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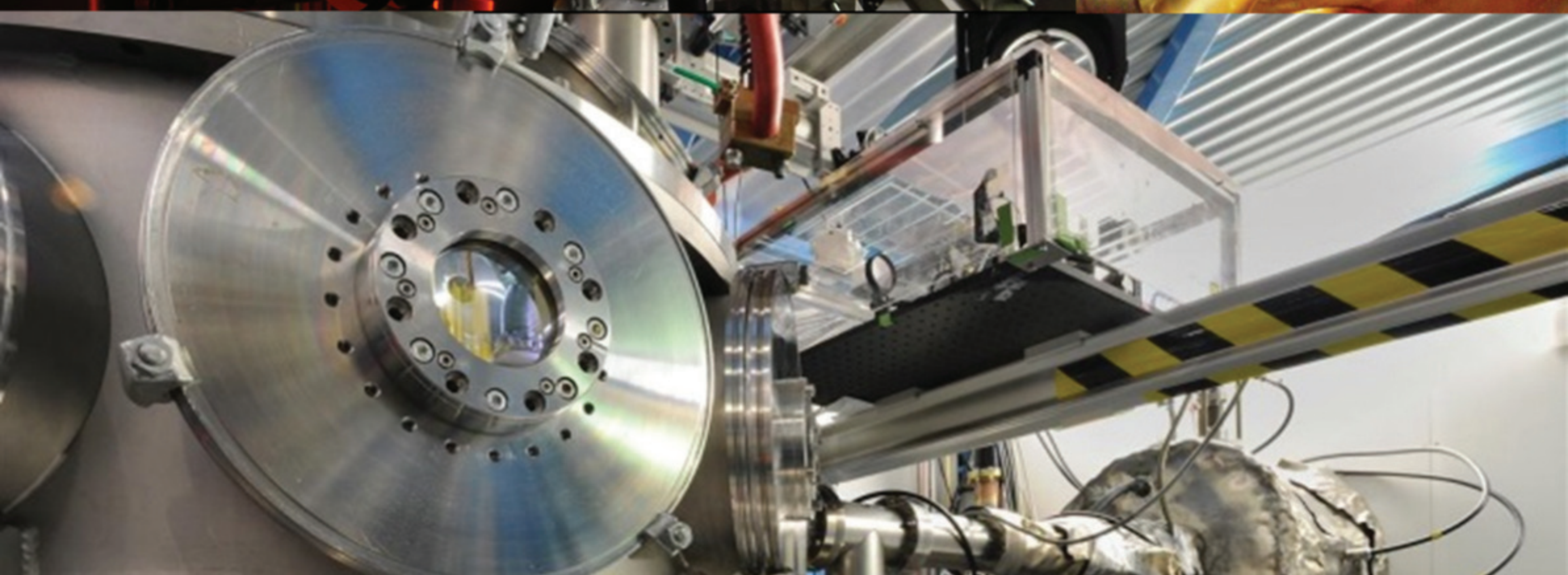


The International Committee on Ultra-High Intensity Lasers

Chairman's Remarks

Chris Barty, ICUIL Chair

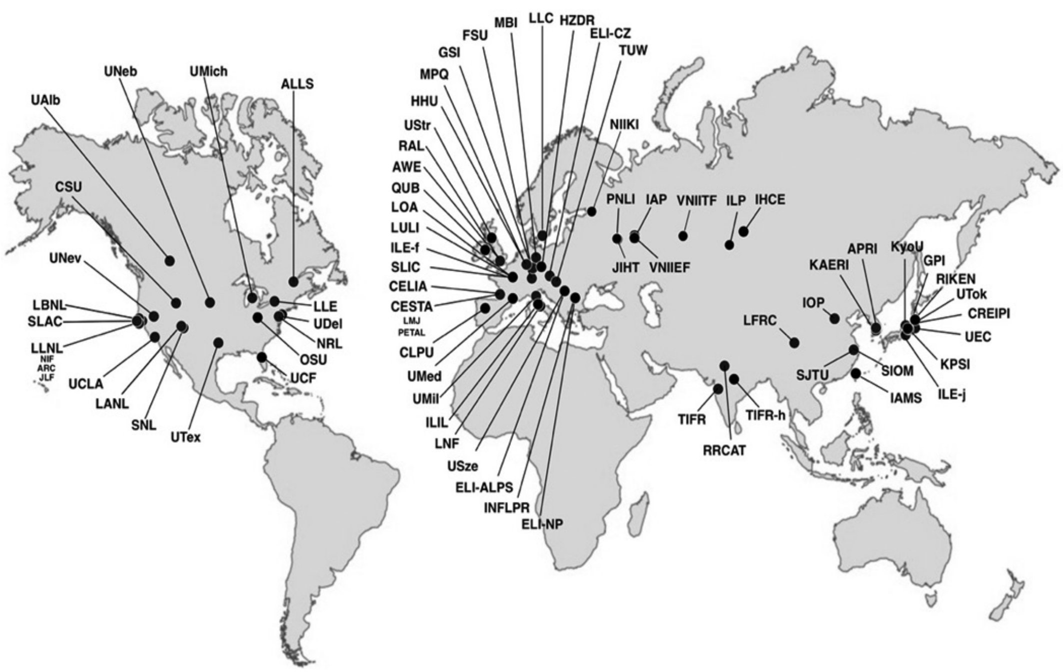
As the chairman of the International Committee on Ultrahigh Intensity Lasers (ICUIL), it is my honor to welcome you to the 9th ICUIL newsletter.

As is evident throughout the contents of this document, worldwide activities related to the development and use of ultrahigh intensity lasers are growing. Over the past year, a major new $B-scale initiative has been approved in China, the ongoing Extreme Light Infrastructure projects in Europe have met key milestones, record new capabilities have been demonstrated at facilities in South Korea and China, and the US National Academies has released its related report "Opportunities in Intense Ultrafast Lasers – Reaching for the Brightest Light." The applications of ultrahigh intensity lasers are now being discussed at a growing number of topical meetings worldwide and new applications-specific projects such as the Nuclear Photonics initiative out of Darmstadt, Germany have successfully established government funding support.

