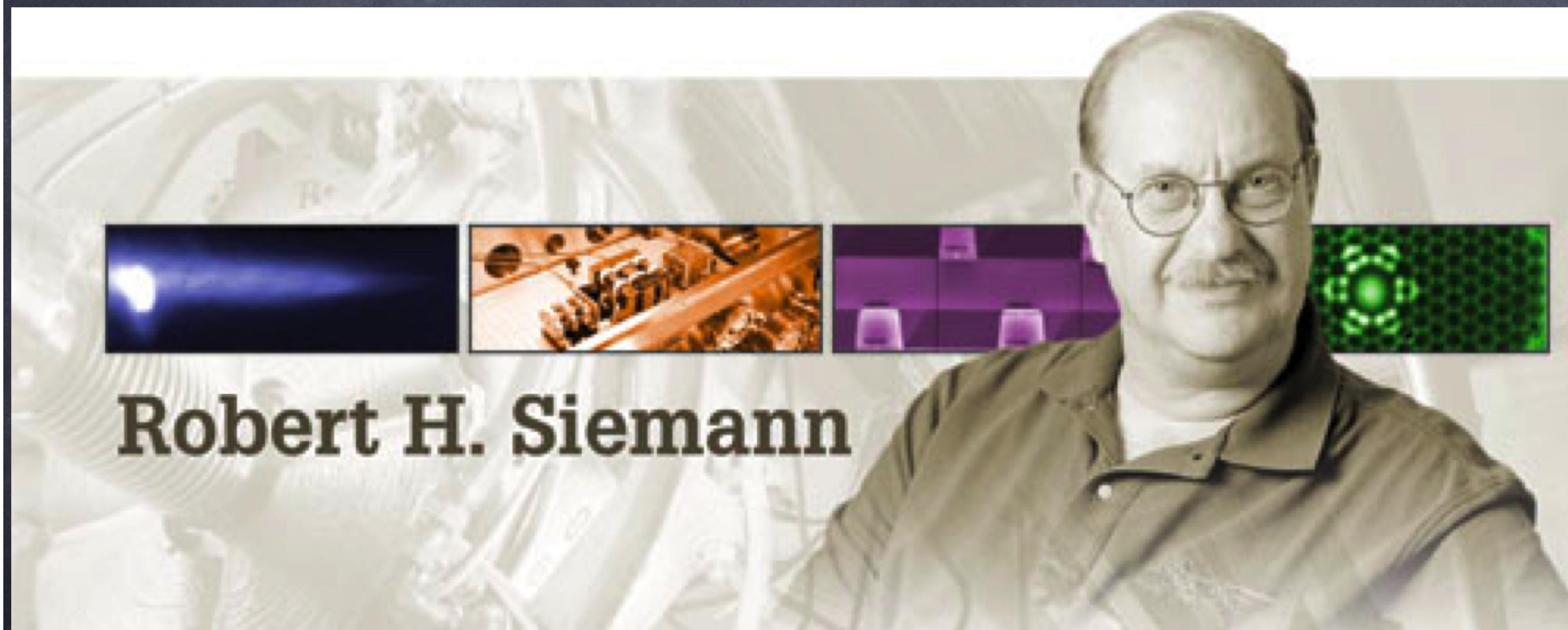
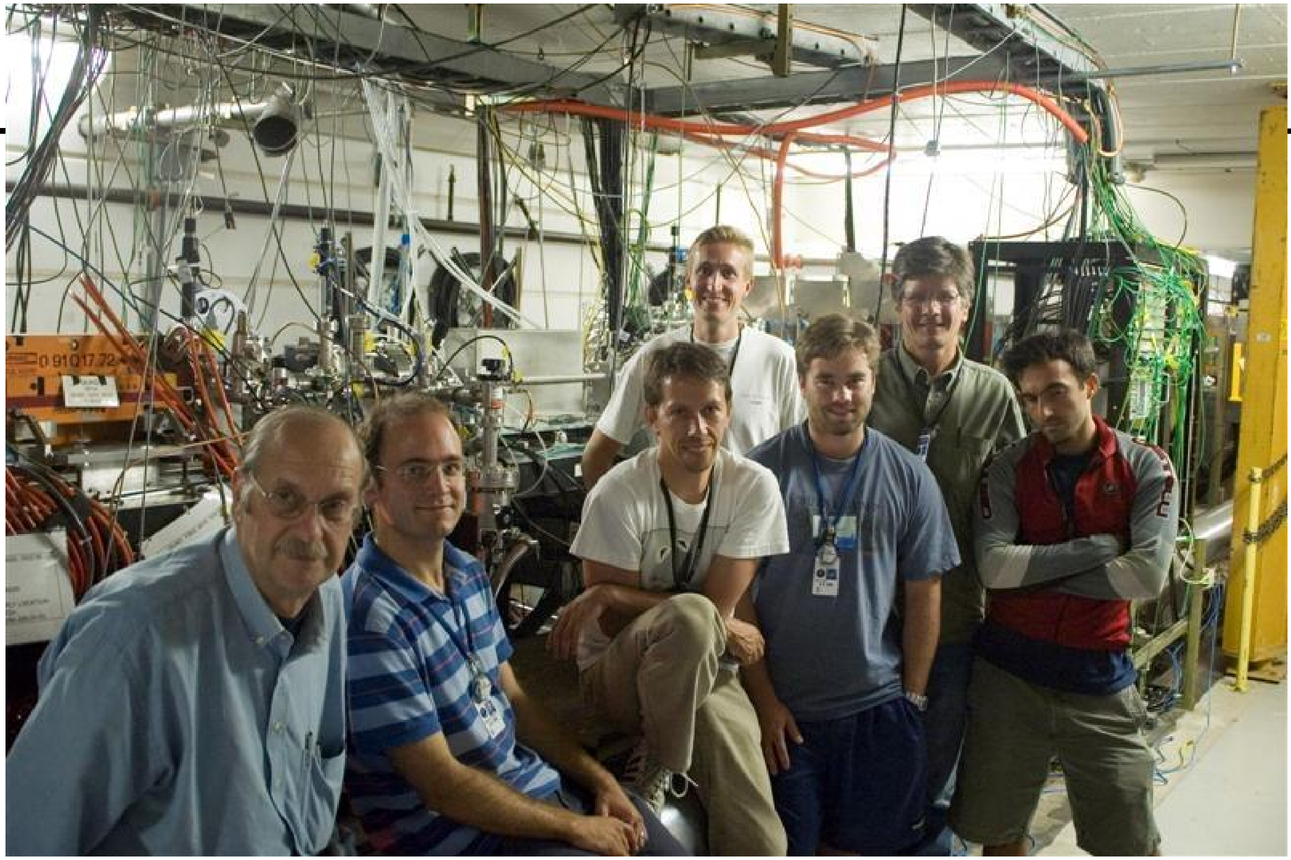
In memory of Bob



Bob Siemann Memorial Symposium *July 7, 2009*

Bob Siemann and the Plasma Wakefield Accelerator Collaboration at SLAC



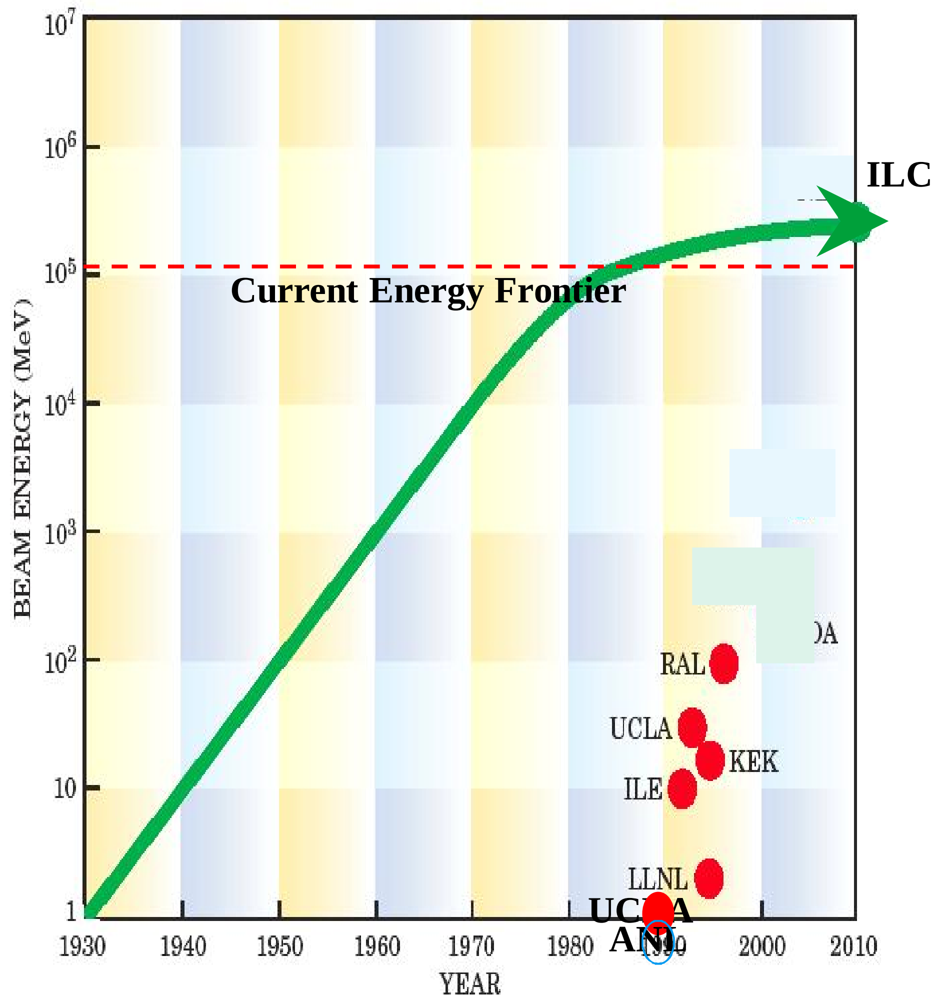
Tom Katsouleas

Professor and Dean, Duke University, Pratt School of Engineering

DUKE ENGINEERING EDMUND T. PRATT, JR. SCHOOL OF ENGINEERING

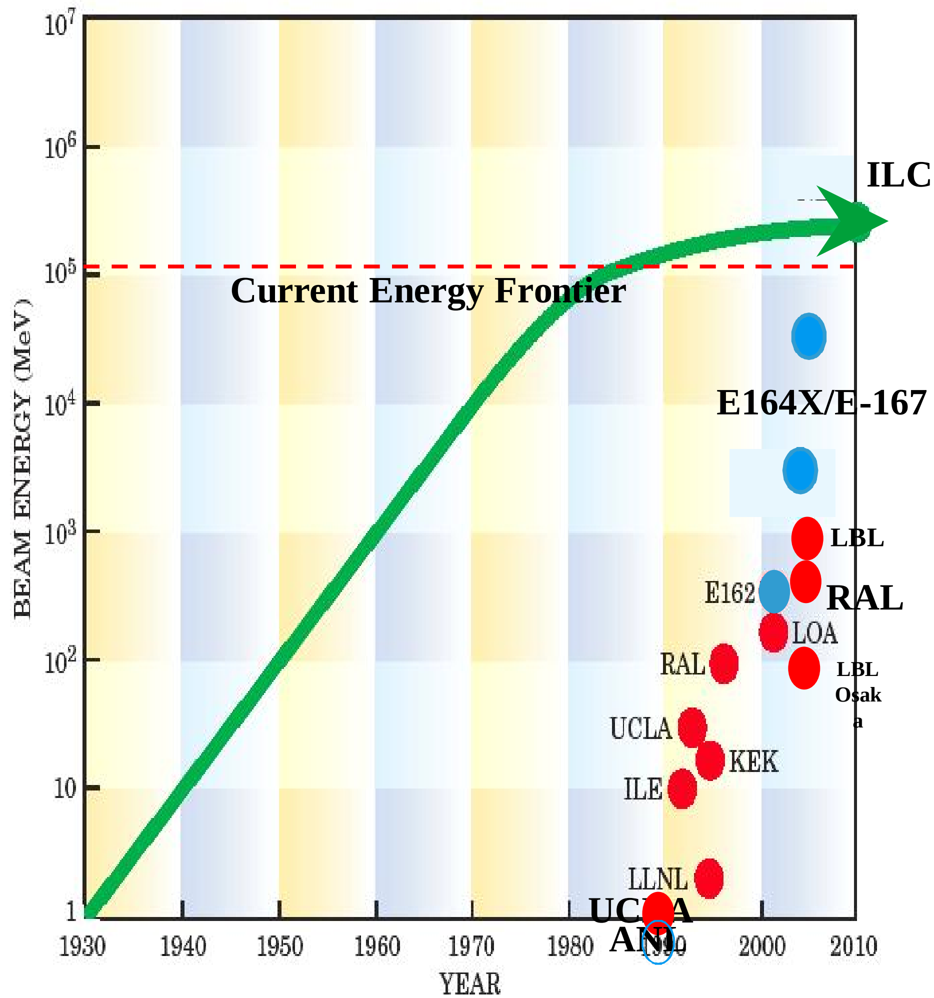
Plasma Accelerators – History (BB)

