Commissioning program of the 704 MHz SRF gun at BNL

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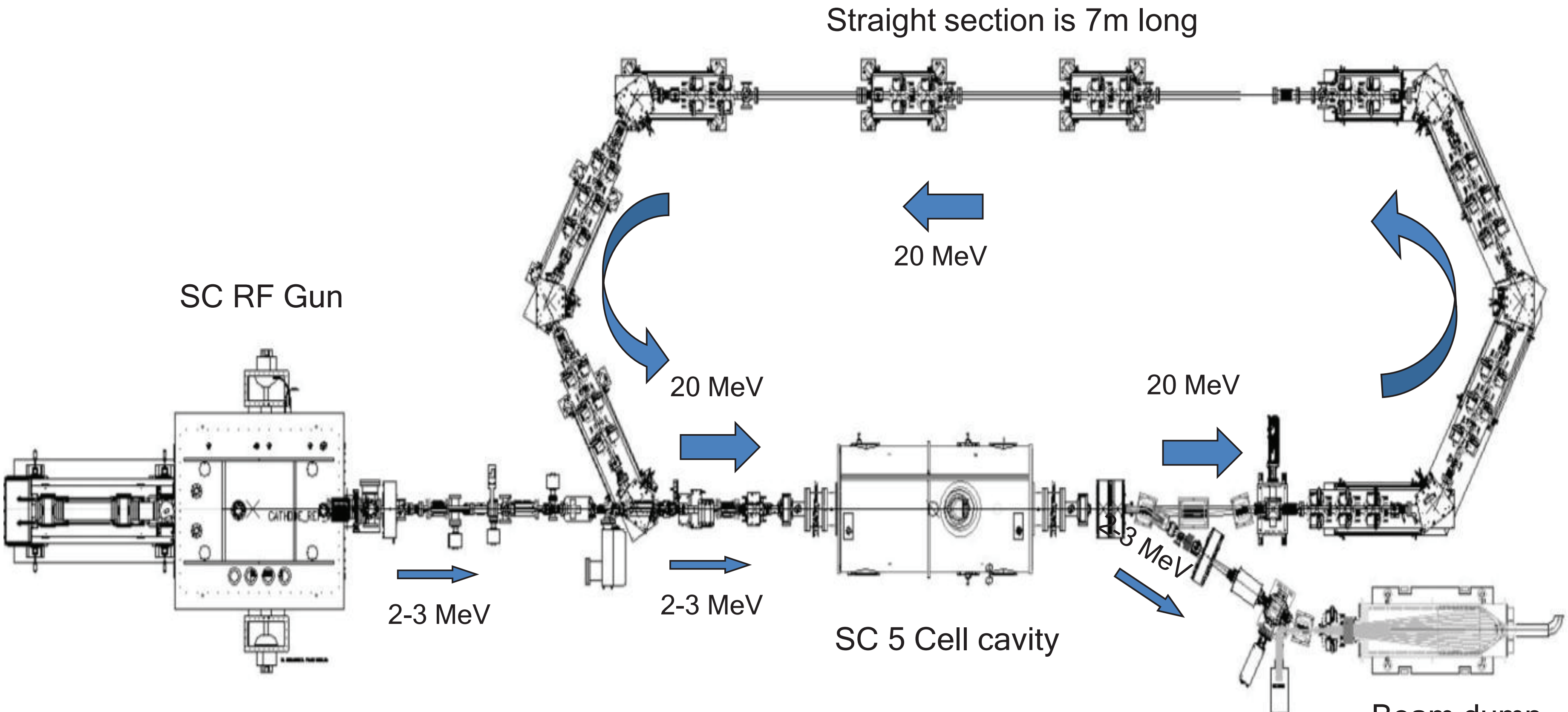
Outline

- Brief Introduction of the BNL R&D ERL and SRF gun
- Milestones of SRF gun building and commissioning
- Beam commissioning results
- Summary

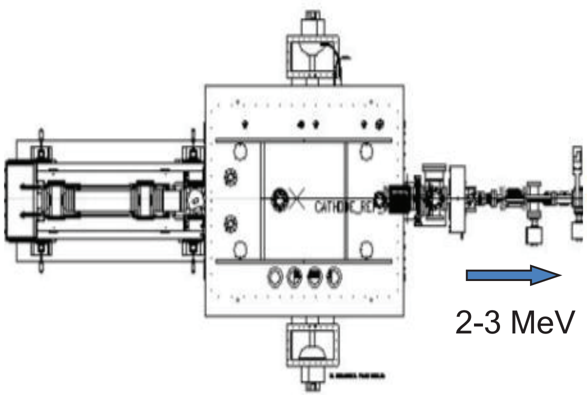
The R&D Energy Recovery Linac at BNL

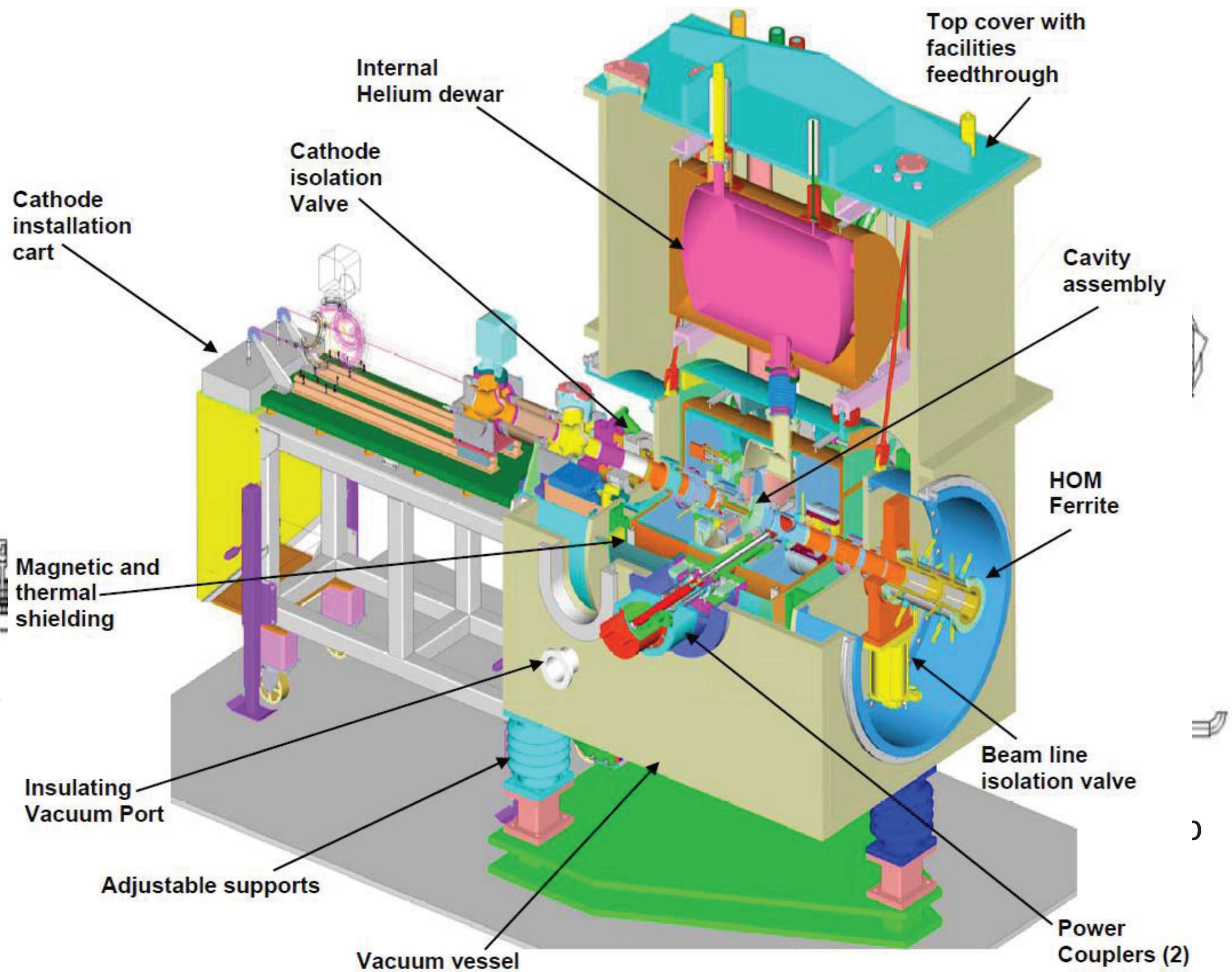


- The beamline was completed and the ARR for ERL commissioning was done in mid May.
- SRF gun is currently under beam commissioning.

The R&D Energy Recovery Linac at BNL

SC RF Gun





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SRF gun Milestones

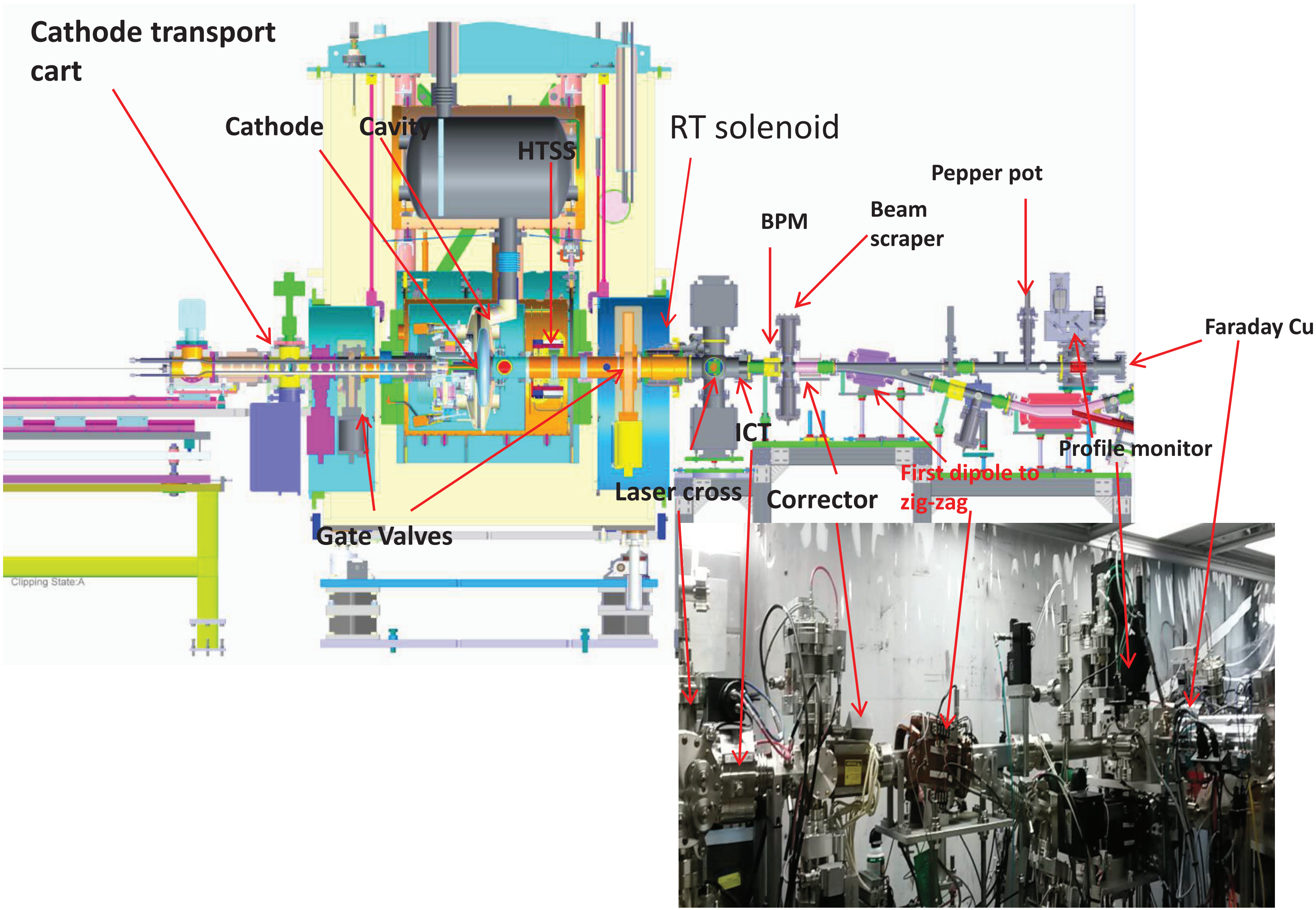
❖ ***Building up:***

1. Mid. 2010: vertical cavity test in Jlab, reached 2.9 MV w/o cathode stalk.
2. Mid 2011: 500 kW CW fundamental power coupler conditioning.
3. 2011 to 2013: Installation of the whole cryostat; Preparation/commissioning the subsystems: cryo, LLRF, vac, instrumentation, cathode preparation system…

