COHERENT ELECTRON COOLING PROOF OF PRINCIPLE INSTRUMENTATION DESIGN*

D. M. Gassner #, V. Litvinenko, R. Michnoff, T. Miller, M. Minty, I. Pinayev, BNL, NY 11973 USA

Abstract

The goal 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. This paper will describe the instrumentation systems proposed to meet the diagnostics challenges. These include measurements of beam intensity, emittance, energy spread, bunch length, position, orbit stability, and transverse and temporal 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 is presently in the preliminary design stage; some subsystem installation at RHIC IR2 will start during 2012 with initial system commissioning in FY15.

DIAGNOSTICS FOR THREE BEAMS

Careful measurements and tuning will be necessary to align, control, and monitor the three co-propagating beams (ion, electron, & laser) each with diverse characteristics in the RHIC beam line, to enable the desired complex interactions within the series of three cooling sections. The suite of instrumentation devices will provide measurements to ensure the co-propagating electron and ion beam are sufficiently overlapped and centered in the 32 mm wiggler apertures. The CeC demonstration will only cool the yellow RHIC beam due to the limited wiggler aperture, and not enough room for both of the counter rotating RHIC beams while one is being cooled in the wiggler center. The purpose of the FEL is to amplify the electron density that was modulated by the ion beam. The IR radiation emitted from the FEL during this amplification process will be analyzed to determine the quality of the electron and ion beam alignment and characteristics of the cooling process.

ELECTRON BEAM DIAGNOSTICS

The electron beam diagnostics will provide the necessary measurements to commission the 112 MHz SRF Gun, then transport the 2 MeV beam through the 704 MHz SRF Linac to a short auxiliary 21.8 MeV beam line to allow Linac commissioning. The 21.8 MeV beam will then be merged with the RHIC beam line so the electron and ion beams overlap well through the modulator, FEL wigglers and kicker. After the kicker, the electron beam will be steered out of the RHIC beam line and transported to a dump.

Table 1: Electron Beam Parameters

Electron Beam Energy	21.8 MeV
Charge per Bunch	0.5 – 5 nC
Electrons per Bunch	$3.1 - 6.2 \times 10^9$
Electron Beam Current	78 uA
RMS Norm Emittance	≤5 mm mrad
Rep Rate	78.3 kHz
RMS Energy Spread	$\leq 1 \times 10^{-3}$
RMS Bunch Length	10 ps
RMS Trans beam size	1 mm
e-beam power	1.7 kW

*Work supported by the auspices of the US Department of Energy
#gassner@bnl.gov

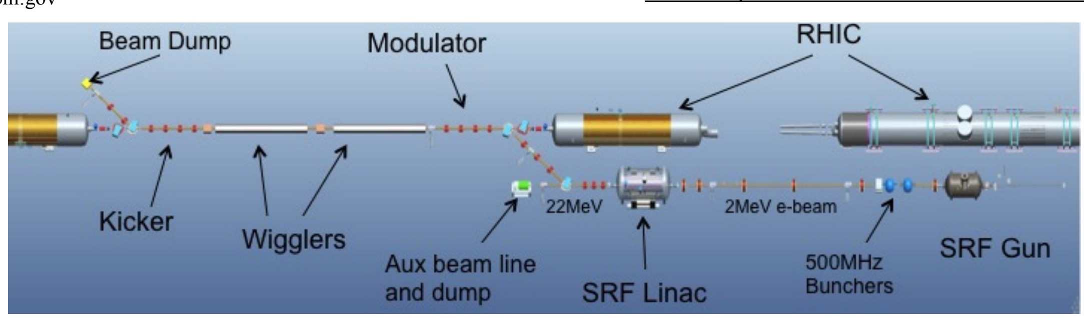

Figure 1: CeC PoP beam line layout. The Modulator, Wigglers and Kicker will be located at the RHIC IR2.

ISBN 978-3-95450-121-2

Electron Beam Position Monitors

There are 11 dual plane 9.3 mm diameter button style BPM pick-ups in the 40 meter electron beam line. Libera Brilliance Single Pass electronics from Instrumentation Technologies will process signals from the BPMs.

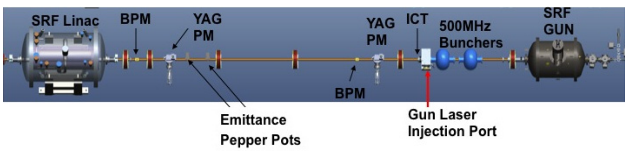

Figure 2: Beam diagnostics in the 2 MeV transport from the SRF Gun to the SRF Linac.

