CEBAF INJECTOR FOR K_L BEAM CONDITIONS

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KLF Collaboration Meeting

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Outline

- Motivation
  - K_L Beam Requirements
- Space charge
  - Space charge effect for high bunch charge
- GPT simulations
- Measurements
- Comparison between simulations and measurements
- Summary
- To-do list

CEBAF K_L Beam Requirements

- Jefferson Lab K_L experiment will run at CEBAF with much lower bunch repetition rates
- CEBAF injector bunch currents and repetition rates for K_L experiment.

Current (µA)	Repetition Rate (MHz)	Sub-harmonic of 499 MHz	Bunch Charge (pC)	Equivalent 249.5 MHz current (µA)
2.5	15.59	32nd	0.16	40
2.5	7.80	64th	0.32	80
5.0	15.59	32nd	0.32	80
5.0	7.80	64th	0.64	160

64 ns

128 ns

- With existing gun (130 kV), can't achieve 0.64 pC from current laser, laser development is required to achieve bunch repetition rates.

- Power amplification is necessary for higher beam currents required

Amaryan, Moskov, et al. arXiv:2008.08215v3 [nucl-ex] 4 Mar 2021

Space Charge

Space Charge Force

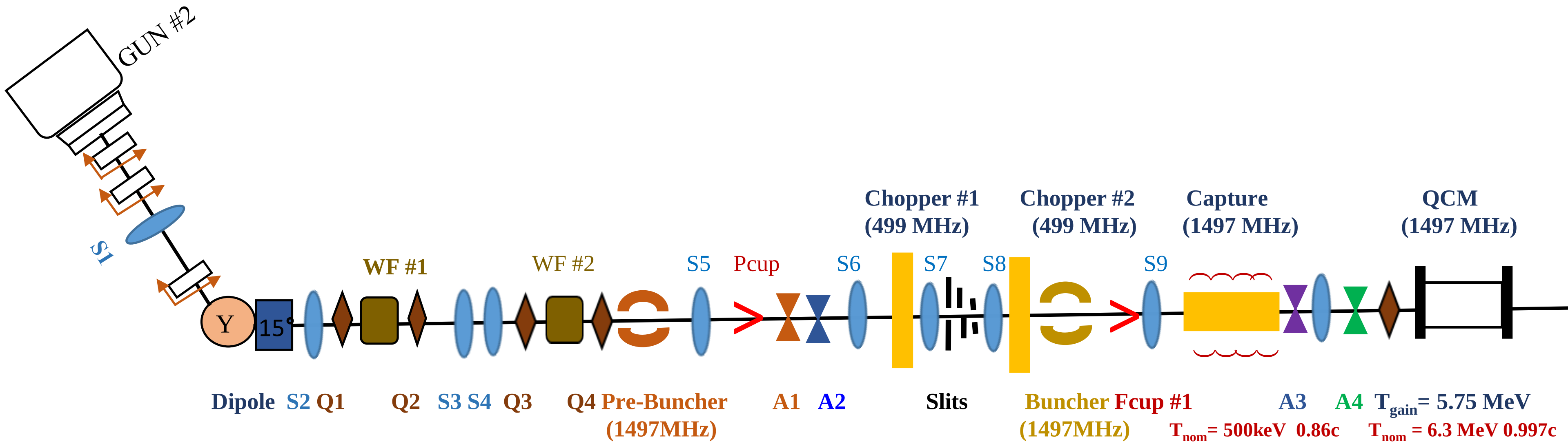
- Space charge forces are the Coulomb repulsive forces inside this region of charge accumulation
- Space charge forces can degrade beam quality and cause instabilities resulting in emittance growth, energy spread, halo formation, particle losses and even can set up upper limit for beam current
- For a Gaussian distribution with $\sigma_x = \sigma_y = \sigma_r$

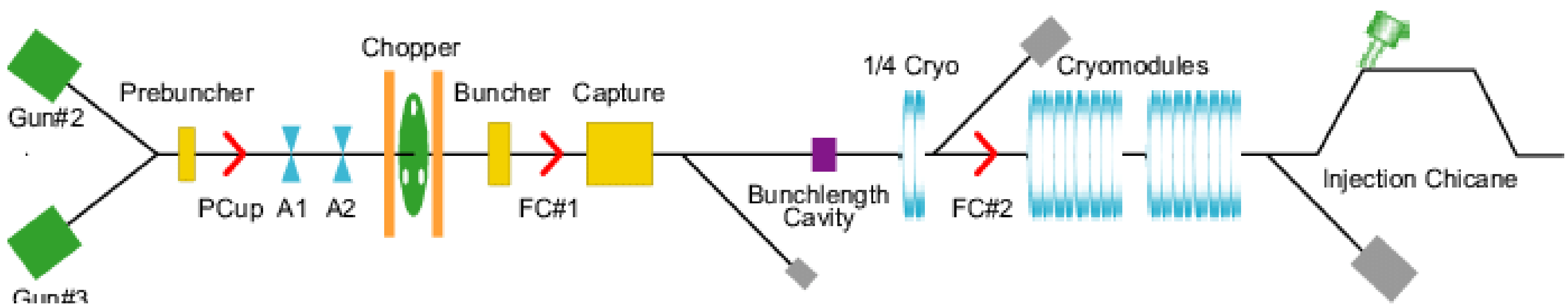
$$\rho(r,z) = \frac{q_0}{\left(\sqrt{2\pi}\right)^3 \sigma_z \sigma_r^2} \exp\left(-\frac{z^2}{2\sigma_z^2}\right) \exp\left(-\frac{r^2}{2\sigma_r^2}\right)$$

$$F_r(r,z) = qE_r\left(1-\beta^2\right)$$

$$= \frac{q}{2\pi\epsilon_0\gamma^2}\frac{q_0}{\sqrt{2\pi}\sigma_z}\exp\left(-\frac{z^2}{2\sigma_z^2}\right)\left[\frac{1-\exp\left(-\frac{r^2}{2\sigma_r^2}\right)}{r}\right]$$

