E31x collaboration

Progress and perspectives of the “E310: Trojan Horse-II” program at SLAC FACET-II

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Abstract

Plasma photocathodes utilize a comparatively low-power laser pulse to release and inject electrons directly inside an electron-driven plasma wakefield via selective ionization of a dopant gas or ion species. This injection process is therefore largely decoupled from wake formation and driver evolution dynamics. Also known as “Trojan Horse” injectors, plasma photocathodes promise a pathway towards controlled production of ultra-high brightness electron beams with emittances on the order of ~10 nm rad and kA peak-currents [1].

We report on recent progress and perspectives of the “E310: Trojan Horse-II” experimental program at the Facility for Advanced Accelerator Experimental Tests II (FACET-II) at SLAC National Accelerator Laboratory, which utilizes a 10 GeV electron driver and a mixture of hydrogen and helium for wake formation and injection, respectively.

We will provide an overview of principal experimental design aspects and discuss further advancements of the experimental setup towards implementing plasma photocathodes under various injection geometries. Experimental results from first ionization tests will be presented on a dedicated poster.

Introduction

Trojan Horse Injection, also known as Plasma Photocathode Injection, uses a laser pulse that is focused into the plasma blowout that is driven by a relativistic electron bunch. The blowout and affiliated wakefield arise in the plasma of a low ionization threshold (LIT) medium, whereas the laser pulse releases electrons from a species with a higher ionization threshold (HIT). The HIT electrons are trapped at the rear of the blowout and from the witness bunch (cf. Figure 3 and 6).

The E-310: Trojan Horse-II experimental program aims to demonstrate Plasma Photocathode injection at SLAC FACET-II. The program follows the FACET E210: Trojan Horse collaboration, which demonstrated a transverse Trojan Horse injection experimentally (cf. Figure 3) [2]. Building on the E210 experience and the improvements of the FACET-II linear accelerator [3], the E310 program aims to not only reproduce the transverse injection, but also demonstrate a collinear injection, which is simulated to reach witness beam emittances on the nm rad scale.

Downstream Injection Chamber

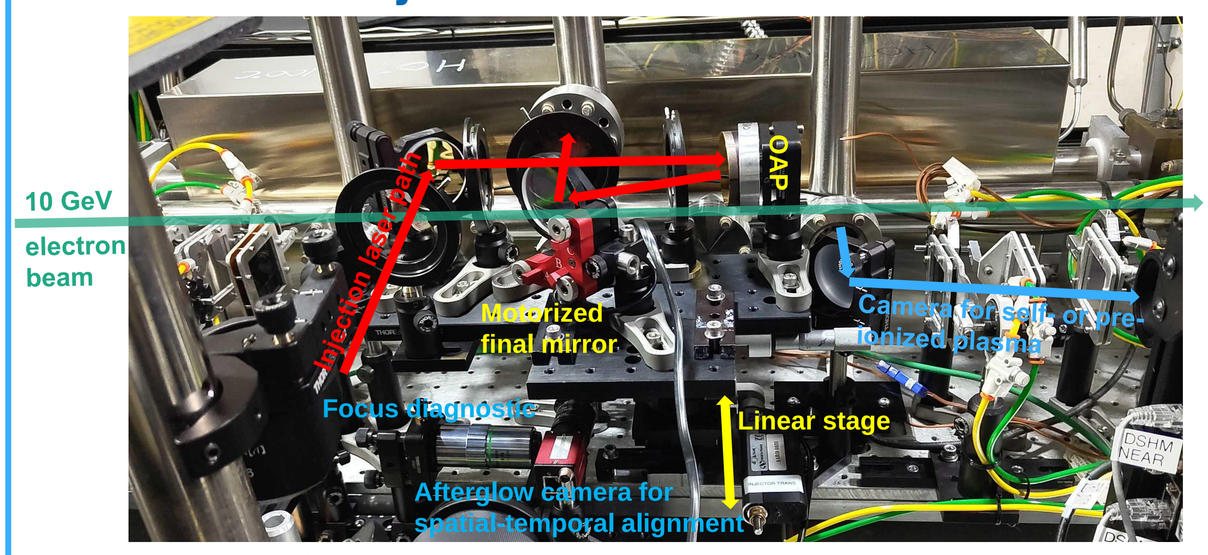


Figure 1: Downstream injection chamber with the installed transverse injection line.

