Resonant wakefield excitation observed in long plasma channels

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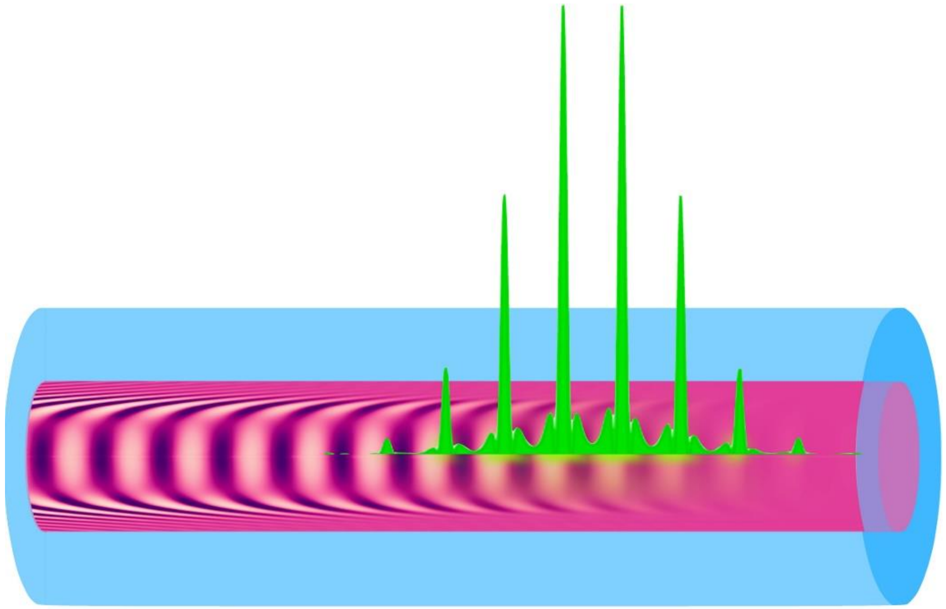
Motivation – GeV acceleration at kHz repetition

- In the multi-pulse laser wakefield accelerator (**MP-LWFA**) the wakefield is excited resonantly by a pulse train.

- Recent simulations show
  1.7 J, 1 ps pulse ➡ 0.65 GeV electrons
  in **100-mm**-long plasma channels.

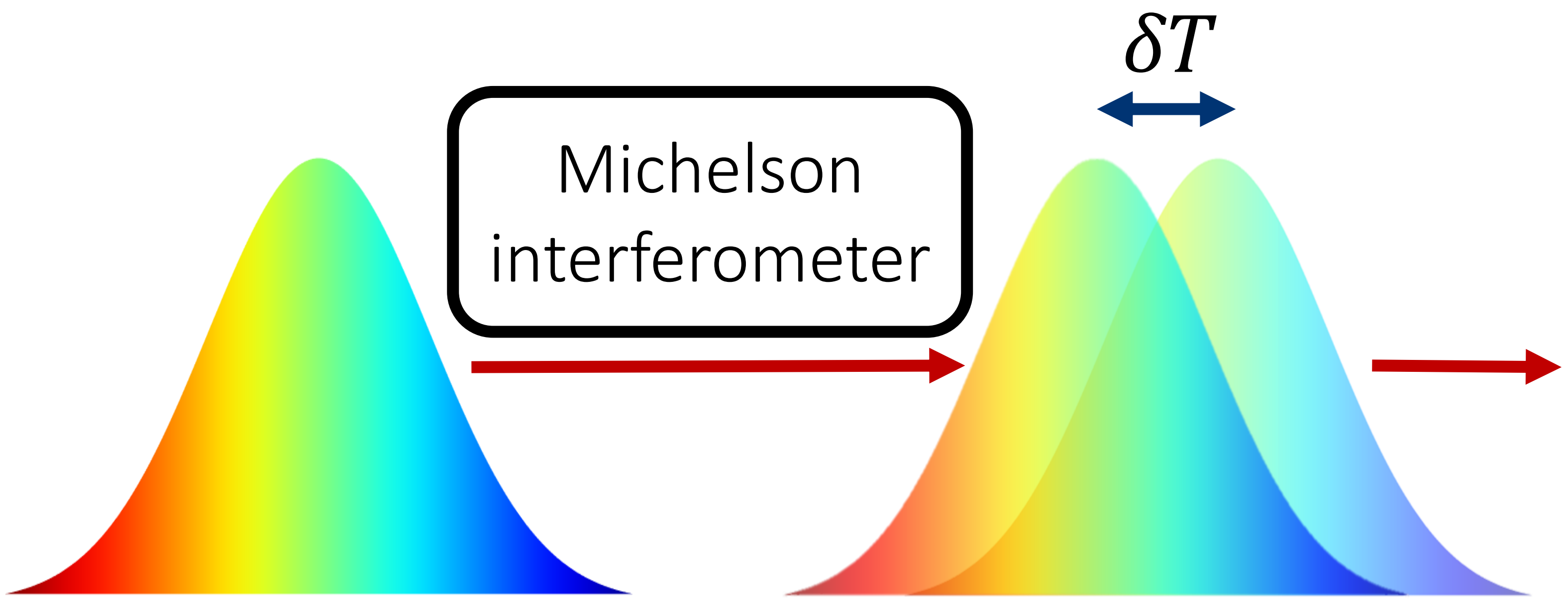
- Objectives:
  - Guide ~ 2 J laser pulse trains over 100 mm propagation using a plasma channel
  - Demonstrate resonant wakefield excitation in the channel



S. M. Hooker *et al.*, Journal of Physics B, **47**, 234003 (2014)
O. Jakobsson *et al.*, Physical Review Letters, **127**, 184801 (2021)

