Driver / witness bunch PWFA experiments at FLASHForward

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The FLASHForward project

Beam-driven plasma-based accelerator research

2018
- Beam plasma dechirper

2019
- Efficiency maximisation & beam loading control
  - kHz to MHz plasma response
  - Drive depletion

2022
- Emittance preservation

2024
- 10 kW avg. power operation

2026

2030
- 10 kW stage with 40% efficiency & witness property conservation
FLASH as PWFA injector

- FLASH (Free-Electron Laser Hamburg) as electron injector for PWFA
- Longitudinal phase space (LPS) shaping with 3rd harmonic module
- LPS measurement: Transverse deflecting cavity in parallel photon beamline

\[
\begin{align*}
\gamma &= 600 - 1200 \text{ MeV} \\
\Delta \gamma / \gamma &= 0.1 \% \\
Q &= 0.3 - 1 \text{ nC} \\
\sigma_z &= 130 - 300 \text{ fs (rms)}
\end{align*}
\]
FLASHForward beamline status

Post plasma diagnostics

✓ Large energy range electron spectrometer
✓ X-band TDS
- High res. spectrometer

Electron beam line

✓ Collimator apparatus in dispersive section
✓ Two sets of quadrupoles: matching & final focussing
✓ Beam capture after plasma

Beam - plasma interaction chamber
Adjustable via hexapod Diagnostics (OTR / YAG)
Plasma channel:
Argon
Discharge triggered $n_p \sim 1-3 \times 10^{16} \text{ cm}^{-3}$
Core experiments at FLASHForward

**Core Study I — X-1: Plasma Cathode**

- **PI:** K. Pöder

**Core Study II — X-2: Plasma Booster**

- **PI:** C. Lindstrøm

**Core Study III — X-3: High-Average Power PWFA**

- **PI:** R. D’Arcy
X-2: External injected PWFA at FLASHForward

- Driver / witness generation
- Preserved 0.1% energy spread
- Transport through 195 mm plasma (Talk: K. Poder)
- TDS commissioning (Talk: P. Gonzalez)
- Goals:
  - Emittance preservation
  - High overall efficiency
  - Beamloading
  - Depletion
- Stable witness acceleration
- Wakefield measurement
- Near-‘matched’ beams
Precision driver / witness bunch pair generation

- Negatively chirped bunch: E-t correlation
- Set of collimators in dispersive section
- Precise tunability of driver / witness specifications (depending on incoming bunch)

Precision driver / witness bunch pair generation

Driver / Witness observed in XTDS

- Negative
- Set off
- Precise speciﬁc

Stable high gradient acceleration

High shot-to-shot stability demonstrated at 1.6 GV/m
Optimised beamloading - tunability is key

- Fine multi-dimensional parameter scan:
  - Plasma density
  - Driver / Witness separation position

1. Precision tunability of driver - witness bunch pair
2. High beam and plasma stability

Energy spread preservation
Wakefield measurements so far

Available techniques

- Spectral interferometry
- Shadowgraphy
- Self-mapping
- Transverse electron probe

(LWFA, $n_0 = 10^{10}$ cm$^{-3}$)

A. Sävert et al., PRL, 2015.
(LWFA, $n_0 = 10^{19}$ cm$^{-3}$)

C. J. Zhang et al., PRL, 2017.
(LWFA, $n_0 > 10^{17}$ cm$^{-3}$)

(PWFA, $n_0=10^{14}$ cm$^{-3}$)

(PWFA, $n_0 = 10^{14}$ cm$^{-3}$)

(PWFA, $n_0=10^{17}$ cm$^{-3}$)
Contributing a direct wakefield measurement

The following slides, which showed our concept of the wakefield measurement and the results, unfortunately had to be removed.
Summary / Outlook

- FLASHForward: stable PWFA
- Generation of driver-witness pair
  - High flexibility / tunability
  - Enables acceleration optimisation
- Direct and precise PWFA wakefield measurement
- Benchmarking of PIC simulations in GV/m regime

- Beamline modifications
  - XTDS installed
  - Emittance measurement diagnostics
- Longer plasma cell
  - Now: 50 mm / 195 mm

- Emittance preservation
  - High overall efficiency
    - Beamloading
    - Depletion
Thank you for your attention ... 

... and your support

DESY technical support (M-Division) 
FLASH management & operators