In the fall of 2018, ICUIL's 8th International Conference on Ultrahigh Intensity Lasers will take place in Lindau, Germany. Preliminary indications are that the 2018 meeting will be the largest attended to date. As an organization, ICUIL also continues to evolve, grow and change. We have a new representative from the Southern Hemisphere, Prof. Heinrich Hora of the University of New South Wales and a new board member, Prof. Dino Jaroszynski of the University of Strathclyde who in the fall of 2017 assumed the role of ICUIL treasurer. We on the ICUIL committee owe special thanks to our previous treasurer, Prof. Tsuneyuki Ozaki of INRS-EMT for his many years of service, his excellent stewardship of ICUIL's finances and his thoughtful and enthusiastic participation on the ICUIL board.

In other news three of ICUIL's senior members recently received notable recognition. Alexander Sergeev, present co-chair of ICUIL, was selected to be the president of the Russian Academy of Sciences. Gerard Mourou, ICUIL's first chairman, was selected as the 2018 recipient of the American Physical Society's Arthur L. Schawlow prize in laser science, and Toshiki Tajima, ICUIL's chairman from 2008 to 2016, was selected as the 2018 recipient of the Association of Asia-Pacific Physical Societies (AAPPS) Division of Plasma Physics (AAPPS-DPP) Subramanyan Chandrasekhar Prize of Plasma Physics.

It is our hope that you will find this newsletter to be a convenient snapshot of worldwide activities and that you will use this document as a motivation to visit the ICUIL website at www.icuil.org and to participate in upcoming ICUIL related activities.



ICUIL.org World Map of Ultrahigh Intensity Lasers

Farewell from the ICUIL Treasurer 2008 to 2016

Tsuneyuki Ozaki

I would like to start off by thanking all members of ICUIL for giving me the opportunity to take part in serving this vibrant community. My involvement as Treasurer of ICUIL started in October 2008 at the biennial ICUIL Conference held in Tongli, China. Since 2003, I have been a professor at the Institut national de la recherchescientifique (INRS) near Montreal, Canada, and from 2006 to 2012, the Director of the Advanced Laser Light Source (ALLS). Since 2008, with the excellent support from the members and Board of ICUIL, I was gradually trained into the Treasurer position, organizing committee finances and discussing ICUIL business. The periodic teleconferences of the Board were highly stimulating, and it has been an absolute pleasure working with my colleagues. In 2016, I was also lucky enough to organize the ICUIL 2016 conference at Montebello, Canada. While this required a great deal of energy (my students found me passed out in a couch after the conference), organizing this conference reinforced my belief that ICUIL is an excellent example of a tight-knit community that has succeeded in truly promoting the exciting science and technology of ultra-high intensity lasers. Capitalizing on my experience with ICUIL, I have recently taken on the responsibility as Chair of Commission 17 of IUPAP on "Laser Physics and Photonics". I hope that Iwould be given the chance to continue working together with ICUIL in the coming years to promote our common interests.

On behalf of the high intensity laser community, the ICUIL Board members would like to express our gratitude to Tsuneyuki for his accomplishments as ICUIL Treasurer and his collegial support for nearly a decade. Tsuneyuki supported four successful biennial conferences, including the most recent conference in Montebello, Canada which set a record for the largest number of attendees. His efforts made this a truly productive and memorable conference for all. We wish Tsuneyuki great success in his new role as Chair of Commission 17 within IUPAP as he works to promote the exchange of information among the members of the international scientific community in the general field of Quantum Electronics including the physics of coherent electromagnetic energy generation and transmission, the physics of interaction of coherent electromagnetic radiation with matter, and the application of quantum electronics to technology. He will maintain liaison with other IUPAP commissions and working groups, such as the ICUIL, with a view to collaborating and cooperating in joint endeavors.

Alexander Sergeev – New President of the Russian Academy of Sciences

On September 26, 2017 Academician Professor Alexander Sergeev, Director of the Institute of Applied Physics in Nizhny Novgorod and ICUIL Co-chair was elected as President of the Russian Academy of Sciences.

The ICUIL community cordially congratulates Alexander Sergeev on this outstanding step in his career, and wishes him success on this thorny path. We are sure that the science in Russia and worldwide will greatly benefit from this election.

His vision of the first-priority measures for the further development of the Russian science and the RAS the newly elected President outlined in the pre-program with a focus on 20 most important tasks to be solved. They include among others

- formulation of the scientific and technical doctrine based on the real state of the scientific complex and determining the need for conducting fundamental research on various horizons of the country's development;
- re-integration of the RAS into the national economy of the country through its participation in large high technology projects and programs, including in the framework of the Strategy of Scientific and Technological development of Russia;
- restoration and strengthening of RAS with the leading scientific and technical corporations of the country;
- supporting the activities aimed at strengthening the position of Russian science in the world through the policy of "scientific diplomacy";
- more efficient use of the potential of foreign members of the RAS; and active participation in the international projects.

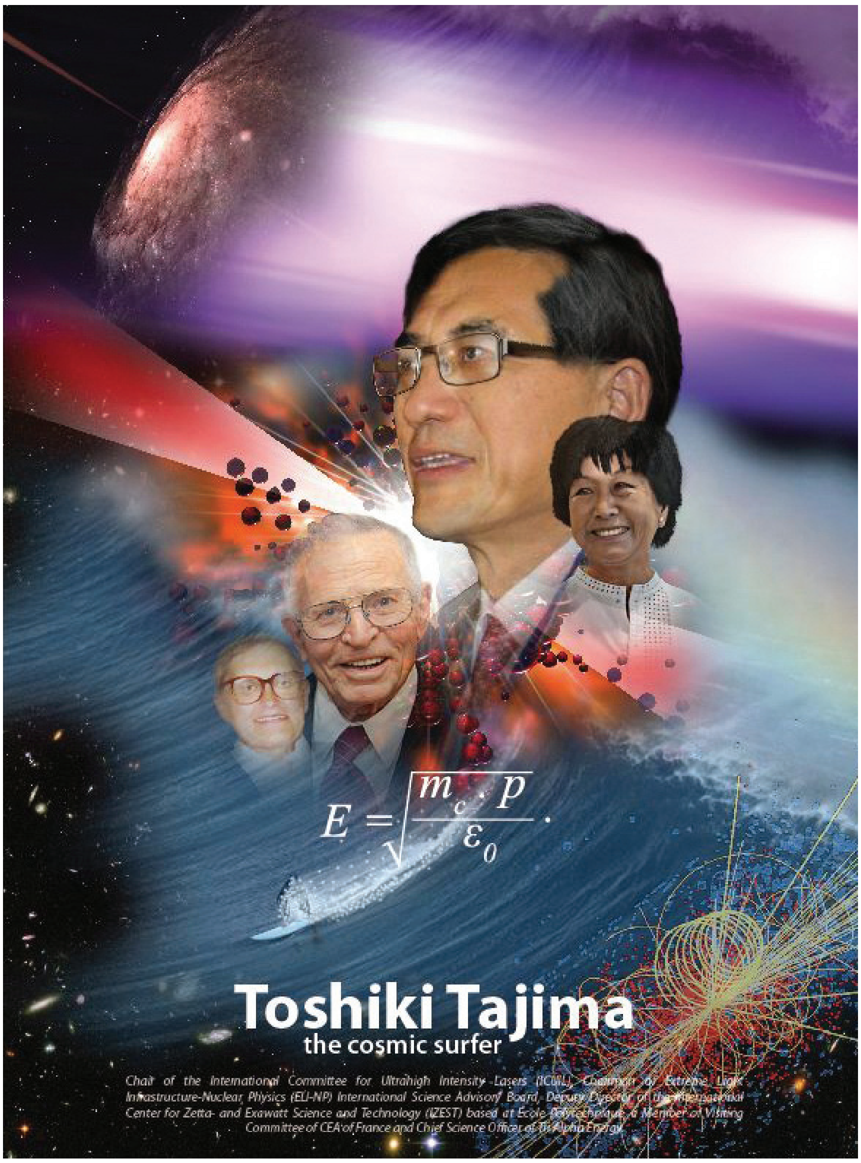
In Honor of Professor Toshiki Tajima – Inventor of Laser Wake Field Acceleration

