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ATF Newsletter

Special Issue: 17th ATF Users' Meeting

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ATF ACCELERATOR TEST FACILITY

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1. Introduction

For nearly a quarter of a century, the Brookhaven Accelerator Test Facility (ATF), sponsored by the U.S. Department of Energy's (DOE's) Office of High-Energy Physics (HEP), has provided free access to its laser- and electron-beams for a broad category of qualified researchers. As a proposal-driven user facility, the ATF welcomes proposals that are synergistic with the missions of the DOE's Office of Science. The proposed research may address long-term accelerator R&D in fundamental accelerator science, as well as the development of accelerator technology in many of the related fields supported by the DOE's newly established program for Accelerator Stewardship. Proposals are solicited from across the scientific community; encompassing universities, laboratories, and industry, regardless of the source of funding or the intended application of the accelerator science and technology pursued.

Every year, researchers working in accelerator science and technology and related fields submit new proposals for evaluation, in a peer-review process, by the ATF Program Advisory Committee (APAC) that normally meets during the ATF Users' Meeting. This year the 17th APAC and ATF Users' Meeting offered current and potential ATF users the opportunity to get together to discuss their recent achievements and future plans. The event had been widely advertised via multiple outreach channels. It attracted nearly fifty participants from six countries. Progress from twenty-two active user experiments was reported and eleven new experiments were reviewed. This diverse program covers such areas as ion generation, plasma/laser/dielectric wakefield acceleration, Compton scattering, IFELs, beam instrumentation, photo-injector R&D, structure-driven accelerators, FELs, THz generation, beam manipulations, among others.

Presentation slides from the meeting are available at http://go.usa.gov/FCaF

Based on the APAC's recommendations, we will update the ATF's user program as is discussed in Section 4 of this Report.

2. The status of the ATF

The past two years, since the 16th ATF Users' Meeting in April 2012, were extremely eventful for the ATF. These particular events have proven very important in defining the present status of the ATF, which now differs greatly from that of two years ago.

Administrative changes in 2012 included the appointment of a new Scientific Program Director, and ATF Director, and transfer of the ATF to a different department within BNL. In May 2013, we received a call from the DOE to submit a proposal to upgrade the ATF to a comparative review process alongside with proposals from SLAC (for FACET-II) and FNAL (for ASTA). The proposal was presented in October 2013 after extensive deliberations with BNL personnel and with help from external advisory boards, viz., APAC, and a, specially formed, Laser Advisory Panel. In February 2014, the DOE announced funding for Stage 1 of the upgrade to ATF-II. The ATF mission and source of funding is now provided by the Accelerator Stewardship program of the Office of High-Energy Physics (http://science.energy.gov/hep/research/accelerator-rd-stewardship), and ATF has been recognized as the flagship facility for this program.

The ATF-II upgrade officially began in July 2014 when the funds became available. This launched our long-term ATF-II upgrade project that will further strengthen the ATF's position as a world-class facility at the forefront of Advanced Accelerator research and Accelerator Stewardship. These exciting changes were discussed at the ATF Upgrade Workshop, held as a back-to-back event in conjunction with the 17th ATF Users' Meeting (see http://go.usa.gov/sQzW).

Until the ATF-II upgrade is complete, our users still can rely on our usual standard of continuing support at the present facility. The main difference for this year lies in expanding the priorities of the ATF user program, mandated by the newly established Stewardship mission. This changing atmosphere was addressed in the introductory talk at the meeting, given by Eric Colby (DOE), titled "The Accelerator Stewardship Program and the Role of the BNL-ATF". He noted that throughout its 25-year history, the BNL-ATF has operated successfully as a user facility dedicated to advanced accelerator R&D, accepting user proposals based on their scientific merit. Scientific progress from such R&D, conducted at the ATF, has enabled key advances in a broad range of fields. Among ongoing active experiments, roughly half support long-term R&D that is predominantly of interest to BES, NP, DARPA, and DNDO, among others. The ATF serves a broad and varied population of users from various laboratories, universities and industries. Colby then discussed the reasons for, and the meaning and purposes of the ATF's inclusion in the DOE Stewardship mission. He deemed that important among them were the following:

- An upgrade to a larger facility
- Increased priority for technology demonstrations
- Continued broadening of ATF stakeholders
- Designation of the BNL-ATF as an Office of Science User Facility

HEP expects that the BNL-ATF will continue its tradition of serving a broad community of users in accelerator science and technology. He stresses the need to actively look for ways to broaden this community by the following means:

- Advertising the available facilities and capabilities
- Enhancing/establishing connections with other Federal Agencies that develop and apply accelerator technology
- Playing a stronger role in the translational R&D needed to adapt accelerator technology to new industrial applications

These changes are already reflected in a new user program further shaped by the 17th ATF Users' Meeting, reported here. It includes details of a number of new technological demonstrations in addition to the fundamental aspects of accelerator physics for which the ATF became well known.

