Record Performance of CeC SRF Gun

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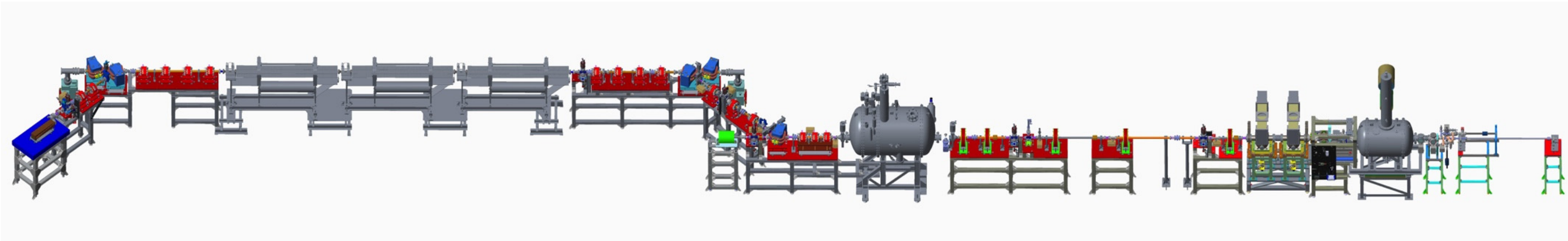
Record Beam Generated by SRF Gun Operating in CW Mode

- Bunch charge exceeds 2 nC
- Beam 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	2100
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

Coherent Electron Cooling Project

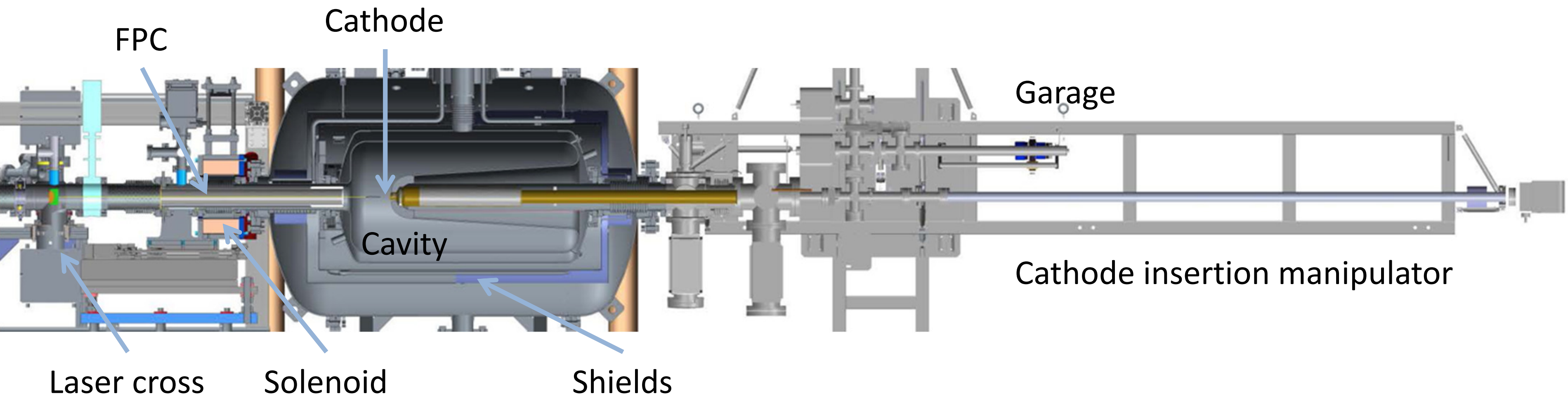


Electron beam is generated by 113 MHz SRF gun with photocathode driven by a 532 nm laser. Two 500 MHz copper cavities provide energy chirp and beam is compressed to desired peak current. After compression beam is accelerated by a 704 MHz SRF cavity and merged into CeC PoP structure having three helical undulators.

Electron Beam Parameters for CeC

- Gun energy 1.5-2 MeV
- Beam charge 1-5 nC
- Final beam energy 22 MeV
- Normalized emittance < 5 mm mrad
- Energy spread 10^{-3}
- Pulse repetition rate 78 kHz

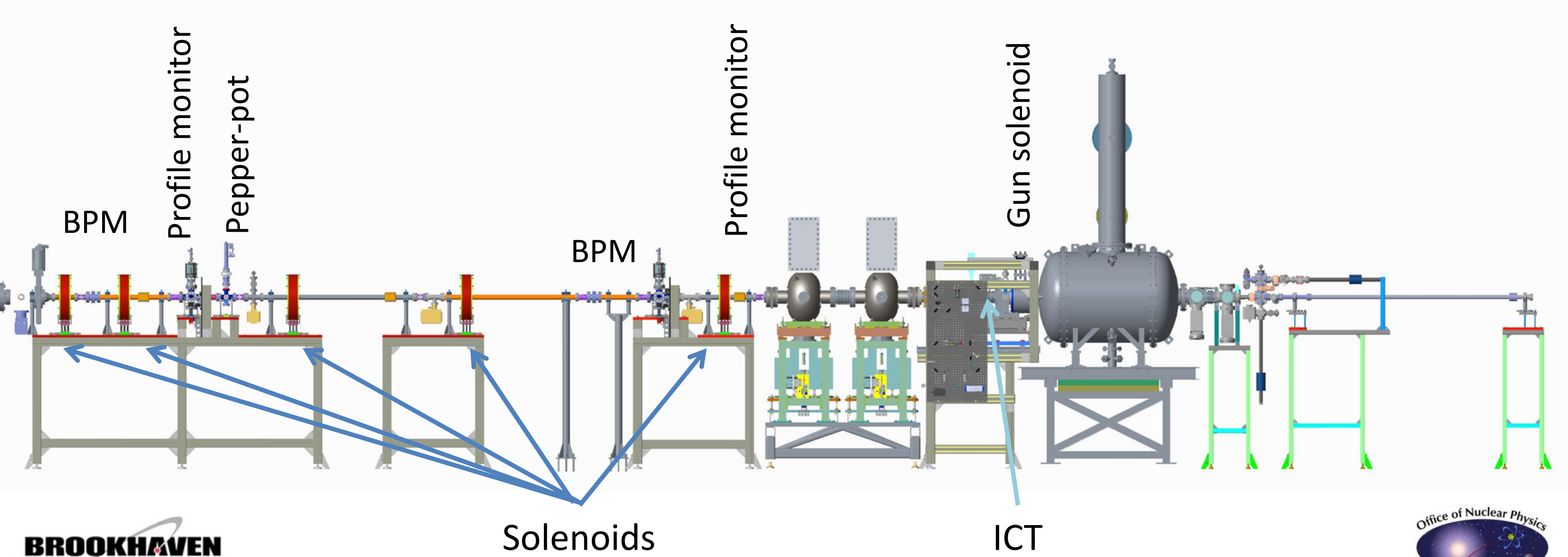
CeC SRF Gun



- Quarter-wave cavity
- 4 K operating temperature
- Manual coarse tuner
- Fine tuning is performed with FPC
- 2 kW CW solid state power amplifier
- CsK_2Sb Cathode is at room temperature
- Cavity field pick-up is done with cathode stalk (1/2 wavelength with capacitive pick-up)
- Up to three cathodes can be stored in garage for quick change-out
- Design gradient 22.5 MV/m

Diagnostics for Low Energy Beam

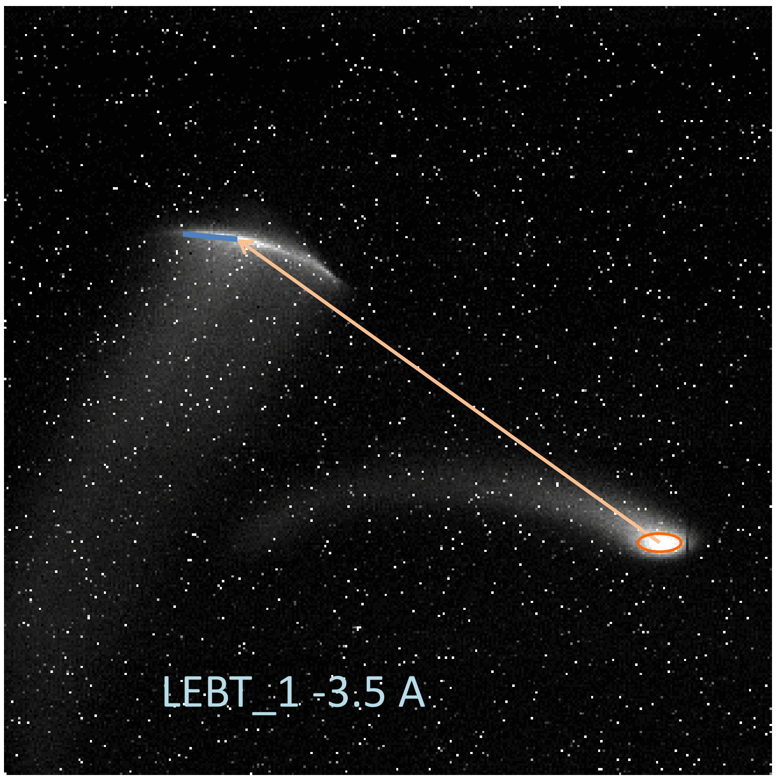
- Integrating current transformer (1.25 nV s/nC)
- Two beam profile monitors with 1.3 megapixel cameras
- Pepper-pot in front of the second profile monitor
- Two BPMs
- Low power beam dump with Faraday cup

