WG3: Electron sources and injectors

Luca Cultrera and Erdong Wang

Photocathodes challenges:

- Photocathodes for high power:
  - **Alkali antimonides** up to 65 mA;
  - 10% in the ”green”;
  - **Available at several labs** / commercial product;
  - Ps time response time;
  - **Few days operational lifetime**;
  - Halo from transverse laser profiles;
  - Microbunching instability

- Photocathodes for spin polarized beams:
  - GaAs based SL are the only real choice;
  - DBR yield improved QE;
  - Lifetime is still limited;
  - Halo from tails (transverse and longitudinal);
  - Critical for some projects;

- Photocathode R&D community is focusing on cathodes for ”new applications”
  - Time resolved microscopy;
  - High brightness for utra-fast diffraction;
  - Dielectric acceleration;

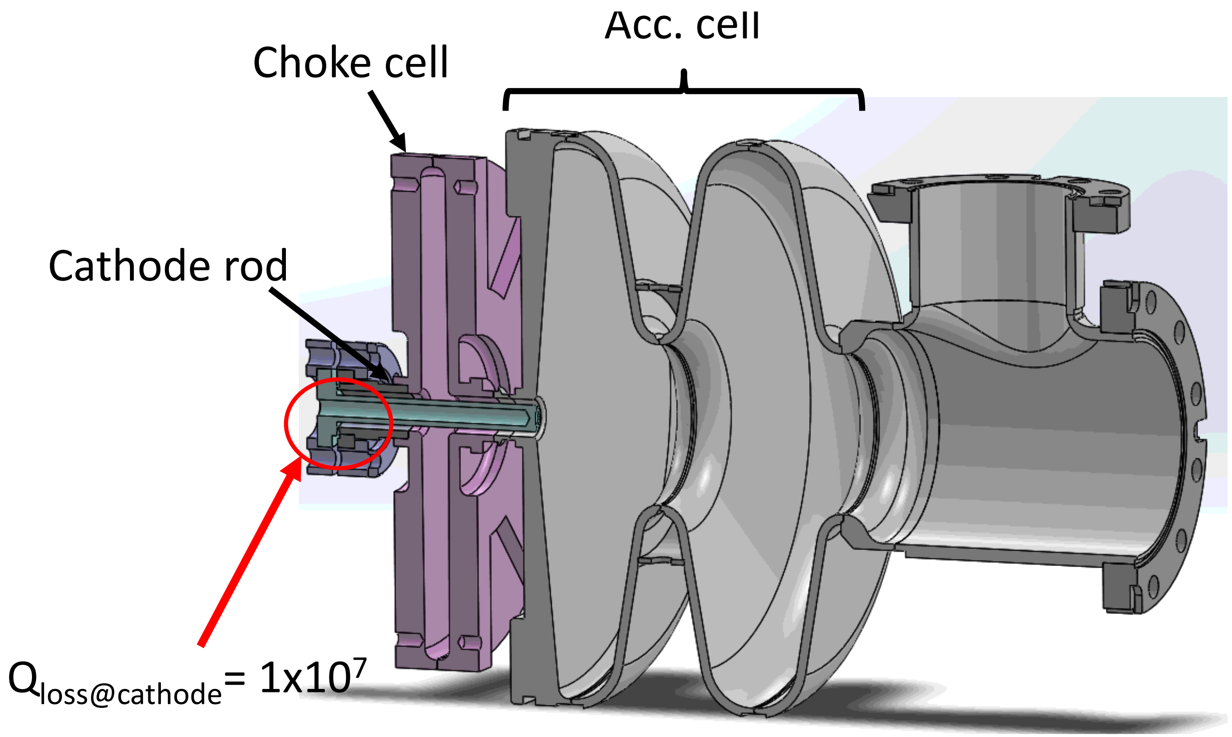
Thermionic cathodes can deliver the 100 mA current required for coolers

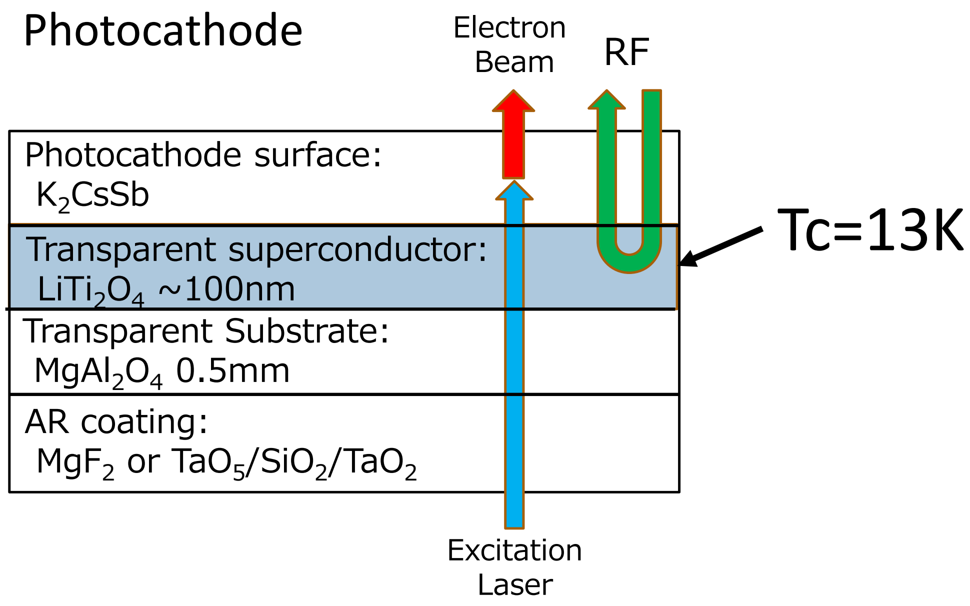
Vertical Test Results and Preparation for Horizontal Test of the KEK SRF Gun #2

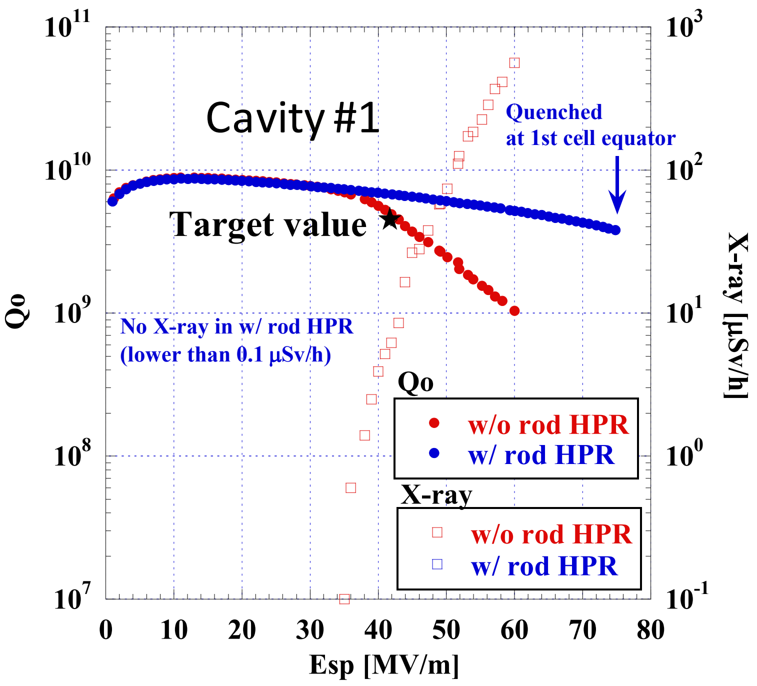
SEPTEMBER 18TH , 2019

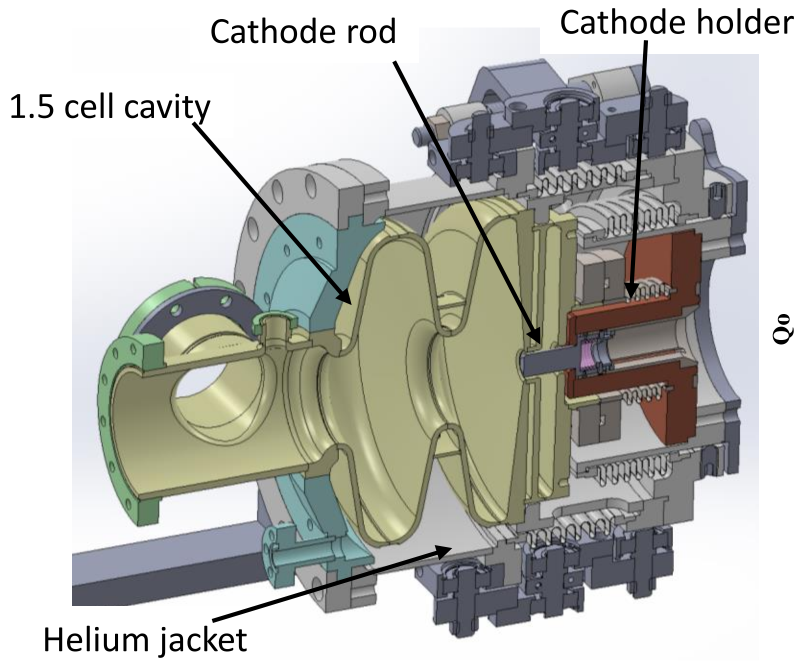
TARO KONOMI (KEK)

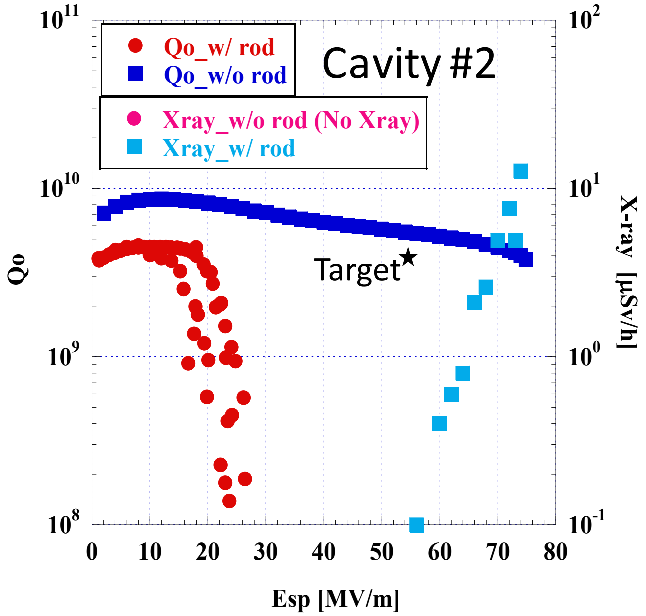
Parameter	Value
Beam energy	**2 MeV**
Projected emittance	**0.6 mm.mrad**
Projected energy spread	**0.09%(1.84 keV)**
Peak electric field	**41.9 MV/m**
Peak magnetic field	95.2 mT
RF phase	55°
Geometrical Factor	135.6 Ω (TESLA 270 Ω)
Target surface resistance	30 nΩ (ILC target)
Target Q value	4.5×10^9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



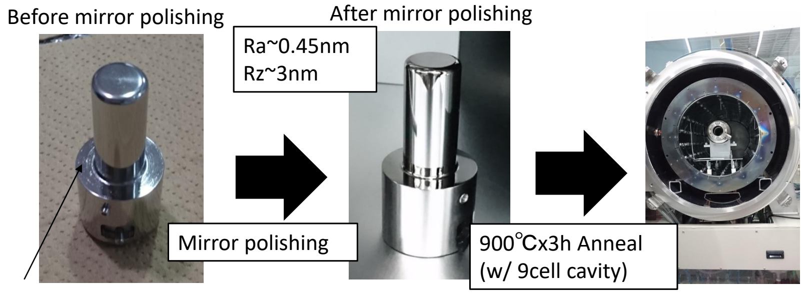




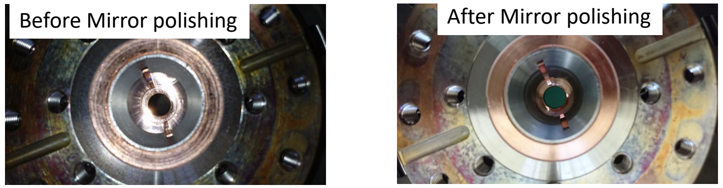




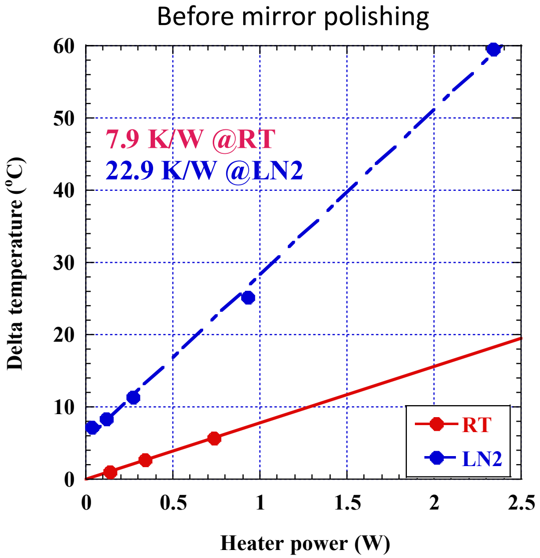
We applied mirror polish to the contact surface.

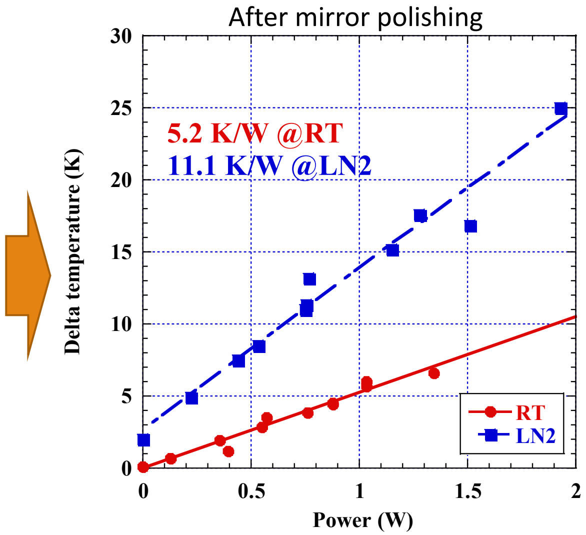


The turning track remained on the contact surface.

