SRF QWR Gun at BNL CeC PoP

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Presenting on behalf of the group listed on next page.

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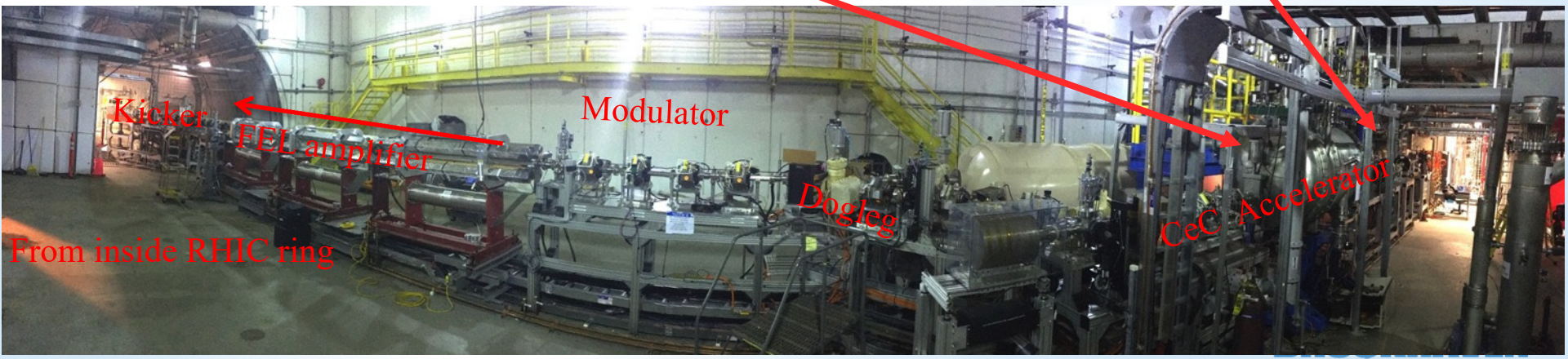
- Discussion

Introduction

- What is CeC PoP
  - SRF accelerator for proof-of-principle Coherent electron Cooling experiment
  - Goal of this experiment: provide high bunch charge electron (up to 5 nC) to cool a single bunch in RHIC
- The SRF portion

