Multialkali Cathode for High Current Electron Injector- Fabrication, Installation and Testing

T. Rao, E. Wang. Kayran. I. Pinayev,

Brookhaven National Laboratory

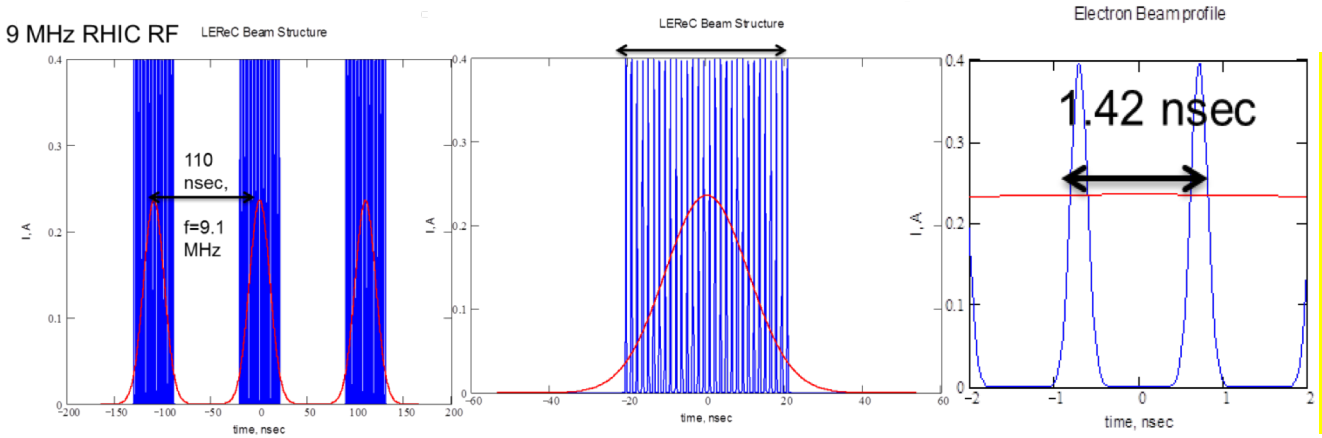
On behalf of CeC and LEReC groups

Outline of the Talk

- Introduction
- K-Cs-Sb cathode for CeC
  - Cathode preparation
  - Transfer to CeC
  - Performance in SRF gun
- Na-K-Sb cathode for LEReC
  - Sequential evaporation
    - Fabrication
    - Performance
  - Co-evaporation
    - Cathode preparation
    - Transfer to LEReC
    - Performance in DC gun

e beam Goals for CeC and LEReC

Parameters for LEReC

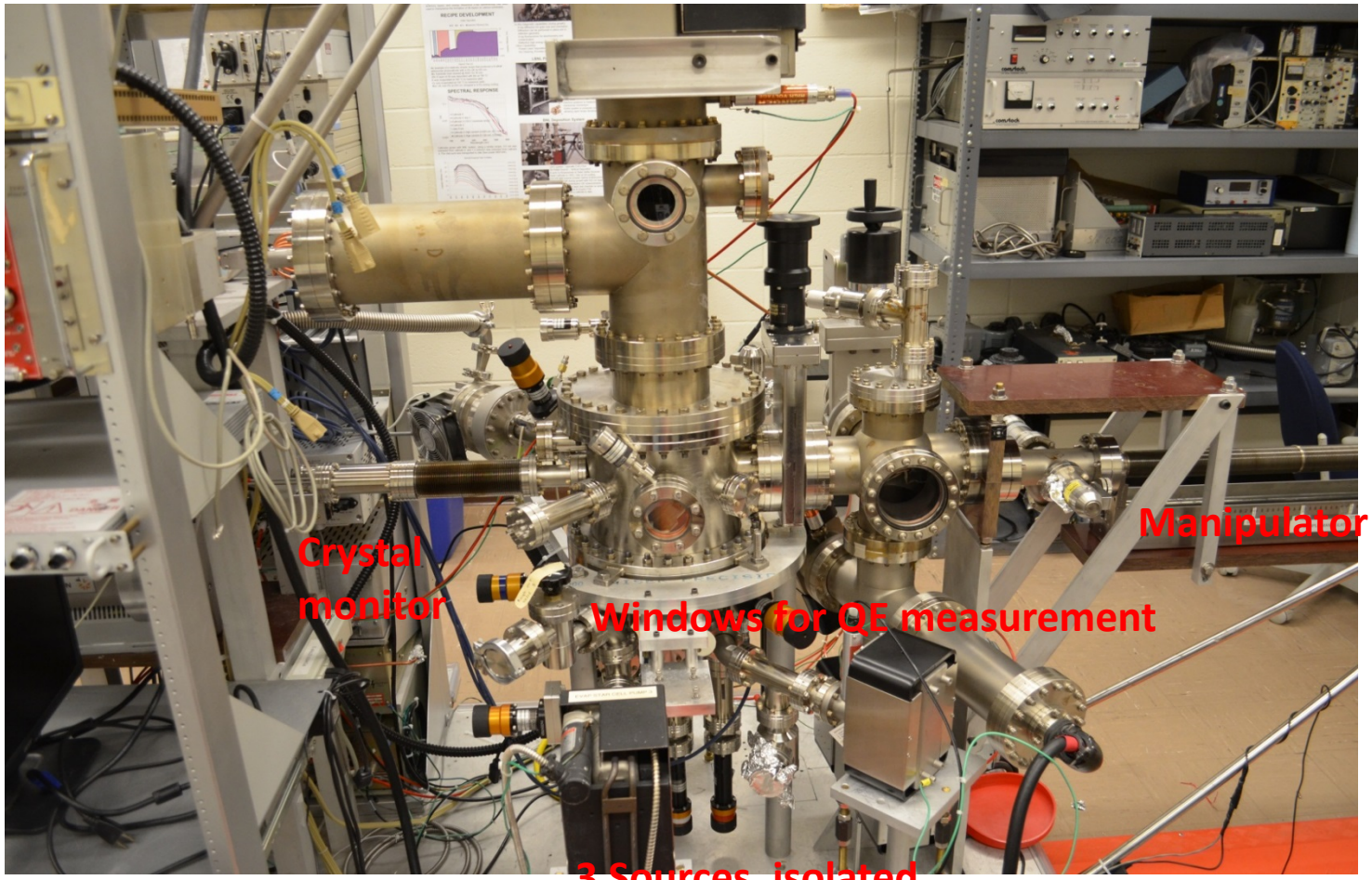


Charge/bunch: 100 pC
Pulse duration: ~ 100 ps RMS
Average current for 2 MeV beam: 30 mA
Average current for 5 MeV beam: 50 mA

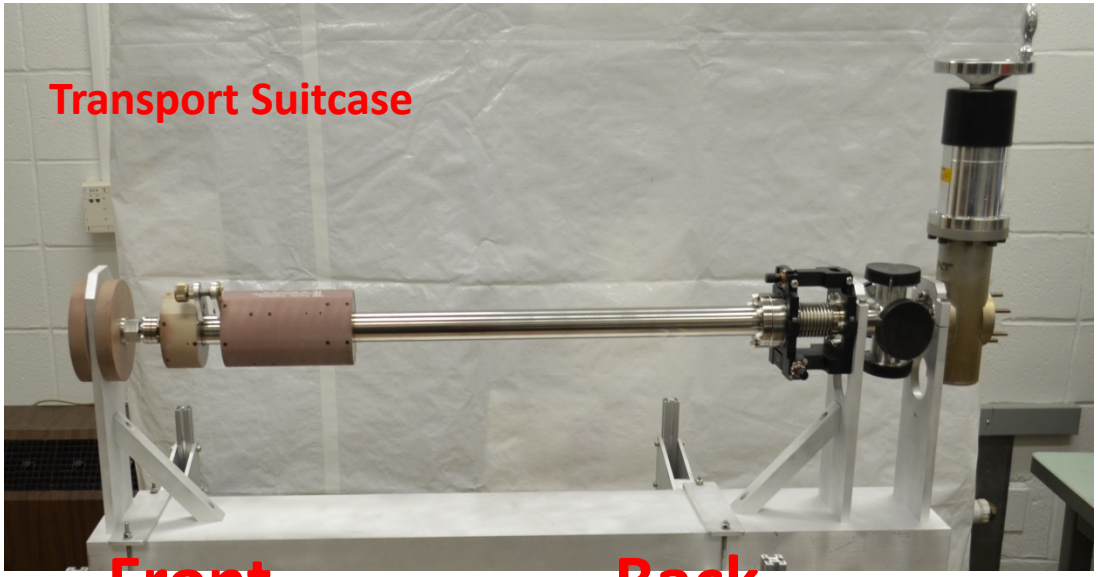
Parameters for CeC	
Charge per bunch, nC	1.4
Initial bunch full length, ps	100-500
Initial radius, mm	2.5
Bunch rep-rate, kHz	78.2
Average beam current, mA	0.3
Injection kinetic energy, MeV	2.0
Maximum beam energy, MeV	21.8