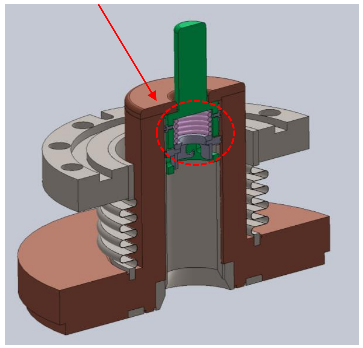


- Thermal contact resistance become about half by mirror polishing.
- However, This is still insufficient, we plan to increase the pressing force by changing the spring in the cathode.





Spring to generate pressing force



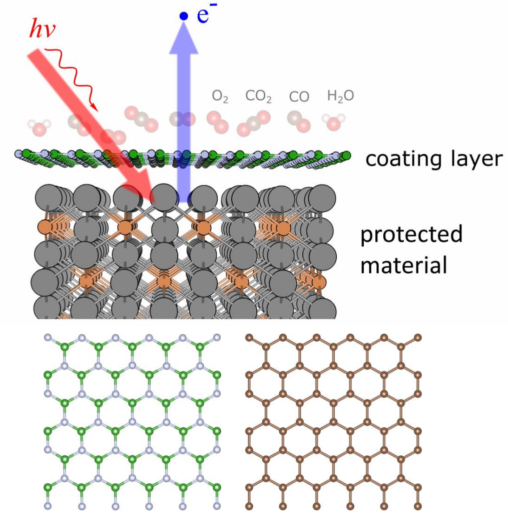
Cathodes with protective overlayers

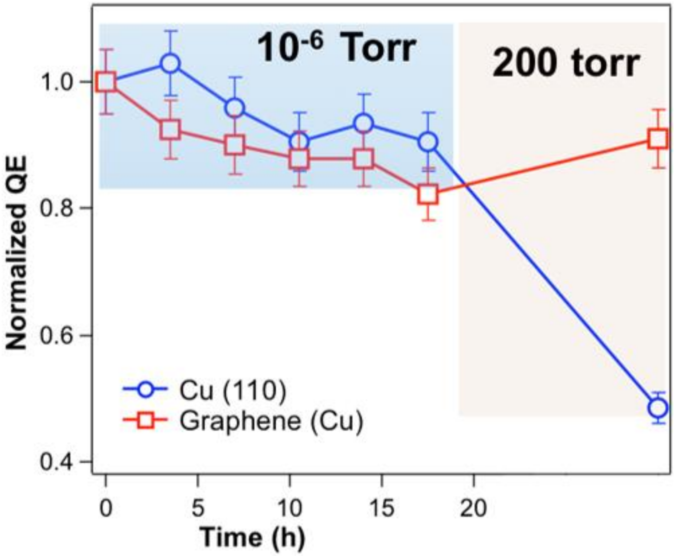
John Smedley
Nathan Moody
Hisato Yamaguchi

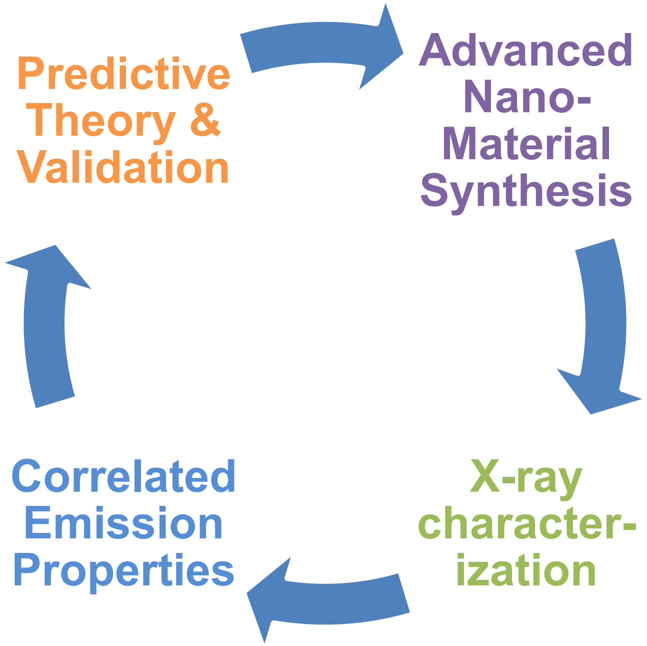
Progress in the BNL-LANL cathode collaboration

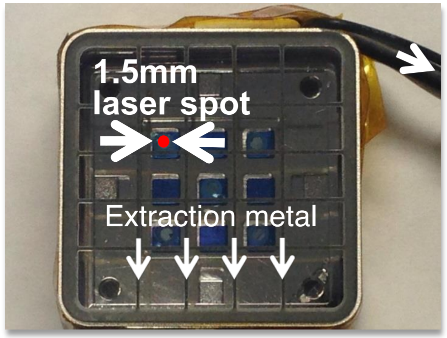
Goals:

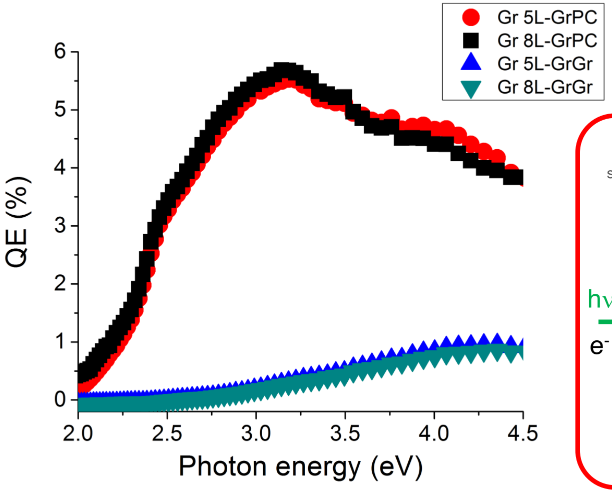
- Block chemically active species from contaminating surface
- Armor vs ion bombardment
- Prevents Cs desorption/ limits thermal decomposition
- Modify electron affinity
- Modify electron Energy and MTE spectrum?
- Reduce Roughness?

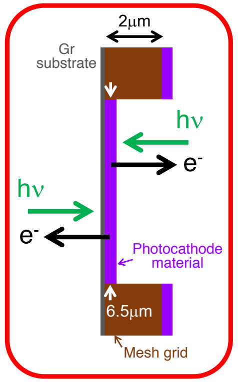


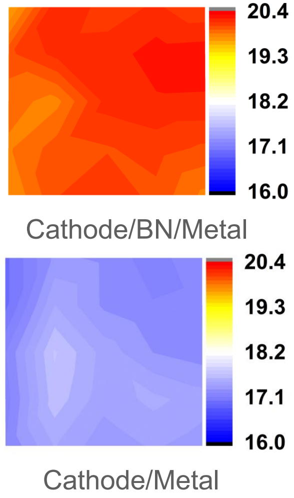






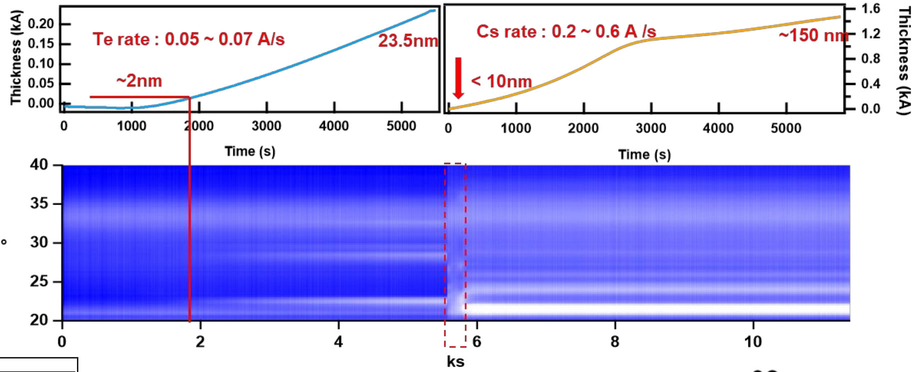




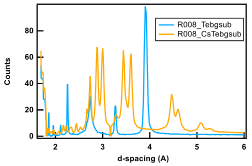


Cs-Te Results (presented by Mengjia Gaowei at P3-2018) show the efficacy of real-time characterization: co-deposition gives smooth single phase

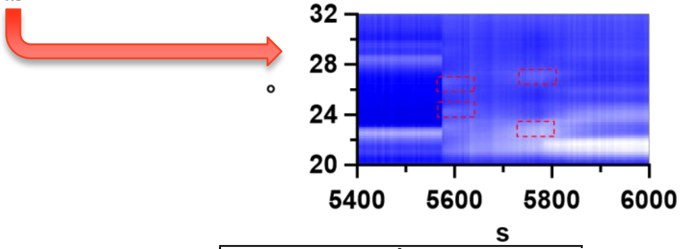
Sequential growth

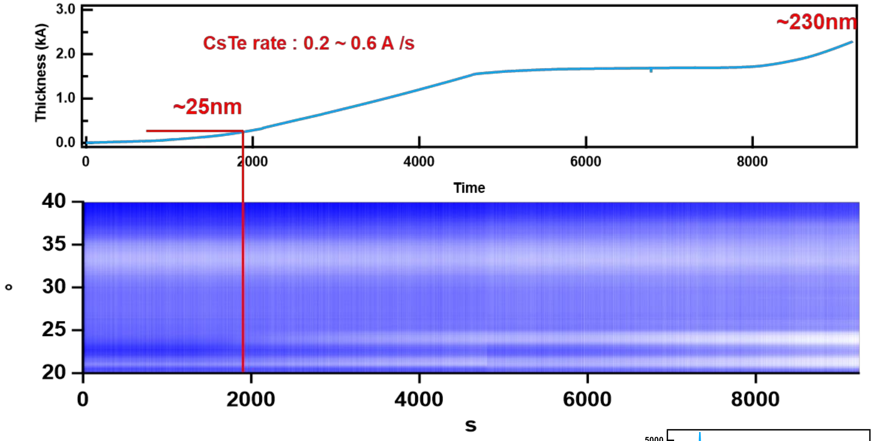


XRD

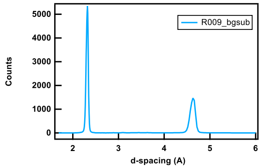


XRD

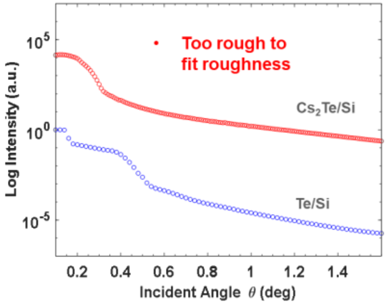


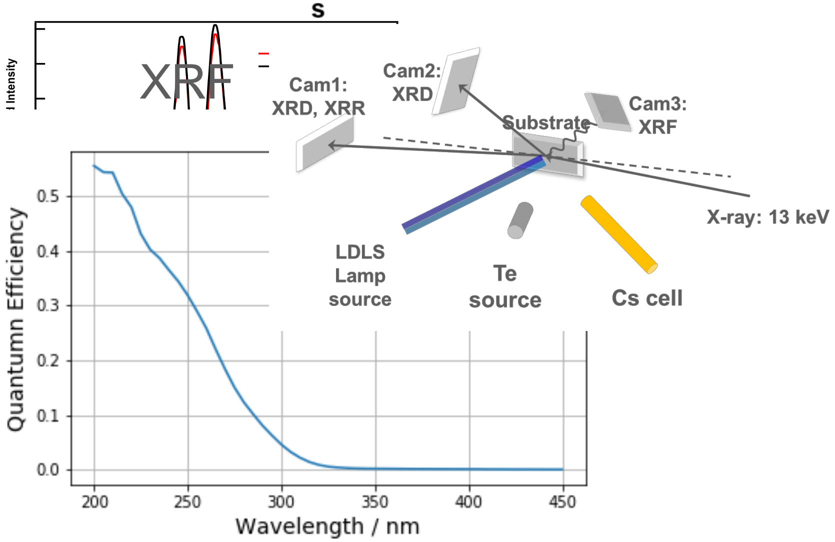


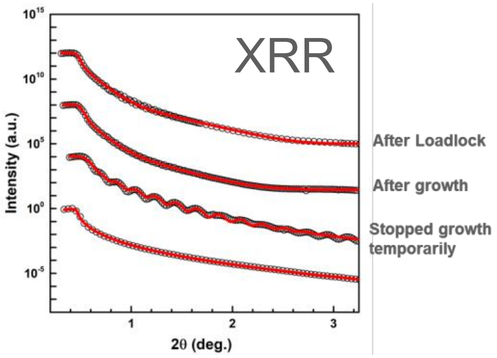
Co-deposition growth



XRD







- Nearly all of the crystalized Te has dissolved
- Low counts in diffraction peaks
- Multiple phase of Cs-Te compound co-exist

- Well crystalized
- Single phase, smooth

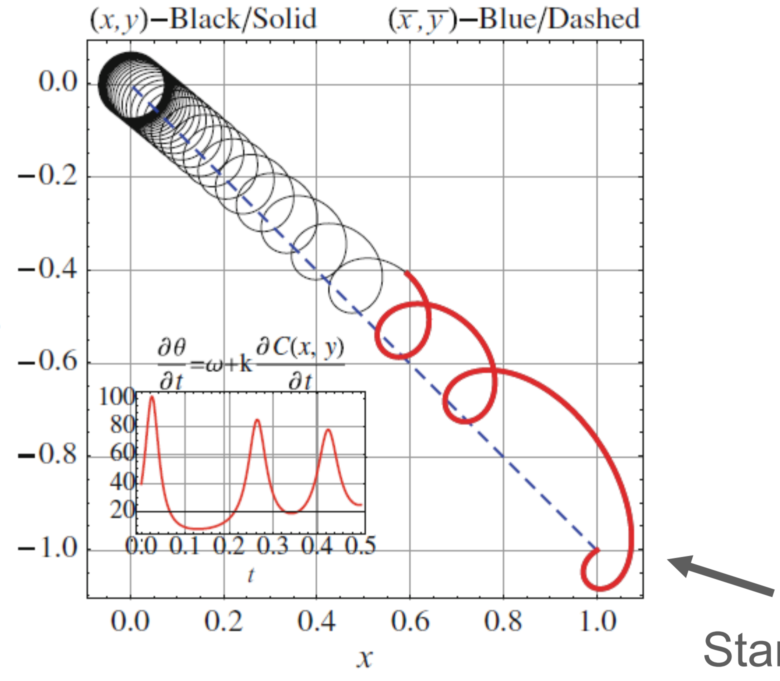
Towards automated growth: control and supervision of material growth without a synchrotron (at least not every time)

