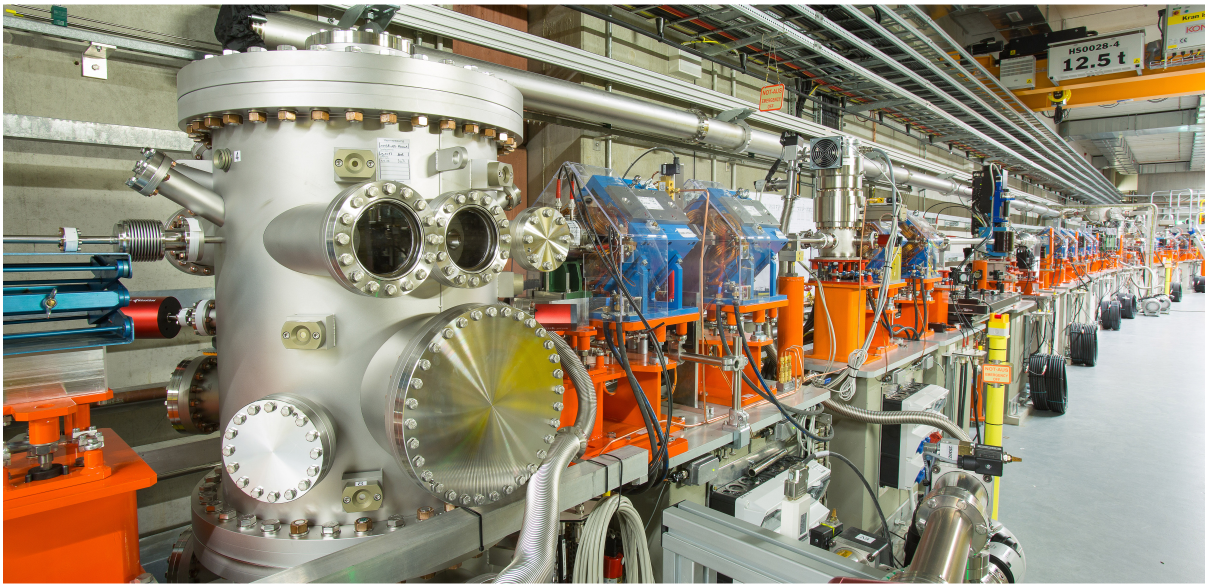

Figure 1. The FLASHForward electron and laser beamlines upstream of the central interaction chamber (2018-01-23).

General Information and Project News

The commissioning of the FLASHForward beam line is now well under way. This includes: lossless transmission to the dump; comprehensive diagnostics studies (electron spectrometer, emittance measurements, etc.); e-beam transmission through the 1.5 mm diameter plasma cell; and preparation for operation with gas and plasma in June.

In the laser laboratory, known as the BOND lab, the differential pumping cube for 10 Hz operation has been installed. Preparations to benchmark the first FF» plasma cell before installation in the tunnel during the FLASH summer shutdown are under way. Research into active plasma lenses also continues.

The entire DESY laboratory has recently been intensively reviewed as part of the POF ("Programme-Oriented Funding") exercise carried out in all Helmholtz Association Laboratories every five years. DESY in general received an excellent review; in particular, FLASHForward was given the highest review grade of "outstanding".

Members of the FLASHForward group played a full part in recent meetings, including the ALEGRO workshop in Oxford in March, looking at the specification of a future particle-physics collider as an input into the CERN Strategy discussions which will begin in 2019. Group members also attended the IPAC18 conference in Vancouver at the end of April.

One paper has been published by group members since the last Newsletter:

M. Gross, J. Engel, J. Good, H. Huck, I. Isaev, G. Koss, M. Krasilnikov, O. Lishilin, G. Loisch, Y. Renier, T. Rublack, F. Stephan, R. Brinkmann, A. Martinez de la Ossa, J. Osterhoff, D. Malyutin, D. Richter, T. Mehrling, M. Khojoyan, C. B. Schroeder, and F. Grüner, "Observation of the Self-Modulation Instability via Time-Resolved Measurements", *Physical Review Letters* 120, 144802 (2018)

We are pleased to welcome Jimmy Garland to the group. He has joined us from CERN in May as a DESY Fellow. His primary area of work will be the investigation of the efficacy of CSR-induced centroid-offset mitigation through the implementation of an additional bunch compressor in FF».

Congratulations also go to Lena Kononenko, who successfully defended her thesis "Controlled Injection into Laser-Driven Wakefield Accelerator" on May 24th.

A date for your diaries: the first FLASHForward Users Meeting will take place at DESY on 4th - 6th December 2018. Further information will be provided nearer the time.

