Experimental Study of Transverse and Longitudinal Wakefield Amplitudes Driven by a Self-Modulating Proton Bunch in Plasma

Motivation: A detailed understanding of the wakefields driven by a self-modulating proton bunch is crucial for the design and realization of a future accelerator based on the concept.

Measurement: Seed-timing scan. We varied the location of the seed (laser pulse position) from -205 to + 445 ps.

With this measurement we change:

shape and amplitude of the initial seed wakefields;
number of protons in the plasma.

→ change of wakefields growth rate and amplitude

Analysis: We study the

transverse wakefield amplitude: transverse, time-integrated self-modulated proton bunch distribution;
longitudinal wakefield amplitude: accelerating externally injected electrons.

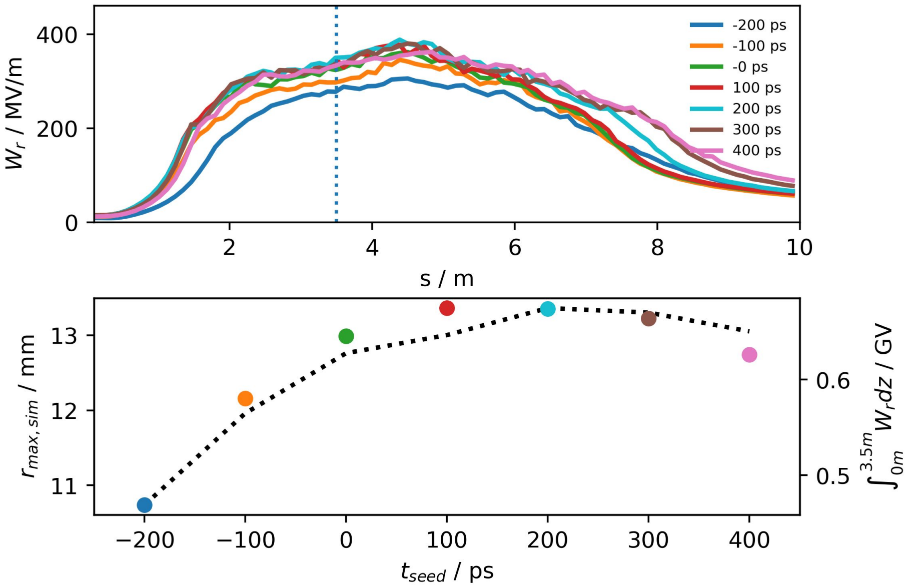
Conclusions:

We confirm experimentally that the excited wakefield amplitude depends on the number of protons that contribute to driving the wakefields as well as the amplitude and shape of the initial seed wakefield amplitude. Observed trends are in good agreement with theory and simulations.

M. Turner for the AWAKE Collaboration

Transverse Wakefields

Concept, Method, Simulation result



1) Check where defocused protons radially exit the wakefields: between 3-4m.
2) Integrate transverse wakefields along that distance and check where along the bunch the fields are maximum. ξ = ~320, 330, 380, 420 ps for t_{seed}: -200 to +100, 200, 300 and 400 ps.
3) Plot the amplitude of the transverse wakefields at that ξ location and integrate over the plasma interaction distance. ⇒ wakefields growth rate proportional to the $\int W_r dz$.
4) Propagate the proton distribution to the experimental measurement location and identify the maximum radius of the distribution. ⇒ $r_{max} \propto \int W_r dz$