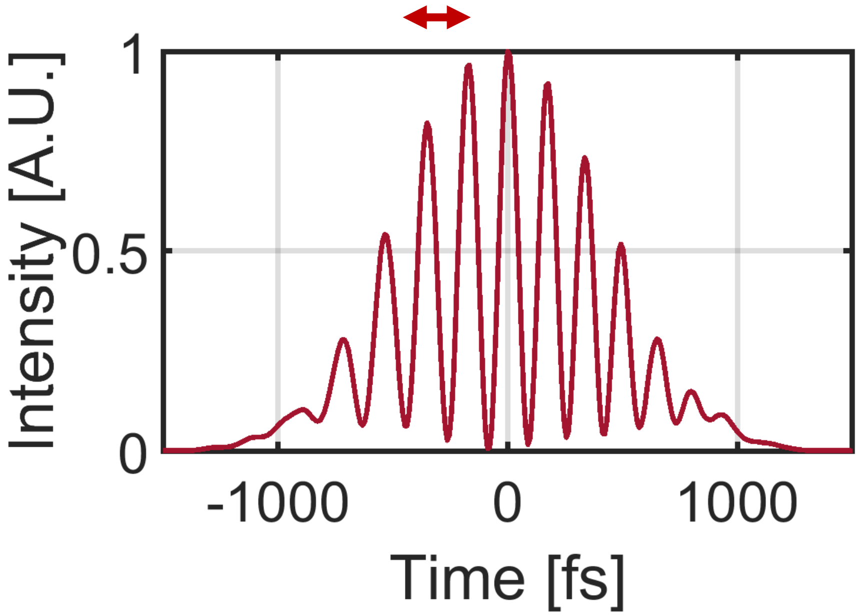
Experimental setup

Pulse train generation and measurement



Long pulse with spectral chirp

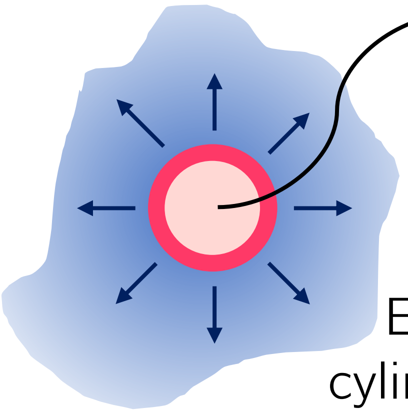
$\delta\tau = 170$ fs spacing

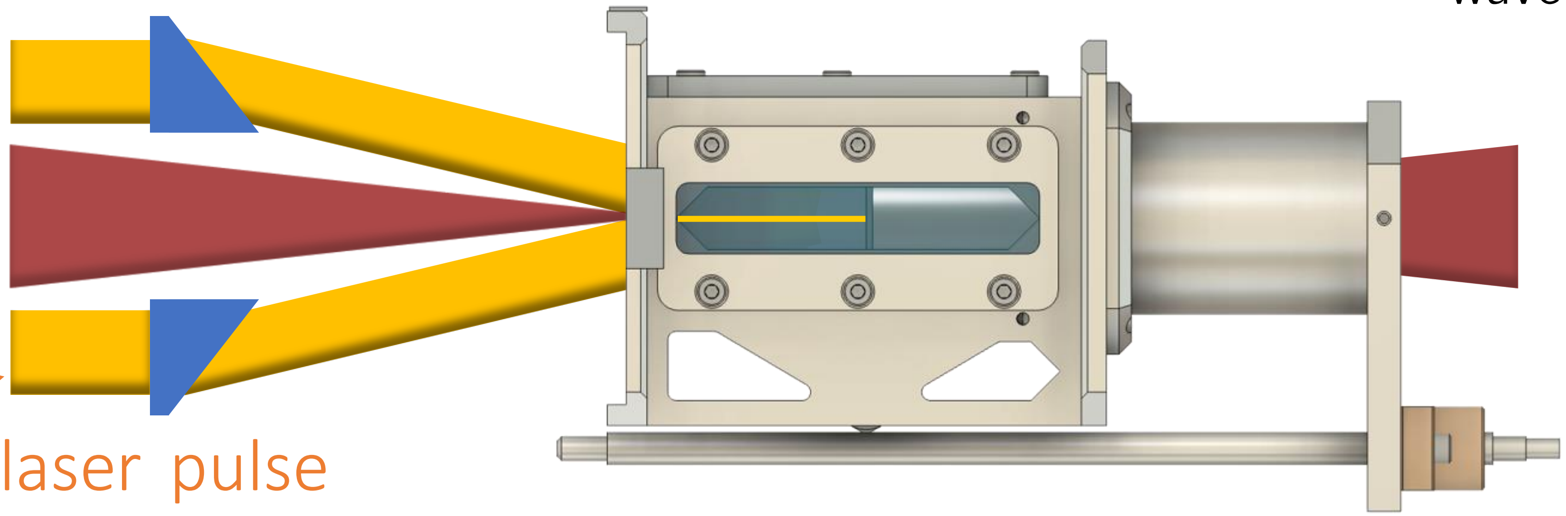


Retrieved from single-shot autocorrelation measurements

Experiments were performed at Astra-Gemini TA3, CLF UK.

