Electron and Positron Acceleration Using Plasma Accelerators

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UCLA

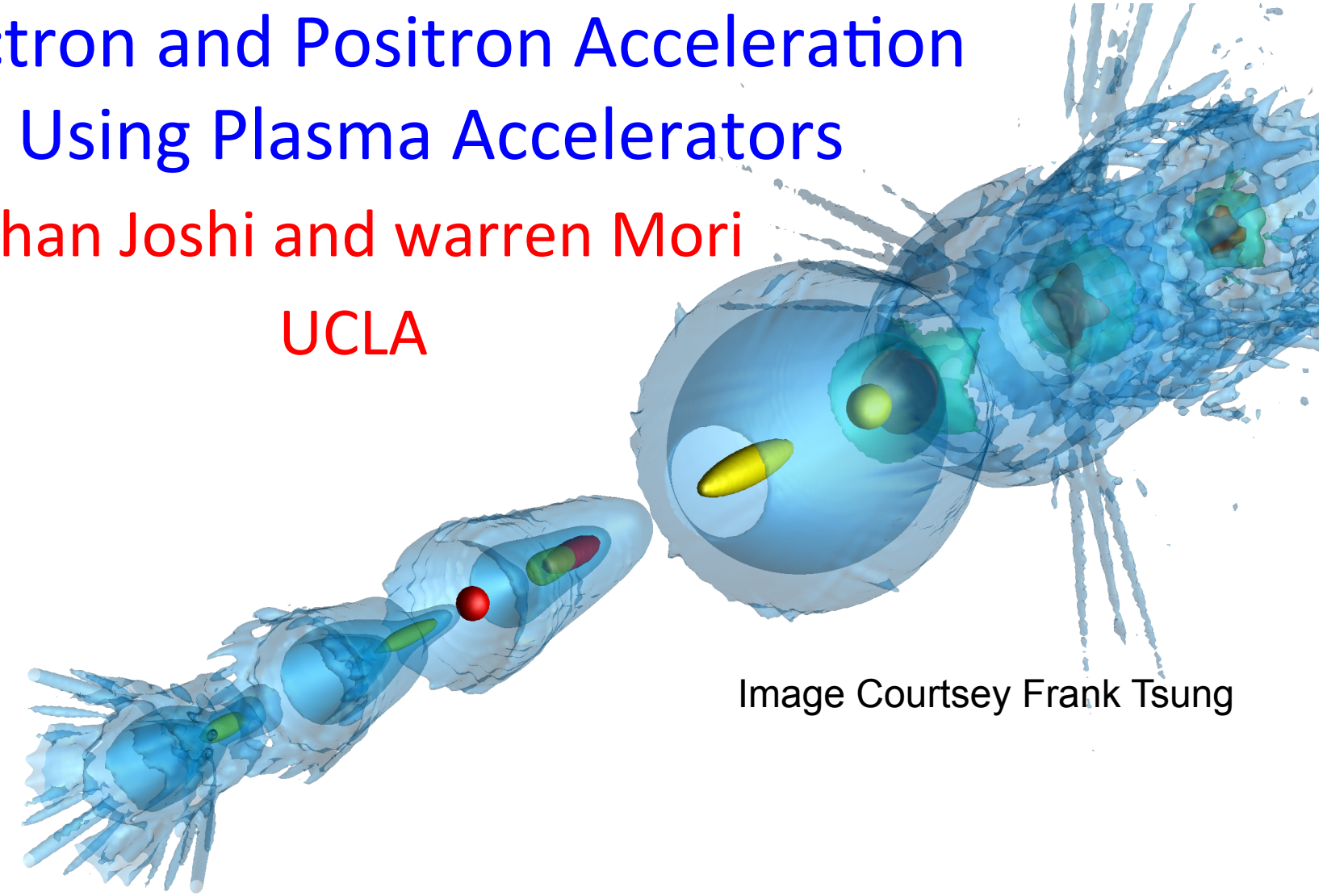


Image Courtsey Frank Tsung

Work supported by U.S. D.O.E. Plasma Fest UCLA

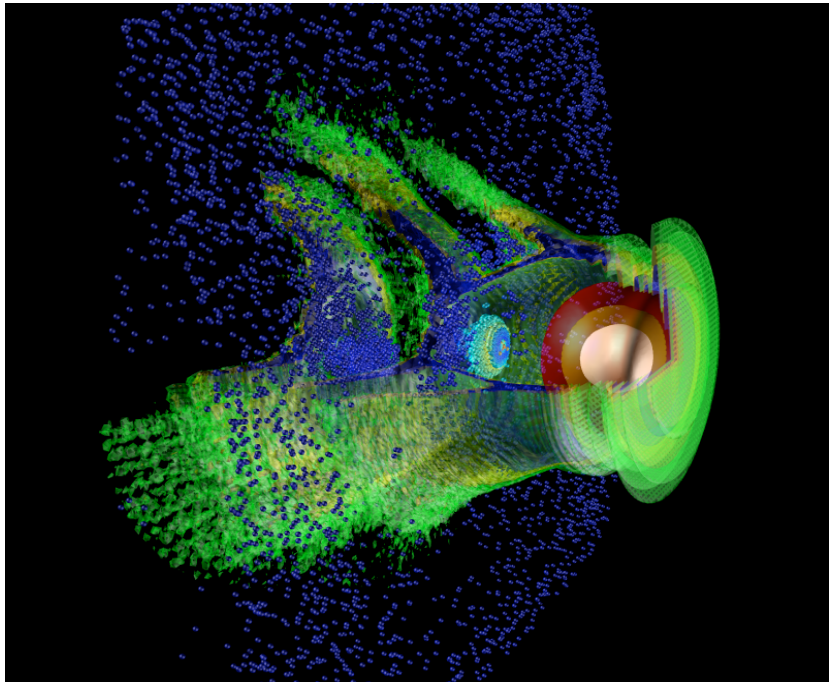
Use Collective Fields for Particle Acceleration