Gérard Mourou, Professor, EcolePolytechnique Haut Collège
Zhihong Lin, Professor of Physics and Astronomy , University of California, Irvine
Dr. Michl Binderbauer, TAE Vice President, Chief Technology Officer

January 25th-26th, 2018 the Laser High Field community celebrated the 70th birthday of one of its founders, mentor and inventor, Professor Toshiki Tajima at the University of California, Irvine (UCI). This renaissance man with boundless imagination has been the driving force in building connections among the domains of ultrafast optics, plasma physics, nuclear physics and astrophysics but also nuclear medicine and pharmacology. Toshiki Tajima bridged the atomic and subatomic domains, revolutionized Laser Science and established the foundation of High Field Science and Technology. He is also the co-founder and deputy Director of IZEST*at the Ecolepolytechnique (France).

His most acclaimed contribution has been the invention with John Dawson in 1979 of Laser Wakefield Acceleration (LWA). The same concept extended to electron and proton beams by P. Chen, J. Dawson, R.WW Huff, and T. Katsouleas was demonstrated a few years later at SLAC and CERN.

Toshi Tajima's socio-economic impact has been towering involving more than 100 laboratories, 2000 researchers. Toshi Tajima was particularly active in the creation of large scale facilities in Japan Kansai with KEPSI, the Extreme Light Infrastructure ELI-NP in Romania, Czech Republic, ELI-Beam Lines and Hungary, ELI-ALPS. This activity represents >$3B investment.



Among the most prestigious awards he received the 2015 Fermi Prize, 2013 Einstein Professorship of CAS, the Blaise Pascal Chair by the Ile-de-France and the Nishina Memorial Prize from Japan. He was elected to the Russian Academy of Sciences in 2016. Today, using Toshiki Tajima scientific legacy the entire high field domain carries the hope to revolutionize high-energy physics beyond today's existing frontiers.

A cluster of more than 100 distinguished scientists and personalities from around the world including Barry Barish, 2017 Nobel prize, Robert Hunter, former Reagan's Energy Director, Jacques Biot, Président of the Ecolepolytechnique (France), Thierry Massard representative of the French DOE, attended the event at UCI. It was a distinguished honor to hear Barry Barish giving his 2017 Nobel Prize lecture on the detection of Gravitational Waves and his applications. Alongside, an impressive roster of more than 30 distinguished scientists, former Toshiki colleagues or students described their interaction with the honoree at the International Zeptosecond Exawatt Science and Technology Center.

Dense Relativistic Nanowire Array Plasmas for Micro-Scale Fusion

Alexander Pukhov[1], Alden Curtis[2], Chase Calvi[3], James Tinsley[4], Reed Hollinger[2], Vural Kaymak[1], Shoujun Wang[2], Alex Rockwood[3], Yong Wang[2], Vyacheslav N. Shlyaptsev[2], and Jorge J. Rocca[2,3]

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Laser-driven nuclear fusion may deliver bright sources of monoenergetic fusion neutrons with a number of applications in neutron imaging and tomography, neutron scattering and diffraction for the study of material structure and dynamics, as well as neutron and neutrino detector development. Nuclear fusion is regularly created in spherical plasma compressions driven by multi-kiloJoule pulses from the world's largest lasers. The recent experiments at the National Ignition Facility used 1.9 MegaJoule laser pulses to produce a record 7.6×10^{15} neutrons (4×10^9 neutrons/Joule) from deuterium-tritium fuel implosions. In addition, D-D fusion neutrons bursts have been produced using energetic sub-ns pulses of a few hundred Joules from chirped pulse amplification lasers, and using petawatt class lasers. However, all these experiments are limited to repetition rates of a few shots per hour or less.

Compact femtosecond lasers also are able to demonstrate fusion reactions. The targets used include deuterated bulks or thin films, cryogenic D_2, and deuterated clusters. Specifically, the irradiation of deuterated clusters formed in gas jets with low energy femtosecond laser pulses allows for efficient volumetric heating of plasmas with an average ion density of about 1×10^{19} cm^{-3} in which cluster explosions accelerate ions to multi-keV average energy. Neutron generation efficiencies of $\sim 1\times10^5$ fusion neutrons per Joule were obtained in the form of short sub-ns bursts, a value similar to those obtained with multi-kiloJoule laser. The ultrafast irradiation of ordered nanowire arrays share with nanoclusters the advantage of efficient volumetric heating, but have the additional advantage of creating media with several orders of magnitude higher average plasma density.

