High Charge High Current Beam from BNL 113 MHz SRF Gun

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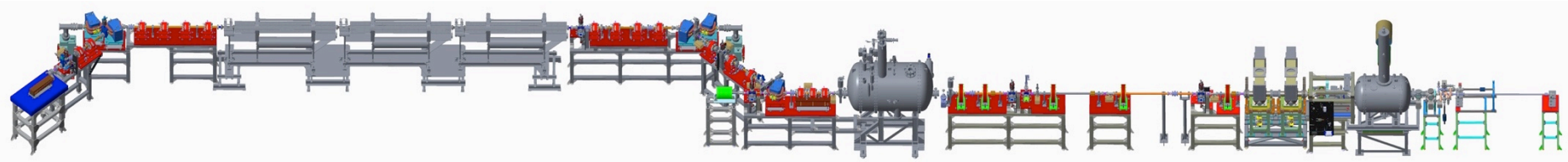
C-AD, BNL

Coherent Electron Cooling Project



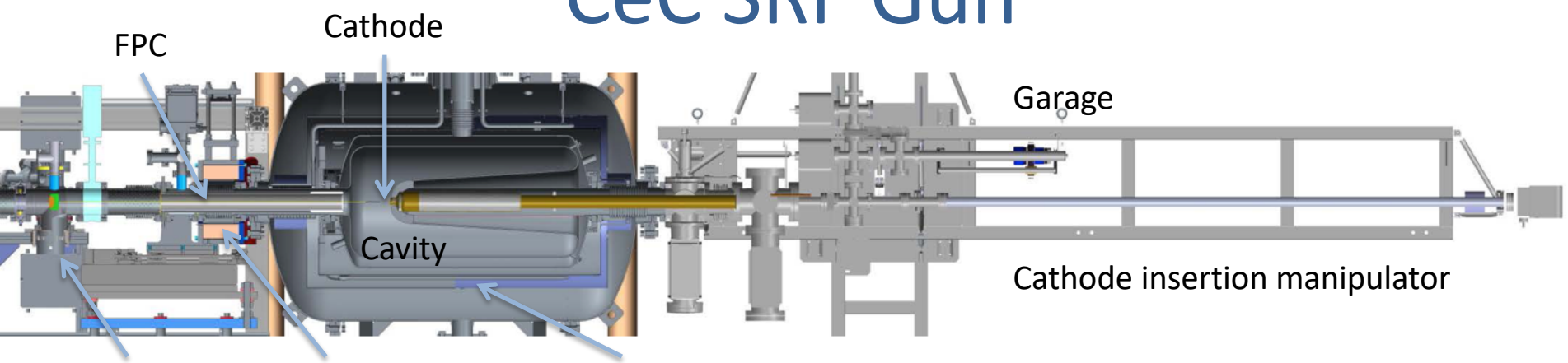
Electron beam is generated by 113 MHz SRF gun with photocathode driven by a 532 nm laser. Two 500 MHz copper cavities provide energy chirp and beam is compressed to desired peak current.

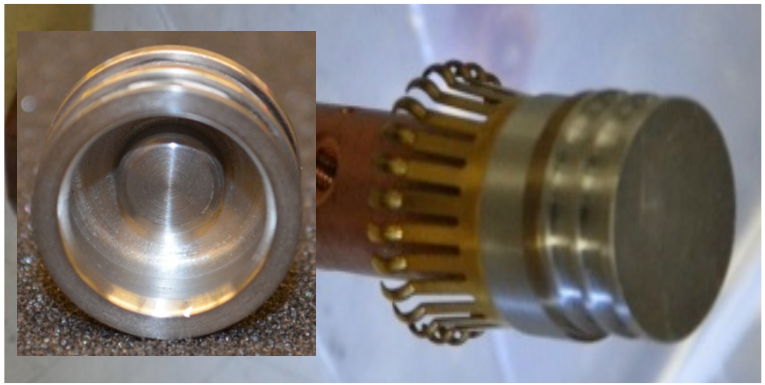
After compression beam is accelerated by a 704 MHz SRF cavity and merged into CeC PoP structure having three helical undulators.

Electron Beam Parameters for CeC

- Gun energy 1.1 MeV
- Beam charge 1-5 nC
- Final beam energy 14.6 MeV
- Normalized emittance ~0.3 mm mrad
- Energy spread 10^{-3}
- Pulse repetition rate 26 (78) kHz

CeC SRF Gun

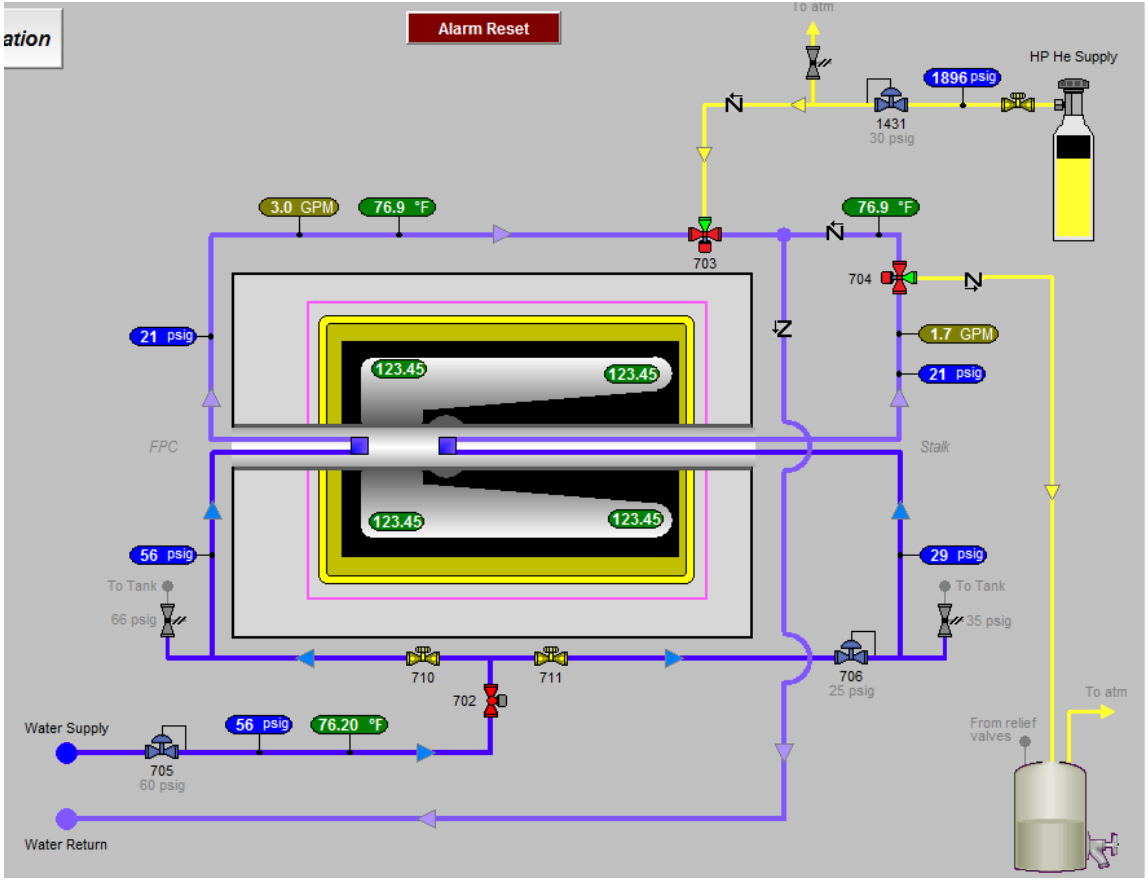




Photocathode end assembly

- Quarter-wave cavity
- 4 K operating temperature
- Manual coarse tuner
- Fine tuning is performed with FPC
- 4 kW CW solid state power amplifier
- CsK_2Sb Cathode is at room temperature
- Cavity field pick-up is done with cathode stalk
- Up to three cathodes can be stored in the garage
- Design gradient 22.5 MV/m