- **Goal:**
  - Automatically identify ideal growth conditions
  - Maintain ideal growth in dynamic conditions where "correct" parameters may shift with time

- **Algorithm: extremum seeking (ES)**
  - Applies sinusoidal variation to inputs
  - Minimizes cost parameter with (multiple) inputs
  - Works by spending more time near minimum than at higher values

- **ES algorithm:**
  - $\frac{dx}{dt} = \alpha\omega \cdot \sin(\omega t + kC)$
  - X: input value
  - α, k, ω are tuning parameters
  - C is the function to be minimized

- **Next step: characterize the material using x-ray toolset**



Starting point

Example of ES for motion where

$$\frac{d\theta}{dt} = \omega + \frac{dC}{dt}$$

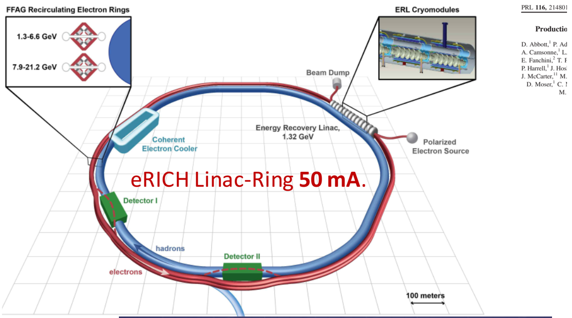
$$C = x^2 + y^2$$

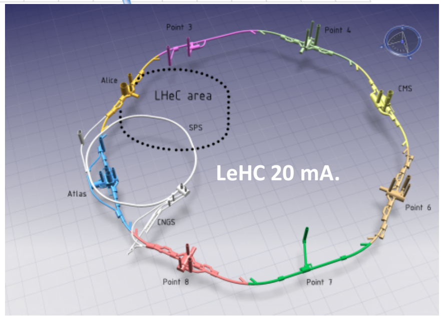
Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

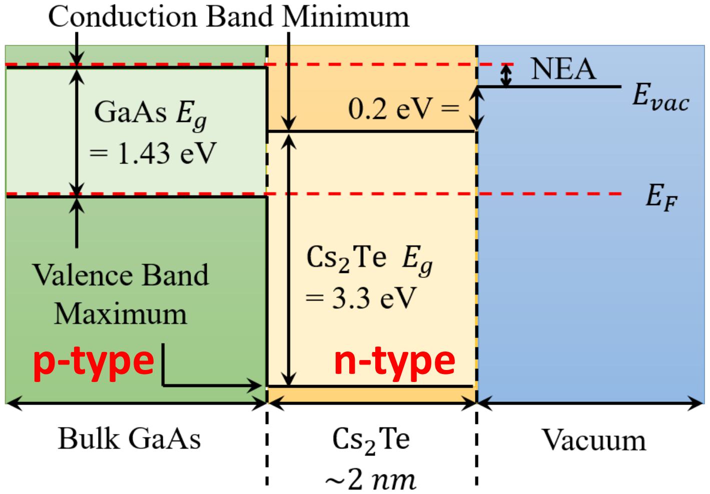
High current polarized electron sources development

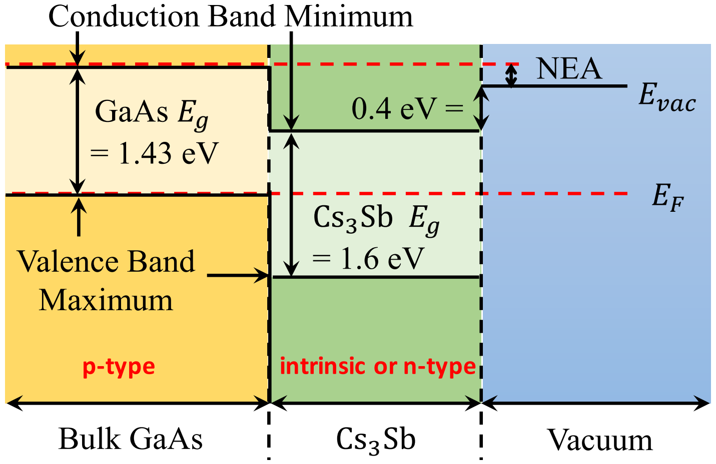
Luca Cultrera

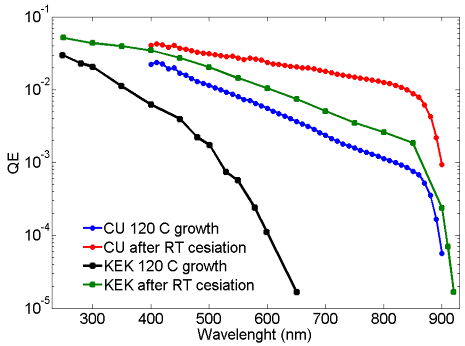
QE , LIFETIME , SPIN POLARIZATION

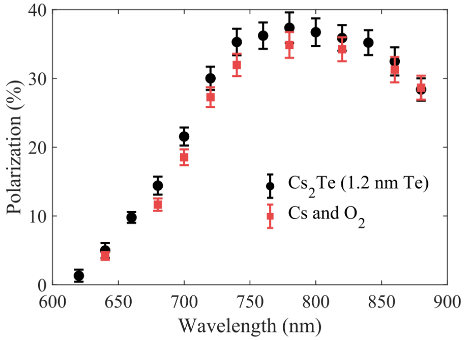






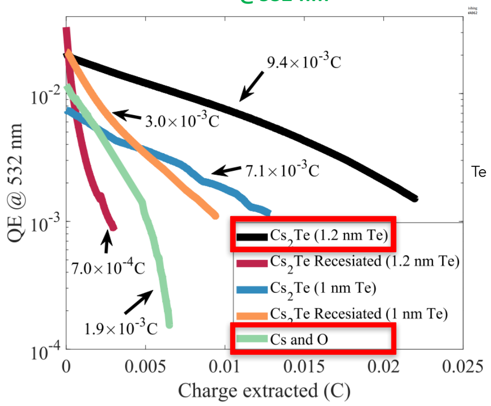


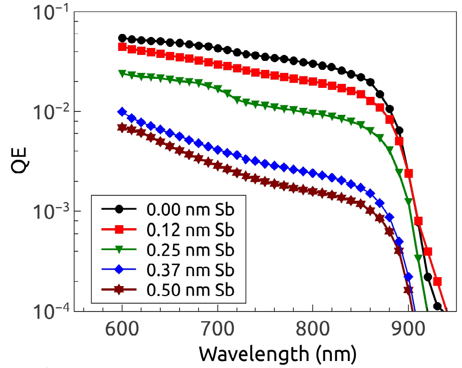


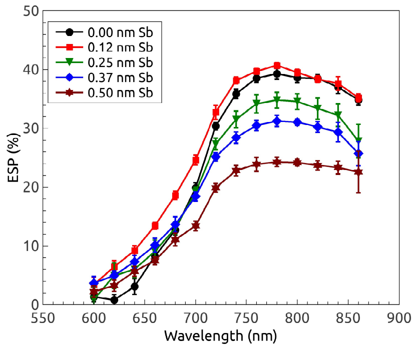


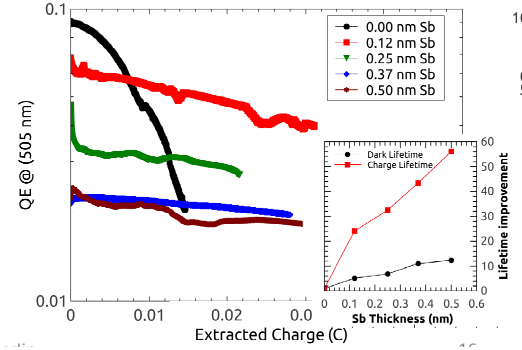
5X LIFETIME!

@532 nm





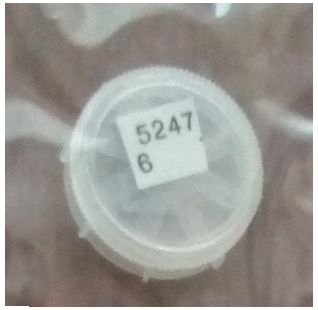


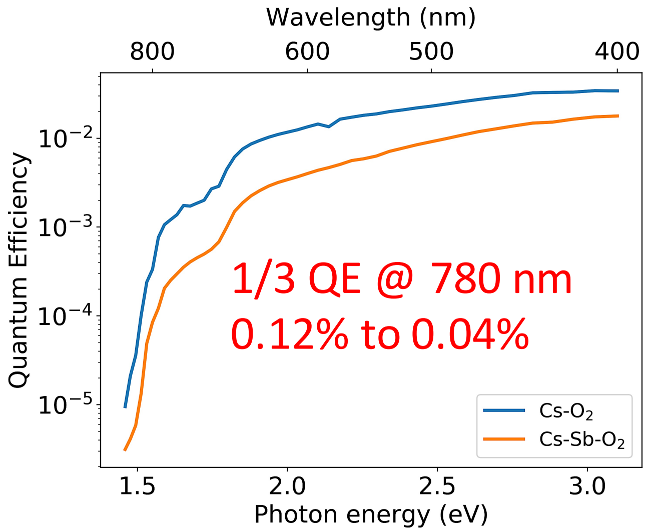


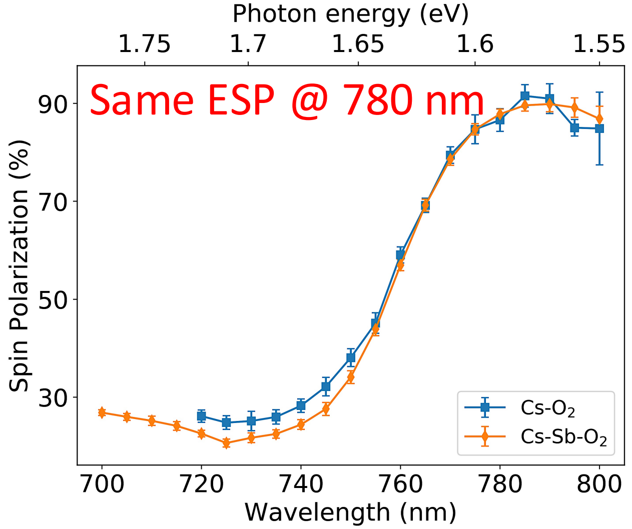
YES!!

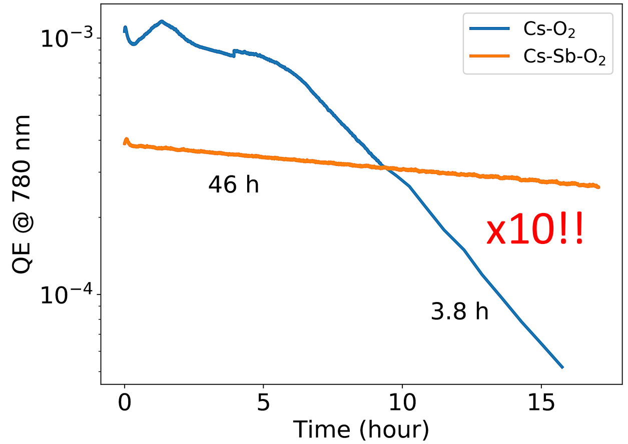
- Preliminary results!

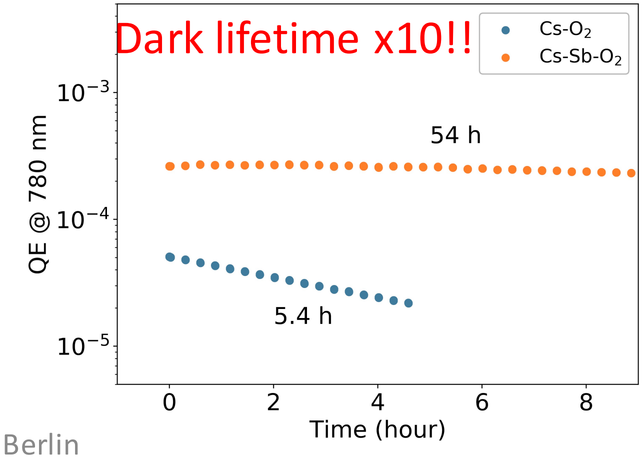
SL GaAs/GaAsP non DBR with P>80% @780nm From Jlab injector group Activated with 0.12 nm Sb







