MOIACC002 Cathodes A (08:55 - 10:10)
on 19-JUN-17 ERL17 CERN

DEVELOPMENT OF SRF GUN APPLYING NEW CATHODE IDEA USING A TRANSPARENT SUPERCONDUCTING LAYER

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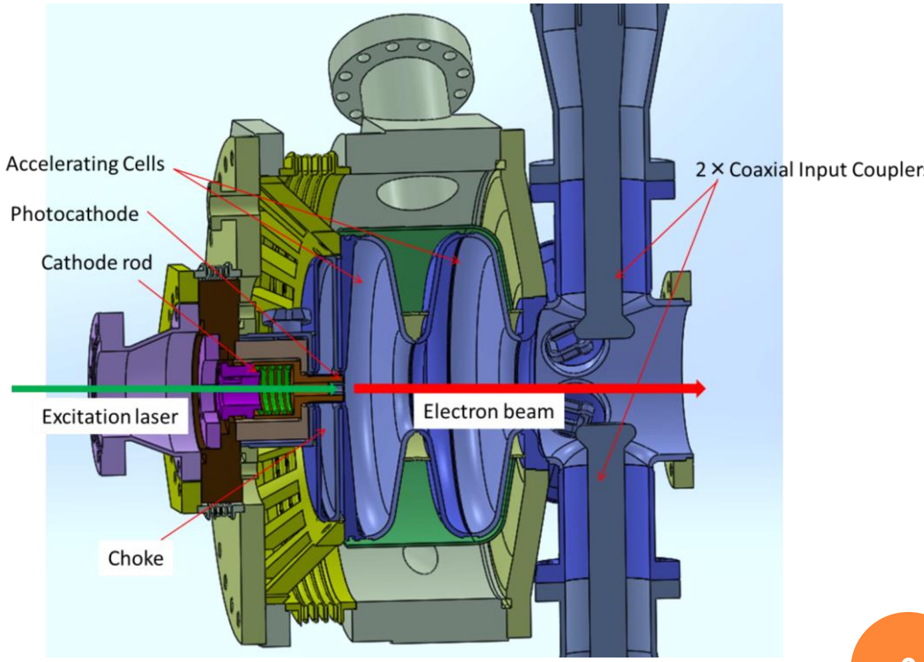
1-1 Target of the KEK SRF gun

- KEK Started SRF gun development for future linac base accelerator.
- 3 GeV KEK- ERL was selected as the target parameters to simulate the gun design.
  - Target parameters are same as KEK ERL DC gun.
- Key point of the SRF gun development is back side excitation structure.

Target parameters (KEK-ERL)

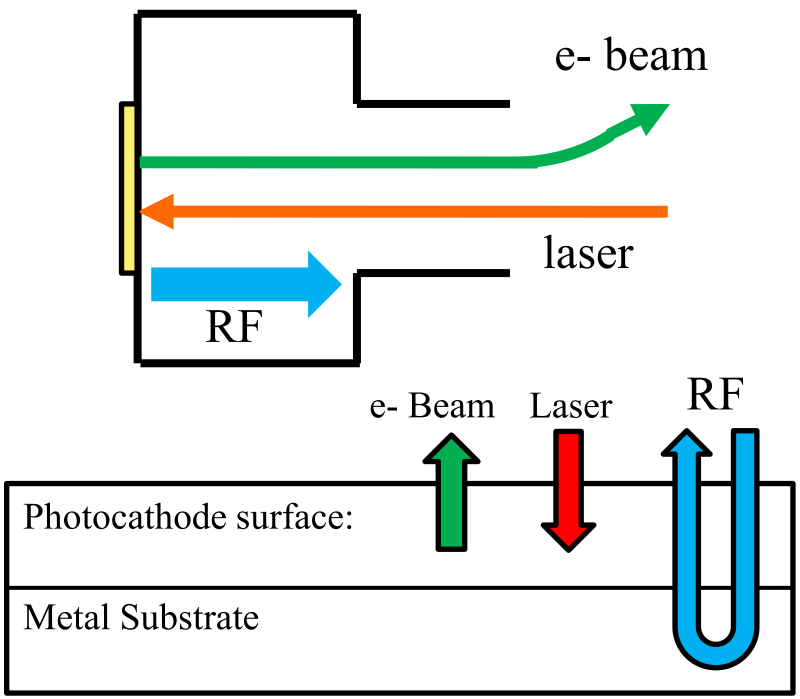
Parameters	Value
RF frequency	1.3 GHz
Beam energy	2 MeV
Current	100 mA
Bunch length (rms)	3 ps
Bunch charge	77 pC
Repetition frequency	1.3 GHz
Normalized emittance	< 1π mm mrad
Energy Spread	< 0.1%



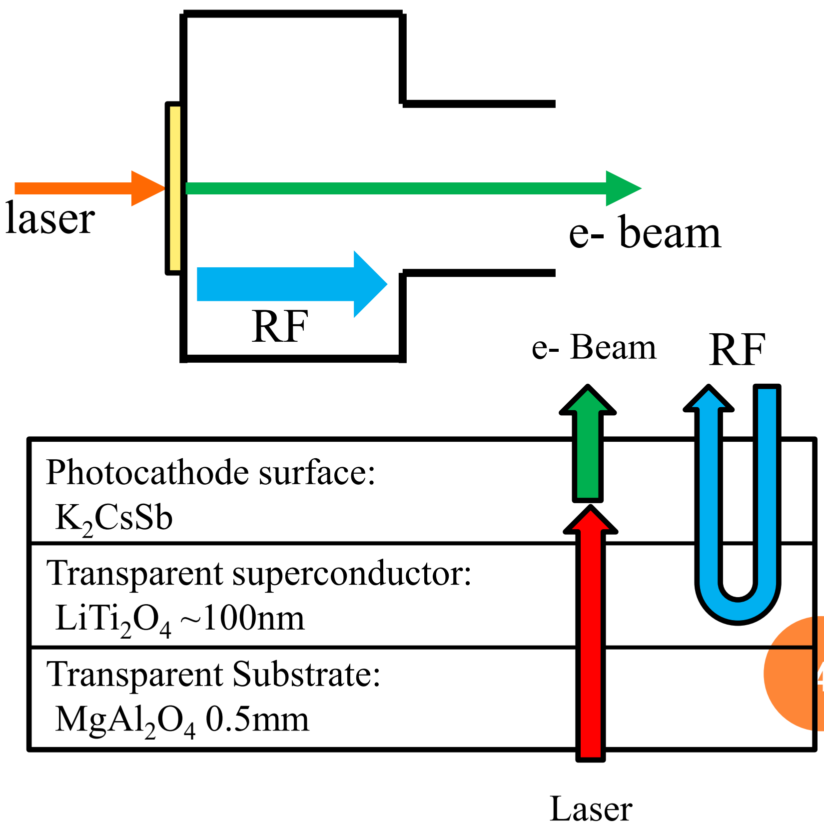
1-2 Design concept of the KEK SRF gun

- Merits of back side excitation
  - Simple RF cavity and beam line structure.
  - Laser control could be more precisely.
    - Laser 3D distribution control is necessary for low emittance beam.
- We propose a photocathode structure using transparent superconductor.
  - The superconductor protects transparent substrate from RF damage
  - RF leakage from photocathode can be blocked and surface electric field on the photocathode can be kept high.

(a) Front side excitation



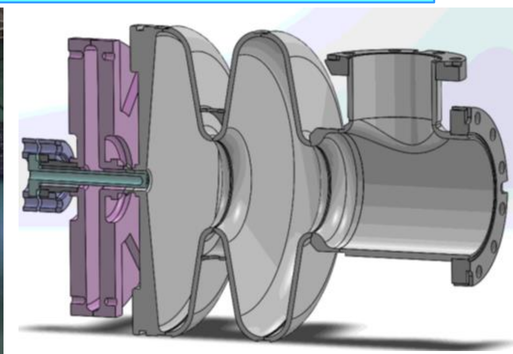
(b) Back side excitation

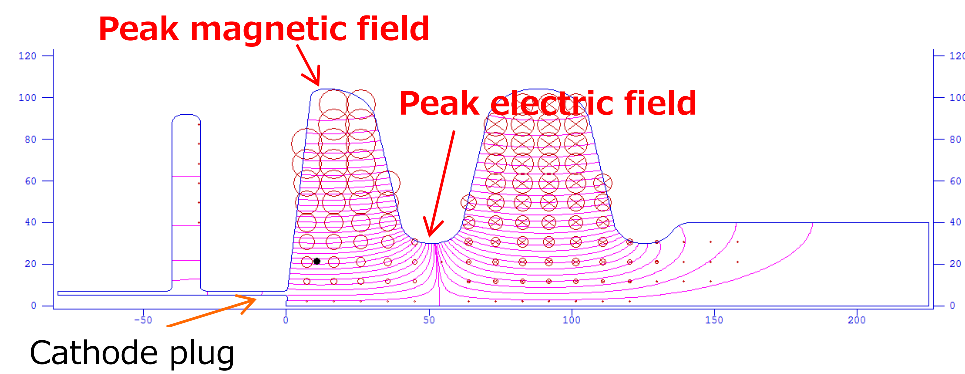


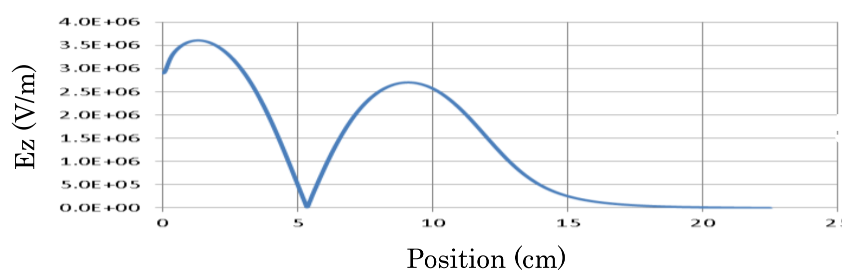
2-1 RF parameters

- KEK SRF gun #1 was designed to check basic RF parameters (maximum Esp, Qo).
- Beam parameters and cavity shape were designed by SUPERFISH and GPT.
  - Slope of the cavity was designed to compensate the space charge effect.
- Target Qo values are estimated from ILC target.