❖ ***Commissioning:***

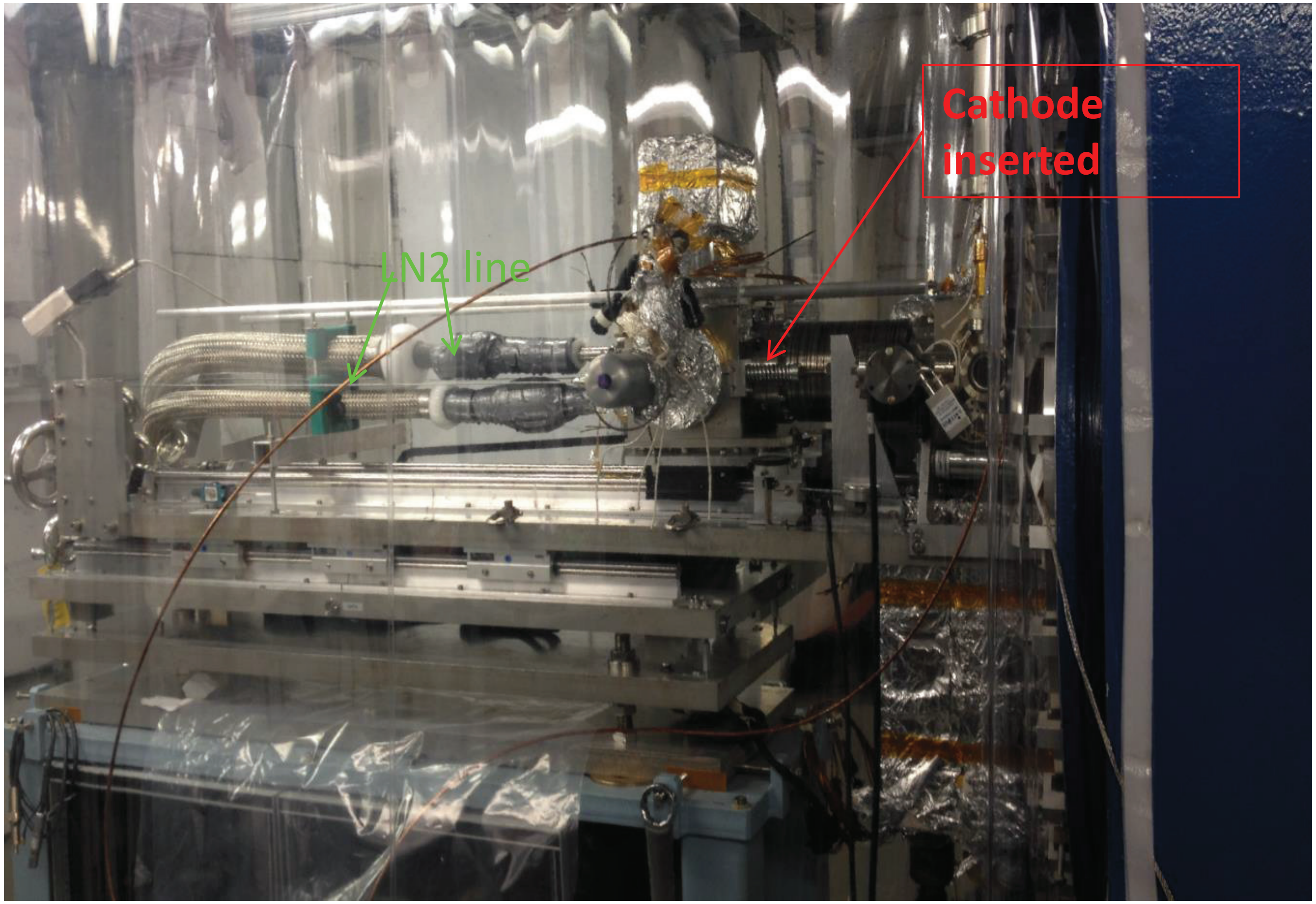
1. Nov. 2012 to Mar. 2013: Commissioned SRF gun cavity w/o cathode stalk inserted.
   →Demonstrated the SRF gun to be able to operate at 2.0 MV CW.
   →The amplitude stability is 2.3e-4 rms and the phase stability is 0.035 deg rms.
2. Aug. to Oct. 2013: Commissioned SRF gun cavity with copper cathode stalk inserted.
   →Found operational parameters: 1.85 MV, 180 ms, 1 Hz - limited by multipacting in the stalk.
   →Design a new multipacting-free cathode stalk with Ta tip for high QE => high current electron beam.
3. May 28 to Jun. 18, 2014: Commissioning with Cs_3Sb photocathode and dark current was observed.
   → Understood the reasons for no photoemission beam and resolved the issues;
   → Demonstrated that the SRF cavity's performance was not degraded by photocathode insertion.
4. Nov. 17, 2014 : First photoemission beam commissioning
   → Observed photoemission beam, measured beam parameters and cathode's QE.
5. March to April, 2014: Multipacting free cathode stalk
   → Demonstrate the multipacting-free cathode stalk is "Truly Mulitpacting-free".
6. June 1 to present, 2015: High charge beam commissioning with new cathode stalk.
   → 0.55 nC per laser pulse

SRF gun commissioning configuration



Cathode stalk insertion

- We developed a cathode stalk insertion procedure from the first try of beam test. During the cathode insertion, vacuum was maintained below 5E-10 Torr.



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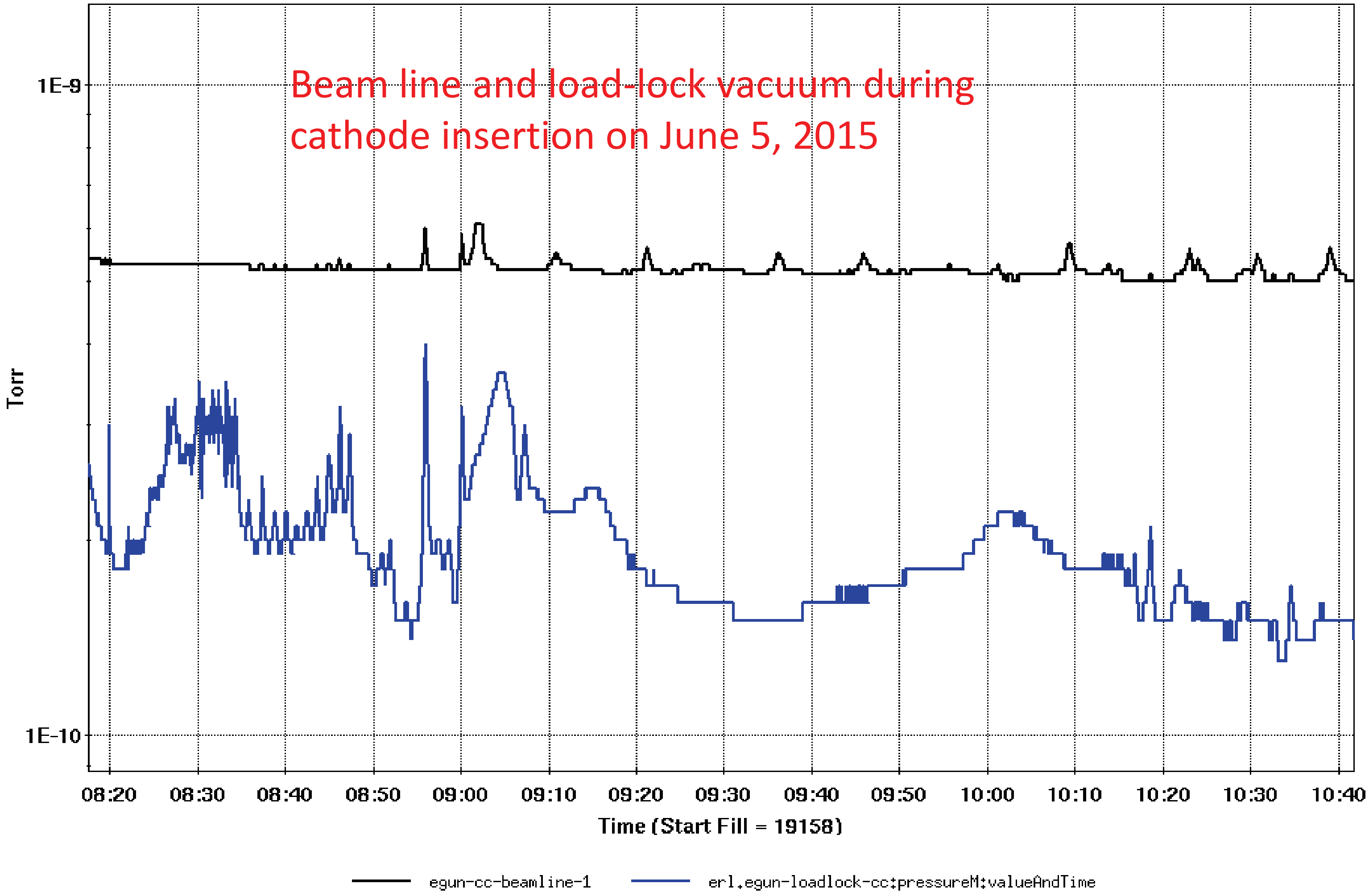
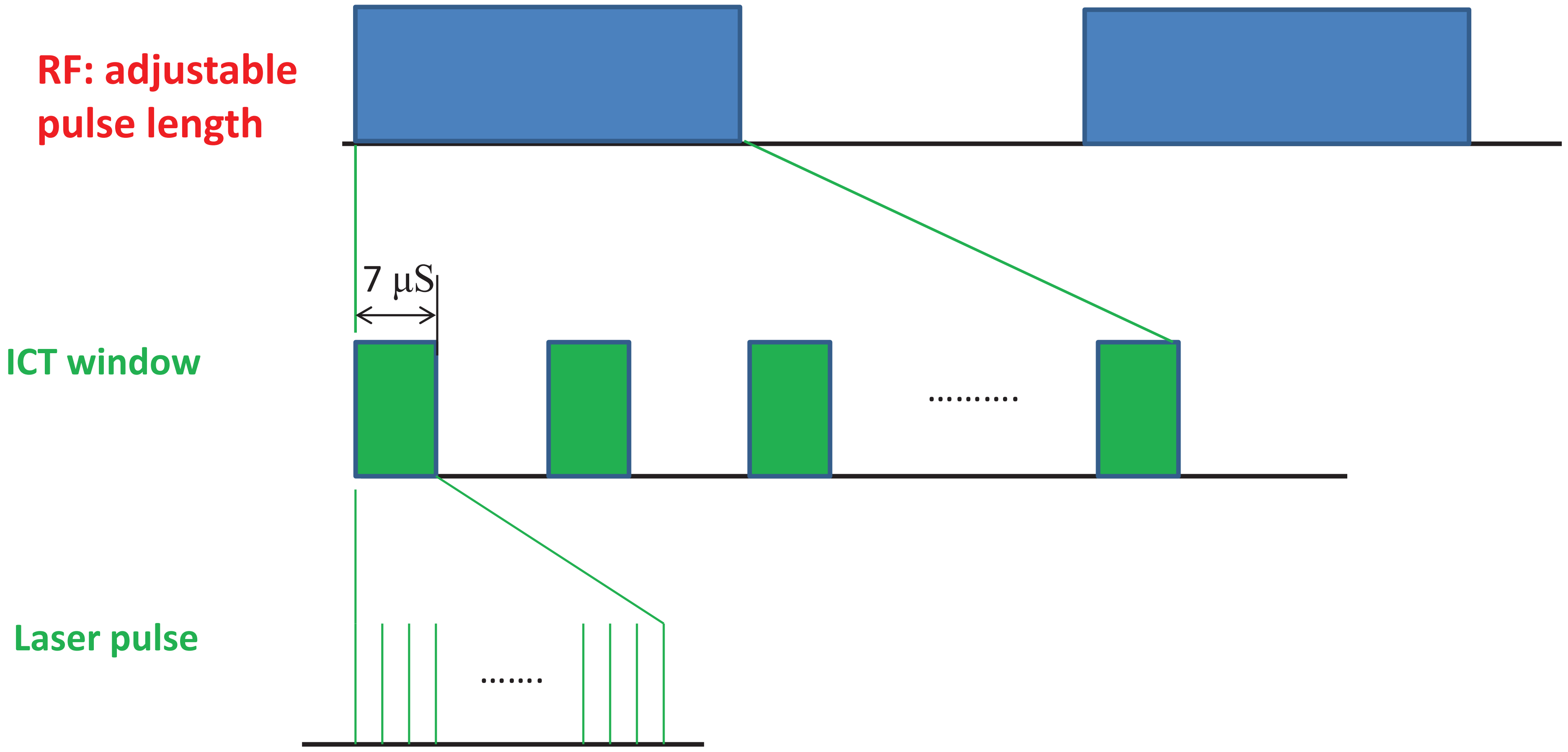


