500kV DC gun for ILC

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Introduction

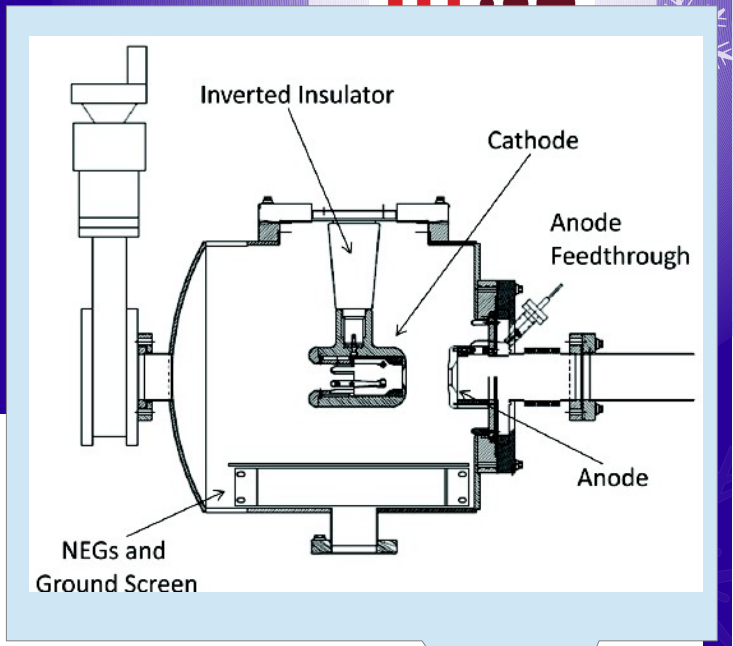
ILC Design parameter

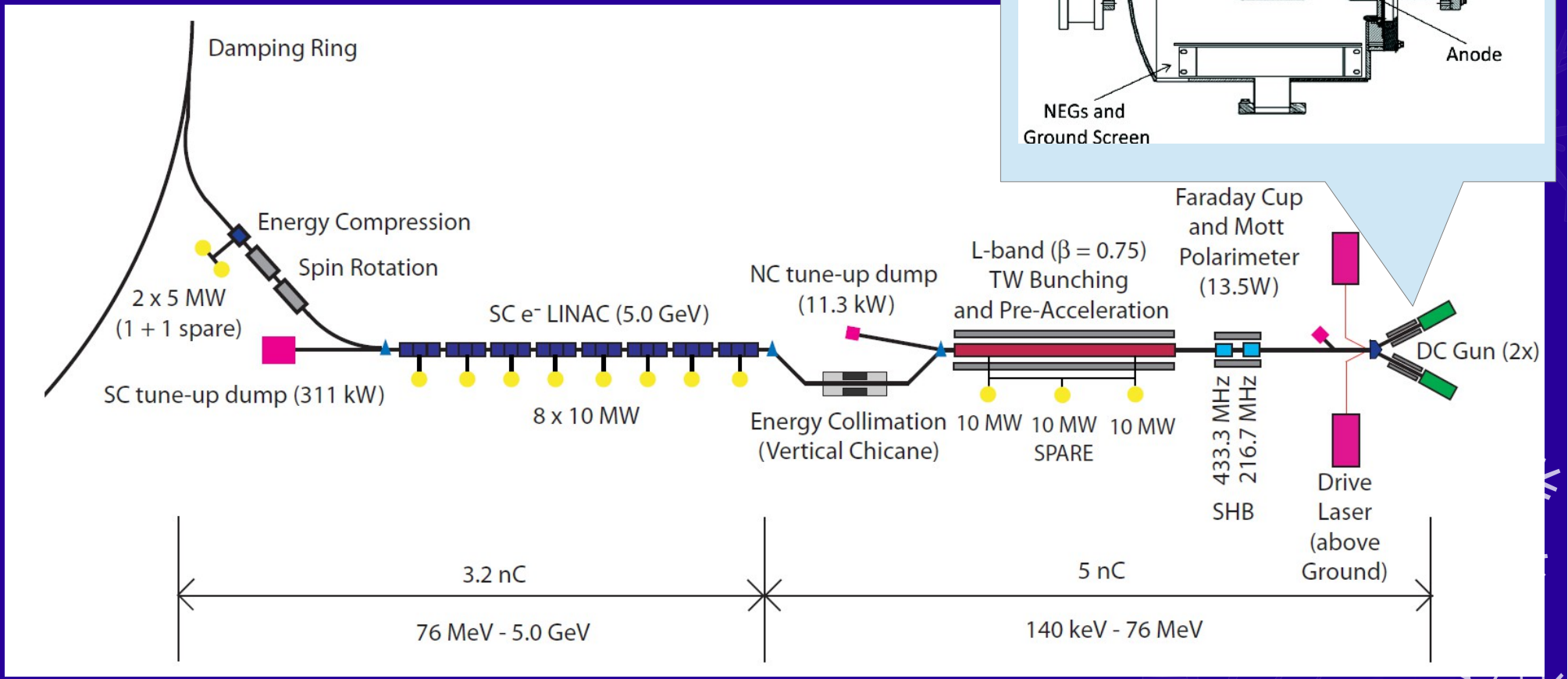
Table 4.1. Electron Source system parameters.

Parameter	Symbol	Value	Units
Electrons per bunch (at gun exit)	N_-	3×10^{10}	
Electrons per bunch (at DR injection)	N_-	2×10^{10}	
Number of bunches	n_b	1312	
Bunch repetition rate	f_b	1.8	MHz
Bunch-train repetition rate	f_{rep}	5	Hz
FW Bunch length at source	Δt	1	ns
Peak current in bunch at source	I_{avg}	3.2	A
Energy stability	σ_E/E	<5	% rms
Polarisation	P_e	80 (min)	%
Photocathode Quantum Efficiency	QE	0.5	%
Drive laser wavelength	λ	790±20 (tunable)	nm
Single-bunch laser energy	u_b	5	µJ

ILC electron source (1)

- NEA GaAs/GaAsP superlattice cathode.
- 200kV inverted type DC gun.
- >80% pol. , 3.2nC/bunch at IP.





ILC electron source (2)

- NEA GaAs/GaAsP for polarization is not compatible to RF Gun; DC photo-cathode gun is the only solution for LC.
- Current density from 200kV gun is limited by space charge resulting ~1ns bunch length.
  - 1ns → 200ps : two SHBs (316.7 and 433.3MHz).
  - 200ps → 20ps : TW 1.3GHz buncher (β=0.75).
  - Solenoid field for focusing.
- It is desirable to increase HV for shorter initial bunch length.
  - Simplfy the bunching section.
  - Potentially less beam loss and less margin.
- Improving 200kV → 500kV, the bunch length becomes 4 times shorter.

