High Charge High Current Beam from 113 MHz SRF Gun

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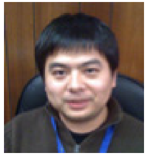

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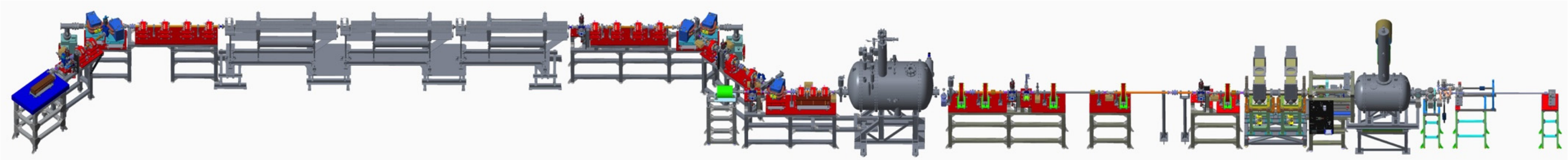
Coherent Electron Cooling Project



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 1.25 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 78 kHz

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Performance of SRF Guns

Main experimental results for five operational CW SRF photo-injectors

Parameter	CeC	FZD [1]	HZB [2]	NPS [3]	UW [4]
RF frequency, MHz	**113**	1300	1300	500	200
Type of the cavity	**QW**	Elliptical	Elliptical	QW	QW
Number of cells	**1**	3.5	1.4	1	1
LiHe temp, K^o	**4**	2	2	4	4
Beam energy, MeV	**1.25-1.5**	3.3	1.8	0.47	1.1
Charge per bunch, nC	**10.7**	0.3	0.006	0.078	0.1
Beam current, μA	**120**	18	0.005	<0.0001	<0.1
Dark current, nA	**< 1**	120	-	< 20, 000	< 0.001
E_{cath}, MV/m	**10 - 20**	5	7	6.5	12
Photocathode	**CsK_2Sb**	Cs_2Te	Pb	Ni	Cu
Laser wavelength, nm	**532**	266	266	266	266

Note: QW –quarter-wave cavity

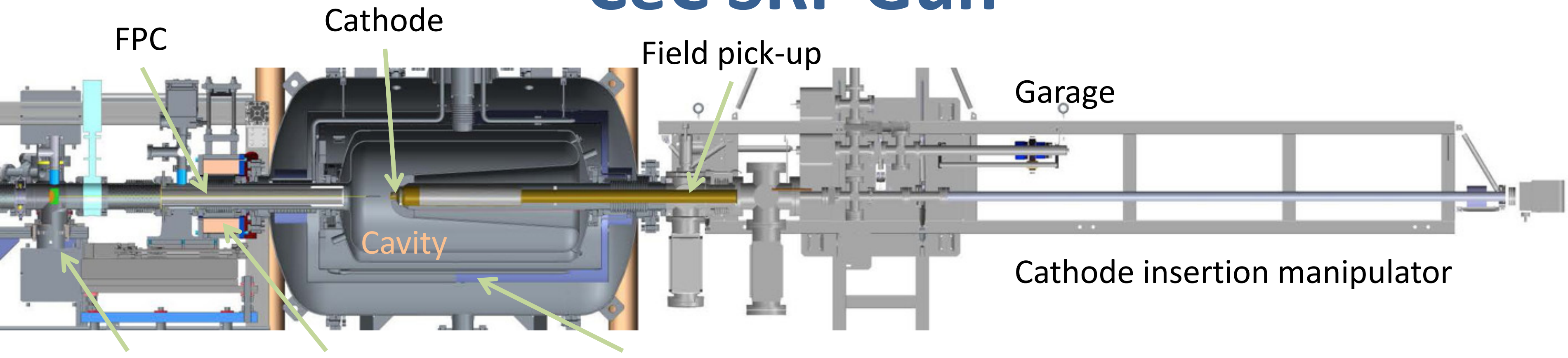
[1] A. Arnold et al., Nuclear Instruments and Methods in Physics Research A **593** (2008), p.57

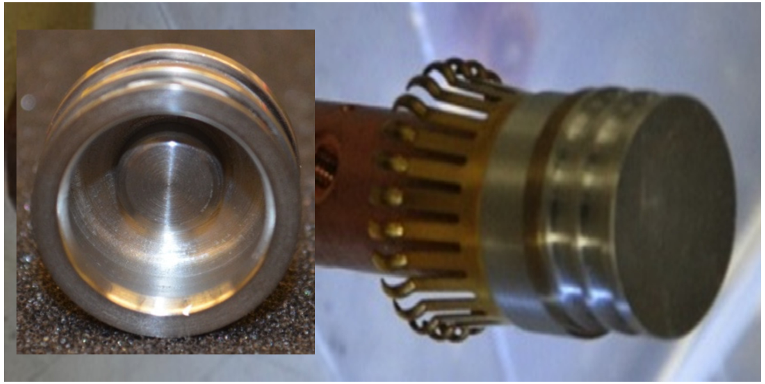
[2] M. Schmeißer et al., Proc. of IPAC 2013, Shanghai, China, 2013, p. 282

[3] J. R. Harris at al., Phys. Rev. Phys. Rev. ST Accel. Beams **14**, 053501 (2011)

