Modeling the L|PWFA hybrid accelerator using PIConGPU

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Hybrid Collaboration

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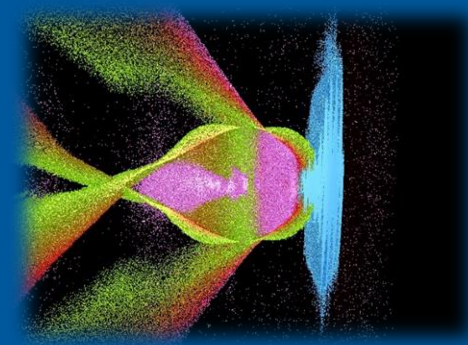
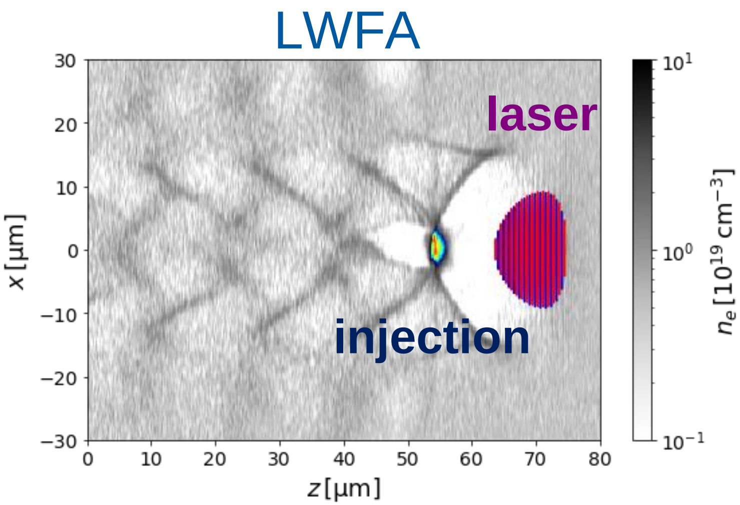
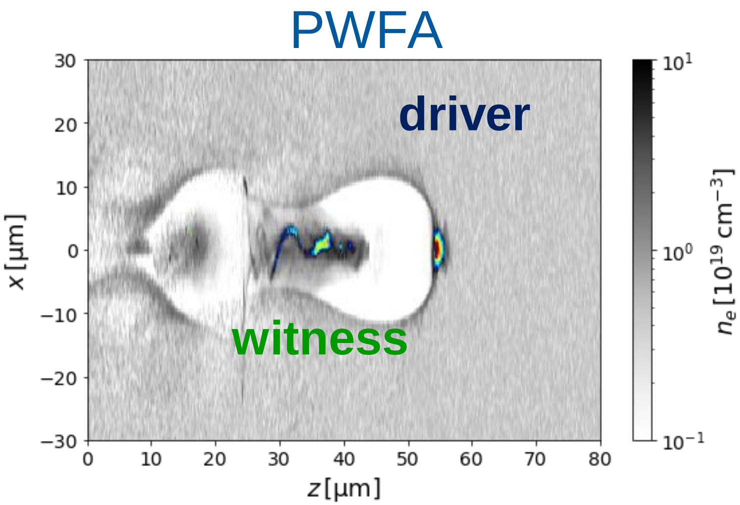
2) Technische Universität Dresden
3) Deutsches Elektronen-Synchrotron (DESY)
4) University of Strathclyde
5) Ludwig-Maximilian Universität München (LMU)
6) Laboratoire d'Optique Appliquée (LOA)



Combining LWFA and PWFA

A compact source for high brightness electron beams





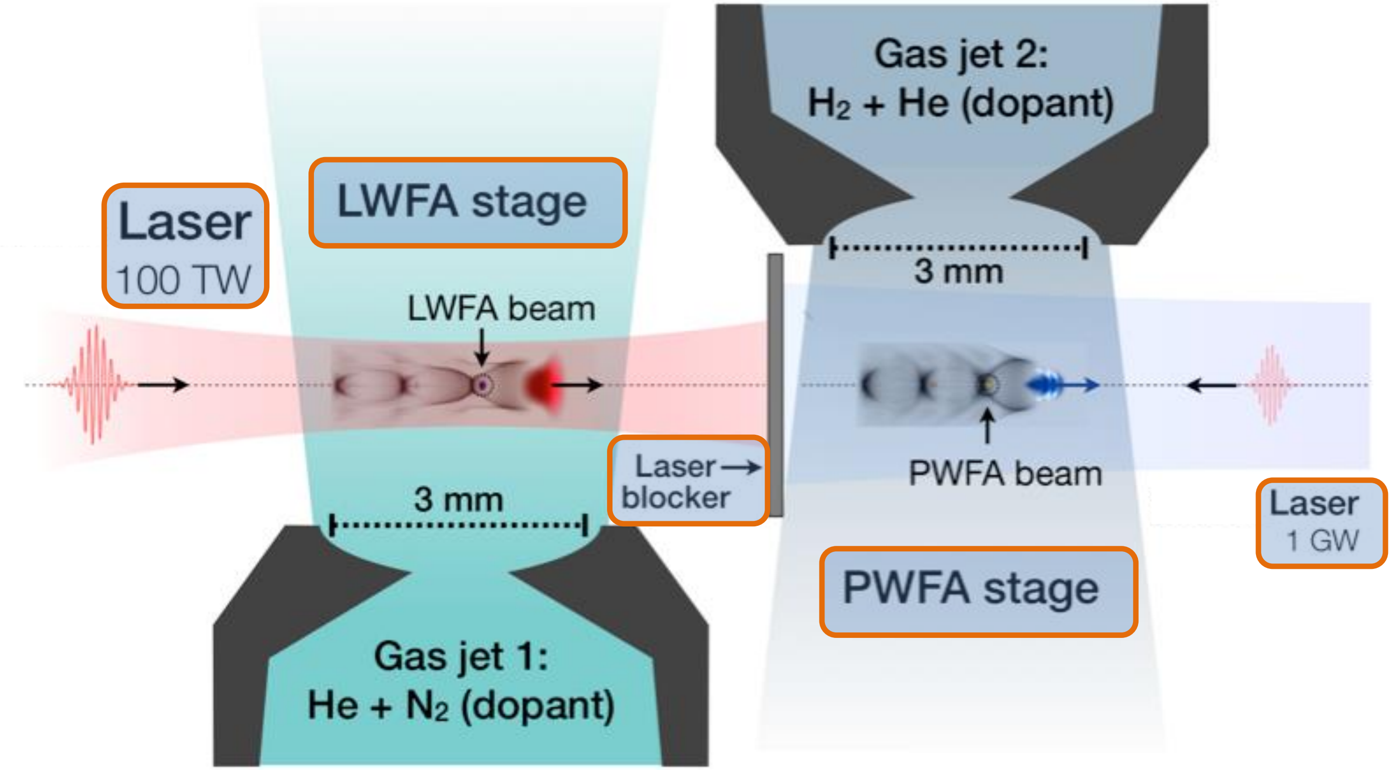
- driven by high-power laser pulse
- compact, laboratory-sized
- provides high-current electron beam

- driven by high-current beam
- km-sized facilities (FACET SLAC)
- capable of producing high-brightness witness beams