Gun Water System



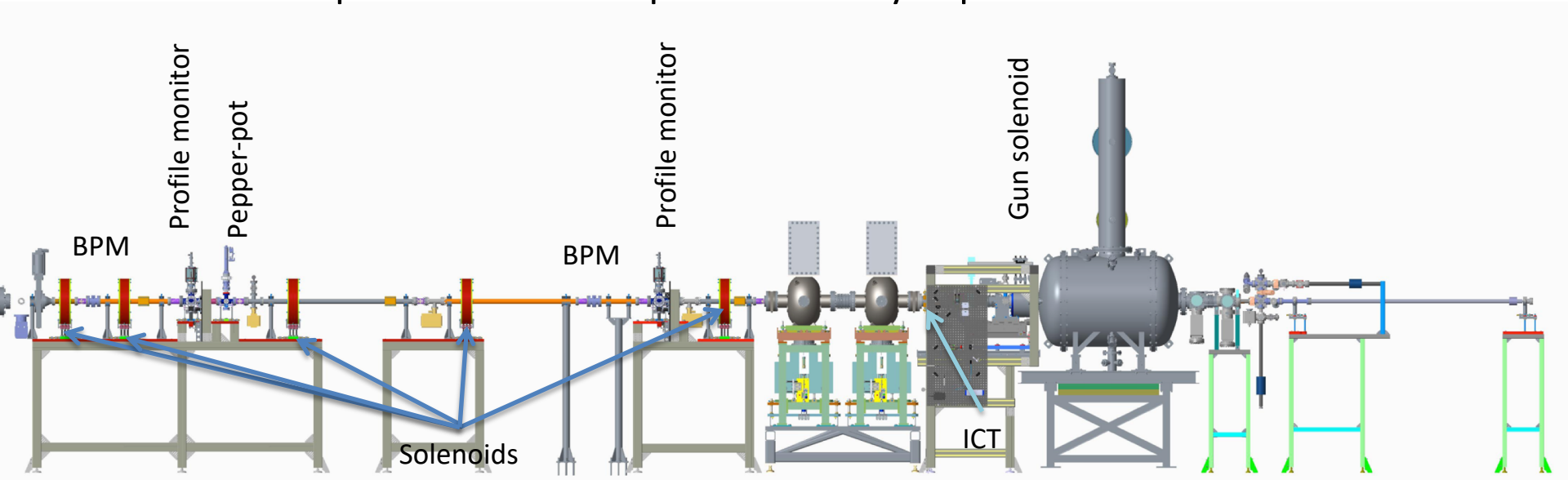
Record Beam Generated by SRF Gun Operating in CW Mode

- Bunch charge exceeds 3 nC
- Beam full energy 1.6-1.7 MeV (CW), >2 MeV (pulse)
- We have demonstrated electrical field at time of emission exceeding 21 MV/m

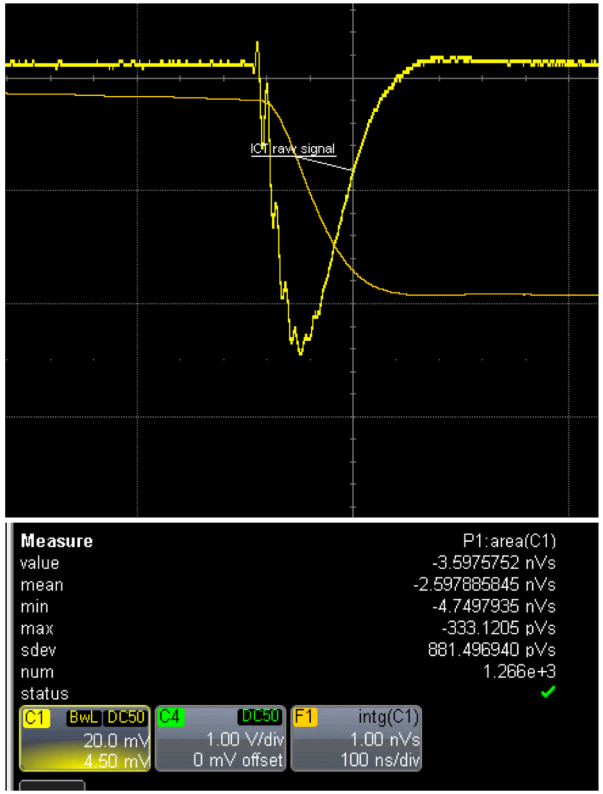
	FZD	HZD	NPS	Wisconsin	CeC
Charge, pC	300	6	78	100	3900
E, MV/m	5	5-7	6.5	12	21
Frequency	1.3 GHz	1.3 GHz	500 MHz	200 MHz	113 MHz
Cathode	Cs_2Te	Pb	Nb	Cu	CsK_2Sb

Diagnostics for Low Energy Beam

- Integrating current transformer (1.25 nV s/nC)
- Two beam profile monitors with 1.3 megapixel cameras
- Pepper-pot in front of the second profile monitor
- Two BPMs
- Low power beam dump with Faraday cup



First Beam Observation



Emission was observed over 100 degrees span.

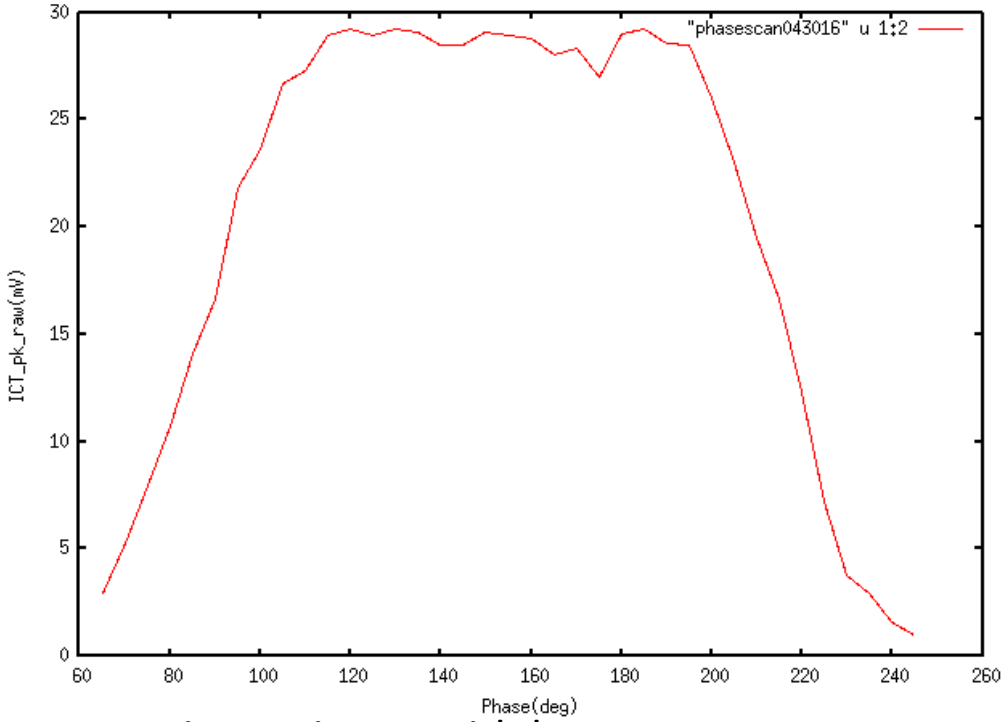
We have found that beam charge is limited by space charge forces

E_{laser}	Q	QE
375 nJ	0.5 nC	0.3%
1 µJ	0.66 nC	0.15%
6 µJ	1.24 nC	0.05%

After 50% laser spot size increase we were able to observe 3 nC charge.

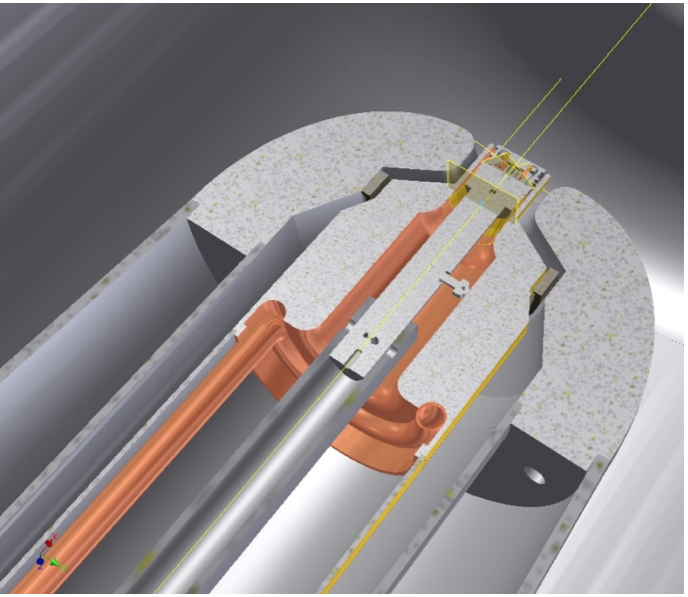
We have increased pulse repetition rate from few Hz to 5 kHz (laser max) and observed 15 µA current.