Follow the group on Twitter at **@FForwardDESY** or visit us online at **forward.desy.de**

WG1: Plasma simulations

Coordinators: Alberto Martinez de la Ossa (UHH), Jorge Vieira (IST)

Hose instability studies

A manuscript entitled “Intrinsic Stabilisation of the Drive Beam in Plasma Wakefield Accelerators” has been submitted to Physical Review Letters. This article proposes an effective solution to the hose instability of the drive beam in plasma wakefield accelerators (PWFAs). It is shown that the beams can be rapidly stabilised (see Figure 1) by appropriately adjusting the transverse size of the drive beam at the entrance of the plasma target. Owing to the intrinsic variation of the focusing fields along the drive beam under these conditions, different parts of the beam oscillate incoherently, thereby preventing the onset of the hosing instability. This stabilisation principle is of fundamental importance for the stable operation of PWFAs and future applications based on PWFAs.

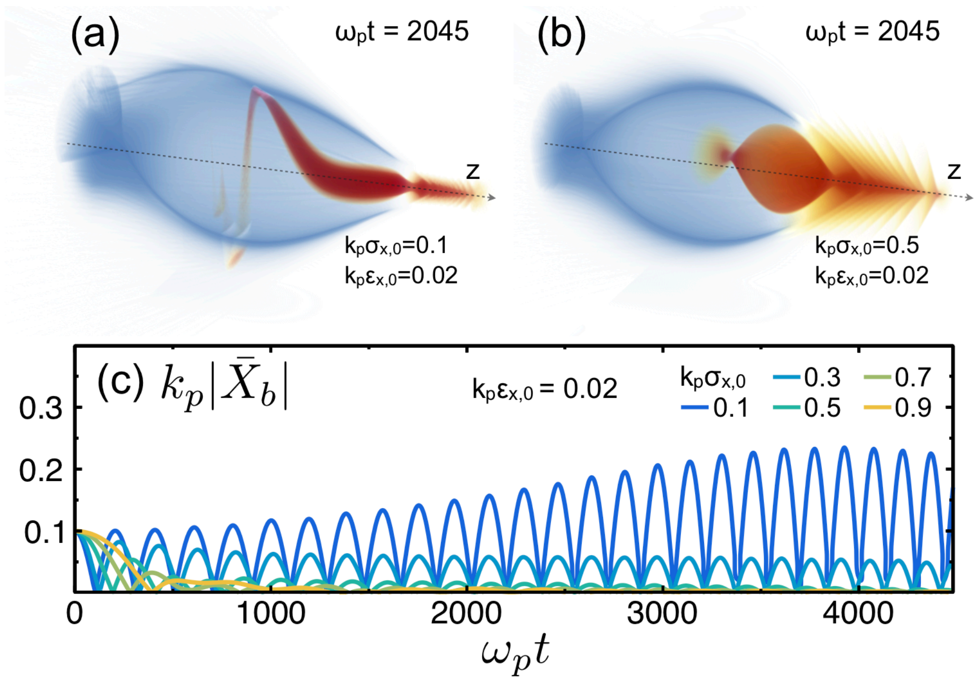

Figure 1. Results from HiPACE simulations showing the beam (red) and the plasma (blue) electron density after some propagation. (a) A narrow beam with an initial tilt is driving a plasma wave in the blowout regime and undergoes hosing. (b) The same beam with a five times greater spot size at focus exhibits stable transport. (c) Average centroid deviation evolution for the central slice of the driver beam for five different cases with different spot size values at the vacuum-to-plasma interface.

Start-to-end simulations

A new HiPACE simulation employing an optimised driver/witness double bunch has been carried out. The beams were optimised for minimal transverse centroid deviations at the plasma target (see WG2 report). In order to suppress further the onset of the hosing instability, the transverse size of the driver beam at the plasma entrance is adjusted to the plasma blowout size (see above), while the witness beam is at a waist and matched to the focusing fields for emittance preservation. As a result of this optimisation, the drive beam could propagate in a more stable way and the witness beam could be successfully transported and accelerated (see Figure 2).

