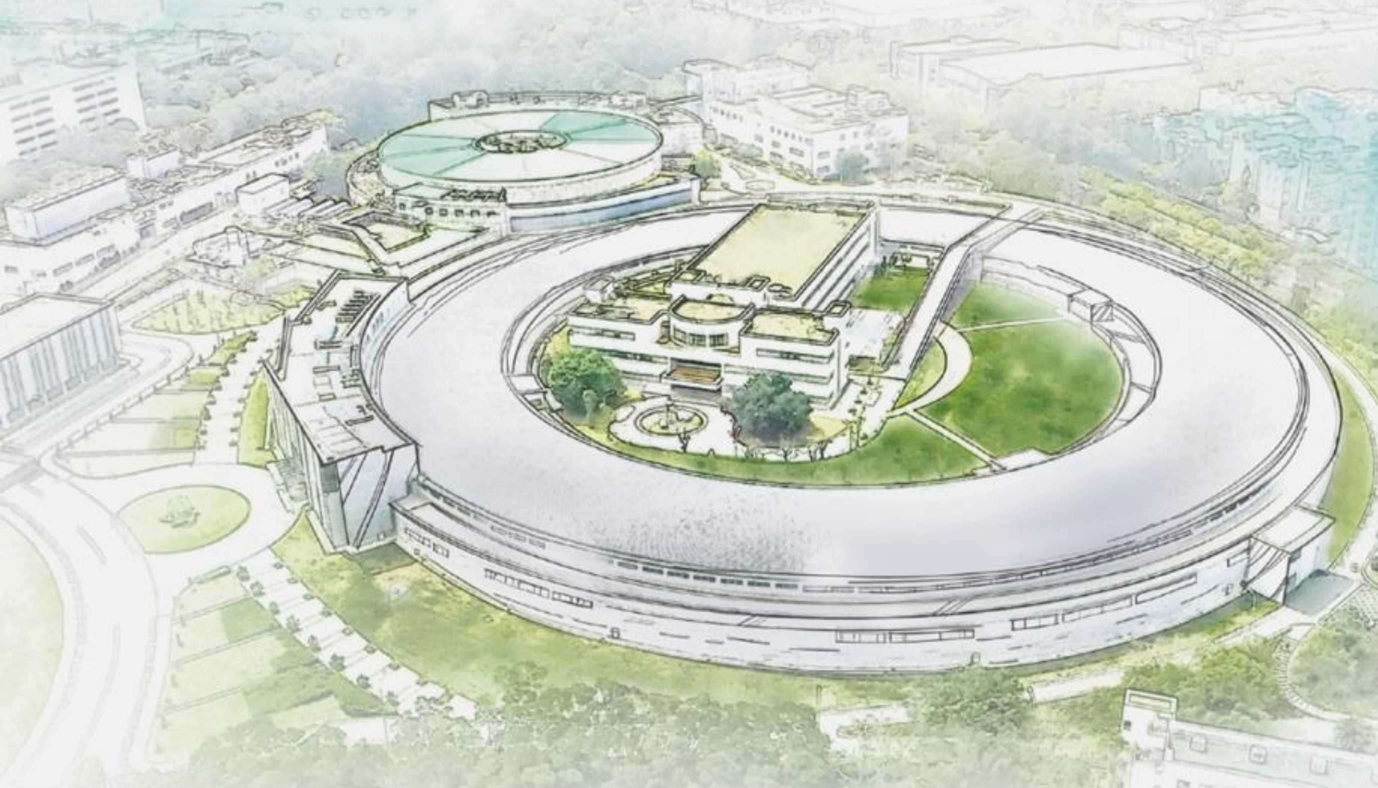
国家同步輻射研究中心
National Synchrotron Radiation Research Center

Feasibility study of the Polarization control of synchrotron radiation in NSRRC



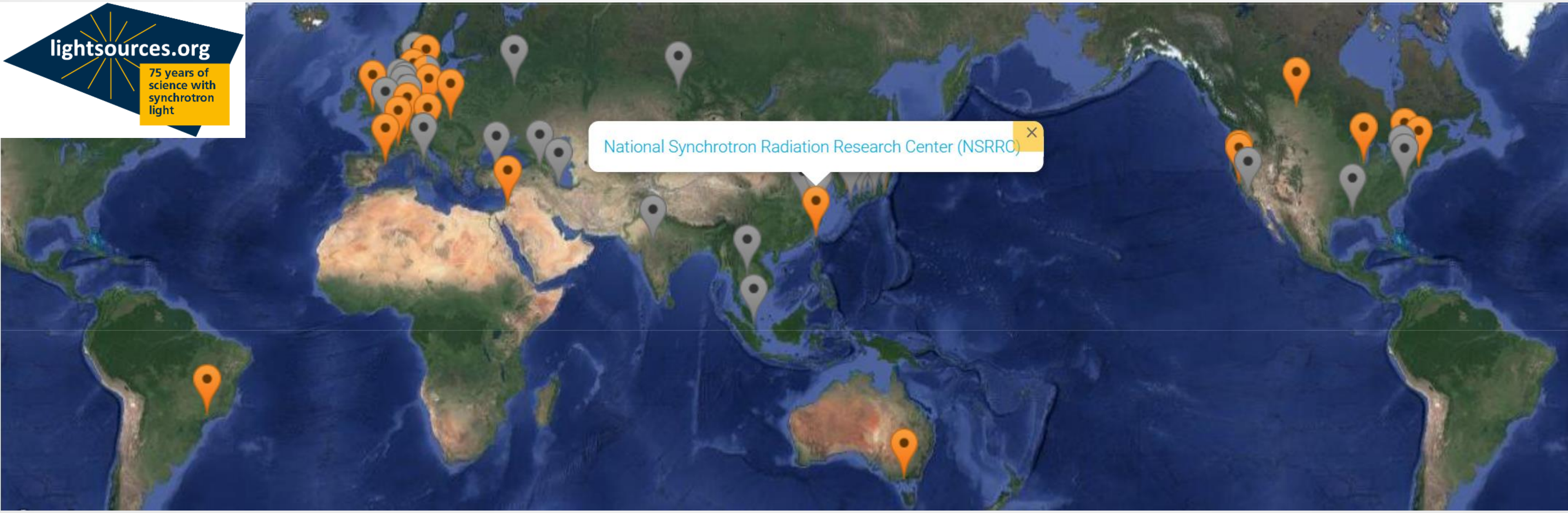
TingYi Chung (鍾廷翊)
April 13, 2023

AFAD Asian Forum for Accelerators and Detectors 2023
12-14 April 2023

Introduction_Light source

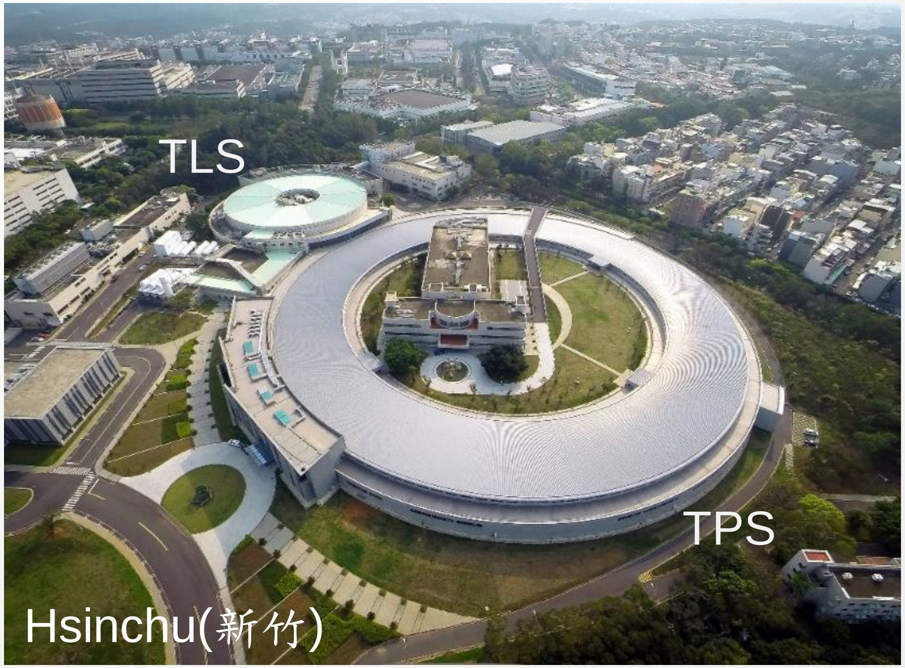
There are more than 50 light sources in the world (operational, or under construction).

