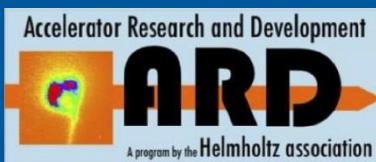


Traveling-Wave Electron Acceleration

**Beyond the dephasing and depletion limits
of laser-wakefield acceleration**

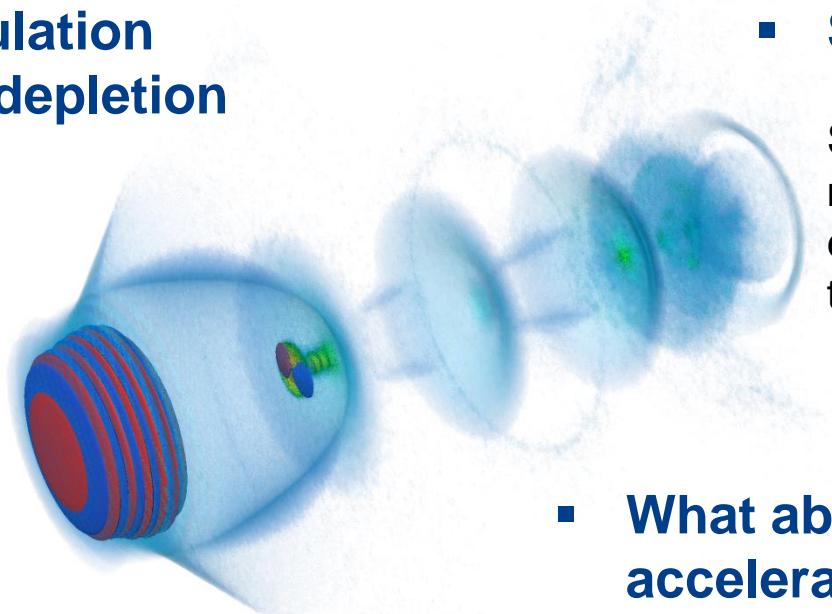
Alexander Debus¹, Richard Pausch^{1,2}, Axel Hübl^{1,2}, Klaus Steiniger^{1,2},
René Widera¹, Ulrich Schramm^{1,2}, Thomas E. Cowan^{1,2} and Michael Bussmann¹

¹ Helmholtz-Zentrum Dresden – Rossendorf , ² Technische Universität Dresden



What keeps Laser-wakefield acceleration from electron energies beyond 10 GeV?

- **Self-phase modulation and laser pump depletion**



- **Staging is hard!**

Synchronization, Beam size matching, Laser in/outcoupling emittance growth in beam transport, etc.

- **Dephasing limit**

Laser propagates below vacuum speed of light, so accelerated electrons outrun wakefield

- **What about Plasma-wakefield accelerators?**

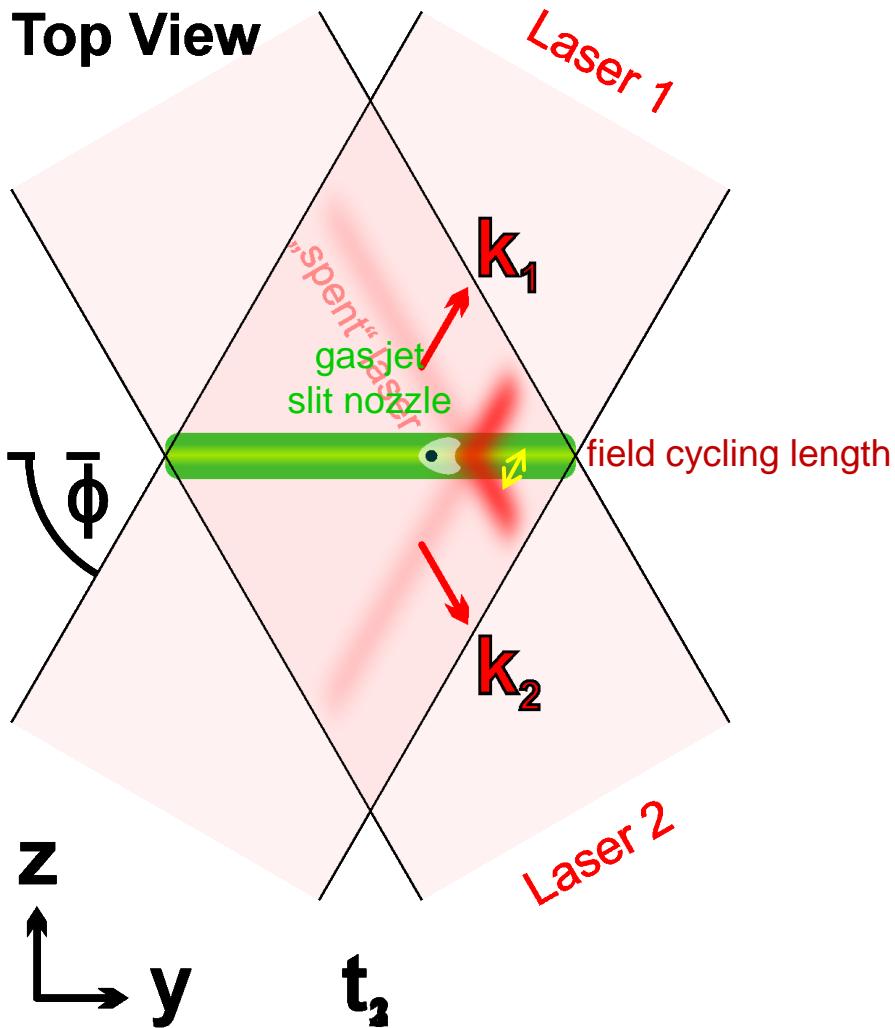
Another accelerator required, energy gain limited by transformer ratio, beam-instabilities.

- **Laser pulse guiding**

Extended distances at low densities

Traveling-Wave Electron Acceleration (TWEAC)

Top View



- Pulse-front tilted laser enforces vacuum speed of light propagation of laser overlap in plasma.

$$\alpha = \Phi/2 \rightarrow v_g \equiv c$$

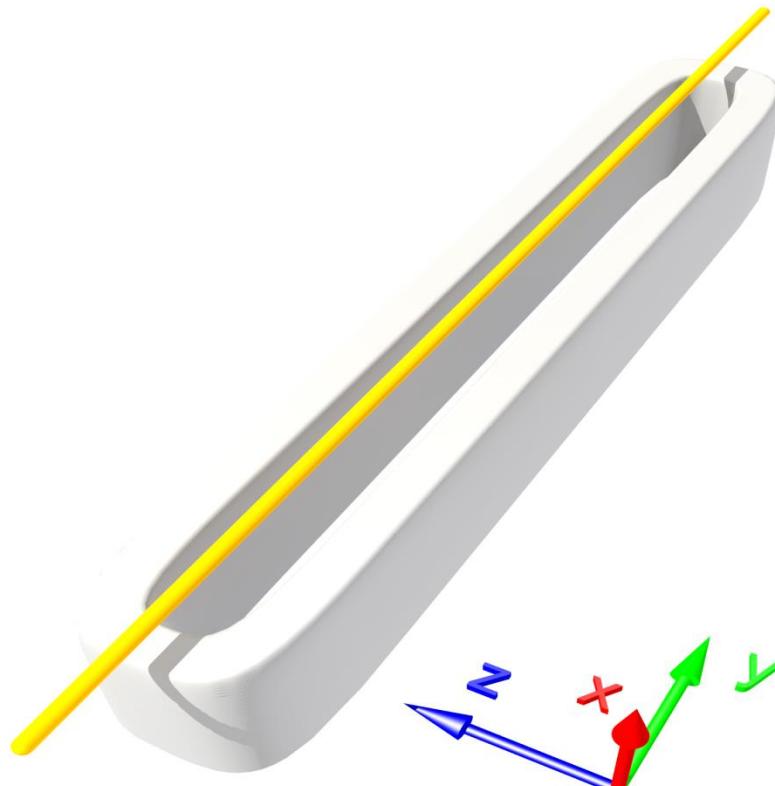
- Oblique laser beam geometry continuously feeds a „fresh“ portion of the laser beams into an unperturbed plasma.

