Summary of Working Group 5: Plasma devices, plasma and beam diagnostics

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Abstract. The presentations and proceedings of Working Group 5 (plasma devices, plasma and beam diagnostics) at the fourth European Advanced Accelerator (EAAC) Workshop reported on experimental demonstrations and simulation studies for new concepts in the field of plasma/beam diagnostics and plasma devices. New schemes, as well as the development of those already well benchmarked, were described, covering a breadth of concepts ranging from the diagnosis of how both hot and cold plasmas evolve in time to how in time they may be applied to future high-energy-physics and photon science facilities.

1. Introduction

The discussions and presentations in Working Group 5 covered a wide range of experimental demonstrations and simulated concepts, generally falling into the categories of techniques used to diagnose & optimise properties of plasma-wakefield systems and then the subsequent application of these optimised plasma-based schemes to outstanding problems within the field. As such, the summary of this working group is separated into the following sections:

• Diagnostics for both cold and hot plasma properties
• Diagnostics for particle beams
• Application of plasma-based concepts and devices for future facilities

2. Plasma diagnostics

A precise understanding of the plasma spatial and temporal profile is essential in order to produce high quality beams. Several groups are working on such characterisation and reported their results during the conference.

The FLASHForward team at DESY reported [1] on the use of two different methods to measure the evolution of the plasma density with time: two-colour laser interferometry and atomic emission spectroscopy. They reported excellent agreement between both methods. This information was then used for a better modeling of the longitudinal profile of the plasma. In Oxford a multi-pulse laser system was used to perform frequency domain holography on a temporally evolving plasma [2]. The Frascati group have built a setup where the plasma density is measured using the spectral enlargement of the radiation emitted (Stark broadening effect) analogous to one of the methods performed at FLASHForward [3]. The University of Jena group [4] used few-cycle microscopy to record shadowgrams [5] and polarograms, both used to...
gain a deeper insight into the plasma properties. This technique allowed that group to observe an unexpected result: interesting modulations in asymmetric raman scattering was observed with the magnitude and direction of this phenomena clearly correlated to the direction of the laser chirp [6]. The AWAKE team reported that, by varying the arrival time of the protons relative to the seed laser, they could infer the evolution of the plasma column [7].

The University of Colorado group developed the well-known conception that, in beam-driven plasma-wakefield accelerators (PWFA), a mismatch between the drive beam and the plasma can lead to significant beam quality degradation and thus transverse emittance increase [9]. However, to ensure correct matching they recommended the use of a passive plasma lens (cf Sec. 4) that would focus the drive beam to the required size. The group at the University of Oxford investigated the production of plasma channels with axicon lenses, further reporting on the numerical modelling of chromatic effects in such setups [10].

3. Beam diagnostics
As well as a clear understanding of the plasma properties, it is essential to also make accurate measurements of both the driver and witness beams in any plasma accelerator experiment. Interesting new developments were reported during this conference.

The FLASHForward team at DESY reported on the comparison between integrating current transformers (ICTs) and resonant cavities as devices to measure the bunch charge [11]. It was shown that cavities are less sensitive to the electromagnetic noise. Additionally at DESY, silicon strips from the ATLAS detector were used as position detectors for a spectrometer [12].

Several speakers reported that mismatched beams in the transverse plane may lead to emittance blow up and filamentation. The LOA teams proposed a method to measure the gamma rays emitted due to the betatron oscillation of the beam in order to characterise this phenomenon [13]. The CLEAR facility at CERN was used to test a beam position monitor based on Coherent Cherenkov diffraction [15]. The group from University of Colorado presented a device based on electro-optical sampling (EOS) to measure the beam position [14]. The beam position monitor based on EOS proposed by the University of Colorado has the advantage of also giving information on the longitudinal profile of the bunch. Also using EOS, the Frascati team has shown their ability to distinguish fast electrons from protons during TNSA experiments with the FLAME laser [16]. The FLASHForward group at DESY reported on their recent commissioning of a Transverse Deflection Structure (TDS) operating in the X-band regime, to be used in future for diagnosis of the longitudinal and transverse properties of driver and witness bunches in PWFA experiments [17]. Also using a TDS the SwissFEL team presented simulations showing that they could achieve a resolution of 350 as on the temporal profile of a Dielectric Laser Accelerator [18].