Combine both to build a compact PWFA accelerator

Concept of the hybrid LWFA-PWFA accelerator

Schematic layout of the combined setup



~0.5 nC injection via
self-truncated ionization injection

high-brightness witness beam
acceleration

Demonstration of a compact plasma accelerator powered by laser-accelerated electron beams
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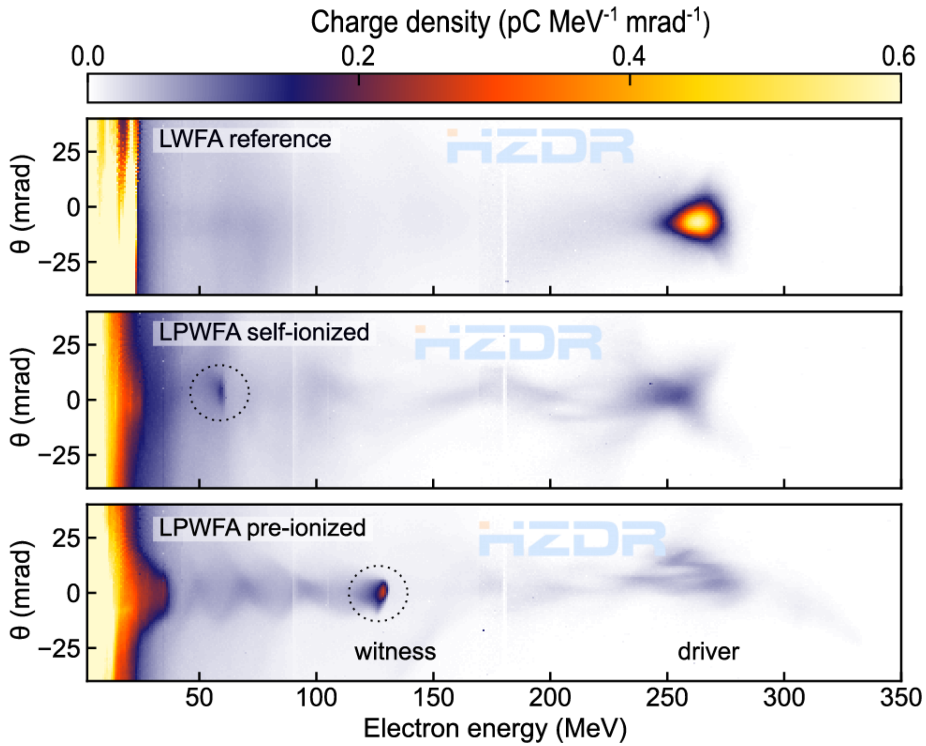
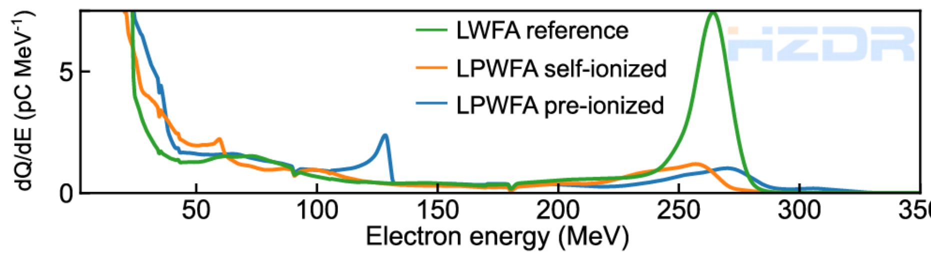
Proof of principle L|PWFA experiment

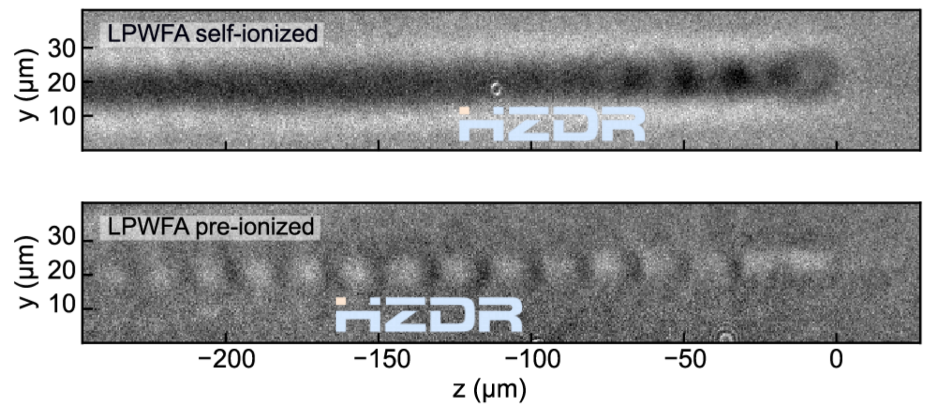
Setup realized at HZDR



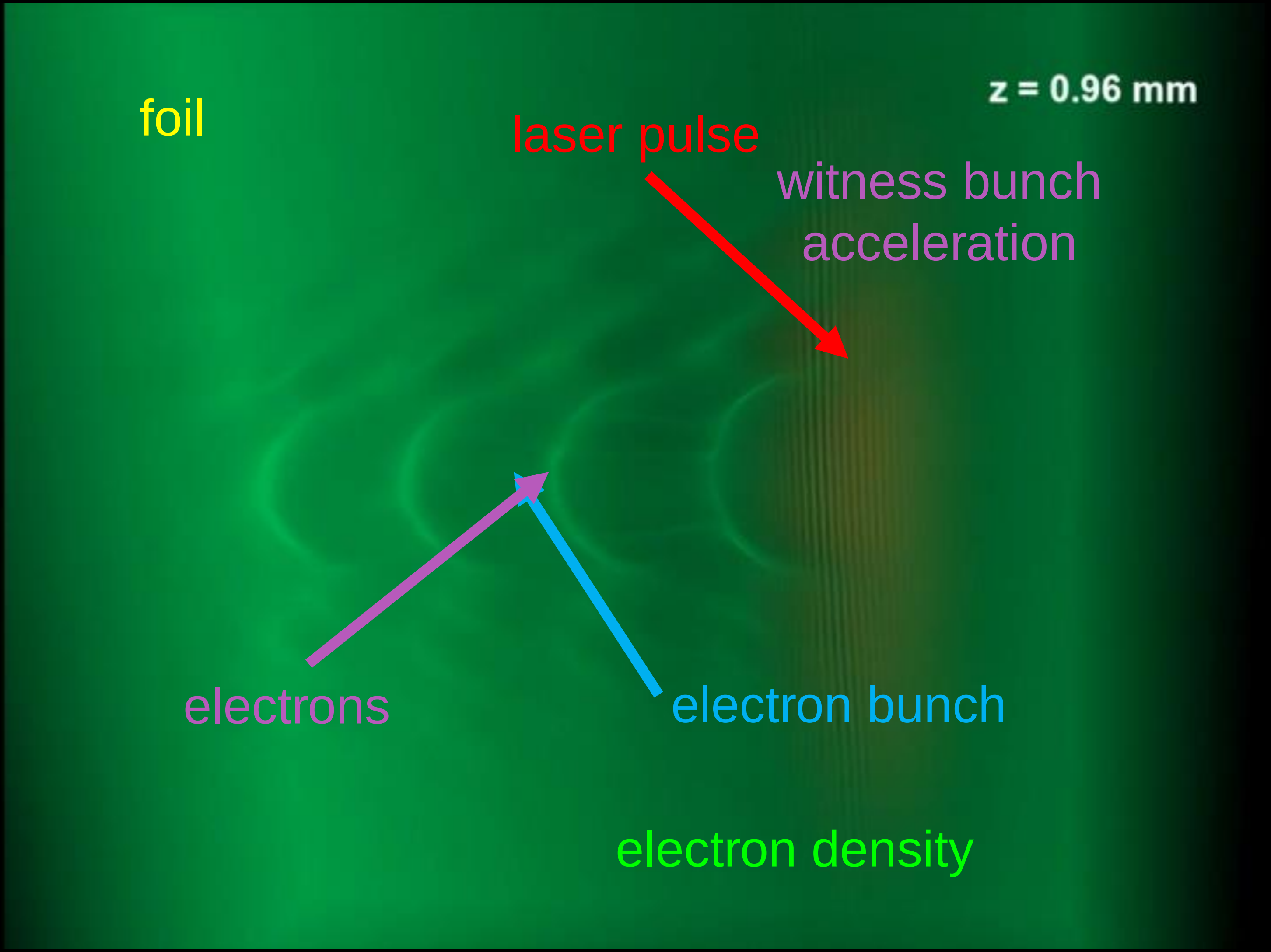
Witness bunch acceleration was demonstrated.