Fabrication Chamber for CeC cathode K-Cs-Sb cathode

Main Chamber Base pressure ~ 1x 10 $^{-11}$ Torr, dominant residual gas H_2

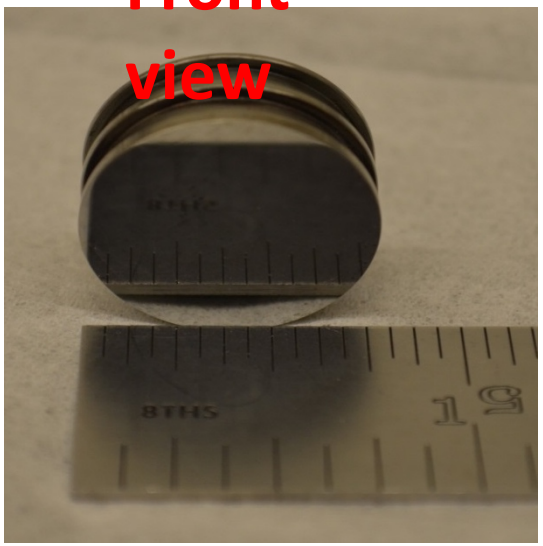


Transport Suitcase



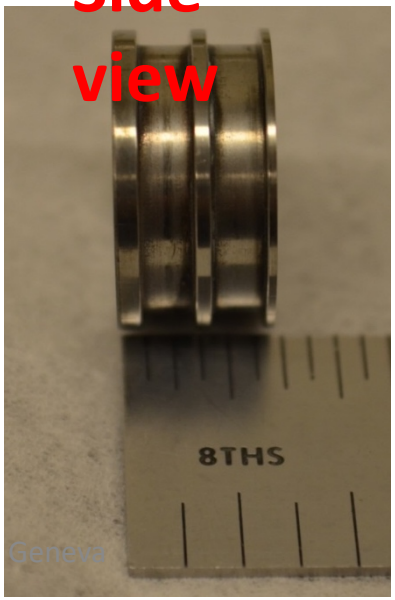
Moly Puck, polished to optical finish
Rinsed in Hexane, cleaned in ultrasonic bath

Front view

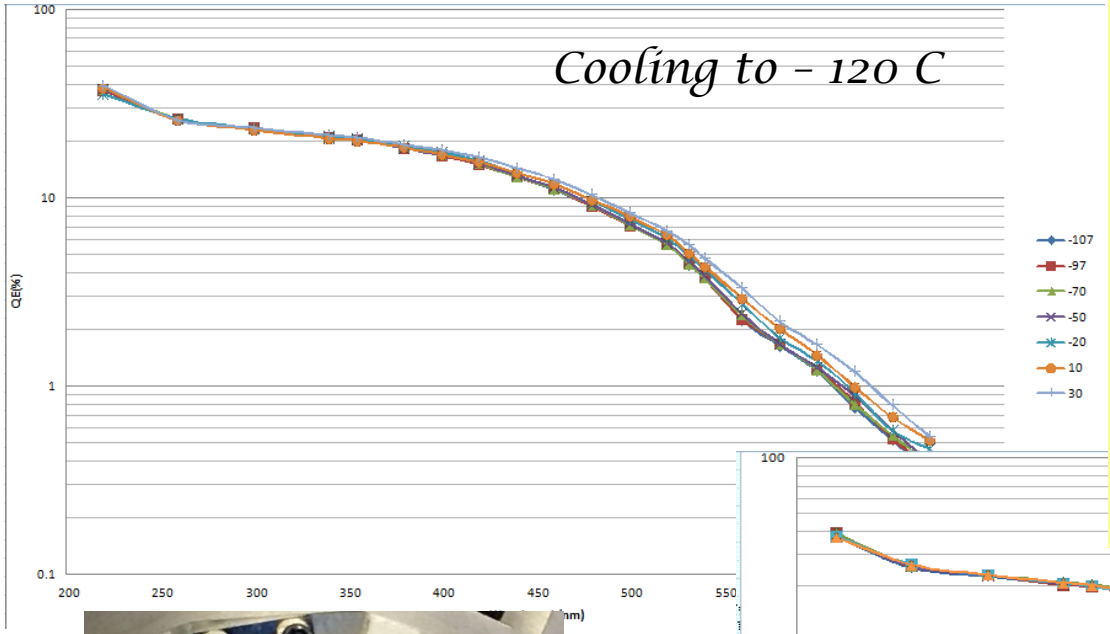


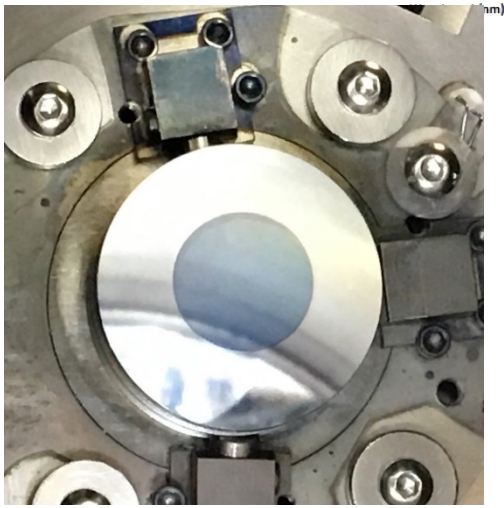
Back view

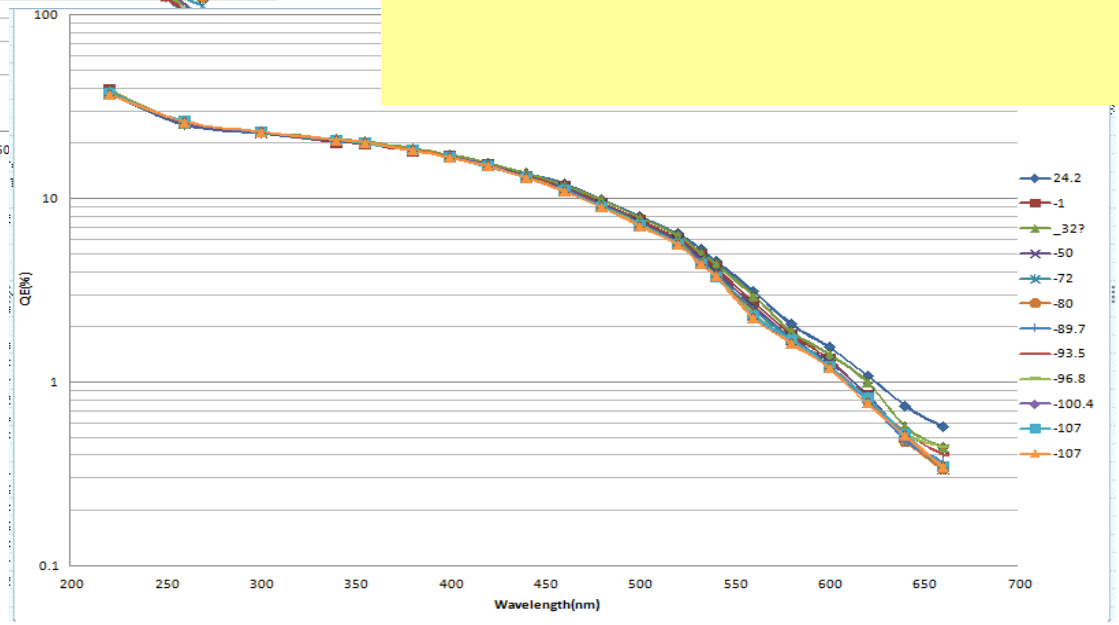
Side view



Cathode Performance



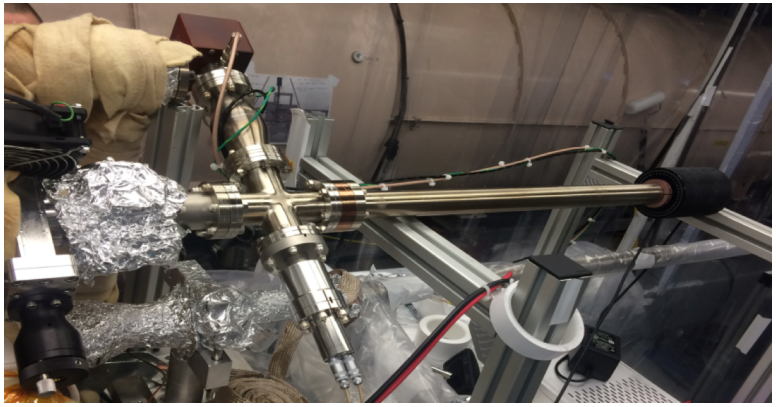




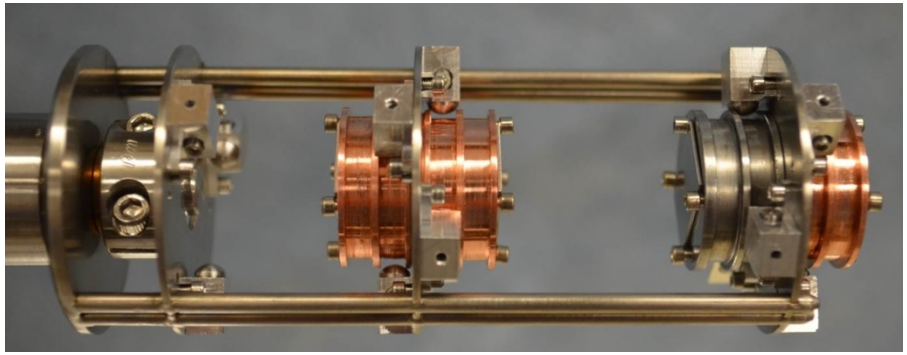
- Procedure
  - 100 Å of Sb with the substrate @ ~ 100 °C
  - 200 Å of K with substrate @ 125 °C
  - Evaporate Cs @ 130 °C for max. QE

Cathode Transfer

- The cathode is prepared in a dedicated cathode preparation system in Instrumentation Div..
- The cathode is moved into transport cart which has low-10^{-10} torr scale vacuum.
- Transport cart moved to RHIC tunnel in this vacuum
- Cart connected to the SRF gun in a class-100 clean enclosure.
- The load lock section is baked about 2 days and reach 10^{-9} torr scale Vacuum.
- QE evolution monitored inside the transport cart during bake. We make sure that the cathode still has a good QE before moving it into the SRF gun.

