cERL 500 kV DC-gun Achievements, troubles, technical issues

e-Linac Reliability Workshop (remote)
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KEK

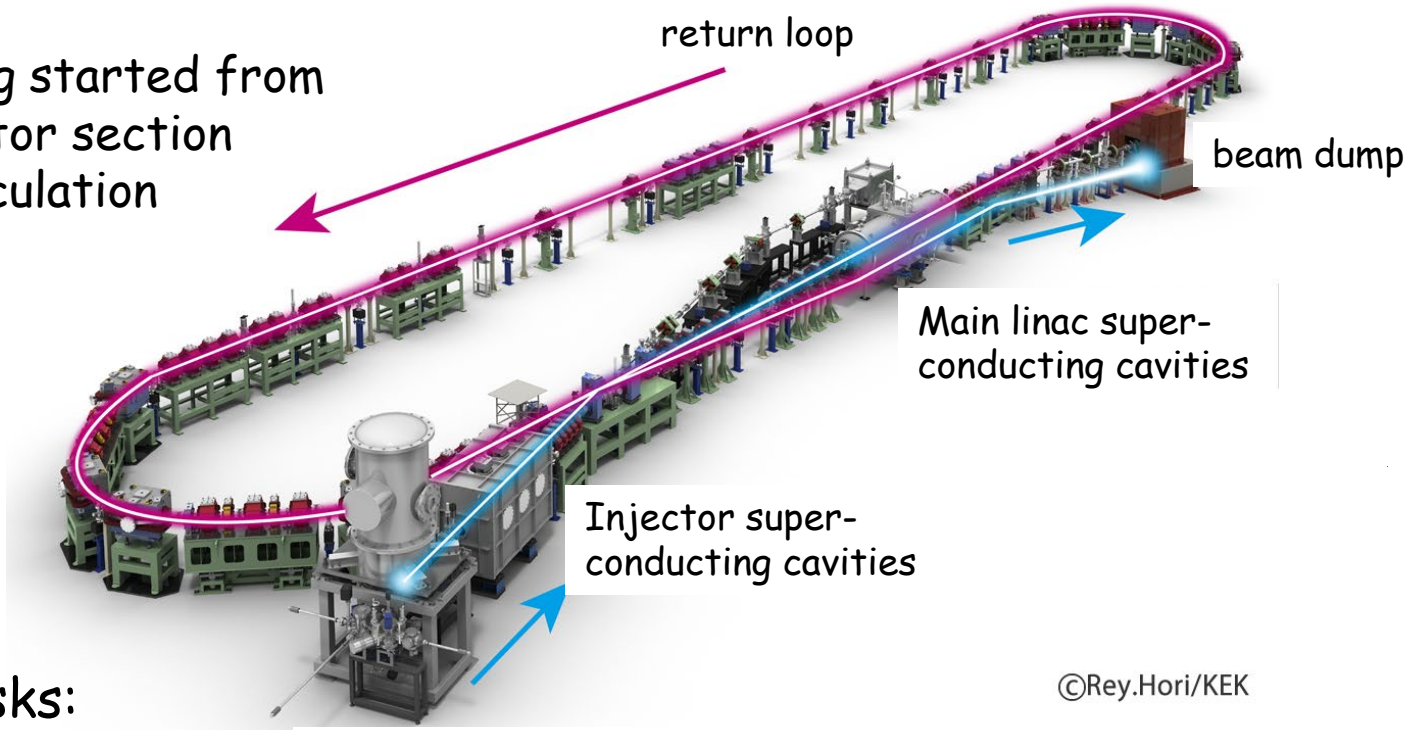
Outline

- Introduction: Compact-ERL & 500 kV DC-guns
- Achievements
  - HV conditioning for stable operation
  - 500 kV operation history
- Troubles
  - Vacuum leak
  - Serious discharge event
- Future technical issues
- Conclusion

Compact-ERL @ KEK

Proof of key technology at the Compact-ERL

The commissioning started from
Apr. 2013 :Injector section
Dec. 2013 :Recirculation

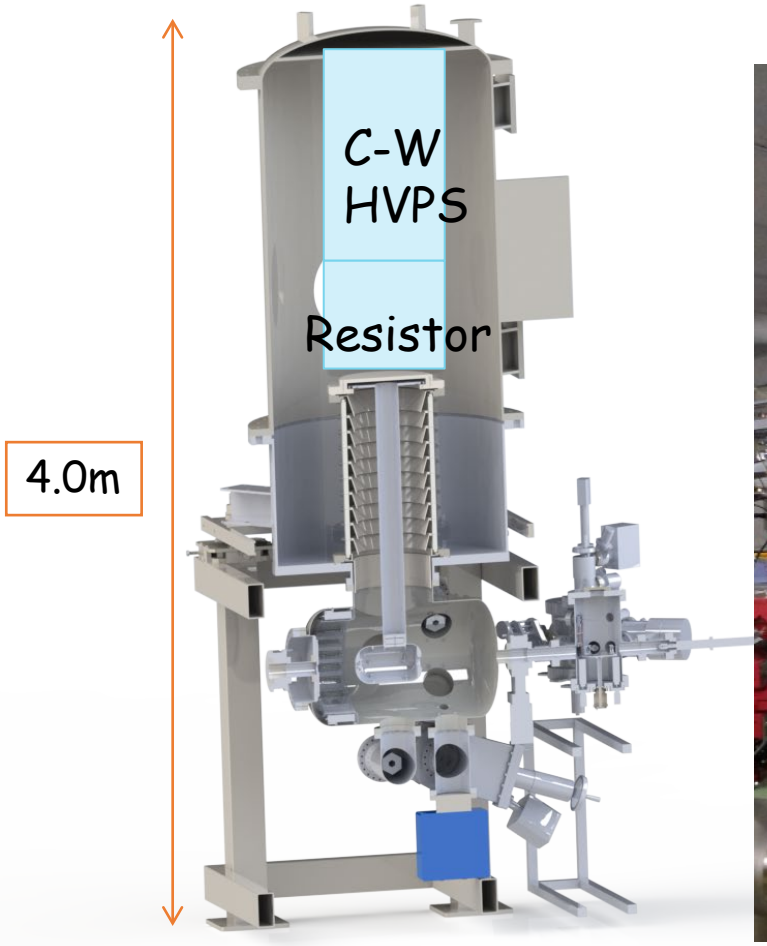


Electron gun tasks:
- 1.3 GHz CW beams
- Long cathode lifetime
- Low emittance ($\varepsilon_{n.rms}$:0.1 ~1 mm.mrad)
- High avarage current (>10 mA)

Mar. 2016:
Energy recovery operation with 900 uA CW beam.
(~5.5 pC/bunch, 162.5 MHz)