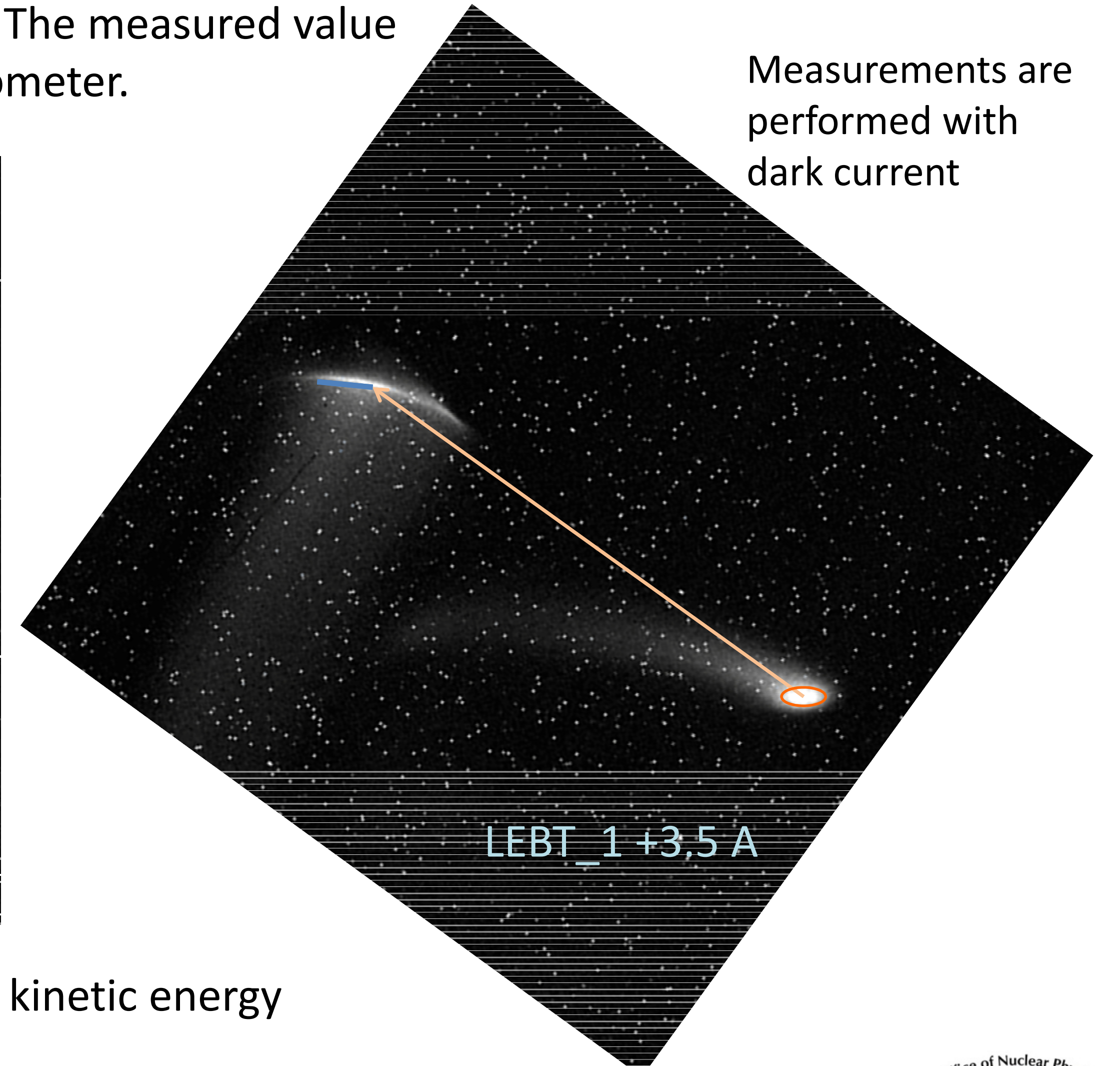


Beam Energy Measurement

We utilized rotation of the electron beam by a calibrated solenoid to measure beam energy. The measured value was confirmed with energy spectrometer.

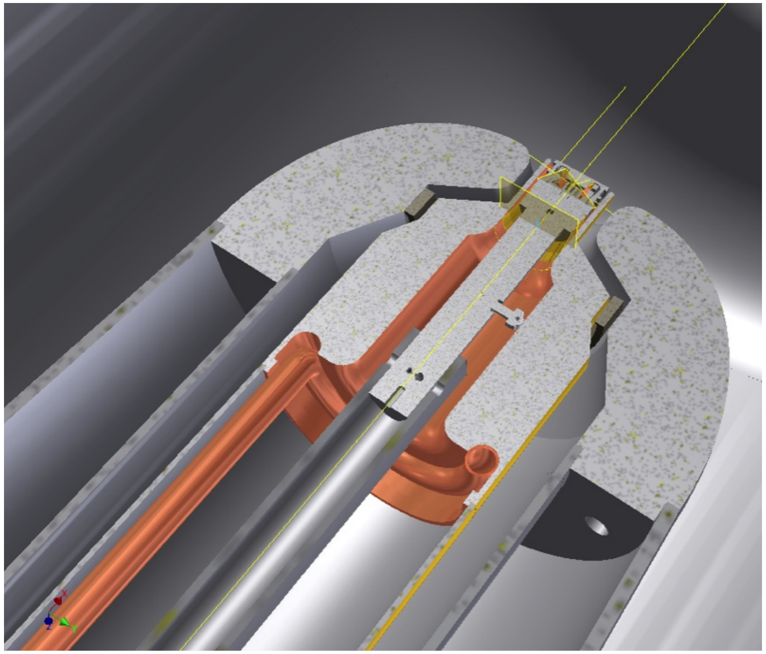
Measurements are performed with dark current

