Photocathode-driven injector linac design for ~~Korea-4GSR~~ KLS

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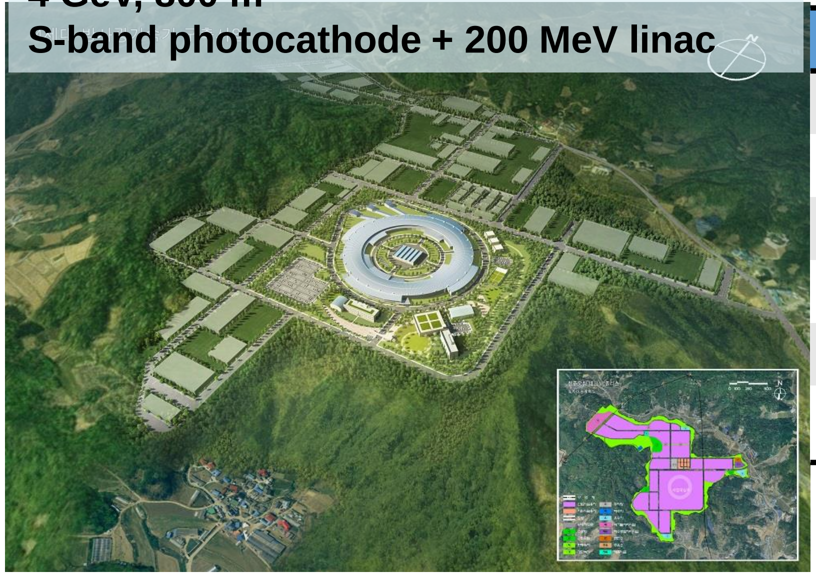
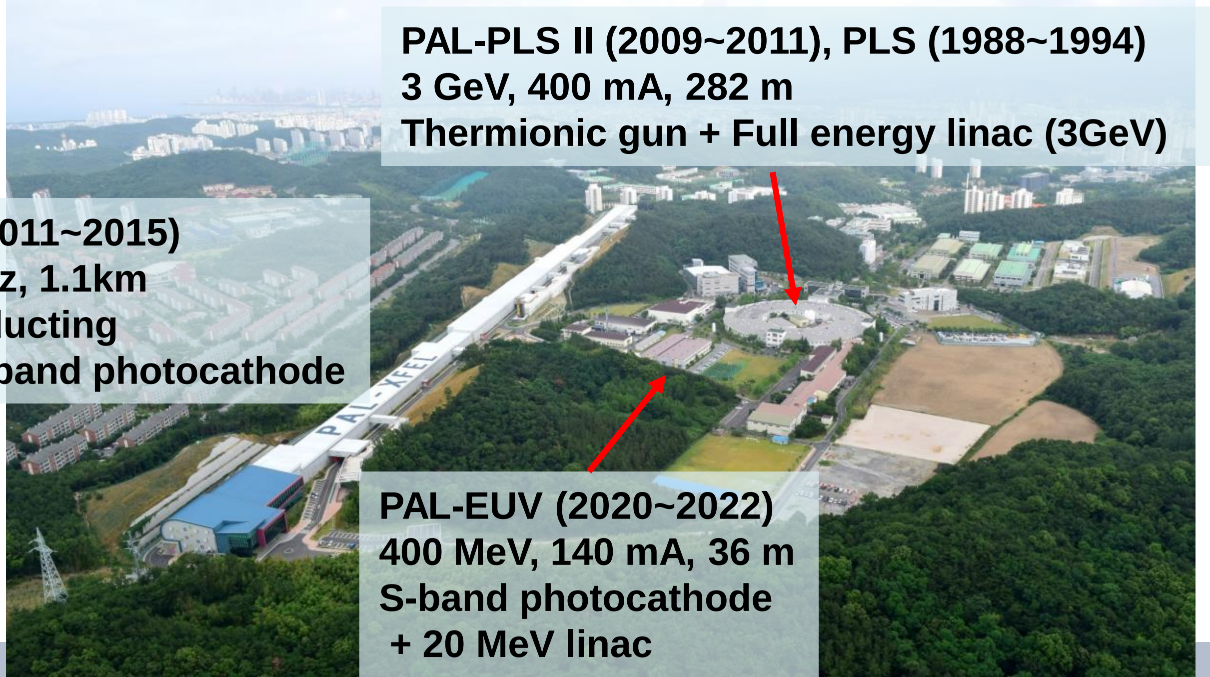
Photon sources in Korea

KLS (2021~2029)
4 GeV, 800 m
S-band photocathode + 200 MeV linac



Parameter	Units	PLS-II	KLS
Electron energy	GeV	**3**	**4**
Horiz. Emittance	pm	**5800**	**58 (RB: 39)**
Vert. Emittance	pm	~ 58	~ 5.8 (RB: 39)
Bunch length (rms)	ps	20	13 (50 with HC)
Circumference	m	**280**	**800**
Harmonic #		470	1332

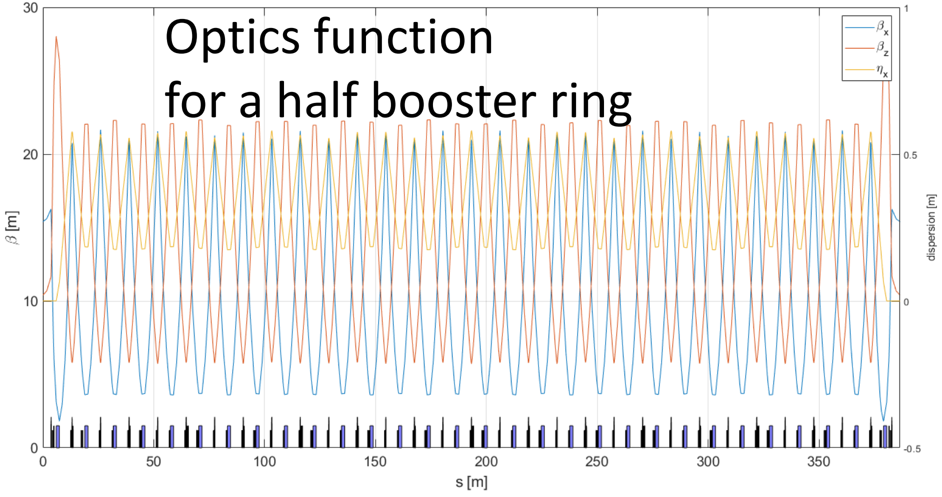


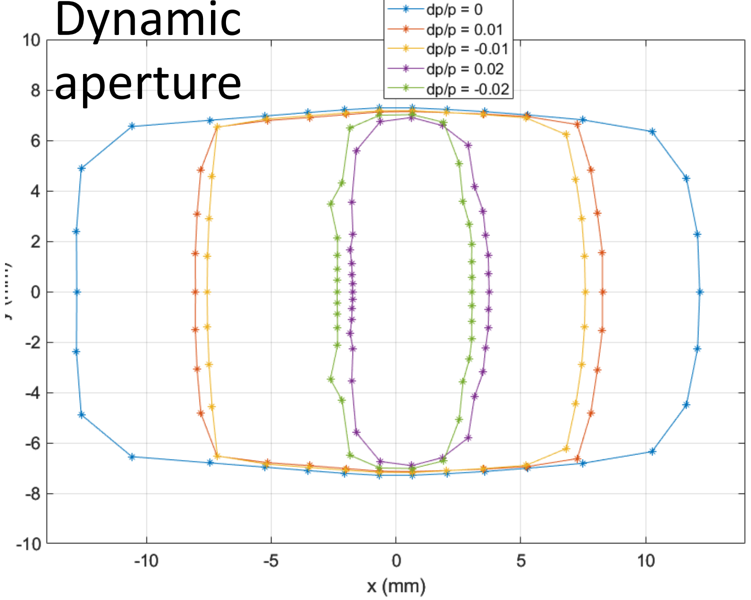
PAL-PLS II (2009~2011), PLS (1988~1994)
3 GeV, 400 mA, 282 m
Thermionic gun + Full energy linac (3GeV)

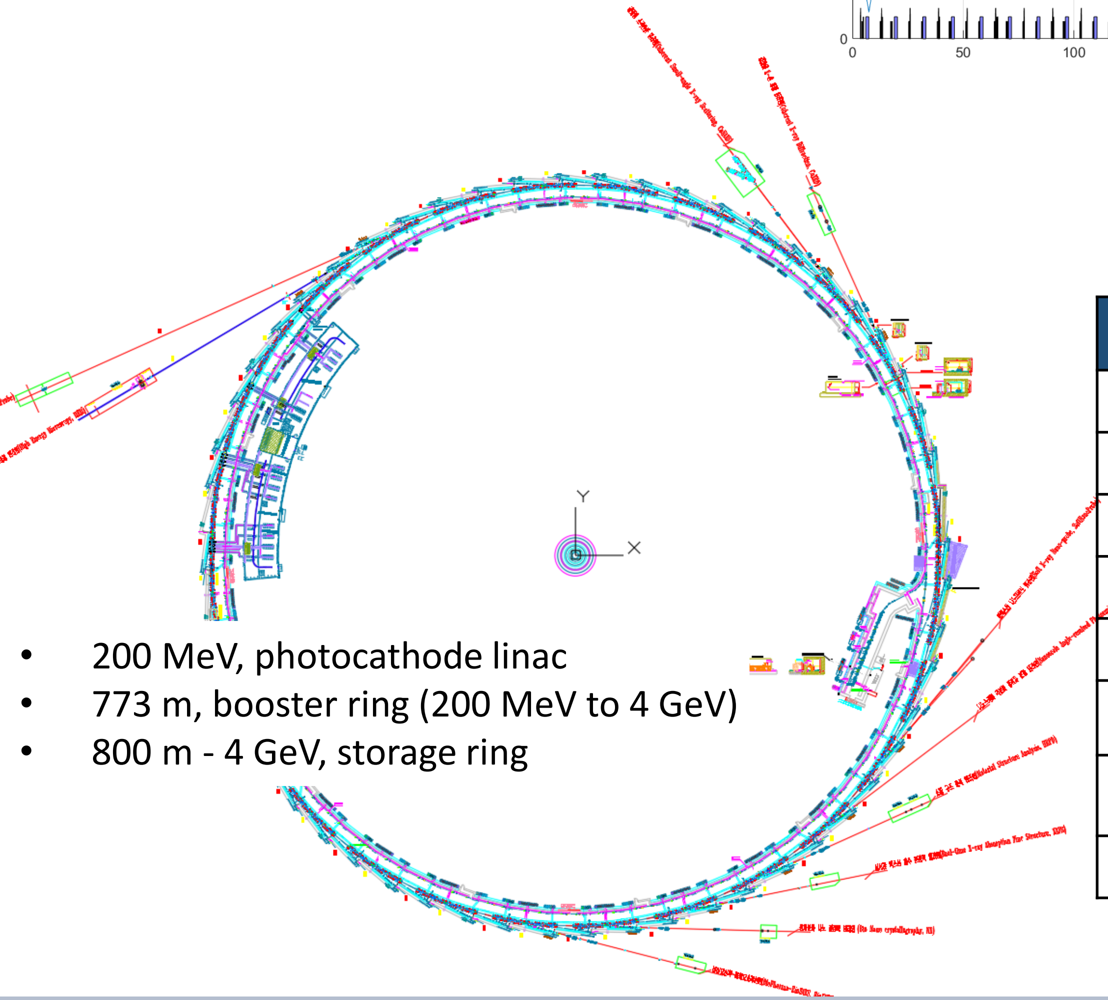
PAL-XFEL (2011~2015)
10 GeV, 60 Hz, 1.1km
Normal conducting
Based on S-band photocathode