- 1979 Tajima & Dawson Paper
- 1981 Tigner Panel rec'd investment in adv. acc.
- 1985 Malibu, GV/m *unloaded* laser 'beat' wakes, world-wide effort begins – Richter poses "GeV Challenge" for advanced concepts
- 1988 ANL maps beam wakes (5 MV/m)
- 1992 1st e- at UCLA
- 1994 'Jet age' begins --100 MeV in laser-driven gas jet at RAL (but scaling from mm to cm or m with lasers not obvious)
- 1997 Bob enters the field at Snowmass…



Plasma Accelerators – History (AB)

- 1997 Snowmass – Bob approached with idea of GeV energy gain in a 1m SLAC-driven wake; identifies Ralph Assmann to work with us on proposal to PAC
- 1998 PAC Approval
- 1999 E-157 begins – Dom Perignon on ice in Bob's office - focusing, matching, deceleration
- 2001 E162 250 MeV acceleration, refraction, e+
- 2004 E164 -- GeV acceleration!
- 2004 'Dawn of Compact Accelerators' (monoenergetic beams at LBNL, LOA, RAL)
- 2007 E167 Energy Doubling at SLAC (champagne opened)

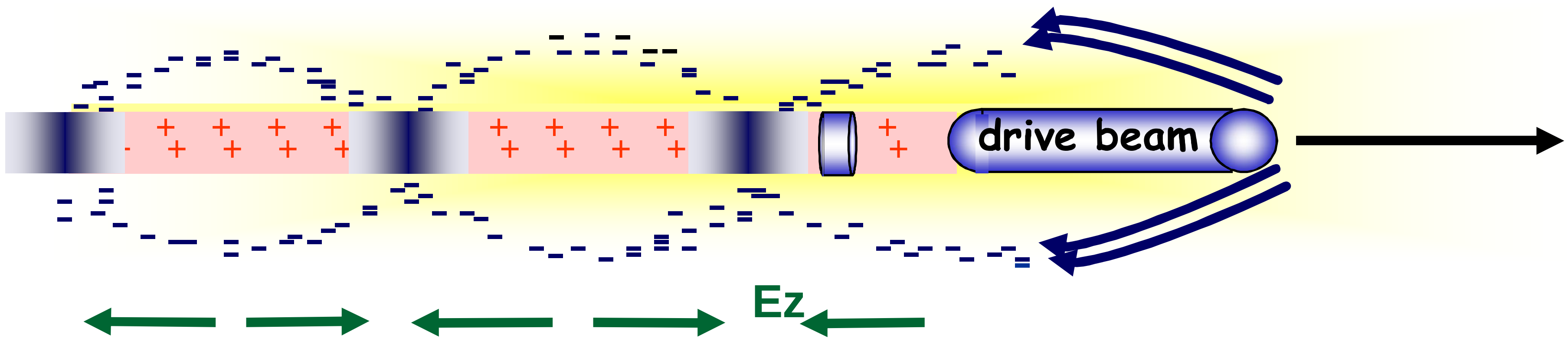


Leonardo deVinci, Study of Wakes:1509

Nonlinear Wakefield Accelerators

(Blowout Regime)

Rosenzweig et al. 1990 *Pukhov and Meyer-te-vehn 2002 (Bubble)*



- Space charge or radiation pressure of driver displaces plasma electrons
- Plasma ion channel exerts restoring force => space charge oscillations
  - Linear focusing force on beams ($F/r=2\pi ne^2/m$)
  - Optical guiding of lasers

The E-157 Plasma Wakefield Experiment

Collaboration:

T. Katsouleas, S. Lee, P. Muggli USC

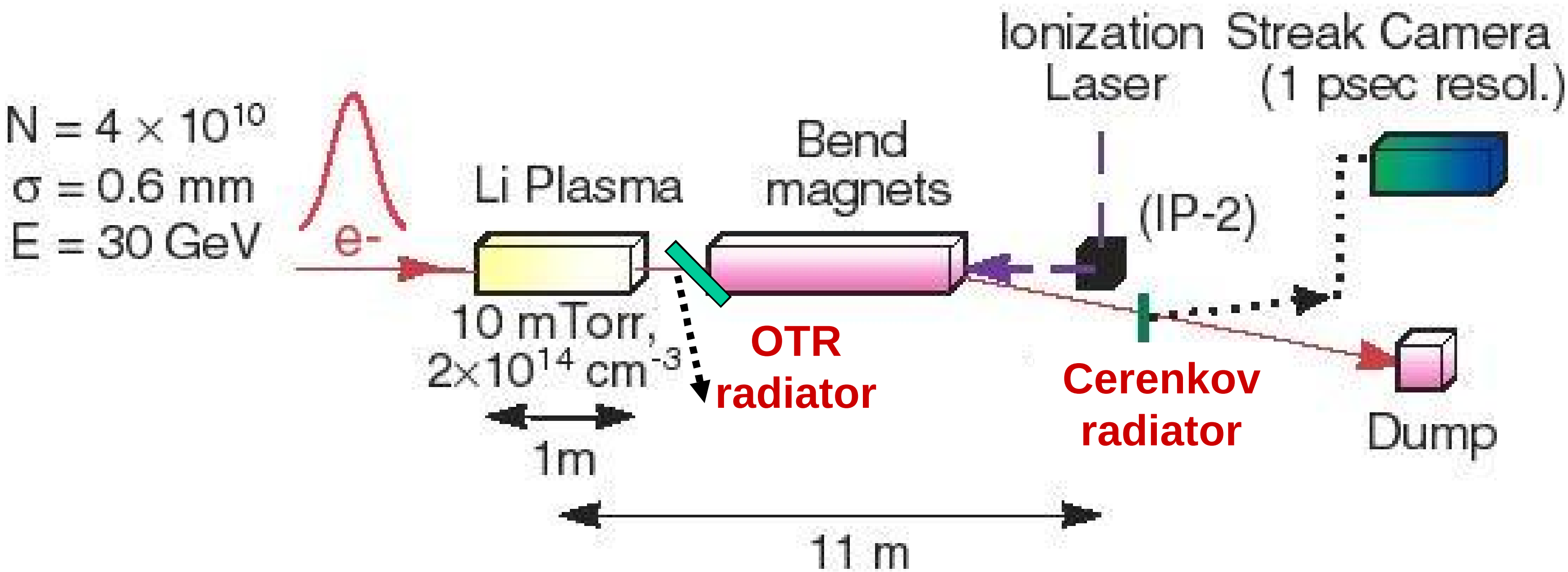
P. Catravas, S. Chattopadhyay, E. Esarey,P. Wolfbeyn LBNL

R. Assmann, P. Chen, F. J. Decker, M. Hogan, R. Iverson,
S. Rokni, R. H. Siemann, D. Walz, D. Whittum, SLAC

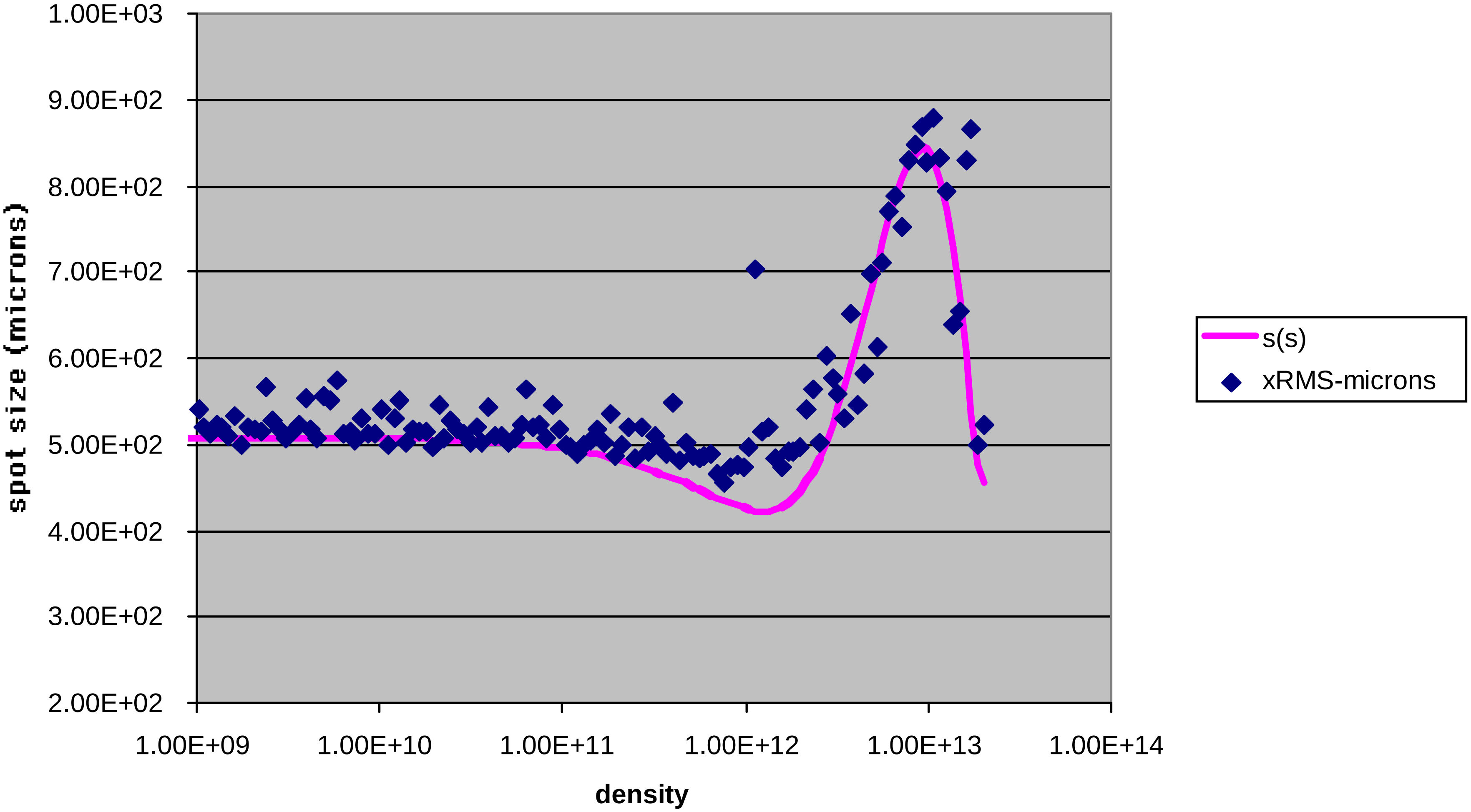
B. Blue, C. Clayton, R. Hemker, C. Joshi, K. Marsh, W. Mori, S. Wang, UCLA

Schematic of E-157

Plasma Wakefield Experiment



Week 1: Spot Size Data at Cerenkov detector Show Betatron Oscillations in Agreement with Simple Blowout Theory => Focusing Strength 6000 T/m!



