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U.S. DEPARTMENT OF ENERGY

Generation of Polarized Electron Beams: Unveiling the First RF Electron Gun with GaAs Photocathode

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Outline

- GaAs cathodes and CeC SRF gun
- Cathode production and gun preparation
- QE evolution and degradation
- Peak performance of GaAs cathode and its beam's quality
- Summary

Choice for highly polarized beam – GaAs

Characteristics of existing GaAs cathodes:

1. Very sensitive and require vacuum better that 10^{-11} torr to operate: sensitive to contaminations like CO2, water, etc.
2. Operate with low voltage DC guns (0.1-0.3 MeV) for polarized sources
3. Charge per bunch as well as beam quality can be limited by low voltage/accelerating gradient

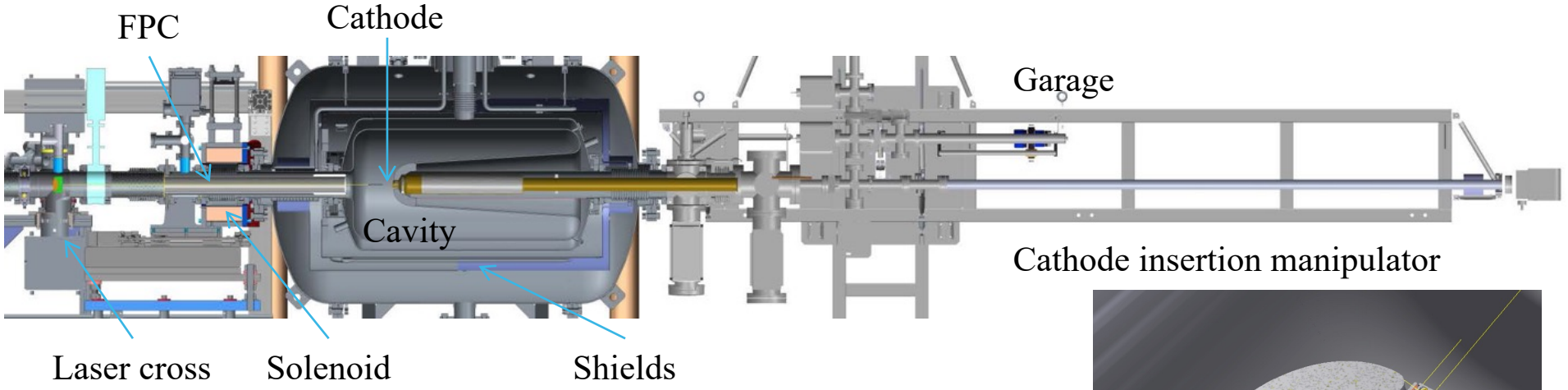
Our approach:

extend to RF guns, which could accelerate electrons to energy of a few MeV and significantly increase the available accelerating gradient at the cathode surface.

- Higher extracted charge
- Better beam quality

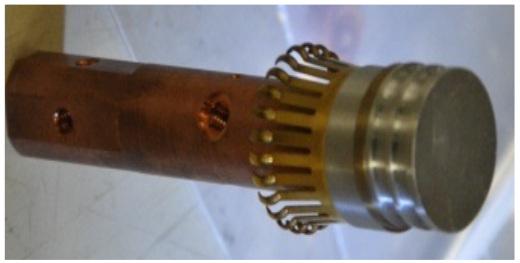
CeC RF gun

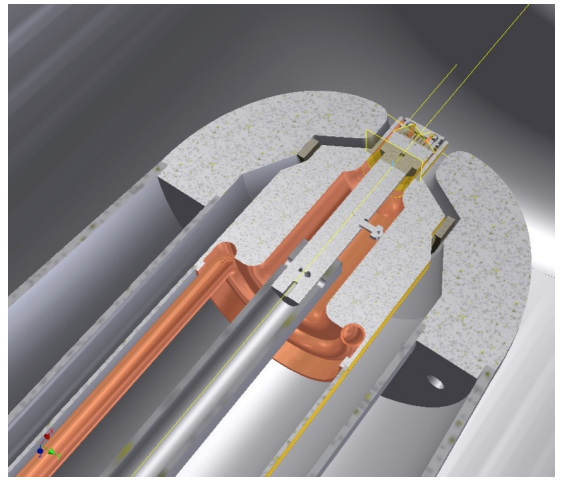
- The CeC SRF gun demonstrated successful operation with CsK_2Sb photocathodes, which could successfully operate for few months without significant degradation of their QE. This was the main reason why there was a promise that our CeC SRF gun could be capable to operate with GaAs photocathodes.



