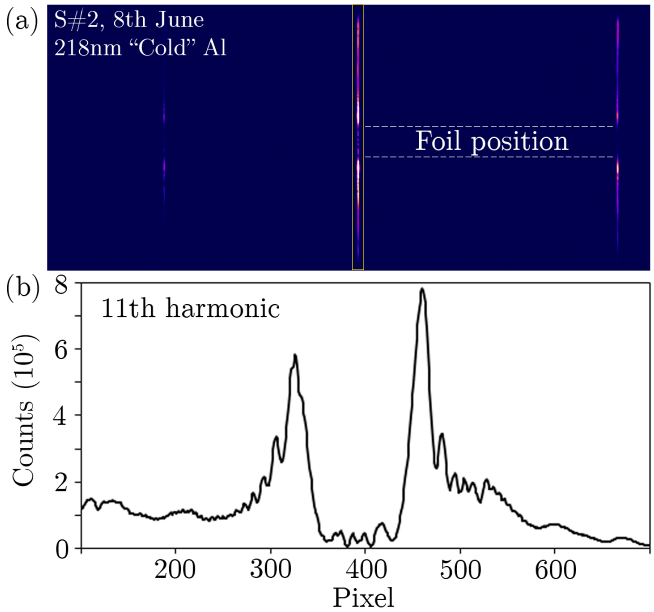
High Intensity/Energy Science

XUV collisional absorption of warm dense aluminium

B. Kettle, T. Dzelzainis, S. White, L. Li, B. Dromey, M. Zepf, C. L. S. Lewis, D. Riley *(Queen's University Belfast, UK)*
R. Heathcote, C. Spindloe, S. Spurdle *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
G. O. Williams, S. Künzel, M. Fajardo *(GoLP/Instituto de Plasmas e Fusão Nuclear, Lisboa, Portugal)*
A. Rigby, G. Gregori *(Dept of Physics, University of Oxford, UK)*
H. Dacasa, Ph. Zeitoun *(Laboratoire d'Optique Appliquée, France)*

This report describes an experiment to measure the collisional absorption of warm dense matter (WDM) aluminium in the XUV regime. Thin aluminium sample foils were radiatively heated to WDM conditions using adjacent palladium heater foils. A separate high harmonics probe, generated using the short pulse beam 7 and an argon gas jet, was used to test the resulting target absorption.

The chosen photon energies of the harmonics probe make collisional absorption the dominant process for transferring energy to the target. This process is theoretically challenging, and experimental evidence can help to verify the conflicting models currently published.



A 'cold' data shot (#2, 8th June) for a 218 nm Al sample.
(a) Raw flatfield spectrometer data with the 9th, 11th and 13th order harmonics visible. The spatial position of the foil has been highlighted.
(b) Lineout of the 11th harmonic across the spatial direction.

Contact: B.Kettle (bkettle01@qub.ac.uk)

Phase transitions in shock-compressed bismuth identified using single photon energy dispersive x-ray diffraction

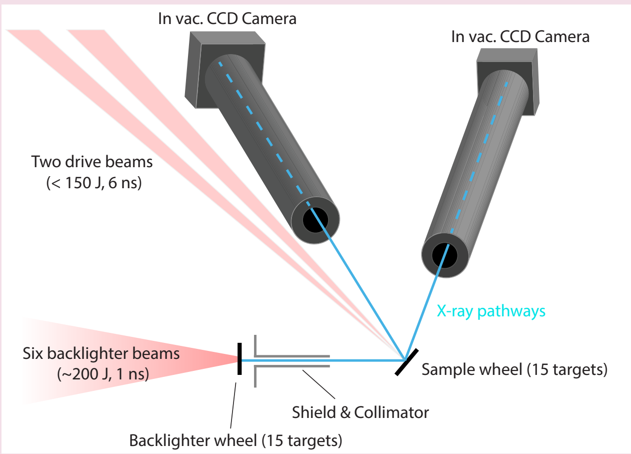
R. Briggs, M. G. Gorman, A. Coleman, M. I. McMahon *(School of Physics & Astronomy, The University of Edinburgh, UK)*
M. Suggit, S. Patel, P. Stubley, J. S. Wark *(Dept of Physics, University of Oxford, UK)*
A. Higginbotham *(Dept of Physics, University of York, UK)*
G. W. Collins, J. H. Eggert, J. A. Hawreliak *(Lawrence Livermore National Laboratory, California, USA)*
R. Clarke *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Dynamic compression of materials using high-power laser facilities allows access to extreme P-T states that lie well beyond the current limits of diamond anvil cell techniques. However, collecting x-ray diffraction data from samples at such conditions is extremely difficult, as the very high laser intensities used to drive the metallic foil that produces the nanosecond-duration x-ray source creates a hostile environment, in which the x-ray noise from the drive lasers generates very large backgrounds that can eclipse any diffraction signal from the sample. Here we present evidence for phase transitions in shock-compressed bismuth using the, relatively new, Single Photon Energy Dispersive X-Ray (SPEDX) diffraction technique. Experiments were performed on the Vulcan laser at the Central Laser Facility.

We observe diffraction from the (110) bcc peak of Bi-V, and, from its measured lattice parameter, the sample's pressure was determined to be approximately 16 GPa, the maximum pressure at which the peak was observed. This could indicate a lower estimate of shock melting for bismuth, thought to lie between 16 and 24 GPa.

Contact: M. I. McMahon (m.i.mcmahon@ed.ac.uk)

These experiments are crucial for improving the quality of observed x-ray diffraction of a sample in the extreme (and hostile) conditions generated during laser shock compression.



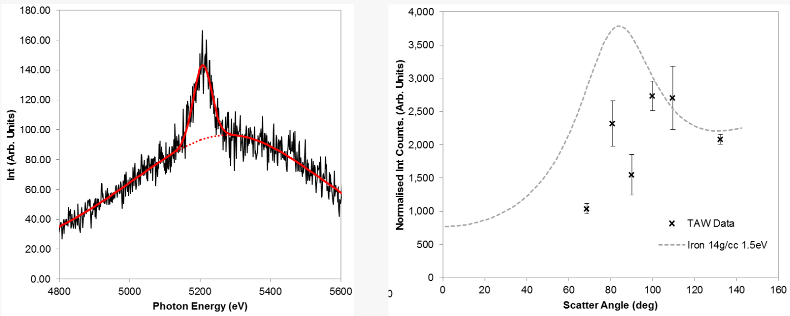
Experimental set-up within the target chamber.