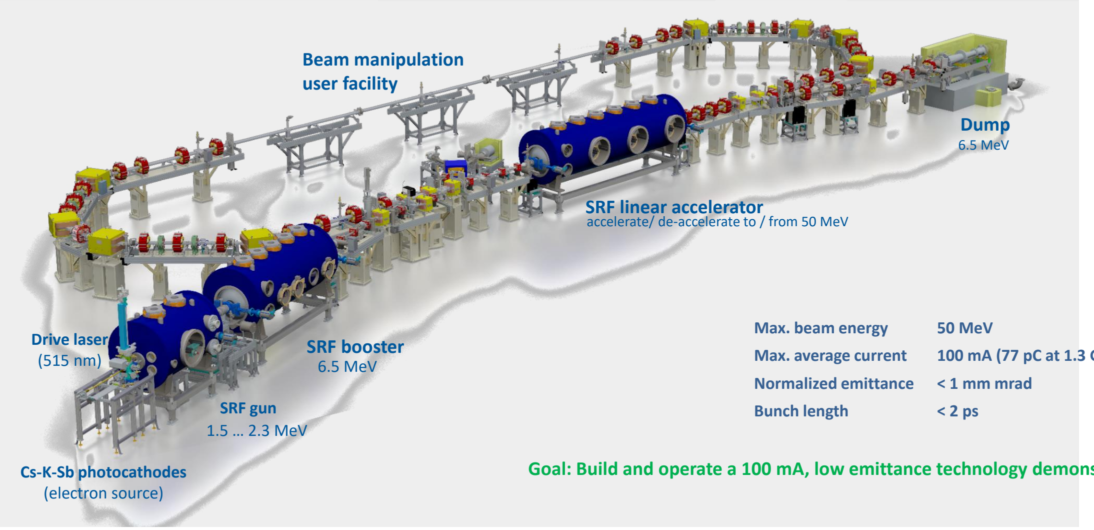




Photocathode preparation and characterization at HZB

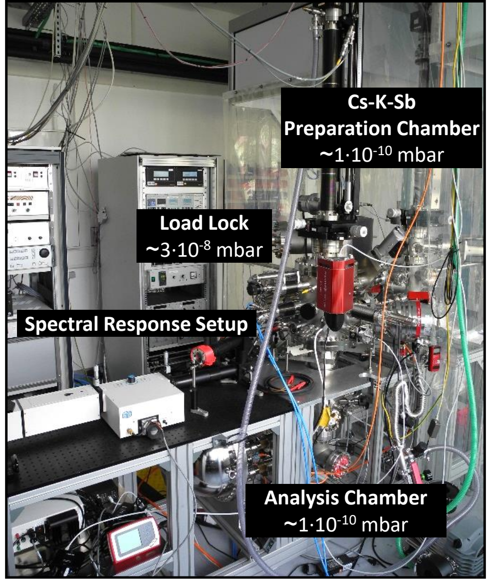
Sonal Mistry

BERLIN ENERGY RECOVERY LINAC PROTOTYPE: bERLinPro

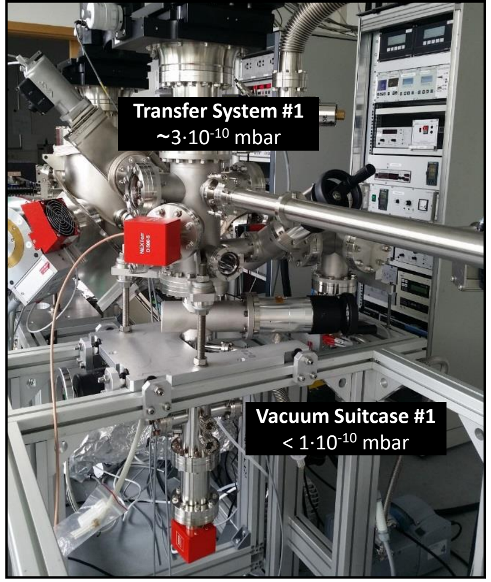


PHOTOCATHODE INFRASTRUCTURE FOR BERLINPRO

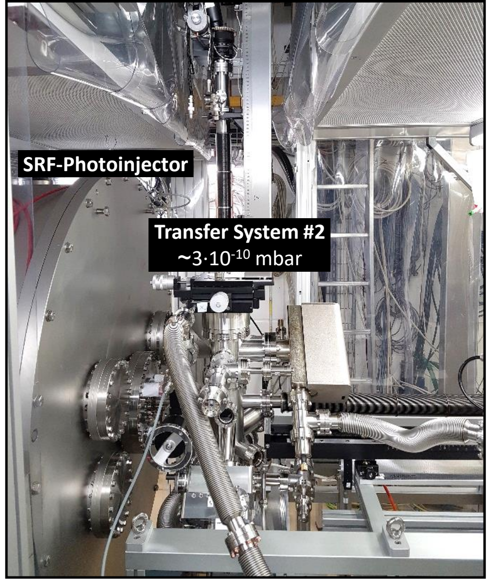
Preparation & Analysis System (PAS) w/ spectral response setup



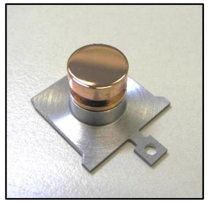
Transfer system #1 at the PAS w/ vacuum suitcase



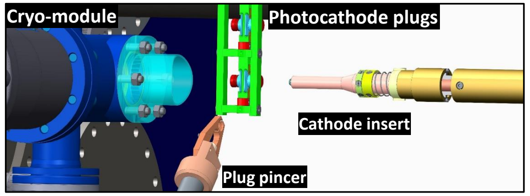
Transfer system #2 at the SRF-photoinjector module



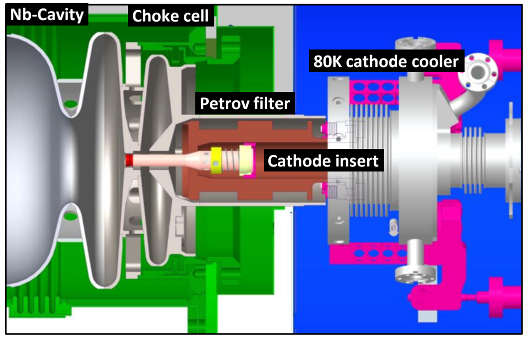
Plug selection and cleaning:

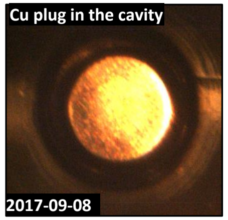


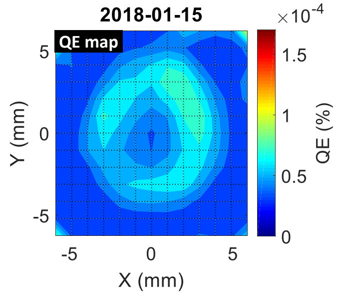
- Plug design developed in-house
- Snap-fastener mechanism on modified omicron sample holder
- Surface cleaning in UHV
- Transfer via vacuum suitcase to transfer system at the SRF photoinjector

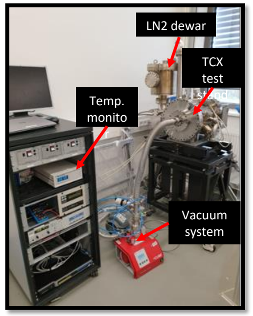


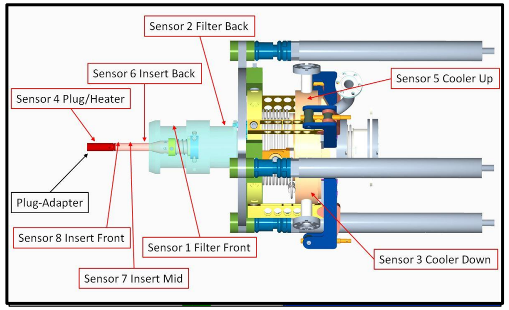
Cathode / Cavity Interface:

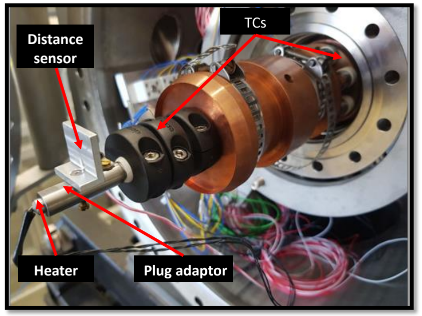






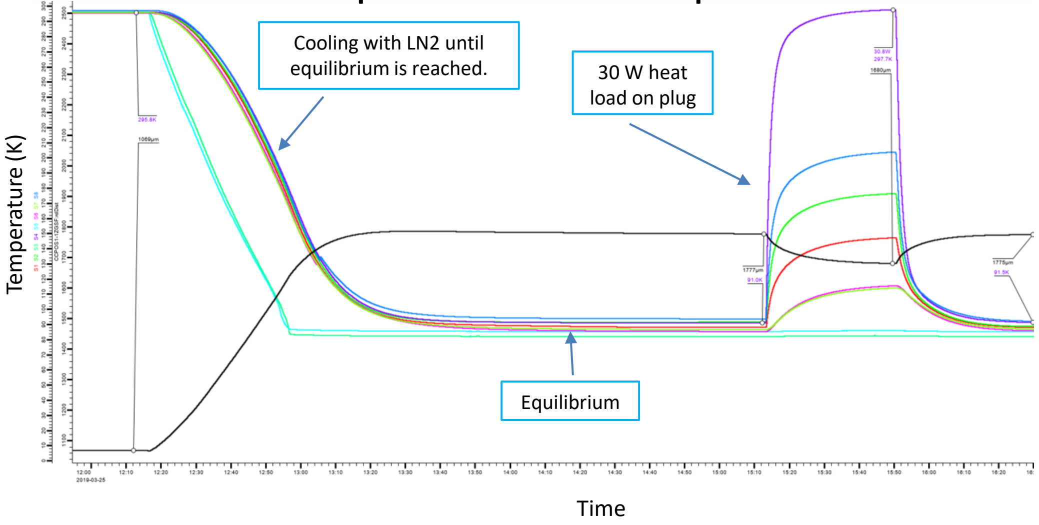






- New UHV Design Multicentre manipulator
- XYZφ
- Radiative heating
  - Ta foil heater
  - Heats back of flag style sample plate
- LN2 cooling tank
  - Cu coil heat exchanger
- Improved vacuum

Example of TCX measurement procedure



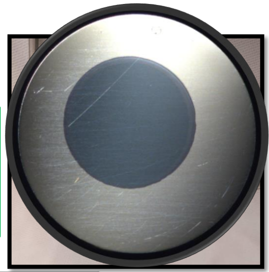
- **30 W heat load upper limit for safe operation of Cs-K-Sb**
- **Exchange mechanism of insert can handle thermal load of 30 W**

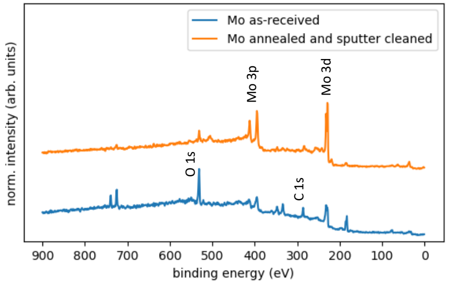
Aug 2019

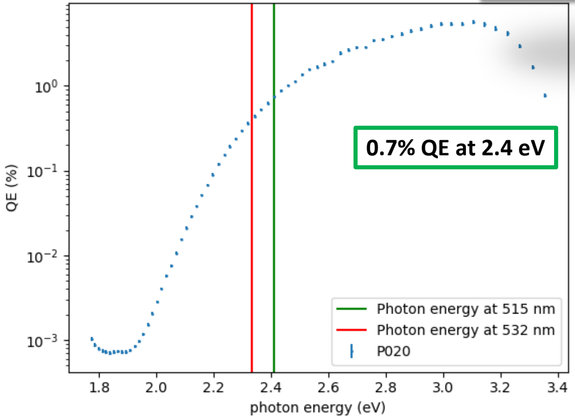
FIRST GROWTH AFTER UPGRADE 28.08.2019

Mo **Sb** **Cs-K-Sb**

Next steps for optimising growth
- Sb layer
- Sample temperature, positions
- Mo plug roughness





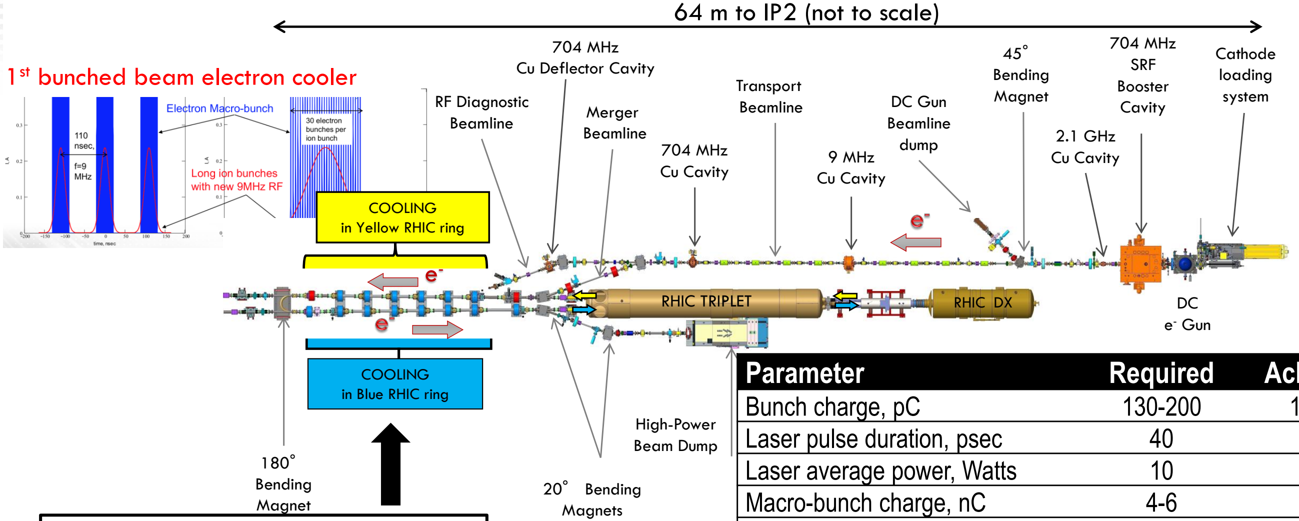


High Current Performance of Alkali Antimonide Photocathode in LEReC DC gun

Mengjia Gaowei on behalf of the Electron source and the LEReC group
Brookhaven National Laboratory

BROOKHAVEN NATIONAL LABORATORY

Low Energy RHIC electron Cooling (LEReC)



Energies E : 1.6, 2.0 MeV
Luminosity gain : 4×

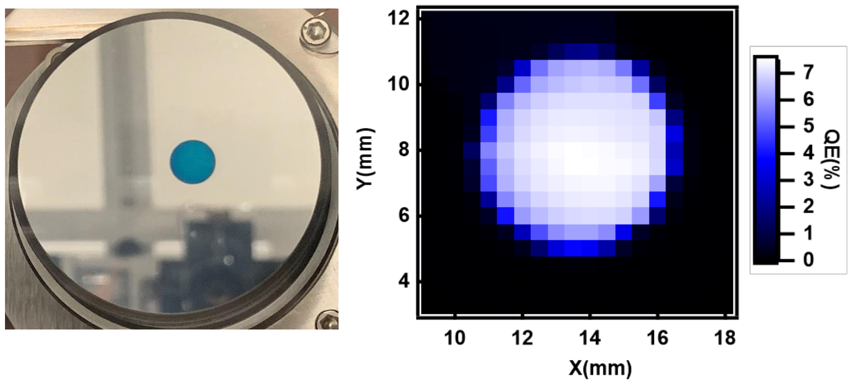
Parameter	Required	Achieved*
Bunch charge, pC	130-200	10-200
Laser pulse duration, psec	40	40
Laser average power, Watts	10	10
Macro-bunch charge, nC	4-6	6
Macro-bunch rep. rate, MHz	9.3	9.3
Average Current, mA	36-55	14-30
Kinetic Energy, MeV	1.6 -2.6	1.6-2.0
Normalized emittance, µm	<2.5	1.6
RMS energy spread, x10^{-4}	<5	<2

* D. Kayran *et al.*, "First results from Commissioning of LEReC," in *Proc. 10th Int. Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May 2019

