Insight through Accelerators.

KEK

高エネルギー加速器研究機構

SuperKEKB RF Gun Injector Design and Operation

IAS Program on High Energy Physics, 01.13. 2022

Rui Zhang (KEK ACCL-5, Injector Group)

kek50th anniversary

50th Anniversary Since 1971 Keep Accelerating

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Contents

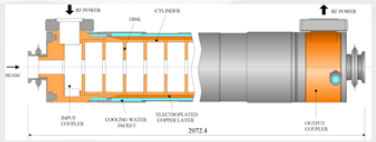
- Introduction of SuperKEKB Linac injector
- SuperKEKB RF gun system
  - RF gun cavity
  - Photocathode
  - Laser system of RF gun
- 2021c operation status and achievements
- Summary and outlook

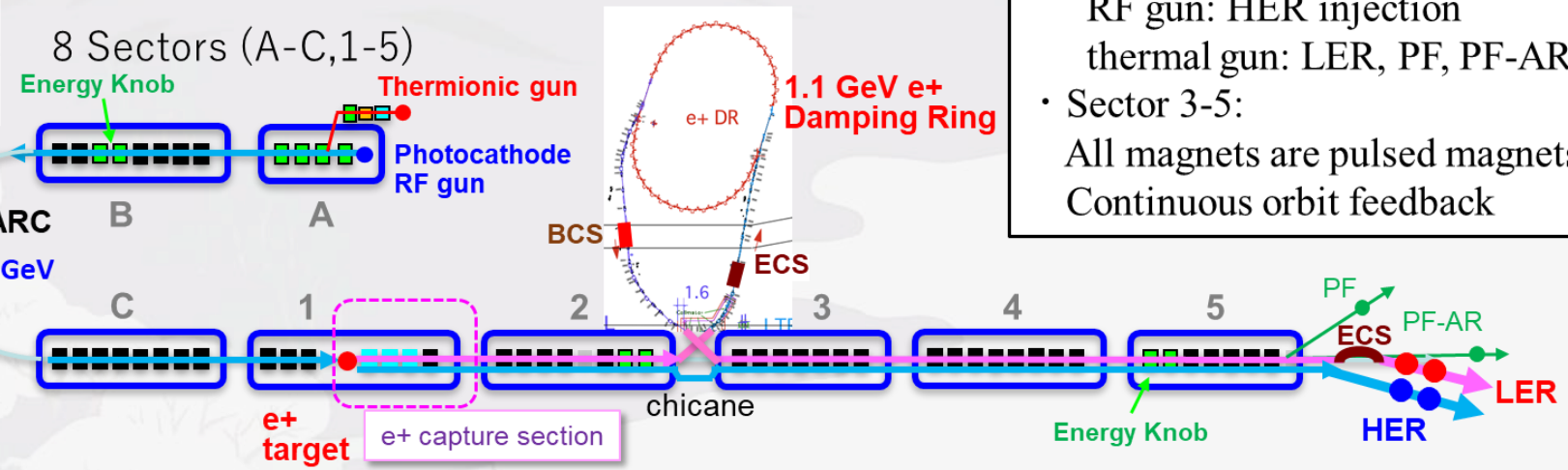
kek50th anniversary

50th Anniversary Since 1971 Keep Accelerating

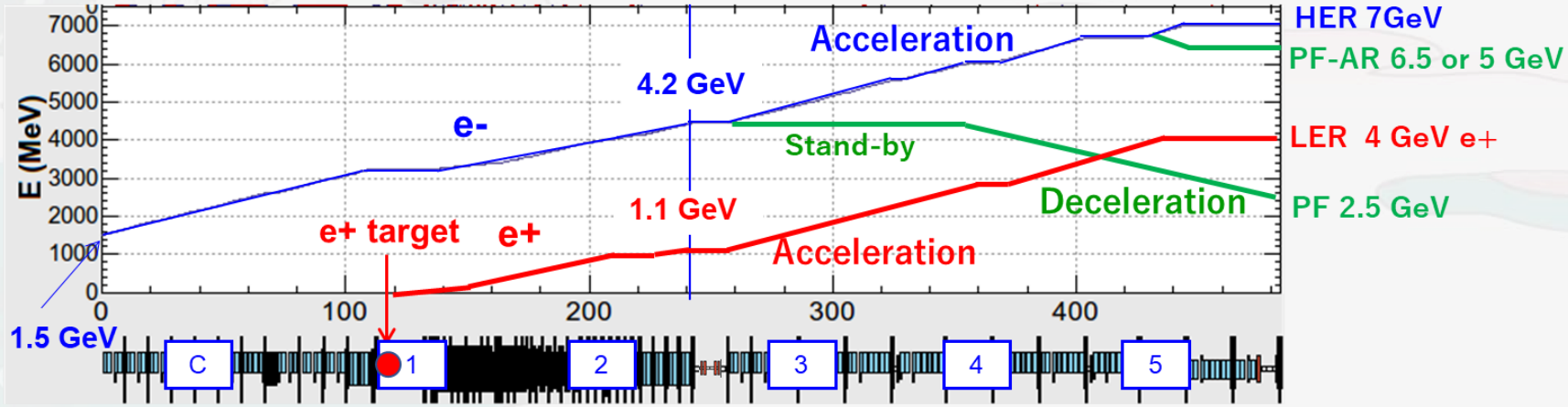
General Layout of SuperKEKB Linac

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





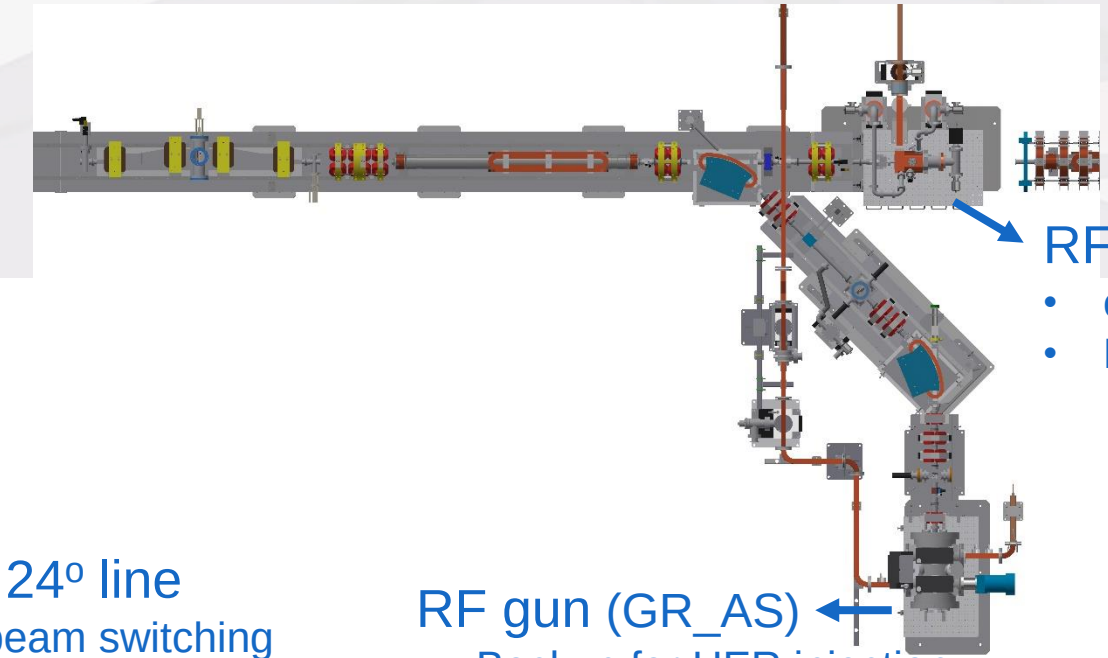
- Two electron sources:
  RF gun: HER injection
  thermal gun: LER, PF, PF-AR
- Sector 3-5:
  All magnets are pulsed magnets.
  Continuous orbit feedback



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

Electron Source Part of Linac

Top view



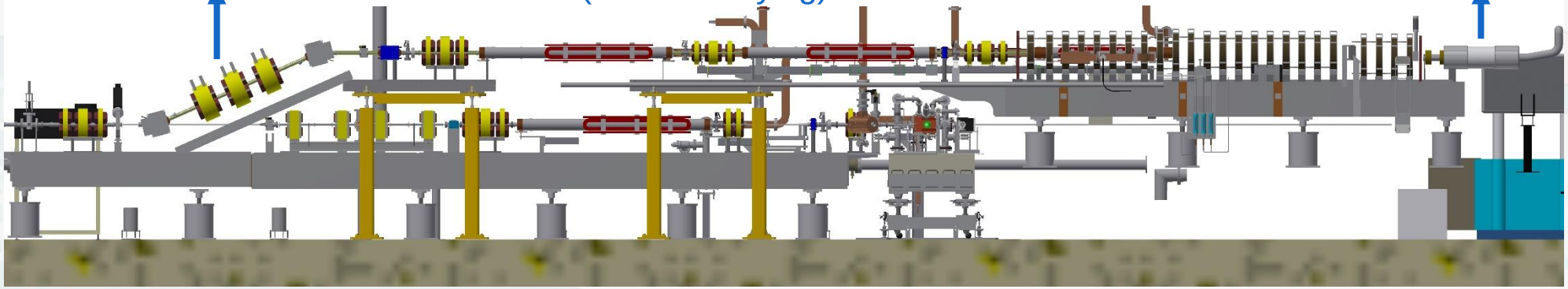
RF gun (GR_A1)
- e^- : 0.1 - 3 nC (KBE for HER injection)
- Primary RF gun

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

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

RF gun (GR_AS)
- Backup for HER injection (Under studying)

Side view



SuperKEKB Requirements

	Electron HER 7 GeV	Positron LER 4 GeV
Normalized Emittance	40 / 20 [μm]	100 / 15 [μm]
Energy Spread	0.07%	0.16%
Bunch Charge	4.0 nC	4.0 nC

Stable electron beam with high charge and low emittance is required for SuperKEKB

SuperKEKB RF Gun

Requirements

- 4 nC electron charge generation capability
- 10 μm emittance preservation
- Long term continuous operation

4 nC Beam Operation

- Less space charge effect
  - Longer pulse: 20 - 30 ps
- Essential strong focusing field
  - Preserves the low emittance from the RF gun
- Stable long time operation
  - Lower electric field: < 100 MV/m

Side coupler or cut disk gun cavity structure is preferred

S-band RF Gun System for SuperKEKB

RF gun cavity: strong focusing electric field & high acceleration efficiency

- Quasi travelling wave side coupler (QTWSC): A1 primary RF gun
- Cut disk travelling wave structure (CDTWS): A1 secondary RF gun