X-ray scattering at breakout from warm dense iron

S. White, S. Kar, B. Kettle, M. Calvert, C. L. S. Lewis, D. Riley *(Queen's University Belfast, UK)*
A. Rigby, M. Oliver, G. Gregori *(University of Oxford, UK)*
E. Tubman, C. D. M. Murphy, N. Woolsey *(Dept of Physics, University of York, UK)*

The study of warm dense matter using x-ray scattering techniques has proven to be a valuable technique for characterization of these dense, transient plasma states. Considerable interest has been focused on the study of relatively light elements such as hydrogen and lithium, up to carbon. Carbon and hydrogen are interesting in particular, as they are thought to be present, under warm dense conditions, in the cores of Jovian mass planets. There is, however, major motivation to extend research to heavier elements such as iron, as not only is iron thought to be present in the core of Earth and the rocky planets of our own solar system, but also in many so called 'super earths' which have recently been discovered. Accurate planetary modelling will require an in-depth understanding of how iron behaves under the extreme temperatures and pressures at the heart of an Earth-mass planet.

In this article we present initial results from an experiment undertaken at the target area west laboratory, to measure the angularly resolved x-ray scattering cross-section of iron under extreme pressure and temperature, similar to that of the Earth's core. The experiment employed a novel geometry, which allowed us to probe much more uniform samples of iron than previously possible.



Left: Example of a typical data shot on one of the scattering spectrometers. Data shown here was collected at a scattering angle of 68.6°±6.0°.

Right: Comparison of experimental results of the scattering power to an estimate based upon calculating the ionic structure factor using an HNC model with a screened Yukawa potential and calculating ionic form factors using the approach of Pauling.

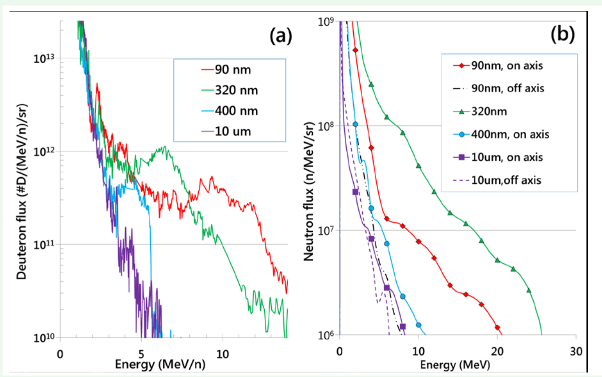
Contact: Dr S. White (swhite06@qub.ac.uk)

Neutron production from ultrathin foils by radiation pressure driven ions

A. Alejo, S. Kar, H. Ahmed, D. Doria, A. Green, D. Jung, C.L.S. Lewis, G. Nersisyan, M. Zepf, M. Borghesi *(Queen's University Belfast, UK)*
A.G. Krygier, R.R. Freeman *(The Ohio State University, USA)*
R. Clarke, J. Fernandez, J.S. Green, M. Notley *(CLF, STFC Rutherford Appleton Laboratory, UK)*
J. Fuchs, L. Vassura *(Laboratoire pour l'Utilisation des Lasers Intenses, École Polytechnique, France)*
A. Kleinschmidt, M. Roth *(Technische Universitat Darmstadt, Germany)*
J.T. Morrison *(Propulsion Systems Directorate, Air Force Research Lab, Ohio, USA)*
Z. Najmudin, H. Nakamura *(Blackett Laboratory, Imperial College London, UK)*
P. Norreys *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK; Dept of Physics, University of Oxford, UK)*
M. Oliver *(Dept of Physics, University of Oxford, UK)*
J.A. Ruiz *(Universidad Politécnica de Madrid, Spain)*

An ultra-short burst of fast neutrons would have a wide range of applications in science, industry, healthcare and security. However, the limitation in accessing large neutron facilities has led to an increasing interest in finding table-top sources. Laser-driven ion accelerators have been investigated as a possible solution, mainly by using the ions accelerated via the Target-Normal Sheath Acceleration (TNSA) mechanism impinging on suitable neutron converter targets. Despite being a robust mechanism, TNSA exhibits a slow ion energy scaling with respect to the incident laser intensity ($E_{ion} \propto \sqrt{I_L}$), with a beam predominantly formed by protons, reducing the range of possible nuclear reactions involved in the neutron generation.

Here we report on the neutron generation using radiation-pressure driven ion acceleration (RPA). This mechanism holds the advantage of generating higher energy ion beams, including heavy ions, with high laser-ion conversion efficiency and low divergence. Unlike typical experiments, where a secondary converter target is needed, a high-flux, directional neutron beam was produced from the primary target itself when the RPA mechanism was involved.



(a) Appearance of narrow-bandwidth features in the deuterium spectra as the thickness is reduced.
(b) Variation of the neutron spectrum depending on the target thickness, showing improved neutron generation when RPA is the dominant mechanism.

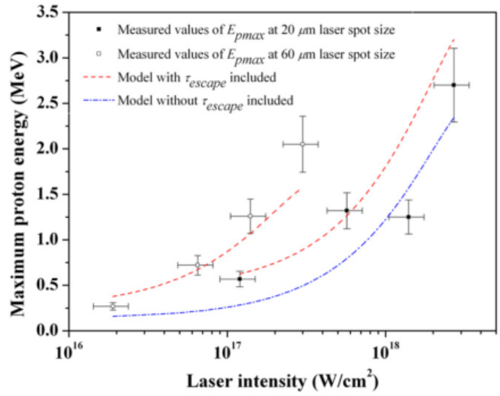
Contact: Dr S. Kar (s.kar@qub.ac.uk)

Modelling the effect of laser focal spot size on sheath accelerated protons in intense laser-foil interactions

C. M. Brenner, D. Neely
(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)

P. McKenna
(Dept of Physics, University of Strathclyde, Glasgow, UK)

We present an approach to modelling the effect of the laser focal spot size on the acceleration of protons from ultra-thin foil targets irradiated by ultra-short laser pulses of intensity 10^{16}–10^{18} W/cm^2. The importance of including lateral expansion of hot electrons at the rear surface of a thin foil irradiated by an intense laser pulse in modelling ion acceleration is demonstrated, with the introduction of an additional term in the definition of the ion acceleration time. This additional escape time term, τ_{escape}, accounts for the time it takes for laterally-transporting hot electrons to escape the accelerating sheath area on the rear surface. In the case of a large focal spot diameter (> 20 µm) this term is significant compared to laser pulse durations of < 50 fs, and is a dominating factor in defining the acceleration time. An approach that combines the modified acceleration time with a plasma expansion model, along with calculations for the hot electron temperature and density, is used to model the maximum proton energy and is found to be in good agreement with experimental results. Further experimental investigation at large focal spot sizes, and various laser and target parameters, would be very useful in order to verify that the modelling approach presented in this paper can be expanded beyond the specific irradiation conditions described in this study.