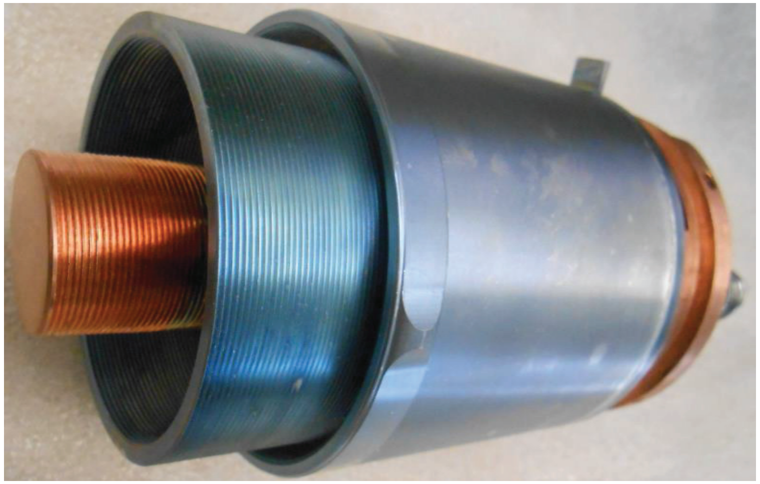
Beam structure



- SRF gun: Pulse to CW 2MV
- Laser: LUMERA: Nd: YVO4, single pulse to 9.38 MHz, up to 6 W at the cathode surface.

First beam commissioning: Nov, 2014

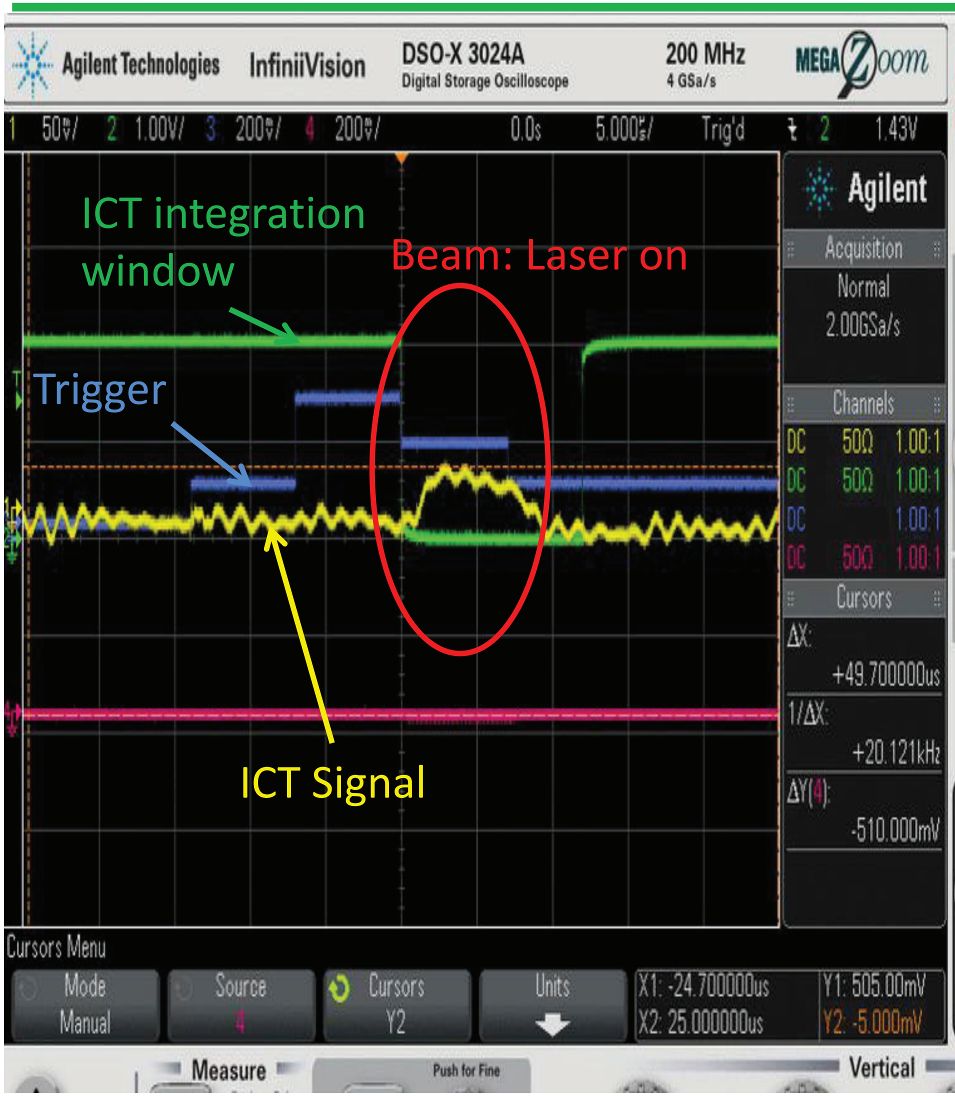
- Cathode stalk: Copper substrate.

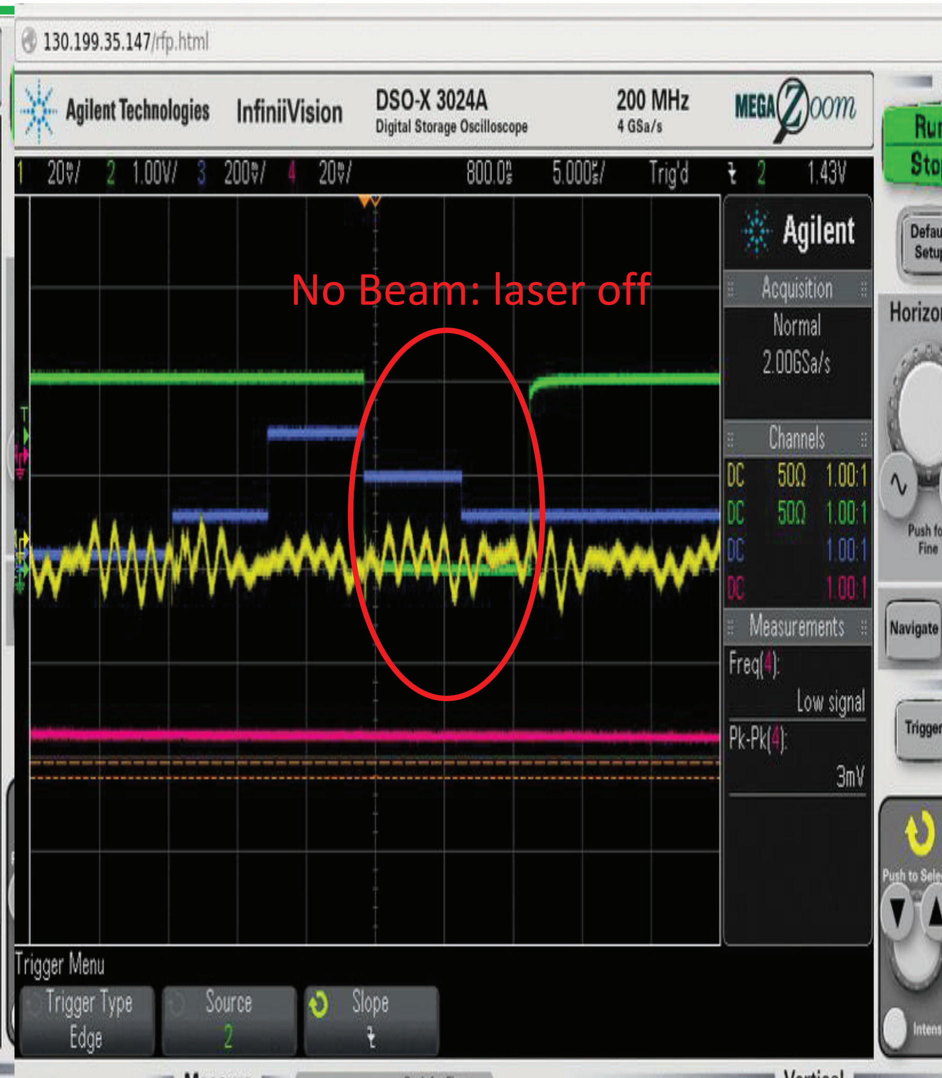


- Cathode: Cs_3Sb photocathode, 2.5E-3 of QE on the fresh cathode and decayed to 3.5E-4 before inserting into the gun for beam test.

- RF: 1.2 MV, in pulse mode.