Cavity Phase Scan



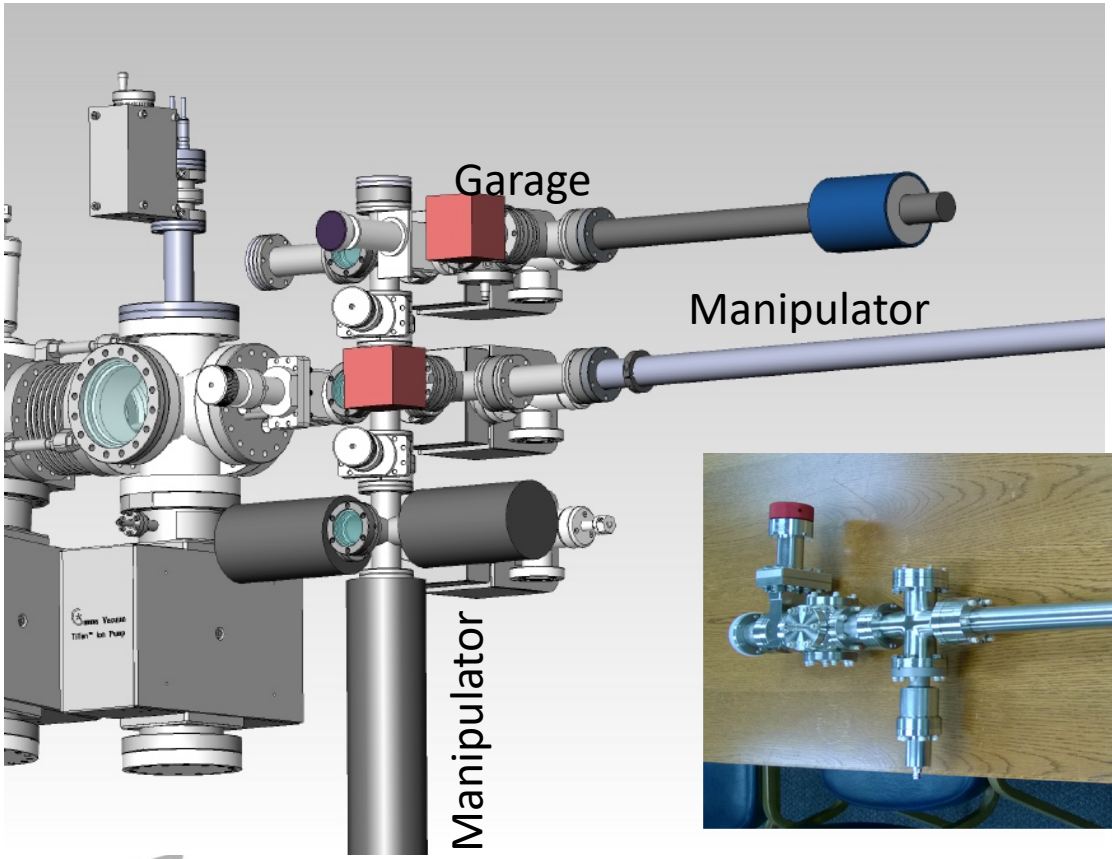
Cavity phase scan is consistent with last year measurements and simulations.
More than 180 degrees range is due to the long laser pulse (40° of RF phase).

Post-Installation Improvements

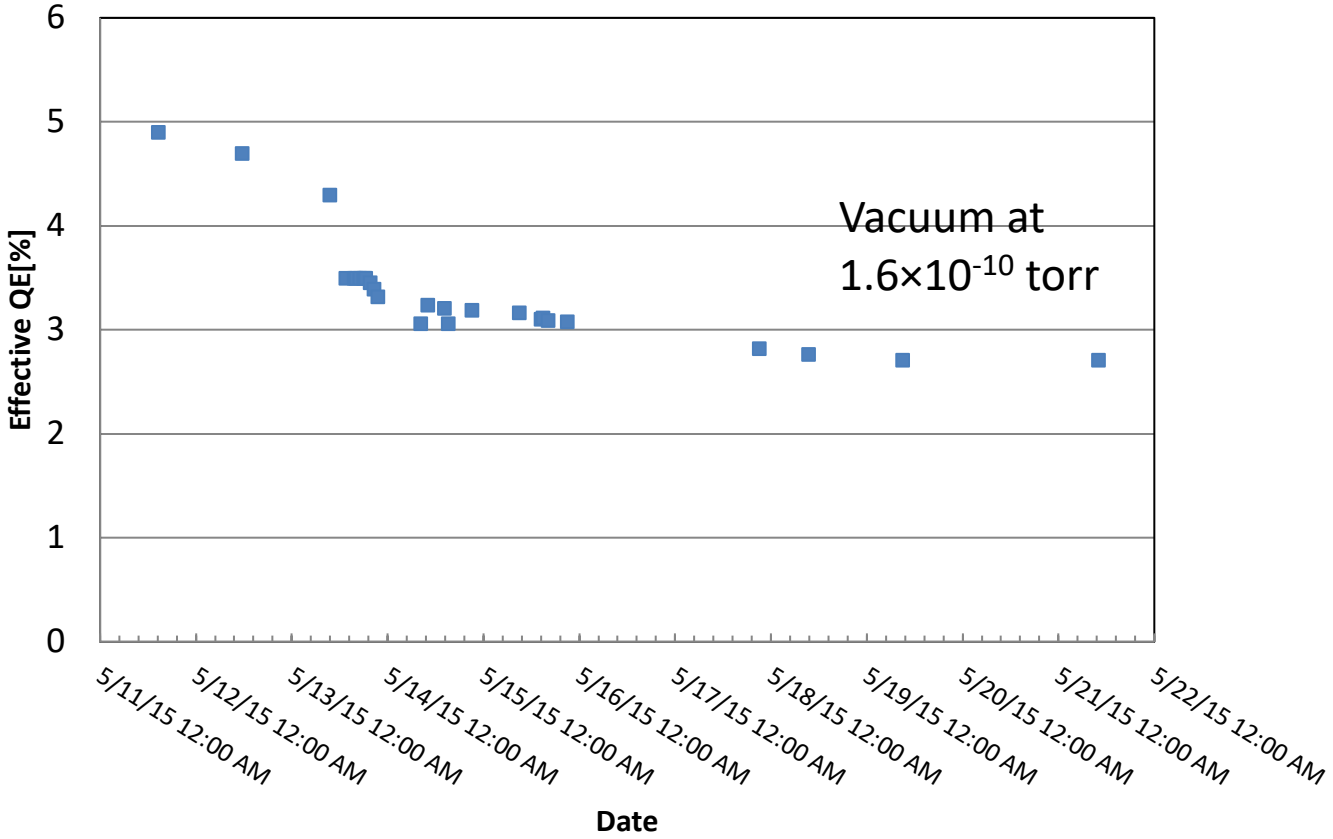


- Long conditioning cycle with molybdenum puck to suppress multipacting in the FPC area
- Helium discharge cleaning to reduce dark current
- Added port for QE monitoring inside the garage
- Added NEG getters to improve vacuum during cathode transfer
- Used mask for the cathode deposition system and developed automated start procedure to overcome multipacting zone the cathode stalk
- Re-built cathode launch system