The E-162/E-164 Collaboration:

C. Barnes, I. Bluenfield, F.-J. Decker, P. Emma, M. J. Hogan, R. Iverson, R. Ischebeck, N. Kirby, P. Krejcik, C. O'Connell, P. Raimondi, R.H. Siemann, D. Walz

Stanford Linear Accelerator Center

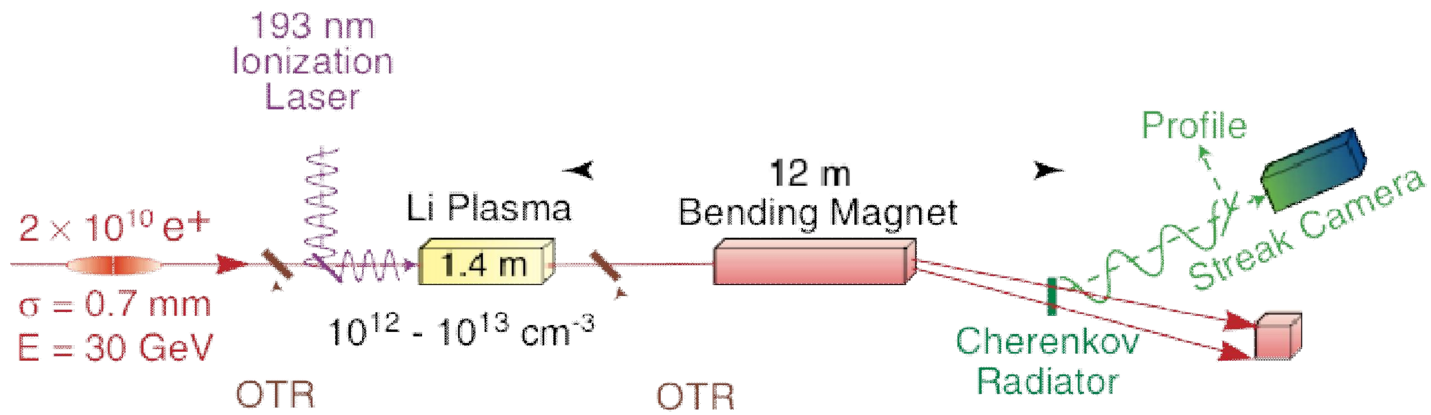
B. Blue, C. E. Clayton, C. Huang, C. Joshi, D. Johnson, K. A. Marsh, W. B. Mori, W. Lu, M. Zhou

University of California, Los Angeles

T. Katsouleas, S. Deng, S. Lee, P. Muggli, E. Oz

University of Southern California

E-157: Experimental Layout

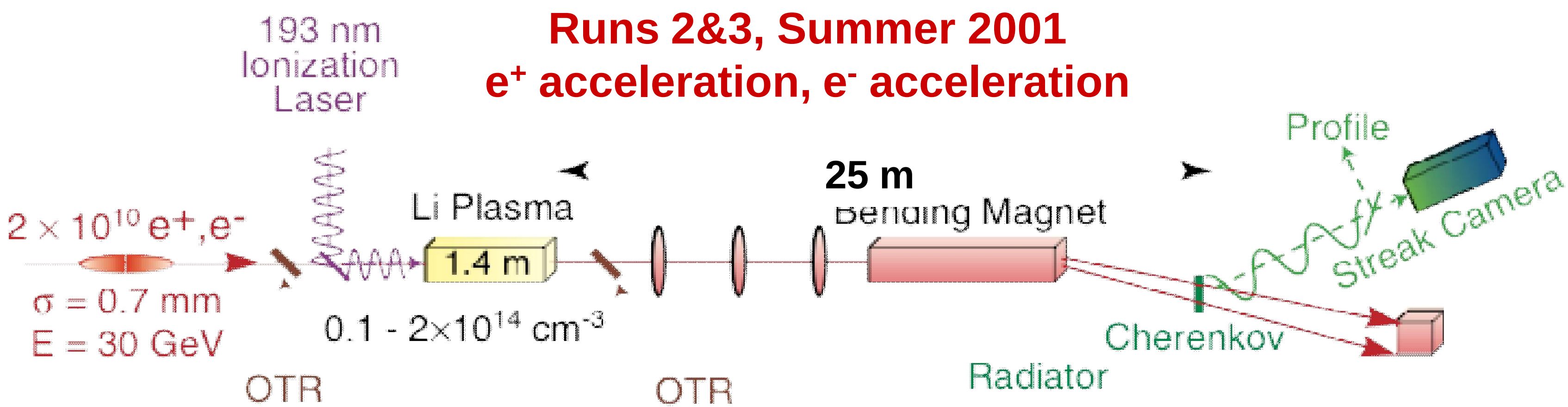


E-162 Apparatus & Runs

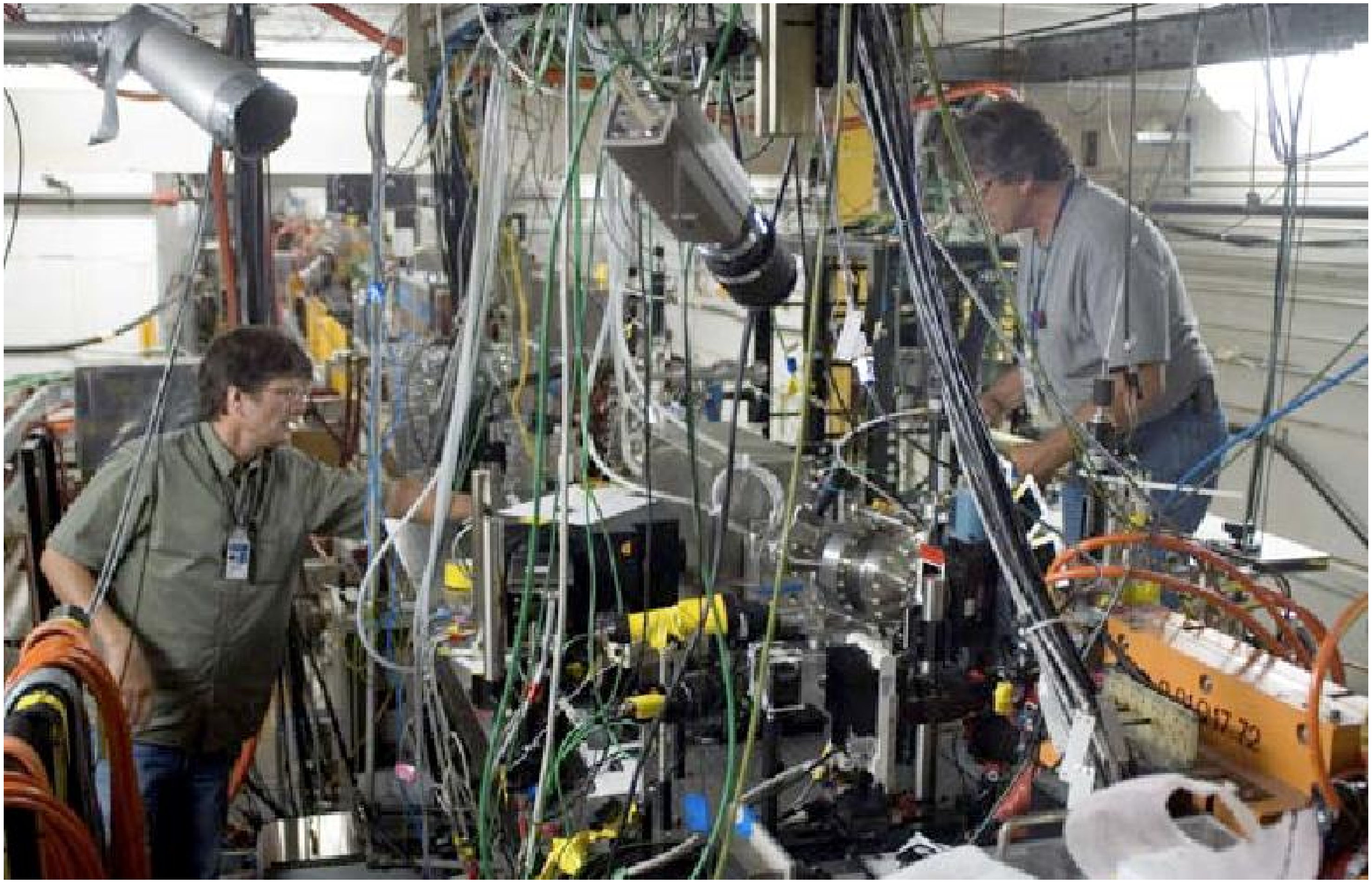
1. **Better magnetic optics upstream ⇨ smaller spots at plasma entrance**
2. **Quadrupoles downstream + FFTB dump magnet ⇨ imaging spectrometer**

Runs 2&3, Summer 2001

e^+ acceleration, e^- acceleration

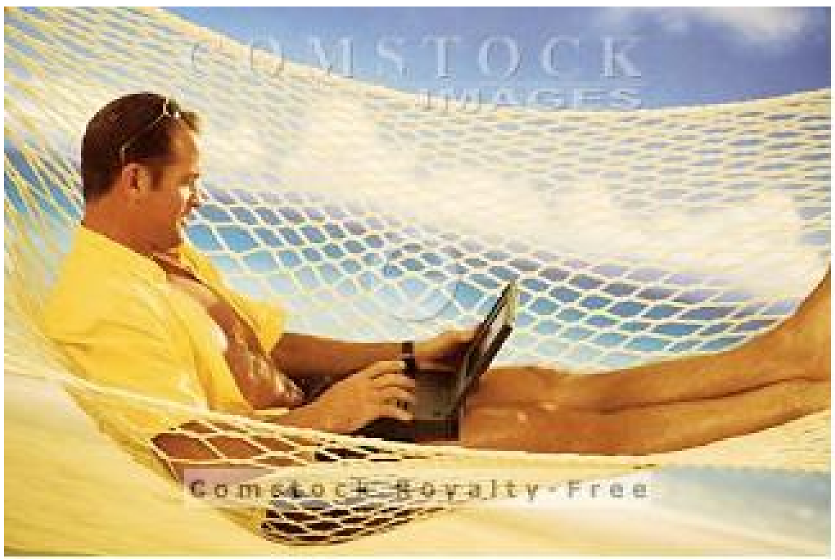


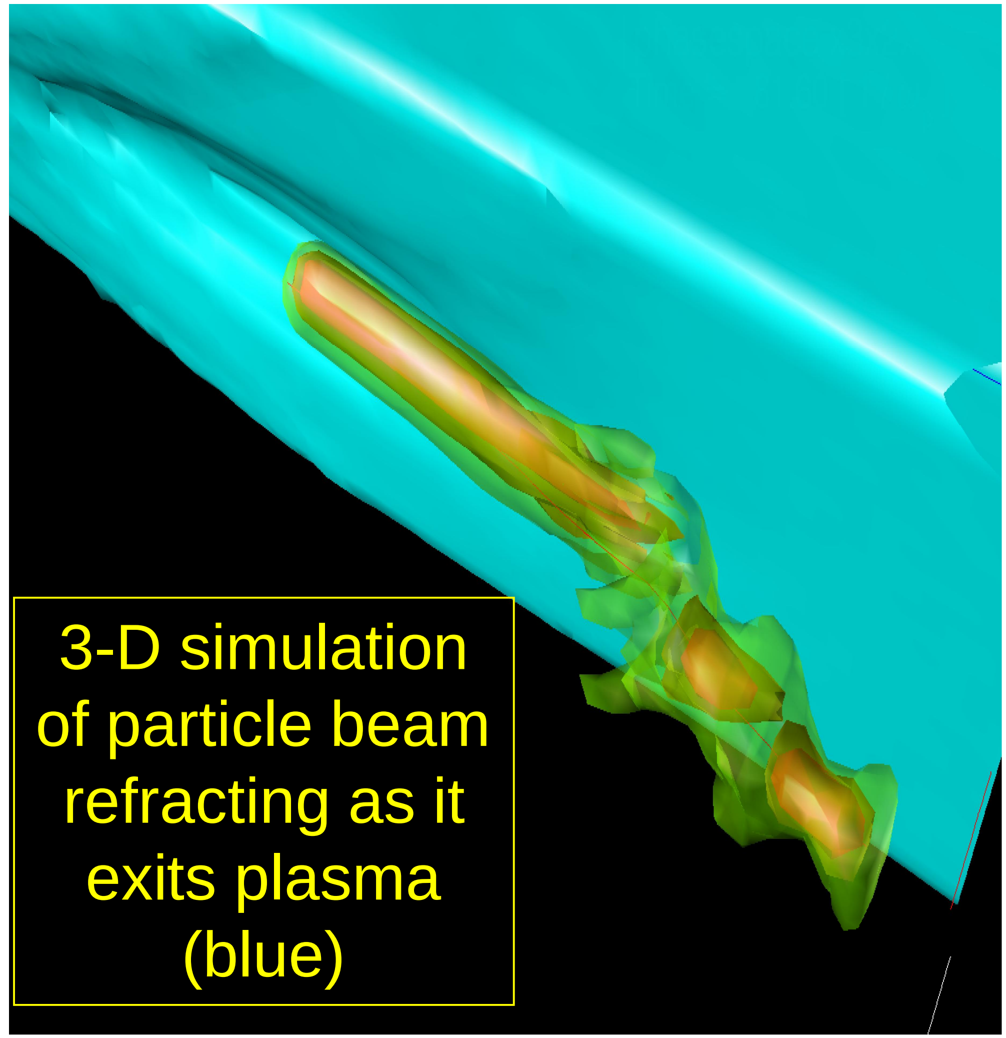
Plasma Accelerator Research: Bob's Perspective of Experimental Work



