Positron Acceleration in a Narrow Plasma Column: Concept and Initial Results of Electron Beam Guiding

AAC

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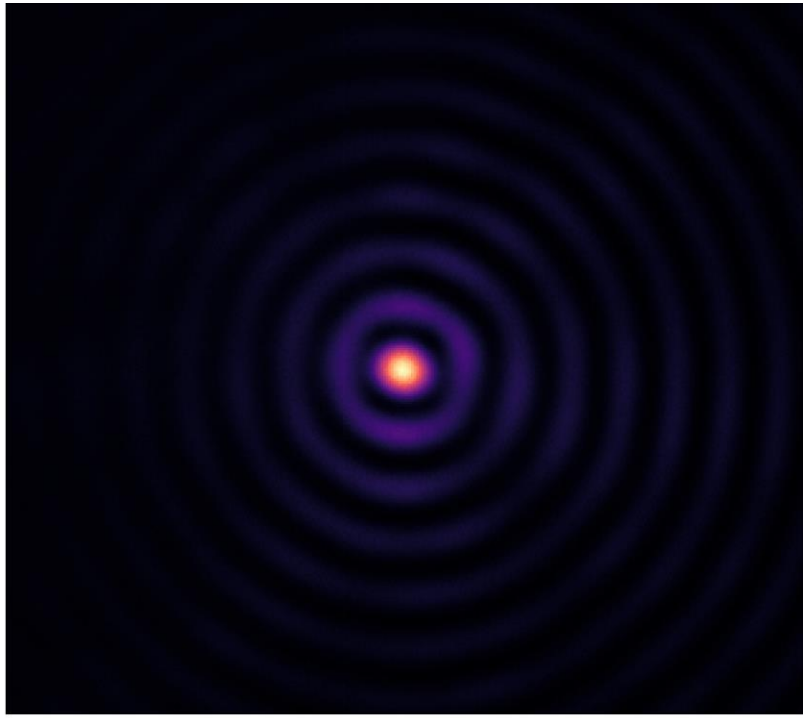
BELLA

Outline

- **Positron Acceleration in a PWFA**
  - Challenges
  - Proposed scheme – narrow plasma column
- **Narrow Plasma PWFA**
  - Transverse field – beam guiding
  - Longitudinal field – reduced strength
- **Experiment**
  - FACET-II
  - E333 experiment set up and execution
- **Experimental Evidence**
  - Beam guiding
  - Reduction in energy loss



We present the concept of the narrow column PWFA and initial results of electron beam guiding.

Positron Acceleration in a PWFA — Challenges

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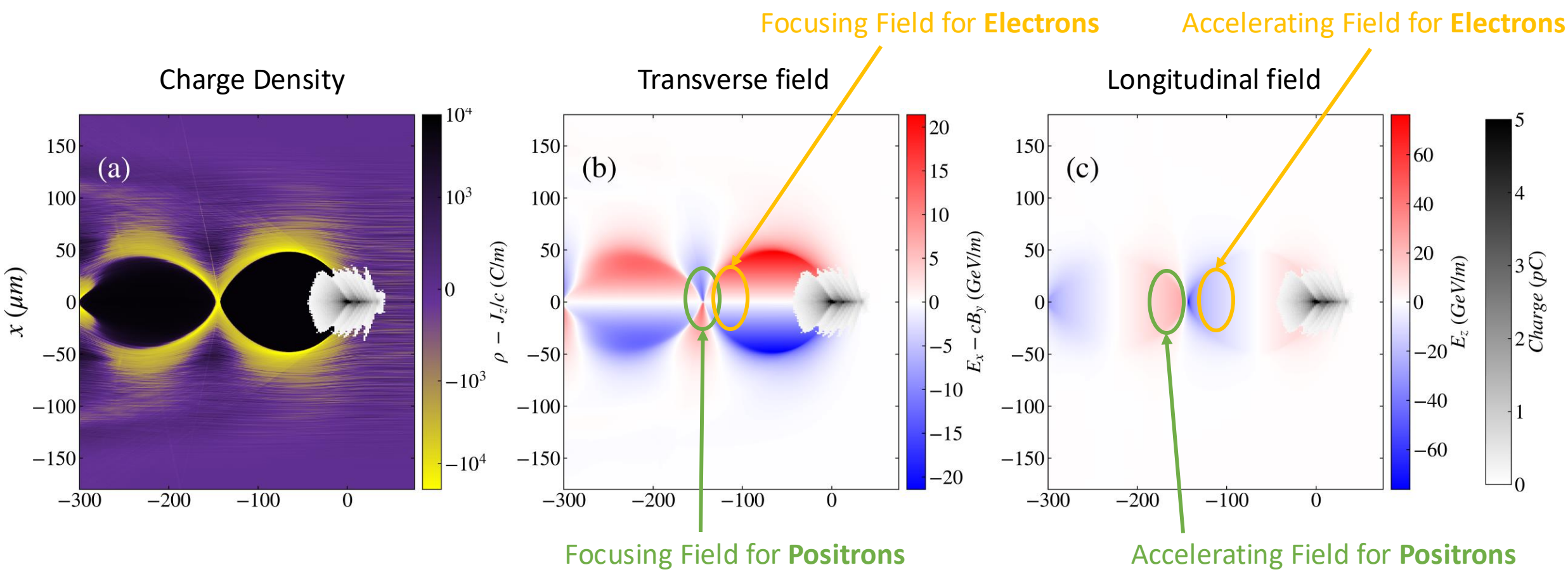

Transverse focusing is a major challenge that must be solved to realize positron PWFA.

Narrow Plasma Column PWFA

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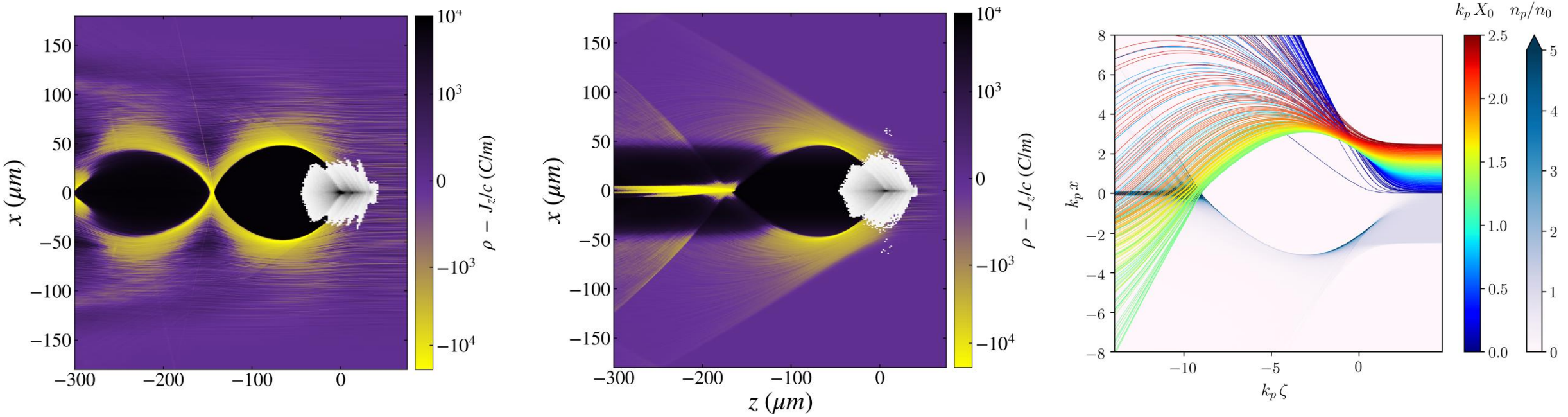

Sheath electrons return to different longitudinal positions depending on their initial transverse position.

S. Diederichs, C. Benedetti, E. Esarey, J. Osterhoff, and C. B. Schroeder, "High-quality positron acceleration in beam-driven plasma accelerators," *Physical Review Accelerators and Beams*, vol. 23, no. 12, 2020.