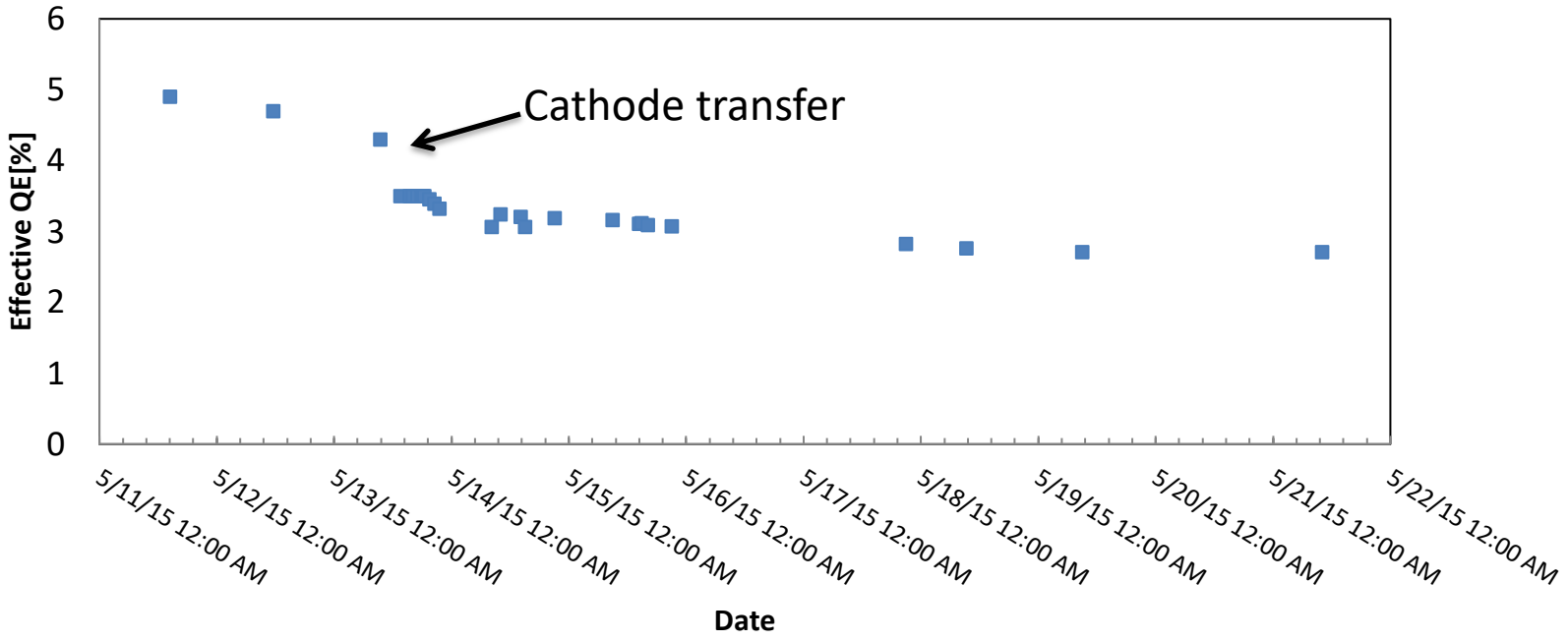


112 MHz gun cathode transferring chamber



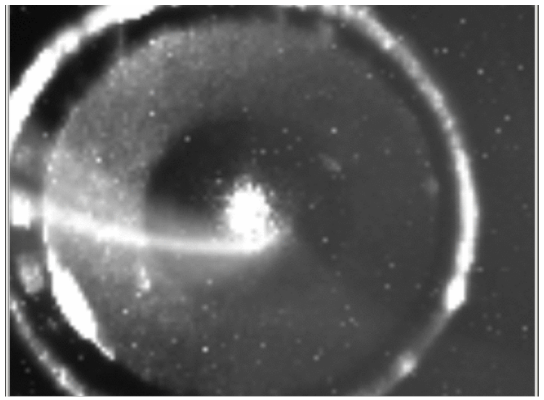
cathode stack

Photocathode transfer

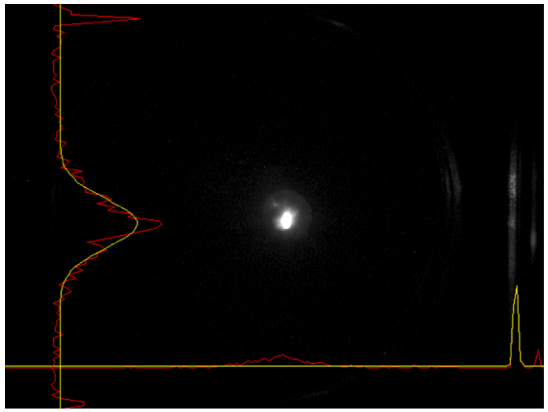


- In garage, the QE dropped about 2% in transferring due to load-lock bake. Then the QE is almost stabilized with the lifetime more than months.

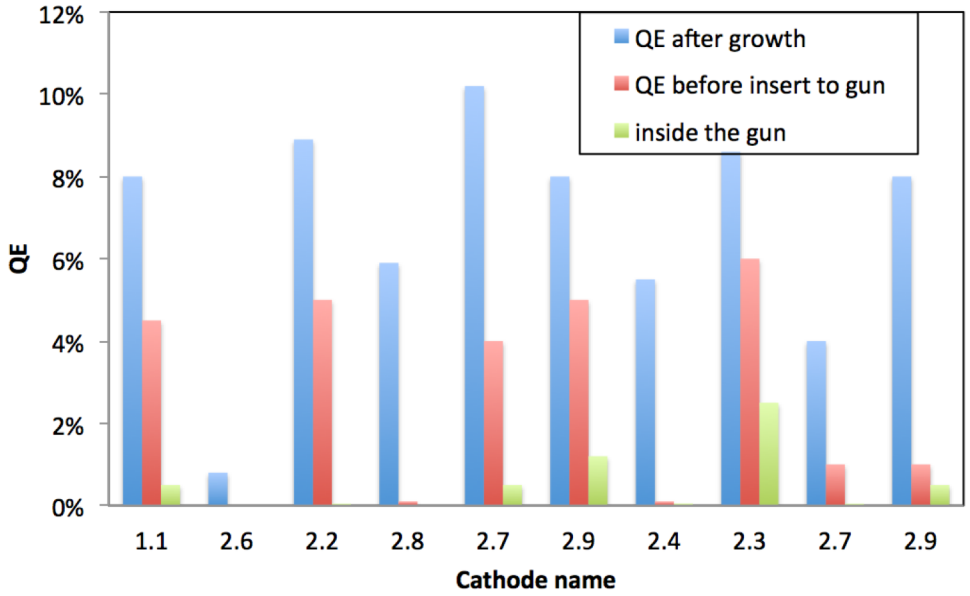
Insert cathode into gun



Laser on the cathode

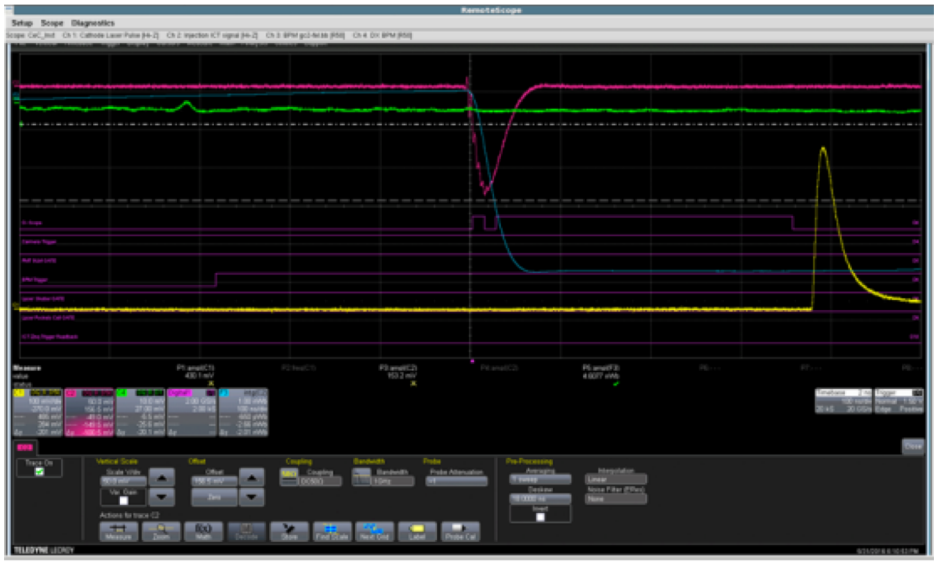


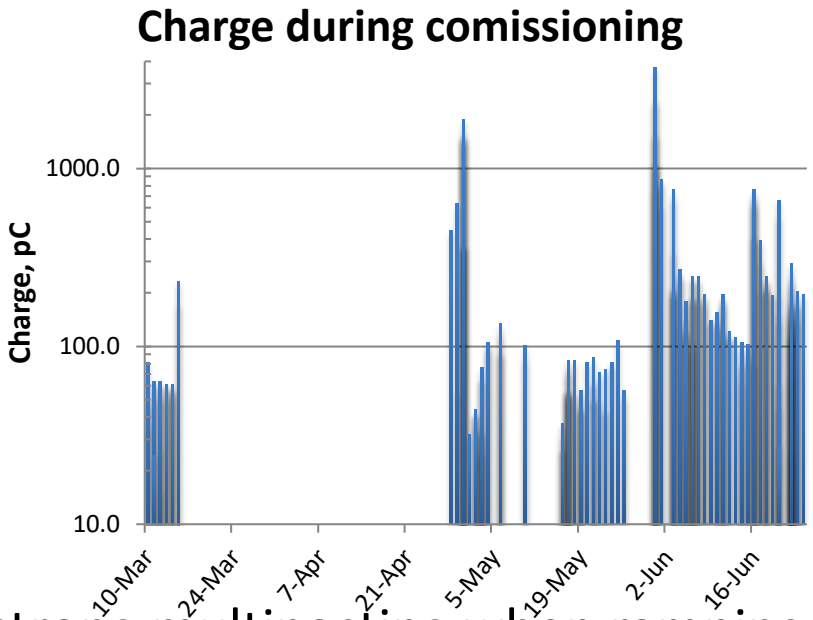
Beam spot on YAG



- Total of ten cathodes delivered in to 112 MHz gun from 2015 to 2016.
- Seven cathodes survived during cathode transfer from preparation chamber to RHIC tunnel and keeping in storage chamber for a week.
- Three cathodes lost QE due to either power outage to ion pump or garage misassembly.

