U.S. DEPARTMENT OF ENERGY

Office of Science

ATF Newsletter

Spring 2015

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ATF NAMED SC USER FACILITY UNDER THE HEP, ACCELERATOR STEWARDSHIP PROGRAM

ATF Status Update

Ilan Ben-Zvi & Igor Pogorelsky

Welcome to the Spring 2015 issue of the ATF newsletter. The last two issues were specially dedicated to the ATF User Meeting and Upgrade Workshop held in October 2014. Here, we briefly review what has been happening at the ATF so far in FY15.

The big recent news is that the ATF has been approved as a formal Office of Science User Facility in the Accelerator Stewardship subprogram of the High Energy Physics program. This is a privileged status, which carries responsibilities and high visibility. This designation portrays the high-level recognition of the ATF's past performance, current significance and future importance to the Office of Science, the craft of accelerator science and technology and the international community of users from industry, academia and major laboratories. It also conveys the significance of the ATF to BNL, a laboratory in which accelerator science and technology has always played a key role.

You can see progress, so far, from this year's user experiments briefly summarized on the next page. Also, three highlights from our diverse user program are addressed in separate articles:

Mono-energetic ion beams (p. 3) are now being stably produced in the setup that combines CO_2 and Ti:Sapph lasers on a supersonic hydrogen jet. These new findings will be reported at SPIE symposium in Prague this month (Imperial College/NRL).

The monumental task of imbedding a CO_2 laser into one of the electron beam lines is completed, and researchers position themselves to study **inverse Compton scattering** (p. 5) from laser- and electron- beams colliding inside a close-loop active laser cavity (RadiaBeam).

The first semester of a new **Experimental Accelerator Physics course** (p. 6) for graduate students is in full swing at the ATF. This new initiative will increase the ATF impact on education of a new breed of accelerator scientists (SBU).

Our users might view the ATF to be business as usual with a statistically stable rate of beam time delivered over the reported period (see operations summary on p. 2);

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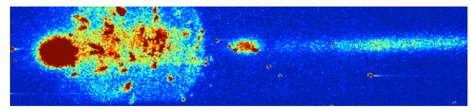
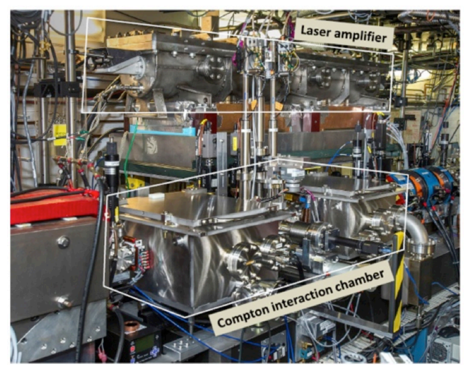
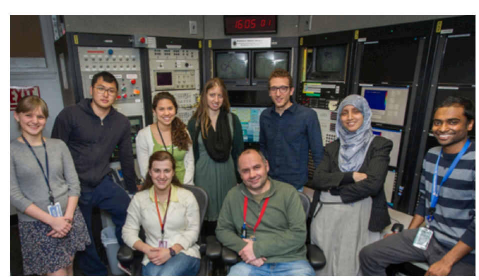






however the ATF staff is becoming heavily engaged in designing and constructing the new ATF-II facility, discussed at our Upgrade Workshop in October. New beam lines and experimental halls will be erected inside a newly constructed blockhouse in building 912. The first stage of this project is scheduled for completion in 2018. However, we plan the first ATF-II house warming, before the end of 2015, with the first user experiment; the Ultrafast Electron Diffraction experiment is going into business in a large clean room that will also accommodate the ATF solid-state lasers.

Completion of Stage 1 of the ATF-II upgrade will open to users three spacious experiment halls supplied with up to 150 MeV electron bunches with down to 100 fs bunch length in combination with a 100 TW, 100 fs, 10 µm laser beam from our next-generation CO_2 laser, recently named BESTIA (Brookhaven Experimental Supra-Terawatt Infrared at ATF) surely to complement LBL's BELLA. The ambitious parameters projected for this first CO_2-CPA (Chirped Pulse Amplification) laser are within reach after a recent proof-of-principle demonstration of stretching and recompression in our presently operational laser. The first report of this will be made public next month at CLEO.

