Current Status of PAL-XFEL Project

15 May 2013

Heung-Sik Kang
On behalf of PAL-XFEL Project Team

Korean 4-th generation Light Source: PAL-XFEL

0.1-nm Hard X-ray 10-GeV XFEL

- **Project Period: 2011 ~ 2015**
- **Total Budget: 400 M$**
- **Accelerator Length: 1.1 km**

◆ **Wavelength**

- **Soft x-ray: 10 nm ~ 1 nm**
- **Hard X-ray: 1.0 ~ 0.1 nm**
  - **Extendable to 0.06 nm**

◆ **Undulator Beamline**

: 3 Hard X-ray / 2 Soft X-ray lines

Building		
Linac Hall		780
	1. Assembly	10
	2. Linac	710
	3. BTL	60
Undulator Hall		250
XFEL Beamline		80
	1. Front-end	20
	2. Experiment hall	60
Total Length [m]		1110

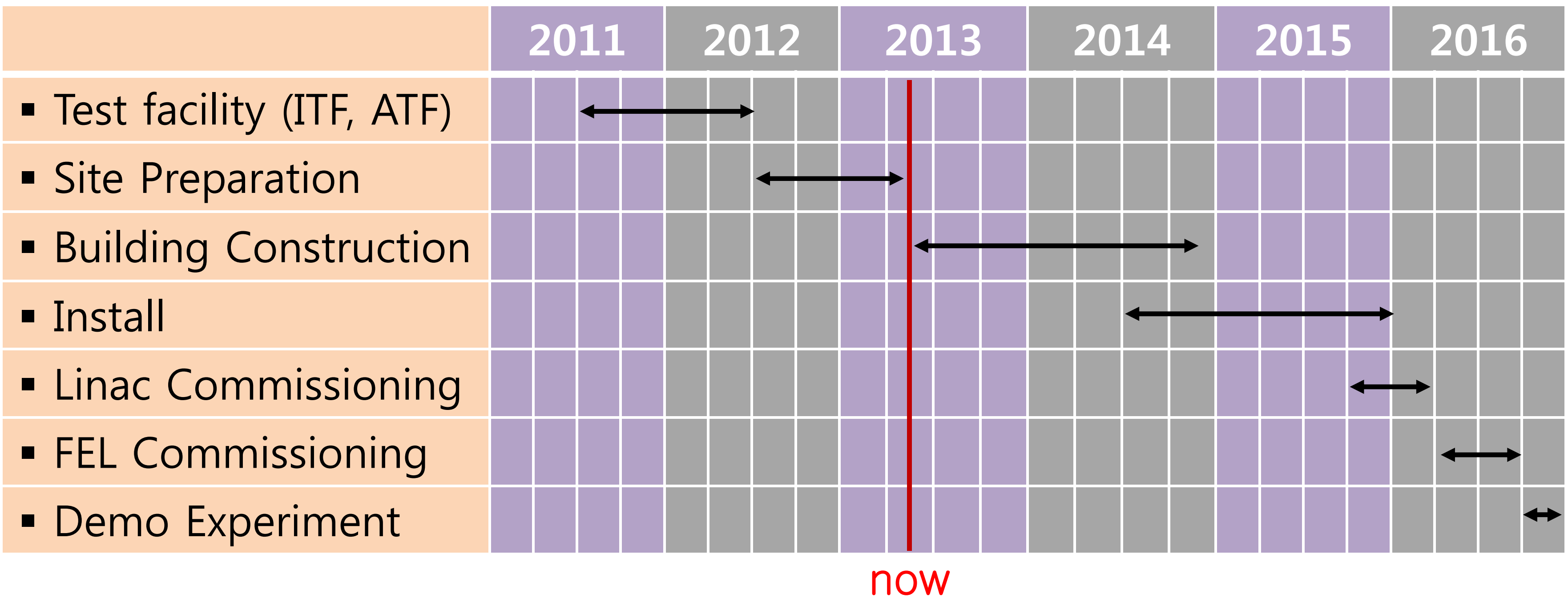
PAL-XFEL Site as of May 2, 2013

Status of PAL-XFEL project as of May 9

- **Building and Infra-structure**
  - Site preparation work was finished in early May 2013.
  - Building construction has started and will be completed by November 2014

- **Accelerator system**
  - Sub-system development is finished or underway
  - Ordering contract of major sub-system will be completed by September 2013.
  - New concept is being studied to be implemented into the Baseline : self-seeding and ISASE

Project Schedule



Building Construction Ceremony on 9 May 2013

Building Construction Ceremony on 9 May 2013

Microbunching Instability Workshop at Pohang on May 8-10, 2013

Parameters of PAL XFEL

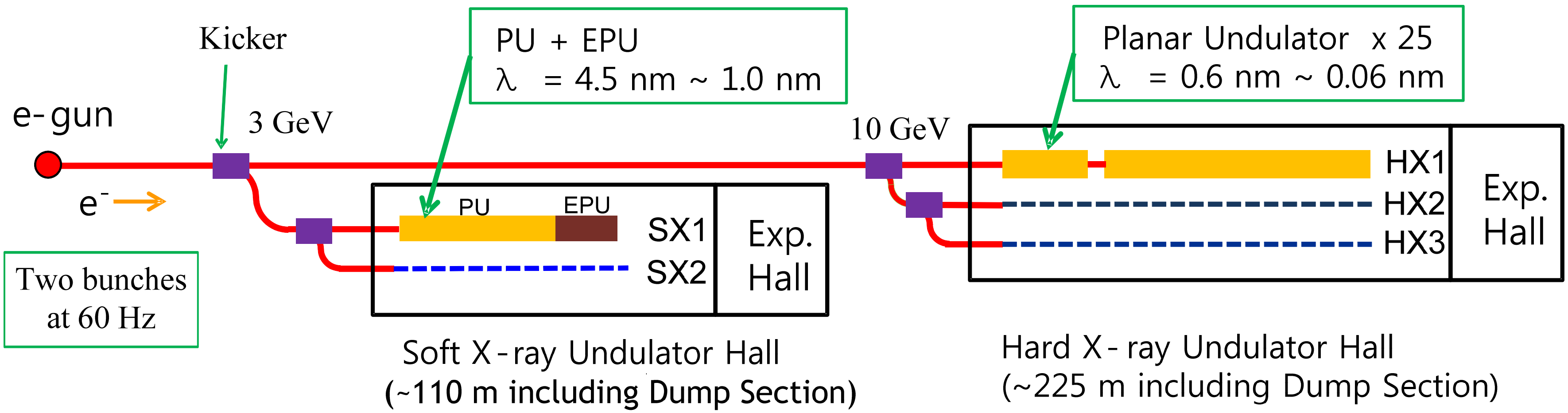
- Machine Parameters
  - 10 GeV S-band linac / 0.2 nC / 0.4 mm-mrad / 60 Hz
  - Bunch current: > 3 kA at undulator
  - Photo-cathode RF-gun
  - Variable gap out-vacuum undulator: 5 m long and 7.2 mm min. gap
  - Aim to provide photon flux over 1 x 10+12 photons/pulse @ 0.1 nm

    = 30 GW with 60 fs (15 GW from Ming-Xie formula)

    = 60 GW with 30 fs ➔ achieved by Self-seeding or ISASE

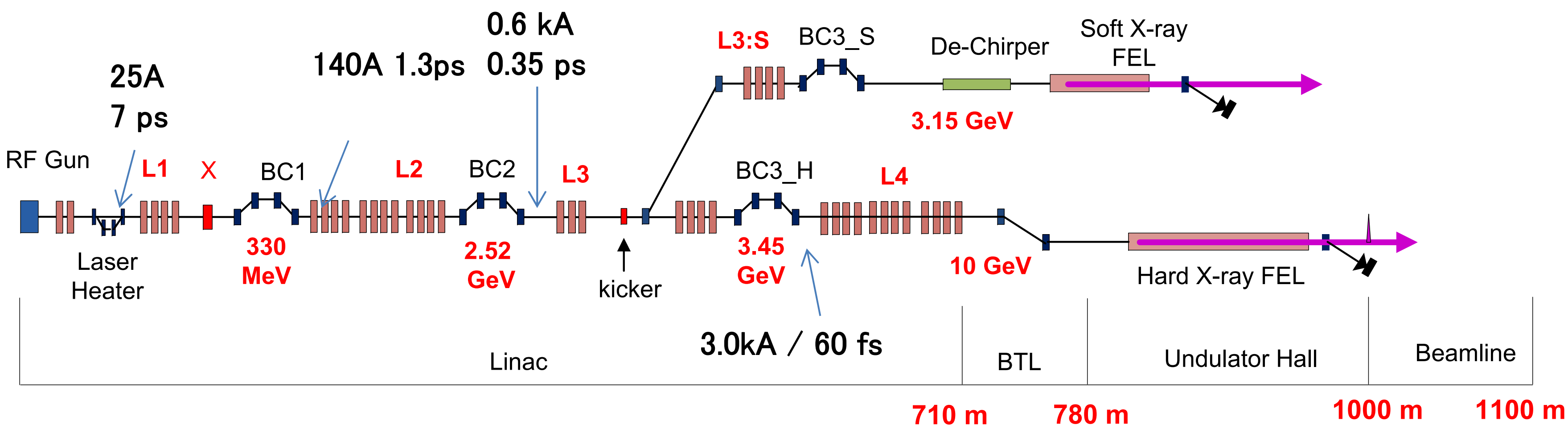
- Features
  - Three bunch compressor lattice
  - Dechirper system using corrugated structure at the soft x-ray FEL line

Two Undulator Lines for Phase 1



Undulator Line	HX1	SX1
Wavelength [nm]	**0.06 ~ 0.6**	**1 ~ 4.5**
Beam Energy [GeV]	**4 ~ 10**	**3.15 (2.55)**
Wavelength Tuning	**0.1 ~ 0.06 (Undulator Gap) 0.6 ~ 0.1 (Beam Energy)**	**3 ~ 1 (Undulator gap) 4.5 ~ 3 (Beam Energy)**
Undulator Type	**Planar**	**Planar + APPLE II**
Undulator Period [cm]	**2.44**	**3.4**
Undulator Gap [mm]	**7.2**	**8.3**

Three-Bunch Compressor Lattice



- 3-BC lattice
  - **Very flexible in control of bunch current and bunch length by changing the BC3 bend angle of each X-ray FEL Line.**

