

The 29th KEKB Accelerator Review Committee

Electron gun/Positron source

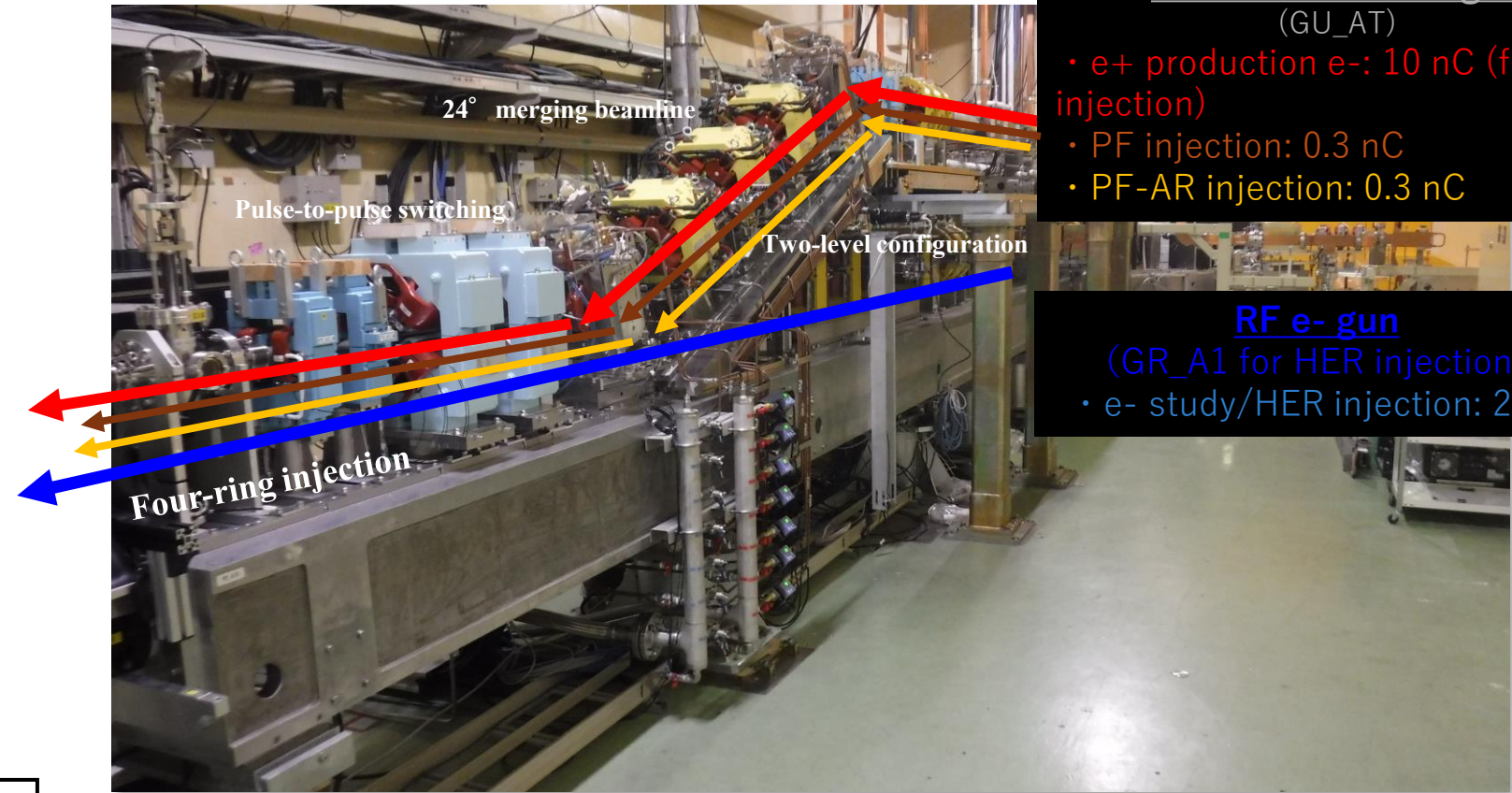
Xiangyu Zhou (Particle source G)

Oct. 27, 2026

Pulse to pulse switching: RF e- gun/Thermionic e- gun

Contents

- Thermionic DC Electron Gun
 - Positron target and capture section
- RF Election Gun
 - RF Cavity
 - Photocathode
 - Laser source



Thermionic DC e- gun (GU_AT)

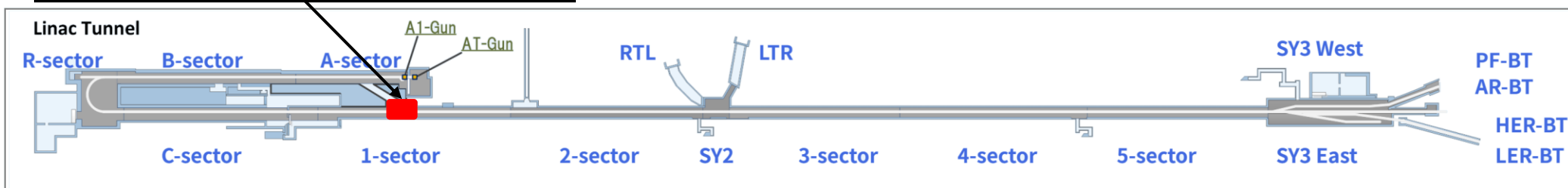
- e⁺ production e⁻: 10 nC (for LER injection)
- PF injection: 0.3 nC
- PF-AR injection: 0.3 nC

RF e- gun

(GR_A1 for HER injection)

- e⁻ study/HER injection: 2 nC

Positron target and capture section



Thermionic DC Electron Gun: Status and Maintenance

● Operational Status

- Operates reliably as the primary electron source for positron production.

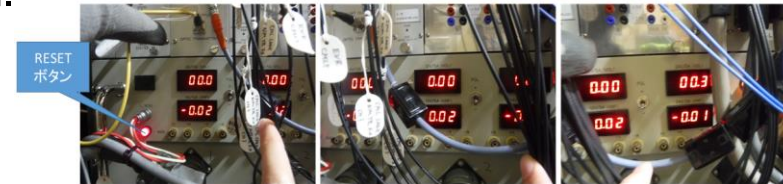
● Aging Equipment and Maintenance

- Replaced the NIM power supply in the high-voltage (HV) station. (Mar. 2026)
- Aging components remain a concern; backup equipment has been prepared.

● Thermionic cathode Management

- Thermionic cathode are normally replaced during the annual summer maintenance period. No replacement was performed in 2026.
- The remaining stock of the current cathode type is limited. Alternative cathodes from other manufacturers will be considered.

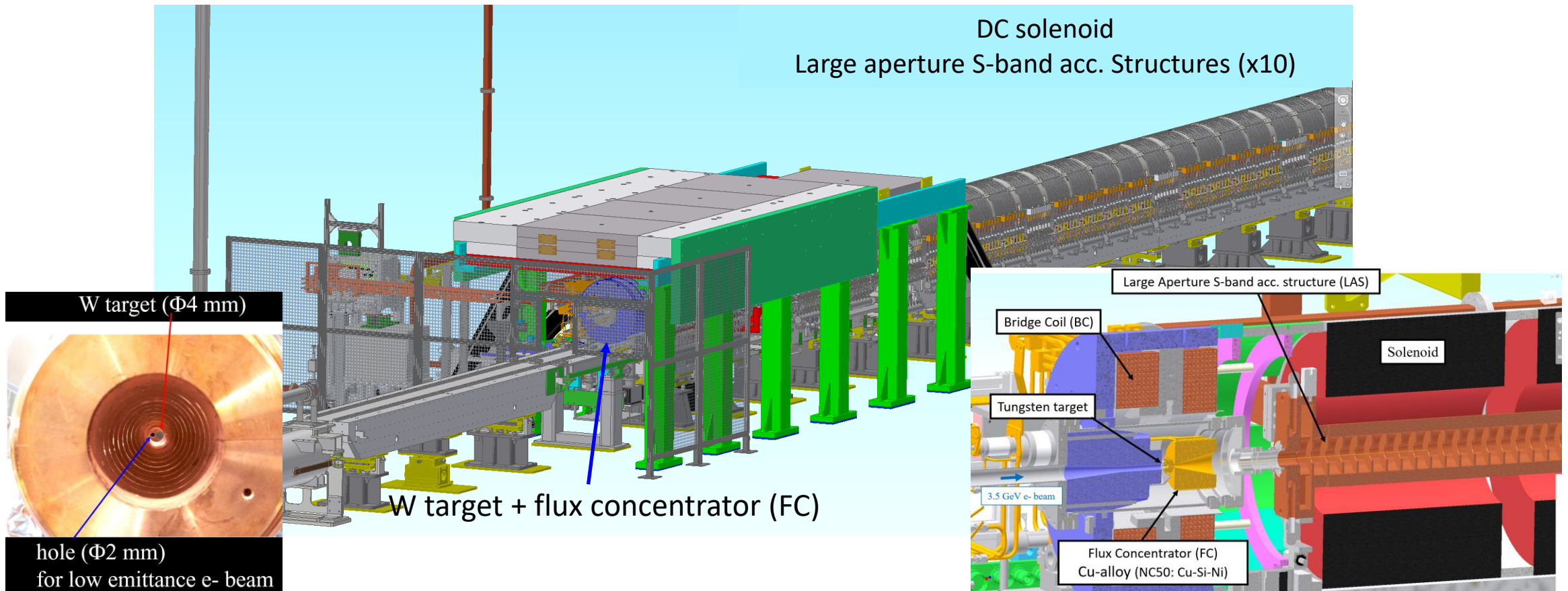
NIM-POWER SUPPLY Unit in GU_AT HV-ST



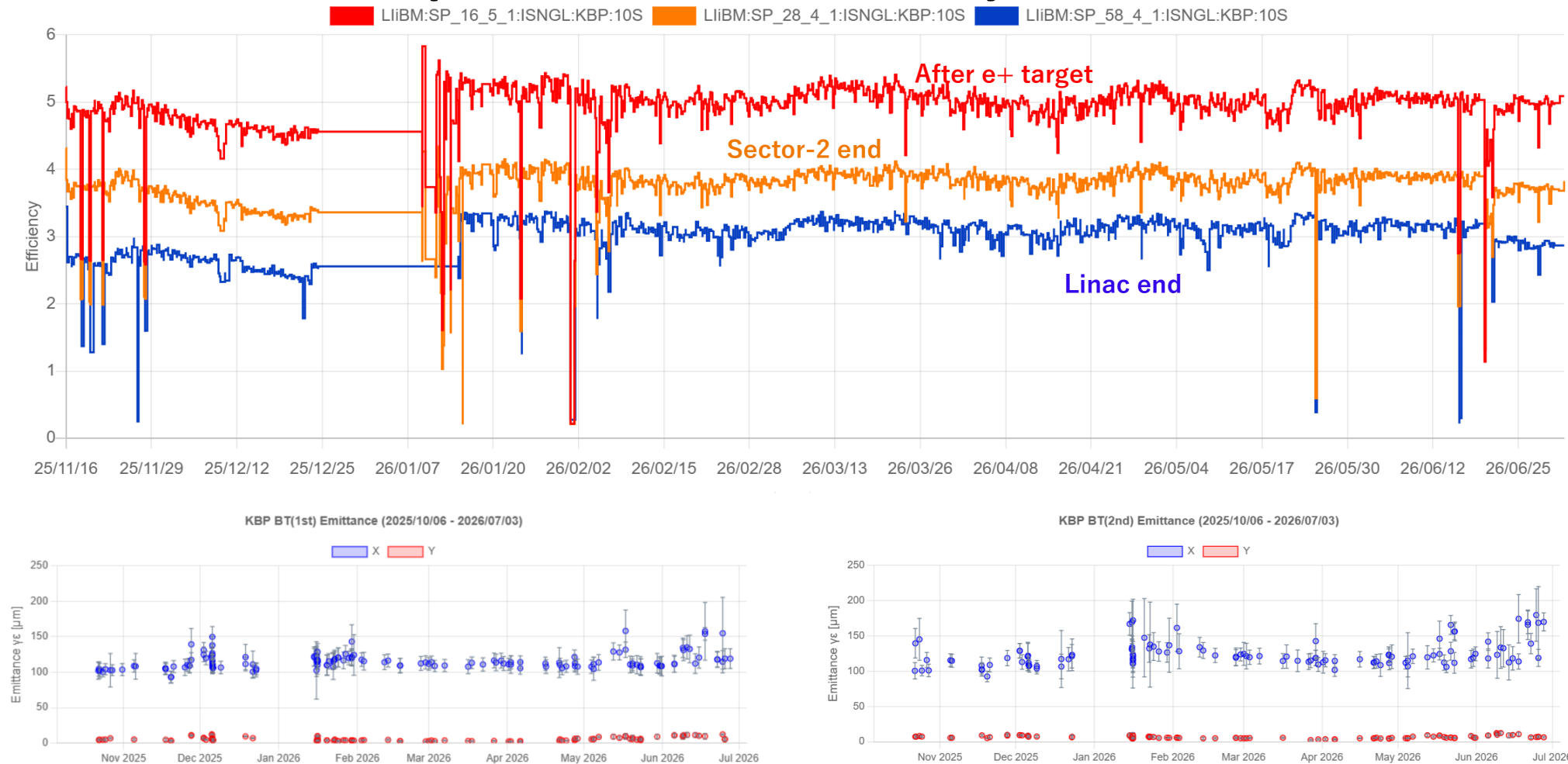
Each digital meter displays a voltage of 0V and a current of 0A.

Positron target and capture section at 1-sector

- A 3.5 GeV electron beam is directed onto the tungsten target.
- A flux concentrator (FC) and a DC solenoid collect and focus the positrons.
- Ten large-aperture S-band accelerating structures accelerate the captured positrons.



e⁺ bunch operation history

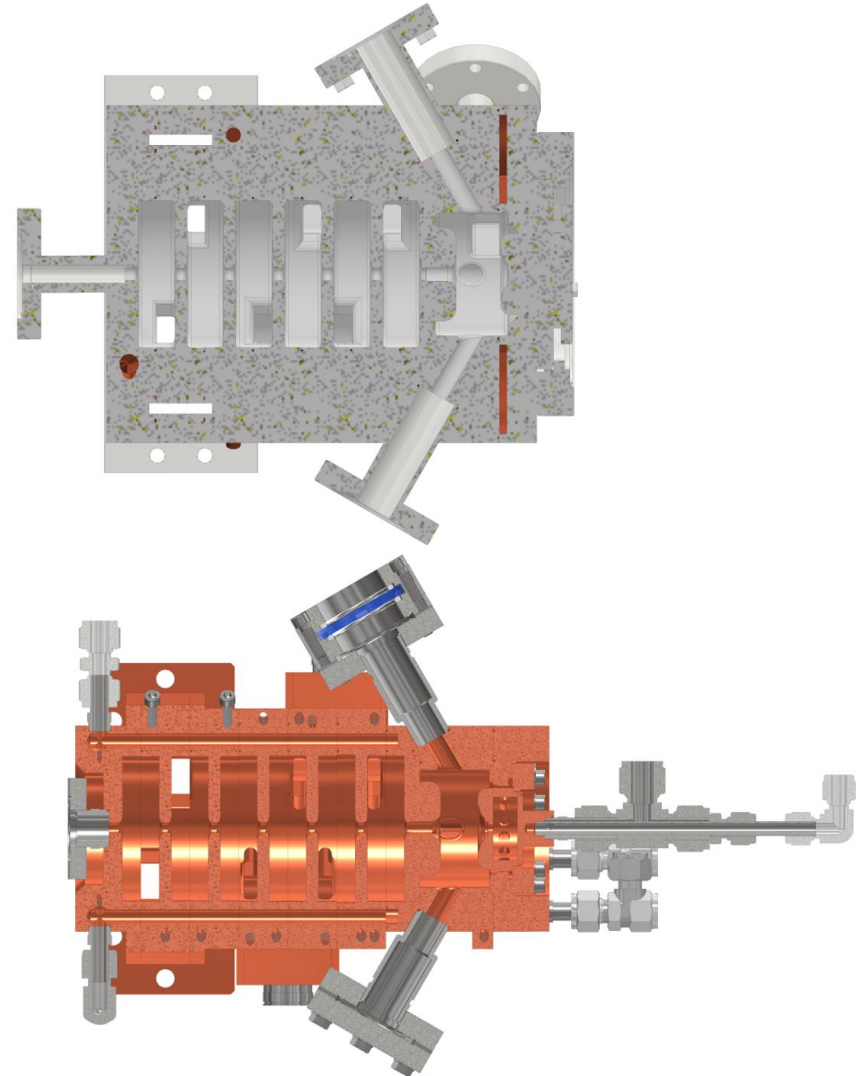
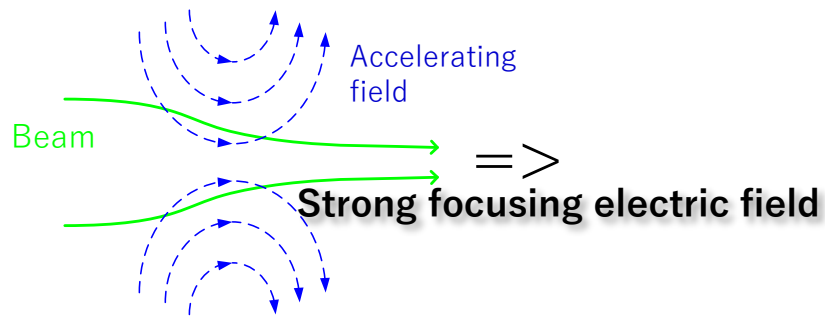
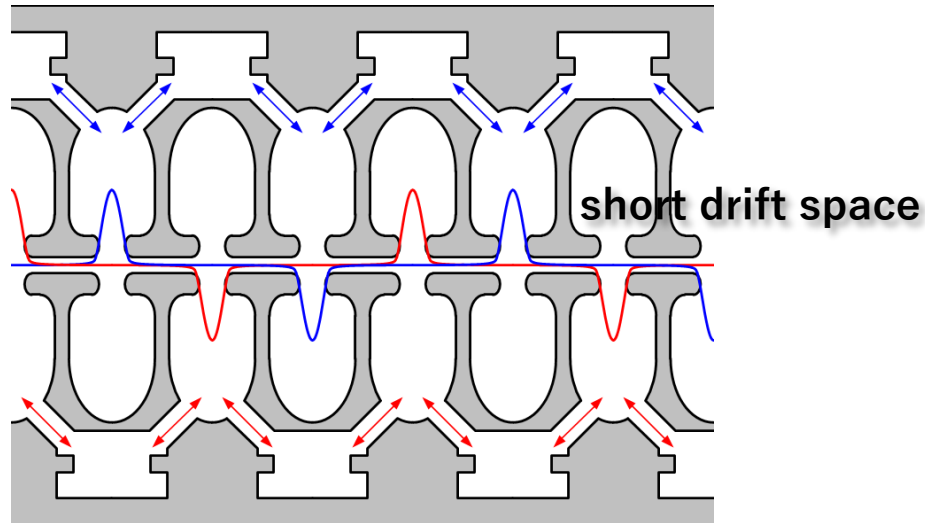


- At the end of sector-2, we can stably produce **3.5 nC** of positron charge, sufficient for 3 nC operation.
- Machine learning based automatic tuning can help to increase and stable the e⁺ bunch charge.
- e⁺ generation system (flux concentrator, power supply, DC solenoid) has worked fine.