Until the ATF-II upgrade facility is complete, the ATF will continue serving its users at its present location (Bldg. 820), offering them three electron-beam lines with e-beam energy up to 80 MeV, synchronized with a picosecond, terawatt CO_2 laser (and two solid-state lasers at lower power). The ATF can produce high-brightness electron bunches measuring <10 μm RMS transversely, and 30 μm (100 fs) longitudinally, with a variable charge, energy, and emittance; it can generate bunch trains with tunable spacing, as well as interacting these beams with plasma and lasers. The reduction in the size of the focus (to <10 μm) afforded by our permanent mini-quadrupoles is a new feature that benefits a broad class of experiments such as Dielectric Wake Field Acceleration (DWFA) and Plasma Wake Field Acceleration (PWFA), and, in particular, a quasi-nonlinear regime of PWFA.

Our 10-μm CO_2 laser supports studies of strong-field phenomena in the mid-IR spectral domain that opens up a host of new research opportunities. We note that our laser support team continues the upgrade to the CO_2 laser; recently, it attained 2 TW peak power. We have completely rebuilt the front end (10- μm pulse injector), which is now a Ti:Sapph- pumped OPA. Further improvements are anticipated in the near future, and, in three years a new 100-TW laser will be available at ATF-II. Figure 1 shows the ATF's improved CO_2 laser system.

The ATF has also proven to be an excellent place to train students in the physics of beams. Three more PhD students completed their thesis research at the ATF, and have graduated, since the Users' Meeting of 2012, making a total of 36 graduates through the ATF's history.

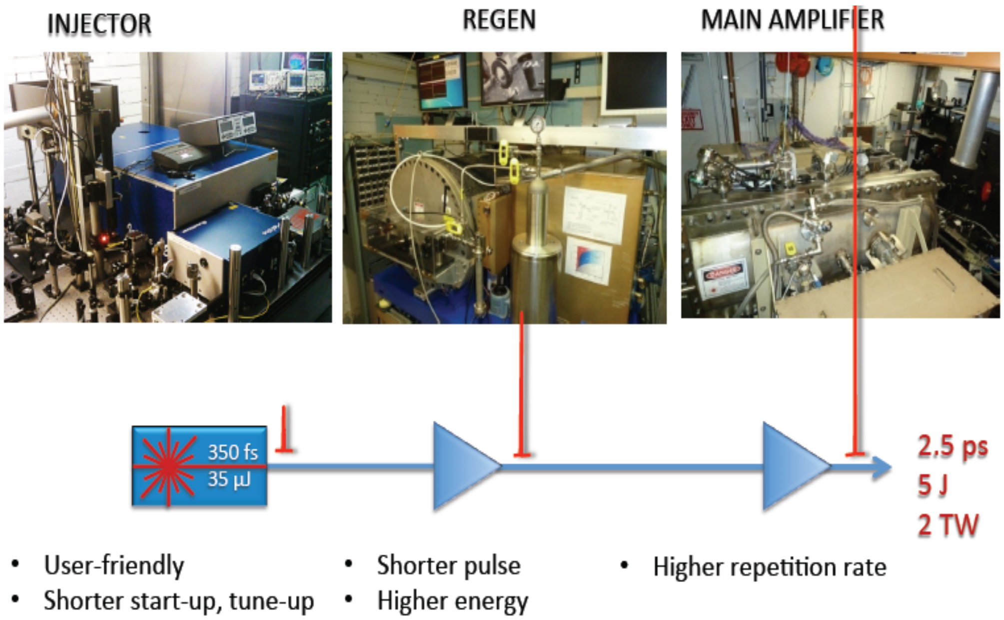

Figure 1. The ATF's improved CO_2 laser system.

