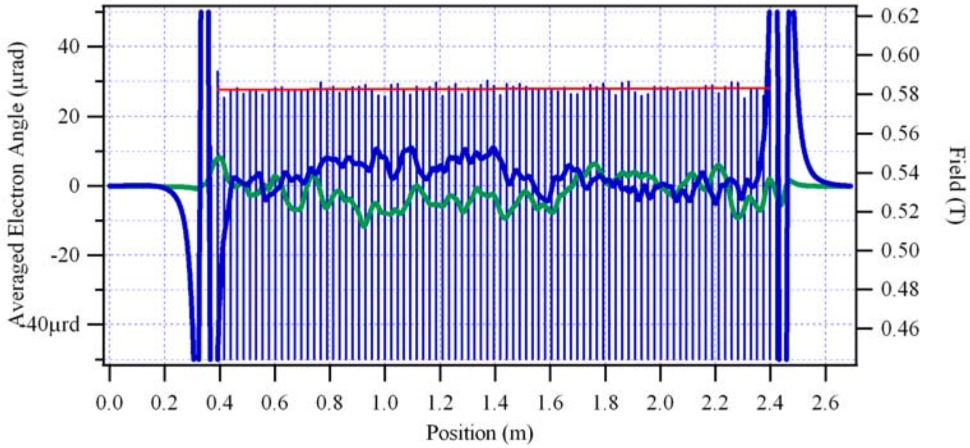
The beam of MAX II survives any mode of operation for the EPU (16 mm gap). Further studies on the influence on the beam and the settings of the correction coils are in progress.

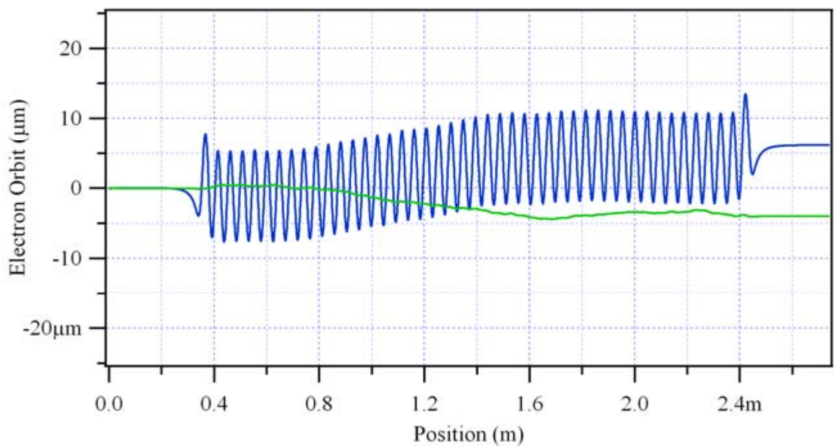
The phase errors and field integrals are small for the planar, vertical and helical mode.

The inclined mode shows larger phase errors ~10 deg.

MAX II EPU

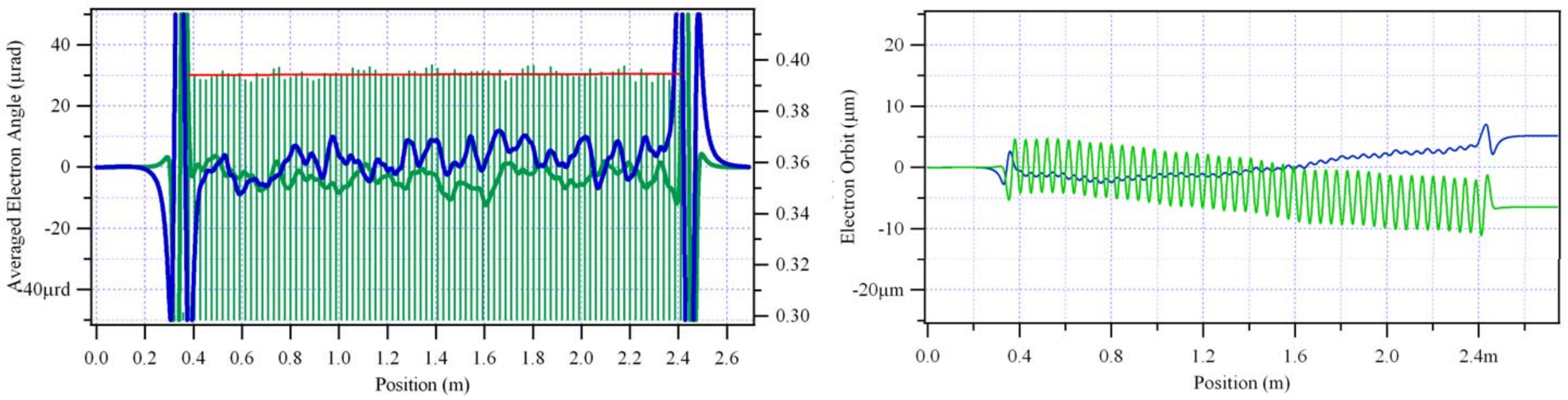
16 mm Gap, Planar Phase





Gap (mm)	Ix (Gcm)	Iy (Gcm)	Jx (Gcm^2)	Jy (Gcm^2)	By (T)	RMS Phase Angle Error (deg)	Photon Energy (eV)
14.5	24	-21	-	-	-	2.1	-
16	28	-28	1990	3080	0.5827	2.1	108.13
18	29	-31	3130	1680	0.5099	2.0	131.95
20	30	-33	1190	250	0.4485	2.0	157.39
25	30	-32	-1410	1260	0.3243	2.3	229.30
30	30	-33	-1840	2500	0.2335	2.6	301.90
35	28	-32	-2570	3350	0.1676	2.8	361.48
40	27	-29	-2070	3370	0.1202	2.8	402.60
50	22	-26	-2250	3500	0.0616	2.3	441.90

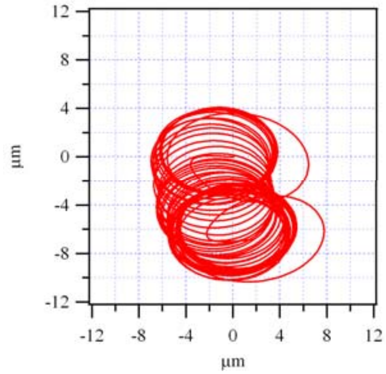
MAX II EPU
16 mm Gap, Vertical Phase

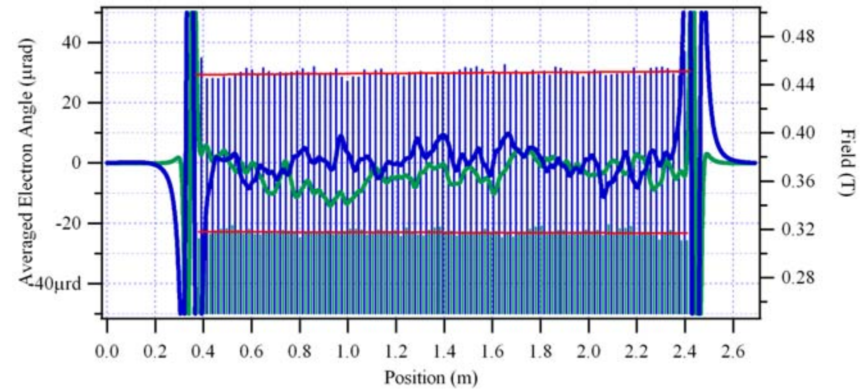


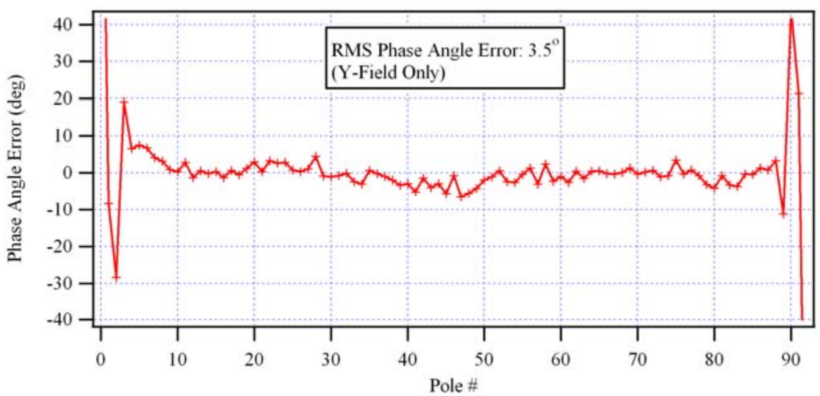
Gap (mm)	Ix (Gcm)	Iy (Gcm)	Jx (Gcm^2)	Jy (Gcm^2)	By (T)	RMS Phase Angle Error (deg)	Photon Energy (eV)
14.5	9	-50	-	-	-	2.6	-
16	19	-44	3240	2590	0.3944	2.3	184.44
18	23	-42	690	2460	0.3310	2.0	224.04
20	27	-38	0	2380	0.2786	1.8	263.22
25	28	-35	-2780	2470	0.1829	1.8	347.22
30	29	-30	-2270	2660	0.1212	1.8	401.61
35	28	-28	-2830	3240	0.0810	1.7	430.76
40	25	-26	-3610	3390	0.0544	-	-
50	22	-23	-2670	3480	0.0249	-	-

