STATUS OF PROOF-OF-PRINCIPLE EXPERIMENT FOR COHERENT ELECTRON COOLING*

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Abstract

Coherent electron cooling (CEC) offers a potential to significantly boost the luminosity of high-energy, high-intensity hadron colliders. To verify this concept, we conduct proof-of-principle (PoP) experiment at the RHIC [1]. In this paper, we describe the current experimental setup that will be installed into the RHIC's 2 o'clock interaction regions. We detail the current design, the status of acquiring equipment, and our estimates of the expected beam parameters.

PROJECT OVERVIEW

Figure 1 shows the system's overall layout. The electron beam will be generated by a CsSb photocathode inside the 112 MHz SRF gun. Two 500 MHz copper cavities then will provide energy chirp for ballistical compression of the electron beam, which then will be further accelerated to 22 MeV in the 704 MHz 5-cell SRF linac.

We use a dogleg to merge the electron- and ion-beams. The ions "imprint" their distribution into the electron beam via a modulation in the density of the space charge. This modulation is amplified in an FEL comprising a 7-m-long helical wiggler.

The ions co-propagate with electron beam through the FEL. Therein, the ion's average velocity is matched to the group velocity of the wave-packet of e-beam density modulation. A three-pole wiggler at the exit of the FEL tunes the phase of the wave-packet, such that the ions with the central energy experience the maximum e-beam density modulation where the electric field is zero. The time-of-flight dependence on the ions allows the electrical field, induced by the density modulation, to reduce ion beam's energy spread [2].

The used electron beam is bent away from the ions' path and is damped.

RF SYSTEM

112 MHz RF Gun

Niowave was awarded the task of modifying the 112 MHz cavity and building a new cryomodule. The design modifications included adding two manual tuners to adjust the cavity's frequency to the nearest harmonic of the RHIC's revolution frequency. The design of system was reviewed successfully and accepted in February 2012. The gun is expected to be ready in January 2013.

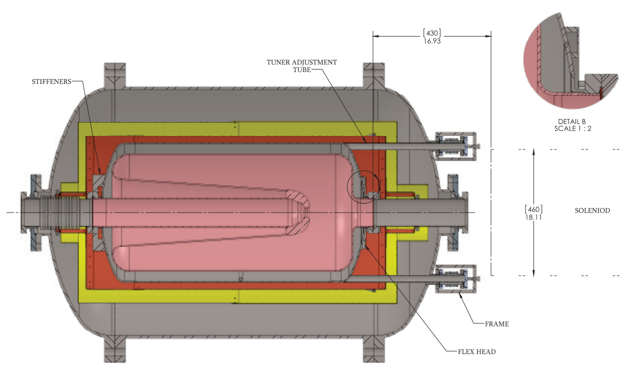

Figure 2: Cross-section of the proposed design of the 112-MHz SRF gun. Two tuners will be added allowing precise setting of the resonant frequency.

500 MHz System

We have two 500 MHz copper cavities on long-term loan from the Daresbury Laboratory, UK. Presently, the cavities are being conditioned, and will be installed into the RHIC tunnel during summer/fall of 2012. Anticipating the readiness of the RF power and controls by the end of this year, we plan to begin testing the cavities in early 2013.

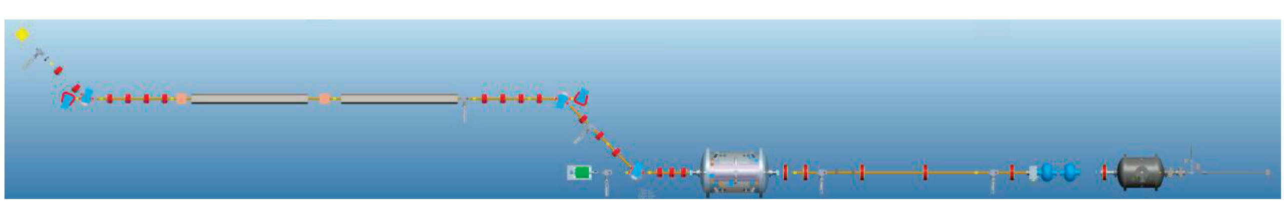

Figure 1: The layout of the CeC PoP experiment.

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704 MHz Accelerating Cavity

The 20 MV accelerating cavity was fabricated by Advanced Energy Systems. The accelerating structure of this copper prototype is illustrated in Fig. 3. An RFQ was placed for bids on the linac's cryostat.

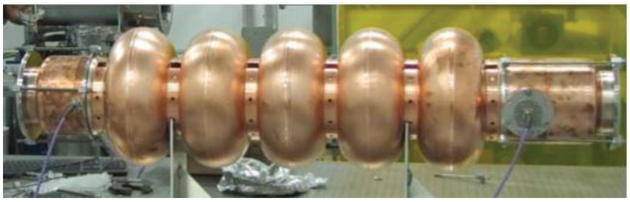

Figure 3: Copper prototype of 704 MHz accelerating structure.

GUN SECTION

The design of the low-energy section was modified to improve the beam's performance (Fig. 4). Six solenoids focus the beam transversely. These changes improved both the beam and the uniformity of the peak current in the compressed bunch. More on the design of this section is given in [3].

