



ATF UPGRADE PROPOSAL

ATF Newsletter

Winter 2013/14

www.bnl.gov/atf
Follow @ATFatBNL

IN THIS ISSUE

Message from the ATF Director

For over a quarter of a century, the Brookhaven National Laboratory's ATF has been a destination for advanced accelerator research. With 16 user experiments in our active portfolio, the user research program addresses a wide spectrum of topics in accelerator science and instrumentation making our only experimental hall a very crowded place.

At the DOE review in October 2013, the ATF unveiled a plan to considerably expand our capabilities in serving the growing user community. The ATF upgrade proposal, still pending DOE approval, is now accessible at <http://www.bnl.gov/atf/docs/ATFupgrade.pdf>. We propose moving the ATF to another building where the number of radiation-shielded experimental halls will quadruple. Simultaneously, the planned six-fold increase in the linac's electron energy and hundred-fold increase in our CO₂ laser peak power will heighten the ATF's position at the forefront of the advanced accelerator research.

The recently announced ATF Upgrade Workshop (see poster here <http://www.bnl.gov/atf/docs/Poster-users2014.pdf>) will become a forum for conveying to our user community new research opportunities afforded by the combination of a high-brightness compressed electron beams and a unique ultra-fast 10- μ m laser. Feedback from this community will help us to reshape our plans according to the needs of future experiments.

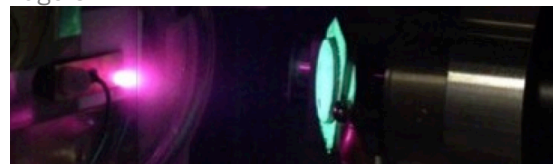
Our next User and Advisory Panel Meeting, coordinated with the ATF Upgrade Workshop, will review active experiments and new proposals. You are encouraged to attend our back-to-back events; please mark your calendar for October 14-17, 2014.

Experimental Overview

ATF is becoming more deeply engaged with the [Development of Ultra-Fast 10- \$\mu\$ m Laser Technology](#). New laser front-end based on an all-solid-state optical OPA replaces an outdated multi-staged picosecond pulse slicing system. Amplified OPA pulses will serve user experiments soon. This is a step in an extensive program of upgrading the ATF CO₂ laser system to 50-100 TW peak power at sub-picosecond pulse length. The 3-year upgrade plan, reviewed by

Quasi-nonlinear Plasma Wakefield Acceleration

Page 3



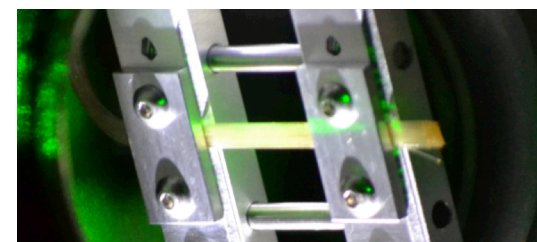
Demonstration of a Tunable, RF-Free, Passive, Beam Dechirper

Page 4



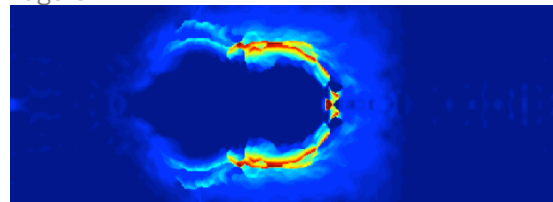
Demonstration of Advanced Profile Monitors

Page 4



Impurity Free Ion Beams Accelerated by 1 TW CO₂ Laser Pulses

Page 6



a panel of experts in October 2013, includes also integrating new amplifier stages filled with CO₂ isotopes, stretcher-compressor technique, and nonlinear self-chirping with femtosecond compression.

Extreme Ultraviolet Lithography This SBIR II experiment conducted by Radiabeam fulfilled its first goal: A train of picosecond CO₂ pulses carrying 20 J of the total energy has been demonstrated from an amplifier capable to deliver only about 1/40th of this in a single pulse. The next step is putting a laser/e-beam interaction point inside the amplifier cavity to demonstrate the proportional increase in the cumulative photon yield via inverse Compton scattering. This method is envisioned for EUV metrology.

High-Brightness Picosecond Ion Beam Source Experimental and simulation studies continue within the frames of the BNL-funded LDRD and user participation from Imperial College (London) and Stony Brook Univ. There, researchers explore a new promising approach of optimum sculpturing the plasma density profile by focusing a well-tailored laser pre-pulse onto a gas jet. See [page 6](#) for a contribution from Nathan Cook, graduate student from Stony Brook University who received an award for the best oral talk at the BNL Young Researchers Symposium in November 2013. Congratulations Nathan!