A few cycle laser probe clearly show beam-driven plasma waves.



Looking into the L|PWFA using PIConGPU
an ISAAC visualization

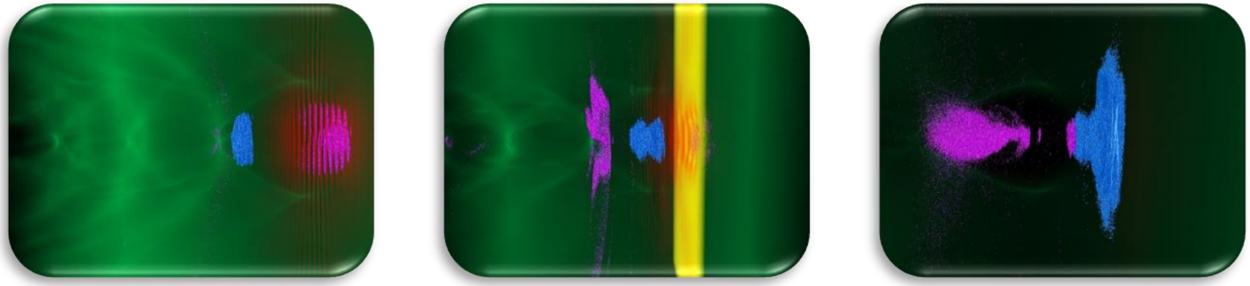


Start-to-end simulations of L|PWFA using PIConGPU

An open source, fully relativistic, 3D3V particle-in-cell code

PIConGPU

picongpu.hzdr.de



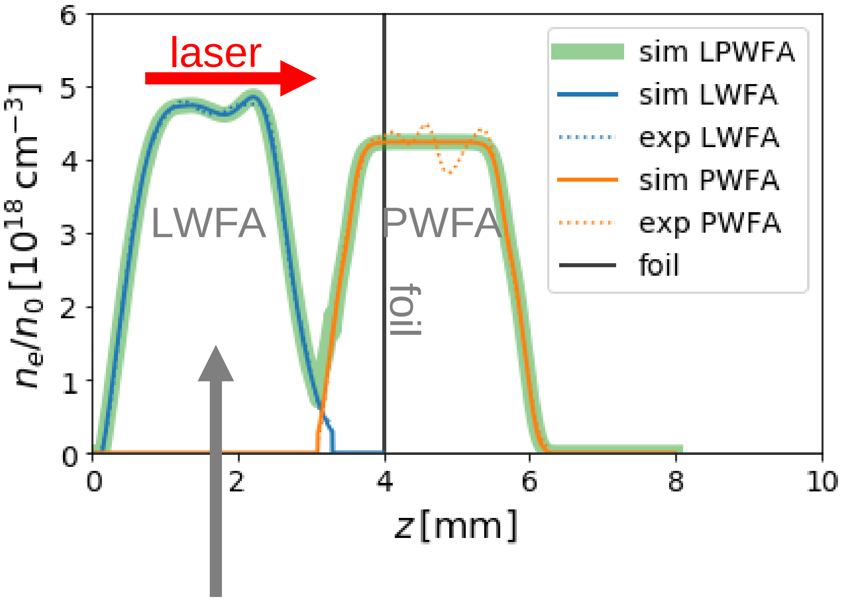
- Use **3D, start-to-end simulations** for comprehensive dynamics, such as identifying source of electron driving the PWFA stage.
- Main simulation campaign over 50 simulation setups and several Mega-CPUh total.
- Combination of LWFA and PWFA provides more knobs for getting things wrong.
- Long simulations are demanding with regard to performance, accuracy and stability.

DRESDEN concept HZDR

How the initial L|PWFA hybrid setup is modeled

- Include experimentally measured density profile
- Use different particle species to study PWFA injection process
- Use combined BSI+ADK ionization model
- Both pre-ionized and self-ionized PWFA stage can be simulated.

measured and **simulated** density profile:

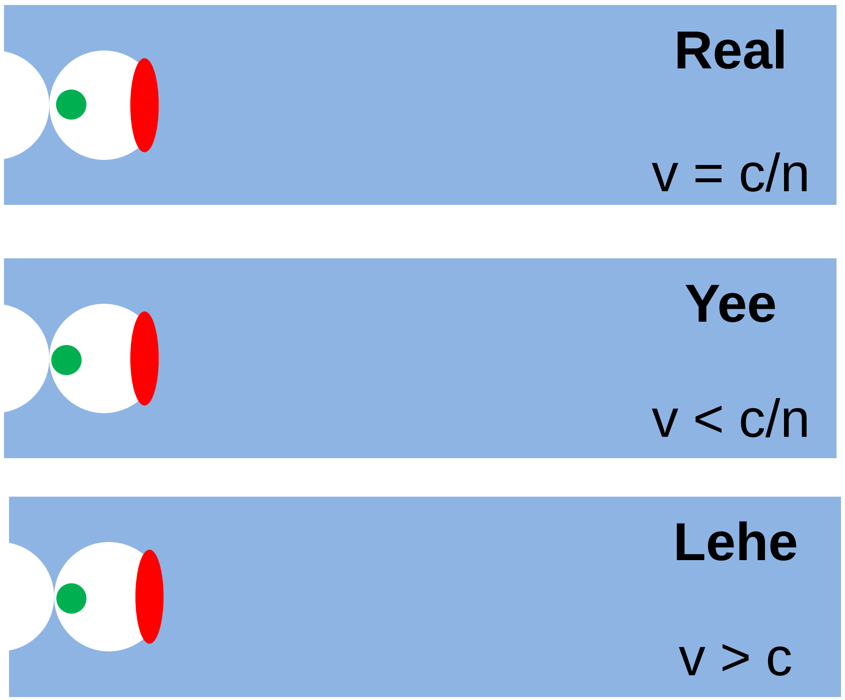


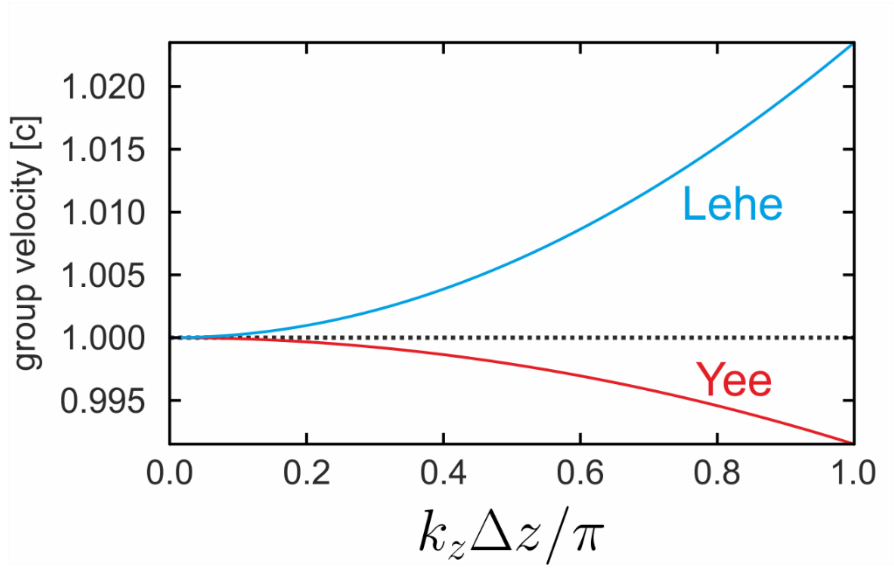
Now: let's have a detailed look at the LWFA stage and issues arising in laser modeling

1st generation

Numerical issues we encountered

From numerical Cherenkov with Yee to dephasing with Lehe





Can be avoided
with higher resolution.

