國家同步輻射研究中心
National Synchrotron Radiation Research Center

Development of elliptical polarization undulators for TPS

Ting-Yi Chung

Magnet group, NSRRC, Taiwan

Outline

- Characterizations and status of EPUs in Phase-I at TPS
- Motivation of two collinear EPU48
- Heat load issue
- Design and construction of EPU48
- Performance of EPU48
- Dynamic multipole error issue
- Conclusion

Characterizations of EPUs

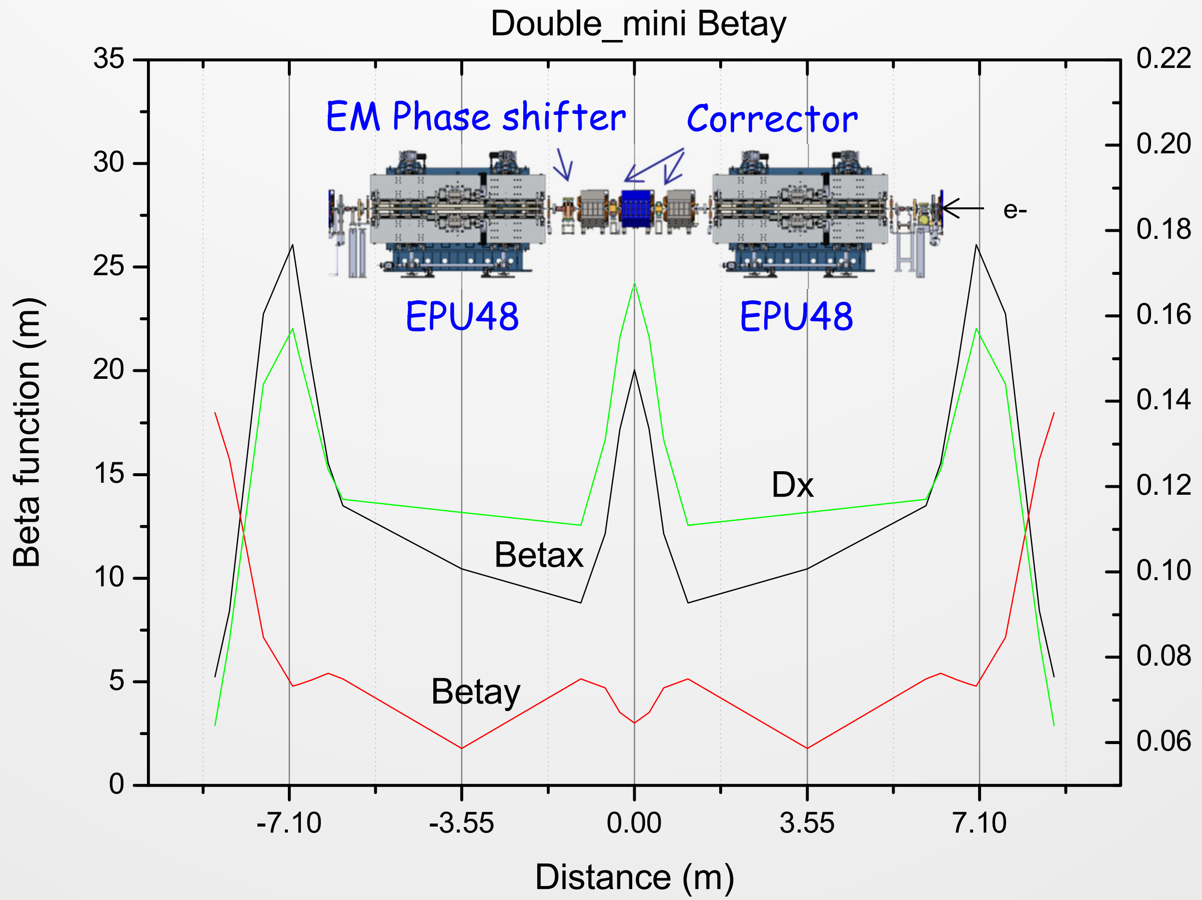
Two kinds of period and three APPLE-II EPUs total are designed, constructed, and installed in Phase-I at TPS. Both EPUs can cover the K-edge absorption of the most abundant elements on Earth (C, Ni, O, Si) and the L-edge absorption of the important transition metal (Fe, Co, Ni, Cu).

	EPU46	EPU48 x2
Photon energy* (eV)	270-2000	230-2000
Deflection parameter	3.48/2.32	3.72/2.47
Period Length (mm)	46	48
Number of effective periods	82	67
Total physical length (m)	3.89	3.43
Range of magnet gap (mm)	13.5≦G≦110	13≦G≦120
Maximum field strength (T)	By=0.81 Bx=0.54	By=0.83 Bx=0.55
Remanence NdFeB (T)	≧1.22	≧1.24

* Operating at 3GeV

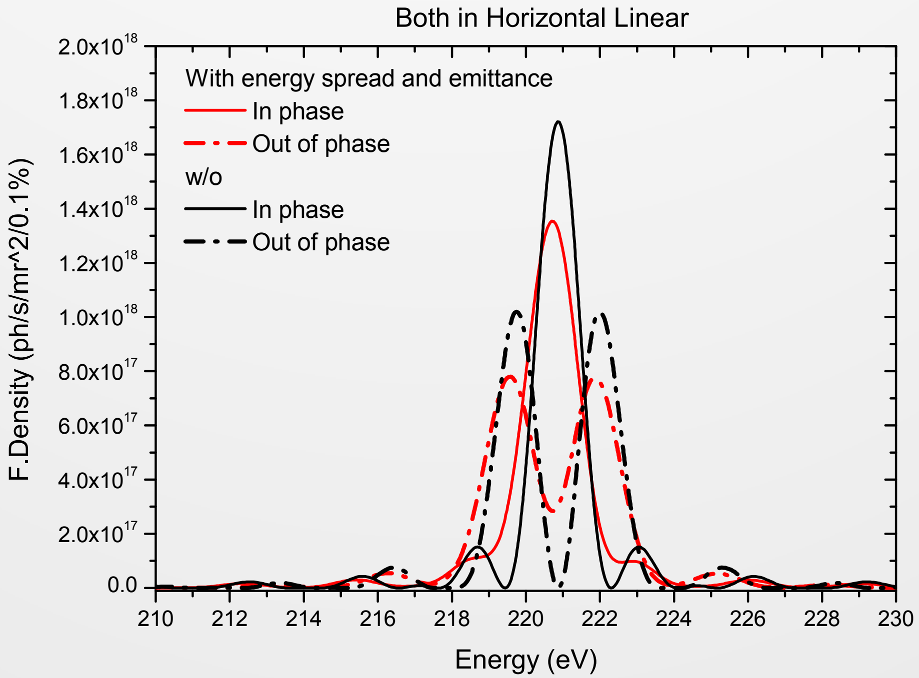
Motivation of two collinear EPU48

High polarization mode : double EPU48 with the same polarization are phase matched using a phase shifter between both EPU48. Interference effect increases the intensity of flux.
Rapid change polarization mode : double EPU48 with opposite polarization obtain linear or circular polarized radiation with any required polarization direction depending on the phase shifter setting.