Transformational R&D for a TeV scale e^+e^- collider

To address critical physics issues for realizing an accelerator based on advanced concepts at the energy frontier in the next decade. A by- product will be compact accelerators for industry & science

The UCLA Particle-in-Cell and Kinetic Simulation Software Center (PICKSC) Funded by NSF

The mission of the Particle-in-Cell and Kinetic Simulation Software Center (PICKSC) at UCLA is to support an international community of PIC and plasma kinetic software developers, users, and educators, and to increase the use of this software for accelerating the rate of scientific discovery. It aims to make available and document illustrative software programs for different computing hardware, a flexible Framework for rapid construction of parallelized PIC programs, and several distinct production programs. It will also include activities on developing and comparing different PIC algorithms and documenting best practices for developing



PWFA Experiments Carried out at SLAC since 2000

- At FACET , 2km of SLAC linac provides 50fs, 3 nC, 20 GeV e^-, e^+ pulses at 1-10 Hz
- When focussed to a few microns I > 10^{19} W/cm^2, P > 200TW or W = 30 J in 50fs
- Very reliable &Comparable to highest power lasers

The FACET E200: PWFA Collaboration mandate

To Accelerate at a high gradient, narrow energy spread bunch of electrons and positrons containing a sufficient Charge so as to extract a significant fraction of energy from the wake.

E. Adli, J. Allen, W. An, C.I. Clarke, C.E. Clayton, S. Corde, J.P. Delahaye, A.S. Fisher, J. Frederico, S. Gessner, S.Z. Green, M.J. Hogan, C. Joshi, M. Litos, W. Lu, K.A. Marsh, W.B. Mori, P. Muggli, N. Vafaei-Najafabadi, D. Walz, V. Yakimenko

Principal Spokespersons

M. Litos et al 2014
S. Corde et al 2015

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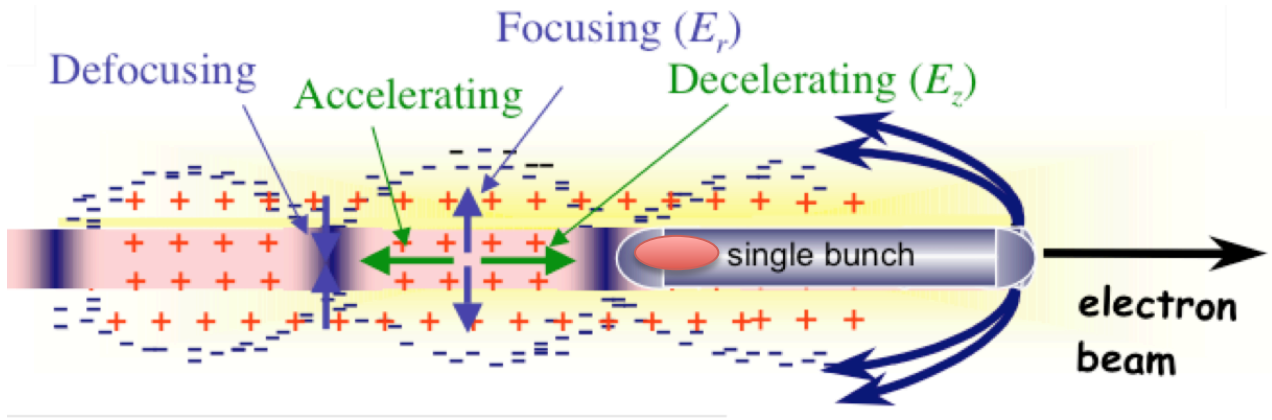
Beams Excite and Interact with Collective Fields

(Blowout Regime $n_b > n_p$)