From: Chan Joshi, UCLA Personal archives

Plasma Accelerator Research: Bob's Perspective of Computer Simulation Work



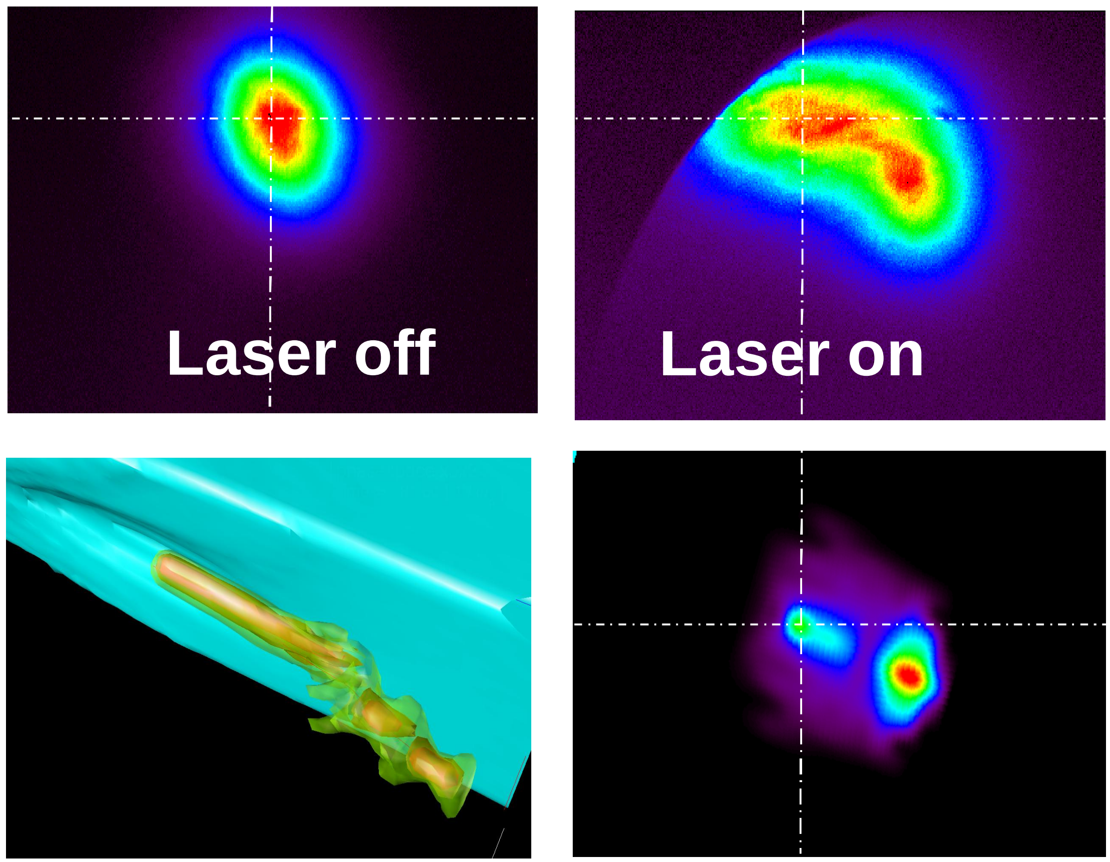


3-D simulation of particle beam refracting as it exits plasma (blue)

Refraction of an Electron Beam: Interplay between Simulation & Experiment

Experiment (Cherenkov images)

3-D OSIRIS PIC Simulation

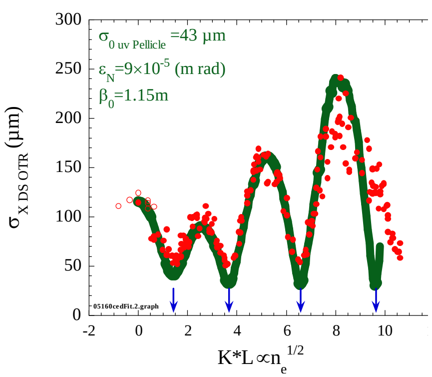


- 1st 1-to-1 modeling of meter-scale experiment in 3-D!

P. Muggli et al., Nature 411, 2001

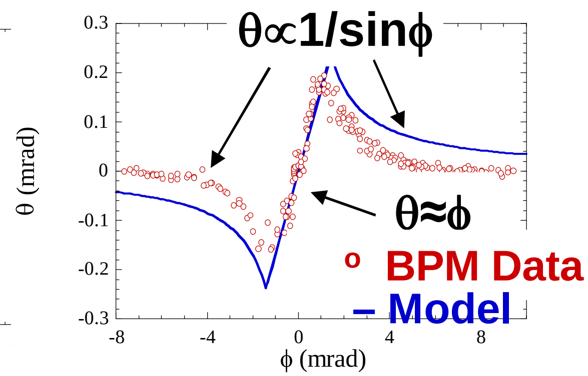
☐ E-157 & E-162 have observed a wide range of phenomena with both electron and positron drive beams:

e^- & e^+ Focusing



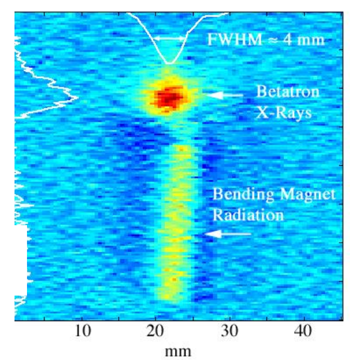
Phys. Rev. Lett. 2002, 2003

Electron Beam Refraction at the Gas–Plasma Boundary



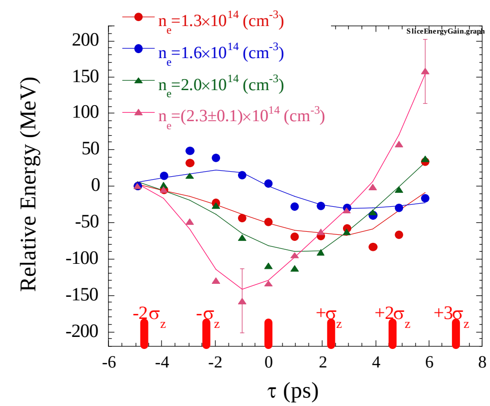
Nature 2002

X-ray Generation



Phys. Rev. Lett. (cover) 2002

Wakefield acceleration

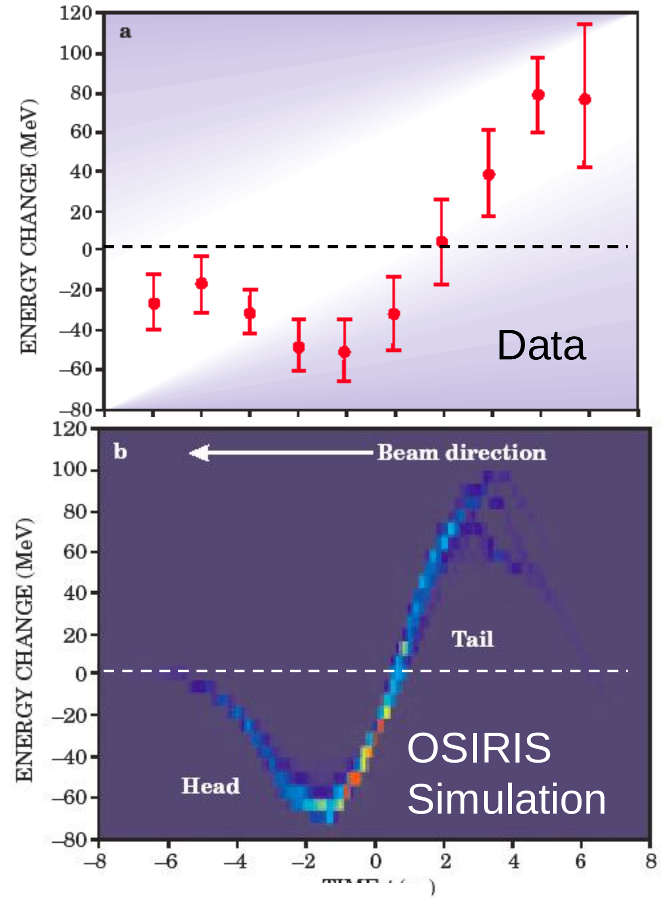


To Science 2003

Time resolved acceleration of positrons

E-162

Energy change



Time

- **Loss ≈ 50 MeV**
- **Gain ≈ 75 MeV**

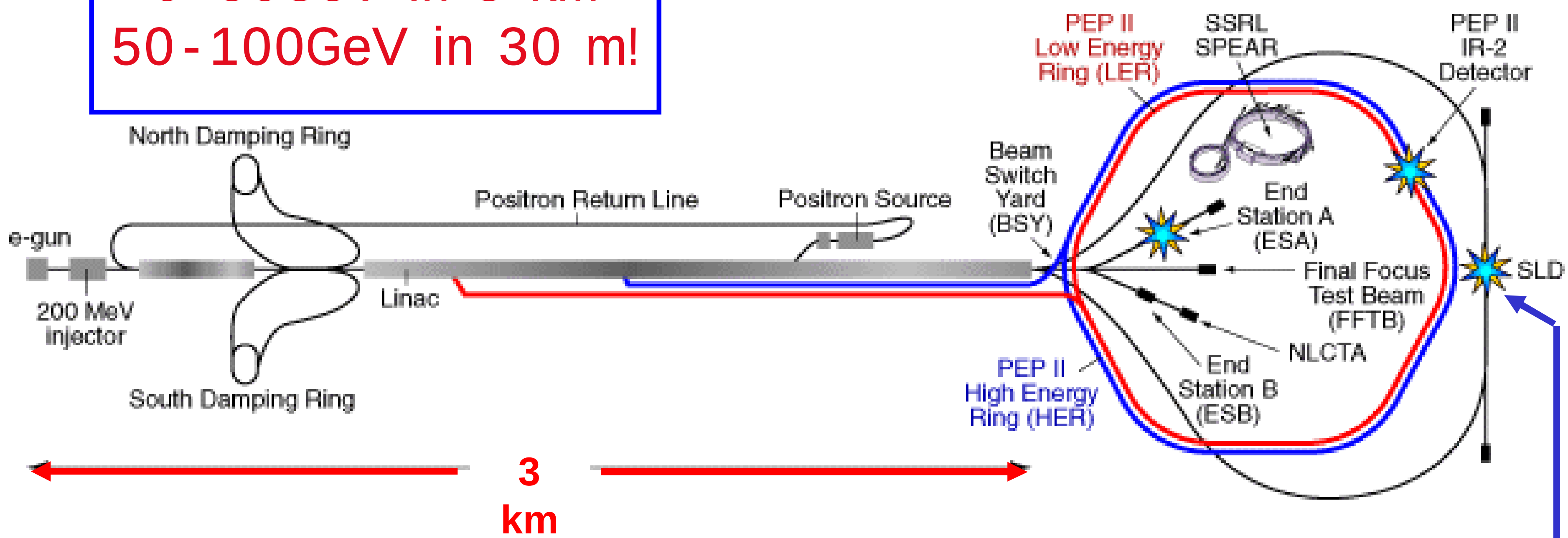
B. Blue et al., Phys. Rev. Lett. 2003
R. Bingham, Nature, News and Views 2003

