



Experimental capabilities at the ARCTURUS laser laboratory – versatile development and diagnostics platform for advanced plasma-based accelerator experiments

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The experimental area at the ARCTURUS laser laboratory at Heinrich Heine University Düsseldorf (HHU) provides a versatile research and development platform, designed for supporting flexible configurations of advanced laser-driven and hybrid laser- and electron beam-driven plasma accelerator concepts, as well as offering a test-bed for novel diagnostic approaches.

The experimental setup has already enabled a series of laser-driven plasma accelerator experiments and has seen continuous additions and refinements in complementary diagnostics abilities.

Future experiments at ARCTURUS laboratory are envisioned to be developed in a community-driven and collaborative approach.

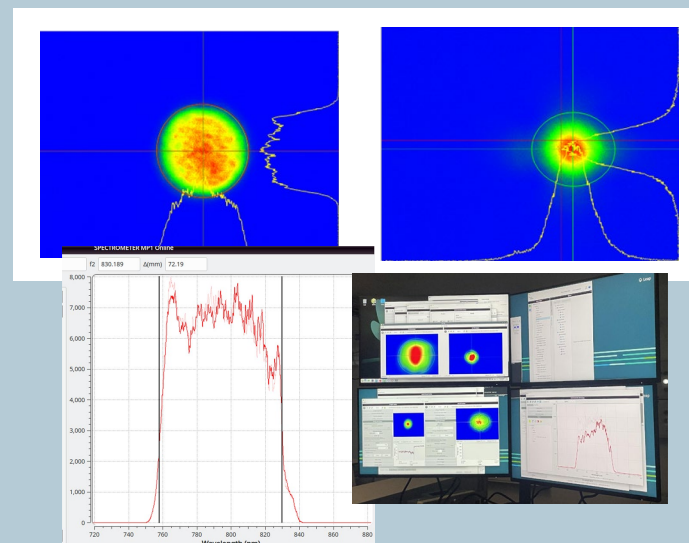
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ARCTURUS Experimental Platform

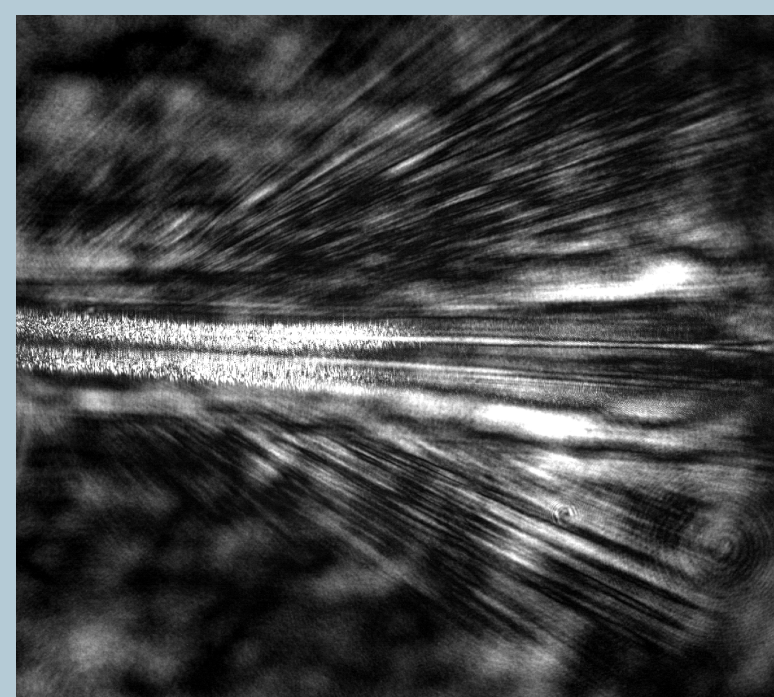
implemented - in commissioning - in development

Laser metrology

- ~30 NF/FF cameras, pointing and energy monitors from oscillator to target
- Full-power replica focus monitor
- Full-power spectral phase reconstruction
- Post-interaction laser spectroscopy
- Closed-loop adaptive mirror correction