[4] J. Bisognano at all, Proc. of NA PAC'13, 2013, Pasadena, CA, USA, p. 622

CeC SRF Gun

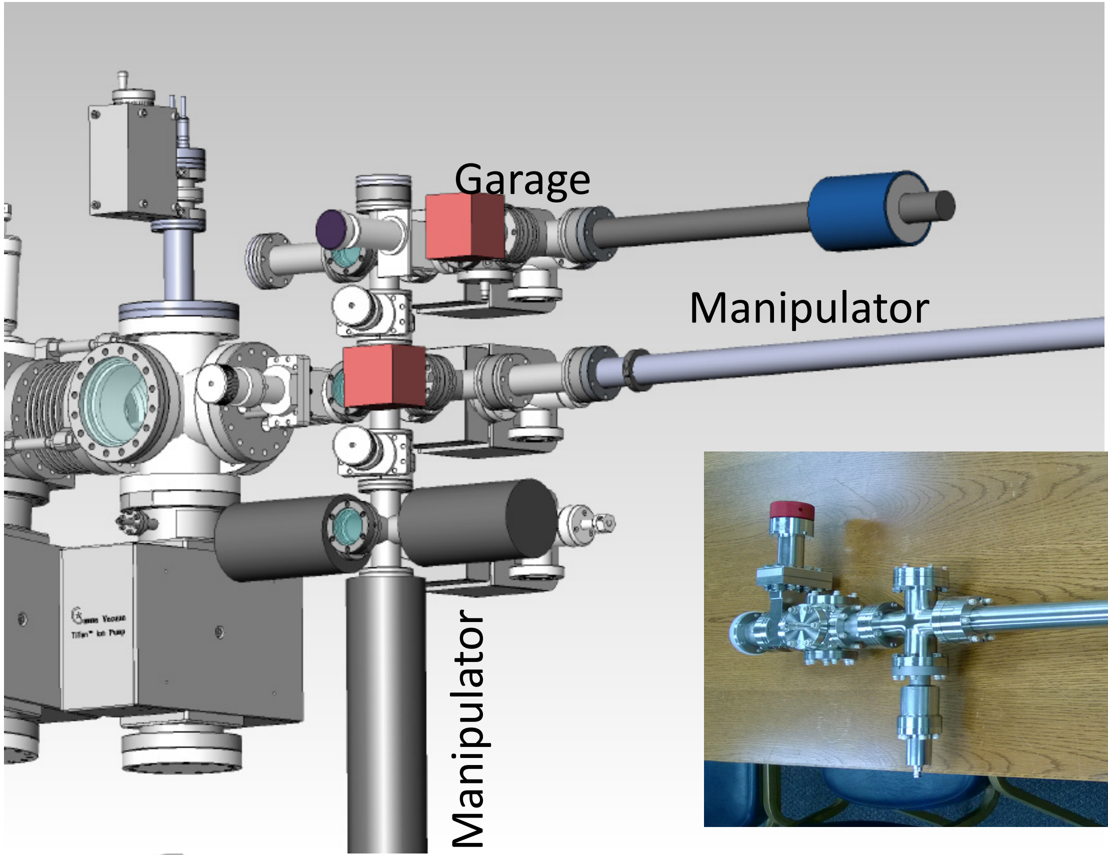




Photocathode end assembly

- Quarter-wave cavity
- 4 K operating temperature
- Manual coarse tuner
- Fine tuning is performed with FPC
- 8 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

Modified Cathode Launch System



Added port for QE monitoring inside the garage
Added NEG getters to improve vacuum during cathode transfer
Added port aligner for long manipulator

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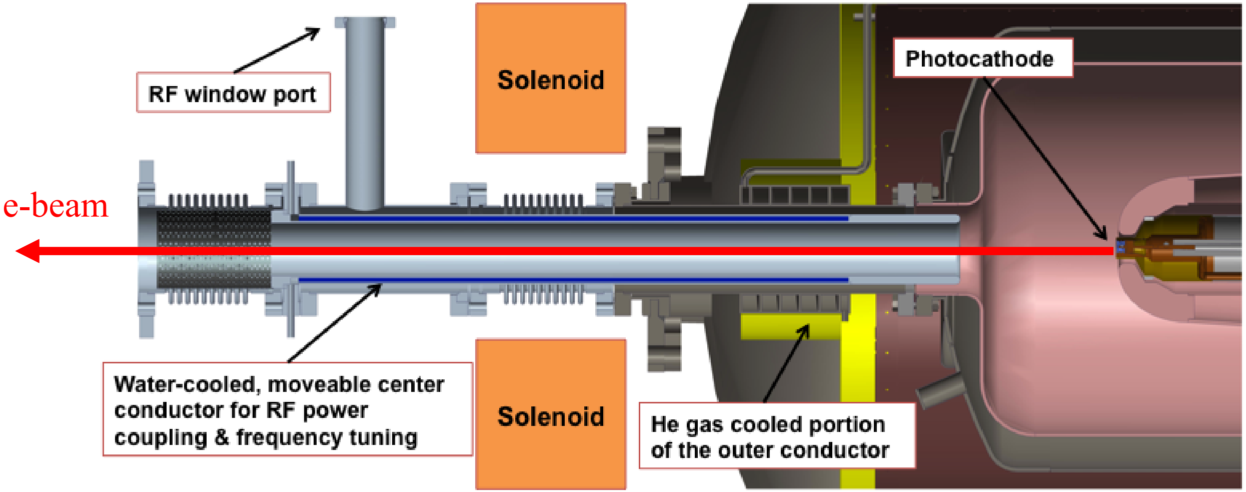
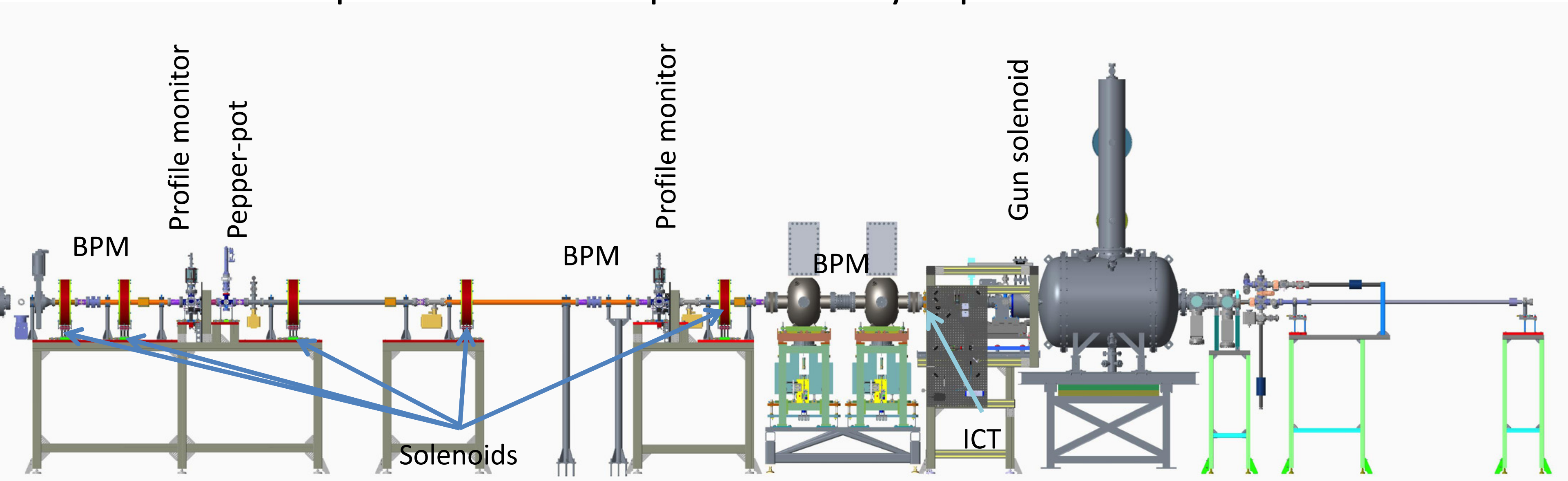
Fundamental Power Coupler/Frequency Tuner



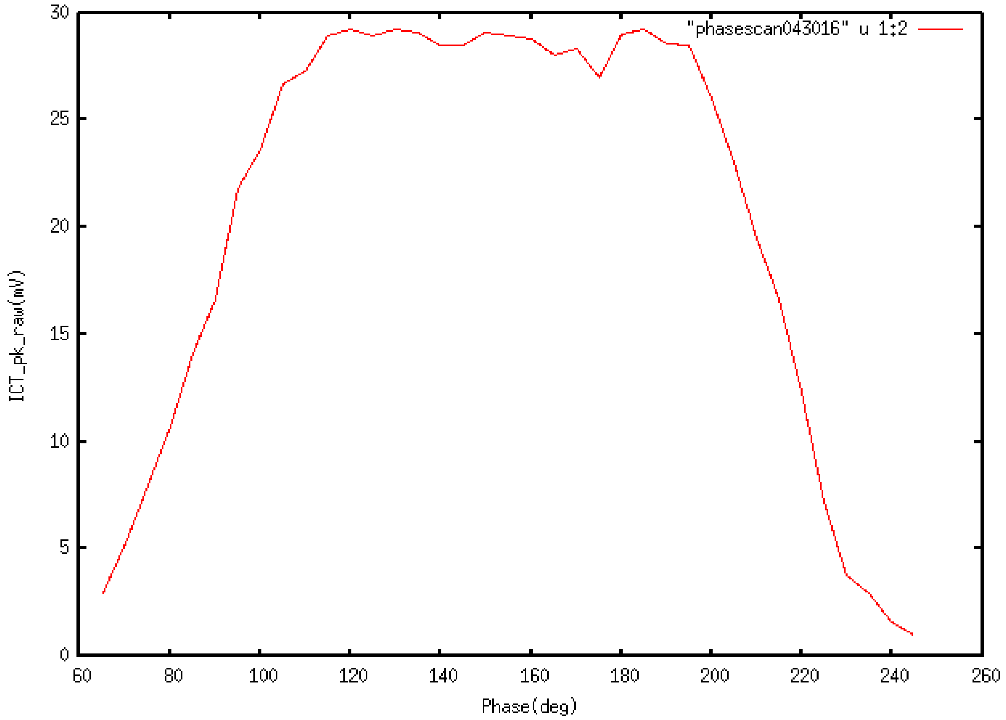
- Fundamental RF power coupling and fine frequency tuning is accomplished via a coaxial beam pipe at the beam exit port. With the travel of ±2 cm, the tuning range is ~6 kHz. Coarse tuning is accomplished manually via mechanical linkages outside the cryomodule.
- The center conductor and RF windows are water cooled. The outer conductor bellows (copper plated) are air cooled.
- The center conductor is gold plated to reduce heat radiated into cold SRF cavity.