Operations also continue on the electron beam side; the last quarter saw various instrumentation tests alongside multiple different experiments.

Plasma Wakefield Acceleration in the Quasi-nonlinear Regime The group from UCLA saw first significant results after the installation and commissioning of their new experimental chamber. *"A major milestone in establishing the quasi nonlinear PWFA regime was recently accomplished with the establishment of blowout at ATF"* - [Page 3](#)

Beam Manipulation by Self-Wakefield This experiment, performed by Euclid Techlabs, looks at the effect of the wake generated when a beam passes through a dielectric structure, on the beam itself. The group have been testing different types of dielectric and geometric designs of capillary, through which the beam passes.

Corrugated Plate De-chirper and High Resolution Fiber-Mesh Diagnostic The ATF also provides services to small business; most recently Radiabeam took advantage of the electron beam to test two newly developed pieces of hardware. The De-chirper is a passive device designed to remove chirp that is commonly introduced to the beam during bunch compression, typically in FEL type experiments. The fiber-mesh diagnostic is a transverse beam profile monitor that was compared to the YAG crystal screens at the ATF. The *"viability of the FMD for high-precision, single-shot transverse beam profile characterization"* was successfully demonstrated - [Page 4](#)

ERL Button BPM Testing A group from the Energy Recovery Linac of the Collider-Accelerator department at BNL made use of the ATF for testing of both in house and commercial electronics for use with the Pick-up electrode button BPMs which are to be used in the soon to be commissioned ERL. Testing will continue, with optimized electronics design, later in the year.

Publications

N. P. Dover, C. A. J. Palmer, M. Babzien, N. Cook, A.E. Dangor, G. Hicks, M. Ispiriyan, C. Maharjan, M. N. Polyanskiy, J. Schreiber, P. Shkolnikov, M.J.V. Streeter, O. Tresca, V. Yakimenko, I. Pogorelsky, Z. Najmudin, Optical probing and simulation of shock waves in just overdense plasmas irradiated by an intense CO₂ laser, Laser & plasma acc. workshop 2013.

Operations

**ATF e-beam Activities
(2013/10/01-2013/12/31)**

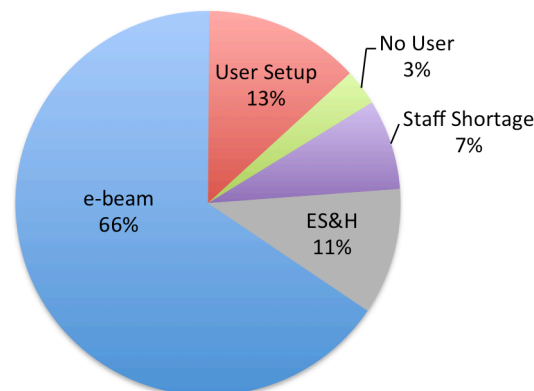


Figure 1: Total possible running time for this period: 61 days.

Electron Beam Status Beam time has increased from 43 %, in the summer quarter to 66%, in the past quarter due to a decrease in user setup time stemming from the types of experiment performed. Typical beam parameters ranged from energy 50-65 MeV and charge 30 – 500 pC (see page left for more info on e-beam activities).

Experiments Served:

- AE50 – PWFA in the Quasi-nonlinear Regime
- AE52 – Beam Manipulation by Self-wakefield
- AE56 – High Resolution Fiber-mesh Diagnostic
- AE57 – Corrugated Plate Dechirper
- AE58 – ERL Button BPM Testing

CO₂ Laser Status The last quarter of 2013 was dedicated mostly to facility development. This included preparations for the 100 TW upgrade, through implementation of the new Optical Parametric Amplifier and transformation of the CO₂ laser areas into a clean room environment. Other activities have focused on setup for the Extreme Ultraviolet Lithography experiment (see left).

Experiments Served:

- AE35 – High-Brightness ps Ion Beam Source
- AE59 – EUVL Compton Source

KEY CONTACTS

Director

Igor Pogorelsky igor@bnl.gov
For CO₂ laser scheduling

Operations coordinator

Mikhail Fedurin fedurin@bnl.gov
For experiment scheduling and proposals

Safety officer

Karl Kusche kusche@bnl.gov
For installations, training and hazards

Newsletter Editor

Christina Swinson cswinson@bnl.gov
For newsletter submissions and to subscribe

Igor Pogorelsky, Ilan Ben-Zvi, Mikhail Polyanskiy, BNL ATF - Research highlights and plans, Laser and plasma accelerator workshop 2013.