PAL-EUV (2020~2022)
400 MeV, 140 mA, 36 m
S-band photocathode
+ 20 MeV linac

KLS LINAC requirements







- 200 MeV, photocathode linac
- 773 m, booster ring (200 MeV to 4 GeV)
- 800 m - 4 GeV, storage ring

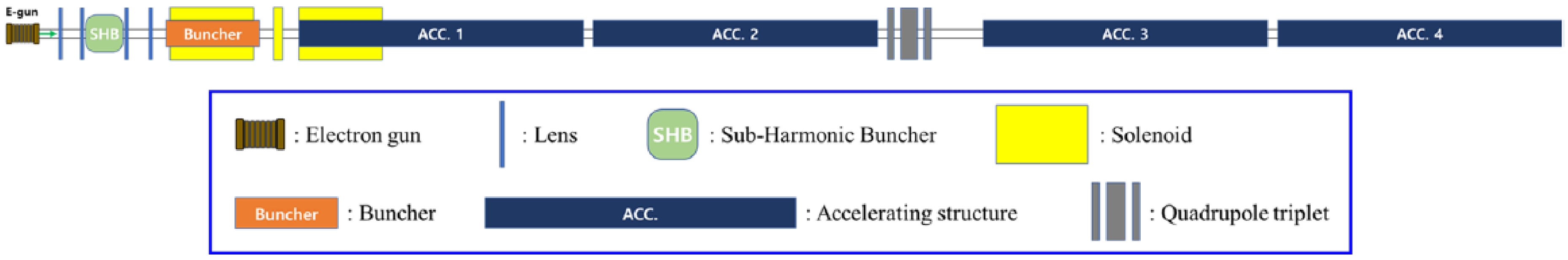
<u>Energy range for 100% injection, ± **1.5** %</u>

	Multi-bunch	Single-bunch
Energy	200 MeV	200 MeV
Frequency	2997.56 ± 0.1 MHz	2997.56 ± 0.1 MHz
Emittance (at 200 MeV)	≦ 10 nm	≦ 10 nm
Relative energy spread (rms)	**≦ 0.3 %**	**≦ 0.3 %**
Pulse to Pulse energy jitter(rms)	**≦ 0.2 %**	**≦ 0.2 %**
Bunch charge (charge stability)	**1 to 3 nC (5%)**	**0.01 to 1 nC (2%)**
Pulse duration	128 ns (64 bunches)	6-8 ps FWHM
Repetition rate	2 Hz	2 Hz (60 Hz)

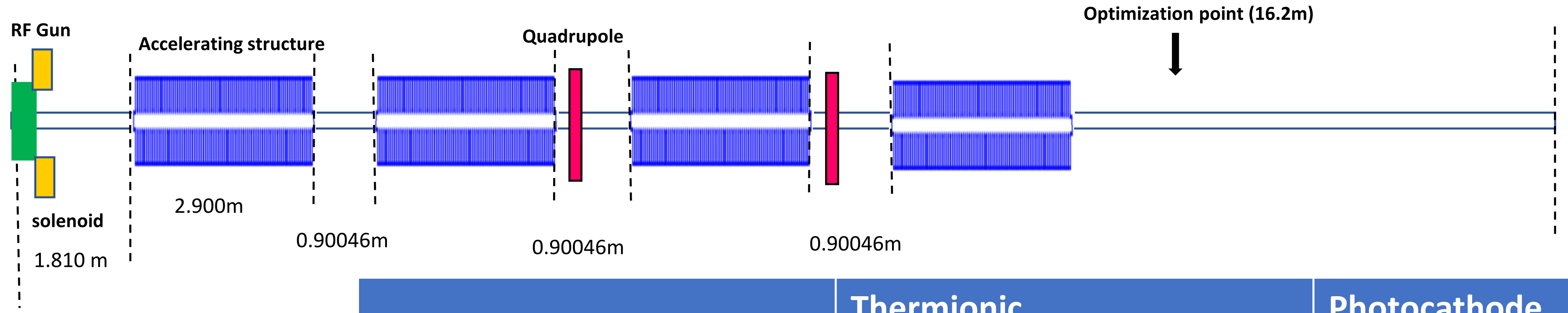
Thermionic vs. photocathode gun, 1 nC

- Thermionic (e.g. SIRIUS in Brazil)

: Initial beam Twiss parameters obtained from CST simulations,used as input for the PARMELA simulation

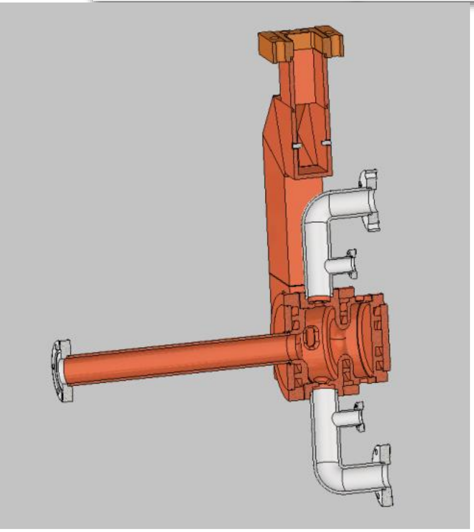


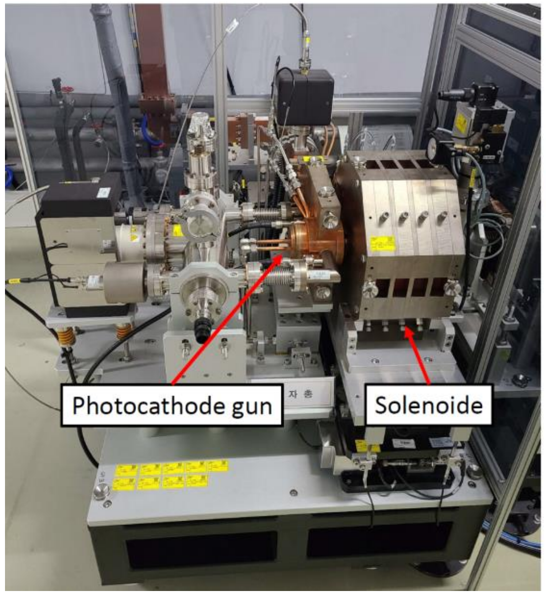
- Photocathode : ASTRA simulation

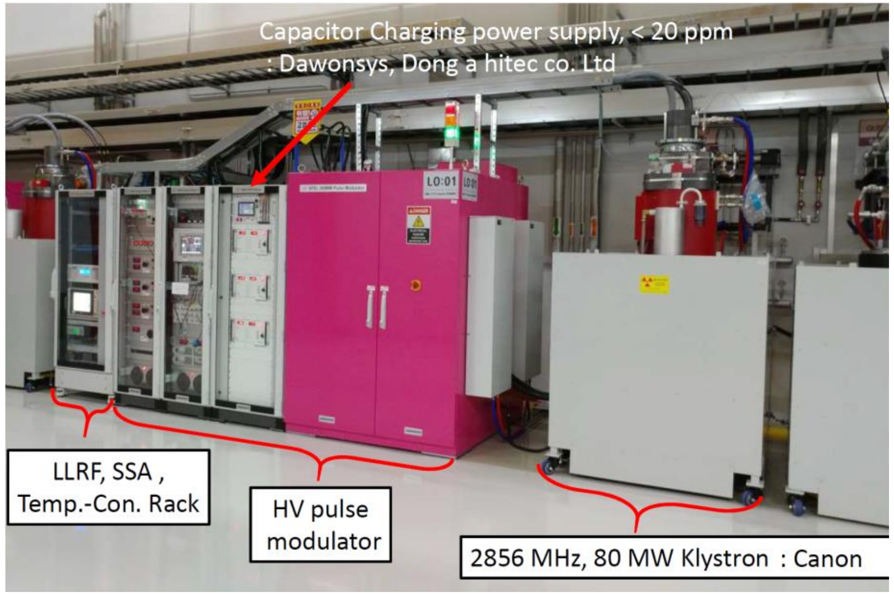


	Thermionic	Photocathode
Emittance X (nm-rad)	130 (norm. 54 mm-mrad)	8.4 (norm. 3.3 mm-mrad)
Emittance Y (nm-rad)	150 (norm. 62 mm-mrad)	8.2 (norm. 3.2 mm-mrad)
Energy spread at 200 MeV	0.3%	0.2%

