Stable positron acceleration in self-generated quasi-hollow channels

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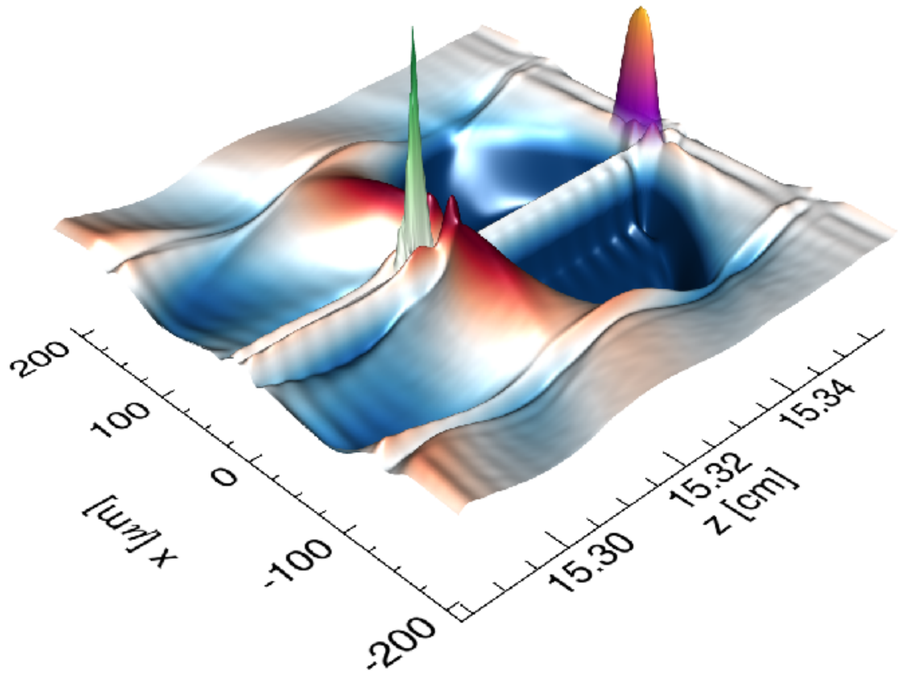
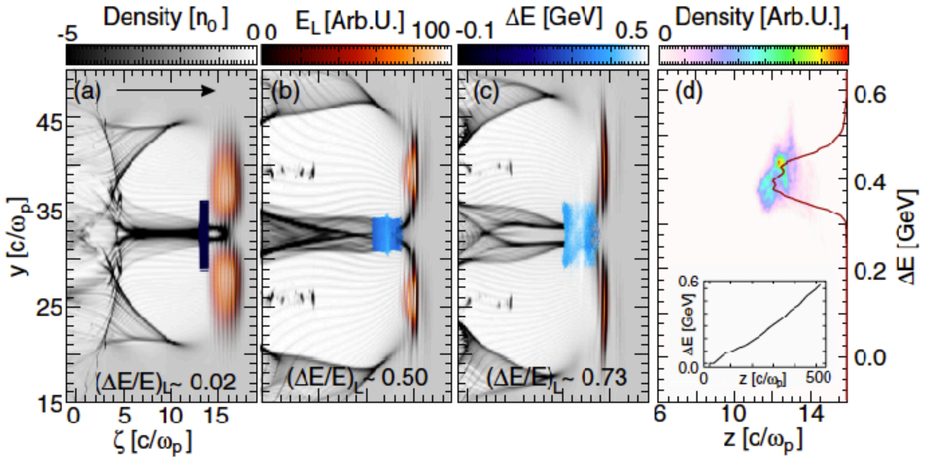


Simulations performed at Marenostrum at Barcelona Supercomputing Center and JUWELS at Jülich Supercomputing Centre

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]



1 S. Corde *et al.*, Nature **524**, 442 (2015)
2 J.Vieira and J.T. Mendonça., PRL **112**, 215001 (2014)

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].