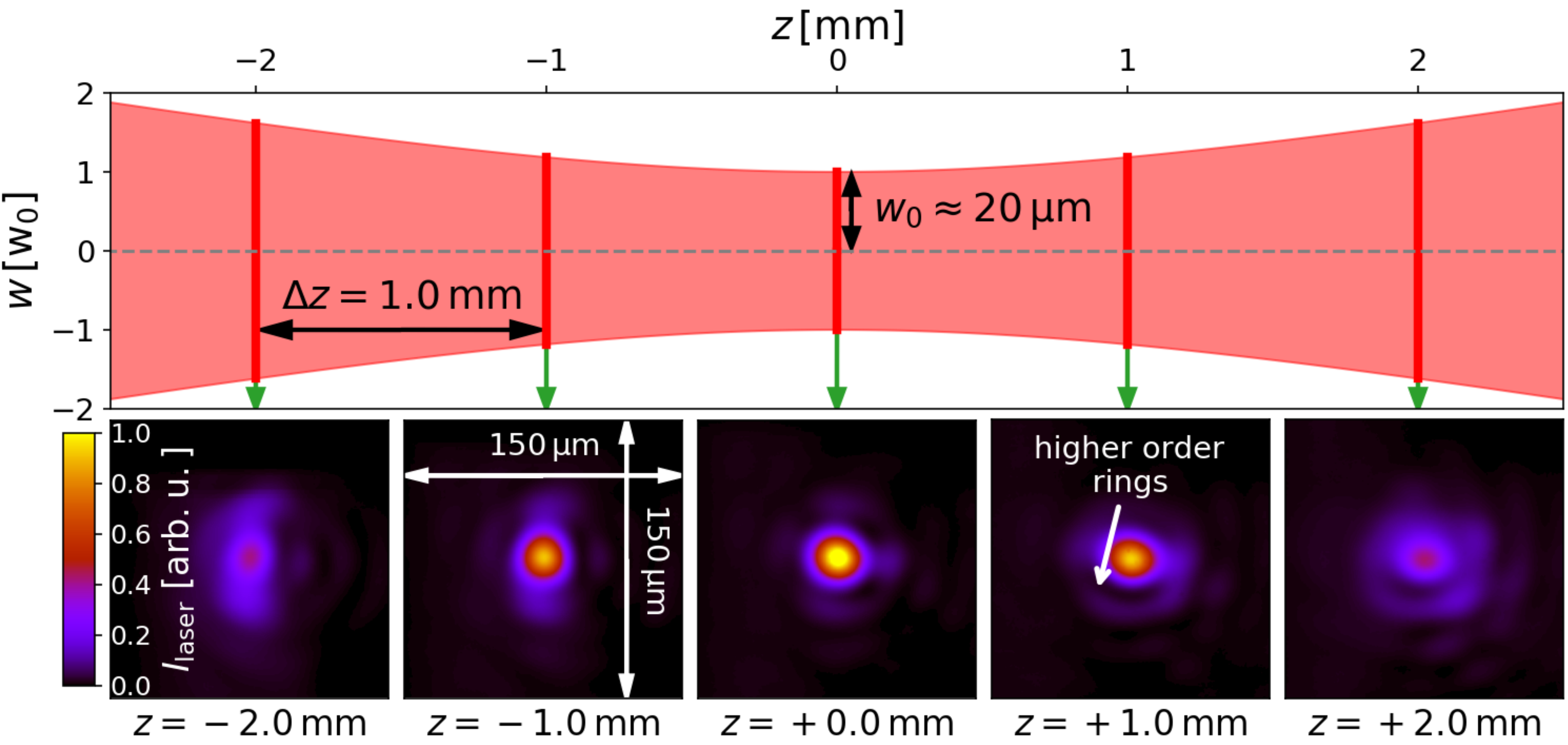
Higher resolution (44nm / 73as) requires more compute power and memory.

Simulations now require 192 Nvidia k80 GPUs.

2^{nd} generation

Laser modes as measured in the experiment

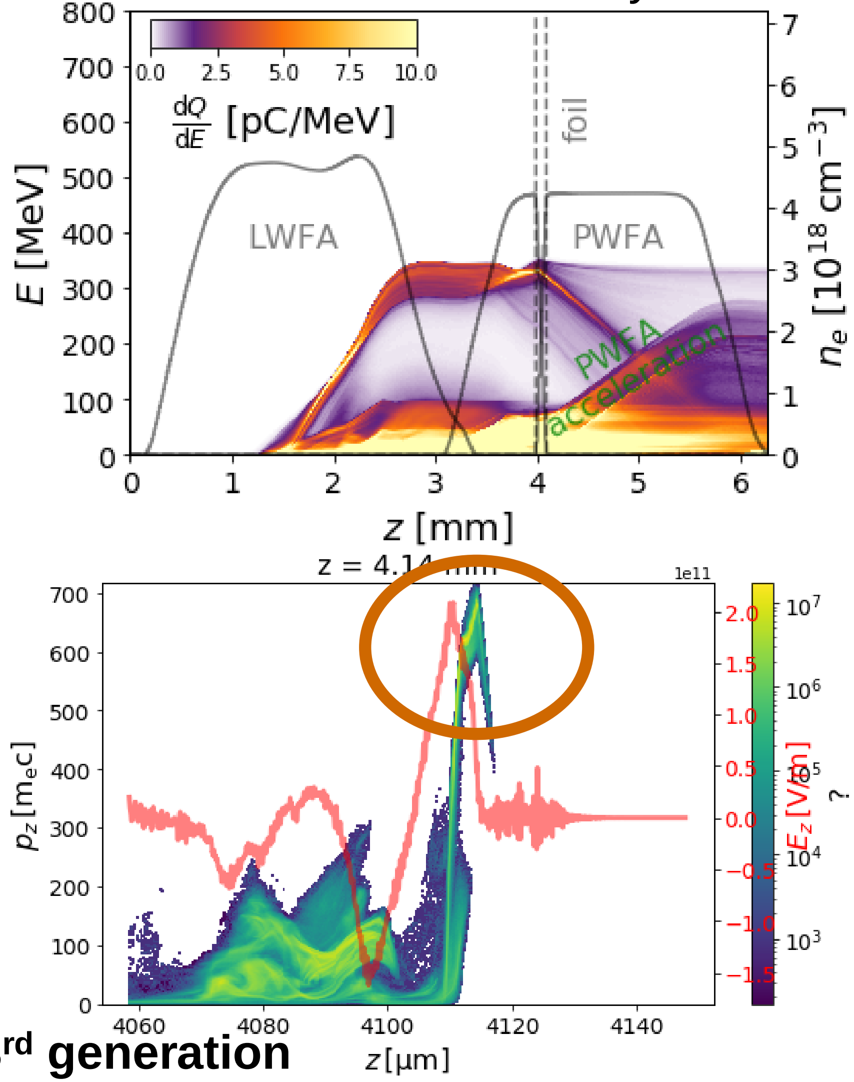
It does not look that bad – does it have an influence?



