Stable positron acceleration in self-generated quasi-hollow channels

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Simulations performed at Marenostrum at Barcelona Supercomputing Center
and JUWELS at Jülich Supercomputing Centre
Positron acceleration and hollow channels

**Positron acceleration**

- Linear regime has low acceleration gradients and non-linear transverse forces
- Blowout regime has a very limited region of accelerating and focusing fields for positrons.
- Some alternatives studied are
  - Self-loaded wakefields\(^1\) [energy transfer from head to tail]
  - On-axis filaments driven by Laguerre-Gaussian lasers\(^2\)

**Hollow channels**

- Hollow channels are promising candidates for electron and positron acceleration.
  ✓ (Nearly) vanishing transverse forces\(^3\); emittance preservation
  ✓ Long drivers are allowed; high transformer ratio
  ✗ Beam breakup instabilities are a severe constrain for this scheme\(^4\)
- Hollow channel generation
  - Laser with high order Bessel profile\(^5\)
  - Tightly focused positron beams\(^6\)
- Recent breakthrough: coaxial plasma filament mitigates beam breakup\(^7\).

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1 S. Corde et al., Nature **524**, 442 (2015)
4 C. B. Schroeder et al., PRL **82**, 1177 (1999)
7 A. Pukhov and J. P. Farmer, PRL **121**, 264801 (2018)
Quasi-hollow channels have been proposed as a way to mitigate beam breakup for acceleration of electron beams. 

This work

- Self-consistent generation of a quasi-hollow channel with structures near the axis that can focus positrons.
- Positron acceleration in the generated structures
- Hosing is not a problem!
  - Slow growth
  - Saturates at acceptable levels

1 C. B. Schroeder et al., PoP 20, 080701 (2013)
Hollow channel generation
how we generate an almost hollow channel with structures that can focus $e^+$

Positron acceleration
optimizations, beam evolution, and stability

Summary and future work
Blowout regime in beam driven plasma accelerators and the long-time plasma evolution

All the simulation results shown in this presentation are in 3D using **Osiris 4.0** with the Fei solver for Cherenkov mitigation.

**SLAC-like driver beam**
- \( E = 10 \text{ GeV} \)
- \( q = 3 \text{ nC} \)
- \( \sigma_x \times \sigma_y \times \sigma_z = 10 \times 10 \times 10 \text{ (\mu m)^3} \)
- Gaussian profile

**Hydrogen plasma**
- Uniform profile
- \( n_0 = 1 \times 10^{16} \text{ cm}^{-3} \)

- Previous work: how does the energy deposited by the beam in the plasma is distributed among the particles and fields at large timescales?\(^2\)
- Observation of quasi-hollow channels in certain regimes.

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1 F. Li et al., Computer Physics Communications 214 (2017)
2 R. Zgadzaj et al., submitted.
Ponderomotive-like force rules the plasma long-time evolution

Looking over several plasma wave periods

Ponderomotive-like average fields dictates the ion motion\textsuperscript{1,2,3}

- Gray region: ions are attracted towards the axis.
- White region: ions are pushed away from axis.

\textsuperscript{1} J.Vieira et al., PRL \textbf{109}, 145005 (2012)
\textsuperscript{2} M.F.Gilljohann et al., PRX \textbf{9}, 011046 (2019)
\textsuperscript{3} R. Zgadzaj et al., submitted.
Unpublished results
Hollow channel generation
how we generate an almost hollow channel with structures that can focus e*

Positron acceleration
optimizations, beam evolution, and stability

Summary and future work
Unpublished results
Positron beam is accelerated with minimal hosing growth
Positron beam is accelerated without losing quality

Acceleration characteristics

- Initially chirped energy$^*$ is partially compensated during acceleration$^\ddagger$
- Acceleration gradient 3.5GV/m
- < 30% emittance growth
- Somewhat optimized beam-loading

$^*$ For hosing mitigation [T.Mehrling et al., PRL 118, 174801 (2017)]
$^\ddagger$ A. Ferran Pousa et al., PRL 123, 054801 (2019)
Hosing growth and saturation

- Simulations still ongoing…
- Black curve: initially symmetric beam
- Blue and red curves: seeded hosing

Saturation at very reasonable values!
Hollow channel generation
how we generate an almost hollow channel with structures that can focus $e^*$

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Summary and future work
Summary & Future Work

Generation of a quasi-hollow channel with structures that can focus positrons

Simulations show quality positron acceleration in this scheme
- Small emittance growth
- Minimal hosing growth, saturation at reasonable values

On-going work: seeding hosing
- Promising results thus far

Setup not fully optimized. Driver(s) beam(s) optimization (charge, shape) could lead to higher acceleration gradients. Plasma density and gas used could also have an impact