Excitation of beam-driven plasma-waves in a hybrid LPWFA

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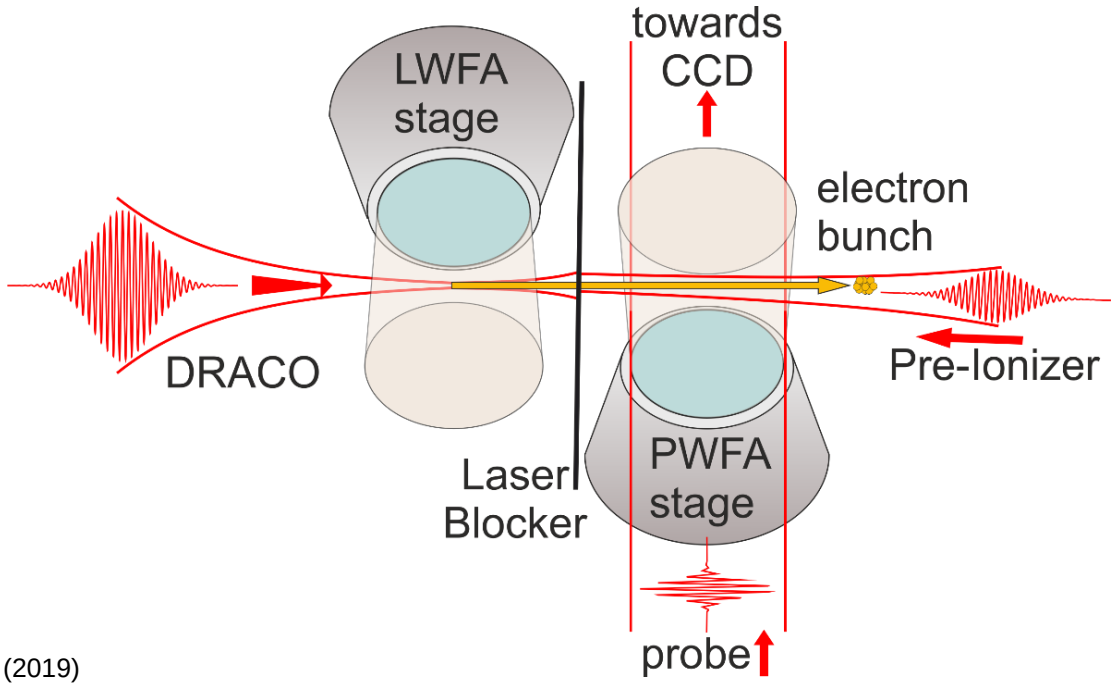
Hybrid Collaboration

Motivation and Setup

- PWFA: promissing concept for **generation** and **acceleration** of **high quality** electron beams
- PWFA blowout regimes (Lotov, 2004)[1]: e.g. **strong beam** regime
  - **efficient energy transfer** to the plasma
  - **robust** wakefield cavity
  - quasi **linear accelerating and focusing field**: promissing to reach **high quality** witness beams
  - Driver requirements: **high peak currents** (> 17kA), transversal ($\boldsymbol{\sigma_r \lesssim c/\omega_p}$) and longitudinal ($\boldsymbol{\sigma_z \approx c/\omega_p}$) matching with the plasma frequency

→ **LWFA** is able to generate GeV class[2] electron bunches with **high peak currents** (> 10 kA)[3]

→ **Using LWFA bunch to drive PWFA,** could reach strong beam regime in a compact setup



