Electron sources at ATF/LUCX facility of KEK Part-II

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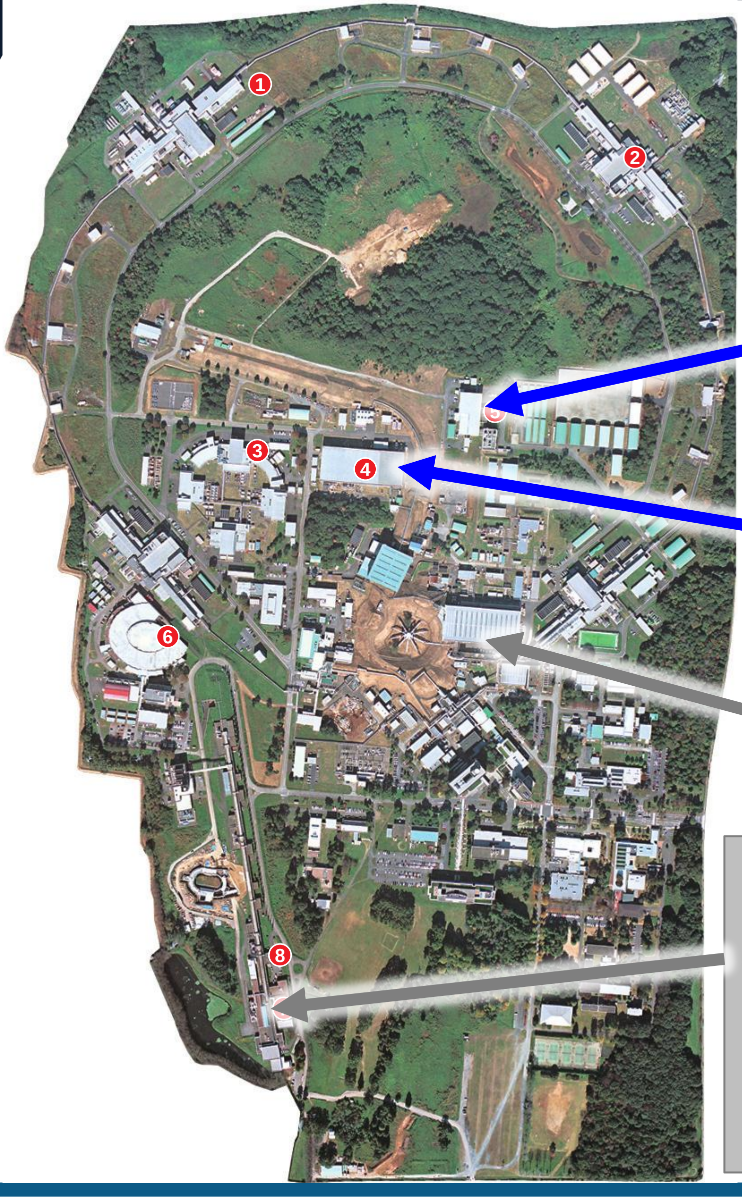
16 February 2015

Part-II

focused on experiences of Cs_2Te photocathode at KEK

- preparation and transport
- experiences with the RF gun

Electron sources of the KEK Accelerators



Cs_2Te photocathode RF gun
- well established
- compact and longer lifetime

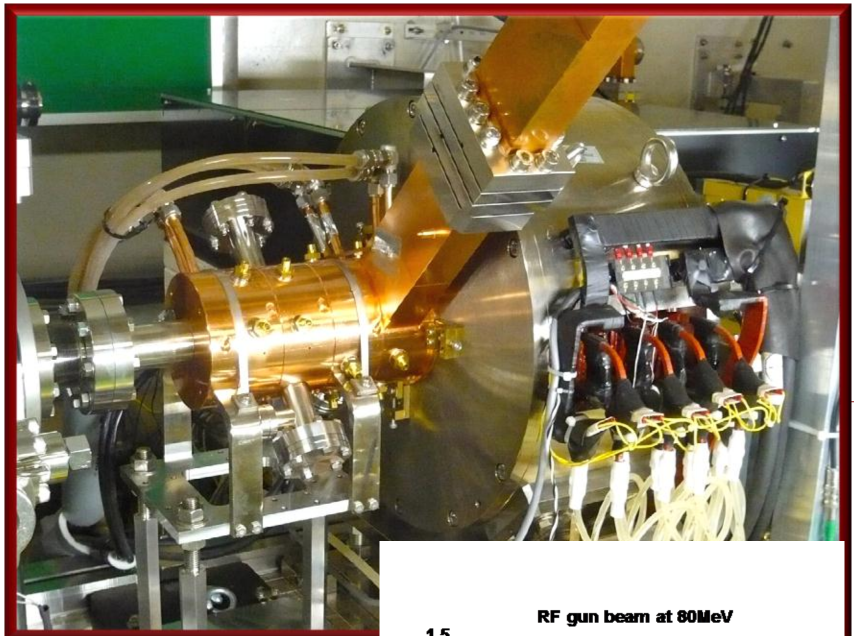
STF
L-band 1.3 GHz

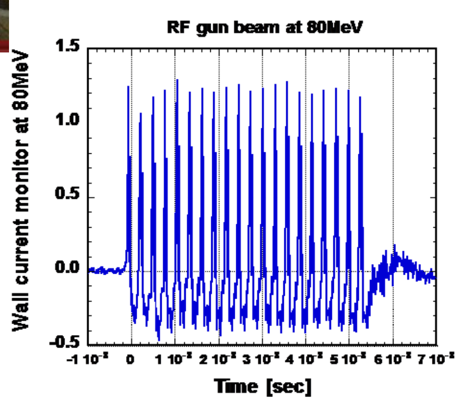
ATF/LUCX
S-band 2.8 GHz

cERL (500kV DC gun for CW)
GaAs photocathode

KEKB
Thermionic Gun
SuperKEKB
Quasi traveling wave side coupled cavity gun
advanced, under development

Electron source of ATF





Cs_2Te Photocathode RF Gun

RF gun: S-band 3.6 cell

Typical operation for ATF

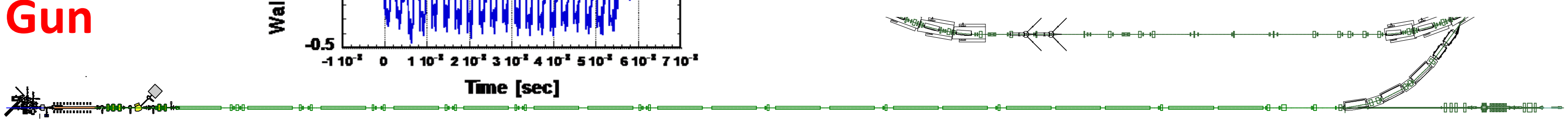
- **5 MeV** (limited by available RF power)
- 1~20 bunch/pulse (2.8 ns spacing)
- **$1x10^{10}$ electrons/bunch**
- 3 Hz repetition

Laser

- Nd:YAG: 266 nm
- 357 MHz
- 1 uJ/bunch
- 1~20 bunch by pockels cell

Cathode

- **Cs_2Te: QE ~1%**



1.3 GeV S-band Electron LINAC (~70m)

Present merits of Cs_2Te photocathode

Photocathode	QE	
Pure Metals (Cu, Mg,…)	$10^{-5} \sim 10^{-4}$	• UV laser • can handle in air • back bombardment
Cs_2Te	**$10^{-2} \sim 10^{-1}$**	• UHV is required, Oxidation • UV laser is required • longer lifetime • well established
Multi-Alkaline CsKSb,…	10^{-2}	R&D phase **attractive green laser response**
Others,…	…	…

Higher intensity e- beam generation by a reasonable laser power

example for ATF:

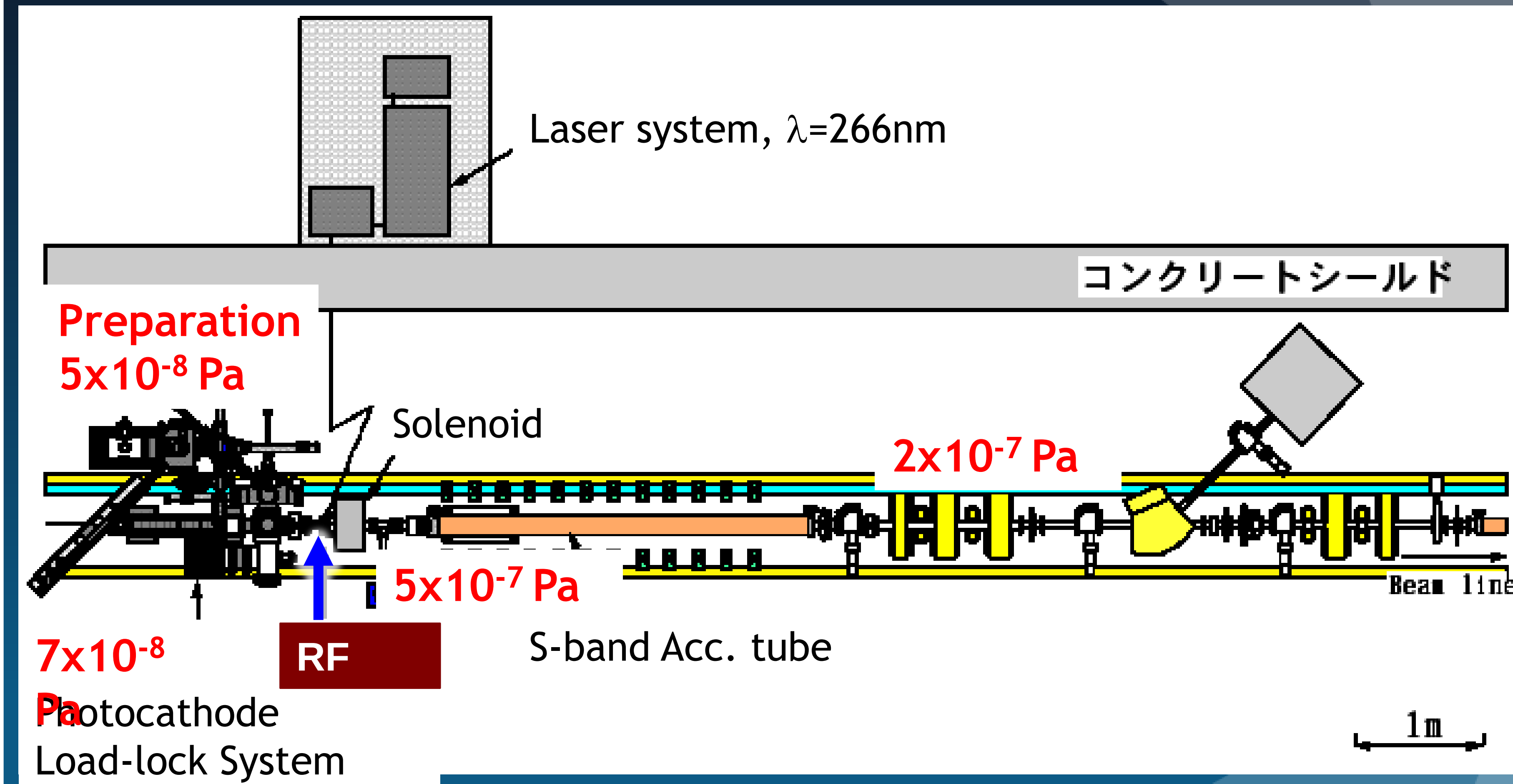
$$2\times10^{10}\ e^-/\text{bunch} = 1\ \%\ (\text{QE}) \times 2\ \mu\text{J/laser-pulse}$$

QE (Quantum Efficiency)
= Number of electrons / Number of laser photons

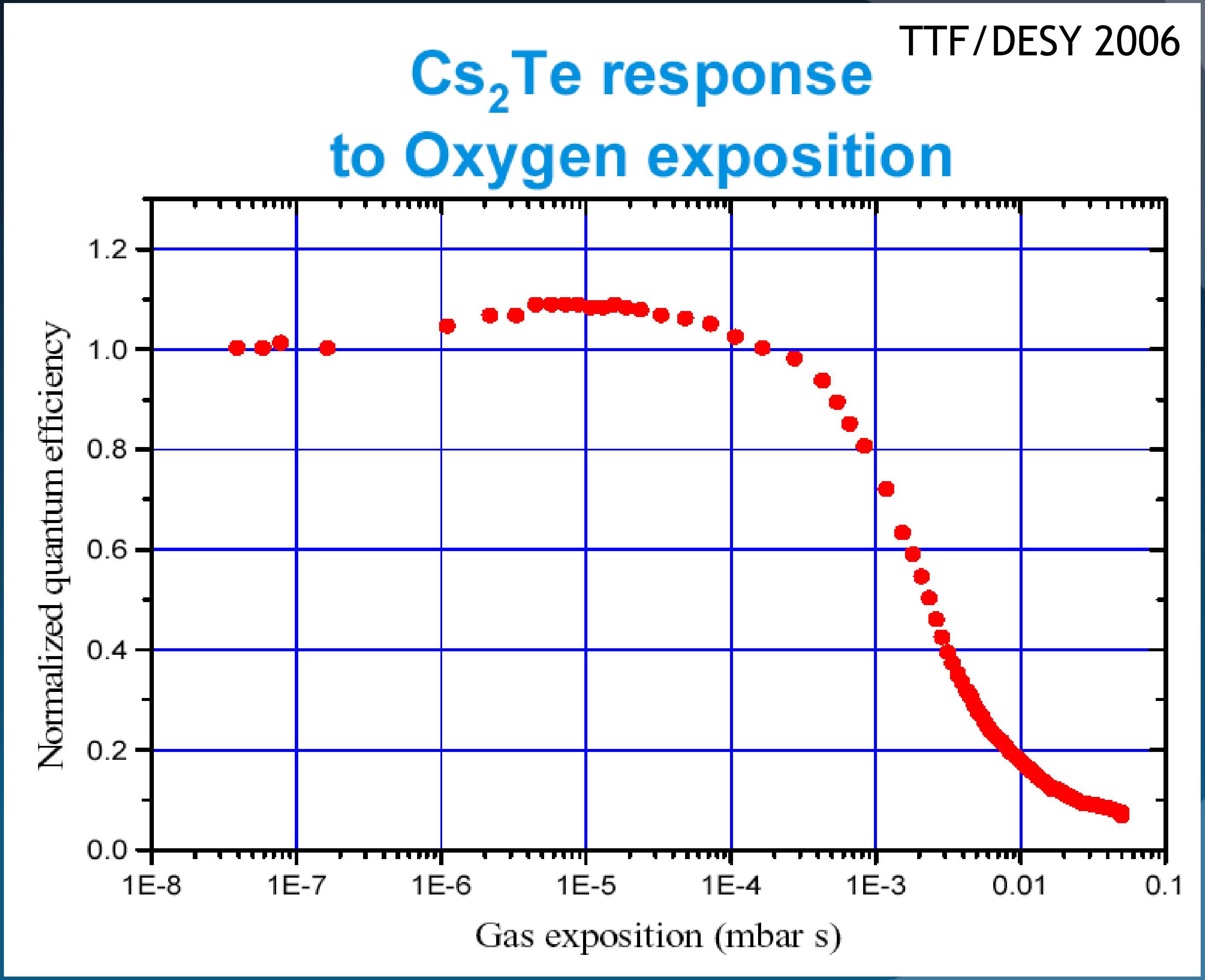
Handling in vacuum

- Cs_2Te photocathode should be handled in UHV to keep QE.
- How good vacuum is required?
- ATF RF gun: 5×10^{-7} Pa
- QEs of early samples after the vacuum work were low even if the pressure reached nominal level.
- QEs of later samples, after several Cs_2Te preparations, become better and better. Pressure was not improved significantly.
- Oxidation of the Cs_2Te layer is a major candidate of degradation of QE.
- Vacuum quality, amount of oxygen, should be considered.

Vacuum pressure around the ATF 80MeV Injector



Handling in vacuum

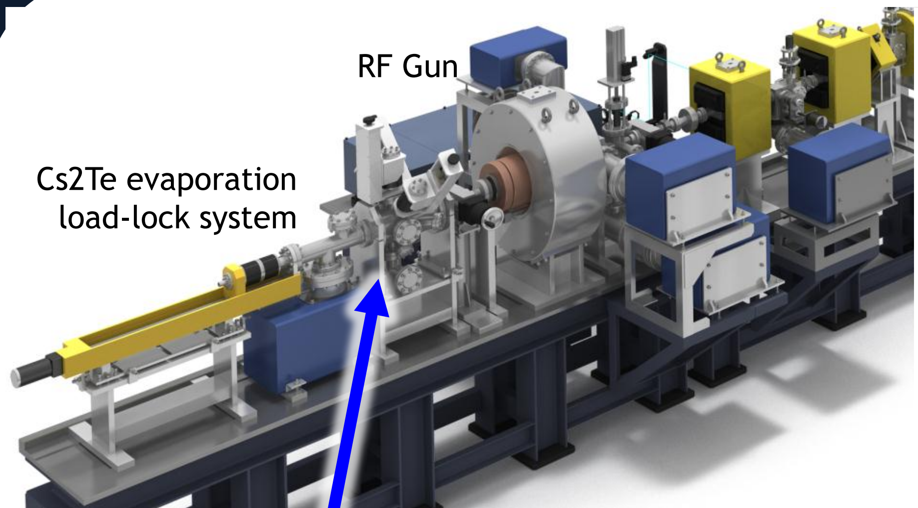


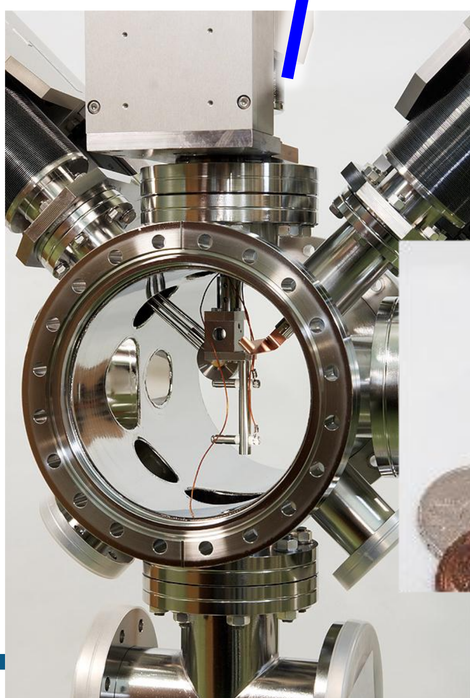
Photocathode transport in vacuum

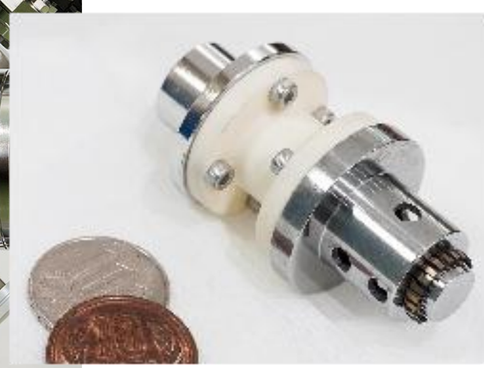
- STF system
  - continuous vacuum connection
  - preparation system is just behind the RF gun
- ATF system
  - continuous vacuum connection, sectioned by valves, between Cs_2Te preparation and RF gun
  - preparation system is far from the RF gun
- LUCX system

  separated; cathode is transferred by in vacuum carrier

STF photocathode system





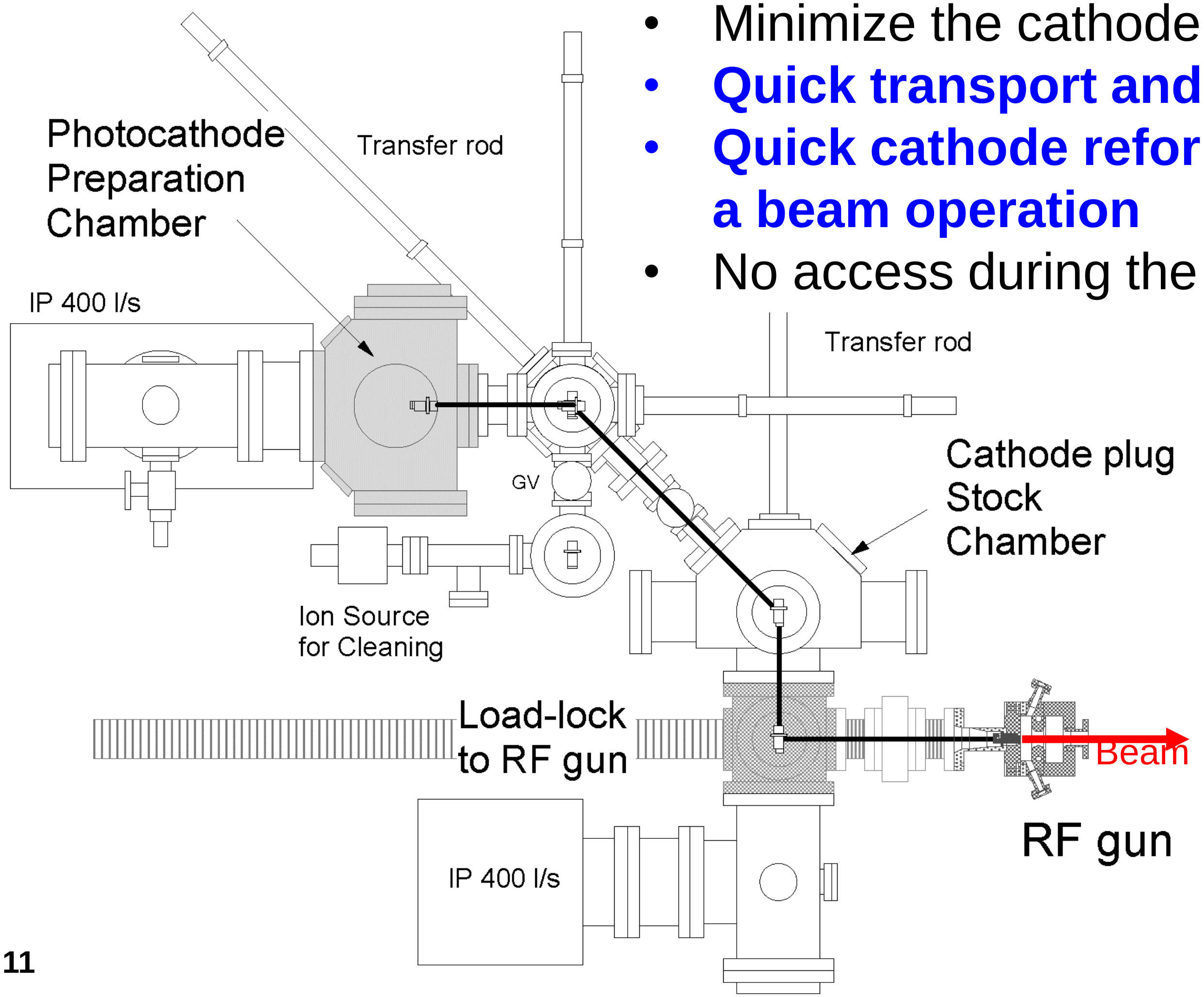


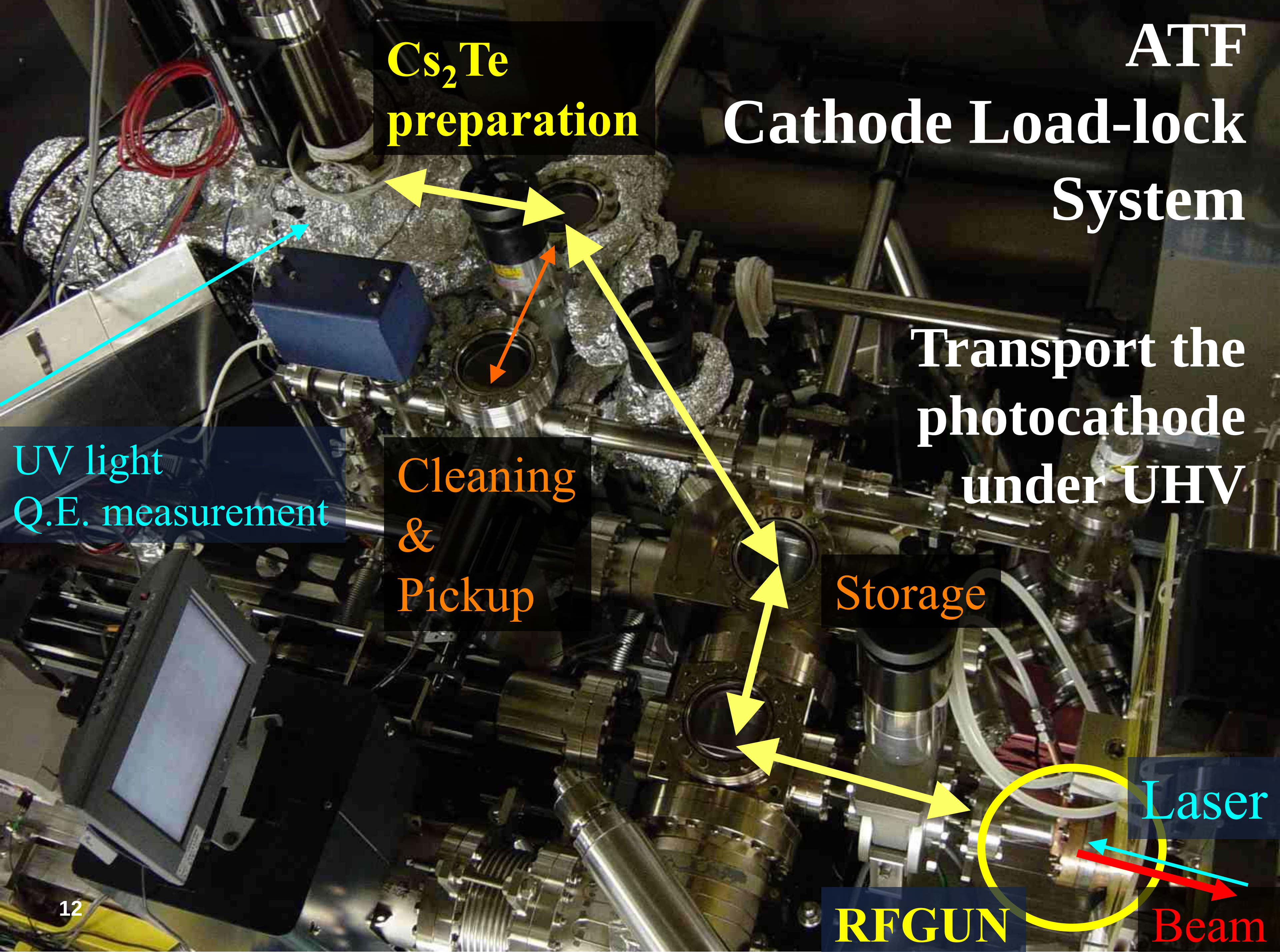
L-band RF Gun
Cs_2Te Photocathode

- **Evaporation system**
  - **similar method as ATF/LUCX**
  - **located behind the RF gun**
- **Cathode plug**
  - **Mo for cathode substrate**
  - **ceramic isolator**
- **Laser**
  - Nd:YAG: 266 nm
  - 162.5 MHz, 1ms, 5 Hz
  - pulse width 12 ps
- **Cathode**
  - **Cs_2Te QE: 0.2~0.5%**

ATF Cs2Te photocathode preparation and load-lock system

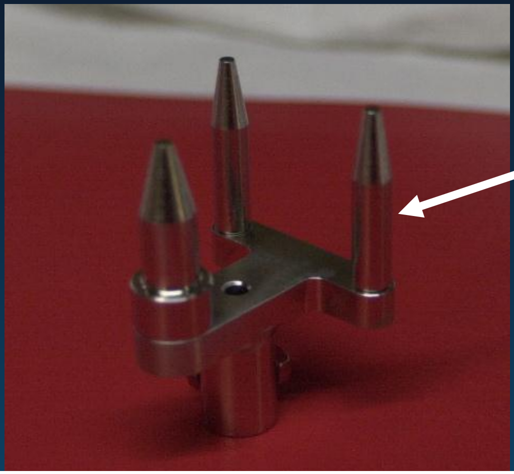
- **No vacuum break transportation**
- Minimize the cathode oxidation
- **Quick transport and QE meas.**
- **Quick cathode reformation then resume a beam operation**
- No access during the ATF operation





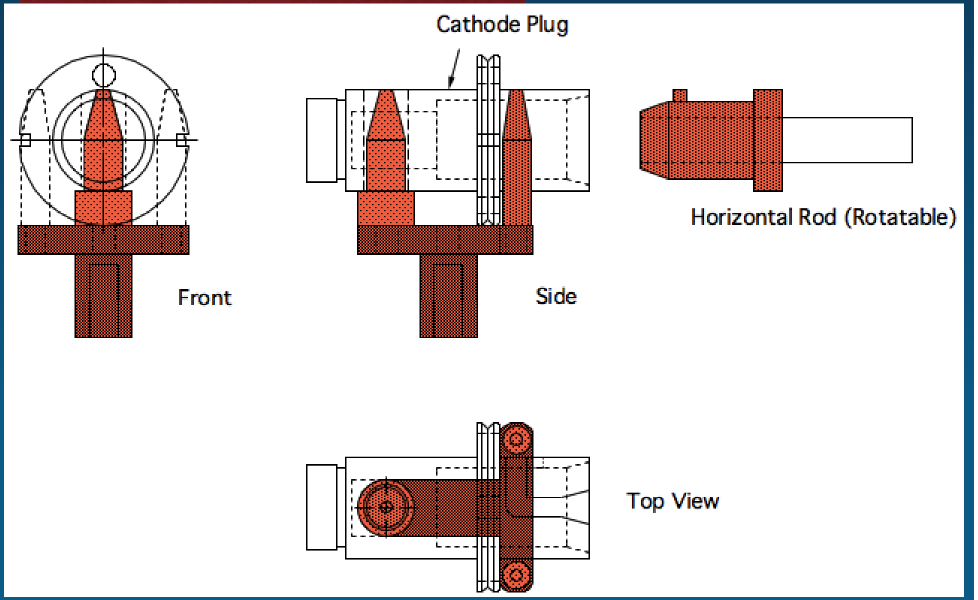
ATF
Cathode Load-lock
System
Cs_2Te
preparation
UV light
Q.E. measurement
Cleaning
&
Pickup
Transport the
photocathode
under UHV
Storage
Laser
RFGUN
Beam

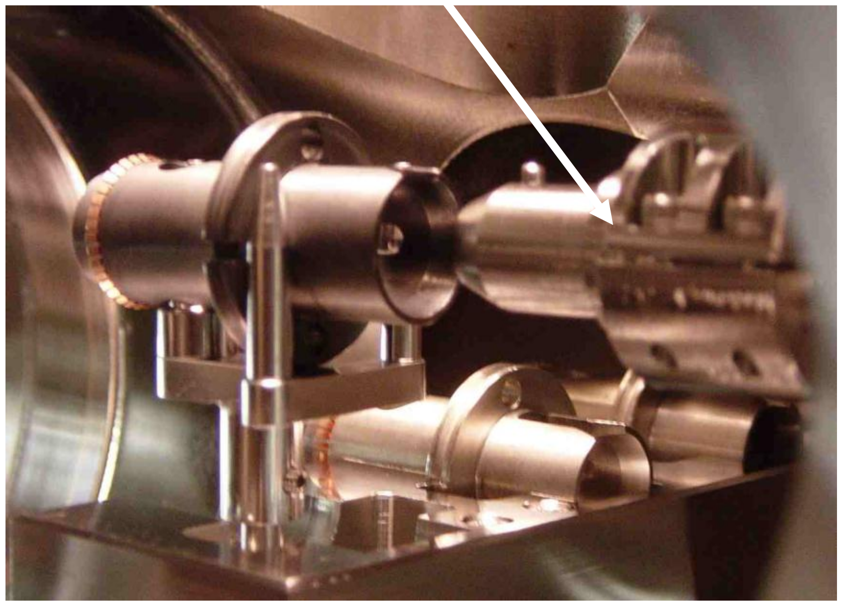
Transport tools of cathode plug



Plug mount for vertical rods
Up/down and rotation

Horizontal rod
Rotate to lock the cathode plug

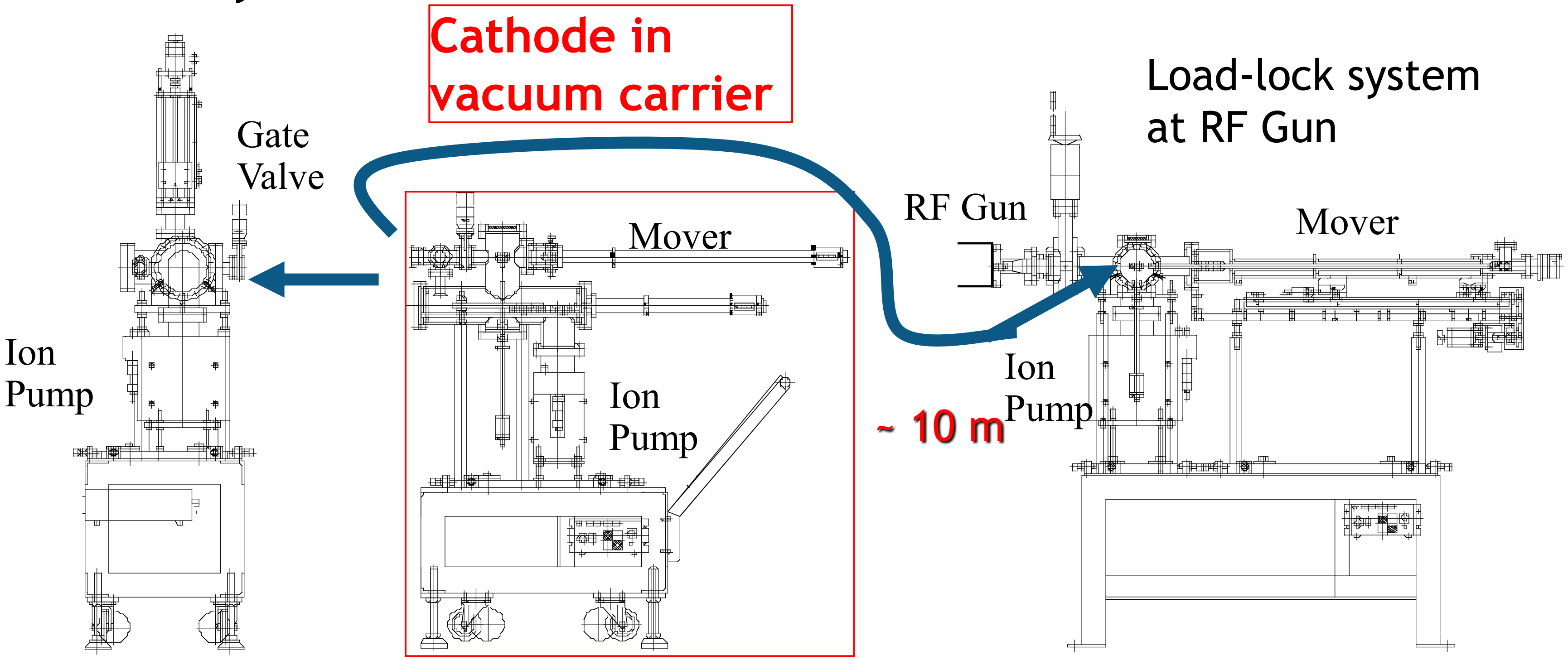




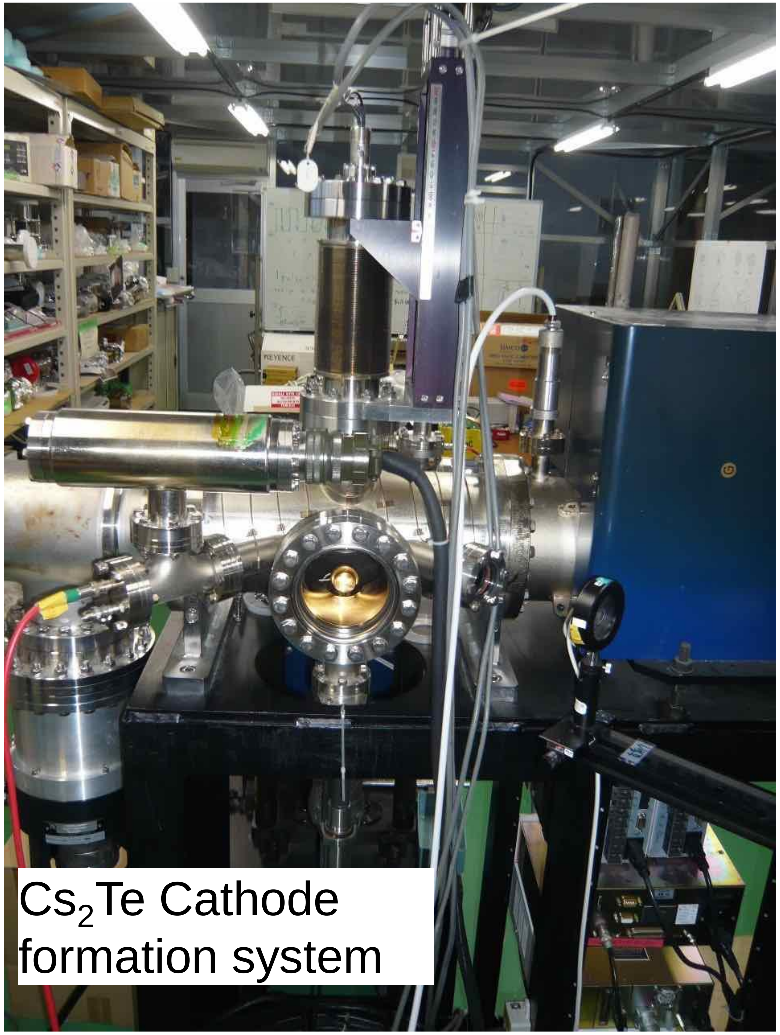
LUCX photocathode system

A carrier box with ion pump is also used to transport the cathode from KEK to Universities.

Cs_2Te Cathode formation system



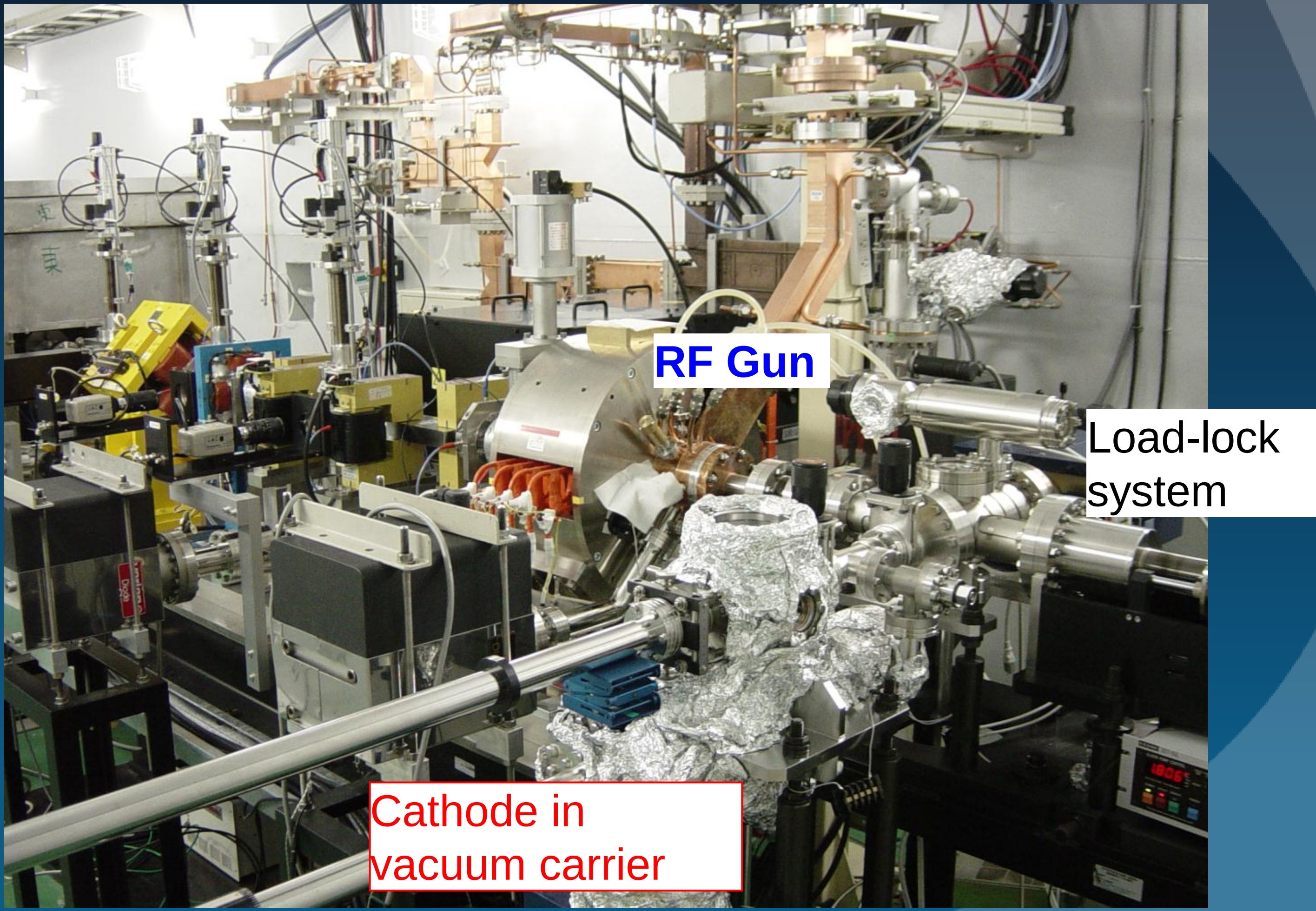
LUCX photocathode system



Cs_2Te Cathode formation system

Cathode in vacuum carrier

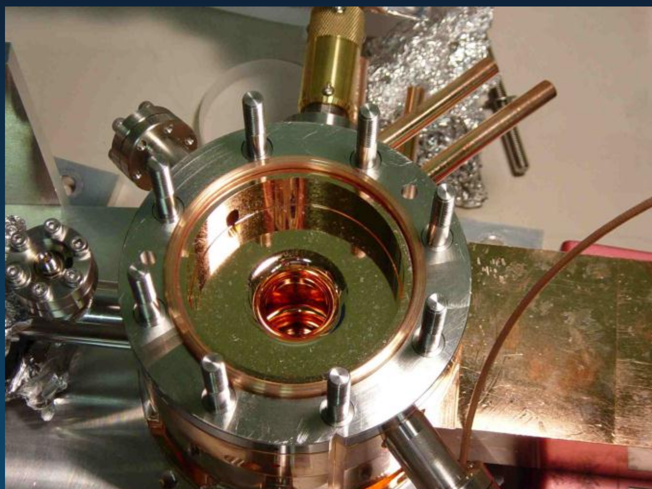
LUCX accelerator and cathode transport

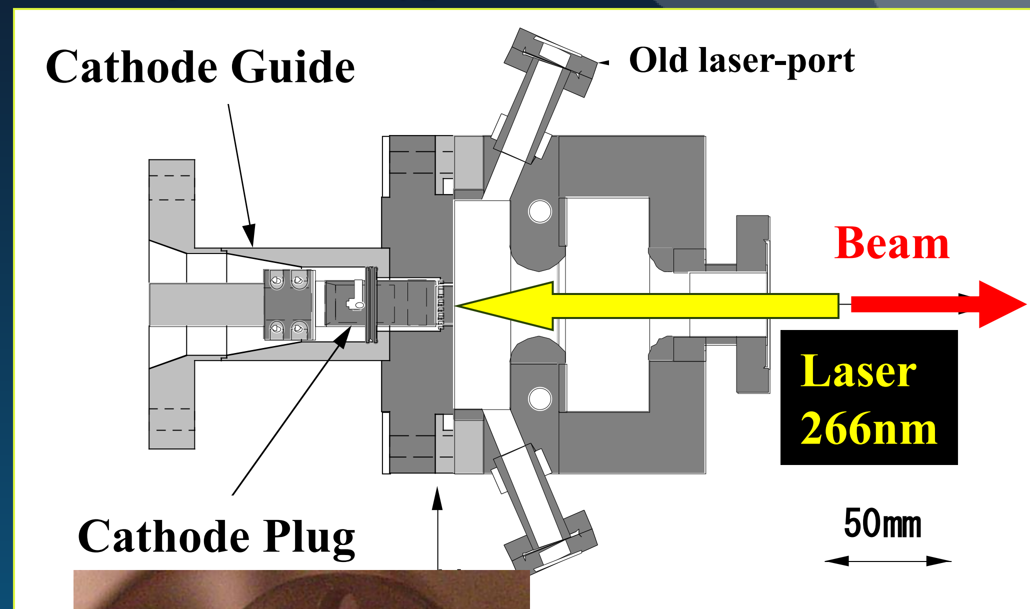


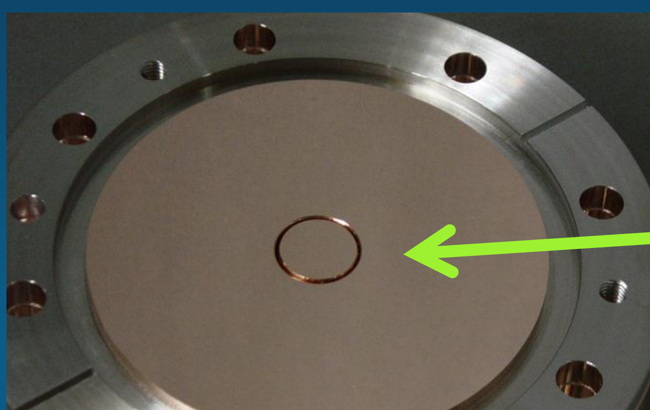
How the photocathode attached on the RF gun?

Example: First Cs_2Te RF Gun at KEK

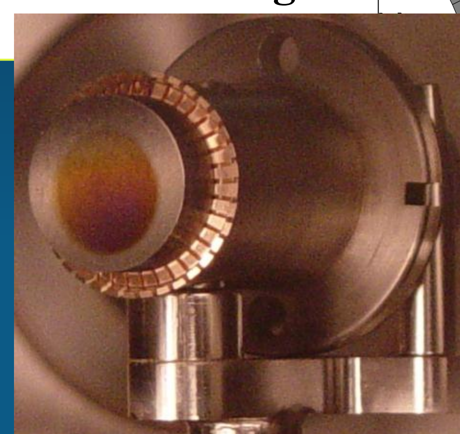
Modified BNL type IV: 1.6 cell, 2856 MHz





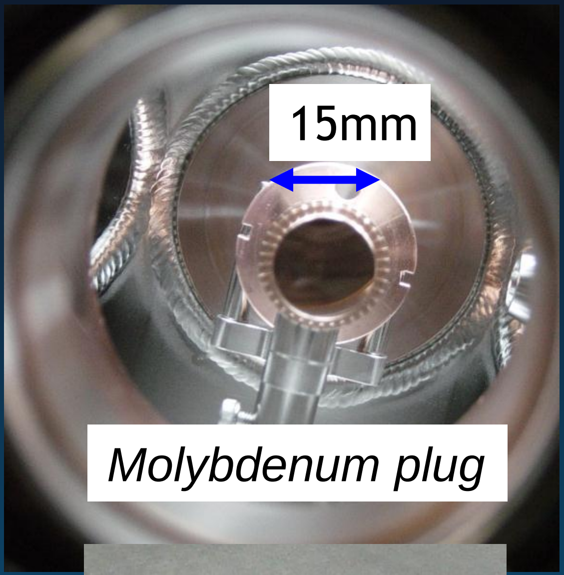


End-plate with Cathode plug



Spring Contactor

Molybdenum substrate for Cs_2Te



Mo is used for the cathode substrate.

Cu was also tried for the commissioning of the first Cs_2Te RF gun at KEK in 2002.

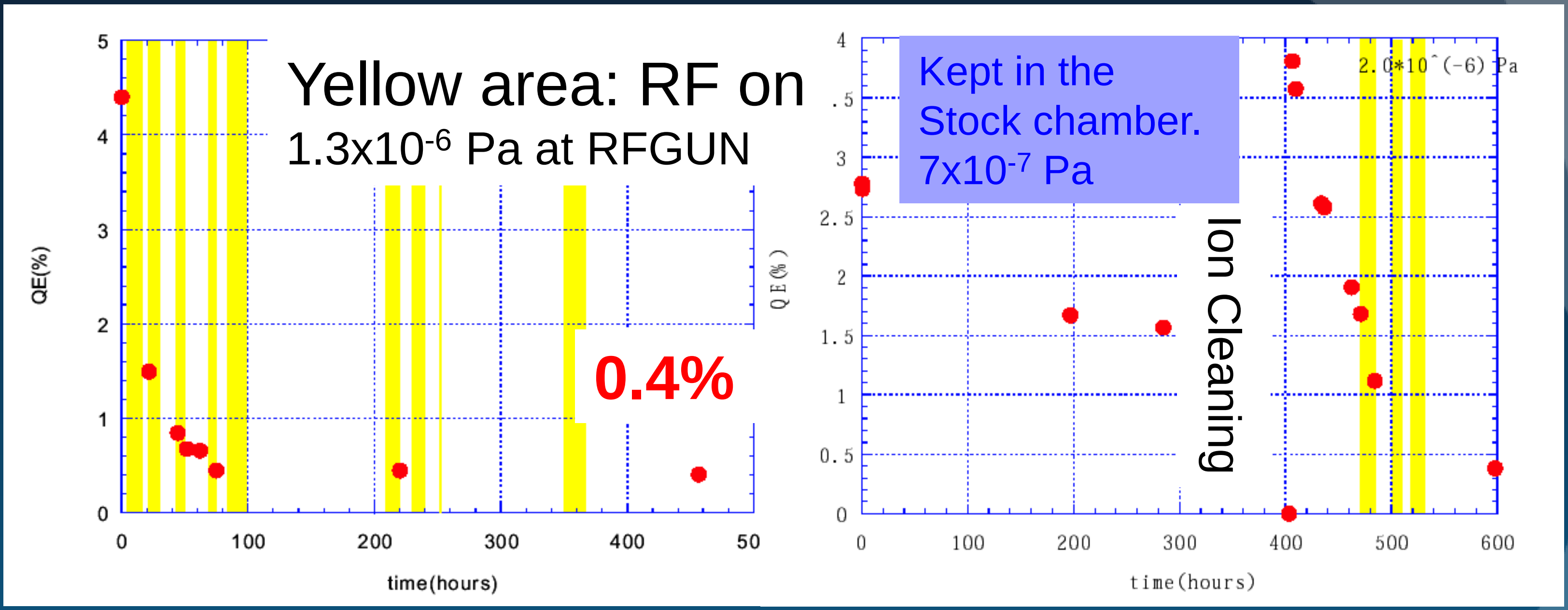
It shows **lower and unstable QE** compare to that of Molybdenum.

Mo plugs for Cs_2Te RF guns at KEK

- **Mirror polished surface**
- Ultrasonic cleaning by Ethanol/Acetone after the machining.
- No other chemical treatment is applied.
- **Ar^+ ion or heat cleaning**

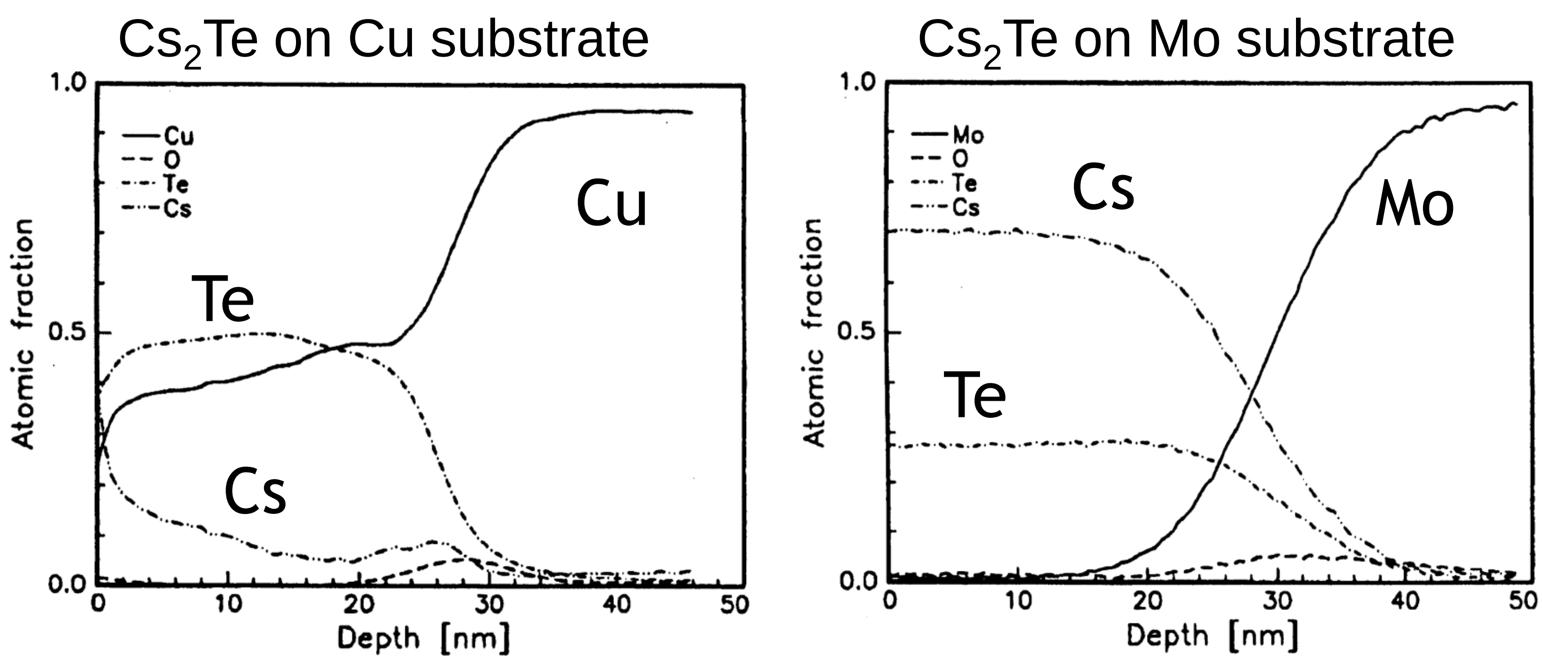
QE of the Cs_2Te photocathode on Cu

Cu-No.1 | Cu-No.2



Vacuum pressure was not good at this commissioning stage but the later Mo sample showed 3% of QE under similar vacuum condition.

Molybdenum substrate for Cs_2Te



A di Bona et al., "Auger and X-ray photoemission spectroscopy study on Cs2Te photocathodes", J.Appl.Phys.80 No.5(1996)3024-3030

Auger analysis shows the ideal atomic fraction for Mo substrate.
It will be a reason of the higher QE than Cu substrate.

Preparation of the Cs_2Te photocathode

Step 1: Surface cleaning

- Argon-ion sputtering is used for ATF to cleanup the substrate surface.
- No heat-cleanup because of the Be-Cu contact on plug.

Step 2: Tellurium layer formation

- Amount of Te is controlled by monitoring the thickness on the sensor located at the equivalent distance.

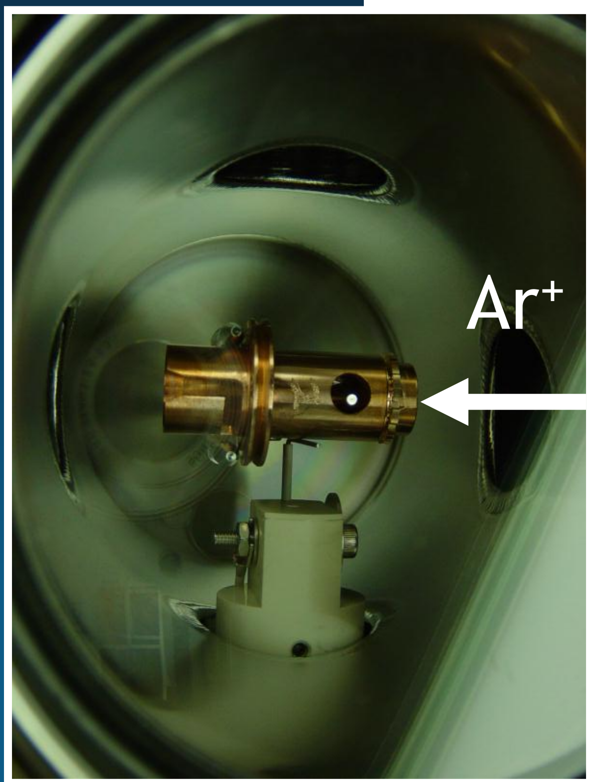
Step3 : Cesium deposition on Te layer

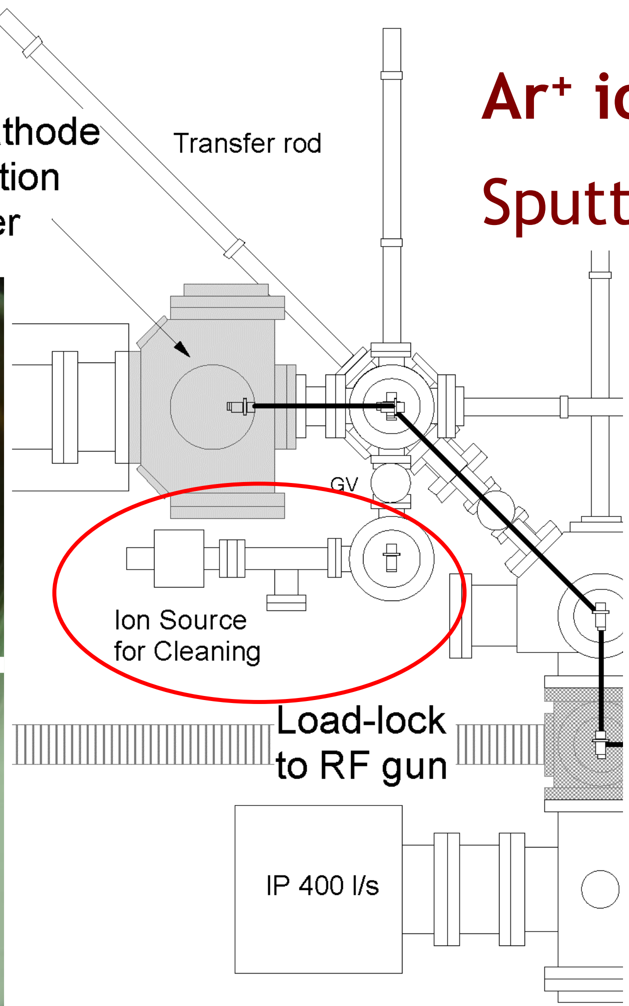
- Amount of Cs is controlled by monitoring the quantum efficiency.

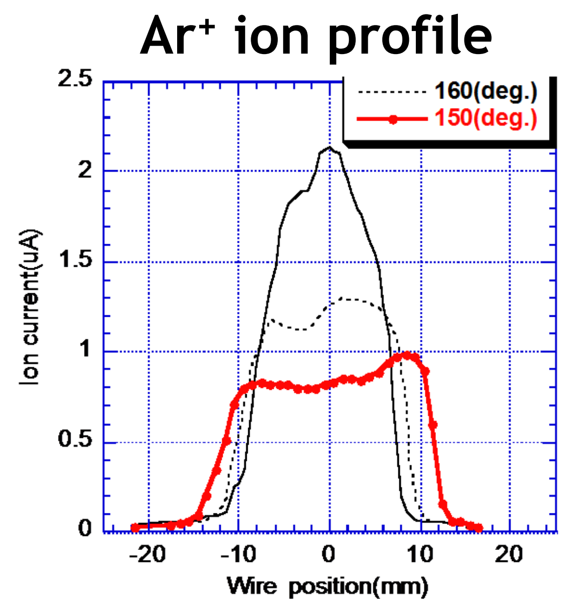
Step 1: Surface Cleaning before Cs_2Te formation

Ar^+ ion bombardment

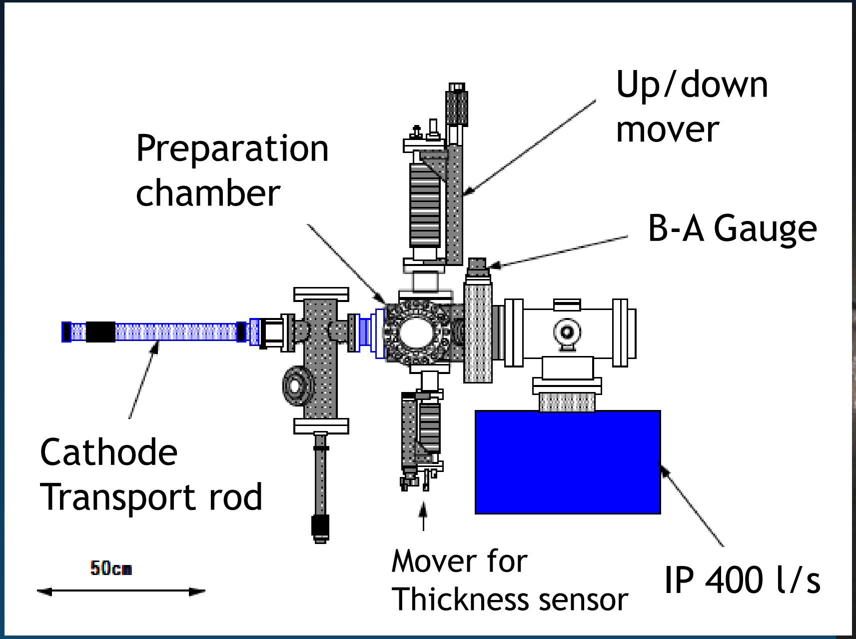
Sputter depth ~50nm.

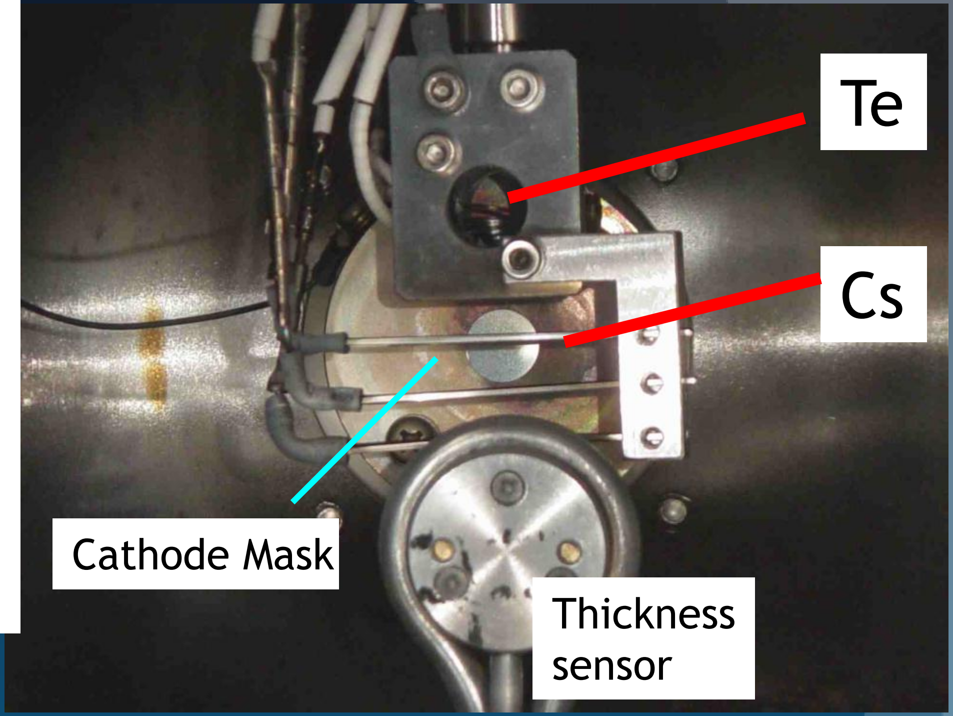


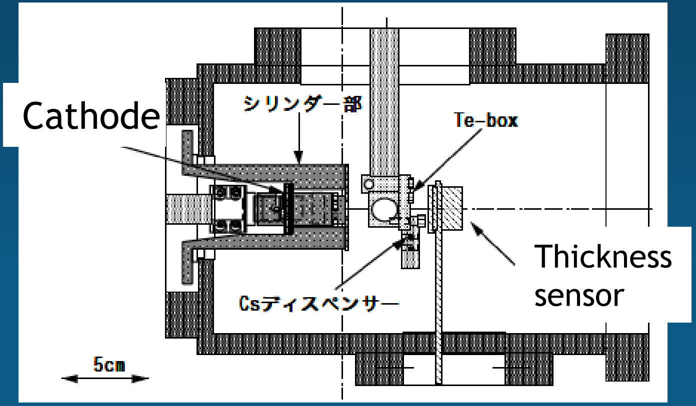




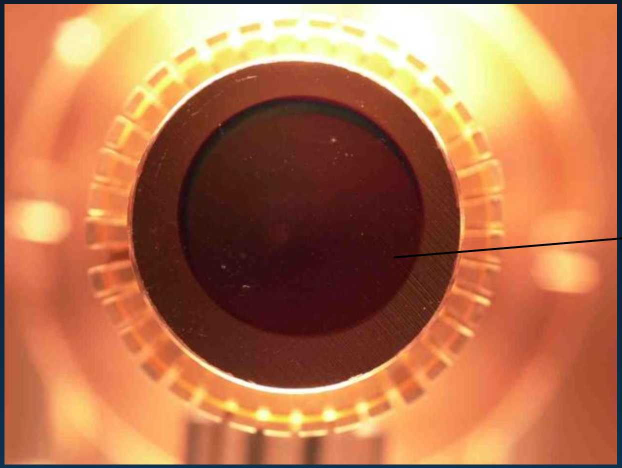
Te and Cs sources





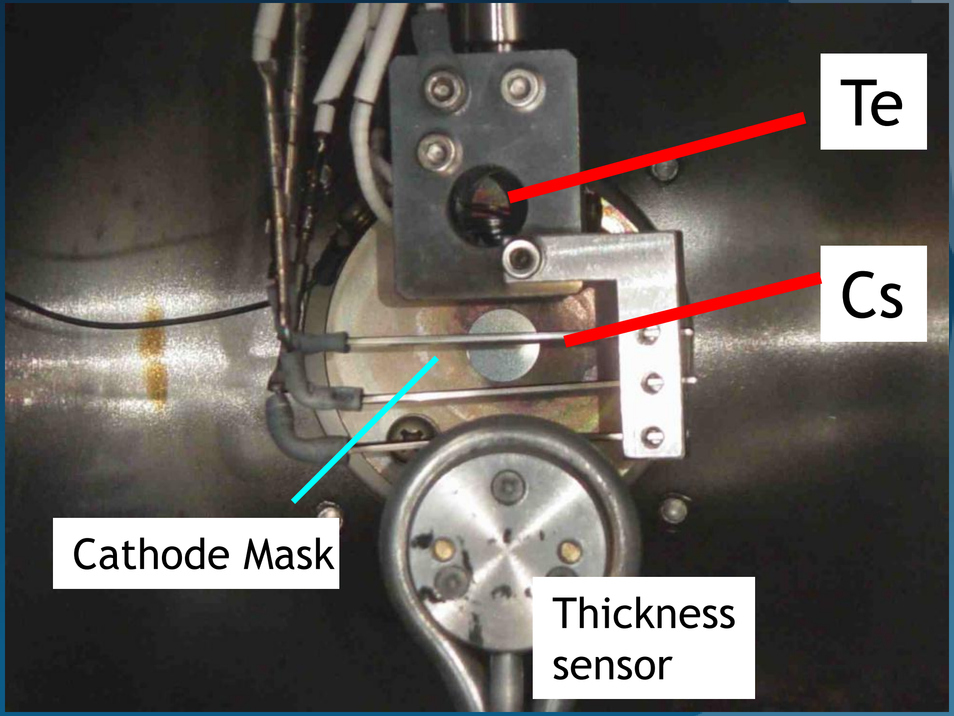


- Select Te or Cs by moving up/down
- Short cyclic up/down to make a uniform evaporation.

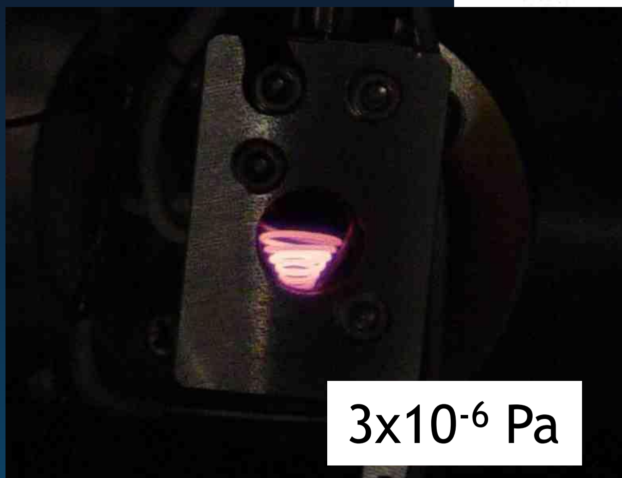


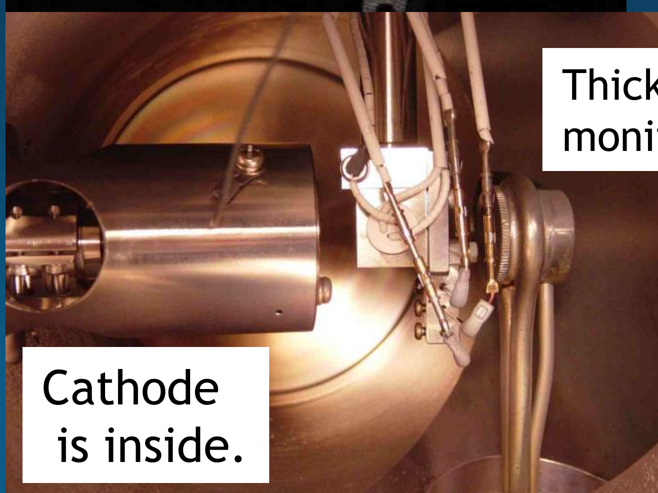
- Put the cathode plug in the cathode holder.
- Mask with ϕ10mm hole prevents the surface edge from the evaporation of Te and Cs.

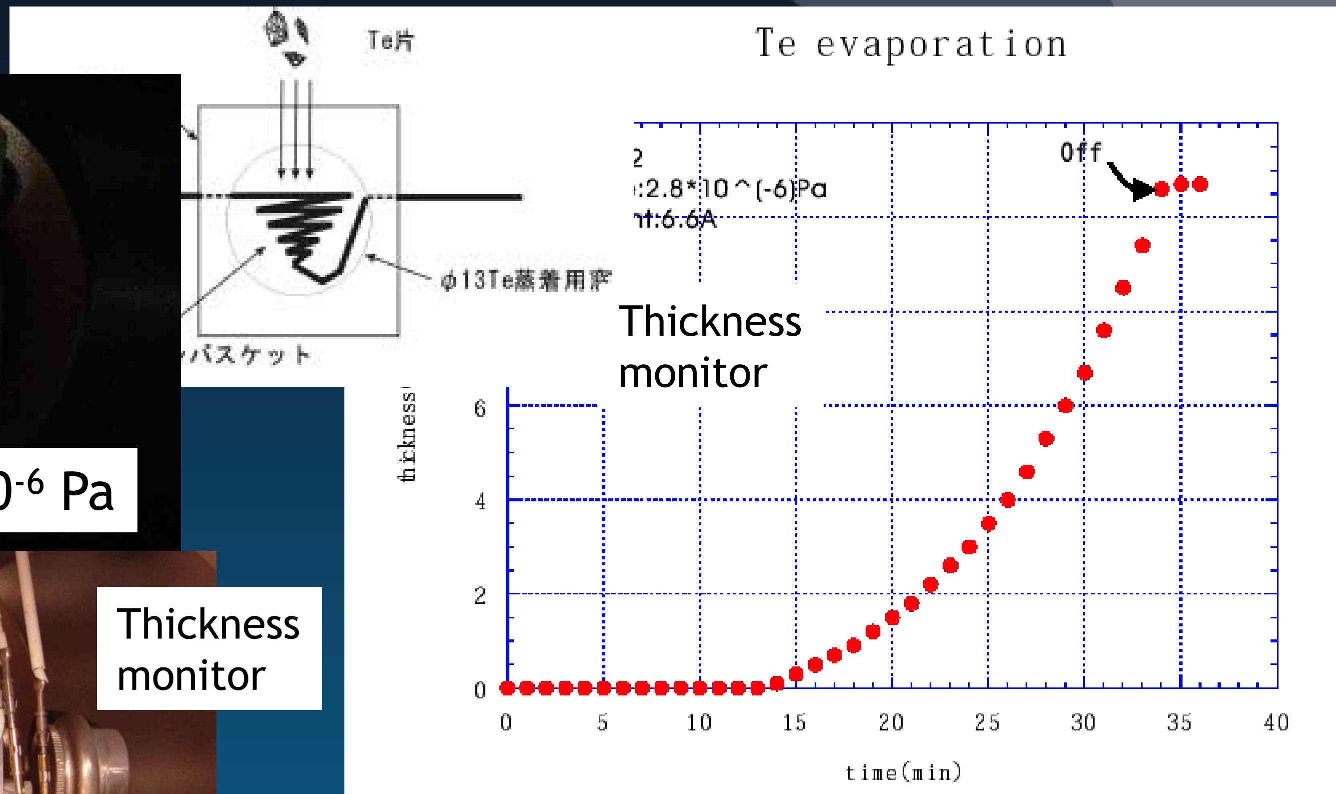
Side view



Step 2: Tellurium layer formation



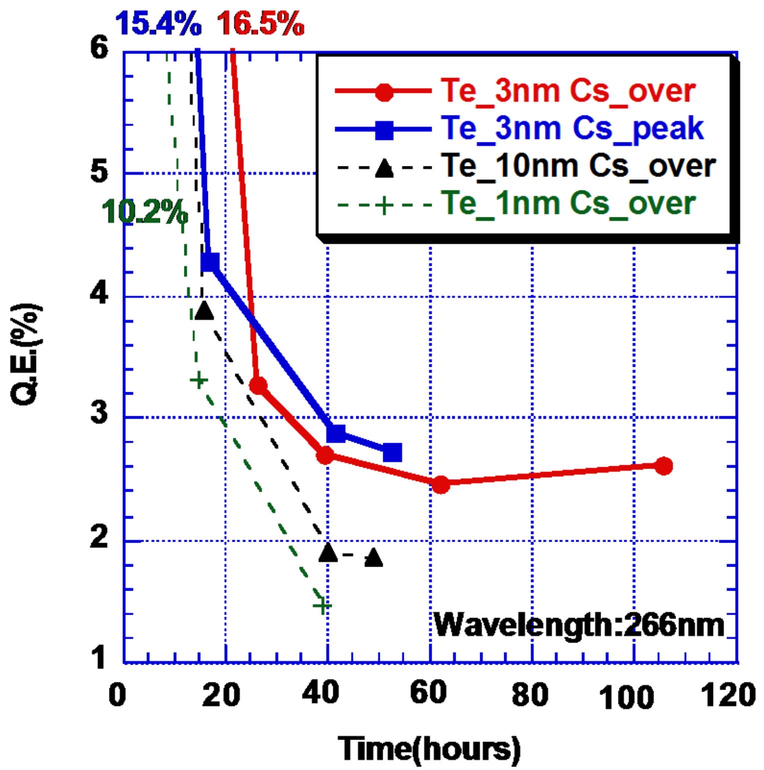




- Te is heated by a Tungsten filament.
- Control the Te thickness by monitoring the thickness coated on the sensor placed at equivalent distance.

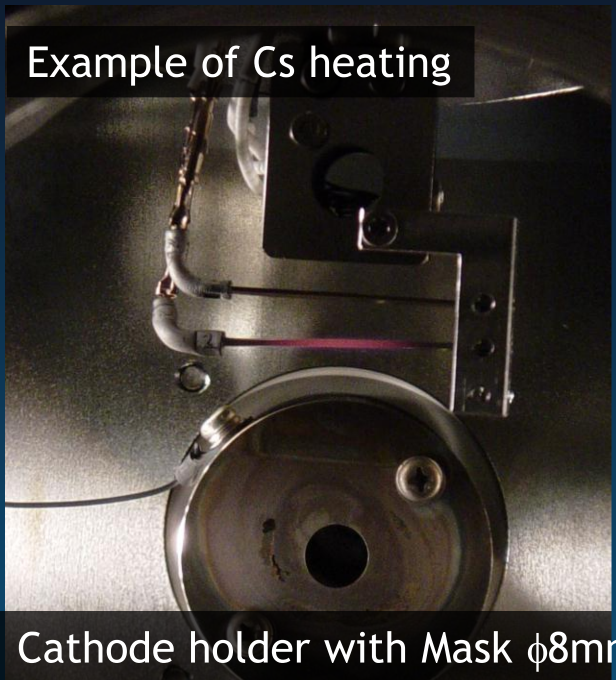
Te thickness dependence on QE

QE measured under the RF intervals



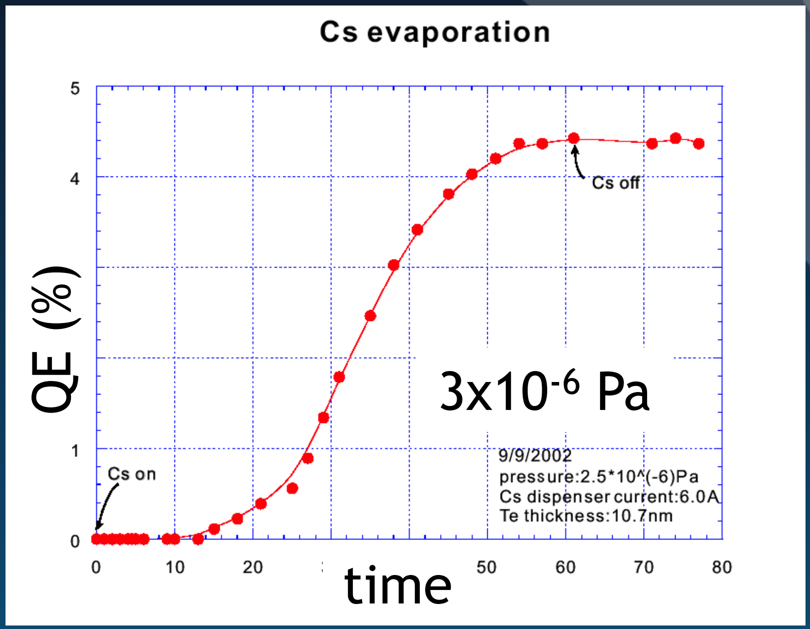
- QE was measured by several hours RF operations.
- Not enough samples indeed
- Results in 2003 showed better QE for the 3 nm sample.
- Sometimes Te-piece tipped in the filament bucket, then several 10 nm of Te was formed accidentally.
- **Typical Te thickness for ATF operation is more than 10 nm but less than 100 nm.**
    - It may be much safe for the RF breakdown in the Gun.

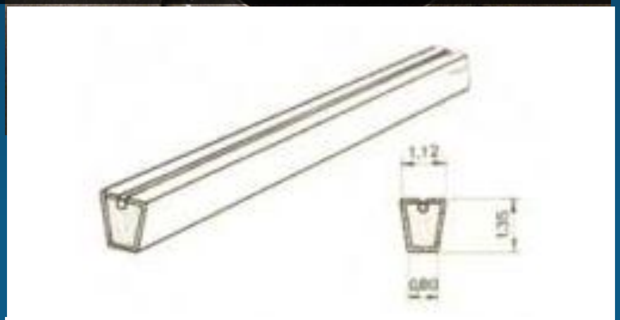
Step 3: Cs deposition on Te layer



Example of Cs heating

Cathode holder with Mask φ8mm

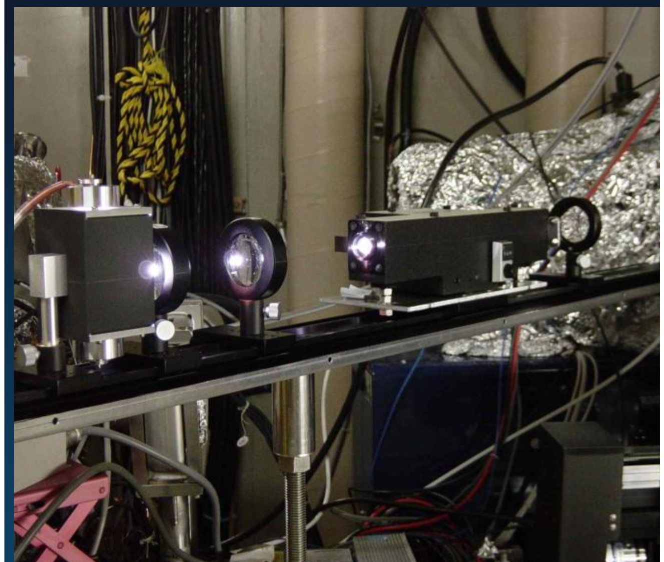




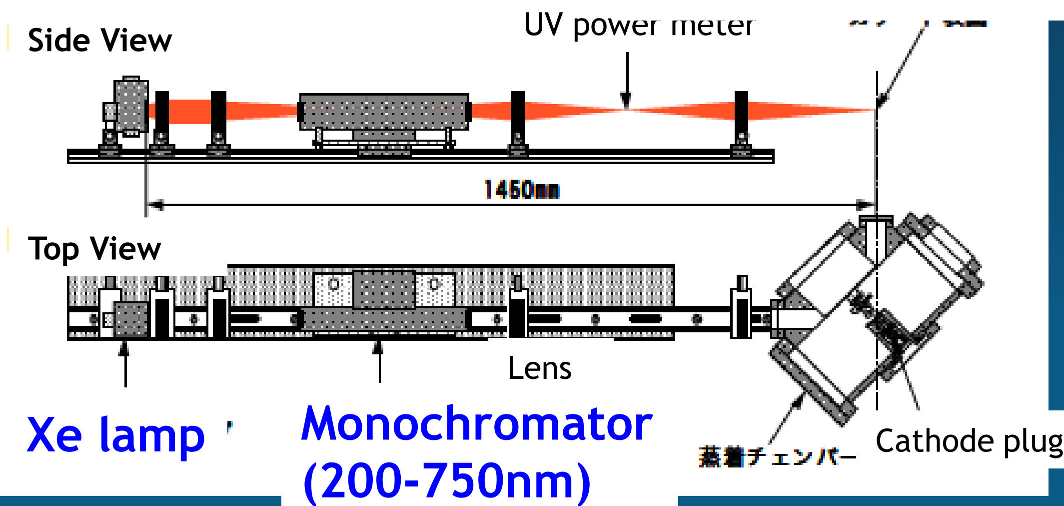
Cs Dispenser by SAES Getters Co.

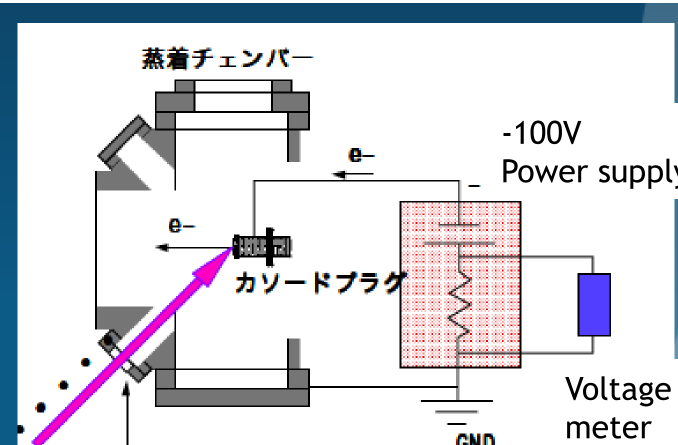
- Control DC current on Cs dispenser.
- One-side evaporation; no thickness monitoring (at ATF)
- **Amount of Cs deposition is determined by monitoring the running QE.**

Measurement of QE



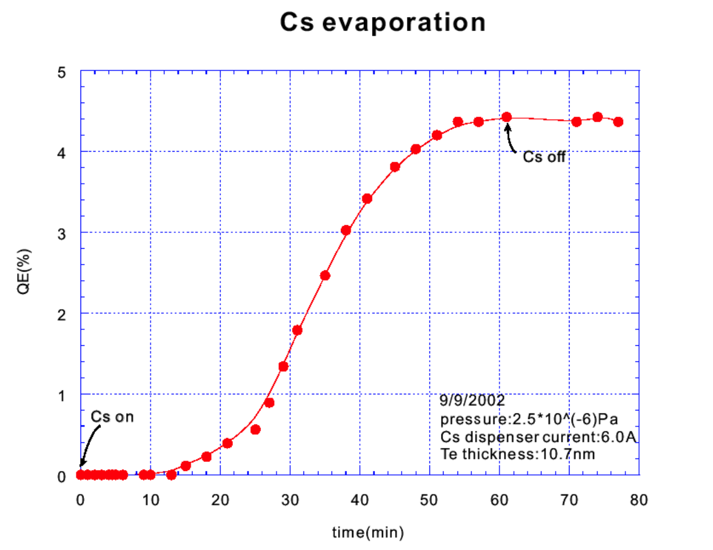
- **QE can be measured when a cathode plug is in the Cs_2Te preparation system.**
  - Quick measurement after RF operation
  - No measurement is possible under a beam operation.
- Monochromator and Xe lamp → 266 nm(laser)
- Measure the photo-emission current by monitoring the drop of voltage on the cathode.



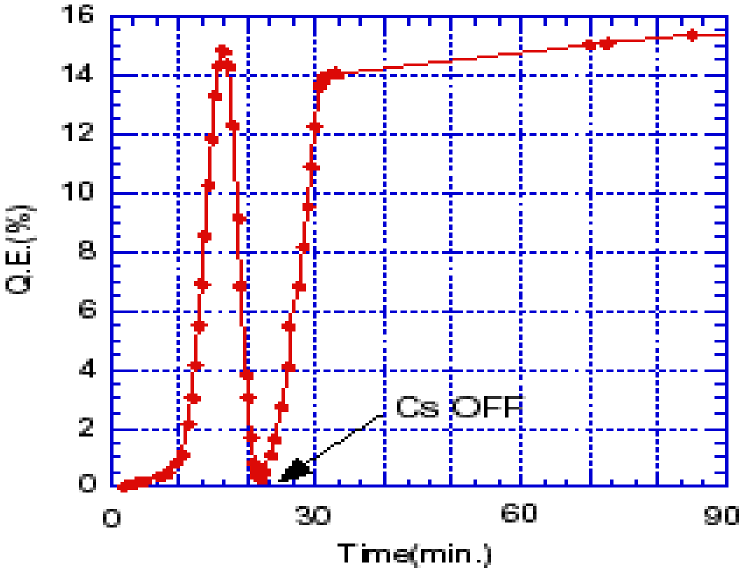


Cs diffusion into the Te layer

Slow Cs deposition



Fast Cs deposition

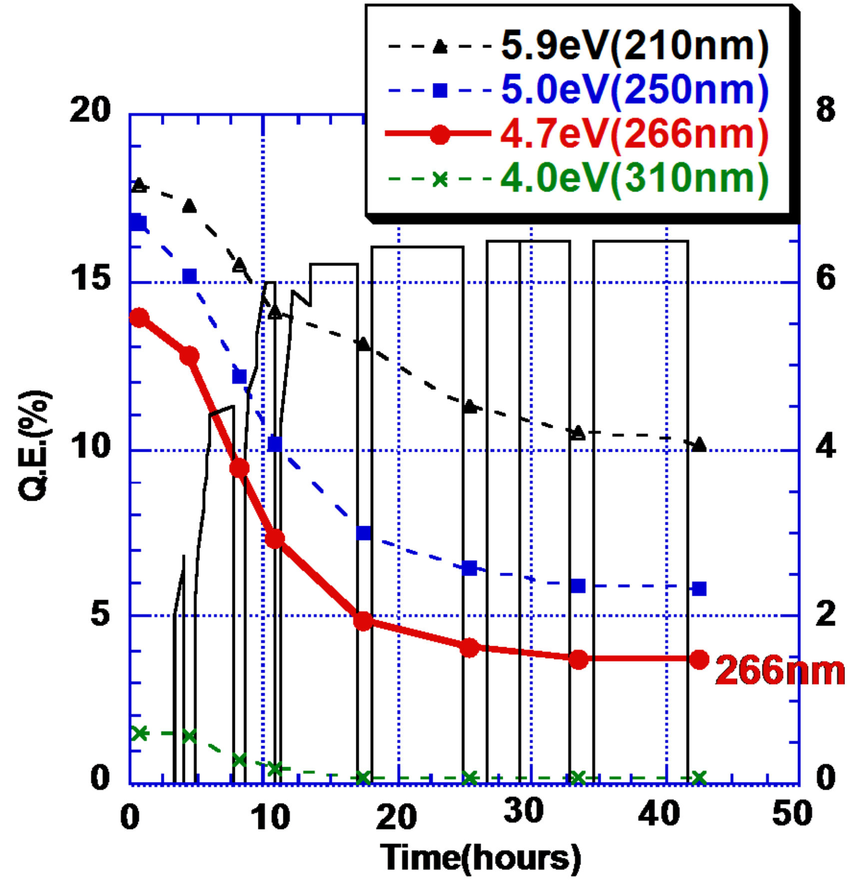


- Slow deposition samples showed the smooth saturation curve on QE . It may suggest the well-formed and stable Cs_2Te layer.
- Fast deposition makes a Cs-rich surface at a moment and QE drops quickly. Then QE is recovered by following the diffusion of Cs into the Te layer.

Experience of the Cs_2Te photocathode with RF gun

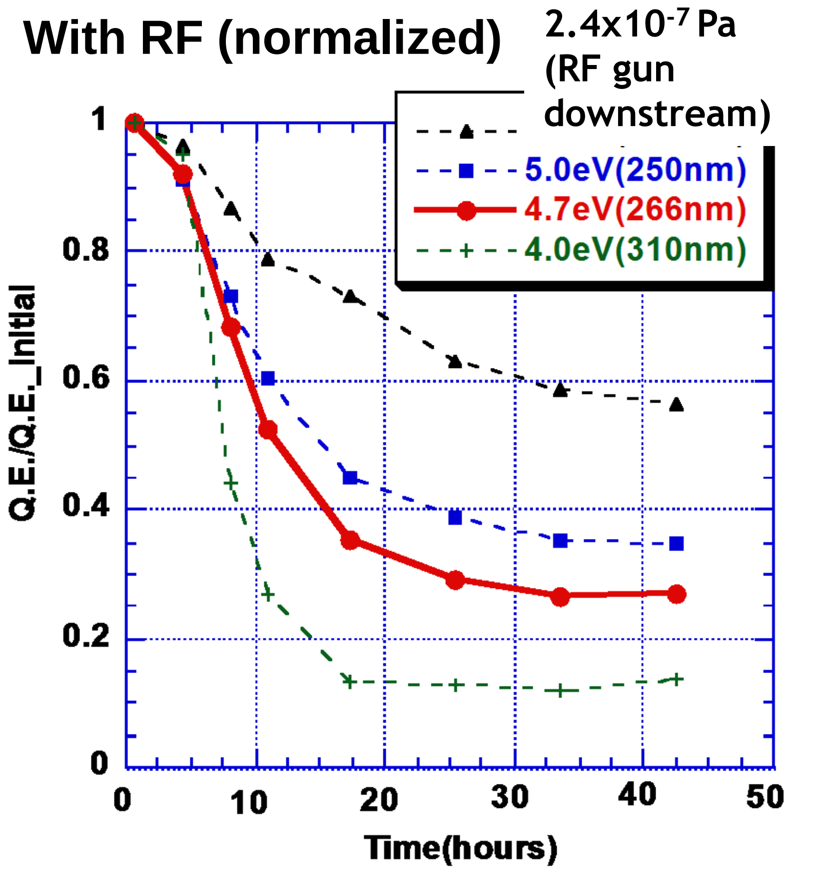
- Quick QE degradation under the RF field was observed
- QE was measured as a function of RF exposure
- Stable QE about a few % was obtained
- Long-term experiences

