Contents

LWFA in a regime of strong-mismatch between the incident laser envelope and the nonlinear plasma response

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We explore a regime of laser-driven plasma acceleration of electrons where the radial envelope of the laser-pulse incident at the plasma entrance is strongly mismatched to the nonlinear plasma electron response excited by it [1][2][3]. This regime has been experimentally studied with the Gemini laser using f/40-focusing optics in August 2015 [4] and f/20 in 2008 [5]. The physical mechanisms and the scaling laws of electron acceleration achievable in a laser-plasma accelerator have been studied in the radially matched laser regime [6] and thus are not accurate in the strongly mismatched regime explored here. In this work, we show that a novel adjusted-a0 model applicable over a specific range of densities where the laser enters the state of a strong optical shock, describes the mismatched regime. Beside several novel aspects of laser-plasma interaction dynamics relating to an elongating bubble shape and the corresponding self-injection mechanism, importantly we find that in this strongly mismatched regime when the laser pulse transforms into an optical shock it is possible to achieve beam-energies that significantly exceed the incident intensity matched regime scaling laws.

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Crunch-in regime of non-linearly driven hollow-channel wakefields

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Relativistic beam-driven wakefield modes inside a hollow-channel plasma are significantly different from those driven in homogeneous plasmas [1]. This work explores a novel "crunch-in" regime of hollow channel using analytical theory and 3D PIC simulations and presents the scaling laws of the accelerating and focusing fields in this regime. An analysis of the dynamics of the regime shows it to be excited due to the collapse of the driven electron-rings from the channel walls onto the propagation axis of the energy source, setting up coherent ring oscillations [2][3]. This regime is thus the non-linearly driven hollow channel, such that the electron-ring displacement is of the order of the channel radius with density buildup that exceed the plasma density by many times. We present the properties of the coherent structures in the "crunch-in" regime where the channel radius is matched to the beam properties such that channel edge to on-axis collapse time has a direct correspondence to the energy source intensity. We also investigate the physical mechanisms that underlie the "crunch-in" wakefields by tuning the channel radius. Using PIC simulations we show applications of the "crunch-in" regime for acceleration of positron beams with collider-scale parameters while also presenting possible pathways for generating such channel over meter-scale lengths [4].

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Demonstration of beam loading in laser wakefield accelerators

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Laser wakefield acceleration (LWFA) is capable of producing quasi-mono energetic electron beam reaching into GeV energy range with few-femtoseconds bunch duration. Scaling the charge to the nano Coulomb range yielding to hundreds kilo Ampere peak current will open the prospect for a broad range of applications spanning from compact light sources to the future collider. Here we present the capability of such accelerators to generate up to 0.5nC electron bunches within a quasi-mono energetic peak at around 300 MeV, pushing the accelerator into the so-called beam loading regime. We discuss the effect of such high loaded charges to the figure of merit electron beam parameters such as energy and energy spread, transverse as well as longitudinal beam distribution. As the beam loading is optimized, we demonstrate that the beam quality is maintained up to an estimated peak current of about ~50 kA. This is an order of magnitude larger than state-of-the-art conventional accelerators.

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Wakefield acceleration driven by X-ray pulses interacting with solid density targets

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The similarity scaling laws for laser plasma interaction suggest that X-ray pulses can be used to drive wakefields [1,2] in solid density materials. In the past, the generation of X-ray pulses of sufficient intensity has been a major challenge. However, the relativistic electron spring mechanism (RES) [3] has shown promise to generate relativistic intensity pulses with wavelengths in the X-ray regime, improving the prospects for X-ray wakefield acceleration (XWFA). Upon accessing this new regime an important role can be played by a number of previously negligible processes such as radiation reaction, strong field QED effects, Bremsstrahlung and discreteness of plasma particles. The shorter wavelength reduces the a0 for onset of QED effects compared to when using optical wavelengths, which creates a more restrictive criteria for the range of a0 which can provide efficient particle acceleration. Assuming realistic parameters, we investigate the XWFA regime using the three dimensional Particle-In-Cell (PIC) code ELMIS incorporating QED effects [4] and present the prospects of the XWFA regime for electron acceleration and radiation generation.

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Simulation Studies on Generation and Detection of Muon Beam Driven by Laser Plasma Accelerators

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The state-of-the-art laser plasma accelerators routinely produce ultra-short electron bunches of multi-GeV energy using compact PW-class laser systems [1]. There are also ongoing efforts to produce 10 GeV electron beams using multi-PW laser system [2]. The ultra-relativistic electron beams interaction with a dense high-Z target generate highly directional intense bremsstrahlung photon beams with a continuous energy spectrum extending up to incident electron energy. Further, the photon beam interaction with an optimally chosen primary target itself or a secondary target can lead to generation of a significant number of highly directional muons with unique characteristics [3]. An intense source of muons on compact laboratory scale accelerators can be potentially motivate its applications to muon radiographies, and perhaps also to studies related to compact muon colliders. We shall present here a simulation study based on single particle tracking code "G4beamline" [4,5] to find optimum interaction conditions for maximizing the yield of muons and also to understand the characteristics of the generated muons for electron beams in the energy range ~ 1 – 10 GeV. It was noticed in simulations that the electron beam interaction with the target produces muons along with huge background of high energy photons, electron-positron pairs, protons, and neutrons rendering direct detection and characterizing muons experimentally challenging. In this context, the simulations results will be helpful for optimal generation and unambiguous detection of muons in future experiments. We shall also present here our plans and preparations for generation of muons using the electron beams produced by the 4-PW laser systems (at Centre for Relativistic Laser Science, Institute of basics sciences, South Korea) and also for detecting them in near future.