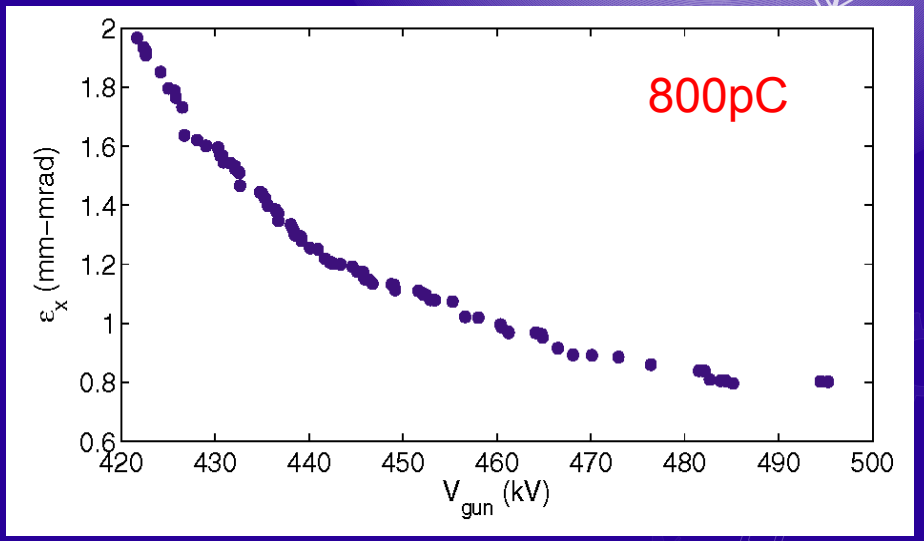
500kV DC gun

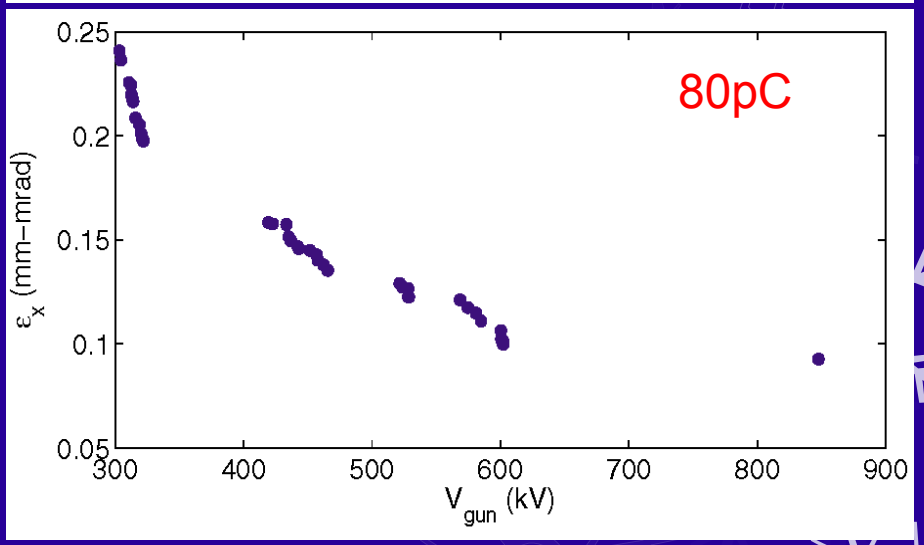
HV DC gun program in Japan

- Photo-cathode HV DC gun R&D program has been carried out by a collaboration among JAEA, KEK, Nagoya U. and Hiroshima U. since 2007.
- This is a common effort for multiple projects: ERL light source, Laser Compton Scattering photon source(Quantum Beam project), and Linear Colliders.
- 500kV and high beam current operation has been confirmed in a test beam line.
- The gun is now under commissioning as the injector of Compact ERL at KEK which is a demo-machine for GeV class ERL light source.

Impact of HV on emittance

- Beam emittance is grown by non-linear space charge.
- High field of the gun makes the beam emittace better by preventing the emittace growth.





I. V. Bazarov and C. K. Sinclair, PRSTAB 8, 034202 (2005).

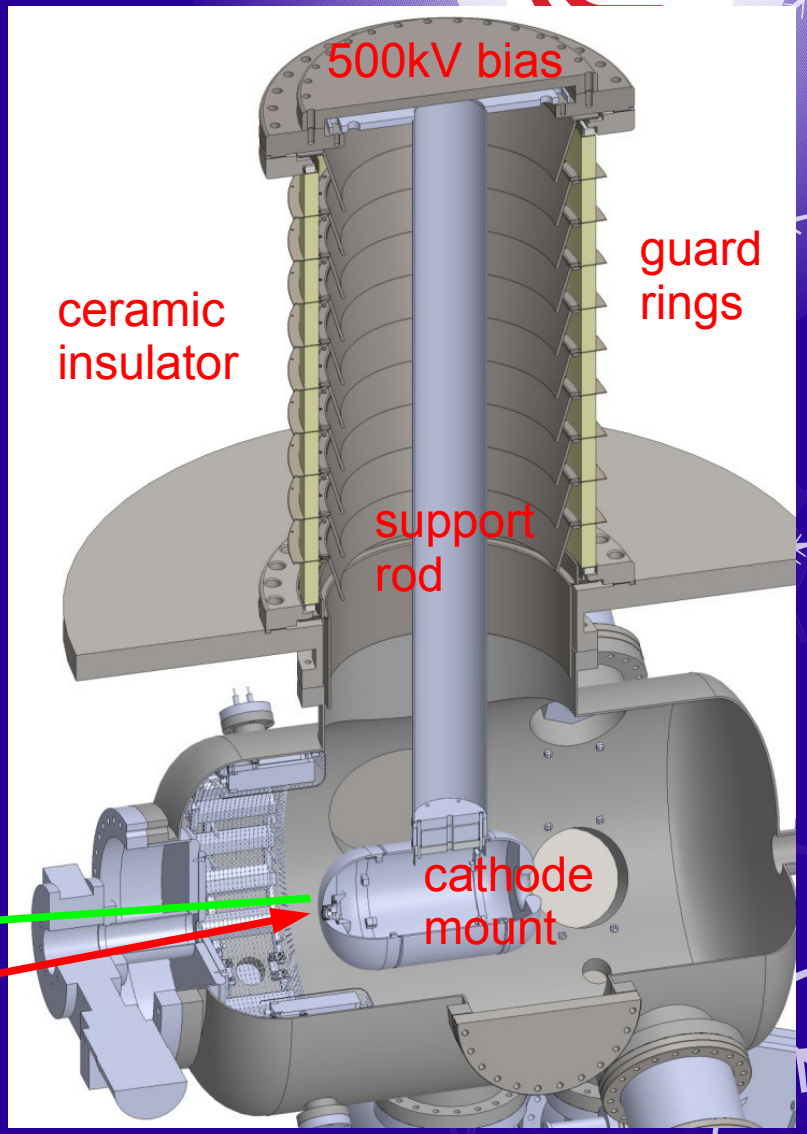
ERL Project in Japan

- The next generation SR light source based on 3 GeV ERL (PERL) has been proposed.
- PERL is extendable to X-ray FEL oscillator.
- For technical demostration, cERL (compact ERL) is now under commissioning.
- cERL: Laser Compton X/γ-ray sources.

Parameters	Value
Energy	35/245 MeV
Current	10mA
Emittance (norm.)	0.1-1.0 mm.mrad

500kV DC gun

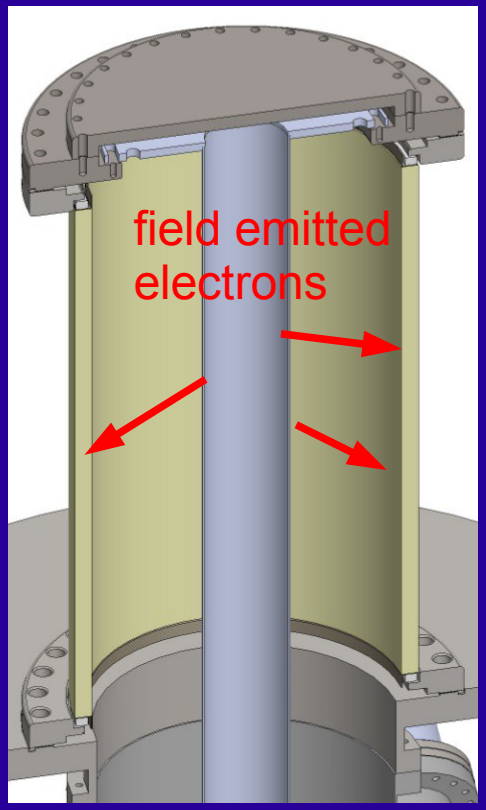
- 500kV DC biased gun with ceramic insulator.
- High voltage and high field are essential for high brighness and low emittance beam generation.
- Guard rings on the ceramic insulator prevent HV breakdown and ceramic punch through.
- The guard rings are also effective to prenvent cocentration of the bias voltage in a small region.