Positron Acceleration — Narrow Plasma Column

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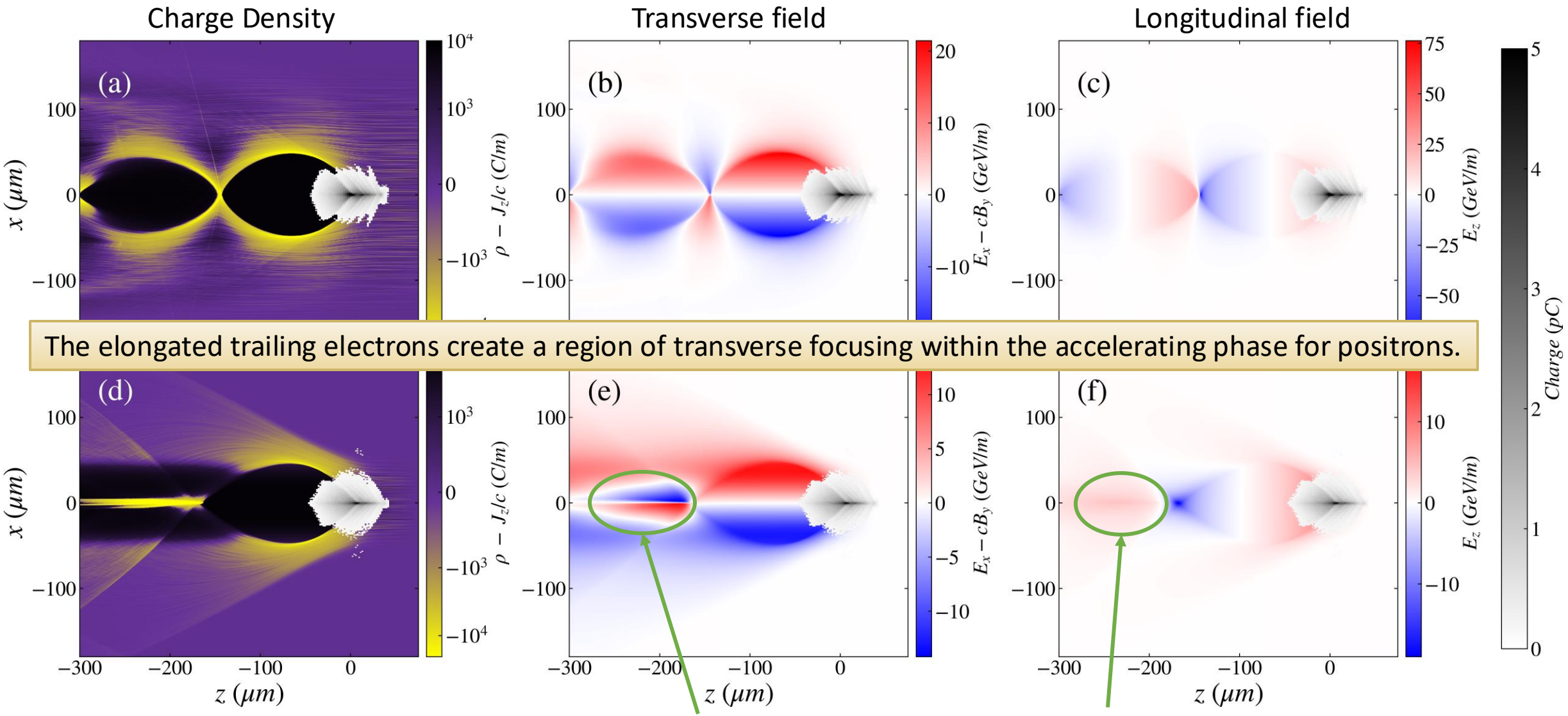
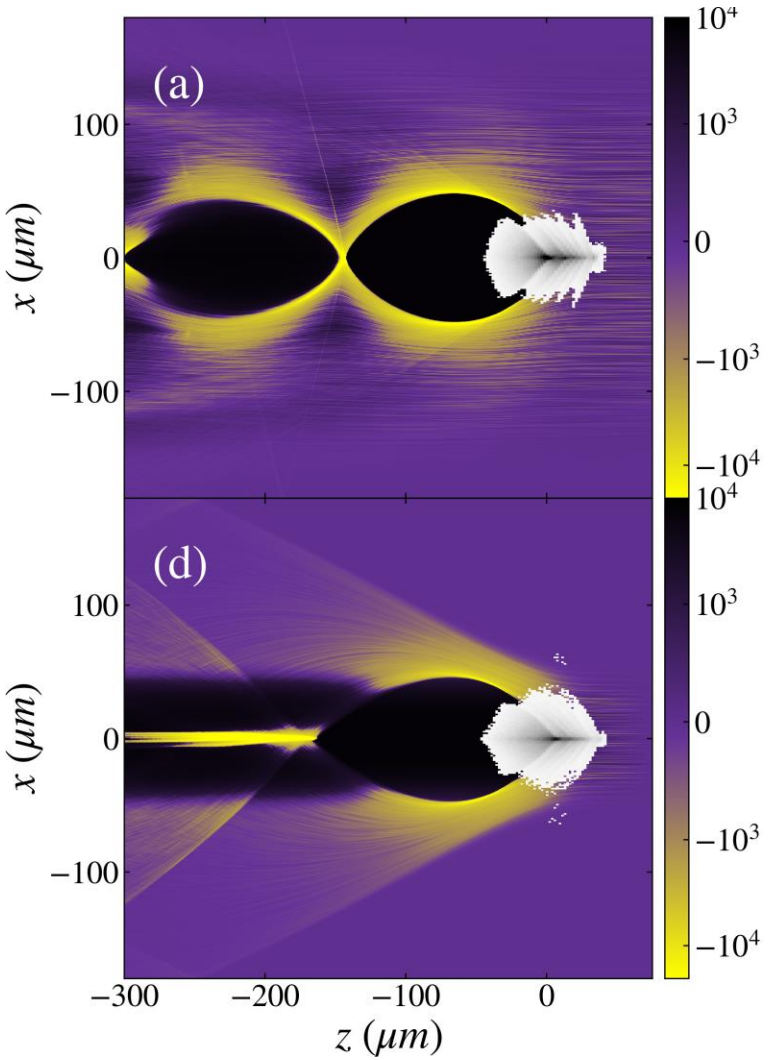


The elongated trailing electrons create a region of transverse focusing within the accelerating phase for positrons.

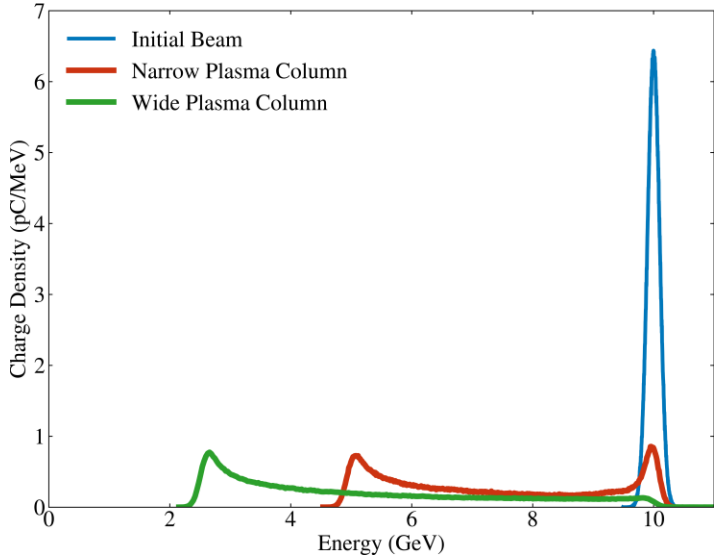
Focusing Field for **Positrons**

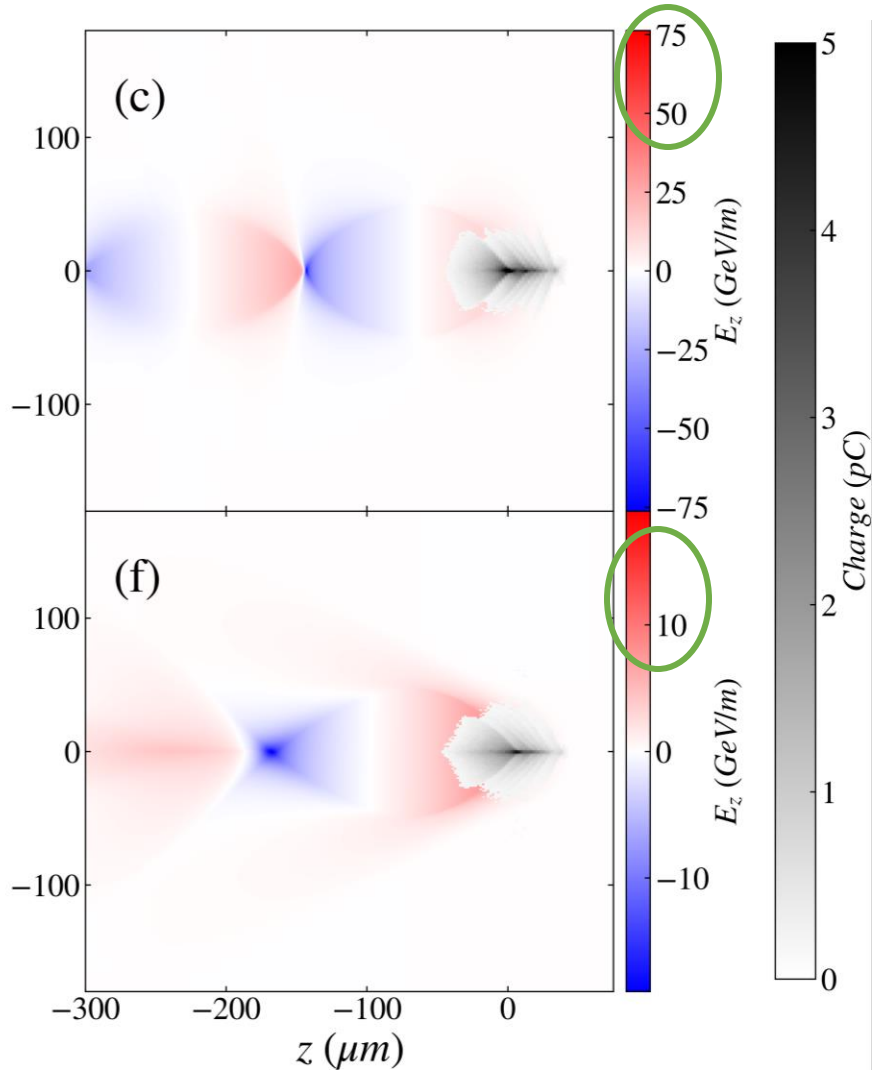
Accelerating Field for **Positrons**

Longitudinal Fields



- Less sheath electron current in the narrow column PWFA
- Weakened longitudinal field the narrow column PWFA





The reduction in energy loss in narrow column PWFA is a signature of being in the narrow column regime.

Misalignment to a Plasma Column

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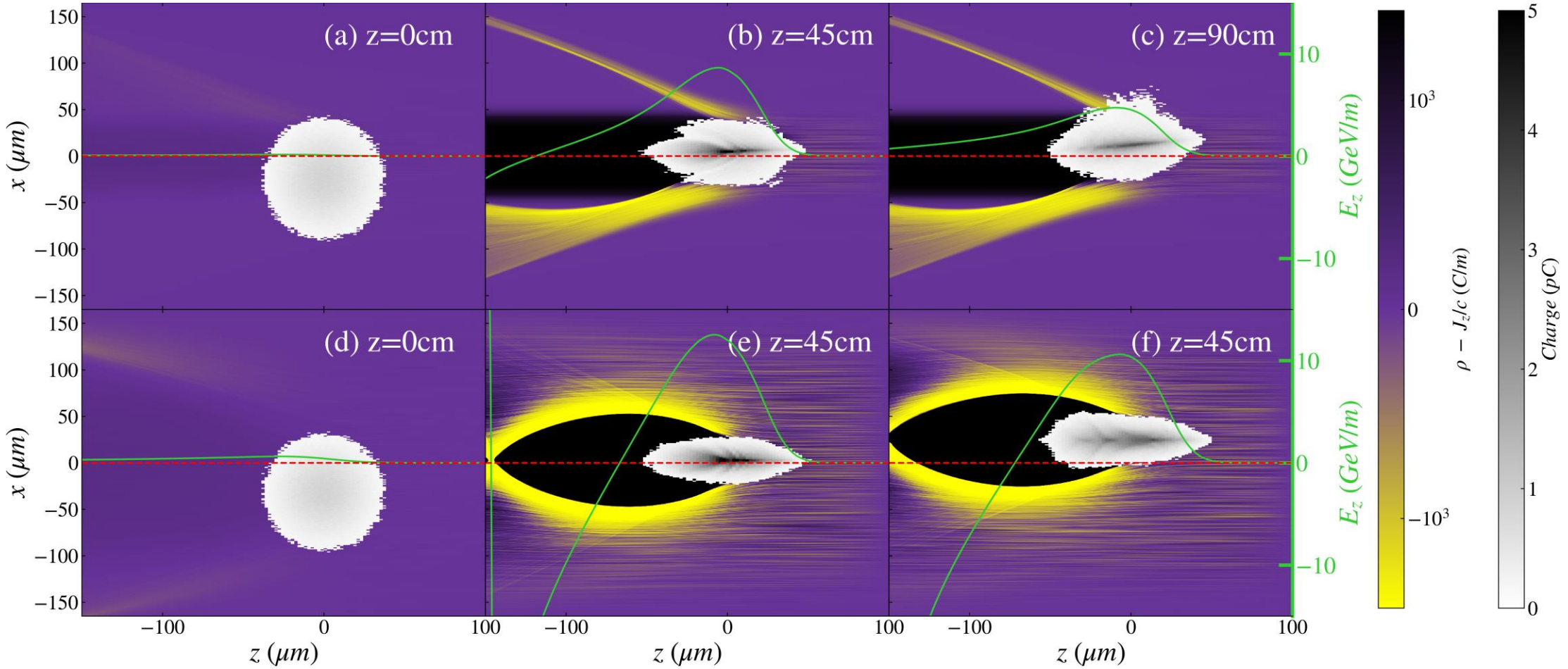
Misalignment: The beam's position or angle is offset/tilted relative to the column center.



