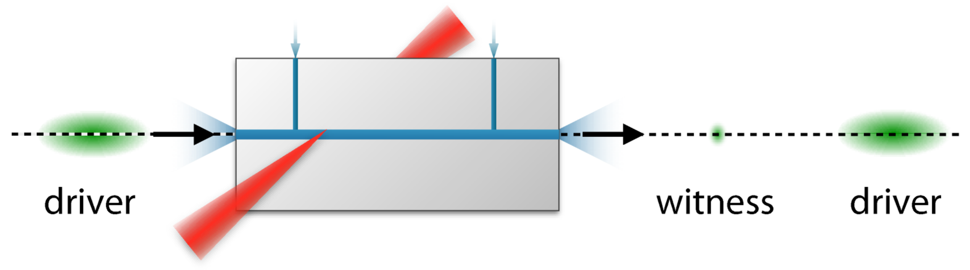
Optimization towards the demonstration of high-quality electron-beam generation from a density downramp injection in a beam driven PWFA at FLASHForward.

A. Knetsch[1], B. Sheeran[1,2], A. Aschikhin[1,2], S. Bohlen[1,2], T. Brümmer[1], L. Boulton[1,3], G. Boyle[1], J. Chappell[1], R. D'Arcy[1], S. Diederichs[1,2], M. Dinter[1], B. Foster[1,2], J. Garland[1], L. Goldberg[1,2], P. Gonzalez Caminal[1,2], S. Karstensen[1] P. Kuang[1], V. Libov[1], C. A. Lindstrøm[1], K. Ludwig[1], F. Marutzky[1], T. Mehrling[1], M. Meisel[1,2], P. Niknejadi[1], A.M. de la Ossa[1], K. Poder[1], P. Pourmoussavi[1,2], A.Rahali[1], J.H. Röckemann[1,2], L. Schaper[1], A. Schleiermacher[1], B. Schmidt[1,2], J.Schaffran[1], S. Schroeder[1,2], J.P. Schwinkendorf[1,2], T. Staufer[2], G. Tauscher[1,2], S. Thiele[1], S. Wesch[1], P. Winkler[2], M. Zeng[1], J. Osterhoff

[1] Deutsches Elektronen Synchrotron, DESY
[2] University of Hamburg
[3] University of Strathclyde

Contact: alexander.knetsch@desy.de, bridget.sheeran@desy.de

Laser-ionzed density downramp injection

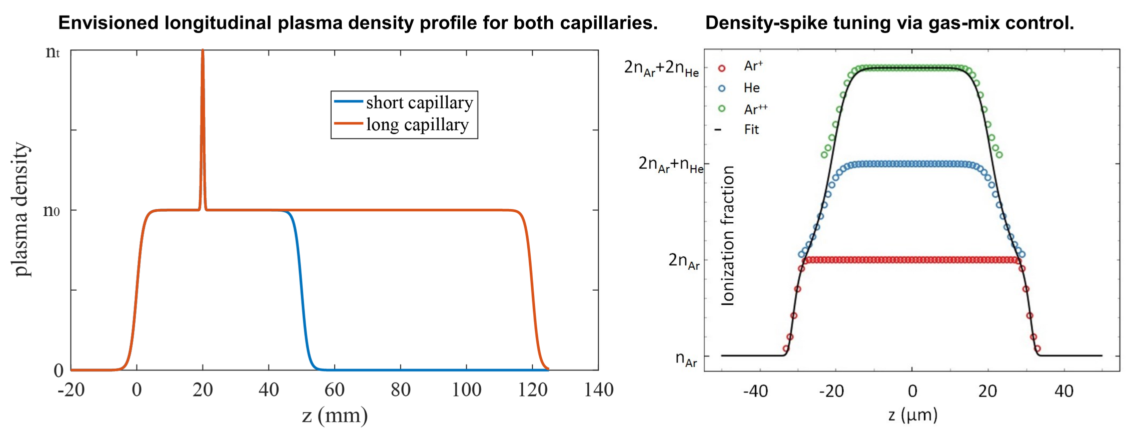


Target witness bunch properties	
Energy	> 1 GeV
Bunch length	1 - 20 µm
Transverse rms normalized Emittance	0.01 µm - 1 µm
ΔE/E	~ 1 %
Current	Order of kA