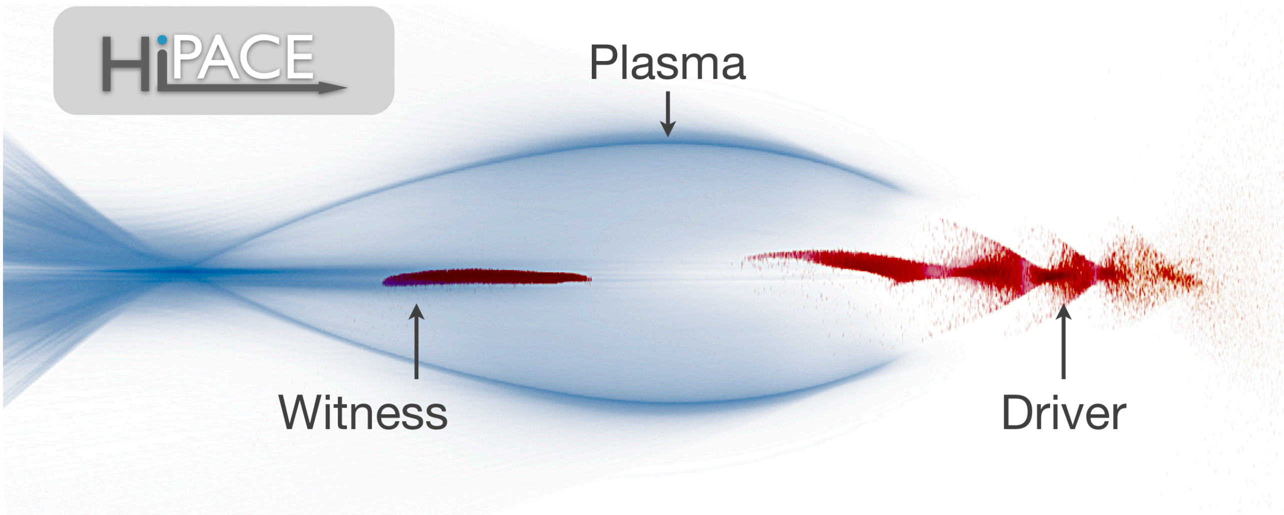

Figure 2. Results from a HiPACE simulation showing the driver and the witness beams (red) together with the plasma (blue) electron density after some propagation.

WG2: Beam dynamics and instrumentation

Coordinators: Vladyslav Libov (UHH), Ivan Konoplev (JAI)

Electron beamline commissioning

At the time of writing the previous WG2 report, the electron beamline was installed down to the screen station in the final-focusing section (named 8FLFMAFF due to its placement 8 m into the FF» matching and final-focussing section), and the commissioning of the beamline had just begun. In January 2018 construction of the beamline was completed, including installation of the missing beam pipe down to the target chamber, the chamber itself, and the diagnostic section downstream of it. Recent work in the WG2 was therefore focused on commissioning of the newly installed beamline.

Beam transmission to dump — After the beamline installation was complete and the vacuum levels were good enough to open all valves, beams were sent to the dump. Initially there were problems with transmission through the thin beam pipes of the differential pumping sections (10 mm inner diameter). This was due to misalignments, which were fixed by adjustments to the beam-pipe supports.

The plots in Fig. 3 show beam images on the 8FLFMAFF screen station and in the electron spectrometer (3FLFDIAG), which acts also as the beam dump (a glass window flange is installed at the end of the beamline, 10m downstream of the plasma target, which prohibits sending the electron beam through it due to charge build-up; therefore, the 3FLFDIAG operates as a dump and is included in the technical beam interlock).

