Development of a 500 kV DC Gun with Narrow Gap

Tuesday, 9 June, 2015
ERL2015@Stony Brook University, NY, USA

M. Yamamoto, T. Miyajima, T. Uchiyama,
Y. Honda, X. Jin, M. Kobayashi
High Energy Accelerator Research Organization (KEK)

N. Nishimori, R. Nagai, R. Hajima
Japan Atomic Energy Agency (JAEA)

M. Kuriki
Hiroshima University

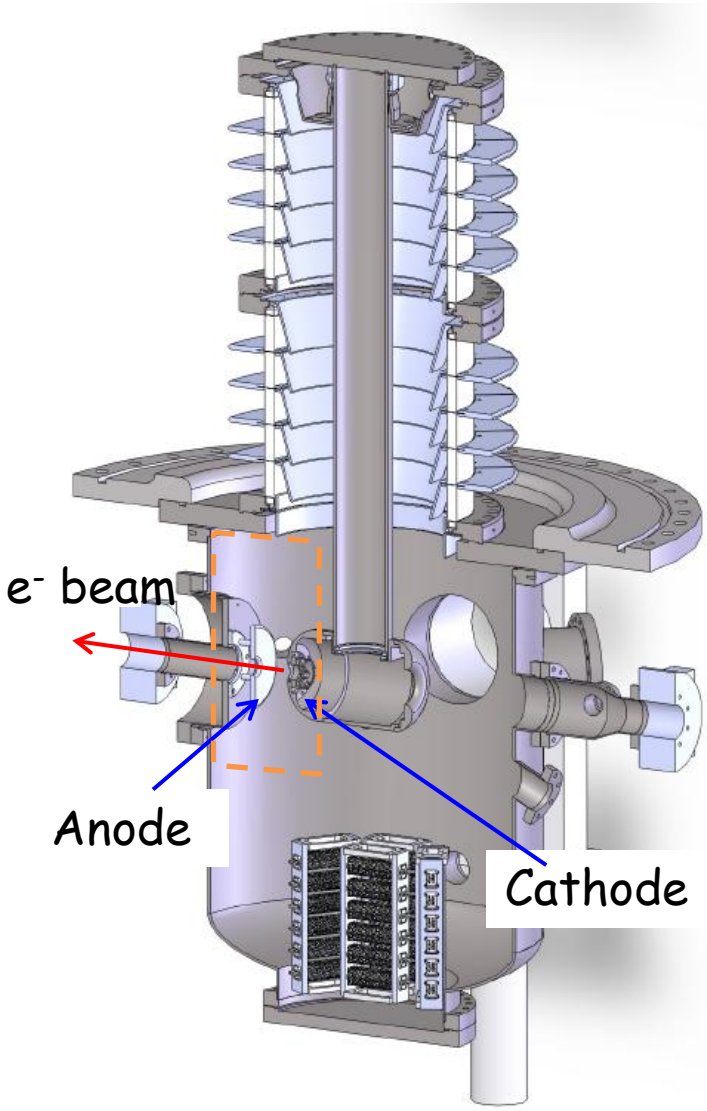
H. Kurisu
Yamaguchi University

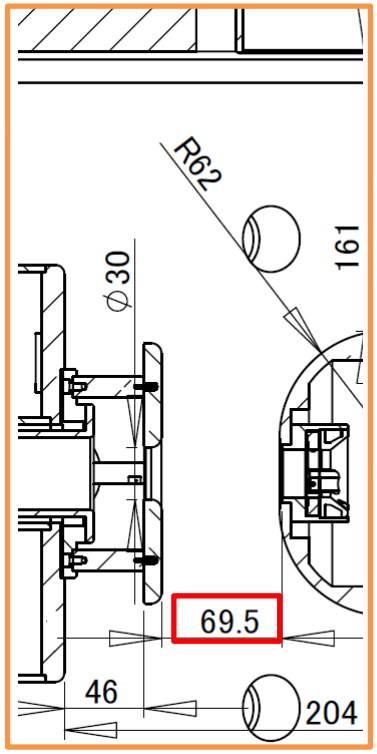
PEARL
Photon Factory

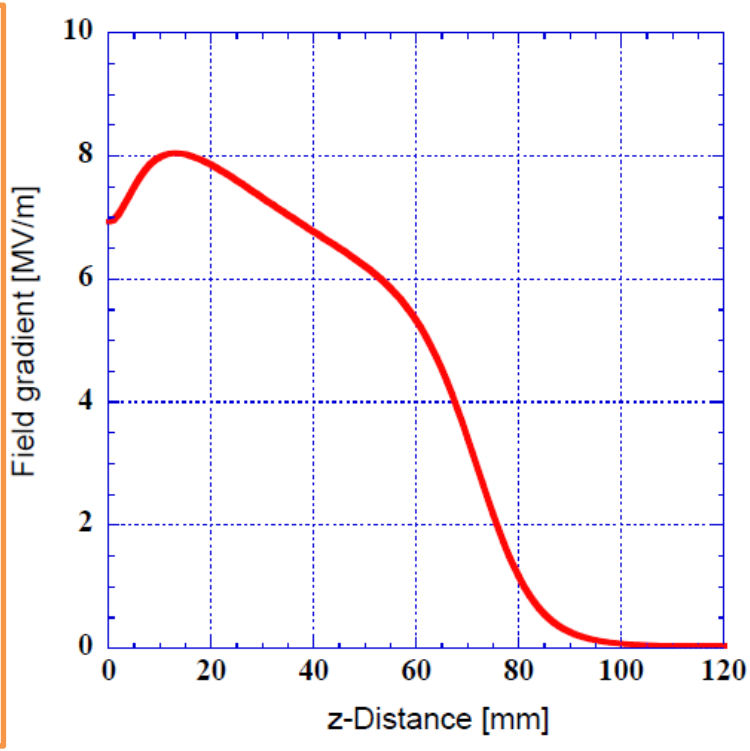
Outline

- Introduction
  - Gun basic configuration
  - Extreme high vacuum systems & baking
- HV test
  - FE problem
  - Conditioning & HV holding test
  - Model of trip voltage increase
- Photocathode preparation & installation
  - Cathodes simultaneous activation system
  - FE problem
- Summary