S-band photocathode based LINAC experiences at PAL







- ❖ **Matured technology in PAL : S-band photocathode**
  - **- 10 years R&D + 10 years operation experience**
  - **- 6 MeV, 250 pC, 60 Hz routine operation since 2016**
- ❖ **Best stability at gun : energy and time**
  - **- CCPS + PFN + sagnoc based sync. + 0.01^{o} LCW stability**
  - **+saturation operation at Klystron provides**
  - **~ Phase stability 0.01 (~10fs), RF power stability 10^{-4}**
- ❖ **Stable Injector operation**
  - **- e- beam energy stability : $5x10^{-5}$**
  - **- beam based feedback provides phase space conservation**

KLS LINAC vs PAL-XFEL

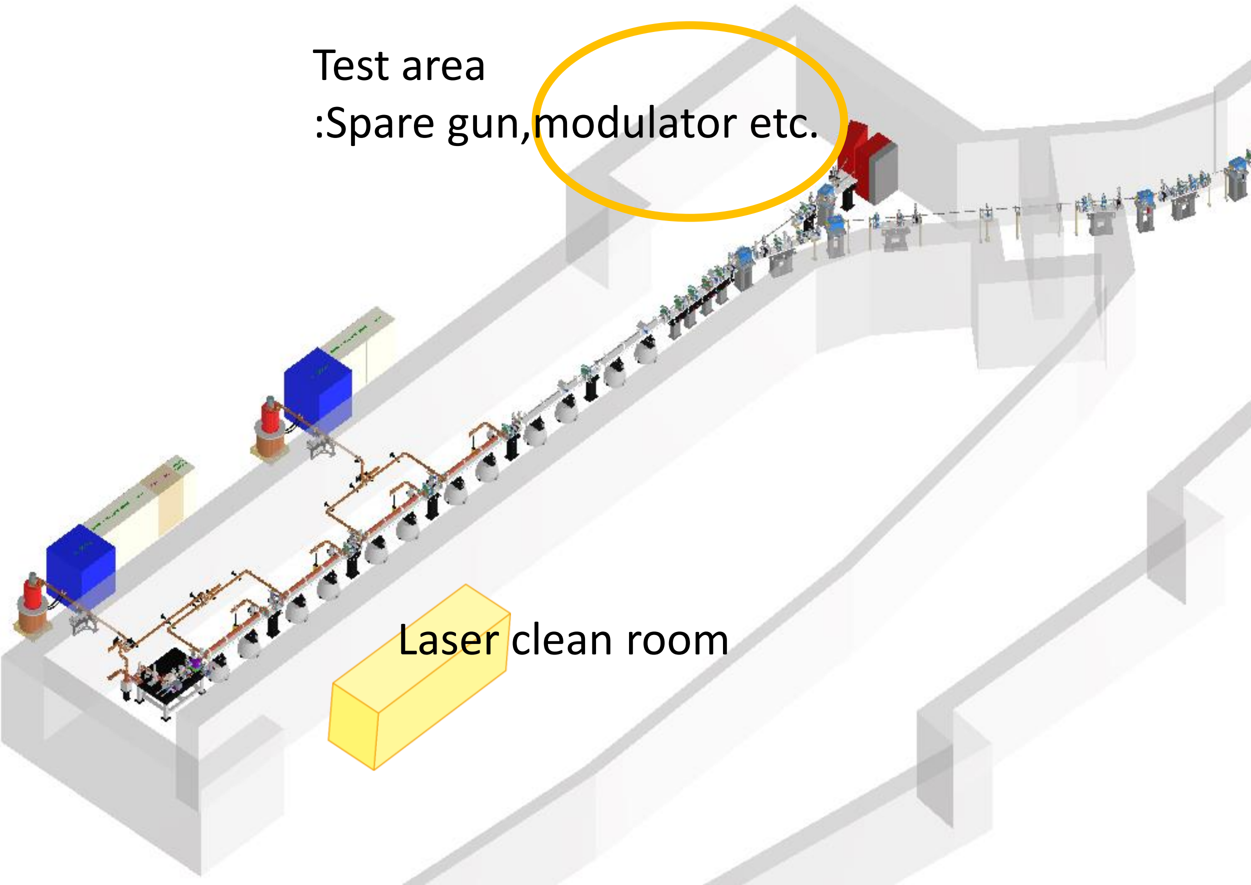
	KLS LINAC	PAL-XFEL
RF frequency	2997.56 ± 0.1 MHz, variable	2856 MHz fixed
Trigger timing	Depending on booster injection timing	fixed
Bunch charge	Multi, 1 to 3 nC Single, 0.01 to 1 nC	250 pC fixed
Pulse duration (number of bunch)	128 ns (64 bunches) 6~7 ps (single bunch)	3 ps FWHM (single bunch)
Repetition rate	2 Hz	≤ 60 Hz Single bunch (two bunch in the future)

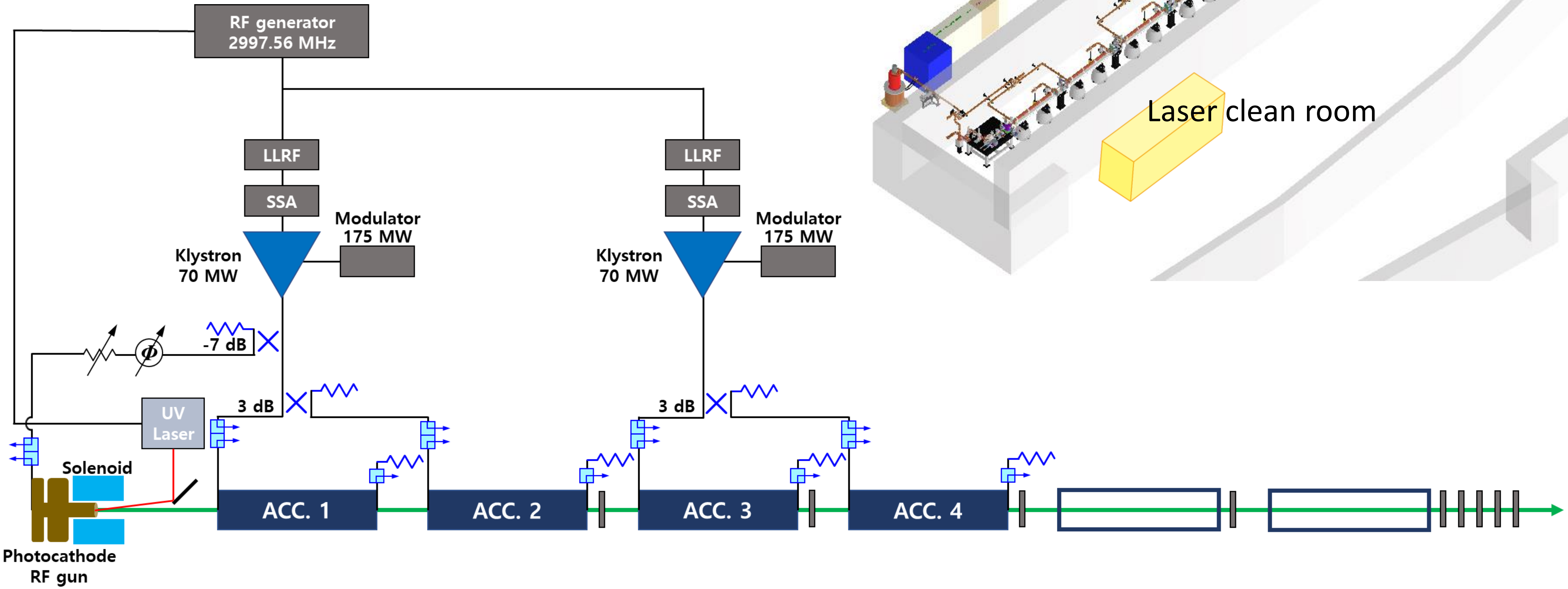
LCW parameters

- Acceleration tube : 25 ~ 30 ℃ (copper 50 KHz/ ℃)
- Photocathode gun : 25 ~ 50 ℃

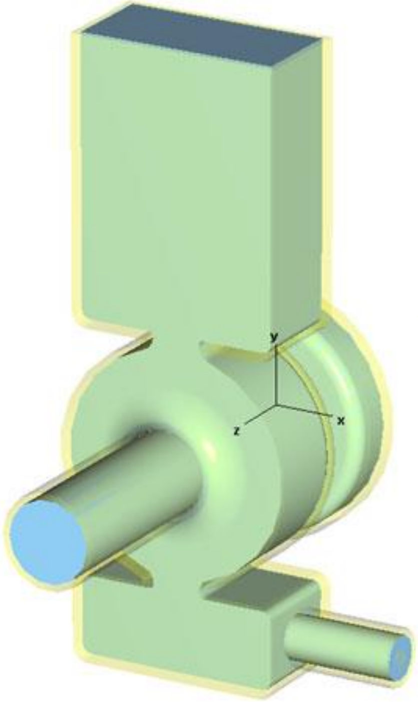
Timing Synchronization System

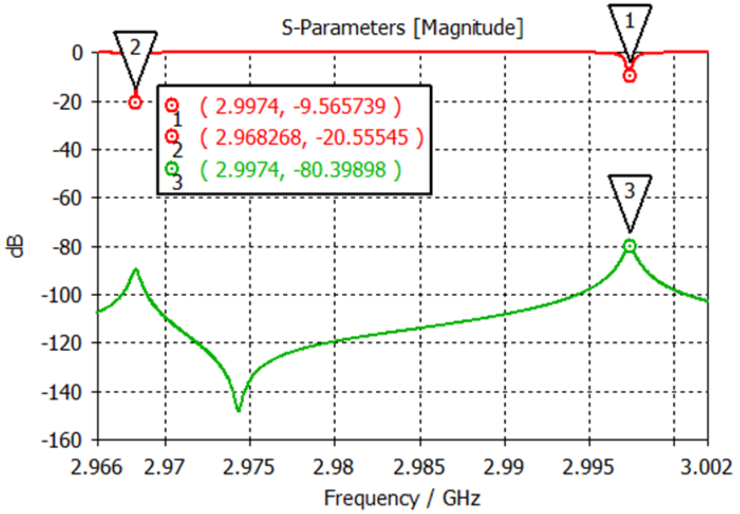
- Pseudo Sync. operation (in the same way as SACLA)
  → synchronous operation