Raw shadowgram

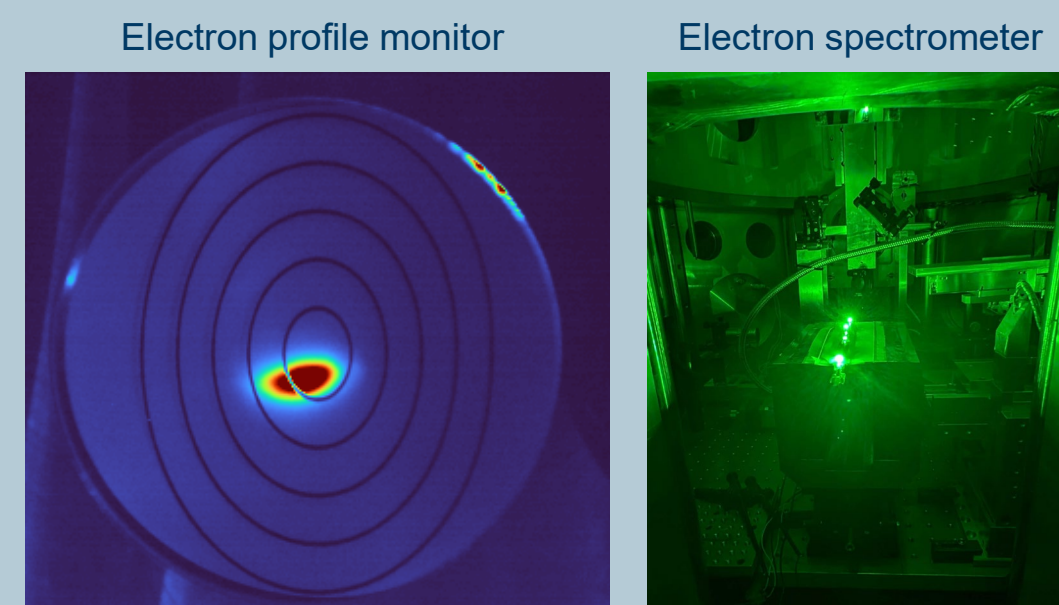


Optical probing

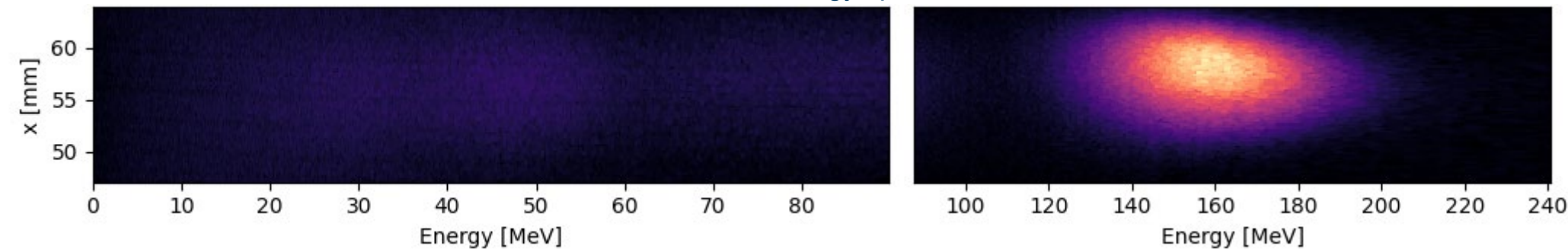
- Independent probe laser pulse compression, adjustable delay and transport on target
- High-resolution shadowgraphy
- Multi-camera shadowgraphy
- Few-cycle shadowgraphy
- Schlieren imaging and dark-field shadowgraphy
- Interferometry and plasma density measurement