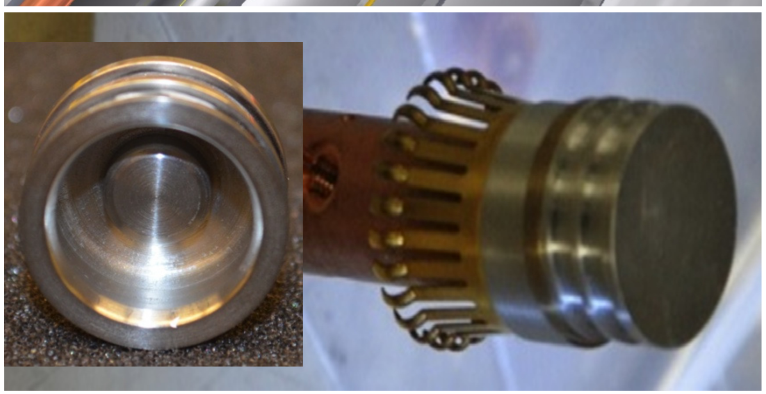




Rotation angle 54° - 1.19 MeV kinetic energy

Problems Encountered

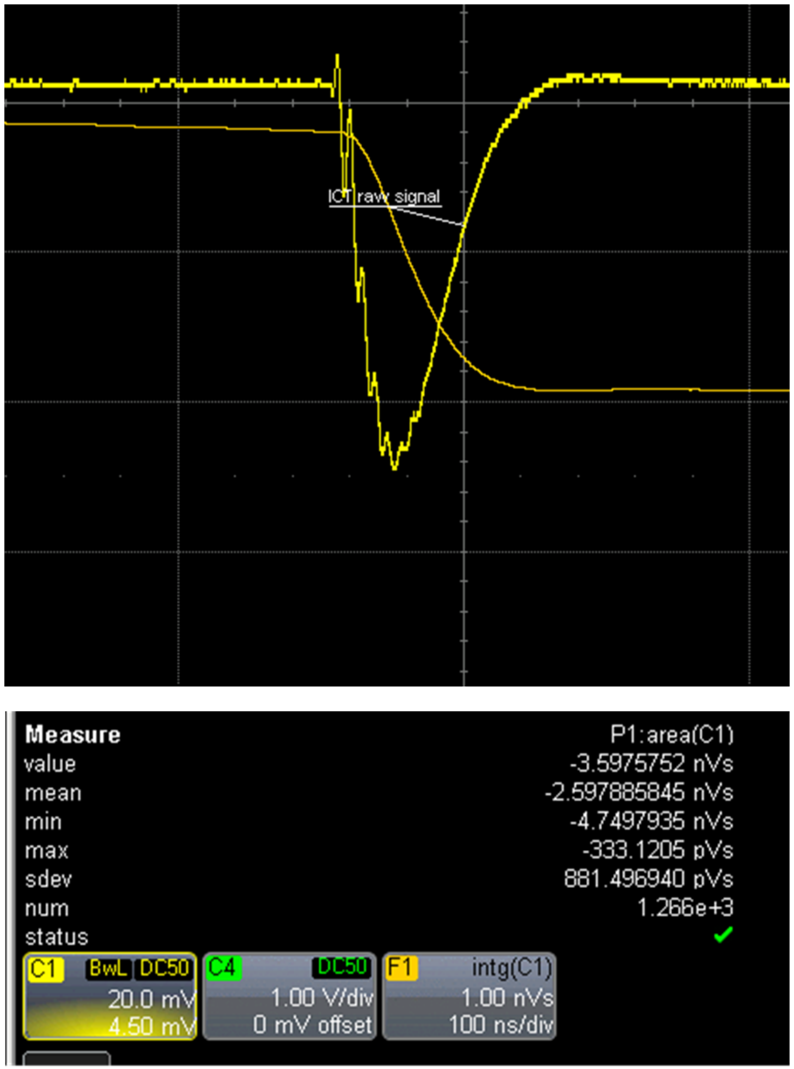




Photocathode end assembly

- Multipacting in the FPC area – long conditioning cycle with molybdenum puck
- Excessive dark current – helium discharge cleaning
- Photocathodes found dead prior insertion into the gun – added port for QE monitoring inside the garage
- Substantial spikes in the residual pressure during insertion into the gun – added NEG getters
- Multipacting inside the cathode stalk – used mask for the cathode deposition system, developing start procedure
- Continuous vacuum problem with cathode launch system – re-build

First Beam Observation



First beam was observed in 2015 with integrating current transformer during phase scan. The charge was 0.5 nC.

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 1.4 nC charge.

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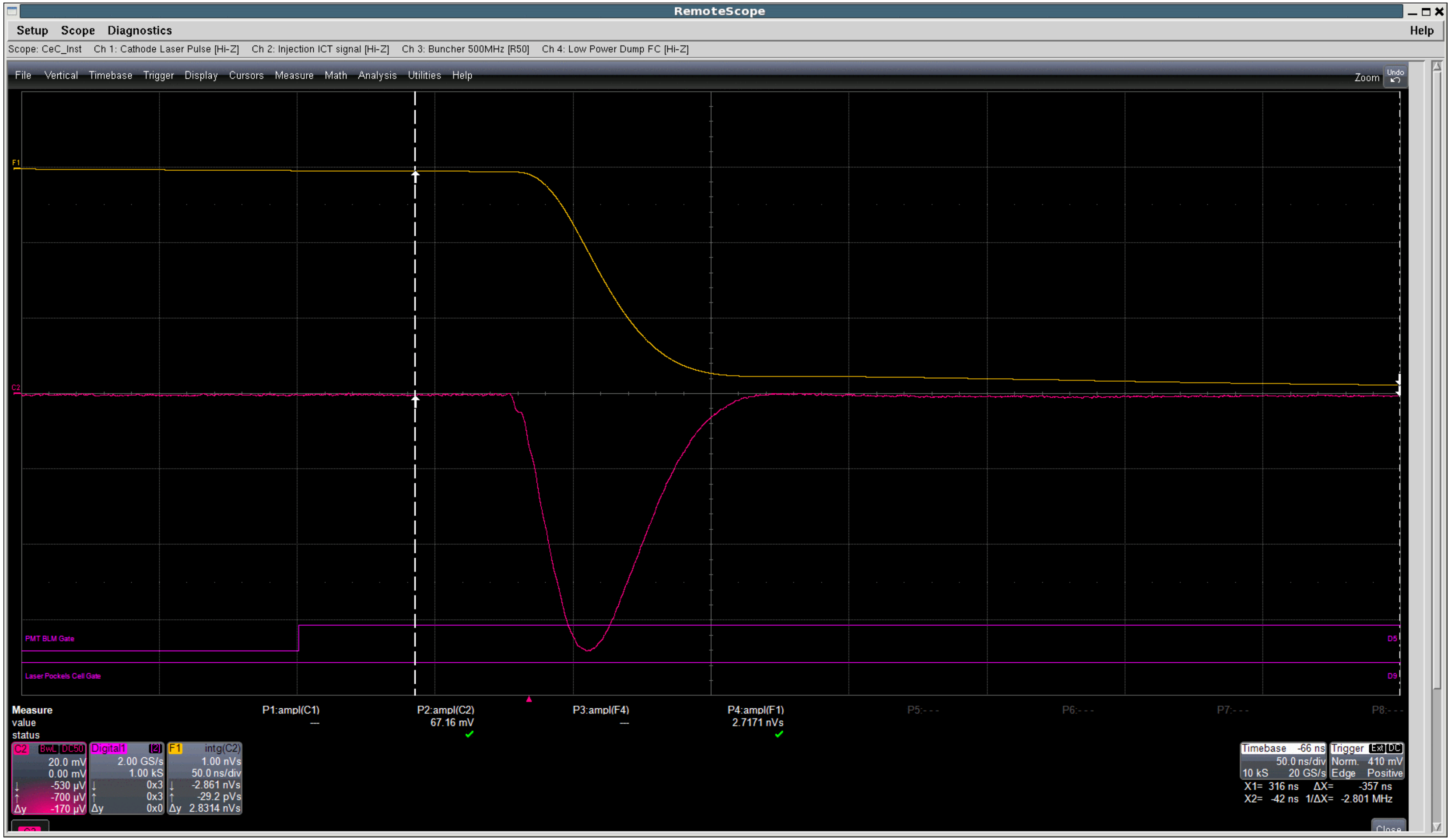
Run 16 Beam Observation



Beam was excited with 1 ns laser pulse with 0.5 µJ energy. 2.7 nVs ICT voltage integral corresponds to 2.1 nC charge. On the second day cathode was demonstrating 1 nC charge (100 pC at the end of the week).

