Advanced Accelerator Physics at SLAC

Beam-Driven Plasma Acceleration: E-157, E-162, E-164, E-164X

T. Katsouleas, S. Deng, S. Lee, P. Muggli, E. Oz
University of Southern California

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Stanford Linear Accelerator Center

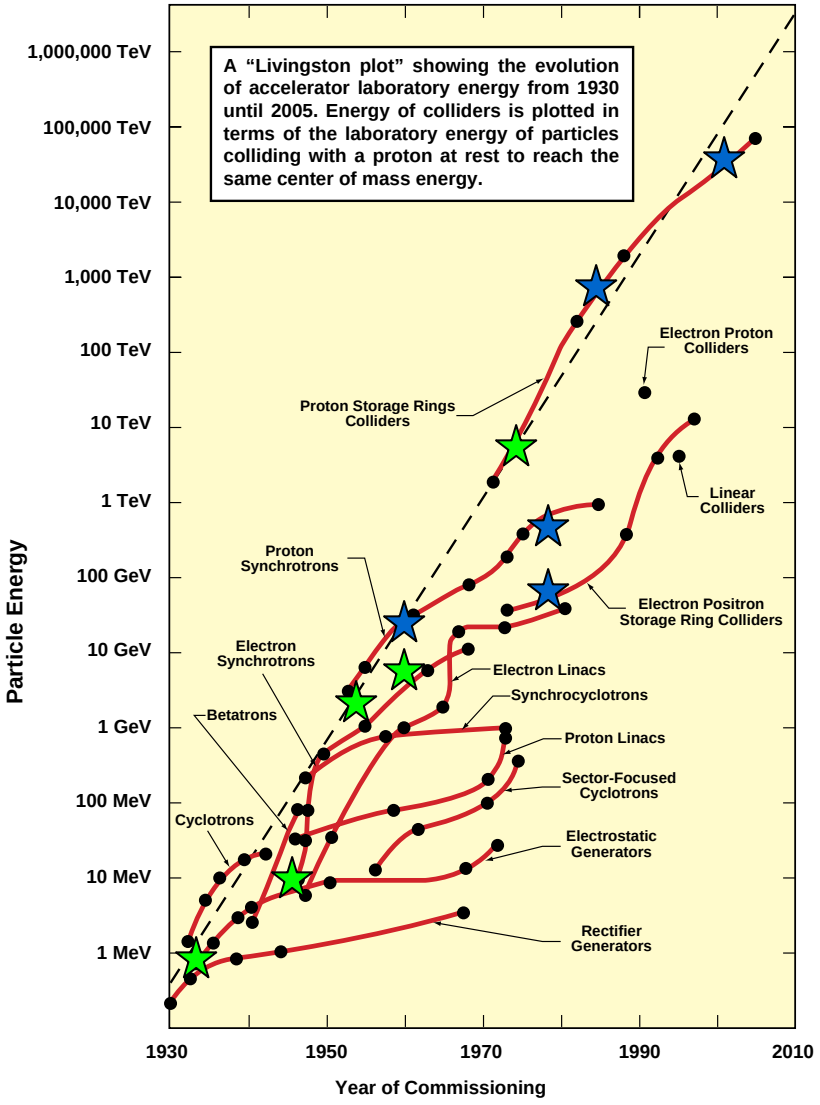
Vacuum Laser Acceleration: LEAP, E-163

R. L. Byer, T. Plettner, T. I. Smith, R. L. Swent
Stanford University

E. R. Colby, B. M. Cowan, M. Javanmard, X. E. Lin, R. J. Noble, D. T. Palmer, C. Sears, R. H. Siemann, J. E. Spencer, D. R. Walz, N. Wu
Stanford Linear Accelerator Center

J. Rosenzweig
University of California, Los Angeles

Science ⇔ Innovation



★ Particle Physics Discoveries

- 2 ν's
- J/ψ
- W & Z
- top

★ Accelerator Innovations

- Phase focusing
- Klystron
- Strong focusing
- Colliding beams
- Superconducting magnets
- Superconducting RF

Vacuum Laser Acceleration: LEAP, E-163

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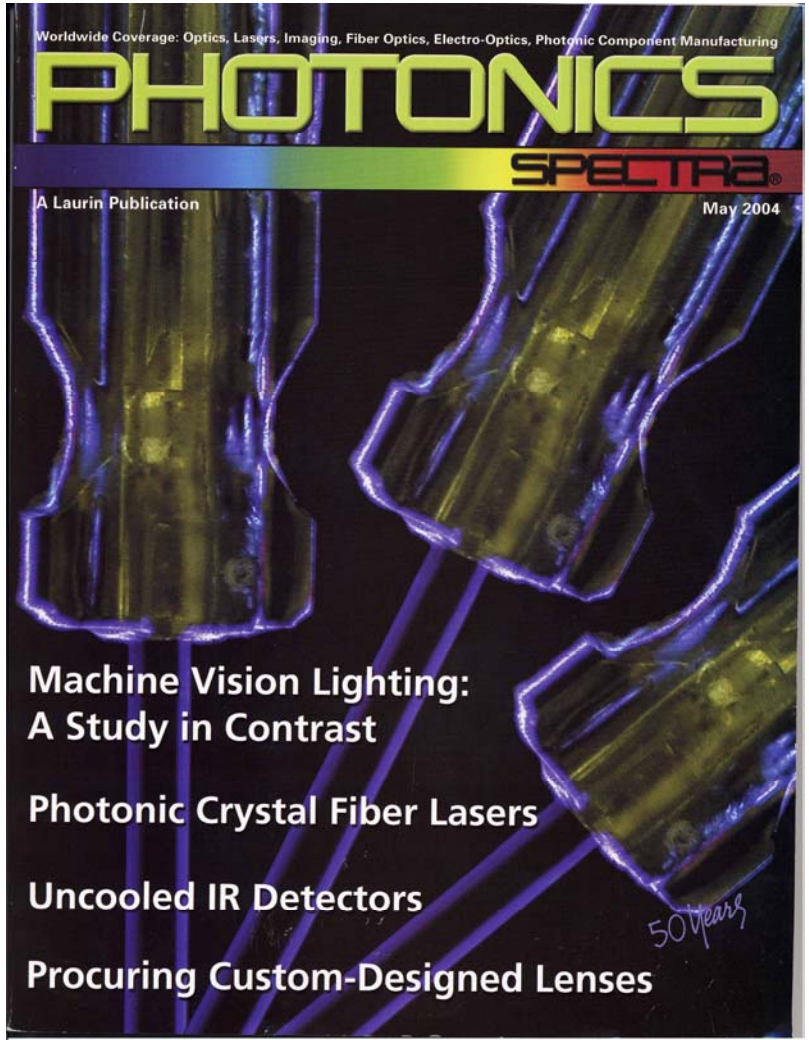
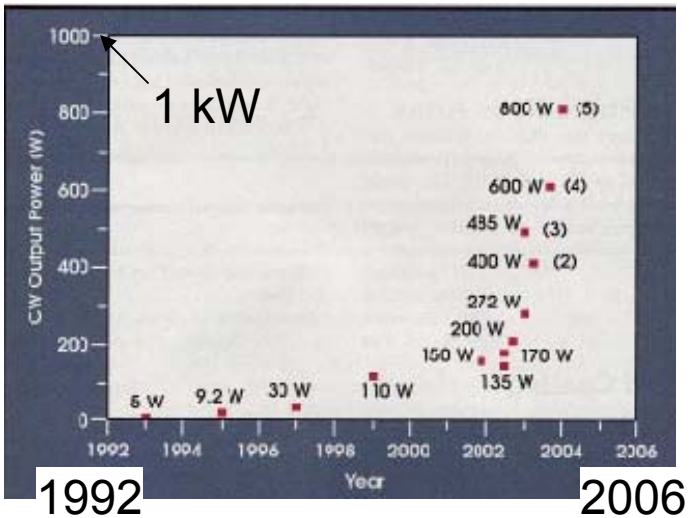
Motivation For This Research