Wide: Plasma effectively homogenous -> Not effect
Narrow: Inhomogenous -> Asymmetric wake

Asymmetric Transverse Force

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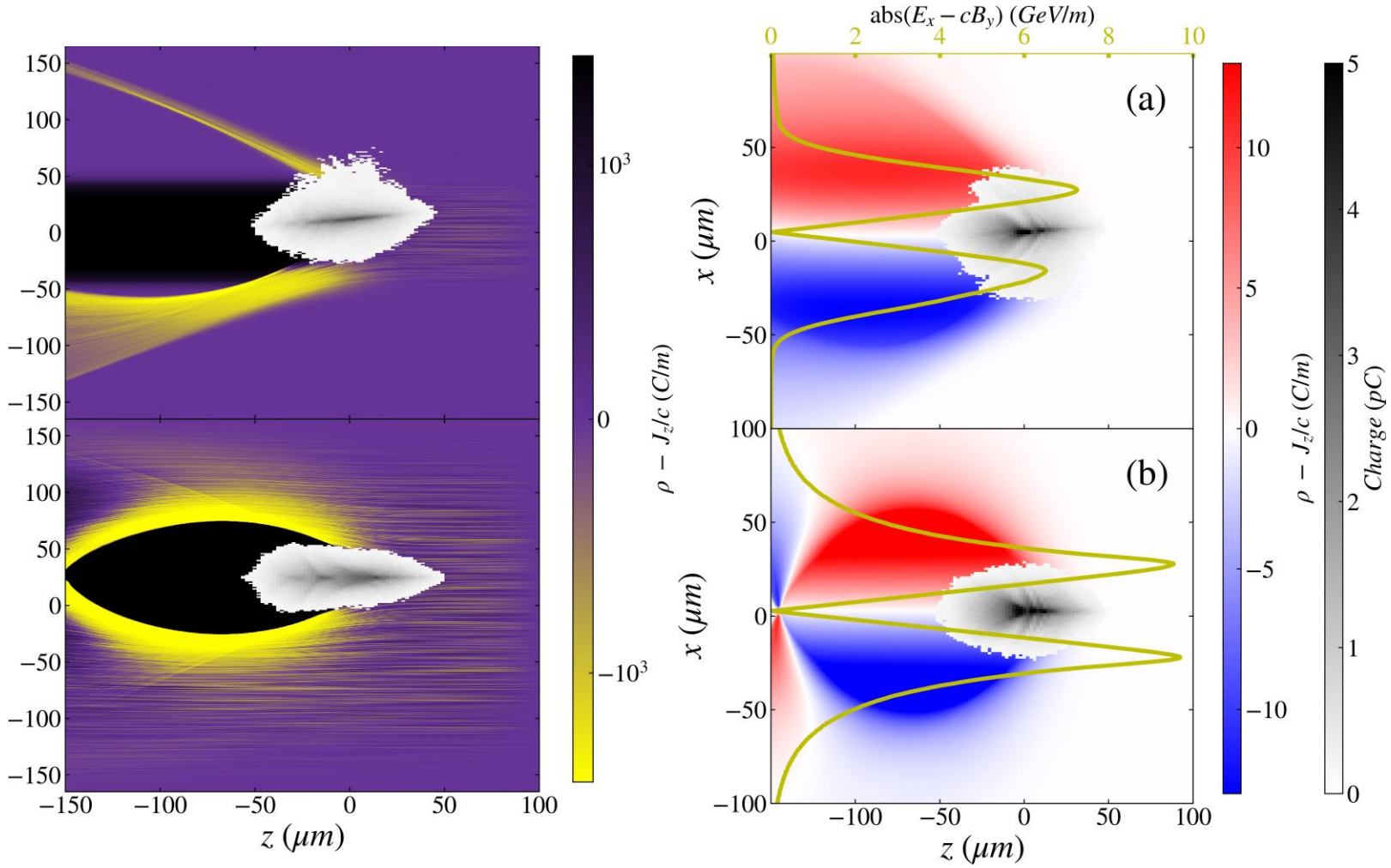
Asymmetric Sheath Electrons
The asymmetric sheath electrons in the narrow plasma column results in asymmetric transverse focusing force.

Asymmetric Transverse Force
The asymmetric transverse focusing force focuses the e-beam to the center of the column.



Asymmetric Wake -> Asymmetric Transverse Force -> Guiding to Channel

Electron Beam Guiding in a Narrow Plasma Column

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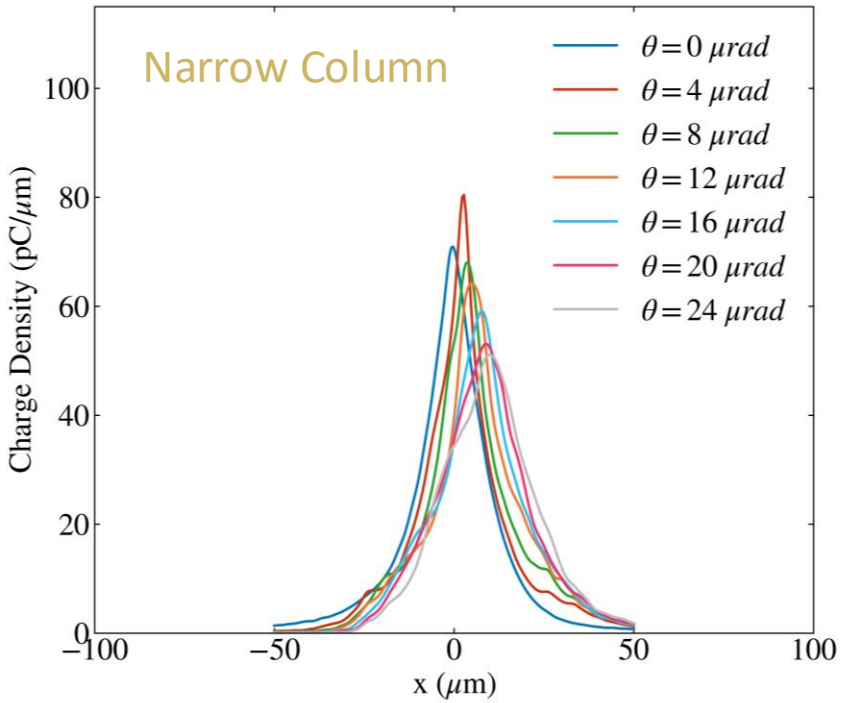
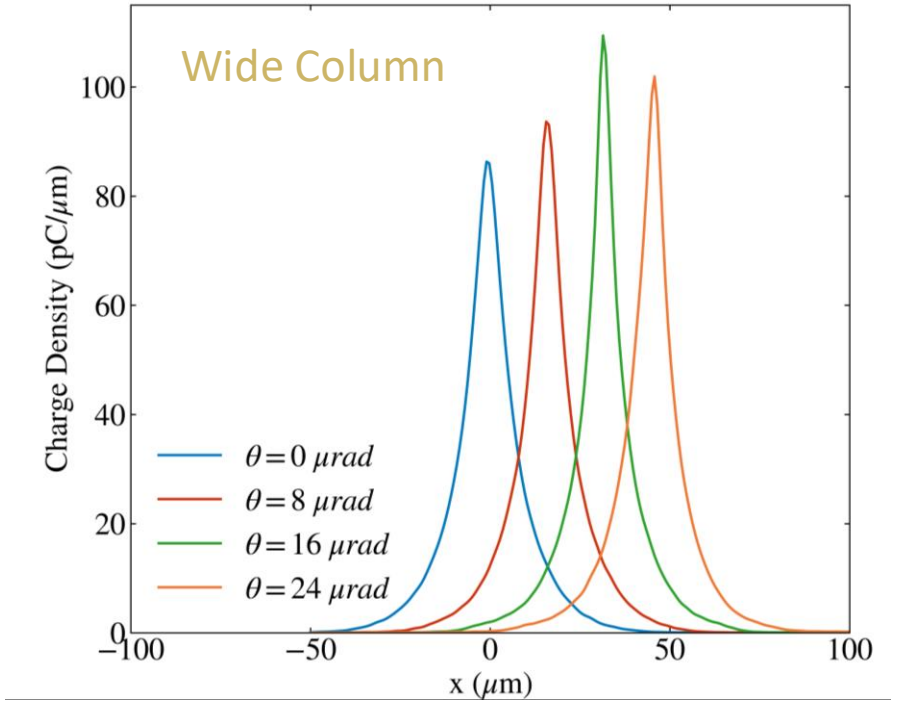
Simulations on Electron Beam Guiding

- We simulate misaligned electron beams traversing through 70 cm plasma in HiPACE++.
- Narrow plasma column -> Guiding
- Wide plasma column -> No Guiding





Electron beam guiding is a unique experimental observable to identify the narrow plasma PWFA.

FACET-II at SLAC National Accelerator Laboratory

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Current Beam Parameters:

Charge	Energy	$\varepsilon_{x,\,y}$	σ_ξ	σ_r	σ_δ
1.6 nC	10 GeV	15, 15 µm-rad	35 µm	35 µm	1%

FACET-II is built to deliver high-energy, high-quality electron beams.

The E333 Experiment at FACET-II

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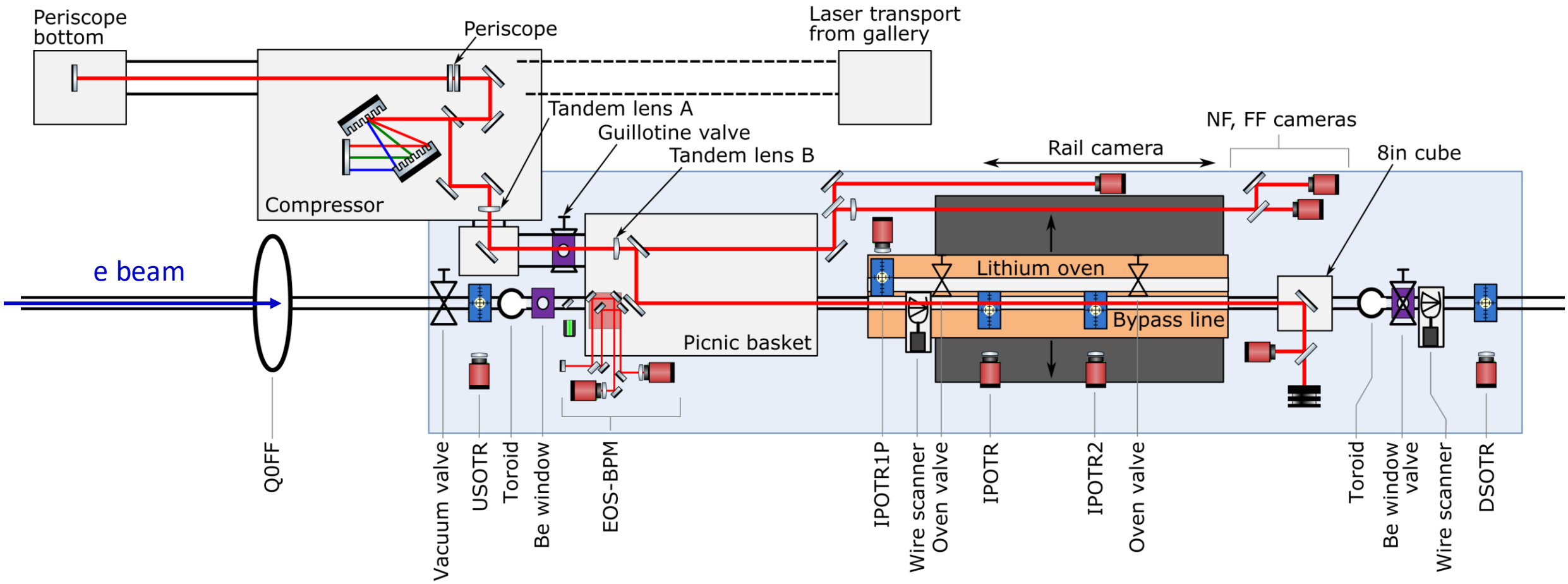

Laser ionized plasma source offers the ability to shape the transverse and longitudinal density profile.