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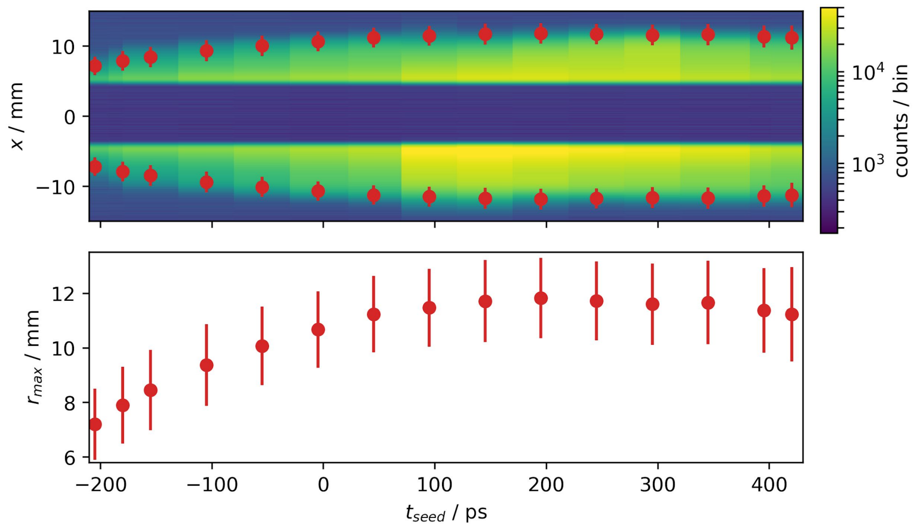
Transverse Wakefields

Measurement result



Observations:

1) r_{max} increases with increasing t_{seed} up to ~200 ps. $\Gamma \propto W_r \propto N_p$.
2) r_{max} decreases? for larger t_{seed}. Makes sense as $W_{r,seed}$ decreases. In agreement with simulation results.

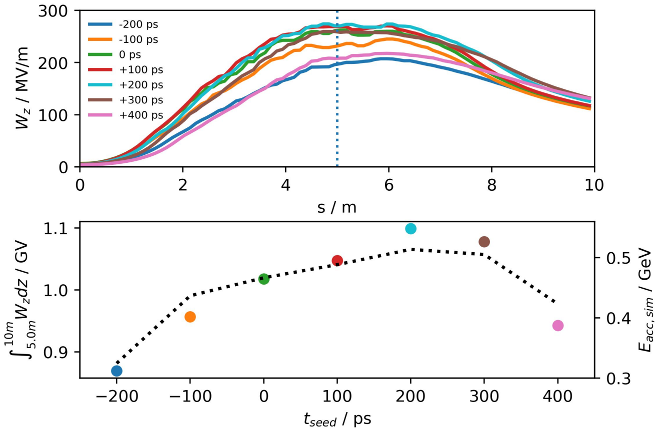
Conclusions:

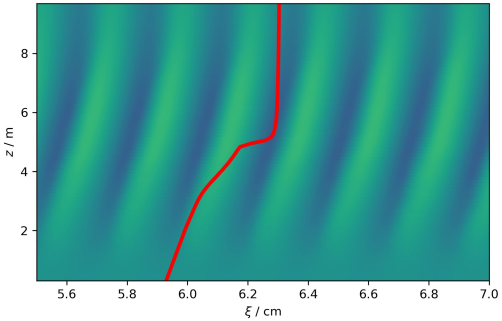
We show experimentally that W_r and Γ depend on N_p and $W_{r,seed}$ the way we expect it.

M. Turner for the
AWAKE Collaboration

Longitudinal Wakefields

Concept, Method, Simulation result





1) Plot the amplitude of the accelerating field at the ξ-location of the electrons.

2) Simulations show the wakefields phase evolves strongly over the first half of the plasma. Electrons only accelerate in the second half.

3) Integrate the amplitude over the 2nd half of the plasma. ⇒ $W_z \propto \Gamma$; $\Gamma(N_p, W_{r,seed})$

4) Observe that electron energy in the simulations follows the same trend as $\int W_z dz$.