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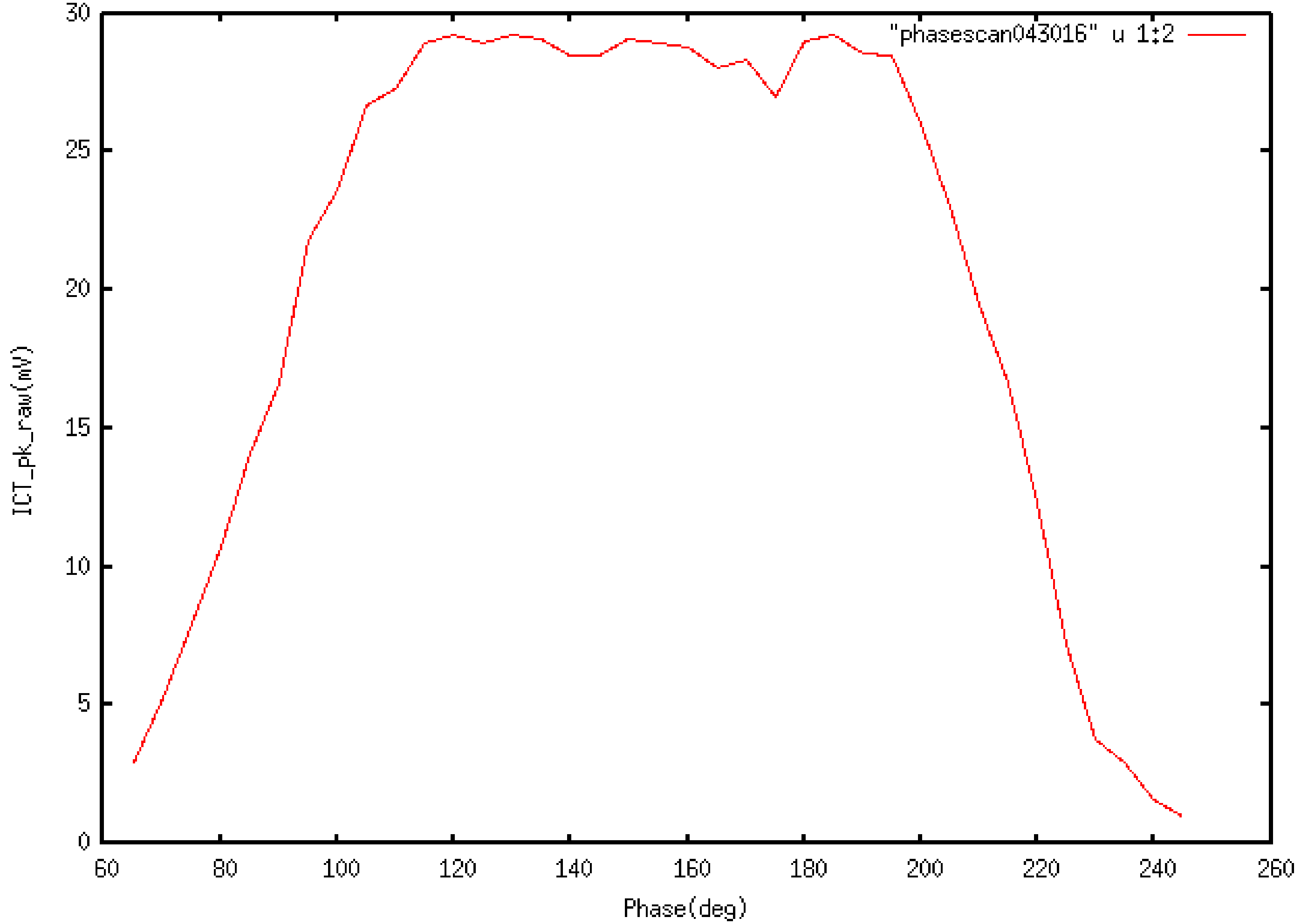
Cavity Phase Scan



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).

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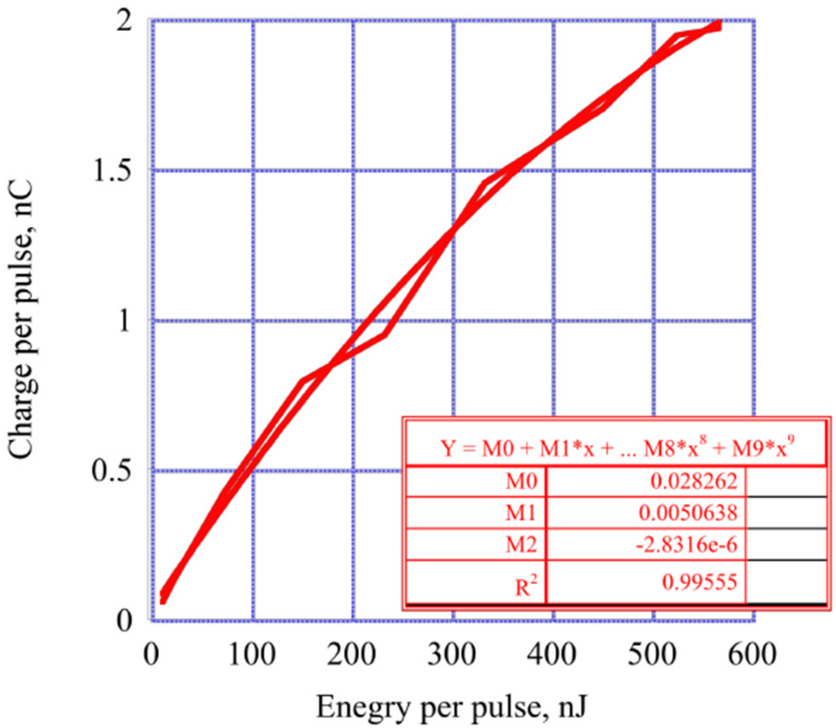
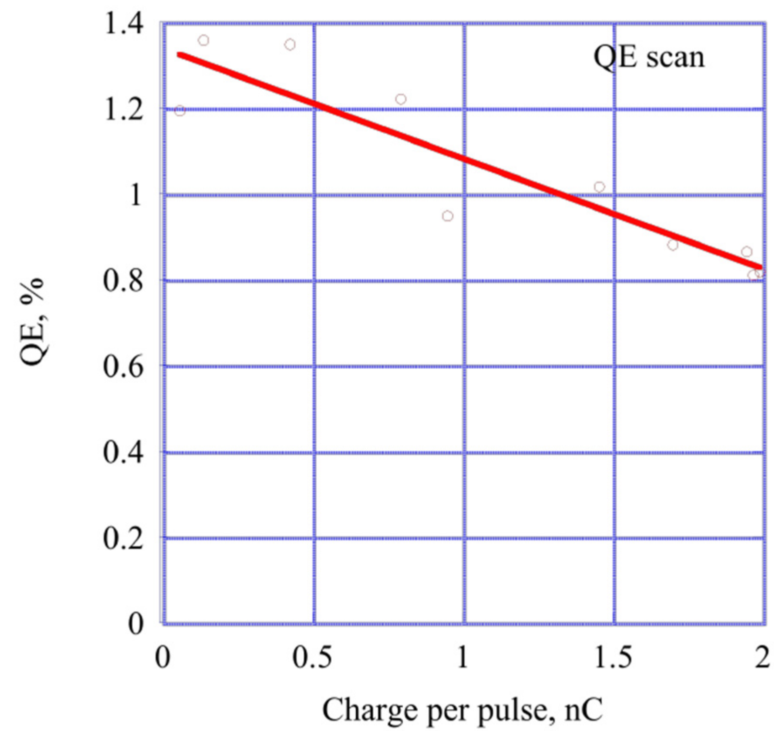
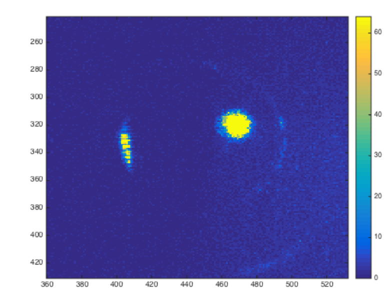
Measuring Quantum Efficiency





The photocathode was excited with 1 nsec laser pulse with varied optical energy. Gun voltage was 1.2 MV and laser spot size 1 mm r.m.s.



