North American Particle Accelerator Conference 2022

Characterization of the Fields Inside the CO_2-Laser-Driven Wakefield Accelerators Using Relativistic Electron Beams

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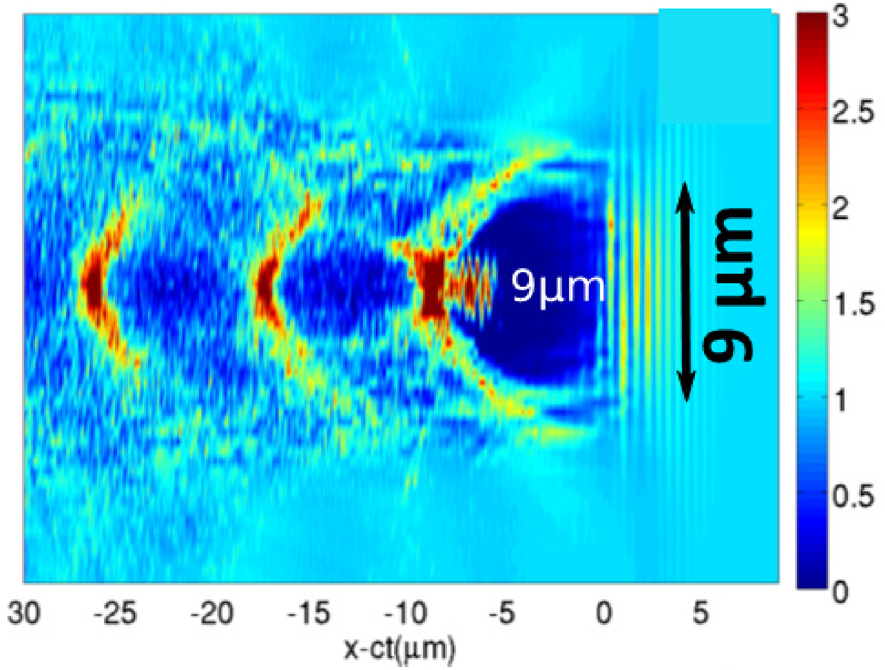
Motivation & Introduction:

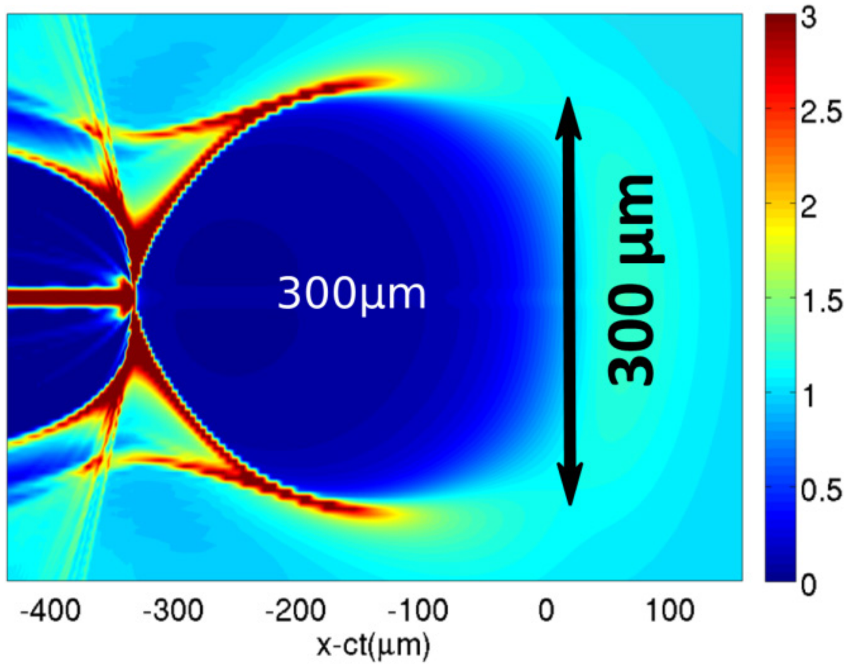
Mid-IR CO_2 laser at Accelerator Test Facility (ATF) at Brookhaven National Laboratory (BNL)

2 ps pulses, up to 5 J energy, **wavelength ~10 um**

λ_{drive}= 0.8 um, 25 TW, 30 fs
n_e = 2e19 cm^{-3}



λ_{drive}= 10 um, 25 TW, 500 fs
n_e = 1e16 cm^{-3}



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Precise and controllable external injection!