J. Limpert *et al*, “Scaling Single-Mode Photonic Crystal Fiber Lasers to Kilowatts”

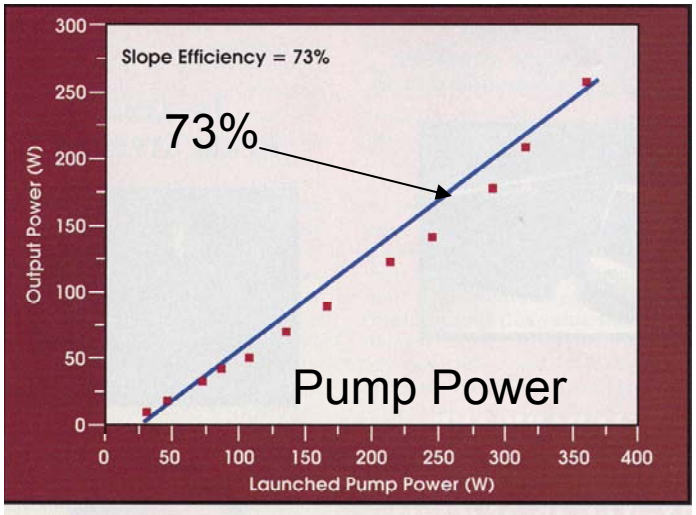


CW Output Power



1992 2006

Output Power



Carrier Phase-Locked Lasers

Diddams *et al*

"Direct Link between Microwave and Optical Frequencies with a 300 THz Femtosecond Laser Comb", *Phys. Rev. Lett.*, **84** (22), p.5102, (2000).

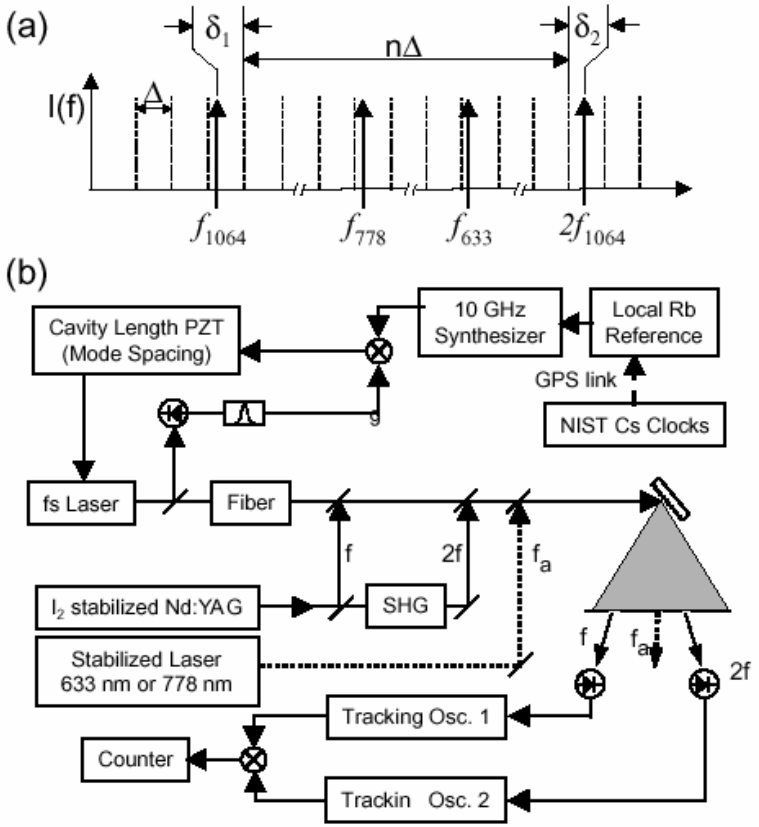


FIG. 1. (a) The femtosecond laser comb spans an octave such that the optical frequency f_{1064} can be expressed as an integer multiple of the comb spacing Δ plus small measured offsets δ_1 and δ_2. (b) Apparatus used for measurement of the optical frequencies in terms of the cesium microwave standard.

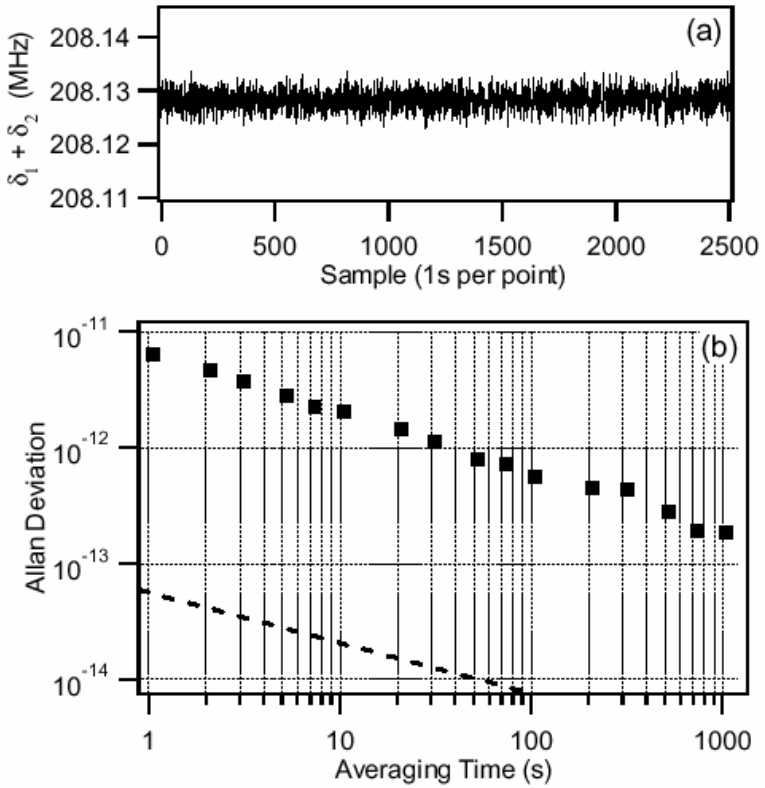
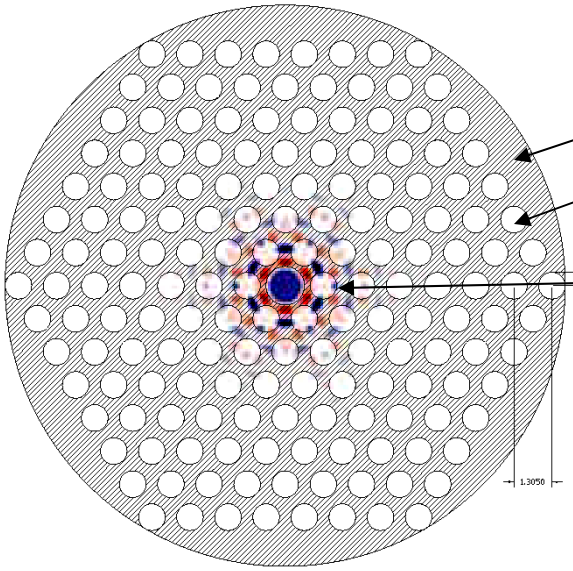


