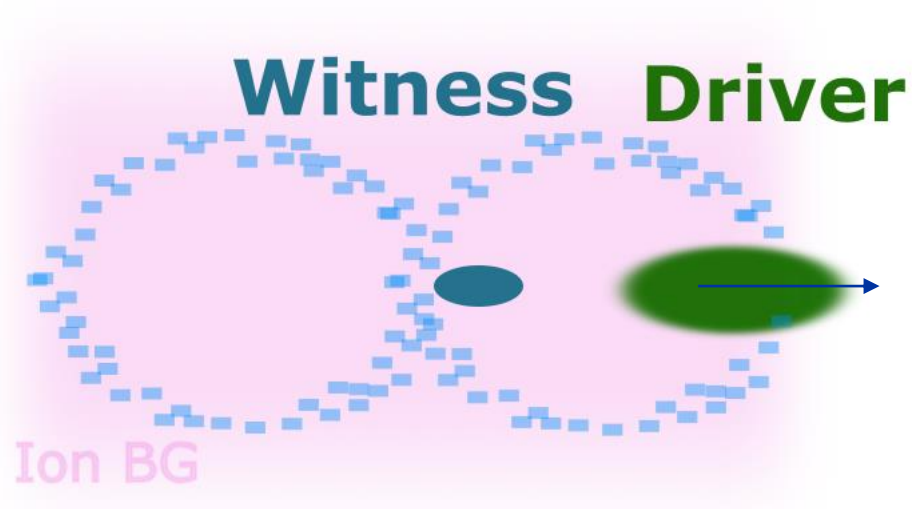


Update on the ion motion analysis

M. Turner, E. Walter, L. Verra, A. Clairembaud, C. Amoedo, E. Gschwendtner, F. Pannell, G. Zevi Della Porta, J. Mezger, J. Pucek, J. Farmer, M. Bergamaschi, N. Lopes, N.Z. van Gils, N. Torrado, A. Sublet, P. Muggli, AWAKE Collaboration



Ion Motion Due to the Ponderomotive Force of Transverse Wakefields



Ion motion:

- due to driver → impulse force
- due to the witness → impulse force
- wakefields → ponderomotive force

Dominant when using many wakefield periods

Uniform

Ions assumed to be immobile

Ions provide restoring force

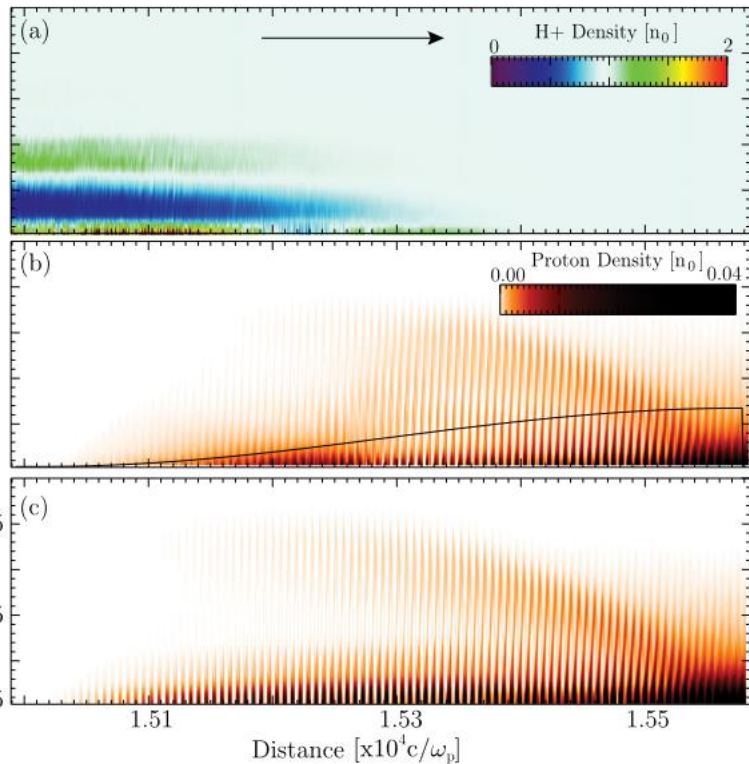
→ Sustaining the plasma electron oscillations