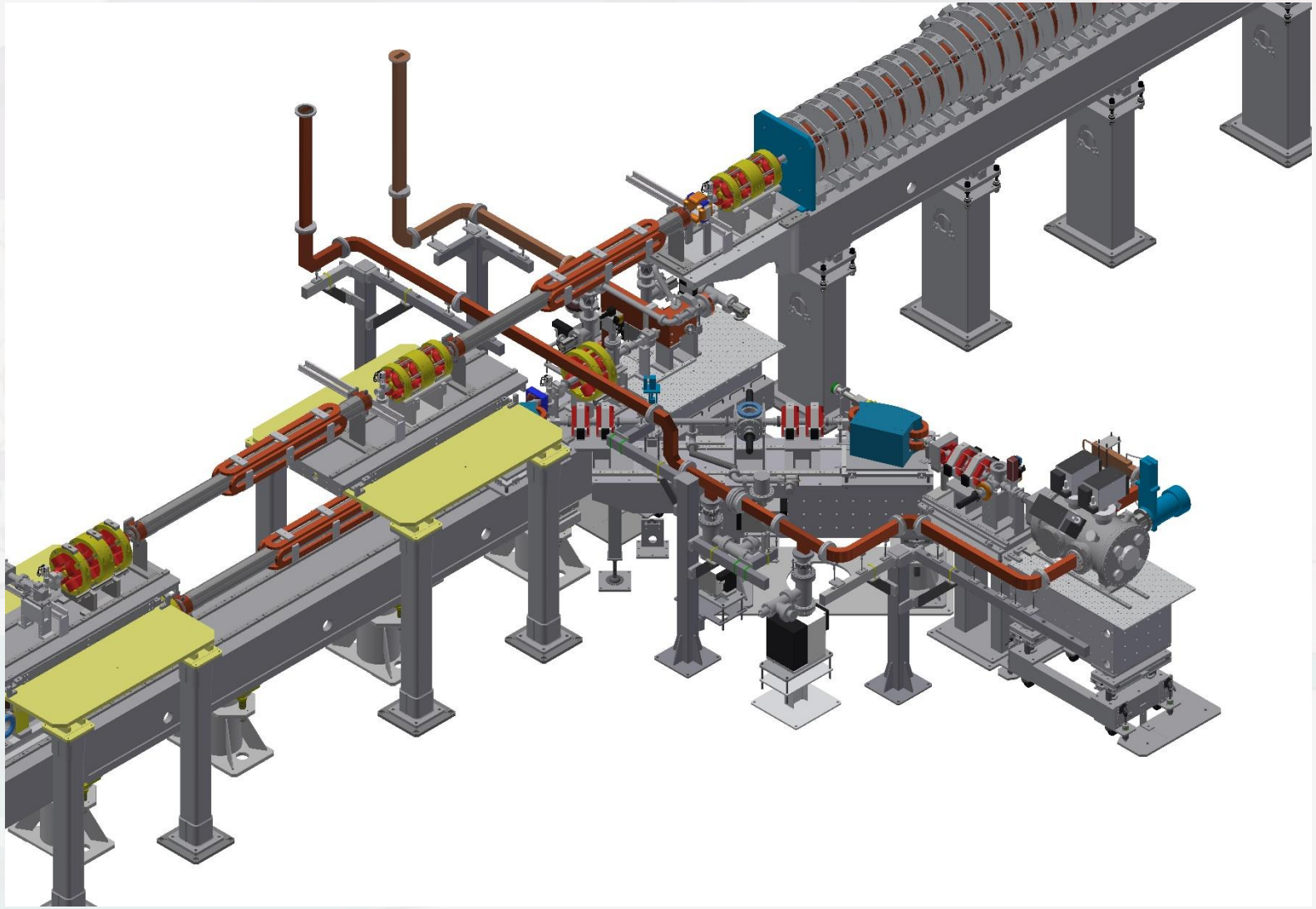
Photocathode: long life time & comparable high QE

- Medium QE with long life time: 10^{-4} - 10^{-3} @266nm > 1 year
- Metal composite: Ir_2Ce or Ir_7Ce_2

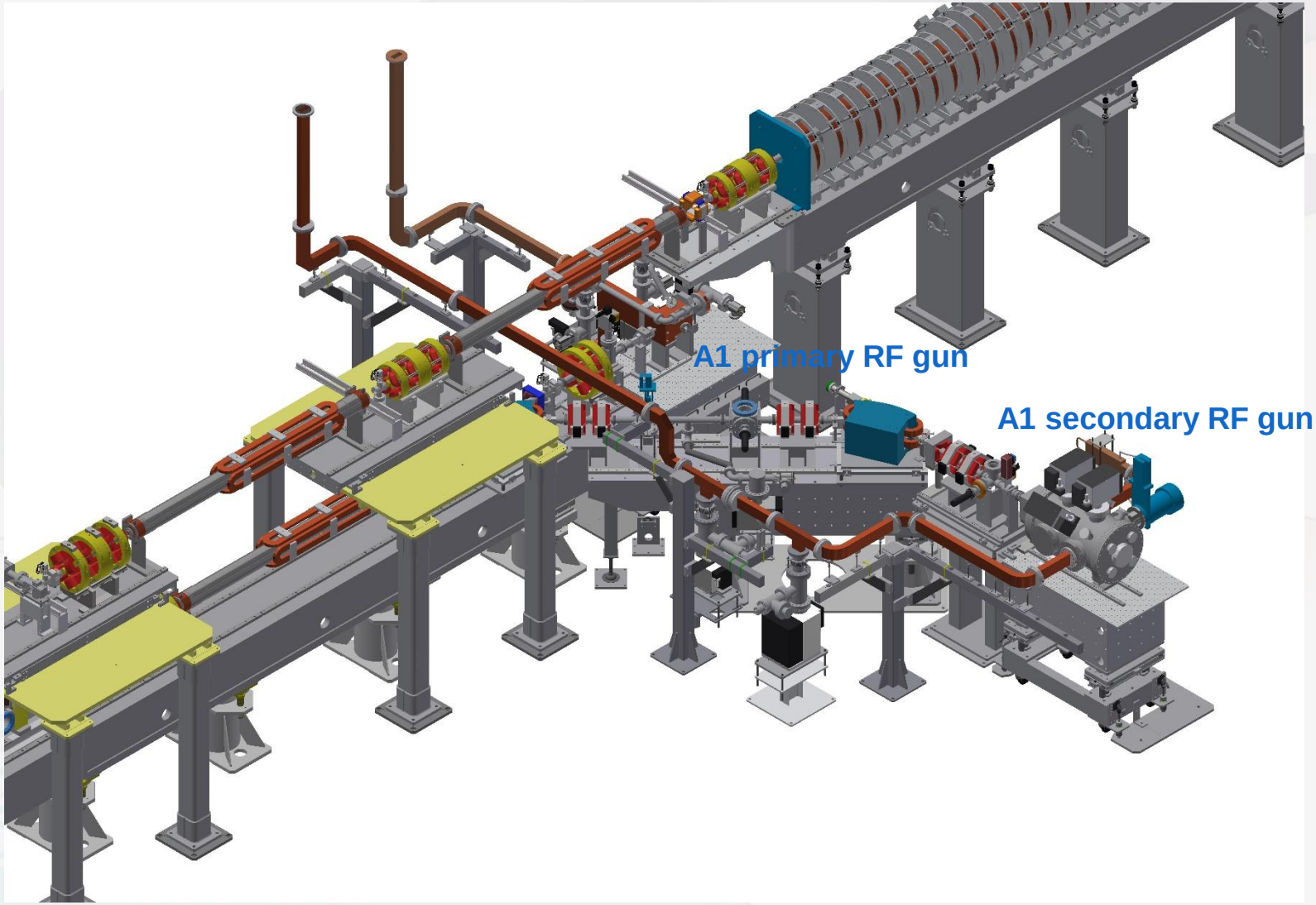
Laser: simple, stable, spatial & temporal reshaping

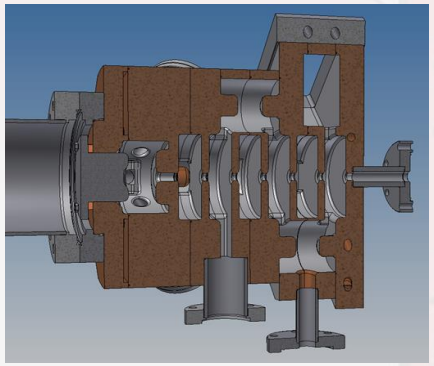
- Laser active material pumped by laser diode directly
  - Yb-fiber & Neodymium (Nd) doped crystal (Nd:YAG): A1 ground laser hut
  - Yb-fiber & Ytterbium (Yb) doped crystal (Yb:YAG): A1 underground laser hut
- Temporal and spatial reshaping for minimum energy spread and emittance

