Hollow Channel Plasma Wakefield Experiments at FACET-II

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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Outline

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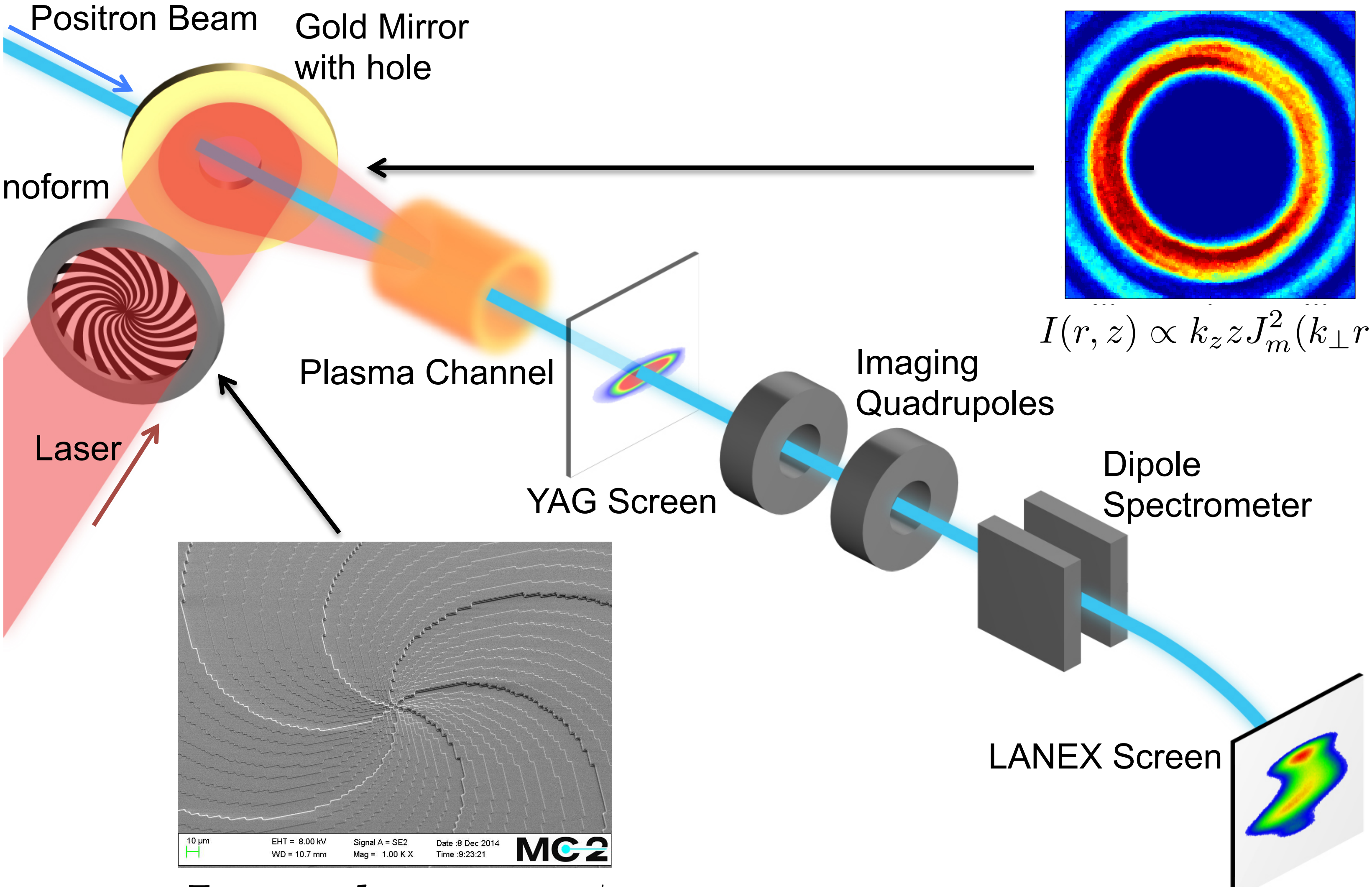
- Results from FACET
- Improved “First Generation” experiments at FACET-II
  - Improved plasma source and plasma profile measurements
  - Understanding the effect of the channel shape on wakefields
  - Exploration of the non-linear regime
- “Second Generation” experiments at FACET-II
  - True hollow channel plasmas
  - Beam break-up mitigation with external focusing

