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BEAMNETUS AT BROOKHAVEN NATIONAL LABORATORY*

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Abstract

BeamNetUS is a national network of accelerator facilities that aims to provide broader access to the unique capabilities of accelerated particle beams. Two facilities at Brookhaven National Laboratory are part of the inaugural year of BeamNetUS, the Accelerator Test Facility (ATF) and the Low Energy Accelerator Development (LEAD) facility, and are scheduled to each host one BeamNetUS user experiment.

The ATF features an RF photocathode electron LINAC, a femtosecond Ti:Sa laser, and a high-peak-power long-wave infrared (LWIR) laser. These tools can be synchronized for joint use or operated individually, facilitating the development of advanced beam manipulation and measurement techniques, accelerator and laser technologies, and the exploration of low-plasma-density regimes.

The LEAD facility provides an ultrafast electron diffraction (UED) apparatus, utilizing an RF electron gun and Ti:Sa laser to enable dynamic studies of material structures, as well as investigations involving low-energy electron beams.

In addition to these two accelerator facilities, Brookhaven National Laboratory provides administrative support for the network. Further expansion is planned for 2026, including both increased user hours at ATF and LEAD as well as the potential inclusion of several other facilities at the lab.

INTRODUCTION

BeamNetUS is a United States Department of Energy (DOE)-sponsored network of accelerator facilities designed to facilitate the broader use and development of accelerator technology [1]. One of the primary missions of BeamNetUS is to raise awareness and improve access to accelerator R&D facilities that are often not normally available for external users. This past fiscal year was the pilot year for the program, with eight proposals awarded beamtime at the nine participating facilities. Two of the BeamNetUS facilities are located at Brookhaven National Laboratory (BNL), the Accelerator Test Facility (ATF) and the Low Energy Accelerator Development (LEAD) facility. In addition to hosting experiments at these two facilities, BNL provides administrative support for the network as whole.

* BeamNetUS is an initiative within the DOE Office of Science to provide expanded access to its suite of accelerator research facilities. This work has been supported by Brookhaven Science Associates under Contract No. DE-SC0012704 with the U.S. Department of Energy, Office of Science.
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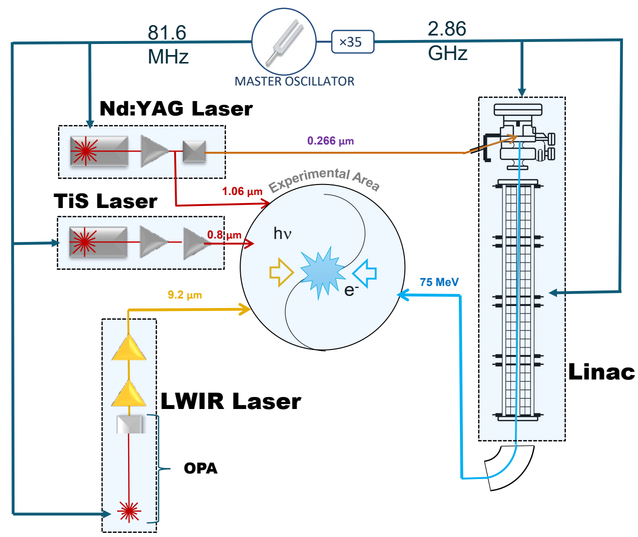

Figure 1: A diagram of the three primary ATF capabilities, consisting of the electron LINAC, the LWIR laser, and the NIR lasers. All three capabilities are synchronized and can be used simultaneously for a single experiment.

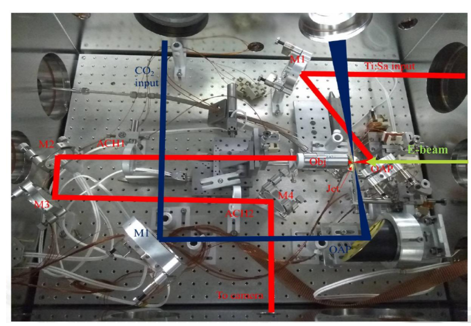

Figure 2: An example of an experimental setup utilizing all three ATF capabilities simultaneously.