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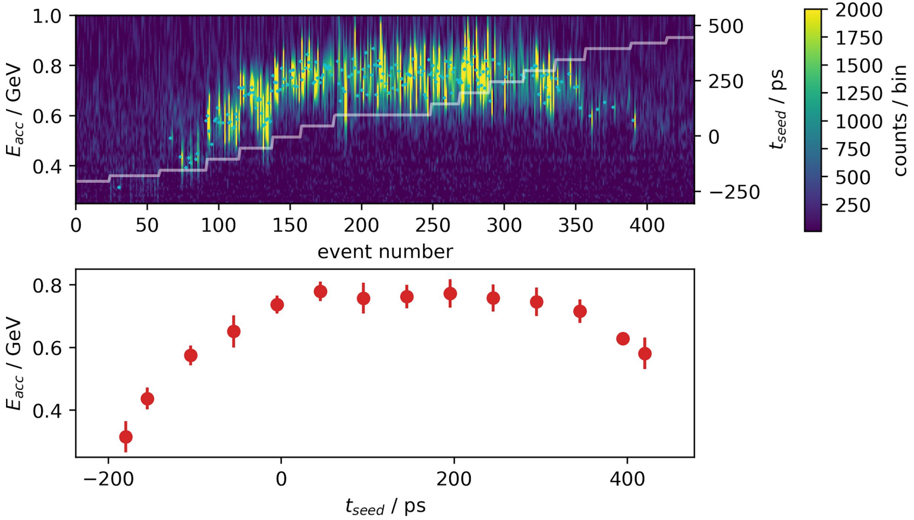
Longitudinal Wakefields

Measurement result



Observations:

1) E_{acc} increases with increasing t_{seed} up to ~200 ps. $\Gamma \propto W_z \propto N_p$.
2) E_{acc} decreases for larger t_{seed}. Makes sense as $W_{r,seed}$ decreases. In agreement with simulation results.

Conclusions:

We show experimentally that W_z and Γ depend on N_p and $W_{r,seed}$ the way we expect it.

There is only one problem… the energy of the accelerated electrons is significantly lower in the simulations.

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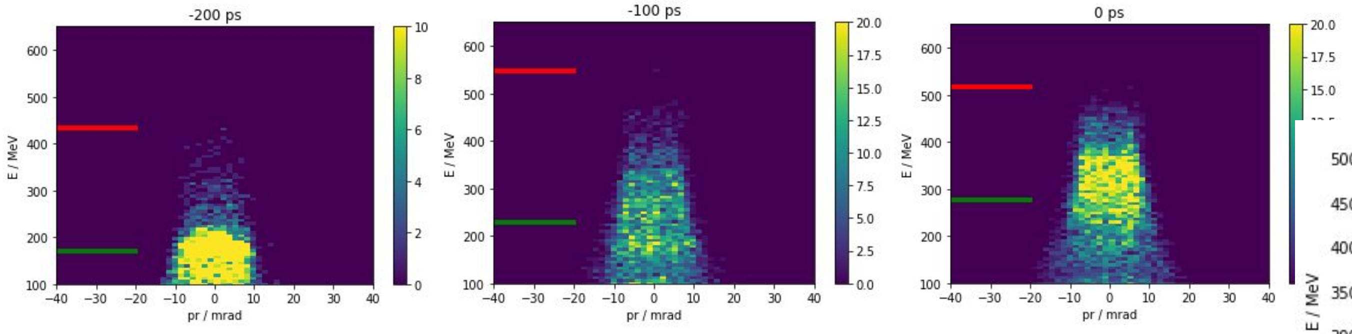