Recently, it has been shown that irradiation of aligned arrays of metallic nanowires with femtosecond laser pulses of relativistic intensity can volumetrically heat dense plasmas to multi-keV temperatures [Purvis et al., Nat. Photonics **7**, 796–800 (2013)], reaching pressures only achieved in the laboratory in spherical compression with the world largest lasers [Bargsten et al., Science Advances **3**, e1601558 (2017)]. Arrays of aligned high aspect ratio nanowires have vacant spaces surrounding the wires that allow for the deep penetration of ultrafast optical laser energy into near solid density material, where light is trapped and practically totally absorbed. Using aligned nanostructures of deuterated polyethylene (CD_2) and ultra-high contrast pulses of relativistic intensities from a compact laser, accelerates ions up to MeV energies in near-solid density media. This opens a new path to efficiently drive fusion reactions with Joule-level lasers [Curtis et al., Nature Communications **9**, 1077 (2018)].

The experiment has been done at Colorado State University. Deuterated nanowire array targets [Fig. 1a] either 200 nm or 400 nm in diameter and ~5 µm in length were irradiated with ultra-high contrast frequency-doubled, $\lambda = 400$ nm, Ti:Sa laser. The laser pulses of up to 1.64 J had 60 fs FWHM duration. The average density of the arrays corresponded to 16 and 19 percent solid density, respectively.

When the laser penetrates the nanowire target, electrons are ripped off the nanowire surface by the large laser field and are accelerated to high energy in the voids. These energetic electrons interact with the nanowires rapidly heating the material to extreme temperatures, causing the nanowires to explode [Fig. 1b,d]. Ions are

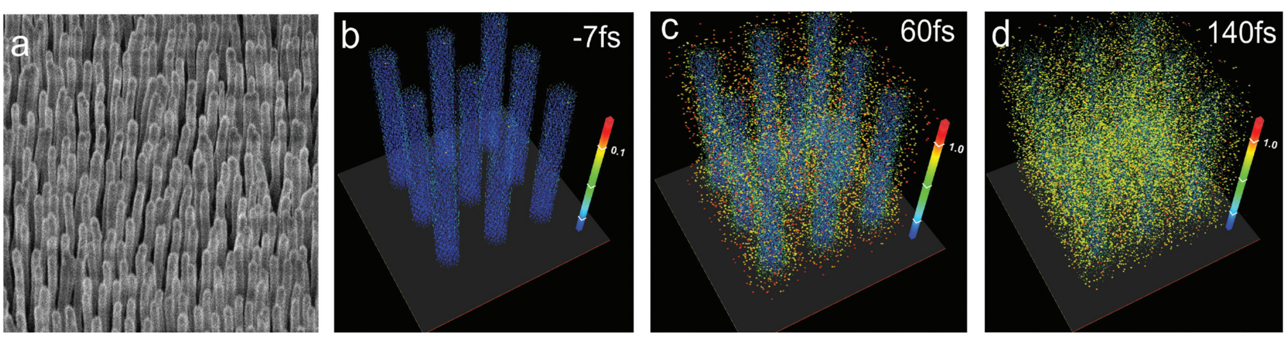

Fig. 1. (a). Scanning electron microscope image of an array of 200 nm diameter CD_2 nanowires. (b-d) 3-D PIC simulation of the evolution of the energy distribution of deuterons in an array of 400 nm diameter CD_2 nanowires irradiated at an intensity of 8×10^{19} W/cm^{-2} by an ultra-high contrast $\lambda = 400$ nm laser pulses of 60 fs FWHM duration. The laser pulses penetrate deep into the array where they rapidly heat the nanowires to extreme temperatures, causing the nanowires to explode [Fig. 1c,d]. Deuterons are rapidly accelerated into the voids up to MeV energies, producing D-D fusion reactions and characteristic 2.45 MeV neutrons. Times are measured with respect to the peak of the laser pulse. The average density of the nanowire array corresponds to 16% solid density.

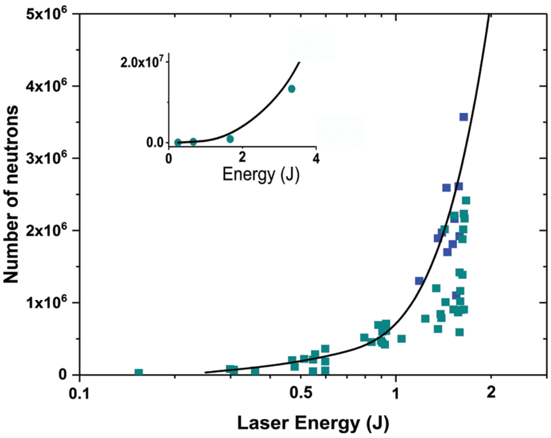

Fig. 2. Neutron yield as a function of laser pulse energy on target. The circles are shots corresponding to a target with 200 nm diameter wires. All the other shots (squares) are for targets consisting of 400 nm diameter wire arrays. The line shows the simulated energy dependence of the neutron yield calculated using deuteron energy distributions computed by the PIC model and nuclear kinetics. The inset extends the simulation to 3.5 J, where the green circles are computed values of the neutron yield. In the simulation the laser spot diameter was an adjustable parameter assumed to be 5 µm.

first rapidly accelerated across the nanowires, and the voids are filled with plasma, creating a continuous critical electron density layer that forbids further coupling of laser energy into the material [Fig. 1d]. The gaps between 400 nm diameter wires in an array with an average density corresponding to 15 percent solid density close in <100 fs. After homogenization of the material, the plasma as a whole begins to expand in the normal direction towards the laser pulse with a characteristic time scale $\tau_s \sim 1.5$ ps, but also towards the substrate, where the energetic deuterons moving into the target cause additional fusion reactions.

The maximum number of neutrons per shot was measured to be 3.6×10^6, corresponding to 2.2×10^6 neutrons/Joule, the largest fusion neutron yield obtained to date for Joule-level laser pulse energies. Furthermore, the number of neutrons was measured to increase superlinearly with laser pulse energy (Fig. 2). The rapid increase is in good agreement with the simulations we conducted using the deuteron ion energy distributions resulting from the PIC simulations and nuclear kinetics. As the laser pulse energy is further increased beyond the values explored here, the optimum D-D neutron production might require a tradeoff between a further increase in the intensity and an increase in the irradiated volume. The higher intensities are also expected to generate a directed flux of high energy deuterons that could be made to impinge in low Z convertors to drive "pitcher-catcher" neutron sources that have been demonstrated to create a large number of high energy neutrons. Finally, the simulations also show that the laser pulse drives a large forward electron current in the area around the wires. At higher irradiation intensities (e.g., 5×10^{21} W/cm^{-2}) this forward current is computed to induce return current densities of tens of Mega-amperes per µm^2 through the nanowires [Kaymak et al., PRL 117, 035004 (2016)]. The resulting strong quasi-static self-generated azimuthal magnetic field will pinch the deuterated nanowires into hot plasmas with a peak electron density exceeding 1000 times the critical density.

