Plasma Wakefield Acceleration Development on FACET II

Chan Joshi on behalf of

E200, 217, 225

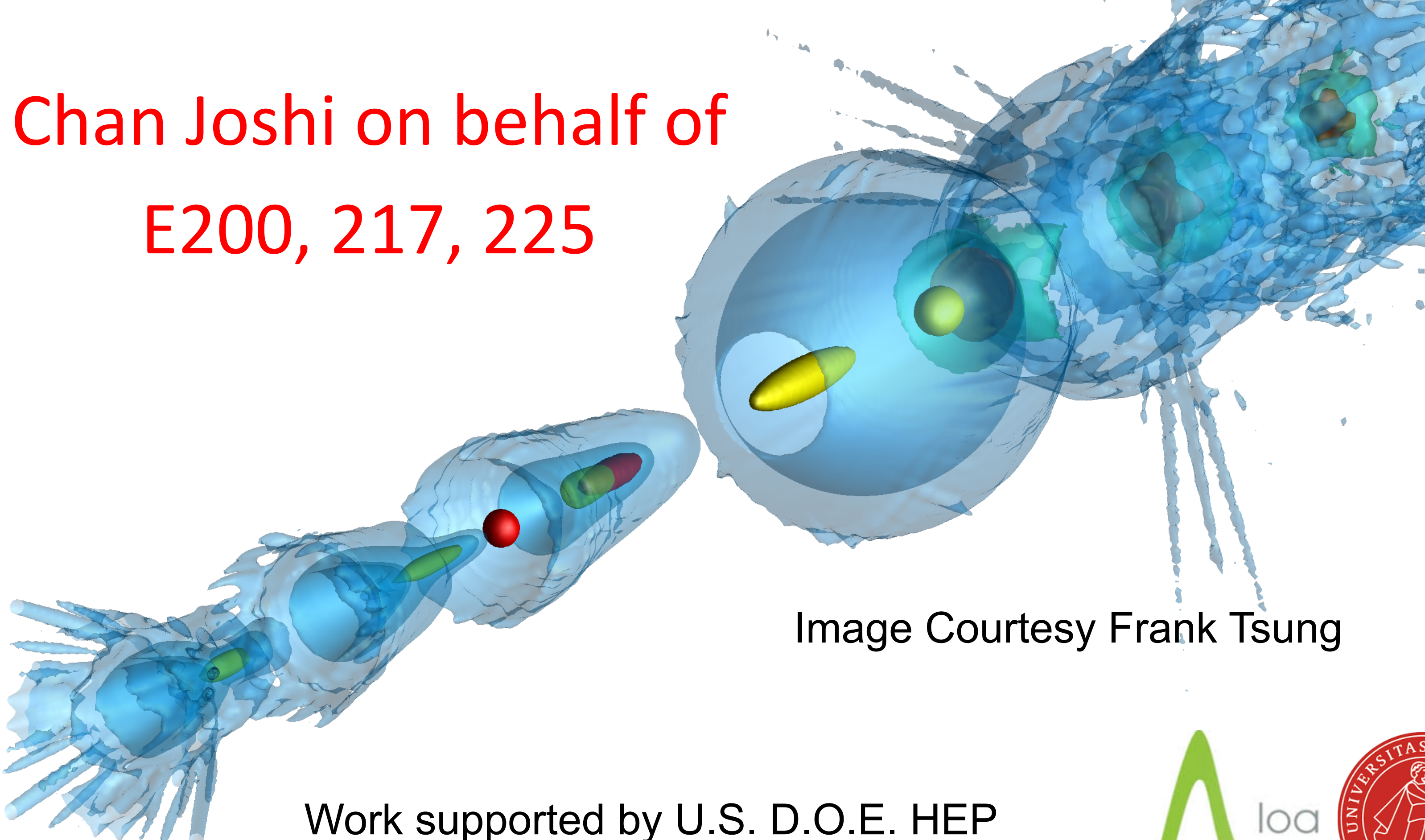


Image Courtesy Frank Tsung

Work supported by U.S. D.O.E. HEP

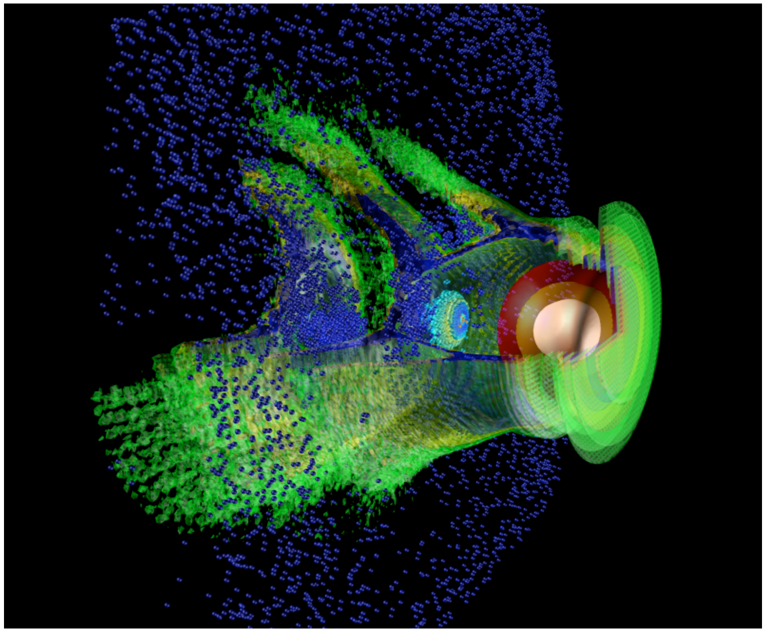
Goals of the PWFA Collaboration at FACET

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

1 M. Litos et al Nature 2014
2 M. Litos et al submitted to PPCF
3 S. Corde et al Nature 2015
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