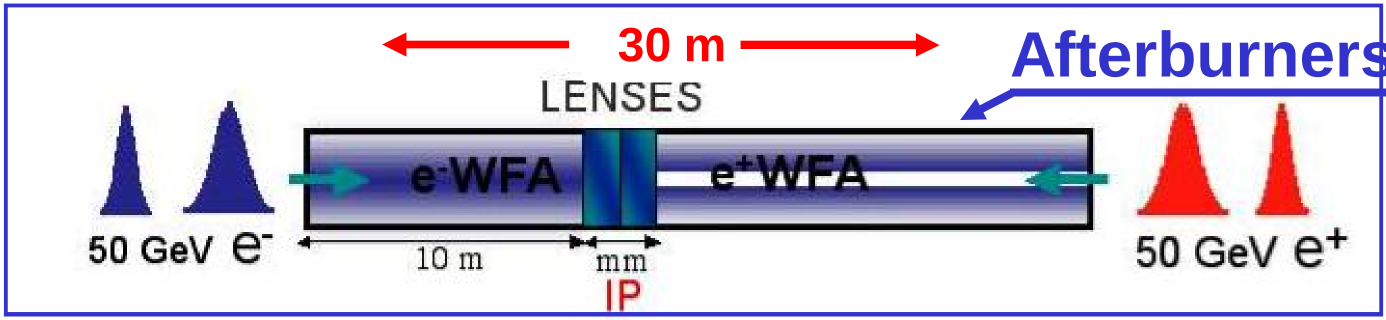
U C L A

USC

GOAL: An Energy Doubler Based on Plasma Afterburners

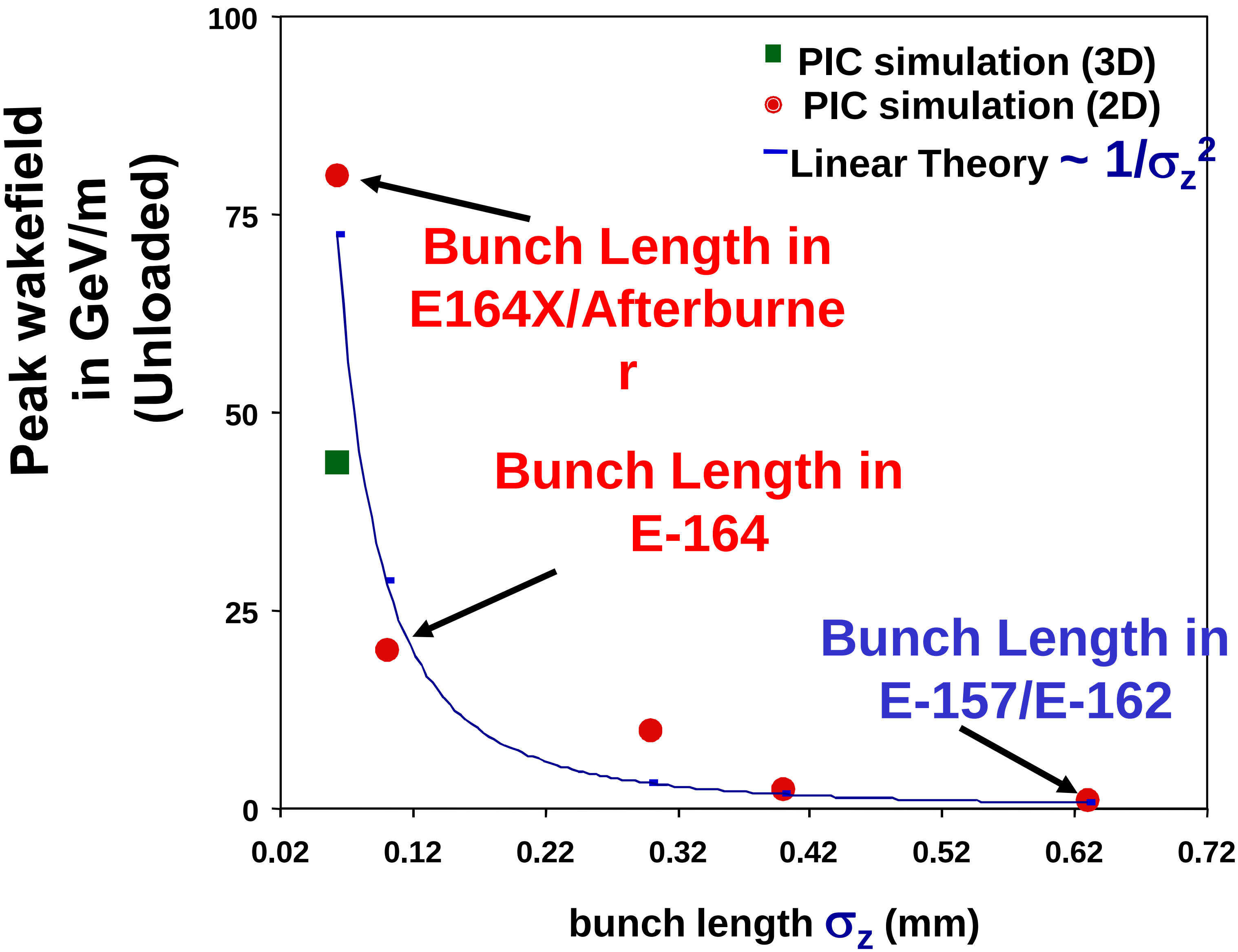
0-50GeV in 3 km
50-100GeV in 30 m!