RF gun cavity: strong focusing electric field

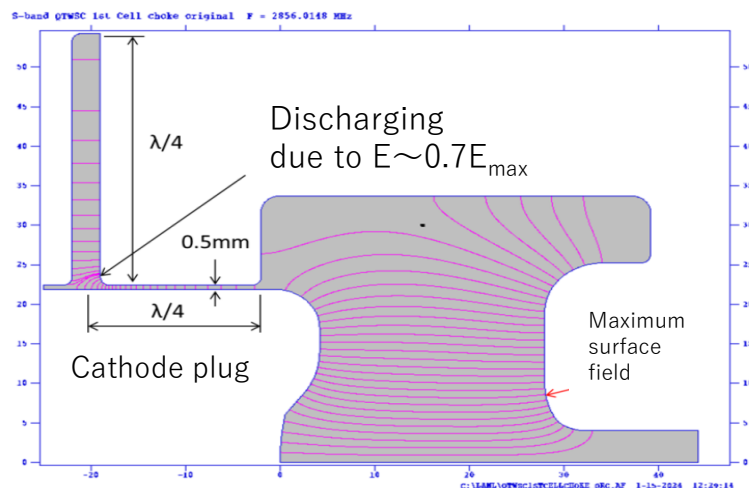
- Quasi travelling wave side coupler (QTWSC): A1 primary RF gun

Quasi traveling wave side couple structure

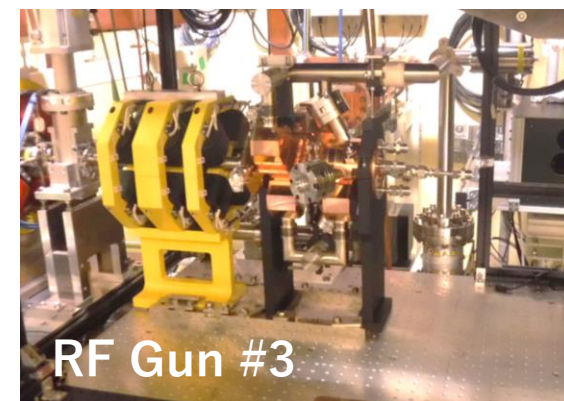
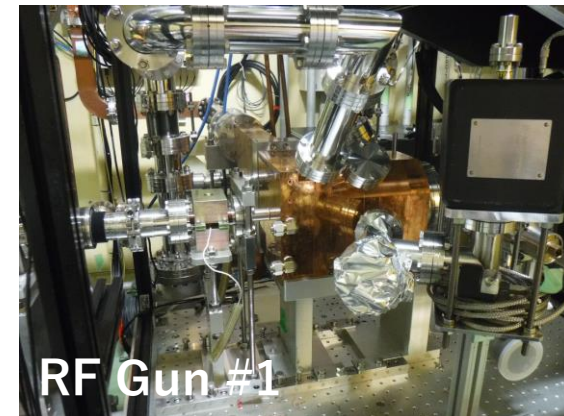
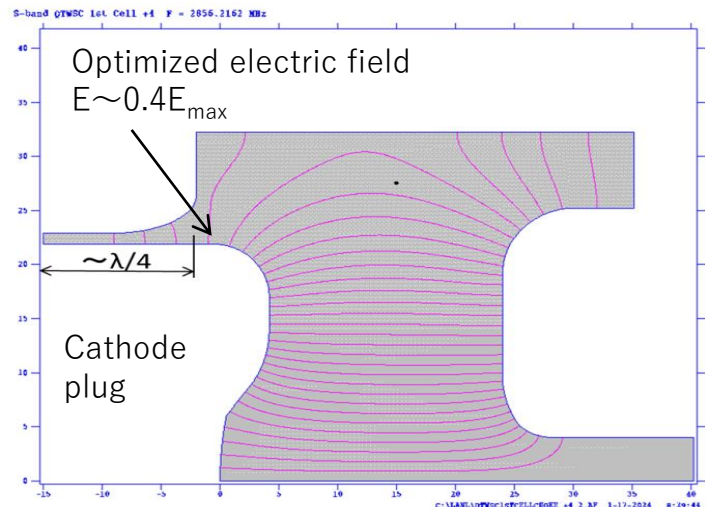


New Quasi-Travelling Wave Side Couple RF-Gun

RF-Gun #1 cathode cell with choke structure for cathode thermal cleaning

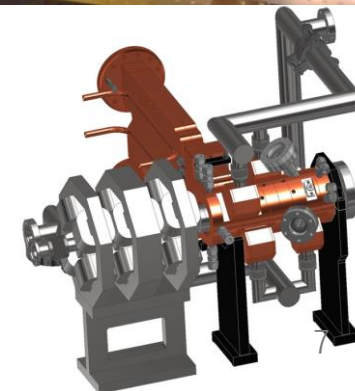


New RF-Gun #2 cathode cell optimized surface field

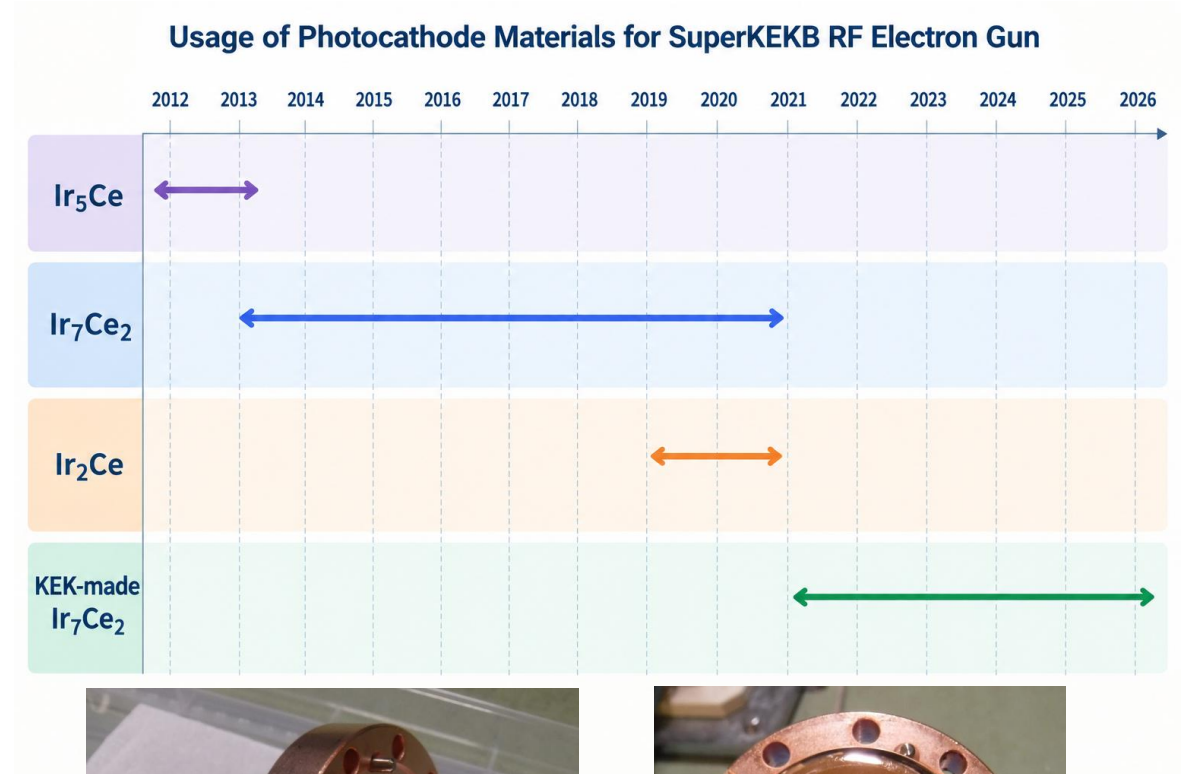
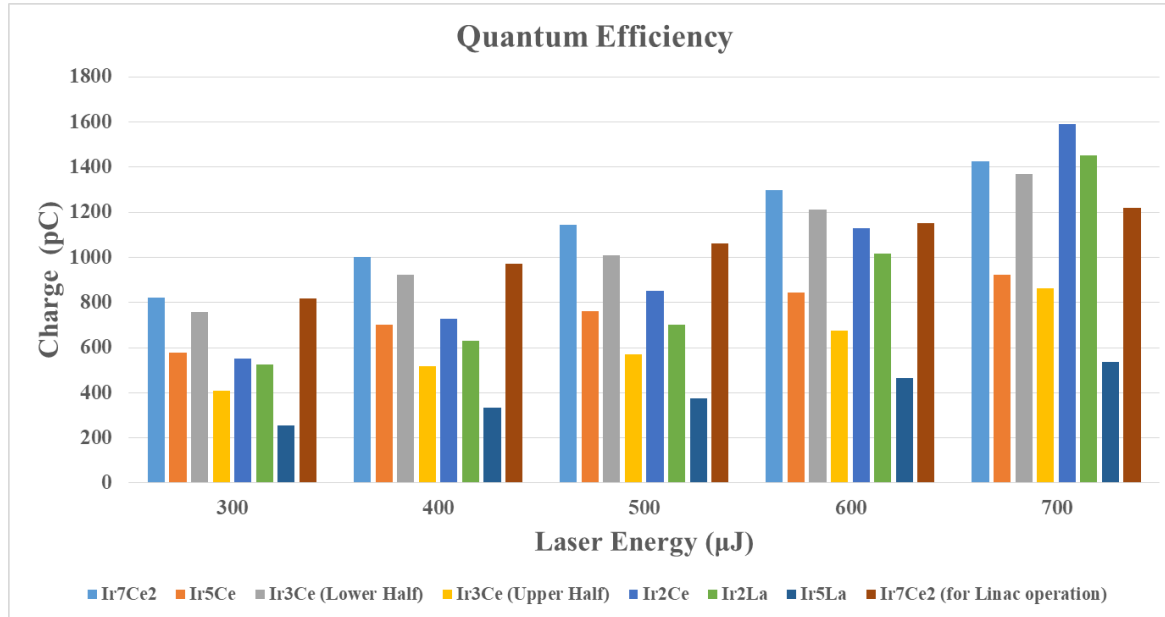


Photocathode RF-Gun Record

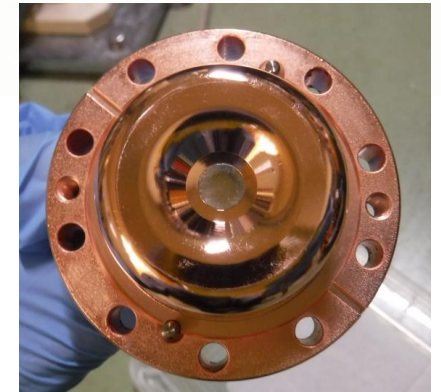
- **RF-Gun #1** (2013.8 – 2025.7)
 - Vacuum chamber contaminated
 - Laser window life-time
 - Dischargetment at choke structure
 - Dark current
 - **RF-Gun #2** (2025.8 – 2026.7)
 - Vacuum-related contamination was resolved.
 - Assembly mix-up (RF width limited)
 - **RF-Gun #3** (2026.8 ~)
 - Based on the Gun #2 design.
- The new design is expected to improve RF-gun reliability and reduce discharge-related problems.



Cathode : Ir_7Ce_2

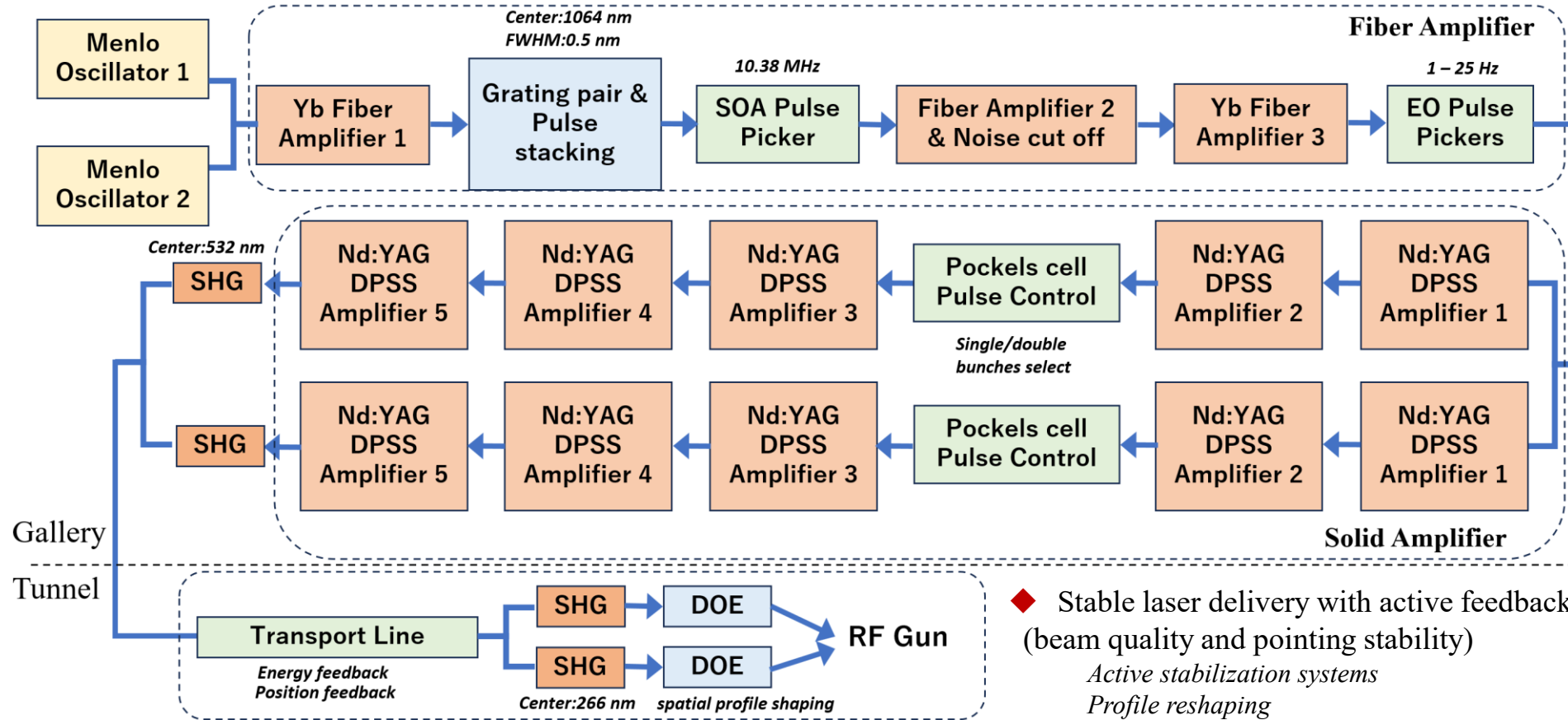


- Developed IrCe photocathodes to achieve a balance between quantum efficiency (QE) and lifetime.
- Systematically investigated and optimized the Ir/Ce composition ratio and fabrication process.
- KEK house made Ir_7Ce_2 cathode has been used in the Linac to date and will continue to be used in future operations.



A1 laser system for RF Gun

Repetition frequency 114.24 MHz
Synchronized with 2856 MHz RF trigger



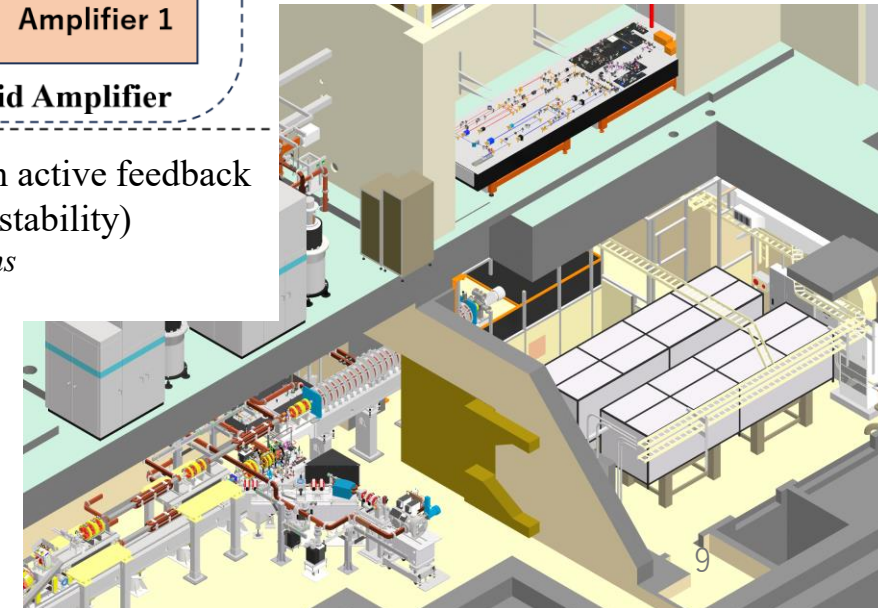
◆ Flexible pulse manipulation
(stability and flexibility)
*repetition rate, pulse selection,
pulse timing, and the two-bunch
operation*

◆ Reliable high-energy amplification
(simple and robust structure)
*2 beam lines
25 Hz operation (Max 50 Hz support)
Quick maintenance*

◆ Stable laser delivery with active feedback
(beam quality and pointing stability)
*Active stabilization systems
Profile reshaping*

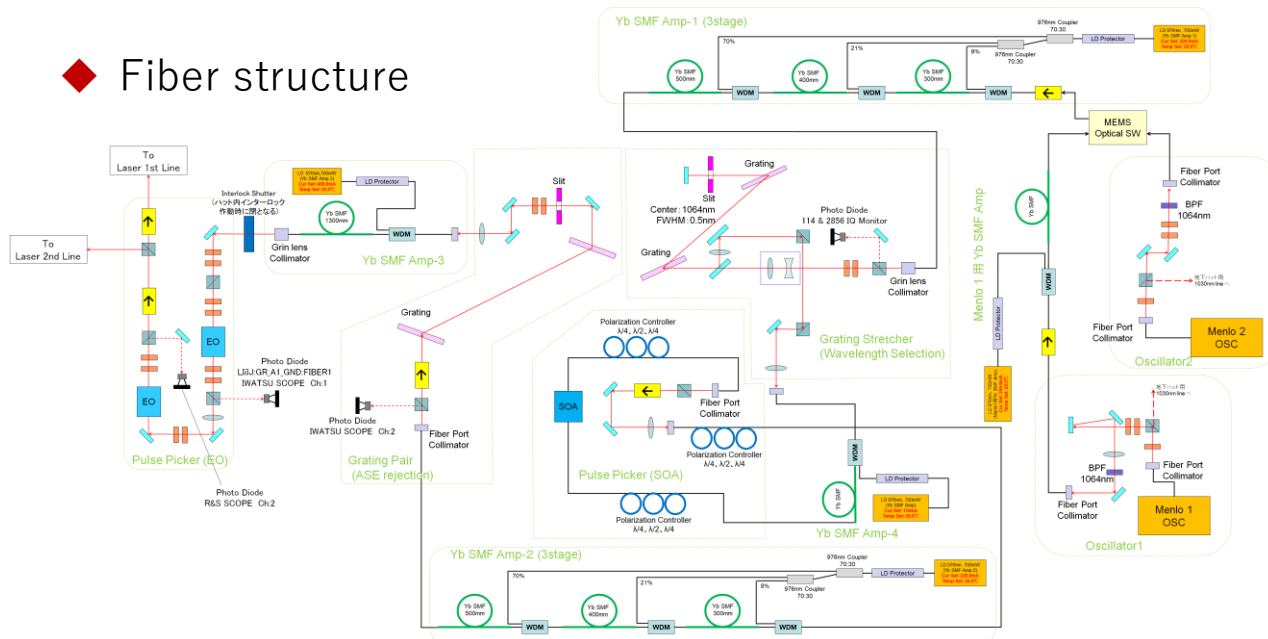
Key Design Concepts of the Electron-Gun Laser System

- The entire laser system was developed and built in-house, allowing for modification and upgrades.
- The functional separation structure can minimize the impact of modifications on the overall system.

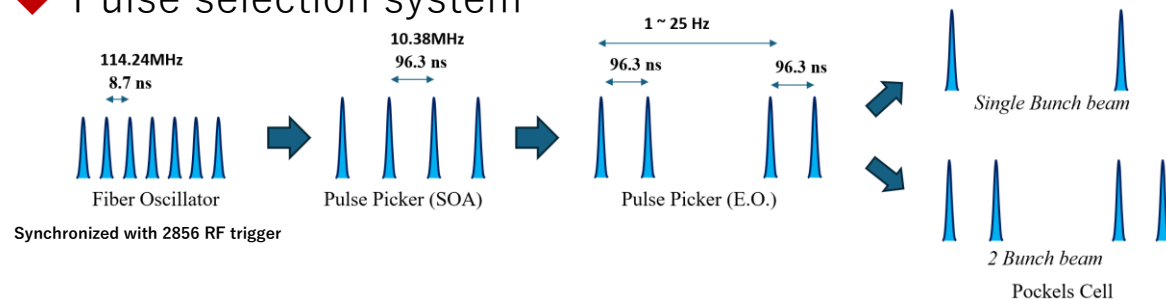


Fiber part

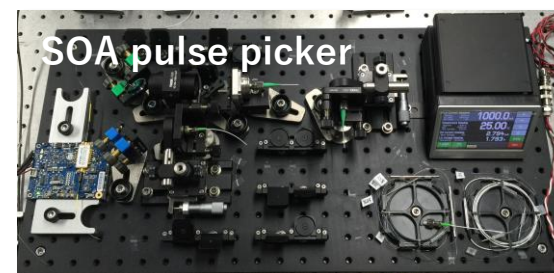
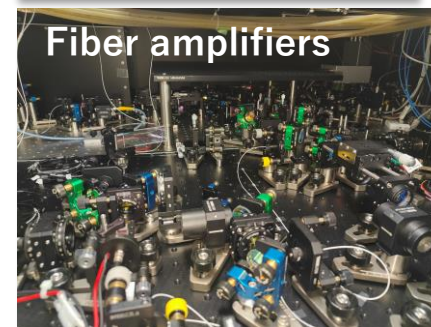
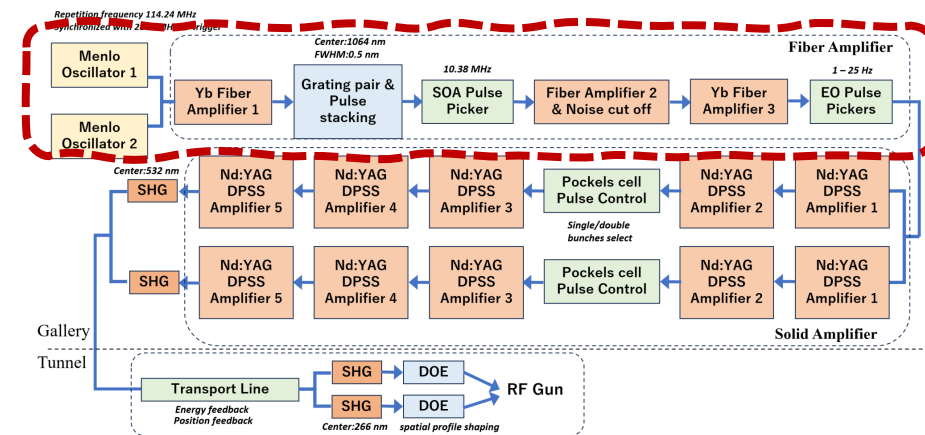
◆ Fiber structure



