Beam Commissioning of PAL-XFEL

J.-H. Han for PAL-XFEL Commissioning Team

Pohang Accelerator Laboratory

PAL-XFEL Project

- Project start in 2011
- Building construction in 2012~2014
- Accelerator components installed in 2015
- Beam commissioning from 14th April 2016 to end 2016
- XFEL user facility from early 2017

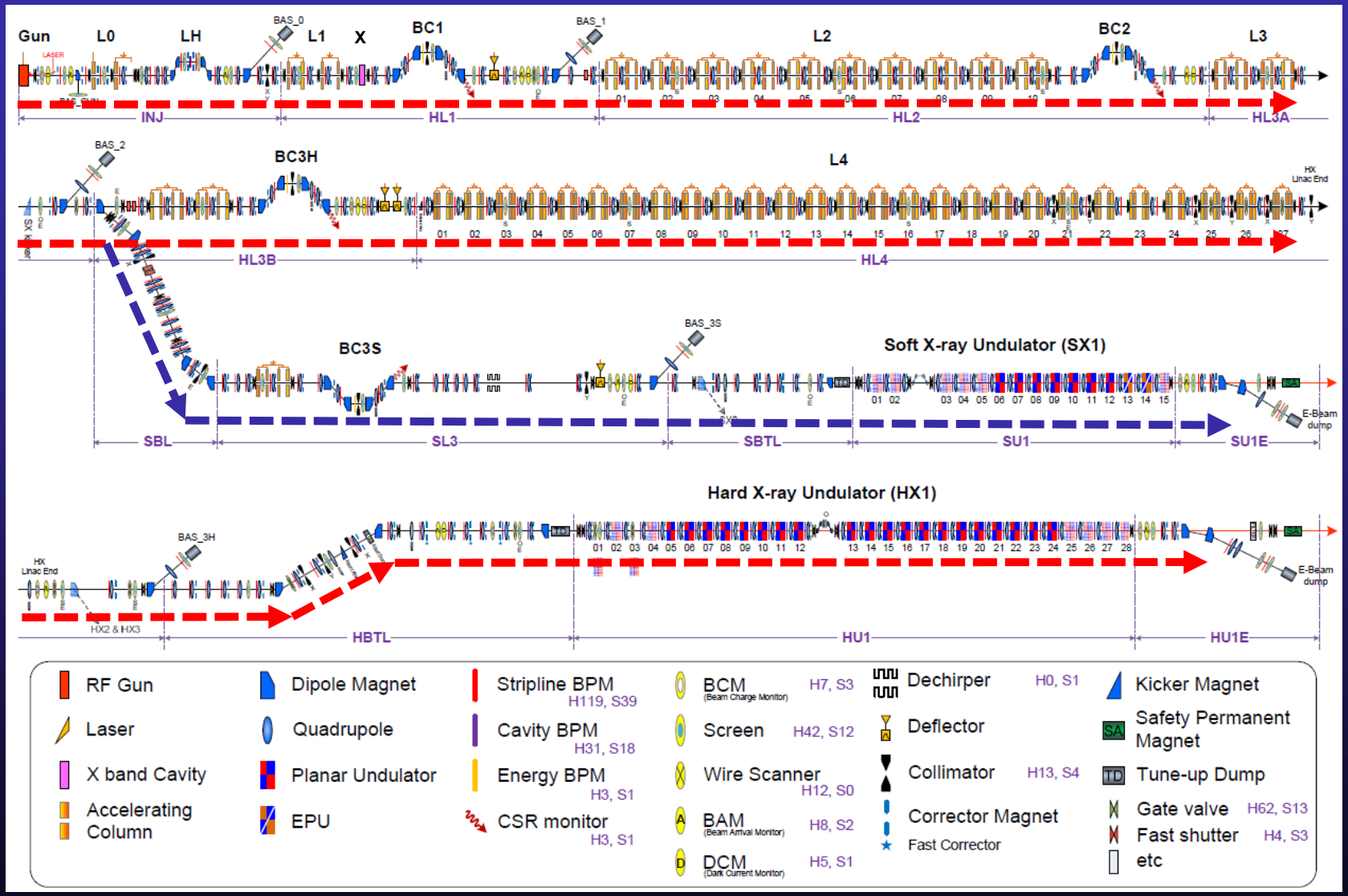
PAL-XFEL Parameter

10 GeV electron linac + two undulator beamlines at Phase-1

Undulator line	Hard X-ray line	Soft X-ray line
Wavelength	0.1 (0.06) ~ 0.6 nm	1 ~ 4.5 nm
Electron beam energy	4 ~ 10 GeV	3.15 GeV (branched)
Undulator type	Planar	Planar (+EPU in future)
Undulator length	5 m	5 m
Undulator period	26 mm	37 mm
Undulator min. gap	8.3 mm	10 mm
Number of segments	20	7 (+EPU in future)
Repetition rate	60 Hz	

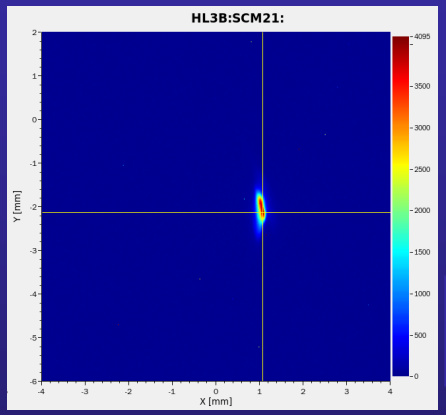
Two more HX beamlines and one more SX beamline planned

PAL-XFEL Layout

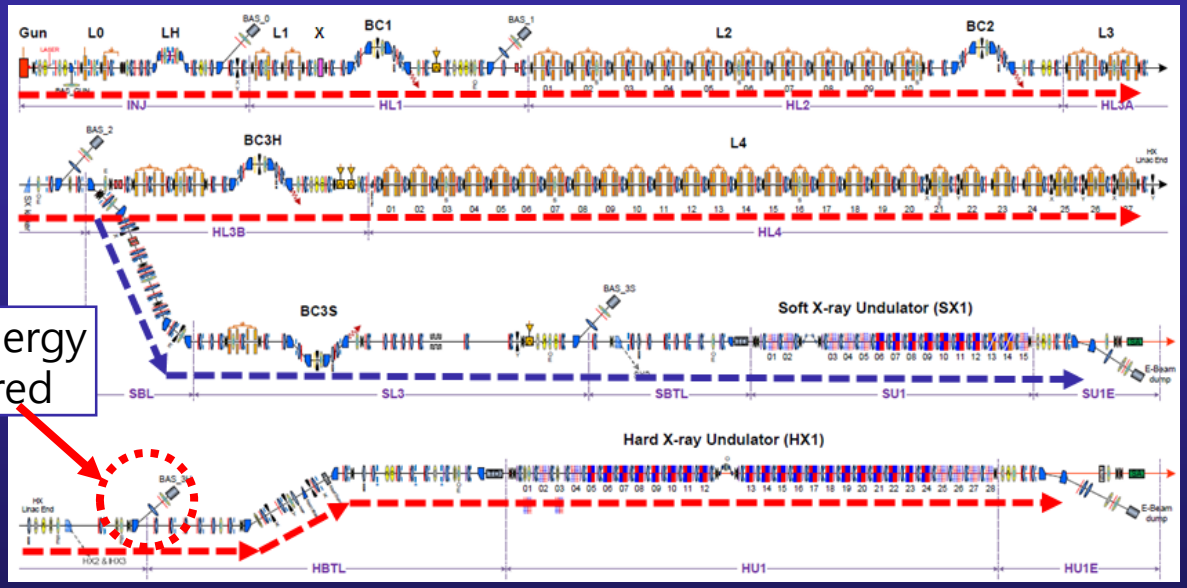


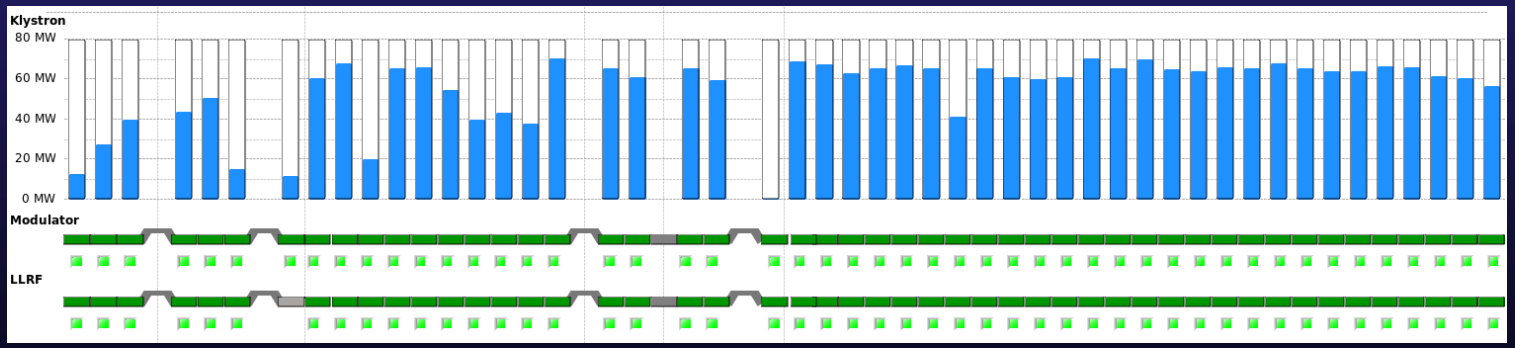
10 GeV Achieved

On 25th April (12th day of beam commissioning)