- Low energy storage rings : ALS, TLS, BESSYII
- Medium energy storage rings : SOLEIL, DIAMOND, CLS, ALBA, TPS, Australian Synchrotron, NSLS II, MAX IV....
- High energy storage rings : SPring-8, ESRF(EBS), APS, PETRA III, PEP-X



Introduction_NSRRC

Light sources in NSRRC, Taiwan.



	Taiwan Light Source (TLS,台灣光源)	Taiwan Photon Source (TPS,台灣光子源)
Electron beam energy (GeV)	1.5	3
Electron beam emittance (nm·rad)	25.6	1.6
Brilliance @1keV and 10keV (Phot/s/0.1%bw/mm^2/mr^2)	~10^{18} and 10^{15}	~10^{20} and 10^{21}
Circumference (m)	120	518
Commissioning	1993	2014

Introduction_Insertion devices

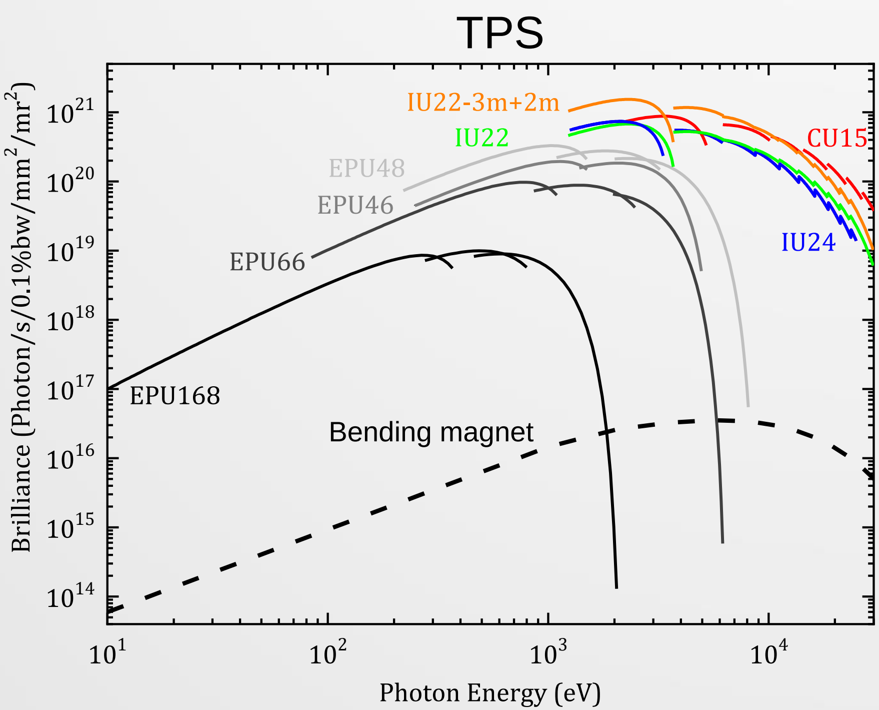
- Insertion devices (ID) play an important role in providing high *B*.

⇒ Compared to BM, ID improve *B* by about 5 orders of magnitude.

- A "*Good* " ID

⇒ Maximizing light emission efficiency, minimizing impact on accelerators.

⇒ ID technologies.



Accelerator type issues for insertion devices

	storage ring	linac / ERL	LWFA
Emittance	E^2	I/E	
Beamsize (μm)	100 (H)-10 (V)	50-10	10-3
vacuum chamber H /V aperture	flat min gap: 5 mm	round (ex : bore 5 mm), min gap : 3 mm	round
charge	high	1 nC	10 pC
Pulse duration	10 ps	100 fs	10 fs
impedance	very critical	critical	critical
field integrals	very critical	very critical	very critical
double field integrals	very critical	very critical	very critical
phase error	very critical for high harmonics operation	critical	critical
multipoles	for beam lifetime and injection efficiency	less critical	not critical

M.E. Couprie, IPAC13, May 13-17

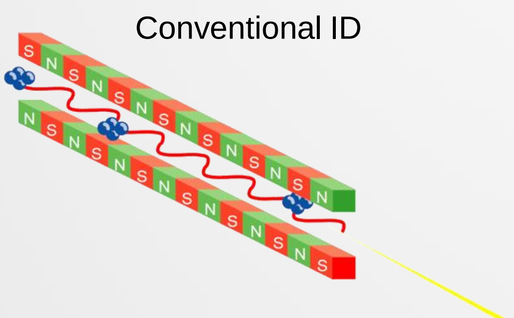
- Longitudinal instability
- Emitted point displacement and angle swing
- Reduce light intensity
- Transverse instability

Polarization control

- In addition to high B, users also need a variety of polarized light.

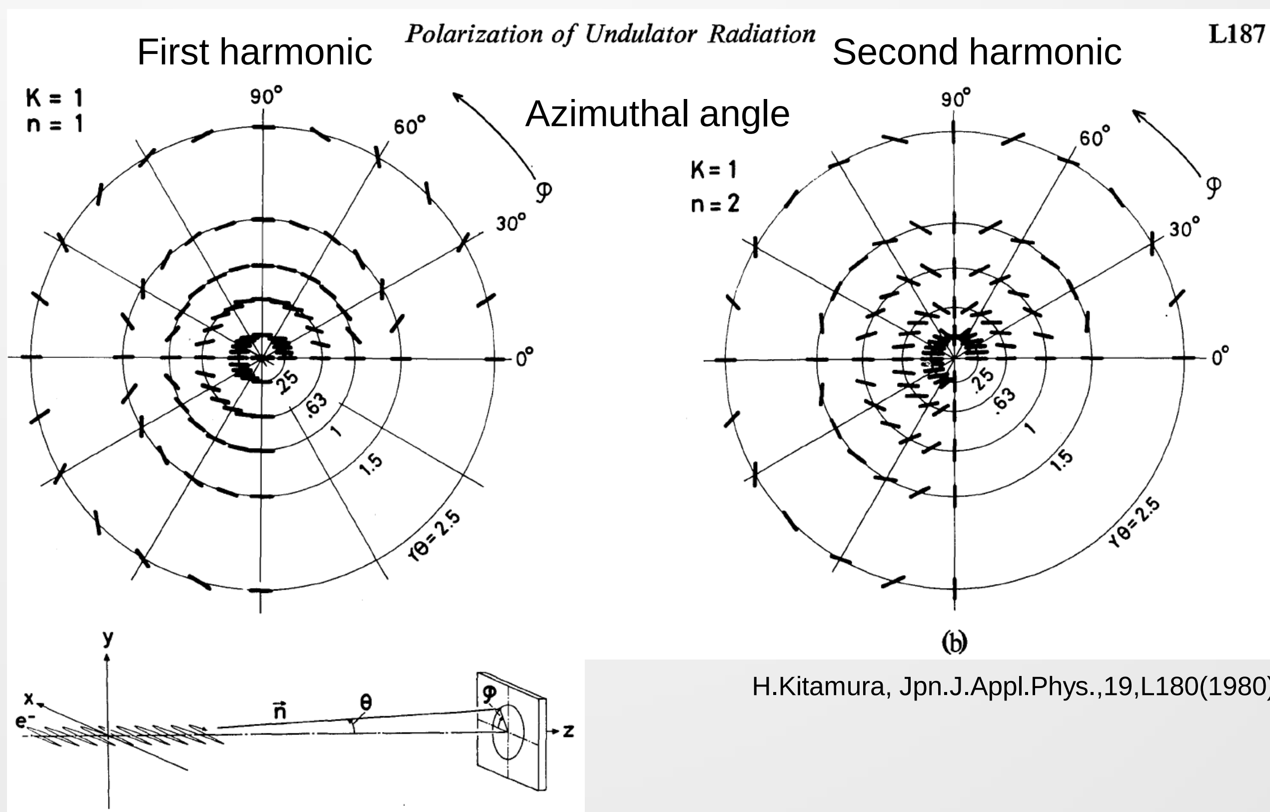
⇒ Conventional ID only provides linearly polarized light.

⇒ Pursuing right and left-handed circular, vertical linear and inclined linear polarization light.



- Two magnet arrays provide vertical magnetic field.
- Electron oscillates in the horizontal plane.

⇒ Horizontal linear polarization.