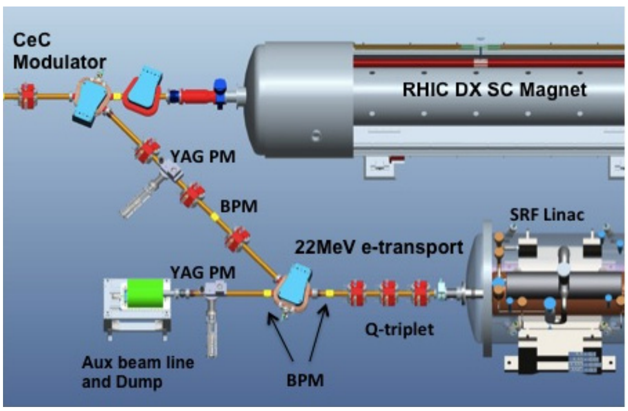

Figure 3: Electron beam diagnostics from the SRF Linac to the CeC modulator.

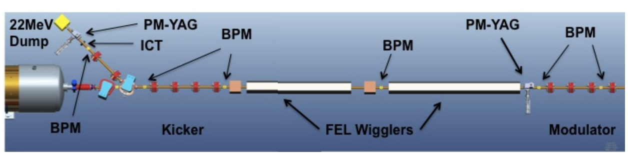

Figure 4: Electron beam diagnostics in the modulator, wiggler, kicker to dump.

Electron Beam Profile Monitors

Transverse beam profiles will be measured using YAG or OTR screens. When in low charge mode we will use 0.1 X 50 mm YAG:Ce screens from Crytur. For higher bunch intensity and energy we will use OTR screens that are comprised of a 250 micron thick silicon wafer coated with ~1000 angstroms of aluminum.

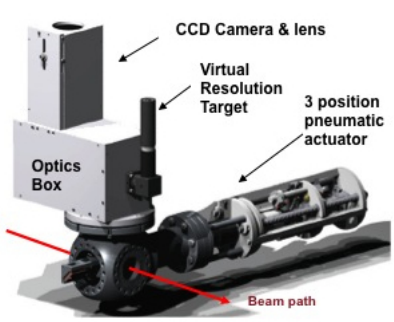

Figure 5: Profile monitor, drawing by Radiabeam.

Images from the YAG or OTR screens are transported through a mirror labyrinth to a 3-motor lens and GigE CCD camera in a local enclosed optics box.

A wire scanner profile monitor is planned upstream of the dump to allow high resolution measurements of the effects of the lasing and cooling process on the electron beam.

Electron Beam Emittance

There are several techniques planned to measure beam emittance. The expected normalized emittance range is 2-10 mm-mrad.

A pepper pot station will be used to measure 2 MeV beam emittance in the injection transport. This station will be comprised of two independently plunging 2mm thick tungsten masks upstream of a YAG profile monitor, one located at 0.25 m, and the other at 0.5m.

The 21.8 MeV beam emittance will be measured in the transport straight out of the SRF Linac using the traditional quad scan technique, and image data from the downstream YAG & OTR profile monitor. Additional measurements will be made by varying the Linac rf phase and analyzing the images on the downstream profile monitors.

Electron Bunch Charge

Bunch-by-bunch & bunch train charge will be measured by a Bergoz in-flange Integrating Current Transformer (ICT). Beam charge signals will be processed by standard Bergoz BCM-IHR Integrate-Hold-Reset electronics 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 dump to allow monitoring of overall transport efficiency.

Electron Beam Loss Monitors

Elevated radiation doses need to be avoided in the electron beam transport and in the wiggler sections where they are especially undesirable as they can lead to a partial demagnetization of the permanent magnets with a detrimental effect on the free-electron laser process. Photomultiplier tube (PMT) based loss detectors will be installed at a variety of locations. 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.

FEL WIGGLER DIAGNOSTICS

The radiation 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 beam 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.

ISBN 978-3-95450-121-2

FEL tuning will include alignment of the electron trajectory and proper relative phase adjustments of the halves of the wiggler using separately powered 3-pole sections downstream of each 3.5 m wiggler. The phase between the wigglers needs to be precise, and the relative electron-ion phase in the kicker is critical for 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 13.1 micron wavelength; this is defined by the electron energy (21.8 MeV), wiggler period (4 cm), and wiggler parameter (aw = 0.427). Due to the helical design all high harmonics will be suppressed (see Fig. 6 and 7).

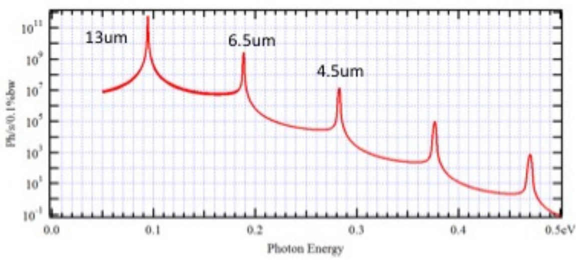

Figure 6: Simulation of spectral flux of spontaneous wiggler radiation using a 100 µA e-beam current, normalized rms emittances are 3.3 microns, and relative energy spread is 3×10^{-4}.

