Bob Siemann
SLAC

HEPAP Subpanel on Accelerator Research

- **Plasma Wakefield Acceleration**
- **Facilities and Opportunities**
- **Concluding Remarks**

Plasma Wakefield Acceleration

Presented by: Bob Siemann
On behalf of: The E157, E162, E-164, E-164X, E167 Collaborations

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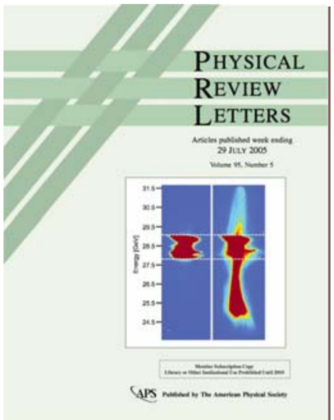
The authors of at least one of our peer-reviewed papers
** = the 14 students in these collaborations*

Plasma Accelerators Showing Great Promise

Scientific Question: Accelerating Gradients > 100 GeV/m have been measured in laser-plasma interactions. Can one make & sustain such high gradients for lengths that give significant energy gain?



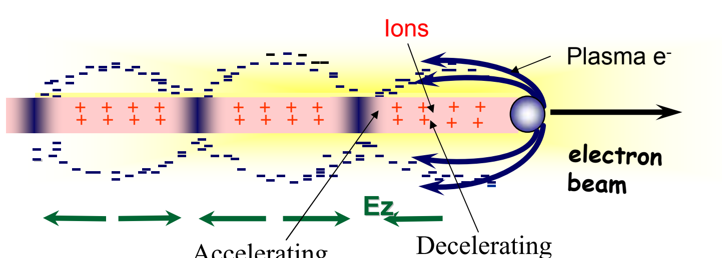
We are studying the underlying beam/plasma physics and looking at issues associated with applying the large focusing (MT/m) and accelerating (GeV/m) gradients in plasmas to high energy physics and colliders

Unique SLAC Facilities

The SLAC Linac & FFTB which have
- **High Beam Energy**
- **Short Bunch Length**
- **High Peak Current**
- **Power Density**
- **e- & e+**

Plasma Wakefield Acceleration - I

PWFA Accelerator Concept



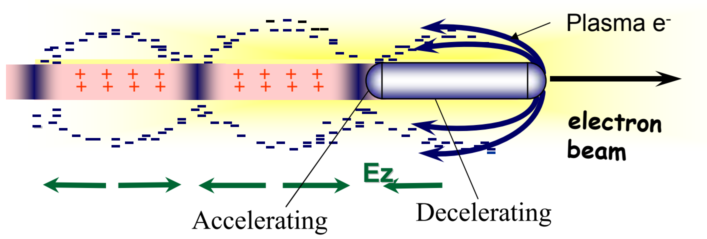
E_z: accelerating field
N: # e^-/bunch
σ_z: gaussian bunch length
k_p: plasma wave number
n_p: plasma density
n_b: beam density

- $E_{z,linear} \propto \frac{N}{\sigma_z^2}$ $\Rightarrow$ Short bunch!

Fully relativistic plasma simulations agree with σ_z dependence

Plasma Wakefield Acceleration - II

Closer to Reality



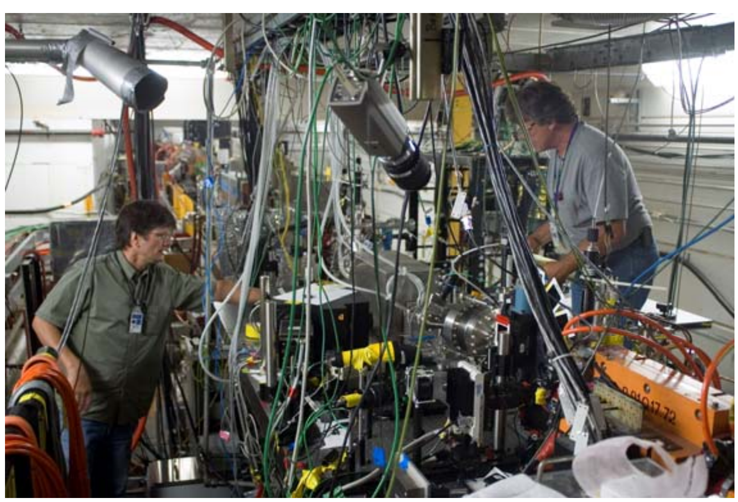
In most of the experiments a single bunch from the linac drives a large amplitude plasma wave which focus and accelerates particles AND the tail of that bunch is used to measure the accelerating field.

