Introduction of Linac and RF Gun Drive Laser System for SuperKEKB

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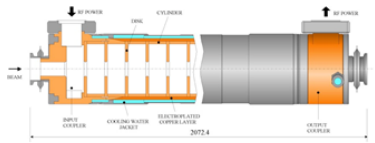
- General introduction of Linac injector for 4 rings
- Development of RF gun drive laser system for SuperKEKB
- Summary and outlook

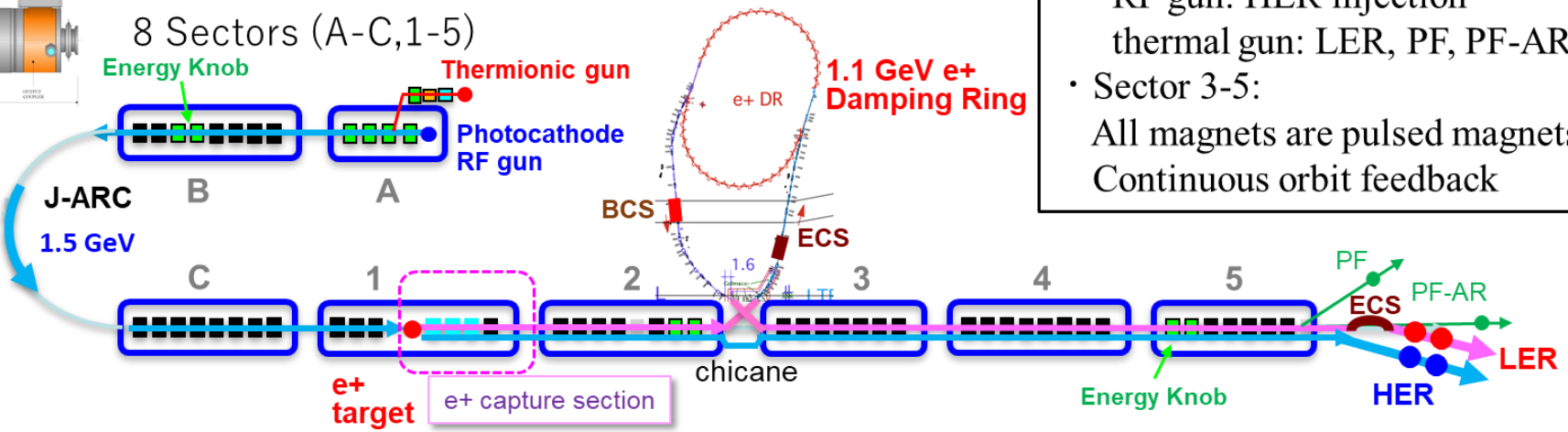
GENERAL INTRODUCTION of LINAC INJECTOR

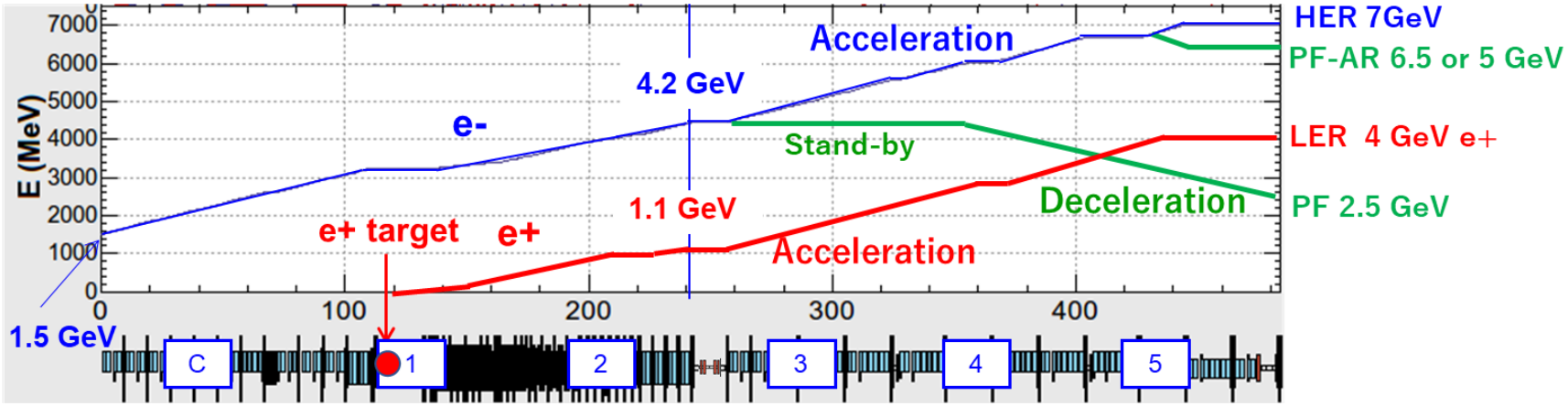
General Layout of Linac Injector

60 klystron units
240 accelerating structures (S-band 2-m-long)



- Two electron sources:
  RF gun: HER injection
  thermal gun: LER, PF, PF-AR
- Sector 3-5:
  All magnets are pulsed magnets.
  Continuous orbit feedback



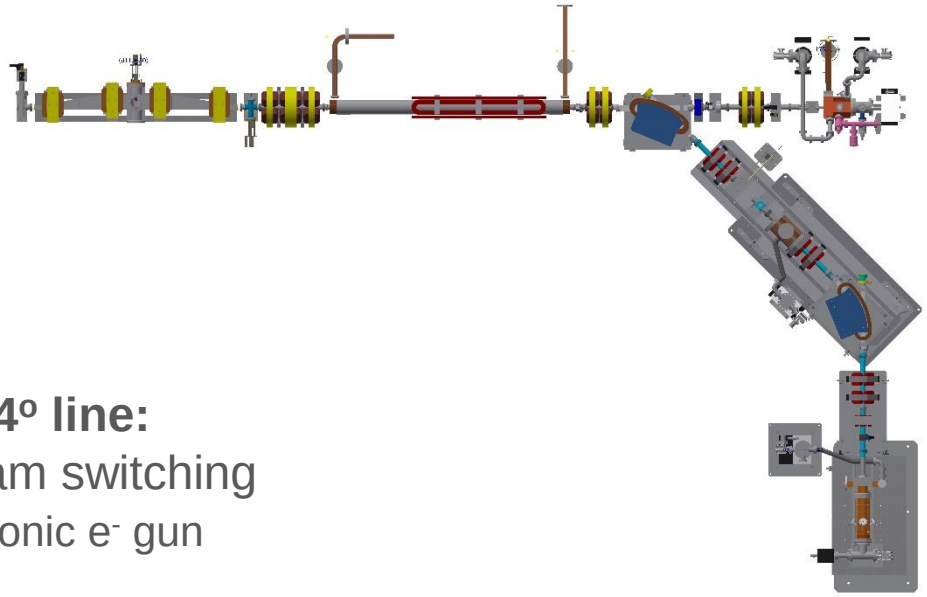


Beam energy variation for each beam mode along the beam line after the J-ARC

GENERAL INTRODUCTION of LINAC INJECTOR

Electron Source Part

Top view

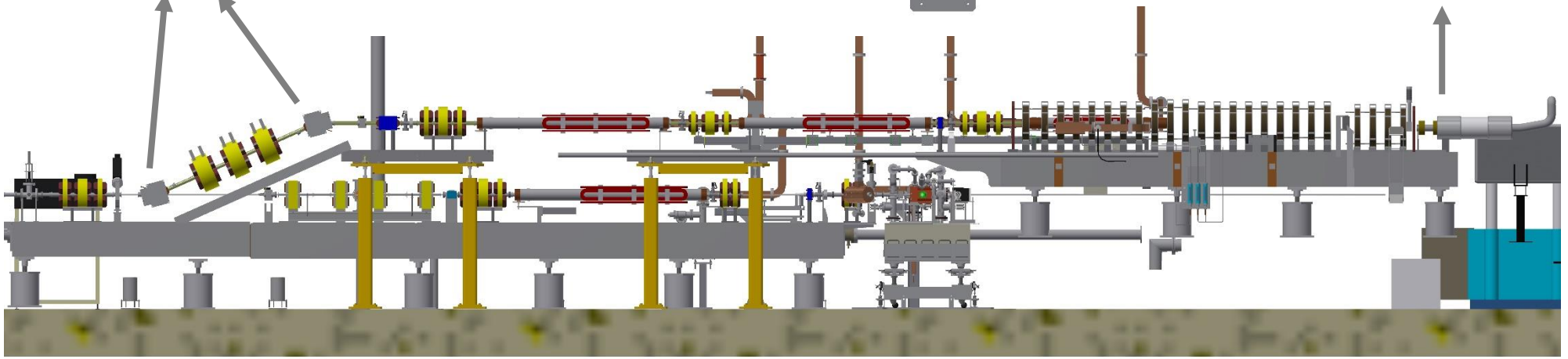


RF gun (GR_A1)
- e^- study: 1 - 3 nC (KBE for HER injection)

Thermionic DC e^- gun (GU_AT)
- e^+ production e^-: 13 nC (KBP for LER injection)
- e^- study: 1 nC (JBE)
- PF injection: 0.1 - 0.3 nC (QFE)
- PF-AR injection: 0.1 - 0.3 nC (ARE)

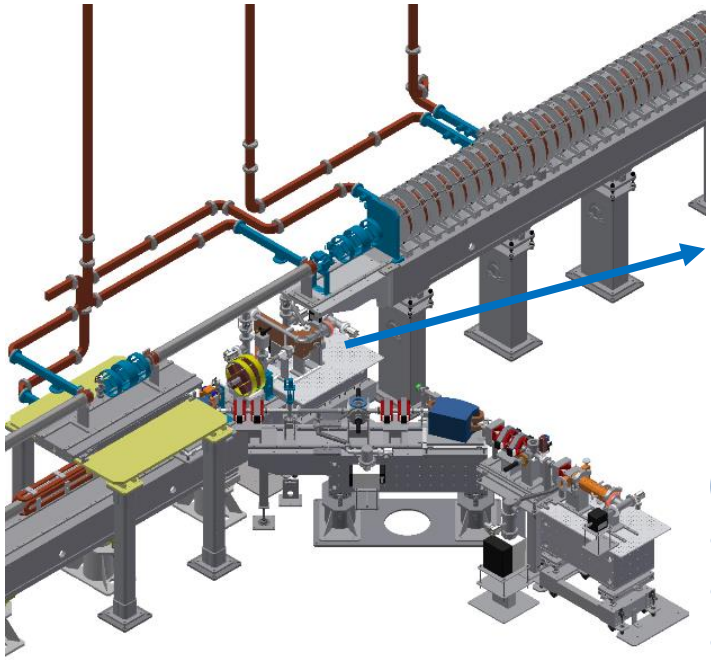
Pulse bends in 24^o line:
Pulse to pulse beam switching for RF e^- gun/thermionic e^- gun