RF Gun in Linac A1 Section



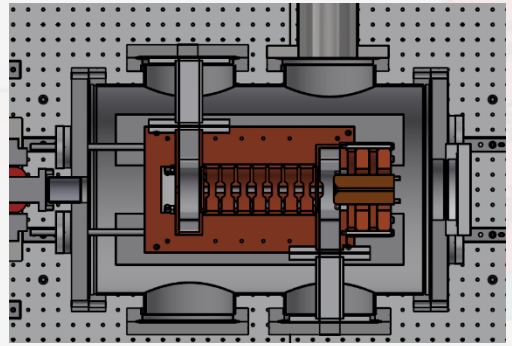
RF Gun in Linac A1 Section





A1 primary RF gun

- QTWSC
- In beam line

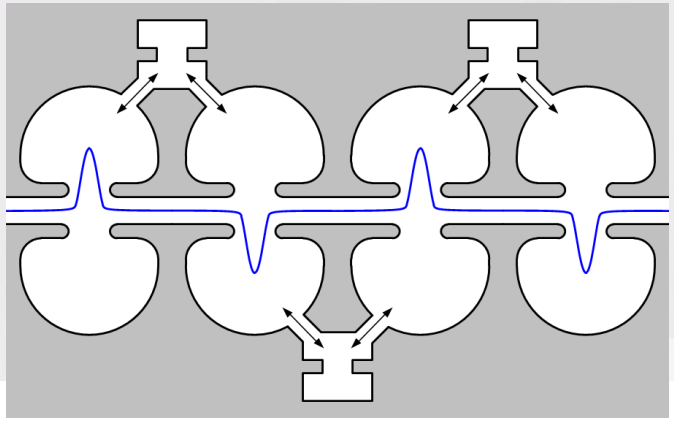


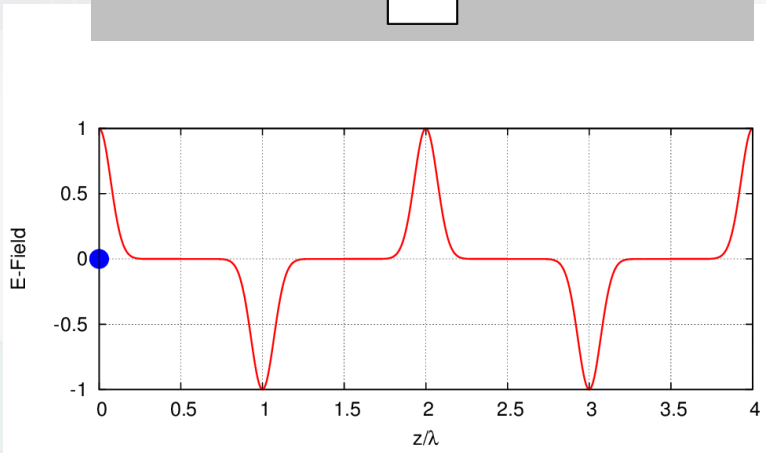
A1 secondary RF gun

- CDSTW
- Perpendicular to the beam line
- Under studying

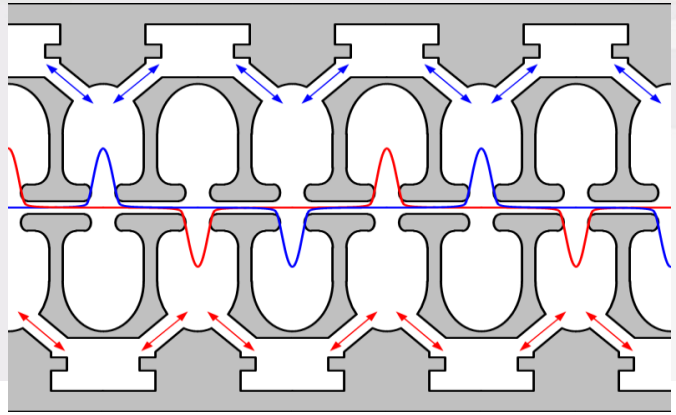
QTWSC RF Gun Design

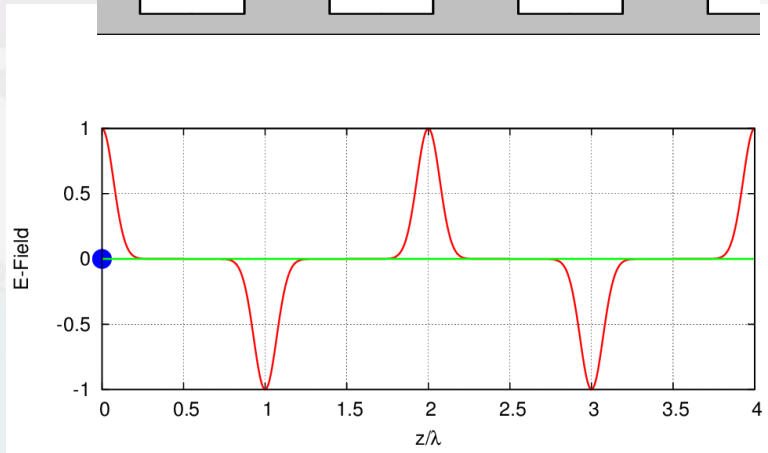
Common SC RF Gun



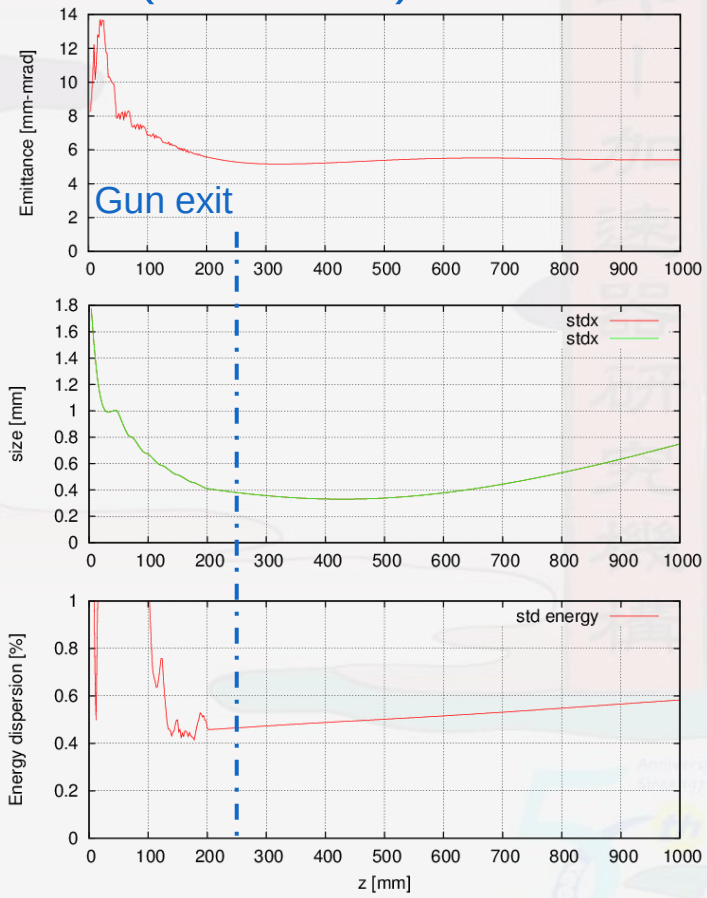


QTWSC RF Gun



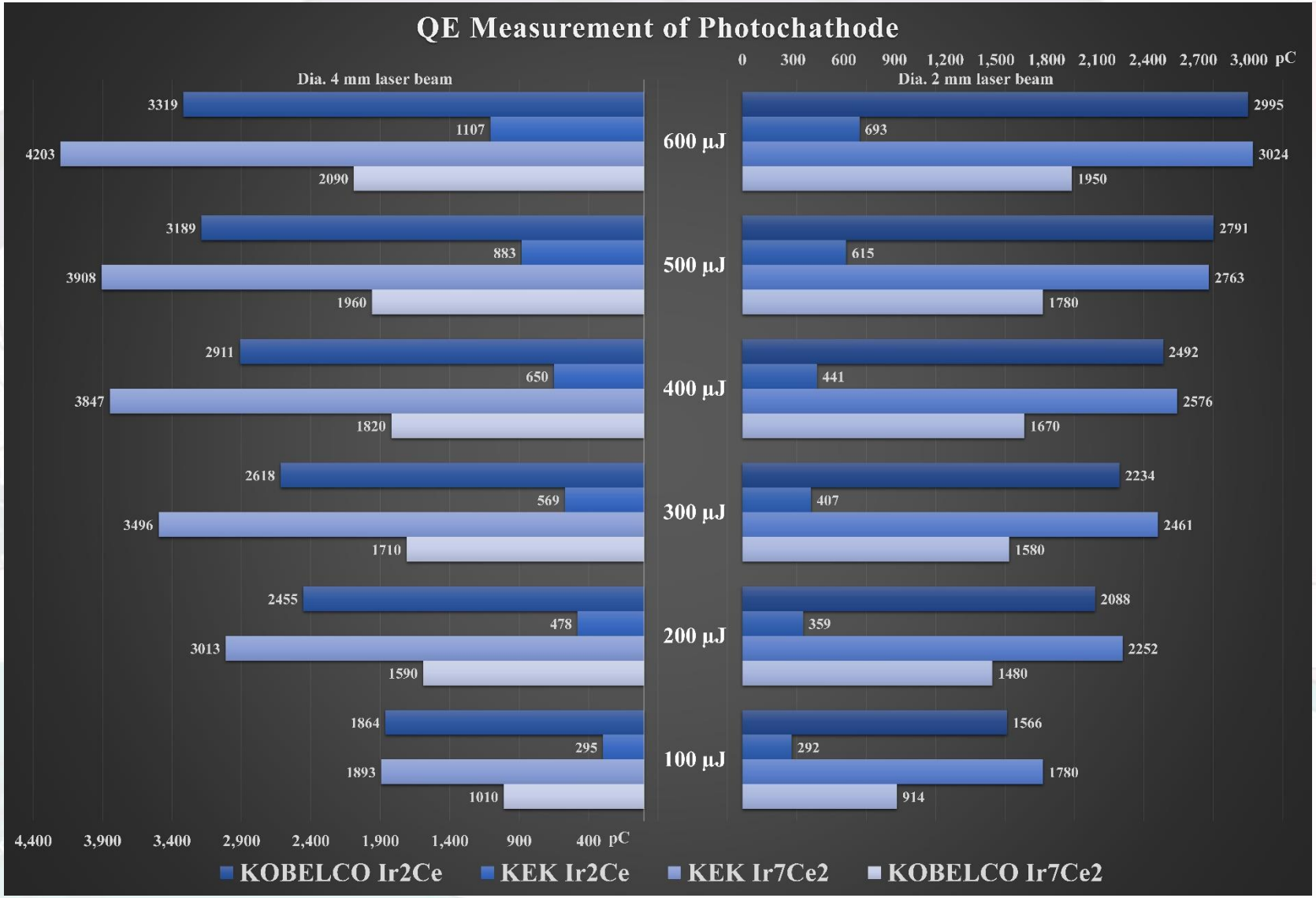


Properties of QTWSC (5 nC case)



Photocathode for RF Gun

Iridium Cerium Alloy Photocathode



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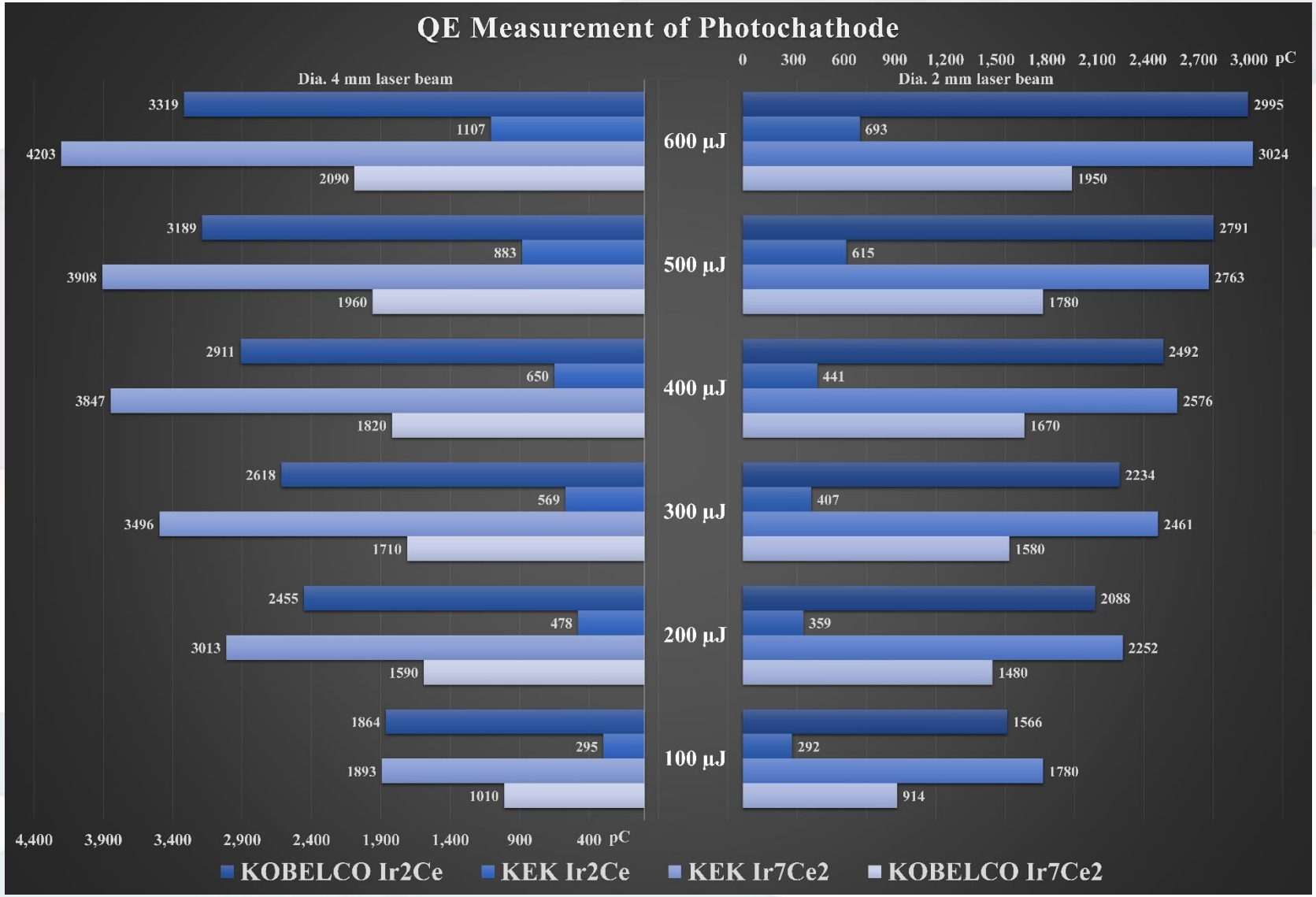
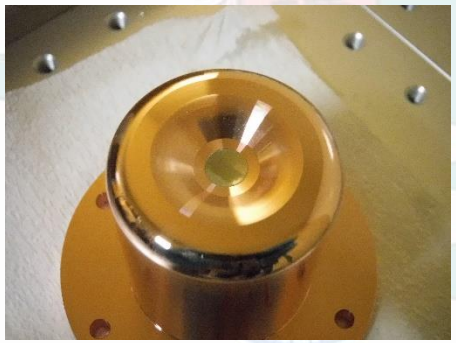