C. Maharjan , N. Cook, P. Shkolnikov, O. Tresca, I. Pogorelsky, M. N. Polyanskiy, N. P. Dover, Z. Najmudin, Real time diagnosis of laser driven ion acceleration process in over dense gas jet plasma, 55th annual meeting of the APS DPP.

O. Tresca, I. Pogorelsky, M. N. Polyanskiy, C. Maharjan , N. Cook, P. Shkolnikov, N. P. Dover, Z. Najmudin, Shock driven acceleration of impurity free ion beam using low density targets, 55th annual meeting of the APS DPP.

N. Cook, C. Maharjan , P. Shkolnikov, O. Tresca, I. Pogorelsky, M. N. Polyanskiy, N. P. Dover, Z. Najmudin, Impurity free ion beams accelerated by a terawatt CO2 laser, 2nd Young Researcher Symposium, BNL

C. Swinson and the ATF Staff & Users, The ATF: A Unique Facility for Advanced Accelerator Physics, 2nd Young Researcher Symposium, BNL

S. Antipov, S. Baturin, C. Jing, M. Fedurin, A. Kanareykin, C. Swinson, P. Schoessow, W. Gai and A. Zholents, Experimental Demonstration of Energy Chirp Compensation by a Tunable Dielectric Based Structure, Accepted for publication, Phys. Rev.

Quasi nonlinear plasma wakefield acceleration

- S. Barber (UCLA)

Plasma wakefield acceleration (PWFA) is an active area of research offering the promise of ultra high acceleration gradients which could drastically shrink the size of conventional accelerators. ATF provides a unique setting for testing numerous salient aspects of PWFA and has produced many significant results in recent years. With the addition of a specially designed experimental chamber which allows for the integration of a strong focusing, adjustable focal length permanent magnet quadrupole (PMQ) triplet, it is our aim to probe the viability of using PWFA in the so-called quasi-nonlinear regime.

Generally it is agreed that operating in the nonlinear or blowout regime promises the best way to accelerate charged particles due to the beneficial transverse focusing effect and position independent longitudinal accelerating fields which arise from the complete expulsion of plasma

electrons from the beam occupied region. However, certain aspects of a linear plasma response can be advantageous such as resonant excitation of wakefields through the use of pulse trains. Simulations suggest that achieving a blowout scenario while maintaining a linear plasma response is, in principle, achievable through the use of low emittance and tightly focused beams which have densities greater than that of the ambient plasma while simultaneously having a smaller total charge than the plasma electrons contained in a cubic plasma skin depth.

A major milestone in establishing the quasi-nonlinear PWFA regime was recently accomplished with the establishment of blowout at ATF. Using the strong focusing PMQ triplet, a ~5 micron scale transverse beam size was achieved. At this scale (along with ~100 A beam current), the beam density exceeds densities of 10^{16} cm⁻³. Direct confirmation of blowout is obtained by the observation of matching the focused beam to the solenoid like focusing field of the blown out plasma. Using a high resolution OTR imaging system, the electron beam

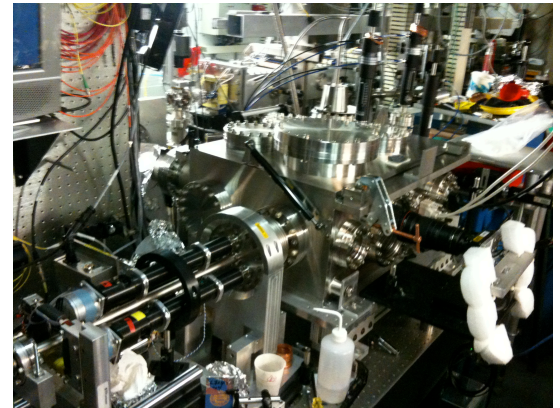


Figure 1: New experimental chamber with integrated PMQ triplet installed on beamline 2.

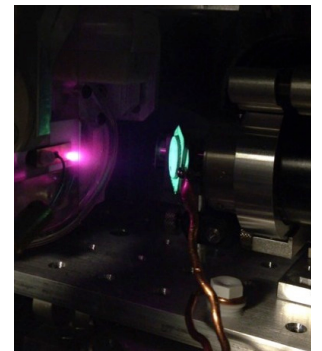


Figure 2: Plasma discharge.