Electron beam diagnostics

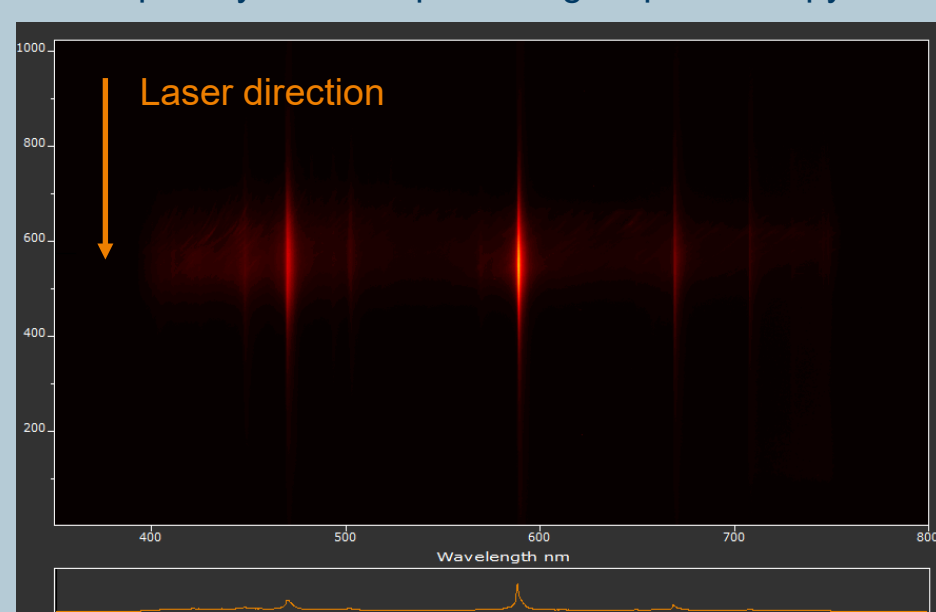
- Profile, pointing and divergence monitor
- Electron spectrometer
- Robust charge calibration
- Current and bunch length monitor
- Emittance measurement



Electron energy spectrum

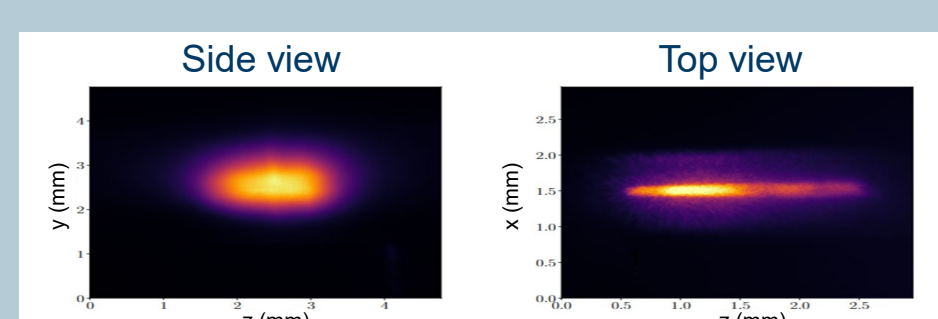


Spatially resolved plasma light spectroscopy



Plasma light emission diagnostics

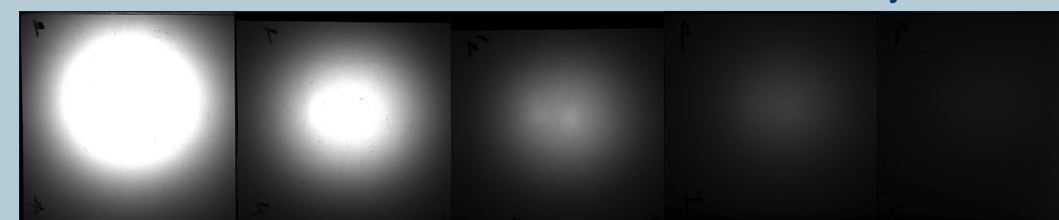
- Broadband and bandpass-filtered cameras for top-view, side-view, Thomson scattering
- Spatio-spectral plasma light characterisation
- Line broadening and ionisation monitor
- Temporal plasma evolution diagnostic