The E333 Experiment at FACET-II

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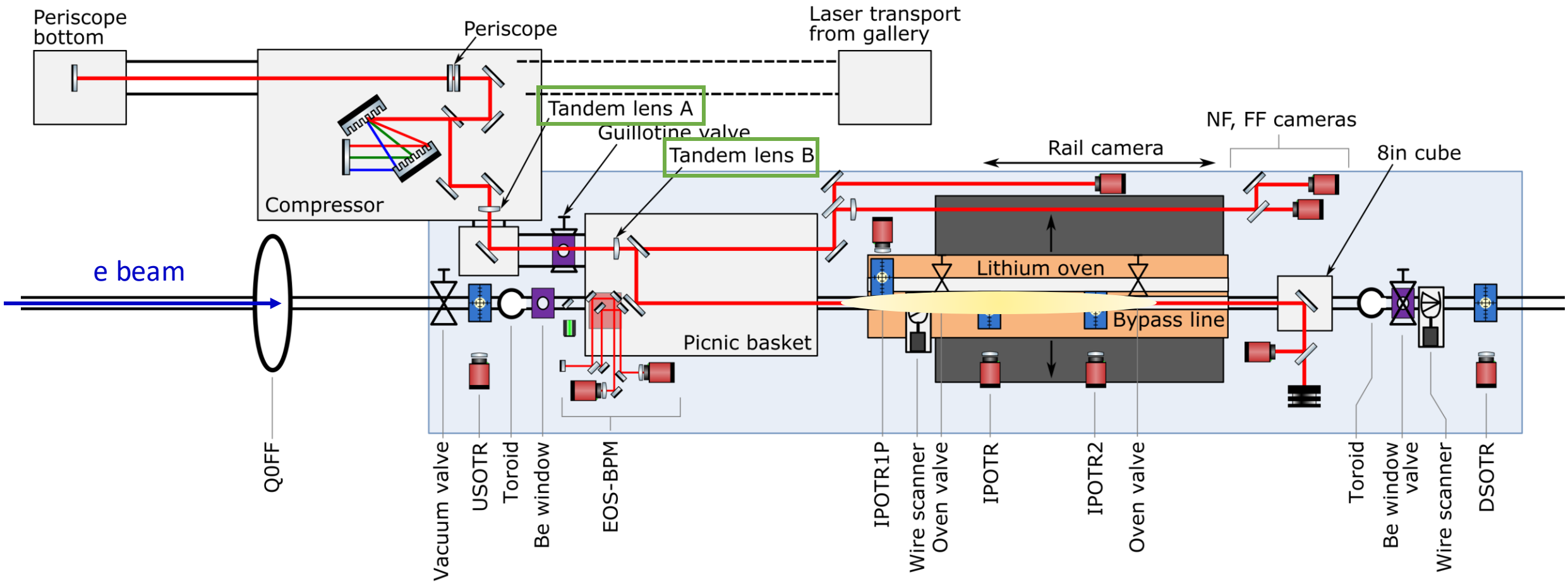

Laser ionized plasma source offers the ability to shape the transverse and longitudinal density profile.

Tandem Lens

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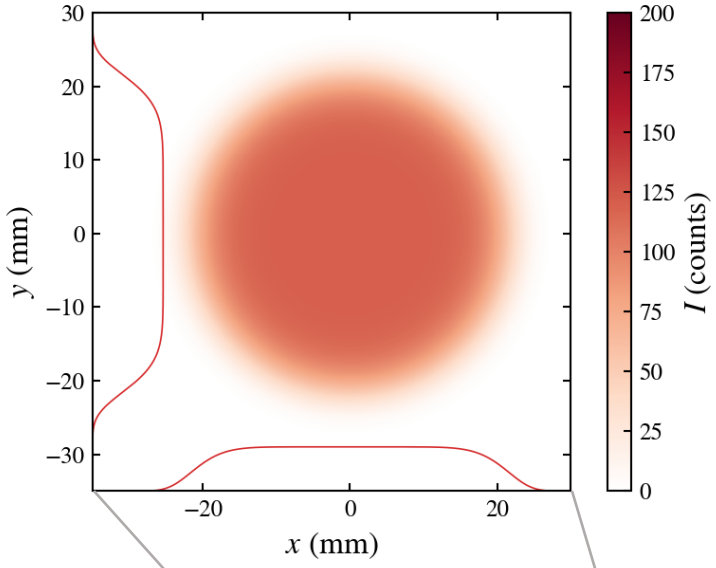
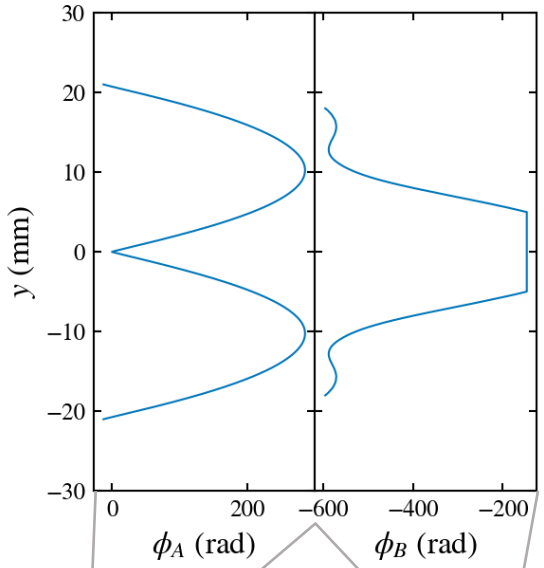
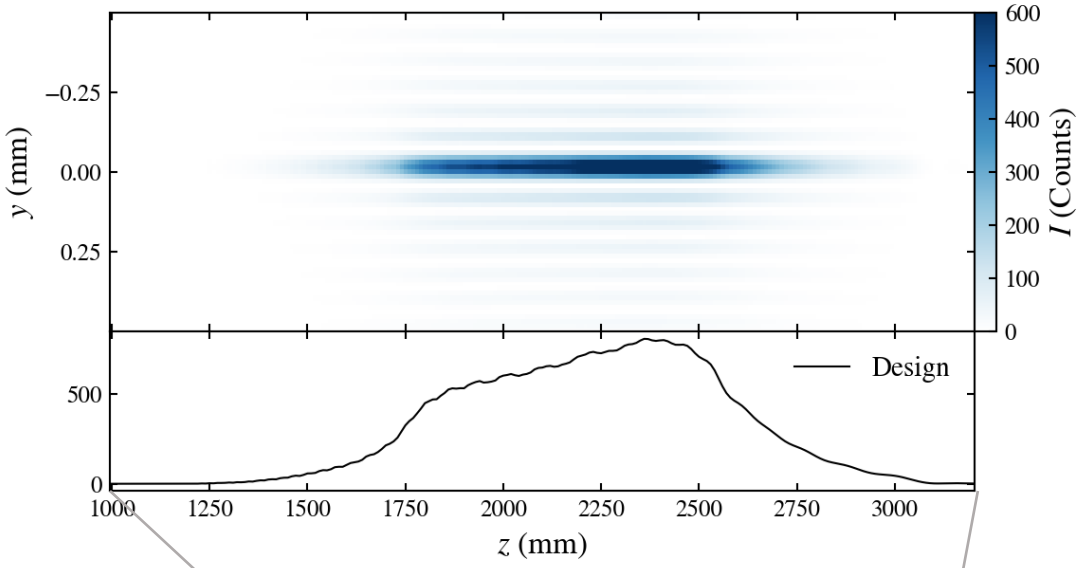
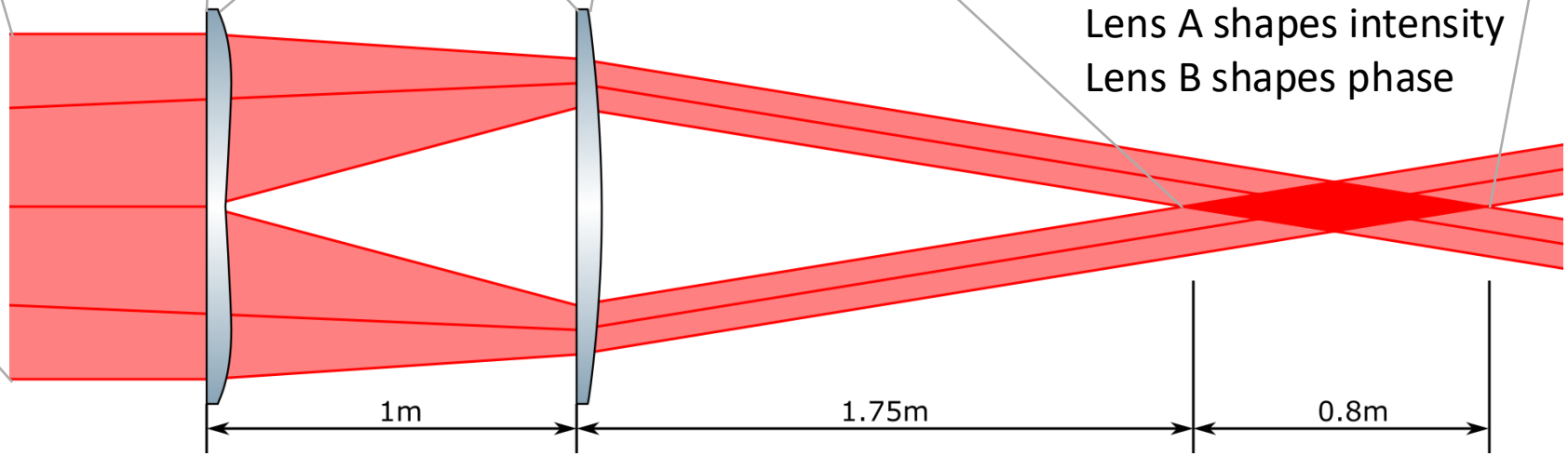