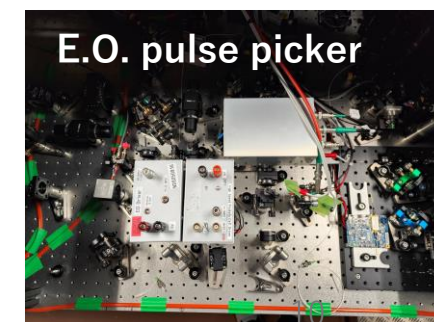
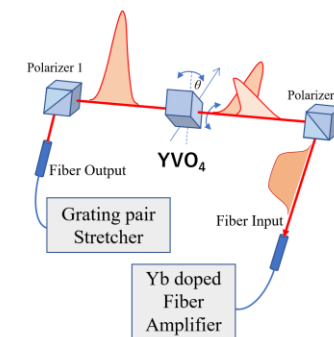
◆ Pulse selection system



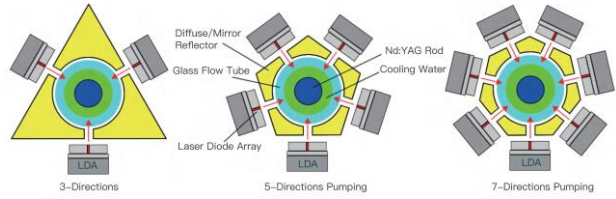
- The fiber system flexibly manipulate the laser signal to meet different operational requirements. (repetition rate, pulse selection, pulse timing, and the two-bunch operation)



◆ Pulse-Stacking Filter (optional)

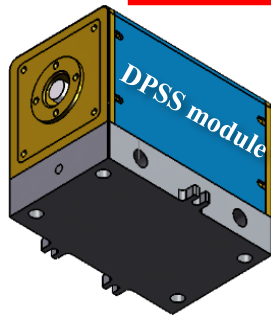
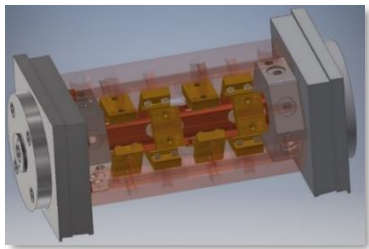


Nd:YAG Solid Amplifier



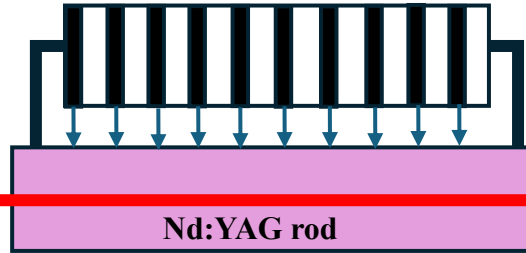
Signal: 1~25 Hz
Single/Double Bunches

1064 nm Signal Beam



DPSS (Diode-Pumped Solid-State) module

808 nm VECSEL pump Stack



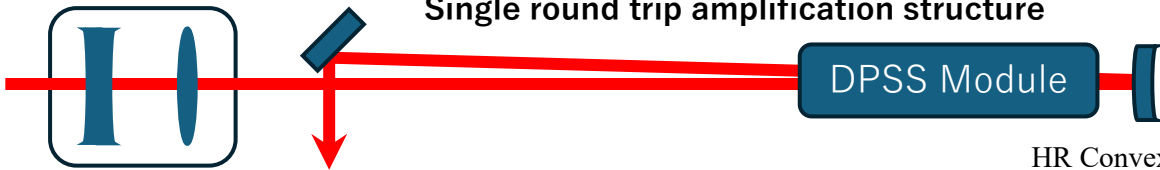
Cooling system

Power Supply

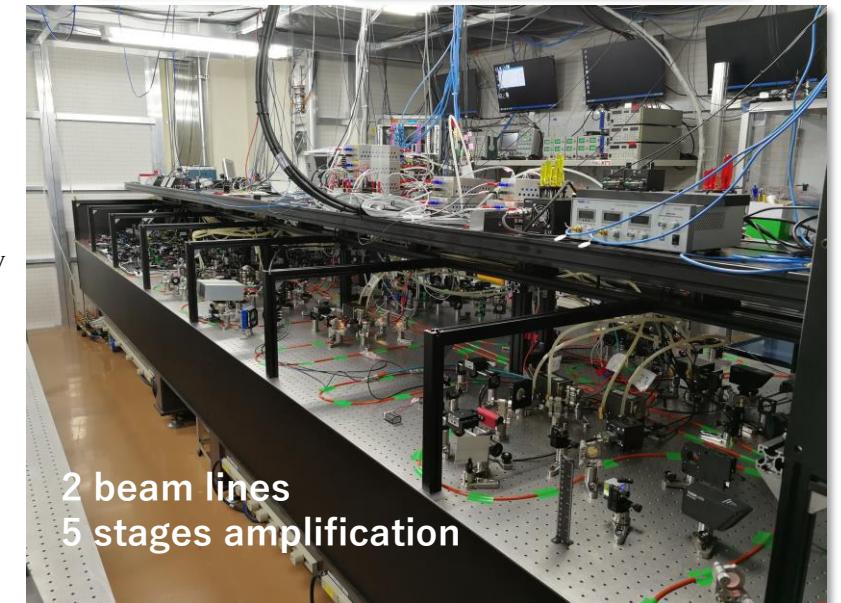
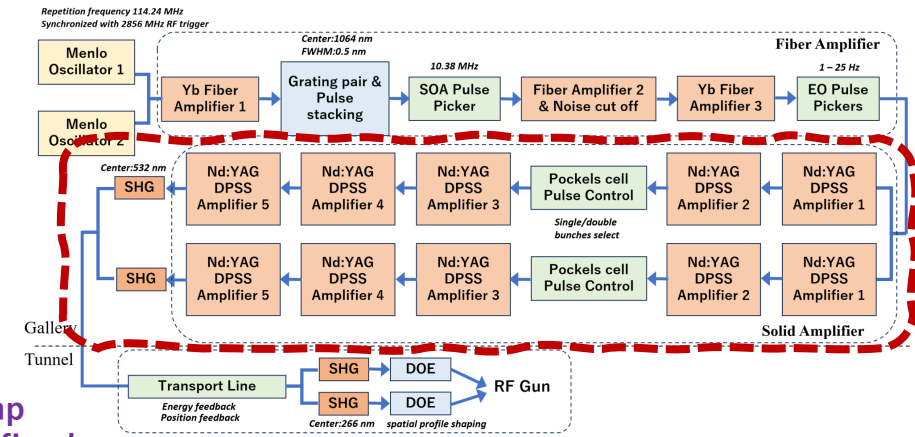
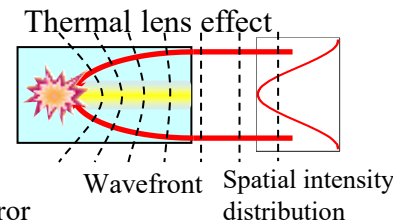
25 Hz pump
operation fixed
(Max 50 Hz support)

Telescope Lens

Single round trip amplification structure



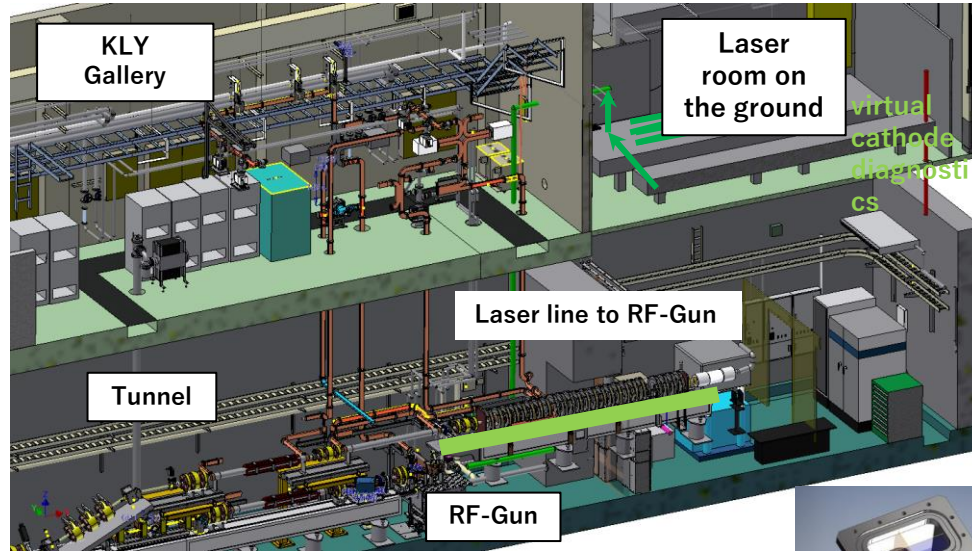
HR Convex mirror



2 beam lines
5 stages amplification

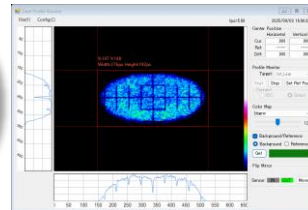
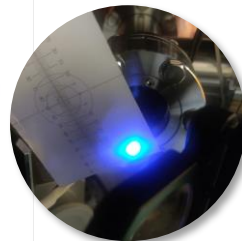
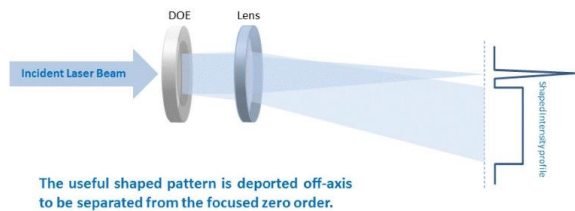
- The solid-state amplifier has relatively large optical losses and is also the part that requires the most maintenance.
- All-in-one DPSS module: simplifying maintenance, and replacement. (recovered with minimum downtime)
- The repetition rate of pump module can be increased to up to 50 Hz.

Transport Line

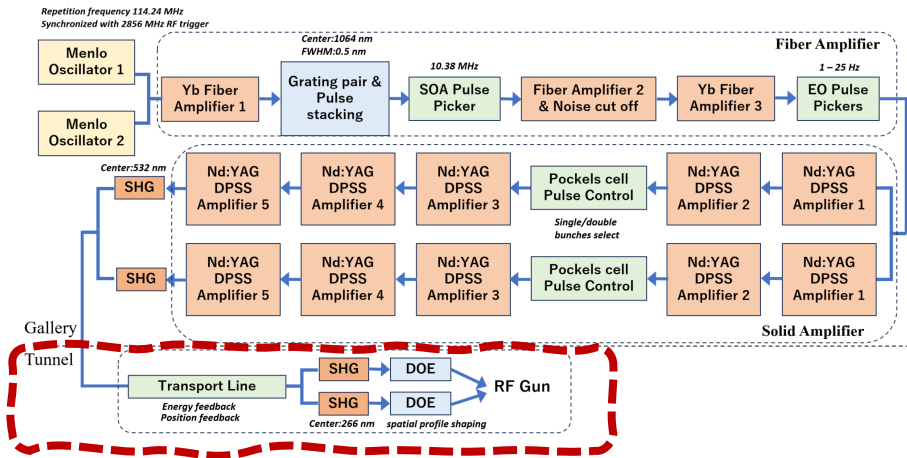


◆ DOE profile shaping

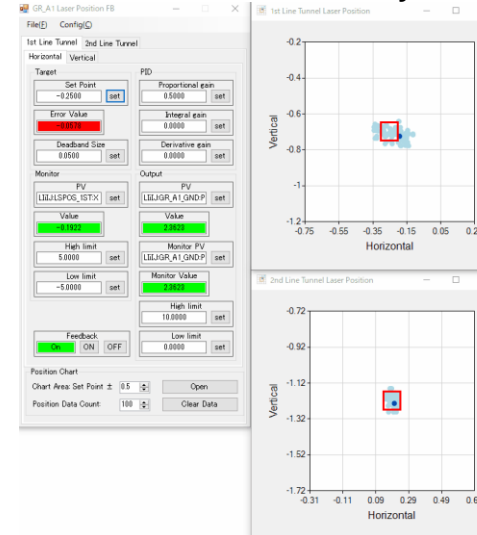
DOE Basics : off-axis configuration
To avoid any zero order hot spot



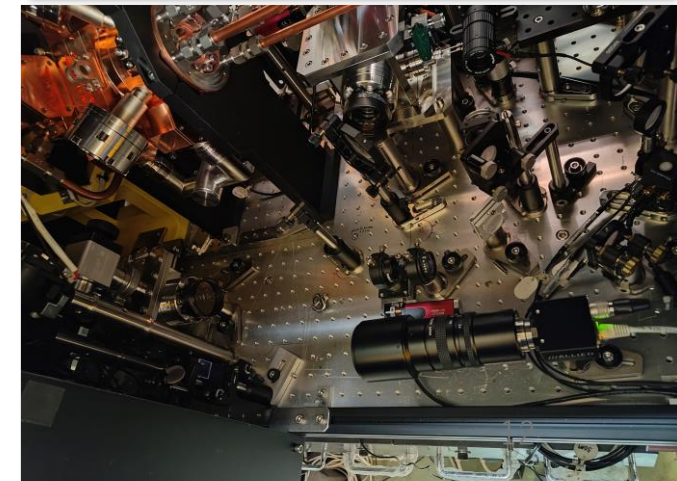
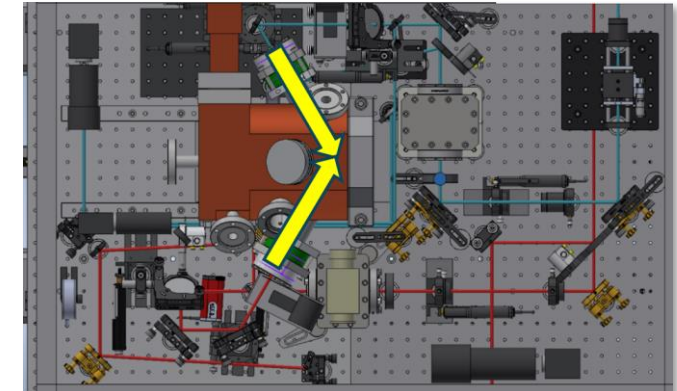
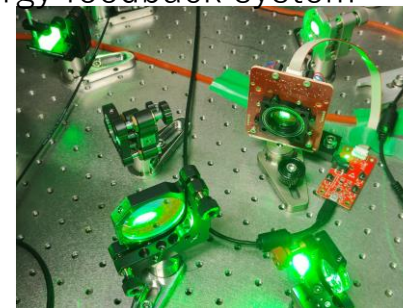
- Remote control, monitoring, and automated feedback systems are extensively implemented throughout the transport line.
- The transport line maintains the beam quality and pointing stability over long path.



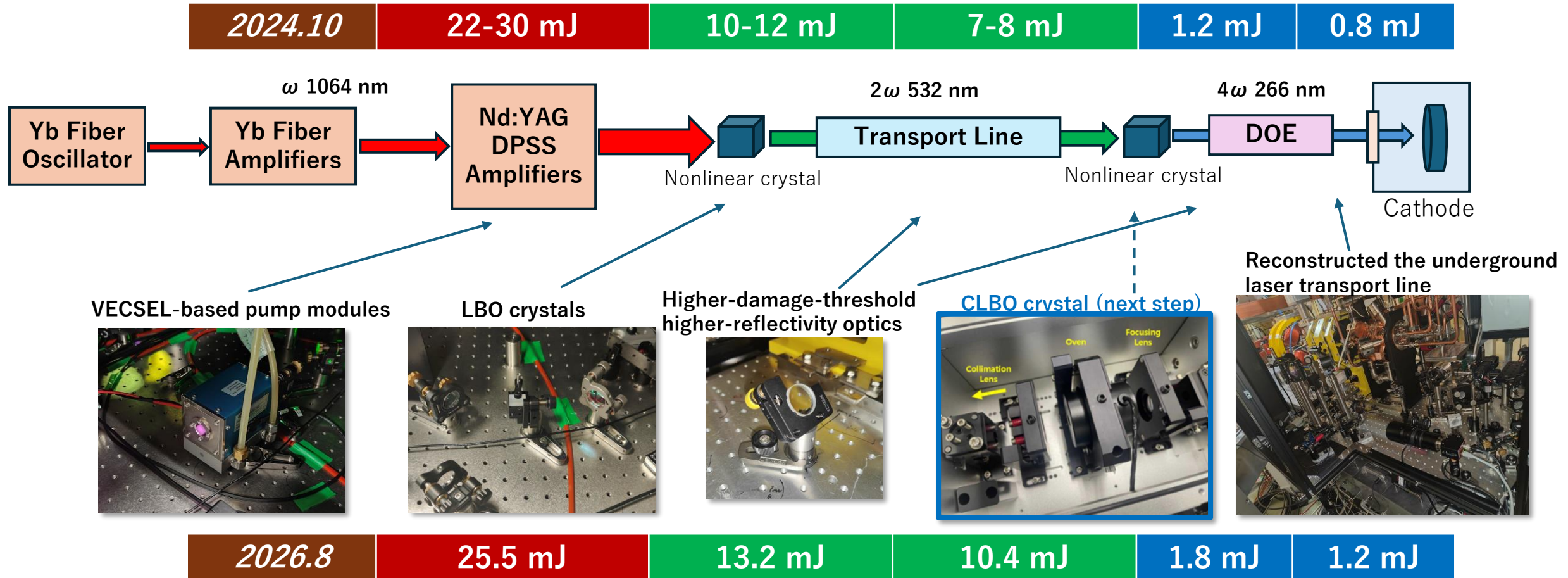
◆ Position feedback system



◆ Energy feedback system



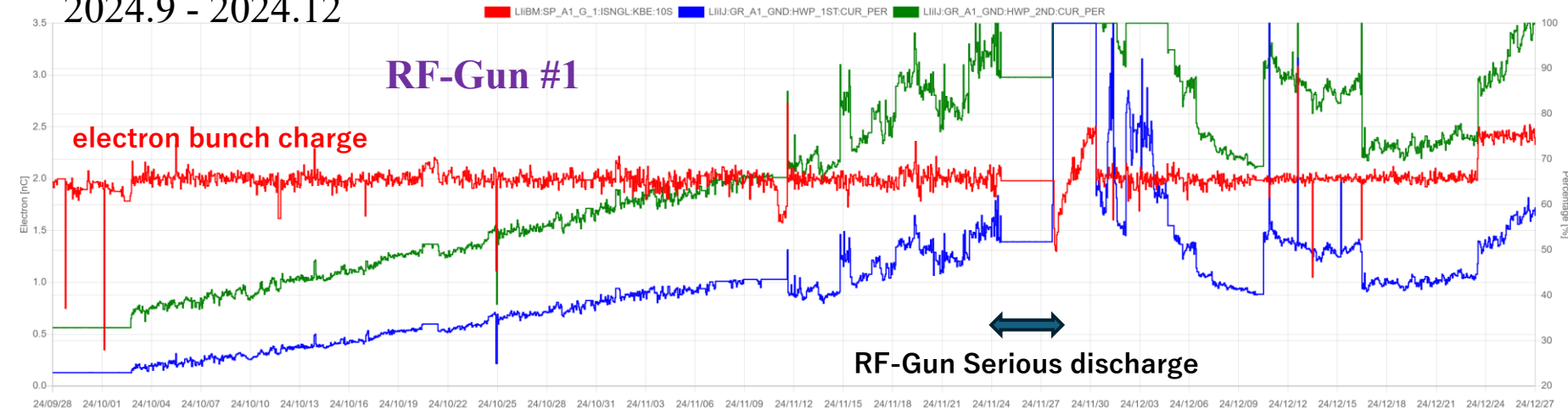
A1 Laser System Upgrades for Higher Efficiency and Reliability



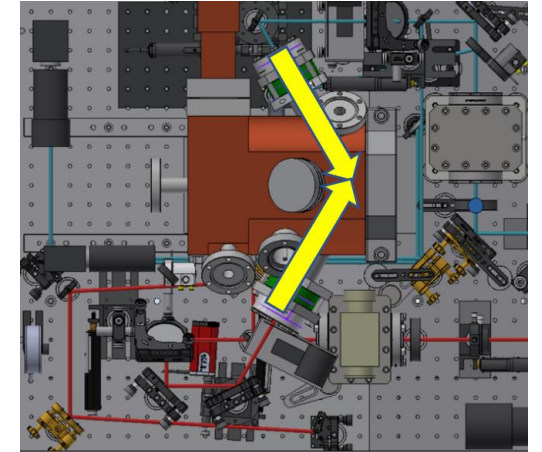
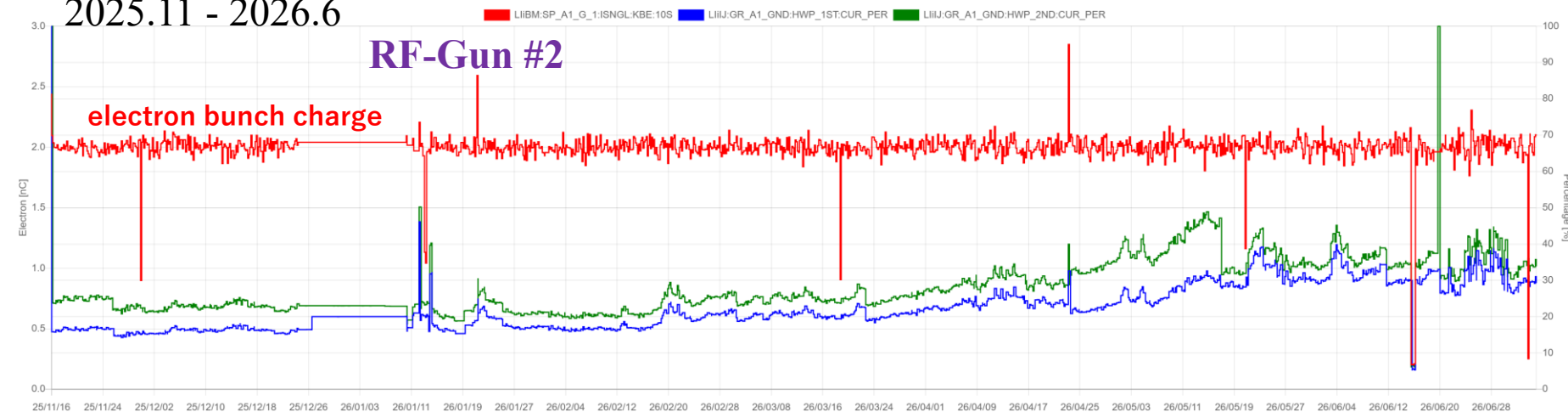
- These upgrades have increased the available laser power margin while reducing optical losses and improving the overall robustness of the system.
- During several months of continuous operation, the laser system has shown stable performance without any laser-related interruptions.