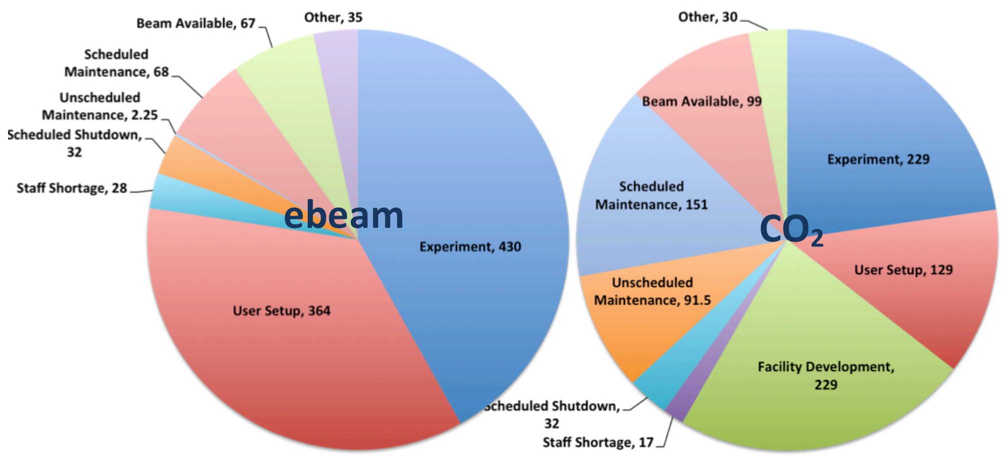
Well, enjoy reading our Newsletter and mark your calendar for the next, 18th, ATF User meeting to be held on October 1-2, 2015. Information about registration and proposal submission will follow during the next few weeks.

Operations etc.

Christina Swinson

Electron Beam and CO_2 Laser Status

So far in FY15 the ATF has played host to nine different experiments. See right for distribution (in hours) of e-beam and CO_2 laser activities.



The following user experiments were served with typical ebeam parameters ranging from 35 – 70 MeV in energy and 100 pC – 1 nC charge and up to 2 TW CO_2 laser peak power:

AE35 – High-Brightness Picosecond Ion Beam Source Based on BNL TW CO_2 laser (SUNY SB). After several years of successful results, this experiment came to completion in 2014. This work will be continued by an Imperial college/NRL collaboration as experiment AE66 – Modification of Gas Jet Density Profile with Hydrodynamic Shocks for CO_2 Laser Ion Acceleration Experiment. See page 3 for a full report.

AE39 – DWA – High Gradient, High Field Dielectric Wakefield Experiments at the ATF (UCLA). This experiment continues R&D into the use of dielectrics in advanced accelerators, most recently investigating chirp correction techniques.

AE41 – RUBICON – 220 MeV/m, 130 MeV Energy Gain Helical IFEL experiment at BNL (UCLA). This IFEL experiment has produced excellent results and multiple publications. See *Nature Communications* **5** 4928.

AE52 – Beam Manipulation by Self-Wakefield at the ATF (Euclid Techlabs). This experiment continues R&D into the use of dielectrics in advanced accelerators, most recently dielectrics for THz radiation sources.

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NEWSLETTER CONTRIBUTIONS
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AE59 – Inverse Compton Source for Extreme Ultraviolet Lithography (Radiabeam). This experiment has completed its installation phase and is now moving to data taking. See page 5 for a full report.

AE62 – Sub-femtosecond beam line diagnostics (UCLA). This experiment is exploring techniques for measuring the length of ultra-short electron pulses.

AE63 – CASE@ATF. A full report of the first hands-on accelerator physics course to be held at the ATF is reported on page 6.

AE64 – Surface Wave Accelerator and Radiation Source Based on Silicon Carbide (U. Tex at Austin). This experiment has developed a SiC structure and is now tackling alignment challenges.

AE67 – Space Radiation Effects Experiments (NASA). Physicists at JPL use the electron beam to determine the effects of radiation on instrumentation to be used for the upcoming Europa mission.

Noted Publications

Planar-Dielectric-Wakefield Accelerator Structure Using Bragg-Reflector Boundaries, G. Andonian *et. al.,* Phys. Rev. Lett. 113.264801

High-brightness intra-cavity source of Compton radiation, I Pogorelsky *et. al,.* J. Phys. B: At. Mol. Opt. Phys. 47 234014

Manipulation of laser-generated energetic proton spectra in near critical density plasma, Charlotte A. J. Palmer et. al., J. Plas. Phys. Vol. 81, 365810103

A complete listing of active and completed experiments, and publications can be found on the ATF website.

