AFAD-2021
16-18 March 2021
Budker INP

Advanced laser-plasma accelerator R&D plans at PAL-ITF

Inhyuk Nam

On behalf of the PAL-ITF team

PAL 포항가속기연구소
POHANG ACCELERATOR LABORATORY

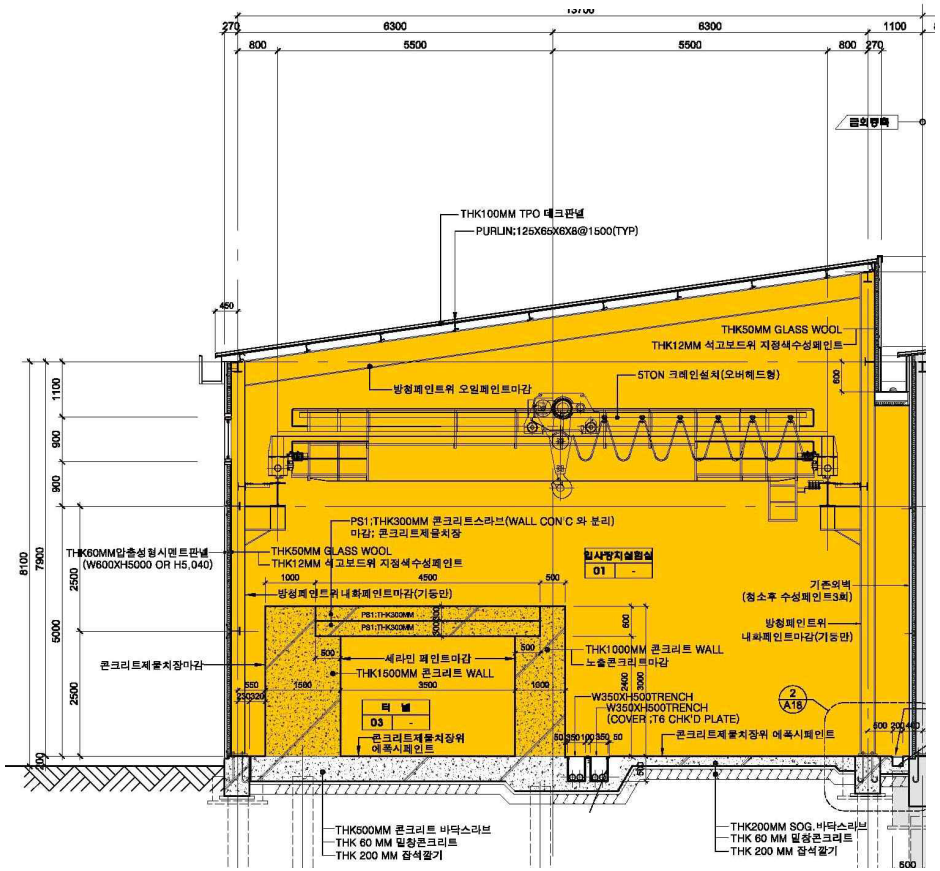
Outlines

- History of PAL-ITF (injector test facility)
- Facility R&D programs up to now
- Re-arrangement of two e-beam lines at PAL-ITF
- On-going R&D activities
- Summary