Table 1 compiles the main technical parameters currently offered to ATF's users.

Table 1. ATF's technical capabilities

Electron energy	70 MeV
Current	100 A
Normalized emittance	1 mm-mrad
RMS energy spread	0.1%
RMS transverse beam size	5 μm
Bunch train period (mask)	500 fs
CO_2 laser peak power	2 TW
Laser pulse length	3 ps
Laser strength a_o	1
Plasma density (capillary)	10^{15}-10^{17} cm^{-3}
Plasma density (jet)	10^{17}-10^{20} cm^{-3}

3. Reports from active and completed experiments

Regulations for users of a DOE user facility require that each research group present a status report to the APAC committee at the Users' Meeting. This year, we had reports from 22 experiments:

AE31 – Multi-bunch Plasma Wakefield Acceleration, Univ. Southern California.
AE35 – High-brightness picosecond ion beam. SUNY SB, Imperial College
AE37 – An X-band, traveling wave, deflection mode cavity. RadiaBeam
AE39 – DWA –high-gradient dielectric wakefield acceleration experiment. UCLA
AE41 – RUBICON - helical IFEL experiment at BNL. UCLA
AE43 – PWFA Holography. U. Texas at Austin
AE45 – Advanced imaging and ultra-fast material probing with inverse Compton scattering. INFN
AE48 – Experimental study of electron-beam microbunching dynamics. Tel-Aviv U.
AE49 – Measurement of coherent terahertz radiation using a real-time interferometer. UCLA
AE50 – Plasma Wakefields in the Quasi-Nonlinear Regime. UCLA
AE52 – Beam Manipulation by Self-Wakefield at the ATF. Euclid Technilabs
AF53 – Nonlinear inverse Compton scattering. UCLA
AF54 – AXIS -5 μm damage test. RadiaBeam/UCLA
AE56 – A High-resolution Transverse Diagnostic Based on Fiber Optics. RadiaBeam
AF57 – Corrugated Plate De-Chirper. SLAC
AF58 – ERL BPM Test. BNL (C-AD)
AE59 – Inverse Compton Source for Extreme Ultraviolet Lithography. RadiaBeam
AE60 – Ultrafast High-Brightness Electron Source, Advanced Energy Systems
AE61 – Transient Noise of MCT Detector Array Due to 70 MeV Electrons. Jet Propulsion Lab.
AF62 – Sub-femtosecond beam line diagnostics. UCLA
AE63 – Stony Brook Accelerator Laboratory Course, CASE@ATF. Stony Brook University
AF64 – Surface Wave Accelerator and Radiation Source Based on Silicon Carbide. U. Texas at Austin

Eight experiments from this list, viz., AE31, AE35, AE49, AF53, AF54, AE56, AF57 and AE61, were reported as complete, adding to our present legacy of total 53 user experiments and feasibility studies completed through the ATF's history. The remainder is still active, with two being upgraded by the ATF Scientific Program Director, following the recommendations of APAC, from feasibility studies (AFs) to regular experiments AE62 and AE64.

Presented users' reports convincingly demonstrate that the experimental program at the ATF continues to excel. Taking pride in our users and their scientific achievements, we present highlights from experiments that generated landmark results in 2013-14:

AE41 – RUBICON - helical IFEL experiment

Demonstration of a record-high acceleration gradient (100 MeV/m) and energy gain (50 MeV) from inverse FEL electron accelerators. More than 50% of the electron beam was captured and accelerated to <2% energy spread (Fig.2). In upcoming experiments, the research group will assure higher precision in phase-matching of the micro-bunched beam from the pre-buncher into the tapered undulator. They will undertake a detailed study of beam emittance after acceleration, and, remarkably, make use of their accelerated beam for inverse Compton scattering (ICS).

