COHERENT ELECTRON COOLING PROOF OF PRINCIPLE PHASE 1 INSTRUMENTATION STATUS*

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Abstract

The purpose of the Coherent electron Cooling Proof-of-Principle (CeC PoP) [1] experiment being designed at RHIC is to demonstrate longitudinal (energy spread) cooling before the expected CD-2 for eRHIC. The scope of the experiment is to longitudinally cool a single bunch of 40 GeV/u gold ions in RHIC. The cooling facility will be installed inside the RHIC tunnel in 3 phases. The status of the instrumentation systems planned for phase 1 commissioning efforts will be described. This paper will also describe updates to the instrumentation systems proposed to meet the diagnostics challenges during the final phase of cooling commissioning [2]. These include measurements of beam intensity, emittance, energy spread, bunch length, position, and transverse alignment of electron and ion beams.

INTRODUCTION

Cooling of ion and hadron beams at collision energy is of critical importance for the productivity of present and future Nuclear Physics Colliders, such as RHIC, eRHIC and ELIC. An effective cooling process would allow us to cool the beams beyond their natural emittances and also to either overcome or to significantly mitigate limitations caused by the hour-glass effect and intrabeam scattering. It also would provide for longer and more efficient stores, which would result in significantly higher integrated luminosity. The scaled down economic version called CeC PoP does not offer optimal cooling conditions, but it includes the most critical and untested elements (from modulator to kicker) and is sufficient for demonstration. The diagnostics systems described here are based on the requirements determined by the latest simulations; additional systems may be added as further simulations look more closely at non-ideal conditions. The CeC PoP phase 1 beam line is presently in the construction phase. The primary goals of this first phase are to test the 112 MHz SCRF gun [3] and 500 MHz buncher cavities and to measure low power 2 MeV electron beam characteristics. Initial system commissioning is planned for early FY15.

ELECTRON BEAM DIAGNOSTICS

During the initial commission phase the electron beam diagnostics will provide the necessary measurements to commission the 112 MHz SRF Gun, then transport the 2 MeV beam through the 11m straight beam line to a low power dump as shown in Fig. 1. During the next phase the low power dump will be replaced with a 704 MHz SRF Linac and the wigglers and associated beam lines will be installed. The 21.8 MeV beam will be transported through the Linac and the FEL wigglers to the high power (10 kW) dump as shown in Fig. 2. During the following RHIC run the wigglers will be relocated into the nearby RHIC transport to allow electron co-propagation with the gold ion bunches and allow initial cooling studies as shown in Fig. 3.

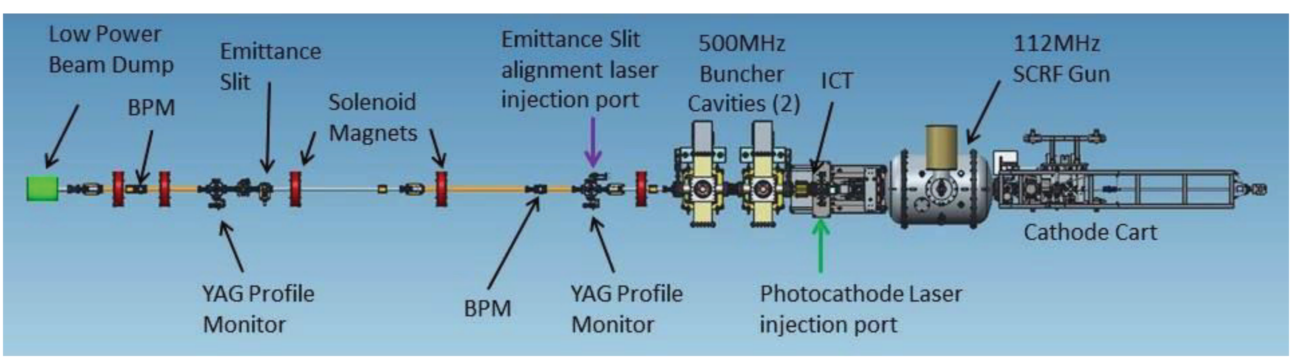

Figure 1: Plan view of the phase 1 electron beam line (2 MeV), the commissioning goals include SCRF gun and buncher testing and beam parameter measurements.

