Demonstration of a millimeter-scale electron-beam driven plasma wakefield accelerator based on hybrid staging

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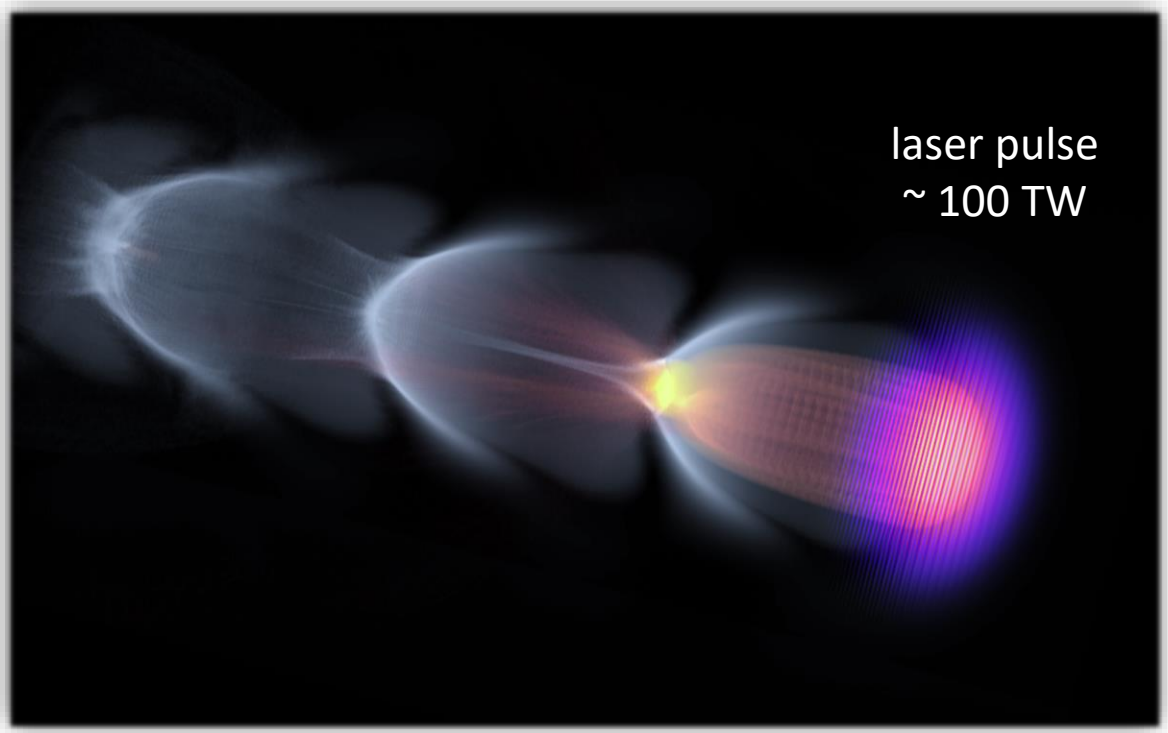
RESEARCH FOR GRAND CHALLENGES

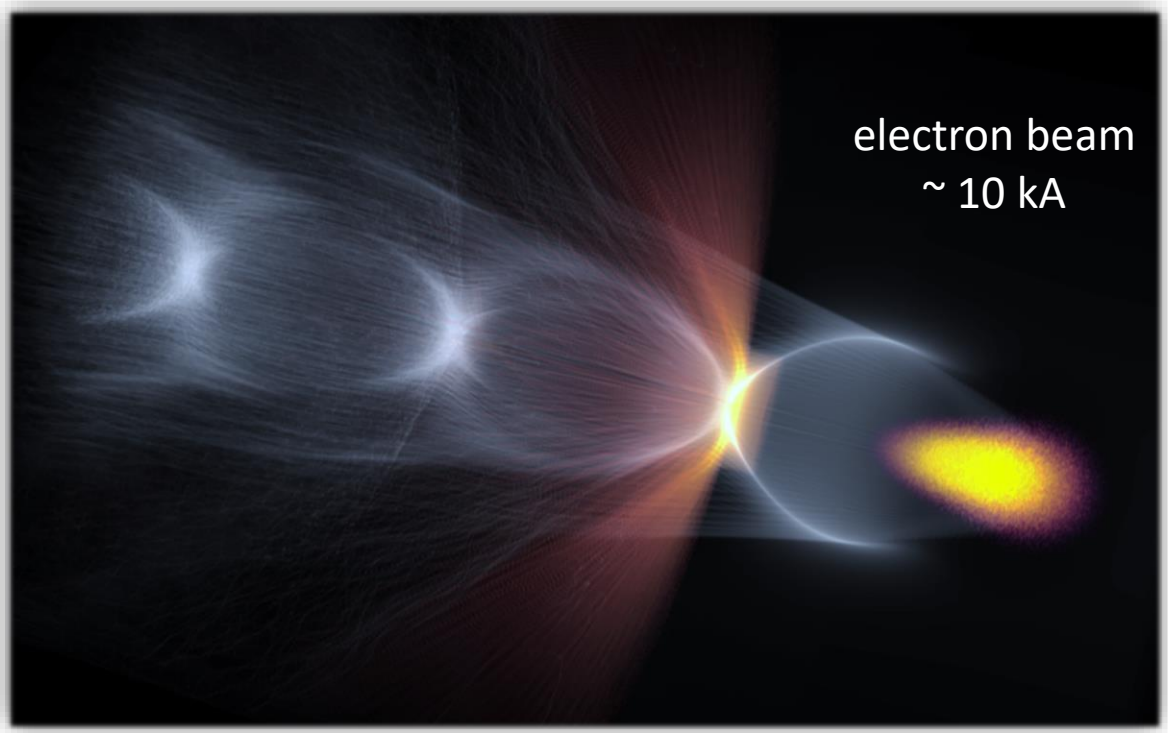
Introduction

Laser-driven wakefield accelerator **(LWFA)**



- short, high-power laser pulse (**E ≈ 10^{13} V/m**)
- high ionization rates
- comparably **many laser systems** available

Particle beam-driven wakefield accelerator **(PWFA)**



- short, high-current electron beam (**E ≈ 10^{10} V/m**)
- favourable for **selective ionisation injection**
- typically needs large and complex accelerator infrastructure,

