Injection tolerance simulations for AWAKE Run 2

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Abstract

• AWAKE uses the SPS proton beam to accelerate electrons

• Run 2 will control acceleration

• Nonlinear behaviour - simulations important

• Unique properties of AWAKE have required new approaches to plasma simulation
Outline

- AWAKE Run 2
- Simulation challenges and solutions
- Conclusions
Plasma can support fields orders of magnitude larger than conventional accelerators

Proton driver avoids the limitations of electron driver (depletion) and laser driver (dephasing)

BUT – proton beam is very long, need to rely on instabilities
AWAKE – self modulation

Transverse two-stream instability modulates beam into a train of microbunches.
AWAKE – self modulation

Transverse two-stream instability modulates beam into a train of microbunches.
Use two plasma cells

- separates driver modulation and acceleration stages
Use two plasma cells

- additional constrains on witness beamline
- need to investigate injection tolerances
- requires plasma simulations
Simulation challenges

Simulation (protons only over 10 m) takes 40,000 CPU-hours over 3,600 cores, 5 TB memory (MPCDF)
Simulation challenges

Driver and witness naturally have disparate timescales

- driver betatron oscillations \( \nu \left( \frac{m_p 2\gamma_p}{m_e} \right) / \omega_p \)
- witness betatron oscillations \( \nu (2\gamma_w) / \omega_p \)  
  500 – 2000 x faster

Previous simulation methods not suitable for witness studies
Use a short, non-evolving driver to mimic long-beam wakefields

**Toy model**

Driver

Witness

Plasma
Toy model

Use a short, non-evolving driver to mimic long-beam wakefields
Toy model includes

- Beamloading
- Matching

both vital for controlled acceleration along the whole plasma

Olsen et al. PRAB 21, 011301 (2018)

But misses

- evolution of the drive beam
- Direct influence of drive beam on witness
Can we separate the driver/witness timescales for complete simulations? Make use of causality

Simulation 1: upstream driver evolution
- driver betatron oscillations \( \sqrt{\frac{m_p 2\gamma_p}{m_e}}/\omega_p \)

Simulation 2: downstream witness acceleration
- witness betatron oscillations \( \sqrt{2\gamma_w}/\omega_p \)
Use a short, non-evolving driver to mimic long-beam wakefields
Code development

Use a short, non-evolving driver to mimic long-beam wakefields
Excellent agreement

$z=0 \text{ m}$
Code development

Excellent agreement

\[ z = 0 \text{ m} \]
Conclusions

Simulations are important to injection tolerances for AWAKE Run 2

Simulations are demanding, parameter scans require code development to separate timescales

Work is ongoing – goal is fully self-consistent simulations of full driver and witness
References

AWAKE project
“Acceleration of electrons in the plasma wakefield of a proton bunch”

Quasistatic PIC
“Particle-In-Cell Codes for Plasma-based Particle Acceleration”
CERN yellow reports (2016) http://dx.doi.org/10.5170/CERN-2016-001.181

Toy model
“Emittance preservation of an electron beam in a loaded quasilinear plasma wakefield”