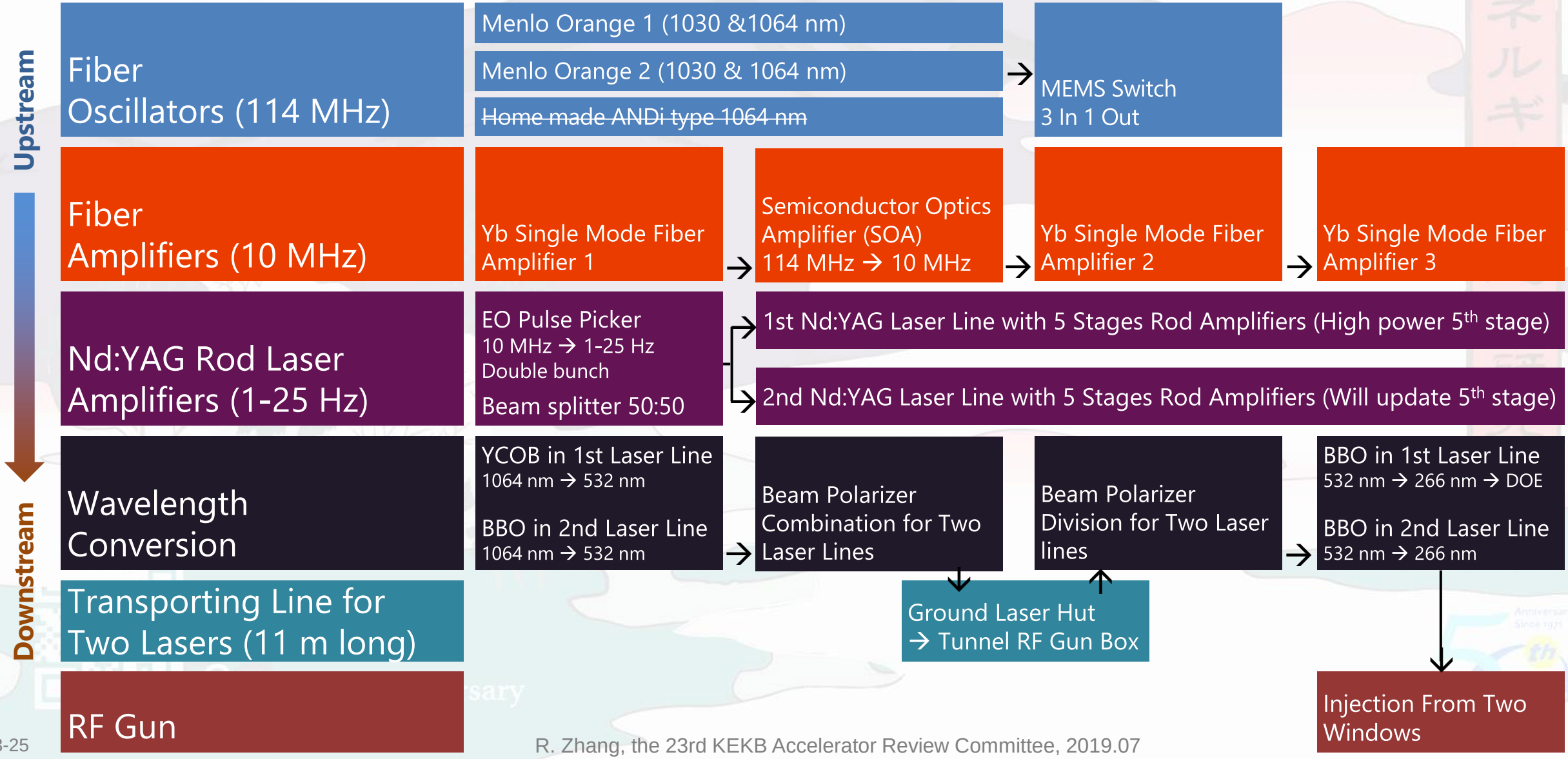
Characteristics of photocathodes

- Quantum efficiency 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 commissioning
- Achievable bigger size (>14 mm)



Laser System for RF Gun

Yb-Fiber and Nd:YAG Hybrid Laser System



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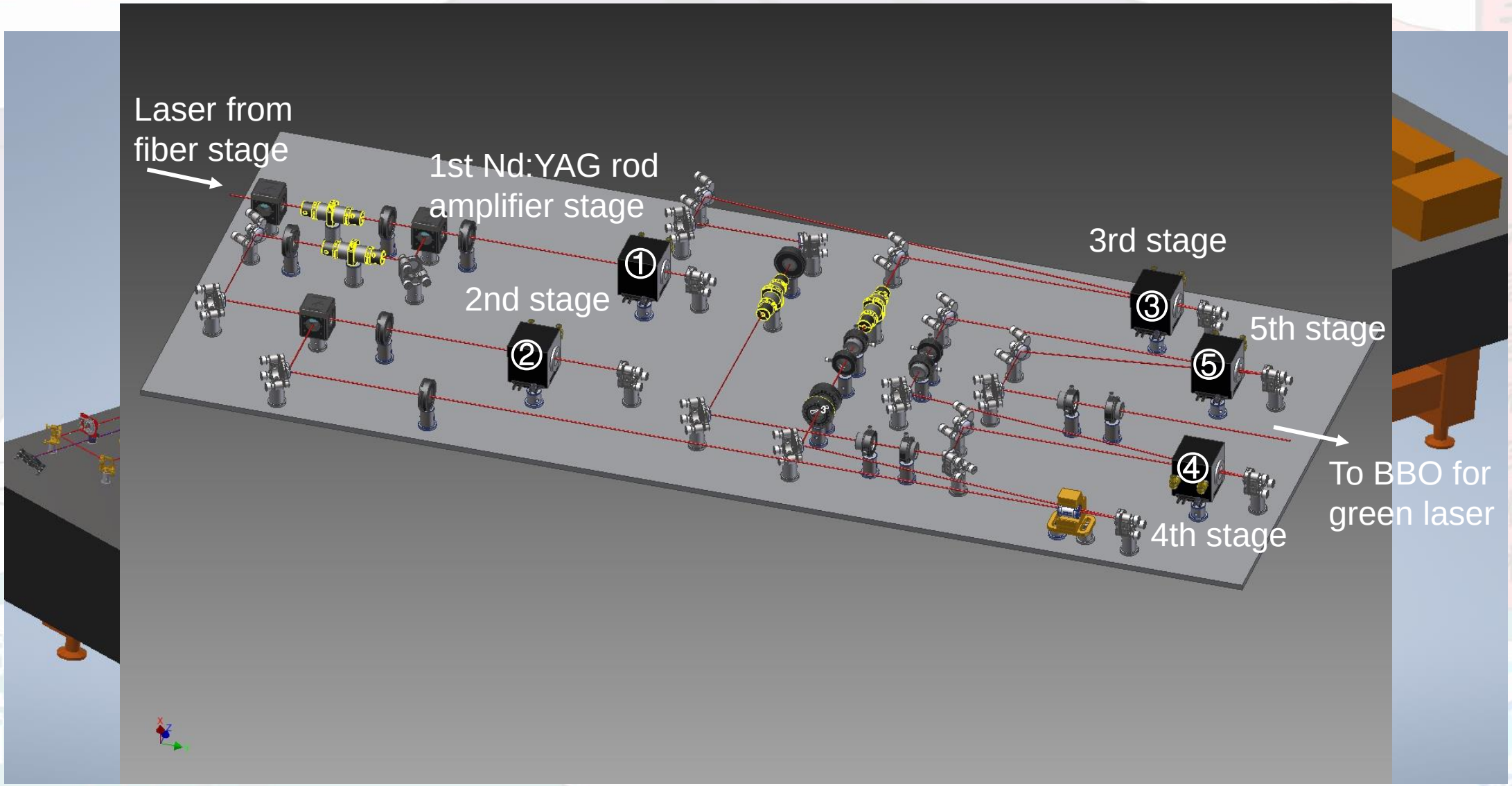