500 kV DC guns (1)

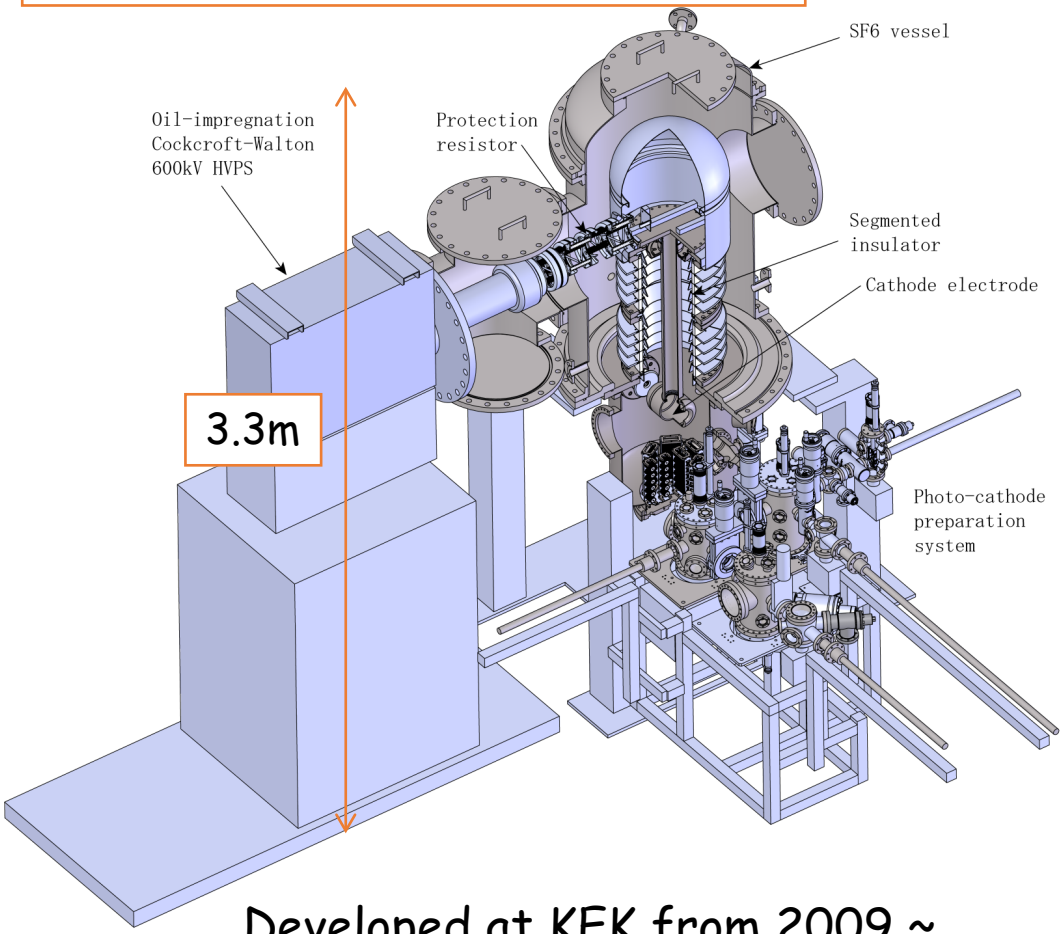
1st DC-Gun & preparation system



Developed at JAEA from 2007 ~
Installed compact-ERL at Oct. 2012.
Beam test started from 2013 ~

500 kV DC guns (2)

2nd DC-Gun & preparation system

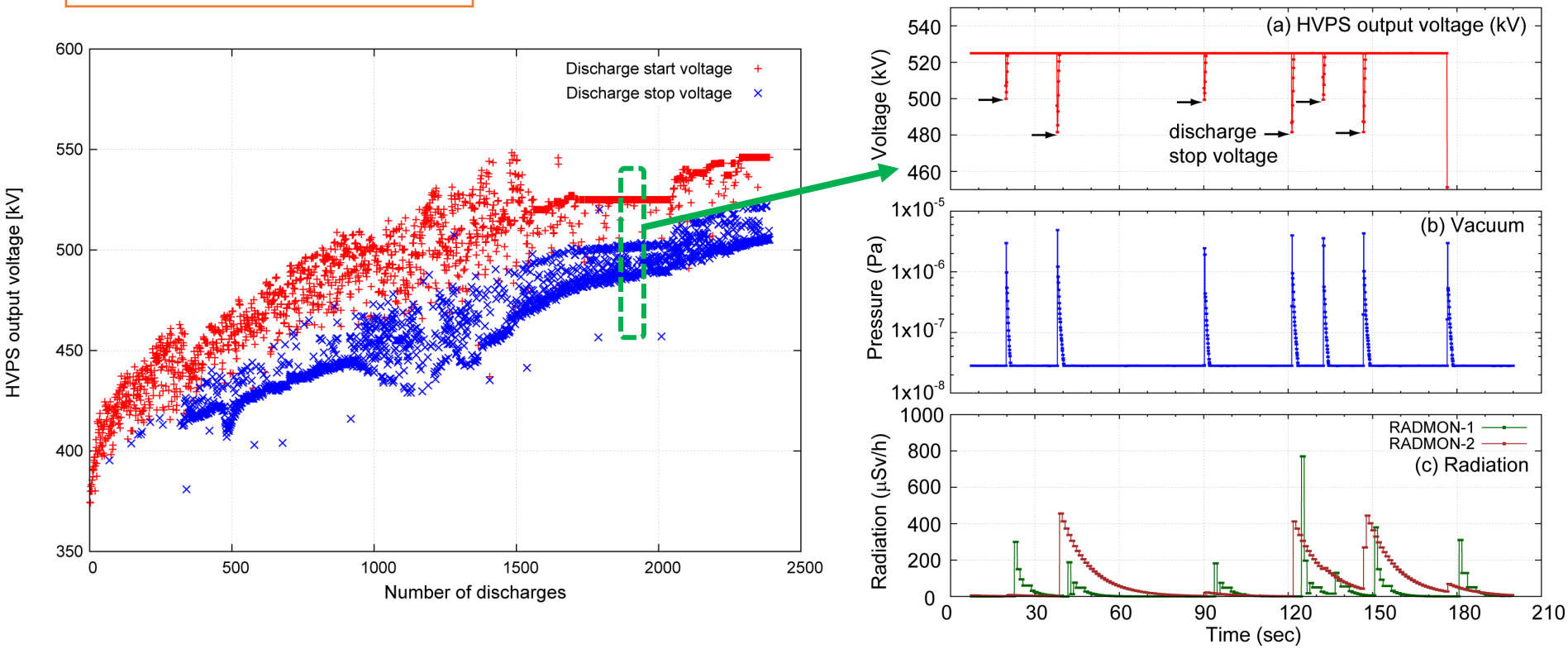


Developed at KEK from 2009 ~
Achieved stable application of 500kV. Beam test started from 2015.
Since 2016, it has been suspended due to budgetary concerns.

