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Successful operation of K_2CsSb photocathode in DC-SRF-II gun

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Photocathode Physics for Photoinjectors Workshop

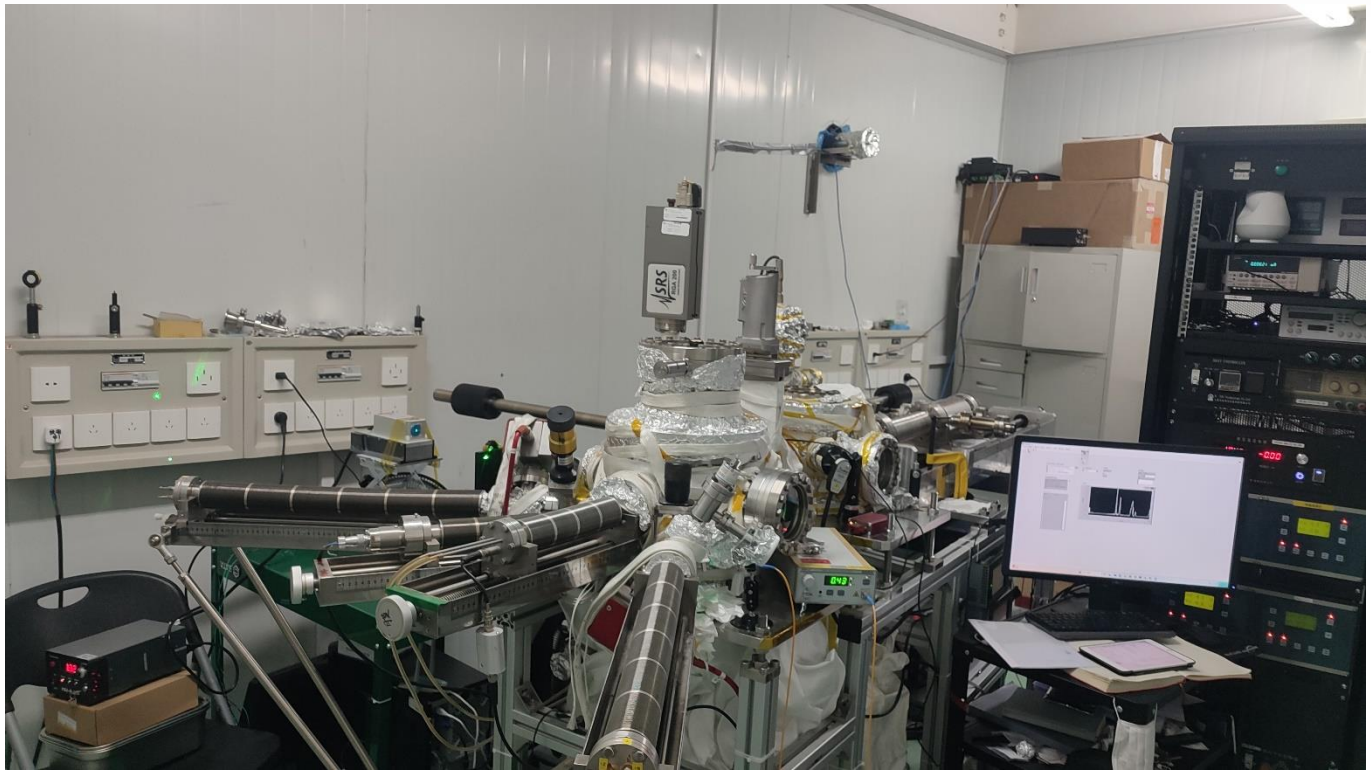
北京大学射频超导加速器实验室

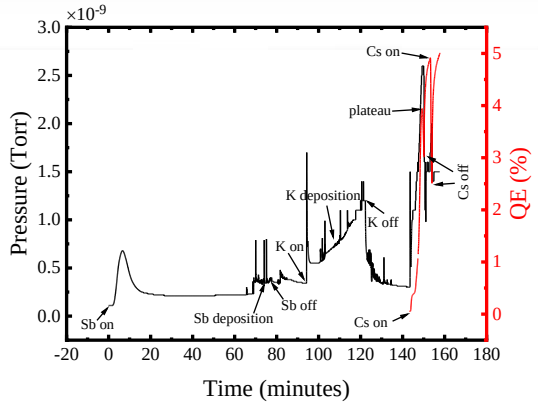
陈佳洱 二〇二三年九月十日

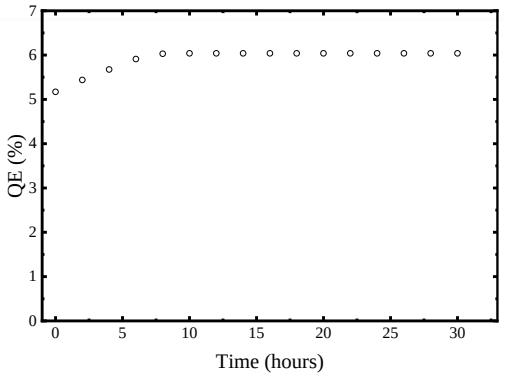
Outline

- Fabrication and Transport of K_2CsSb photocathode
- Performance of the K_2CsSb photocathode in the DC-SRF gun
- Cryogenic effect demonstration
- Summary

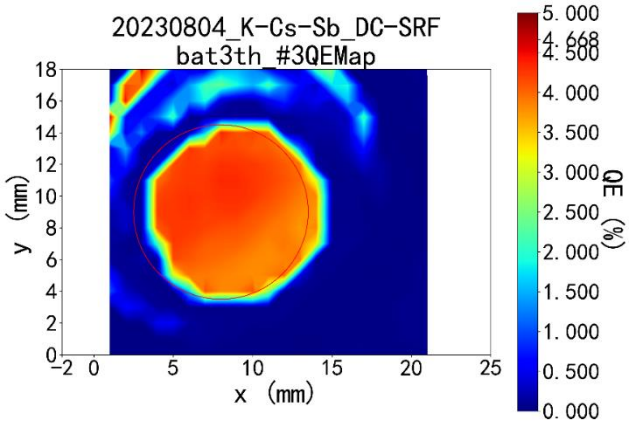
K_2CsSb photocathode deposition system

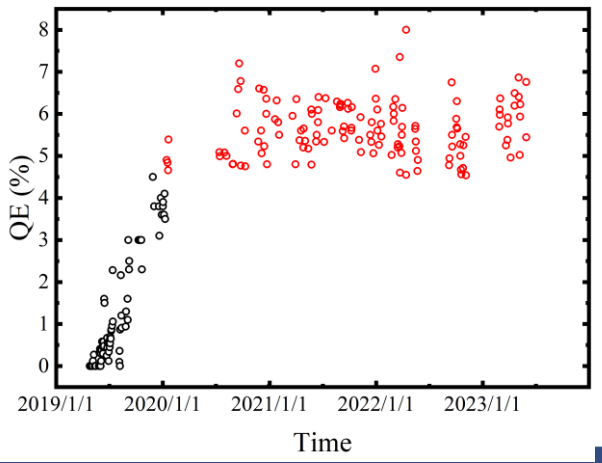


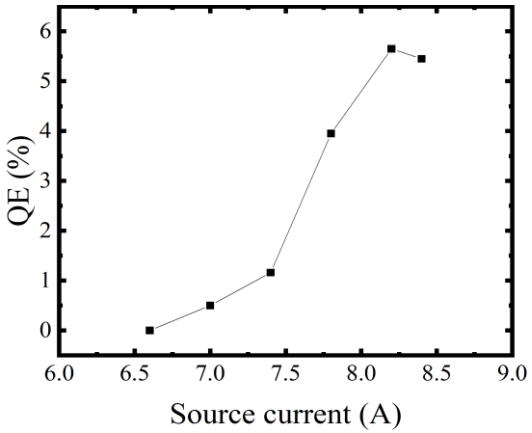


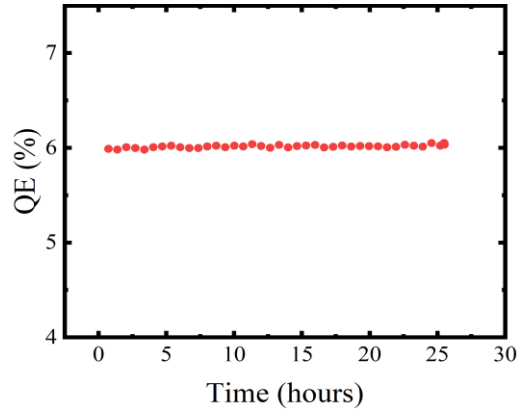


"Fast Cesiation" sequential deposition recipe, the total activation time cost less than 10 min. The QE keeps growing in the following days after activation.



