Plasma acceleration experiments at DESY Zeuthen

Plasma wakefield acceleration and astrophysics in the lab
Status and prospects

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DPG Frühjahrstagung
Würzburg, March 22, 2018
I.  Plasma wakefield acceleration @ PITZ
   •  PITZ
   •  Plasma cells
   •  Self modulation instability
   •  High transformer ratio PWFA
   •  Future plans

II.  Astrophysics in the Lab
   •  Bell’s instability
   •  CW-beam production
   •  Status
Photo Injector Test facility @DESY Zeuthen site

Electron gun test stand 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 structure (TDS)
- Highly flexible photocathode lasers…
Photo Injector Test facility @DESY Zeuthen site

Electron bunch shaping capabilities

- Pulse stacking to form any temporal shape of 14 Gaussians
- Allows e.g. flat-top & triangular bunches
- New system with temporal and transverse shaping is being set up

G. Loisch et al., Nuclear Instruments & Methods in Physics Research A, in press, 2018
Plasma cells

2 cells for different experimental applications

Lithium plasma cell

- Laser-ionised Lithium vapour in heat pipe oven
- Flexible plasma shape

Argon gas discharge cell

- Simple setup
- Density and length scalable
- Density up to \( \sim 10^{16} \text{ cm}^{-3} \) possible
Self modulation instability (SMI)

Resonant plasma wakefields by transversely modulated, long driver bunch

- Rising edge of bunch current drives wakefield
- Transverse fields cause periodic modulation
- Wakefields driven resonantly by microbunches
- Prospects for driving wakefields with high energy proton bunches
- First direct measurement at PITZ
- Use as plasma diagnostics

Gross et al., Physical Review Letters, in press, 2018

Details see next talk by O. Lishilin
High transformer ratio PWFA

Acceleration with high ratio of witness acceleration to driver deceleration

- Fundamental theorem of beamloading limits
  \[ \frac{E_{\text{acc}}}{E_{\text{dec}}} \leq 2 \]
- Only true in linear regime and for symmetrical bunches
- Various asymmetrical bunch shapes proposed
- Best results for PITZ case for "double triangular" bunches
- Transport of long driver challenging due to instabilities (SMI, hosing, etc.)
High transformer ratio PWFA

Acceleration with high ratio of witness acceleration to driver deceleration

- First demonstration of HTR PWFA
- **Transformer ratio of 4.6** $\pm 2.2 \pm 0.7$
- Proof applicability of bunch shaping scheme
- Plasma density $2 \times 10^{13}$ cm$^{-3}$
- Interaction in nonlinear regime to avoid SMI
PITZ PWFA prospects

Future experiments and plans

• Improve photocathode-laser-based bunch shaping (new laser being set up)
• Investigate SMI development by scanning plasma length (future setup of Lithium cell)
• Show dechirping of bunch with large correlated energy spread
• Further studies enabled by improved bunch shaping (e.g. beamloading…)?
Astrophysics in the Lab

Joint project of three DESY-departments (FLA, THAT, PITZ)

- Investigate origin of high energy (~PeV) cosmic-ray particles
- Main candidate: Bell’s instability
- Scale proposed plasma instabilities to laboratory sizes
- Find turbulences in external magnetic field that build up during electron beam passage (which fit Bell’s instability characteristics)

<table>
<thead>
<tr>
<th></th>
<th>Supernova Remnants</th>
<th>PITZ, DESY</th>
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<tbody>
<tr>
<td>Background magnetic field</td>
<td>(~ \times 10^{-10}) T (1µG)</td>
<td>(~ 0.1 ) T</td>
</tr>
<tr>
<td>Plasma number density</td>
<td>(~ 1 ) cm(^{-3})</td>
<td>(~ 10^{13} ) cm(^{-3})</td>
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<tr>
<td>Spatial scale of turbulence</td>
<td>(10^{13} \sim 10^{14}) m</td>
<td>(0.1 \sim 1) m</td>
</tr>
<tr>
<td>Growth time</td>
<td>(~ 100) yr</td>
<td>(~ 10^{-4}) s(^{-1})</td>
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Continuous beam production in an RF accelerator

- Produce a quasi-cw beam via field emission
- Place field emitter tip on gun cathode (right)
- Emit charge in every RF-cycle (bottom left)
- Stretch bunches in booster cavity (bottom right)
- Simulations suggest beams with 650 µs pulse length, 2.0 mA average current and 1.7 MeV mean energy
Astrophysics in the Lab

Status

• Experimental conditions at PITZ difficult (faster growing instabilities might overlay Bell’s instability for given parameters)

• High bunch current (x mA), high energy (xxx MeV), long bunch duration (ms) proton beams would be optimal…

• Simulations still ongoing
• Extended discharge plasma cell in planning
• Ongoing planning of diagnostics
Plasma acceleration @ PITZ

Summary

- Two main goals reached:
  - Investigation of Self Modulation Instability
  - Achievement of High Transformer Ratios in PWFA
- Further studies on PWFA going on to supply input for high energy experiments (bunch shaping schemes, diagnostics, etc.)
- Astrophysics in the Lab project going into second founding period with prospects for fundamental physics experiments at PITZ or other facilities
Thank you

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