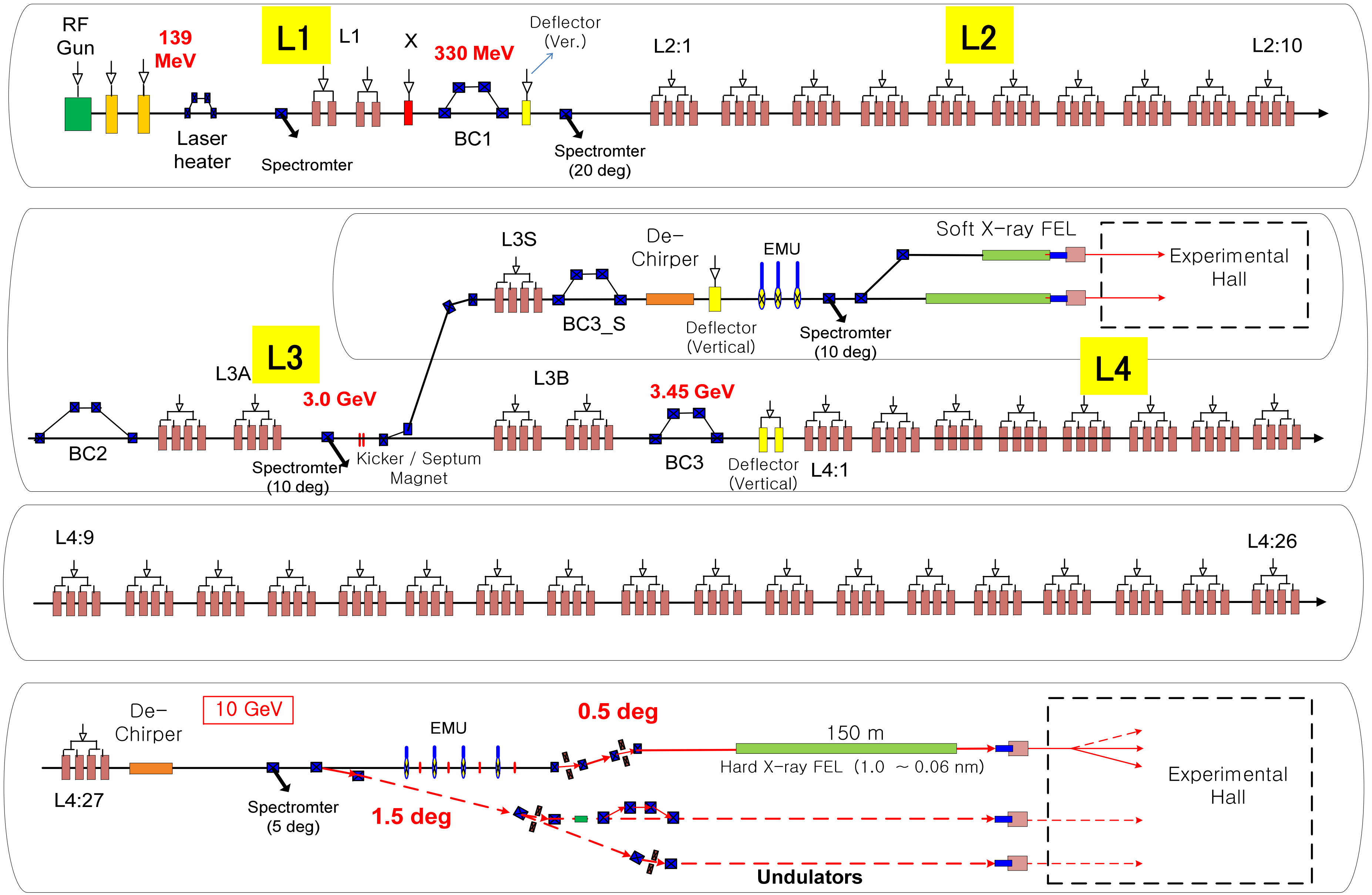
    * Photon beam length for 0.2 nC : 30 ~ 90 fs for hard X-ray

    60 ~ 180 fs for soft X-ray
  - Simultaneous and independent operation for Soft X-ray FEL beamline
  - A dogleg to soft XFEL line is simple and no need to care about instability because of low beam current (600 A)

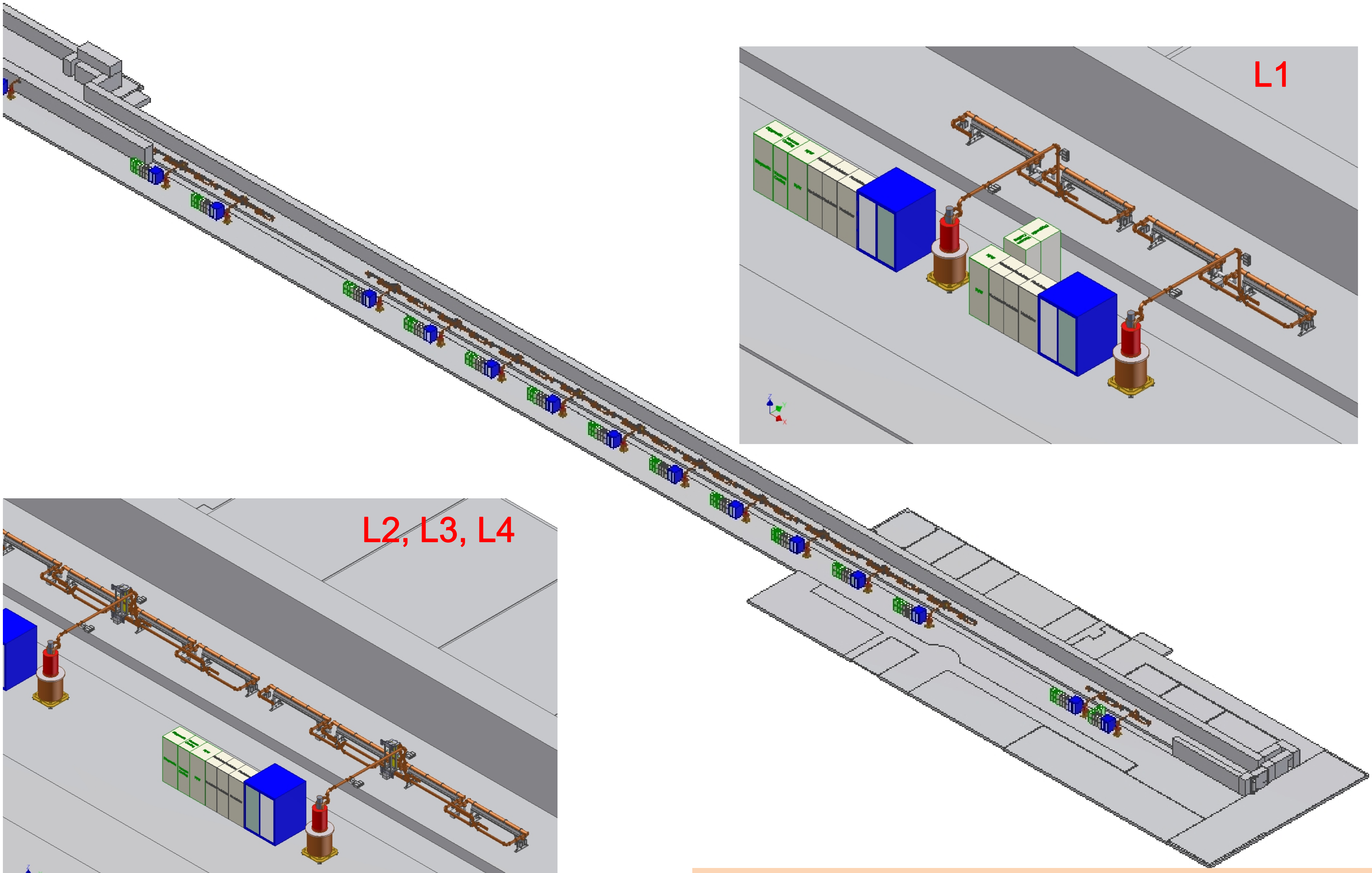
- Switching to Soft X-ray FEL line
  - **Slow kicker** for **pulse by pulse switching** for single bunch operation
  - **Fast kicker** for **Bunch-by-bunch switching for two bunch operation** (50 ns separation)