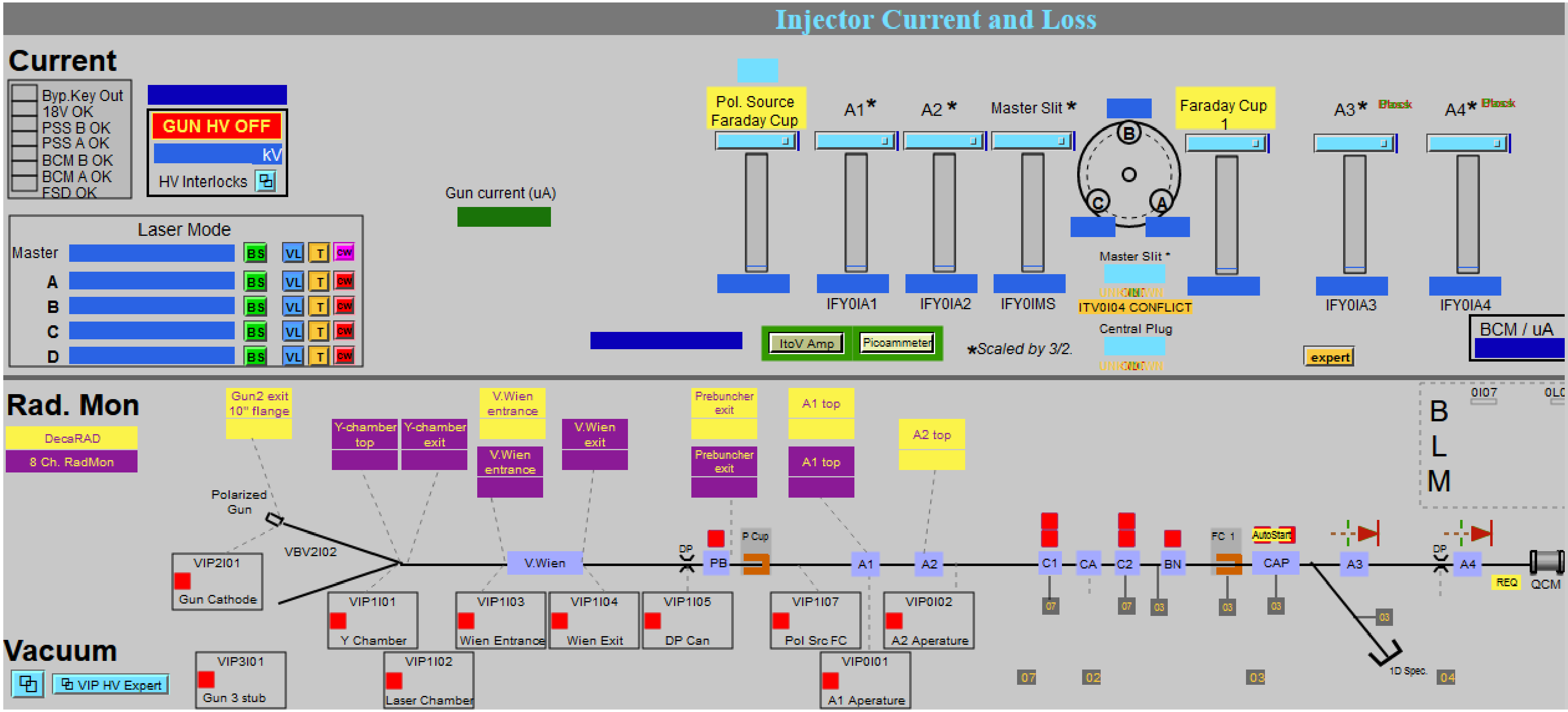
CEBAF Injector Layout





Injector Quick Reference Drawing, D. Moser Revision 17 BETA: DRAFT-6
File: 12GeV_injector_quick_reference_Dwg_rev17_6.ai

Injector Tools for Measurements



Simulation Details

Phase 1 CEBAF Injector Upgraded Model

- Focuses on the beam line between gun and captured solenoid MFA0I03 (S6) upstream of the Chopper 1 RF cavity and retains the pre-upgrade injector beam line downstream from MFA0I03 (S6) onward.