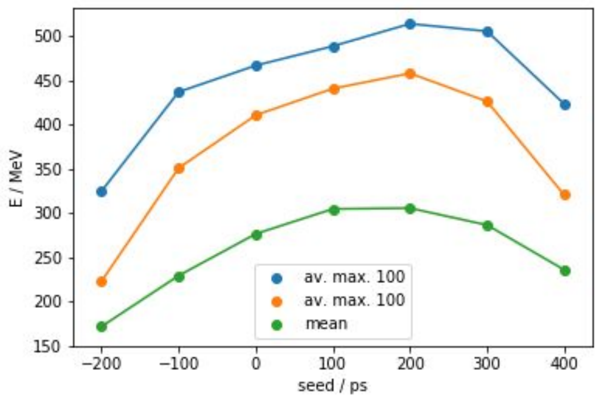

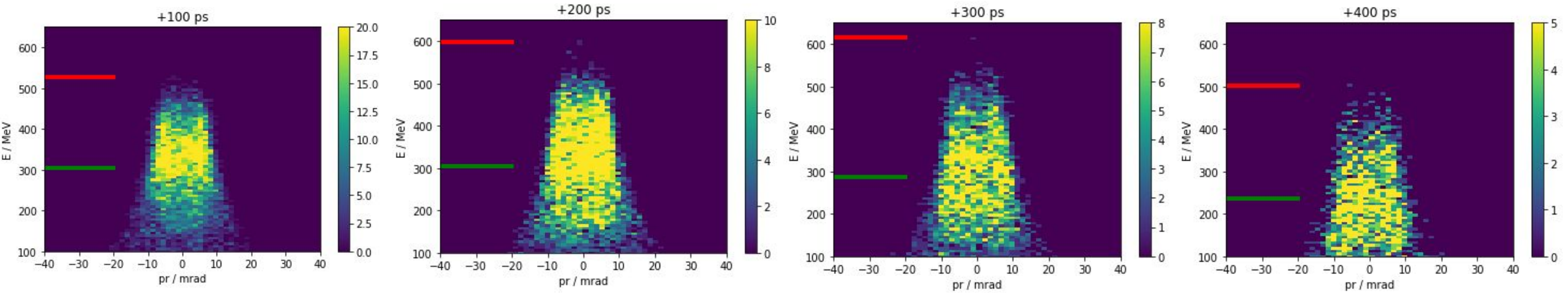

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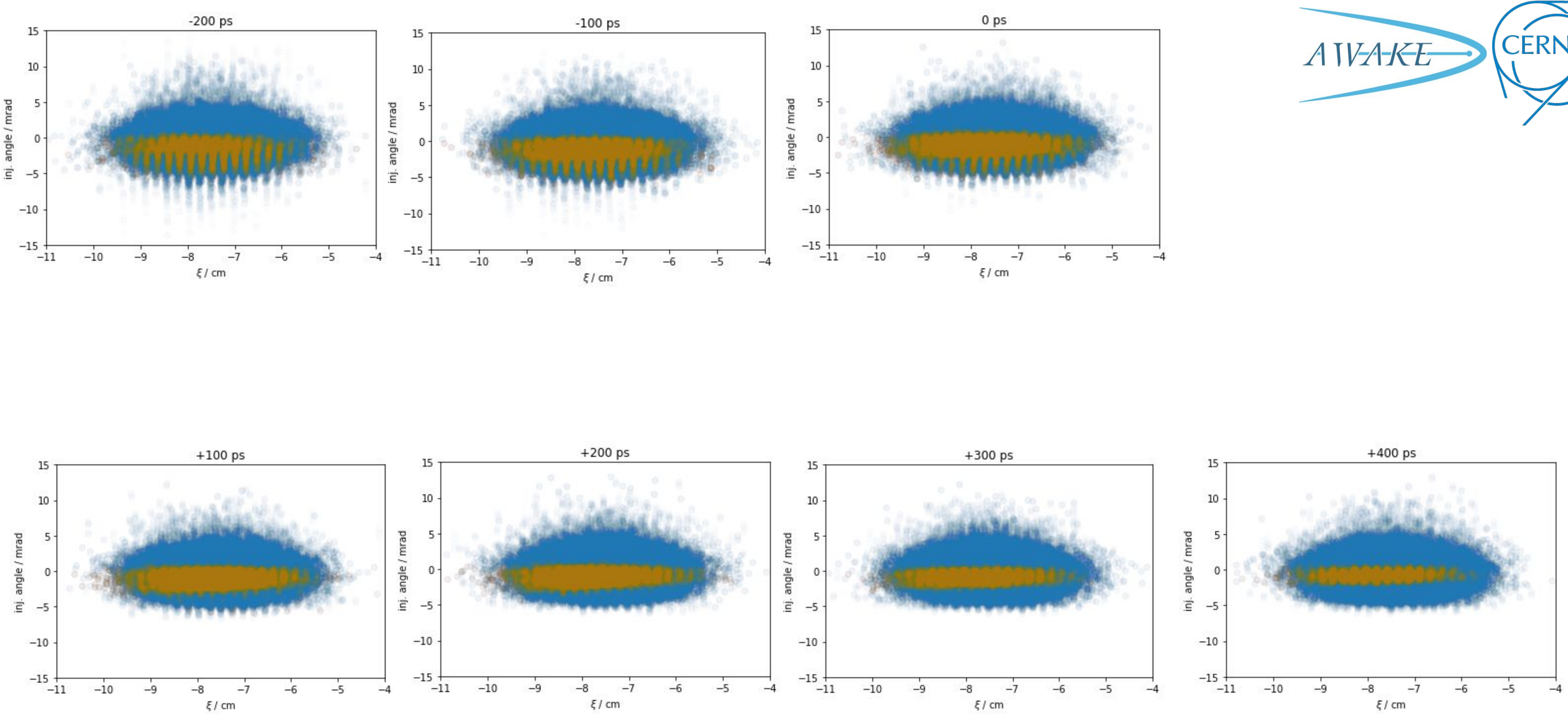