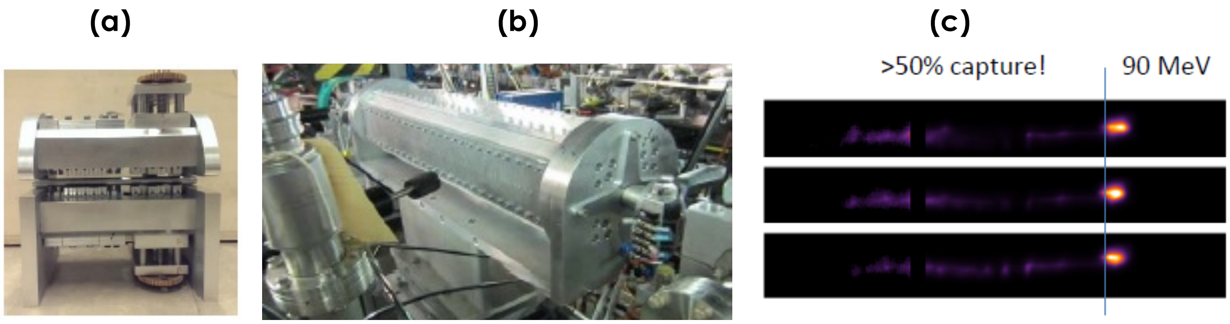

Figure 2. Images from the AE41 experiment: (a) Prebuncher; (b) undulator; (c) Spectrometer image - consecutive shots illustrate the excellent reproducibility of the acceleration process.

AF53 – Nonlinear inverse Compton scattering.

The first direct demonstration of a mass shift effect in the ICS spectrum is illustrated in Fig.3 (a). The experimental observation of high ICS harmonics is in perfect agreement with theoretical expectations (Fig.3 (b), (c)).

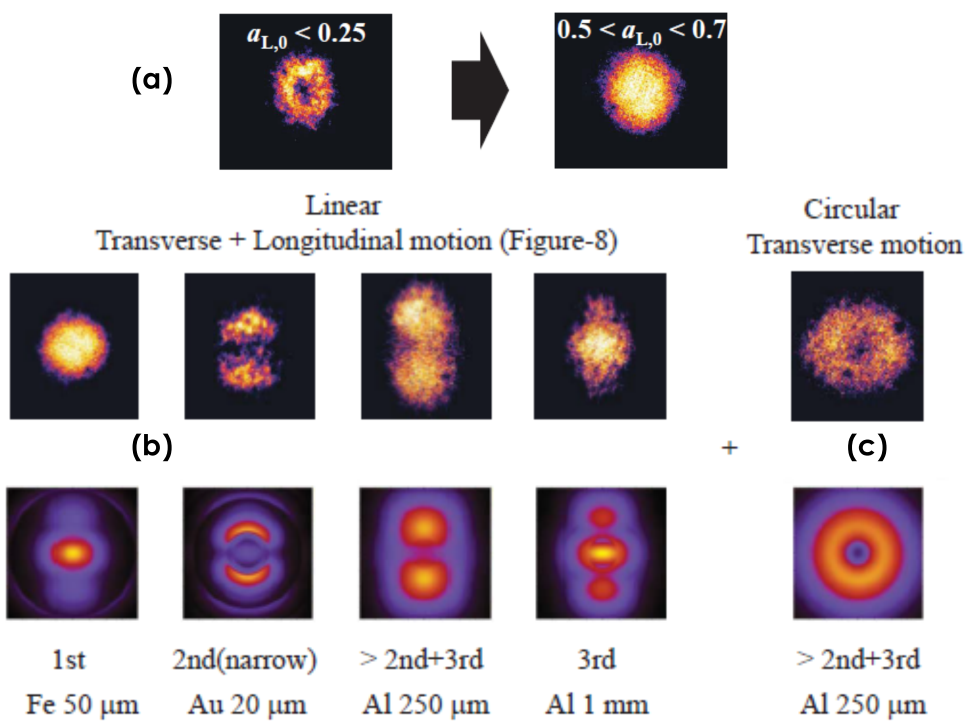

Figure.3 Images from the AF53 experiment: (a) Demonstration of a mass-shift effect when the most energetic axial x-rays fall below the K-edge filter absorption at the increased laser intensity; (b) filtered- out ICS harmonics observed (top) and simulated (bottom); (c) same for a circularly polarized beam.

AE35 - High-brightness picosecond ion-beam

New experimental findings point to the importance of optimizing density profiles for generating shock-wave ions. A novel technique was implemented for all-optical shaping of an over-dense gas target using a CO_2 laser pre-pulse. This resulted in better control over proton- and helium- beams generated from shock acceleration in gas-jet targets. The experiment achieved an energy spread of 10% with a spectral brightness of up to 10^9 proton/MeV/str, and a proton energy of up to 3.2 MeV.