Diagnostics for Low Energy Beam

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

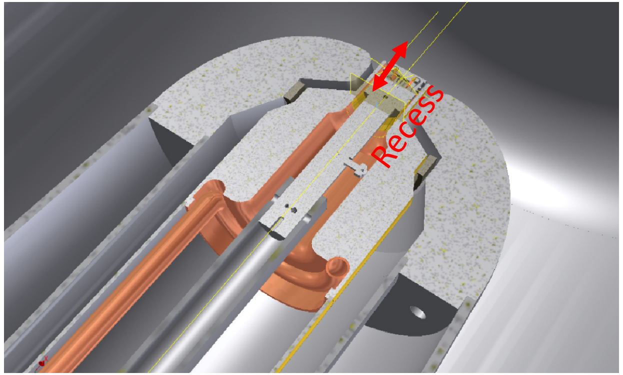


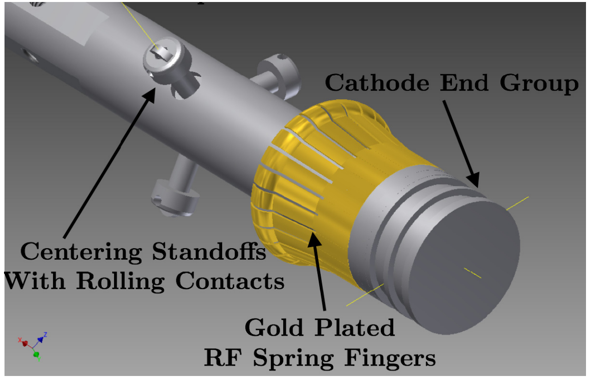
Cavity Phase Scan

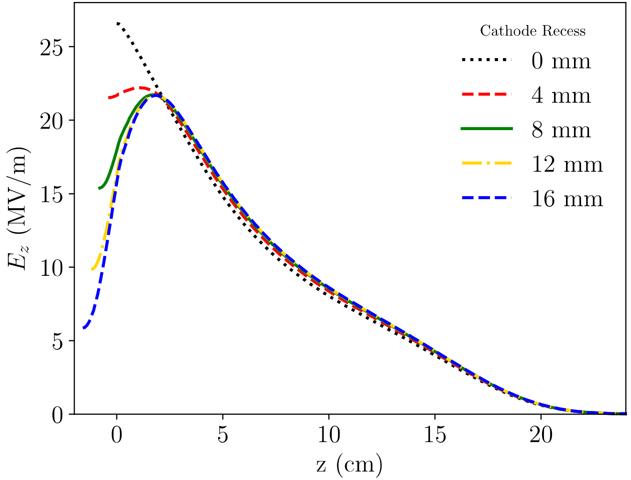


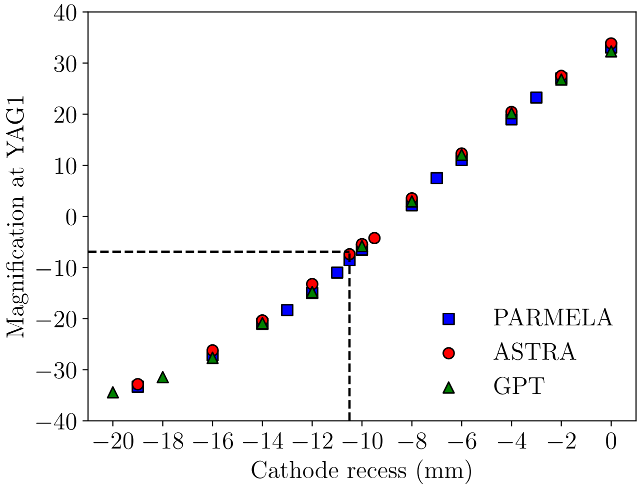
Cavity phase scan is consistent with simulations. More than 180 degrees range is due to the long laser pulse (40° of RF phase).