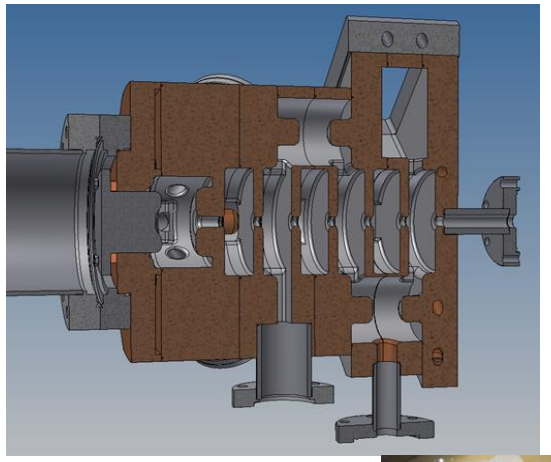
Side view

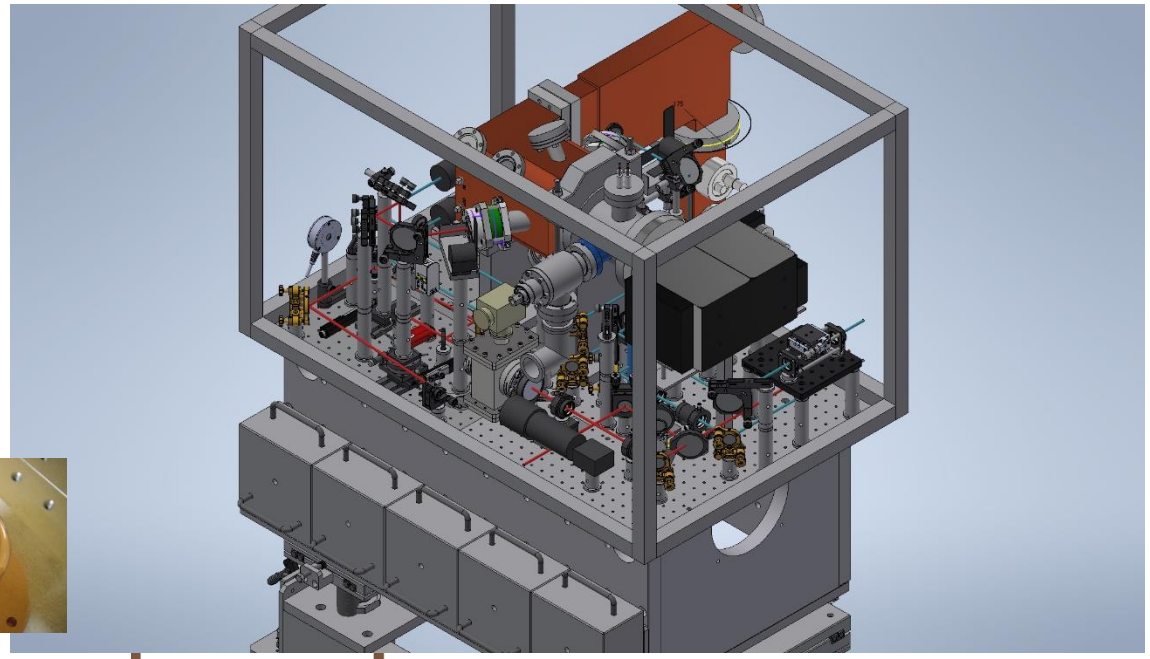


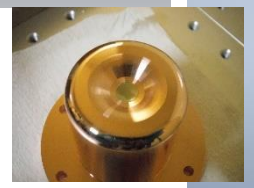
GENERAL INTRODUCTION of LINAC INJECTOR

RF Gun at Sector A1 of Linac





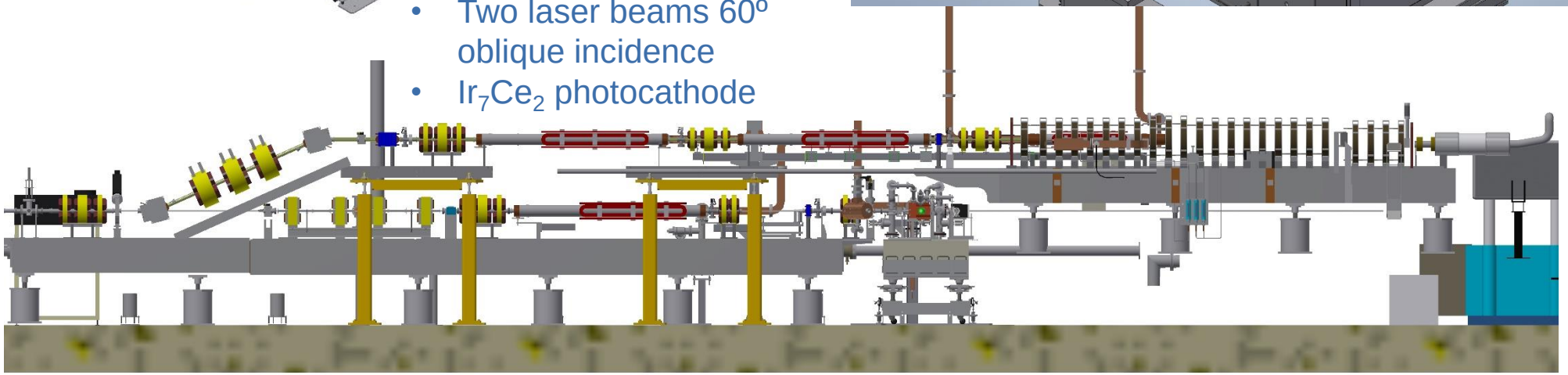




0º RF Gun

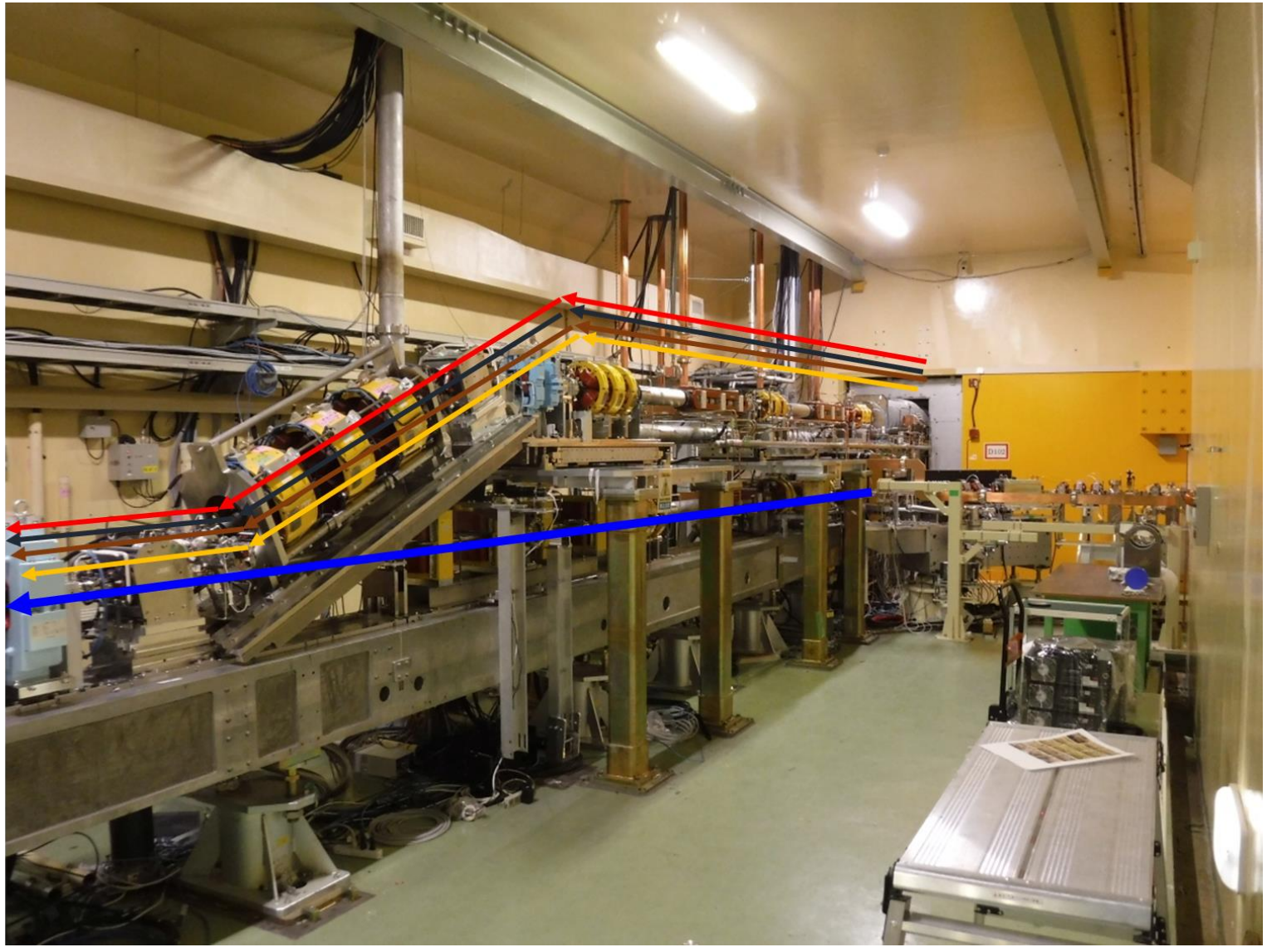
- Primary RF gun
- QTWSC cavity
- Two laser beams 60º oblique incidence
- Ir_7Ce_2 photocathode

Side view



GENERAL INTRODUCTION of LINAC INJECTOR

Electron Beams Merge Part



Thermionic DC e^- gun (GU_AT)
2 subharmonic bunchers (114 MHz, 571 MHz) and 2 bunchers

- e^- for e^+ production (LER): 13 nC
- e^- study: 1 nC
- PF injection: 0.1 - 0.3 nC
- PF-AR injection: 0.1 - 0.3 nC

0º RF Gun

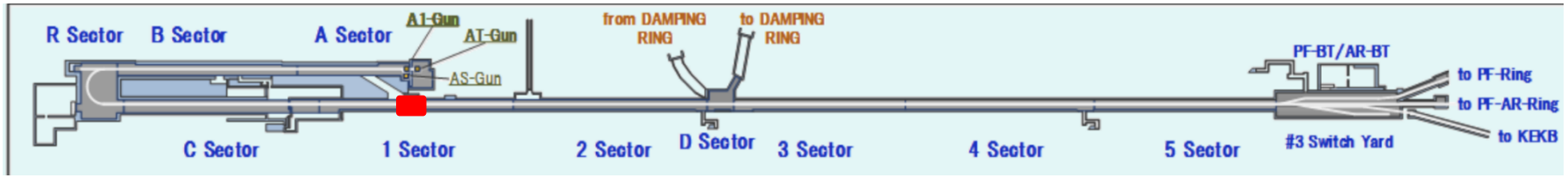
- Primary RF gun
- e^- for HER injection: 2 nC