Dose deposition and secondary radiation

- Dedicated electron spectrometer < 20 MeV
- Energy dose depth characterisation
- Biological sample insertion device
- Betatron radiation characterisation

IP stack for broadband electron dosimetry



Infrastructure

Gas target design and characterisation

Theory and simulations

Control systems integration

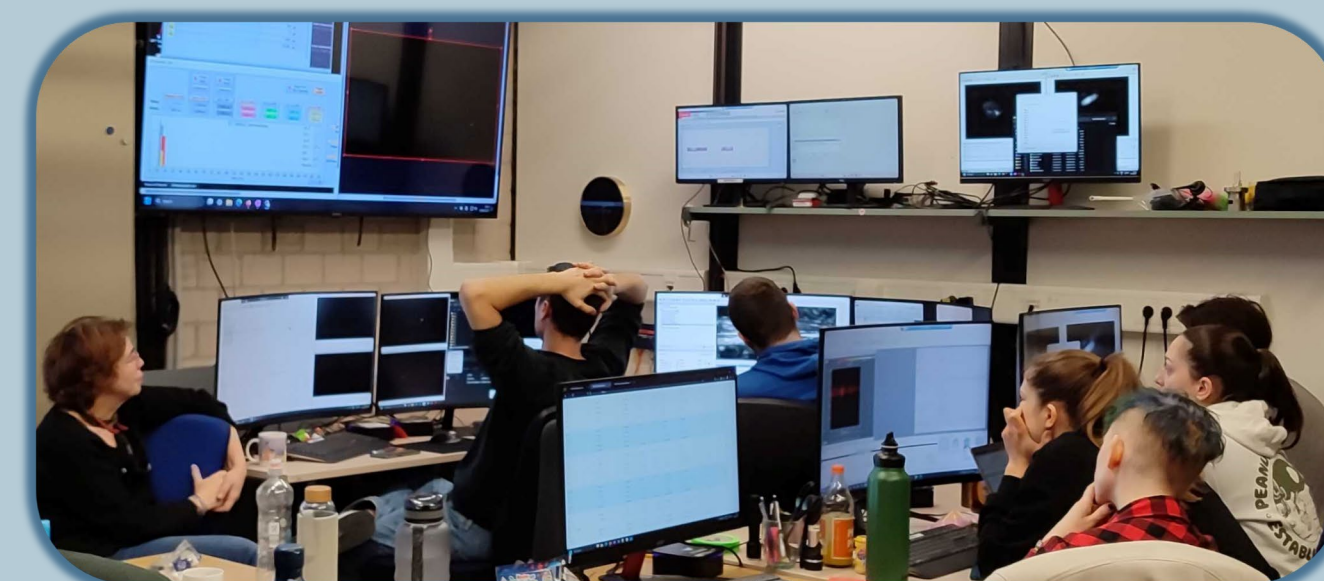
Biomedical dosimetry and space radiation

ARCTURUS Laser

2 x 150-200 TW main laser beamlines
1 x 1 TW beamline for probing
1-5 Hz

R&D Platform

Innovation driven by our students!



