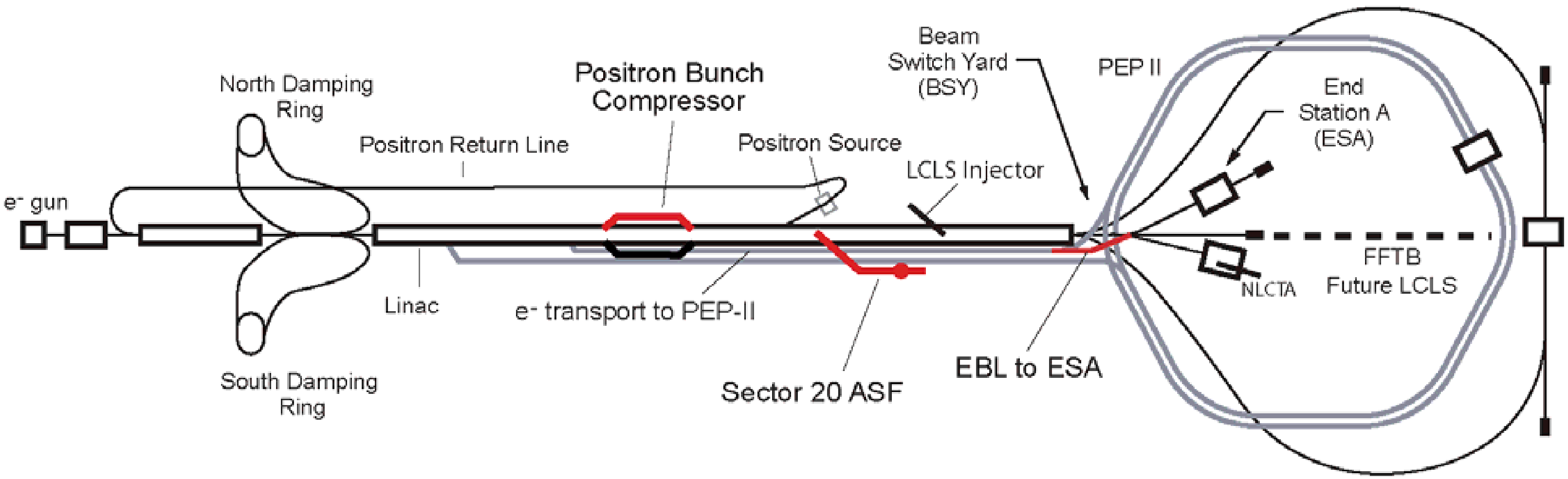
Overview of accelerator science opportunities with FACET ASF

Bob Siemann

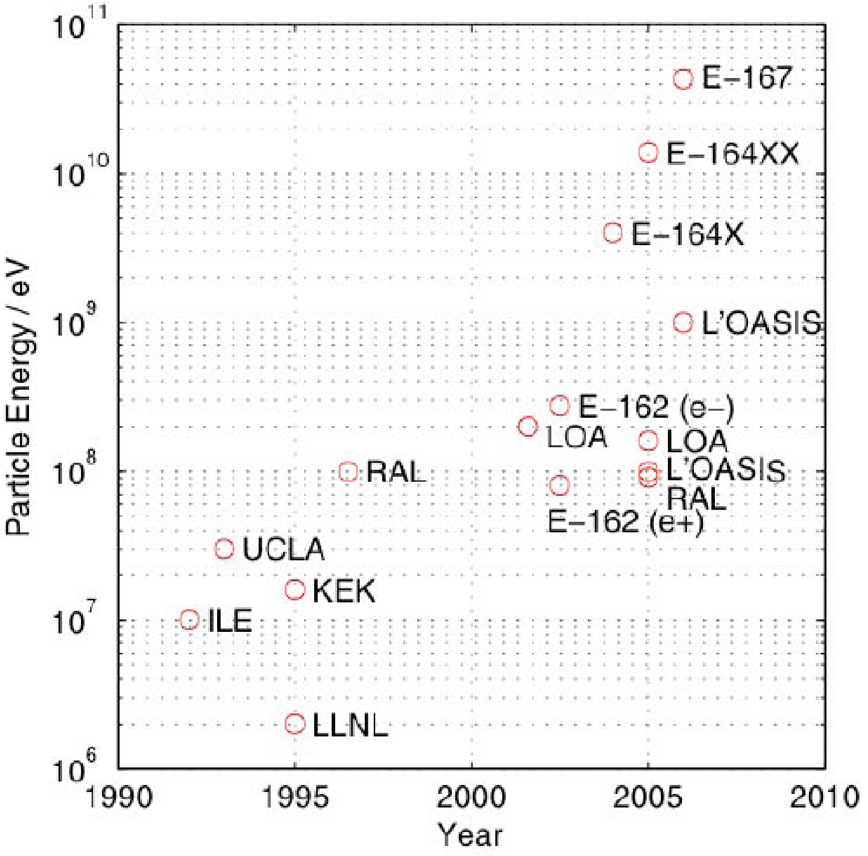
DOE FACET Review, February 19 - 20, 2008



OUTLINE

I. Plasma Wakefield Acceleration
II. Plasma Wakefield Based Linear Colliders
III. Other Science & Users at FACET ASF
IV. Summary & Concluding Remarks