https://accelconf.web.cern.ch/erl2015/talks/tuiblh1021_talk.pdf

HV conditioning for stable operation (1)

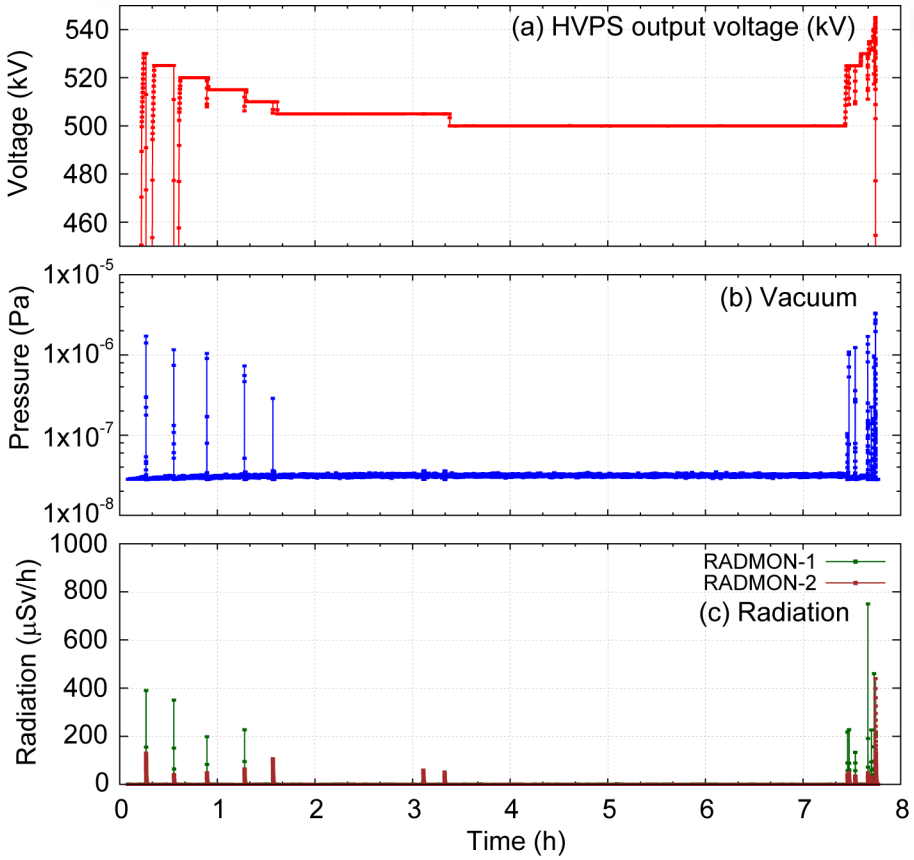
1st DC-Gun results

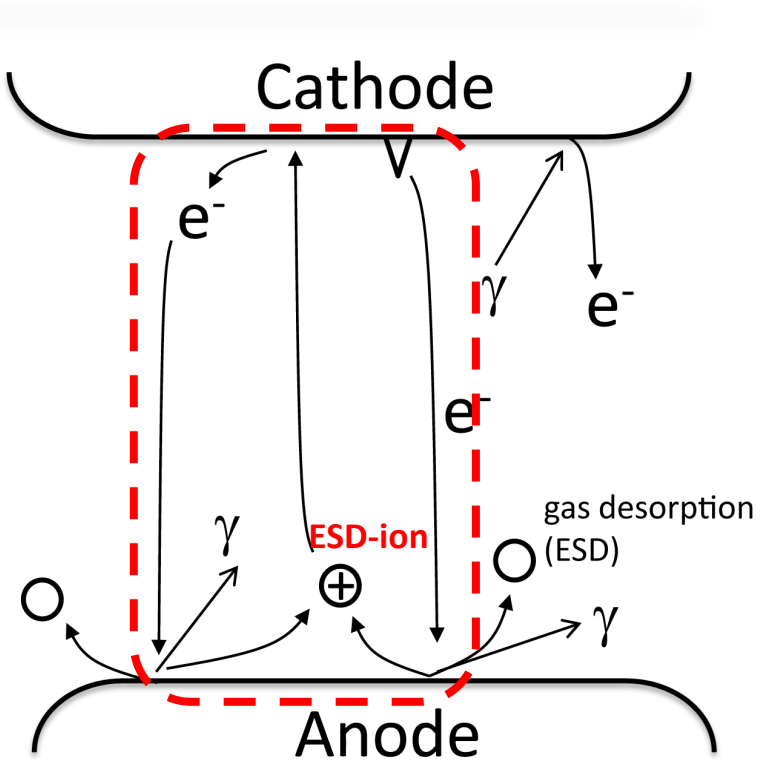


M. Yamamoto and N. Nishimori, Appl. Phys. Lett. 109, 014103 (2016)

- The discharge voltage gradually increased while repeating many discharges.
- The discharge stop voltage has an important meaning.

HV conditioning for stable operation (2)