- General Particle Tracer (GPT) Simulations
- 130 kV Gun

- 1 Prebuncher, 1 Buncher, 5-cell capture section, 1/4 Cryomodule Booster (2 Cornell-style 5-cell cavities)
- Focusing solenoids, quadrupoles
- Dipoles, Wiens, beam diagnostics, choppers are omitted, straight beamline

- 160 µA (0.64 pC, 128 ns) and 80 µA (0.32 pC, 64 ns) beam current at 250 MHz frequency (with space charge3Dmesh)
- These are equivalent to 5 µA, 7.80 MHz and 15.59 MHz repetition rates

- Gaussian beam, beam sizes; $4\sigma_x = 2.237$ mm, $4\sigma_y = 2.093$ mm, laser pulse length 19.10 ps (FWHM=45ps), transverse emittance 0.061 mm-mrad,
- 10k macro-particles

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Beam Sizes (σ_x, σ_y) and Bunchlength (σ_t)

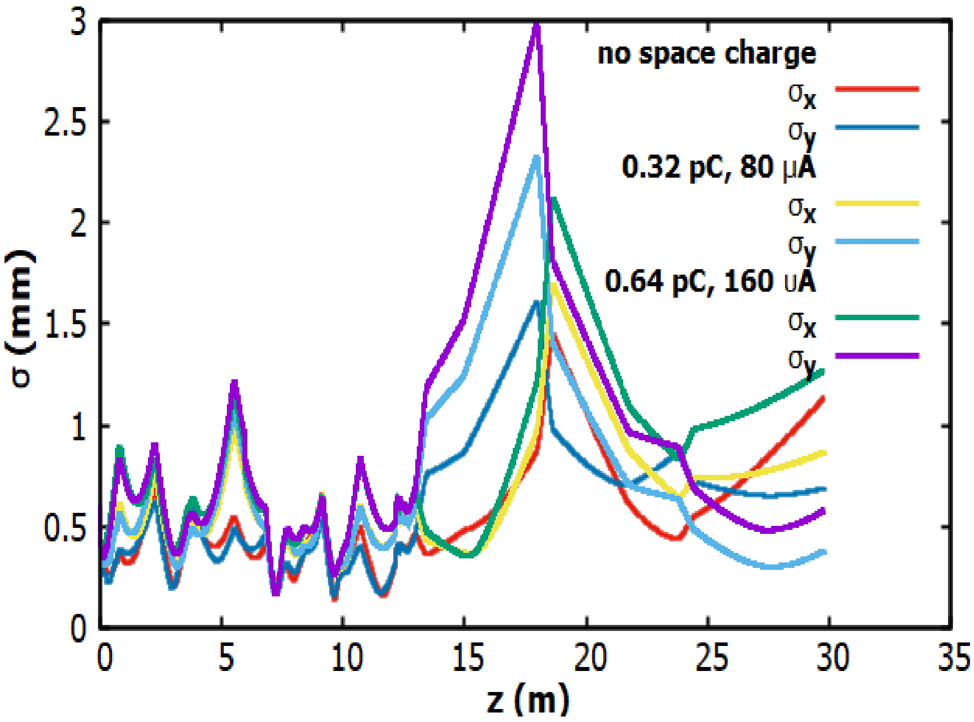

Figure: Beam size evolution along the beamline

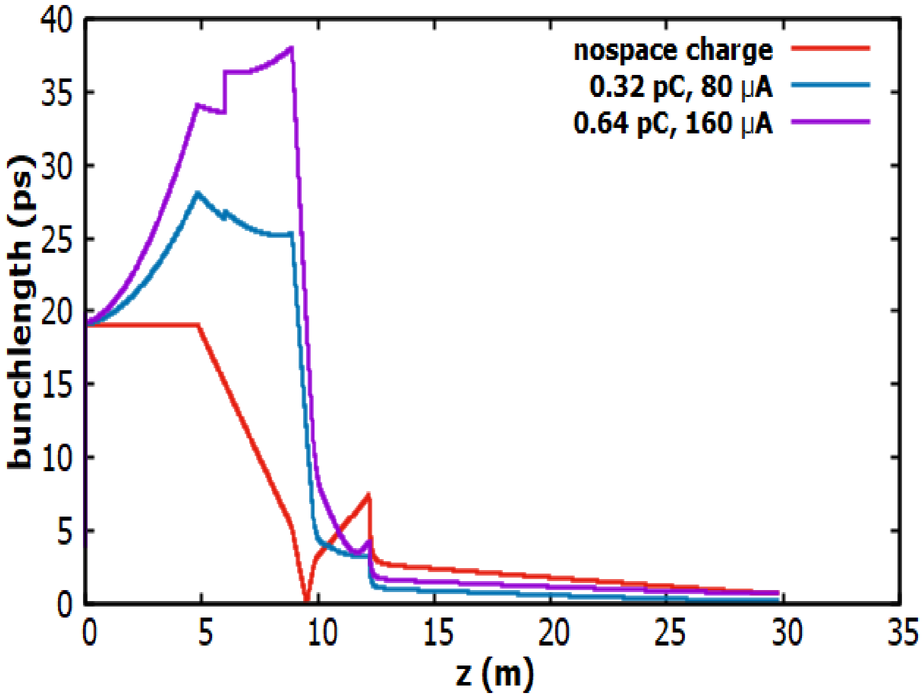

Figure: Bunchlength along the beamline

Normalized Emittances (ϵ_x, ϵ_y)