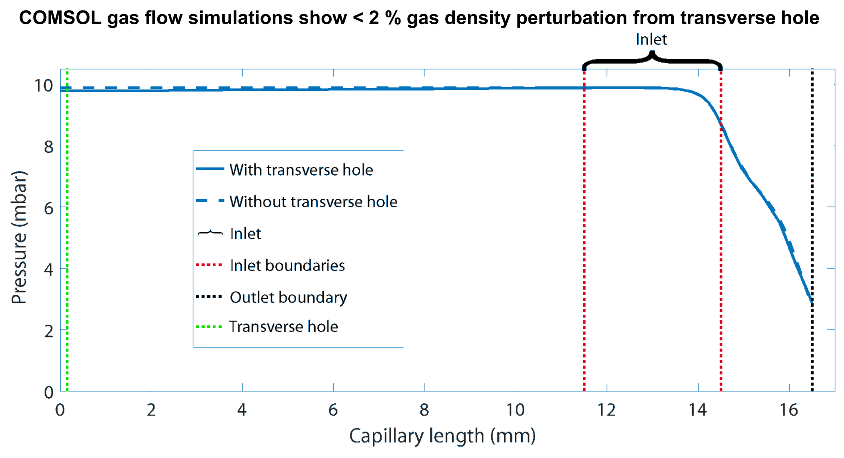
Beam-driven plasma wakefield accelerators allow for the generation and subsequent acceleration of electron beams inside the plasma with substantially lower emittance than the driving electron beam, eventually providing technology for brightness converters for versatile applications. Laser-ionized density downramp injection in PWFA has been identified as a promising injection process for this task [1,2] and recently been experimentally demonstrated for the first time [3]. At FLASHForward we find the unique facility to precisely measure the experimental properties neecssary for the development of a plasma-based electron source. Here, we report on the preparation and comissioning efforts to develop a prototype for a reliable plasma-based electron source.

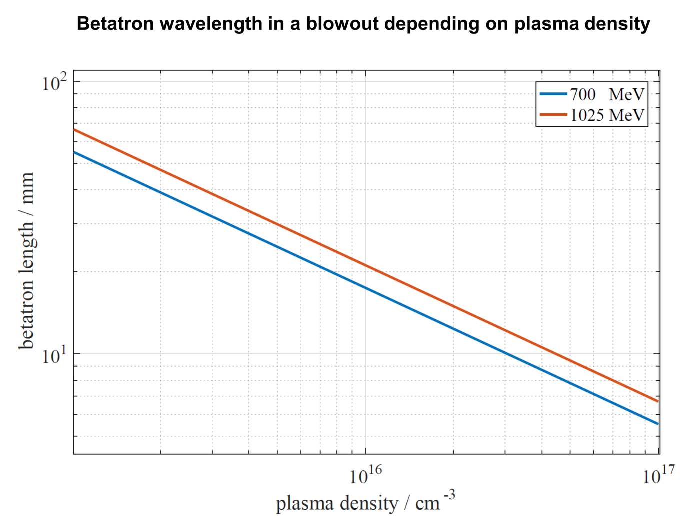
Tunable plasma spikes

- Longitudinal laser for pre-ionization of Ar.
- Transverse laser ionizes Ar^{+}, Ar^{++} and He.
- Plasma density spike controlled via gas mixture.
- Arbitrary gas mixtures with gas mixing reservoir.