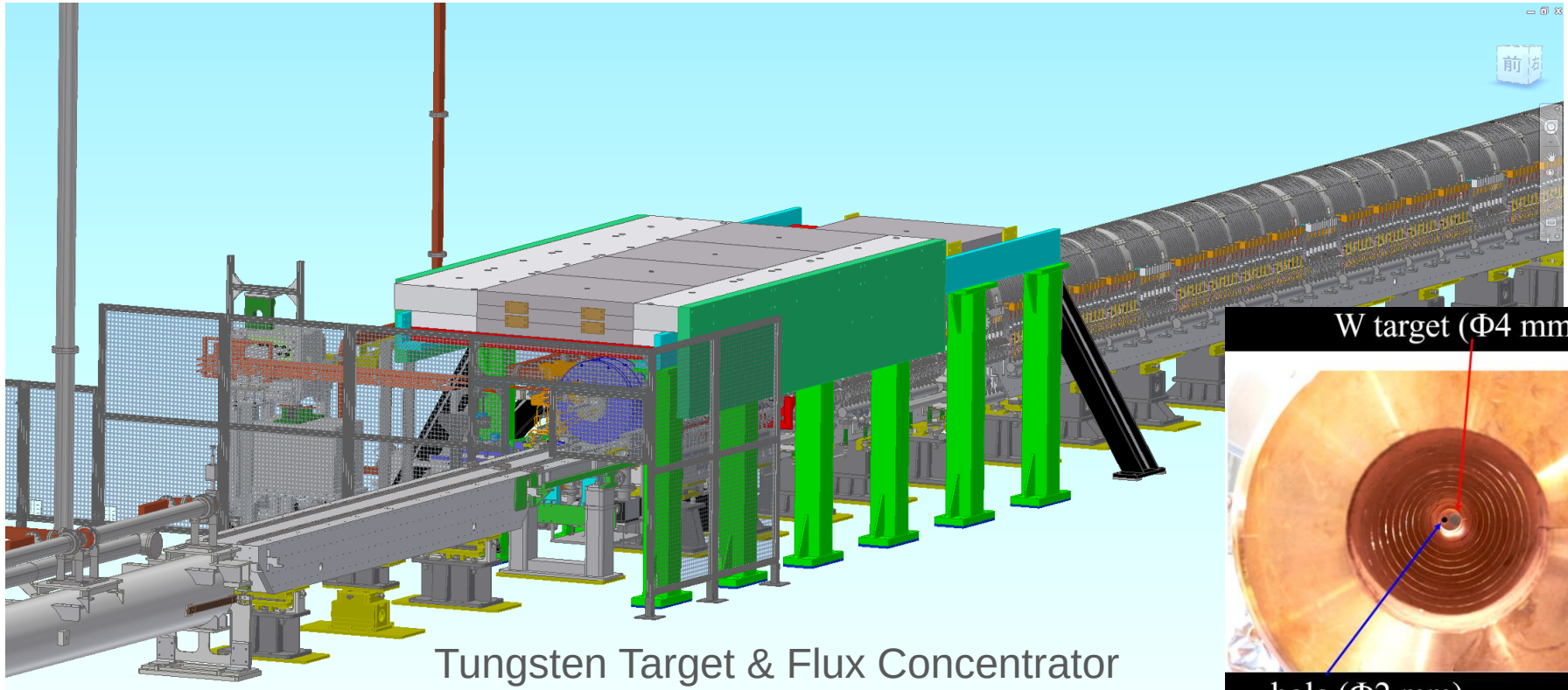
90º RF Gun

- Spare RF gun
- Under testing

GENERAL INTRODUCTION of LINAC INJECTOR

Positron Target and Capture Section



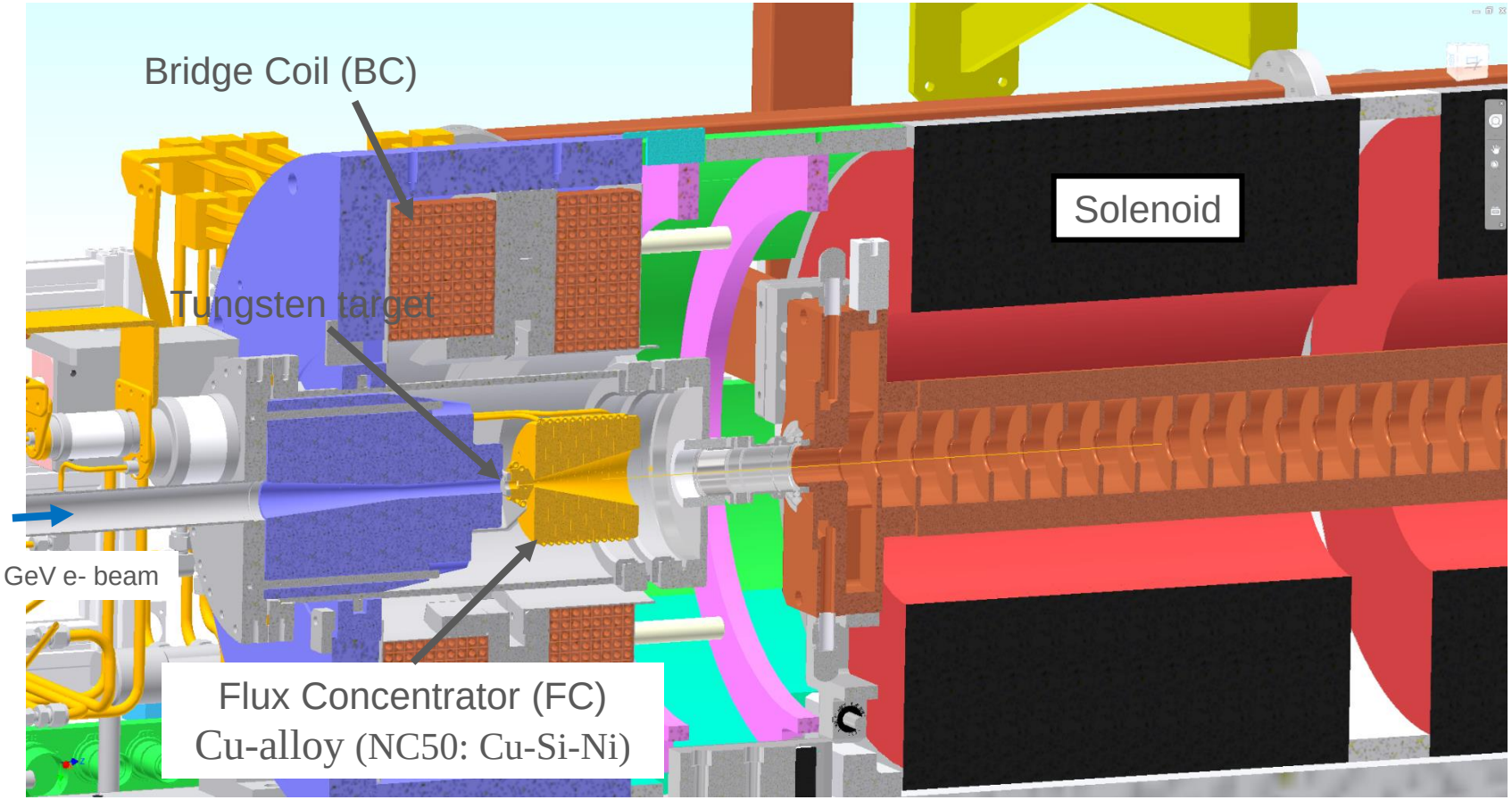


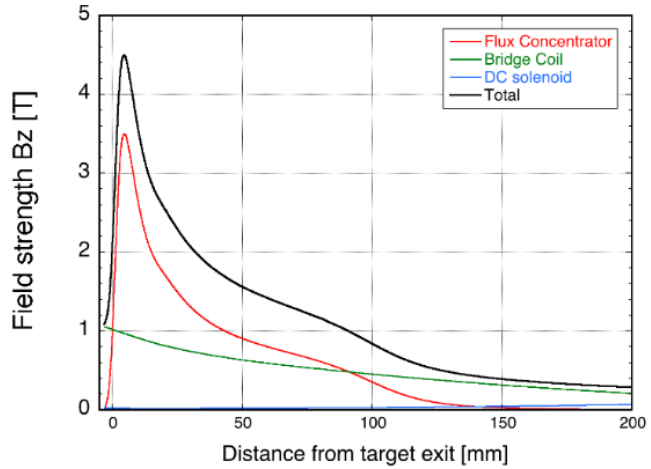
Tungsten Target & Flux Concentrator

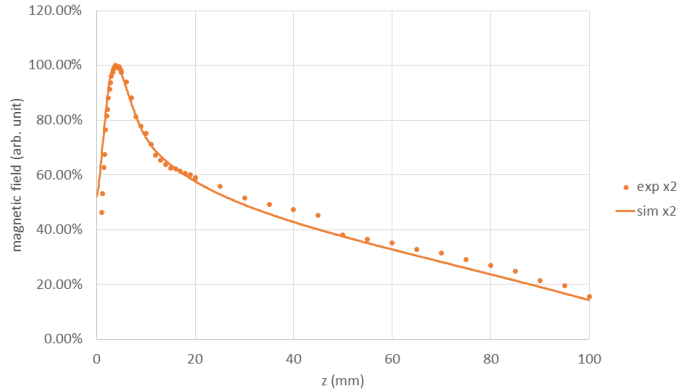
GENERAL INTRODUCTION of LINAC INJECTOR

Positron Target and Capture Section

Large Aperture S-band acc. structure (LAS)

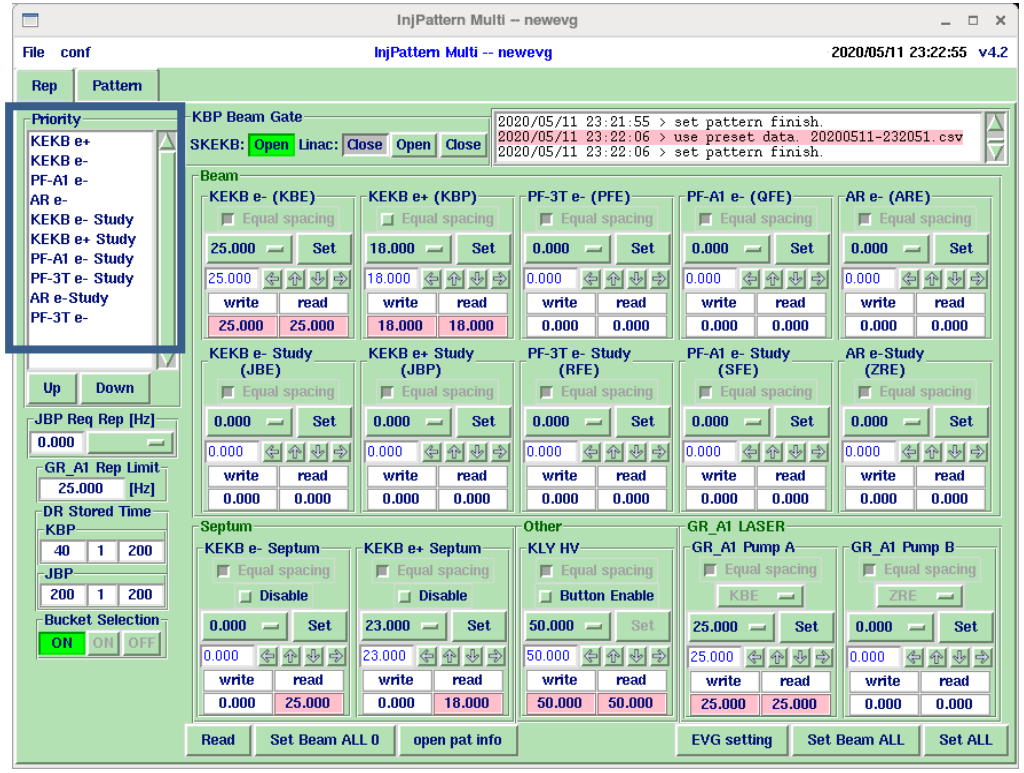


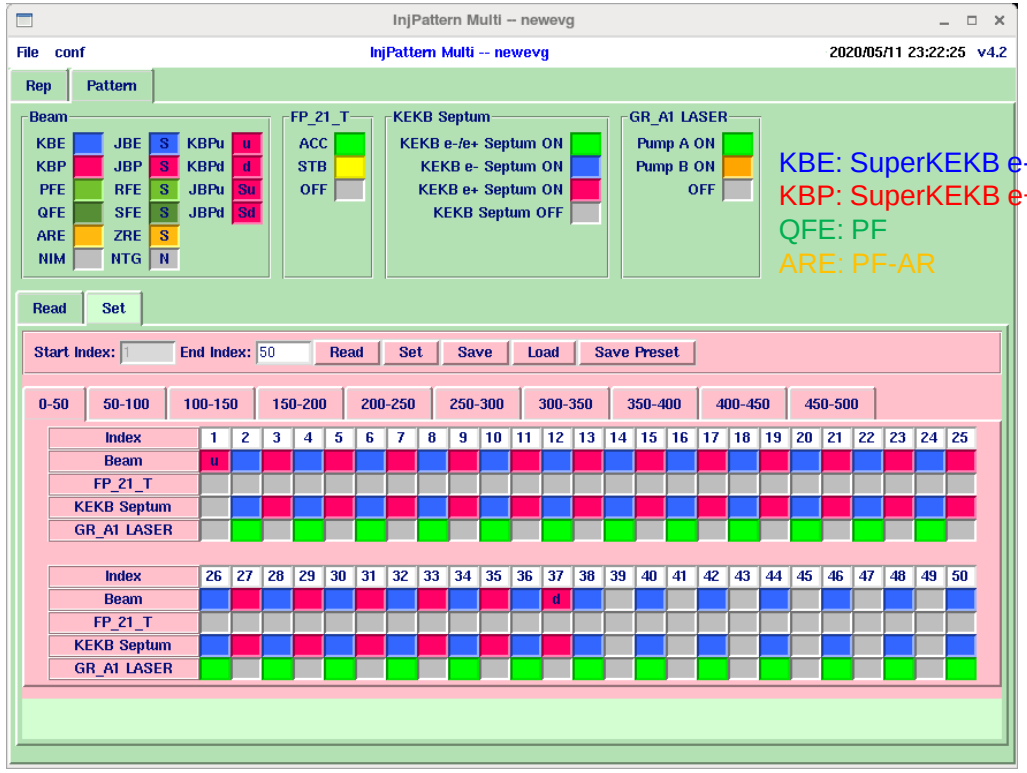




General Introduction of Linac Injector

Beam Injection Pattern Generation for 4-Ring Simultaneous Top-up Injection



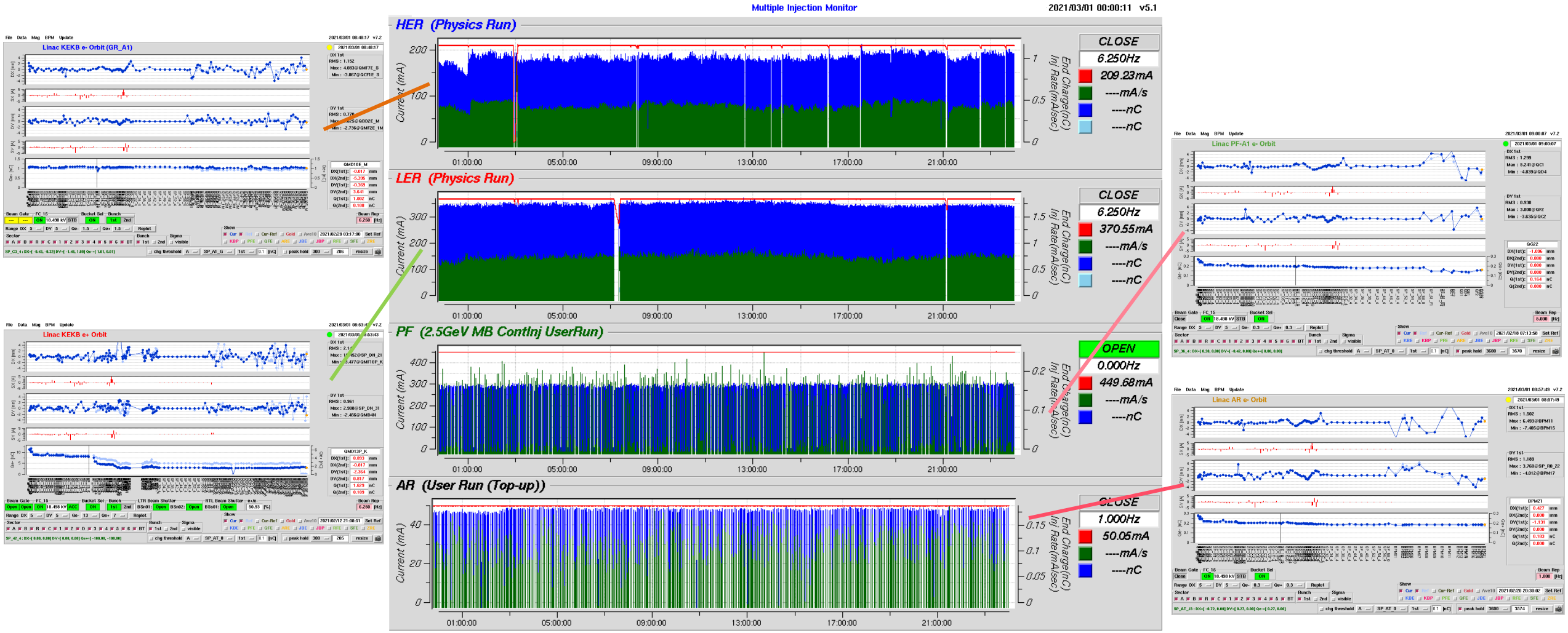


KBE: SuperKEKB e- (HER)
KBP: SuperKEKB e+ (LER)
QFE: PF
ARE: PF-AR

- Selectable beam repetition rate according to the demand from each ring
- Adjustable priority for different case

GENERAL INTRODUCTION of LINAC INJECTOR

Smooth 4-Ring Simultaneous Top-up Injection



DEVELOPMENT of RF GUN DRIVE LASER SYSTEM

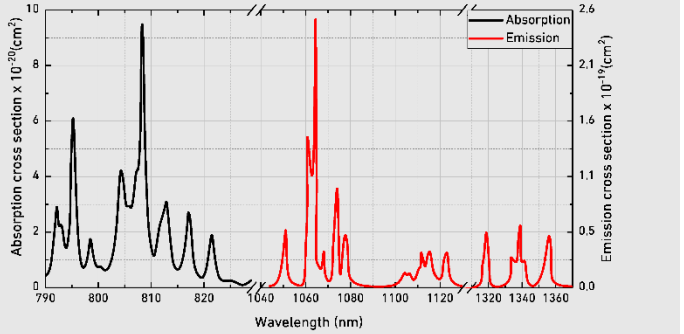
Neodymium-doped YAG (Nd:YAG) and Ytterbium-doped YAG (Yb:YAG) for 1 μm Laser

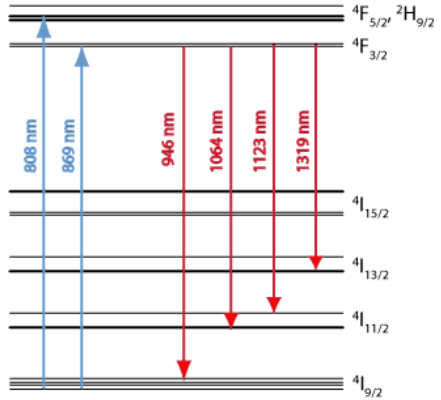
Nd:YAG Laser

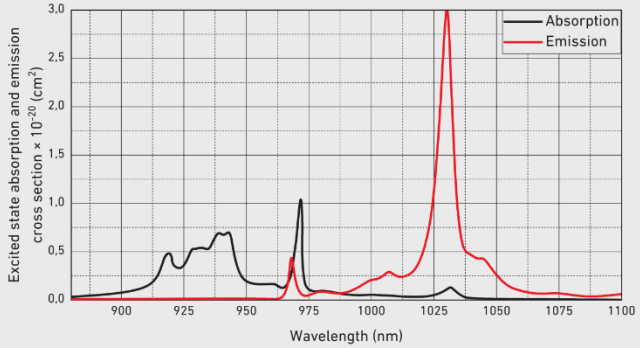
- 4 energy level laser with high quantum defect (24%)
- Short fluorescent time (230 μs)
- Narrow bandwidth (0.67 nm)
- Wide laser pulse (~15 ps for A1 laser)
  $\tau_{FWHM} = 0.44/\Delta\upsilon$ (Bandwidth limit)
- Used in phase II and III