3 T. C. Chiou *et al.*, PoP **2**, 310 (1995)
4 C. B. Schroeder *et al.*, PRL **82**, 1177 (1999)
5 S. Gessner *et al.*, Nat. Comm. **7**, 11785 (2016)
6 L. D. Amorim *et al.*, AIP Conf. Proc. **1777**, 070001 (2016)
7 A. Pukhov and J. P. Farmer, PRL **121**, 264801 (2018)

Generation of a quasi-hollow channel suitable for e^+ acceleration

Quasi-hollow channels have been proposed as a way to mitigate beam breakup for acceleration of electron beams[1]

This work

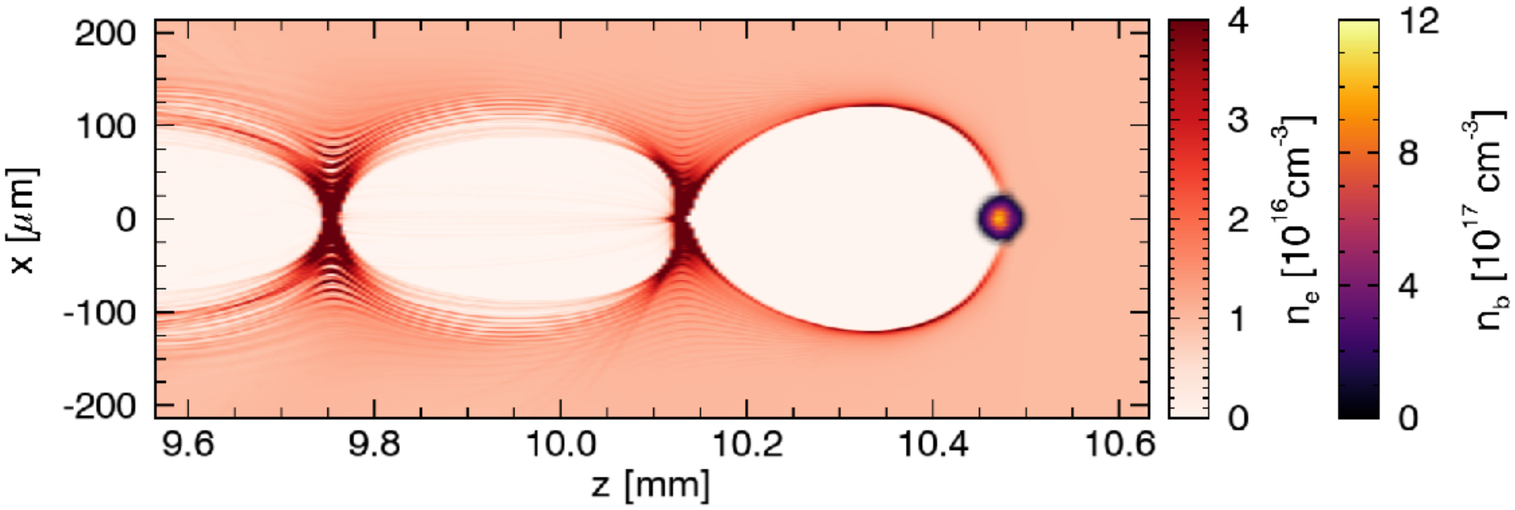
- **Self-consistent generation of a quasi-hollow channel with structures near the axis that can focus positrons.**
- **Positron acceleration in the generated structures**
- **Hosing is not a problem!**
  - Slow growth
  - Saturates at acceptable levels

1 C. B. Schroeder *et al.*, PoP **20**, 080701 (2013)

Contents

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[1]



SLAC-like driver beam

- E = 10 GeV
- q = 3 nC
- $\sigma_x \times \sigma_y \times \sigma_z$ = 10 × 10 × 10 (μm)^3
- Gaussian profile

Hydrogen plasma

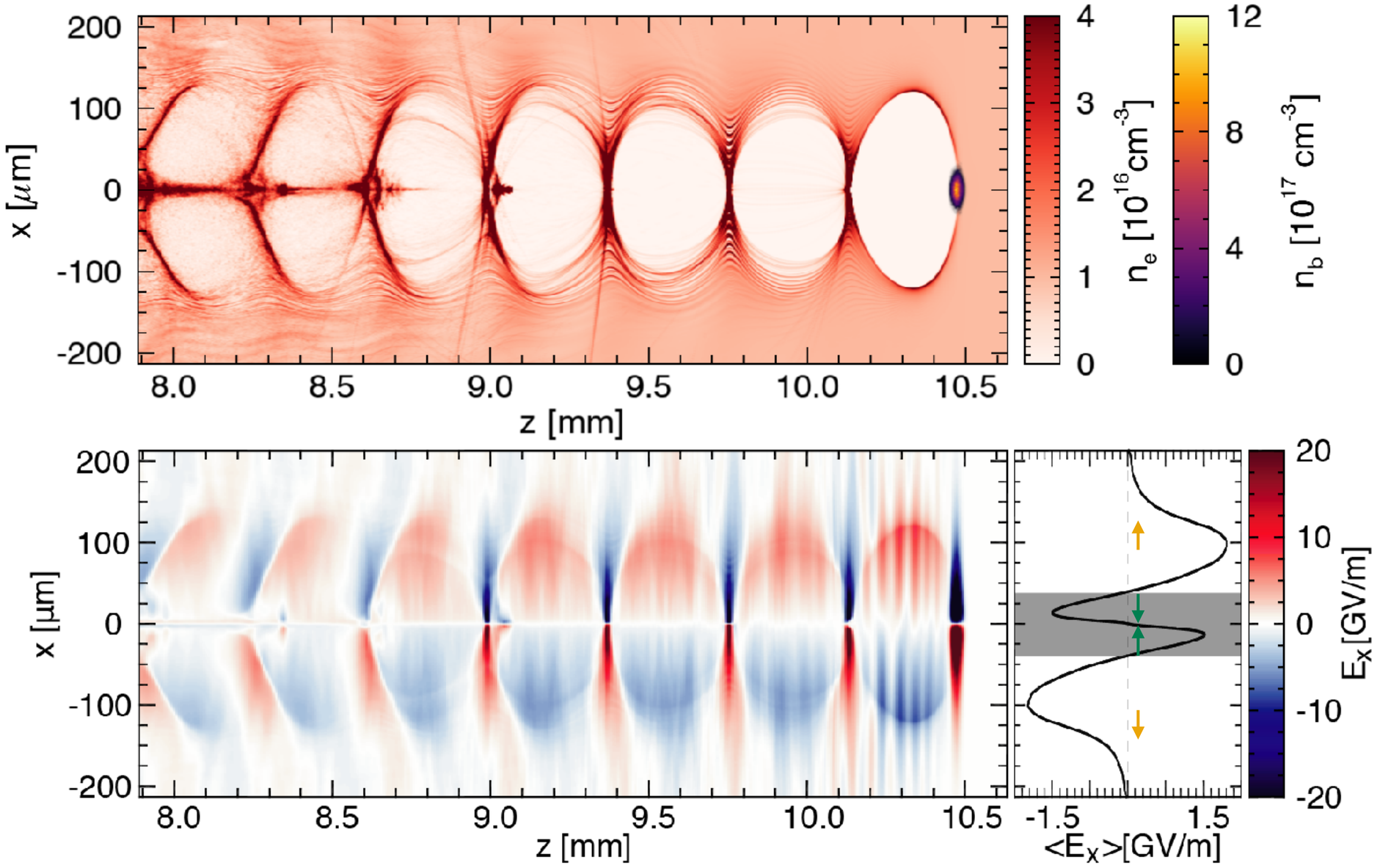
- Uniform profile
- n_0 = 1×10^{16} cm^{-3}

Blowout regime: known for electron acceleration

- 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.

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[1,2,3]

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

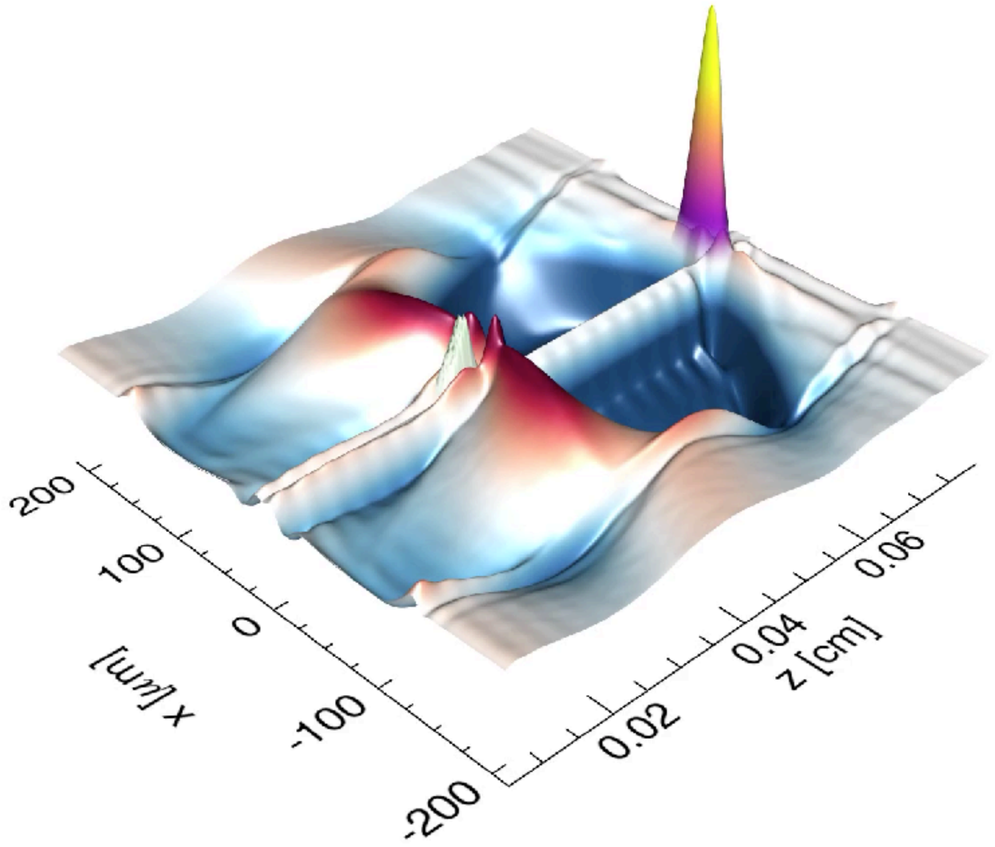
1 J.Vieira *et al.*, PRL **109**, 145005 (2012)
2 M.F.Gilljohann *et al.*, PRX **9**, 011046 (2019)
3 R. Zgadzaj *et al.*, submitted.

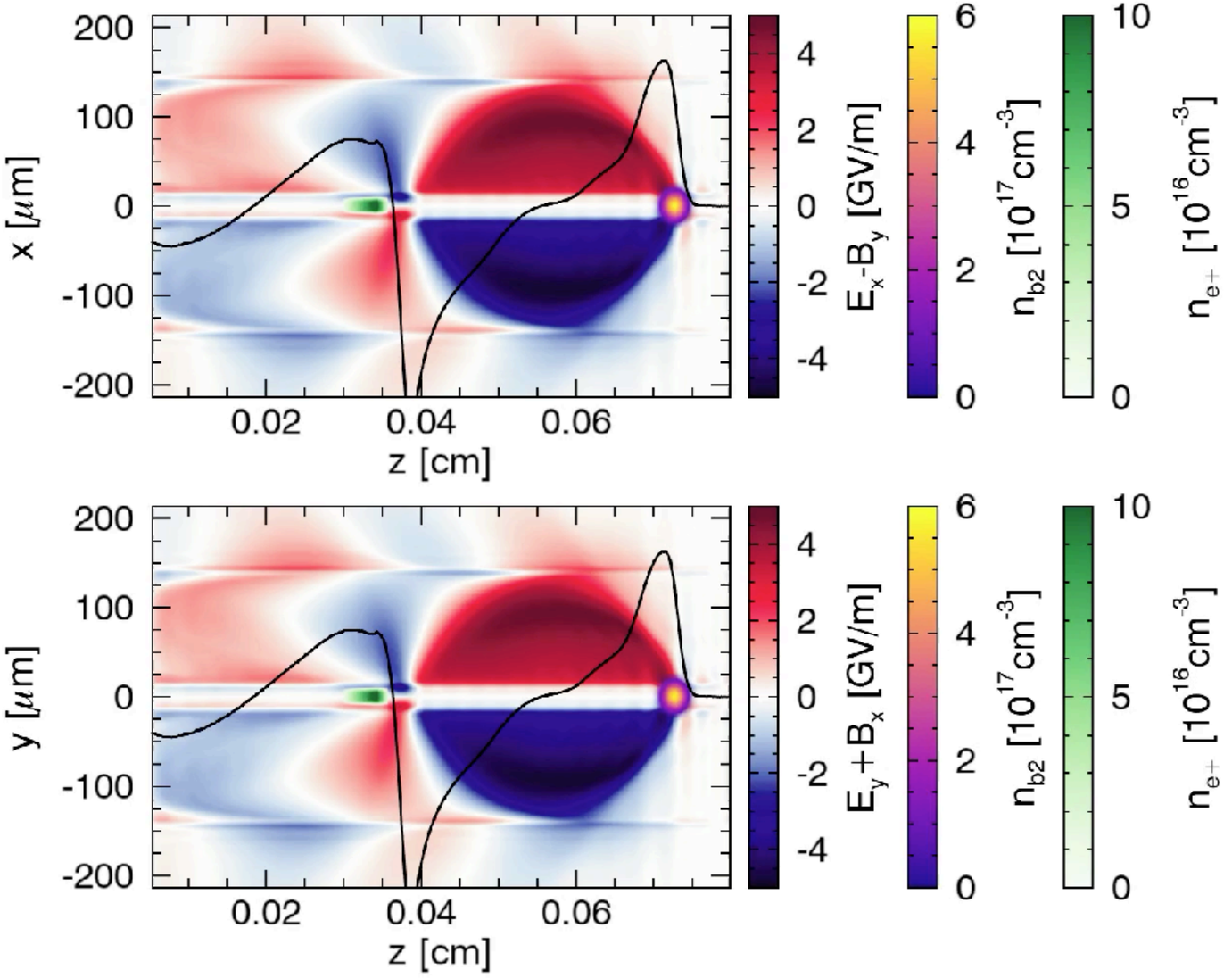
Unpublished results

Contents

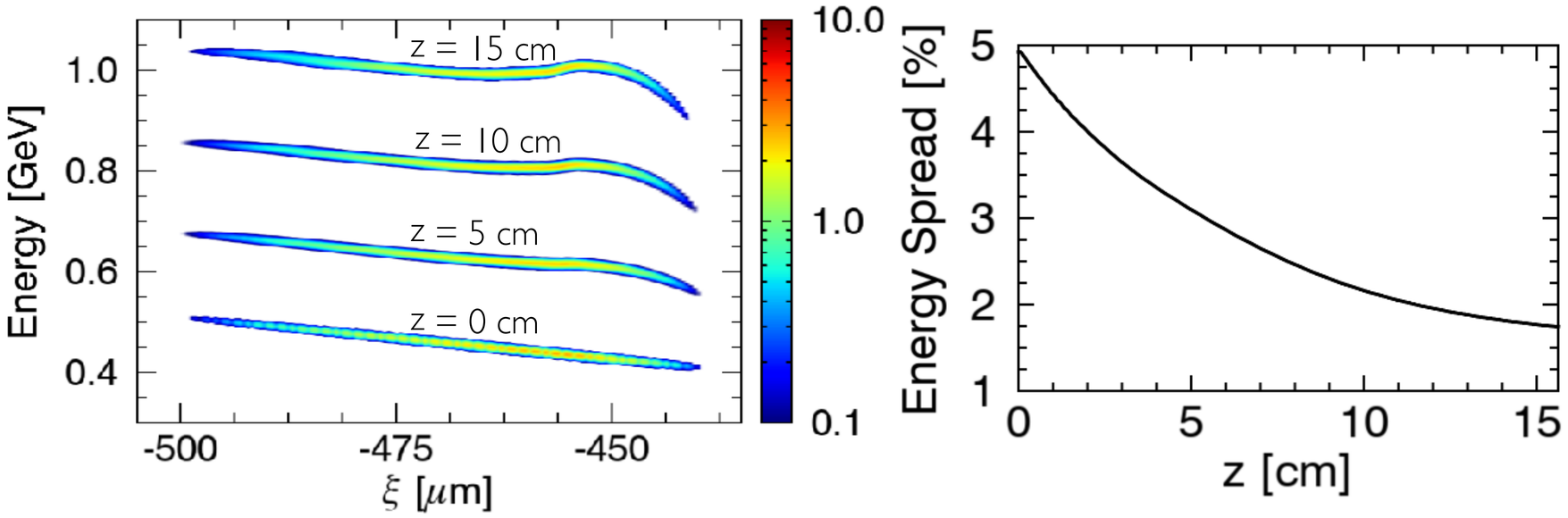
Unpublished results

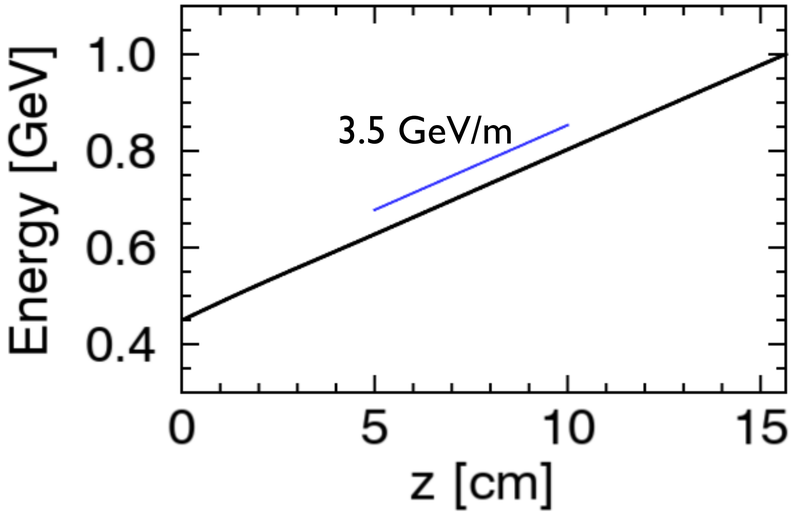
Positron beam is accelerated with minimal hosing growth