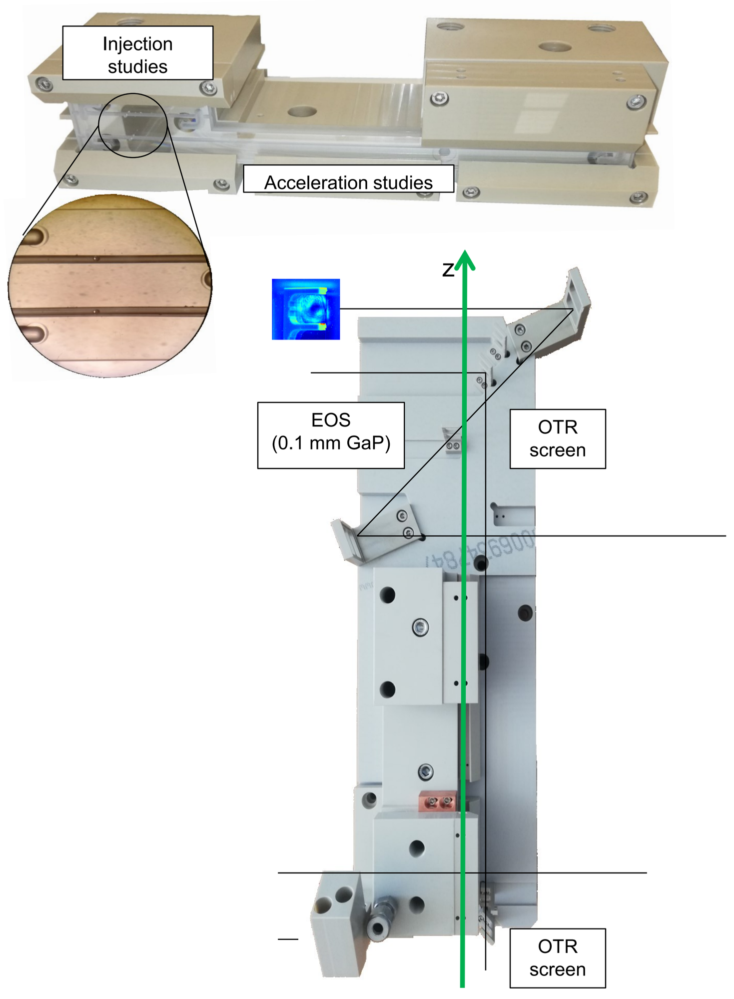


Plasma cell considerations





Acceleration length for injection studies	30 mm
Acceleration length for acceleration studies	180 mm
Injection hole diameter	300 µm
Pre-injection plasma length	20 mm

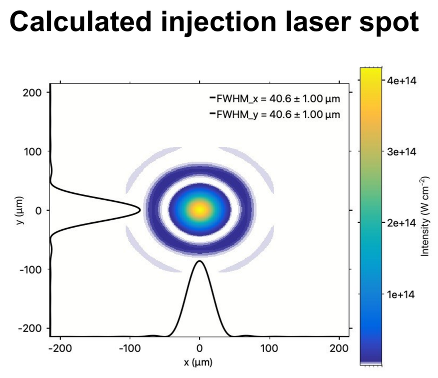


Summary
A plasma target that allows for downramp injection has been developed and tested.
Details

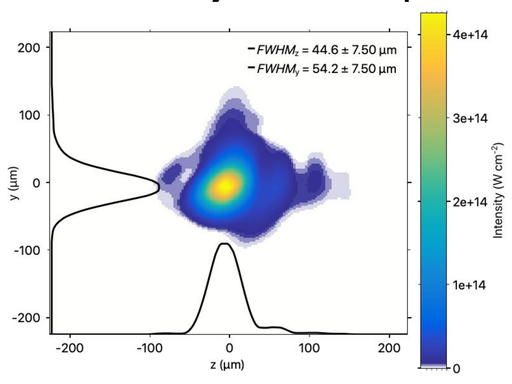
- Transverse holes need to be sufficiently wide for the laser spot size, required for a stable injection, but may not cause a local drop in gas pressure.
- OTR screens are installed at the capillary entrance and downstream of the capillary for spatial alignment between the laser arms and the electron beam.
- Electro-optical cristal installed as part of the electro-optical sampling.
- Injection after 20 mm > $\lambda_{betatron}$ to ensure a repeatable injection process.

