EMITTANCE MEASUREMENTS AND SIMULATIONS IN 112 MHz SUPER-CONDUCTING RF ELECTRON GUN WITH CsK_2Sb PHOTO-CATHODE

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Abstract

The commissioning of the coherent electron cooling (CeC) proof of principle experiment is under way at Relativistic Heavy Ion Collider (RHIC). A 112 MHz superconducting radio frequency photo-emission gun is used to generate the electron beam for this experiment. In this paper we report selected results of experimental emittance measurements and compare them with our simulations.

INTRODUCTION

Coherent electron Cooling (CeC) is a novel technique promising high cooling rates for high energy hadron beams [1], especially important for future BNL's electron-ion collider, eRHIC [2]. CeC promises to outperform other cooling methods by orders of magnitude. Being an untested technique, the CeC will undergo experimental test by cooling a single bunch of gold ions circulating in RHIC [1]. The proof-of-principle experiment is conducted at BNL to demonstrate this technique. The dedicated accelerator, shown in Fig.1, comprising of 113 MHz SRF electron gun, two 500 MHz room-temperature bunching cavities and 704 MHz SRF linac built for this purpose has been commissioned and now is fully operational [3].

The CeC SRF accelerator is using liquid He supplied by RHIC and operates only during RHIC runs. The SRF electron gun with CsK_2Sb photocathode is operating for third season and generates electron beams with kinetic energy of 1.05-1.15 MeV and to 3.9 nC charge per bunch. In this paper, we present selected simulation and experimental results focused on the transverse beam emittance.

SRF GUN AND PARMELA SIMULATIONS

The electrons in the SRF gun are generated from CsK_2Sb photocathode by illumination from green (532 nm) laser generating pulses with 0.25 nsec to 0.5 nsec duration. After accelerating to kinetic energy of 1.05 MeV (total energy 1.56 MeV), the beam propagates through the gun solenoid (located z = 0.65 m from the cathode, further in the text all distances are from the cathode surface), the bunching cavities (turned off for this measurements) and first transport solenoid (LEBT1, at z = 3.65 m) before it can be observes at YAG profile monitor (z = 4.28 m) –see Fig. 2. Being a low energy beam, its beam dynamics is strongly influenced by space charge starting from charge per bunch of few hundreds of pC. The particle tracking code PARMELA [4] has been used to simulate the beam dynamics.

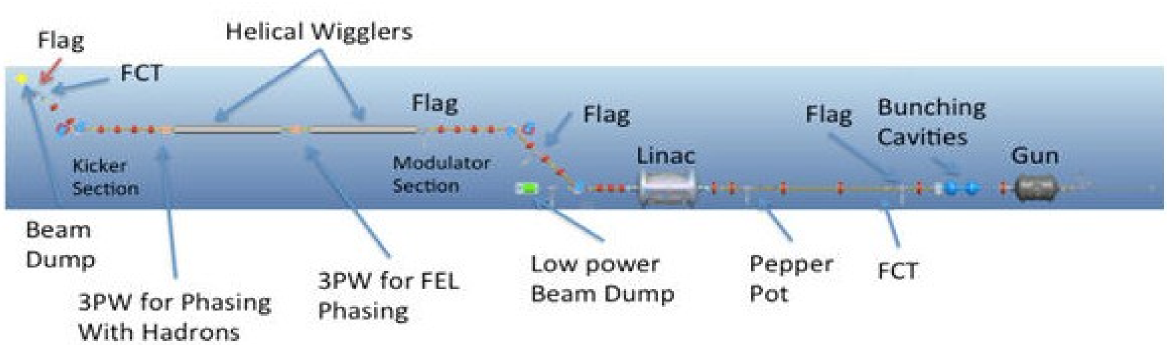

Figure 1: Schematic of CeC Beam.