Quarter-wave SRF 4K Nb gun cavity tuned to operation frequency
Room temperature CsK2Sb high QE photocathode inside adjustable stalk
Photocathode QE lifetime – one to two months
Record low normalized emittance: 0.32 mm mrad at 0.5 nC
Vacuum storage & transportation suit ("garage") with three photocathodes
UHV cathode manipulation system

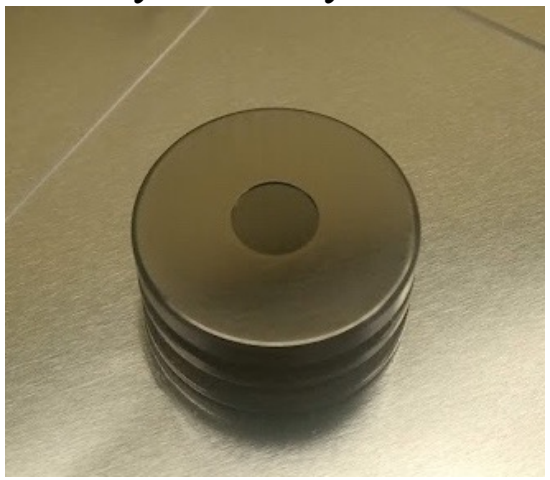
UHV vacuum inside the SRF gun

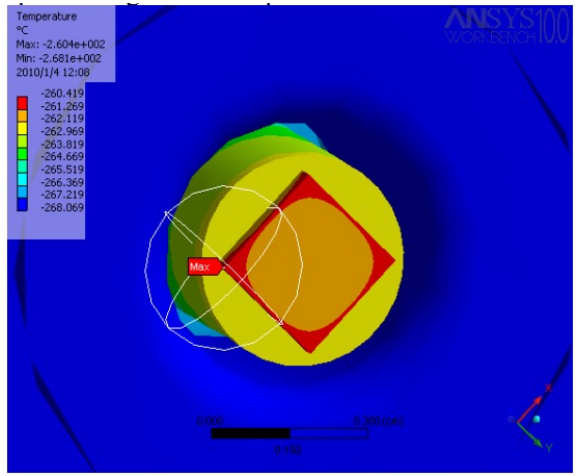




GaAs cathode deposition

The CeC photocathodes are produced in BNL's Instrumentation Department. A deposition system is built in capable of producing both CsK_2Sb and GaAs photocathodes with a Super UHV vacuum transport suit ("garage") with vacuum better than 10^{-11} torr. It also modified two Mo cathode packs: a square GaAs crystal is inserted into the cut in the puck's surface, attached by a thin layer of In and topped with a polished metal cup firmly screwed to the Mo puck.





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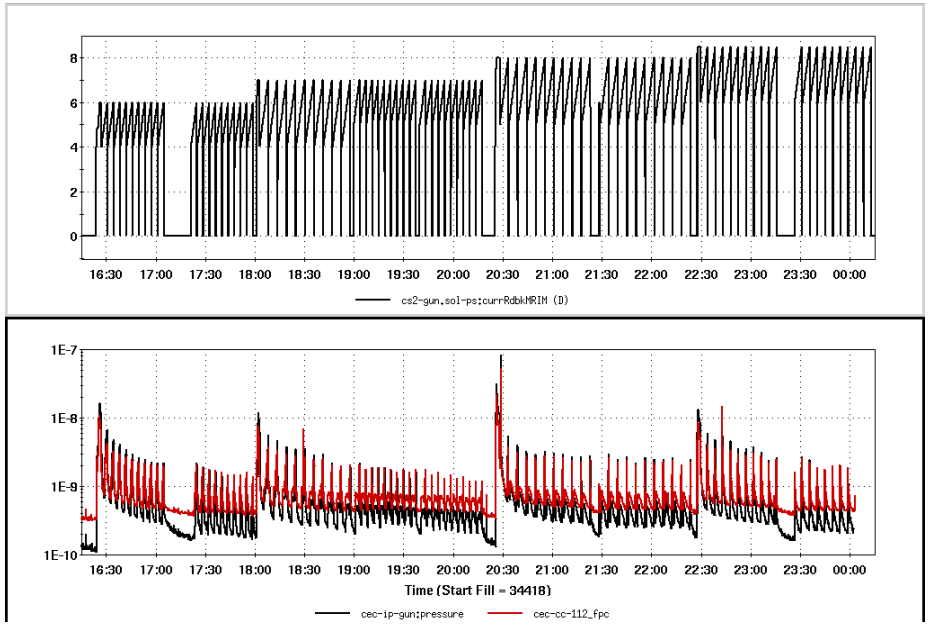
Left: The modified CeC Mo cathode puck with a square GaAs crystal inserted under a metal cup with a 5 mm hole in diameter.
Right: simulations of the RF heating losses in the GaAs crystal.