Laser Parameters	
Energy	20-200 mJ
Pulse Duration	50 fs
Incoming Spot Size	40 mm
Focus Spot Size	60 um



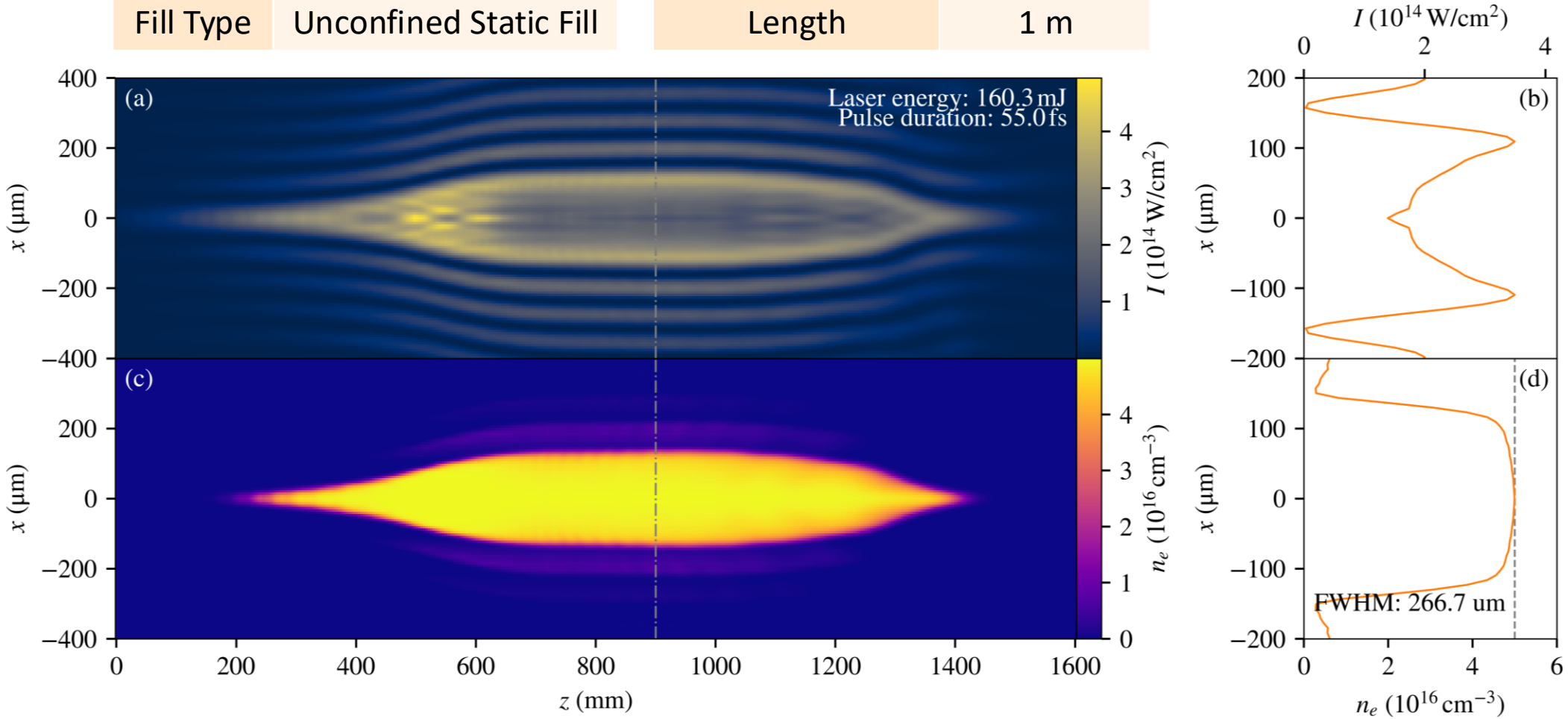
Robert Ariniello

Laser-ionized Plasma Source – Wide Column

University of Colorado **Boulder**

Gas Parameters	
Density	5e16 cm^{-3}
Species	H2
Fill Type	Unconfined Static Fill

Plasma Parameters	
Density	5e16 cm^{-3}
Width (FWHM)	266.7 um
Length	1 m



Laser-ionized Plasma Source – Narrow Column

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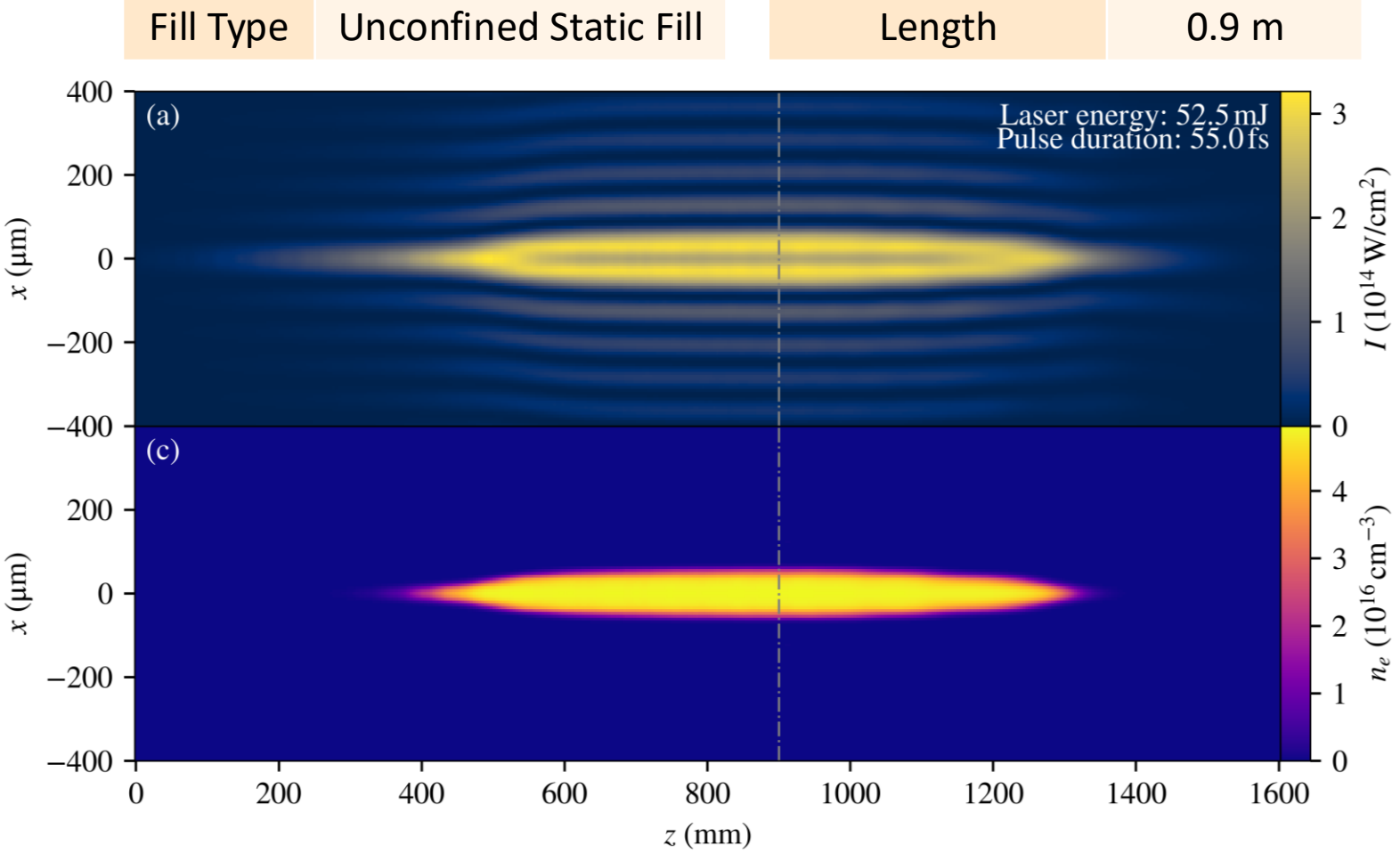
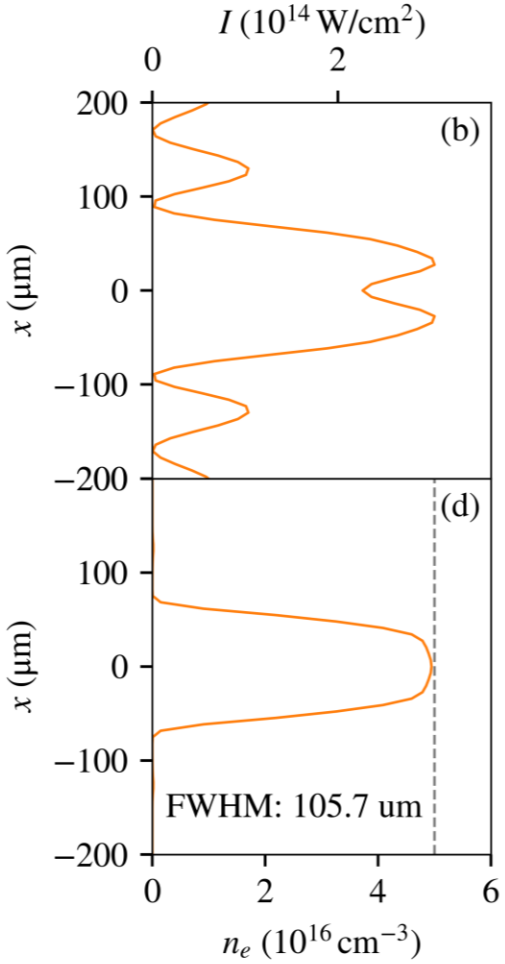
Gas Parameters	
Density	5e16 cm^{-3}
Species	H2
Fill Type	Unconfined Static Fill