beam energy measured



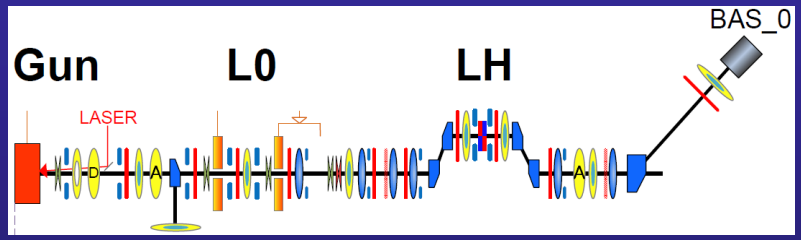


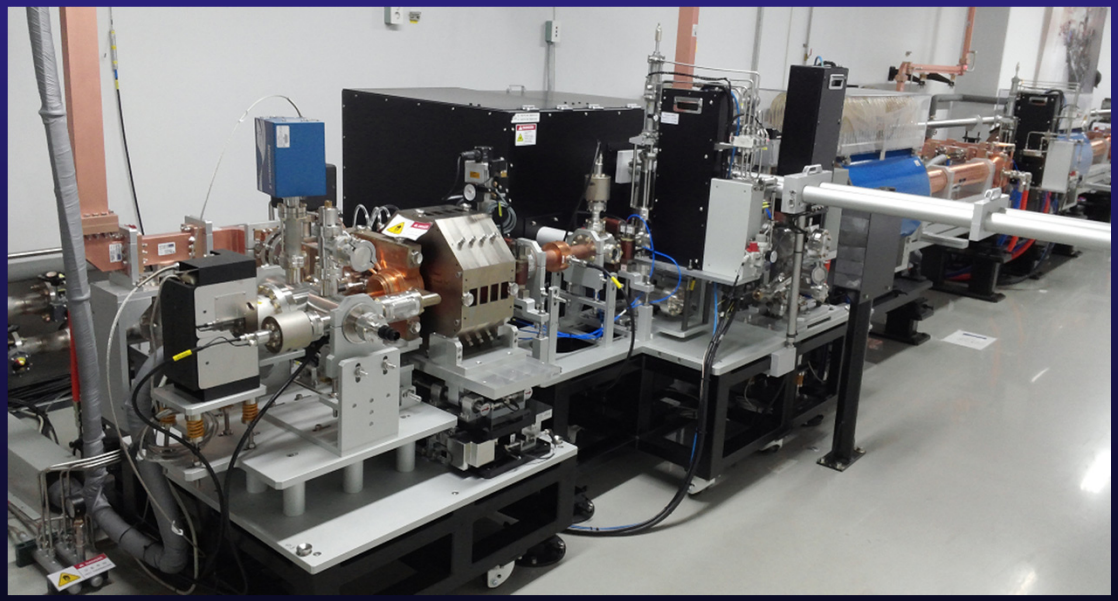
Timeline of Commissioning

- **RF conditioning**: Nov 2015 ~
- **First beam from gun** (6 MeV): 14 April 2016
- **Acceleration to injector end** (130 MeV): 14 April
- **Acceleration to BC1** (350 MeV): 18 April
- **10 GeV acceleration to linac end**: 25 April
- **Injector & linac parameter optimization**: April ~ May
- **Undulator**: May ~ June
- **Free electron laser (SASE) at HX**: June ~
- **SASE at SX:** late 2016
- **User service**: early 2017~ (120 days user run in 2017)

Injector

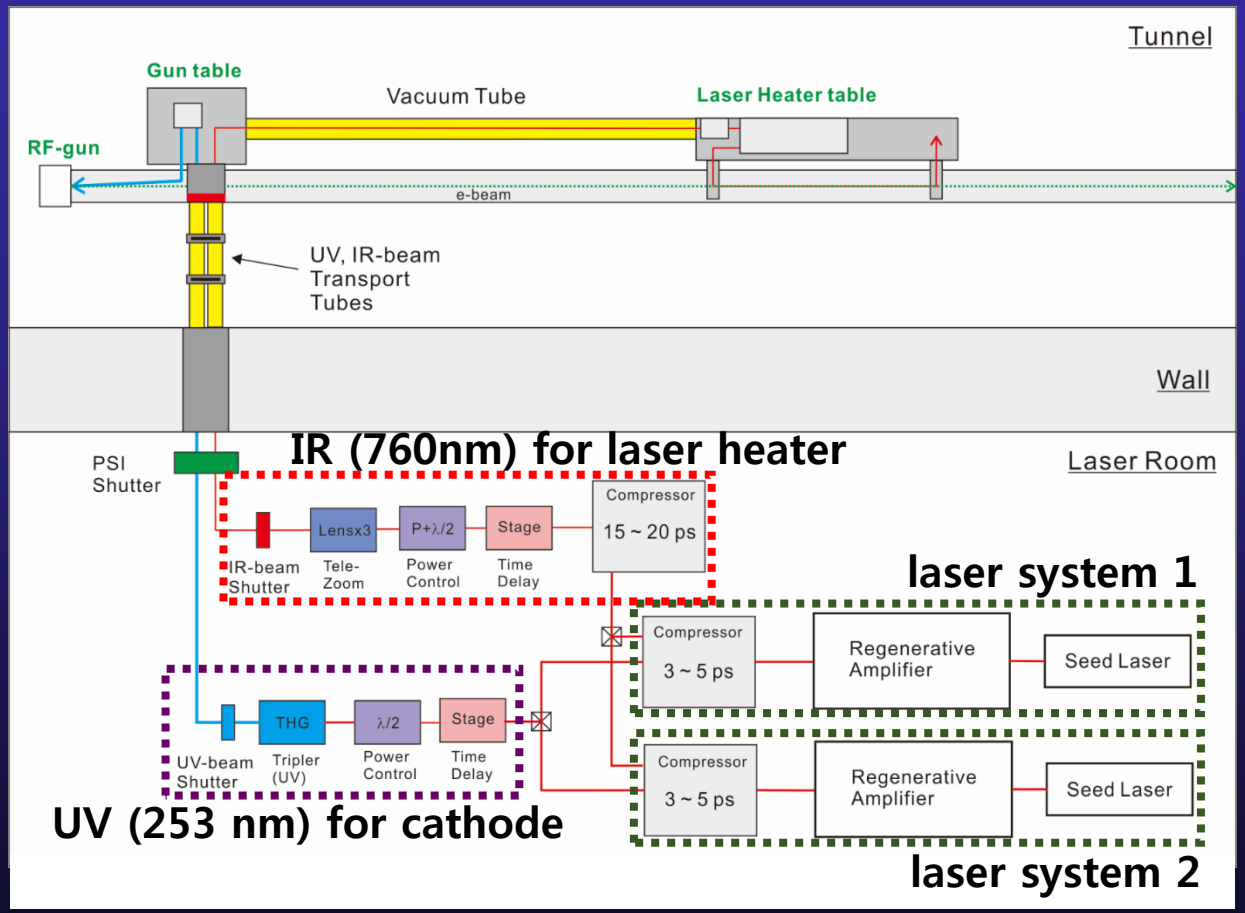
- 1.5 cell S-band photocathode gun
- Two 3 m long S-band accelerating columns
- Focusing solenoids
- Drive laser
- Beam with 200 pC & 137 MeV