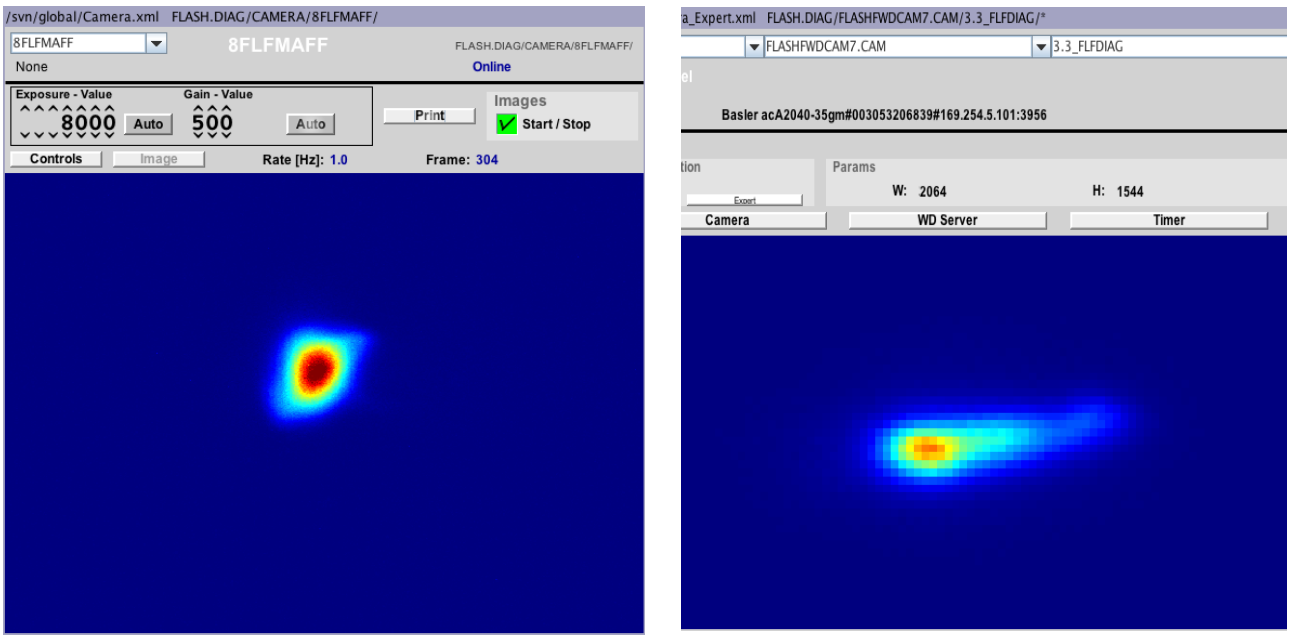

Figure 3. Profile images of the electron beam at the scintillating screens 8FLFMAFF (left) and 3FLFDIAG (right).

Parallel operation with FLASH1, large RF steps — Various tests were performed in order to demonstrate that FLASHForward operation doesn't affect FLASH1. This allowed increasing operation time dramatically by running in parallel with FLASH1 users, when no program for FLASH2 users is planned. Additionally, having future parallel operation with FLASH2 in mind, cross-talk studies between FLASHForward and FLASH2 were performed: FLASHForward magnets were ramped to maximal currents (in both positive and negative directions), and FLASH2 electron and photon beam positions, as well as the photon beam intensity were recorded. This process identified which FLASHForward magnets affect FLASH2 operation.

Another important milestone to facilitate parallel operation with FLASH1 was the demonstration of large RF-steps between FLASH1 and FLASH2 i.e. operation of two beamlines with very different RF settings. This allowed, for example, full beam compression in FLASH1 (as required for SASE operation) and on-crest operation in FLASHForward (as typically needed for beam optics studies), further increasing FLASHForward operation time.

Orbit response — For plasma wakefield experiments it is vital to have good control of the transverse beam phase space at the entrance of the plasma cell, which in turn requires good understanding of the beamline.

A powerful way to test the theoretical beamline model is by performing so-called orbit-response measurements. This essentially represents measurements of the transport matrix elements R_{12} and R_{34} between an arbitrary corrector magnet and an arbitrary beam position monitor. The corrector current, which controls the angular kick imposed on the beam, is varied in a specific range. The resulting dependence of the beam position measured with the BPM is recorded and fitted with a polynomial. The slope of the fit represents the corresponding matrix element (R_{12} for horizontal corrector, R_{34} for the vertical). The matrix element is then plotted as a function of the position of the BPM and compared to theoretical expectations.

Prior to the measurements, BPMs were calibrated using the same procedure i,e. switching off the quadrupoles and sextupoles between a given beam steerer and BPM (thus ensuring there is only a drift space between them. The offset on the BPM is then calculable from corrector current and the drift length.

Figure 4 shows the R_{12} matrix element from the H4FLFCOMP and R_{34} from V6FLFEXTR variations. Theoretical values are computed with Elegant, based on the design optics R56-opt. Good agreement is observed, confirming that the positions of the magnets, their magnetic field measurements, current calibrations and the control system are well understood.

Energy-measurement studies — Energy-spectrum measurements before and after the plasma interaction are crucial for the PWFA experiments. These measurements can be performed at FLASHForward using the 14FLFCOMP scintillator screen (located in the FLF-COMP dispersive section), as well as with the dedicated electron spectrometer after the plasma cell (D3FLFDIAG). The latter was originally designed as a broadband, low-resolution (few %) device; however, with suitable optics, its resolution can be significantly improved, at the cost of the reduced energy bandwidth. To test its resolution, and to evaluate the energy-measurement capabilities of 14FLFCOMP, comparative measurements were performed.