704 MHz 5-cell elliptical cavity

112 MHz Quarter Wave gun



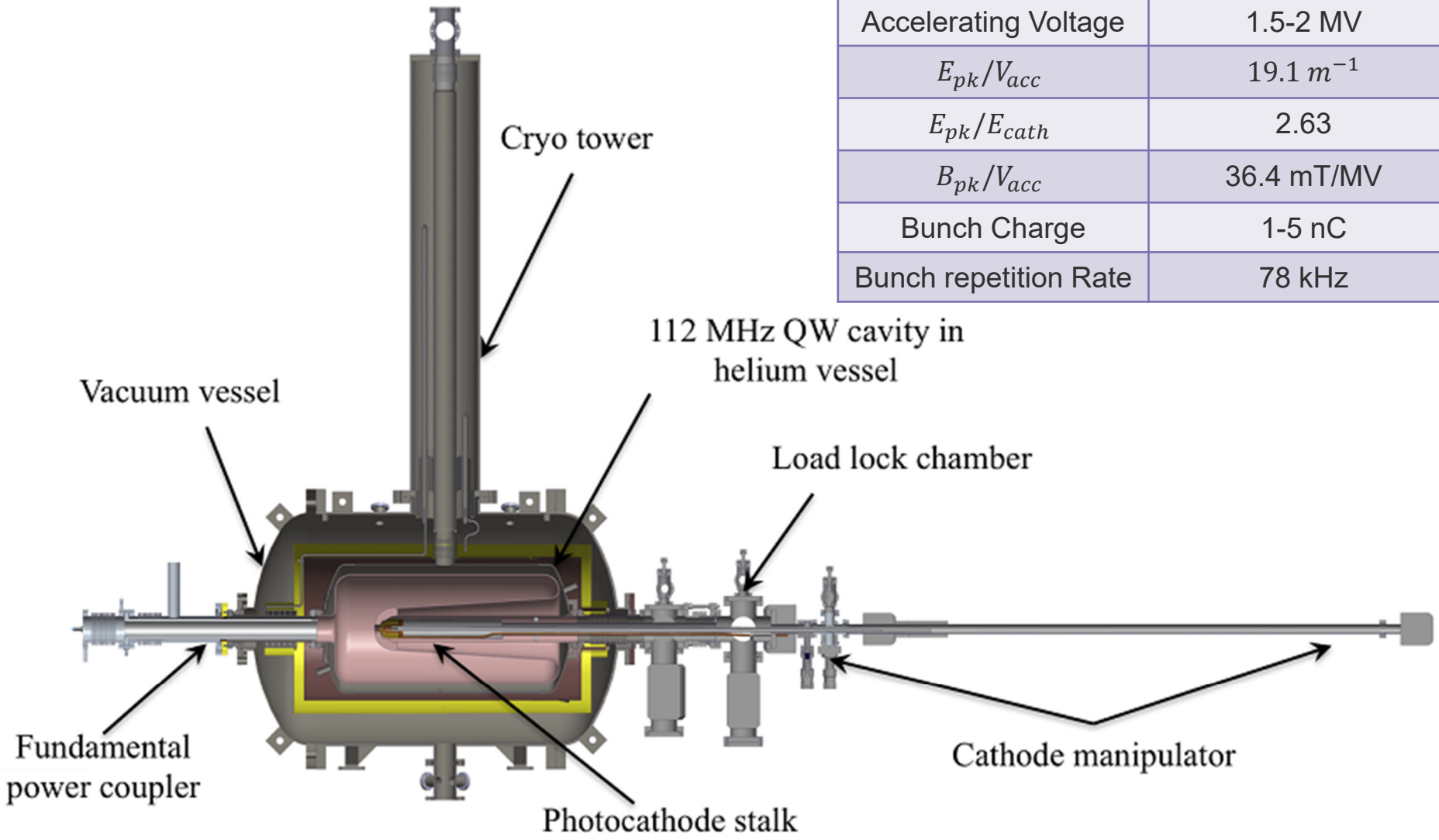
Temptation and Questions need to answer

- Temptation of SRF gun:
  - CW beam
  - Relatively high E field at the cathode surface