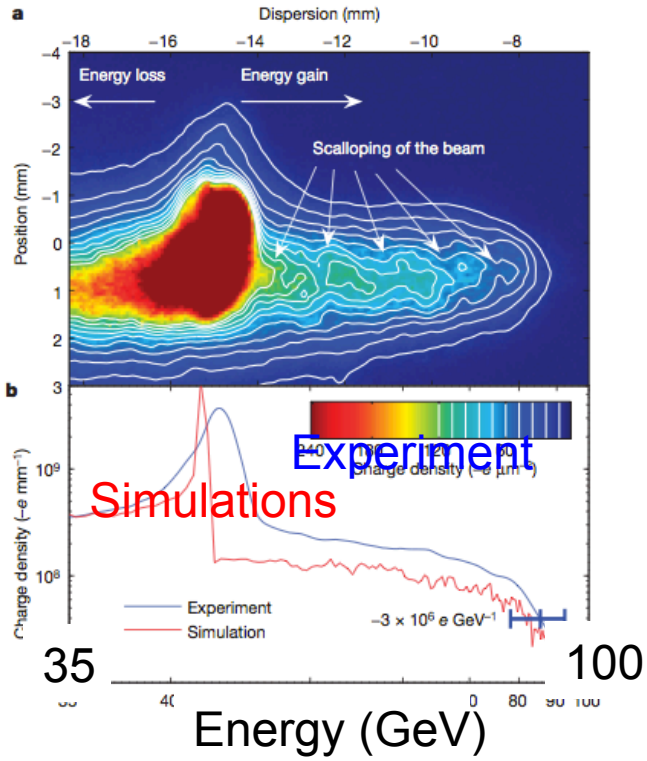


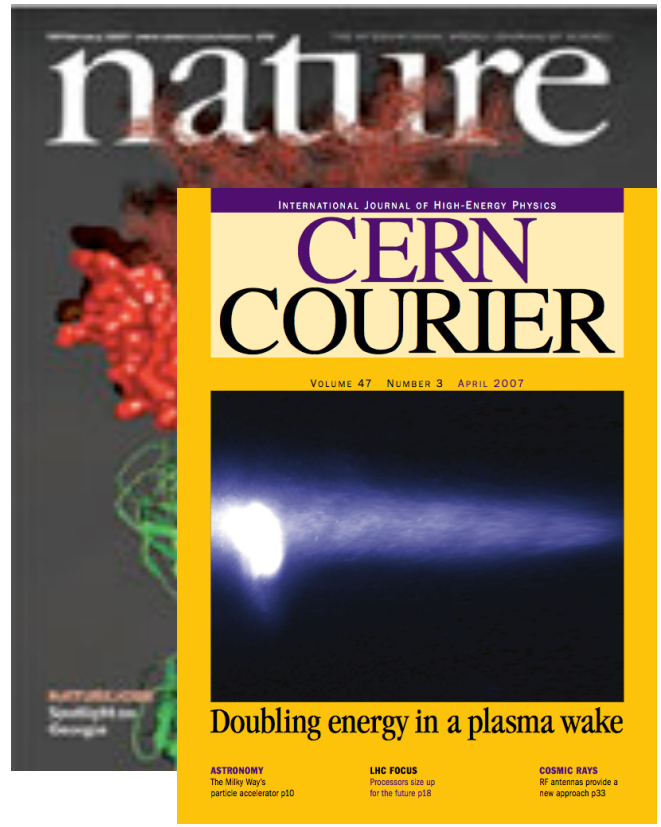
- **Space charge of the beam displaces plasma electrons**
- **Plasma ion channel exerts restoring force => wake oscillation**
- **Linear focusing force on beams ($F/r=2\pi ne^2/m$)**
- **Accelerating field independent of r, focusing force independent of z**
- **No phase slippage**

M. Hogan et al, PRL 2005, P. Muggli et al PRL 2004

NJP 10
, CERN Courier '10

Beam-Driven Wakefield Acceleration from 42 GeV-85 GeV in 85 cm.



