Commissioning Plan for CeC System

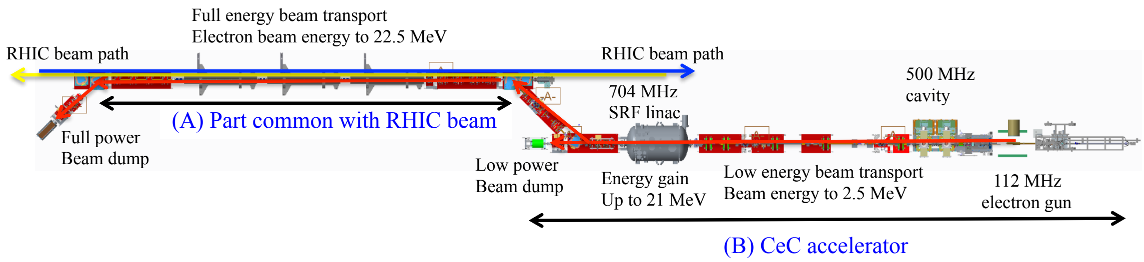

Figure 1. Layout of CeC system: (A) part common with RHIC beam; (B) CeC accelerator. Electron pulses will be generated in a 2-MeV 112-MHz SRF gun and then pass through two 300-kV 500-MHz bunching cavities and transported to the 704-MHz SRF linac for acceleration to full energy up to 25 MeV. The beam will be delivered to the RSC approved dump. Shielding and access controls have been designed for the future full power mode up to 8000 watts. Beam power in the low power mode is less than 1 watt.

Following a successful IRR and ARR, full power commissioning of the CeC system will be allowed with and without interacting with the RHIC beam (e.g. cooling). CeC PoP Experiment will operate Yellow ring with 6 to 12 ion bunches with nominal intensity not exceeding 10^9 ions per bunch and total intensity of $12x10^9$ ions. Beam energy for the full power operation will bellow 25 MeV with power at the dump not to exceed 8 kW.

Initial low power commissioning of the CeC accelerator and CeC system will be conducted in a parallel mode that will not interfere with regular RHIC operation. The modes for such operations are described in the previous Low Power Testing Plan.

CeC PoP Experiment will start from low power commissioning with goals to generate, accelerate and propagate electron beam to the low energy dump.

First, electron beam will be established from the SRF gun and propagated to the diagnostic section. Beam will be characterized by energy and emittance.

Second, beam will be propagated through the 704 MHz SRF linac and accelerated to its maximum energy. After optimizing the beam energy, beam will be characterized using diagnostics down-stream of the 704 MHz SRF linac including the dog-leg. All low-power commissioning will be done with low beam power and low bunch rep-rate.

Third, loss studies will be conducted by intentionally directing low power (<1W) electron beam into various locations of the vacuum chamber. This information will be used for calibrating beam-loss diagnostics and setting limits for the MPS. Concurrent with these fault studies, RCTs will conduct radiation surveys of the external areas that can be occupied.

Fourth, CeC Pop Experiment will establish the safe time gate for propagating electron bunches through IP2 without interfering with regular RHIC operations. When this operation mode is verified, the CeC PoP Experiment will start propagating low-power electron beam through the common section with the RHIC beams, starting from single pulses to establish orbit within ±3 mm from the axis, and verifying beam optics via measuring with single pass BMP electronics.

Fifth, CeC PoP Experiment will gradually increase the electron beam current through the system, established the beam path within ±1 mm from the design orbit. After this, CeC PoP will deploy the helical wigglers and re-establish the beam optics and the orbit as in the previous steps.

Sixth step will be demonstration of the FEL amplifications using low-current beam. CeC PoP Experiment will use IR FEL diagnostics and FEL's phase shifters to demonstrate FEL amplification.

Seventh, CeC PoP Experiment will use a dedicated APEX session to establish interaction mode with RHIC ion beam for the purpose of cooling and to observe ions effects on the FEL radiation.

Eighth, CeC PoP Experiment will determine the limits of the allowable ion beam orbit excursion and activate this feature in MPS system. Following this, an approved full power commissioning plan will then be executed.

Ninth, in a dedicated CeC mode, CeC PoP Experiment will attempt to demonstrate cooling of ion beam using full power e-beam from CeC accelerator. CeC PoP Experiment will use the RHIC diagnostic to observe effect on the CeC on a single ion bunch. Other ion bunches will serve as witness bunches.