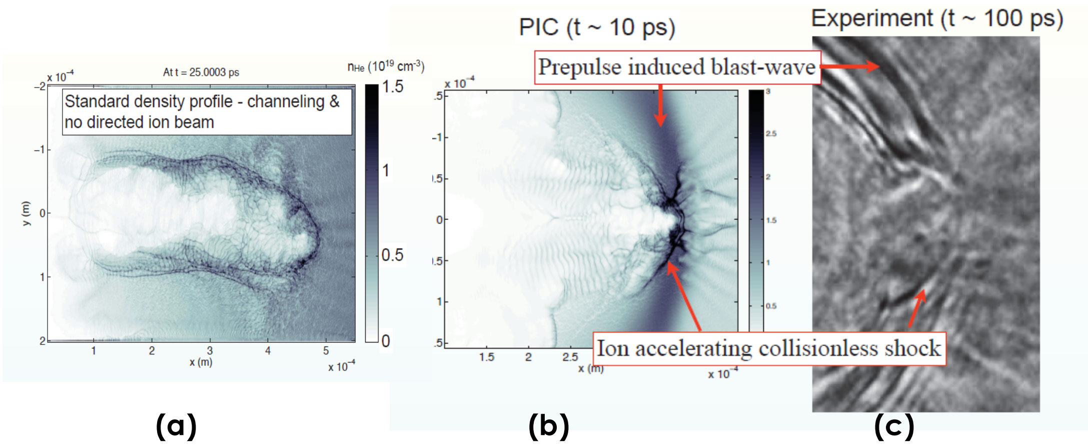

Figure 4. Images from the AE35 experiment: (a) simulations of plasma-density profiles upon focusing a single laser-pulse on a gas jet shows hole boring in plasma that does not produce ions; (b) simulated, and (c) experimentally observed plasma profiles when a laser pulse acts upon a supercritical blast wave produced by the absorption on the laser's pre-pulse in the gas jet.

AE52 - Beam Manipulation by Self-Wakefield.

This experiment demonstrated the correction of energy chirp by a self-induced dielectric wake-field (Fig.5).

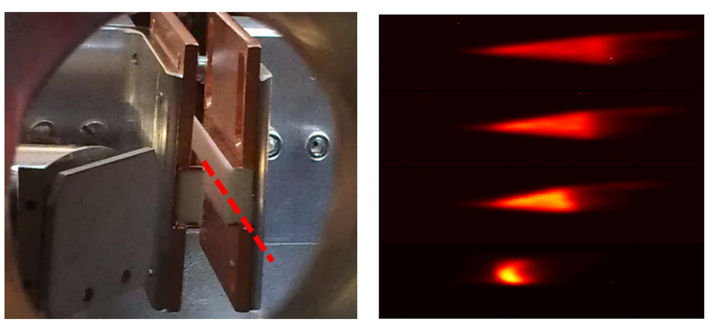

Figure 5. Images from the AE52 experiment: (a) Photo of a planar tunable de-chirper with a red line indicating the direction of an electron beam; (b) Spectrometer image (with energy spread indicated in the horizontal direction) - the energy spread is seen to be significantly reduced when a gap between alumina plates is set to the optimum position.

The following are among other highlights from ATF-hosted research for the reported period:

- Demonstration and study of Plasma Wake Field acceleration in the Quasi-Nonlinear regime (AE50).
- Demonstration of 10% wall-plug efficiency in producing trains of picosecond pulses inside the CO_2 laser-amplifier's cavity, aimed towards building a high-power Compton radiation source (AE59).
- Developing of a novel concept for an ultra-fast CO_2 laser and its partial verification.

Fig.6 further illustrates the diversity of the ATF users' program.