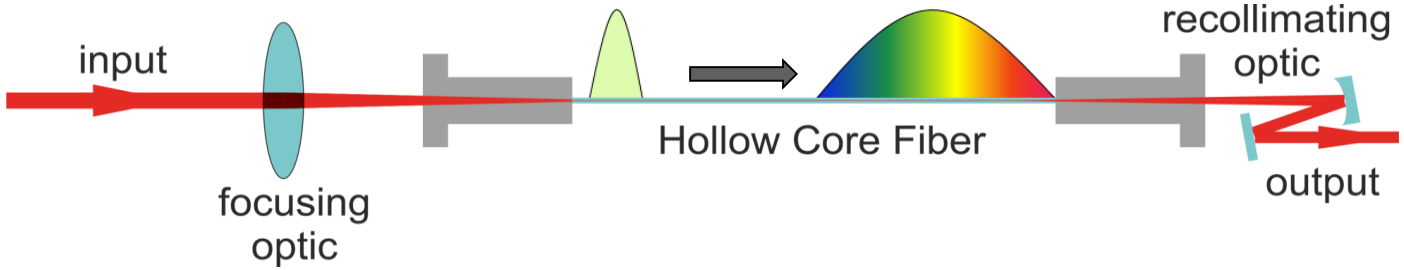
1: K. V. Lotov, *Physical Review E* 69, 046405 (2004)
2: A. J. Gonsalves *et al., Phys. Rev. Lett*. 122, 084801 (2019)
3: J. P. Couperus*, et al., Nat. Commun.* 8, 487 (2017)

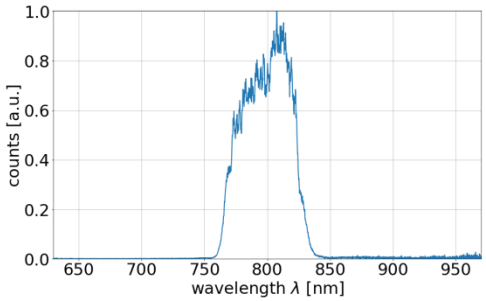
Few Cycle Pulse

→ Important information about PWFA process:

- **Generation** of plasma waves?
- **Structure** of these waves?
- **Interaction strength** between driver beam and plasma?

- Shorter pulse needs broader spectrum (Fourier limit)
- Using spectral broadening inside a hollow core fiber (Self phase modulation (SPM), fiber acts as mode filter)