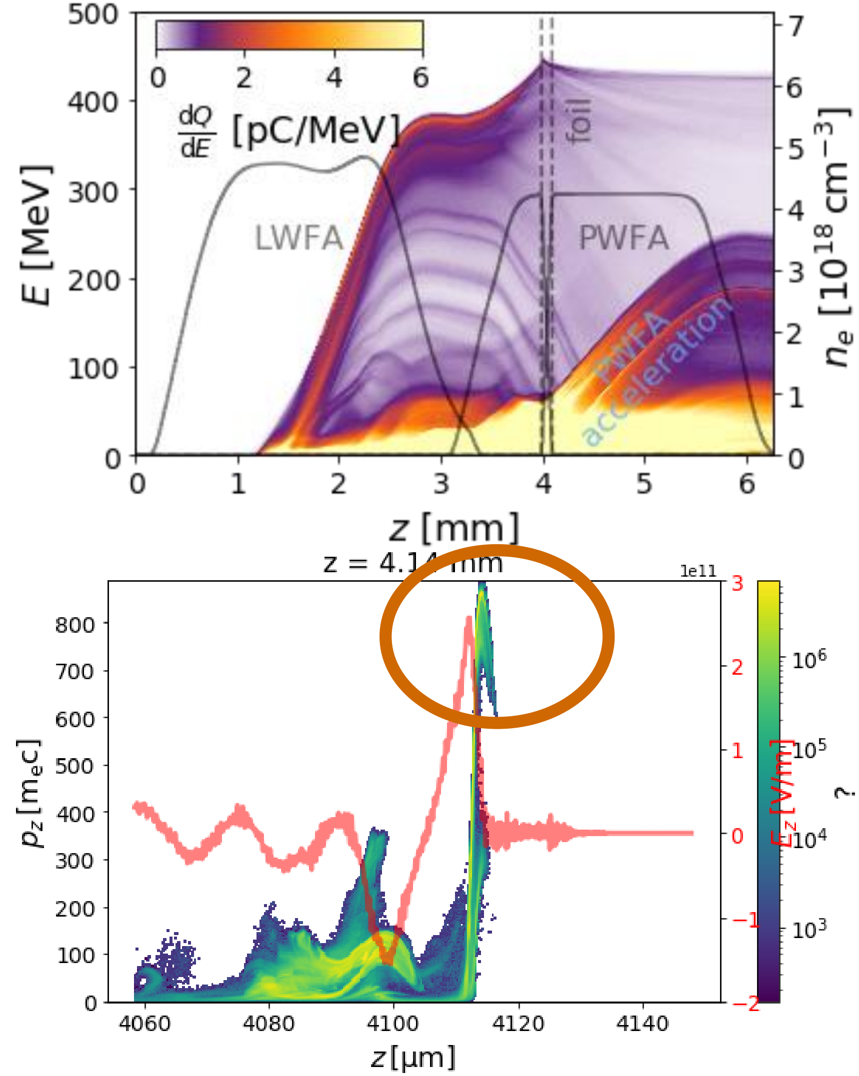
3rd generation

Laguerre modes are required for the laser to model the PWFA drive beam

Gauss mode only



Previously measured Laguerre modes

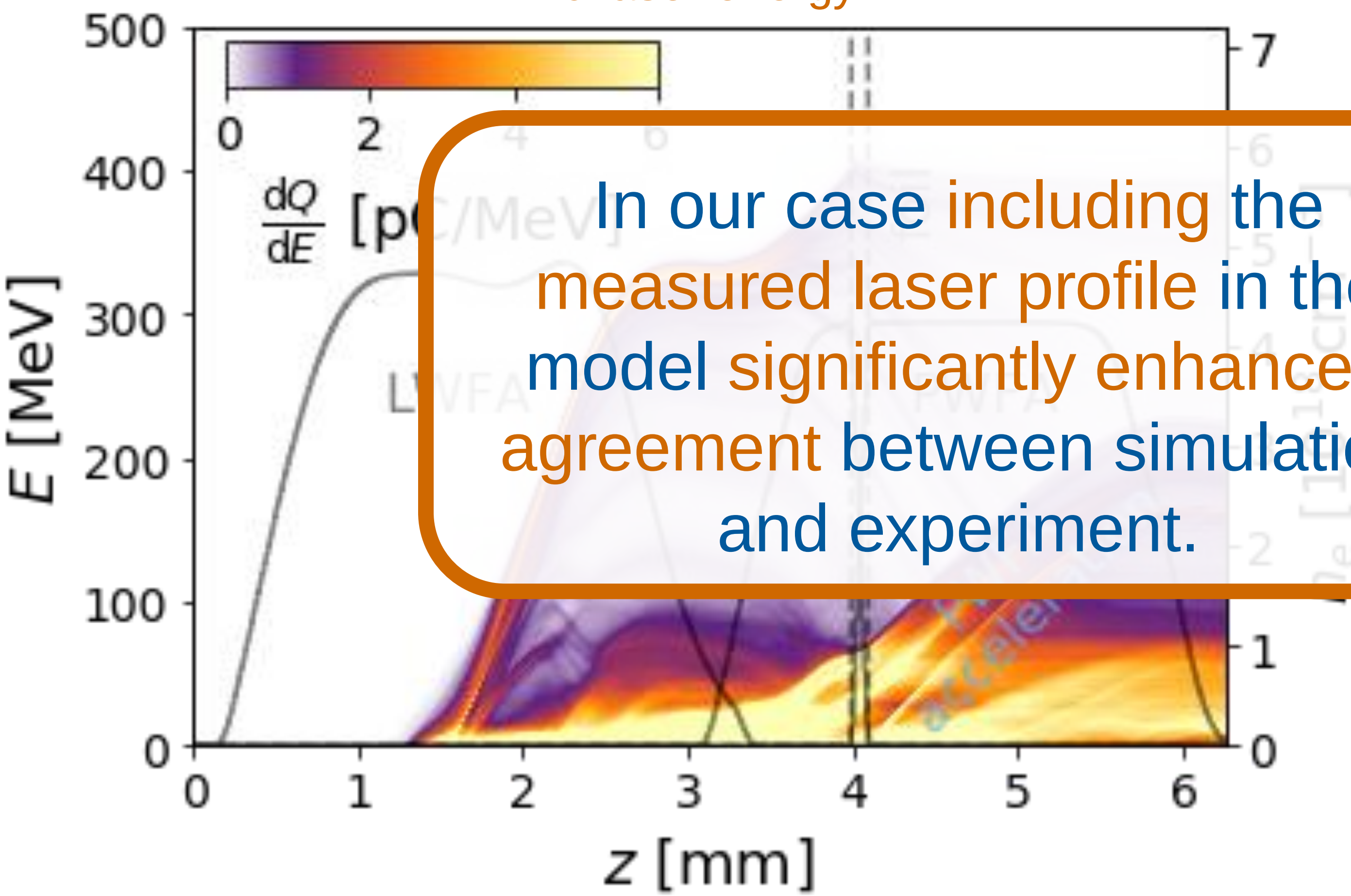


3rd generation

Third generation start-to-end simulation

Included feedback from experiment to get the driver energy right

1.4-1.7 J laser energy



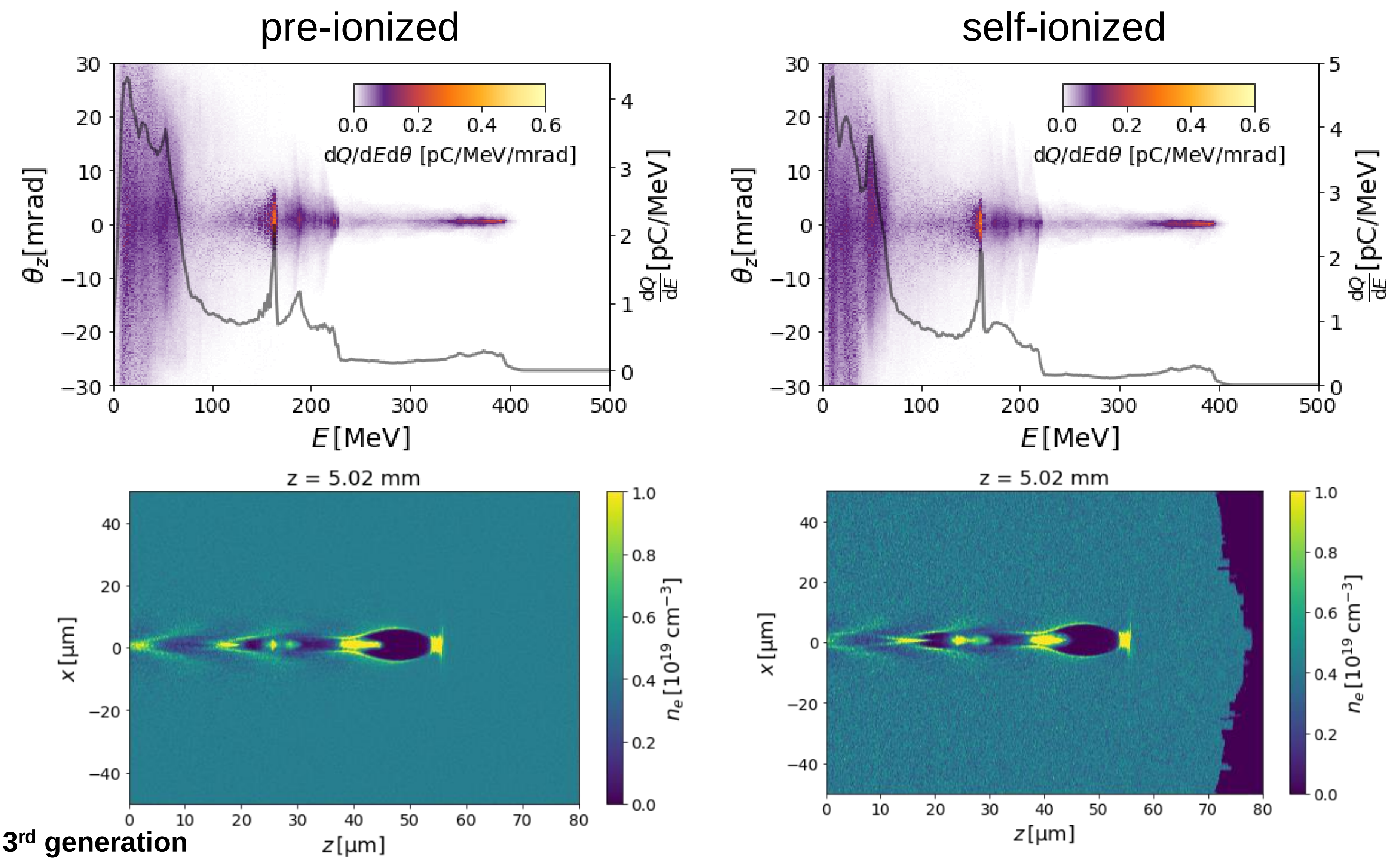