70 mm Gap 500 kV DC gun (2nd 500 kV gun) @KEK





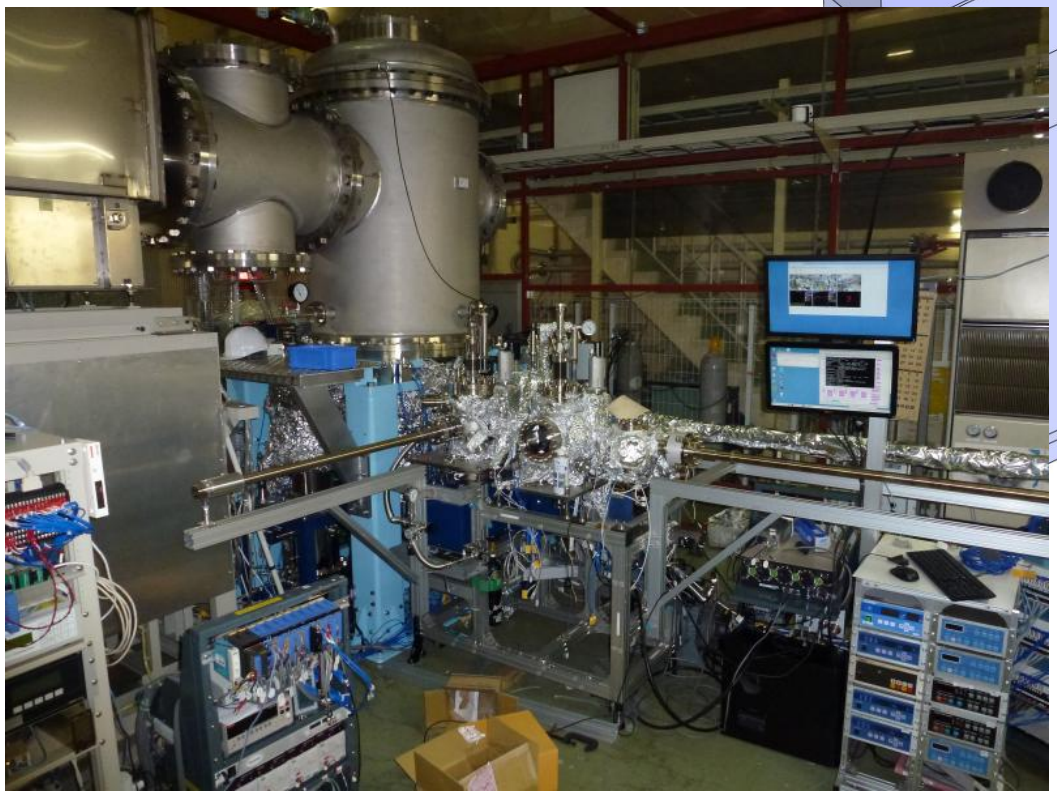


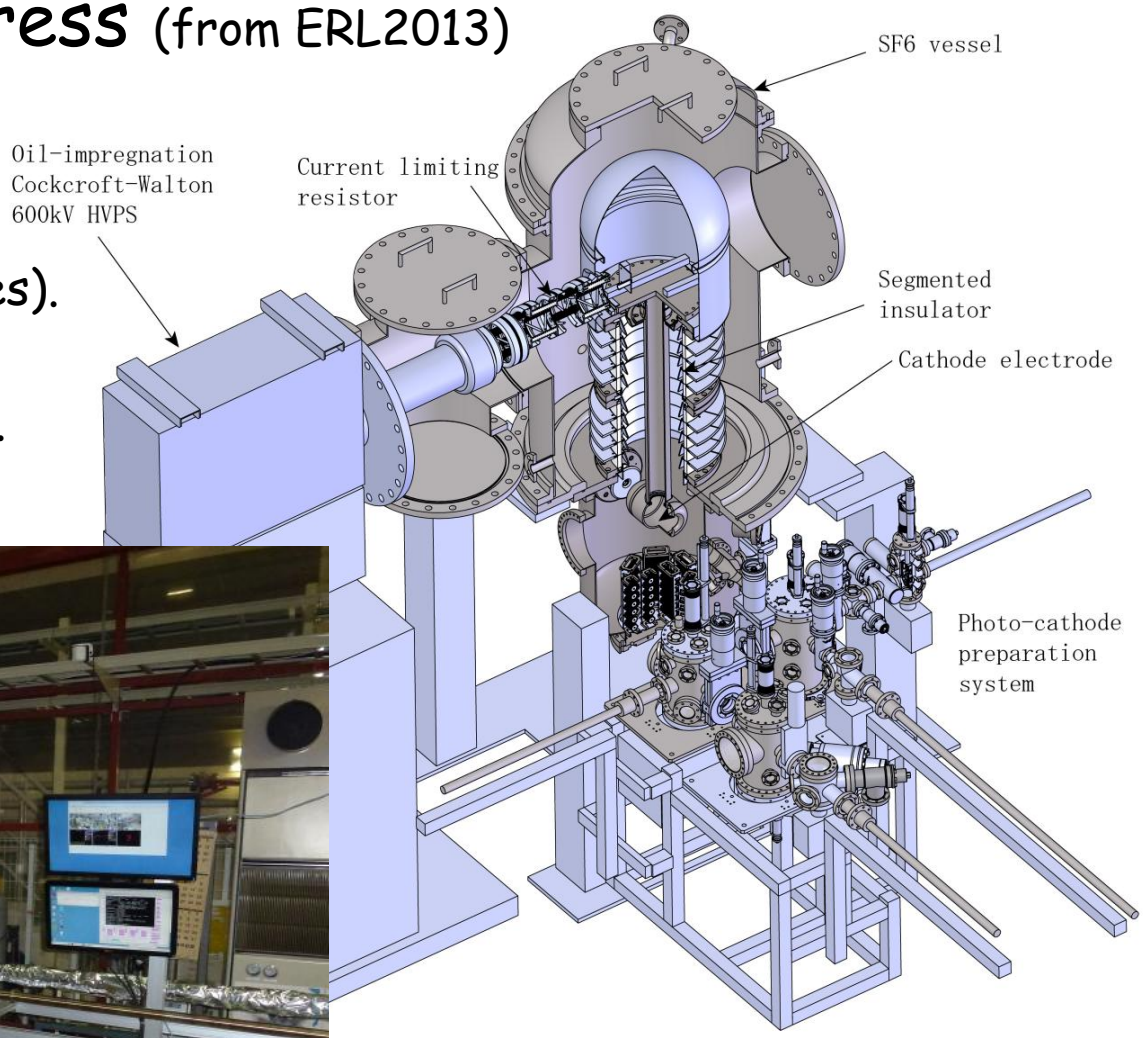
$$\epsilon_n \propto \sqrt{q \cdot \frac{k_B T}{E_{\mathrm{cath}}}}$$

- ✓ 6.9 MV/m @ photocathode center (=E_{cath})
- ✓ 11.0 MV/m @ cathode ball surface

Last 2 years progress (from ERL2013)

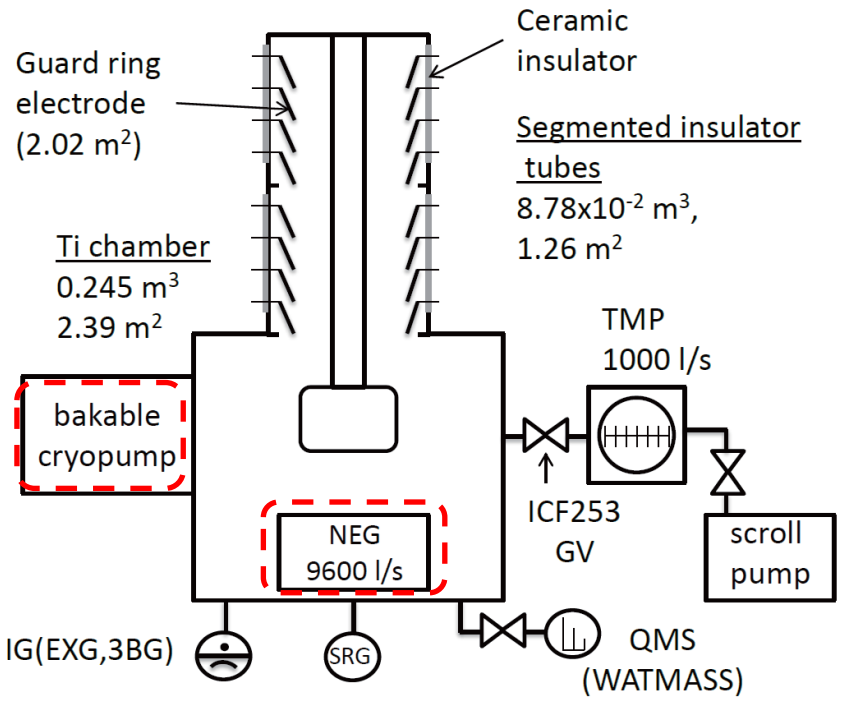
- ✓Baking with main pump system.
- ✓HV conditioning in XHV (4 times).
  2014/May, /Jul, /Aug, 2015/Jan.
- ✓Beam transport & Dump set up.



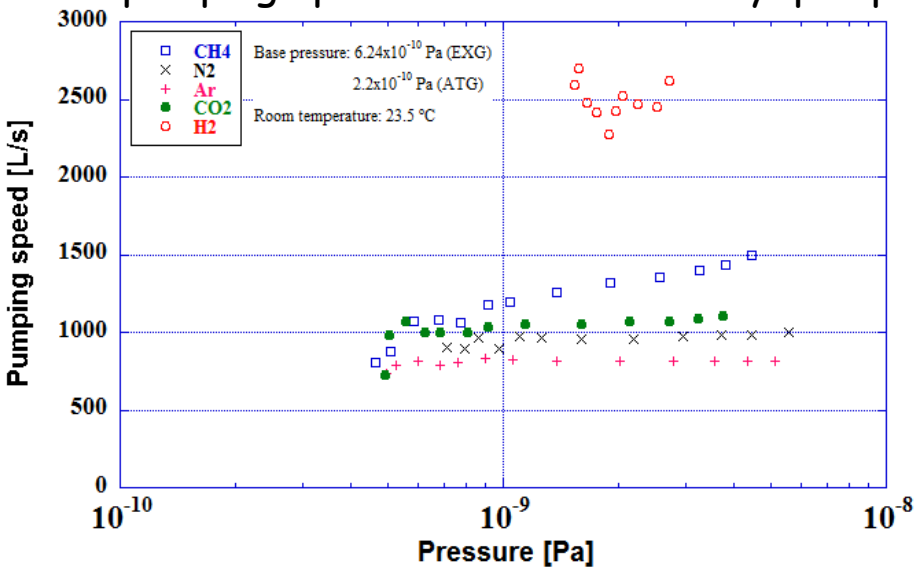


- ✓Demonstrated 3 cathodes simultaneous activation.
- ✓Connected cathode preparation system to the gun.