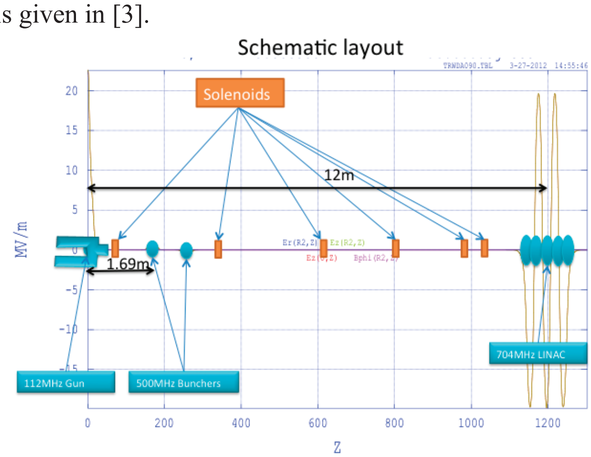

Figure 4: Low-energy section of the gun with increasing distance from the gun to the accelerator cavity.

The JLab's CeC team continues developing the DC gun as a back-up option by testing the first alkali-antimonite photocathode inside the 200-kV inverted photo-gun.

MAGNETS

Five of the six solenoids will be identical to the R&D's ERL design [4]. A new design of a solenoid would accommodate the physical constraints that the gun imposes. The steering in the low-energy section will be accomplished by three trims identical in design with that in the R&D ERL.

Accelerated to 22 MeV, we will bend the electron beam by three 45°-dipole magnets, whose design is in progress. We will place two identical dipoles with opposite polarity (fed in series with the rest of the magnets) on the ions' path to nullify the effects on the ion beam. The latter modification will allow us to commission the CeC accelerator in parallel with continuing the regular operation of the RHIC complex.

Ten quadrupoles (again identical to those in the R&D ERL) will focus the electron beam though the CeC section. The corrector windings therein will steer the e-beam. Eight of these quadrupoles will assure the optimal focusing of the beam in all three sections of the CeC. The last two quadrupoles will be used to increase the beam's size in the dump, and to reduce the power density at its surface.

DIAGNOSTICS

The diagnostics [5] include nine Beam Position Monitors (BPMs) for monitoring beam position, two integrating current transformers for measuring the current and beam transmission, four flags to assess beam size (as well as its emittance and energy spread), and two pepper pots for measuring the emittance of the low-energy beam in the 2 MeV section. We will employ beam-loss monitors to control the irradiation of the helical wiggler. The longitudinal profile of ion beam will be observed using the wall- current monitor with 6 GHz bandwidth. The FEL will be tuned via IR diagnostics (at wavelength of 13 microns). We are finalizing the suite of the IR diagnostics that includes a monochromator, IR camera, an HgCdTe sensor, and power meters.

WIGGLER

We used BNL's PD and LDRD funds to proceed with prototyping a helical wiggler and procuring the cryogenics system for CeC experiment. Figure 5 shows the wiggler's holders of permanent magnets. The wiggler's prototype will be assembled and the magnetic measurements will start in June 2012.

Figure 5: Picture of the magnet holders for the prototype of the helical wiggler.

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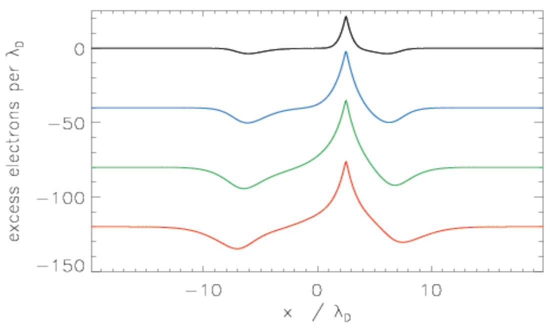
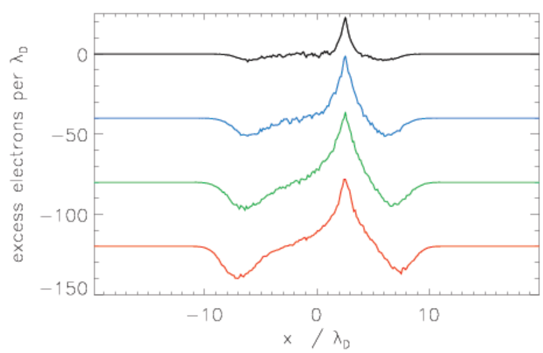
SIMULATIONS

Tech X is progressing towards the start-to-end CeC simulation package, using VORPAL δf algorithm and the Genesis 3D FEL code [6]. Present capabilities include simulating the entire CeC process with the e-beam uniformly focused. Implementing the focusing elements (quadrupoles) into the modulator and the kicker is in progress. In addition, an attempt to develop an alternative 3D FEL code allowing us to use the particles' distribution from VORPAL is continuing. Our comparison of the Vlasov equation with δf PIC demonstrated good agreement [7-10].



a)



b)

Figure 6: Comparison between the solution of the Vlasov equation (a), and VORPAL simulations (b) showing their good agreement.

OTHER SYSTEMS

We are making steady progress with procuring the cryogenic system and the driver laser. The laser will generate flattop pulses of variable durations from 100- to 500-picoseconds, and leading- and falling-edges below 150 picoseconds. The optical peak power should exceed 1 kW at 532 nm. The laser will be synchronized with RHIC timing system via a low-level RF system.

PLANS

We plan to continue optimizing the low- energy path and beam-dump area without changing the geometry of the accelerator. The 500 MHz cavities will be tested at full power in early 2013. We plan to install the SRF gun n during RHIC's shutdown in 2013, and commission it during RHIC's Run 14. The accelerator cavity, wiggler, beam dump, and balance of equipment will be installed during 2014.

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