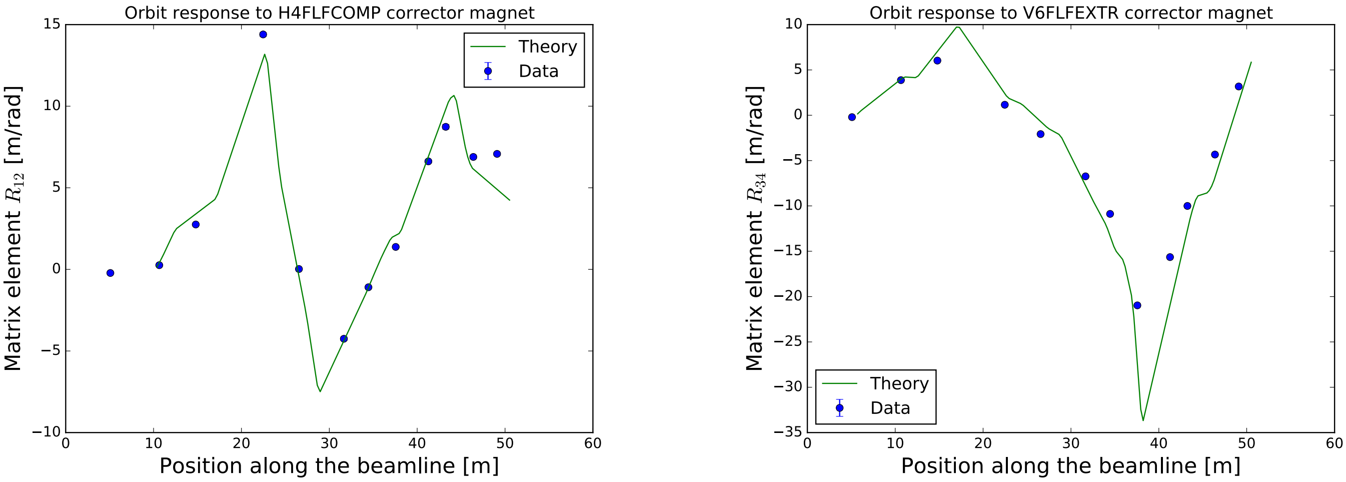

Figure 4. Orbit response of the beam, as measured by a series of BPMs in the beamline, with the horizontal corrector 4m into the FF» compression section (left) and 6m into the FF» extraction section. Also shown are the theoretical values (solid line) computed using elegant, based on a design optic with an optimised R56 value.

Different energy spreads were set and measured in the dispersive section of the FLASH1 LOLA TDS (6SDUMP) as well in the FLASHForward branch.

Figure 5 shows the comparison between the observed energy profiles from all three methods (Screen1 stands for 14FLFCOMP). The left plot represents the so-called Minimum-Energy-Spread case, where the energy spread of the beam is minimised and is equal to $3\text{x}10^{-4}$ rms (as follows from the high-resolution 6SDUMP measurement). The observed profiles from both the 14FLFCOMP and 3FLFDIAG are wider, and therefore allow estimates of their resolution from the width of the distributions - both are around $7\text{x}10^{-4}$ rms. The plot on the right

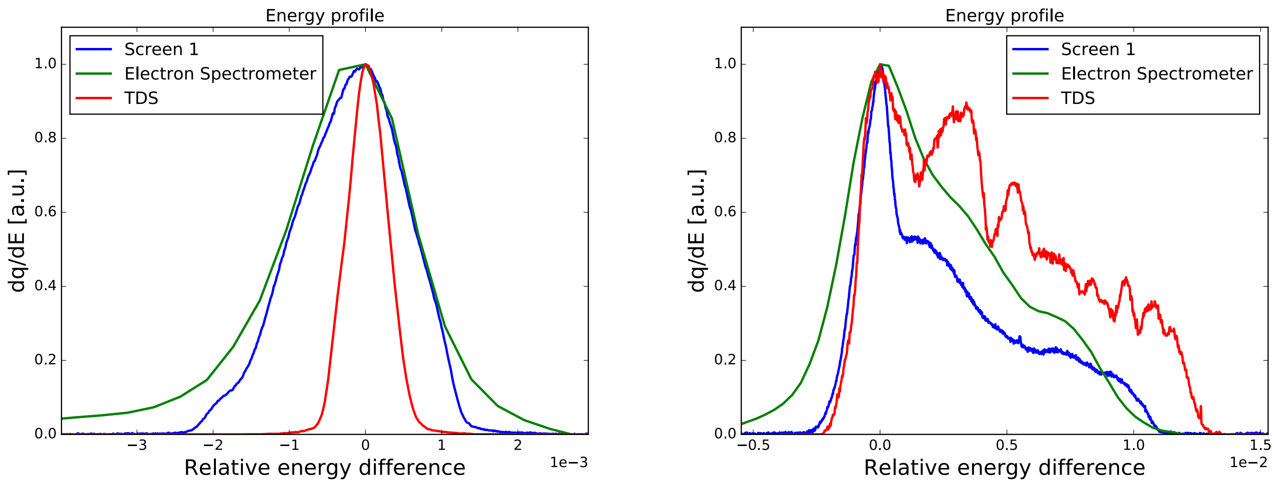

Figure 5. Beam energy profiles measured with three discrete diagnostics: a screen located in the FF» dispersive extraction section (Screen 1); the FF» electron spectrometer; and the LOLA S-band TDS in the FLASH1 beamline. Energy profiles are show for two compression scenarios: minimum energy spread (left) and a beam compressed to 500 fs.

represents the compressed beam (800A, 500 fs). The widths of all three measurements are comparable for this case ($3\text{x}10^{-3}$ rms). This demonstrates that energy spectra of beams with energy spreads at a few per mille level can be indeed measured, which is sufficient for the first plasma experiments. The resolution of both measurements in FLASHForward can be further increased if needed: the resolution of the 14FLFCOMP station is limited by the horizontal beta function, while that of the electron spectrometer is determined by the scintillator screen resolution as well as the optical system.