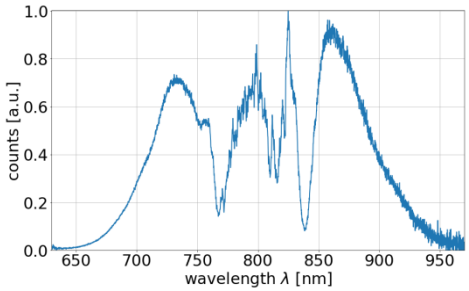




30 fs limited spectrum

SPM

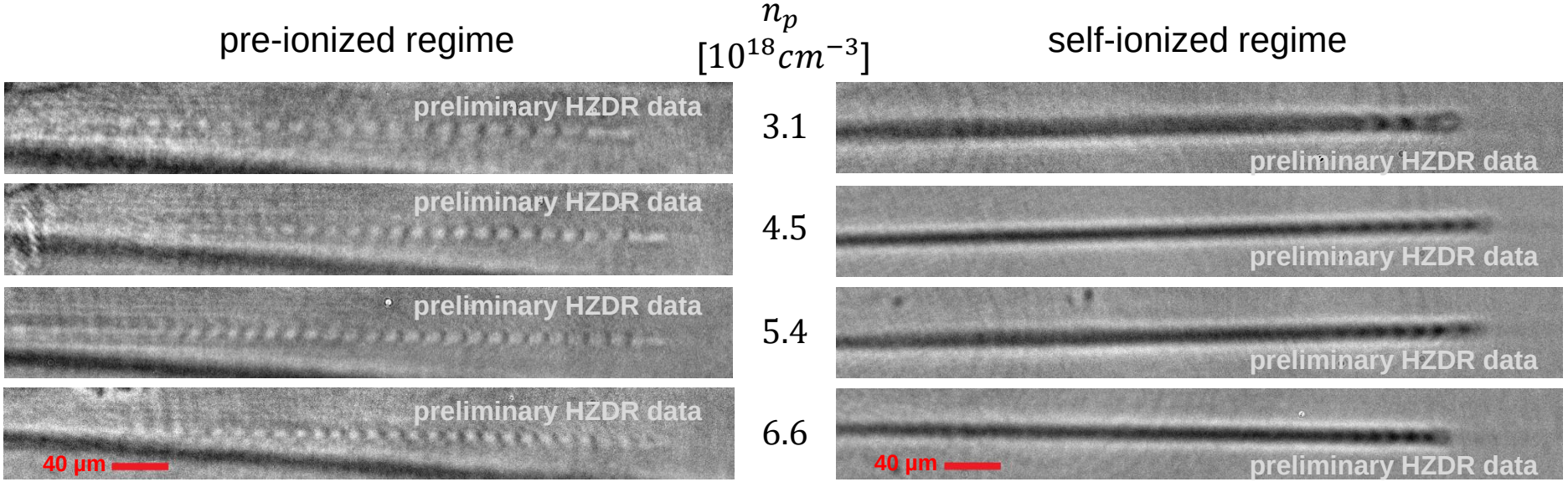
6.5 fs limited spectrum



→ **Ultra-short pulse (< 10 fs)** deployed for probing PWFA at high density[1]

1: M. F. Gilljohann, *et al.*, Phys. Rev. X 9, 011046 (2019)