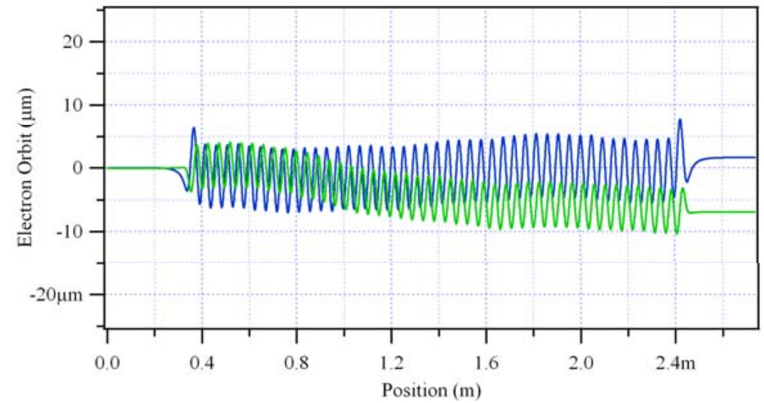
MAX II EPU

14.5 mm Gap
Helical Phase







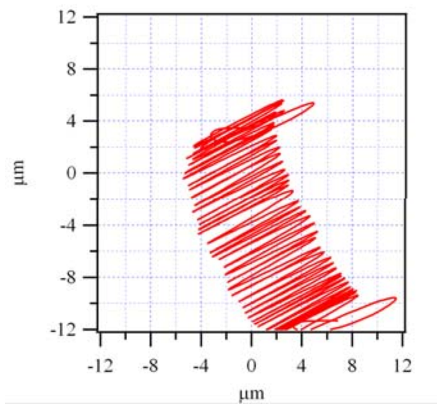


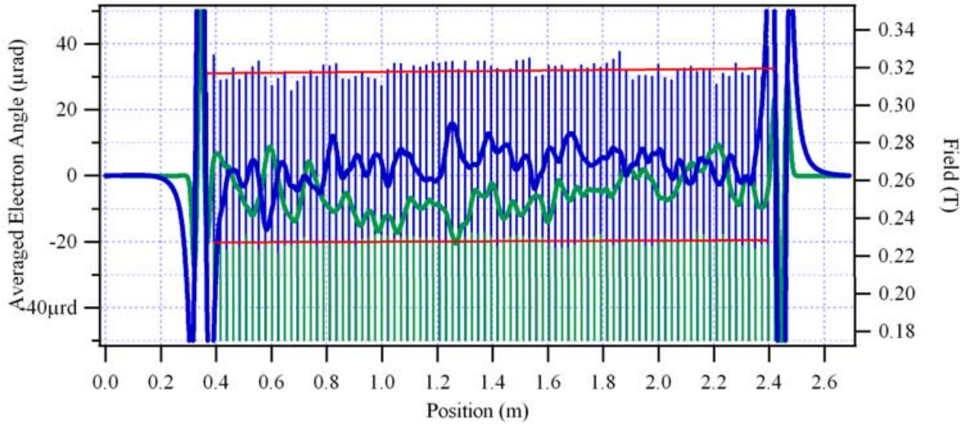
Gap (mm)	Ix (Gcm)	Iy (Gcm)	Jx (Gcm^2)	Jy (Gcm^2)	Bx (T)	By (T)	Photon Energy (eV)
14.5	-84	-82	3440	840	0.3173	0.4498	118.54
16	-45	-42	770	2550	0.2779	0.4085	138.40
18	-27	-38	170	2800	0.2333	0.3592	167.35
20	-16	-38	-1500	2720	0.1963	0.3157	198.36
25	2	-34	-1980	1920	0.1288	0.2279	277.71
30	10	-27	-2140	2830	0.0855	0.1638	345.84
35	11	-25	-2870	2850	0.0571	0.1177	393.98
40	15	-25	-2820	3180	0.0384	0.0844	423.28
50	15	-20	-2360	3310	0.0175	0.0432	448.46