Beam optimisation (start-to-end simulations)

Efforts to mitigate the effects of coherent-synchrotron-radiation on the beam quality, namely reduction of the beam-centroid offsets which lead to the hosing instability, were further continued in WG2, in collaboration with WG1 (see previous section for complementary information).

One of the ways to reduce these offsets is a judicious choice of electron beam optics in and between the bunch compressors of FLASH. As an example, Fig. 6 shows the dependence of the emittance after the final bunch compressor of FLASH (the so-called BC3) on the Twiss

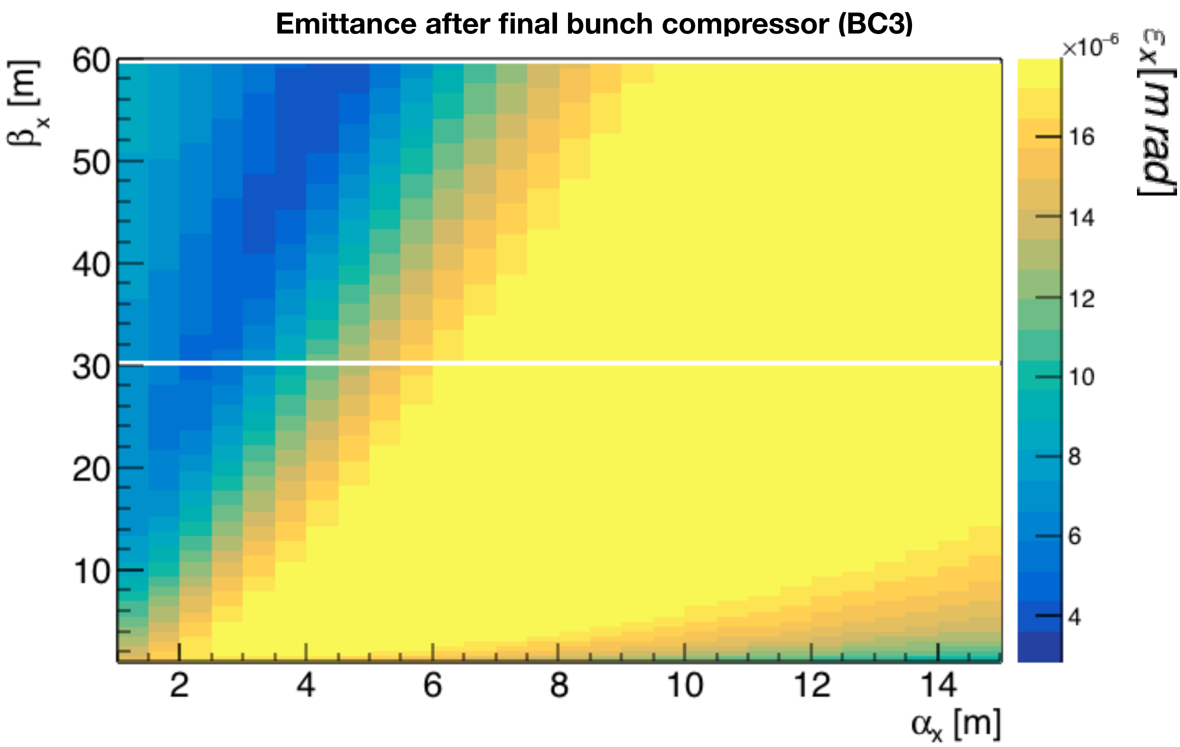

Figure 6. Emittance after the third and final bunch compressor in the FLASH Linac as a function of the transverse Twiss parameters directly in front of it.

parameters in front of it. Clearly, beam optics in the compressor affect the emittance growth significantly and an optimal working point exists.

Figure 7 shows various beam profiles (current, centroid in the horizontal-longitudinal and in the vertical-longitudinal planes) before and after optimisation (blue and red curves, respectively). The offsets in the horizontal plane are significantly reduced after applying the procedure. The effects of CSR do not appear in the vertical, non-dispersive plane. The beam is, therefore, symmetric in both cases.

Other ways to mitigate the centroids, e.g. addition of a third bunch compressor in the