Start the gun with cathode

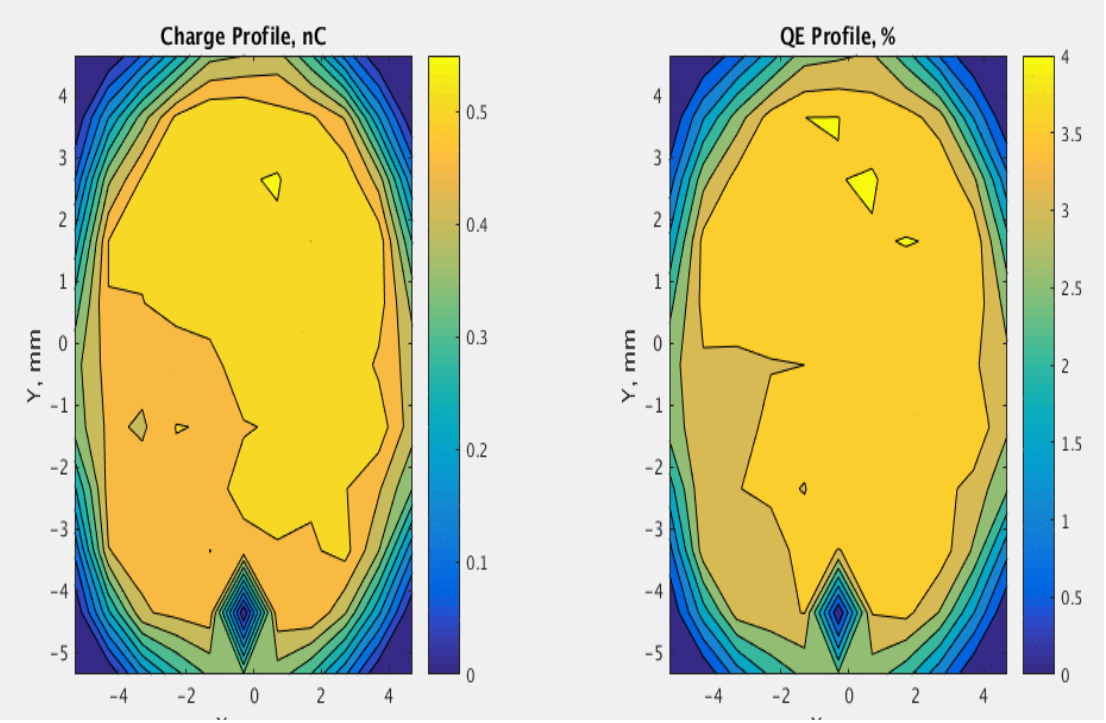




- With Multi-alkali cathode, the gun has strong multipacting when ramping up the power power.
- The gun could operate with a gap voltage in the range of 0.8 MV to 1.3 MV.
- In stable operation, cathode preserved 1.2% QE without decay. However, it is very sensitive to vacuum spikes. the QE will significantly degrade orders of magnitude.
- Maximum 3.7 nC bunch generated from gun

QE map of the latest cathode in SRF gun

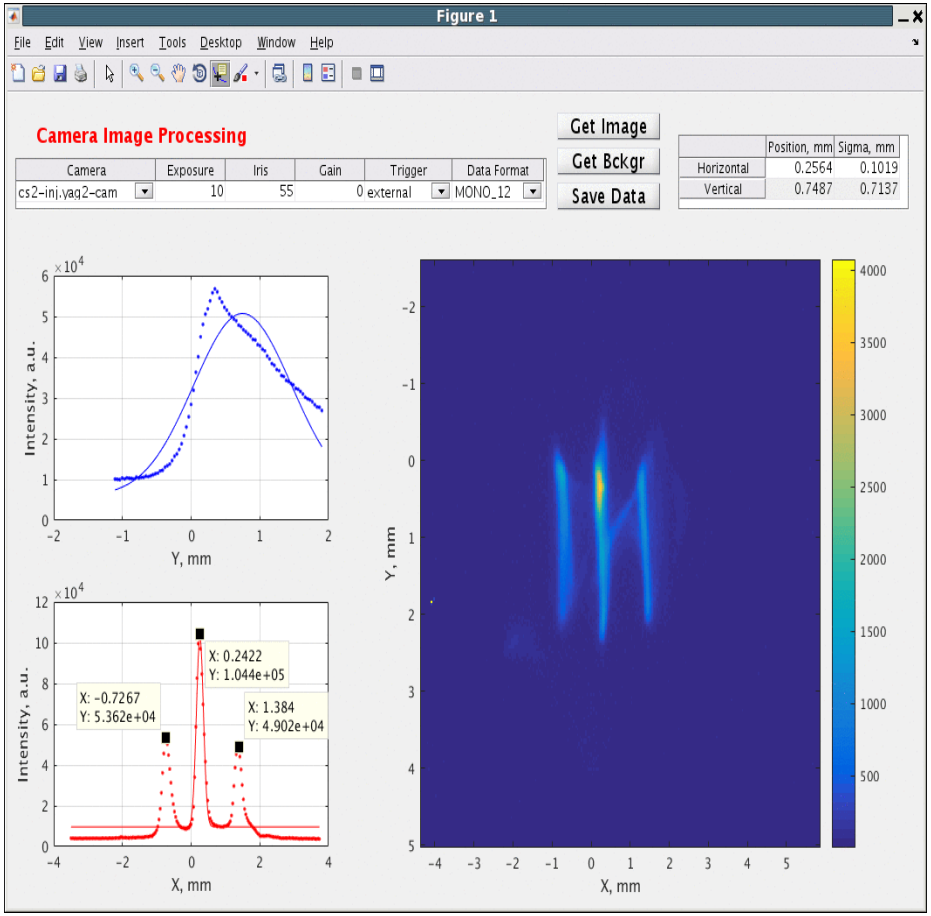
Cathode has been in the gun for months



- Multipacting is the main reason for degradation of high QE. Fine tuning of the RF start procedure could avoid the degradation.

1. Cover all the view-ports on the gun to make sure no ambient light could leak into the gun.
2. Move the main coupler to strong coupling position and off set the center frequency to break the multipacting resonance.
3. Use pulse mode to boost gun voltage to desired range.

Beam Emittance



Charge 640 pC
Beam size 1.3 mm
Divergence 0.29 mrad
R.m.s. emittance 0.37 mm mrad
Normalized 1.2 mm mrad

Beam Image

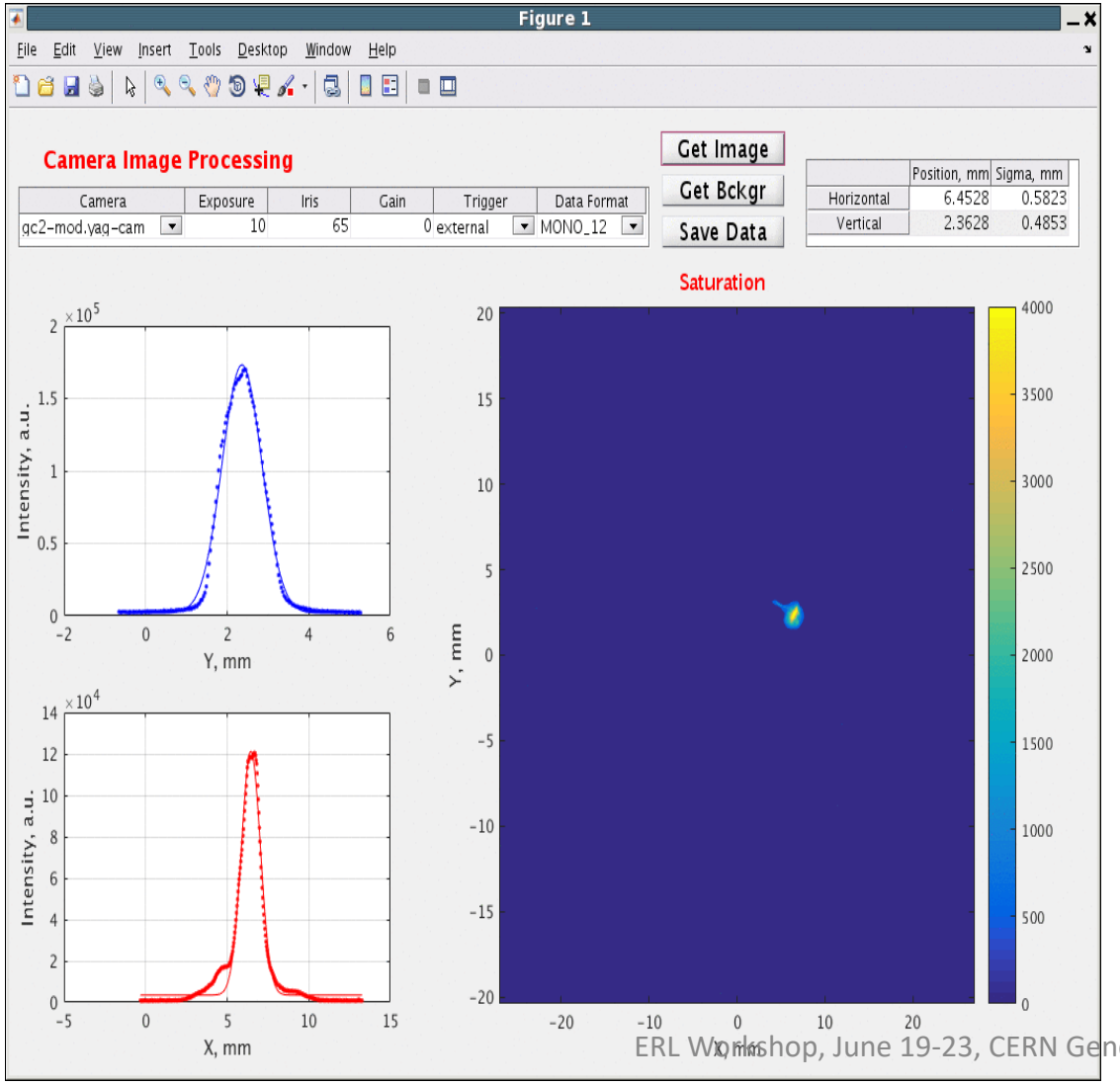
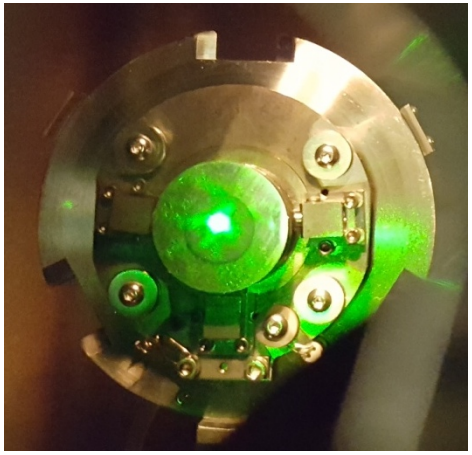
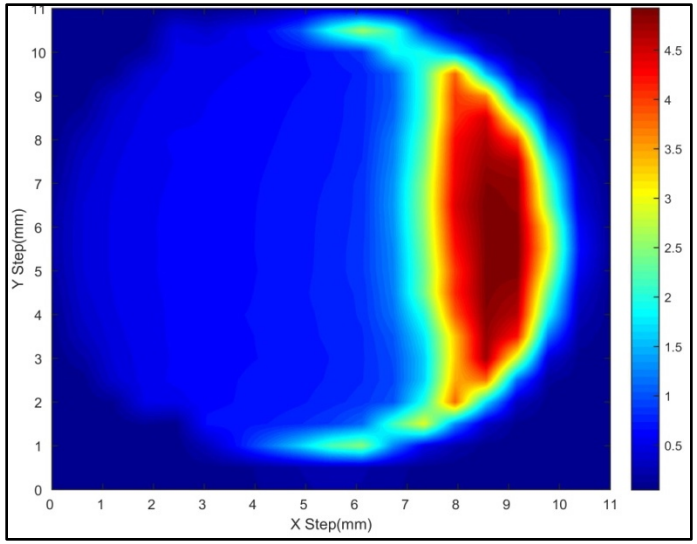