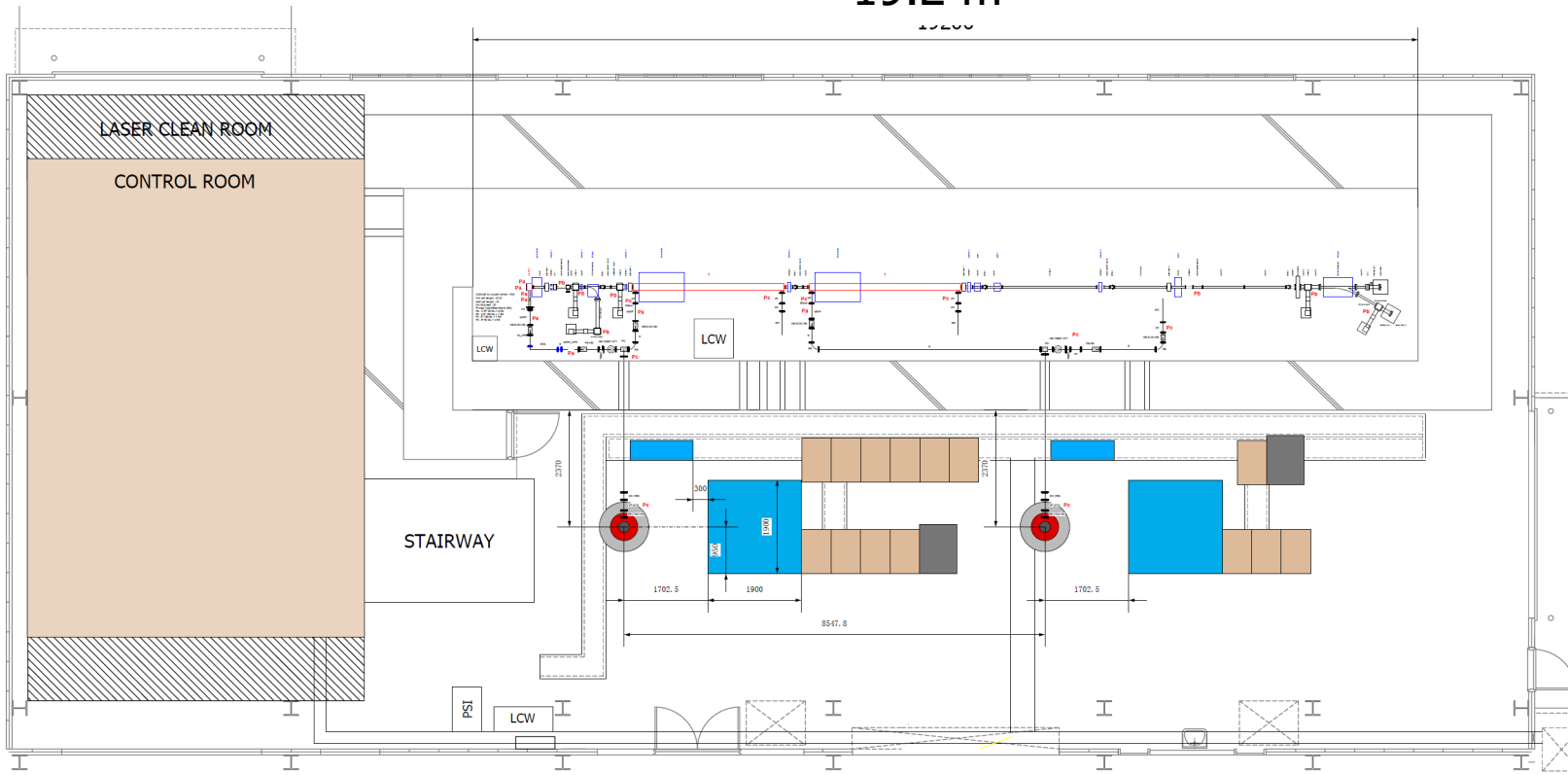

PAL-XFEL
PLS-II
PAL-ITF
PAL-XFEL

ITF layout

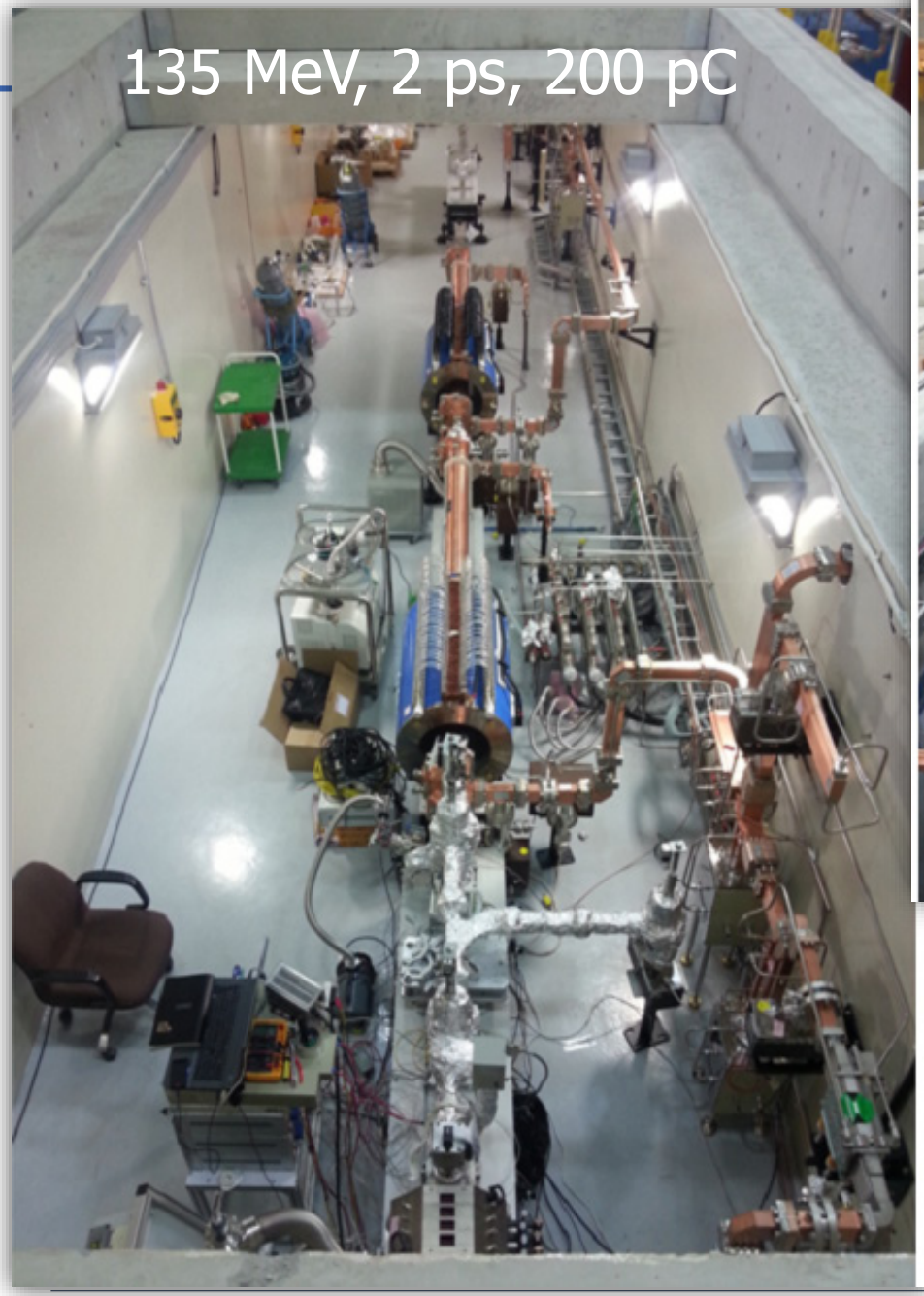
13.7 m



19.2 m

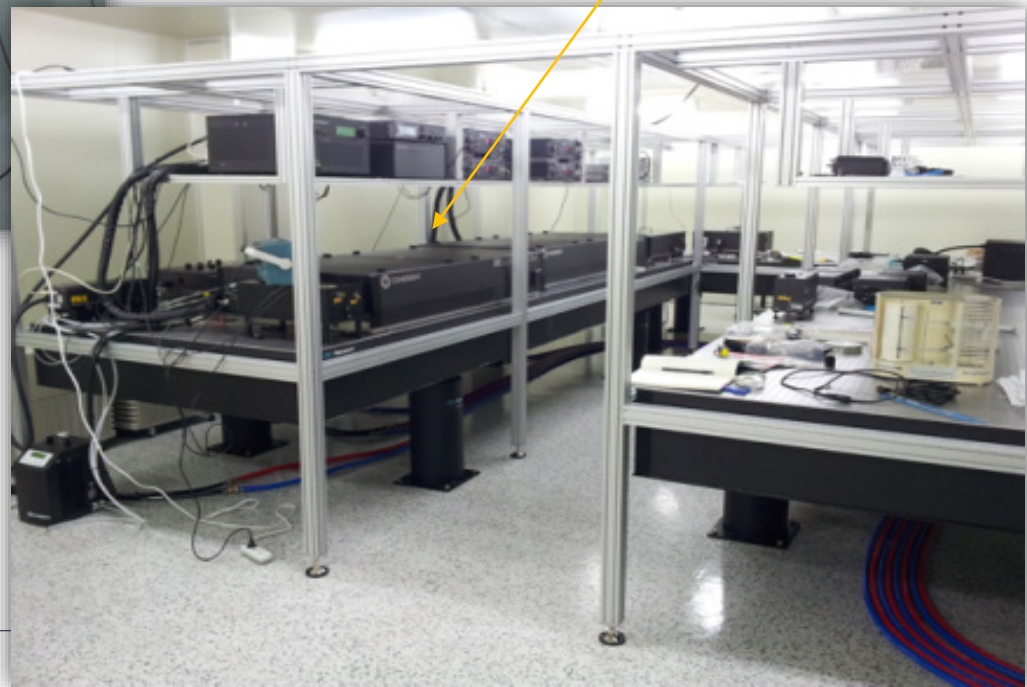


Tunnel 3.5(width) X 19.2(length) X 2.5(height) m



80 MW, 10 Hz RF source
With LLRF

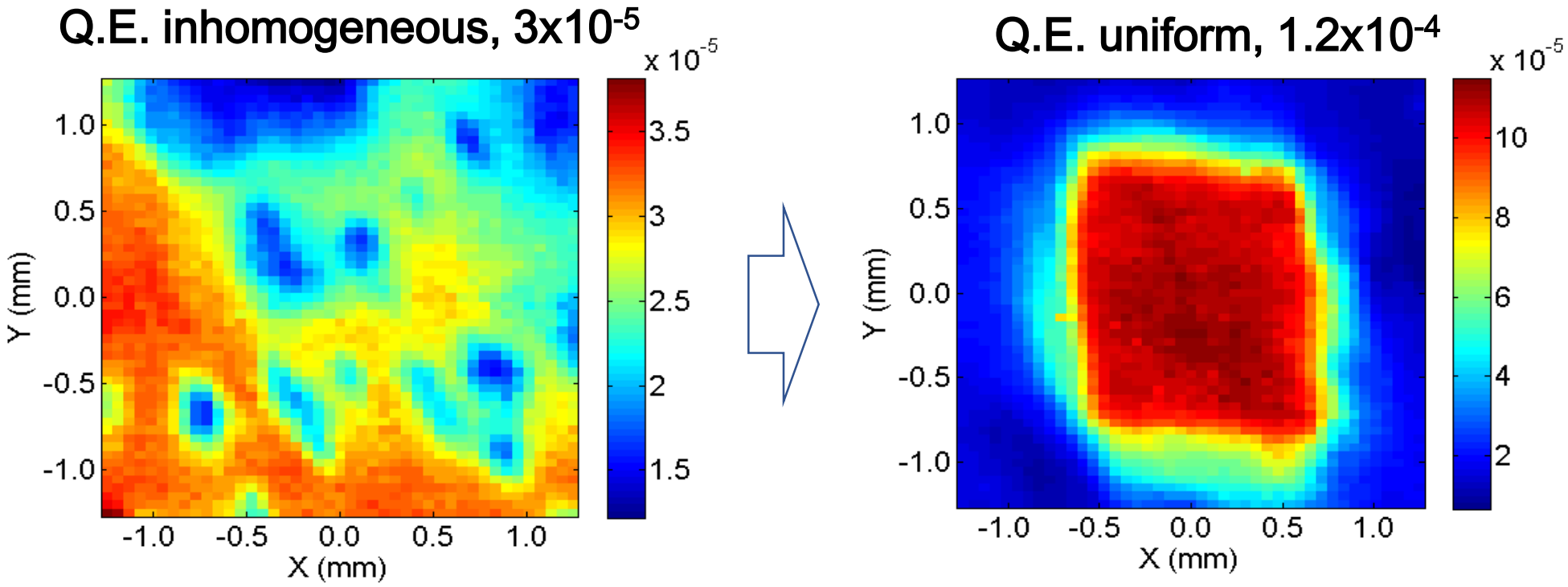
Ps Ti:sapphire, 15 mJ



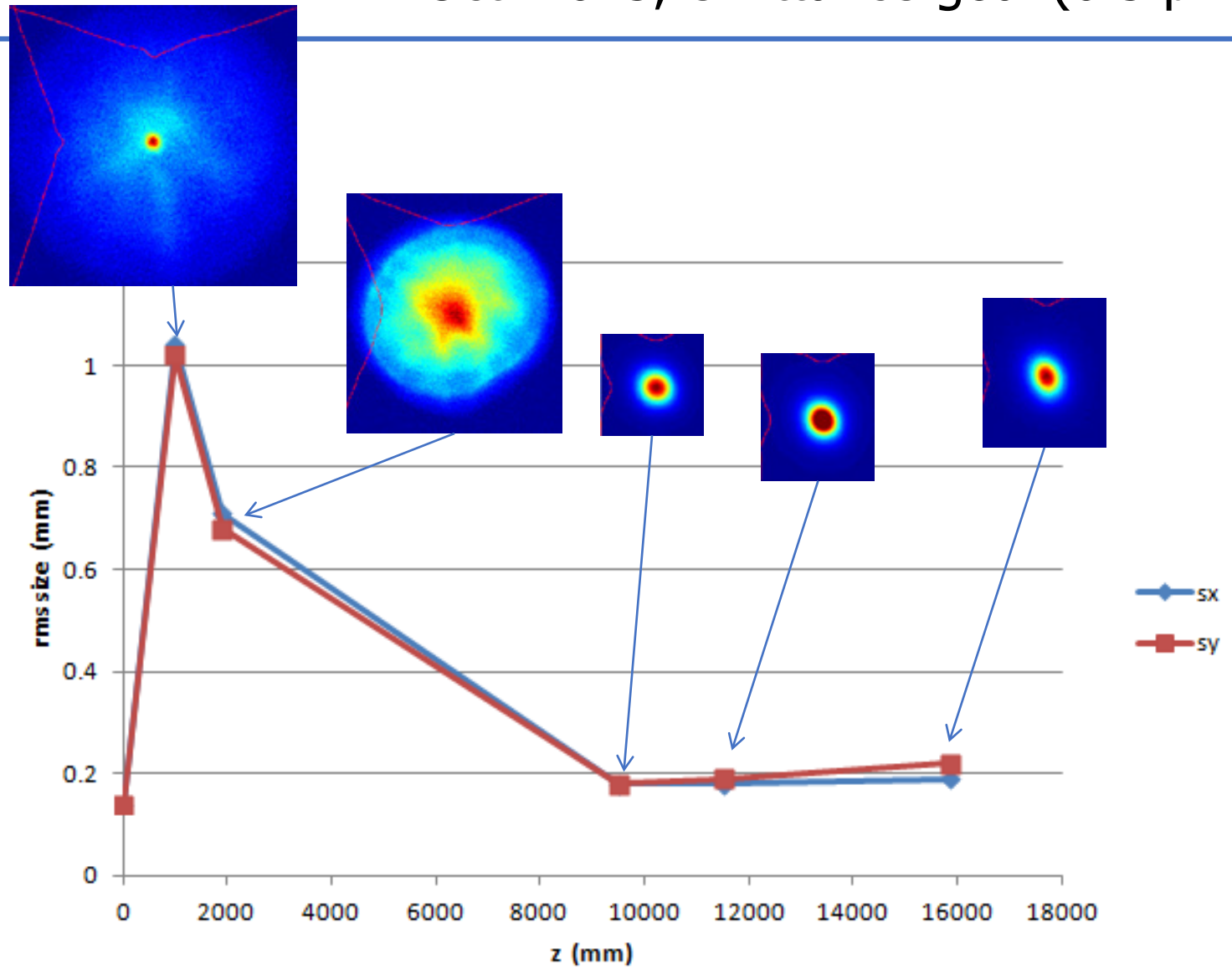
2012

ITF History

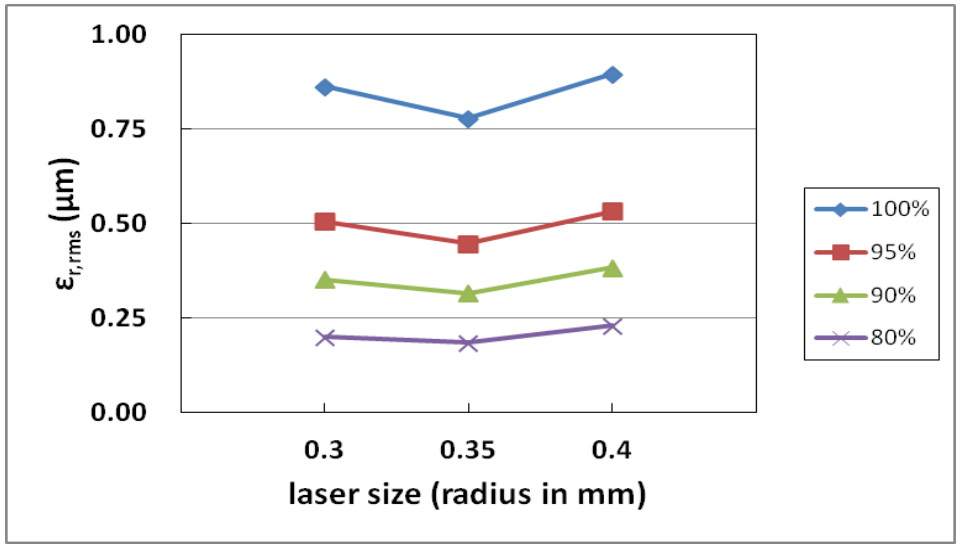
- 2011~2012, construction (135 MeV injector performance demonstration for XFEL)
- Dec. 2012, First beam
- 2013, IR laser cleaning



Oct. 2013, emittance goal (0.5 μmrad) achieved

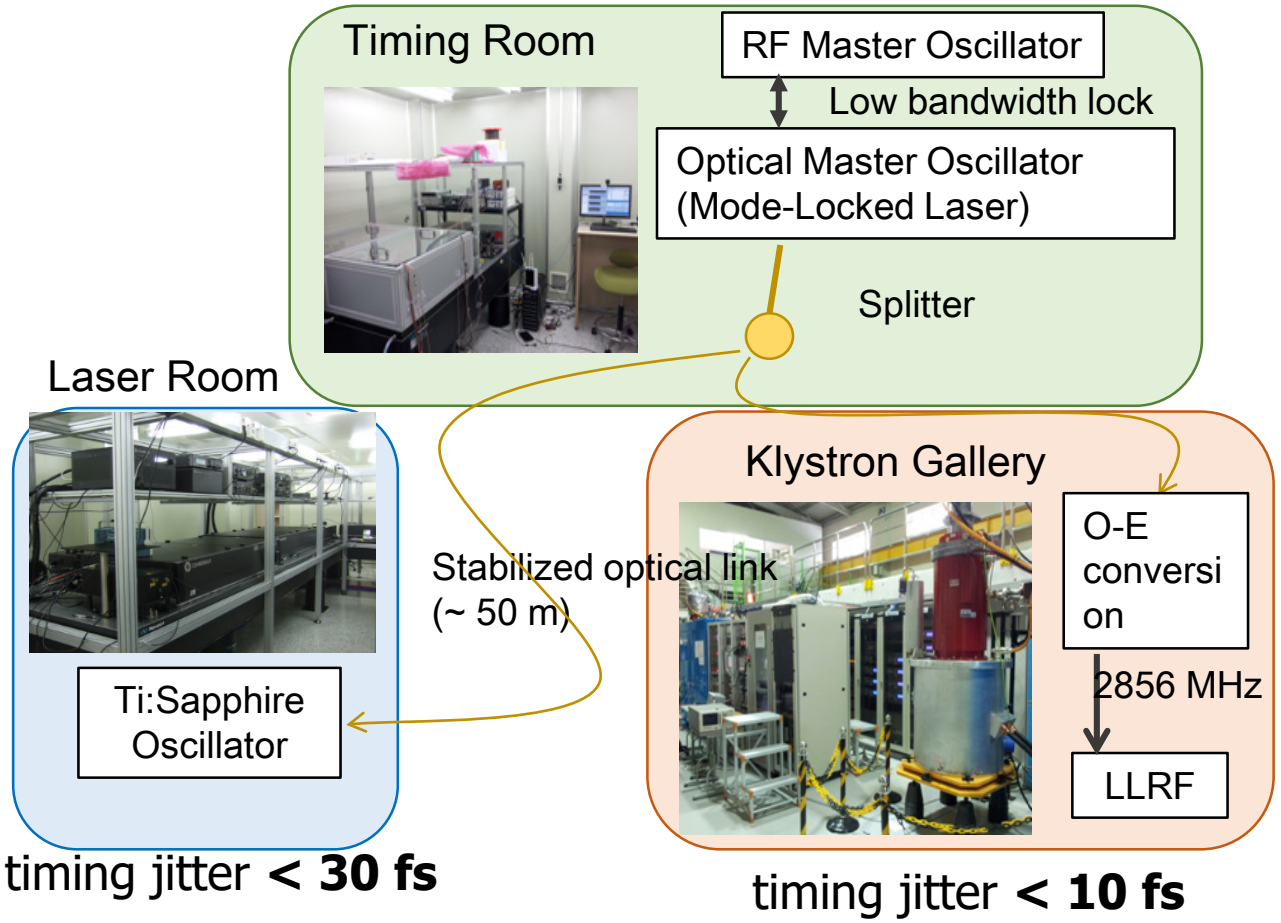


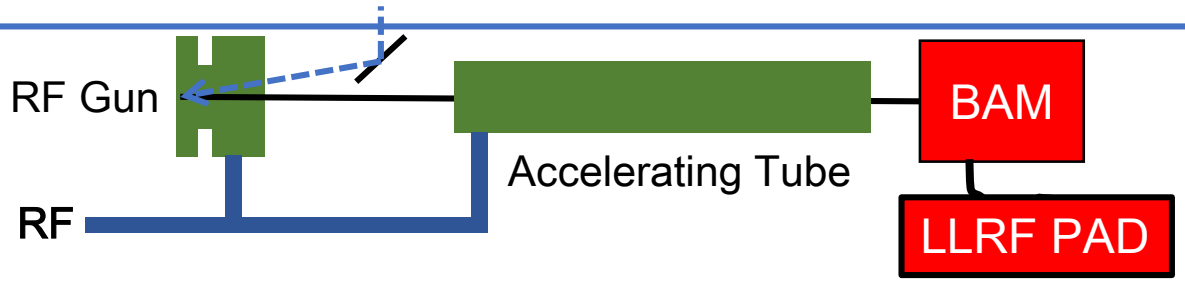
$\varepsilon_x \sim 0.41$ μm (95%)
$\varepsilon_y \sim 0.48$ μm (95%)