- Downstream injection chamber houses multiple diagnostics by default
  - OTR screens for electron beam alignment
  - Afterglow cameras with exchangeable bandpass filters
- Newly installed transverse injection line (cf. Figure 1)
  - 50 fs laser pulse with an energy of about 5 mJ is focused by a 15” focal length OAP
  - The final mirror outside the chamber is motorized
  - Inside the chamber, a ½” mirror brings the laser on the electron beam axis (cf. Figure 2)
  - A linear stage gives the possibility to translate the focus position
- Diagnostics for the transverse injector
  - A focus diagnostic for the OAP focus
  - An afterglow camera for spatial and temporal alignment of the laser axis to the electron beam orbit

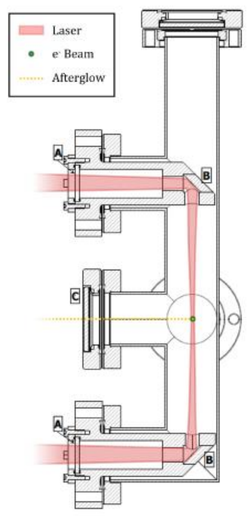


Figure 2: Beam paths inside the chamber [4].

Transverse Trojan Horse injection

- A transversely propagating injector laser benefits from a simpler experimental realization
- E-210 transverse injection is estimated to have reached an emittance of about 1.5 µm rad [2]

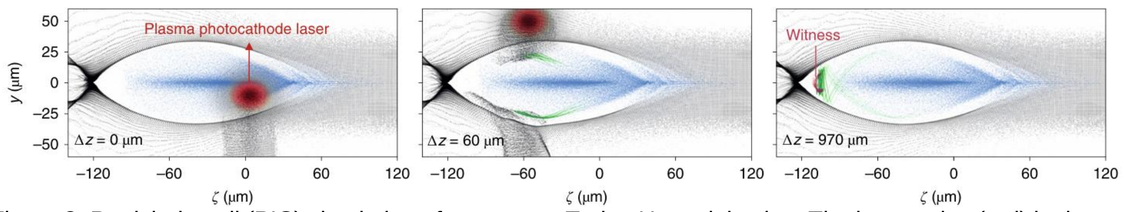


Figure 3: Particle-in-cell (PIC) simulation of transverse Trojan Horse injection. The laser pulse (red) ionizes electrons from the HIT medium. Some of the electrons are within the trapping region (green) and from the witness bunch [2].

Pre-ionization

- A pre-ionized plasma column with a length on the meter scale is critical for any injection geometry
  - It ensure a stable electron beam driven wakefield to inject in
  - Provides an acceleration length to reach GeV scale witness beam energies
- Requirement for a pre-ionization device are:
  - Generate meter scale long and several 100 µm wide plasma of solely the LIT species
- One solution is an axilens (cf. Figure 4)

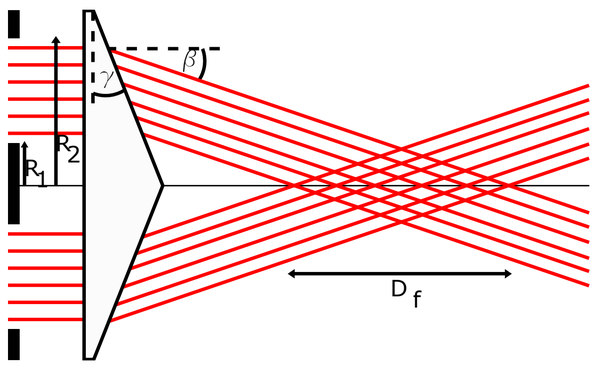


Figure 4: Visualization of an axilens focusing behavior. The angles β and γ characterize the axilens. A mask with inner radius R_1 and outer radius R_2 creates a focal depth of D_f. After [5].

