MP-LWFA to improve LPA repetition rate and efficiency

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Need for high rep rate and efficiency

- Almost all LPAs are relying on Ti:sa lasers and therefore they operate at rep rates smaller than 10 Hz and at wall-plug efficiency smaller than 10^{-3}.

- Accelerators for particle physics require rep rates at the level of a kHz and wall plug efficiencies above 10^{-1}.

- Need for significant improvement.

- A lot of effort to develop **new lasers** or **modify the way plasma wave is driven** in order to use rapidly evolving, high average power lasers, such as thin-disk, fibre or diode lasers.

- Development of **new lasers**

- Industry and many Universities and labs are working on new lasers. Among them: LLNL BAT laser, Berkeley k-Bella, DESY kaldera, EPAC DIPOL/100 Hz project, EuPRAXIA towards 100 Hz, ICL 100 Hz.

- See dedicated talks in this meeting.

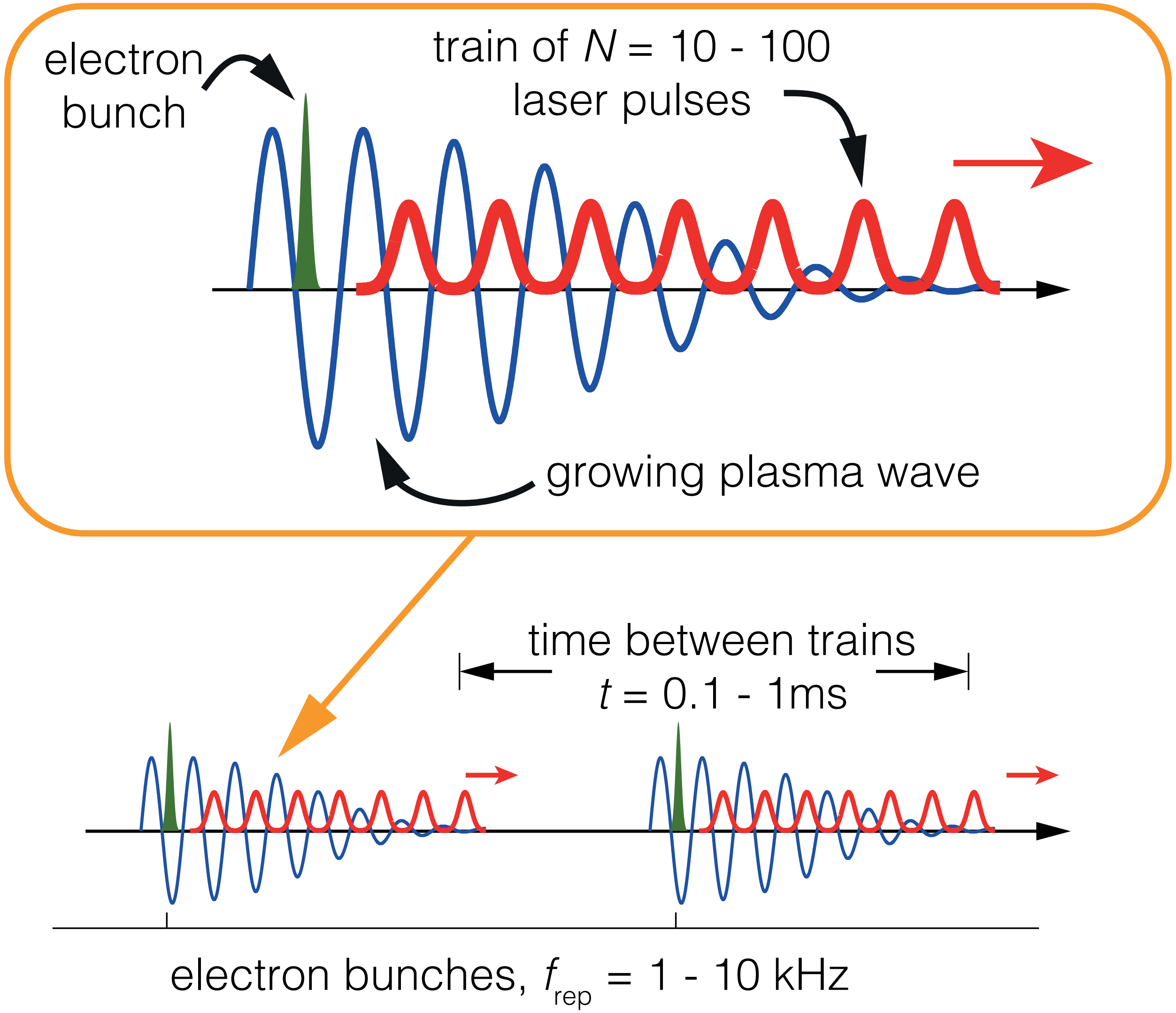
▶ Modify the way LPA is driven.
The MP-LWFA concept:

