High Transformer Ratio PWFA using cathode laser based bunch shaping.


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Outline

1. High Transformer Ratio PWFA
2. Photo Injector Test facility at DESY Zeuthen – PITZ
3. Plasma cell
4. PITZ case in simulation
5. Experimental results
6. Prospects
High Transformer Ratio PWFA

Collinear wakefield acceleration (linear theory):

- Fundamental theorem of beamloading: \( E_{\text{acc}}/E_{\text{dec}} \leq 2 \)
  - Only true for symm. bunches
  - Various proposed bunch shapes

\[ \begin{align*}
V^+ &\quad \text{Head} \\
V^- &\quad \text{Tail}
\end{align*} \]

Jiang, Jing, Schoessow, Power, Gai, PRSTAB 15, 011301, 2012

- Allows trade-off between max. acceleration gradient, max. efficiency & max. witness energy gain per driver energy

High Transformer Ratio:

\[ \frac{V^+}{V^-} > 2 \]

Bane, Wilson, Weiland, SLAC-PUB-3528, 1984
Test bed & preparation of electron guns for FLASH and Eu-XFEL

- 20 m Linac
- 1.3 GHz RF gun
- Max. 25 MeV after CDS booster cavity
- 1 pC – 5 nC bunch charge
- Various diagnostics including transverse deflecting cavity
- Highly flexible photocathode laser…
Bunch shaping @ PITZ

- Photocathode laser based bunch shaping
- Laser pulse shape \(\rightarrow\) electron bunch shape
- Tunable pulse shaper of 13 birefringent crystals \(\rightarrow\) addition of 14 amplitude-tunable Gaussian virtual pulses
- Additional pulse added via delayline as witness
PITZ gas discharge plasma cell

- Gas discharge in **Argon**
- 10mm diameter, **100mm length** discharge channel
- 2-10µs pulses of 200 – 1000A
- Electron windows for vacuum separation
- Densities of **up to 5x10^{16} cm^{-3}**
Transformer Ratio definition for measurements

- No direct field measurement
- No controlled injection of witness bunch (witnessing wide phase range)
- Measuring & simulating “effective Transformer Ratio“:

\[
\frac{E_{\text{s} \text{slice}_\text{max}, \text{witness, Plasma On}} - E_{\text{s} \text{slice}_\text{max}, \text{witness, Plasma Off}}}{\max( E_{(\text{mean-slice-energy}, \text{driver, Plasma Off})} - E_{(\text{mean-slice-energy}, \text{driver, Plasma On})})}
\]

- Worst case underestimating TR: highest energy witness electrons with plasma not necessarily at highest energy without plasma
HTR PWFA @ PITZ simulation

- ASTRA electron beam simulation
- HiPACE simulation of Plasma Wakefield Acceleration
- Transformer Ratio ~ 5.5 (calculated from field amplitudes)
Simulated effective TR ~ 6.2

**Simulated phase space**

**Without plasma**

**With plasma**

**Simulated measurement in dispersive section**
Experimental results – bunch shaping

- Demonstrated various bunch shapes
- Witness bunch delay, total charge and driver-witness charge ratio tunable
100 mm Argon gas discharge plasma \((n_p = \sim 10^{12} - 10^{16} \text{ cm}^{-3})\)

- No stable driver transport at densities above \(\sim 10^{15} \text{ cm}^{-3}\)
- Measured TR= -1.5 – 4.9 (preliminary analysis)
- Driver charges 400 - 900 pC, witness/driver charge ratio 1-5%
- max. energy gain \(\sim 1\text{MeV}\)
Future advanced bunch shaping @ PITZ

- 3D-shaping of bunches using SLMs or dispersed photocathode laser
- Designed for production of quasi-ellipsoidal electron bunches for emittance minimisation
- Independent xz and yz shaping
- Under assembly @ PITZ

Simulated emittance minimisation for PITZ case

SLM based shaping principle
Future advanced bunch shaping @ PITZ

- Compensate space charge effects at photocathode
- Improve bunch slice mismatch
- Better tunability of bunch shape

Current, crystal based shaping

SLM based shaping
Conclusions

> High Transformer Ratios > 2 (preliminary results \( \leq 4.9 \)) measured in a PWFA for the first time

> Stable transport for bunchlength \( \sim \lambda_p \) observed

> No experimental differences for triangular and double triangular beam observed

> Measurements done at low gradients \( (\leq 10 \text{ MV/m}) \)

> Electron bunch cathode laser shaping demonstrated for various shapes

> Experiments with upgraded shaping capabilities will continue
Thank you very much for your attention!