$L(\text{accelerator}) > L(\text{depletion length})$

is fine, as long

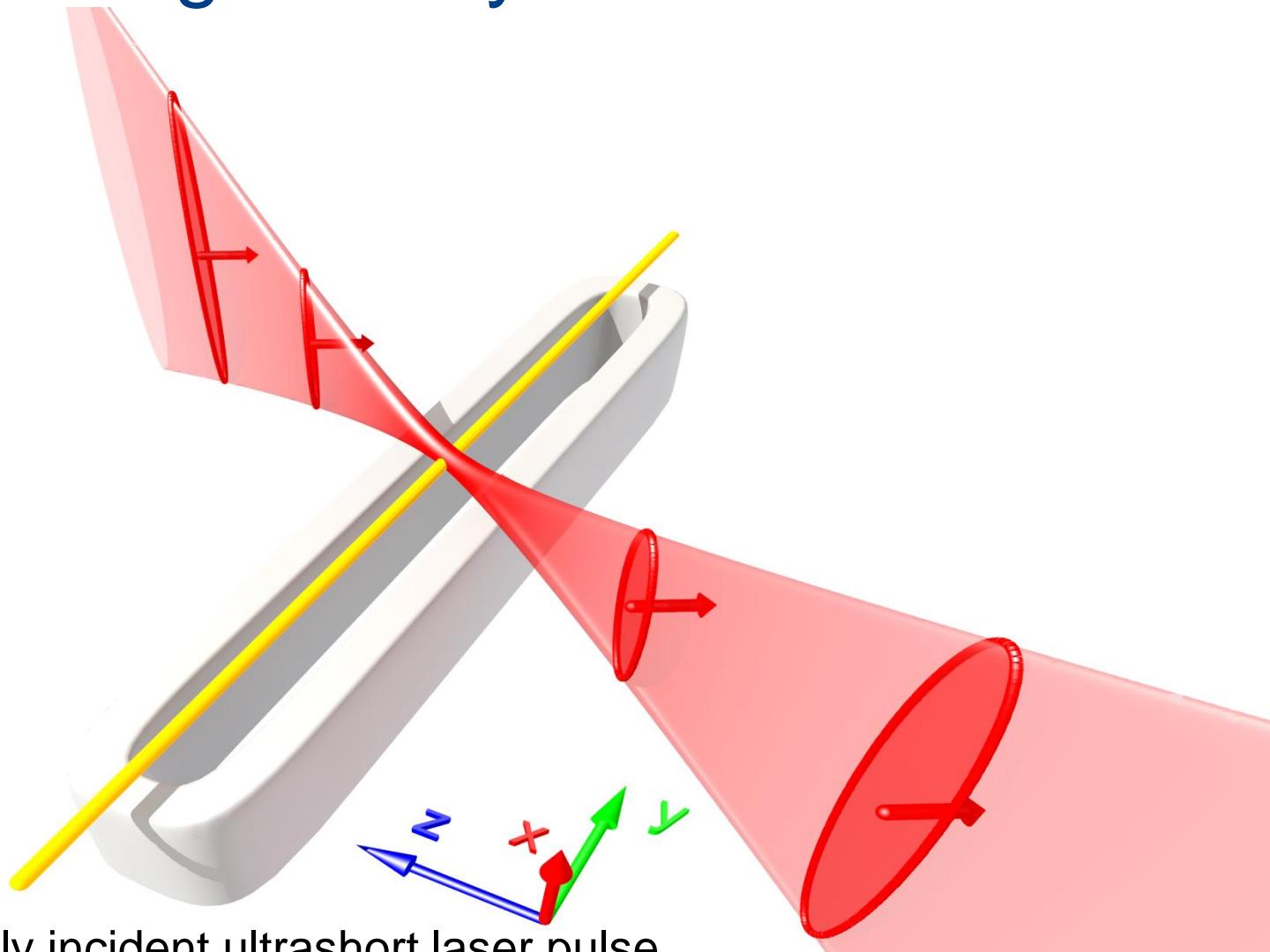
$L(\text{field cycling length}) < L(\text{depletion length})$

TWEAC geometry in a nutshell



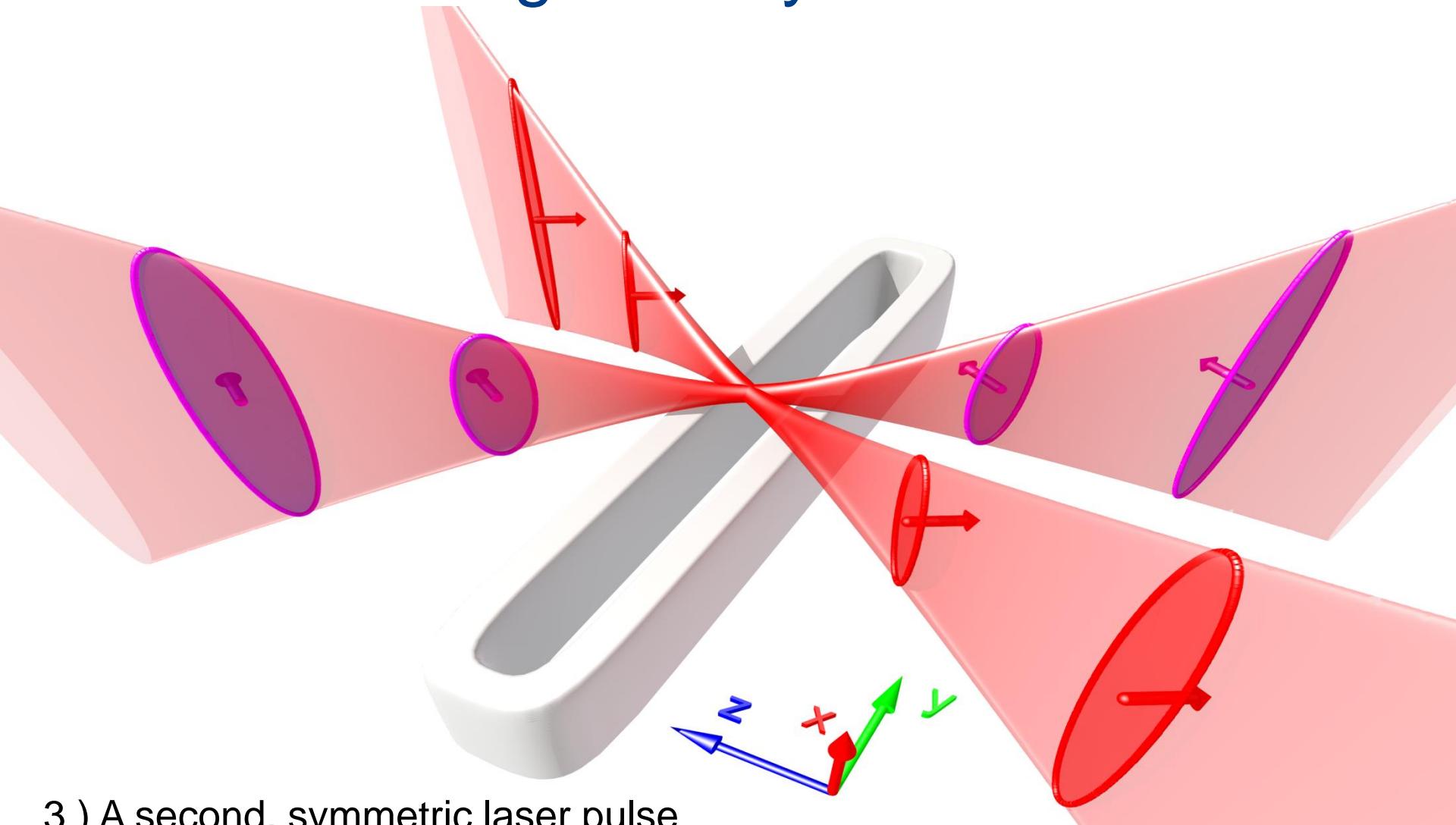
- 1.) An extended gas slit nozzle defines a line focus axis for cylindrical optics.