$\Downarrow$

$\sigma_z \sim \lambda_{plasma}/\pi$ When combined with $E_z \sim N/\sigma_z^2 \quad \Rightarrow \quad n_p \propto 1/\sigma_z^2$

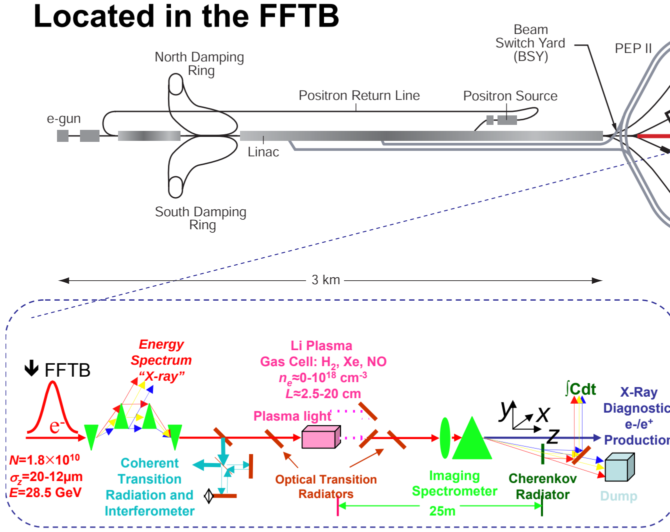
Plasma Wakefield Acceleration - III

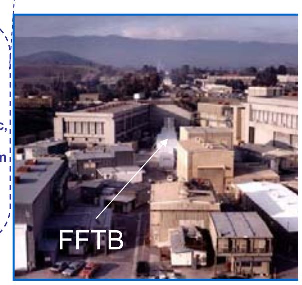
Reality



PWFA Experiments

Located in the FFTB

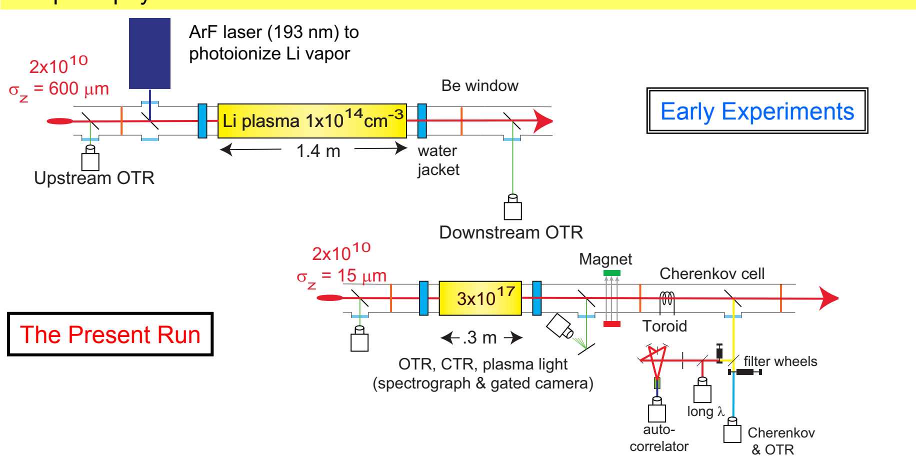




Evolution of One Part Of the Apparatus

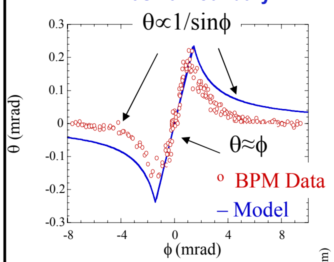
The SLAC linac and FFTB: A stable yet flexible resource and facility