Results from FACET

Creation of Meter-Scale Plasmas



$$I(r,z) \propto k_z z J_m^2(k_\perp r)$$

$$\Psi_m = k_\perp r + m\phi$$

S. Gessner et. al. Nat. Comm. 7, 11785 (2016)

Beam-Based Measurements of the Channel Shape

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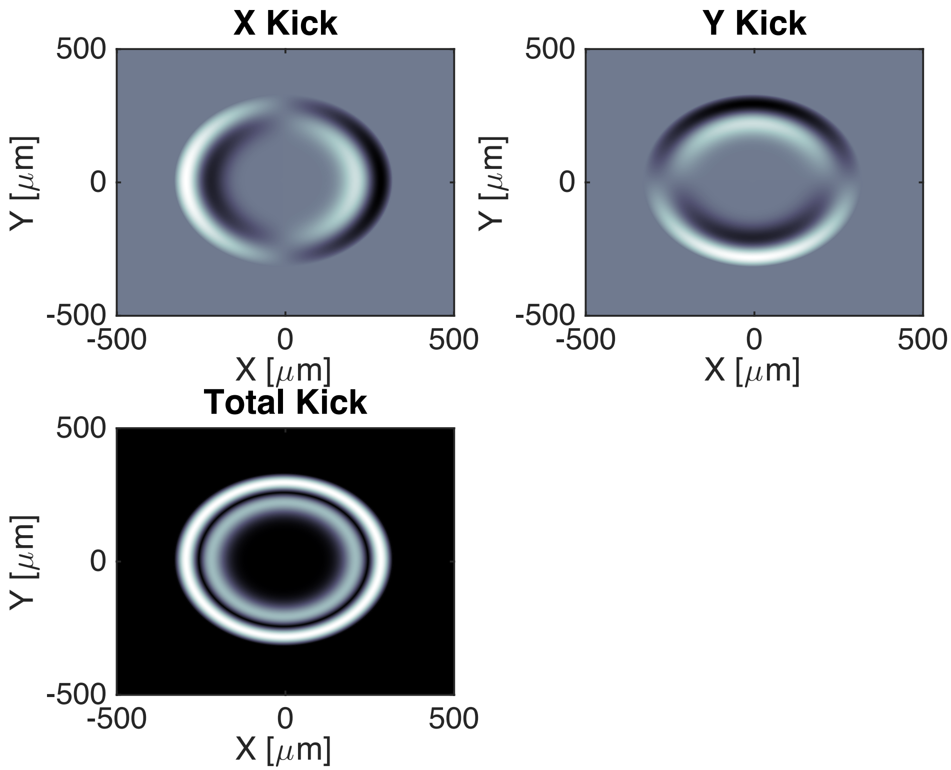
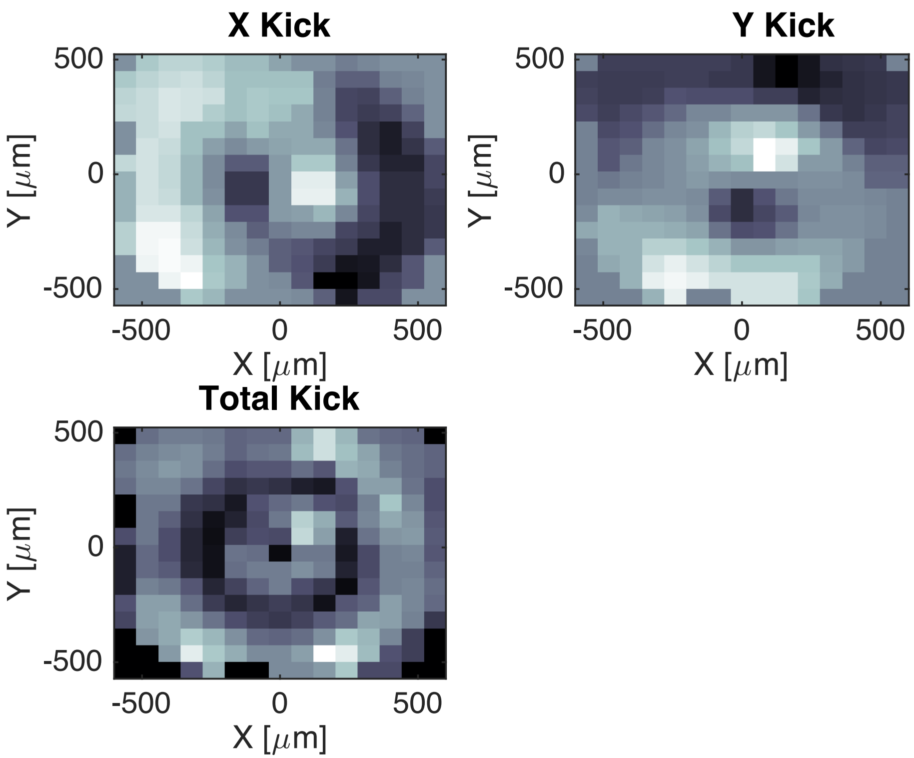
Simplified Model

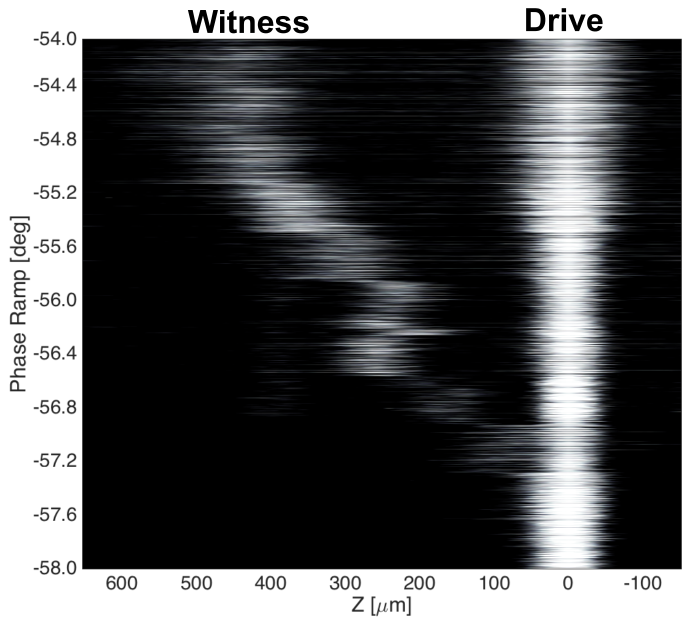


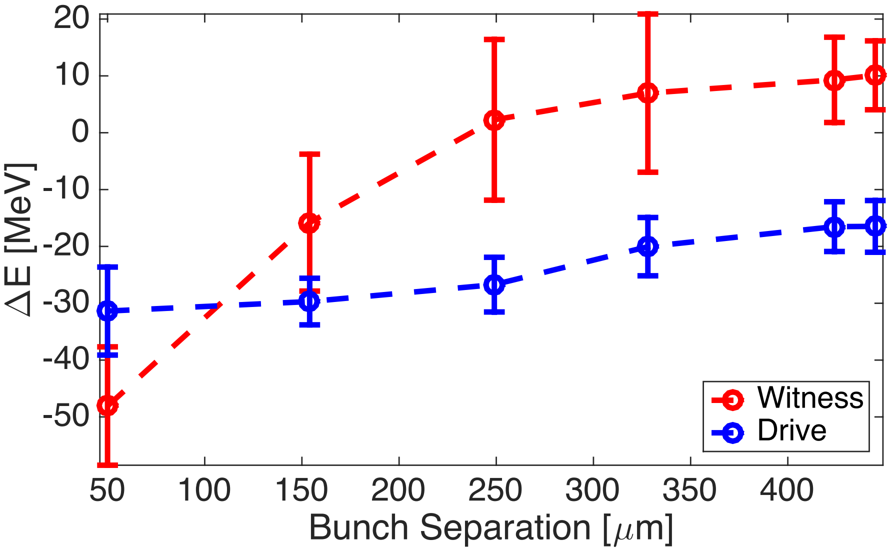
Data



Beam deflection measurements are used to demonstrate the shape of the hollow plasma channel formed by the high-order Bessel laser pulse.