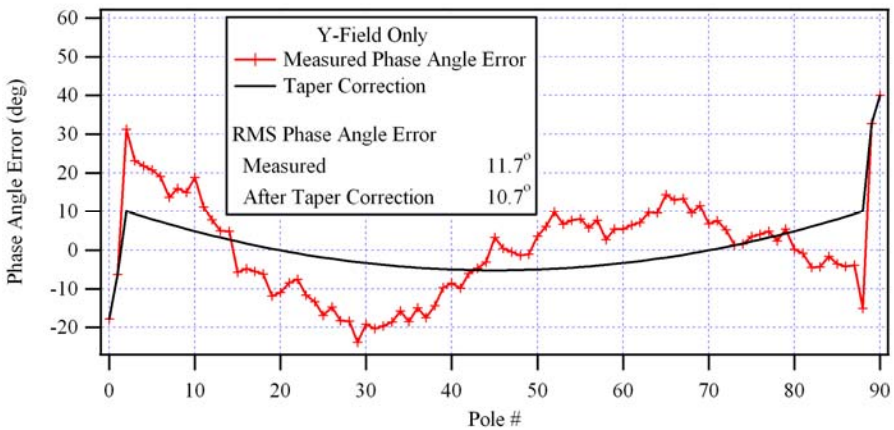
MAX II EPU

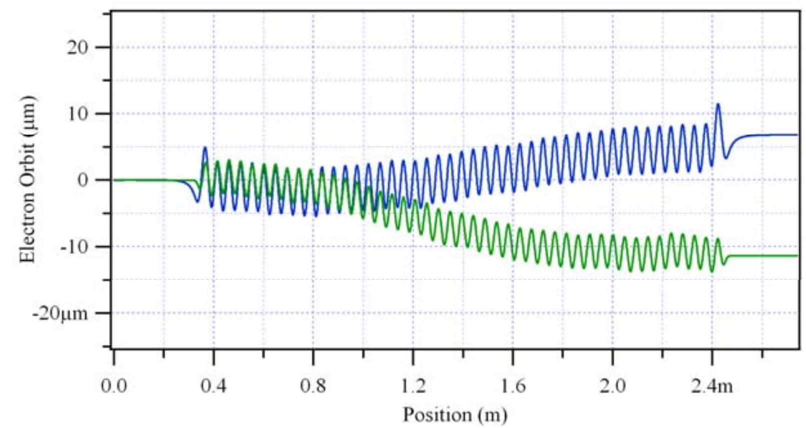
14.5 mm Gap

Inclined Phase, -1/4 Period



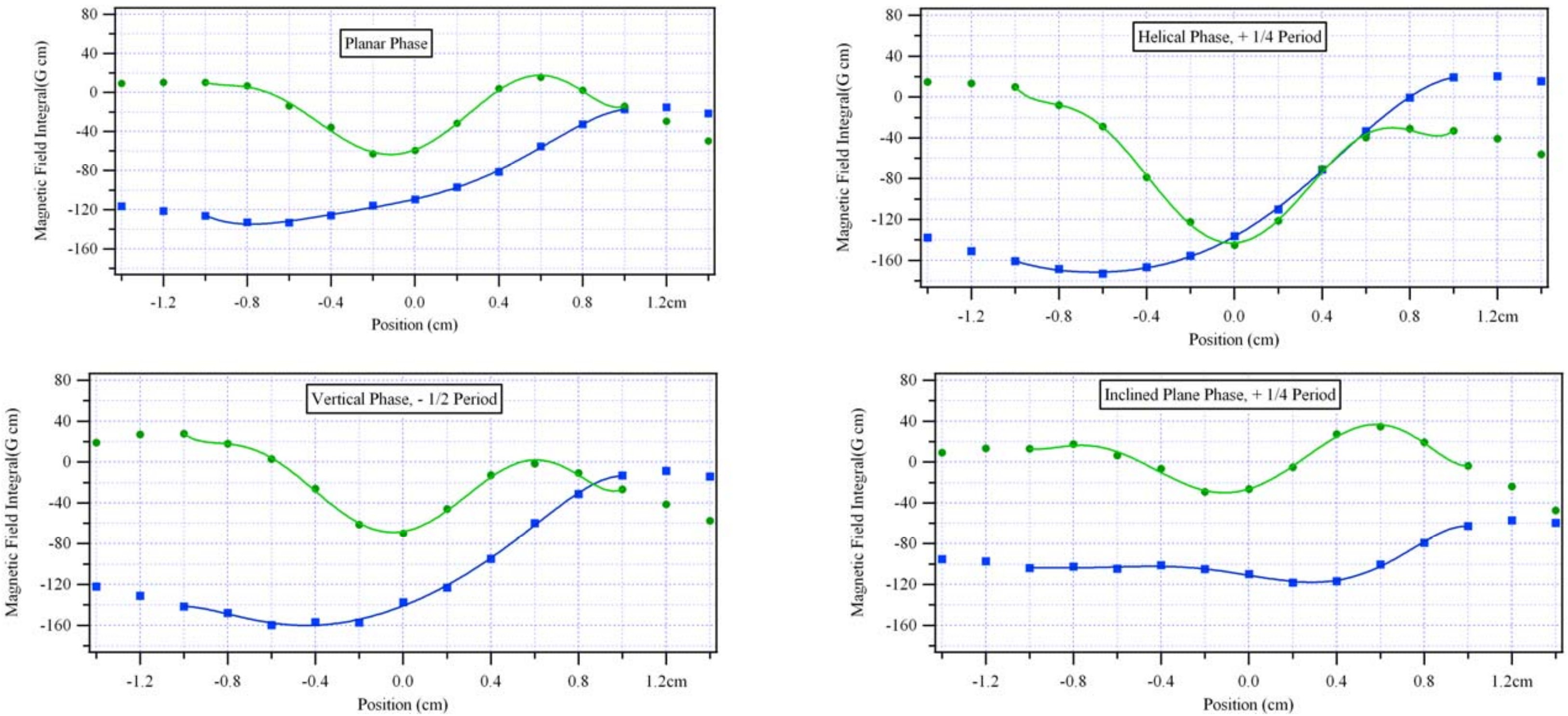






Phase	Ix (Gcm)	Iy (Gcm)	Jx (Gcm^2)	Jy (Gcm^2)	Bx (T)	By (T)	Photon Energy (eV)
(- 1/4 Period)	20	-85	5690	3400	0.2278	0.3181	185.93
(+ 1/4 Period)	29	-53	2020	3790	0.2155	0.3279	183.56

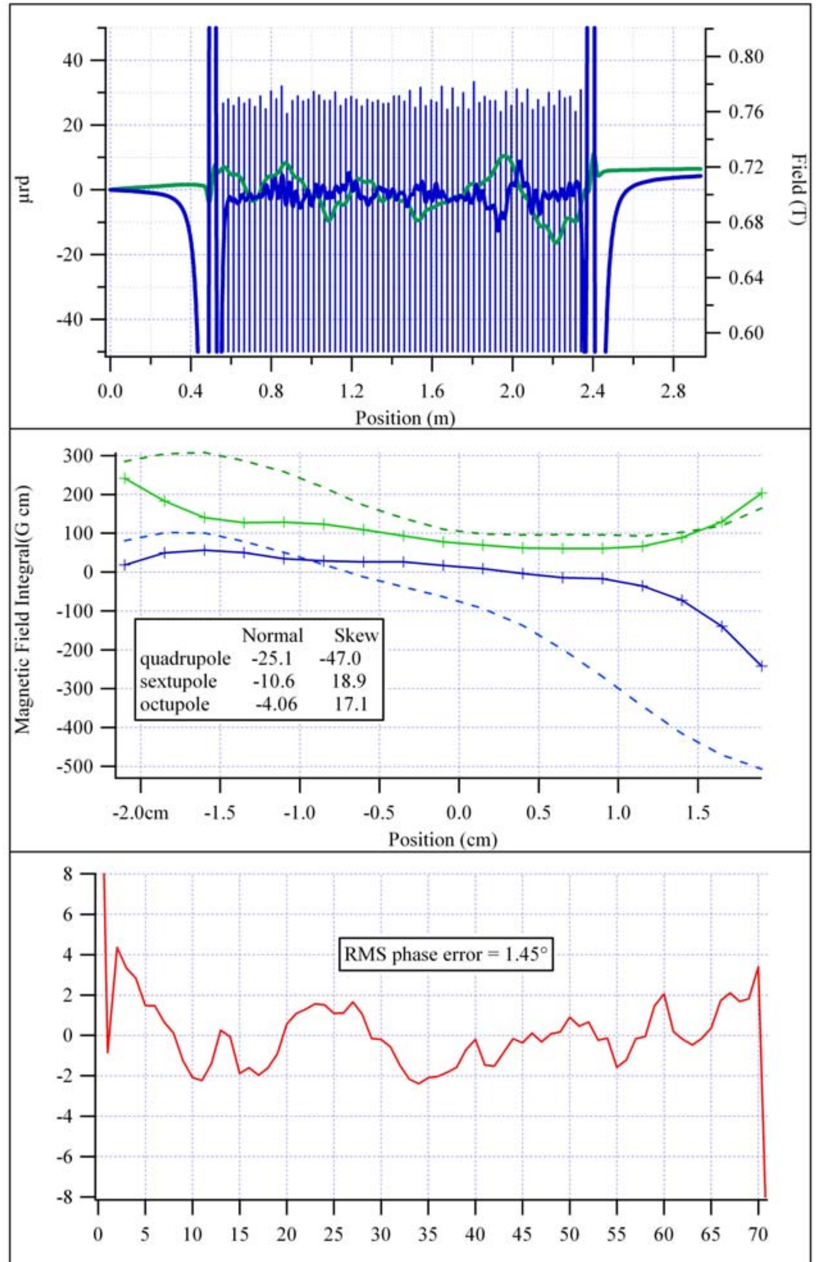
MAX II EPU, Integrated multipoles, 14.5 mm gap



Phase		Normal Multipoles				Skew Multipoles			
		Dipole (Gcm)	Quadru pole (G)	Sextupole (G/cm)	Octupole (G/cm^2)	Dipole (Gcm)	Quadru pole (G)	Sextupole (G/cm)	Octupole (G/cm^2)
Plan		-51 ± 1	49 ± 4	44 ± 6	55 ± 14	-2 ± 2	81 ± 7	327 ± 24	-197 ± 24
Vertical	1/2 Period	-79 ± 1	73 ± 4	99 ± 14	20 ± 14	-10 ± 1	38 ± 4	358 ± 15	-128 ± 15
	-1/2 Period	-83 ± 3	84 ± 8	85 ± 28	-6 ± 28	-11 ± 2	36 ± 7	381 ± 25	-126 ± 25
Helical	1/4 Period	-79 ± 2	121 ± 4	114 ± 14	-8 ± 14	-86 ± 2	14 ± 7	537 ± 25	-64 ± 25
	-1/4 Period	-59 ± 1	3 ± 3	39 ± 10	84 ± 10	74 ± 2	91 ± 6	178 ± 20	-226 ± 20
Inclined Plane	1/2 Period	-53 ± 3	-35 ± 4	-2 ± 14	123 ± 15	31 ± 2	65 ± 7	280 ± 26	-146 ± 26
	-1/2 Period	-86 ± 2	-42 ± 6	94 ± 21	155 ± 21	20 ± 2	71 ± 6	337 ± 22	-187 ± 22

MAX III Planar

Period Length	53.1 mm
Number of Poles	72
Min. Gap	16 mm
B_y	0.77 T
Length	1.96 m
Beam Energy	0.7 GeV

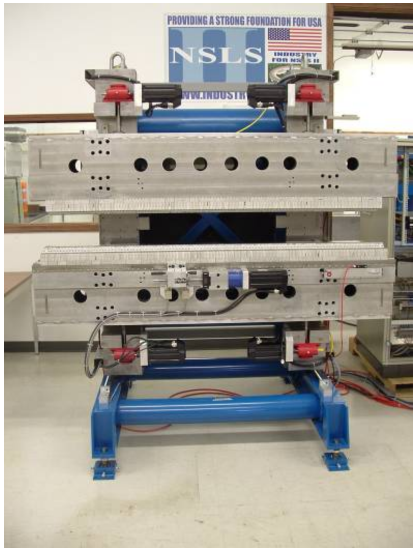


MAX III Planar

The MAX III planar PPM undulator meets all design specifications.