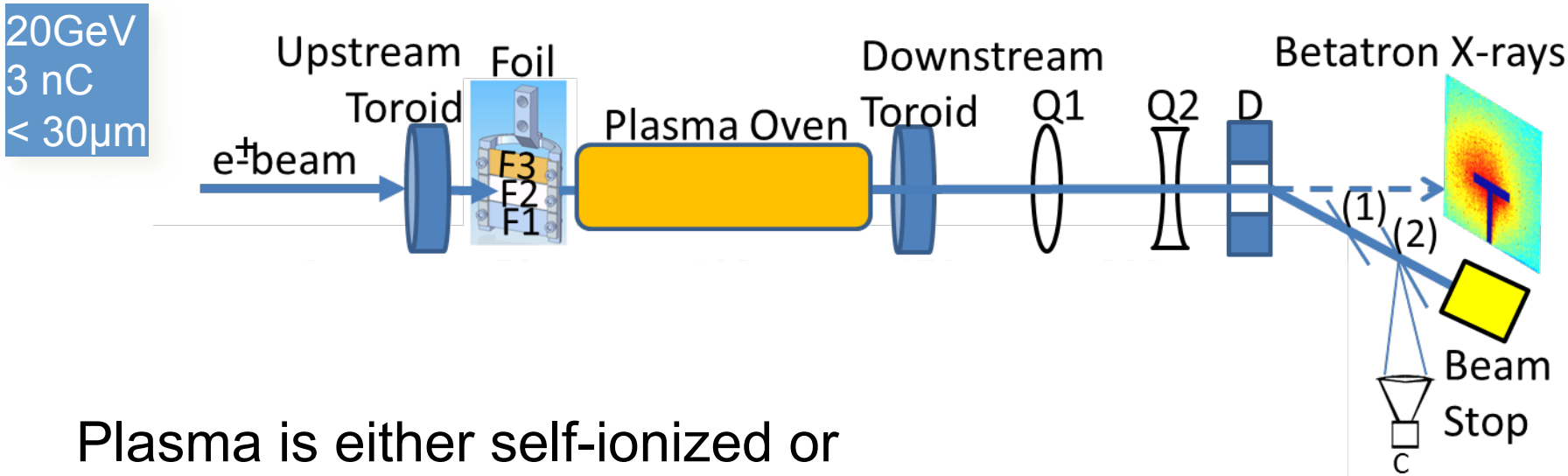


Gradient 50 GeV/m over a meter I. Blumenfeld et al Nature 2007

Plasma Accelerators will be compact but will they be efficient??

E167 Collaboration

Experimental Setup



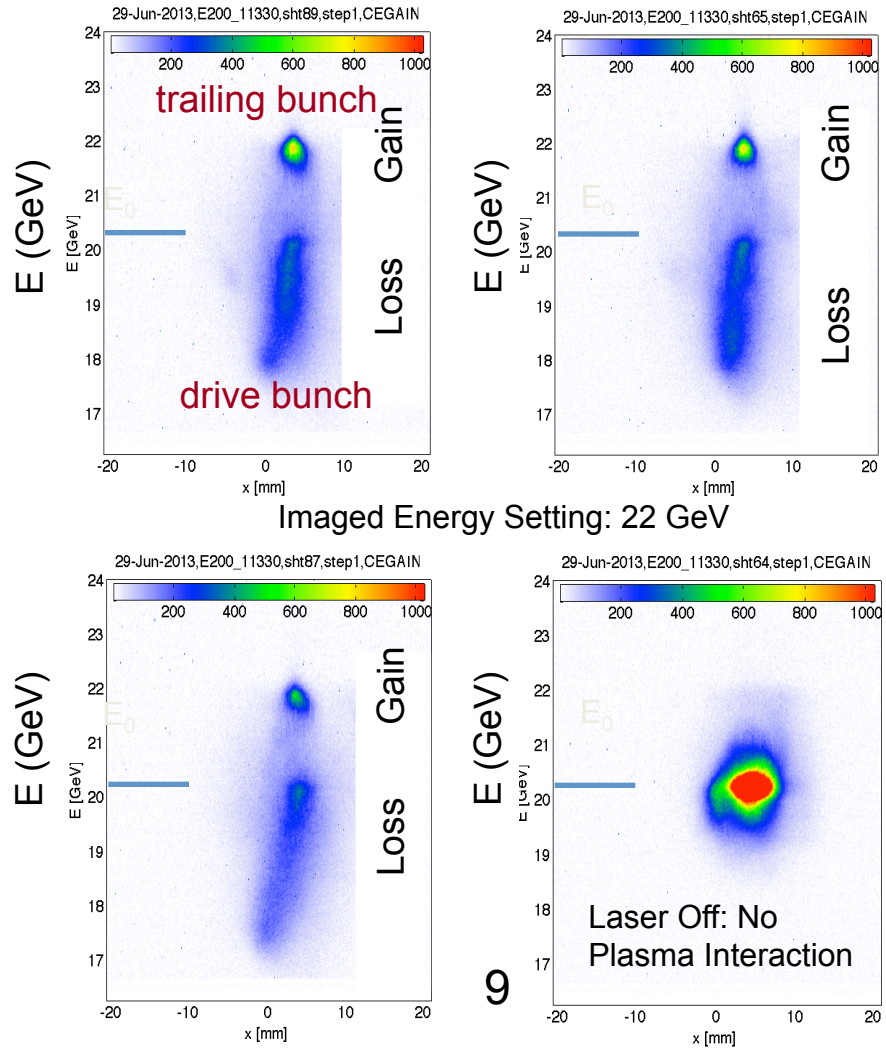
Plasma is either self-ionized or pre-ionized by a 0.75-1.50^0 axicon over up to 1.3 meters using a 250 mJ, 100 fs Ti-sapphire laser