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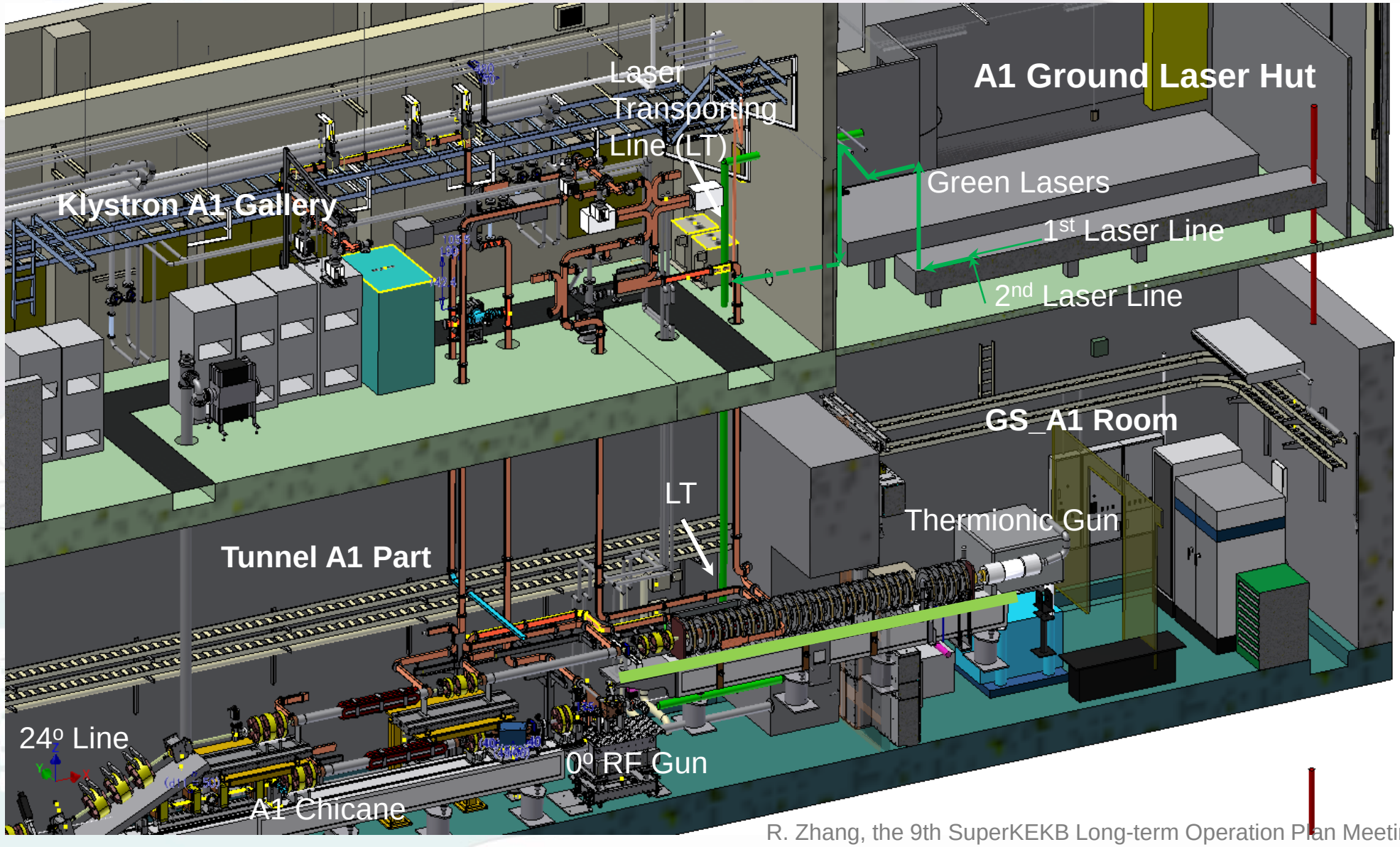

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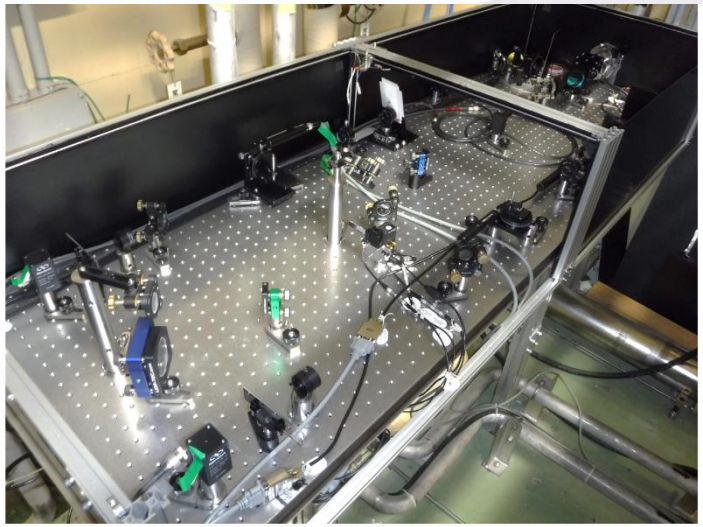

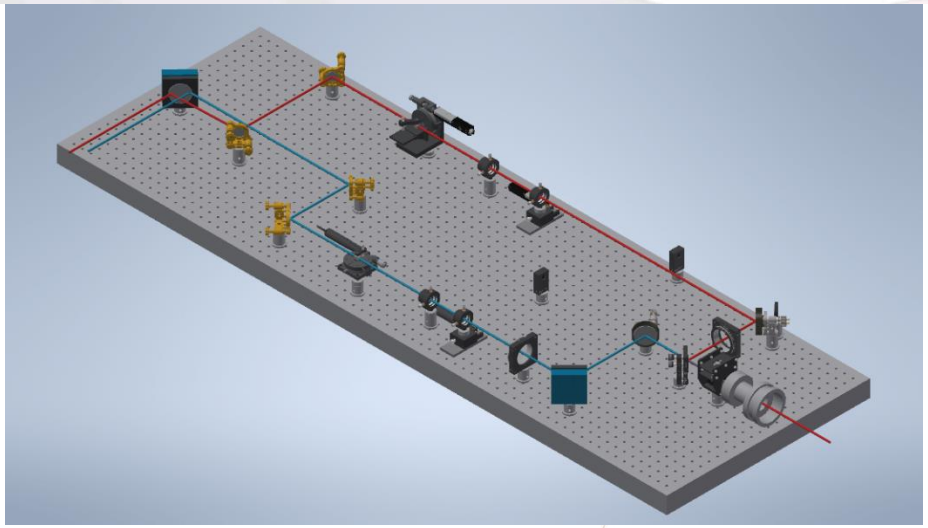

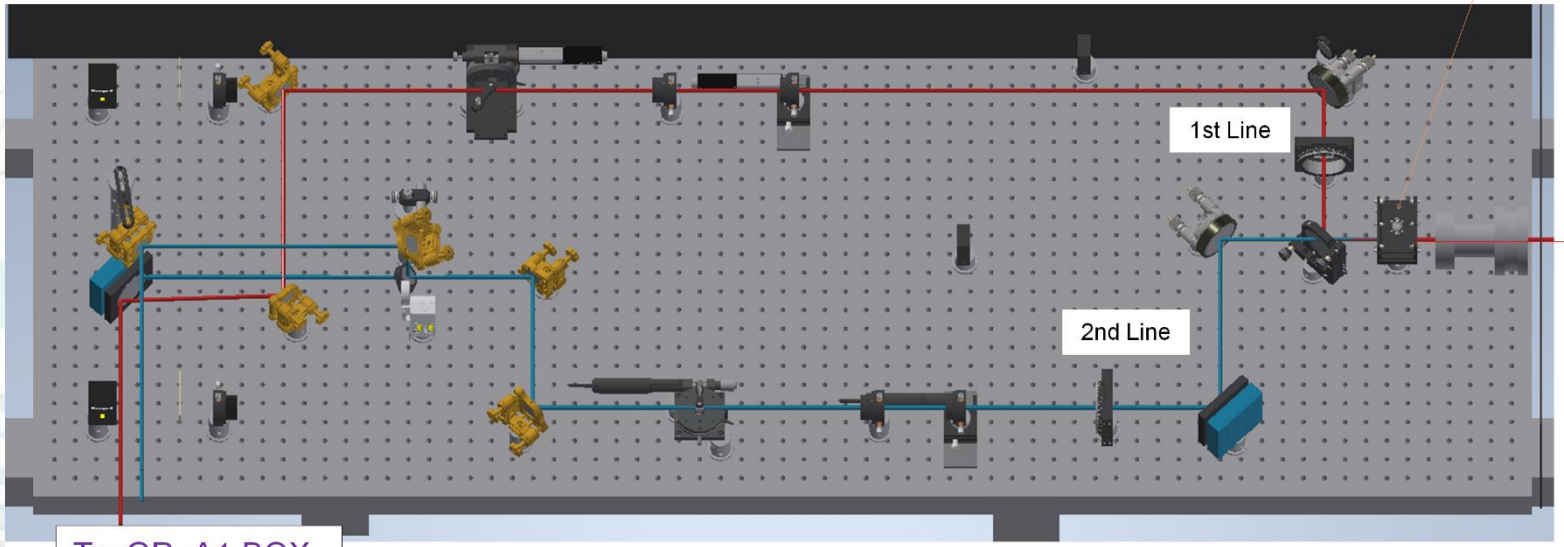

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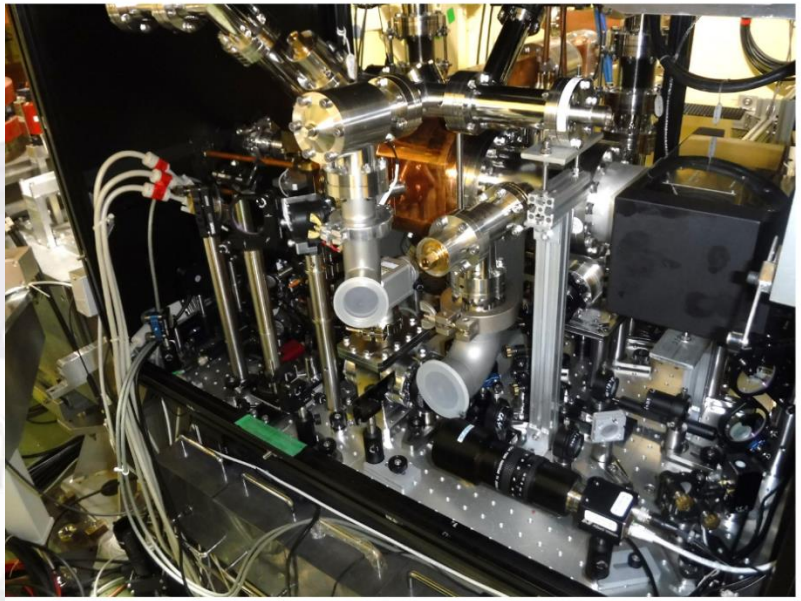
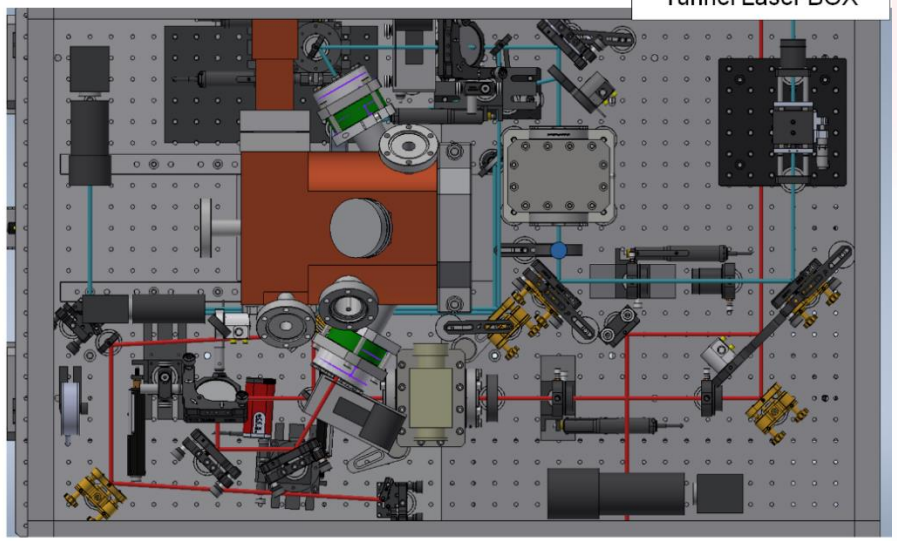
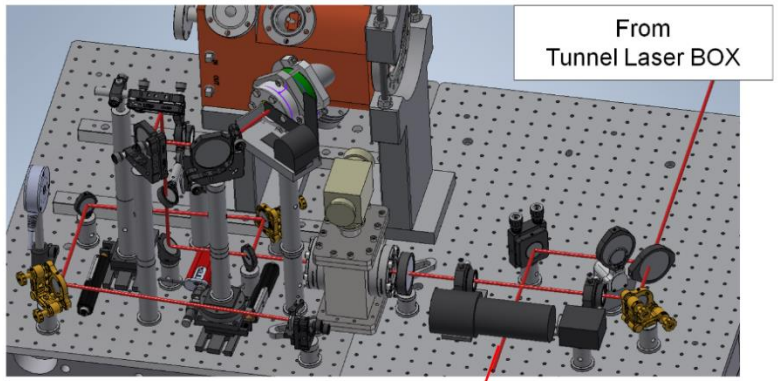
Yb-Fiber and Nd:YAG Hybrid Laser System