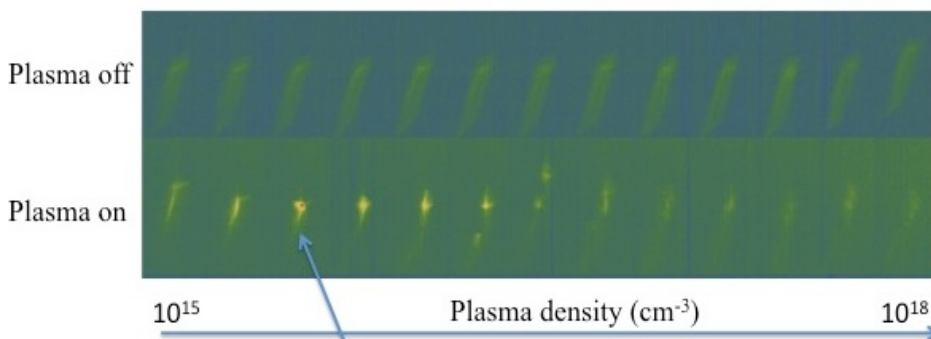


Figure 3: Transverse beam profiles measured with OTR. As the plasma density decreases (and thus the ratio of beam density to plasma density increases) the beam starts to focus up to a point at which the beam is matched to the focusing ion column (indicated by the arrow) providing strong evidence for blowout

transverse size is measured several mm downstream of the plasma capillary while scanning the plasma density. As can be seen in fig 3, the beam transitions from being slightly defocused at high plasma densities to being neatly guided at a specific density corresponding to a matched condition.

Initial tests with pulse trains of variable bunch spacing as well as drive/witness tests show promising results, which suggest hints of resonant plasma behavior.

FOR MORE INFO

Contact: S. Barber sbarber@physics.ucla.edu

Demonstration of a Tunable, RF-Free, Passive, Beam Dechirper

- by M. Harrison (harrison@radiabeam.com; RadiaBeam Technologies, LLC.)

Current and future FEL light sources require extremely short bunch lengths to generate the intensity of x-rays demanded by users. The compression sections of a beamline that create these short beam bunches often leave a residual chirp on the bunch that degrades the effectiveness of undulator sections. In order to maximize the output of light sources, this chirp must be removed. RadiaBeam Technologies has designed, manufactured, and demonstrated a tunable dechirper that requires no power input, using the beam bunch's own wakefield to remove its chirp.

The dechirper consists of a pair aluminum plates with millimeter-sized rectangular corrugations machined into the surfaces. As the beam passes between the two plates, the corrugations isolate and amplify a single THz-range mode of each particle's wakefield. The superposition of each electron's wake produces a longitudinal field that removes the residual positive chirp from the bunch. The strength of this dechirping field is inversely proportional to the square of the separation between the plates, so the structure can be tuned to the beam to achieve maximum performance from downstream undulators.

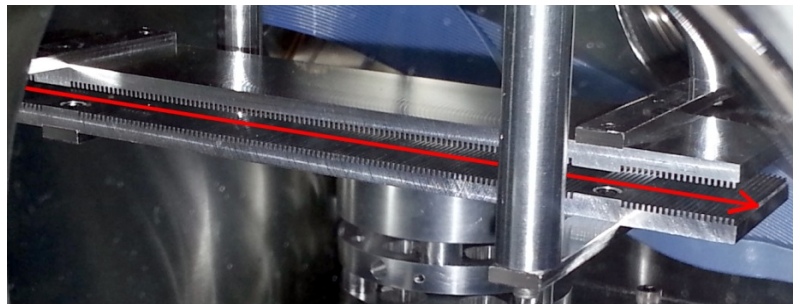


Figure 1: Corrugated plates, as installed at the ATF.

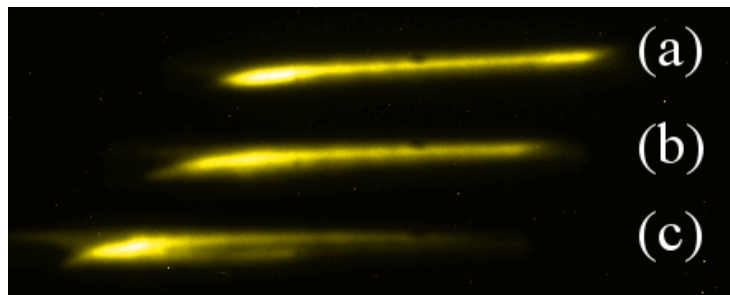


Figure 2: Several photographs of the phosphor on the energy spectrometer with higher energy to the right. The letters indicate the full plate separation: (a) 28.1 mm, (b) 9.02 mm, (c) 3.43 mm. Spectrum (a) represents an energy spread of about 400 keV.

An experimental test of an 18-cm corrugated plate dechirper, as shown in Figure 1, was performed at BNL ATF in early September 2013. Spectrometer measurements are shown in figure 2. These energy spread results matched closely with predictions from wakefield calculations and show an increasing concentration of the bunch energy towards the low-energy/front end as the separation between the plates is narrowed.