Modified Cathode Launch System

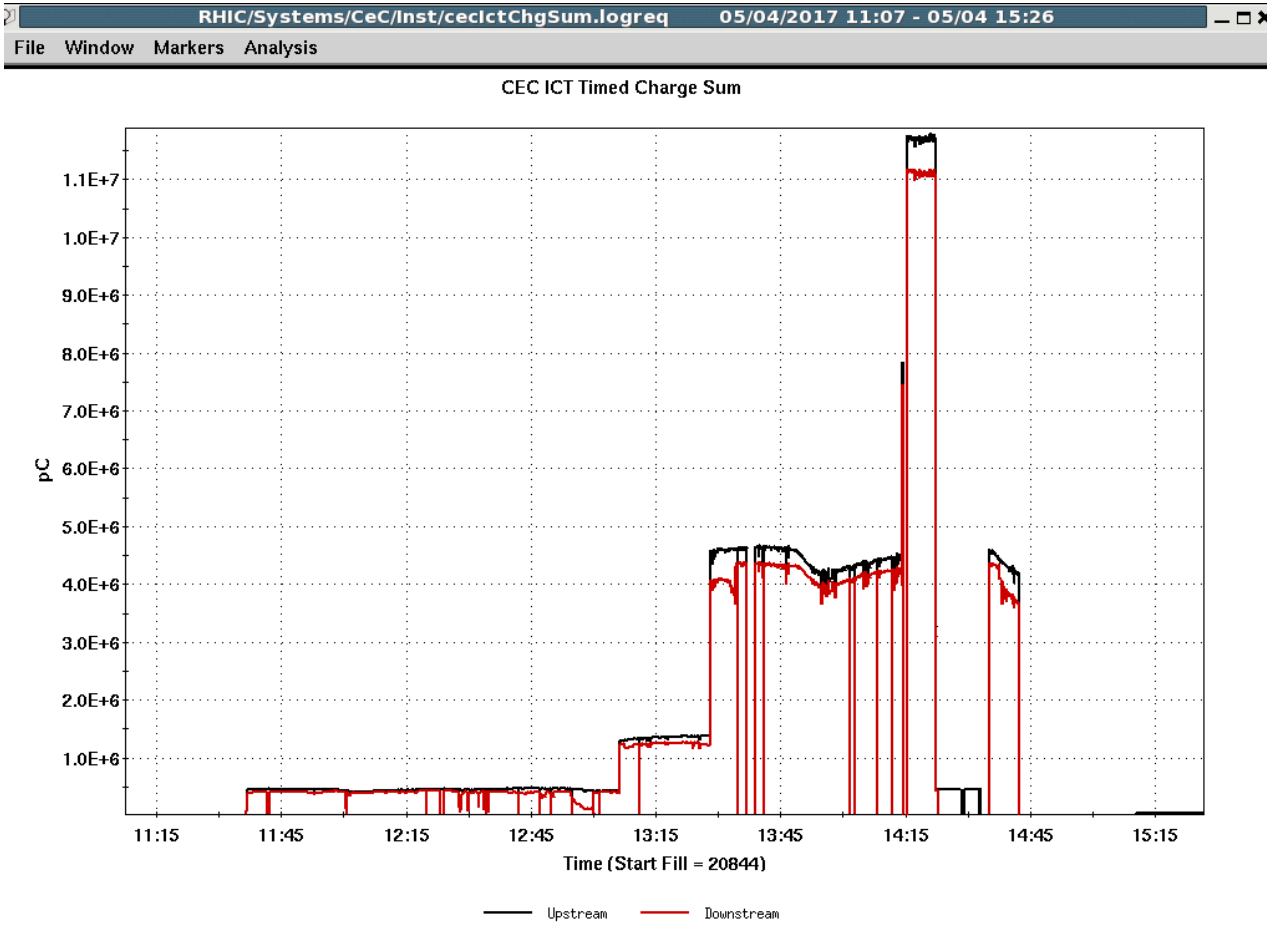


Cathode QE Evolution

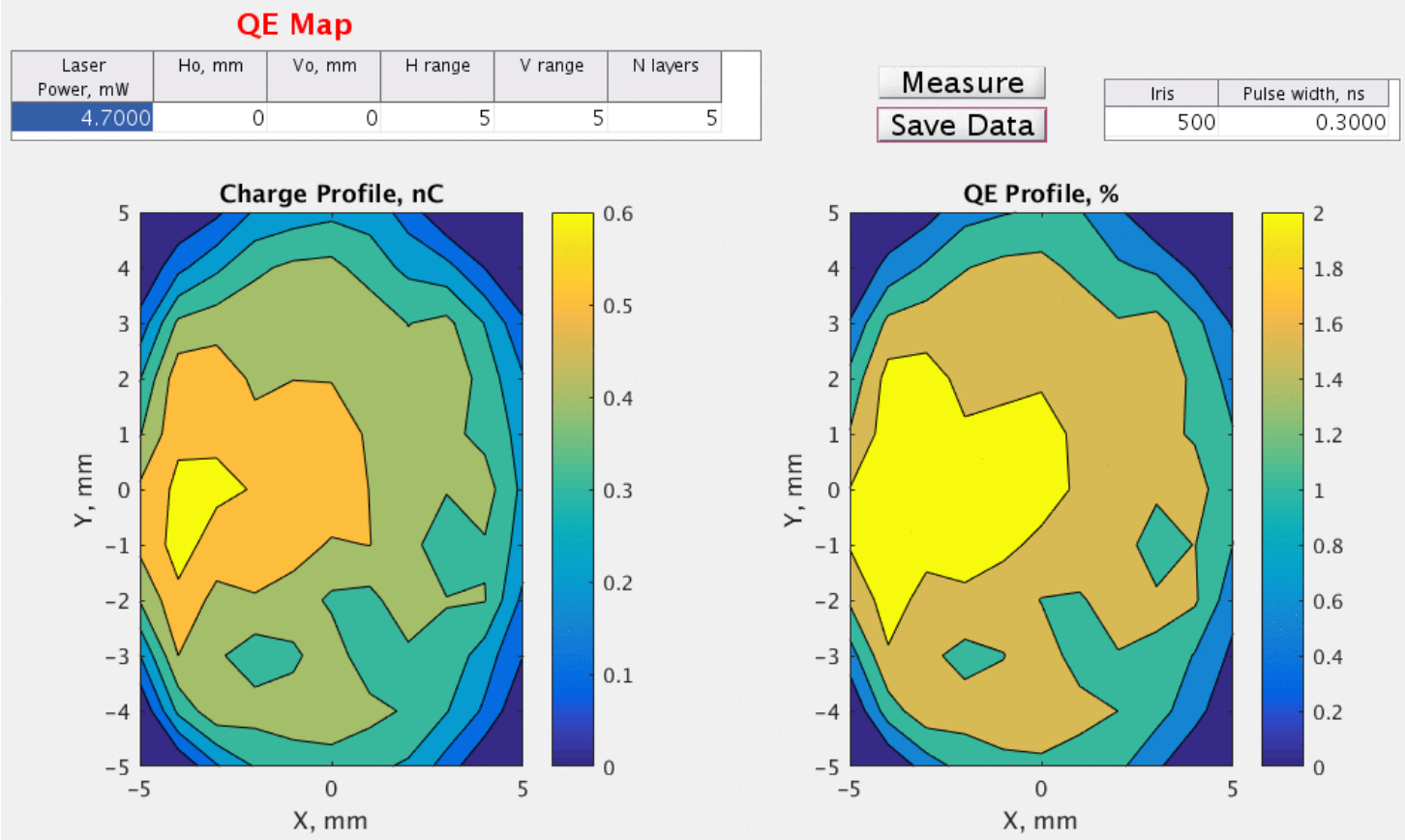


Initial QE is 8-10%, the evolution after transfer is shown.

Beam Current During Radiation Survey



QE Map after Month of Operation



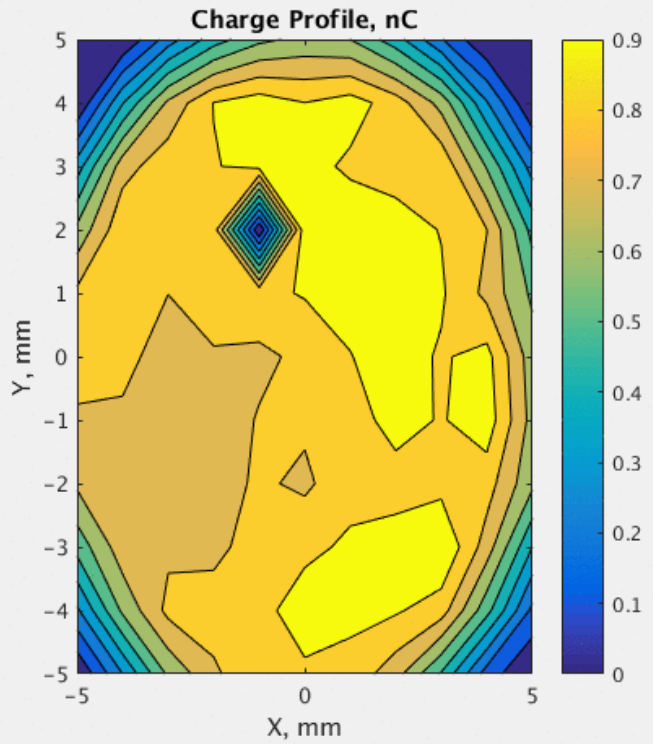
QE Map

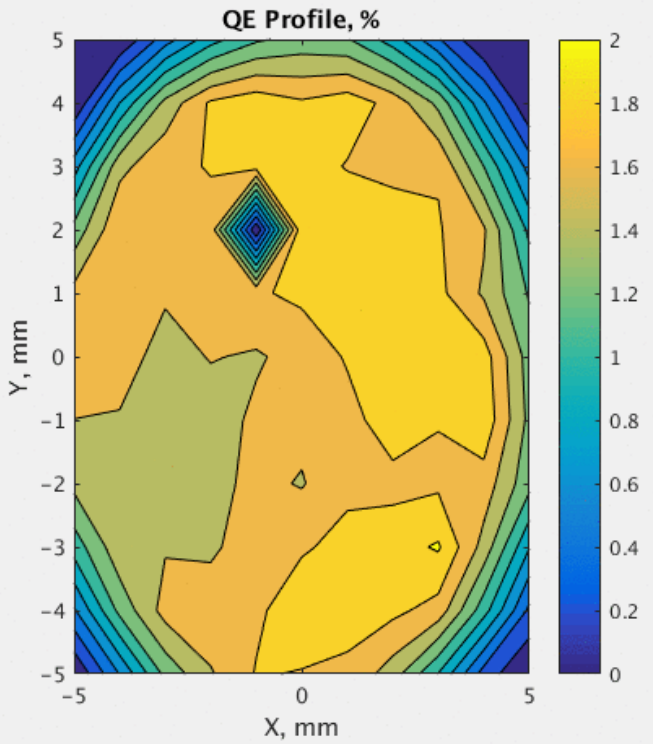
Laser Power, mW	Ho, mm	Vo, mm	H range	V range	N layers
9	0	0	5	5	5

Measure

Save Data

Iris	Pulse width, ns
500	0.5000





QE Map two days later (June 9)

