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Summary of working group 1: Electron beams from plasmas

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A R T I C L E   I N F O

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A B S T R A C T

We briefly summarize the contributions that have been presented in the Working Group 1 sessions, dedicated to electron beams from plasmas.

1. Introduction

Working group 1, "Electron beams from plasmas", covered laser-driven plasma acceleration beam-driven plasma acceleration, hybrid schemes, injection techniques and radiation generation. There was a strong interest in the working group. Seven sessions were filled, with 5 talks of 18 min in each session, a total of 35 talks. In the below we summarize the talks according to themes.

2. Beam-driven plasma wakefield acceleration (PWFA)

The FACET test facility at SLAC has been running from 2012 to 2016. Several new results were presented. C.A. Lindstrøm, U. Oslo, presented measurements of transverse wakefields in positron-driven hollow channel plasmas at FACET. Hollow channels with 500 um diameter of were created with a Gaussian laser passing through a kinoform focusing optics, and a positron drive bunch were used to probe the wakefields, yielding good agreement between measurement and theory. D. Ullmann, U. Strathclyde, presented the trojan horse injection, describing the trojan horse injection mechanism and the torch injection mechanism, showing preliminary results for the trojan horse injection at FACET. E. Adli, U. Oslo, described the attraction and guiding of an ultra relativistic electron beam initially moving parallel to a neutral plasma. This effect was observed experimentally at FACET.

The AWAKE experiment located at CERN presented a number of experimental results on proton-beam self-modulation, taken during the summer of 2017. M. Turner, CERN and TU Graz, presented measurements of proton defocusing due to strong transverse wakefields in the self-modulated beam. The results indicate stronger transverse fields than set up by a long proton beam, indicating the development of the self-modulation. F. Braunmueller, MPP and M. Martyanov, MPP showed complementary measurements of the proton-beam self modulation, based on frequency analysis of coherent transition radiation. The modulation frequency measured with heterodyne receivers agrees well with direct measurement of the modulation frequency using a streak camera. K. Pepitone, CERN presented the status of the AWAKE electron beam injection, showing that the commissioning is well underway and should be completed by the start of 2018. S. Doebert, CERN showed how a possible design of compact, short-bunch electron RF injector for AWAKE Run 2, based on an S-band gun and X-band accelerating structures. V. Minakov, BINP, presented emittance studies of the accelerated electron bunch in two-stage Run 2 AWAKE scenario. Effect of strong emittance blow-up is demonstrated and described and the dependence of this effect on the length of the vacuum gap is also studied with simulations.

FlashForward at DESY is commissioning the beam line and preparing the first experiments, expected to start in 2018. Mr. Knetsch, DESY, Hamburg, reported on the concept of producing high-brightness electron beams from a plasma cathode in the upcoming Flash-Forward X1 campaign. The speaker outlined the group's plans to use the Flash Accelerator's electron 1 GeV, 2.5 kA electron pulses to drive a plasma wave and inject a witness bunch by either density or laser ionization-induced downramp injection. G. Tauscher, DESY, Hamburg, presented theoretical and experimental studies on H_2 plasma generation, arguing that while standard ADK-theory works for in the long pulse regime, other effects including Hydrogen molecule dissociation may be important for shorter pulses, requiring full simulation of fragmentation dynamics. Dr. V. Libov discussed beam quality preservation in a plasma booster at

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FlashForward. High-quality 1 GeV-class electron beams with micrometer emittances from the free-electron laser FLASH will be utilized to generate driver–witness pairs by using a mask in a dispersive section. Alternatively, it is possible to generate two independent bunches directly in the photocathode electron-gun by using a double-pulse laser. He presented the physics case and the current status of the FLASHForward X-2 experiment. The experimental installation is described, with a focus on the electron beam line.

G. Loisch, DESY, Zeuthen presented experimental results on high transformer ratio experiments in the PITZ beam line. Using a ramped bunch profile, transformer ratios up to five were reported, a "first" for PWFA.

R. Pompili, INFN, Frascati, presented PWFA activities at SPARC_LAB including first results from their active plasma lens studies, and strong focusing with plasma lenses where reported, consistent with simulations.