- Develop experience & expertise
- Explore physics



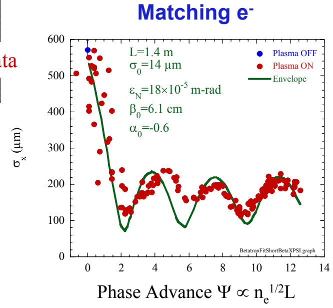
3 Highlights of Early Experimental Results
(σ_z = 600 μm)

Electron Beam Refraction at the Gas–Plasma Boundary



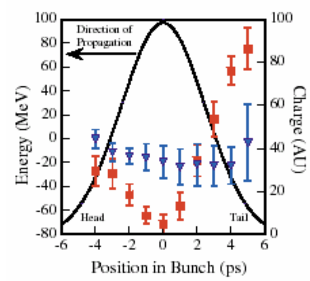
Nature **411**, 43 (3 May 2001)

Matching e⁻



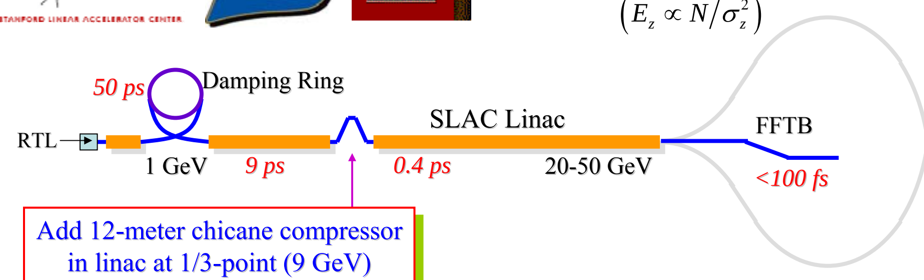
Phys. Rev. Lett. **93**, 014802 (2004)

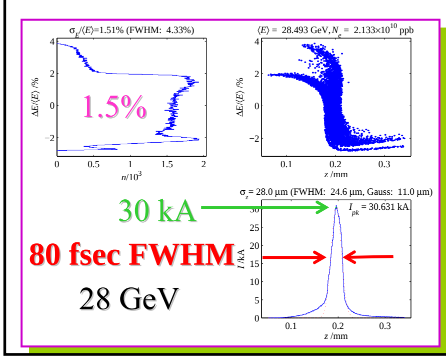
Positron Acceleration



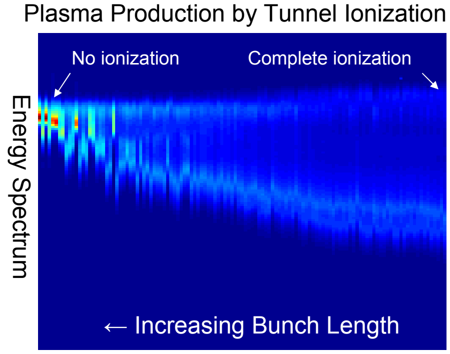
Phys. Rev. Lett. **90**, 214801 (2003)