Heat loss in GaAs crystal of 5 W when operating the SRF gun at 1.25 MV

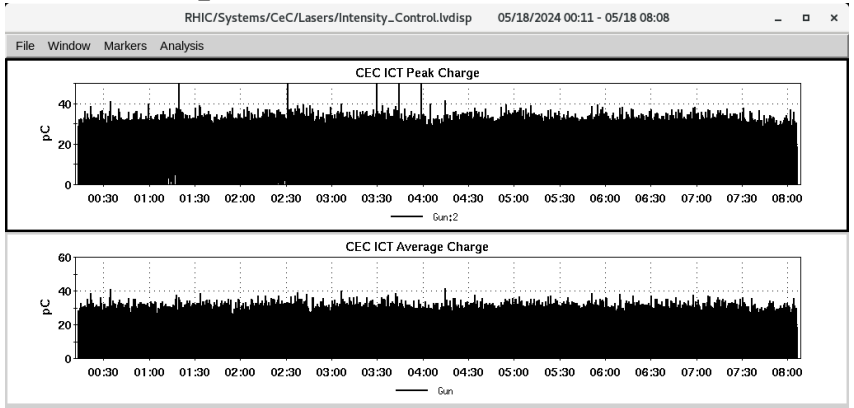
Gun operation for low voltages

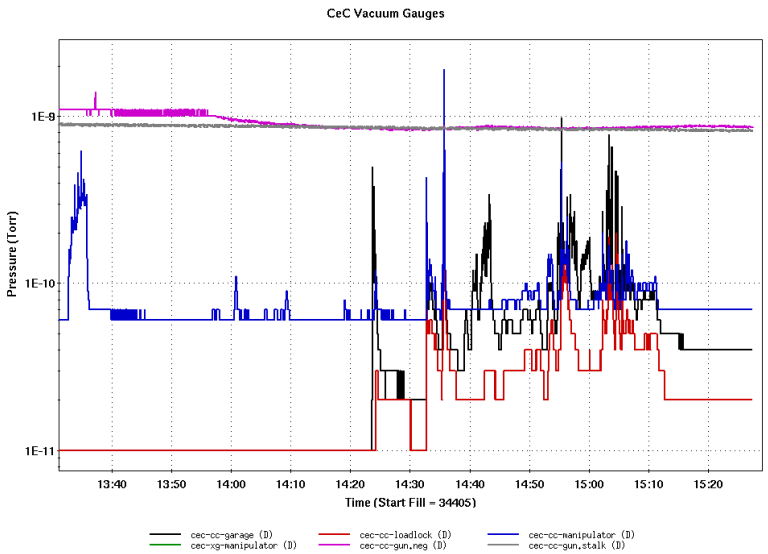
- For the safety of the SRF gun as well as the GaAs cathode, we decided to initially operate the SRF gun at as low energy as possible and developed a dedicated routine to bring up the SRF gun at voltage as low as 52 kV when the losses in the GaAs crystal go below 1 mW.
- Because the gun was designed to operate at a much higher voltage (1.25 MV) and we are approaching to some of the influential Multi-pacting zones (40 – 200 kV). Additional effort was spent to clean up these active areas by exciting vacuum bursts with scanning solenoids while continuing to clean residual gases with vacuum pumps.
- By the time we were ready to insert GaAs cathode there were no vacuum excursion at all gun voltages from 52 kV to 1 MV.



GaAs cathode QE evolution

1. Two GaAs photocathodes produced with initial QE of 4.8% in green light.
2. After the cathode was moved into the garage, the QE dropped to 1%. After that, both GaAs cathodes were kept on the load-lock, where vacuum was in mid-E-12 torr range waiting for the SRF gun to be cooled.
3. The first GaAs cathode was inserted several days later. The cathode QE was estimated to be below 0.5%.
4. During the cathode insertion process, we observed vacuum evolution in various locations at back of the SRF gun. We have reasons to believe that QE of GaAs cathode suffered 5 to 10 fold degradation during this transfer. This is one of the problems we plan to address in the future.