Spectrum and polarization calculation

- Operating in the same polarization modes:
  - The difference of angular flux density between in phase and out-of phase of double EPU will be up to 40%-2% (in the energy range of 0.22-1.7 keV). The phase shifter is necessary.
  - Comparing two collinear EPU48 in double mini beta-y lattice with single 3m long EPU, the flux density increases by a factor of 2.6.
  - Operating in opposite circular modes, no heat load issue due to no higher harmonics. The linear polarization rate decreases to 37%, which is attributed to a long drift space and ID. Operating in a common crossed undulator case, the circular polarization rate reduces to 31%.



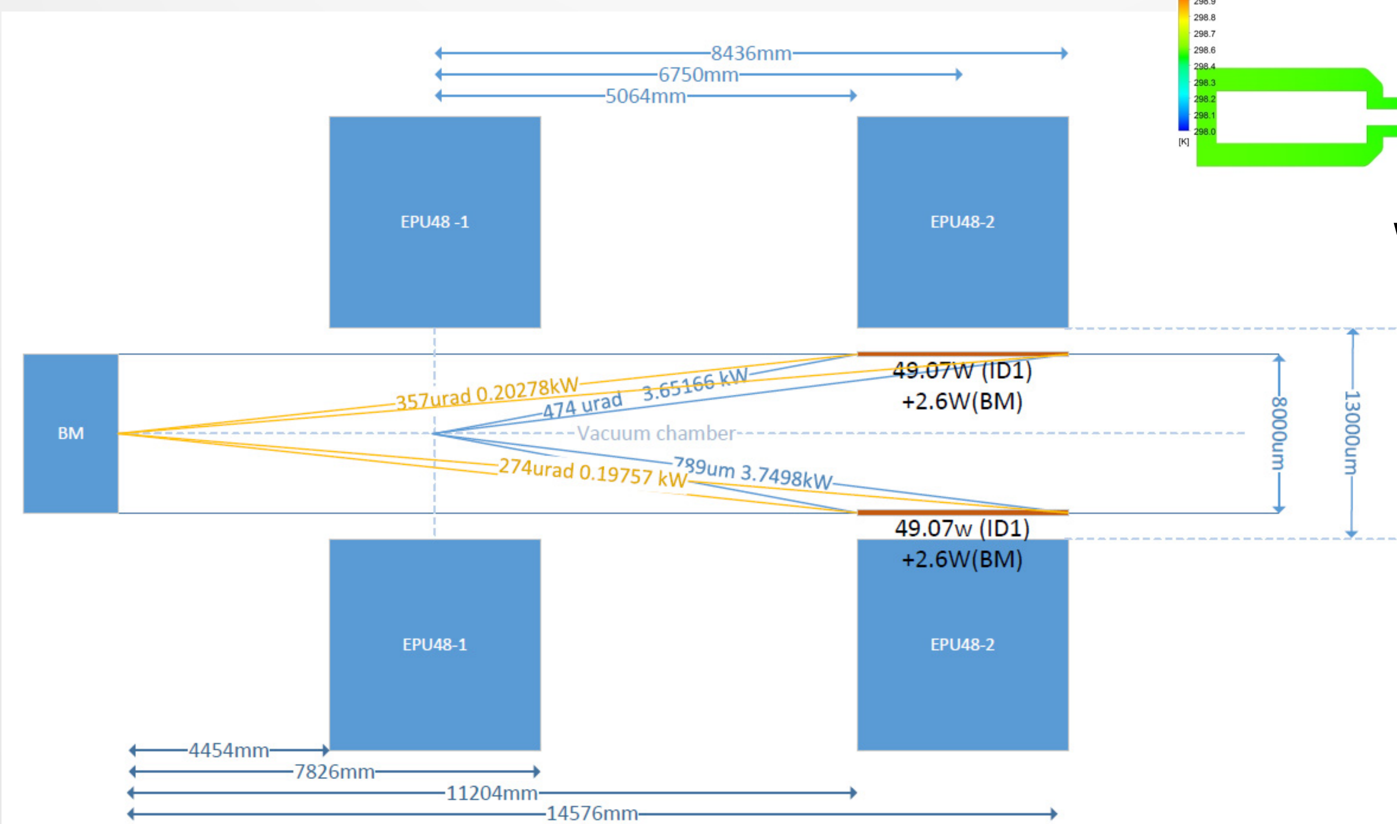
Heat load of two collinear EPU48

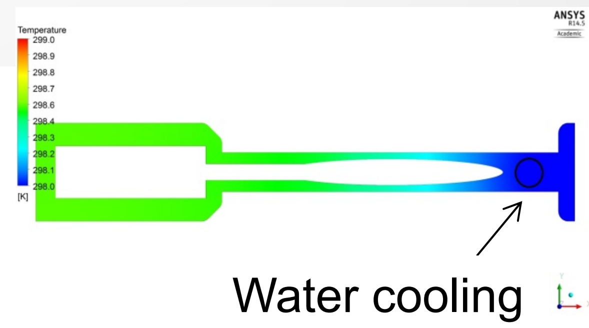
Heat load issue on the straight section vacuum chamber.

⇒ Upstream bending magnet and insertion device will create large heat load on downstream chamber, up to 15.3W/m in the vertical direction.

⇒ Temperature rising of a chamber is less than 0.5^{0}C via water cooling(25^{0}C).

Vertical linear mode



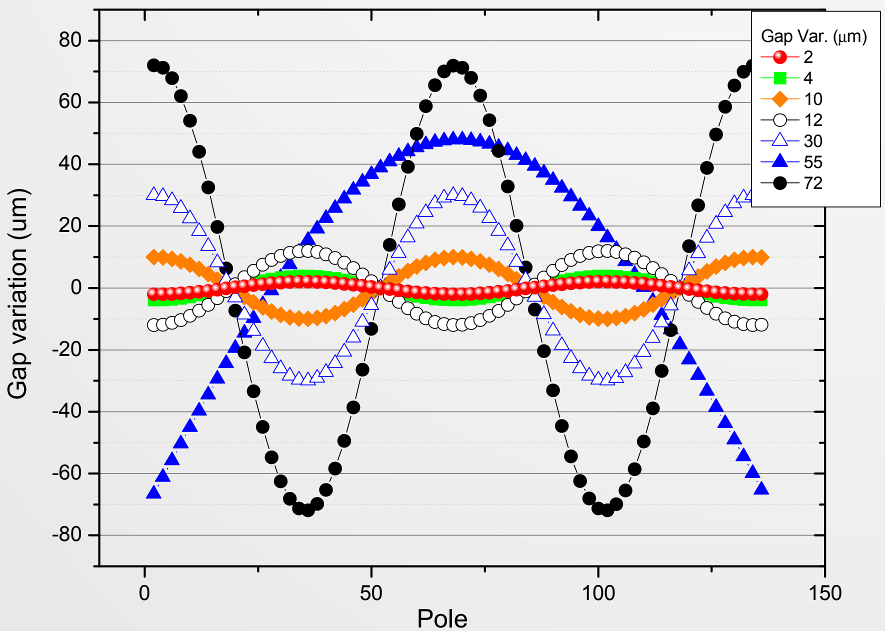


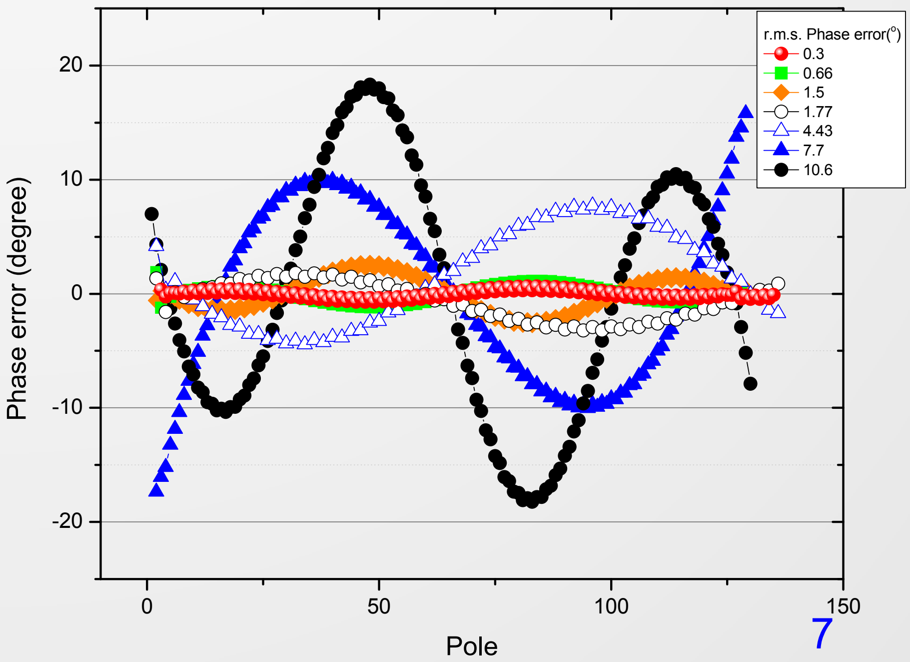
Mechanical consideration of EPU48

Design concept:

•In order to support strong magnetic force (~34kN in horizontal linear mode), the design of a cast support structure, instead of a welded structure, of the EPU48 is to limit the effect of deflections and rotations of the magnet arrays so that the contribution to the r.m.s. phase error is less than 0.5^{o}, corresponding to a gap variation of ±3um.

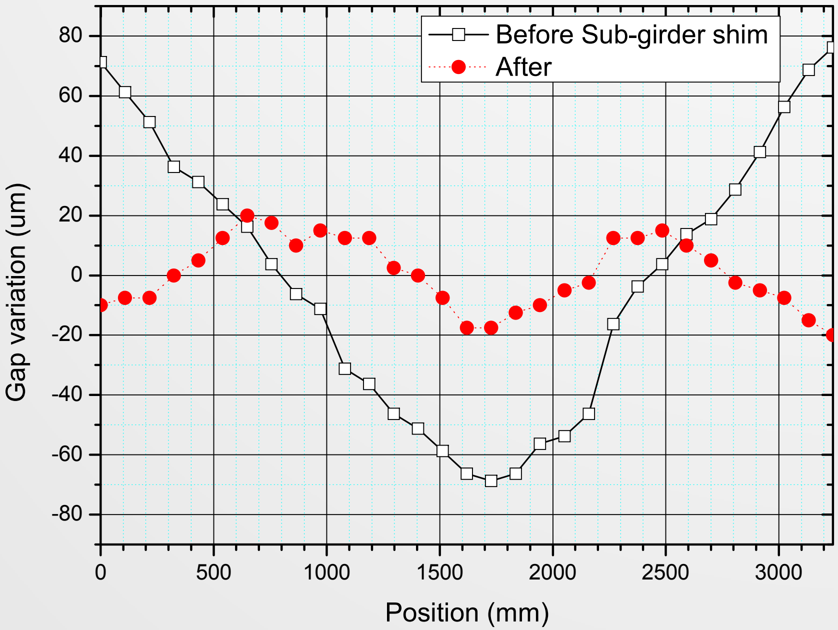
•Deflection of the strong-back, the bearings, the magnet girders, the magnet holders have all evaluated with a 50% safety margin.

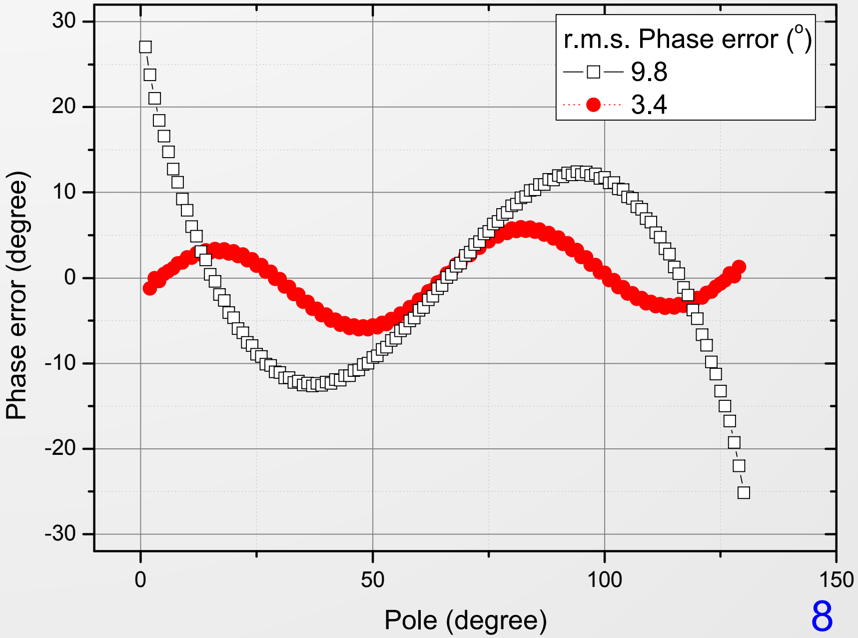




Mechanical performance of EPU48

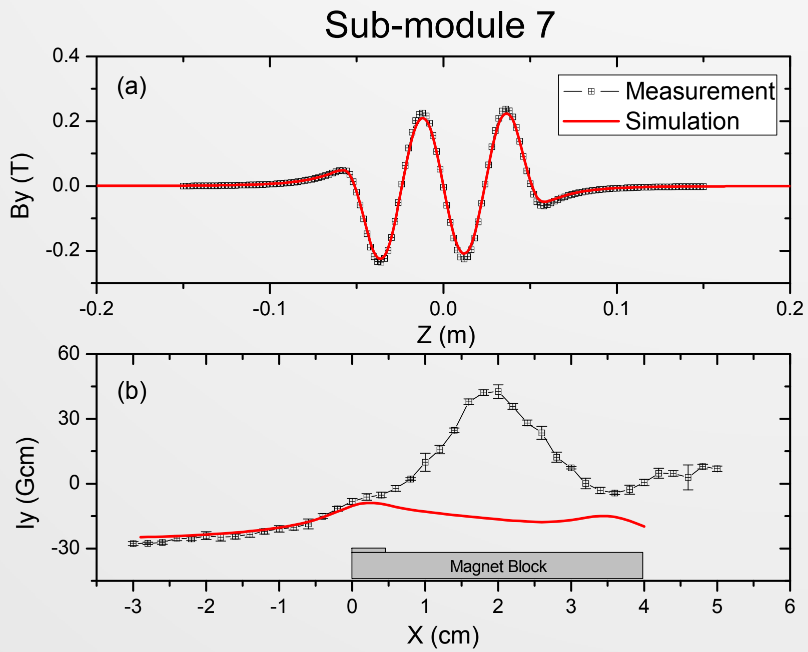
- After sub-girder shim, gap variation has been flattened from ± 75 to ± 20 um. This is able to improve the r.m.s. phase error from 9.8 to 3.4 degree.
- Repeatability of gap and phase movement is less than 2.5 um, which ensures a photon energy deviation is less than one-tenth of the width of the fifth harmonic.
- Lateral deformation of magnet blocks is less than ±10 um.





Magnetic consideration of EPU48

Magnet block sorting strategies :
1.Individual blocks are sorted based on Helmholtz coil measurement.
Importing the component of magnetization of each magnet into RADIA code to minimize the phase error in various polarization modes.
2.Sub-modules holding 7 or 9 blocks are sorted based on Hall probe scan and stretched wire measurements.
To eliminate the influence of inhomogeneity and imperfect of blocks, sub-modules are sorted again based on the simulated annealing (SA).



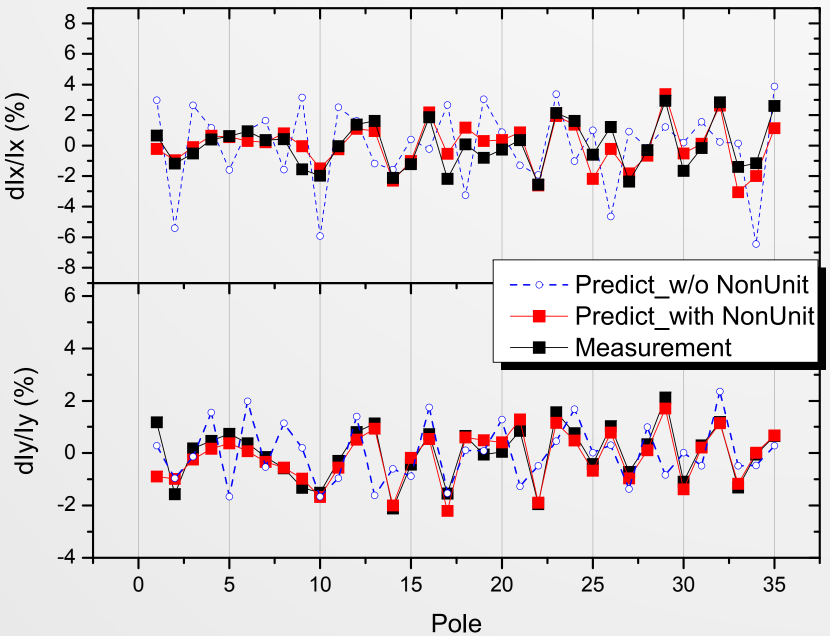
The cost function consists of terms for multipole error and phase error, which means it takes into account the major influences on the electron beam and the spectrum.

$$E = aMP + bESy + cESx + dFSy + eFSx$$

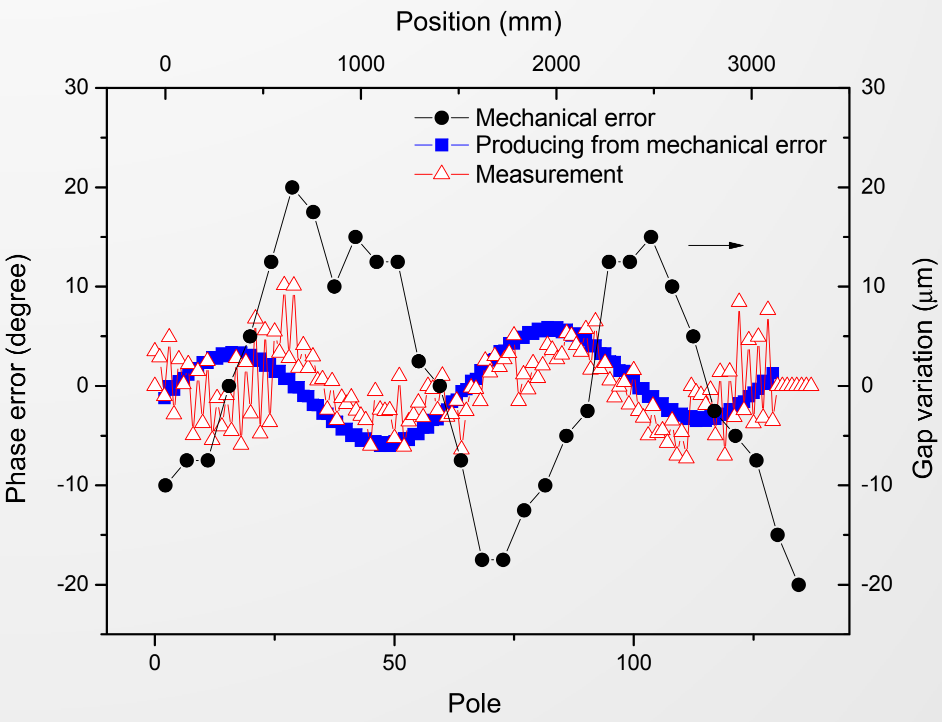
E : cost energy, *MP* : multipole error term, *ESy/x* : error-storage (*ES*) with respect to vertical or horizontal direction, *FSy/x* field storage (*FS*), and coefficients *a* … *e* are weight factors of each term.

Magnetic consideration of EPU48

- The distribution of dI/I is not only the superposition of each sub-module data, but considering the interaction nearby an interface attributed to the non-unit effect.
- The contribution of the non-unit effect is periodic and up to 100Gcm.
- After the sorting, the phase error contributed from magnets is suppressed to that from mechanical error.



I : field integral of poles



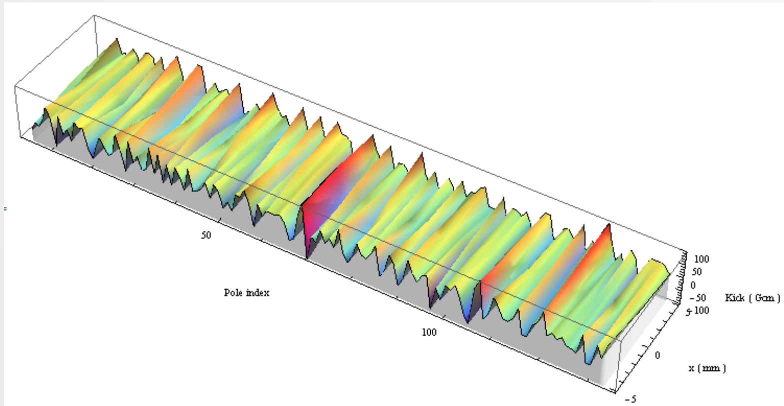
Magnetic consideration of EPU48

Magnetic field shimming algorithm :

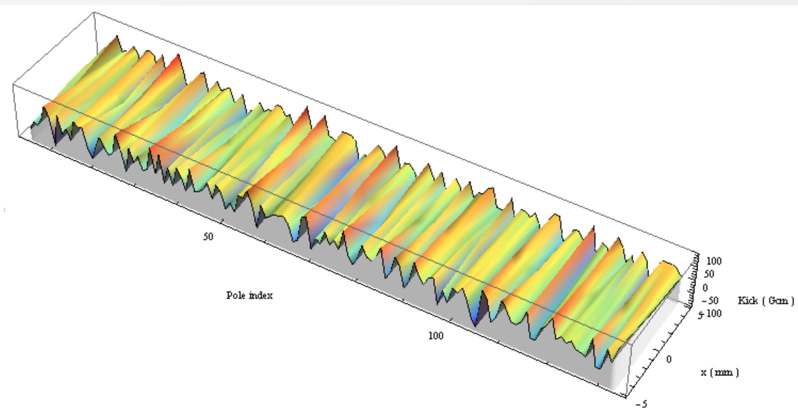
1.Phase error shimming : To improve straightness of trajectories, phase error, and static multipole error in all operation modes using a screw-driven wedge and slide mechanism to move magnet blocks, virtual shimming.

2.Static multipole error shimming : To reduce the residual field integral using magnet chips, located at the extremities of EPU. The best arrangement of chips is achieved based on the simulated annealing.

Before 2D virtual shimming



After 2D virtual shimming

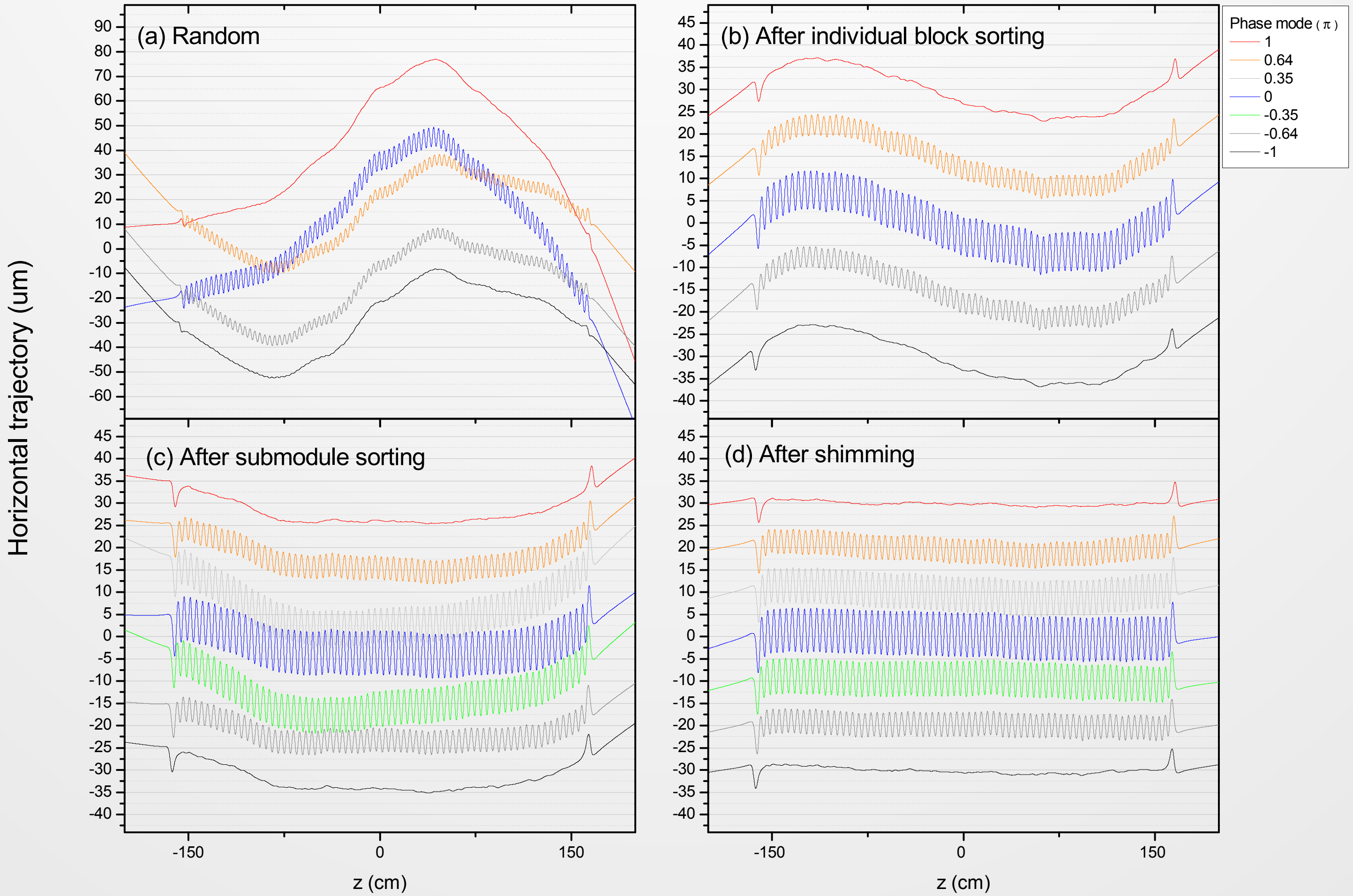


The deviation of field integral in the transverse direction is flattened after the 2D virtual shimming, meaning to reduce the quadrupole error.

Magnetic performance of EPU48

Road map (straightness of trajectories) :

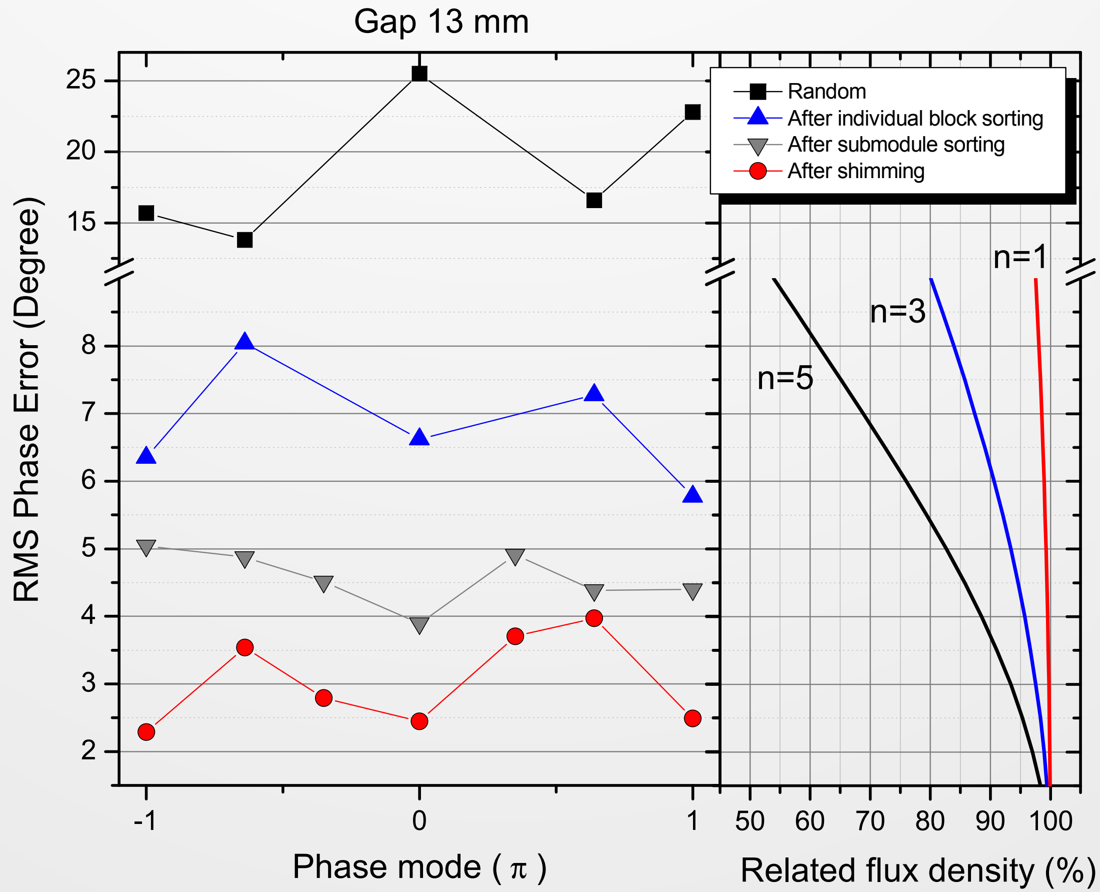
After the submodule sorting, the straightness has been improved within ±11um. After shimming, it has even been improved within ±4um in all operation modes.



Magnetic performance of EPU48

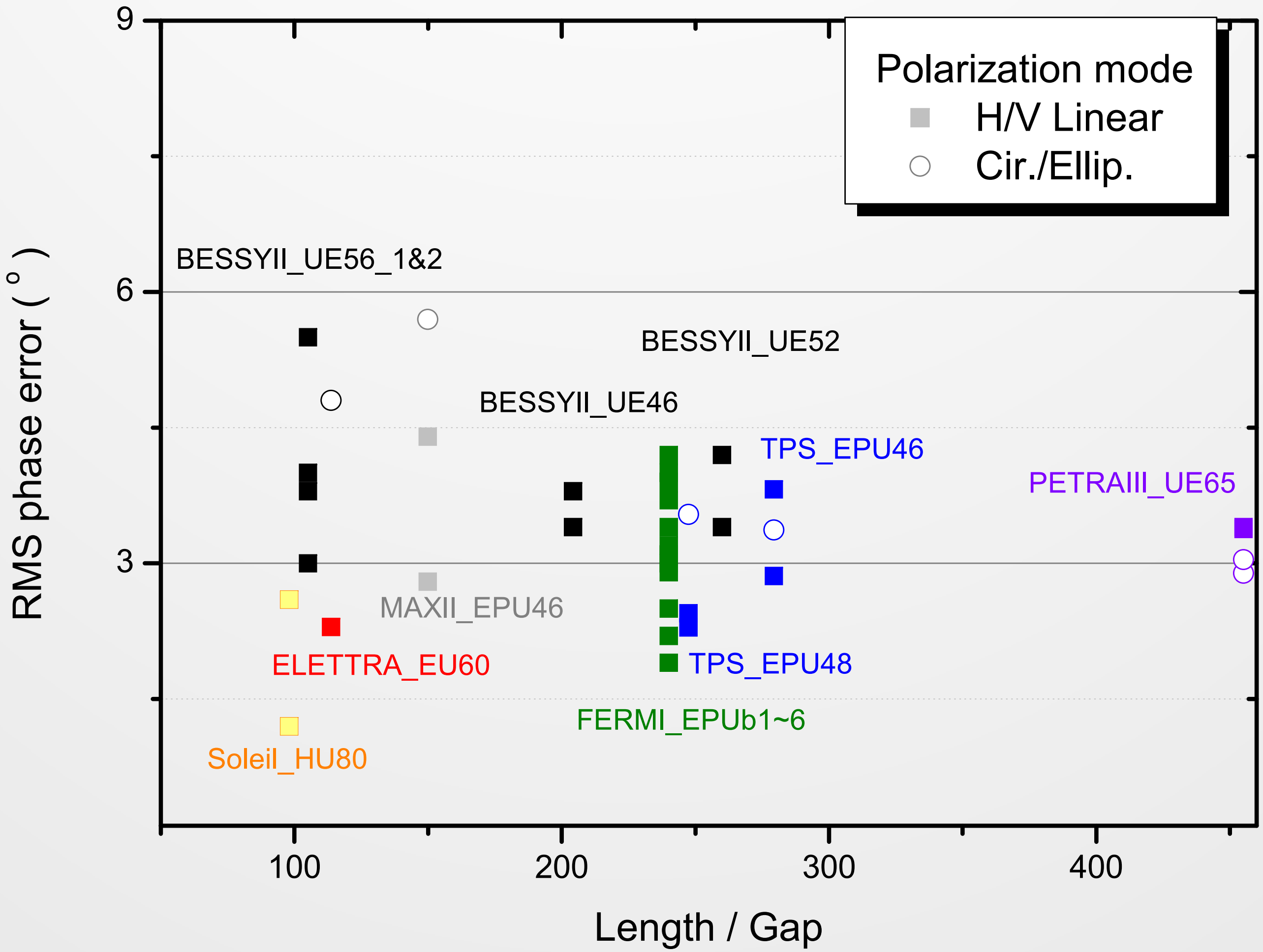
Road map (Phase error) :

- Phase errors for linear/circular mode are better than 2.5/4 degree.
- The flux density of linear polarization mode at the fifth harmonic energy and circular polarization mode in the fundamental harmonic energy are greater than 95% of an ideal value.



Magnetic performance of EPU48

Position in APPLE-II map: Constructing a longer and smaller gap of a undulator is much difficult. Stiff mechanical structures and good quality magnets are essential. Mechanical arts and magnetic field treatments are equally important for a high performance undulator.

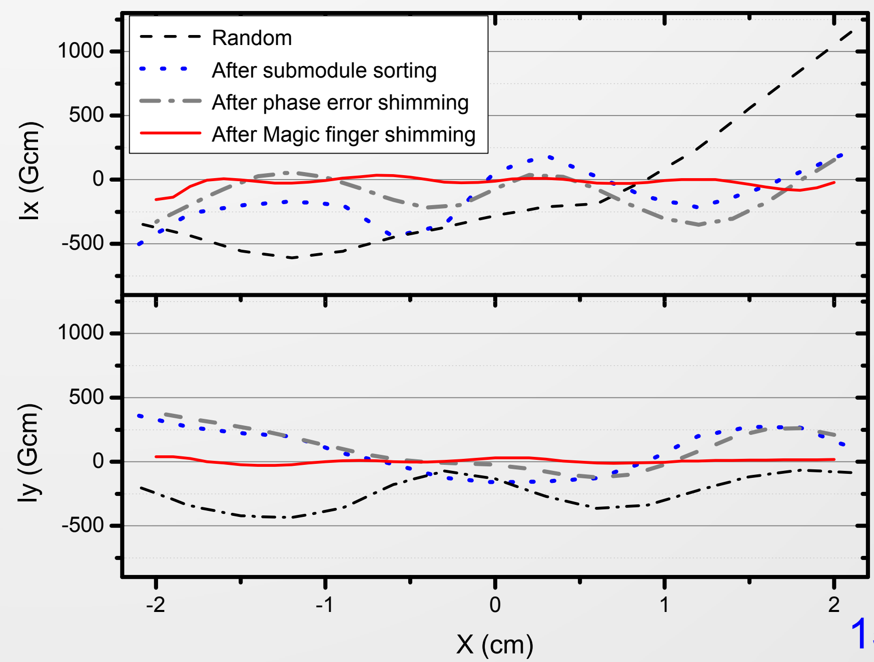


Magnetic performance of EPU48

Gap(mm)	Phase mode	Skew				Normal			
		Di	Quad.	Sext.	Oct.	Di	Quad.	Sext.	Oct.
		Gauss.cm (<100)	G (<50)	G/cm (<100)	G/cm^2 (<100)	Gauss.cm (<100)	G (<50)	G/cm (<100)	G/cm^2 (<100)
13	VLP	-29	20	4	-12	18	25	-19	-3
	LCP	-46	-12	7	-1	-10	9	0	4
	HLP	-14	-6	-3	-3	2	-3	-4	5
	RCP	86	40	-22	-22	34	21	-30	-3

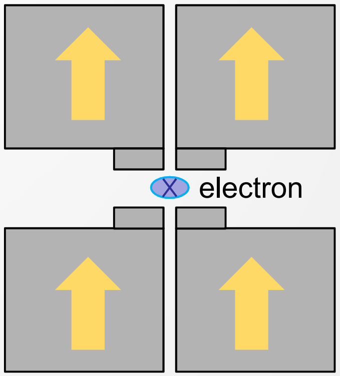
3rd order within x= ± 1.5cm

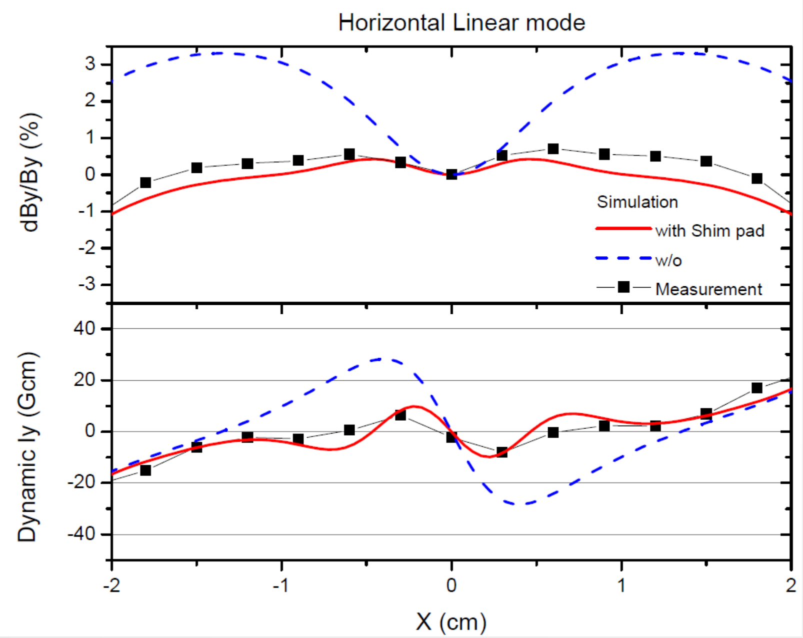
- The static multipole error has been compensated with magnet chips, called magic fingers, based on the simulated annealing algorithm. The results are within ±30Gcm in the range of ±15mm.
- All multipole terms are within the spec.