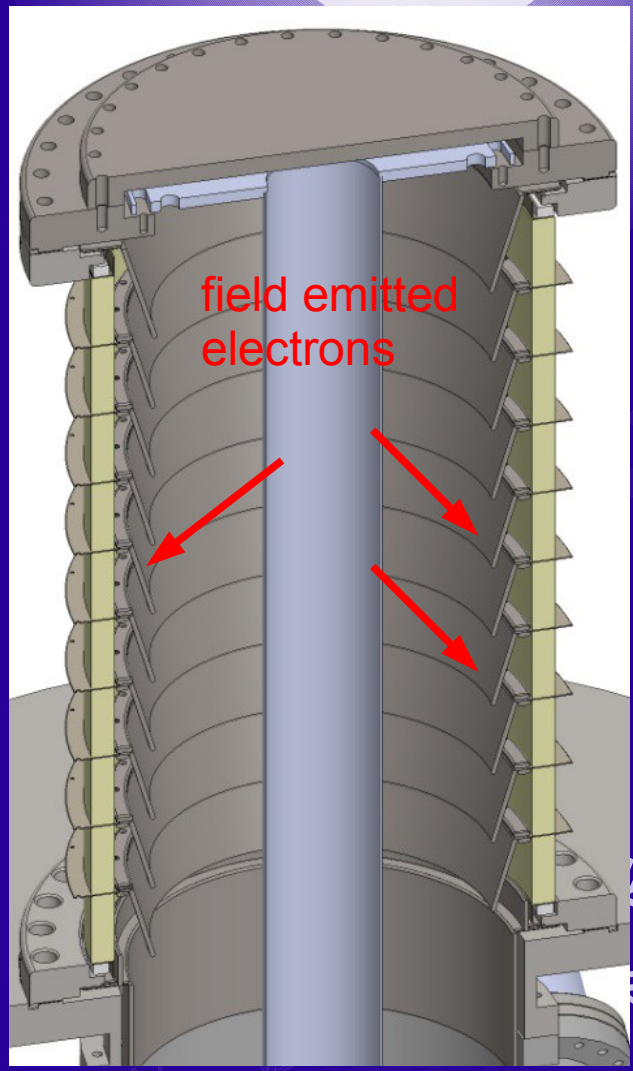
Segmented Struture with guard rings (1)

- HV of DC gun has been limited by ceramic insulator destruction.
- The reason is considered to be field emission from the support rod and field concentration by discharge.
- To prevent these phenomena, we employed segmented structure with guard rings.

One insulator

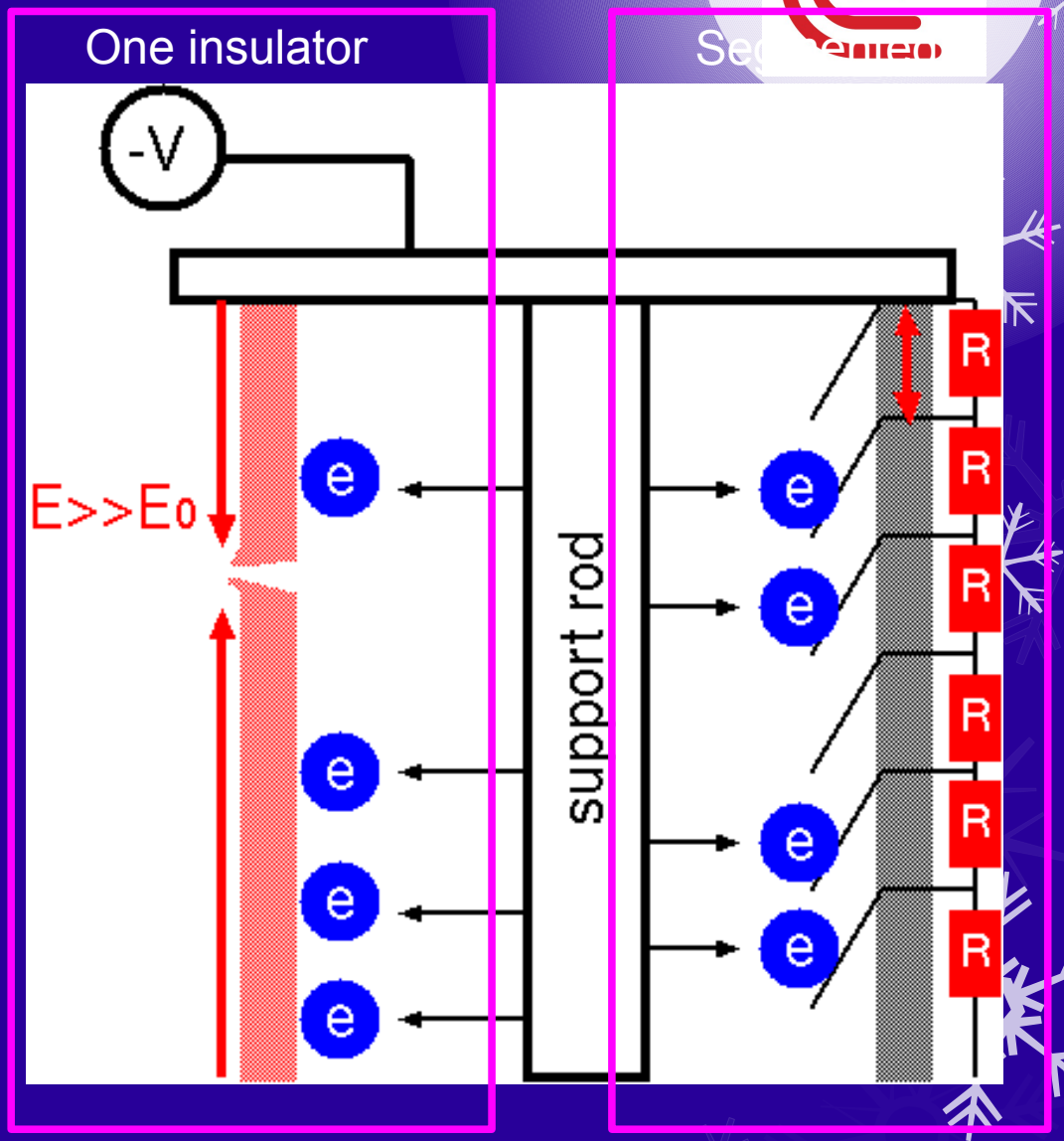


Segmented



Segmented Structure with guard rings (2)