5. Measured QE with beam generated ~ 0.04 – 0.08%.
6. No measurable loss of QE when operating in the gun.

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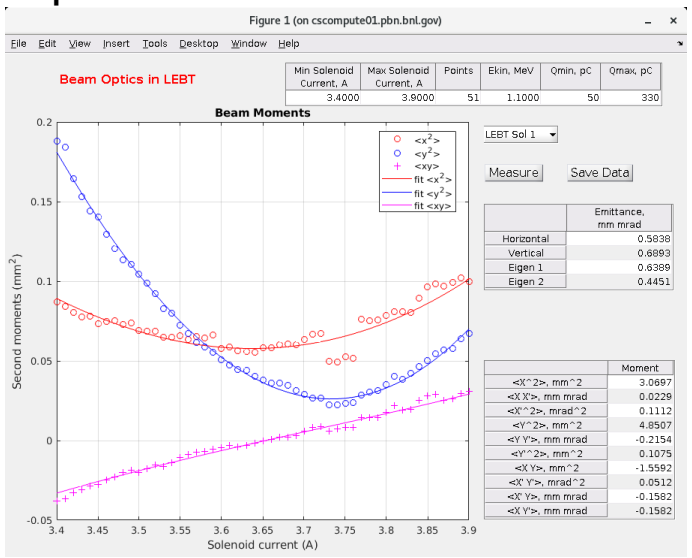
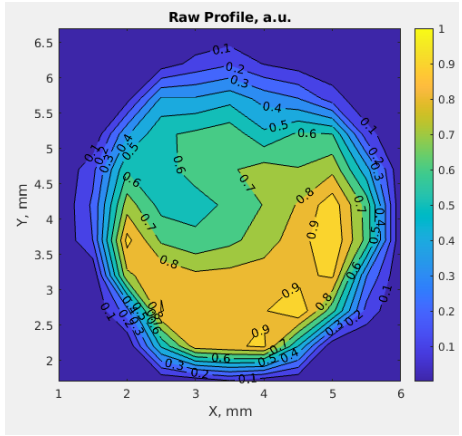
Beam quality and QE degradation

- The quality of the generated electron beam was reasonable with normalized projected emittance ~ 0.8 mm mrad for 100 pC per bunch, which could be further improved if the uniformity of the QE of the cathode can be improved.