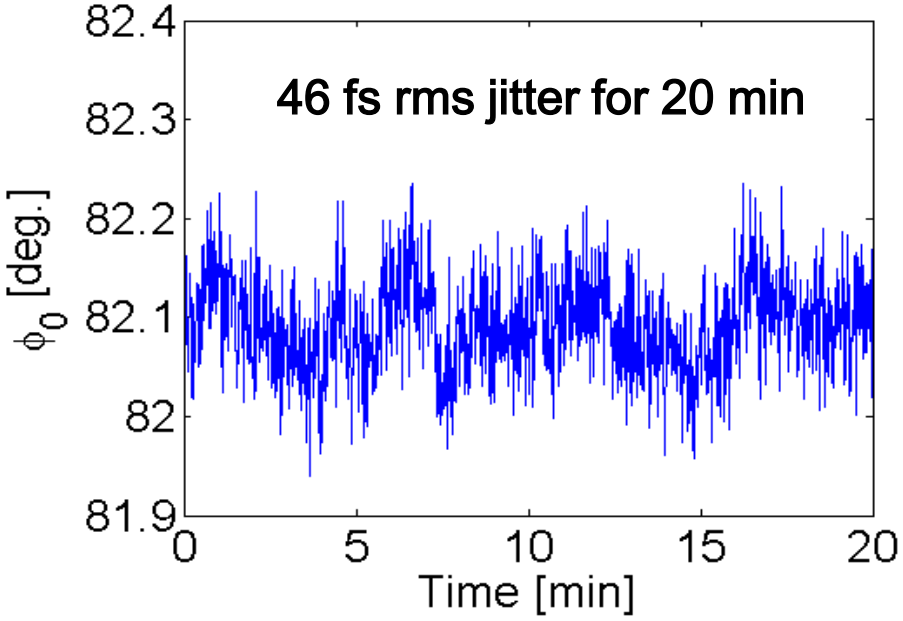


M. S. Chae
J. H. Han

2012~2014, optical timing test





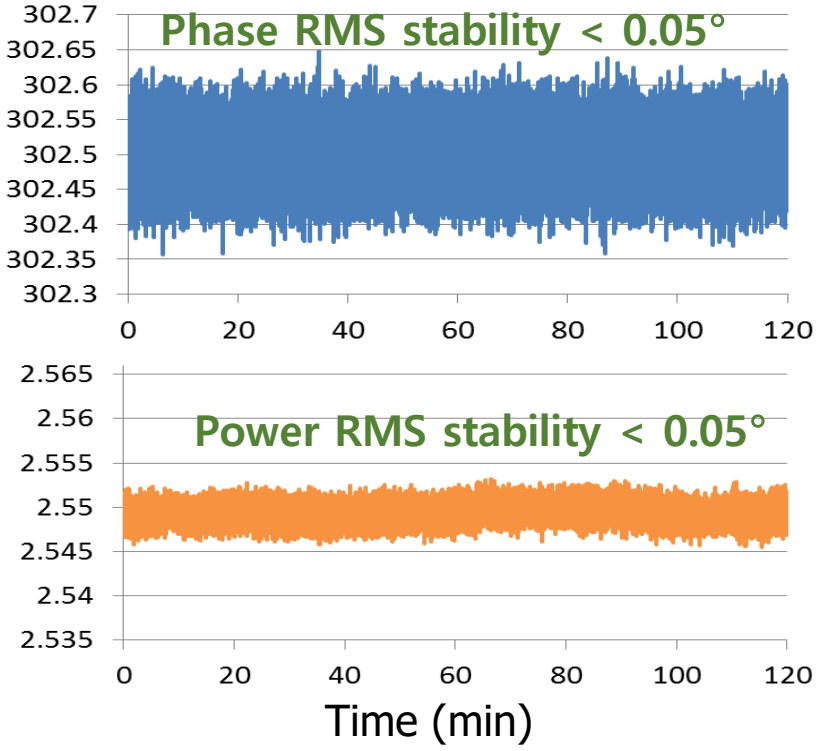


Kwangyun Jung, et al., *Opt. Lett.* **39**, 1577(2014)

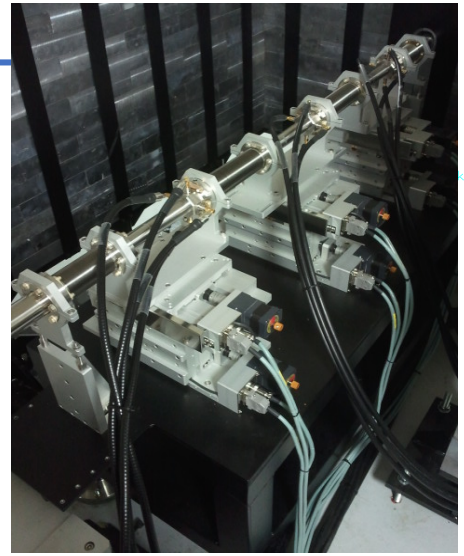
Kwangyun Jung, et al., *J. Lightwave Technol.* **32**, 3742(2014).

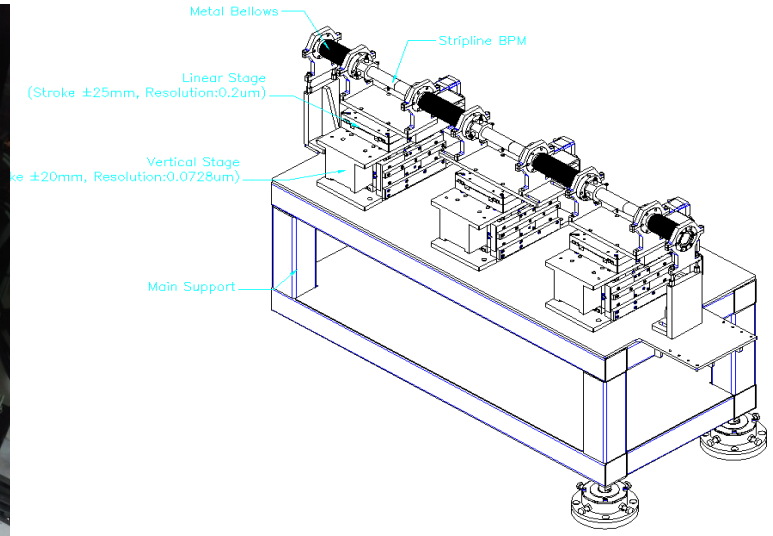
~2015, RF system, diagnostics test

LLRF

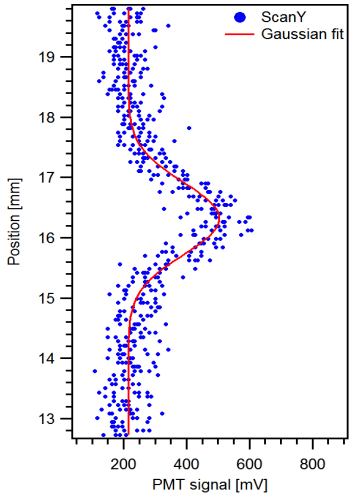


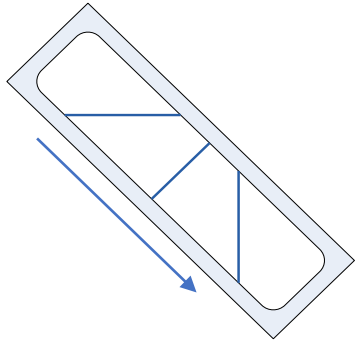
BPM

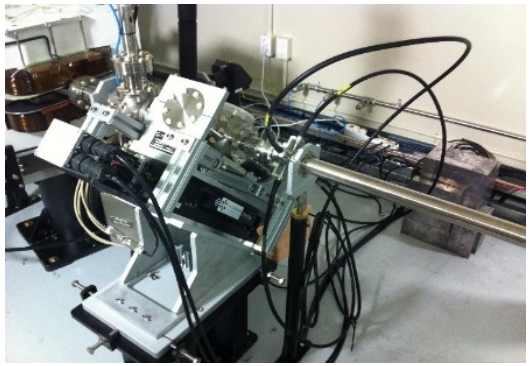


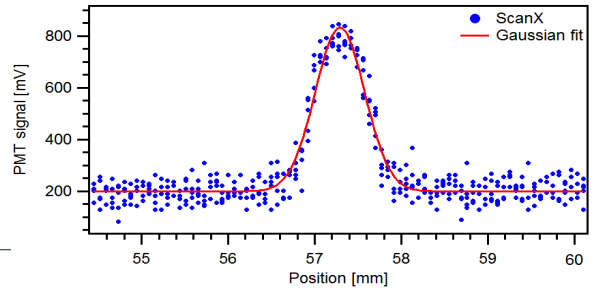


Wire scanner

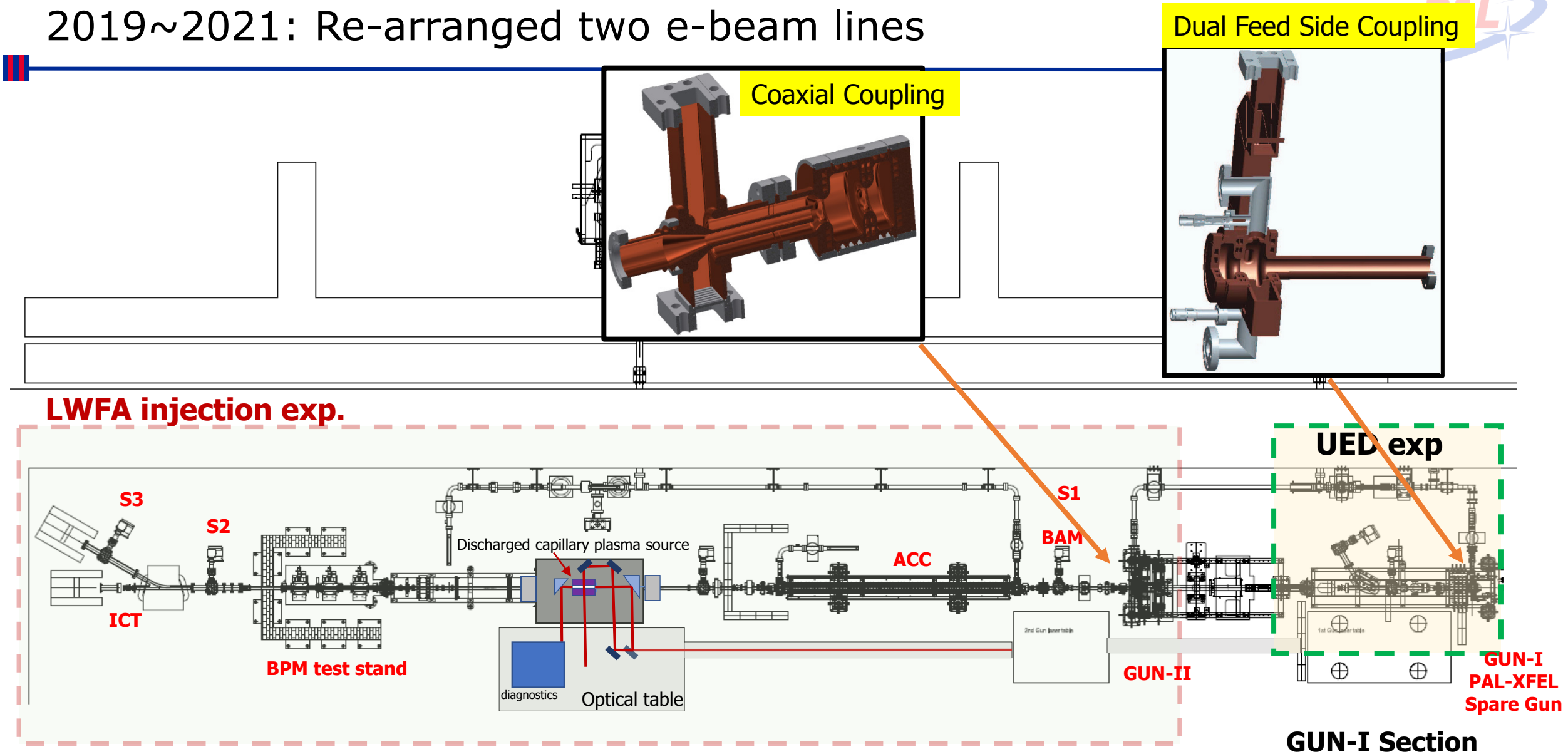








2019~2021: Re-arranged two e-beam lines



GUN-II Section
(200 pC, 70 MeV, 10 Hz)

GUN-I Section
(200 pC, 6 MeV, 10 Hz)

ITF parameters

e-beam parameters

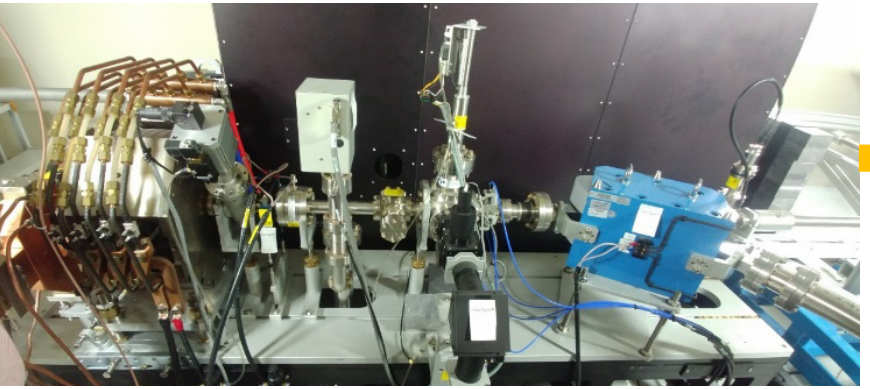
	Gun - I	Gun - II	XFEL
Charge	<250 pC	<250 pC	
Emittance	~0.5 μm	~0.5 μm	
Energy	<6 MeV	70 MeV	
Energy spead	$<2\times10^{-3}$	$\sim1\times10^{-4}$	
Rep. rate	10 Hz	10 Hz	60 Hz
RF Phase stability	5×10^{-2} deg	5×10^{-2} deg	1×10^{-2} deg
RF Amp. stability	5×10^{-4}	5×10^{-4}	1×10^{-4}