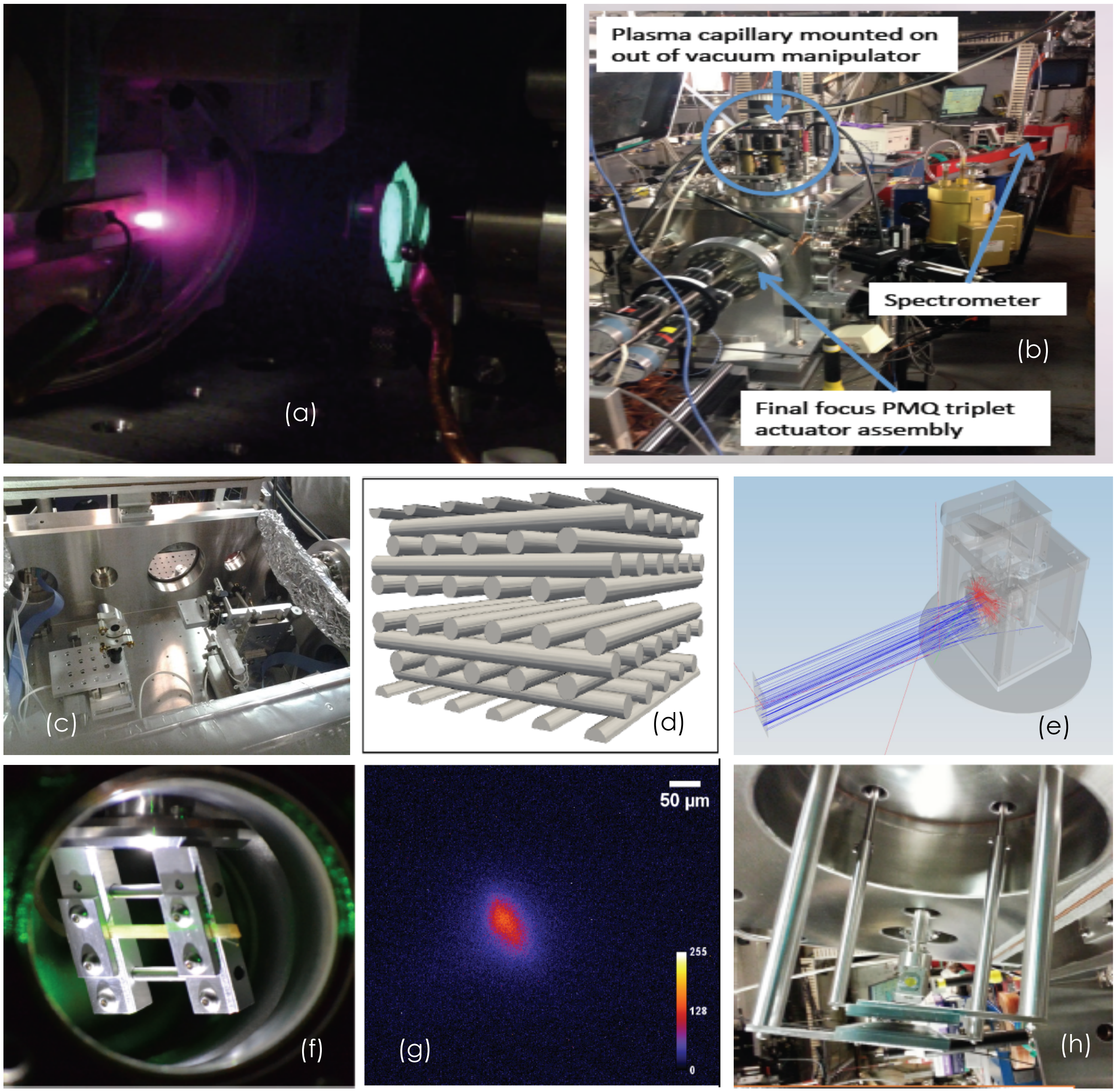

Figure 6. Mosaics with images from a variety of recent user experiments at ATF: (a) AE50 capillary discharge and (b) interaction chamber; (c) AE39 experimental setup for a dielectric wakefield acceleration experiment using a "woodpile" structure in (d); (e) Simulations to the AE61 tests of detector exposure to the ATF 70 MeV electrons to mimic radiation damage during to the planned NASA mission to Jupiter; (f) AE56 fiber-optic beam monitor; (g) AE56 high-resolution image deep-UV TR image; (h) AE56 – assembly for a corrugated beam de-chirper.

4. New experiments and facility upgrades

Several proposals for new experiments presented to the APAC at the 17th ATF User meeting were approved and recommended for beam time:

AE65 - NOCIBUR: An inverse free electron-laser decelerator experiment, UCLA

This experiment, a follow up from a successful RUBICON experiment, will explore reversing the direction of tapering in an undulator and in energy exchange from IFEL to TESSA - a tapering-enhanced stimulated super-radiant amplifier. Reversing the laser-acceleration process will extract most of the energy from an electron beam. Such a high- efficiency conversion of electron beam energy to coherent radiation opens the door to realizing very high average power light sources, such as 13.5-nm for EUV lithography or 10 TW x-ray LCLS.