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Novel gas target design for Laser Wakefield Accelerators

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A novel gas target for Laser Wakefield Accelerators has been simulated, designed and manufactured. The gas target consists of a gas cell and a slit nozzle (named SlitCell) designed to generate a flat top gas density profile along the central gas cell axis. Preserving the flat top hat shape, the gas density can be tuned from 1016 atoms/cm3 up to 1019 atoms/cm3 and the gas target length can be tuned from 0 to 10 cm. The computational fluid dynamics (CFD) simulations of the gas target using Ansys Fluent showed that the length of the SlitCell can be extended tens of centimeters without affecting the shape of the density profile. The CFD simulations have been validated using interferometry and showed a small deviation from the predicted profile. The SlitCell is highly customizable in shape and length thus multiple stages can be assembled together to create a staged SlitCell as required by some of the Wakefield Accelerators experiments.

Estimations for Future Experiments on High Intensity Laser - Electron Scattering at CoReLS

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High intensity laser experiments have provided the opportunity to study novel mechanisms for particle acceleration [1], sources of radiation and fundamental physical processes [2]. The advances in laser technology and the availability of two Petawatt beamlines simultaneously at CoReLS[1] [3] stimulate further research into all optical laser-electron scattering [4]. Such a setup involves the collision between a laser pulse focused at high intensity and an electron beam obtained through laser wakefield acceleration (LWFA).

We performed simulations for the interaction of a laser pulse of intensity of $I=10^{21}$ W/cm^2 with a counter propagating electron beam with energy E_{e-} = 5 GeV. The effects of radiation reaction, photon emission and electron-positron pair production are included by using a QED-PIC code [5]. During the interaction, we observe a broad increase in the energy spread of the electron beam and a total energy loss of 52% of the initial beam energy. Additionally, $N_{e+} = 1.3 \times 10^5$ positrons are generated from the Nonlinear Breit-Wheeler mechanism. We furthermore study the trajectories of the electrons and positrons through a magnetic spectrometer using the GEANT4 software [6]. This type of phenomenological approach allows us to virtually design and simulate the whole experimental setup from the interaction point up to the detection part.

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Development and Characterization of Double Plasma Mirror System for 4 PW Laser

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The development of ultrashort ultrahigh intensity lasers has opened a new field of laser-matter interactions where electrons and ions can reach the relativistic regime [1, 2]. In order to build such a laser, several amplifying stages with chirped pulse amplification are required. During amplification, some of the noise or spontaneous emissions present prior to the main pulse can be amplified enough to generate a pre-plasma on the target surface prior to the main pulse. The main pulse then will no longer interact with a steep density gradient target but a gradual density gradient target due to the pre-plasma generation at the target surface. For ultra-thin targets, the pre-pulse will ionize the target, generating a pre-plasma, and the main pulse will have nothing but the expanded pre-plasma to interact with.

A double plasma mirror (DPM) system [3] was used to dramatically reduce the pre-pulse and the pedestal of the 4 PW laser recently built at Center for Relativistic Laser Science (CoReLS) [4]. Moreover, the plasma mirrors can protect the 4 PW laser by stopping back reflections from the target. The compressed beam with 290 mm beam diameter enters a deformable mirror (320 mm clear aperture with 128 actuators) for a spatial phase correction before it enters the DPM system. After compensating the phase of the laser beam, the beam was delivered to a periscope to convert the laser polarization from p- to s-polarization to enhance the reflection efficiency of the plasma mirror. The beam is then focused to the first plasma mirror surface of DPMs using an off-axis parabolic mirror to minimize aberrations, mainly spherical aberrations. After interacting with the first and the second mirrors of DPMs, the high contrast beam is re-collimated using another off-axis parabolic mirror. Using a secondary periscope, the polarization of the beam is converted back to the p-polarization from s-polarization.

In this study, a precise alignment procedure of the entire system, and the temporal and spatial characterization of the ultrahigh contrast laser beam after passing through the DPM system will be discussed. The contrast ratio over sub-ns range of the pulse was measured using a third-order cross correlator. In addition to this, the far- and near-field images of the beam, as well as the pointing stability were measured as the plasma mirror is repositioned for a fresh surface after every laser shot. These characterizations are crucial for the reliable and repetitive operation of DPM system. The DPM system will be used as a base equipment in laser-matter interaction with ultra-intense and ultrahigh contrast laser pulses, such as laser-driven ion acceleration and its applications [5, 6, 7].