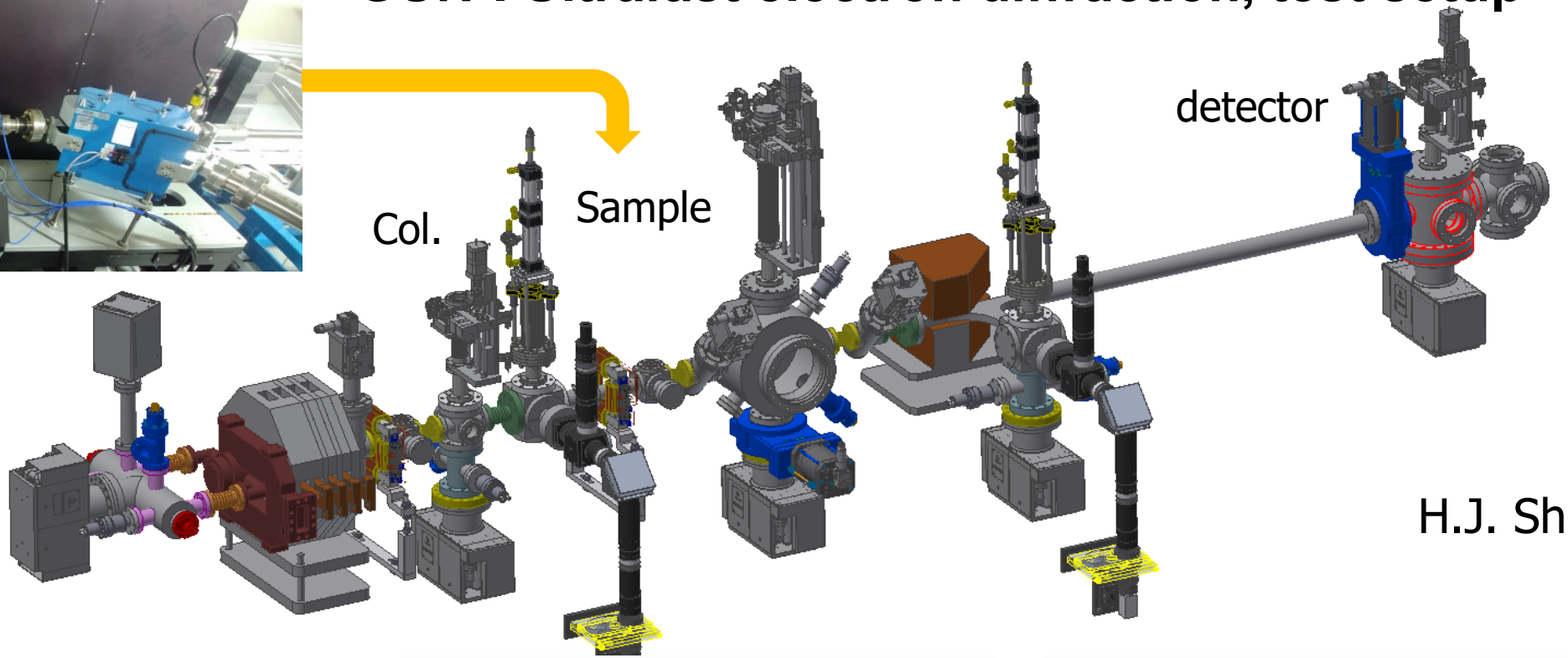
Diagnostics
- ICT, BPM, Screen monitor, BAM, energy analyzer

Laser parameters (760nm, Ti:sapphire)

	ITF	XFEL
Power	14 mJ (760 nm) ~1 mJ (253 nm)	9 mJ (760nm)
Pulse width	> 1 ps (norm. 3ps)	
Rep. rate	120 Hz	
Power stability	0.2% (760 nm) <1% (253 nm)	
Beam size At Gun	0.1~3mm (full beam)	
Sync. jitter	~100 fs	~10 fs

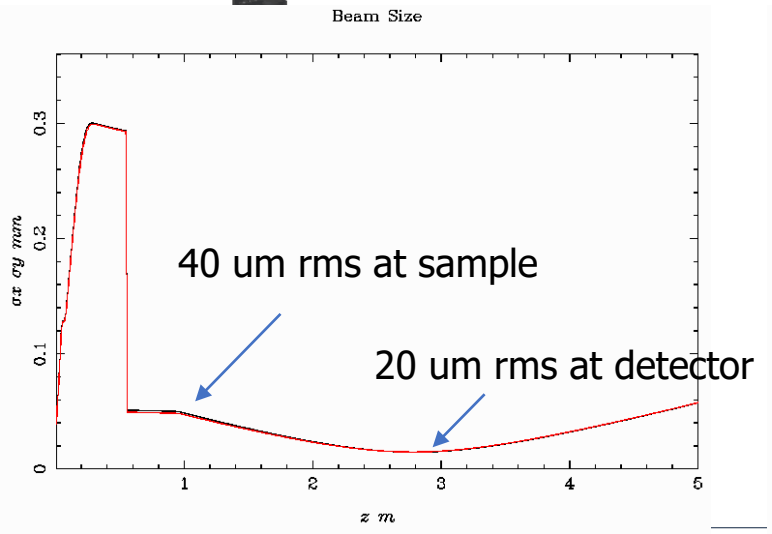
GUN-I Ultrafast electron diffraction, test setup

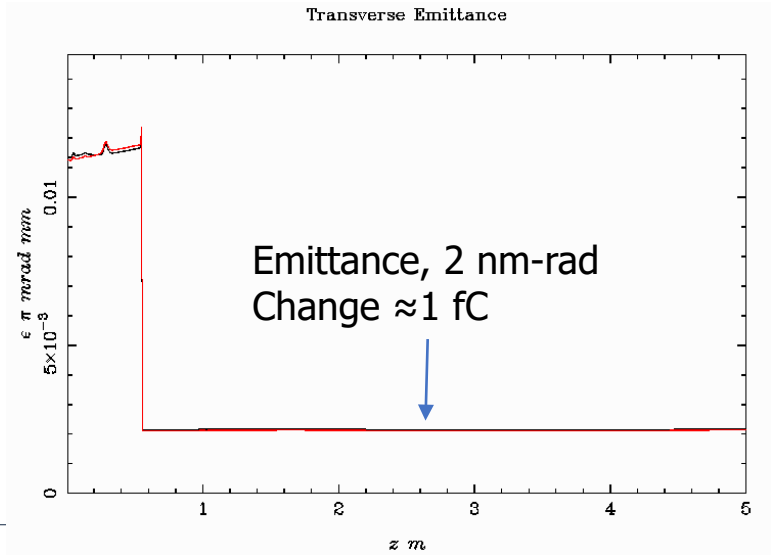




H.J. Shin

ASTRA simulation (J.H. Ko)
- Parameters are refered from "Mega-electron-volt ultrafast electron diffraction at SLAC National Accelerator Laboratory", SP Weathersby *et al.* Review of Scientific Instruments 86. 073702 (2015)
- 4 MeV, 70 fC, 26 fs rms e- beam, 100 um collimator

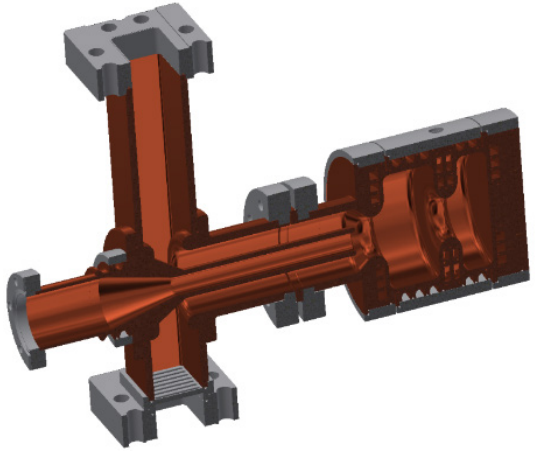


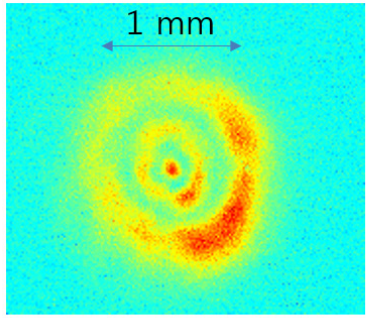


Gun-II emittance test

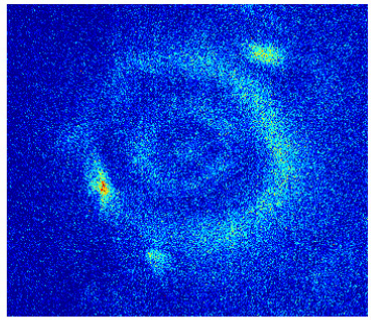
❖ **GUN-II**

- Alternative RF gun for PAL-XFEL
- Coaxial coupler type
- f = 2856 MHz
- Q_0 = 14400
- f_{rep} = 10 Hz
- τ_{pulse} = 2.5 μS

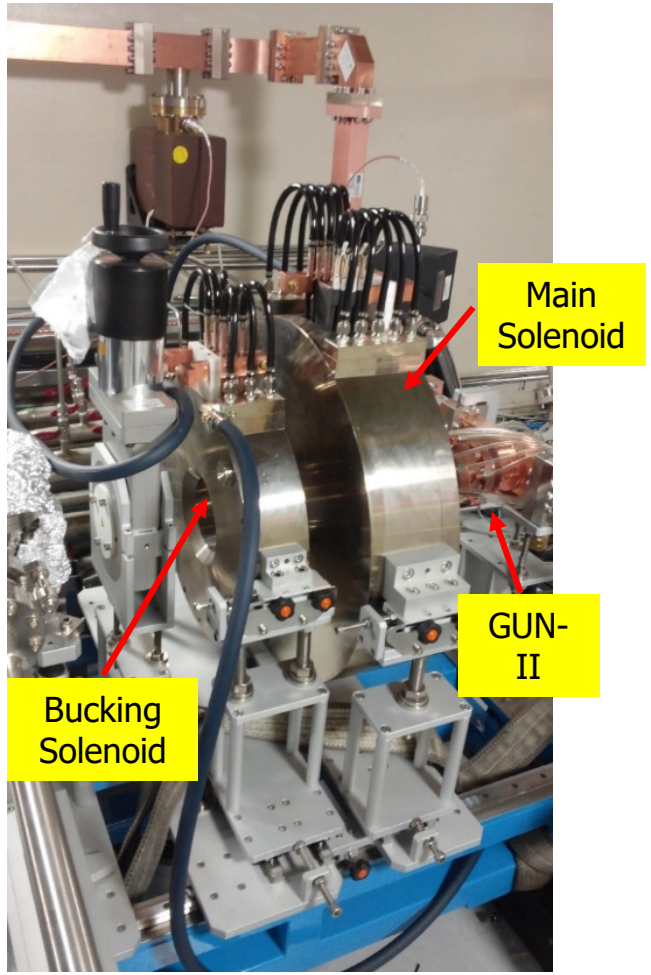




Virtual cathode (laser profile)



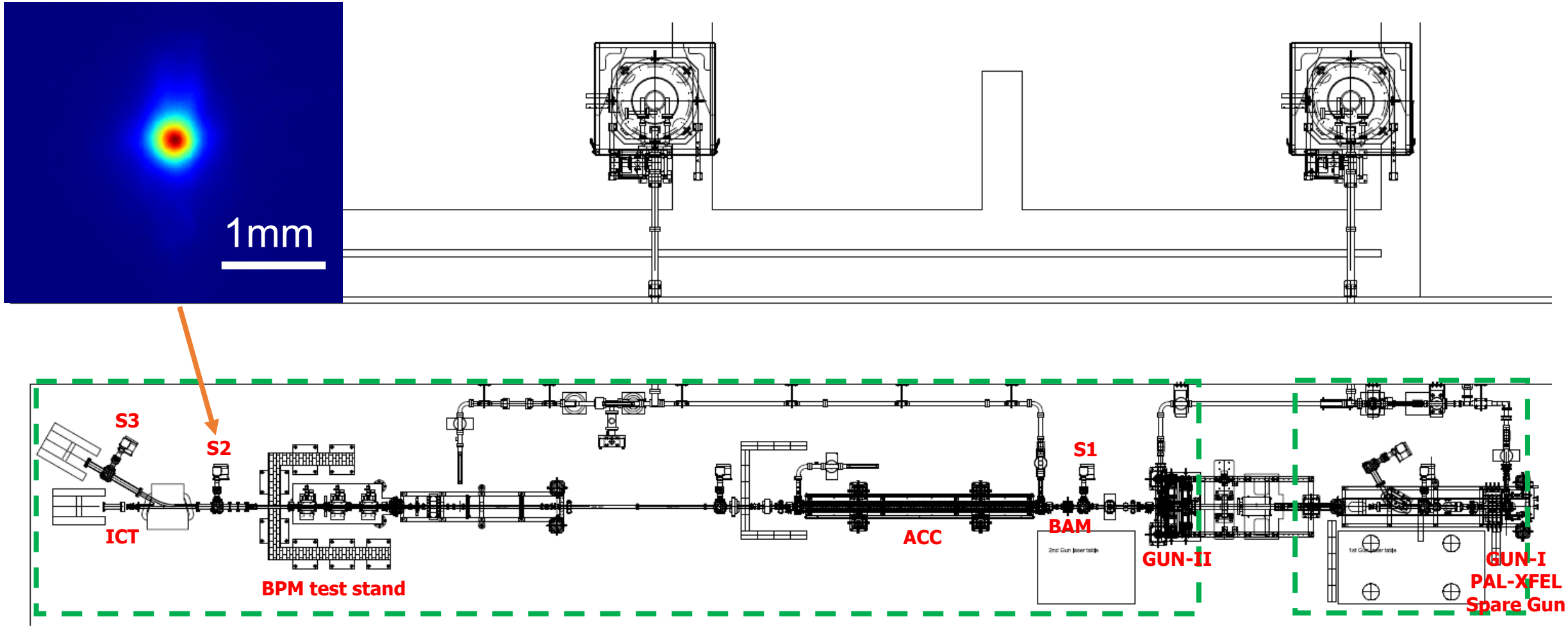
E- beam image at 1st screen



	GUN-I	GUN-II
Repetition rate (Hz) @ $E_{cathode,max}$ = 120 MV/m	120 (60)	700 (10)
$\varepsilon_{n,rms}$ (nmrad) @ 200 pC	0.3 (0.35)	0.2 (no meas.)