Motivation & Introduction:

Reliable diagnostic tools are required!

Diagnostic tools are needed to **characterize the fields** inside such structures and to **improve the means of external injection**.

How is LWFA diagnostic usually done (general idea)?

- Use **optical methods**—lasers.
- These methods **rely on the index of refraction** of your plasma.
- **Optical methods** have been **extensively studied** and have **successfully demonstrated** the ability to capture **shadowgraphs** of the plasma wakes.
- **BUT: will not work well at low plasma densities.**

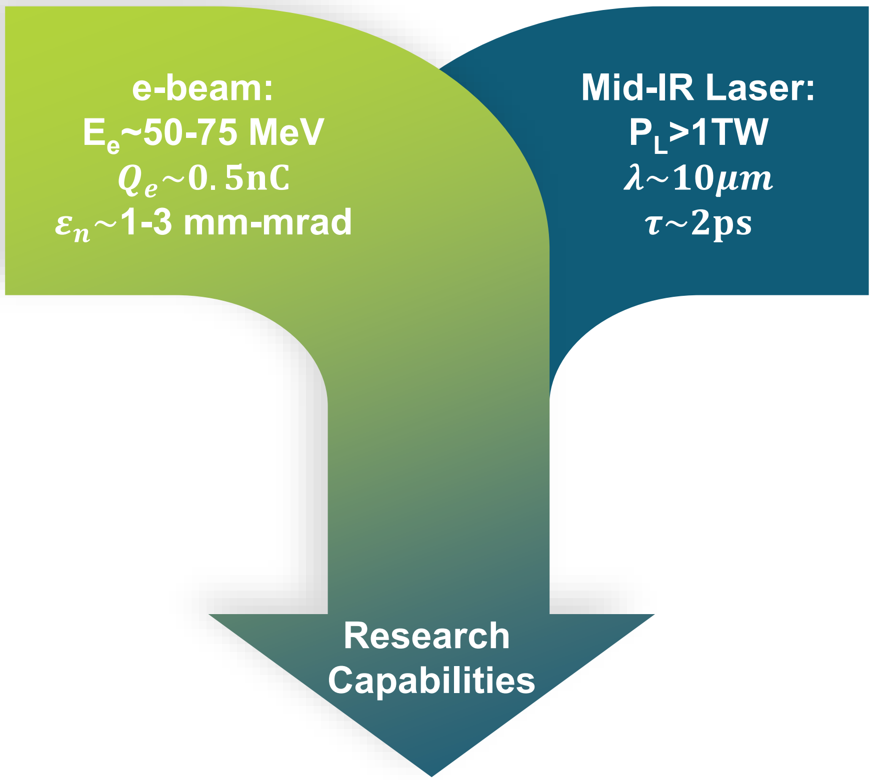
Motivation & Introduction:

CO_2 laser & electron beam capabilities at ATF

Mid-IR Laser:
P_L>1TW
$\lambda \sim 10\mu m$
$\tau \sim 2ps$

Motivation & Introduction:

CO_2 laser & electron beam capabilities at ATF*



1. **Studies of long-pulse laser-plasma interactions in nonlinear regime**
2. **High-resolution density and field probing of LWFA**
3. **External injection in the blowout regime LWFAs**