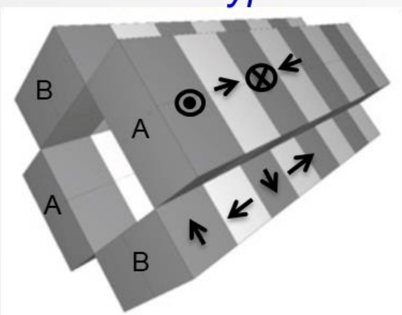


H.Kitamura, Jpn.J.Appl.Phys.,19,L180(1980)

Polarization control

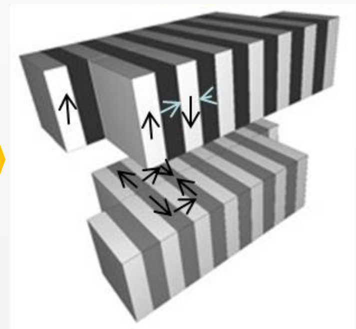
In addition to vertical magnetic fields, horizontal magnetic fields with phase differences are also required. => Elliptically Polarized undulator (EPU)

Onuki type



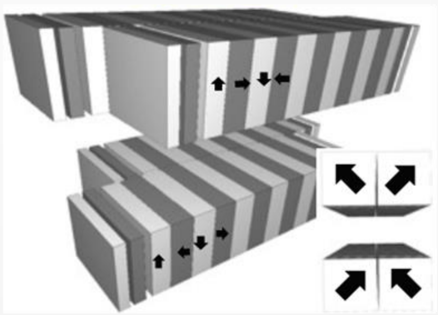
H.Onuki, Nucl. Instr. Meth., A246,94 (1986)

Helios



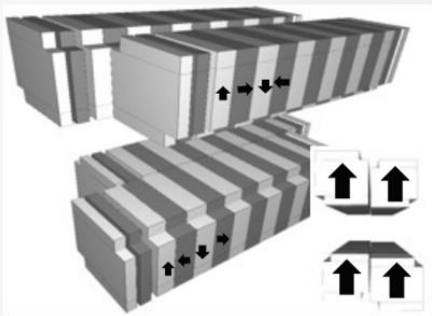
P.Elleaume, J. Synch. Rad.,1,19 (1994)

APPLE-I

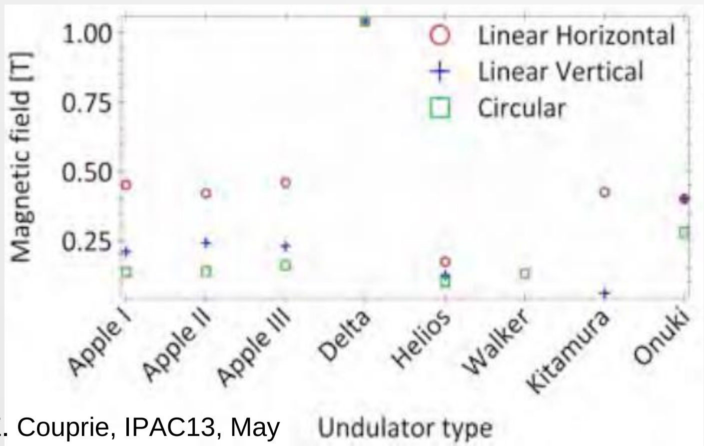


S.Sasaki et al, Jpn.J.Appl.Phys.,31,L194 (1992)

APPLE-II

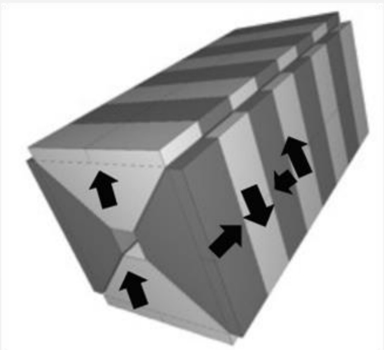


S.Sasaki et al, Nucl. Instr. Meth., A347,87 (1994)



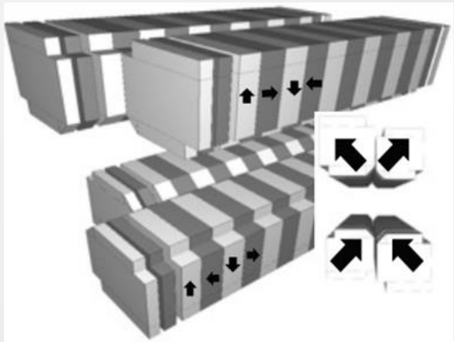
M.E. Couprie, IPAC13, May 13-17

Delta



A.B. Temnykh, P.R.S.T.A,11,120702(2008)

APPLE-III



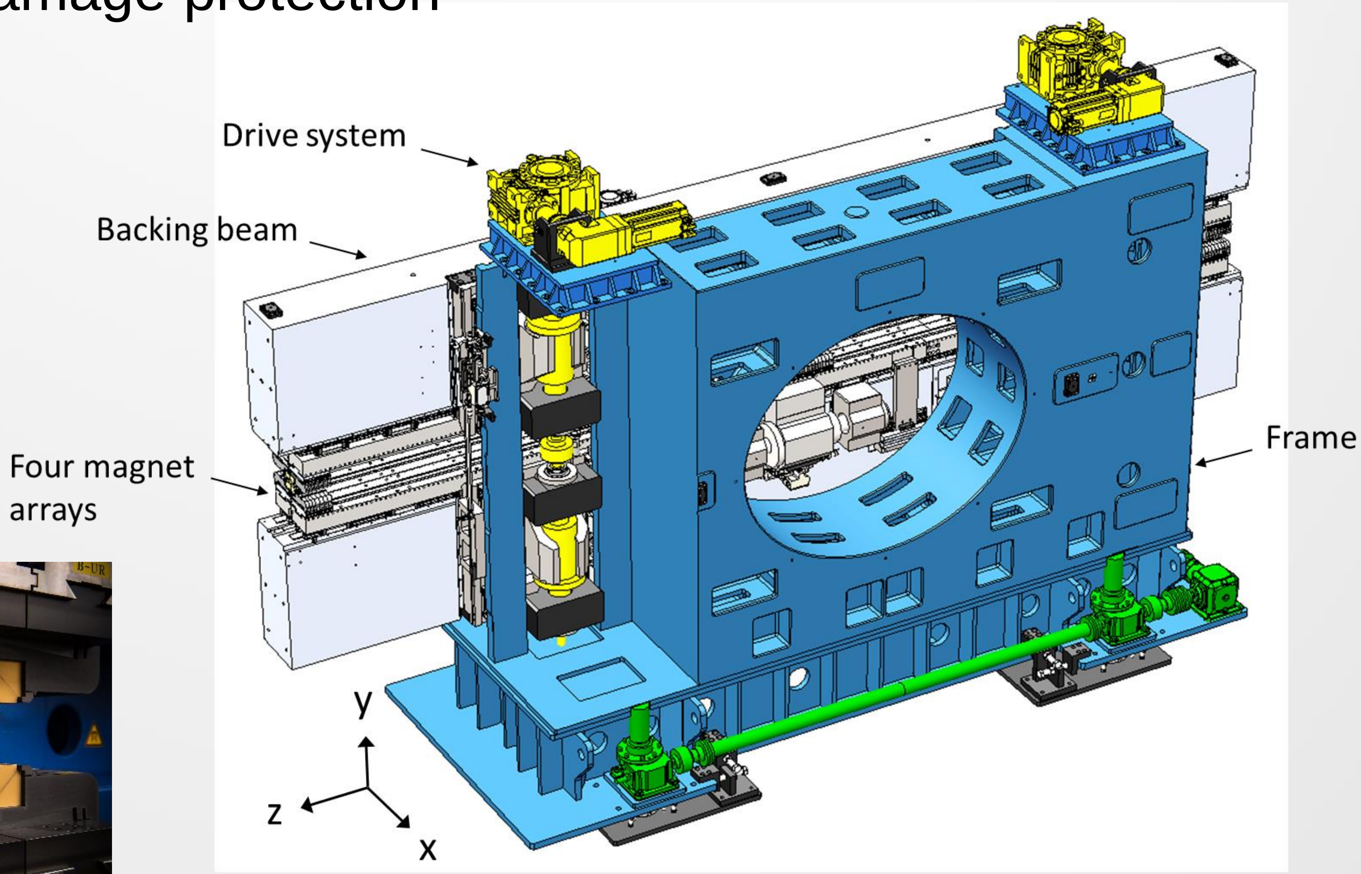
J. Bahrdt et al, 2004 FEL conference

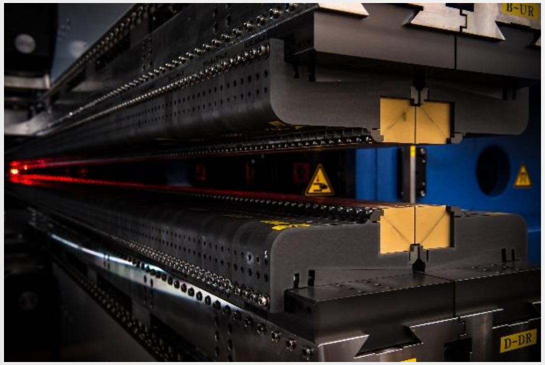
- Delta is only for round gap.
- For various polarization modes, Apple-type has a balanced performance.
- Apple-II is widely accepted, due to convenience of construction.

