Plasma Acceleration Research at FACET

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SLAC PPA DOE HEP Program Review
July 7-9, 2008

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The Beam Driven Plasma Wakefield Accelerator

- Plasma wave/wake excited by a relativistic particle bunch
- Plasma $e^-$ expelled by space charge forces $\Rightarrow$ energy loss + focusing ($>\text{MT/m}$)
- Plasma $e^-$ rush back on axis $\Rightarrow$ energy gain ($>\text{GeV/m}$)
- Linear scaling: $E_{\text{acc}} \approx 110(M\text{eV}/m) \frac{N/2 \times 10^{10}}{(\sigma_z/0.6\text{mm})^2} \frac{1}{\sigma_z^2}$
  $@ k_{pe}\sigma_z \approx \sqrt{2}$
- Plasma Wakefield Accelerator (PWFA) = Transformer
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

FACET Program will demonstrate most of a single stage
Plasma Acceleration has made tremendous progress in the last two decades.

Particle Energy / eV

Year

Beam Driven (e−)
Beam Driven (e+)
Laser Driven (e−)

LLNL
IL E
KEK
UCLA
RAL
LOA

E−162 (e+)
E−162 (e−)
E−164 XX
E−164X
E−167

DOE HEP Office Of Science Issued CD-0 for Advanced Plasma Acceleration Facility February 2008
Progress has been enabled by facilities - Many lasers, but only one SLAC...

High power lasers for AA R&D

**USA**
- BNL & UCLA: CO₂, single shot, < 1 TW
- LBNL: 60TW @ 10 Hz + BELLA (planned)
- Michigan: 500 TW @ 1/min
- Nebraska: 150 TW@ 10 Hz, upgrade 1 PW
- UNR: 100 TW@10 Hz
- UT Austin: 40 TW @ 10 Hz
- UMaryland: 20 TW @ 10 Hz
- UCLA: 10 TW @ 10 Hz

**Asia**
- China: > 500 TW + 1 PW in progress
- India: 10 TW @ 10 Hz
- Japan: 10-100TW @ 10 Hz + 1 PW @ 0.1 Hz
- Korea: 200 TW @ 10 Hz

**Canada**
- ALLS: 200 TW @ 10 Hz – commercial

**Europe**
- France: LIXAM: 1 PW @ 0.1 Hz
  - ILE (in progress): 25 PW @ 1/10 min
  - ELI (planned): 250 PW, single shot
  - LOA: 60TW @ 10 Hz
- Germany: MPQ: 1 PW@ 0.1 Hz
  - Dusseldorf: 40 TW @ 10 Hz
  - Rossendorf: 100 TW@10 Hz
- Italy: INFN: 20 TW @ 10 Hz
- Portugal: 100 TW @ 10 Hz
- Spain: 100 TW @ 10 Hz
- Sweden: Lund: 30 TW@10 Hz
- UK: RAL/IC/Oxford: 500 TW x 2 @ 0.1 Hz
  - Strathclyde: 50 TW @ 10 Hz

*W. Leemans “Lasers and Plasmas” P5 3/08*
FACET is a new facility to provide high-energy, high peak current e⁻ & e⁺ beams for PWFA experiments.
FACET program builds on FFTB work
Studied all aspects of beam-plasma interaction
E-167: Energy Doubling with a Plasma Wakefield Accelerator in the FFTB (April 2006)

* Acceleration gradients of ~50 GV/m (3000 x SLAC)
  - Doubled energy of 45 GeV beam in 1 meter plasma
  - Record Energy Gain
  - Highest energy electrons ever produced at SLAC
  - Significant advance in demonstrating the potential of plasma accelerators

PWFA Mechanism is Different for a Positron Beam

Positron Focusing varies with radius and position along the bunch

- Ideal Plasma Lens in Blow-Out Regime
- Plasma Lens with Aberrations

E-162 Data
Publications & Education

* FFTB Plasma Program produced 29 peer reviewed publications (20 experimental, 9 computation)
  – Physical Review Letters (13)
  – Physical Review Special Topics: Accelerators and Beams (7)
  – Nature (2)
  – Physics of Plasmas (2)
  – Physics Today (1)
  – Physical Review E (4)

* Strong educational component:
  – 3 MS (UCLA)
  – 13 PhD: USC (3), UCLA (6), Stanford (4)

* FACET will be similar
The PWFA-LC concept illustrates the key questions that must be answered:

* High beam loading with both electrons and positrons (required for high efficiency)
* Small energy spreads (required to achieve luminosity and luminosity spectrum),
* Small emittances and small emittance dilution (required to achieve luminosity),
* Average bunch repetition rates in the 10’s of kHz (required to achieve luminosity)
* Multiple plasma stages to achieve the desired energy.
FACET Beam Properties Are Unique In The World

- Energy: 24 GeV
- Charge: 3 nC
- Sigma z: 17 µm
- Sigma r: < 10 µm
- Peak Current: 22 kAmps
- Species: e⁻ & e⁺

Very similar to FFTB/SPPS operation
Single FFTB Bunch Sampled All Phases of the Wake Resulting in ~ 200% Energy Spread
Use a combination of 6D particle tracking in ELEGANT combined with EGS4 to simulate the collimator(s)

**Challenges:**

* Drive bunch needs to both ionize the vapor and drive a large amplitude wake
* Witness bunch needs to be half-plasma period behind the drive bunch (~100µm for 10^{17} e-/cm^3 plasma)
FACET Experiments will accelerate a discrete bunch of particles with narrow energy spread.
High Gradient Positron Acceleration