FIG. 3. (a) Time record of the counted sum of the heterodyne beats at 1064 and 532 nm, which represents a measurement of the 282 THz optical frequency of f_{1064}. (b) The squares are the Allan deviation of the optical frequency computed from the above time record. For comparison, the dashed line is the measured Allan deviation between "JILA East" and "JILA West" Nd:YAG/I_2 systems.

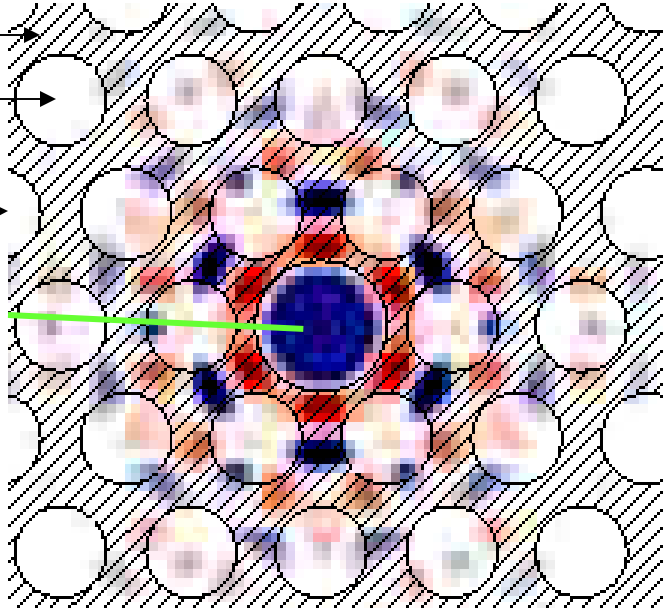
Photonic Crystal Fibers

X. Lin, Phys. Rev. ST-AB, **4**, 051301 (2001).



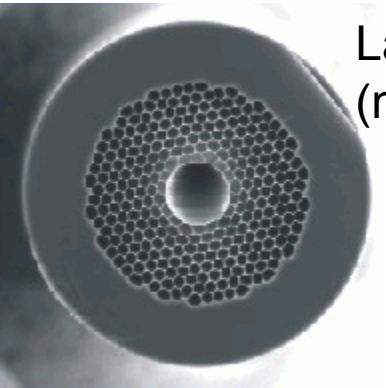
Fused Silica
Vacuum Holes

e⁻ beam passage
radius = 0.678 λ



False color map of E_z

Blaze Photonics

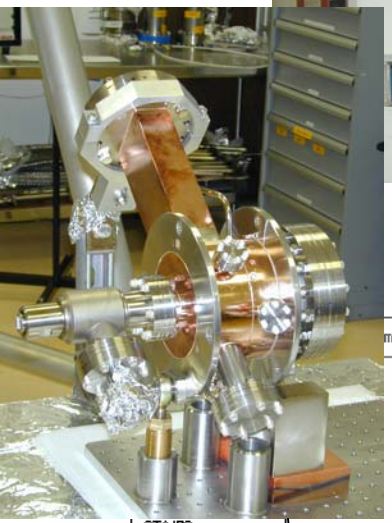


Large aperture fiber
(not an accelerator)

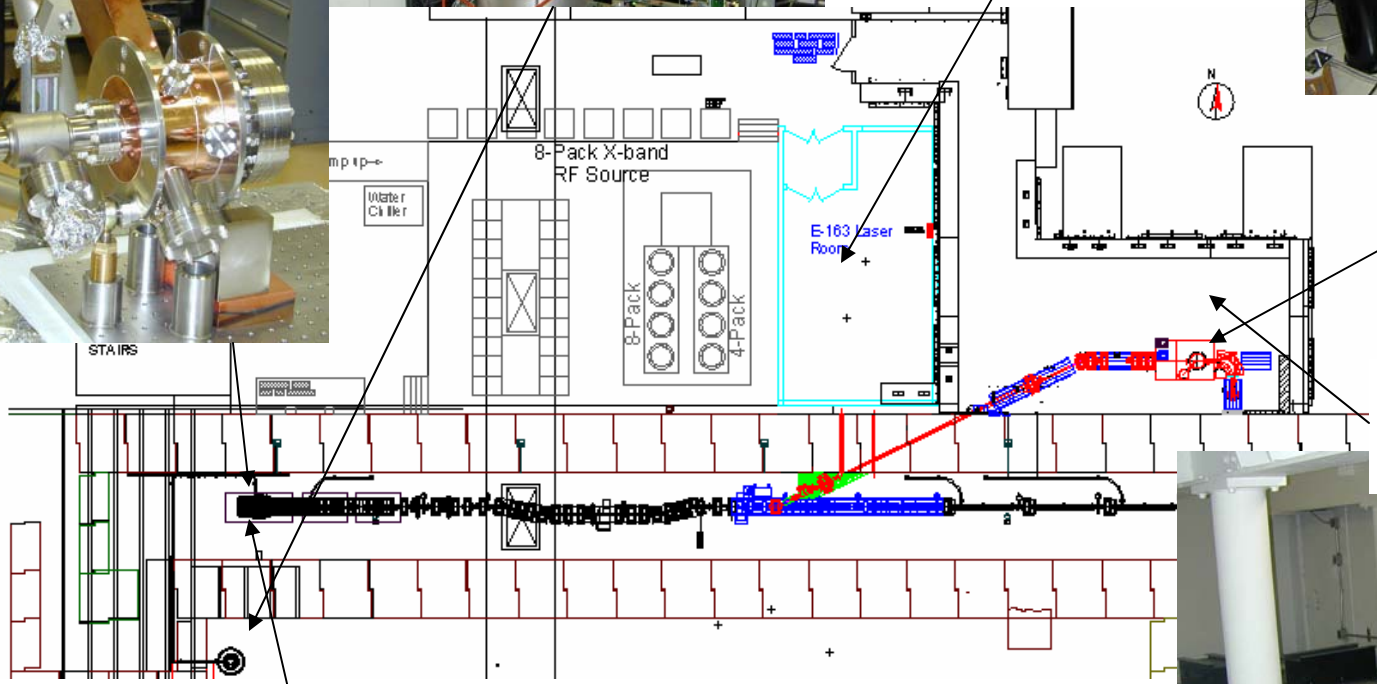
The photonic crystal confines the accelerating mode to the region near the beam tunnel

