A PRELIMINARY EXPERIMENTAL STUDY OF ENERGY CHIRP REDUCTION BY A PLASMA DECHIRPER*

Y. Wu, Y. Du, J. Zhang, Z. Zhou, Z. Cheng, S. Zhou,
J. Hua, C. Pai, W. Lu†
Department of Engineering Physics, Tsinghua University, Beijing 100084, China

Abstract

The preliminary experimental study is presented using a low density plasma dechirper to reduce a correlated energy chirp from the 41.5–MeV beam at the linac in Tsinghua University. The plasma dechirper operates through the interaction of the electron bunch with its self-wake to dechirp itself, leading to a reduction in energy spread. The experimental results demonstrate that the projected FWHM energy spread of the beam can be reduced from 0.5 MeV to 0.4 MeV with a 12 mm long plasma dechirper, which are in good agreement with full three-dimensional particle-in-cell simulations.

INTRODUCTION

In the past decade, great strides have been made in plasma-based acceleration research [1–8]. One major current limitation of plasma-based acceleration for applications on coherent light sources or colliders is its relatively large energy spread due to longitudinal energy chirp. For such cases, in Ref. [9], we propose to use a tenuous plasma section as a passive dechirper. In this scheme, a positively-chirped electron beam with short pulse duration ($\sim fs - ps$) is sent through a short homogeneous tenuous plasma to excite a self-wake. This self-wake within the beam is a decelerating field with a negative slope, therefore it can reduce the positive energy chirp of the beam, leading to a reduction in the energy spread from a few percent level to ~ 0.1 percent level. To systematically study this idea, an experimental program has recently been conducted at Tsinghua University. Below we report the detailed information of the experimental system, the plasma sources and the preliminary experimental results.

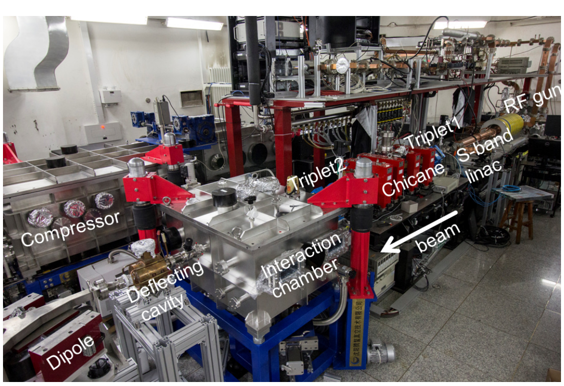

Figure 1: Experimental system at Tsinghua University.

EXPERIMENTAL SYSTEM

The experiment was performed at Tsinghua Thomson Scattering X-ray source (TTX) which combines an ultra-fast TW Ti:sapphire laser system with a synchronized 45 MeV high brightness RF photogun based linac [10–12]. The experimental system is shown in Fig. 1, which consists of three major components: the TW laser system, the 45 MeV high brightness linac and a high vacuum interaction chamber.

The experiment has two key factors: a stable electron beam with a positive energy chirp and a controllable low-density plasma source as the dechirper. To produce the stable positively-chirped electron beam, we run the linac at charge ~ 30 pC and set the RF phase of the linac tube as 25° off crest. At the exit of the linac tube, the mean energy of the beam reaches ~ 41.5 MeV. Then a four-dipole magnet compressor (Chicane) is used to compress the electron bunch from ~ 1 ps to ~ 300 fs (RMS) (see Fig. 2). The electron beam is focused to the entrance of the plasma by two triplets with beam size of $\sigma_r \sim 100\mu$m.

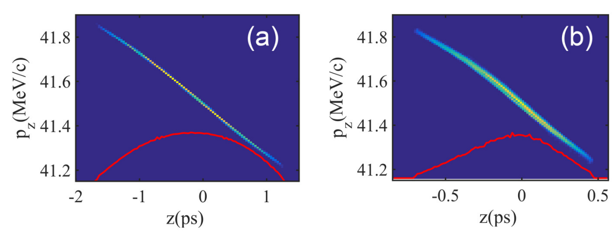

Figure 2: The beam longitudinal phasespaces before (a) and after (b) Chicane, as simulated by ASTRA [13]. Positive z corresponds to the head of electron bunches.