Tenth, CeC PoP Experiment will use CeC system in dedicated mode to characterize parameters of the CeC process.

The table below describes the electron beam parameters, which would be used during t If configuration of CeC PoP Experiment or its mode of operation would be modified in the future, C-AD will perform a USI determination to address the modifications.

Table 1: Range of the CeC PoP Experiment Parameters

Parameter/Mode	Low Power Mode		Future Full Power Mode
	Low Power Beam Dump at (B)	RSC Approved Low Power Dump at (A)	Full power dump
Beam energy, MeV			
Nominal	1.5 MeV – 22 MeV	20 - 22 MeV	20 - 22 MeV
Allowable range	< 25 MeV	< 25 MeV	< 25 MeV
Beam current	< 1 μA	< 4 μA	< 800 μA
Beam power, W	< 1	< 10	< 8,000

The steps of the commissioning the CeC experimental system will include

(a) installation of the equipment;
(b) conditioning of sub-systems;
(c) testing of the systems with low power electron beam

(a) C-AD plans to complete the installation of the equipment before the start of RHIC Run 16. Sub-systems, that do not generate radiation hazards will be tested after the routine industrial safety hazards have been reviewed, field inspected, and authorized to operate by the C-AD Accelerator Systems Safety Review Committee. This could occur prior to the start of the RHIC run. Such system include: water, AC power, environmental controls, equipment controls, power supplies, magnets, vacuum system and diagnostic instrumentation. The laser delivery system would be commissioned inside the dedicated trailer and its delivery to the SRF gun will be tested when the area is secured according the laser safety requirements. Laser operators will be qualified to a BNL approved Laser SOP.

(b) Two of three CeC's RF accelerators are super-conducting (one operating at 2K and the other at 4K) and require liquid He to operate. The liquid He will be provided by RHIC's cryogenic facility or using He Dewars. Conditioning of CeC's three RF systems (112 MHz SRF gun, two 500 MHz bunching cavities and 704 MHz SRF linac) will generate X-rays and will be conducted within the RHIC tunnel radiation enclosure after a sweep is complete and when an approved RSC check-off list has been completed. Completion of functionality tests for the PASS system is documented on the RSC check-off list. Interlocks will block this system from being turned on if PASS is not active. Radiation absorbed dose rates up to 5 rad in an hour are expected in the vicinity of RF cavities during their conditioning.

(c) Low power beam testing will be conducted at low repetition rate (typically 1Hz) and bunch charge not exceeding 10 nC (typically 3 nC). The low power beam testing will be conducted without interacting with or operating with RHIC hadron beam. Low power electron beam (at 1 W) cannot change the orbit of the rigid RHIC ion beams. Low power beam testing will happen in four distinctive modes:

    Mode I: Beam will be accelerated in CeC accelerator and delivered to the low power dump. Energy of the beam will not exceed 25 MeV and the beam power will not exceed 1 W. This mode can be operated any time the IP2 PASS system is activated and CeC systems (including MPS) are operational. During measuring beam parameters we will intercept electron beam with beam-profile or pepper-pot screens. We plan to beam current < 5 nA and beam power < 0.125 W for such measurements. We will use the CeC bending magnet to measure and to calibrate beam energy. Prior to using this mode, we will use one of the APEX sessions to prove experimentally that turning on and changing current in the CeC dipole magnets does not affect both blue and yellow hadron beam in RHIC. This feature is provided by use of compensating dipoles (see Figure 2) installed in the hadron beam pass, which are identical to those bending electron beam, but opposite in sign. All CeC dipoles are powered in series providing full transparency for hadron beams. The loss monitors around the ring will be documented during these tests and the results sent to the C-AD RSC for review.

CeC dipoles should affect RHIC beam at injection energy, which is when RHIC ion beams are most vulnerable. The orbit variation outside IP2 area caused by the CeC dipoles should not exceed $1/10^{th}$ of the hadron beam size. An official record of these results will be provided to the C-AD Chair and the C-AD RSC for review.

In addition, the energy measurements will be conducted with a closed vacuum valve in the dog-leg (see Figure 2) intercepting the beam and preventing it from propagating into RHIC.

