



SINGLE-SHOT, HIGH TRANSFORMER RATIO MEASUREMENTS IN THE NONLINEAR PLASMA REGIME



R. ROUSSEL, G. ANDONIAN, W. LYNN, A. DENG, K. SUNALKAWA, R. ROBLES, C. HANSEL, G. LAWLER, J. ROSENZWEIG University of California Los Angeles

M. CONDE, S. DORAN, G. HA, W. LIU, J. POWER, J. SEOK, E. WISNIEWSKI Argonne Wakefield Accelerator

> **ENERGY** Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.





OUTLINE

- Motivation
- Experiment Overview
 - Emittance Exchange
 - Beamline Design Considerations
 - Hollow Cathode Arc Plasma Source
- Wakefield Measurements
 - Single shot wakefield mapping
 - Observation of high TR
 - Observation of wakefield flattening
 - Probing nonlinearities in the plasma response
- Conclusion



MOTIVATION: TRANSFORMER RATIO

Efficiency of transfer of energy from drive to wakefield

Maximum energy delivered to witness beam is limited by the drive energy and the transformer ratio (TR) **TR < 2** for symmetric beams in a co-linear wakefield accel.



beams (e.g. ramped beams)

UCHICAGO ARGONNELLC U.S. DEPARTMENT OF BENERGY U.S. Department of Energy laborator unaged by UChcago Argonne, LLC



HIGH TR PWFA MEASUREMENTS AT PITZ



Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC



- Beam shaping by laser pulse stacking
- Witness w/ delay to probe wakefields

• TR = 4.6

G. Loisch, Phys. Rev. Lett. **121**, 064801 (2018) G. Loisch et.al., NIMA 909 (2018)



HIGH TR DIELECTRIC MEASUREMENTS AT AWA



Gao, et al. PRL 120.11, 114801 (2018).



5

U.S. DEPARTMENT OF ENERGY Argonne National Laboratory is a U.S. Department of Energy laborator managed by UChicago Argonne, LLC

EXPERIMENT GOALS AT AWA



UCHICAGO ARGONNELLE U.S. DEPARTMENT OF U.S. Department of Energy Bubbarator U.S. Department of Energy Bubbarator

6

Argonne 스

AWA EXPERIMENT DESIGN







ENERGY Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.



THE ARGONNE WAKEFIELD ACCELERATOR



UCHICAGO ARGONNELLE U.S. DEPARTMENT OF U.S. Department of Energy Bubbaraton U.S. Department of Energy Bubbaraton U.S. Department of Energy Bubbaraton

Argonne 스

EXPERIMENT OVERVIEW



UCHICAGO ARGONNELIC Us DEPARTMENT OF US. Department of Energy laboratory is a US. Department of Energy laboratory managed by UCIncipe Argonne, LIC.



CURRENT SHAPING WITH EMITTANCE EXCHANGE



CURRENT SHAPING WITH EMITTANCE EXCHANGE



 $z_f = \{\kappa\xi + [\eta + \kappa\xi(L + L_D)]S_x\}x_i$



HOLLOW CATHODE ARC PLASMA SOURCE



Hollow cathode arc plasma source

- Argon gas
- 8cm x 2cm •
- Characterized with Langmuir probe
- n_0 tunable 10¹³-10¹⁴ cm⁻³

External heating of the cathode allows arc regime access < 50V

Solenoids for confinement







HOLLOW CATHODE ARC PLASMA SOURCE



13

WAKEFIELD MEASUREMENTS







PARTMENT OF ERGY Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.





SINGLE SHOT WAKEFIELD MEASUREMENT





15

UCLA

Argonne 스

CURRENT DENSITY RECONSTRUCTION



Horizontal slit increases temporal resolution **BUT** at the cost of accurate current measurement due to y-z correlation

We can reconstruct the drive profile (up to a radial form factor) by approximating the **quasi-nonlinear regime** as a **linear plasma response** because $n_b/n_0 \sim 1$ in the drive

W. Lu Physics of Plasmas 12, 063101 (2005)

UCHICAGO ARGONNELLC U.S. DEPARTMENT OF U.S. Department of Energy labora U.S. Department of Energy labora



Simulated beam dist. out of EEX

$$n_b'' + k_p^2 (n_b + n_1) = 0$$
$$\nabla \cdot \mathbf{E} = -4\pi e (n_b + n_1)$$
$$n_b(\xi) = \frac{\epsilon_0}{e} \left[\frac{dE(\xi)}{d\xi} + k_p^2 \int_{-\infty}^{\xi} E(\xi') d\xi' \right]$$



CURRENT DENSITY RECONSTRUCTION

Generated various linearly ramped bunch profile heads

- double-triangle
- doorstep

parabolic
Profiles taken from
Lemery and Piot
Phys. Rev. A & B (2015)

Calculated wakefield from single mode convolution

Reconstructed drive profile from wakefield $0 < \xi < L_b$







COMPARISON TO SIMULATION



UCHICAGO ARGONNELLC U.S. DEPARTMENT OF U.S. Department of Energy laboratory is a U.S. Department of Energy laboratory usaded by UChicago Argonne, LLC.

18

UCLA

Argonne 🛆

OBSERVATION OF HIGH TR

Roussel, et al., in prep



UNIFORMIZATION OF DRIVE WAKEFIELD

Roussel, et al., in prep

UCLA

Argonne 스



UCHICAGO ARGONNELLC U.S. DEPARTMENT OF U.S. Department of Energy laborator managed by UCh.cago Argone, LLC

PROBING MULTI-PERIOD NONLINEARITIES

Plasma density is scanned by changing on-axis solenoidal field while keeping the same beam charge

Nonlinearity of system => n_b/n_0

Increasing plasma density reduces nonlinearities

Highest density wakefields appear **sinusoidal**, while low density wakefields have **sawtooth** appearance







SUMMARY

- Observed high TR for PWFA due to nonlinear response from shaped beam
- Observed wakefield flattening due to parabolic head
- System flexibility allows probing nonlinear response
 - Lays foundation for future studies in quasinonlinear regime





Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.



ACKNOWLEDGEMENTS

AWA

- John Power
- Manoel Conde
- Gwanghui Ha
- Jimin Seok
- Eric Wisniewski
- Scott Doran
- Charles whiteford
- Wanming Liu

UCLA

- Ryan Roussel
- Gerard Andonian
- James Rosenzweig
- Walter Lynn
- Kunal Sanwalka
- River Robles
- Claire Hansel
- Aihua Deng
- Gerard Lawler

Supported by DOE SCGSR + DE-SC0017648

UCHICAGO ARGONNELIC (CENERGY Argonne National Laboratory is a US. Department of Energy laboratory us. Department of Energy laboratory managed by UCIncigo Argonne. LIC.



UCI A



Radiasoft

Nathan Cook

BACKUP

Backup slides





LINEAR RAMPS IN THE BLOWOUT REGIME

- Numerical calculation of blowout radius and on-axis wakefield from Lu. et.al
- At low beam densities blowout is sub-relativistic -> response approximates linear regime
- At high beam densities, blowout is relativistic -> wakefield inside drive becomes uniform





UCLA

Argonne 🛆

QUASI-NONLINEAR RESPONSE



UCHICAGO ARGONNELLE US DEPARTMENT of Argonne National Laboratory is a US. Department of Energy laboratory managed by UChicago Argonne, LLC



SINGLE SHOT HIGH TRANSFORMER RATIO MEASUREMENTS IN THE NONLINEAR PLASMA REGIME