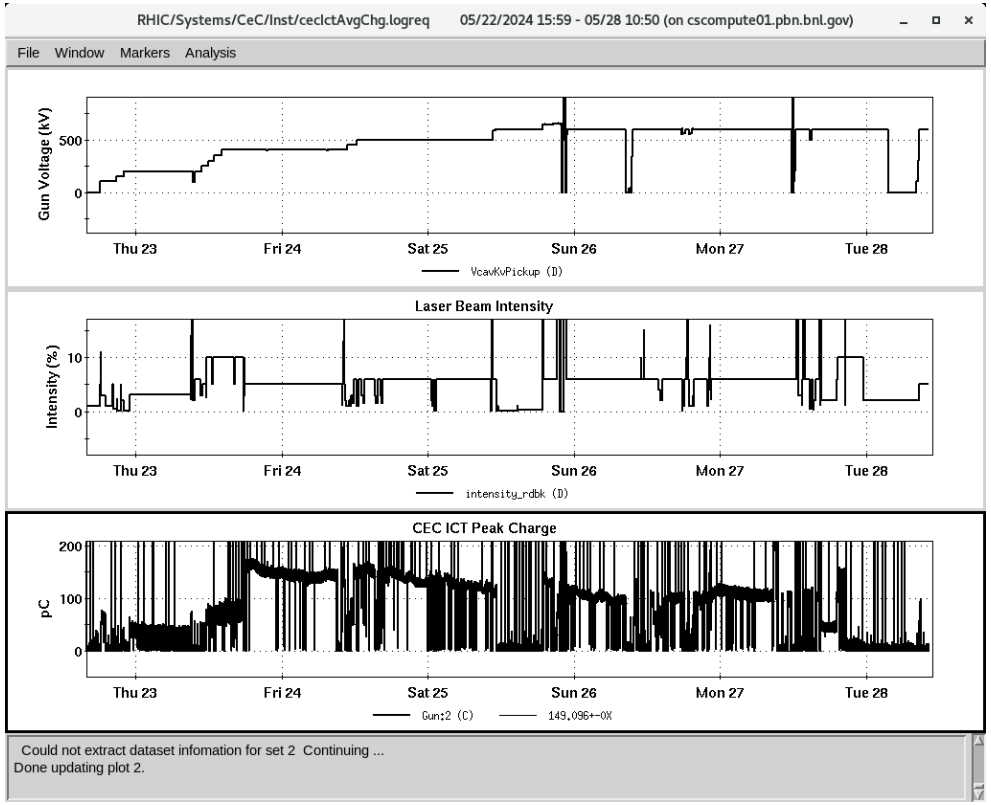


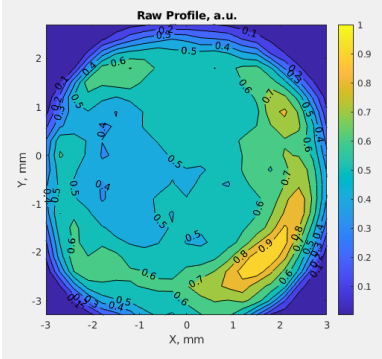
- During operation, QE slightly improved to 0.08 – 0.1%. During the tests the SRF gun experiences number of unfortunate voltage drops (caused by technical problems) and the cathode was exposed to a number of vacuum spikes. After these events QE reduced to 0.045% and later on 0.025%. It is possible that exposing GaAs cathode to poor vacuum resulted in instantaneous QE reduction.

2nd GaAs cathode

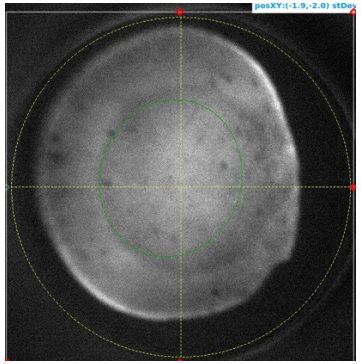
Cathode operates with reasonably stable QE (0.08% -> 0.04% over the week)

Characterize the cathode's performance for various voltages (200 – 700 kV) – emittances ~0.6 - 0.8 um for 100 pC per bunch





Not so uniform QE map

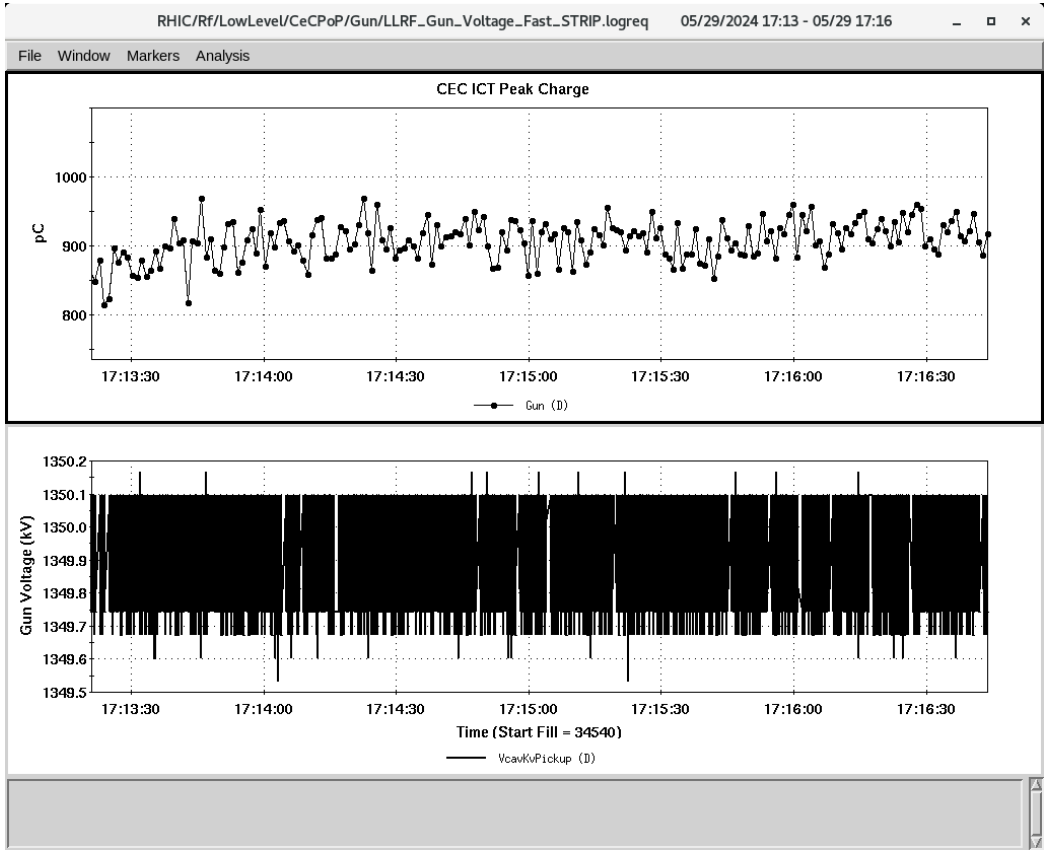


Real beam image shows QE dead spots ~ res. 100 um

Right part of the profile is distorted by the nonlinearities in the beam transport.