→ Assumption $n_e = n_{pi}$

$$\omega_{pe} = \sqrt{\frac{n_e e^2}{\epsilon_0 m_e}}$$

Theoretical and Simulation Work in Literature

Ion motion in the wake driven by long particle bunches in plasmas
 J. Vieira; R. A. Fonseca; W. B. Mori; L. O. Silva, *Phys. Plasmas* 21, 056705 (2014)

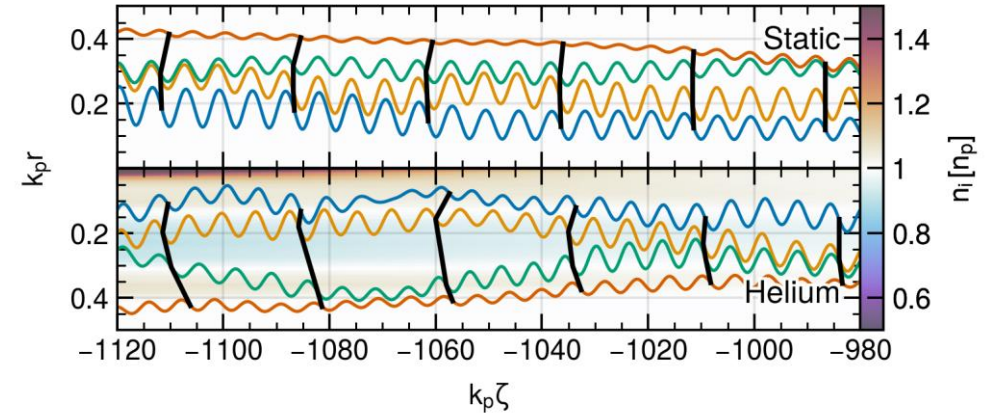


Hydrogen Plasma

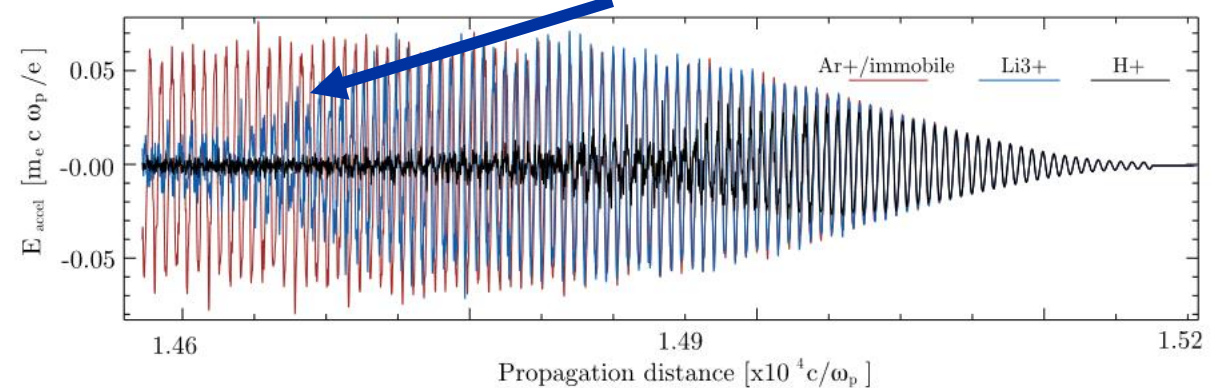
Immobile ion Plasma

Laser driven: Plasma Ions Dynamics in the Wake of a Short Laser Pulse
 L. M. Gorbunov, P. Mora, and A. A. Solodov
Phys. Rev. Lett. 86, 3332 (2001)

