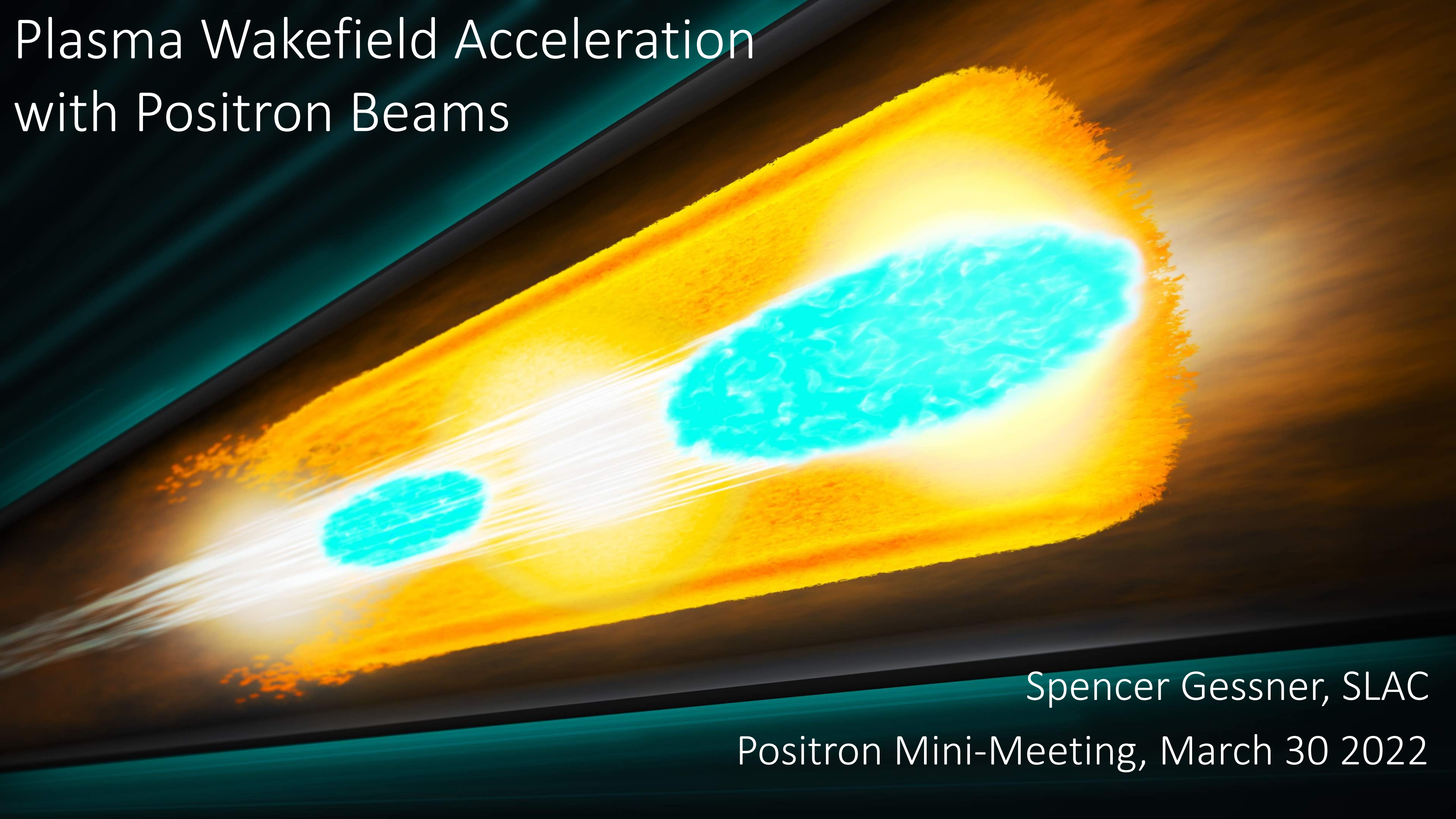
Plasma Wakefield Acceleration with Positron Beams



Spencer Gessner, SLAC

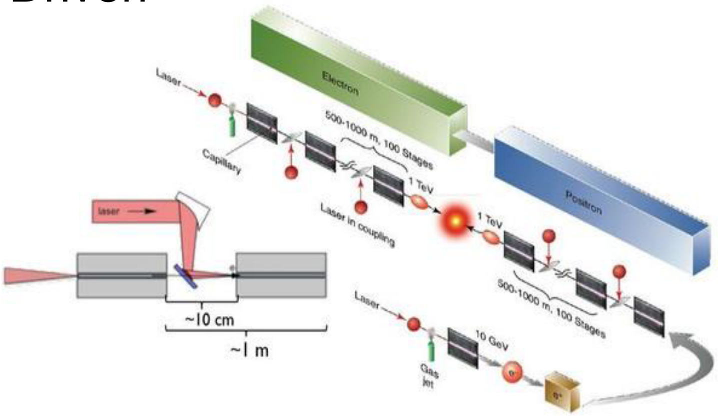
Positron Mini-Meeting, March 30 2022

Intro

- Why is positron acceleration in plasma important?
- Why is positron PWFA important *at SLAC*?
- What are the challenges associated with positron PWFA?

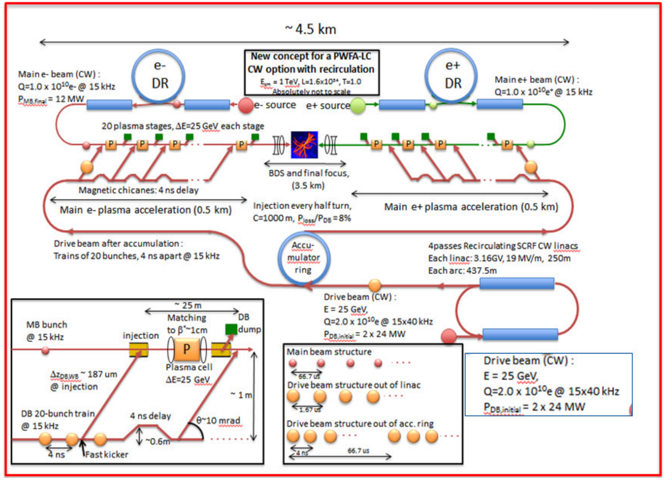
The Plasma Linear Collider

Laser-Driven



C. B. Schroeder *et. al*. Phys. Rev. ST Accel. Beams **13**, 101301

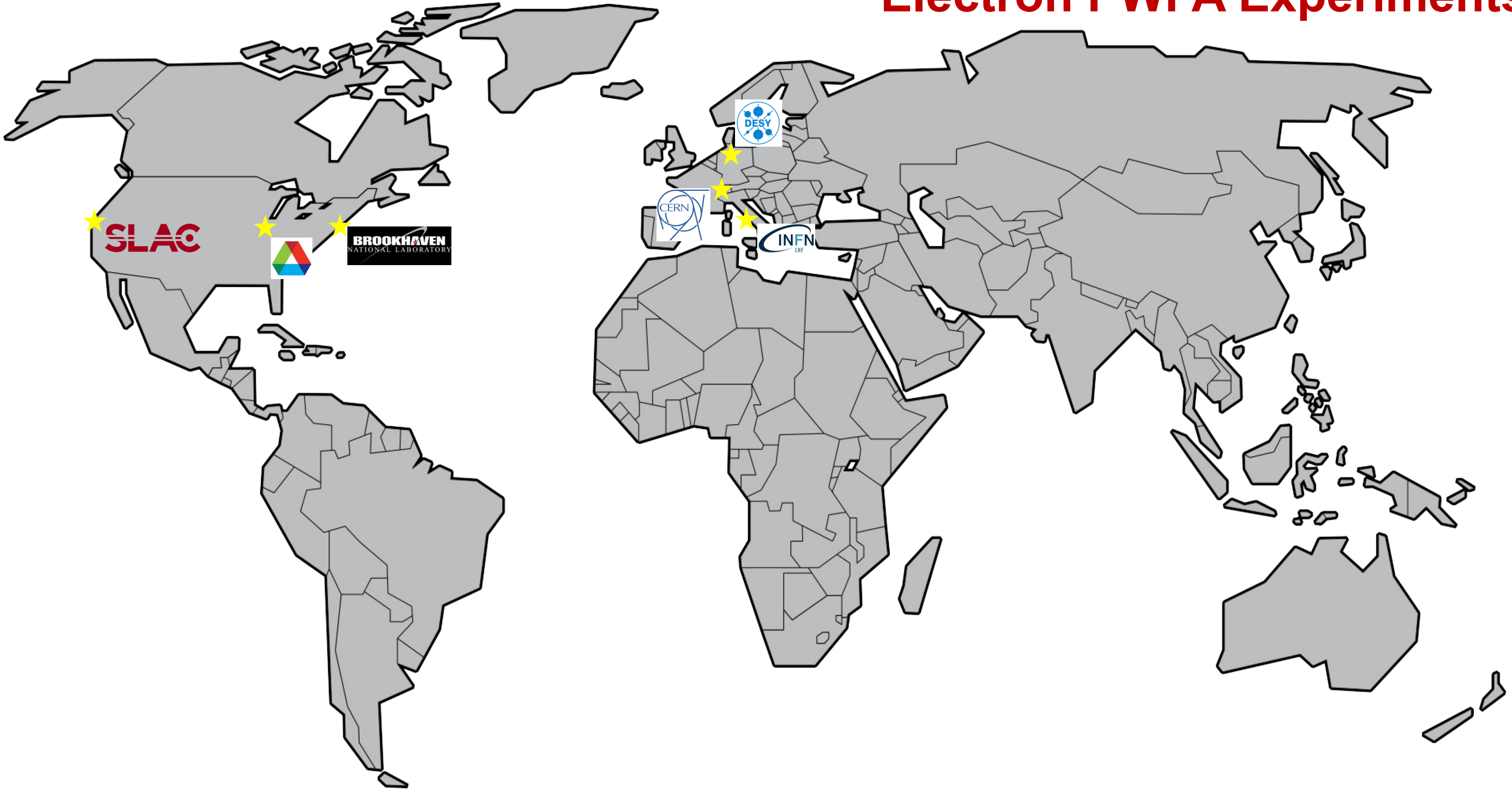
Beam-Driven



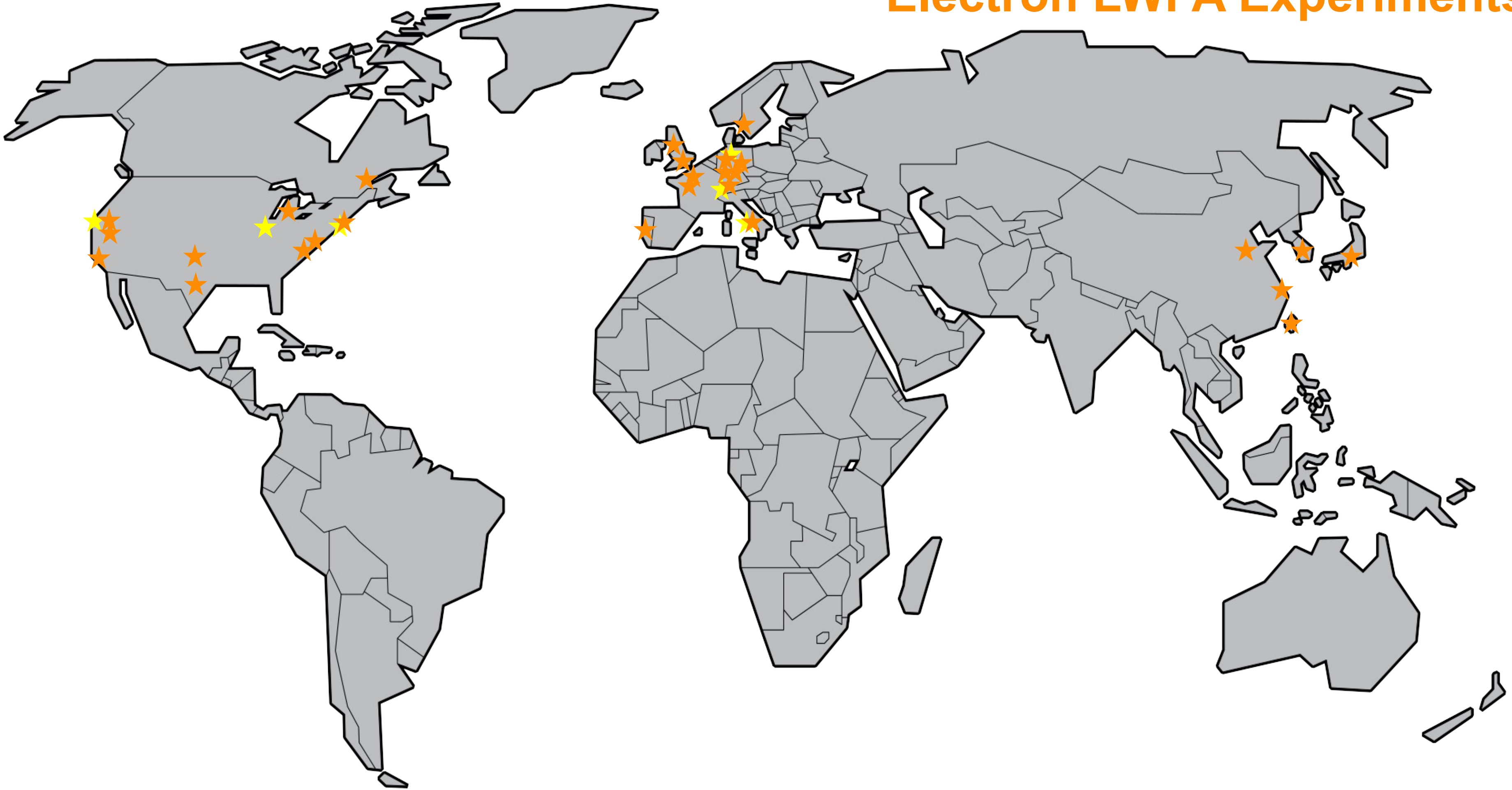
E. Adli *et. al*.,arXiv:1308.1145 [physics.acc-ph]

The positron beam is 50% of a future Plasma Linear Collider!

Electron PWFA Experiments



Electron LWFA Experiments



Positron PWFA Experiments

Positron PWFA Experiments by the Numbers

SLAC

1 Laboratory: SLAC

3* Facilities: FFTB, FACET, *FACET-II

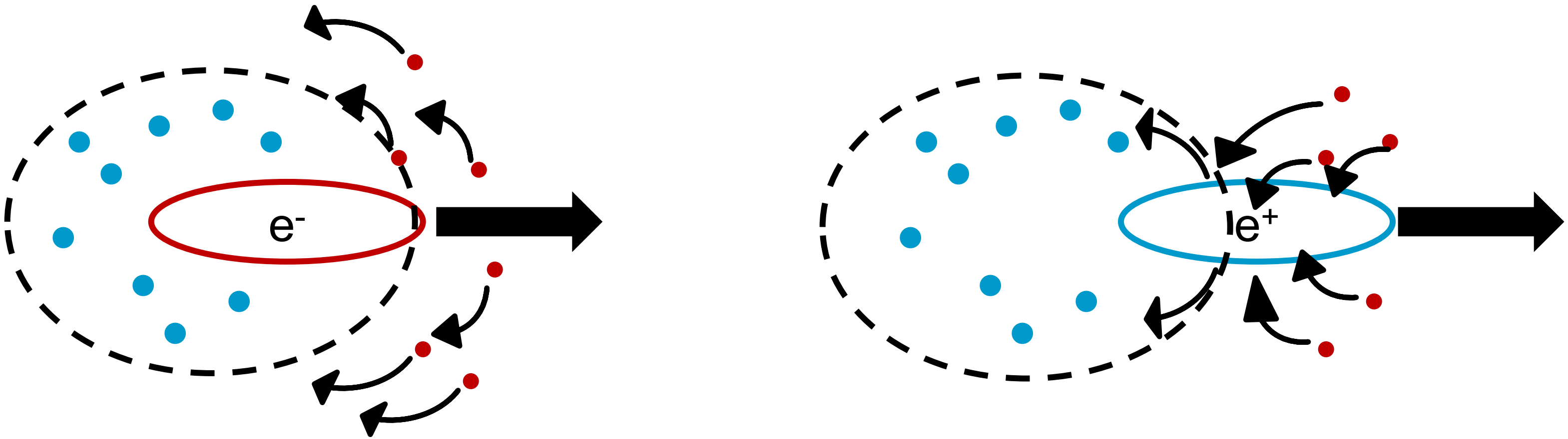
4* Experiments: E162, E200, E225, *E333

8* Publications:

- Ultrarelativistic-Positron-Beam Transport through Meter-Scale Plasmas, M. J. Hogan et. al. *Phys. Rev. Lett.* 90 205002 (2003).
- Plasma-Wakefield Acceleration of an Intense Positron Beam, B. Blue et. al. *Phys. Rev. Lett.* 90 214801 (2003).
- Halo Formation and Emittance Growth of Positron Beams in Plasmas, P. Muggli et. al. *Phys. Rev. Lett.* 101 055001 (2008).
- Multi-gigaelectronvolt acceleration of positrons in a self-loaded plasma wakefield, S. Corde et. al. *Nature.* 524 442445 (2015).
- Demonstration of a positron beam-driven hollow channel plasma wakefield accelerator, S. Gessner et. al. *Nat. Comm.* 7 11785 (2016).
- Acceleration of a trailing positron bunch in a plasma wakefield accelerator, A. Doche et. al. *Nat. Sci. Rep.* 7 14180 (2017).
- Measurement of Transverse Wakefields Induced by a Misaligned Positron Bunch in a Hollow Channel Plasma Accelerator, C. A. Lindstrøm et. al. *Phys. Rev. Lett.* 120 124802 (2018).
- *Acceleration of a Trailing Positron Bunch by a Positron Beam-Driven Wake in a Hollow Channel Plasma, S. J. Gessner et al *To be submitted* (2022).

The positron beam is 50% of a PLC but only receives a small fraction of the research attention.

The Challenge

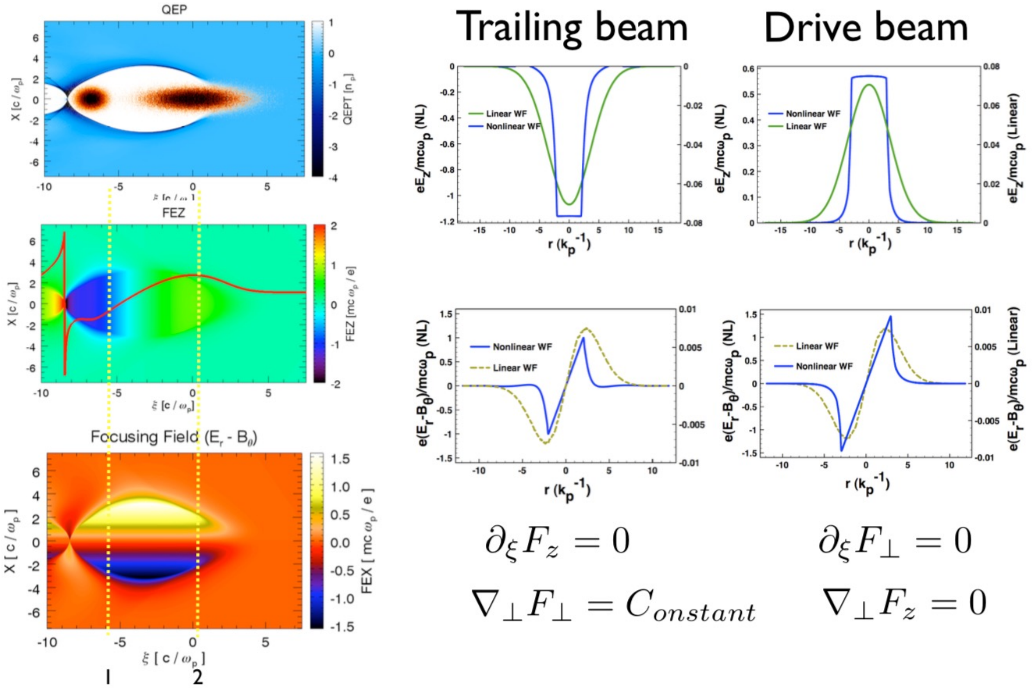


$$m_{ion} >> m_{elec}$$

The plasma electrons are mobile but the plasma ions are not. The plasma responds *asymmetrically* to beams of opposite charge. No other accelerating mechanism exhibits this behavior!

The Case for Electron Acceleration

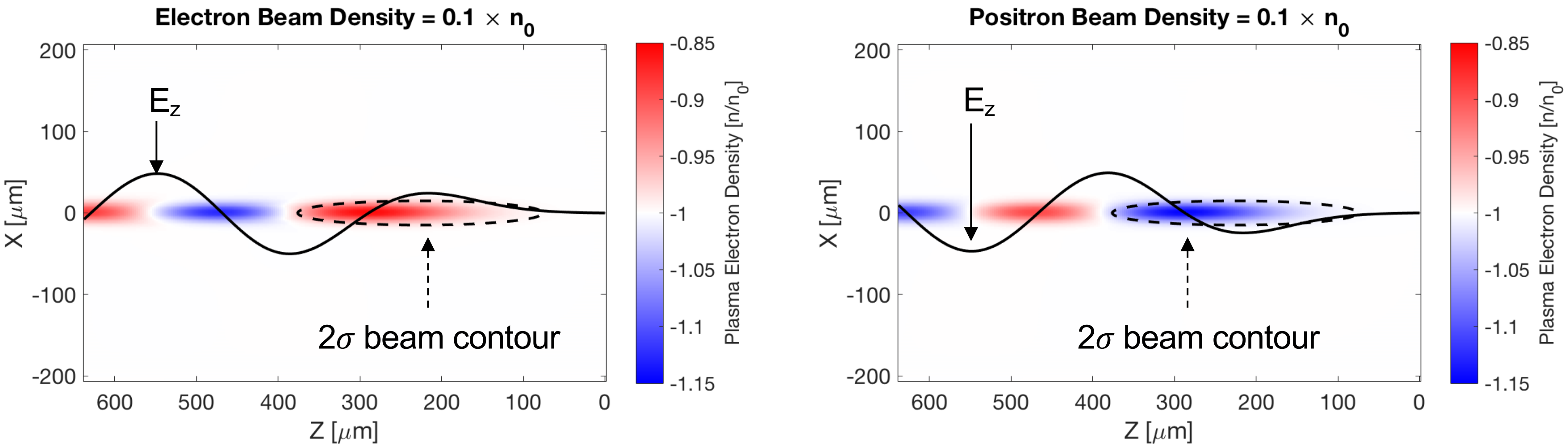
Nonlinear wakefield is IDEAL for accelerating/focusing electrons
Trailing beam does not modify focusing fields of wake



$$\partial_\xi F_z = 0 \qquad \partial_\xi F_\perp = 0$$

$$\nabla_\perp F_\perp = C_{onstant} \qquad \nabla_\perp F_z = 0$$

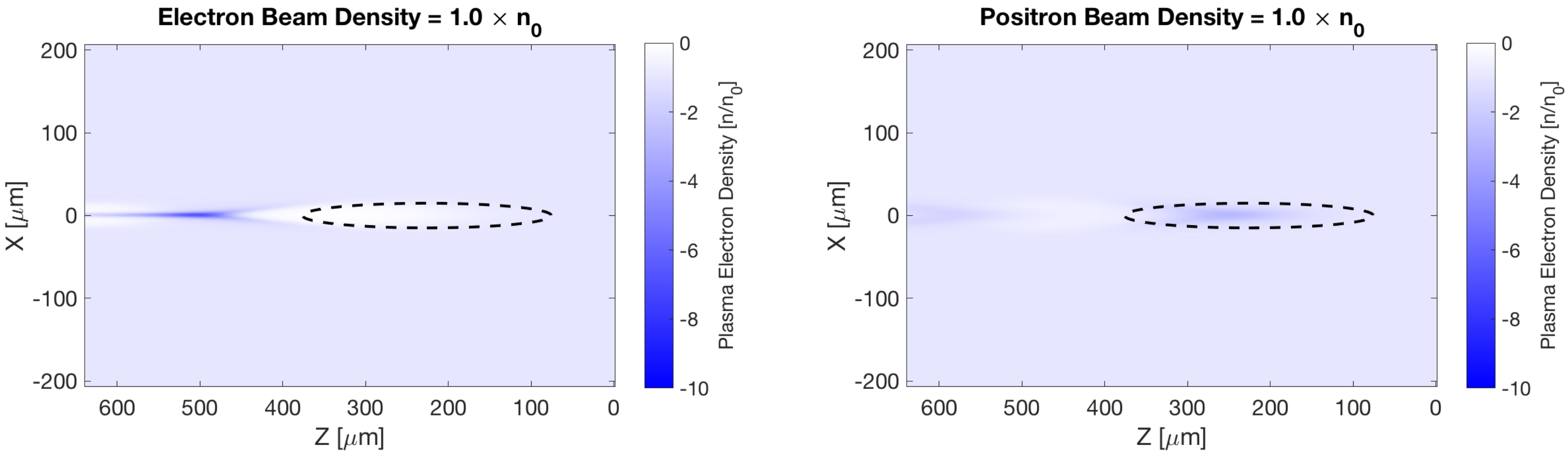
Plasma Response to Beams of Opposite Charge



In the linear regime, the response is symmetric.

QuickPIC Simulation run on Hoffman2 at UCLA

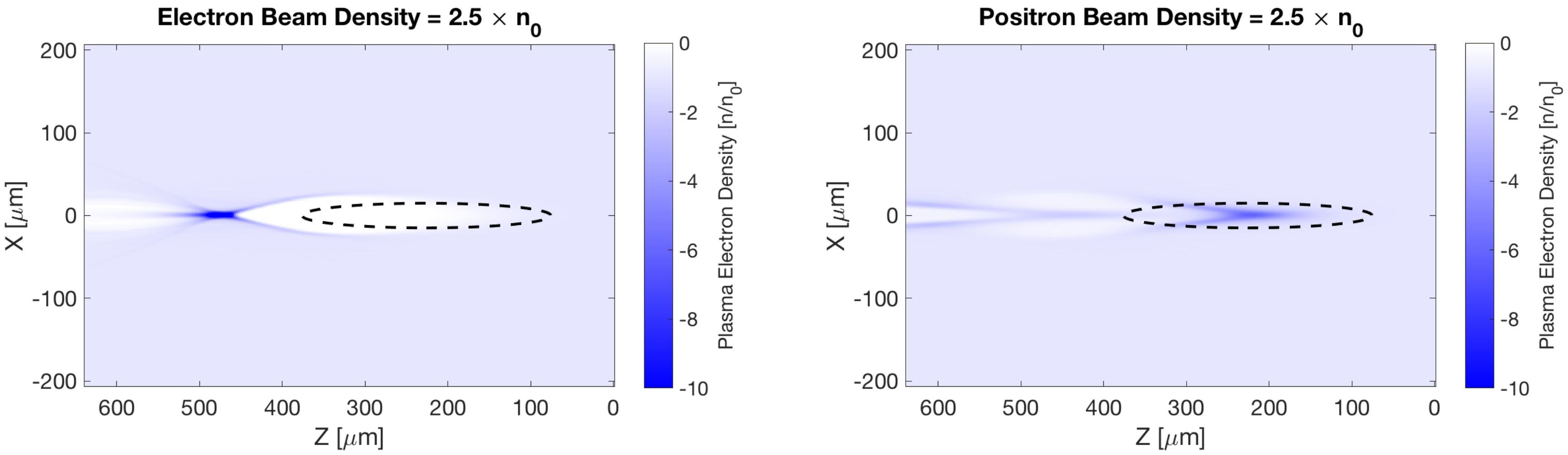
Plasma Response to Beams of Opposite Charge



As we increase the beam charge, the asymmetry becomes more pronounced.

QuickPIC Simulation run on Hoffman2 at UCLA

Plasma Response to Beams of Opposite Charge



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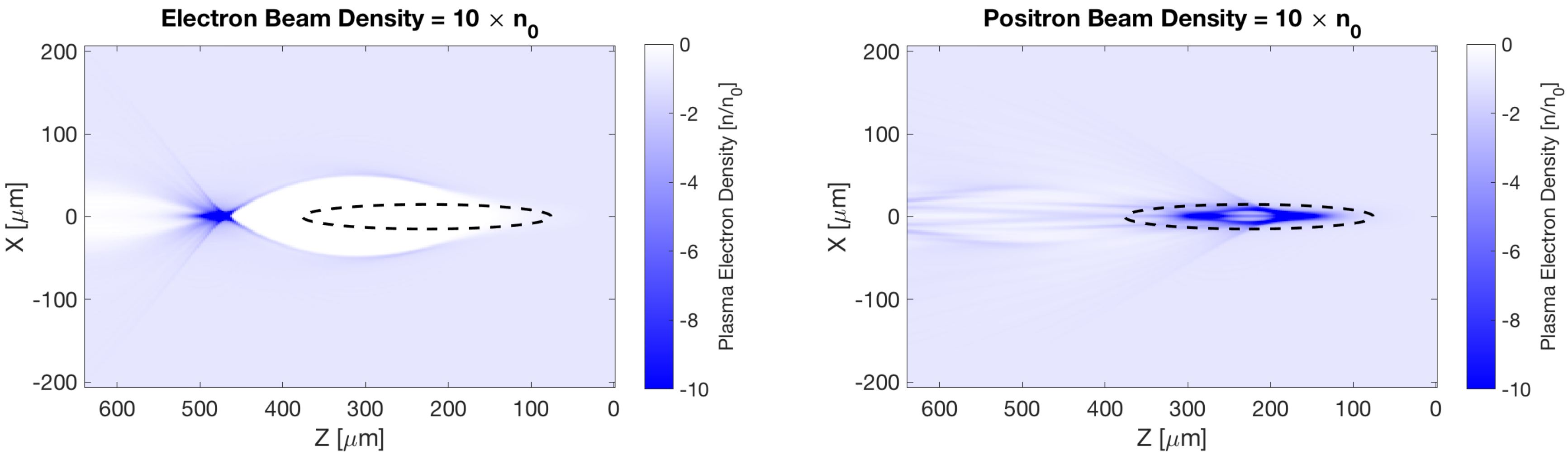