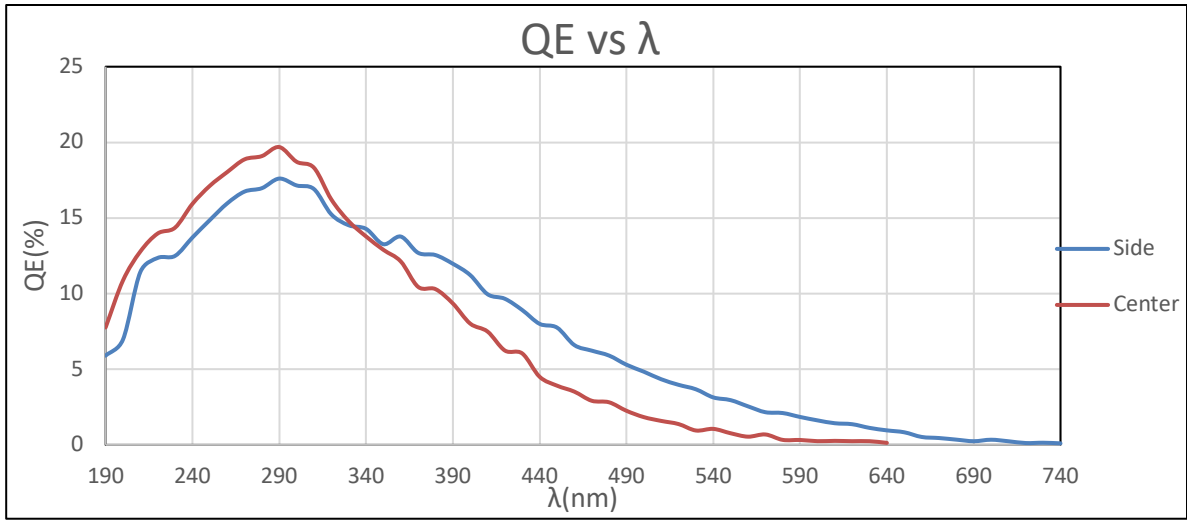
Figure 1
File Edit View Insert Tools Desktop Window Help
Camera Image Processing
Get Image
Get Bckgr
Save Data
Camera | Exposure | Iris | Gain | Trigger | Data Format
qc2-mod.yag-cam | 10 | 65 | 0 | external | MONO_12
Position, mm | Sigma, mm
Horizontal | 6.4528 | 0.5823
Vertical | 2.3628 | 0.4853
Saturation
Intensity, a.u.
Y, mm
Intensity, a.u.
X, mm
Y, mm
X, mm

NA-K-Sb cathode for LEReC.

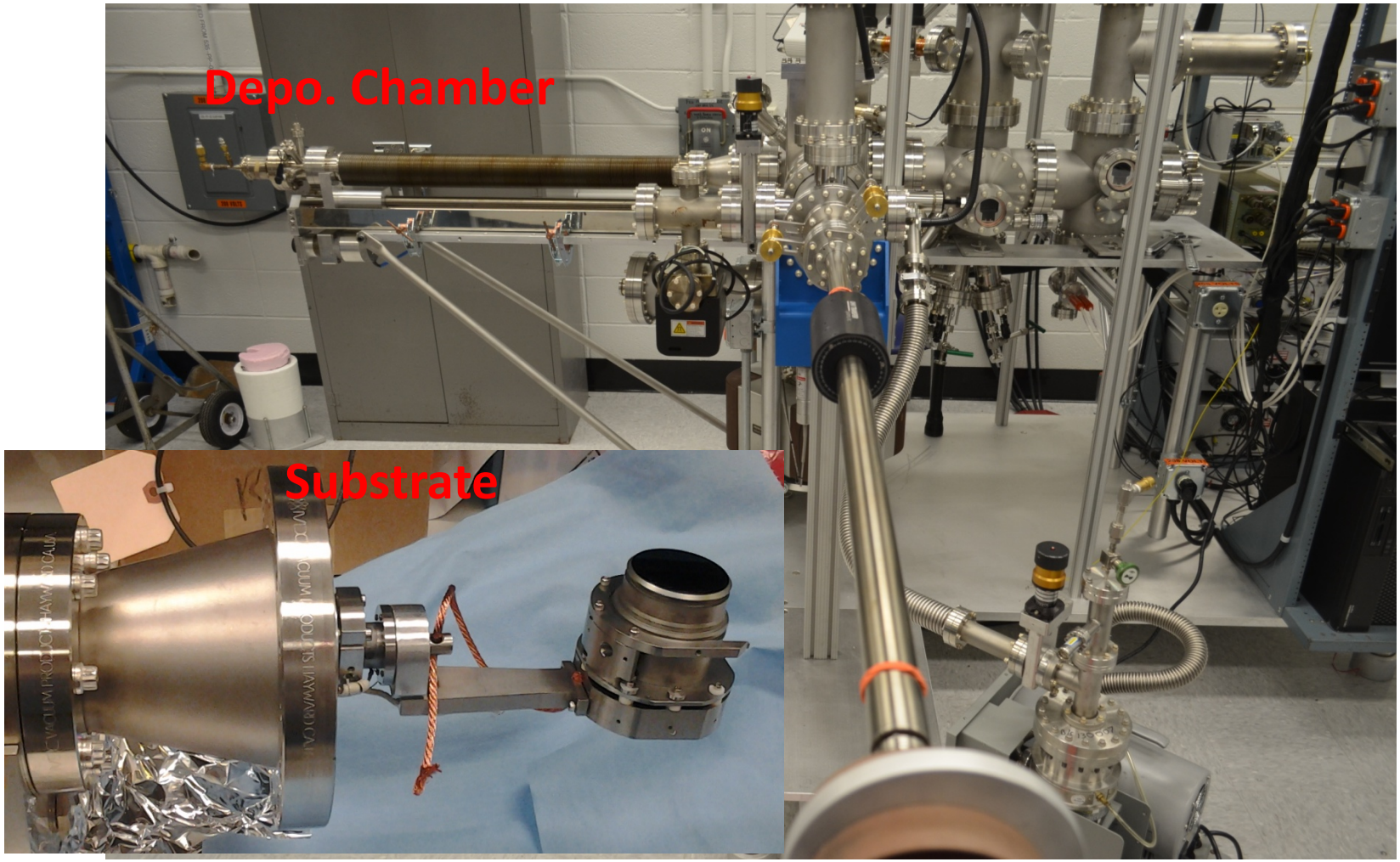
- Sequential evaporation using dispenser sources
- Procedure
  - 100 Å of Sb with the substrate @ ~ 100 °C
  - 200 Å of K with substrate @ 140 °C
  - Alternate evaporation of Na and K with substrate at ~200 °C