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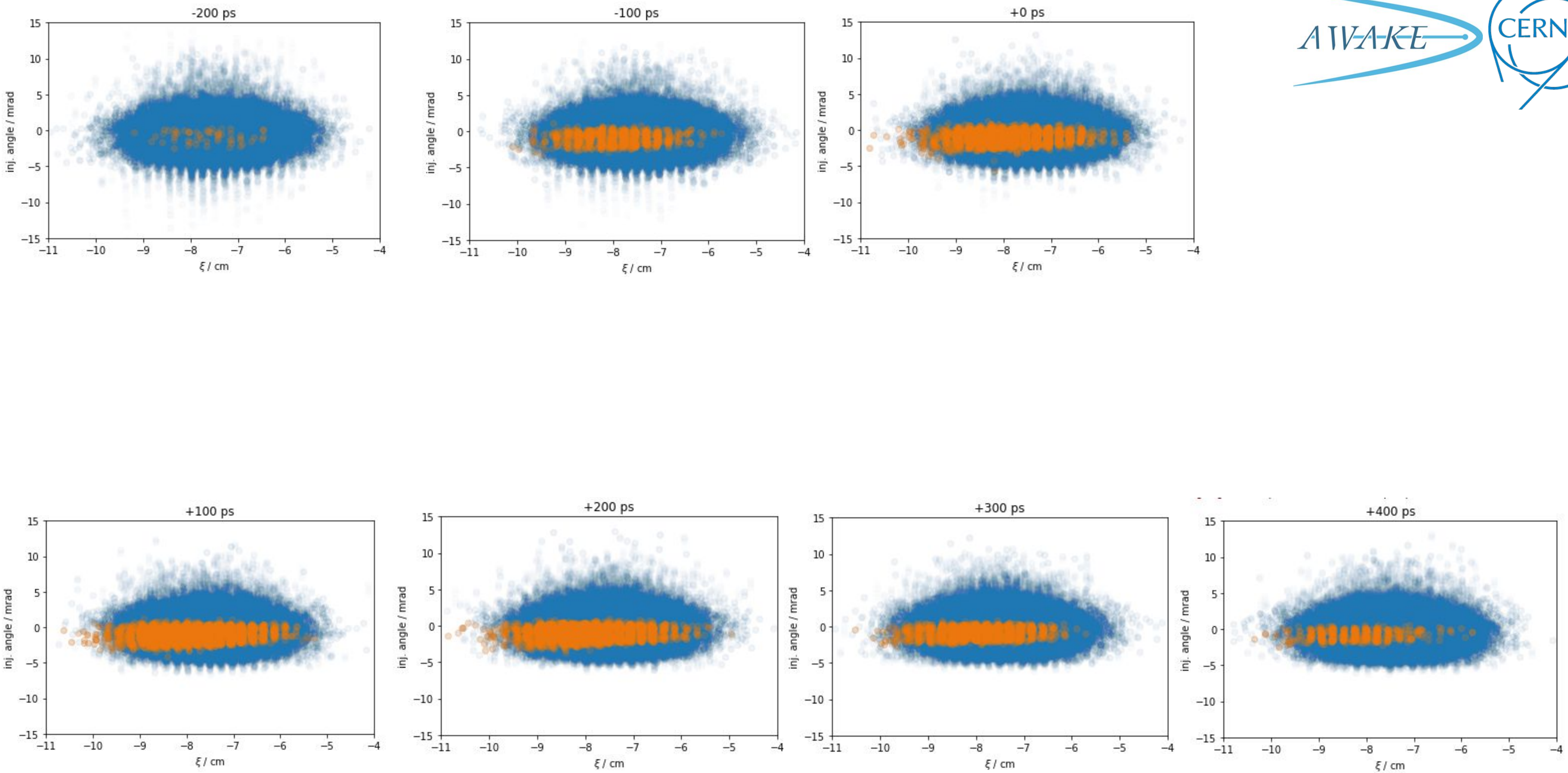