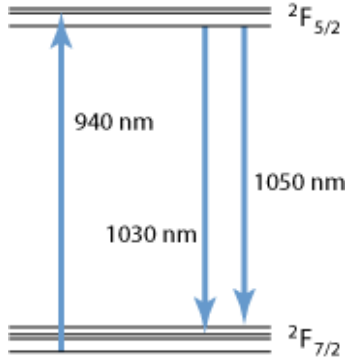
Yb:YAG Laser

- Quasi 3 energy level laser with low quantum defect (8.7%)
- Long fluorescent time (960 μs)
- Wide bandwidth (9.5 nm)
- Narrow laser pulse (~2 ps for A1 laser)
- Used in phase I
- Novel Yb:YAG rod laser system under construction





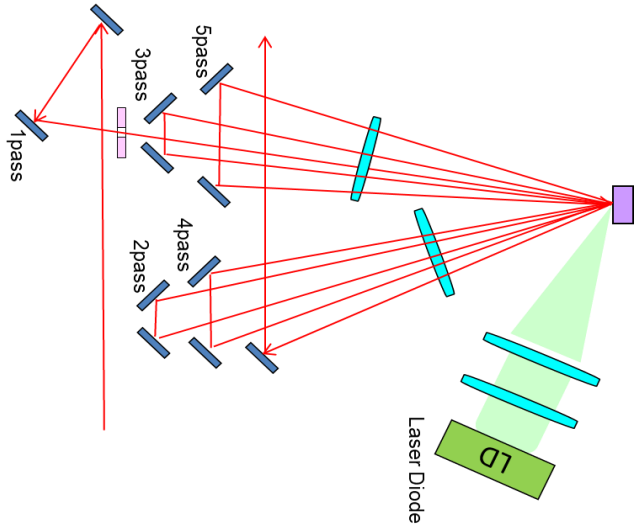


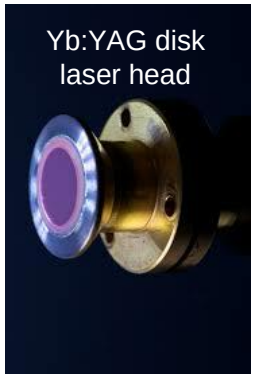


LONG-TERM OPERATION PLAN of LASER SYSTEM for RF GUN

Yb:YAG Disk Laser and Nd:YAG Rod Laser

Yb:YAG thin disk laser

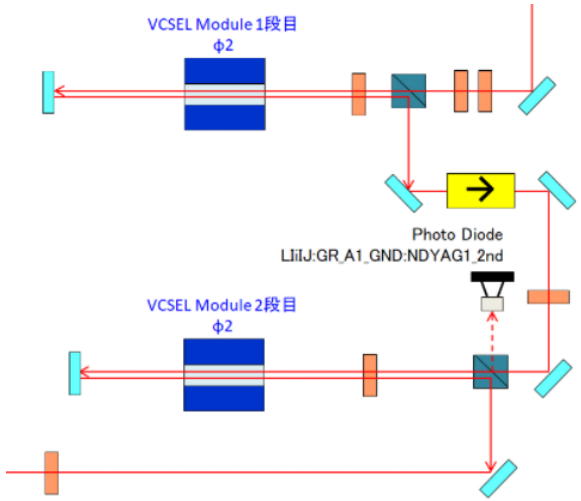




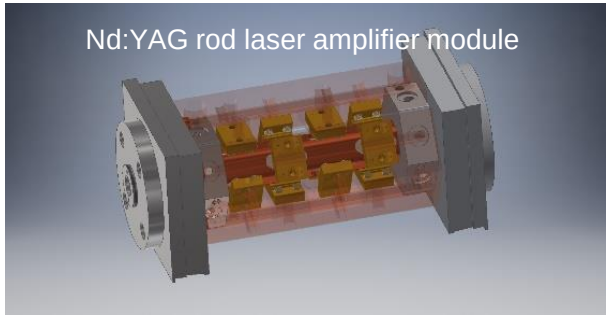
Yb:YAG disk thickness: 1 mm

- Good thermal management and modern laser design
- Necessary multi-pass for amplification
- Used in Phase I
- Poor stability and complex adjustment
- Not suitable for accelerator long term operation

Nd:YAG rod laser



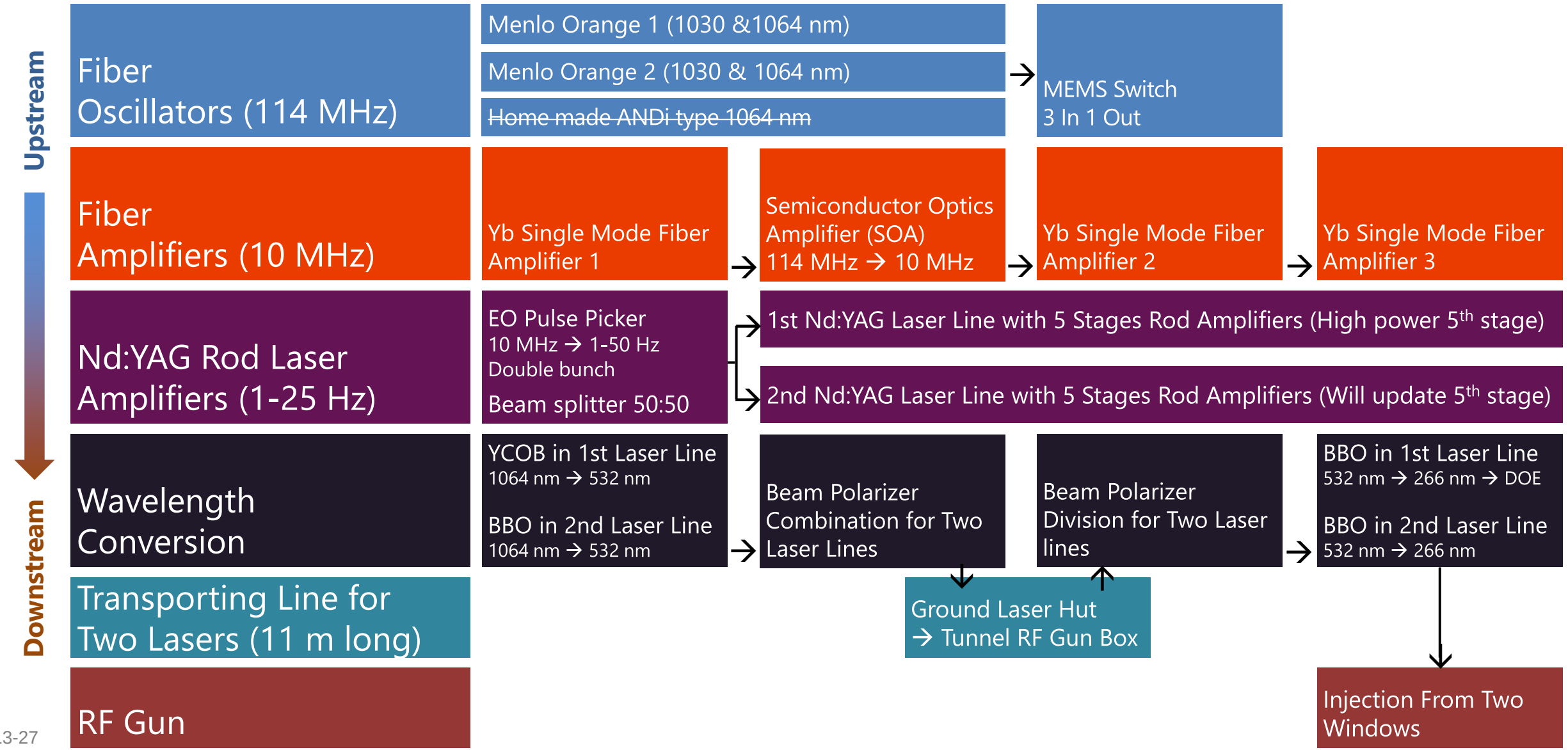
Nd:YAG rod length:
80~95 mm



- Mediocre thermal management
- Single or double-pass for efficient amplification
- Used in Phase II and III
- Good stability
- Simple adjustment and fast recovery during trouble case

INTROCUTION of CURRENT LASER SYSTEM

Yb-Fiber and Nd:YAG Hybrid Laser System



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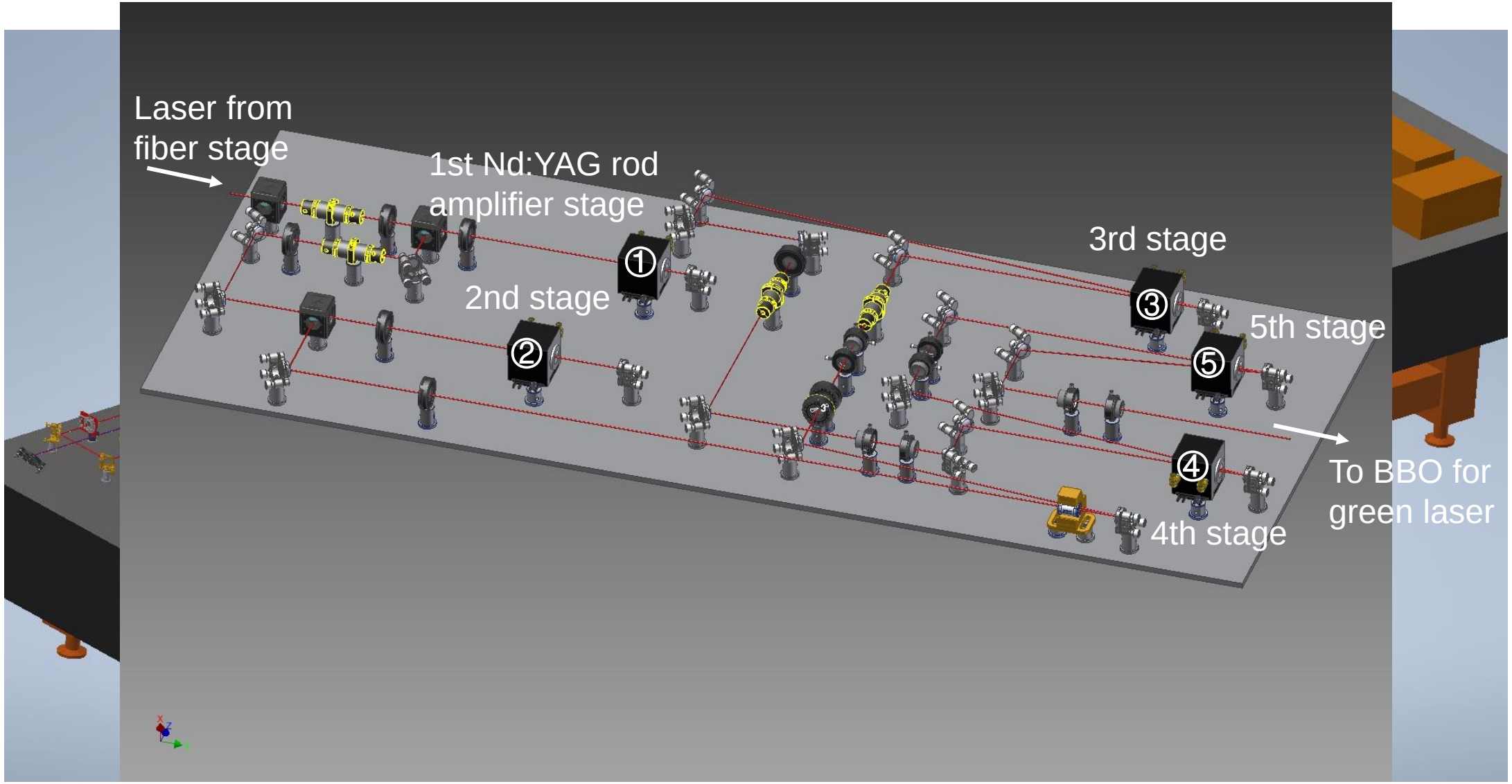
Yb-Fiber and Nd:YAG Hybrid Laser System