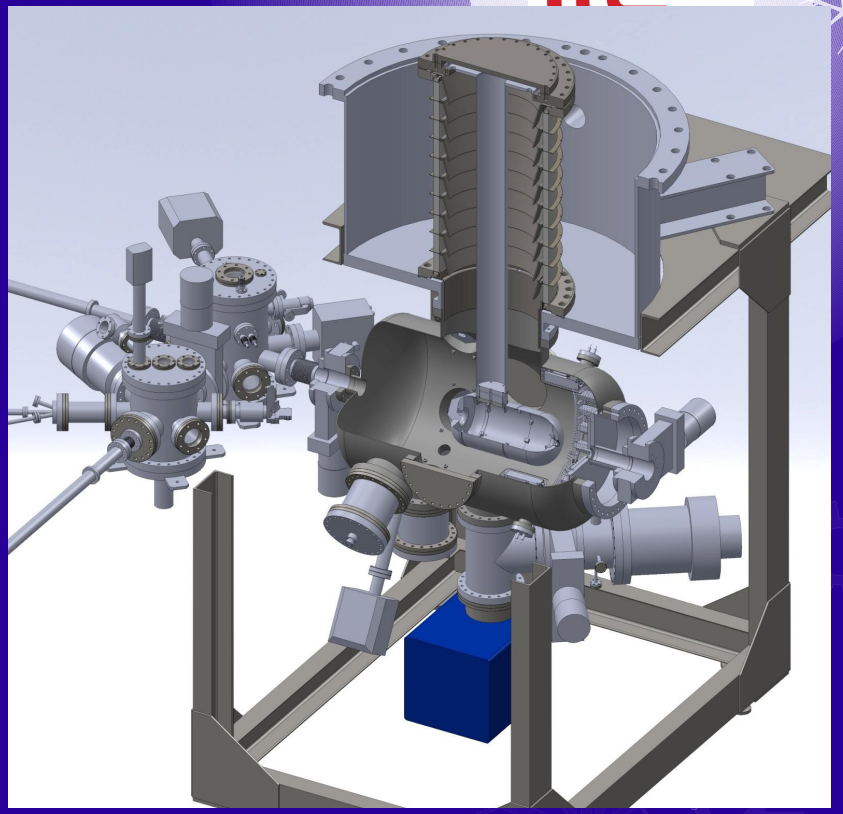
- Guard rings shade the ceramic from electrons emitted from the support rod by field emission.
- The bias voltage is distributed equally among each segments.
- Charge up and voltage concentration resulting ceramic destruction is threfore strongly prevented.

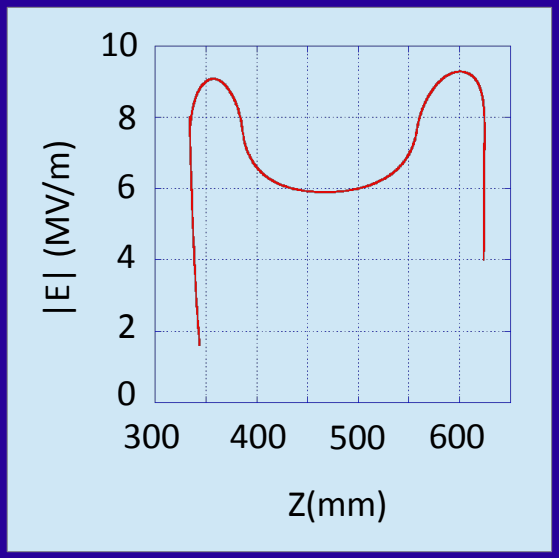


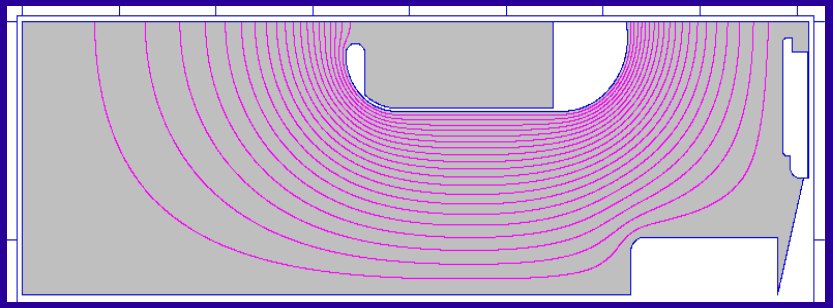
HV and Beam test

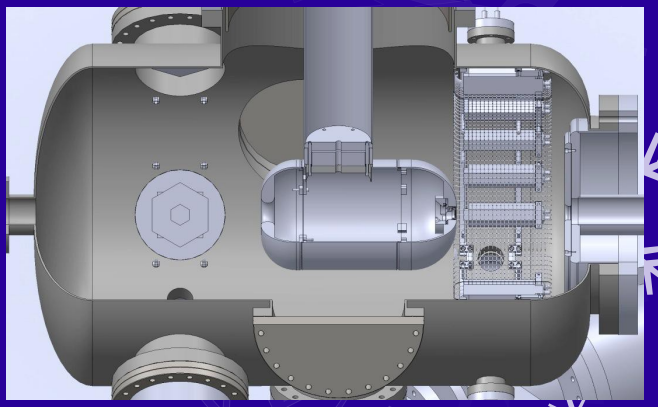
The 500kV DC gun system

- A 500kV DC photo-cathode gun with a cathode preparation system.
- High pumping ability by IP and NEG for extremely low vacuum pressure, <1e-9 Pa.
- Surface field <10MV/m for less field emission.