Main pump installation (2014/Mar)



pumping speed of 4K bakable cryopump

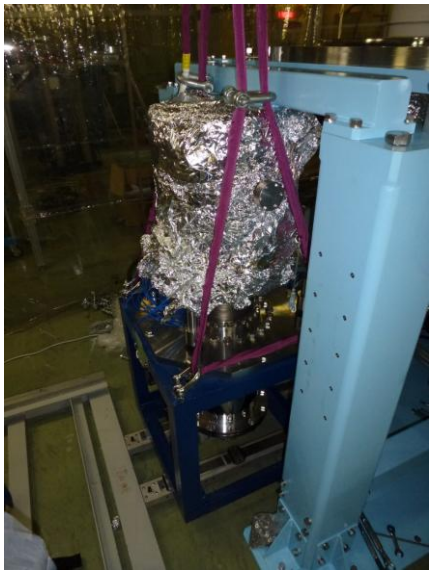


Main pump composition

1. Non Evaporable Getter (NEG)
   D400-2 x 24 = **9600 L/s (H_2)**
   = **4320 L/s (CO)**
   (catalog value)

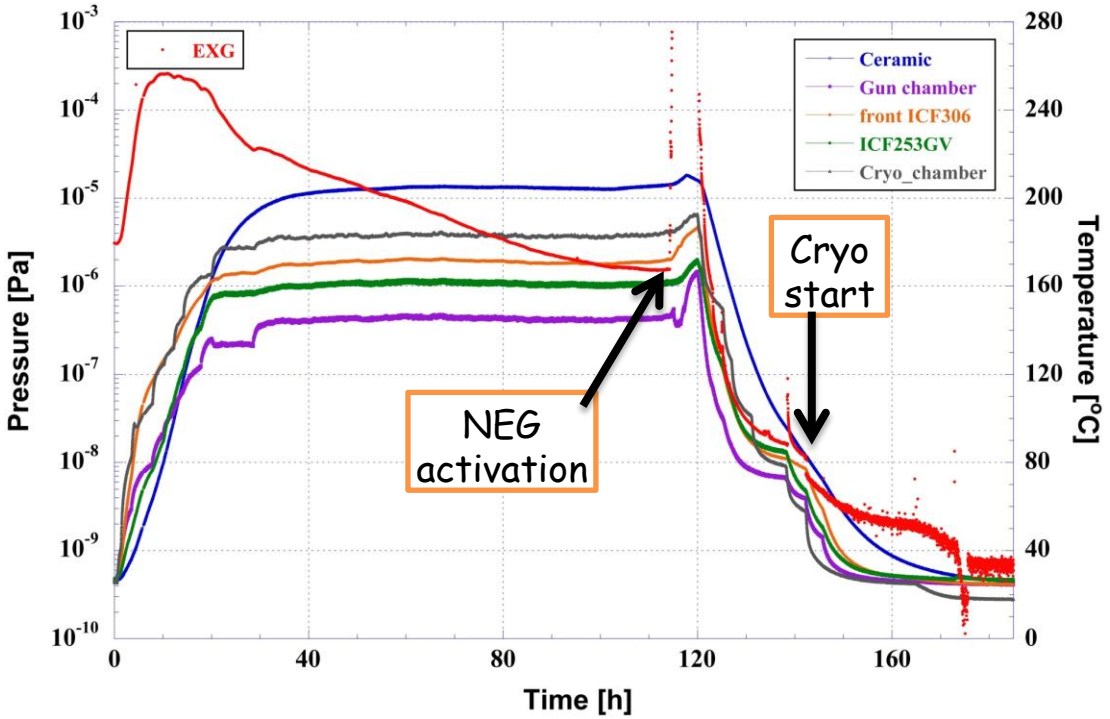
2. 4K bakable cryopump
   ~800 L/s (Ar), ~1000 L/s (N_2,CO_2), ~1200 L/s (CH_4) (measured values@1x10⁻⁹ Pa)

NEG pump set

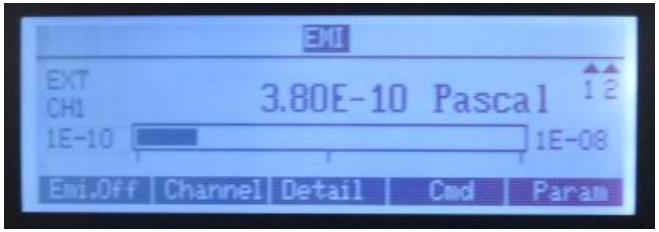


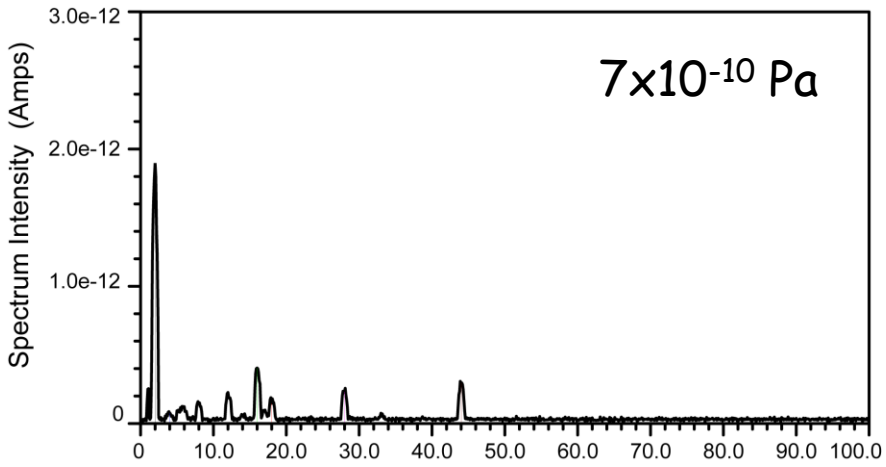
4K bakable cryopump

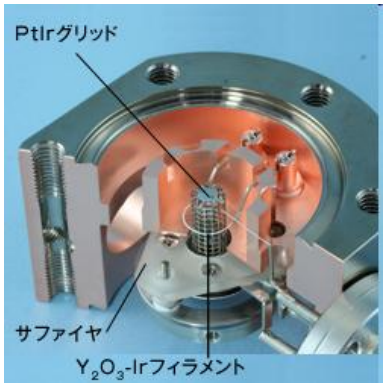
Baking & RGA spectrum in XHV (2014/Mar~Apr)



3B Gauge



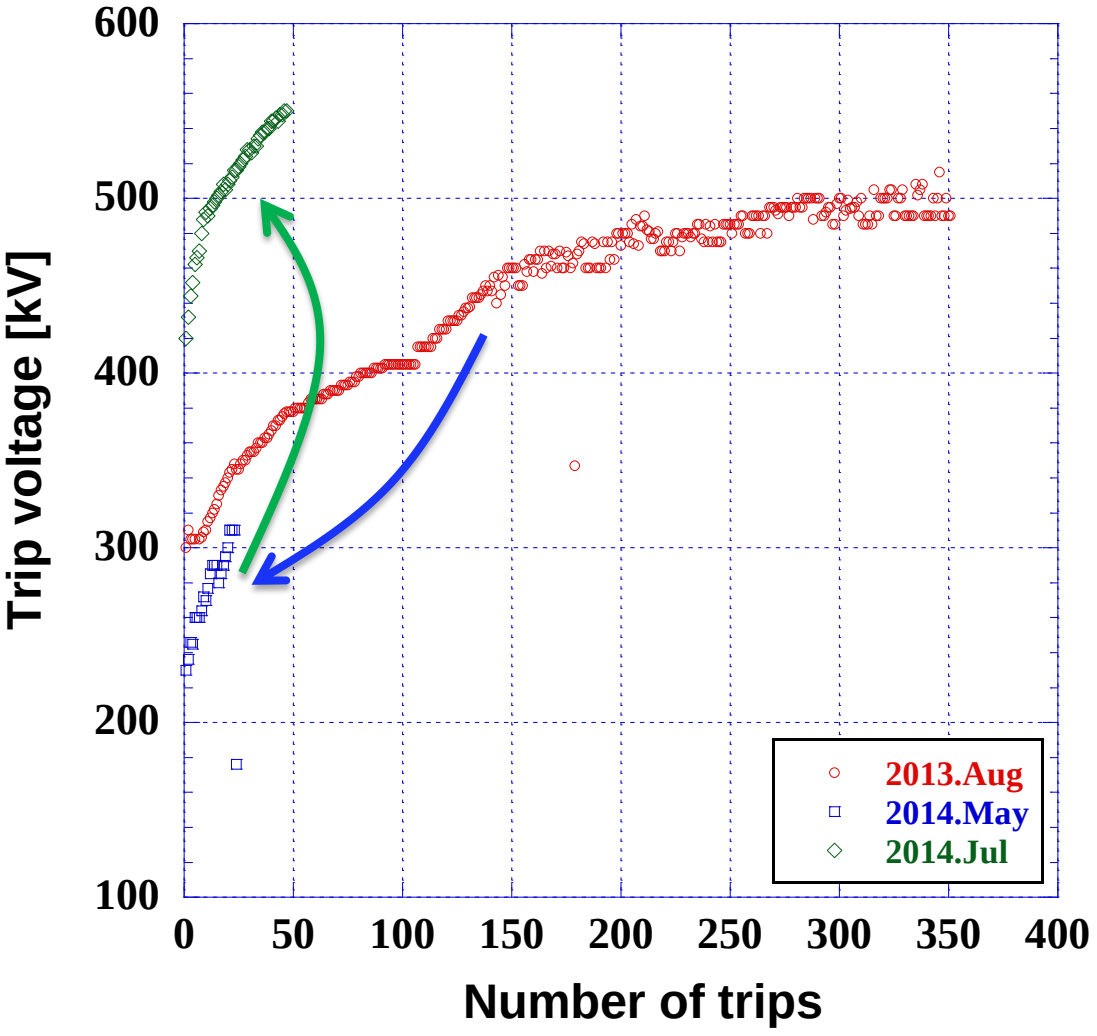




Special RGA ion source for XHV

http://www.vaclab.co.jp/product04.html

HV conditioning history (2013/Aug ~ 2014/Jul)