1.5 cell photocathode (quasi-coupler)

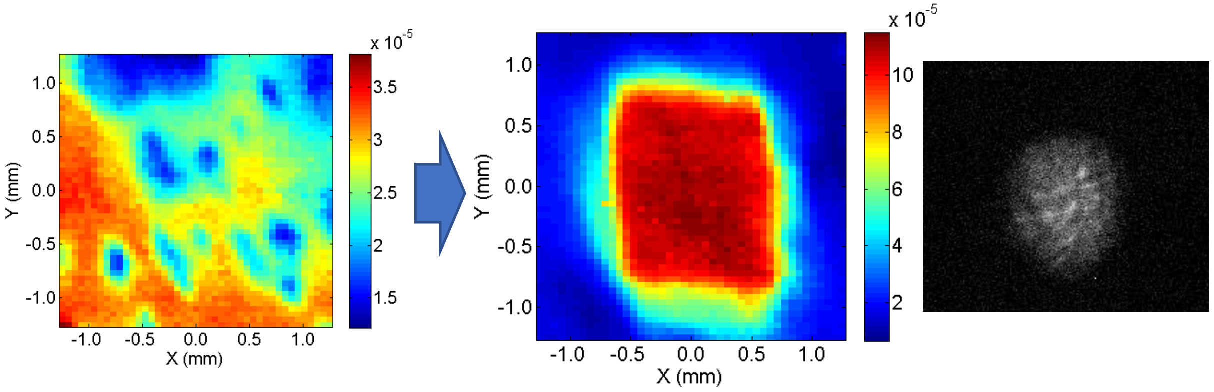




- 2-port cavity composed of a full cell and a half cell
- Coupling coefficient: β = 2.00; Field balance (FB): 1.00
- π-mode frequency: fπ = 2997.40 MHz, Δf = 29.1 MHz

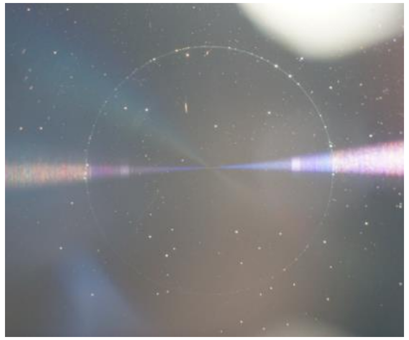
- Laser cleaning

: Low surface damage using ~300 ps long IR laser cleaning



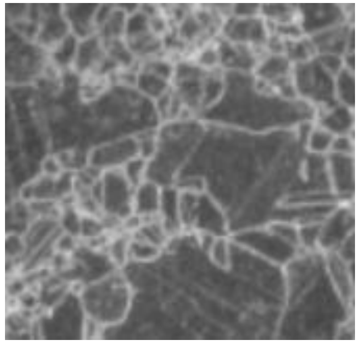
- Implementing single Cu crystal

Single crystal brazing



10mm

OFHC

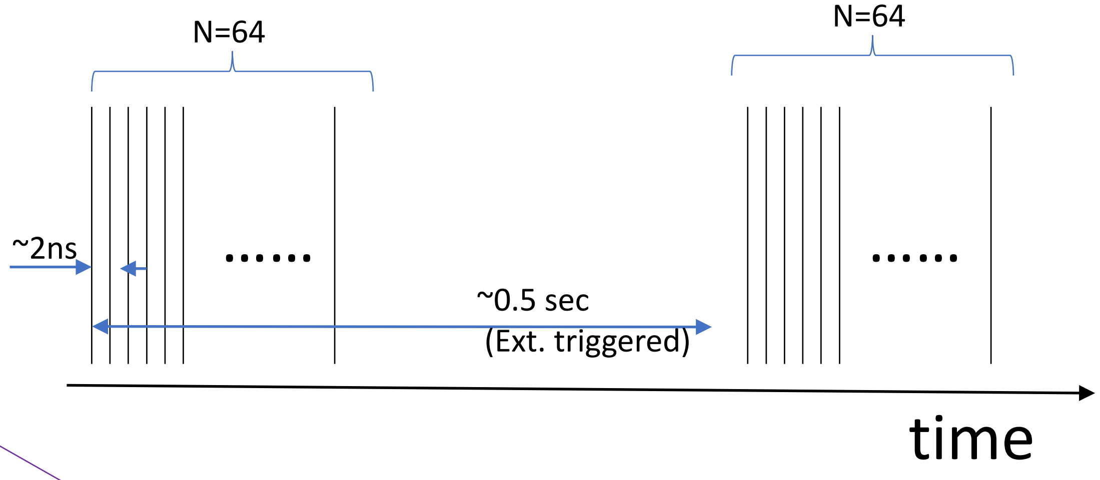


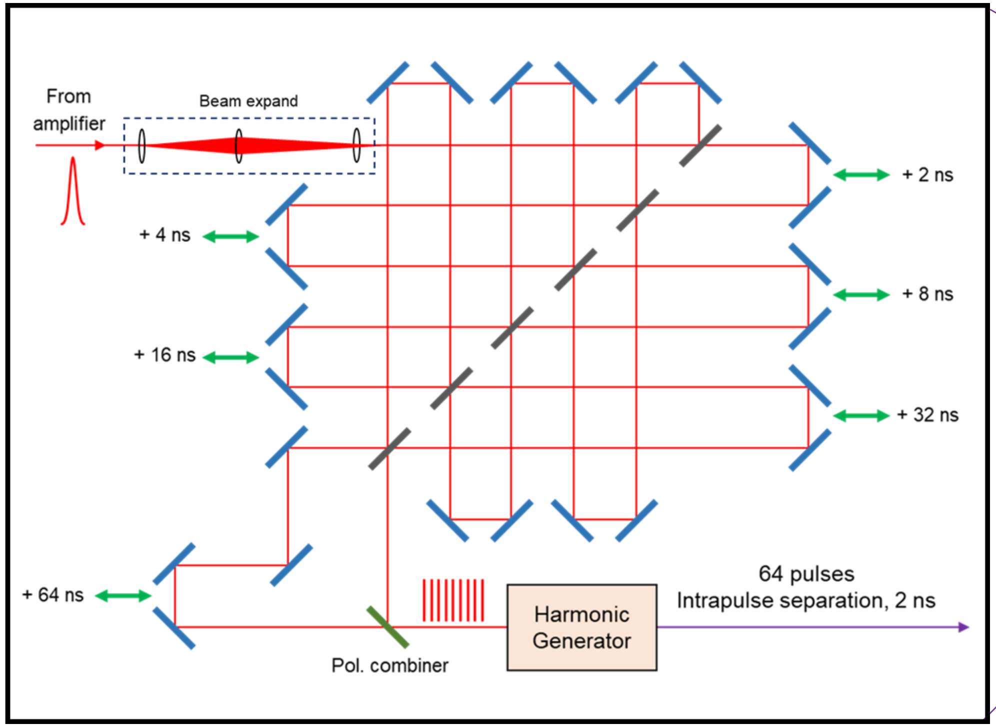
1 mm

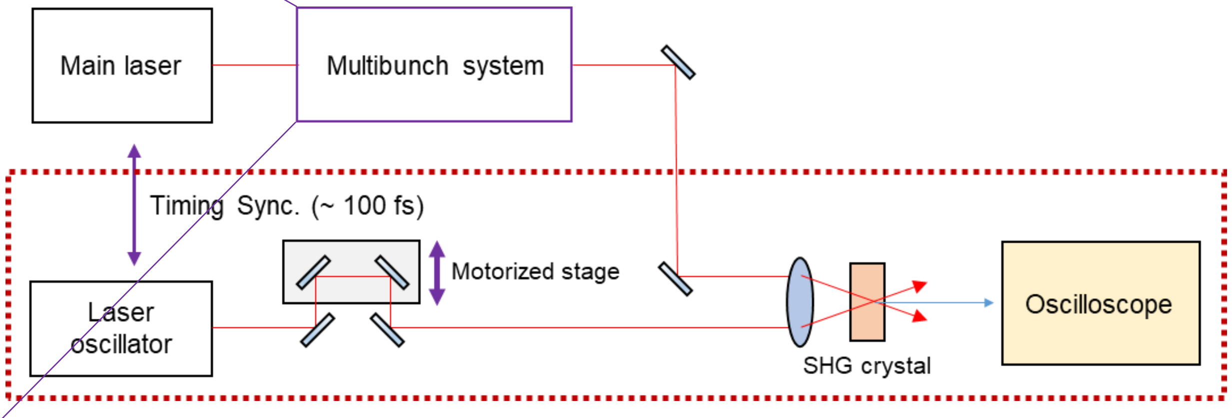
Laser System

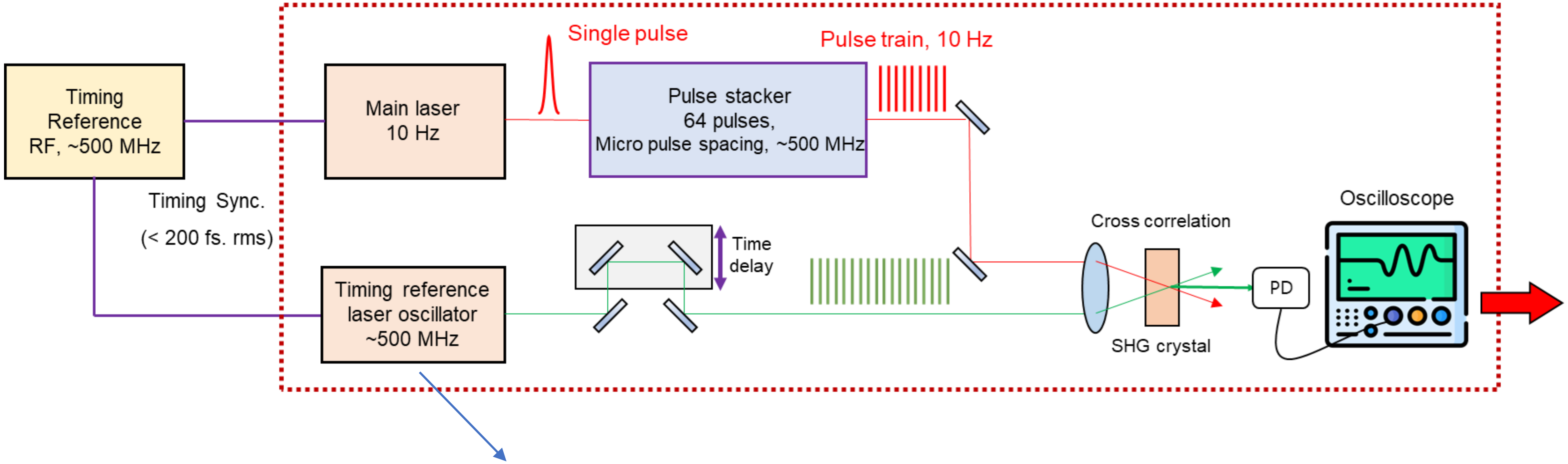
- Yb laser, Regen(~1030 nm), 5 mJ, 4th harmonic for UV

