# Experimental Parameters for Plasma Wakefield Acceleration in a Narrow Plasma Channel

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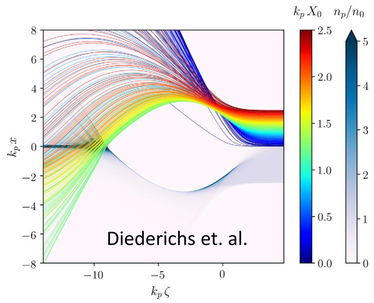
## Motivation – Positron Acceleration

- Narrow plasma channel: The channel size is smaller than the blowout radius.
- In a narrow plasma channel scheme, the sheath electrons return to different longitudinal positions depending on their initial transverse position, creating elongated on-axis trailing electrons.




**The elongated on-axis electrons create a region of transverse focusing field within the accelerating phase for positrons.**

## E333 Experiment at FACET-II

- FACET-II is a research facility at SLAC National Lab at which, 10GeV, 1nC bunches of positrons may be available in coming years.

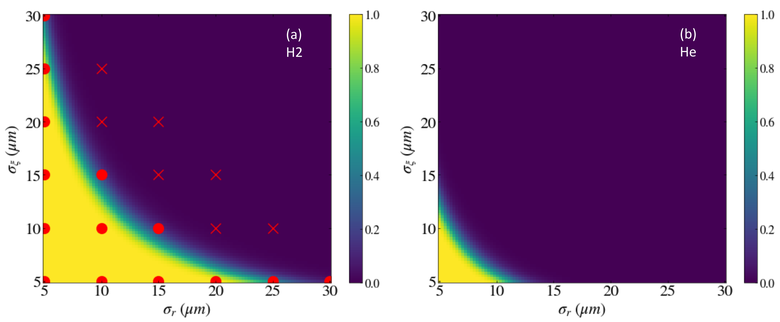
**E333 Phase I Scientific Goal: Experimental demonstration of the elongated trailing sheath electrons and their use for positron acceleration.**

- Part I: **Single electron bunch** — demonstrate the longitudinal field difference in a narrow vs. wide channel.
- Part II: **Two electron bunch** — probe the fields where the sheath electrons cross the axis.
- Sigle bunch beam parameters:

| Charge | Energy | $\varepsilon_{x,y}$ | $\sigma_\xi$ | $\sigma_r$ | $\sigma_\delta$ |
|---|---|---|---|---|---|
| 1.5 nC | 10 GeV | 10, 10 μm-rad | 20 μm | 20 μm | 1% |

## Beam Ionization

- To maintain a controlled size pre-laser-ionized plasma channel, beam ionization needs to be prevented.




(a) Ionization fraction from the ADK model for a Gaussian electron beam of background Hydrogen, red markers are quasi-static PIC: "o" = ionization, "x" no ionization. (b) Beam ionization rate for Helium.

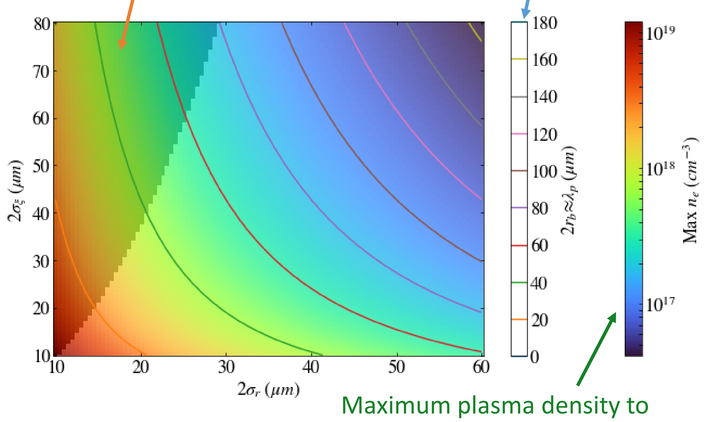
**No beam ionization is expected in the experimental single bunch beam configuration (20μm x 20μm x 20μm).**

## Single Bunch Physics Working Point

- Aim: Find a regime of beam and plasma parameters so that the tail of the electron bunch can probe the elongated trailing sheath electrons.
- Constraint 1: PWFA remains in the blowout regime ($n_b \geq 2n_o$).
- Constraint 2: Bunch length is on the order of blowout wake ($2\sigma_\xi \geq \lambda_p$).

The tail of the electron bunch effectively can probe the elongated trailing sheath electrons