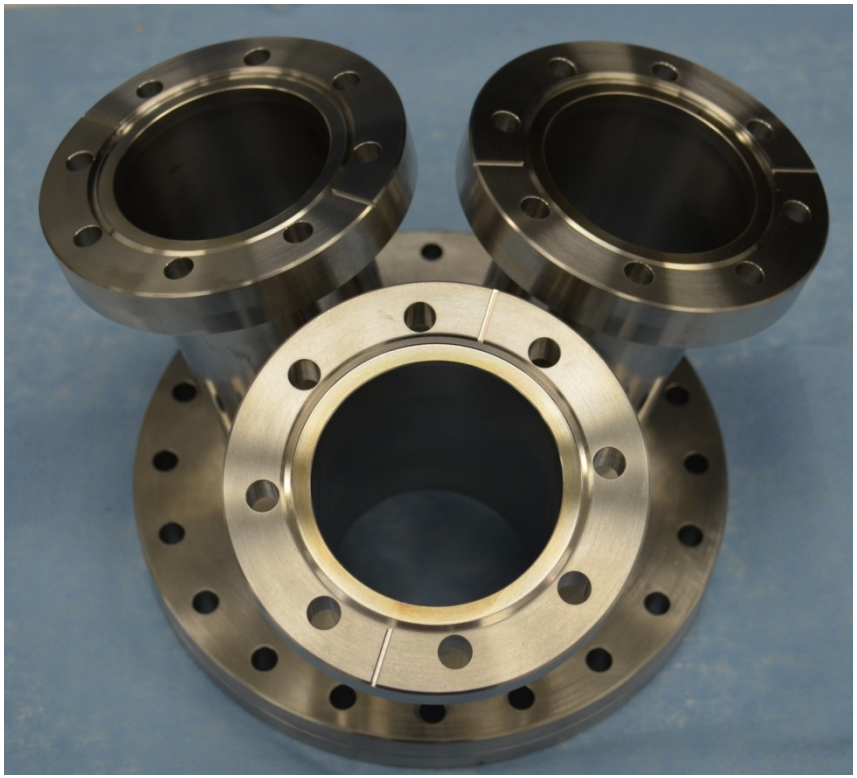




Co-evaporation with effusion cell



Effusion Cell design



Cluster flange for 3 effusion cells

Components of effusion cell

Fabrication process and performance

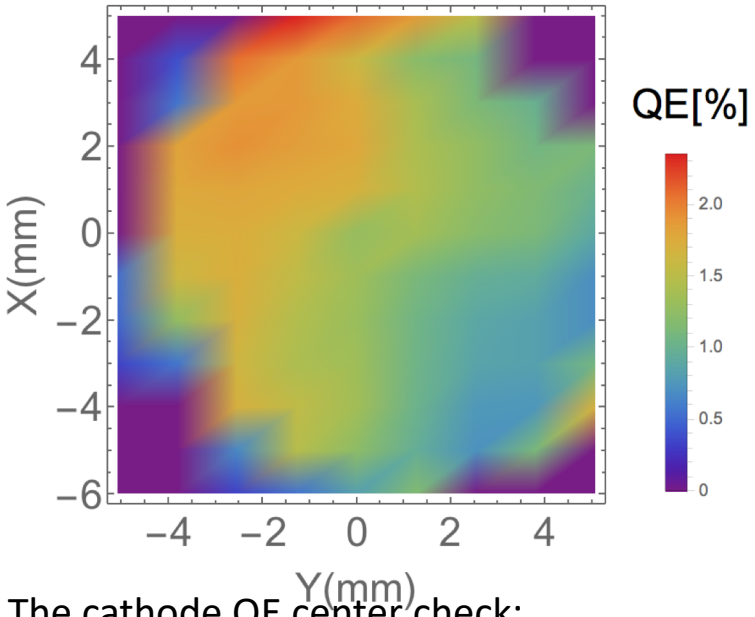
BROOKHAVEN NATIONAL LABORATORY

Tentative procedure:

- Evaporate 100 Å of Sb with substrate at ~ 100°C at a rate of 20 Å/minute
- Set the evaporation rate of K of 3 Å/minute
- Evaporate at 125 °C till QE maximizes
- Heat to 200 °C
- Co-evaporate K and Na till QE maximizes
- Turn off heater, lower effusion cell temperature
- Continue till QE stabilizes and substrate at room temperature

Cathodes QE map (measured at the cathode lab)

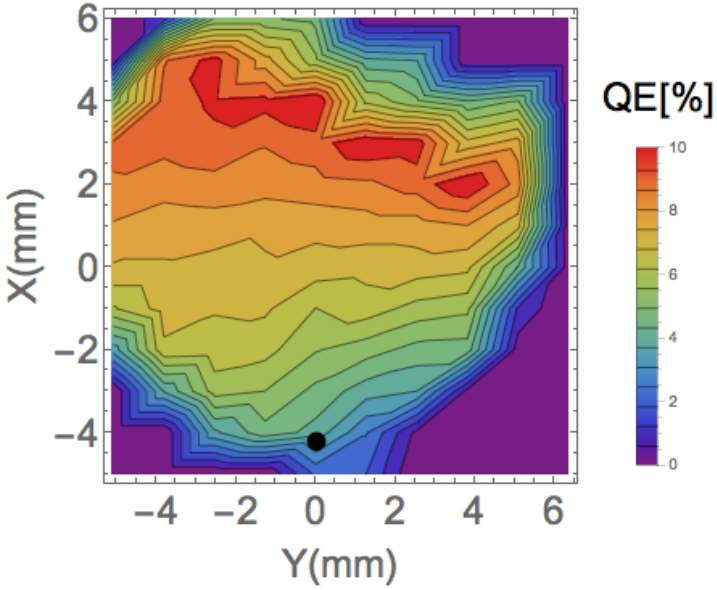
#1



The cathode QE center check:

- in lab: 1.8 %

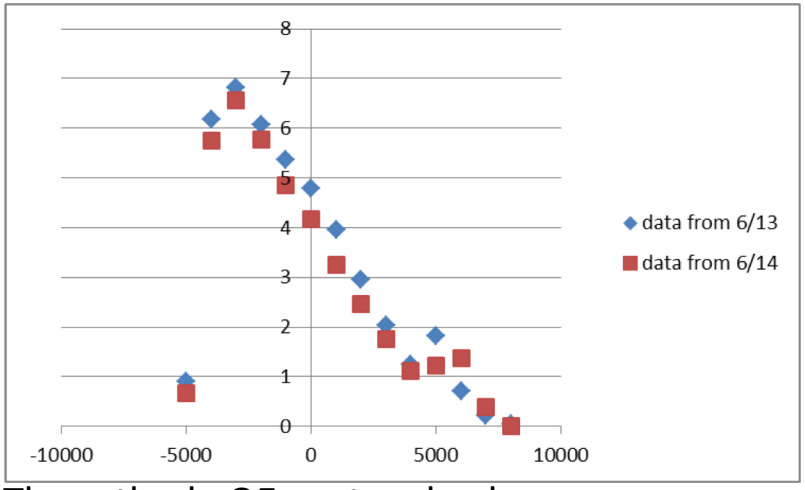
#2b



The cathode QE center check:

- in lab: 7%
- before bake: 6.3%.
- after load-lock baking: 0.35%.

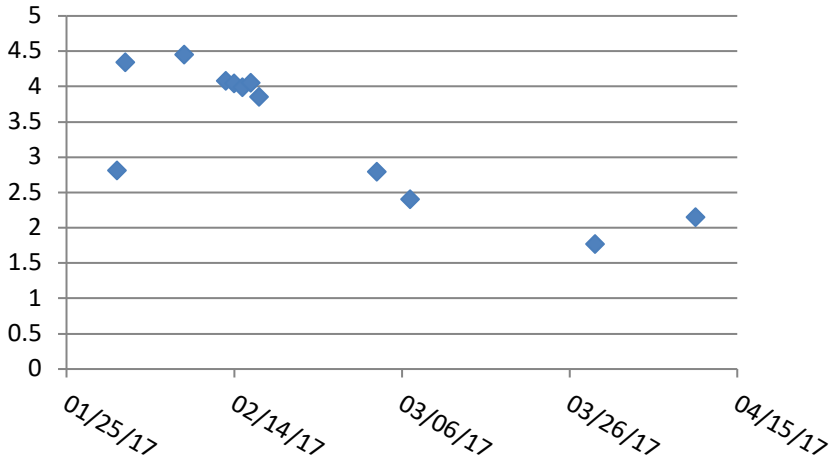
#3

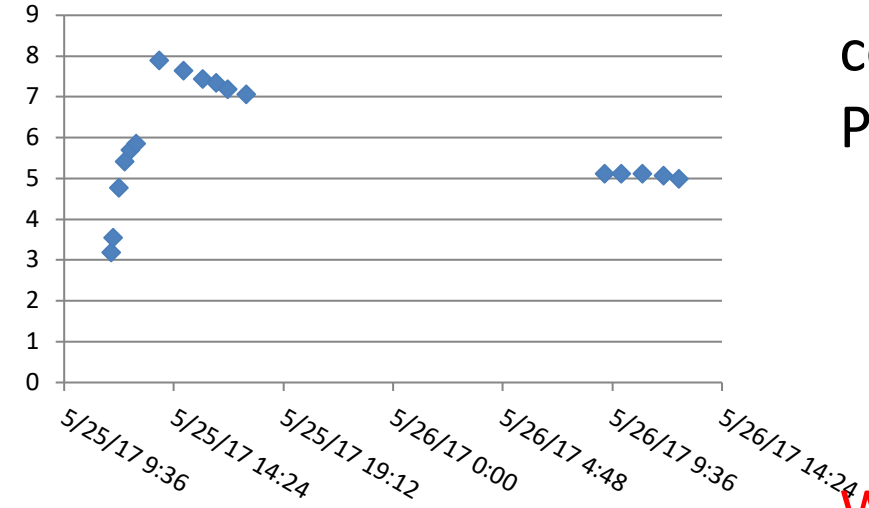


The cathode QE center check:

- in lab: 4 %

QE Evolution in Deposition Chamber





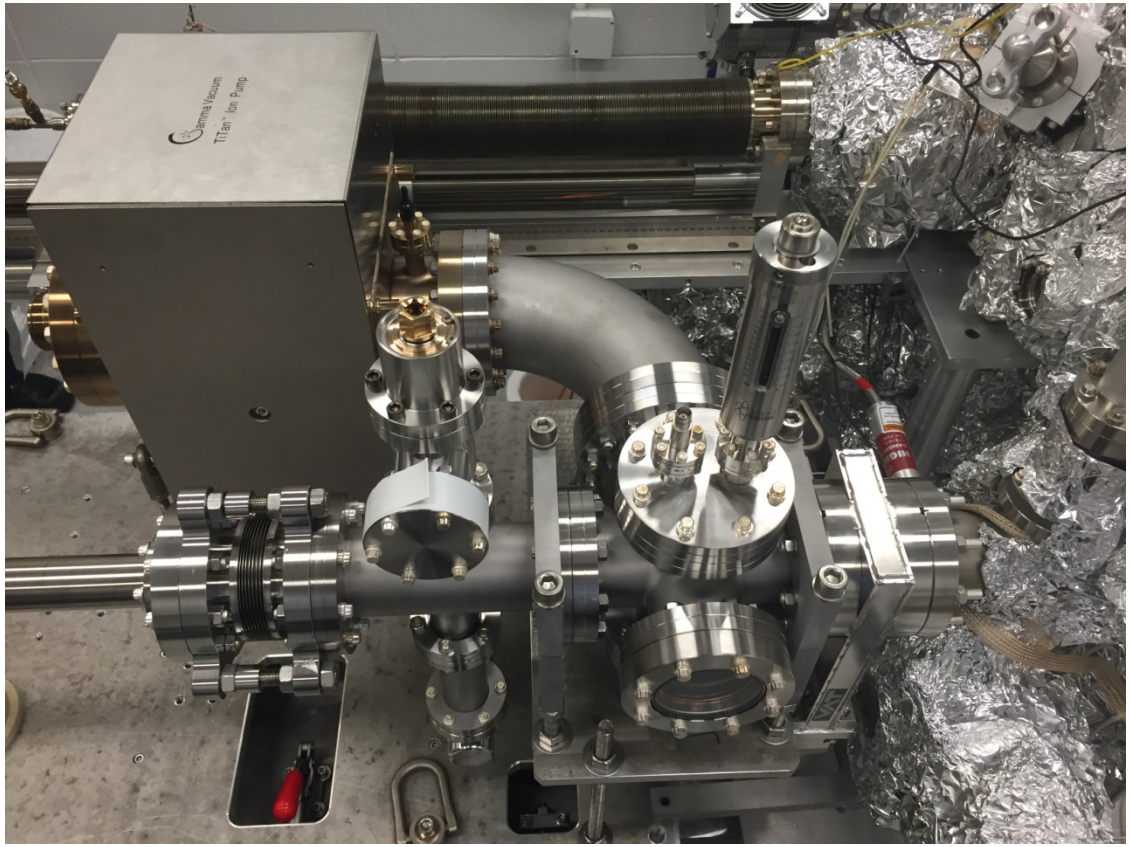
- QE changes over time: Increases in the beginning, decreases over longer time scale
- Changes in QE map as well
- Preliminary analysis indicates exponential decay, higher QE material with smaller decay constant

Possible causes:

- Temperature effect
- Migration of constituent elements
- Contaminants

Working towards systematic study

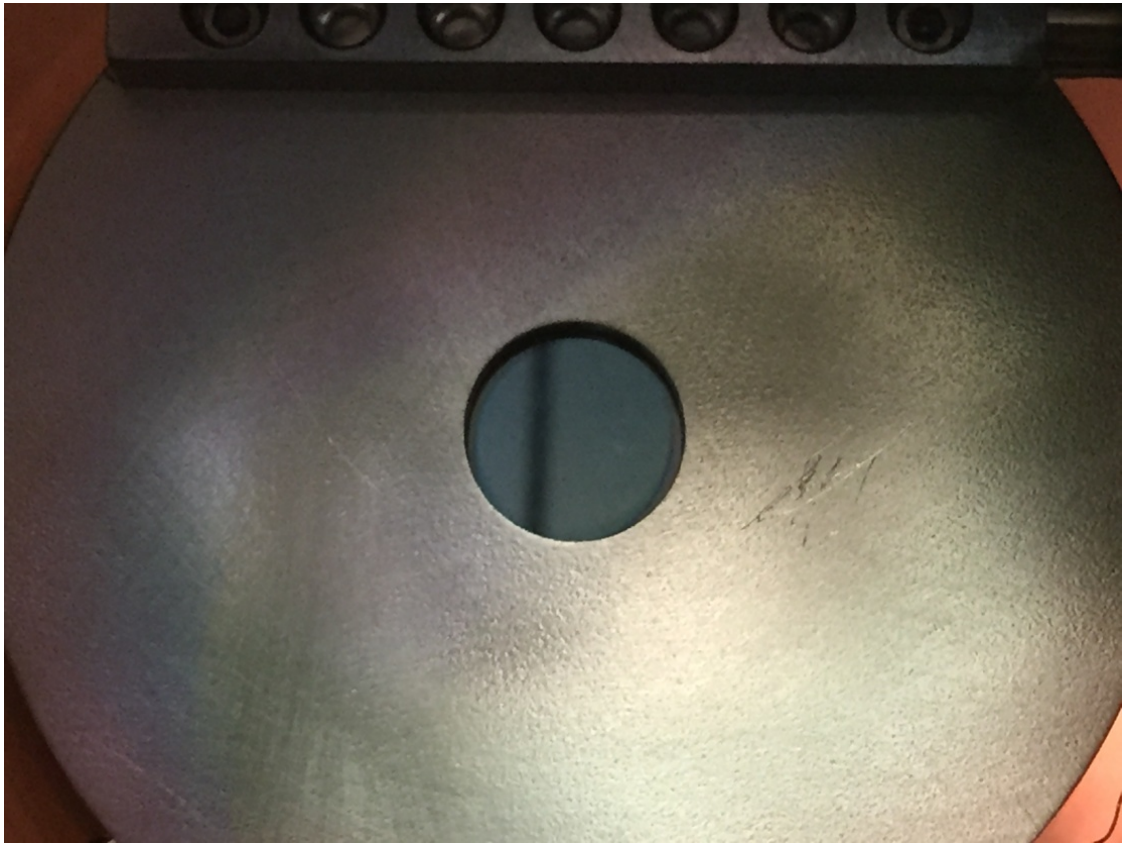
Single Puck Transporter



- Weighs 400 lb
- Low 10^{-9} torr vacuum
- Ability to measure QE
- Data log for pressure