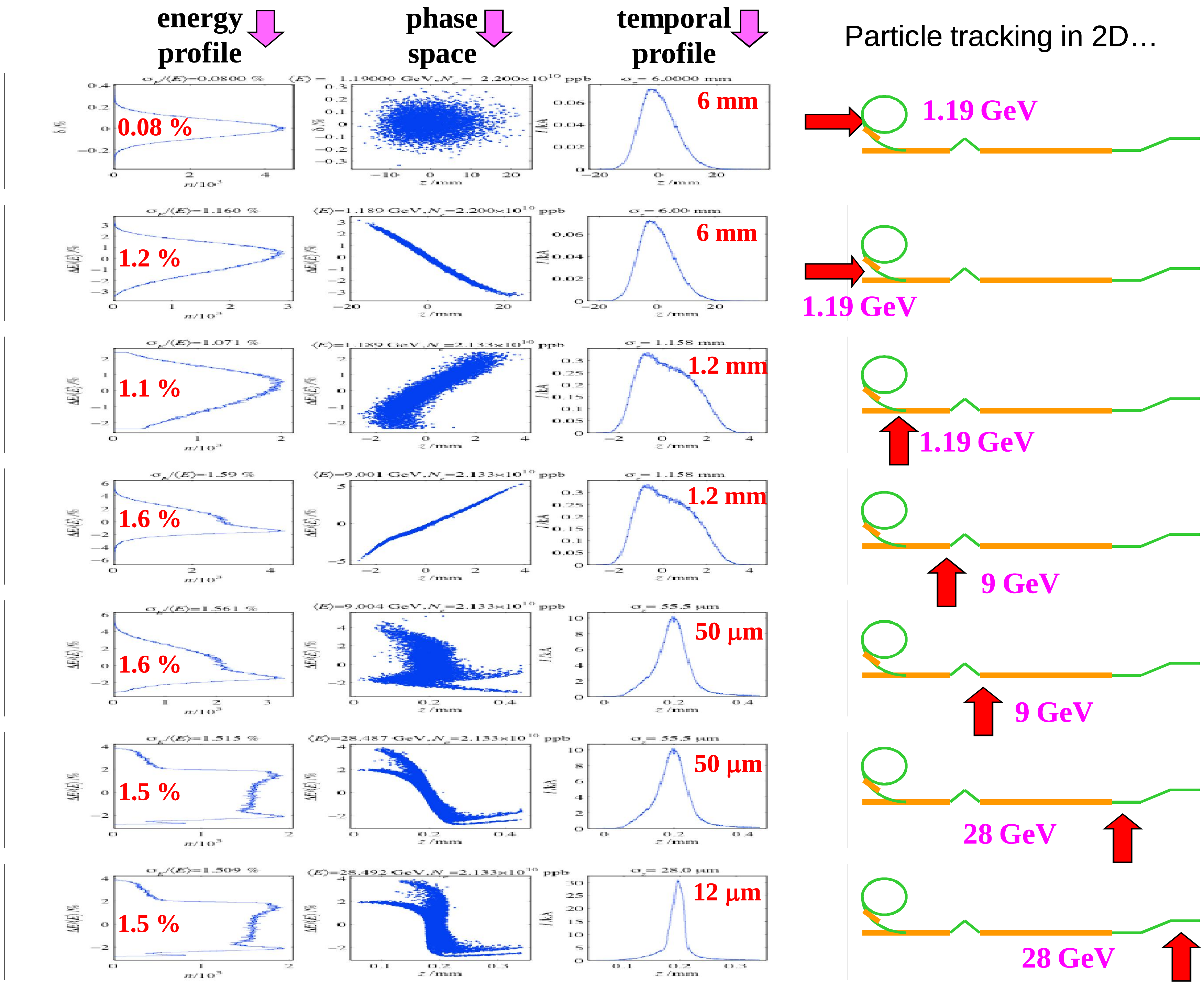
S. Lee et al., Phys. Rev. STAB, 2001

Plasma Wakefield Scaling Law



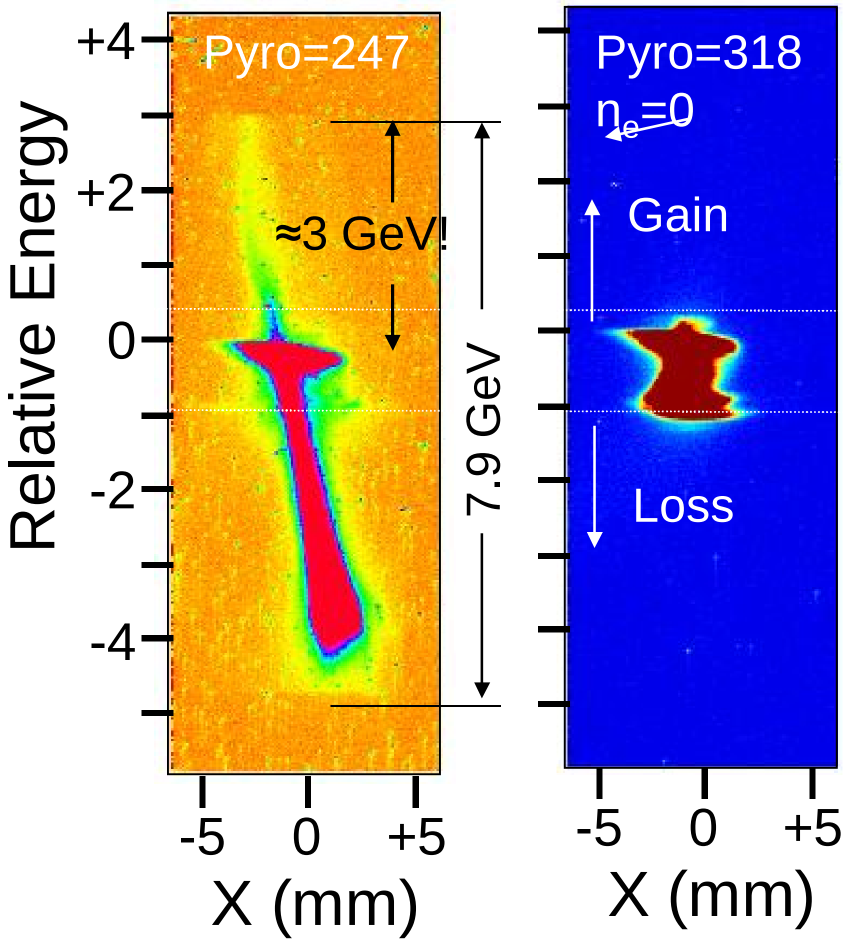
Enter Paul Emma and Pat Krejcik…

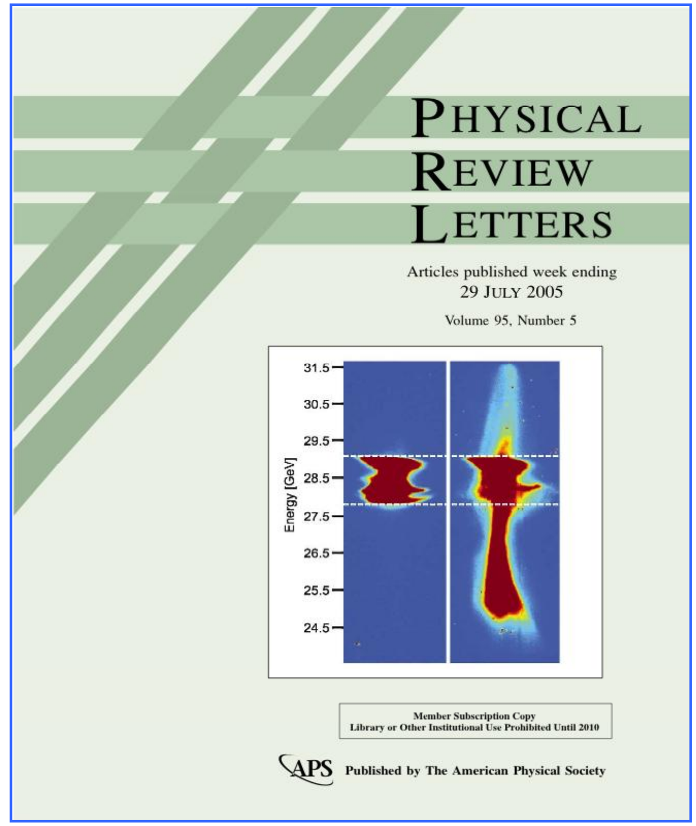
Particle tracking in 2D…



E164X breaks GeV barrier

$L \approx 10$ cm, $n_e \approx 2.55 \times 10^{17}$ cm^{-3}, $N_{b=} \approx 1.8 \times 10^{10}$





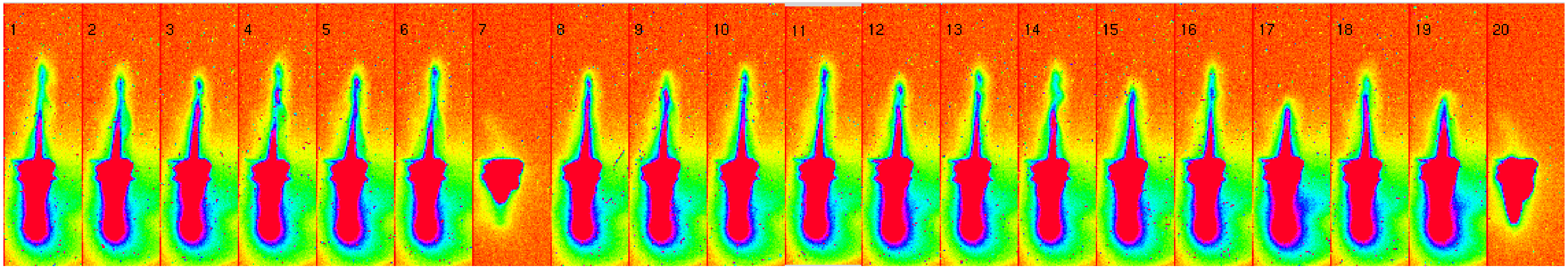
Energy gain exceeds ≈ 3 GeV in 10 cm

M. Hogan, et al. (PRL, July 2005)

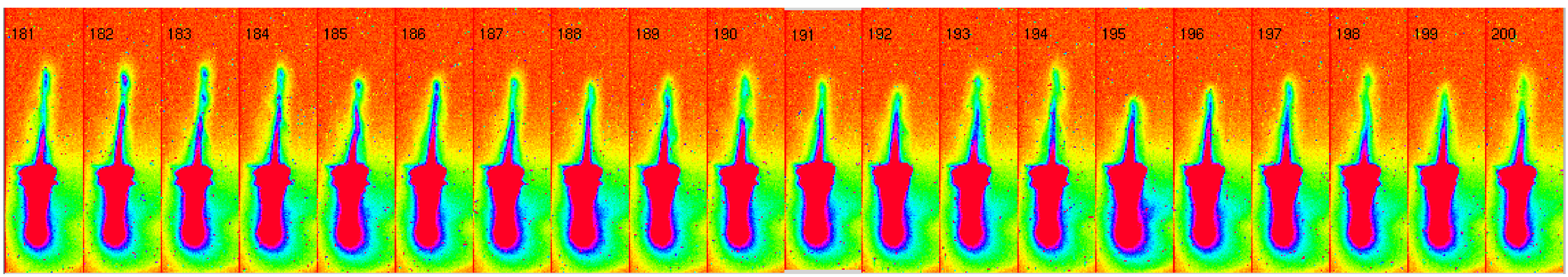
U C L A

USC

Data is very reproducible!

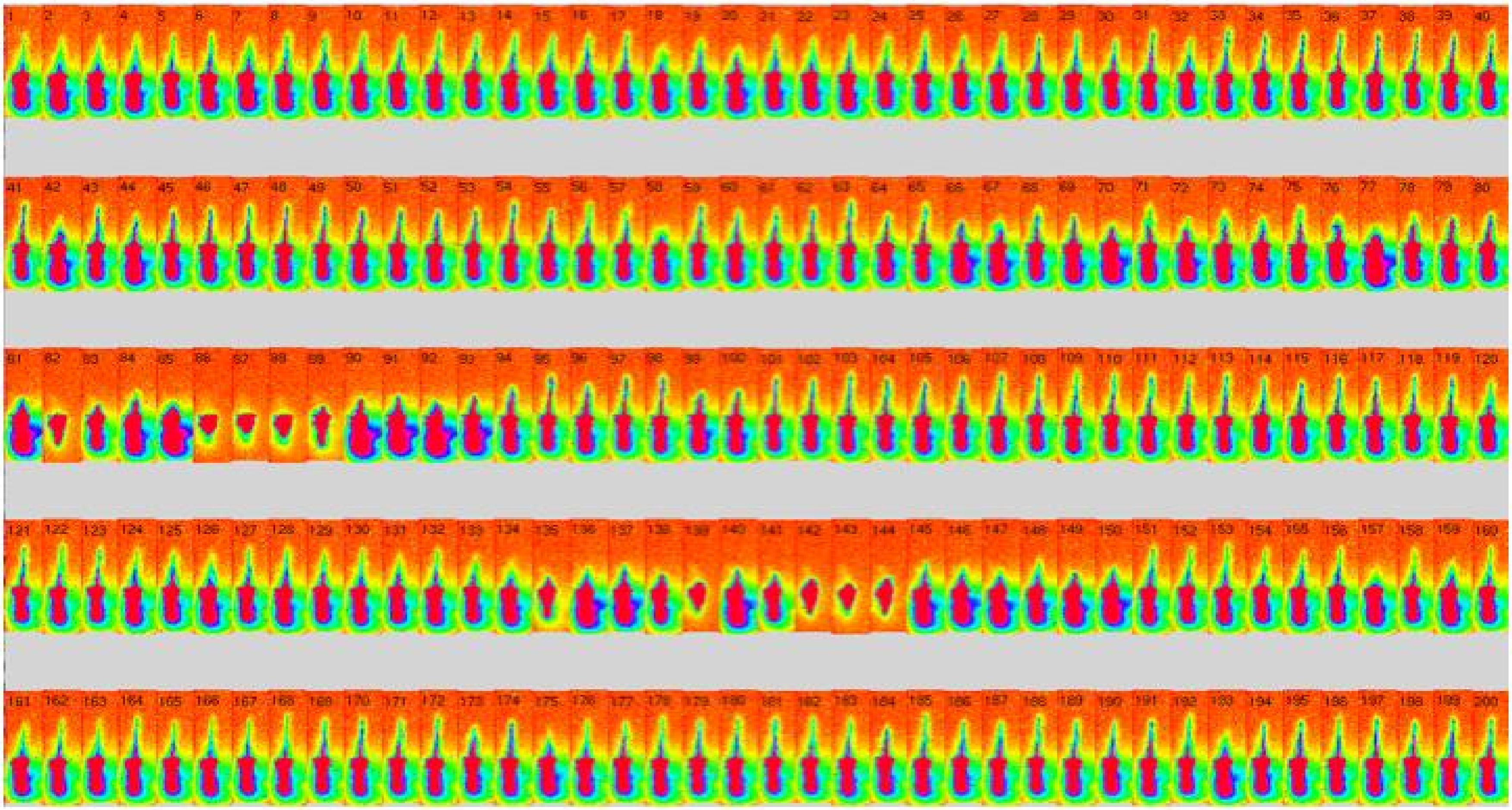


...

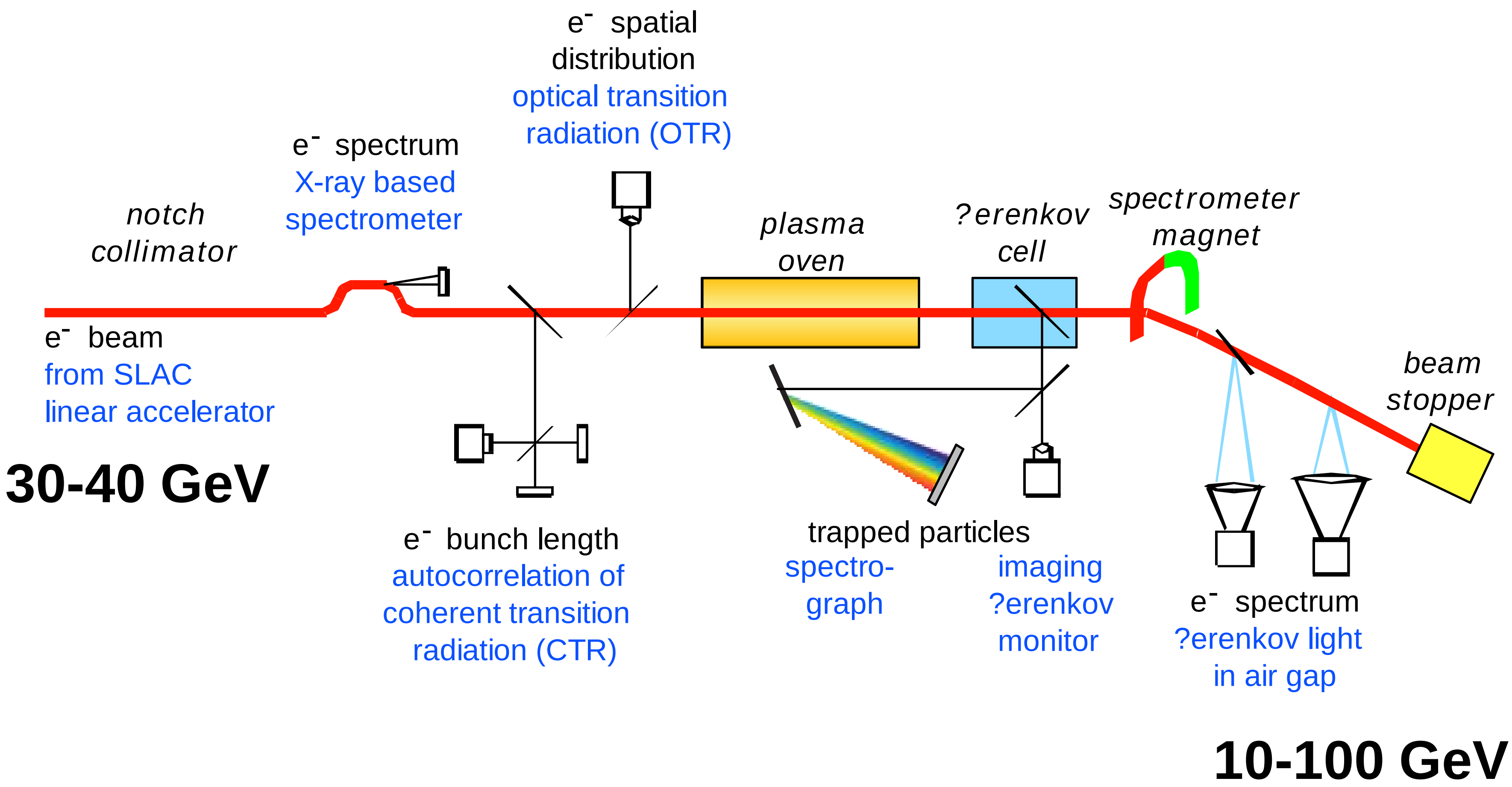


U C L A

Data is very reproducible!