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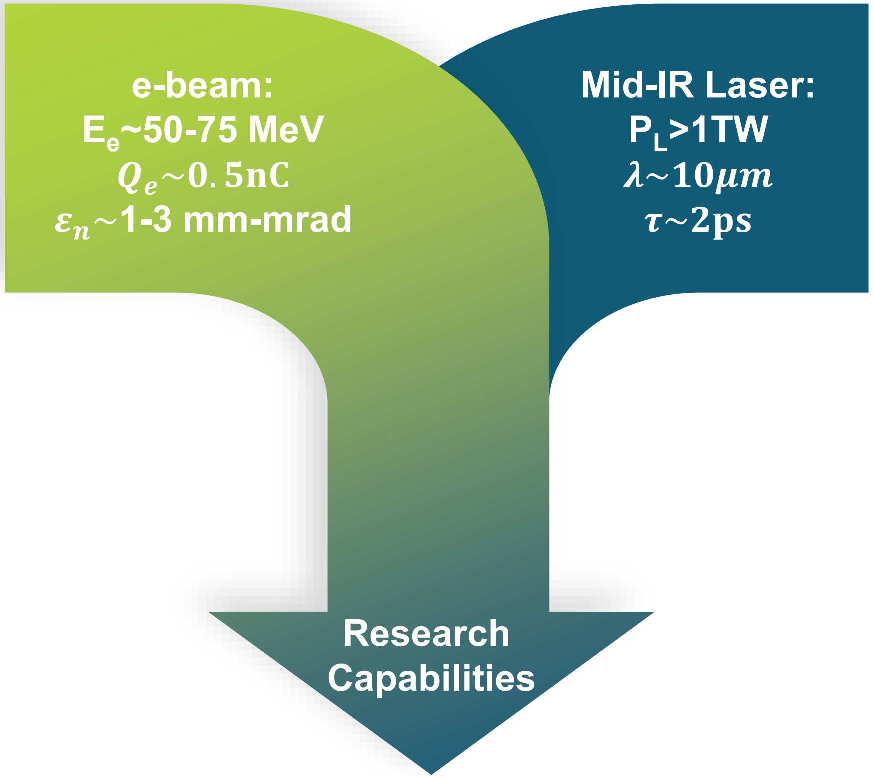
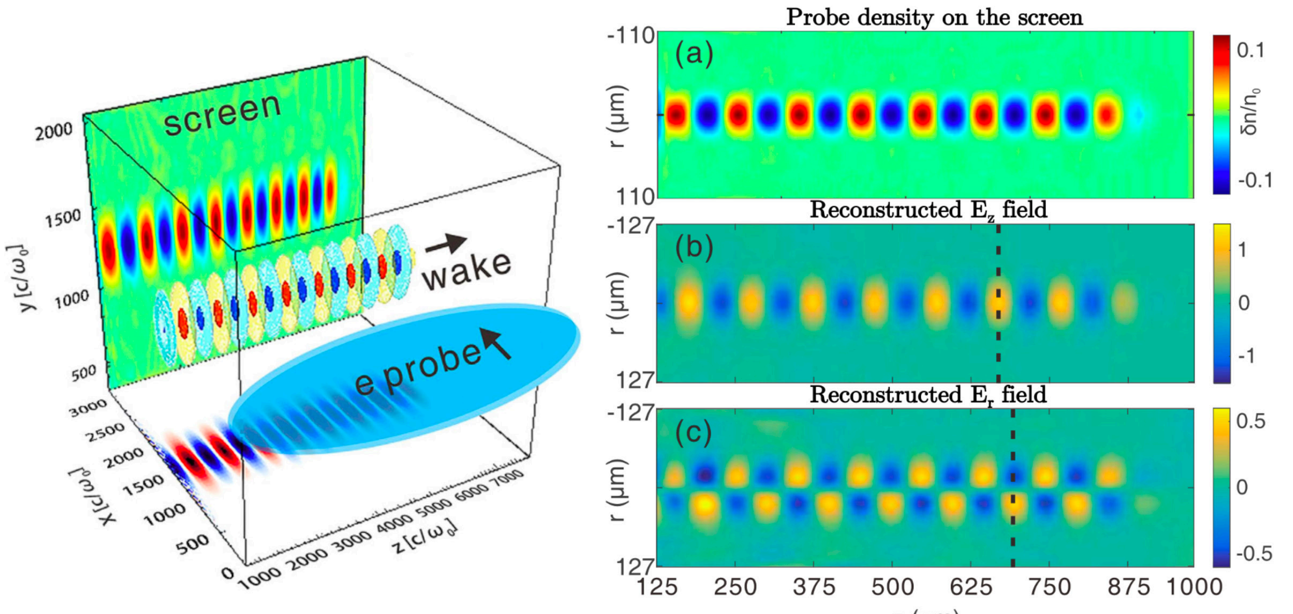
*See talk by M. Palmer (BNL) **MOZE6**

Motivation & Introduction:

CO_2 laser & electron beam capabilities at ATF*





C.J. Zhang et al., Scientific Reports 6:29485 | DOI: 10.1038/srep29485

1. Studies of long-pulse laser-plasma interactions in nonlinear regime
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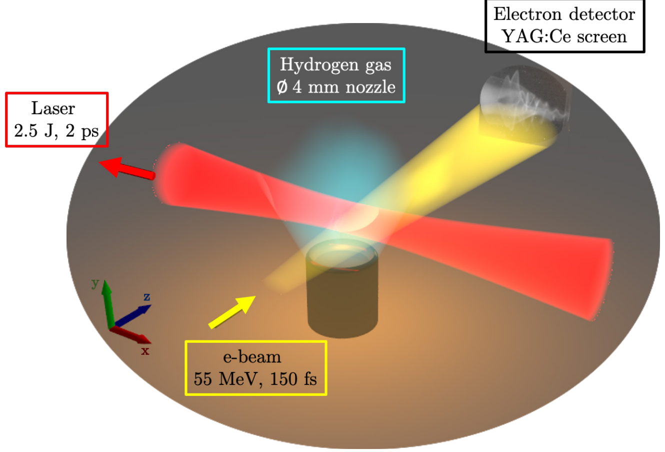
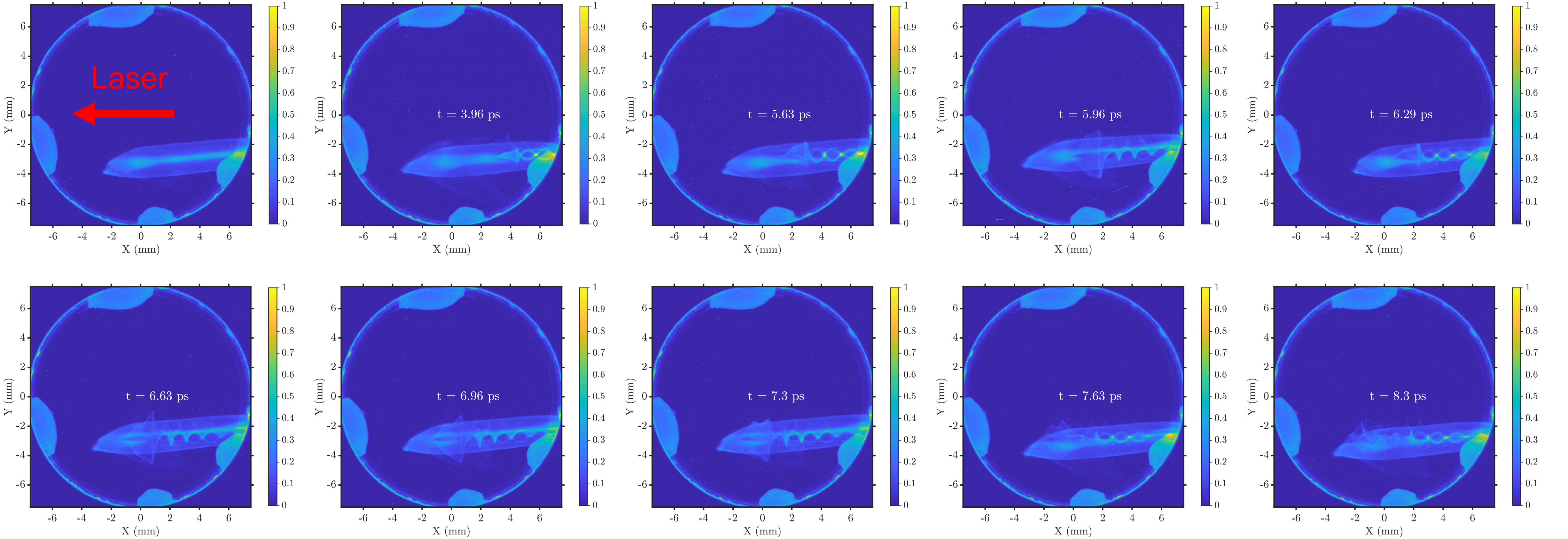
New diagnostic: electron beam probing



Results:

1. obtained images in low-density regime ~1e15 cm^{-3}.
2. obtained time-evolution of the wake by varying the delay between the laser and e-beam