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Automatic tape drive for high-repetition laser-plasma ion acceleration experiments

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In TNSA (target normal sheath acceleration) experiments, the most robust method of accelerating ions by laser, ions are accelerated to multi-MeV energies as a result of the interaction of an intense ultra-short laser pulse with a thin foil. After each shot, the foil has to be moved to a fresh spot and subsequently realigned. As today's terawatt facilities are readily capable of firing at ~10 Hz, it is usually this cumbersome foil refreshing process that severely limits the shot repetition rate of these experiments.

In order to overcome this limitation and use the system to its full potential, we have developed an automatic tape drive. The design includes precise tension control, a laser displacement sensor and a piezo motor driven stage for automatic realignment between shots. In addition to enabling higher repetition rates, the tape target provides a flatter surface compared to traditional foil mounting methods, resulting in better shot-to-shot stability.

While tape drives have been used before for laser-plasma experiments ([1] among others) and recently for ion acceleration as well [2], it has only been realized for relatively thick foils. Our novel design allows for using ultra-thin foils (<5 microns), a necessary requirement for reaching high ion energies in TNSA.

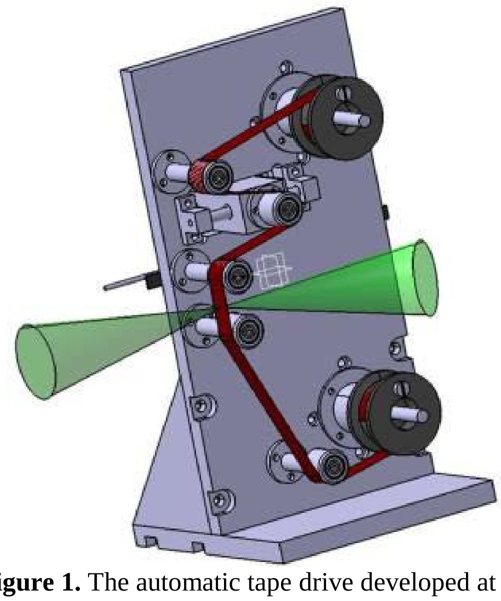

Figure 1. The automatic tape drive developed at LOA.

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Theory of Terahertz Emission from a Plasma with Counterpropagating Laser Wakefields

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The THz radiation is of great importance for many scientific and technological applications. Although the significant progress has been recently demonstrated in generating high-field single-cycle THz pulses with a wide frequency spectrum, generation of narrow-band powerful THz radiation still remains the challenging problem. It is known that plasma is one of the most promising nonlinear medium for generating THz waves. Among the advantages of plasma-based sources are the ability of this medium to sustain long-lived oscillations with extremely large electric fields and possibility to tune the radiation frequency by a simple change of plasma density.

There are different mechanisms for the generation of THz radiation in plasma by particles beams or lasers. This work is focused on the generation of high-field narrowband terahertz radiation by counterpropagating plasma wakes excited in a uniform plasma by femtosecond laser pulses. Such a scheme can generate GW, mJ multi-cycle terahertz pulses with the energy conversion efficiency higher than 10^{-4}. It does not require large external magnetic fields or plasma density gradients and thus can provide a narrow spectral line tunable in a wide frequency range.

Physically, our scheme is based on nonlinear interaction of two potential laser-driven plasma waves oscillating with the plasma frequency ω_p and opposite longitudinal wavenumbers (ω_p, k_1) and (ω_p, $-k_2$) . This interaction results in the superluminal wave of electric current ($2\omega_p$, $k_1 - k_2$) which, in the bounded plasma, can pump vacuum EM waves. Since counter propagating laser pulses can drive wakes only with equal wavenumbers $k_1 = k_2$, the resulting radiation is always emitted transversely to the created plasma channel. In this work, we calculate this radiating current and find that it can produce radiation only for the mismatched transverse profiles of excited wakes. There are two ways how to implement this nonlinear process experimentally. The first one is to collide symmetric laser pulses with some impact parameter ρ (scheme 1), to focus them to different size spots σ_{01} and σ_{02} with the same longitudinal position (scheme 2) or to shift the waists of symmetric beams in the longitudinal direction by the length L (scheme 3). We present a detailed analytical theory for the generation of powerful and narrow-band THz radiation in such schemes and compare these theoretical predictions with article-in-cell simulations. Good agreement between analytical and simulation results allows to use this theory as a reliable tool for estimating the record parameters achievable in further experiments with high-power lasers.