J. Hong

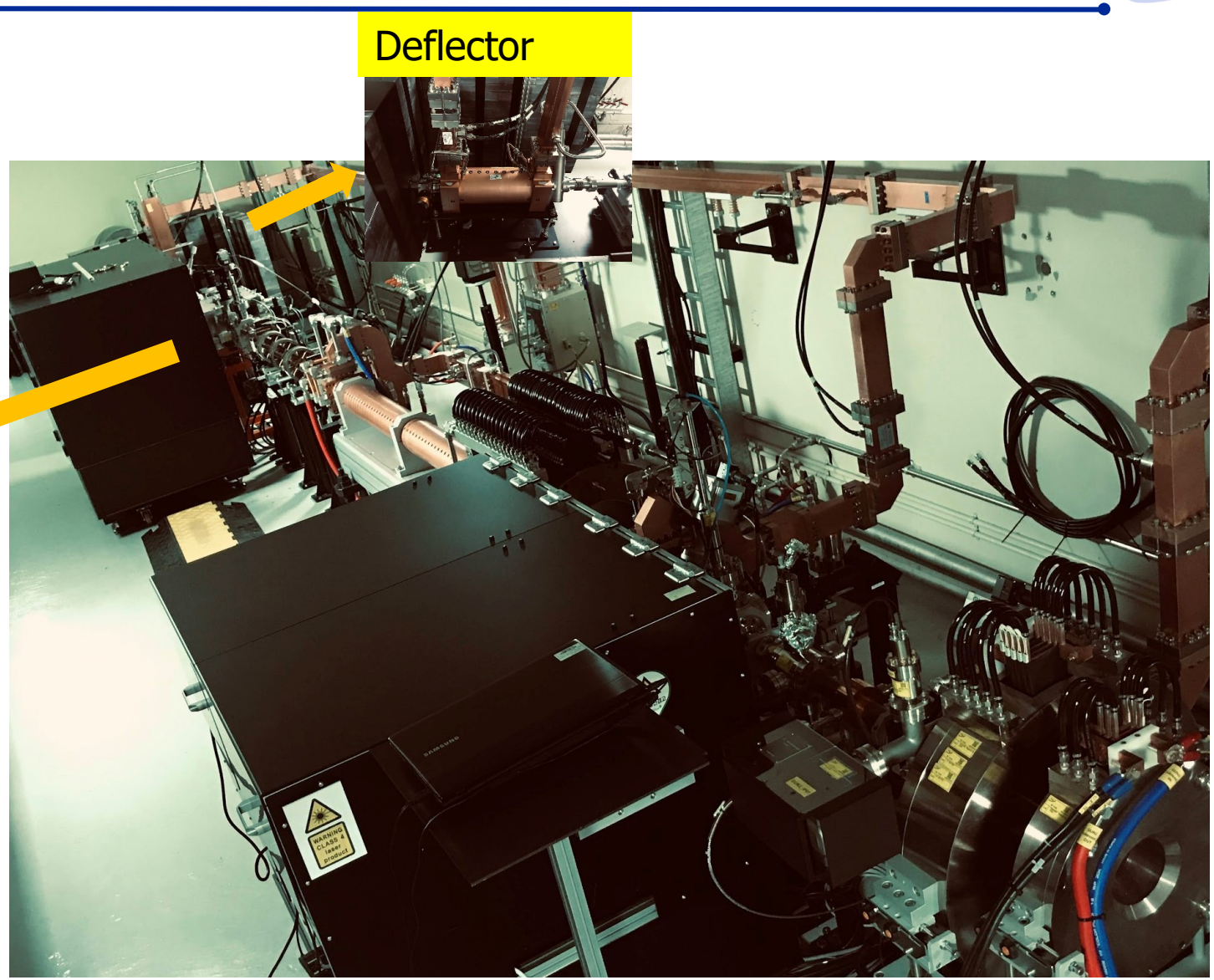
GUN-II Beam profile



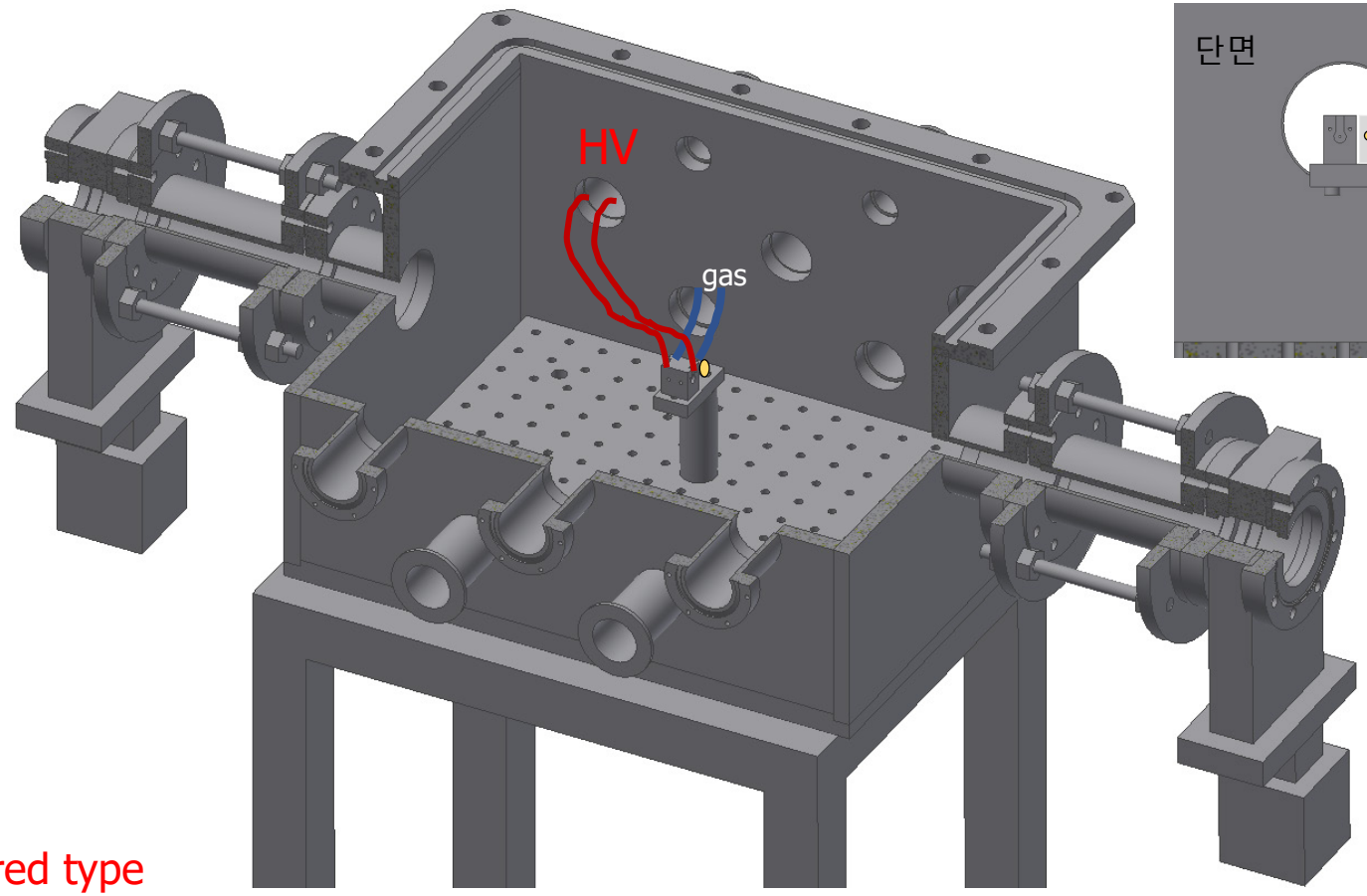
GUN-II Section
(200 pC, 70 MeV, 10 Hz)

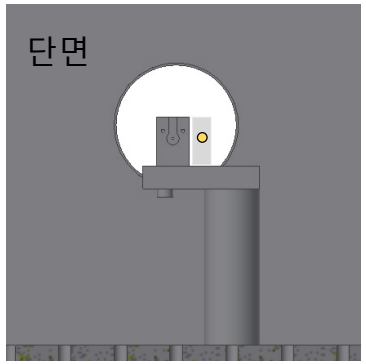
GUN-I Section
(200 pC, 6 MeV, 10 Hz)

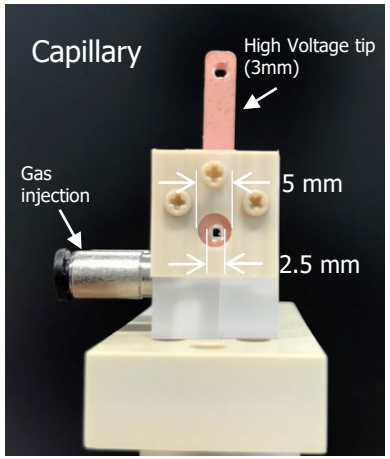
ITF GUN-II beam line (2021.3.8)