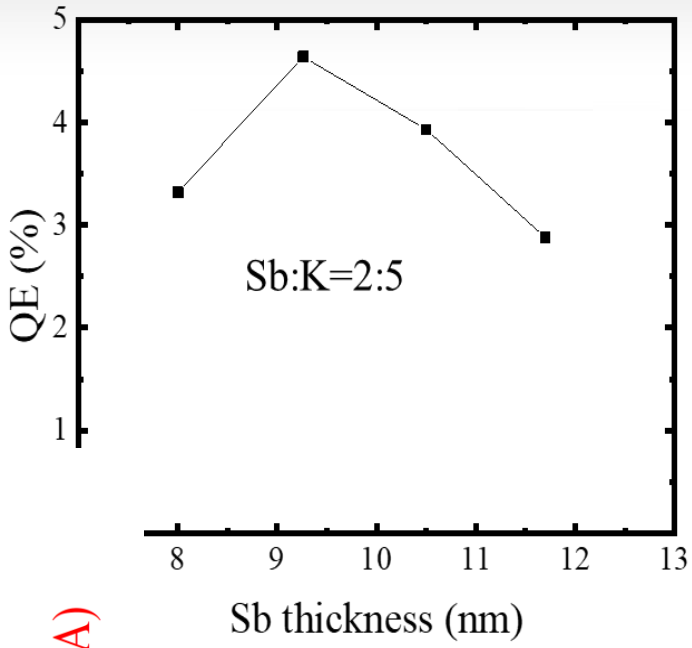


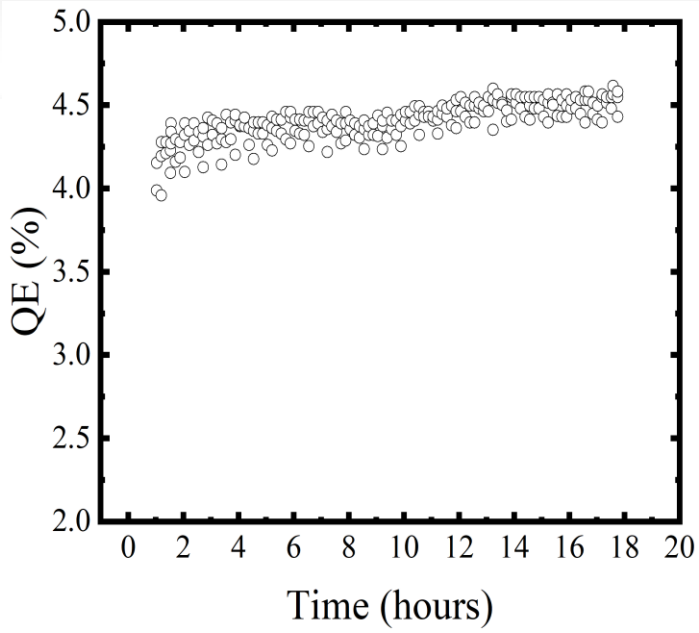


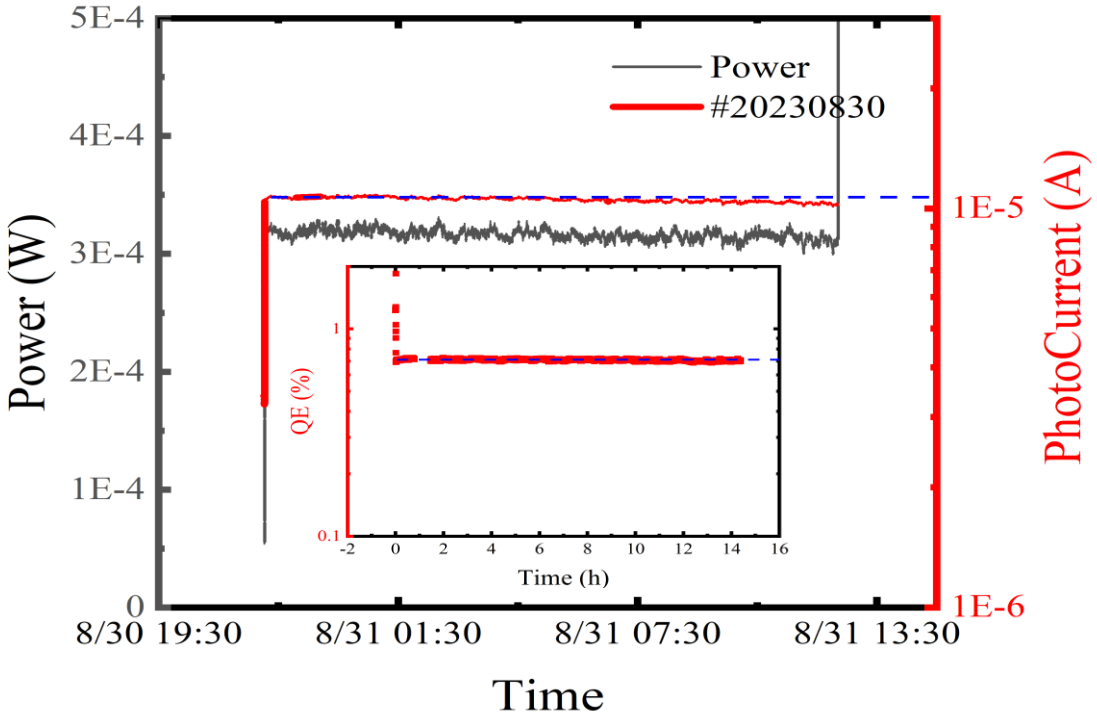


Photocathode grown by co-evaporation method

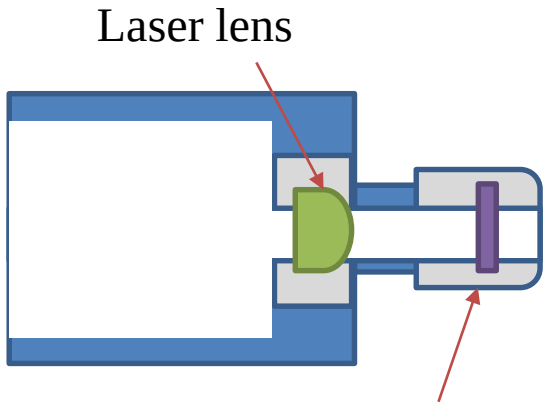
Transparent photocathode





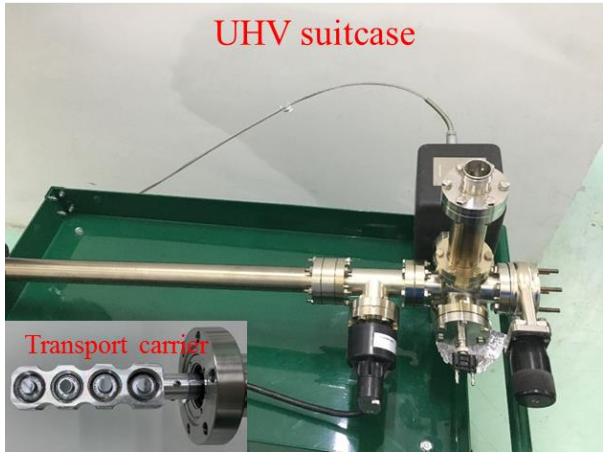


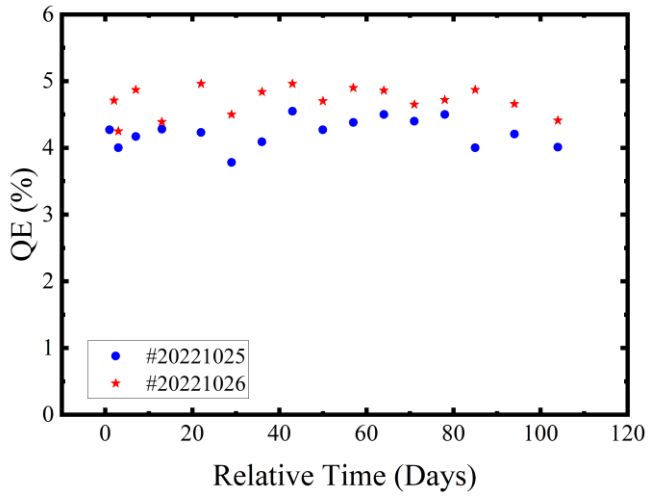
Emission current density with transparent K_2CsSb photocathode

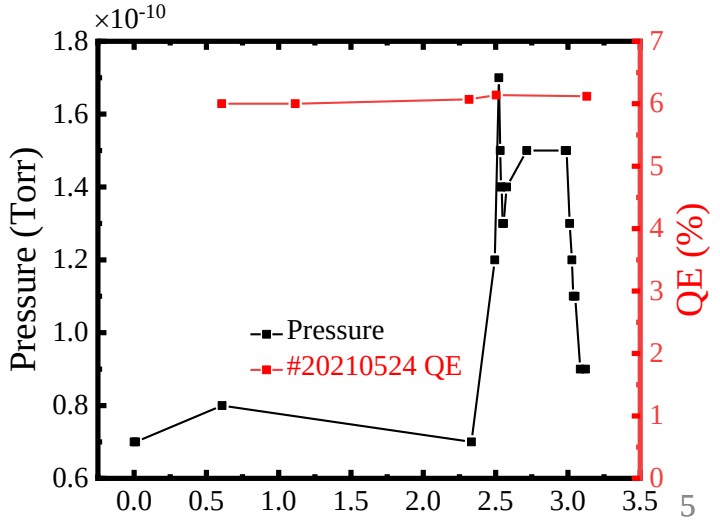


The transparent photocathode has smaller intrinsic emittance, so can be used to reduce the emittance of the gun, also it can be used to heat the plug with IR laser in the DC-SRF gun for the plug is cooled to about 30 by the flowing liquid helium.