Laser Wakefield Acceleration with Nitrogen Gas

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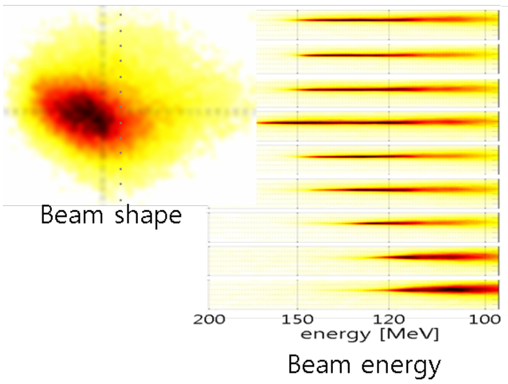
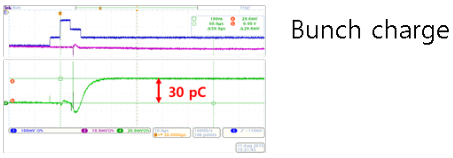
A very high power laser can generate a wakewave inside the plasma which can be used to accelerate electron [1]. Due to the very high acceleration field in this scheme, a compact high energy accelerator can be made. A gas with low atomic number such as hydrogen and helium is widely used as medium for plasma. With such a low z atom, the effect of the ionization, such as ionization induced refraction, can be reduced because the atoms will be ionized far from the peak of the lase pulse. But now the ionization process can be used to inject the electron in the acceleration phase with lower laser intensity [2].

In this work, a pure nitrogen gas was used as an acceleration medium. A 10 TW 40 fs laser was focused at the gas medium generated by using a supersonic gas jet. The plasma density was measured by Nomarski interferometer. A reproducible electron beam was generated with 125 MeV with plasma density 5 x 10^{18} cm^{-3}. The bunch charge was 30 pC. Even low intensity laser, high energy electron was generated by the ionization injection process.





Statistical Beam parameter		
Pointing stability	Δ_h = 2.2 mrad	Δ_v = 2.1 mrad
Beam divergence	θ_h = 7.5 ± 1.1 mrad	θ_v = 4.2 ± 1.2 mrad
Beam energy	124 ± 9 MeV	
Bunch Charge	37 ± 22 Pc	

Figure 1. Accelerated Electron parameters. Beam shape, energy, charge are shown. The table shows the statistical results of the experiments**.**

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Enhancing the electron acceleration and proton acceleration by a right-hand circularly polarized laser interaction with a cone-target exposed to a longitudinal magnetic field

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Laser plasma accelerator has attracted plenty of interest for its remarkable advantages. Electron acceleration and proton acceleration are two main items in it. For our work, the propagation of left-hand (LH-) and right-hand (RH-) circularly polarized (CP) lasers and the accompanying acceleration of fast electrons and protons (accelerated by target normal sheath field) in a magnetized cone-target with pre-formed plasmas are investigated. In this work, the strength of external magnetic field is comparable to that of the incident laser. Theoretical analyses indicate that the cut-off density of LH-CP laser is larger than that without an external magnetic field. When the external magnetic field normalized by the laser magnetic field is larger than the relativistic factor, the RH-CP laser will keep on propagating till the laser energy is depleted. The theoretical predictions are confirmed by two dimensional (2D) particle-in-cell (PIC) simulations. Simulation results show that in the presence of an external longitudinal magnetic field, the energies and yields of fast electrons and protons are both greatly enhanced for RH-CP laser. Besides, the coupling efficiency of laser energy to energetic electrons for RH-CP laser is much higher than that from LH-CP and without an external magnetic field. The divergency of electrons and protons are suppressed remarkably by the external magnetic field. Furthermore, for RH-CP laser, detailed simulation results perform an enhancement of incident laser absorption and the maximum proton energy with increasing external magnetic field.

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Energy partitioning and electron momentum distributions in intense laser-solid interactions

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The generation of energetic electrons through the interaction of intense laser pulses with solid targets is one of the most robust and accessible ways of transferring the laser energy to the charged particles and underlies many important applications, ranging from TNSA to laboratory astrophysics. [1-3] Recent studies have shown that the amount of absorbed laser energy can be increased by introducing structures on the scale of the laser wavelength to the target surface, [4-8] even suggesting that close to 100% absorption is possible. [9]

In this contribution we investigate how the structures not only increase the absorption of laser energy, but also their effect of widening the angular distribution of generated energetic electrons. We study various different microstructured targets and use realistic and contemporary laser parameters in order to bring further understanding to how the properties of the energetic electrons can be controlled on current and future laser systems. We analyse the results of PIC simulations, performed with the code PICADOR [10], and reveal several aspects that can be important for the related applications. As expected, it is found that the structures and their size affect the absorption of the laser energy. However, we also show that the hot electron distribution can be significantly affected by the same structures.

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Measurement of MeV betatron radiation spectra from GeV laser wakefield accelerators