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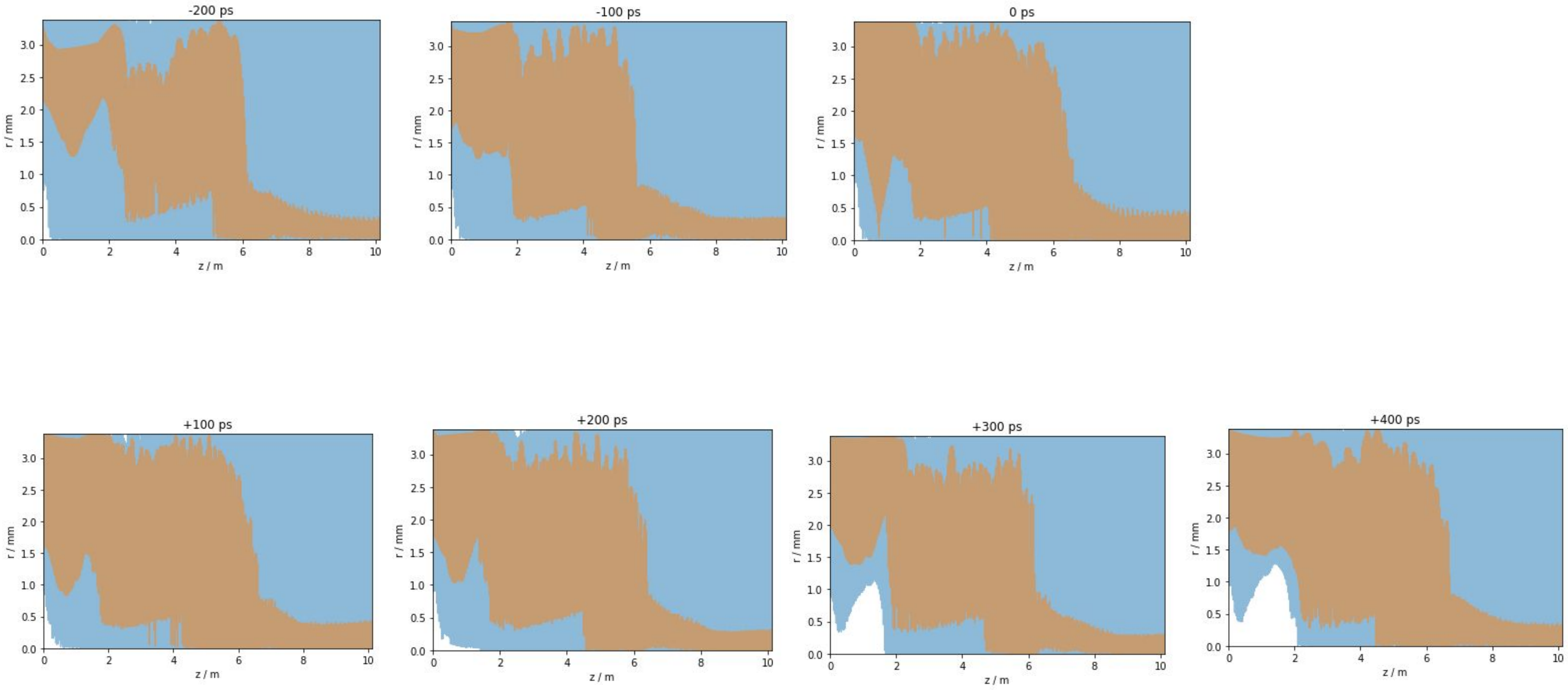