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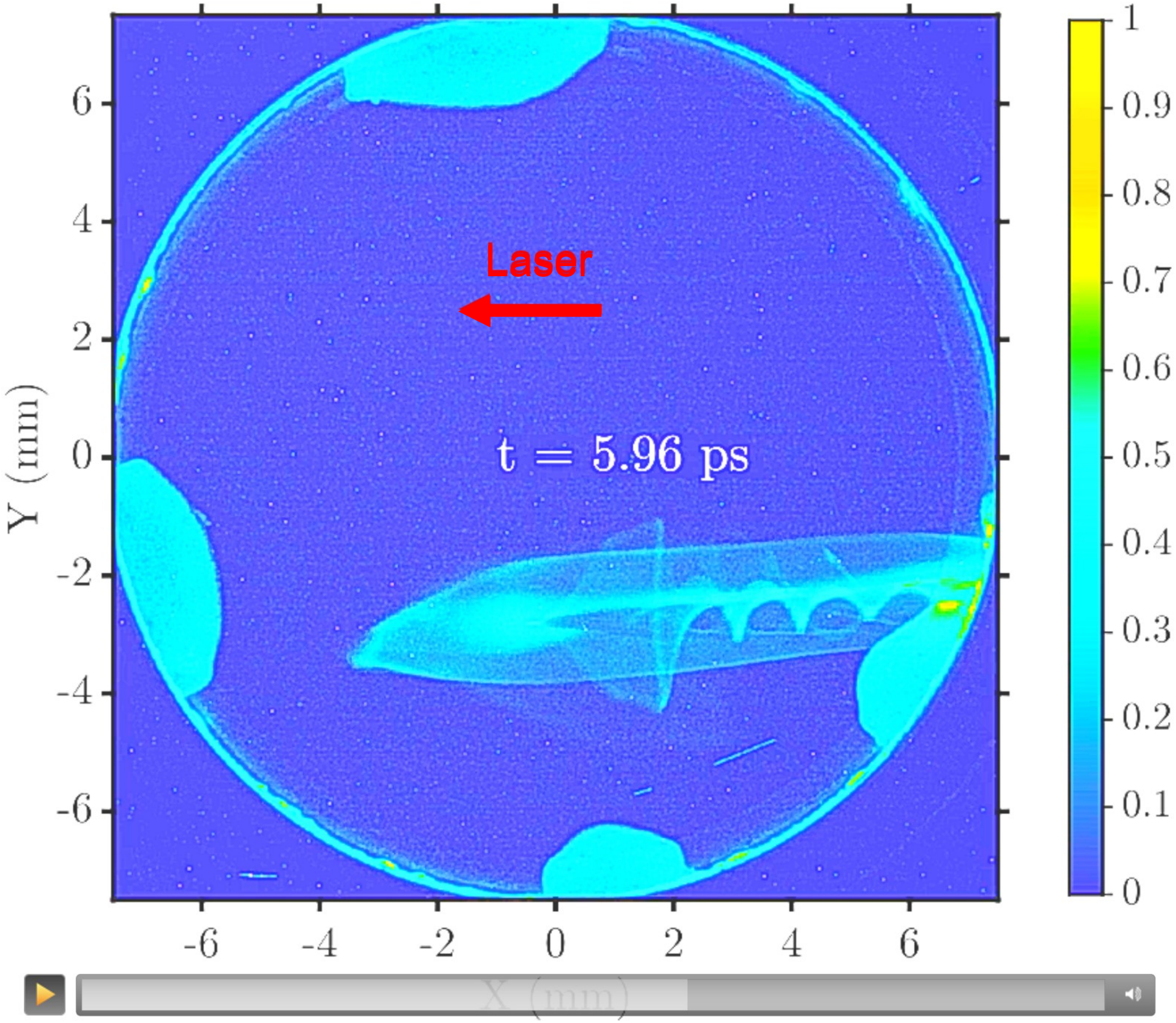
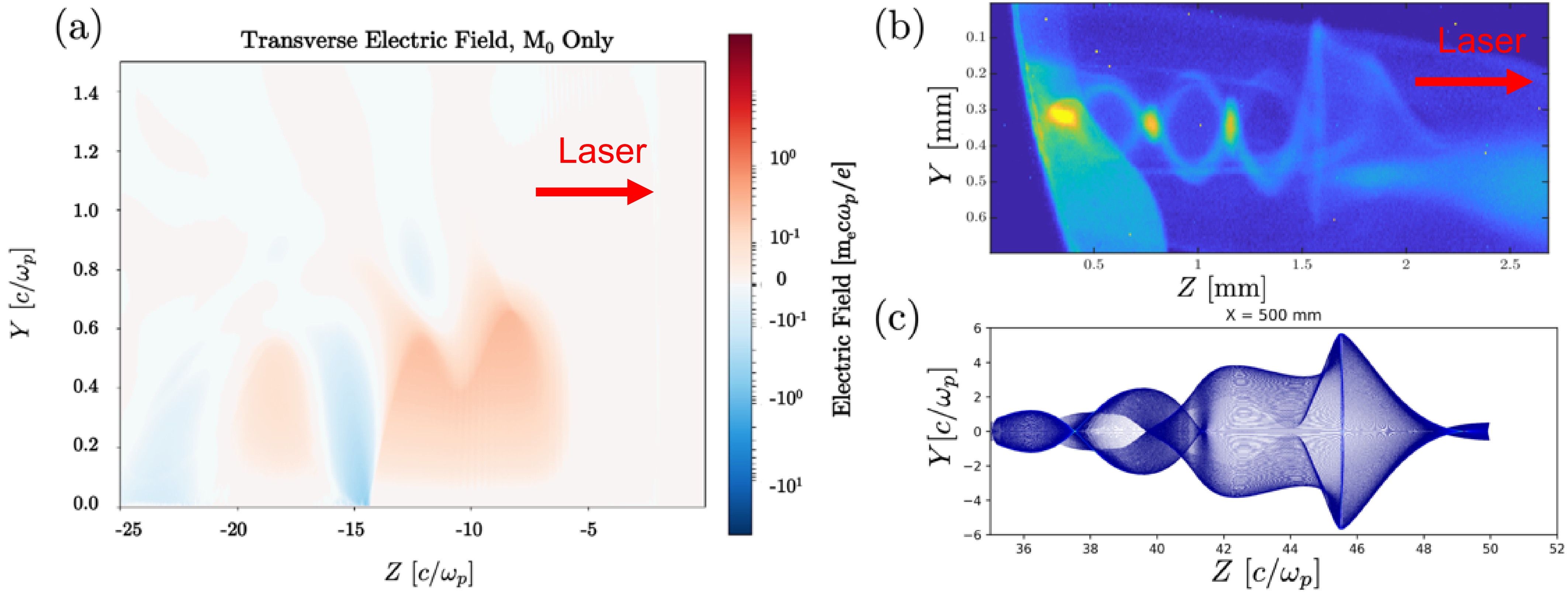
New diagnostic: electron beam probing