HOFI plasma channel waveguide





Pulse train - **2.5 J** on target, **f/40** focusing

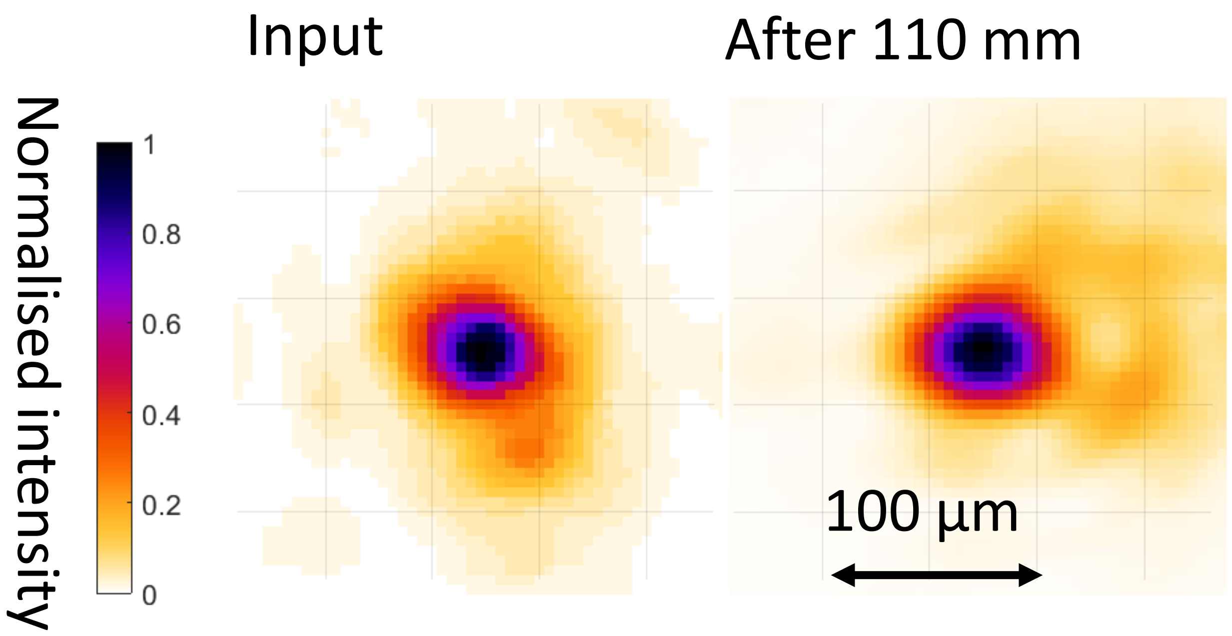
Channel-forming laser pulse
(~40 fs, ~100 mJ)