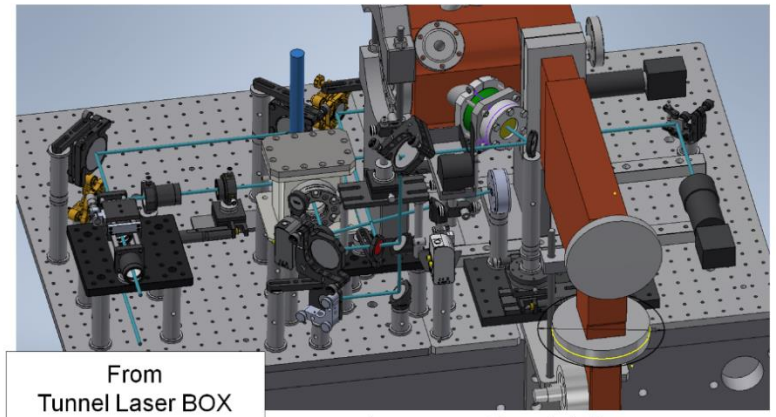




全体の様子



Laser 1st Line

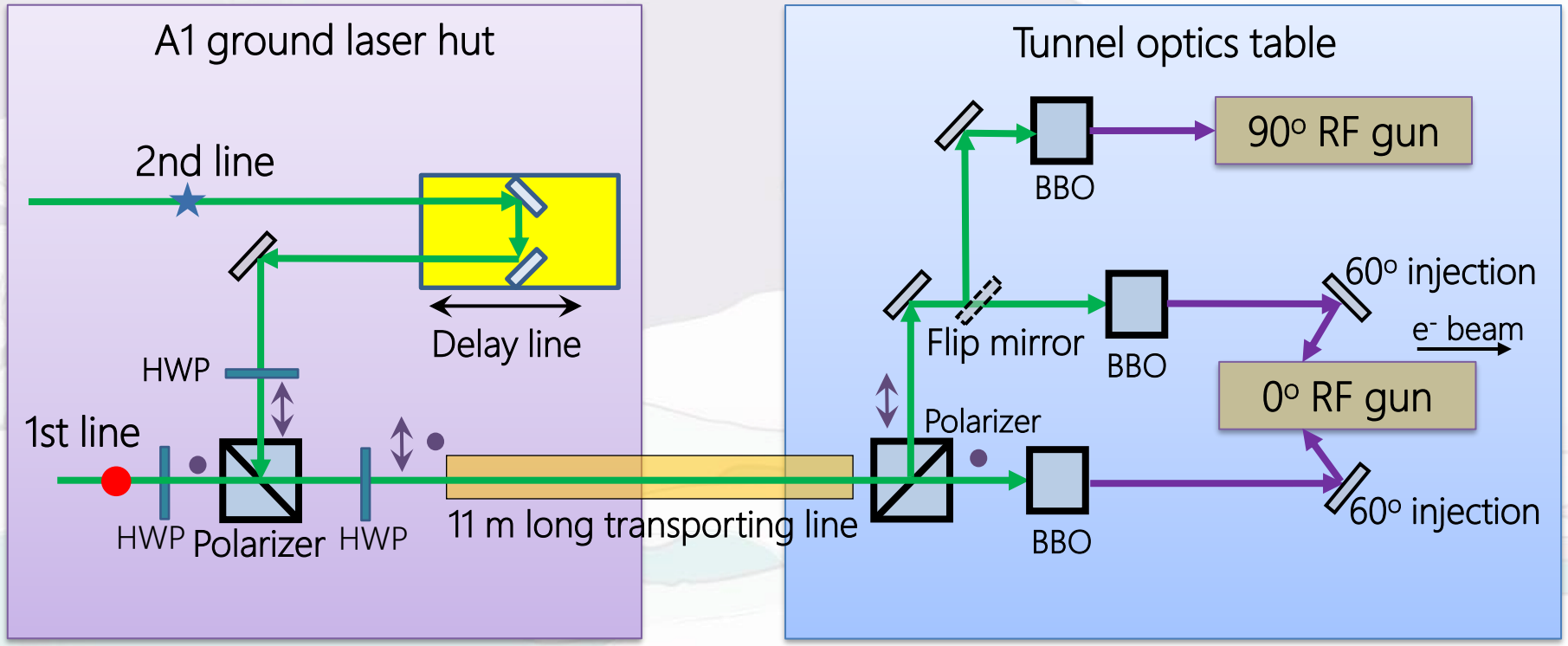


Laser 2nd Line

Laser System for RF Gun

Two Laser Beams Incidence Mode for Better Beam Quality

Simple illustration for 2 lasers incidence (out of ratio)

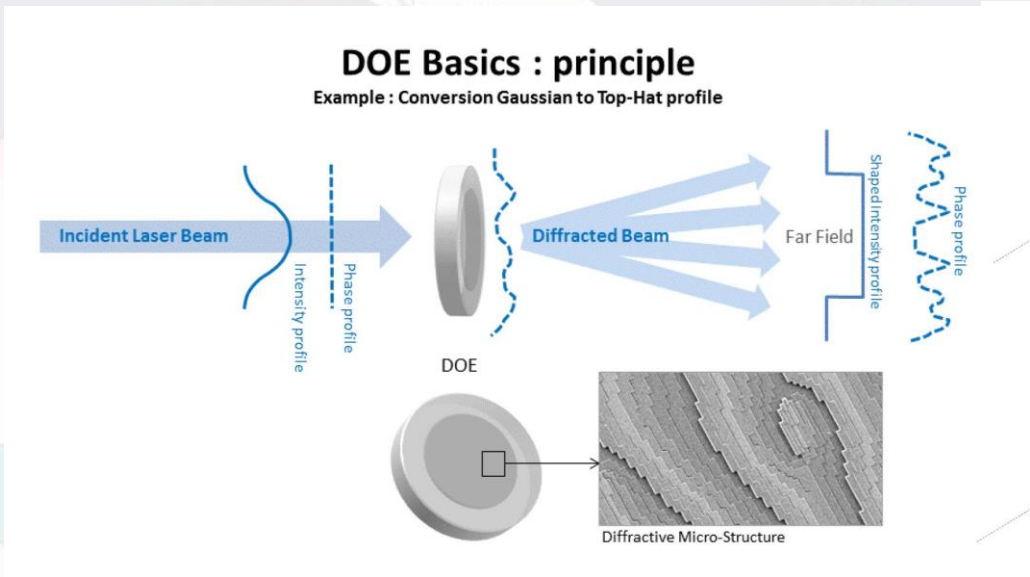


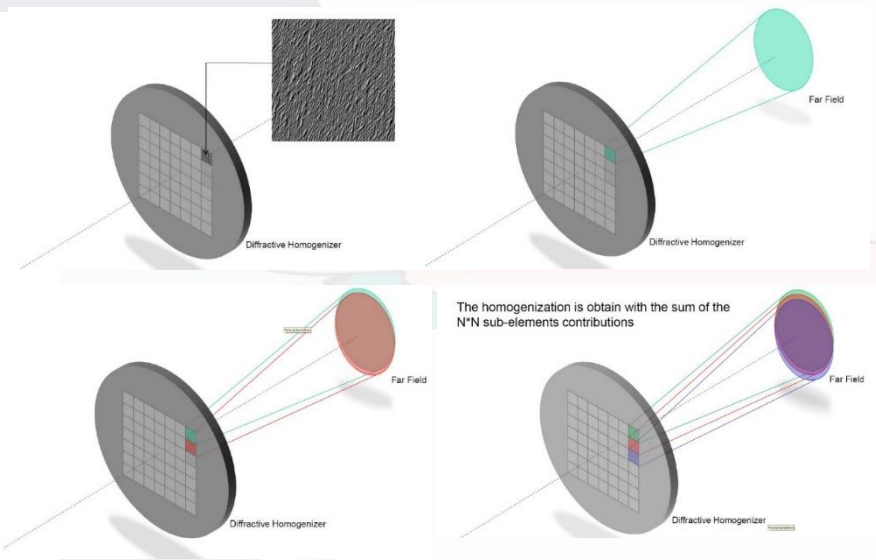
● Laser with vertical polarization, ↕ laser with horizontal polarization, HWP: half wave plate