Plasma Parameters	
Density	5e16 cm^{-3}
Width (FWHM)	105.7 um
Length	0.9 m





Plasma to Electron Beam Alignment

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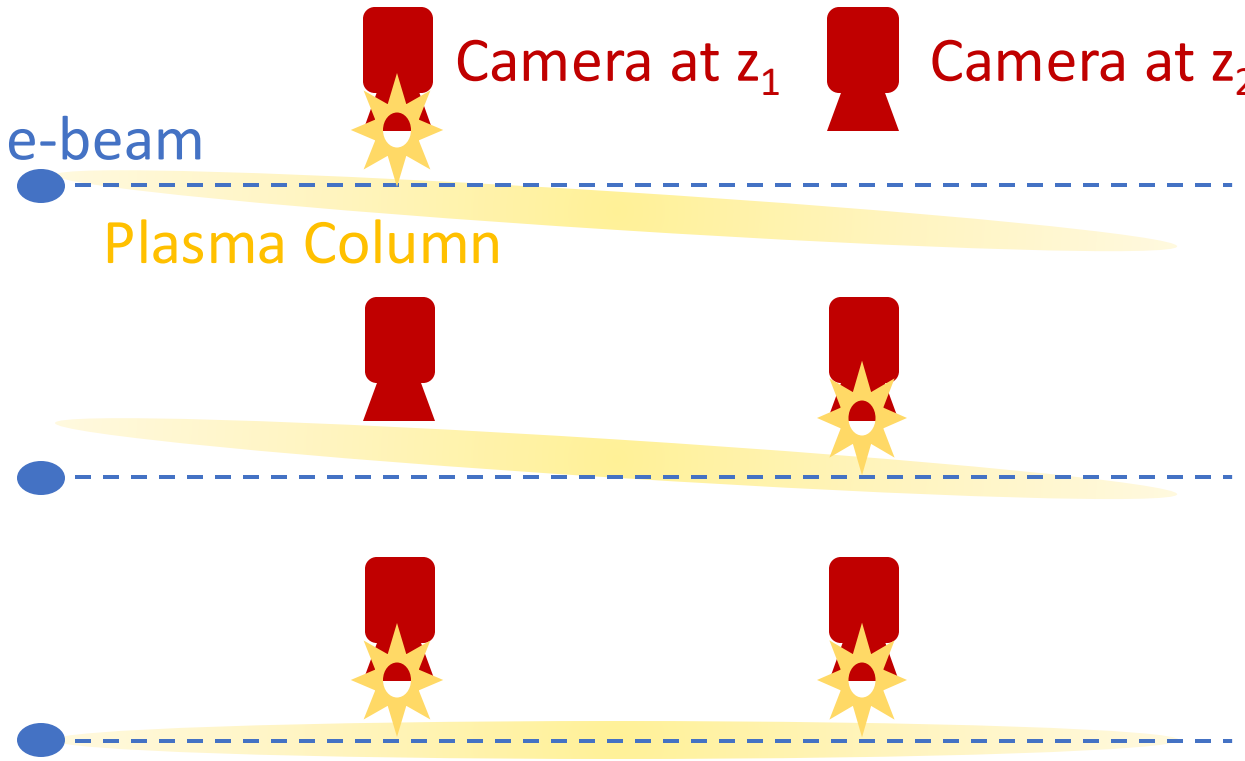
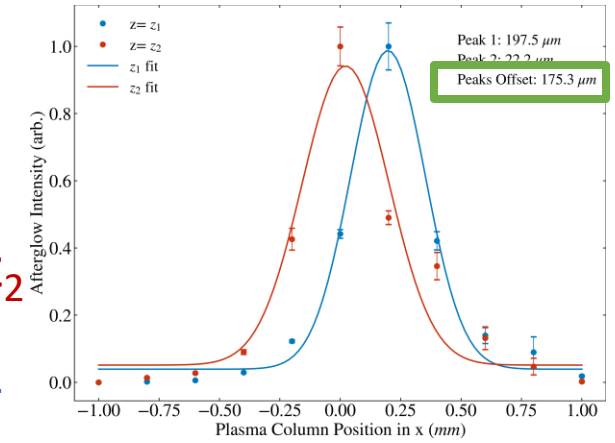
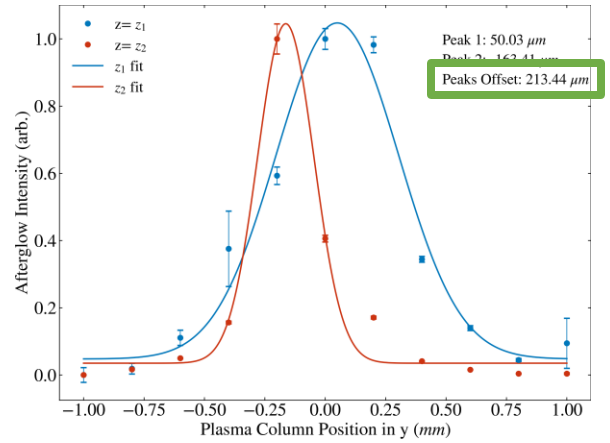
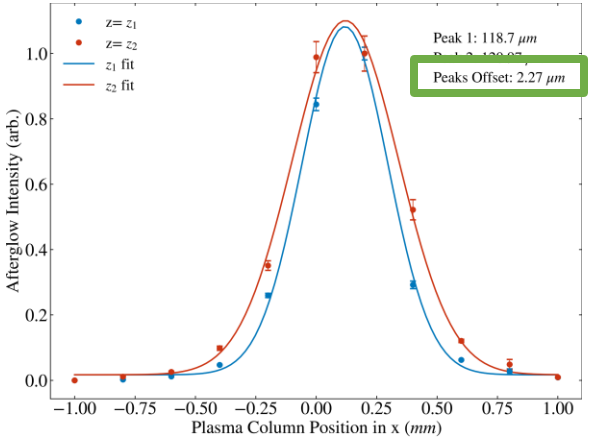
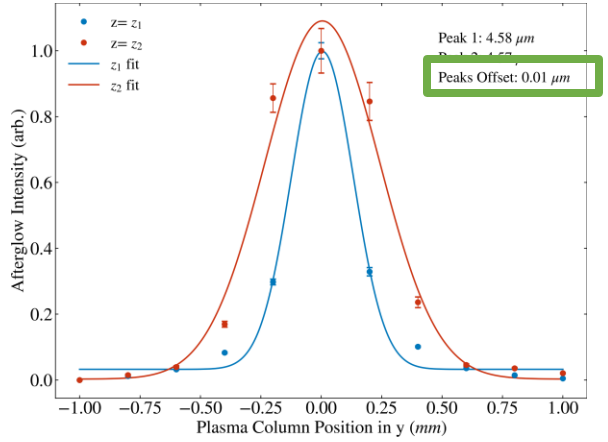
By analyzing the relative plasma light intensity as a function of the transverse position of the plasma column at z_1 and z_2, we determine the misalignment angle and correct it.











1-meter plasma source is aligned to a 10 GeV, 1.6nC electron beam to within 10um.

Experimental Operations

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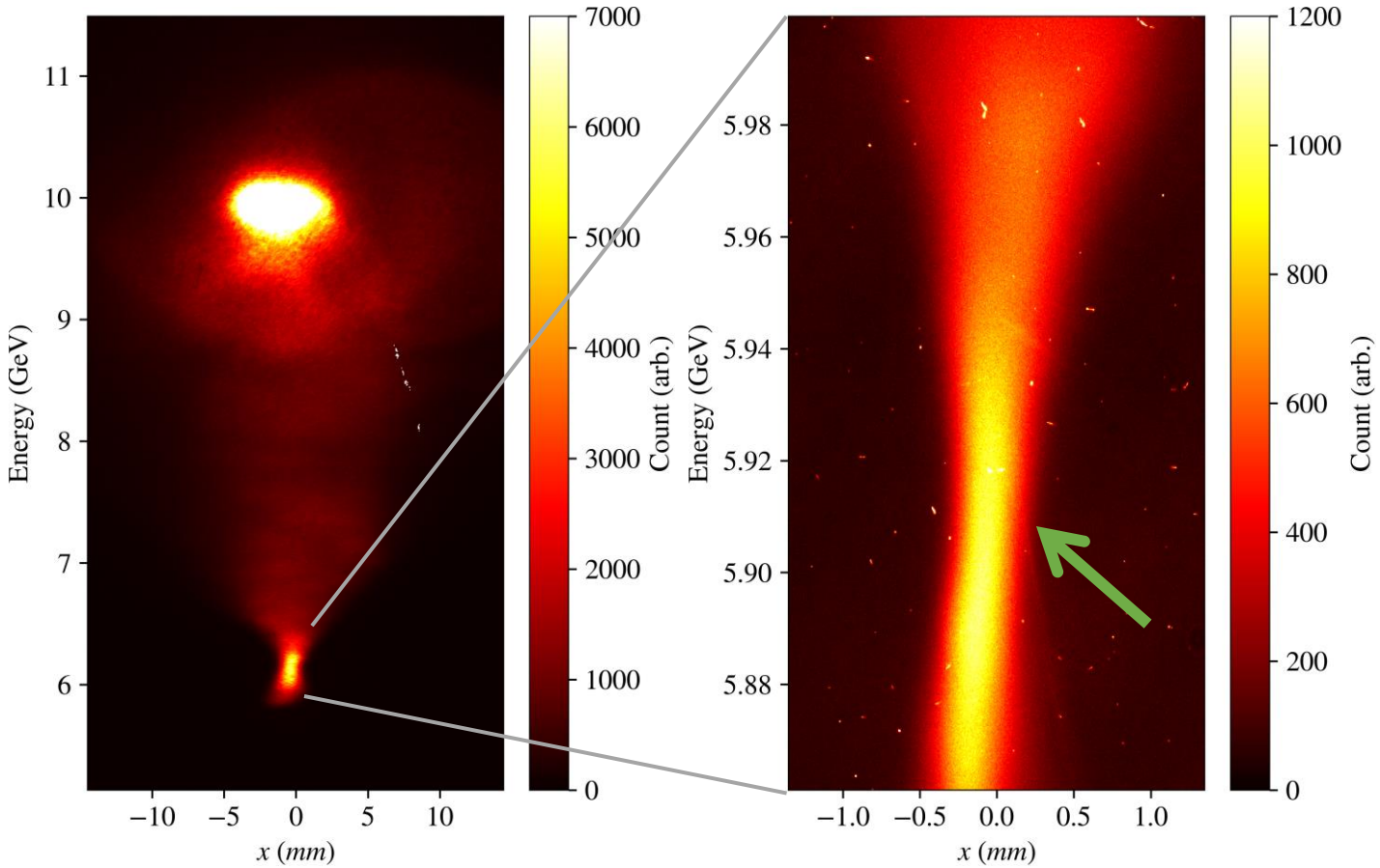
Operations

- Tilt plasma column
- Scan transversely

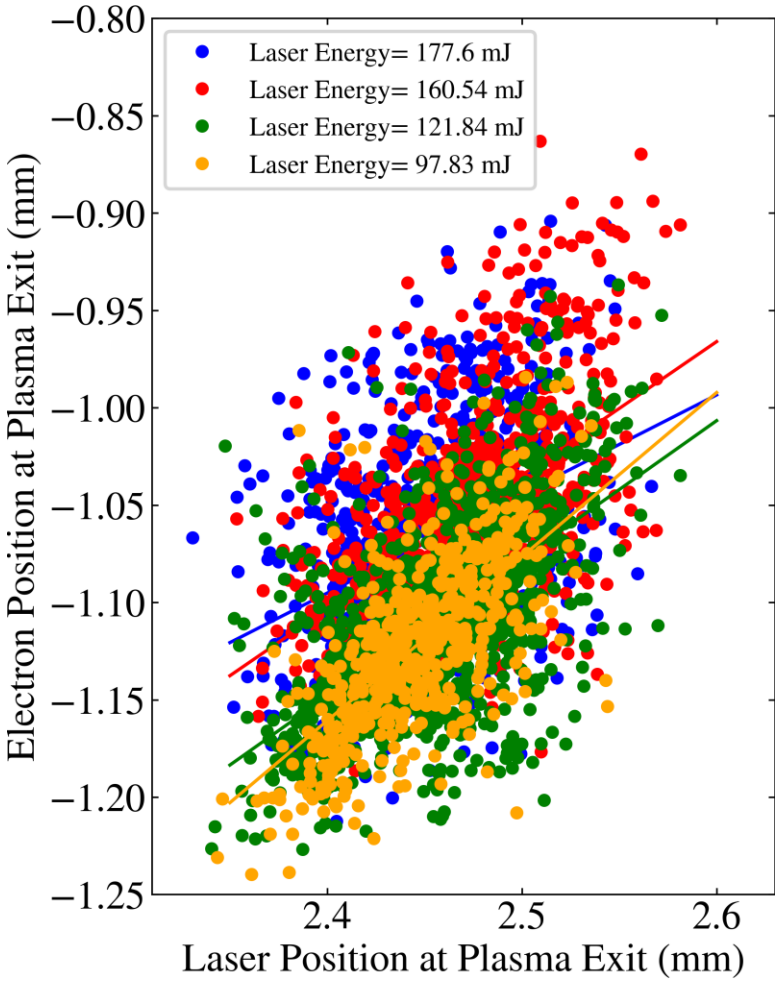
Measurements

- Ionization laser's position at the plasma exit
- Electron beam's position at the plasma exit (scintillation-based electron spectrometer)

Guiding evidence: electron beam positions measured follow plasma positions at exit.