  - Good vacuum due to cryo-pumping.

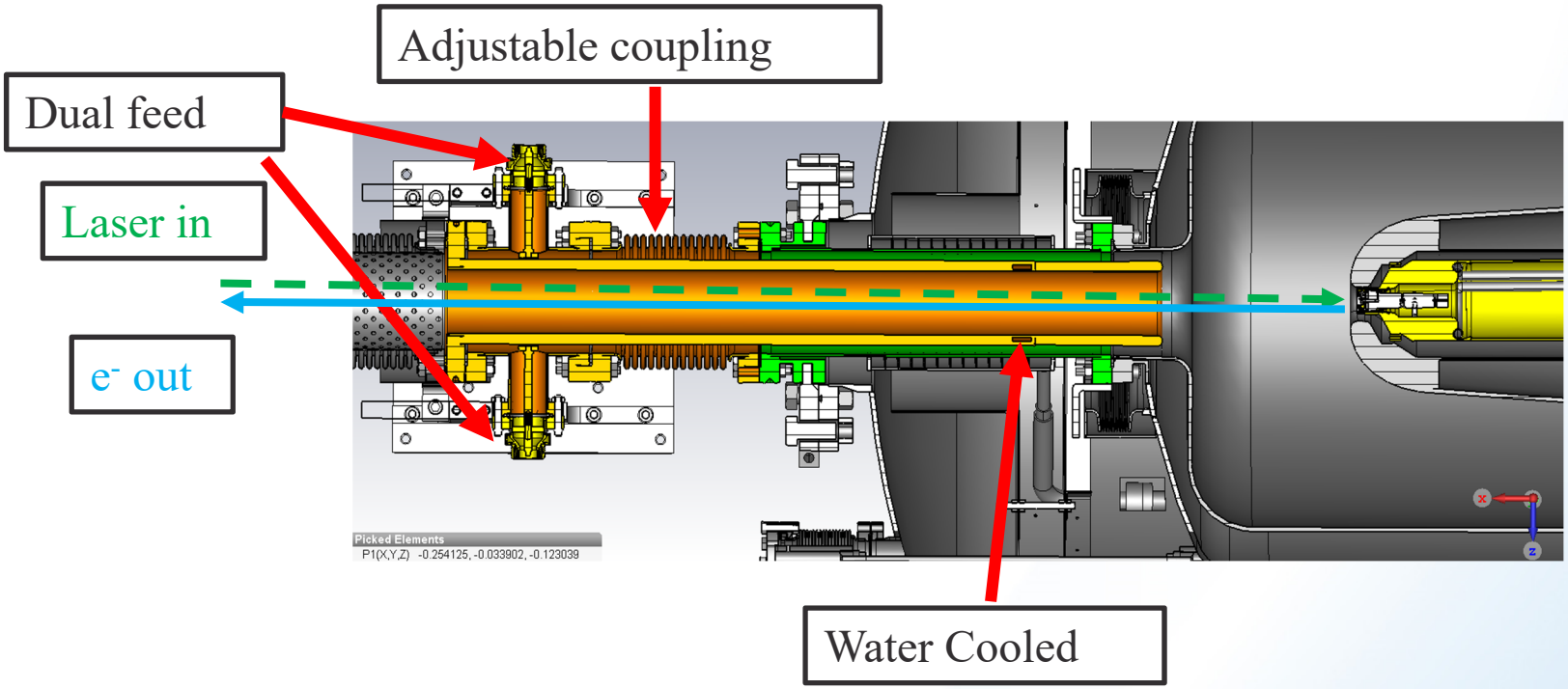
- Questions need to address:
  - Will K_2CsSb cathode survive the SRF cavity?
  - Will SRF cavity survive the K_2CsSb cathode?