2013/Aug. HV Conditioning
(w/o main pump system)
reached 500 kV after ~300 trips

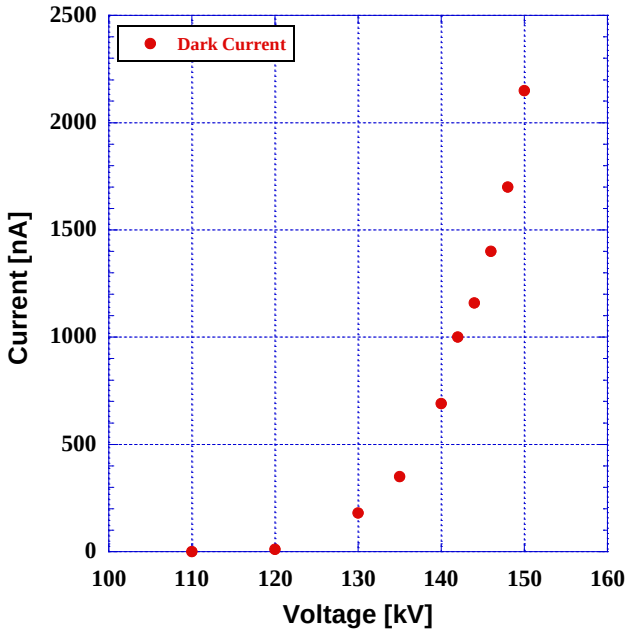
Main pump installation & baking.
XHV (~4x10^{-10} Pa) achieved.

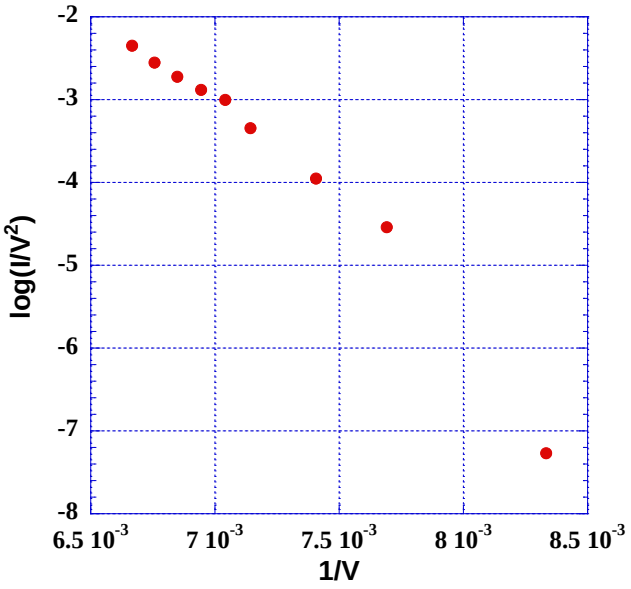
2014/May HV Conditioning
(FE source was generated after 24 trips)

Took off electrode & eliminated dust on the cathode electrode.
Set electrode and baking & rebuilt HV setup again.

2014/Jul. HV Conditioning
(reached 550 kV after 48 trips)

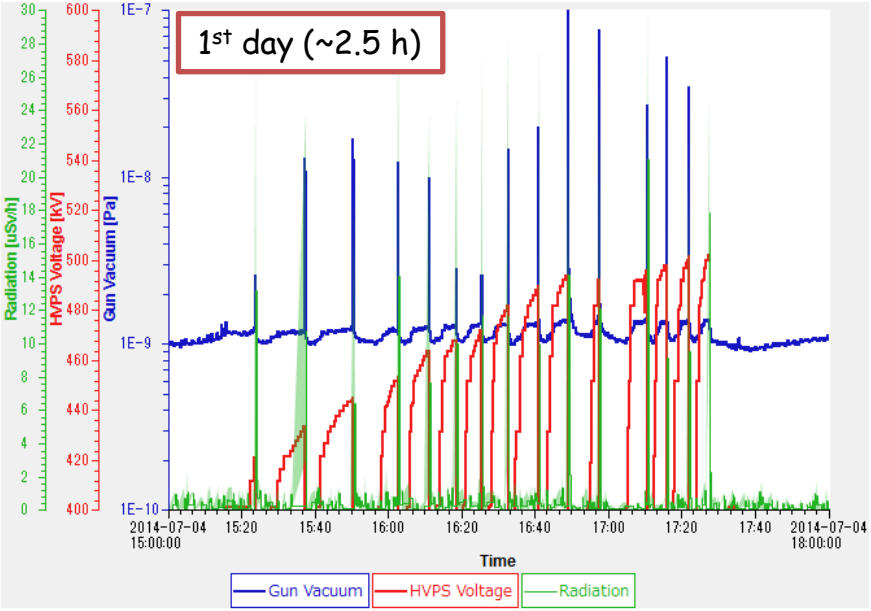
Field emission from a dust (2014/May~Jun)

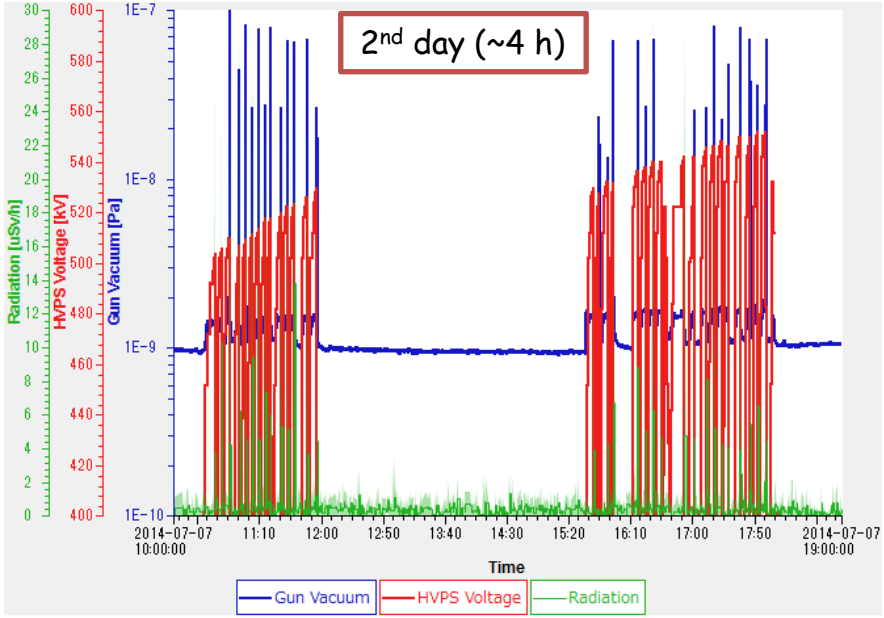


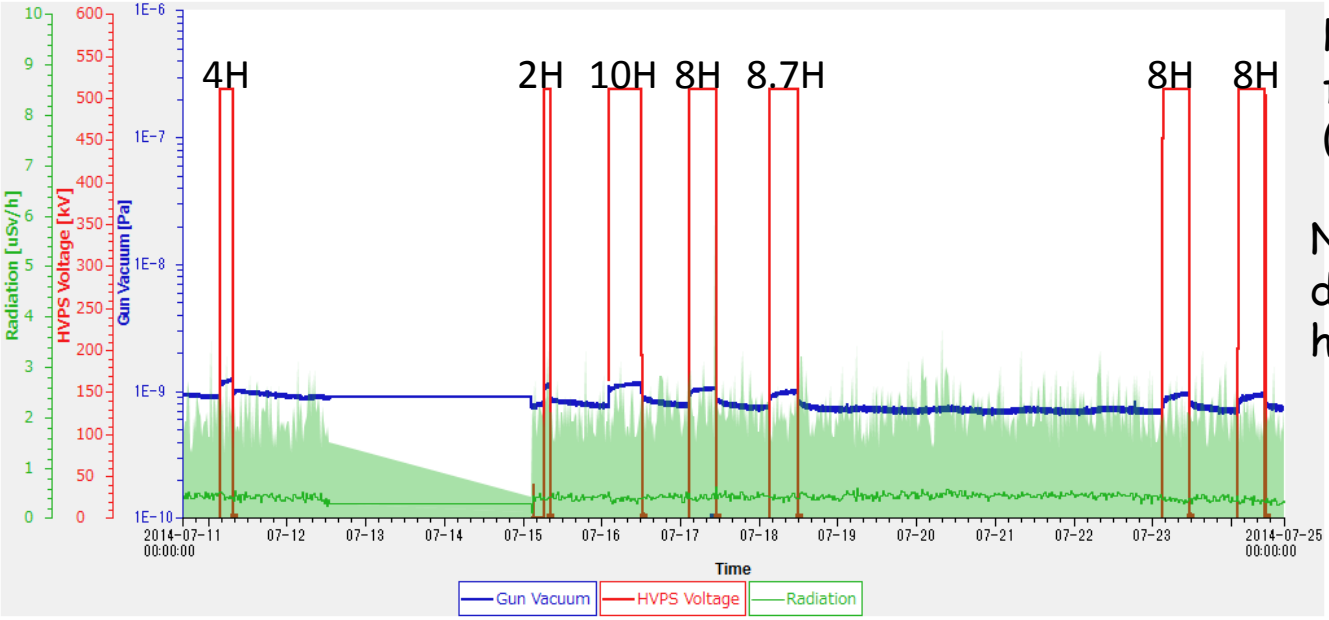


The dust was easily vanished by blowing ionized air.
Finally, the electrode was cleaned by wiping lint free cloth. (with ethanol& dry cloth)