Plasma density dependency

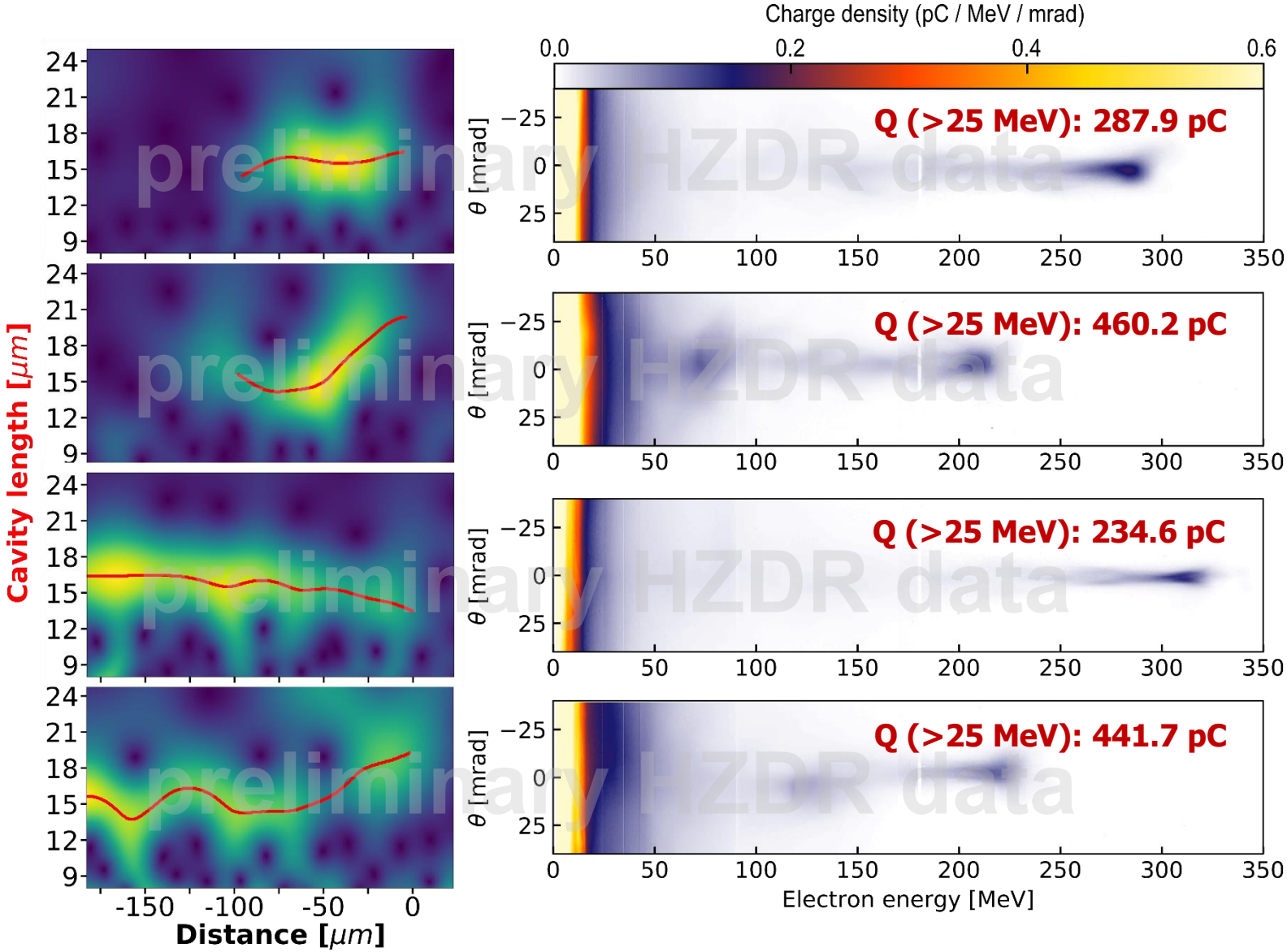


- More robust and visible cavities in pre-ionized than self-ionized case
- Self-ionized case: good matching with expectations for fully ionized Hydrogen:
  Beam is able to **fully ionize Hydrogen** itself

Correlation pl.-wave structure & e-spectrum

self-ionized regime

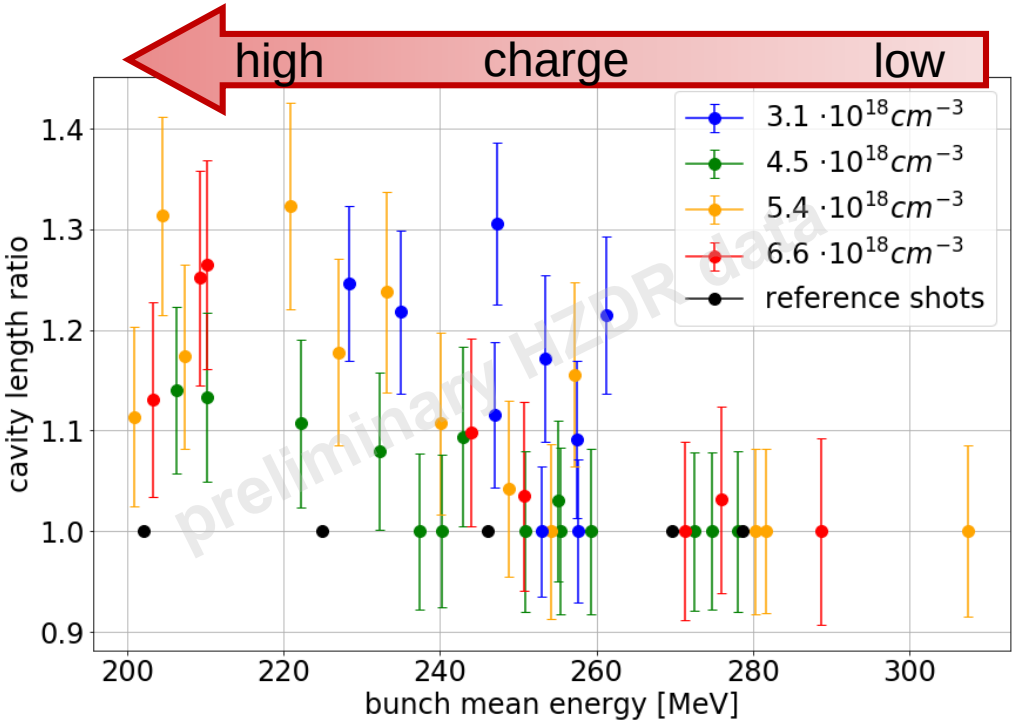
pre-ionized regime



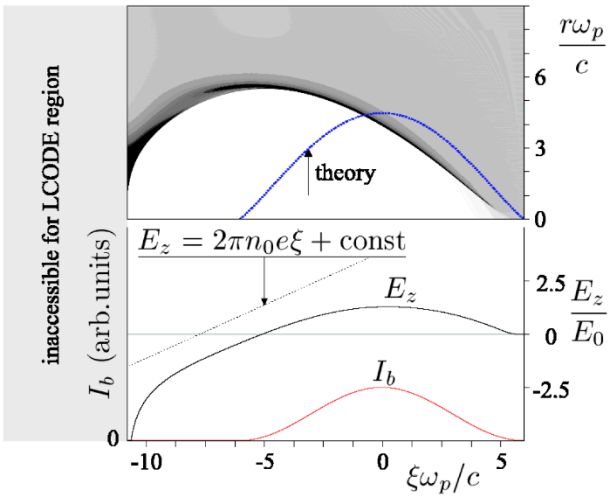
→ **Elongation** of the first cavity depeding on the driver bunch properties