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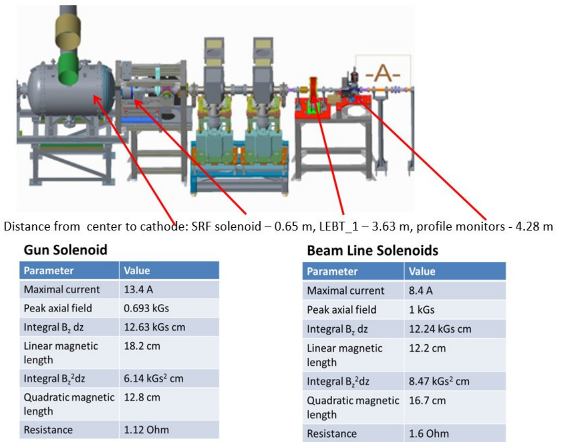
We simulated the evolution of projected emittance and attempt to optimize strength of the gun and LEBT1 solenoids as well as the laser spot size on the cathode. Table 1 summarizes the parameters used in this optimization and result is summarized in Fig. 3.



Gun Solenoid

Parameter	Value
Maximal current	13.4 A
Peak axial field	0.693 kGs
Integral B_z dz	12.63 kGs cm
Linear magnetic length	18.2 cm
Integral B_z^2dz	6.14 kGs^2 cm
Quadratic magnetic length	12.8 cm
Resistance	1.12 Ohm

Beam Line Solenoids

Parameter	Value
Maximal current	8.4 A
Peak axial field	1 kGs
Integral B_z dz	12.24 kGs cm
Linear magnetic length	12.2 cm
Integral B_z^2dz	8.47 kGs^2 cm
Quadratic magnetic length	16.7 cm
Resistance	1.6 Ohm

Figure 2: The SRF electron gun, the gun and LEBT1 solenoids and the YAG profile monitor.

Table 1: Parameters Used for Optimization

Laser spot [mm]	Pulse length [ps]	Bunch charge [nC]	Energy gain [MeV]
1.25 ~ 2.5	300	0.5	1.05

Here is the obtained result of achievable geometrical emittance at YAG1.

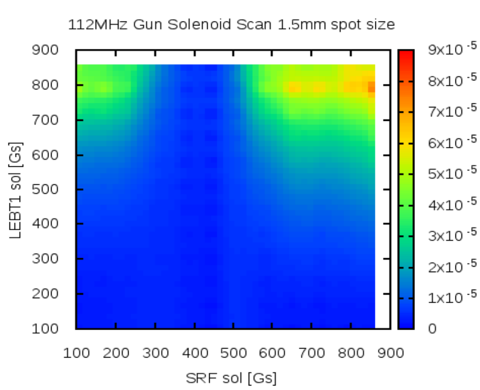


Figure 3: Emittance at the location of the YAG1 profile monitor as function of two solenoid's strengths.

During the optimization the strength of two solenoids and the size laser spot on the photocathode size were varied with the goal of obtaining minimal projected normalized emittance. We used flat top and beer can-like distribution for the laser pulse and shape [5]. Simulations summarized in Fig. 4 showed that in the beam normalized emittance can be kept under one micrometer-radian by proper choice of solenoid settings.

We also found that a relatively large spot size prevents emittance growth in the gun.

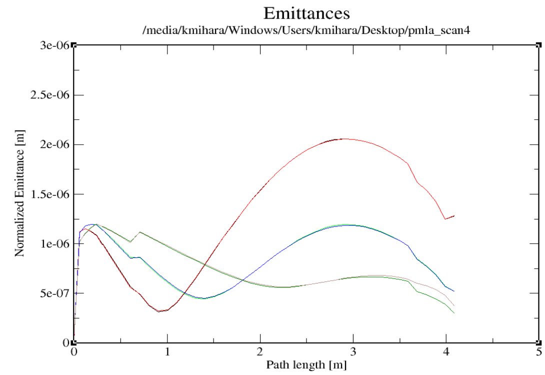


Figure 4: Evolution of the Beam Normalized Emittance for various laser spot sizes: red curve - 1.25 mm, blue curve - 1.8 mm and green curve - 2.5 mm.

EXPERIMENTAL RESULTS

Experimentally beam emittances were measured using system and script detailed in Fig. 5.