E200 Collaboration

Acceleration of a Discrete Bunch of Electrons

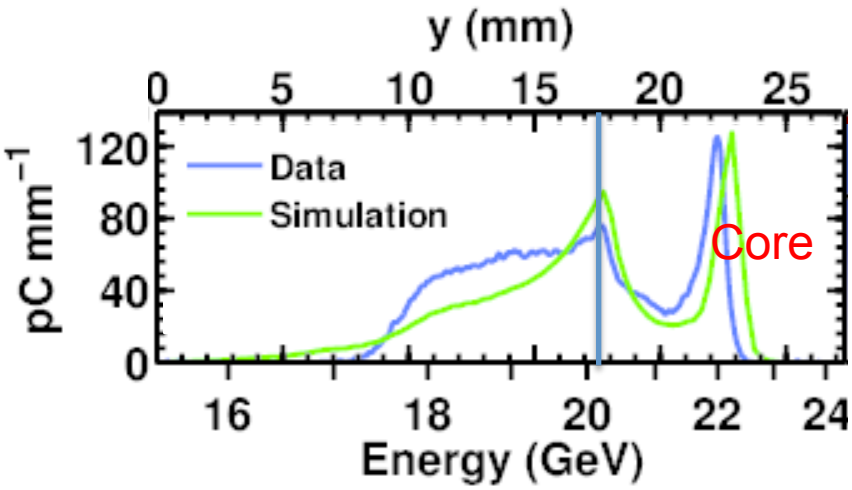
- Use a 30 cm long preformed Li-plasma
- 90 pC in "core" of trailing bunch
- Same amount of charge accelerated outside core
- Core energy gain: 1.7 GeV
- Core energy spread as low as 2%
- Gradient of ~5 GeV/m
- Efficiency of energy extraction up to 30% for core particles