* First experiments will attempt to reproduce E-167 with positrons

* Not trivial when consider the difference in plasma electron response

* Second phase will use two bunches to study beam loading of positron wakes (notch collimator will work equally well with e- or e+)

* Measure halo formation and emittance growth with DSOTR & quad scan in x-plane of dispersed beam to isolate accelerating portion of the wake
Hollow Channel Plasmas may offer better accelerating wakes and reduce emittance growth

* Potential for larger accelerating fields and less aberrated focusing
* Synergy with DWA which may work equally well with e- & e+
* Challenge for plasma source development in field ionized regime
* Potential to engage new users/collaborators:

**GUIDING CHARACTERISTICS OF AN ACoustic standing wave in a piezoelectric tube**

C. M. Fauser, E. W. Gaul, S. P. Le Blanc, and M. C. Downer

* University of Texas at Austin, Department of Physics, Austin, Texas 78712


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STI OPTRONICS

HOLLOW PLASMA CHANNELS FOR POSITRON PLASMA WAKEFIELD ACCELERATION

STI Optronics, Inc.
2755 Northup Way
Bellevue, Washington 98004-1495

Principal Investigator: Dr. Wayne D. Kimura
Positron Acceleration in Electron Beam Driven Wakes is possible in the weakly non-linear regime

Generating closely-spaced mixed-species bunches is simplified by creating the positrons in the plasma.
Sailboat Chicane Upgrade will enable full exploration of $e^+$ acceleration in $e^-$ wakes

- Extract $e^-$ & $e^+$ from damping rings on same linac pulse
- Accelerate bunches to sector 20 5cm apart
- Use ‘Sailboat Chicane’ to put them within 100$\mu$m at entrance to plasma

Beta functions and dispersion in chicanes and FF
Future upgrades will be guided by results

Possibilities:
- **Sailboat Chicane**
  - Positron acceleration in electron wakes with ‘real beam’ of positrons
- **Lower damping ring energy**
  - Better compression, higher peak current
- **Enhanced LCLS style photoinjector**
  - Multiple bunches, bunch trains, shaped pulses with added flexibility
- **NLC/ILC style FF**
  - Sub-micron spots @ IP for ion motion studies
- **Holography of e+ wakes, EO sampling**
### Experimental timeline for FACET Program

<table>
<thead>
<tr>
<th>Experimental Tasks and Milestones</th>
<th>FY09</th>
<th>FY10</th>
<th>FY11</th>
<th>FY12</th>
<th>FY13</th>
<th>FY14</th>
<th>FY15</th>
<th>FY16</th>
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<tbody>
<tr>
<td>Accelerate e- bunch with sufficient charge</td>
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<td>Accelerate e- bunch achieving low energy spread</td>
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<td>Accelerate e- bunch with high efficiency</td>
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<td><strong>Demonstration of electron acceleration: high $\eta$, low $\Delta E$</strong></td>
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<td>Emittance preservation of e- bunch</td>
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<td><strong>Demonstration of a single stage of an electron PWFA-LC</strong></td>
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<td>Acceleration of e+ bunch by e+ drive</td>
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<td>Initial test of e+ acceleration in e- wakes</td>
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<td>Upgrade Sector-20 chicane</td>
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<td>Accelerate e+ by e- drive; charge, low dE/E</td>
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<tr>
<td>Accelerate e+ by e-, high efficiency, low emittance</td>
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<td><strong>Selection of optimum positron acceleration mechanism for a PWFA-LC</strong></td>
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<td>Upgrade injector with rf gun</td>
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<td>Plasma cell with jet and power removal</td>
<td>Study</td>
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<td><strong>Design plasma cell with needed stability and cooling</strong></td>
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*Note: FACET indicates the focus area.*
Plasma accelerator research at FACET is in the context of a broader, longer term effort.

Possible Timeline for PWFA Development

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
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<tbody>
<tr>
<td>FACET I (proposed)</td>
<td>Construction</td>
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<td>FACET Upgrade(s)</td>
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<td>Upgraded Program</td>
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<td>Preliminary design and parameters of PWFA-LC are defined</td>
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<td>FACET II (future option)</td>
<td>Construction</td>
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<td>Staging of Two 25GeV Modules</td>
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<td>Multi-bunch Operation</td>
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<td>Shaped profiles for High Efficiency</td>
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<tr>
<td>Optimized design of PWFA-LC is produced</td>
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Overview of Financial Data - FY2008

**FY 2008 FTE by Job Category**

- Administrative / Technician, 0.32
- Engineer / Computing Professional, 0.88
- Temporary PhD, 0.28
- Graduate Students, 0.23
- Permanent PhD, 1.15

**Total FTE: 2.8**

**FY 2008 Total K$ by Activity**

- Allocation of PPA DPS, 134
- Plasma, 548

**Total K$ of PLASMA: 548**
Overview of Financial Data 2007-2010

FY 2007-2010 Total K$ By Cost Type
PLASMA

FY 2007-2010 Total K$ by Activity
PLASMA

Labor  M&S  Allocation of PPA DPS

SLAC Annual Program Review
The FACET Program will address many of the current questions pertaining to a PWFA-LC:

- TeV CM Energy
- 10's MW Beam Power for Luminosity
- Positron Acceleration
- Vigorous extension of known technologies

![Diagram of FACET Program](image)

5.7 GeV in 39 cm