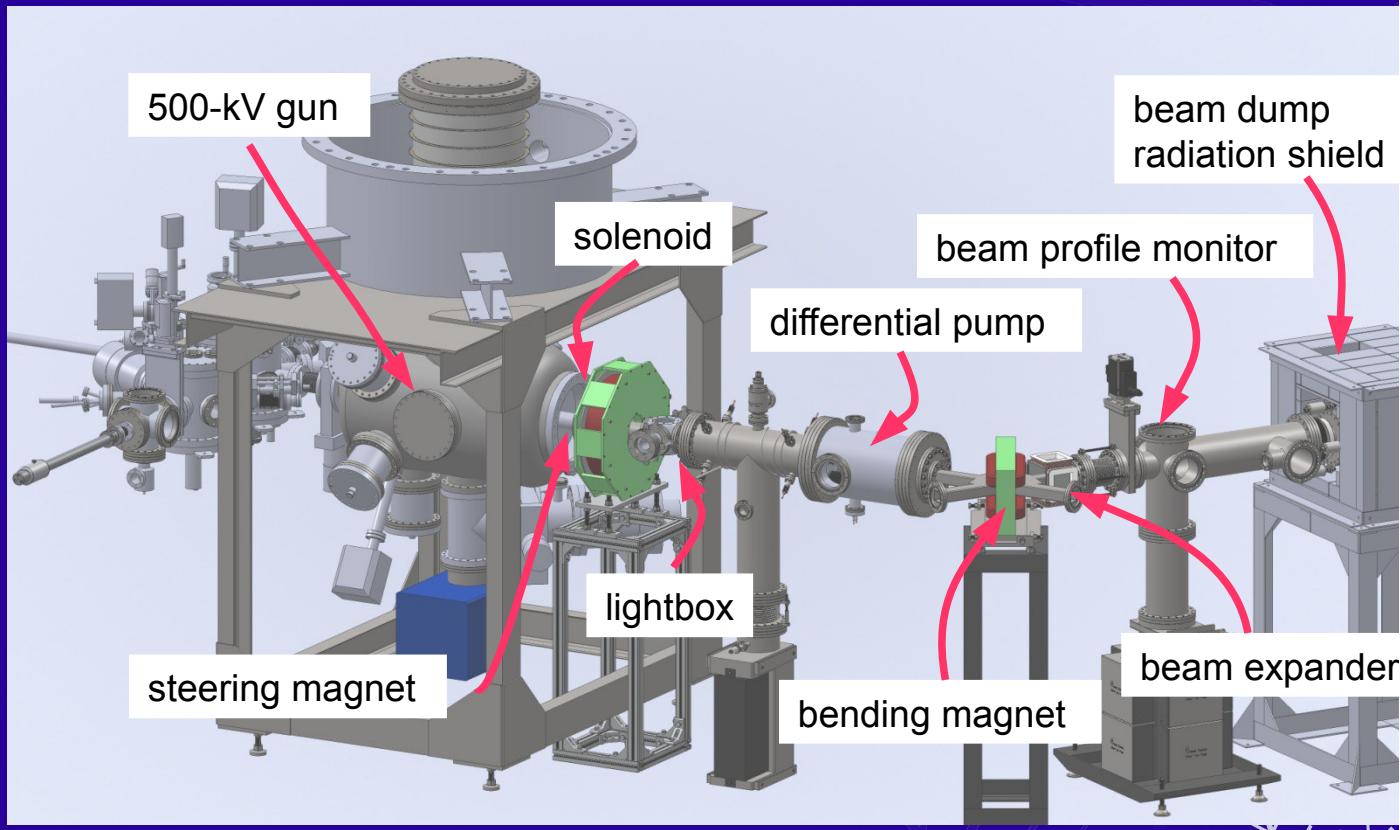






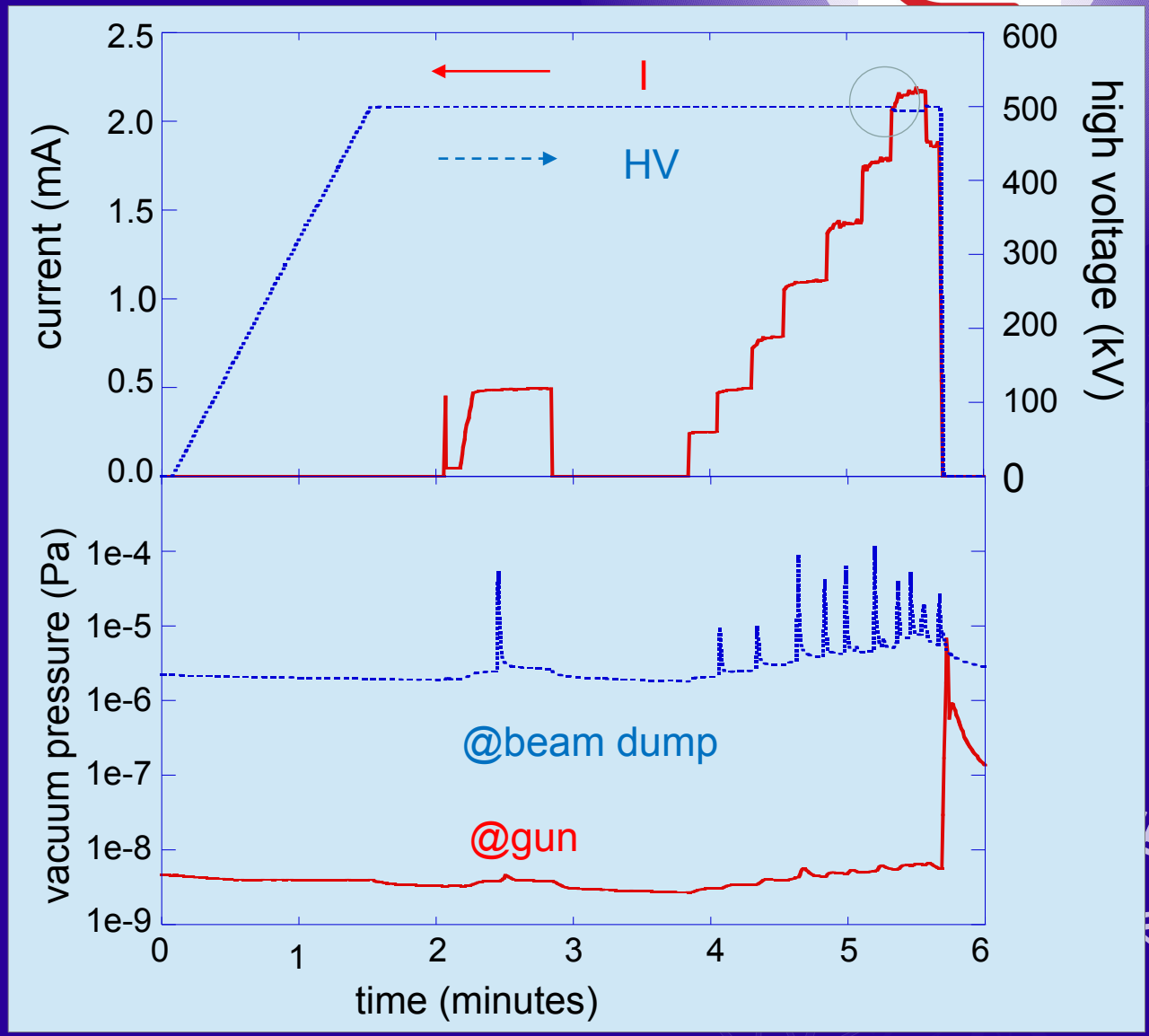
JAEA DC gun beam line

- HV and beam test was carried out at JAEADC gun beam line.
- Laser: 5W 532nm.
- σ_x=0.1mm.
- Water cooled beam dump which is capable to measure the beam current.
- Differential pumping to prevent cotamination to the cathode.