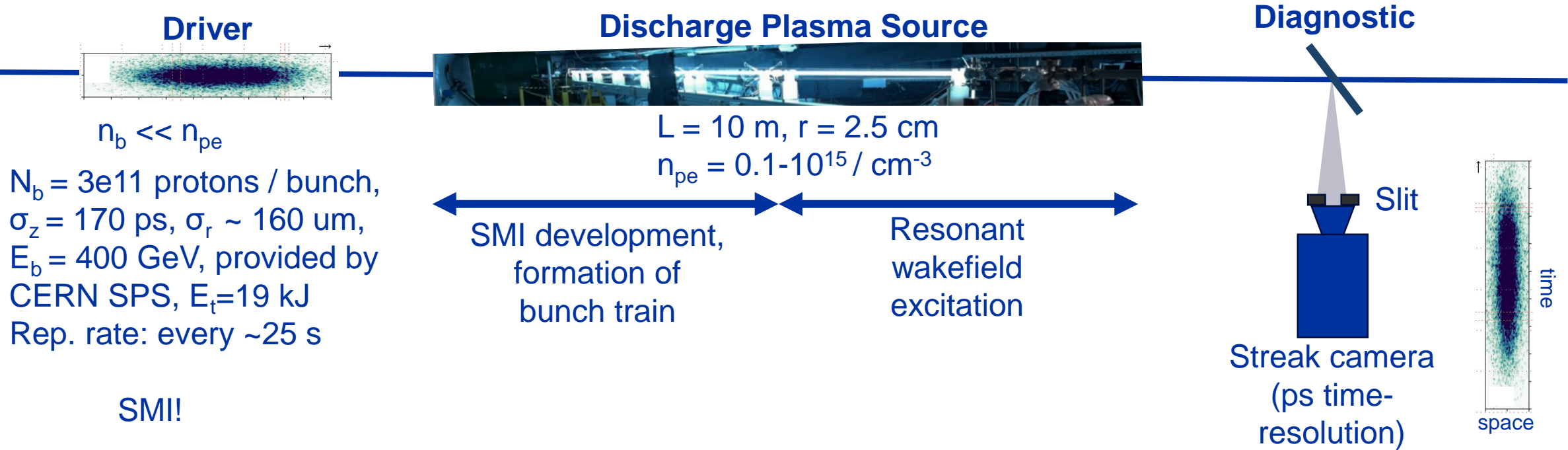
Local change of electron oscillation period
 E. Walter



Loss of decoherence reduces Wakefield amplitude



Experimental Setup



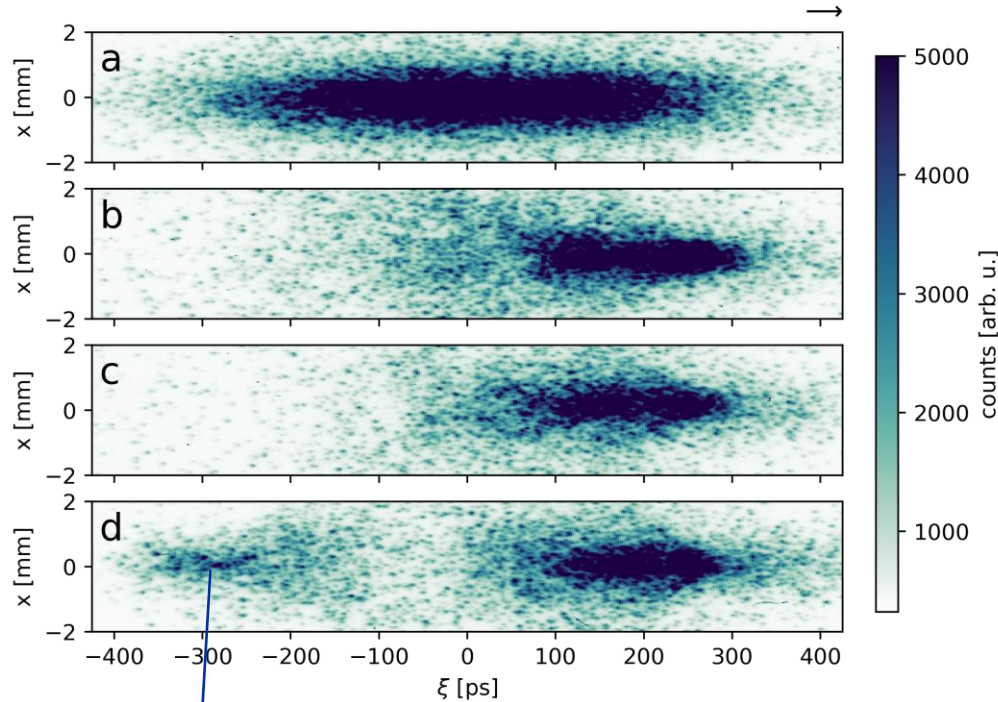
Effect of Ion Motion on the Bunch was Observed Clearly