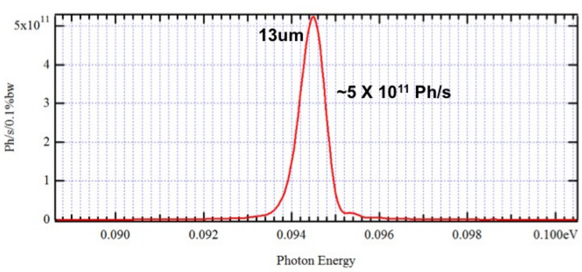

Figure 7: Spectral flux detail of the main harmonic.

The wiggler radiation will be extracted from a port in the RHIC DX magnet cryostat through a ZnSe window (available from II-VI Infrared) that is transparent from 0.54 to 20 um. An IR beam line will provide a light path to a multipurpose IR diagnostics station away from the RHIC beam line to reduce possible radiation damage.

The FLIR A615 IR camera with sensitivity from 7.5-14 um can measure transverse beam profiles, see Fig 8.

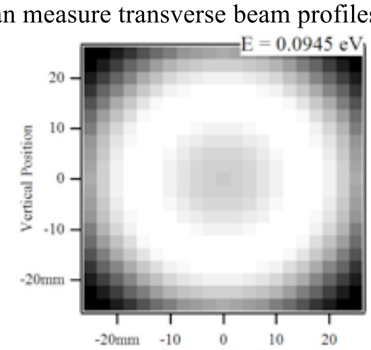

Figure 8: Simulation of the transverse distribution of the optical power 15 m from wiggler. The dip in the middle is due to the spiral electron motion from the helical wiggler.

The IR spectrum can be measured using an Acton VM-504 from Princeton Instruments. This Czerny-Turner type monochromator can be configured with a 75-grooves/mm grating. During the cooling process cooling we expect the see variations in line width.

The IR intensity will be measured with either HgCdTe (such as Hamamatsu P5274 MCT detector) or Si:Ga detectors. The average expected power will range from tens of nW (at low charge) to few mW when lasing.

A calibration test laser beam can be used to confirm the alignment of the cooling structures and the functionality of the equipment in the IR diagnostics station. This laser light can be sent through the upstream RHIC DX magnet, then through the CeC elements, and the downstream DX magnet, and finally steered to the IR diagnostics station.

RHIC ION BEAM DIAGNOSTICS

The primary diagnostics for monitoring of the cooling process will be the RHIC Wall Current Monitor [2] and Schottky monitors. A new wideband Schottky pick-up is being designed for improved monitoring of the longitudinal stochastic cooling characteristics that may also be useful for CeC. The valuable experience gained using these instruments during the successful stochastic cooling commissioning will be applied to the CeC effort. A simulation of CeC on the longitudinal bunch profile is shown in Fig 9.

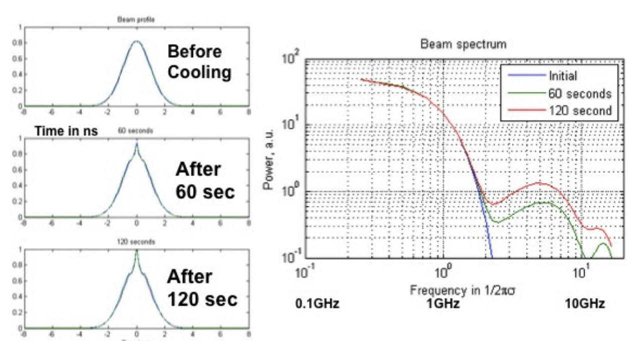

Figure 9: Simulation of RHIC gold 40GeV/n, (rms bunch length 1.5ns) longitudinal bunch profiles during the CeC PoP process with optimal conditions.

The existing RHIC DX BPMs will be used to center the $1\text{x}10^9$/bunch, 2 mm mrad rms norm emittance gold beam in the wigglers. The RHIC closed loop orbit system will ensure ion beam position stability.

During the tuning process there should be evidence of anti-cooling that can be measured by the existing RHIC BLM system and IPMs.

Studies will be conducted that focus on making CeC related measurements with RHIC ion beams over the next few years to prepare for the demonstration experiment.

ISBN 978-3-95450-121-2

ACKNOWLEDGMENTS

The authors would like to thank CeC community for the years of concept development, and especially A. Fedotov for the cooling simulations, Y. Hao, C. Liu, G. Wang, K. Mernick, M. Wilinski for helpful discussions, and C. Brutus for the layout drawings.

REFERENCES

[1] Litvinenko, V et al., “Proof-Principle Experiment for FEL-Based Coherent Electron Cooler”, PAC2011, THOBN3

[2] Cameron, P et al., “The RHIC Wall Current Monitor System”, PAC99, WEA116, page 2146.

ISBN 978-3-95450-121-2