    First bunch → Hard X-ray, Second Bunch → Soft X-ray

PAL-XFEL Layout

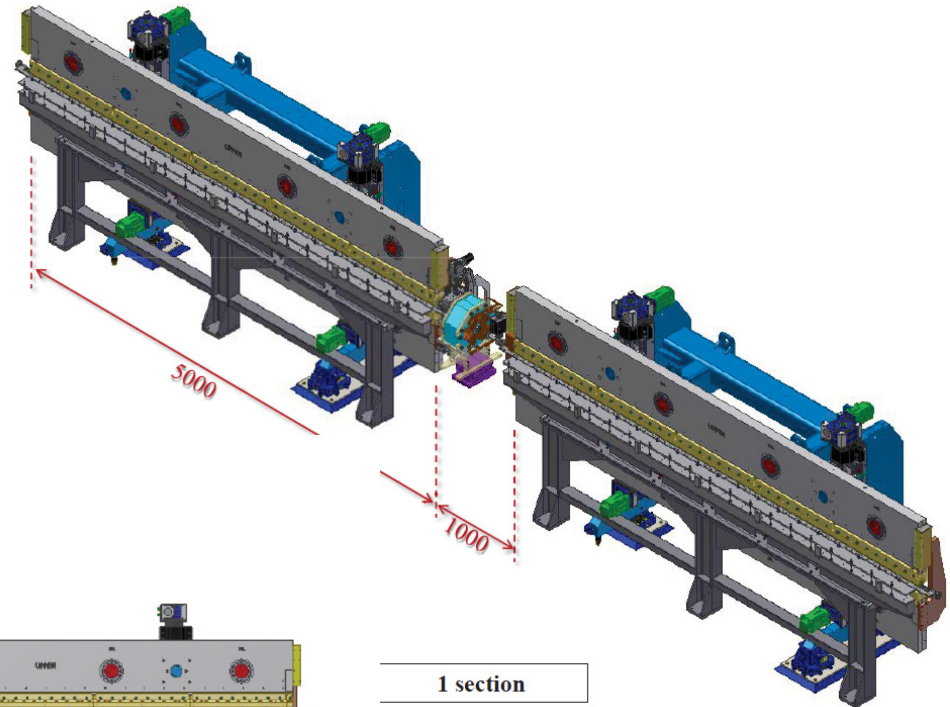


3-D model of Linac

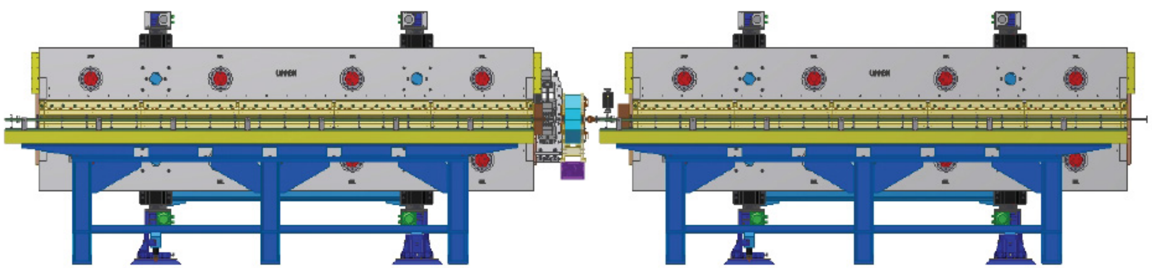


WEPFI045: PAL-XFEL Accelerating Structures

Undulator



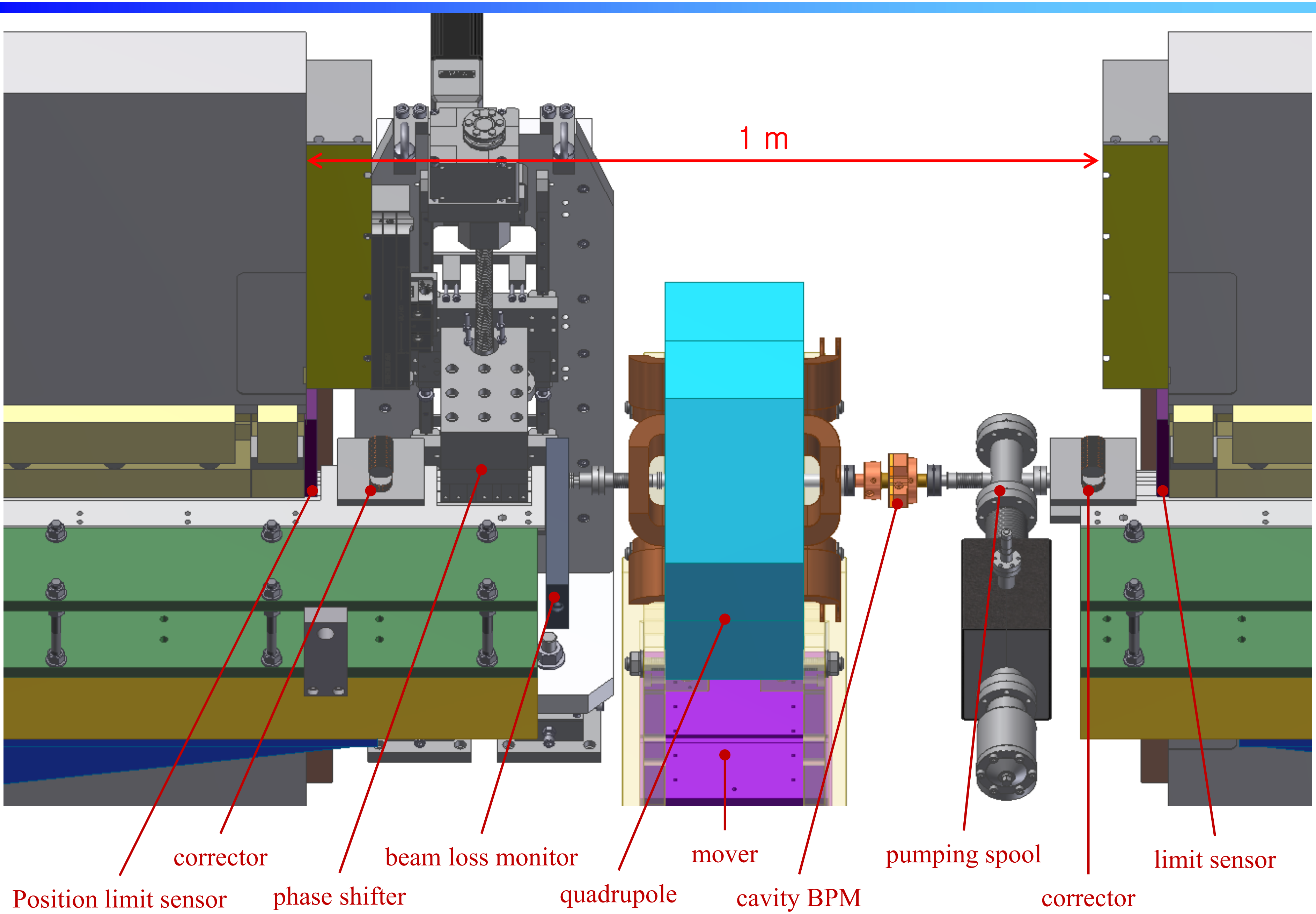
Undulator 구간 상세도



1 section

- EU-XFEL undulator design
- 5-m long
- A space for 24 undulators

Undulator intersection

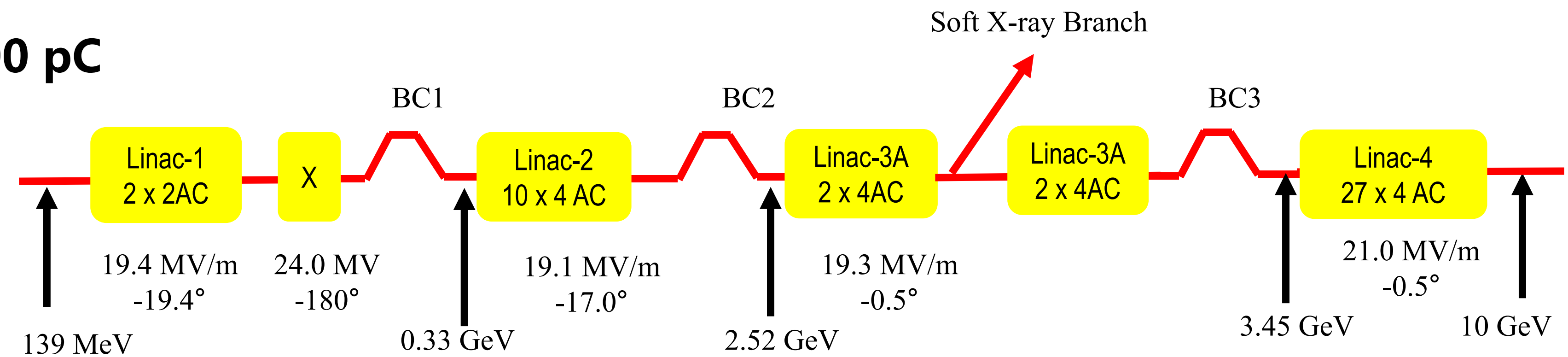


Development of Sub-system

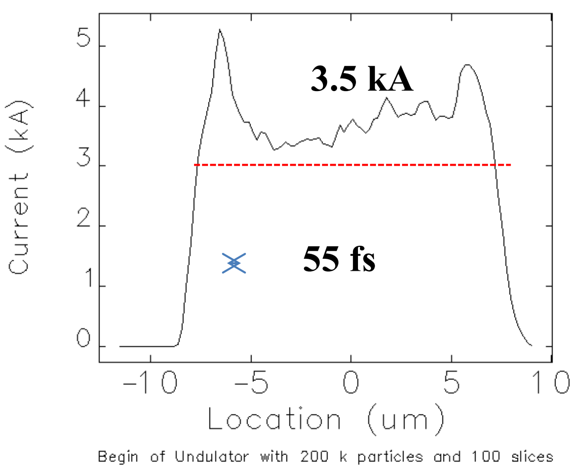
Klystron modulator
Undulator and phaseshifter
Undulator chamber
Injector Test Facility

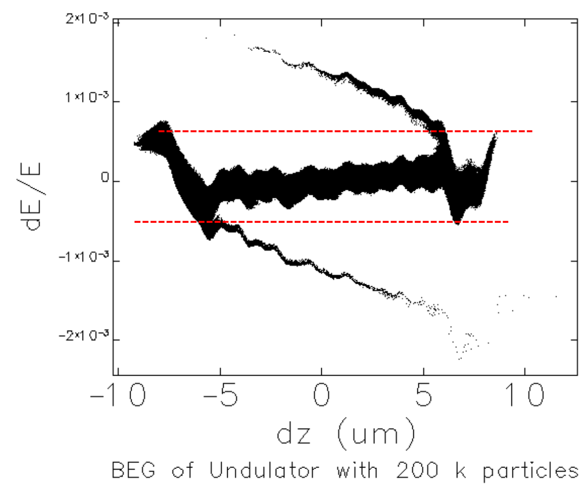
Start-to-End Simulation for Hard X-ray Line

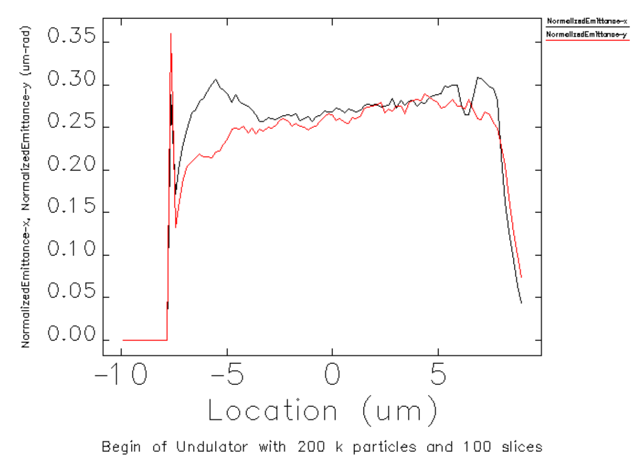
200 pC



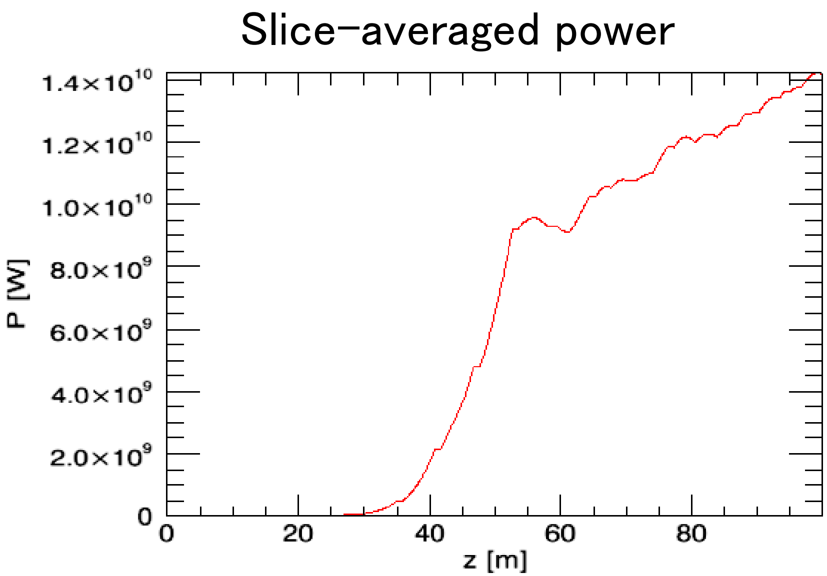
Current, energy spread , and emittance at the entrance of undulator