Transport from deposition chamber to guns







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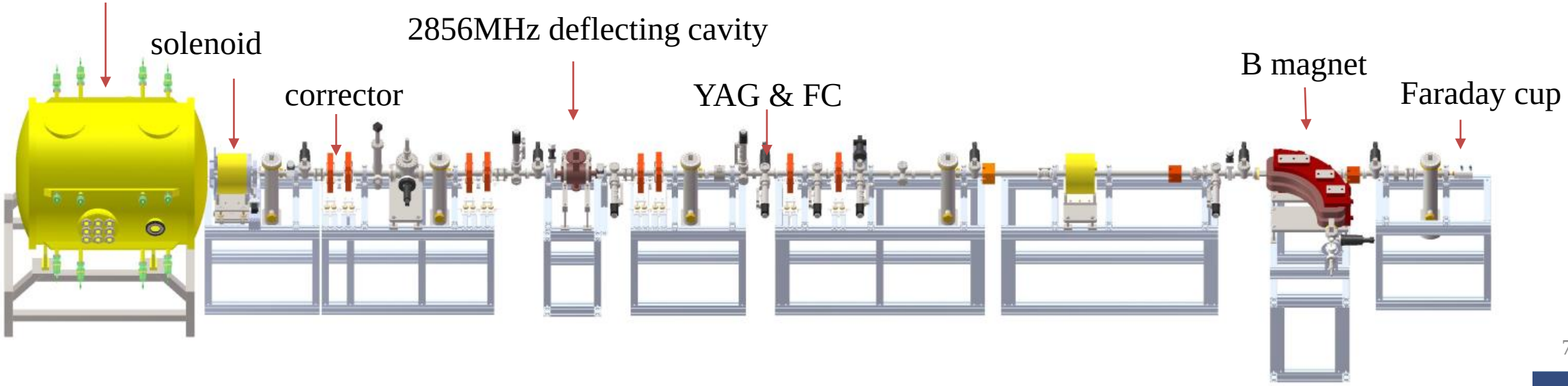
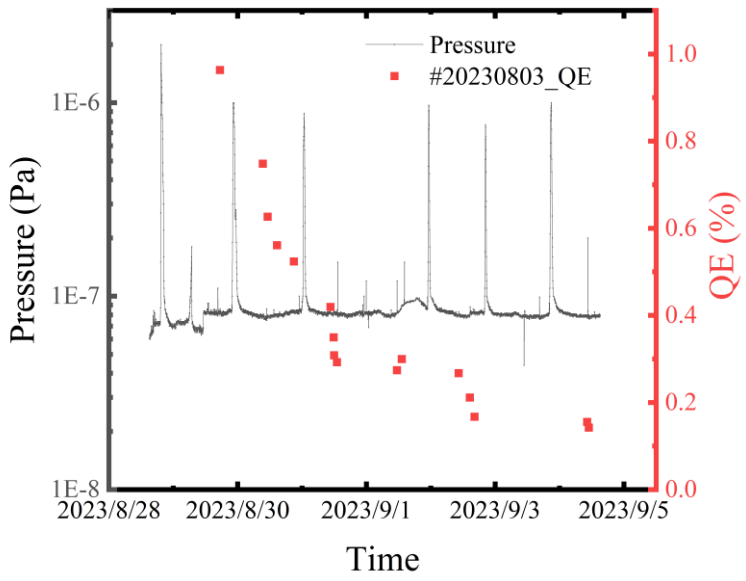
DC-SRF-II parameters and layout

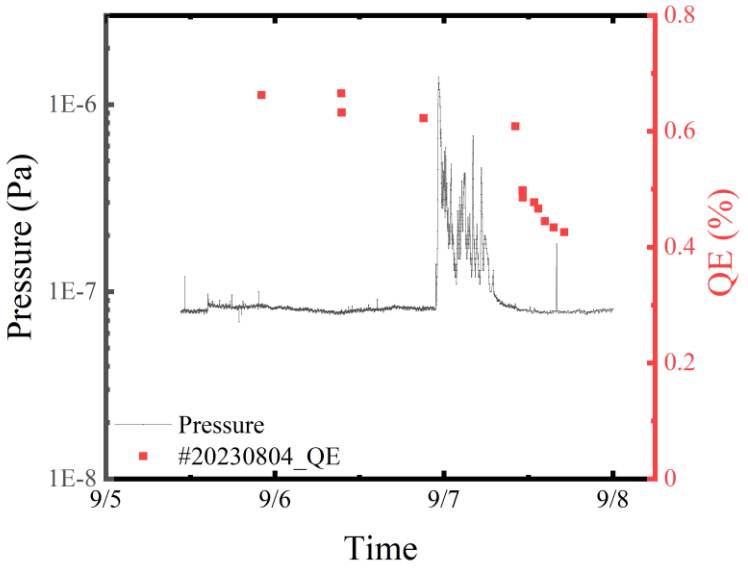
Parameters	Unit	Value
Beam energy	MeV	~2
DC voltage	kV	100
Dark current	pA	100(CW)
Bunch charge	pC	10-100
Bunch repetition rate	MHz	1, 81.25
Normalized RMS emittance	mm.mrad	0.28 @ 20 pC；0.43@ 50 pC；0.58 @ 100 pC
Laser wavelength	nm	515

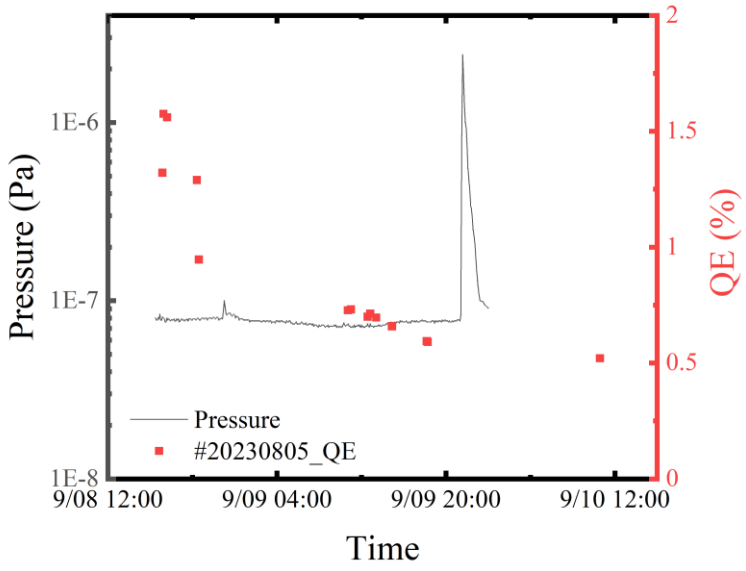
DC-SRF-II gun

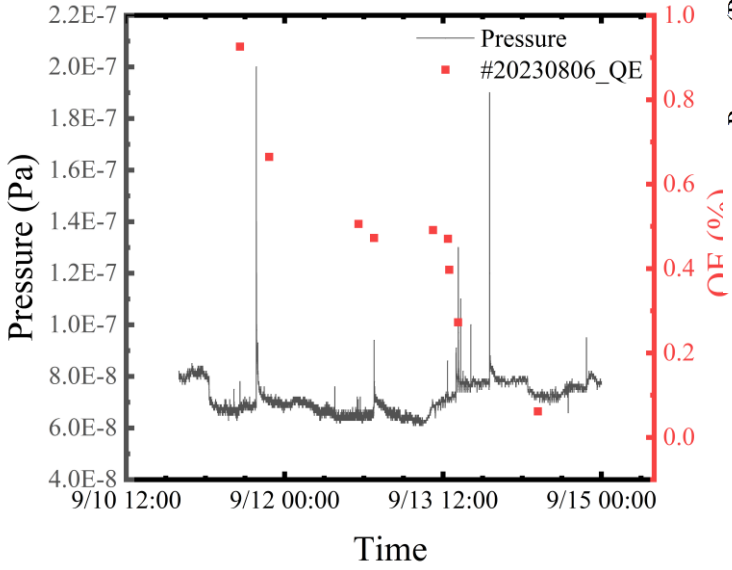


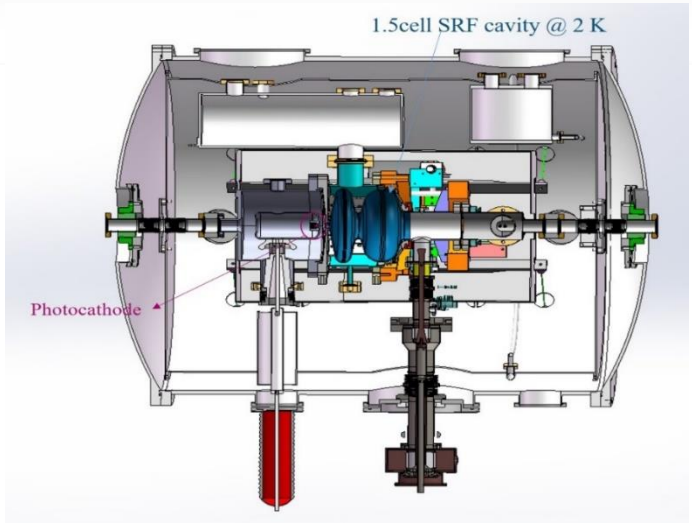
Lifetime of the photocathode in DC-SRF gun