Unless…

Combine both in a staged setup

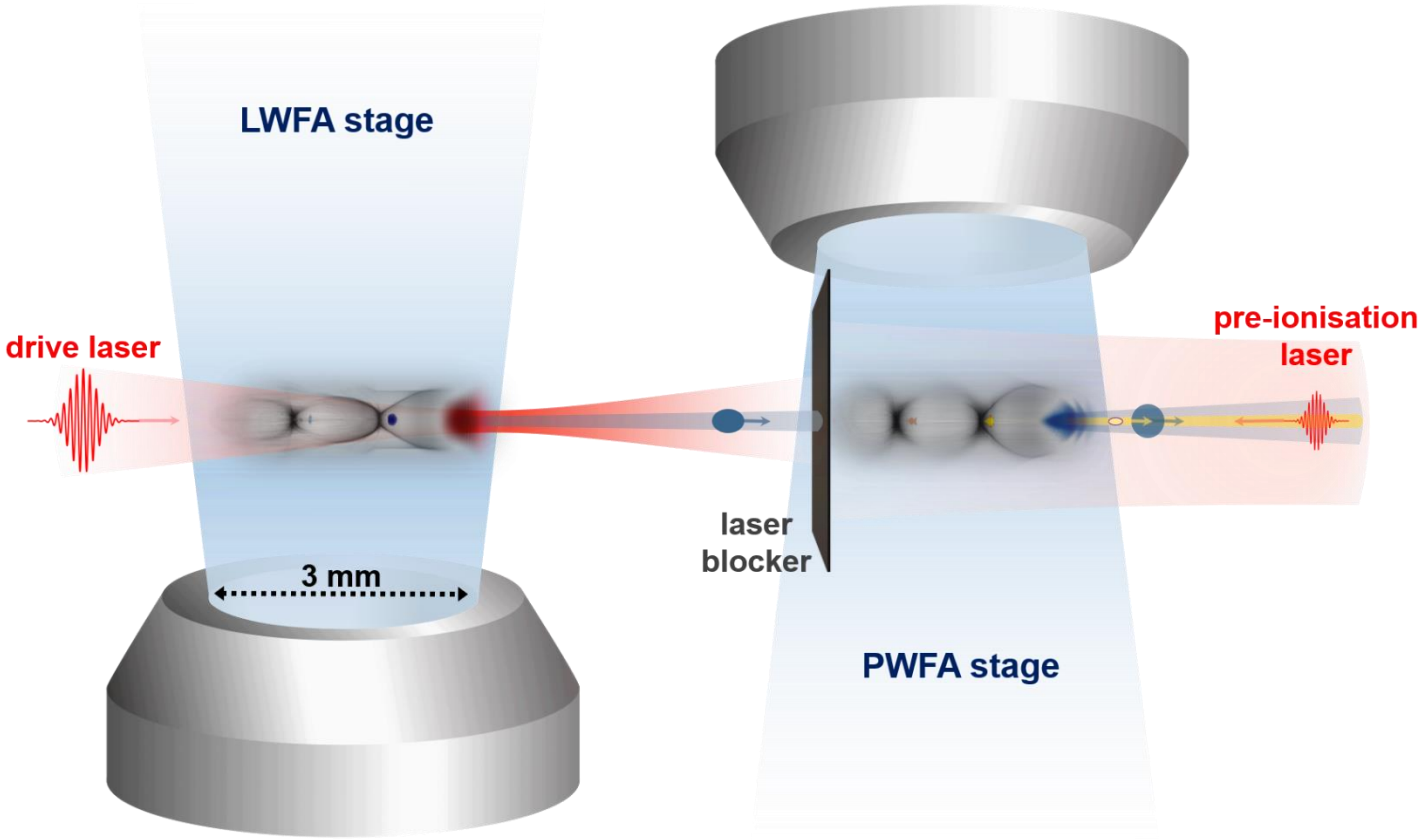
Hybrid staging concept – energy and brightness transformer

LWFA stage

- provides PWFA driver
- optimised to generate **high-current** beams
- beam quality is of secondary concern
- sizable energy spread **even beneficial** (more stable)
- produces intrinsically short beams (~20 fs)
- ideal drive beams for **high-density PWFA**

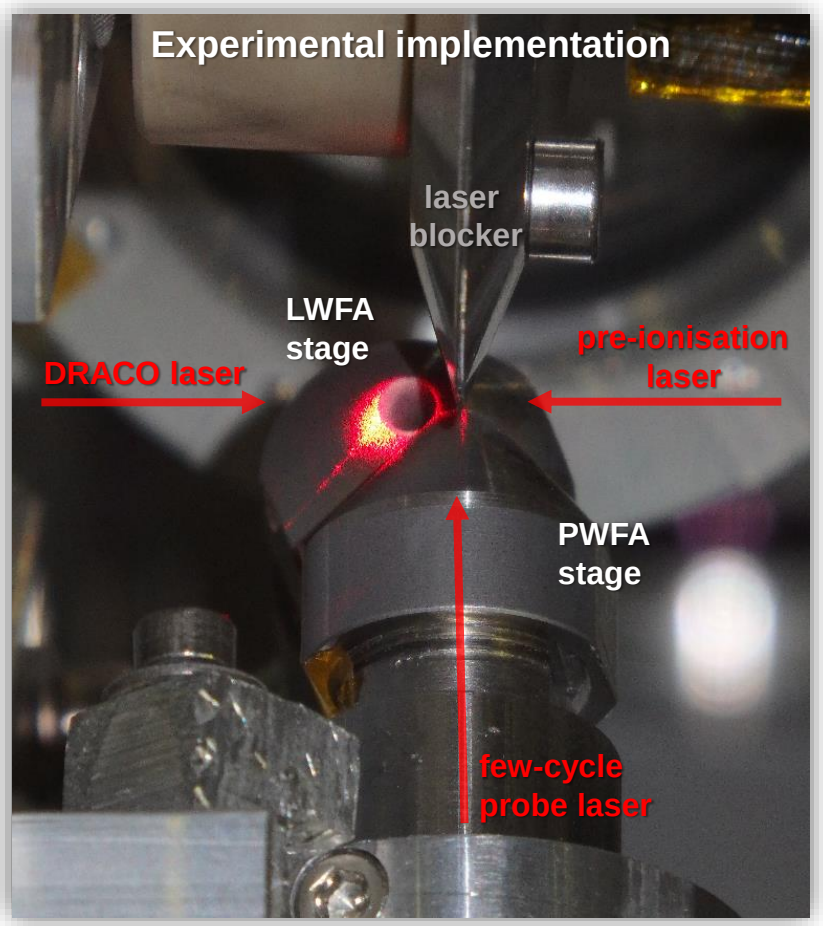
PWFA stage

- either pre-ionised by a laser
- or ionised by the space-charge field of the LWFA beam
- enables selective, driver-decoupled, **controlled ionization injection** (via wakefield or injection laser)
- dephasing-free acceleration
- persistent beam loading conditions
- ultimately serves as **energy** and **quality transformer**