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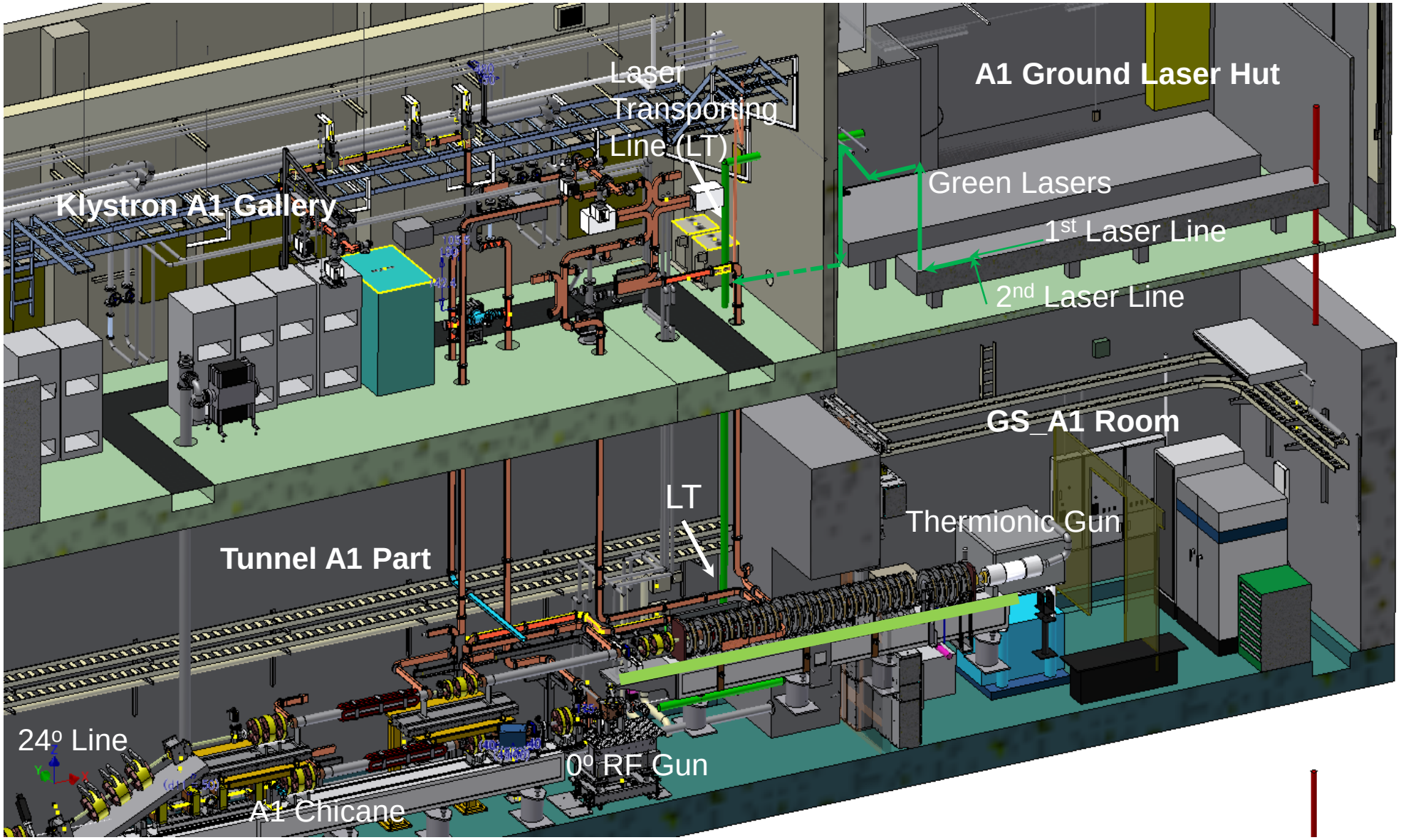
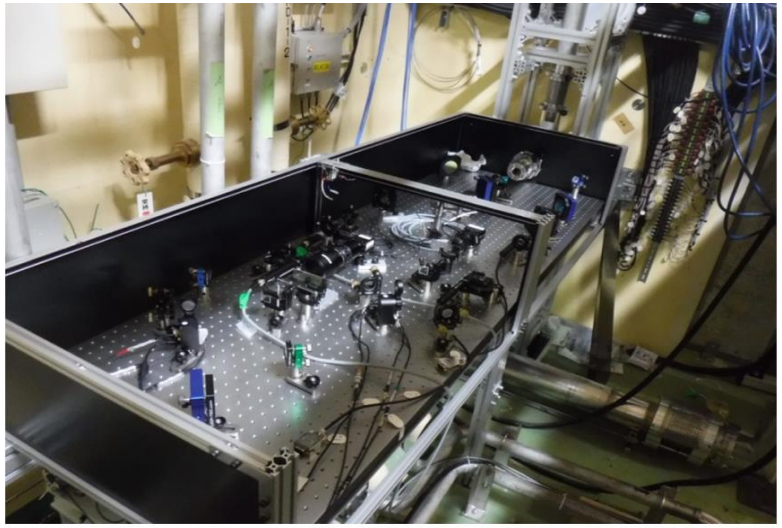
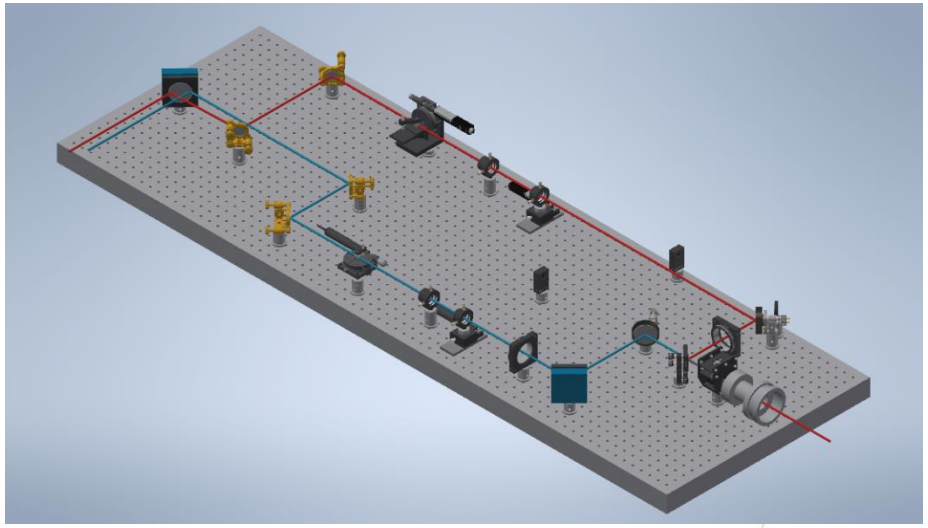
Yb-Fiber and Nd:YAG Hybrid Laser System