3. Laser-driven plasma wakefield acceleration (LWFA)

The first two talks by Dr. Poder, Imperial College London (IC) and Mr. Couperus from HZDR, reported on important progress in classical laser-wakefield acceleration (LWFA), by outlining new routes to improving the beam parameters. The IC group reported on a dramatic increase in stability, charge and high-energy cutoff (> 2 GeV) when using an f/40 focusing geometry on the 250 TW ASTRA Gemini laser instead of the standard f/20 focus. This was attributed to enhanced bubble dynamics leading to reduced dephasing due to the weaker self-focusing action. HZDR reported on high-charge (250 MeV, > 200 pC), quasi-monochromatic beams from the 100 TW Draco laser. They employed a new self-truncated ionization-induced injection scheme, where loading of the wake occurs so rapidly by ionization-enhanced injection that the beam's own self-fields prohibit further self-injection after the first massive injection event. This leads to a very stable acceleration performance.

Prof. Hooker from Oxford University shifted the focus towards a new scheme for producing high-luminosity LWFA beams with future high-average power laser architectures, especially fibre or thin-disc burst mode lasers. Since such lasers will be delivering their energy in a pulse train instead of a single high-power pulse, the Oxford group experimentally investigated and successfully demonstrated the resonant excitation of wakefields with pulse trains from the ASTRA laser facility.

The last talk in the Monday session by Dr. Kando from KPSI Japan challenged the popular tacit assumption that in LWFA the electron beam is synchronized to the drive laser pulse within a few fs time window. He presented his finding that in a self injection scheme, albeit driven by a rather weak laser pulses, the timing jitter between driver laser and electron bunch can amount to several 100 fs. This was found by an electro-optic sampling measurement between the electron self-fields and a probe pulse split off the driver pulse. If N_2 is added to the target gas to support ionization injection, this jitter vanishes within the measurement accuracy of approx. 100 fs. A possible explanation is that it takes several plasma oscillation periods for the wave to break in the self-injected scheme with a weak driver, and that this breaking point depends on laser parameter fluctuations. This finding warrants a closer look also in other experiments before claims regarding the alleged synchronization between laser and electrons/X-rays can be made.

4. Hybrid LWFA–PWFA schemes

Dr. A. Martinez De La Ossa (DESY) showed a laser-to-beam-driven plasma wakefield accelerator. He combined a LWFA stage providing an electron beam which subsequently drives a PWFA stage in the highly nonlinear regime. This scenario explicitly makes use of the advantages unique to each method, particularly exploiting the capabilities of PWFA schemes to provide energy-boosted high-brightness beams, while the LWFA stage inherently fulfils the demand for compact high-current electron bunches required as PWFA drivers. He presented a design study based on theoretical considerations and full-detailed particle-in-cell simulations, aiming to address the feasibility and the capabilities of this promising strategy.

Mr. Max Gilljohann (Ludwig-Maximilians-Universität München) presented his talk about the research Towards Hybrid Accelerators. In his talk he presented the first direct observation of laser-accelerated electron bunches driving their own wakefields in an independent gas target, which is a first step towards a table-top plasma wakefield accelerator. Furthermore, he showed measurements of a controlled injection technique that can be used to generate stable driver and witness bunches, for which simulations indicate the possibility of actual beam-driven wakefield acceleration of the witness bunch in their upcoming experiments.

5. Injection

This session started with a talk by Dr. Döpp from LMU Munich on an in-depth parameter study of different ionization mechanisms and their combination to produce multiple controlled electron bunches. While the baseline setup produced high-charge (> 200 MeV, > 250 pC), low divergence beams with unprecedented spectral density and bandwidth from a shock-front injector driven by the 100 TW ATLAS laser, the study showed the effects of combining this approach with ionization injection (higher stability, more charge), colliding pulse injection (two independently tunable bunches) and the ensuing effects of beam loading (spectral narrowing and downshift) for the first and/or both pulses collectively.

The talk by Mr. Rozario from Imperial College reported on recent findings with clustered gas targets in a LWFA scenario, where an improved charge and energy was recorded for cluster-enhanced injection. The speaker presented the results of OSIRIS-simulations that underpin an enhanced ionization injection regime due to the efficient cluster absorption of laser energy and a possible enhanced self-guiding regime in the cluster medium.