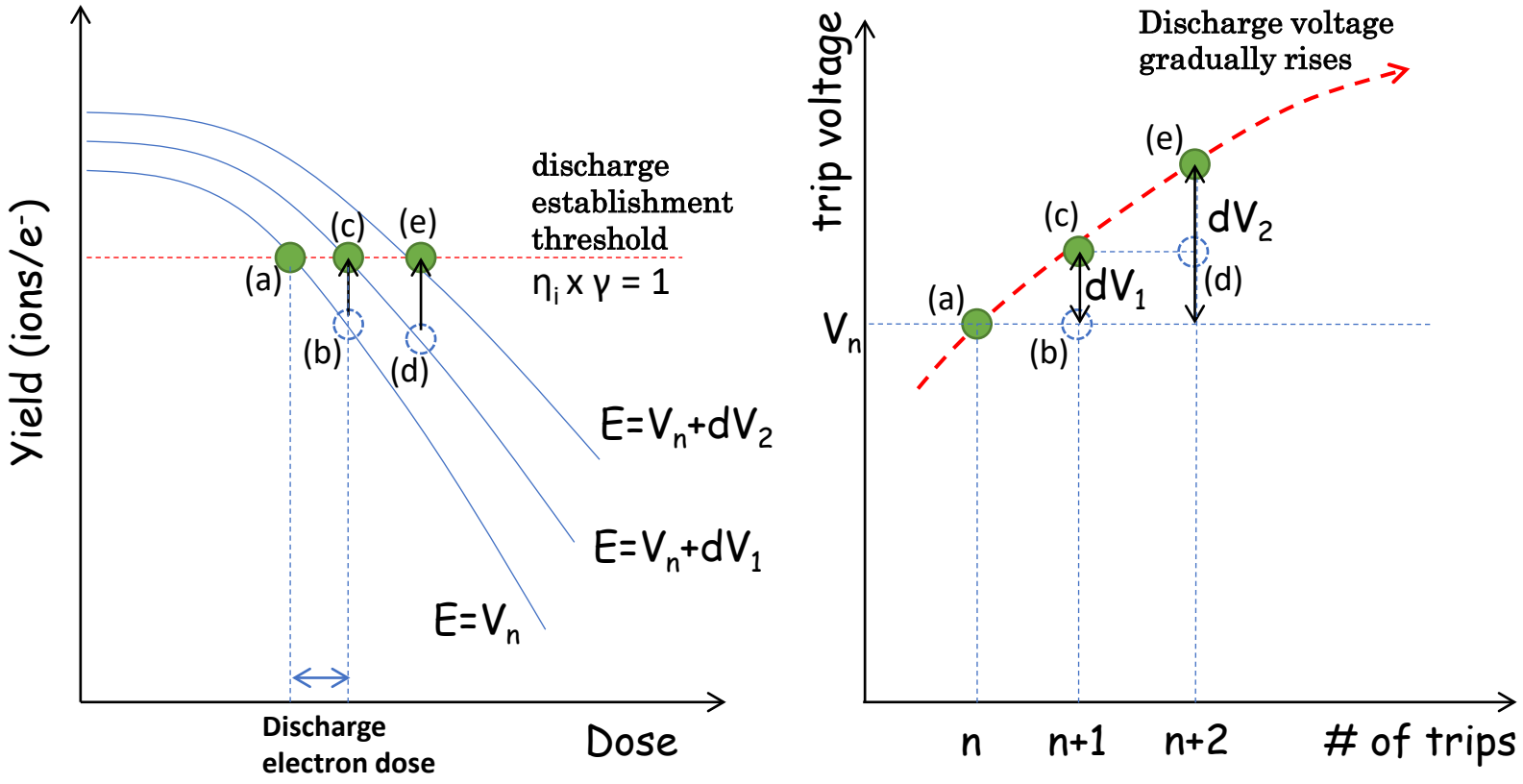




- The discharge stop voltage after HV conditioning is about 502 kV.
- Discharge occurs above 505 kV. The higher the voltage, the higher the discharge frequency.
- No discharge occurs at 500 kV.

ESD-ions may form a discharge circuit.

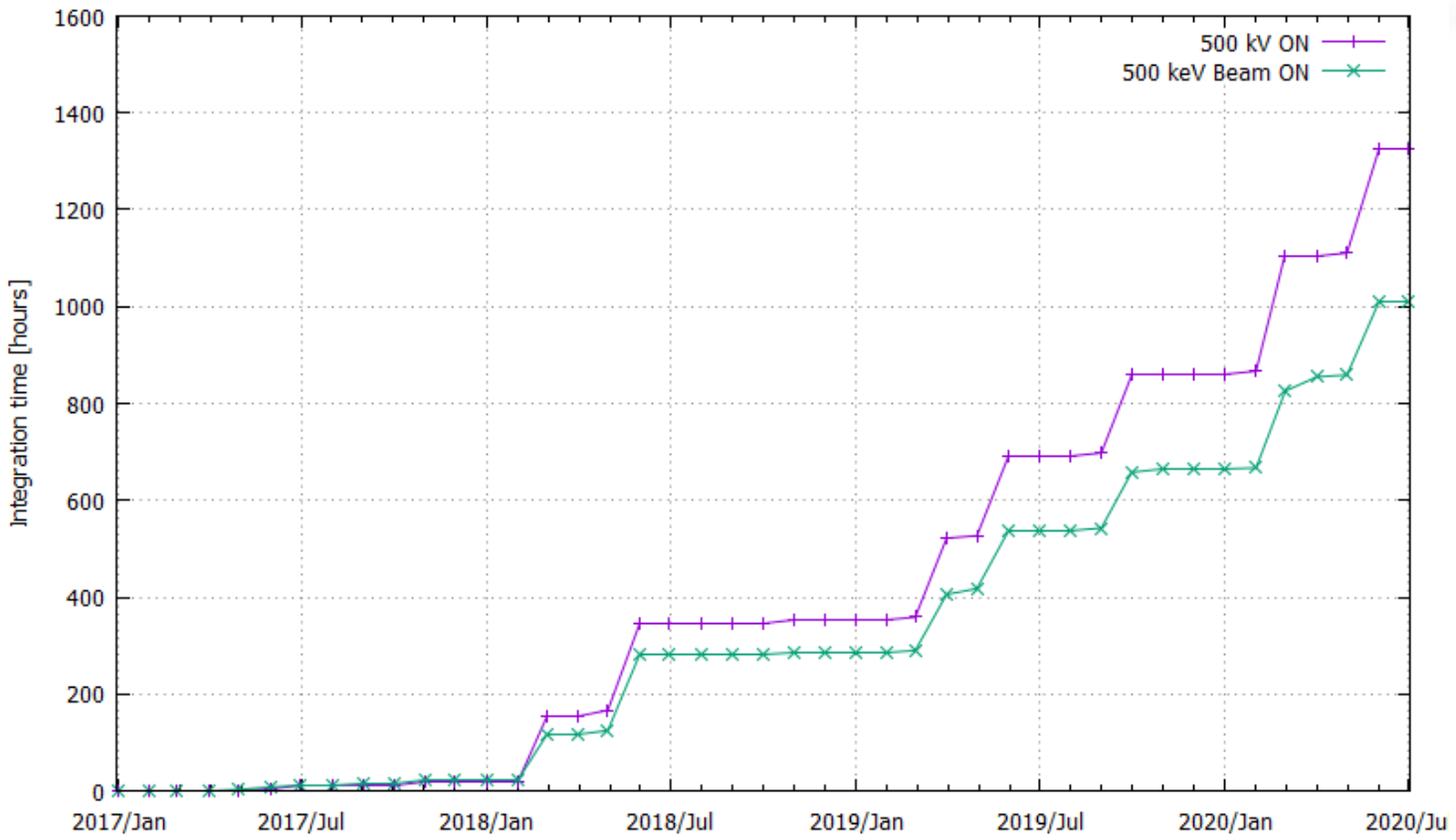
HV conditioning for stable operation (3)



- The discharge establishment threshold is defined as the product of the yield of ESD-ion and the ratio of SE by ion impact becomes 1.
- ESD-ion yield is decrease by discharge electron impact dose.