Cavity

Frequency	112 MHz
R/Q (Acc. Def.)	126
Q_0	$>3.5 \times 10^9$
Operation Temp.	4.5 K
Accelerating Voltage	1.5-2 MV
E_{pk}/V_{acc}	19.1 m^{-1}
E_{pk}/E_{cath}	2.63
B_{pk}/V_{acc}	36.4 mT/MV
Bunch Charge	1-5 nC
Bunch repetition Rate	78 kHz



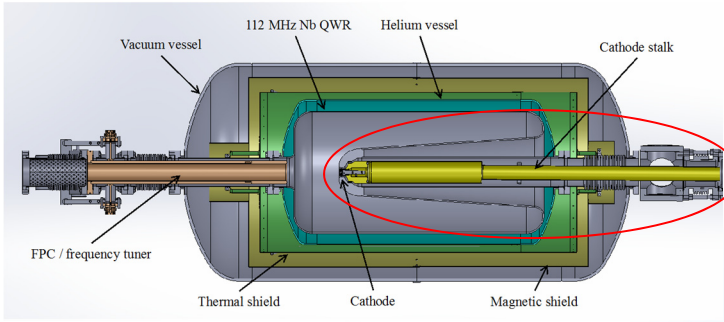
FPC



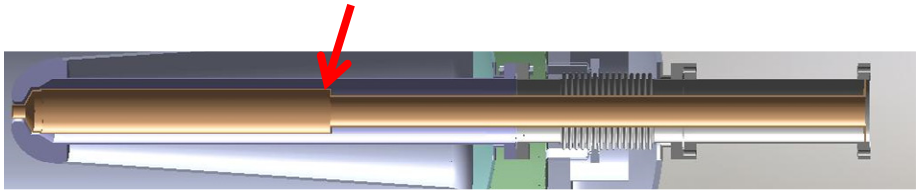
- Made of Stainless steel, coated with 25 um copper and 1um gold;
- Qext adjustable from 5e6 to 8e7;
- Travel distance: 3 cm;
- Water cooled to room temperature.

S. Belomestnykh: SRF & warm RF components for CeC PoP

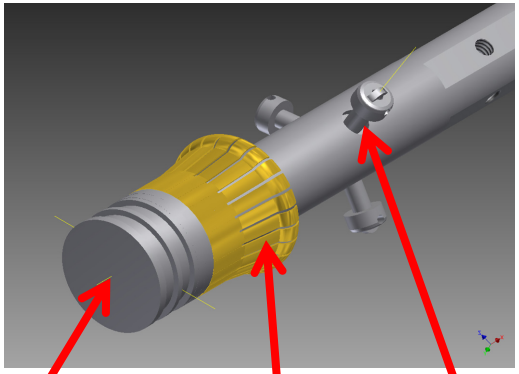
Cathode Stalk



Varying diameter to form quarter-wave transformer to decrease RF loss.



- Stainless steel, 25 um copper, 1um gold;
- Quarter-wave transformer, reduces the transverse field on cathode;
- Water cooled to room temperature;
- Rexolite® “spider” serve as support.