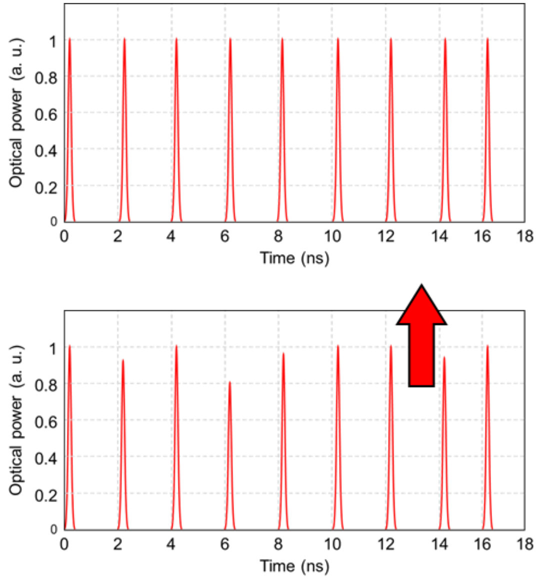
- Single/Burst mode convert
  - Convert time (<1 min)

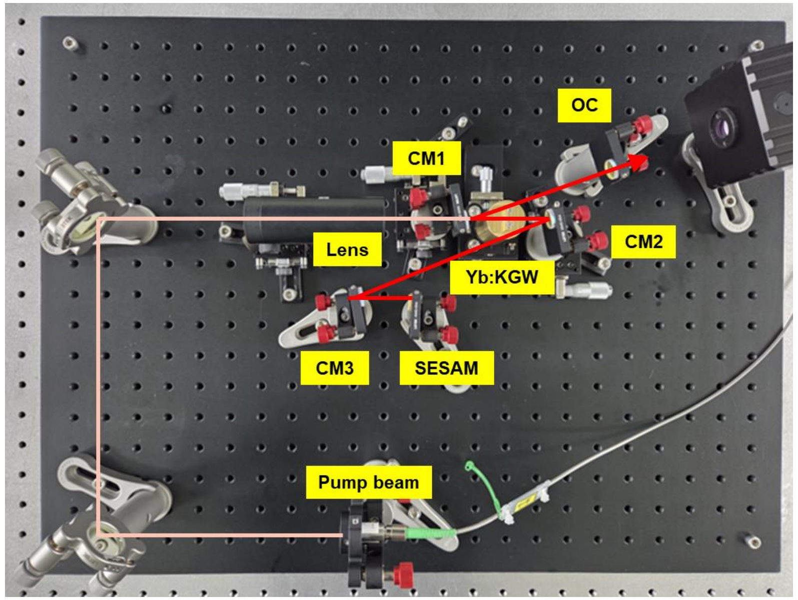




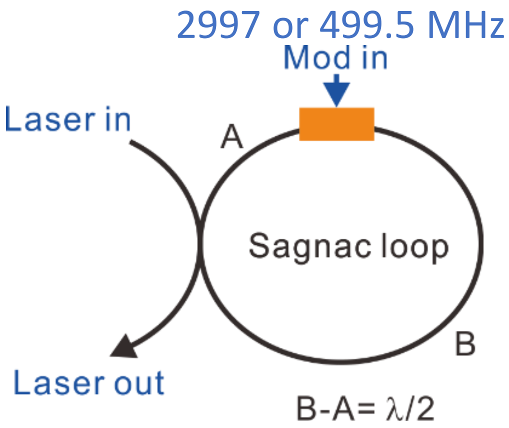




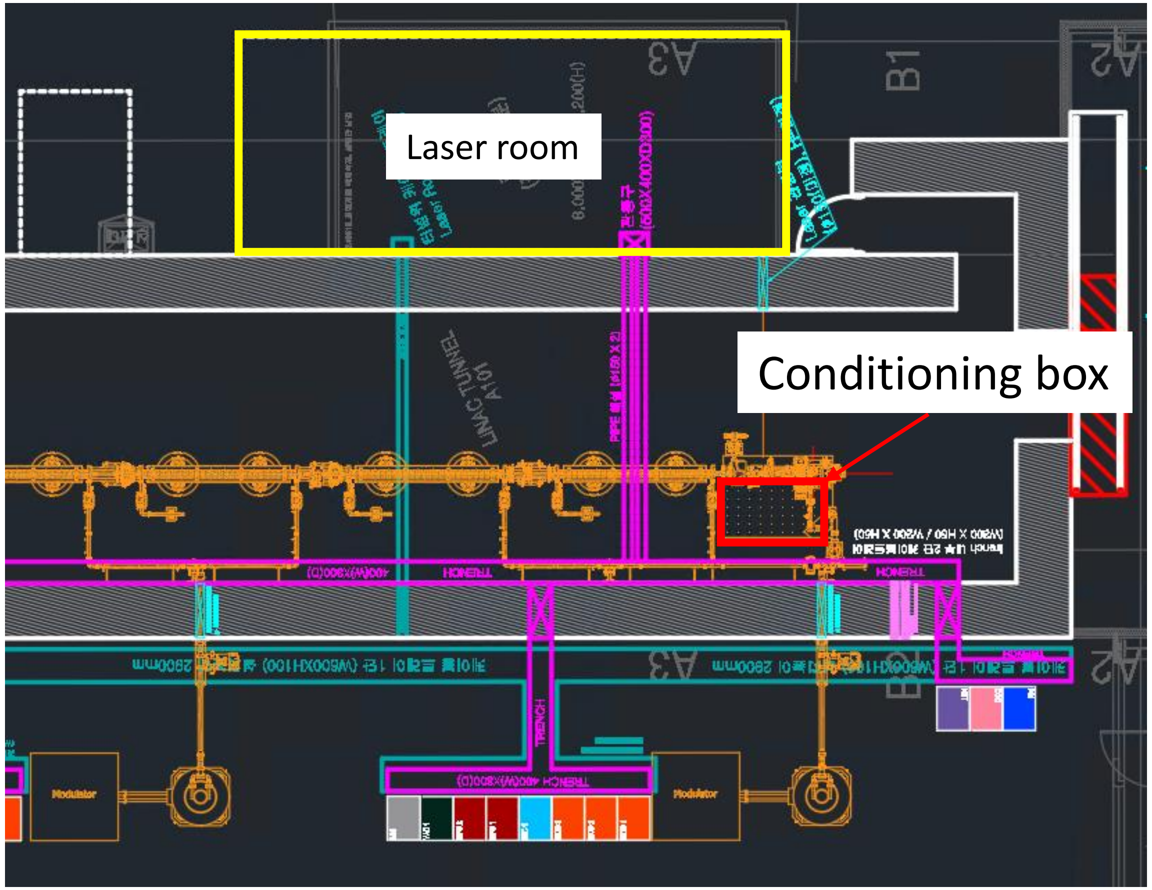


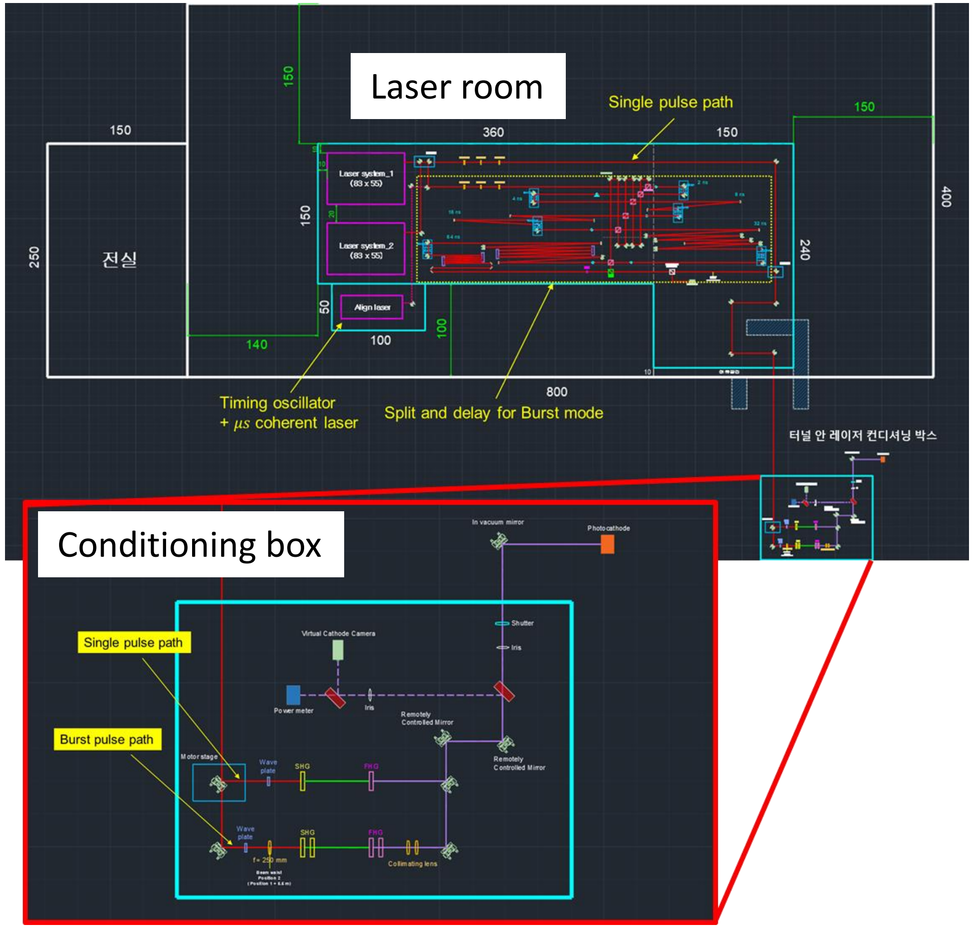


- Home built laser synchronization < 30 fs rms



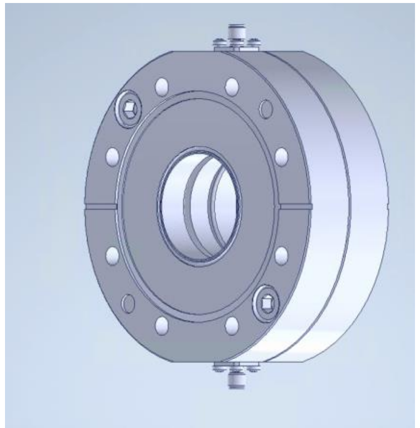
Poster : TUPO068 by Namseok Go
Design for a Femtosecond-Synchronized Nanosecond Laser Pulse Train System for the Korea-4GSR