Mapping the Longitudinal Wakefield

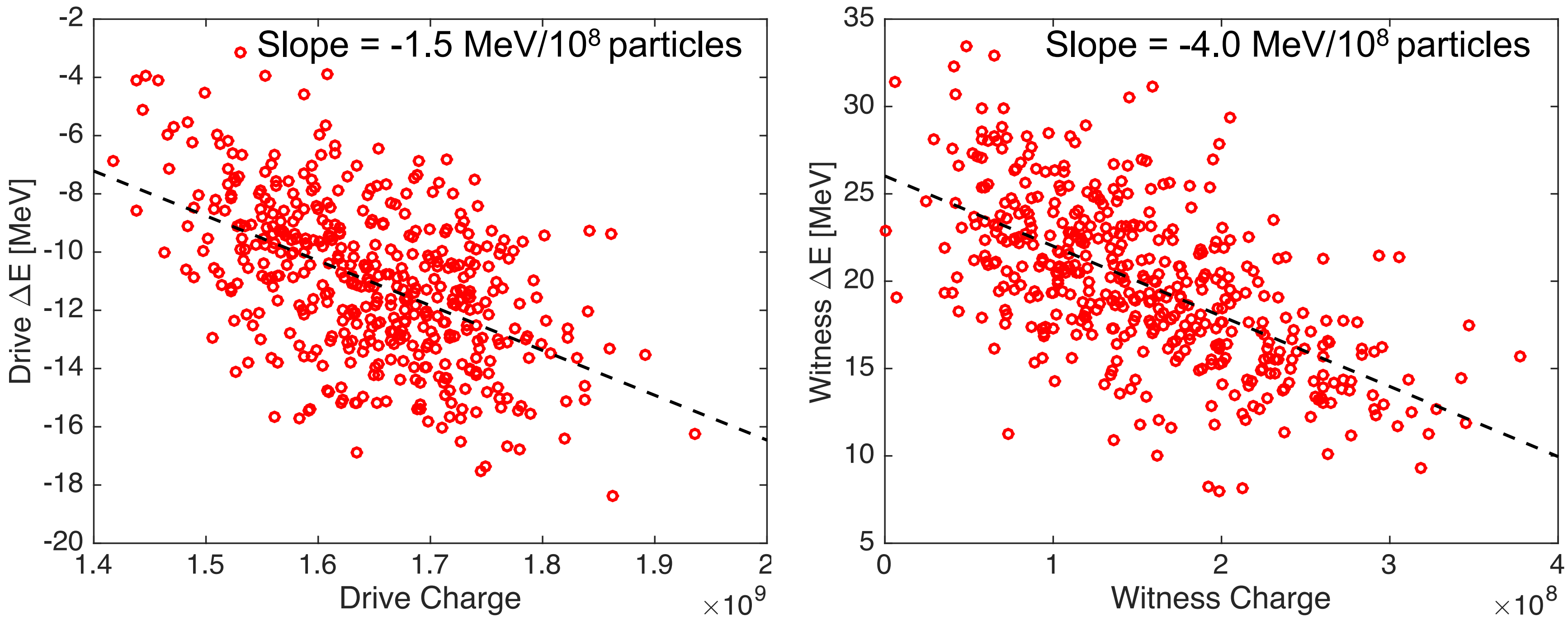




We observed for the first time the acceleration of positrons in the hollow channel plasma wakefield. We were able to map out the longitudinal wakefield by varying the separation between drive and witness beams.

Carl Lindstrøm is performing a similar analysis for the transverse wakefield.

Beam Loading



Beam loading is an important consideration when trying to optimize the gradient and efficiency. The average drive-to-witness efficiency in this experiment was 18% with an average transformer ratio of 1.8.