- A train of laser pulses (red) -or a long, modulated pulse - will resonantly excite a growing plasma wave (blue) if the pulses (modulations) are spaced by the plasma period.

- High average power lasers, such as thin-disk, fibre or diode lasers could provide the driving laser pulse trains operating at multi kHz rep rate.

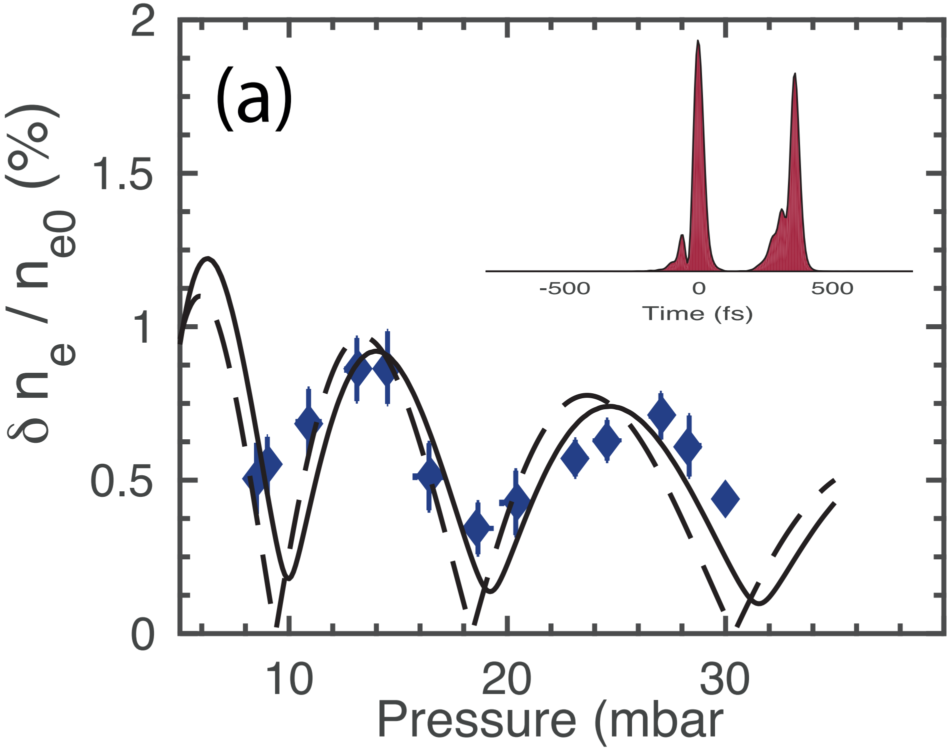
▶ Our research:

1. Investigate whether a train of laser pulses can drive LPA.
2. Develop a method to make trains of laser pulses.

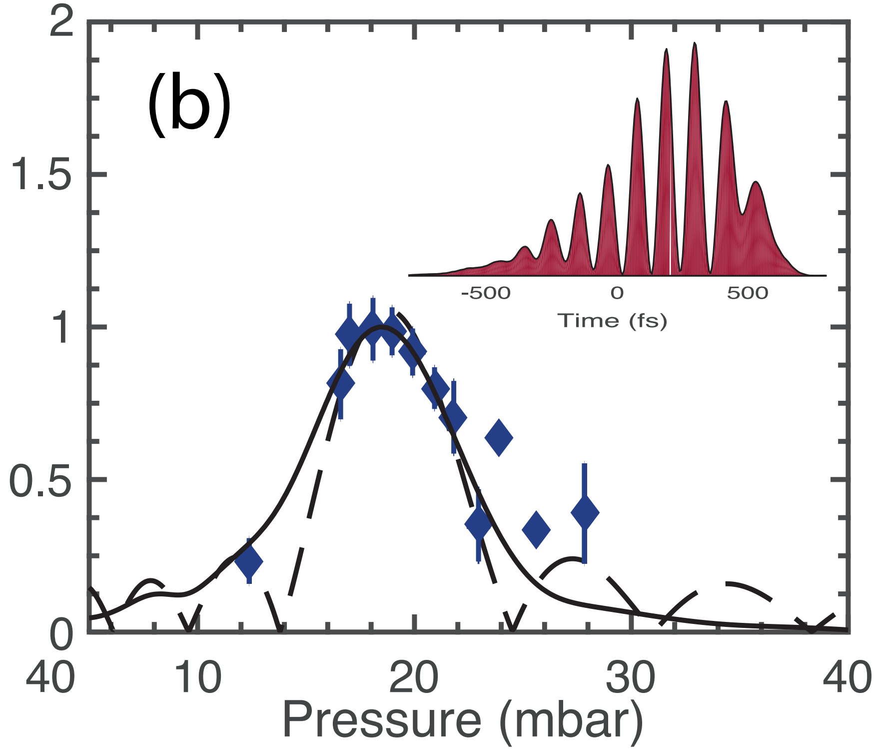


Plasma wake driven by MP-LWFA

N = 2 pulses train



N = 7 pulses train

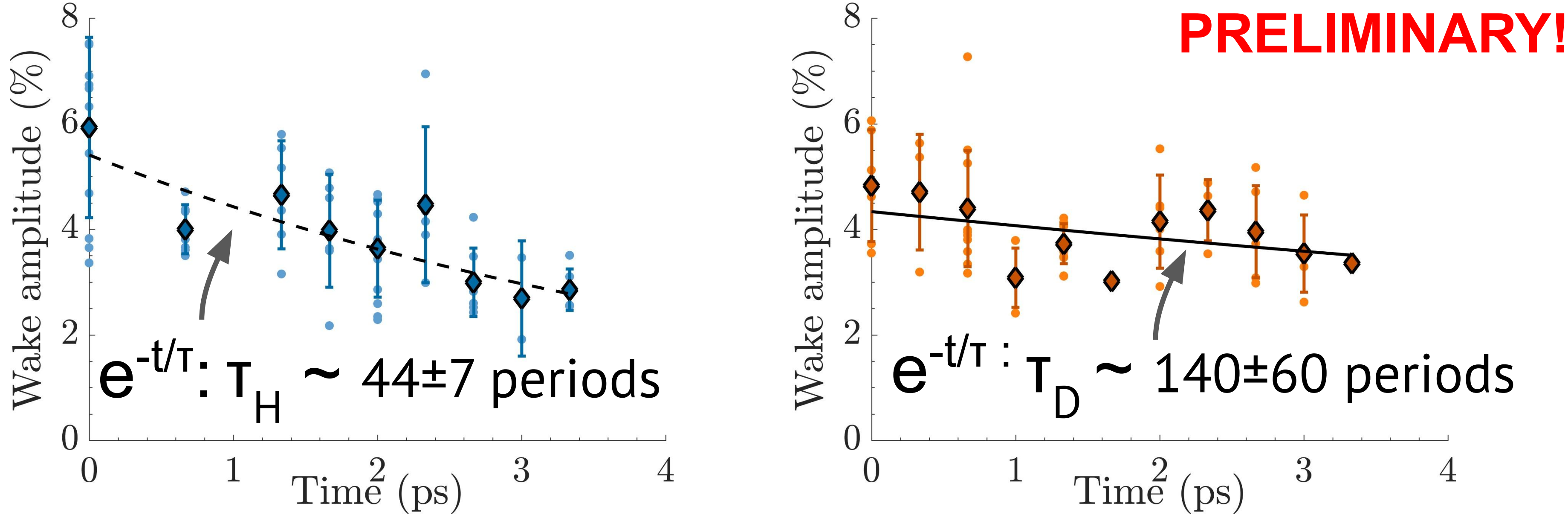


Relative wakefield amplitudes, measured as a function of gas cell pressure.

- On the way there is a new experiment at ASTRA/GEMINI laser to drive larger plasma wakes.

Ion motion not a showstopper

Hydrogen (20 mbar) Deuterium



Relative wakefield amplitudes, measured as a function of the time behind the driving laser pulse.

- Trains of laser pulses can be tens of plasma periods long.

Long distance propagation and hosing; PIC