Acknowledgements: The work was supported by the Air Force Office of Scientific Research under award number FA9560-14-10232 and FA9550-17-1-0278, and by Mission Support and Test Services, LLC. We acknowledge the contributions of Zhenlin Su and Jose Moreno and Conrad Buss.

Detection of Radiation Reaction in Laser-electron Collisions

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June 28, 2018

The first successful detection of radiation reaction in laser-electron collisions not only broke the world record for photon energies from Compton scattering, but also hints at what to expect in the quantum regime. These experiments pave the way for forthcoming experiments in the QED-dominated regime of laser-matter interactions, raising the prospect of producing dense pair plasmas using lasers and probing extreme astrophysical environments in the laboratory.

Successfully describing and measuring radiation reaction, the momentum kick a charge experiences when emitting an energetic photon, is a long-standing issue in physics. The development of a classical theory has engaged such illustrious physicists as Abraham, Lorentz, Dirac, Landau and Lifshitz [1]. Part of the difficulty in realising experimental measurements of radiation reaction is that it only becomes significant for ultrarelativistic particles in strong electromagnetic fields. Now, with the prospect of focusing multipetawatt lasers to intensities in excess of 10^{23} Wcm^{-2}, there has been an increasing interest in reaching a regime in which radiation reaction is not only important, but dominant. In these interactions quantum effects will manifest themselves as corrections to radiation emission and as processes without classical analogues such as nonlinear pair creation [2]. This raises the possibility of creating plasma-based sources of dense electron-positron pairs and energetic γ rays, as well as studying extreme astrophysical environments in the laboratory, at high-intensity laser facilities including the Laboratoire pour l'Utilisation des Lasers Intenses (LULI) in France, the Centre for Relativistic Laser Science (CoReLS) in South Korea, the pillars of the Extreme Light Infrastructure (ELI)

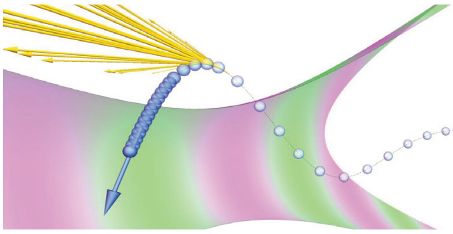

Fig. 1. An electron (blue) oscillates under the action of strong laser fields (green/purple), emitting energetic bursts of γ rays (yellow). The recoil of this emission causes the electron to slow down.

in Europe, the Shanghai Superintense Laser Facility (SULF) in China, and the Exawatt Centre for Extreme Light Studies (XCELS) in Russia.

There are two parameters that control the interaction physics in strong fields: a_0 and χ. a_0 is the classical (relativistic) nonlinearity parameter, which compares the energy gain of an electron over a single laser wavelength to its rest mass; χ is the quantum nonlinearity parameter, which compares the electric/magnetic field in the rest frame of the electron to the Sauter-Schwinger field of quantum electrodynamics (QED). This critical field does work equal to the electron mass over a Compton wavelength, and marks the onset of nonperturbative quantum effects. χ controls the magnitude of the energy losses, as the radiated energy (per unit energy E, per laser cycle τ_L) is $(\tau_L /E)(dE/dt) \simeq 3\alpha a_0\chi$. It is also the ratio of the typical energy of the emitted photon to that of the electron: when $\chi \sim 1$, the emission must be treated quantum-mechanically. Reaching a regime when the total radiative loss is of order 10% in a 10-cycle laser pulse requires $a_0\chi > 0.5$. As $\chi \simeq 0.1(a_0/20)(\gamma/1000)$, this is readily achievable with existing high-intensity lasers, where the largest $a_0 \sim 20$, in collisions with wakefield-accelerated electron beams, which now reach GeV energies [7].

This 'all-optical' configuration is already used as a source of high-energy γ rays [8, 9]. However, the energy loss of the electron beam because of radiation emission has only recently been confirmed in an experiment using the Gemini laser at the Central Laser Facility (Rutherford Appleton Laboratory, UK). The collaboration, lead by scientists from Imperial College London, used one arm of the Gemini laser to accelerate electrons in a gas jet to several hundred MeV and focussed the other to high-intensity, as shown in Fig. 2. Despite fluctuations in the energy spectrum of the electron beam and the pointing of two beams, the high repetition rate of the laser system allowed the scientists to gather several shots where the beams collided successfully.

This was determined by measuring the γ ray yield from shot to shot in a scintillator stack, and looking for shots where the signal was significantly above background. Senior author of the study Dr. Stuart Mangles, said: "The real result then came when we compared this detection with the energy in the electron beam after the collision. We found that these successful collisions had a lower than expected electron energy, which is clear evidence of radiation reaction." Further analysis of the scintillator data allowed the 'critical energy' ε_{crit} of the γ rays to be reconstructed: this quantity is close to the median energy of the spectrum, i.e. 50% of the photons have an energy $\varepsilon > \varepsilon_{crit}$, and it also controls the shape of the spectrum through $dN/d\varepsilon \propto \varepsilon^{-2/3} \exp(-\varepsilon/\varepsilon_{crit})$. When these results were compared to the energy of the electrons, which was determined by a shift in the energy spectrum, it was found that the lower the electron energy, the harder the photon spectrum (see Fig. 3). This too is evidence of radiation reaction; in its absence, the correlation would be reversed. The critical energies, which were in excess of 30 MeV, mean that the experiment produced the highest-energy photons yet obtained in an all-optical Compton configuration.