Observation of monoenergetic protons from a near-critical gas target tailored by a hydrodynamic shock

Y.-H. Chen[1], M. H. Helle[2], A. Ting[2], D. F. Gordon[2], M. N. Polyanskiy[3], I. Pogorelsky[3], M. Babzien[3], and Z. Najmudin[4]

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Monoenergetic ion beams can be produced by the interaction of an intense laser pulse with a near-critical plasma target. Collisionless, electrostatic shocks launched into the plasma by laser hole-boring [1] and heating [2] have been identified as the main acceleration mechanisms. Using terawatt CO_2 lasers and gas targets, operating at several times critical density (n_c~10^{19} cm^{-3}), ion acceleration had been experimentally observed by Palmer et al. at the ATF [3] and by Haberberger el al. at UCLA [2]. The UCLA group reported that the ion acceleration relies on the intrinsic pulse train structure of their CO_2 laser system. Optimal acceleration occurs when the plasma density profile at the front side of the target is steepened by the radiation pressure imposed by earlier, weaker pulses before the most intense one arrives. Recently, from the AE35 Experiment at ATF, Tresca et al. found that the quasi-monoenergetic ions can be obtained by tailoring the density profile with a low-energy pre-pulse [4]. The pre-pulse deposits its energy to the gas around the focal volume and drives an expanding blast wave, forming a sharp density gradient across the shock front before the main pulse arrives.