TWEAC geometry in a nutshell



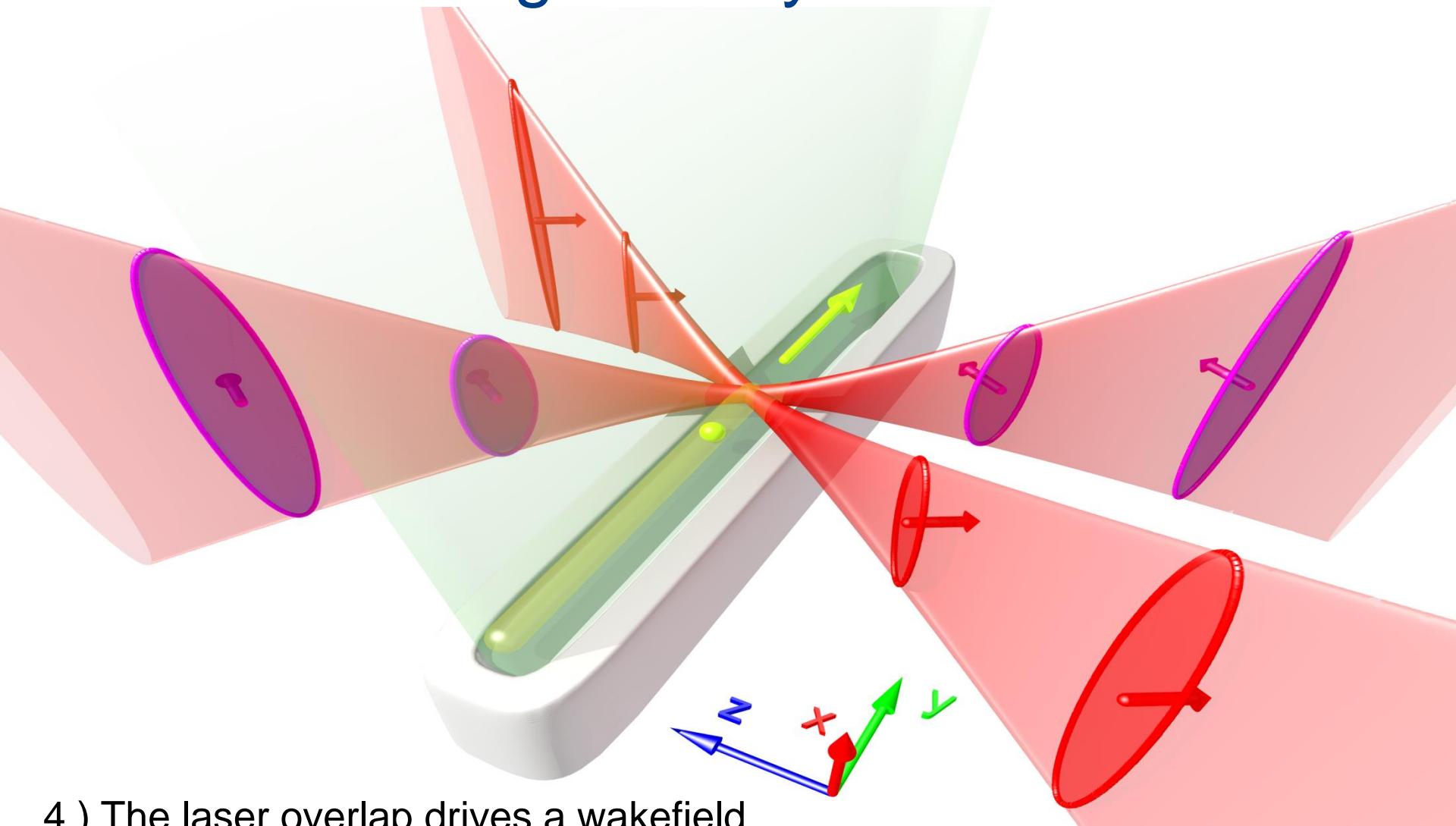
2.) A first, obliquely incident ultrashort laser pulse with a carefully tuned pulse-front tilt creates a comoving focus.

TWEAC geometry in a nutshell



3.) A second, symmetric laser pulse overlaps with the first laser.

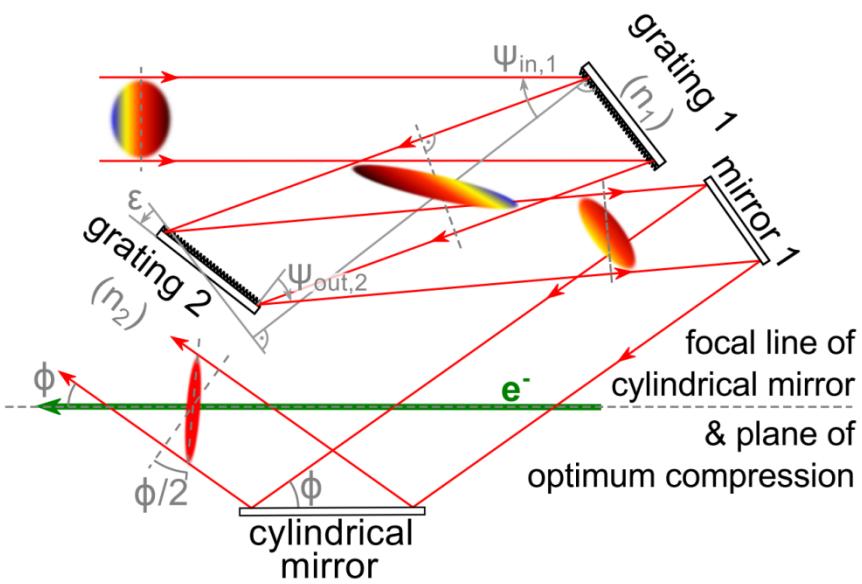
TWEAC geometry in a nutshell



4.) The laser overlap drives a wakefield moving with the vacuum speed of light.

TWEAC type lasers are experimentally feasible using standard optics

Optical setups for TWEAC are similar to Traveling-Wave Thomson-Scattering



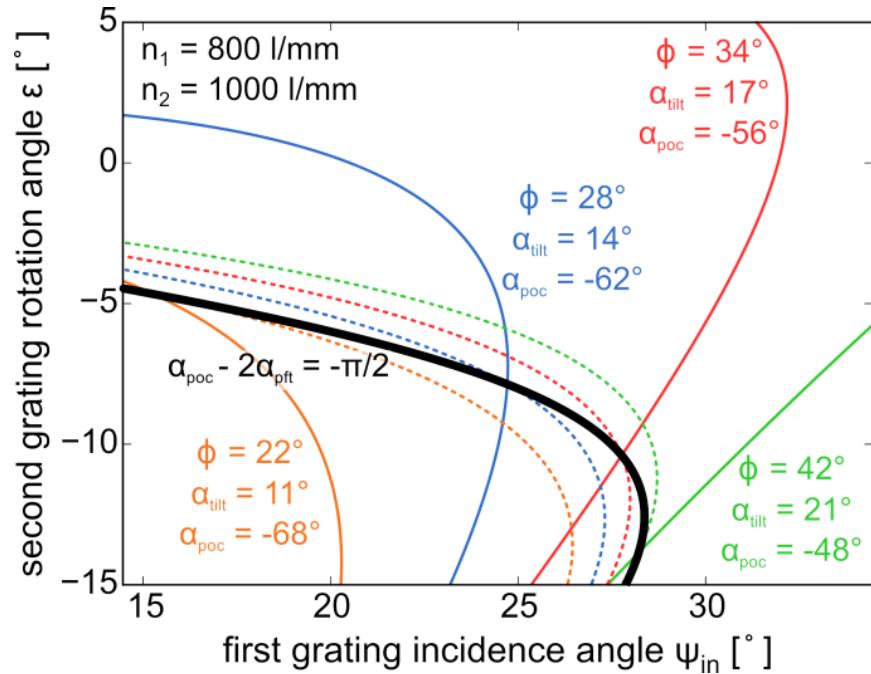
Traveling-Wave Thomson-Scattering aims for
High photon yields per shot, low bandwidths, tunability and all-optical FELs

A. Debus *et al.*, *Appl. Phys. B* **100** (2010) 1, 61

K. Steiniger *et al.*, *J. Phys. B* **47** (2014) 23, 234011

K. Steiniger *et al.*, "Building an Optical Free-Electron Laser in the Traveling-Wave Thomson-Scattering Geometry", to be published

Pulse synthesis using two-grating setups provides tunability by varying pulse-front tilt.