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A high-flux, wide-range gamma-ray spectrometer specifically for spectral characterization and measurement of angularly dependent spectra of betatron radiation generated by GeV electron beams from laser wakefield accelerators (LWFAs) are presented. The experiment was carried out at the PULSER laser system, which has the capability of delivering 1.1 PW pulses of 28 fs duration at a repetition rate of 0.1 Hz, operated at the IBS-CoReLS. Electron beams produced through the LWFA process [1] were characterized with a 1.3-T field and 30-cm long magnetic spectrometer and three scintillator screens. Betatron radiation from the gas cell was detected outside the interaction chamber through a 2-cm thick Acrylic window, where electron beams of interest were swept out from the laser propagation axis due to deflection in the spectrometer magnet. The gamma-ray spectrometer consists of a series of imaging plates (IPs) alternatively stacked with 15 filters of increasing Z number from Al to Pb. In order to measure the angularly dependent gamma-ray spectrum, we used another spectrometer comprising sectored range filters, where the transmission photon intensity was measured with an IP. A range filter spectrometer is composed of 23 sectored filters comprising an Al, Cu, Sn, and Pb quadrant, each of which is assembled from 5 or 6 sectors with different thickness. The gamma-ray spectra were obtained by unfolding the photostimulated luminescence values (PSLs) recorded on the IPs with the response functions modeled with the Monte Carlo code Geant4. The PSL values of the IP are simulated by using Geant4 from the total energy deposited in a phosphor layer. We presented the responses of the IP to 0 – 100 keV x-rays, which are simulated by Geant4 in comparison with the measured and modeled sensitivities resulted from the exposure experiment to monoenergetic x-rays. The simulated responses are in good agreement with the measured and modeled sensitivities for overall relative PSL values and characteristic x-ray absorption energies. The analyses of betatron radiation from GeV laser wakefield-accelerated electron beam confirm a radiation spectrum characterized by synchrotron radiation with the critical photon energy of 2 MeV and an approximately isotropic angular dependence of the peak photon energy and photon energy-integrated fluence [2]. As expected by the analysis of betatron radiation from LWFAs, the results indicate that unpolarized gamma-rays are emitted by electrons undergoing betatron motion in isotropically distributed orbit planes [3].

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Twisted plasma waves driven by intense light-spring laser pulses

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The orbital angular momentum is an intrinsic degree of freedom of light that results in doughnut shaped laser intensity profiles with twisted wavefronts. The orbital angular momentum from the laser is not transferred to the plasma waves in the underdense plasma, below solid density [1]. This picture changes dramatically when the laser driver contains multiple OAM levels characterized by distinct frequencies. The beating between each mode results in a spiralling laser intensity profile, also known as a light spring [2]. We show that a light spring laser driver can efficiently transfer OAM to the plasma wave. Unlike a Gaussian laser pulse driver, where the wakefield amplitude decreases with the pulse duration (because the ponderomotive force becomes smaller), we show that the wakefields can be resonantly excited by the light spring driver. The wakefield amplitude can then grow secularly along a long light spring, paving the path to excite strongly nonlinear plasma waves using lasers with non-relativistic peak intensities. We also show that the twisted wakefield structure modifies particle trapping and acceleration. An additional trapping condition, related to the conservation of angular momentum, forces trapped particles to execute helical trajectories as they de-phase in the wakefields, leading to the generation of helical particle (electron and/or positron) bunches. Unlike in no-OAM plasma waves, particles can be trapped even if their longitudinal velocity is below the longitudinal wakefield phase velocity. Although the energy gain is generally smaller, trapped particles can rotate in the wakefields indefinitely, without ever entering into defocusing regions. In addition to radial variations of the laser spot-size, light springs can also rotate azimuthally when a plasma channel is present. This interesting feature can be used to reduce or increase the phase velocity of the plasma wave. Light springs can then be employed to drive superluminal phase velocity plasma waves, which can contribute to prolong the acceleration distance in a plasma accelerator [3]. We support our theoretical findings with three-dimensional particle-in-cell (PIC) simulations using the PIC code Osiris [4].

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Current development status of electron acceleration at kHz-repetition rate for ultrafast electron diffraction

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Ultrafast electron diffraction (UED) is a powerful complementary method to X-ray diffraction for inspecting structural information in dynamic phenomena such as photo-induced phase transformation in crystals, dynamics of surface phenomena, etc [1]. State-of-the-art electron beam source for UED use combination of photocathode and RF gun to generate and accelerate electrons up to 2.8 MeV with 40-fs duration [2]. However, overall temporal resolution is limited to ~130 fs, due to jitter between electron beam and pump laser. Electron acceleration via laser-plasma interaction is an attractive alternative method, because it realizes jitter-free synchronization between electron beam and optical beam for pump-probe experiments with enhanced spatiotemporal resolution due to shorter pulse duration. Generation of ~0.1 MeV electron beam at 0.5 kHz-repetition rate has been demonstrated using a sub-TW Ti:sapphire laser system [3]. In this presentation, current status of development of electron source suitable for ultrafast electron diffraction (UED) using 1 kHz-repetition rate sub-TW Ti:sapphire laser at Center for Relativistic Laser Science, Institute for Basic Science will be presented.

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Generation of energetic dense plasma jets by a high-intensity Laguerre-Gaussian laser pulse

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The generation of energetic particle beams in ultra-intense laser-plasma interaction has been popularly investigated due to the various potential applications such as charged particle acceleration, high-energy photon generation, and laboratory astrophysics [1]. In this presentation, we show that energetic dense plasma jets can be generated with a Laguerre-Gaussian (LG) laser pulse [2]. In the three-dimensional particle-in-cell simulations of the interaction between a LG laser pulse and a solid-density foil, we observed that collimated plasma jets of an overcritical density are ejected in the laser propagation direction with a speed comparable to the speed of light. Such ejection was attributed to the unique field structure of the LG laser pulse, i.e. a hollow intensity profile in the transverse plane. Under such a field, a plasma is focused to the optic axis by the transverse ponderomotive force. Then it is accelerated by the longitudinal ponderomotive force due to the rising part of the laser pulse and the electrostatic force due to the separation of electrons and ions. We expect that the resultant energetic dense plasma jets are very useful in aforementioned applications.