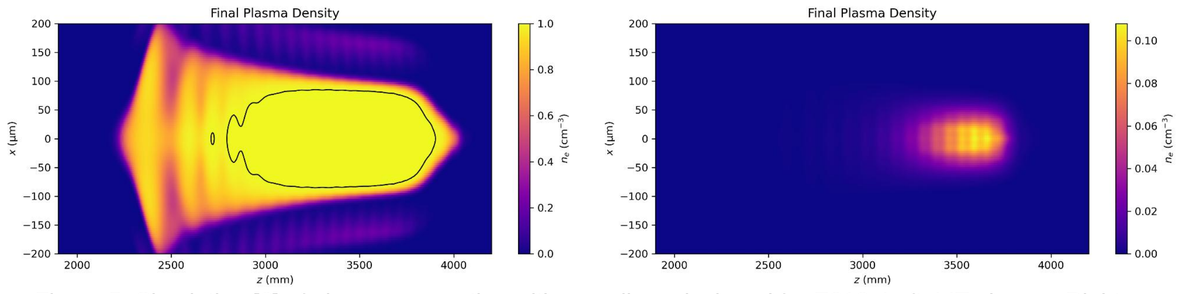
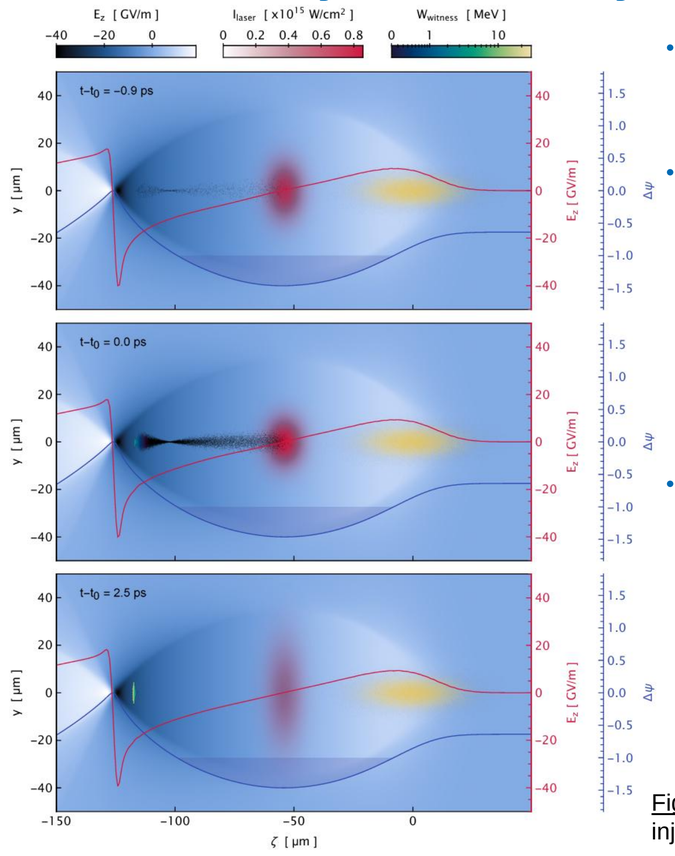


Figure 5: Simulation [6] of plasma generation with an axilens designed for E310. Left: LIT plasma. Right: residual HIT plasma. Axilens design, simulation and plots from Adam Hewitt.

Collinear Trojan Horse Injection



- A co-propagating injection laser releases electrons with a minimal residual transverse momentum
- The experimental set-up is more demanding than in a transverse configuration
  - A holed mirror on the electron beam axis that does not interfere with the pre-ionization optics
  - Alignment of pre-ionized plasma channel, electron beam orbit and injection laser
- A larger chamber than the downstream injection chamber at FACET-II would circumvent many space constrains
  - Room for plasma and laser diagnostics
  - Extraction and transport of witness beams
  - Prevention of unnecessary B-integral accumulations

Figure 6: PIC simulation of collinear Trojan Horse injection [7].

Perspectives

The E310-Trojan Horse II program at SLAC FACET-II installed a transverse injection line and is preparing for experiments. A suitable axilens for pre-ionization is available and soon to be tested. An experimental demonstration of nm rad scale emittances from collinear Trojan Horse injection would open the pathway towards heigh energy physics, next generation light sources such as free electron lasers (FEL) and QED studies [1].

Furthermore, laser based electron accelerators provide electron beams capable of driving a wakefield, an approach known as hybrid LWFA→PWFA [8]. Hybrid wakefield acceleration in combination with Trojan Horse injection promises to become a compact source for x-ray FELs [9] (cf. Figure 7).

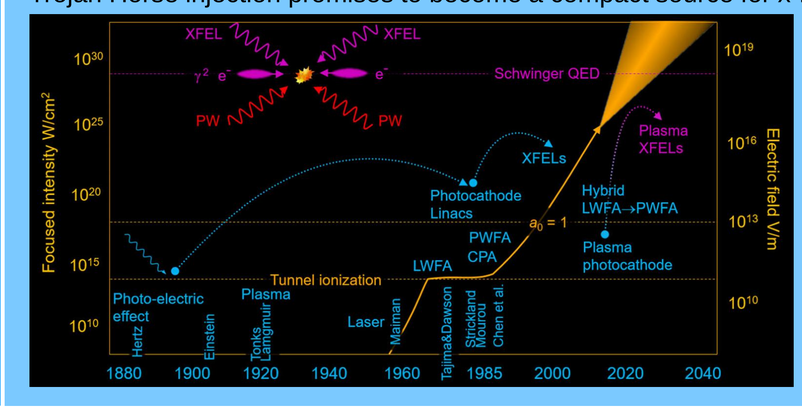


Figure 7: A visualized history and outlook of light and beam sources and their intensity and electric field scaling [1].

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