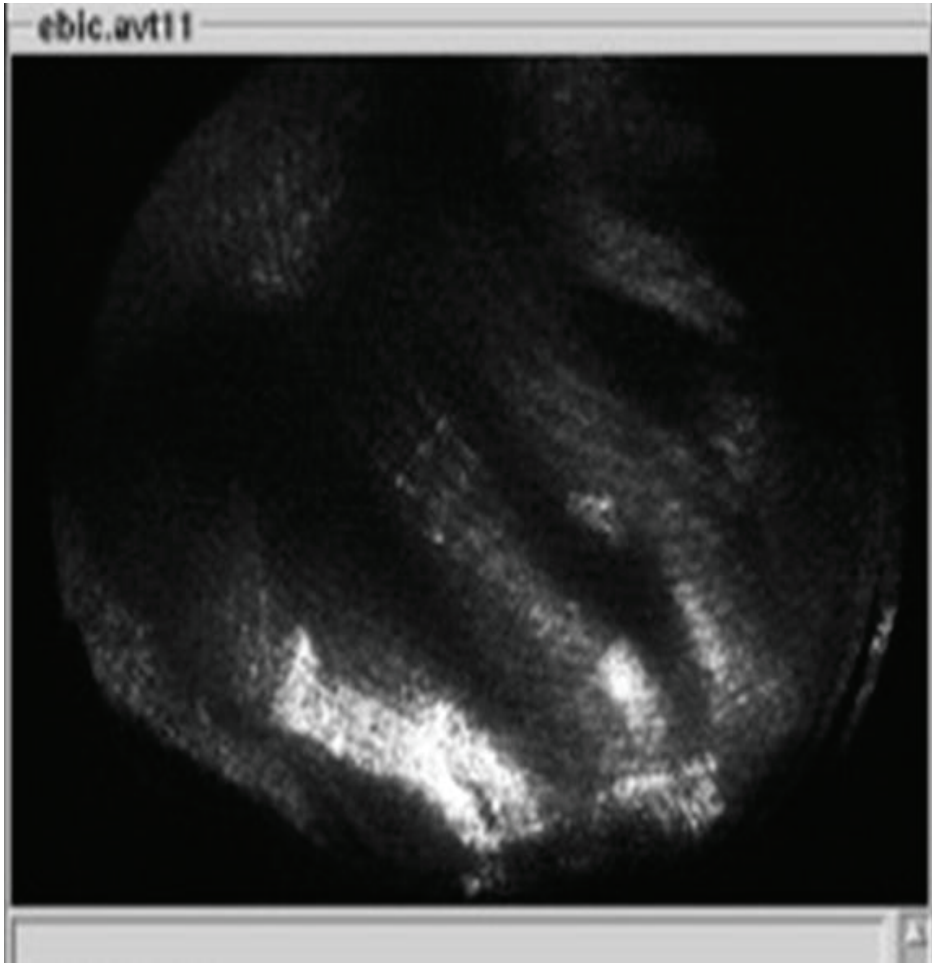
First photoemission beam: observed beam by ICT



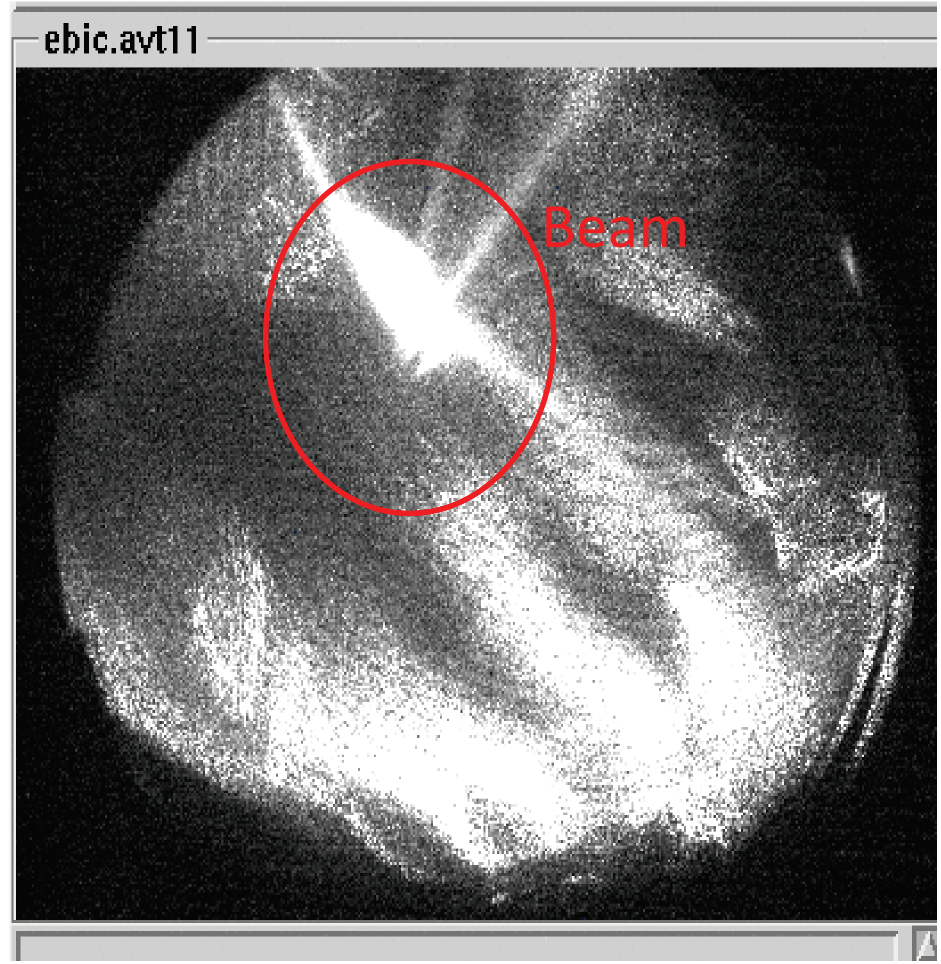


- ➢Gun voltage is 1.2 MV;
- ➢Laser power: 3 Watt average or 0.3 uJ per pulse

First observed beam on Beam profile monitor

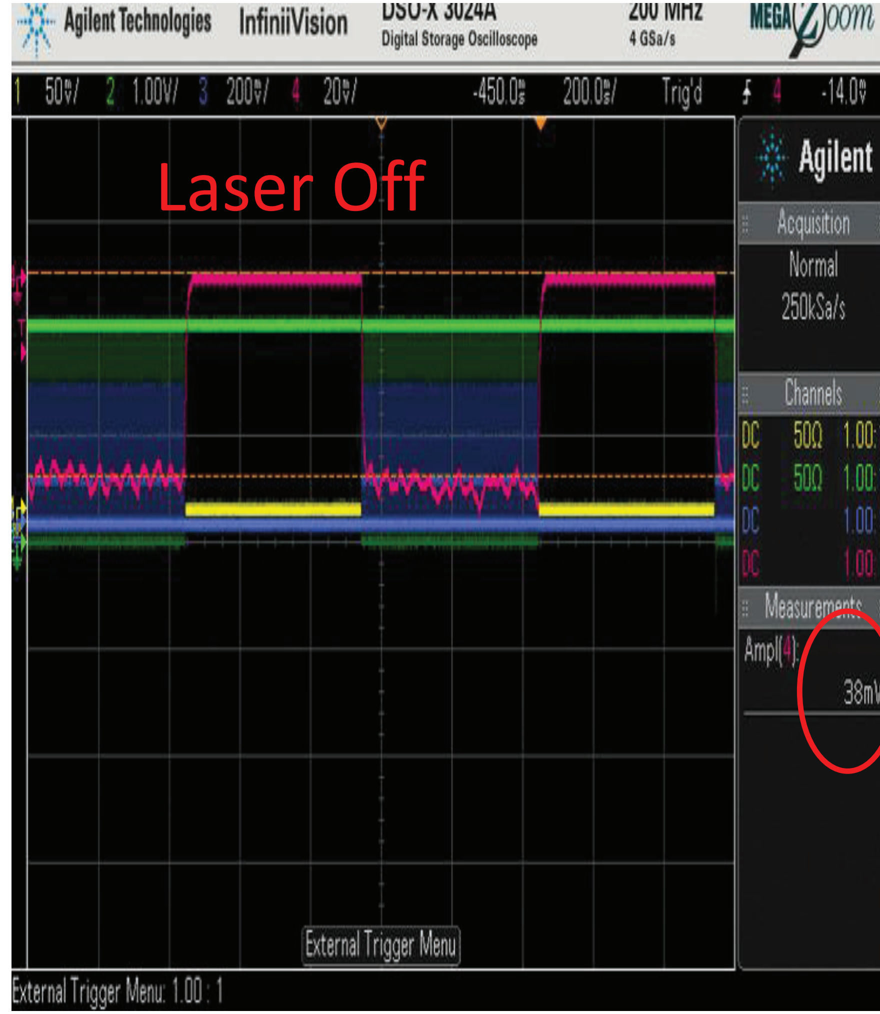


RF off



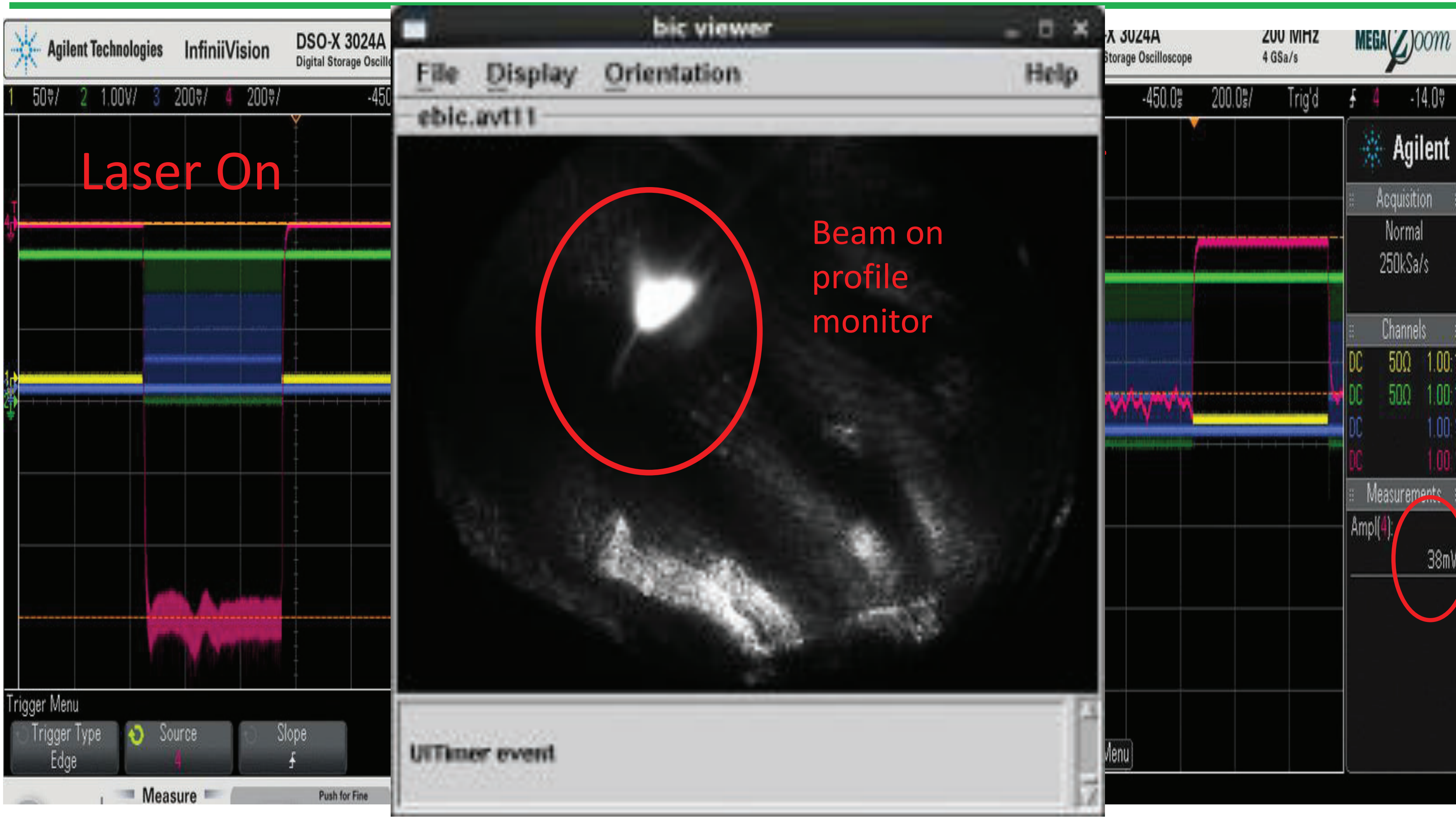
RF on

1 μA Beam



- Parameters: Laser: 6.08 Watt; RF: 1.2 MV, 500 ms;
- Beam: bunch charge: 7.7 pC, photoemission current 1 μA, dark current:38 nA;
- Focusing the beam with RT solenoid.