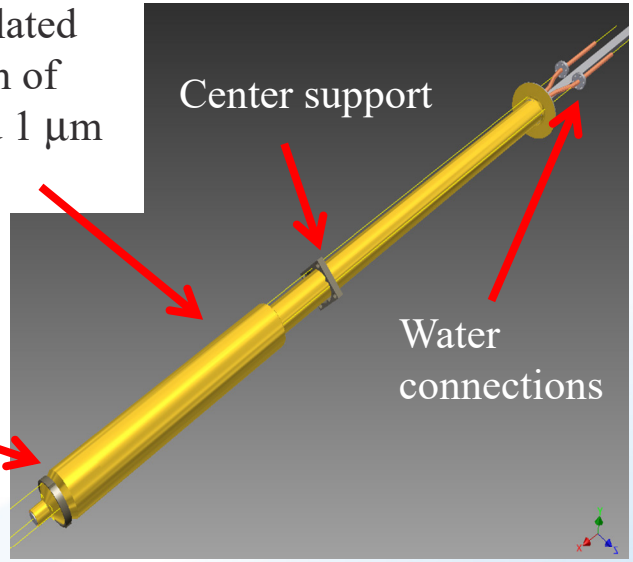


Cathode puck

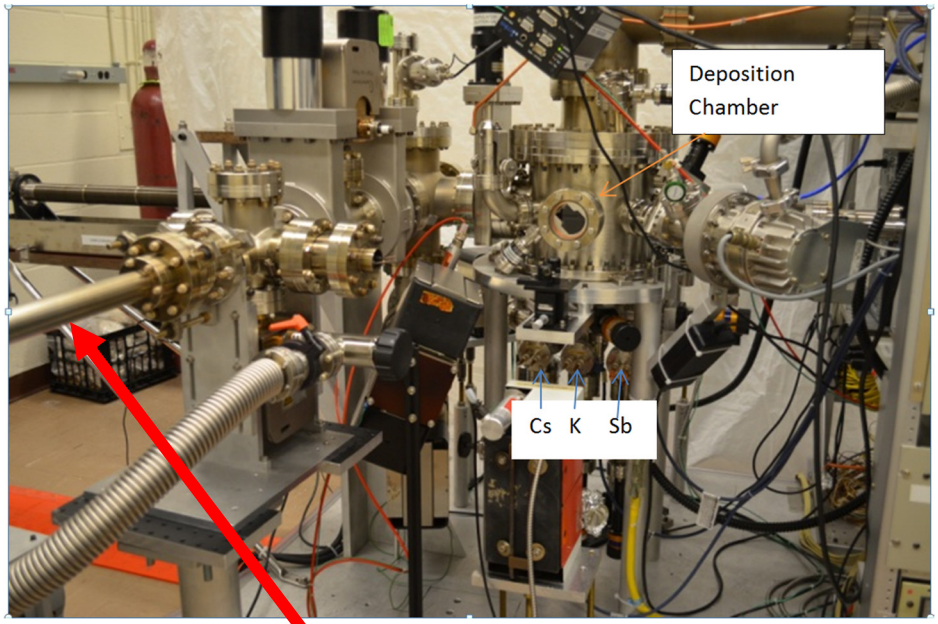
Centering standoffs

Gold plated RF spring finger contacts

SS tubes plated with 25 µm of copper and 1 µm of gold



Cathode Fabrication

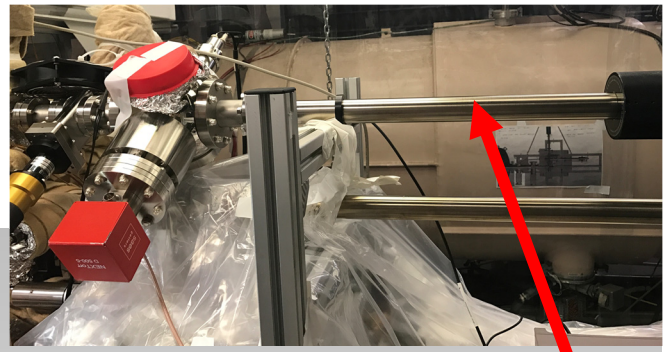


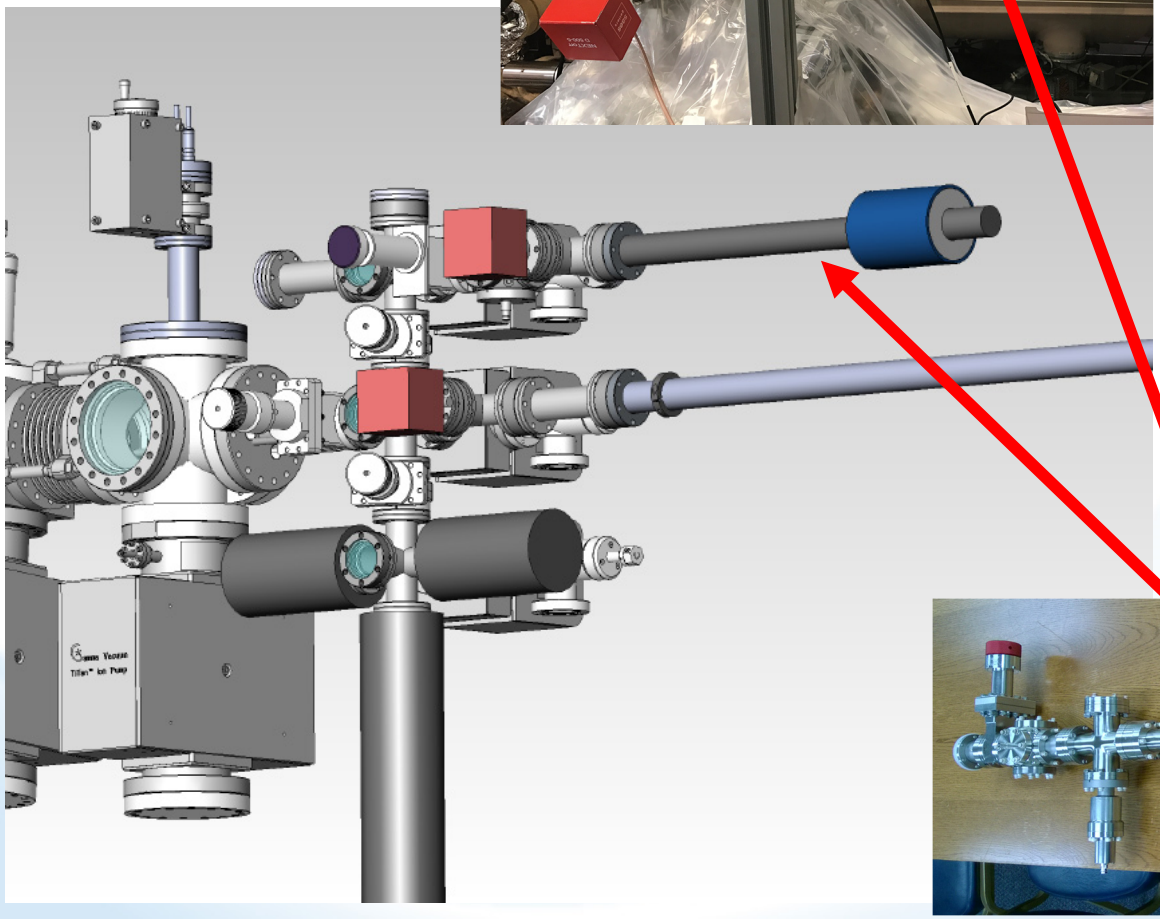
"Suite case"