Short Bunches
$\left(E_z \propto N/\sigma_z^2\right)$

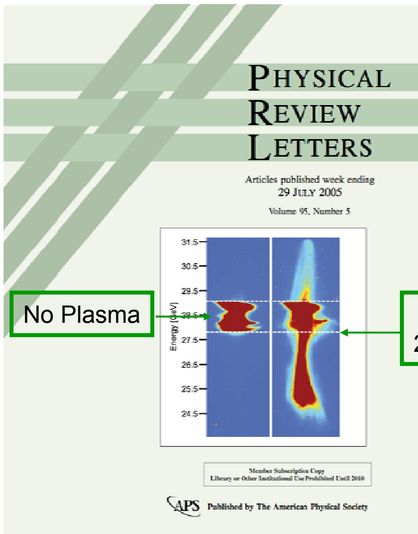




Plasma Production by Tunnel Ionization



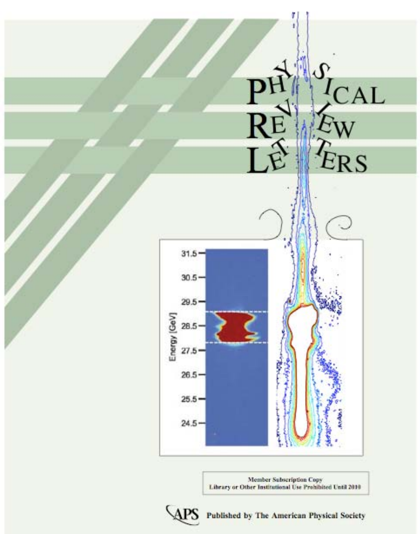
Summer 2004: Accelerating Gradient > 27 GeV/m! (Sustained Over 10cm)*



- Electrons have gained > 2.7 GeV over maximum incoming energy in 10cm
- Confirmation of predicted dramatic increase in gradient with short bunches
- First time a PWFA has gained more than 1 GeV & two orders of magnitude larger than previous beam-driven results

* Large energy spread after the plasma is an artifact of doing single bunch experiments

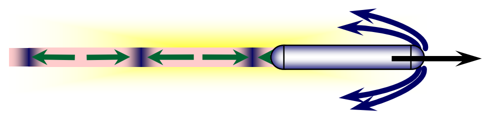
Summer 2005: Next PRL Cover??



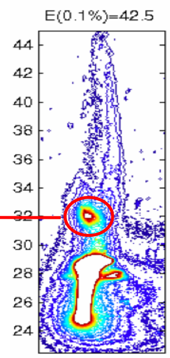
- Increased Beamline apertures
- Increased plasma length to 30 cm
- Electrons have gained > 10 GeV

Large amplitude plasma waves are sustained for at least 30 cm!

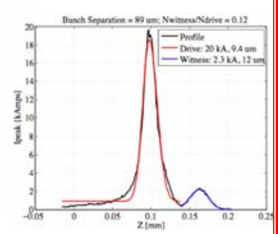
Always New Things to Look At!



Narrow Energy Spread

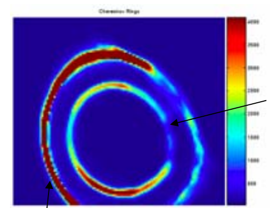


Next Step = 2-bunches produced by collimation



Trapped Particles

Coherent (at λ ~ 500 nm) Cherenkov Radiation



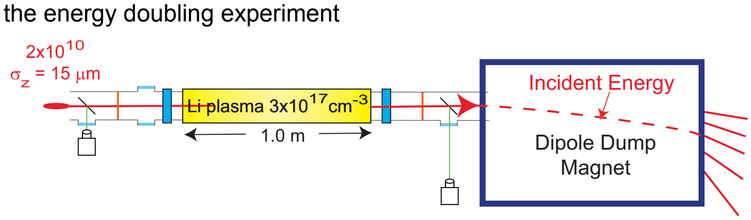
~ 80 MeV

Either > 500 MeV or bunching of the 28.5 GeV beam

Future Plasma Acceleration Research

Three different time horizons

I. The remainder of the lifetime of the FFTB
- two bunch experiment
- understanding of the trapped particles from the plasma
- the energy doubling experiment



II. The Intermediate term – experiments at the NLC Test Accelerator
III. Long term - high energy experiments with short bunch e^+ at SABER