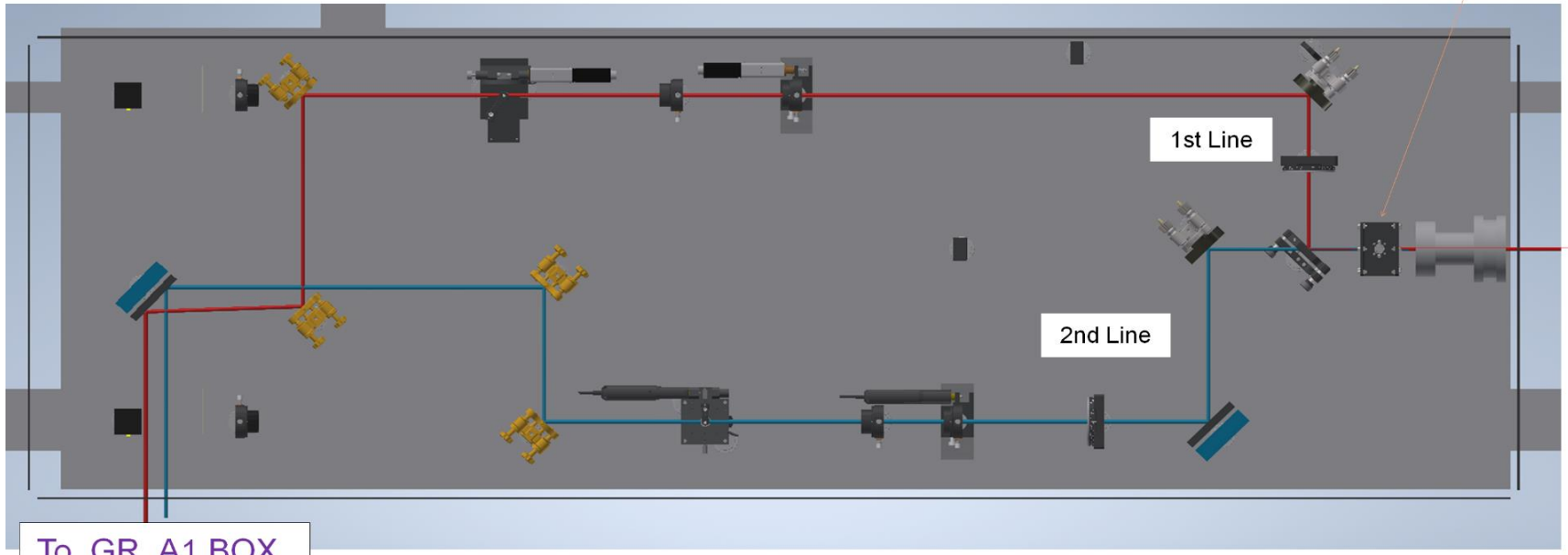


INTROCUTION of CURRENT LASER SYSTEM

Yb-Fiber and Nd:YAG Hybrid Laser System

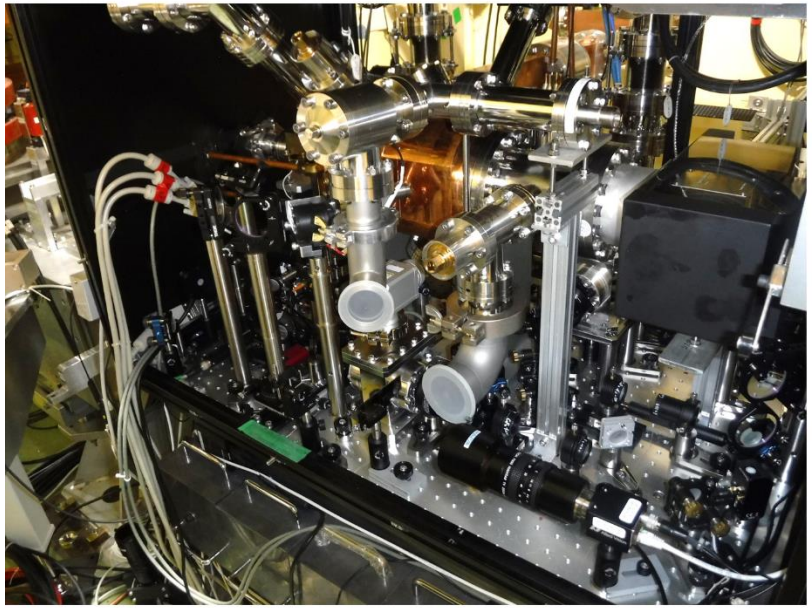


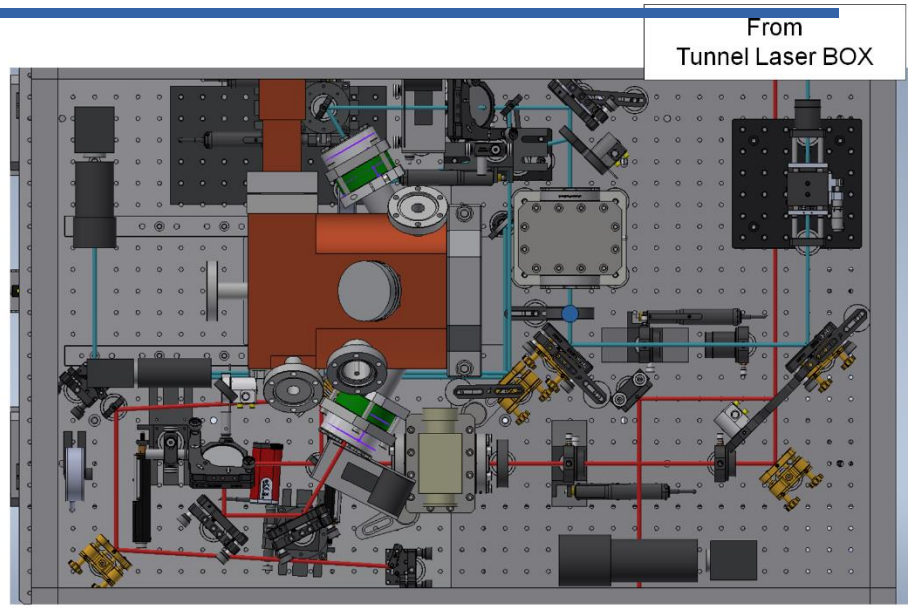




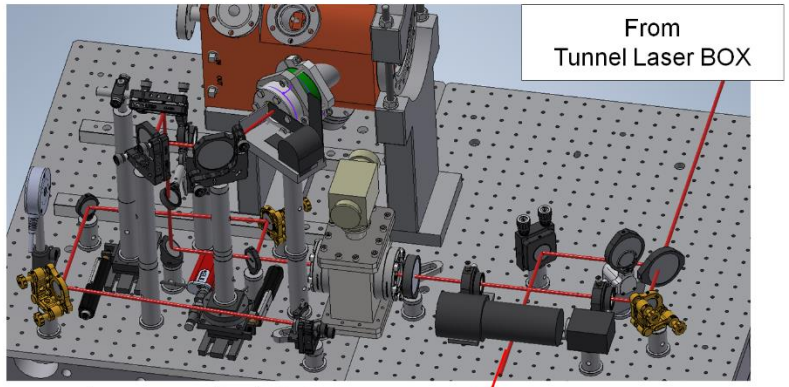
INTROCUTION of CURRENT LASER SYSTEM

Yb-Fiber and Nd:YAG Hybrid Laser System

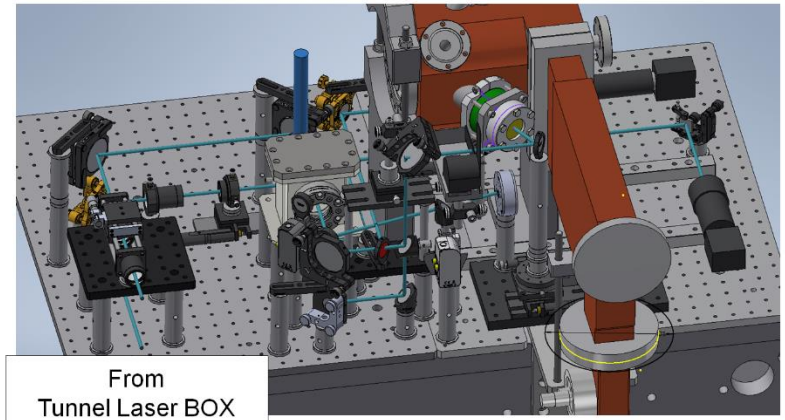




全体の様子



Laser 1st Line

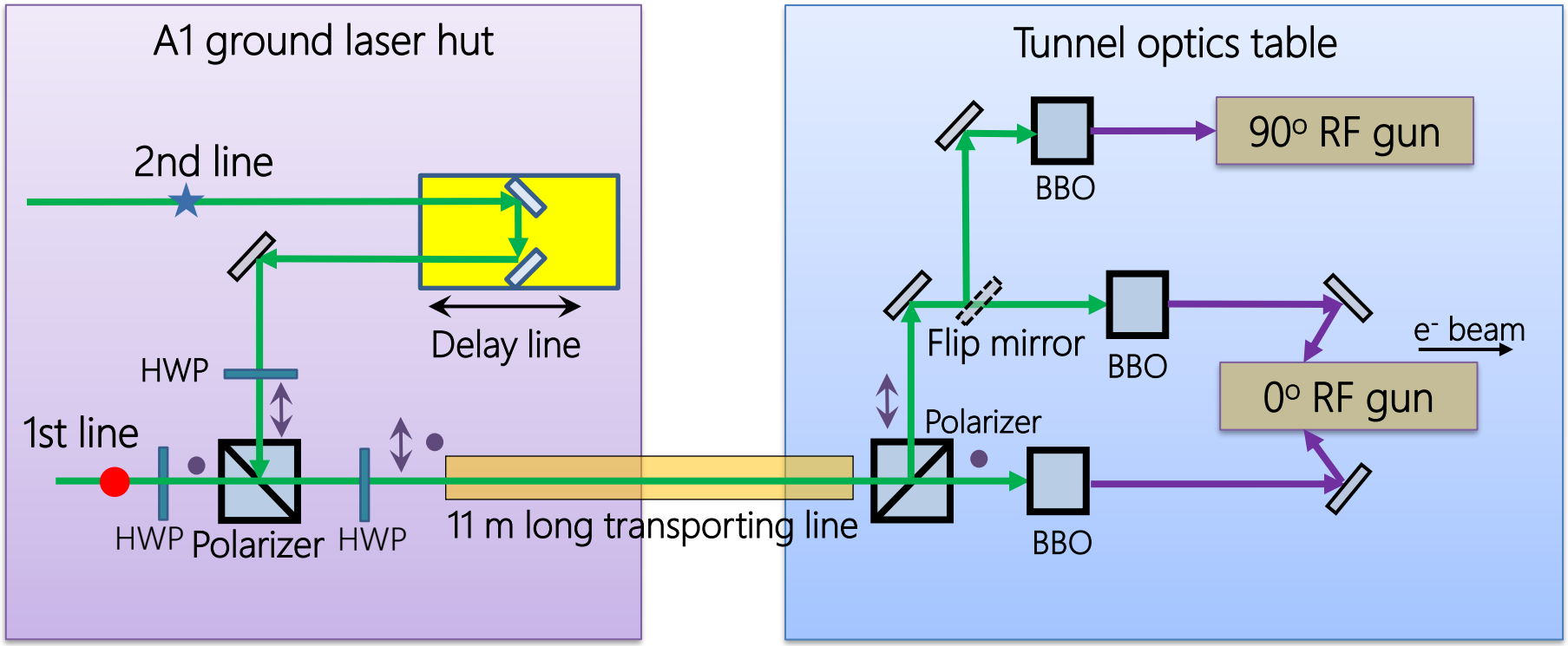


Laser 2nd Line

INTROCUTION of CURRENT LASER SYSTEM

Yb-Fiber and Nd:YAG Hybrid Laser System

Simple illustration for 2 lasers incidence

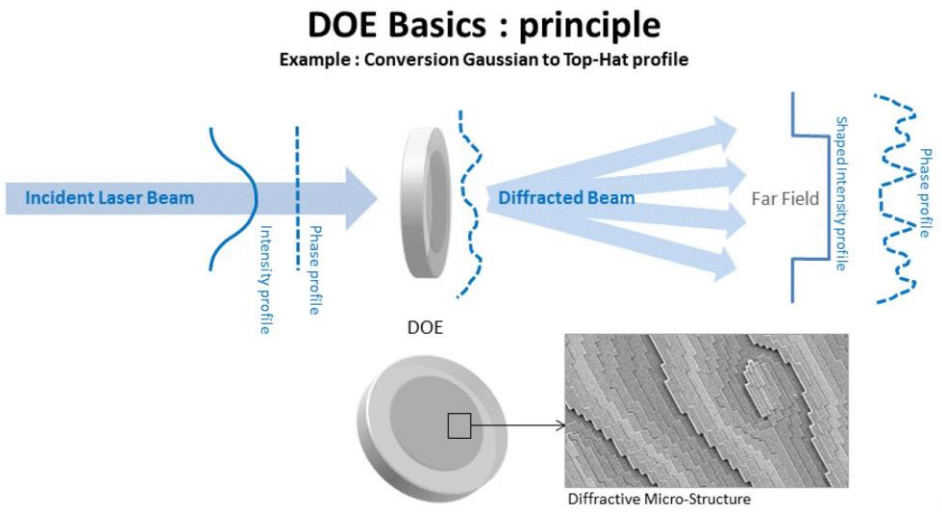


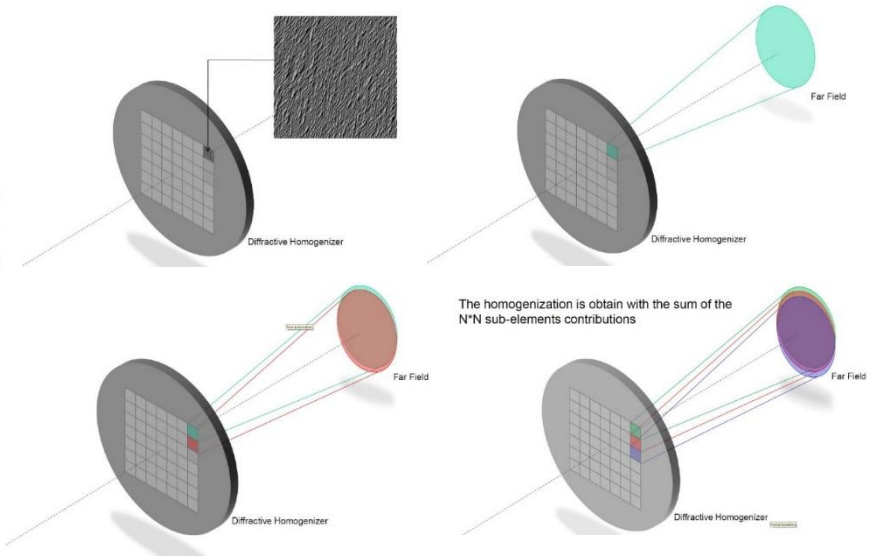
● Laser with vertical polarization, ↕ laser with horizontal polarization, HWP: half wave plate

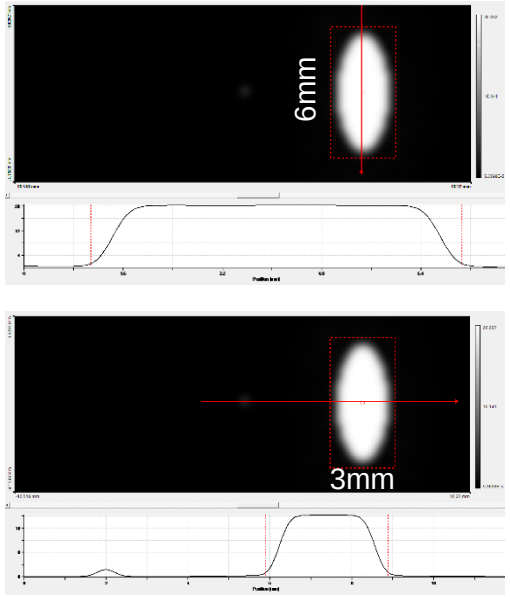
INTROCUTION of CURRENT LASER SYSTEM

DOE for Laser Spatial Distribution Reshaping

- DOE: Diffractive Optical Element for high quality e^- beam
- Principle: Diffraction optics by lens and micro-configuration
- Desired intensity distribution can be realized (phase coding)
- World's first application of DOE in UV laser part



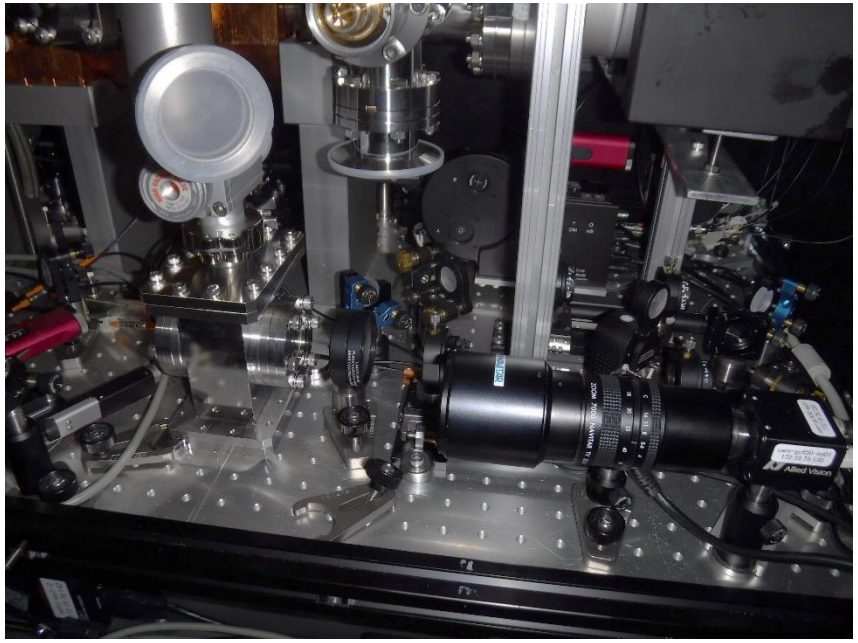


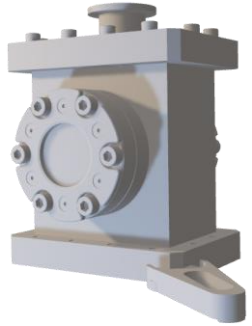


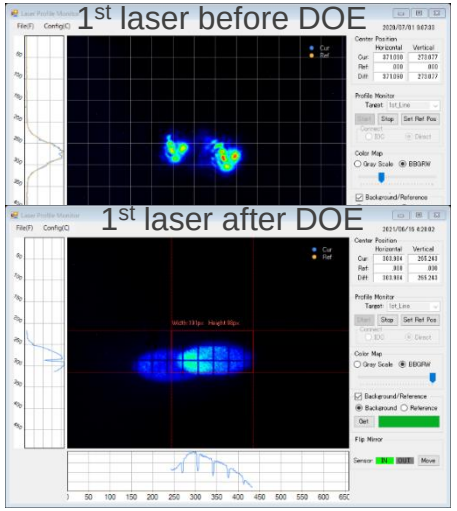
INTROCUTION of CURRENT LASER SYSTEM

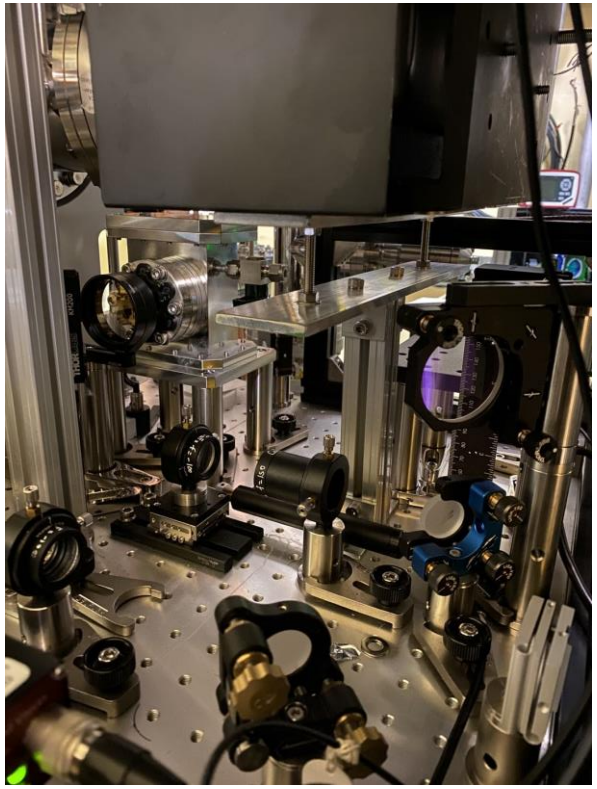
DOE for Laser Spatial Distribution Reshaping

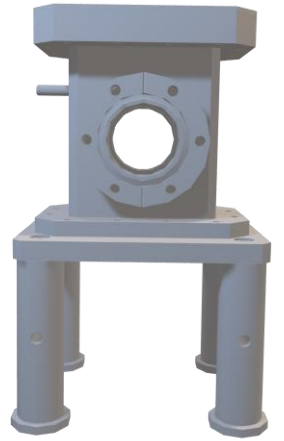
- Application DOE in 1st laser line from 2020c and in 2nd laser line from 2021c
- Elliptical flat-top spatial distribution on the surface of photocathode (LA6mm SA3mm) for low emittance e^- generation and avoiding RF gun discharge