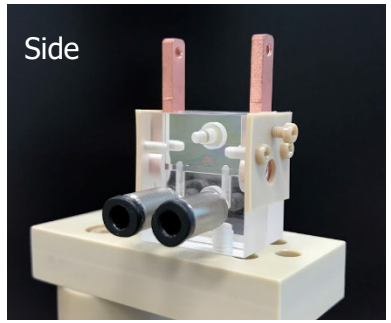


Developed discharge capillary source

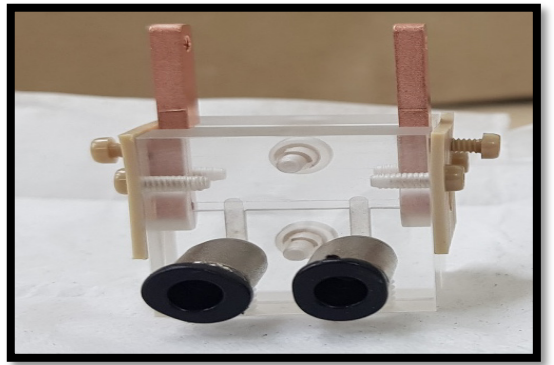


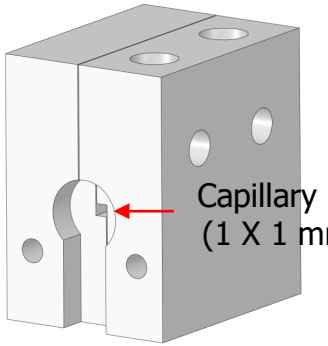




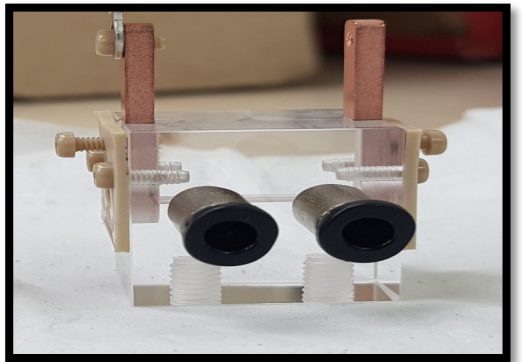


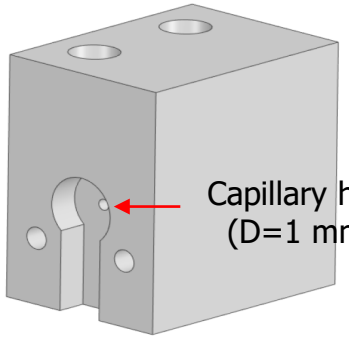
Squared type





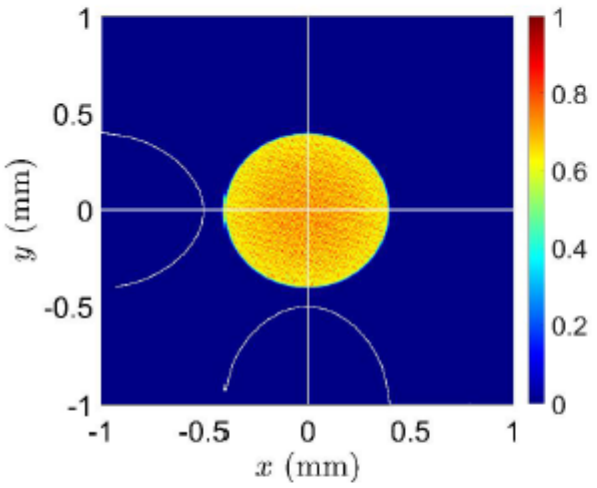
Cylindrical type





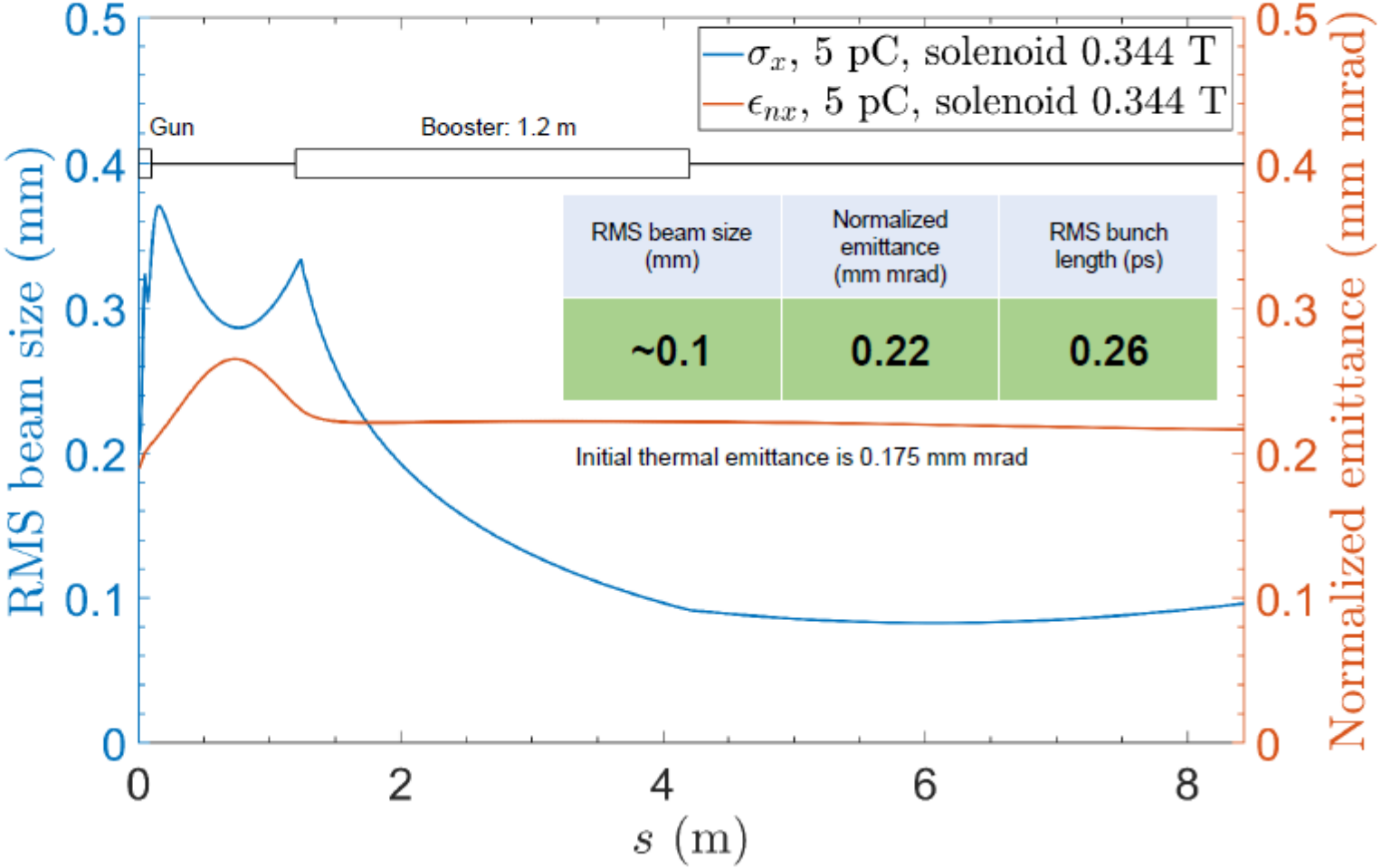
Beam size, emittance using 5 pC beam

Initial distribution



Un-truncated Initial RMS beam size	0.8 mm
Truncate parameter C_sig	0.50
Truncated RMS beam size	0.2 mm
RMS bunch length	0.1 ps

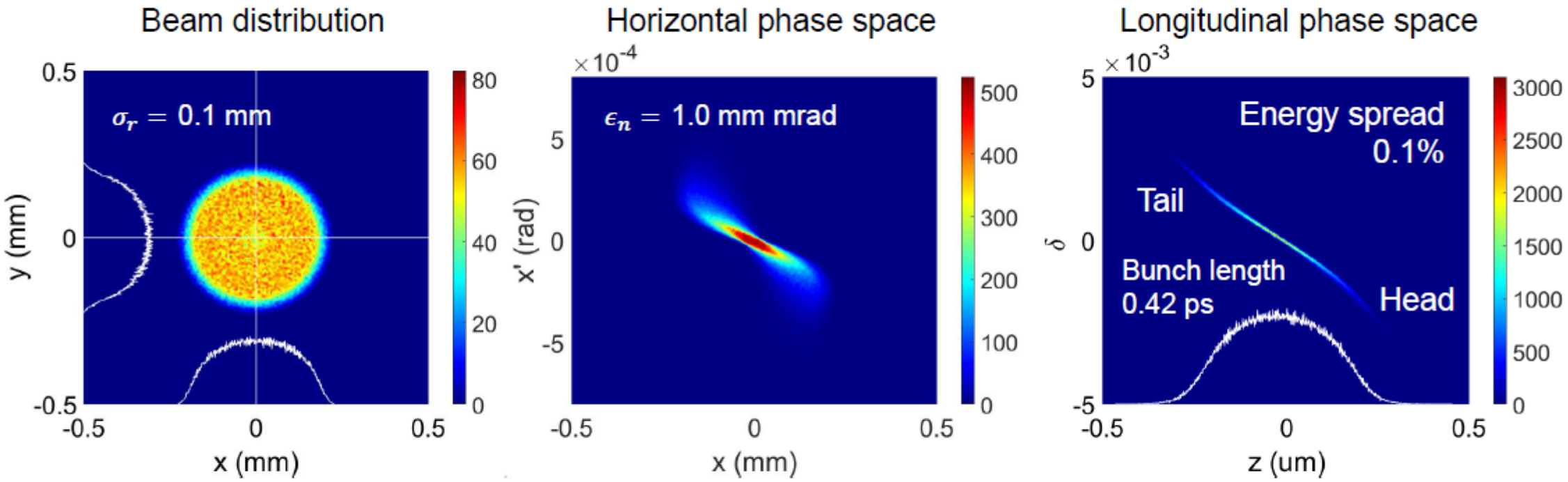
➢ Target position (8.43 m) is located at the end of this plot



RMS beam size (mm)	Normalized emittance (mm mrad)	RMS bunch length (ps)
~0.1	**0.22**	**0.26**

S.Y Kim (UNIST)

Phase space at target position

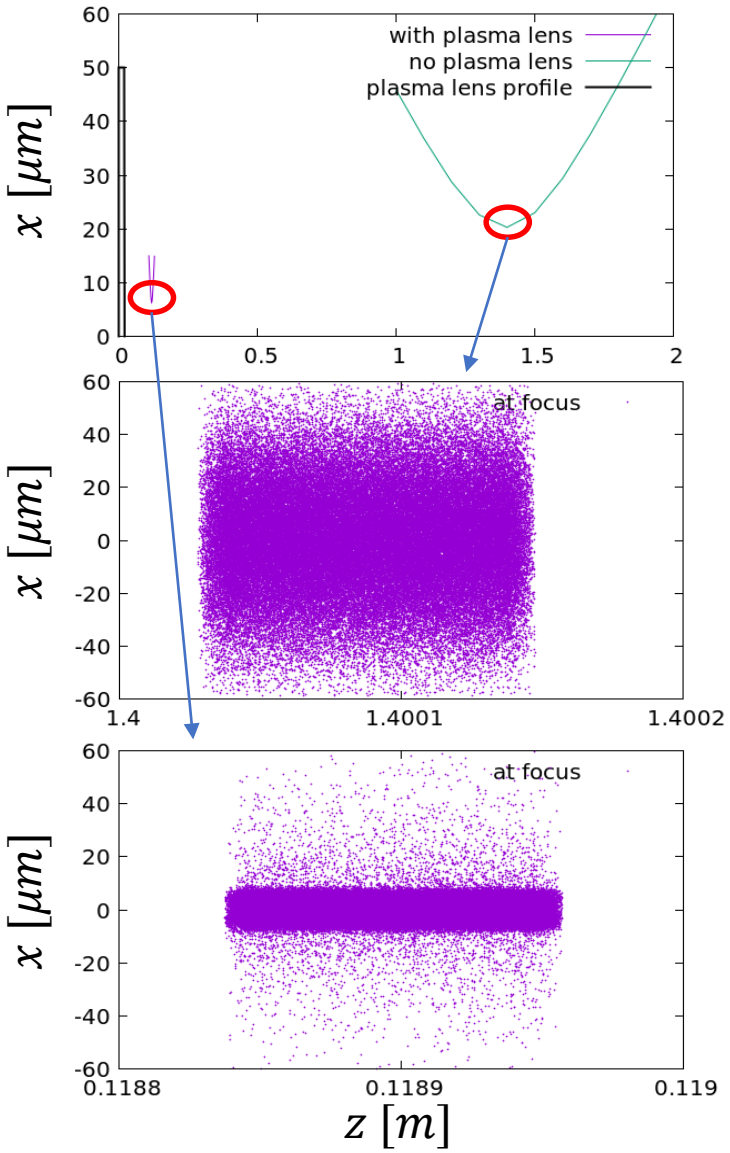


❖ For the low-emittance less than 0.5 mm mrad, we need to cut the initial distribution to reduce the nonlinear space charge force, and need to adjust the booster position

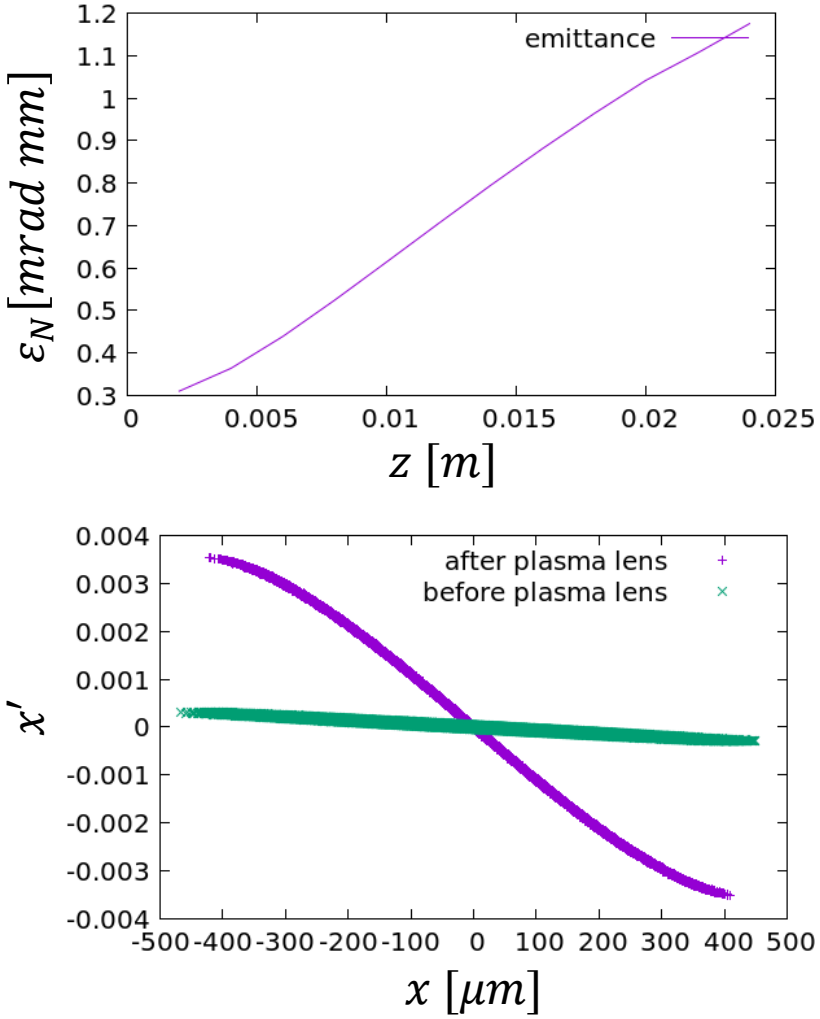
S.Y Kim (UNIST)

Plasma lens simulation

Track calculation (ASTRA)



PIC simulation



PIC parameters

<u>Capilary</u>

$$I_0 = 80\ [A]$$
$$R_0 = 500\ [\mu m]$$
$$L = 2\ [cm]$$

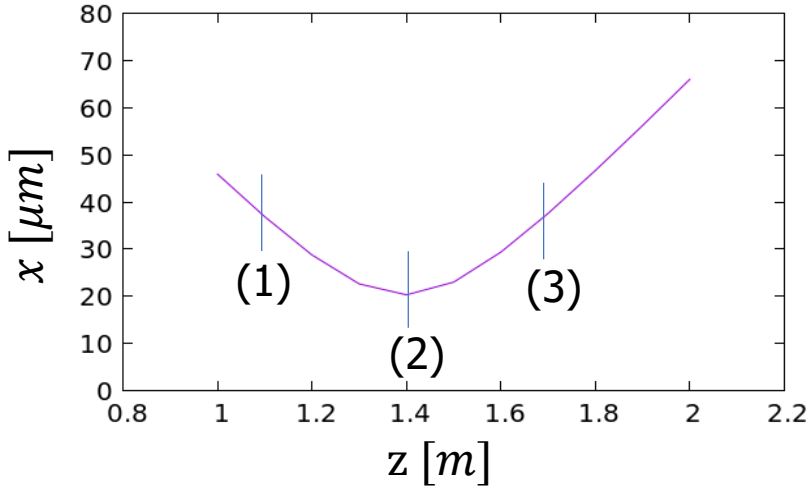
<u>e-beam</u>

$$n_0 = 2.3 \times 10^{19}\ [m^{-3}]$$
$$L = 100\ [\mu m]$$
$$\varepsilon_N = 0.305\ [mrad\ mm]$$
$$\beta_x = 10\ [m]$$
$$\alpha_x = 7$$
$$charge = 1\ [pC]$$