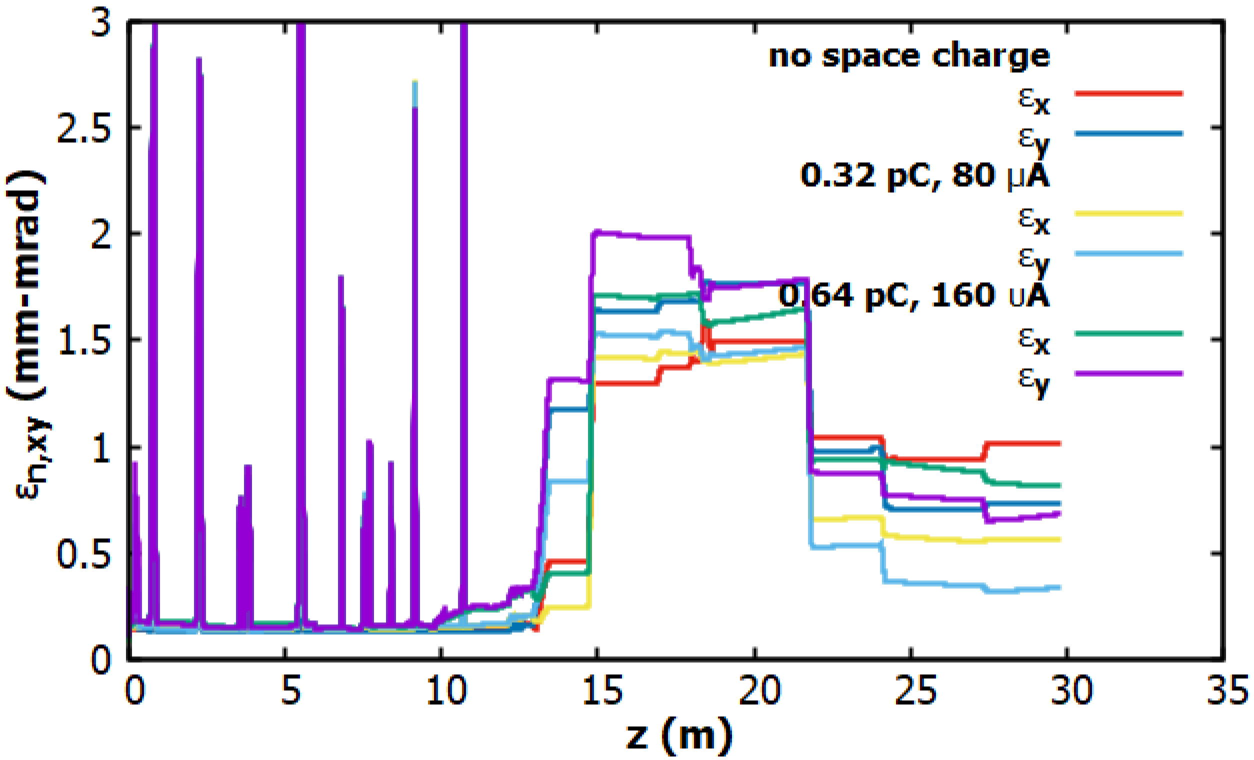

Figure: Normalized transverse emittance along the beamline

Simulation Results

Beam Transmission

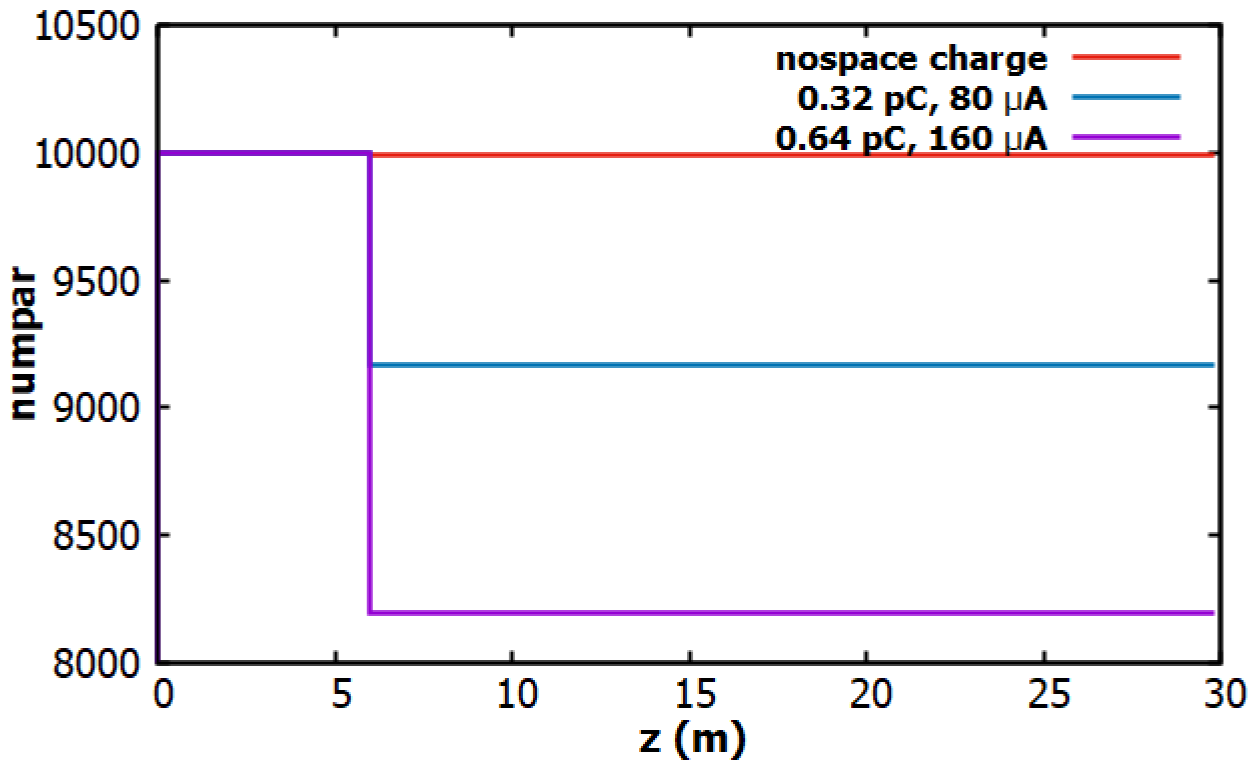

Figure: Beam transmission for different bunch charges (current)