AE66 - Modification of Gas Jet Density Profile with Hydrodynamic Shocks for CO_2 Laser Ion Acceleration Experiment, NRL, Imperial College (London)

Performed in collaboration with the team from AE35, the experiment will explore the shock-wave acceleration of ions in a properly profiled gas-target. The main difference lies in using an external solid state laser, instead of the CO_2 -laser pre-pulse to produce a pressure discontinuity, thereby conferring better control (Fig.7).

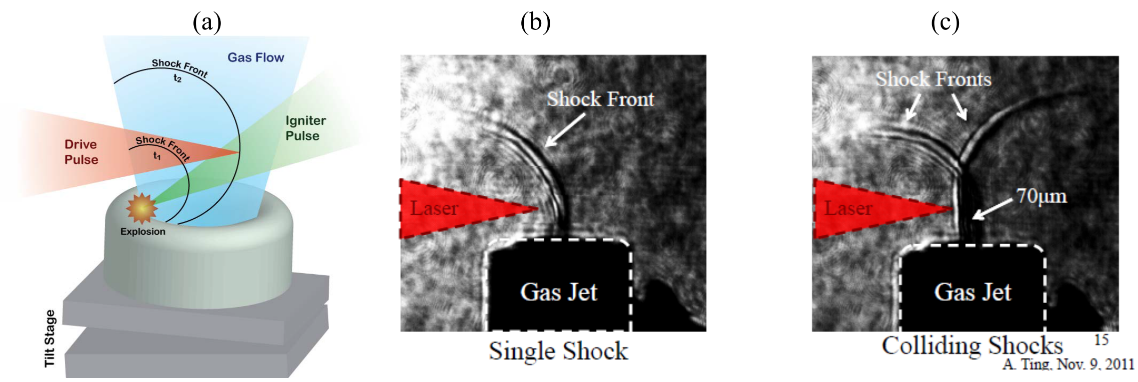

Figure 7. Images to illustrate the concept of the AE66 experiment: (a) Principle for driving a blast wave with an external laser: (b) and (c) earlier experimental results of gas profiling with laser blast waves (NRLs)

AE67 - Space Radiation Effects Experiments, NASA

Jupiter's magnetic field, being 20 times stronger than the Earth's field, is many orders- of- magnitude more efficient in trapping >10 MeV electrons, which hardly exist in the Earth's environment. This makes it important to test the Europa spacecraft's subsystems and payload instruments using ATF's electron beamlines.

AE68 - Ramped Beam Generation Using Dielectric Wakefield Structures, RadiaBeam.

Electron bunch ramping improves the transform ratio in wakefield acceleration experiments. The proposed experiment aims to produce ramped bunches by a dielectric wake field while consecutively demonstrating an improved DWFA according to the principle diagram presented in Fig. 8.

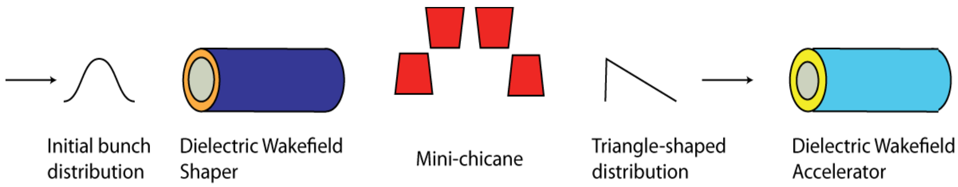

Figure 8. Principle diagram of the proposed AE68 setup

AF69 - Key physics study of LPI with NCD plasma using laser machined plasma structure, Tsinghua Univ.

This project approved for a feasibility study adds further diversity to dynamic manipulation of the plasma density distribution for ion- and electron- laser acceleration via using an external ionizing laser directed transverse to the main CO_2 laser beam.

AE70 - Nonlinear Inverse Compton Scattering, UCLA, Tokyo Univ.

Capitalizing on the success of a feasibility study AF53, this newly approved experiment is aimed to using a Bragg x-ray spectrometer for in-depth exploration of nonlinear phenomena in ICS, such as a relativistic mass shift and harmonic generation. A new dual-wavelength ICS excitation regime will be explored as well.