Long-Term Laser Power Requirement for 2 nC Operation

2024.9 - 2024.12



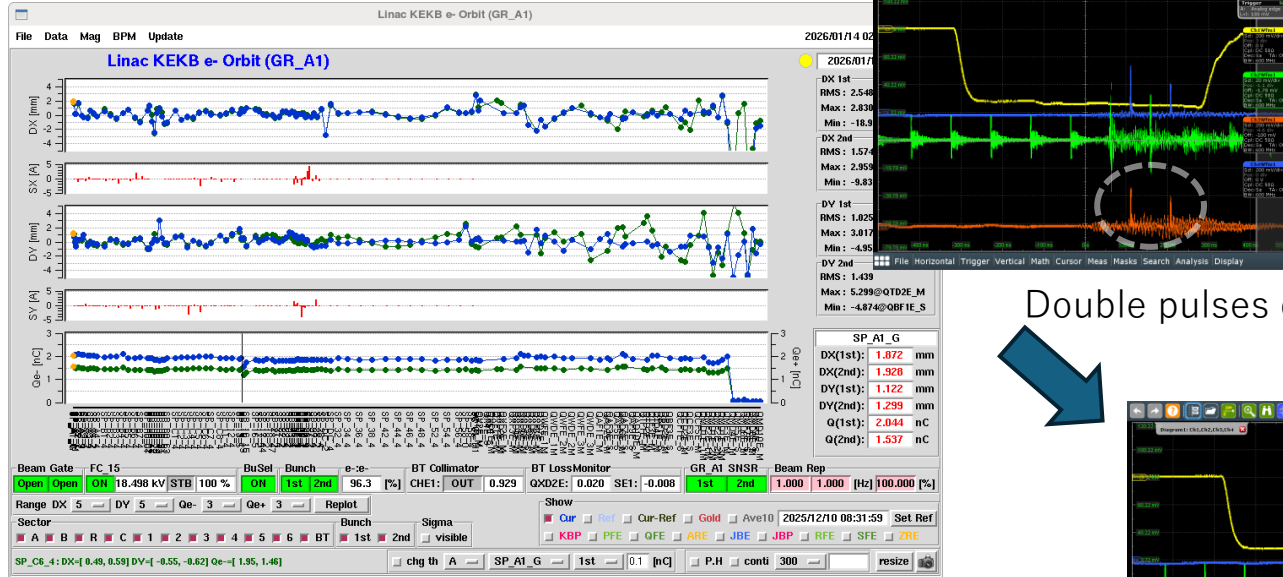
2025.11 - 2026.6



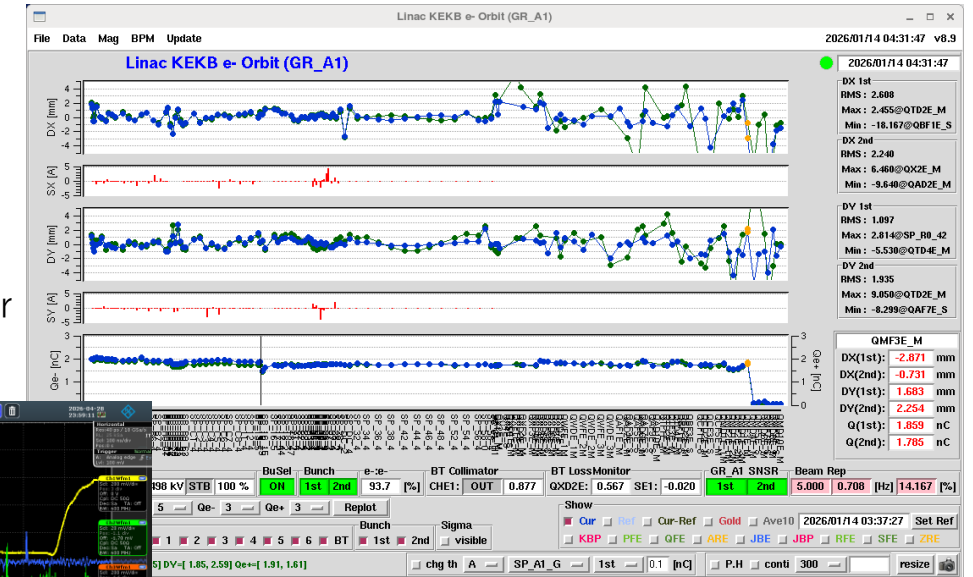
- The main reason was a vacuum problem in the RF gun #1.
 - Dischagement at choke structure
 - Contamination of the laser entrance window reduced the laser transmission.
- The continuous efficiency decrease is not be observed. No serious discharge.
- The cathode cleaning by laser is no needed.
- We expect that laser power is no longer the primary limitation for maintaining the high bunch charge.

2-Bunch Operation Issue: Bunch-to-Bunch Charge Imbalance

● Before modification

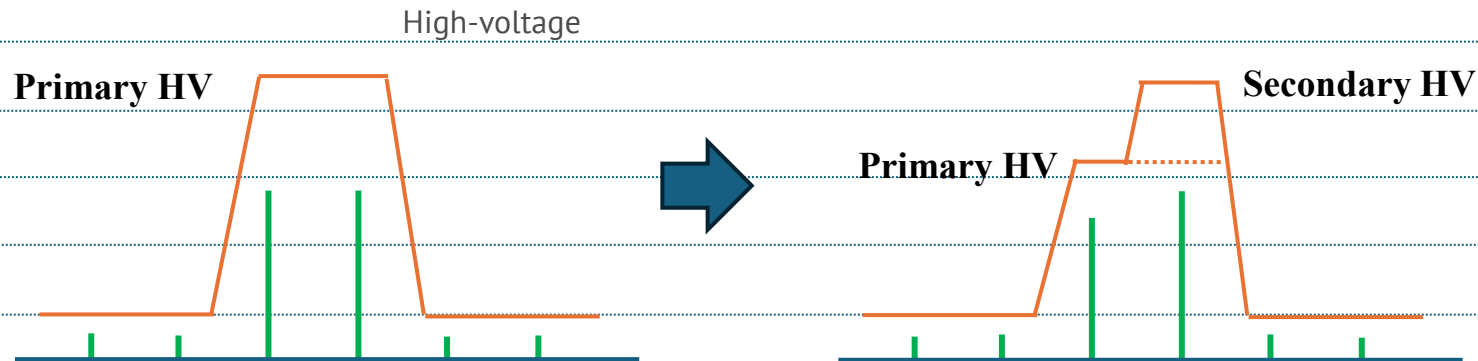
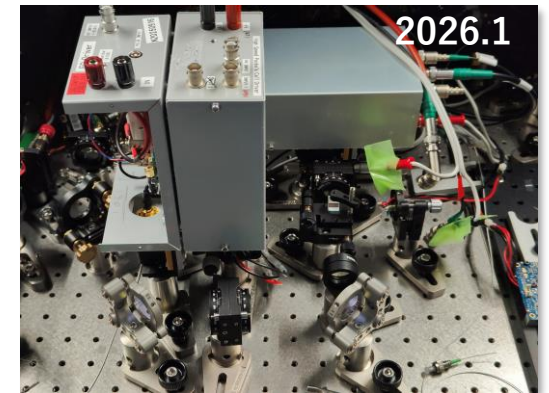
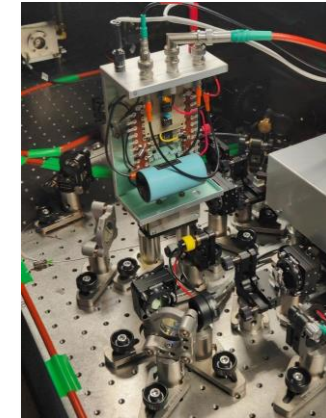
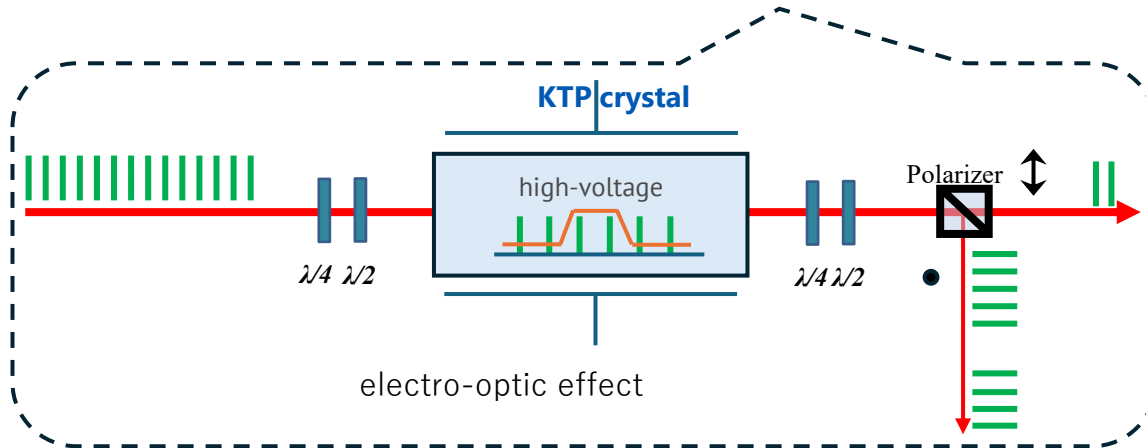
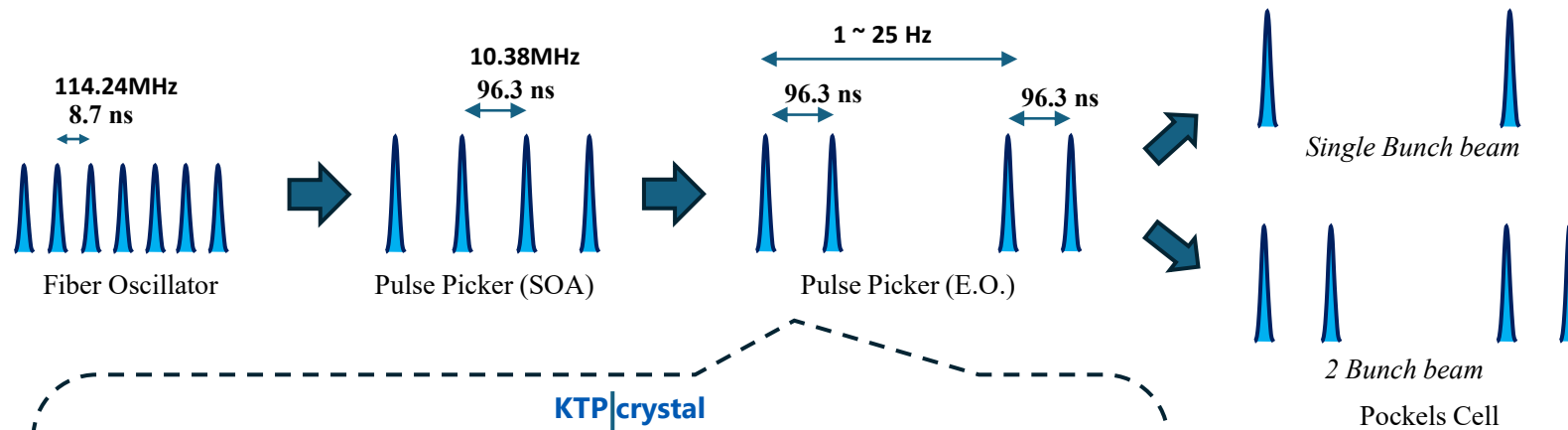


● After modification



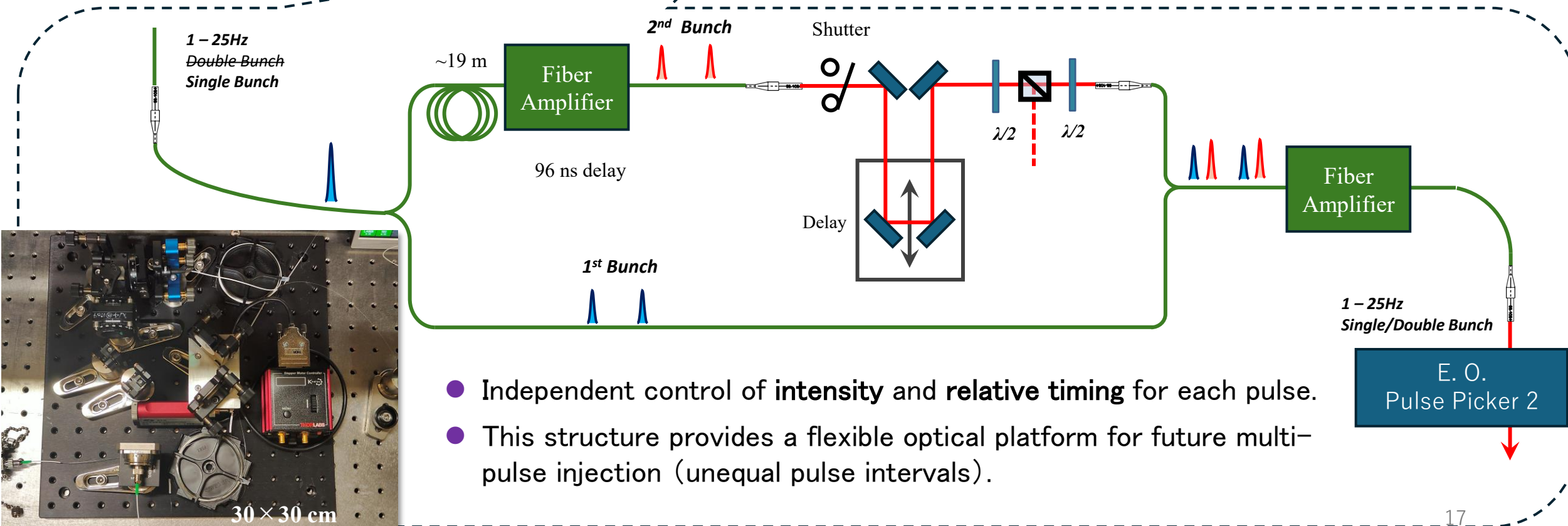
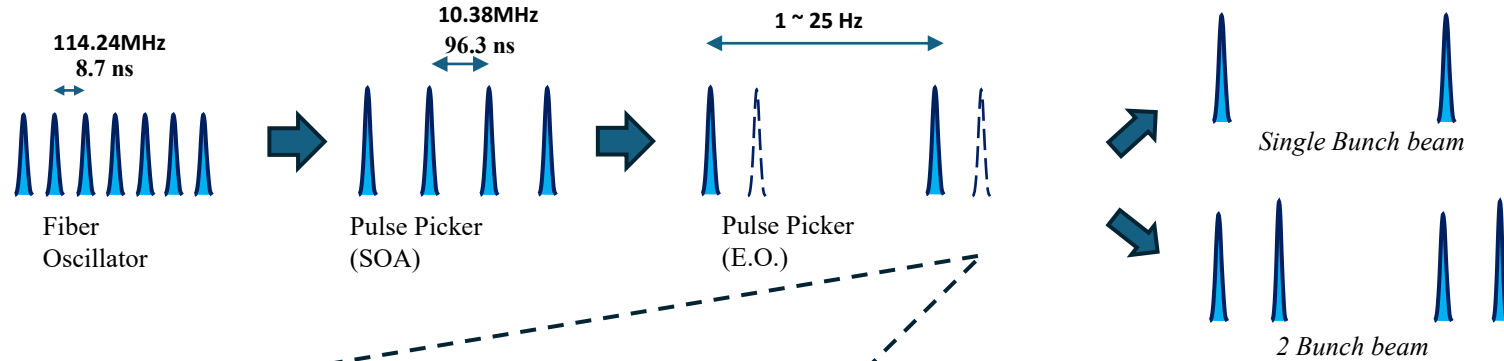
- In 2-bunch operation, the second bunch had a lower charge than the first bunch.
 - Gain depletion in the laser amplifier
 - The photocathode responds differently to the second laser pulse, resulting in lower electron emission.
- To compensate for these effects, the second laser pulse must be stronger than the first one, to equalize the two electron bunches. (Adjusted remotely during operation)

E.O. Pulse picker reform for 2-Bunch intensity control



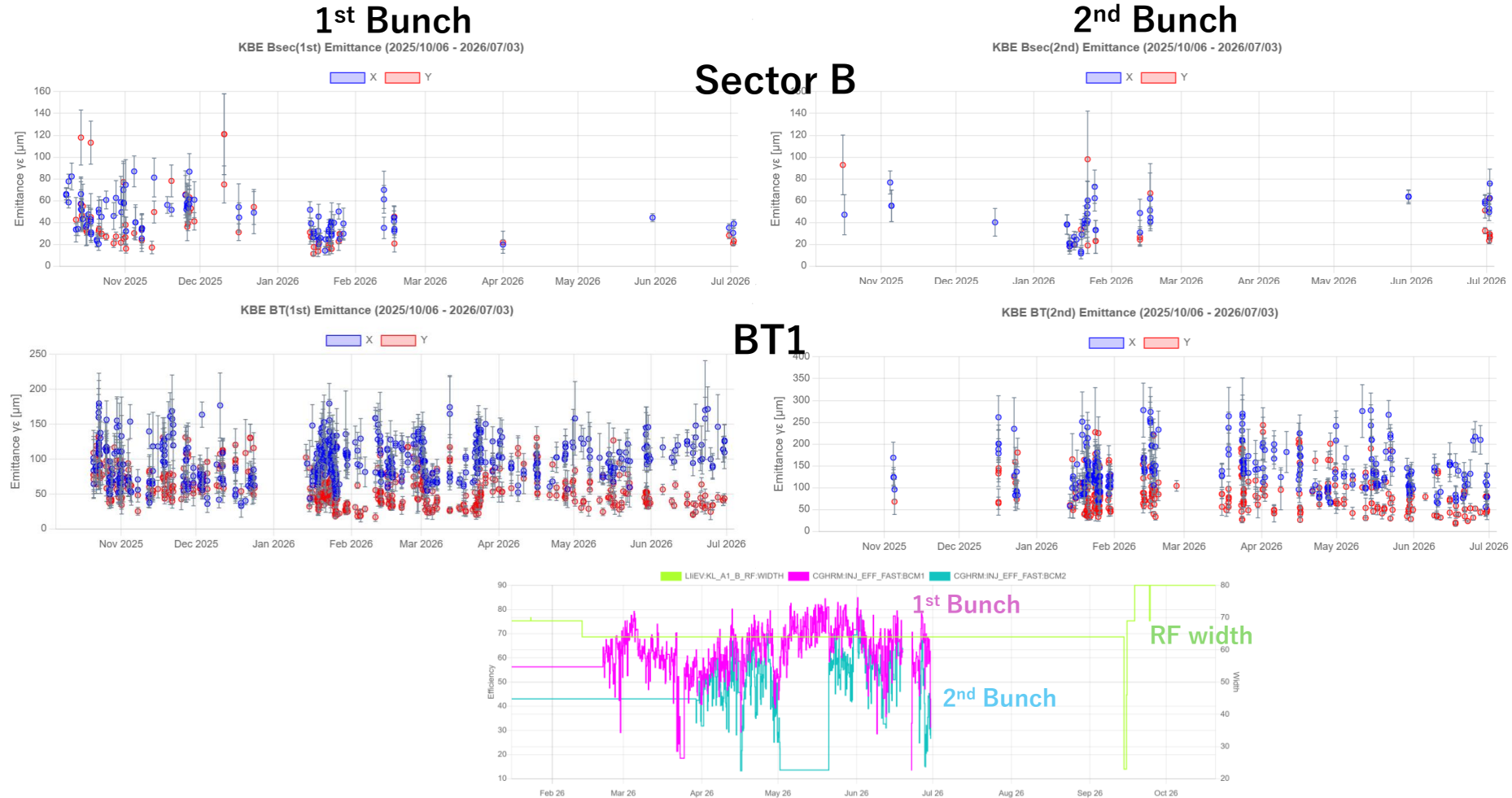
- EO driver upgrade:
Single-voltage $\rightarrow$ Two-voltage control
- Only the high-voltage drive of the EO pulse picker was modified, without changing the existing optical system.