GPT Simulation

Effects of Laser spot size and laser Pulse Length

- 160 μA, 0.64 pC
- Laser spot sizes : 0.25 mm, 0.50mm, 0.75 mm, 1.00 mm
- Laser Pulse lengths: 19.10 ps, 23.35, 27.60 ps, 31.85 ps

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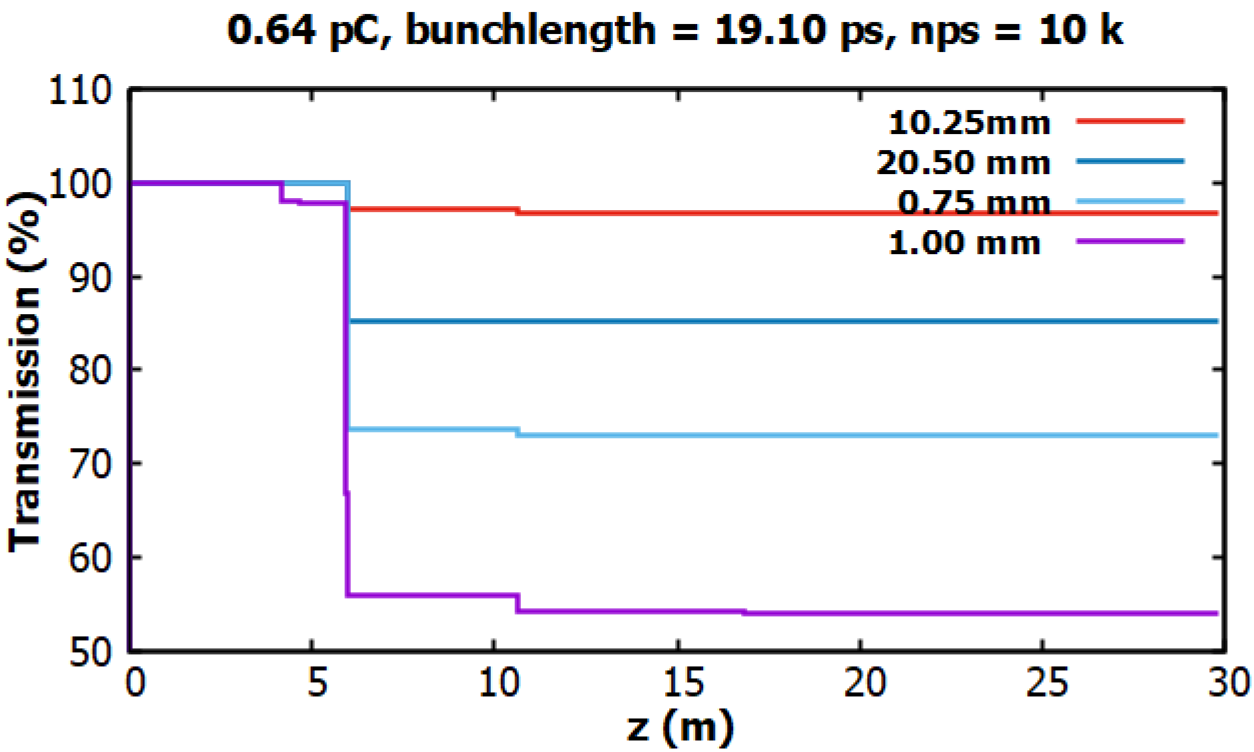
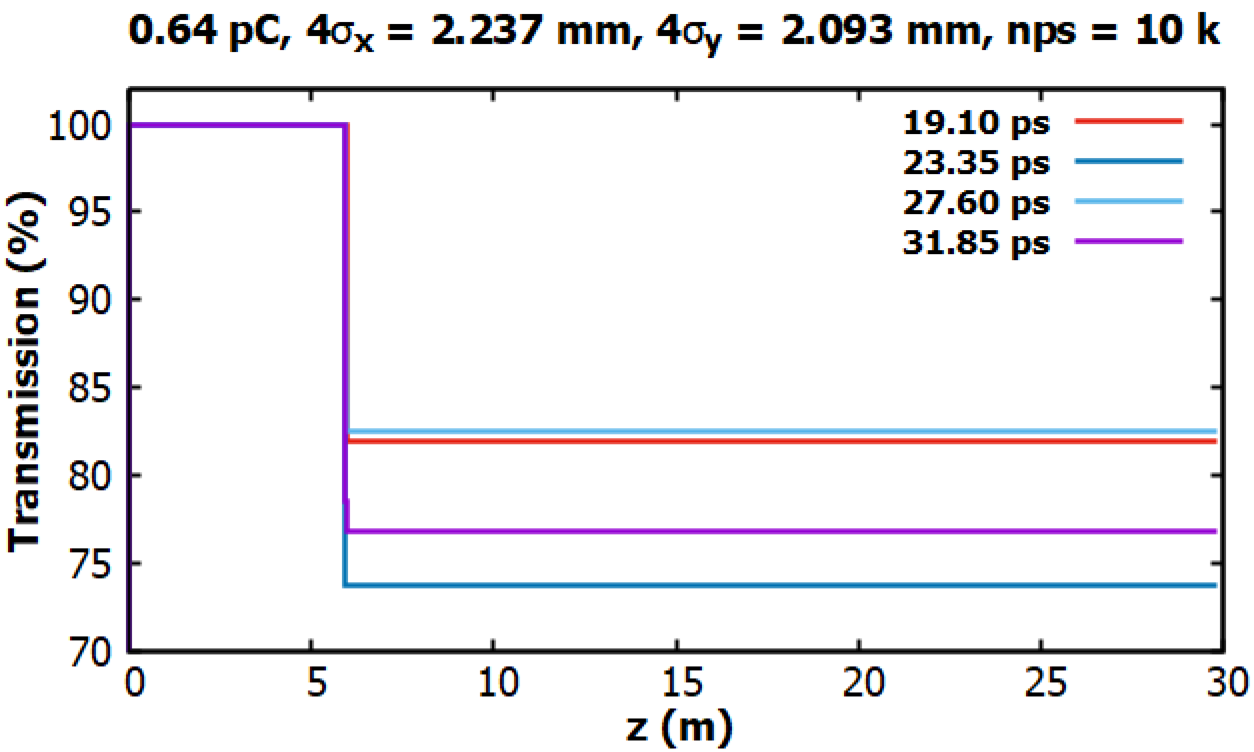
Laser spot size variation