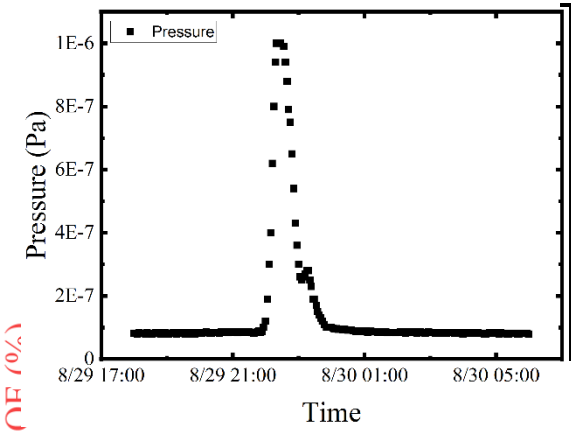


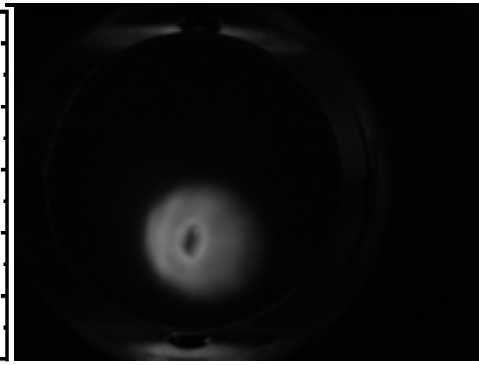








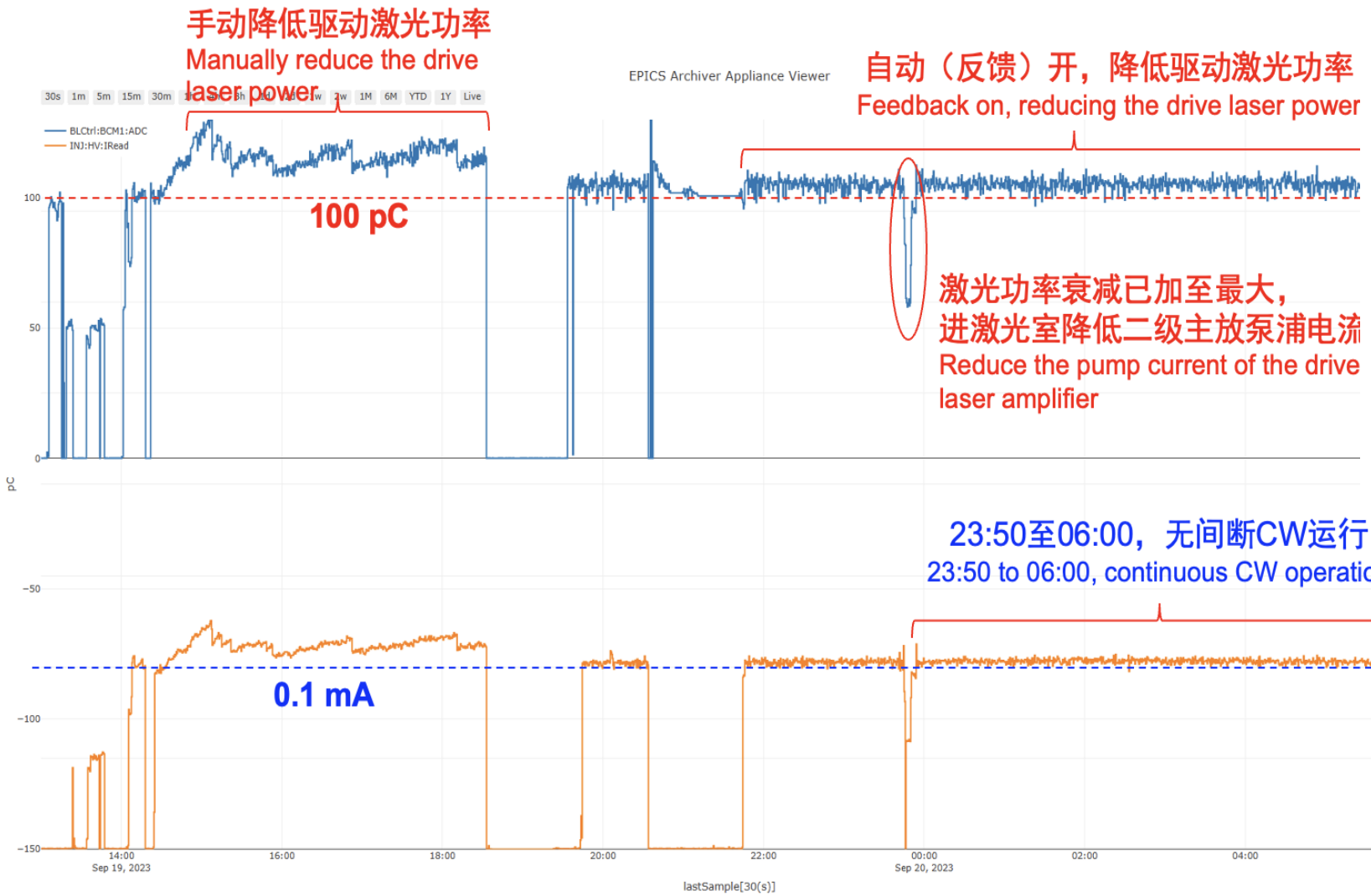


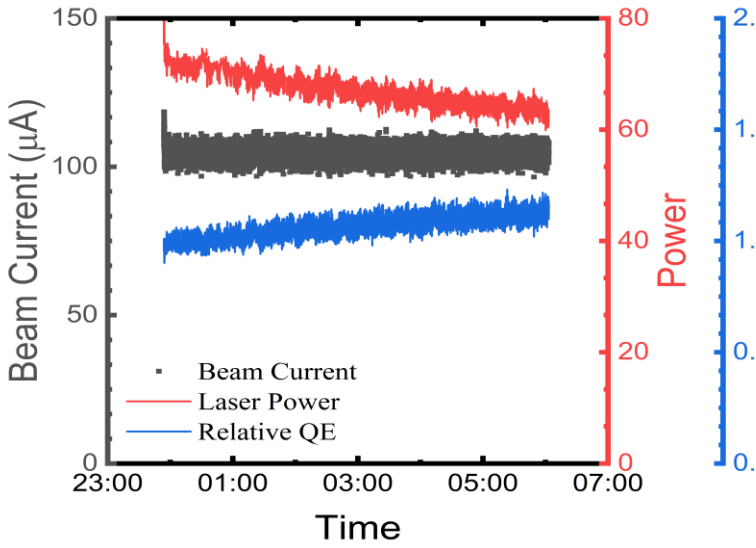


The photocathode in the suitcase is about 5%, when inserted into the gun, the QE dropped to about 1% immediately. When the cathode is returned to the suitcase, the QE is 5% again.

The QE of the photocathode is influenced by the vacuum of the cavity. The vacuum is mainly determined by the cryogenic system, when the 2K system is closed, the gas released by the cavity may poison the photocathode inside of the cavity.