Dual-Path Optical Conditioning for Independent Pulse Control



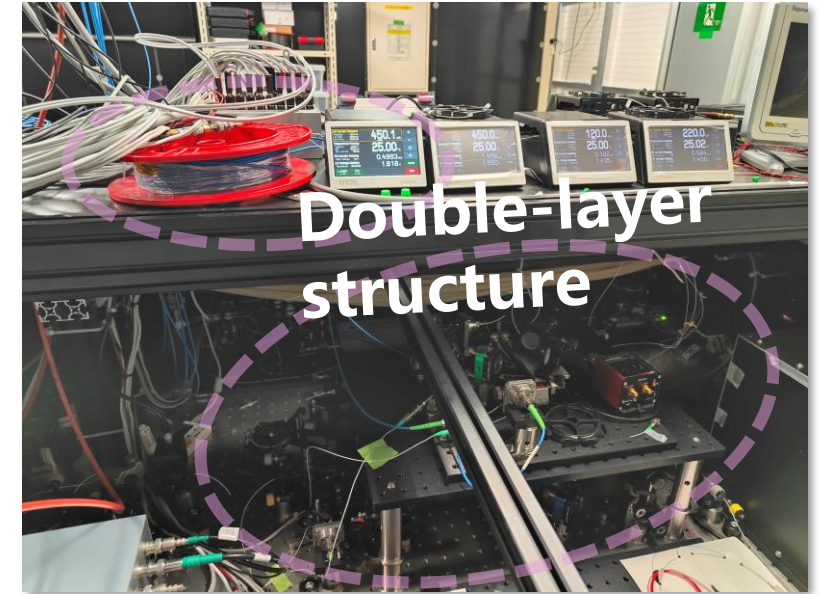
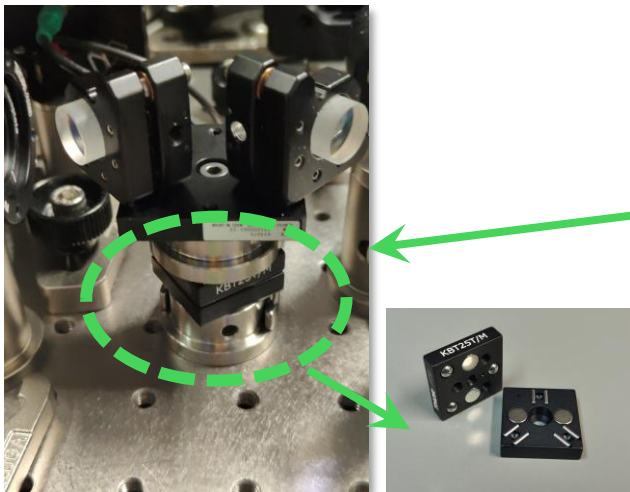
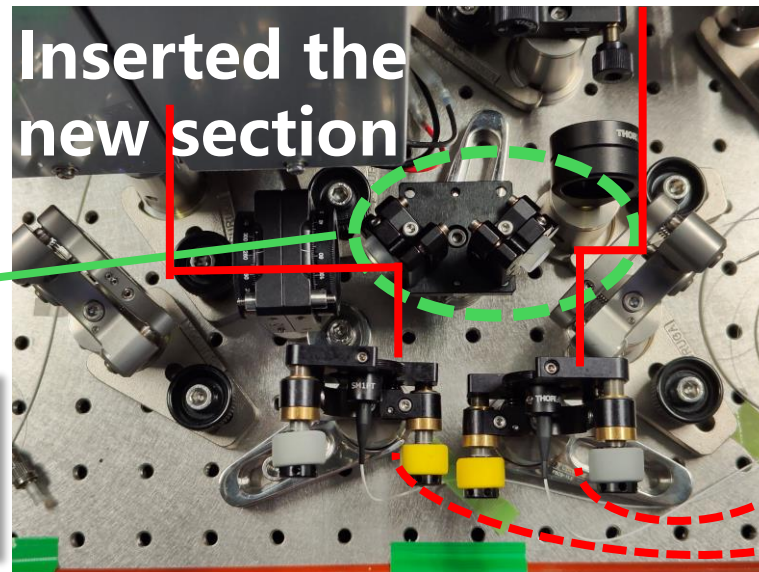
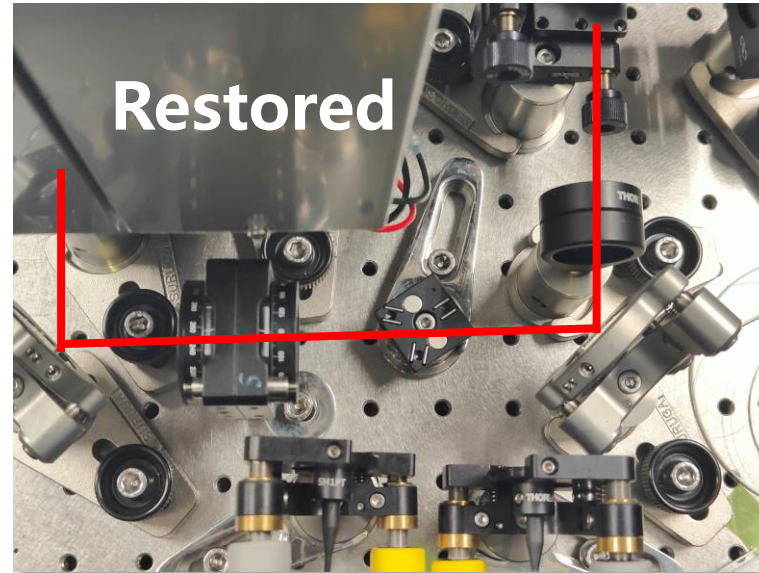
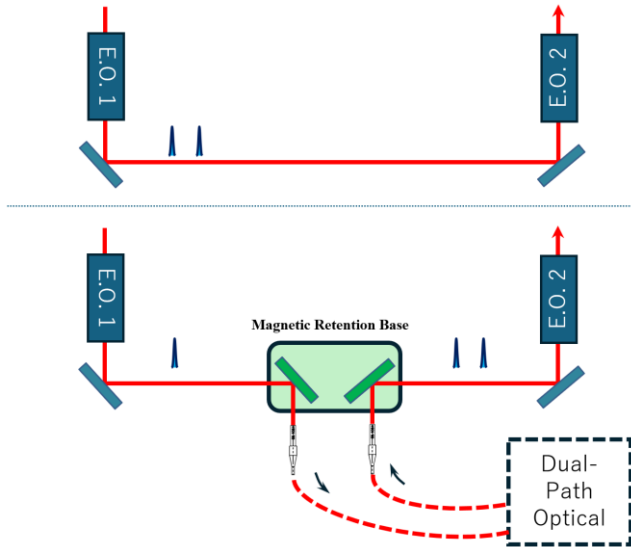
- Independent control of **intensity** and **relative timing** for each pulse.
- This structure provides a flexible optical platform for future multi-pulse injection (unequal pulse intervals).

Emittance Stability During 2026 Operation



- Emittance remained broadly stable over the operation, indicating consistent beam quality.
- No significant difference was observed between the two bunches in the beam quality from the RF gun.
- Investigate the slightly lower injection efficiency of the 2nd bunch. (RF width, pulse intervals)

Modular and Reversible Integration



- **Modular and reversible design:** Flexible upgrades with minimal impact on system reliability.
- **Future expandability:** Supports future multi-pulse upgrades without modifying the existing constructure.

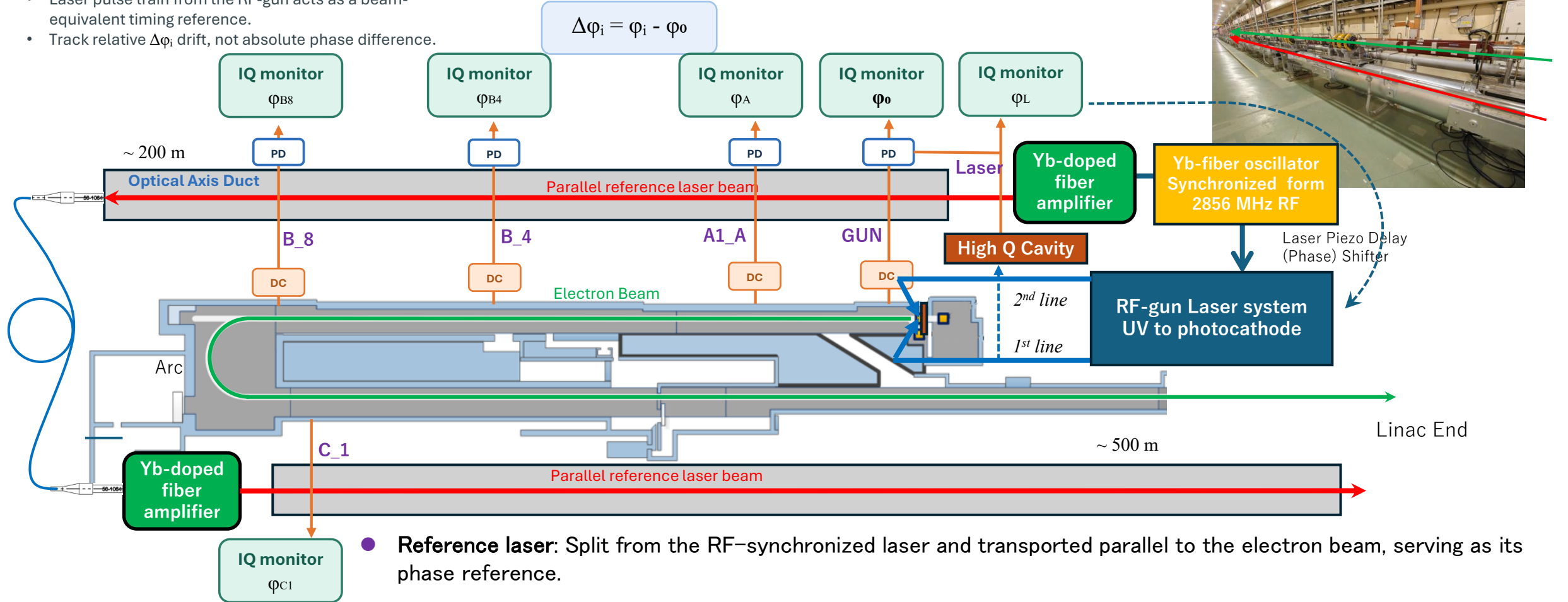
Optical Reference-Based RF Phase Monitoring for Linac

-A direct measurement of RF phase stability

Key idea:

- Laser pulse train from the RF-gun acts as a beam-equivalent timing reference.
- Track relative $\Delta\phi_i$ drift, not absolute phase difference.

- Relative drift of the phase difference between the reference laser and the local accelerating RF



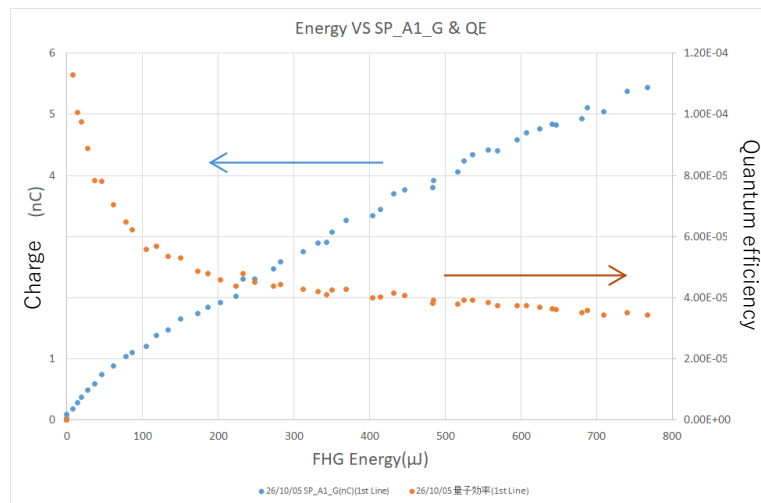
- **Reference laser:** Split from the RF-synchronized laser and transported parallel to the electron beam, serving as its phase reference.
- **Phase measurement:** IQ monitors measure the phase difference between the reference laser and local accelerating RF.
- **Relative phase monitoring:** RF-gun phase difference as the reference for monitoring relative phase drift along the linac.
- **Laser phase feedback:** First, feedback to compensate phase drift between the RF-gun laser and RF-gun.

Beam charge performance with the new RF gun RF-Gun #3

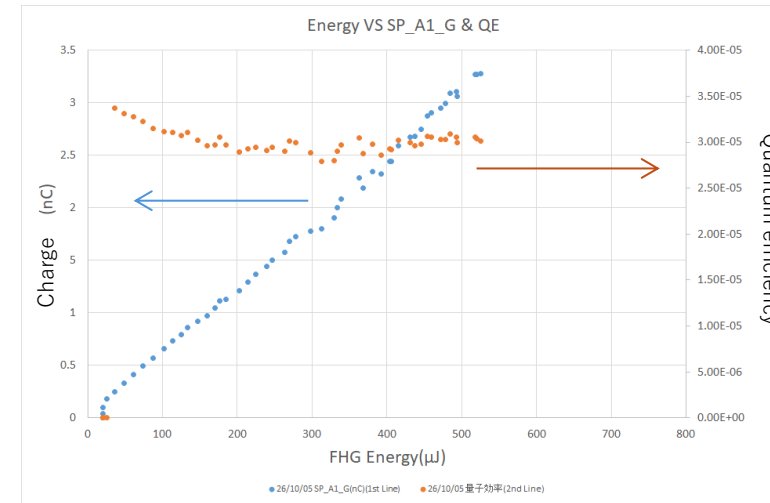
Charge vs Laser Energy

Oct. 05, 2026

1st Laser line



2nd Laser line

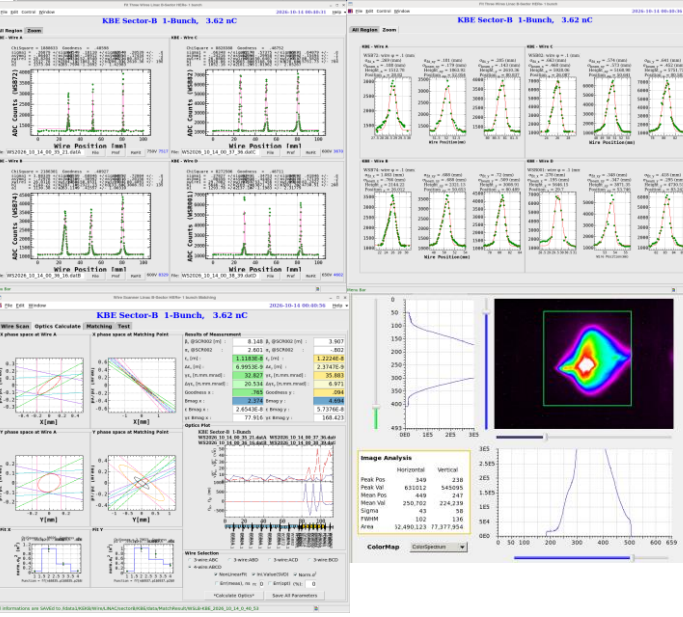
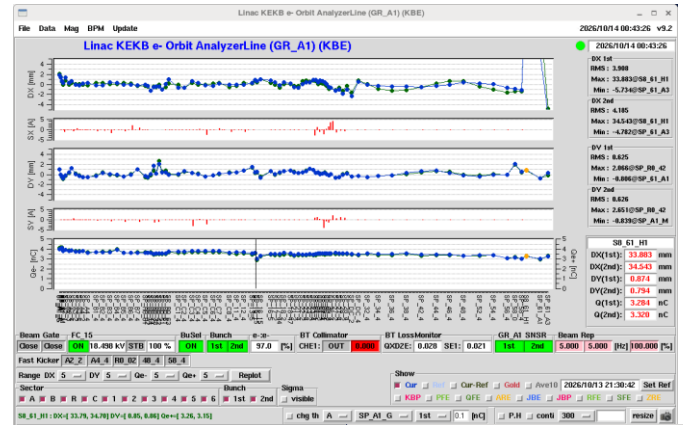


- Both laser lines achieved sufficient output to generate electron beams at charges well above 2 nC.
- In routine operation, two laser pulses are used simultaneously to improve stability.

RF-Gun #3

Oct. 13, 2026

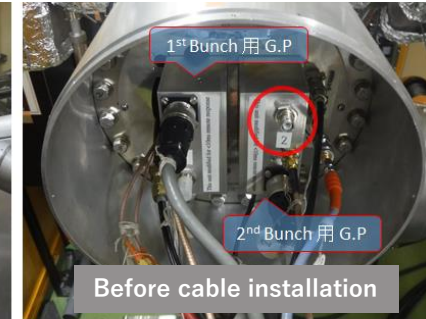
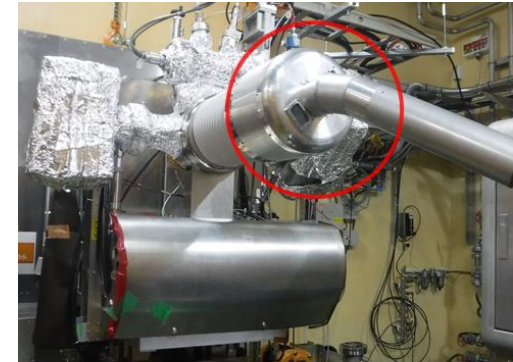
RF-Gun #3



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Increasing Electron Beam Charge by Optimizing Bunch Width and SHB Parameters

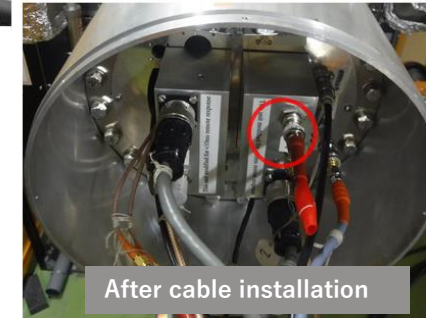
- To achieve the 4 nC positron intensity target, we are investigating ways to increase the electron charge from the DC thermionic gun.
- Test only the second bunch, increasing Grid pulse width from 0.8 ns to 1.1 ns.
- Optimize SHB voltage and RF phase to improve longitudinal bunching.



2026.10.14



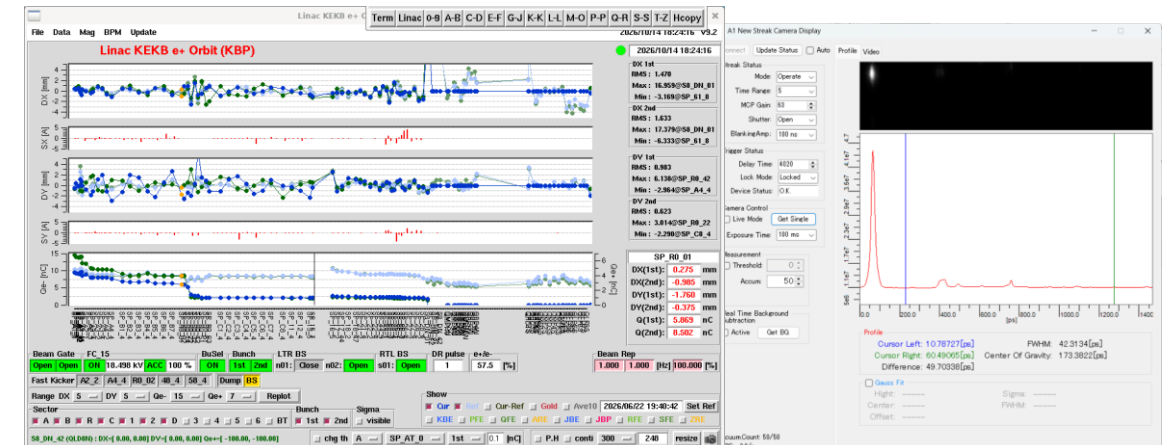
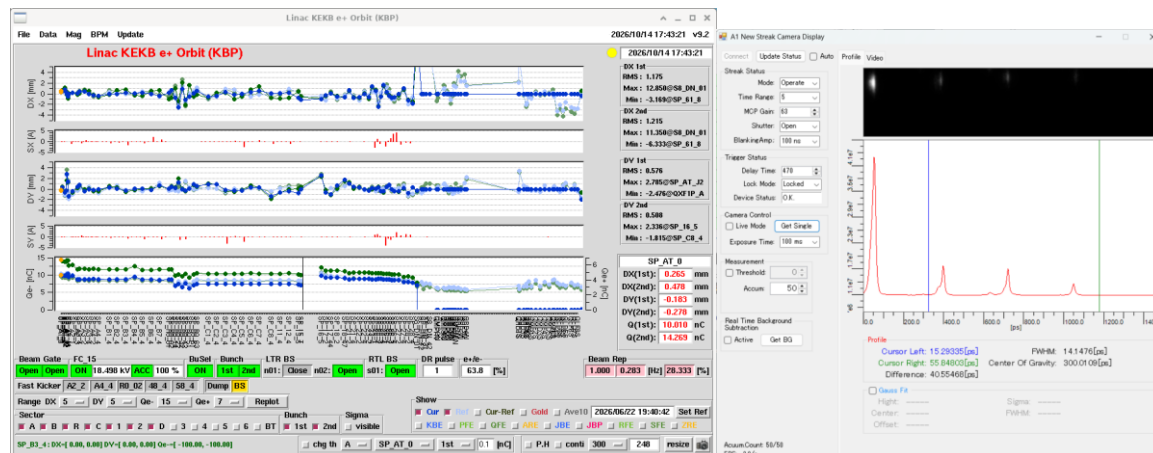
Cable for pulse-width adjustment (for 1.1 ns)



After cable installation

- The second-bunch charge increased from 10 nC to 15 nC. The main-bunch charge increased by approximately 10%, but satellite bunches were also generated.