Beam Transmission with spot size variation at cathode

Simulation Results

Pulse length variation



Beam Transmission with laser pulse length variation

Measurement : Beam Transmission, Pulse Length

Measurements were done:

1. 05-20-2022
2. 05-18-2022
3. 02-16-2022
4. 01-26-2022

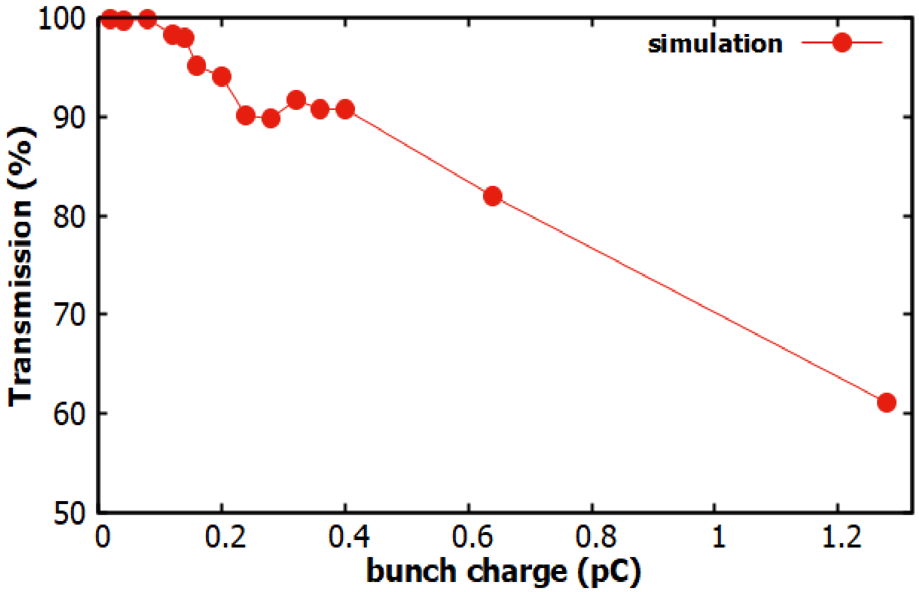
Investigated the limits for :

- 250 MHz, ≈ 162 μA CW beam, 0.65 pC bunch charge
- 250 MHz chopper scan for finding laser pulse length
- 500 MHz beam, ≈ 200 μA CW beam, 0.40 pC bunch charge
- 500 MHz chopper scan for finding laser pulse length