Simulations of the collision confirmed that the critical energies and electron energy loss were consistent with theoretical expectations of radiation reaction. The critical energies predicted in the absence of radiation reaction (the green region in Fig. 3) were not consistent with the measured electron energies. However, the limited number of shots, together with experimental uncertainties, meant that the experiment could not distinguish between different models of radiation reaction at high significance. The models compared were a fully classical model based on Landau and Lifshitz (orange) and a stochastic QED model of radiation reaction (blue). An important difference between these two is that in classical electromagnetism there is no upper bound on the frequency of radiation that can be emitted. This causes the total energy loss to be overestimated, as well as the number of photons with energy comparable to that of the electron. This explains why the classical model predicts a higher critical energy than the quan-

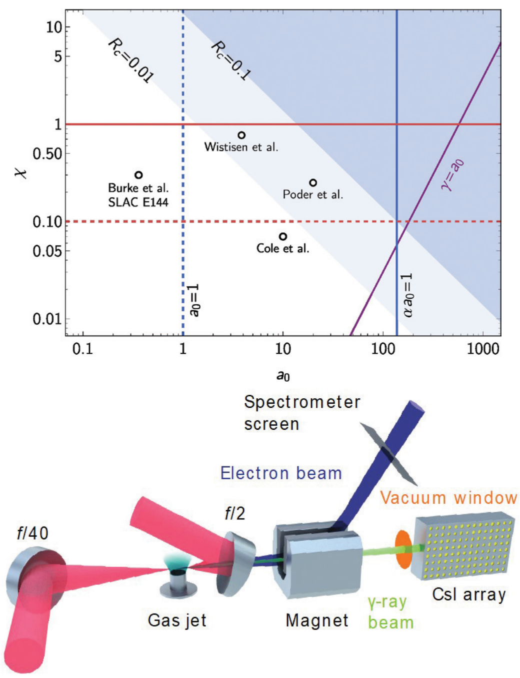

Fig. 2. Experimental progress towards radiation reaction and the quantum regime, from SLAC experiment E144 [3, 4], to the latest studies using the Gemini laser at the Central Laser Facility in the UK [5, 6]. To the left, the phase space shows how the current experimental efforts line up in terms of parameter values, and that there are large unexplored regions that will be reachable using next generation systems. To the right we see the all-optical setup for the experiment reported by Cole et al. [5]

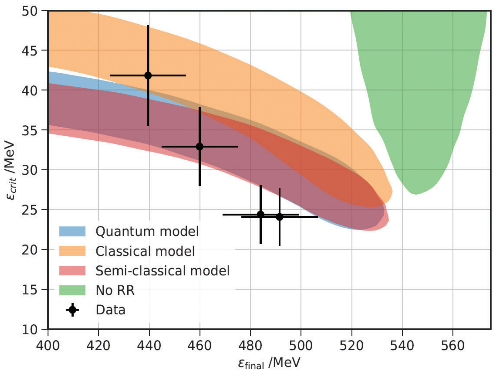

Fig. 3. The key experimental result: the lower the final energy of the electron beam ε_{final}, the harder the γ ray spectrum. This is parametrized by the 'critical energy' ε_{crit}, which controls the shape of the spectrum $dN/d\varepsilon \propto \varepsilon^{-2/3} \exp(-\varepsilon/\varepsilon_{crit})$. The sign of this correlation indicates that radiation reaction has occurred in the collision; in its absence the gradient would be reversed. The coloured regions give the theoretical expectation at 1σ for different models of radiation reaction. [Adapted from Cole et al. [5]]

tum model does. A 'modified classical' model is obtained by reducing the radiated power by a factor $g(\chi)$ that accounts for quantum corrections to the spectrum. While this does not include stochastic effects, these are expected to become significant only at larger χ. For the parameters reported by Cole et al, there is no significant difference between the predictions of the stochastic and the modified classical models of radiation reaction (compare the red and blue regions in Fig. 3).

That radiation reaction did indeed occur in the laser-electron collision was the conclusion of another experiment on the Gemini laser led by scientists from Queen's University Belfast. The setup differed in that a gas cell, rather than a gas jet, was used, thereby producing electron beams at higher energies. Like Cole et al, this team used the total γ ray signal to isolate successful collisions, while the data analysis was based on comparing the detailed shape of the electron energy spectrum between shots with and without the colliding laser. By comparing the spectra to simulation predictions, the team found that their results were better explained by the 'modified classical' model of radiation reaction than by either the classical or stochastic model.

These results leave high-field physics in an interesting place. While both experiments produced clear evidence of radiation reaction, there remain open questions that will be resolved only by further study. Indeed, the collaboration led by Imperial College will be returning to the Gemini laser later in 2018, armed with the lessons of the first experimental run. The aim is to obtain hundreds of collisions with improved stability and higher electron energy. It is hoped that these new data will shed light on the exact nature of radiation reaction, improving our understanding about the fundamental interaction of charged particles with strong electromagnetic fields. The results so far represent a vital first step towards this goal.

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Experimental evidence for short-pulse laser heating of solid-density target to high bulk temperatures

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The investigation of the Warm dense matter (WDM) is one of the hottest topics in modern physics. The matter here is characterized by a density close to or above that of a solid, and by a temperature >1 eV. This regime is challenging because Coulomb interactions, atomic physics, and electron degeneracy must be considered together. Meanwhile, WDM is ubiquitous throughout the Universe. And it is of high relevance for the ignition of inertially confined fusion fuel.

To investigate WDM, samples need to be prepared at homogeneous temperatures and densities, i.e. in gradient-free conditions. The short-pulse lasers allow heating solids over ultrafast time scales but are limited to extremely thin (nm-scale) foils. Ultrafast particles generated by the same lasers permit heating thicker (µm-scale) samples; however, an ultrahigh temporal contrast for the laser pulse is needed to maintain gradient-free conditions.

Recent experiments performed in Nizhny Novgorod, Russia at the Institute of Applied Physics RAS with the PEARL laser facility showed that almost isochoric heating to high temperatures (300 eV) of µm-thick solid-density foil can be achieved in a compact and efficient manner.

PEARL is an Optical Parametric Chirped Pulse Amplification (OPCPA) laser system. With this technology no signal is triggered before the pump pulse arrival.

Hence, the prepulse duration is limited to the duration of the pump. Although no contrast enhancement technique such as plasma mirrors or cross wave polarization (XPW) has been utilized in the setup, the temporal contrast in intensity, and in the nanosecond range, after compression was measured to be $1/(2\times10^8)$.

The pulse was focused on an Aluminum (Al) foil. The on-target laser energy reached 8 J in a 60 fs pulse. The wavefront correction system enabled reaching a focal spot of 2.9 μm radius with resulting intensity of $\sim2.5\times10^{20}$ W/cm^2.