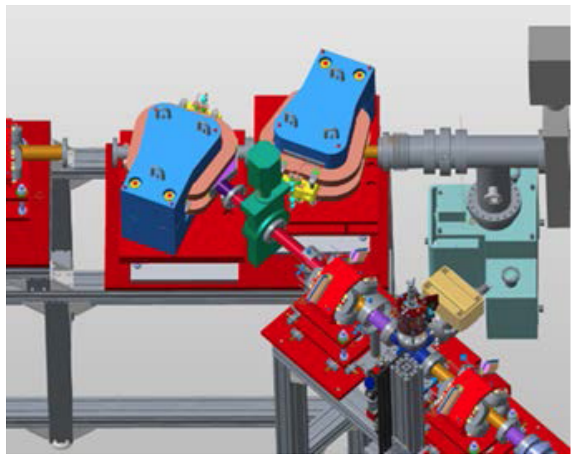

Figure 2. End of the CeC system dog-leg after which electron and ion beams merge. A pair of identical dipoles with opposite field direction is fed in series and provides zero field integral (null-angle) for the hadron beams circulating in RHIC. The bilaterally symmetric pair of dipoles is installed at the electron beam exit to the Low Power Dump. The vacuum valve (green) separating the CeC accelerator from RHIC vacuum pipe will be closed when CeC is in Modes I and II.

Mode II: Parallel to the RHIC collider operation and transparent for RHIC beams. In this mode CeC Pop physicists will propagate electron beam to the RSC Approved Low Power Beam Dump at the end of the transport and guarantee that electron beam does not interact with either yellow or blue hadron beam circulating in RHIC. This feature will be provided by low-level RF system, which controls CeC PoP Experiment laser permits. Specifically, RHIC beam pattern has an abort gap of at least 0.9 μsec (270 m) long. In the middle of this gap, the low-level RF system will provide a time window allowing generation of CeC laser pulse – see Figure 3. In this configuration, electron beam will travel at the same velocity close to that of the hadron beam and propagate through the IP2 without any interaction with hadron beams circulating in RHIC beam. We will have a dedicated APEX session to establish that the electron beam generated by such scheme passes through the IP2 common section in the middle of the abort gap and within ± 100 nsec from its center. This will be verified by observation of the signals from IP2 common beam-position monitors using a digital oscilloscope.

When this mode is verified, we will make an official record of these results and provide them to the RSC Chair.

Mode III: Dedicated CeC mode. This mode will be exercised either during dedicated APEX session or during dedicated CeC RHIC time. In this mode we will operate CeC accelerator simultaneously with ion beam circulating in Yellow RHIC ring. Hadron beam in Blue ring will be prohibited using established RHIC procedures. We will operate Yellow ring with 6 to 12 ion bunches with nominal intensity not exceeding 10^9 ions per bunch and total intensity of $12x10^9$ ions. This mode had been established for APEX sessions at RHIC and is within RHIC beam safety analysis where one complete RHIC fill (111 ion bunches; $5x10^{11}$ Au ions or equivalent) was treated as a point loss. This mode will be used for establishing reliable propagation of the electron beam through the common section and establishing that the ion beam imprints its shot noise structure into the electron beam.