- Using EPOCH 2D and FBPIC 2D with cylindrical symmetry PIC codes we checked:

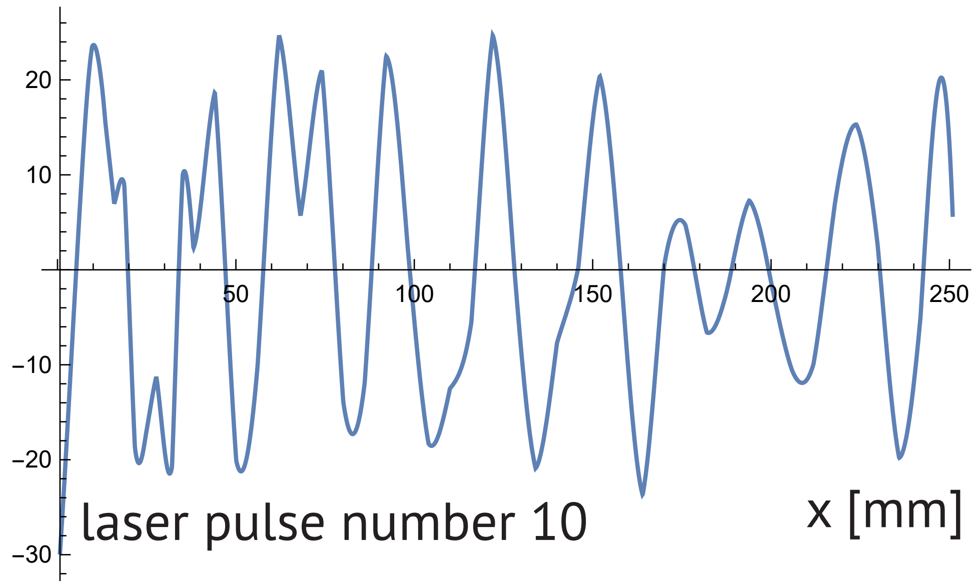
- trains of laser pulses can propagate tens of cm in a plasma waveguide. We plan now to test this experimentally.

- hosing instability doesn't grow in a plasma waveguide.

EPOCH 2D
A train of ten 80 mJ laser pulses propagating 25 cm in a plasma waveguid

Laser pulses are displaced transversly by $w_0/20$ increments, such that the pulse number 10 is 18 μm away from the axis. and the pulse number 1 is on the axis.

transverse position of the peak of the negative E_y electric field in μm



Summary

- Trains of laser pulses can drive LPAs tens of cm long.

- We will concentrate now on methods to make trains of laser pulse.