Table 1: 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°
1^{st} integral, vertical field	< 100 G-cm	17 G-cm
1^{st} 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 EPU



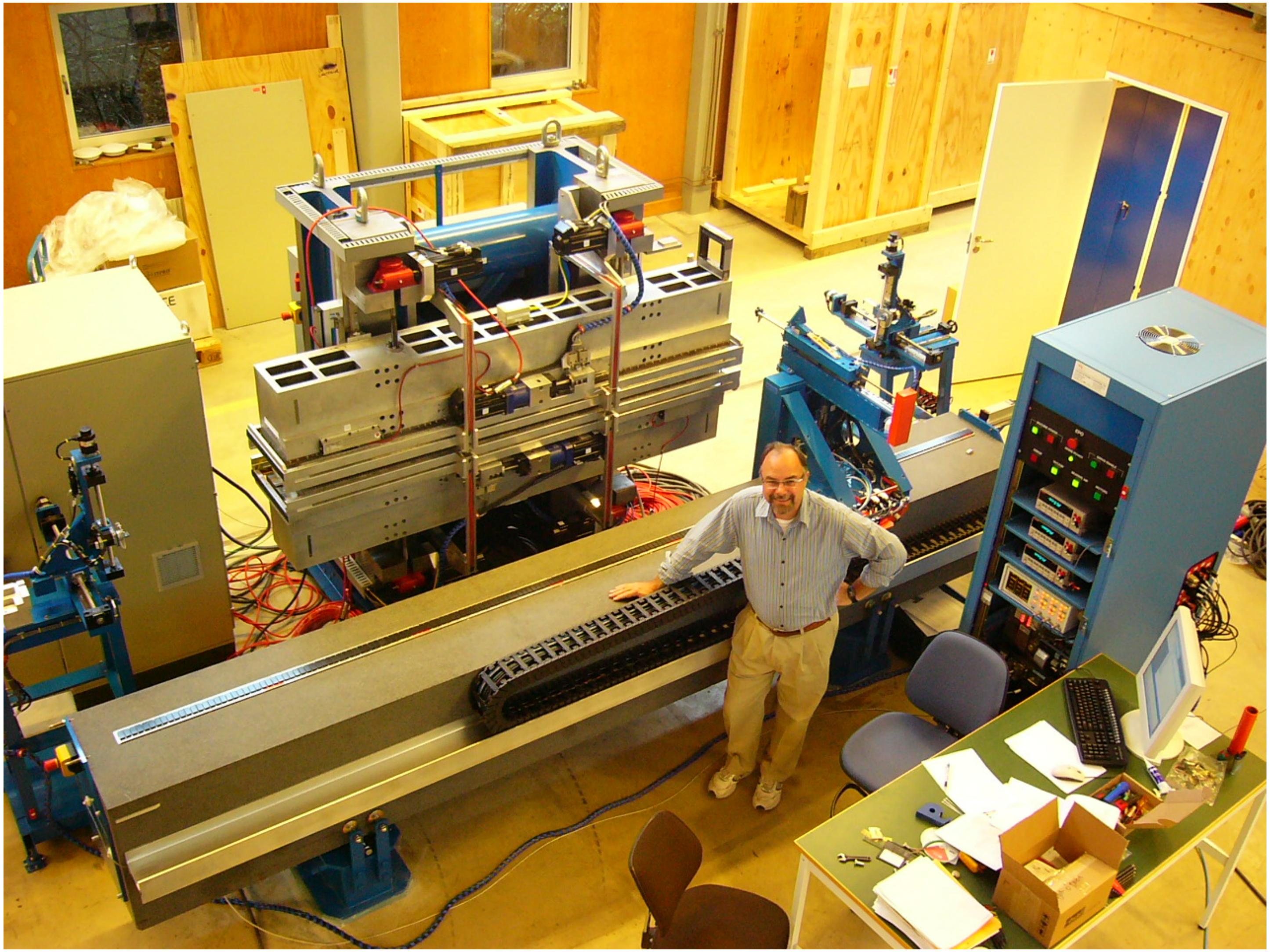
The final tuning and measurements will be finished in the near future.

Preliminary results indicate small phase errors and controllable field integrals.

It will be challenging to run this EPU on the MAX III ring with 700 MeV energy of the stored electron beam.

Period Length	69.1 mm
Number of Poles	57
Min. Gap	15 mm
B_x	0.688 T
B_y	0.909 T
Length	1.96 m
Beam Energy	0.7 GeV

Magnetic measurement system



Specifications of the magnetic measurement system

Granite Dimensions	Length – 5000 mm, Width - 400 mm, Height - 500 mm, Weight - 3992 Kg
Granite Tolerance	Flatness – 2.5 um per 300 mm or better; Straightness – 2.5 um per 300 mm or better
Power	240 or 480 VAC, Single Phase, 20 Amps, Ground
Air	120 PSI, 1 SCFM, 2 micron, filter, dry,
Vacuum	28 inches of Hg, pump provided
Travel	Long Axis – 3800 mm, Vertical – 290 mm, Horizontal - 290 mm
Position Feedback	Long Axis -79.25 nm per count , Optodyne Laser; Vertical Axis – 50 nm per count, Renishaw Tape Scale; Horizontal Axis – 50 nm per count, Renishaw Tape Scale
Magnetic Filed Measurement	.1 Gauss to 1 Tesla, 20 bit range, as output by the FW Bell uncompensated port
Data Conversion	22 bit range At the Kiethly DVM
Trigger Distance	Programmable

The flip coil has a resolution of 3 Gcm.

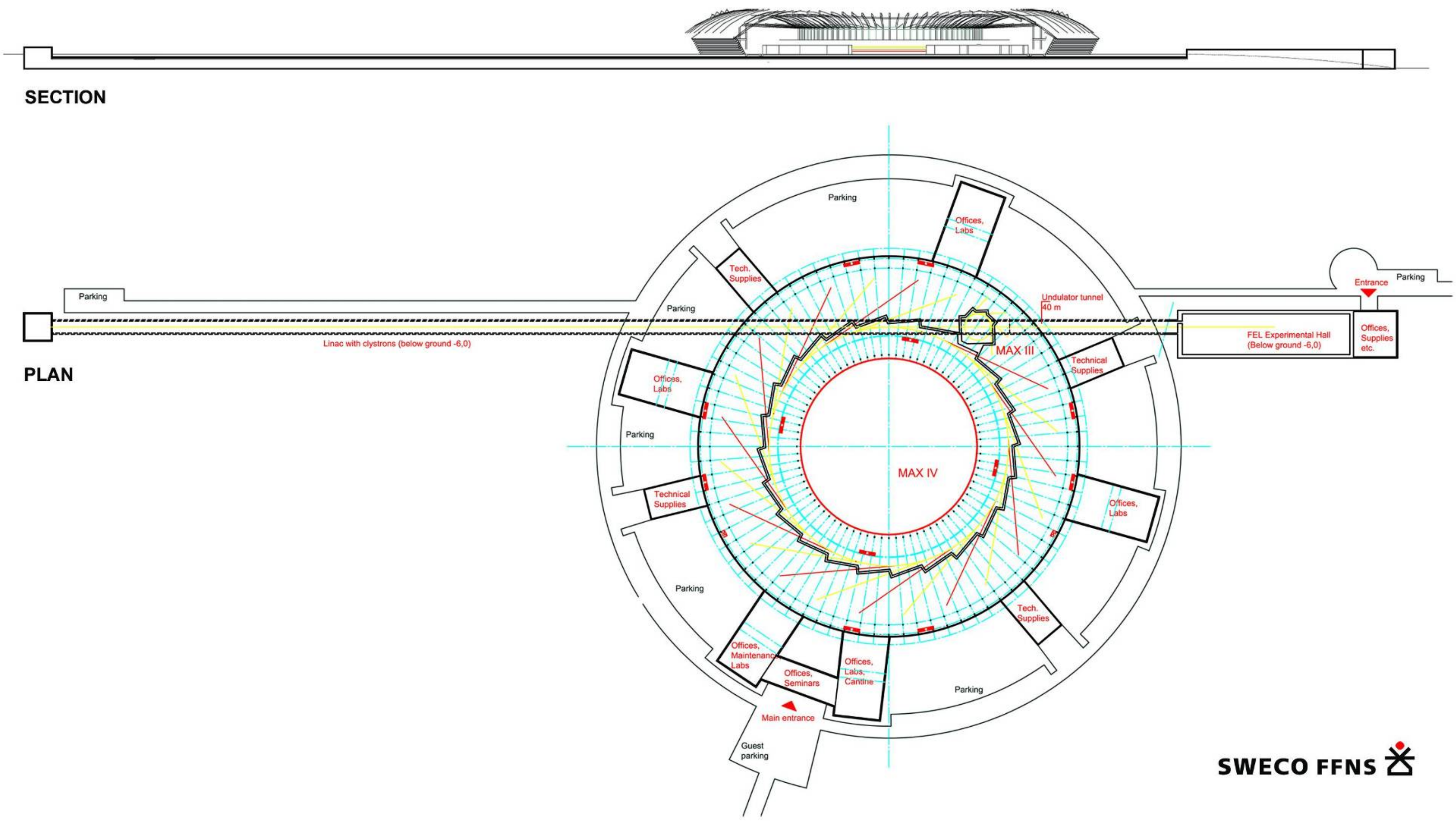
Problem:
Large difference in the centerline for the x- and y-element.
Two measurements of the EPU field needed. Calibration?

Solution:
Buy new 3 axes Hall probe. Stability in time? Calibration?