S. Pokharel, A. Hofler, G. Krafft

Comparison : Measurement vs Simulation

Beam Transmission



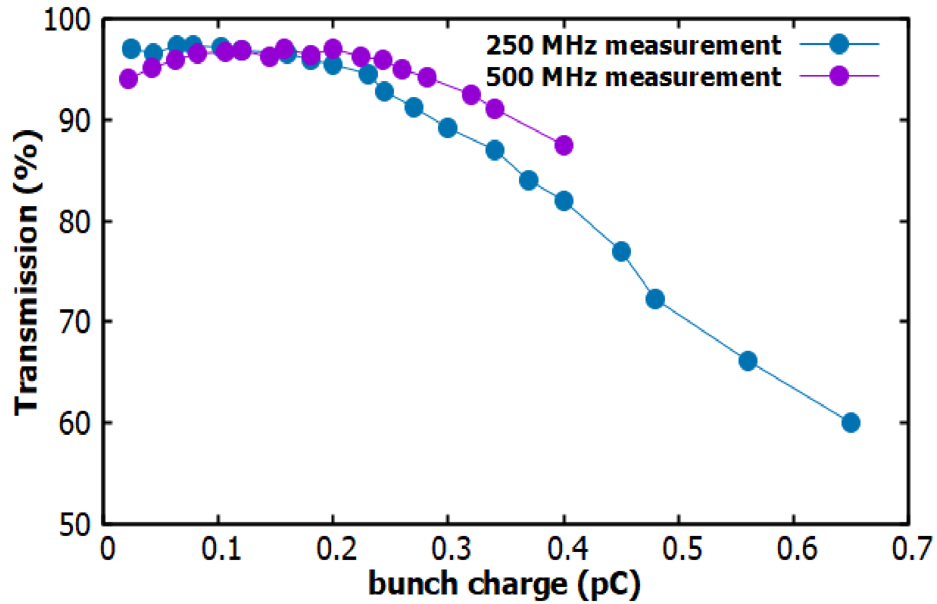
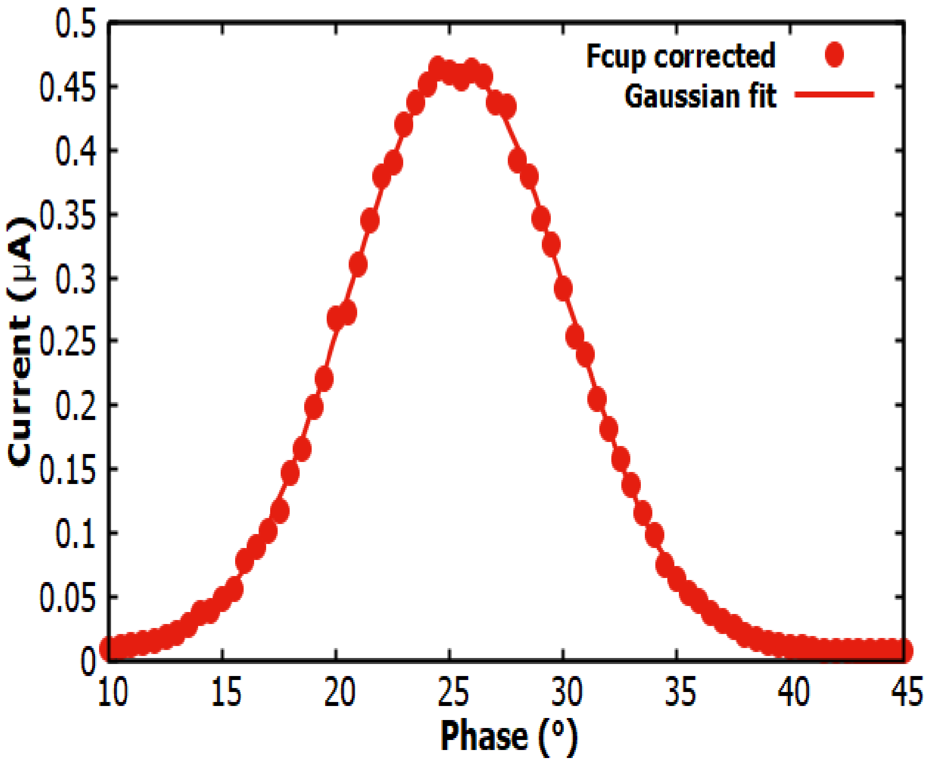


Figure : Beam transmission vs. bunch charge

Measurement : Pulse length determination

Chopper scan is used for the measurement



$$f(x) = \frac{a}{\sigma\sqrt{2\pi}} \exp(-\frac{(x-\mu)^2}{2\sigma^2})$$

Final set of parameters

a	= 5.68386	+/- 0.02094	(0.3683%)
σ	= 4.86611	+/- 0.02072	(0.4257%)
µ	= 25.3378	+/- 0.02069	(0.08165%