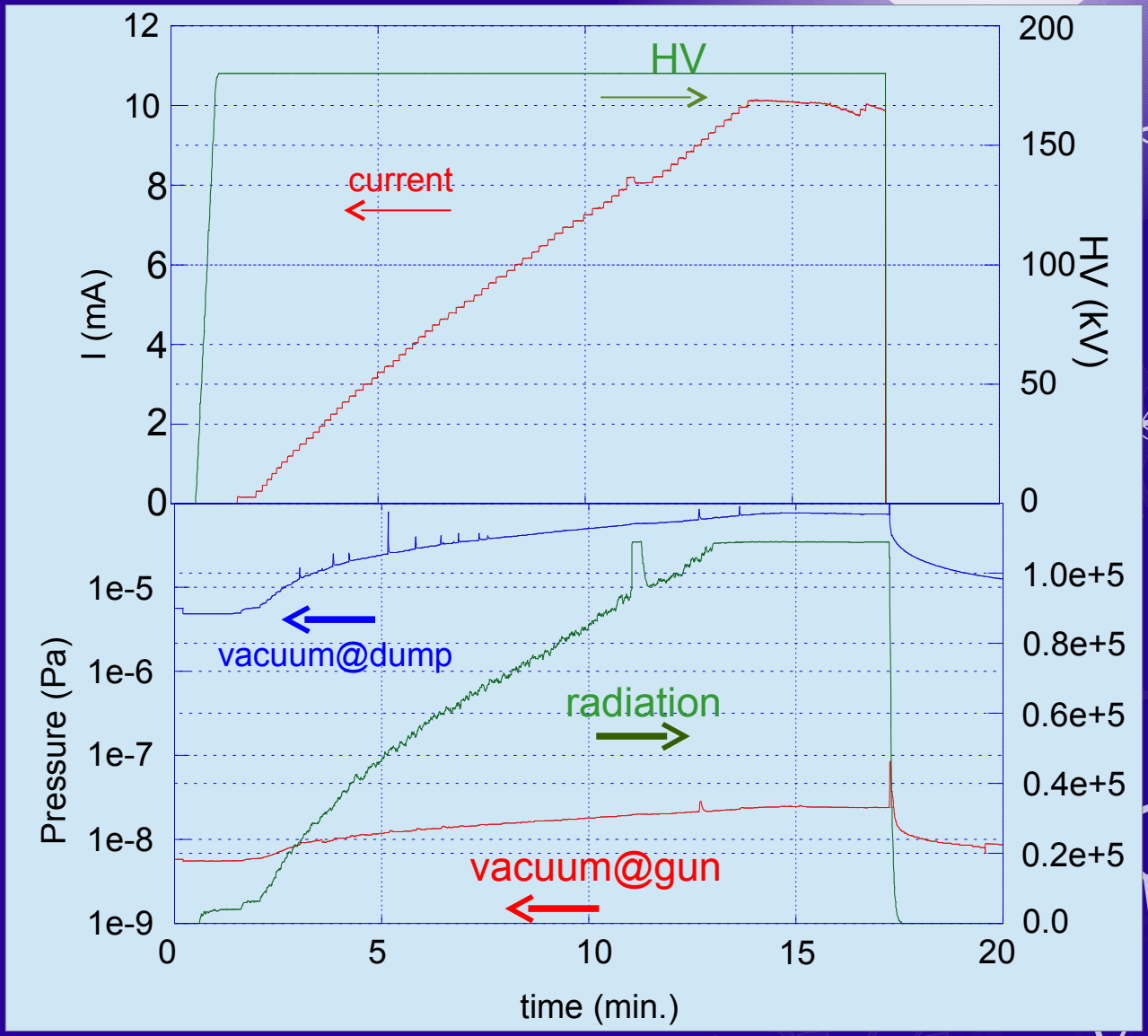
500keV Beam Operation

- After HV conditioning up to 550kV, 500kV was quickly achieved.
- > 2.0mA current was achieved with 1.5 W laser and 0.28% QE.
- Vacuum pressure at gun was maintained at UHV during the operation.



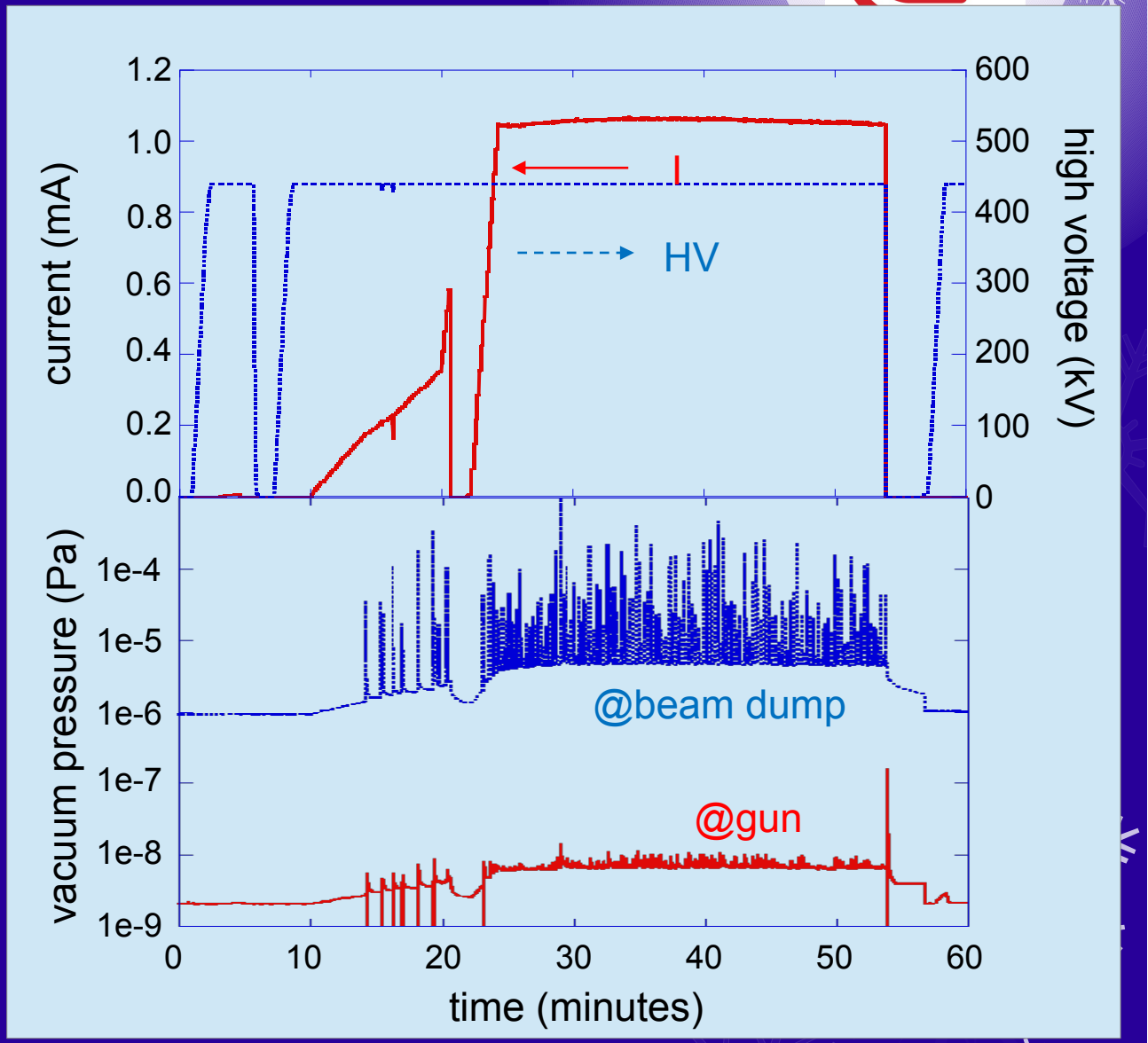
10mA Beam operation

- 10 mA beam operation has been demonstrated.
- The test was carried out at lower voltage (180keV) due to field emisson from dust which was fixed by wiping.
- 10mA was achieved , but a significant vacuum pressure escalation was observed.



Operational Lifetime

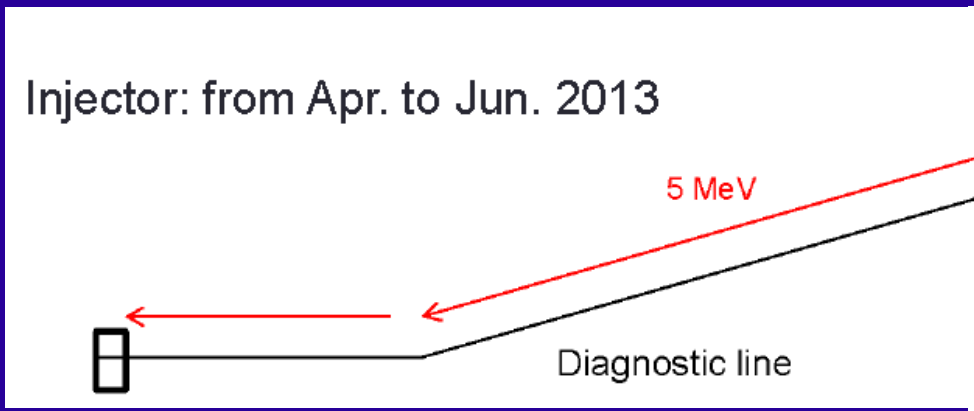
- Operational lifetime was examined by contineous beam operation.
- Beam current decay was observed showing QE degradation.
- Charge lifetime was extracted to be 48C.
- It is enough for LCs, but not sufficient for ERL light source.