Using transition radiation, the Dresden group has observed sub-fs micro-structures in laser-driven plasma accelerator (LWFA) electron bunches, subsequently comparing the micro-structure produced from different internal injection regimes [19]. At CERN the CLEAR team compared several coherent radiation phenomena and, despite being well within the formation length of the radiation, no shadowing was observed [15]. Looking at the Future, the SLAC group reported on the use of Machine Learning to create virtual diagnostics [20]!

4. Plasma applications
The previous sections of this summary have outlined some of the excellent diagnostics work being carried out within the community with the aim to better understand the properties of the laser/particle beams driving the plasma acceleration process as well as those of the plasma environment in which this process occurs. Once these beams and plasmas are accurately diagnosed and understood it becomes possible to then start considering the ways in which their favourable properties may be applied to other challenges faced within the field.
The strong focusing gradients inherent to plasma acceleration schemes results in highly divergent beams upon exit of the plasma environment. As such, these beams are difficult to capture and refocus using conventional optics. Active plasma lenses, with their large kT/m gradients and radially symmetric focusing, offer one route to solving this problem. Recent studies performed at the CLEAR facility, CERN, have demonstrated that, by operating within a specific parameter range using heavy gas species, these high-gradient devices can operate aberration-free [21]. Having explained the origin of non-linearities in these devices the ultimate goal would be to construct an apochromatic lattice from these plasma lenses in order to capture and couple beams between acceleration stages, the concepts of which were presented by The University of Oslo group [22].

Due to the demonstration of these active plasma lenses operating free of aberrations, interest in their use to address other challenges in the field has arisen. For example, recent studies performed by Berkeley demonstrated the radially symmetric focusing of laser-accelerated MeV-level proton beams with an active plasma lens [23]. The Frascati group also devised the use of a tunable active plasma lens and a metallic collimator to catch & transport a witness bunch whilst removing the driver [24]. Although this concept remains a work of simulation with possible limited use at high average powers it demonstrates the interest in utilising the high gradients of plasma devices beyond that of simply accelerating particle beams.

Plasma lenses offer an exciting route to strongly capturing highly divergent beams exiting plasma. However, particle beams accelerated in intrinsically high-gradient plasma environments will develop a large correlated chirp if left unchecked. It is therefore essential to mitigate these energy spreads, expected to be on the tens-of-percent-level in some schemes, in order to avoid deleterious chromatic effects when focused with high gradients. Work performed by the FLASHForward team at DESY has been presented on how to use the large decelerating gradients generated and subsequently experienced by a particle bunch driving a plasma wakefield to remove this correlated chirp with dechirping gradients orders of magnitude beyond other state-of-the-art methods. If these types of plasma dechirpers can be operated in a staged way they could drastically improve the applicability of plasma acceleration schemes to future facilities.

In addition to the utilisation of plasma devices in a standalone scheme, they may also be combined with other novel accelerator hardware in a hybrid approach. For example, a hybrid guiding scheme was proposed whereby a dielectric capillary tube, inside which a plasma channel is generated, may be used to efficiently guide a high intensity laser focused at the entrance of this structure by the combined refraction of the channel and reflection at the capillary walls. The efficiency of this guiding scheme as a laser-plasma accelerator has been investigated through numerical simulations by the CNRS team [26]. Additionally within the context of laser-plasma accelerators, conventional approaches may be used in a novel accelerator environment to manipulate the electron beam phase space, dispersion, and energy spread in order to tune the wavelength of spontaneous emission in an undulator beamline. This concept was shown by the Synchrtron SOLEIL team at LOA [27].

5. Conclusions
The presentations and discussions of Working Group 5 covered a wide range of topics, focusing on how to better understand the beams and plasmas in plasma-wakefield schemes through improved diagnostics methods and subsequent optimisations, with considerations as to how these optimised high-gradient plasma schemes may be used to solve some of the outstanding problems within the field. The plethora of experimental results from recent years demonstrate the acute interest in optimising the already exciting field of plasma acceleration. When added to the discussions and simulations of ways in which these novel accelerator schemes can be further developed in future, the outlook for the community seems bright indeed.
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