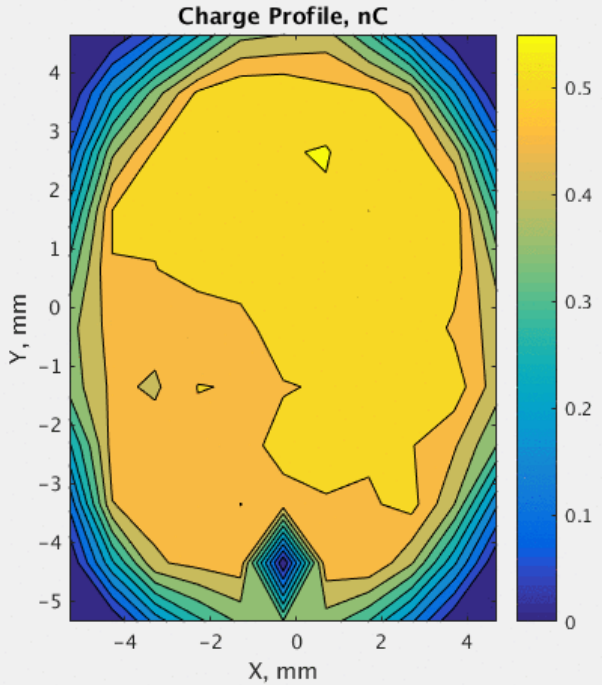
QE Map

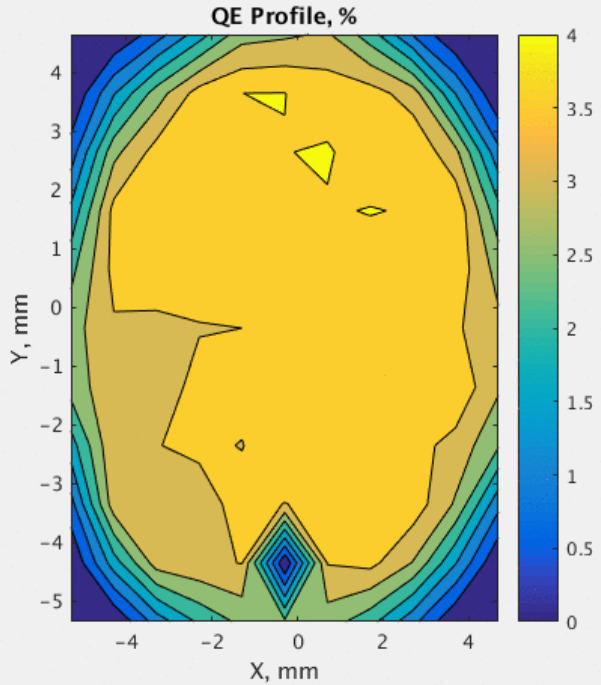
Laser Power, mW	Ho, mm	Vo, mm	H range	V range	N layers
2.5000	-0.3000	-0.3500	5	5	5

