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PROPOSAL FOR A HIGH TRANSFORMER RATIO CW DIELECTRIC ACCELERATOR

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Abstract

Advanced CW accelerators are one of high priority directions identified by Advanced Accelerator Concepts Research Roadmap Workshop Report. High transformer ratio of beam-driven accelerators is critically important for cost-effective FEL systems. We present a proposed experiment for demonstrating a high transformer ratio CW dielectric accelerator using operational SRF accelerator built for Coherent electron Cooling experiment. This accelerator operates with CW electron beam comprised of 78 kHz train of electron bunches. Electron bunches with controllable longitudinal and charge up to 10 nC per bunch are generated in 1.25 MV SRF photo-electron gun. This bunches are ballistically compressed to duration of 10-to-30 psec and accelerated to 15 MeV in SRF linac. Such bunches would be excellent drivers of high-transformer ratio DWA accelerators. In this paper we present expected performance of proposed CW DWA accelerator.

INTRODUCTION

Beam-driven wakefield accelerators are promising candidates for TeV class high energy colliders and compact FELs [1-5]. Very high acceleration gradients (GV/m level) have been achieved in all wakefield acceleration schemes [6-8]. Beam driven plasma wakefield acceleration (PWFA), laser-drive plasma wakefield acceleration (LWFA) and beam-driven structure wakefield acceleration (SWFA, including metallic, dielectric, or hybrid) are all currently considered as promising technologies for a future LC.

Plasma based schemes produce extremely high gradients, however, this technology cannot reliably be applied for positron acceleration that meet the LC requirements [7-9]. In recent years, a hollow channel plasma has been investigated as a method for accelerating positrons. Nevertheless, it suffers technical challenges like forming an ion free vacuum channel for positron passage and also sacrifices high gradients [10,11].

The DWA is capable of > 100 MV/m level gradient in the THz regime and is capable of both electron and positron acceleration. In a DWA structure, an intense drive bunch traverses the evacuated central region of the tube, creating Cherenkov wakefields in the dielectric that propagate outwards at the Cherenkov angle. The Cherenkov fields are then reflected by the dielectric boundary back towards the center axis where a witness bunch arrives and is accelerated [12]. The DWA approach resolves the high gradient THz source problem by using radiated fields from short drive bunches [12].

The DWA structure has already been demonstrated to sustain high gradients in experiments done at FFTB [13] and FACET [14]. However, these early experiments were operated at low repetition rate (1~10Hz) whereas the LC requires repetition rates on the order of 10 kHz [11] and enormous power. One way to handle the high-power requirements is to move the operating frequency into the THz range. Scaling up wakefield structures to the THz frequency range (200-900 GHz) allows significant increases in the accelerating gradient >> 100 MV/m level [13]. At the same time, thermal management and pulse heating for the structures becomes a serious and critical issue. We will address the temperature rise of the dielectric bulk structure and metal surfaces of the copper cladding of the THz structures. We plan to optimize the THz structure design for high accelerating gradients (>100 MV/m) and high repetition rates (>10 kHz) as required for LC applications and future wakefield accelerator based FELs [14] so as to take into account thermal management at high repetition rates.

The proposed experiment also aims to demonstrate high transformer ratio CW dielectric accelerator using the operational SRF accelerator built for Coherent electron Cooling (CeC) experiment [14-16]. This accelerator operates in a CW mode with 78 kHz rep-rate if the election bunches. Electron bunches with controllable longitudinal duration and charge up to 10 nC per bunch are generated by a 1.25 MV 113 MHz SRF photocathode gun. These bunches are ballistically compressed to a duration of 10-to-30 psec and accelerated to 15 MeV in a subsequent 703 MHz 5-cell SRF linac. Such bunches would be excellent drivers of high-transformer ratio dielectric based wakefield accelerators. The SRF gun's photocathode laser is equipped with a programmable system allowing the pulse shaping required for high transformer ratio operations. Using this system and ballistic bunch compression we will generate triangularly shaped electron drive bunches. This shape will be confirmed using off-crest operation of the linac, a bending magnet spectrometer and a horizontal profiling screen. This system, which already has demonstrated sub-psec resolution, will allow us to adjust and verify the shape of 10-to-30 psec bunches experimentally

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PROPOSED RESEARCH

We propose to investigate CW operation of a DWA structure at high transformer ratio (R ~20) and high-gradient (E_z ~100 MV/m). This will allow us to study both thermal and charging effects of the dielectric at CW operation. The fully operational CW SRF accelerator built for Coherent electron Cooling demonstration experiment (Figs. 1 and 2, see details in [15-27]) at the Collider-Accelerator Department (BNL) can generate longitudinally shaped electron beams with charge up to 10 nC per bunch. Initial gunches are generated at the photocathode of the 1.25 MeV SRF gun. The bunch structure is then compressed in 9-meter long bunch compressor to a desirable duration using chirp introduced by 500 MHz RF cavities. The compressed bunch is finally accelerator for energy of 15 MeV by 704 MHz RF linac. The system operates in pulsed and CW mode with bunch rep-rate of 78 kHz. This will allow the testing of DWA structures in operational conditions relevant to both the LC and FEL dielectric-based schemes.