Video of the transport process

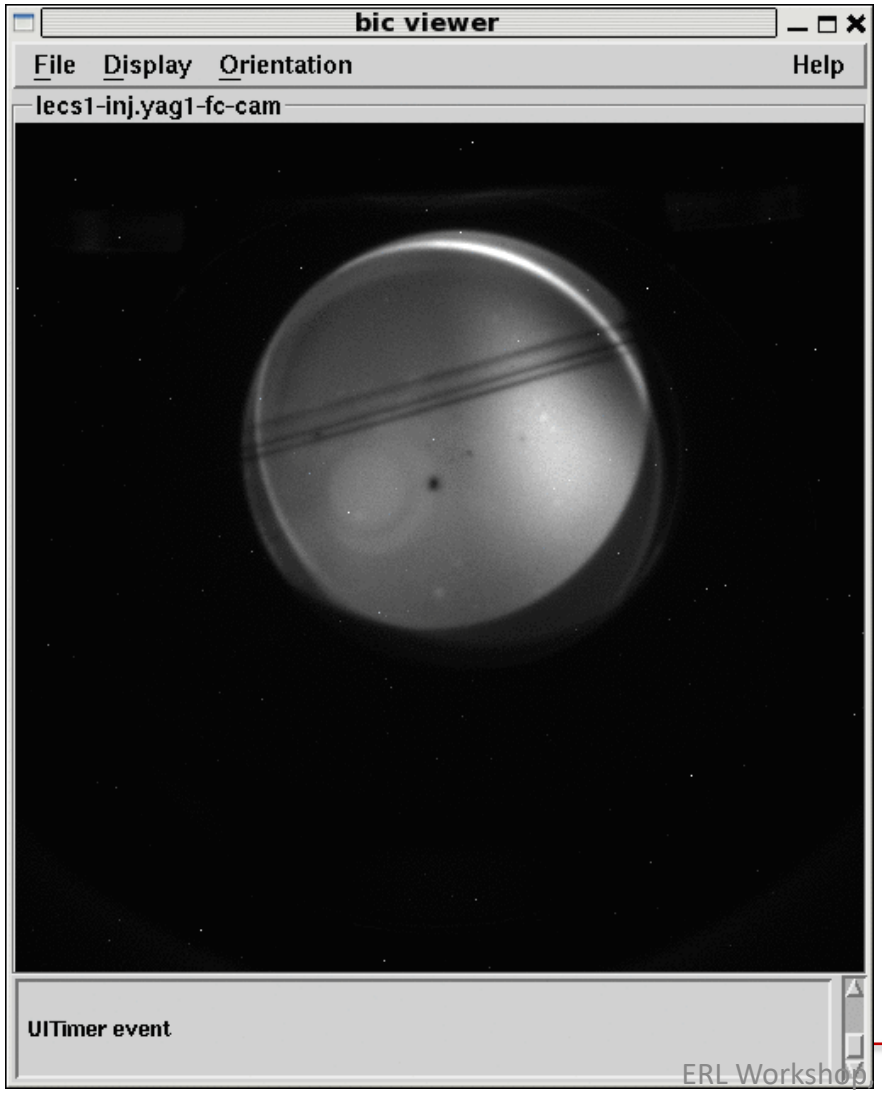
cathode-transport-041217.wmv



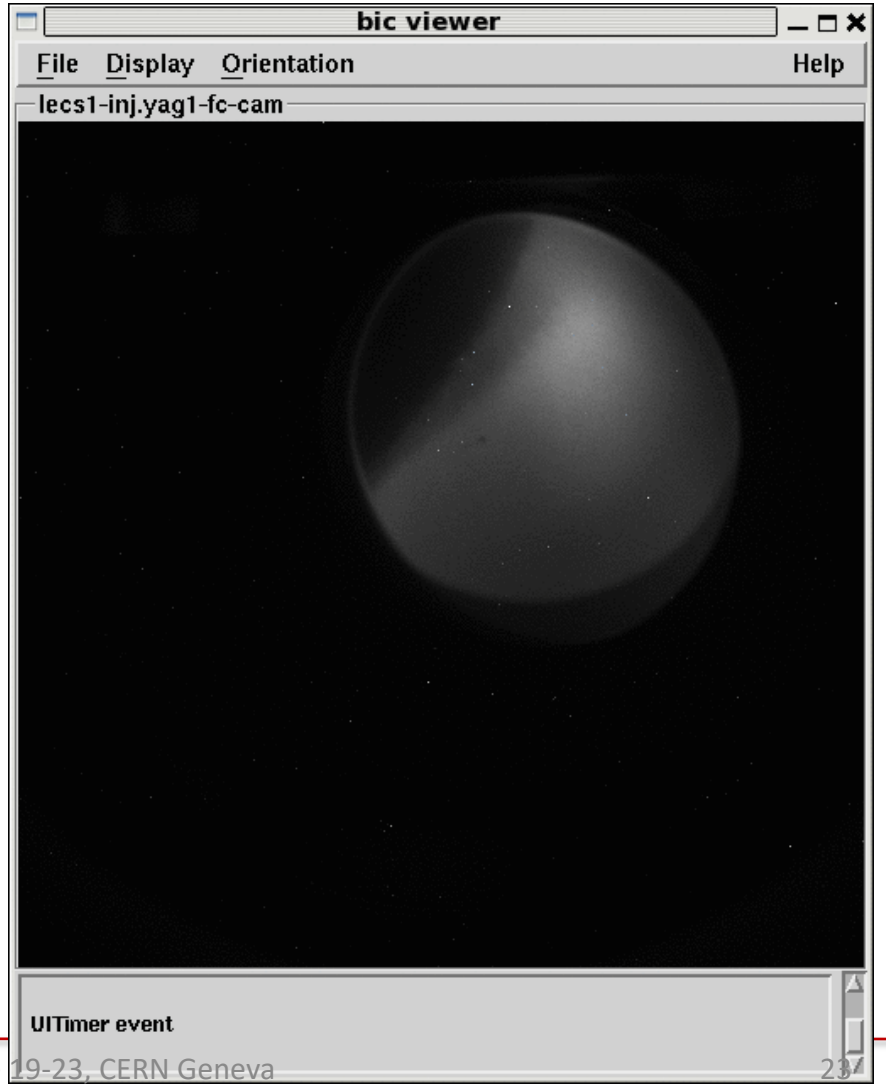
Photograph of the first cathode transported to LEReC

Lamp Beam

Cath #1



Cath #2



4 Macrobunches operation

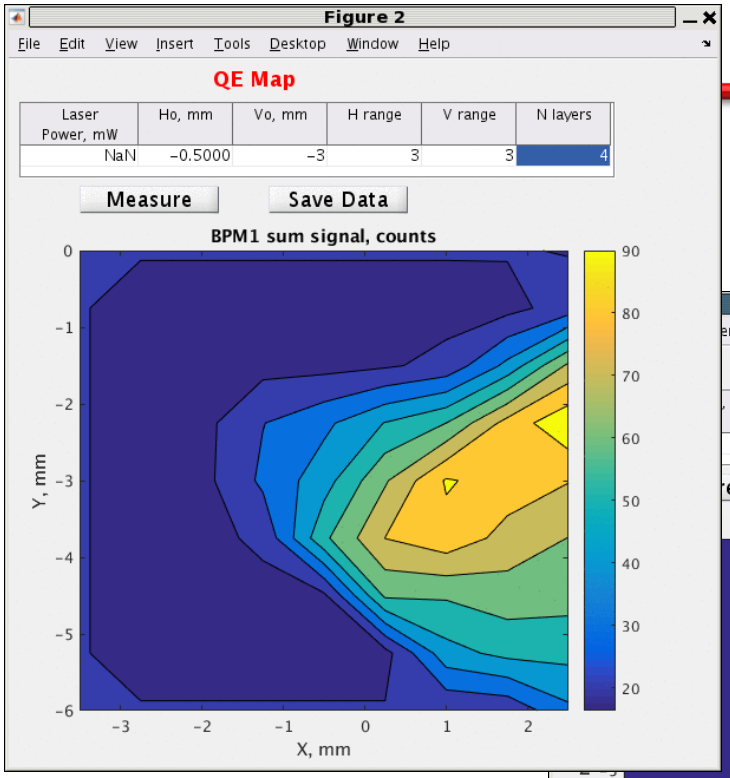
FCT signal

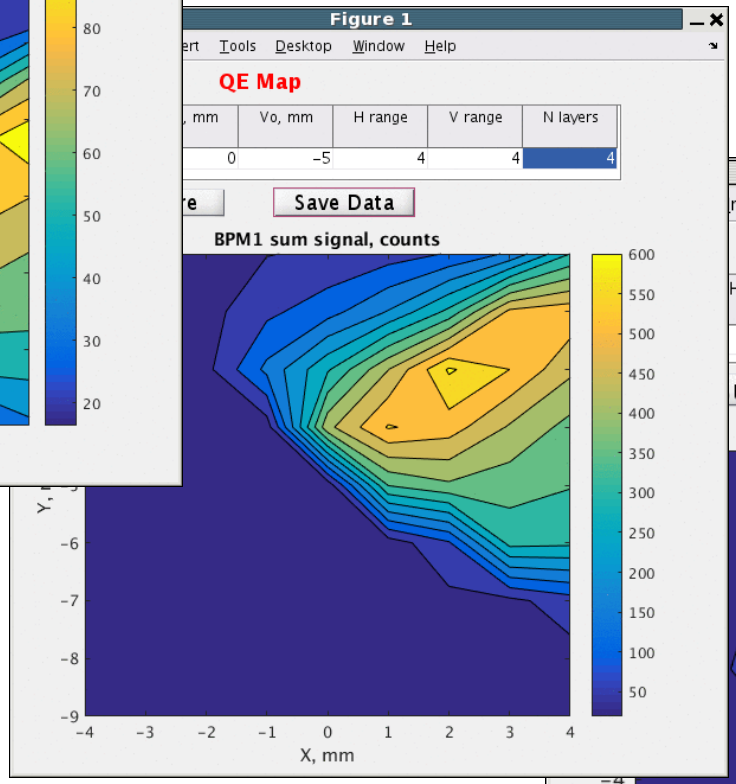
CT detected sig

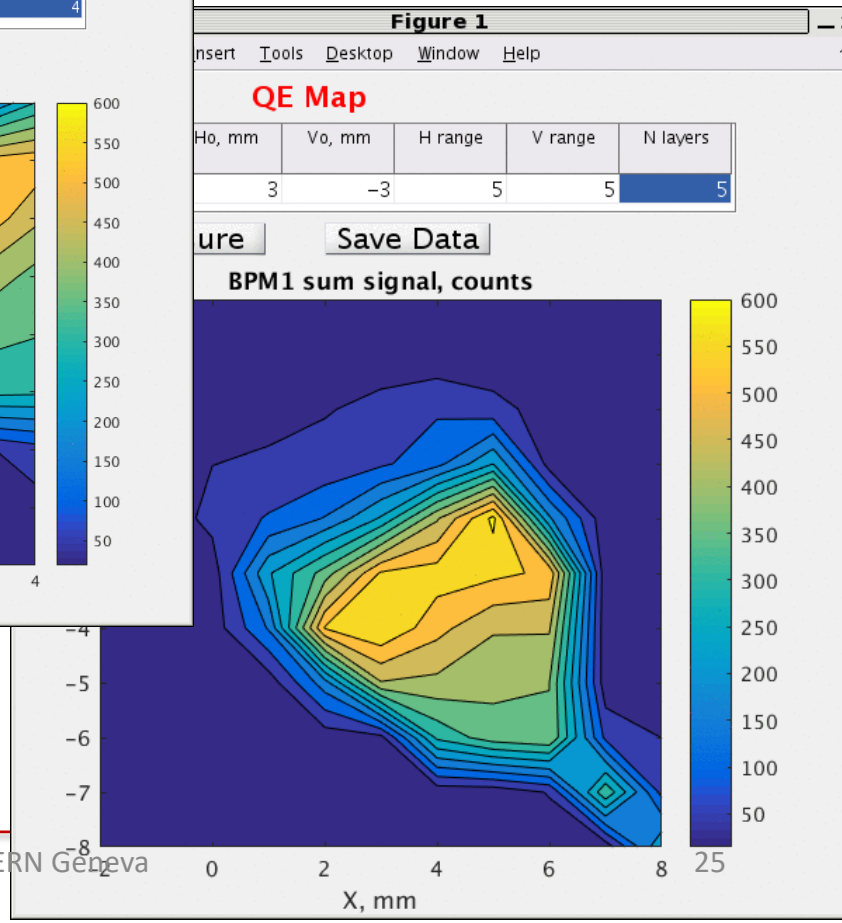
FC signal

Laser pulse structure

QE scans.(same cathode different initial position based on readings)







QE in the gun has not been calculated- laser power measurement yet to be done

	Suitcase	Grow	Lab QE	Inserted	Removed	Lamp DC (POF)	Bunch Charge
Cath#1	#2	Jan 30	1.7%	Apr 17	May 30	40 nA	25 pC
Cath#2b	#1	May 17	7%	June 2	June 14	40 nA	33 pc
Cath#3	#2	June 13	7%	June 16?		??	130 pC

QE of cath. #1 in gun was ~0.1%- 8 hour exposure to 9 scale vacuum during bake of load-lock
QE of cath. #2 dropped to 0.8 after baking load-lock, even though valve temperature was not increased- pressure log was not connected
QE of cath. #3 estimated to be > 2% in the gun (~ factor of 2-3 reduction in QE)
-modifications : Better base pressure, cooled flange, retracted puck, no latency in transfer
Ion pump turned off for ~ 20 s when ion pump power supply was changed

Conclusions

- CeC
  - Cathode fabrication for CeC experiments is mature
  - E beam expectations mostly met
- LEReC
  - 3 cathodes delivered to DC gun
  - ~40 mA produced in 4 macrobunches
  - Commissioning is in progress
  - More research needed for 24/7 operation