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FACET: THE NEW USER FACILITY AT SLAC*

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Abstract

FACET (Facility for Advanced Accelerator and Experimental Tests) is a new User Facility at SLAC National Accelerator Laboratory. Its high power electron and positron beams make it a unique facility, ideal for beam-driven Plasma Wakefield Acceleration studies. The first 2 km of the SLAC linac produce 23 GeV, 3.2 nC electron and positron beams with short bunch lengths of 20 μm. A final focusing system can produce beam spots 10 μm wide. User-aided Commissioning took place in summer 2011 and FACET will formally come online in early 2012. We present the User Facility, the current features, planned upgrades and the opportunities for further 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 requires 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 and highly compressed beams. As a test facility unlike any other, it has also attracted groups interested in beam diagnostic techniques and terahertz studies.

The first phase of the construction was completed in May 2011. Beam commissioning began in June and was interleaved with the installation of five experiments. Users were invited to aid with the commissioning for the month of August during which time experimental hardware and software were checked out and some first measurements were taken.

FACET is currently in the process of becoming a Department of Energy User Facility for High Energy Physics.

THE FACILITY

FACET is designed to deliver both electrons and positrons to experiments with short bunch lengths and small spot sizes. Experiments are located in positions along the beamline favourable to their requirements. The design parameters for two experiment locations are given in Table 1.

Table 1: FACET Beam Design Parameters

Parameter	THz Table	IP Area
Energy [GeV]	23	23
RMS Energy Spread [%]	1.5	1.5
Charge/pulse e^-, e^+ [$\times 10^{10}$]	0.5-2.0	0.5-2.0
Bunch Length σ_z	15-40	15-40
Beam size $\sigma_x \times \sigma_y$ [μm]	1100×7	14×6
Repetition Rate [Hz]	1-30	1-30

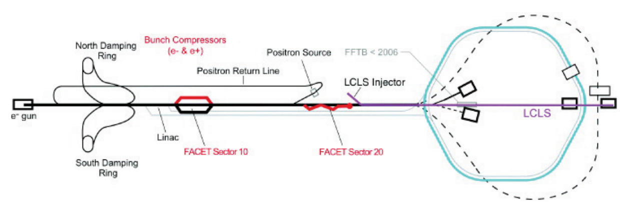

Figure 1: The FACET experimental area and final focus is two thirds of the distance down the SLAC linac in "sector 20". The option to run with positrons will be available in early 2012 after the installation of the positron bunch compressor in "sector 10".

Linear Accelerator

FACET uses the first two-thirds of the historic SLAC linear accelerator to accelerate electrons up to 23 GeV (Figure 1). An extraction kicker after the acceleration 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 using the same beamline as the electrons.

Bunch Compression

Three stages of bunch compression are used to deliver the ultra-short bunches (with σ 17 μm or 57 fs) to FACET experiments.

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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 ∼50 um. This is a magnetic chicane in Sector 10 of the linac. The energy of the beam is 9 GeV. Currently, only the electron half has been installed. The positron chicane will be built in February 2012 and will be 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 ∼15 μm. This chicane can be set to compress either electrons or positrons.

Final Focus

The optics in FACET were designed to deliver a small, round beam at the "Interaction Point" (IP). The longitudinal position of the IP can be shifted using upstream quadrupoles. A series of experiments that require small spot sizes can therefore be supported just by changing the optics rather than by switching the experiment in and out of a single IP location.

Notch Collimator

To be installed in the autumn of 2011, the notch collimator will selectively collimate the incoming electron or positron bunches, effectively producing two bunches. In wakefield acceleration studies, these bunches are termed the drive and witness bunch. It will be installed in the middle of the final compression stage where energy is strongly correlated with position.

The collimator will have interchangeable jaws and can deliver two electron bunches or two positron bunches with 100-200 μm separation. The collimator is designed to allow for variable charge and duration of the witness bunch and for ramped-charge drive bunches [1].

Sailboat Chicane

A proposed upgrade to the third-stage bunch compressor in sector 20, called the "sailboat chicane", would allow electrons and positrons to both be delivered to the experiments at the same time. The electrons and positrons would not only be sharing the linac, they would be sharing the final focus too. By carefully tuning the positron arm of the sailboat chicane, it would be possible to deliver the positron bunch from half a RF wavelength ahead of the electron bunch (5.25 cm) to 100 μm behind the electron bunch.

EXPERIMENTAL PROGRAMME

The first round of proposals for FACET have been peer-reviewed. Nine proposals and one Letter of Intent were submitted. As part of User Aided Commissioning, five experiments were invited to run. In the first formal run of FACET beginning February 2012, all five will continue with two more in addition.

The principal area for experiments at FACET is the IP Area (Figure 2) immediately after the final focus system. The optics are designed to focus the beam in this area. Twenty-four feet of optical breadboard support experiments and associated diagnostics. Upstream of the IP Area, there is an eight foot optical table currently used for THz studies. Towards the FACET dump, there is a final optical table currently used for beam diagnostics only.