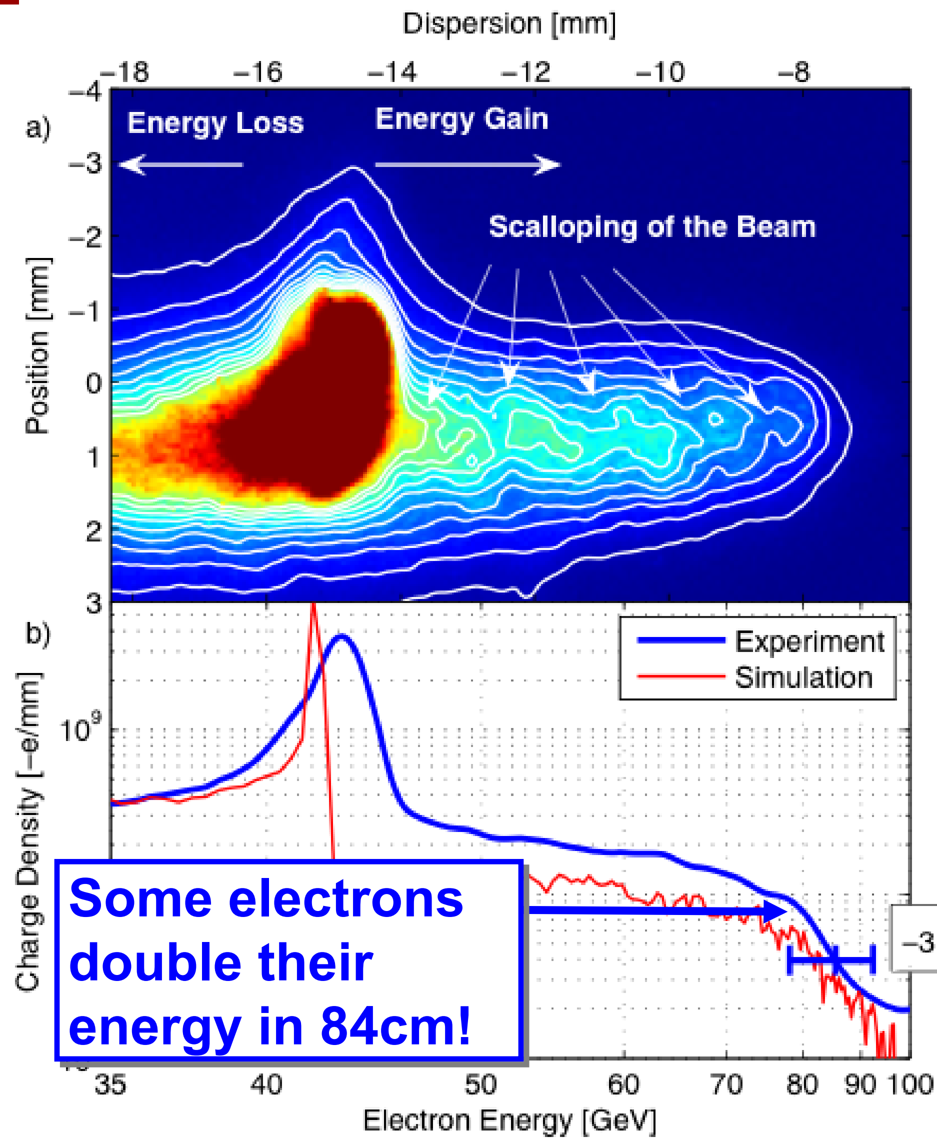
I. Plasma Wakefield Acceleration



Plasma Wakefield Acceleration Past and Future

- **Why Plasmas?** No breakdown limit & gradients 10 – 100 GeV/m
- Beam plasma interactions were studied during seven years of experiments in the FFTB.
- The culmination was the doubling of energy of some electrons to E > 80 GeV. Gradient ~ 50 GeV/m
- The results of these experiments show that plasma wakefield acceleration holds promise for dramatic reduction in the size/cost of HEP accelerators

FACET ASF is the facility needed for the next steps in the development of plasma wakefield acceleration



I. Blumenfeld *et al*, Nature **45**, 741 (2007)

A Unique Beam

Beam Parameters at the Focal Point for Plasma Experiments

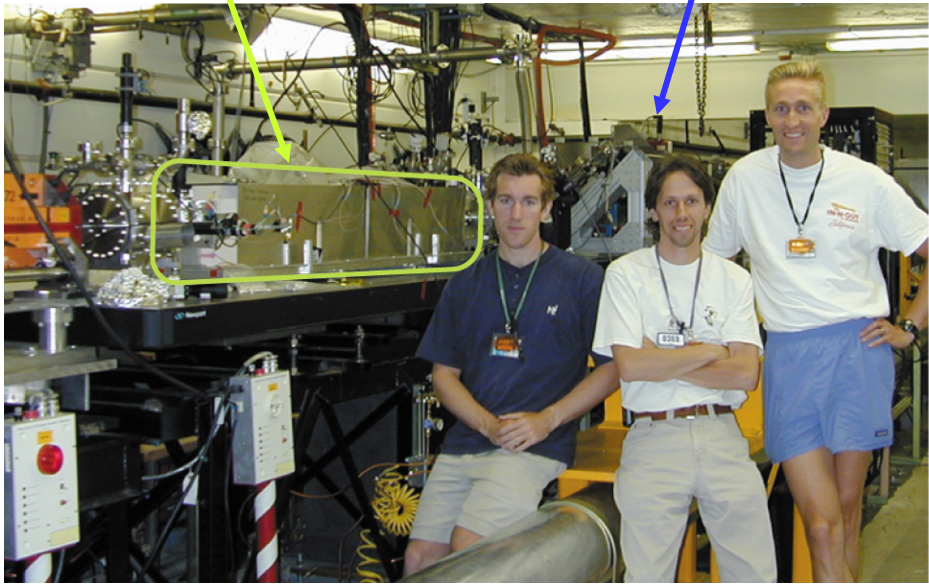
- electrons and positrons
- 23 GeV
- $2x10^{10}$ (3 nC)
- 10 μm nominal spot size
- 16 μm bunch length with 4% FW δp/p
- peak current ~ 20 kA

These are what is needed for high energy physics!

A unique opportunity - Only place in the world where such a beam exists and is likely to exist in the future

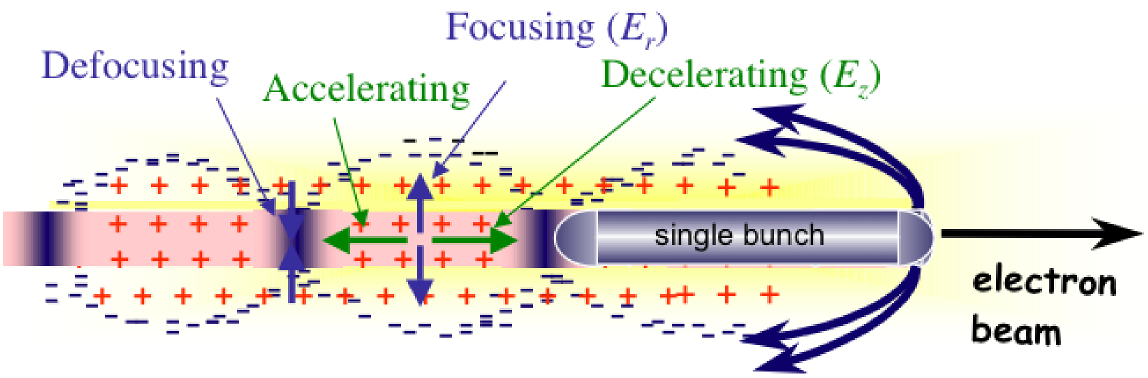
12' long optical table holding plasma and other apparatus