Experimental Evidence of Electron Beam Guiding



Data Elimination

Presenting shots that have comparable deacceleration with the aligned case (deacceleration charges reach 6GeV) -> the e-beam goes through the entire plasma column.

Data Presentation

Plot the ionization **laser's position** at the plasma exit and the **electron beam's position** at the plasma exit.

Plasma Width Control

Decreasing the ionization laser's energy narrows the plasma width.

A linear relationship with a slope of 1 means guiding.

Measurements at Various Tilt Angles

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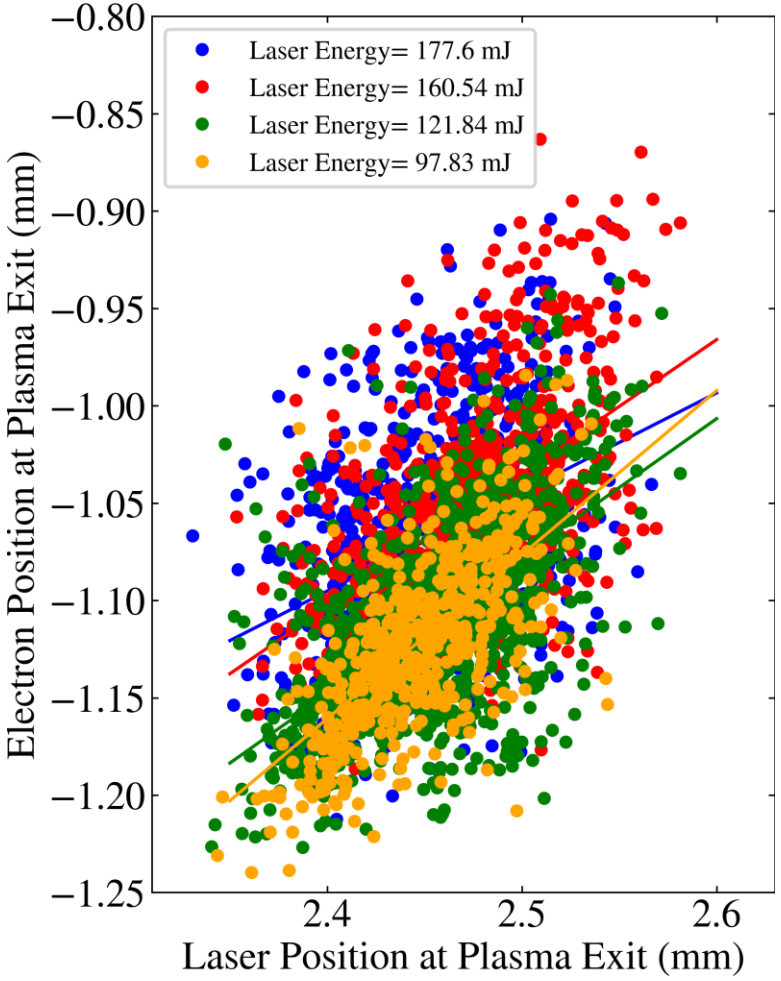
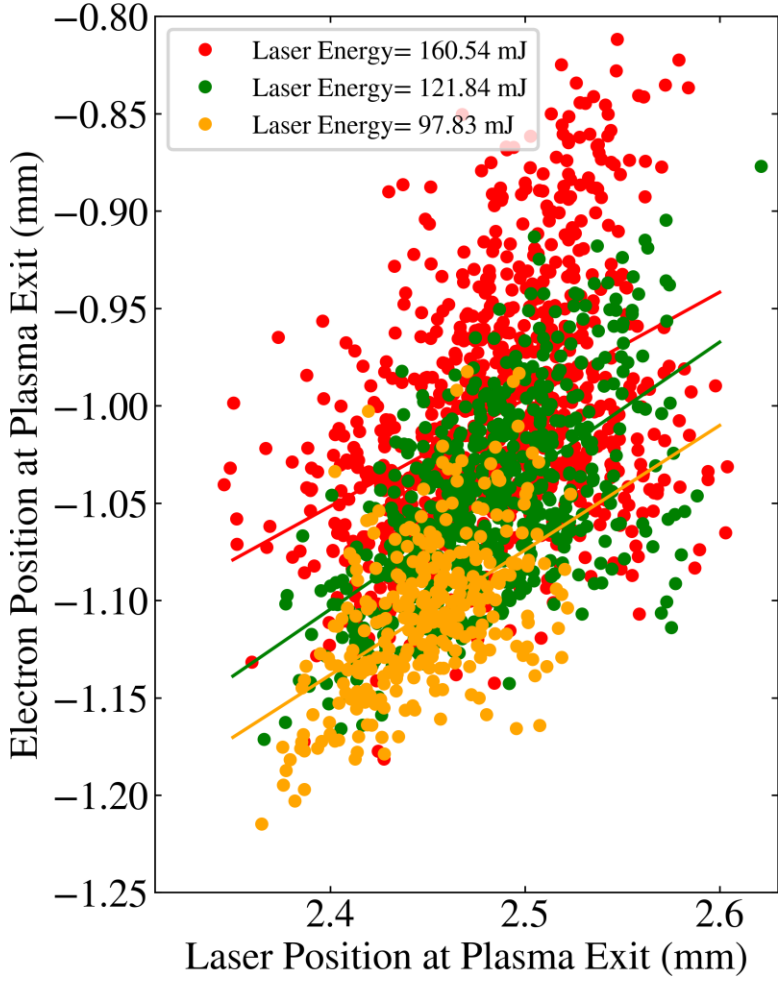
Θ=32urad



Θ=64urad



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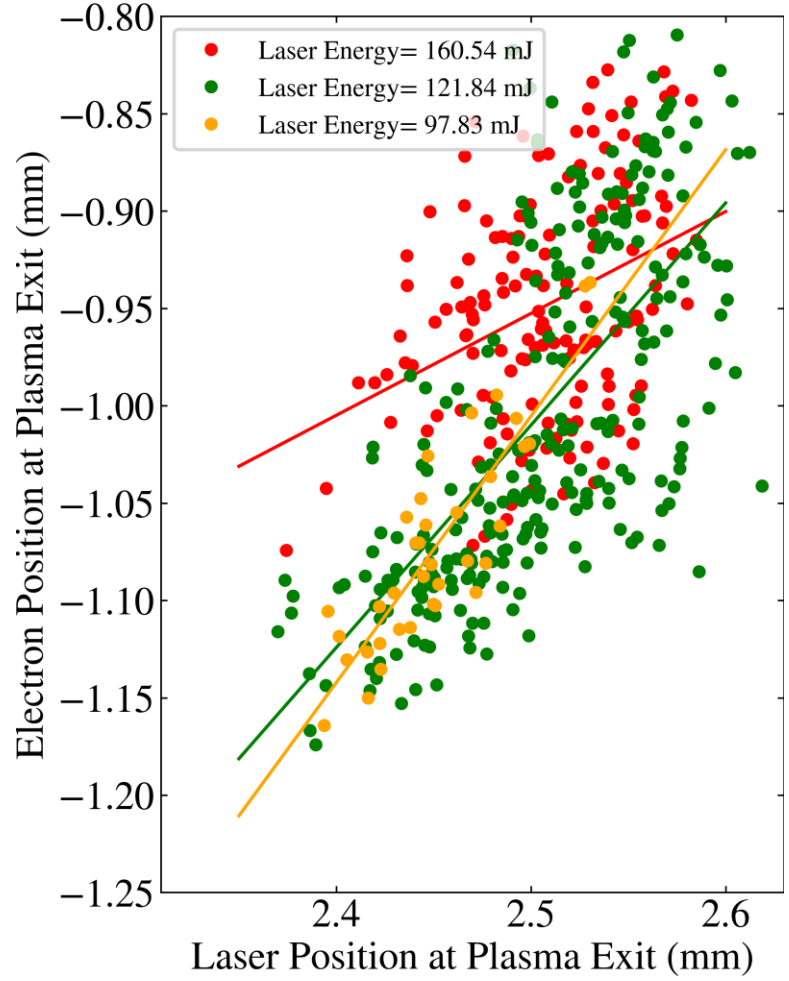
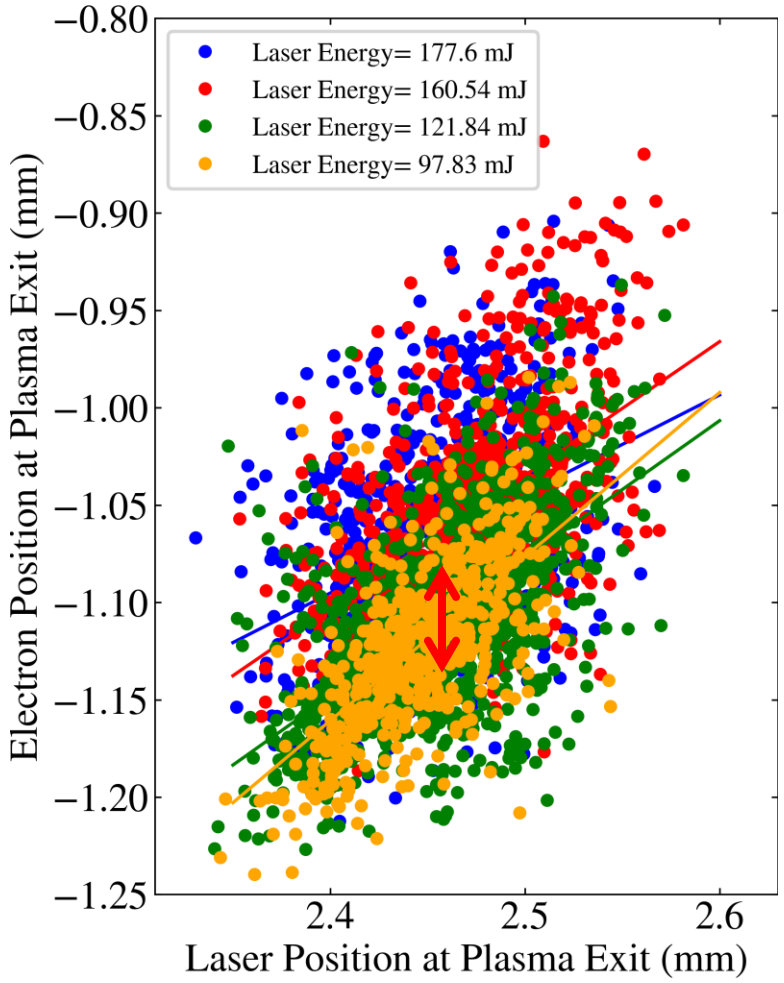