According to this mechanism, the discharge does not occur below the discharge stop voltage. (Discharge establishment threshold ≅ Discharge stop voltage)

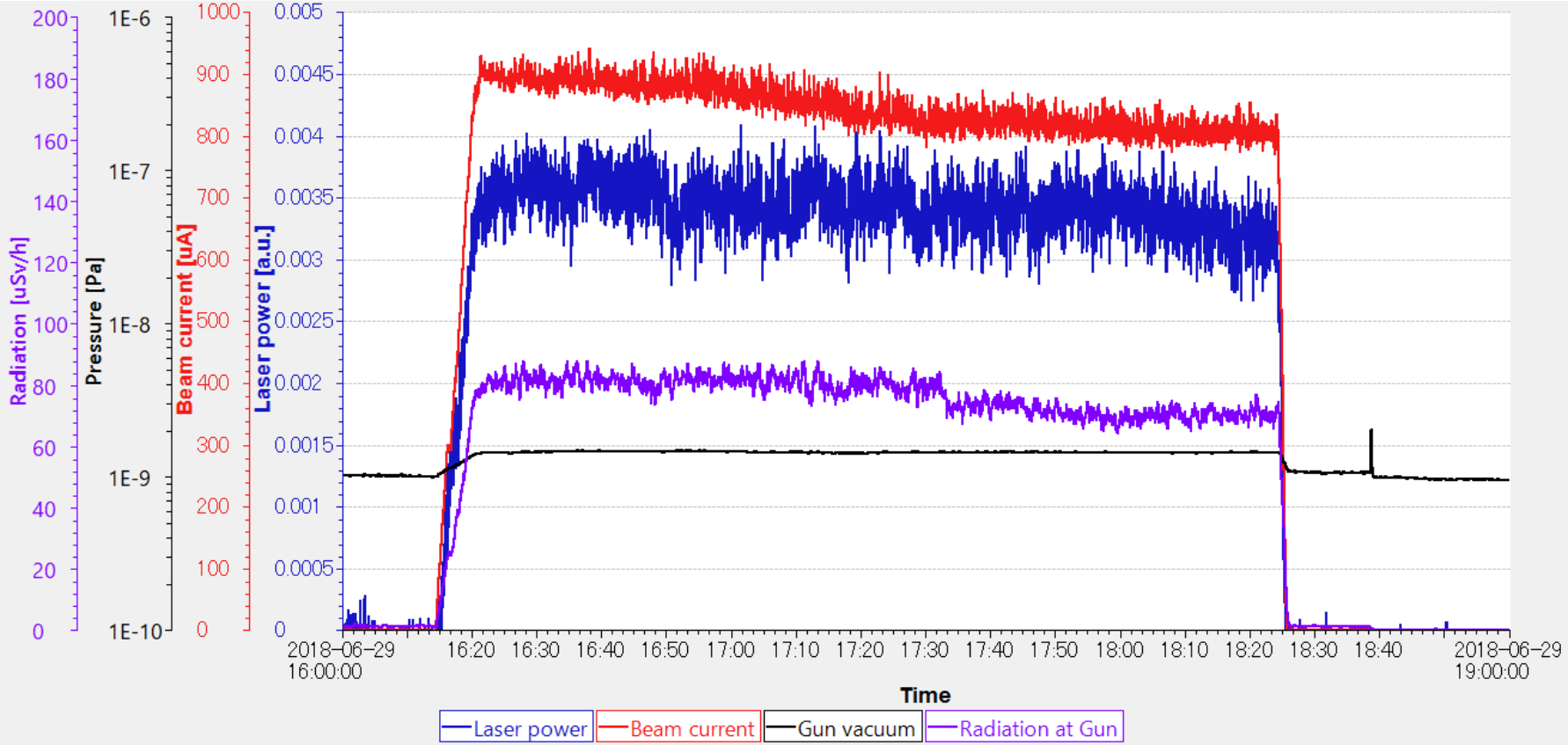
500 kV operation history (1)



- cERL DC-gun 500 kV Operation history from May 2017 to July 2020.
- 500kV holding time 1327 hours, total beam supply 1011 hours.
- During this time, there was no discharge caused by the electron gun.

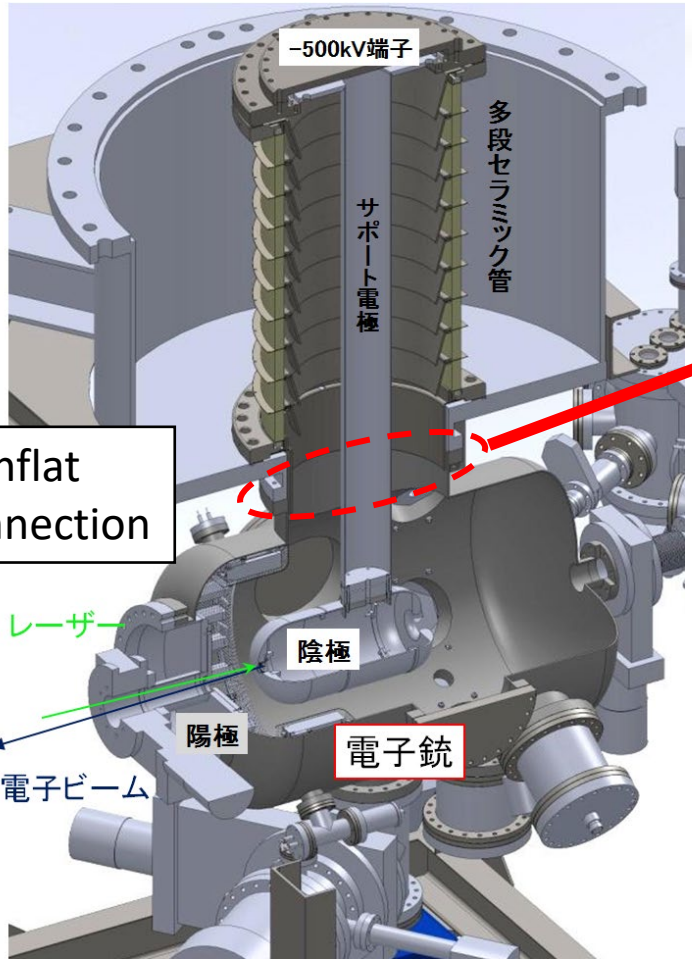
<u>Stable operation is guaranteed below the minimum discharge stop voltage.</u>