E163 – Laser Acceleration Experiment

STANFORD LINEAR ACCELERATOR CENTER



Ti:Sapphire Laser System

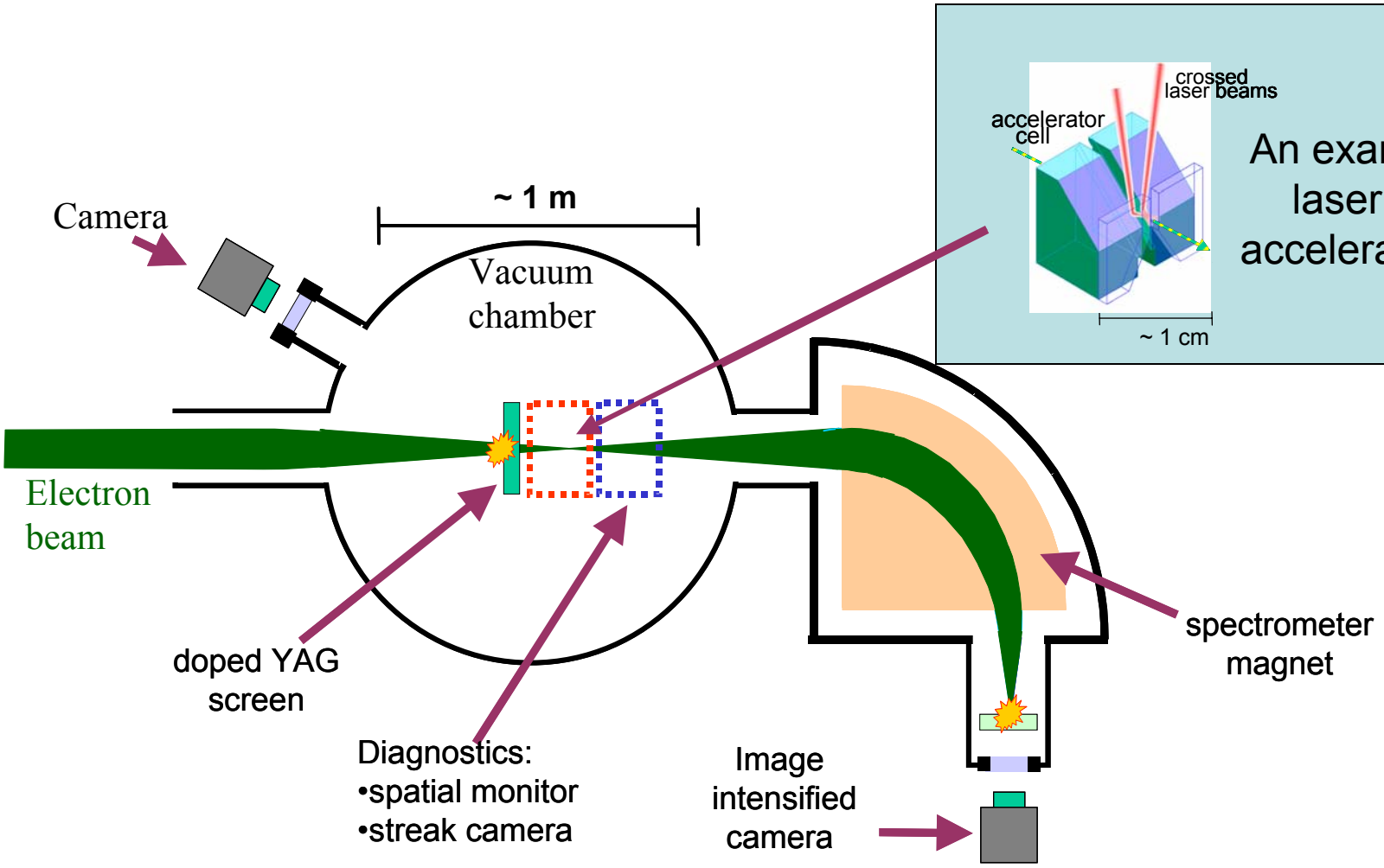


Experiment

60 MeV Experimental Hall

RF PhotoInjector

The E163 Experimental Setup



Beam-Driven Plasma Acceleration: E-157, E-162, E-164, E-164X

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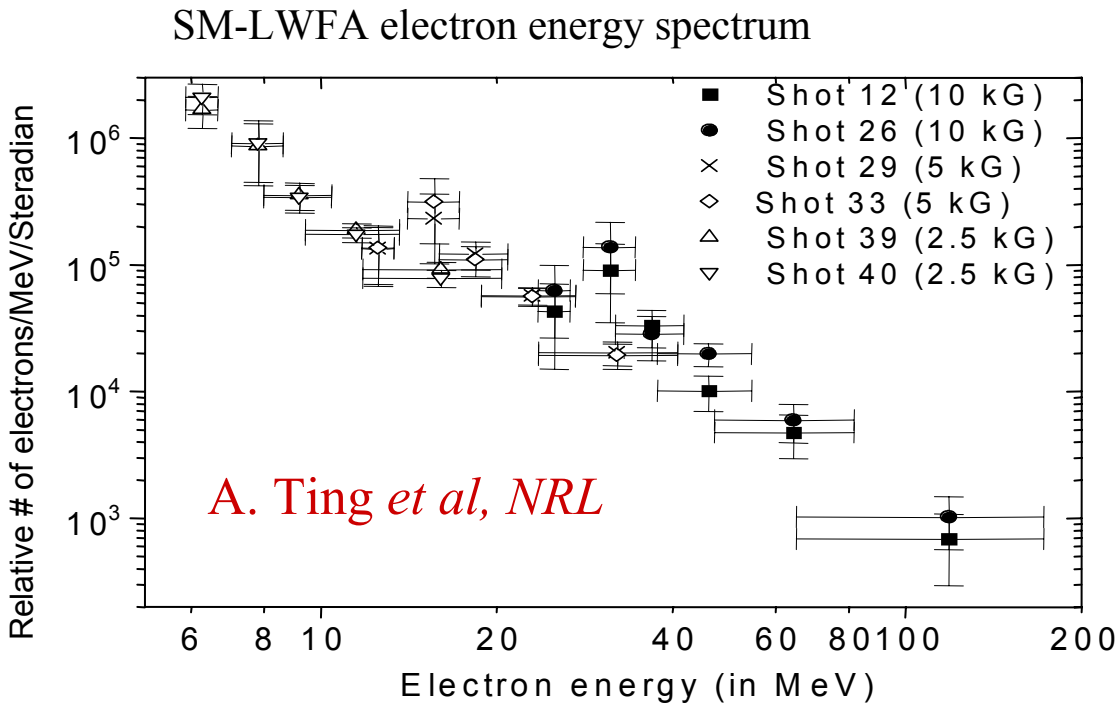
Plasma Wakefield Acceleration E157, E162, E164 & E164X

Motivation For These Experiments

Extraordinarily high fields developed in beam plasma interactions but there are many questions related to the applicability for focusing and acceleration

