E-162: Positron and Electron Dynamics in a Plasma Wakefield Accelerator

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- Extraordinarily high fields developed in beam plasma interactions
- Many questions related to the applicability of plasmas to high energy accelerators and colliders
- E-157: First experiment to study Plasma Wakefield Acceleration (PWFA) of electrons over meter scale distances
- Physics for positron beam drivers qualitatively different (flow-in vs. blow-out) E-162
Outline

Motivation for positrons

Differences between positrons and electrons in PWFA
  - “Flow-in” vs. “blow-out” regimes

Transverse wakes in homogeneous plasmas
  - Opportunity to do unique physics with minimal investment

Longitudinal wakes in hollow and homogeneous plasmas
  - Hollow channels to optimize the accelerating wake for positrons
  - Required improvements to the experimental apparatus

Study matched beam propagation and longitudinal wakes of electrons
Why Positrons?
For Example -- The Afterburner Idea

- Double the energy of Collider w/ short plasma sections before IP
- 1\textsuperscript{st} half of beam excites wake -- decelerates to 0
- 2\textsuperscript{nd} half of beams rides wake -- accelerates to 2 \times E_o
- Make up for Luminosity decrease \( \propto \frac{N^2}{\sigma^2} \) by halving \( \sigma \) in a final plasma lens
Space charge of drive beam displaces plasma electrons

Plasma ions exert restoring force => Space charge oscillations

Wake Phase Velocity = Beam Velocity (like wake on a boat)

Wake amplitude $\propto N_b / \sigma_z^2$

(for $4\sigma_z \approx \lambda_p \propto \frac{1}{\sqrt{n_o}}$)
E-162: $e^+ \& e^- \text{ Dynamics in PWFA}$

**Electron Dynamics**
- Blow-out
- Flow-in

**Positron Dynamics**
- Flow-in
3D Positron Beam Modeling
Transverse Dynamics

Electron Simulation

Positron Simulation

Electron Data

Missing Positron Data

Longitudinal Wake Optimization for Positron Beams:

Homogeneous Plasma

Hollow Plasma Channel
Wakefields of positron and electron

\[ N = 2 \times 10^{10}, \quad \sigma_z = 0.4 \text{mm} (~1.3 \text{ps}), \quad \sigma_r = 75 \mu \text{m} \]
\[ n_p = 4.34 \times 10^{14} \text{cm}^{-3} \]
For a positron drive beam and a homogeneous electron plasma the accelerating wakes have a lower amplitude than electron beam driven plasma waves – require a high resolution imaging spectrometer
Why are positron wakes smaller?

Phase mixing due to different arrival time of sucked-in electrons

Gradient can be made larger by using a hollow plasma channel
Wakes in Hollow channel

electron

positron
Hollow channel plasmas can be optimized (plasma density vs. channel radius) for positron acceleration.

Accelerating wake for electron and positron beams as a function of the hollow plasma channel radius. For the electron case (filled blue circles) the wake amplitude decreases with channel radius, where as for positrons (open red circles) the wake has an maximum for a channel radius equal to $c/\omega_p$. 
The accelerating wake for a positron beam driven plasma wave can be optimized by using a hollow channel plasma.

UV profiles 0.3 m (a) and 1.3 m (b) from a damaged UV optic with ~500 µm hole in reflective coating (center of images) as well as other forms of damage. The structure of the resultant mask in UV fluence is preserved over the required length to photo-ionize a hollow channel plasma.
Optimization of the Experimental Set-up

- Imaging spectrometer
- Matched beam propagation for electrons
E-162: $e^+ & e^-$ Dynamics in PWFA

Aerogel

Dump magnets

Quad
Move experiment from IP1 to IP0 where optics are available to:
- Image plasma entrance and exit onto aerogel and have a true imaging spectrometer
- Match beam into plasma
Optics @ IP0 allow matching into the plasma

\[ \beta_{\text{beam}} = \frac{\sigma^2}{\varepsilon} = \frac{1}{K} = \beta_{\text{plasma}} \]

- Plasma transparency condition broadened (@ plasma exit)
- Use imaging spectrometer

\[ \sigma_0 = 10.5 \, \mu m \]
\[ \varepsilon_N = 5 \times 10^{-5} \, \text{m rad} \]
\[ n_e = 1.5 \times 10^{14} \, \text{cm}^{-3} \]

Matched @ \( n_e = 1.5 \times 10^{14} \, \text{cm}^{-3} \)

\[ \sigma = 10.5 \mu m \pm 2.4\% \]
\[ 1.4 < n_e < 2.7 \times 10^{14} \, \text{cm}^{-3} \]

\[ \sigma_0 = 10.5 \, \mu m \]
\[ \varepsilon_N = 5 \times 10^{-5} \, \text{m rad} \]
\[ \beta_0 = 13 \, \text{cm} \]
Conclusions:

- PWFA physics for positrons fundamentally different than for electrons
- E-157 has produced a number of significant results with electrons
- E-162 will be the first experiment to study the issues of PWFA with positron beams
- Strong collaboration eager to use the facility developed in the FFTB to study PWFA
Experimental Program

• Run 1: A First Look at Positron Propagation in Long Homogeneous and Hollow Plasmas
  • Use working E-157 apparatus
  • Positrons in homogeneous and hollow plasmas
  • Transverse dynamics (time integrated & time resolved) in the “flow-in” regime

• Run 2: High Resolution Energy Gain Measurements of Positrons
  • Move to new location in FFTB to build true imaging spectrometer
  • Positrons in homogeneous and hollow plasmas
  • Detailed structure of longitudinal wakes (acceleration)

• Run 3: High Resolution Energy Gain Measurements of Electrons
  • Electrons in homogeneous and hollow plasmas
  • Matched beam propagation in a long plasma
  • Higher resolution acceleration measurements