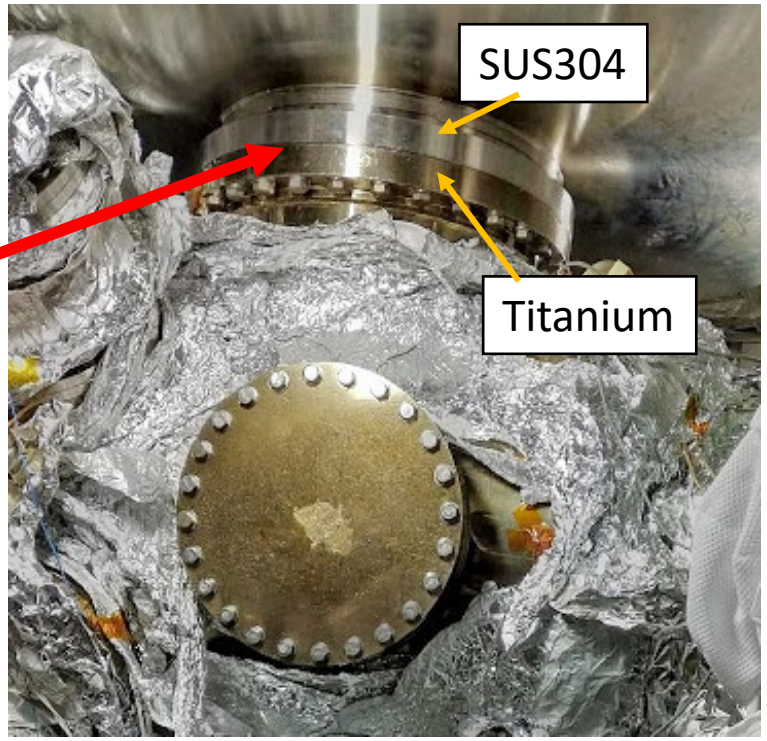
500 kV operation history (2)



- The QE decreases by about 10% in about 2 hours.
- The increase in vacuum during operation is small.
- The radiation was mainly due to beam loss in the second arc section.

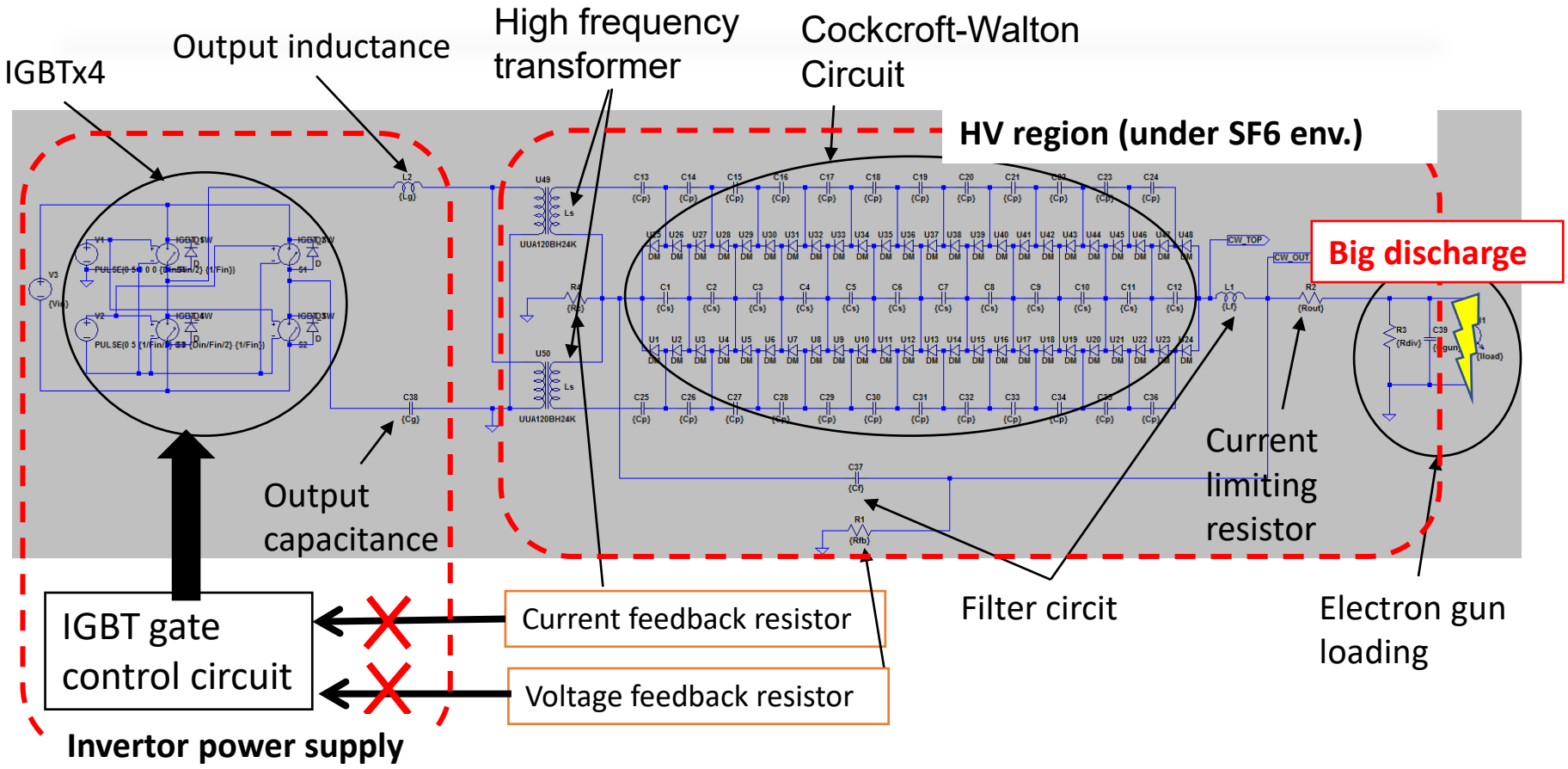
Trouble 1: Vacuum leaks





- Leakage at titanium-stainless steel large diameter flange connection.
- The cause is due to the difference in the coefficient of thermal expansion.
- Currently, VACSEAL is used to stop the leak as a first aid.
- Scheduled to be replaced with a thick gasket during this year's shutdown.