- Heat the substrate at 350 C for 6 hours;
- hold it at 90 C;
- 10 nm Sb approximately 1 Å/s;
- raised the substrate's temperature to 130 C;
- ~20 nm of potassium @ 0.6 Å/s;
- Then the heater was turned down in order for the substrate to be cooled at around 1 C/min;
- Evaporated Cs and watch QE increased steadily;
- When the photocurrent reached a plateau, turn off heater, turn on cold N_2, reduce Cs until 80 C;
- Cold down to room temperature quickly by cold N_2.

E. Wang, ERL2015

Cathode Launch System





- The cathode is moved into transport cart which has low 10^{-10} torr scale vacuum.
- Disconnecting the transport cart from the preparation system and connecting the cart to the SRF gun require a class 100 clean enclosure.
- The loadlock section is baked about 2 days and reach 10^{-9} torr scale Vacuum.
- We keep monitoring the QE evolution inside the transport cart.

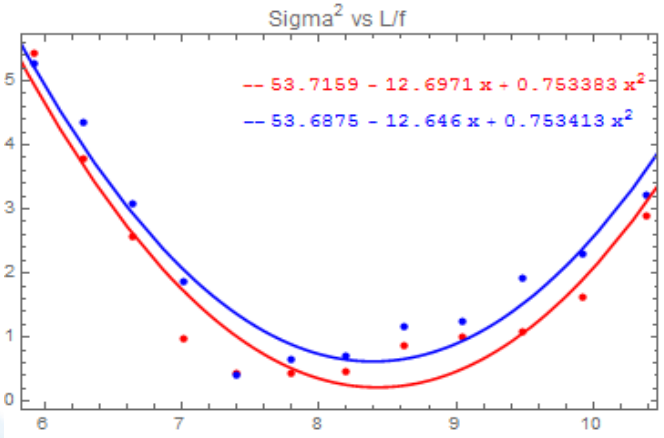
Beam Performance

Early results were presented by I. Pinayev in NAPAC2016

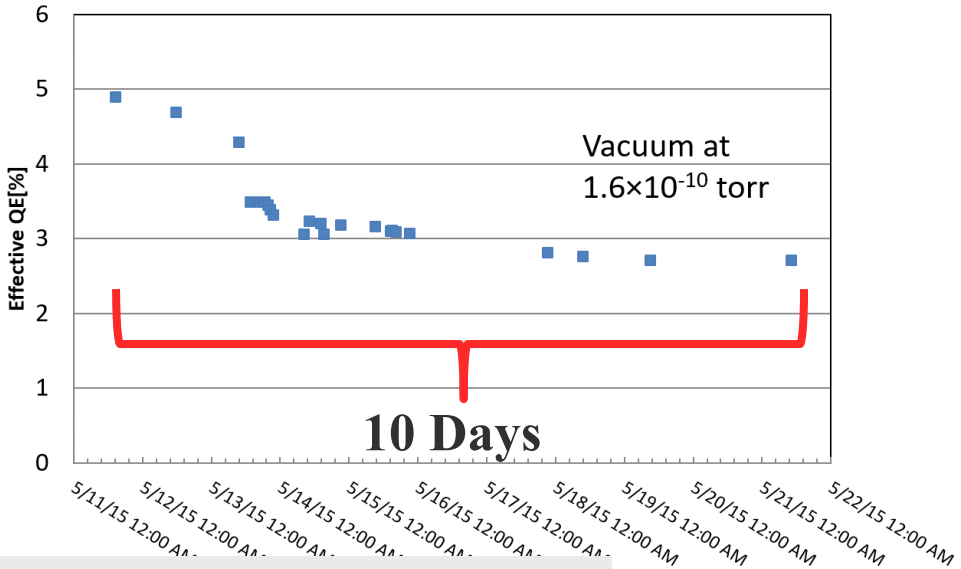
- World record bunch charge for an SRF Gun
  - 10.7 nC per bunch maximum achieved