To produce the low density plasma source, we utilize laser ionization in the mixed gases (e.g., H_2 and He) with different ionization potentials (IP). We choose proper laser intensity such that the lower IP electrons (H_2) can be ionized while the higher IP electrons (He) cannot be ionized. Slit gas nozzles with different lengths have been designed and manufactured (Fig. 3 (a)). Gas density profiles are measured and calibrated by interferometry using Argon gas in an off-line density measurement platform [12]. Figure 3 (b) shows the calibration curve that the gas density varies with the gas pressure for a 12 mm×2 mm slit gas nozzle which is used in the experiment. Figure 4 shows a schematic of our experimental arrangement (a) and the actual setup inside the chamber (b) for the ionization laser. A ~ 30 fs (FWHM), infrared laser pulse is sent into the interaction chamber after compression and finally focused to above the middle of the

* Work supported by the National Natural Science Foundation of China (Grant No. 11535006).
† weilu@tsinghua.edu.cn

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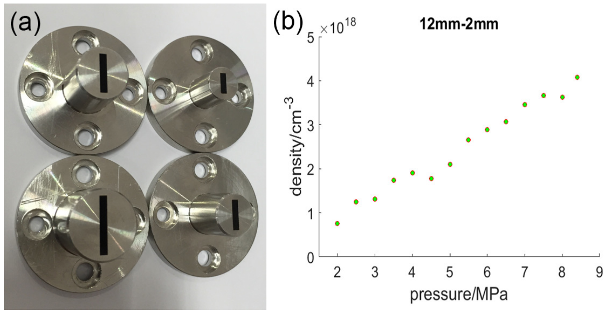

Figure 3: Plasma source development. (a) Slit gas nozzles with different lengths. (b) The calibration curve that the gas density varies with the gas pressure for a 12 mm×2 mm slit gas nozzle which is used in the experiment.

slit gas nozzle with size of 110 μ m (FWHM) (see Fig 4 (c)) to ionize the gas. The laser pulse energy on target is ~ 3.5 mJ per pulse such that only H_2 in the gas mixture (0.1% H_2 + 99.9% He) can be ionized to create low density plasma. The plasma density in the experiment is ~ 5×10^{14} cm^{-3} and the plasma length is 12 mm. The electron beam and the ionization laser are coupled by a mirror with a 3-mm central hole. Some main parameters are summarized in Table 1. The electron beam energy spectrum is measured by using the dipole and a scintillating YAG screen. In the experiment, a 70-μm vertical tungsten slit is implemented before the dipole to improve the resolution of the energy spectrometer.

Table 1: Parameters of the Electron Beam and Plasma

electron beam and plasma parameters	
beam mean energy	41.5 MeV
beam charge	30 pC
beam length	$\sigma_z \sim 300$ fs
beam transverse size	$\sigma_r \sim 100$ μm
plasma density	$\sim 5 \times 10^{14}$ cm^{-3}
plasma length	12 mm

EXPERIMENTAL RESULTS

Figure 5 (a) shows the typical electron beam energy profiles (10 shots) without laser produced plasma obtained in the energy spectrometer. The energy spectra for these plasma-off shots are shown in Fig. 5 (b). The shade regions correspond to the standard deviation. It is clear to observe that the positively-chirped electron beam in our experiment is with good reproductivity. Fig. 5 (c) shows one beam energy profile sample of plasma-on shot for comparison. The energy spectrum of this case is shown in Fig. 5 (d), which reveals that the projected FWHM energy spread of the beam was reduced from 0.5 MeV to 0.4 MeV with a 12 mm long plasma dechirper at a plasma density near 5×10^{14} cm^{-3}. We have performed a series of three-dimensional (3D) particle-in-cell (PIC) simulations using code OSIRIS [14] based on our experimental parameters and good agreement have been obtained between the experimental and simulation results.