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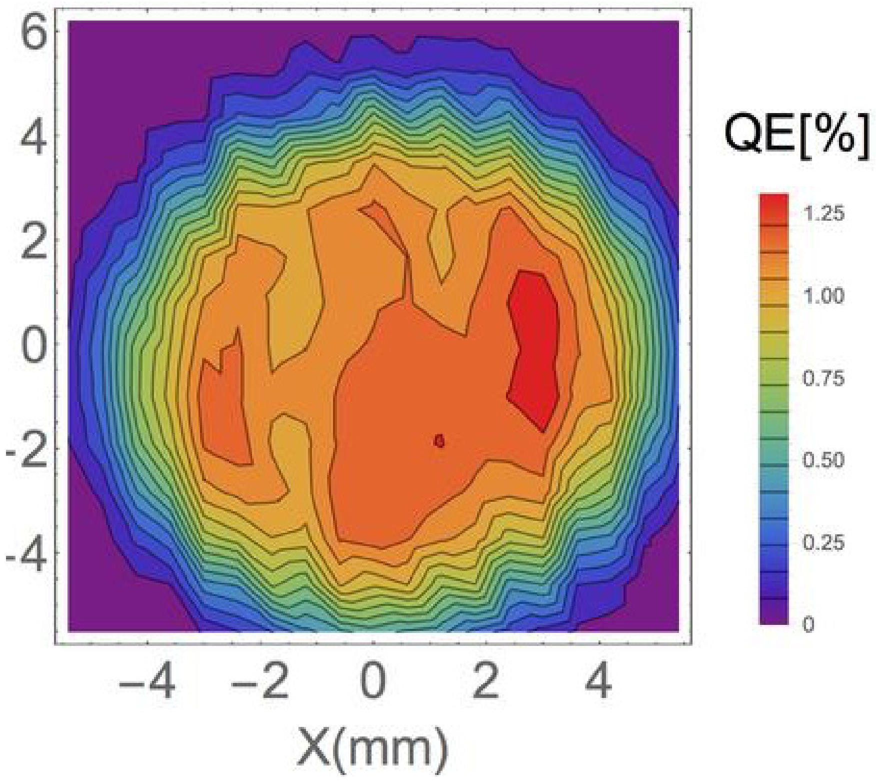
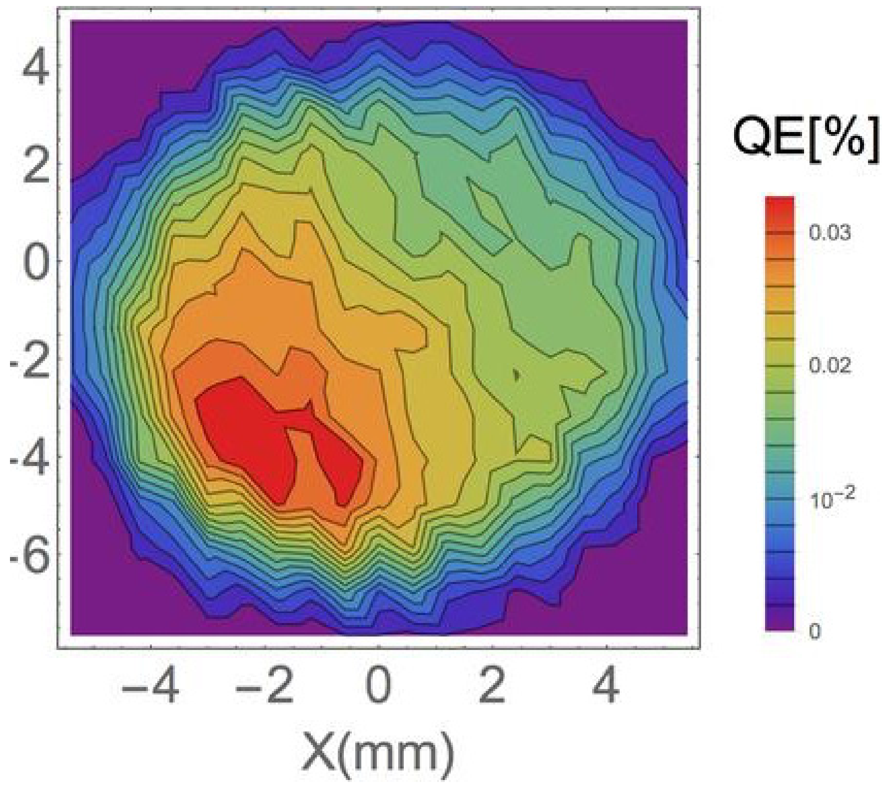
QE Map

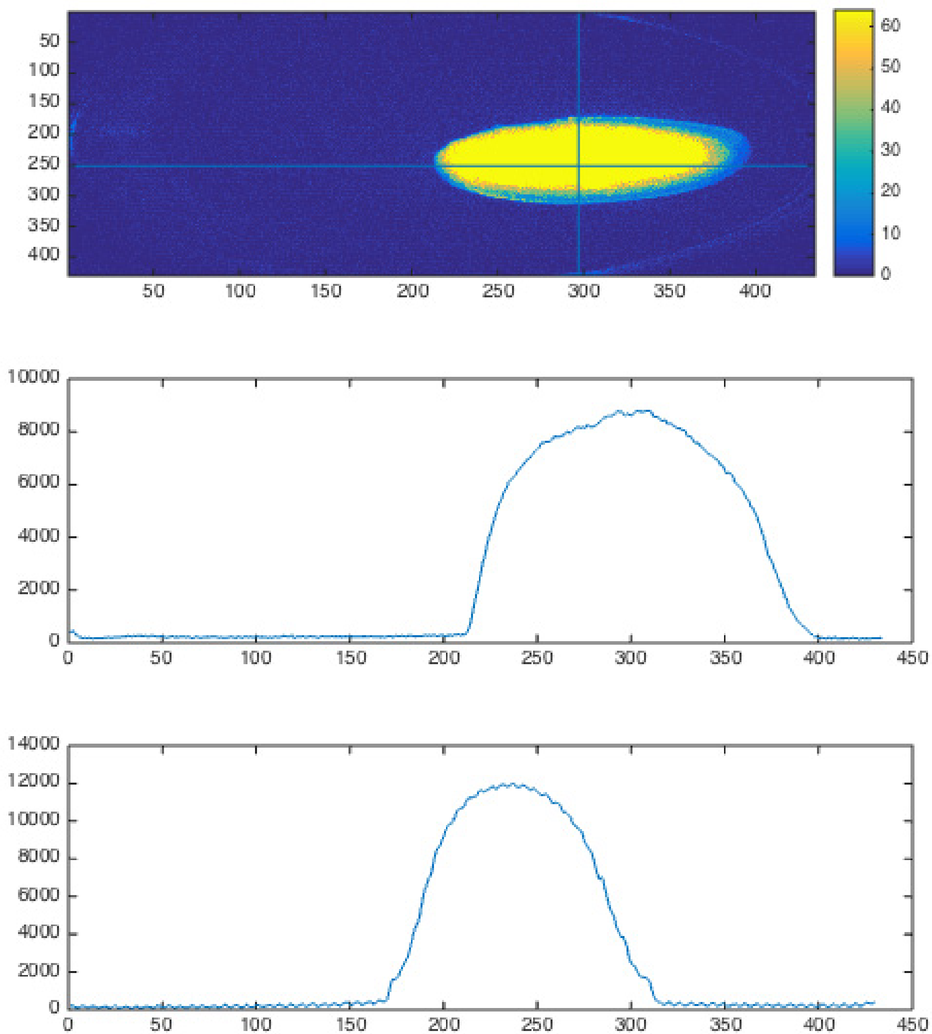
Fresh cathode



Used Cathode



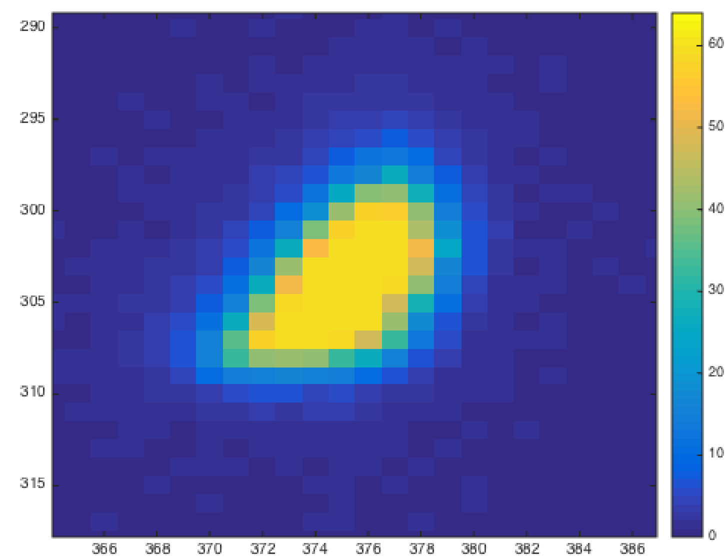
Beam Profile



Beam profile is acquired on the second profile monitor prior insertion of the slits for the emittance measurement. Beam charge is 1 nC.

Beam size f.w.h.m.