Parameter	Value
Beam energy	**2 MeV**
Projected emittance	**0.6 π mm.mrad**
Projected energy spread	**0.09%(1.84 keV)**
Peak electric field	**41.9 MV/m**
Peak magnetic field	95.2 mT
RF phase	55°
Geometrical Factor	135.6 Ω (TESLA 270 Ω)
Target surface resistance	30 nΩ (ILC target)
Target Q value	4.5×10^9
Target cavity loss	8 W

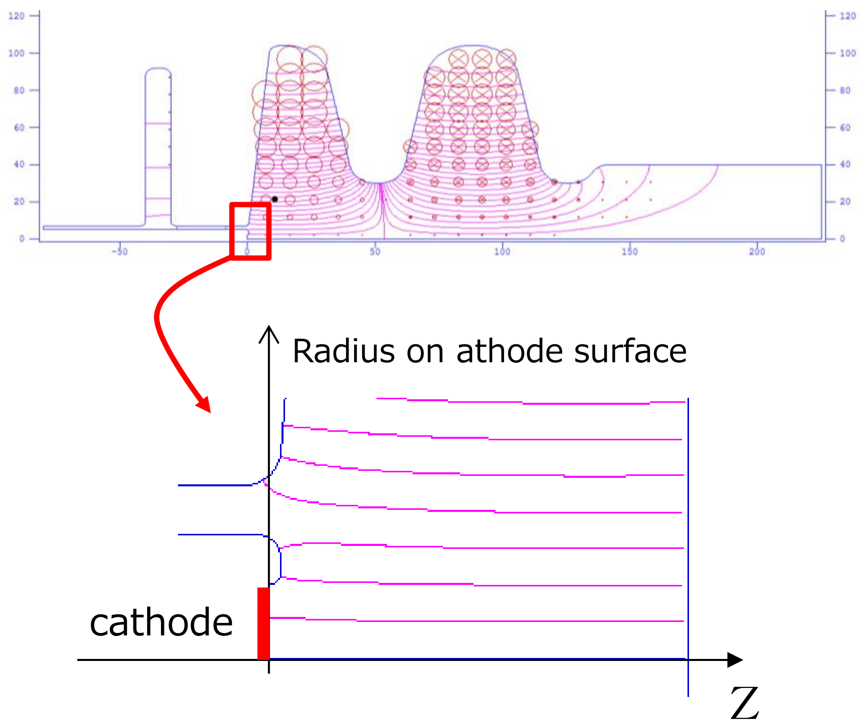




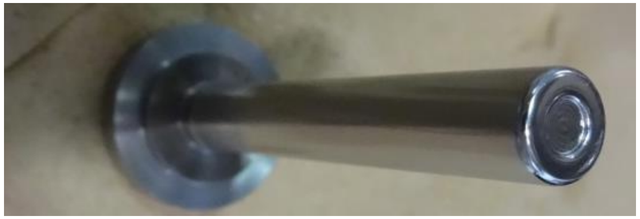


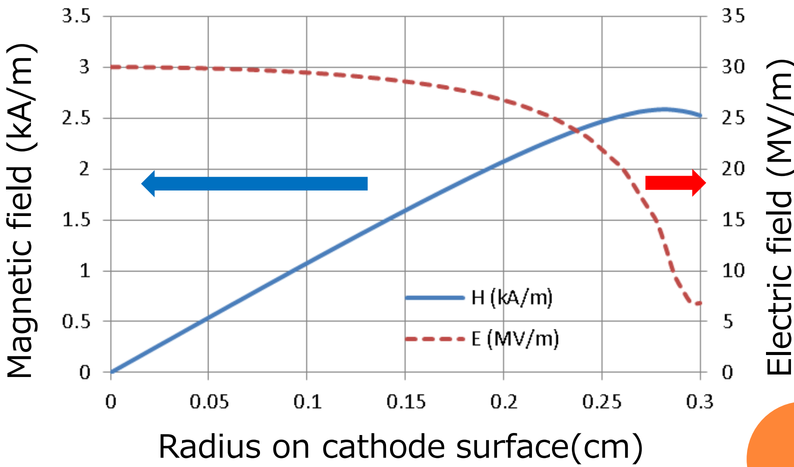
2-1 RF parameters on photocathode

- Peak electric on the photocathode is 70% of iris peak electric field.
- RF critical magnetic field of the photocathode should be higher than 2.6 kA/m (3.3 mT).
    - It is enough smaller than niobium. Niobium is ~200 mT at 2K
- High gradient tests (Vertical tests) were done with dummy cathode rod.
    - Dummy cathode rod was shaved out from bulk niobium and doesn't have the cathode mount structure.