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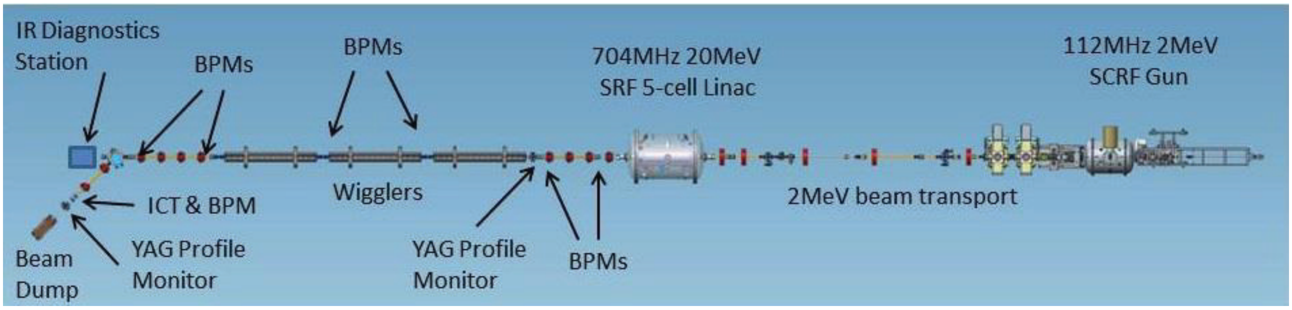

Figure 2: Plan view of the phase 2 electron beam line, the goals are to test 704 MHz 20 MeV Linac and wigglers.

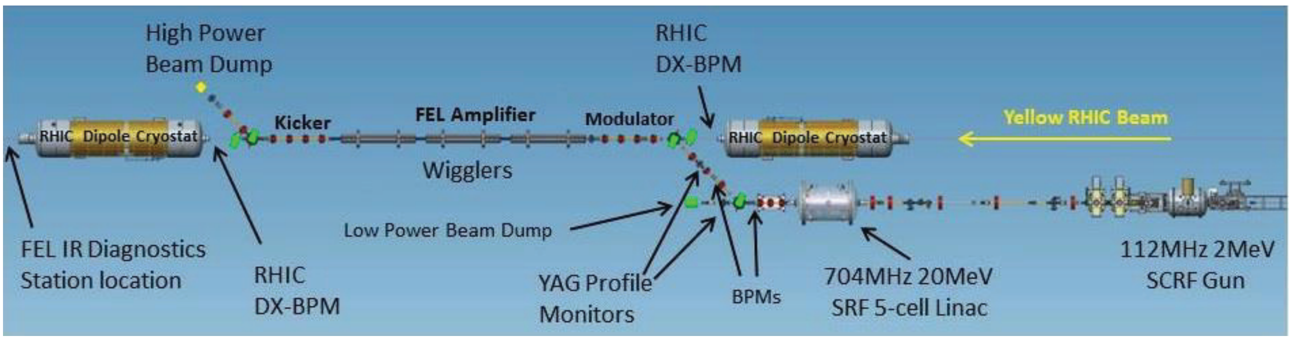

Figure 3: Plan view of the final phase 3 configuration to demonstrate cooling of RHIC gold beam.

Bunch Charge and Current

Electron bunch and bunch train charges will be measured by a Bergoz [4] in-flange Integrating Current Transformer (ICT-CF6-60.4-040-020:1-H-UHV-THERMOE) with 1.25Vs/C sensitivity and the AISI 316LN option. Beam charge signals will be processed by Bergoz BCM-IHR Integrate-Hold-Reset electronics with the 10 kHz option feeding a beam synched triggered digitizer. An ICT will be installed in the upstream portion of the 2 MeV transport and another just upstream of the high power dump to allow monitoring of the overall transport efficiency. Due to the 10 kHz measurement rate limitation only a subset of the planned 78 kHz bunches will be measured.

The low and high power beam dumps will be electrically isolated to allow measurement of the collected electron beam.

Beam Position Monitors

There are 11 dual plane button style BPM pick-ups in the 40 meter electron beam line. All of the 15mm diameter BPM buttons and associated housings are provided by MPF Products Inc.[5], except for the housings downstream of each wiggler that are provided with the wiggler structures from BINP as shown in Fig. 4.

During phase 1 commissioning Libera Brilliance Single Pass electronics from Instrumentation Technologies will process signals from the two BPMs downstream of the gun. We plan to utilize new in-house VME based BPM electronics modules presently in development for the remaining downstream BPMs. These modules are based on a Xilinx Zynq processor/programmable logic array combination which allows for great flexibility in designing custom processing algorithms for a variety of bunch frequencies and types. The current design incorporates 500 MHz and 707 MHz band pass RF filters in the analog input section which are suited for electron beam measurements. A different configuration also allows the use of a 39 MHz low pass filter instead for hadron beam measurements. A set of four A/D converters can be clocked at rates up to 400 MHz and provide four channels of measurement on each hardware board which will correspond to each dual-plane BPM module. Each VME module has its own Ethernet connection to the network which allows direct access to data from standard controls software tools. The first series of hardware boards have been received at BNL and are currently under testing and evaluation.