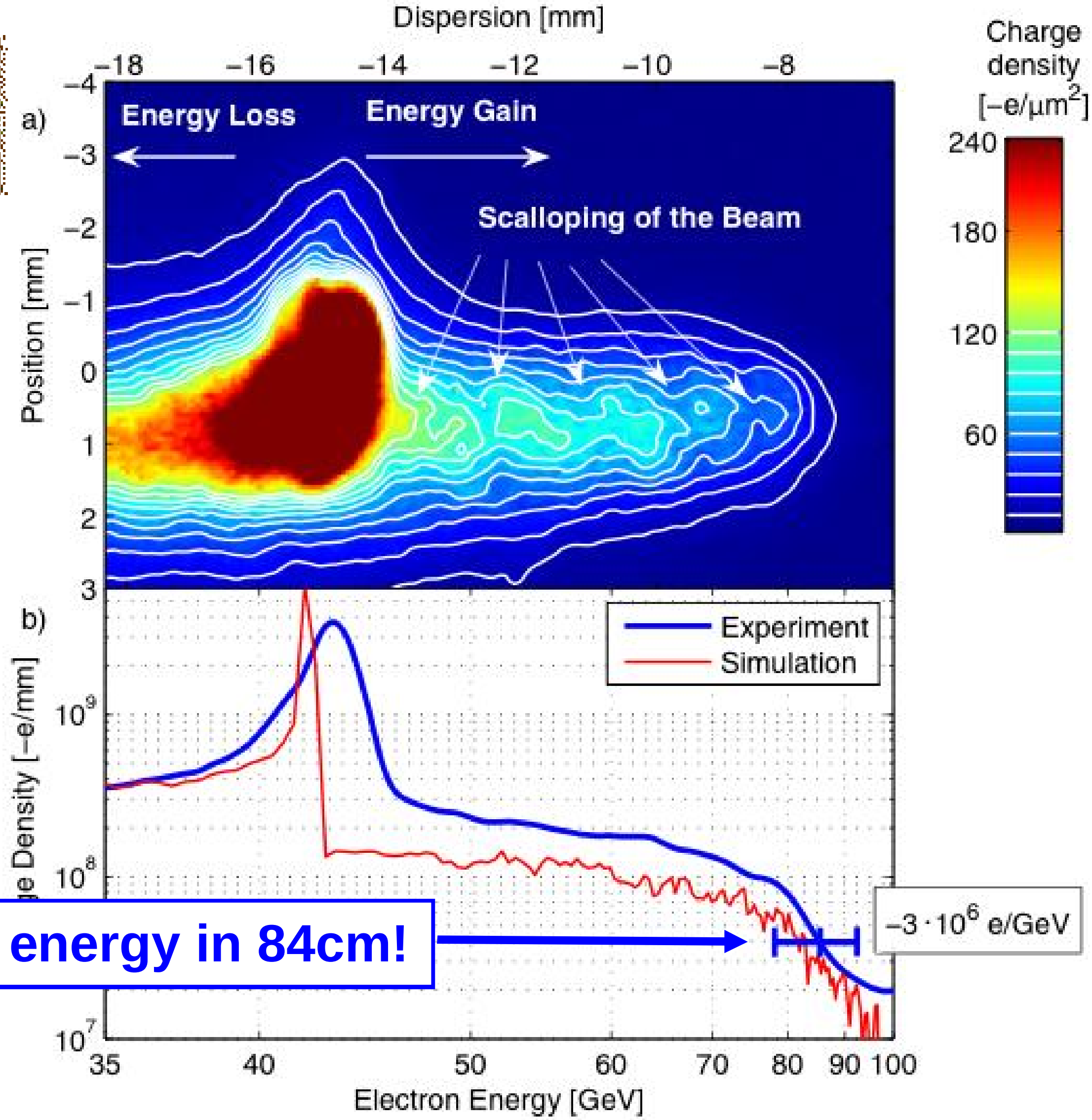


E-167 Experimental Setup



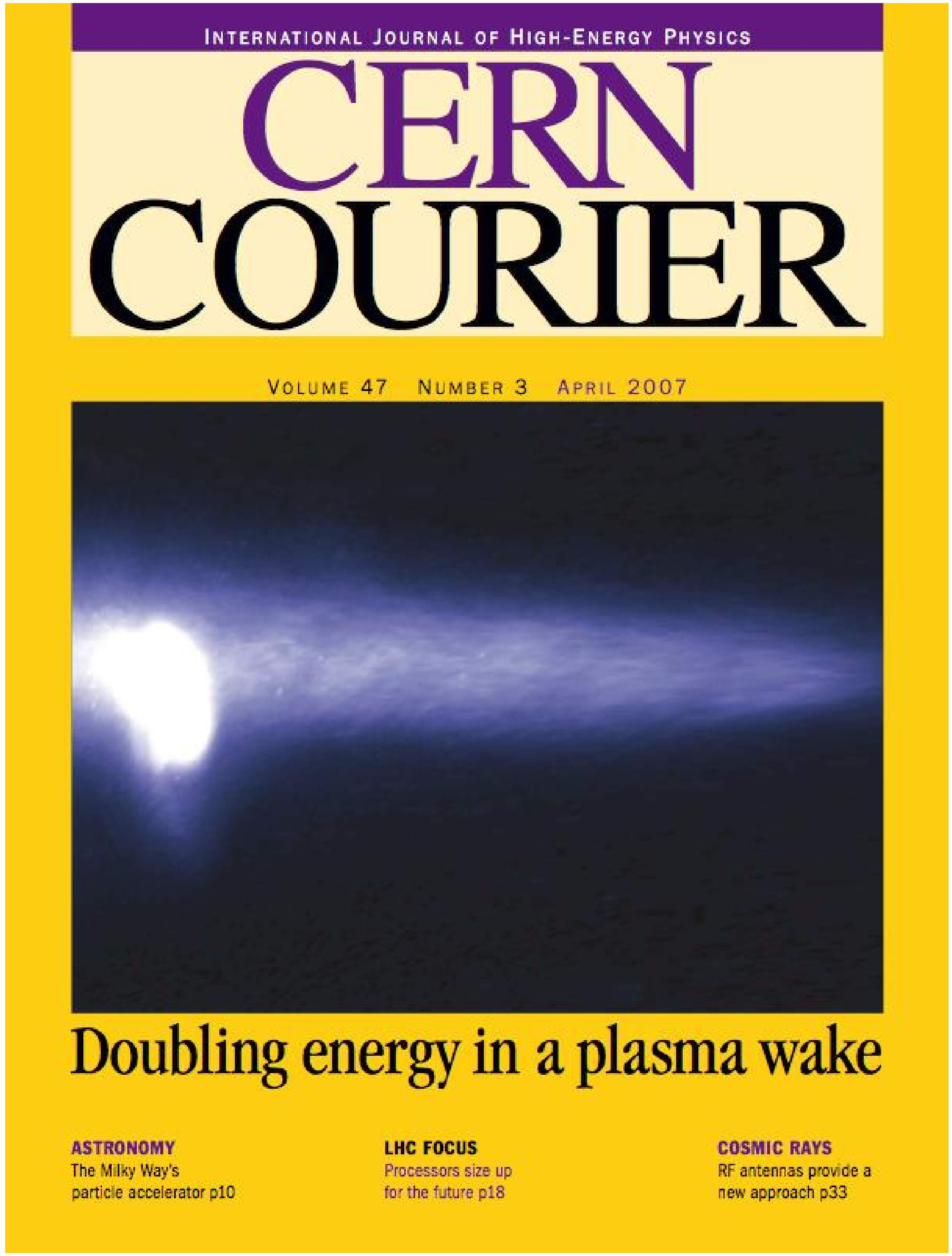
E-167: Energy Doubling with a Plasma Wakefield Accelerator in the FFTB

Linac running all out to deliver compressed 42GeV Electron Bunches to the plasma
Record Energy Gain
Highest Energy Electrons Ever Produced @ SLAC
Significant Advance in Demonstrating Potential of Plasma Accelerators



Some electrons double their energy in 84cm!

Nature vol 445,p741 (2007)


International Journal of High-Energy Physics

CERN COURIER

Volume 47 Number 3 April 2007

Doubling energy in a plasma wake

ASTRONOMY
The Milky Way's particle accelerator p10

LHC FOCUS
Processors size up for the future p18

COSMIC RAYS
RF antennas provide a new approach p33

Work supported by DOE

Plasma Acceleration has put Physics at the Forefront of Science

Acceleration, Radiation Sources, Refraction, Medical Applications

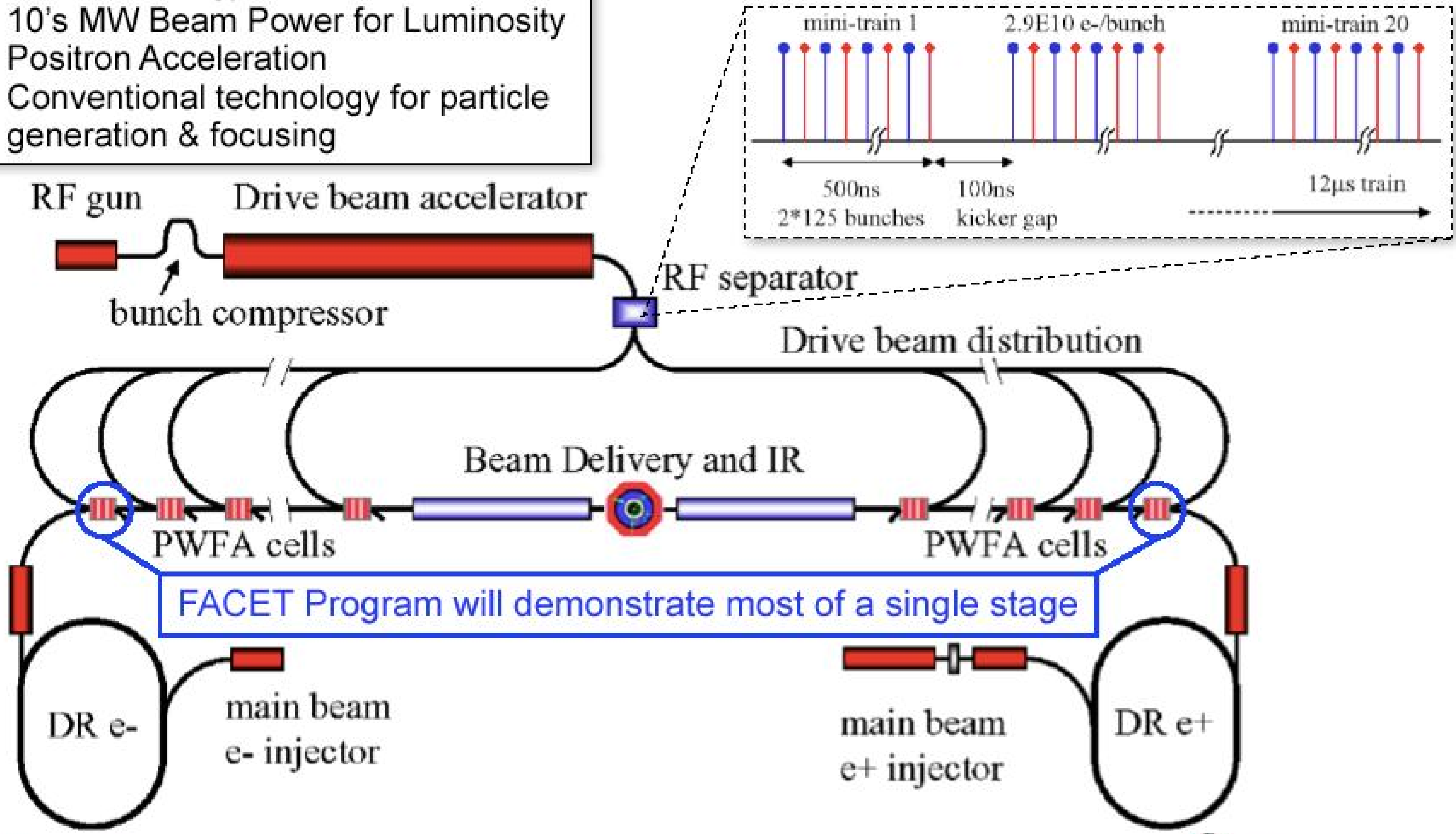
From good Physics to a good Collider is a Grand Challenge worth pursuing