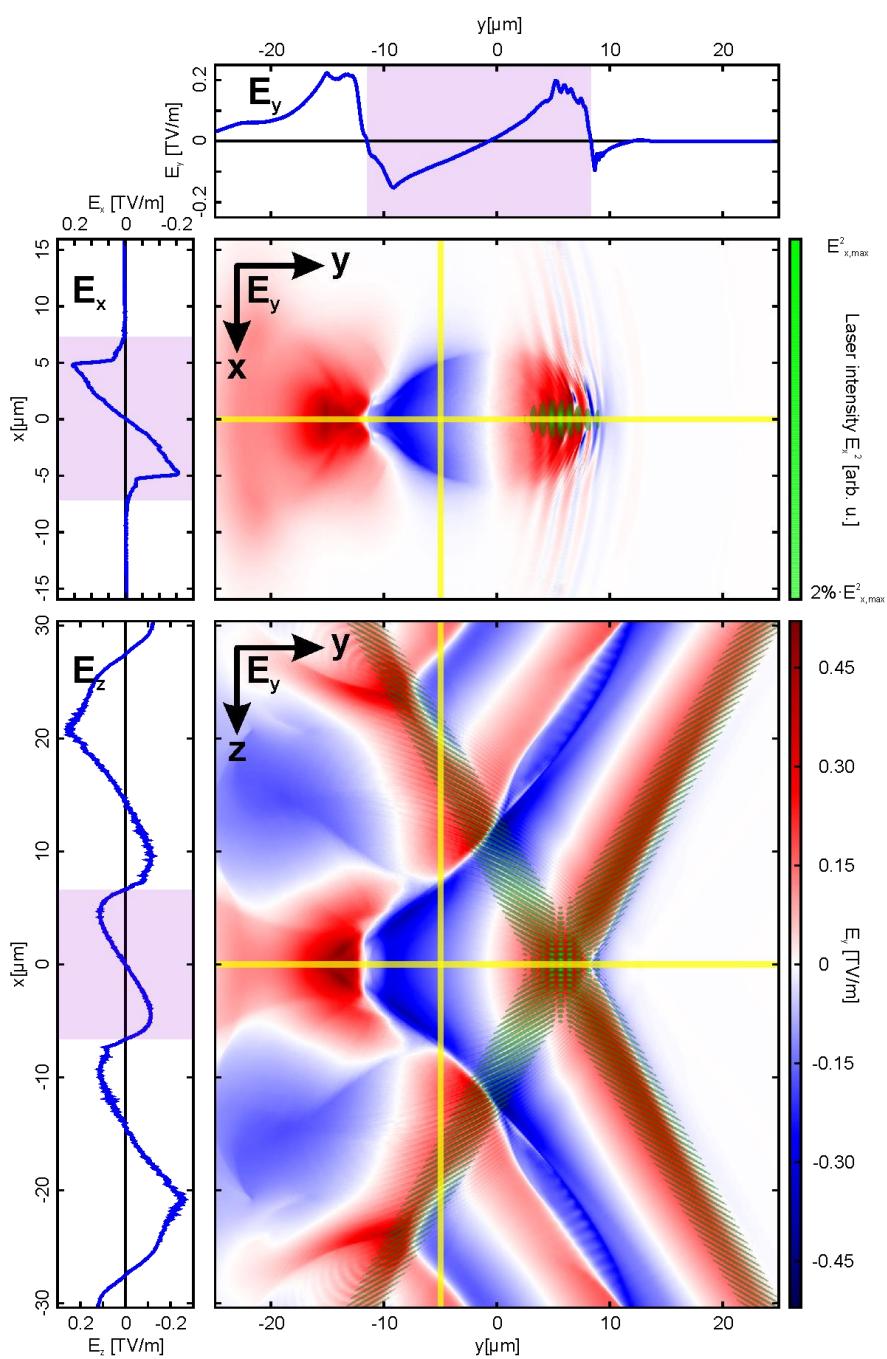


Poster (Wednesday): A. Debus, K. Steiniger *et al.*
Laser pulses for Traveling-Wave Electron Acceleration and Thomson Scattering

Simulate TWEAC using PICoN GPU

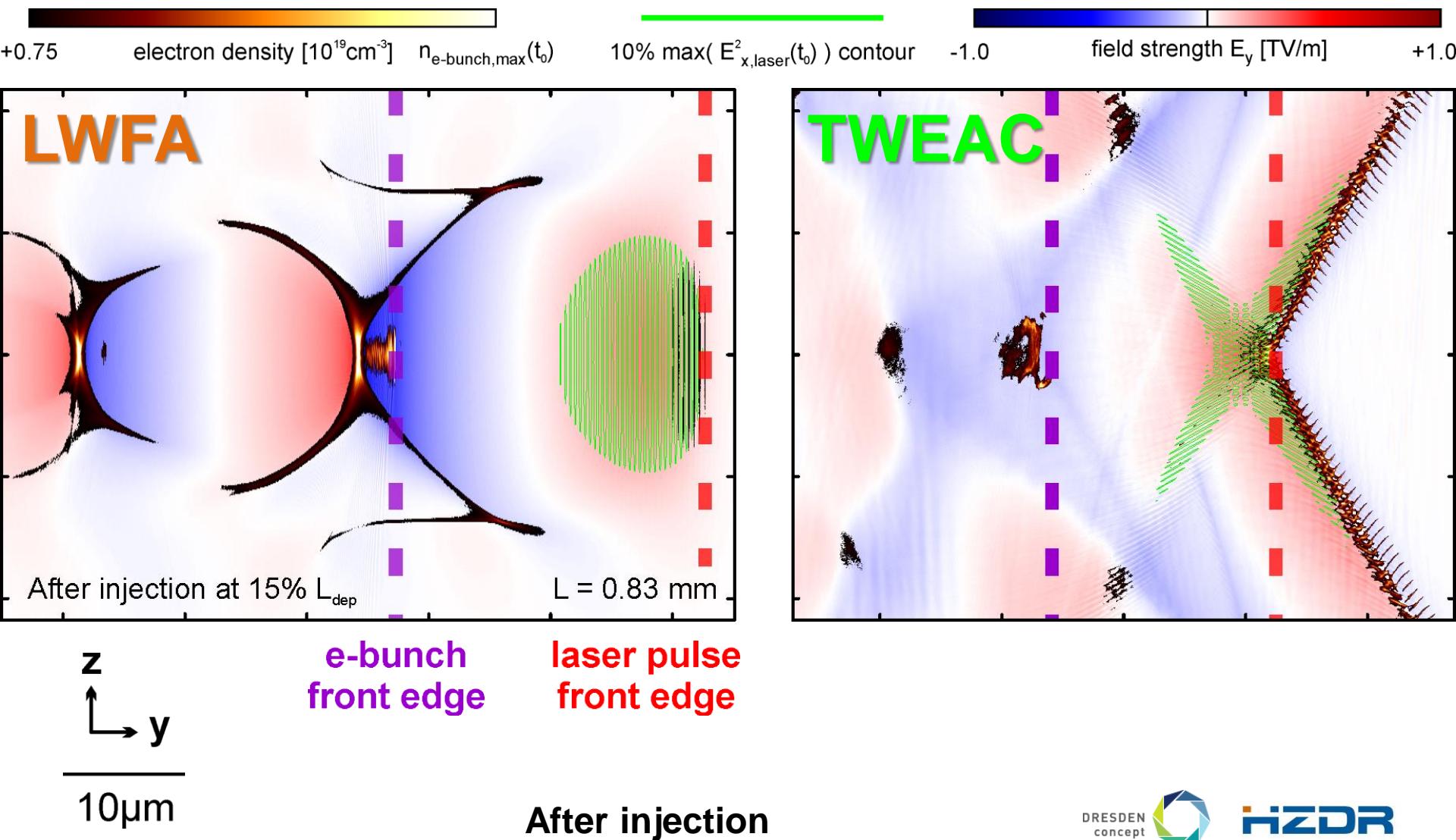
- Field strengths of plasma cavity and focusing fields are comparable to LWFA.
- V-shaped cavity profile in the plane of laser propagation.
- Existance of side cavities.
- At constant density self-injection is absent.

