Overview of accelerator science opportunities with FACET ASF

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I. Plasma Wakefield Acceleration
• **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 $\sim 50$ 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

Some electrons double their energy in 84cm!

A Unique Beam

Beam Parameters at the Focal Point for Plasma Experiments

- electrons and positrons
- 23 GeV
- $2 \times 10^{10}$ (3 nC)
- 10 μm nominal spot size
- 16 μm bunch length with 4% FW $\delta p/p$
- 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

Beam-plasma experimenters and experimental region in FFTB
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,

\[ eE_{\text{linear}} = 100 \, \text{GeV} / m \left( \frac{N}{1.8 \times 10^{10}} \right) \left( \frac{20}{\sigma_z (\mu m)} \right)^2 \]
An Important FACET Research Goal

Efficient acceleration of a beam of electrons
• 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 \((10^{12} - 10^{14} \text{ cm}^{-3})\) and long bunches (600 μm)

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

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II. 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**

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

Parameters

- $E_{CM}$: 1 TeV
- Luminosity: $3 \times 10^{34}$
- Drive Bunch: $3 \times 10^{10}$
- Drive Bm Energy: 25 GeV
- Drive Bm Freq: 500 kHz
- High En Bunch: $1 \times 10^{10}$
- # of Plasma Cells: 20
- PWFA Efficiency: 30%
- Collision Freq: 25 kHz
- $\sigma_x$ at IP: 0.32 μm
- $\sigma_y$ at IP: 3.2 nm
III. Other Science & Users at FACET ASF
Other Experiments at FACET ASF

- The FACET ASF emphasis is on plasma wakefield acceleration

- But, the beam is unique \( \Rightarrow \) there will be other scientific opportunities

- 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, $\varepsilon_N \sim 2-3\times10^{-6}$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.

E. Oz et al, PRL 98, 084801 (2007)
• 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

Dielectric Wakefield Acceleration

M. C. Thompson et al, submitted to PRL
Ultrafast and High Field Magnetization Dynamics

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

FFT B 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!)

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
FFT8 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.
FFTBE Test Beams

- **T-447** Single Pulse Damage in Materials (Sept 2000) – Solid State
- **T-448** Magnified Optical Transition Radiation Test (Oct 2000) – Lab Astro
- **T-450** Damage Test in Diamond for LCLS (Oct 2000) – High Grad. Accel
- **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

FACET-ASF focal point
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