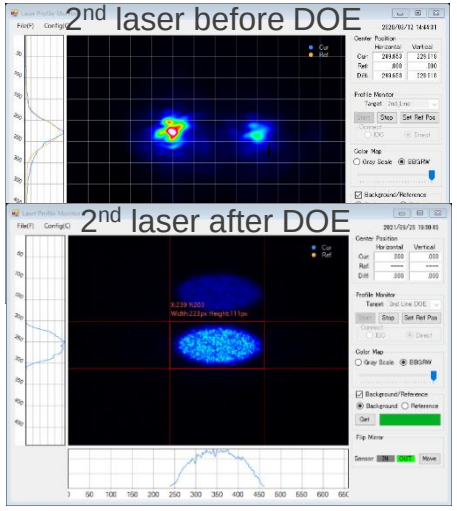








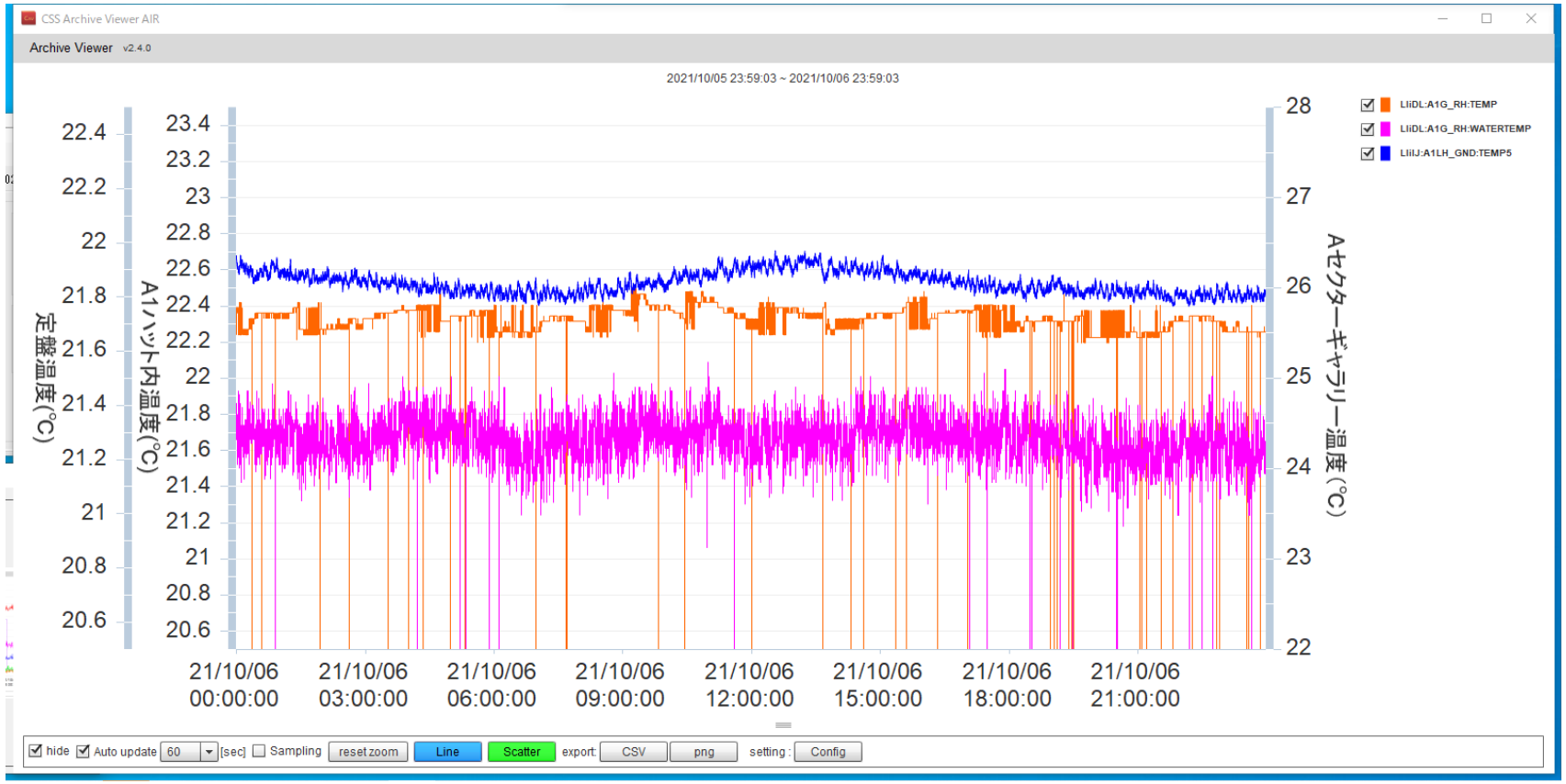




INTROCUTION of CURRENT LASER SYSTEM

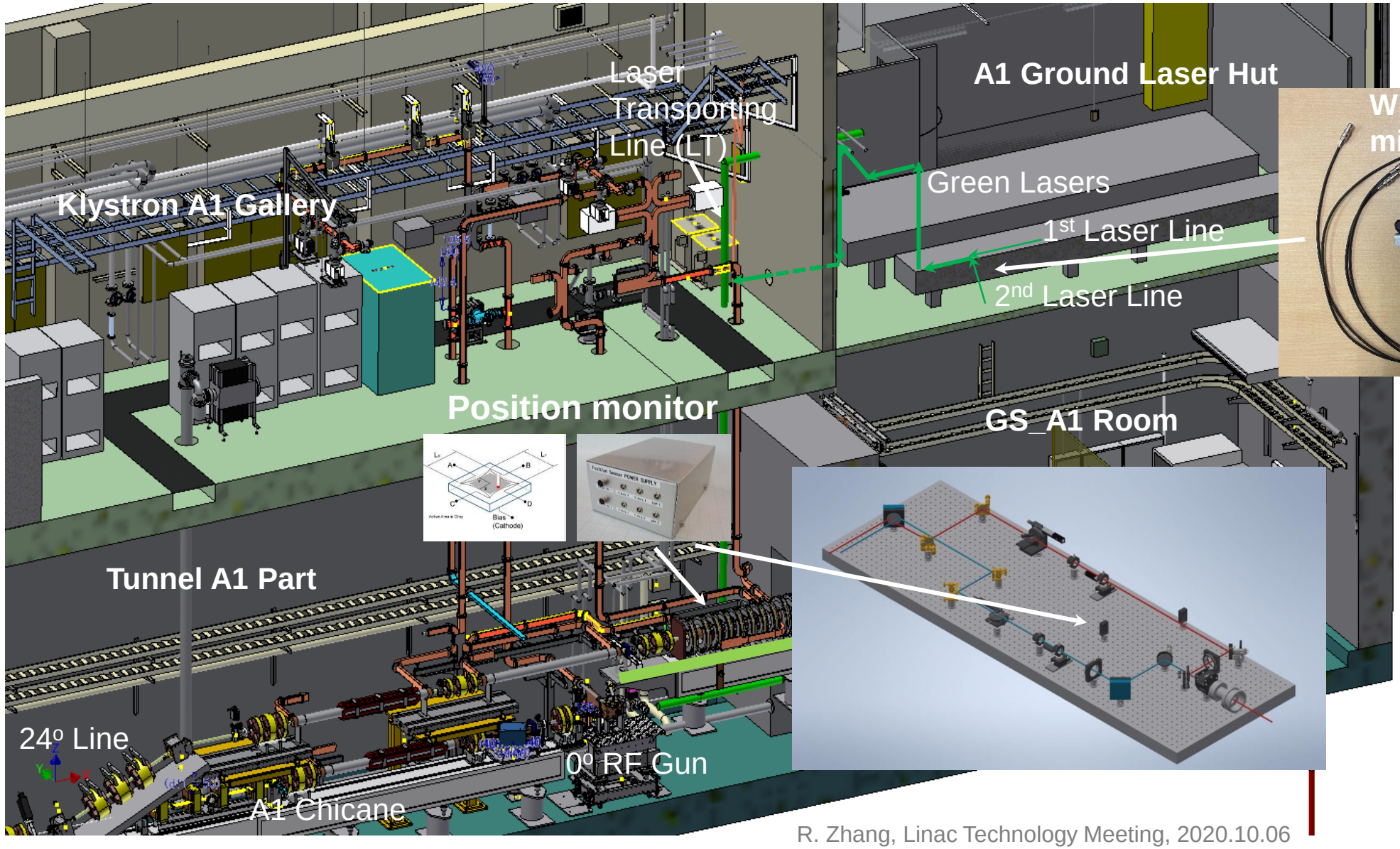
Laser Pointing Stability Fluctuation in A1 Laser Ground Laser Hut

- Daily temperature drift in A1 ground laser hut due to Klystron gallery and outside environment
- Long laser transporting line from ground to tunnel
- Laser pointing stability affects stability of electron beam from RF gun



INTROCUTION of CURRENT LASER SYSTEM

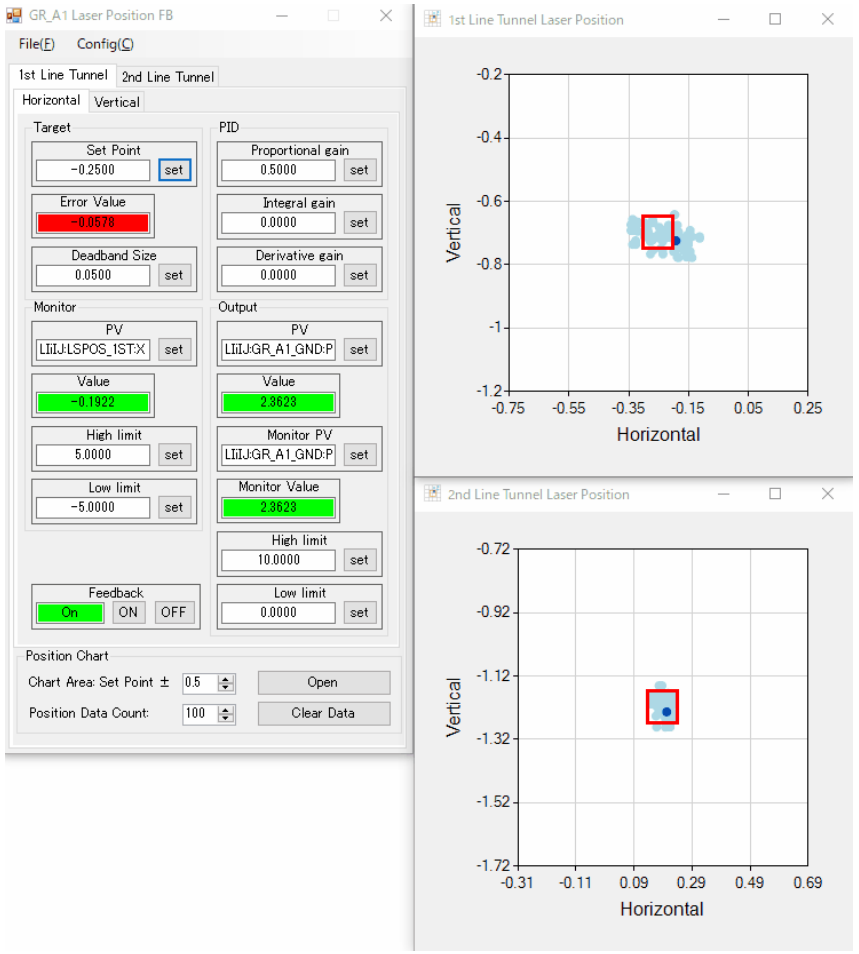
Beam Position Monitor and Feedback System