Peak performance of the GaAs cathode

- Since we found that GaAs cathode in this configuration could operate at high voltages ~ 1 MV, we switched to our regular mode of SRF gun operation that we used with CsK_2Sb photocathodes.
- Using this regular mode of operation, we tested that GaAs cathode could operate at voltages as high as 1.375 MV. Maximum charge per bunch observed with this photocathode was ~ 0.9 nC.



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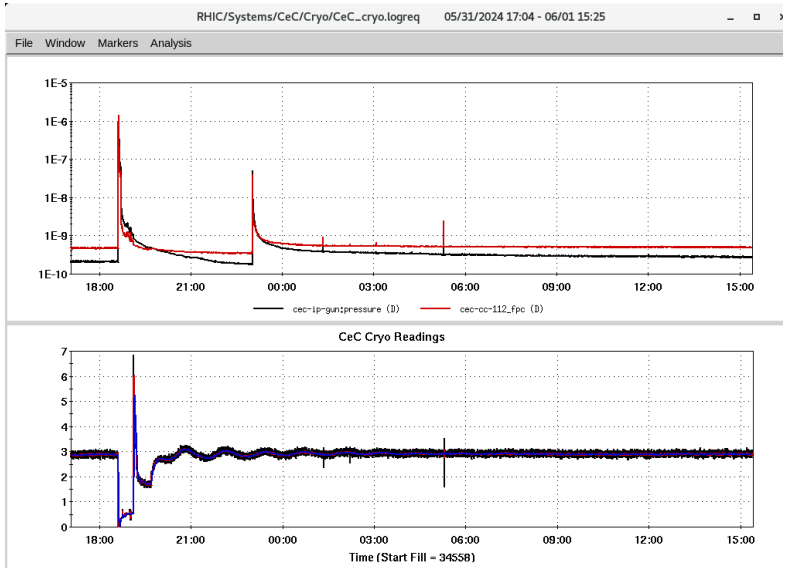
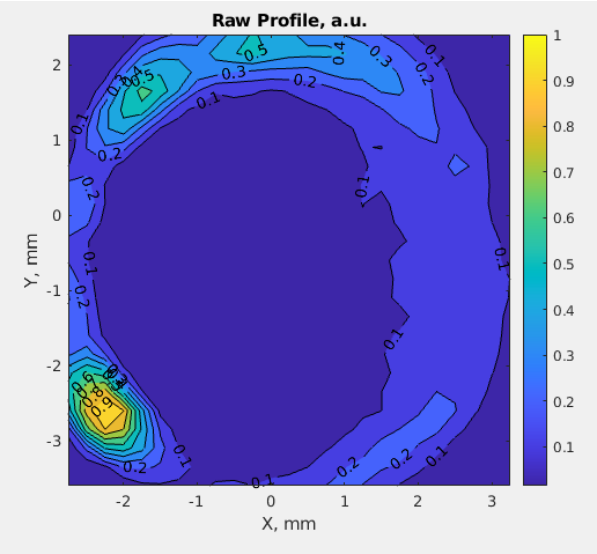
Power dips and QE poisoning

- The QE dropped and stayed at 0.04% level for few more days before strong power dips affect the cryogenic equipment resulting in the huge (1E-6 tor level) vacuum bursts. These vacuum bursts come from the reduction of cold He gas flow through cooling channels of the cold to warm transition chamber. Rise of the temperature results in evaporation of accumulated gases frozen at the surfaces of the vacuum chambers.
- C-AD cryogenic group developed a very dedicated method of keeping the flow of the cold He gas nearly constant to avoid any vacuum bursts, but serious power dip violated the conditions, and the resulting vacuum burst caused immediate factor ten in QE degradation. What is also became evident that these burst deposited “aggressive gases” at the surfaces of the GaAs cathode caused a gradual but constant QE reduction.