U.S. DEPARTMENT OF ENERGY

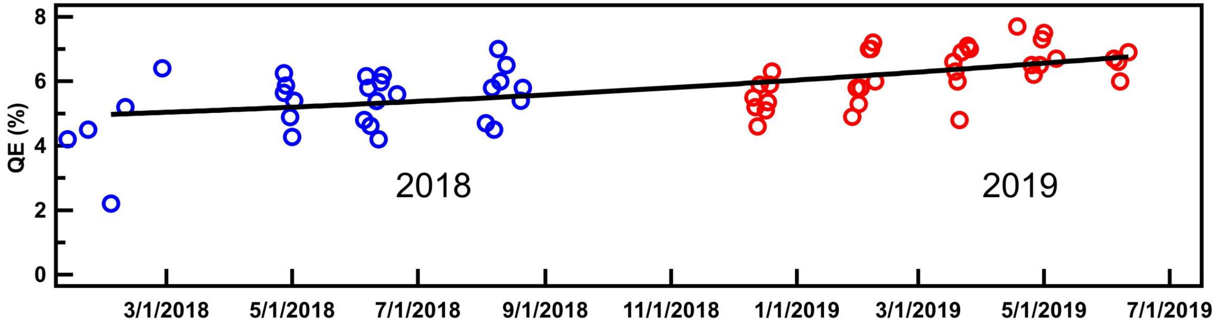
2

QE uniformity



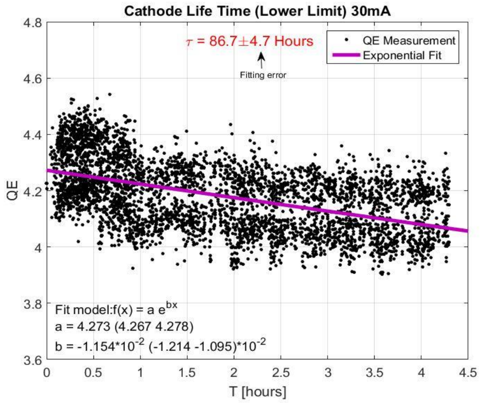
- **Off-center design for the LEReC run 18~19**
- **Cathode is 6 mm in diameter**
- **Cathode QE was mapped after the deposition, with X-Y stepper motors controlling a green laser.**

Summary of 2018-2019 cathode production

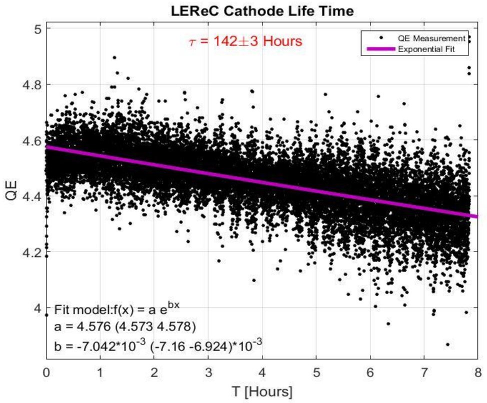


Cathode lifetime in the gun: 2018

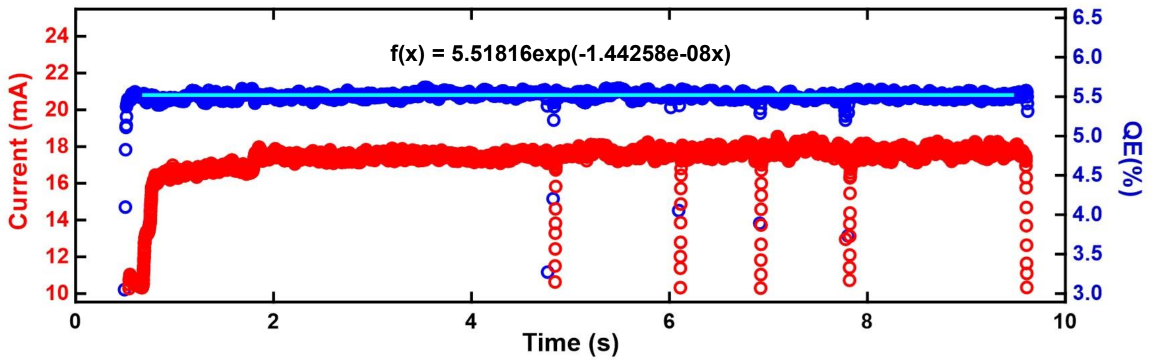
30 mA beam current, t = 87 h, QE > 4%



25 mA beam current, t = 142 h, QE > 4%

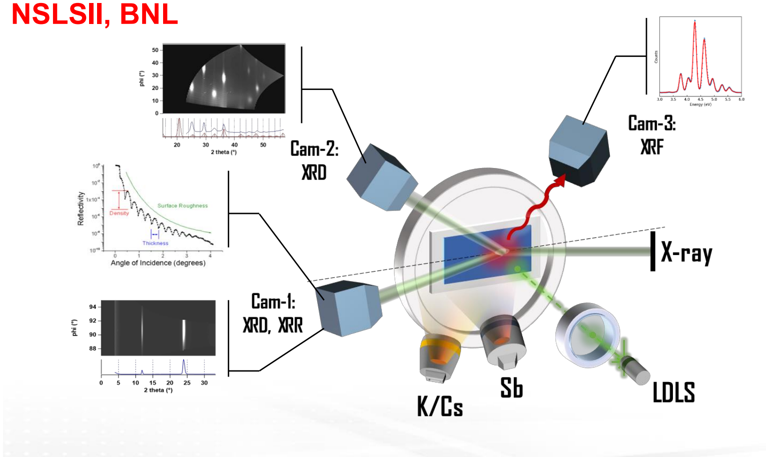


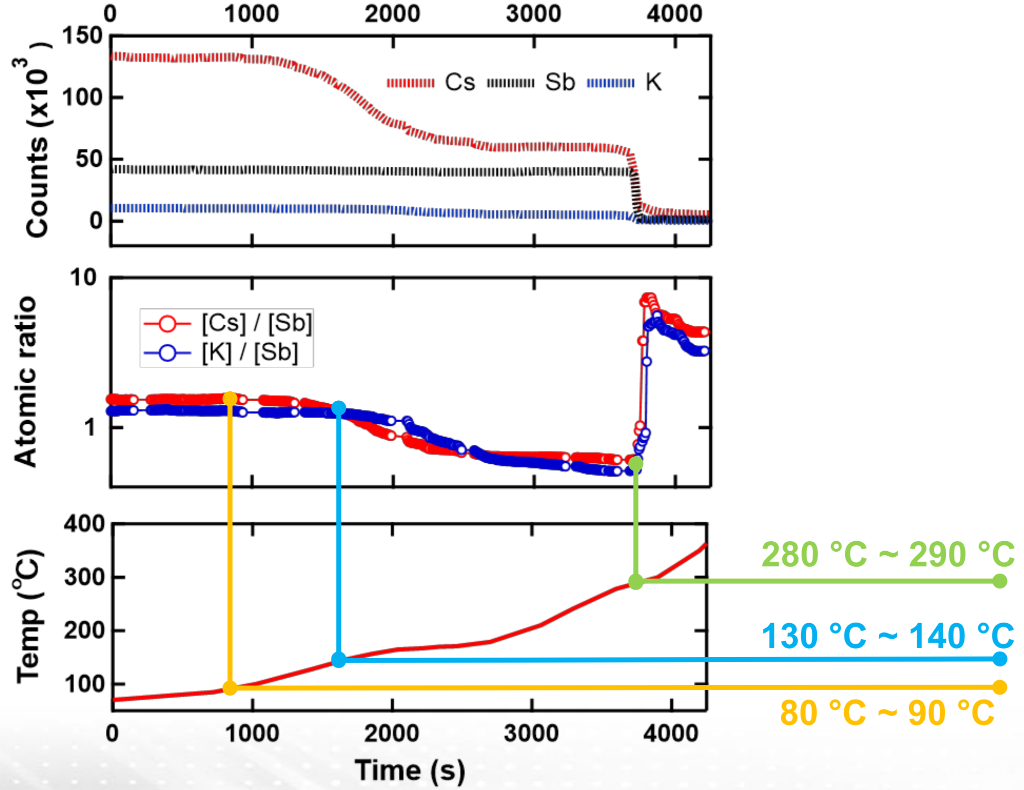
17mA beam current, QE =5.5 %, infinite lifetime during CW operation



Experimental setup: *Operando* chamber

Beamline 4-ID, NSLSII, BNL

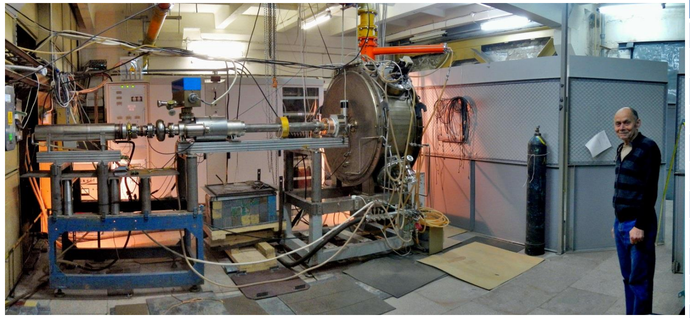




Latest Results of CW 100 mA Electron RF Gun for Novosibirsk ERL Based FEL

V. Volkov, V. Arbuzov, E. Kenzhebulatov, E. Kolobanov, A. Kondakov, E. Kozyrev, S. Krutikhin, I. Kuptsov, G. Kurkin, S. Motygin, A. Murasev, V. Ovchar, V.M. Petrov, A Pilan, V. Repkov, M. Scheglov, I. Sedlyarov, S. Serednyakov, O. Shevchenko, S. Tararyshkin, A. Tribendis, N. Vinokurov , BINP SB RAS, Novosibirsk

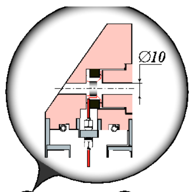
The most powerful in the world Novosibirsk CW FEL driven by ERL can be more powerful by an order of magnitude with this RF Gun

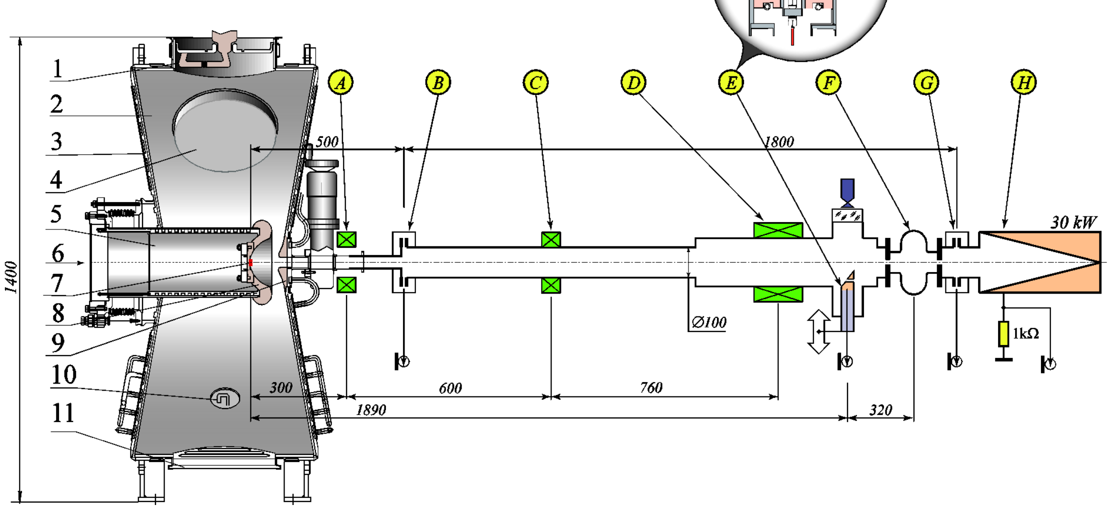


Measured rf gun characteristics	
Average beam current, mA	≤100
Cavity Frequency, MHz	90
Bunch energy, keV	100 ÷ 400
Bunch duration (FWHM), ns	0.06 ÷ 0.6
Bunch emittance, mm mrad	10
Bunch charge, nC	0.3 ÷ 1.12
Repetition frequency, MHz	0.01 ÷ 90
Dark Current Impurity, mkA	0
Radiation Dose Power, mR/h	100/2m
Operating pressure , Torr	~10^{-9}-10^{-7}
Cavity rf loses, kW	20

RF Gun Features: *Gridded thermionic dispenser cathode driven by special modulator*

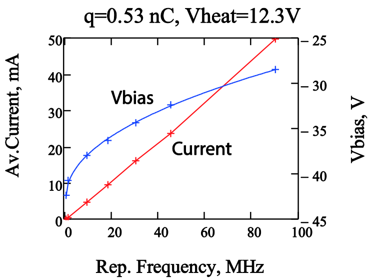
1-Power input coupler; 2- Cavity shell; 3-Cavity back wall; 4-Sliding tuner; 5-Insert; 6-Cathode injection/extraction channel; 7-Thermionic cathode-grid unit; 8-Concave focusing electrode; 9-Cone like nose; 10-Loop coupler; 11-Vacuum pumping port;



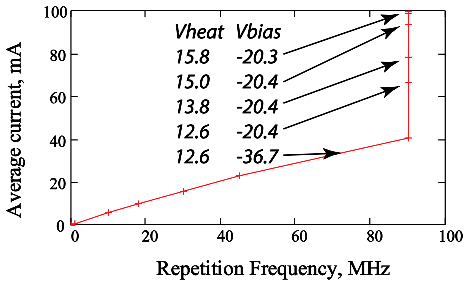


A-Emittance compensation solenoid; B-First Wall Current Monitor (WCM); C, D -Solenoids ; E-Wideband WCM and transition radiation target; F – Test Cavity; G-third WCM; H-Faraday cup and Water-cooled beam dump

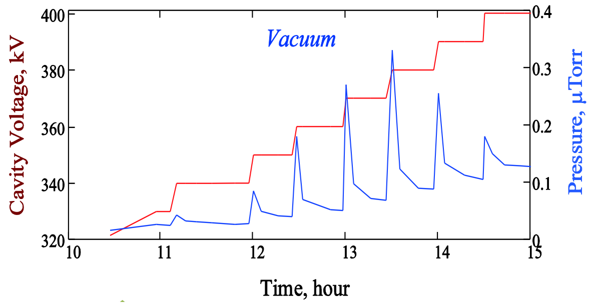
Vlaunch=100 V



Vlaunch=120 V

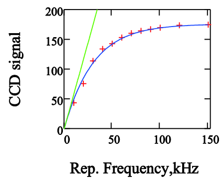


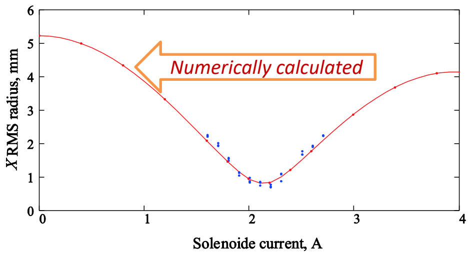
The Typical Mode of current rising is Repetition frequency increasing at q=1.1 nC=const