1 μA Beam



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Design and commissioning of the new cathode stalk

Three reasons for new cathode stalk:

- **Strong multipacting occurred at various field levels in the choke-joint cathode stalk.**

  => Design a multipacting-free cathode stalk for reduction of conditioning time.

  =>CW operation.

- **To replace Cu substrate with Ta.**

  => High QE for high charge/current operation.

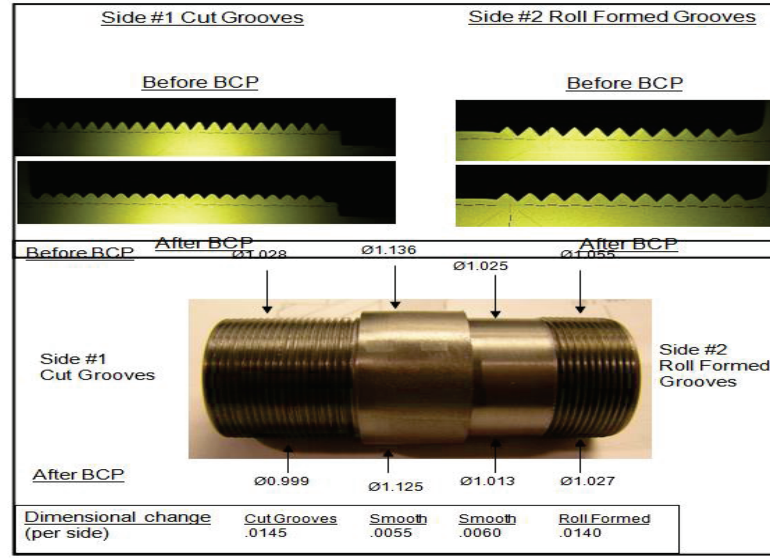
  => Reserve the cathode lifetime.

- **To reduce cathode stalk heat loading**

  => Improve the LN2 cooling.

Multipacting in the Cu cathode stalk

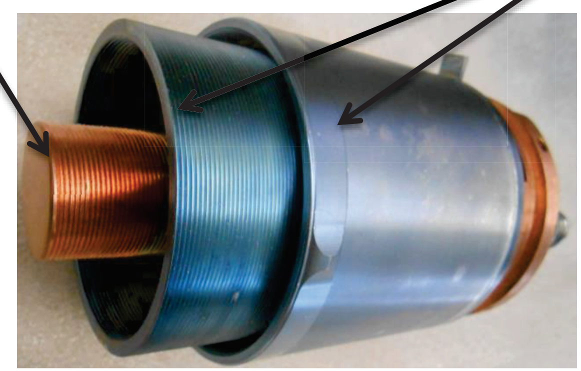
BCP distorted Nb triangular grooves



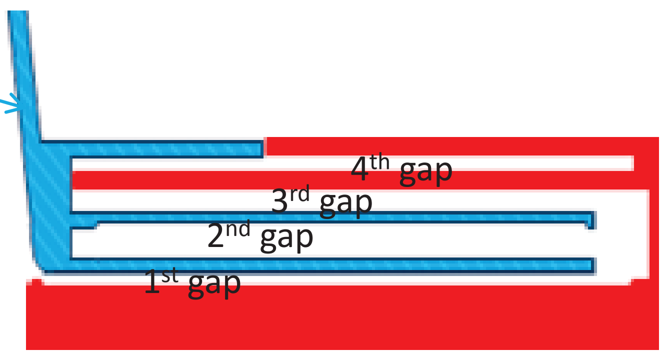
insert

Cu cathode stalk

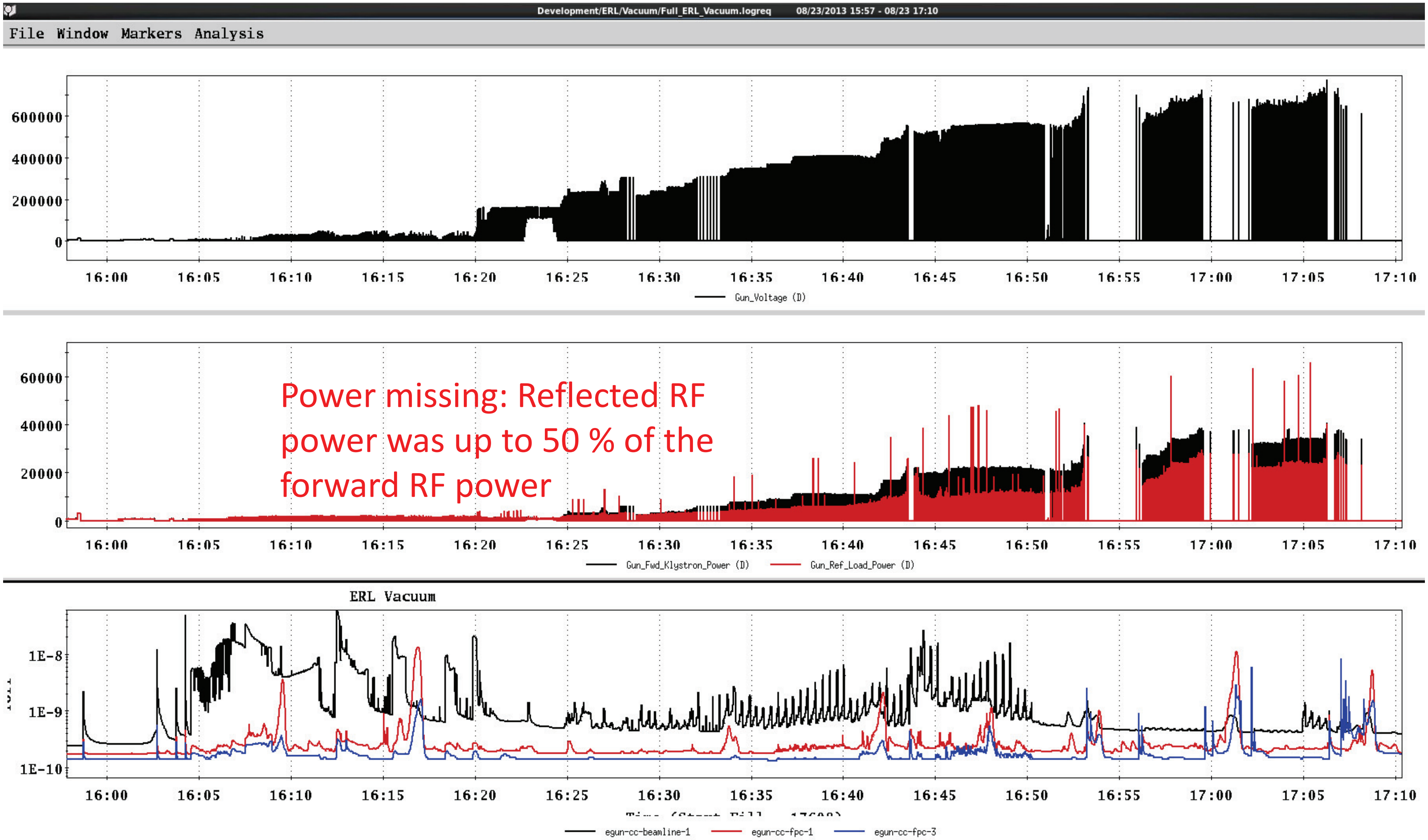
Stainless steel



Nb cavity

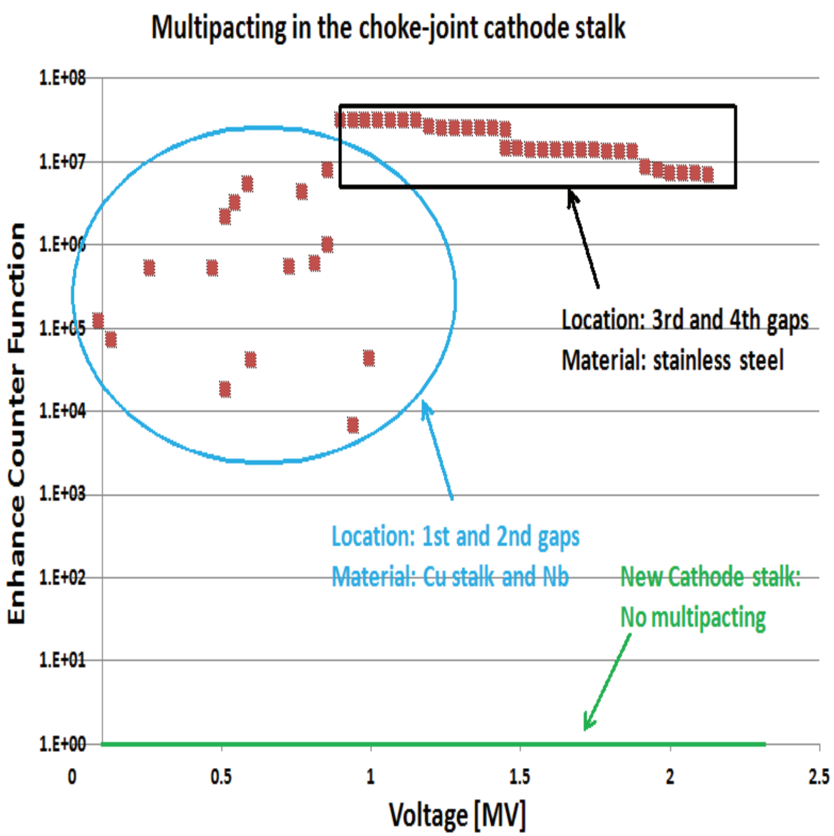


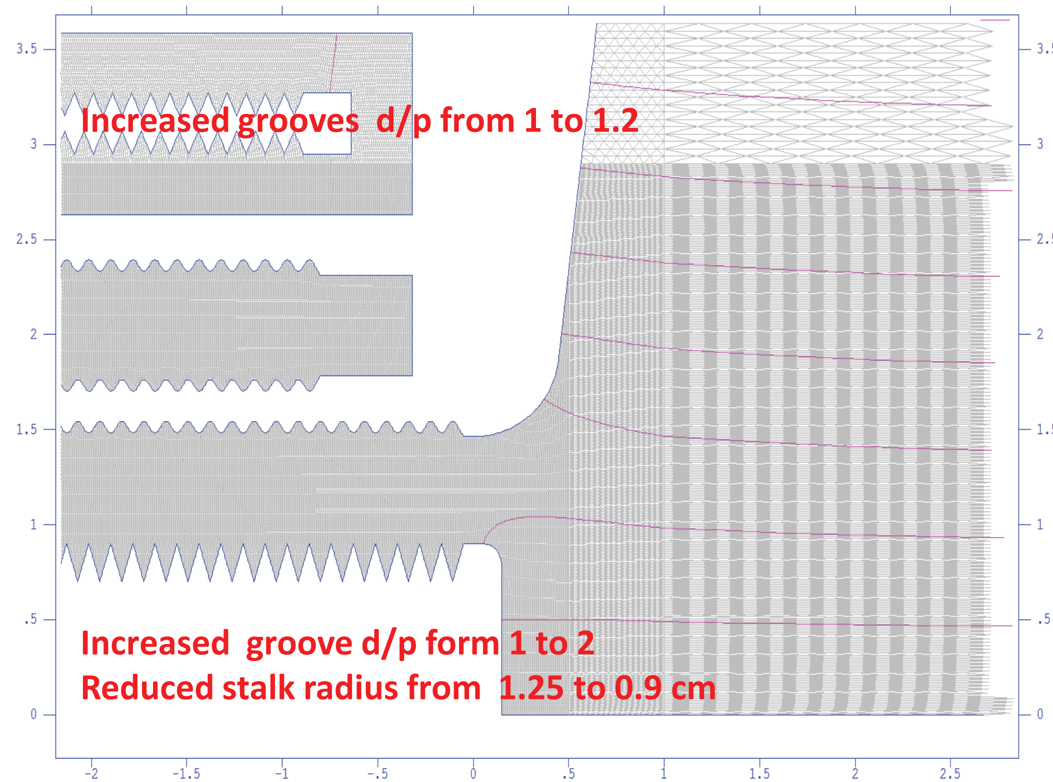
Multipacting in the Cu cathode stalk



- After conditioning for 7 days and average 10 hours per day, the gun reached 1.85 MV with 18% of duty factor.