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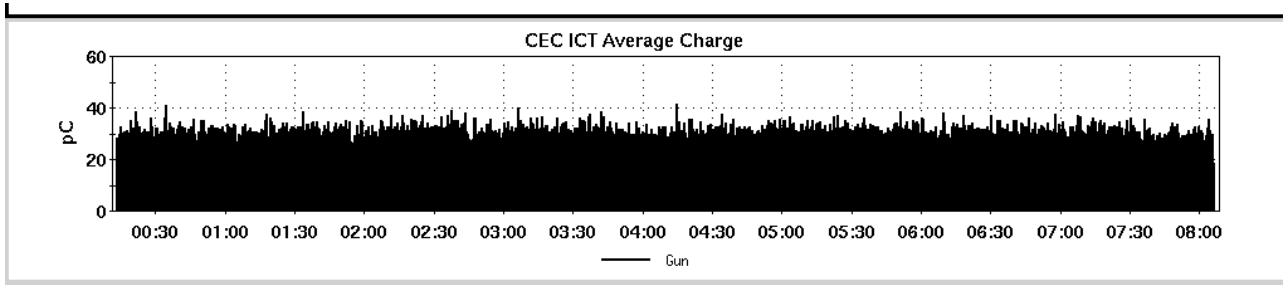
Summary of the GaAs cathodes tests

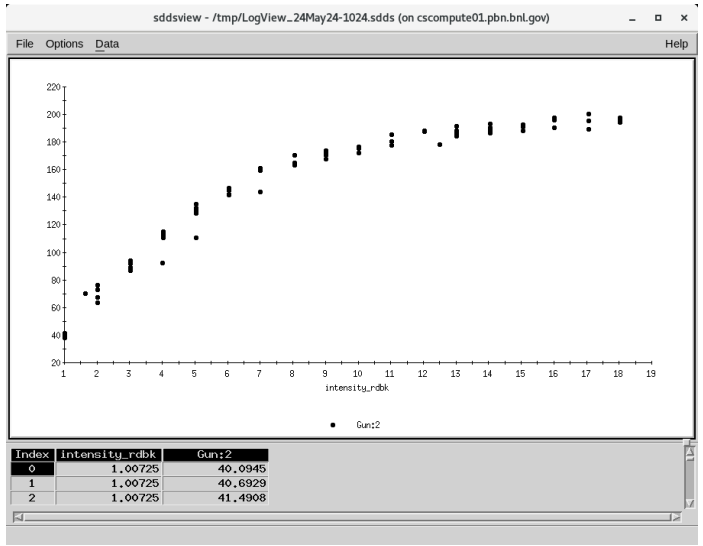
1. We demonstrated that GaAs cathode can successfully operate in the CeC SRF gun at voltages above 1 MeV (maximum tested was 1.375 MV) for extended periods of time with out significant QE degradation. They also can generate change per bunch exceeding 0.9 nC.
2. We clearly observed significant degradation of QE during cathode transfer and this portion of the experiment needs significant improvements. Creation of more uniform QE is needed for generating better quality beam.
3. Normal operation of the CeC SRF gun results in excellent vacuum inside the cavity and the location of the cathode. Maintaining these condition is important part for future successful operations with GaAs cathodes.