Main laser and transverse ionizing laser arm

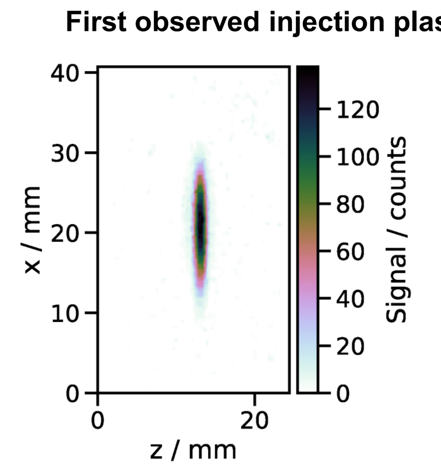
Calculated injection laser spot



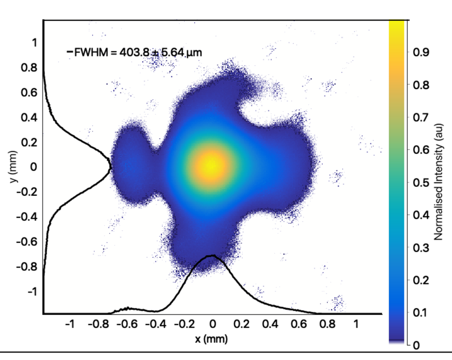
Measured injection laser spot



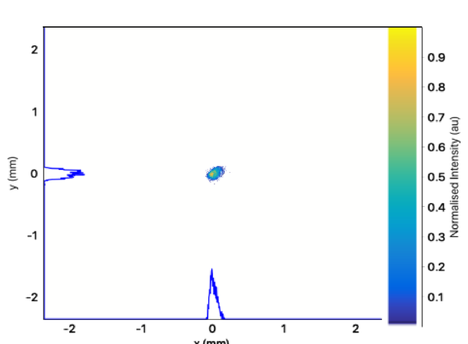
First observed injection plasma



Measured pre-ionization laser spot on OTR screen

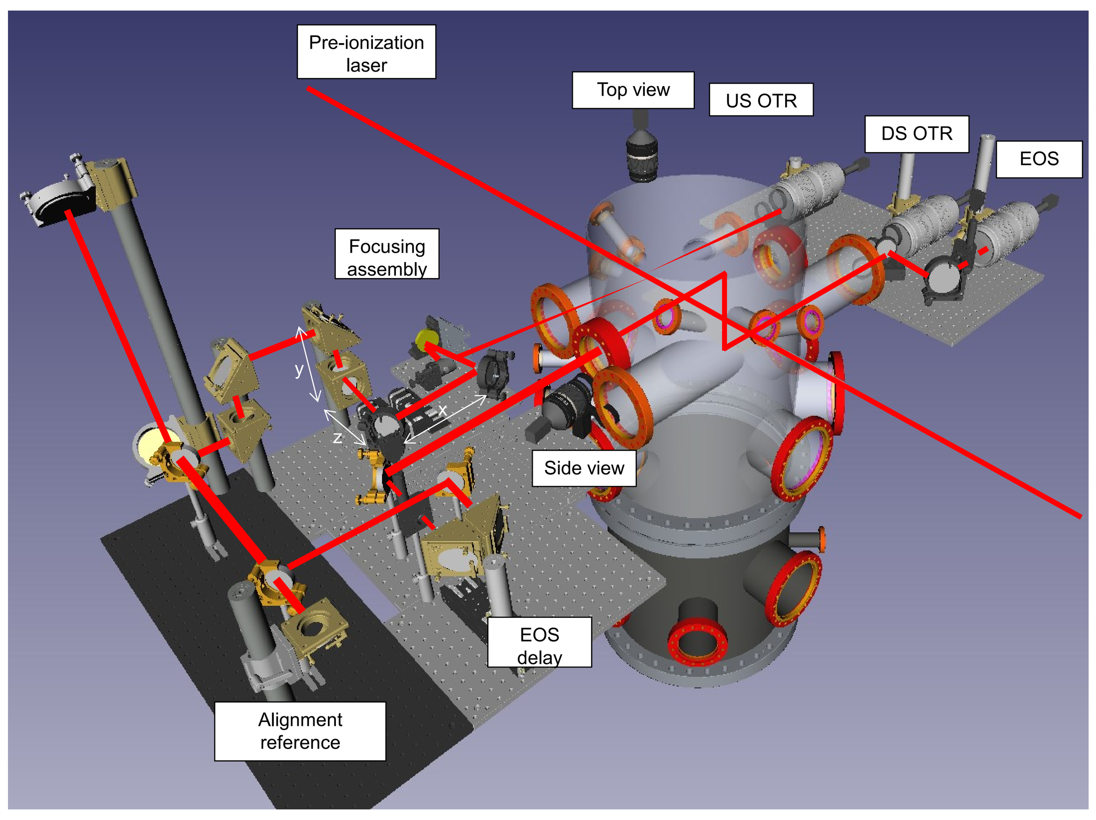


Measured electron beam on OTR screen



Summary
Measurements of the laser and electron beam spots show that the main plasma is wide enough for a stable PWFA. Planned transverse spot sizeshave been achieved and plasma-generation with both laser arms was demonstrated.