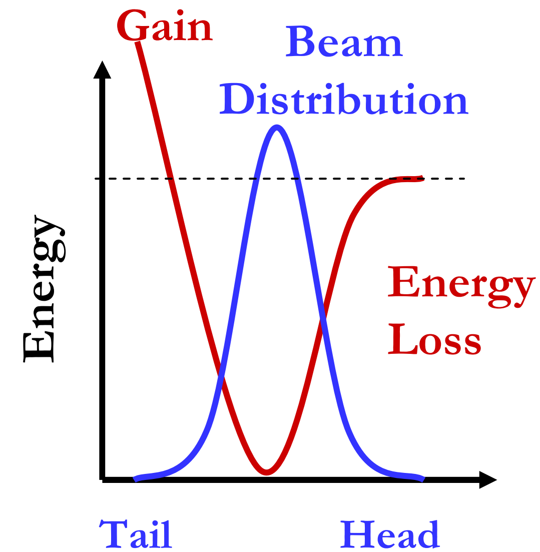
Final focus quads



Beam-plasma experimenters and experimental region in FFTB

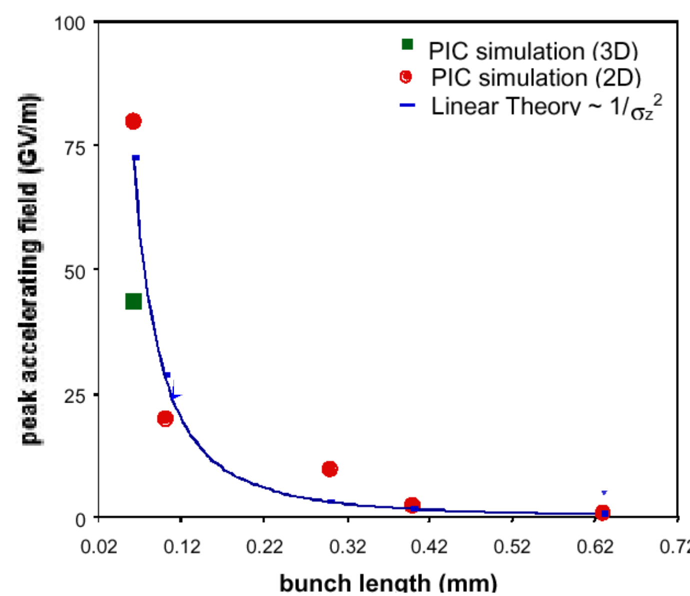
Plasma Wakefield Acceleration





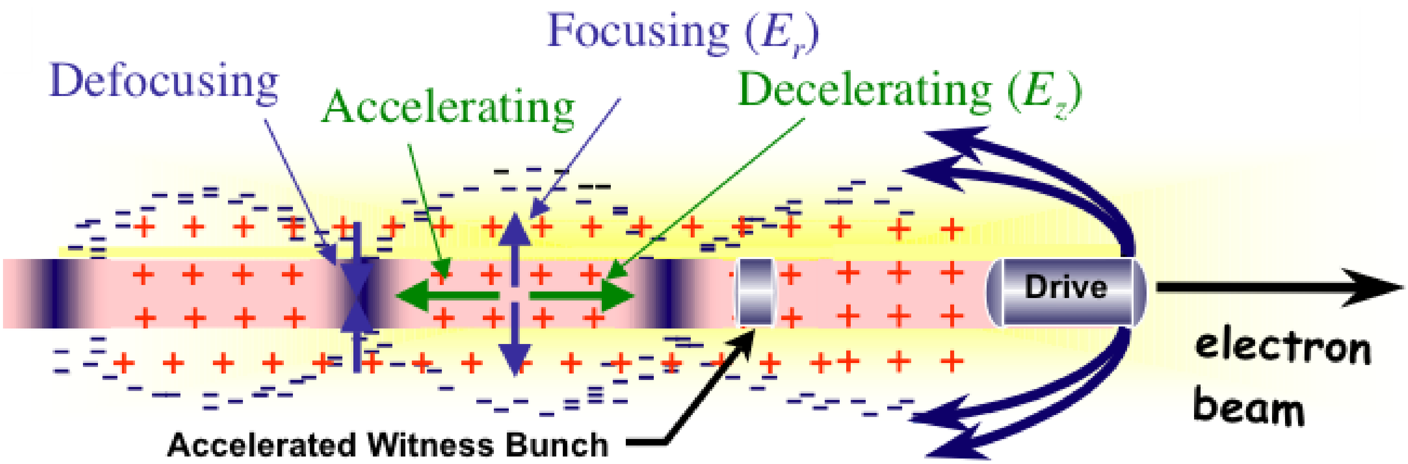
- Plasma wave/wake excited by a relativistic electron bunch
- Plasma electrons expelled by space charge forces ⇒energy loss to electrons & focusing from ion channel
- Plasma electrons rush back to axis to produce accelerating gradient
- In the linear theory, which is an approximation in the regime of the experiments,

$$eE_{linear} = 100\,GeV/m \left(\frac{N}{1.8\times 10^{10}}\right)\left(\frac{20}{\sigma_z(\mu m)}\right)^2$$



An Important FACET Research Goal

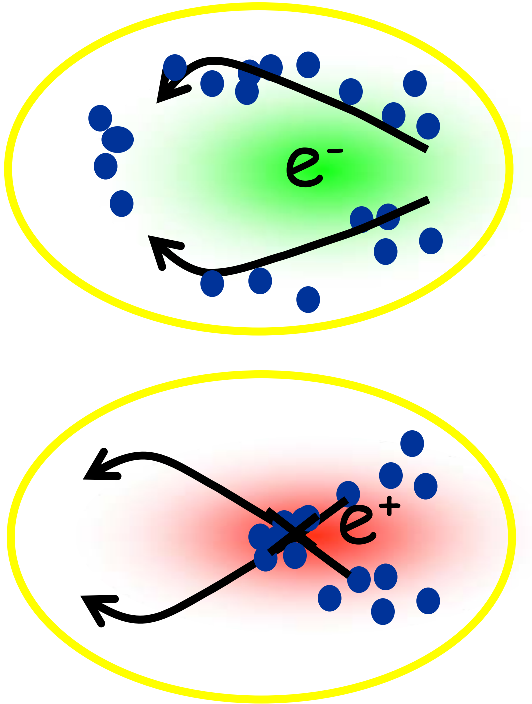
Efficient acceleration of a beam of electrons



Positrons

• e+ and e- behave differently in plasmas. Plasma electrons are **expelled** by an electron beam leaving an ion column behind but they **flow in** to the beam for positrons

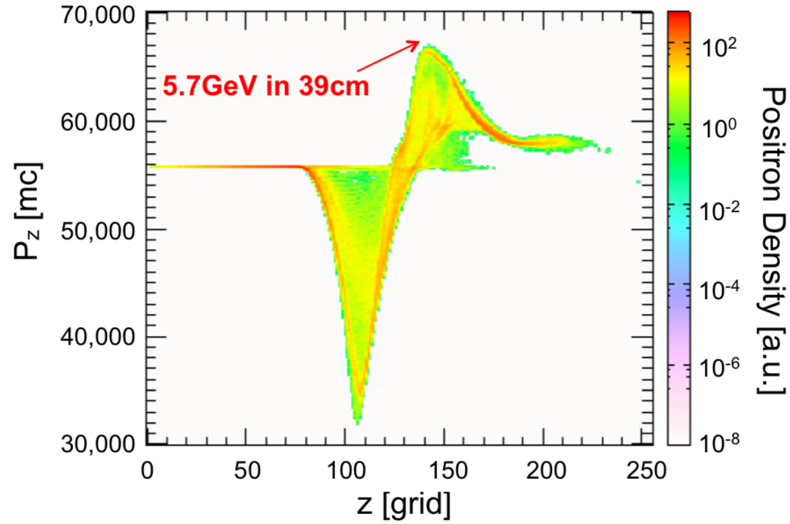
• e+ acceleration (G ~ 70 MeV/m) and focusing (including aberrations) have been measured for low density plasmas (10^{12} – 10^{14} cm^{-3}) and long bunches (600 μm)



Experiments with high peak current e+ beams will be a major research topic at FACET