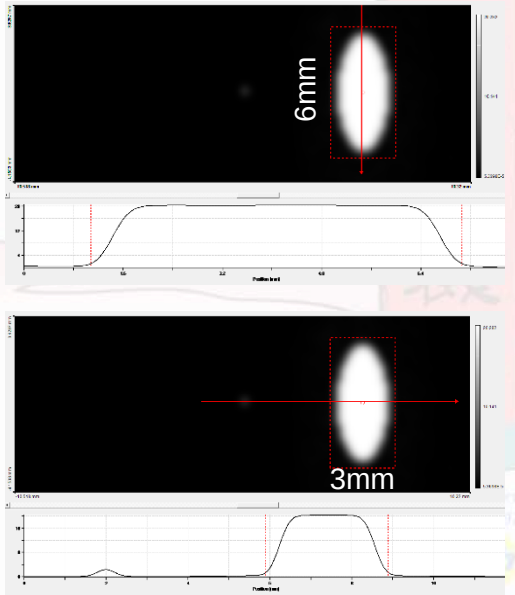
Laser System for RF Gun

Spatial Reshaping for Lower Emittance

- 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



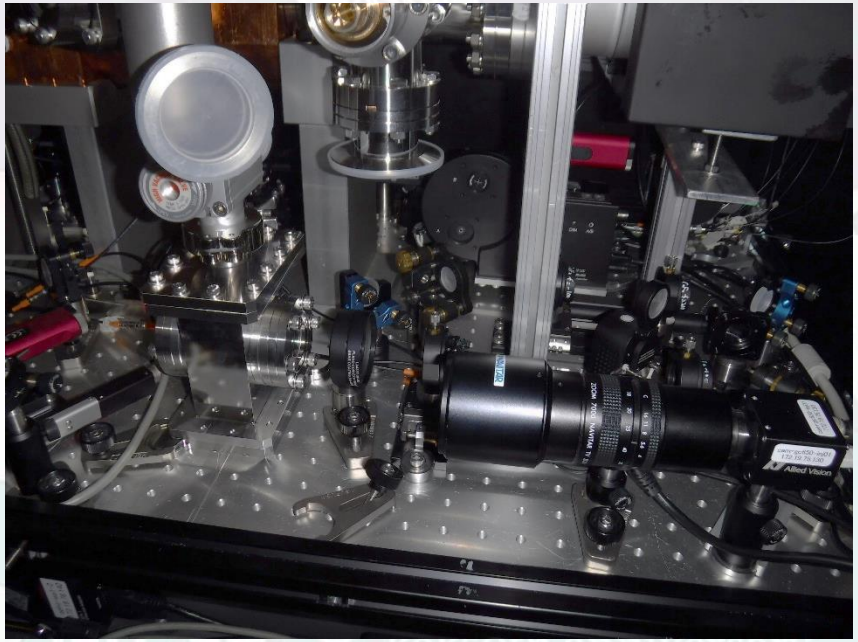


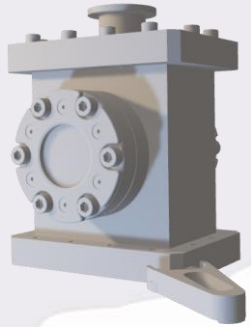


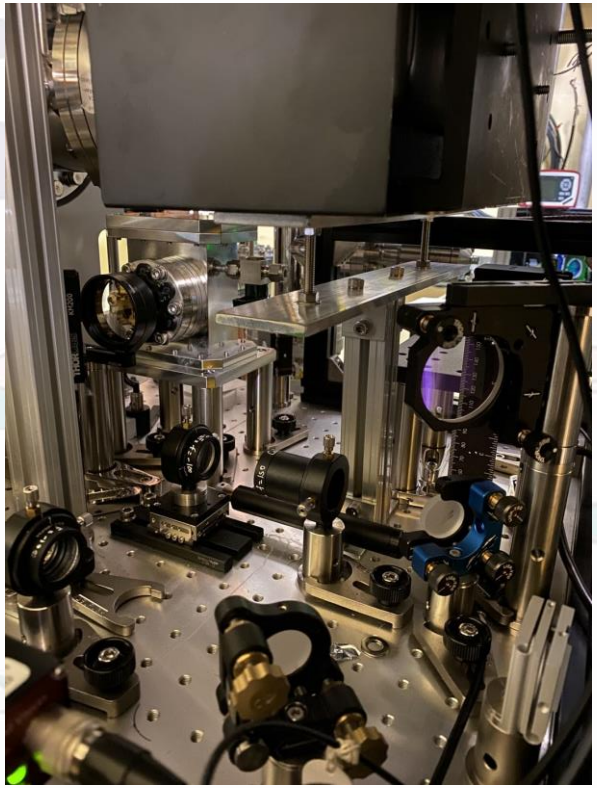
Laser System for RF Gun

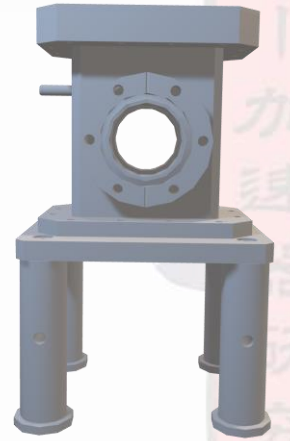
Spatial Reshaping for Lower Emittance

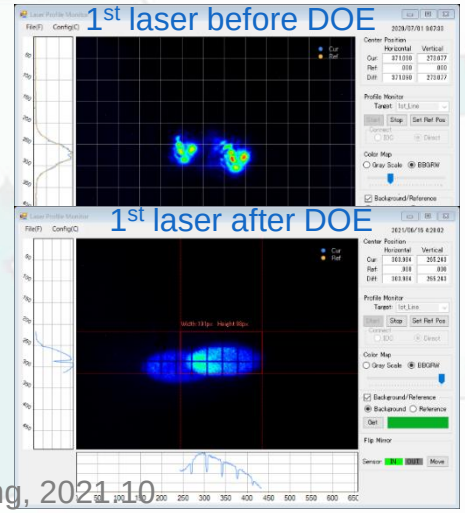
- Application DOE in 1st laser line from 2020c and in 2nd laser line from 2021c
- Elliptical flat-top spatial distribution on the surface of photocathode (LA6mm SA3mm) for low emittance e^- generation and avoiding RF gun discharge

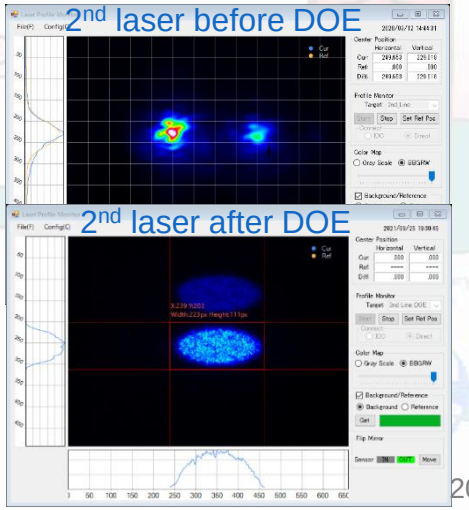








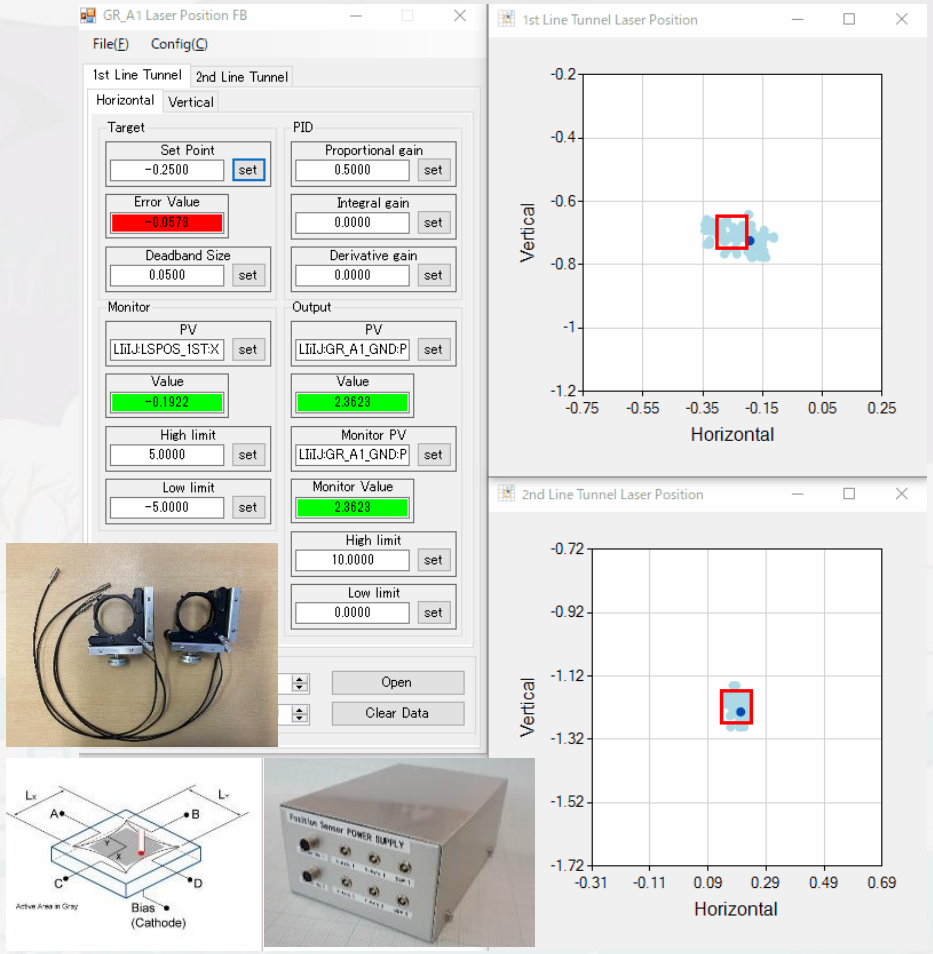




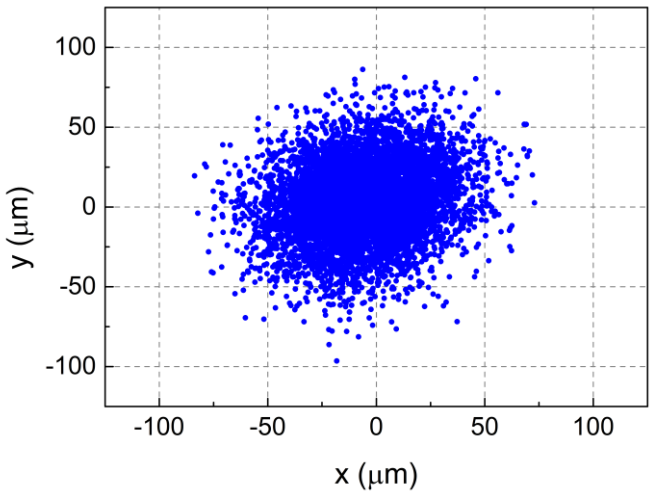
2021c Operation Status & Achievements

Better Laser Pointing Stability

Laser position feedback system

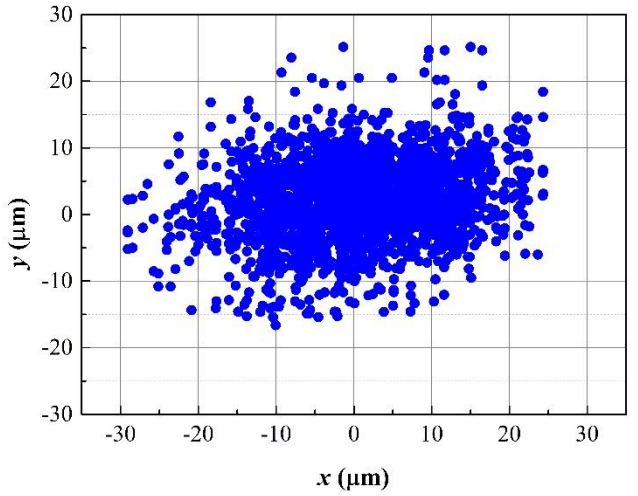


Laser pointing stability at virtual photocathode



Measured in 2019.06
without DOE & laser position feedback

H 2σ: 48.04 ± 0.51 μm
V 2σ: 46.08 ± 0.69 μm



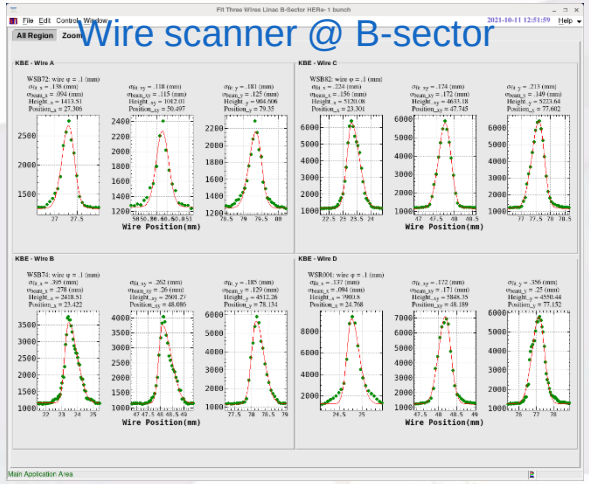
Measured in 2021.06
with DOE & laser position feedback