Modeling the Plasma Boundary

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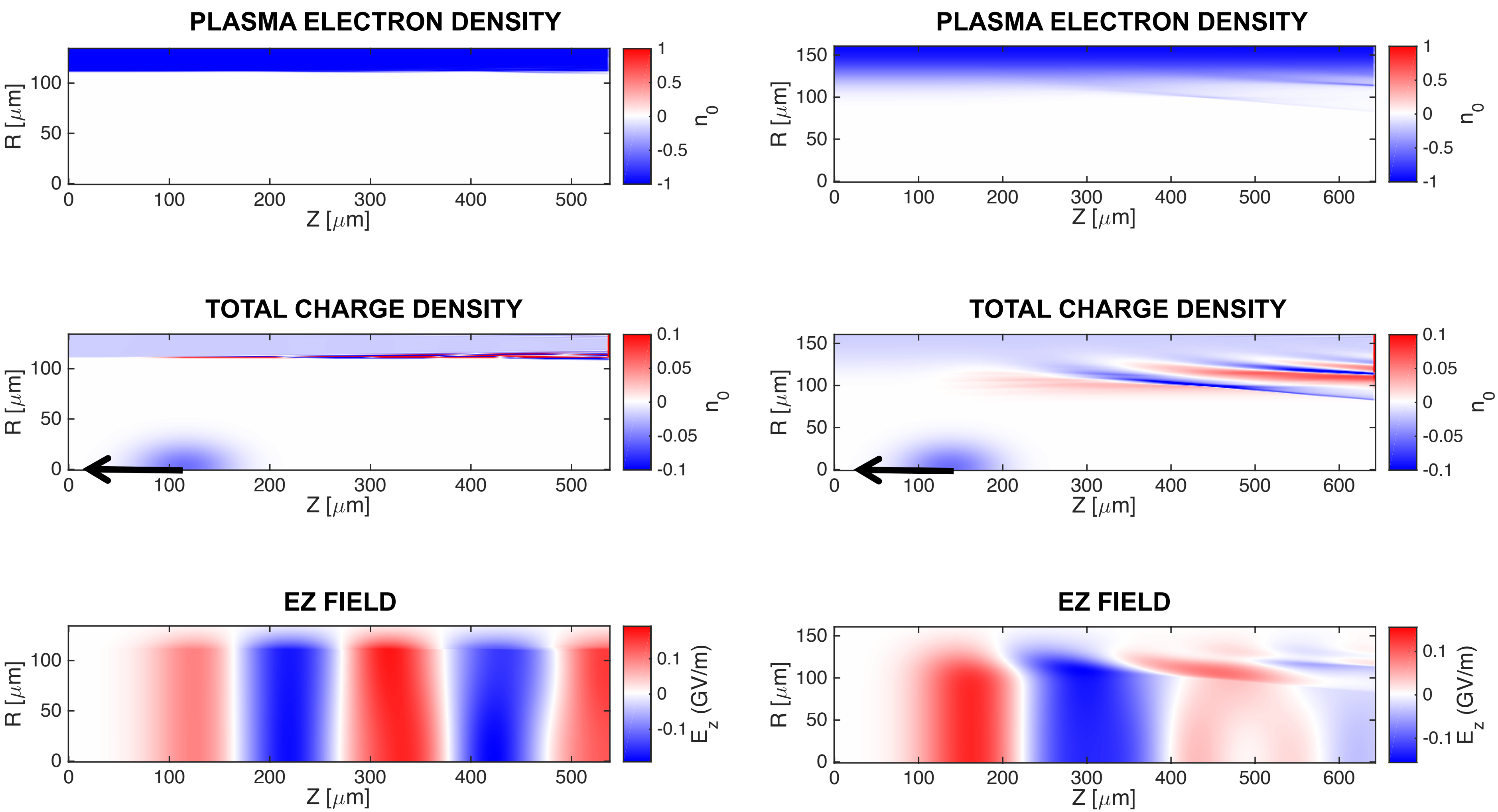
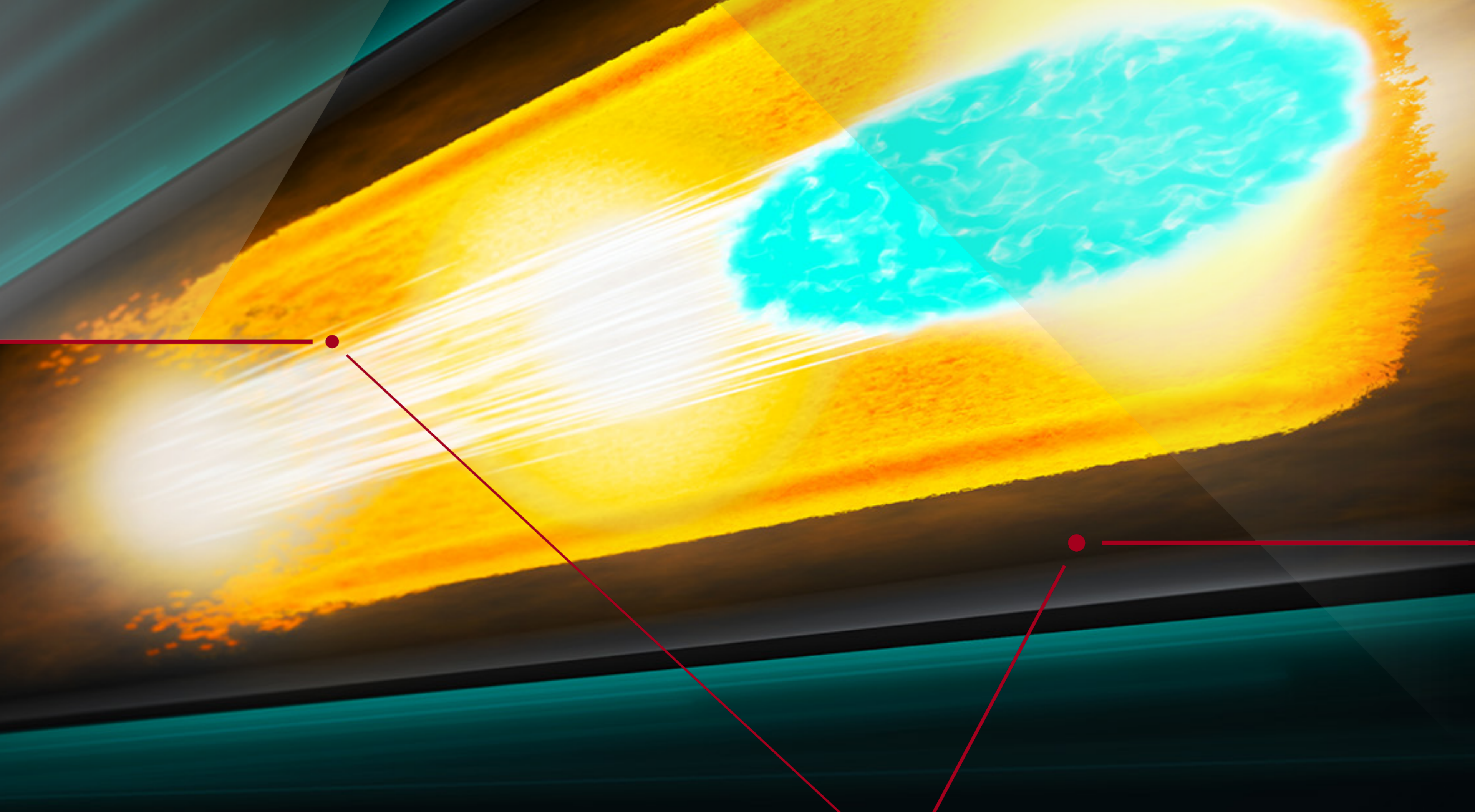