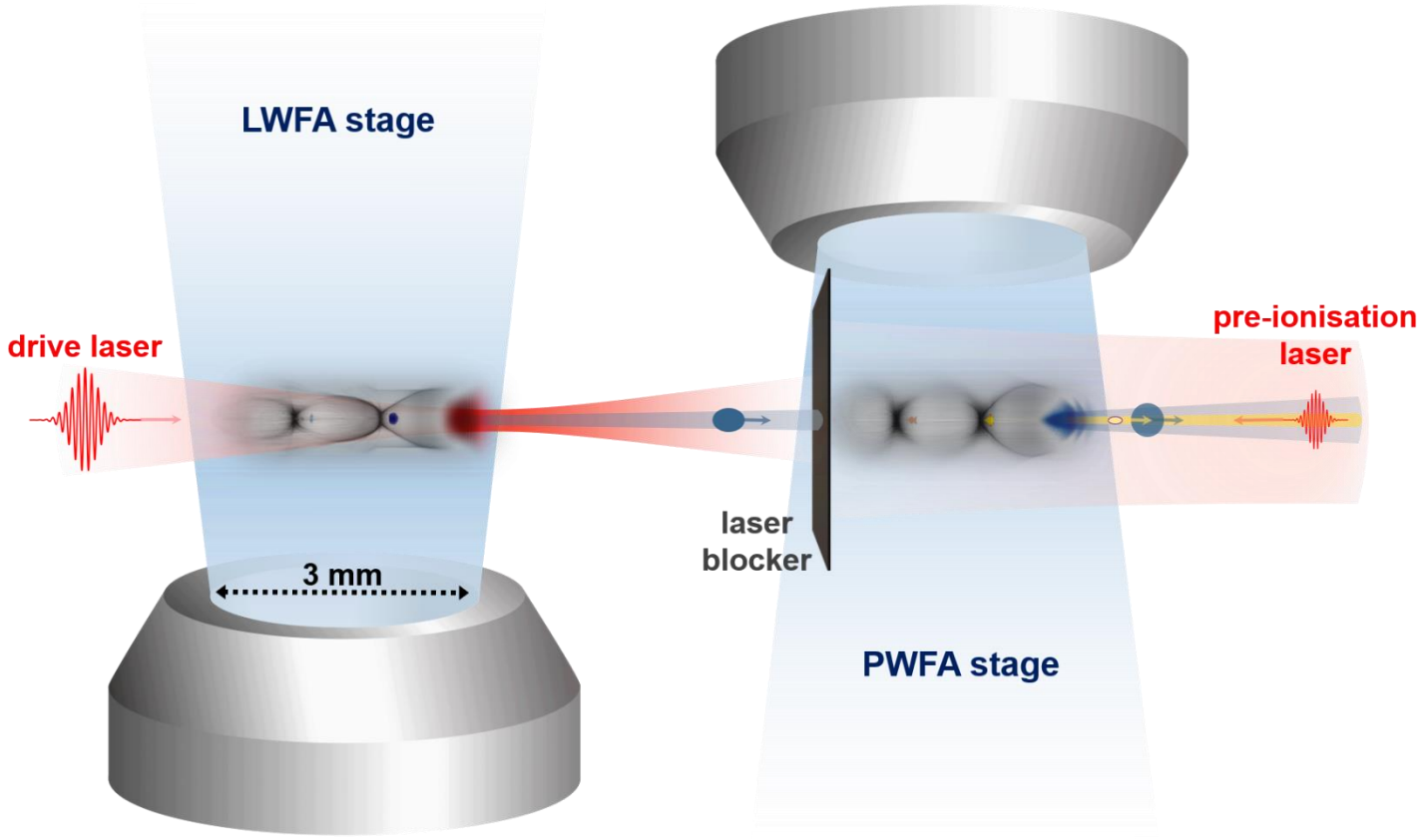


harness individual benefits of both schemes in a compact setup, complementary R&D approach to RF-based PWFA systems, promising prospects for high-brightness beam generation

Hybrid staging concept – energy and brightness transformer



no vacuum gap between stages



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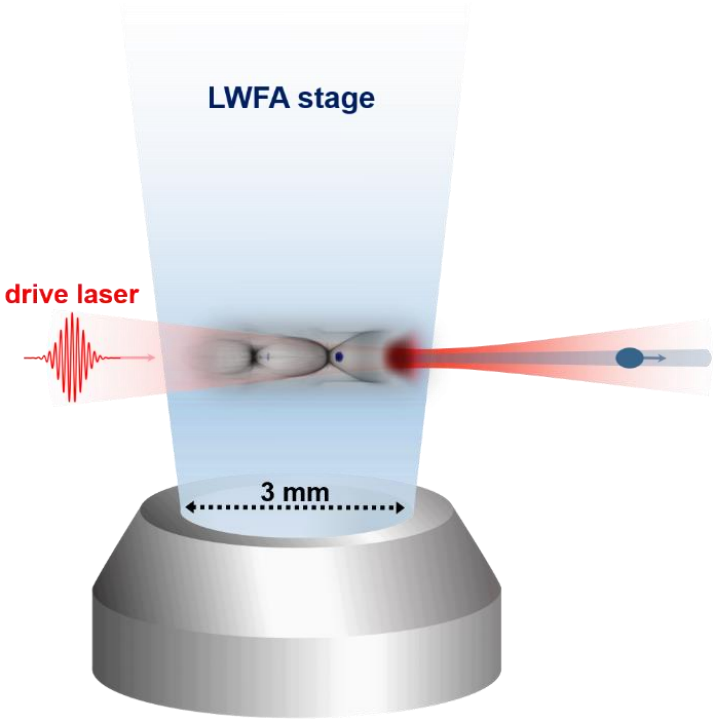
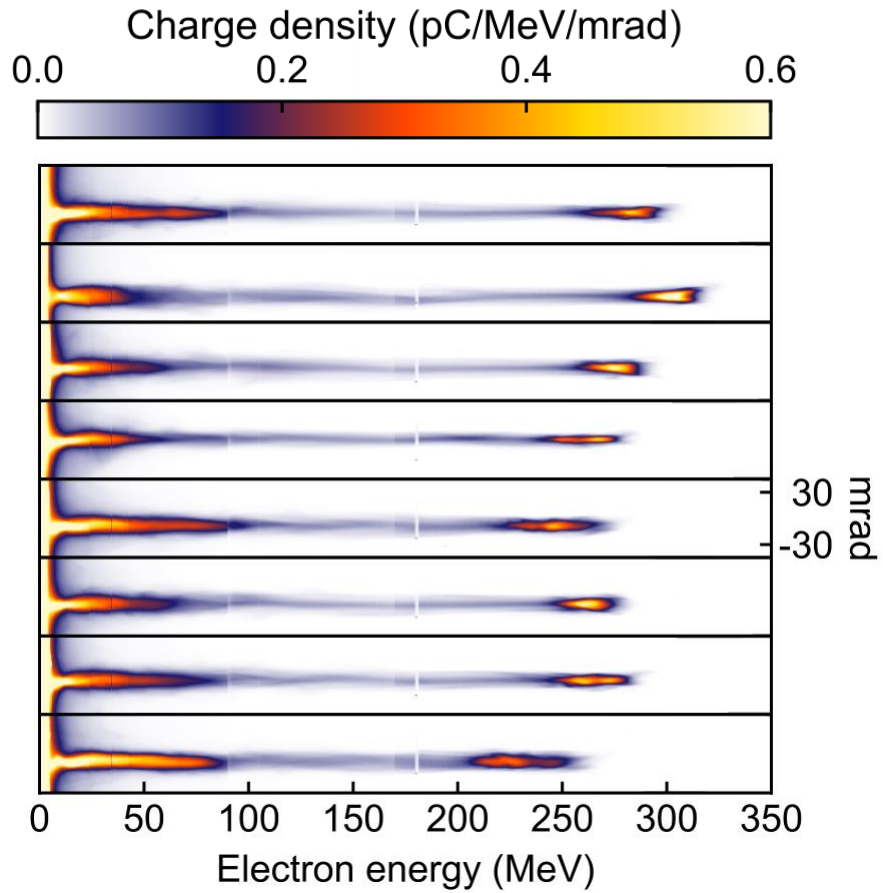
LWFA stage