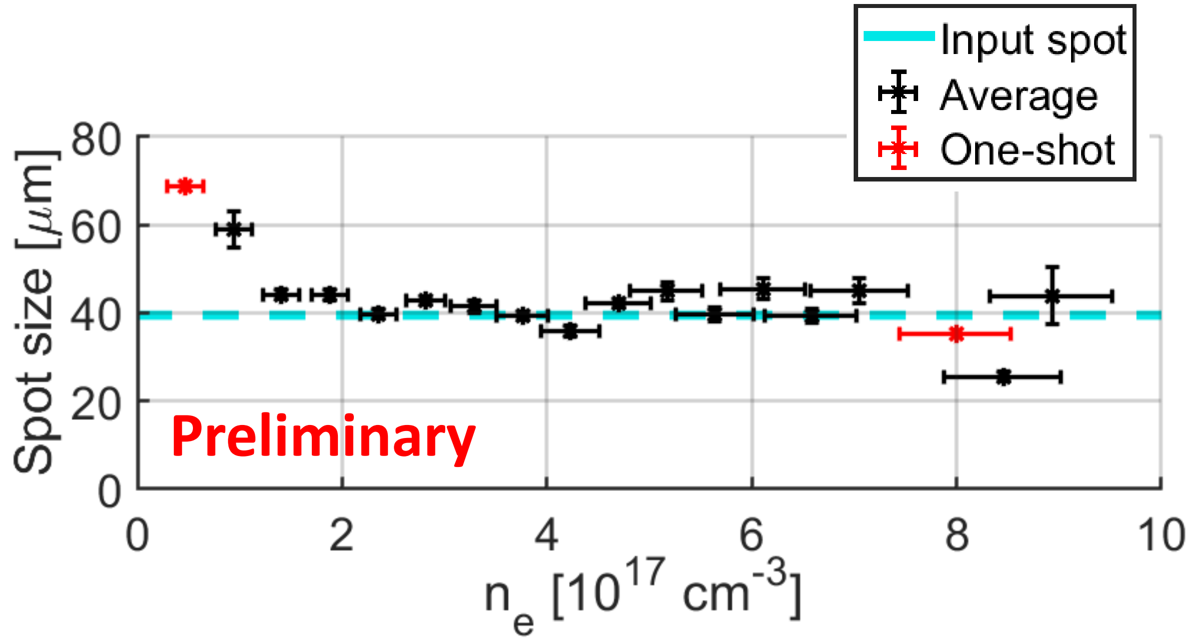
Gas cell, length variable to **110 mm**

A. Picksley *et al.*, PRAB, 23(8), 81303 (2020)
A. Picksley *et al.*, PRE, 102(9), 53201 (2020)

Guiding results

Optical guiding over 110 mm

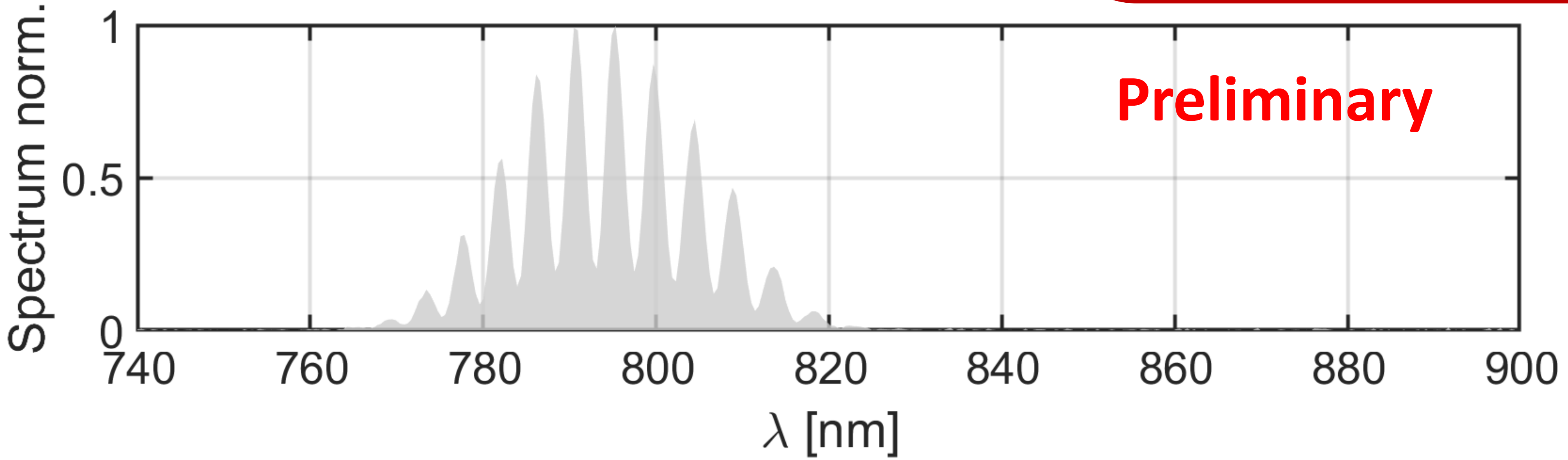




Resonant wakefield excitation

Transmitted spectra