Trouble 2: Serious discharge event (1)



November 2020:

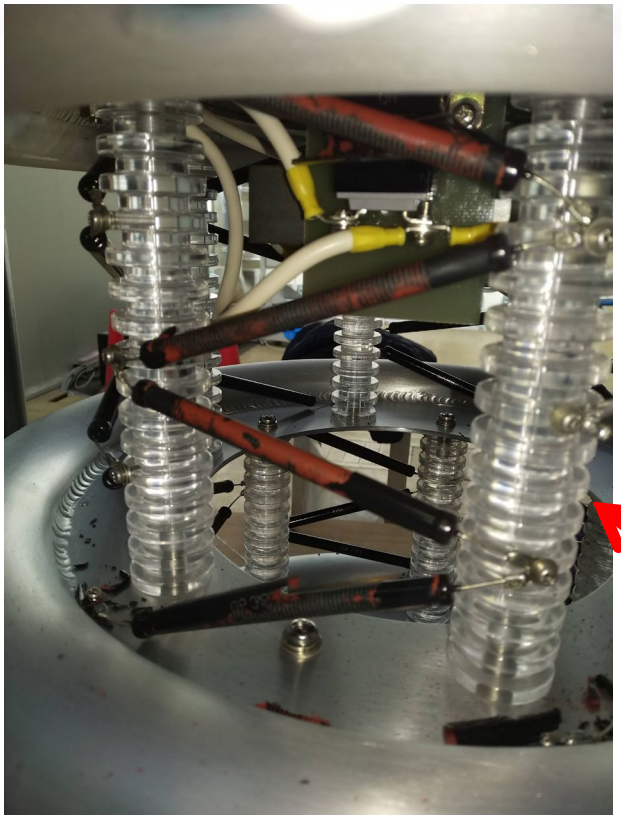
Feedback monitor line is disconnected during new inverter power supply adjustment.

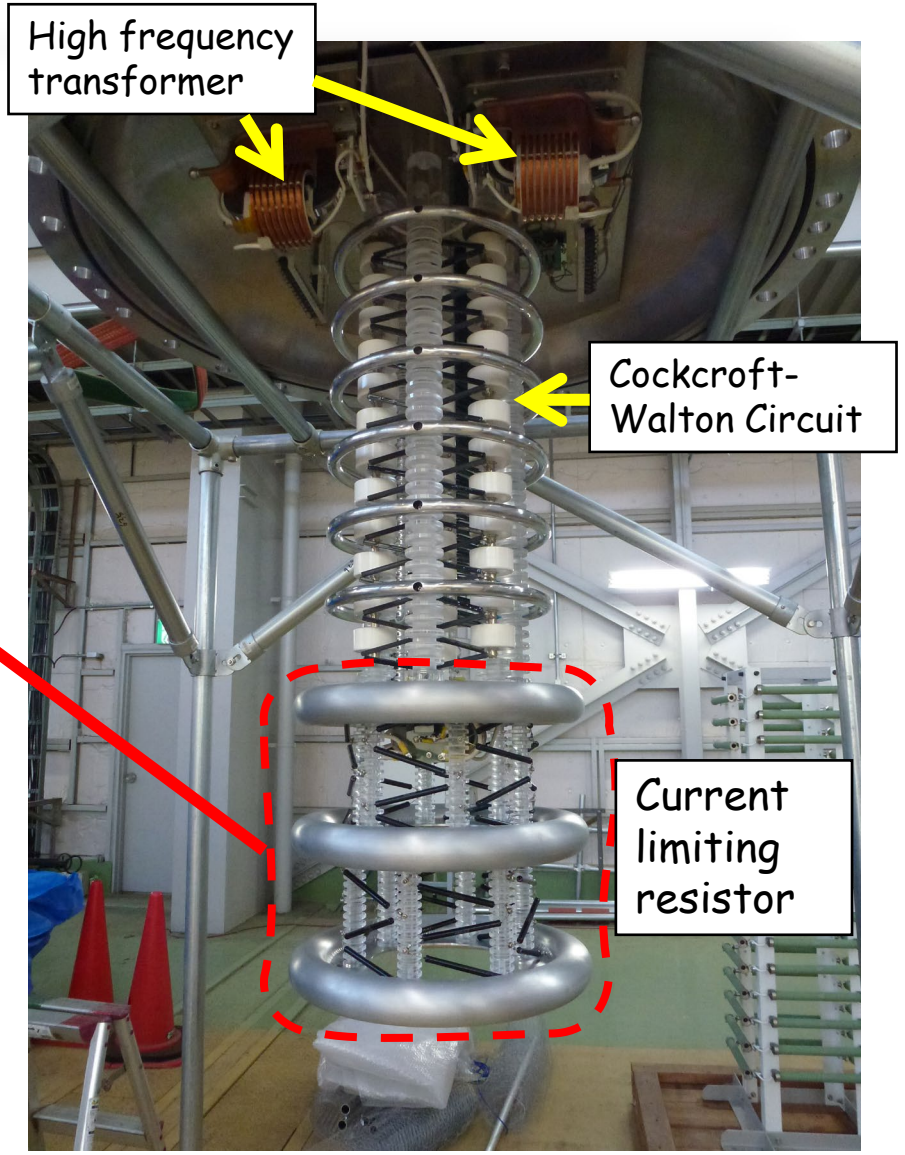
Turn on the power for test operation, the maximum output of ~600 kV can be applied instantly.

Frequent arc discharge occured for 20 second intermittently.

vacuum gauge stops abnormally and IGBT fails.

Trouble 2: Serious discharge event (2)