σ = 4.866° = 5.57 * 4.866 = 27.10 ps,
FWHM ≈ 64 ps

Figure: 1.5 µA current at Pcup for 250 MHz Laser

Measurement : Pulse length determination

Chopper scan is used for the measurement

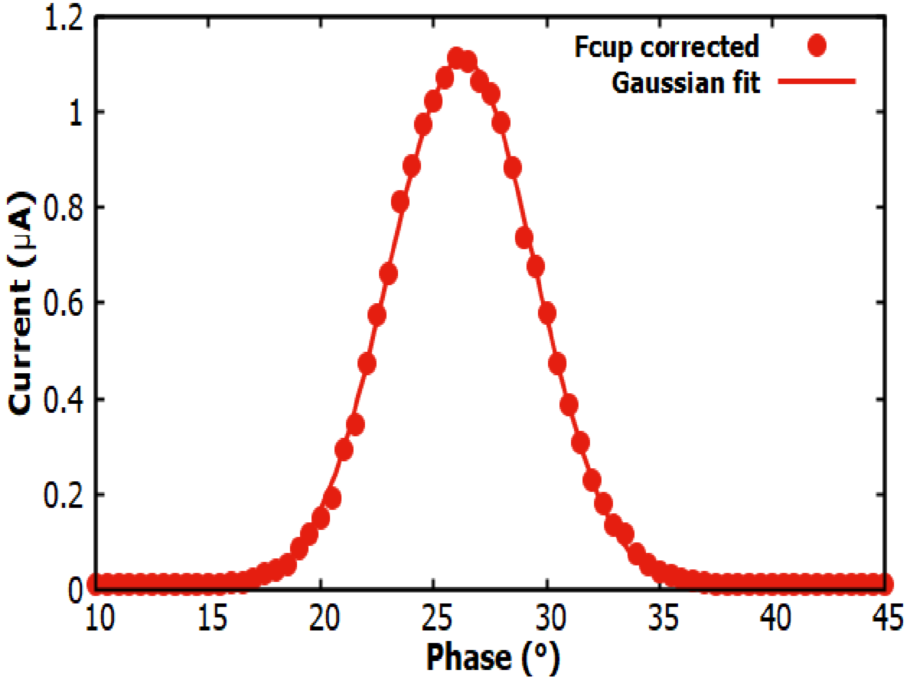


Figure: 3.1 μA current at Pcup for 500 MHz Laser

$$f(x) = \frac{a}{\sigma\sqrt{2\pi}}\exp(-\frac{(x-\mu)^2}{2\sigma^2})$$

Final set of parameters

a	= 9.0319	+/- 0.03932	(0.4354%)
σ	= 3.23726	+/- 0.01629	(0.5031%)
μ	= 26.2674	+/- 0.01627	(0.06195%)

σ = 4.866° = 5.57 * 3.23726 = 18.03 ps,
FWHM ≈ 43 ps

The Gaussian fit for 500 MHz is narrower than it for 250 MHz.
That means, the bunch length is greater for 250 MHz.

Measurement : Pulse length determination

Chopper scan is used for the measurement

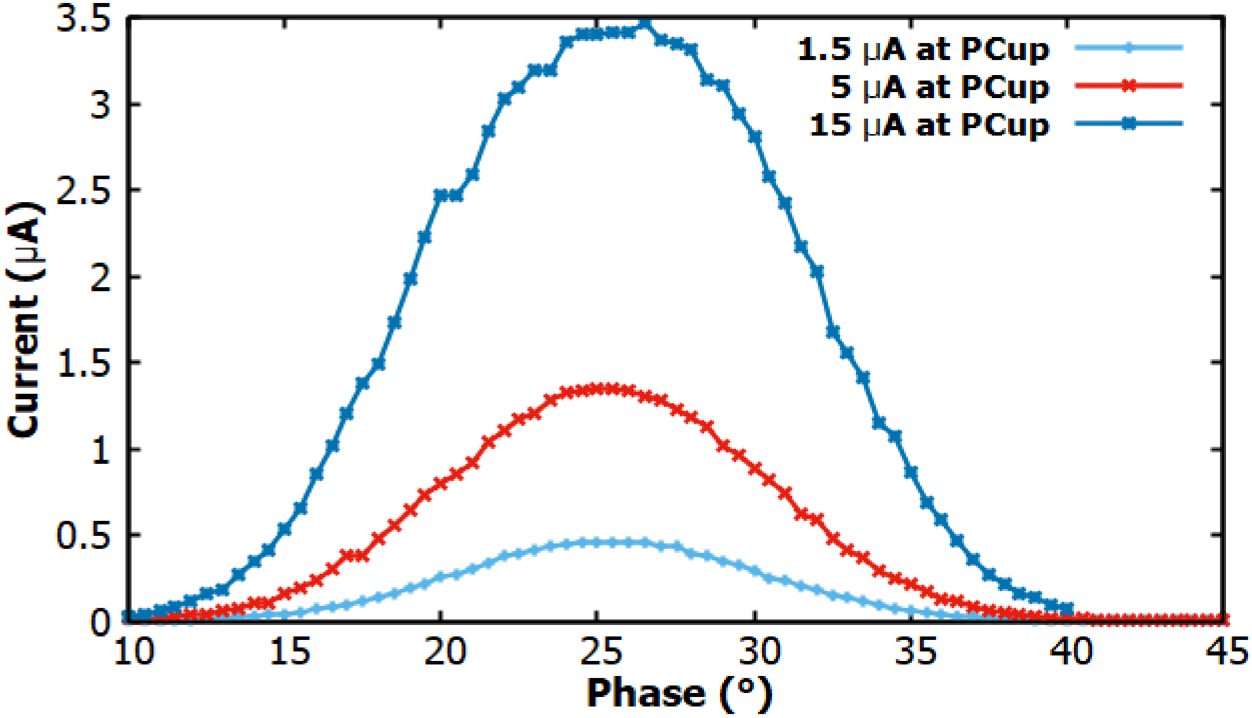


Figure: different current at Pcup for 250 MHz Laser

The Gaussian distribution has wider span with increasing current
that means bunch length of the beam increases along the beamline for higher bunch charge.

Summary

- CEBAF Upgraded Injector Model for K_L experiment (130 kV gun), high and low bunch charge beam simulated
- The laser pulse lengths and laser spot sizes are varied
- At 0.64 pC, nominal conditions, part of baseline for K_L experiment the loss is about 18% from simulation.
- Measurement were done for low and high current for different laser frequencies and compared with the simulation results.
- From the measurements, we found that the maximum bunch charge (bunch current) that can be transmitted is 0.4 pC (100µA at 500 MHz) with about 12% loss at A1.
- For 250 MHz, the maximum bunch charge met the K-Long experiment requirement but the losses in apertures are high, about 38%.
- Chopper Scan were performed for finding the bunch length for different Laser frequencies

To-do List

- Comparison between simulations and measurements from measurement to see if the simulation matches the measurement as the laser power increased for 130 kV gun especially for 250 MHz.

- **K-Long will run with a 200 KV gun**

- Perform simulation with 200 keV injector layout with proper choices of optical pulse lengths and spot sizes, so we can make hardware decisions relevant for the K-Long experiment

Thank you!

Namaste

Questions, Comments, Suggestions ??