8 W. An et al PRSTAB 2014
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

T 6) Ion Motion and it's effect on emittance?

✓ 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?

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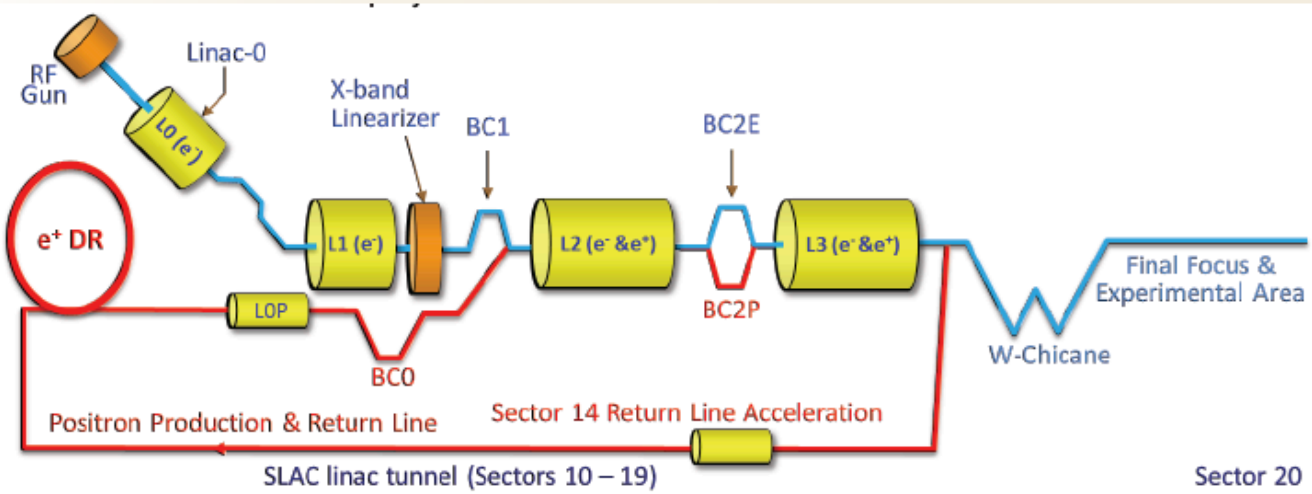


High Charge
High Energy
Low emittance
Small spot size
e+ and e-Beams

	Drive Beam	Injector Beam
Energy (GeV)	10	0.135
Charge (nC)	0.7-5	2
Emittance (microns)	3.2	3.2
σ_z (µm)	1-20	
σ_r (µm)	6-20/6-13	