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Radial equilibrium of the drive beam in a plasma wakefield accelerator

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An axisymmetric low-emittance charged particle beam in a dense plasma quickly reaches equilibrium with the wakefield it excites. Decelerated parts of the beam evolve towards some universal equilibrium state that is derived and described for the first time.

The universal equilibrium state is rather unusual. The beam density is strongly peaked near the axis and has a 1/r singularity. The radial electric field is approximately constant up to a small radius determined by the initial beam emittance. The beam radius is constant along the decelerated part of the beam and equals approximately one half of the initial beam radius. The beam emittance varies along the beam in proportion to the square root of the potential well depth that confines beam particles radially. The frequency of transverse particle oscillations in this well strongly depends on the oscillation amplitude and, for most particles, is several times higher than the commonly used estimate. The transverse momentum distribution of beam particles depends on the observation radius and is not Gaussian.

Positron driven plasma hollow channel wakefield acceleration

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High quality, economic and efficient light and particle beams are vital in our community for ultrafast detailed diagnostics, for collisions that mimic the extreme scenarios of our universe, and for medical treatments and analysis. Plasma based accelerators are promising candidates to deliver such beams because of the high fields and accelerating gradients that they can withstand, since they are not limited by their material breakdown. Recent efforts have shown the potential of plasma wakefield acceleration techniques [1] to provide GeV energy gain in meter long plasmas [2] with high efficiency [3] and to be used in multiple stages [4]. The application of the standard nonlinear wakefield accelerators to positron bunches is challenging [5], because their transverse fields are mainly defocusing for positrons. Therefor several alternative configurations are being considered [6,7] including the use of plasma near [8] and complete hollow channels [9,10].

Recently we proposed a positron acceleration scheme [11] which consists of sending a tightly focused positron beam into a homogeneous plasma of electrons and ions where its space charge repels the ions and forms a plasma hollow channel behind it. Inside the channel the transverse forces are negligible and the accelerating gradient is of the order of the standard nonlinear electron wakefield accelerators, making this scheme suitable to accelerate trailing positrons. Along with determining the main properties of the initial beam for ideal channel generation and positron bunch acceleration we have been studying effects of the plasma return currents and beam asymmetries in their transverse evolution through numerical simulations done with the particle in cell code OSIRIS [12].

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Controlled electron injection using nanoparticles in laser wakefield acceleration

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Laser wakefield acceleration (LWFA) is a promising scheme for future electron accelerator due to its huge accelerating field over 1 GeV/cm. In the past decade, LWFA has progressed remarkably to achieve multi-GeV energy, small energy spread, and stable electron beam generation. In the LWFA process, the maximum achievable energy can be increased with a higher laser power, lower electron density and longer plasma medium. For electron acceleration of 10 GeV energy, a multi-PW laser pulse is required to drive wakefields in a plasma medium with tens-of-cm length and a few 10^{17} cm-3 electron density. At such a low density, however, the electron injection can be prohibited due to a higher injection threshold of electron momentum. Thus, initiating electron injection in such a low-density plasma is a critical issue for accelerating high energy electron beams driven by with multi-PW laser pulses.

In this presentation, we propose a controllable electron injection scheme by inserting nanoparticles into nonlinear plasma wave. These nanoparticles can provide a unique plasma condition of the very localized high-density zone in an ambient plasma. When an intense laser interacts with a nanoparticle in a plasma, a very strong and localized electrostatic field can be generated as a result of the field ionization (or charge separation). This nanoparticle field can induce localized electron injection and the electron injection can be controlled by nanoparticle parameters such as density, size, and position. The effects of the nanoparticle parameters on LWFA were investigated by the multi-dimensional particle-in-cell (PIC) simulations. In the PIC simulations, we found that mono-energetic electron beam can be produced by the nanoparticle insertion scheme, and the beam charge and energy spread of the accelerated electron beam depend on nanoparticle size, density and position.

Quantum Theory of Charges in Noninertial Frames

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Non-inertial frames have nontrivial spacetime, in particular, the Rindler spacetime for a uniformly accelerating charge and the Born spacetime for a rotating charge. The quantum theory of charges in non-inertial frames is much different from that in inertial frames. We explore the QED effect in the Rindler spacetime and the Born spacetime and discuss possible physical implications in intense laser physics and astrophysical phenomena.