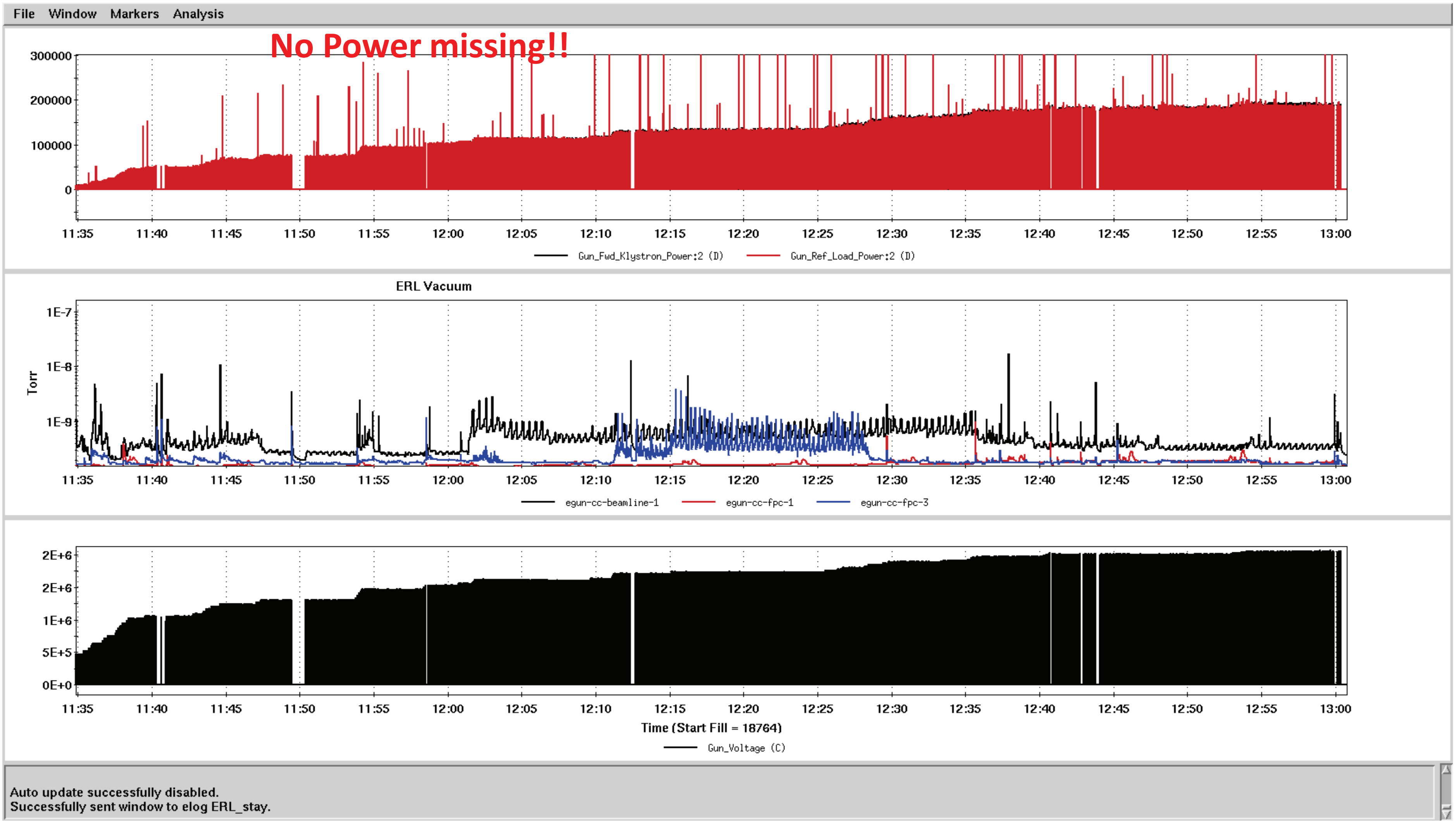
Design of the multipacting-free cathode stalk





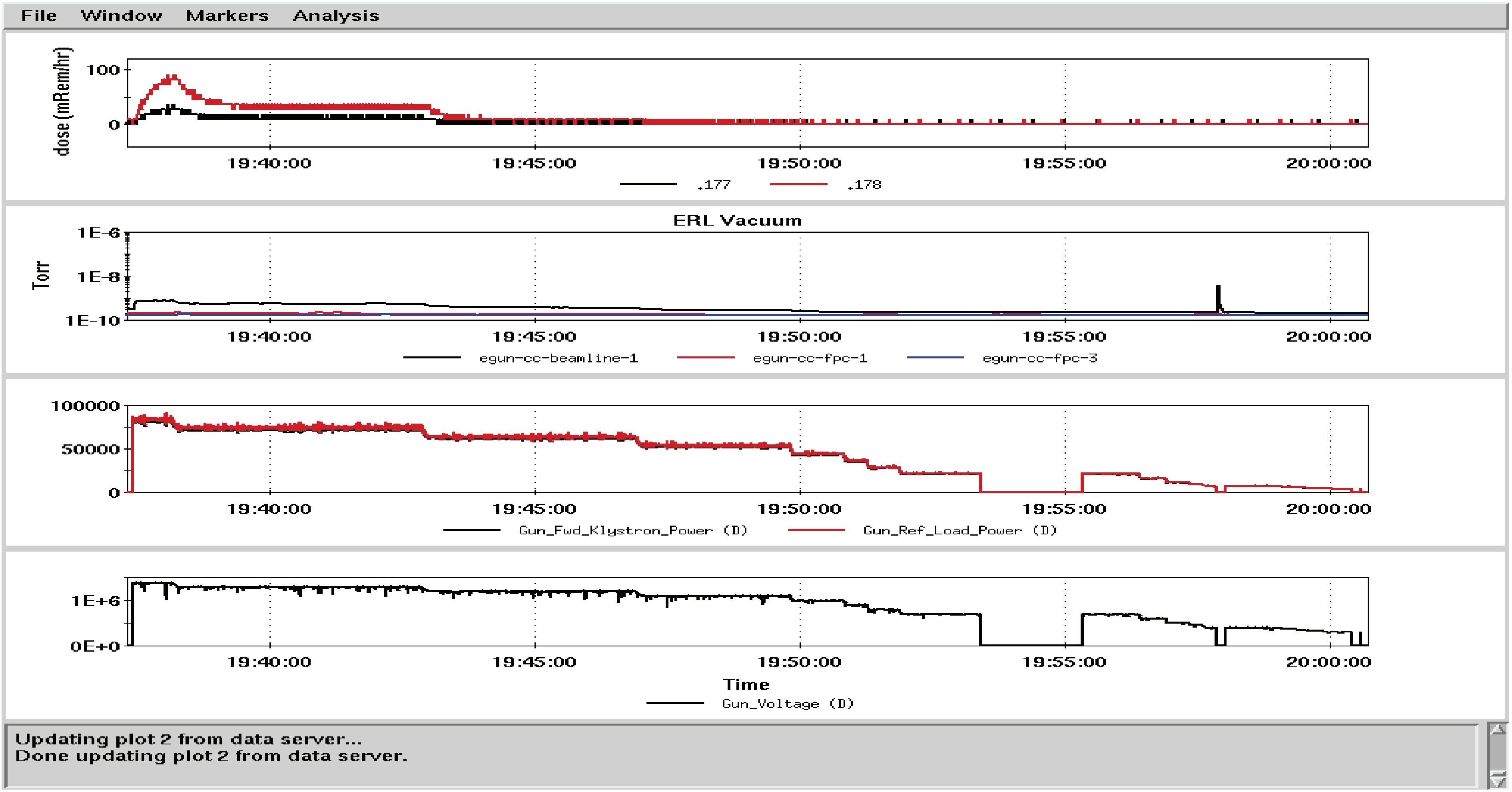
- To suppress the multipacting in the 1st gap, the ratio of the groove's depth/period (d/p) is increased from 1 to 2;
- To suppress the multipacting in the 3rd and 4th gaps, the ratio of the groove's d/p is increased from 1 to 1.2;
- To suppress the multipacting in the 2nd gap (Nb part), the cathode radius is reduced from 1.25 to 0.9 cm, which pushes the field higher.

Multipacting-free cathode stalk test results



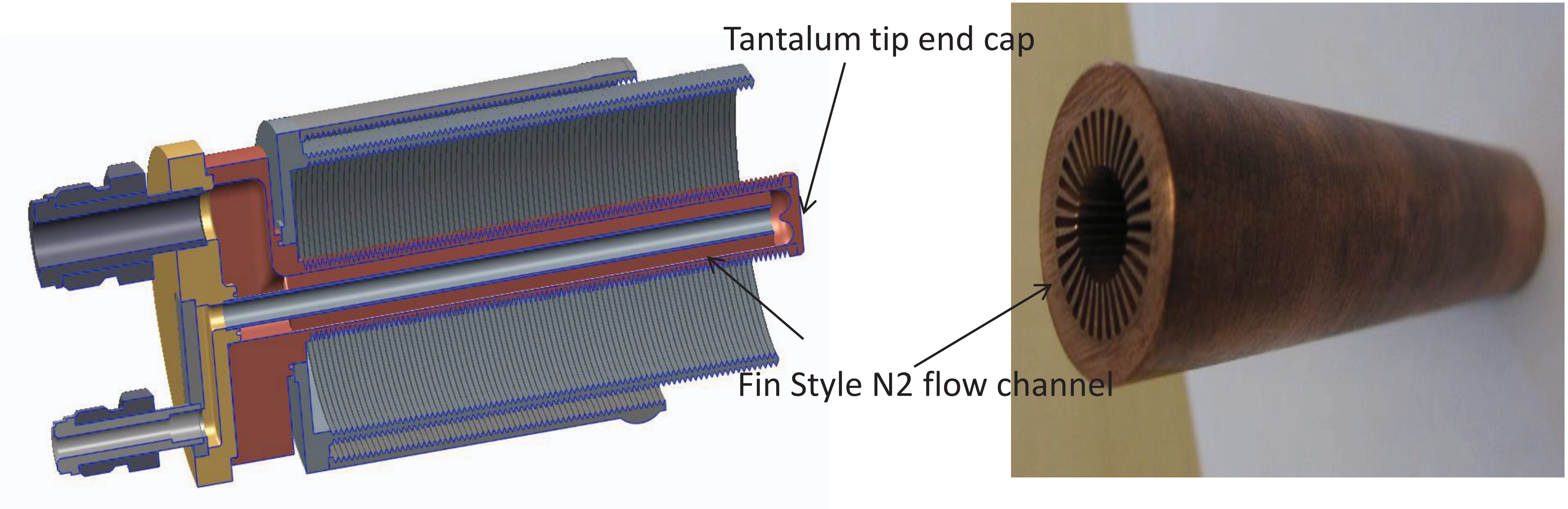
➢Within the first 1.5 hours, the cavity voltage goes up to 2 MV in pulse mode without multipacting.