Metrology

Full-power laser diagnostics

Plasma monitoring and probing

Electron beam characterisation
Dosimetry

Applications and research paths

Hybrid LWFA-PWFA

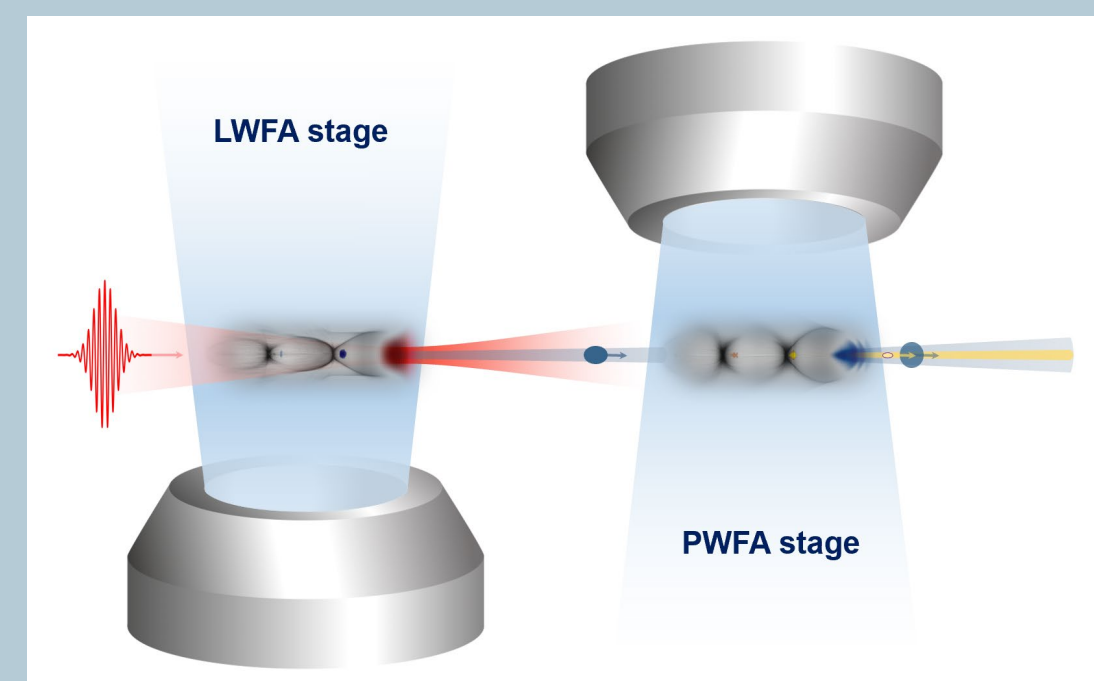
High-brightness electron beams

Compact X-ray sources

Research and Development Prospects

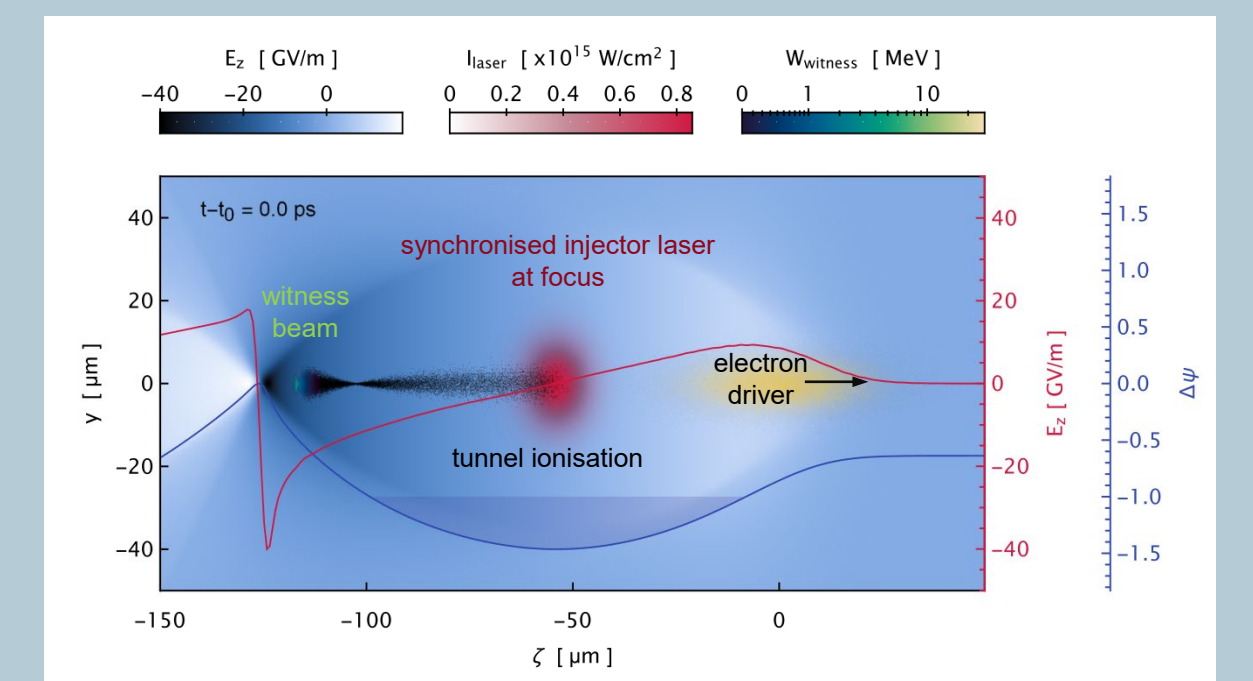
Hybrid LWFA-PWFA [1]