Measured values of E_{pmax} plotted as a function of peak laser intensity compared to model calculations, with and without inclusion of the τ_{escape} term in equation. At each focal spot size, the laser intensity was varied by varying the laser energy only, while keeping the laser pulse duration constant throughout.

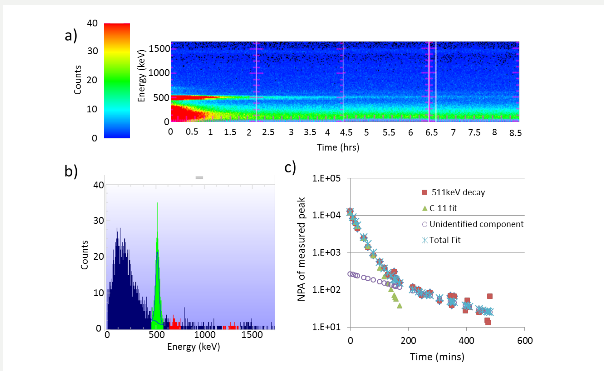
Contact: C. M. Brenner (ceri.brenner@stfc.ac.uk)

Proton activation history on the Vulcan high-intensity petawatt laser facility

R.J. Clarke, S. Dorkings, R. Heathcote, K. Markey, D. Neely
(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)

High-intensity lasers are an effective source for the acceleration of high-energy particles. Using different interaction configurations, they can be optimized for the acceleration of electrons, protons, heavy ions, high-energy photons, or neutrons. However, laser facilities operating at intensities in the region of 10^{19} W/cm^2 or above can easily generate levels of activity that must be both monitored and controlled to mitigate unwanted exposure to personnel. The knowledge of radiation source terms, through both experiments and modelling, is now well understood and for the most part can be dealt with through the use of shielding and specialized beam dumps. Shielding to ensure the safety of personnel has always been a critical requirement, and is a fundamental step within the design phase.

Unlike most other particle accelerators, most high-power laser facilities are still accessed by personnel post-shot with few or no capabilities for remote handling. As a result, the secondary activation and control of components that lie around the interaction is of great importance to safety. In this paper, we present a 10-year history of activation data on the Vulcan petawatt facility, and discuss the primary sources of activation and the potential impact on future laser facilities.



Measured decay products from an activated plasma mirror from Target Area Petawatt. Data is taken using a Scionix 2" NaI detector coupled to a Canberra Osprey MCA running in Multi-spectral scaling (MSS) mode.
a) MSS buffer data showing full spectrum against elapsed time (from measurement start)
b) Snapshot of the spectrum showing the 511 keV peak from the β+ decay
c) Plotted net peak area (NPA) of the 511 keV decay with associated fit for the ^{11}C decay and a presently unidentified component with an approximate half life of 2.3 hours

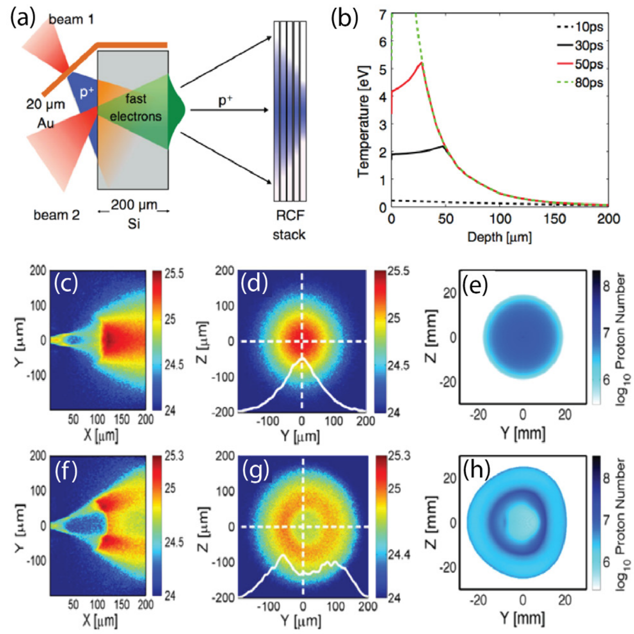
Contact: R. J. Clarke (rob.clarke@stfc.ac.uk)

Tunable mega-ampere electron current propagation in solids by dynamic control of lattice melt

D. A. MacLellan, D. C. Carroll, R. J. Gray, P. McKenna *(SUPA/Dept of Physics, University of Strathclyde, Glasgow, UK)*
G. G. Scott *(SUPA/Dept of Physics, University of Strathclyde, Glasgow, UK; STFC Rutherford Appleton Laboratory, Didcot, UK)*
N. Booth, D. Neely, H. W. Powell, A. P. L. Robinson *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
M. Burza, C-G. Wahlström *(Dept of Physics, Lund University, Sweden)*
M. P. Desjarlais *(Sandia National Laboratories, New Mexico, USA)*
F. Du *(Institute of Physics, Chinese Academy of Sciences, Beijing, China)*
X. H. Yuan *(Dept of Physics & Astronomy, Shanghai Jiao Tong University, China)*

This report describes a numerical and experimental investigation into the effect of resistivity gradients, produced by lattice melting in solid targets, on the generation of resistive magnetic fields and the transport of fast electrons. A proton beam produced in separate laser-solid interaction is used to heat the target isochorically, melting the target lattice in a tunable manner, whilst a separate pulse drives fast electrons through the sample. These tailored heating profiles result in the generation of resistively generated magnetic fields, enabling the fast electron current propagation to be manipulated.

In this way, critical properties of the fast electron beam, such as its divergence, spatial profile and symmetry, may be actively tailored without the need for complex target geometries.



(a) Experimental layout
(b) Temperature profile within the Si target resulting from the proton-driven heating, at given times (t_{heat}) after the arrival of the most energetic protons. Side and front view of electron density (m^{-3}) in initially unheated (c-d) and proton heated (f-g) silicon. (e) and (h) are the corresponding modelled proton-spatial intensity maps arising from the rear-surface density profiles in (d) and (g), respectively.