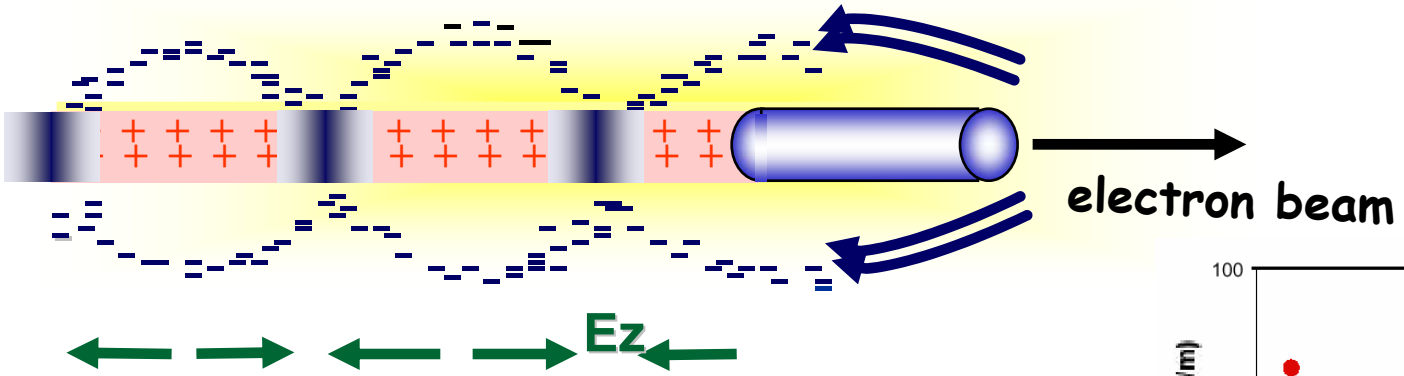
Self modulated laser wakefield acceleration

E > 100 MeV, G > 100 GeV/m

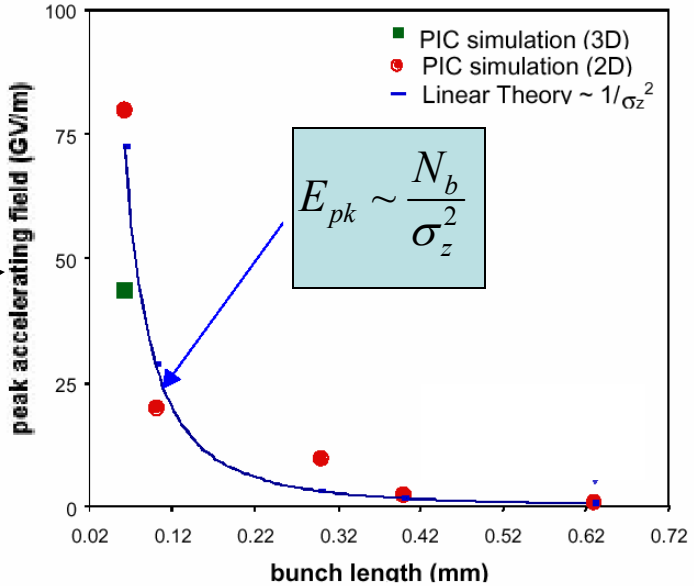


Physical Principles of the Plasma Wakefield Accelerator

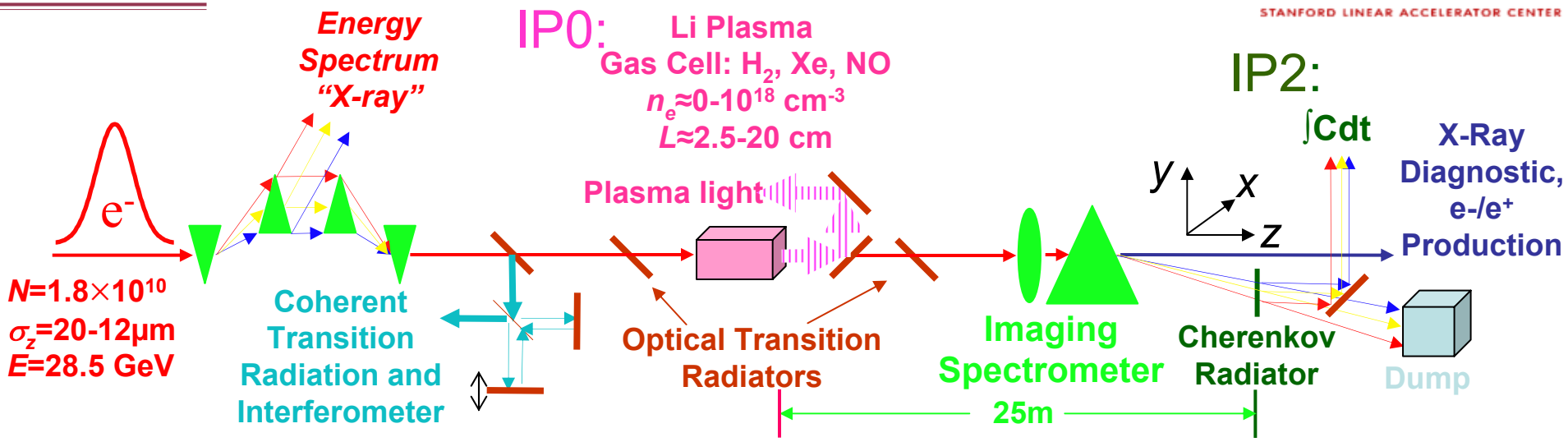
- Space charge of drive beam displaces plasma electrons
- Plasma ions exert restoring force => Space charge oscillations
- Wake Phase Velocity = Beam Velocity



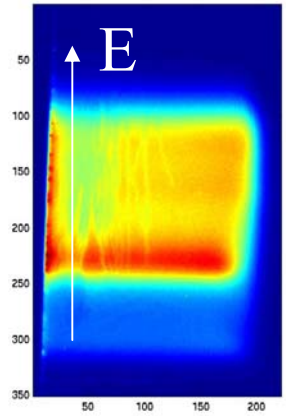
- When $\sigma_z/\lambda_p \sim 1$ ($\Rightarrow N_p \sim 1/\sigma_z^2$)



Apparatus Located in the FFTB

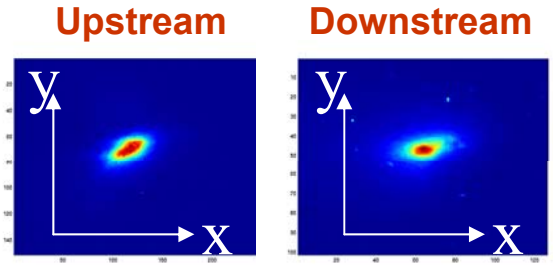


- X-ray Chicane



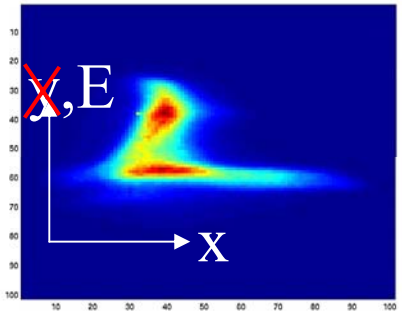
-Energy resolution ≈60 MeV

- Optical Transition Radiation (OTR)



