Stable positron acceleration in self-generated quasi-hollow channels

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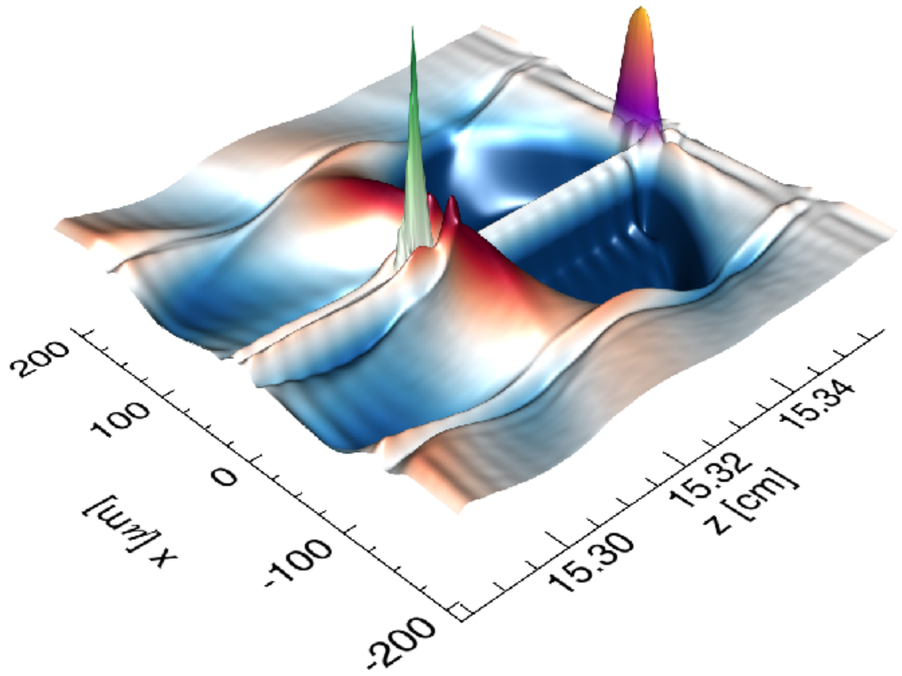
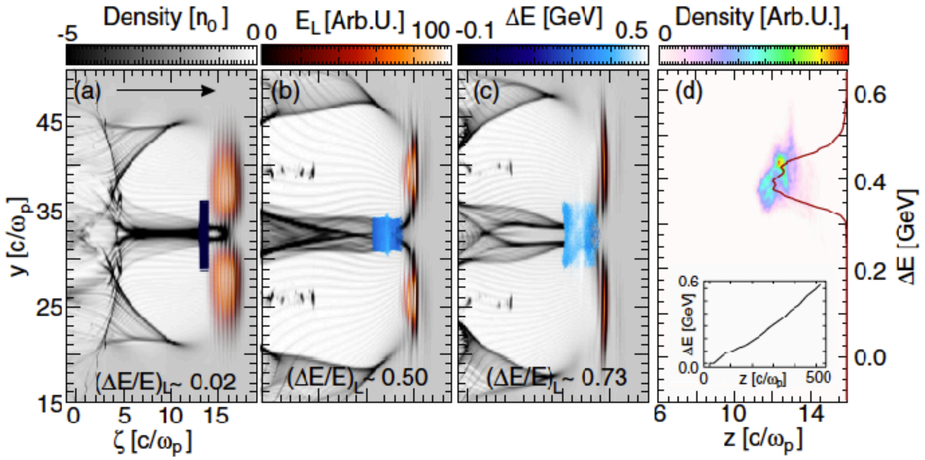


Simulations performed at Marenostrum at Barcelona Supercomputing Center and JUWELS at Jülich Supercomputing Centre

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

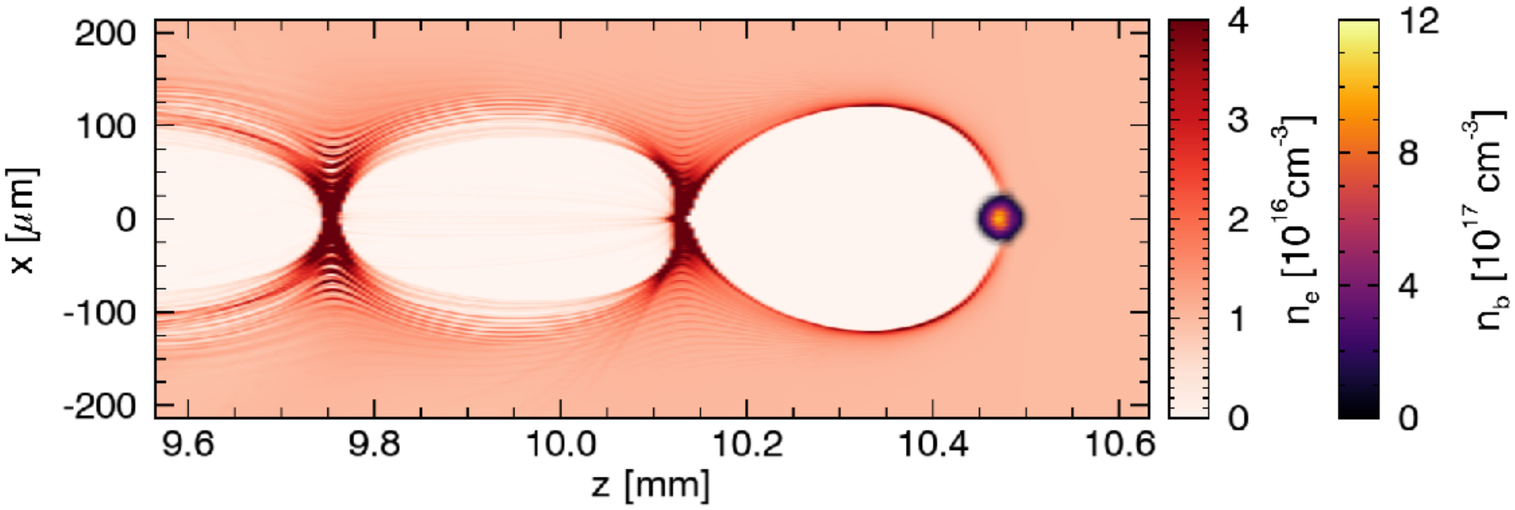
- **Self-consistent generation of a quasi-hollow channel with structures near the axis that can focus positrons.**
- **Positron acceleration in the generated structures**
- **Hosing is not a problem!**
  - Saturates at acceptable levels

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
- $\sigma_x \times \sigma_y \times \sigma_z = 10 \times 10 \times 10$ $(\mu m)^3$
- Gaussian profile

Hydrogen plasma

- Uniform profile
- $n_0 = 1 \times 10^{16}$ cm^{-3}

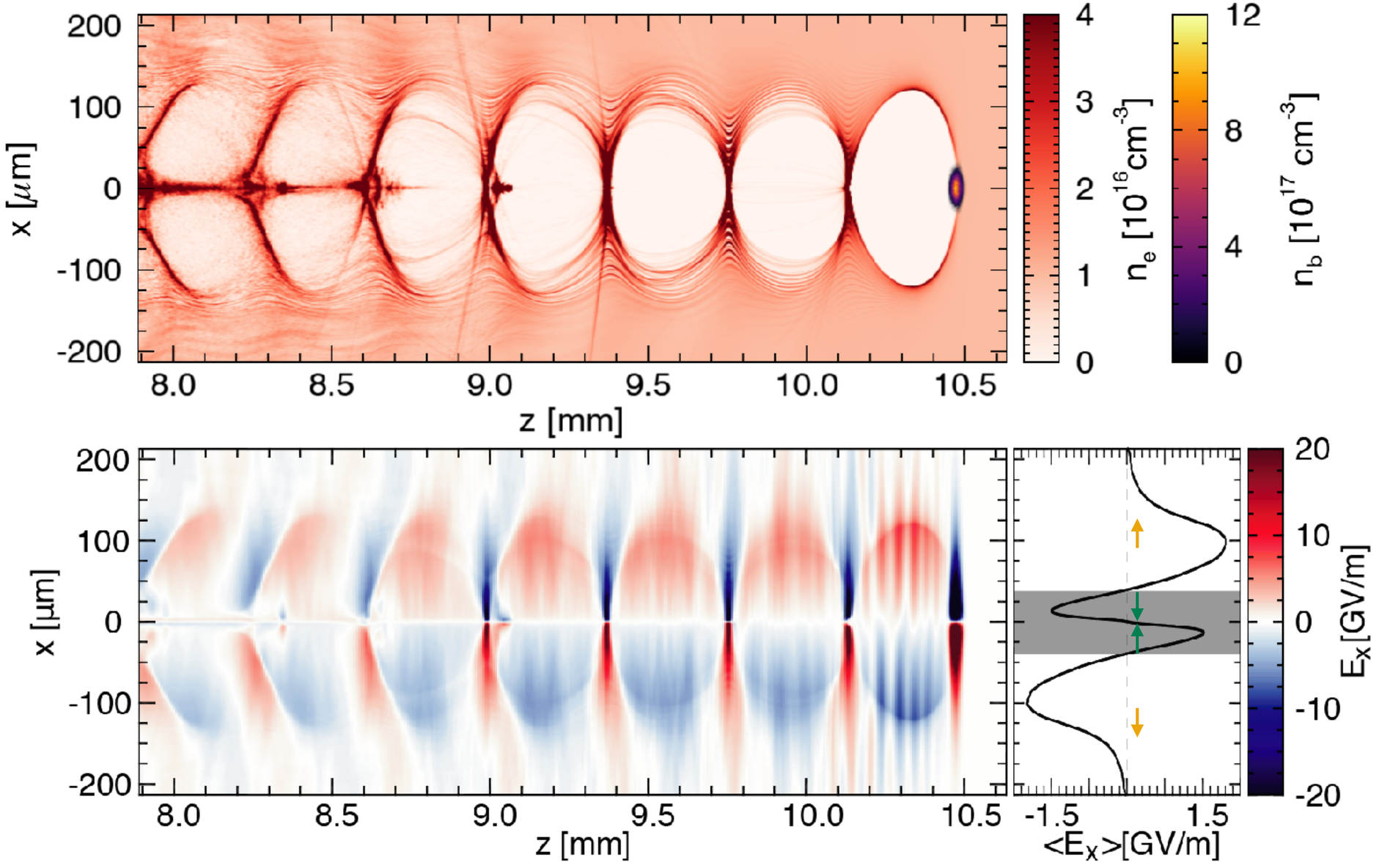
Others kinds of drivers under investigation

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.

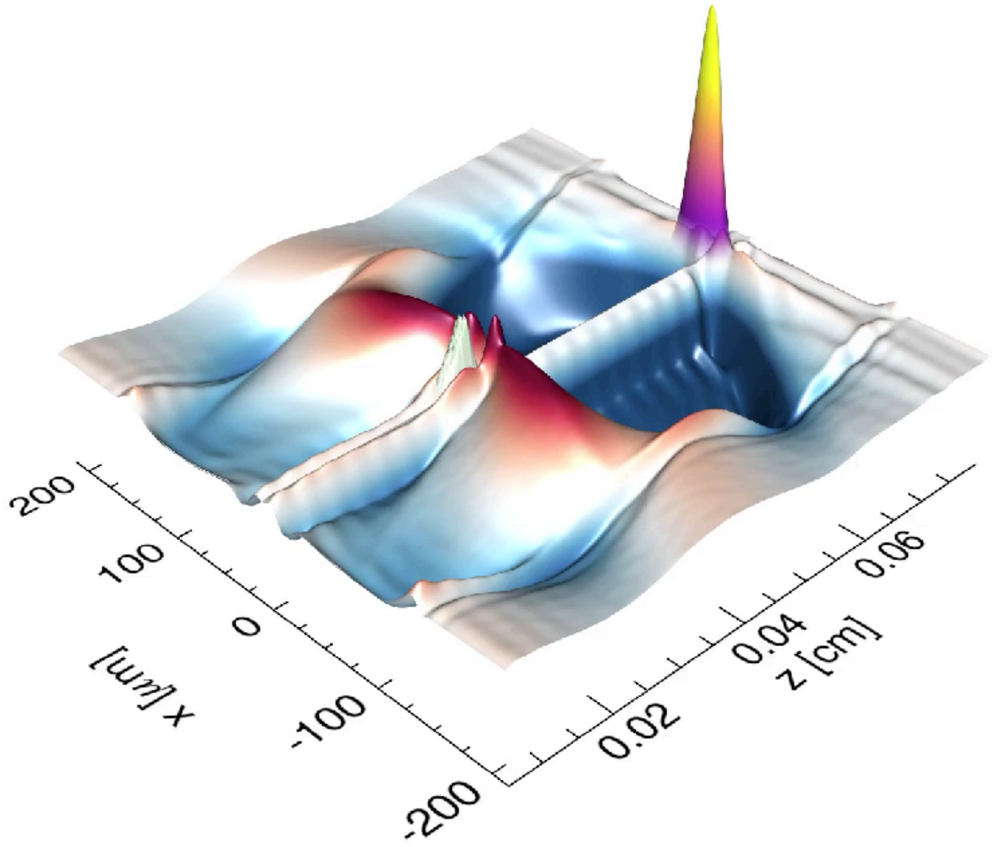
1 J.Vieira *et al.*, PRL **109**, 145005 (2012)
2 M.F.Gilljohann *et al.*, PRX **9**, 011046 (2019)
3 R. Zgadzaj *et al.*, submitted.

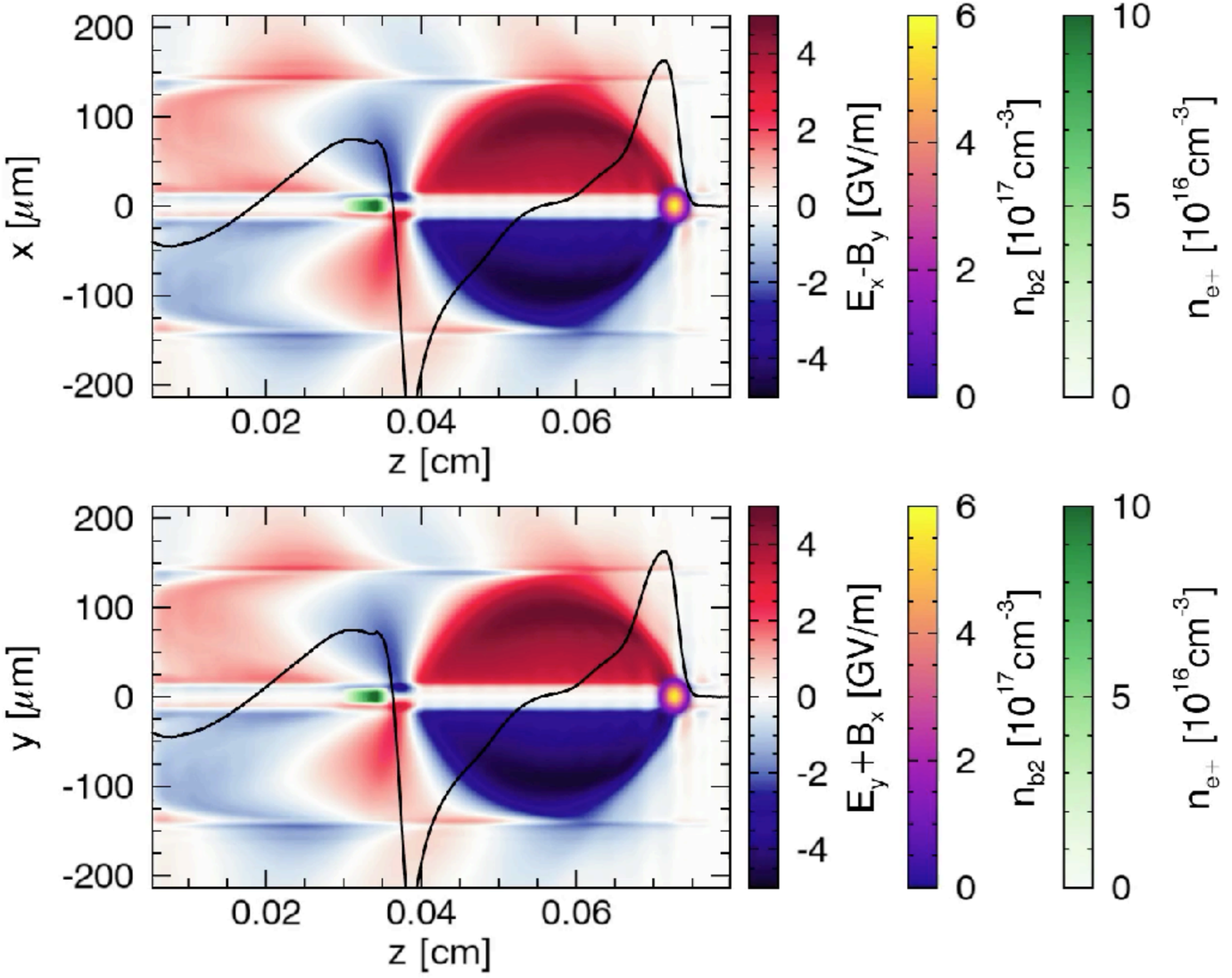
Unpublished results

Contents

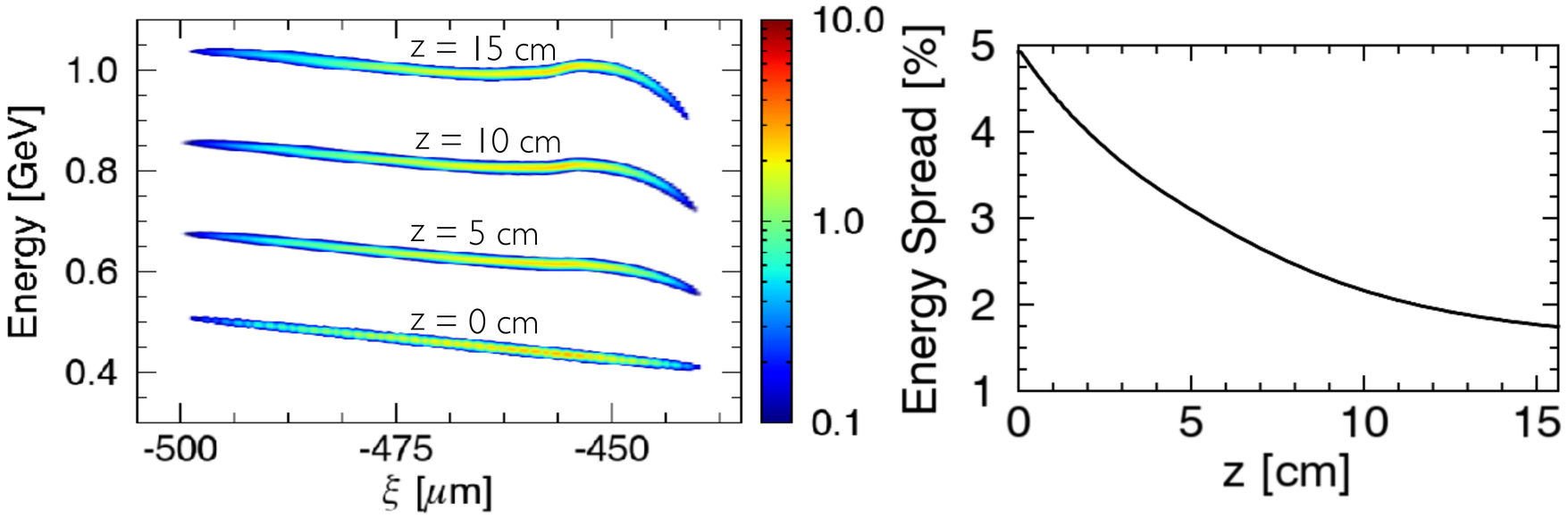
Unpublished results

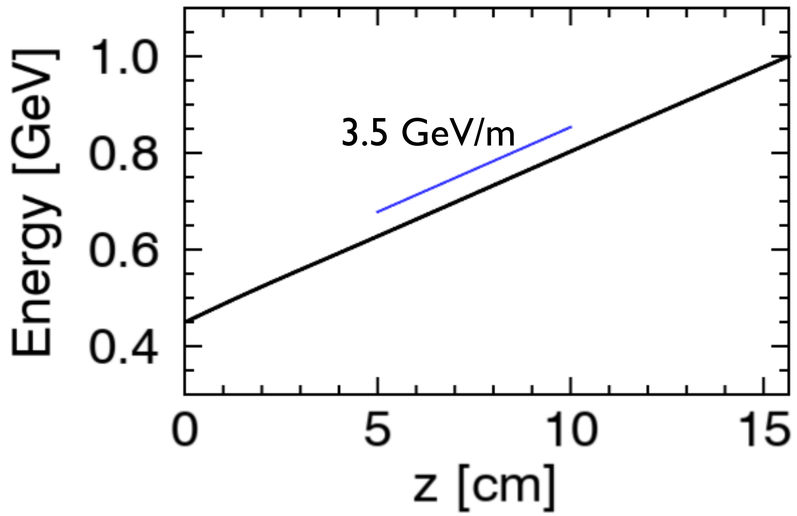
Positron beam is accelerated with minimal hosing growth

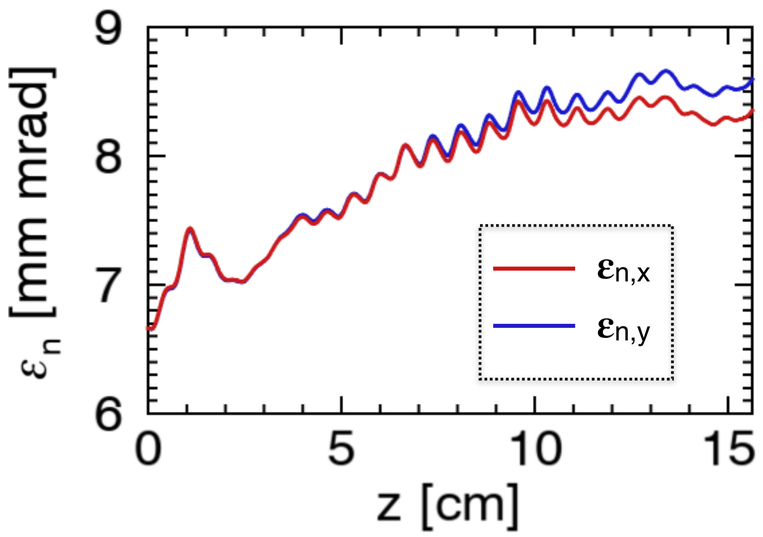




Positron beam is accelerated without losing quality







e⁺ and driver parameters

- **Initial e⁺ beam parameters**
  - E = 450 MeV
  - q = 100 pC
  - $\sigma_x \times \sigma_y \times \sigma_z = 7.5 \times 7.5 \times 53\ (\mu m)^3$
  - Triangular profile†
- **Initial e⁻ driver beam parameters**
  - E = 10 GeV
  - q = 1.5 nC
  - $\sigma_x \times \sigma_y \times \sigma_z = 10 \times 10 \times 10\ (\mu m)^3$
  - Gaussian profile

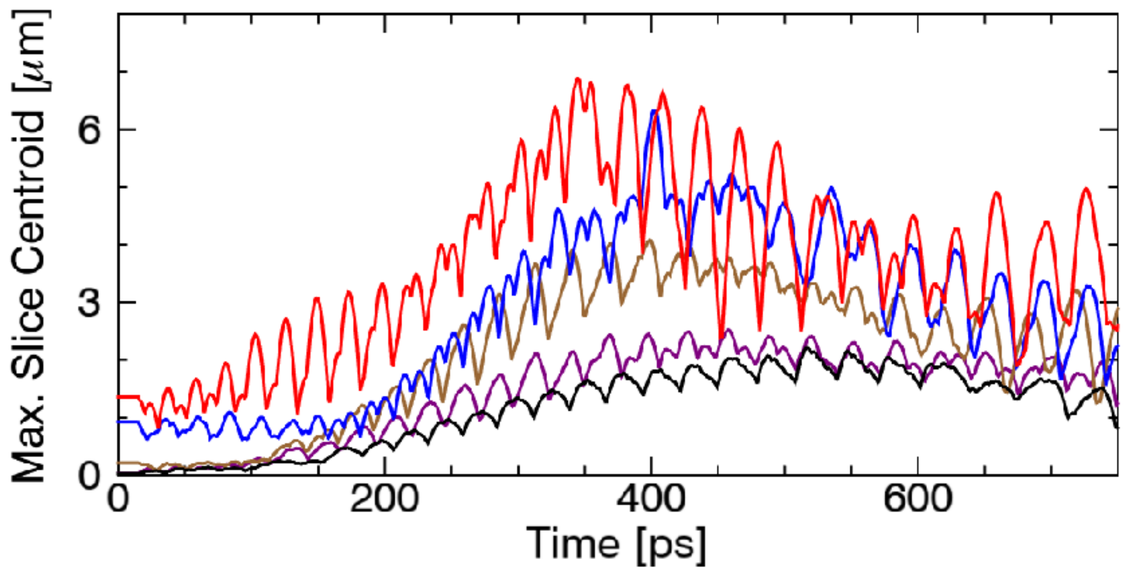
Acceleration characteristics

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

†Tzoufras *et al.*, PRL **101**, 145002 (2008) * For hosing mitigation [Mehrling *et al.*, PRL **118**, 174801 (2017)] ‡Pousa *et al.*, PRL **123**, 054801 (2019)

Hosing saturation

Hosing growth and saturation



- Black curve: initially symmetric beam
- Other curves are different levels of initial seed

Saturation at very reasonable values!

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Summary & Future Work

Plasma long-time evolution after the blowout generates a quasi-hollow channels 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: optimal beam loading and different drivers

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