Demonstrated great performance experimentally

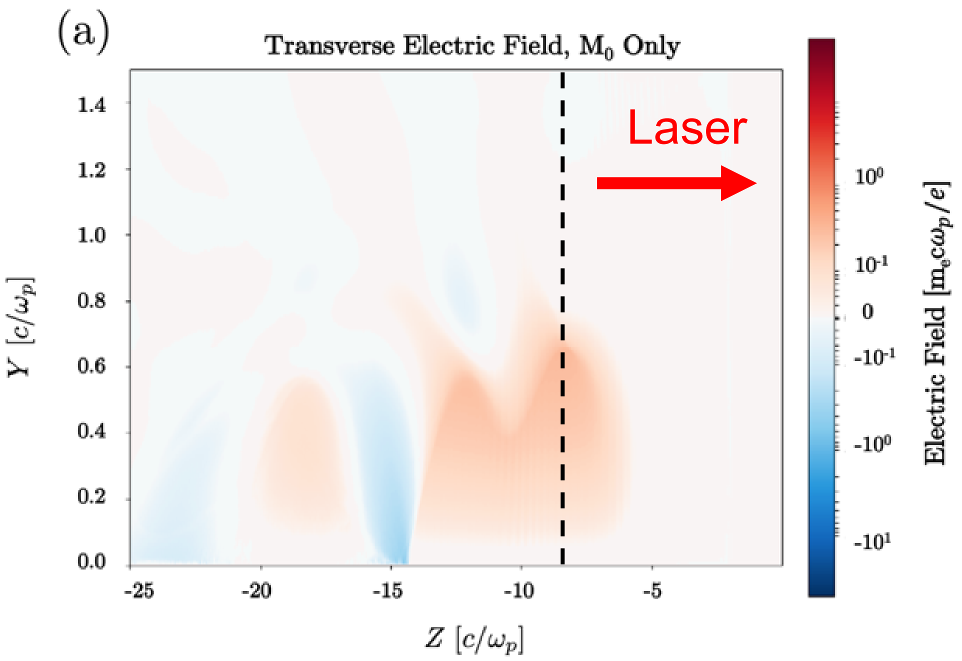
Interpreting the results: simulations vs experiment