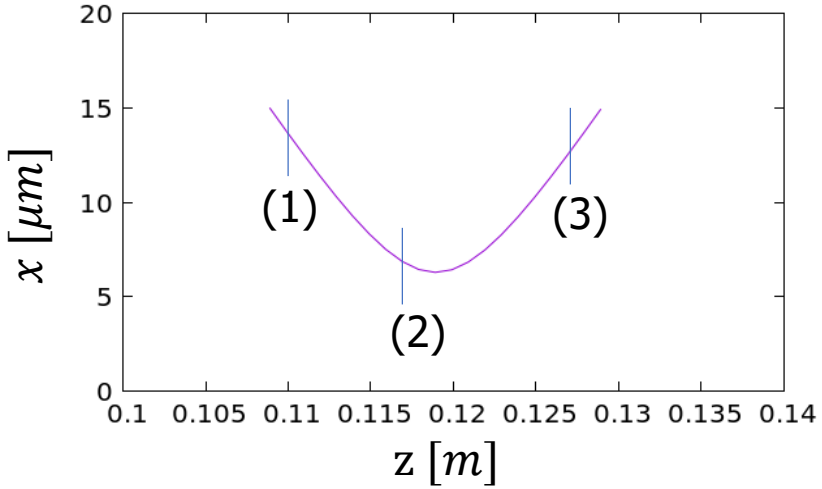
Myung Hoon Cho (PAL)

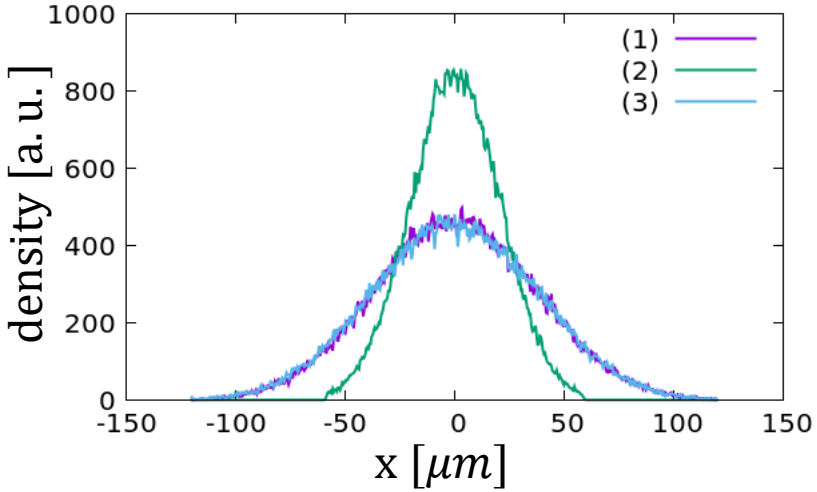
Plasma lens simulation

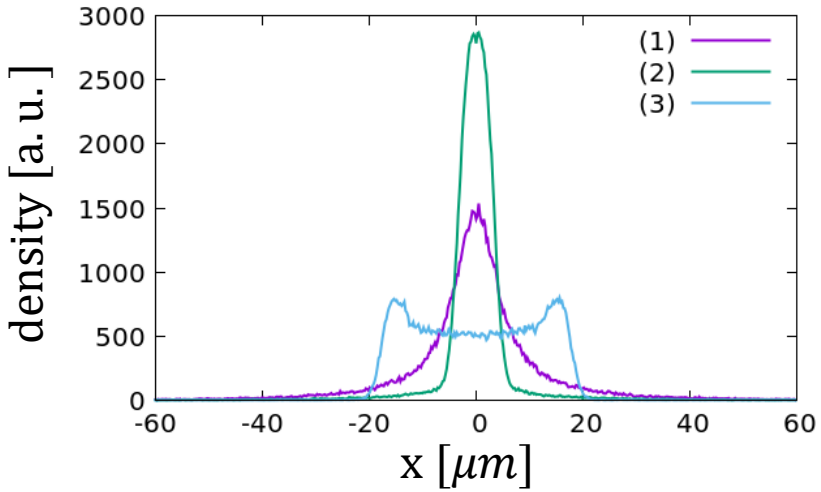
without plasma lens



with plasma lens







Myung Hoon Cho (PAL)

Preliminary PIC simulation test results

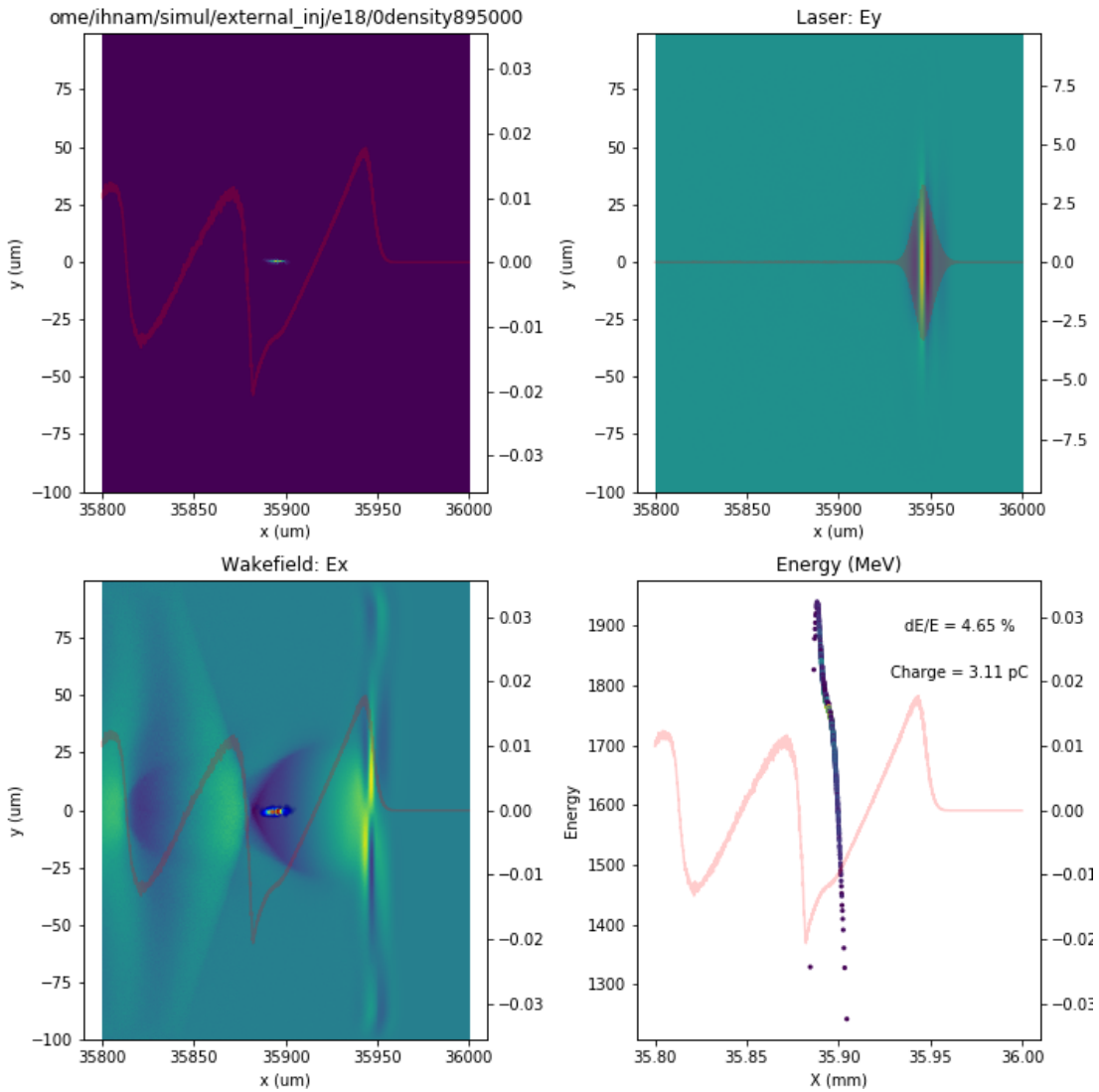
LWFA with external injection

e-beam (from RF photocathode)
- Charge: 5 pC
- Pulse duration: 30 fs (FWHM)
- Energy: 70 MeV
- Emittance: 0.2 mm mrad
- Beta: 10 um

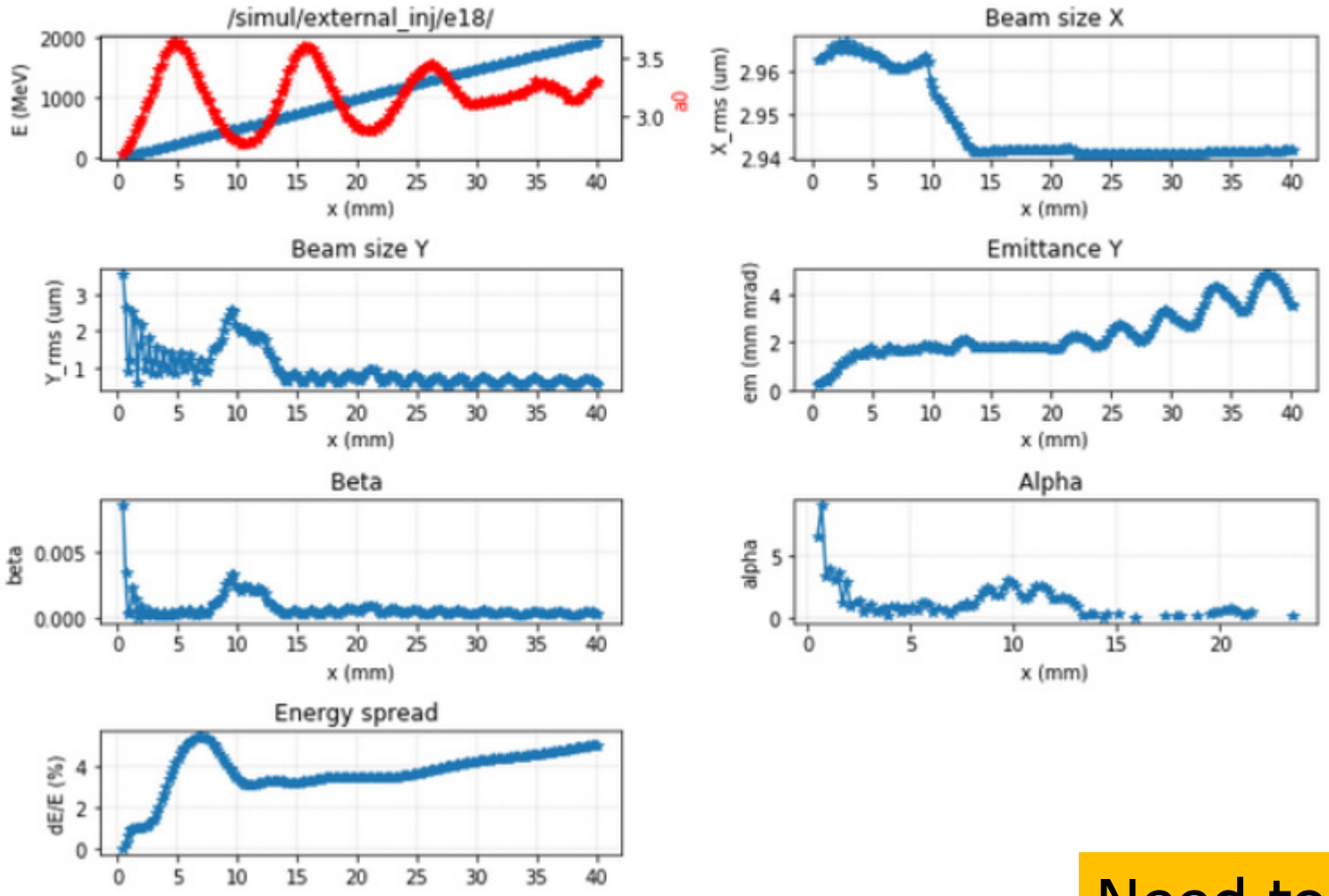
Laser
- a_0: 3
- λ_0 = 800 nm
- Pulse duration: 40 fs
- Pulse width: 50 um (FWHM)

Plasma
- Ne: 3 x 10^{17} cm^{-3}
- Ramp: 30 mm
- Guiding structure

PIC parameters
- 2 dimension
- Box size: 200 x 200 μm^2
- dx = $\lambda_0/20$
- dy = $\lambda_0/10$



PIC simulation results



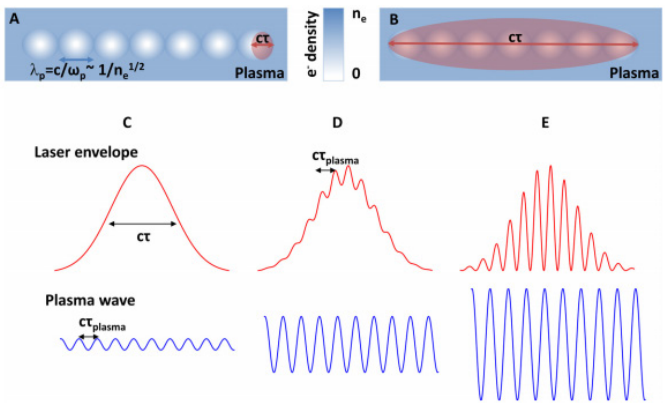
Results:
- Beam energy = 2 GeV
- Emittance = 4 mm mrad
- Energy spread = 4%

Target:
- Beam energy = 2 GeV
- Emittance = 1 mm mrad
- Energy spread = < 1%

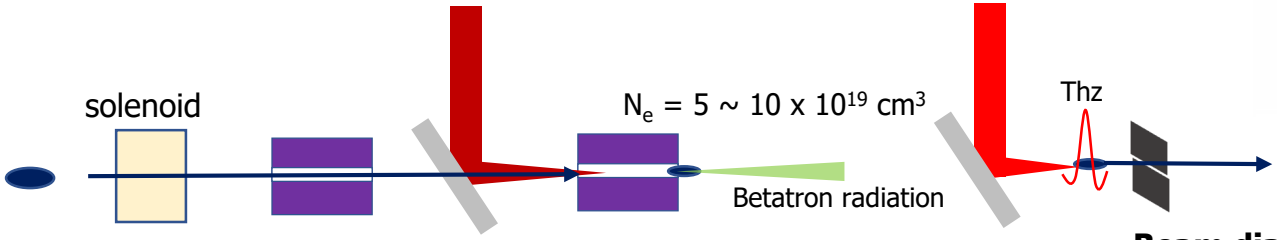
Need to optimize !