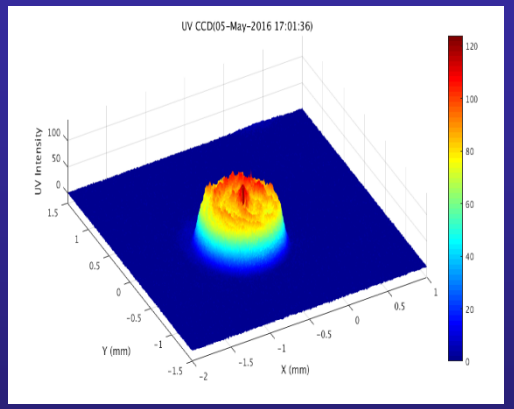


Injector Laser

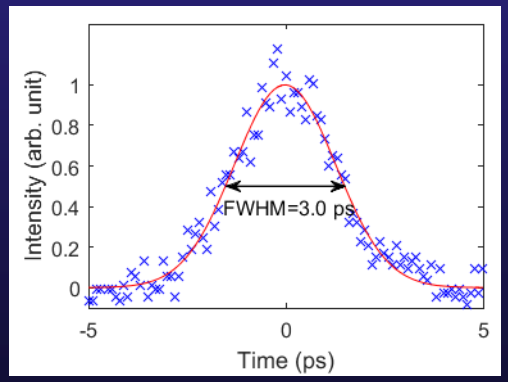
<Laser system layout>



<UV laser profile>

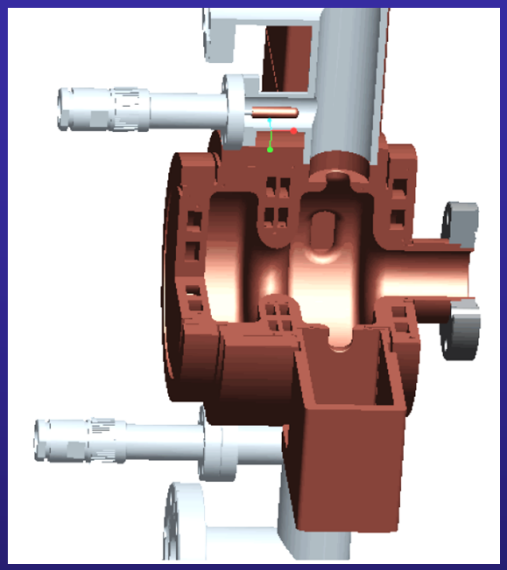


transverse profile



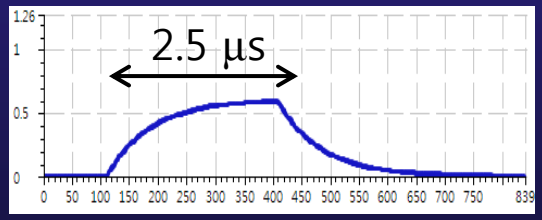
longitudinal profile

RF Gun

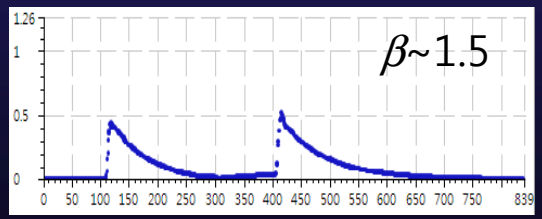


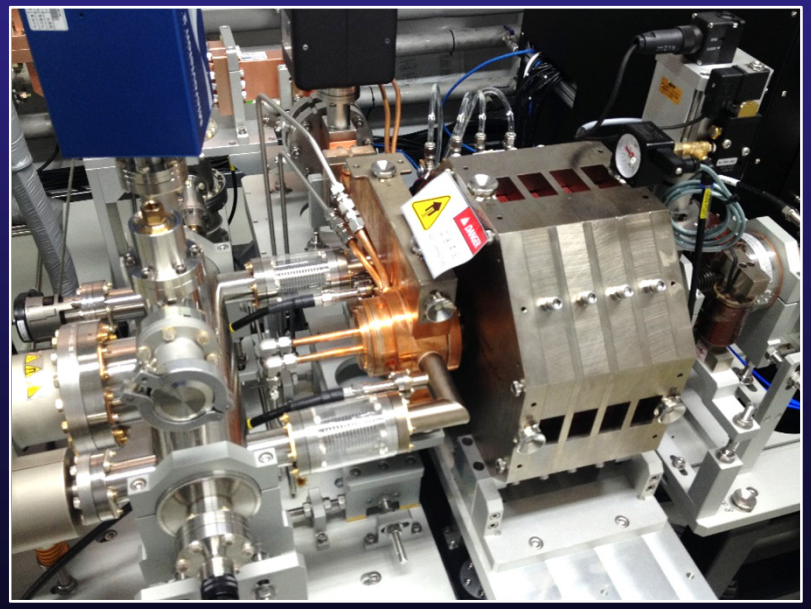
- Operates at 2856 MHz
- Developed at PAL
- Designed for 120 Hz at 120 MV/m
- 4 holes at full cell for field symmetry
- 2 RF probes

stored power in the gun



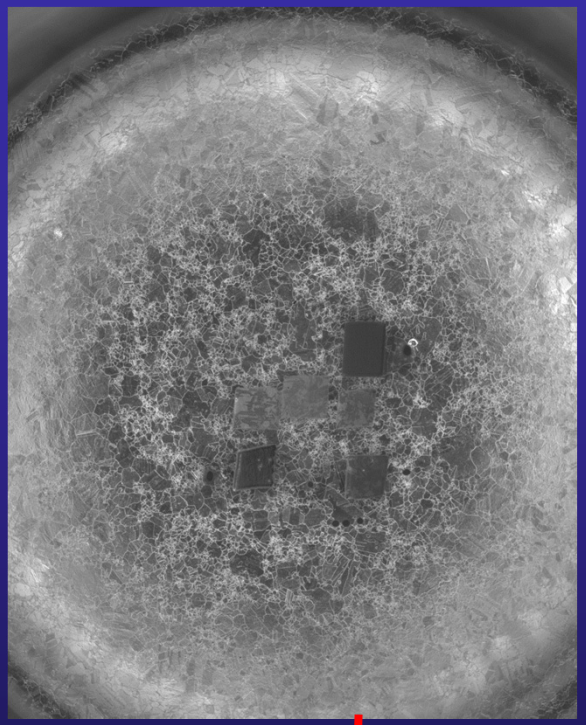
reflected power from the gun

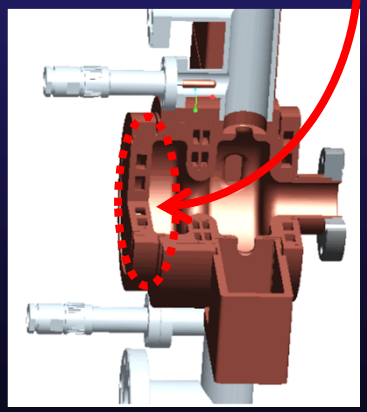




Photocathode

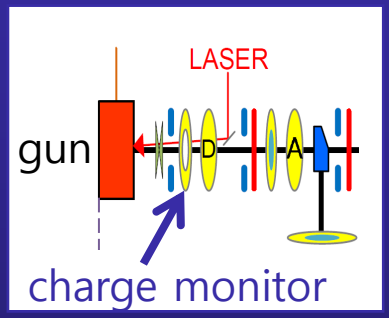
- Back plane of the gun cavity made from polycrystalline copper
- Diamond machining with surface roughness ~ 100 nm
- Vacuum < 10^{-10} mbar measured with the nearest gauge
- Quantum efficiency ~ 2.5×10^{-4} measured at 200 pC, 120 MV/m