Transverse positions of the Hall elements:

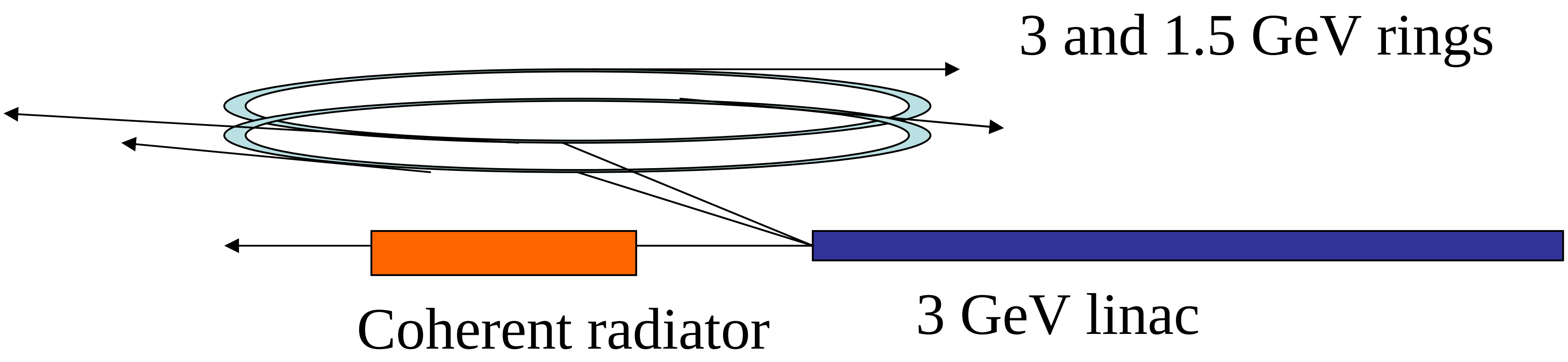
Hall Element	X (mm)	Y (mm)
X	0.31	-0.673
Y	-0.118	0.100
Z	-0.521	0.132

The MAX IV light source




MAX IV
Odarslövsvägen
Utmarksvägen
E22
Östra Ringen
Lundalänken
Lund Science Park

The MAX IV Light Source



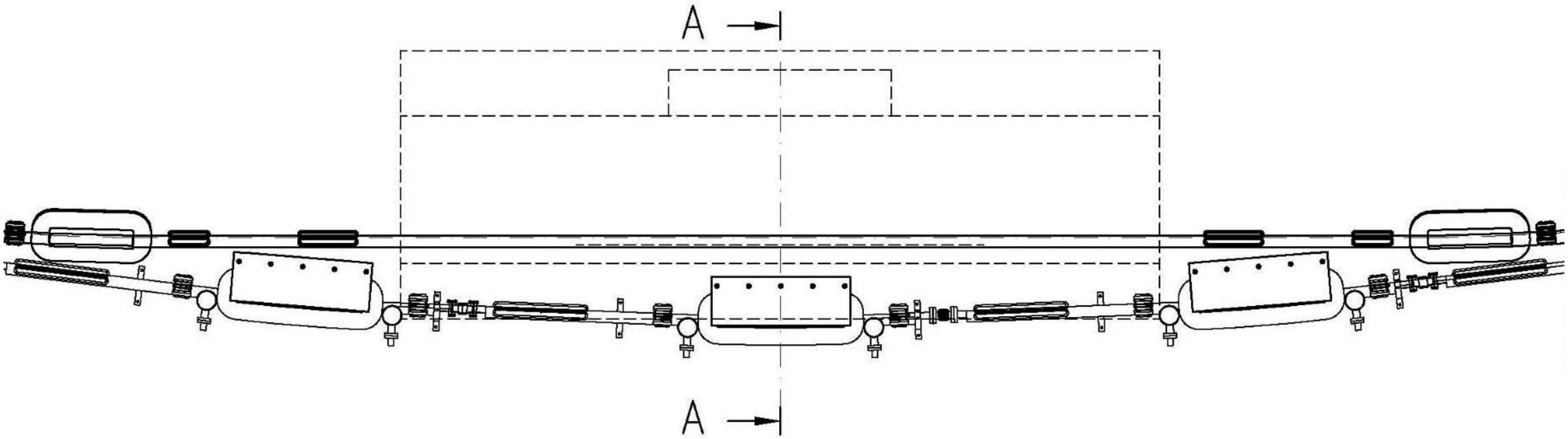
- The 3 and 1.5 GeV rings have the same lattice structure and are placed on top of each other.
- Magnets directly machined out from solid iron blocks allowing for compact lattices and very small emittances.
- Linac FEL driver for cascaded High Gain Harmonic Generation coherent radiation.

The 3 GeV and 1.5 GeV rings have the same lattice structure and are placed on top of each other.

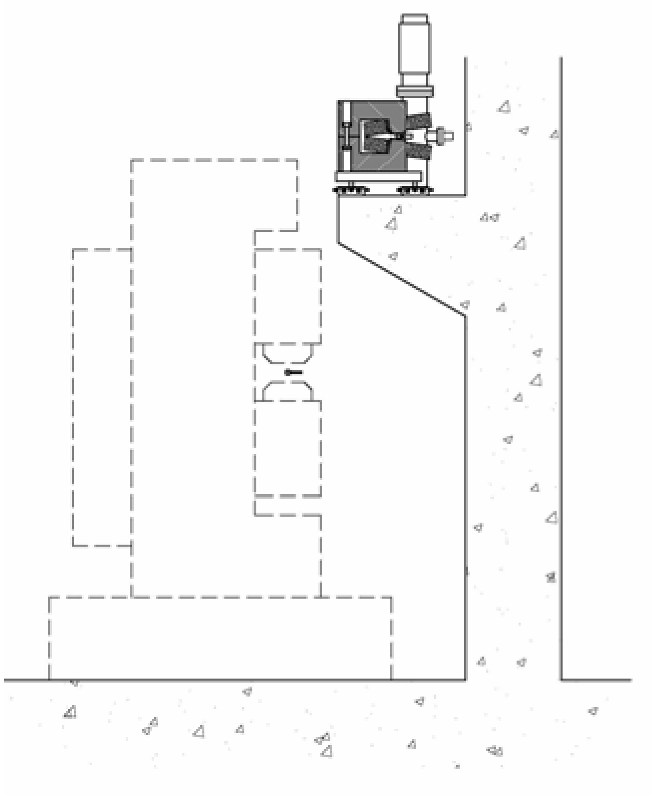
There is a 12-fold symmetry in the lattice.

The two rings are turned 15 degrees relative to each other.

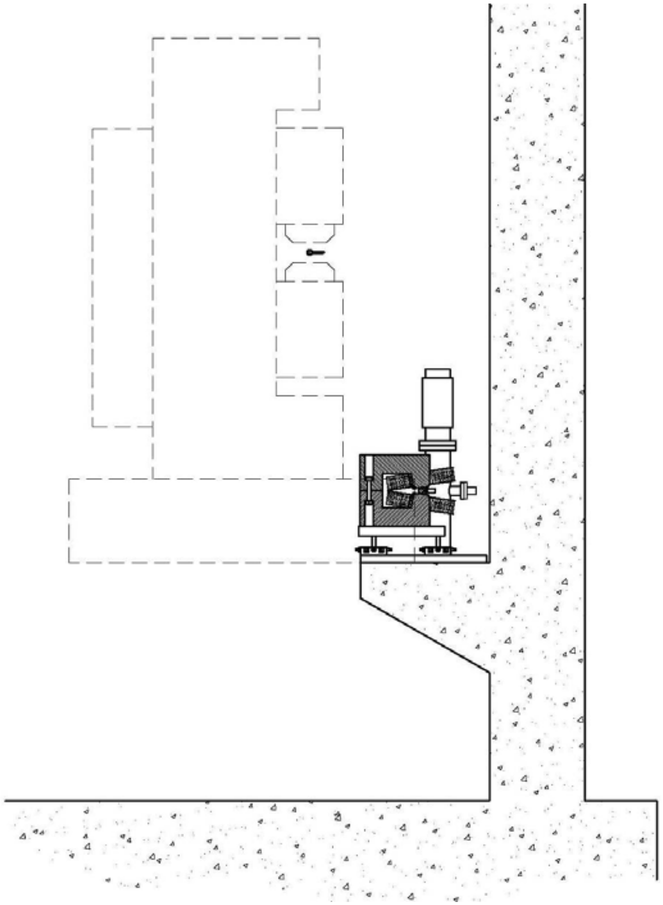
This gives space in the straight sections for the insertion devices.