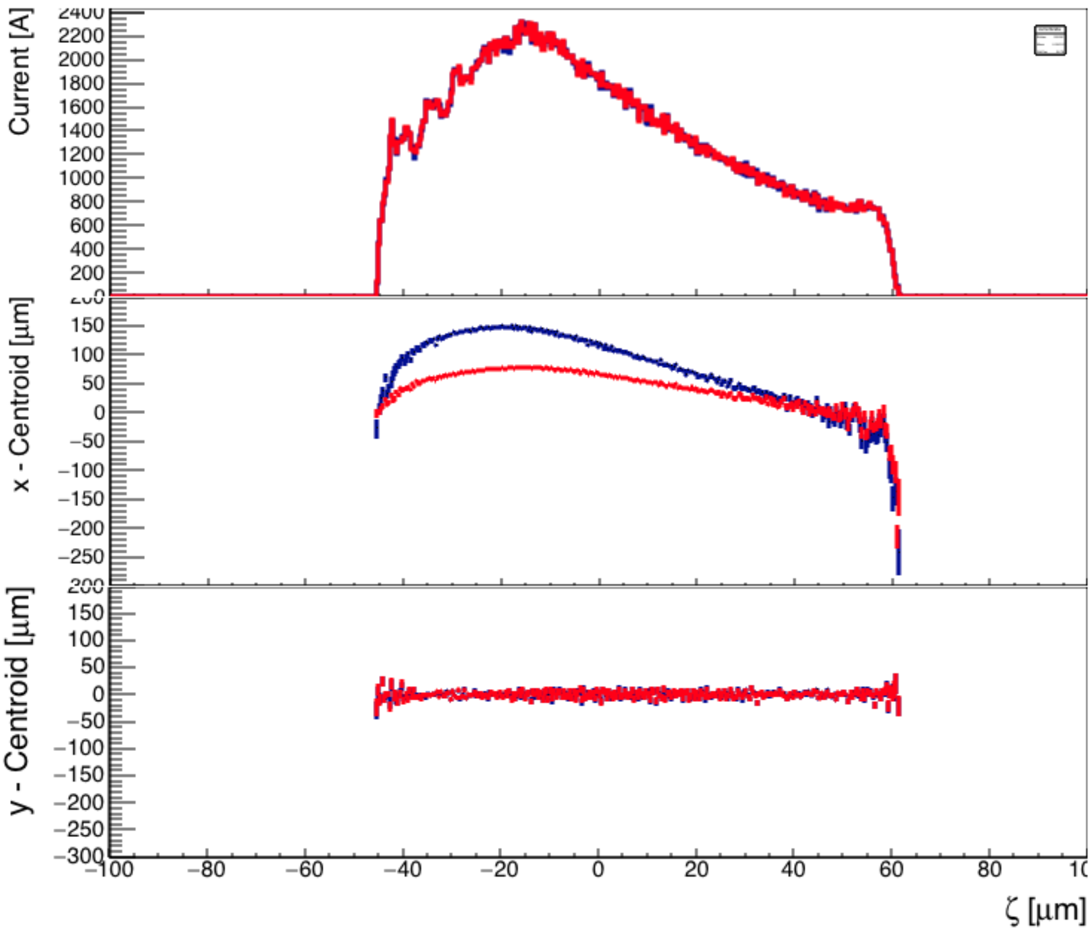

Figure 7. Profiles of the beam current, x-centroid, and y-centroid all as a function of the longitudinal coordinate of the bunch. The two curves per plot represent the beam profiles before (blue) and after (red) optimisation to minimise the CSR-induced centroid offset.

FLASHForward beamline, are under study.

Beamline upgrade

The current beamline will be extended to accommodate an X-band transverse deflection cavity downstream of the plasma cell. The corresponding conceptual design, including specifications of magnets and diagnostics types, is ready, and the current focus is on the technical design. The first version of the 3D model was already produced by the DESY ZM1 group, based on the design developed in WG2. This allowed identification of several minor contentions between components which have already been fixed by adjusting the component position in the lattice design. The final drawings are currently underway and will be presented in subsequent newsletters.

WG3: Plasma sources

Coordinators: Lucas Schaper (DESY), Patric Muggli (MPP)

FFWD beamline installation

After problems with the 6D plasma-cell holder-mover system, the FLASHForward target chamber had to be temporarily removed from the beamline tunnel and was replaced by a pipe to allow experiments with electron beam optics as well as further tweaking of the laser beam focus and diagnostics to continue. With the mover fixed, the complete target and its infrastructure were installed such that first experiments will be possible in the period leading up to the FLASH summer shutdown. The diagnostic installation inside the chamber now offers different types of scintillating as well as OTR screens to allow diagnostics on the electron beam propagating through the chamber. They also allow overlap with the longitudinal co-propagating laser beam. For first tests of future experiments on density-downramp injection, a diagnostic for overlap with a selectively ionising transverse beam has been implemented. The target itself is a 33mm-long 1.5mm-diameter capillary coupled with a discharge circuit allowing flat-top pulses of variable amplitude with a maximum of 400 ns duration and a fast rise time of 20 ns for plasma formation. In addition to wake formation and plasma-based acceleration by an external drive beam, this setup also supports further studies on plasma lensing.