Controlling Cathode Recess/Focusing

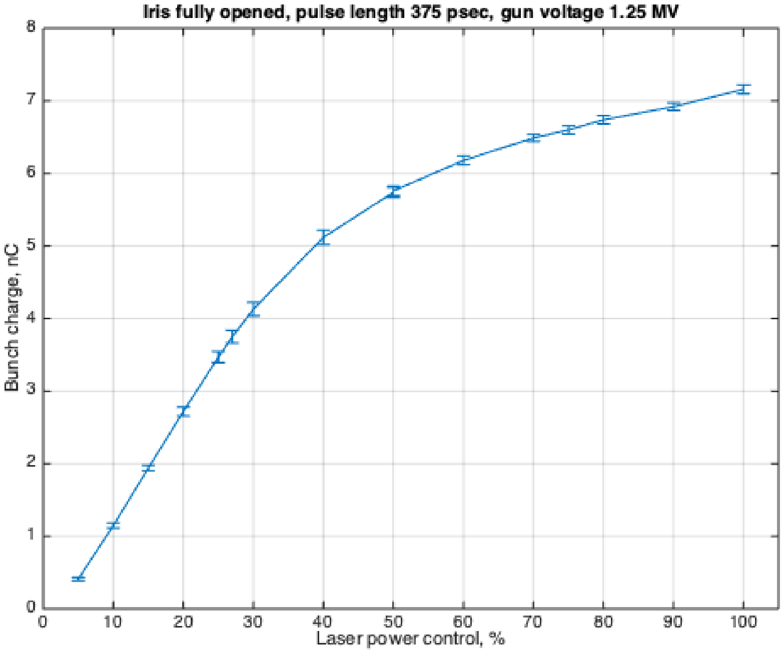


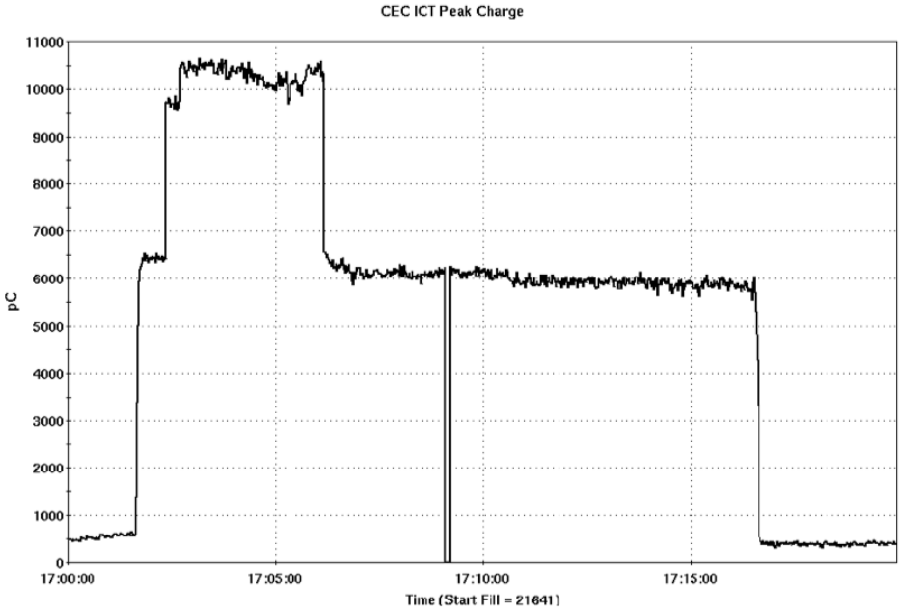






Beam Charge vs. Laser Power

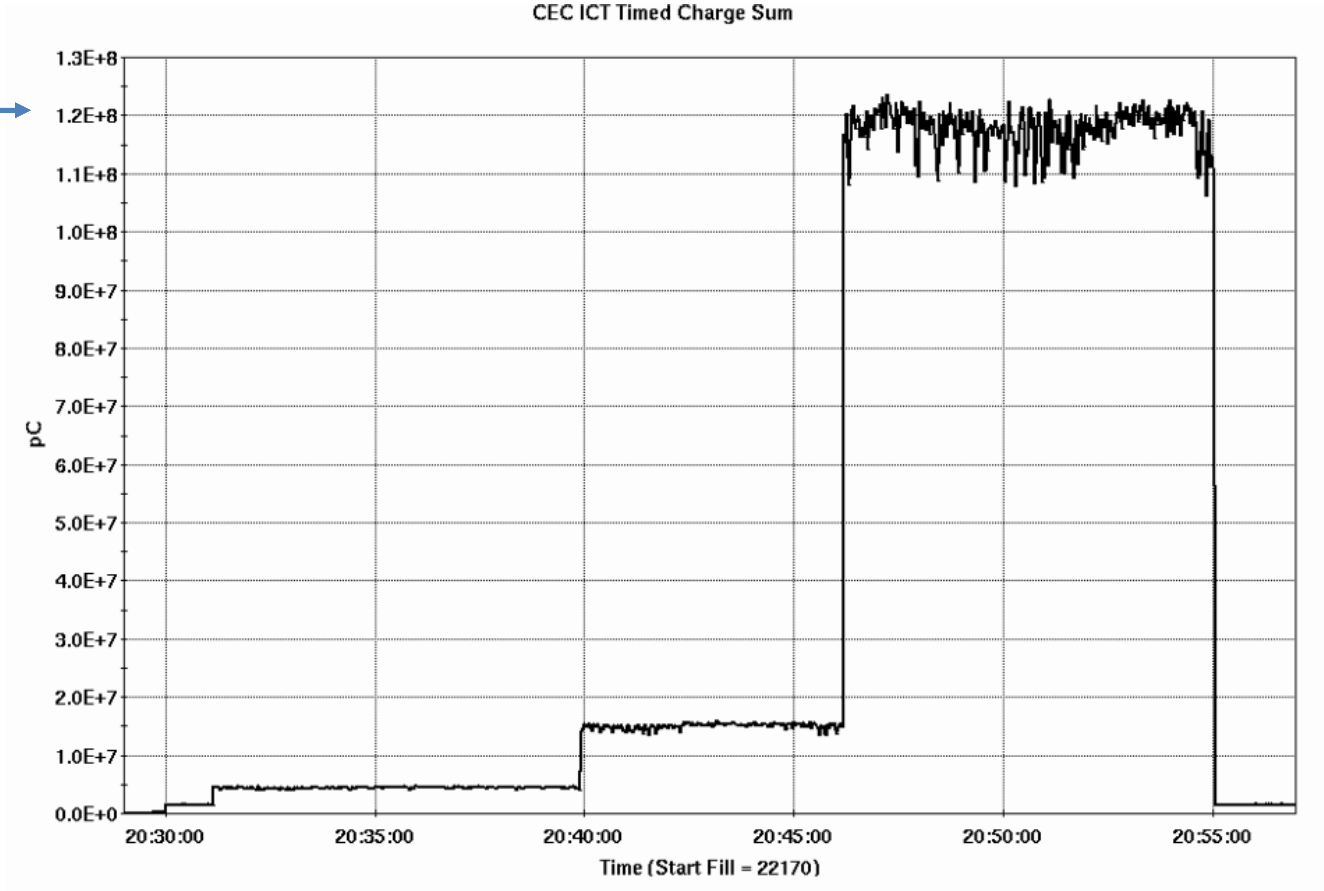




Gun voltage 1.25 MV
Laser spot 6 mm diameter