V. Litvnenko, HBB19

- Record low normalized emittance: 0.32 mm mrad at 0.5 nC
- QE lifetime from one to two months
  - Room temperature water cooled cathode (i.e. not cold)
  - Requires automatic He blowout system in case of water flow failure

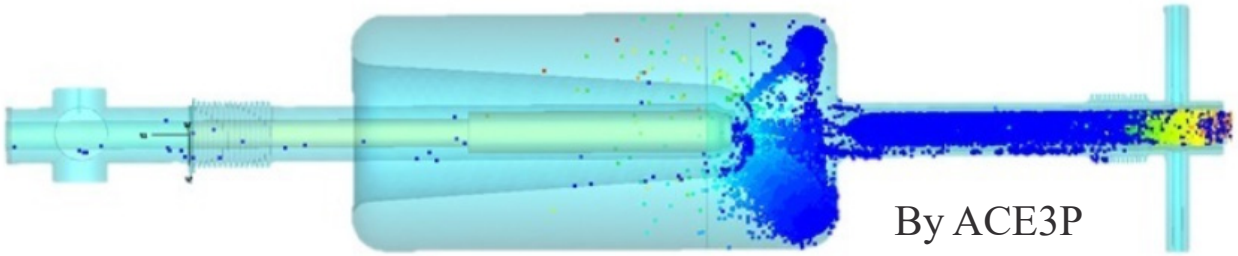


Measurements by Kentaro Mihara

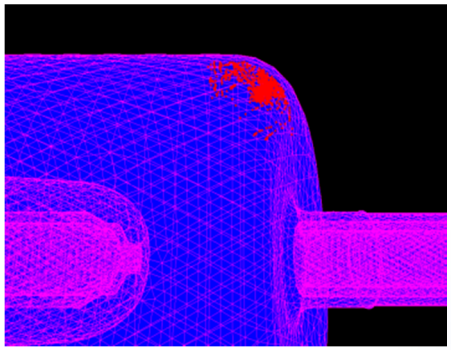


THP079 Performance of the Coherent Electron Cooling SRF Accelerator

Multipacting and Mitigation



By ACE3P

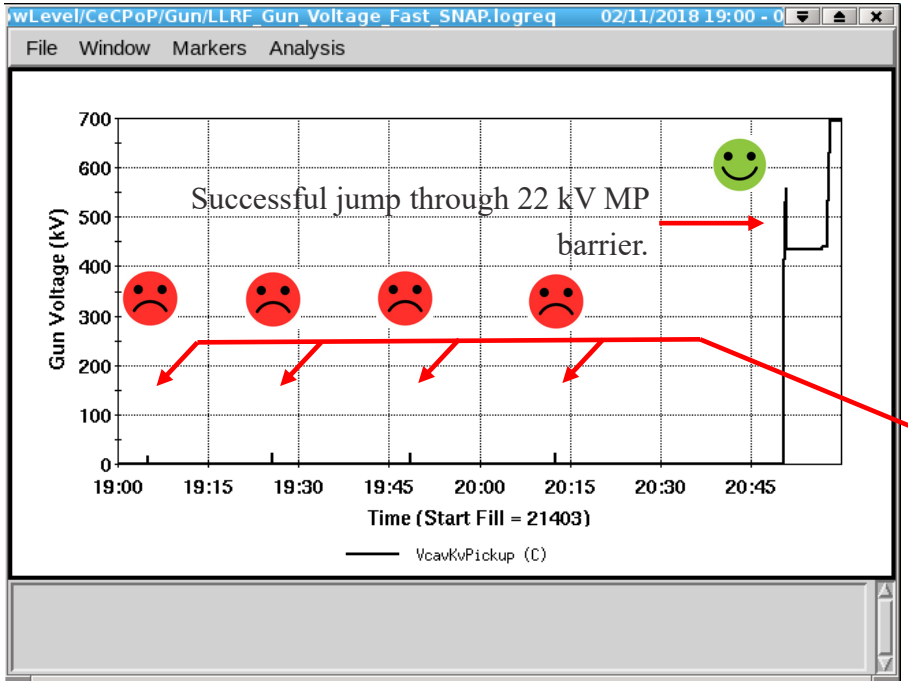


By self-developed GPU code

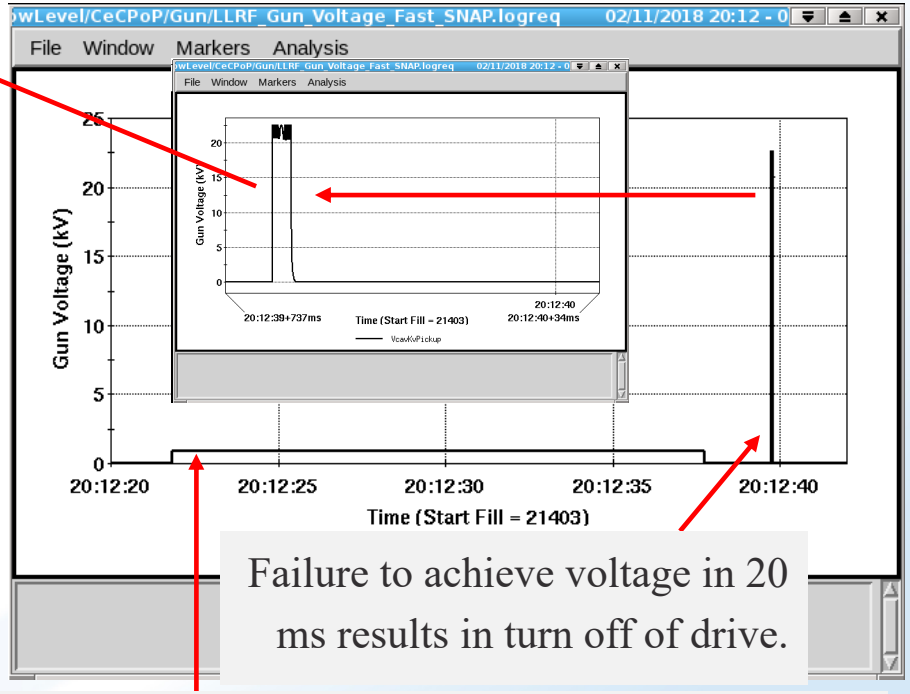
40 kV MP

- MPs? Plenty!
  - 2kV, 22 kV, 30 kV, and 40 kV …
  - Predicted by simulation and encountered in real.
- Will kill the cathode instantly if not dealt with care.
- Break through required strong coupling (for which we have the ability to adjust the FPC)
- LLRF implemented automated turning on script to prevent excessive trap time.

LLRF Script Solution for Gun Start Operation



- Multiple repeated attempts to turn on result in getting stuck at 22 kV MP barrier.
- Attempts last only 20ms, controlled by LLRF MP trap code.
- Prevents significant energy deposition => vacuum activity which would kill cathode QE.



- Lengthen period between attempts from ~ 20 min to ~ 40 min => 5th attempt = successful turn on.
- **Cathode QE not impacted by turn on attempts as MP related vacuum activity is kept minimal.**

Failure to achieve voltage in 20 ms results in turn off of drive.

1 kV turn on (2.3 kV MP level just above) to allow PLL to lock on to cavity resonance.