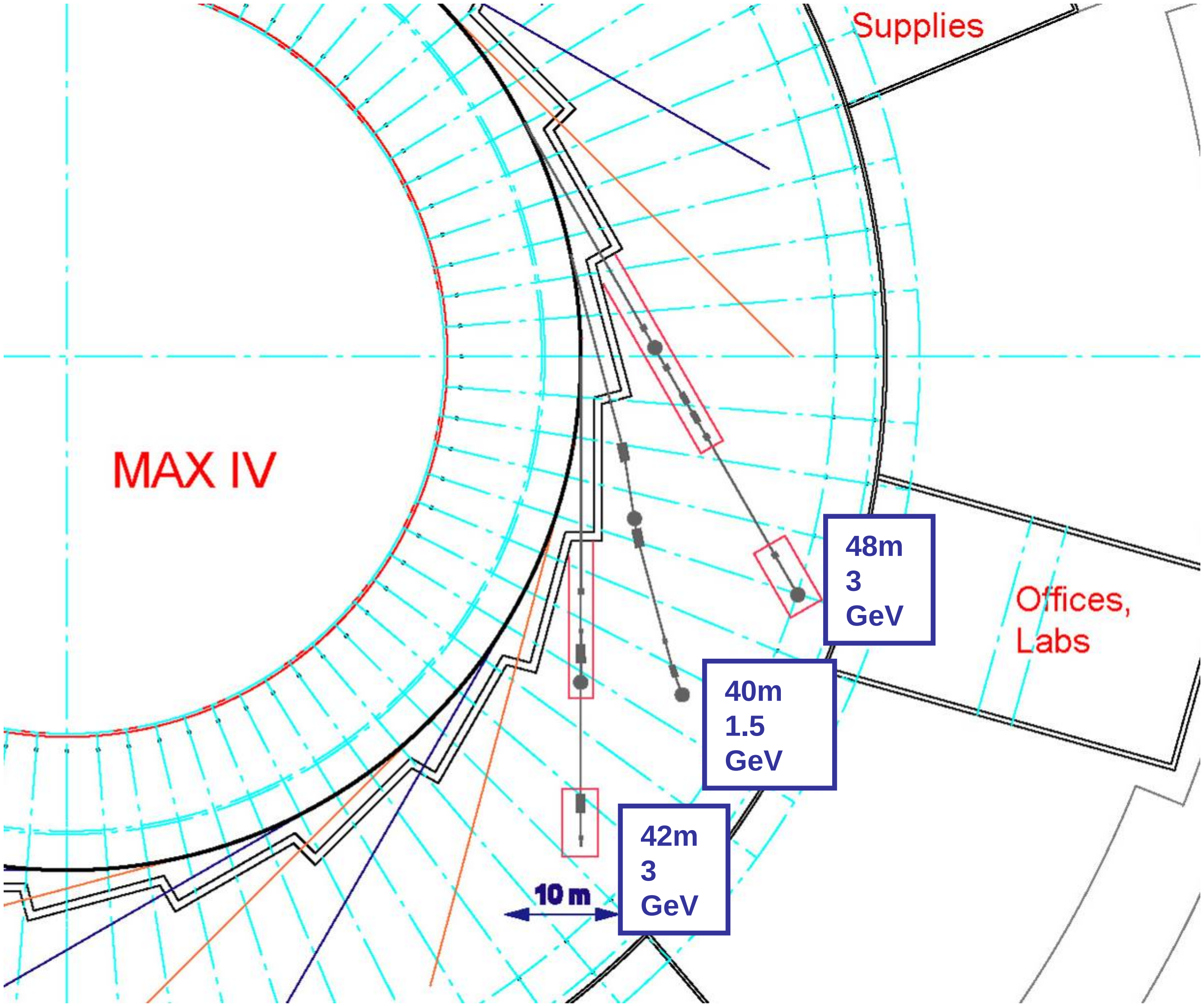


ID on 3 GeV ring and dipole on1.5 GeV ring.



ID on 1.5 GeV ring and dipole on 3 GeV ring.




Supplies
MAX IV
48m
3
GeV
40m
1.5
GeV
42m
3
GeV
10 m
Offices,
Labs

MAX-IV Insertion devices

The MAX IV facility will be unique with three low emittance storage rings at different energies in combination with the linac injector.

- 3 GeV – hard x-rays
- 1.5 GeV – soft x-rays
- 700 MeV – UV and IR light
- 0.5-3.5 GeV linac – high peak brilliance in short pulses

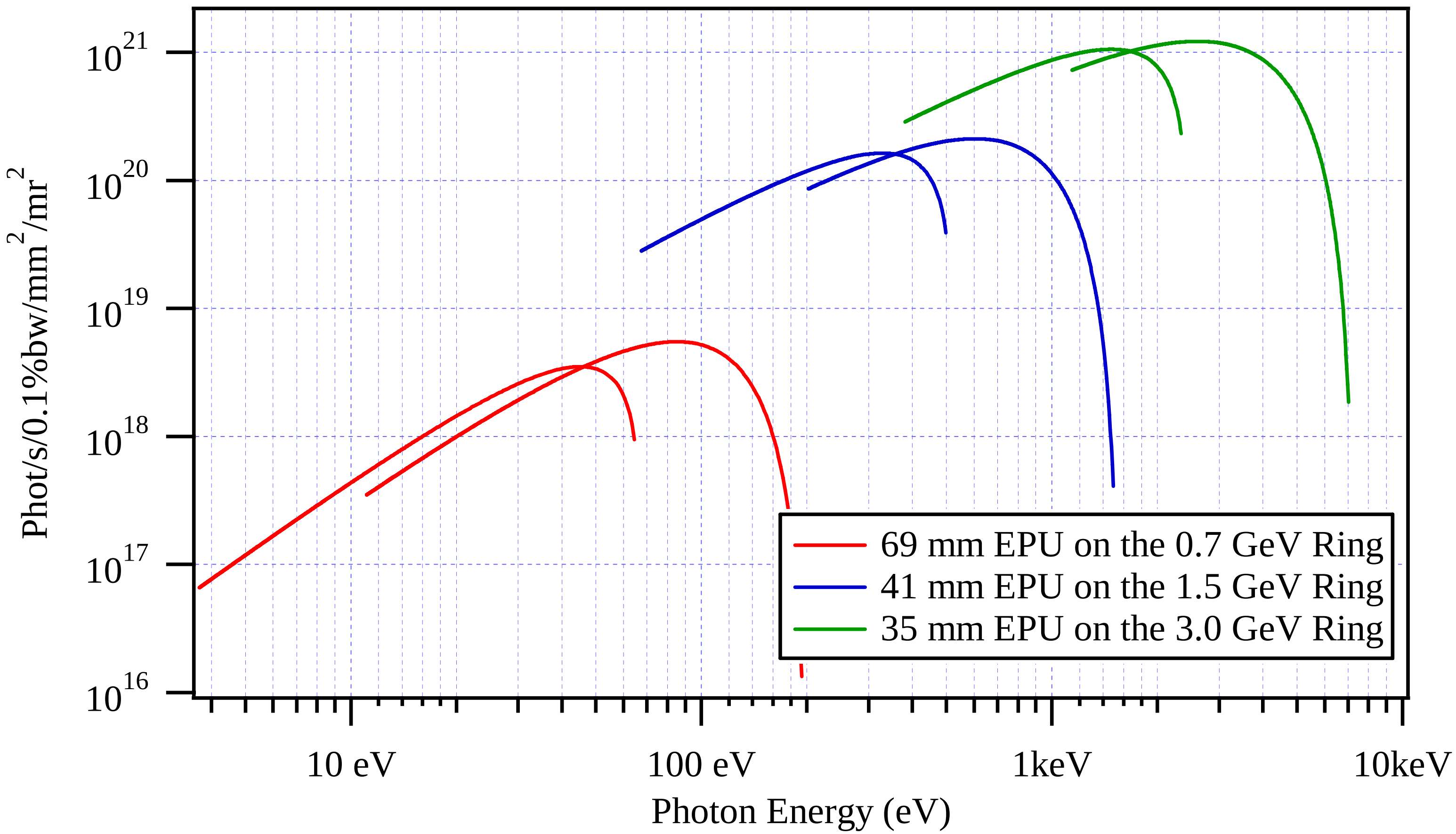
The MAX IV storage rings are designed for the installation of small aperture short period undulators. A long bunch length and soft end magnets give a low heat load.

The MAX IV facility is also especially suitable for EPUs:

- “Thin” vacuum chambers, 7 and 9 mm thick respectively
- 4.6 m long straights allow 4 m Long EPUs
- No need for high K-Values which gives small effects on the stored beam

Ring	**3 GeV**	**1.5 GeV**	**700 MeV**
Length of straight sections	4.6 m	4.6 m	2.65 m
Vertical beam stay clear aperture	4 mm	6 mm	11 mm

Brilliance for EPUs at the MAX IV Light Source



- 1.98 m long 69.1 mm period EPU with 57 poles on the 0.7 GeV ring
- 4 m long EPU with 41 mm period and 193 poles on the 1.5 GeV ring
- 4 m long EPU with 35 mm period and 226 poles on the 3 GeV ring.