Bunch length 375 psec

Beam Current During Experiment

120 μA



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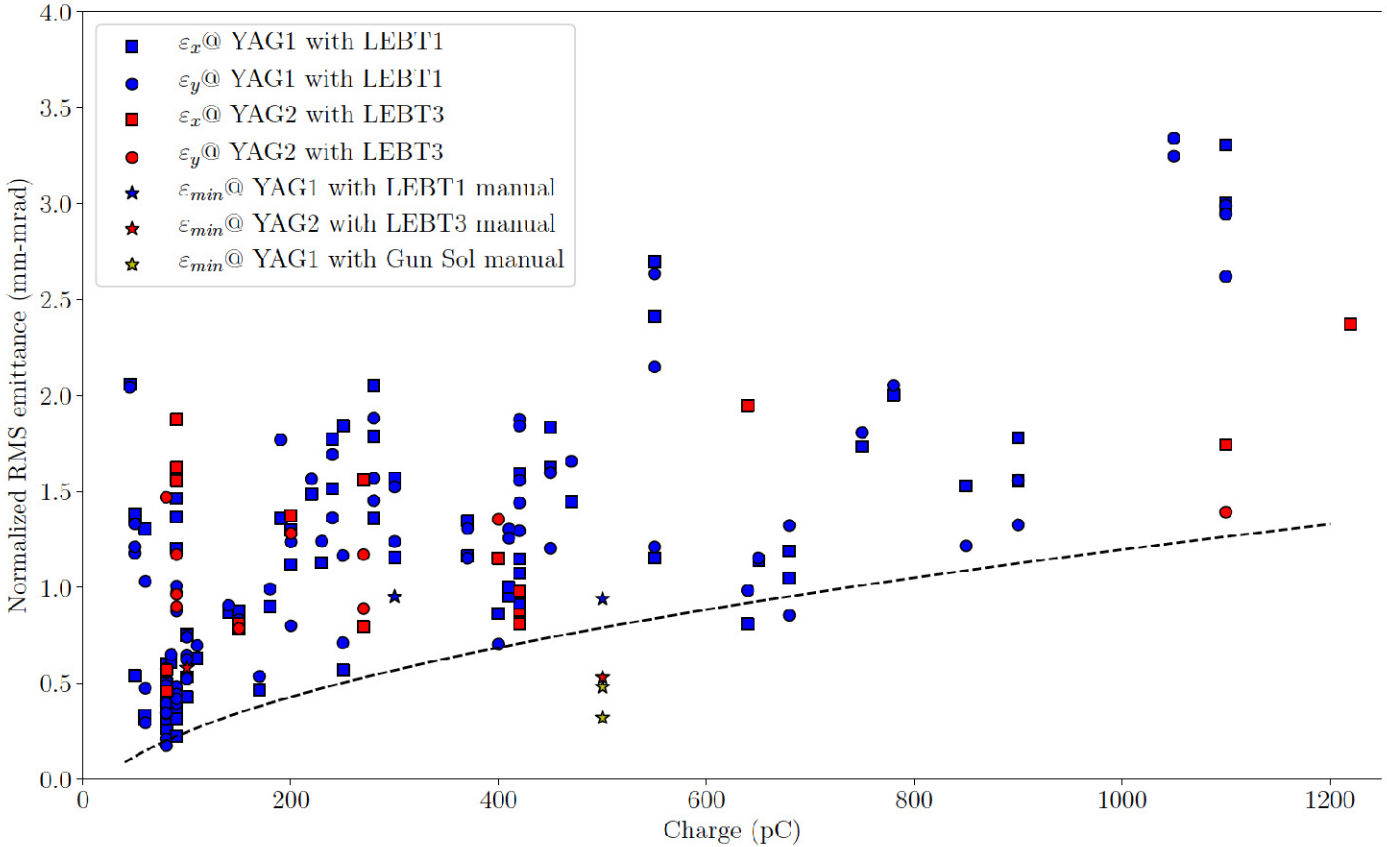
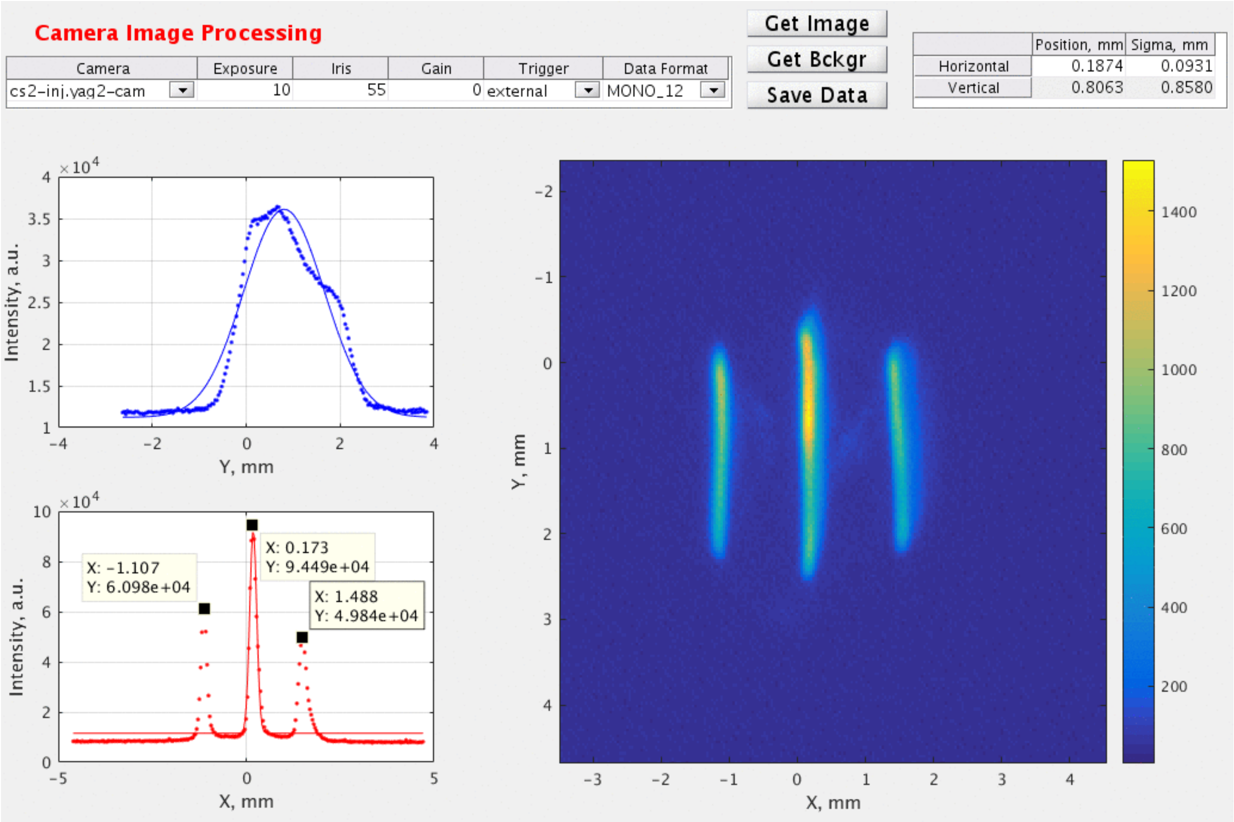
Measured Emittances for Variety of Settings