Multipacting-free cathode stalk test results (CW)

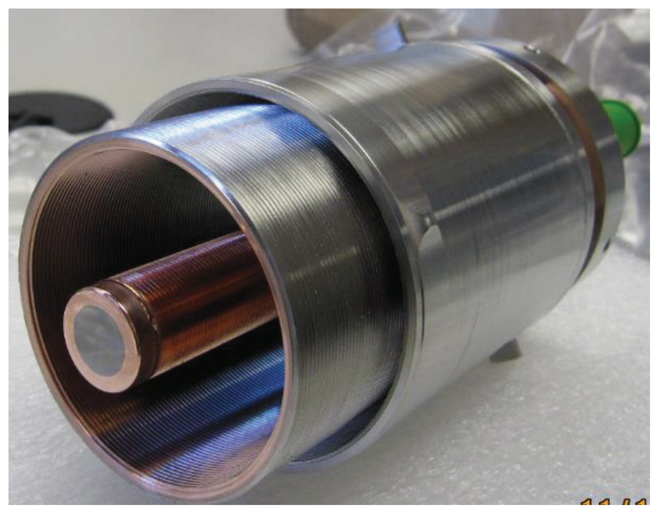


- After less than 10 hrs conditioning, it is stable CW operation from 0.4 MV to 1.3 MV CW.
- Above 1.4 MV, field emission started. We decided to use this cathode stalk for beam test as the field is good enough for initial beam tests.

Thermal analysis and test results of new cathode stalk



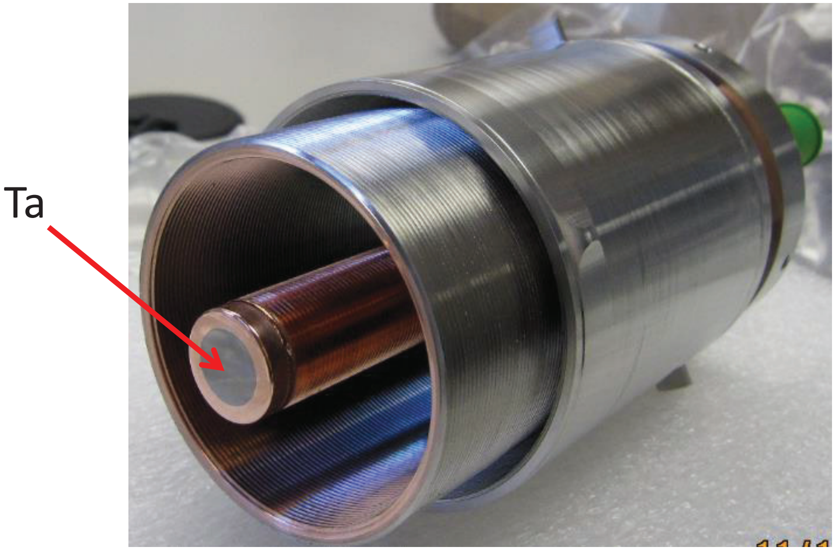
- Heat load to 2K Helium (2 MV): 5.22 W
- Heat Absorbed by Nitrogen gas : 656.3 W, which is smaller than the cooling capacity: 736 W.
- Maximum Temp on cathode Stalk= 83.1 K



- Experiments showed that the heat load with this stalk has negligible static heat load, which compared to 7 Watt of the old stalk.
- Temp monitor shows the LN2 temp.

Recent beam commissioning: June, 2015

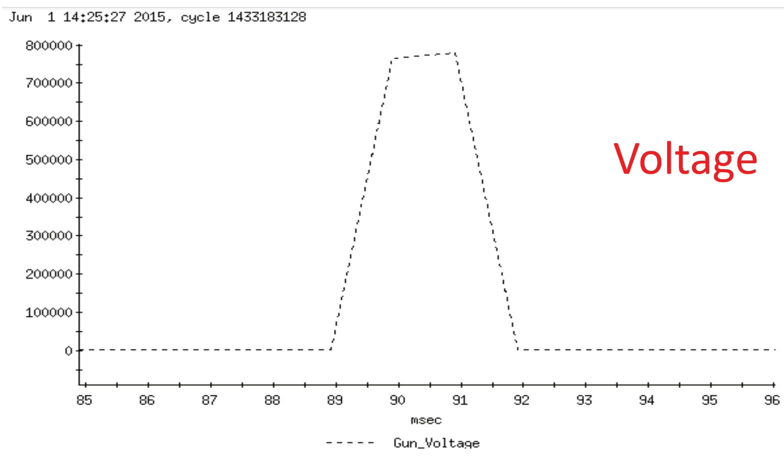
- Cathode stalk: multipacting-free cathode stalk with Ta tip.

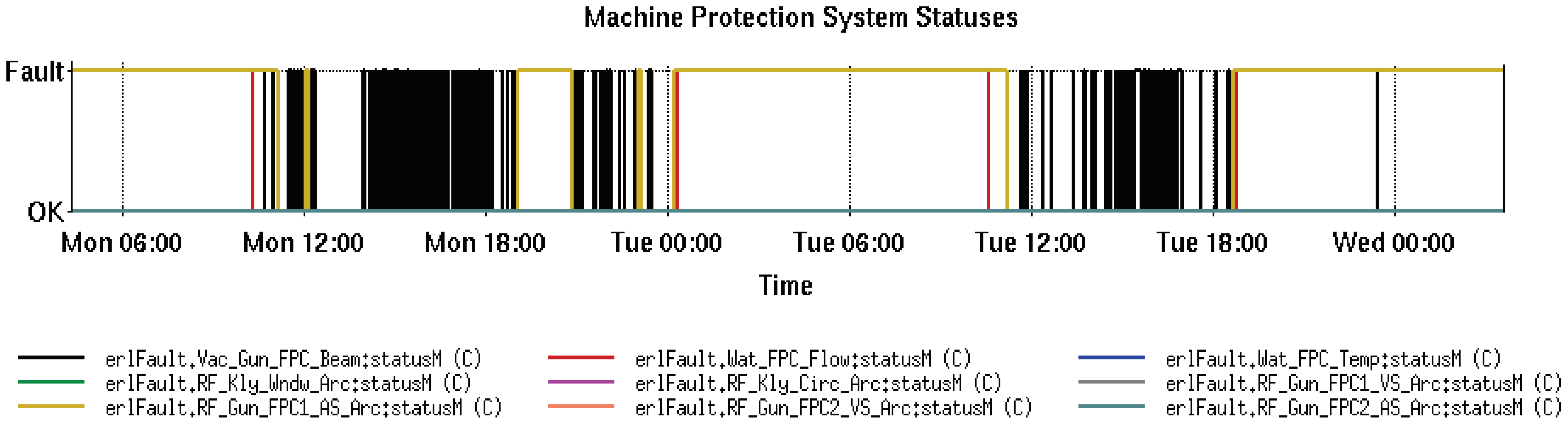


- Cathode: K_2CsSb photocathode, 3.8% of QE on the fresh cathode stalk and stay the same up before inserting into the gun.

- RF: 0.85 MV, pulse mode due to multipacting. The reason for multipacting is because the surface was contaminated during cathode growth. With a better mask, the issue can be resolved.

Gun status



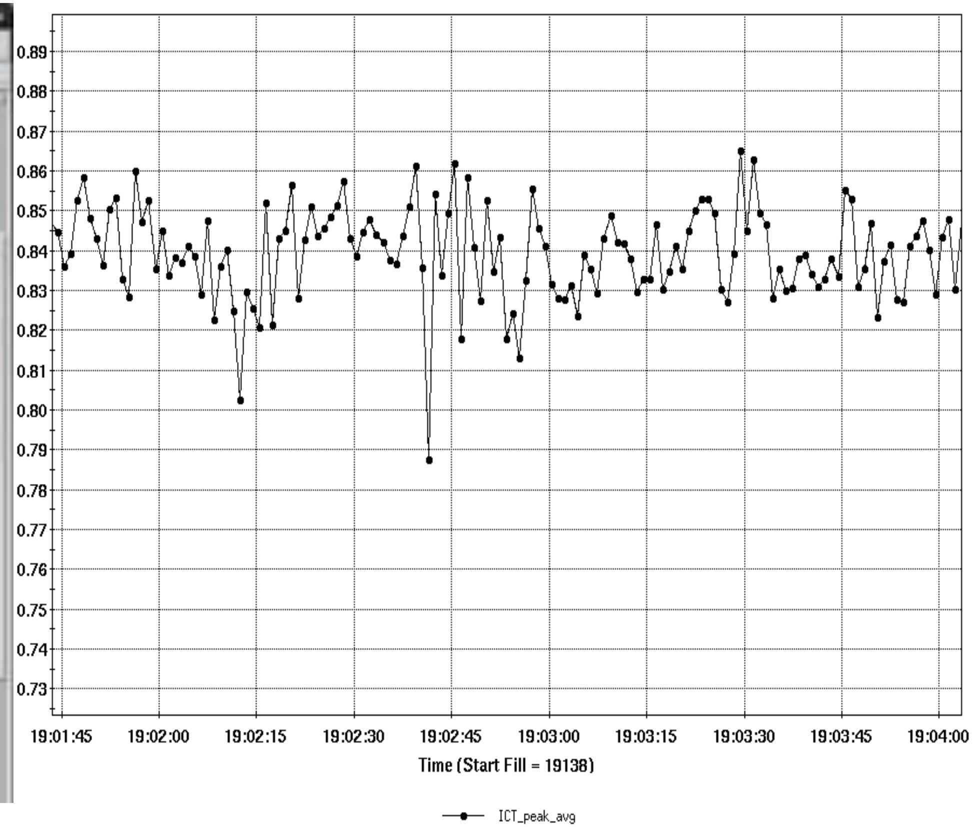


- Vacuum kept tripping RF due to mulitpacting (no radiation observed during the test). The reason for multipacting was understood as stalk contaminating during cathode growth.
- Beam test started with 3ms, 1Hz RF pulse. After 2 hours conditioning, it was stable at 10 ms @ 0.85 MV, and 3 ms @1.1 MV.