Vacuum

Xenon
A=131

Argon
A=40

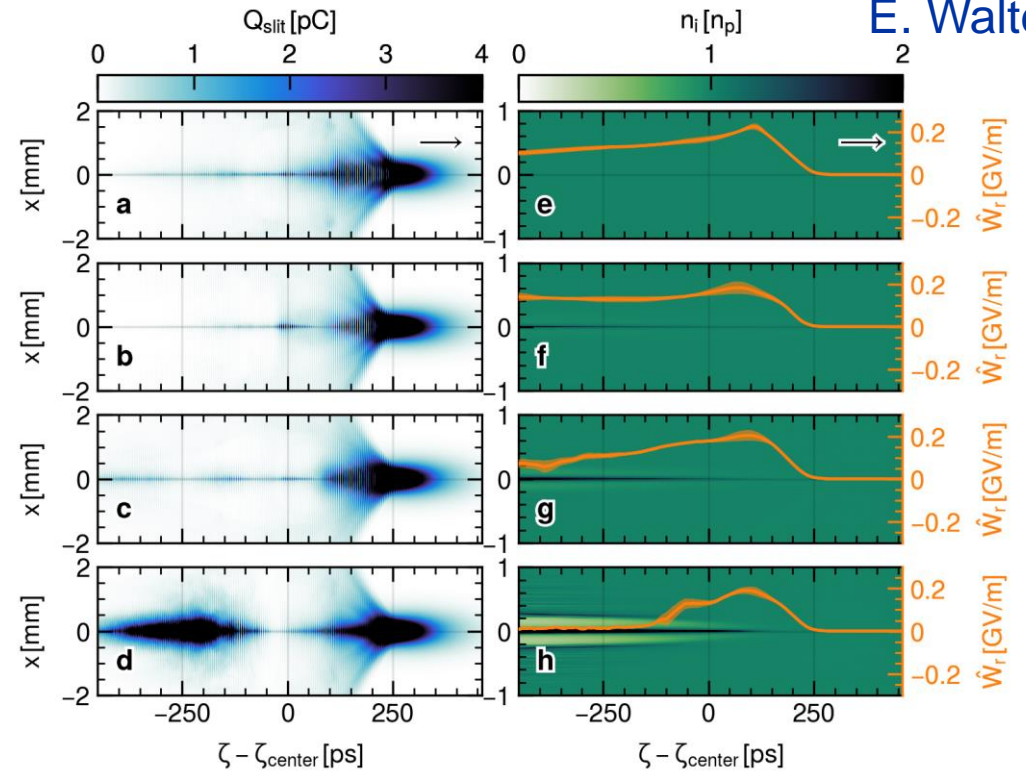
Helium
A=4



Appearance
of a bunch tail

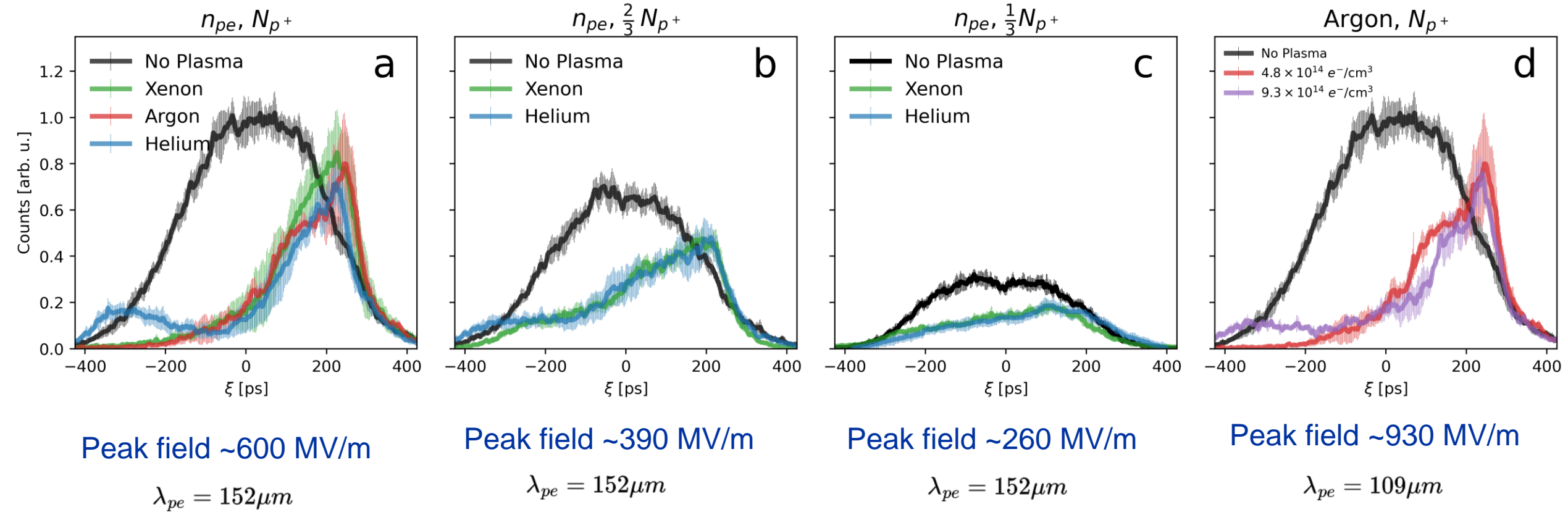
Effect scales with
ion mass!

E. Walter



Simulations at experimental parameters confirm that it is indeed the ion motion caused by the ponderomotive force. SMI: simulations have a different seed level → qualitative agreement confirms physics mechanism at play

Scaling with Wakefield Amplitude



$$F_p = \frac{e^2}{4m_e \omega_{pe}^2} \nabla \hat{E}^2$$

Effect scales with
wakefield amplitude!

Story of the Paper (1/2)

- Physics of how ion motion affects plasma wakefield accelerations has been explained theoretically and was shown by simulations → Many high impact publications (since 2001) → Interesting topic
- In 2018, ion motion was observed in shadowgraphy images
- We built an experiment to demonstrate the effect and show the scaling (change ion mass and wakefield amplitude)
 - Allowed to obtain first experimental observation that ion motion is altering wakefields → observe effect of changes wakefields on a beam

Story of the Paper (2/2)

- Physics of how ion motion affects plasma wakefield accelerations has been explained theoretically and was shown by simulations → Many high impact publications (since 2001) → Interesting topic
- In 2018, ion motion was observed in shadowgraphy images
- We built an experiment to demonstrate the effect and show the scaling (change ion mass and wakefield amplitude)
 - Allowed to obtain first experimental observation that ion motion is altering wakefields → observe effect of changes wakefields on a beam
- Results are important because:
 - First evidence that ion motion does affect wakefields
 - Ion motion has consequences for all wakefield accelerators (also using single drivers)
 - Bad: emittance growth, whose magnitude may be unacceptable
 - Good:
 - 1) ideas to change the mass of the plasma ions to adiabatically match the beam to the changing focusing profile of the plasma focusing force;
 - 2) moderate ion motion to detune the resonance and growth of the hose instability.

Summary & Conclusions

- Effect of ion motion on the wakefields and proton bunch was observed.
 - Measurements are clear and unambiguous.
- Physics has been discussed in literature based on theory and simulations.
 - Shadowgraphy images have shown cone like features resulting from ion motion.
 - We are the first ones to demonstrate experimentally that wakefields can be altered.
 - Work is important because ion motion physics has consequences (good/bad) for wakefield accelerators.
- For AWAKE: Important that ion motion does not alter wakefields at or before the location where electrons are injected.
 - Rubidium sufficiently heavy choice at GV/m field strength level.
- Paper writing is in progress.
 - → challenge is to make the work more quantitative.