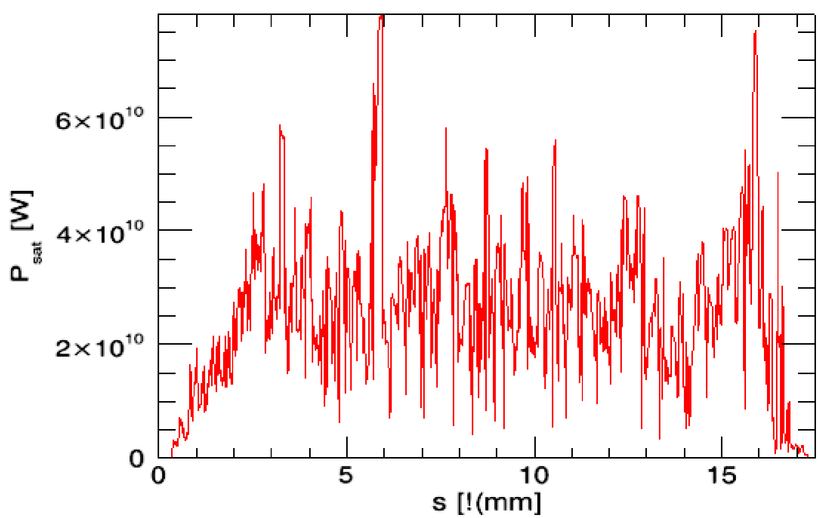


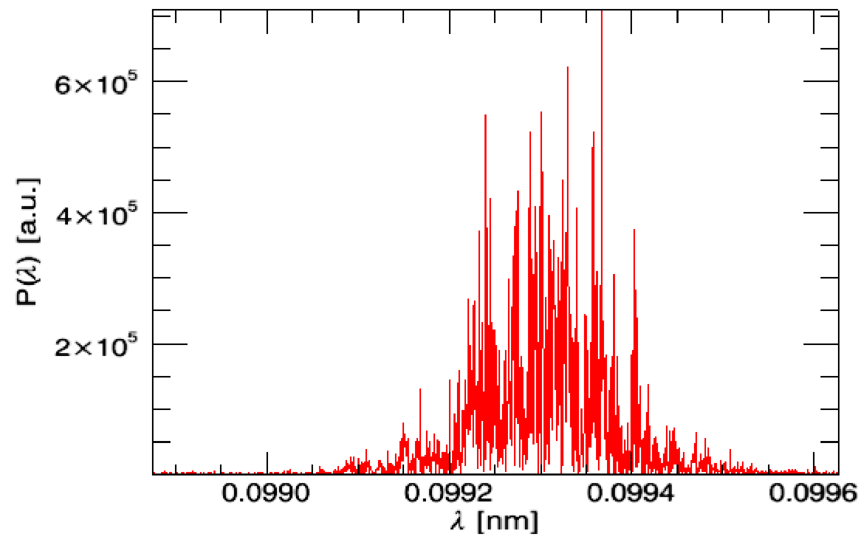




SASE: Time-dependent simulation







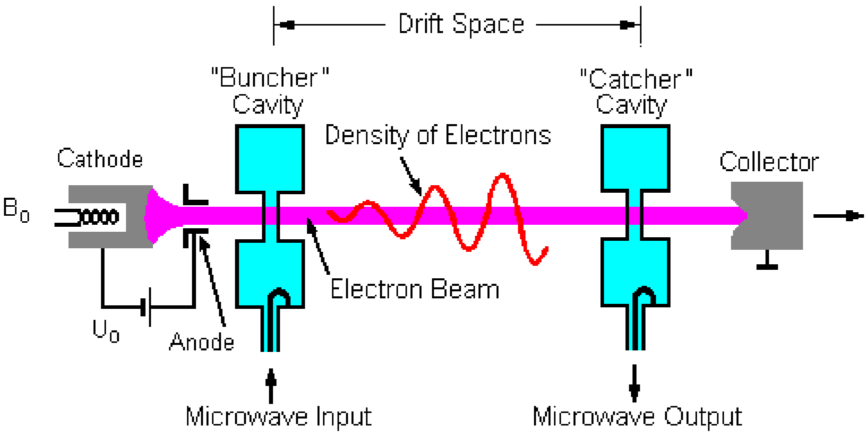
Tolerance Study for Linac RF parameters

	L1	X	L2	L3, L4	Current Variation [%]	Arrival time variation [fs]	Energy jitter
200 pC for SASE	0.1 deg 0.02 %	0.1 deg 0.04 %	0.1 deg 0.02%	0.5 deg 0.1 %		18.2	2.1 E-4
	0.05 deg 0.02 %	0.1 deg 0.04 %	0.05 deg 0.02%	0.5 deg 0.1 %	13	10.7	1.7 E-5
100 pC for Self-seeding	0.02 deg 0.02 %	0.05 deg 0.04 %	0.02 deg 0.02%	0.5 deg 0.1 %	13	26.0	4.6 E-5

RF stability requirement

- phase : 0.03 degree
- amplitude : 0.01 %

Klystron Beam Voltage Stability Requirement

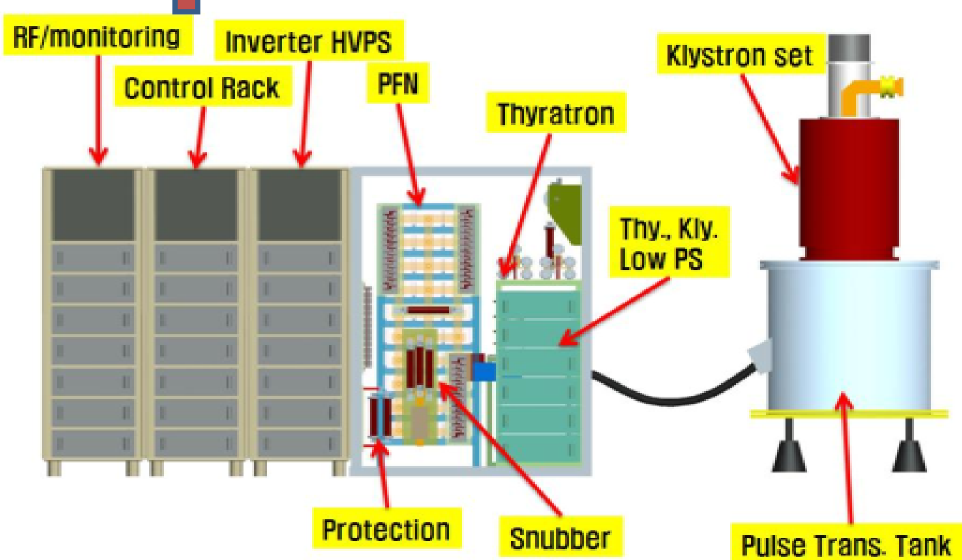


$$\frac{\Delta V}{V} = -\frac{m\,c^2}{e}\,\frac{\lambda_0}{L}\,\frac{(\gamma^2 - 1)^{3/2}}{V_0}\,\frac{\Delta\theta}{360}$$

- Because of a very short RF pulse length (a few mirco-second) of normal conducting Linac, the RF phase stability is determined by the pulse-to-pulse stability of klystron beam voltage.
- Klystron modulator should be stable enough to satisfy the requirement.

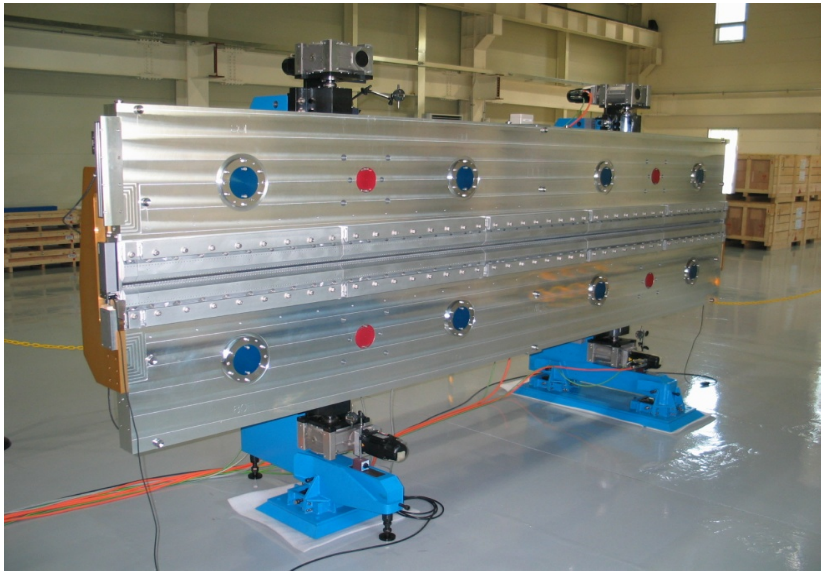
	S-band	X-band
Frequency, GHz	2.856	11.424
wavelength, m	0.10	0.03
Klystron cavity distance, m	0.65	0.6
Klstron voltage, kV	400	420
RF phase stability requirement, degrees	**0.03**	**0.05**
Klystron beam voltage stability, ppm	**55.3**	**26.1**

50-ppm Stability Inverter PS-type Modulator



- Collaborated with two local companies
- Both companies achieved the stability of **30 ppm**.

Prototype of Undulator



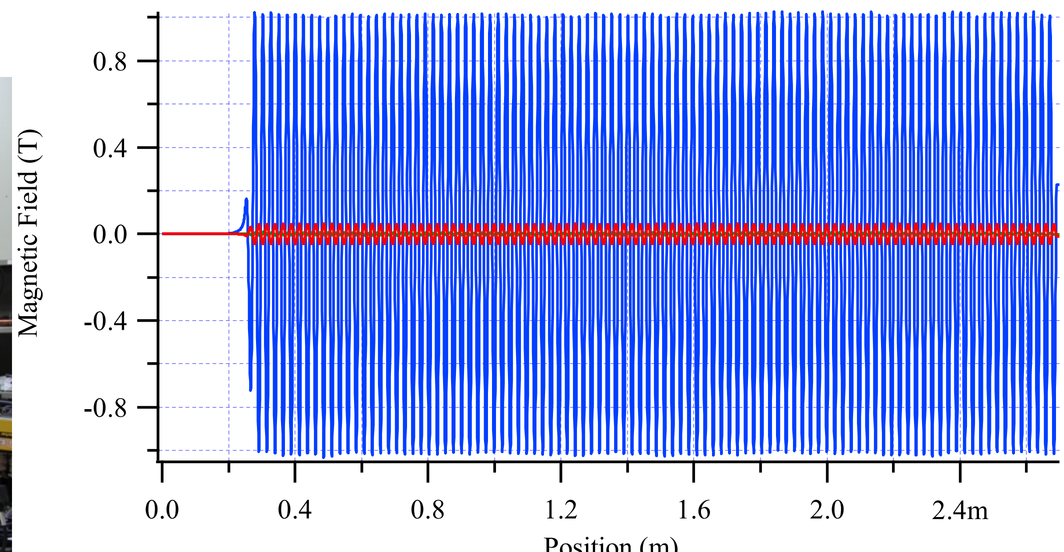
Gap control test

Field measurement

- EU-XFEL undulator design is benchmarked. MOU to use the EU-XFEL design is agreed on 2011 June btw. PAL and EU-XFEL.