Contact: P. McKenna (paul.mckenna@strath.ac.uk)

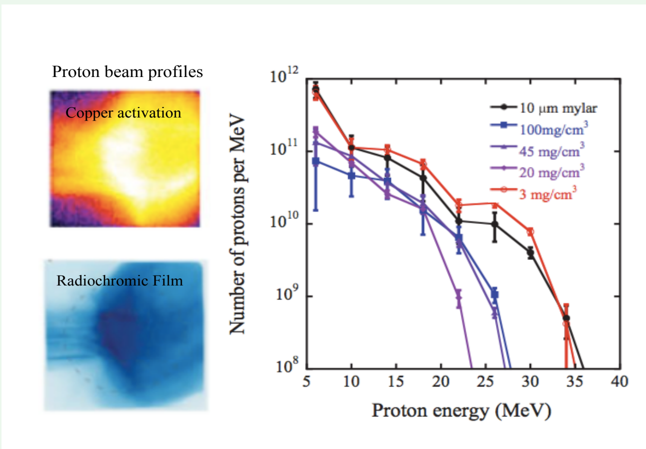
Characterization of laser-driven proton beams from near-critical density targets using copper activation

L. Willingale, A. G. R. Thomas, K. Krushelnick *(University of Michigan, Ann Arbor, USA)*
S. R. Nagel, C. Bellei, *(Lawrence Livermore National Laboratory, Livermore, California, USA)*
R. J. Clarke, R. Heathcote, *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
A. E. Dangor, C. Kamperidis, S. Kneip, S. P. D. Mangles, Z. Najmudin *(Blackett laboratory, Imperial College London, UK)*
M. C. Kaluza *(Institut für Optik und Quantenelektronik, Helmholtz Institut Jena, Germany)*
N. Lopes *(Blackett Laboratory, Imperial College London, UK; GoLP, Instituto Superior Tecnico, Portugal)*
W. Nazarov *(University of St Andrews, Fife, UK)*
P. M. Nilson *(University of Rochester, USA)*

High-energy proton beam acceleration from near-critical density plasma targets was characterized using a copper activation diagnostic. Both the proton spectra and beam profile were measured using this technique. Very-low density foam targets were used to produce plasma densities of between $0.9n_c$ and $30n_c$, where n_c is the critical plasma density.

An increased laser-accelerated hot electron density at the rear target-vacuum boundary was implied for the lowest density targets from the observed enhanced proton acceleration. Channel formation and collimation of the hot electrons inside the target lead to this increase. Particle-in-cell simulations demonstrate the correlation between the channel depth and longitudinal electric field strength in support of the experimental observations.

Contact: L. Willingale (wlouise@umich.edu)



(Left) Proton beam profiles recorded using: (top) the copper activation stack and imaged post-shot using image plate detectors; and (bottom) directly on the radiochromic film stack layers for a 20 mg/cc foam target.
(Right) The proton spectra extracted from the copper activation stacks for different density targets.

Evidence of locally enhanced target heating due to instabilities of counter-streaming fast electron beams

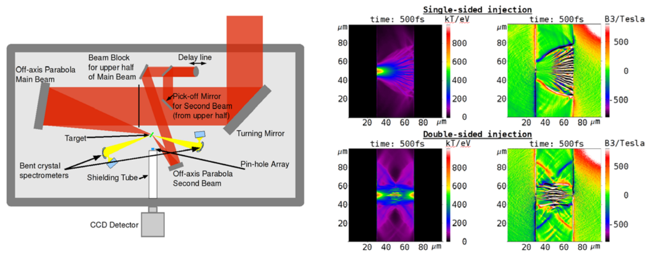
P. Koester, C.A. Cecchetti, L. Labate, T. Levato, L.A. Gizzi *(Intense Laser Irradiation Laboratory at INO, Italy)*
N. Booth, M. Notley, R. Pattathil *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
H. Chen *(Lawrence Livermore National Laboratory, California, USA)*
R.G. Evans *(Blackett Laboratory, Imperial College London, UK)*
G. Gregori, B. Li, J. Mithen, C.D. Murphy *(University of Oxford, UK)*
M. Makita. D. Riley *(Queen's University Belfast, UK)*
N. Woolsey *(Dept of Physics, University of York, UK)*

Understanding the dynamics of counter-streaming fast electron beams is important for a variety of research fields, including laser-driven x-ray and particle sources, the fast ignition approach to inertial confinement fusion, and astrophysical phenomena.

An experimental study aimed at investigating the role of instabilities in a system of counter-streaming fast electron beams was performed. The fast electron beams were generated through double-sided irradiation of a layered target foil. X-ray spectroscopy of the emission from the central Ti layer showed a higher temperature for double-sided irradiation with respect to single-sided irradiation. Simulations suggest that the locally enhanced target temperature in the case of counter-streaming fast electron beams might be attributed to the current-filamentation instability.

The counter-propagating scheme is a promising candidate for the efficient generation of hot dense matter, which is of great interest for the study of radiative and transport processes in inertial confinement fusion and astrophysical research.

Contact: P. Koester (petra.koester@ino.it)



Left: Schematic of the experimental setup.
Right: Temperature (left) and magnetic field (right) maps at 500 fs, as obtained from LSP simulations for a single electron beam (top) and for two counter-propagating electron beams (bottom) in a 40 μm thick target. The total energy injected into the target is the same in both cases.

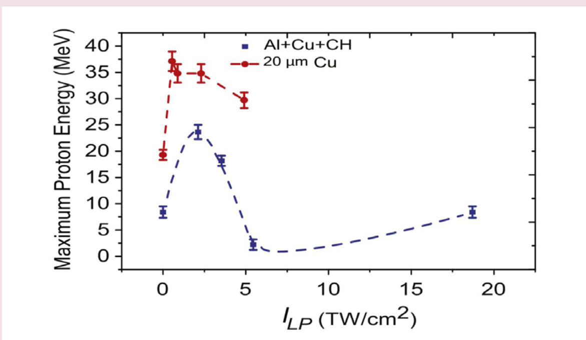
Laser pulse propagation and enhanced energy coupling to fast electrons in dense plasma gradients

R. J. Gray, M. Coury, M. N. Quinn, O. Tresca, P. McKenna *(University of Strathclyde, Glasgow, UK)*
D. C. Carroll, C. M. Brenner, D. Neely *(University of Strathclyde, Glasgow, UK; & CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
X. H. Yuan *(University of Strathclyde, Glasgow, UK; State Key Laboratory of Transient Optics and Photonics, Xian Institute of Optics and Precision Mechanics, Chinese Academy of Sciences, People's Republic of China)*
M. Burza, C-G. Wahlström *(Dept of Physics, Lund University, Sweden)*
K. L. Lancaster *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
X. X. Lin, Y.T. Li *(Beijing National Laboratory of Condensed Matter Physics, Institute of Physics, People's Republic of China)*

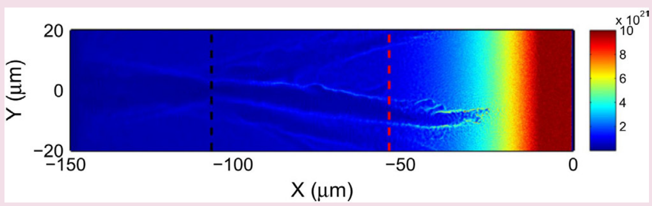
We demonstrate, experimentally and via particle-in-cell simulations, that there is an optimum density gradient for efficient energy coupling to electrons in the interaction of an intense (10^{20} W/cm^{-2}), picosecond laser pulse with a dense plasma. This optimum occurs due to strong self-focusing and channelling, which drives absorption over an extended volume in the plasma. At longer density gradients the laser quickly filaments, resulting in a decrease in overall laser energy coupling.