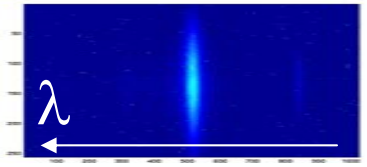
-1:1 imaging, spatial resolution ≈9 μm

- Cherenkov (aerogel)



- Spatial resolution ≈100 μm
- Energy resolution ≈30 MeV

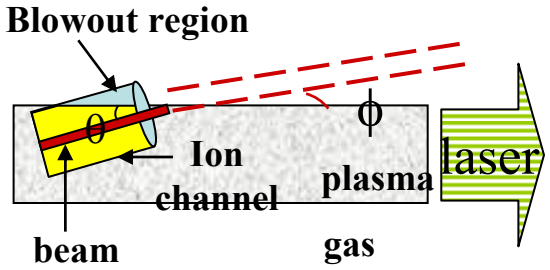
- Plasma Light



Some E-157 & E-162 Highlights

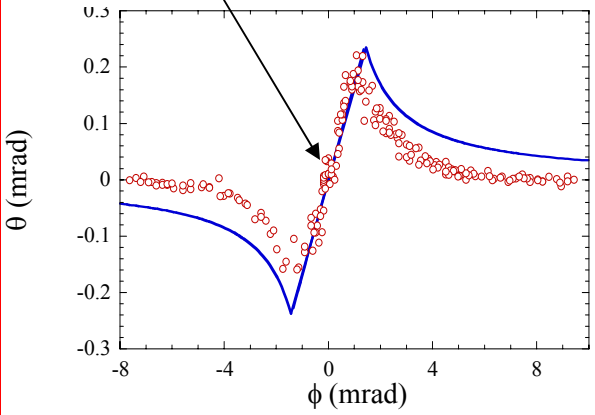
STANFORD LINEAR ACCELERATOR CENTER

Electron Beam Refraction at the Gas–Plasma Boundary

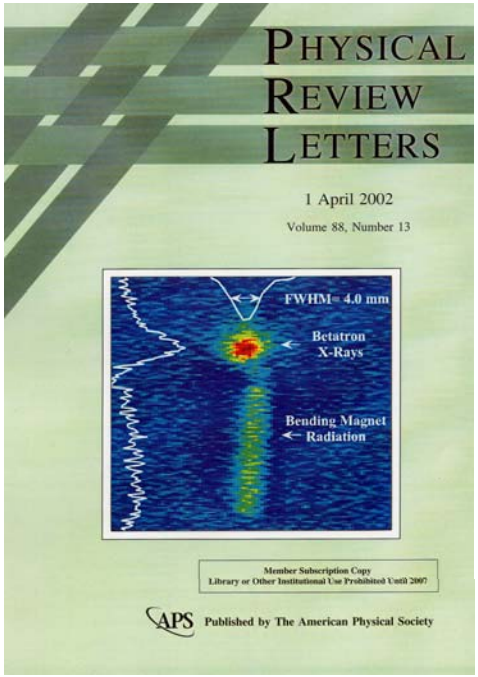


Impulse Model **Data**

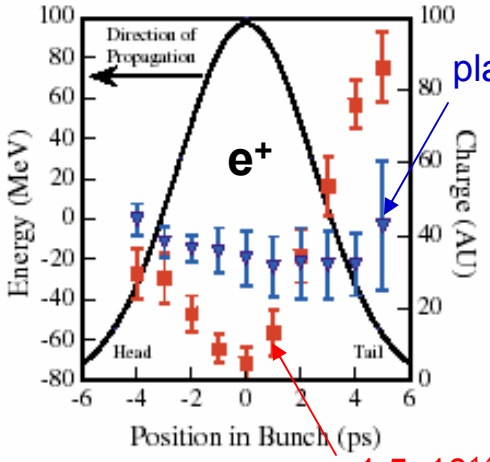
Total internal reflection



X-Ray Production



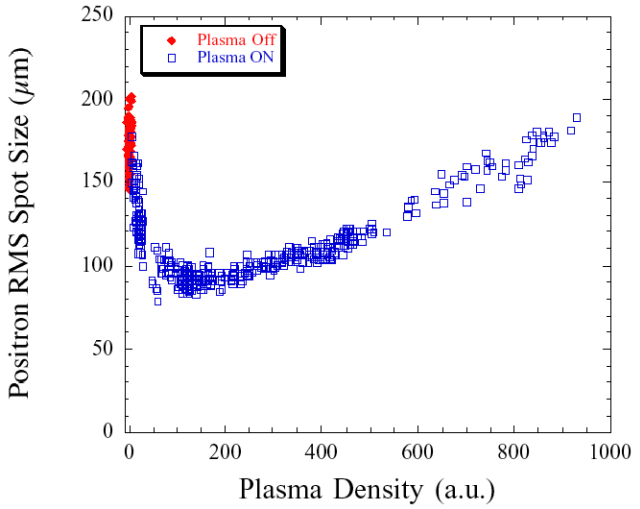
e^+ Acceleration