During the phase 3 cooling demonstration an electron bunch will co-propagate with a 40 GeV/u gold bunch in the yellow RHIC ring. The electron-ion alignment strategy utilizes the button DX BPMs (ions only) located at the ends of the RHIC warm section in addition to the button BPMs in the common cooling region. Filters will be used to separate the analog beam position signals of the long 10ns ion bunch and the short 10ps electron bunch to allow separate BPM electronics modules to measure both beam positions in the common region.

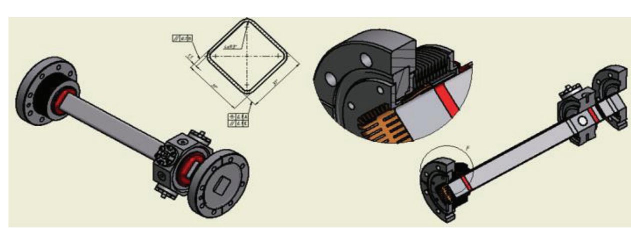

Figure 4: Beam Position Monitor pick-up assembly downstream of each Wiggler section provided by BINP.

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Electron Beam Emittance

There are several techniques planned to measure beam emittance. The expected normalized emittance range is 2-10 mm-mrad. An emittance slit station will be used to measure the space-charge dominated 2 MeV beam emittance in the injection transport. This station consists of a 3-position plunging 2 mm thick tungsten mask located 0.5 m upstream of a YAG profile monitor. The 0.2 mm wide slits are 2 mm apart as shown in Fig 5.

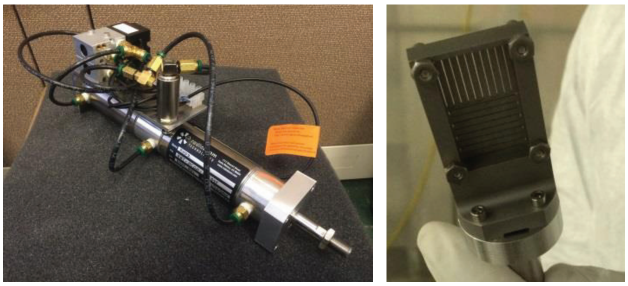

Figure 5: Emittance slit 3-position plunger on left, and tungsten mask with 0.2mm horizontal and vertical slits.

The profile monitor upstream of the emittance slit is configured with a green diode laser and adjustable 3X beam expander to allow convenient alignment of the slit mask to ensure quality measurements can be made on the downstream profile monitor as shown in Fig. 6. A mirror mounted in the vacuum chamber on the back of the YAG mirror is used to direct the alignment laser towards the emittance downstream slit mask as shown in Fig. 7.

The 21.8 MeV beam emittance can be measured in the auxiliary beam line transport straight out of the SRF Linac using the traditional quad scan technique using image data from the downstream YAG profile monitor. The energy spread can be measured using the profile monitor located after the first dipole downstream of the Linac.

Longitudinal Profile Measurement

Longitudinal bunch length measurements will be made by varying the Linac rf phase and analyzing the images on the downstream profile monitor after the first dipole magnet. To fully utilize the electron beam cooling capacity a uniform longitudinal beam profile is needed [6]. A two frequency injector system tuned for this requirement will be utilized.

Transverse Profile Monitors

Transverse beam profiles will be measured using pneumatic plunging 0.1 X 30 mm YAG:Ce screens mounted in profile monitor stations as shown in Fig. 6 and 7. There will be six located of these stations installed at key locations in the beam transport.

Images from the YAG screen that is oriented orthogonal to the electron beam are transported by two mirrors and fixed lens to a GigE CCD camera. Software was developed that allows line-out profile data at any angle cut through the image as shown in Fig. 8.