The next two talks by Mr. Candeias Lemos, University of Rochester (LLE), and Mrs. Gallardo Goncales from Lund University both presented very similar, but independent findings on the onset of direct laser acceleration (DLA) in an ionization-induced LWFA scenario. In both cases, ionization injection loaded the bubble so strongly that the head of the electron bunch interacts with the driving laser pulse's tail and a characteristic 2-lobe angular electron emission pattern was observed in the laser polarization direction. Together with an observed laser energy transfer into the lobes' electron populations, according to PIC simulations, this signature is characteristic for DLA. In the LLE experiment, the overlap was achieved by increasing the overall plasma density and reducing the plasma wavelength relative to the laser duration, in Lund a similar effect was achieved by increasing the nitrogen concentration for ionization injection, which prevents injection from terminating too early.

The final talk in the Thursday session came from Mr. Ekerfeldt, also from Lund, on a PIC-simulation-based parameter study of density-down-ramp trapping. The parameters density step height and width were varied in a series of PIC runs in order to study their influence on injected charge, bunch length and bunch emittance. Mr Ekerfeldt's findings indicate that while the charge increases by lengthening the density gradient, this adversely affects the longitudinal and transverse bunch emittance, underlining the need for steep plasma gradients for high-quality beam production in pure downramp/shock-front injection schemes.

6. Radiation generation

Mrs. A. Hannasch from University of Texas (Austin) presented Inverse-Thomson scattered X-rays from laser plasma accelerators and plasma mirrors. They converted a GeV laser-plasma accelerator (LPA)

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driven by the Texas Petawatt Laser into a compact, femtosecond-pulsed, tunable gamma-ray source by inserting a 12 to 100 μm-thick transparent low Z (glass or plastic) foil ~3 cm after the accelerator exit. The foil acts as a plasma mirror (PM) that retro-reflects spent drive laser pulses (1.17 eV) with field strength a0 ~ 0.3 back onto trailing electrons (peak Lorentz factor tunable from 1000 to 4400). Scaling of the generated signal with PM position, thickness and material indicates also that bremsstrahlung generated by GeV electrons within the PM is negligible. Resulting gamma-ray photon energy, inferred from the measured electron energy distribution on each shot, was peaked from 5 to 85 MeV.

Dr. Jonathan Wood (Imperial College, London) discussed Enhanced Betatron Radiation from a Laser Wakefield Accelerator in a Long Focal Length Geometry. A self-guided, self-injecting laser wakefield accelerator driven by a 120 TW laser pulse was implemented in a long focal length (f/40) geometry. Electrons were accelerated beyond 1.9 GeV in a 10 mm long plasma while maintaining a betatron source size below 0.5 micrometres. When the plasma length was extended beyond 10 mm a second electron bunch was injected with a high charge per unit bandwidth, which increased the number of betatron X-ray photons by a factor of five at moderate photon energies (16 keV critical energy). Simulations suggest this second injection resulted from a dynamic evolution of the bubble size. By further increasing the laser power to 240 TW the peak brightness of the betatron beam increased too, with the whole beam containing 3×10^{10} photons above 1 keV.

J. Ferri from Chalmers University of Technology showed that due to a difficulty to both optimize the electron energy and wiggling in compact and spatially coherent X-ray betatron sources driven by laser-plasma accelerators, betatron sources is limited by a low energy efficiency and a photon energy in the 10's of keV range. He proposed a scheme that improves the energy efficiency, with about 1% of the laser energy transferred to the radiation, and that the gamma-ray photon energy exceeds the MeV range when using a 15 J laser pulse. This would allow to achieve MeV betatron sources.

Dr. A.R. Rossi (INFN Milano) presented simulation results about high brightness, plasma boosted beams for driving a Free Electron Laser (FEL) with wavelength below 1 nm. This work is in the framework of the EuPRAXIA project. A 30–40 pC, sub micron normalized emittance, electron bunch with 500 MeV energy and longitudinally compressed down to few tens of fs is injected in a laser driven plasma wave. There, its energy is brought to 1 GeV (and up) by preserving, as much as possible, its good quality and high peak current. Insertion and matching into plasma is accomplished by either standard, high performances, beam optics or by plasma sensing effects. At plasma exit, a similar strategy is employed as well as for matching into an undulator. By employing different plasma target, he discussed about working point stability and showed FEL performances for a few selected cases.