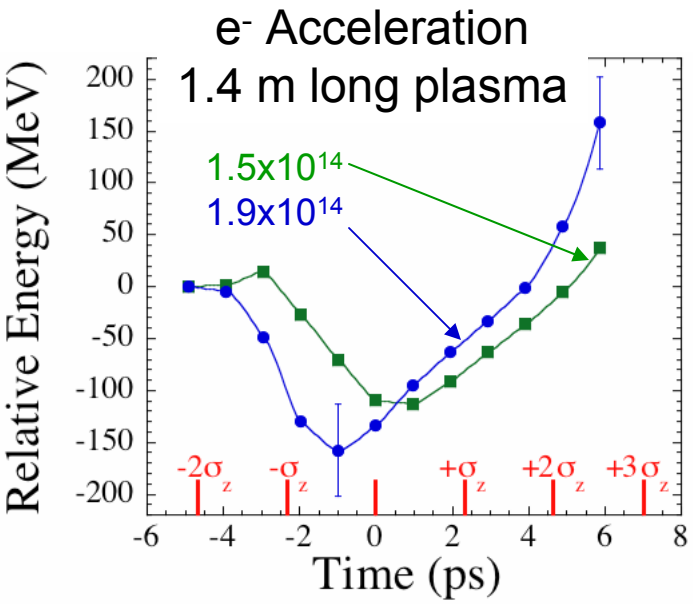
No plasma

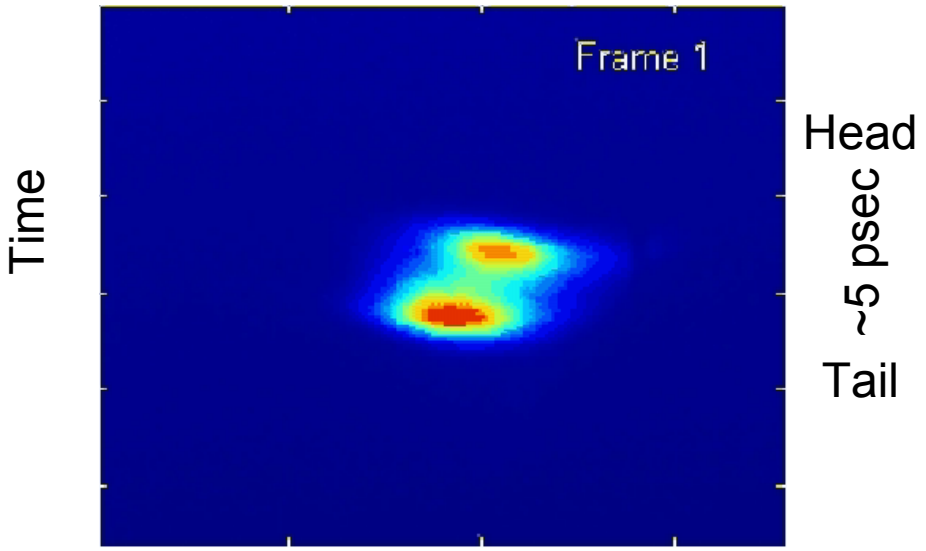
1.5×10^{14} cm^{-3}

e^+ Focusing

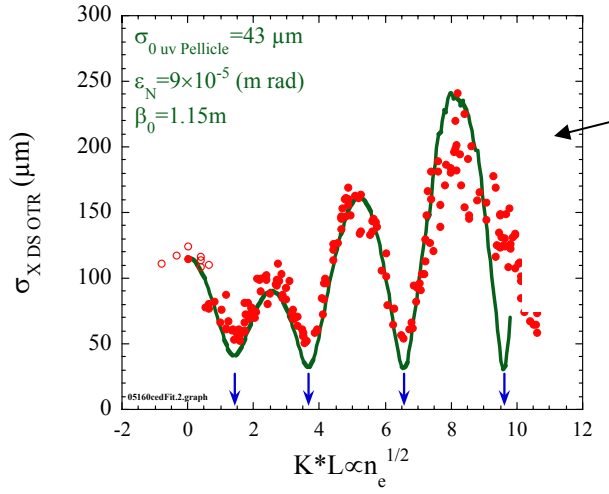


Some E-157 & E-162 Highlights

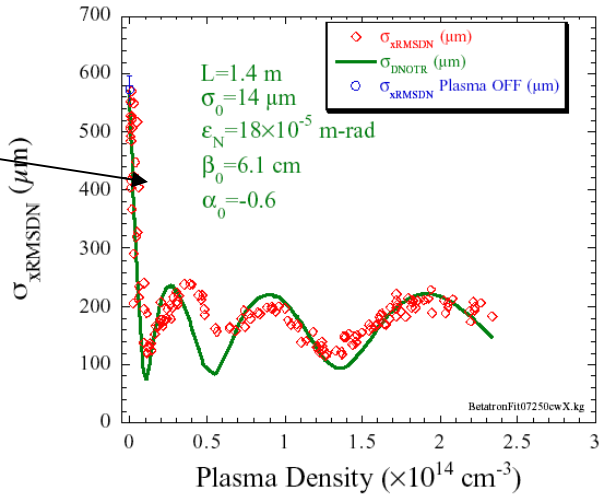




Transverse Wakefields and Betatron Oscillations



Mismatched
Matched



e164 & e164x

PLASMA WAKEFIELD ACCELERATOR EXPERIMENT

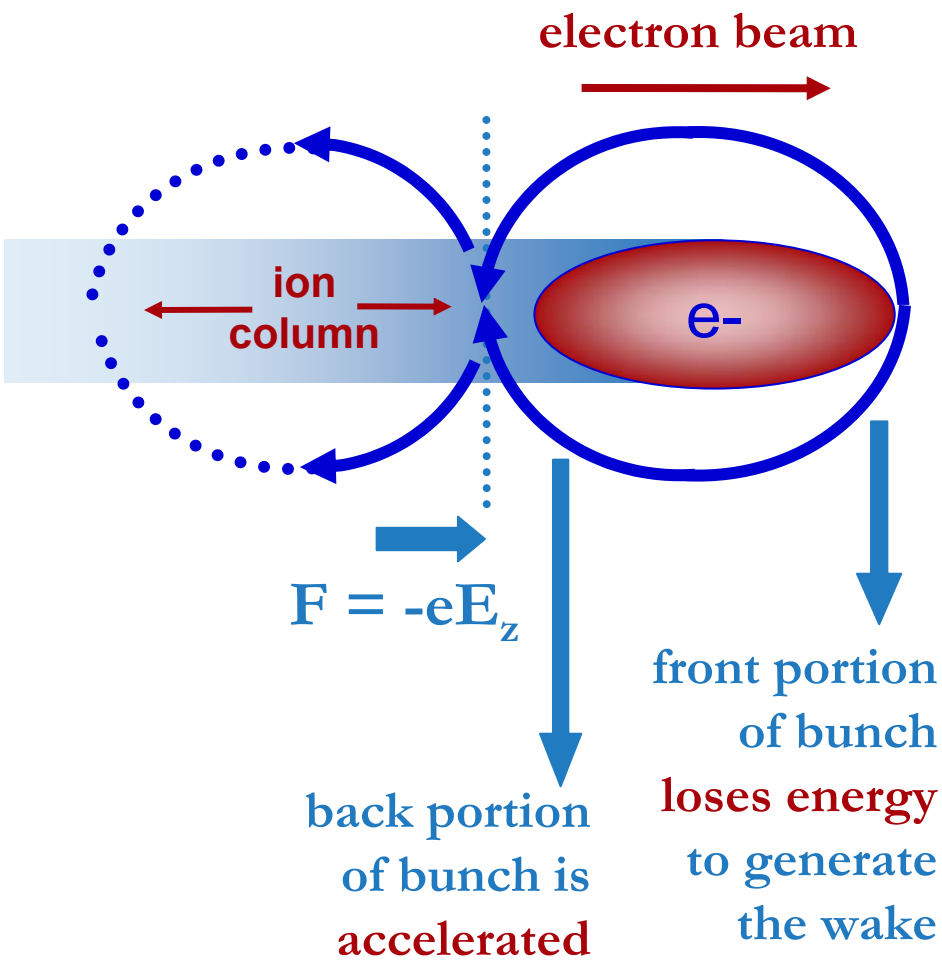
SLAC STANFORD LINEAR ACCELERATOR CENTER

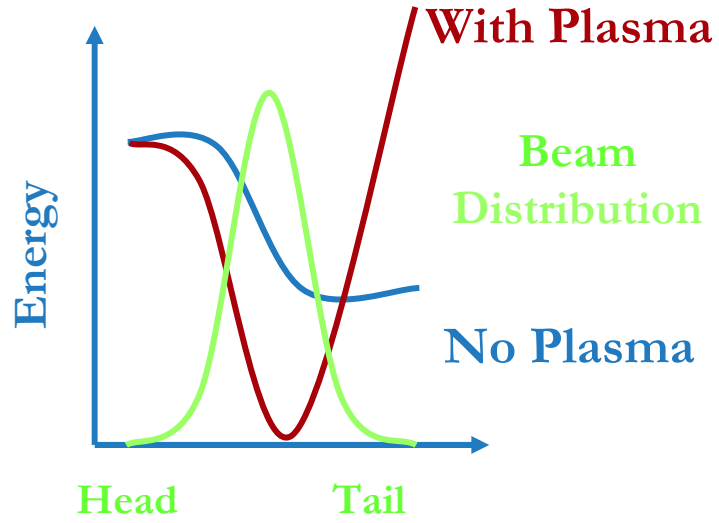
USC

UCLA

Recent results address the question of whether large gradients can be generated and sustained over appreciable distances