Unstable interactions between circularly polarized lasers and thin plasma foils

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Thin plasma foils have been considered as sources of highly energetic ion beams or ultrashort electromagnetic pulses. To stabilize laser-foil interactions, $a_I \leq \zeta$ has been recommended as an experimental condition, where a_I and ζ are the incident amplitude and the surface density [1]. This condition increases the radiation pressure and the reflectance of lasers. However, we recently found that irradiated foils can be unstable even when $a_I \leq \zeta$. In this poster, we suggested an equation modifying $a_I \leq \zeta$. According to the equation, the foils can become broad or even broken despite strong radiation pressures by perfectly reflected lasers. This novel phenomenon was verified by the one-dimensional particle-in-cell simulation. In addition, the relativistic skin depth and the amount of protons in the foil were modified and verified as well.

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Transition from absolute to convective instability via density modulation for backward stimulated R aman scattering

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Backward stimulated Raman scattering (BSRS) is very important in inertial confinement fusion, it has already been studied widely and is still an important subject now. In our work, the effect of a static sinusoidal density modulation on the temporal growth rate of backward stimulated Raman scattering (BSRS) is discussed by kinetic theory and Vlasov simulation. Theoretical analyses indicate that with increasing the density modulation amplitude ε, the temporal growth rate of BSRS will be decreased gradually and transition from absolute to convective instability can be controlled via density modulation. One-dimensional Vlasov simulation is used to confirm this prediction, simulation results show that the temporal growth rate will decrease with increasing the density modulation amplitude ε, which is consistent with the kinetic theory. Moreover, transition from absolute region to convective region via density modulation is also observed from variation of the temporal growth rate of BSRS. The temporal growth rate in the case of density modulation wave-number $k_s = 0.1k_l$ (k_l is wave-number of Langmuir wave) decreases faster with increasing ε than that in the case of $k_s = 0.5k_l$ because of generation of more modes which will make Landau damping of Langmuir wave stronger. In addition to generation of other modes, increase of the effective damping due to decrease of the resonant region where BSRS occurs with increasing density modulation amplitude ε is also a reason for the reduction of the temporal growth rate.

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Simulation and preliminary experimental results of plasma dechirper and external injection acceleration

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Plasma dechirper can be used to remove the characteristic linear energy chirp of an electron or positron beam generated from plasma accelerators. The electron or positron beam interacts with its self-wake to dechirp itself, such that the energy spread of this beam can be reduced from a few percent level to ~0.1 percent level[1].

External injection of beams into a plasma accelerator and acceleration with minimal degradation of their quality provides a promising route to make plasma acceleration a realistic technology for user-applications.

In the last two years, we have carried out a lot of preparatory work for the plasma dechirper and external injection acceleration experiments in Tsinghua University. A TW laser system is synchronized with a 45 MeV high brightness RF photogun based linac with a sub-150 fs (RMS) time jitter between the laser pulse and the electron bunch. A high vacuum interaction chamber, a compact permanent magnetic spectrometer and various gas jet nozzles have been designed and manufactured.

For the plasma dechirper experiment, the preliminary experimental results demonstrate that the projected FWHM energy spread of the 41.5-MeV chirped electron beam can be reduced from 1.2% to 0.9% with a 12 mm long plasma dechirper, which are in good agreement with full three-dimensional particle-in-cell (PIC) simulations. For the external injection acceleration experiment, stable 32 MeV, 1~2 pC electron beams from the linac were compressed by a Chicane, focused to a 200-um radius (RMS) and then injected into the linear wakefield excited by a 10TW, 30fs laser. The preliminary experimental results show that up to 20% electrons can be accelerated and the maximum energy gain reaches 0.35 MeV in a 6 mm long plasma by optimizing the plasma density and the laser focal plane position, corresponding to an average gradient of about 60 MV/m, which are in reasonable agreement with the 3D PIC simulations.

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Preliminary experiment on intense ultra-short mid-infrared pulse generation in the blowout regime

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Mid-infrared radiation has widespread applications in physics, chemistry, and biology as it covers the fundamental vibrational absorption bands of many molecules and compounds. Specifically, intense ultra-short mid-infrared pulses have great potential in phase-matched high harmonic generation in the X-ray region [1], multidimensional spectroscopy [2], and mode-selective photochemistry [3]. In our recent experiments, we demonstrate that through laser-plasma interaction in the blowout regime, intense ultrashort mid-infrared pulses can be generated with quite high conversion efficiency. In this experiment, a 30fs, 300mJ, 800nm, 10Hz Ti:sapphire laser is irradiated into a 2.5mm supersonic gas jet, undergoes strong photon deceleration [4, 5] by interaction with the plasma, and generates mid-infrared pulses with wavelength extending from 800nm to 6μm. We measure the spectra and energy of the mid-infrared pulses simultaneously in every single shot. The energy of the generated mid-infrared pulse within the spectral range of 2-6μm reaches 18mJ, corresponding to conversion efficiency as high as 6.0%. The process is analyzed with three-dimensional particle-in-cell simulations. Good agreement is found between numerical simulation and experimental results.