In our case including the measured laser profile in the model significantly enhanced agreement between simulation and experiment.

- reducing laser energy
- assuming previously measured laser modes
- adjusting the vacuum focus position

3rd generation

Third generation start-to-end simulation

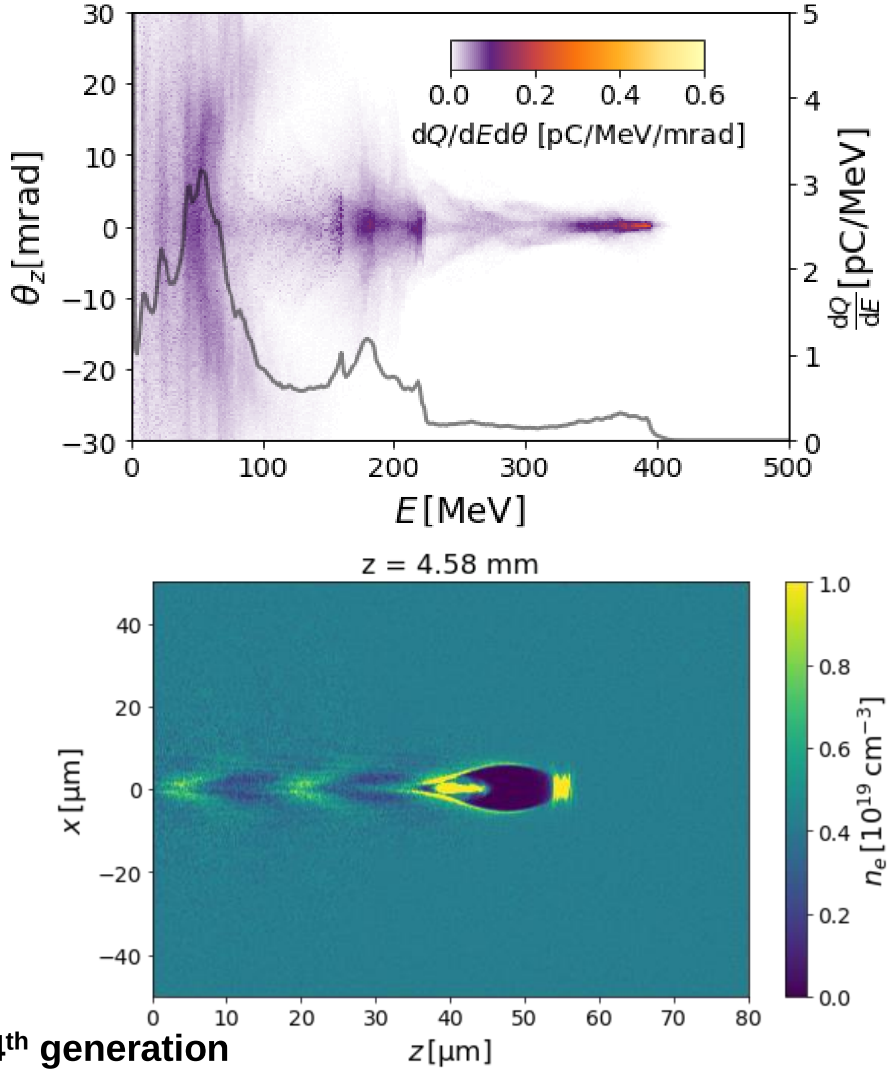
Driver divergence is too low - blowout regime is always reached