FOR MORE INFO

Contact: M. Harrison harrison@radiabeam.com

Demonstration of Advanced Profile Monitors

B. Jacobson, G. Andonjan, S. Wu, A. Murokh, M. Ruelas, M. Harrison, T. Campese, A. Bechtel, R. Agustsson and R. Li

An important capability at any accelerator facility is imaging of the transverse beam distribution. The quality of modern beams requires detailed images of structure on the 10's of micron to sub-micron scale. To this end, two advanced profile monitors were tested at the ATF in September 2013.

The Fiber Mesh Diagnostic (FMD, figure 1) is a transverse beam profile monitor based on the emission and detection of Cerenkov radiation produced in an ordered array of SiO₂ fiber optic strands by a relativistic e-beam. The fiber optics couple to a standard CCD array sensor and sub-10 μm resolution is achievable with appropriate packing considerations. The transverse one-dimensional profile is reconstructed from the raw image by a MATLAB-based control system. The results are similar in nature to a wire scanner with the profile obtained in a single shot.

A prototype was tested at the BNL ATF and its accuracy was compared to YAG:Ce based profile monitors. Emittance was measured with the FMD using the quadrupole scan technique and compared to a fit to multiple YAG:Ce screens, as shown in figure 2. The results show reasonable agreement (~4mm-mrad) and demonstrate the viability of the FMD for high-precision, single-shot transverse beam profile characterization. Future tests will address issues of fiber lifetime in high-radiation environments and an upgraded user-interface.

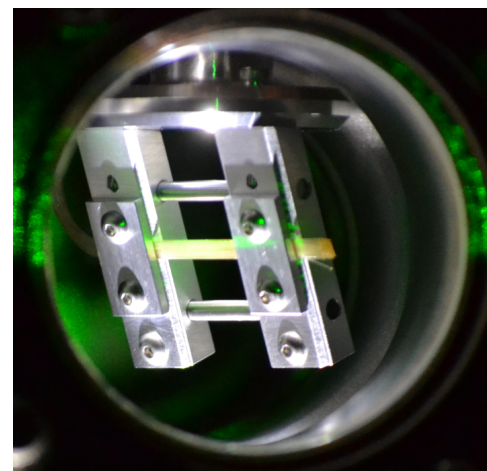


Figure 1: FMD in situ - with green laser along beam axis.