In addition during the second phase FACET II will develop positron capability

Ref: Table 4. 1 and 5.4 FACET CDR

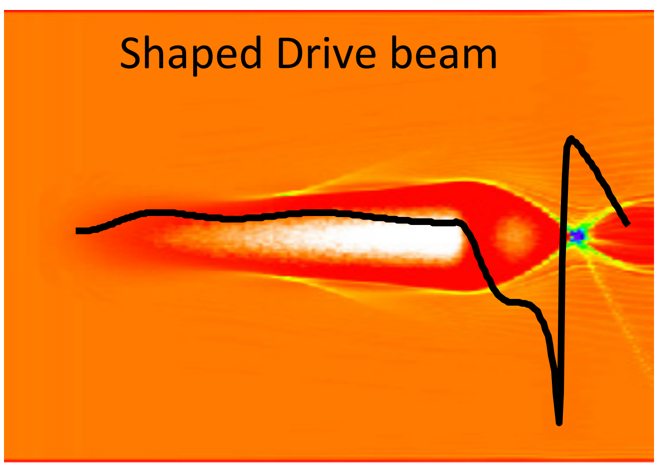
1) High Transformer Ratio (T) Problem

$T = E^+/E^- = W^+/W^-$ for a non evolving wake

$T \leq 1$ for a symmetric drive beam and loaded wakes

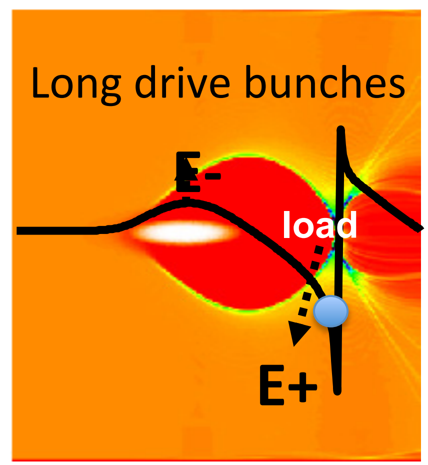
A PWFA based Linear Collider(PWFA-LC) may be cheaper if lower energy but high charge bunches could be used to drive T > 2 loaded wakefield stages.

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



See FACET II CDR for more details

Beam Load may
Have to be generated
In situ



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

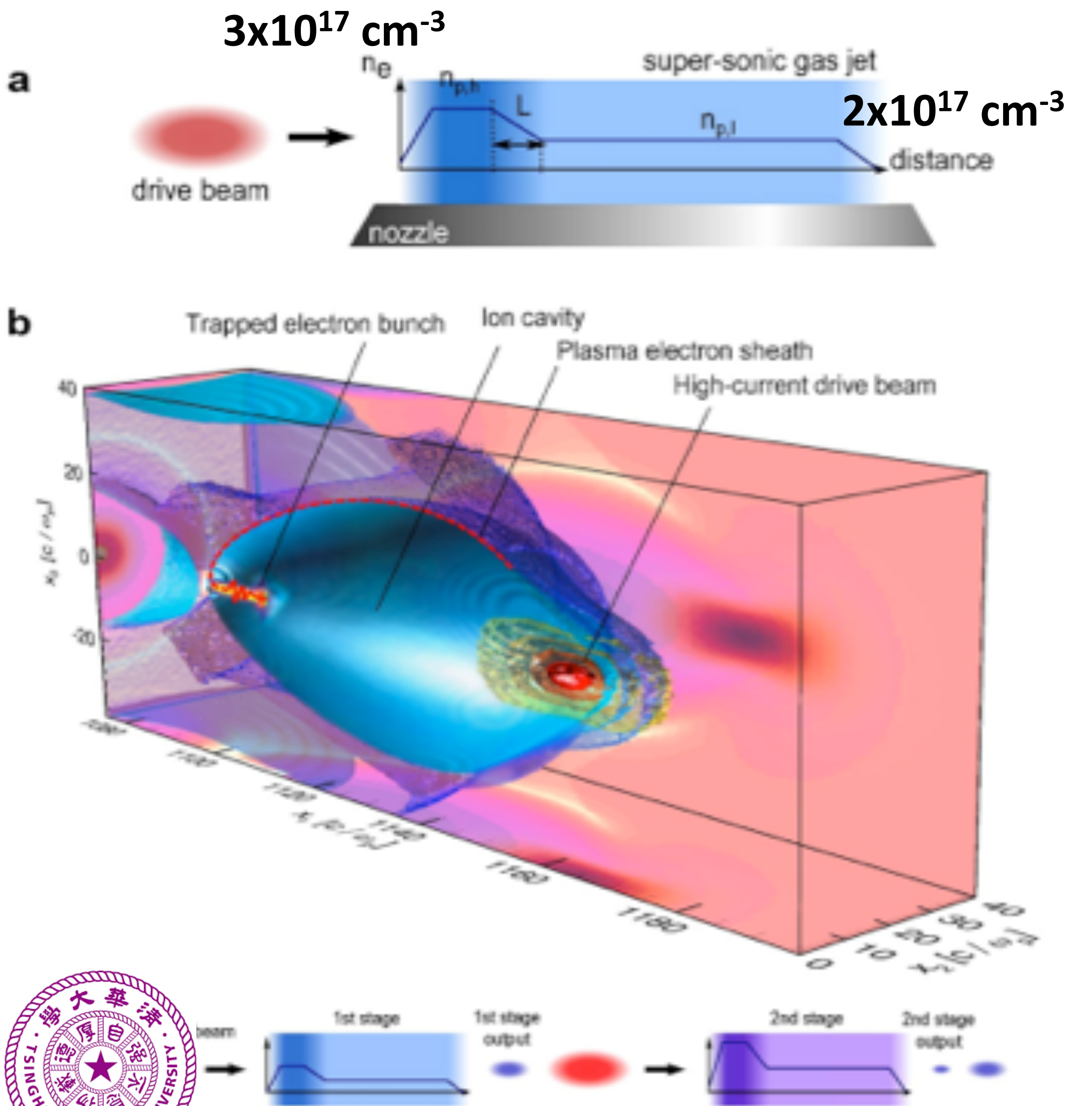
$$B_n \approx \frac{2I}{\varepsilon_n^2}$$