Measure

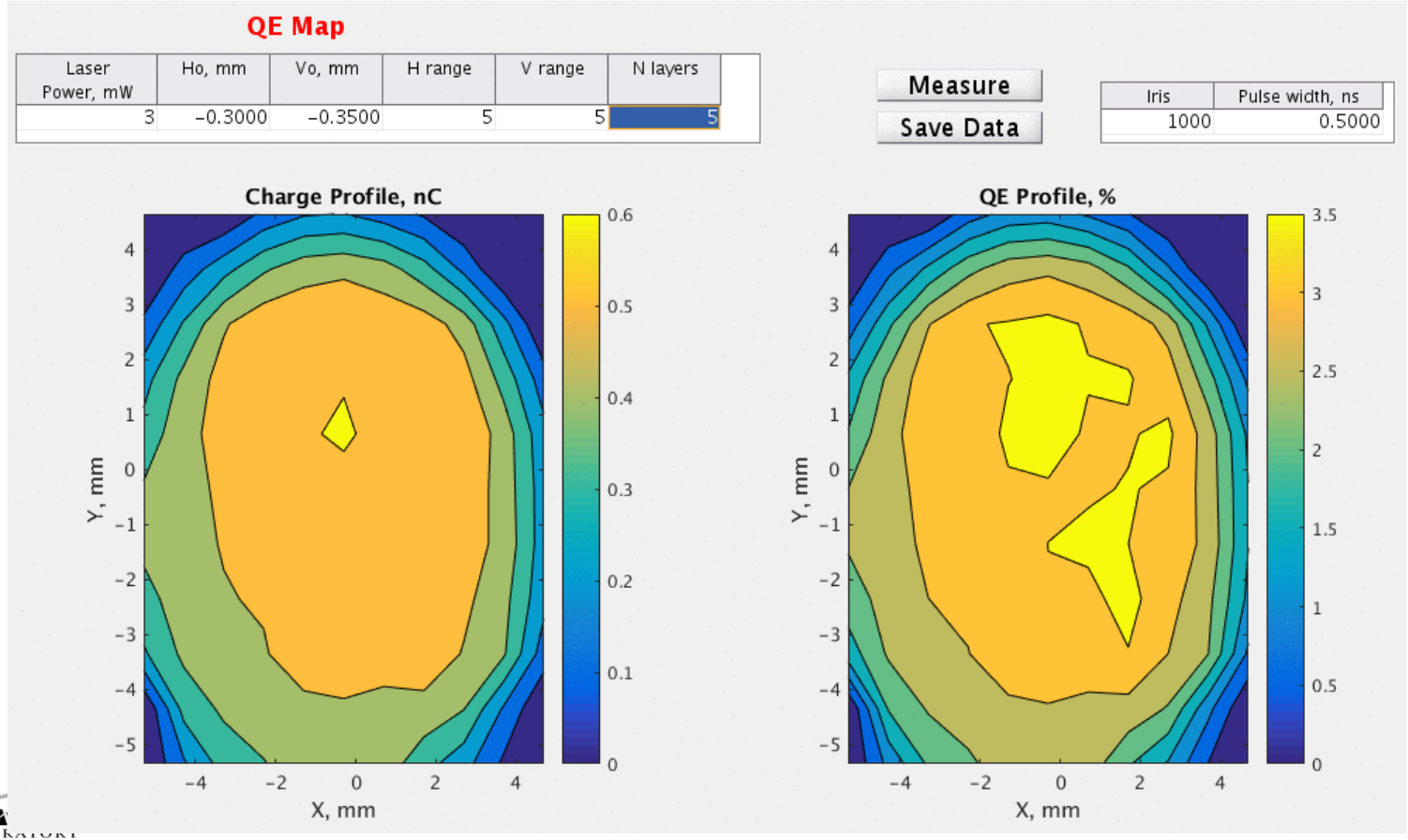
Save Data

Iris	Pulse width, ns
300	0.5000

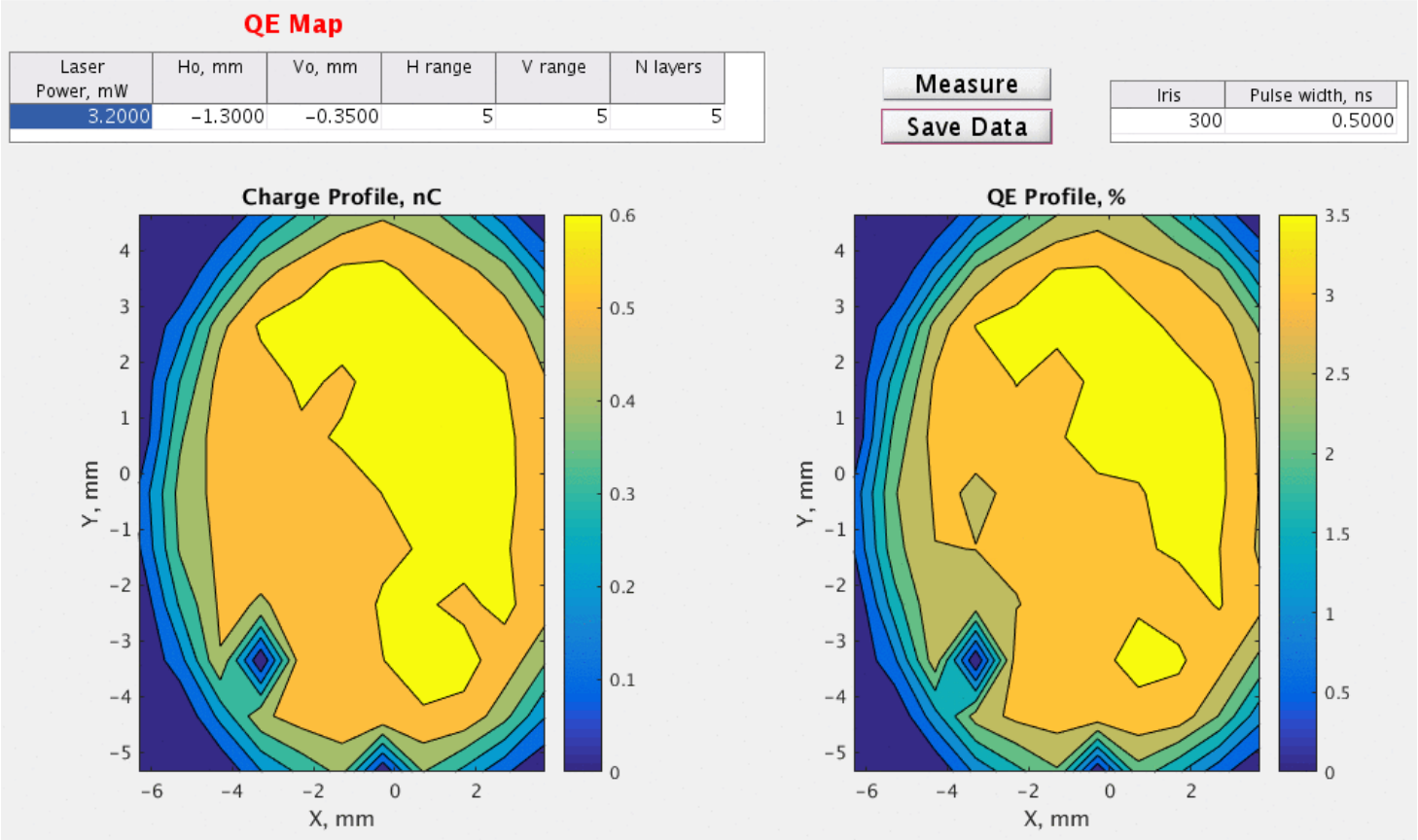




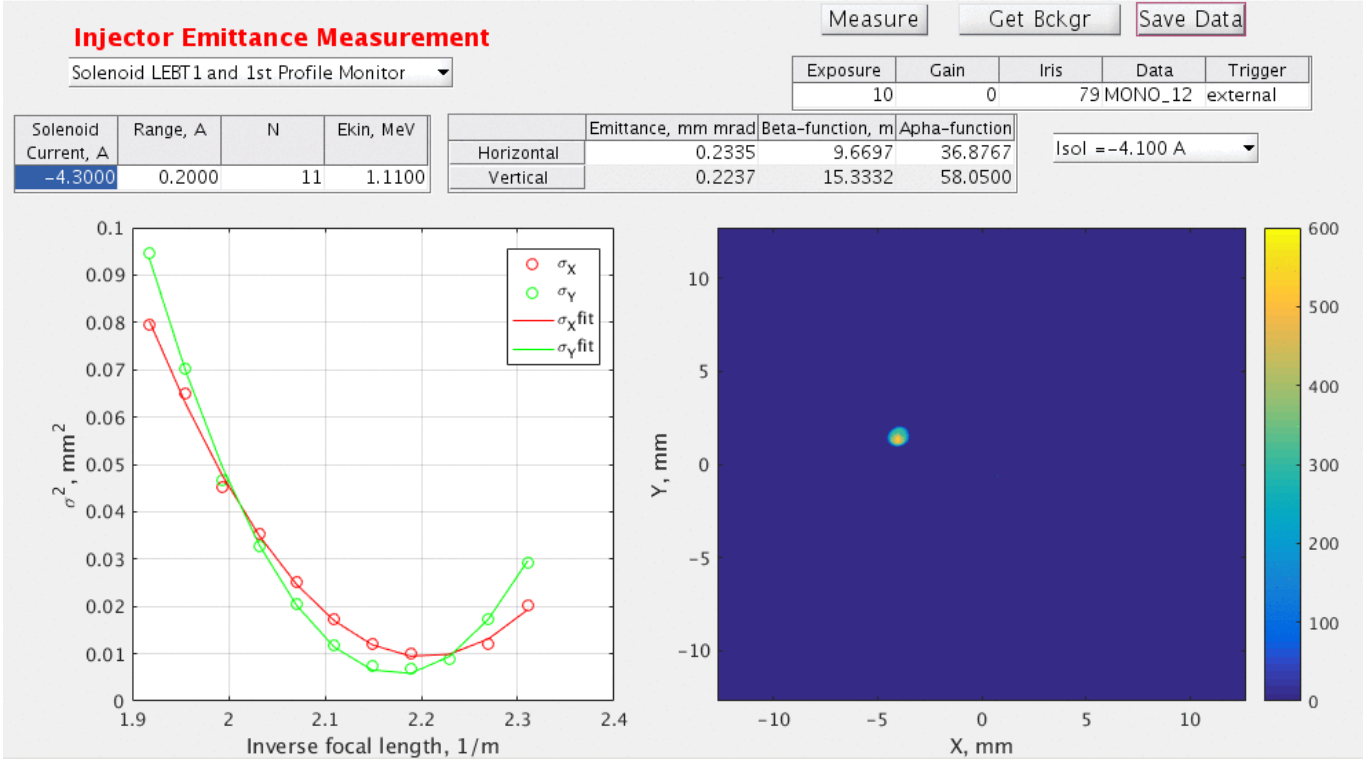
June 11


QE Map
Laser Power, mW
Ho, mm
Vo, mm
H range
V range
N layers
3
-0.3000
-0.3500
5
5
5
Measure
Save Data
Iris
Pulse width, ns
1000
0.5000
Charge Profile, nC
QE Profile, %
Y, mm
X, mm

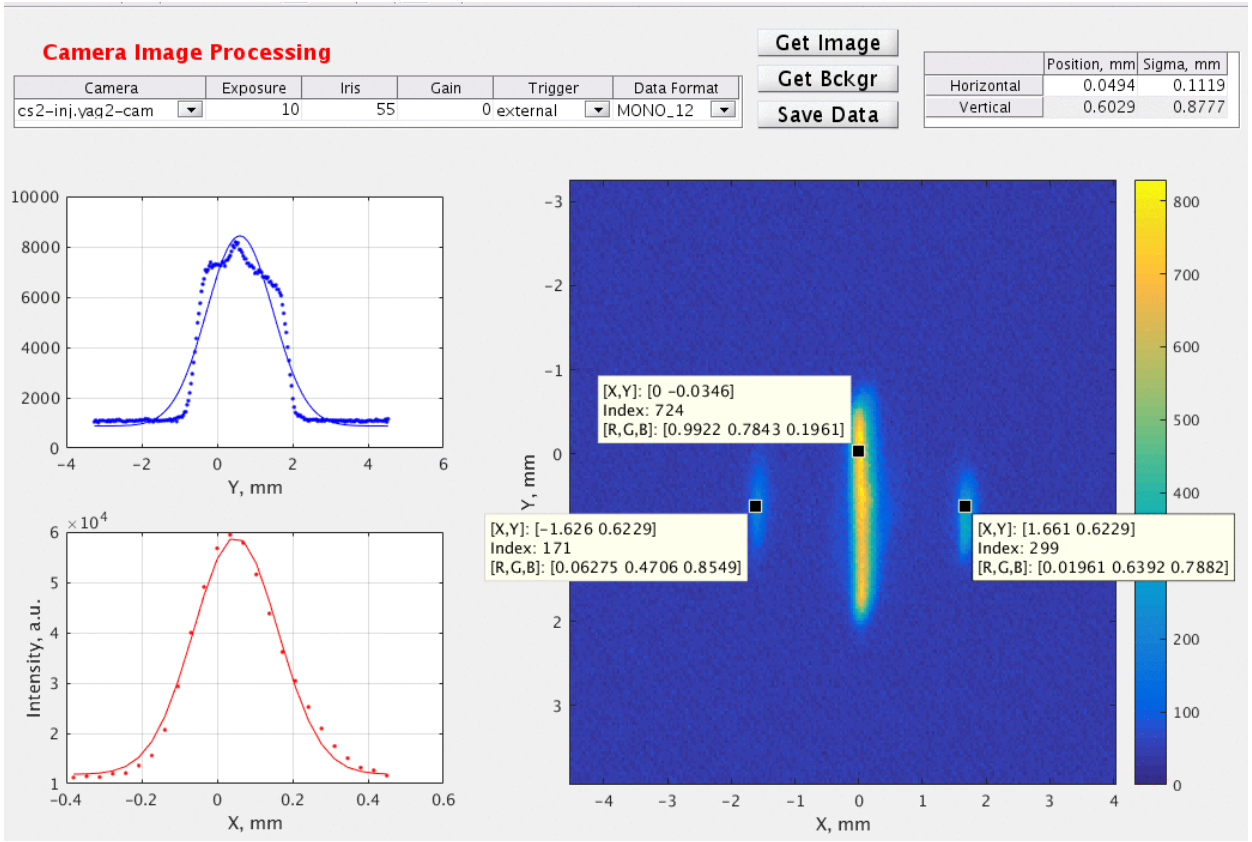
June 12


QE Map
Laser Power, mW
Ho, mm
Vo, mm
H range
V range
N layers
3.2000
-1.3000
-0.3500
5
5
5
Measure
Save Data
Iris
Pulse width, ns
300
0.5000
Charge Profile, nC
QE Profile, %
Y, mm
X, mm