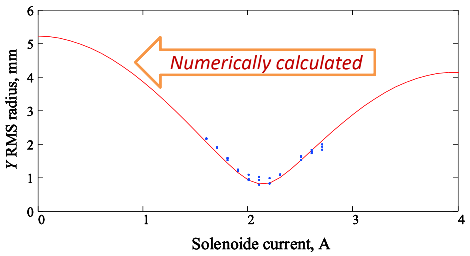


Emittance measurements

by solenoid focusing method with using transition radiation sensor







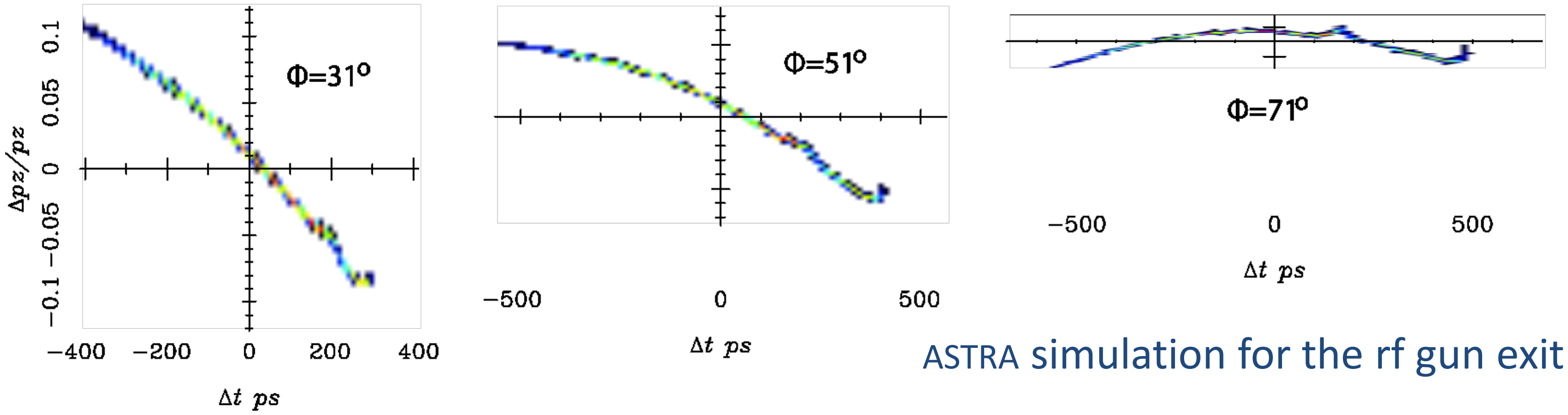
Measured normalized emittance ε=15.5 mm mrad can be compensated by solenoid focusing to ε=10 mm mrad.

Numerical data processing of CCD camera image and distortion compensated optics were used.

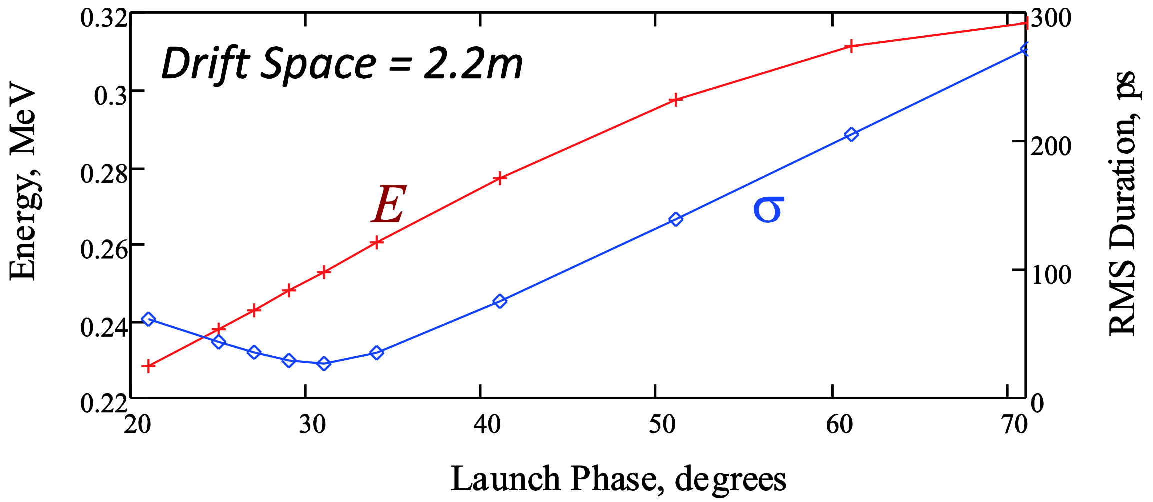
Deviation of measured radius from calculated one is 9% so we can trust to our numerical ASTRA calculations.

Launch Phase (Φ) functions

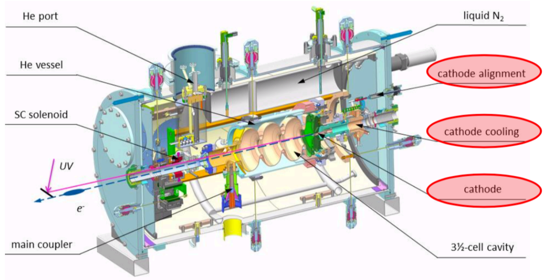
are the reason of velocity bunching and jitter compensation effects



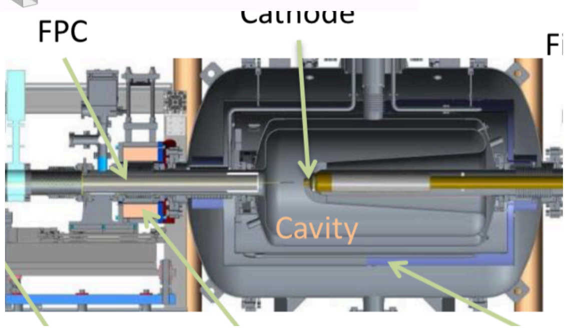
ASTRA simulation for the rf gun exit



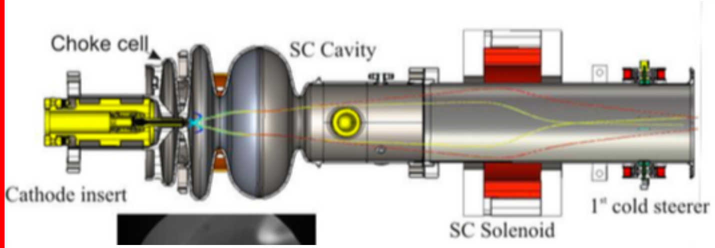
SRF



He port
He vessel
SC solenoid
UV
main coupler
liquid N_2
cathode alignment
cathode cooling
cathode
3½-cell cavity



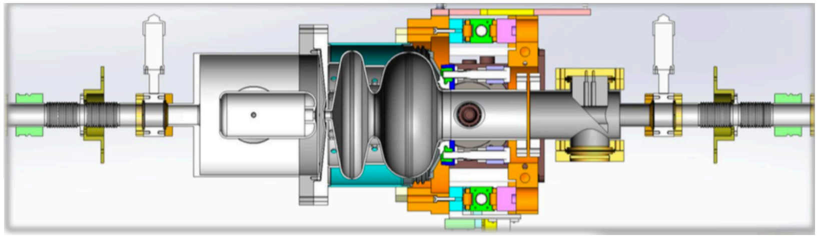
FPC
Cavity



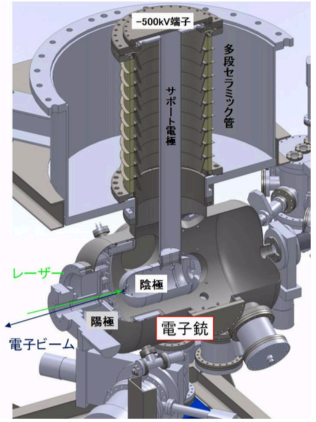
Choke cell
SC Cavity
Cathode insert
SC Solenoid
1" cold steerer

Cavity #2

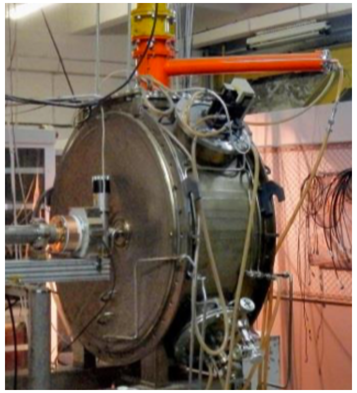
DC+SRF

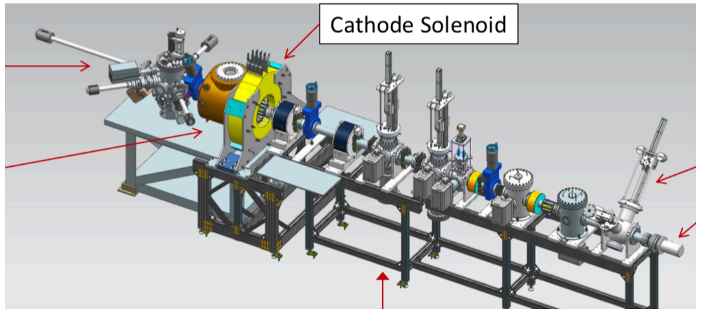


DC



−500kV端子
多段セラミック管
サポート電極
レーザー
陰極
陽極
電子銃
電子ビーム



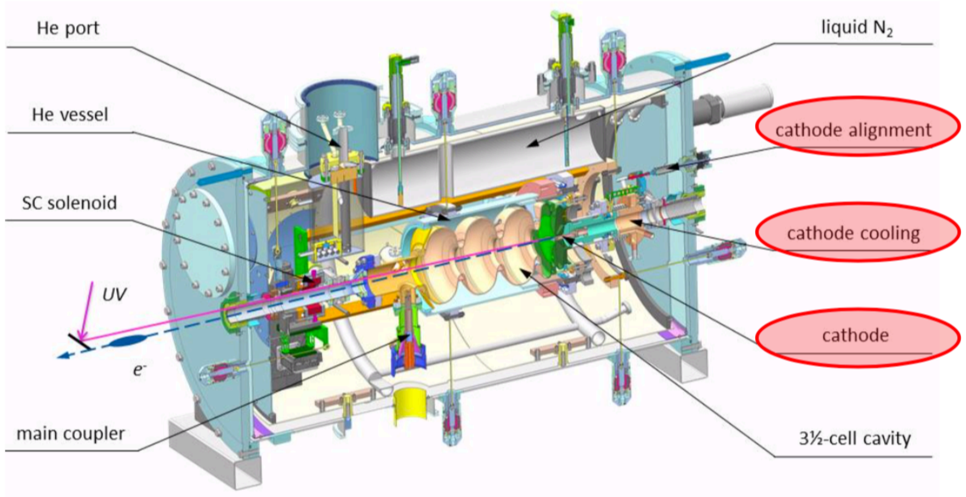


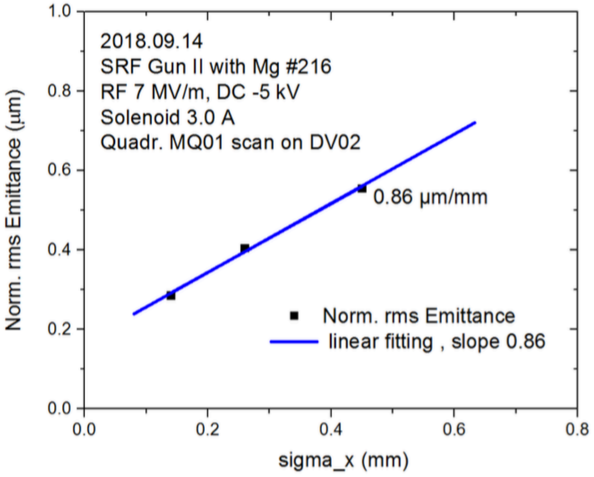
Cathode Solenoid

Metal and semiconductor photocathodes in HZDR SRF gun

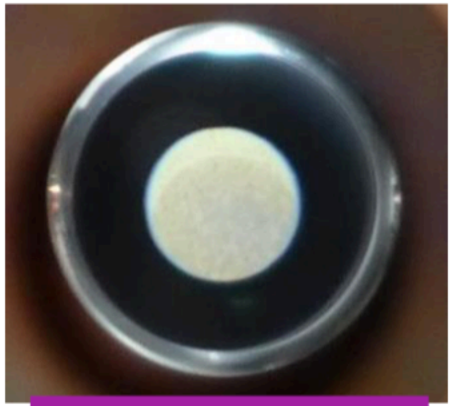
? Thermal emittance

Stable operation: 2017

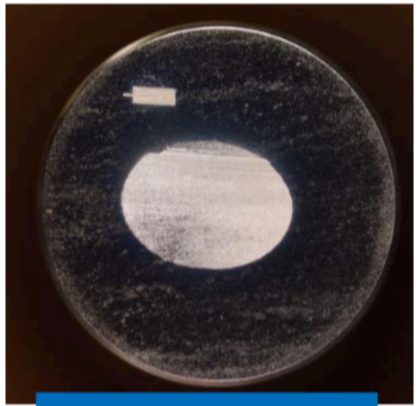




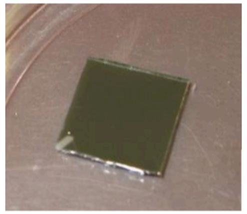
- Mg: Robust, in operation
- Cs_2Te: Better thermal contact
- GaN: Good QE in UV.