High current requires short,
Low emittance bunches

ε_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

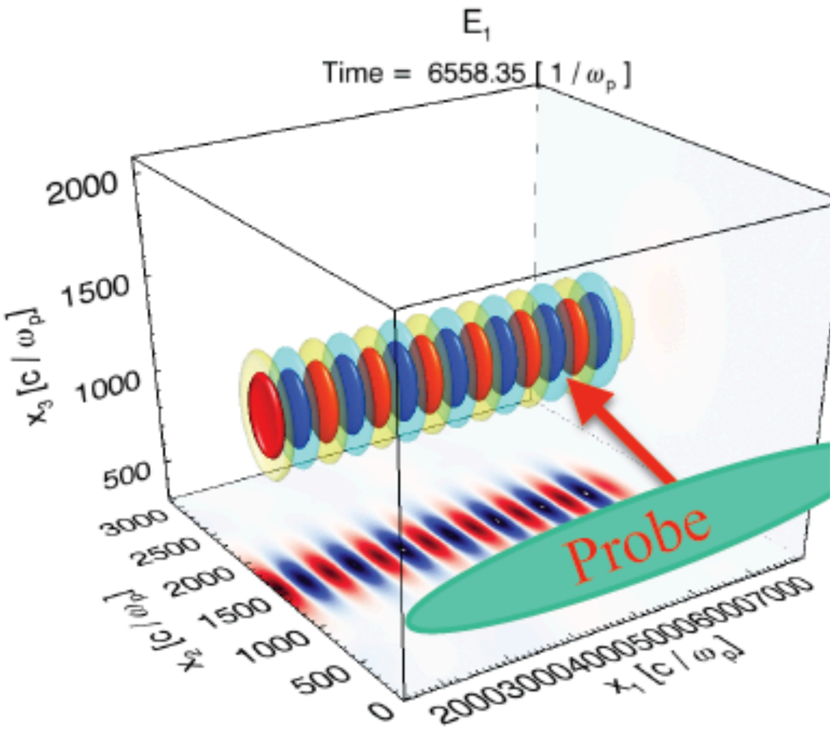
L=260 µm

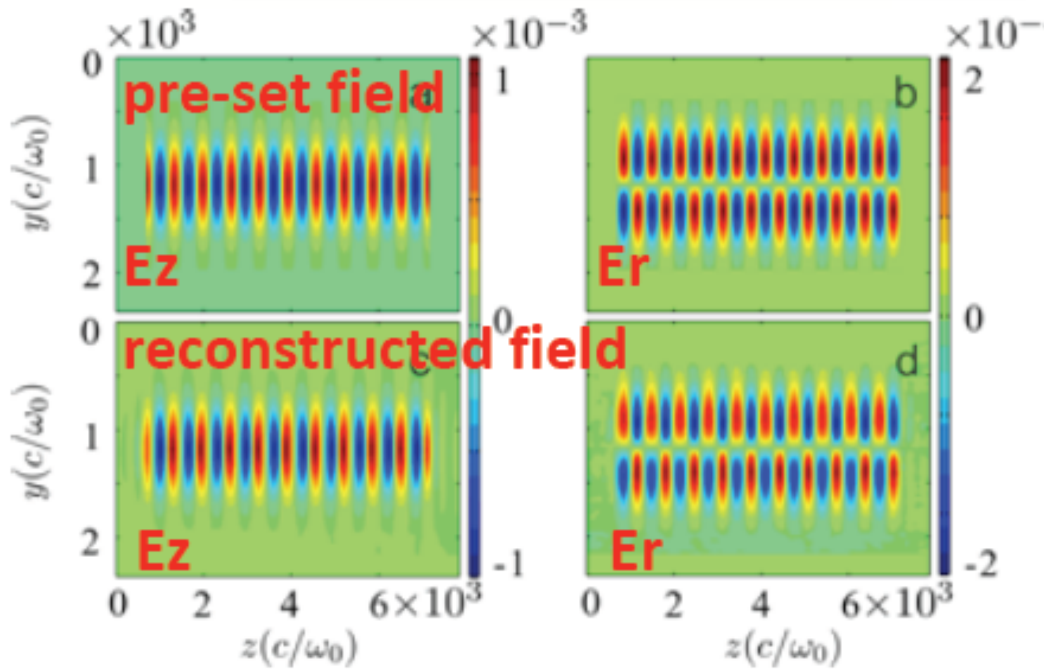
Injected Beam
230 pC, 27 kA,
B_n=3.8x10^{18} Arad^{-2}m^{-2}
ε_n= 120x120 nm