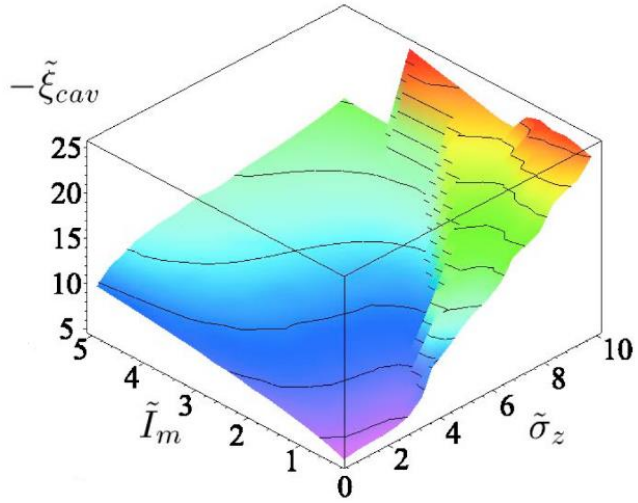
Elongation of the first cavity

- Elongation is larger for shots with smaller bunch energy
  - → Due to **beam loading in LWFA**: **high charge bunches** have intrinsically **less energy**
  - → Indication for charge dependeny of this elongation



- Predicted already in Lotov 2004 paper, but for a smaller transverse size





figures from: K. V. Lotov, Physical Review E 69, 046405 (2004)