$a_0=3.5$ each arm ; $a_0 = 7.0$ in overlap
 $\Phi=60^\circ$; $n_e=6.4 \cdot 10^{18} \text{ cm}^{-3}$; $\tau=10\text{fs}$ (FWHM)

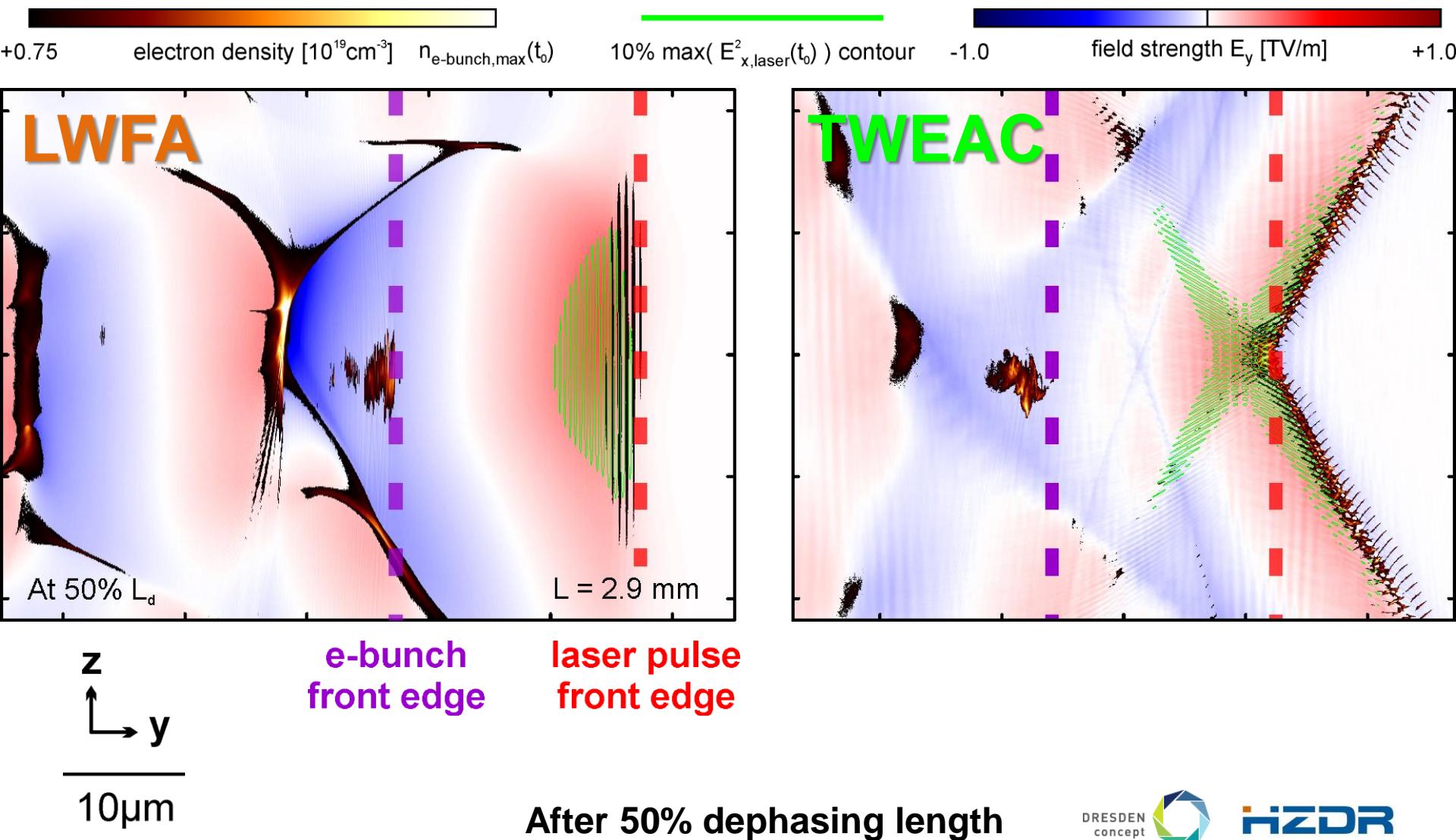


PICoNGPU is Open Source
Download at picongpu.hzdr.de

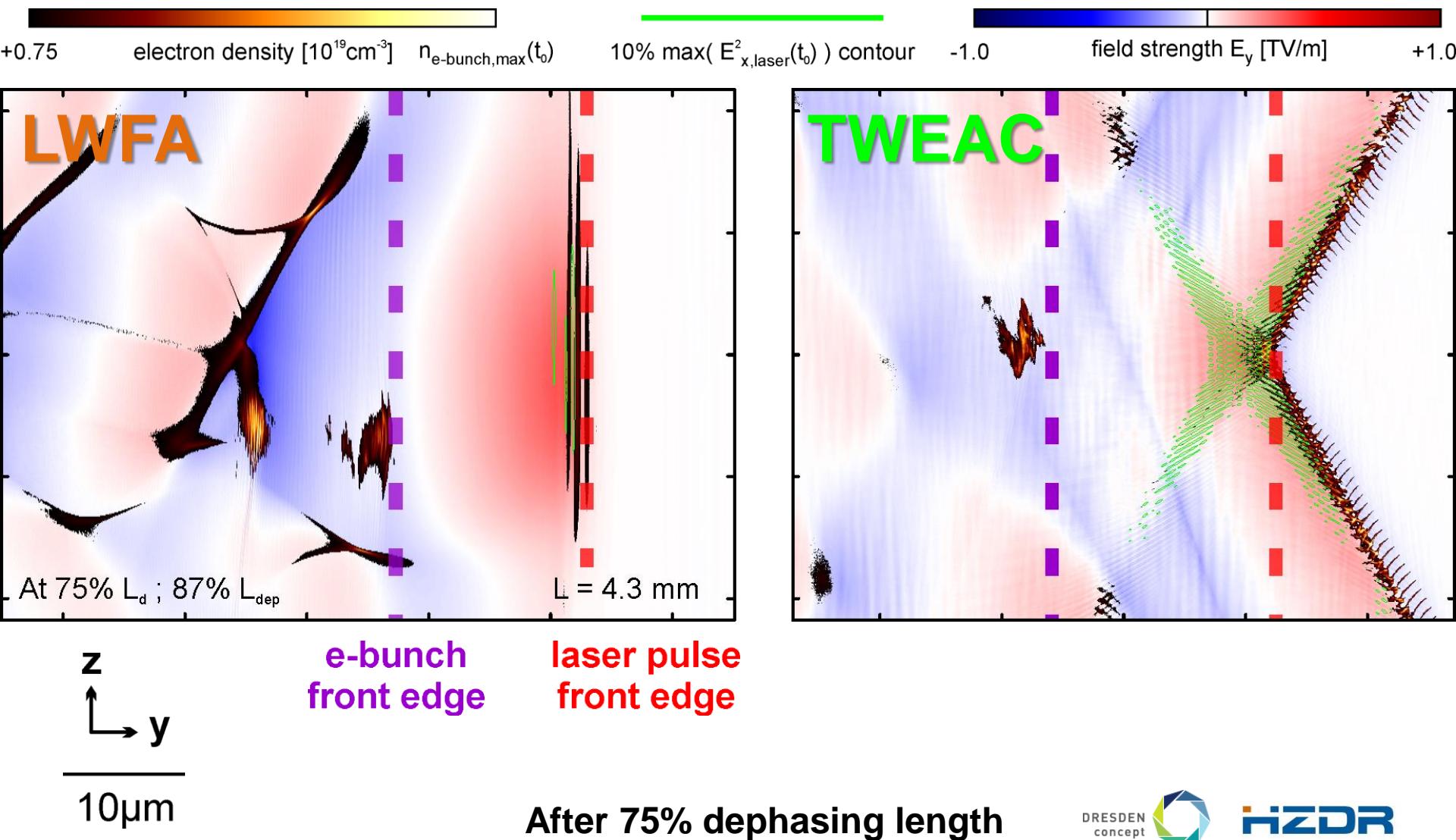
TWEAC eliminates the dephasing and depletion limit.