The results show that, by dynamically controlling the plasma density gradient, it is possible to significantly enhance the laser energy absorption and coupling to fast electrons.

Contact: R. J. Gray (ross.gray@strath.ac.uk)



Maximum proton energy as a function of laser intensity, I_{LP}, for a 123μm Al-Cu-CH and 20μm Cu target.



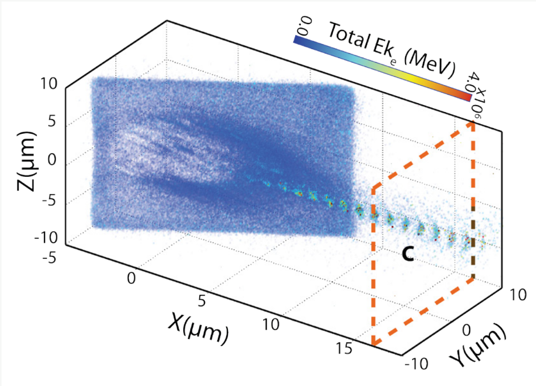
2D PIC simulation results showing electron density, n_e, in units of cm^{-3} after 1500 fs.

Proton acceleration enhanced by a plasma jet in expanding foils undergoing relativistic transparency

H.W. Powell, M. King, R.J. Gray, D.A. MacLellan, B. Gonzalez-Izquierdo, H. Padda, P. McKenna *(University of Strathclyde, Glasgow, UK)*
L.C. Stockhausen, R. Torres *(Centro de Láseres Pulsados, Salamanca, Spain)*
G. Hicks, N.P. Dover, Z. Najmudin *(Imperial College London, UK)*
D.R. Rusby, D.C. Carroll, R.J. Clarke, I.O. Musgrave, D. Neely *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
S. Kar, M. Borghesi *(Queen's University Belfast)*

The Target Area Petawatt laser was used to investigate experimentally ion acceleration on thin foils(≤40 nm in thickness), with 2D and 3D particle-in-cell simulations used to aid understanding of the internal particle and field dynamics. The protons, accelerated by target normal sheath acceleration (TNSA) and radiation pressure acceleration (RPA) mechanisms, were angularly separated and identified through their signature features observed via a spatial-intensity distribution measurement.

A high-energy proton population with low divergence is detected when the target becomes relativistically transparent due to heating and expansion. The simulations indicate that, in these conditions, a plasma jet is formed at the rear of the target, expanding into the sheath-accelerated proton layer.
This jet is supported by a self-generated azimuthal magnetic field, and the electrons contained within are accelerated to super-thermal energies directly by the propagating laser pulse. The propagation of these electrons through the ion layers enhances the energy of the nearby protons. By adding a controlled pre-pulse, it is possible to demonstrate the sensitivity of this jet formation and energy enhancement to the rising edge profile of the laser pulse.



3D PIC results showing the total electron energy contained within the formed plasma jet.

Contact: M. King (m.king@strath.ac.uk)

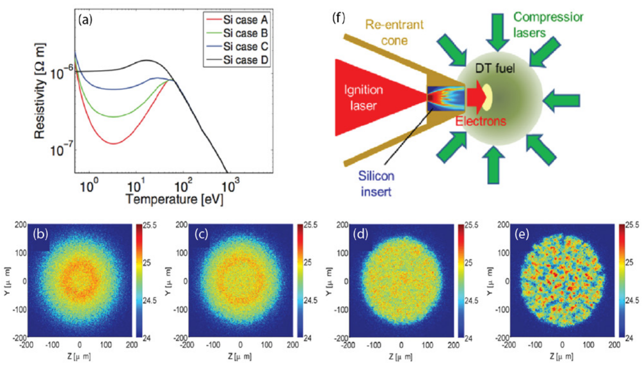
Influence of low-temperature resistivity on fast electron transport in solids: scaling to fast ignition electron beam parameters

P. McKenna, D. A. MacLellan, N. M. H. Butler, R J Dance, R. J. Gray
(University of Strathclyde, Glasgow, UK)
A. P. L. Robinson, D. Neely *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
M. P. Desjarlais
(Sandia National Laboratories, Albuquerque, USA)

Numerical investigation of the definitive role played by low temperature electrical resistivity is conducted by 3D hybrid particle-in-cell simulation, both in the sub-kJ and kJ regimes applicable to lab experiments and fast ignition relevant parameters respectively.

Calculations provide resistivity profiles for both ordered and disordered cases, and these are used (alongside intermediate cases between these) for simulation to assess the sensitivity of fast electron transport to both the magnitude of resistivity, and the shape of the resistivity-temperature profile. It is found that the magnitude and profile shape both strongly affect the resistively-generated magnetic fields and, thus, the fast electron transport pattern. The scaling of these results to the giga-ampere currents relevant to fast ignition schemes is also addressed.

Contact: P. McKenna (paul.mckenna@strath.ac.uk)



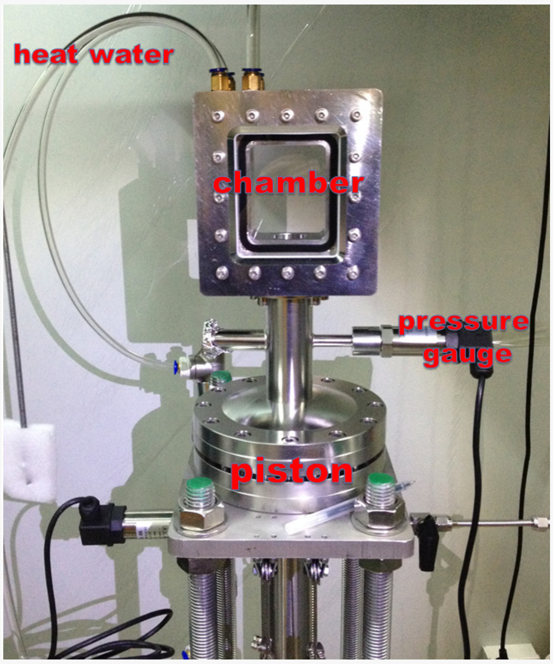
(a) Calculated resistivity-temperature curves for ordered (case A) and disordered (case D) and two intermediate cases (cases B, C). A transition from an annular to a filamented electron beam transport pattern is observed with decreasing degree of lattice order (b) case A, (c) case B, (d) case C, and (e) case D.
(f) Potential usage of cone FI target scheme with a silicon insert to induce an annular fast electron beam transport.