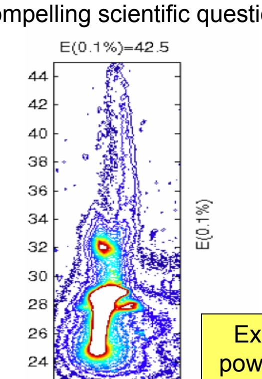
Return to these in a few minutes

Facilities and Opportunities

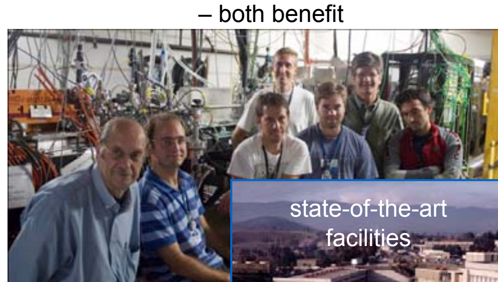
Facilities and Opportunities

The plasma acceleration program at the FFTB provides an excellent example of the ingredients of a successful accelerator research program

Compelling scientific questions



University/national lab collaboration – both benefit

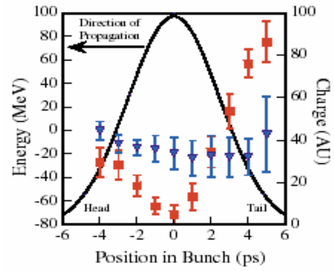


Experienced experimentalists, powerful scientific apparatus and rapid scientific progress follow naturally from these three

Scientific Questions & Collaborations

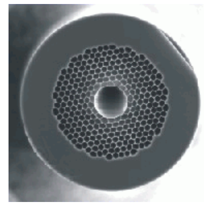
Potential of plasma acceleration
(USC/UCLA/SLAC)

Positron Acceleration



Limits of high gradient acceleration
(ANL/LBNL/Maryland/MIT/NRL/SLAC)

The photonics revolution
& particle acceleration
(Stanford/SLAC)



State-of-the Art Facilities: The NLCTA

The NLCTA is located in End Station B, which is the location of some ILC & LARP R&D, high gradient research, and the laser acceleration experiment (E163)

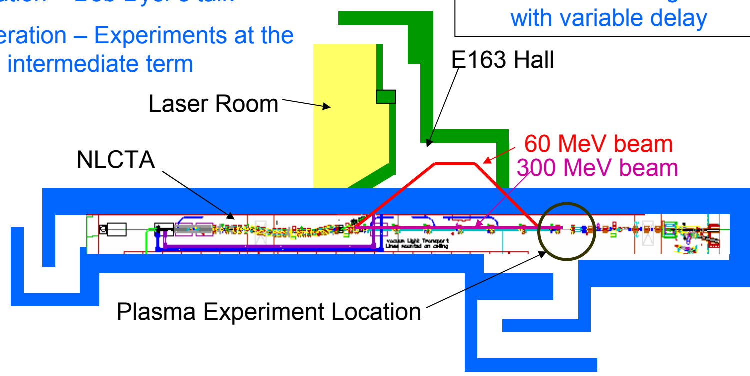
- Significant investment in the past for the warm ILC – 300 MeV X-band linac
- Augmented with an S-band photoinjector for E-163
- Additional X-band and L-band RF power is being developed or is available
- Ti:Sapphire laser system installed
- Space for experiments at 60 MeV and at 300 MeV

Accelerator Research at the NLCTA

Use of the NLCTA for ILC related R&D continues and this R&D relies on some of the same systems as the non-ILC accelerator research
Concentrate on non-ILC accelerator R&D at the NLCTA for this subpanel

- High gradient RF studies – Sami Tantawi's talk
- Laser acceleration – Bob Byer's talk
- Plasma acceleration – Experiments at the NLCTA in the intermediate term