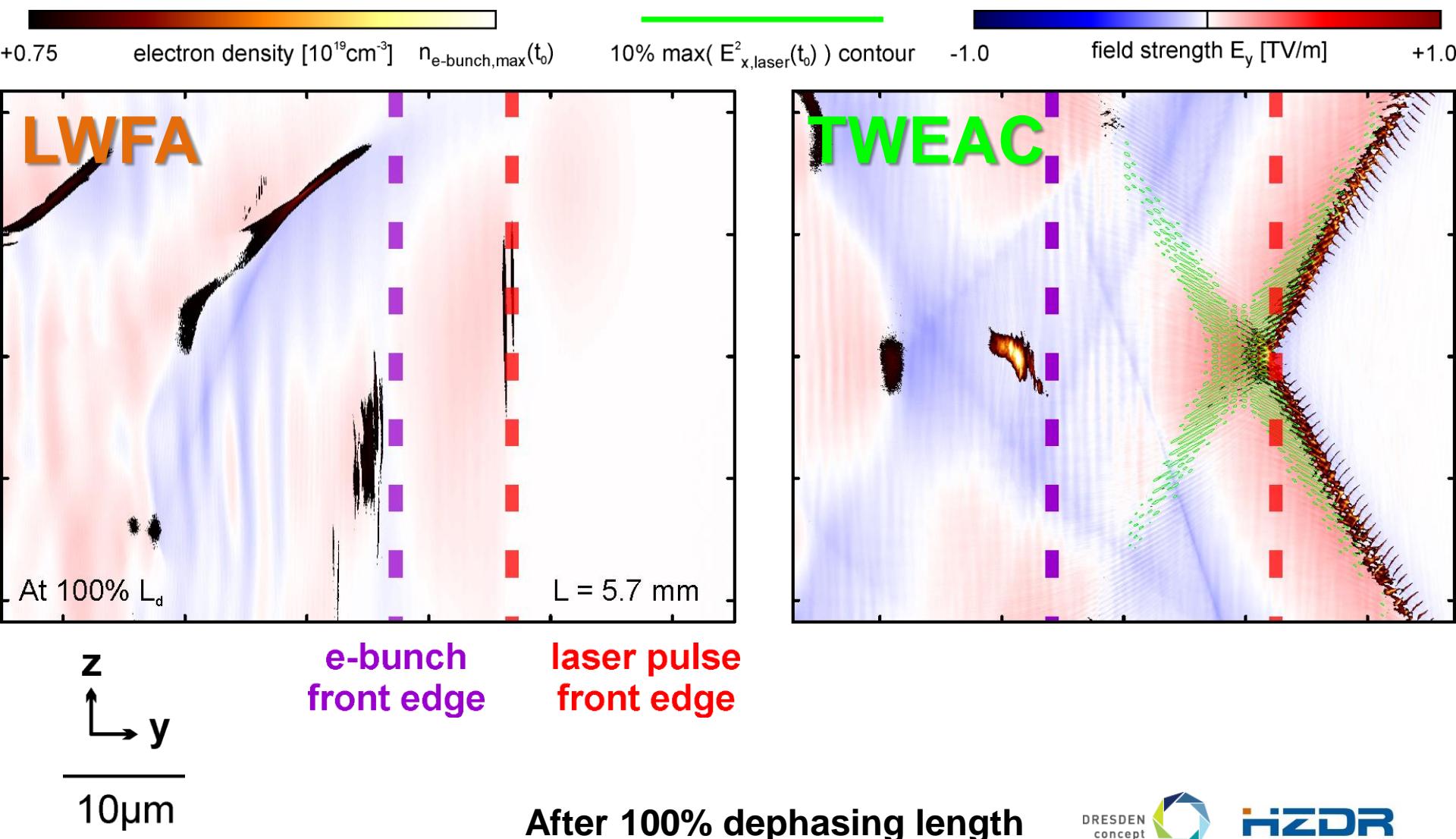
TWEAC eliminates the dephasing and depletion limit.



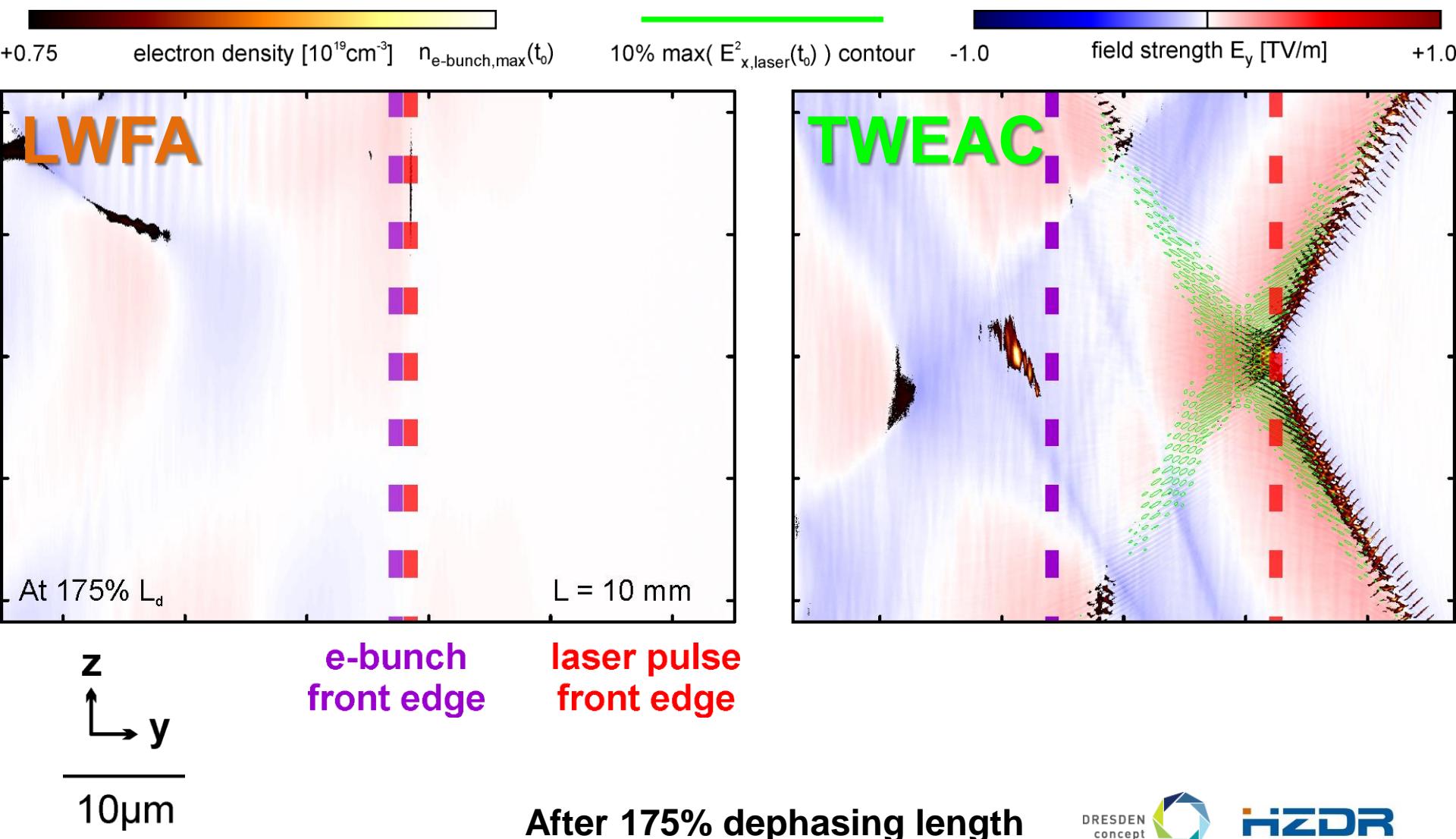
TWEAC eliminates the dephasing and depletion limit.