Generate > 5 kA beams

- self-truncated ionisation injection
- generates quasi-monoenergetic peaks

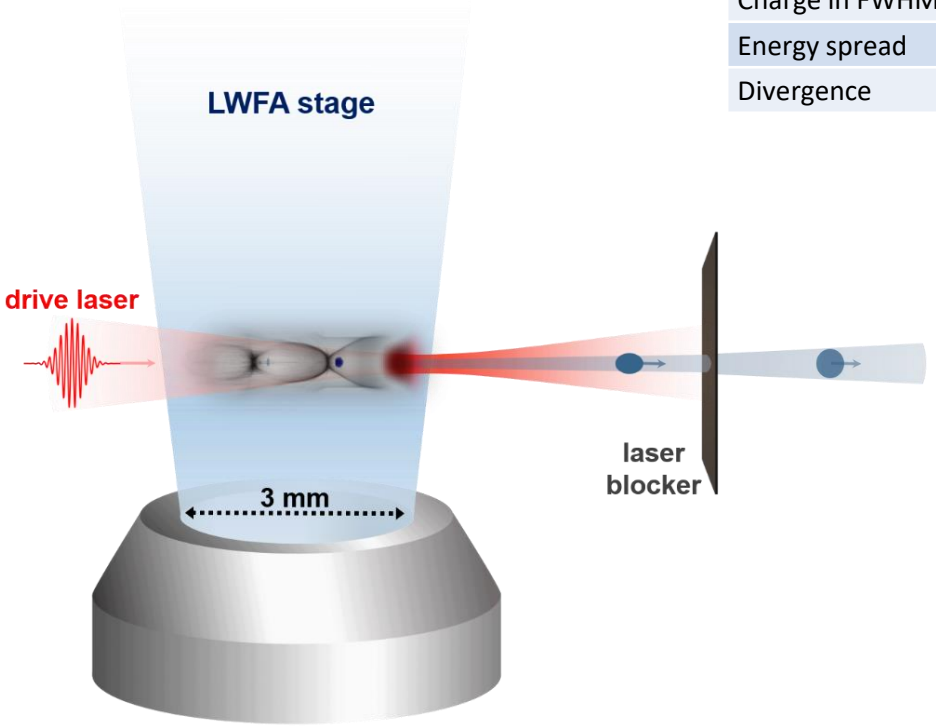




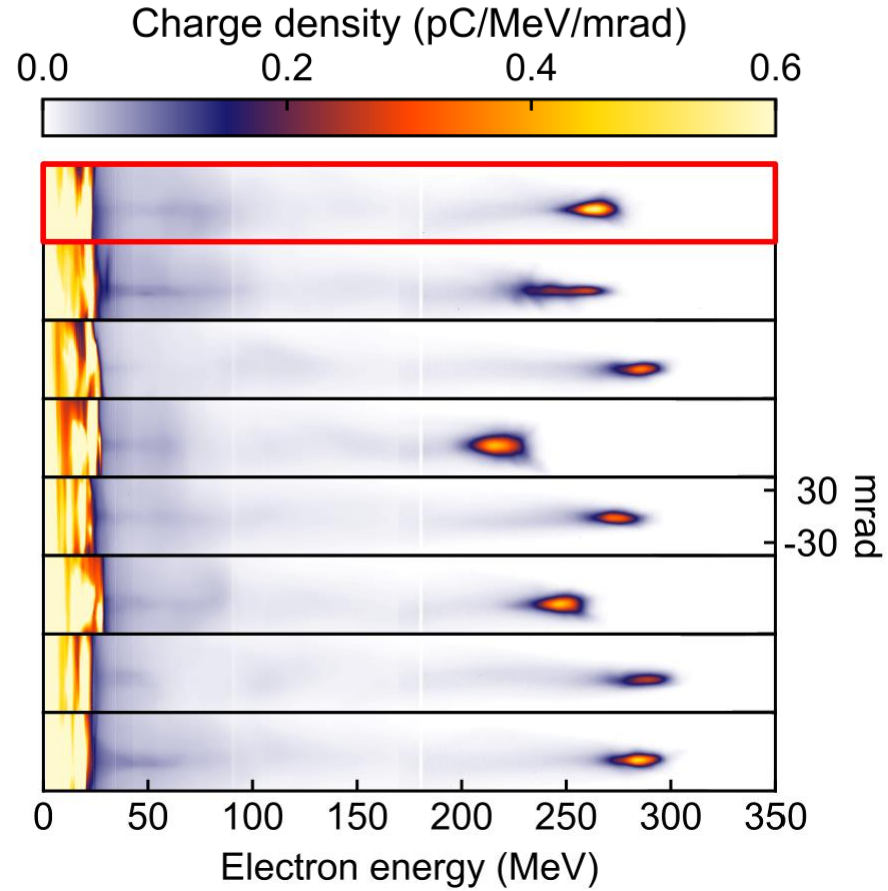
LWFA stage

When adding the laser blocker (12.5 μm steel foil)

- the charge, energy and energy spread are conserved
- the beam divergence increases, but does not compromise its capability to drive a wakefield