The experiments are well supported by diagnostics [2]. There are beam position monitors and toroids throughout FACET. Beam profile monitors using optical transition radiation (OTR) and a wirescanner provide beam spot size information in the IP Area. A pyroelectric detector measuring coherent transition radiation (CTR) measures the relative bunch length. Synchrotron x-rays are detected in the third-stage bunch compressor chicane to give a measure of the energy spread of the beam entering FACET's experimental area. As part of the support for acceleration studies, there is an energy spectrometer at the dump using Cherenkov light emitted in a defined air-gap.

Plasma Wakefield Acceleration

SLAC has a great history of plasma wakefield acceleration (PWFA) with record breaking studies at the Final Focus Test Beam (FFTB) culminating in the successful acceleration of electrons from 42 GeV to 85 GeV in 85 cm [3]. The collaboration will begin at FACET with field-ionised lithium plasma followed by caesium or rubidium plasma.

The experiment will utilise the notch collimator to produce a drive and witness bunch with both electrons and positrons. Plus, in later stages, the plasma will be pre-ionised by a laser.

The apparatus for these studies was installed and fully checked-out with beam in August 2011 [4].

Wakefield Acceleration in Dielectric and Metallic Structures

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

The facility provides a vacuum chamber with motorised stages capable of movement on six axes for the use of experiments with short (∼cm) structures. The apparatus was installed and the controls were checked out as part of the User Aided Commissioning.

Bunch Profile Measurement

Measuring bunch profiles of a few fs in a non-invasive, single-shot manner is a challenge for future light sources

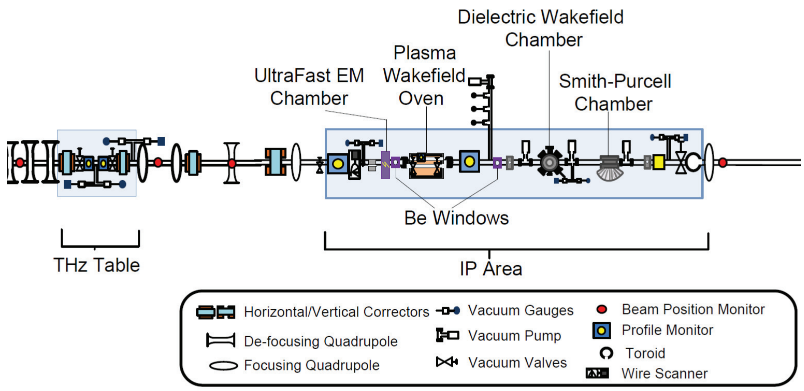

Figure 2: For commissioning FACET in August 2011, five experiments were installed. Four were in the IP Area. Optics for THz measurements were set up on an upstream table.

and plasma accelerators and FACET provides the perfect test-bed for bunch profile measurement techniques for this regime.

In one experiment at FACET, coherent Smith-Purcell radiation is detected and used to reconstruct the longitudinal profile of the electron bunch [6]. First measurements took place during commissioning in August 2011. The longitudinal profile was shown to be non-Gaussian and larger than the designed bunch length following the three stages of compression.

CTR studies using THz radiation from 1 μm titanium foils in the beam also provided a bunch length measurement. This group used a Michelson interferometer to extract an absolute bunch length. Measurements during commissioning agreed with those using Smith-Purcell radiation.

These tests of diagnostic methods prove the great synergy between the machine and experimenters. The results will be used to calibrate the one-shot pyroelectric detector measurement of CTR from the titanium foils.

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. The coherent THz radiation can be extracted and focused to experiments studying materials in these intense fields. Calculations indicate that the fields created are 0.6 V/Å or more making FACET the brightest THz light source in the world.

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 [7]. To decouple the effects of the electrical fields from optical switching, the materials will also be exposed to the extracted THz radiation at the THz table location.

COMMISSIONING

The beam commissioning of FACET with electrons is continuing until 16th September 2011. There will be time for improvements, installations and upgrades, particularly to ready the positron delivery, until another month of beam commissioning with both electrons and positrons starting February 2012.

Early signs indicate beam sizes at the IP 30 μm x 30 μm and bunch lengths close to 20 μm. Full charge has been delivered. Though more energy is available, the commissioning has mainly taken place with reduced energy around 20 GeV. This is for greater overhead of available klystrons and better stability.

FUTURE RUNNING

FACET plans to operate for four to five months each year for the next five years. There will be periods of dedicated beam tuning prior to each experimental run to ensure good beam delivery to the users. User runs will come in blocks separated by opportunities to install new apparatus or instrumentation. We are actively seeking proposals for the latter half of the 2012 run and for 2013.

REFERENCES

[1] R.J. England et al., AIP Conf. Proc., 1299, pp. 478-482 (2010).

[2] S.Z. Li and M.J. Hogan, PAC'11, New York, March 2011.

[3] I. Blumenfeld et al., Nature 445, 741-744 (2007).

[4] S.Z. Li, these proceedings, WEPZ023.

[5] M.C. Thompson et al., Phys.Rev.Lett., 100, 214801 (2008).

[6] R. Bartolini, these proceedings, WEOBB03.

[7] I. Tudosa et al., Nature 428, 831-833 (22 April 2004).