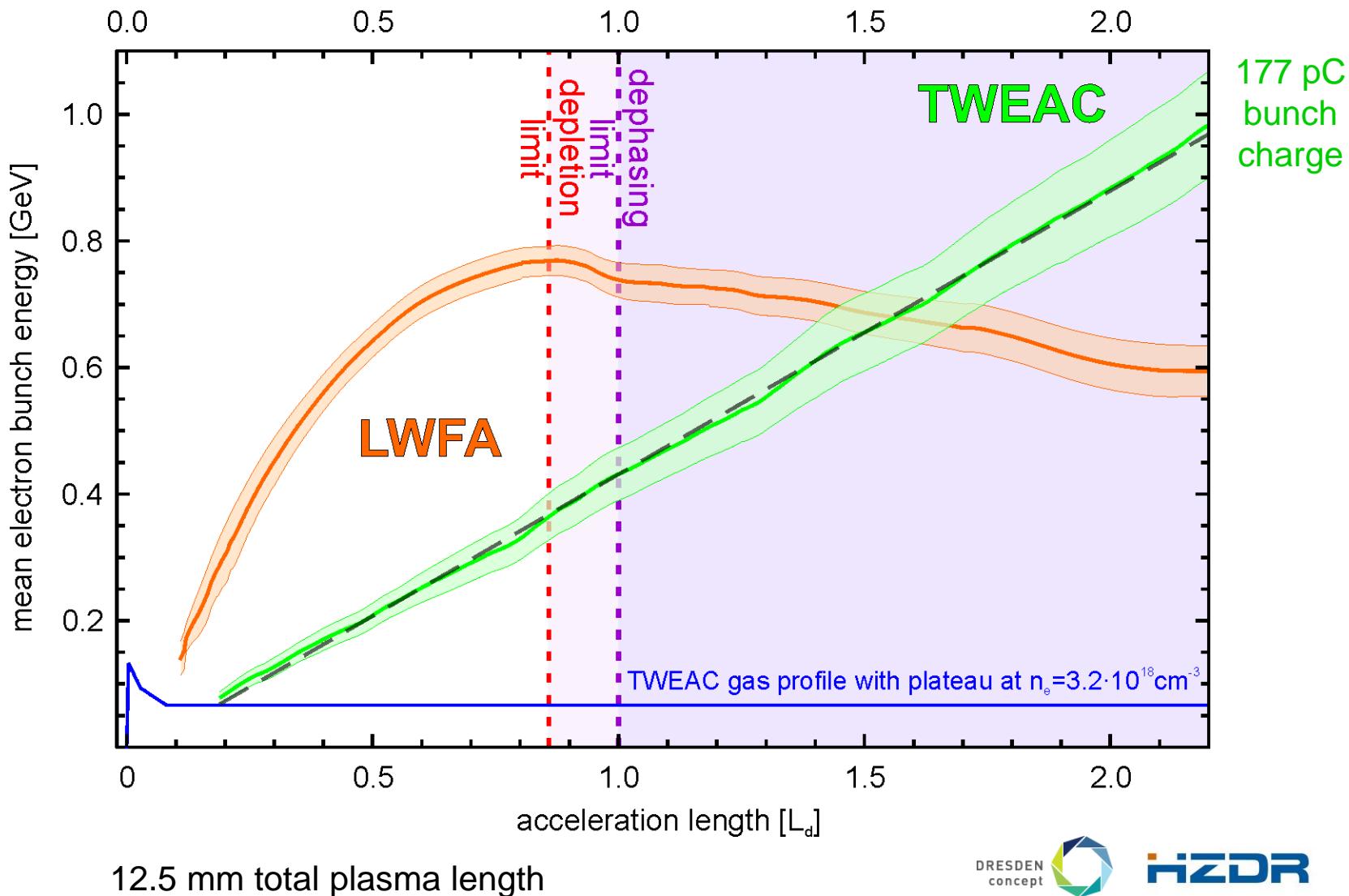
TWEAC eliminates the dephasing and depletion limit.



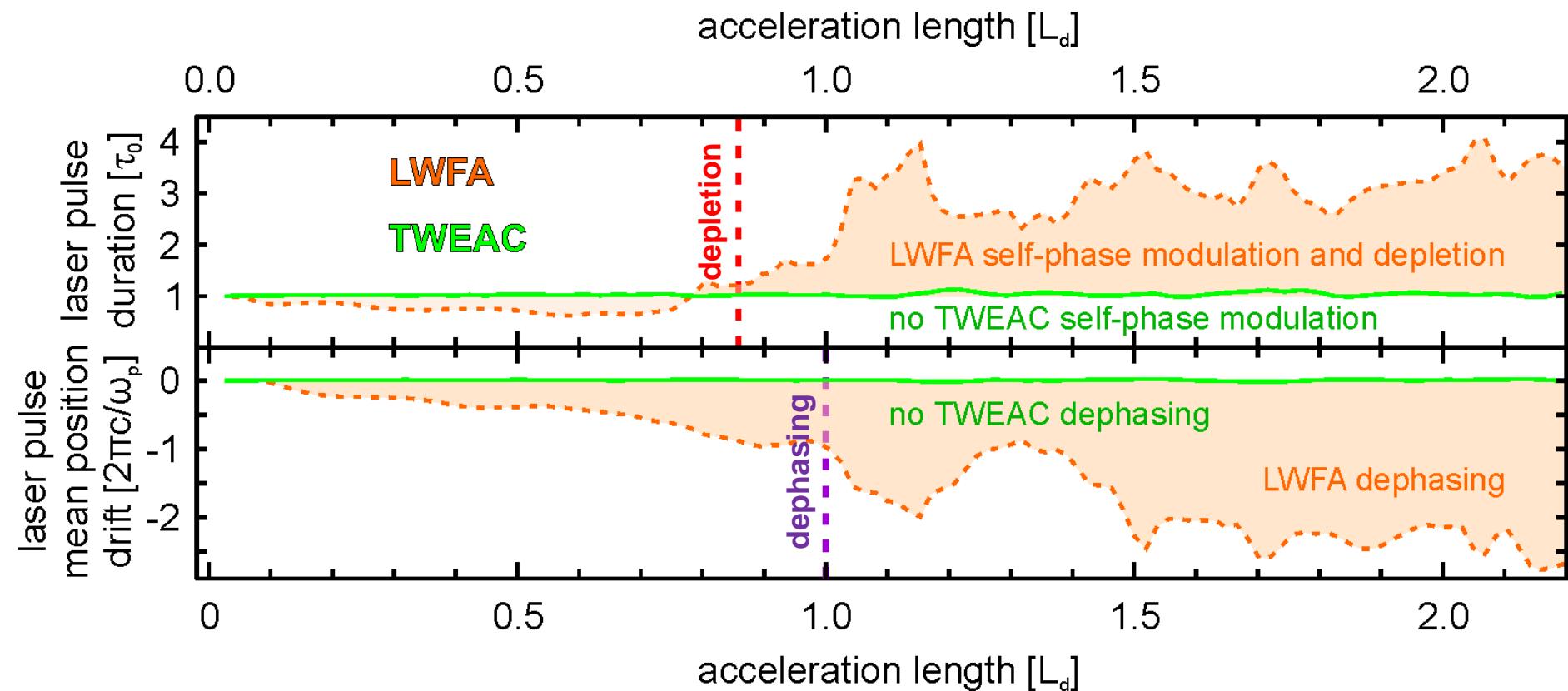
TWEAC eliminates the dephasing and depletion limit.



TWEAC mean electron energy evolves linear with acceleration distance.