Key: G ~1/(bunch length)^2





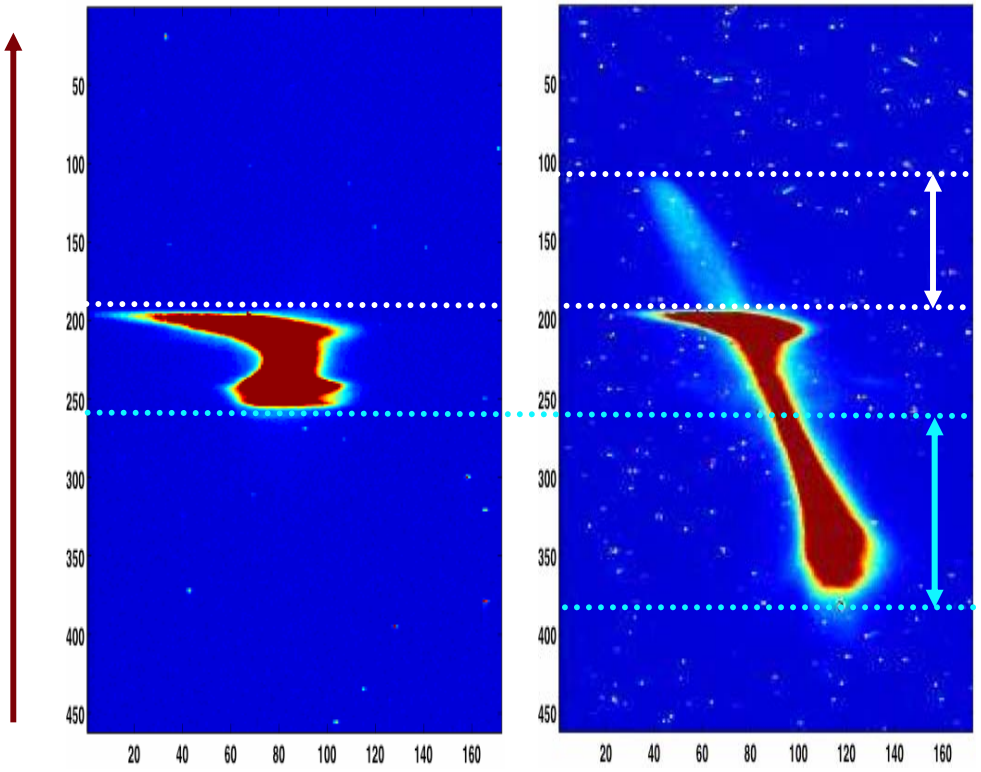
e164 & e164x
PLASMA WAKEFIELD ACCELERATOR EXPERIMENT

SLAC
STANFORD LINEAR ACCELERATOR CENTER

USC

UCLA

High-gradient acceleration of particles possible over a significant distance



Tilt is due to small, uncorrected horiz. dispersion

$$\rho = 2.11 \times 10^{17} cm^{-3}$$

$$L \approx 10 cm$$

e164 & e164x
PLASMA WAKEFIELD ACCELERATOR EXPERIMENT

SLAC
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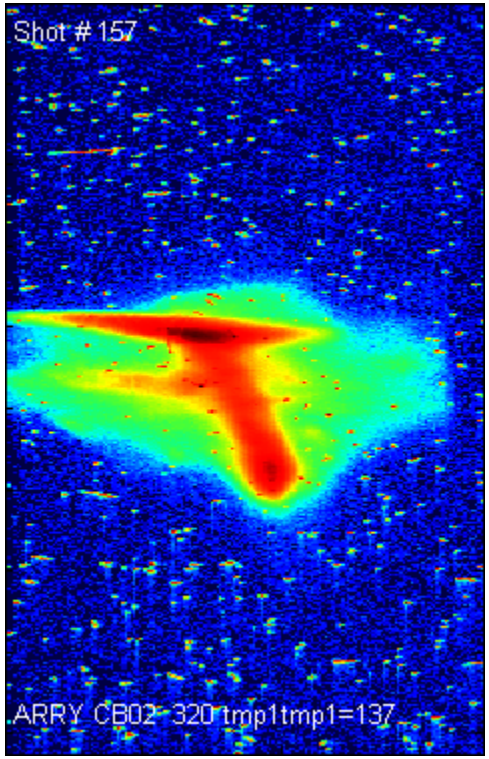
USC

UCLA

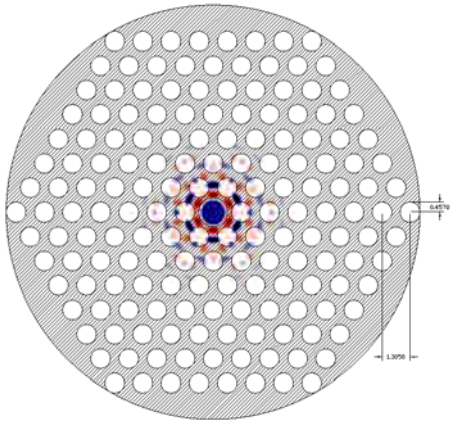
A single 200 sec long run sorted by a rough measurement of peak current

Density = $2.55 \times 10^{17}/cm^{-3}$



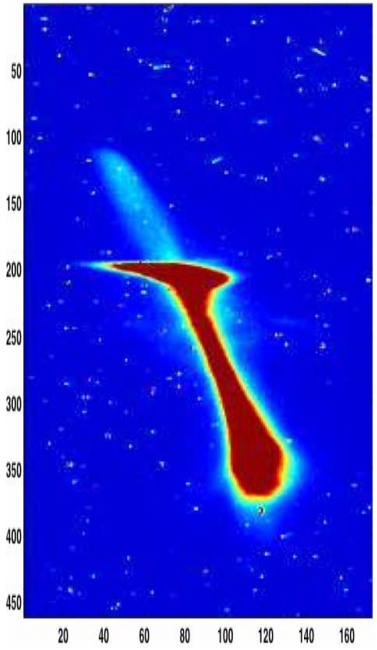
7.4 GeV

Summary



Laser-driven accelerator structures

- Based on rapidly advancing field of photonics
- Concepts for accelerator structures
- Analyses of wakefields and efficiency
- Promise of rapid experimental advances with construction of SLAC experiment E163

Plasma Wakefield Acceleration

- Electron & positron transport and acceleration in a long plasma
- Accelerating gradients greater than 15 GeV/m sustained over 10 cm
- Many results to come: higher gradients, more energy gain, trapped particles, multiple bunches, …