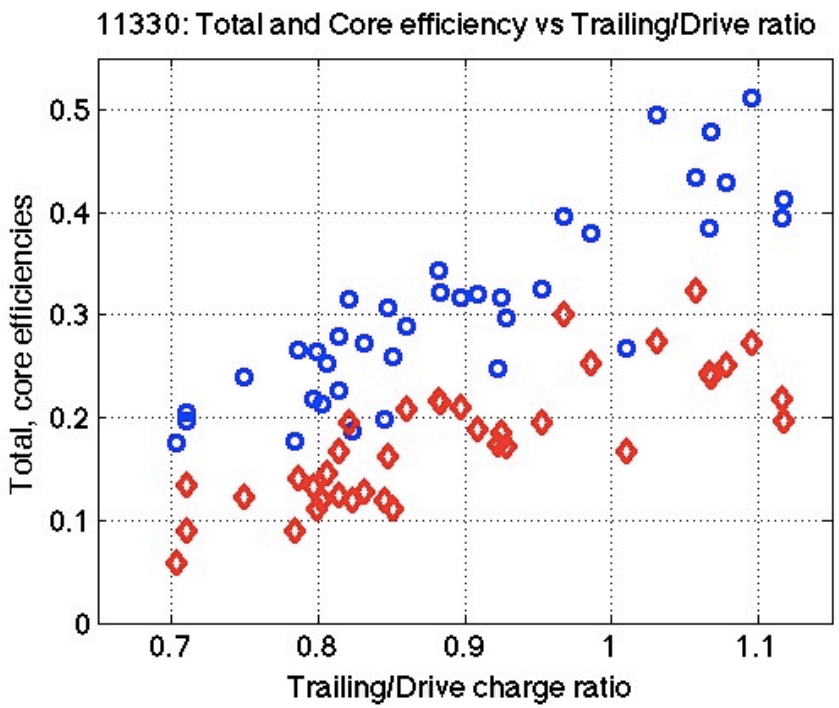
Spectrally dispersed final beam



Evidence for Beam Loading

Efficiency Variation is correlated to Trailing Bunch/ Drive Bunch charge ratio

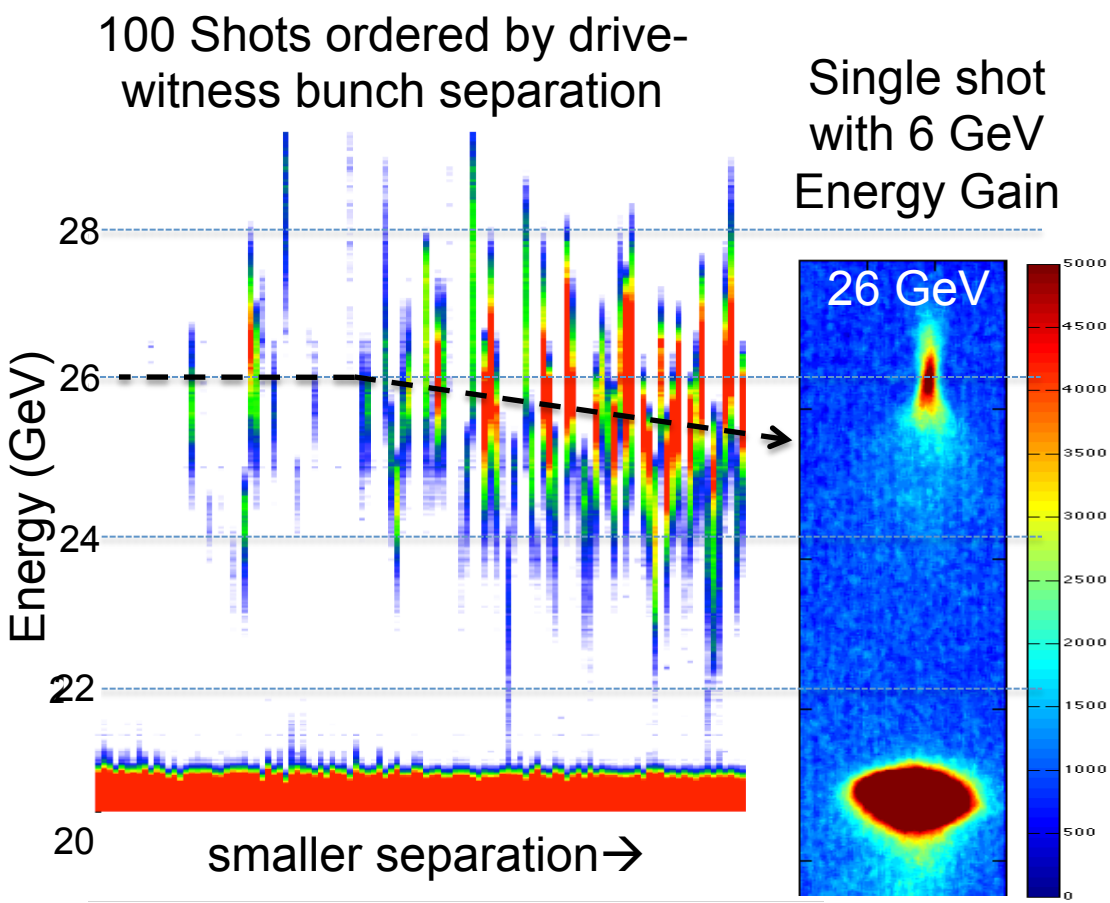




For a given drive bunch charge
as trailing charge increases
E_+ flattens as the wake is strongly loaded
Therefore efficiency expected to increase