CW operation at 0.1 mA



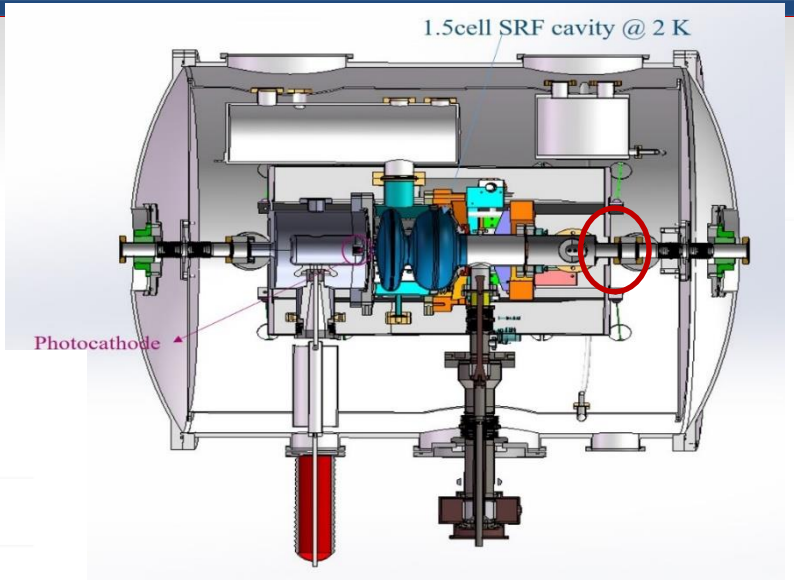


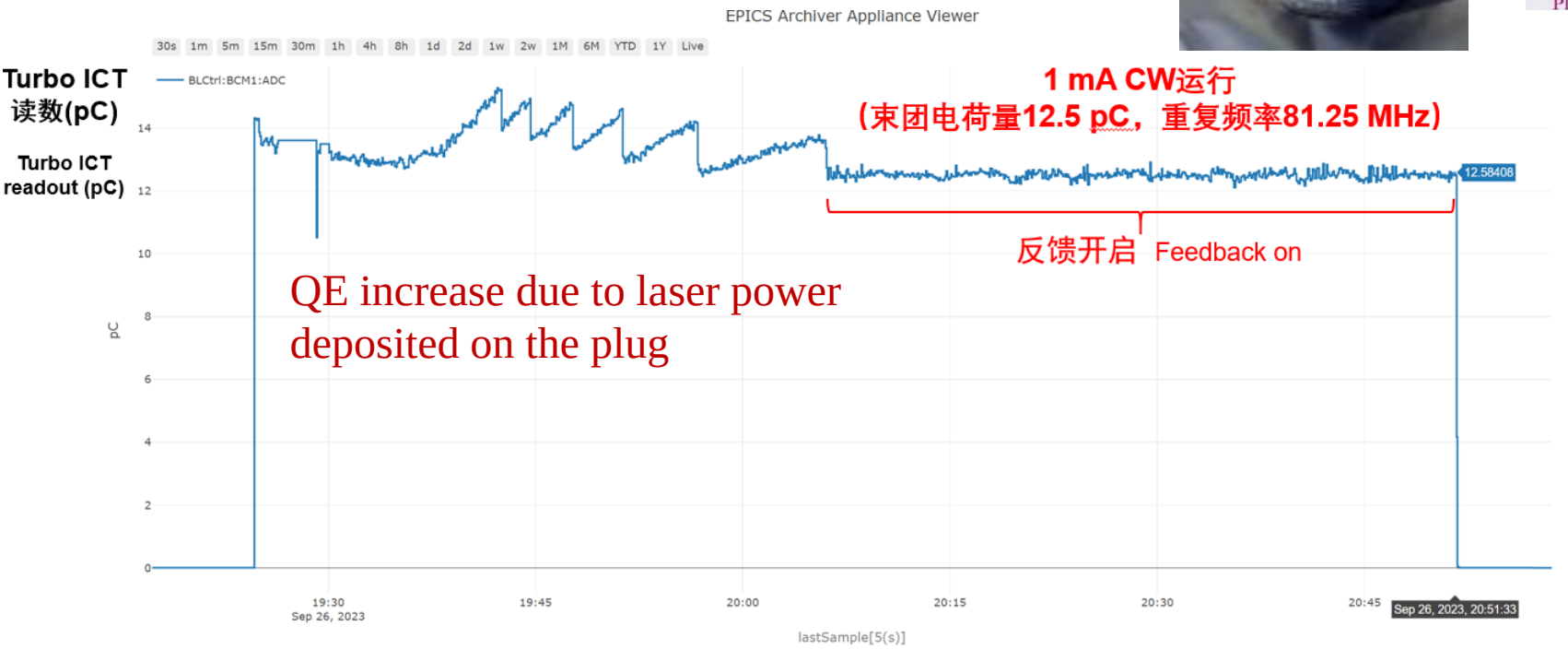
The emittance of the electron beam at the exit of the DC-SRF-II is 0.58 mm.mard with a bunch charge of 100 pC and 0.43 mm.mrad for 50 pC.

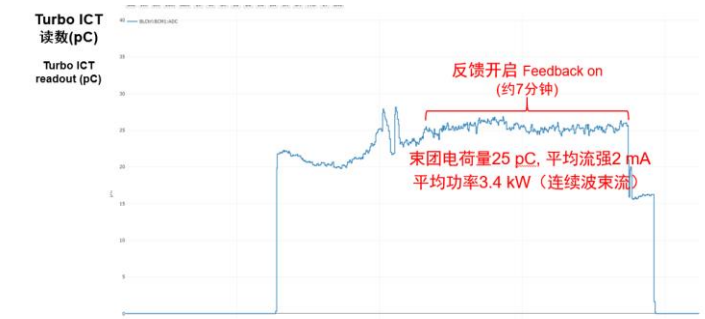
For more details, please contact: huangsl@pku.edu.cn

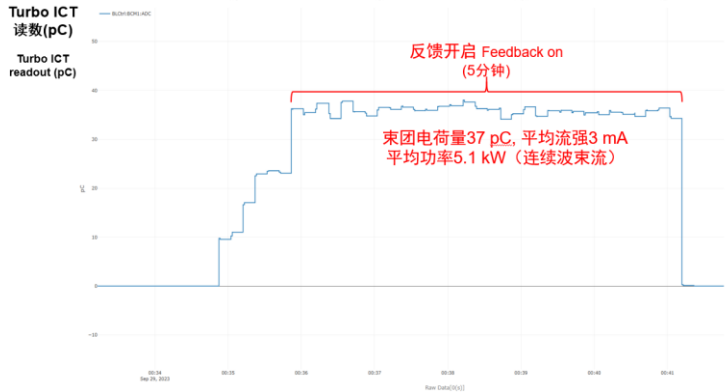
High current operation

CW operation at high average current---1 mA









2~3 mA CW average current(12~40 pC, 81.25MHz) also achieved in DC-SRF-II gun, the main limitation is the heat induced SC cavity quench from the beam tube connected to the SC cavity.

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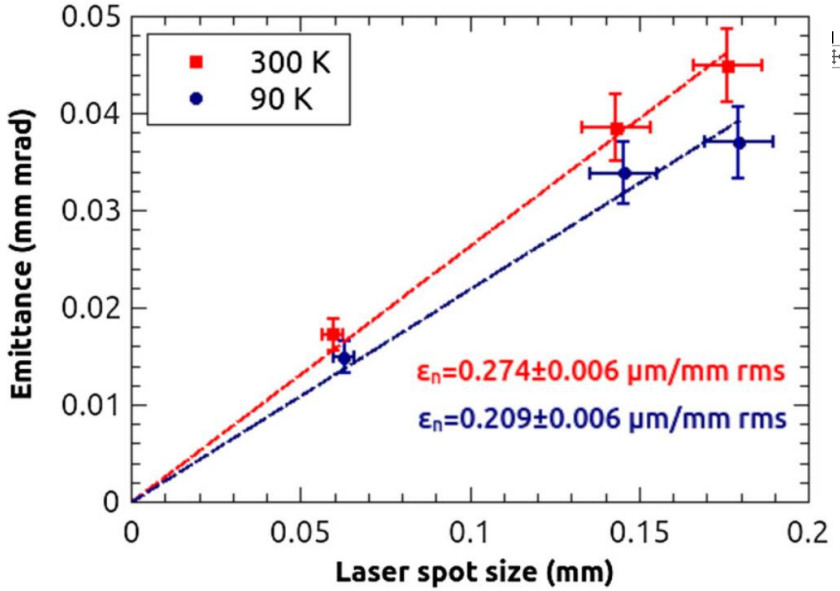
Compensation of QE at cryogenic temperature

- The cryogenic effect for alkali antimony photocathode(QE drops with decreasing temperature) had been observed at BNL, Cornell, Jlab, PKU, etc, and a lot of models have been built to explain this effect.
- Only observed in alkali antimony photocathode, Cs_2Te and GaAs has no such effect(At HZDR, Cs_2Te also works at LN2 temperature)
- Decrease of QE can be compensated with IR red laser or by flowing water
- First observed in the electron gun at ~30 K, and delivered the cold electron beam that can be used in the XFEL machine. May contribute a large part in the emittance reduction, the intrinsic emittance of K_2CsSb photocathode in the DC-SRF-II gun will be measured in the following experiment.