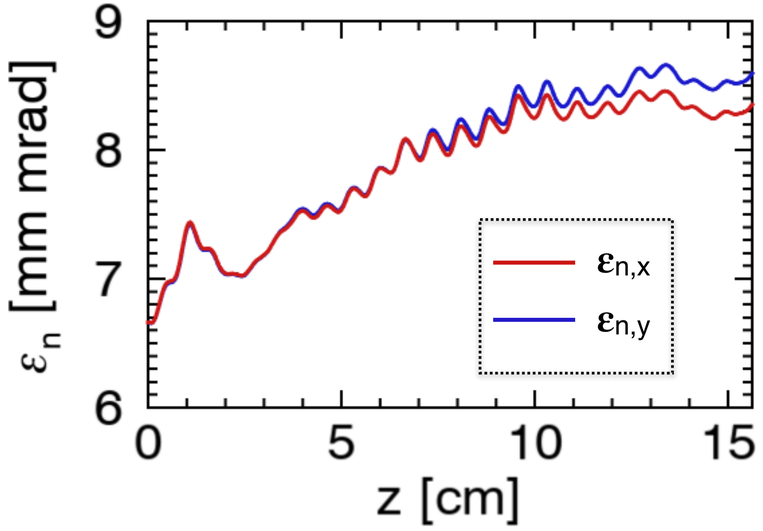




Positron beam is accelerated without losing quality







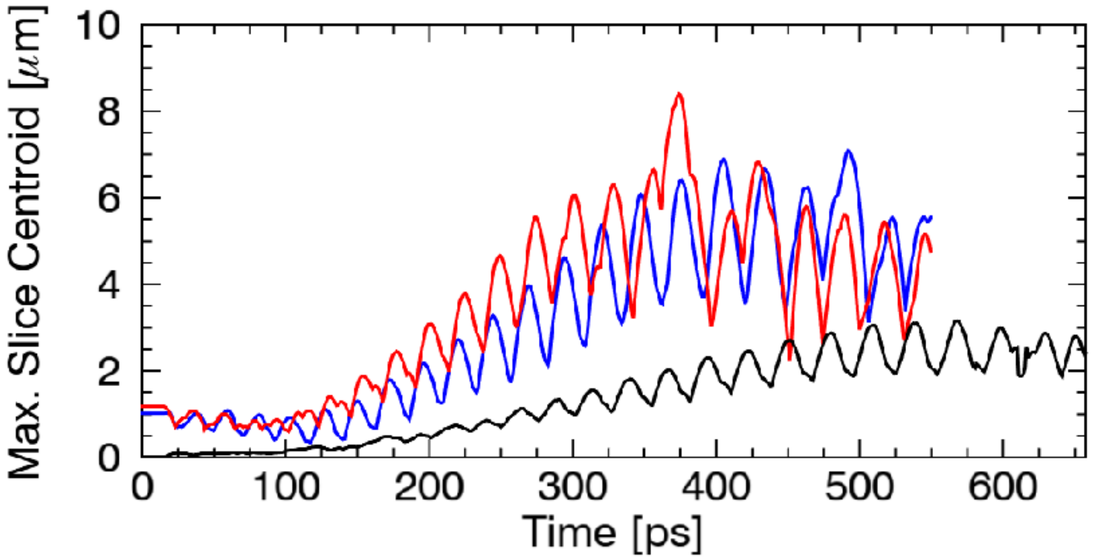
Acceleration characteristics

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

* For hosing mitigation [T.Mehrling *et al.*, PRL **118**, 174801 (2017)] ‡ A. Ferran Pousa *et al.*, PRL **123**, 054801 (2019)

+ hosing saturation

Hosing growth and saturation



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

Saturation at very reasonable values!

Contents

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