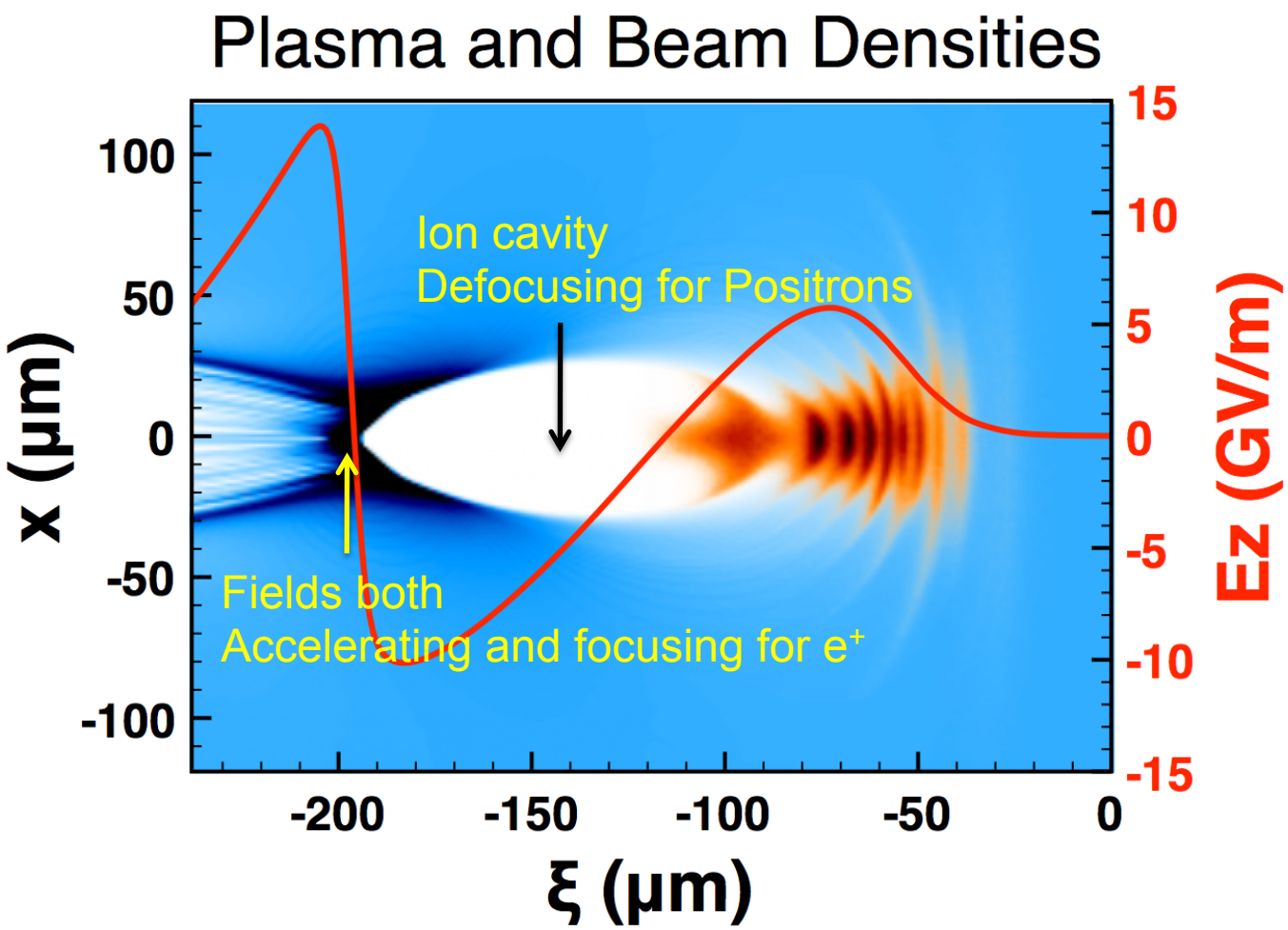
M. Litos et al, Nature 4th Nov, 2014

Increased Plasma Length → Increased Energy Gain



- NEW: increased plasma length from 30cm to 130cm
- → Increased energy gain
- Reduced plasma density to 5×10^{16} cm^{-3} for better coupling
- Early analysis:
  - ~100pC accelerated
  - O(10%) energy spread
  - mean energy gain 6 GeV

Electron Beam Driven Nonlinear Wakes not very Useful for Accelerating a Positron Bunch



Regime for High-Gradient Acceleration and Focusing of Positrons Discovered

Compressed e+ bunches can produce highly nonlinear wakes with desirable properties