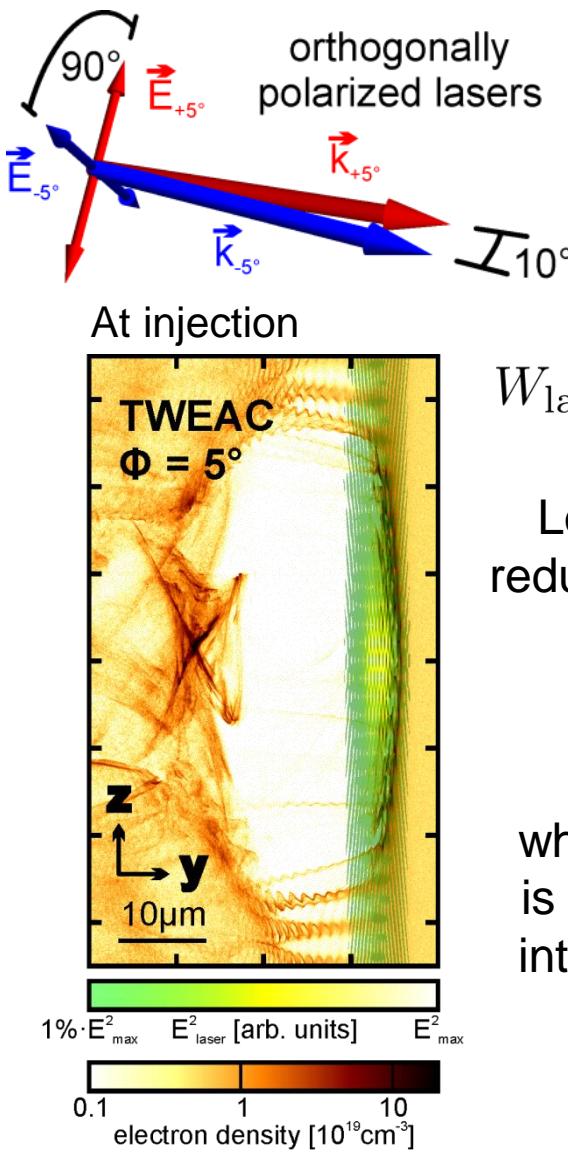
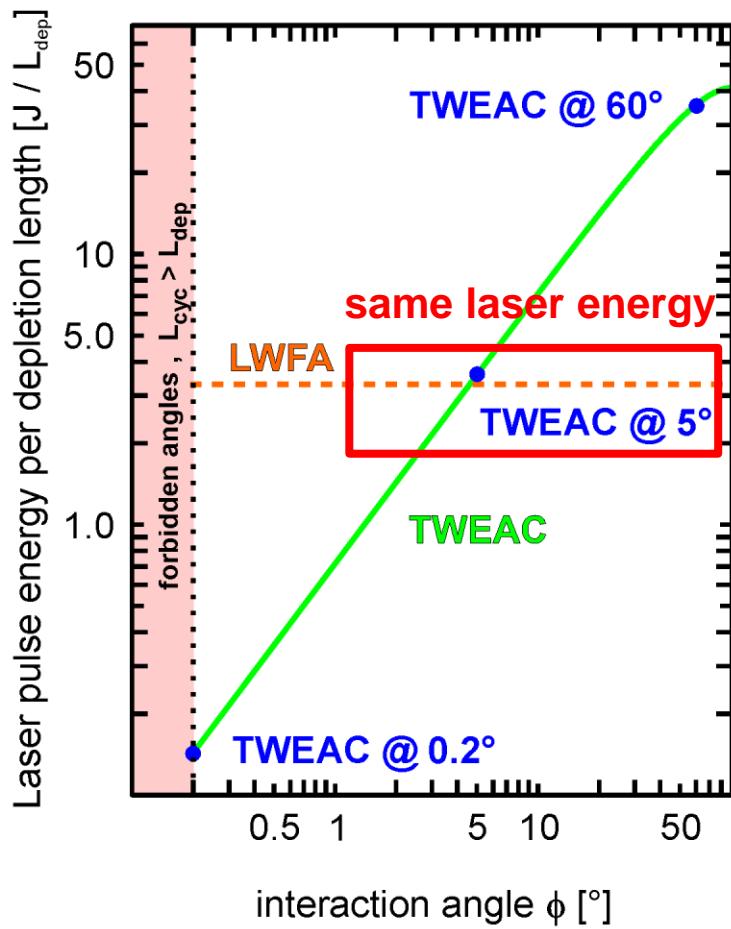


TWEAC maintains quasi-static plasma conditions.



→ **TWEAC accelerator length can be made longer without dephasing or depletion.**

How does TWEAC scale in laser energy?



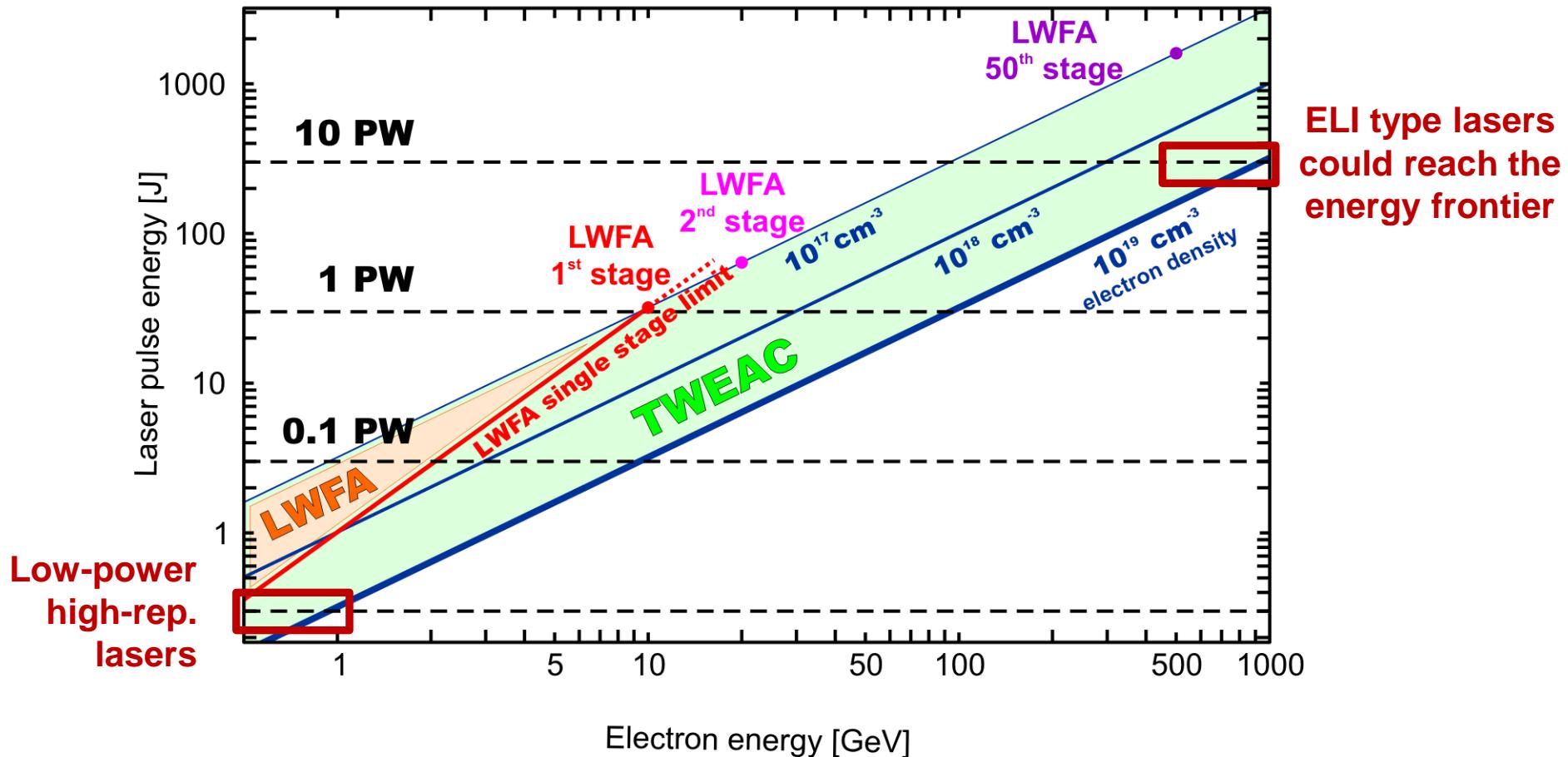
$$W_{\text{laser}} \propto a_0^2 \tau_0 L_{\text{int}} w_x \sin(\phi)$$

Low incidence angles ϕ reduce required laser energy, provided that

$$L_{\text{cyc}} < L_{\text{dep}}$$

where $L_{\text{cyc}} = L_{\text{trans}} / \sin(\phi)$ is independent of the total interaction distance L_{int} .

How does TWEAC scale in laser energy?



Paper submitted

A. Debus *et al.*, „Breaking the dephasing and depletion limits of laser-wakefield acceleration“

LWFA scaling based on

C. B. Schroeder *et al.*, *Phys. Rev. Spec. Top. - Accel. Beams* **13**, 101301 (2010).

Conclusions

Traveling-wave electron acceleration (TWEAC)

- Eliminates the LWFA dephasing and depletion limits.
- Quasi-static plasma conditions without (parasitic) self-injection.
- No laser self-phase modulation along direction of electron acceleration.
- Can in principle be arbitrarily extended in a single stage up to the energy frontier.

Thank you for your attention!

Paper submitted

A. Debus *et al.*, „*Breaking the dephasing and depletion limits of laser-wakefield acceleration*“