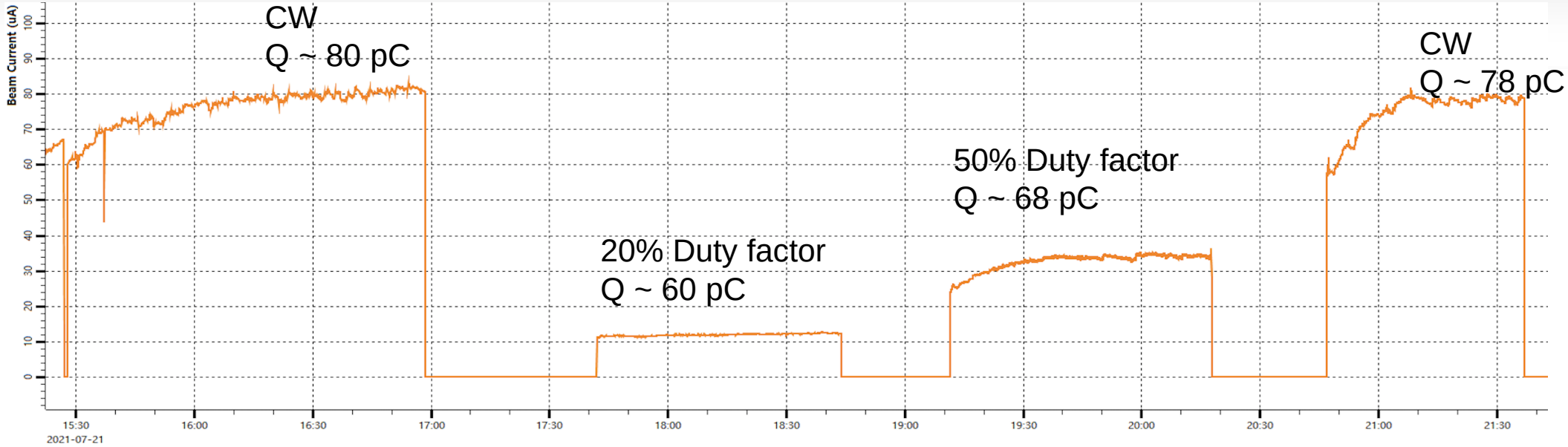


Intrinsic emittance reduction for Cs_3Sb photocathode at 90 K measured by Cornell

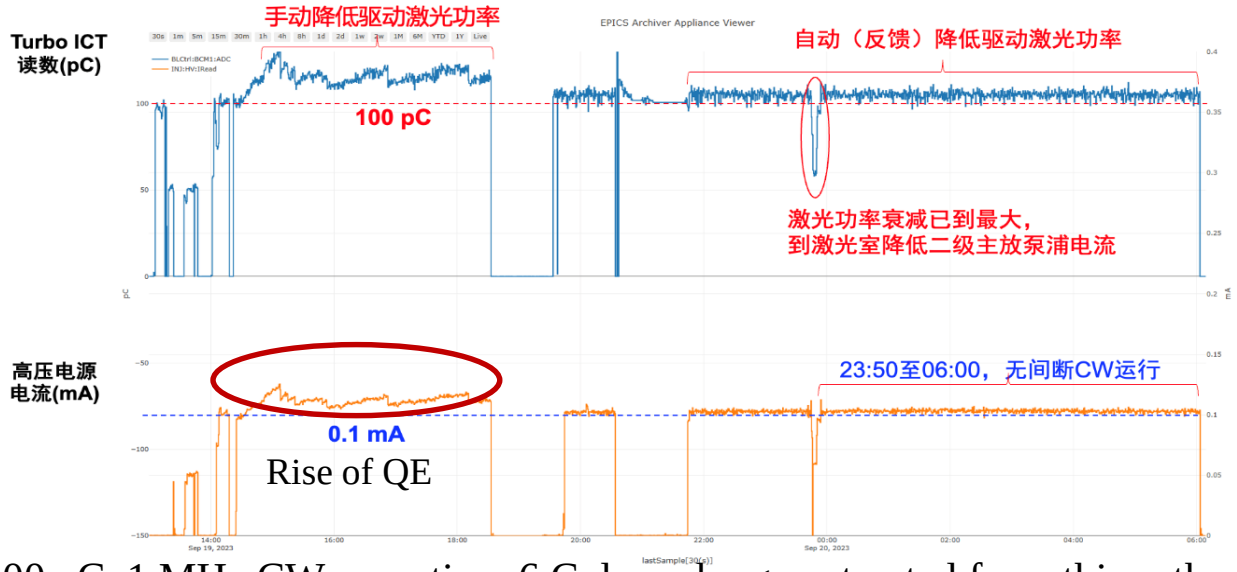
Table 1: the optimized emittance for DC-SRF-II gun @Q = 100 pC, E = 2.38 MeV, z = 5.4 m

Intrinsic emittance(mm · mrad)	Emittance (mm · mrad)	Beam radius (mm)	Percentage of Intrinsic emittance
0.2	0.307	1.105	34.47%
0.3	0.332	1.100	47.59%
0.4	0.365	1.108	58.14%
0.56	0.428	1.099	68.85%
0.78	0.527	1.085	76.89%

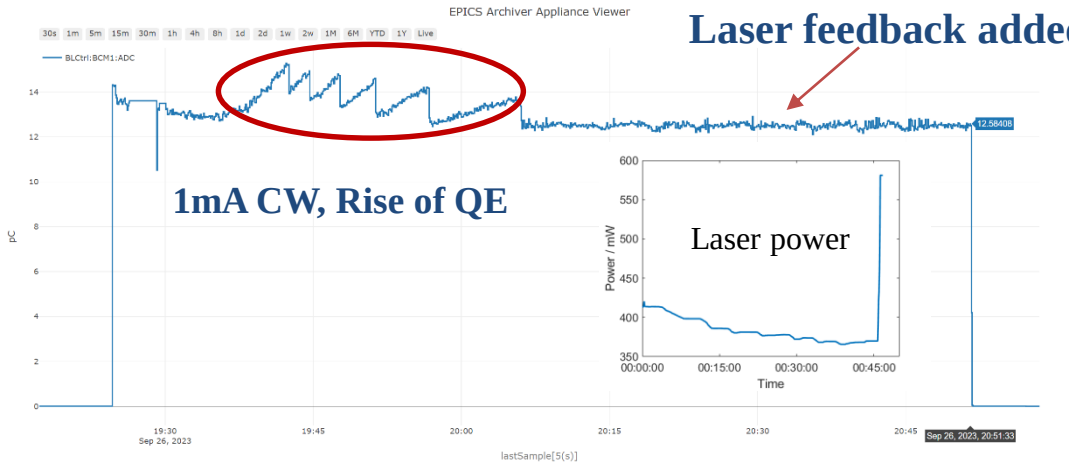
QE increasement during the beam experiment



Rise of photocurrent by 1MHz, 0.65W CW laser irradiation, Experiments on Jul 21, 2021