Emittance of 430 pC Beam



Beam size 1.2 mm

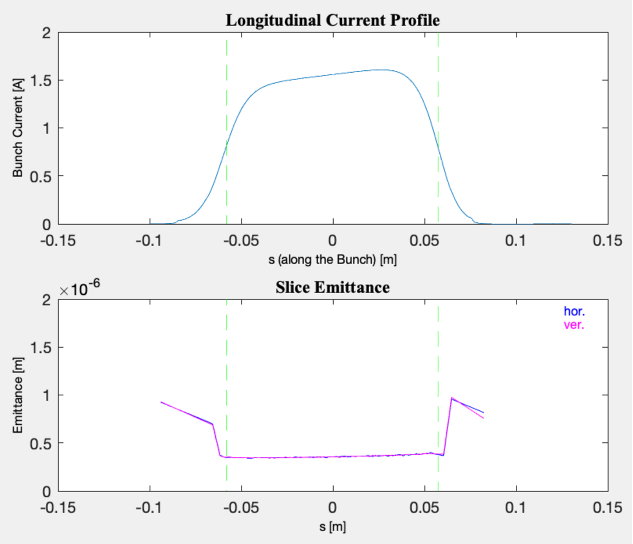
Divergence 0.27 mrad

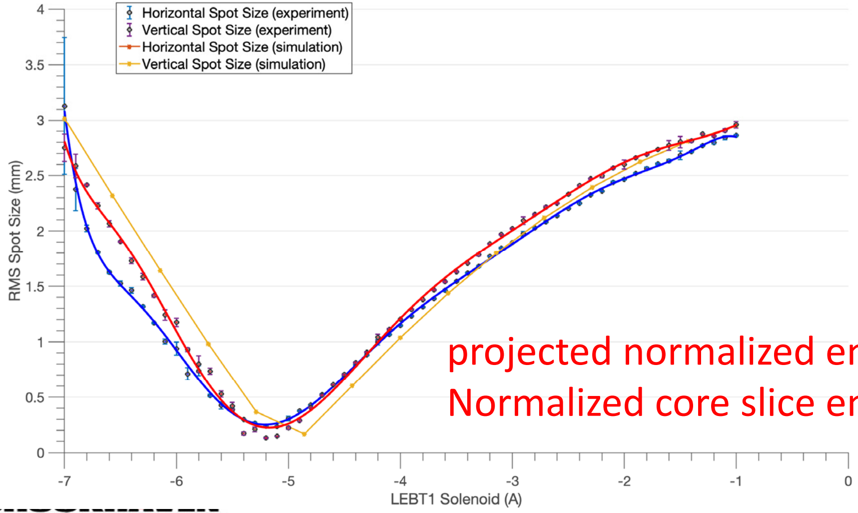
R.m.s. emittance 0.32 mm mrad

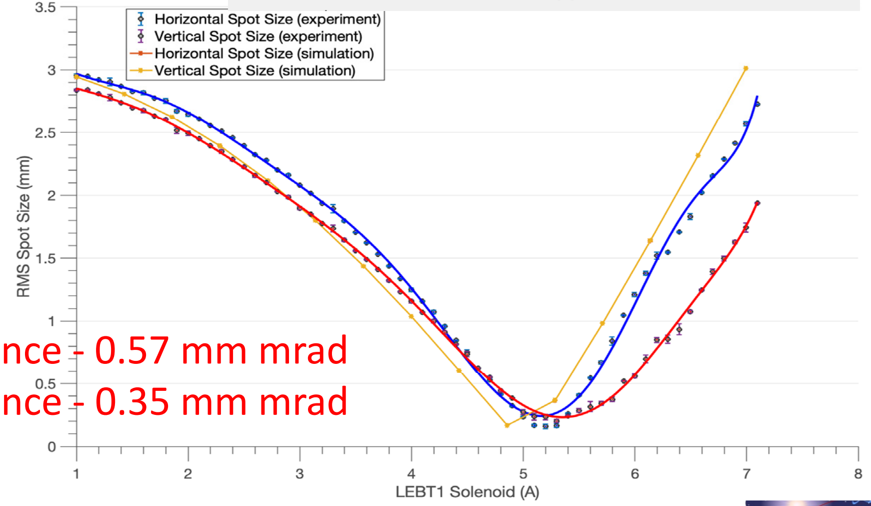
Normalized 0.98 mm mrad

Emittance Measurement

Gun energy: 1.25 MV
Laser spot on cathode r.m.s. size: 0.8mm (3.2 mm diameter)
Bunch charge: 600 pC
Bunch length: 400 ps
Gun solenoid: 8.6 A
LEBT1 solenoid varied from -7 to -1 A (left) and 1 to 7 A (right)







projected normalized emittance - 0.57 mm mrad
Normalized core slice emittance - 0.35 mm mrad

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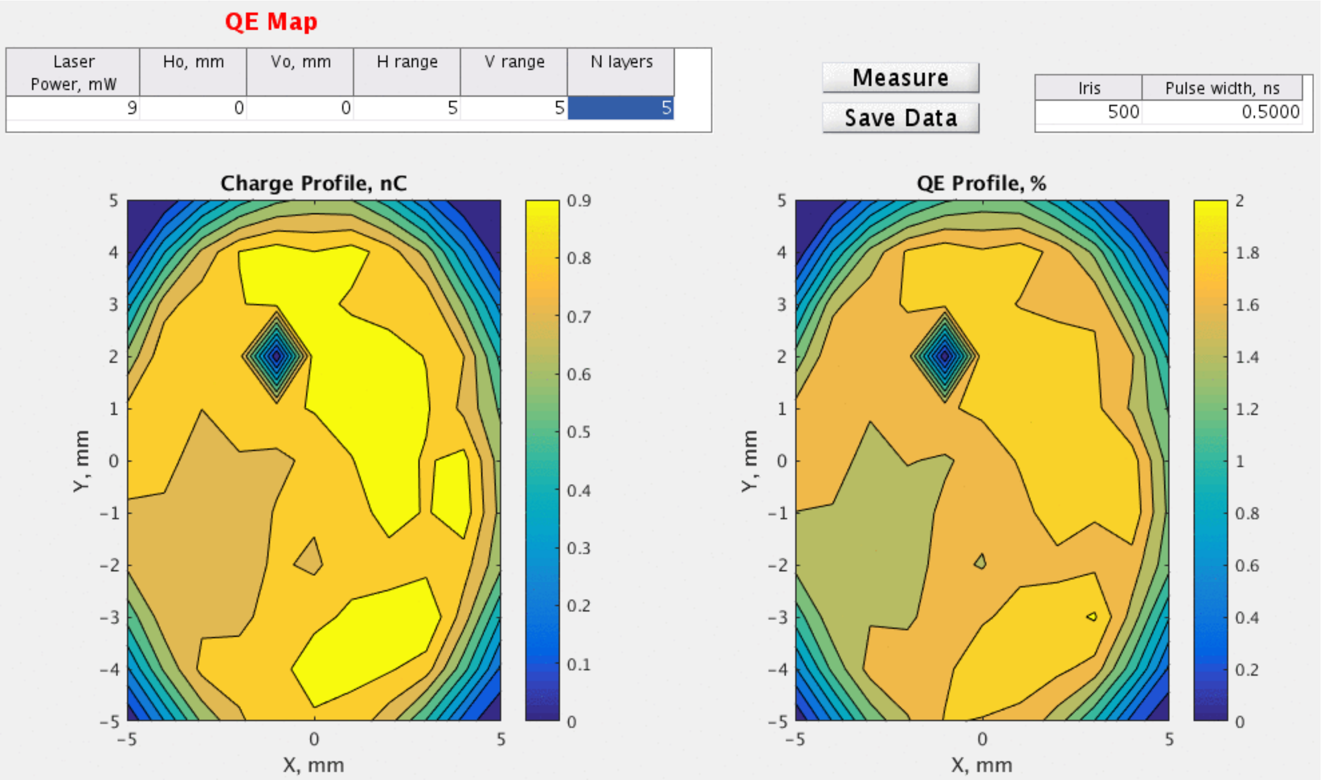
QE Map after Cathode Change (June 7th)