A high-resolution X-ray spectrometer was installed to observe the radiation from the front surface of the target. Its crystal was aligned to operate in the photon energy range of 1.47–1.74 keV. The spectrum shown in Figure 1 exhibits Ly_α (1727 eV) and He_α (1598 eV) lines together with their satellites. There is also a recombination continuum that is reflected by the third order of the spectrometer crystal. The continuum is consistent with the emitted plasma temperatures of ~300 eV. There are also spectral components that attributed to the emission of KK and KL hollow atoms. To generate the X-rays required to produce the hollow atoms, the fast electrons need to be longitudinally refluxed multiple times. For this reflux to take place the density gradients at the surfaces need then to be sharp.

This is consistent with the density profile obtained from the hydrodynamic simulation. It shows that although there is a substantial underdense preplasma, most of the target persists to have solid-density and the density gradient at the front surface is small and sharp.

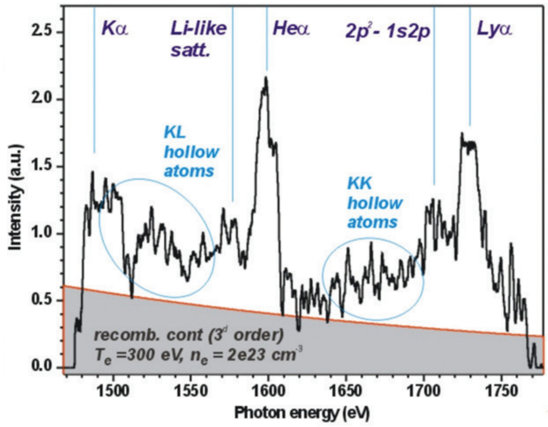


Fig. 1. X-ray spectrum measured by means of the spectrometer from the front surface of an Al target and accumulated in four shots

Modeling of the X-ray spectra gives a measurement of the temperature of the target bulk. The fitting of the continuum and the ratio between the Heα and Lyα lines intensities, corresponds to the emission of an Al plasma at $\sim2\times10^{23}$ cm^{-3} density and 280–320 eV electron temperature.

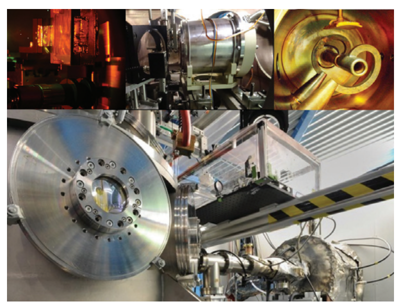
In summary, by using a high-power, high-contrast femtosecond laser system, a highly efficient coupling of laser radiation to the surface of a solid has been achieved, resulting in heating of the target of μm thickness to a temperature of 300 eV, preserving a small density gradient at the front surface. Such effective energy deposition is owed to the intrinsic high contrast of the laser which results from the OPCPA technology it is based on.

Germany Invests 30 M€ in to Demonstrate User-oriented Laser-driven Particle Facilities

Dr. Thomas Kühl
GSI Helmholtzzentrum, Professor, HI Jena and Mainz University

Laser-driven particle acceleration has been studied in the laboratory for the past twenty years. Electrons with an energy in excess of 4 GeV and protons nearing the 100 MeV mark have been demonstrated using the state of the art ultra-high intensity (UHI) lasers at various laboratories worldwide. The versatility of UHI lasers is such that this performance can be obtained in many places for a moderate investment, such that many recommend going from the laboratory experiment to the demonstration of user-oriented laser-driven particle facilities.

The Helmholtz Association in Germany has decided to support this move and is investing 30 M€ in the ATHENA project that will establish two laser-driven particle facilities in Germany, one at the Deutsche Elektron-Synchrotron (DESY) in Hamburg and the second at the Helmholtz center Dresden Rossendorf for ions. The Helmholtz center for heavy ion research (GSI) in Darmstadt is part of this effort and focuses on the coupling of laser-accelerated light ions into standard accelerator components.



With ATHENA, the test stand at GSI will be equipped with the necessary hardware to study the reliability of such sources for applications that use the sub-nanosecond duration and high particle numbers of the laser-generated ion pulses. This could be used for instance in time-resolved studies of fast processes on the nanosecond scale as well as showing that such a laser-based source is capable of being coupled to GSI's accelerator. In addition to experimental demonstrations, a large effort of ATHENA will be to push the development of effective high-average-power high-energy lasers, one of the current bottlenecks in laser-driven particle acceleration.

The Exawatt Center for Extreme Light Studies (XCELS) Strengthens Cooperation with European Partners

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Successfully ending on August 31st, 2018, CREMLIN was a Coordination and Support Action (CIA) supported by the Horizon 2020 framework programme of the European Union (EU) for 36 months, intending to foster cooperation in the research infrastructures' sector between the European Union and the Russian Federation. The project, funded by the EU with a budget of 1.7 MEUR, had a particular focus on the six Russian magascience projects, and was gathering 19 Beneficiaries, among which 6 Russian organizations where the megascience projects are hosted or planned and 13 European research infrastructures and organizations. The coordinator of the project was DeutschesElektronen-Synchrotron (DESY). More information about the project can be found at https://www.cremlin.eu.

The six Russian megascience projects

In 2011, based on a highly selective process, the government of the Russian Federation identified 6 national projects of very large research infrastructures, generically called the "megascience" projects, which were proposed to international cooperation.

- Scientific and Research Reactor Complex **PIK** at NRC "Kurchatov Institute" B.P. Konstantinov PNPI, Gatchina
- Nuclotron-based Ion Collider Facility **NICA** at Joint Institute for Nuclear Research, Dubna
- Fourth Generation Special-purpose Synchrotron Radiation Source **SSRS-4** at NRC "Kurchatov Institute", Moscow
- Exawatt Center for Extreme Light Studies **XCELS** at Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod
- Super Charm-Tau Factory **STC** at Budker Institute of Nuclear Physics, Novosibirsk
- **IGNITOR** Fusion Project at NRC "Kurchatov Institute", Moscow

One of the work packages of CREMLIN, WP6, was dedicated to the collaboration with the Exawatt Center for Extreme Light Studies (XCELS), hosted by the Institute of Applied Physics of the Russian Academy of Sciences in Nizhny Novgorod. The other partners of this work package were the Extreme Light Infrastructure Delivery Consortium (ELI-DC AISBL), and the French Atomic Energy Commission (CEA), represented by the Lasers, Interactions and Dynamics Laboratory (LIDYL).