Simulations performed in OSIRIS 2D on UCLA Hoffman2 Cluster

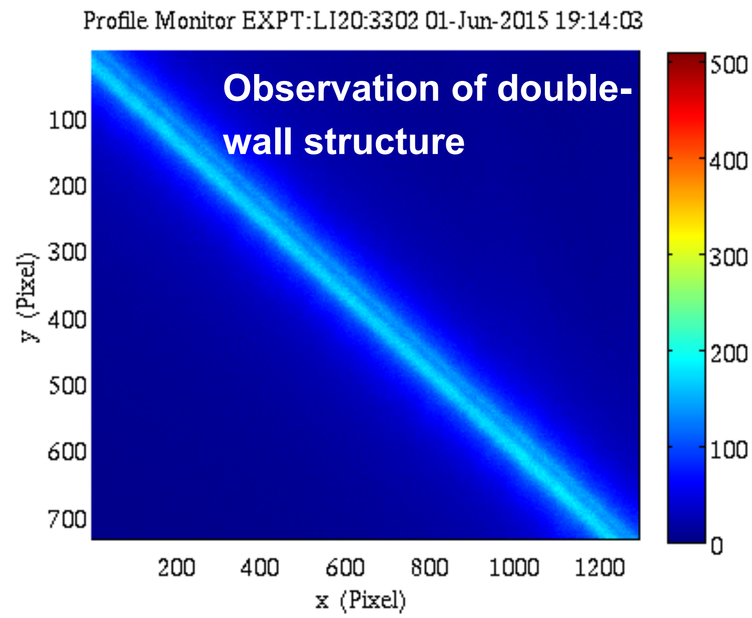
Improved 1st Gen Experiments



Gas Source Plasmas

Gas source plasmas have advantages over lithium vapor sources:

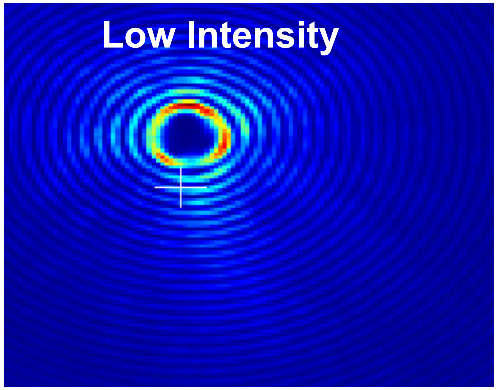
- Direct observation of hollow channel profile
- Can use a high-charge drive beam

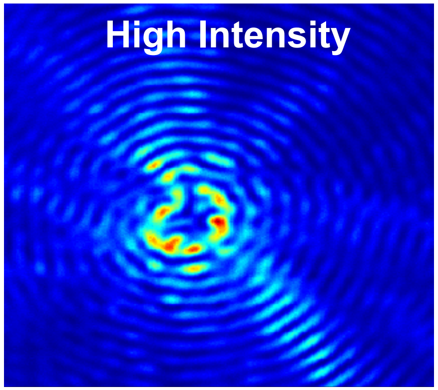


Gas sources are difficult to ionize and self-phase modulation effects the laser profile.

Action Items:

- Investigate peak intensity compatible with transmitting focusing optic (UCLA, CU Boulder)
- Develop reflective high-order Bessel optics





Interferometry with Hollow Channels

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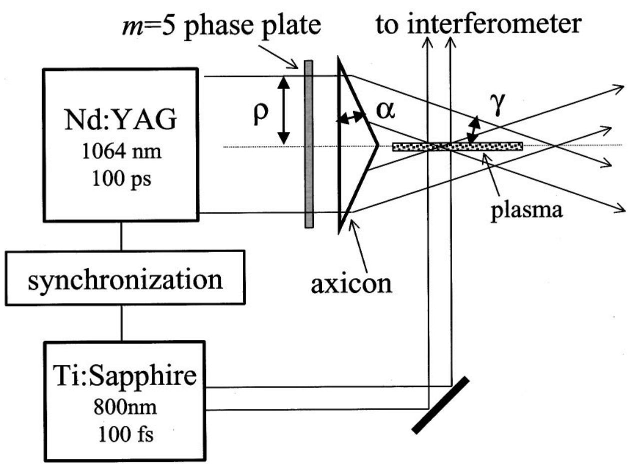
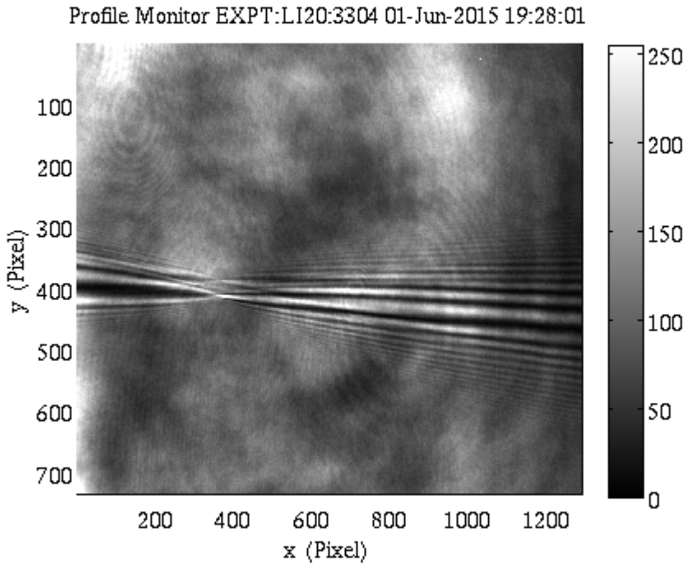
Beam-based measurements of plasma shape are limited:

- Convolves beam shape with channel shape
- Requires O(1000) shots to reconstruct channel shape

Interferometric measurements can reconstruct plasma channel shape on a shot by shot basis.