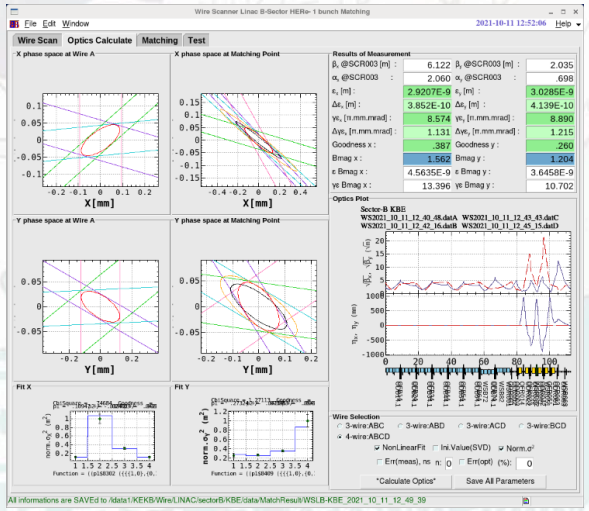
H 2σ: 24.30 ± 3.06 μm
V 2σ: 10.08 ± 0.46 μm

R. Zhang, the 120th B Factory Project Committee, 2021.10; N. Toyotomi (Mitsubishi SC)

2021c Operation Status & Achievements

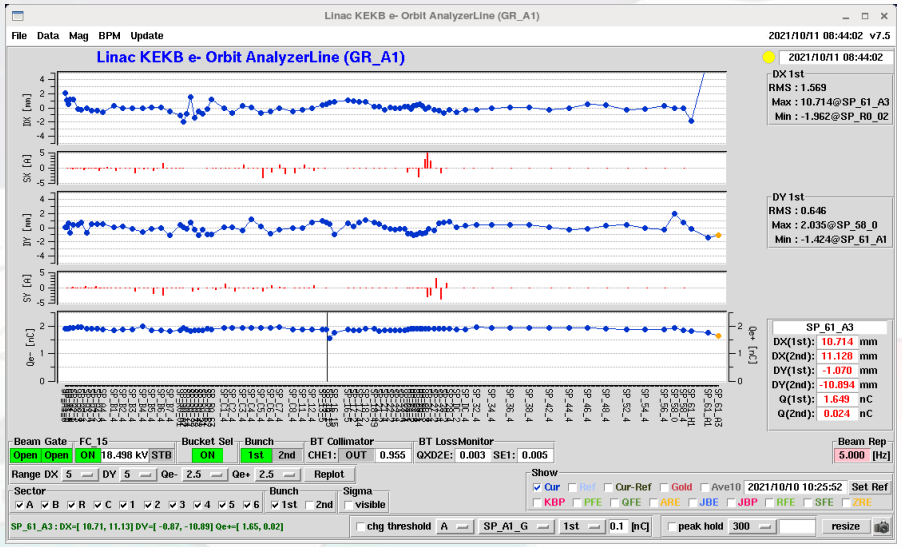
Best Emittance Record under High Charge

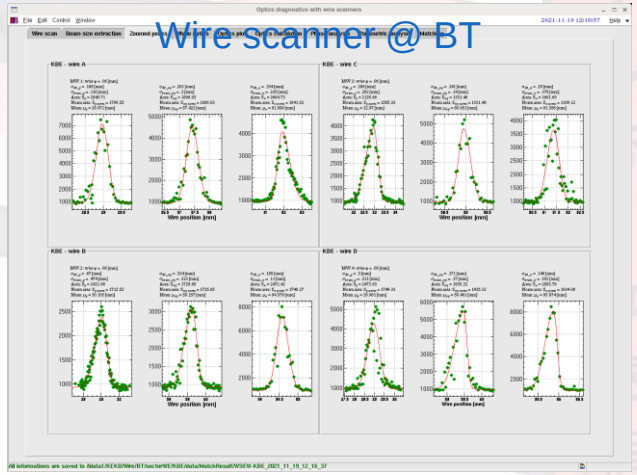


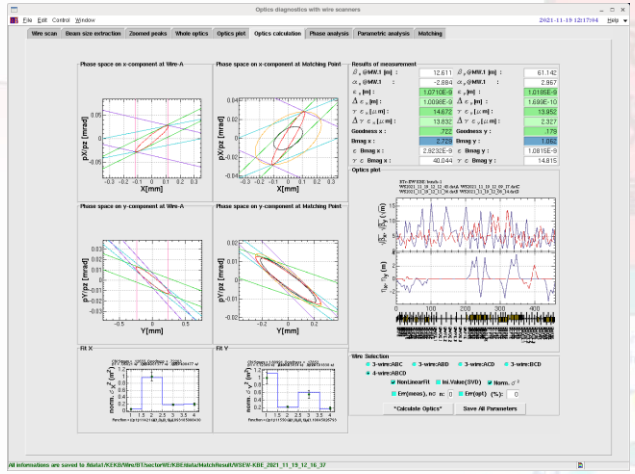


Wire scanner @ B-sector

- Two lasers incidence mode
- 2 nC from the 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





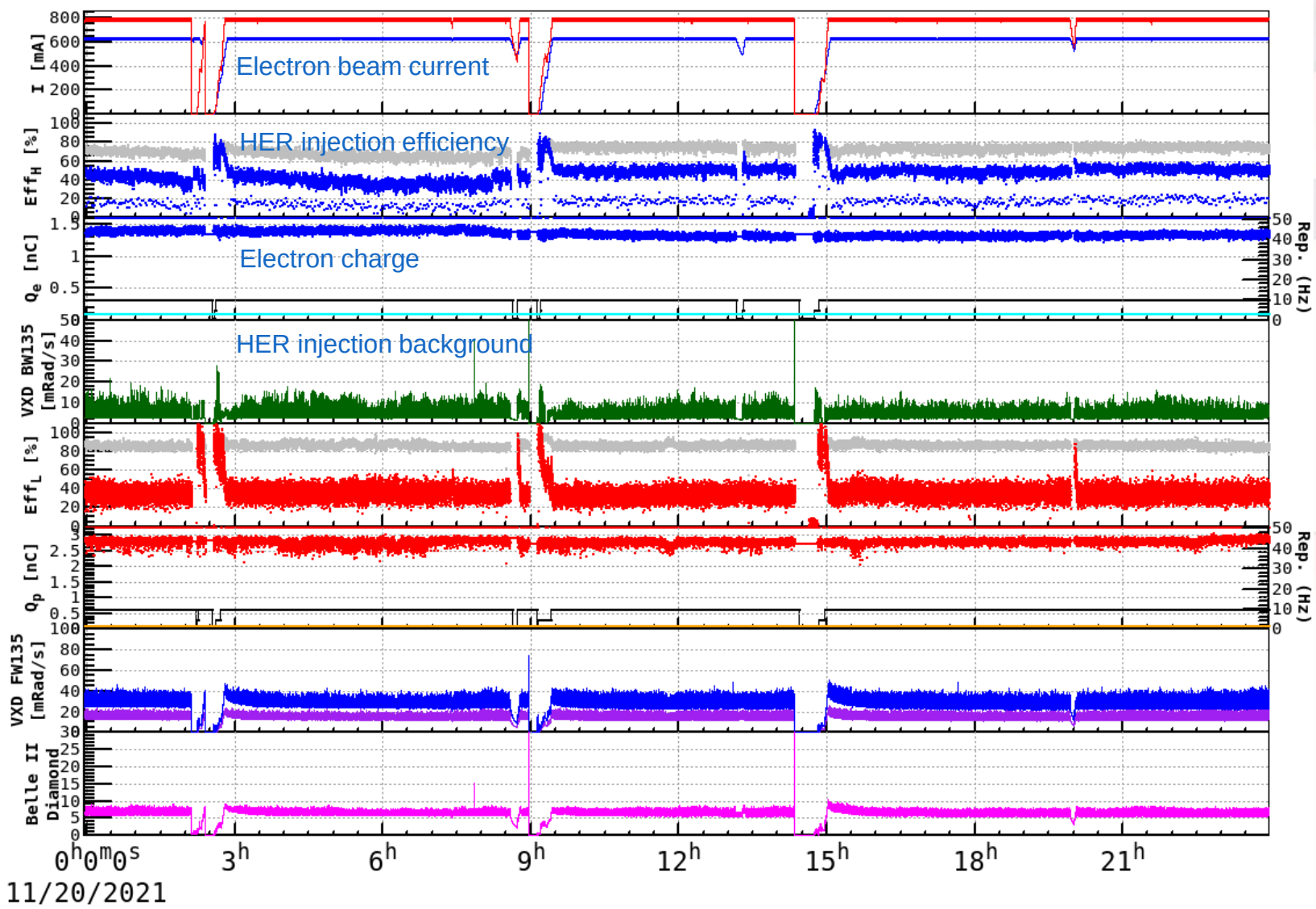


Wire scanner @ BT

- $\gamma\varepsilon_x = 14.672 \pm 7.795\ mm \cdot mrad$
- $\gamma\varepsilon_y = 12.027 \pm 1.934\ mm \cdot mrad$
- Best record

2021c Operation Status & Achievements

Stable and Continuous RF-gun Injection for HER



HER e$^-$ beam injection

- Stable and continuous e$^-$ beam operation for injection
- Comparable higher injection efficiency than 2021ab operation case
- No trend of photocathode QE degradation
- Reliable laser system and feedback system
  - Position feedback
  - Laser pulse energy feedback
  - RF phase feedback
- Stable 4-ring simultaneous injection

2021c Operation Status & Achievements

Stable and Continuous RF-gun Injection for HER

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Insight through Accelerators.

KEK

高エネルギー加速器研究機構

Summary & Outlook

- SuperKEKB RF-gun system worked well during 2021c operation
- Laser system update is in progress (2022.01.04-01.14)
- Study of the secondary RF gun will be done in 2022 operation
- New laser system (Yb:YAG) for 50 Hz double bunch operation and temporal reshaping is under construction

THANKS

kek50th anniversary

50th Anniversary Since 1971 Keep Accelerating