CONCLUSION

The preliminary experimental study is presented using a low density plasma dechirper to reduce a correlated energy chirp from the 41.5−MeV beam at the linac in Tsinghua University. The plasma dechirper operates through the interaction of the electron bunch with its self-wake to dechirp itself, leading to a reduction in energy spread. The experimental results demonstrate that the projected FWHM energy spread of the beam can be reduced from 0.5 MeV to 0.4 MeV with a 12 mm long plasma dechirper, which are in good agreement with full three-dimensional particle-in-cell simulations.

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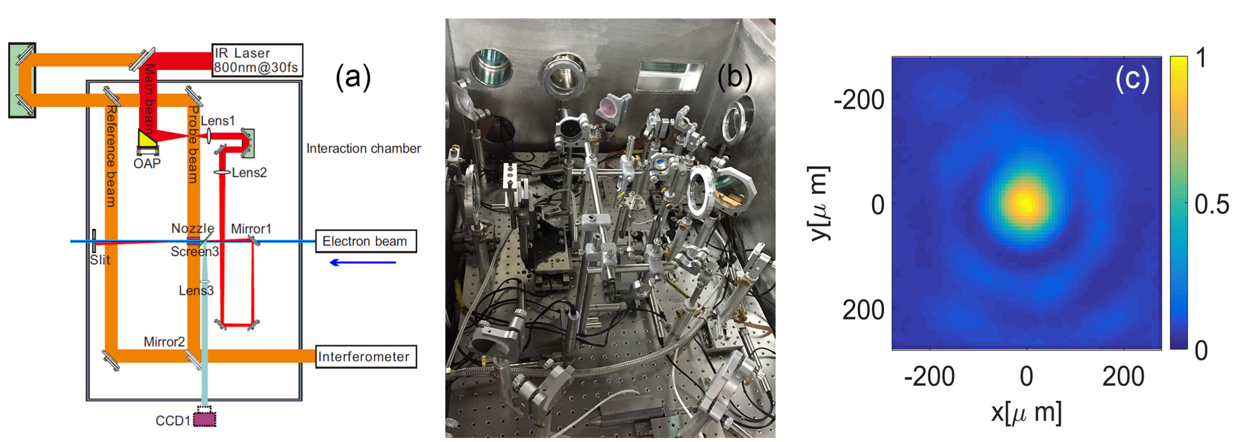

Figure 4: A schematic of the experimental arrangement (a) and the experimental setup inside the interaction chamber (b). Mirror1 has a 3-mm hole in center. (c) The laser focal spot above the middle of the slit gas nozzle and the focal size is measured to be 110 μm (FWHM).

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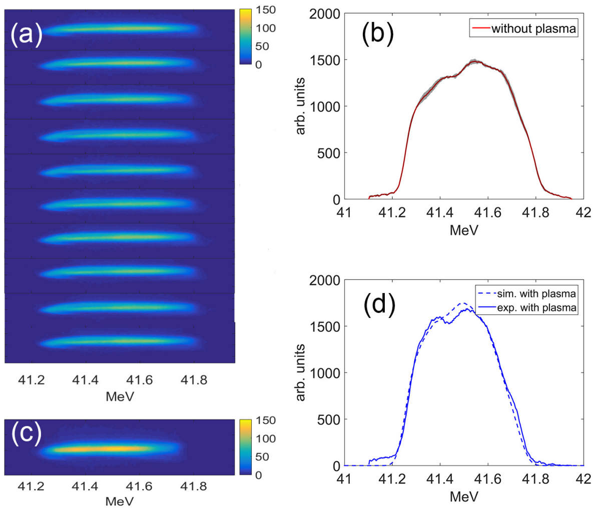

Figure 5: The typical energy profiles (10 shots) of the electron beam observed in the energy spectrometer without laser produced plasma. (b) The energy spectra for the plasma-off shots. (c) One beam energy profile sample of plasma-on shot. (d) The energy spectra for this plasma-on shot case. The solid line shows the experimental result and the dashed line shows the simulation result.

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