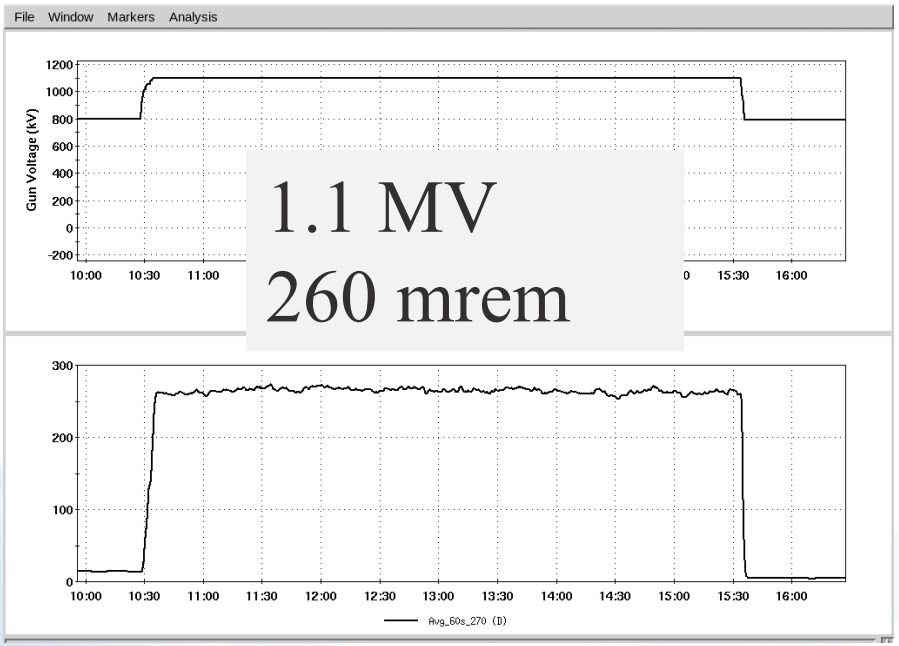
V. Litvinenko, HBB 2019

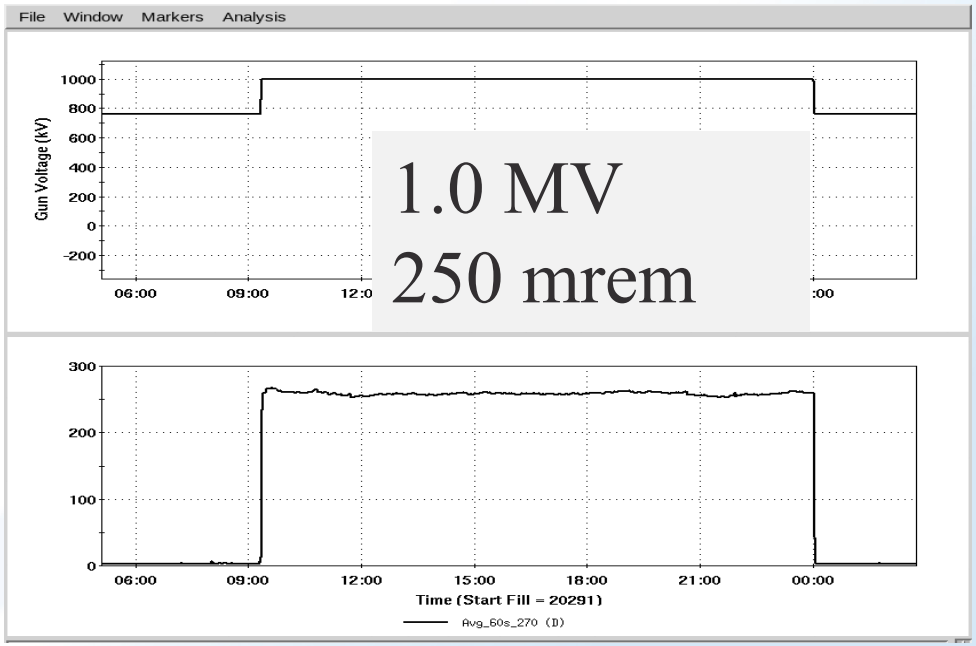
Cavity Performance over years

Typical Gun voltage vs radiation

4 cathodes

2016 → 2017





Conclusion

- Our SRF gun generate electron bunches with
  - Very low normalized projected emittances (sub-μm at 1 nC).
  - Charge per bunch exceeding 10 nC .
  - Average current reached 150 uA.
- The high QE room temperature CsK_2Sb photocathodes operate for months in 1.23 MeV CW SRF gun without any significant degradation. We did not detect any degradation caused by generating CW electron beam.

Reference

- Vladimir N. Litvinenko, Yichao Jing, Jun Ma, et al., “High brightness CW electron beams from Superconducting RF photoemission gun,” HBB 2019.
- I. Pinayev, V. N. Litvinenko, J. Tuozzolo et al., “High-gradient high-charge CW superconducting RF gun with CsK2Sb photocathode” e-print arXiv:1511.05595 [physics.acc-ph]
- E. Wang, “Characterization of multi-alkali antimonide cathodes at cryogenic temperature and its performance in SRF gun,” in Presented at the Workshop on Energy Recovery Linacs(Stony Brook University, 2015).
- H. Xie, I. Ben-Zvi, T. Rao, and E. Wang, “Experimental measurements and theoretical model of the cryogenic performance of bi-alkali photocathode and characterization with Monte Carlo simulation,” Phys. Rev. Accel. Beams, 19, 103401 (2016)
- T. Xin, J. C. Brutus, Sergey A. Belomestnykh, et al.,“Design of a high-bunch-charge 112-MHz superconducting RF photoemission electron source”Review of Scientific Instruments 87, 093303 (2016); doi: 10.1063/1.4962682
- I. Petrushina, V. N. Litvinenko, I. Pinayev, et al.,"Mitigation of multipacting in 113 MHz superconducting RF photo-injector", Phys. Rev. Accel. Beams 21, 082001.
- Kentaro Mihara, Vladimir N. Litvinenko, Irina Petrushina, et al., "Emittance Measurements and Simulations from SRF Gun in CeC Accelerator", FEL2017, Santa Fe, NM, USA
- I. Pinayev, W. Fu, Y. Hao, et al, “Performance of CeC PoP Gun During Commissioning”, NAPAC2016, Chicago, IL, USA
- J.C. Brutus, S. Belomestnykh, Y. Huang, V. Litvnenko, et al., “Mechanical Design of 112 Mhz SRF Gun FPC for CeC PoP Experiment”, PAC2013, Pasadena, CA, USA