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Dynamically Ionization-Stabilized Radiation Pressure Acceleration of Ions Driven by Intense Lasers

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Laser-driven ion acceleration is conceived to be one of the main applications of many powerful laser facilities that are being projected, built, or already in operation around the world. It opens a way for a future new generation of compact accelerators providing high-quality ion beams for many applications in medicine, industry, science and others. Among various acceleration schemes, radiation pressure acceleration (RPA) is regarded as one of the most promising schemes to obtain high-quality ion beams. Although RPA is very attractive in principle, it is difficult to be achieved experimentally. One of the most important reasons is the dramatic growth of the multi-dimensional Rayleigh-Taylor-like (RT) instabilities. Such instabilities lead to heating and loss of co-moving electrons in the plasma sheet, consequently Coulomb explosions and acceleration destructions of the latter [1]. How to suppress the instability of RPA is currently one of the most challenging problems. In this talk, we report a novel method to achieve stable RPA [2,3] of ions from laser-irradiated ultrathin foils is proposed, where a high-Z material coating in front is used. The coated high-Z material, acting as a moving electron repository, continuously replenishes the accelerating ion foil with comoving electrons in the light-sail acceleration stage due to its successive ionization under laser fields with Gaussian temporal profile. As a result, the detrimental effects such as foil deformation and electron loss induced by the Rayleigh-Taylor-like and other instabilities in RPA are significantly offset and suppressed so that stable acceleration of heavy ions are maintained.

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Direct Ion acceleration using ponderomotive beat wave of twisted Laser Beams

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A high-intensity laser in the interaction with a solid target can excite an intense electrostatic field that can accelerate ions via several mechanisms [1]. The high electromagnetic fields of such lasers can also directly interact with ions and accelerate them to high energies. An all-optical mechanism of ion acceleration in vacuum with two counter-propagating plane waves has been proposed in Ref. [2]. The one-dimensional (1D) model shows that a suitable frequency chirping of lasers drives a beat wave with variable phase velocity that can traps particles and accelerates them longitudinally. However, the multi-dimensional effects associated with the transverse field structure of a finite-width laser beam are not considered. In this work, the 1D theory of Ref. [2] will be generalized in order to incorporate 3D effects. In the other words, direct ion acceleration by two counter-propagating focused laser beams with variable frequencies is considered and the multi-dimensional effects associated with the finite transverse dimension of lasers are investigated. It is shown that the Gaussian laser beams provide a defocusing transverse force that stops the acceleration process as ions propagate towards regions of smaller laser fields. On the other hand, the Laguerre-Gaussian (LG) laser beams with identical orbital angular momentum (OAM) can confine the on-axis ions radially as they accelerate to high energies. It is shown that the OAM of LG lasers can be used to control the angular momentum of the accelerated ion beam. The OAM is an intrinsic degree of freedom of light which leads to twisted phase fronts and can be described by higher order LG modes [3]. The interaction between OAM light with matter has been the subject of intense research over the last two decades [4]. Recently, intense LG lasers are used as drivers to excite large amplitude plasma waves for high gradient electron and positron acceleration in strongly nonlinear regimes [5].

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Electrostatic shock ion acceleration using a circularly polarized laser pulse

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Electrostatic shock has been attracting much attention due to its ion acceleration on moving shock front. When a driving laser pulse accelerates plasma block and heats up plasma medium, the block can propagate as the electrostatic shock reflecting incoming ions. Overdense plasma was required to transfer laser momentum to the block and a linearly polarized laser pulse was essential to heat up overdense plasma. We recently suggested electrostatic shock ion acceleration using a near-critical density plasma and a circularly polarized laser pulse (CP) for the first time. In this situation, continuous laser pressure effectively transfers its momentum to the block regardless of near-critical density plasmas. And plasma is heated via not JxB heating, but a combination of relativistic transparency and beat wave. Our particle-in-cell simulations show that high velocity electrostatic shock is early generated by CP in near-critical density plasmas. Due to high velocity, high energy ion beam is obtained than LP-driven shock. A quick generation of shock can increase a charge of reflected ion beam interacting with much ion in plasmas of finite size. And a formation of CP-driven shock is rarely affected by rear side plasma width but laser transmittance mainly influences on the shock formation. It means that CP-driven shock is instantly onset inside plasmas and heating process is strongly related with laser transmittance.

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Recycling of reflected laser pulse using an auxiliary plate in TNSA

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We suggest recycling of a reflected laser pulse using an auxiliary plate to boost ion beam in target normal sheath acceleration (TNSA). In an ordinary TNSA, a large fraction of the laser energy is reflected from the target. In our scheme, the auxiliary plate reflects back the reflected laser pulse to the main target again building up the accelerating sheath field. In two-dimensional particle-in-cell simulations, we observed that the maximum ion energy and the beam charge were increased by up to 60 percent and by a factor of three compared with the ordinary single-target system, respectively. Moreover, momentum angular distribution of the ion beam was adjusted as symmetry or anti-symmetry by controlling an angle of the second irradiation via an angle of the auxiliary plate. We found that the beam charge and the maximum ion energy are larger for shorter distance between the main target and the auxiliary plate. And the auxiliary plate is also effective in reinforcement of the sheath acceleration even in the presence of pre-plasmas. Our simple idea would be intuitively easy to understand and immediately apply to the experiment.

References

[1] Y.K.Kim, T.Y.Kang, M.Y.Jung and M.S.Hur, submitted (2017).