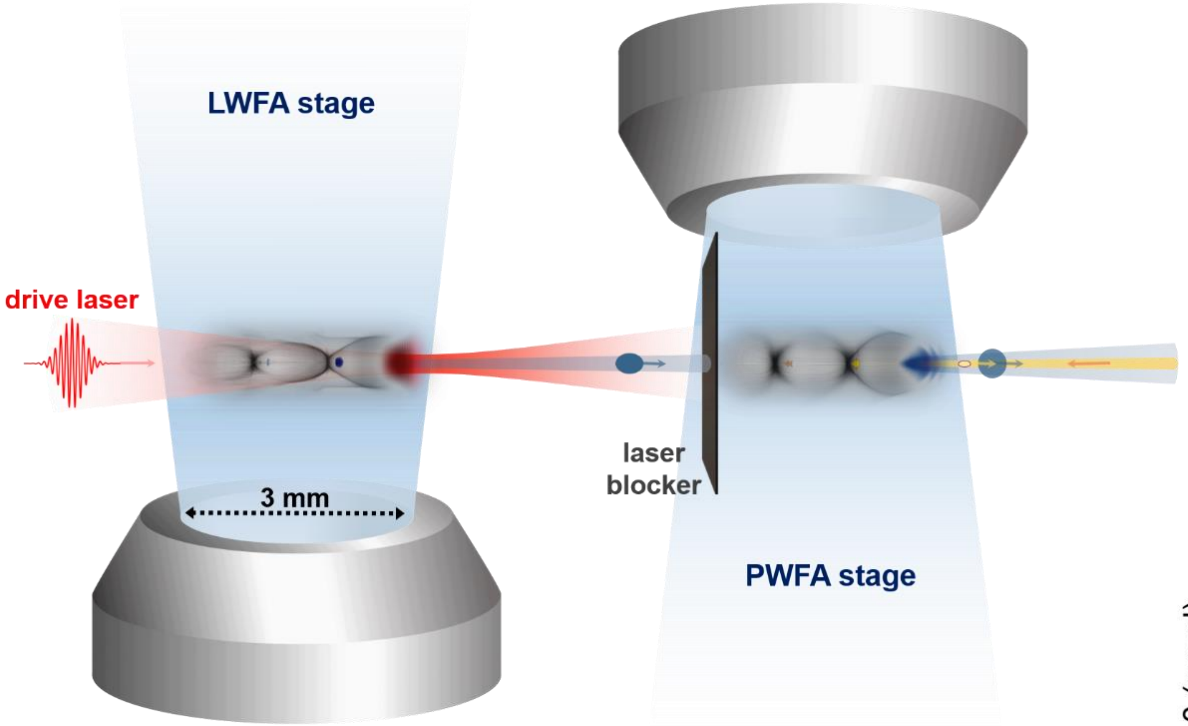
Beam parameter	Mean ± s.e.m.
Energy	262 ± 9 MeV
Charge in FWHM	104 ± 12 pC
Energy spread	24 ± 4 MeV
Divergence	6.2 ± 0.4 mrad



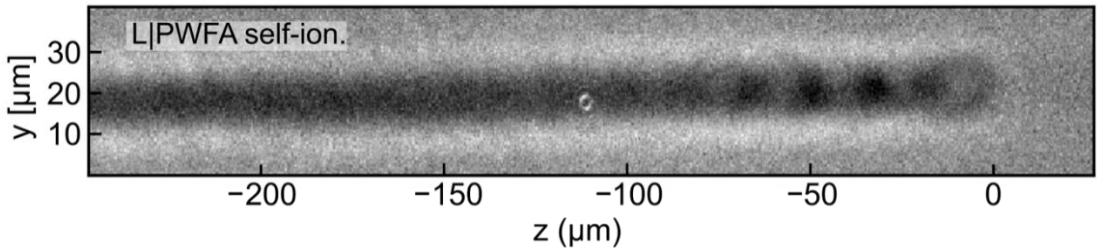
Hybrid staging results

Self-ionised PWFA

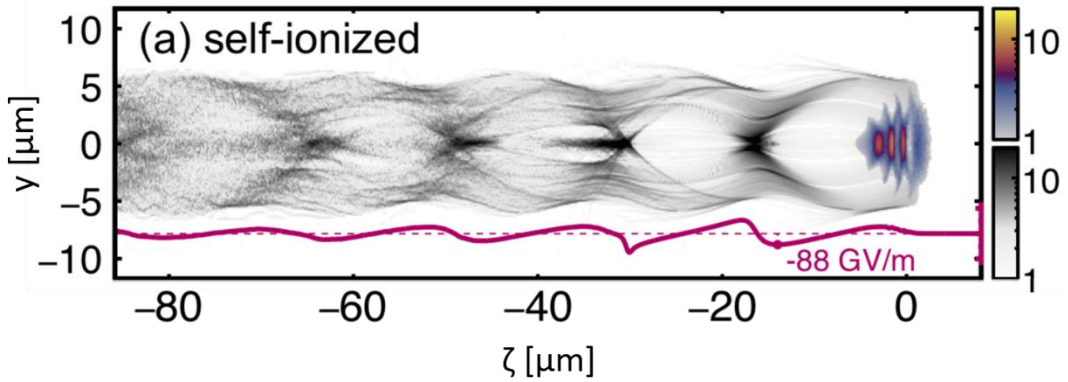
- LWFA beam ionises plasma, drives plasma wave
- only fraction of the driver contributes to wakefield formation
- comparably weak wakefield amplitude
- drive beam degradation observed on spectrometer
- together with witness beam signatures