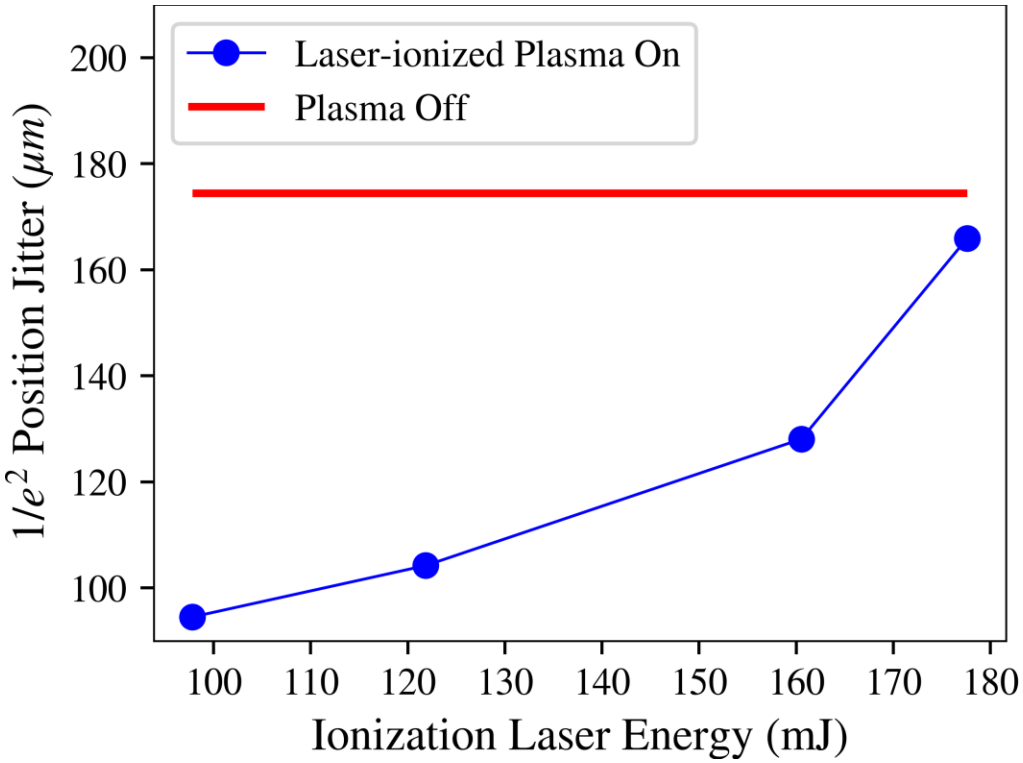
Electron beam guiding evidence appears in various plasma widths and at various tilt angles.

Experimental Evidence of Narrow Plasma Generated



E-beam Position Jitter Spread at Exit

The position jitter of the e-beam at the plasma exit reflects the width of the plasma column because the **plasma column entrance** serves as a aperture.



Electron beam position jitter at the plasma exit is a measure of the size of the plasma column.

Experimental Evidence of Reduction in Energy Loss

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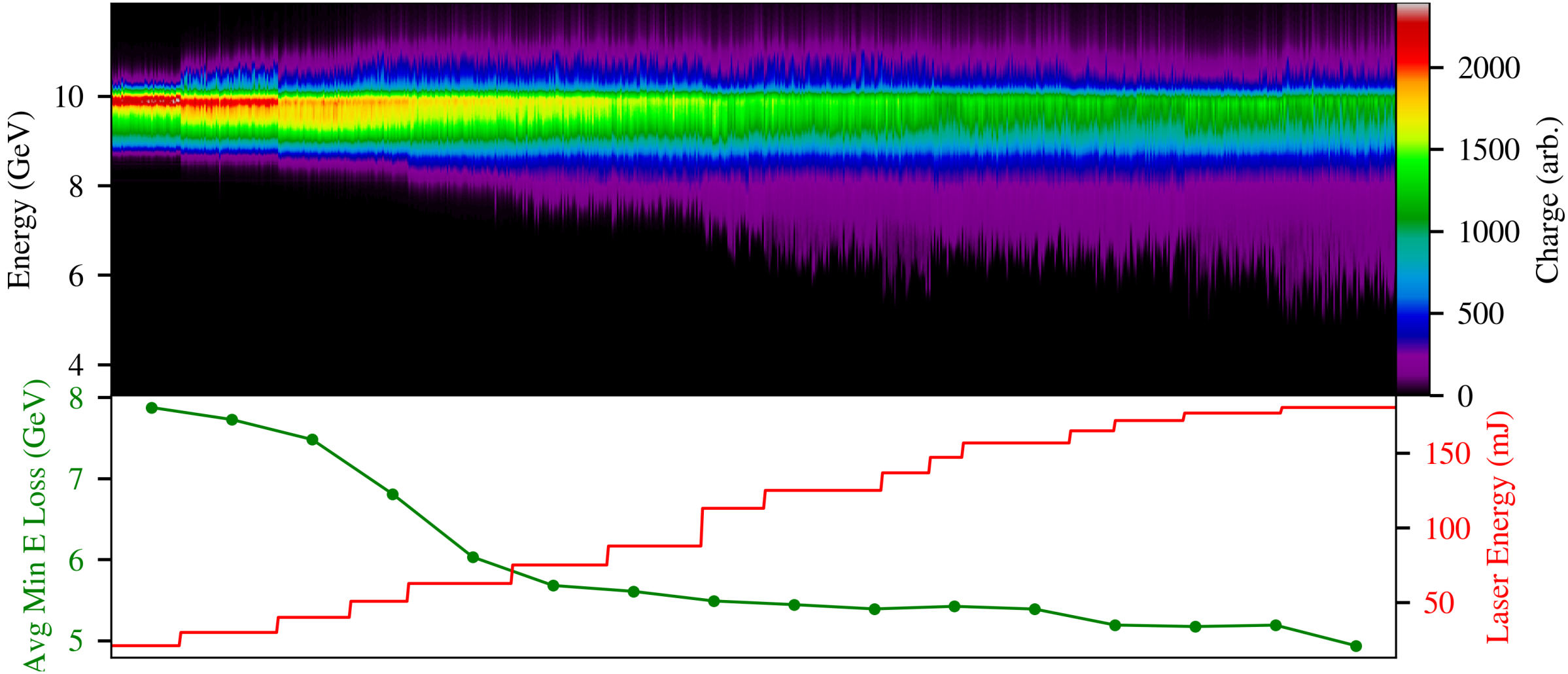


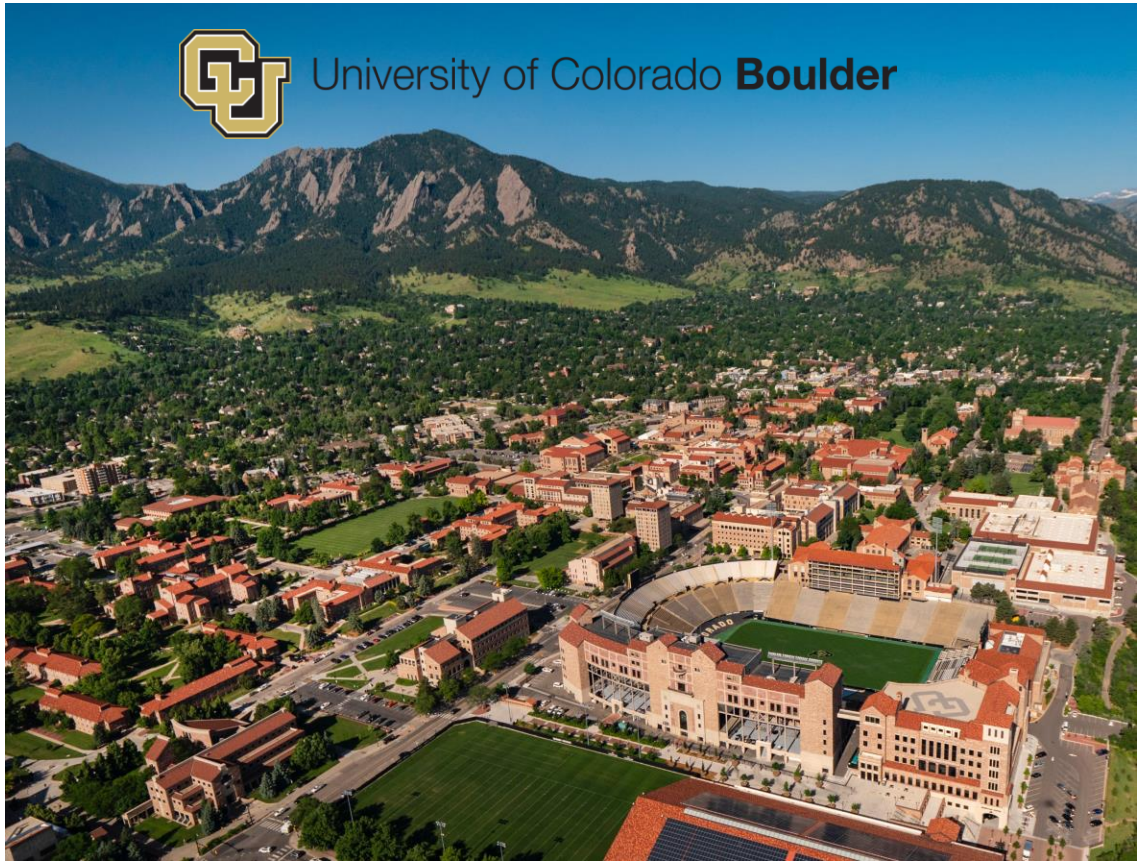
Reduced e-beam energy loss is observed as the ionization laser energy decreases.

Summary

- We describe the **positron PWFA technique** in a narrow plasma column.
- We simulate that the **transverse focusing force of the wake is asymmetric** when the driving electron beam offsets from the center.
- This asymmetric transverse force **guides the electron beam** along the plasma column trajectory.
- We report **preliminary experimental evidence** of the guided electron beam in a narrow column PWFA, plasma width measurement and a reduction in energy loss with respect to PWFA in a wide plasma column.

We demonstrate the production of a narrow column plasma experimentally and see the guiding effect.
We advance the understanding of related experimental challenges.

Thank You for Your Attention



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