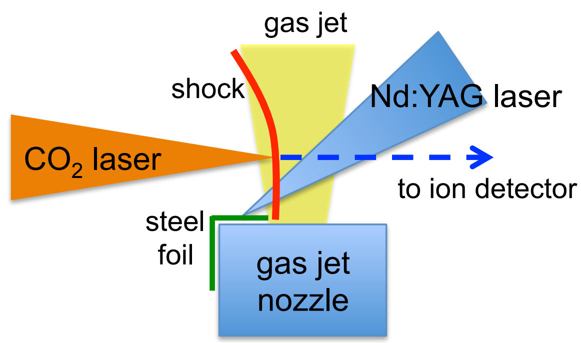

Fig. 1. Experiment setup

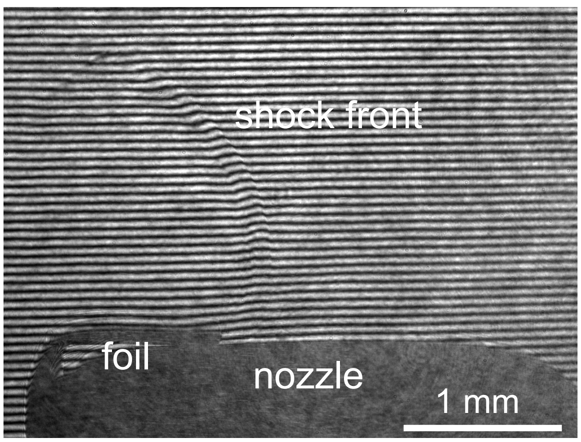

Fig. 2. Interferogram of shock

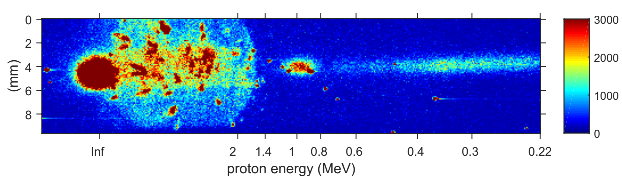

Fig. 3. Observed proton energy

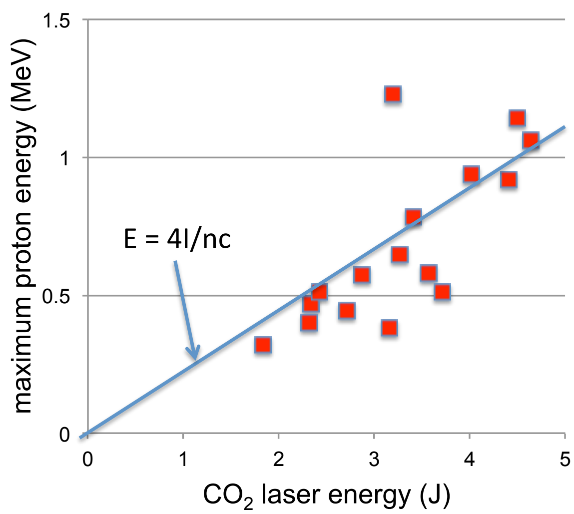

Fig. 4. Proton energy VS laser pulse energy

The Naval Research Laboratory has previously demonstrated a technique of shaping the gas target profile [5] for high intensity Ti:Sapphire laser plasma acceleration experiments [6]. We have been applying this technique at ATF for laser-driven proton acceleration using the picosecond terawatt CO_2 laser. The experimental setup is shown in Fig. 1. A piece of stainless steel foil is mounted near the 1-mm-diameter orifice of the gas jet nozzle, and a 5 ns, 70 mJ Nd:YAG laser pulse is focused on it. The laser-ablated material is ejected from the foil surface at supersonic velocity, launching a hydrodynamic shock into the hydrogen gas jet before the CO_2 laser pulse arrives. This creates a sharp density spike followed by a depression region at the front edge of the target. The density spike is ~ 6 times the local density over a length of ~< 100 μm.

Fig. 2 shows a sample interferogram of the hydrodynamic shock 30ns after the YAG laser pulse. The CO_2 laser pulse is focused to ~ 1 mm above the orifice with a spot radius w_0 = 60 μm and maximum a_0~1. A typical proton energy spectrum exhibiting a quasi-monoenergetic feature at 1 MeV is shown in Fig. 3 (signal registered at locations corresponding to > 1.5 MeV is caused by photons from the interaction region). Note that the hydrodynamic shock is generated by an external laser source with < 5% shot-to-shot energy fluctuation, and therefore is more stable than the previous CO_2 pre-pulse method. During the experimental campaign we were able to observe accelerated protons in approximately 20 consecutive shots. This also enables the CO_2 laser energy scan versus maximum proton energy while maintaining the same gas and shock parameters, as shown in Fig. 4. The solid line represents the theoretical maximum proton energy from laser hole boring process $E = 4I/nc$ with $n = n_c$, which agrees quite well with the experiment data.

[1] S. C. Wilks et al., Phys. Rev. Lett. 69, 1383 (1992).
[2] D. Haberberger et al., Nature Phys. 8, 95 (2012).
[3] C. A. J. Palmer et al., Phys. Rev. Lett. 106, 014801 (2011).
[4] O. Tresca et al., arXiv:1503.06180 (submitted to PRL)
[5] D. Kaganovich et al., J. Appl. Phys. 116, 013304 (2014).
[6] M. H. Helle et al., submitted to Advanced Accelerator Concept Workshop proceedings 2014.

FOR MORE INFORMATION

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High-brightness intra-cavity Compton radiation source

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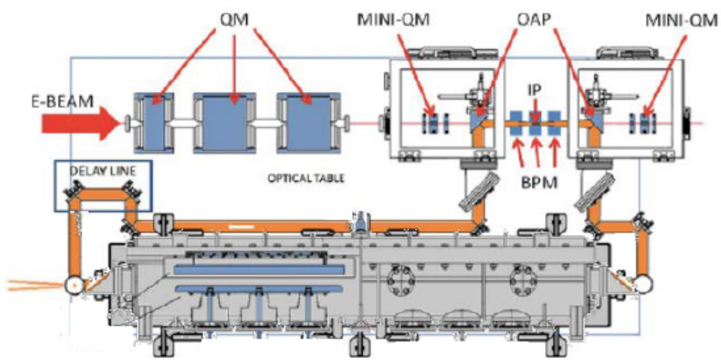
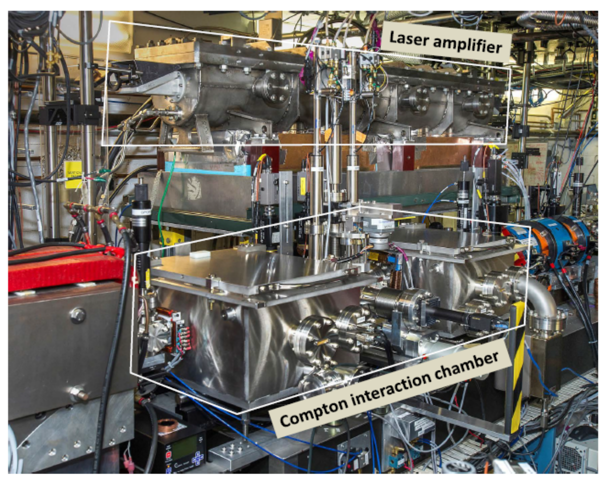
By providing 10–12 times more photons per Joule than do 1 µm solid state lasers, 10 µm CO_2 lasers are natural candidates for efficient realization of high-brightness x-ray sources by inverse Compton scattering (ICS) in counter-propagating laser and electron beams. A testament to this is the fine record of ICS users' experiments conducted at ATF since 1997. Femtosecond pulse duration and ultra-high peak brightness and energies, potentially in access of 3rd-generation Synchrotron Light Sources (SLSs), achievable in a relatively compact room-size configuration make ICS an attractive candidate for future compact light sources fitting the university, industry, and mobile platform formats.