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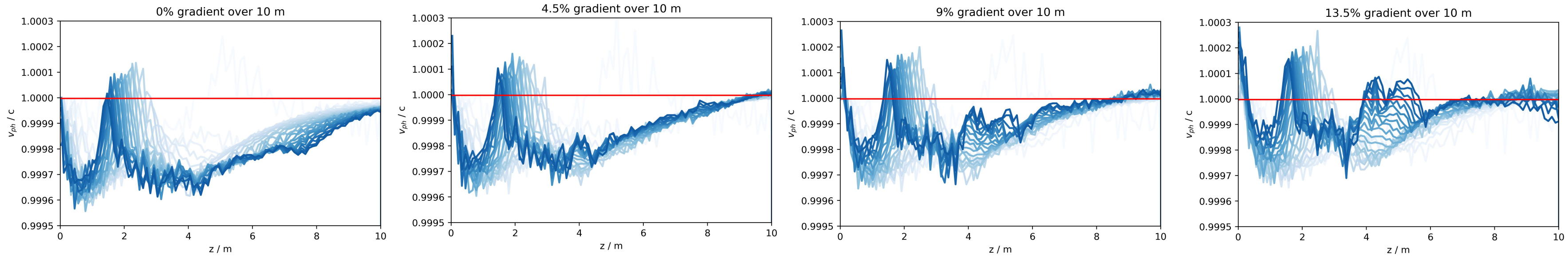
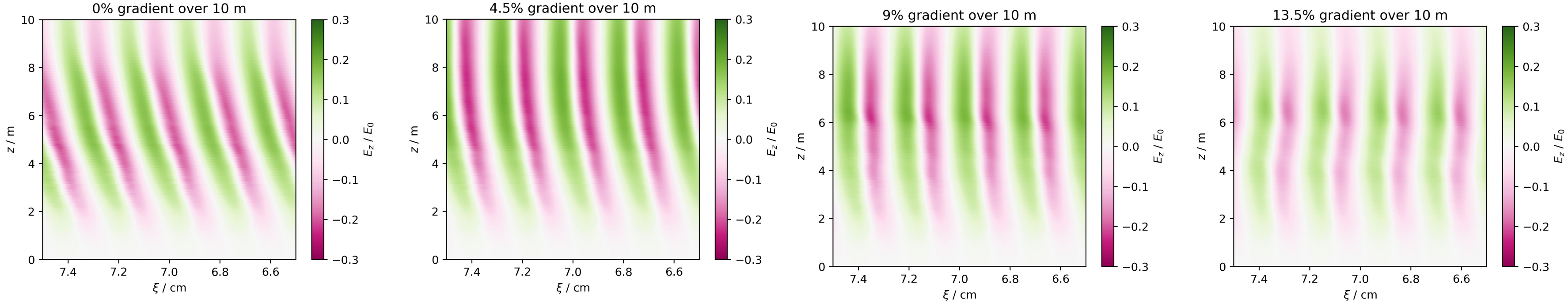
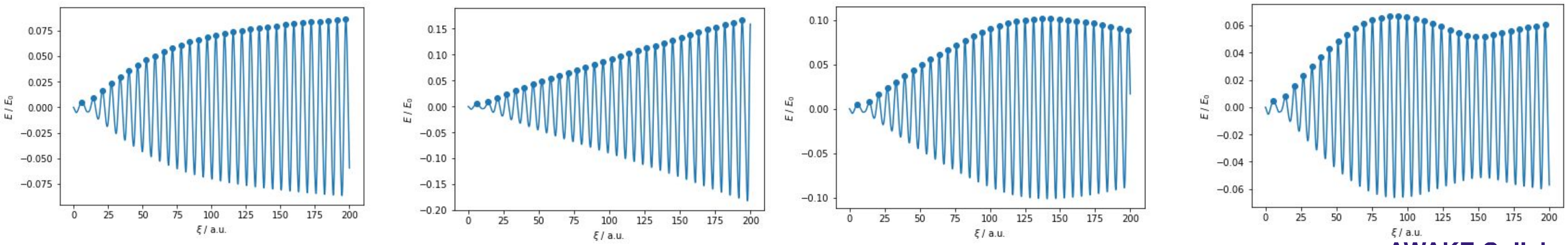