AE71 - CO_2-laser-driven GeV wakefield accelerators with external injection, SUNY SB, UCLA, Un. Texas in Austin, Tsinghua Univ.

This experiment marks an important beginning, which is a new generation of LWFA experiments – viz., a regime never afforded previously with CO_2 lasers. An ongoing ATF CO_2 laser upgrade towards higher peak power and shorter pulse-duration, combined with the availability of synchronized electron beams, opens new opportunities, among others, for investigating novel regimes of efficient low-plasma-density, high-current LWFA with external seeding. Several research groups from, SUNY SB, Univ. of Texas at Austin, LBNL, SLAC, NRL and Tsinghua Univ. have expressed interest in participating in the LWFA experiments with a CO_2 laser. Fig. 9(a) shows an example of simulations published by Wei Lu, Tsinghua University who predicts achieving "ultra-cold" electron bunches with the 50-nm normalized emittance via UV-ionization seeding inside a CO_2-produced plasma bubble

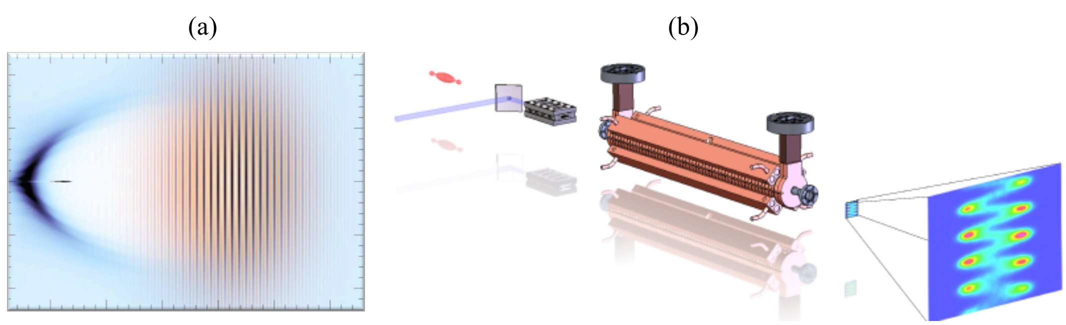

Figure 9. (a) A 2-TW CO_2 laser produces a plasma bubble that accelerates an externally seeded electron bunch to 200 MeV at a 50 nm normalized emittance; (b) Principle diagram of the AE62 attosecond-beam diagnostic based on an x-band deflection cavity and an IFEL energy modulator.

We expect that the scope and the quality of ATF user research will progress alongside the continuing expansion of the facility's technical capabilities offered to users. In addition to the CO_2 laser upgrade, we will soon bring on line an X-band RF power source to energize a deflection cavity that will add a high-resolution technical diagnostic to benefit a broad category of beam-based experiments. One of them is the AE62 experiment illustrated by Fig. 9(b).

5. Conclusions

After completing its 17th Users' Meeting and setting a user program for the 2015 experimental campaign, ATF starts a new journey across a vast landscape of multi-disciplinary explorations, the scope of which is further broadened by the newly established Accelerator Stewardship program. The improved ATF technical capabilities described here will benefit our users further; some of which may become available before the next ATF Users' Meeting. These short term improvements include the following: Commissioning of the, RadiaBeam designed, x-band deflection cavity in the ATF's electron beamline and continuing the improvements in the ATF's CO_2 laser parameters and beam delivery to experiments. In 2015, we plan testing of a CPA technique never implemented previously with CO_2 lasers that promises to multiply the laser's power. The same year we plan to install and test our first in-vacuum CO_2 optical transport line; this will allow delivery of an elevated laser power to user experiments installed in the electron beam lines. This, in-vacuum laser beam transport, will stop the beam's degradation due to the Kerr effect during its propagation through the air. These kinds of innovations will allow the ATF users to advance their experiments through an increase in available options.

However, much more is expected within the 3- to 4-year time frame when the ATF-II upgrade will transform the facility by increasing its science reach and productivity. This was the subject of the ATF-II Upgrade Workshop that took place immediately after the 17th ATF Users' Meeting on October 16-17, 2014. Please see http://www.bnl.gov/atf/news.php for a report from this meeting.

Those who are interested in becoming ATF users, please check our website http://www.bnl.gov/atf/.