Positron Acceleration at FACET

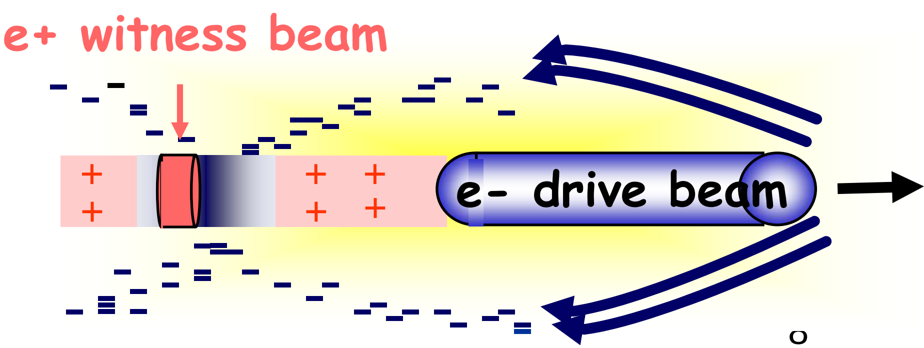
The e+/plasma interaction must be understood through experiments, and these experiments can only be performed at the FACET



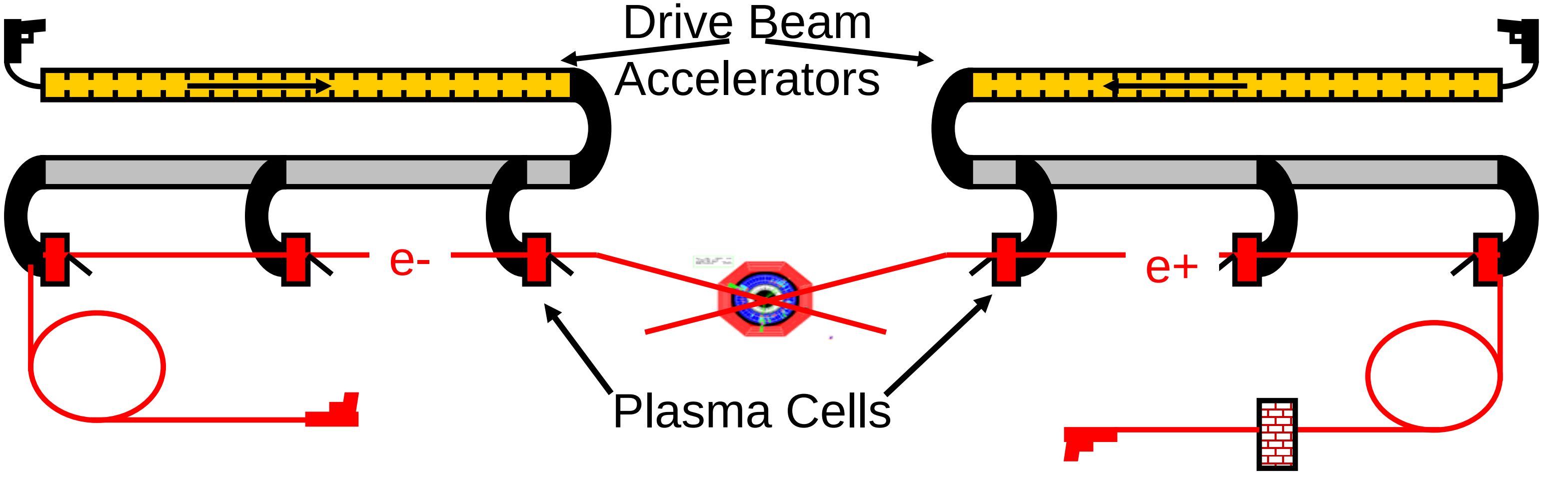
- e+ acceleration has been simulated for high peak current bunches. The beam distribution evolves initially but settles to a stable equilibrium with a peak energy gain of 5.7 GeV in 39 cm.

- Possibility of using a hollow channel plasma as a way to have first plasma electrons arrive at the same time

- Possibility of e+ acceleration in the wake of an e- bunch



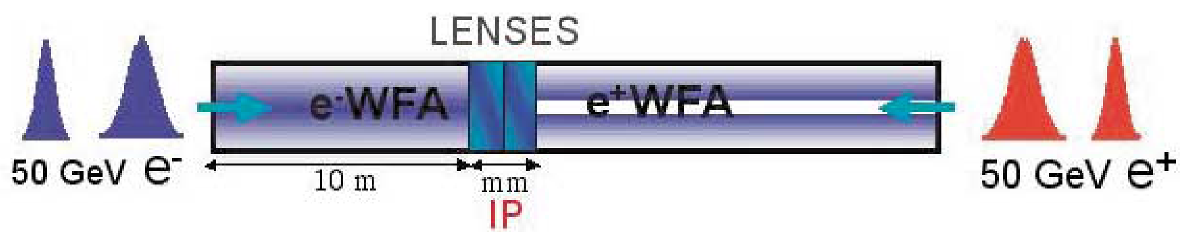
II. Plasma Wakefield Based Linear Colliders



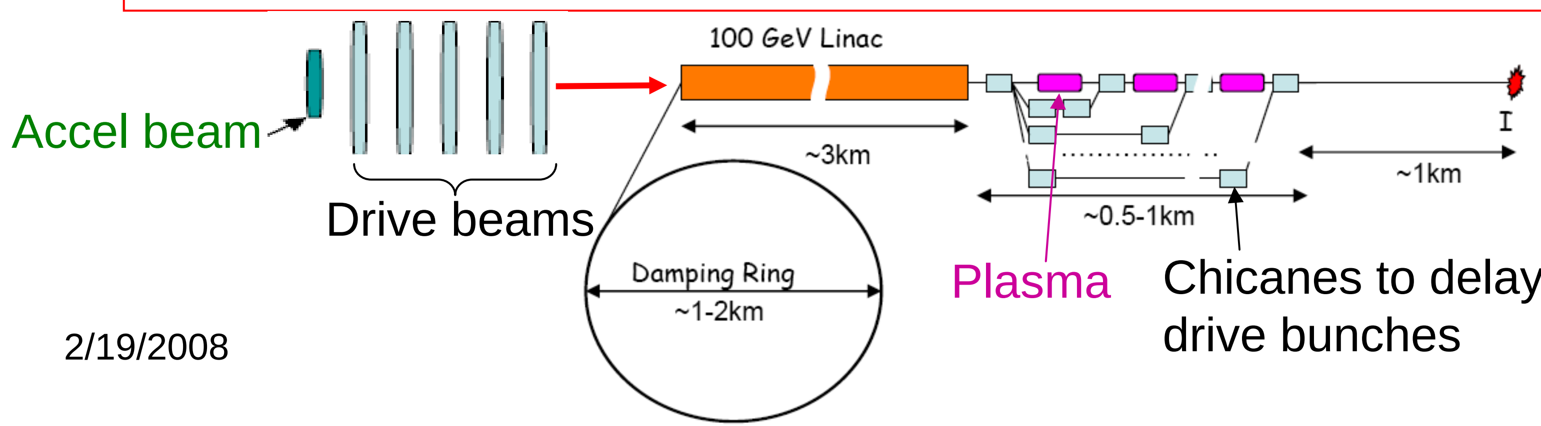
Plasma Wakefield Based Linear Colliders

- Experiments to date show that plasma wakefield acceleration holds promise for dramatic reduction in the size/cost of HEP accelerators.
- But, important open questions that remain to be answered
- What would a linear collider based on plasma wakefields look like?
- Three concepts are illustrated