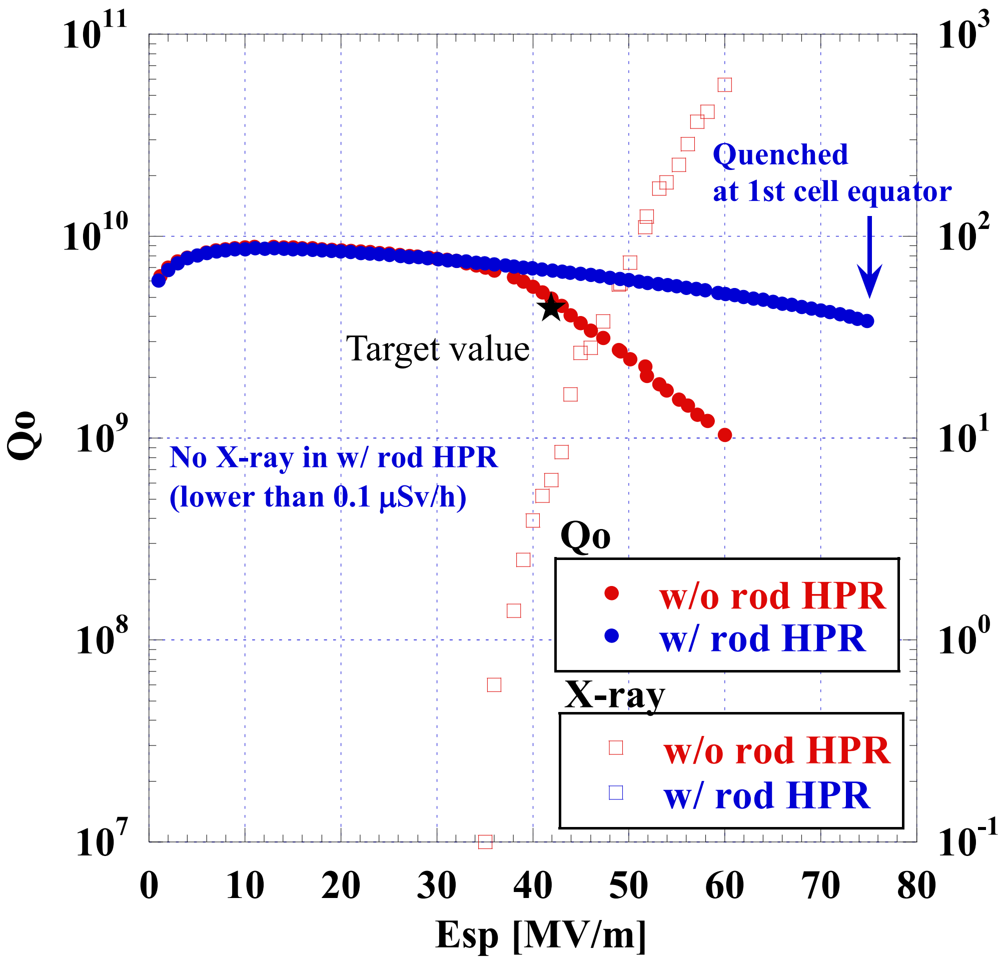
Dummy cathode rod made of niobium

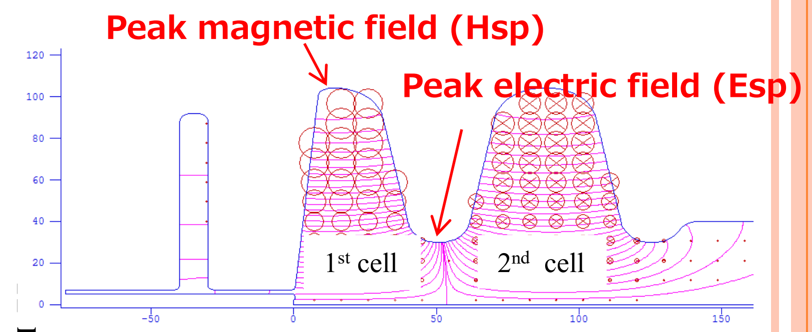




2-2 Vertical test results

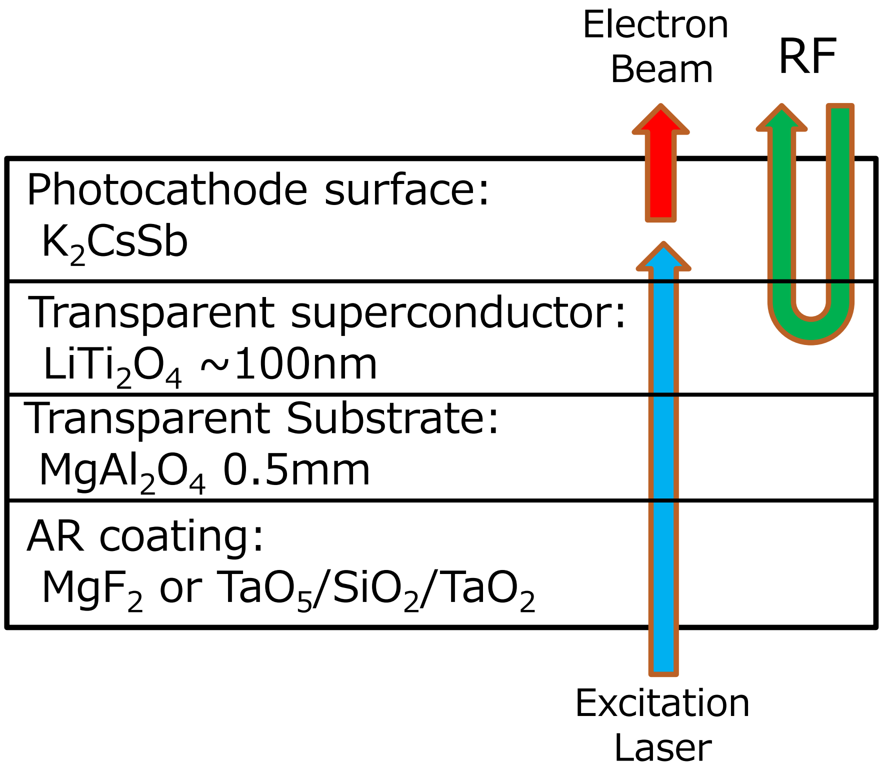
- The cathode plug cleaning is important to achieve high gradient
- After HPR, the peak surface electric field reached 75 MV/m and X-ray couldn't be observed.
- However HPR should not apply to the transparent superconductor because it is very thin and delicate.
    - We have to search other method for cleaning for example hydrogen cleaning or sputtering.

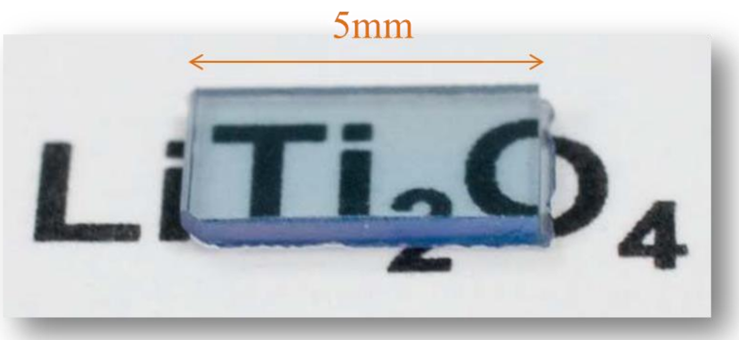




3-1 Concept of the photocathode.

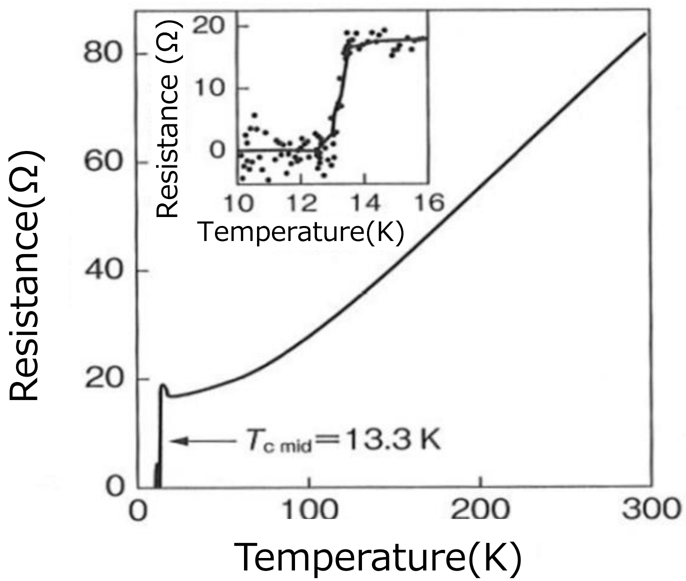
- There are 4 layers in the photocathode.
  - Photocathode surface is K_2CsSb.
    - The lattice constant of K_2CsSb (0.861 nm) is close to $LiTi_2O_4$ (0..8405 nm).
  - The transparent superconductor $LiTi_2O_4$ can block the RF leakage and transmit the excitation visible light at the same time
  - $MgAl_2O_4$ is the substrate for epitaxial growth of $LiTi_2O_4$.
  - AR coating is a option for increasing laser efficiency.
- The photocathode performances are evaluated by quantum efficiency, initial emittance and critical DC magnetic field.

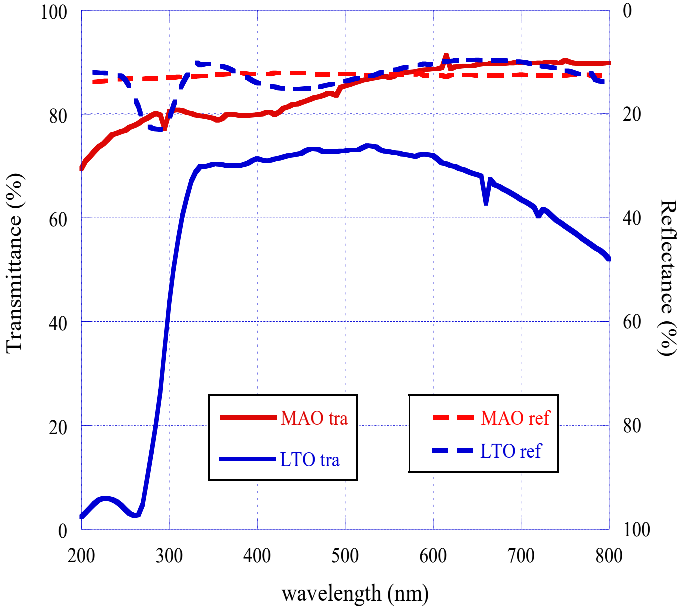




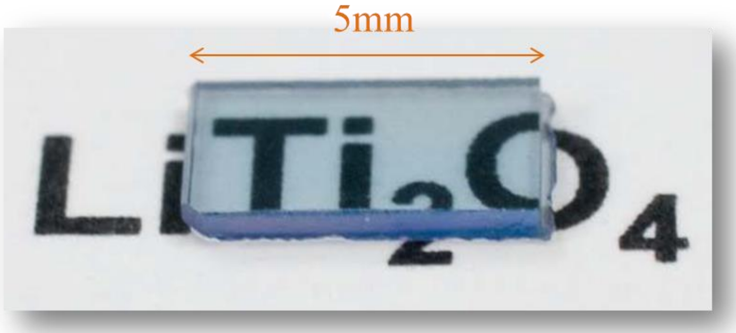
3-1 Transparent superconductor

- Transition temperature is ~13K. Transmittance is 75% at 530nm.
- If we will apply AR coating to decrease the reflection.
  ⇒We will use the MgF_2 or $TaO_5/SiO_2/TaO_2$ layer.





Parameter	Value
Tc mid	13.3 K
Resistivity	3.3×10^{-4} Ωcm (at R.T.)
Lattice constant	$a_{LTO} = 0.8405$ nm
Transmittance	75 % (at 530 nm)
Carrier density	$1.1 \times 10^{22}\ cm^{-3}$
Hall mobility	0.8 (280K), 6.0 (15K) $cm^2V^{-1}S^{-1}$