$$\Delta\omega = \frac{\omega_p^2}{2\,\omega_0}\frac{\delta n_{e,0}}{n_{e,0}}\Delta z\, k_p \cos(k_p\zeta)$$



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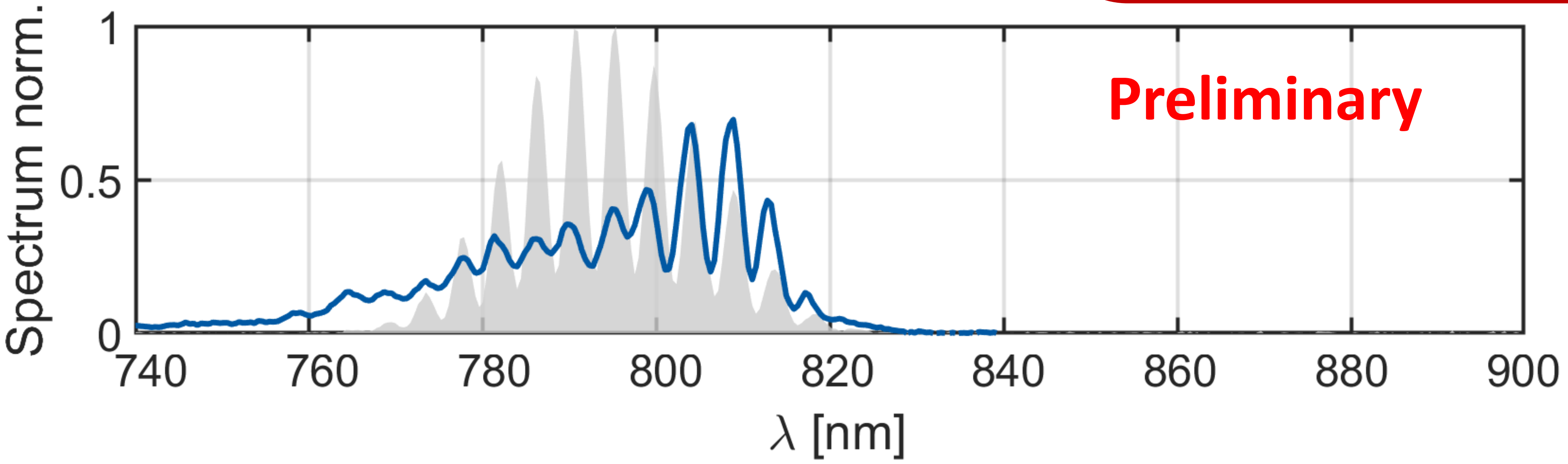

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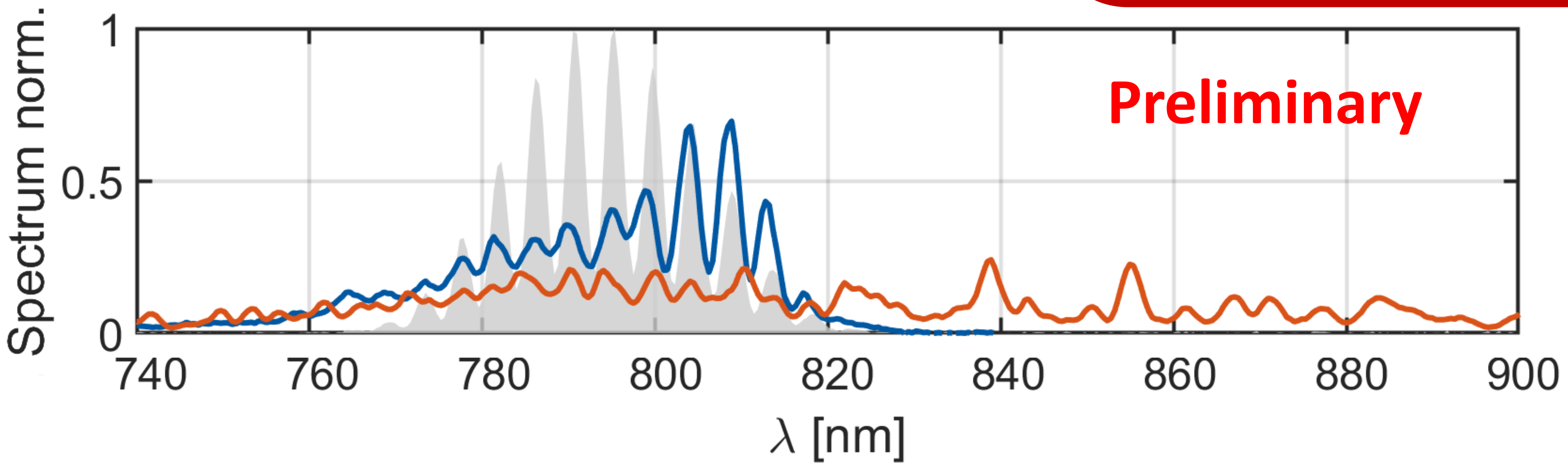