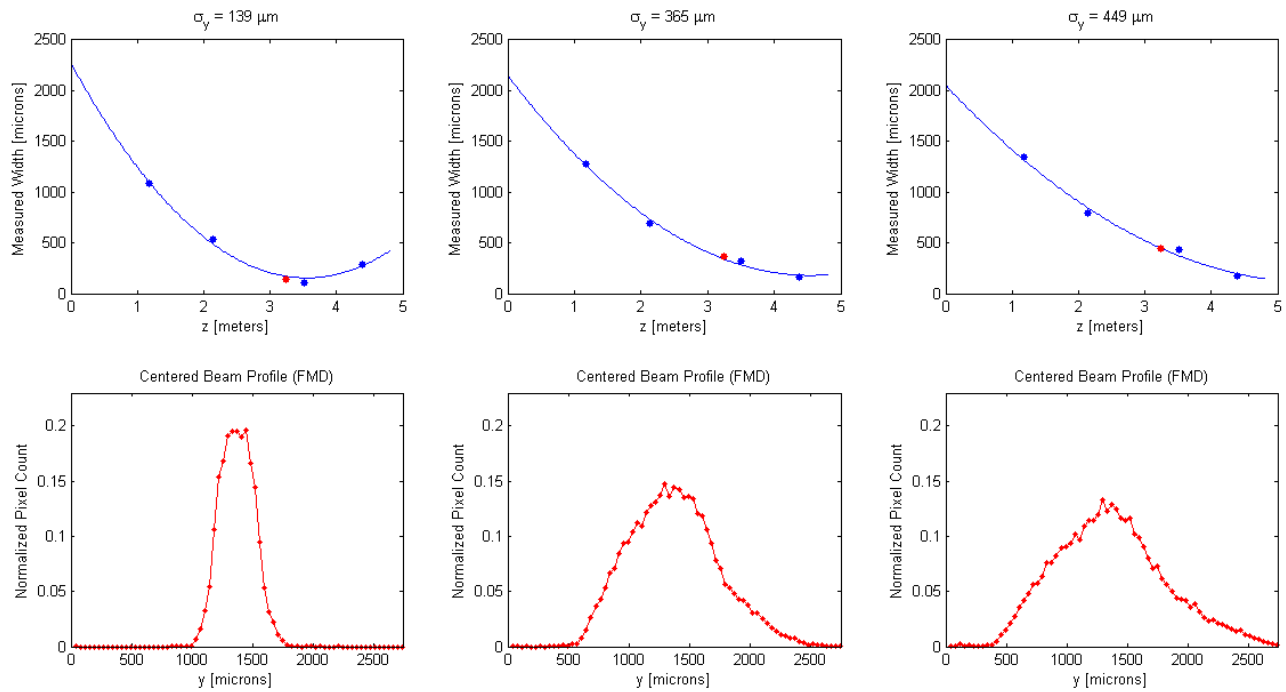


Figure 2: Top row – Beam widths measured with YAG:Ce (blue dots), and fit (solid blue line) with FMD measurement superimposed (red). Bottom row – Averaged beam profile at indicated position.

A transition radiation (TR) based profile monitor operating in the Deep Ultraviolet (DUV) and a microscope-objective as the collector was also tested at the ATF. The imaging system is similar to others demonstrated at the ATF, but approximately doubles the resolving power by using DUV-TR. The TR is deflected away from the e-beam by a dielectric mirror and into an in-vacuum infinite conjugate microscope objective. The collimated light exits the vacuum chamber through a viewport and is passed through a DUV bandpass filter and onto a CCD array (Figure 3). The standard CCD has a $4.56 \mu\text{m}$ pixel size, 1392×1040 resolution, and is sensitive down to 250 nm . The microscope objective and subsequent imaging tube lens provide an object-side pixel size of $1 \mu\text{m}/\text{pixel}$.

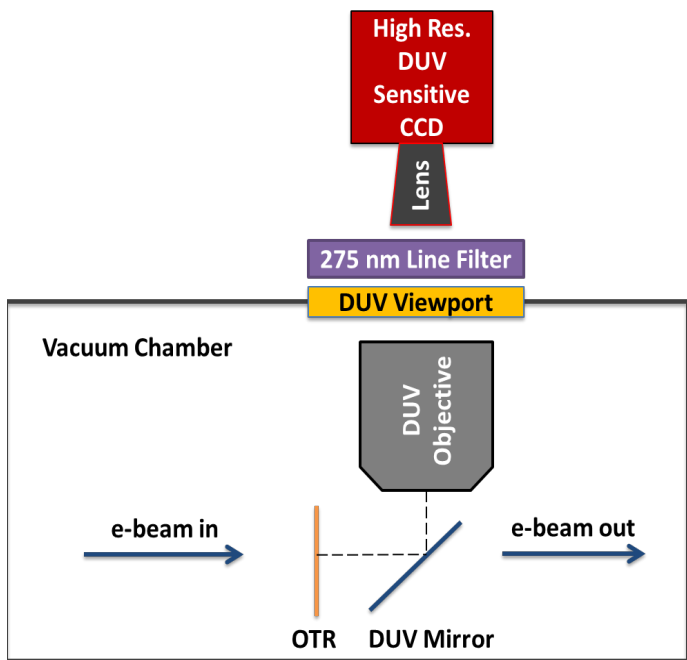


Figure 3: Cartoon of component layout as tested at the ATF.

The prototype DUV-TR imager was tested at the ATF on beamline 2 with spot sizes down to $50 \mu\text{m}$ and a charge of 500 pC , as shown in figure 4. Good agreement was found with adjacent YAG:Ce profile monitors and structure of approximately $5 \mu\text{m}$ was observed. Further tests are planned in 2014 with a 500 nm object-side pixel size.

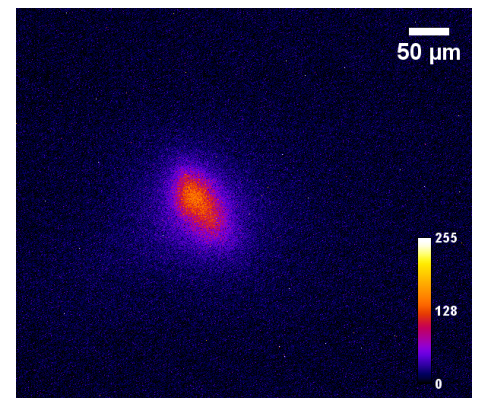


Figure 4: 500 pC beam profile with a resolution $\sim 1 \mu\text{m}/\text{pixel}$ taken during test at ATF.

FOR MORE INFO

Contact: M. Reulas ruelas@radiabeam.com

Impurity Free Ion Beams Accelerated by 1 TW CO₂ Laser Pulses

N. Cook with N.P. Dover, C. Maharjan, Z. Najmudin, M. Polyanskiy, P. Shkolnikov, I. Pogorelsky, O. Tresca

Acceleration of protons by intense laser pulses has become an increasingly active area of study amongst nuclear, plasma, and accelerator physicists. Considerable progress has been made using thin foils as targets for high intensity lasers at optical wavelengths.