HV conditioning & holding test (2014/Jul)



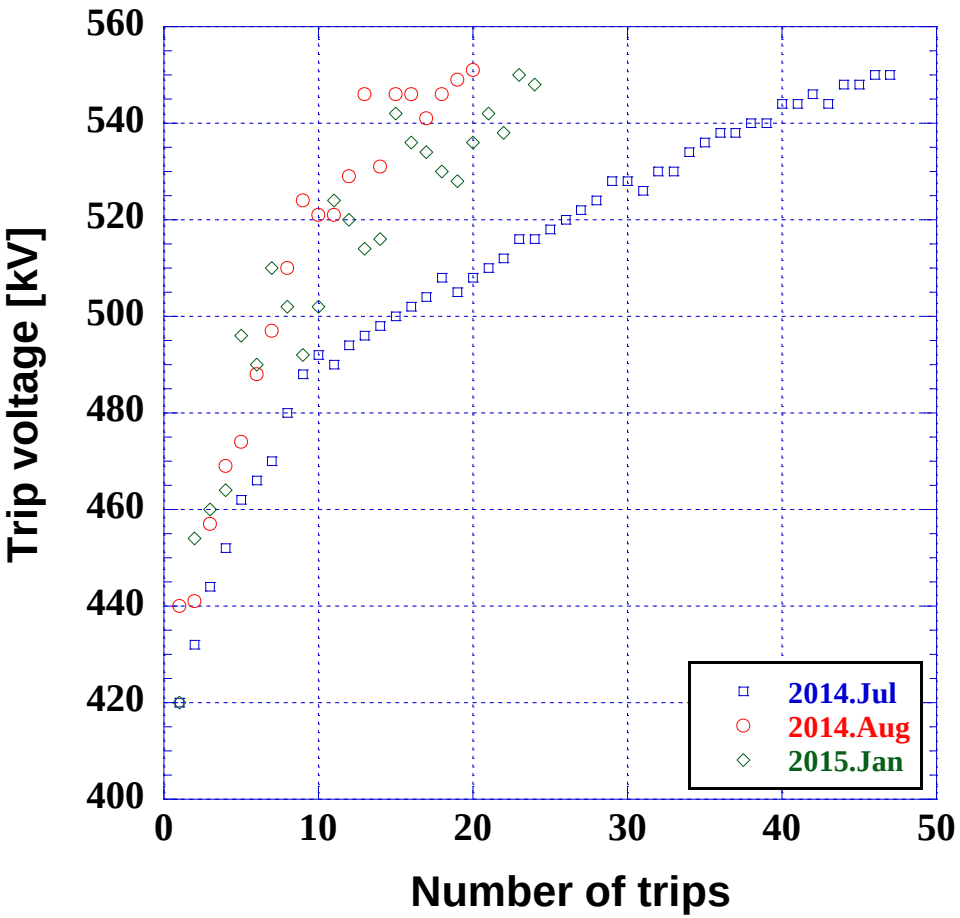




HV conditioning was finished in a short time (~7 hours).

No breakdown happened during 50 hours 500 kV-holding test.

HV conditioning repeatability (2014/Jul ~ 2015/Jan)



2014/Jul. HV Conditioning
(reached 550 kV after 48 trips)

~3 weeks shutdown
~1 week for XHV establish

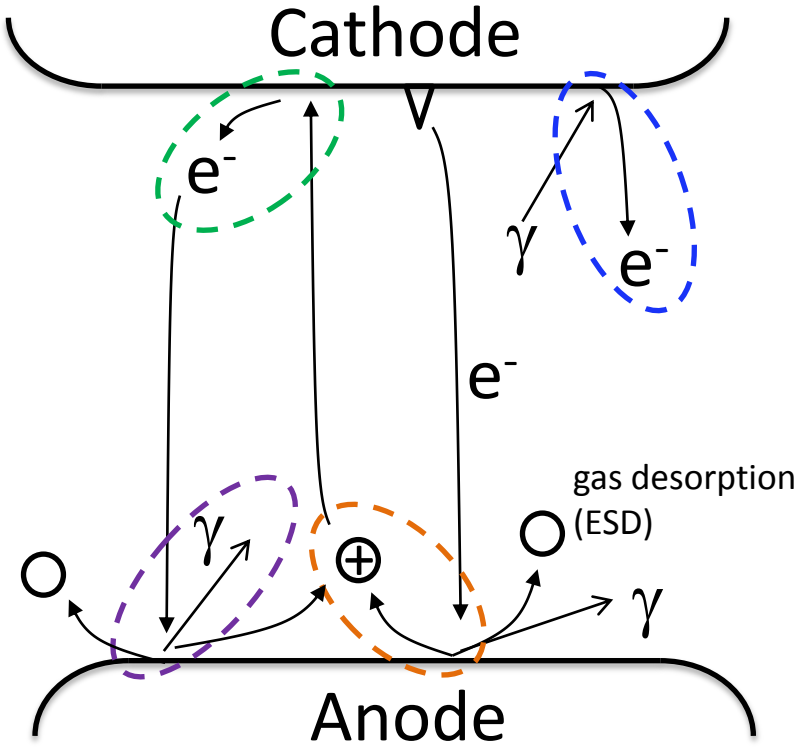
2014/Aug. HV Conditioning
(reached 550 kV after 20 trips)

~3.5 months shutdown
~1 week for XHV establish

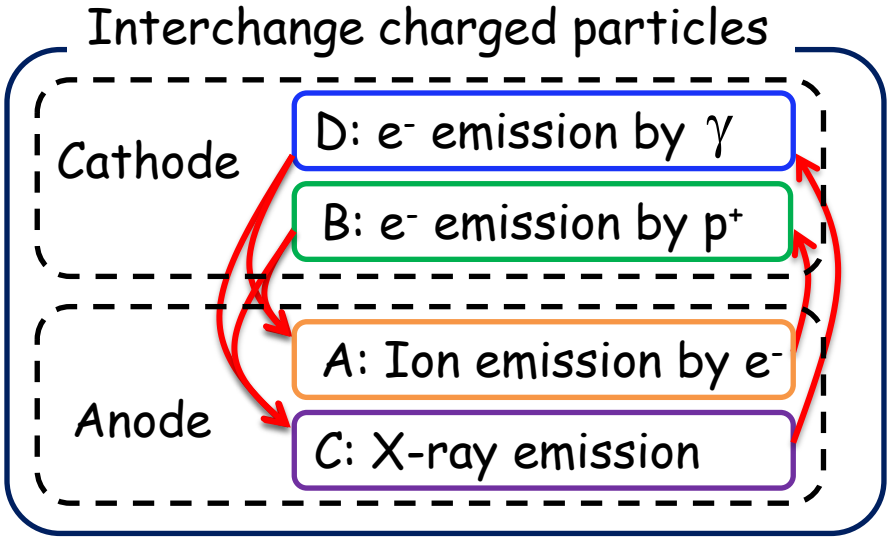
2015/Jan. HV Conditioning
(reached 550 kV after 23 trips)

Almost trip events were hardly detected emission current (≤1 nA) just before trip happened. Almost trip voltage increased continuously as if the trip voltage was memorized. How we can explain this ?

Breakdown process in vacuum gap



In case of ...
* DC bias in UHV.
* small dark current condition.
(a small seeding for breakdown process)



Four essential coefficients (A~D)

A: Electron induced ion emission
B: Ion induced electron emission
C: Photons produced by a electron
D: Electron produced by a photon

J.G.Trump & R.J. van de Graaff, J. Appl. Phys. 18, (1947) 327

$\overline{avg(A*B+C*D)>1}$

Discharging & Vacuum trip.