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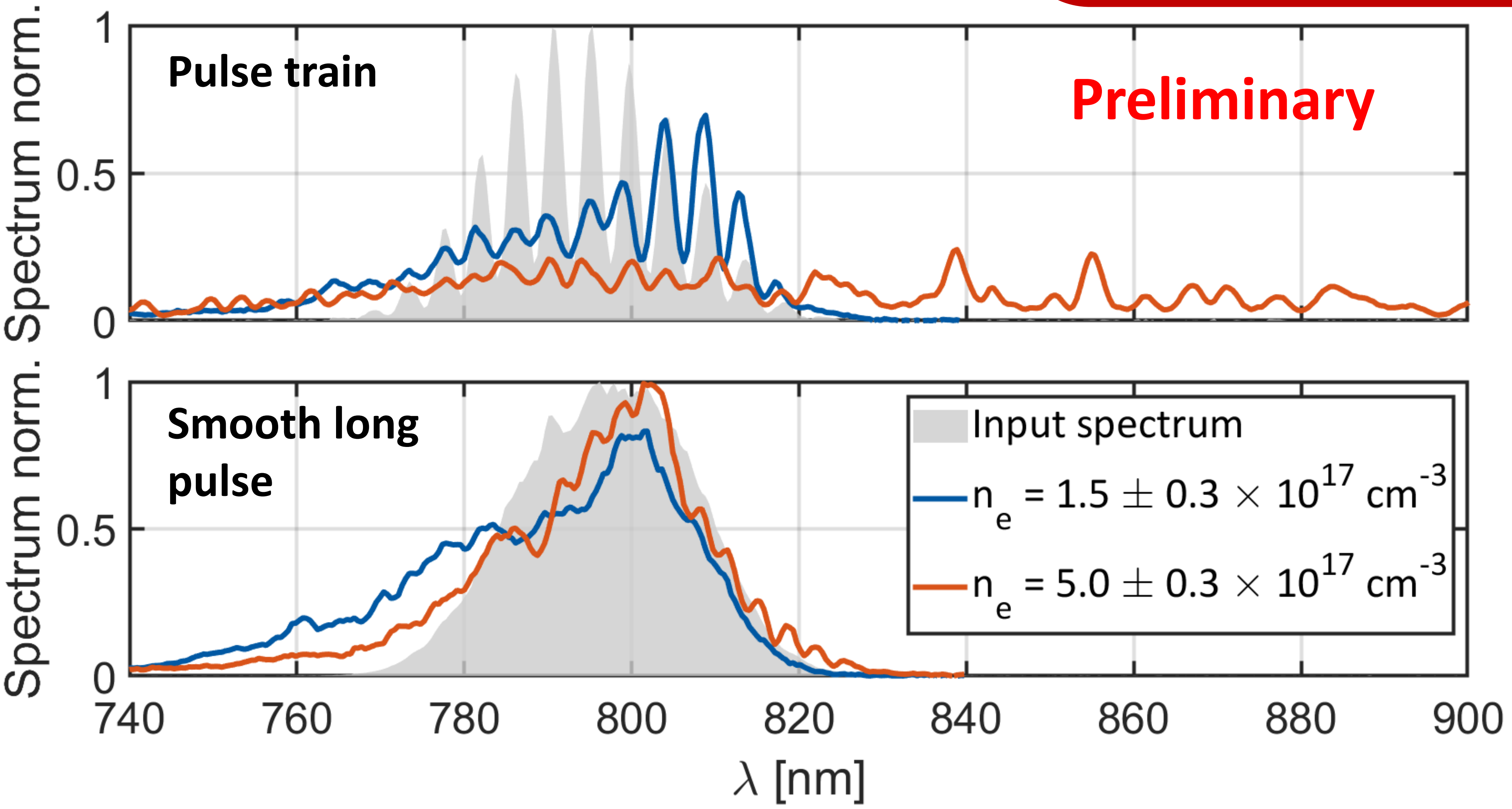
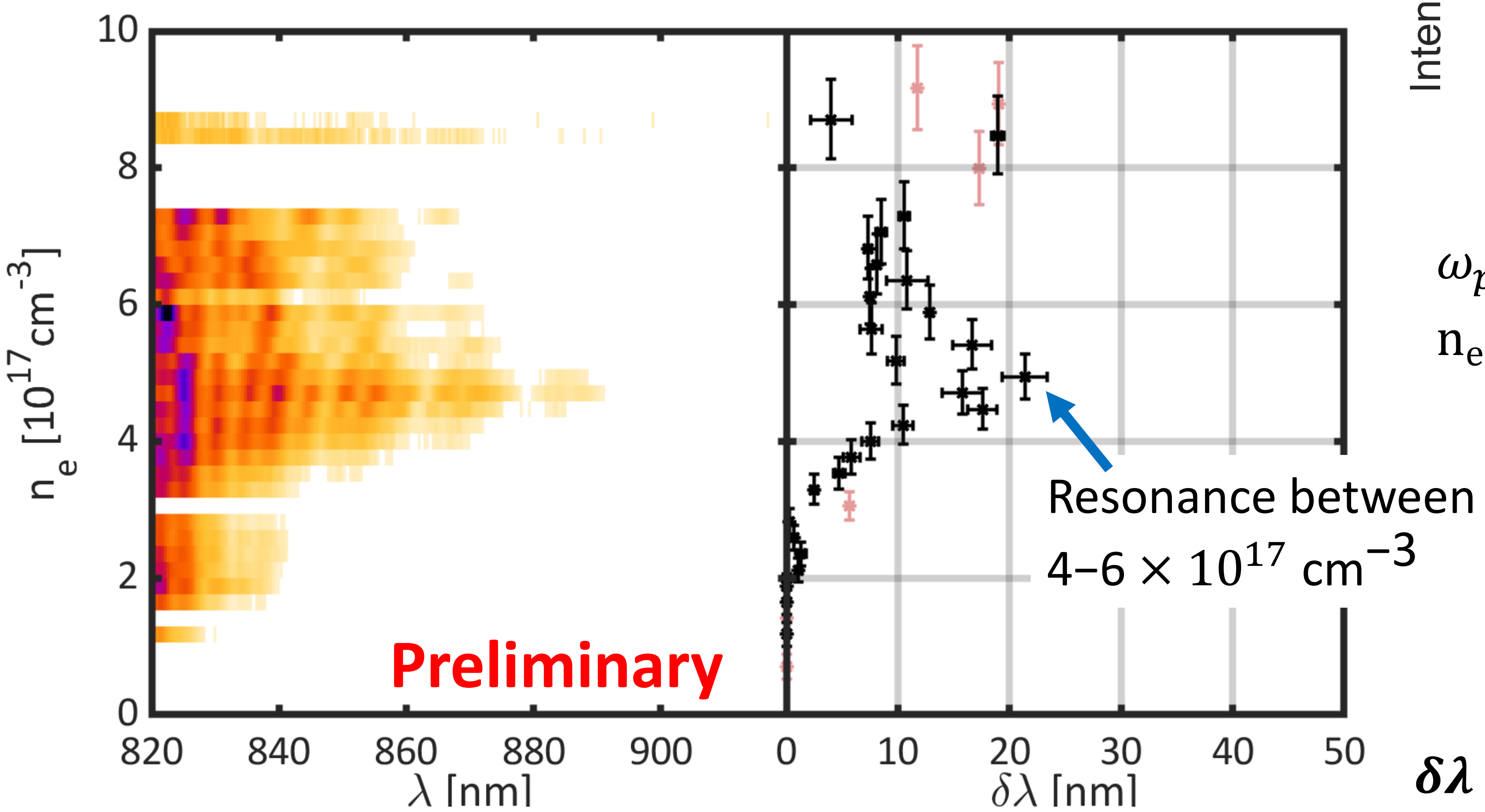
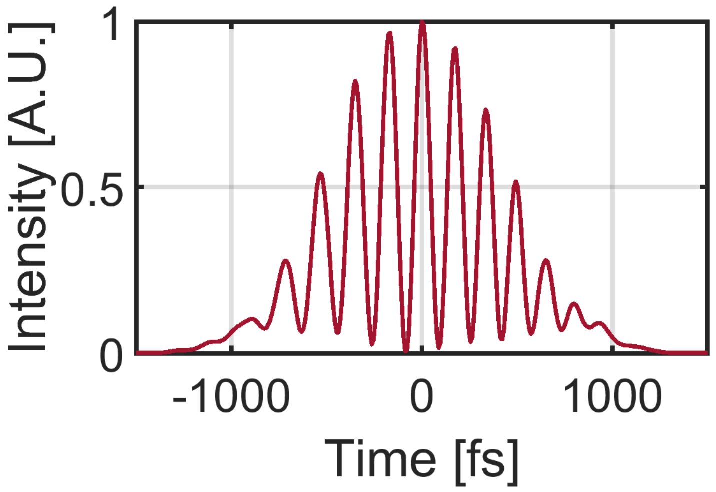