ACCELERATOR TEST FACILITY

The Accelerator Test Facility (ATF) has supported user experiments for over 30 years, and, since 2015, has been designated as a DOE Office of Science national user facility [2]. The facility offers three primary capabilities: the electron LINAC, the long-wave infrared (LWIR) laser, and the near-infrared (NIR) lasers, summarized in Fig. 1. A unique feature of the facility is that any combination of the three capabilities can be utilized simultaneously for a single experiment. In fact, around 40 % of user experiments over the past year required the use of all three capabilities, with an example setup shown in Fig. 2.

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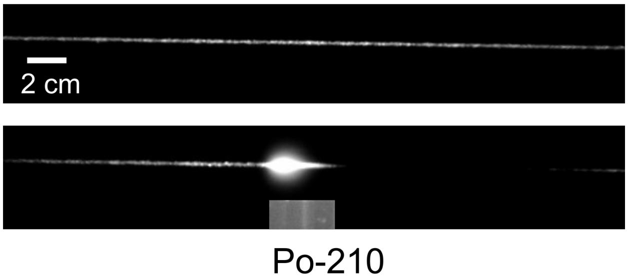

Figure 3: A recent experimental result featuring the remote detection of radioactive material using the ATF LWIR laser [6].

The electron LINAC is capable of producing beams with an energy between 20–75 MeV, depending on user needs. The beam is generated by a high brightness photocathode in an rf gun to improve beam quality. Typical beam parameters are a normalized emittance of 1 mm·mrad, a peak current of 100 A, a repetition rate of 1.5 Hz, a bunch charge of between 0.2 and 2 nC, and an energy spread of 0.1 %. If required for increased average current, the LINAC is capable of running in a bunch train mode as well.

The LWIR laser system uses isotopic carbon dioxide amplifiers [3] to achieve a peak power of 5 TW with a pulse length of 2 ps at a wavelength of 9.2 µm. Current upgrade plans for this laser are focused on reducing the pulse length, with a goal of 15 TW in 500 fs by 2028 and 25 TW in 100 fs by 2029.

Due to the favorable λ^2 scaling of ponderomotive effects and $1/\lambda^2$ scaling of the critical plasma density, the LWIR laser is particularly effective for driving plasma interactions, for example in the study of laser wakefield accelerators [4] or astrophysical effects [5]. Additionally, the long wavelength allows for an extended filament to propagate through atmosphere, enabling radioactive materials to be detected by triggering avalanche ionization in air, as seen in Fig. 3 [6].

To supplement these two systems, the ATF also provides a Ti:sapphire laser and an Nd:YAG laser, which is used both for user experiments and for generating the UV light for the photocathode. The Ti:sapphire laser has a pulse energy of 100 mJ and a pulse length of 70 fs, while the Nd:YAG laser has a pulse energy of 100 mJ and a pulse length of 14 ps.

The pilot year BeamNetUS experiment being conducted at ATF is titled "Optical Waveguides for Enhanced Laser-Electron X-ray Production", with Gerrit Bruhaug from Los Alamos National Laboratory serving as the principal investigator.

Suggested areas for future ATF proposals include novel electron acceleration, high brightness radiation sources, electron beam manipulation, radiation tests, directed energy research, and fundamental plasma science. Generally, any experiment either leveraging the unique LWIR capability or requiring the interaction of multiple beams is well-suited for this facility.

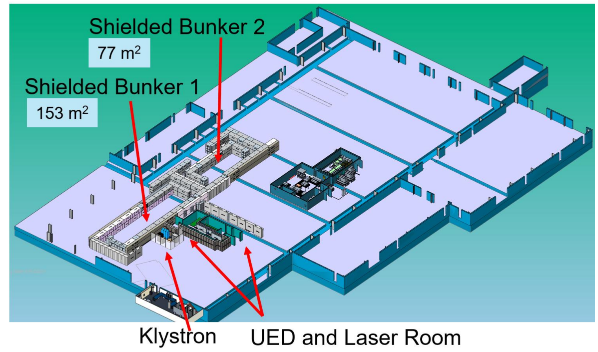

Figure 4: A floor plan of the LEAD facility, showing the two shielded bunkers and the existing UED beamline.