- Variable gap out-vacuum
- Undulator period: 2.44 cm
- Minimum gap: 7.2 mm
- Length: 5 m

Field measurement data



THPME026: Preliminary Results of the PAL- XFEL Prototype Undulator Magnetic Measurements

Prototype of Phase Shifter

EU-XFEL type phase shifter (230 mm long)

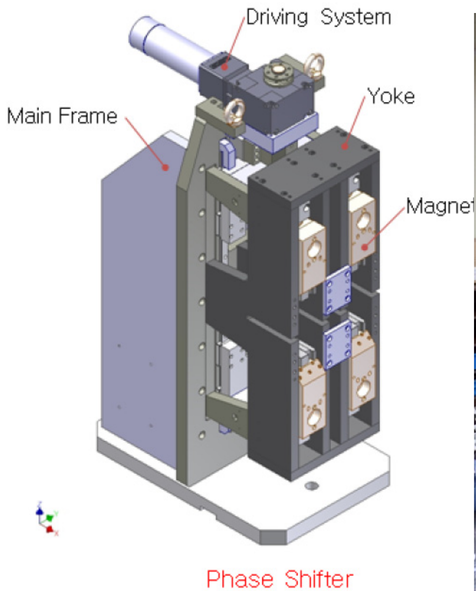
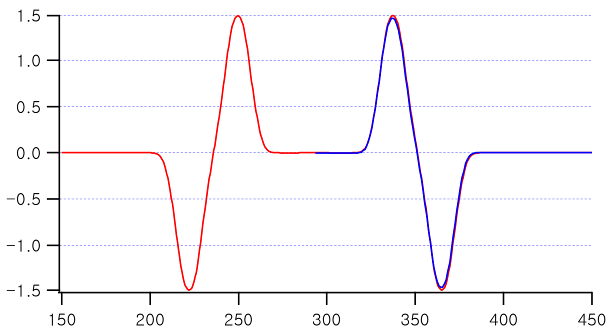


그림 1 Phase Shifter 3D 모델링(전면부)



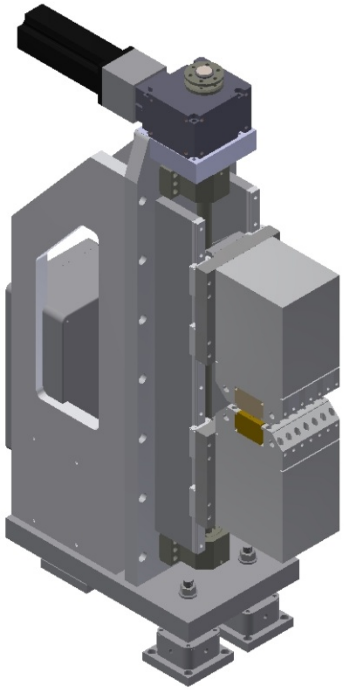
Major Parameters of PAL-XFEL PS

Continuously tunable for 3.0-1.0 nm radiation at E=3.15 GeV, with 0.8 mm inter-undulator length

Magnetic length :	~100 mm
Min gap :	7.2 mm
Max gap :	> 100.0 mm
Max Phase integral:	~6,300 T^2mm^3
Phase control accuracy	: ±10 degree
Gap Control accuracy	: ± 20 um
Full Magnet size	20.000 (T) X 30 (H) X 50 (W)
Half Magnet size	10.995 (T) X 30 (H) X 50 (W)
Magnet material	Br > 1.26T, Hcj 1670 kA/m

A 100 mm long PM based Phase shifter is developed for PAL-XFEL with smaller phase integral.

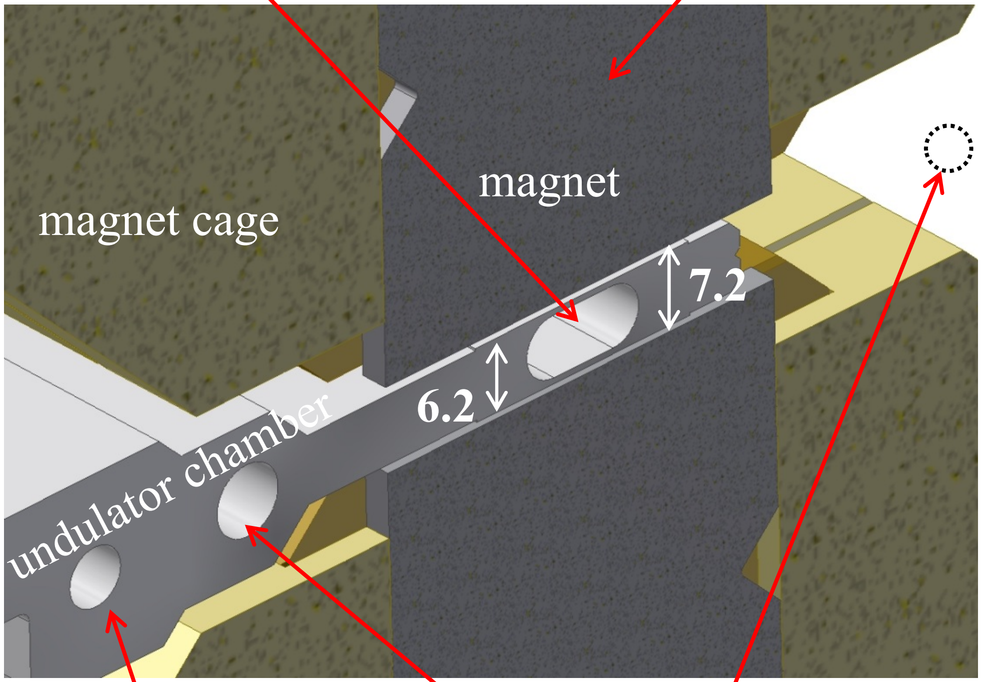
THPME027: Design and Fabrication of Prototype Phase Shifter for PAL XFEL



U-Chamber Cross section & Fabrication Procedure

Cross section

e–beam chamber
– Cross section 5.2 x 11 mm
– Thickness: 0.5 mm

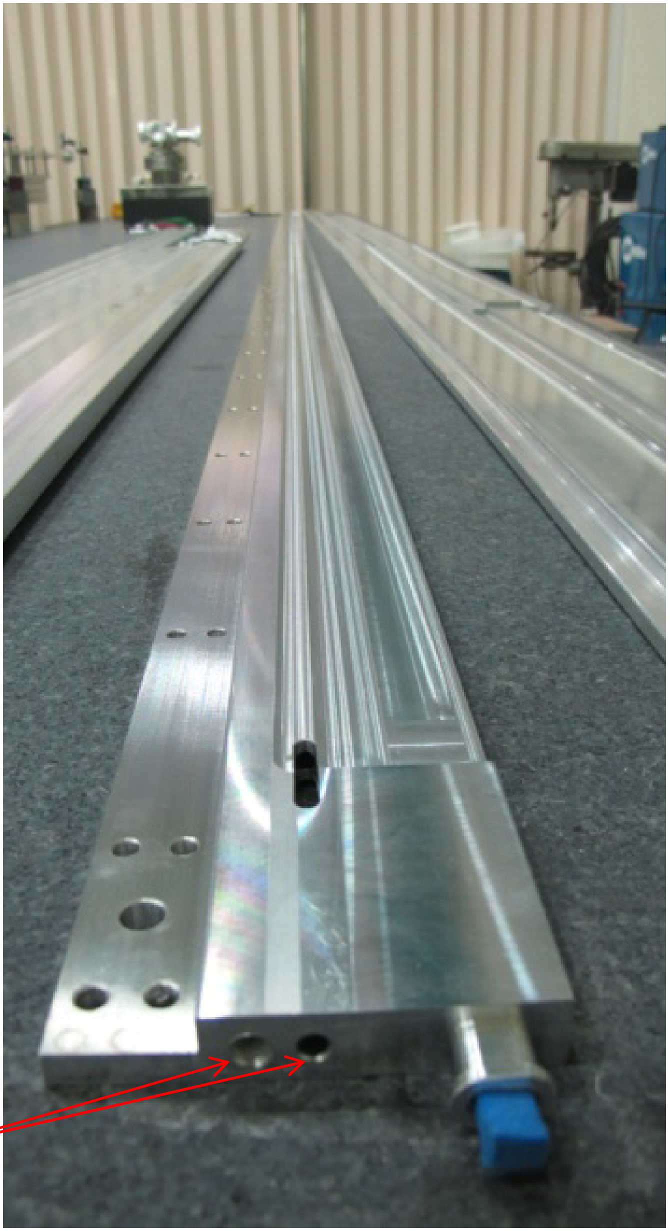


Fabrication procedure

1. Extrusion
   - controlled gas enviorment.
2. Correction
   - stretching in controlled gas env.
3. AFM polishing (if needed)
4. Precision machining
5. Chemical cleaning
6. Welding

Prototype of Undulator chamber

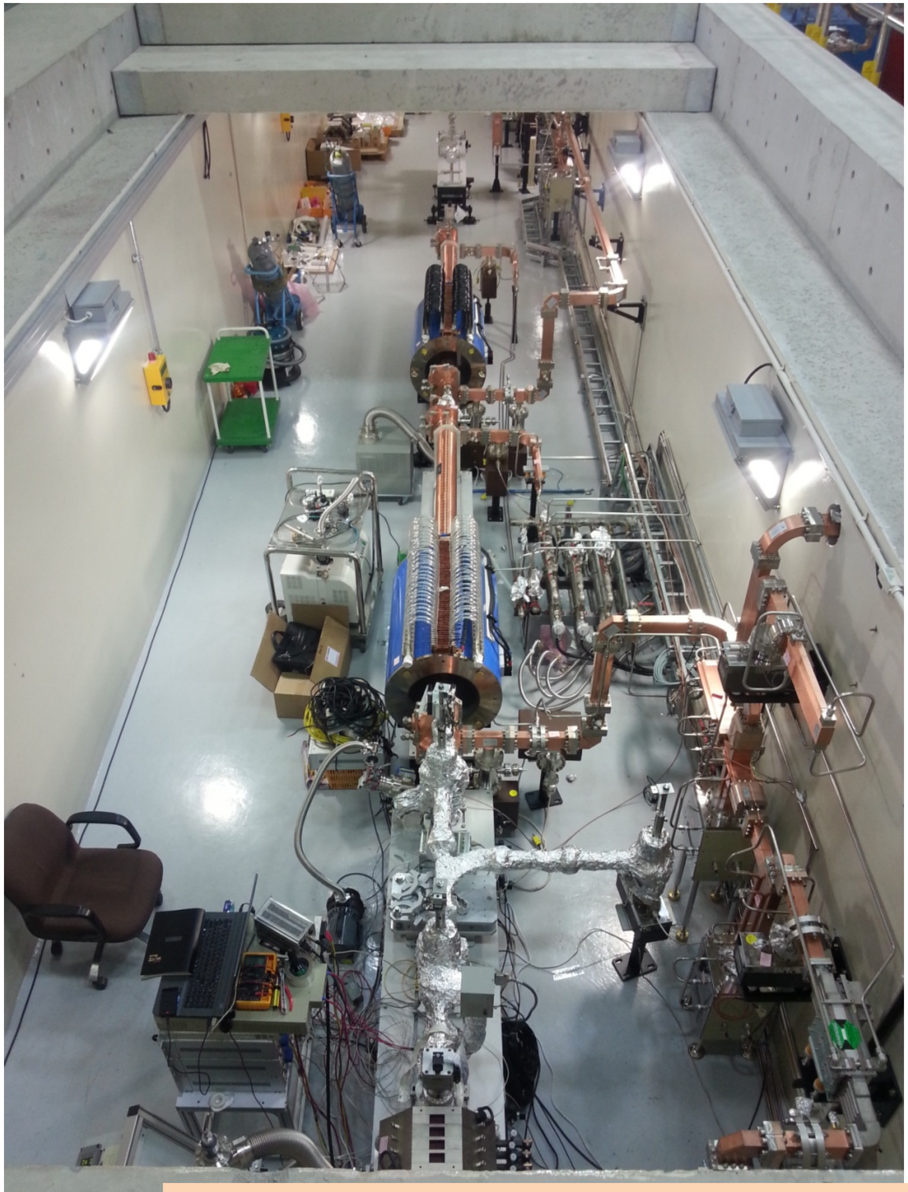
Parameter	Value
Undulator length , m	5.0
Undulator period , cm	2.44
Undulator gap , mm	7.2
Material	A6063-T5/T6
Aperture (V x H) , mm	5.2 x 11
Thickness , mm	0.5±0.05
Flatness	< 50
Clearance (pole to chamber), mm	0.5



Surface measurement result
- Surface roughness : < 150 nm
- Oxidation layer thickness : < 5 nm

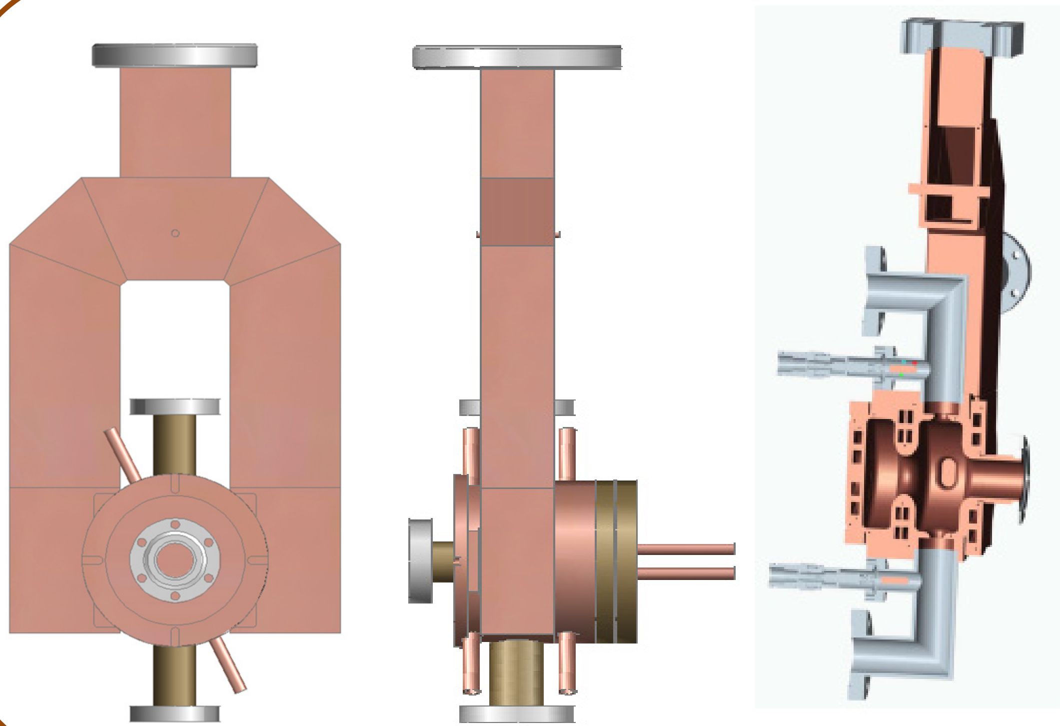
Holes for Cu coil and LCW

Injector Test Facility



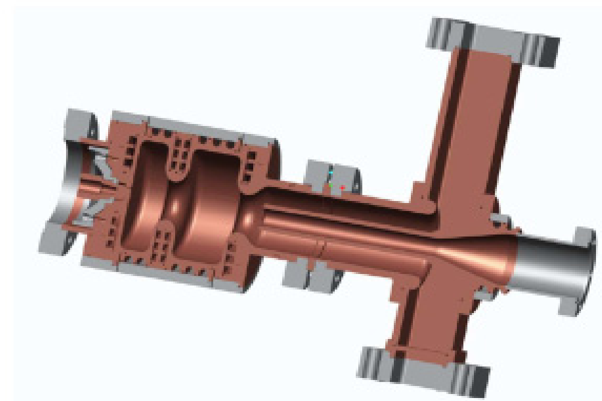
WEPWA043: Construction of Injector Test Facility (ITF) for the PAL XFEL

Two candidate designs for the PAL-XFEL gun



PAL-XFEL baseline gun : dual-coupler gun with additional two-holes to reduce quadrupole field

PRST AB 14, 104203 (2011)
Emittance growth due to multipole transverse magnetic modes in an rf gun

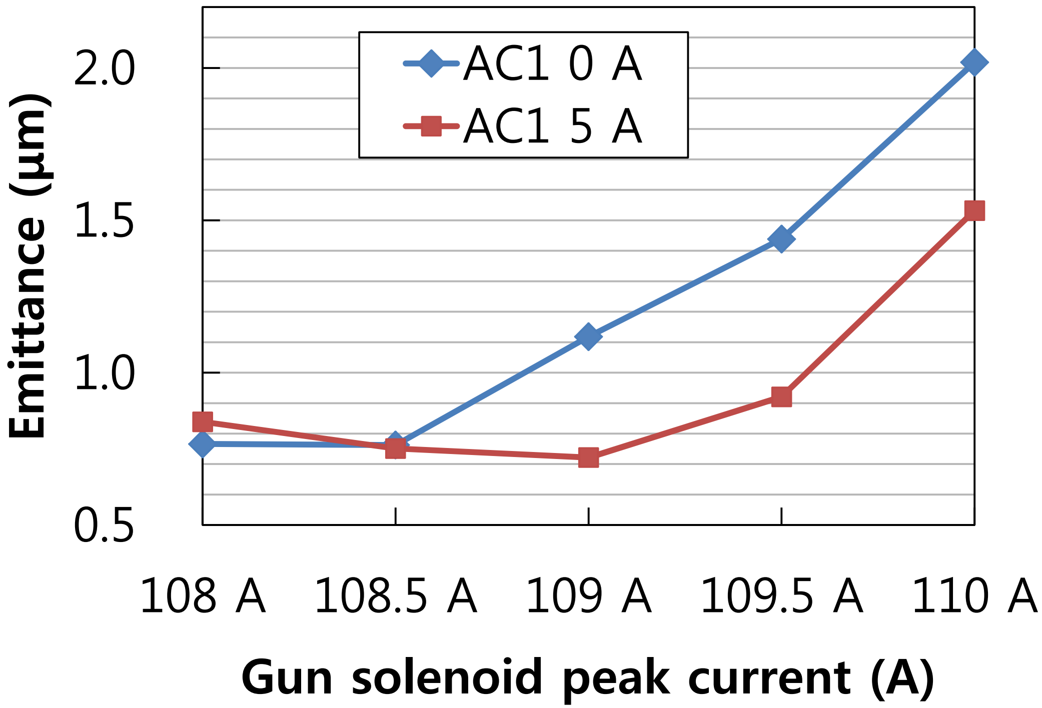


Alternative gun design :

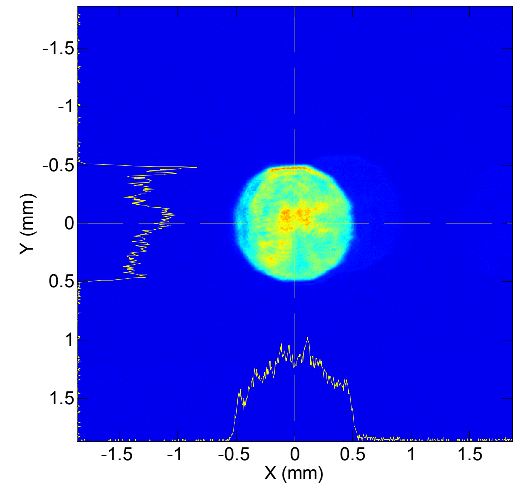
fully-symmetric coaxial coupler and cathode plug.