- Next step: Investigate how to eliminate satellite bunches at the ARC-section.



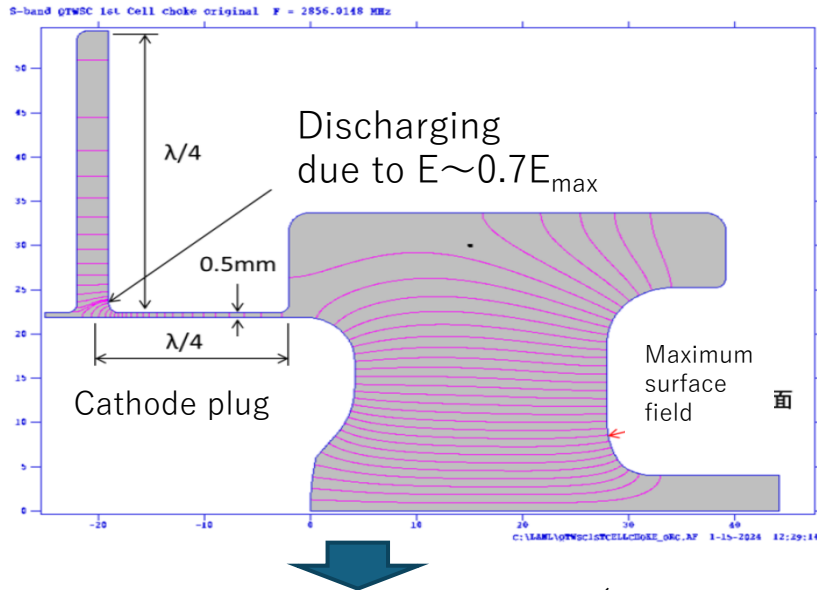
Summary and Future Plans

- Thermionic DC electron gun (Electron source for positron production)
 - Aging components remain a concern; backup equipment is prepared.
 - The maximum bunch charge is currently limited to approximately **10 nC (e+ : 3.5 nC)**.
 - Thermionic cathode inventory is limited; testing an alternative cathode is planned.
- RF electron Gun (Electron source for HER)
 - RF Cavity
 - Replaced Gun #1 with the Gun #2, resolving vacuum-related contamination and the progressive degradation of laser injection efficiency.
 - Installed Gun #3, based on the Gun #2 design; **beam tests demonstrated transport at 3 and 4 nC.**
 - Photocathode
 - Continue using the KEK house made Ir₇Ce₂ cathode.
 - Laser source
 - Continuously improved laser intensity, conversion efficiency, and long-term stability.
 - Modified the EO pulse-picker drive to compensate for the intensity imbalance between the two bunches.
 - Increase the injection efficiency of 2nd bunch
- Future plans
 - **Higher bunch charge of DC Gun:** Optimize the bunch width and SHB parameters to increase the electron-bunch charge.
 - **Dual-path laser system:** Enable independent control of the intensity and timing of each laser pulse to optimize injection efficiency and prepare for future multi-pulse operation.
 - Prepare for future multi-pulse operation(4-7 bunches)
 - **Laser phase monitoring and feedback:** Develop an optical-reference-based RF phase monitoring system to measure phase drift along the linac, starting with laser-phase feedback.

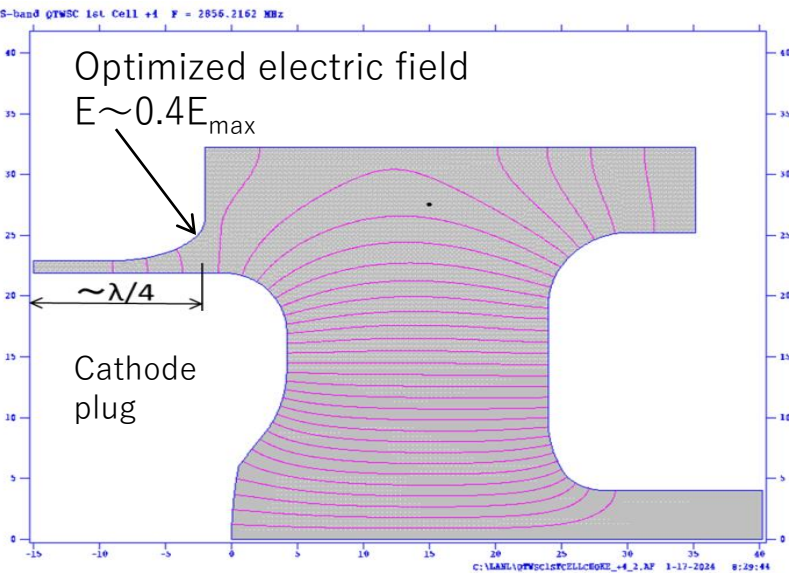
Backup

LINAC / RF-Gun recent trouble

Current RF-Gun cathode cell with choke structure for cathode thermal cleaning



New RF-Gun cathode cell (install @ FY2025)

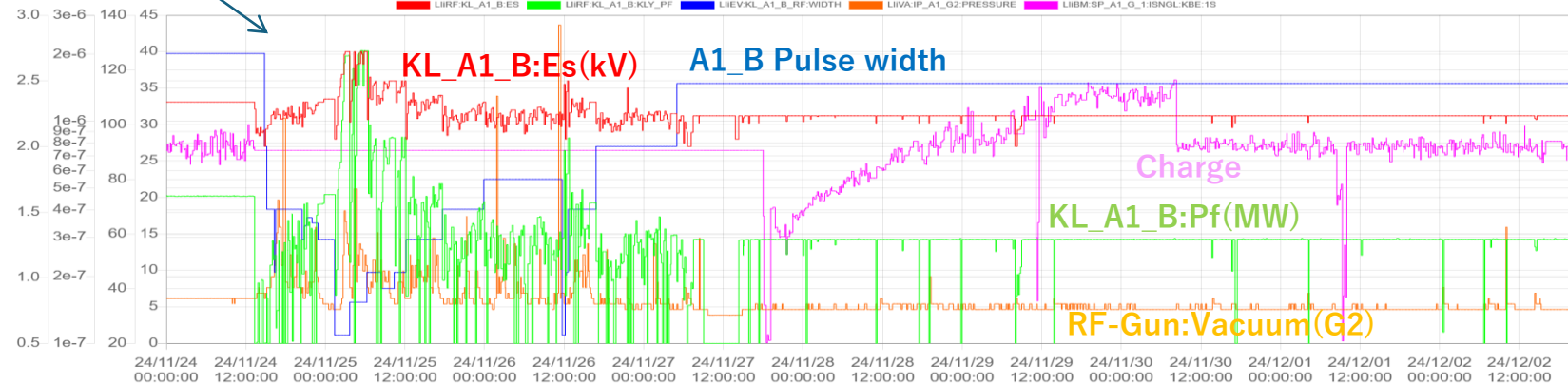


RF-Gun Serious discharge(11/24)

HER Injection unavailable due to RF-Gun down

KEKB Tunnel Access

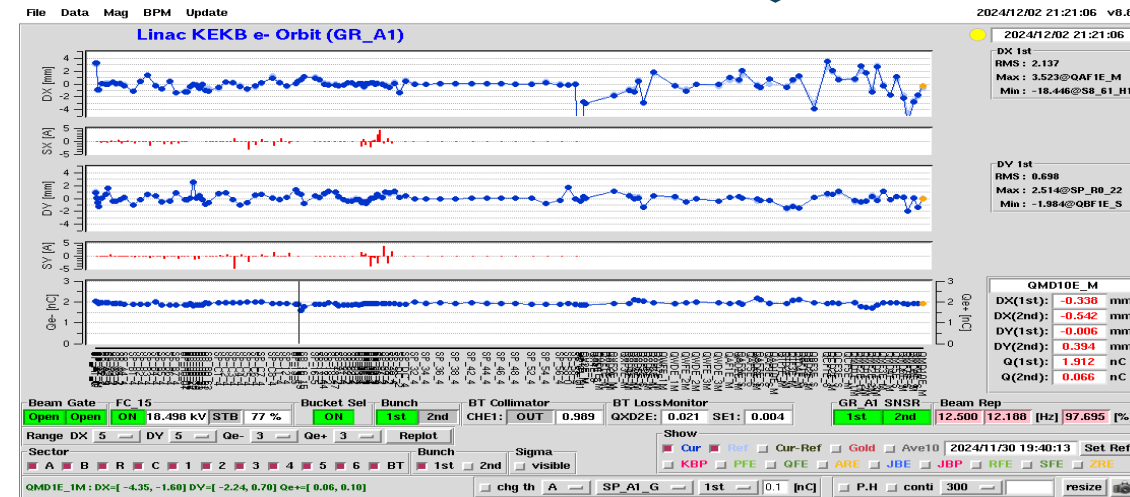
LINAC Maintenance Day



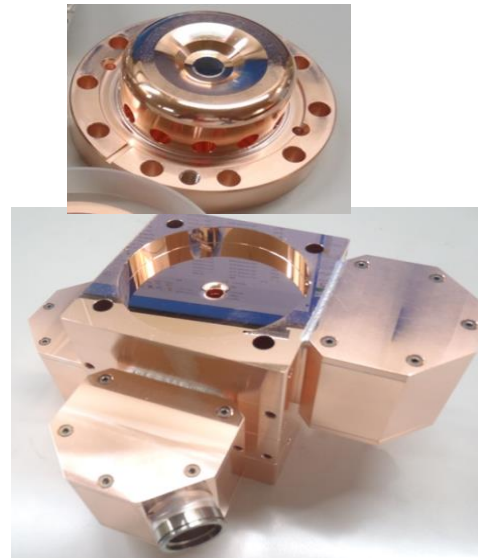
Normal operation 14MW, 1.1us

Not fully recovered 9MW, 1 us

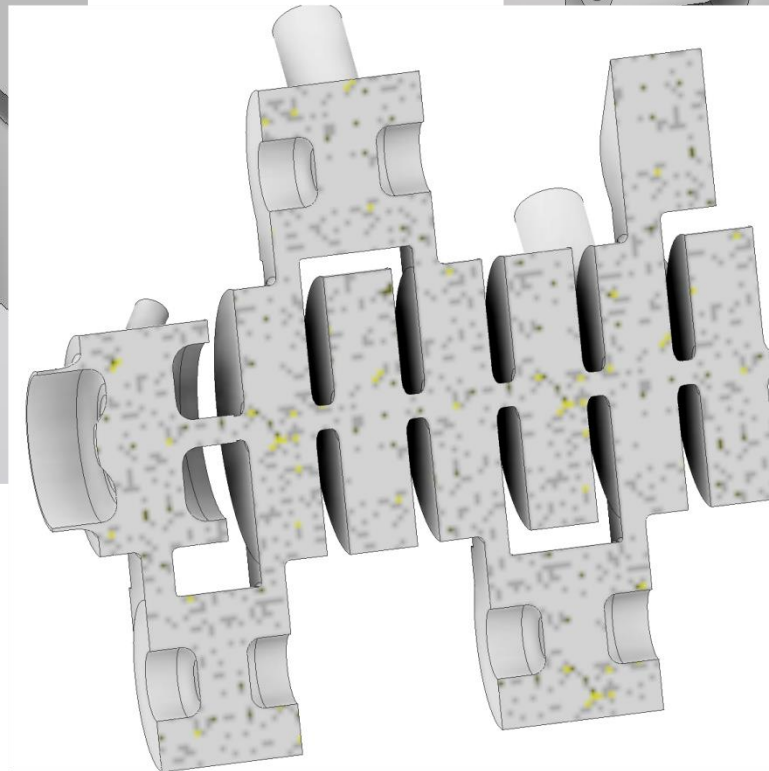
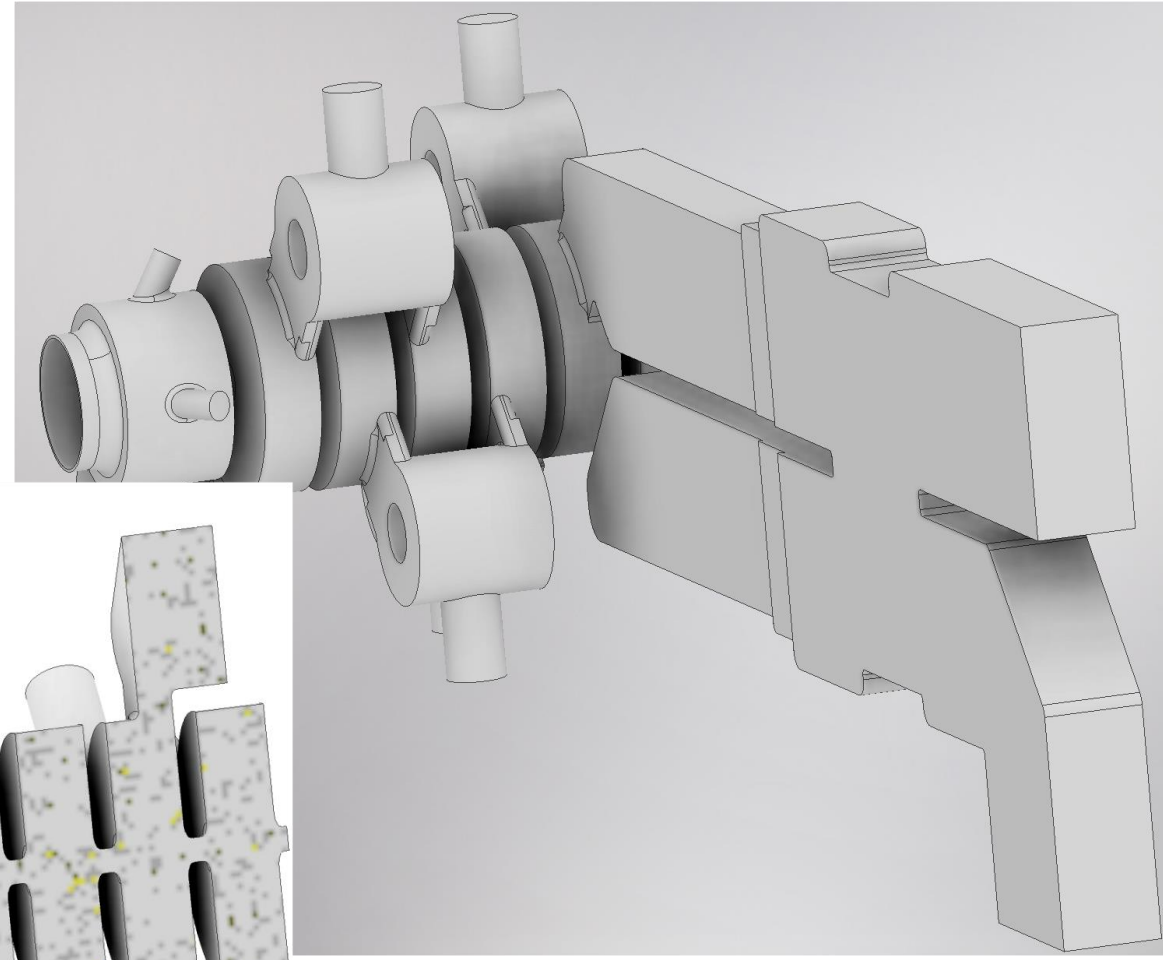
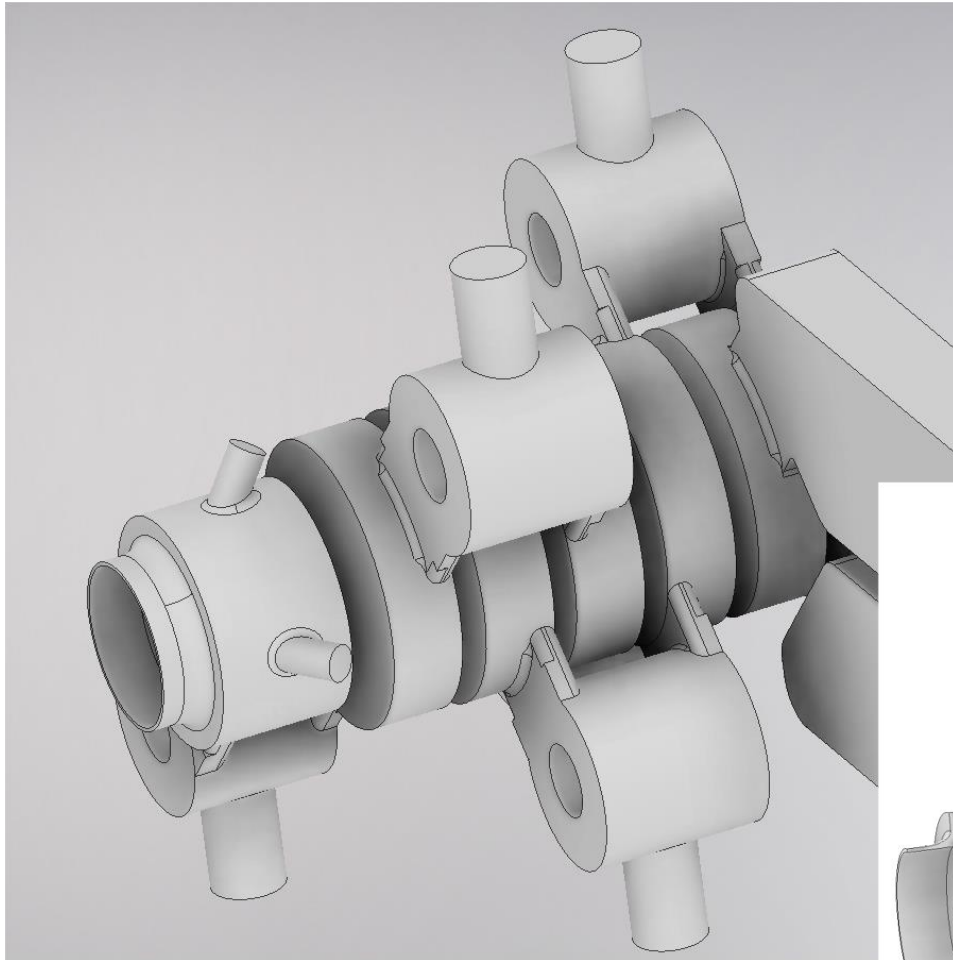
Charge recovered