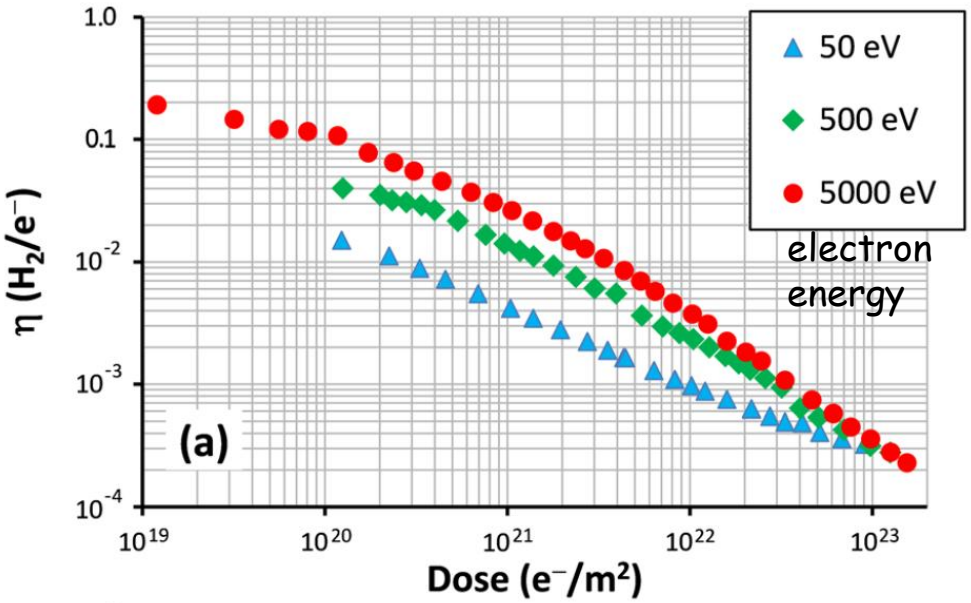
$\overline{avg(A*B+C*D)<1}$

Finished discharge phenomenon

Model of trip voltage memory phenomenon

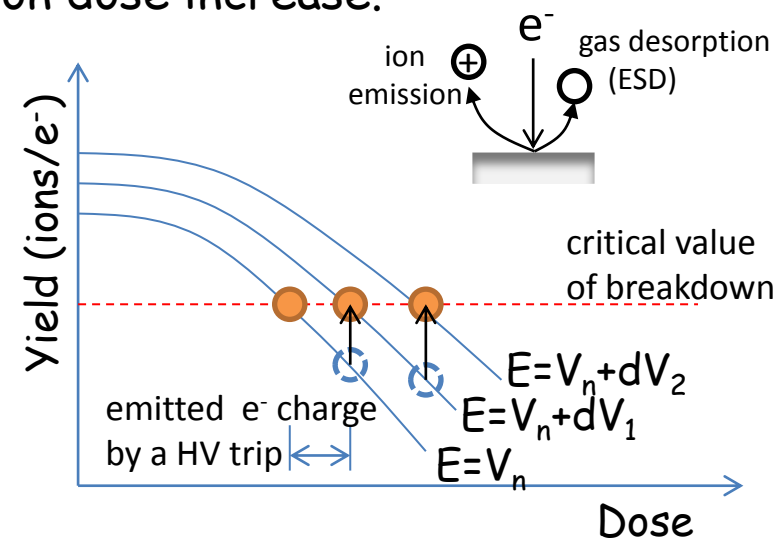
Electron induced ion (H^+,H_2^+,etc.) emission is probably related electron stimulated desorption (ESD) phenomenon.
ESD yield is decrease drastically by electron dose increase.

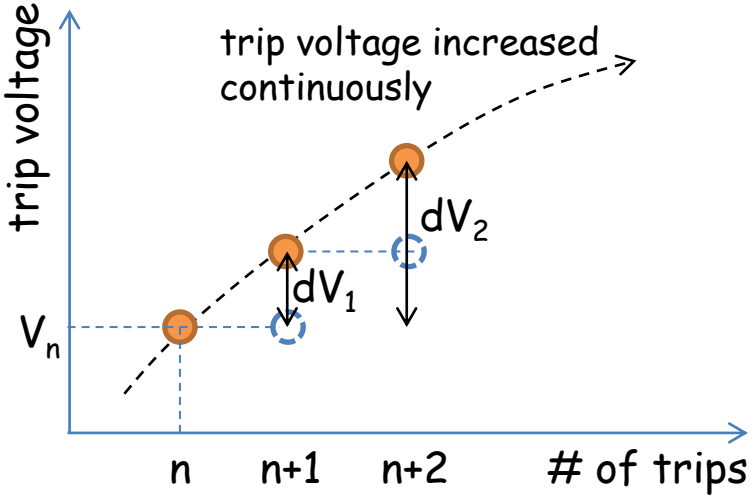
Hydrogen desorption from SUS316L



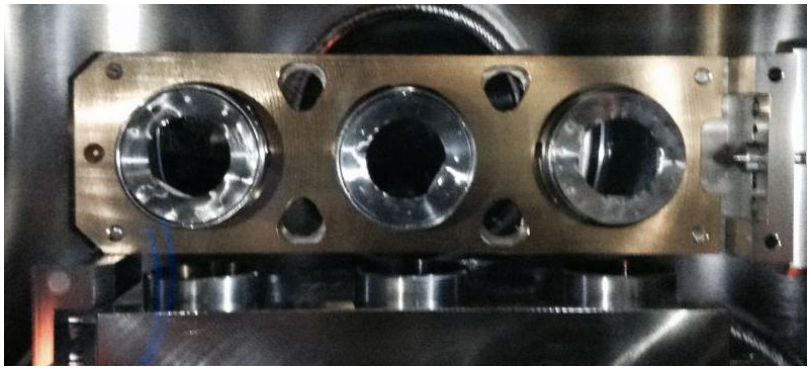
Oleg B.Malyshev et al., J.Vac.Sci.Technol.A 31 (2013) 031601

✓ ESD property of anode surface may give a important hint to know a limitation of breakdown voltage.

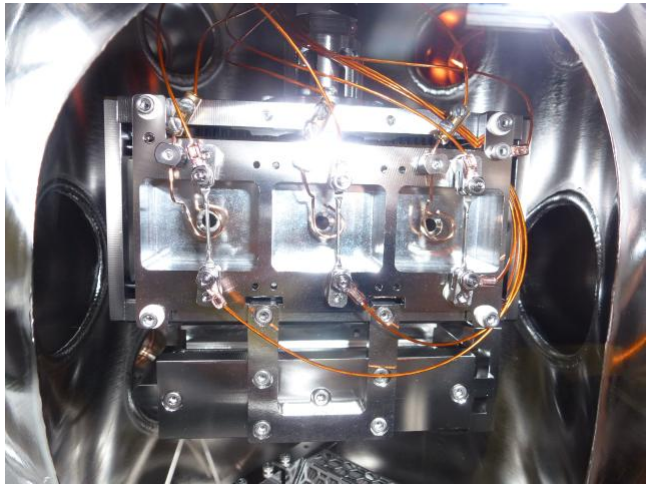




Cathode preparation system

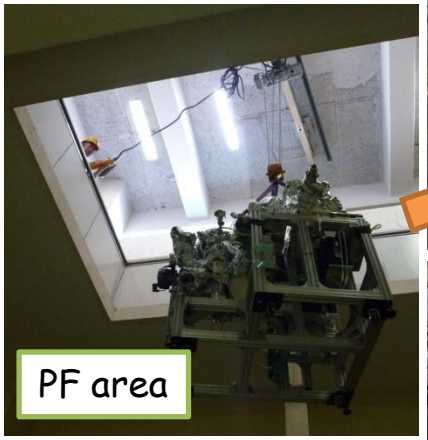


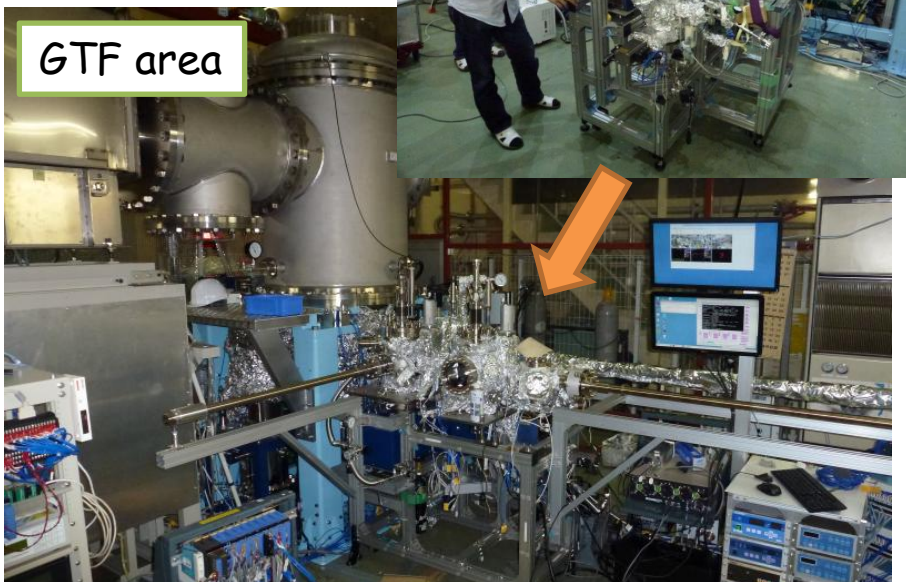
Three cathodes simultaneous activation (QE:6~10%) were successful. (2014/Sep.)