3-2 Photocathode development chambers

Quantum efficiency

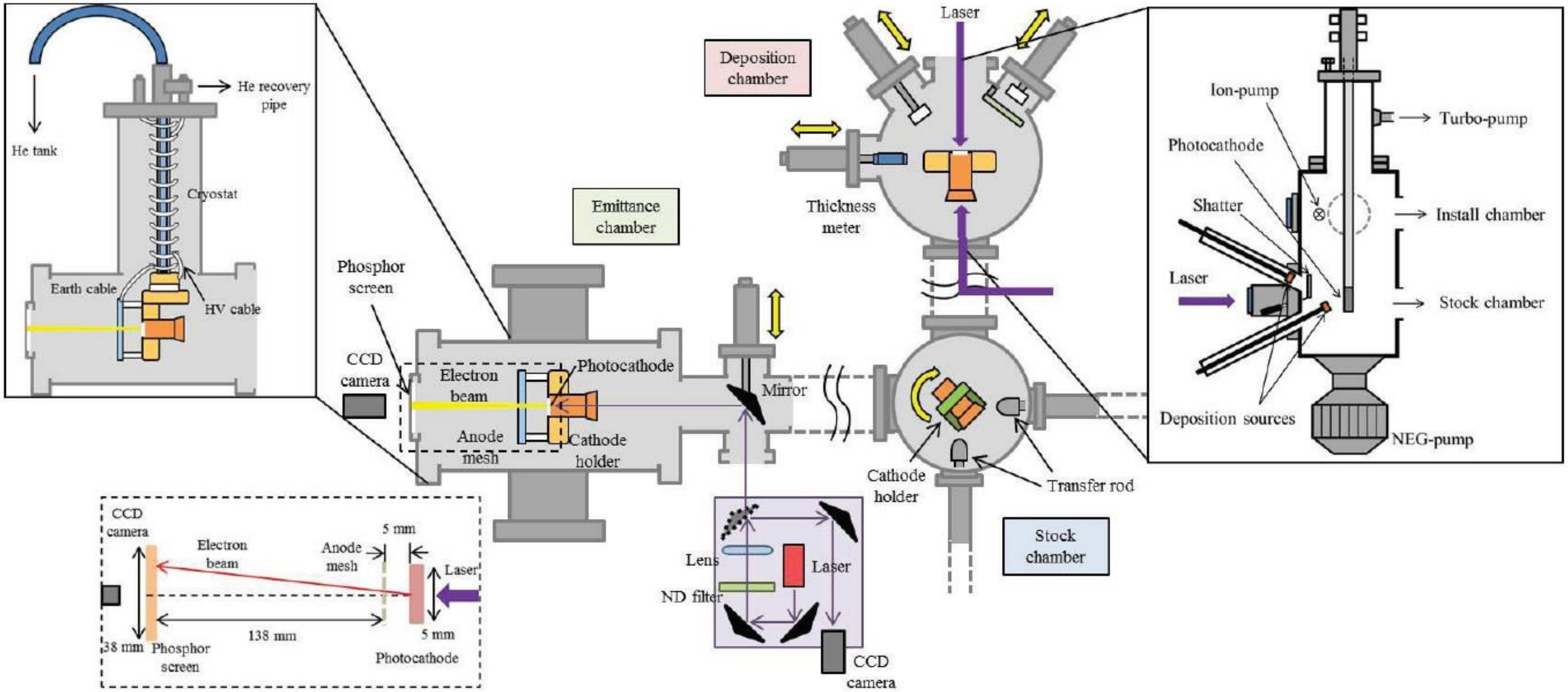
- QE was measured at deposition chamber.
- Xenon lamp were used to measure QE spectrum.
- Excitation light can be inject from back and front. Transmittance can be measured.

Initial emittance measurement

- The photocathode can be cooled down to 6.7 K.

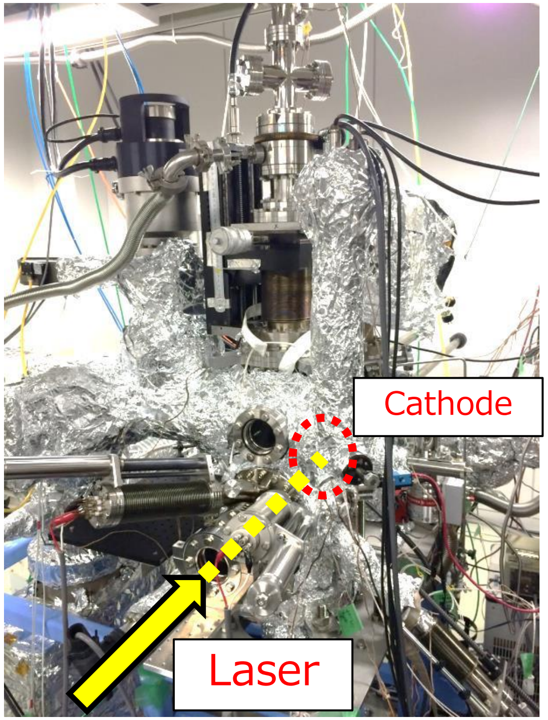
Critical magnetic field

- The photocathode was taken out from chamber and measured by SQUID MPMS7 (Quantum Design, Inc.)

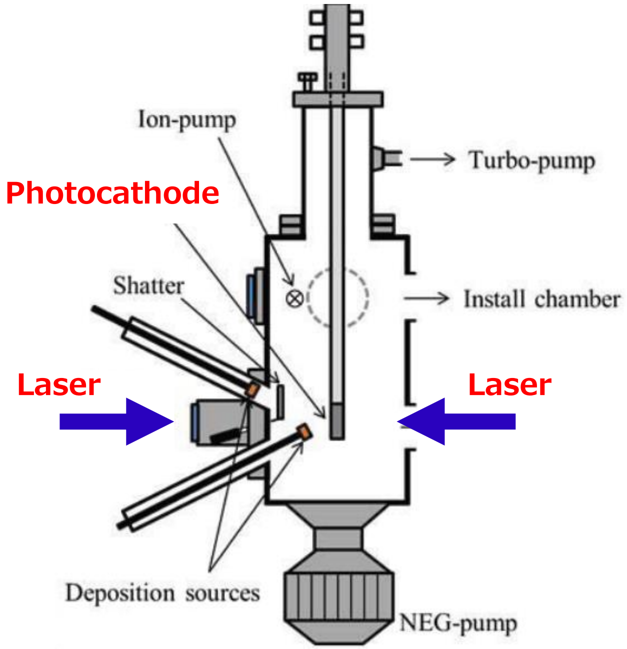


3-3 Photocathode deposition

- The photocathode deposition chamber has cesium (SAES), potassium (SAES) and bulk antimony evaporation sources.
- Laser and xenon lamp can inject from front and back side of the photocathode.
- The chamber vacuum is $6\times10^{-8}\sim1\times10^{-7}$ Pa during the deposition.
- Base pressure is 1×10^{-8} Pa.

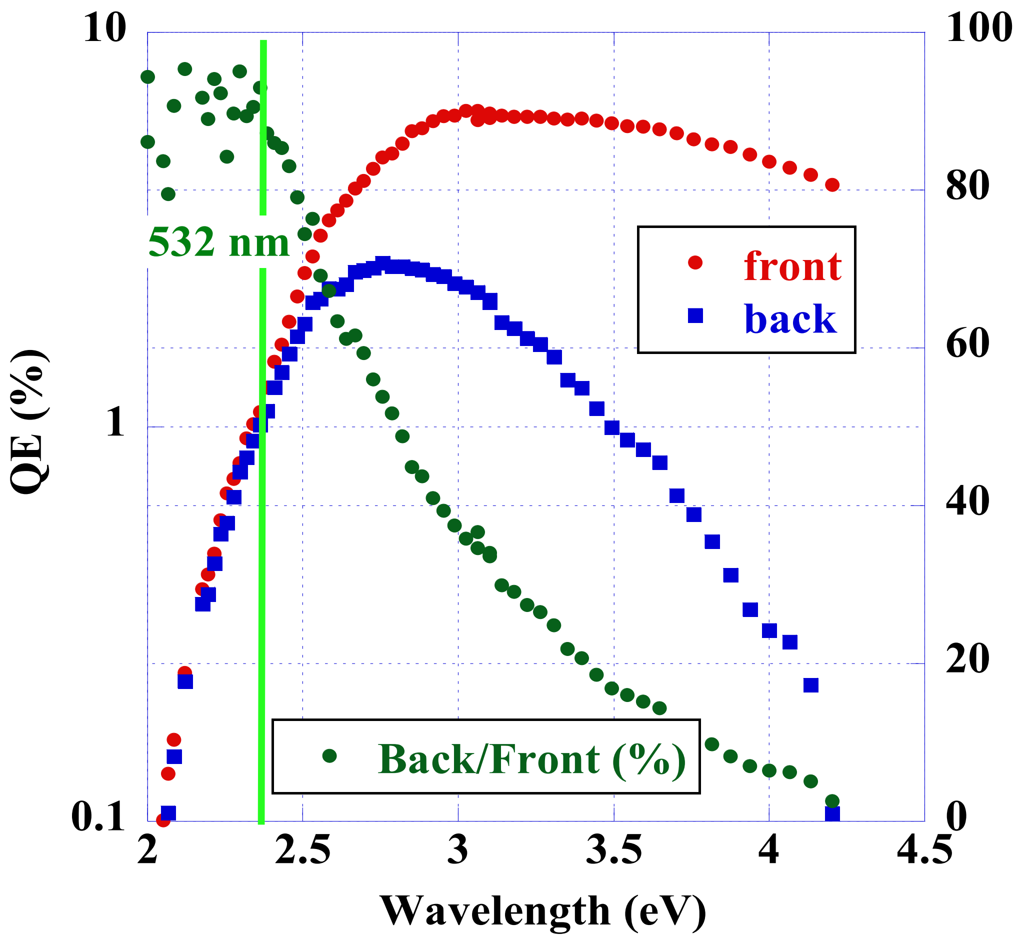


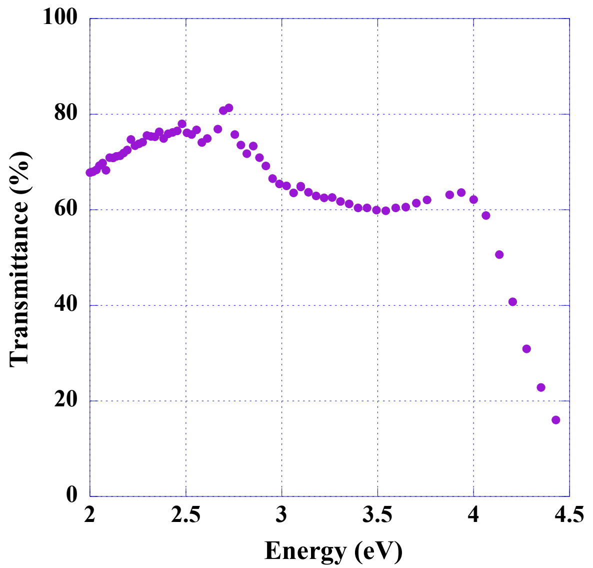
Procedure	Condition
Heat cleaning	~500 °C x 3 hours
Sb deposition	150°C , Thickness 10nm (Transmittance decrease 20-30%)
K deposition	~120 °C, QE peak
Cs deposition	100 °C, QE peak