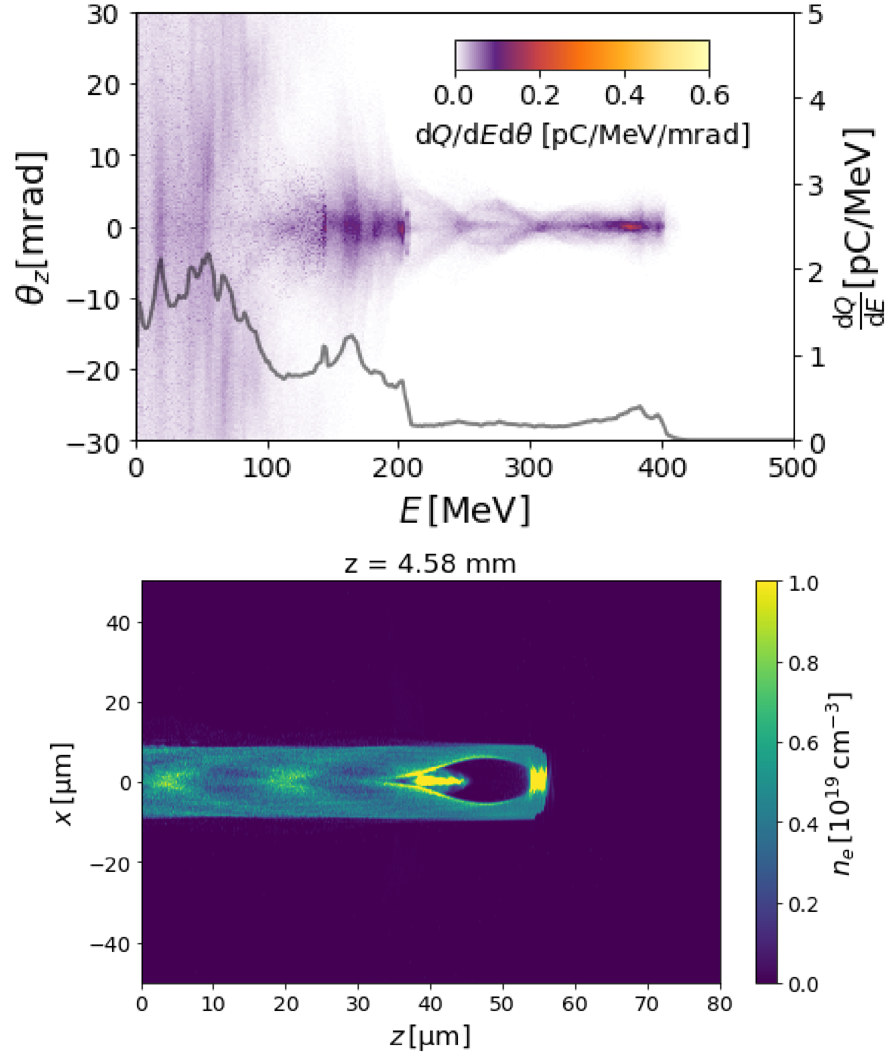
3rd generation

Increasing laser blocker foil density and thickness
to fully block the laser leads to increase in driver divergence

pre-ionized



self-ionized

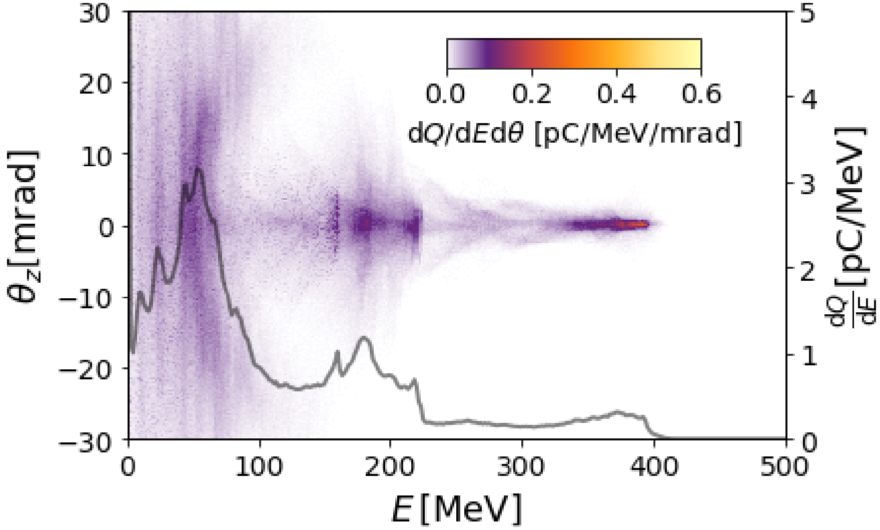


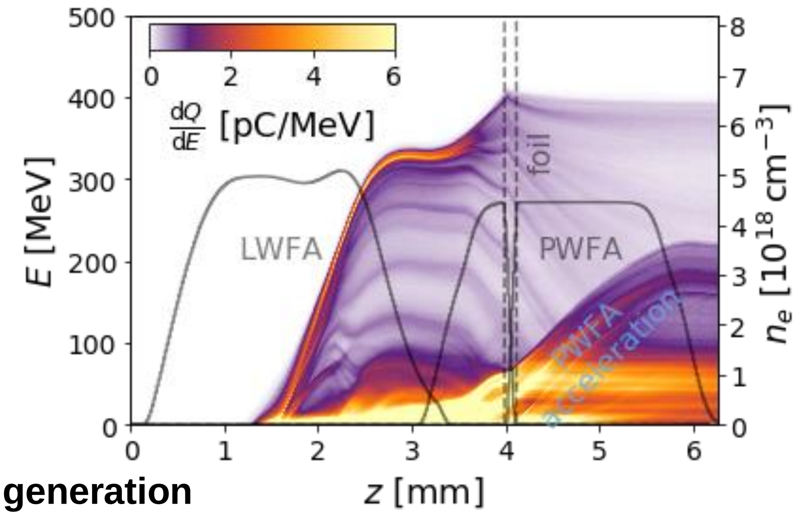
4th generation

Increasing laser blocker foil density and thickness

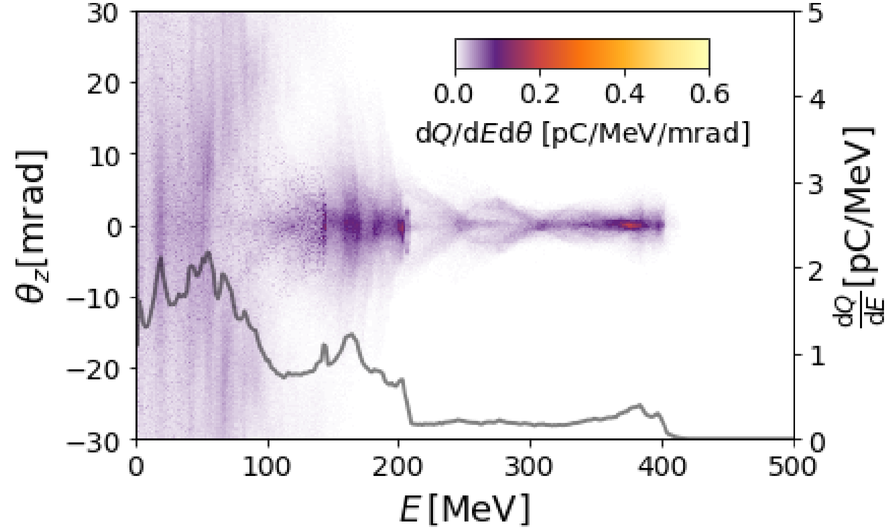
to fully block the laser leads to increase in driver divergence