Emittance Measurements

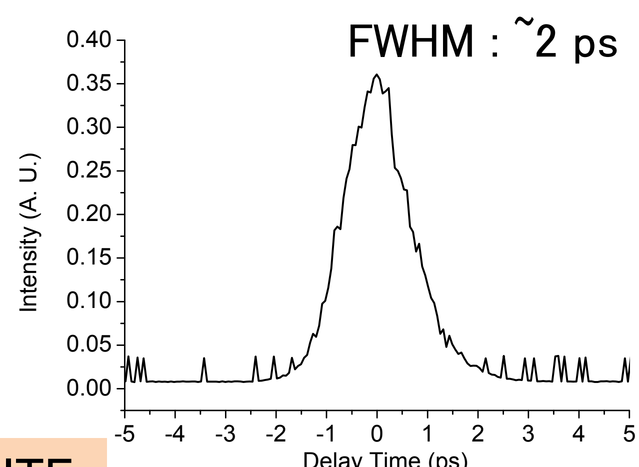
Projected emittance measurement with single quad scan



Transverse laser profile



Longitudinal laser profile



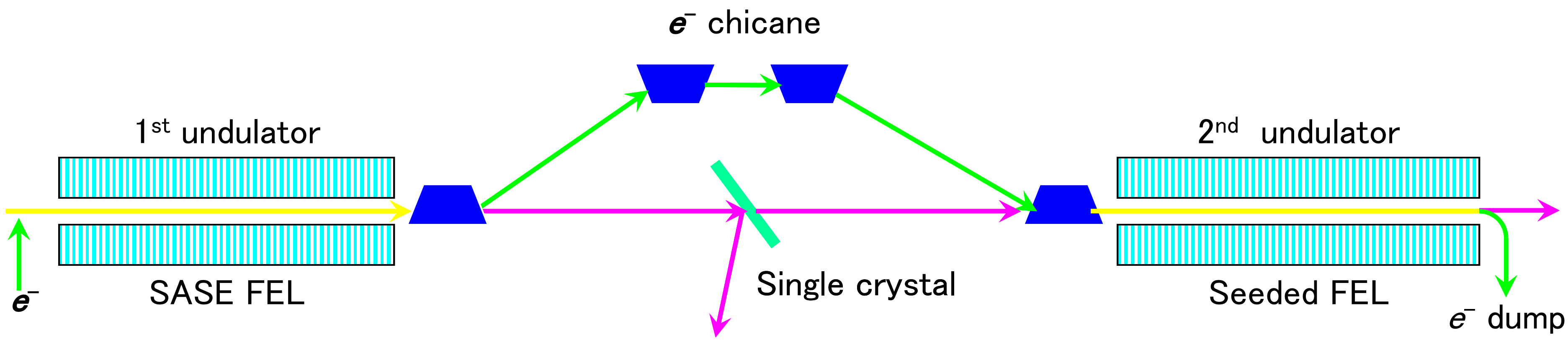
Charge : ≥ 200 pC
Energy: 139 MeV
Repetition rate: 10 Hz

$\varepsilon_{x,100\%} \sim 0.71$, $\varepsilon_{y,100\%} \sim 0.78$,

New Concept for increasing radiation power and narrow bandwidth

HARD X-RAY SELF-SEEDING

HXRSS @ PAL-XFEL



8 keV: 34 m
13 keV: 46 m

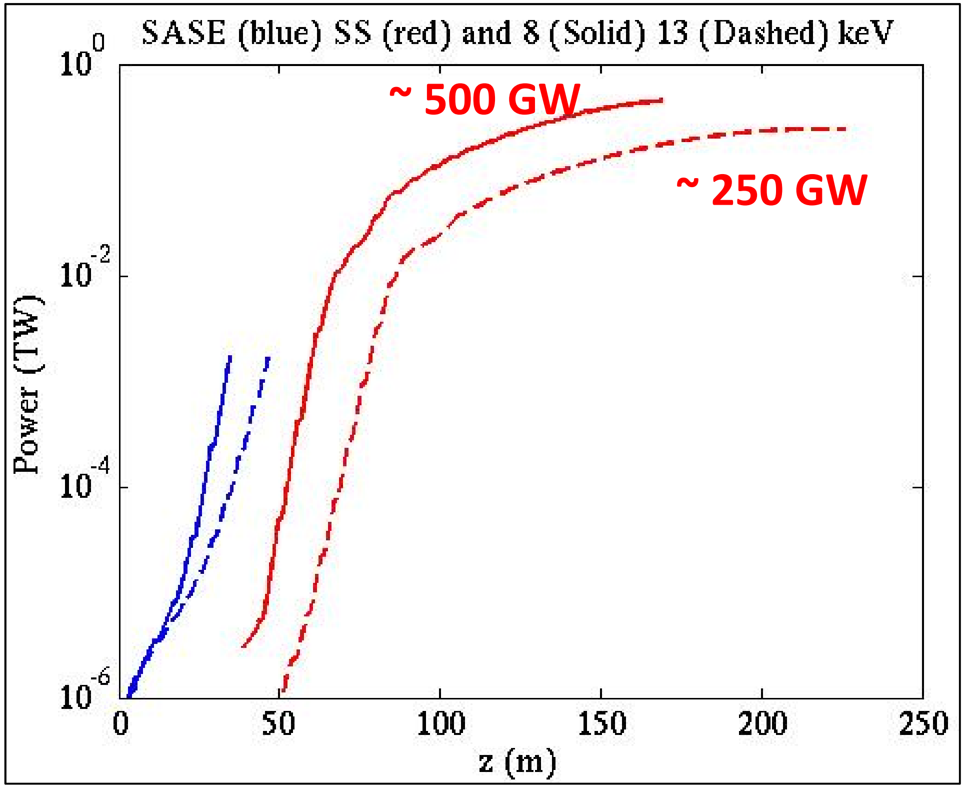
8 keV: (400) 8.7E−06
13 keV: (642) 1.6E−06

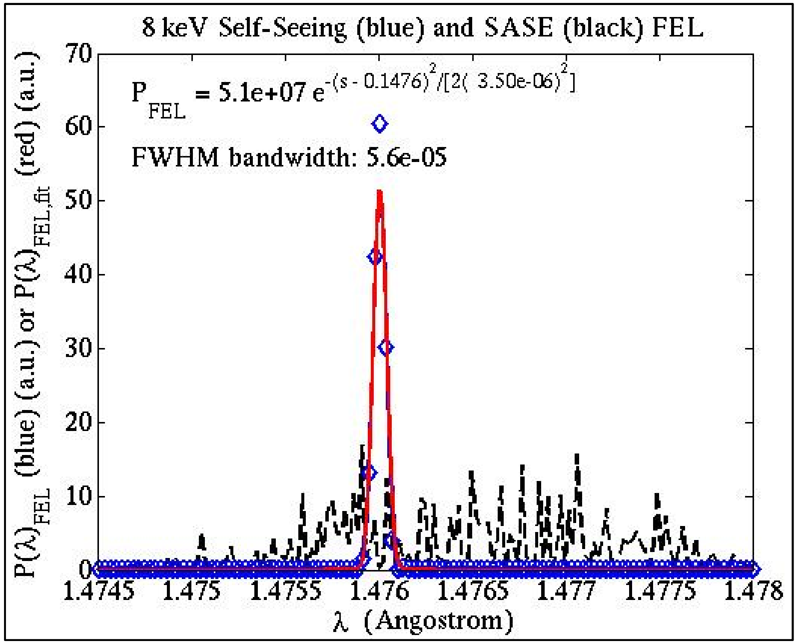
8 keV: 130 m
13 keV: 170 m

Collaborated with J. Wu in SLAC

Self-Seeding Simulation

- With full length of 225 (red solid) m as compared to 130 m (red dashed), *i .e.*, about 100 m left for other purpose

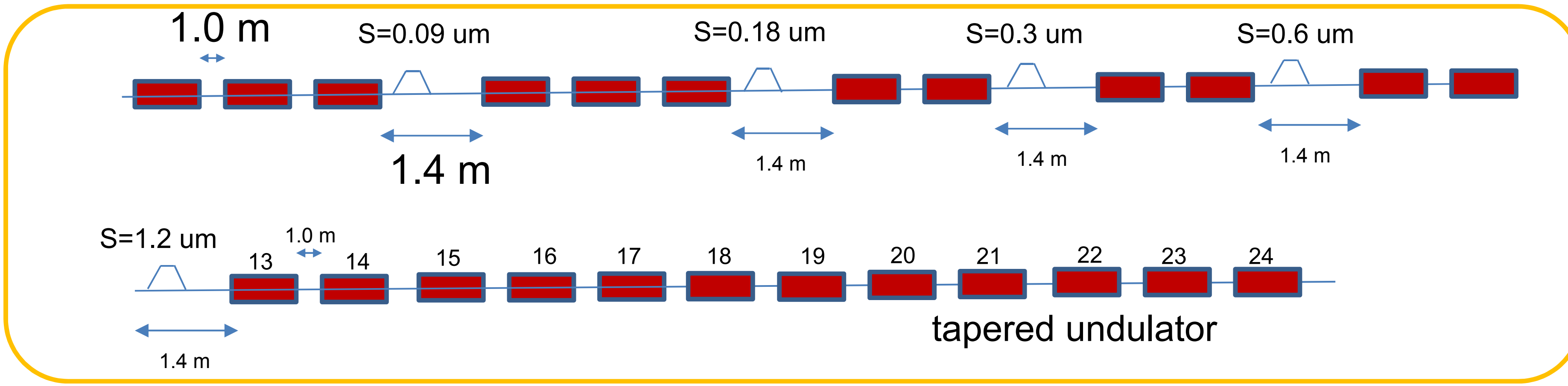




Collaborated with J. Wu in SLAC

ISASE Scheme

- Self-seeding: narrow bandwidth, but too high intensity fluctuation (over 70%)
  very sensitive to beam energy jitter
- Improved SASE (iSASE) scheme: Pellegrini and J. Wu
  - introduces repeating delays of the electron beam respect to the radiation field
  - increase the cooperation length and generate a smaller bandwidth than SASE
  - less sensitive to beam energy jitter
  - a tapered undulator enables ultra-high peak power.



