• Plasma Wakefield Acceleration Development on FACET II

Chan Joshi on behalf of E200, 217, 225

Image Courtesy Frank Tsung

Work supported by U.S. D.O.E. HEP
Goals of the PWFA Collaboration at FACET

Transformational R&D for a TeV scale $e^+e^-$ collider

To address critical physics issues for realizing an accelerator based on advanced concepts at the energy frontier in the next decade. A by-product will be compact accelerators for industry & science.
PIC Simulations Critical to PWFA Program: The UCLA Particle-in-Cell and Kinetic Simulation Software Center (PICKSC)

PI W.B. Mori, co-Pis V.K. Decyk, F.S. Tsung, and R. Caflisch.
http://picksc.idre.ucla.edu

The mission of the Particle-in-Cell and Kinetic Simulation Software Center (PICKSC) at UCLA is to support an international community of PIC and plasma kinetic software developers, users, and educators, and to increase the use of this software for accelerating the rate of scientific discovery.
PWFA Program on FACET is on Track to Successfully Complete All it’s Proposed Tasks

• Tremendous progress on both electron and positron acceleration at FACET
  Both e- and e+ have now shown
  Acceleration of a significant (100 pC) charge \(^{1,2,3}\)
  Small ( < 5%) energy spread at 9(6) GeV energy gain for electrons (positrons) \(^2\)
  High (~ 4 GeV/m) loaded gradients \(^{1,2,3}\)
  High (~ 30%) energy transfer efficiency per unit length \(^{1,3}\)
  Encouraging results on hollow channel PWFA (230 MeV/m) \(^6\)
  Encouraging results on low emittance (factor 10 better than drive beam emittance) beam generation \(^4\)

What are some of the remaining scientific issues?
Work Published or Submitted to Peer Reviewed Journals

2. M. Litos et al submitted to PPCF
4. N. Vafaei et al submitted to PPCF
5. N. Vafaei et al, PRL 2014
6. S. Gessner et al, to be submitted
7. C. Clayton et al, to be submitted
9. E. Adli et al, to be submitted
10. S. Corde et al, submitted
11. S. Li et al, PPCF 2014
What Are Some of the Outstanding Issues?

✓ 1) High transformer Ratio Problem

✓ 2) Generation of Ultra-low Emittance Beams

✓ 3) Matching of two stages involving a Plasma Accelerator

✓ 4) Preservation of low emittance during acceleration

✓ 5) Staging

✓ 6) Parallel development for positrons

Specific examples are in the FACET II CDR as part of UCLA/Tsinghua/SLAC PWFA Contributions
Why Is FACET II the Ideal Facility for PWFA?

In addition during the second phase FACET II will develop positron capability
Ref: Table 4. 1 and 5.4 FACET CDR

<table>
<thead>
<tr>
<th></th>
<th>Drive Beam</th>
<th>Injector Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (GeV)</td>
<td>10</td>
<td>0.135</td>
</tr>
<tr>
<td>Charge (nC)</td>
<td>0.7-5</td>
<td>2</td>
</tr>
<tr>
<td>Emittance (microns)</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>σ_z (μm)</td>
<td>1-20</td>
<td>6-20/6-13</td>
</tr>
<tr>
<td>σ_r (μm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1) High Transformer Ratio (T) Problem

\[ T = \frac{E^+}{E^-} = \frac{W^+}{W^-} \] for a non-evolving wake
\[ T \leq 1 \] for a symmetric drive beam and loaded wakes

A PWFA based Linear Collider (PWFA-LC) may be cheaper if lower energy but high charge bunches could be used to drive \( T > 2 \) loaded wakefield stages.