Inside view of activation chamber

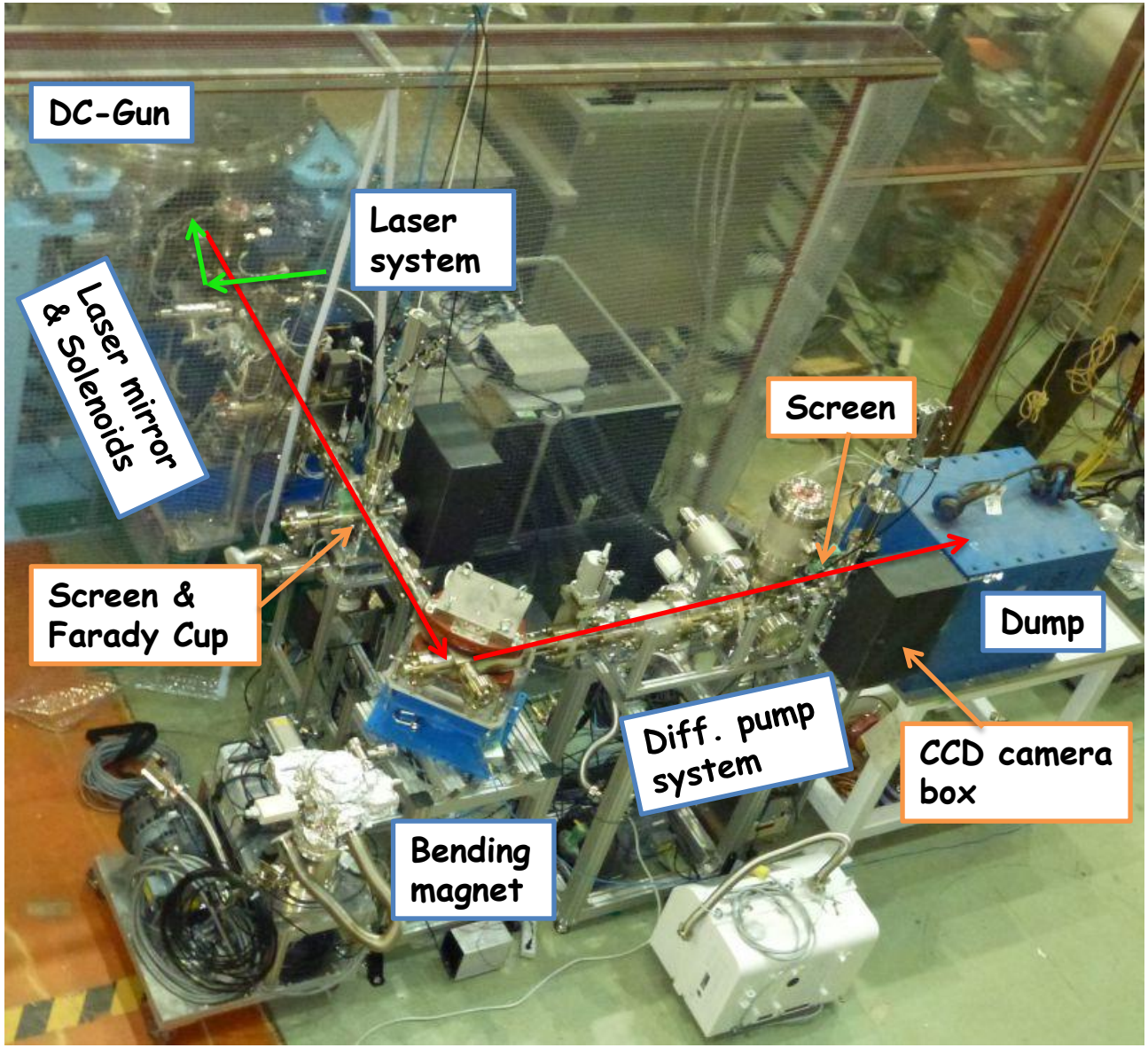
Last cathodes-activation was done in 2015/Jan. and transported to the storage chamber.
~2 months storage cathode was still alive.

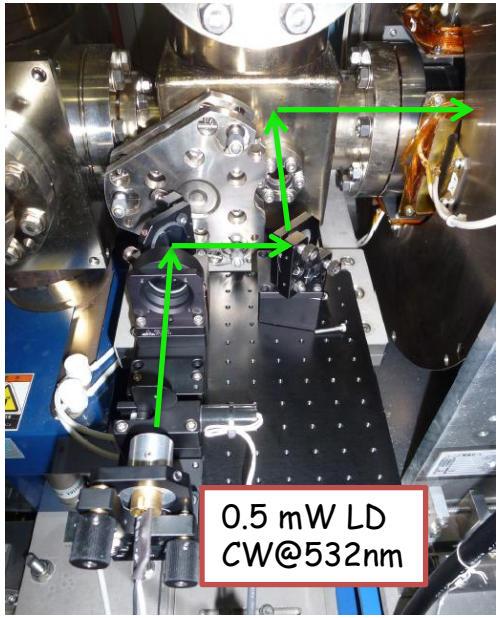




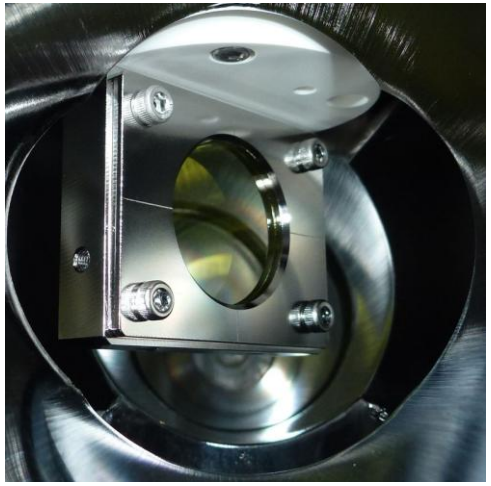
The prep. system was moved 2014/Oct.
Reconstruct & connected to the gun 2014/Nov~Dec.