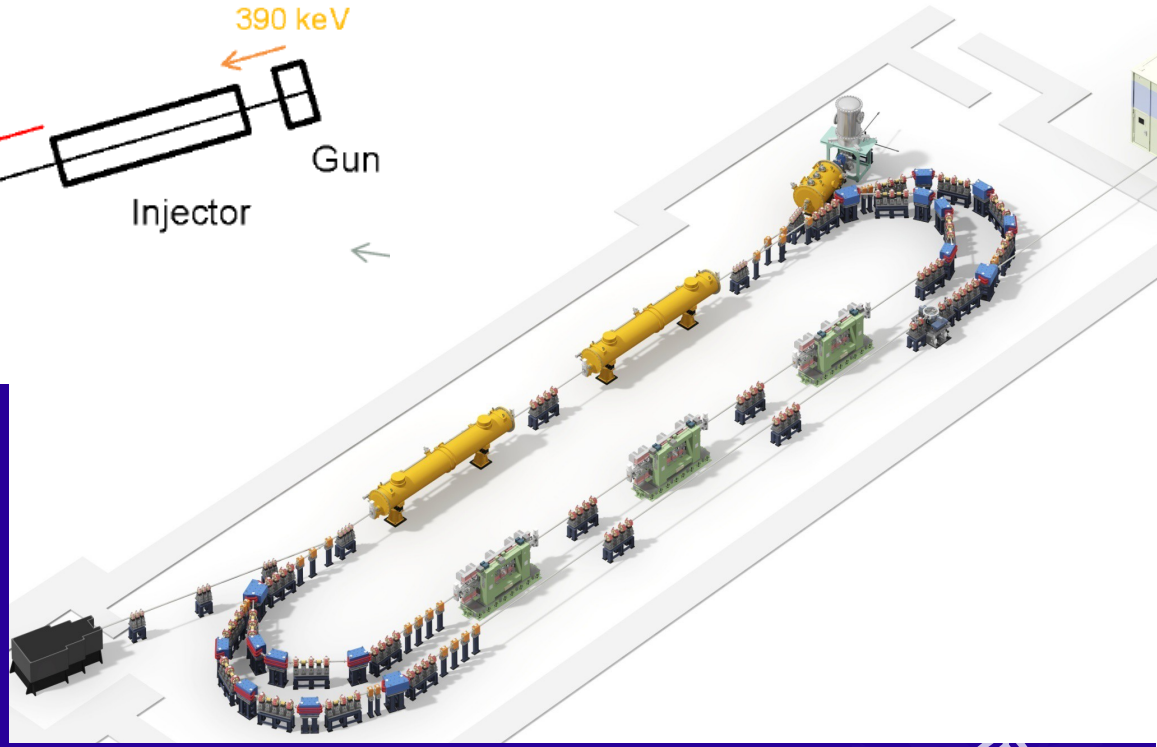


Laser power = 0.37W
QE = 0.68%

Operation at cERL

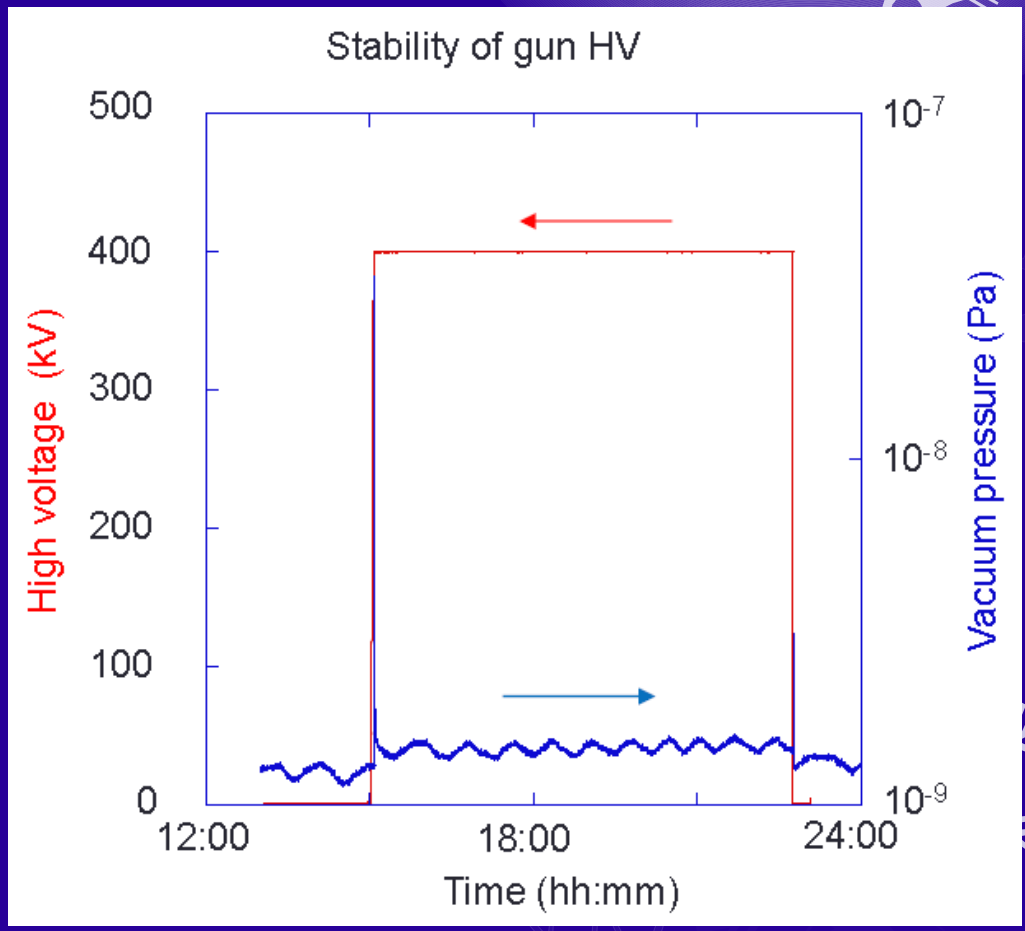
- The developed gun has been moved to cERL at KEK.
- CERL is now focused on commissioning of the injector.





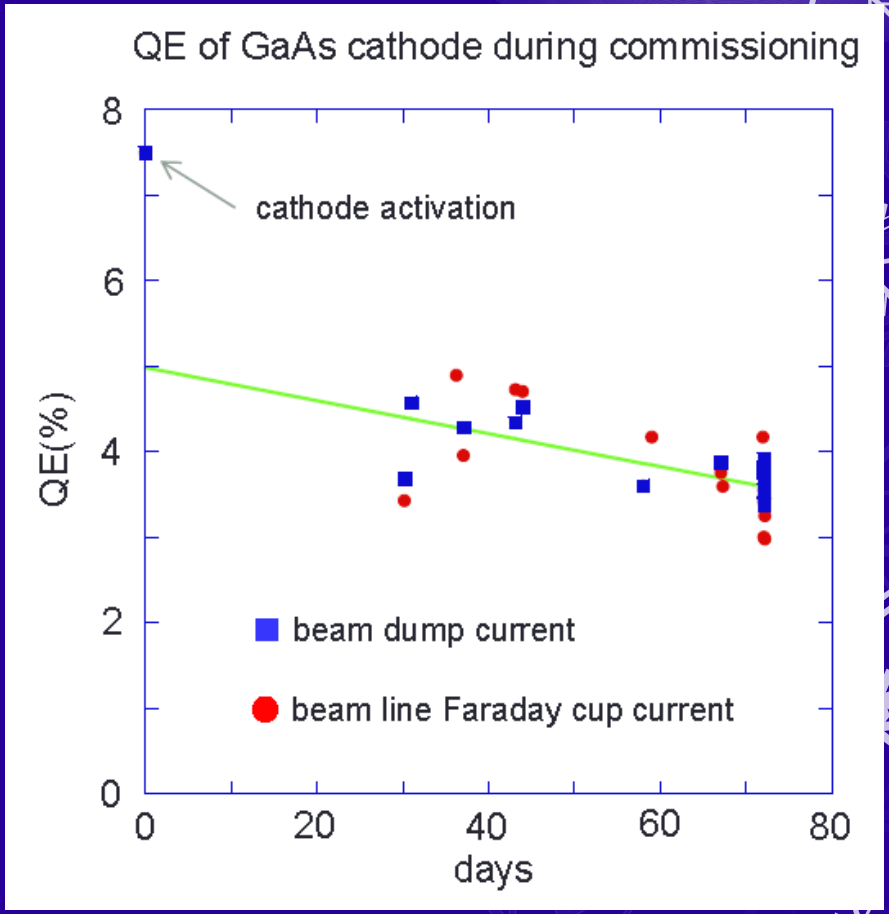
HV stability

- 10 of 12 segments of the insulator ceramic are used due to soot on two segments.
- The gun is operated in 390kV. Voltage per segment is almost equivalent to that of 500kV on 12 segments.
- HV is quite stable during operation.
- The vacuum pressure is also stable at 1.3e-9 Pa.