A Freon™-filled bubble chamber for the spectra measurement of ultrashort gamma ray bursts

W. B. Zhao, Y. B. Zou, H. Y. Lu, J. E. Chen, X. Q. Yan *(Peking University, Beijing, People's Republic of China)*
W. J. Ma, J. H. Bin, F. Lindner, J. Schreiber *(Dept of Physics, Ludwig Maximilian University of Munich, Germany)*
D. Corvan, J. Warwick, M. Coughlan *(Queen's University Belfast, UK)*
M. Zepf *(Queen's University Belfast, UK; Helmholtz Institute Jena, Jena, Germany)*
H. Wang *(Helmholtz Institute Jena, Jena, Germany)*
P.S. Foster, S. Spurdle, D. R. Symes *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Recently, many experiments have demonstrated that bright ultrashort gamma-ray bursts can be generated from the interaction of high-power lasers with plasma . These bursts, typically with sub-picosecond duration, are very promising light sources for ultrafast gamma-ray radiography. However, their short pulse duration also poses challenges on the measurement of the spectra. Conventional solid-state spectrally-resolved detectors are unsuitable, because the pulse durations of these bursts are orders of magnitude shorter than the response time of the detectors. Here we report a novel Freon™-filled bubble chamber detector for the spectra measurement of ultrashort gamma-ray bursts in the range of 0.4 - 4 MeV. This detector was used in a Gemini campaign in January 2015. It simultaneously recorded thousands of bubble traces created by scattered Compton electrons. By analyzing the length and angle of the traces, the gamma-ray spectra can be convoluted in the range of 0.4 - 4 MeV with high efficiency and resolution.

Contact: Y. B. Zou (zouyubin@pku.edu.cn)
W. J. Ma (wenjun.ma@physik.uni-muenchen.de)



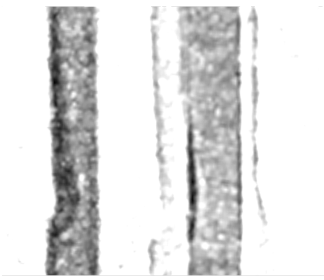
Photograph of the detector, with components labelled

Ultrafast imaging of laser-driven shocks using betatron x-rays from a laser wakefield accelerator

J.C. Wood, K. Poder, J.S.J. Bryant, J.M. Cole, Z. Najmudin, S.P.D. Mangles *(The John Adams Institute, Imperial College London, London SW7 2AZ, UK)*
N.C. Lopes *(Imperial College London, UK & GoLP/Centro de Fisica dos Plasmas, Portugal)*
D. Chapman, D. Eakins, M. Rutherford, T. White *(Institute of Shock Physics, Imperial College London, UK)*
E. Hill, S. Rose, M. Sherlock *(Blackett Laboratory, Imperial College London, UK)*
K.T. Behm, K. Krushelnick, A.G.R. Thomas, Z. Zhao *(University of Michigan, USA)*
W. Schumaker, S. Glenzer *(Stanford University, California, USA)*
F. Albert, B.B. Pollock *(Lawrence Livermore National Laboratory, California, USA)*
N. Booth, P. S. Foster, R. H. H. Scott *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Laser wakefield accelerators have been shown to produce electron beams of GeV energy, with energy spreads of a few percent in plasma lengths of approximately 1 cm. They also produce a beam of hard, bright x-rays, referred to as 'betatron radiation', with intensity high enough for single shot imaging and a few fs duration, making them a highly interesting source for applications. The micron scale source size permits high resolution imaging in a compact geometry.

We present measurements of the x-rays, indicating that their spectral flux is described by a synchrotron spectrum with critical energy 25±5 keV and that they come from a micron sized source. $7\pm3 \times 10^9$ photons are produced per shot with a narrow divergence, allowing single shot high magnification x-ray imaging. By imaging a shock travelling at ~6 km s^{-1}, we have demonstrated the potential of this femtosecond x-ray source for observing rapidly evolving phenomena at high resolution.



X-rays generated by a laser wakefield accelerator, known as betatron x-rays, were used to image laser-driven shocks in silicon travelling at speeds of approximately 6 km s^{-1}. The left and right images show the shock propagation in untamped and tamped 50 micron thick silicon.

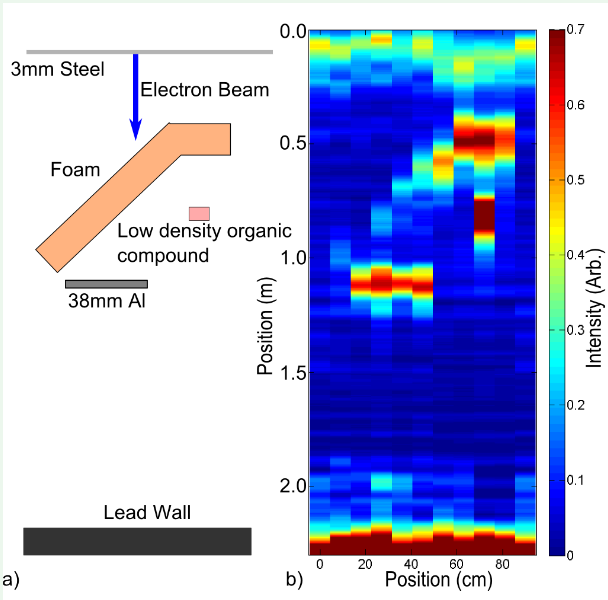
Contact: J. C. Wood (jonathan.wood08@imperial.ac.uk)

A laser-driven pulsed x-ray backscatter technique for enhanced penetrative imaging