Beam Transport & Dump section



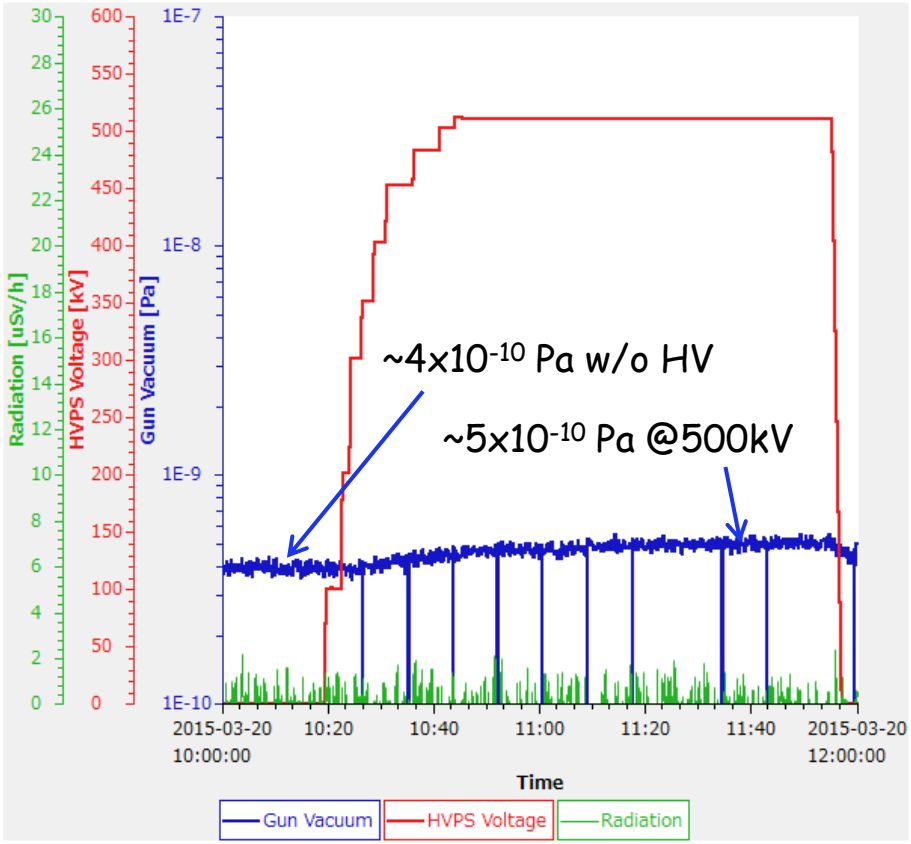


Laser system



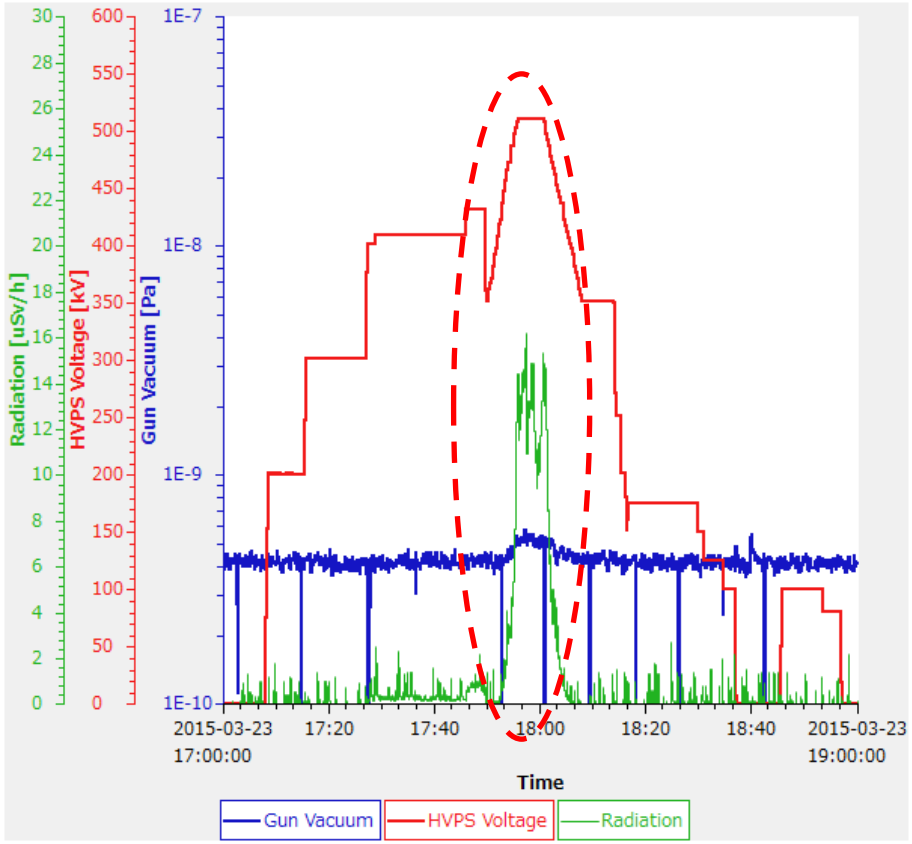
YAG screen

Field emission problem by cathode installation



Before photocathode installation
(Equipped with SUS dummy puck)

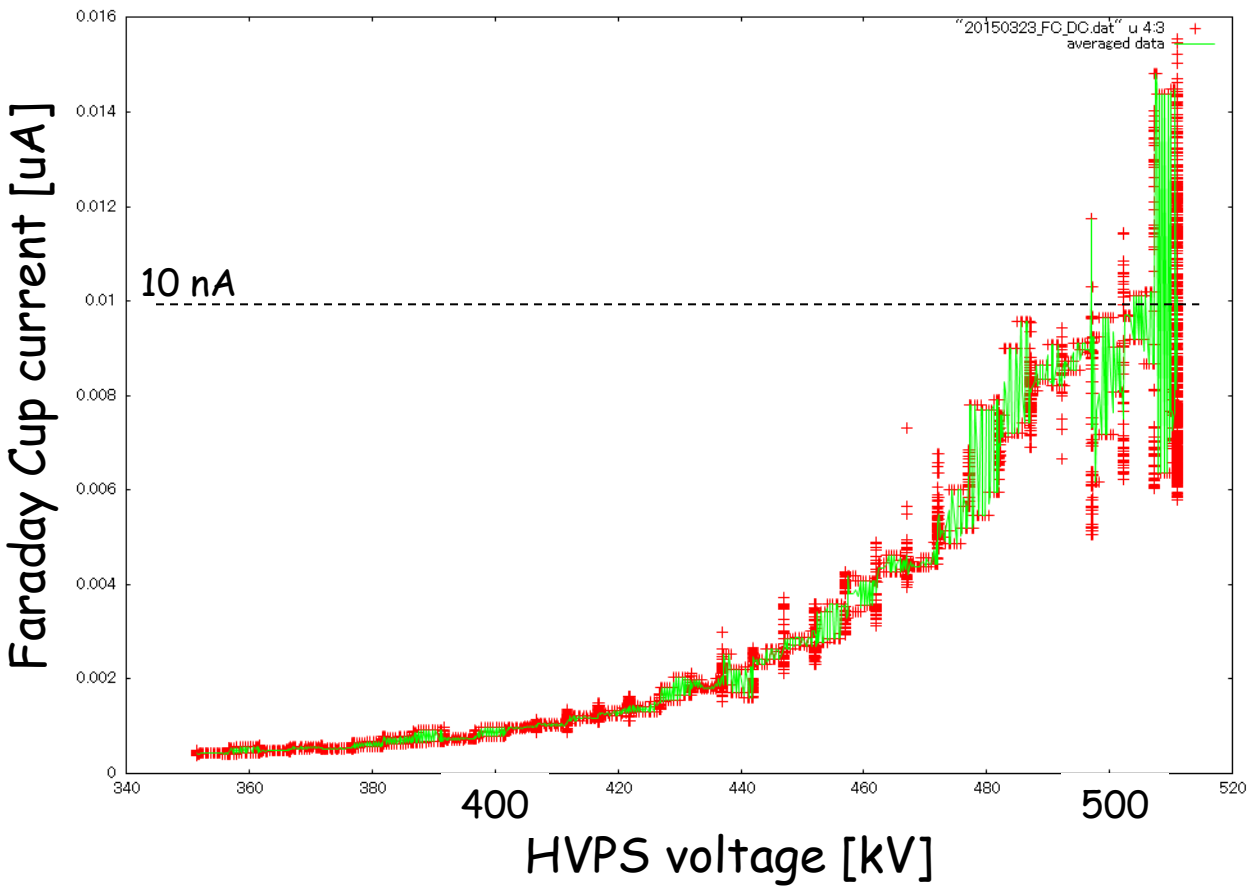
Only BG level radiation, dark current (<1 nA) were detected under a 500 kV condition.

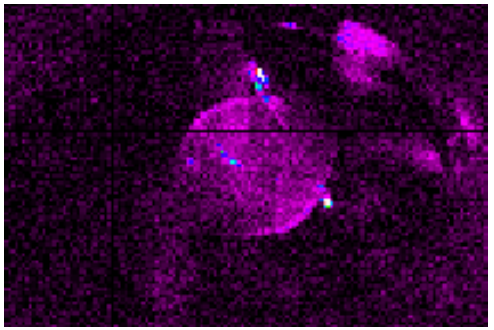


After activated photocathode installation
(Bulk GaAs)

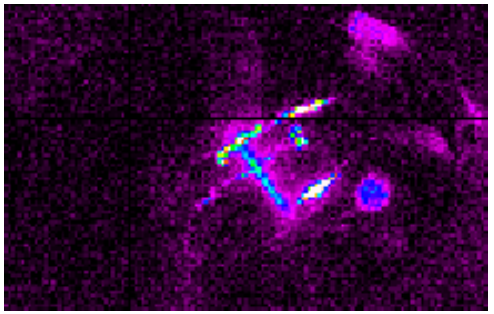
About 15 uSv/h radiation, ~4 nA dark current to anode electrode were detected under a 500 kV condition.

Dark current beam profile (w/o laser irradiation)

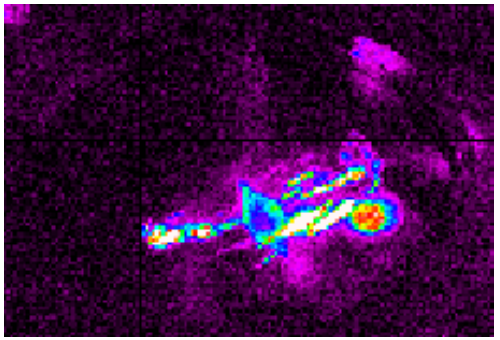




350 kV



400 kV



450 kV

Photoemission by stray light of ion gauge was exist. (<0.5 nA)

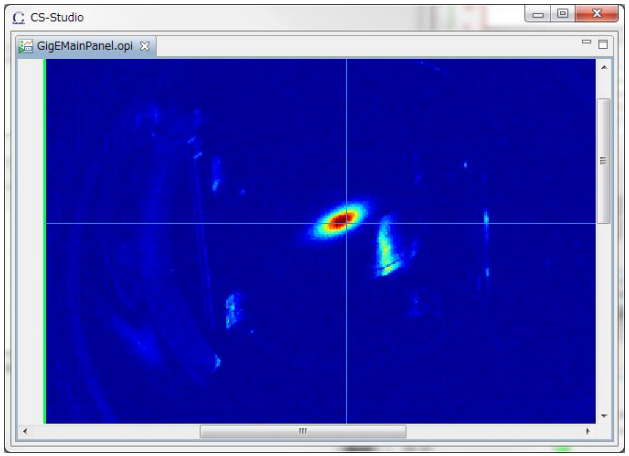
Some field emitters exist near the photocathode. Field emission current was increased when the gun voltage over 400 kV.

Summary

- Extreme high vacuum was established by NEG & bakable cryopump.
- HV conditioning up to 550 kV & 50 hours holding test of 500 kV were successful.
  - Fortunately, FE problem was solved by easy way.
- A model of trip voltage memory mechanism was proposed.
- Cathode preparation system was constructed.
  - Three cathodes simultaneous activation was successful.
  - ~2 months storage cathode was alive.
- Unfortunately, FE problem was come back by a cathode installation.
  - Investigations of FE source & the point at issue are underway.

Now & Feature plan

- 400 keV beam study is just started.
- Preparations for mA class high current cw-beam operation are underway.
  - Radiation shield
  - Water cooled beam dump
  - Fast interlock system



400 keV beam profile near the dump (with laser irradiation)

Acknowledgement

H. Iijima for construction beam transport & dump line and many wiring works.
T. Michikawa, S. Nagahashi, R. Takai and T. Obina for making a lot of IOC programs and many advices about devices control.
F. Watanabe for advice of XHV measurements.