An "afterburner" on an existing linear collider

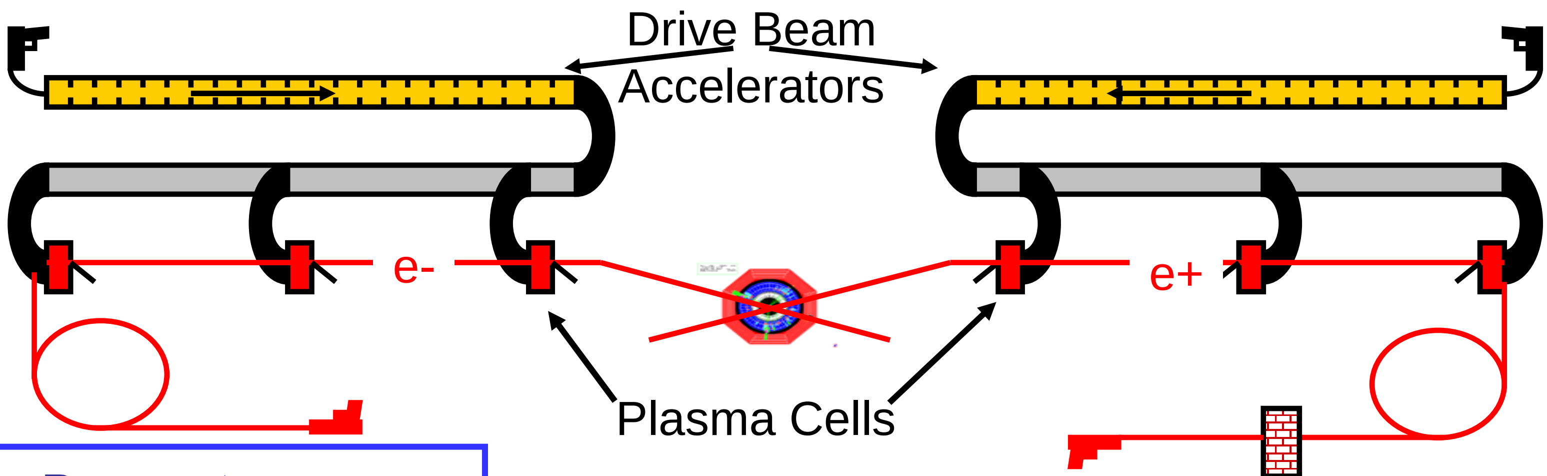


A multistage afterburner with same charge drive and accelerated beams



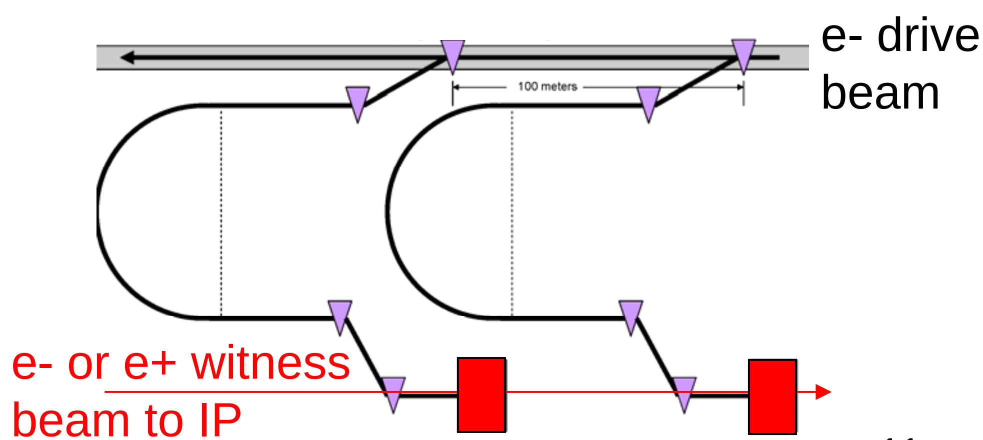
Multistage Plasma Wakefield Collider

A multistage collider with e- drive beams for e- and e+

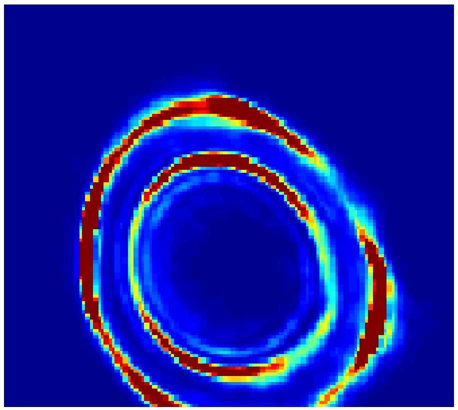


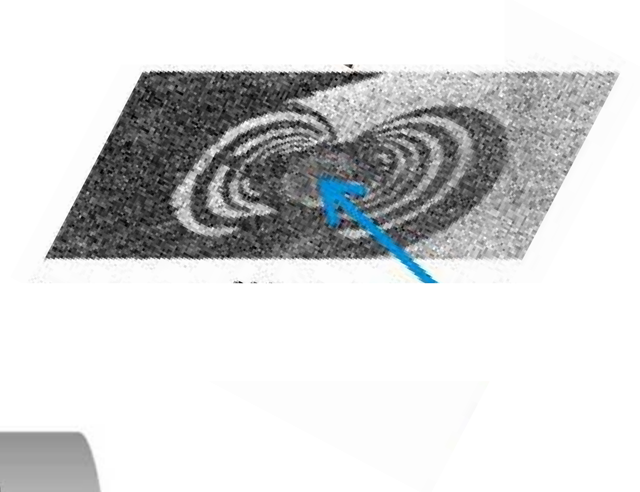
Parameters

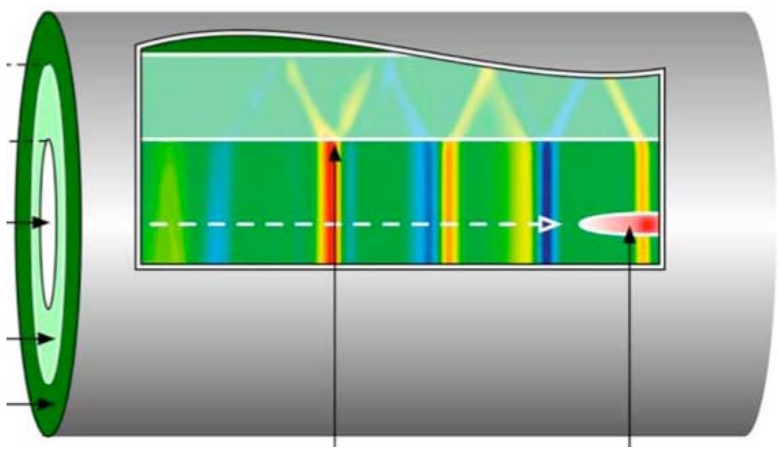
E_{CM}	1 TeV
Luminosity	3×10^{34}
Drive Bunch	3×10^{10}
Drive Bm Energy	25 GeV
Drive Bm Freq	500 kHz
High En Bunch	1×10^{10}
# of Plasma Cells	20
PWFA Efficiency	30%
Collision Freq	25 kHz
σ_x at IP	0.32 μm
σ_y at IP	3.2 nm