Beams

Faraday Cup

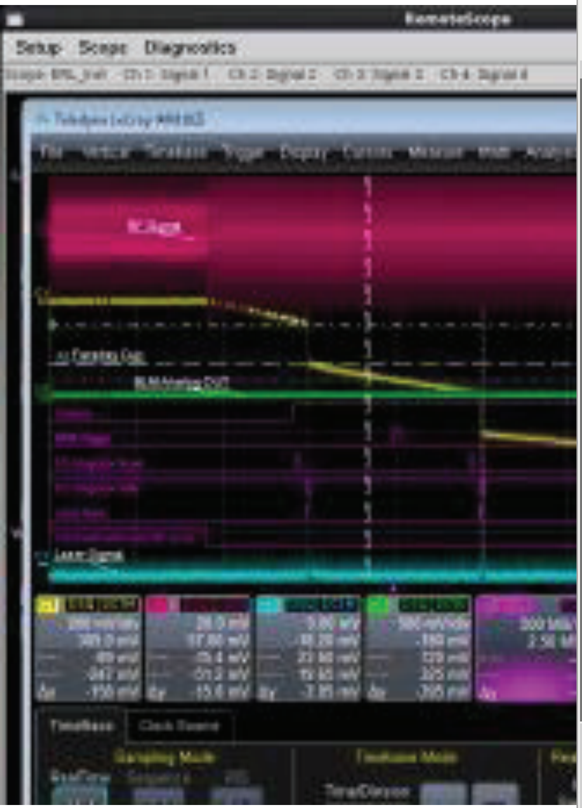
ICT signal in log

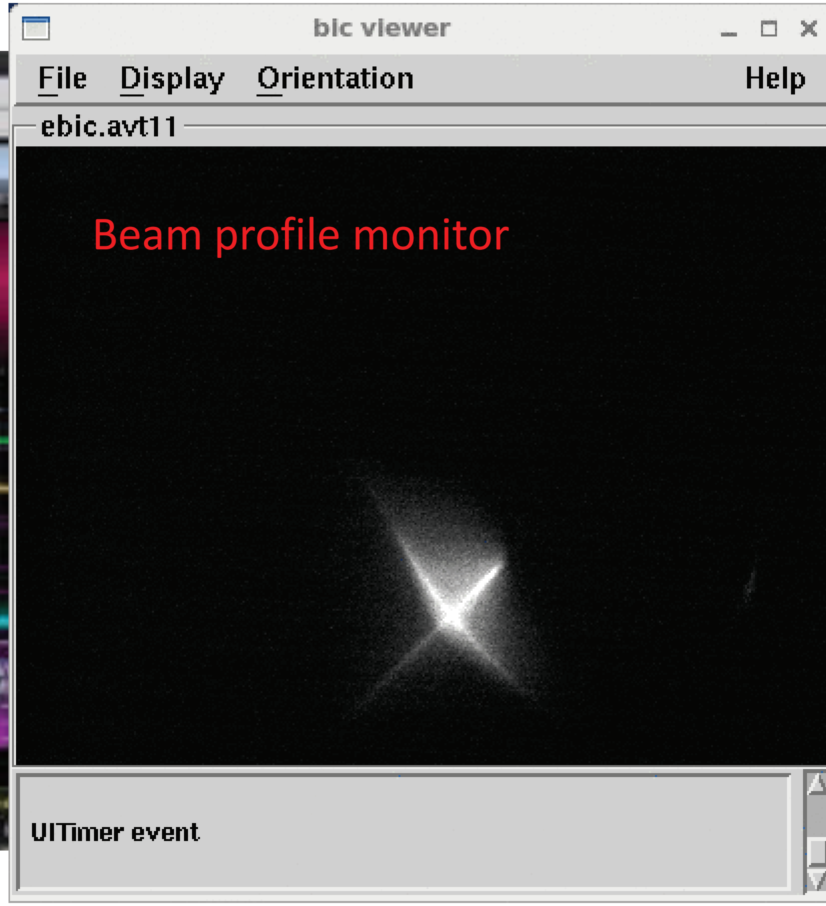


- QE was measured as 0.9% at low charge (20 pC), and 0.24 % at high charge (400 nC) due to space charge.
- There was not QE degradation, as it was back to 0.9 % at low charge after 3-day tests.

Beams

Faraday Cup





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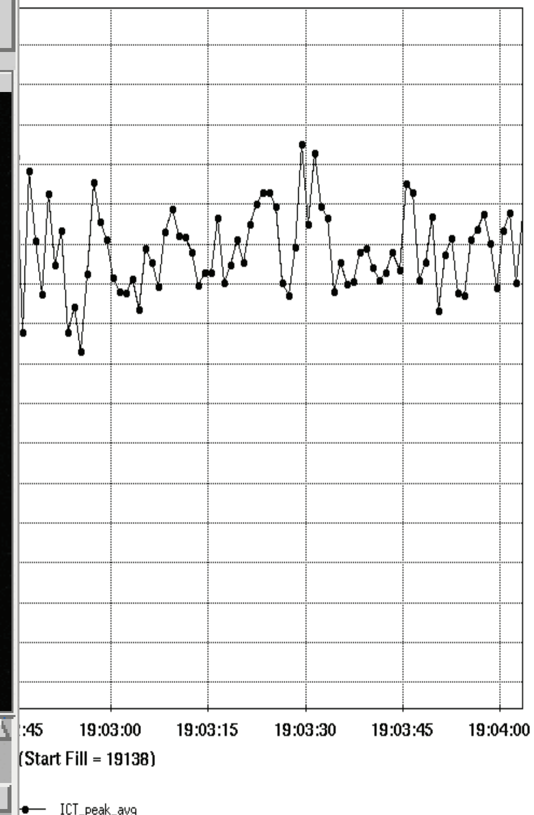

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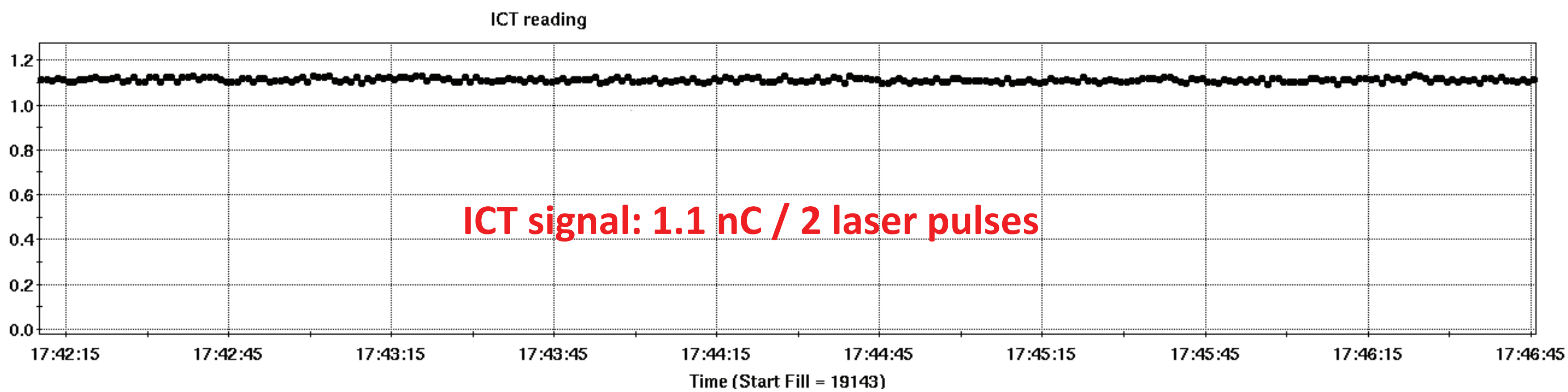
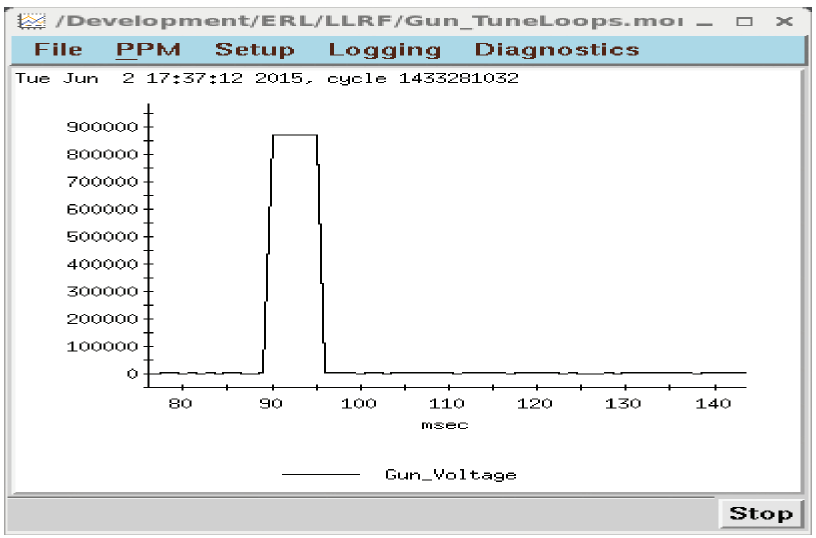
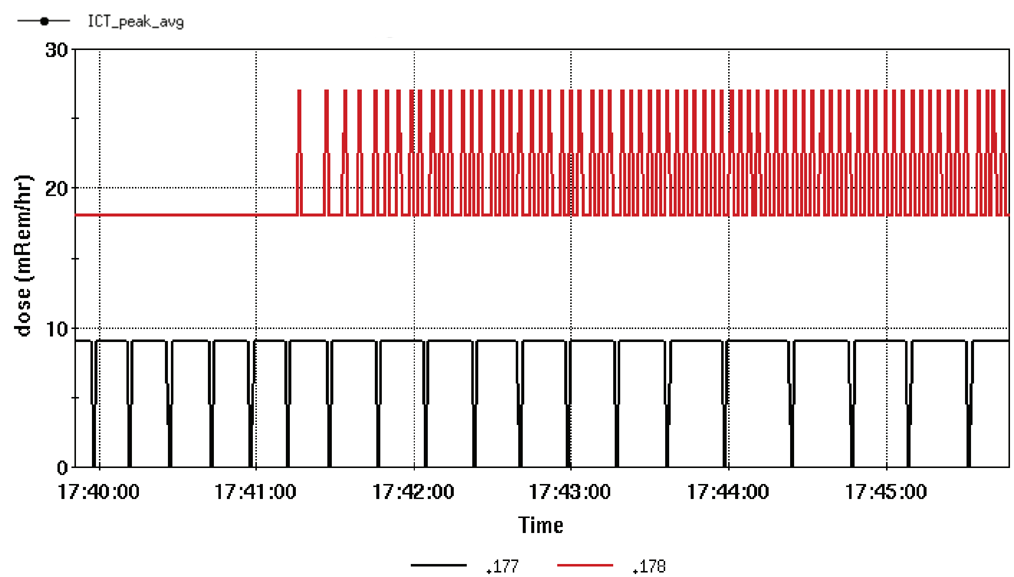
Highest bunch charge







- Laser: 2 pulses in a ICT window, maximum laser power 3.6 W.
- Bunch charge: 1.1 nC measure in ICT or 0.55 nC per laser pulse.

Summary

- SRF gun has made great progress in the past two years, with all the subsystems tested, installed and functioning well.
- The SRF gun cavity reached CW 2 MV without cathode stalk insertion.
- Mulitpacting occurred in the copper cathode stalk. A multipacting-free cathode stalk with Ta tip was designed, fabricated and tested as a truly multipacting-free stalk. With this stalk, we can expect for a high charge, high current SRF gun.
- 1 μA photoemission beam (7.7 pC/bunch, 1.25 MeV) was measured during the first beam commissioning in Nov, 2014.
- The highest bunch charge reached 0.55 nC per bunch (0.85 MeV) in June 2, 2015.
- There is no sign of cavity degradation due to operating with photo-cathode.

ERL teamwork (uncompleted list)

BNL:

Zeynep Altinbas, Dana Beavis, Sergey Belomestnykh, Ilan Ben-Zvi, Paul Bergh, Suresh Deonarine, Jesse Fite, David Gassner, Lee Hammons, Ramesh C. Gupta, Harald Hahn, Chung Ho, James Jamilkowski, Stephen Jao, Prerana Kankiya, Dmitry Kayran, Robert Kellermann, Nikolaos Laloudakis, Robert Lambiase, Edward Lessard, Vladimir Litvinenko, George Mahler, Leonard Masi, Gary McIntyre, Wuzheng Meng, Robert Michnoff, Toby Allen Miller, John Morris, Igor Pinayev, David Phillips, Vadim Ptitsyn, Triveni Rao, Pablo Rosas, Thomas Roser, Scott Seberg, Thomas Seda, Brian Sheehy, Loralie Smart, Kevin Smith, Victor Soria,, Andrew Steszyn, Roberto Than, Erdong Wang, Andreas Warkentien, Daniel Weiss, Huamu Xie, Alex Zaltsman.

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