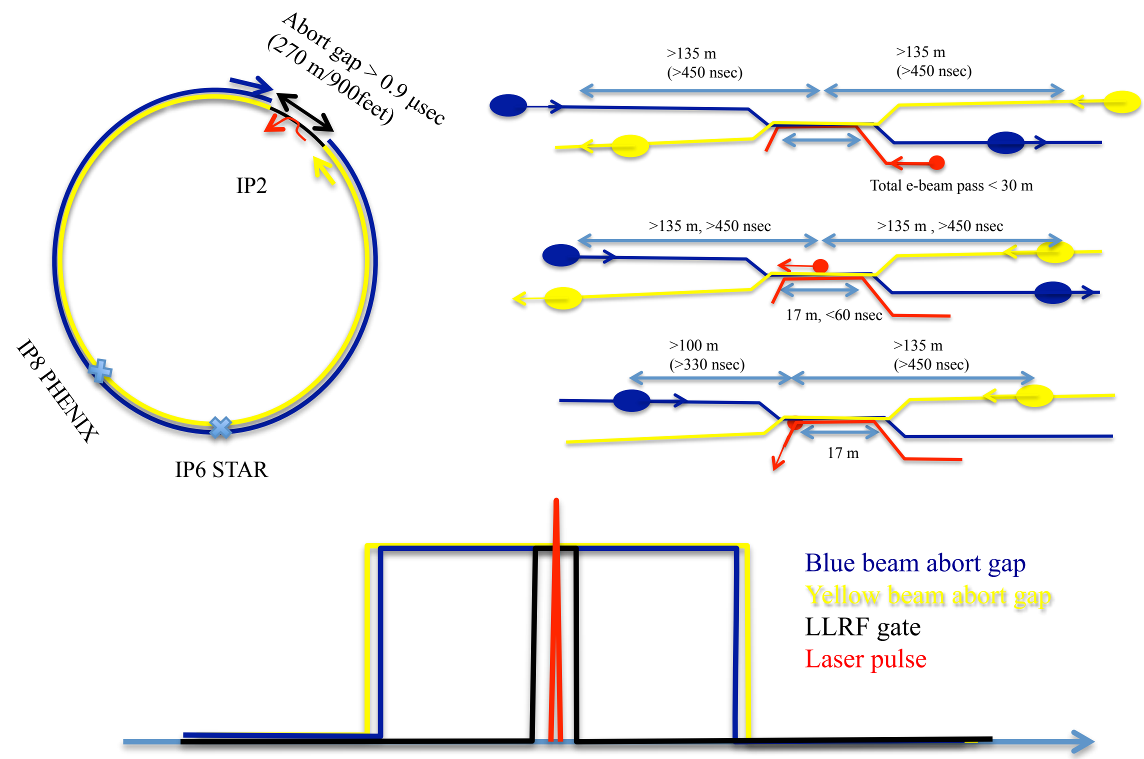

Figure 3 In RHIC, colliding hadron beams have an abort gap that is typically 1 microsecond long but always longer than 0.9 microseconds. By design, these abort gaps always overlap at IP8 and IP2. It provides a long period when there are zero hadrons in the 19-m long straight section common for yellow and blue hadron beam and CeC's electron beam. CeC Pop Experiment will use 200 nsec of this gap to propagate electron beam in the common section. The gate window for this propagation will be opened by the RHIC/CeC low-level RF system.

There is a single intercepting beam profile monitor installed in the common section. It is prevented from being inserted by a tagged mechanical lock. This lock can be removed and the beam profile monitor could be inserted to tracing electron beam. Such operation will be following a dedicated administrative procedure of removing the lock for this dedicated beam operation and then installing it back, prior to any injection of hadron beam into RHIC.

The only hadrons, which can collide with electron beam, will be de-bunched hadrons (lost from the main bunch train) and spread nearly-evenly around RHIC circumference. The amount of such hadrons is strictly controlled during RHIC operation, mostly because of the background they provide to the detectors and also to avoid "dirty" beam dumps. Large numbers of hadrons in the abort gap is defeating the entire purpose of the abort gap. Thus, the total population of de-trapped hadrons is kept well under 1% of the total beam (< $3x10^{11}$ protons or $2x10^{9}$ ions), using when necessary a abort gap cleaning devise (ARTUS). Only a small portion of these ions (34 m out of 3.8 km, < 1%) can collide with a single electron bunch.

Hence, the worst-case scenario, which assumes the CeC electron bunch disrupts the de-bunched hadrons,, could not cause loss of more than $3x10^{9}$ protons or $2x10^{7}$ ions per electron bunch. Finally, the chronic losses could not exceed the rate of populating the abort gap with de-bunched hadrons. That rate cannot exceed the total loss from the hadron beams during regular RHIC operation, whose lifetime is from 3 to 10 hours. Hence, the chronic loss would not exceed that already occurring in RHIC during standard operations.

In addition, the test 25 MeV electron beam at 1 W power level cannot change the orbit or stability of the 10-250 GeV RHIC hadron beams, should they inadvertently occupy the same space.

(d) **Mode IV**. Full power operation of the CeC system will be allowed with and without interacting with the RHIC beam (e.g. cooling). We will operate Yellow ring with six to twelve ion bunches with nominal intensity not exceeding 10^{9} ions per bunch and total intensity of $12x10^{9}$ ions. Beam energy for the full power operation will bellow 25 MeV with power at the dump not to exceed 8 kW.