NAE Grand Challenges for the 21st C

1. Solar energy economical
2. Fusion energy
3. Carbon sequestration
4. Manage N cycle
5. Clean water
6. Engineered medicines
7. Health informatics
8. Secure cyber-space
9. Prevent nuclear terror
10. Urban infrastructure
11. Reverse engineer the brain
12. Virtual reality (think Holodeck)
13. Personalized learning
14. Tools of scientific discovery

A Concept for a Plasma Wakefield Accelerator Based Linear Collider

- TeV CM Energy
- 10's MW Beam Power for Luminosity
- Positron Acceleration
- Conventional technology for particle generation & focusing



First Self-consistent PWFA-LC

Luminosity	3.5×10^{34} cm^{-2}s^{-1}
Luminosity in 1% of energy	1.3×10^{34} cm^{-2}s^{-1}
Main beam: bunch population, bunches per train, rate	1×10^{10}, 125, 100 Hz
Total power of two main beams	20 MW
Main beam emittances, $\gamma\varepsilon_x$, $\gamma\varepsilon_y$	2, 0.05 mm-mrad
Main beam sizes at Interaction Point, x, y, z	140 nm, 3.2 nm, 10 μm
Plasma accelerating gradient, plasma cell length, and density	25 GV/m, 1 m, 1×10^{17}cm^{-3}
Power transfer efficiency drive beam=>plasma =>main beam	35%
Drive beam: energy, peak current and active pulse length	25 GeV, 2.3 A, 10 μs
Average power of the drive beam	58 MW
Efficiency: Wall plug=>RF=>drive beam	50% × 90% = 45%
Overall efficiency and wall plug power for acceleration	15.7%, 127 MW
Site power estimate (with 40MW for other subsystems)	170 MW

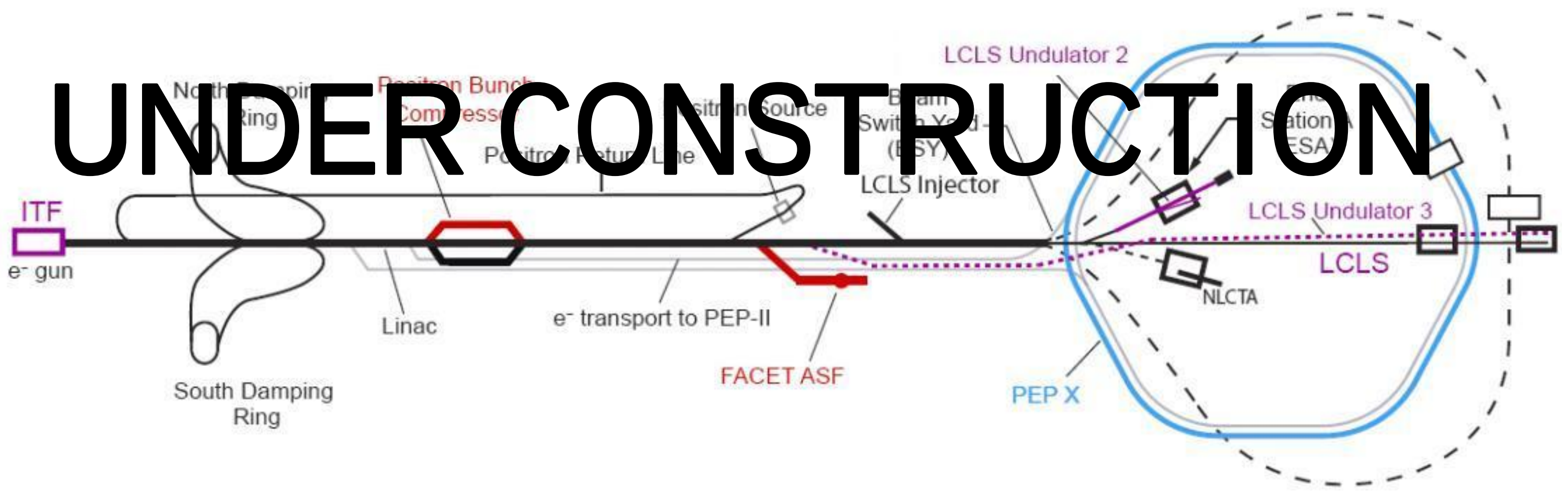
Critical Issues

- Positron acceleration
- Modeling
- Beam loading - create/phase 2nd bunch
- Transverse beam dynamics
  - Hosing
  - Lenses
  - Pointing jitter sub-nm
  - Ion motion (Rosenzweig, 2005)
  - Synchrotron radiation
- Plasma source development
  - Beam-ionized sources, μs - ns refresh?

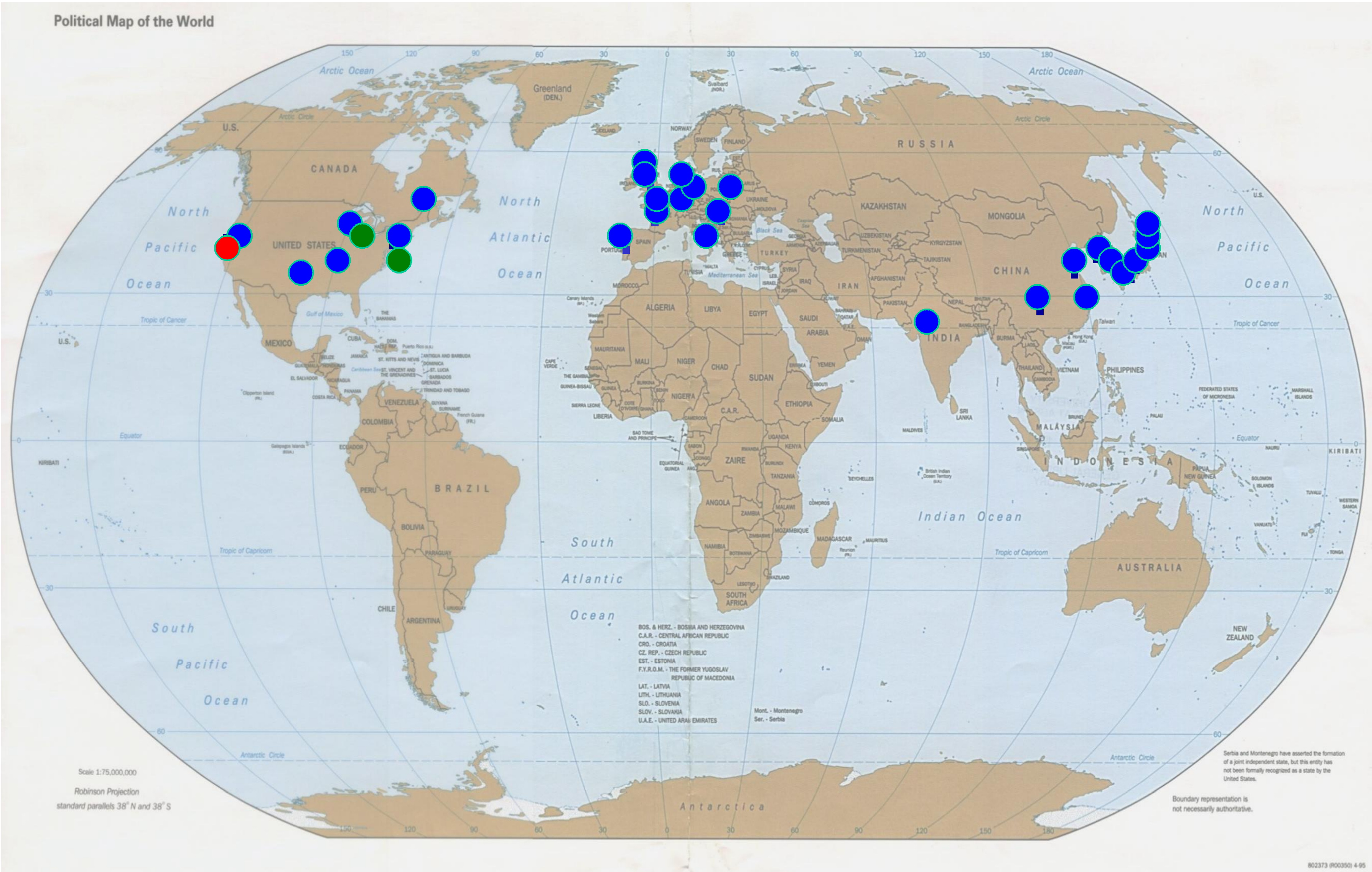
FACET will address most issues of a single stage

FACET: Facility for Advanced Accelerator Experimental Tests

- Use the SLAC injector complex and 2/3 of the SLAC linac to deliver electrons and positrons
  - Compressed 25 GeV beams → ~20 kA peak current
  - Small spots necessary for plasma acceleration studies
- Two separate installations
  - Final bunch compression and focusing system in Sector 20
  - Expanded Sector 10 bunch compressor for positrons



US and Worldwide Experimental Effort on Plasma Accel



Laser Wake Expts   Electron Wake Expts   e-/e+ Wake Expts

Courtesy Rasmus Ischebeck

Plasma accelerator research and Bob's legacy still burning brightly

Present Collaborators

* B. Allen USC
* W. An UCLA
* K. Bane SLAC
* L. Bentson SLAC
* I. Blumenfeld SLAC
* C.E. Clayton UCLA
* S. DeBarger SLAC
* F.-J. Decker SLAC
* R. Erickson SLAC
* R. Gholizadeh USC
* M.J. Hogan SLAC
* C. Huang UCLA
* R.H. Iverson SLAC
* C. Joshi UCLA
* T. Katsouleas Duke University
* N. Kirby SLAC
* N. Li SLAC
* W. Lu UCLA
* D.B. MacFarlane SLAC
* K.A. Marsh UCLA
* W.B. Mori UCLA
* P. Muggli USC
* Y. Nosochkov SLAC
* S. Pei SLAC
* T.O. Raubenheimer SLAC
* J.T. Seeman SLAC
* A. Seryi SLAC
* R.H. Siemann SLAC
* P. Tenenbaum SLAC
* J. Vollaire SLAC
* D. Walz SLAC
* X. Wang USC
* W. Wittmer SLAC

SLAC Duke UNIVERSITY UCLA USC