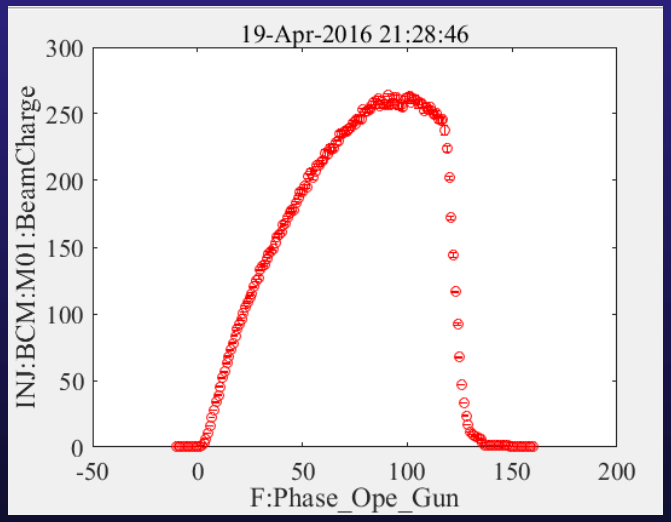




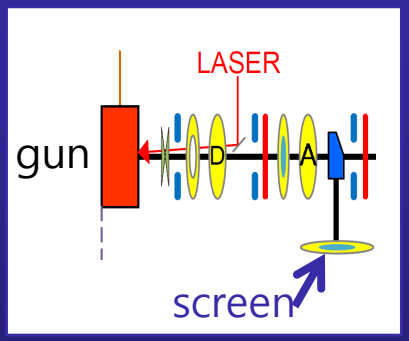
Gun RF Phase Scan

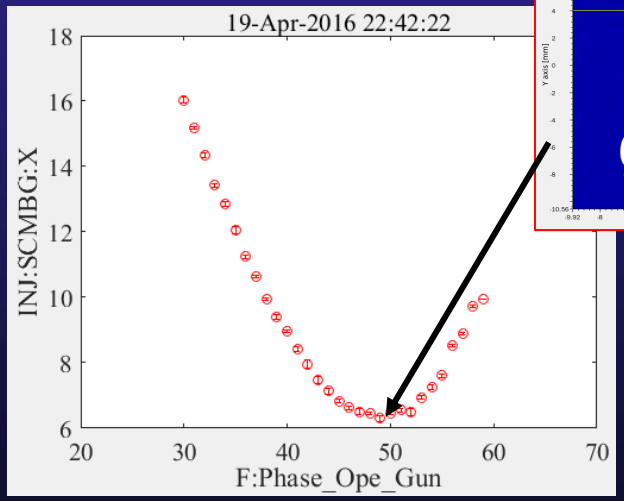
Phase scan for bunch charge

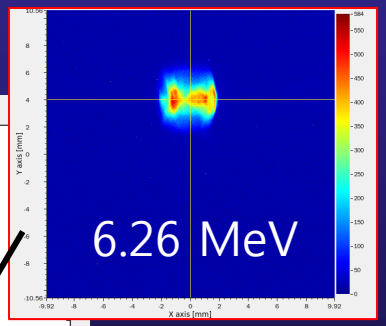




Phase scan for beam energy



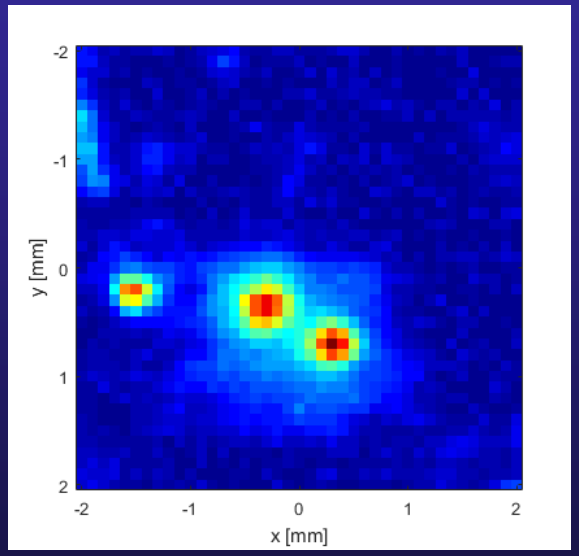




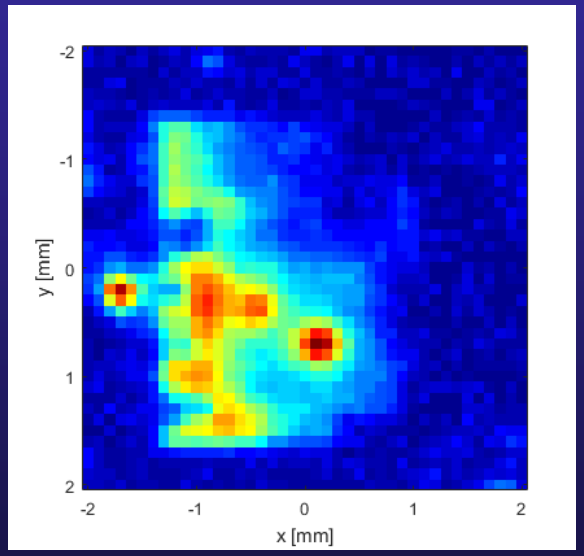
Laser Cleaning of Cathode

- Laser cleaning using IR laser pulse with 130 μm FWHM size
- 3 × 3 mm cathode area irradiated without RF power with 100 μm step
- Quantum efficiency maps taken for 4 x 4 mm area

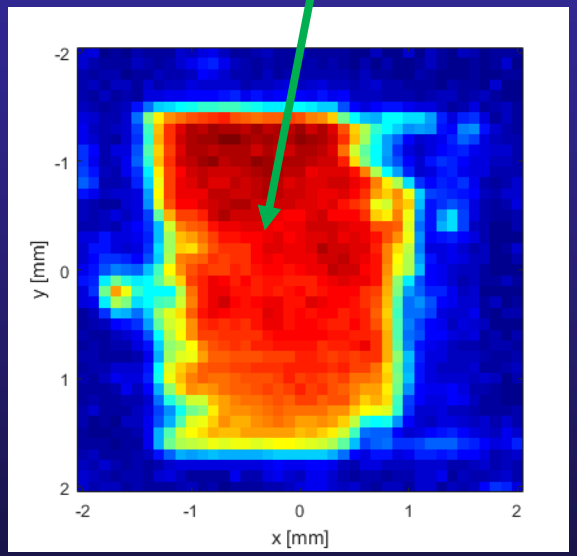
QE ~ 2.5×10^{-4}



Before cleaning
vacuum <1×10^{-10} mbar



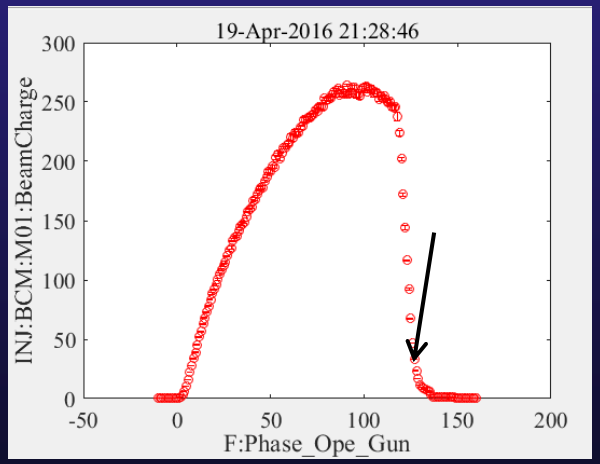
After 2nd cleaning
with 1.16 mJ IR laser
vacuum ~5×10^{-10} mbar
recovered after cleaning

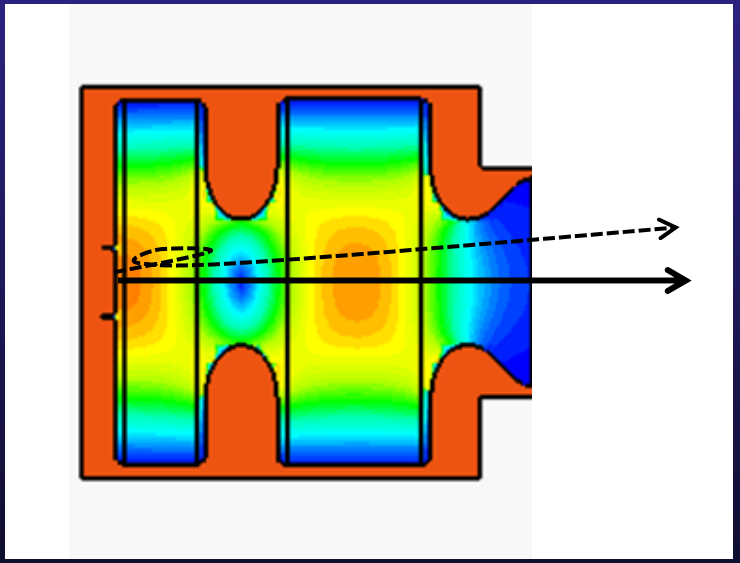


After 4th cleaning
with 1.39 mJ IR laser
vacuum ~1×10^{-9} mbar
recovered after cleaning