2nC , Normalized Emittance : 40 x 45 μm at BT1

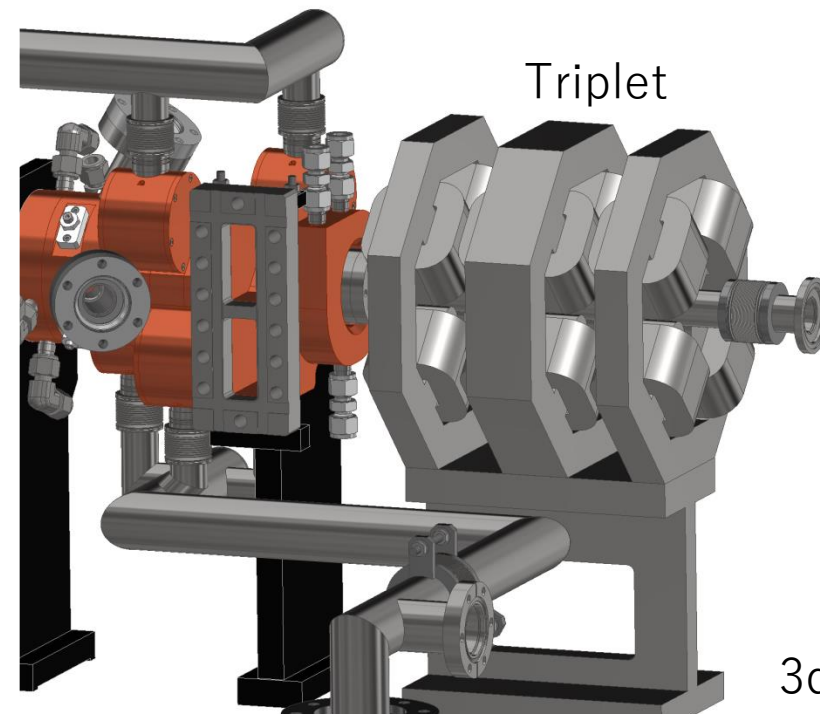
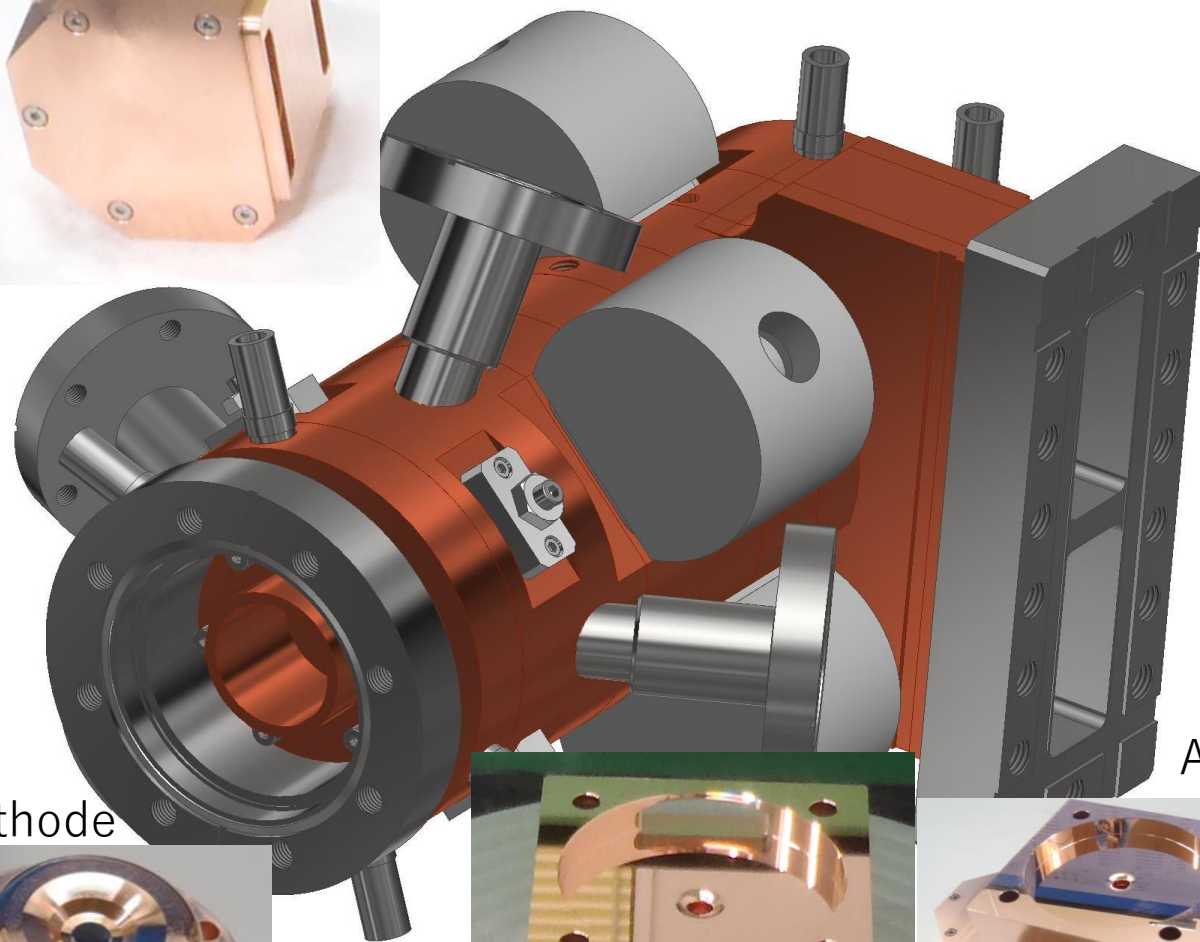
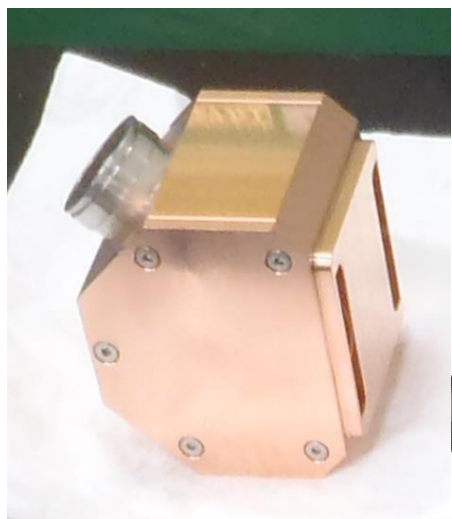


New Quasi Travelling Wave RF-Gun Cavity



New RF-Gun cavity

Side couple cavity

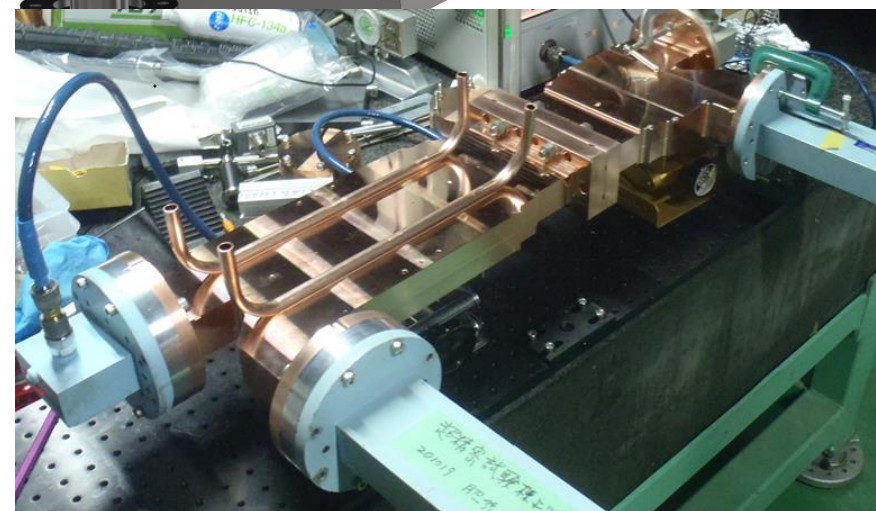
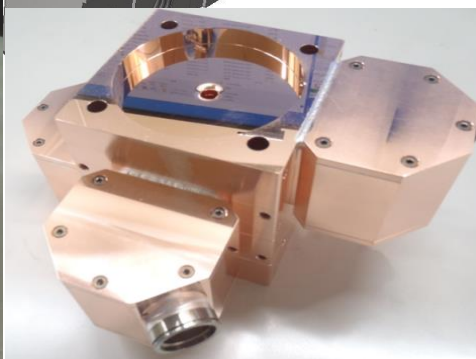
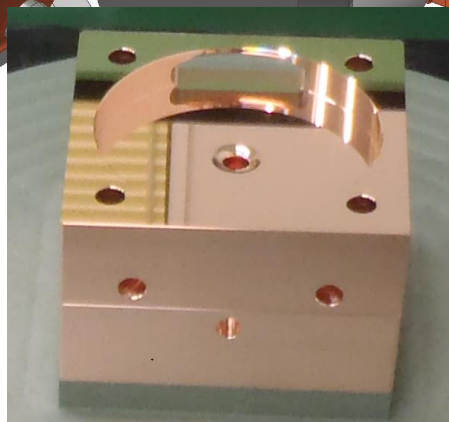
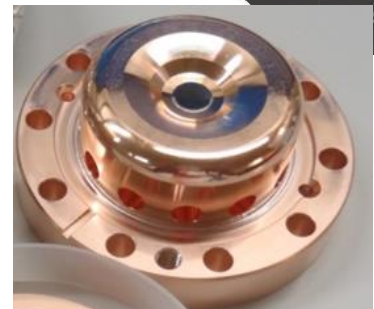


Triplet

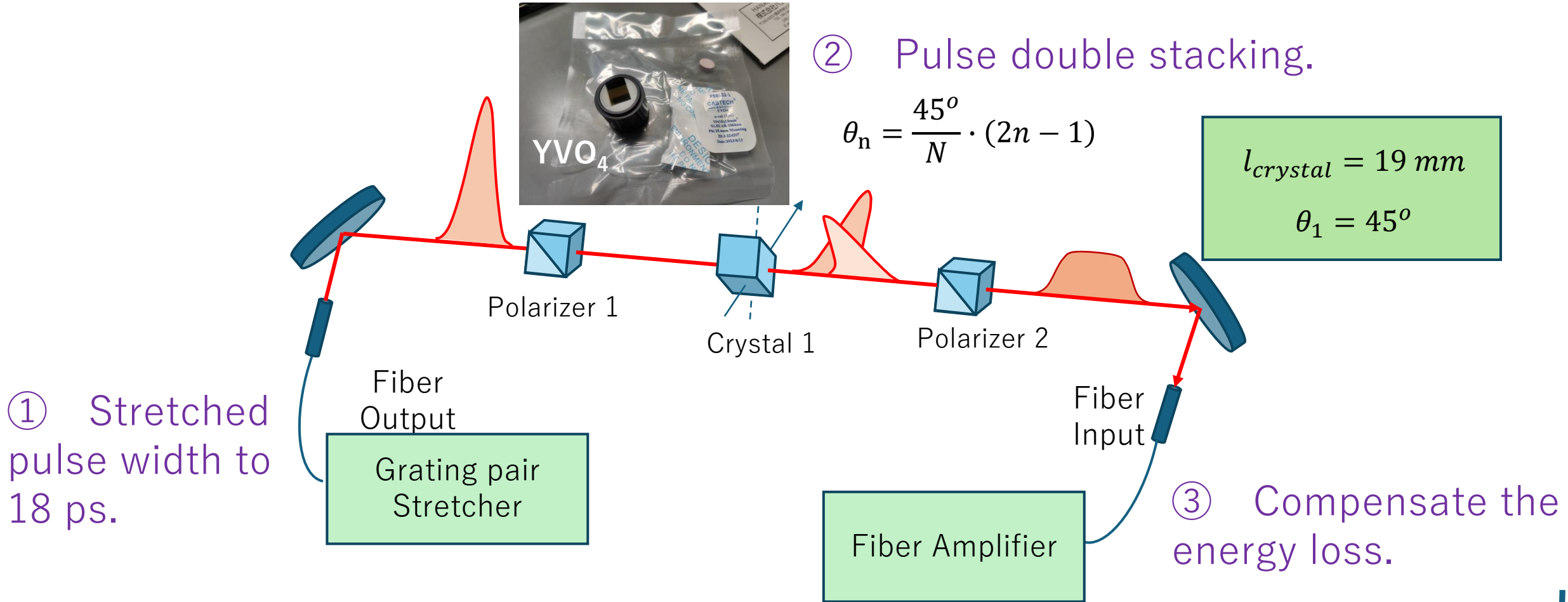
3dB Hybrid

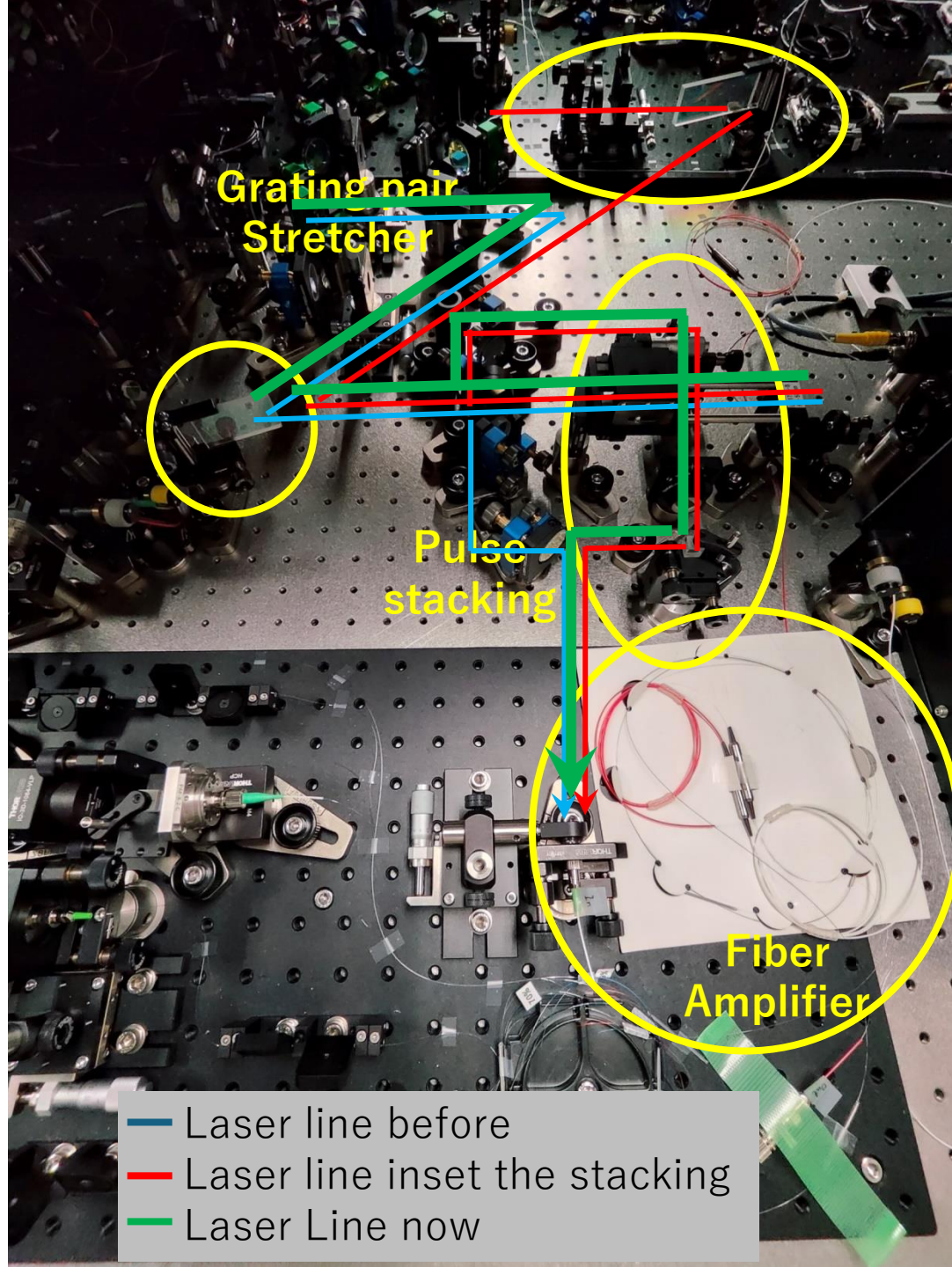
After blazing

Cathode



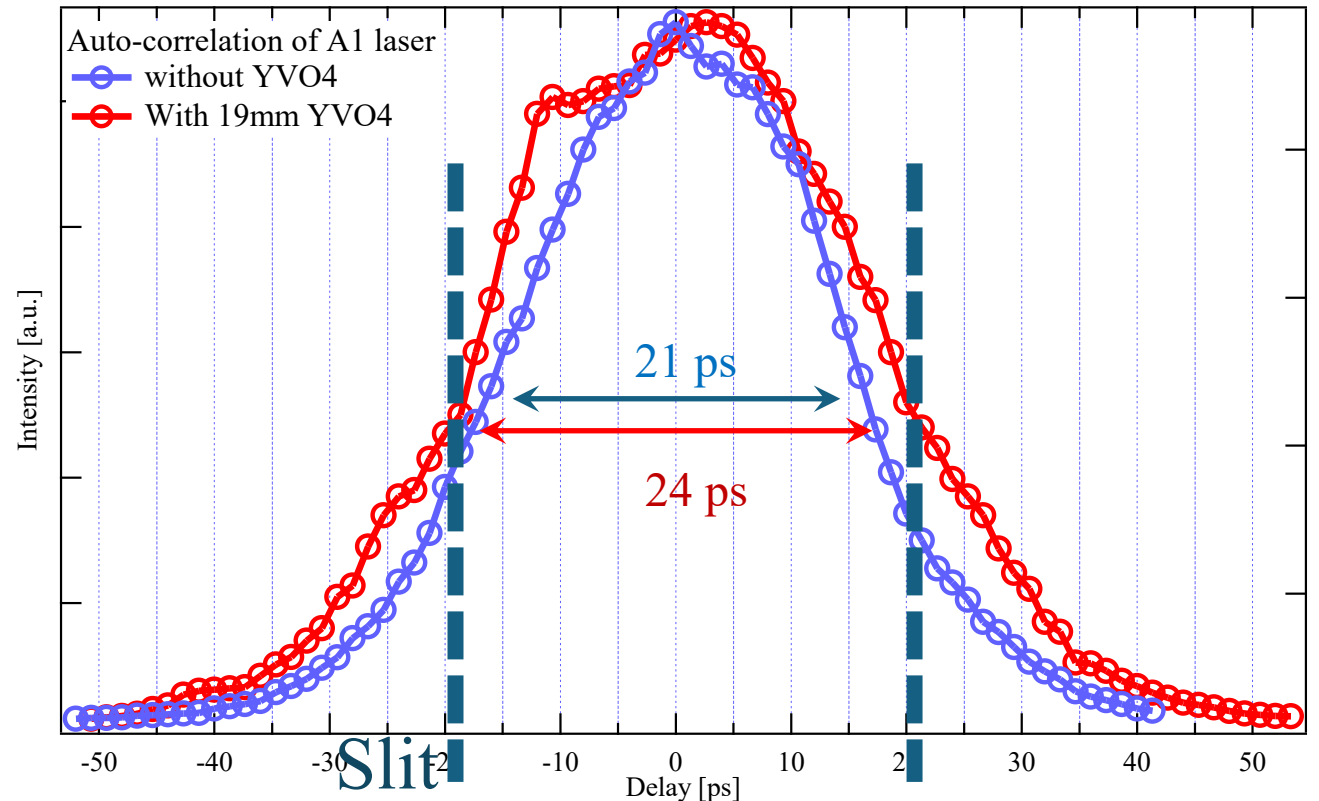
The Single-stage Pulse Stacking Birefringent Filter





Setup diagram

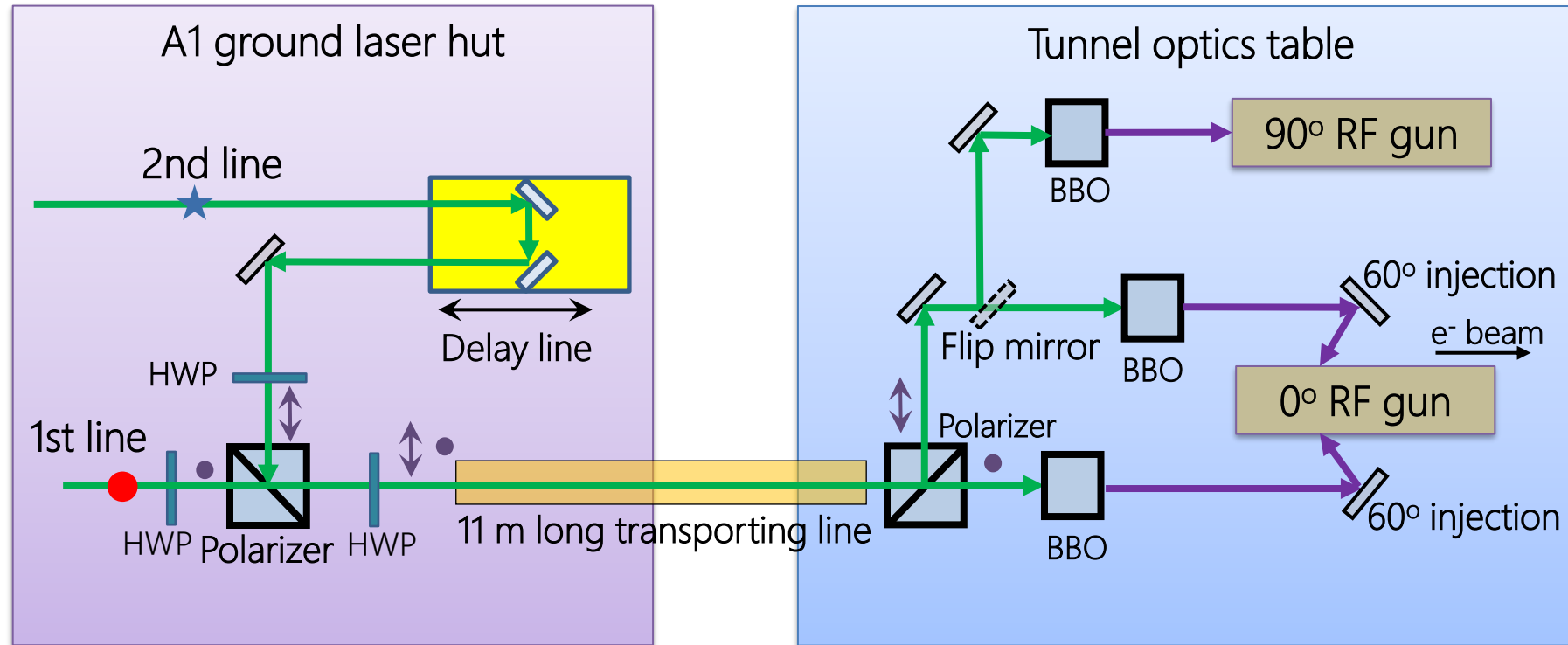
- The new fiber amplifier compensate the energy loss of the pulse stacking.
- After the modification, there is no impact on main laser amplification efficiency and electron generation rate.
- Due to the optical path expansion, it is necessary to adjust the phase delay of the SOA pulse picker and EO pulse picker.
- For double bunch amplification, the efficiency of the second pulse is reduced.