- horizontal 9 mm
- vertical 6 mm



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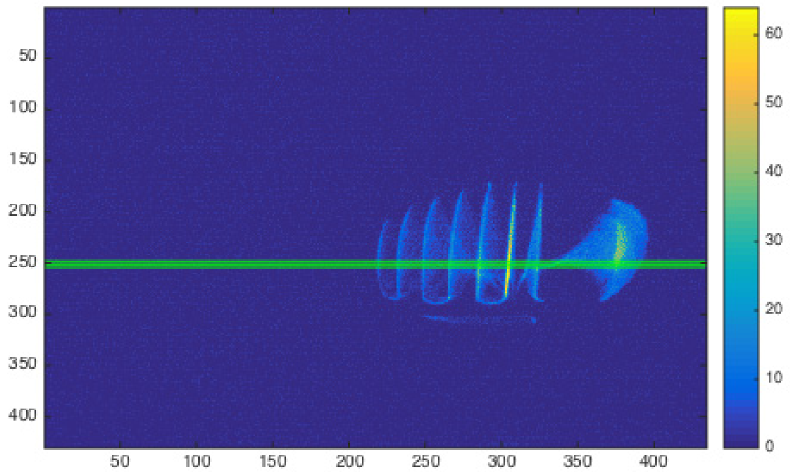
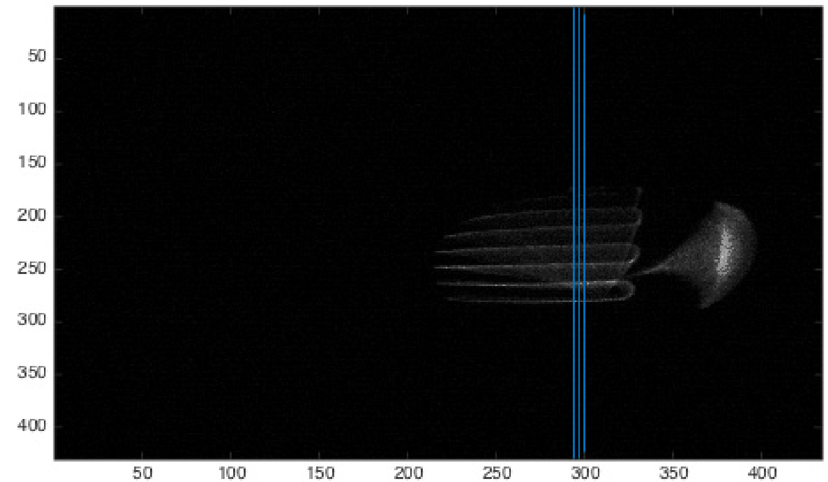
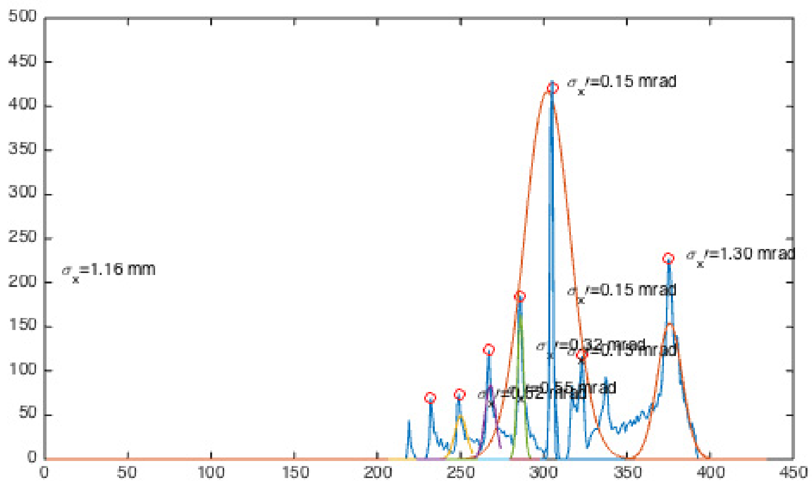
Emittance Estimate for 1 nC

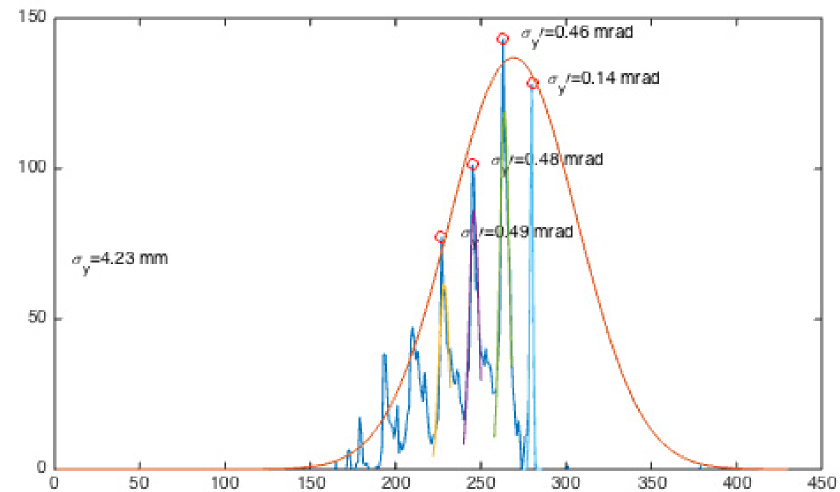




σ_x'=0.15 mrad

σ_y'=0.5 mrad

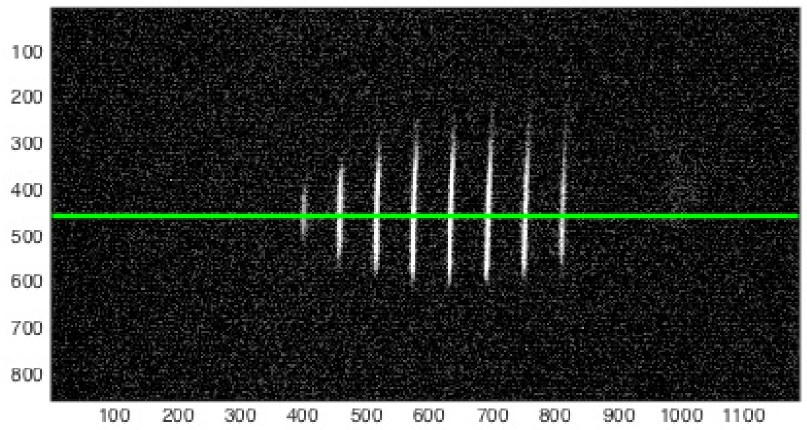


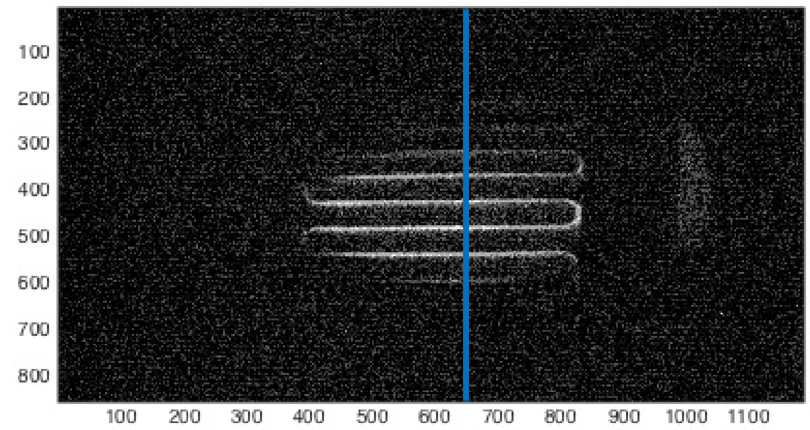


e_{nx} ~ 2.3 mm mrad

ε_y ~ 5.9 mm mrad

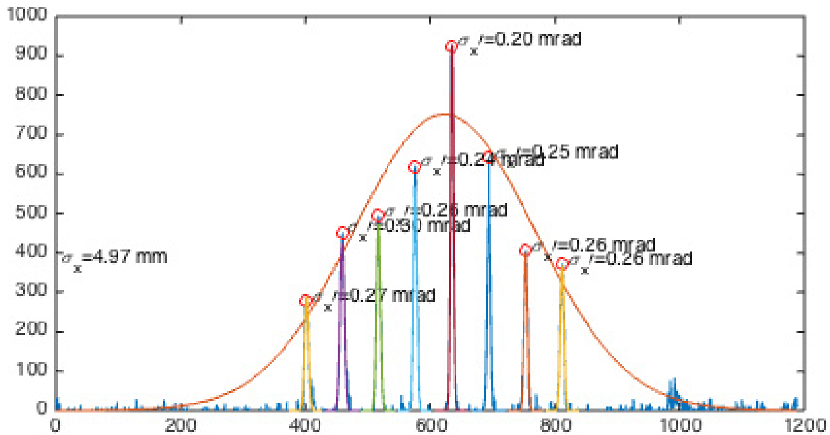
Emittance Estimate for 100 pC

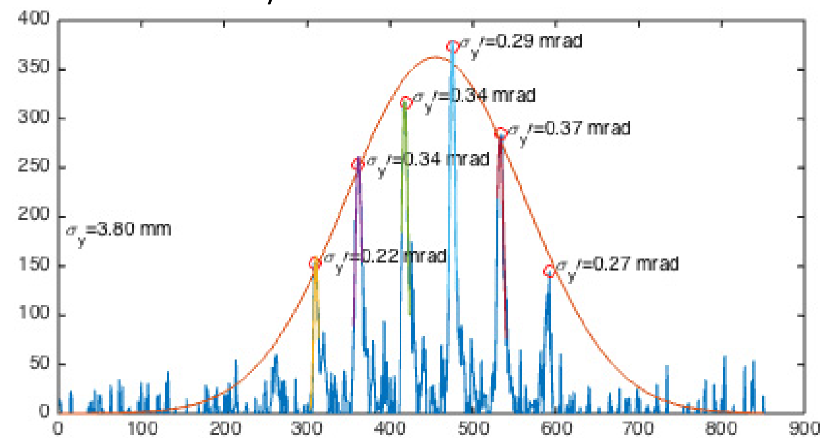




e_{nx} ~ 3.4 mm mrad

ε_{ny} ~ 3.7 mm mrad





Fresh results – May 9th, 2016

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Conclusions

- 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
- The quantum efficiency and cathode lifetime are sufficient for the project needs and we hope to improve them
- Beam parameters are in the specifications