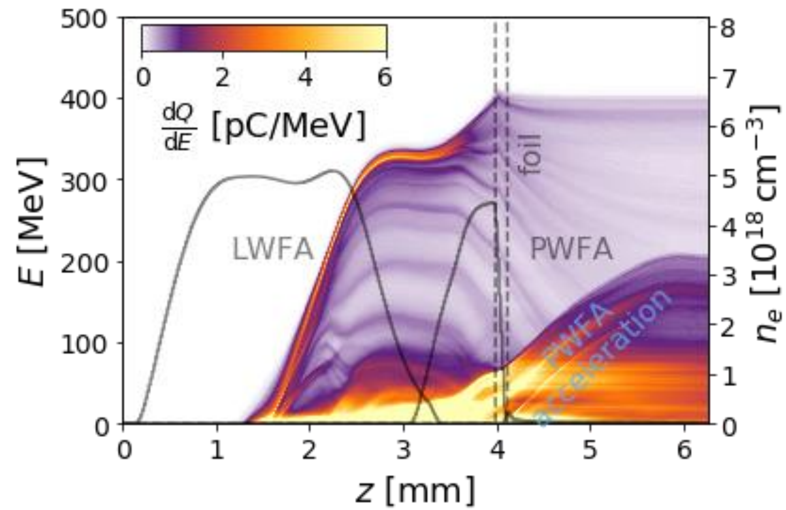
pre-ionized





self-ionized

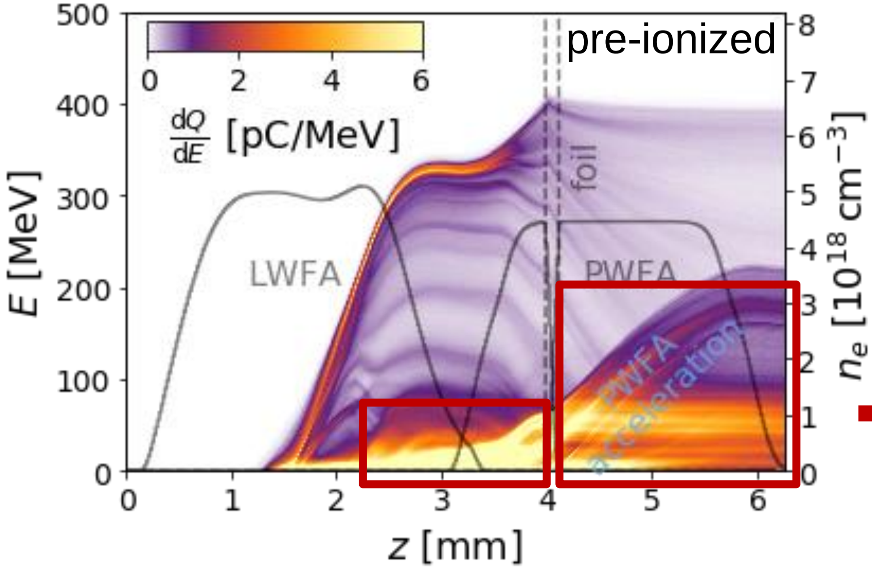




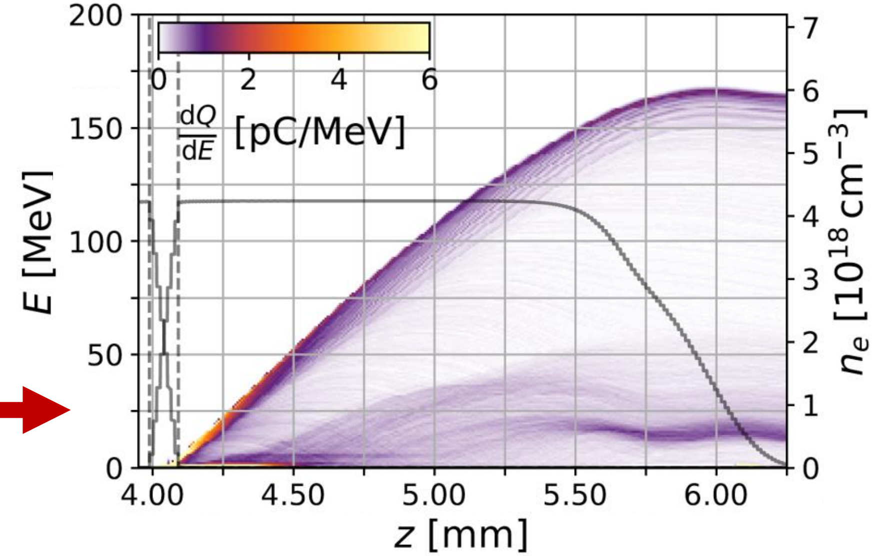
4th generation

Injected electrons originates from both downramp injection in the first jet & from directly behind the foil

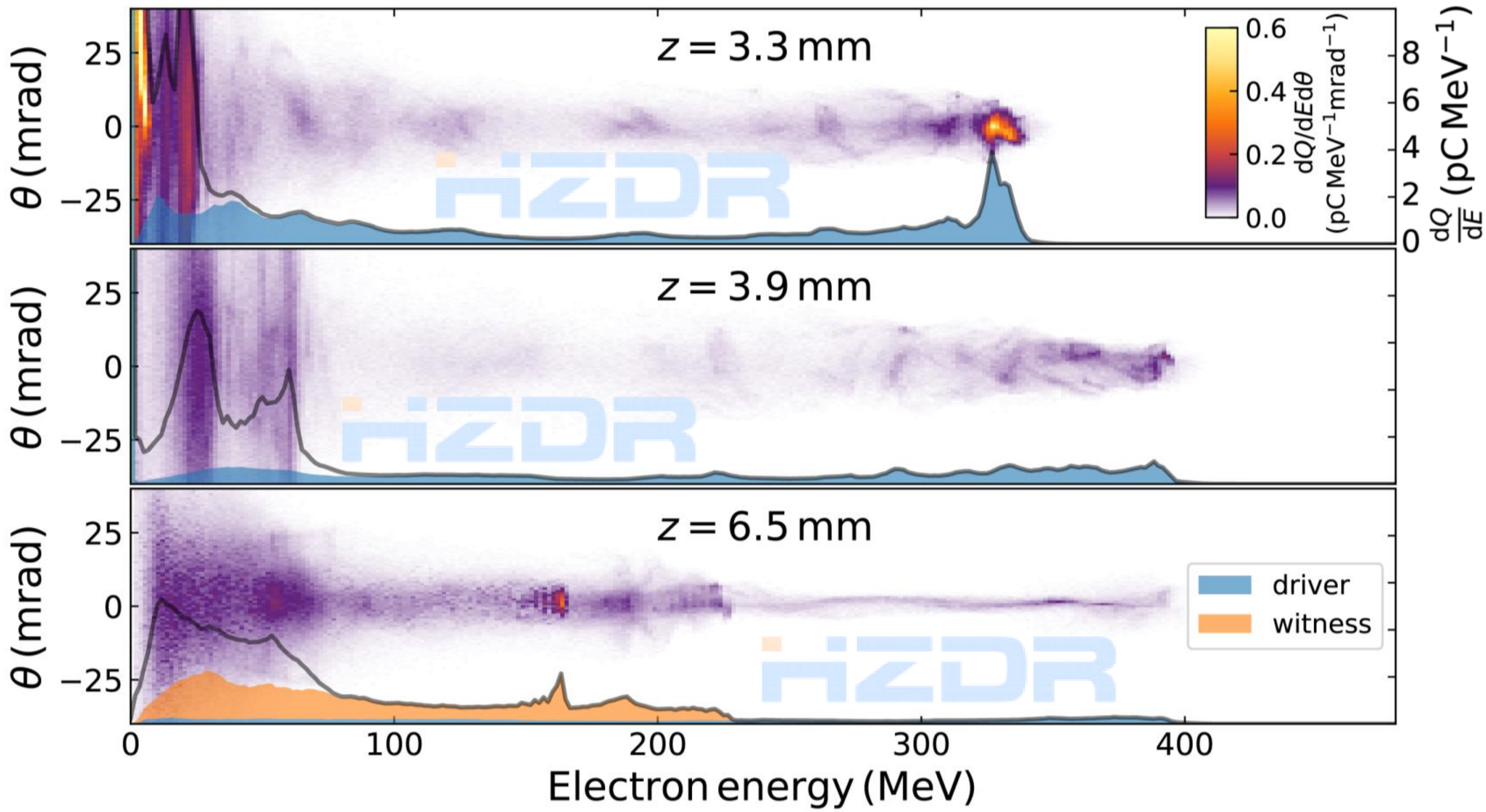
All electrons



Only electrons originating injected behind the foil



Resulting start-to-end simulations shows good agreement with experiment



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Summary and Conclusions

reproducing witness bunch acceleration in the hybrid scheme

- The L|PWFA hybrid scheme enables building a compact, **laboratory sized PWFA** accelerator.
- Both stages operate in the blowout regime, thus **simulations** are required for **understanding** the detailed laser plasma dynamics and **optimizing** the setup.
- **Reproducing** the experimental setup with the simulation is **essential** to capture the plasma dynamics correctly.
- **Start-to-end simulations** of the L|PWFA using PIConGPU show good agreement with measured features (energy spectra, angular distributions, charge, gradients, …).

Thank you for your attention!