Resonant wakefield excitation

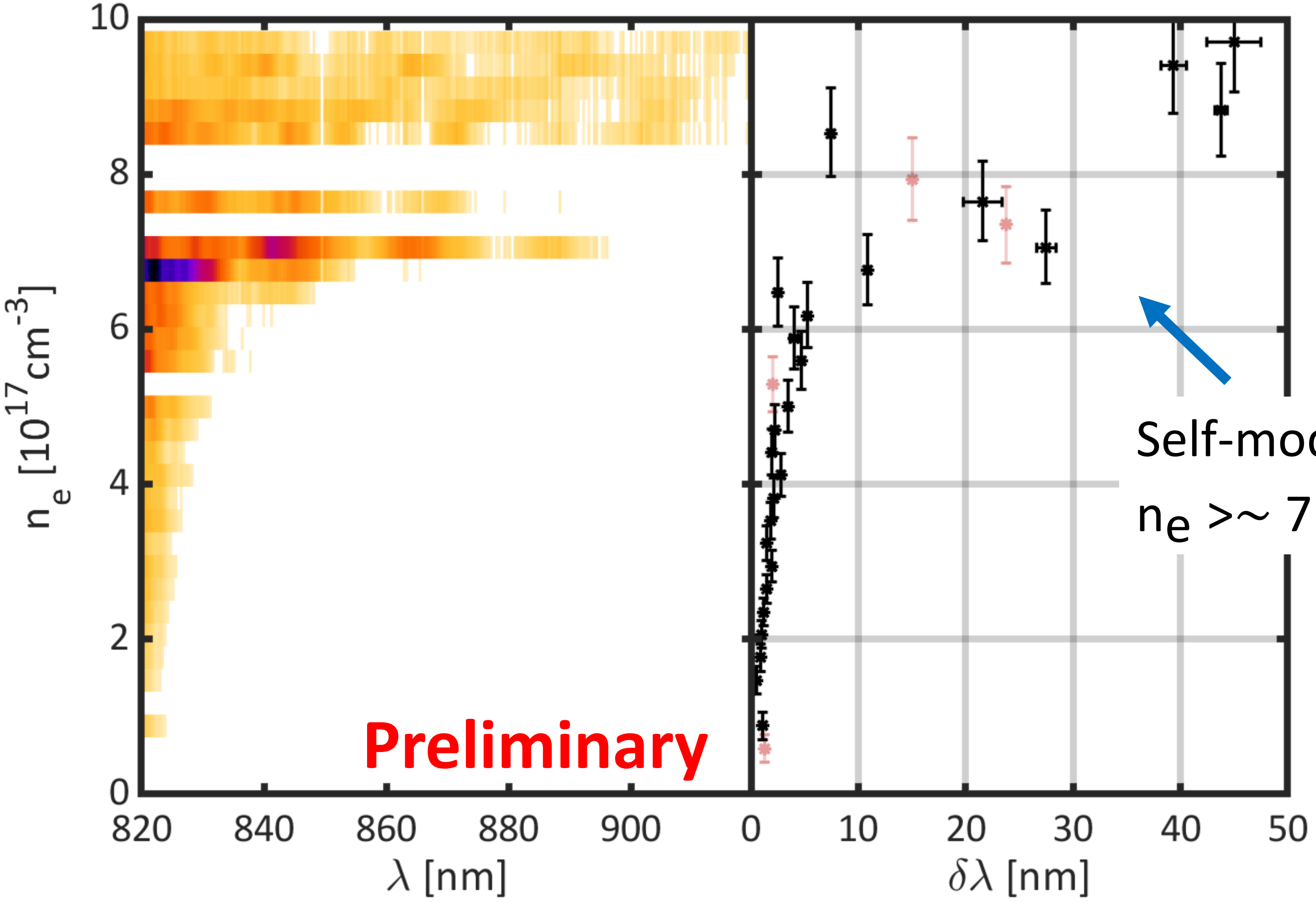




$\omega_p \propto 1/\delta\tau$ at 170 fs implies $\mathrm{n_e} = 4.3 \times 10^{17}$ cm^{-3}

$\boldsymbol{\delta\lambda}$ given by $\sum \lambda f(\lambda) / \sum f(\lambda)$

Smooth pulse – no resonance

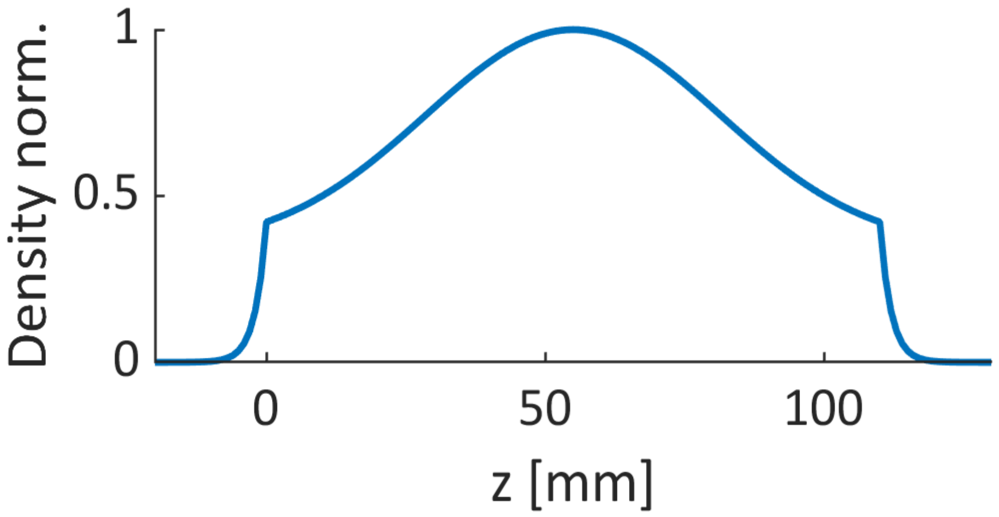


Self-modulation for $n_e >\sim 7 \times 10^{17}\ \mathrm{cm}^{-3}$

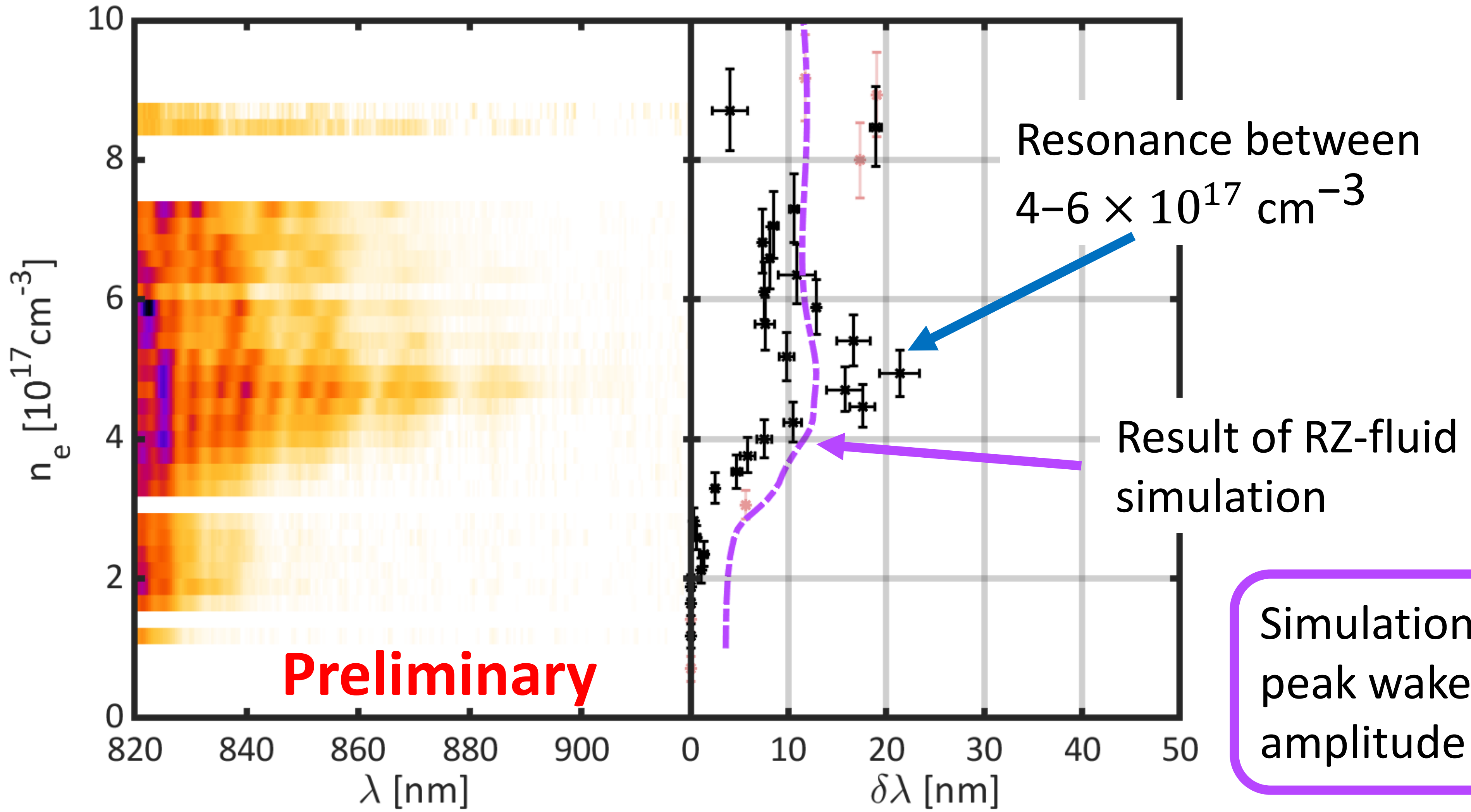
Simulations (in progress)