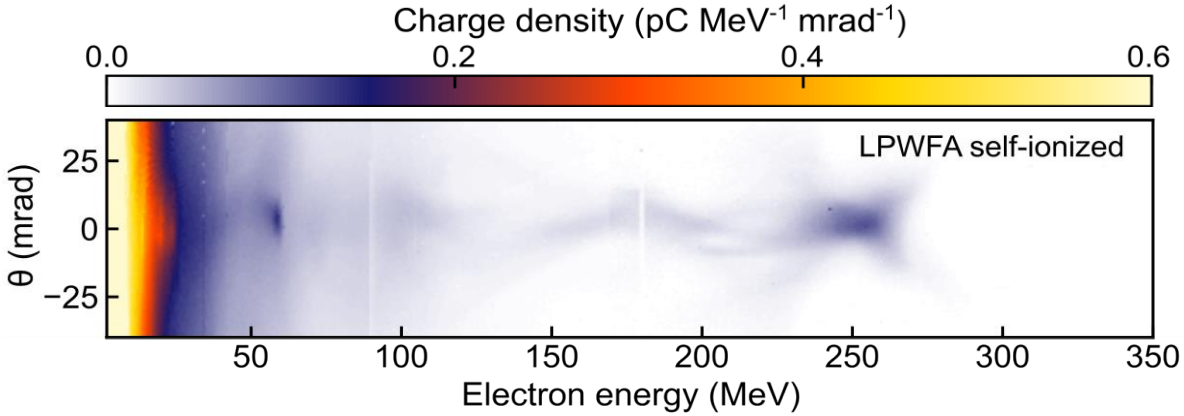
few-cycle shadowgram



simulation



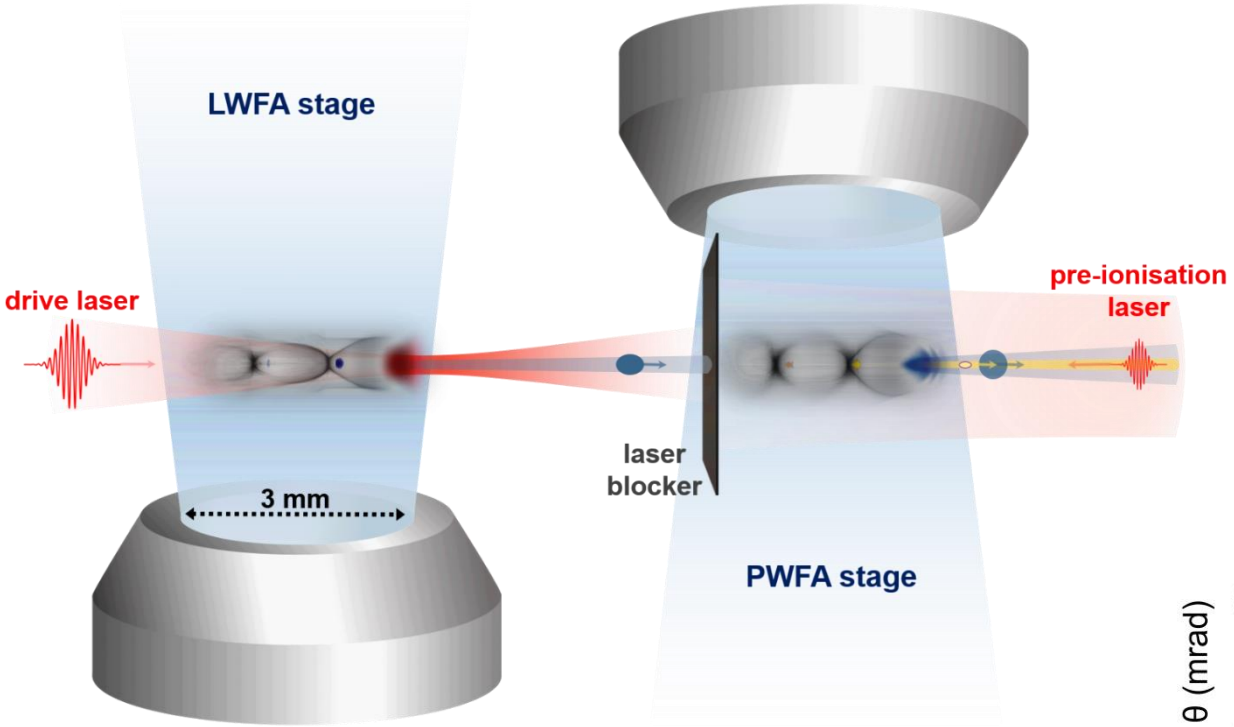
sample spectrum



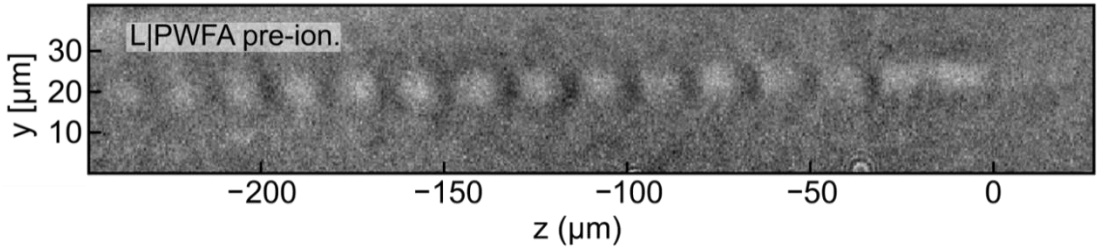
Hybrid staging results

Pre-ionised PWFA

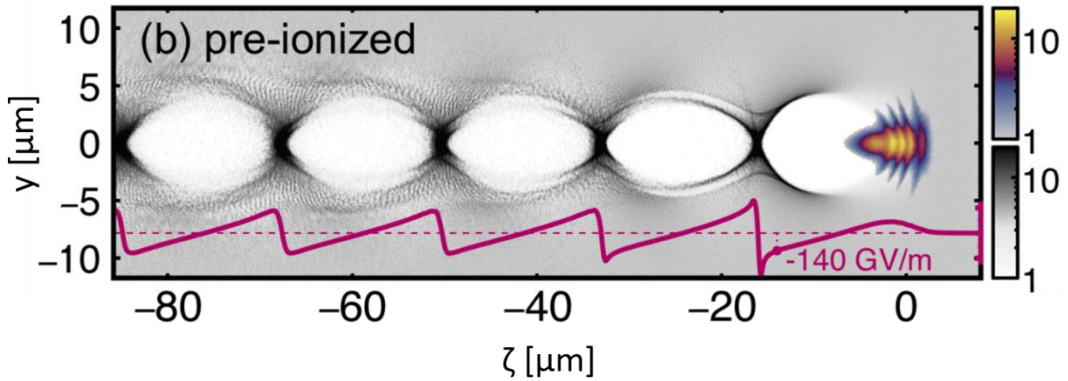
- allows the whole drive beam to form the plasma wave
- consequently leads to larger wakefield amplitude
- and stronger drive beam degradation
- and higher witness beam energies