Gun Laser BBA

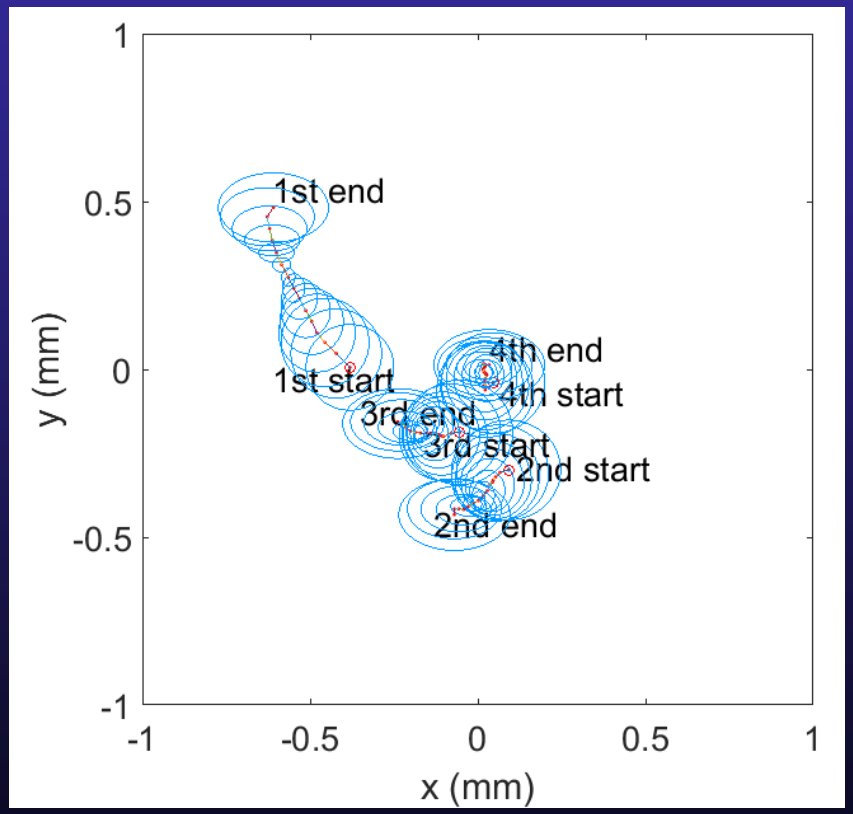
- Drive laser position aligned on cathode center (gun RF field center)
- Gun field reduced from 120 to 90 MV/m for laser align (no dark current on gun screen) and gun solenoid switched off
- Beam position at gun screen while scanning RF gun phase around 110° from 0-crossing for RF focusing and large phase delay

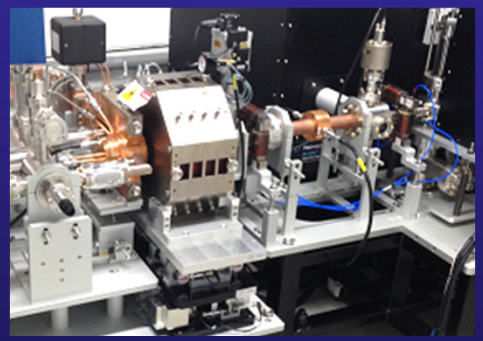


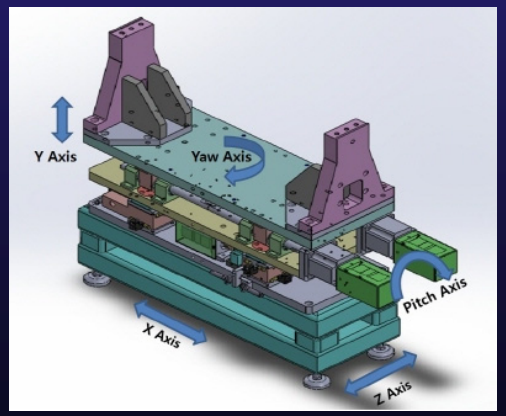


Gun Solenoid BBA

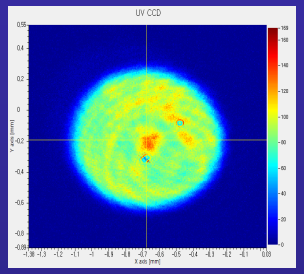
While scanning gun solenoid current from 80 to 115 A at 90 MV/m gun field, beam position movement measured at gun screen
After 3rd trial, we aligned the gun solenoid so that the beam position movement within 50 μm at the screen