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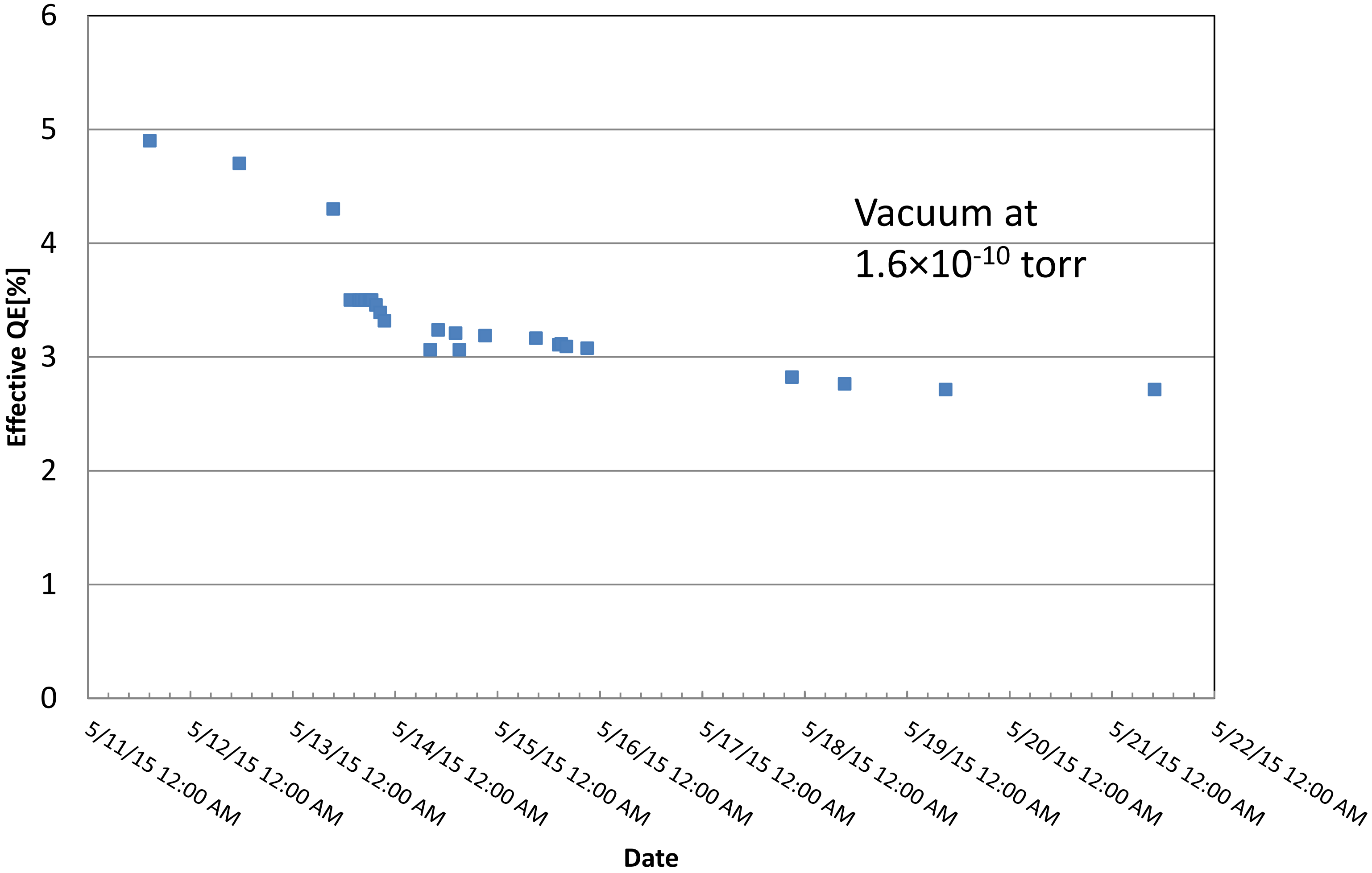
Cathode QE Evolution

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



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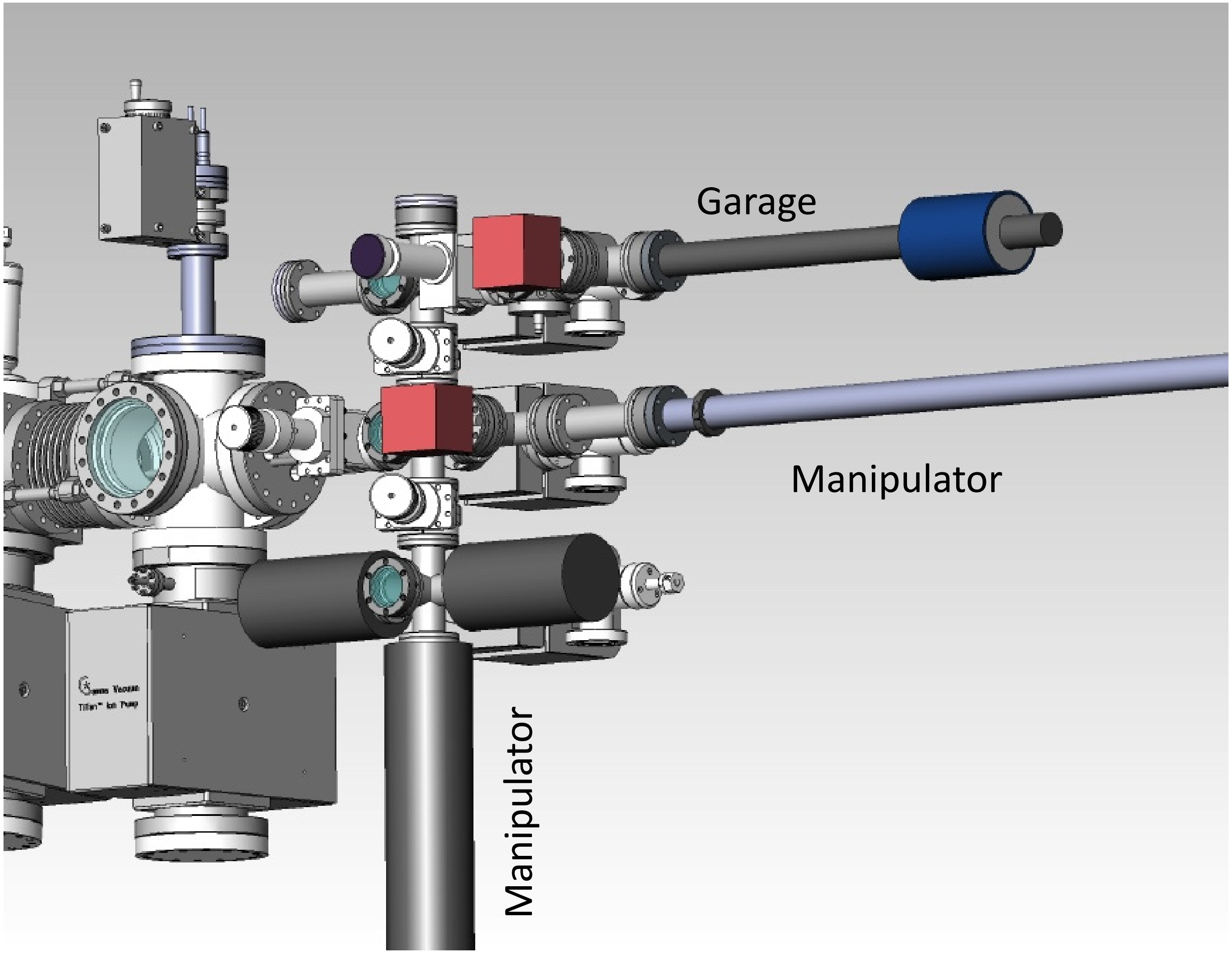
Modified Cathode Launch System