Laser System for RF Gun

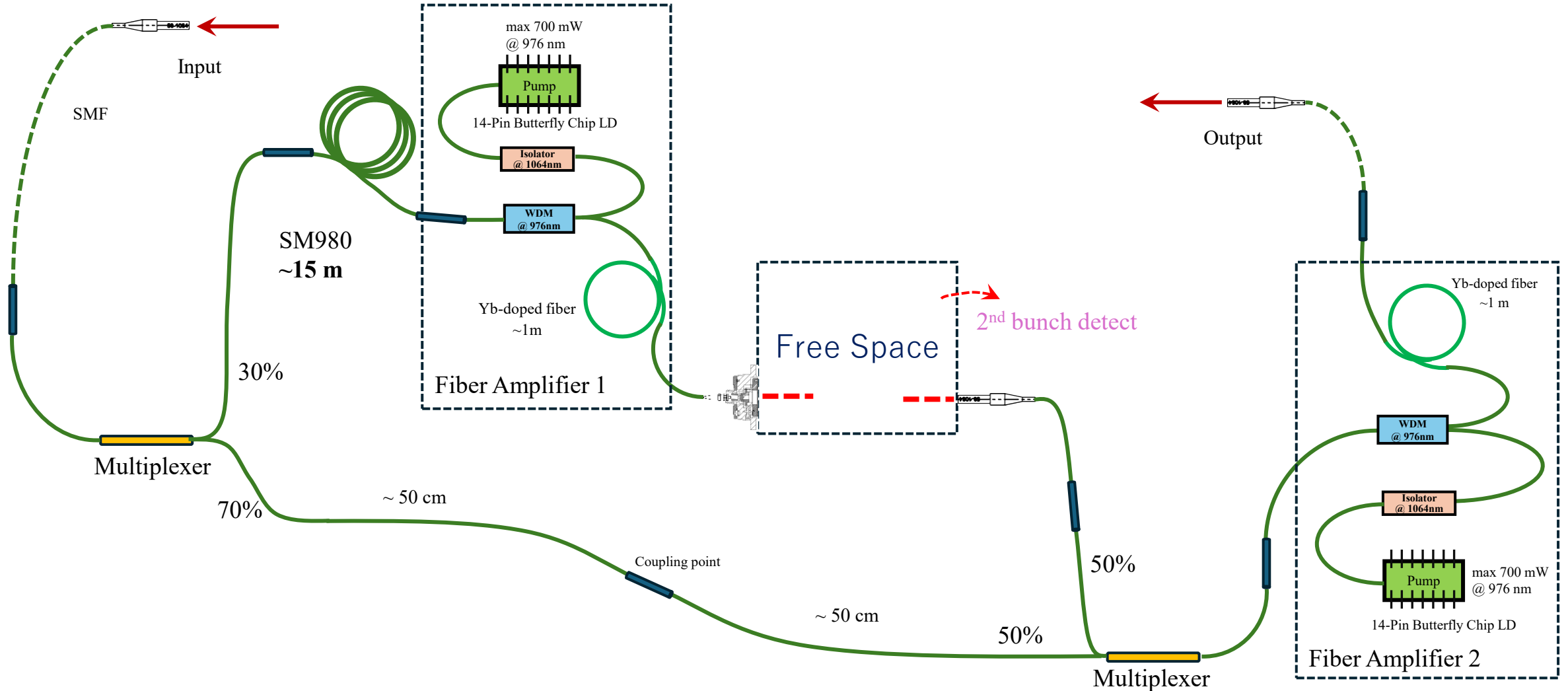
Two Laser Beams Injection Mode for Better Beam Quality

Simple illustration for 2 lasers incidence (out of ratio)

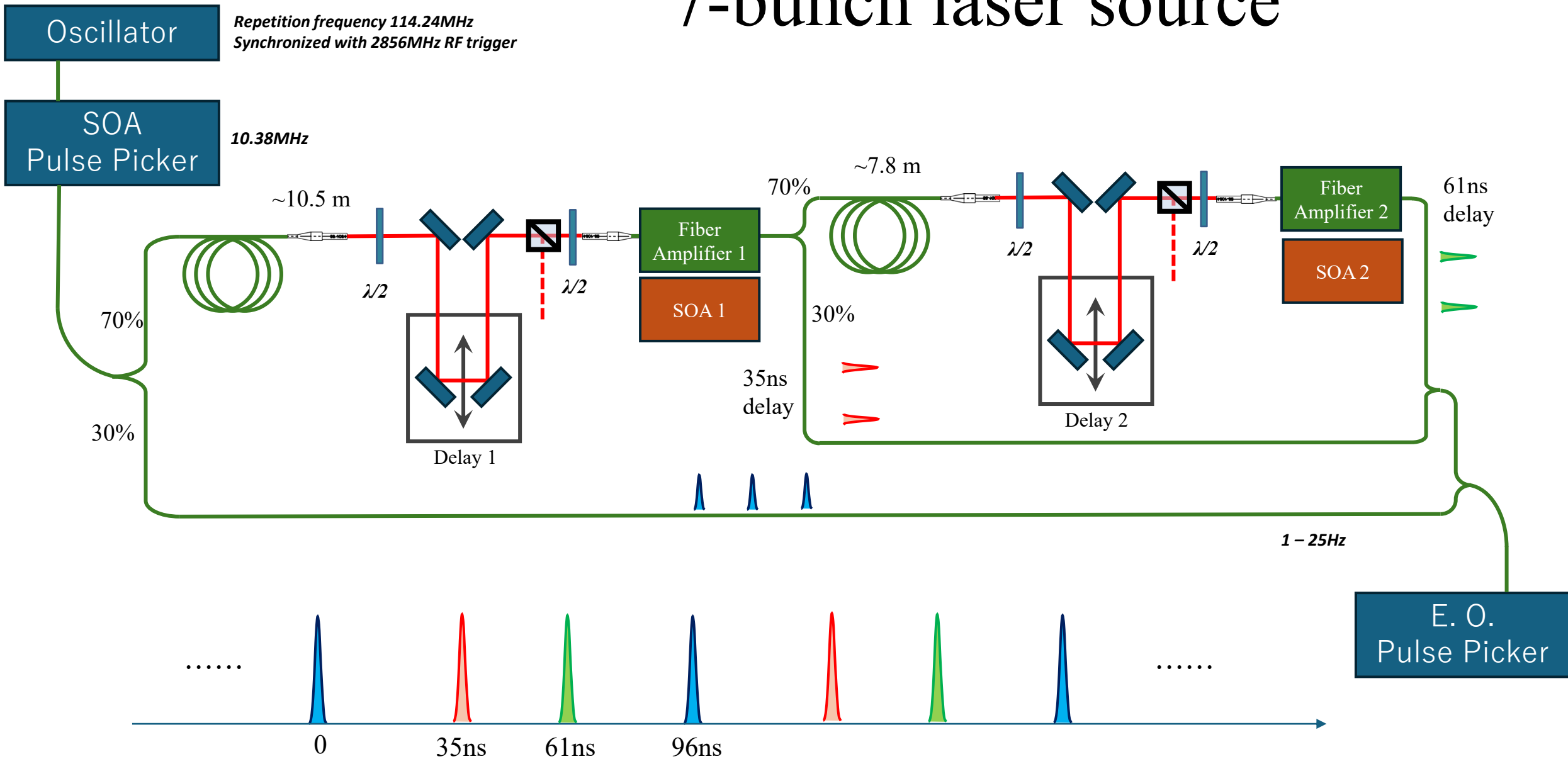


- Laser with vertical polarization, $\updownarrow$ laser with horizontal polarization, HWP: half wave plate

Dual-Path Optical Conditioning for Independent Pulse Control

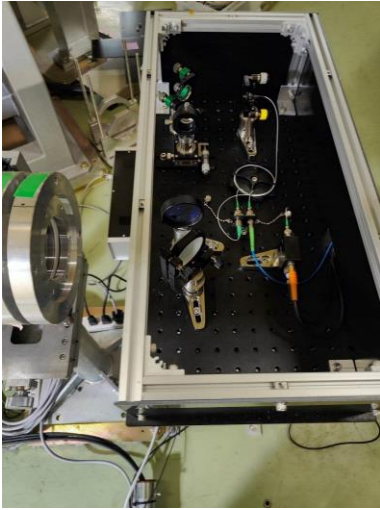


7-bunch laser source

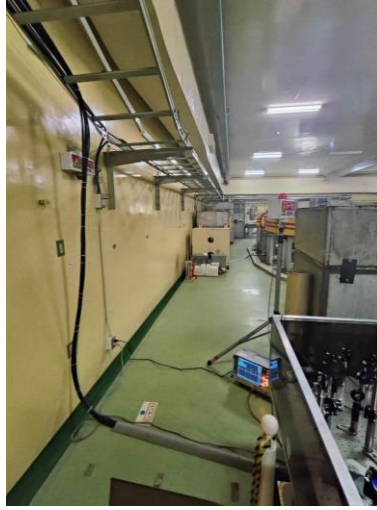


Laser Phase Monitor System Expansion

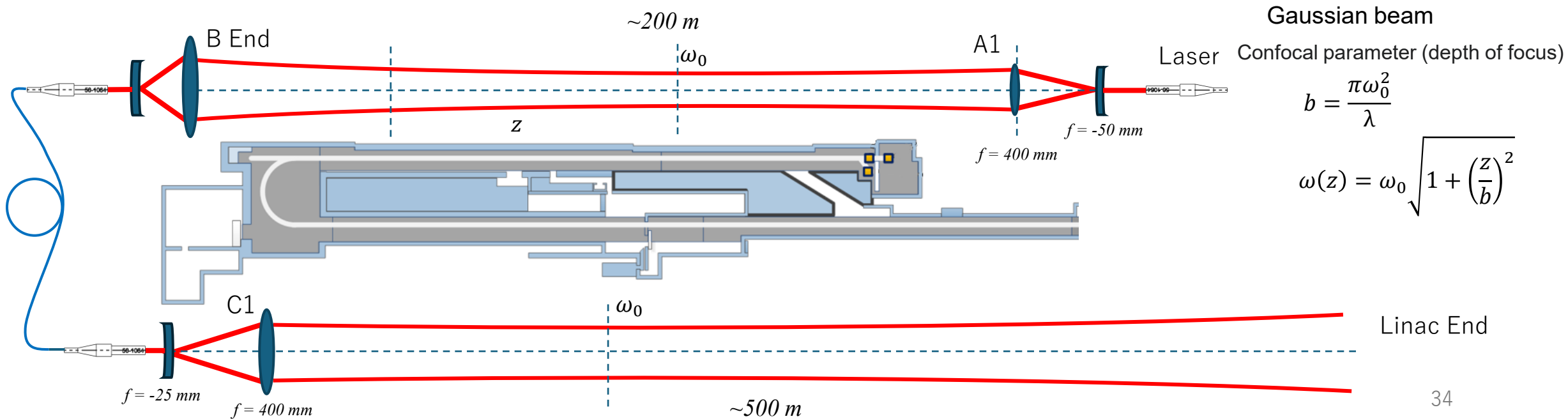
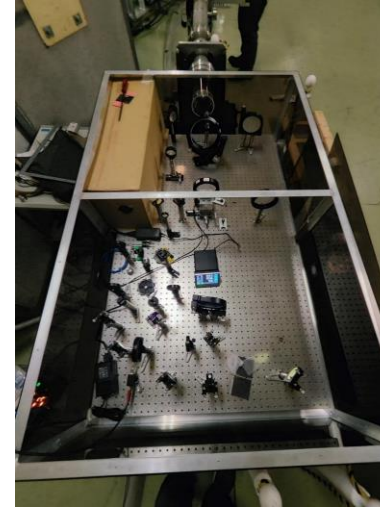
B8



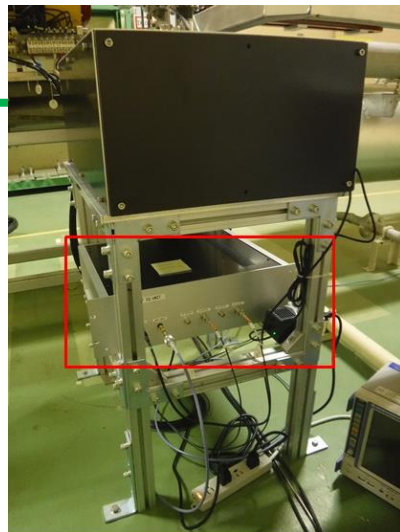
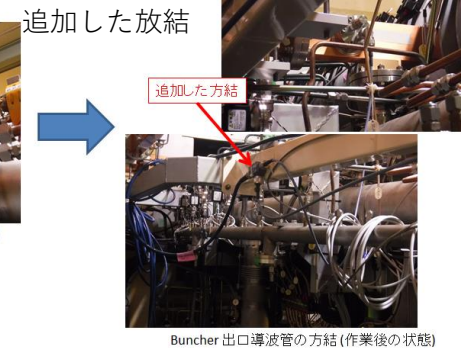
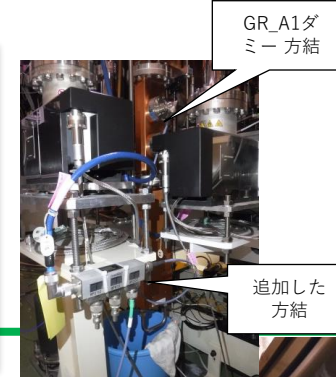
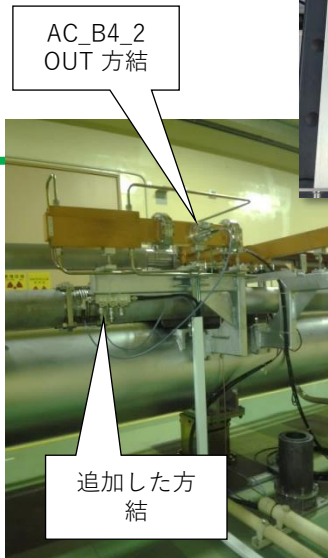
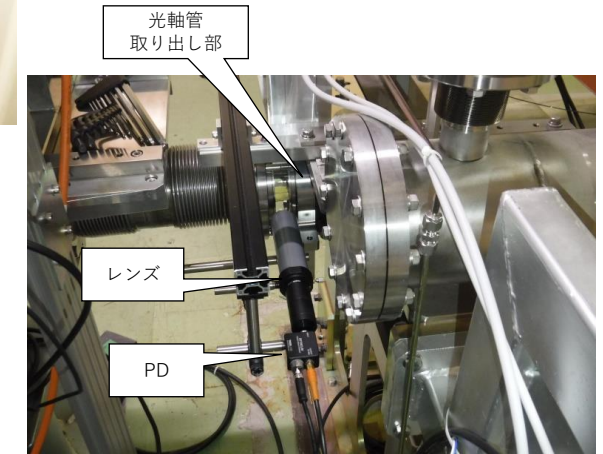
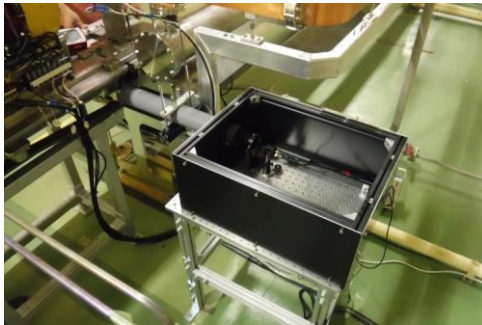
ARC



C1



Installation of IQ monitor

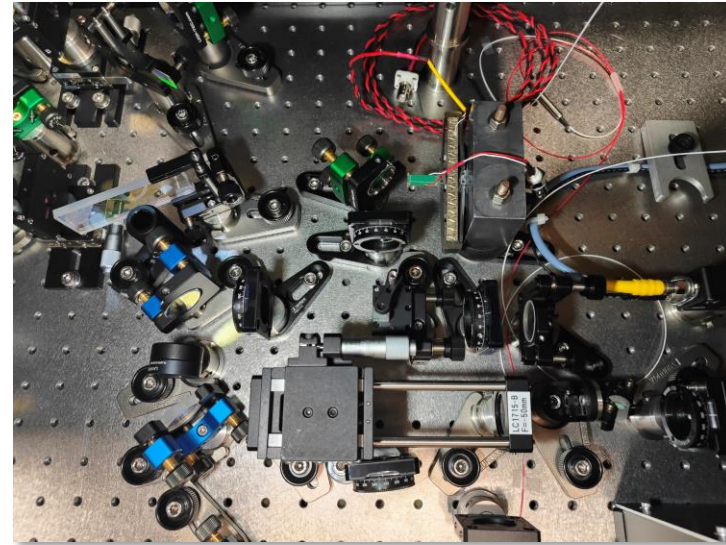
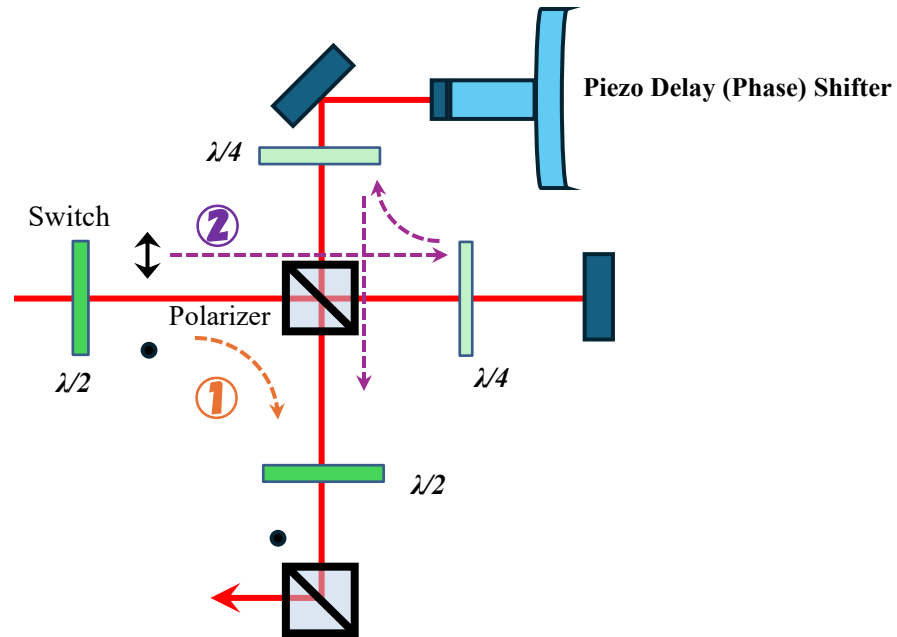


トンネル内 B-3 ユニットに設置した
IQ ユニット

出口導波管の方結にケーブル接続して方結を設置
(導波管架台に結束バンドで固定)。
追加した方結の OUTPUT に RFモニター用ケーブルを接続。
結合出力に IQユニット用のケーブルを接続。

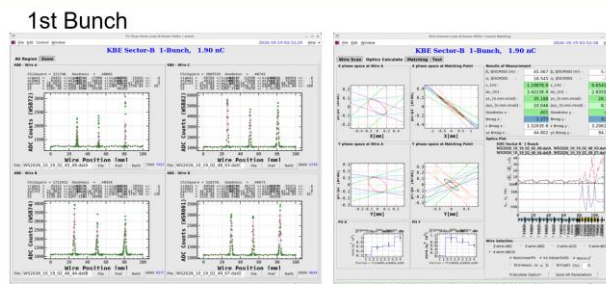
GR_A1用IQユニット

Modular and Reversible Integration of Piezo

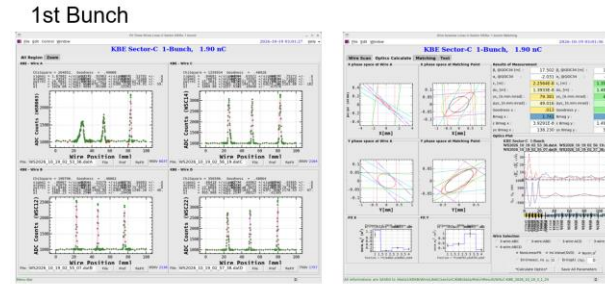


Orbit tuning of 3nC using Gun #3

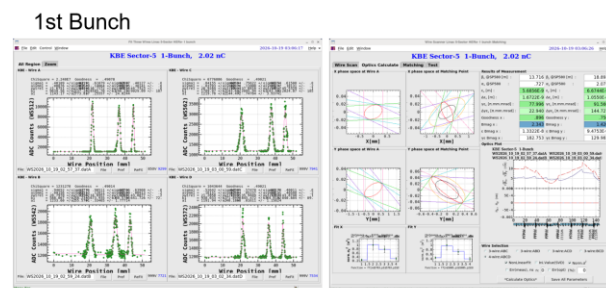
SP_A1_G 2nC ビーム Wire Scanner 測定 Bセクター



SP_A1_G 2nC ビーム Wire Scanner 測定 Cセクター



SP_A1_G 2nC ビーム Wire Scanner 測定 5セクター



SP_A1_G 3nC ビーム Wire Scanner 測定結果まとめ

sec	1st Bunch				2nd Bunch			
	EmitX	ΔX	EmitY	ΔY	EmitX	ΔX	EmitY	ΔY
B	29.782	10.25	24.078	15.295	39.525	12.614	26.611	6.16
C	35.761	370.441	52.858	9.067	74.16	312.204	54.342	10.949
5	105.955	29.435	120.13	84.475	72.383	15.147	132.238	81.079