Emittance of 150 pC Beam

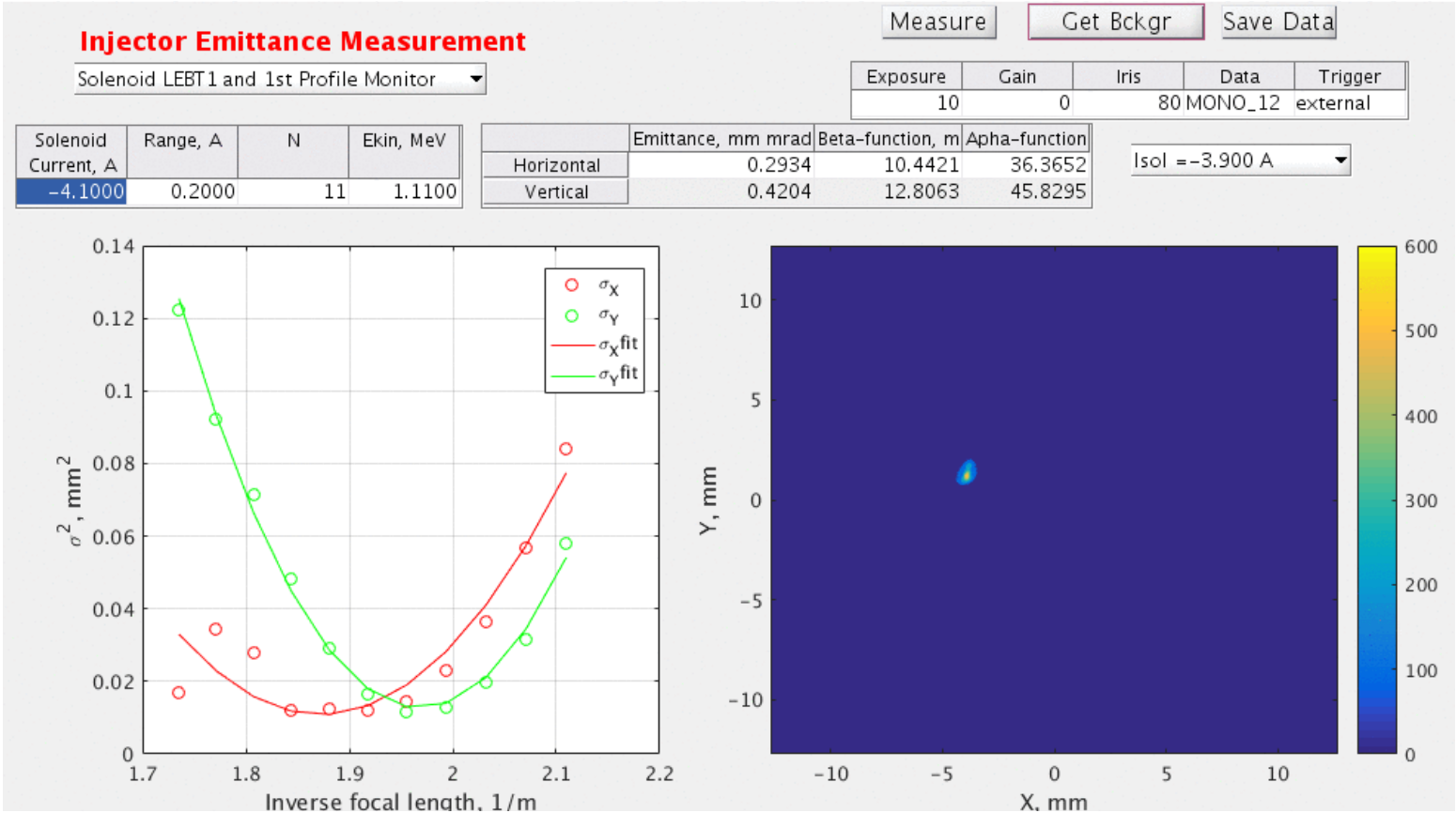


170 pC

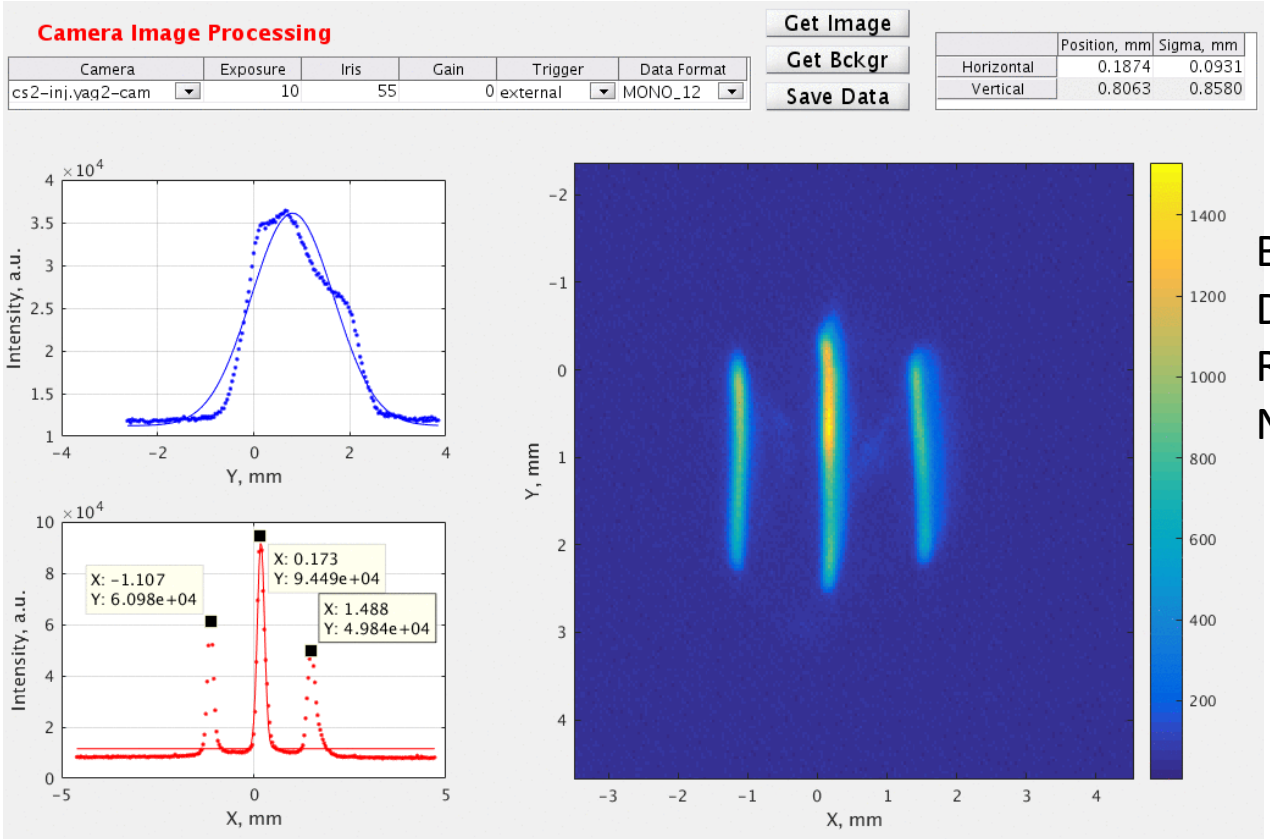


Beam size 1.0 mm
Divergence 0.31 mrad
R.m.s. emittance 0.31 mm mrad
Normalized 0.95 mm mrad

400 pC


Injector Emittance Measurement
Solenoid LEBT 1 and 1st Profile Monitor
Measure
Get Bckgr
Save Data
Exposure 10
Gain 0
Iris 80
Data MONO_12
Trigger external
Solenoid Current, A -4.1000
Range, A 0.2000
N 11
Ekin, MeV 1.1100
Emittance, mm mrad
Beta-function, m
Apha-function
Horizontal 0.2934 10.4421 36.3652
Vertical 0.4204 12.8063 45.8295
Isol =-3.900 A
σX
σY
σXfit
σYfit
σ2, mm2
Inverse focal length, 1/m
Y, mm
X, mm