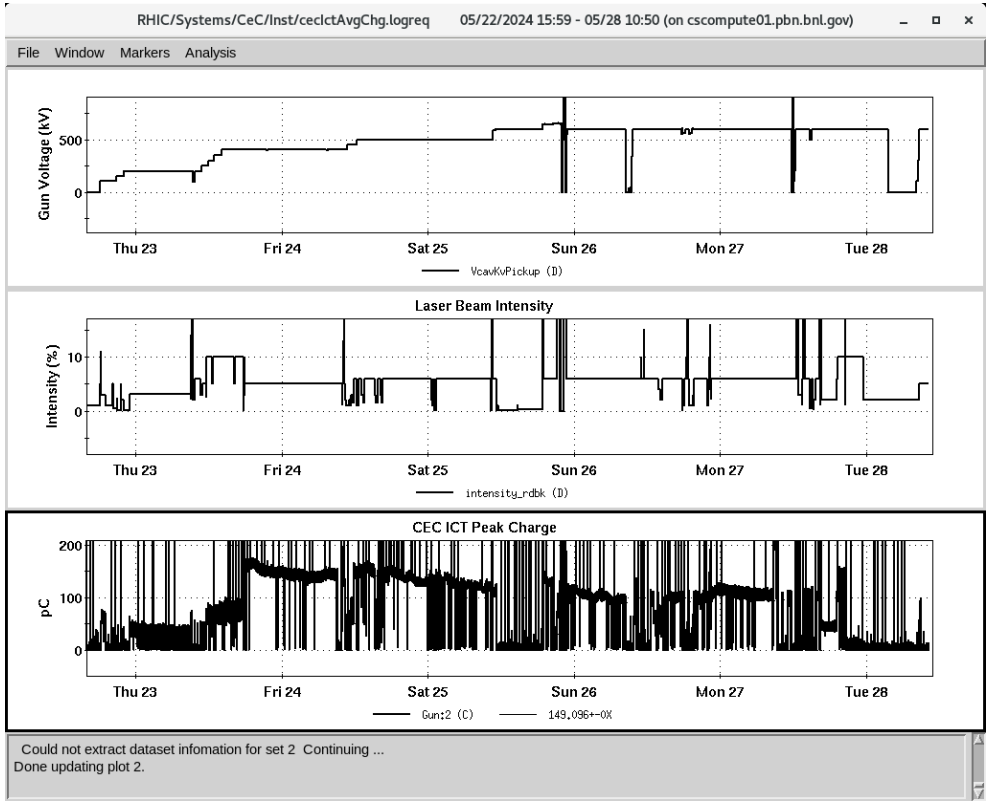


4. It apparent that exposure of GaAs cathodes to burst of aggressive gases frozen at the cold surfaces of the gun would cause not only instantaneous reduction of the QE but its continuous and relatively fast degradation till complete QE depletion.
5. We demonstrated GaAs cathodes can survive in SRF guns and plan to continue it towards generating polarized electron beam during next RHIC run. The CeC system is currently equipped with Compton polarimeter built by JLab collaborators. We plan to procure IR laser, use optical fiber delivery system and polarimeter located at the gun laser table in order to demonstrate generation of the polarized electron beam.

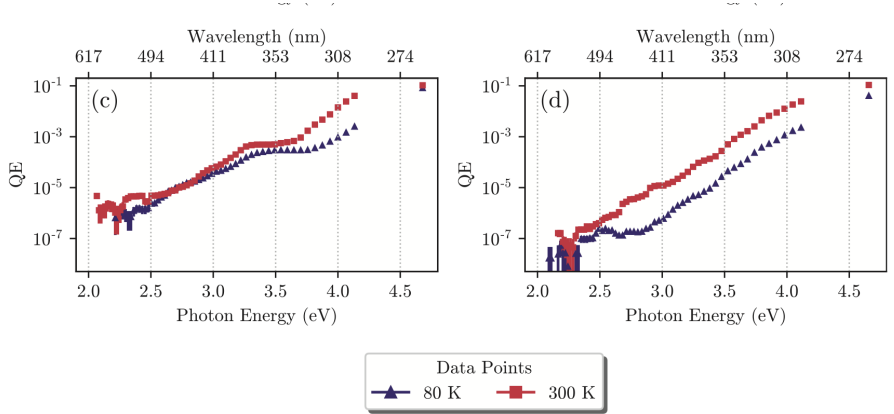
Back up slides

- Operate the 2nd GaAs cathode in low voltages (< 1 MV)
- Generates photo-electrons in linear regime ~ 100 pC per bunch due to low QE (< 0.1%)
- Little vacuum activities were observed
- Cathode operates with reasonably stable QE (0.08% -> 0.04% over the week)
- Characterize the cathode's performance for various voltages (200 – 700 kV) – QE, emittances ~0.8 um for 100 pC

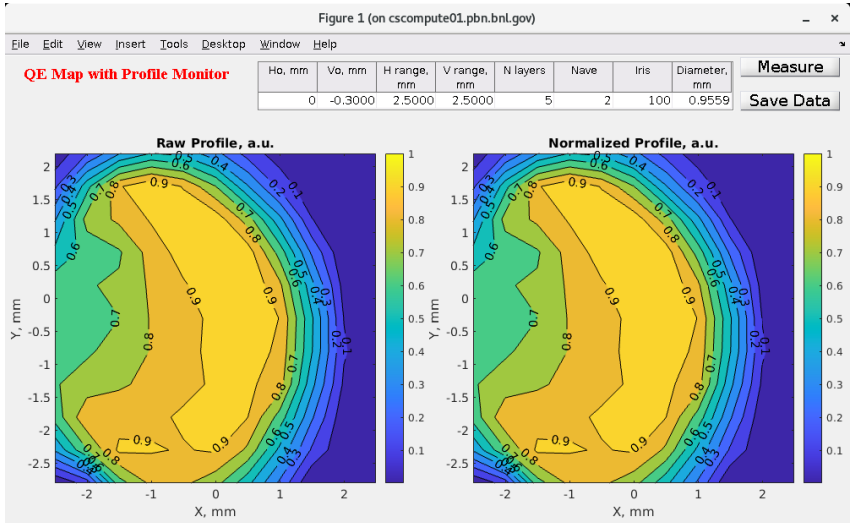




- RF group switched gear to synchronize the high voltages (> 1 MV) with laser/diagnostic
- QE map indicates cathode is burning off slowly
- Preliminary discussion showed the electrons are unlikely to be generated from CsTe layout
- Real demonstration will wait till Run 25 when polarization can be measured.



Day 2



Day 5