These experiments reach the highest proton energies, but at the expense of beam quality and energy spread. An alternative is to use the radiation pressure of the laser to drive hole-boring or shock wave acceleration of ions from a low density target. The ponderomotive force of the laser can push electrons in an under-dense plasma further into the target, forming a critical surface in the plasma which generates extremely high electric fields. This field perturbation may recede at a velocity v , subsequently reflecting ions at twice that velocity. Experiments conducted at the ATF in 2009 using intense, circularly polarized, CO₂ laser pulses demonstrated acceleration by producing collimated bunches of protons with energies greater than 1 MeV and narrow energy spread, [1] [2]. Recent improvements to the ATF CO₂ laser system have allowed for the production of single ps-scale pulses with TW peak power [3]. Using a linear polarized single pulse causes significant heating of the target electron population, supporting shock wave propagation at higher speeds [4].

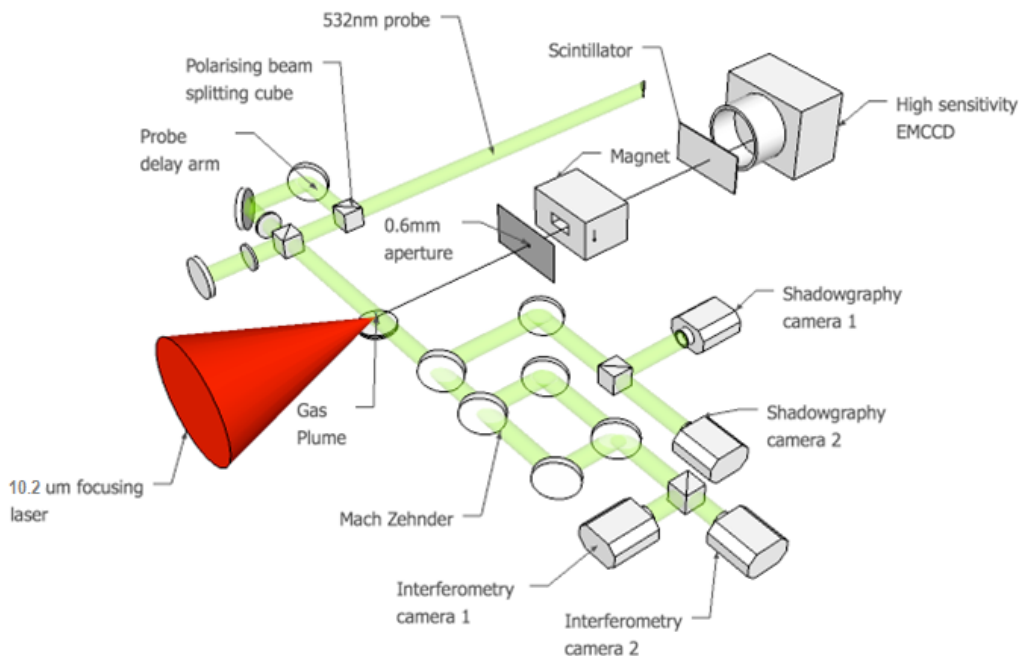


Figure 1: A frequency doubled YAG is split into two 14 ps pulses. The group delay of the pulses is synchronized with the CO₂ laser, while single pulse delay can be controlled from ~ 50ps to several ns. The pulses intersect the plasma orthogonally to the CO₂ axis, and are then directed to a camera for shadowgraphy and a Mach-Zehnder interferometer for density profiling.