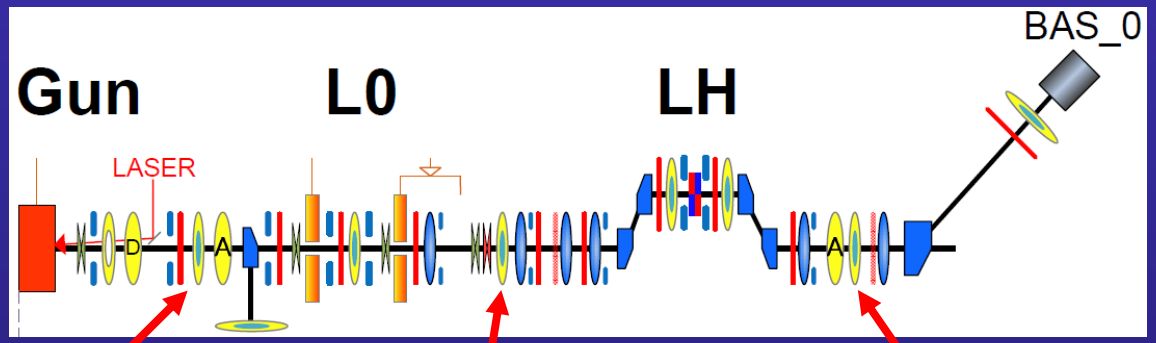


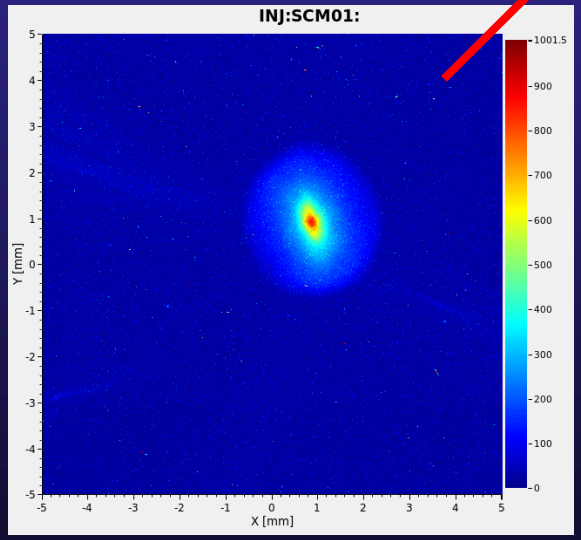


Beam Shape in Injector

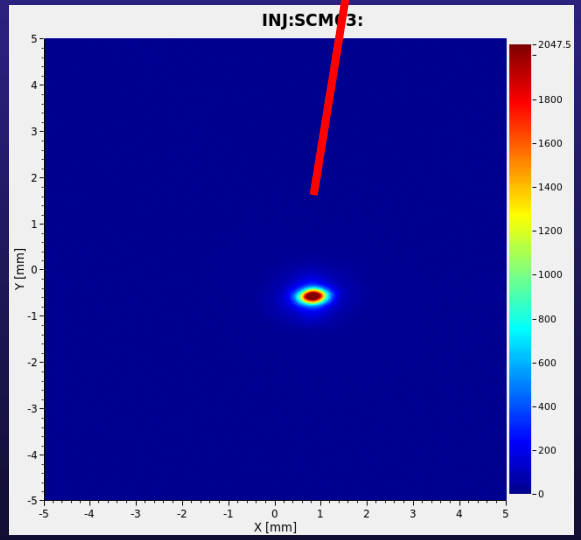


Drive laser

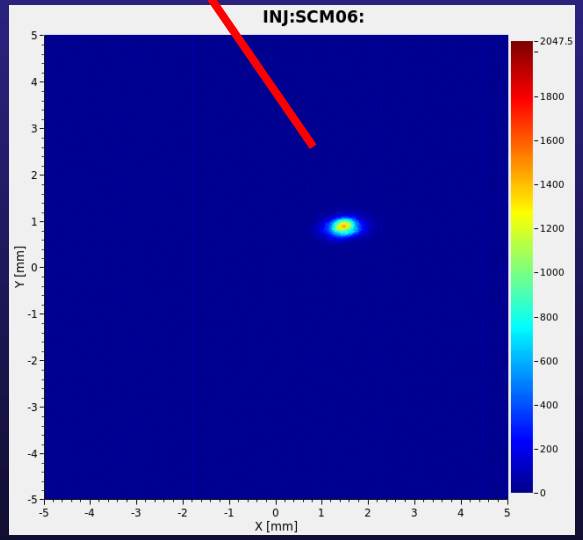




After gun



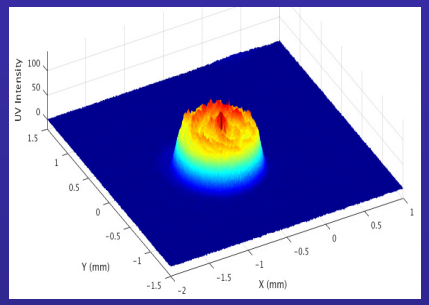
After L0

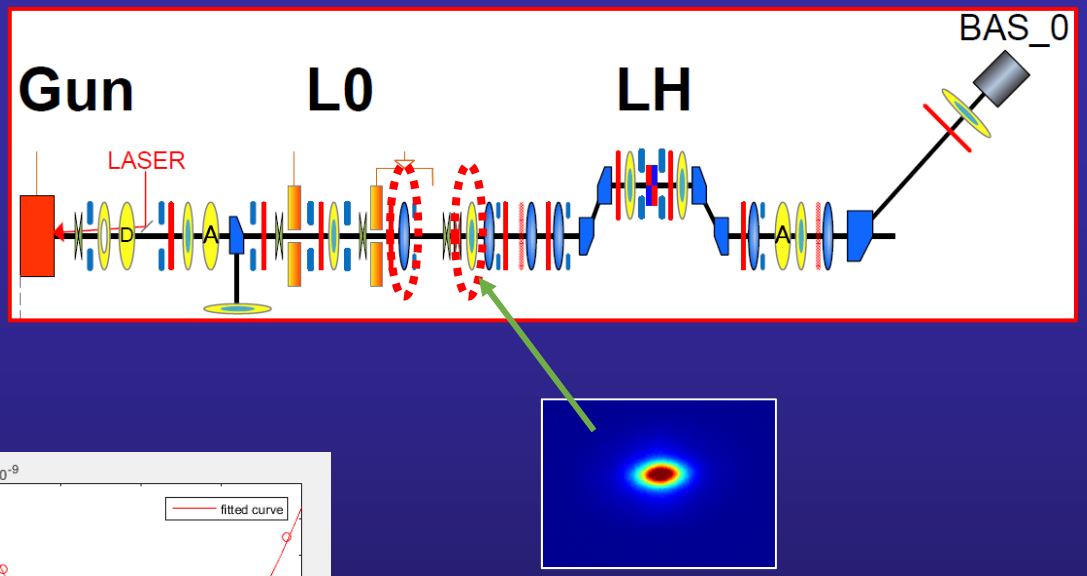


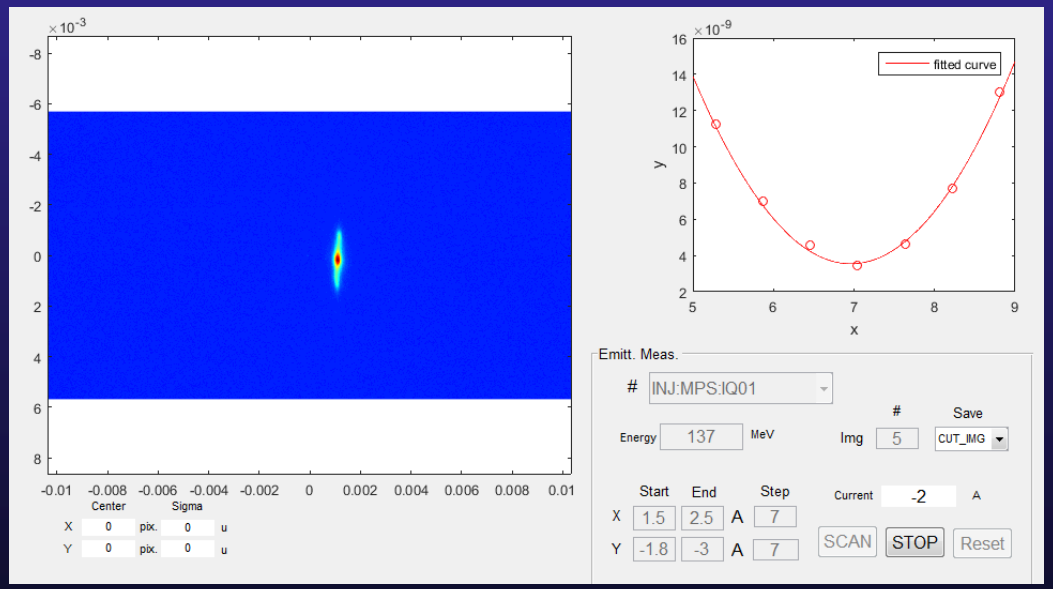
After laser heater

Emittance at Injector

laser
ϕ ~1 mm
l ~3 ps







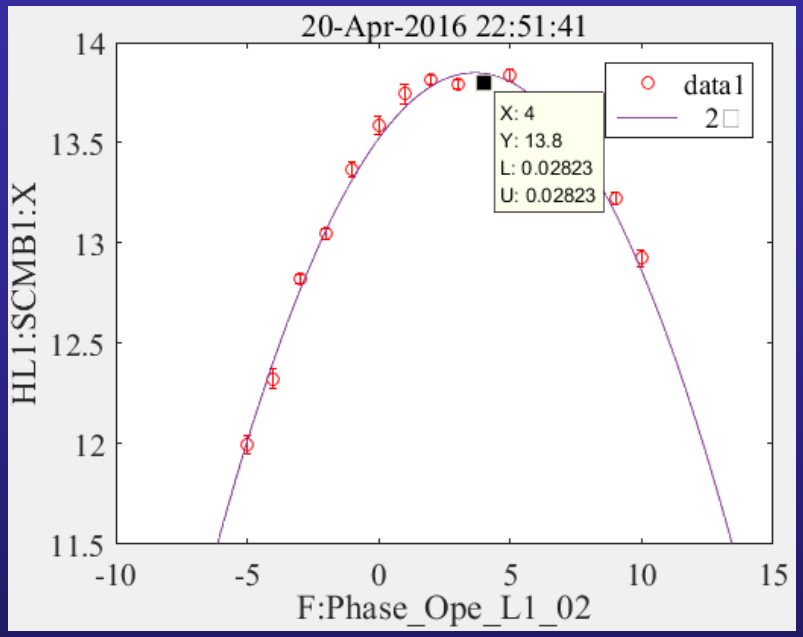
Best measured projected transverse emittance so far:

ε_x ~ 0.8x mm mrad

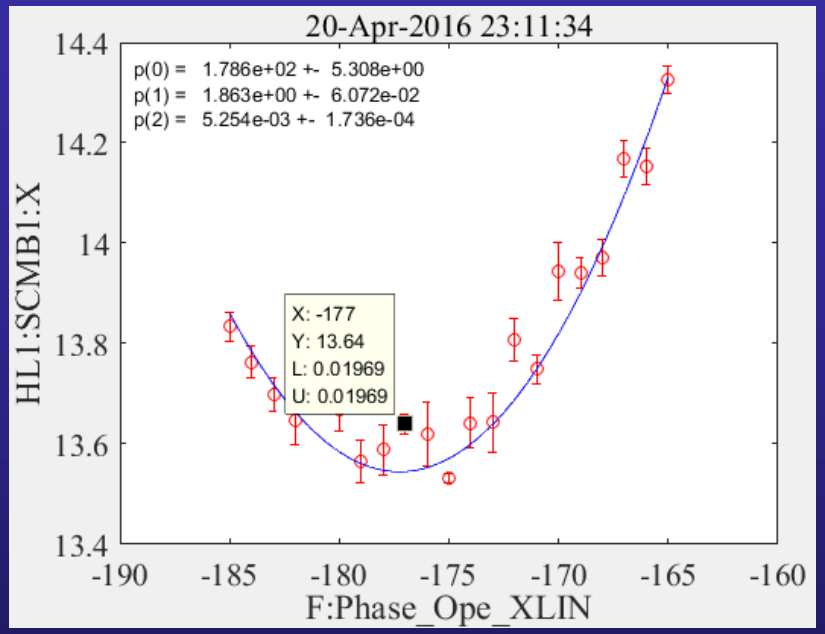
ε_y ~ 0.4x mm mrad

(200 pC, 137 MeV, 95% rms)