The new photocathode laser system of the SRF accelerator provides a unique opportunity to demonstrate an ultra-high transformer ratio, >20, that has never been demonstrated before. An additional laser will be used to generate the witness bunch.

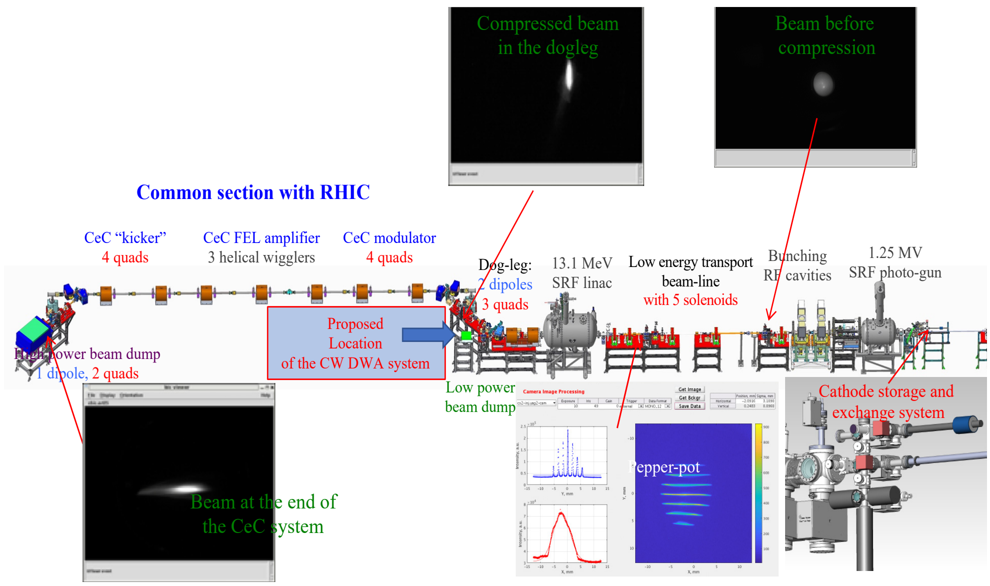
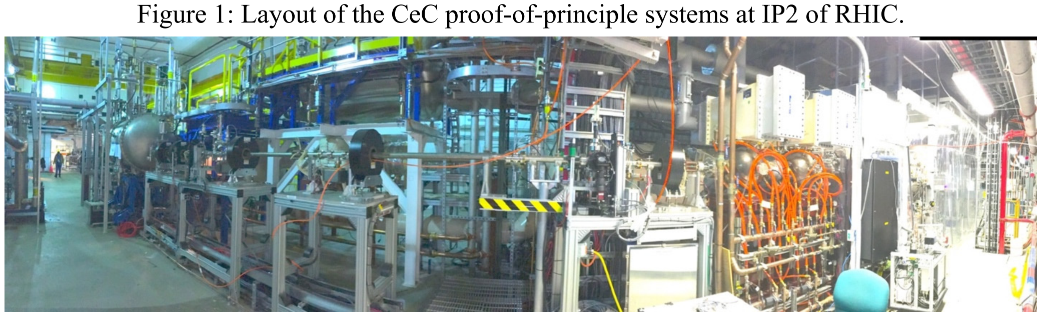


Figure 1: Layout of the CeC proof-of-principle systems at IP2 of RHIC.



(c) (b) (a)

Figure 2: Panoramic shot of the CeC CW accelerator (right to left): (a) the SRF gun area; (b) 9-meter long low energy beamline with 5 solenoids and two diagnostics stations for ballistic bunch compression; (c) 704 MHz 5-cell SRF linac. The yellow-blue structure above the accelerator is support for the 2Ko and 4Ko CeC LiHe systems.

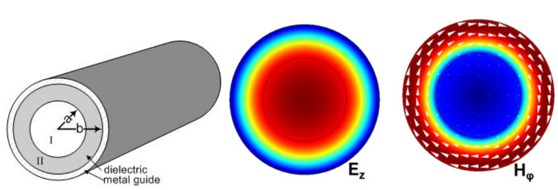


Figure 3: Partially Dielectric-Loaded Circular Waveguide: The dielectric tube has inner radius *a* and outer radius *b*. Region I is vacuum; region II is dielectric and the outermost layer is metal.

DWA Case Studies Two cases for the DWA structure (Fig. 3) have been studied based on two beam parameter regimes. In Case #1, illustrated in Fig. 4(a), the combined wakefield of 4 dominant modes was simulated for a triangular 3 nC, 20 psec electron bunch. In Case #2, illustrated in Fig. 4(b), the combined wakefield of 4 dominant modes was simulated for a triangular 1.5 nC, 10 psec electron bunch.