- 2D cylindrical fluid simulations
- Use experimental laser pulse train parameters
- Longitudinal gas profile may not have been uniform – assume some shape informed by experiment
- Also running 2D PIC simulations to take ionisation and envelope evolution effects into account

Longitudinal density profile (best guess)



Resonant wakefield excitation



Simulation suggests peak wakefield amplitude = **10 GV/m**

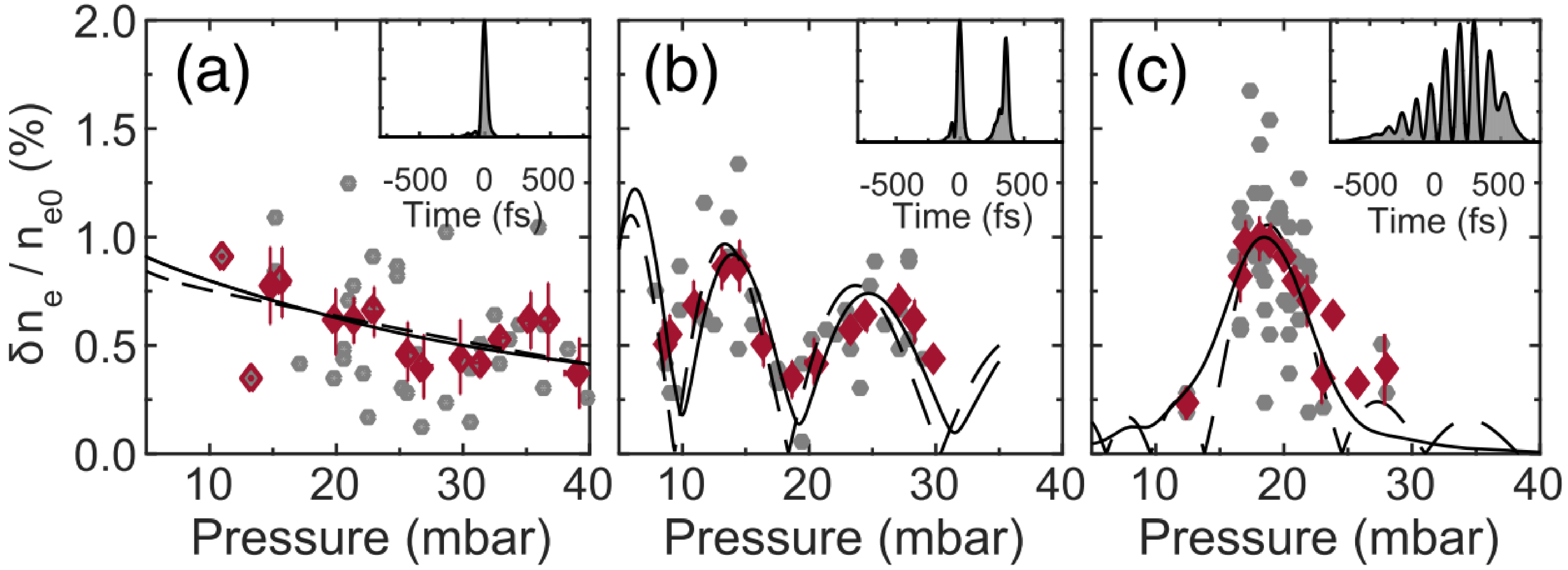
Summary

- We have demonstrated guiding of **2.5 J, 1 ps** pulse trains of 10 pulses over **110 mm**
- We observed redshifts in the drive spectrum, indicating wakefields were resonantly excited inside the channel
- The resonance observed is consistent with RZ-fluid code simulations, suggesting we achieved a peak accelerating gradient of **~10 GV/m**
- Opens up LWFA to new laser technologies, that could work at kHz-repetition-rates and high wall-plug efficiencies

Thank you!

Previous experimental results

Train of 7 pulses over 3 mm



J. Cowley *et al.*, Physical Review Letters, **119**, 044802 (2017)