7. Techniques to improve on acceleration techniques and beam quality

Dr. Alexander Debus (Helmholtz-Zentrum Dresden-Rossendorf) proposed a Travelling-Wave Electron Acceleration scheme moving beyond the dephasing and depletion limits of laser-wakefield acceleration. He has shown how to simultaneously solve several long standing limitations of laser-wakefield acceleration that have thus far prevented laser-plasma electron accelerators (LWFA) to extend into the energy realm beyond 10 GeV. His scheme, called Travelling-Wave Electron Acceleration (TWEAC), eliminates both the dephasing and depletion constraints. The wakefield driver is a region of overlap of two obliquely incident, ultrashort laser pulses with tilted pulse-fronts in the line foci of two cylindrical mirrors, aligned to coincide with the trajectory of subsequently accelerated electrons. TWEAC leads to quasi-static acceleration conditions, which do not suffer from laser self-phase modulation, parasitic self-injection or other plasma instabilities.

Dr. Daniel Papp (ELI-ALPS, ELI-HU) presented Laser wakefield electron acceleration with high power, few-cycle mid-IR lasers. The study of LWFA using mid-IR laser drivers is a promising path for future laser driven electron accelerators, when compared to traditional near-IR laser drivers operating at 0.8–1 μm central wavelength (λ_{laser}), as the necessary vector potential (a_0) for electron injection can be achieved with smaller laser powers. In this work, he performed 2D PIC simulations with λ_{laser} ranging from 0.8–3.2 μm. Such few-cycle systems are currently under development, aiming at Gas High Harmonics Generation applications, where the favourable $(\lambda_{laser})^2$ scaling extends the range of the XUV photon energies. By keeping a_0 and n_e/n_{cr} (n_e being the plasma density and $n_c r$ the critical density for each λ_{laser}) as common denominators in simulations, they have done comparisons between drivers with different λ_{laser}, with respect to the accelerated electron beam energy, charge and conversion efficiency. While the electron energies are mainly dominated by the plasma dynamics, the laser to electron beam energy conversion efficiency shows significant enhancement with longer wavelength laser drivers.

Dr. S. Romeo (LNF-INFN) presented a high quality plasma wakefield acceleration experiment in the linear regime at SPARC_LAB. Starting from well established cold fluid plasma model, he presented a set of equations to describe the fields generated by a low quality driver. Those equations will be used to fix the trailing bunch requirements for an high quality acceleration. In such a way the high brightness trailing bunch suffers a lower degradation while accelerated in a linear regime plasma wakefield, with beam loading effect results to be not negligible for this kind of trailing bunches in realistic situations. By assuming energy spread compensation, he demonstrated that the transverse matching of the trailing bunch does not depend on driving bunch parameters.

Dr. J. Vieira (Instituto Superior Tecnico) presented Particle acceleration in twisted plasma waves with orbital angular momentum. He showed a technique on how to control the individual trajectories of plasma electrons and investigated the properties of structured plasma waves that contain orbital angular momentum. Twisted plasma waves can generate helical particle bunches, where individual bunch particles execute spiralling trajectories that can be driven by light spring laser drivers, which are characterized by spiralling intensity profiles. As a result the phase velocity of twisted plasma waves driven by the light spring drivers can be regulated in parabolic plasma channels, and that this property might be attractive to extend the acceleration distances.

Prof. G. Fiore (Università Federico II, and INFN, Napoli) presented the impact of short laser pulses on cold low-density plasmas. By applying a recently developed plane hydrodynamical model to the impact of a very short and intense laser pulse normally onto a diluted plasma at rest, he determined the motion of the plasma electrons shortly after the beginning of the laser-plasma interaction and analytically derived the main features of the induced wakefield in the plasma.

Dr. J. Holloway (The University of Oxford) presented two-Pulse Ionization Injection with simultaneous space–time focused pulses. Controlling the injection of electrons into laser wakefields is important for improving the quality of the accelerated bunches, and reducing their shot-to-shot jitter. He proposes the two-pulse ionization injection (2PII) scheme in which electrons ionized from a dopant species by a tightly focused trailing pulse are trapped in the quasi-linear wake driven by a leading pulse. It provides tighter localization of the injection, leading to reduced energy spread and reduced emittance. PIC simulations were presented showing how this approach can improve the electron bunch properties and control the spectrum and brilliance of betatron X-rays they generate.

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