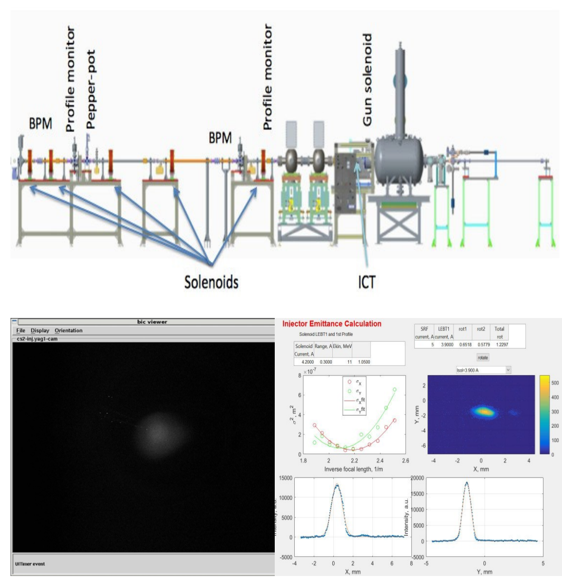


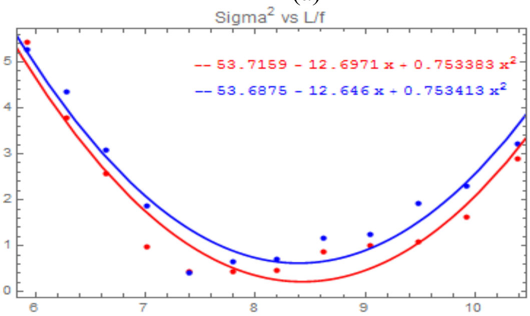
Figure 5: System layout (top), camera shots from YAG1 profile monitor (bottom left), and Matlab script for emittance analysis (bottom right).

Measurements had been done in three configurations:

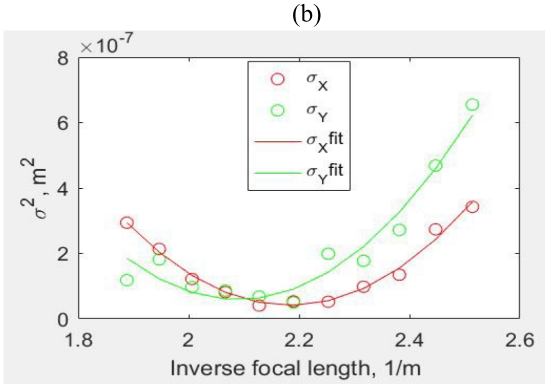
1) gun solenoid scan and YAG1 profile monitor.
2) LEBT1 solenoid and YAG1 profile monitor.
3) LEBT3 solenoid and YAG2 profile monitor.

In all case, the SRF gun voltage was at 1.05 MV and the charge per bunch was about 0.5 nC. Some of experimental results of the emittance measurements by the above solenoid's scan are shown in Fig. 6. Measured normalized emittances in horizontal plane were 0.32, 0.94, 0.53 mm mrad, correspondingly.

(a)



(b)



(c)

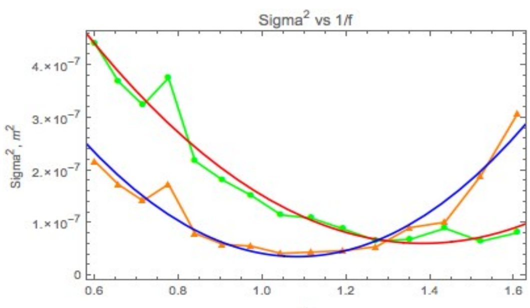


Figure 6: Results of three emittance measurements performed using three different solenoid's scans: (a) the gun solenoid and YAG1 profile monitor; (b) the LEBT1 solenoid and YAG1 profile monitor; (c) LEBT3 solenoid and YAG2 profile monitor.

Possible explanation of larger value of the beam emittance measured using LEBT1 solenoid is its close proximity to the YAG 1 profile monitor and limited resolution of the later. We plan to continue detailed studies of the beam emittance from our unique SRF gun.

CONCLUSIONS

All the experimental results indicate that our SRF gun is generating electron bunches with normalized emittance at submicron scale for bunch charges ~0.5 nC. It means that the 113 MHz SRF gun is an effective way of generating CW beam (in our case 78 kHz rep-rate provided by the laser) with high charge per bunch and sub-micron normalized emittances. Our results are in a decent agreement with our simulation using PARMELA, but we will pursue further verification and more detailed comparison. As PARMELA predicts, the fine adjustment of laser spot size is necessary to minimize the normalized emittance. In our low energy transport beam line we have a "pepper pot" system located in front of the YAG2 profile monitor, which we plan to use for further measurements and analysis our beam.

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