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Observation of resonant wakefield excitation by pulse trains guided in long plasma channels

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The multi-pulse laser wakefield acceleration (MP-LWFA) scheme [1] provides a route for GeV-scale accelerators operating at kilohertz-repetition-rates driven by picosecond-duration laser pulses such as those available from thin-disk lasers. We recently published theoretical work proposing a new scheme of GeV accelerator based on MP-LWFA, which we call the Plasma-Modulated, Plasma Accelerator (P-MoPA) [2]. In this scheme, trains of pulses are generated from a long, high-energy drive pulse via the spectral modulation caused by a low amplitude wakefield driven by a leading short, low-energy seed pulse. Our simulations show that temporal compression of the modulated drive pulse yields a pulse train that can resonantly drive a wakefield, allowing for acceleration of a test electron bunch to 0.65 GeV in a 100 mm long plasma channel [2].
In earlier work we demonstrated resonant excitation of a plasma wakefield in a 4 mm long gas cell by a train of N ~ 7 laser pulses [3]. In the present work we investigate resonant excitation of plasma waves by trains of N ~ 10 pulses guided in a long hydrodynamic optical-field-ionized (HOFI) plasma channel [4-6].
We present the results of recent experiments with the Astra-Gemini TA3 laser at the Central Laser Facility for parameters relevant to the accelerator stage of the P-MoPA scheme. We demonstrate guiding of 2.5 J pulse trains in a 100 mm long plasma channel. Measurements of the spectrum of the transmitted laser pulse train show that a wakefield was resonantly excited in the plasma channel. We compare these experimental results with numerical simulations, which allows us to deduce the acceleration gradient of the plasma wakefield driven by the guided pulse train.
To our knowledge, these results are the first demonstration of resonant excitation of a plasma wakefield in a plasma channel.

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[3] J. Cowley et al., PRL, 119, 044802 (2017)
[4] R.J. Shalloo et al., PRAB, 22, 041302 (2019)
[5] A. Picksley et al., PRAB, 23, 081303 (2020)
[6] A. Picksley et al., PRE, 102, 053201 (2020)

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Primary authors: ROSS, Aimee (University of Oxford); Ms ARCHER, Emily (University of Oxford); Dr CHAPPELL, James (University of Oxford); Mr COWLEY, James (University of Oxford); Dr FEDER, Linus (University of Oxford); Mr JAKOBSSON, Oscar (University of Oxford); Dr JONES, Harry (University of Liverpool); Dr PICKSLEY, Alexander (University of Oxford); Dr REID, Lewis (University of Liverpool); Mr WANG, Wei-Ting (Warren) (University of Oxford); Mr VAN DE WETERING, Johannes (University of Oxford); Dr BOURGEOIS, Nicolas (Central Laser Facility); Dr CORNER, Laura (University of Liverpool); Prof. WALCZAK, Roman (University of Oxford); Prof. HOOKER, Simon (University of Oxford)

Presenter: ROSS, Aimee (University of Oxford)

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