Self-Modulated LWFA with external electron beam injection

SM- LWFA scheme



- **Betatron X-ray source**

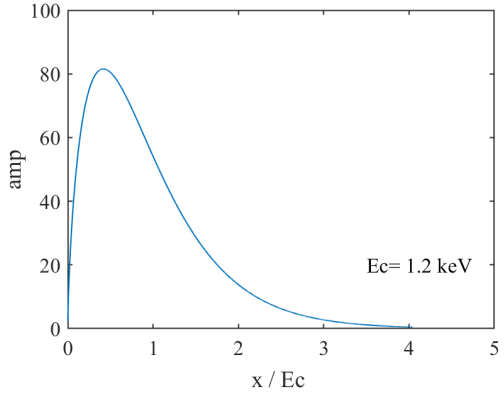


Beam transverse size: 50 um → ~5 um

- **Discharge capillary plasma waveguide R&D**
  - Controlled plasma density gradient
  - Stable discharge assisted with a nano-second laser system
  - Compact discharged system
  - Minimum gas leak to the chamber

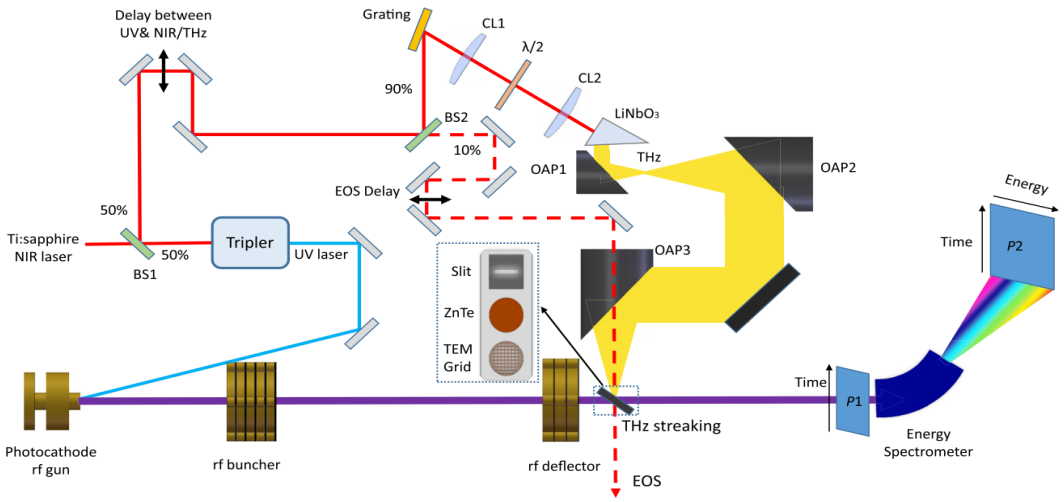
- **Measurements**
  - Betatron radiation X-ray: ~ 0.1 – 4 keV
  - Modulated energy spectrum by wakefield

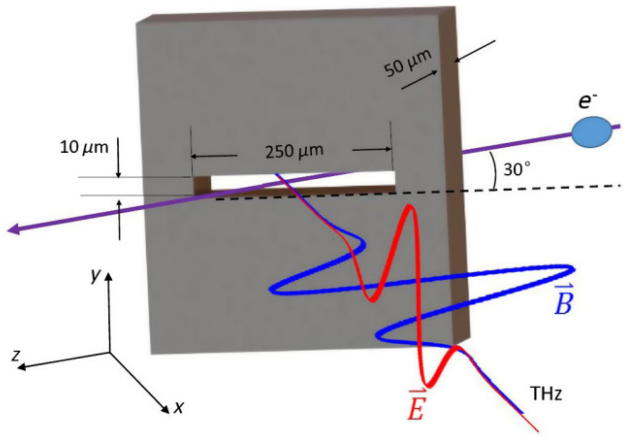
Betatron radiation



e-beam/THz research at ITF

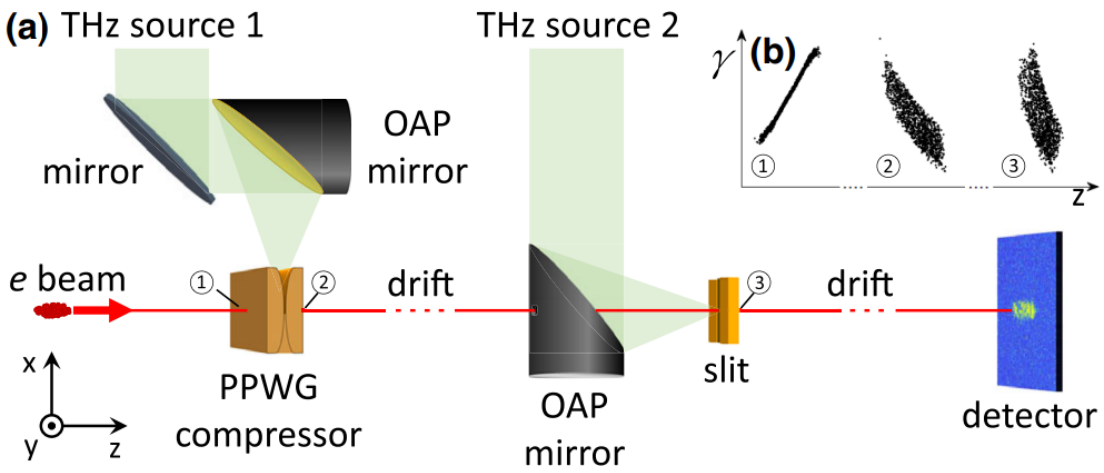
➢ THz streaking for electron bunch characterization

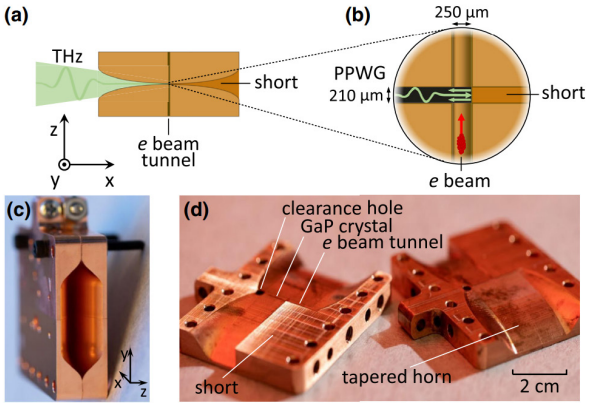




L. Zhao et al., *Phys. Rev. X* **8**, 021061 (2018)

➢ THz-driven electron bunch compressor



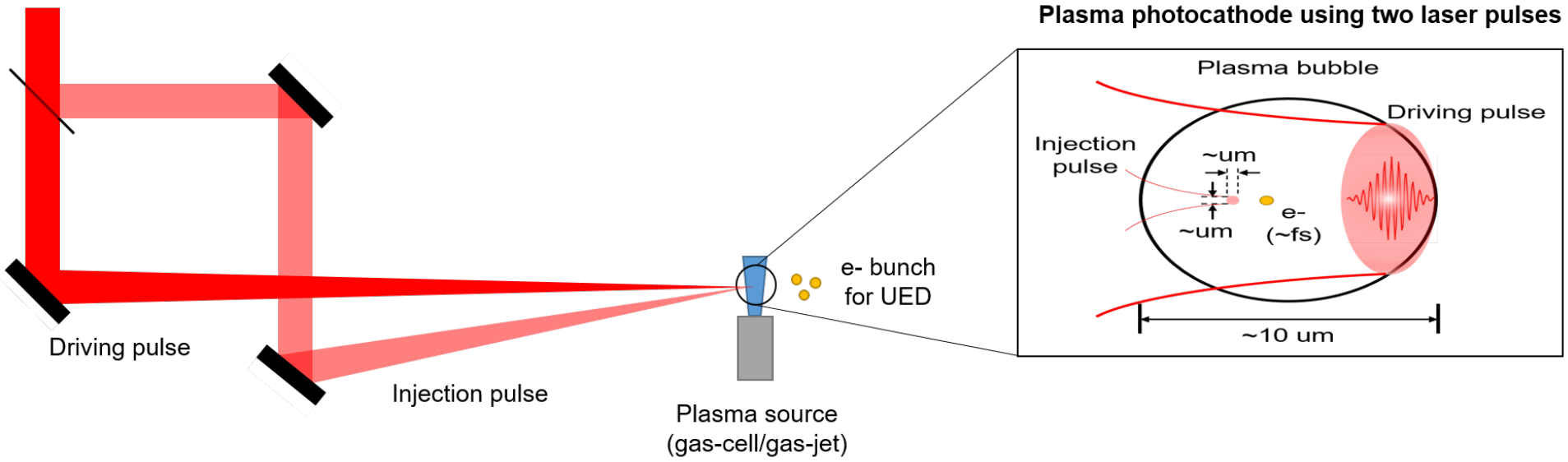


E. C. Snively et al., *Phys. Rev. Lett.* **124**, 054801 (2020)

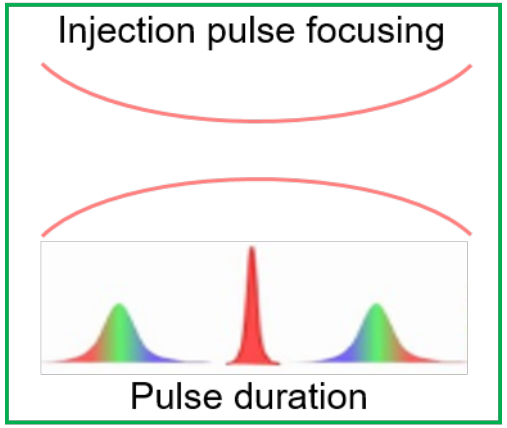
Dogeun Jang (PAL)

Laser-driven plasma photocathode

Two laser pulse ionization injection scheme



SSTF



✓ **Injection pulse type**

- Type I: Tight focusing w/ single cycle pulse → < 5 um, < 5 fs
- Type II: Simultaneous spatial & temporal focusing (SSTF)
- Type III: Combination of Type I & II

✓ No intrinsic jitter between pump laser and e- beam for UED experiments

Summary

- The tested photocathode at PAL-ITF has been successfully used for PAL-XFEL
- Recently, PAL-ITF has been re-arranged for future accelerator R&D and e-beam users
- Two electron beam lines are installed:
  - GUN-I: 1-5 MeV, < 100 fs for UED
  - GUN-II: 10 – 70 MeV, 30 fs ~ 2 ps for advanced accelerator R&D
- Developed discharge capillary source for LWFA R&D and plasma lens
- Planned experiments
  - Plasma lens
  - LWFA with external injection
  - Diagnostics of ultrashort e-beam using THz
  - THz driven accelerator, compressor
  - Laser driven plasma photocathode (Laser only)
  - Compact mm-scale accelerator
- We currently initiate various advanced accelerator R&D programs
- Near future, we will upgrade the laser system up to tens of TW scale for LWFA, and install a bunch compressor for ultra short e-beam with a high current.

Members and collaborators

Advanced Compact Accelerator R&D TFT at PAL

- Chang-bum Kim – ITF director, e-beam diagnostic
- Inhyuk Nam – ITF operation, e- beam/plasma/THz research
- Changki Min – ITF accelerator, ITF laser system
- Sung-Hoon Jung – ITF laser system
- MyungHoon Cho – Simulation code, e-beam/plasma research
- Minseok Kim – Laser system, laser/plasma research, SSTF
- Dogeun Jang – THz source, e-beam/THz research
- Suckho Ahn – Discharge system
- Garam Han – e-beam transport system
- Seung Hwan Shin – Compact mm-scale accelerator
- Hyung Sup Gong – Fabrication of compact mm-scale accelerator

Collaborators

- Prof. Hyyong Suk, Si Hyun Lee (GIST)
- Prof. Mose Jung, Prof. Min Sup Hur, Seong-Yeol Kim, Chang-Kyu Sung (UNIST)

Thanks for your attention