FACET: SLAC'S NEW USER FACILITY*

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Abstract

FACET (Facility for Advanced Accelerator Experimental Tests) is a new User Facility at SLAC National Accelerator Laboratory. The first User Run started in spring 2012 with 20 GeV, 3 nC electron beams. The facility is designed to provide short (20 μm) bunches and small (20 μm wide) spot sizes, producing uniquely high power beams. FACET supports studies from many fields but in particular those of Plasma Wakefield Acceleration and Dielectric Wakefield Acceleration. The creation of drive and witness bunches and shaped bunch profiles is possible with "notch" collimation. FACET is also a source of THz radiation for material studies. Positrons will be available at FACET in future user runs. We present the User Facility and the available tools and opportunities for future experiments.

INTRODUCTION

Accelerators are our primary tool for discovering the fundamental laws to the universe. Each new frontier we probe requires a new, more powerful method. Accelerators are therefore increasing in size and cost. The future of this field will require new accelerating techniques that can reach the high energies required over shorter distances. New concepts for high gradient acceleration include utilising the wakes in plasma and dielectric and metallic structures. FACET was built to provide a test bed for novel accelerating concepts with its high charge, highly compressed beams. As a test facility unlike any other, it has also attracted groups interested in beam diagnostic techniques and terahertz studies. In addition, the SLAC linac offers opportunities to study conventional acceleration structures and accelerator physics.

FACET construction was completed in May 2011 and it became a United States Department of Energy User Facility for High Energy Physics in January 2012. FACET was commissioned [1] and the first User Run began in April and will continue through to July 2012.

FACET has a five year program, operating four months every year until 2016. Proposals are solicited every year and peer reviewed with the highest ranked experiments gaining beam time.

THE FACILITY

FACET delivers electron bunches to experiments with tightly focused transverse beam sizes and ultra-short bunch lengths. Positron bunches will be delivered to experiments that request them starting in 2014.

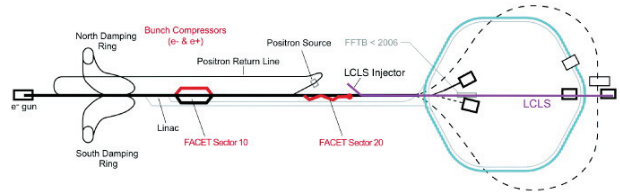

Figure 1: The SLAC linear accelerator and associated facilities. Two kilometers of s-band accelerating structures lead into FACET's final focus section. FACET's dump separates the first 20 sectors of the linac from the final 10 which are used by LCLS.

Multiple experiments share the same beam line and the waist of the beam is shifted according to the location of the experiment. The design parameters are given in Table 1 along with the best beam parameters that have been the achieved during the first user run.

Table 1: FACET beam design parameters and the best beam parameters achieved during the first FACET User run.

Parameter	Design Goal	User Run 1 2012
Energy [GeV]	23	20
RMS Energy Spread [%]	1.5	1.5
Charge [nC]	3	3
Bunch Length σ_z	<30	est. 20
Beam size $\sigma_x \times \sigma_y$	<15×15	20×20
Repetition Rate [Hz]	30 Hz	1-10 Hz

Linear Accelerator

FACET uses the first two-thirds of the SLAC linac to accelerate electrons up to 20 GeV (Fig. 1). An extraction kicker after the accelerating structures can direct the electrons to either the FACET experimental area and dump or into a positron target. Positrons are generated at the target and boosted to 200 MeV. They are then transported to the start of the linac and accelerated such that they enter the positron damping ring at 1.2 GeV. The positrons are then accelerated to maximum energy of 20 GeV using the same beamline as the electrons.

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Bunch Compression

Three stages of bunch compression deliver the ultra-short bunches (with a design value of σ_z of 17 μm or 57 fs) to FACET experiments.

The first stage of compression occurs on injection from the damping ring to the linac. The bunches are compressed from 5.5 mm in the damping ring to 1.5 mm in the linac.