The working group had several objectives, among which: i) identify and map the research interests and needs of EU and Russian partners for scientific cooperation in the framework of the XCELS project; ii) develop proposals for measures and action plans to foster joint research projects towards the implementation of the project; iii) jointly develop and refine concepts for international standards for access, user policy, and governance of future large laser facilities, to only cite a few.

In the framework of CREMLIN, several high-level workshops and round tables have been organized in both Russian Federation and European Union (Germany, France and Romania) to address the scientific case and the technological challenges of the XCELS project, well beyond the current state of the art. In addition to the scientific and technological aspects, CREMLIN also explored organizational aspects of XCELS as a research infrastructure, namely in terms of internationalization, governance, users' access etc. The possible contributions of the European industry, namely from the lasers, optics and photonics sector, to the implementation of the XCELS project have been also explored in a dedicated workshop gathering industry representatives and promoters of XCELS.

The working group has concluded the work by a series of recommendations, in view of supporting the implementation and creating best conditions for a possible future integration of XCELS in the European fabric of research infrastructures. The cooperation with key European leaders in the laser science and technology sector, on the one hand, and with well-established European research infrastructures with proven expertise in delivering user access, on the other hand, was identified as being essential to the success of the design, implementation and future operation of XCELS. For the further elaboration of a technical design for XCELS, carrying out joint EU-Russian research and development efforts in high-field physics was also pointed out to be of special relevance. The production of a 2-channel demonstrator for XCELS may be an interesting step to further undertake. The importance of the cooperation with existing European networks, like for instance Laserlab Europe, and with the Extreme Light Infrastructure (ELI) was also highlighted. Finally, the establishment of a business plan for XCELS was identified as a crucial step towards the achievement of a sustainable funding of the future infrastructure.

While project timeline extends over the period 2019-2025, satisfied by the success of CREMLIN, the partners would like to further extend their collaboration, possibly by taking part into a future call for applications for Research and Innovation Actions (RIA), which is currently under preparation by the European Commission.

International Zeptosecond Exawatt Science and Technology Scientific and Socio-Economic Outlook IZEST Fall Meeting, November 2017, INP Orsay

Extreme light is one of the most exciting domains in the laser field today. It relies on the generation of ultra-high peak power obtained by delivering the energy over a short time. Today, laser peak power exceeds typically the PW or thousand times the world grid power. The ability to produce and focus this gargantuan power over a size 10 times smaller than a hair offers unfathomable possibilities in science, technology, medicine and is a harbinger to a floodgate of socio-economic applications.

France is a well-established academic and industrial leader in lasers. Under the initiative of the Ecole Polytechnique, we proposed 10 years ago to the EU and Ile de France the construction of a Pan-European Infrastructure capable to generate the highest peak power ever produced and explore laser mater interaction at the highest possible intensities with the aim to carry out fundamental research and promote new societal applications. The infrastructure research within the framework of the 10 PW project named Apollon is currently performed on the plateau of Palaiseau.

While the LULI has the responsibility of implementing Apollon, IZEST was created in 2011 to be the prospective branch with the aim to look beyond the horizon set by ELI in terms of peak power and average power. IZEST is also looking at novel applications in science and engineering.

During the conference we described the most avant-garde laser concepts under development to segue from the petawatt to the exawatt, giving access to extremely short time structures down to the attosecond-zeptosecond regime. Pulses will be so short that the highest peak power in the x-ray regime could be reached with a modest amount of energy in the joule level yielding intensities in the Schwinger regime enough to materialize light.

The intensity of the X-ray pulse could generate gargantuan accelerating gradients in solids enough to accelerate electrons over a centimetre to the TeV level or relativistic protons widening the range of applications in subatomic physics, cosmology, vacuum physics and the like.

IZEST is always seeking new applications for the lasers they develop. For example, a few years ago, we proposed as new laser (ICAN) XCAN that could deorbit millions of small debris circling around the globe. The first test could be on the Space Station.

The infrastructures are now halfway through completion. As the initiator of both projects, ELI and Apollon, the EcolePolytechnique has carried out a study to gauge the socio academic impact of these world-class projects at all levels, regional, national and international. The conclusion of this report made at the meeting was one of the conference highlights.

Nuclear Photonics 2018

The 2nd international conference devoted to the pursuit of photon-based nuclear science and applications, Nuclear Photonics 2018, took place in Brasov, Romania from June 24th to 29th, 2018. (http://nuclearphotonics2018.eli-np.ro)

The rapidly evolving field of nuclear photonics has been enabled by the development of ultra-bright, quasi-mono-energetic gamma-ray sources based on laser-Compton scattering and by the worldwide development of $B-scale user facilities housing ultrahigh intensity lasers capable of producing field strengths of relevance to nuclear interactions. With an approximately 50% increase in attendance relative to the inaugural 2016 meeting held in Monterey, California, Nuclear Photonics 2018 clearly demonstrated a strong and growing community interest.

The nuclear-related topics discussed in Brasov embraced fundamental nuclear science and spectroscopy, nuclear medicine including radiography and radiotherapy, industrial non-destructive material imaging and evaluation, isotope-specific nuclear materials detection and management, photo-fission and materials transmutation, photon-enabled pulsed neutron generation and science, photon-enabled pulsed positron generation and science, photon-based hadron beams and applications, nuclear astrophysics and cosmology, and gamma-ray science above the giant dipole resonance.

The meeting's 200 attendees from 20 countries included experts in gamma-ray source development, ultrahigh intensity laser development, nuclear physics and nuclear-related applications. The five day conference comprised 4 tutorials, 1 keynote, 25 invited talks, 48 contributed talks and 75 posters. Representatives from the Romanian government and the US ambassador participated in the welcoming ceremony. During the course of the week, the participants from Darmstadt, Germany also announced that a major new initiative on nuclear photonics in Germany had been funded.

Prior to the start of the 2018 conference, the attendees were invited to tour the Extreme Light Infrastructure – Nuclear Physics facility in Magurele, Romania. At ELI-NP, they visited the high intensity laser, gamma beam, target fabrication and detector assembly laboratories as well as various gamma-beam and high intensity laser experimental halls. Commissioning of two 10 PW beam lines of ELI-NP was underway and by the time of the visit the laser system had produced uncompressed, amplified, chirped pulses consistent with the eventual production of 3 PW peak power pulses. Further amplification and commissioning of this system will continue into 2019.

At the conclusion of the Brasov conference it was announced that Nuclear Photonics 2020 will be held in Japan and will be hosted by the nuclear science and laser science groups of the University of Osaka.

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