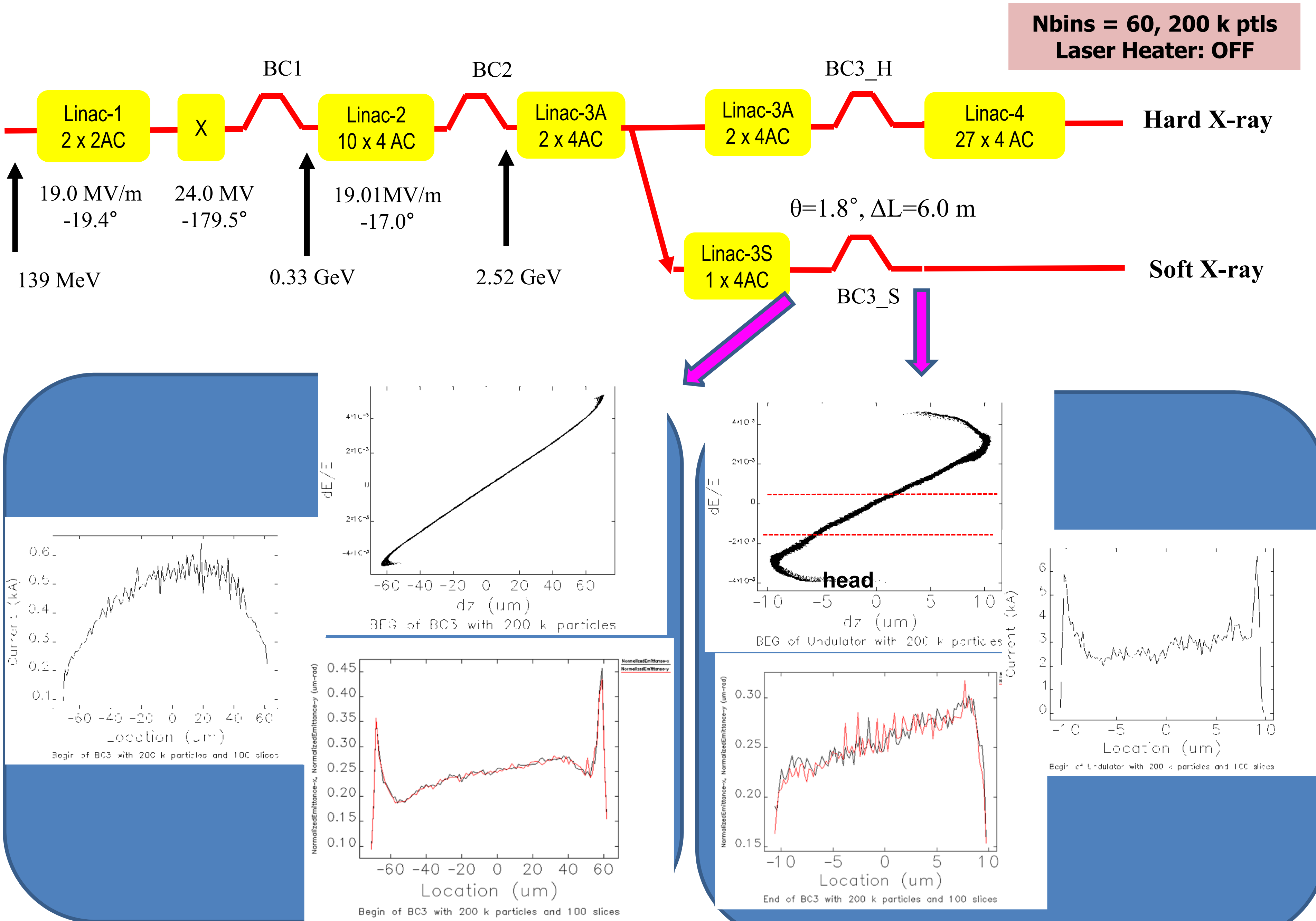
λ [nm]	Slippage/ 5-m undulator	Total slippage (12 undulatos) in SASE mode	Total slippage in ISASE mode
0.15	0.03 um	0.36 um	1.56 um

- Chicane (R56 = 2.4 μm) is 0.6 m long
- Only 2 m (0.4 m x 5) is increased

Collaborated with J. Wu in SLAC

Dechirper System

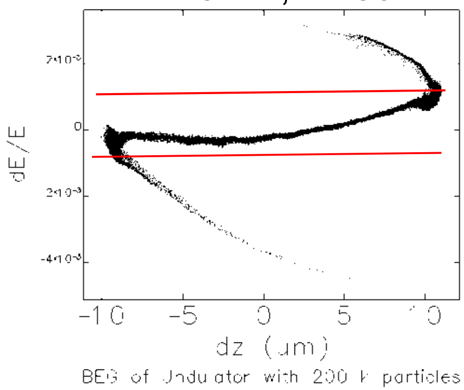
Start-to-End Simulation for Soft X-ray FEL Beamline



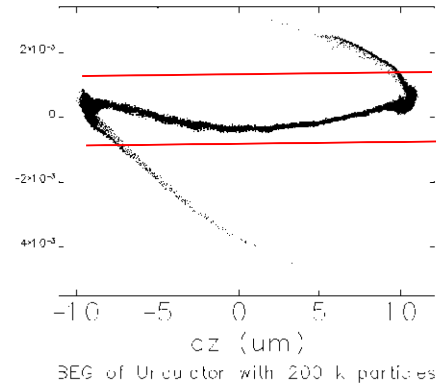
Simulation of longitudinal wake

a) Smooth, resistive pipe

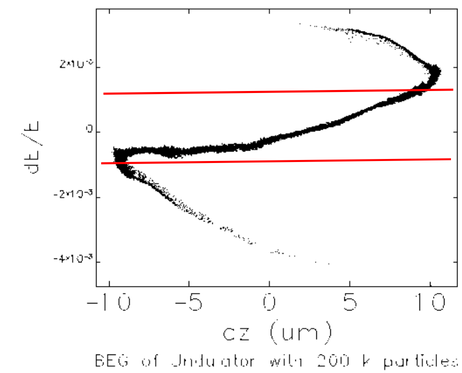
R= 5mm, L= 50m



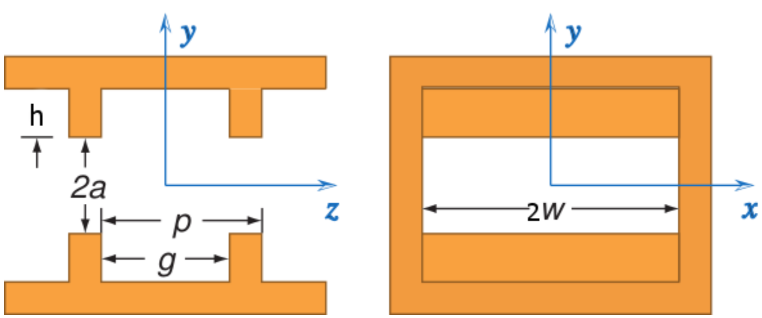
R= 5mm, L=65m

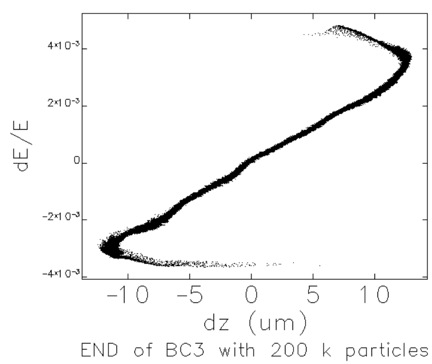


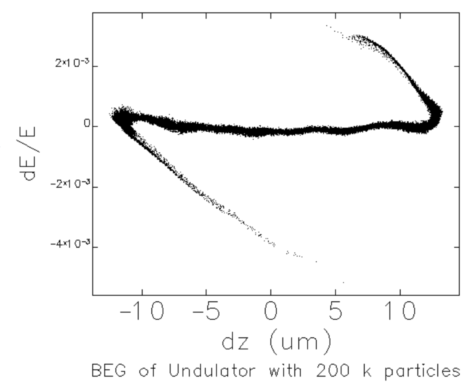
R= 3 mm, L=15m



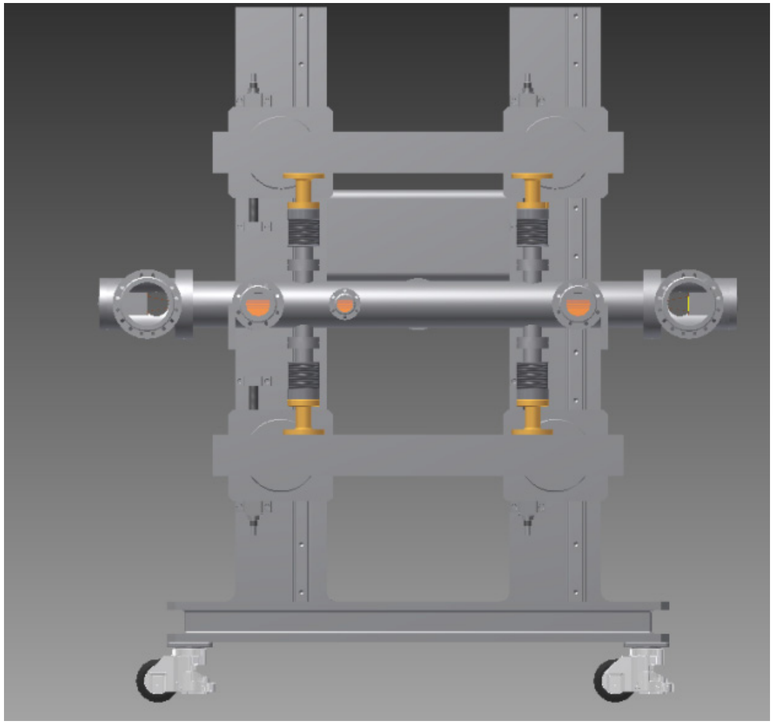
b) Corrugated pipe with radius of 3 mm, L=15 m

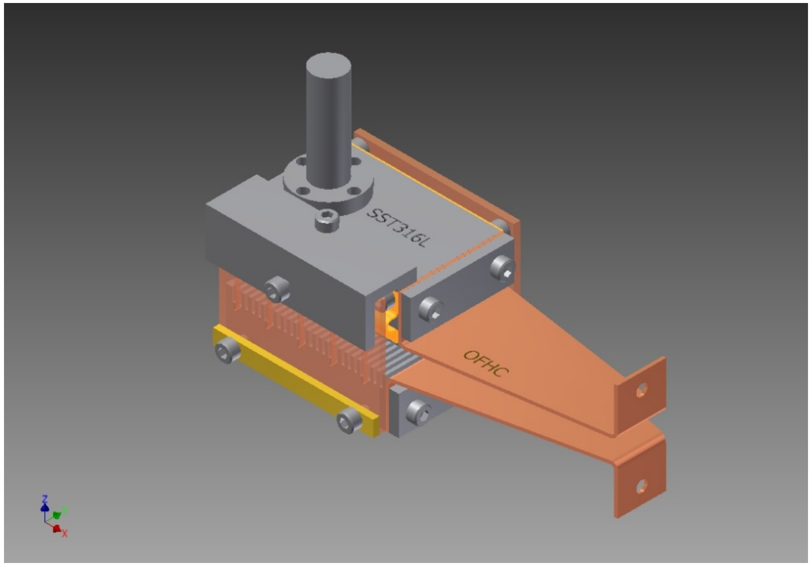






One-meter long proto-type dechirper





Adjustable gap type using two parallel plates with corrugations

corrugation period : 0.5 mm
corrugation depth : 0.6 mm
corrugation gap : 0.3 mm
Width of plate : 50 mm
Gap of two plates : 1 ~ 30 mm.

- **Collaborative R&D with SLAC (K. Bane, Z. Huang, G. Stupakov) and LBNL (P. Emma, Marco)**

- **Beam test at Injector Test Facility in July 2013**

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Thank you for your attention