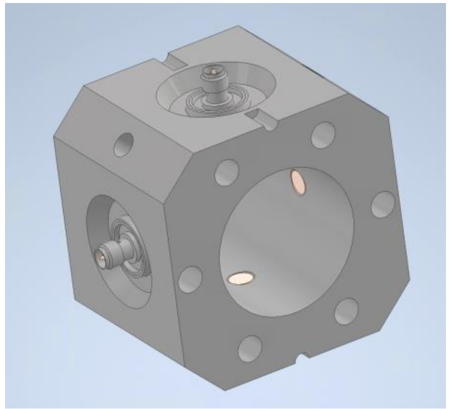
LINAC Beam Diagnostic Devices

Integrating Current Monitor



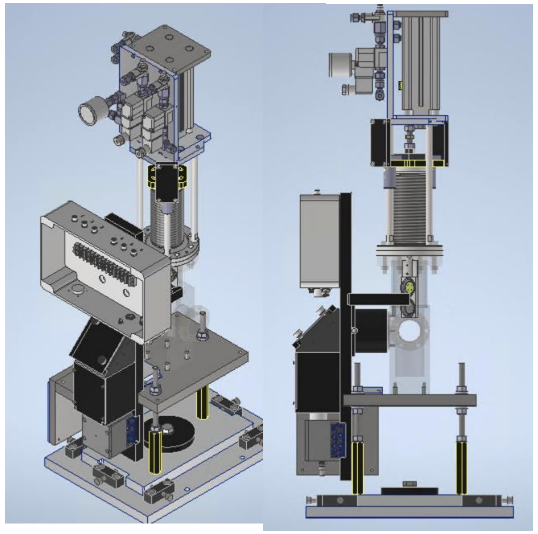
- Beam pulse charge measurement
    - 64 bunches/pulse
    - Beam Transmission
- Bergoz, ICT
- Resolution: 2 pC

Beam Position Monitor



- Pickup: 6 mm diameter
- Electronics: Libera Single Pass E
- Resolution: 1 μm at 1 nC
- Bunch-by-bunch measurement at BAS

Beam Profile Monitor (Screen)



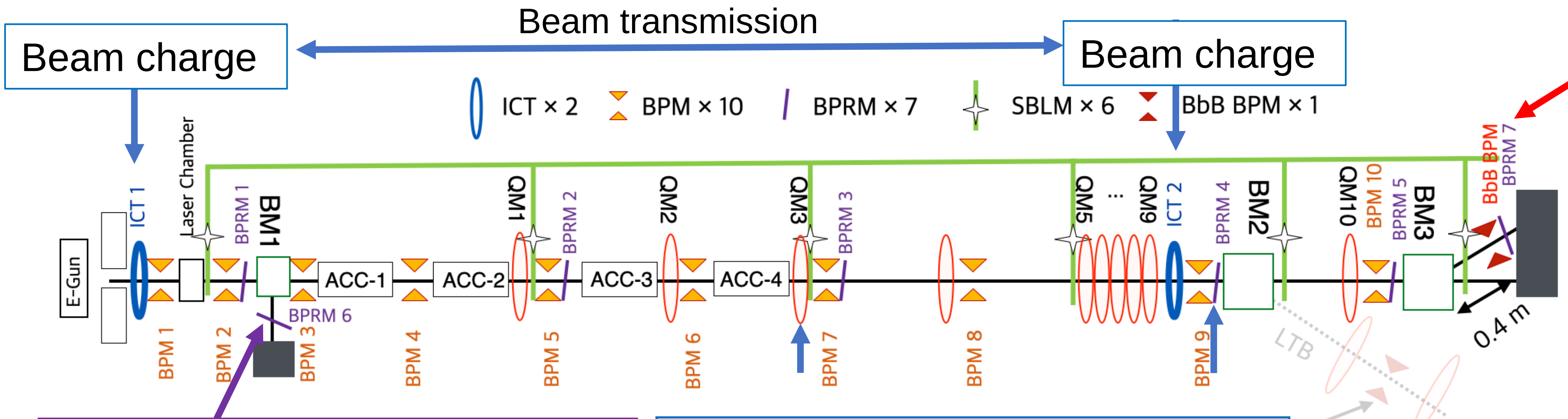
- Dual YAG, OTR screens
    - YAG for low charge
    - OTR for high charge and precise measurement
- Resolution: estimated from Simulation
    - Position: 20 μm at 10 pC
    - Size: 5% at 10 pC
- Emittance & Twiss parameters
- Energy & energy spread

Beam Loss Monitor

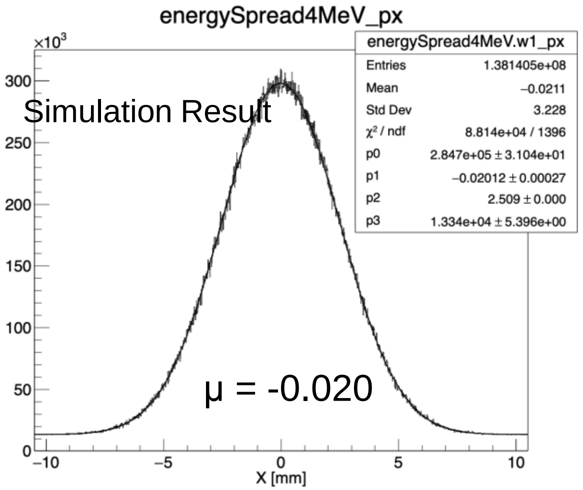
- CMOS-Based Beam loss Monitor
    - Scintillator
    - Photon Detector: CMOS Camera
- Maximum Acquisition Rate: 100 Hz

LINAC Beam Parameter Measurements

Bunch-by-bunch energy measurement with GHz BW oscilloscope

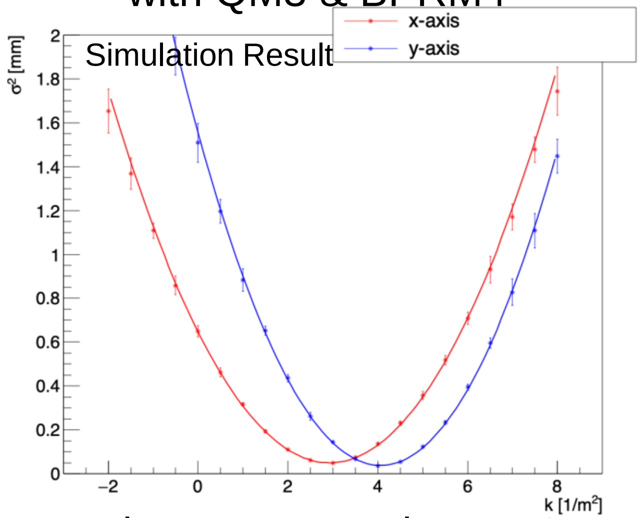


4 MeV energy measurement with BM1 & BPRM 6



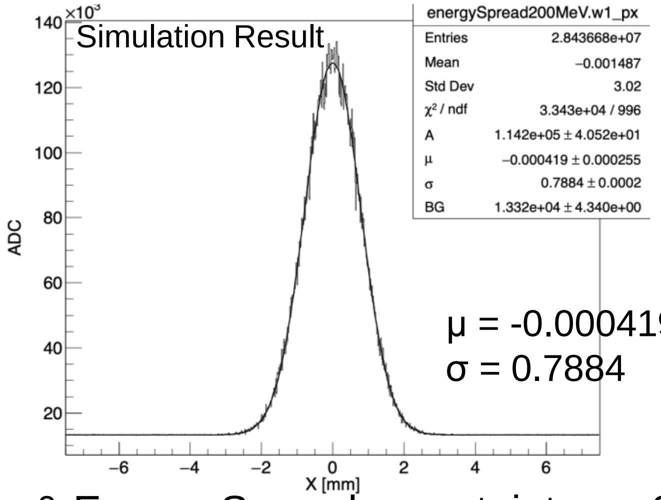
Energy uncertainty : ~ 0.1%

Emittance Q-Scan with QM3 & BPRM4



Emittance uncertainty: ~1%

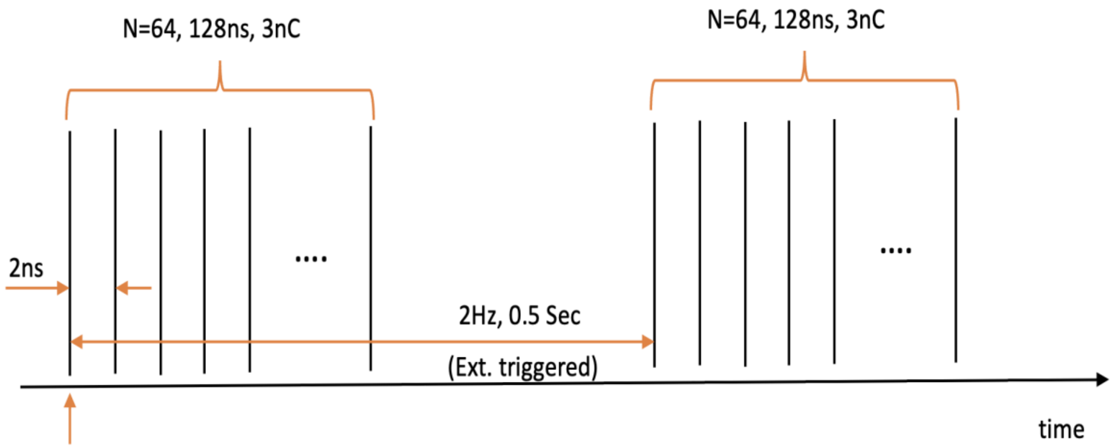
200 MeV energy & energy spread Measurement with BM3 & BPRM 7