However, due to a relatively low duty cycle limited by the laser repetition rate, the average brightness of ICS sources is orders of magnitude below that of SLSs, thereby, limiting their application potential. Catching up in this parameter is important for promoting ICS to the new-generation compact light sources, for seeding FELs, using ICS for polarized positron source production in future e-e+ linear colliders, nuclear materials interrogation, and for metrology purpose in the next-generation of EUV lithography.

Efforts are underway to bridge this gap. One such research direction is multiplying the source's repetition rate and increasing its average brightness by placing the Compton interaction point inside a laser cavity filled with fast-recurring laser pulses. Important for this approach is the fact that the laser and electron beam losses on Compton scattering are typically negligible. This allows for closed-loop beam multiple re-circulations with efficient multiplication of the ICS source repetition rate and average power.

The ATF's AE59 experiment conducted by RadiaBeam Technologies LLC, funded by the DOE SBIR Phase II grant, made a decisive step in realizing this idea by completing the installation of an active optical-laser storage cavity and ICS interaction chamber in one of the ATF linac beam lines. A CO_2 laser pulse produced by the ATF laser system is injected into a cavity where a dedicated intra-cavity laser amplifier supports the pulse circulation for ~100 round trips, proportionally increasing the cumulative laser energy available for interaction with a matched train of electron bunches.





Principle diagram (top) and a picture (bottom) of the RadiaBeam experiment setup in the ATF electron beamline.

A principle diagram and picture of the experiment setup are shown in the figure above. Researchers are making final tunes of the electron- and optical- beams prior to bringing them to interaction.

FOR MORE INFORMATION

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Accelerator Laboratory Course at the ATF

M. Fedurin, D. Kayran, D. Stratakis and V. Litvinenko (BNL)

The Center for Accelerator Science and Education (CASE) is as a joint venture between Stony Brook University (SBU) and Brookhaven National Laboratory (BNL). Since education in accelerator science and technology is historically an important part of the ATF mission, CASE established a classroom at the ATF with the purpose of teaching a graduate level advanced accelerator laboratory course using the unique facilities available at the ATF.

The purpose of this course is to introduce the fundamentals of beam physics via experimental investigation on scaled experiments employing electron beams as well as to provide an introduction to numerical and computational methods for accelerator physics. Emphasis is placed on modeling beam dynamics; the example applications will be relevant to the ATF components. The course is intended for graduate students and advanced undergraduate students who want to familiarize themselves with principles of accelerating charged particles and gain knowledge about contemporary particle accelerators and their applications. Upon completion, students are expected to understand the basic principles and relations of beam dynamics, many of which they will have experimentally verified. Furthermore, the students are expected to be able to effectively utilize computational beam dynamics simulation techniques and have a basic understanding of the requirements for developing such tools.

ATF operations coordinator Mikhail Fedurin (front) with students of the first practical accelerator physics laboratory to be held at the ATF. This course provides a great opportunity for students to receive first hand experience of accelerator operations. You can see more ATF snaps at http://bnl-atf.smugmug.com

Major topics that will be covered during the semester are:

- Source physics
- Magnet measurements
- Optical imaging and processing using both fast and integrating devices
- Phase space mapping and emittance measurement
- Longitudinal dynamics and energy spread, beam control

The course, which is entitled "Fundamentals of Accelerator Physics and Technology with Simulations and Measurements Lab", has been added in the graduate course curriculum of the Department of Physics and Astronomy at Stony Brook University and was attended by 8 students during Spring 2015 semester. Over the course of 11 weeks, each student was able to conduct a total of eight experiments and to utilize key computational beam dynamics simulation techniques to model those. Three accelerator physicists, Dr. M. Fedurin, Dr. D. Kayran, and Dr. D. Stratakis, with the support of the ATF staff members, taught the class. This course, which is supervised by Prof. Vladimir Litvinenko, will be offered every year and is expected to strengthen ties with the Stony Brook science community.

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