III. Other Science & Users at FACET ASF







Other Experiments at FACET ASF

o The FACET ASF emphasis is on plasma wakefield acceleration

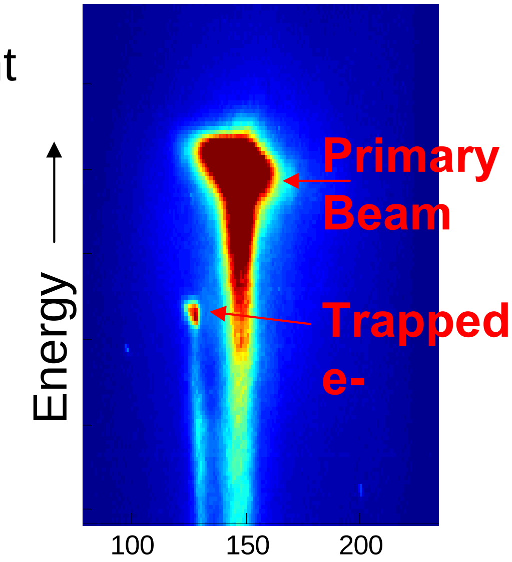
o But, the beam is unique $\Rightarrow$ there will be other scientific opportunities

o Look at 3 of them that have produced interesting results at the FFTB that will have substantial follow-on experiments at FACET

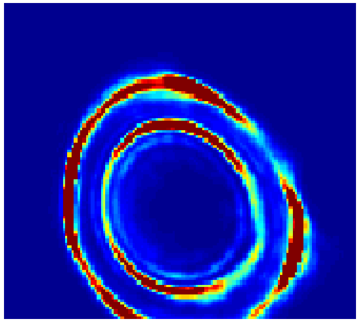
- Trapped electrons in plasmas
- Dielectric wakefield acceleration
- High speed magnetic switching

“Trapped” Electrons

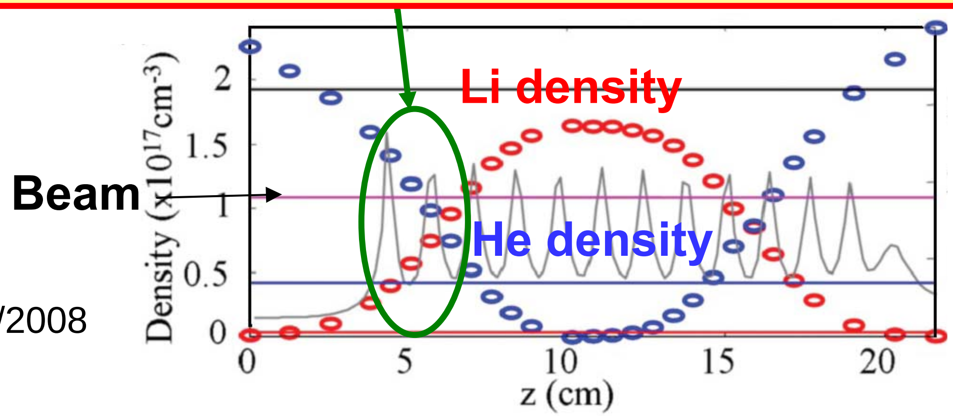
- Electrons with unusual properties observed during high gradient plasma wakefield experiments
  - Narrow energy spread for some events
  - Coherent visible Cherenkov radiation ⇒ short bunch
  - Low emittance, ε_N ~ 2-3x10^{-6}m matched to the plasma
- Theory and simulations show these electrons are
  - Produced by beam field ionization of He buffer gas (that contains Li vapor) in the region where there is partial pressure of He and Li &
  - Then accelerated in the plasma wakefield



Can these electrons be made into a useful electron source? Improve measurements of their properties, improve yield and control them at FACET.



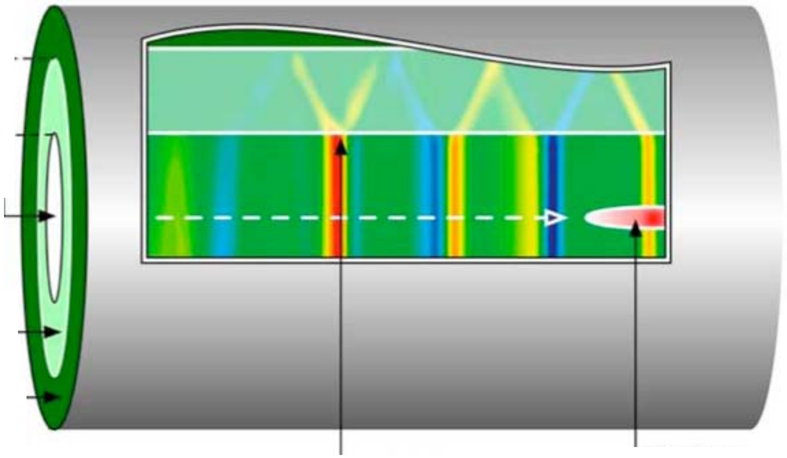
Angle Imaged Cherenkov Radiation



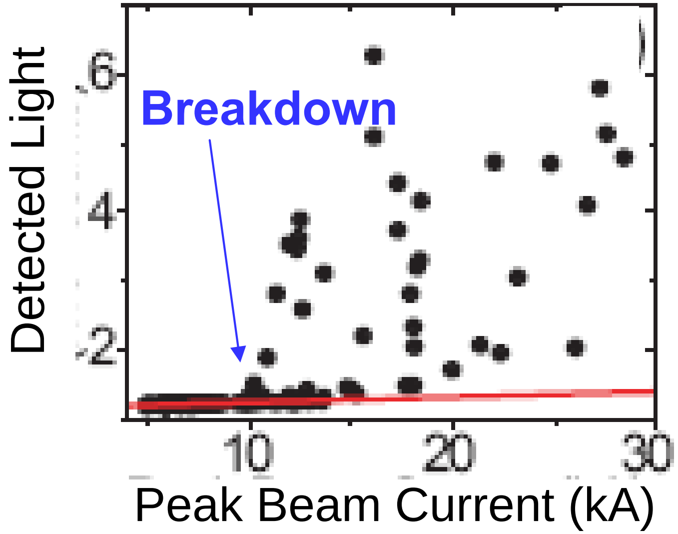
2/19/2008

E. Oz *et al*, PRL **98**, 084801 (2007)

Dielectric Wakefield Acceleration



- Bridge the gap between RF and laser power sources in accelerators where fields are determined by material boundaries
- A first experiment was performed in the FFTB with 1 cm long dielectric fibers
- Goal = measurement of the breakdown threshold
- The results were surprising. The breakdown surface field = 13.8 GV/m corresponding to a decelerating field of 5.5 GeV/m



Extend fiber length to 10 cm and then 1 m at FACET to measure the length dependence of breakdown and to measure deceleration and acceleration