- Developing and testing LPAs with GeV energies and operating at kHz rep rate requires infrastructure beyond capacity of most of universities and labs. Therefore there is a need to have a dedicated lab which could provide such infrastructure (safety!) for external users.

Questions for the community

Part 1

1) Where do you see HEP applications of advanced accelerators in 30 years?

Since 2004 Dream Beam papers until now, 18 years, there has been a significant progress but this rate of progress is not big enough to think about colliders in 30 years. GeV electron beams for fixed target experiments or ep colliders are more realistic as well as electron injectors or production of secondary particles and radiation. QED might also be an area where advanced accelerators can find applications. As muons might lead to new physics, advanced accelerators as sources of muons and muon accelerators should be considered.

2)What intermediate physics applications/steps do you see until a HEP linear collider?

EuPRAXIA type programme. It is important that there are accelerators which operate 24/7. Without many years of continues operation (like in the case of RF accelerators which have been improved based on applications and practice), I don't see how one can get to colliders.

3)What is the synergy with related fields?

Related fields would provide users giving feed back.

4)What is the role of your work here?

Without high rep rate, efficient LPA there would be difficult to find HEP applications.

Questions for the community

Part 2

1) What are the important milestones for the next 10 years to get there from today?

Continue research on improving parameters of electron and positron beams and testing that they can be **achieved simultaneously**. Staging with high coupling efficiency, high rep rate with feed back and feed forward stabilization. Getting users who would confirm that the field is needed.

2) What additional support is needed to achieve these?

Big accelerator labs have to move >10% of their resources into novel accelerators.

3) What should be proposed as deliverables until 2026? Please list in order of priority.

a) Measurements and calculations of **correlations** of electron beam parameters to find out what beam parameters can be achieved simultaneously. That there are no show stoppers such as electron bunch charge correlation with the energy spread or transverse emittance.

b) A realistic plan of how to get high quality, high charge positron beam and a place to start implementing this plan.

4) Is the R&D work for each of those deliverables already funded and, if not, what additional resources/ support would be needed.

See point 2 above.

Questions for the community

Part 3

1) What key R&D needs can be achieved in existing R&D facilities?

Existing R&D facilities need to be changed from multi-purpose to dedicated facilities as simple things have been done and current R&D requires a lot of access time.

2) What is the role of the already planned future facilities in Europe and world-wide?

Get enough beam time for difficult problems to be solved and be a hub where people exchange ideas and work together beyond small university groups.

3) What can be done with the existing and planned funding base?

Funding for the whole of science is zero sum game. We need to present good arguments for our field to be funded.

4) Is completely new facility needed?

Yes, but it can be a transformation of an old facility such as a part of CERN.

5) Are additional structures needed beyond existing networks and projects, e.g. a design study for a collider or an advanced accelerator stage?

Yes, see point 2 in Part 2.

Acknowledgements

This work was supported by:

- Engineering and Physical Sciences Research Council (EPSRC UK) [grant number EP/V006797/1]
- Science and Technology Facilities Council (STFC UK) [grant numbers ST/J002011/1, ST/P002048/1, ST/S001964/1, ST/M50371X/1, ST/N504233/1, ST/R505006/1, ST/S505833/1]
- Engineering and Physical Sciences Research Council [Studentship No. EP/N509711/1]
- Helmholtz Association of German Research Centres [Grant number VH- VI-503]
- This material is based upon work supported by the Air Force Office of Scientific Research under award numbers FA8655-13-1-2141 and FA9550-18-1-7005.
- This work was supported by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 653782.
- US Dept. of Energy (Grant No. DESC0015516), Dept. of Homeland Security (Grant No. 2016DN077ARI104), National Science Foundation (Grant No. PHY1619582), AFOSR (Grants No. FA9550-16- 10121 and FA9550-16-10284)
- The plasma HEC Consortium EPSRC grant number EP/L000237/1,
- CLF and the Scientific Computing Department at RAL for the use of SCARF-LEXICON computer cluster
- ARCHER UK National Supercomputing Service