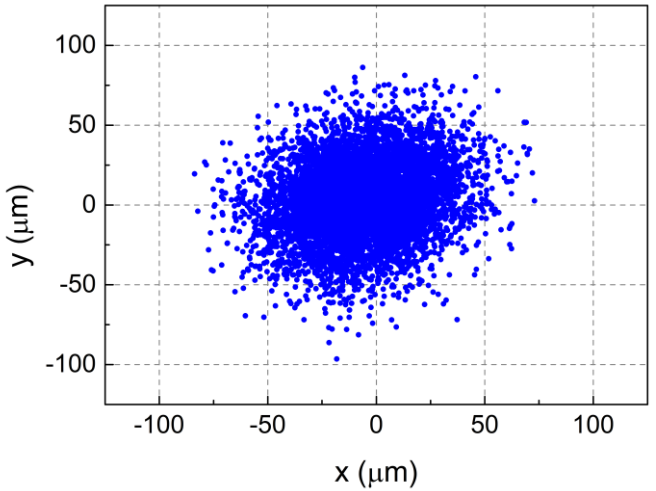
INTROCUTION of CURRENT LASER SYSTEM

Beam Position Monitor and Feedback System

Laser position feedback system

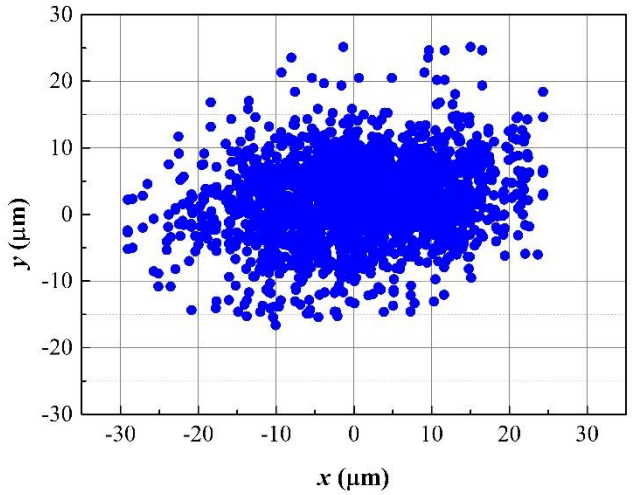


Laser pointing stability at virtual photocathode



Measured in 2019.06 without DOE & beam position sensor

H 2σ: 48.04±0.51
V 2σ: 46.08±0.69

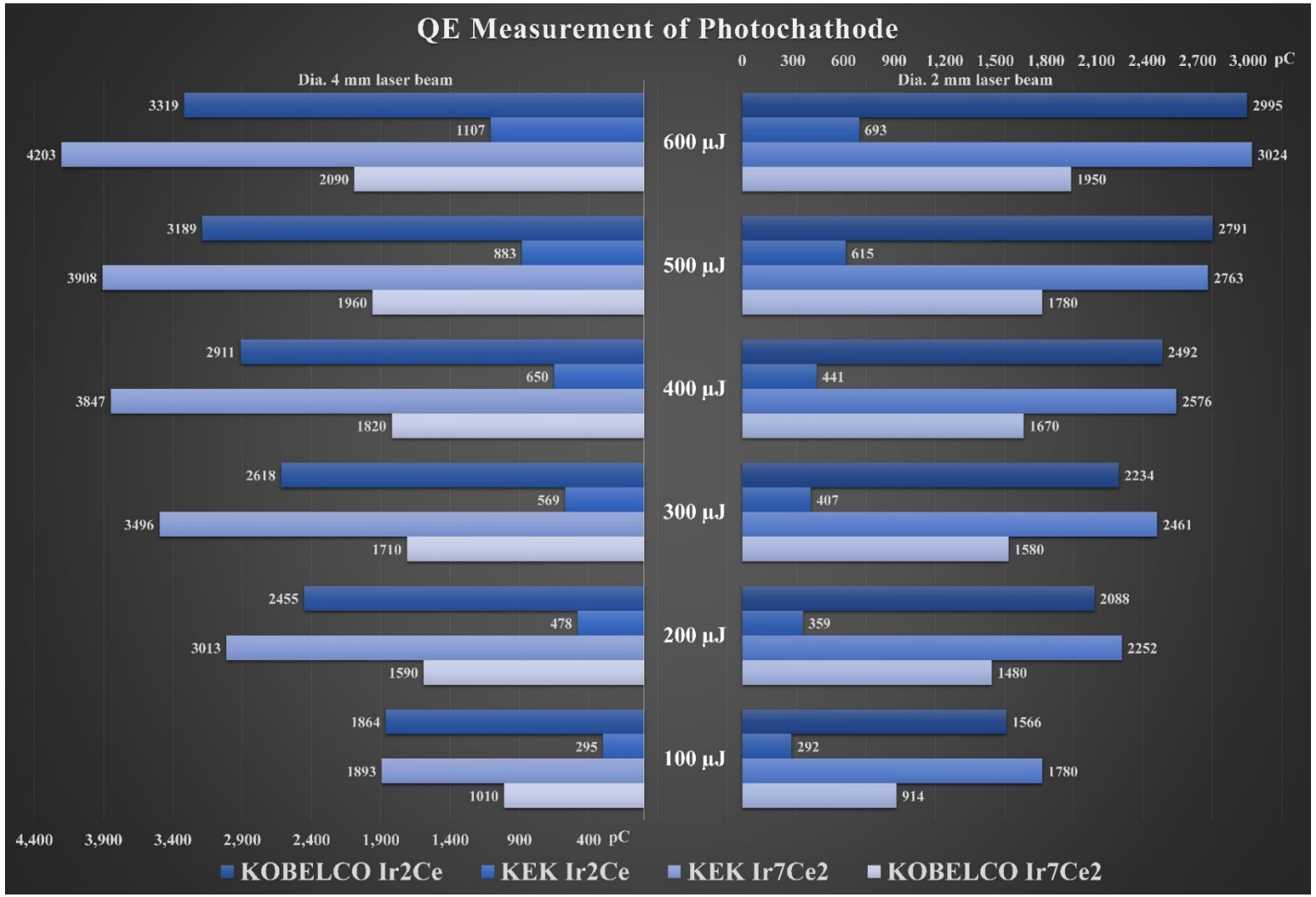


Measured in 2021.06 with DOE & beam position sensor

H 2σ: 24.30±3.06
V 2σ: 10.08±0.46

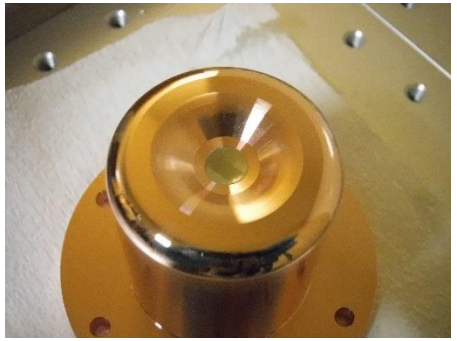
INTROCUTION of CURRENT LASER SYSTEM

Photocathode for RF Gun



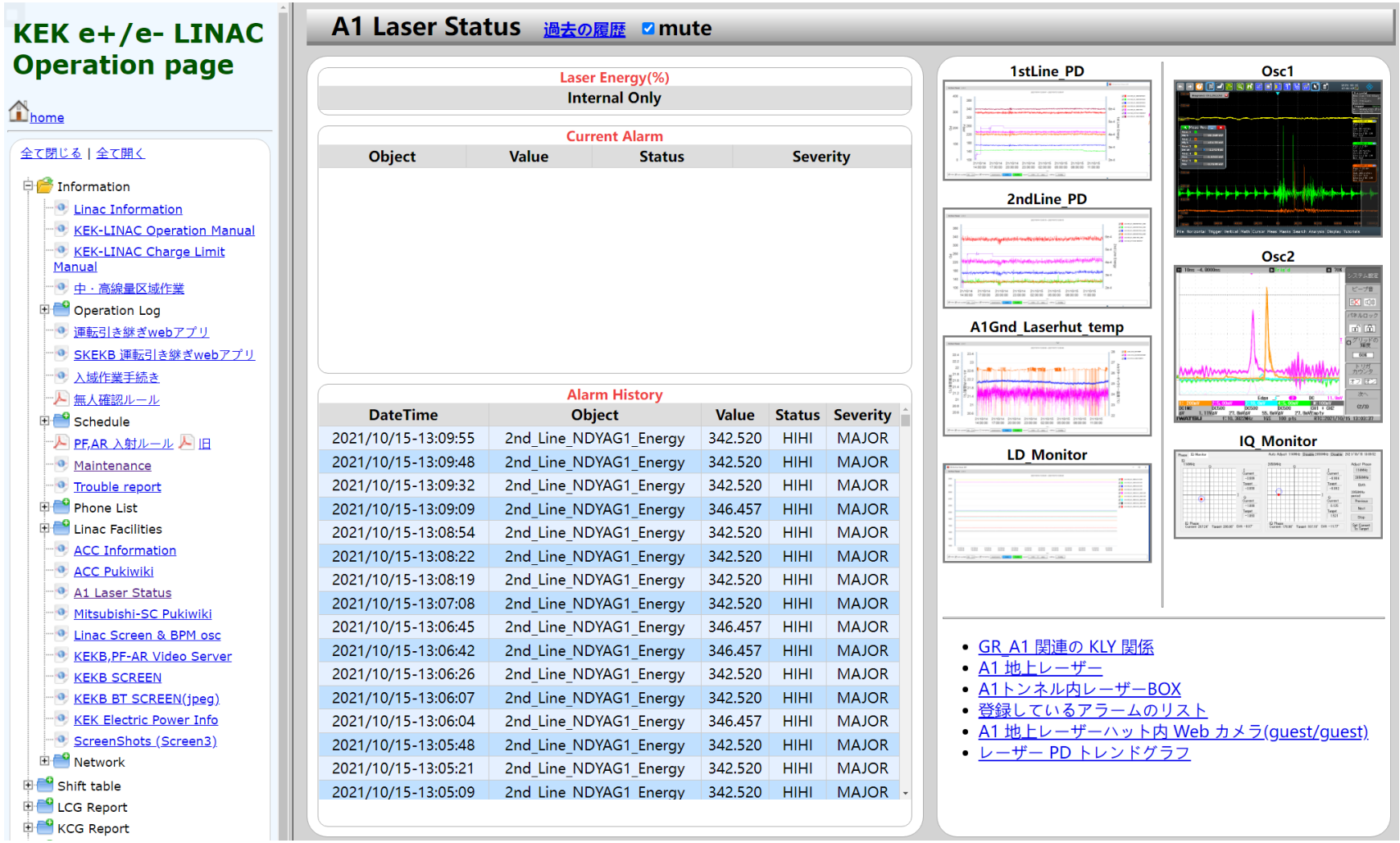
Quantum Efficiency of Photocathode

- QE Ranking:
  KEK Ir_7Ce_2 >
  KOBELCO Ir_2Ce >
  KOBELCO Ir_7Ce_2 >
  KEK Ir_2Ce
- Discharge Probability
  KEK Ir_7Ce_2 <
  KOBELCO Ir_2Ce
- Adoption of KEK Ir_7Ce_2 from 2021ab
- Achievable bigger size



INTROCUTION of CURRENT LASER SYSTEM

Laser Status Monitoring Information Page



KEK e+/e- LINAC Operation page

home

全て閉じる | 全て開く

- Information
  - Linac Information
  - KEK-LINAC Operation Manual
  - KEK-LINAC Charge Limit Manual
  - 中・高線量区域作業
- Operation Log
  - 運転引き継ぎwebアプリ
  - SKEKB 運転引き継ぎwebアプリ
  - 入域作業手続き
  - 無人確認ルール
- Schedule
  - PF,AR 入射ルール 旧
  - Maintenance
  - Trouble report
- Phone List
- Linac Facilities
  - ACC Information
  - ACC Pukiwiki
  - A1 Laser Status
  - Mitsubishi-SC Pukiwiki
  - Linac Screen & BPM osc
  - KEKB,PF-AR Video Server
  - KEKB SCREEN
  - KEKB BT SCREEN(jpeg)
  - KEK Electric Power Info
  - ScreenShots (Screen3)
- Network
- Shift table
- LCG Report
- KCG Report

A1 Laser Status 過去の履歴 mute

Laser Energy(%)

Internal Only

Current Alarm

Object	Value	Status	Severity

Alarm History

DateTime	Object	Value	Status	Severity
2021/10/15-13:09:55	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:09:48	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:09:32	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:09:09	2nd_Line_NDYAG1_Energy	346.457	HIHI	MAJOR
2021/10/15-13:08:54	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:08:22	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:08:19	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:07:08	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:06:45	2nd_Line_NDYAG1_Energy	346.457	HIHI	MAJOR
2021/10/15-13:06:42	2nd_Line_NDYAG1_Energy	346.457	HIHI	MAJOR
2021/10/15-13:06:26	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:06:07	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:06:04	2nd_Line_NDYAG1_Energy	346.457	HIHI	MAJOR
2021/10/15-13:05:48	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:05:21	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR
2021/10/15-13:05:09	2nd_Line_NDYAG1_Energy	342.520	HIHI	MAJOR

1stLine_PD

2ndLine_PD

A1Gnd_Laserhut_temp

LD_Monitor

Osc1

Osc2

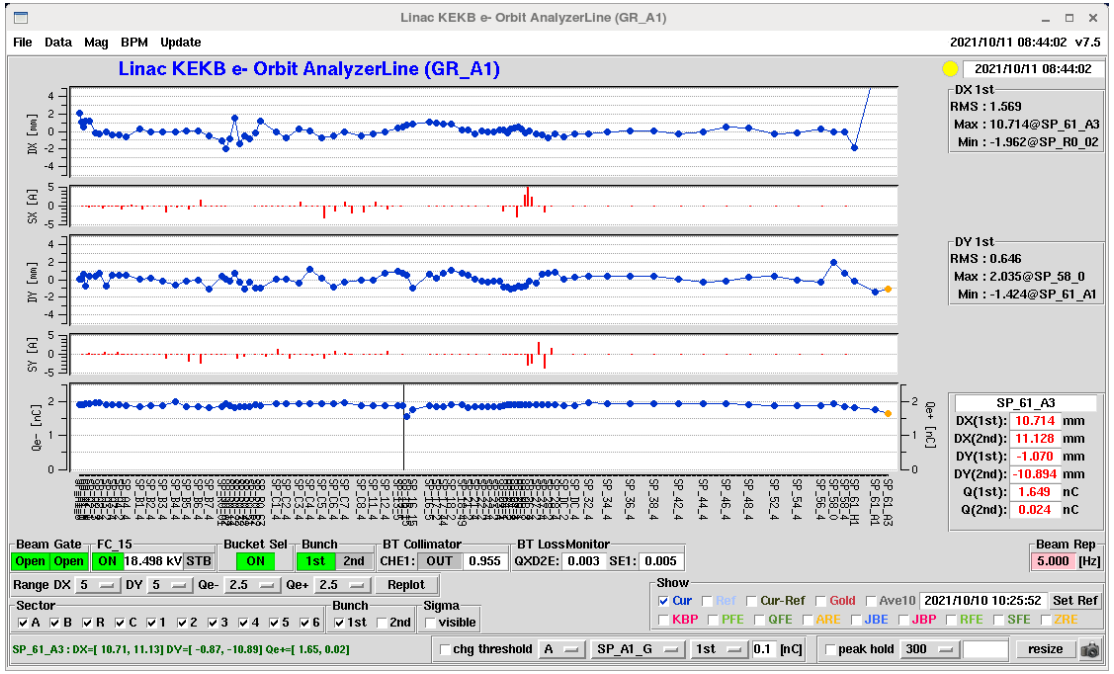
IQ_Monitor

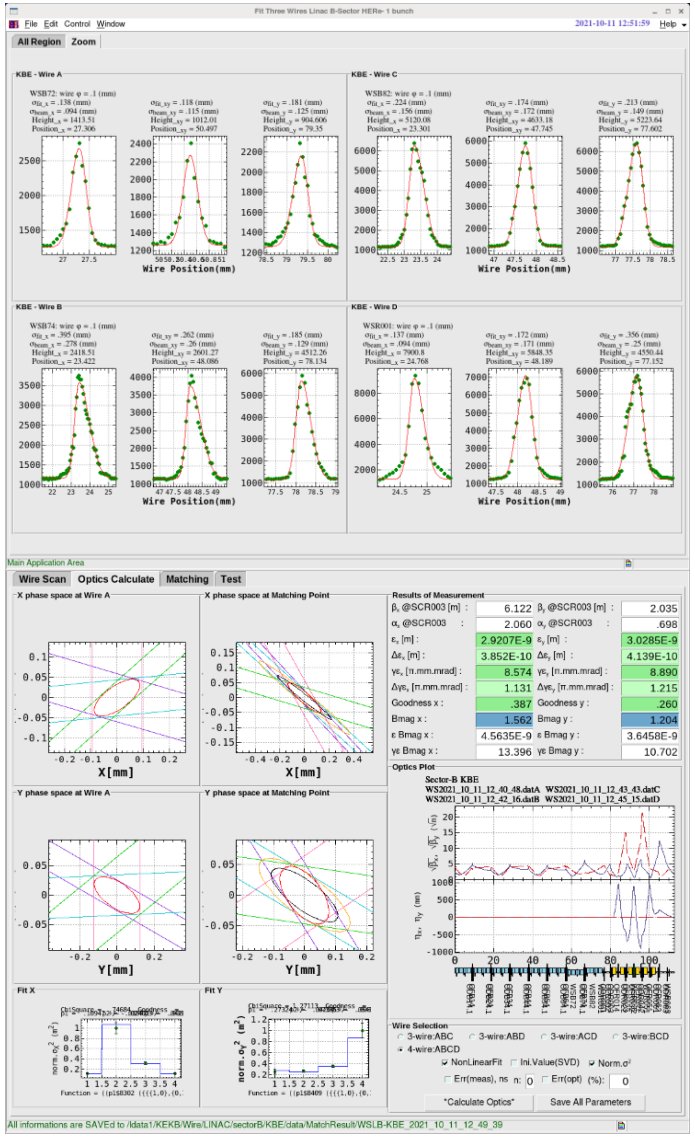
- GR_A1 関連の KLY 関係
- A1 地上レーザー
- A1トンネル内レーザーBOX
- 登録しているアラームのリスト
- A1 地上レーザーハット内 Web カメラ(guest/guest)
- レーザー PD トレンドグラフ

https://www-linac.kek.jp/ope/opelog2/opelog.html

INTROCUTION of CURRENT LASER SYSTEM

2 nC Low Emittance Electron Beam Generation





Two lasers incidence at 2021c (2021.10.11)

- 2 nC after RF gun for HER beam (by partial energy of two lasers)

Single laser incidence at 2021c (2021.10.18)

- 1st laser energy: 250 uJ → Peak charge: 1.4 nC
- 2nd laser energy: 250 uJ → Peak charge: 1.5 nC

Wire scanner @ B-sector (2021.10.11)

- With DOE and position feedback system
- Two lasers incidence
- 2 nC from RF gun
- $\gamma\varepsilon_x = 8.574 \pm 1.131\ mm \cdot mrad$
- $\gamma\varepsilon_y = 8.890 \pm 1.215\ mm \cdot mrad$
- The best record so far

SUMMARY & OUTLOOK

- **Summary**
  - Linac injector operates well for successful 4-ring simultaneous top-up injection
  - Stable operation of Yb-fiber/Nd:YAG laser provides continuous SuperKEKB HER injection

- **Outlook**
  - Current Yb-fiber/Nd:YAG laser will be upgraded during 2021 winter maintenance for higher energy
  - Novel Yb-fiber/Yb:YAG laser system is under construction (as one part of Linac Upgrade Project)

THANKS