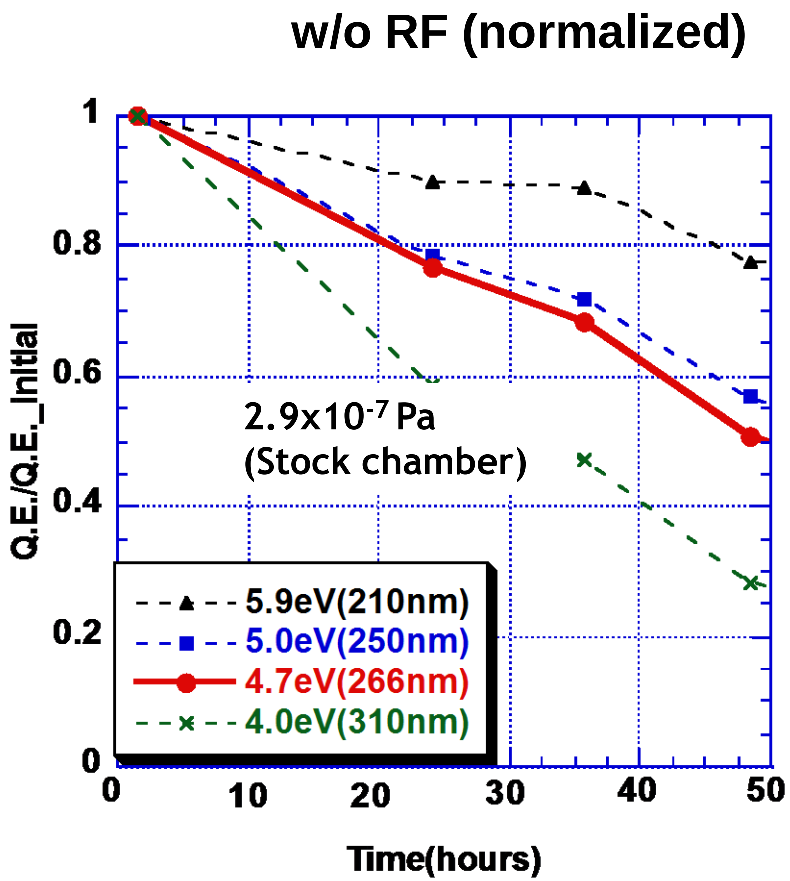
Quantum efficiency under the RF field



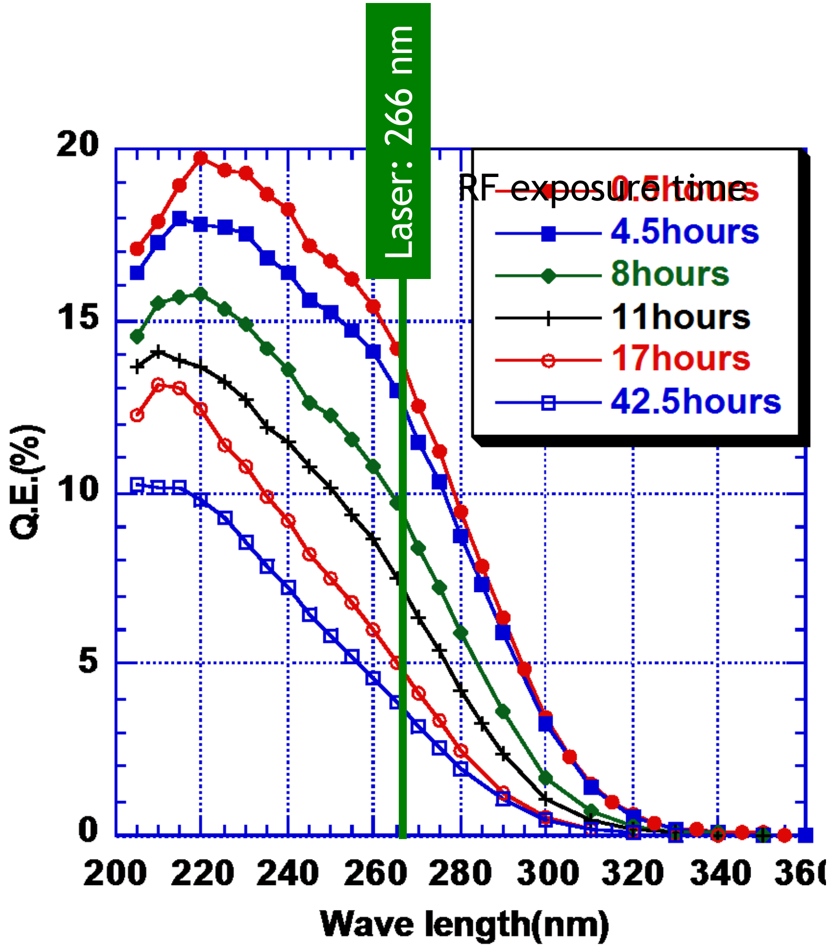
- Initial QE was sufficiently high ~ 14 %.
- **It drops quickly and reaches stable level when the RF is fed into the RF gun.**
- All QE measurements were done by moving the photocathode from the RF gun to the Cs_2Te preparation chamber.

Quantum efficiency under the RF field





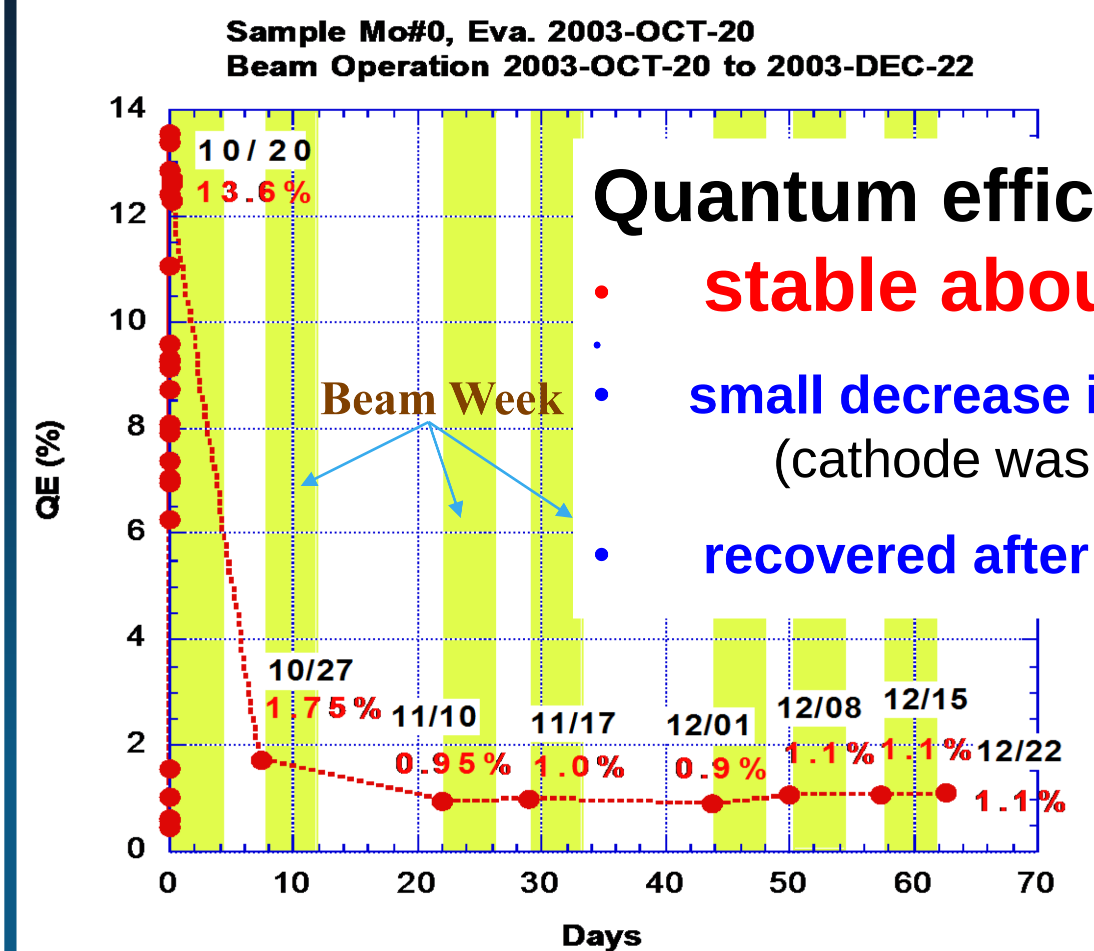
Wavelength dependence of QE for Samples exposed by RF



- **QE degradation: all wavelength**
- **Peak shifts to shorter wavelength (higher energy)**
- It may suggest the electron affinity of photocathode is changing.
- Not a physical damage?
- Oxidation by worse vacuum under RF?

Photocathode:
Long-term examples

Two months history of the quantum efficiency under the ATF operation



Quantum efficiency was …

- **stable about 1%.**
-
- **small decrease in the shutdown week?**
  (cathode was kept in the RF gun. 5×10^{-7} Pa)
- **recovered after the beam generation?**

Reforming the Cs_2Te on the used photocathode

Cleaning then forming the Cs_2Te

- same as brand-new cathode as expected; QE more than 10%.

Forming the Cs_2Te without cleaning

a few samples after several-months operation were tried reforming without cleaning.

Case 1: both Te and Cs

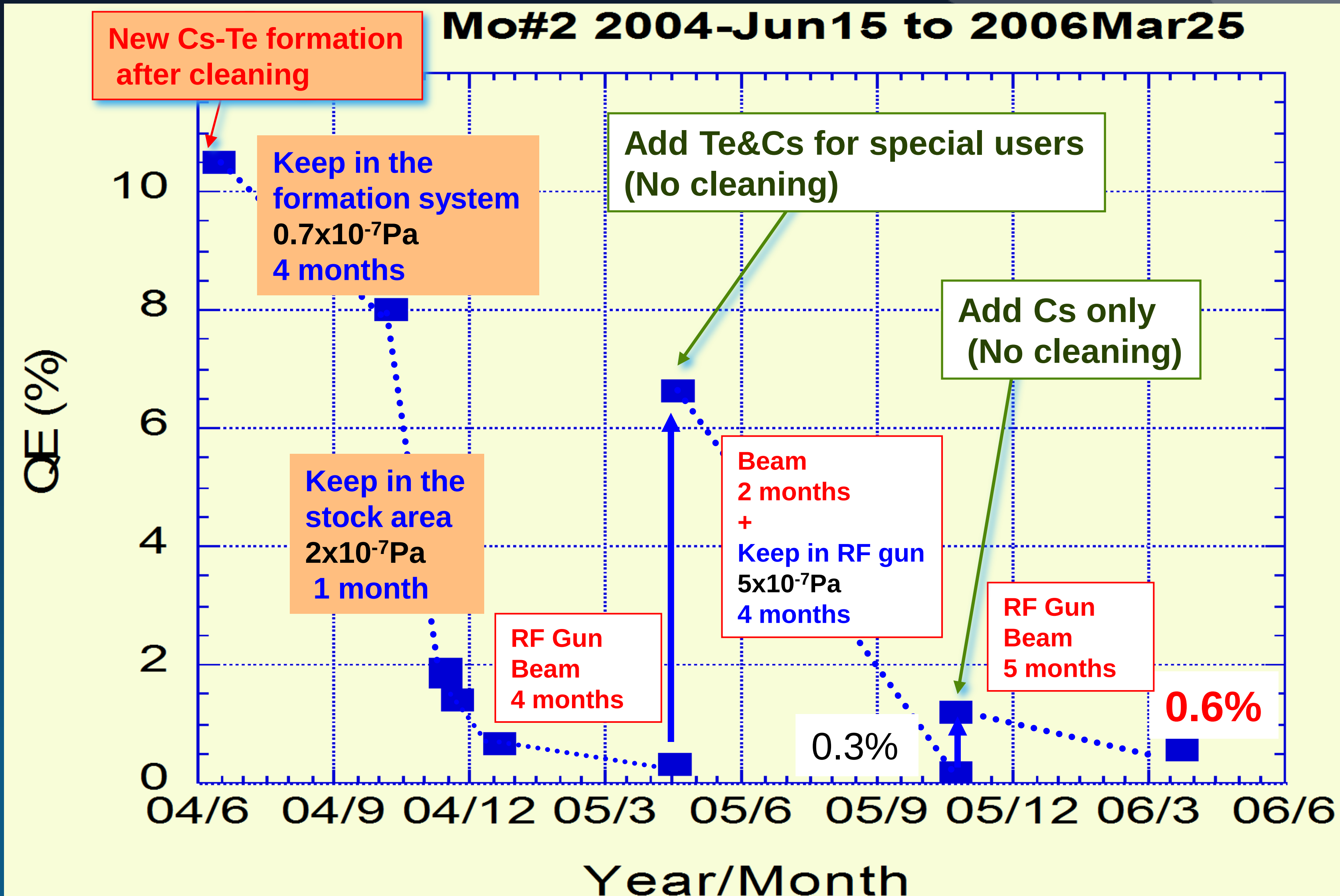
QE was recovered but less than 10%; i.e., 0.4% → 6.7%.

Case 2: Cs only

not recovered well; QE 0.3% → 1.2%.

We did the cleaning in general but Cs only for sudden request of high intensity beam in the past.

Reforming the Cs_2Te on the used photocathode



More long-term (years) experience at ATF

- We have two long-term samples.
  - a sample of two years operation
  - a sample of three years operation (presently used)

Both of them shows the stable quantum efficiency more than 0.5% (likely ~1%).

- Surface
- Dark current with Cs_2Te

Cathode surface after long-term operation

- A lot of small spots were observed.
- They were scattered over the plug surface.
- somehow much on the Cs_2Te area (??)
- **~1% of QE was confirmed with these spots**
- We are not sure that spots are due to Cs_2Te because we have no long-term sample without Cs_2Te.

Summary

- Cs_2Te photocathode system at KEK are presented.
- More than 10 % of Quantum Efficiency (QE) is routinely achieved when Cs_2Te is formed.
- About 1 % of QE is usually realized through the RF gun operation.
- Good vacuum quality, less oxygen condition, is a key to realize and keep a higher QE.

Thank you for your attention!