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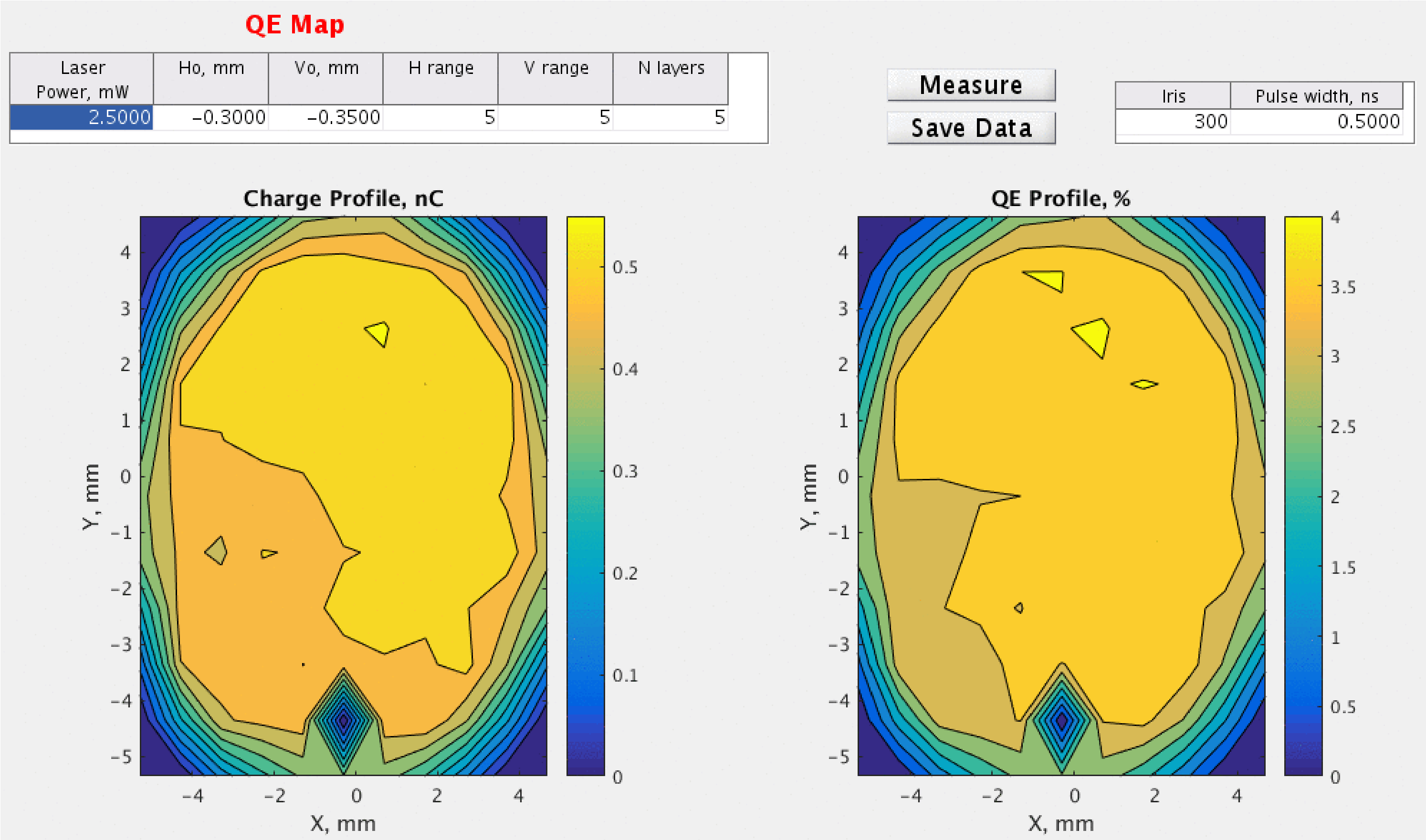
QE Map two days later (June 9th)



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June 11th

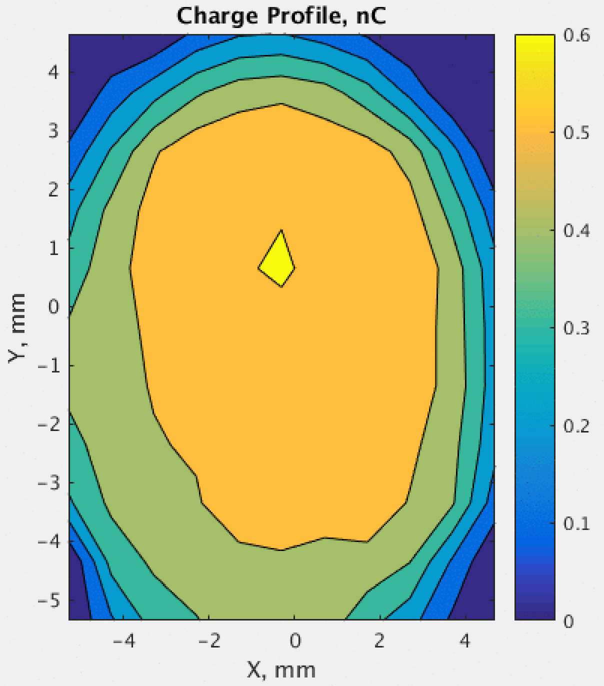
QE Map

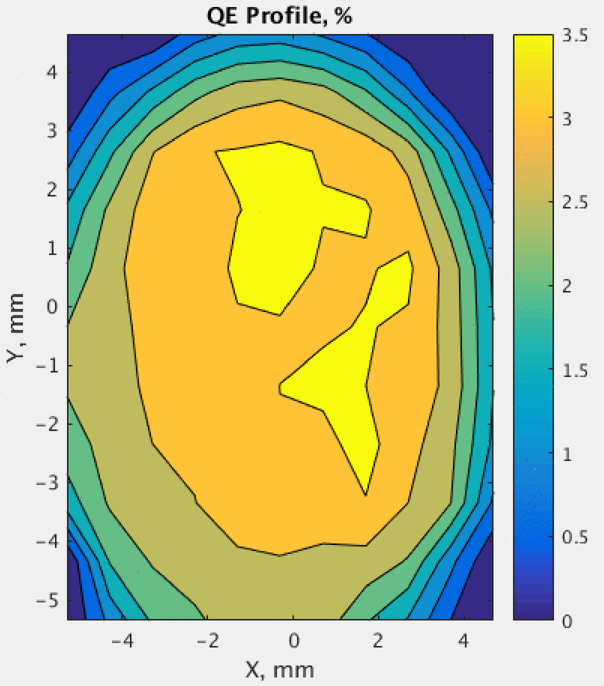
Laser Power, mW	Ho, mm	Vo, mm	H range	V range	N layers
3	-0.3000	-0.3500	5	5	5

Measure

Save Data

Iris	Pulse width, ns
1000	0.5000





June 12th

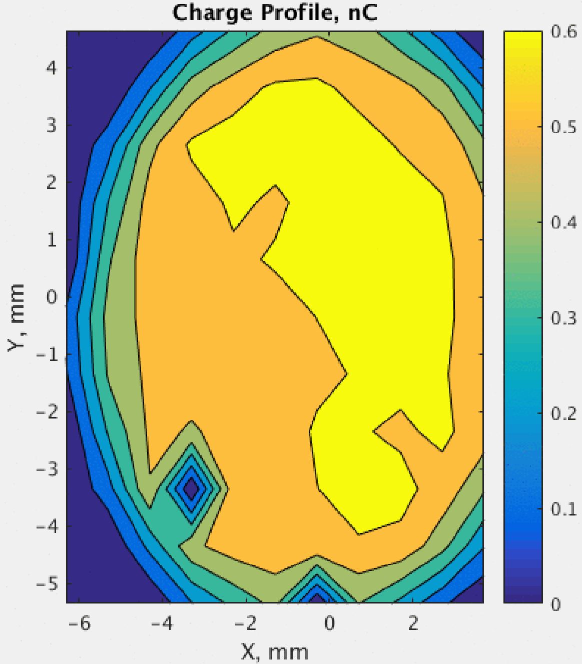
QE Map

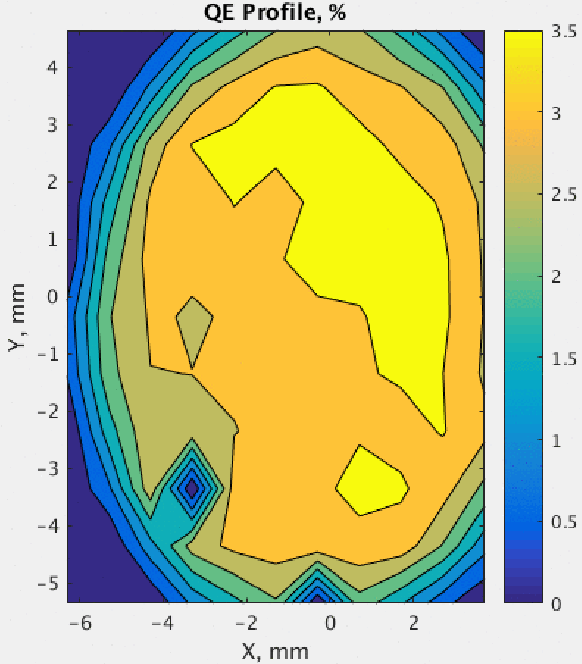
Laser Power, mW	Ho, mm	Vo, mm	H range	V range	N layers
3.2000	-1.3000	-0.3500	5	5	5