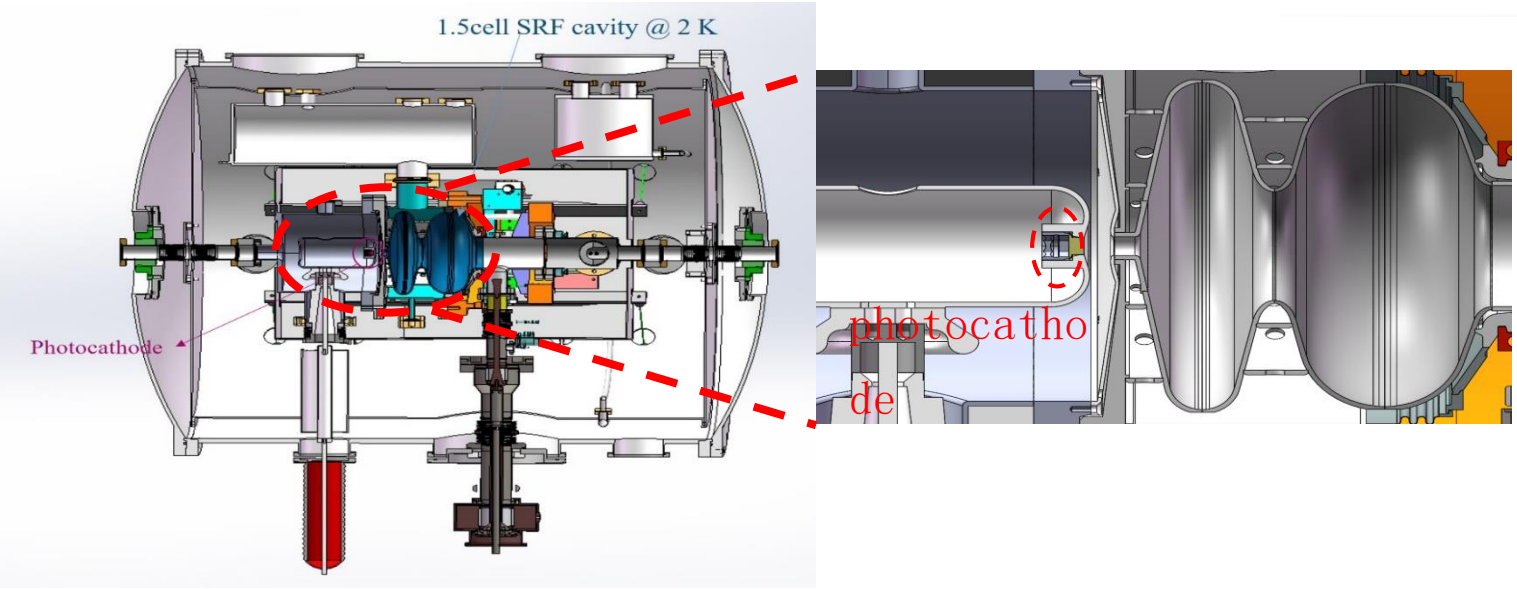


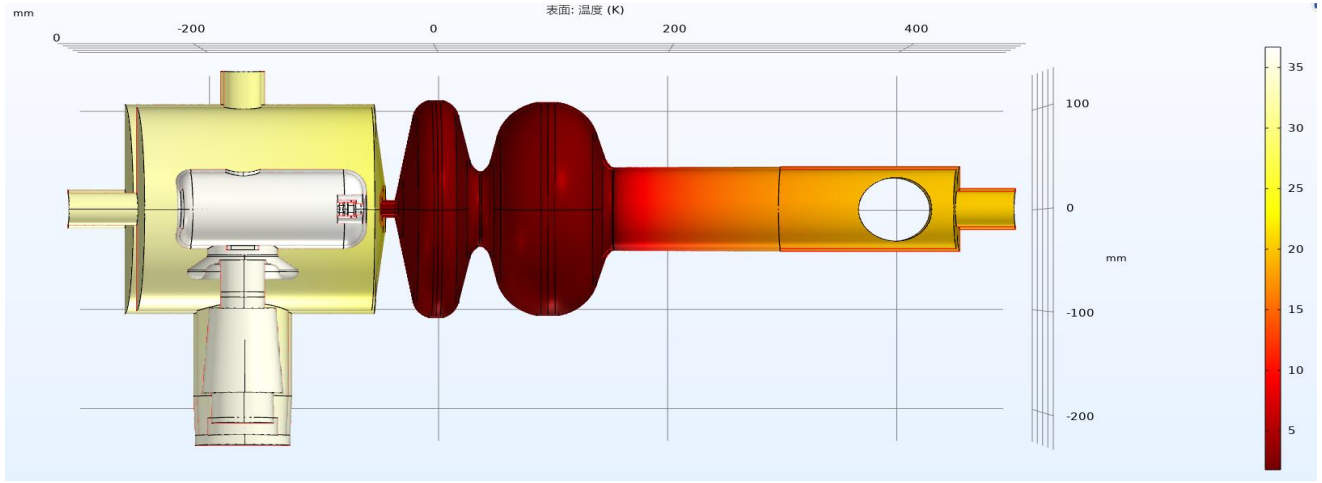
100 pC, 1 MHz CW operation, 6 Colum charge extracted from this cathode #202309



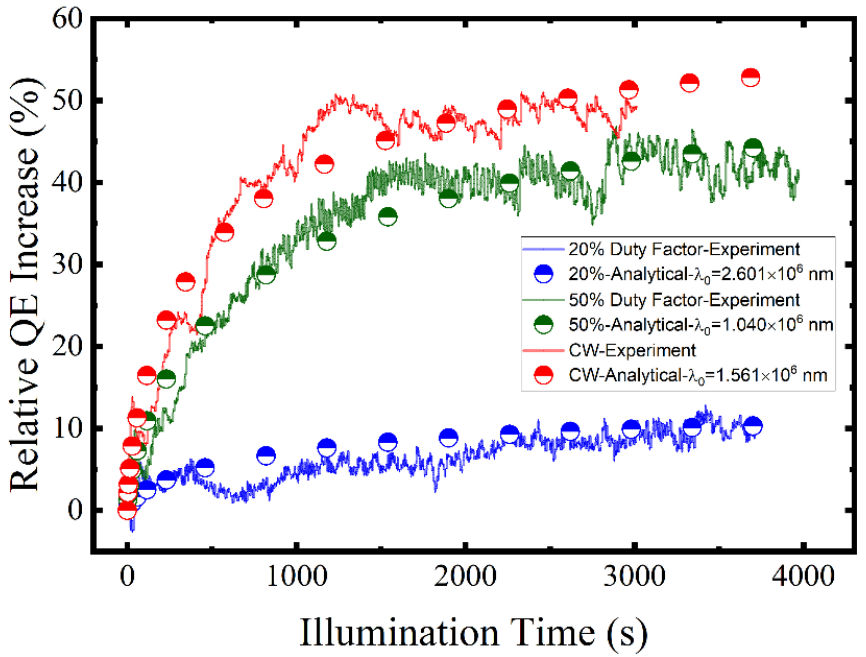
13 pC, 81.25 MHz CW operation on September, 2023

Analytical model of the cathode performance at ~30 K in the gun



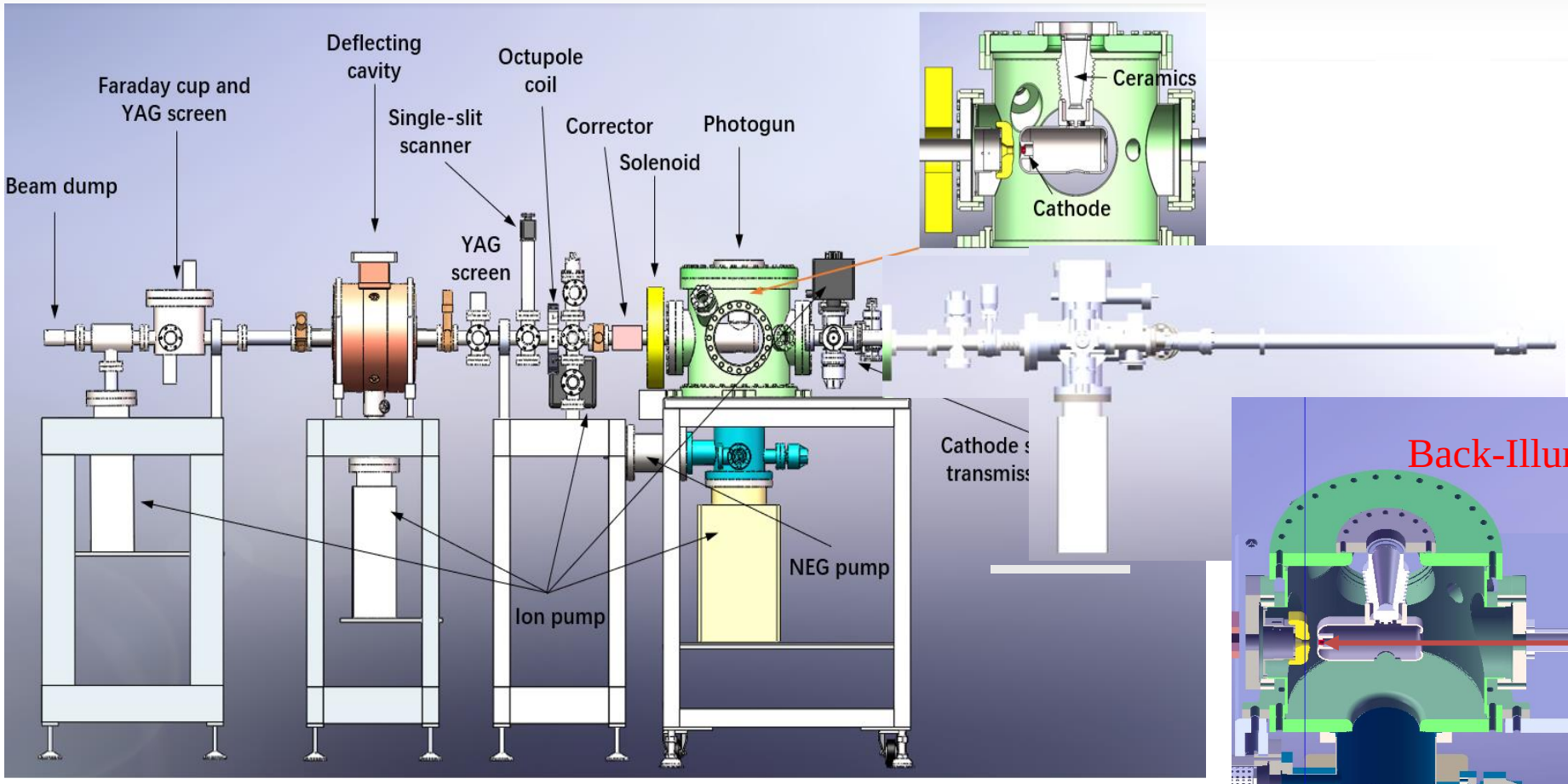


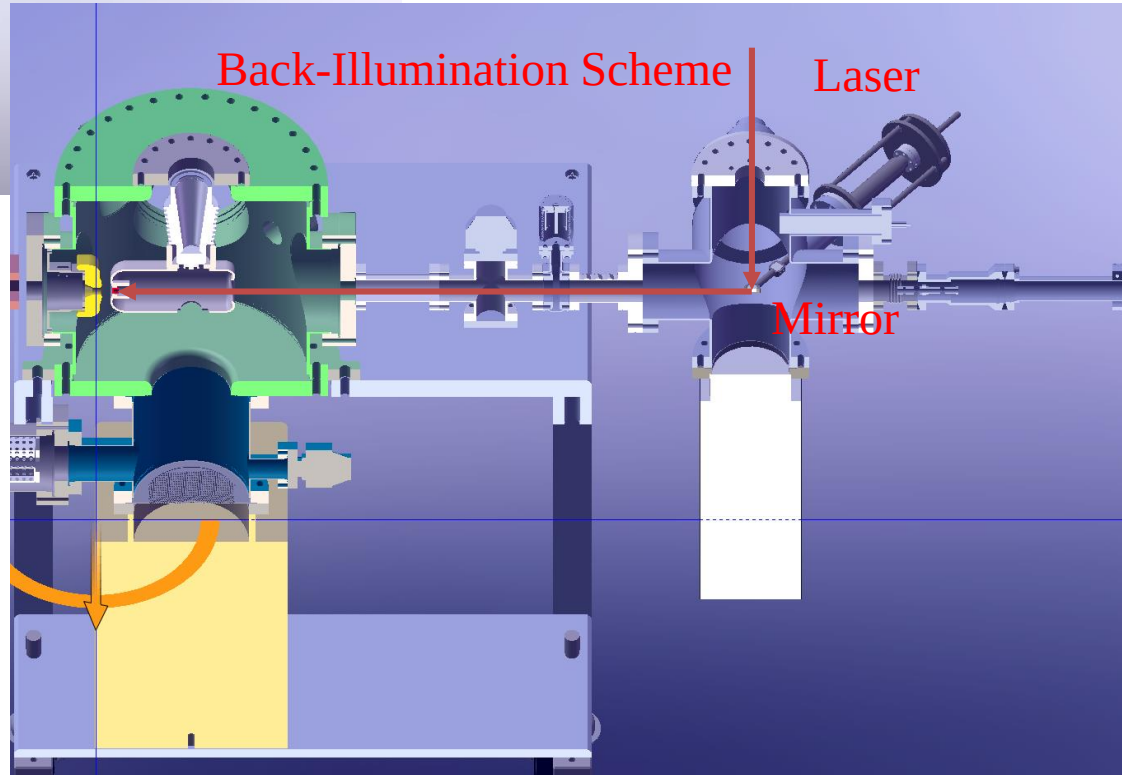
Simulation results of temperature distribution