Active plasma lenses

In addition to the findings of the active plasma lens campaigns of the beam time at the Mainz Mikrotron (MaMi), which have now been submitted for publication, one week of beam time at the CLEAR facility at CERN (together with theoretical studies) developed understanding of the properties of active plasma lenses. A setup was implemented that offered the flexibility to change from inhomogeneous field gradients, as already observed and published, to an aberration-free lens with a linear focussing field. Detailed results on the aberration-free plasma lens will be published in the near future. With a slightly tweaked setup and two more weeks of beam time from mid-May, further studies of the emittance evolution and, hopefully, preservation of the aberration-free plasma lenses are imminent.

Target development

For the FLASHForward test laboratory, in which a 25TW laser system offers the opportunity to perform experiments and diagnostics of beams produced by laser wakefield acceleration, a gas-jet-based target with an added differential pumping stage has been developed, enabling 10 Hz operation with the currently existing infrastructure. This will not only allow for diagnostic tests at the actual repetition rate of FLASHForward but also for implementation of adaptive systems allowing for fast tuning of parameters influencing electron beam properties. First experiments have already been successfully performed.

WG4: Photon Sources

Coordinators: Pardis Niknejadi (DESY), Carl Schroeder (LBNL)

FEL photon source

A schematic of the preliminary beam-optics lattice designed by WG2 for the X-band TDS is shown in Fig. 7. This design will be used for the initial post-plasma installation. It is designed in such a way as to allow for the future installation of undulator sections between current beamline elements. Flexibility has also been included in the beamline design to incorporate insights to be gained from the first FLASHForward experiments later this year, as well as future simulation studies of the FEL beamline. A proposal to the the Jülich computing cluster for the systematic study of the FLASHForward FEL beamline, with the 3D FEL code Puffin (Parallel Unaveraged FEL Integrator), is being prepared. This proposal requests 1-2 Million core hours as part of a collaboration with the LUX group (DESY) and University of Strathclyde. In addition, Puffin has been installed on the DESY Maxwell cluster for preliminary studies and to produce the plots needed for the proposal. The preliminary studies will also include the investigation of some of the unique modelling capabilities of Puffin such as transport of beams with large energy spread through the undulator and the full frequency spectrum of FEL radiation exiting the undulator. The CPU-heavy investigation is expected to begin in Autumn 2018.

Auxiliary photon sources

Modification and studies in the FLASHForward test and preparation (BOND) laboratory, aiming to investigate the utility of ICS photons as an electron diagnostic, are still in progress.

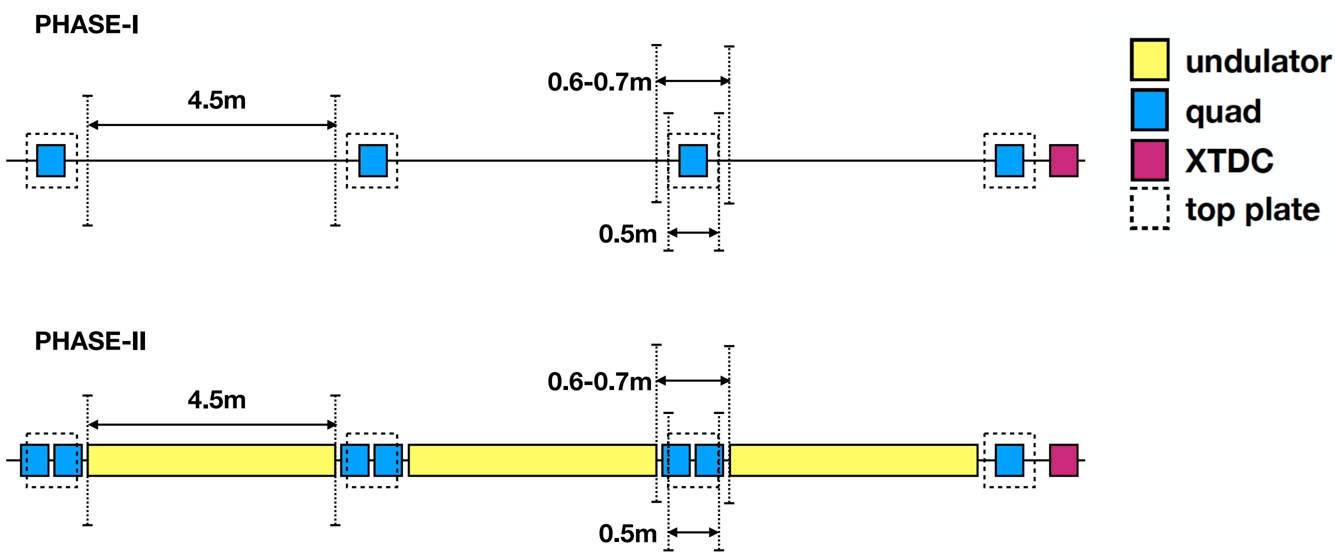

Figure 7: Schematic of the preliminary beam optic lattice for post-plasma section of FLASHForward PHASE-I and PHASE-II.