20 GeV energy gain using a 10 GeV FACET II Drive Bunch

See FACET II CDR for more details
Future Colliders and Light Sources will require ultra-low emittance beams

Can PWFA provide the necessary small emittance bunches?

\[ L = \frac{N_e + N_e - f_r}{4\pi \sigma_x \sigma_y} \]

Small spot size requires
Small emittance and narrow
Energy spread

\[ B_n \approx \frac{2I}{\epsilon_n^2} \]

High current requires short,
Low emittance bunches

\( \epsilon_n \) smaller than 100 nm will be required for both collider and light source applications
2) Generation of Ultra-low Emittance Beams (i)

Downramp Injection

Drive Bunch
1 nC 10x10x10 μm bunch

L=260 μm

Injected Beam
230 pC, 27 kA,
B_n=3.8x10^{18} \text{ Arad}^{-2}\text{m}^{-2}
\varepsilon_n = 120x120 \text{ nm}

Use thin Gas cell with 200 μm Holes to produce density ramps in ambient laser ionized Hydrogen gas

Ref: FACET II CDR
Probing wakes directly Using an electron beam

Courtesy of Chaojie Zhang
Snapshot of down-ramp injection

Variation of fields caused by plasma density down-ramp and injected bunch lead to extra momentum modulation of probe.

Drive beam:
10 GeV, 1 nC, sigma_r = 15 μm, sigma_z = 20 μm;

Probe Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>200 MeV</td>
</tr>
<tr>
<td>Energy Spread</td>
<td>20%</td>
</tr>
<tr>
<td>Emittance</td>
<td>3 mmmrad</td>
</tr>
<tr>
<td>Duration</td>
<td>35 fs</td>
</tr>
<tr>
<td>Spot size</td>
<td>1 mm</td>
</tr>
</tbody>
</table>

100μm downramp
1.1 × 10^{17} cm⁻³
7.7 × 10^{16} cm⁻³

Courtesy of Chaojie Zhang
2) Generation of Ultra-low Emittance Beams (ii)

Colliding Beam Injection

\[ \varepsilon_n = 6 \text{nm} \]

seen in 3D PIC simulations: Two transversely colliding lasers overlap inside the wake such that the peak intensity just exceeds the ionization threshold

F. Li et al Phys Rev Letts 2013
3) Matching of two stages involving a Plasma Accelerator

Injection of FACET photoinjector bunch into PWFA stage driven by 10 GeV bunch

Talk by Xinlu Xu

Matching of beam emnating from one PA into another PA
Talk by Karl
3) Matching of two stages involving a Plasma Accelerator Using Density Ramps: talk by Xinlu Xu

Courtesy of Xinlu Xu
4) Emittance Preservation During Acceleration

- PWFA in the blow-out regime has the necessary field structure to maintain the emittance of the accelerating bunch.

\[ \partial_\xi F_r = \partial_r F_z = 0 \]

Panofsky-Wenzel Theorem

Need to measure field structure and correlate it with emittance growth. How do non ideal effects such as asymmetric beam shape or emittance affect emittance preservation of the beam load?
Considerable Success in mapping the Field Structure of the wake

Energy Spectrum of the Drive Bunch

Comparison between Experiment And simulations
Snapshot of two-bunch experiment

drive beam:
10 GeV, 4 nC
sigma_r = 5 um,
sigma_z = 20 um;

trailing beam:
0.1 GeV, 288 pC
sigma_r = 2 um,
sigma_z = 2 um;

beam separation: 93.5 um
np = 2e17 cm^-3;

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Courtesy of Chaojie Zhang
5) Staging Problem

All the essential elements of the staging problem (injection, acceleration and extraction can) be addressed on FACET II.

Use the well characterized 135 MeV Photo-Injector bunch to inject into wake driven by 10 GeV drive beam.

We then dump the drive beam, extract the accelerated beam and measure the throughput charge, energy spread, emittance growth as a function of plasma parameters.
Conclusions

• FACET II (Phase I and II) is necessary for continued and meaningful progress of PWFA Concept for HEP applications.

• The UCLA/SLAC/Tsinghua/U. Oslo/LOA team is the right team with the proven track record, experienced manpower and ideal mix of theorists, simulationists and experimenters to carry out this program.

• The proposed program will tackle the critical issues so that the potential of the scheme as a candidate for a future high-energy collider can be meaningfully assessed within a finite time period.