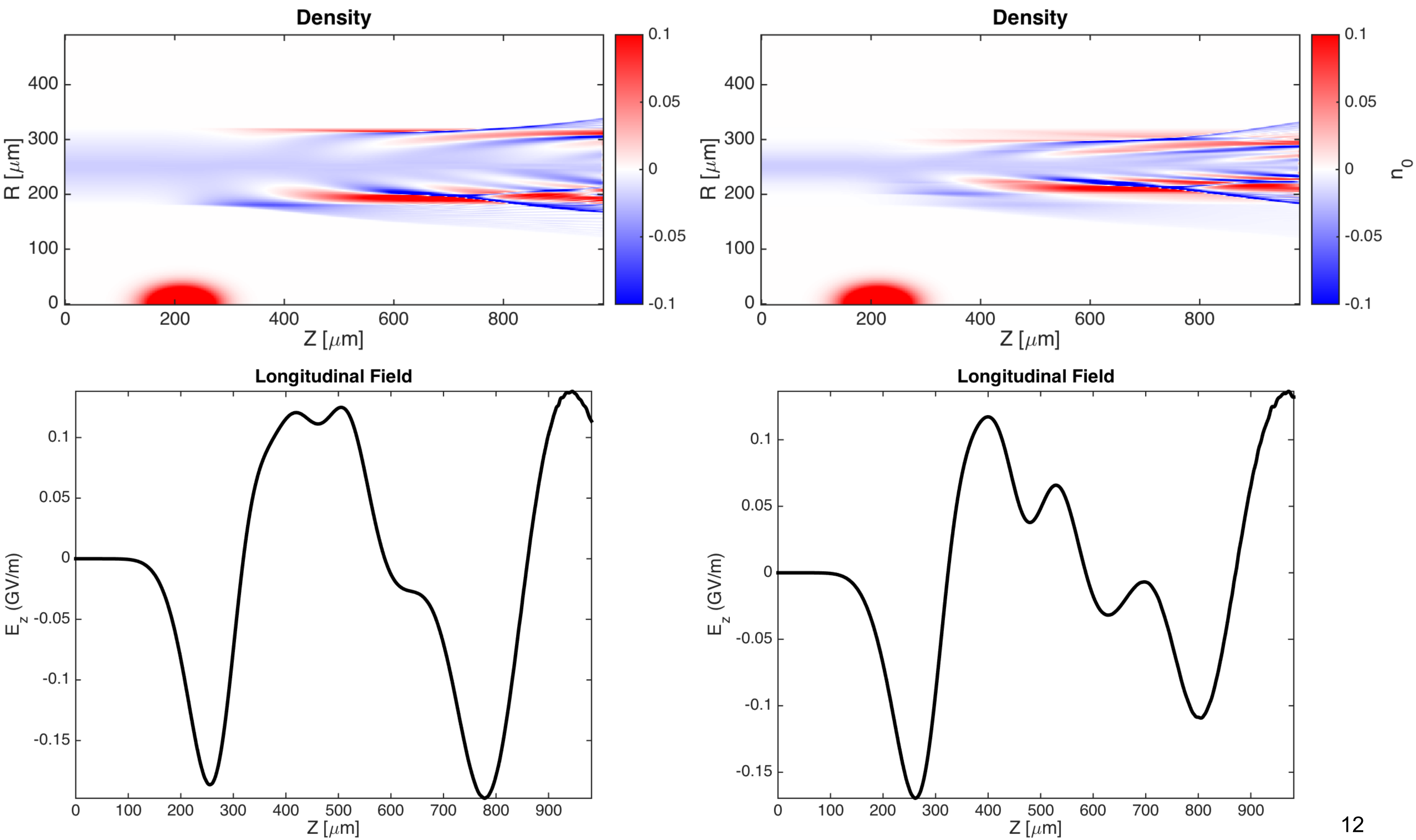
J. Fan, et. al. PRE 2000



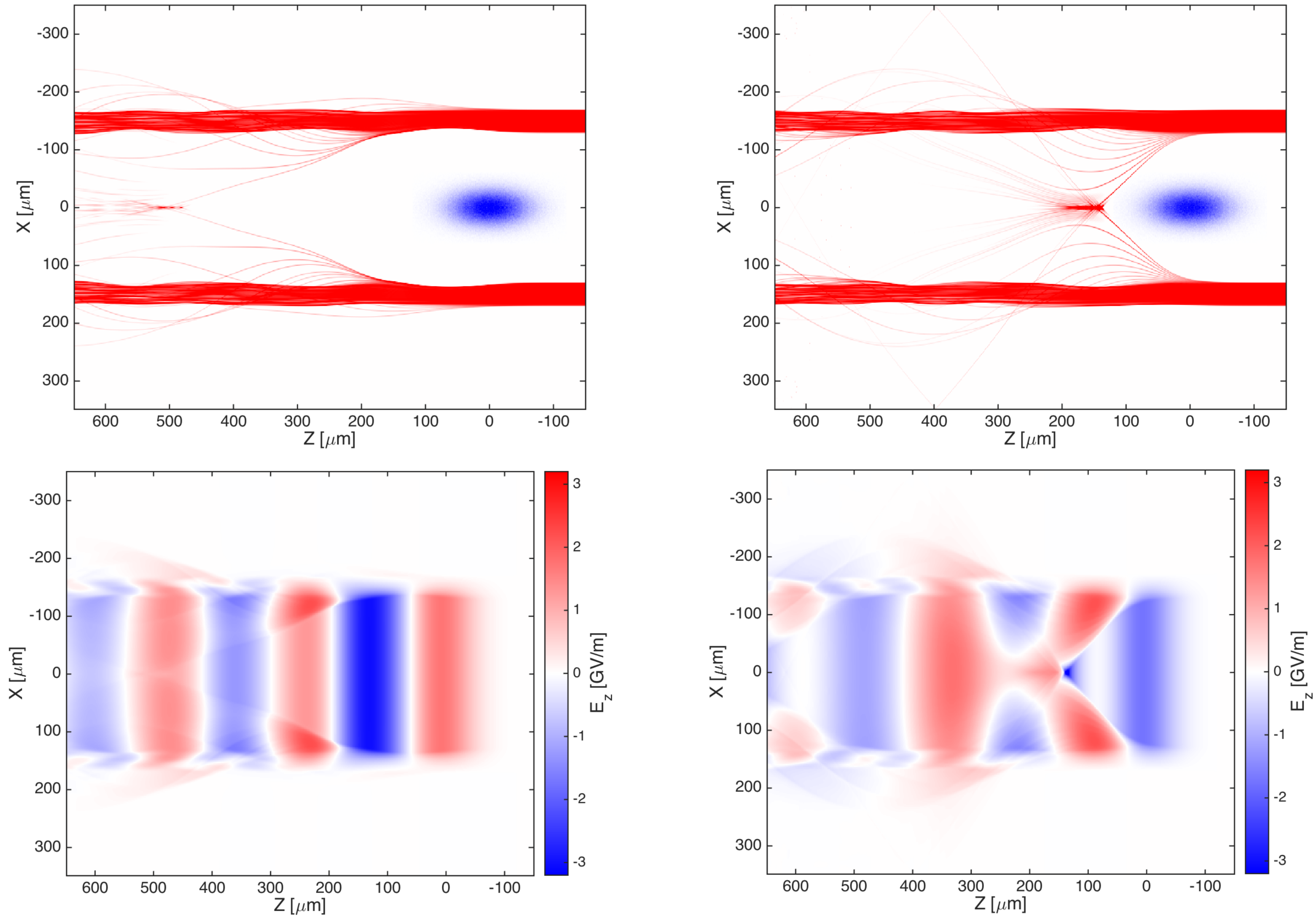
Action Items:

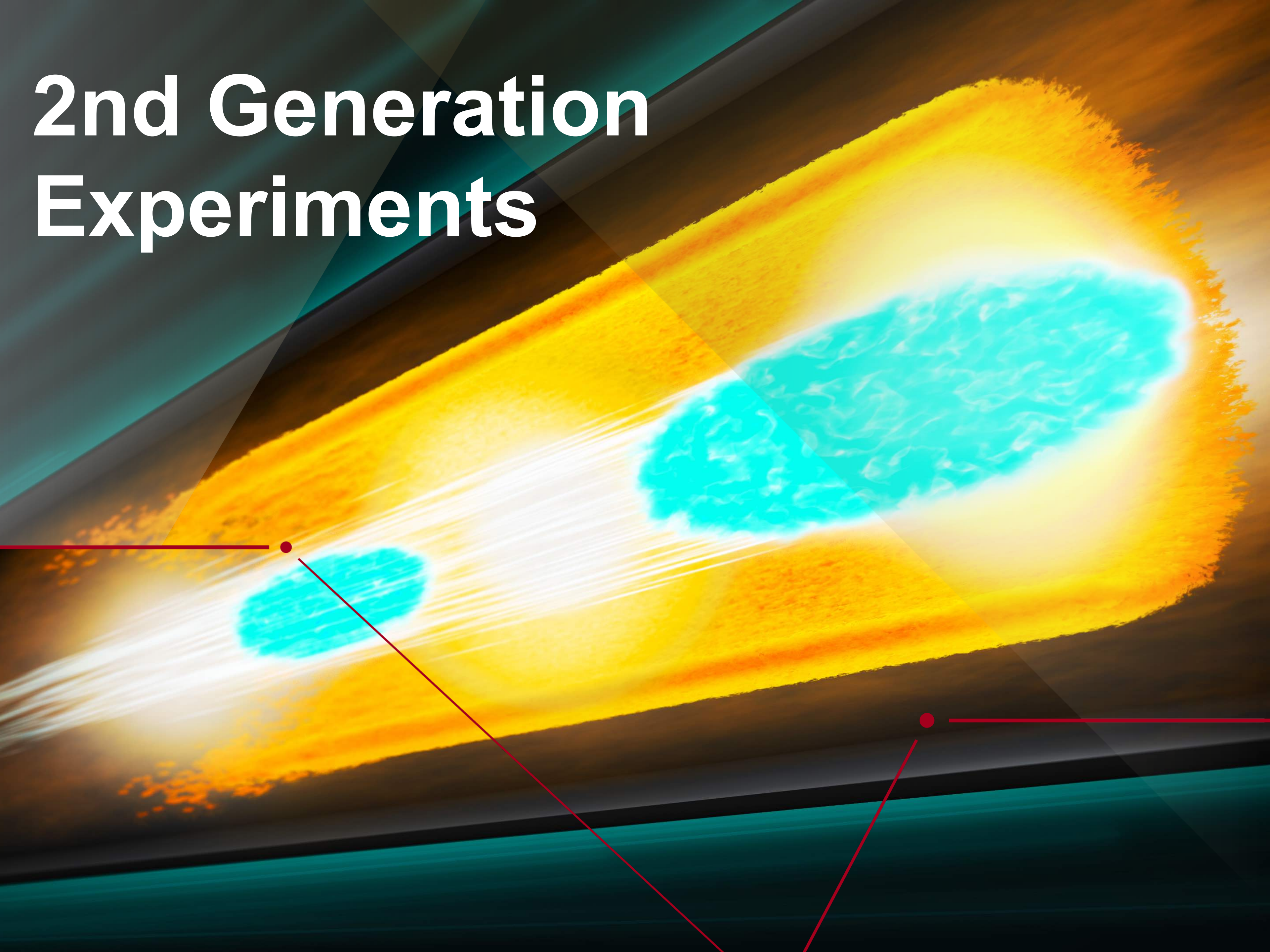
- Demonstrate channel shape measurements with interferometry prior to implementation at FACET-II (UCLA, UT Austin, UC Boulder)

Exploration of Different Channel Shapes



Exploration of the Non-Linear Regime




2nd Generation Experiments

How do you form a True Hollow Channel Plasma?