Flat field undulators

The undulator should give the highest possible peak field for a short period length

In vacuum undulators at ambient temperature

- Mature technology - high quality in vacuum undulators can be ordered from industry
- Performance is not expected to increase without findings of new magnetic materials

In vacuum undulators at cryogenic temperature

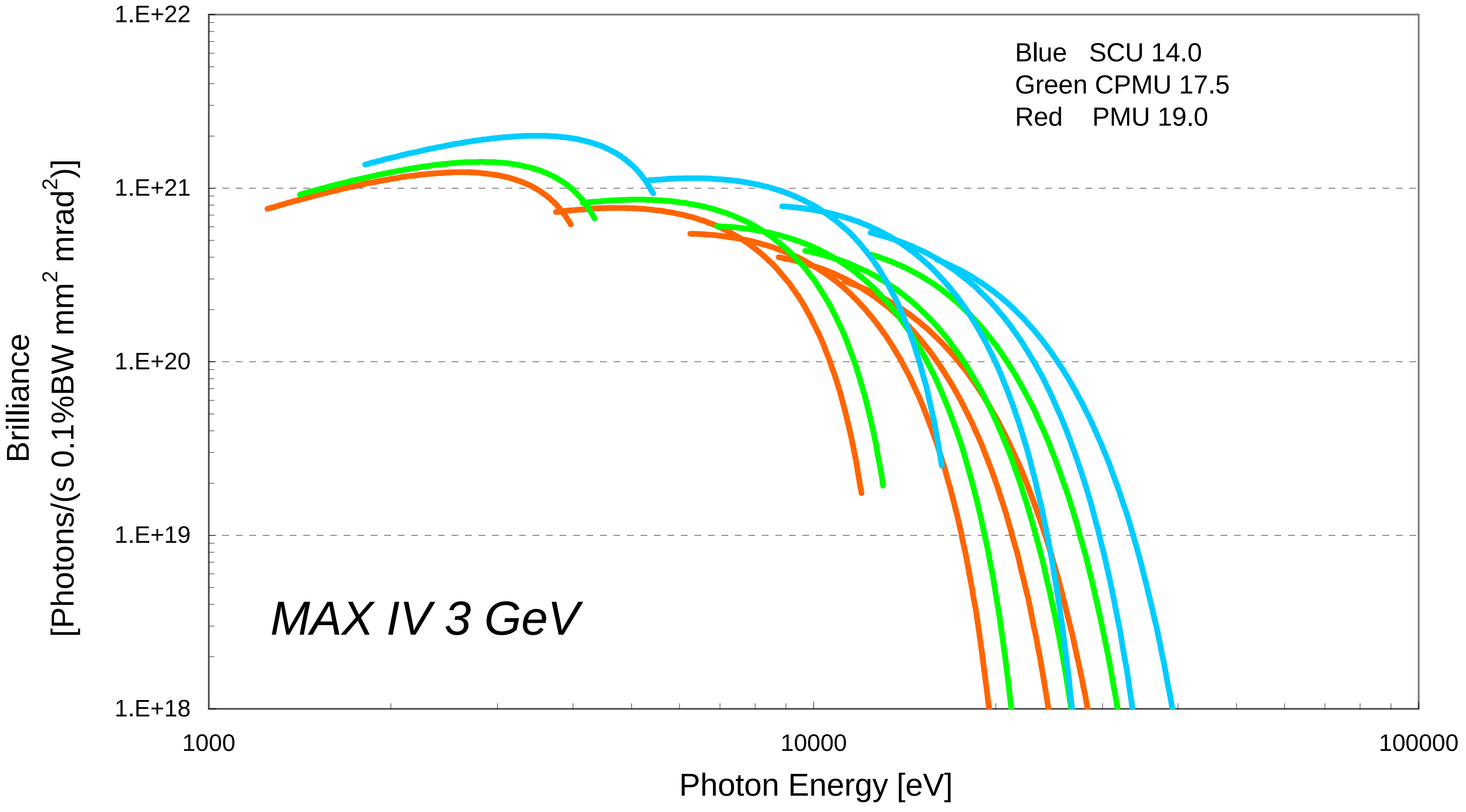
- The performance of the permanent magnet material can be increased by lowering the temperature to 100-150 K as suggested by [1].
- Development is at present being carried out both in Europe, Asia, and in the US.

Superconducting undulators

- A promising option for obtaining high peak fields at short period lengths.
- Not yet a mature technology.
- Development is at present being carried out both in Europe, Asia, and in the US.

[1] T. Hara, T. Tanaka, H. Kitamura, T. Bizen, X. Maréchal, T. Seike, T. Kohda, and Y. Matsuura, Physical Review Special Topics – Accelerators and Beams, Volume 7, 050702 (2004).

Brilliance at the MAX IV 3 GeV storage ring

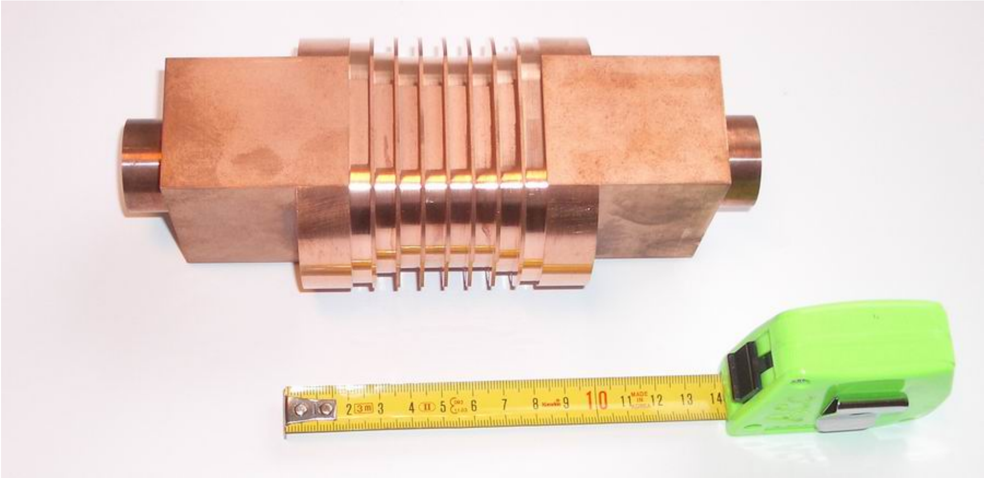


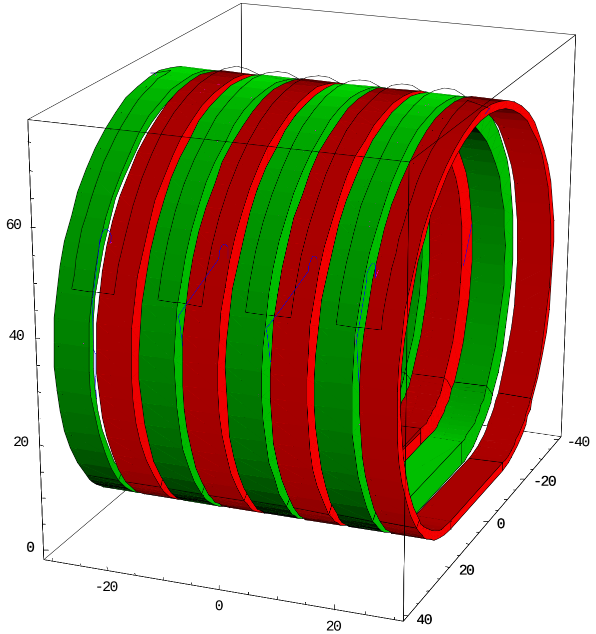
Brilliance for the harmonics 1,3,5,7 and 9 for the undulators SCU 14.0, CPMU 17.5, and PMU 19.0.

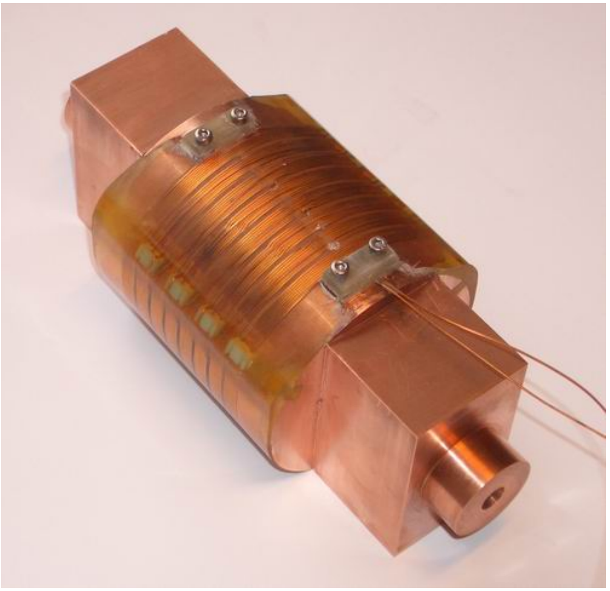
The plot is for a K-value in the range 0.5 – 2.2.

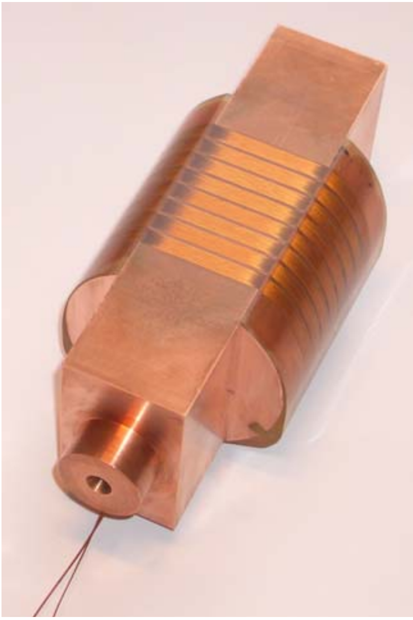
Prototype of coil for superconducting undulator

Period length 15 mm
Gap 4.4 mm
K-value >2.2
Iron free magnet
Fixed gap device









Test runs with prototype

Test cryostat at MAX-lab.