430 pC



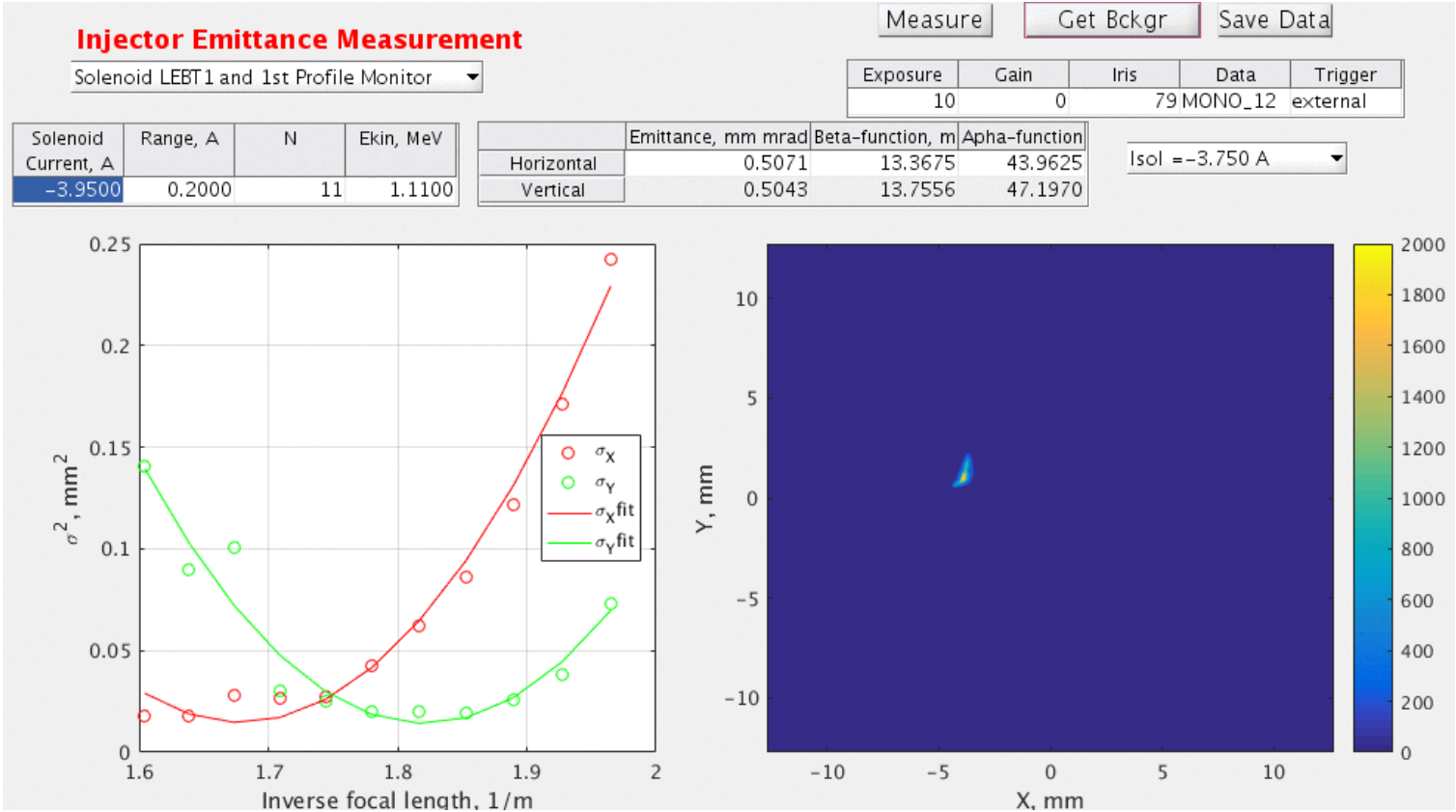
Beam size 1.2 mm

Divergence 0.27 mrad

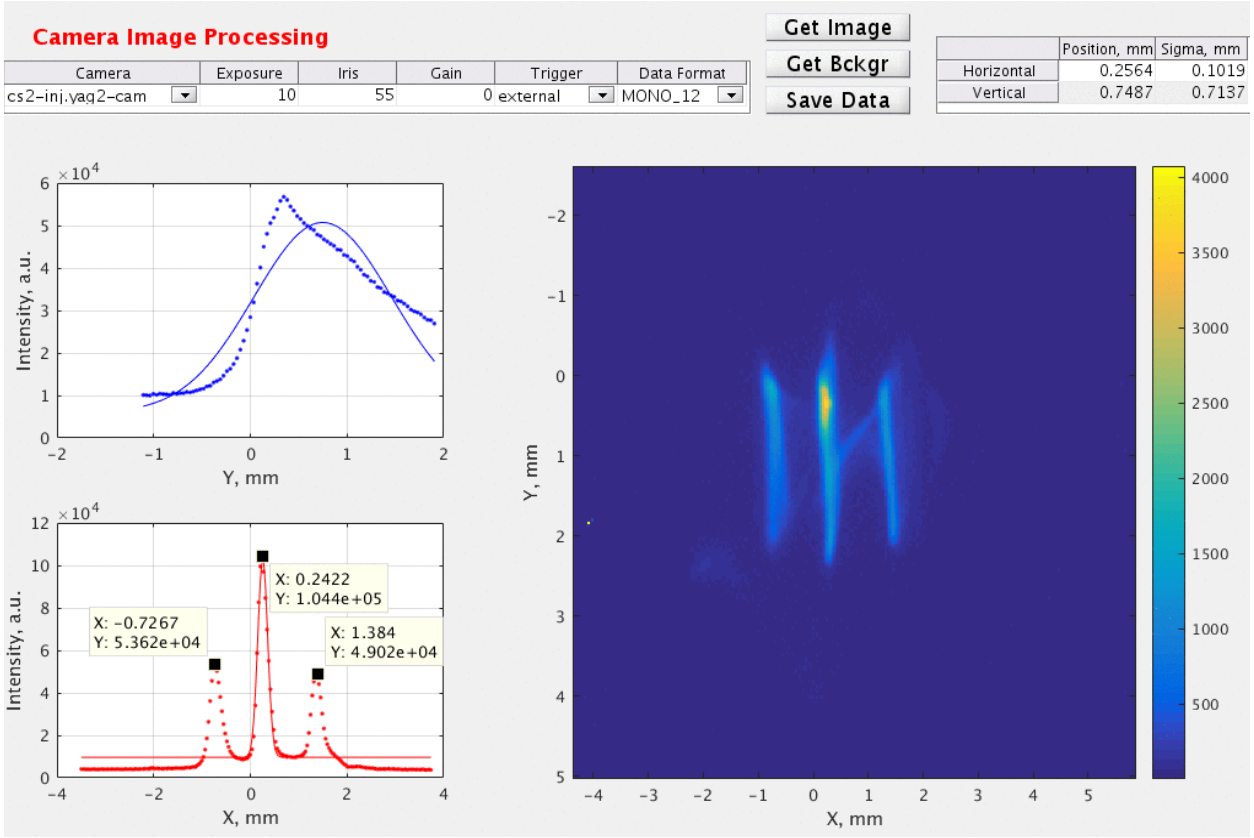
R.m.s. emittance 0.32 mm mrad

Normalized 0.98 mm mrad

640 pC

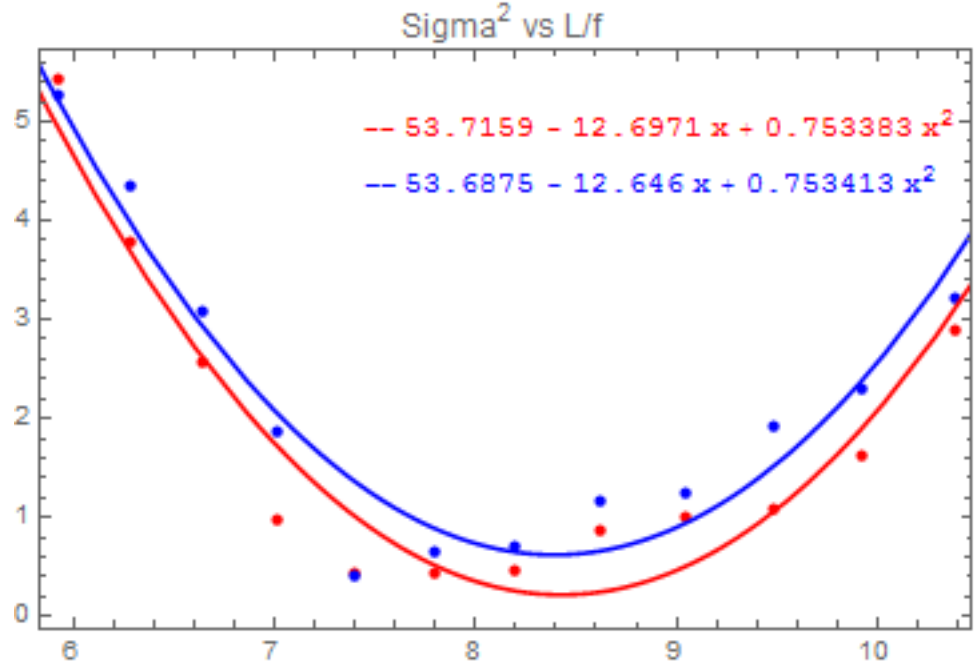

Injector Emittance Measurement
Measure
Get Bckgr
Save Data
Solenoid LEBT1 and 1st Profile Monitor
Exposure 10
Gain 0
Iris 79
Data MONO_12
Trigger external
Solenoid Current, A -3.9500
Range, A 0.2000
N 11
Ekin, MeV 1.1100
Emittance, mm mrad
Beta-function, m
Apha-function
Horizontal 0.5071 13.3675 43.9625
Vertical 0.5043 13.7556 47.1970
Isol =-3.750 A
σ2, mm2
Inverse focal length, 1/m
σX
σY
σXfit
σYfit
Y, mm
X, mm

640 pC



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

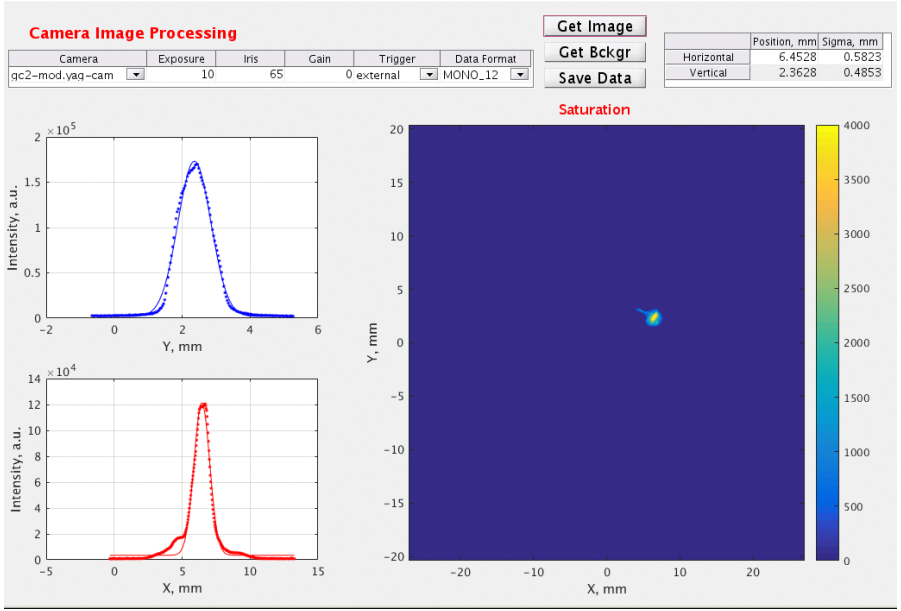
Best Achieved Emittance



The beam size was measured on the first profile monitor with scan of the gun solenoid. Beam kinetic energy is 1.04 MeV, beam charge 0.5 nC. Normalized emittance is 0.32 mm mrad.

Presented at IPAC'17

- We have demonstrated the record parameters for the SRF gun
- Warm cathode contributes to high QE and high beam charge
- Low frequency of the gun allows to generate electron beam close to conditions in a DC gun and fully utilize available field gradient
- Good vacuum inside SRF gun provides long lifetime for the cathode



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