The next stage was built in 2002 to compress electron bunches further to $\sim$50 μm. This is a magnetic chicane in Sector 10 of the linac. The positron arm of the chicane was built in March 2012 and is exactly symmetric to the electron chicane.

The third and final compression occurs in another magnetic chicane 20 m upstream of the experimental area. This brings the length of the bunch to a σ_z of $\sim$17 μm. This chicane can be set to compress either electrons or positrons.

Final Focus

The optics in FACET are designed to deliver a small, round beam at the "Interaction Point" (IP). The longitudinal position of the IP can be changed using upstream quadrupoles. Therefore, a series of experiments that require small spot sizes at different locations along the beam line can be supported by changing the optics.

Notch Collimator and Jaw Collimator

The notch collimator was installed in March 2012 to selectively collimate the incoming electron or positron bunches, effectively producing two bunches [2]. In wakefield acceleration studies, these bunches are termed the drive and witness bunch. The two bunches are separated by $\sim$160 μm, which is ideal for wakefield studies.

The notch collimator is a tantalum blade that can be inserted into the beam path in the middle of the last chicane. At this location, energy is strongly correlated with position in x so by removing a portion of the beam in x, two bunches separated in z are formed. The separation can be changed as well as the amount of charge in each of the drive and witness bunch.

A jaw collimator immediately downstream is able to shape the bunch, producing ramped-charge drive bunches.

Transverse Deflecting Cavity

A x-band transverse deflecting cavity allows single-shot measurement of the longitudinal profile of the bunch. Located upstream of the experiments but downstream of the notch collimator, it deflects the bunches transversely according to the longitudinal position in the bunch. The deflected bunch is then intercepted by a downstream profile monitor screen providing an image of the temporal distribution of the bunch.

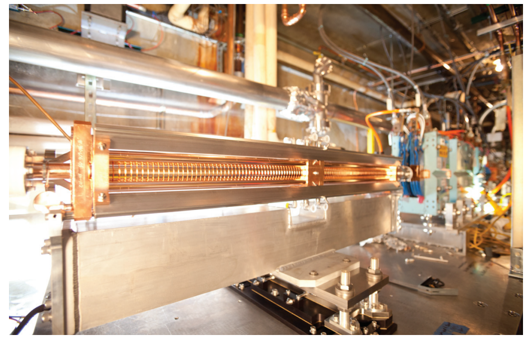

Figure 2: A X-band transverse deflecting cavity was installed in 2012 to provide longitudinal profile diagnostics.

EXPERIMENTAL PROGRAMME

Two rounds of proposals for FACET have been peer-reviewed and awarded beam time. A third round of proposal review is scheduled for October this year. In the first FACET user run, which started in April 2012, nine experiments are expected to get data. Three new experiments will join the FACET programme in 2013.

The main area for experiments at FACET is the "IP Area" (Fig. 3) immediately after the final focus system. The optics are designed to focus the beam in this area. 8 metres of optical breadboard support experiments and diagnostics.

Upstream of the IP Area, there is a 2.5 m optical table currently used for THz studies. Towards the FACET dump, there is a final optical table currently used for beam diagnostics.

The experiments are supported by diagnostics [3]. There are beam position monitors and toroids through the linac. Optical transition radiation (OTR) beam profile monitors and a wirescanner provide beam spot size information in the IP Area. Pyroelectric detectors measure coherent transition radiation (CTR) providing a monitor of the bunch length. Synchrotron x-rays from a wiggler magnet in the third-stage bunch compressor chicane are intercepted to measure the energy spread. As part of the support for acceleration studies, there is an energy spectrometer at the dump table that uses Cerenkov light emitted in a defined air gap.

Plasma Wakefield Acceleration

SLAC has a history of plasma wakefield acceleration (PWFA) with studies at the Final Focus Test Beam (FFTB) culminating in the acceleration of electrons from 42 GeV to 85 GeV in 85 cm [4]. The initial studies at FACET use field-ionised lithium plasma and rubidium plasma. The experiment uses the notch collimator to produce a drive and witness bunch with electrons. In 2013, the plasma will be pre-ionised by a laser and in 2014, positrons will be used.