M. C. Thompson *et al*, submitted to PRL

Ultrafast and High Field Magnetization Dynamics

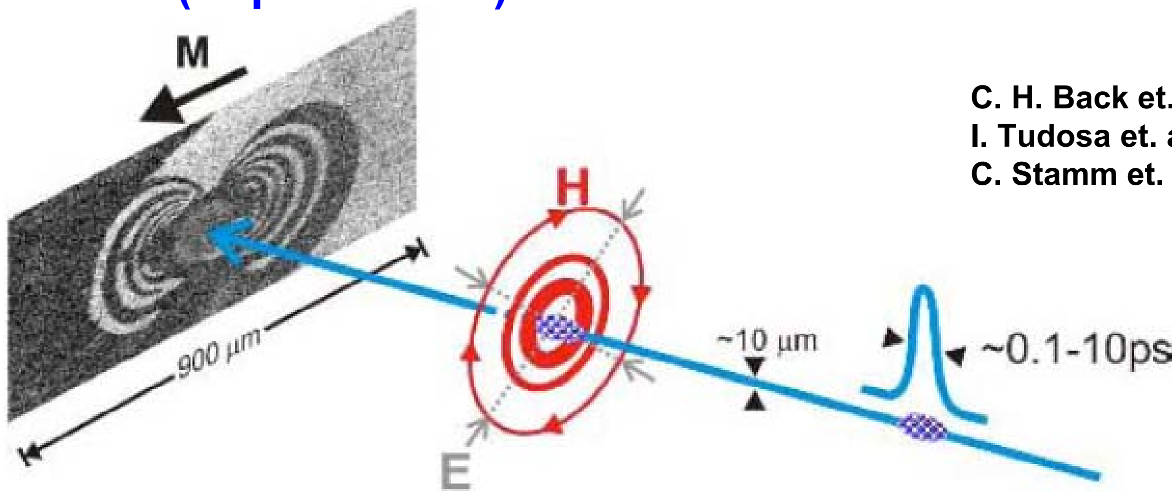
STANFORD LINEAR ACCELERATOR CENTER

The future of magnetic recording lies in smaller bits and faster switching

FFTB experiments demonstrated:

- **Ultrafast precessional switching**
- **Increased damping at high magnetic fields from spin wave instabilities**
- **Generation of a *NEW* type of magneto-electronic anisotropy (unpublished!)**
- **Modification of electronic structure and non-linear conduction at high fields (unpublished!)**

C. H. Back et. al. Science 285, 864 (1999)
I. Tudosa et. al. Nature 428, 831 (2004)
C. Stamm et. al. Phys. Rev. Lett. 94, 197603 (2005)



Magnetic Sample | Electromagnetic Field of the Beam | 28 GeV variable temporal length beam

The FACET beam offers important opportunities in material sciences, condensed matter physics and chemistry

Users & Experiments at FACET ASF

Separate discussions for plasma wakefield and for other experiments

Plasma Wakefield Experiments

FFTB History

- The FFTB experiments were performed by a USC/UCLA/SLAC (and in the beginning LBNL) collaboration
- 60% of the 41 authors of peer reviewed papers of this collaboration were from USC, UCLA & LBNL

We need to broaden the participation in this research and plan to hold a workshop to develop the concept of a plasma wakefield based linear collider and to engage a larger community of researchers

Other Experiments

FFTB History

- The availability of the FFTB beam stimulated experiments run either as full scale experiments or as test beams (magnetism & dielectric wakefield experiments were performed as test beams

This will happen with FACET ASF

FFTB Experiments

- **E-144 Non Linear Compton Scattering**
  First measurement of non-linear Compton scattering out to n=4 using 1µm TW laser crossed with 46.6 GeV e^- beam.

- **E-150 Plasma Lens**
  Experiment using short, high density plasma lens to de-magnify the beam size at the IP by a factor of 2.

- **E-157, E-162, E-164, E-164X, E-167 Plasma Wakefield Acceleration**
  Program to develop new methods for achieving very high accelerating gradients, strong plasma focusing, and related technology.

- **E-165 Fluorescence in Air from Showers (FLASH)**
  A Program to quantitatively understand the production of light by cosmic rays in the upper atmosphere, using controlled laboratory conditions.

- **Experiment E-166 Polarized Positron Production**
  An undulator-based technique applicable to a future linear collider.

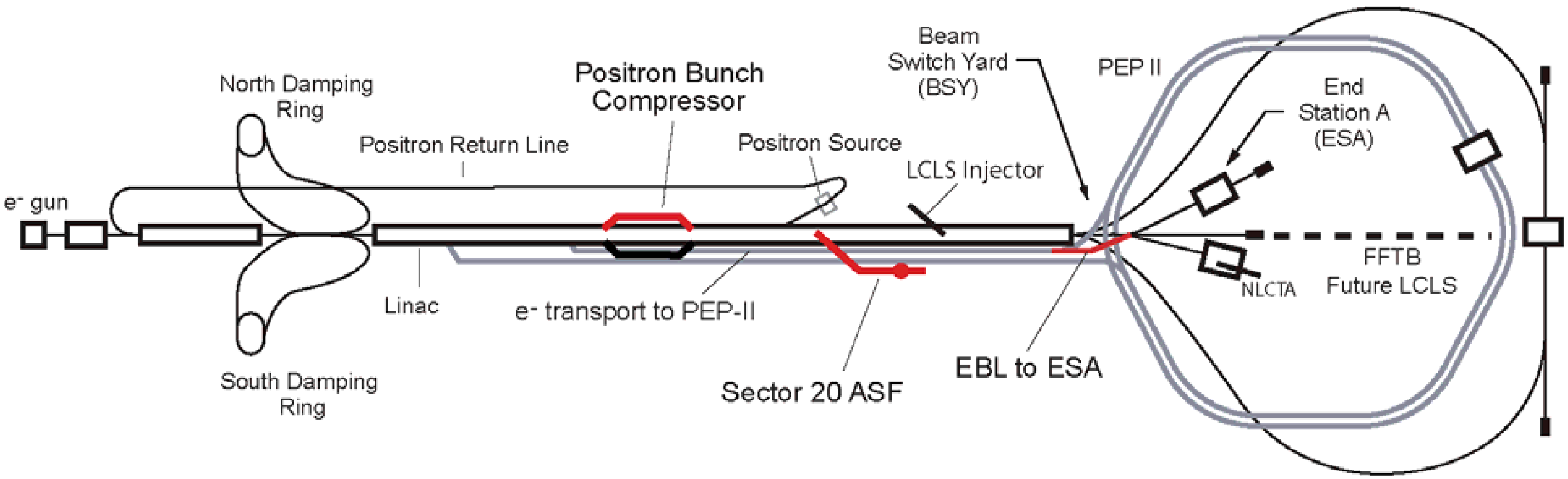
- **SPPS Physics with Extremely Short X-ray Pulses**
  Program involving generation and use of extremely short x-ray pulses.