at 10 m



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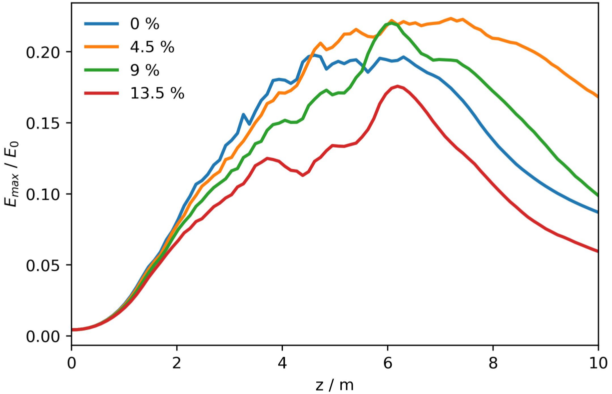

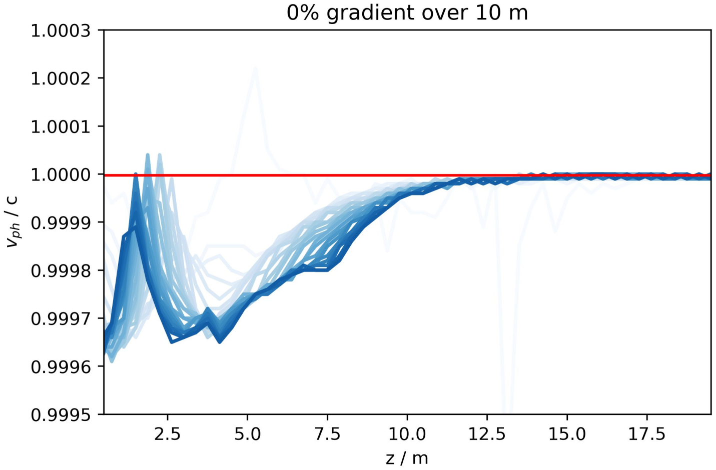

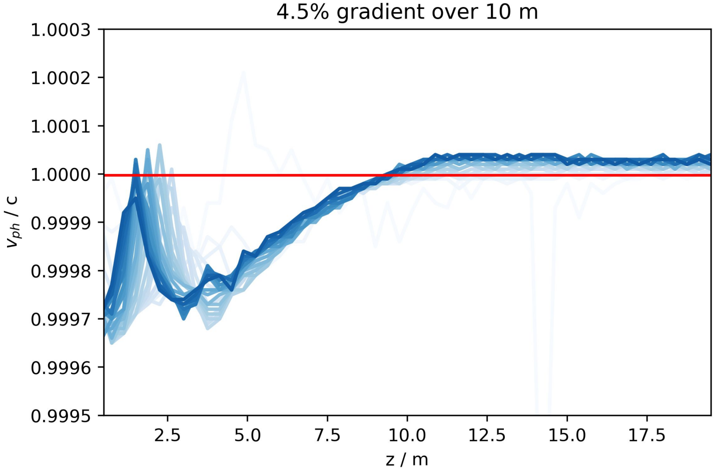

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