An example -
Drive-witness configuration
with variable delay

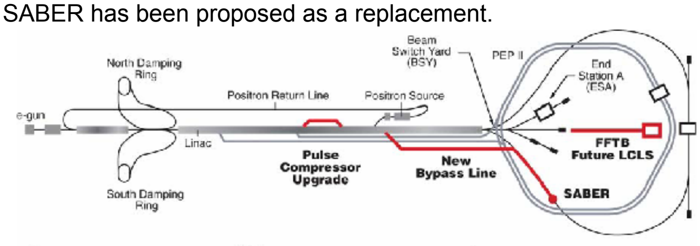


State-of-the Art Facilities:
SABER

The FFTB has been a gold mine for science
- Plasma acceleration (E157, E162, **E164, E164X, E167**)
- Plasma focusing (E150)
- Positron production (E166)
- High energy cosmic rays (FLASH (E165))
- Short pulse x-ray physics (**SPPS**)

Short Bunches

The LCLS will be constructed in the straight-ahead line presently occupied by the FFTB, and SABER has been proposed as a replacement.



Science at SABER

The SABER white paper includes science in
- Plasma Wakefield Acceleration and Beam-Plasma Physics
- Inverse Compton Scattering
- An Intense THz Light Source for Surface Chemistry
- Magnetism and Solid State Physics
- Laboratory Astrophysics Experiments

Energy	Up to 30 GeV nominal
Charge per pulse	3 nC e^- or e^+ per pulse with full compression; 5 nC without full compression.
Pulse length at IP	30 µm with 4 % momentum spread; 42 µm with 1.5 % momentum spread.
Spot size at IP	10 µm nominal (η = η' = 0)
Momentum spread	4 % full width with full compression; < 0.5 % full width without compression.
Drift space available for experimental apparatus	2 m from last quadrupole to focal point. Approximately 23 m from the focal point to the Arc 3 magnets

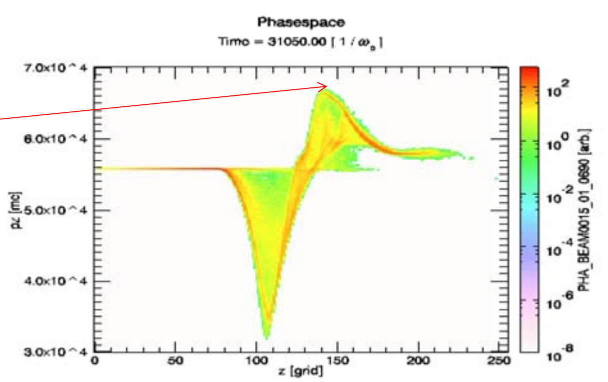
Plasma Experiments at SABER

Short Pulse e+ Are the Frontier

Evolution of a positron beam/wakefield and final energy gain in a **self-ionized** plasma

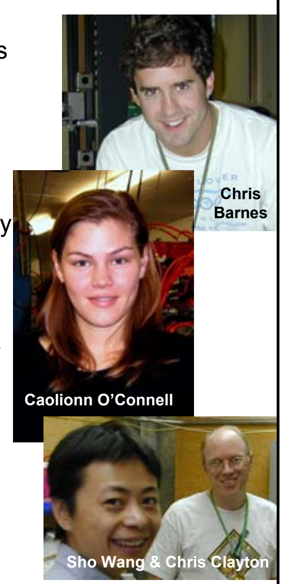
5.7 GeV in 39cm

$N = 8.8 \times 10^9$
$\sigma_r = 11\ \mu m$
$\sigma_z = 19.6\ \mu m$
$n_p = 1.8 \times 10^{17}\ cm^{-3}$



Concluding Remarks

Accelerator Research at SLAC



Accelerator research at SLAC is relevant to high energy physics with research

- Supporting operating accelerators
- Designing the International Linear Collider
- Exploring the technology and physics for accelerators in the future

Past accomplishments have been crucial in defining high energy physics today - storage rings and linear collider

The research includes theory, simulation, experiment, and technology development.

- The results support accelerators that are centerpieces for other sciences. For example the LCLS.

Collaboration and education are vital aspects of our work.

- We work hand-in-hand with scientists from other labs and universities
- Education of students from collaborating institutions and from Stanford