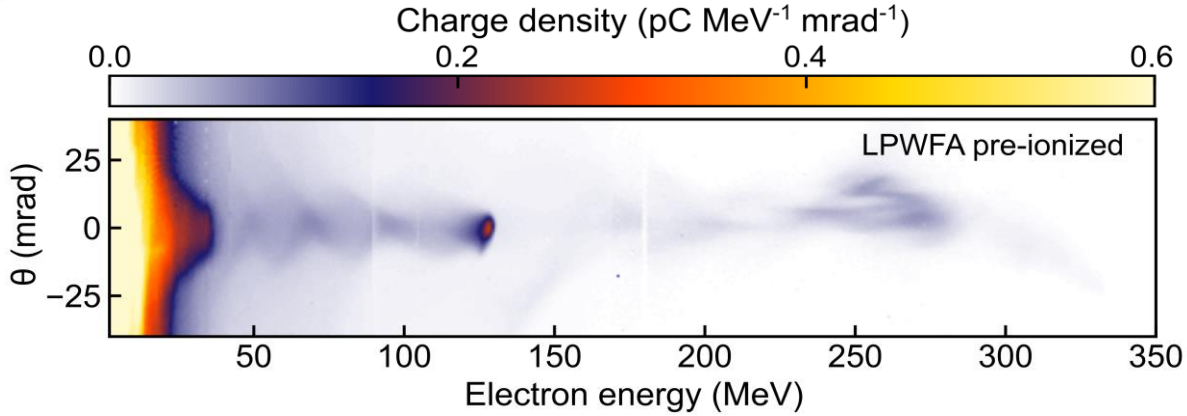
few-cycle shadowgram



simulation



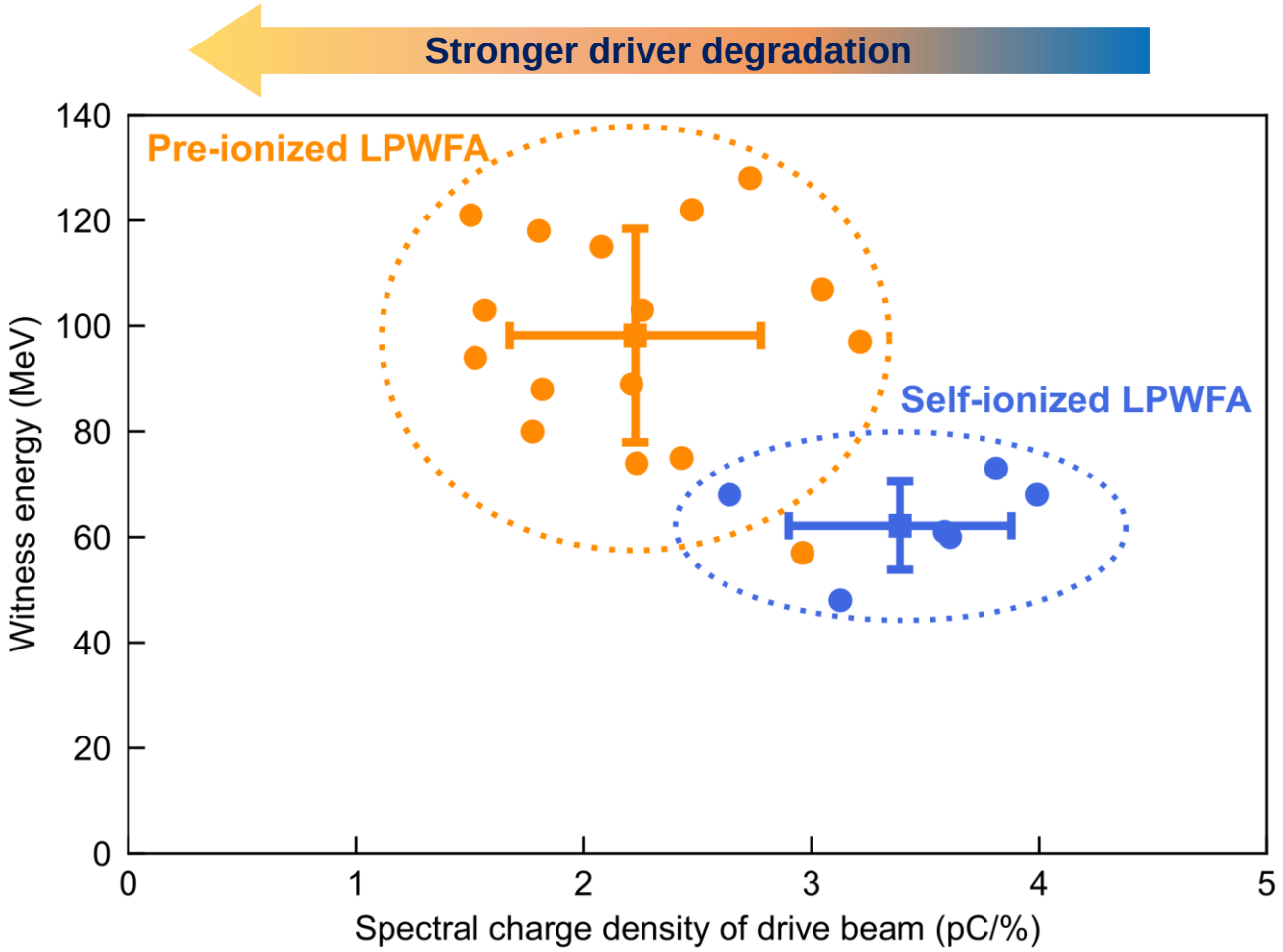
sample spectrum

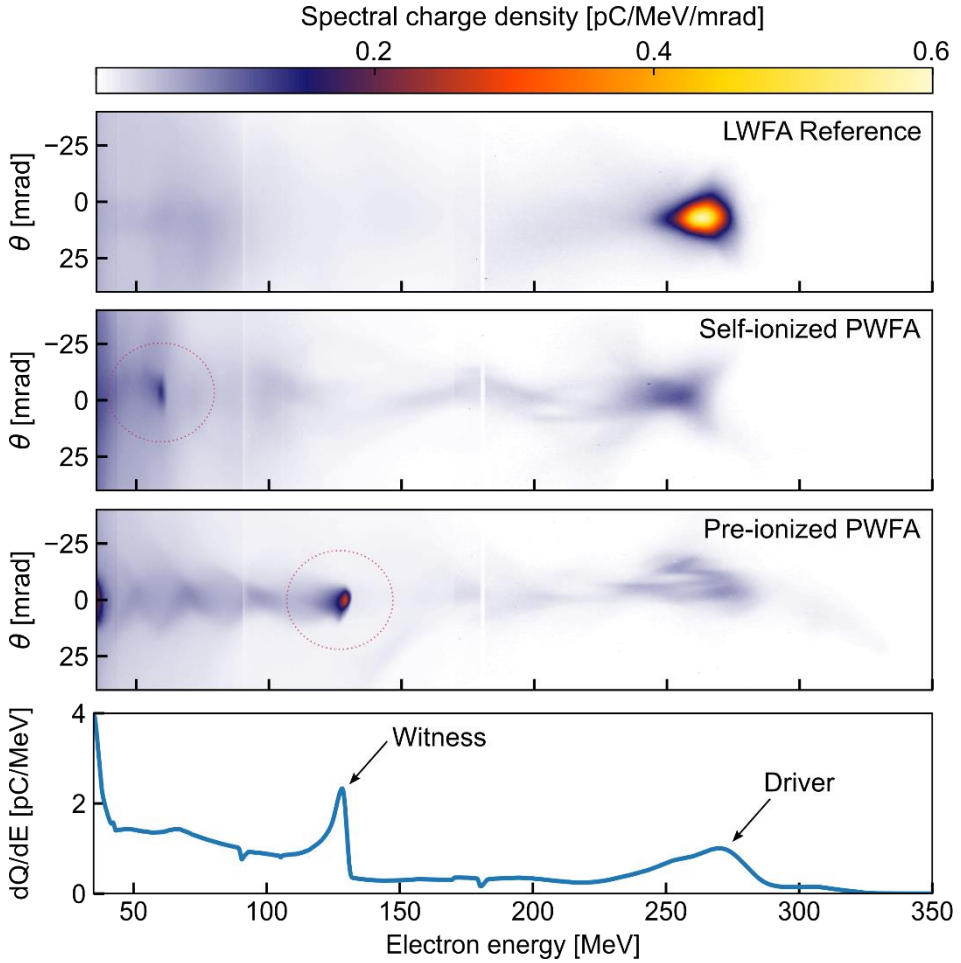


Hybrid staging results

Witness energy and driver degradation

- pre-ionisation results in consistently higher witness energies
- conclusive evidence for succesful PWFA operation





Summary & outlook

Hybrid LWFA-PWFA staging

- compact LWFAs can deliver **ideal drivers for high-gradient PWFAs**
- PWFAs provide **dephasing-free, stable wakefields** for optimal beamloading
- **intrinsic synchronisation** of electron and laser beams
- facilitates high-brightness injection schemes such as plasma photocathode
- hybrid staging ultimately serves as **beam energy and quality transfomer**
- can be implemented at typical, widely accessible LWFA facilities