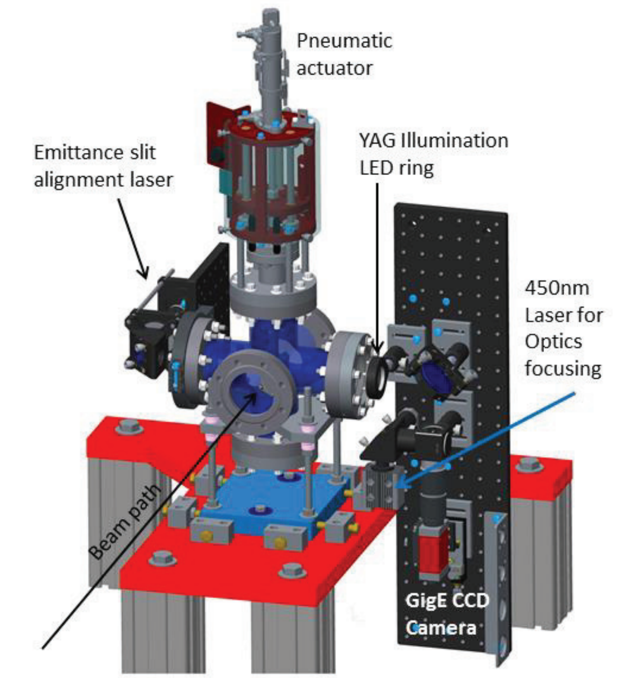

Figure 6: YAG Profile Monitor with emittance slit alignment diode laser injection port and 450 nm diode laser used for optics focusing.

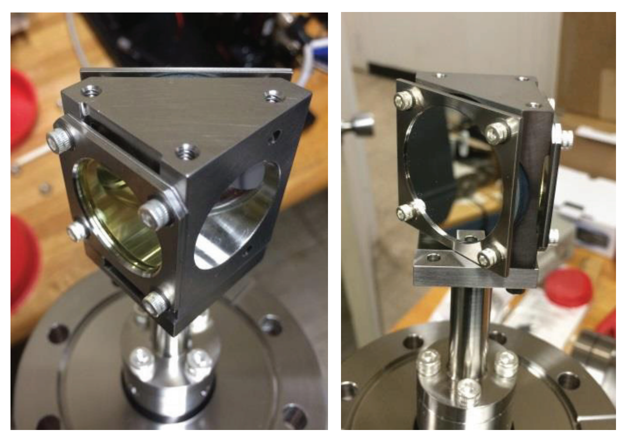

Figure 7: YAG screen head with 45 degree beam image mirror at left, at right the other side is shown with 45 degree laser alignment mirror behind the image mirror.

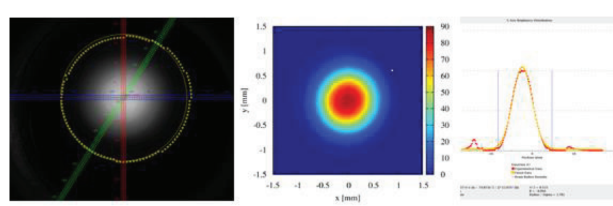

Figure 8: Beam profile monitor image signal processing examples.

Electron Beam Loss Monitors

Beam loss detectors will be distributed at 14 key locations throughout the beam line to provide a tuning aid

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and will be used to optimize transport efficiency. Elevated radiation doses need to be avoided especially in the wiggler sections where they can lead to a partial demagnetization of the permanent magnets with a detrimental effect on the free-electron laser process. The primary loss sensor will be a photomultiplier tube based loss detector. The design of this detector is based on ones developed at Jefferson Lab and used at CEBAF. CeC PoP will plan to use the Hamamatsu R11558 PMT in the detectors.

Loss signals will be processed using a VME module developed at JLAB that provides dual parallel analog circuits for each detector. An integrating channel provides fast response (<1 us) with configurable interlock threshold comparison for machine protection, a second channel which employs a log–amp provides wide dynamic range (>50 dB) for tuning [7].

FEL WIGGLER DIAGNOSTICS

The laser light from the FEL wiggler will be used for monitoring the lasing and cooling process. Characteristics of the spontaneous radiation will be an indication of the electron beam trajectory and the quality of the electron and ion bunch overlap. The positively charged ions will attract the electrons and each cloud surrounding the ion will radiate coherently in the wiggler, thus substantially increasing the optical power due to the effective increasing of shot noise. FEL tuning will include alignment of the electron trajectory and proper relative phase adjustments of the three wiggler sections using separately powered phase shifters and dipole correctors downstream of each 2.8 m wiggler (2.5 m of 60 poles + 30 cm for 2 ½ matching poles). The phase between the wigglers needs to be precise, and the relative electron-ion phase in the kicker region is critical to demonstrate cooling. The FEL gain needs to remain in the linear range for effective cooling and is expected to be on the order of 100, therefore the IR power will rise by four orders of magnitude. The wiggler radiation will be concentrated around a 14 micron wavelength. There will be a dedicated FEL IR diagnostics station located downstream of the wigglers [8].

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