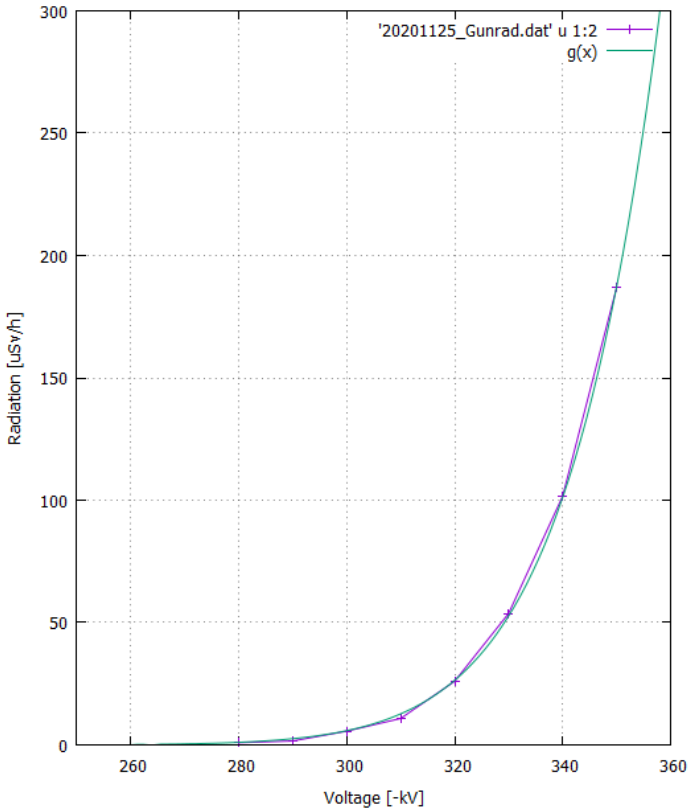




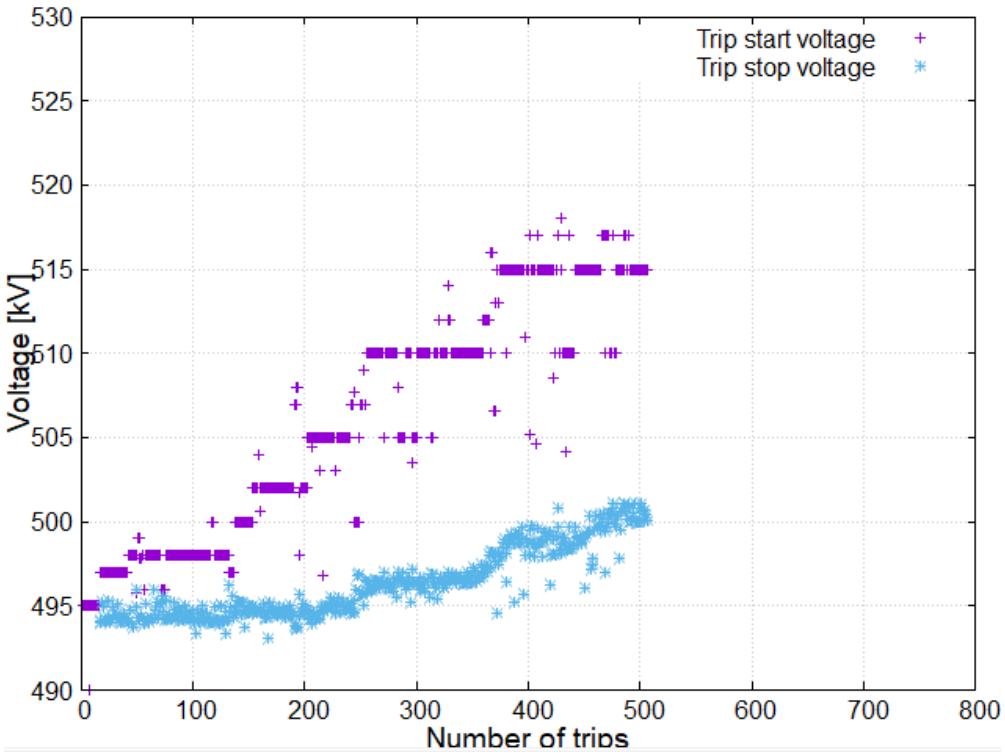
- Burnout of current limiting resistor.
- In the accident, use low resistance (66kΩ) for high current CW operation.
- No particular damage other than burning of the resistor.

Trouble 2: Serious discharge event (3)

Before electrode wiping



After electrode wiping & HV conditioning



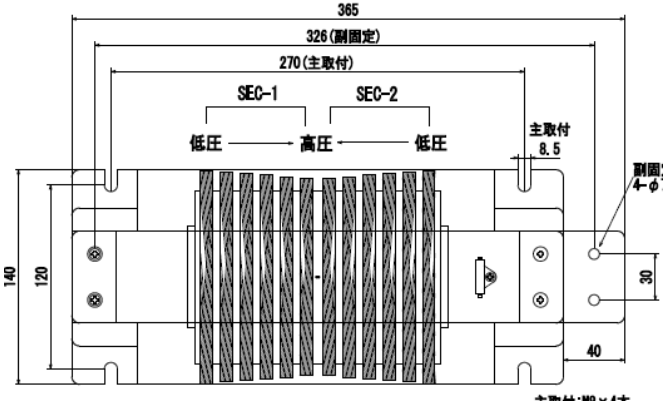
- The FE source disappears by wiping the electrodes.
- 490kV DC-gun operation in February 2021. The FE source reoccurs during additional conditioning.
- 390kV DC-gun operation after October 2021.

FE sources that could not be removed by conditioning could be removed by wiping with a lint-free wiper.

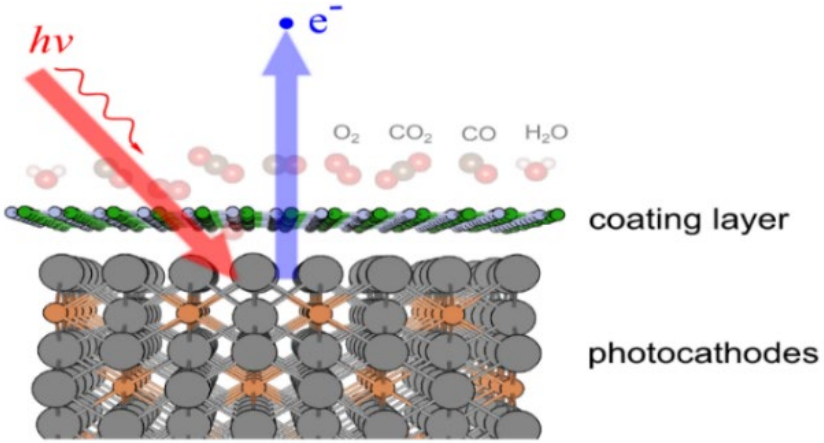
Future technical issues

HVPS output enhancement

- The drive frequency of the inverter is designed 40kHz for reduce the voltage ripple in HV output.
- Currently, the heat-problem of high-frequency transformers is bottleneck.
- Remodeling of a high frequency transformer is underway.



Photocathode lifetime improvement



- The lifetime of NEA-GaAs is short in a high-current operation.
- Considering switching photocathode from NEA-GaAs to CsK2Sb.
- Furthermore, R&D of photocathode protecting layer is underway in US-Japan cooperation.

- L. Guo et al., "Graphene as reusable substrate for bialkali photocathodes", Appl. Phys. Lett. 116 251903 (2020).
- F.Liu et al., “Photoemission from Bialkali Photocathodes through an Atomically Thin Protection Layer”, ACS Appl. Mater. Interfaces 14 1710 (2022).

Summary

- ✓ Established HV conditioning method for stable operation.
  - ✓ Confirmed stable application of 500kV for both DC-guns.
  - ✓ 500 kV holding time for over 1300 hours.
  - ✓ 500 keV beam supply for over 1000 hours.
- ✓ Achieved XHV condition by using titanium chamber.
  - ✓ An indispensable environment to use NEG-GaAs photocathode.
  - ✓ Large-diameter flanges leak at the connection with the SUS flange.
- ✓ Serious discharge event due to wiring error
  - ✓ Connection resistance burnout. No damage to the electron gun and high voltage generator.
  - ✓ FE source relapsed. FE source is removed by wiping the electrodes.
- ✓ Preparation for 10 mA CW-beam operation.
  - ✓ The problem of insufficient HV power output. Modification of high frequency transformer against heat generation.
  - ✓ Transition photocathode from NEA-GaAs to CsK2Sb.
  - ✓ R&D of the photocathode protecting layer is also underway with Japan-US cooperation.