FFTB Test Beams

– Solid State
– Lab Astro
– High Grad. Accel

T-447 Single Pulse Damage in Materials (Sept 2000)
T-448 Magnified Optical Transition Radiation Test (Oct 2000)
T-450 Damage Test in Diamond for LCLS (Oct 2000)
T-451 High Energy Neutron Spectra Measurement (March 2001)– Detector & Technology
T-452 STAR Endcap Calorimeter Detector Prototype Test (Jan 2001)
T-453 Radiation Damage in Diamond for LCLS (April 2001)
T-454 Measurement of Neutron Spectra (June 2001)
T-455 Measurement of the Calorimeter for the Local Polarimeter at Phenix/RHIC (Aug 2001)
T-456 Magnetization Dynamics in Magnetic Films (Sept 2001)
T-457 Measurement of Neutron Energy Spectra Using Bonner Multi-Sphere Spectrometer (June 2002)
T-460 Characterization of Askaryan Effect in Rock Salt (June 2002)
T-461 High Atmosphere Air Fluorescence (June 2002)
T-462 Magnetization Dynamics of Soft-Magnetic Films (June 2002)
T-464 Correlation of Linac Transverse Deflection Cavity with FFTB Streak Camera (June 2002)
T-465 Magnetization Dynamics in the Sub-picosecond Time Scale (May 2003)
T-466 UCLA Electromagnetic Calorimeter (EMC) Prototype (May 2003)
T-467 Measurement of FFTB Backgrounds for E166 (Jan 2004)
T-468 Diamond Detector Response (July 2003)
T-470 DASH: Diamond Detectors for FLASH (June 2004)
T-471 Incoherent Radio Emission from Showers (July 2004)
T-472 Neutron Energy Spectra Measurements (June 2004)
T-473 Diamond Detector Response (July 2004)
T-478 Magnetism with Ultrashort Magnetic Field Pulses
T-481 Ultra-high Gradient Cerenkov Wakefield Acceleration (August 2005)
T-482 XTR as an Electron Beam Diagnostic (August 2005)

IV. Summary & Concluding Remarks



Review Agenda

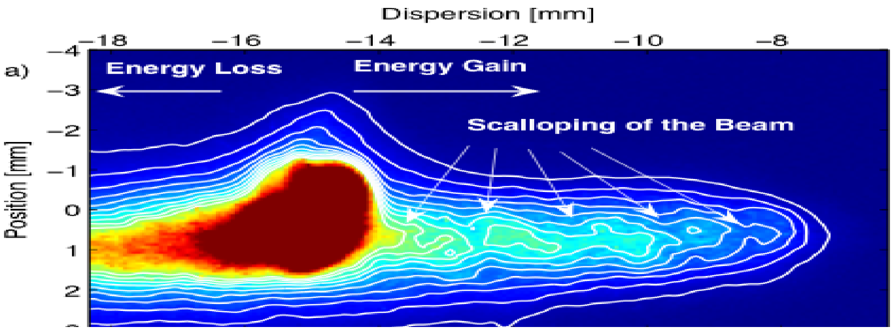
Topics introduced in this talk will be expanded on in the next talks

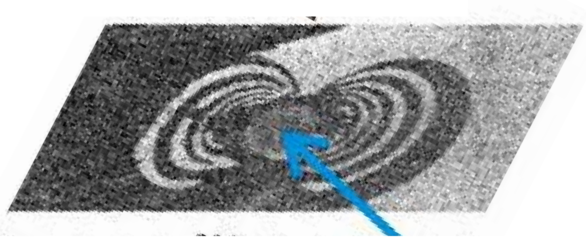
Tom Katsouleas	Concept for a compact TeV plasma wakefield based linear accelerator
Warren Mori	Key physics topics for plasma wakefield accelerator research
Patric Muggli	Status and challenges of the plasma wakefield acceleration experimental program
Mark Hogan	Future plasma wakefield accelerator experiments with FACET ASF
Jamie Rosenzweig	Dielectric wakefield accelerator experiments and FACET ASF
Jo Stöhr	Other experiments using FACET ASF

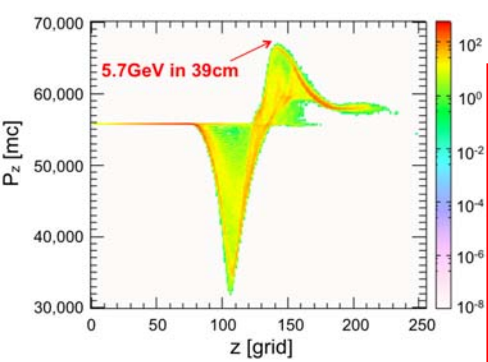
Facilities and Opportunities

The ingredients of a successful accelerator research program

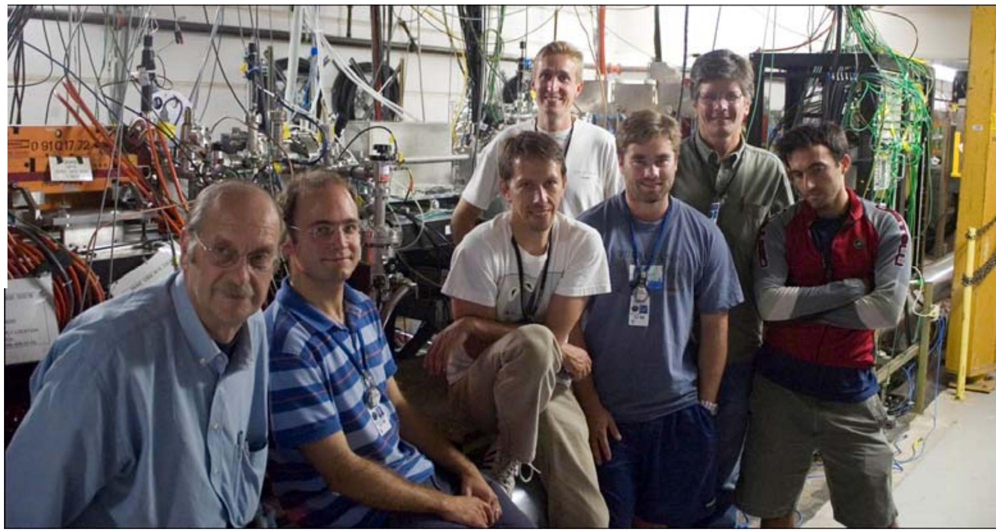
Compelling scientific questions





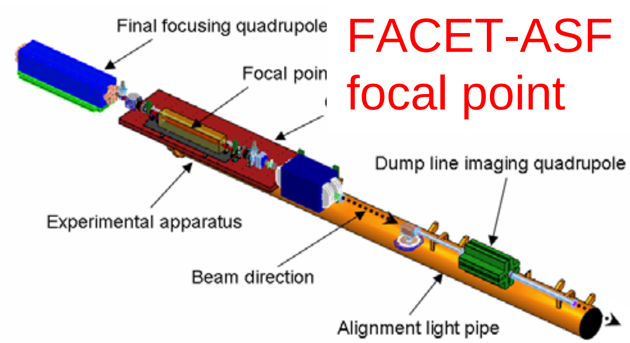


University/national lab collaboration – both benefit



Experienced experimentalists and state-of-the-art facilities lead to rapid progress addressing compelling scientific questions.

State-of-the-art facilities



Concluding Remarks

- FACET ASF is a unique opportunity - Only place in the world where such a beam exists and is likely to exist in the future

- It is the facility needed for the next steps in the development of plasma wakefield acceleration

- There will be other significant scientific opportunities because of the unique beam