L. A. Wilson, C. M. Brenner, R. J. Clarke, J. L. Collier, P. Foster, J. Greenhalgh, C. Hernandez-Gomez, R. Pattathil, D. Symes, D. Neely *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
R. M. Deas, P. P Black, S. E. Black, D Lockley,R. M. Moss, M. D Whittle *(DSTL, Kent, UK)*
D. R. Rusby, P. McKenna *(University of Strathclyde, Glasgow, UK)*
A. Alejo, M. Borghesi, S. Kar *(Queen's University Belfast, UK)*
J. Bryant, J. C. Wood, Z. Najmudin *(Imperial College London, UK)*
B. Edwards *(Innovations, STFC Rutherford Appleton Laboratory, Didcot, UK)*

X-ray backscatter imaging can be used for a wide range of imaging applications, in particular for industrial inspection and portal security. The application of this imaging technique to the detection of landmines is currently limited, due to the surrounding sand or soil strongly attenuating the 10 s to 100 s of keV x-rays required for backscatter imaging. Here, we introduce a new approach involving a 140 MeV short-pulse (<100 fs) electron beam generated by laser wakefield acceleration to probe the sample, which produces bremsstrahlung x-rays within the sample, enabling greater depths to be imaged.

An x-ray backscatter image of an array of different density and atomic number items is demonstrated. The use of a compact laser wakefield accelerator to generate the electron source, combined with the rapid development of more compact, efficient and higher repetition rate high-power laser systems, will make this system feasible for applications in the field.



An array of objects, including 38 mm thick Al, 0.14 m thick insulation foam, and a low-density organic compound are shown.
a) Diagram of the set-up of an array of test objects.
b) Example of an x-ray backscatter image of the object array shown in a).

Contact: L. A. Wilson (Lucy.wilson@stfc.ac.uk)

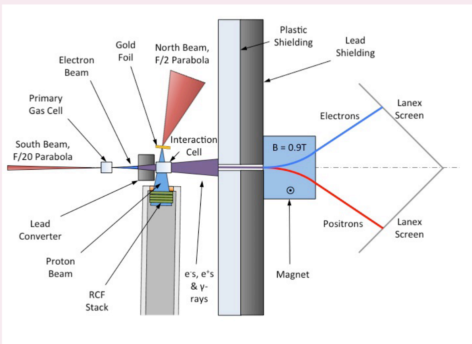
Interactions of relativistic electron-positron bunches with ambient plasmas in a regime relevant to the study of astrophysical jets

G. Sarri, J. R. Warwick, T. Dzelzainis, D. J. Corvan, M. Yeung, D. Doria, M. Zepf *(Queen's University Belfast, UK)*
W. Schumaker *(SLAC National Accelerator Laboratory, California, USA)*
L. Romagnani *(Laboratoire LULI Ecole Polytechnique, France)*
D. R. Symes *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*

Neutral electron-positron plasmas (EPPs) are theorised to play a major role in astrophysical phenomena, such as Active-Galactic Nuclei, Pulsars and Gamma-Ray Bursts (GRB).

It is thought that the magnetospheres associated with compact rotating astrophysical objects (black-holes, neutron stars) are teeming with EPPs, which are ejected in polar outflows and relativistic jets. These highly-collimated jets travel light years beyond their host galaxy's boundaries, and produce a termination shock via their interaction with the intergalactic medium (IGM). It is theorised that this EPP/IGM interaction is responsible for the generation of strong, long-lived magnetic fields conducive to the generation of GRBs.

In this experiment, a relativistic neutral EPP was generated and subsequently propagated through an electron-ion plasma, in a regime pertinent to the study of astrophysical jets. Preliminary analysis indicates beam filamentation, which produces multi-Tesla magnetic fields consistent with the generation mechanism thought to occur at the termination shock of astrophysical jets.



Schematic of the experimental layout. Outside of the experimental plane, and not shown in the figure, is a collection optic used to image the rear surface of the interaction cell to observe the beam profile.

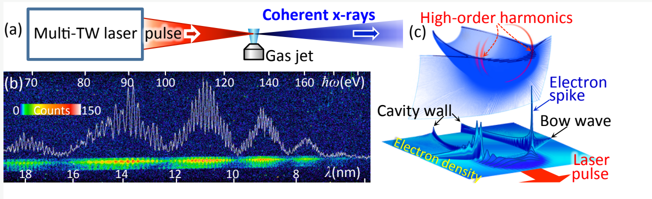
Contact: Dr G. Sarri (g.sarri@qub.ac.uk)

High order harmonics from relativistic electron spikes

A. S. Pirozhkov, M. Kando, T. Zh. Esirkepov, A. Ya. Faenov, Ta. A. Pikuz, T. Kawachi, A. Sagisaka, J. K. Koga, M. Mori, K. Kawase, T. Kameshima, Y. Fukuda, L.-M. Chen, I. Daito, K. Ogura, Y. Hayashi, H. Kotaki, H. Kiriyama, H. Okada, T. Imazono, K. Kondo, T. Kimura, T. Tajima, H. Daido, S. V. Bulanov *(Kansai Photon Science Institute, Japan Atomic Energy Agency)*
N. Nishimori *(Laser Application Technology Division, Japan Atomic Energy Agency)*
Y. Kato *(The Graduate School for the Creation of New Photonics Industries, Shizuoka, Japan)*
P. Gallegos, J. Green, P. Foster, C. Brenner, D. R. Symes, P. Rajeev, D. Neely
(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)
H. Ahmed, B. Dromey, M. Borghesi *(Queen's University Belfast, UK)*
E. N. Ragozin *(P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia)*
M. Coury, P. McKenna *(University of Strathclyde, Glasgow, UK)*

High-order harmonic generation is one of the most fundamental processes of nonlinear optics. The spatial and time coherence of high-order harmonics allows the tightest focusability and generation of ultrashort pulses required for applications. Various nonlinearities produce high-order harmonics in a wide range of laser-matter interaction regimes. We provide a detailed description of experiments performed with the J-KAREN and Gemini lasers, where we discovered a new regime of relativistic high-order harmonic generation by multi-terawatt femtosecond lasers in gas targets. The coherent x-rays, consisting of hundreds of even and odd harmonic orders, were generated with both linearly and circularly polarized pulses, and reached the 'water window' spectral range. The results were explained using particle-in-cell simulations and catastrophe theory. We give a comprehensive account of simulations and the harmonic generation mechanism, and model where a tightly-focused laser in plasma forms structurally stable electron spikes coherently emitting high-order harmonics.

Our work paves the way towards a bright coherent x-ray source based on compact lasers and accessible, repetitive, and debris-free gas jet targets. Such a source will be crucial for fundamental research and numerous applications requiring pumping, probing, imaging of microscopic objects, and for attosecond science.