Construction challenges

Reduce magnetic field error to achieve *"Good"* EPU.

1. Reducing mechanical deformation
2. Compensating magnetic errors
3. Radiation damage protection

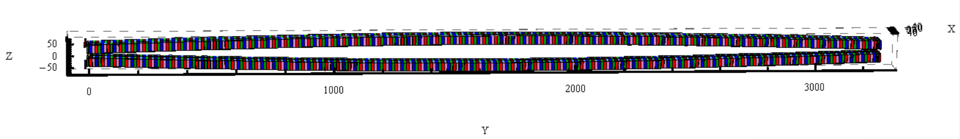


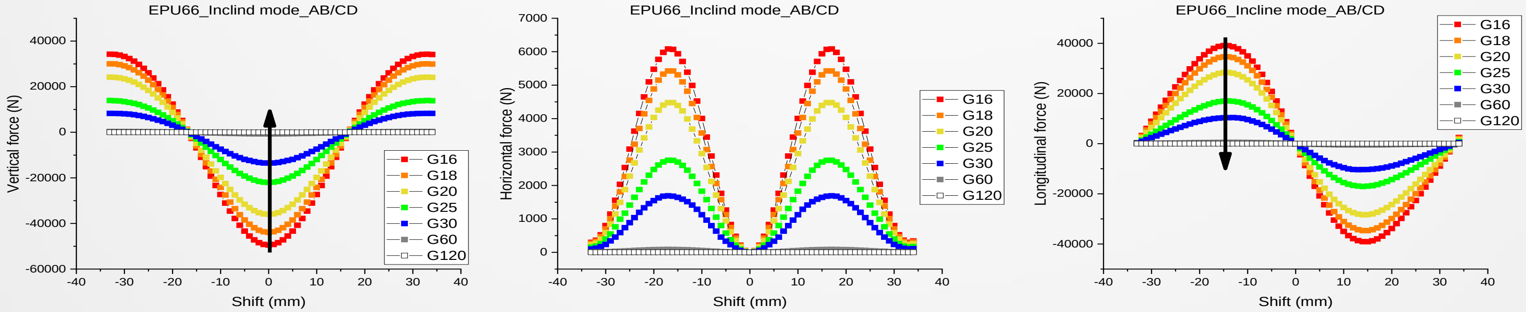


Construction challenges

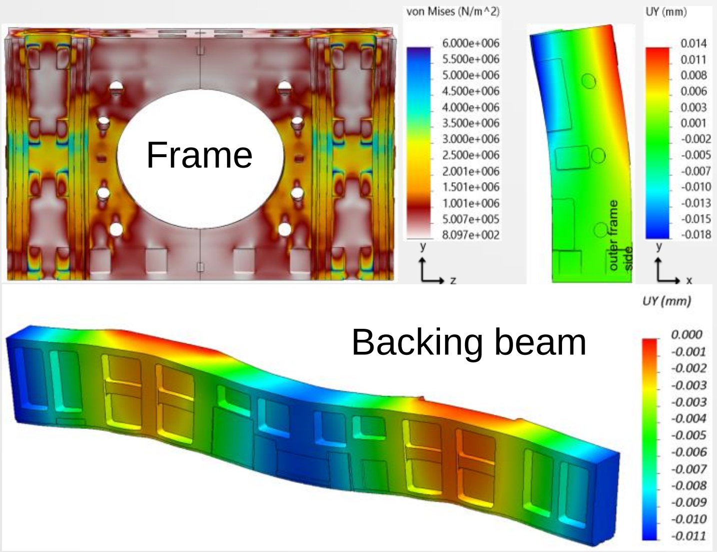
EPU suffers three dimensions of attractive or repulsive forces.

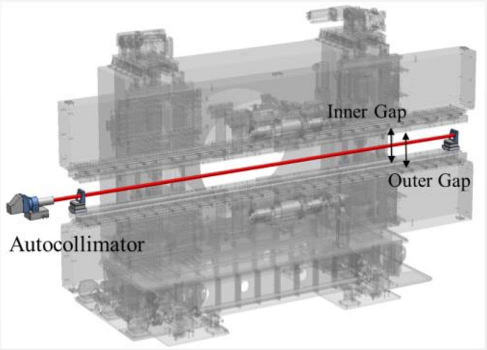
⇒ In addition to mechanical lifetime, mechanical deformation causes systematic errors in the magnetic field.

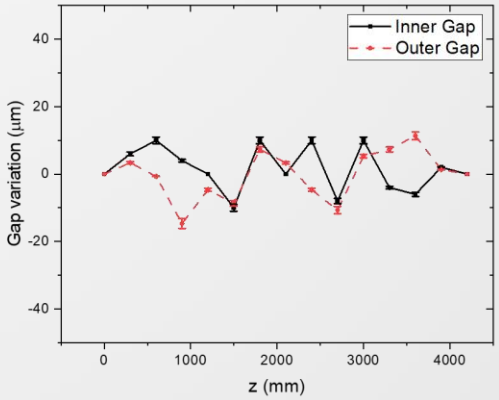




Maximum magnetic force exceeds 5 tons in TPS EPU.







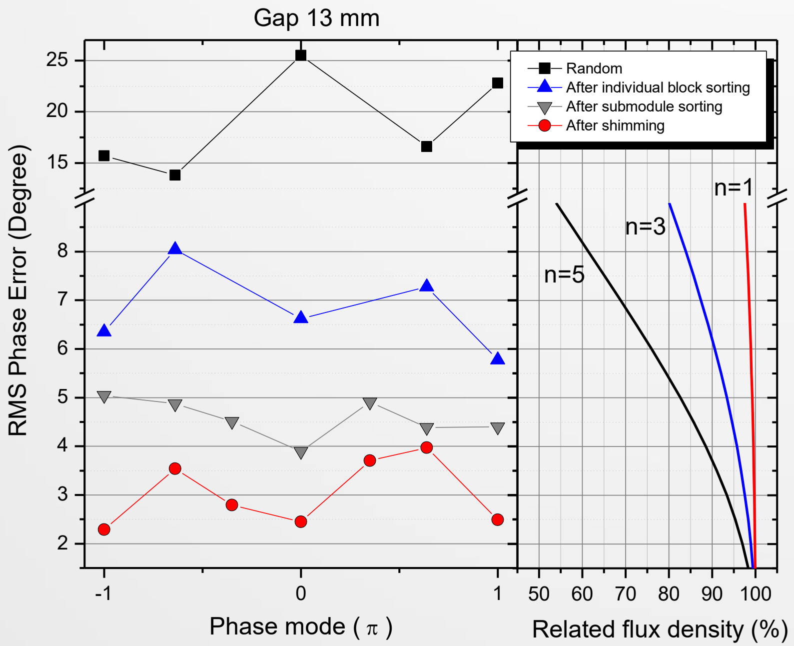
- Optimize mechanical structure: dimensions, supporting points, material..etc.
- Gap variation < 20μm.

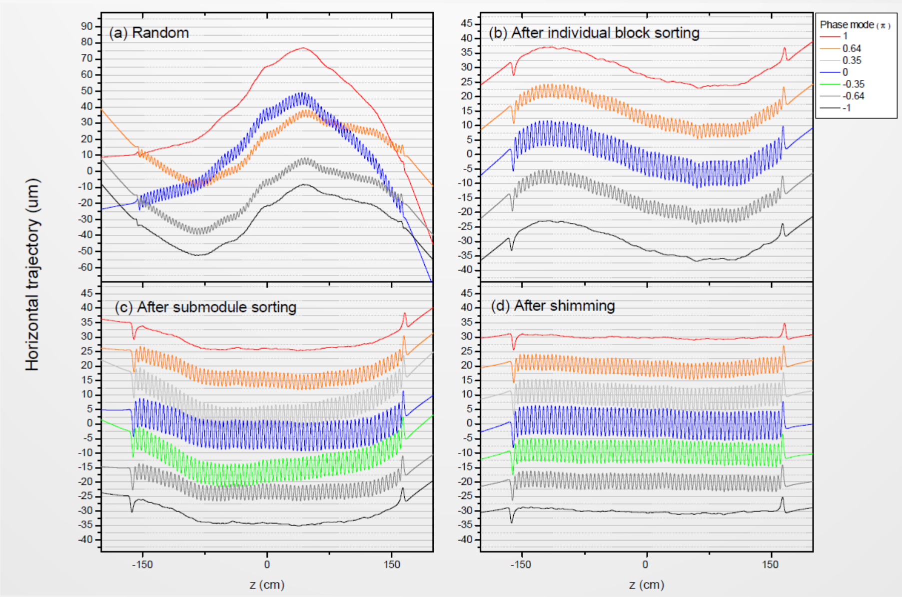
Construction challenges

EPU is composed of more than 1000 “non-identical” magnets, with errors of magnetic moments.

⇒ To reduce random error, a strategy of magnet sorting and shimming process are developed in NSRRC.

⇒ To ensure good light’s quality.



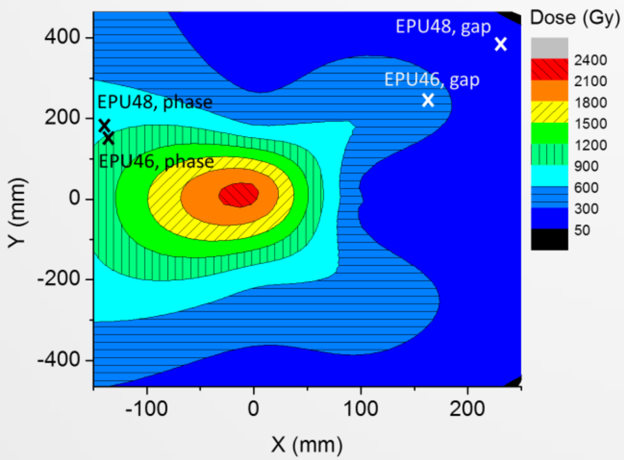


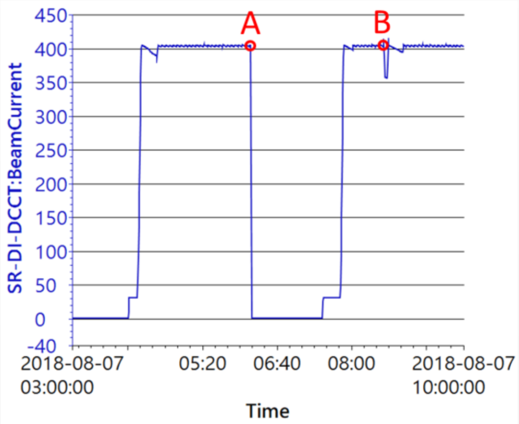
- Efficient sorting and shimming can significantly shorten the construction time.
- The flux density of high harmonics is greater than 95% of an ideal value.
- Straightness of trajectories satisfies the FEL requirement.

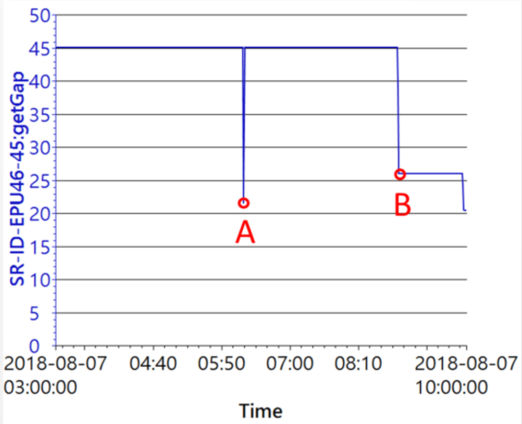
Construction challenges

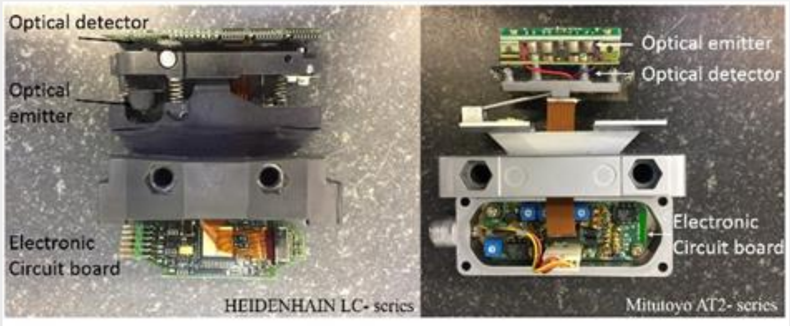
- EPU operates in radiation environment.
- A malfunction of driving system is found to follow an electron beam dump or loss.

⇒ Encoders, contain semiconductor devices, have soft errors by radiation damage.









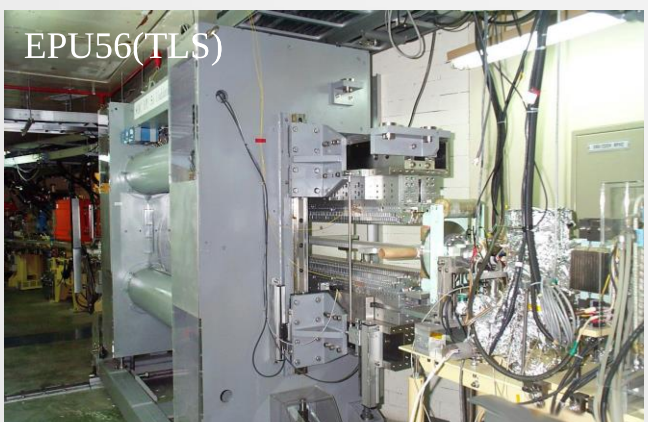
NSRRC strategies,

1. New design of drive systems to decrease the number of electronic components required.
2. Encoders are enclosed in a tenth value layer required for gamma rays.
3. Encoders are distant from electron beam.

APPLE-II type EPUs at NSRRC

After years of research and development, NSRRC has many experiences in building “Good ” EPUs.

	Year	Beam line	ID	Contents	Remarks
TLS	1999	5	EPU56	λ_u = 56mm, G_{min} = 20mm, L = 3.9m	The longest EPU in the world, at that time.
TPS	2015	45	EPU46	λ_u = 46mm, G_{min} = 14mm, L = 3.8m	Refurbished by NSRRC
	2015	41	EPU48A	λ_u = 48mm, G_{min} = 13mm, L = 3.4m	Double EPUs for a long straight section
	2015	41	EPU48B		
	2020	27	EPU66	λ_u = 66mm, G_{min} = 16mm, L = 4.4m	Flat wire installed within a gap
	2020	39	EPU168	λ_u = 168mm, G_{min} = 27.2mm, L = 4.4m	Flat wire installed, for EUV beamline
	2021 (under construction)	43	EPU56	λ_u = 56mm, G_{min} = 16mm, L = 4.4m	Flat wire installed within a gap
		33	EPUT66	λ_u = 66mm, G_{min} = 16mm, L = 2.6m	Dual taper EPU
		35	EPU66	λ_u = 66mm, G_{min} = 16mm, L = 0.8m	Installed in the RF cavity downstream



World Accelerator Development

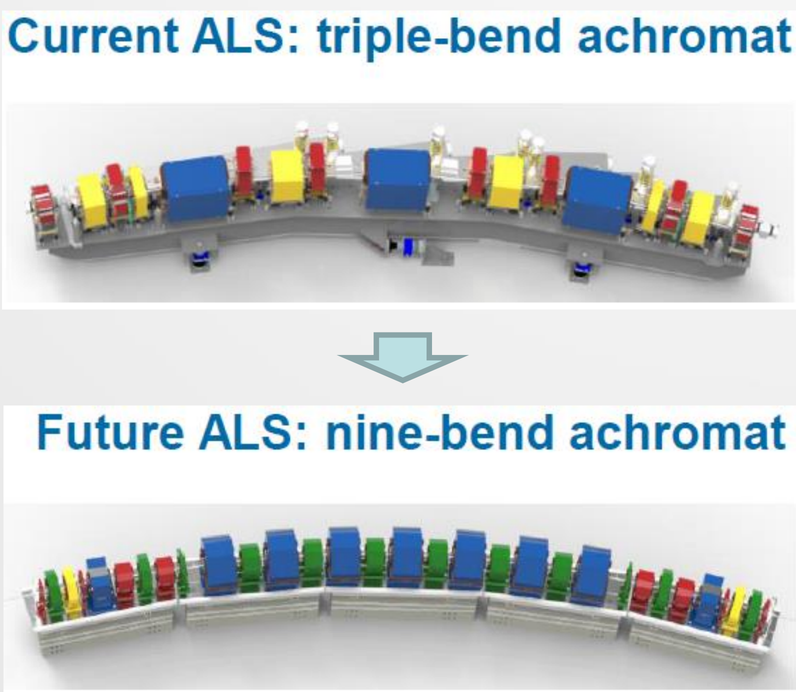
To improve brightness and coherence, the emittance of an electron beam is reduced by multibend achromat (MBA) lattice design.

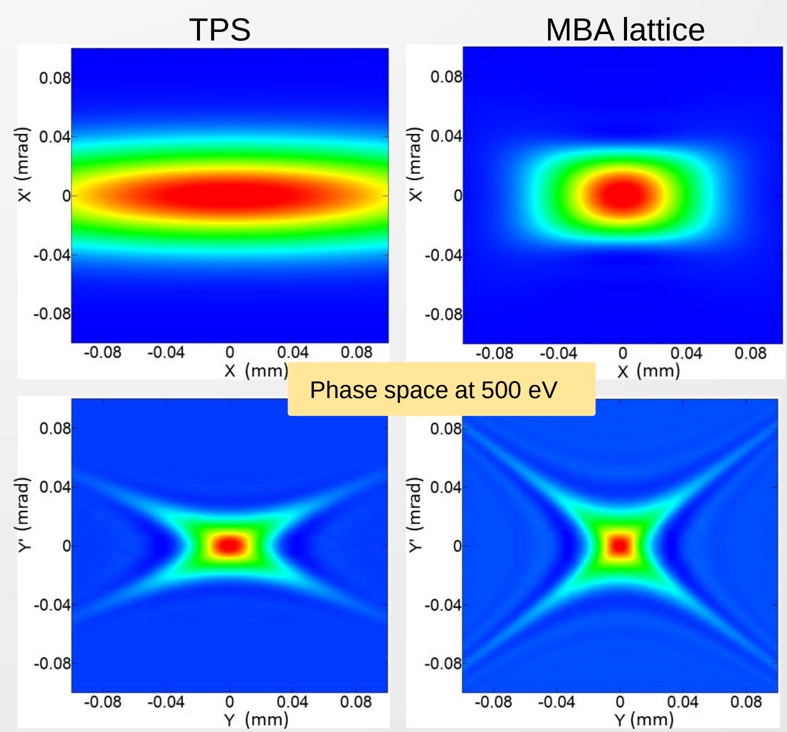
- The number of magnets increases, resulting in a reduction in the space available for ID.

⇒ Problem of reduced photon flux.

- The emittance reduces especially in the horizontal direction.

⇒ Magnets can approach the electron beam more closely to remedy the disadvantages of ID shortening.



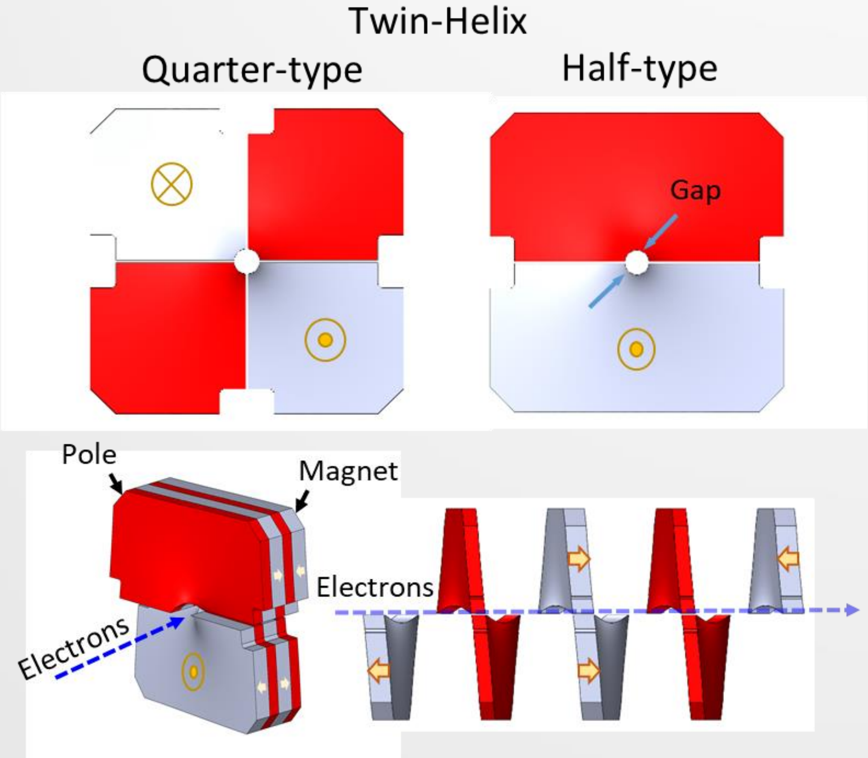


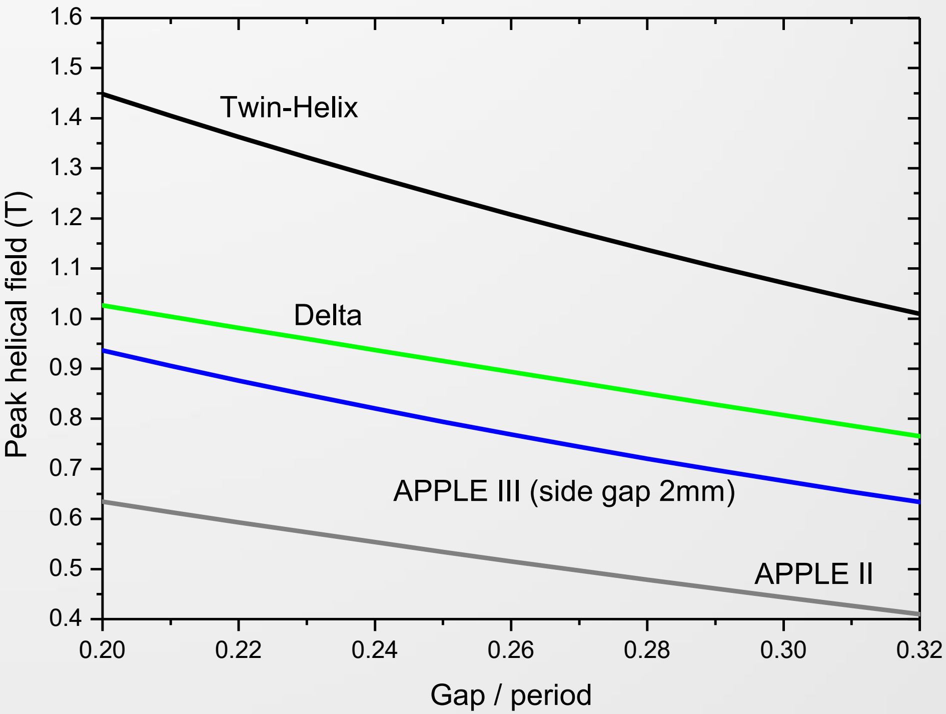
Short period EPU

Twin Helix Undulator

- Round gap undulator.
- Helically, instead of flat, shaped poles and magnets.

⇒ Thanks to the hybrid design and helical structure, the THU generates the highest helical fields and the largest good field region.





Short period EPU

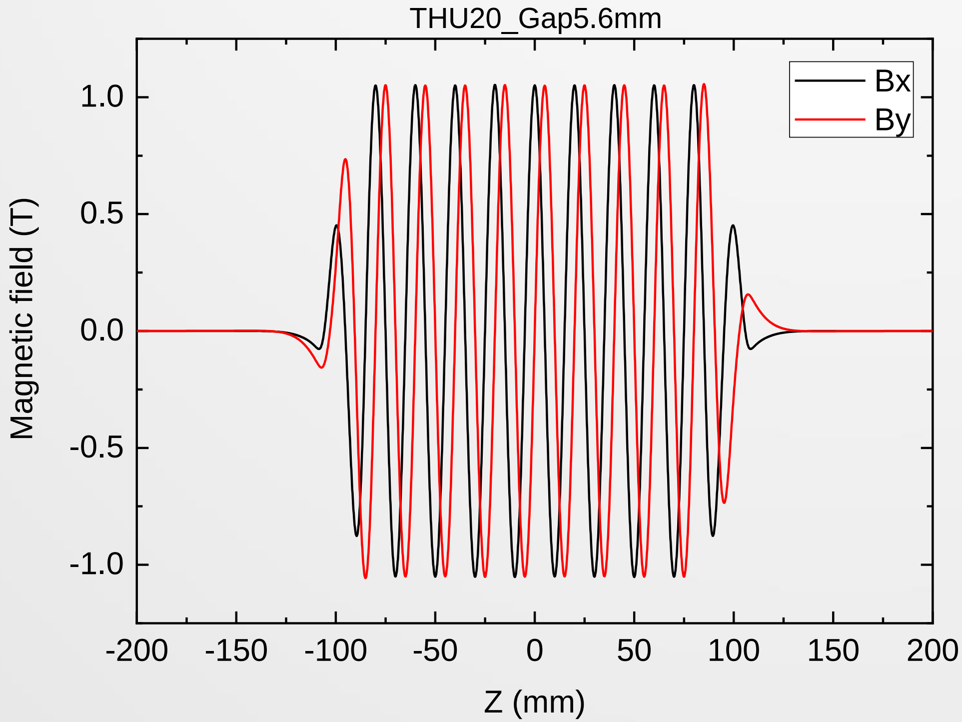
Twin Helix Undulator

- THU provides the strongest helical field with the shortest period.

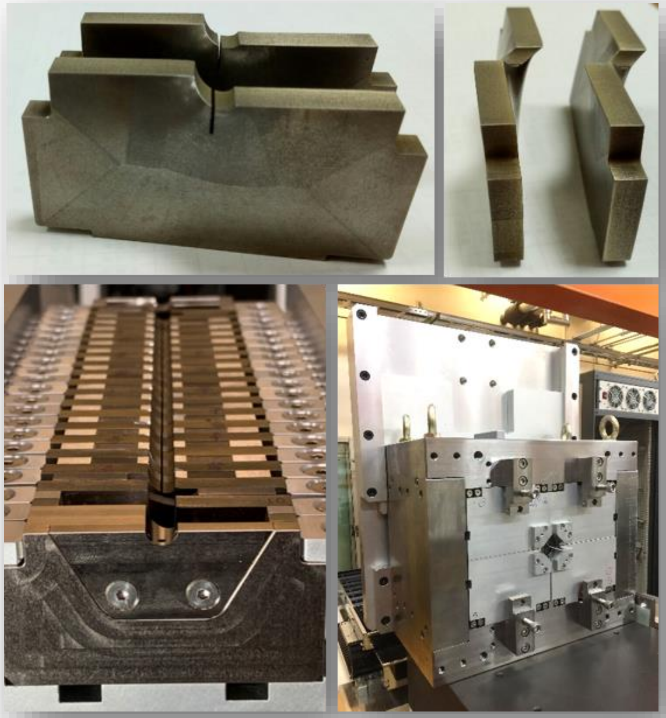
⇒ Technical challenges to overcome, such as machining and mounting of magnet surfaces and shimming.

- Only circular polarization.

⇒ THU is suitable where only a circular polarization is required, such as modulators in FEL.



Prototype THU

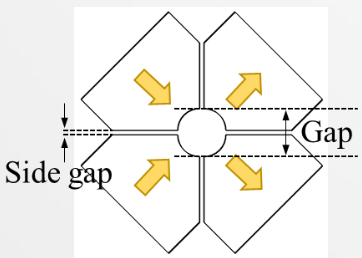


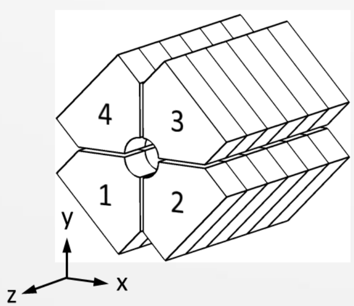
Short period EPU

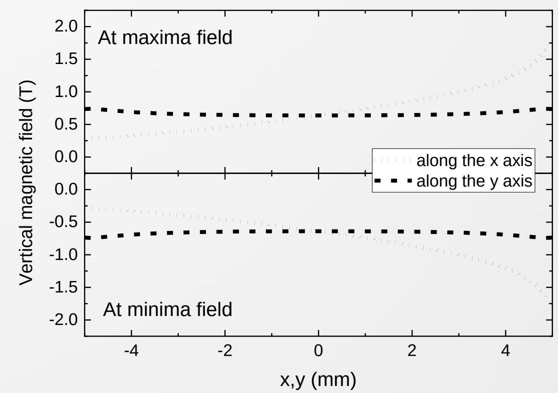
Delta undulaor

- Various polarizations.
- Round gap undulator.
- A compact design. To change the magnetic field is to adjust the phase instead of the gap.

⇒ An obvious transverse field gradient (TFG) ~ 100T/m, 5 times larger than normal lattice quadrupole magnets.







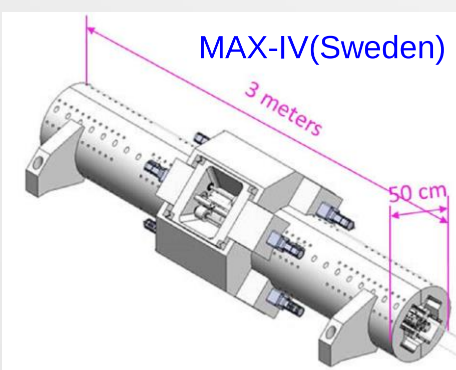


Figure 3: Schematic view of compact APPLE X undulator.

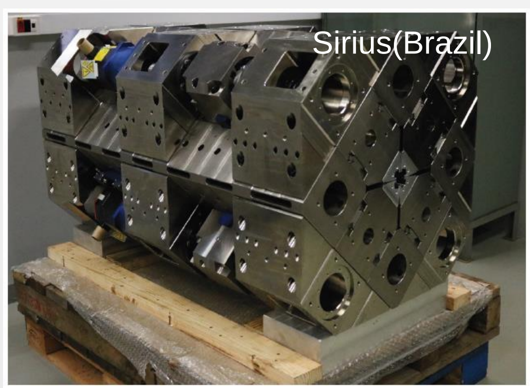
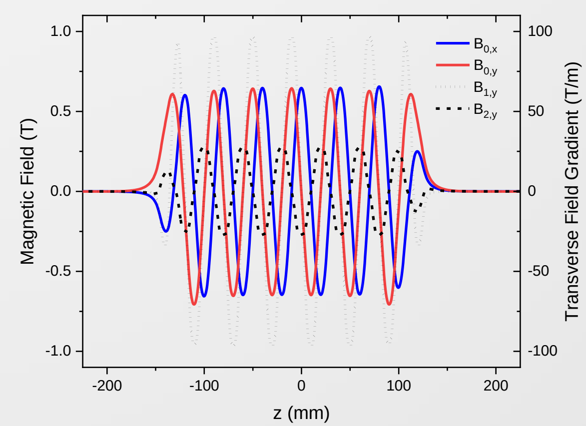


Figure 6: Delta undulator prototype.



Short period EPU

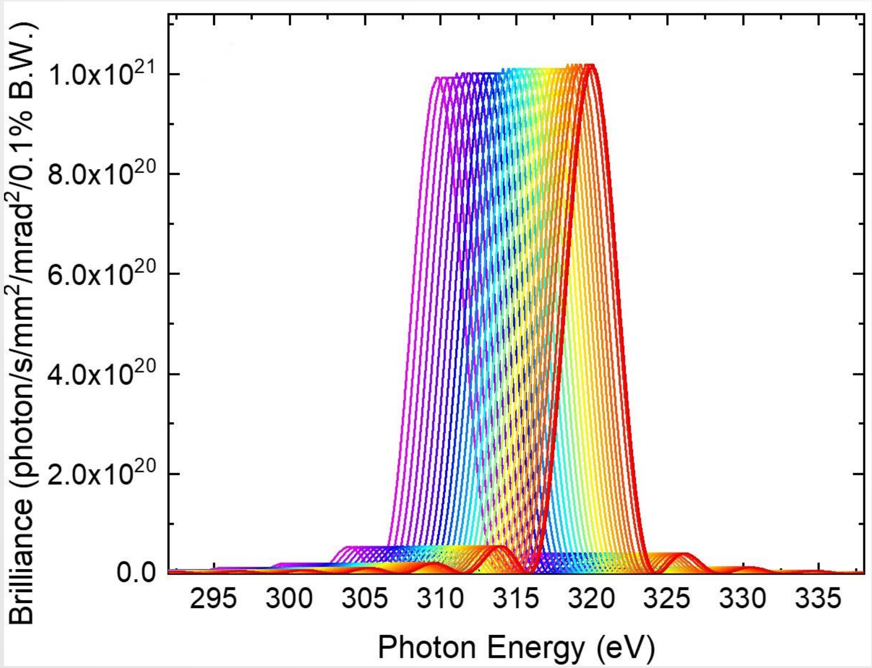
Delta undulaor

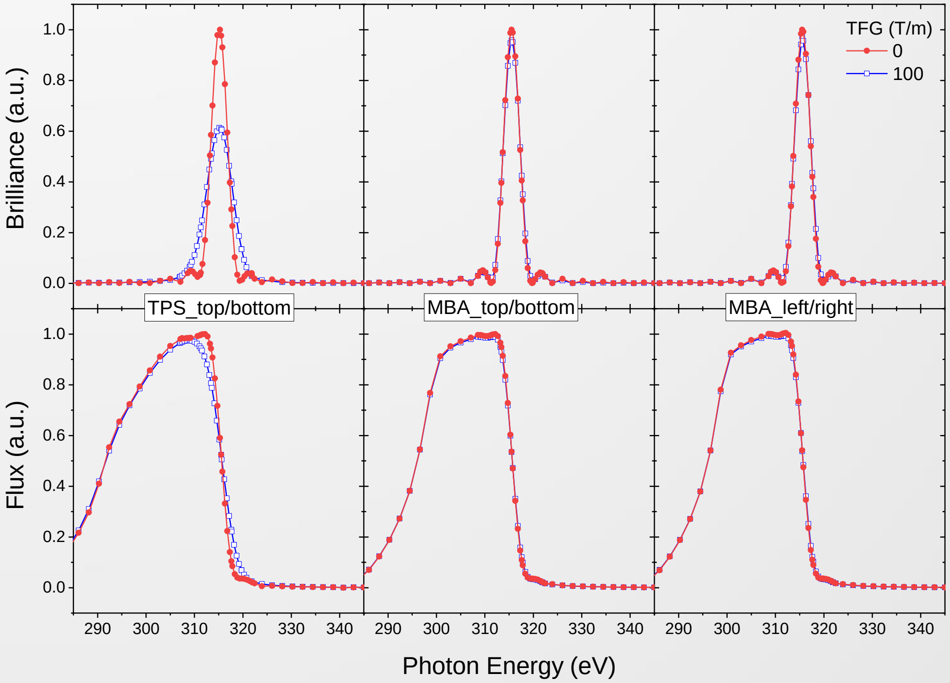
- TFG causes finite emittance electrons suffer different magnetic fields.

$\Rightarrow$ Resonant energy shifts, bandwidth broadening.

$\Rightarrow$ For the large emittance, the brightness will be significantly reduced; however, for the small emittance such as in the case of MBA lattice, the spectrum effect is not significant.

$\Rightarrow$ The emittance ~ 100 pm·rad, the effect of TFG ~ 100T/m on spectrum is minor.





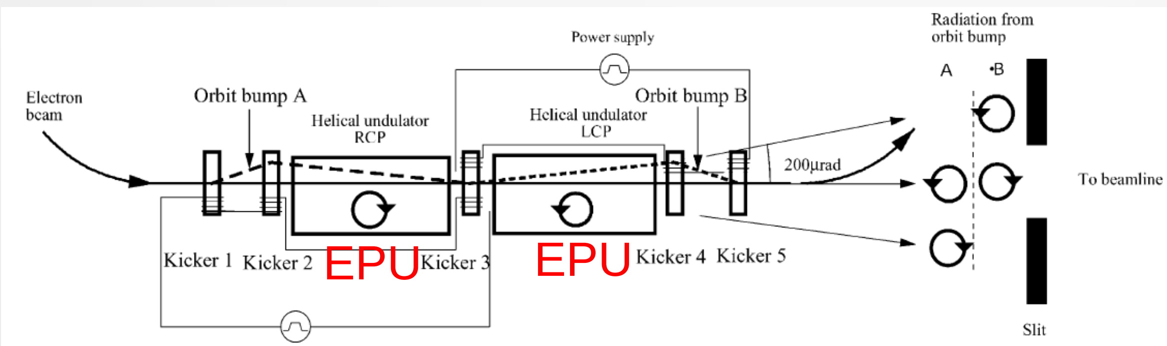
Fast Switching Polarization

- Unique requirements
- Two schemes are implemented. Both require the installation of two different polarized EPUs, and only one can be used each time.

$\Rightarrow$ Efficiency of space usage is less than 50%.

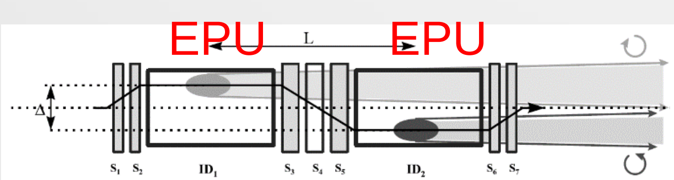
$\Rightarrow$ New ideas are needed, especially in the space limited case, such as MBA.

Spring8 (Japan)



- Fast change electron orbit; aperture fix.
- Two EPUs with different polarizations.

Swiss light source



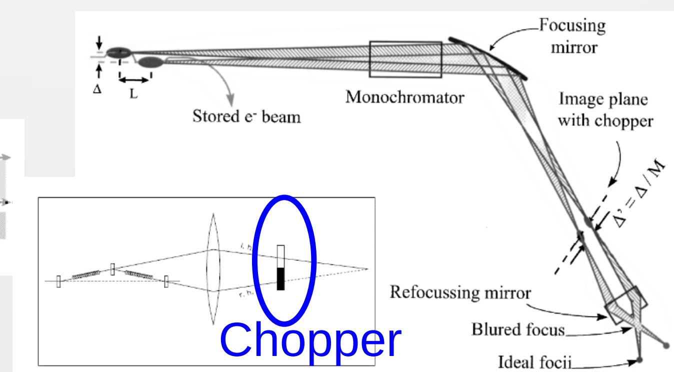


Fig. 1. Sketch of the operating principle used for rapid helicity switching in top view.

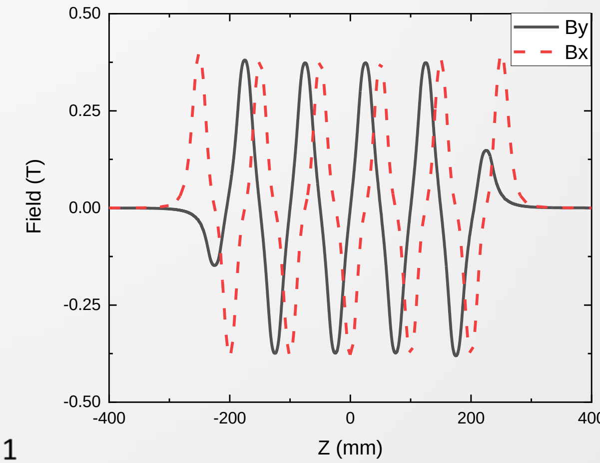
- Electron orbit fix; switching chopper.
- Two EPUs with different polarizations.

Fast Switching Polarization

electromagnet and permanent magnet

- Exotic concept, an undulator is composed of an electromagnet (EM) and a permanent magnet (PM). EM provides By; PM generates Bx.
- Polarization switching using the rapid change of polarity of excitation currents in the EM; Bx is adjusted on altering horizontal gaps of PM.

⇒ The preliminary design of the magnet can provide the minimum energy to fulfill the EUV region. (Constructing and verifying)



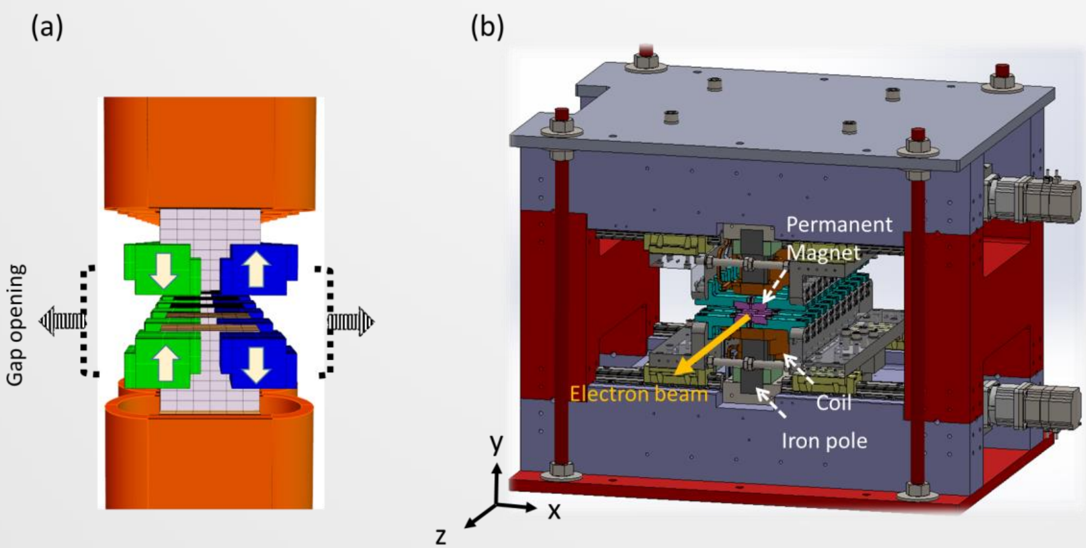


Table 1

Physical length	0.55	m
Period length	100	mm
Vertical gap	15	mm
Max. Hori./Vert. magnetic field	0.37	T
Spe. Max current	300	A
Spe. Min/Max horizontal gap	5/120	mm
Permanent magnet (Br)	1.24	T

Conclusions

- The development of insertion devices dramatically improves the brightness of the synchrotron radiation source.
- Various polarized light requirements can be fulfilled by the development of Elliptically polarized undulator (EPU).
- NSRRC is not only working on the development of APPLE-II but also researching new types of EPUs to meet upcoming MBA lattice.
- A short period EPU and an EPU that allows for fast polarity switching are the directions that NSRRC is pursuing.

Thank you so much for your attention.