- LWFA optimised for high-current PWFA drivers
- Miniaturised PWFA R&D platform enabling studies on high plasma density operation, injection concepts and diagnostics
- Hybrid staging as brightness transformer and/or energy booster



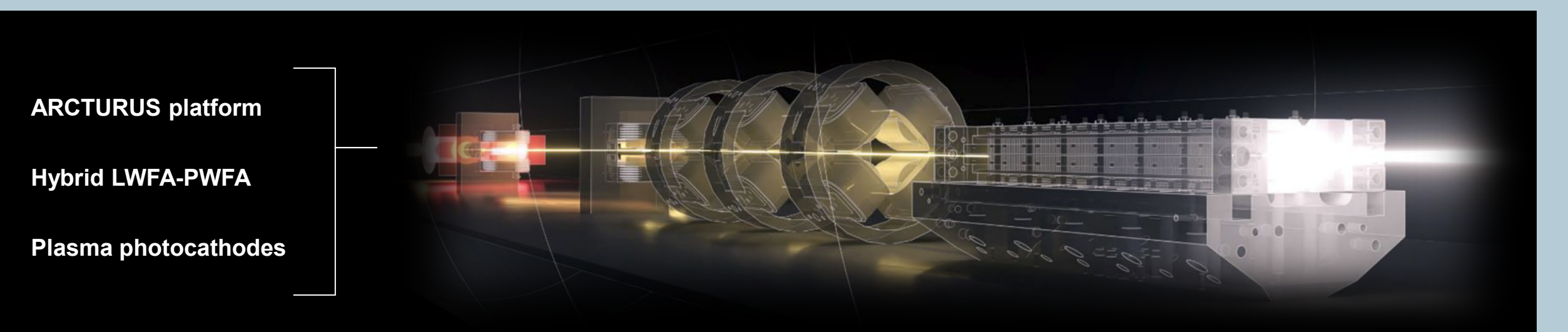
Plasma photocathodes [2]

- Injector laser releases electrons at controlled locations inside the wake with minimal residual transverse momentum
- Ultra-high brightness witness beams
- Intrinsic synchronisation of injector and wake in hybrid LWFA-PWFA



Compact X-ray sources

- Betatron radiation source development, diagnostics and sample irradiation
- Miniaturised high-brightness electron sources for compact XFELs
- Plasma-based XFEL conceptual design and prototyping



Diagnostics and infrastructure

- Flexible setup for diagnostics development
- System monitoring, control systems integration, structured data acquisition
- Optimisations through machine learning and virtual simulation experiments

Biomedicine and space radiation

- High electron dose-rate delivery
- Dose-depth profile optimisation for treatment of superficial cancers
- Accurate representation of space radiation environment for spacecraft components

[1] B. Hidding et al., "Progress in Hybrid Plasma Wakefield Acceleration", Photonics 2023, 10, 99. doi: 10.3390/photonics10020099
[2] A. F. Habib et al., "Plasma Photocathodes," Annalen der Physik, vol. 535, no. 10, 2023-09, doi: 10.1002/andp.202200655