

RESULTS FROM PLASMA WAKEFIELD EXPERIMENTS AT FACET*

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Abstract

We report initial results of the Plasma Wakefield Acceleration (PWFA) Experiments performed at FACET - Facility for Advanced aCcelerator Experimental Tests at SLAC National Accelerator Laboratory. At FACET a 23 GeV electron beam with 1.8×10^{10} electrons is compressed to $20\mu\text{m}$ longitudinally and focused down to $10\mu\text{m} \times 10\mu\text{m}$ transverse spot size for user driven experiments. Construction of the FACET facility completed in May 2011 with a first run of user assisted commissioning throughout the summer. The first PWFA experiments will use single electron bunches combined with a high density lithium plasma to produce accelerating gradients $> 10 \text{ GeV/m}$ benchmarking the FACET beam and the newly installed experimental hardware. Future plans for further study of plasma wakefield acceleration will be reviewed.

FACET BEAM COMMISSIONING

FACET, the Facility for Advanced aCcelerator Experimental Tests, was first commissioned in June 2011. The beam parameters achieved to date are presented in Table 1, as compared to their nominal design values. The beam is focused to an interaction point (IP) for plasma wakefield acceleration (PWFA) experiments, one of the major programs at FACET. The goal is to demonstrate high-gradient acceleration with low energy spread and high efficiency that can apply to future advanced accelerators and/or colliders.

To help with beam tuning, beam diagnostics techniques are developed and implemented at FACET with details provided in [1]. The beam trajectory and current are measured by beam position monitors (BPM) and Toroids while the bunch length and transverse spot size are measured by bunch length monitor and optical transition radiation (OTR) profile monitors, respectively. The OTR profile monitors (USOTR and DSOTR) are located upstream and downstream of the PWFA experiments to provide measurements of the beam size before and after the beam-plasma interaction. An example of the beam spot size with Gaussian fits to its profile projections is shown in Fig. 1. A chicane in a plane of large horizontal dispersion deflects the beam vertically. X-rays from the resulting stripe of syn-

Table 1: FACET beam requirements and corresponding plasma parameters at the interaction point (IP) for PWFA experiments in single bunch operation.

Parameter	Design	Achieved
Particle Type	e^- or e^+	e^-
Beam Energy	23 GeV	$\sim 20 \text{ GeV}$
Energy Spread (r.m.s.)	1.5%	$\sim 1\%$
Dispersion (η)	$< 10^{-5} \text{ m}$	$\geq 0.014 \text{ m}$
Charge per Pulse	3.2 nC	3 nC
Bunch Length (σ_z)	$20\mu\text{m}$	$> 70\mu\text{m}$
Beam Size ($\sigma_{x,y}$)	$13\mu\text{m}, 5\mu\text{m}$	$> 58\mu\text{m}, > 40\mu\text{m}$
Peak Current	22 kA	5 kA
Repetition Rate	1 – 30 Hz	1 – 10 Hz
Plasma Type	Lithium or Cesium	Lithium
Vapor Density (cm^{-3})	$(0.1 - 3) \times 10^{17}$	$(0.5 - 2.5) \times 10^{17}$
Plasma Length	20 – 100 cm	30 – 40 cm

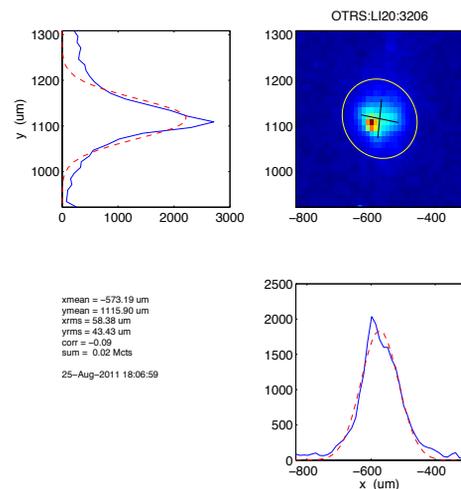


Figure 1: An image from the downstream OTR profile monitor provides a measurement of the transverse beam size $\sigma_x = 58.38\mu\text{m}$ and $\sigma_y = 43.43\mu\text{m}$.

chrotron radiation are intercepted by an off axis scintillator crystal made of Cerium doped Yttrium Aluminum Garnet (YAG:Ce). The X-ray intensity is proportional to the beam intensity giving a measurement of the beam energy spectrum. Figure 2 is an image captured by a UNIQ CCD camera with 1392×1040 active pixels, and the energy spread is measured to be about 1%.