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Laser ablation of a capillary:

APPLIED PHYSICS LETTERS **95**, 031101 (2009)

A plasma microlens for ultrashort high power lasers

Yiftach Katzir,[1,a)] Shmuel Eisenmann,[1] Yair Ferber,[1] Arie Zigler,[1] and Richard F. Hubbard[2]
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(Received 26 April 2009; accepted 1 July 2009; published online 20 July 2009)

We present a technique for generation of miniature plasma lens system that can be used for focusing and collimating a high intensity femtosecond laser pulse. The plasma lens was created by a nanosecond laser, which ablated a capillary entrance. The spatial configuration of the ablated plasma focused a high intensity femtosecond laser pulse. This configuration offers versatility in the plasma lens small *f*-number for extremely tight focusing of high power lasers with no damage threshold restrictions of regular optical components. © *2009 American Institute of Physics*.
[DOI: 10.1063/1.3184788]

Acoustic modulation of a gas:

APPLIED PHYSICS LETTERS VOLUME 73, NUMBER 20 16 NC

Guiding characteristics of an acoustic standing wave in a piezoelectric tube

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(Received 26 May 1998; accepted for publication 15 September 1998)

Propagation of an He–Ne laser beam through a gas filled piezoelectric tube is used to characterize the guiding properties of a radially driven acoustic standing wave. Impedance matched driving at 1 MHz of the 5-cm-long piezotube yields radial density perturbations of 0.005 at 40 V driving voltage. The frequency spectrum of the cavity resonances is used to measure the damping of the standing wave due to shear viscosity in Ar. © *1998 American Institute of Physics.*

ARTICLES
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nature physics

Time reversal and holography with spacetime transformations

Vincent Bacot[1], Matthieu Labousse[1,2†], Antonin Eddi[3], Mathias Fink[1*‡] and Emmanuel Fort[1*‡]

Wave control is usually performed by spatially engineering the properties of a medium. Because time and space play similar roles in wave propagation, manipulating time boundaries provides a complementary approach. Here, we experimentally demonstrate the relevance of this concept by introducing instantaneous time mirrors. We show with water waves that a sudden change of the effective gravity generates time-reversed waves that refocus at the source. We generalize this concept for all

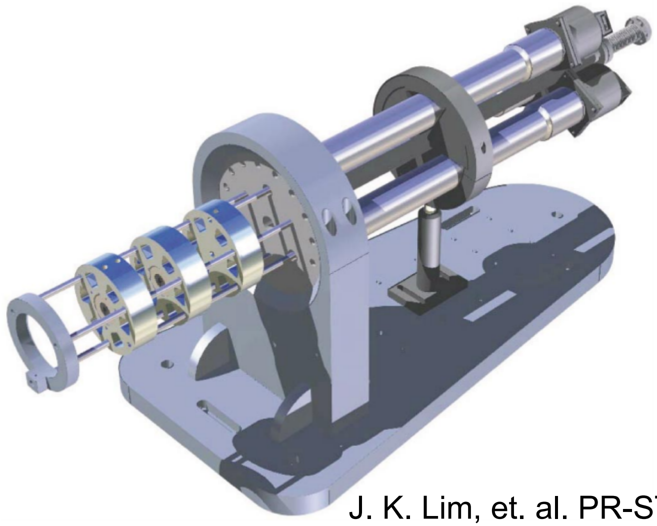
Action Item:

- We need to search for a solution by looking in fields not directly related to PWFA.

How do you suppress the BBU?

The growth length of the BBU is a few cm for FACET and FACET-II parameters.

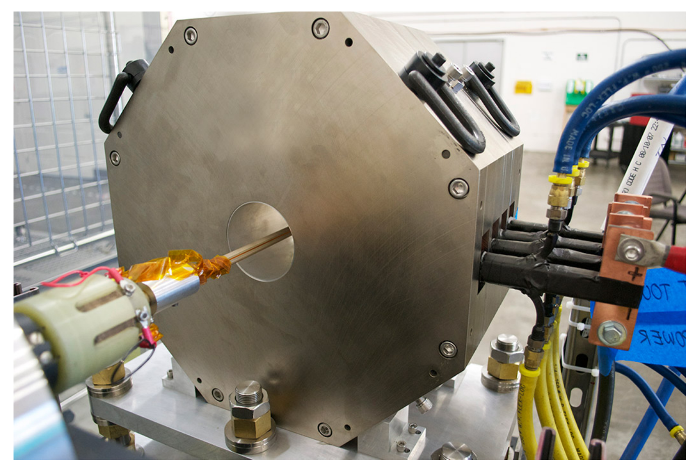
An external focusing lattice requires a comparable betatron wavelength.



J. K. Lim, et. al. PR-STAB 2005

Action Items:

- Develop theory of hollow channel wakefield in strong external fields.
- Investigate if strong PMQ triplets or solenoids can be used in conjunction with the hollow channel plasma.



RadiaBeam

Conclusion

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FACET was the only facility in the world which could provide a positron beam, high power laser, and plasma source. All of these components were needed to successfully demonstrate the acceleration of positrons in a hollow channel plasma.

FACET-II provides these same tools and more.

We may need to look outside the accelerator physics community to solve the problem of generating a truly hollow channel plasma.