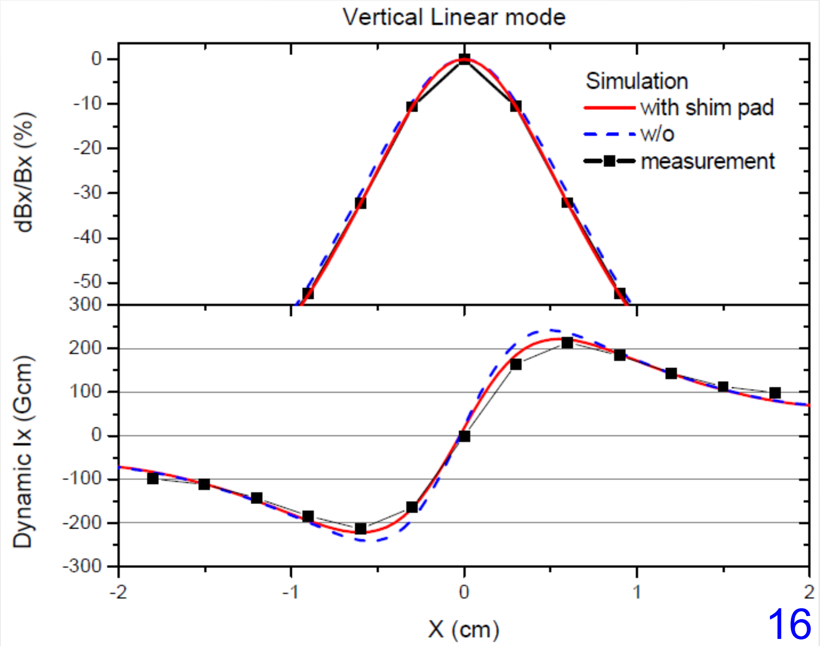


Dynamic multipole error

- A horizontal injection scheme makes a tight requirement of horizontal good field region. APPLE-II type, however, has a gap between magnet rows and an inherent narrow Bx good field region.
- A shim pad design on magnets can improve roll off of vertical field By.
- The second order kick is responsible for dynamic multipole due to narrow Bx good field region.

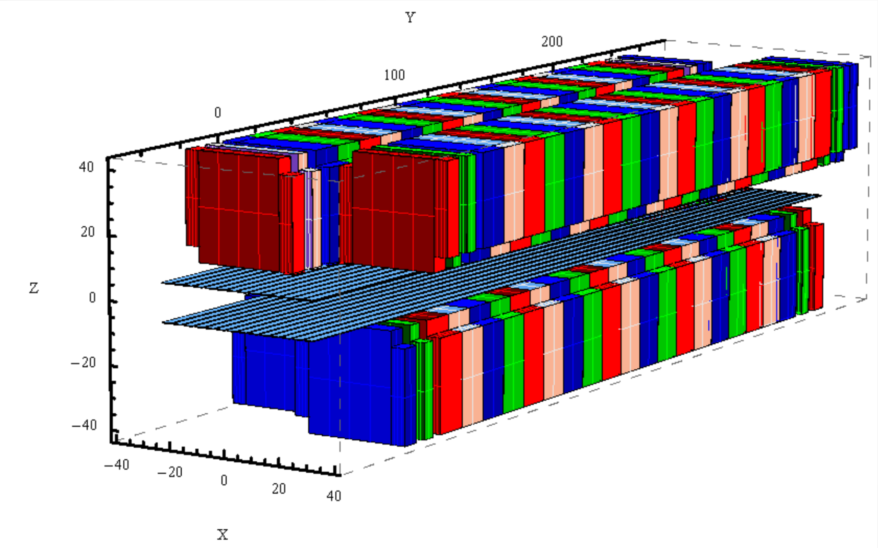


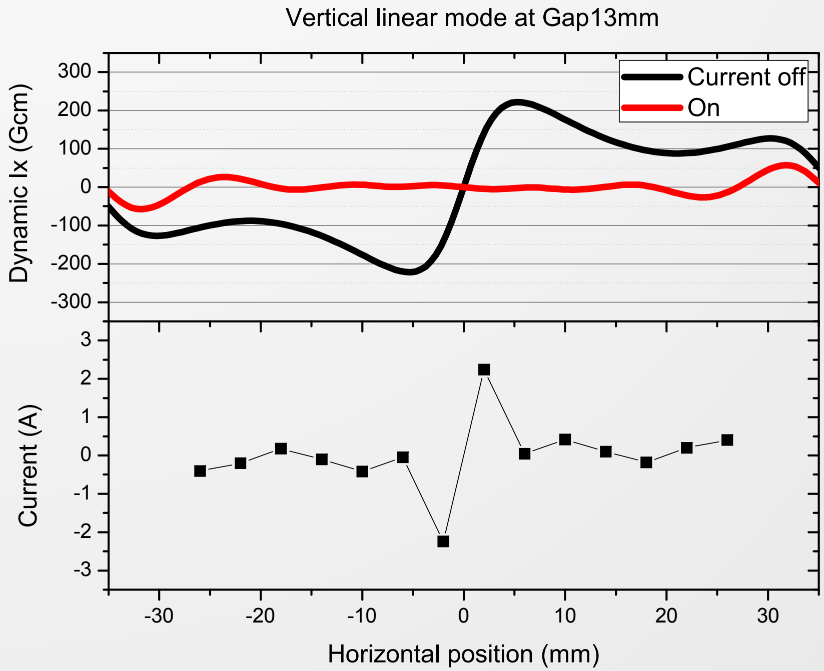




Dynamic multipole error

- The active shim system based on a similar scheme used at BESSYII is adopted to compensate dynamic multipole error.
- The effect of the ID second order kicks can be compensated by the counteracting first order correction with the current strips.





Conclusion

- There is interference between our two collinear EPU48s. The phase shifter is necessary to phase matching both radiation.
- The EPU48s are designed carefully and constructed completely in NSRRC. Sorting and shimming algorithms are developed based on a sequence of magnetic field error analysis, separating the contribution of magnetic material and mechanical parts. The performance of EPU48 is qualified to achieve the requirements of electron and photon beams.
- The shim pad design on a magnet can solve the dynamic multipole issue of vertical field. Constructing the flat wire system for compensating the dynamic multipole errors of horizontal field is ongoing.

Thank for your attention.

EPU48_front view

EPU48_back view