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Table 2: Measurements of Plasma Oven Parameters

Parameter	Teststand	FACET
Buffer Gas Pressure	12.61 Torr	12.65 Torr
Heater Power	739 W	720 W
Voltage	120 V	120 V
Current	6.16 A	6 A
TC1	910.4°C	907.5°C
TC2	911.7°C	909.1°C
TC3	912.0°C	910.1°C
TC4	911.9°C	910.6°C
TC5	907.0°C	902.6°C

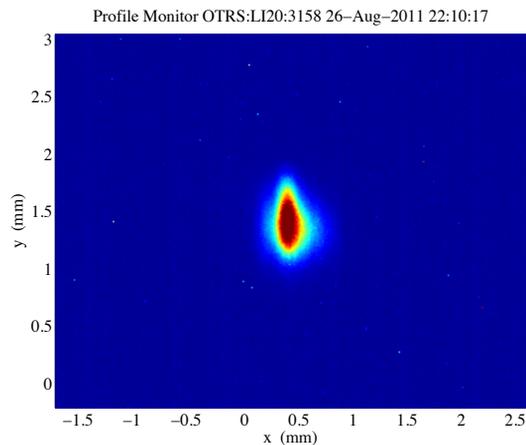


Figure 5: An image from the Cerenkov light based energy spectrometer. Any energy loss will show up toward the right side of the spectrum and energy gain will be on the left. No energy gain or loss is observed.

Simple calculations suggest that it requires $\sigma_r[\mu\text{m}]\sigma_z[\mu\text{m}] \leq 1000$ to reach ionization and to drive the wakefield for $Q = 3$ nC and $\varepsilon_{i,Li} = 5.39$ eV. Therefore, with the beam parameter achieved in Table 1, no ionization is expected to occur yet. Plasma particle-in-cell (PIC) simulations (Fig. 6) show a few options for ionization to occur. One way is to have the beam size and bunch length smaller than $40\mu\text{m}$ and $20\mu\text{m}$ or vice versa since the field needs to be greater than 6 GV/m to ionize Li. In order to perform many of the planned experiments the FACET beam parameters must be close to the design parameters in Table 1.

SUMMARY AND PLANS

The experimental hardware and operation of the plasma heat-pipe oven have been successfully commissioned. Plasma wakefield acceleration was not observed because the electron bunch density was insufficient to ionize the lithium vapor. The remaining commissioning time in summer 2011 will be dedicated to delivering the FACET design parameters for the experimental programs which will begin in early 2012. PWFA experiments require the shorter

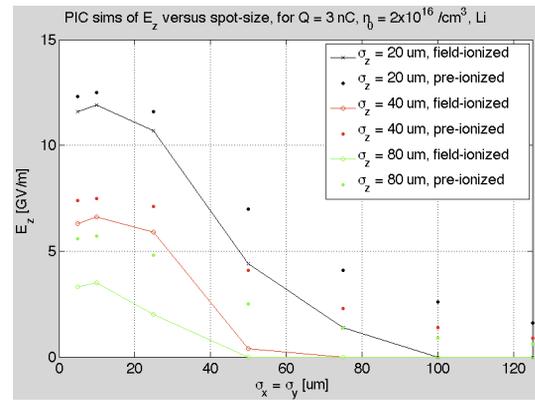


Figure 6: Wakefield amplitude vs beam spot size from PIC simulations for field-ionized and pre-ionized cases.

bunches and smaller transverse sizes to create the plasma and drive large amplitude wakefields. Low emittance and high energy will minimize head erosion which was found to be a limiting factor in acceleration distance and energy gain. We will run the PWFA experiments with the design single bunch conditions in early 2012.

Future PWFA experiments at FACET are discussed in [5][6] and include drive and witness bunch production for high energy beam manipulation, ramped bunch to optimize transformer ratio, field-ionized cesium plasma, pre-ionized plasmas, positron acceleration, etc.. We will install a notch collimator for two-bunch operation as well as new beam diagnostics such as the X-band TCAV [7] to resolve the two bunches. With these new instruments and desired beam parameters in place next year, we will be able to complete the studies of plasma wakefield acceleration in the next few years.

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