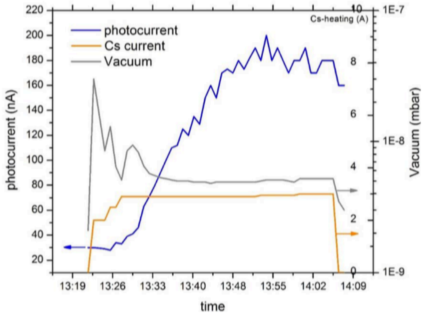
Cs$_2$Te on Mo plug



Mg pug #216

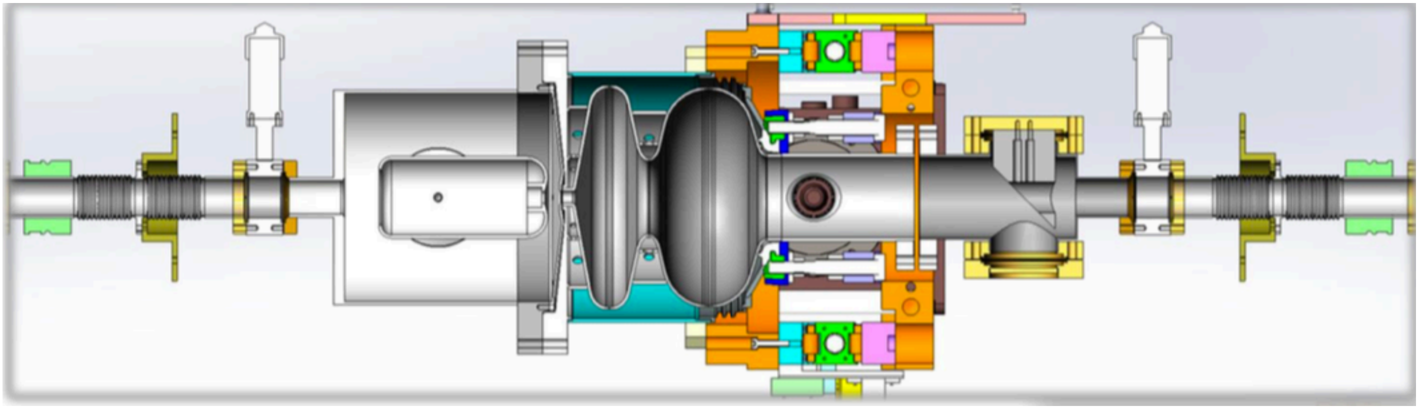


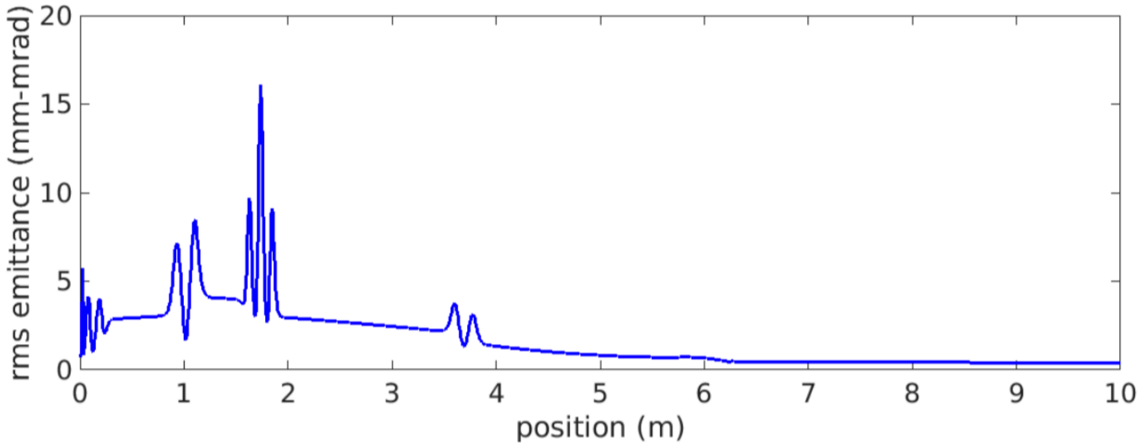
P-GaN on sapphire



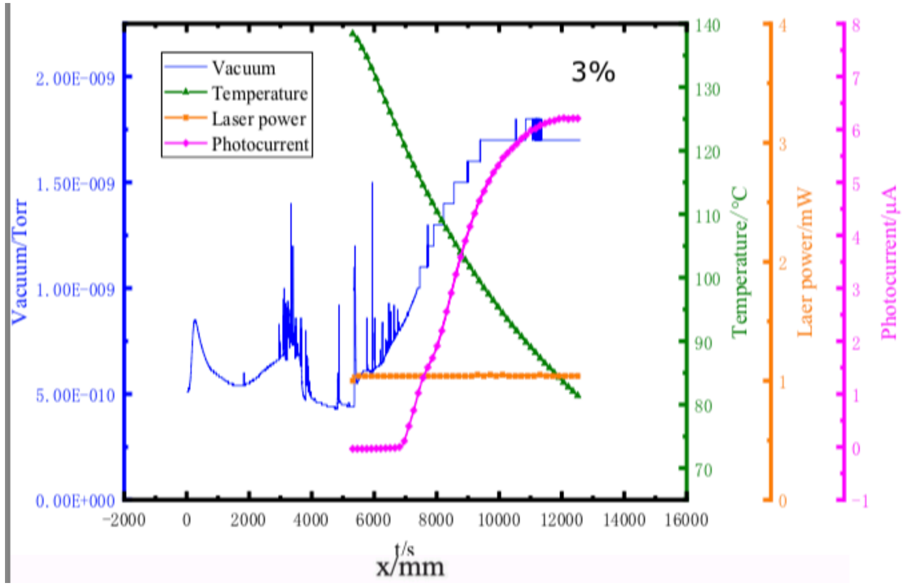
DC-SRF Photoinjector at PKU

Stable operation: 2014





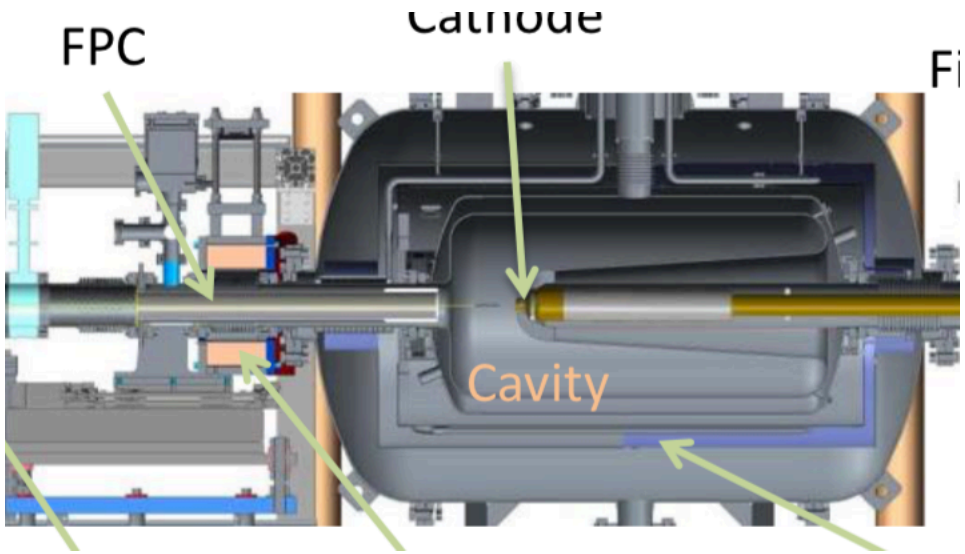
beam energy: 17 MeV, Emittance: 0.28 μm, RMS bunch length: 3.8 ps

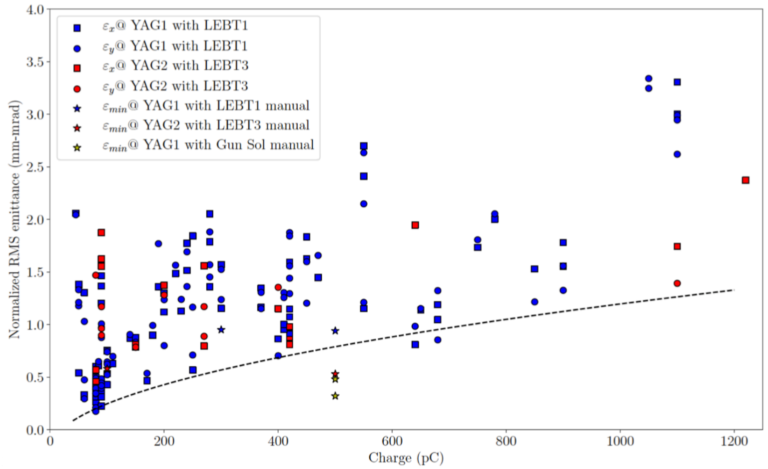


- The first 3.5 cell dc-srf gun is in operation
- The new 1.5 cell gun aims to small emittance by optimizing geometry, increase DC voltage, change cathode material

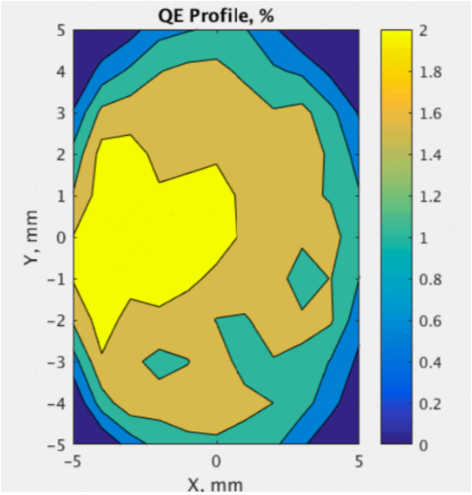
High Charge High Current Beam from 113 MHz SRF Gun

Stable operation: 2017





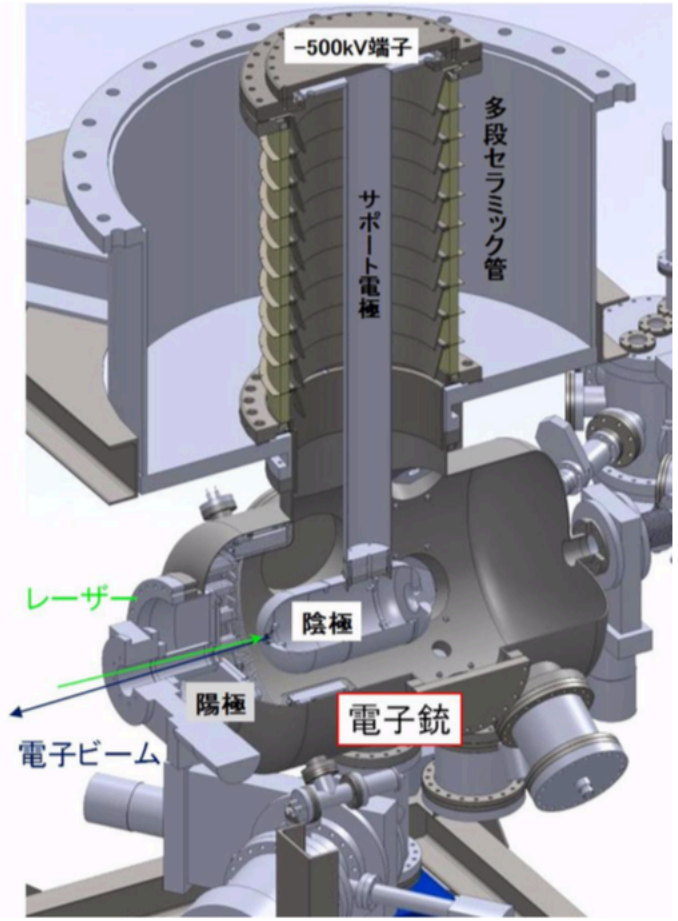
- K-Cs-Sb: >1 mongth lifetime
- Maximum: 10 nC,120 uA
- 600 pC: rms emittance:0.57(0.35) mm-mrad