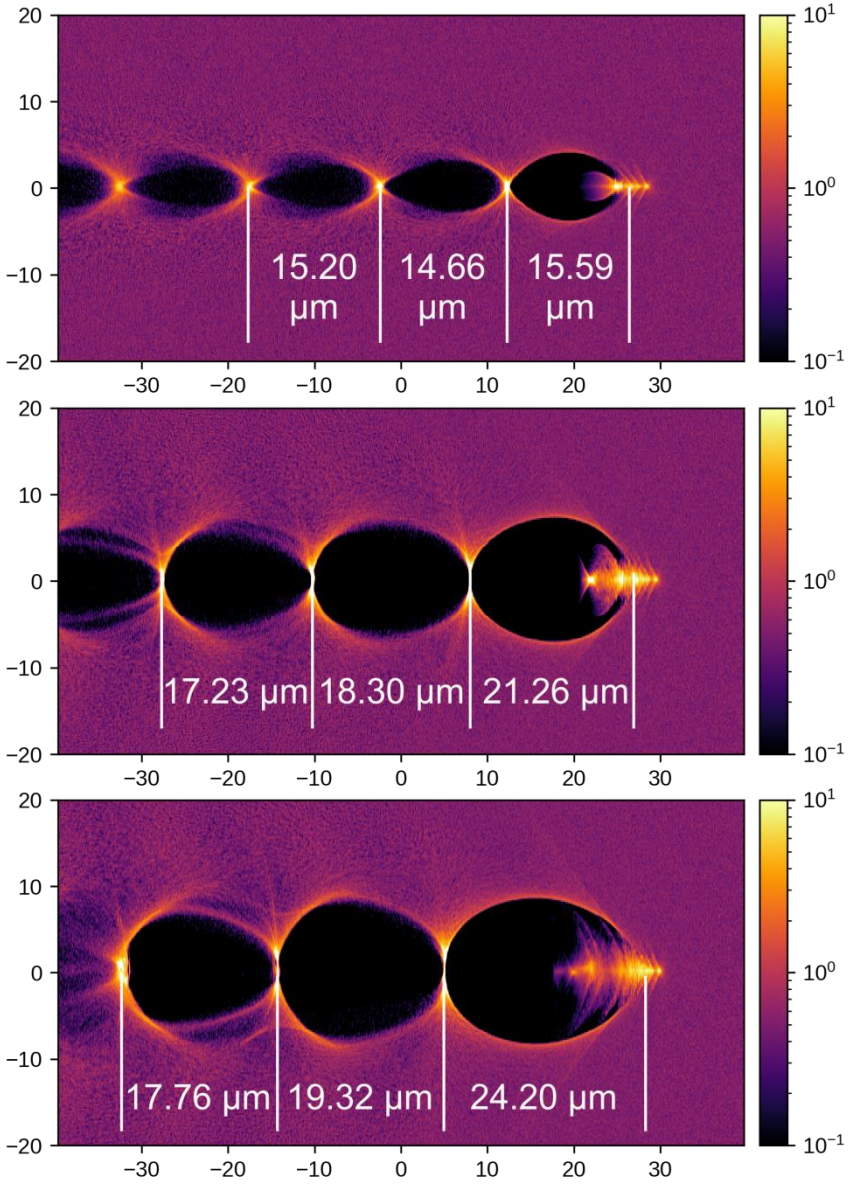
Simulations of the correlation

- Simulation of gaussian shaped electron bunches entering pre-ionized target

100 pC

400 pC

700 pC



→ Behavior as observed in experiments:

→ **High charge causes elongation** of the cavities, both: relatively to the following cavities AND in general

→ Structures between cavities become smaller

PIConGPU

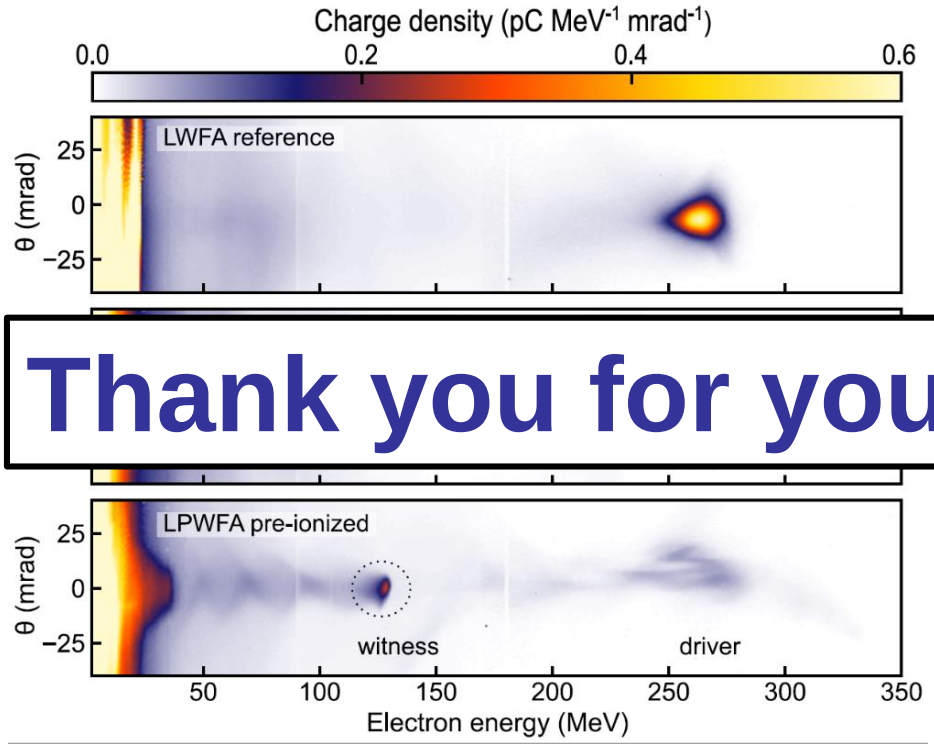
simulations by Alexander Debus, HZDR

Summary and Outlook

- High peak current **LWFA beam** is able to **drive plasma wave**
- Observation of a charge dependend elongation of the first cavity

→ Indication: with **LWFA beams** as drivers it is possible to **enter the strong beam regime**

→ Plasma wave **probing as diagnostic for interaction strength** (peak current) of the driver beam



See Talk:
Thomas Heinemann,
Thursday 18:00, WG
Laser-driven electron

Thank you for your attention!

Wednesday evening,
Thomas Heinemann
Susanne Schöbel