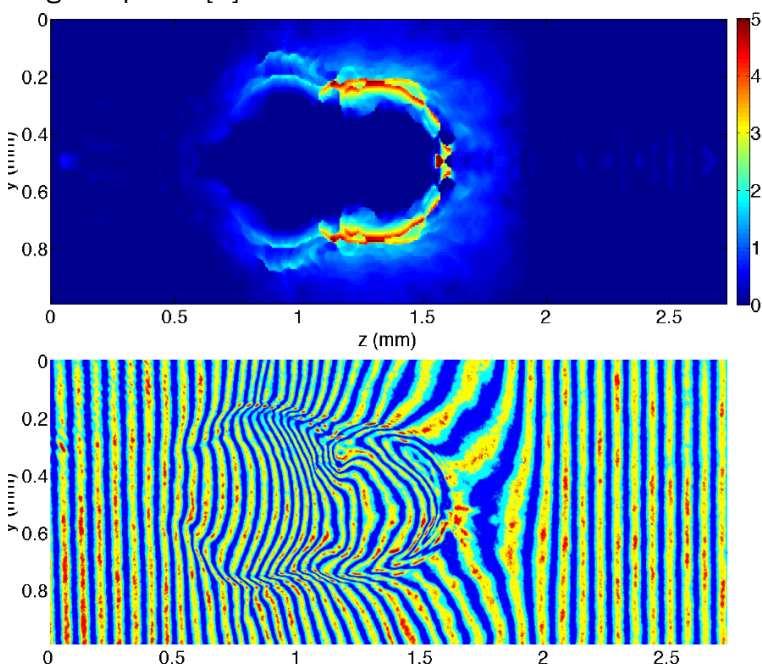


Figure 2: Bottom, interferometry shows the He plasma formed above a 1 mm nozzle, 132 ps after laser incidence. Above, the plasma density has been extracted, showing the time-resolved electron density. The laser travels left to right.

The ponderomotive potential of a laser scales with λ^2 , meaning laser acceleration at longer wavelengths necessitates significantly lower intensities. Utilizing an isotopic CO₂ mixture in a regenerative amplifier, we amplify a 10.2 μm CO₂ pulse in a high pressure amplifier, resulting in a single 5 ps pulse providing a maximum of 1 TW power [3]. The pulse is then focused down to a spot size of 50 μm , providing on-target intensities of more than 10^{16} Wcm^{-2} . Because plasma critical density scales as λ^{-2} , the use of 10 μm laser light allows for the use of high purity, high repetition rate gas jet targets. We use 1 mm and 2 mm cylindrical nozzles to produce high-density gas jets. At these densities, the gas is transparent to optical wavelengths; as such we use a frequency doubled 14 ps Nd:YAG laser pulse to probe the gas during and after the laser plasma interaction (LPI), as shown in figure 1.

One unique advantage of the gas jet target is the ability to use multiple species of target ions. While proton acceleration from Hydrogen gas jets promises the widest variety of applications in industry and medicine, Helium gas provides a critical test bed for laser plasma dynamics. Experiments performed using Helium gas show clear evidence of plasma channeling behind an energetic density

perturbation. This behavior is illustrated in fig 2. A principle challenge for RPA schemes is the creation of proper plasma conditions to generate a fast moving density spike; a single linearly polarized pulse is insufficient to both prepare the plasma and accelerate ions. Current efforts at the ATF are being made to use a preliminary pulse with controlled intensity and delay to heat and shape the plasma. By creating a sharp longitudinal density profile with uniformly hot electrons, the accelerated beam's intensity and energy spread are improved.

This work has been presented at the most recent NA-PAC Meeting in Pasadena, the APS DPP 2013 Meeting in Denver, and most recently the 2013 Brookhaven Young Researcher's Symposium. Presenter Nathan Cook was awarded an oral presentation prize for his talk, titled "Impurity Free Ion Beams Accelerated by a 1 TW CO₂ Laser". Ongoing improvements to the CO₂ laser and the upcoming transition to ATF 2 will further enhance experimental capabilities and anticipated results.



Figure 3: At the 2013 BNL Young Researcher Symposium, Nathan Cook received one of three oral presentation awards for his talk, "Impurity Free Ion Beams Accelerated by a 1 TW CO₂ Laser". Cook is a graduate student in the Department of Physics and Astronomy at Stony Brook University.

References

- [1] C. Palmer et. al. Phys. Rev. Lett. 106 (2011) 014801.
- [2] Najmudin et. al. Phys. Plasmas. 18 (2011) 056705.
- [3] M.N. Polyanskiy, I. Pogorelsky, & V. Yakimenko. Optics Express, 19 (2011) 7717-7725.
- [4] Haberberger et al. Nat. Phys. 8 (2012) 95–99.

FOR MORE INFO

Contact: N. Cook ncook@bnl.gov , I. Pogorelskiy igor@bnl.gov

Upcoming Schedule

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
22		1/2 Holiday	Holiday			28
January			Holiday			4
5	Maintenance					11
12	Maintenance					18
19	Holiday	AE52 - DWFA (Euclid), BL2				25
February	AE52 - DWFA (Euclid), BL2					1
2	AE50 - PWFA in QNR (UCLA), BL2					8
9	AE50 - PWFA in QNR (UCLA), BL2					15
16	Holiday	AE50 - PWFA in QNR (UCLA), BL2				22
March						1
2	AE53 - Nonlinear Compton (UCLA)					8
9	AE53 - Nonlinear Compton (UCLA)					15
16	AE53 - Nonlinear Compton (UCLA)					22
23						29
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday