Demonstration of the Hollow Channel Plasma Wakefield Accelerator

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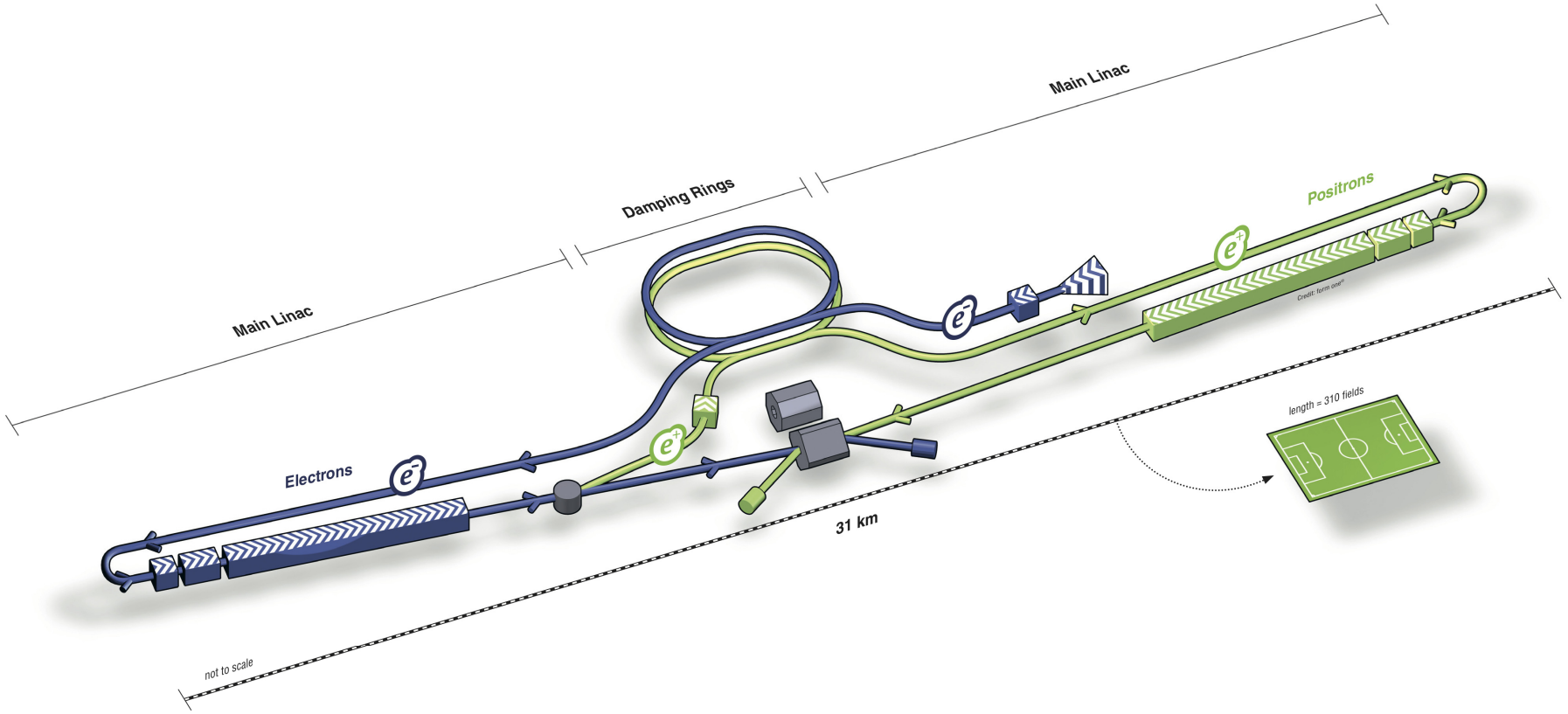
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Motivation: Make the LC an Energy-Frontier Machine



1 TeV ⟶ 100 TeV

Solution: Use Plasma!

Compactness:

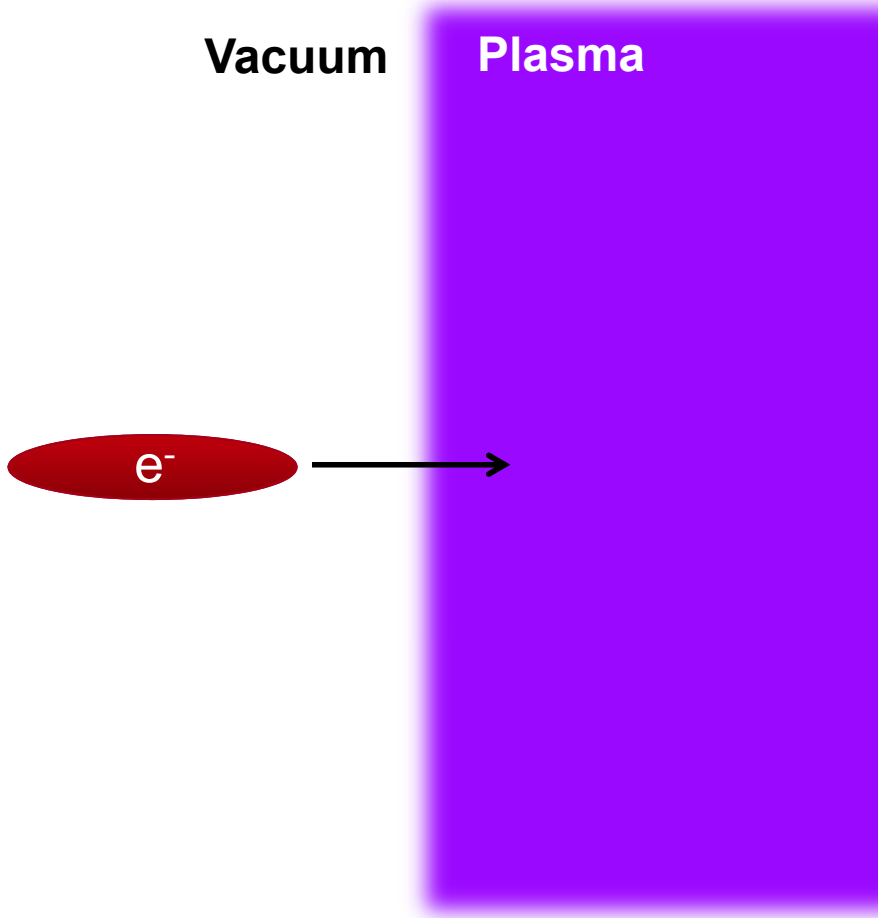
- High-gradient acceleration of electrons and positrons
- Plasma-lensing for the beam delivery system

High Luminosity:

- Efficient energy transfer from drive beam to witness beam
- Mitigation of beamstrahlung with plasma at the IP

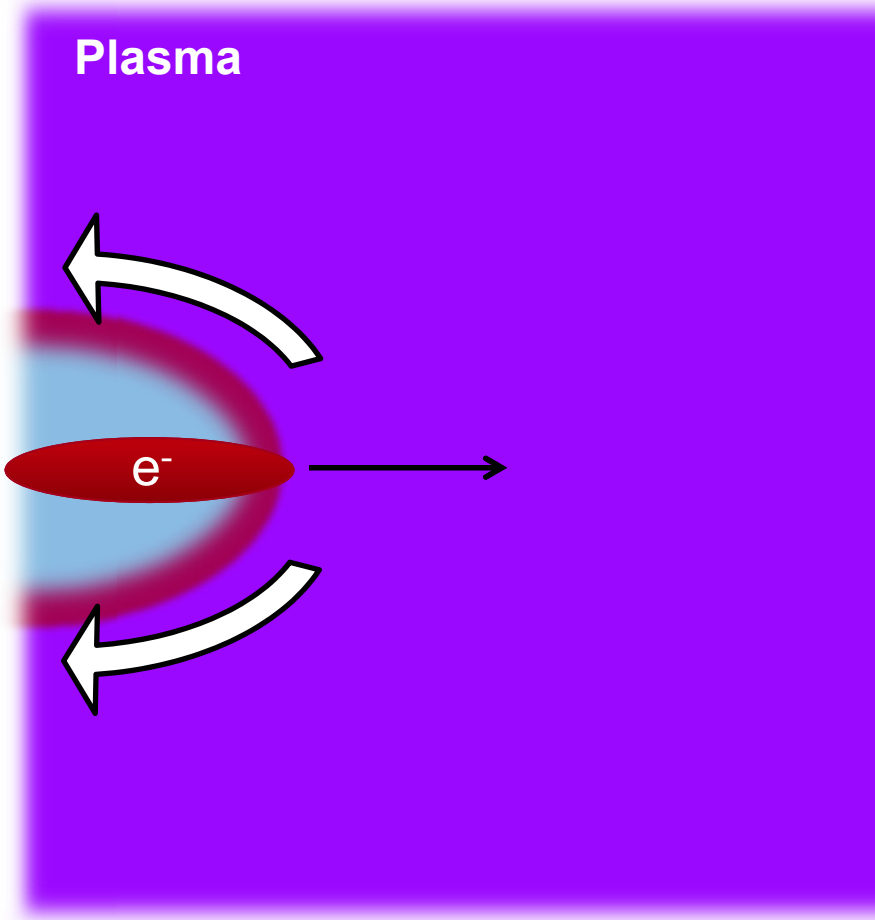
This talk: High-gradient acceleration of positrons by **Plasma Engineering**

How does Plasma Wakefield Acceleration Work?



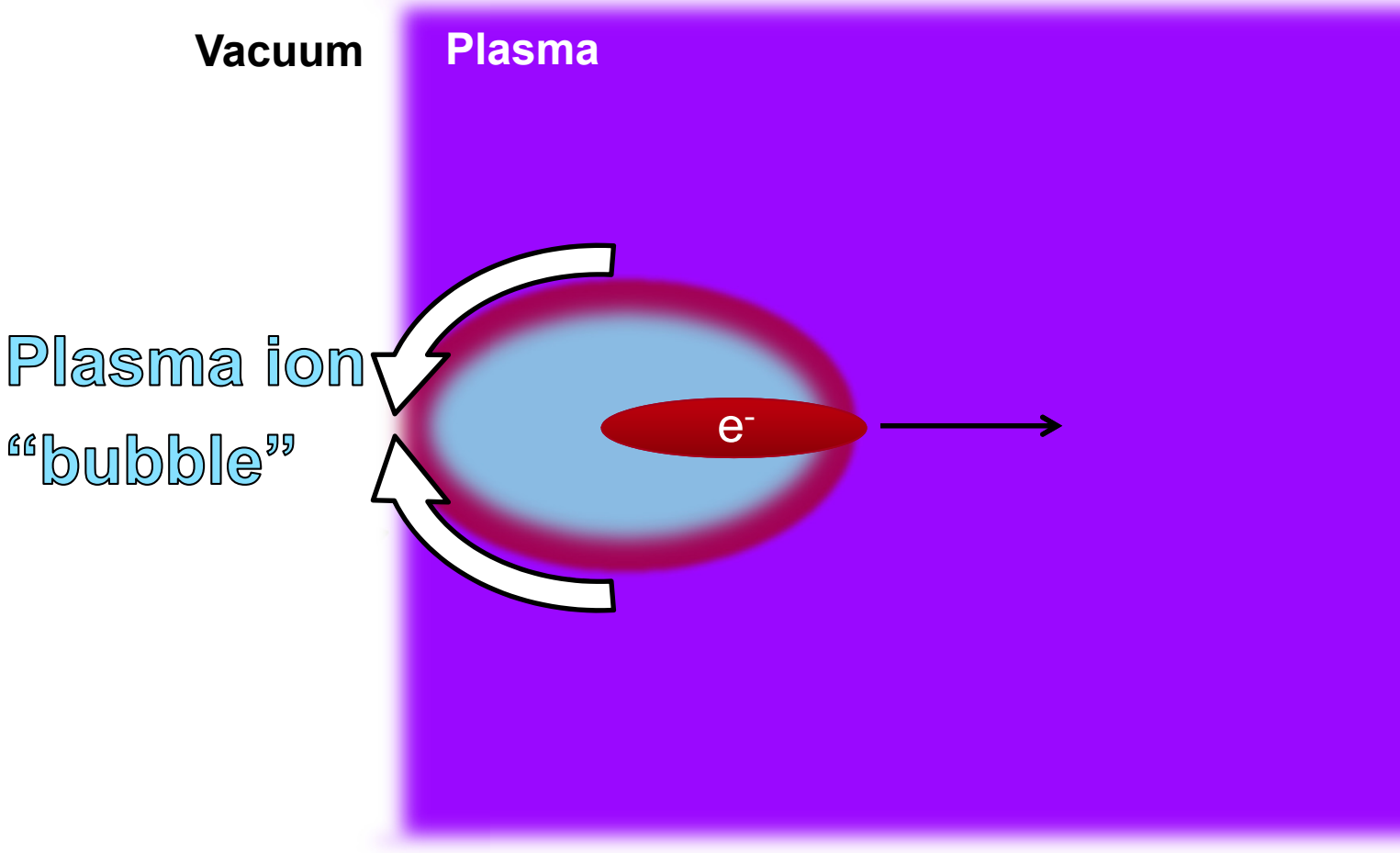
An electron beam propagates to the right into a neutral plasma.

How does Plasma Wakefield Acceleration Work?



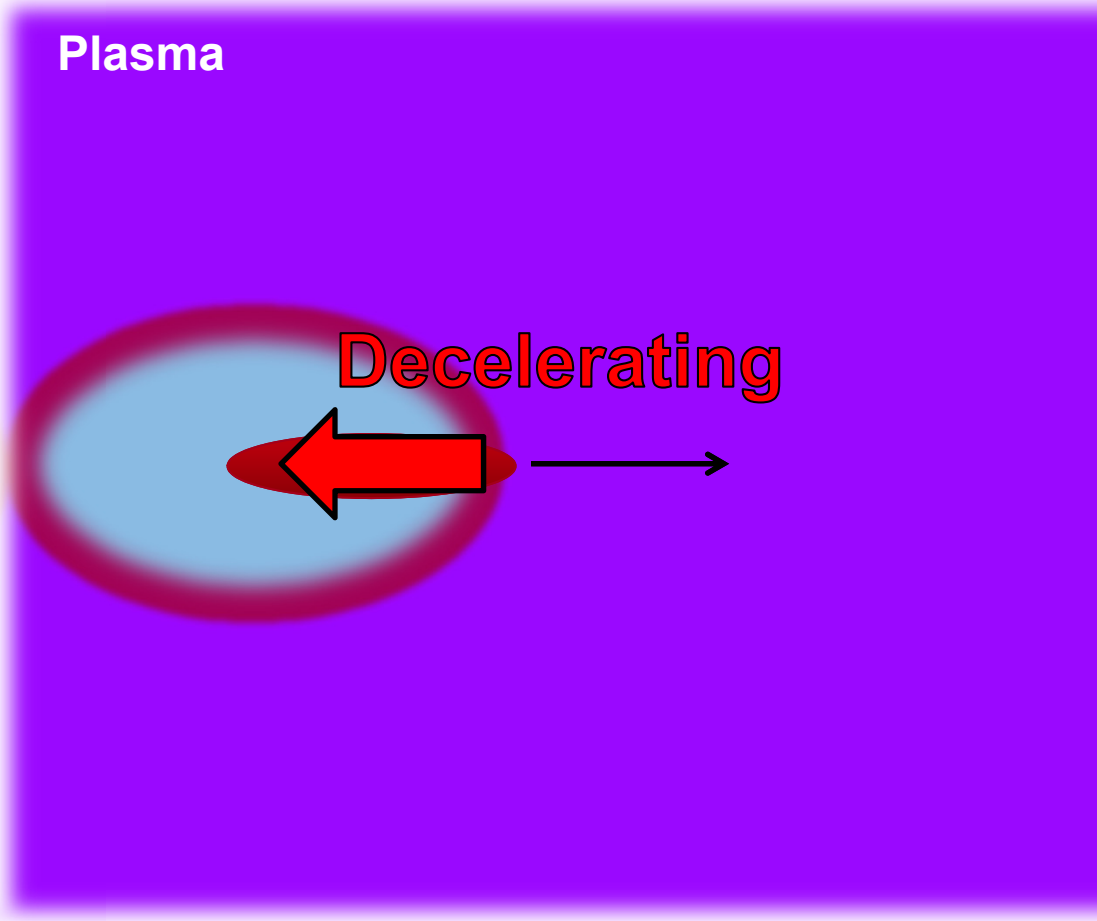
As the beam enters the plasma, plasma electrons are expelled, leaving behind plasma ions.

How does Plasma Wakefield Acceleration Work?



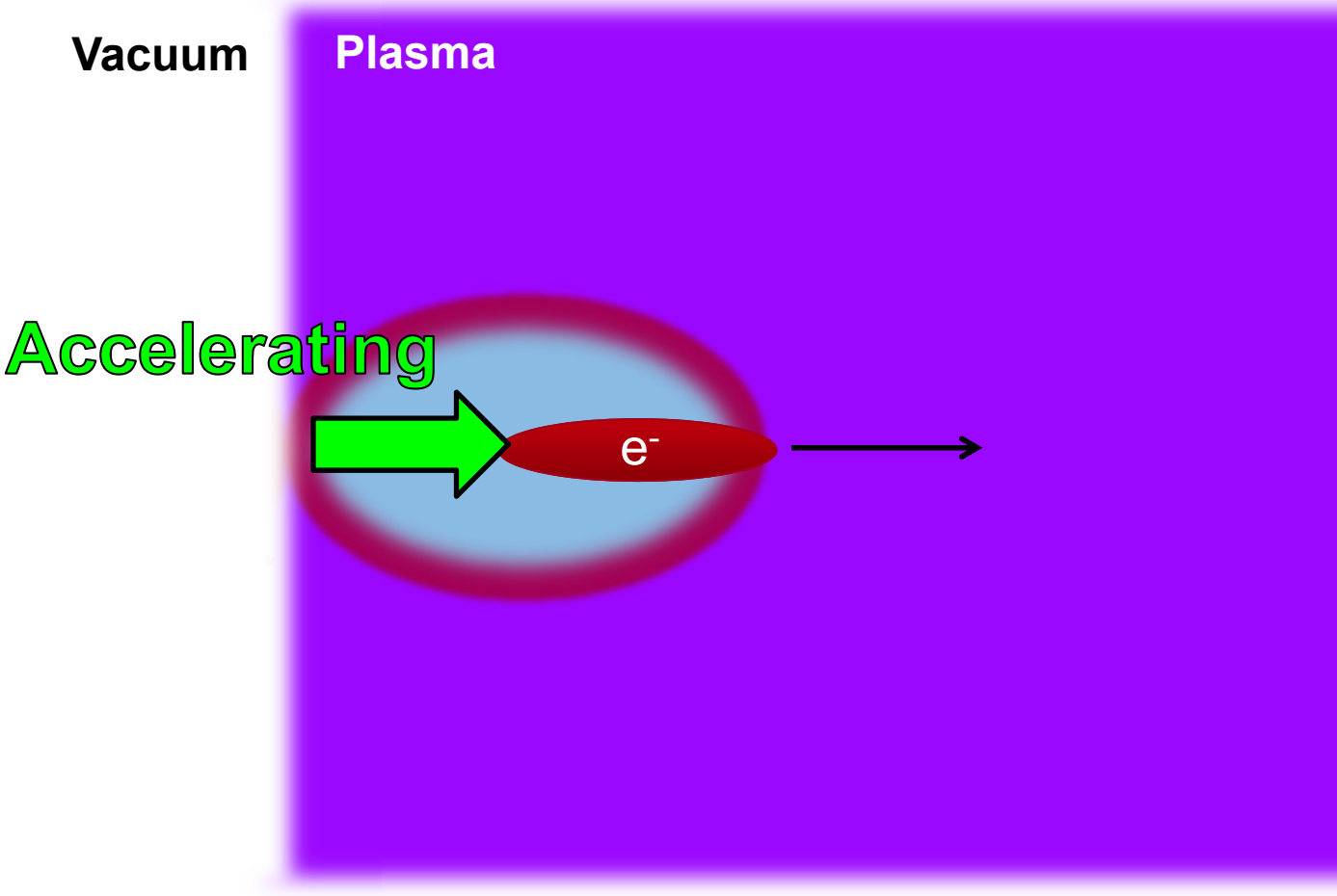
The plasma ions are heavy and stationary. They exert a restoring force on the plasma electrons pulling them back to the axis.

How does Plasma Wakefield Acceleration Work?



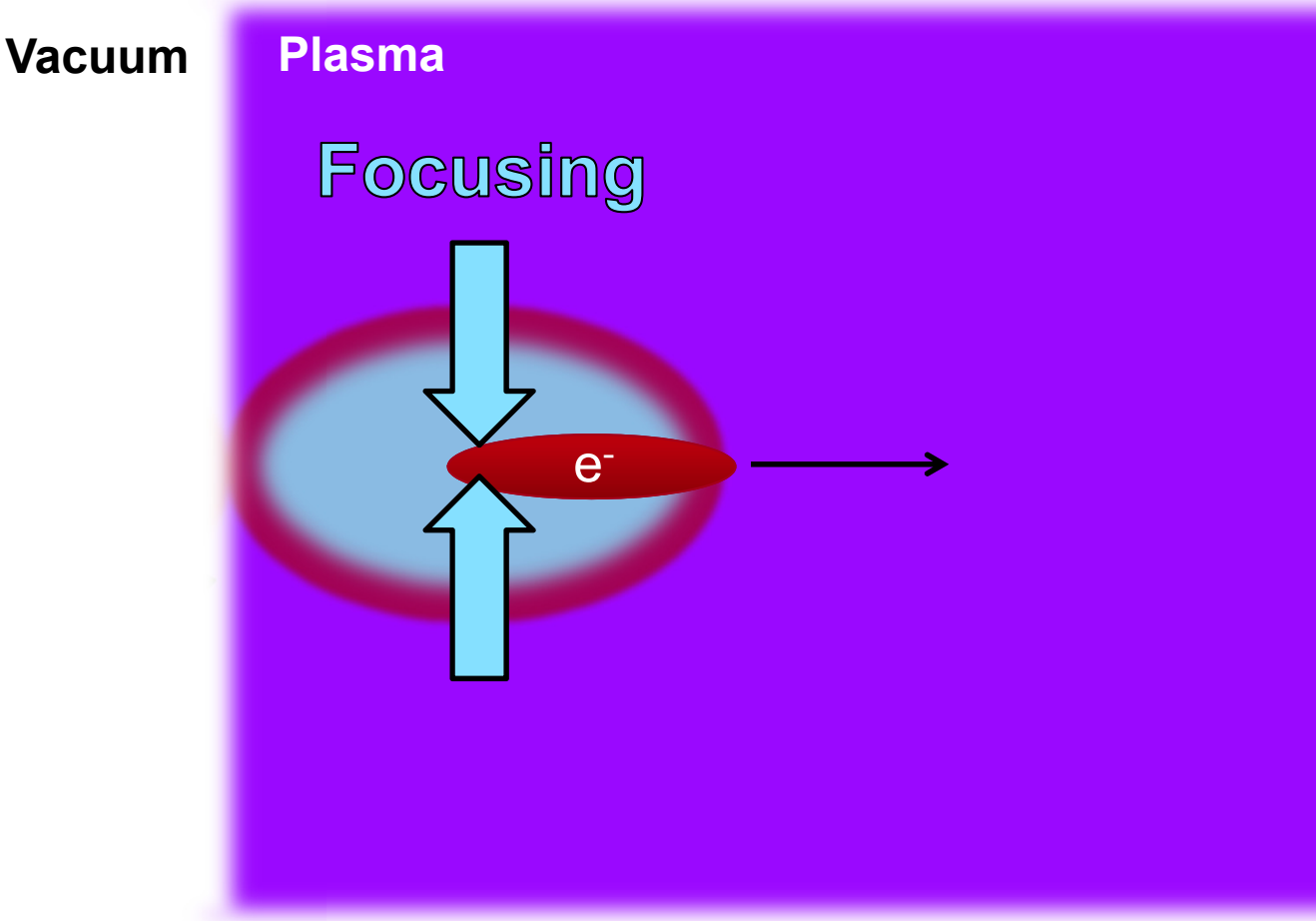
The field is decelerating in the front half of the bubble. The plasma extracts energy from the electron beam.

How does Plasma Wakefield Acceleration Work?



The field is accelerating in the back half of the bubble. Beam electrons can extract energy from the plasma wake in this region.

How does Plasma Wakefield Acceleration Work?



The field is focusing *everywhere* in the bubble.

How does Plasma Wakefield Acceleration Work?

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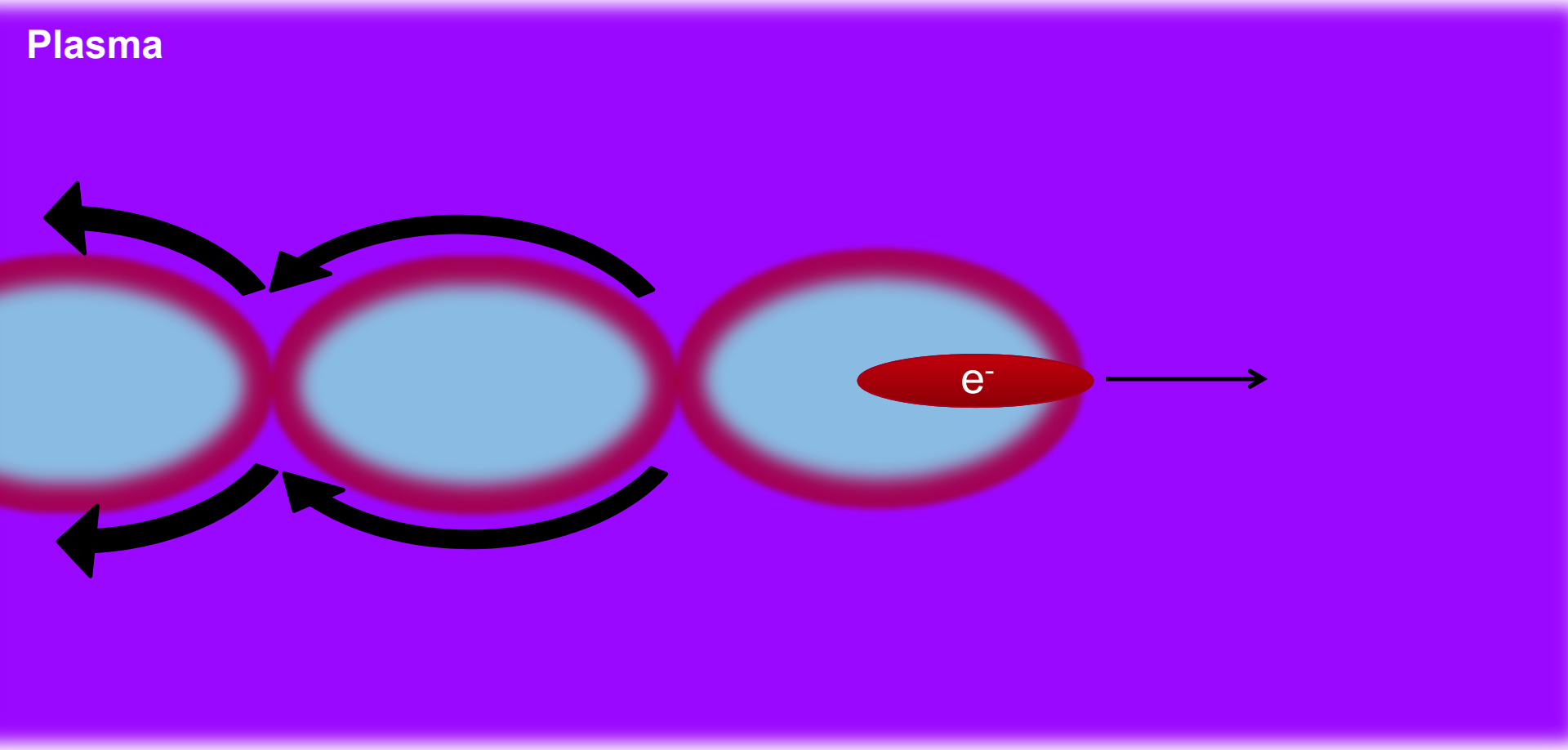

The plasma electrons keep oscillating after the beam has passed by.

How does Plasma Wakefield Acceleration Work?

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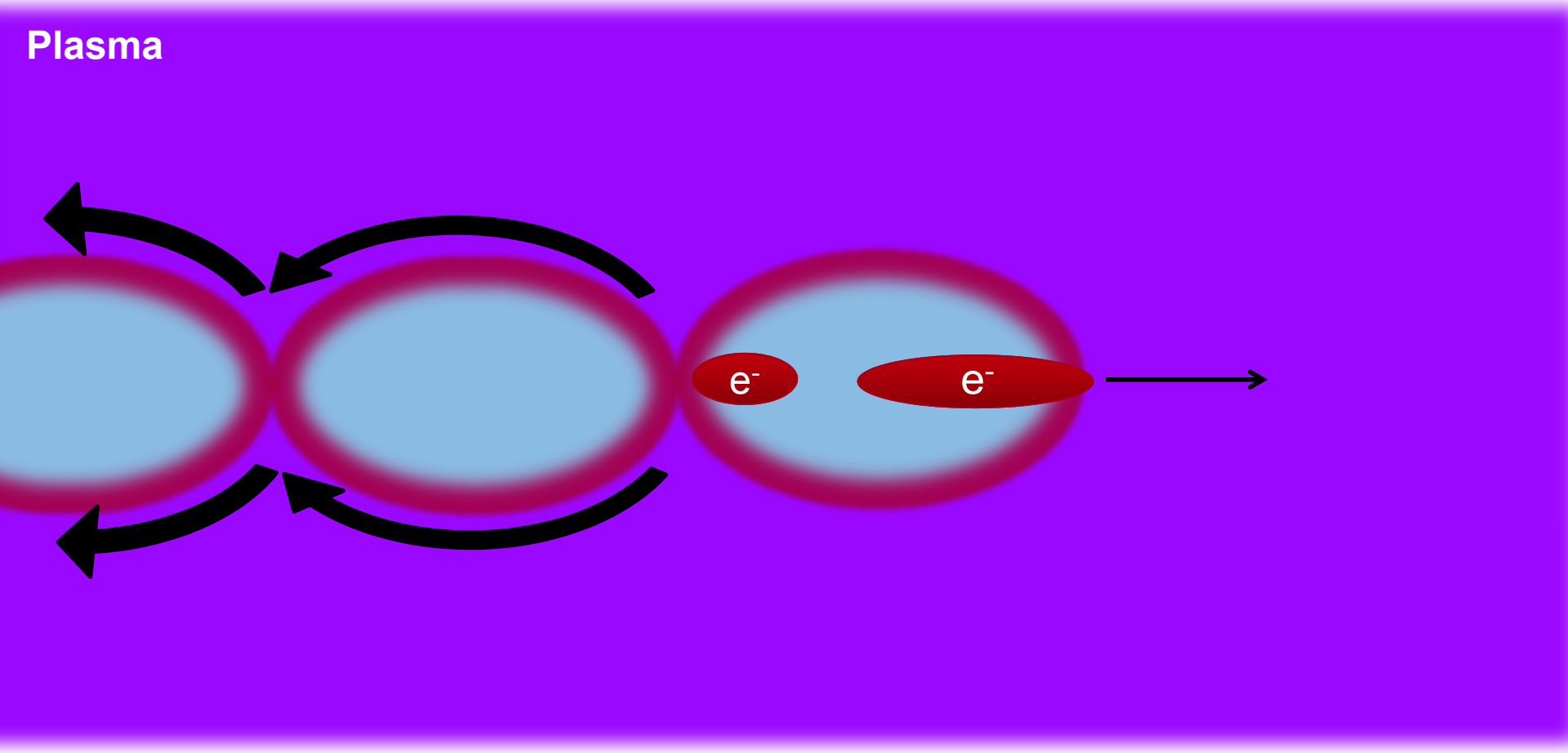

To extract energy from the wakefield, we place a "witness" bunch in the back of the bubble, where it can ride the wake and gain energy.

How does Plasma Wakefield Acceleration Work?

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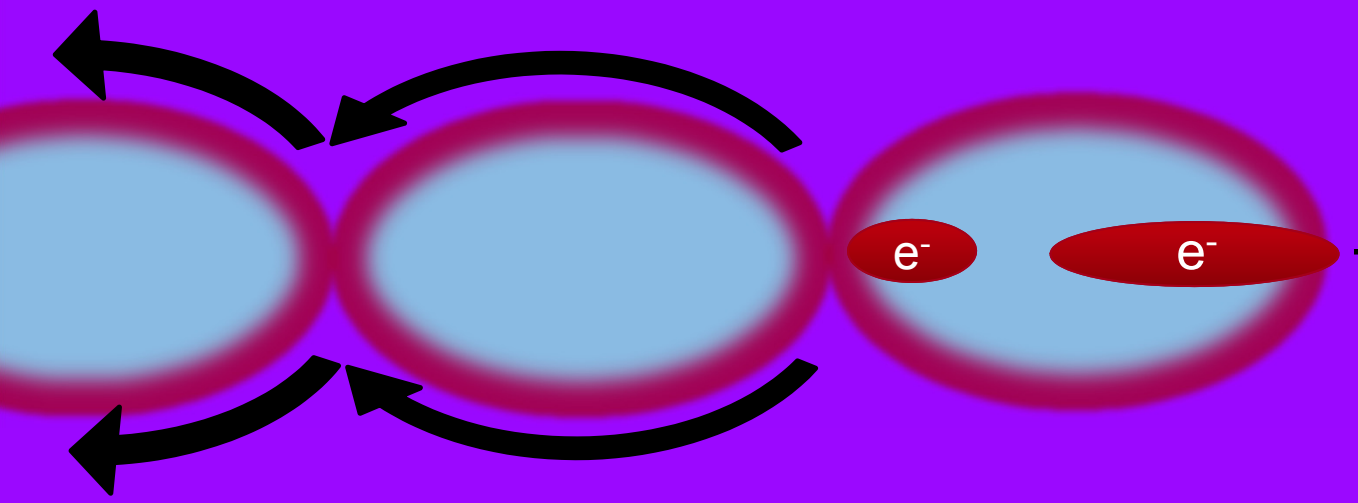
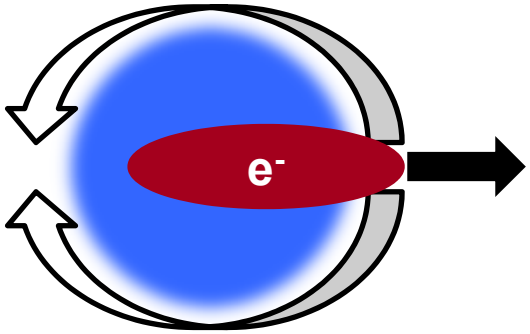
Plasma

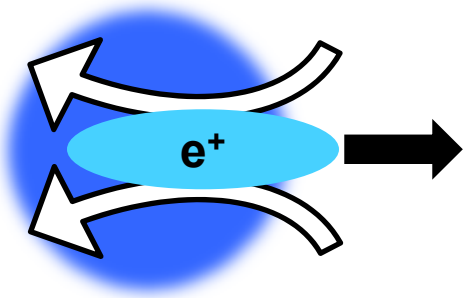
Demonstrated at FACET in 2014
4.4 GeV/m



To extract energy from the wakefield, we place a "witness" bunch in the back of the bubble, where it can ride the wake and gain energy.

The Problem with Positrons





$$m_i >> m_e$$

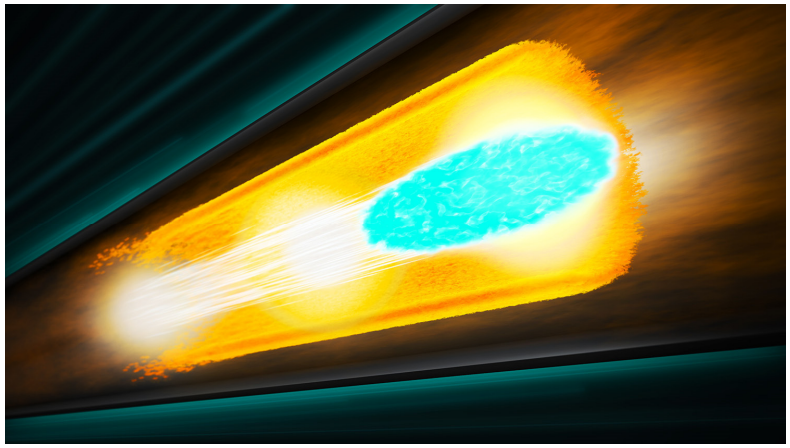
The plasma electrons are mobile but the ions are not.

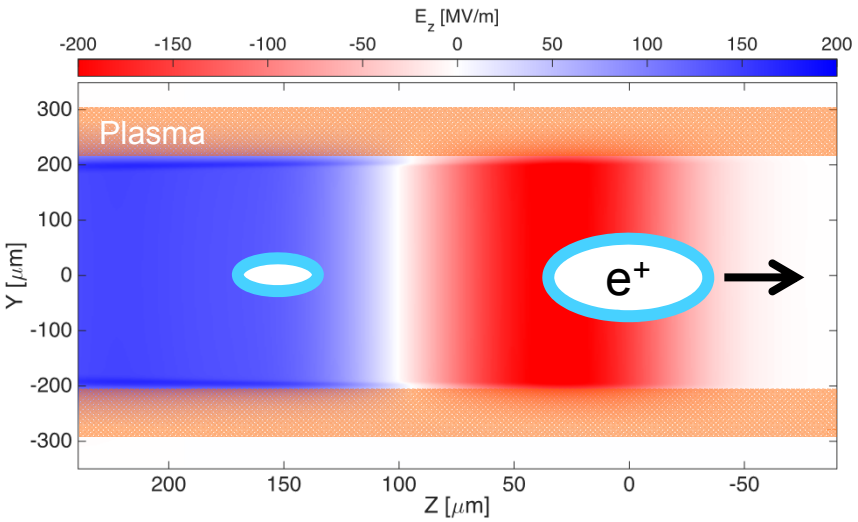
The symmetry of the accelerating mechanism is broken.

Hollow Channel Plasmas

First proposed in 1995, hollow channel plasmas are an attempt to *engineer* the plasma to produce the desired fields.

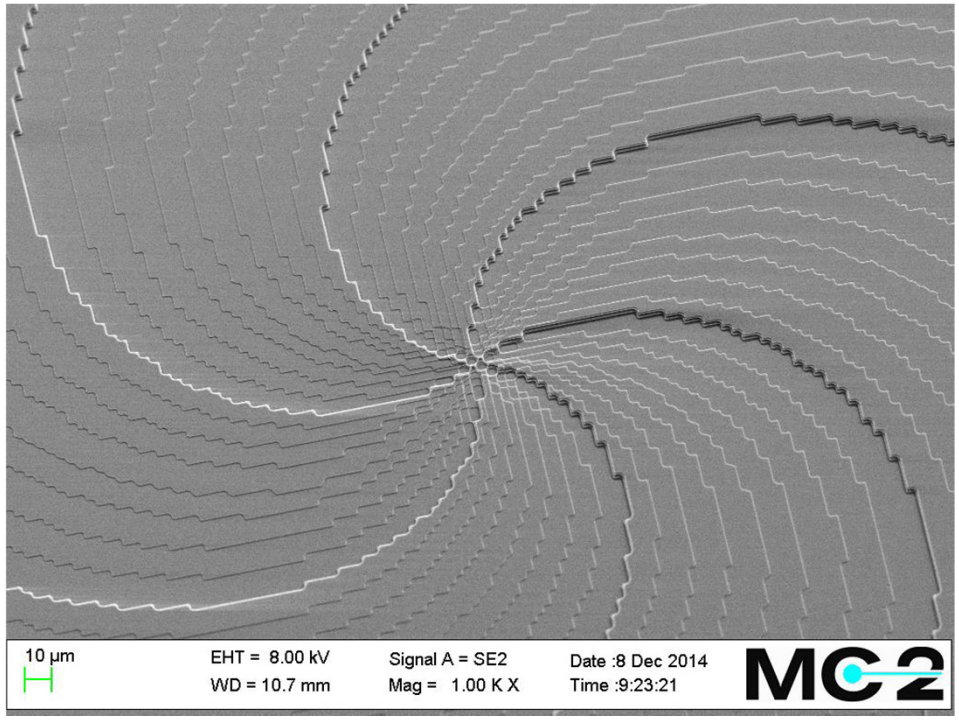
FACET, at SLAC National Accelerator Laboratory, is the first facility that combines all of the necessary ingredients needed to carry out this experiment.

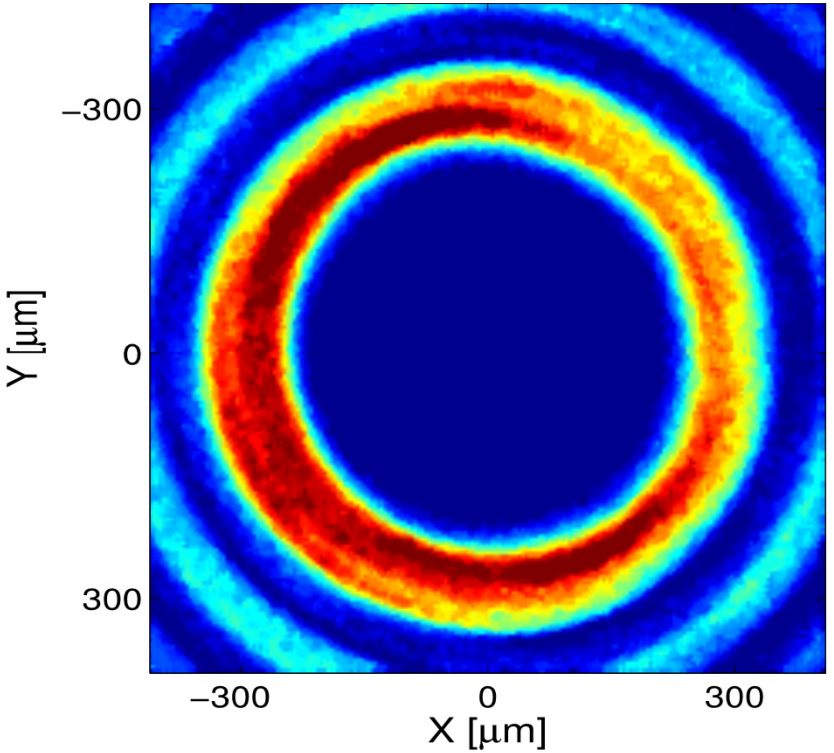




T.C. Chiou et al., *Physics of Plasmas* (1995).
T.C. Chiou and T. Katsouleas, *PRL* (1998).
C.B. Schroeder et al., *PRL* (1999).

How do you make a hollow channel plasma?



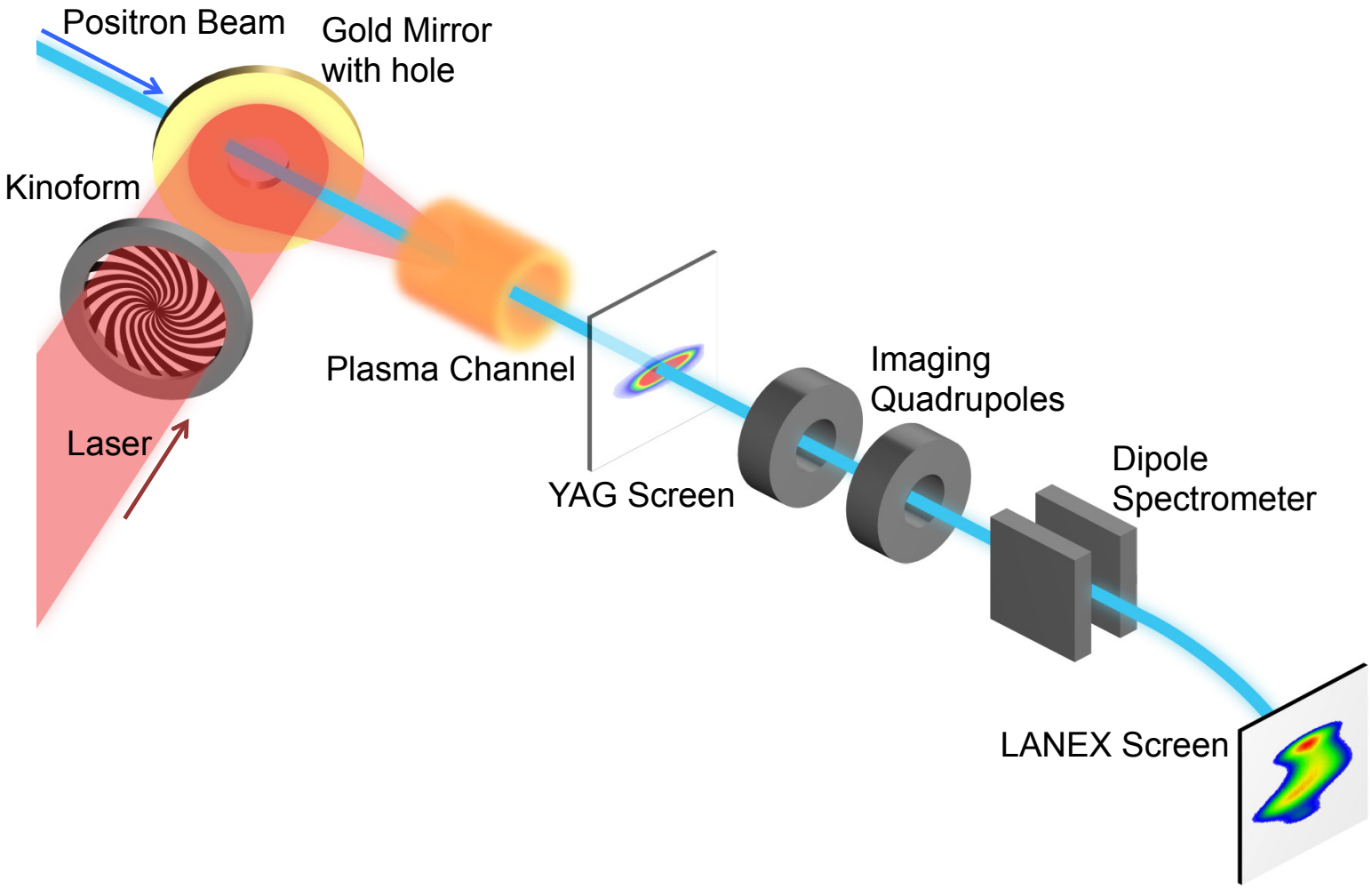


Phase profile: $\Psi_0 = k_\perp r + m\phi$

Intensity profile: $I(r,z) = \eta I_0 2\pi\gamma^2 kz J_m^2(k_\perp r)$

N. Andreev, et al. *Quant. Electr.* (1996).
J. Fan, et al. *Phys. Rev. E* (2000).
W. Kimura et al. *Phys. Rev. ST-AB* (2011).

Experimental Setup



How do we measure the shape of the channel?

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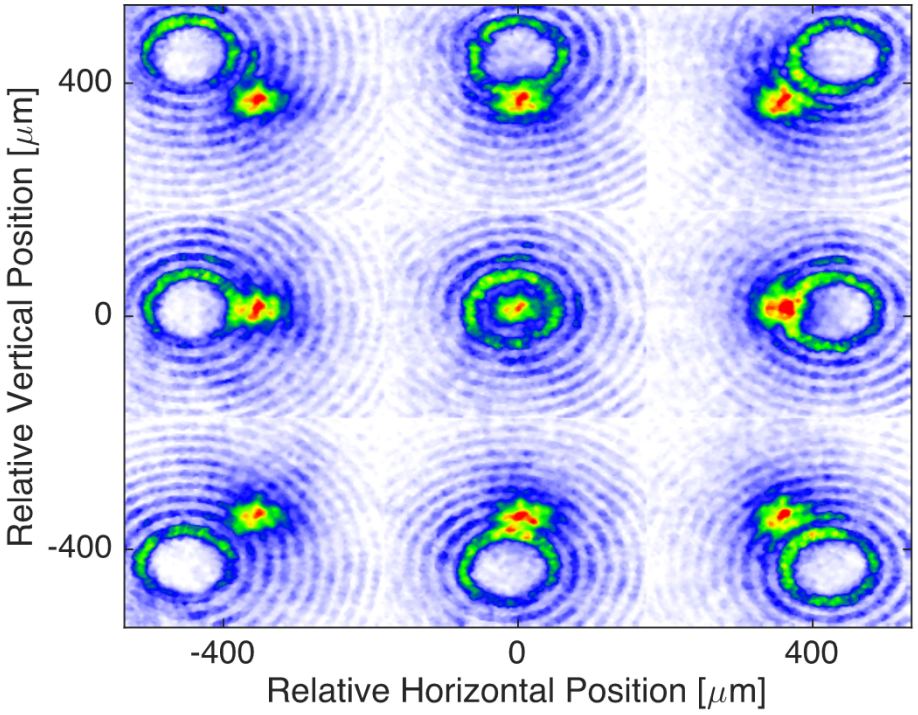
The positron beam (bright spot) feels an attraction to the nearest ionized region (ring).

We shift the laser in parallel to the beam trajectory, and measure it's affect on the beam.

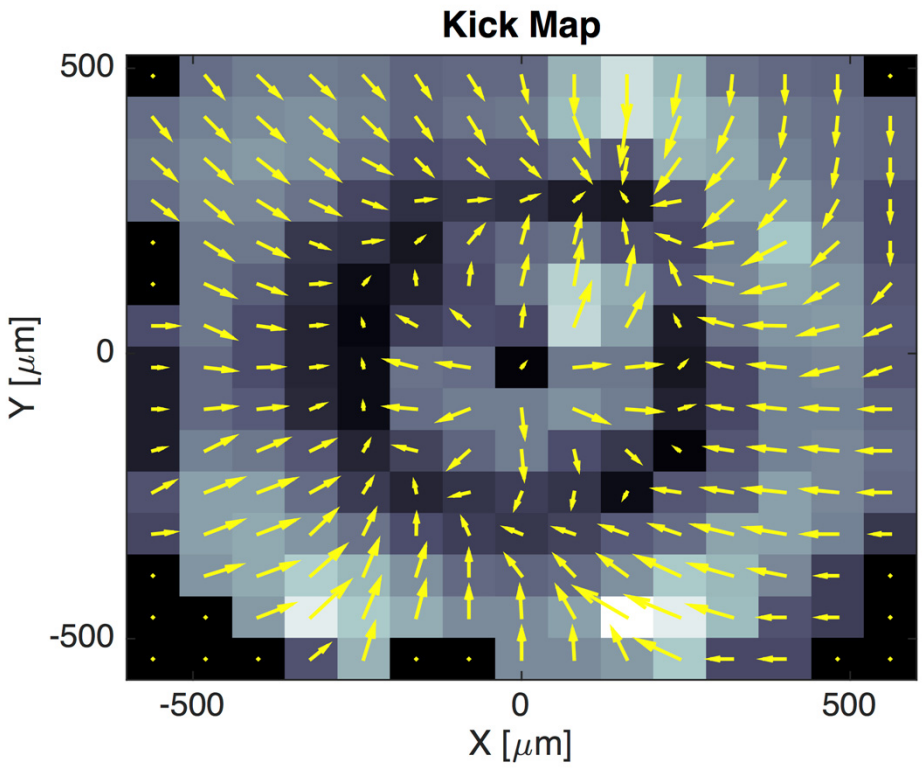


How do we measure the shape of the channel?

SLAC

We use a beam profile monitor downstream of the plasma to measure changes, or “kicks”, to the beam trajectory.

The Kick Map shows that the beam is attracted to an annular region with the expected radius, and there is a point in the middle of the channel where the beam is not deflected at all.

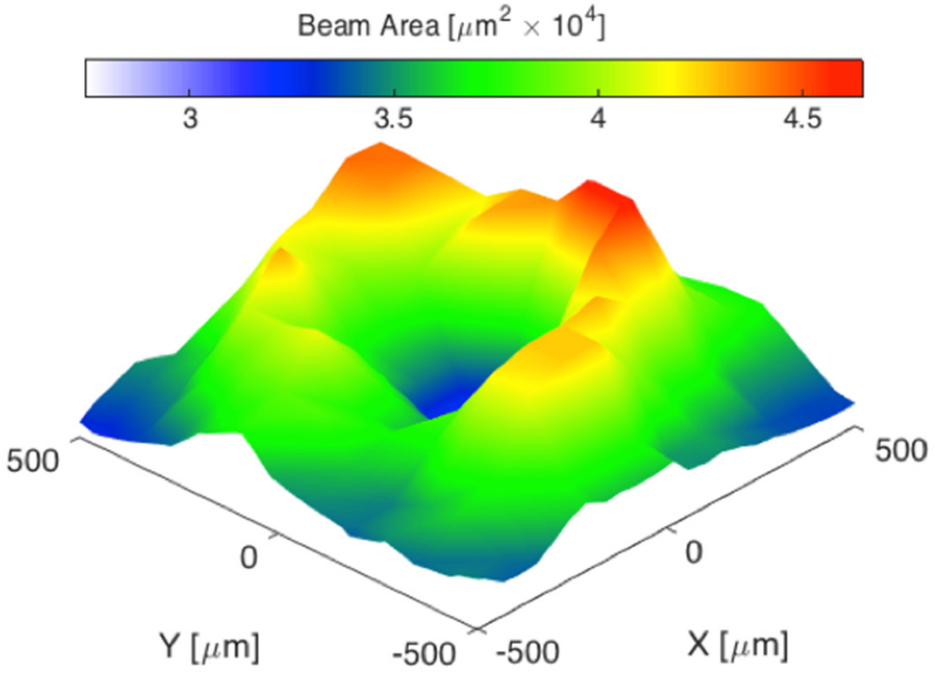


How do we measure the shape of the channel?

SLAC

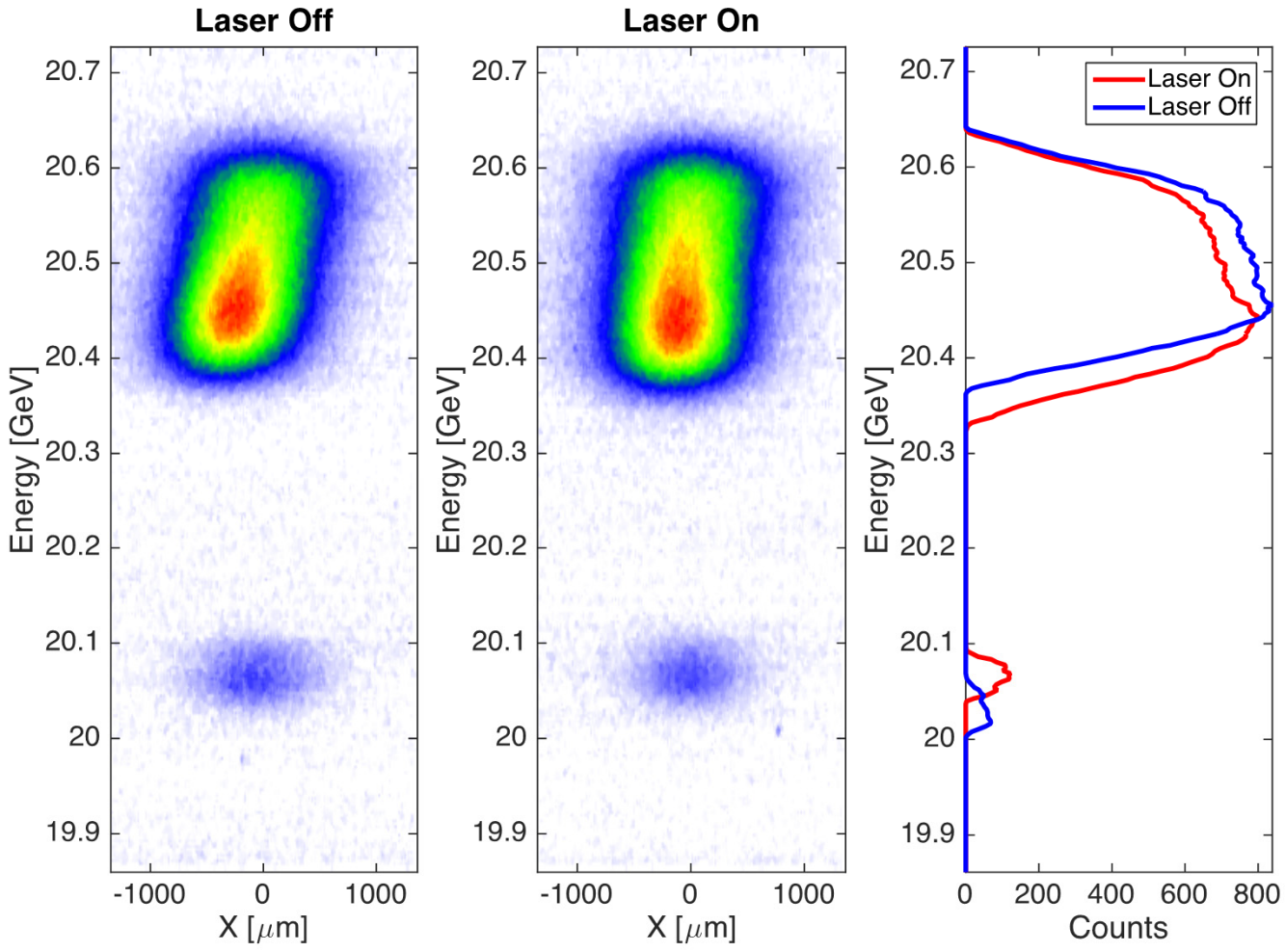
We also use the beam profile monitor to measure changes, to the transverse beam size. The beam size increases when the beam interacts with the plasma channel.

Both the Kick Map and Beam Area Measurement (Volcano Plot) are consistent with an annular plasma channel.



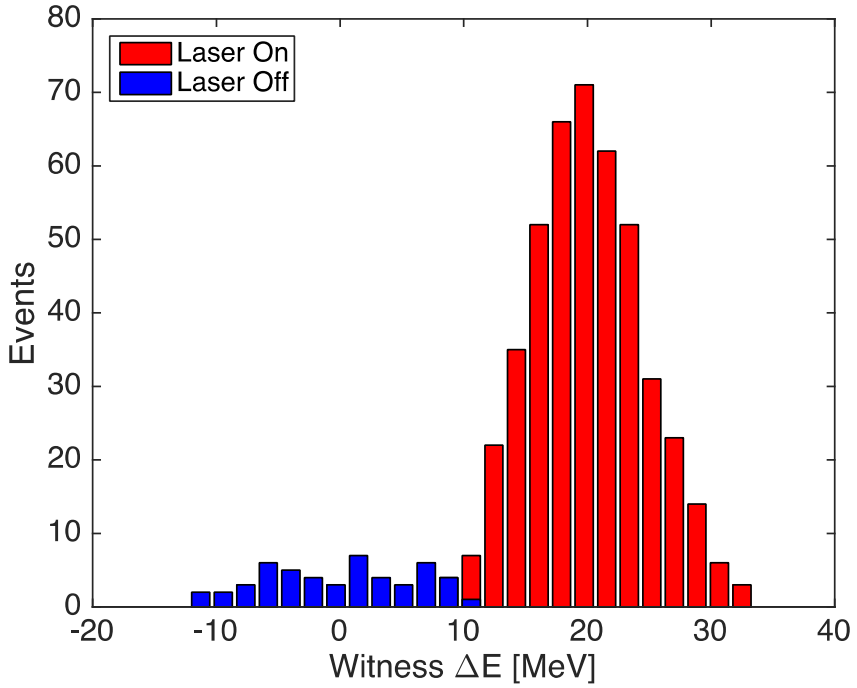
Acceleration of a Witness Beam using HC-PWFA

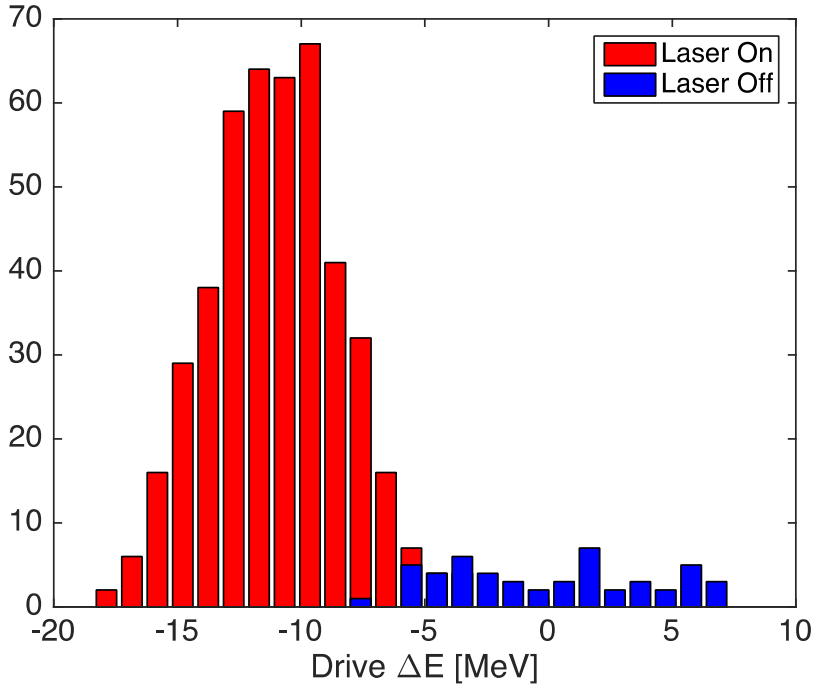
SLAC



Energy gain of up to 33.4 MeV in 25 cm long channel!

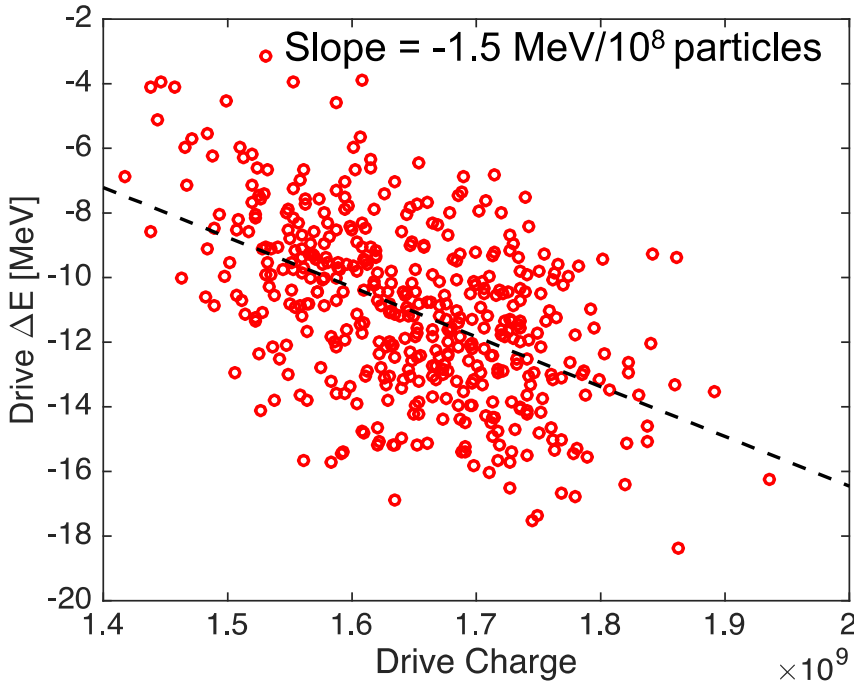
High Transformer Ratio

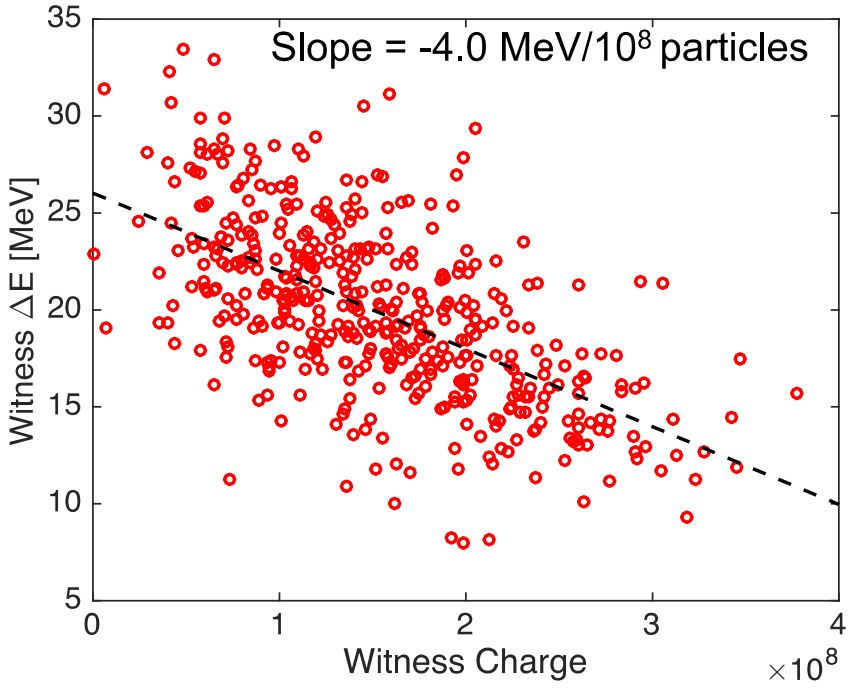




The witness beam gains about 20 MeV on average, while the drive beam loses about 11 MeV, giving a transformer ratio of 1.8.

Beam Loading





Beam loading is an important consideration when trying to optimize the gradient and efficiency. The average drive-to-witness efficiency in this experiment was 18%.

Conclusion

The plan for a plasma-driven linear collider is ambitious, but we are making progress on all fronts.

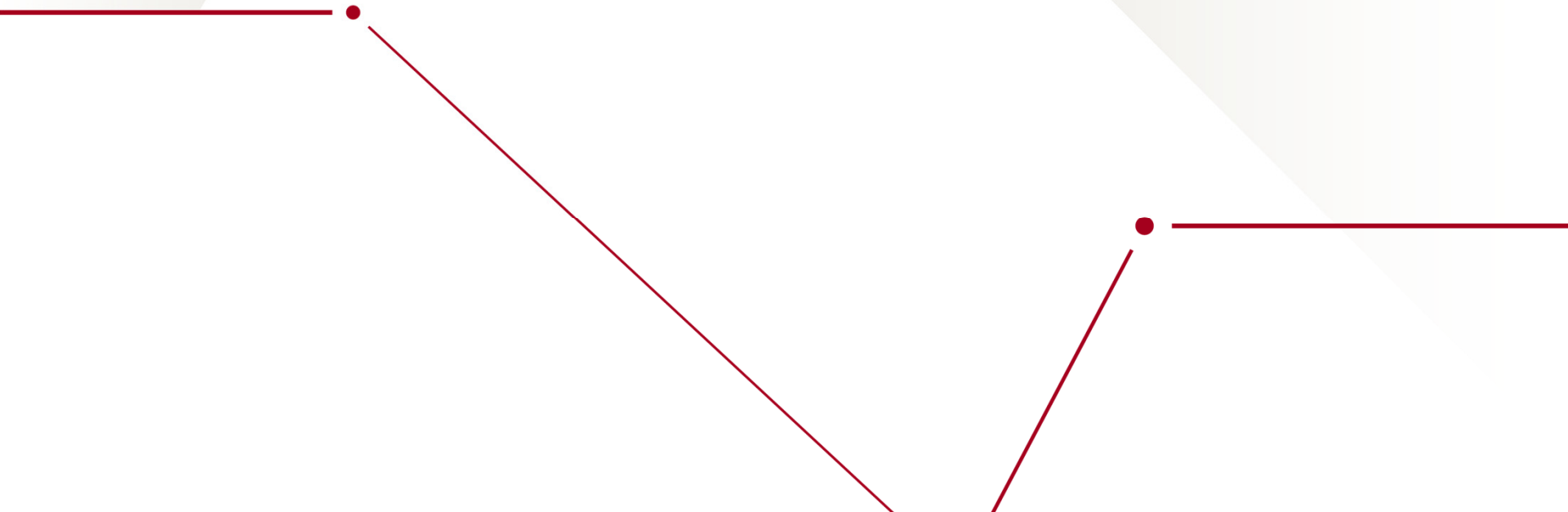
We have advanced beyond simply sending beams into plasmas. We now employ spatio-temporal engineering of *both* beams and plasmas.

The timeline for a plasma linear collider depends on the availability of research facilities:

- AWAKE – Proton Beam Driven PWFA **2016**
- FlashForward – Electron Beam Driven PWFA **2017**
- FACET II – Electron and Positron PWFA **2019**

Looking forward to more positron PWFA at FACET-II !

Thank You!



Collaboration

UCLA SLAC

SLAC

J. Allen, C. Clarke, J.P. Delahaye, J. Frederico, C. Hast, M. Hogan, S. Green, M. Litos, N. Lipkowitz, B. O'Shea, D. Walz, V. Yakimenko, G. Yocky

UCLA

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E. Adli, C. A. Lindstrom

S. Corde, A. Doche, C. Beekman

Thank you to my advisor Tor Raubenheimer!