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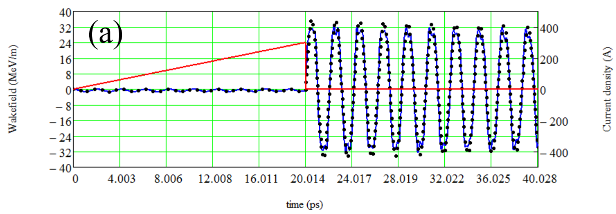
High repetition rate is ultimately needed for particle accelerators but until now wakefield accelerators have only been demonstrated in the single shot or low rep-rate regime. A number of questions related to the operation of wakefield accelerators in the CW operation remain.

Beam aperture(ID)	Material(εr/tgδ)	Wall thickness	Length	1st mode freq.	1st mode Vg
400μm	Quartz (3.8/1e-4)	75μm	10cm	483GHz	0.371c



Wakefield gradient ~ 100 MV/m, transformer ratio ~ 22.

Beam aperture(ID)	Material(εr/tgδ)	Wall thickness	Length	1st mode freq.	1st mode Vg
200μm	Quartz (3.8/1e-4)	65μm	2.5cm	645GHz	0.299c

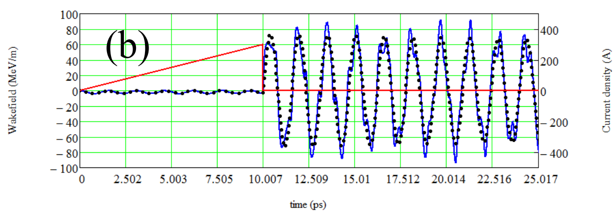


Figure 4: DWA parameters for case 1 (a) and 2 (b). Red line is the shape of the e-bunch, black dots – the wakefield of the dominant mode, blue continues line – combined wakefield of 4 dominant modes.

Two concerns of particular to DWA structures are: 1) thermal effects and 2) charging effects. Fig. 9 shows our previous studies of temperature rise in DWA operating at accelerating gradients ~ 1GeV/m fir three materials: quarts, sapphire and diamond. It clear that high thermal conductivity of diamond (1000-fold of that in quartz) would allowing operating with high repetition rate ~100 kHz.

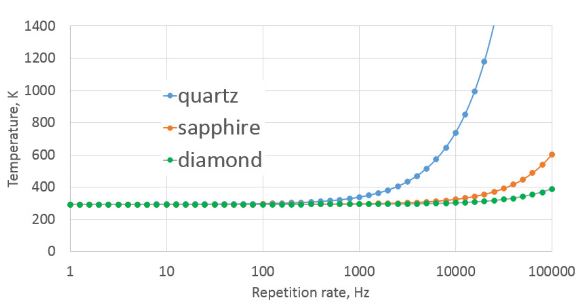


Figure 5: Steady state temperature distribution for 200 ps pulse length, 1GV/m gradient at various repetition rates.

We propose to simulate the thermal effects, to design and build CW DWA structures and to test experimentally. Surface charging is always a concern for dielectric wakefield accelerator, although, based on previous experiences, the dielectric structure will not charge up as long as the RF field appears. However, up to date, the observations have only been validated in the single short or low repetition rate regime. The proposed experiments will provide a great opportunity to investigate this issue. The proposed experiment will require a very modest modification of the excising SRF CW accelerator (see Fig. 6).

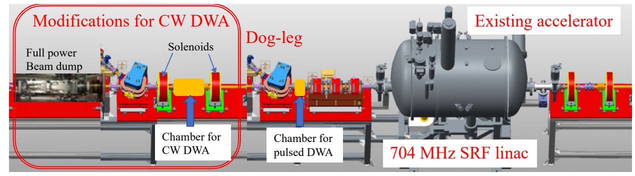


Figure 6: The end of the CeC accelerator with the quadrupole triplet and proposed modification to the system: a small chamber for initial pulsed DWA experiment and extension of the beamline for the CW DWA experiment terminated by the full power e-beam dump.

This modification includes adding extending the straight path if the CeC SRF accelerator and adding the DWA study chamber, the full power beam dump and the dipole magnet spectrometer to analyse the excited wake-field structures.

CONCLUSION

We propose to experimentally investigate the challenges of building and operating a CW DWA structure with high transformer ratio at high gradients. We suggest this can be most easily be done by utilizing the already existing CW SRF accelerator at Collider-Accelerator Department (BNL) and operating it with CW electron beams at high charge per bunch and to generate electron bunches with the necessary triangular profile.

The first step of the proposed experiments would be done using pulsed mode of the operation to verify the DWA structure performance and the value of obtainable transformer ratio. The second step of experiment would done using our CW mode of operation: After confirming the performance of the DWA structure in the pulsed mode, we will start to increase the bunch rep-rate in steps from 1 Hz to 100 Hz, 1 kHz, 7.8 kHz and finally to 78 kHz, while monitoring beam losses and the temperature of the DWA structure.

The proposed experiments would yield the first comprehensive study of high-gradient DWA operations in the CW regime and with high transformer ratio.

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