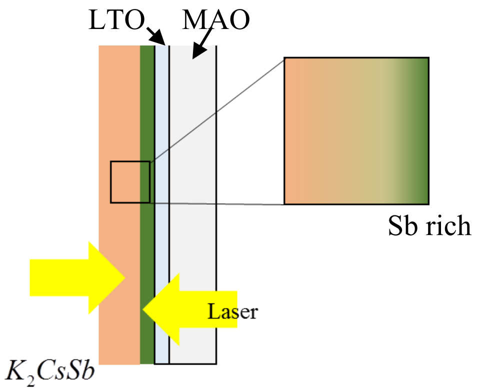


3-3 Quantum efficiency

- The threshold energy is 1.85±0.15eV. This is same value as other studies.
  ⇒ K_2CsSb deposition on the transparent superconductor was successful.
- The ratio of back and front side QE can't be explain by the transmittance of LTO.
  ⇒ We suspect Sb rich layer exists on the boundary.
- But It is not a problem for gun operation because we will use 532nm laser.
  - At 532nm, back side QE is 90% of the front side.

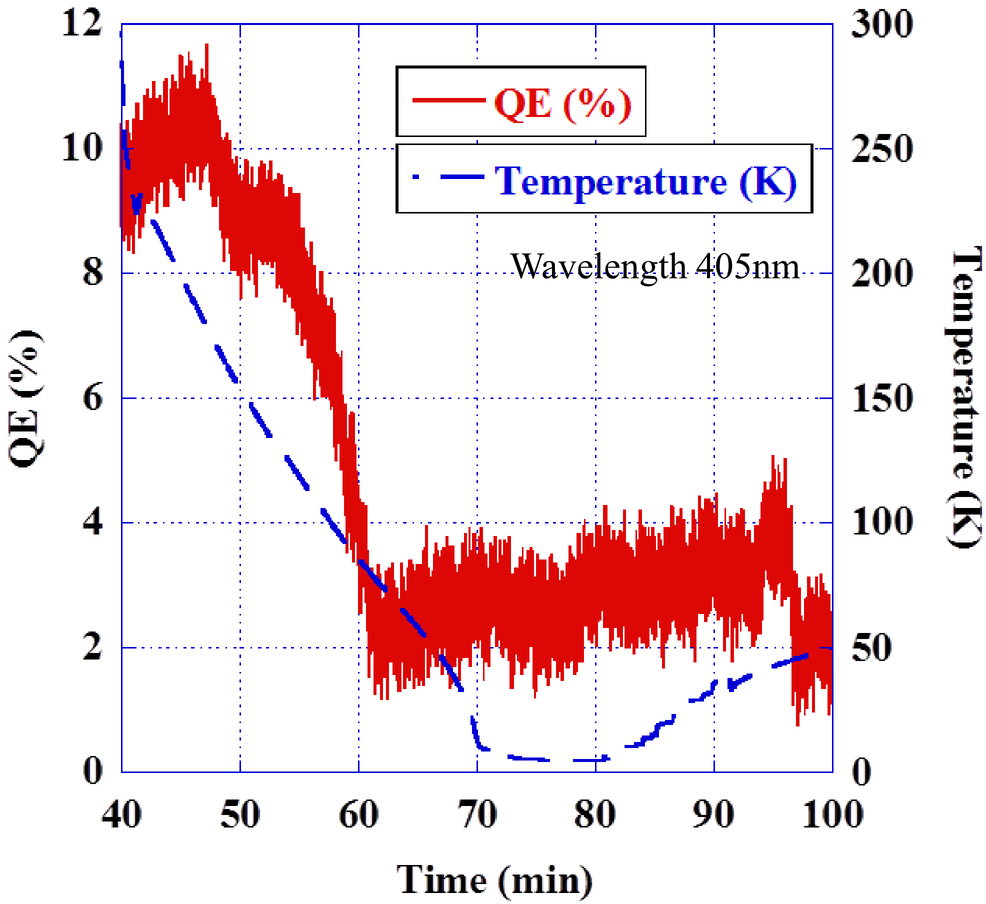




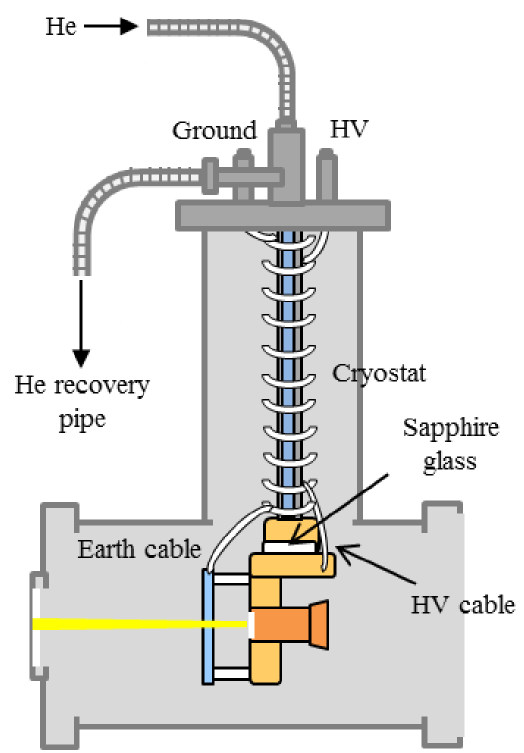


3-3 Quantum efficiency at low temperature

- We transferred the photocathode to initial emittance chamber which has a LHe small cryostat.
- QE was decreased during cooling.
    - We suspect residual gas was absorbed on the photocathode surface and increase the surface work function.
- Further study of photocathode performance at cryogenic temperatures and ways to improve this performance is essential for the photocathode development.



Initial emittance chamber

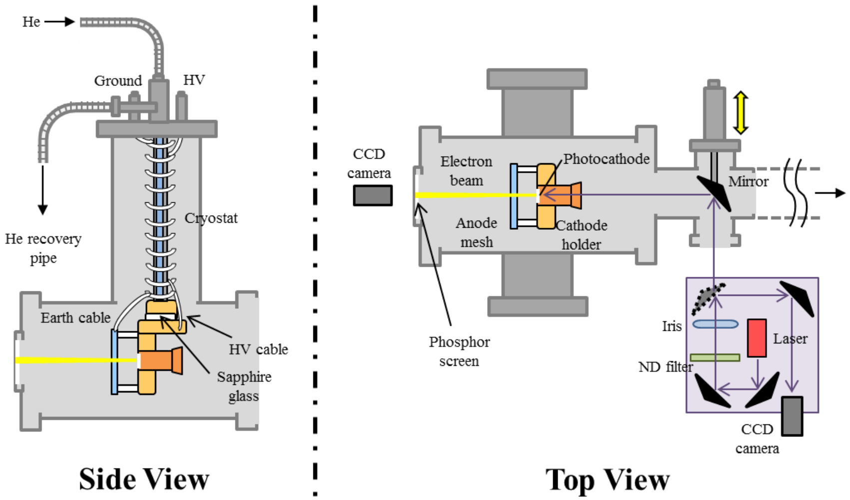


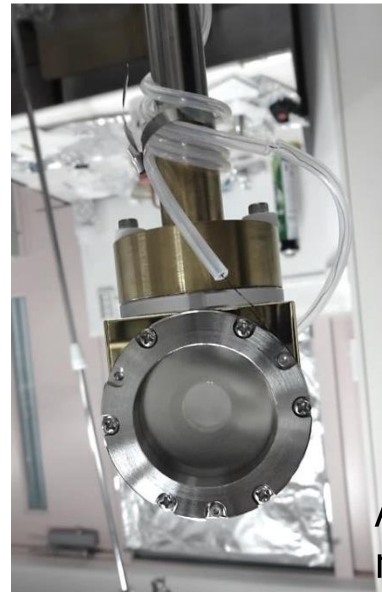
chamber pressure: 3.6×10^{-8} Pa

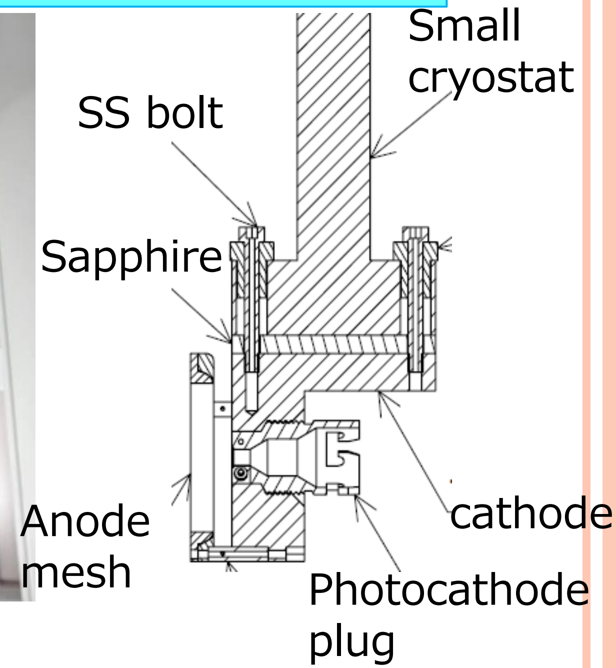
3-4 Initial emittance

- Initial emittance was calculated by measuring the expansion of beam size.
- Parallel plate DC gun consists of thin anode mesh and cathode block.
- Laser was inject from backside of the photocathode. laser spot side is Φ~0.1mm