Measure

Save Data

Iris	Pulse width, ns
300	0.5000





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QE Map after Month of Operation

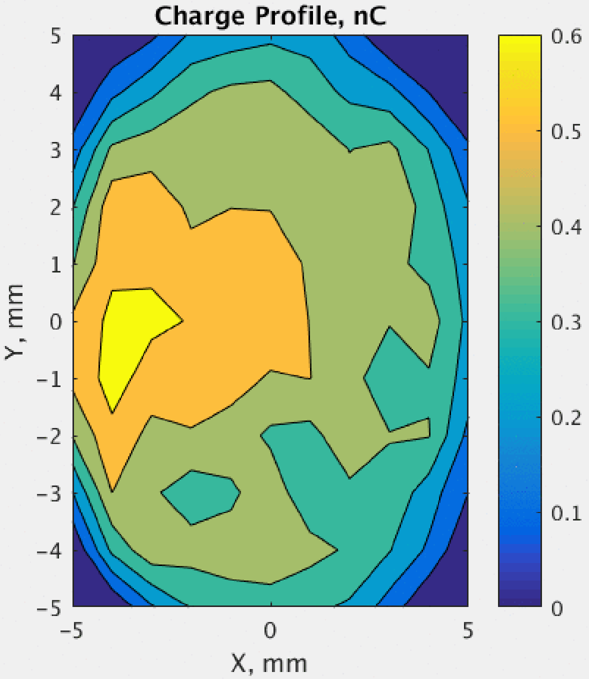
QE Map

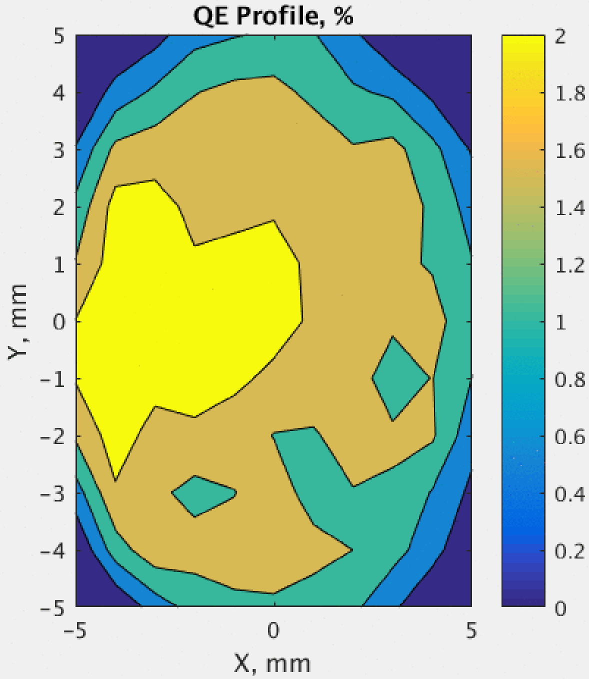
Laser Power, mW	Ho, mm	Vo, mm	H range	V range	N layers
4.7000	0	0	5	5	5

Measure

Save Data

Iris	Pulse width, ns
500	0.3000





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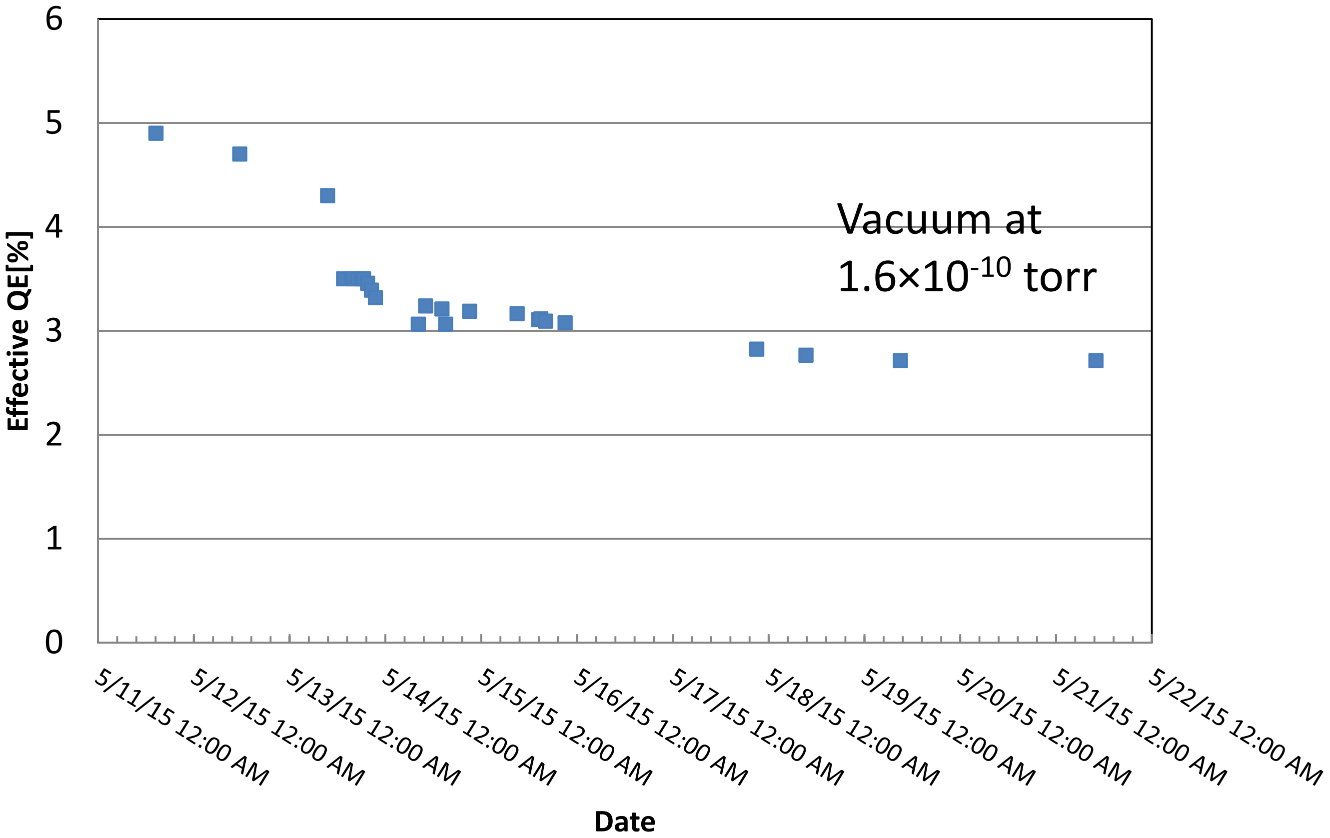
Cathode QE Evolution



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

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Conclusions

- We have demonstrated the record parameters for the SRF CW gun both in charge per bunch and transverse emittance
- Photocathode at room temperature has high QE
- 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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