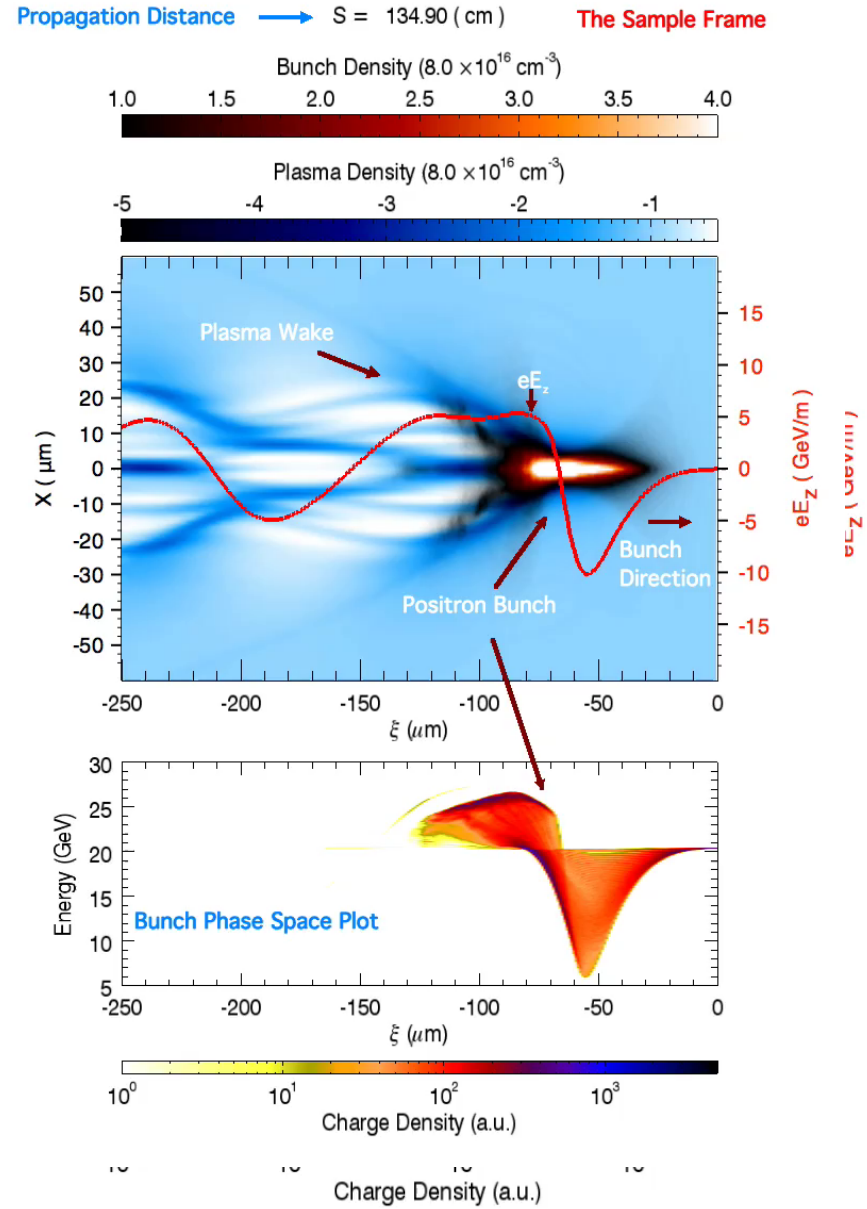
These wakes are quasi-non evolving

A significant portion of the bubble Can focus and accelerate positrons

The wakefield reverses even before the peak of the positron bunch

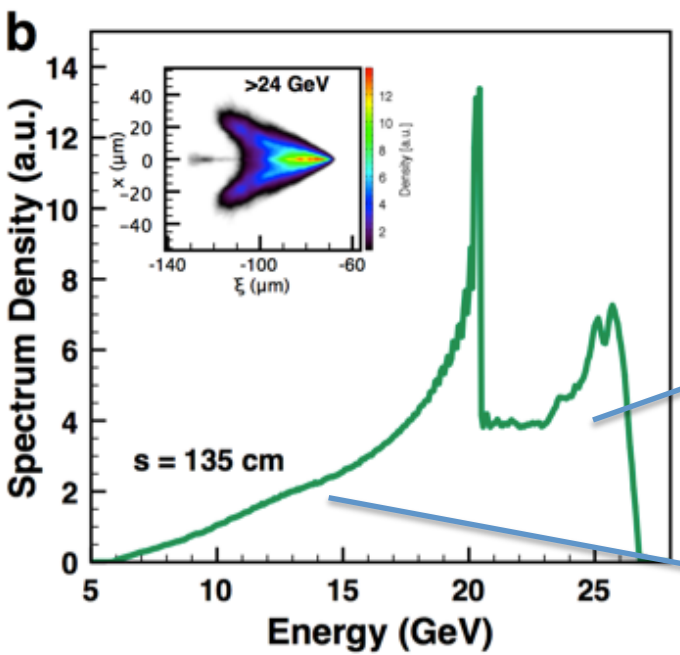
Wake is self loaded by the back half of The positron beam -> narrow energy spread and high energy- extraction efficiency

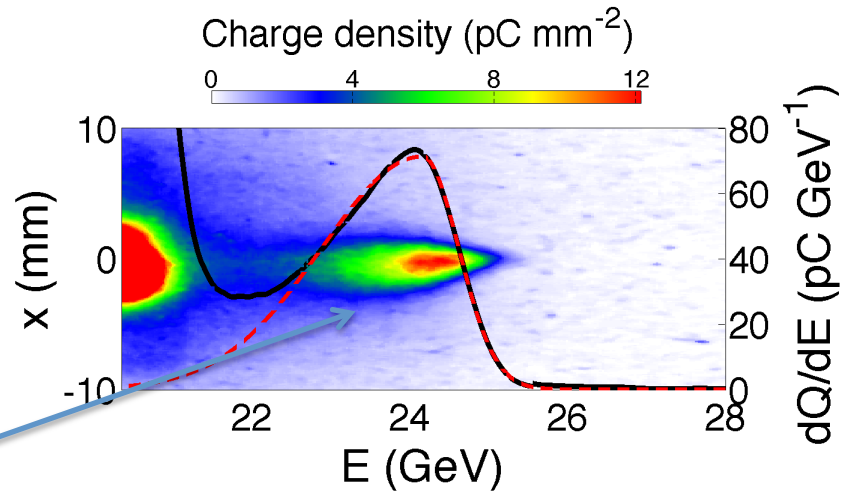
1.4×10^{10} e^+
σ_r=70μm, σ_z=30μm
ε_n=50x200μm

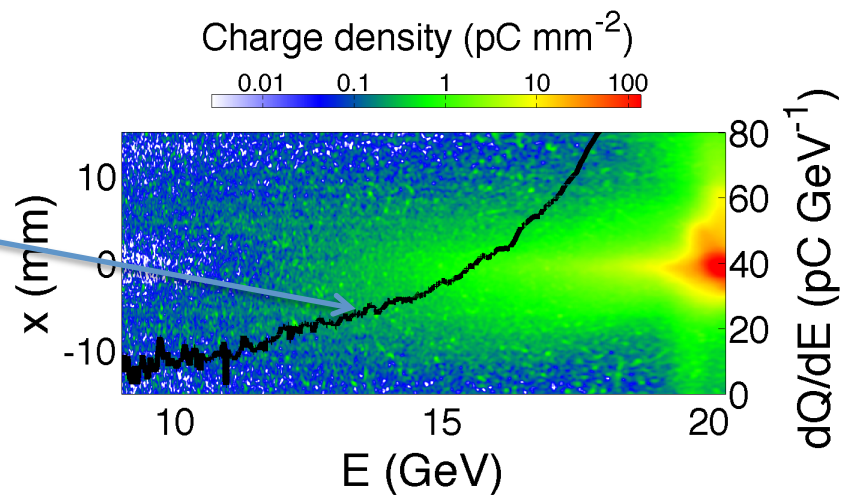


Experiments show formation of a Spectrally Distinct Accelerated Positron Peak from a Single Drive Bunch

S. Corde et al Nature Aug 27 2015
W. An et al to be submitted







Simulated Spectrum

Measured Spectrum

Summary of Positron Acceleration Results

1) A new regime for positron acceleration called "self-loaded" wake experimentally demonstrated

2) A single positron bunch splits into two with energy transfer from the front to the back of the bunch

2)First multi GeV/m gradient acceleration of positrons

3) Energy gain of 5+ GeV in 1.2 m

4) Over 100pC of positrons accelerated with a 3% energy spread and an energy extraction efficiency of 30%

Status of PWFA at FACET

- Tremendous progress on both electron and positron acceleration at FACET

  Both e- and e+ have now shown

  Acceleration of a significant charge

  Small energy spread

  High gradients

  High energy transfer efficiency per unit length

Next Great Challenge is emittance preservation and generation of ultra-low emittance beams