Blowout diameter



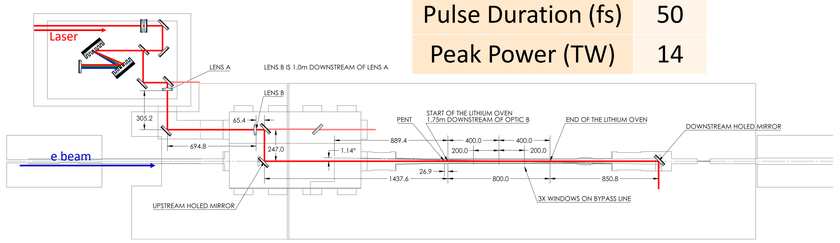

Maximum plasma density to remain in the blowout regime

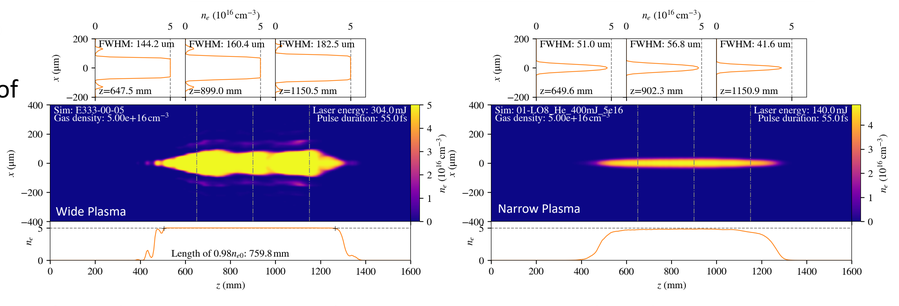
**Probing the trailing sheath electrons by the tail of the single bunch beam is unfeasible in experiment.**

## Laser Ionized Plasma Source

- Plasma source: Unconfined gas ionized by laser
- Optics: Axicon lens or previously designed diffractive optics for E300.
- Plasma density constraint: Plasma refraction — available optics with gas density above 6e16 $cm^{-3}$ lead to unusable plasma source due to excessive plasma refraction.

| Laser Parameters | |
|---|---|
| Energy (mJ) | 350 |
| Pulse Duration (fs) | 50 |
| Peak Power (TW) | 14 |

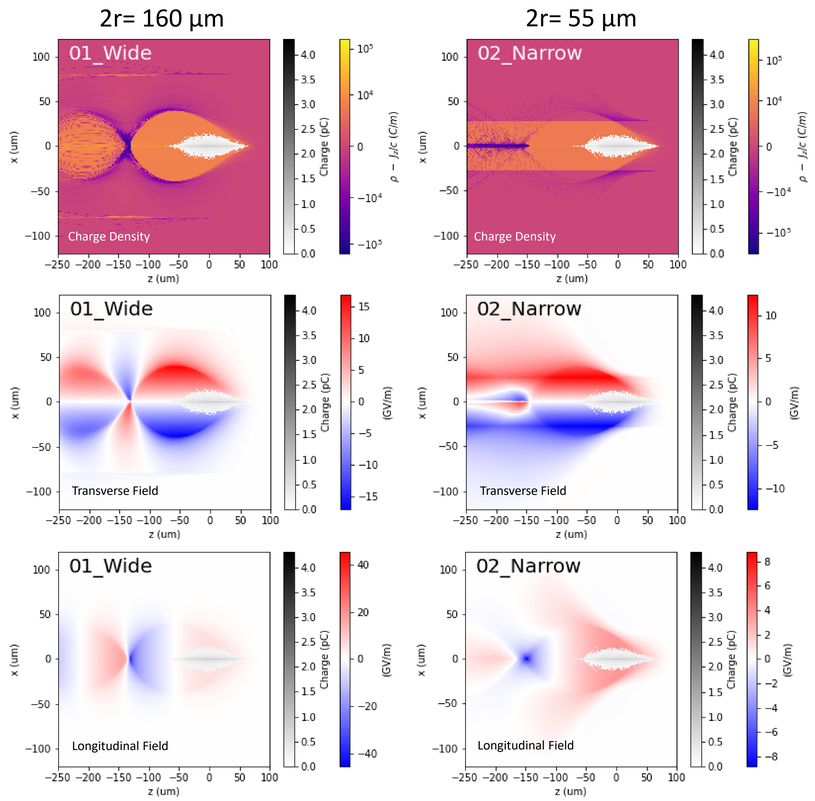


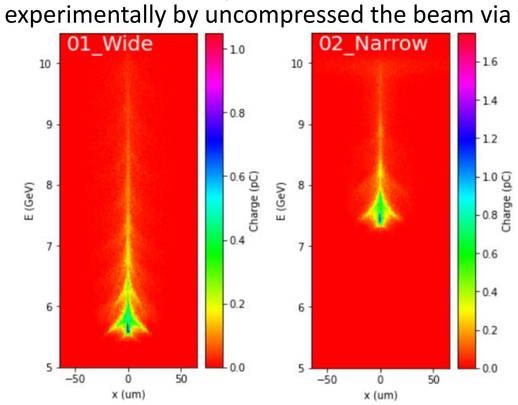

## Laser Ionized Plasma Source

| Type | Species | Optics | Gas Density | Laser Energy | FWHM |
|---|---|---|---|---|---|
| Wide | H2 | 0.7° Axicon | 5e16cm$^{-3}$ | 304mJ | 160.4μm |
| Narrow | He | Diffractive Optics | 5e16cm$^{-3}$ | 140mJ | 56.8μm |

## PWFA in Narrow and Wide Plasmas




The bunch length ($\sigma_\xi$ ) is stretched to 35μm, which is archivable experimentally by uncompressed the beam via the final focus magnets.




Energy spectra after 70cm propagation.

**The difference in energy spectra is an experimental indication of the existence of narrow plasma in single-bunch PWFA experiments.**

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