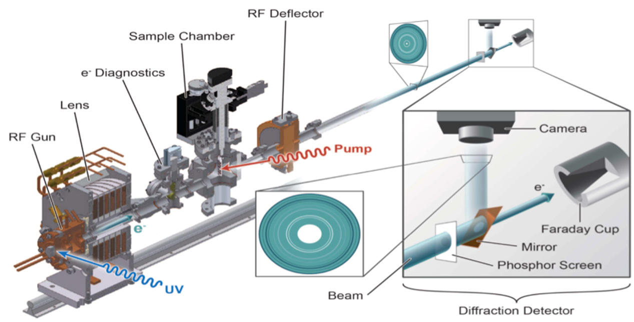

Figure 5: A diagram of the current UED beamline [8]. Note that the RF deflector shown in the diagram is no longer installed.

LOW ENERGY ACCELERATOR DEVELOPMENT FACILITY

The Low Energy Accelerator Development (LEAD) facility [7] consists of the existing ultrafast electron diffraction (UED) beamline [8] and two shielded bunkers. It is designed to be a flexible facility supporting a wide range of experiments that utilize low energy electron beams. A floor plan is shown in Fig. 4.

The UED beamline, shown in Fig. 5 produces a 3 MeV electron beam from the same type of photocathode and rf gun as the ATF LINAC. The bunch length is around 200 fs, and the bunch charge is typically between 20 and 200 fC, at a repetition rate of up to 48 Hz. A probe-defining aperture, just before the sample chamber, can be used to reduce the beam size to 100 µm on target. The sample chamber supports up to 9 samples and is compatible with samples mounted on standard TEM grids. This beamline has previously been employed for materials science, e.g., ultrafast phase transitions [9], and for testing machine learning algorithms for improved accelerator performance [10].

Currently, a beamline extension is planned for the UED beamline to facilitate new classes of experiments, including single-event effect testing by the NASA Jet Propulsion Laboratory. Figure 6 shows a diagram of the extension, with the current UED beamline ending at the component labeled "UED detector." The extension is primarily composed of a new large sample chamber, which offers a flexible space for placing samples to be irradiated by the electron beam, as well as UED samples that do not have the vacuum compati-

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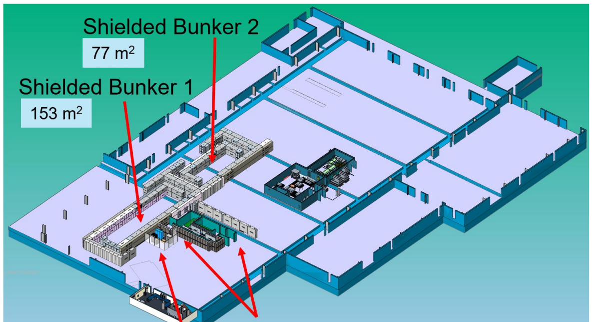

Figure 6: A diagram of the planned extension to the UED beamline, including a flexible sample chamber for both UED and single-event effect testing.

bility to be mounted in the current sample chamber. A new detector enables the collection of diffraction data from the new sample chamber, and the dipole spectrometer allows for measurements such as electron energy loss spectroscopy (EELS).

Additionally, two shielded bunkers are available, one with an area of 153 m^2 and one with an area of 77 m^2. These bunkers provide the infrastructure for testing novel accelerator components. For example, bunker 1 is currently scheduled to test a high average current electron cyclotron resonance accelerator (eCRA), while bunkers 2 is scheduled to test a novel superconducting RF gun.

The pilot year BeamNetUS experiment being conducted at LEAD is titled "Benchmarking Anisotropic Phonon Dynamics in the 2D Magnet CrSBr", with Byron Freelon from the University of Houston serving as the principal investigator.

Suggested areas for future LEAD proposals include ultrafast electron diffraction, materials science, single-event effect testing, AI/ML accelerator control, and accelerator technology development. Generally, experiments that require low beam energies and/or adaptable experimental spaces are well-suited for this facility.

CONCLUSION

The two BeamNetUS facilities at BNL provide a unique set of capabilities for users, supporting a wide range of scientific interests. Expanded user hours are planned in FY26, as well as potential expansion to two additional facilities, the Tandem Van de Graaf facility and the NASA Space Radiation Laboratory, both of which provide various species of accelerated ions.

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