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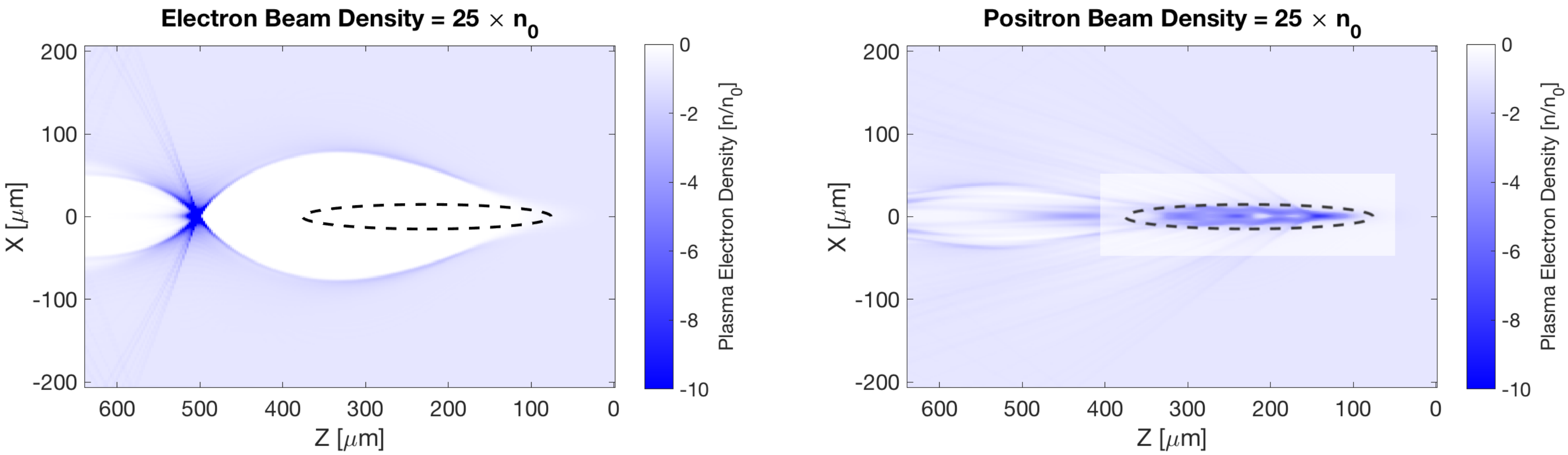

As we increase the beam charge, the asymmetry becomes more pronounced.

And more complicated.

QuickPIC Simulation run on Hoffman2 at UCLA

Takeaways

SLAC

- The nonlinear blowout regime works well for electron acceleration.
  - It is conceptually simple. The bubble is defined by a plasma electron sheath.
  - The transverse force saturates after blowout occurs.
  - The accelerating field can be flattened with the correct selection of witness beam parameters.

- The nonlinear regime is challenging for positron acceleration.
  - Typically, there is no region in the wake with an excess of plasma electrons that can provide uniform focusing to a positron beam.
  - Even if such a region existed, the presence of a positron witness beam would modify the plasma electron density.
  - A dense positron beam will attract more plasma electrons on-axis. This in turn focuses the positron beam. The transverse force does not saturate.