Diagnostic setup

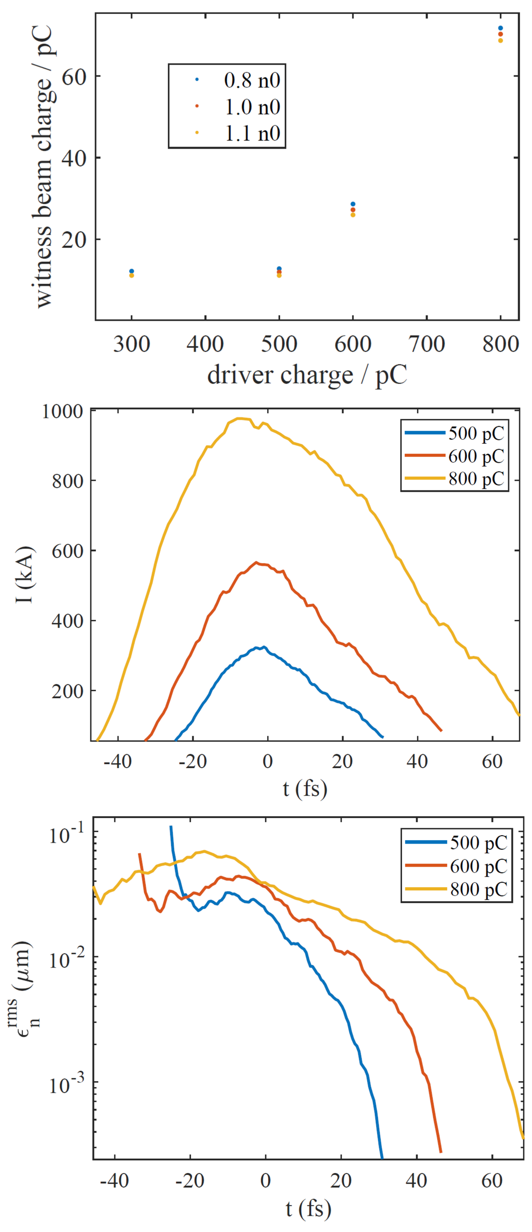


Summary
Diagnostics and the laser beamline, designed for the downramp injection have been set up and tested.
Details

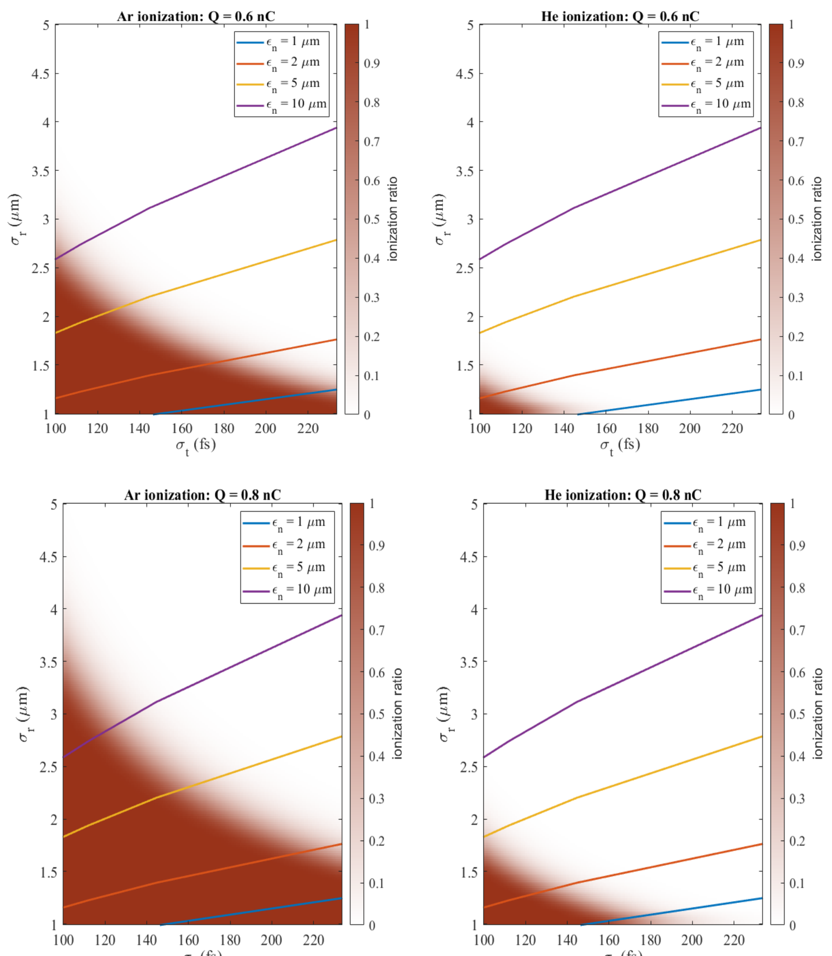
- Focussing assembly for precise positioning of injection plasma without compromising focal spot quality.
- Fast diode and cameras for coarse timing of laser arms to electron beam.
- Top-view camera for plasma-afterglow observation

Drive beam considerations

Osiris Injection simulation
σ_t = 160 fs
Charge and gas density are varied.