→ **complementary approach to RF-based PWFA systems**

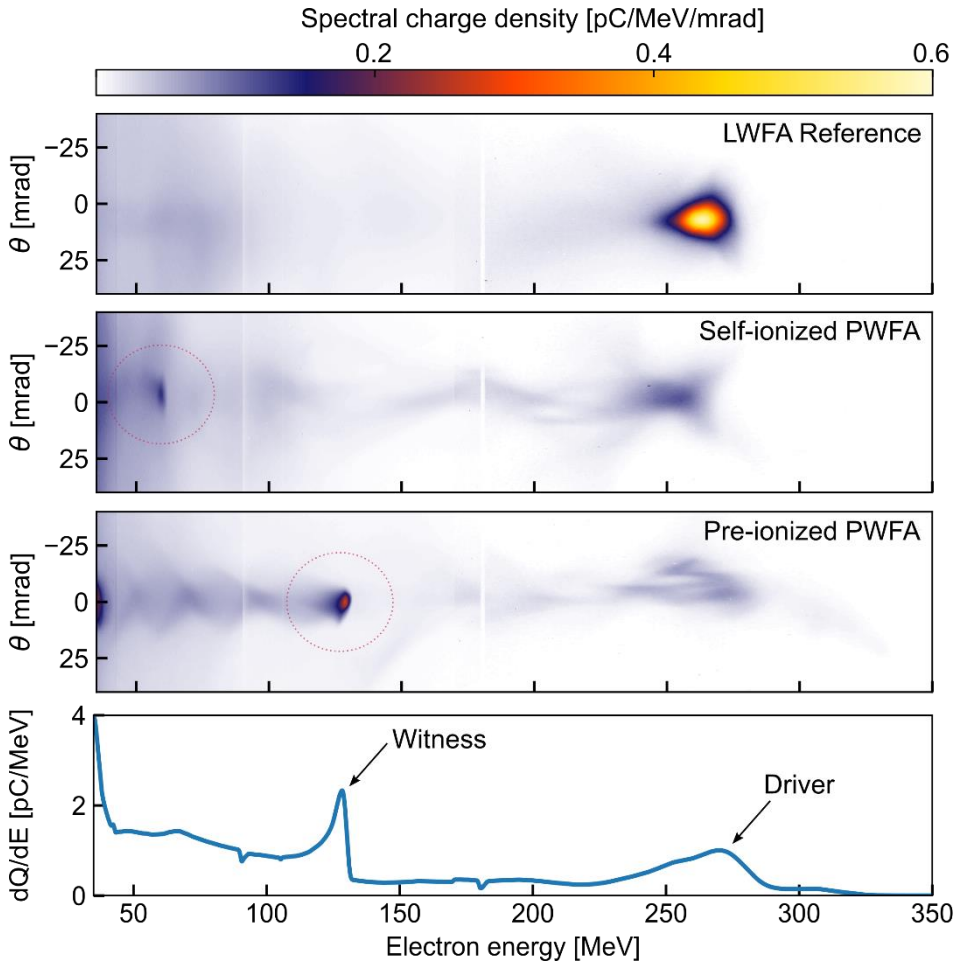
Experimental results so far

- observation of driver degradation
- direct observation of beam-driven plasma waves
- witness beam acceleration

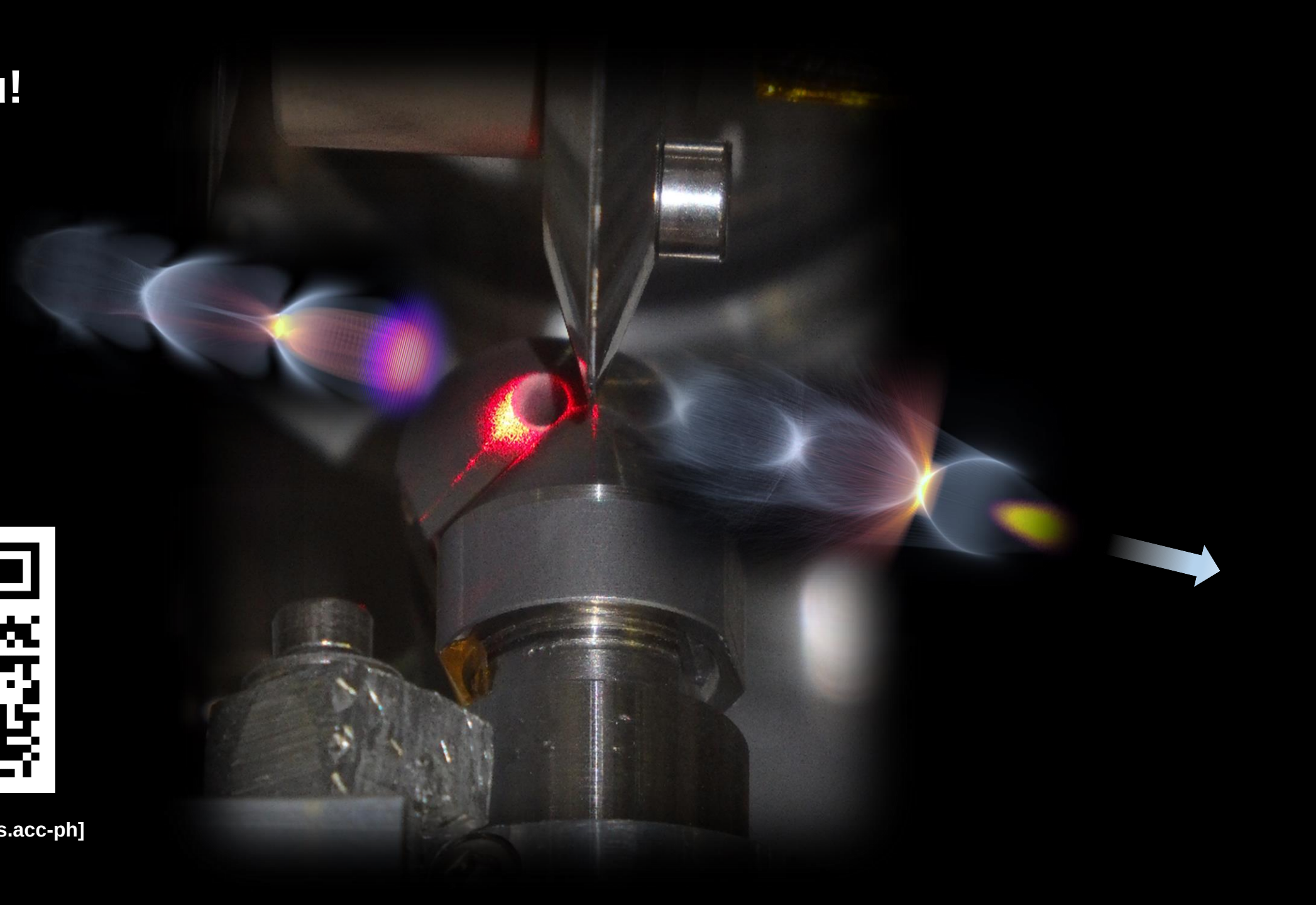
→ **demonstration of miniaturised PWFA driven by LWFA beams**

Next steps

- study beam-driven plasma waves in various regimes
- increase witness beam energy
- energy booster for LWFA dual-beams
- controlled internal injection in second stage
- realise beam-brightness transformer



Thank you!



link to preprint

arXiv:1909.06676 [physics.acc-ph]