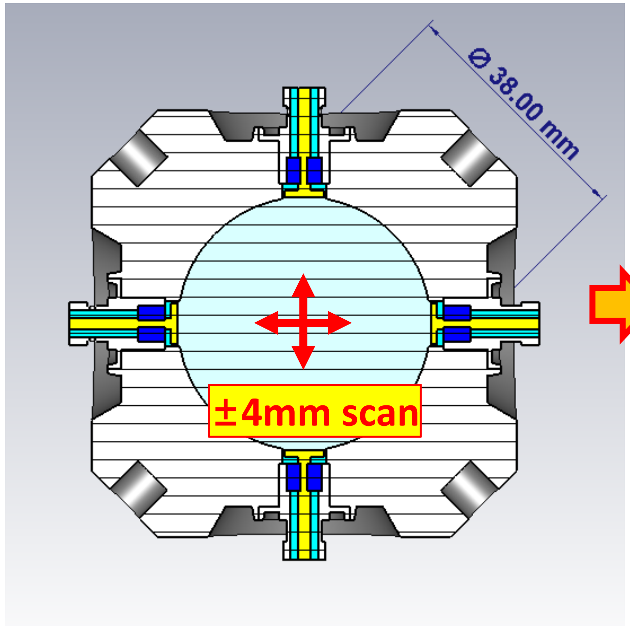
Energy & Energy Spread uncertainty : ~ 0.01%

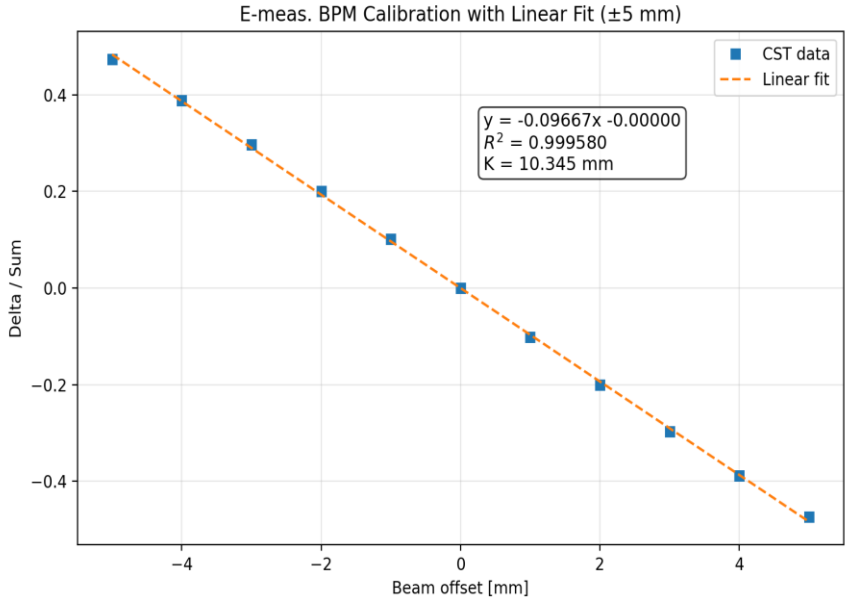
Bunch Resolved Energy Measurement

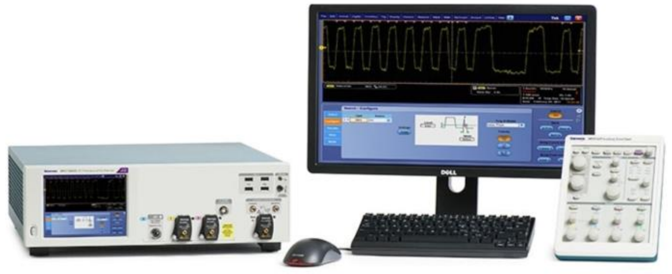
- **Bunch-by-bunch energy measurement at LTB**
  - BbB analyzing module
  - **BbB BPM sensitivity: K_x ~ 10 mm**
- **High-speed direct sampling using 50–100 GS/s oscilloscope**
  - **Expected energy resolution: ~0.025% (~50 keV @ 200 MeV)**
  - Equivalent BPM position resolution: **~110 µm at D_x ~ 0.45 m**
- **E-meas. Resolution requirement for Feedback: ≤0.05% (~100 keV @ 200 MeV)**
  - Corresponding BPM position change: **~225 µm**
  - Expected measurement resolution is better than the feedback requirement
- **Sufficient for monitoring Linac energy stability**
  - Relative energy spread specification: **≤0.5% (~1 MeV)**
  - Pulse-to-pulse energy jitter specification: **≤0.2% (~400 keV)**
- **Bunch-resolved energy information will be used for injection energy stabilization feedback**



Multi-bunch mode of 4GSR Linac.