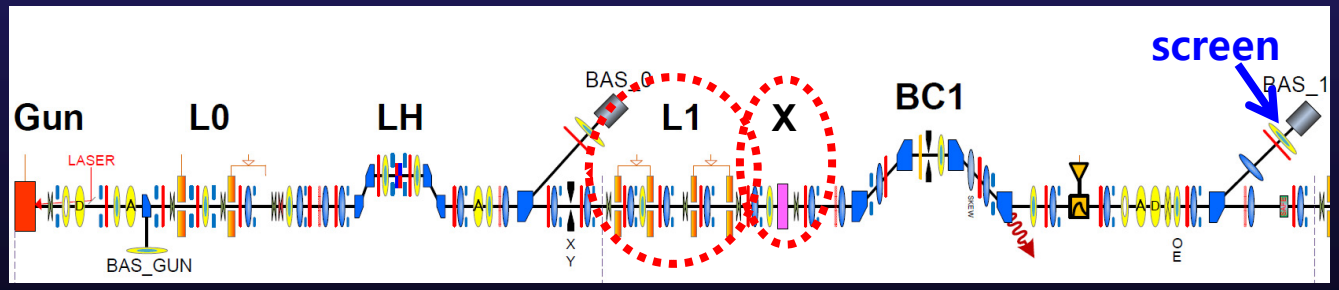
Phase Scan for On-crest



L1-02 phase scan

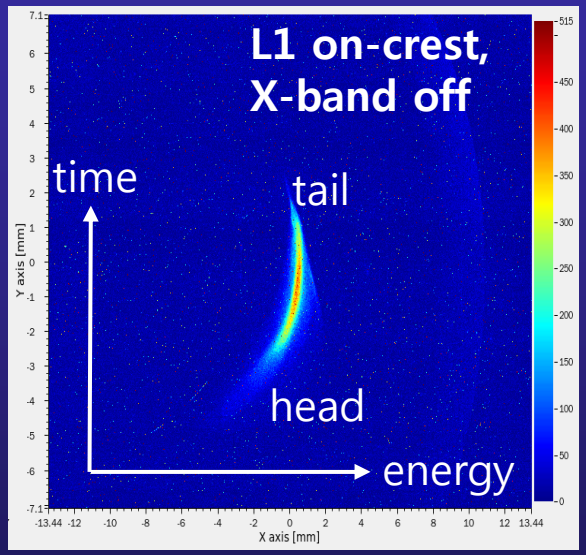


X-band phase scan

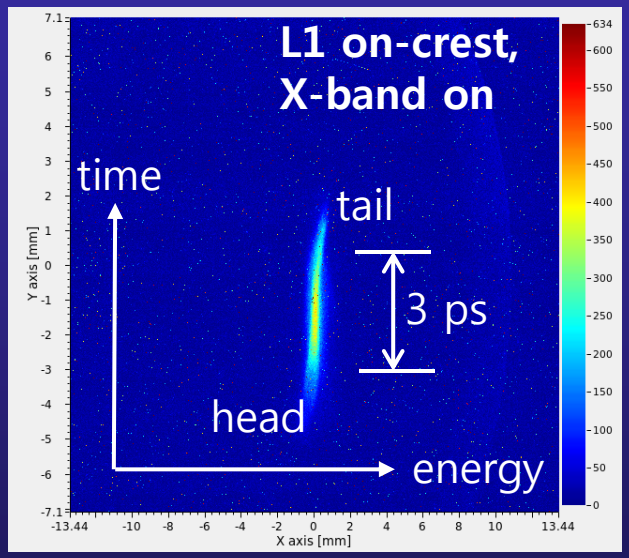


Linearization using X-band

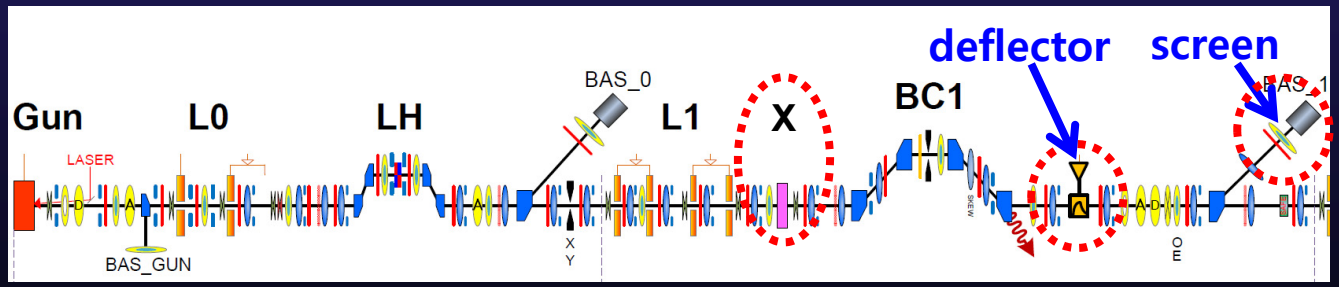
Linearization of longitudinal phase space using X-band cavity



S-band curvature shown

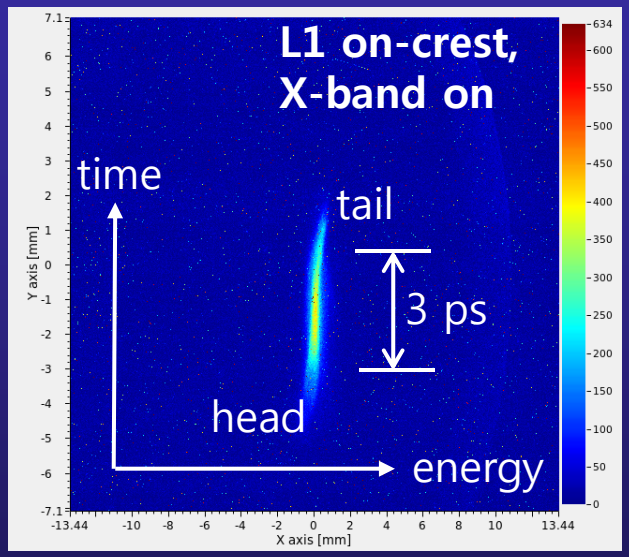


S-band curvature linearized

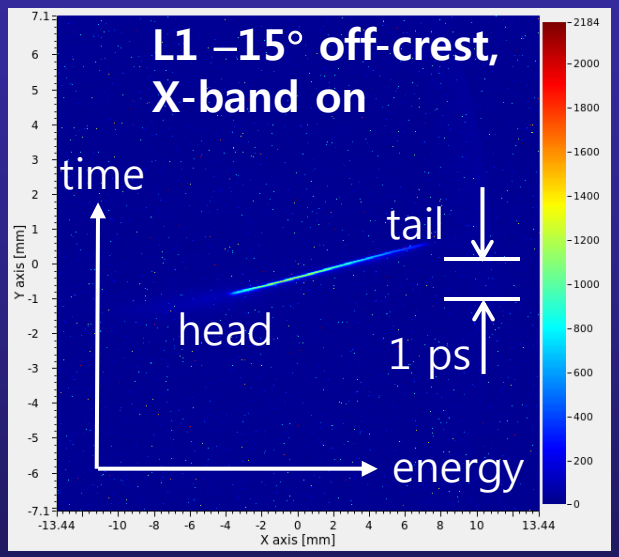


Bunch Compression at BC1

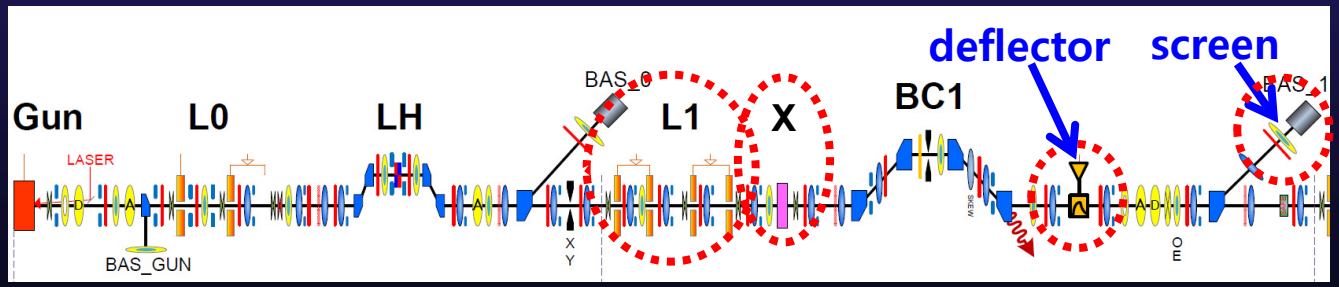
Bunch compression by applying –15° off-crest phase at L1