Beam-ionization supression

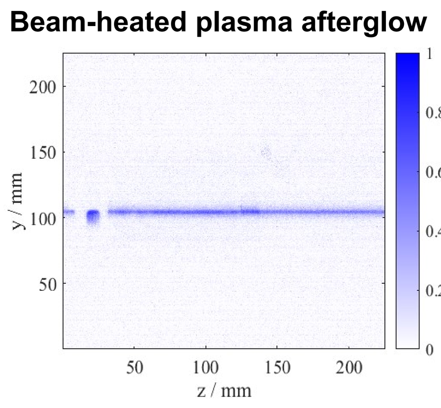


Summary
Simulations and calculations for suitable electron-beam parameters have been identified with PIC simulations and calculations.
Details

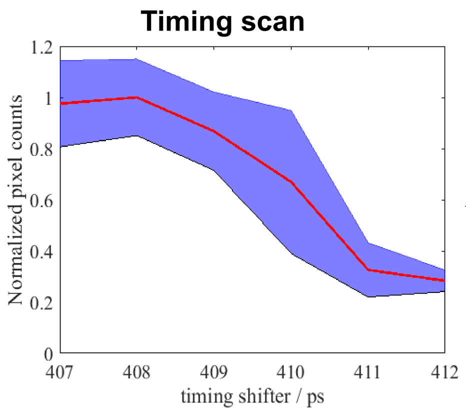
- Drive beam peak current > 1.5 kA for injection.
- Drive beam Helium ionization omitted for matched drive beam at ϵ_{norm}^{t}~2 µm, σ_t≤170 fs and Q ≤ 0.8 nC

Laser-to-beam timing

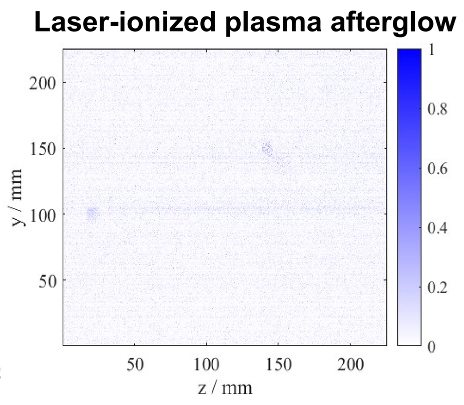
Beam-heated plasma afterglow



Timing scan



Laser-ionized plasma afterglow



Summary
A plasma-afterglow based method [4] for fs-synchronisation of time-of-arrival between electron beam and laser pulse has been comissioned.
Details

- Laser oscillator synchronized to FLASH RF with 30 fs rms jitter.
- Coarse timing with fast diode and OTR camera.
- Fine adjustment of synchronous time-of-arrival via enhanced-plasma glow.
- 2 ns transverse laser delay range with respect to pre-ionization laser.
- Relative time-of-arrival jitter between laser and electron beam on target < 1 ps
- Electro-optical sampling to measure timing jitter at IP and as feedback reference.

Summary

- **Installation of setup for injection complete and tested.**
- **Target drive-beam parameters identified.**
- **FLASHForward is ready for injection**

Outlook

- **First injection foreseen for Fall 2019.**
- **Studies for repeatability of injection process.**
- **Slice Emittance and bunch length measurements.**
- **Optimization of witness-beam parameters.**
- **Input to future kHz injection applicability.**

References

[1] Wittig, G., Karger, O., **Knetsch, A.,** et al. (2015). Optical plasma torch electron bunch generation in plasma wakefield accelerators. *Physical Review Special Topics-Accelerators and Beams*
[2] de la Ossa, A. Martinez, et al. "Optimizing density down-ramp injection for beam-driven plasma wakefield accelerators." *Physical Review Accelerators and Beams* 20.9 (2017): 091301.
[3] Deng, A., Karger O., Heinemann T., **Knetsch, A.**, et al. "Generation and acceleration of electron bunches from a plasma photocathode." *Nature Physics* (2019) ,1-5
[4] Scherkl, P., **Knetsch, A.**, et al. (2019). Plasma-photonic spatiotemporal synchronization of relativistic electron and laser beams. *arXiv preprint arXiv:1908.09263.*

WG1 #245