New regime of high-order harmonic generation by relativistic-irradiance (>10^{18} W/cm^2) laser focused into a gas jet target. (a) Experimental set-up: Multi-terawatt (10-120 TW) femtosecond (30-50 fs) laser pulses focused into a helium gas jet target (~10^{19} cm^{-3}) produce bright coherent x-rays, consisting of hundreds of even and odd harmonics. (b) Typical single-shot raw data and its lineout. (c) 3D particle-in-cell simulation, demonstrating high-order harmonic generation by the sharp oscillating electron density spikes appearing at the joint of boundaries of wake and bow waves excited in tenuous plasma by the laser pulse.

Contact: A. S. Pirozhkov (pirozhkov.alexander@jaea.go.jp)

Ultrahigh brilliance multi-MeV gamma-ray beams from nonlinear relativistic Thomson scattering

G. Sarri, D. J. Corvan, H. Ahmed, C. Harvey, M. Zepf *(Queen's University Belfast, UK)*
W. Schumaker, K. Krushelnick, A. G. R. Thomas, Z. Zhao *(University of Michigan, Ann Arbor, USA)*
J. M. Cole, S. P. D. Mangles, Z. Najmudin *(Imperial College London, UK)*
A. Di Piazza, C. H. Keitel *(Max-Planck-Institut für Kernphysik, Heidelberg, Germany)*
D. Symes *(CLF, STFC Rutherford Appleton Laboratory, Didcot, UK)*
M. Yeung *(Helmholtz Institute Jena, Germany)*

The generation of high-quality, multi-MeV gamma-ray beams is an important field of study, pertinent to fundamental research, cancer radiotherapy, active interrogation of materials, and radiography of dense objects. Several mechanisms for generating such gamma-ray beams have been proposed, including bremsstrahlung emission, synchrotron emission, Compton scattering, and in-flight positron annihilation. Bremsstrahlung sources are the most commonly used technique (particularly in medicine), but the generated γ-rays have a broad divergence, which, in conjunction with the source size, place a limitation on the peak brightness.

Here, we report on the generation of a high-quality γ-ray beam through the scattering of an ultrarelativistic electron beam in the field of a relativistically intense laser ($a_0 \approx 2$). The generated γ -ray beam is of narrow divergence (< 2.5 mrad), multi-MeV (6 to 18 MeV), and has ultrahigh peak brilliance (> 1.8 x 10^{20} photons s^{-1} mm^{-2} 0.1% BW).

The reported brilliance is the highest ever achieved in the multi-MeV regime that, coupled with the ultra-short duration of the γ–ray beam (~10 fs), makes this a unique source for practical applications.

Contact: Dr G. Sarri (g.sarri@qub.ac.uk)

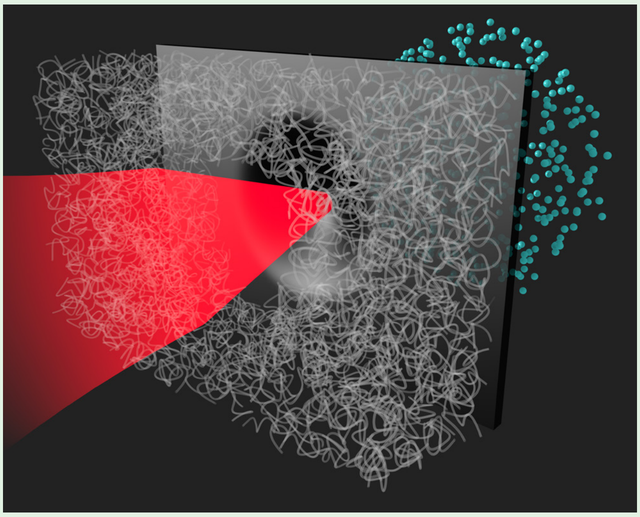
Plasma-optics pushes the limit of laser-driven ion acceleration

J. Schreiber, J. H. Bin, D. Kiefer, C. Kreuzer, W. J. Ma *(Ludwig Maximilian University of Munich, Germany)*
H. Y. Wang, X. Q. Yan *(Peking University, Beijing, People's Republic of China)*
M. J. V. Streeter *(Blackett Laboratory, Imperial College London, UK)*
M. Yeung, S. Cousens, P. S. Foster, B. Dromey *(Queen's University Belfast, UK)*
M. Zepf *(Queen's University Belfast, UK; Helmholtz Institute Jena, Germany)*
R. Ramis *(Universidad Politécnica de Madrid, Spain)*
J. Meyer-ter-Vehn *(Max-Planck-Institut für Quantenoptik, Garching, Germany)*

The enormous force from radiation pressure exerted onto a nanometer thin, diamond–like carbon (DLC) foil by a high intensity laser pulse can enhance efficient acceleration of carbon ions. Kinetic energies up to 30 MeV were reached in our initial experimental demonstration of this novel radiation pressure acceleration (RPA) scheme in 2009. Those studies revealed grand technological challenges posed by current laser technology in our pursuit of peak intensities well beyond 10^{21} W/cm² with ideally abrupt temporal profiles.

Current experimental results reveal that near-critical plasmas, due to the intensity-dependent relativistic mass-increase of the electrons, can form strong nonlinearities that tightly focus the laser to a near-diffraction limited spot size and temporally steepen the pulse front. This novel relativistic plasma-optic effect has been realised with more sophisticated targetry - depositing micrometer thin carbon-nanotube foam onto DLC target foils in LMU's DLC-factory. These multi-layer targets were tested in a collaborative laserlab-europe experiment at STFC Rutherford Appleton Laboratory's Gemini laser, which brought together researchers from Germany, the UK, Spain and China. RPA of carbon ions up to 240 MeV kinetic energy has been achieved.

This recent accomplishment is an important milestone for our research focus on laser-driven ion acceleration at the Munich Centre for Advanced Photonics (MAP Centre of Excellence Cluster), with promise for extending kinetic energies to the GeV level for envisioned applications at the Centre for Advanced Laser Applications (CALA) in Munich.



(Artist's impression, courtesy of Isabella Cortrie, LMU)

The laser pulse from one of the Gemini-arms is focused onto Carbon-Nanotube (CNT) foam – DLC composite targets. Within the CNT-foam plasma with near-critical electron densities, the laser undergoes relativistic self-focusing and pulse-front steepening on micrometer length scales before it impinges onto 10 nm thin DLC-foil. Due to the substantially decreased focal spot paired with the steep rise, radiation pressure acceleration becomes more effective.

Contact: J. Schreiber (joerg.schreiber@mpq.mpg.de)