position	Valve	Beam tube
measured/K	35.17	17.06
simulation/K	32.5	18.6
error	7.9	9.3

Compensation of QE in HV DC gun

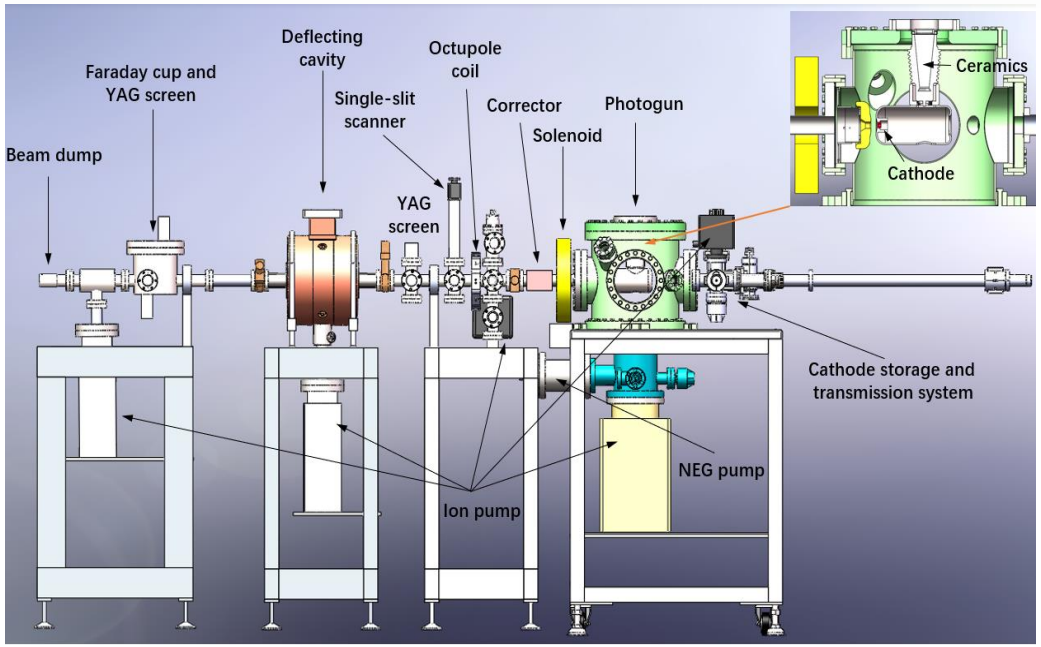


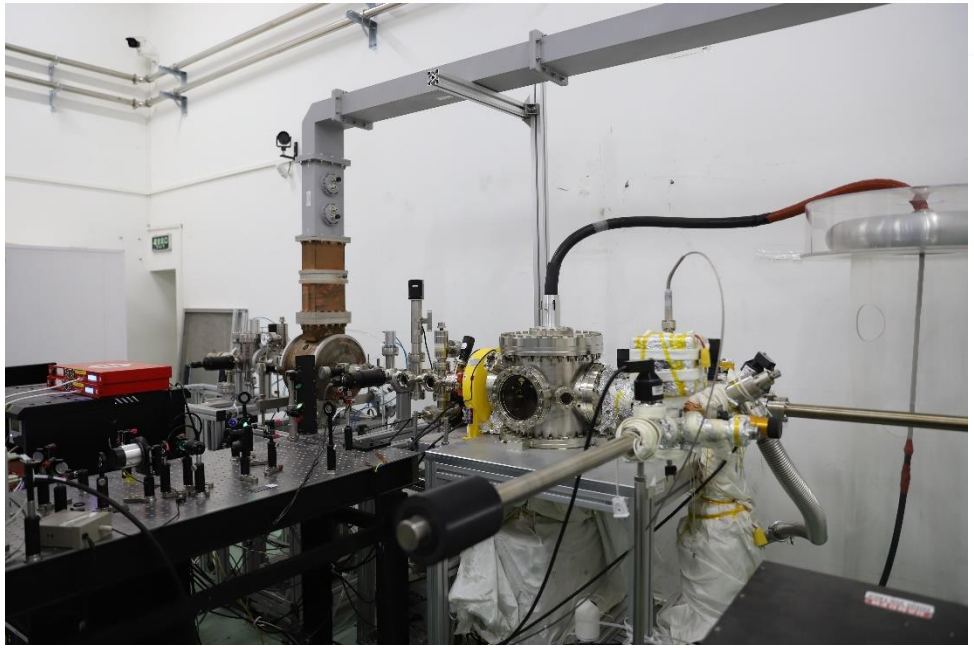


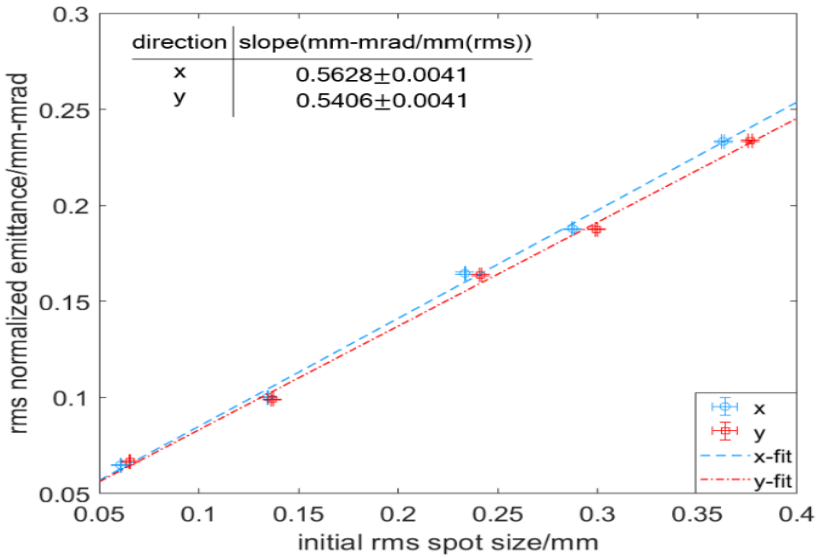
The cathode can be heated with IR laser from the back side, the transport chamber has been designed and will be commissioned next month. And the back-illuminated photocathode can also be used in the DC-SRF gun.

A cryocooler has been ordered and arrived soon, which can be installed in the HV DC gun to measure the intrinsic emittance at cryogenic temperature.

Intrinsic emittance of K_2CsSb photocathode measured in HV DC gun







parameters	value
Beam size[mm]	0.25~1
Bunch charge[fc]	~100 fc
Beam repetition rate[MHz]	CW
Laser wavelength[nm]	401, 450, 520, 635

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Summary

1. The fabrication process has been mature and 6-8% K_2CsSb photocathode has been produced(sequential and co-evaporation) both in reflection and transmission mode regularly at PKU.
2. The photocathode has been operated in the DC-SRF gun, and worked reliably in the cryogenic environment. The QE of the photocathode is stabilized at around 0.6% after inserted into the gun. During the CW beam experiment, the QE gradually increase to 2~3 times. The QE of the cold cathode can return to original value (>5%) when extracted back to the suitcase.
3. The cryogenic effect of alkali antimony photocathode can be compensated by using the back-illumination method.
4. The vacuum of the gun is very important for the survival of the cathode. The vacuum in the SC cavity of the DC-SRF gun will be improved to low -8 Pa level in the future (about low -7 Pa now).
5. The CW operation of the gun can last for 16 hours at 0.1 average current(100 pC, 1 MHz), and 1~3 mA average current(CW, 81.25 MHz) has been demonstrated for this gun.
6. The intrinsic emittance of the K_2CsSb photocathode has been measured at room temperature and will be measured in the HV DC gun and DC-SRF-gun at cryogenic temperature.

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Thanks for your attention!

北京大学射频超导加速器实验室

陈佳洱　二〇二三年九月十日