Liq. He from MAX-Wiggler system

400 A power supply from MAX-Wiggler

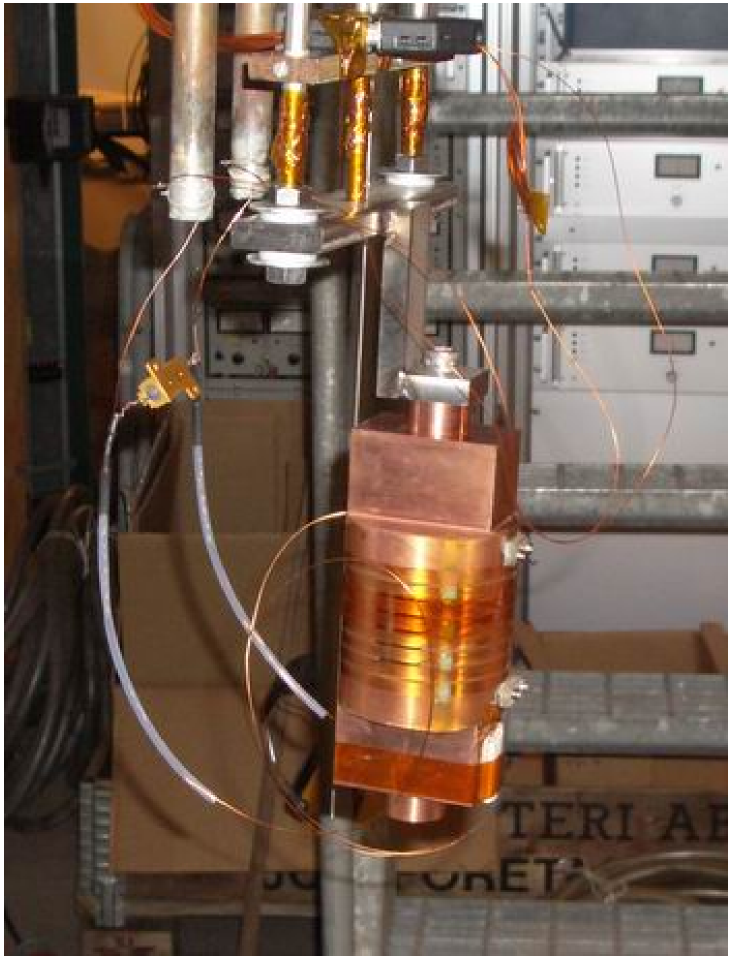
After totally ~5 quenches 400 A is reached

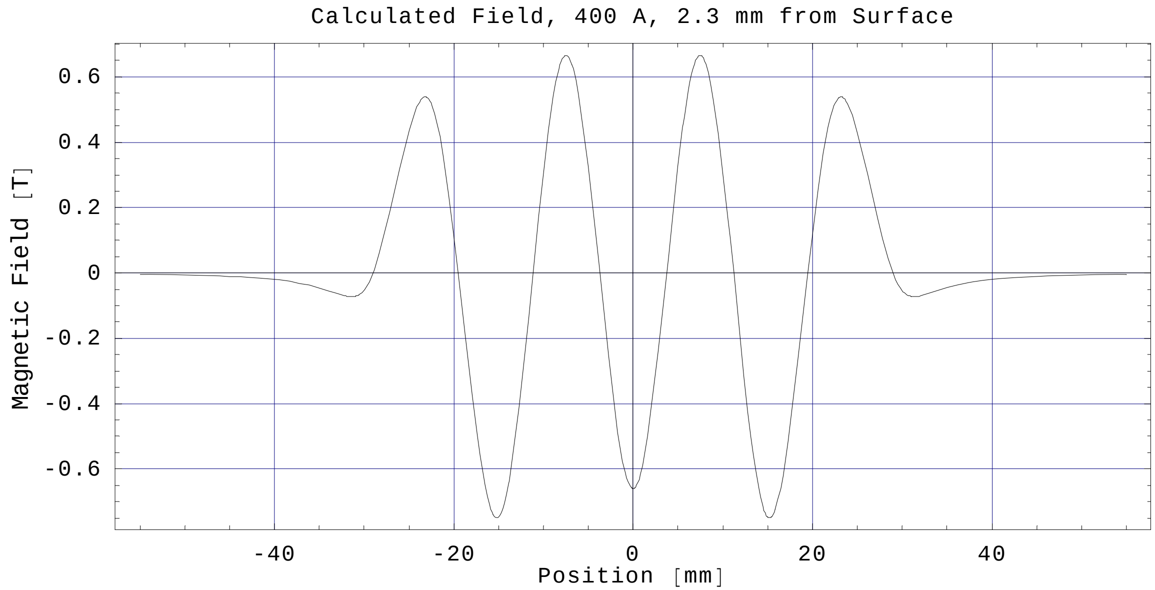
400 A = 1.02 kA/mm^2, The goal is 440 A

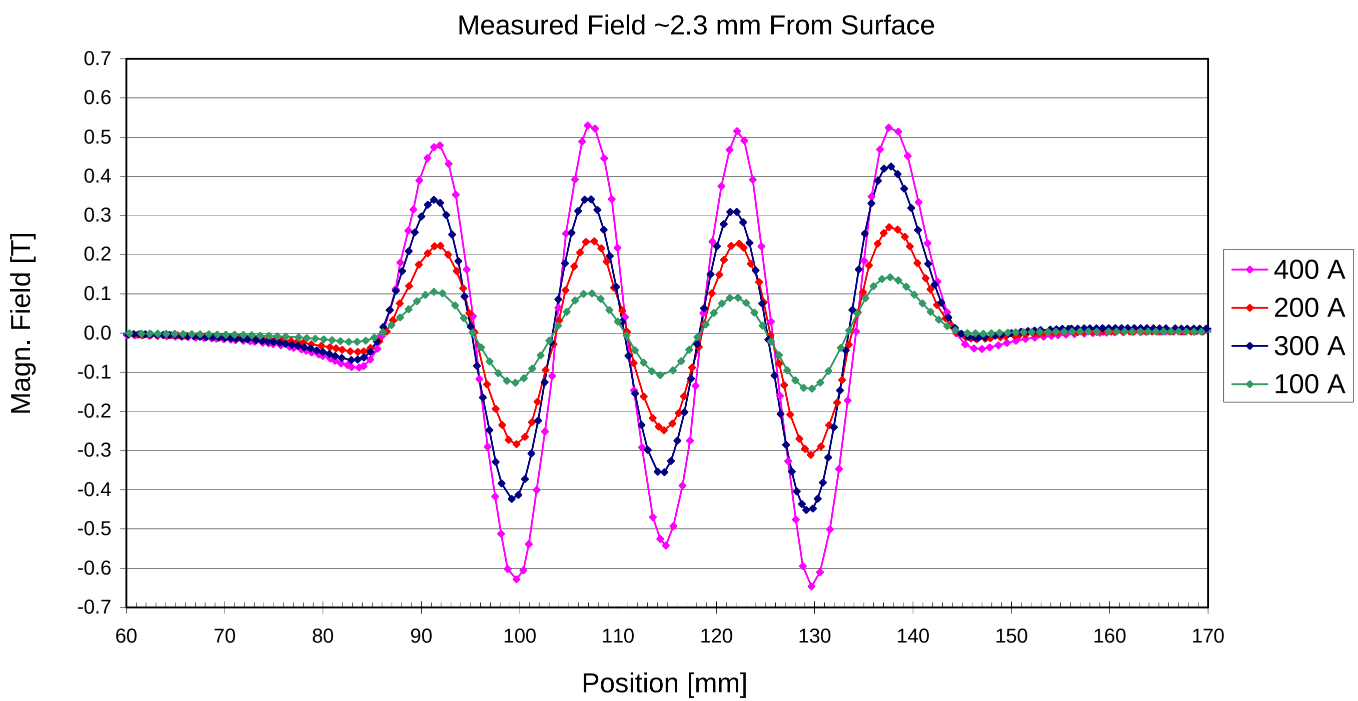
Measurement with Hall probe has been done

Bad alignment of Hall probe carrier

Calibration and driving current?




Calculated Field, 400 A, 2.3 mm from Surface
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
Magnetic Field [T]
-40
-20
0
20
40
Position [mm]


Measured Field ~2.3 mm From Surface
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
Magn. Field [T]
60
70
80
90
100
110
120
130
140
150
160
170
Position [mm]
400 A
200 A
300 A
100 A

Two points of discussion for the workshop:

1. Joint initiative on compact, well aligned, temperature controlled, stable, and calibrated Hall probes.

2. Superconducting magnets – cryostats and Hall probes.

Thank you for listening