Not compressed
(S-band curvature linearized)



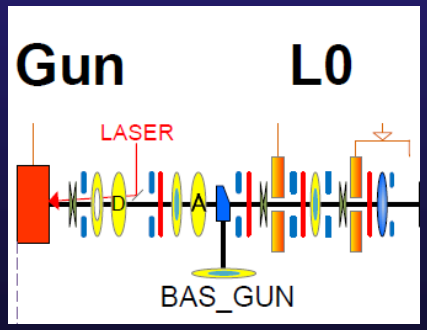
3x compressed
(S-band curvature linearized)

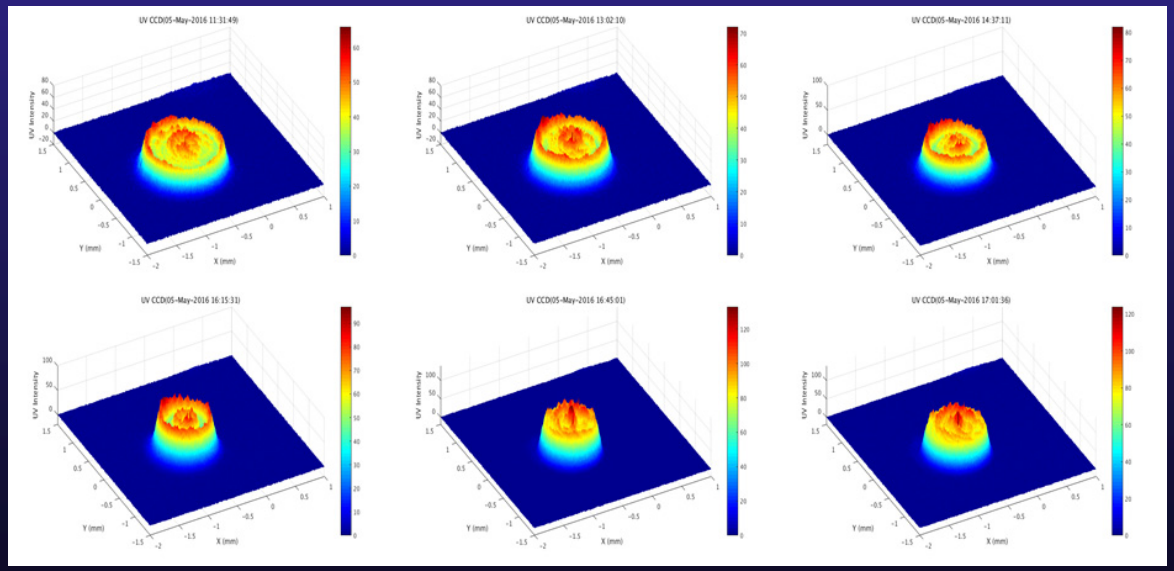


Ongoing Commissioning – 1

Fine Tuning of Injector Parameters
→ Minimum Transverse Emittance

- Gun gradient
- Gun solenoid field
- Gun phase
- L0 gradient
- Drive laser shaping

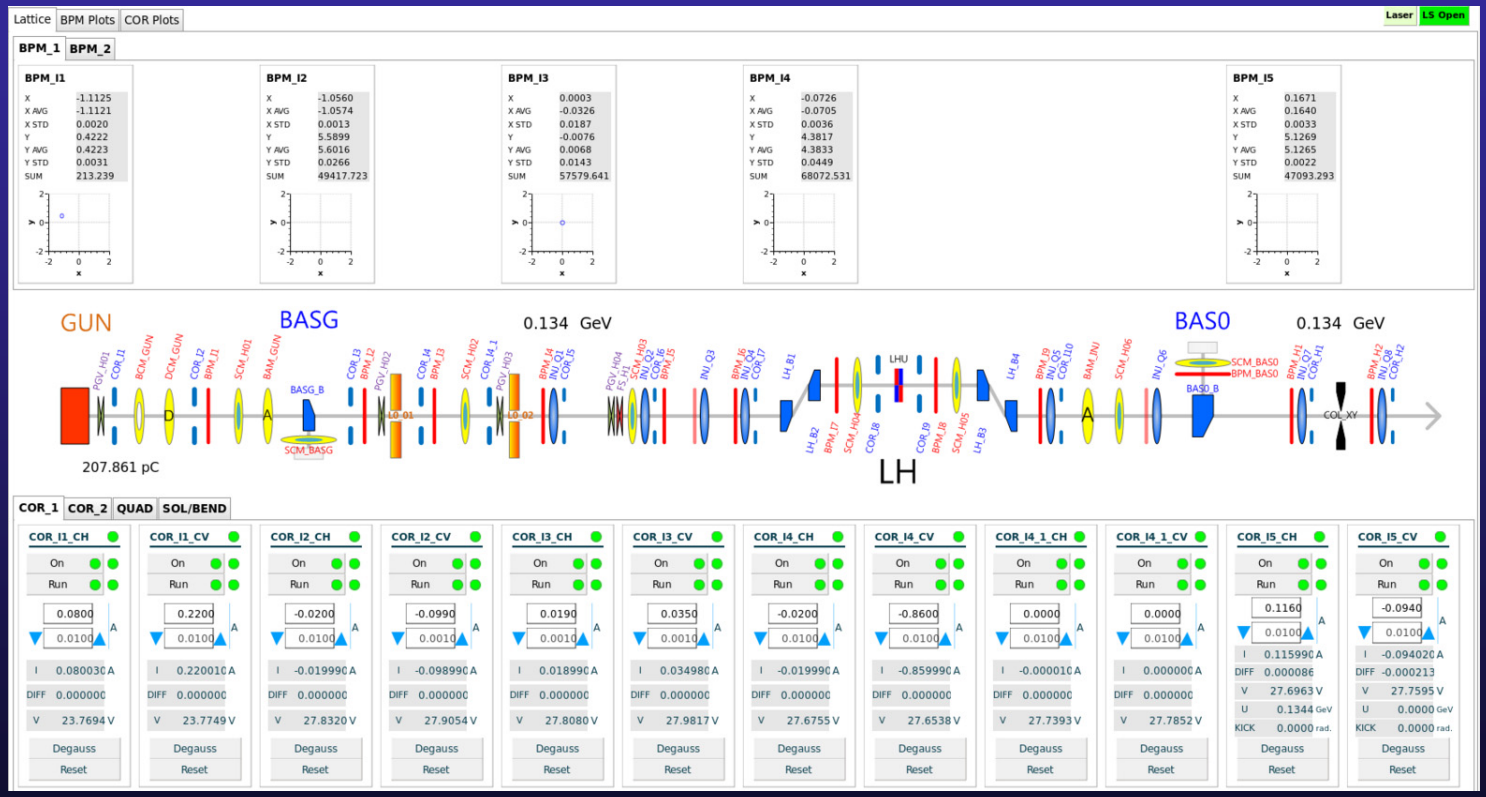




Ongoing Commissioning – 2

BBA for Injector and Linac

through cavities and magnets using BPMs and correctors



Tasks to be done for Linac

- Beta matching & dispersion correction
- Beam energy feedback
- Bunch compression feedback at BCs
- Beam position feedback at beam transport line

Tasks to be done for Undulator

- BBA thought undulator line (quads, correctors)
- Undulator & phase shifter steering table
- Undulator height alignment with beam
- Undulator K measure vs gap
- Phase shifter gap optimization
- Spontaneous emission
- SASE saturation

Summary

- PAL-XFEL construction including accelerator components installation ready
- Beam commissioning started on 14 April 2016
- 10 GeV acceleration succeeded on 25 April
- Injector and linac parameter optimization ongoing
- Undulator commissioning to start soon
- User service to start from early 2017

Thank you for attention!

The PAL-XFEL commissioning team
thank the PAL staffs
for their magnificent contribution
to the beam commissioning.