QE in operation

- NEA GaAs is used for the commissioning.
- The 1/e lifetime is 7 month.
- It is enough for the low current commissioning.



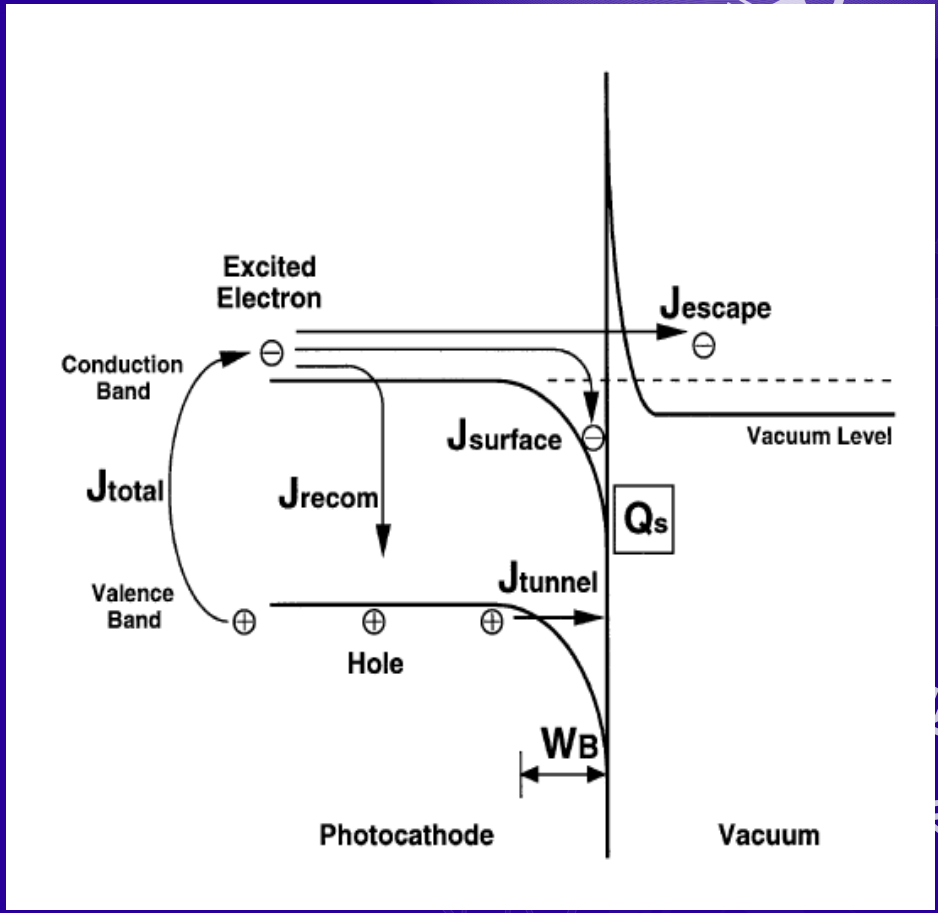
500kV DC gun for ILC

500kV DC Gun for ILC

- Space charge limited current is 25.9A (8.2A/cm^2).
  - 500kV Bias voltage,
  - 0.1m cathode-anode gap,
  - 10mm radius of cathode,
- Bunch length for 4.8nC (50% margin) charge is 190ps instead of 1ns.
  - Bunching factor is only 10 for 20ps for L-band booster.
  - 1.3GHz buncher is enough for bunching according to TDR design.

Another limit: SCL

- Another limitation becomes dominant in this current density.
- SCL : Surface charge limit by photo-voltage effect.
- A part of electrons are captured by the surface potential and its raise the potential wall to vacuum.



K. Togawa, NIMA (414), pp431–445(1998)
G.A. Mulhollan, Phy. Lett. A 282 (2001)

Surface Charge Limit

- The photo-voltage effect is compensated by facilitating recombination between the electrons and holes.
- Heavy p-dopesd surface relaxes SCL.
- 5.0A/cm^2 is achieved by 2.0x10^{19} doping density.
- It is sufficient for 120 or 200kV DC gun, but not sufficient for 500kV ILC gun which requires 9.0A/cm^2.
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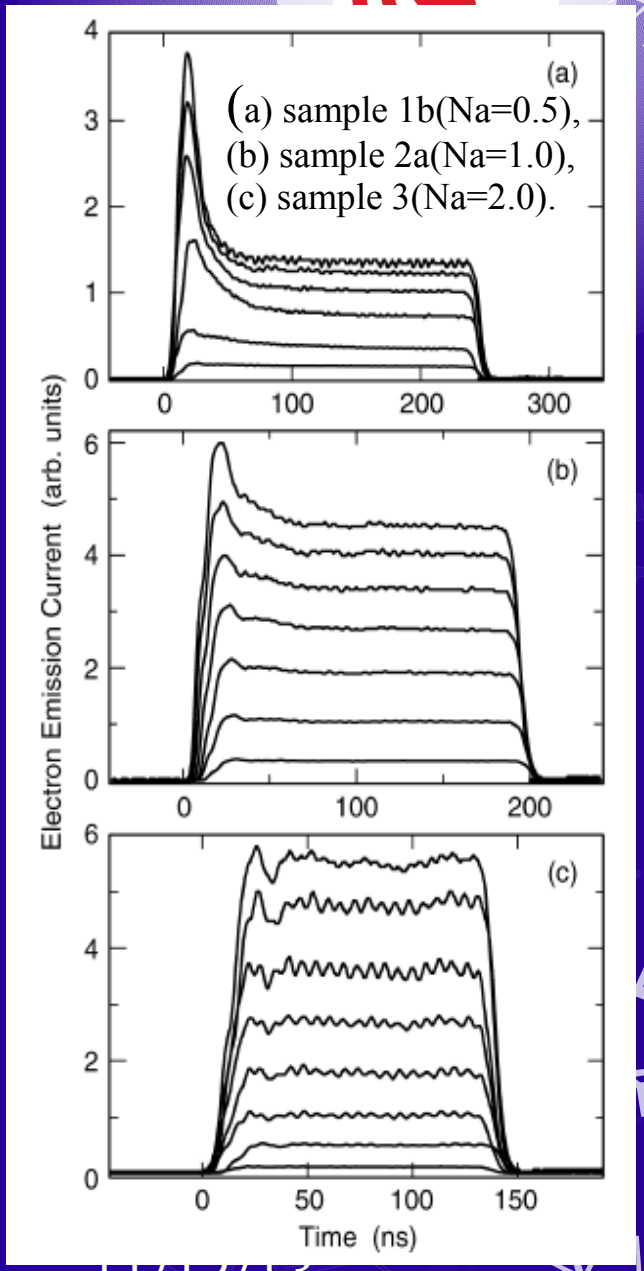

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Summary

- 500kV DC photo-cathode gun is developed for high birghtness electron beam applications.
- Stable operation at 500kV has been confirmed.
- 10mA beam generation has been demonstrated.
- The gun in cERL commissioning shows good performances.
- The technology is applicable for ILC; It omits potentially SHBs.
- Surface charge limit becomes siginificant again. We have to solve it.

500kV DC gun R&D group

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