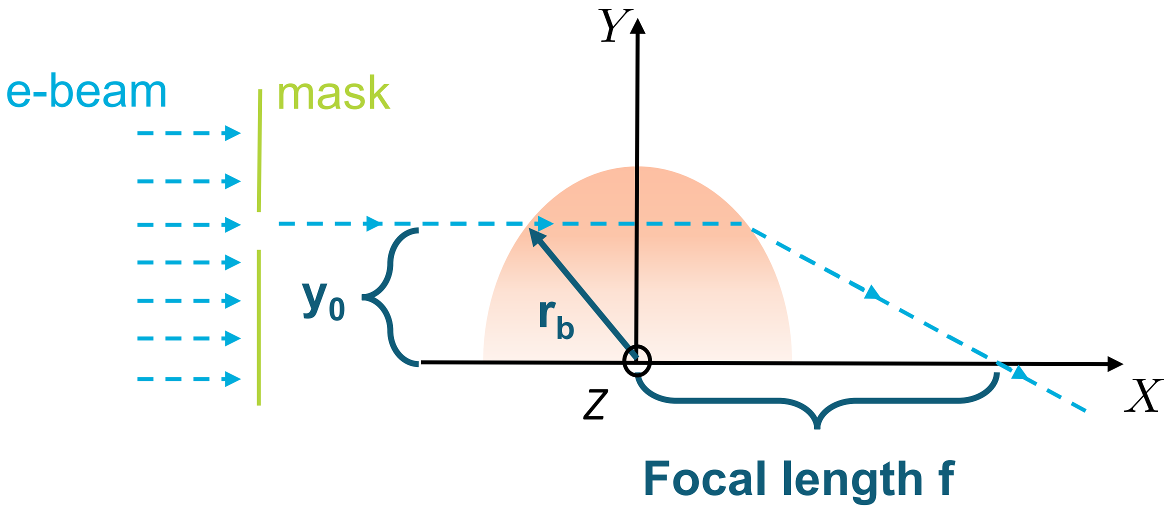


(a) Transverse electric field distribution of the excited wake obtained using OSIRIS;
(b) Experimentally captured image of the e-beam passing through an excited wake ~5.6 ps after the CO_2 has entered the region of interest;
(c) e-beam probe simulation results obtained 50 cm away from the interaction point.

M. Petrusky, "PICTURING PLASMA: STUDYING THE SIMULATED TRANSVERSE PROBING OF LASER WAKEFIELD ACCELERATORS"

Future plans: radial field characterization





Linear focusing force in a bubble: $F_r = kr$ (wakefield theory suggests $k \approx 0.5$)

$$f \approx \underbrace{\frac{pc}{2F_\perp^{max}}}_{\text{Focal length}} \underbrace{\left(1 - \left(\frac{y_0}{r_b}\right)^2\right)^{-1/2}}_{\text{Depth of field}}, \text{ where } F_\perp^{max} = kr_b$$

Focal length **Depth of field**

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If we can measure the focal length, we can characterize the field inside the bubble.

Summary:

- Direct measurement of the wakefield using an electron beam as a probe has been proven to be effective.
- Interpretation of the results is not straightforward in the non-linear regime and requires supporting simulations.
- By using a thin-lens approximation and selectively illuminating different sections of the wake at low densities, we are aiming to measure the focal length due to the wake and map the radial fields of the wake.

Thank you for listening!

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