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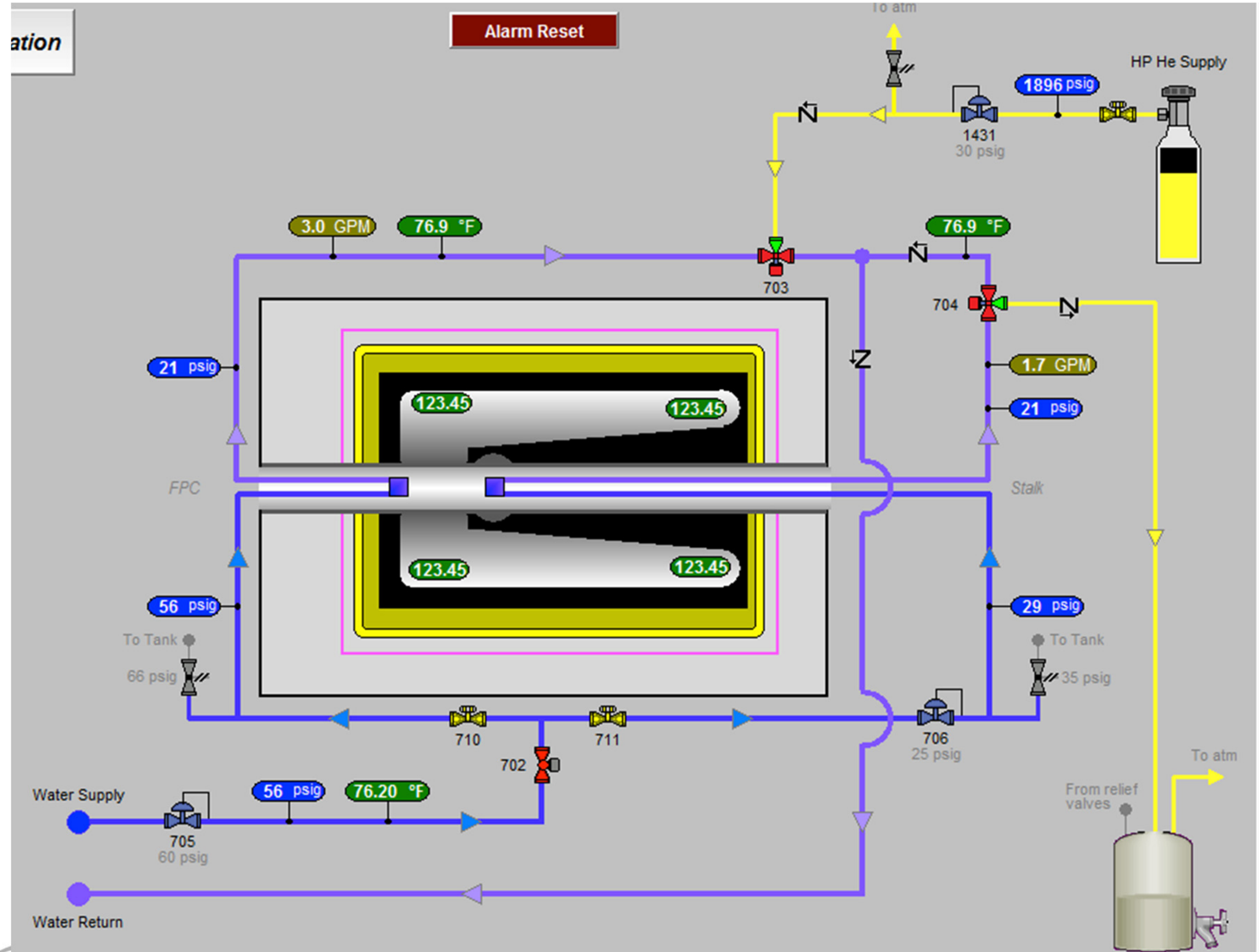
Gun Water System



Principle of Coherent Electron Cooling

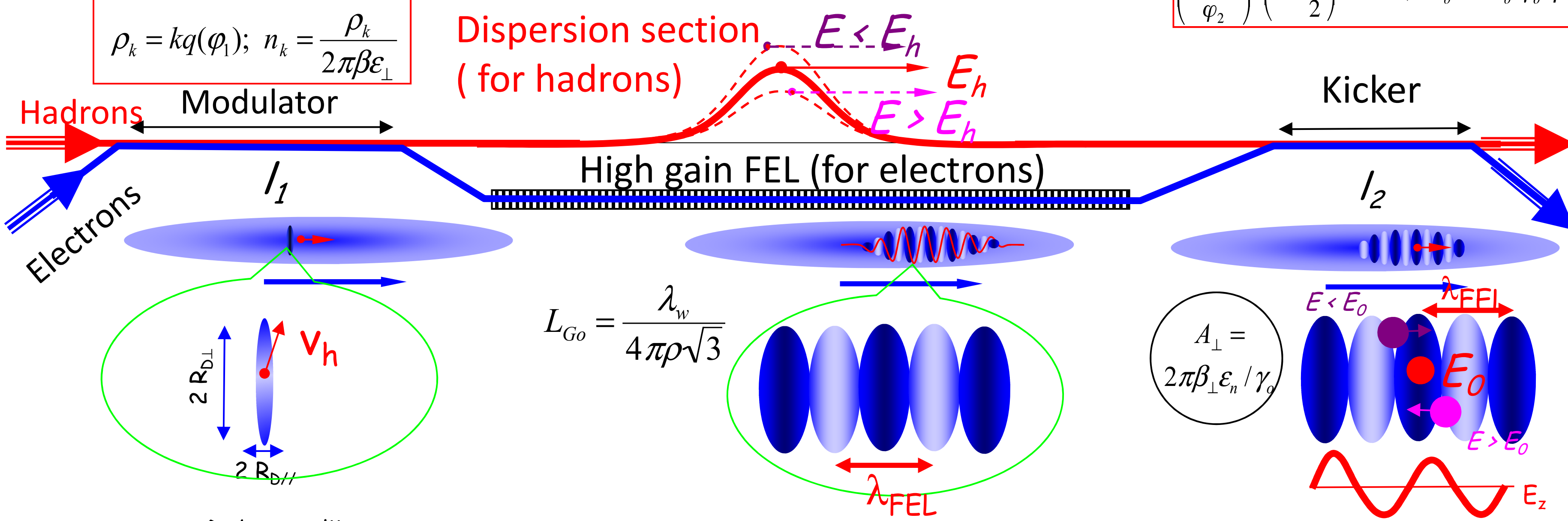
At a half of plasma oscillation

$$q_{\lambda_{FEL}} \approx \int_0^{\lambda_{FEL}} \rho(z)\cos(k_{FEL}z)\,dz$$

$$\rho_k = kq(\varphi_1);\ n_k = \frac{\rho_k}{2\pi\beta\varepsilon_\perp}$$

$$c\Delta t = -D\cdot\frac{\gamma-\gamma_o}{\gamma_o};\ D_{free} = \frac{L}{\gamma^2};\ \ D_{chicane} = l_{chicane}\cdot\theta^2 ......$$

$$\Delta E_h = -e\cdot\mathbf{E}_o\cdot l_2\cdot\sin\left(k_{FEL}D\frac{E-E_o}{E_o}\right)\cdot\left(\frac{\sin\varphi_2}{\varphi_2}\right)\cdot\left(\sin\frac{\varphi_1}{2}\right)^2\cdot Z\cdot X;\ \ \mathbf{E}_o = 2G_o e\gamma_o/\beta\varepsilon_{\perp n}$$



Debye radii

$$R_{D\perp} = \frac{c\gamma\sigma_{\theta e}}{\omega_p} \quad R_{D\perp} >> R_{D//}$$

$$R_{D//,lab} = \frac{c\sigma_\gamma}{\gamma^2\omega_p} << \lambda_{FEL}$$

Amplifier of the e-beam modulation in an FEL with gain $G_{FEL} \sim 10^2\text{-}10^3$

$$\mathbf{E}_o = 2G_o\gamma_o\frac{e}{\beta\varepsilon_{\perp n}}$$

$$n_{amp} = G_o\cdot n_k\cos(k_{cm}z)$$

$$k_{cm} = \pi/\gamma_0\lambda_{FEL}$$

$$\Delta\varphi = 4\pi en \Rightarrow \varphi = -\varphi_0\cdot\cos(k_{cm}z)$$

$$\vec{\mathbf{E}} = -\vec{\nabla}\varphi = -\hat{z}\mathbf{E}_o\cdot X\sin(k_{cm}z)$$

$$X = q/e \cong Z(1-\cos\varphi_1) \sim Z$$

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