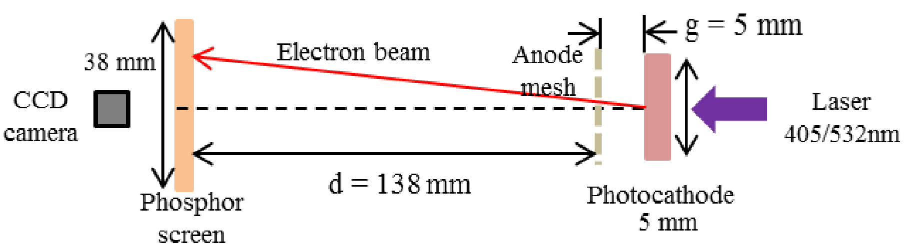
Initial emittance chamber scheme







Initial emittance measurement scheme and equation



Gap voltage (kV)

$$\frac{\varepsilon_n}{\sigma_x} = \frac{1}{2g+d}\cdot\sqrt{\frac{2eV}{mc^2}}\cdot\langle r^2 - \sigma_x^2\rangle^{1/2}$$

Beam radius

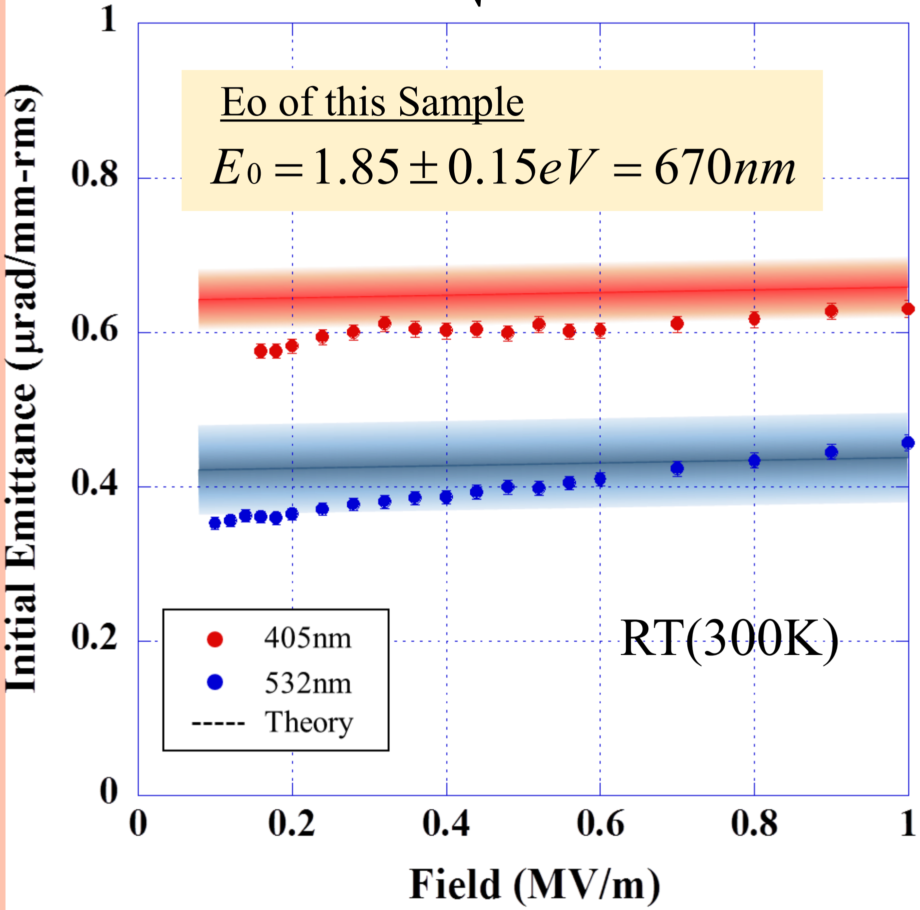
Laser radius

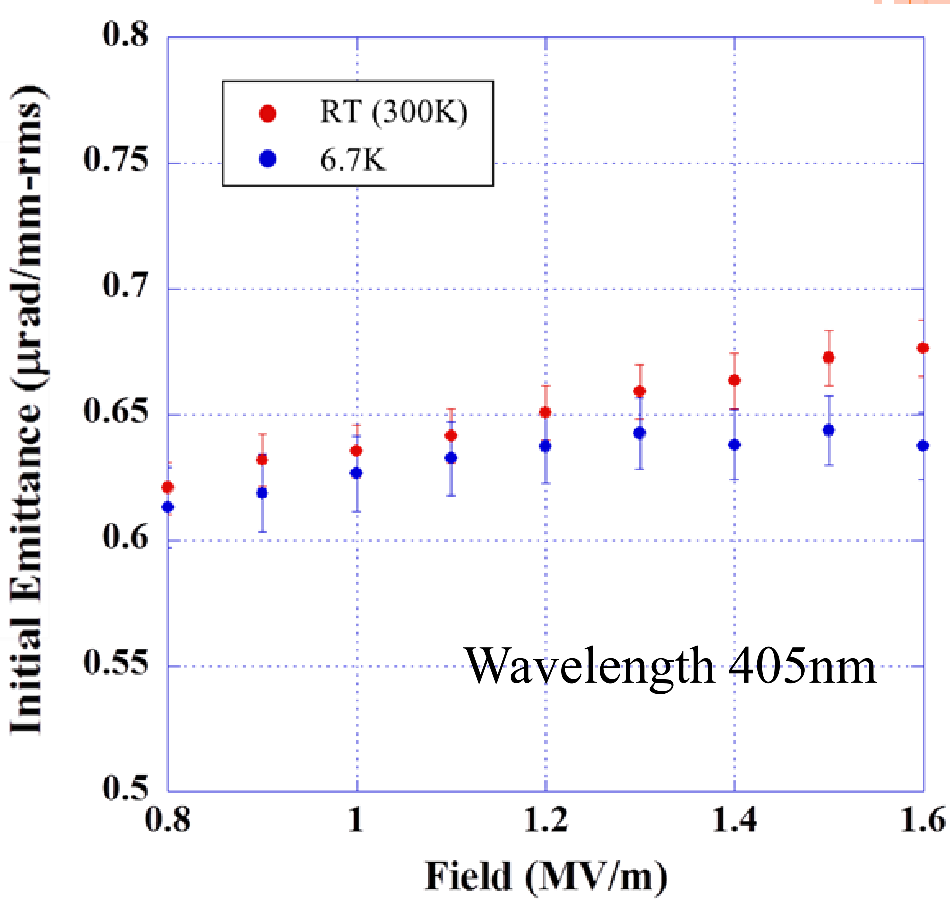
3-4 Initial emittance

- The measurement results at RT almost agree with theory.
- Initial emittance should be constant regardless of the electric field
  - The measured data is rising along with electric field.
  - We suspect anode was bended with electric field, because it is 20 μm thin film.

Theory: $\varepsilon_n = \frac{R}{2}\sqrt{\frac{2(\hbar\omega - E_0 + \phi_{sch})}{3mc^2} + \frac{2k_BT}{mc^2}}$

Shottky effect: $\phi_{sch} = \sqrt{\frac{eV}{4\pi\varepsilon_0}}$





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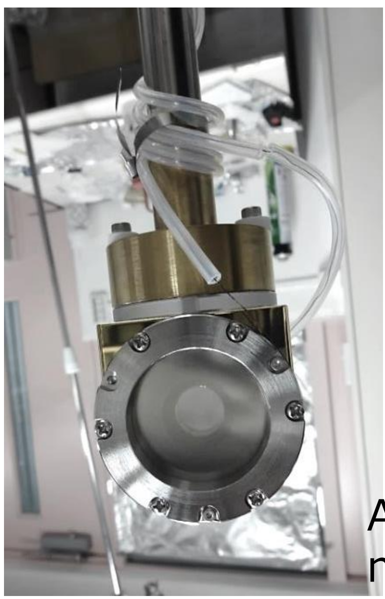
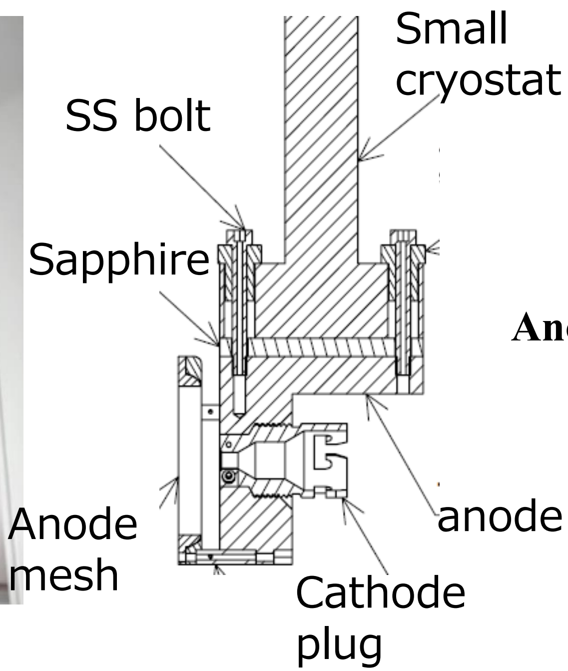
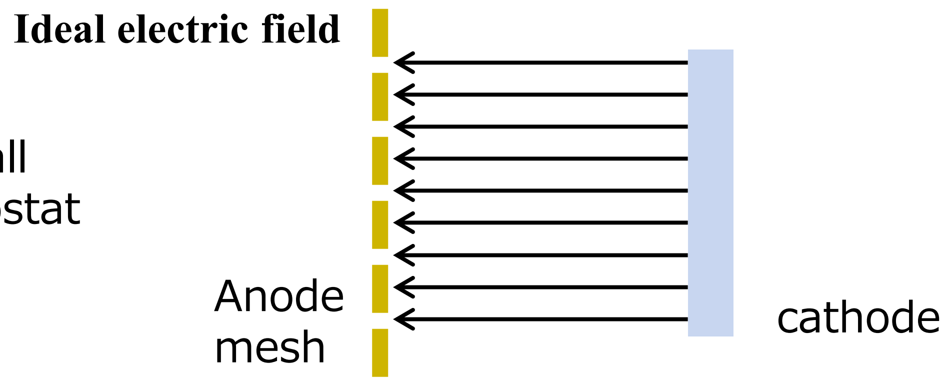
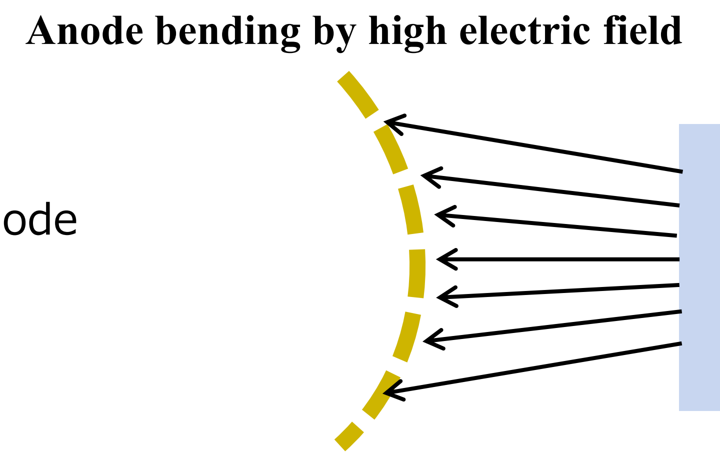




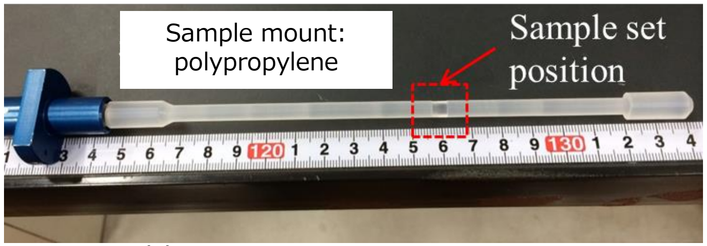


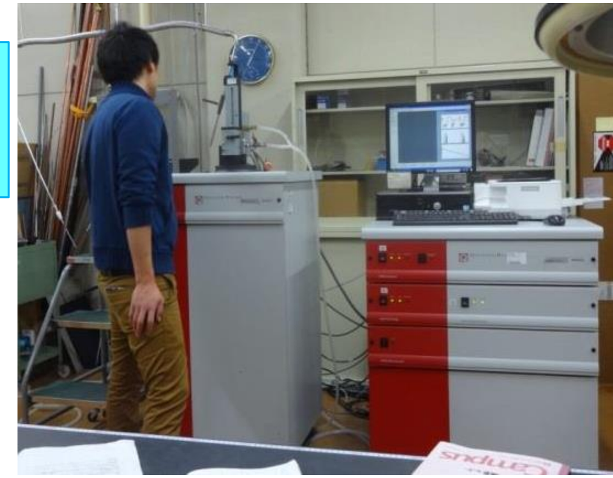


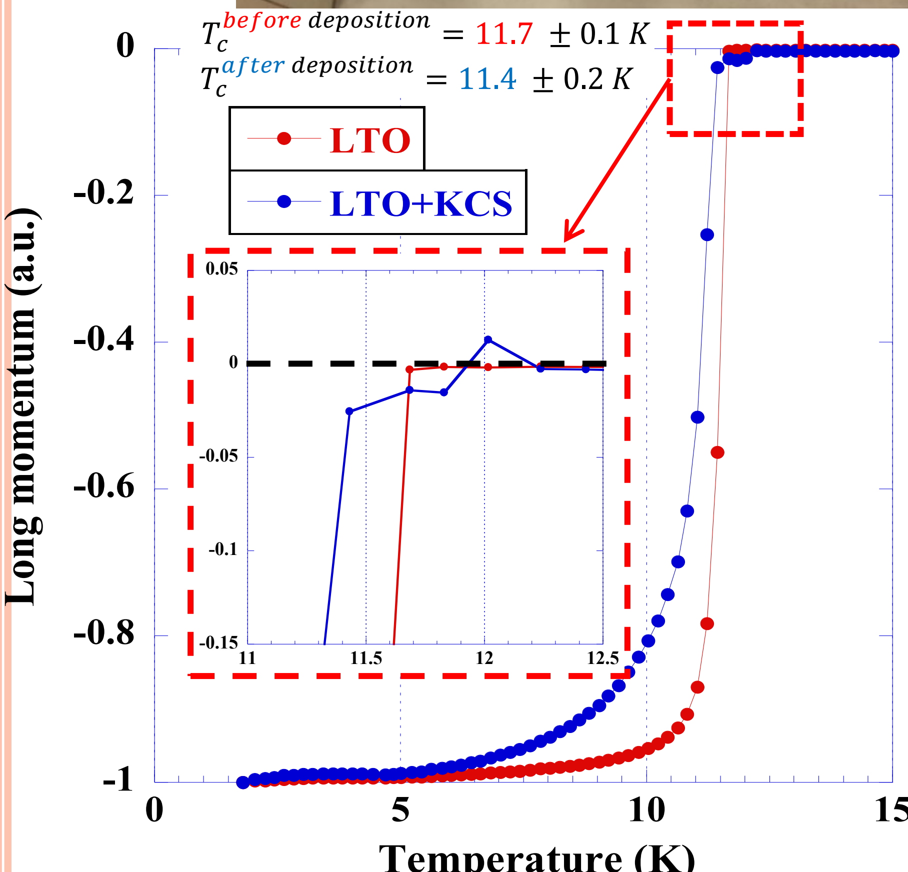
Divergence electric field is created

3-5 Critical magnetic field

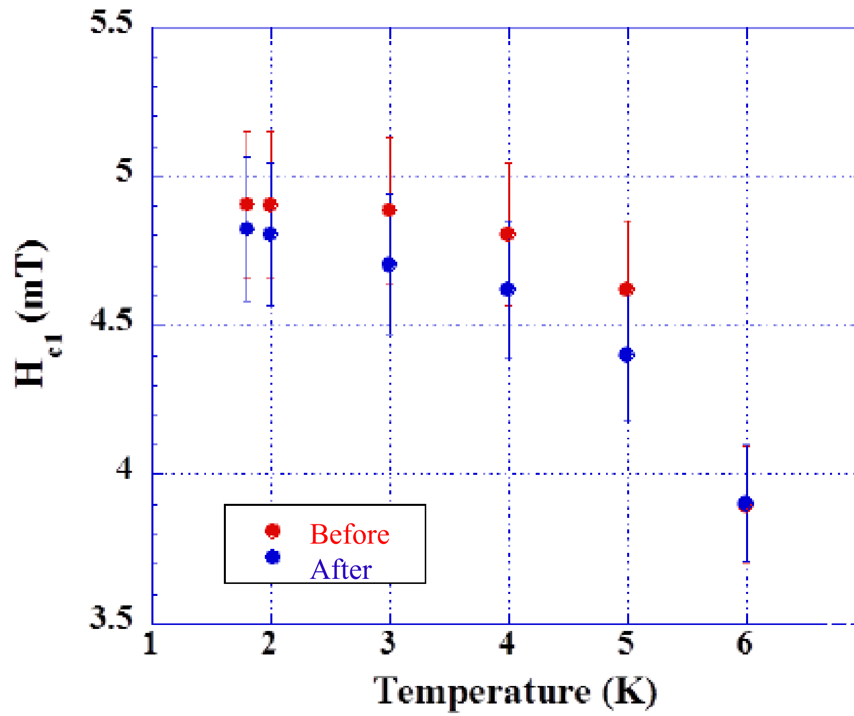
- The critical temperature and critical magnetic field were not changed before and after K_2CsSb deposition.
- Critical magnetic field is higher than the SRF gun operation.





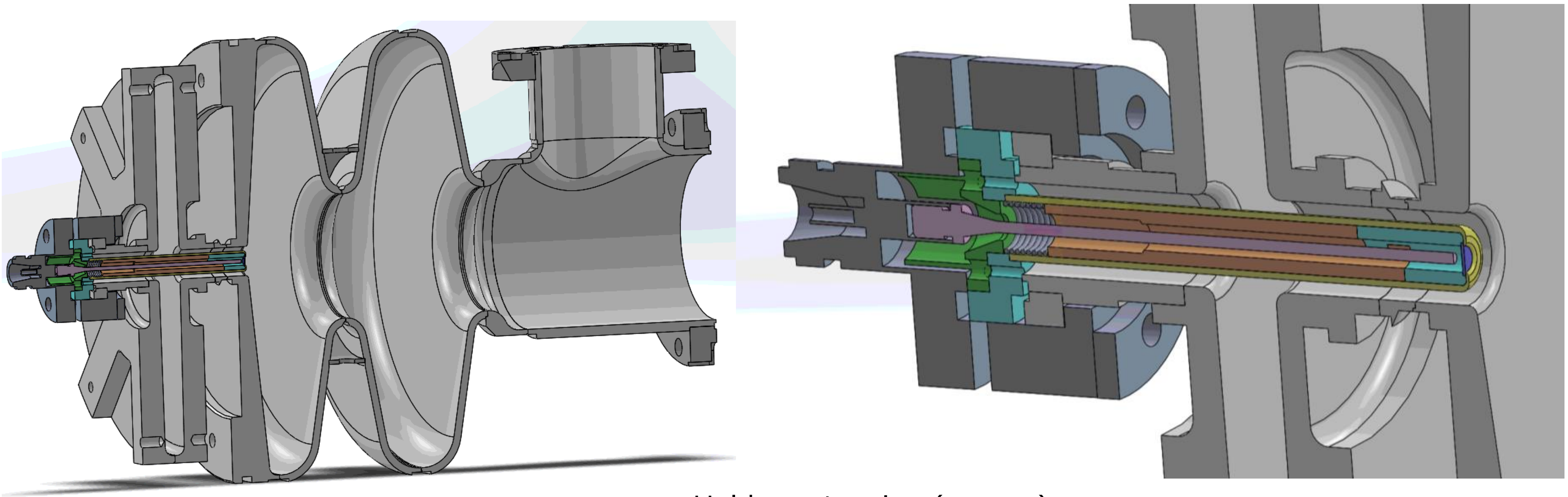


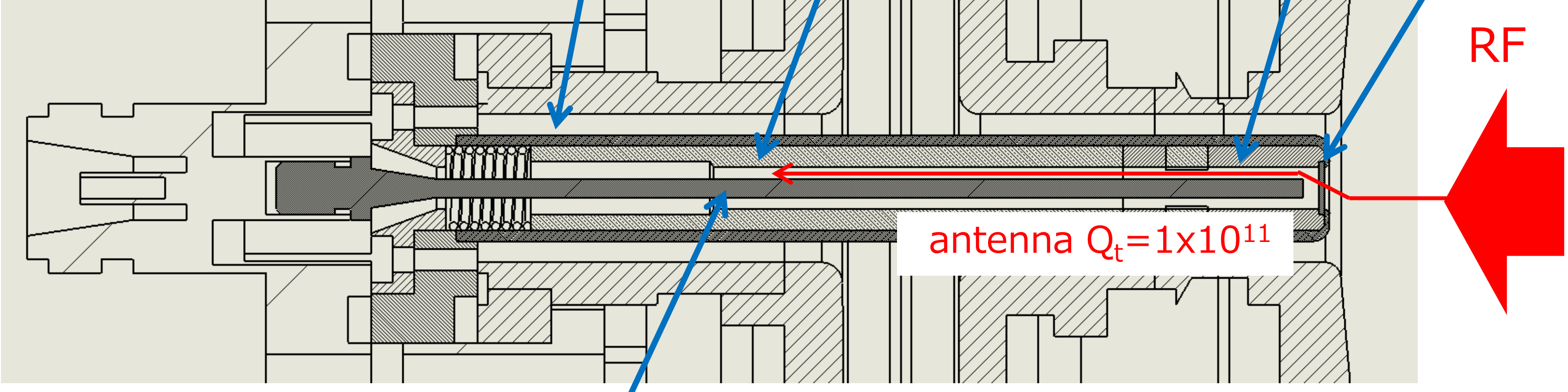
Target RF magnetic field is 3.3mT



4 Plan of the KEK SRF gun development

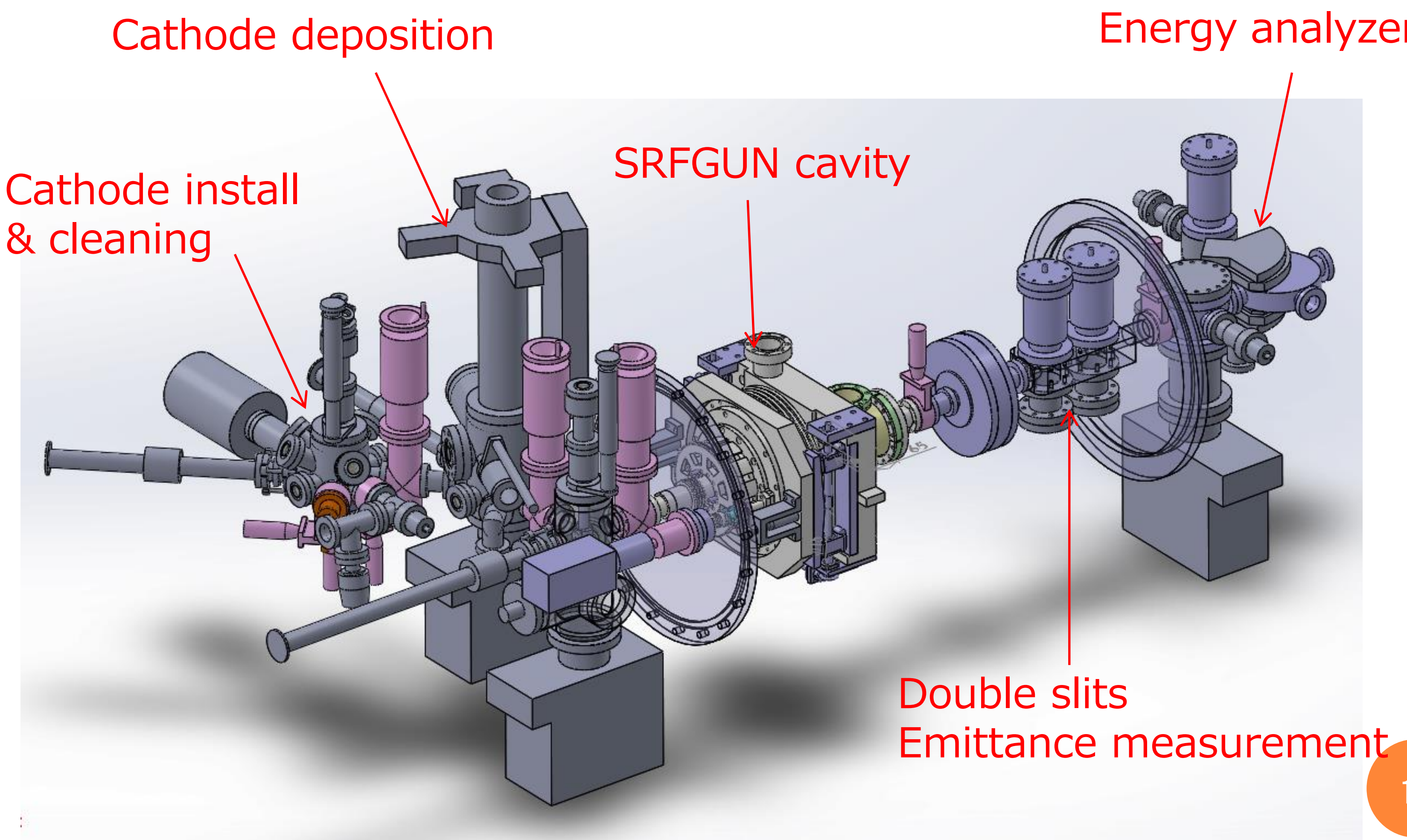
- A new cathode rod for KEK SRF gun #1 can mount 5mm square sample.
- It can monitor the RF leakage. The coupling is $1\text{x}10^{11}$.





4 Plan of the KEK SRF gun development

- We are designing the SRFGUN #2 for small current beam test.
- This is not a final version.



5 Summary

- KEK SRF gun has been developed for 3GeV KEK ERL

- Prototype #1 cavity was designed to check the RF parameters.
  - Target Esp is 42 MV/m, it correspond to Eacc = 20MV/m of TESLA cavity.
  - After HPR, the peak surface electric field reached 75 MV/m and X-ray couldn’t be observed.

  ⬇

  - We have to search other method for cleaning because $LiTi_2O_4$ is thin and delicate.

- Basic properties of the photocathode using transparent superconductor were measured.
  - QE ratio from back side was 90% of front side at 532 nm.
  - Initial emittance almost agreed with theory.
  - Critical magnetic field satisfy the SRF gun operation.
  - QE decrease during cooling down.
  - Further study of photocathode performance at cryogenic temperatures and ways to improve this performance is essential for the photocathode development.

Thank you for your attention !