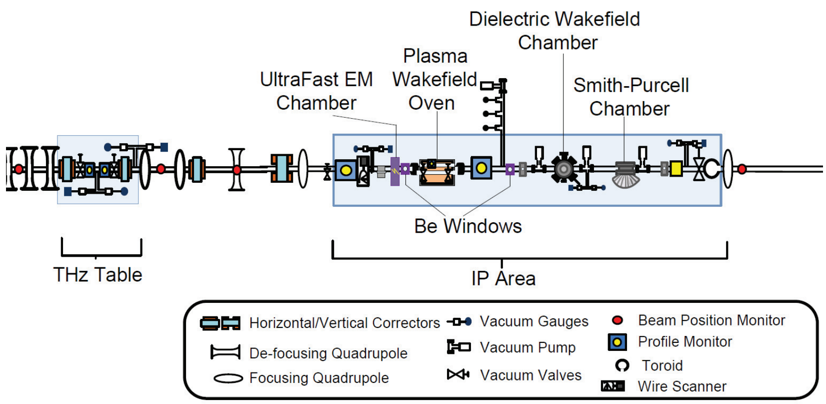

Figure 3: The IP Area includes two chambers that can be used to insert samples into or near the beam (UltraFast EM Chamber and Dielectric Wakefield Chamber). There is also an oven used in plasma acceleration studies plus experimental diagnostic devices such as the Smith-Purcell Chamber.

Wakefield Acceleration in Dielectric and Metallic Structures

Other concepts for accelerating structures involve wakefields in dielectric or metallic materials. Wakefield measurements in structures are common to facilities around the world but FACET is the only facility that offers multiple GV/m fields. Previous studies at FFTB indicate that longitudinal breakdown thresholds are in this regime for dielectric structures [5].

FACET provides a vacuum chamber with motorised stages with six axes of motion for wakefield experiments with short (∼cm) structures.

Bunch Length and Profile Measurement

Measuring bunch profiles of a few fs in a non-invasive and cost-effective manner is a challenge for future light-sources and accelerators. FACET provides a test-bed for bunch profile measurements in this regime.

In one experiment, coherent Smith-Purcell radiation is detected and used to reconstruct the temporal profile of the electron bunch [6]. Another group reconstructs temporal profiles from the power spectrum of the THz radiation from 1 μm titanium foils using a Michelson interferometer [7].

Materials and THz Studies

The short bunch length and high bunch charge at FACET makes it an excellent THz electric field and light source. When the beam passes through thin metal foils, transition radiation is produced with little degradation to the main electron beam.

Calculations indicate that the CTR electric fields created are 0.6 V/Å or more when the beam's transverse size and length are optimised and the pulse contains 13 mJ making FACET the brightest THz light source in the world [7]. Preliminary measurements at an unoptimised source show 0.015 V/Å and 0.69 mJ of THz energy per pulse [8].

The THz radiation can be extracted, focused and delivered to experiments. A THz transport line will be installed after the current user run to bring the THz radiation out of the accelerator tunnel to a local laser room to study materials in these intense fields and perform biological and chemical imaging. There is also ongoing work into other THz sources.

Currently an experiment is taking advantage of the intense electrical fields associated with the electron beam to probe domain switching in magnetic solids on the femtosecond timescale [9]. This "Ultrafast Electromagnetic Switching" experiment inserts thin magnetic foils into the beam to be exposed to a single electron bunch.

FUTURE FOR FACET

FACET will operate for four months each year for the next five years. There will be periods of dedicated beam tuning prior to each user run to ensure good beam delivery to the users. In 2013, positron beams will be commissioned for delivery to FACET's experiments in 2014. New proposals for experiments, whether a part of the wakefield acceleration program or a general beam physics or material science program, can be submitted throughout the year.

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