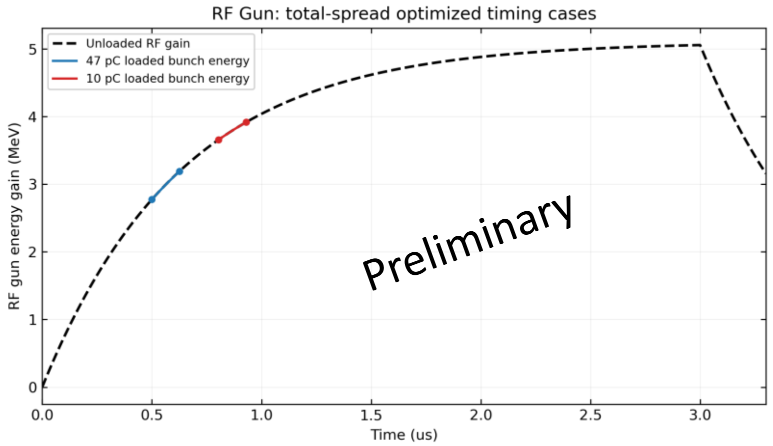


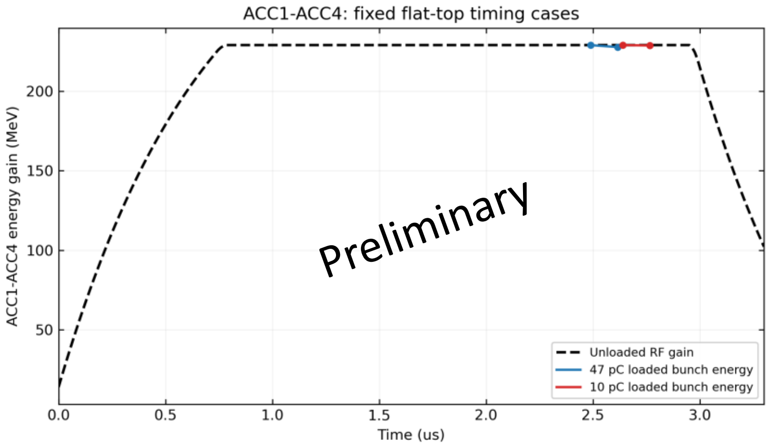



Commercial High speed Digitizer
50~100GS/s

Energy control: Beam loading, etc

- Beam loading



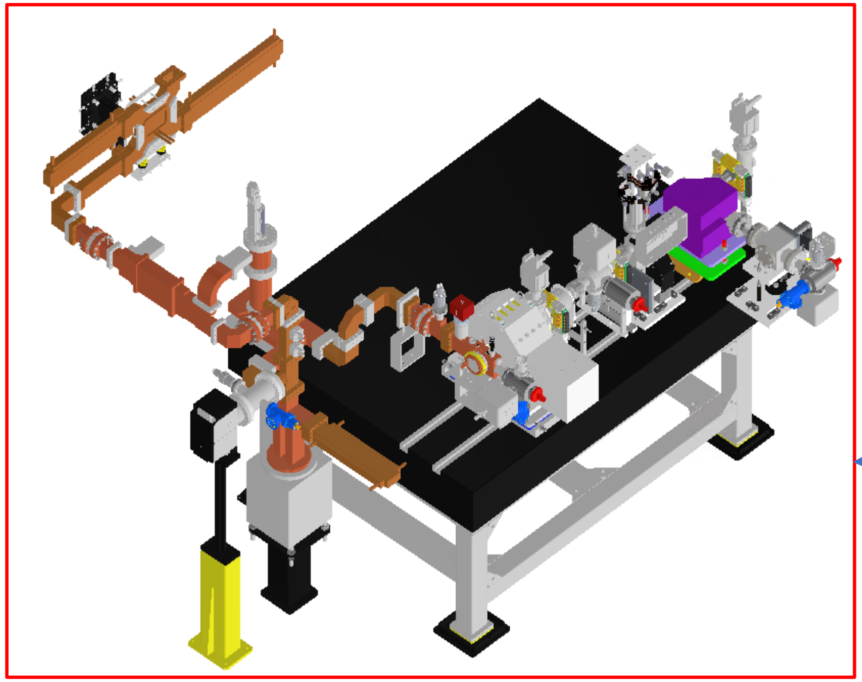


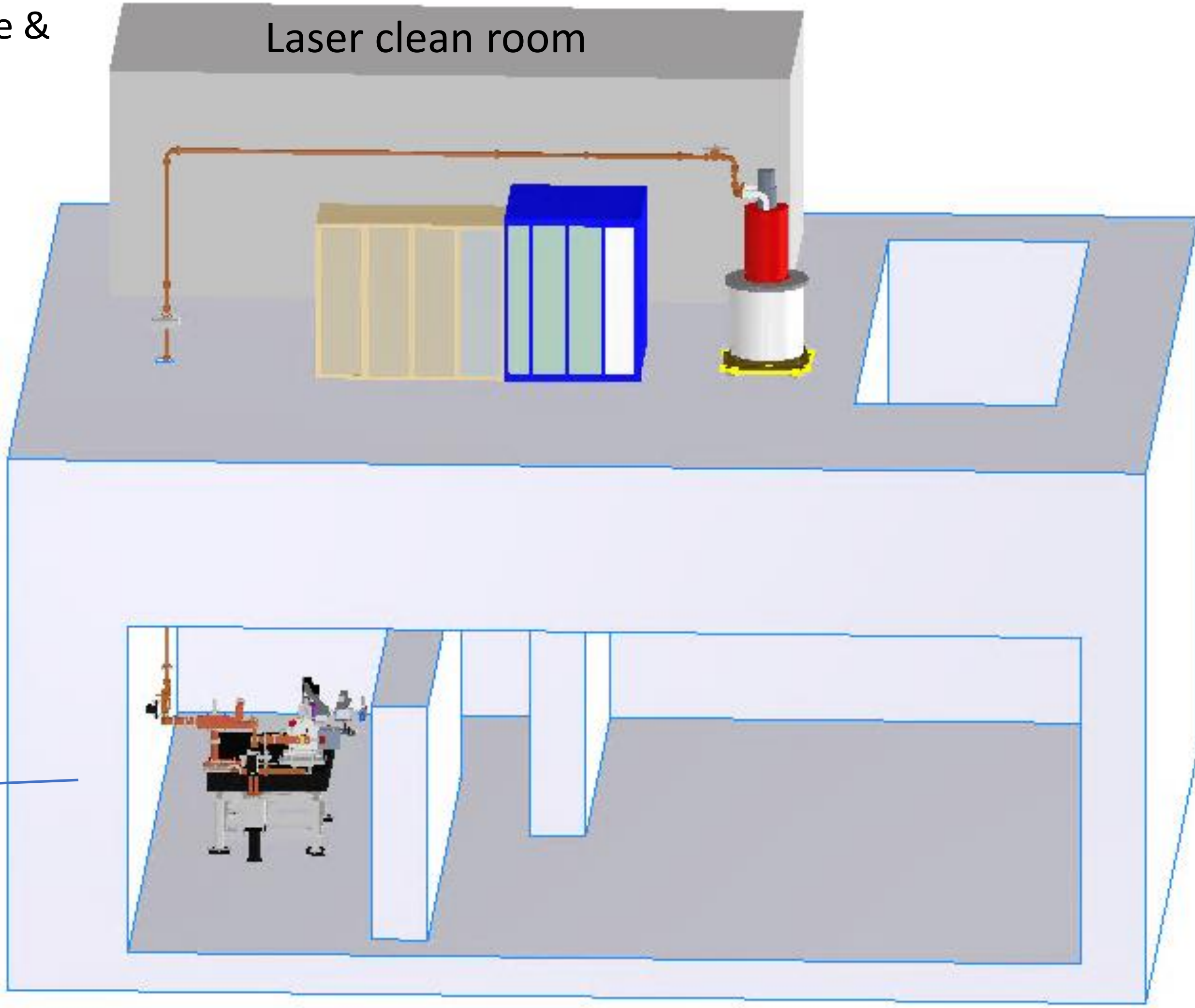
Bunch charge (pC)	Section	Injection time (ns)	Tail-bunch beam-loading loss (MeV)	Bunch-to-bunch RMS energy spread (%)
47, (47x64=3nC)	RF Gun	500.0	0.002190, **0.05%**	4.074289
	ACC1–ACC4	2490.0	1.227277, **0.6%**	0.156143
	RF Gun + ACC1–ACC4	—	1.229467	0.101497
10, top-up	RF Gun	804.0	0.000466, **0.01%**	2.000615
	ACC1–ACC4	2640.0	0.261123, **0.13%**	0.033148
	RF Gun + ACC1–ACC4	—	0.261589	0.000341

- Energy feedback : LLRF amplitude control with operating 2nd klystron as near saturate regime

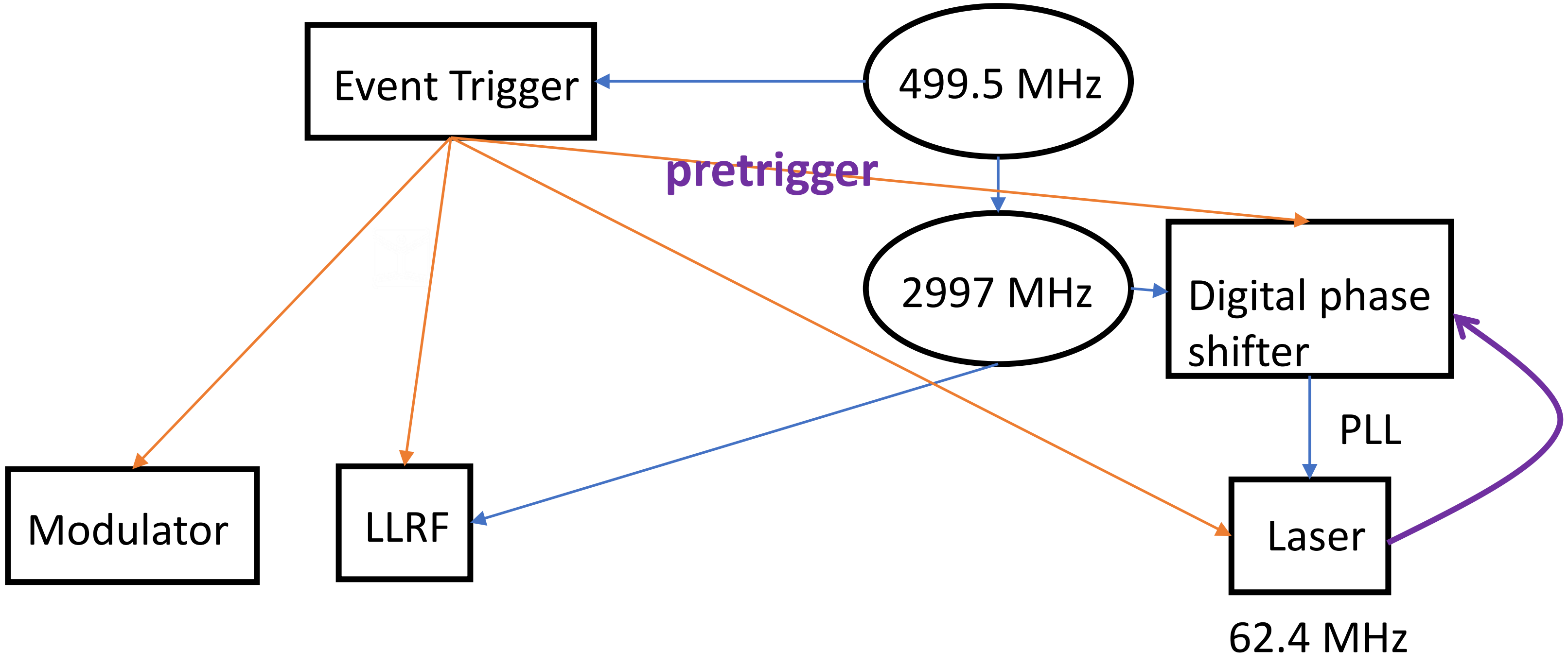
Multibunch test at the gun before the installation

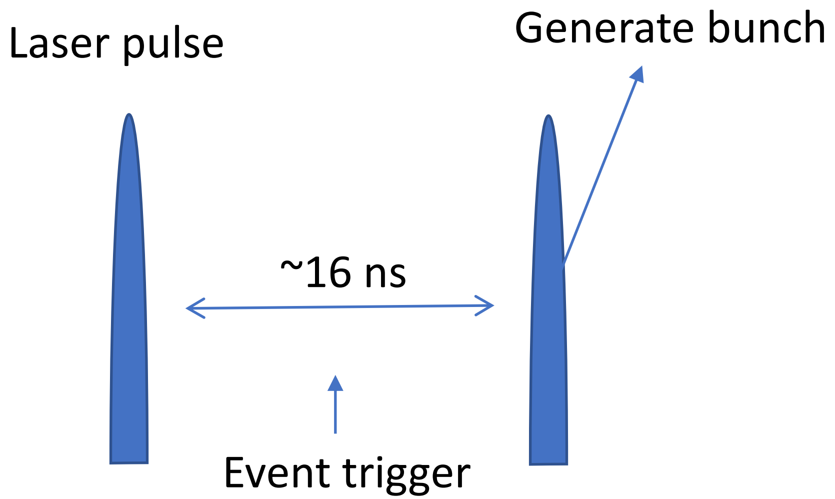
- Test 2997.56 MHz photocathode RF gun(QE, dark), injector laser (single & multi), high power phaseshifter, attenuator, klystron, modulator, LLRF
- Test timing control, diagnostics (energy, bunch charge)





Bunch by bunch timing control





- 2 Hz bunch by bunch timing control requested by booster.
- Digital phase shifter scan and position laser pulses to right timing with ~0.005 degree (~5 fs) resolution.

Summary

- XFEL instruments are further optimized to use in KLS LINAC.
- Photocathode based LINAC provides small beam size and energy spread for the booster injection of KLS
- Passive multipulse laser generation ensures robust operation of multibunch generation.

Milestones

- 2026 : Gun, high power RF components, Klystron, modulator, LLRF, SSA and laser will procured
- 2028 : Gun test including multi-bunch, gun QE
- 2029 : Installation

Special thanks to

- KLS LINAC advisory committee, Hiroshi Matsumoto (KEK), Takahiro Inagaki (RIKEN SPring-8 Center), John Smedley (SLAC)

- MOGA simulation, Chanmi Kim, Chong Shik Park, Eun-San Kim, Seung Hwan Shin, Seong Hee Park at Korea Univ.