QE after one month

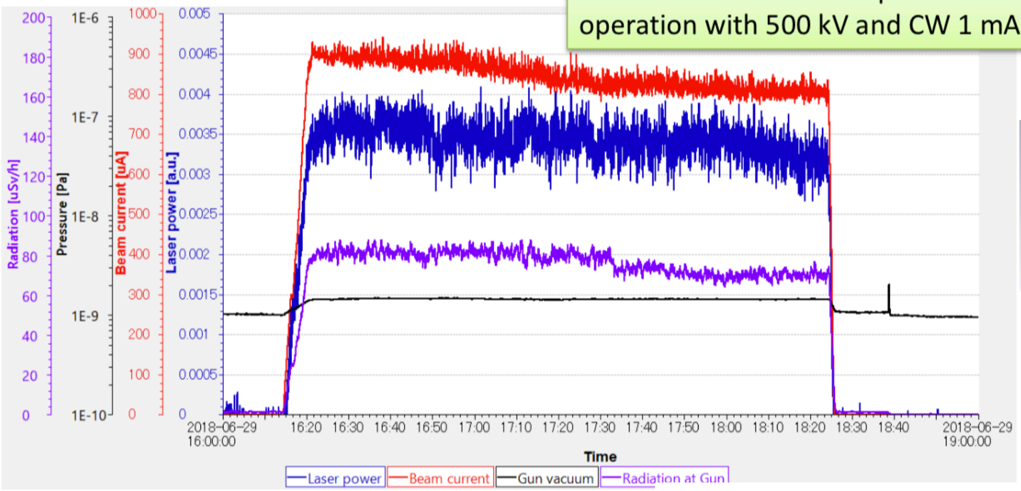
Injector Development at KEK

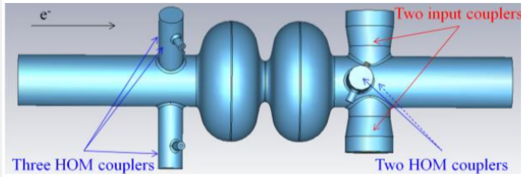
Start operation: 2016
June 2019 60 pC

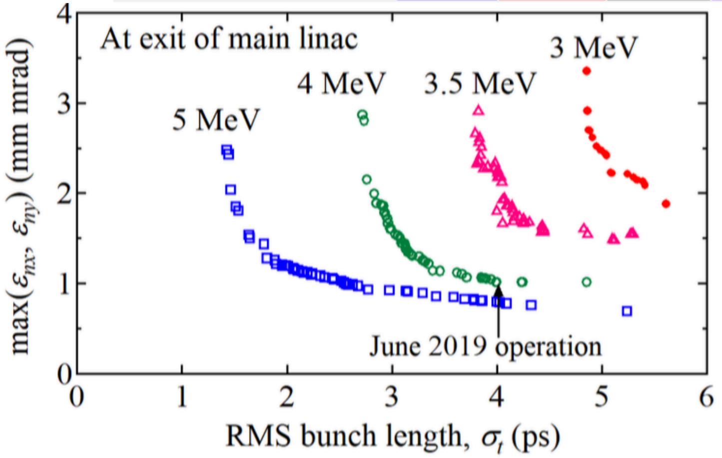


by *courtesy* of M. Yamamoto

World record: Stable DC photocathode gun operation with 500 kV and CW 1 mA



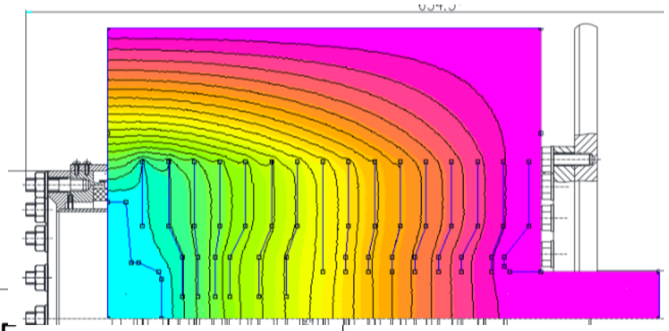


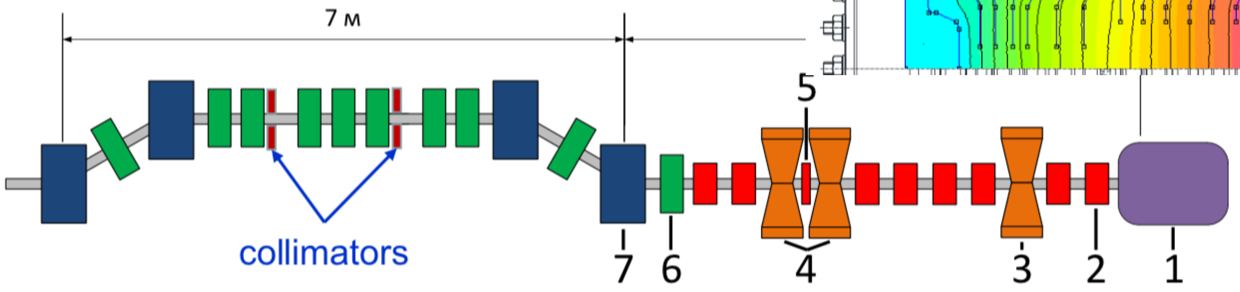


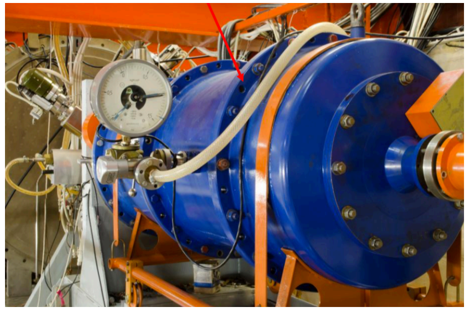
	Design	Analysis 1	Analysis 2
ε_{nx} (πmm · mrad)	1.42	1.87	1.937 ±0.286
ε_{ny} (πmm · mrad)	1.48	0.88	0.826 ±0.018

- Stable high voltage DC gun
- 7.7 pC→ 60 pC
- 4MeV injection energy by improving optics

Novosibirsk ERL Injector





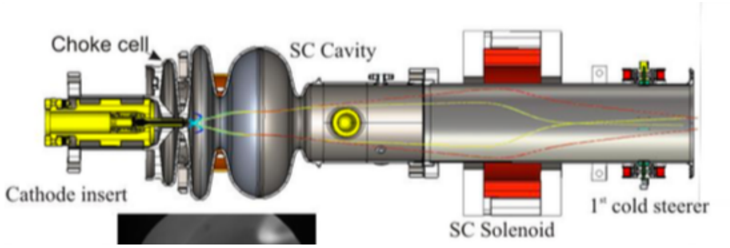


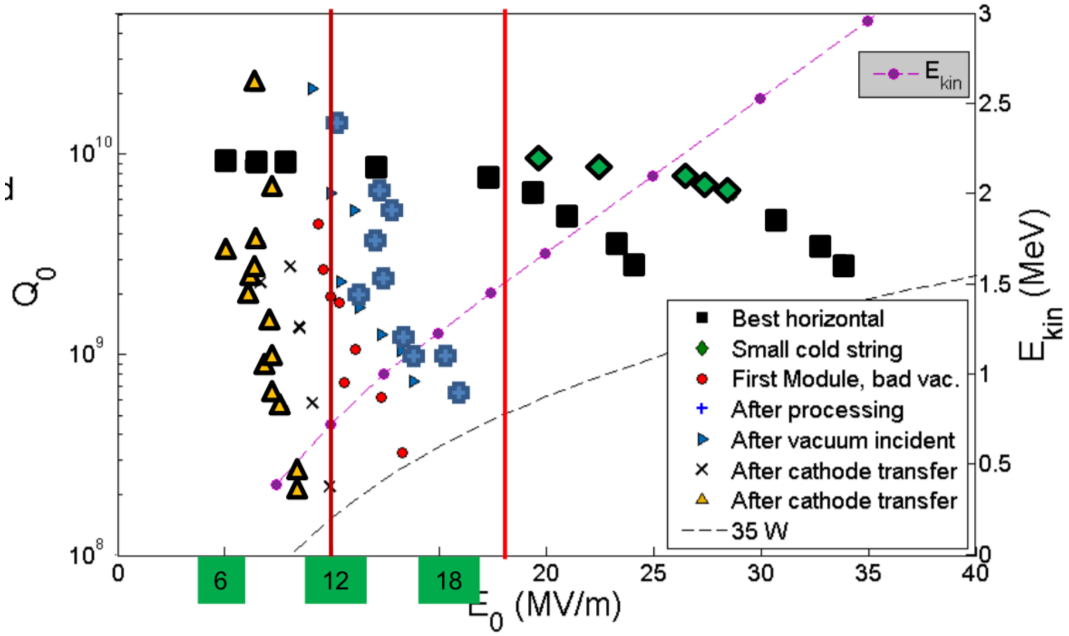
Minimal normalized emittance (gun), µm	8
Minimal normalized emittance (final), µm	15
Maximal bunch charge, nQ	2
Maximal repetition rate, MHz	22.5
Maximal average current, mA	50
Maximal gun voltage, keV	300
Output beam energy, MeV	1.8

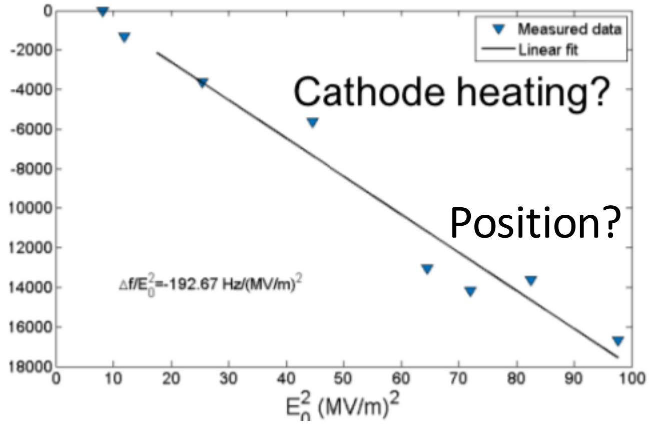
Solenoid current, A	Normalized emittance, µm
0.0	18.5
4.0	16

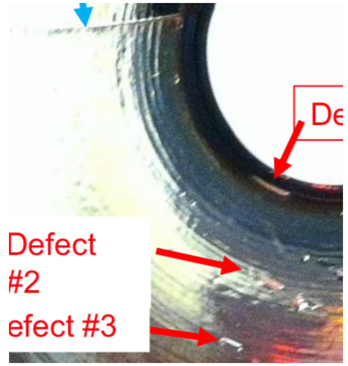
- provides the beam quality sufficient for all current applications
- Measured beam parameters are in a good agreement with the simulation
- increase the average current and FEL radiation power

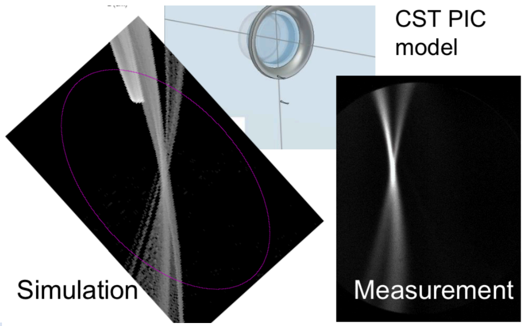
Status of SRF Gun for bERLinPro





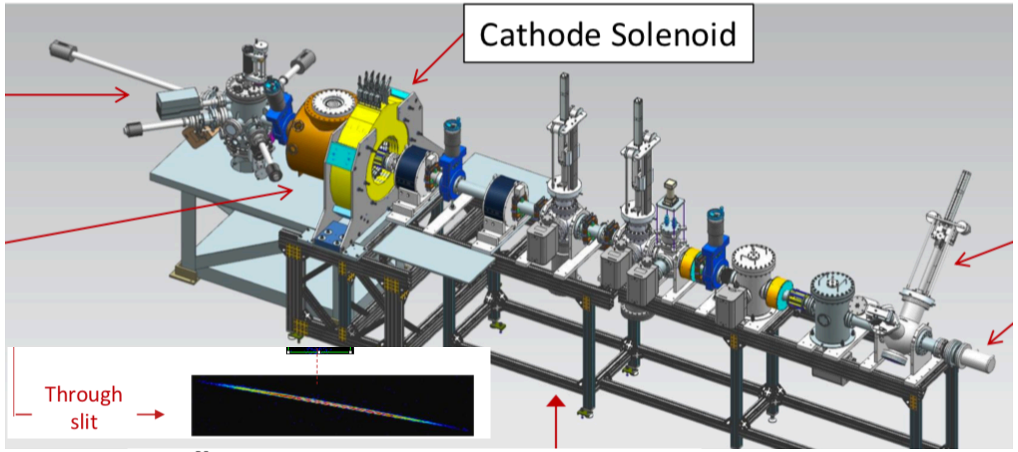


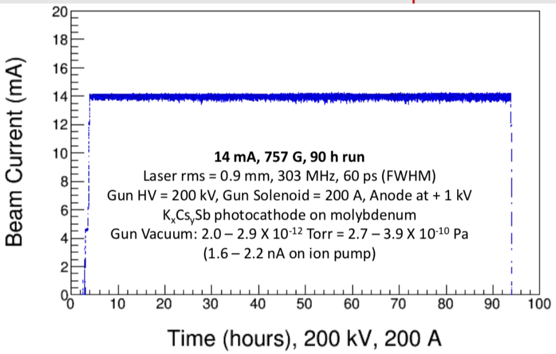


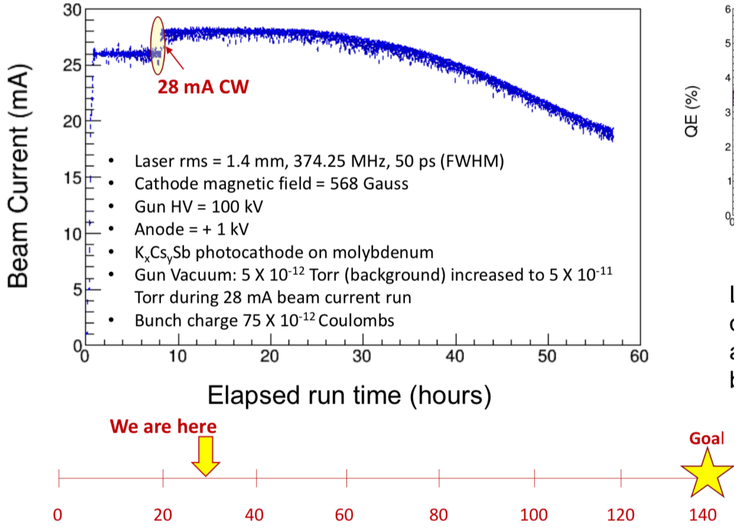


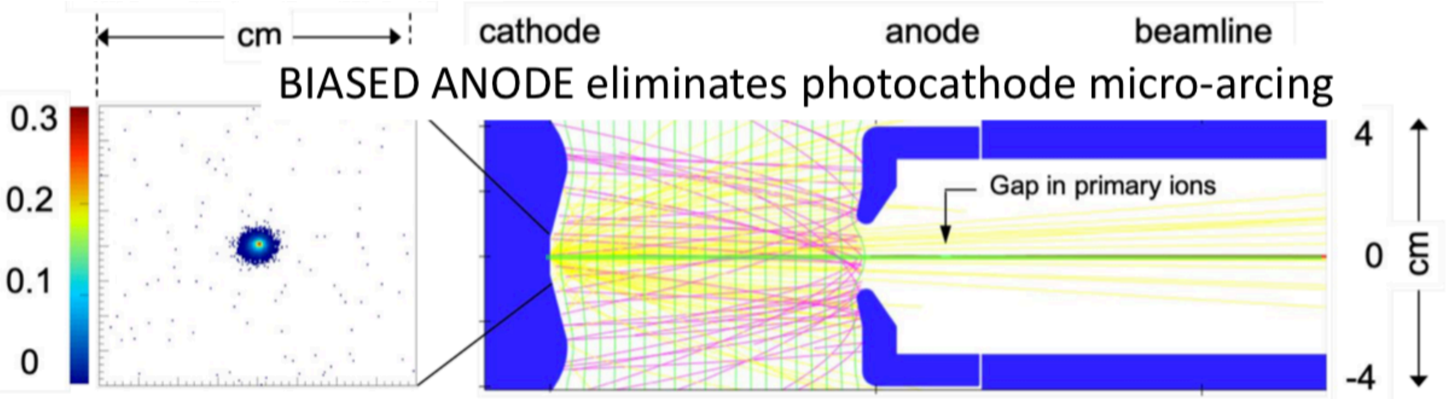
- Generated beam by Cu
- Field emission caused by defects
- Fix the gun, to commissioning 2020

Magnetized beam generated from DC gun for JLEIC Electron Cooler









BIASED ANODE eliminates photocathode micro-arcing

- Long lifetime at >10 mA, magnetized
- Bias anode is helpful
- To test thermionic gun

Gun summary

	HZDR	PKU	BNL	KEK	Novosibirsk	HZB	Jlab (magnetized)
Status	In operation	In operation	In operation	In operation	R&D	R&D	R&D
Gun energy [MeV]	4	4	1.3	0.5	0.3	1.5-2.3	0.3
Cathode material	Mg(Cs2Te)	Cs2Te	KCsSb	GaAs	Thermionic	KCsSb	KCsSb
Bunch charge [pC]	300	50	10,000	60	2,000	100	700
Ave. current [mA]	0.03(1)	1	0.12	1	102	/	28
Peak current [A]	100	9	1.5 @600pC	13	3/5		9.3
Lifetime	1 year	3 weeks	1-2 months	10 hrs?	Year ?	/	90 hrs
Nor. Emittance[um]	13	1.5	0.57@ 600pC	0.8/1.9	8	<0.5	<2 26(drift)