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

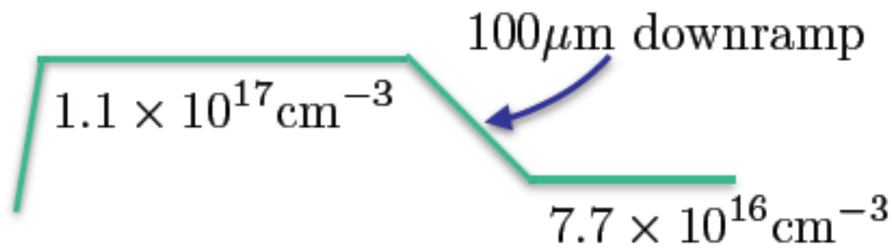
Snapshot of down-ramp injection

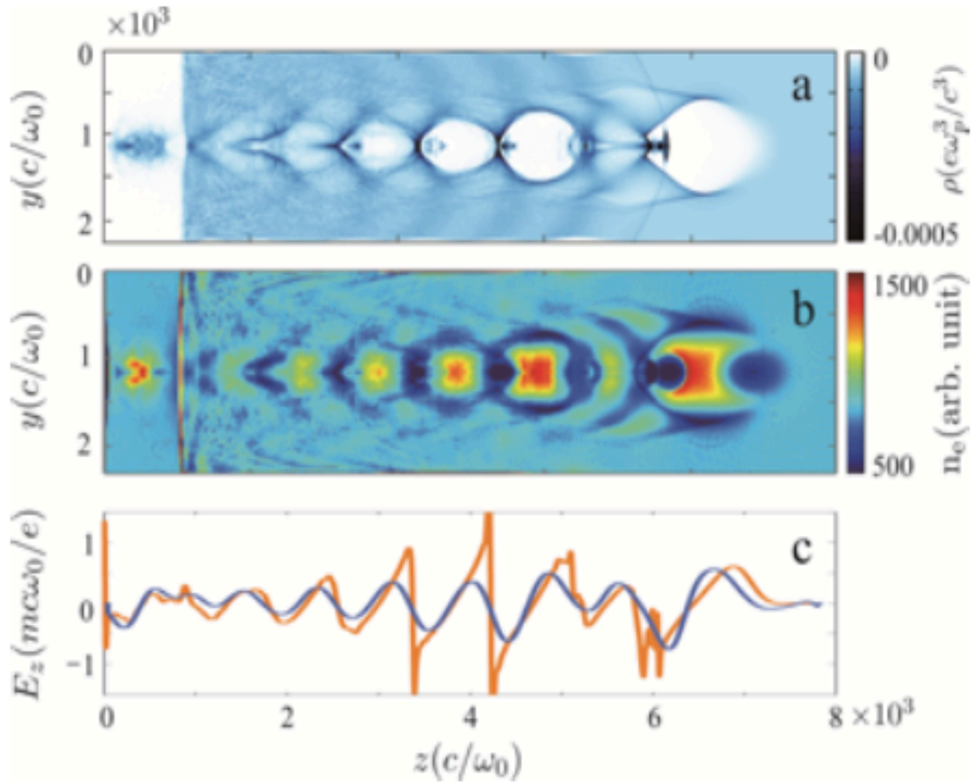
Variation of fields caused by plasma density down-ramp and injected bunch lead to extra momentum modulation of probe.

drive beam:
10 GeV, 1 nC, sigma_r = 15 um, sigma_z = 20 um;

Probe Parameters

Energy	***200 MeV***
Ene Spread	***20%***
Emittance	***3 mmmrad***
Duration	***35 fs***
Spot size	***1 mm***





Courtesy of Chaojie Zhang

2) Generation of Ultra-low Emittance Beams (ii)

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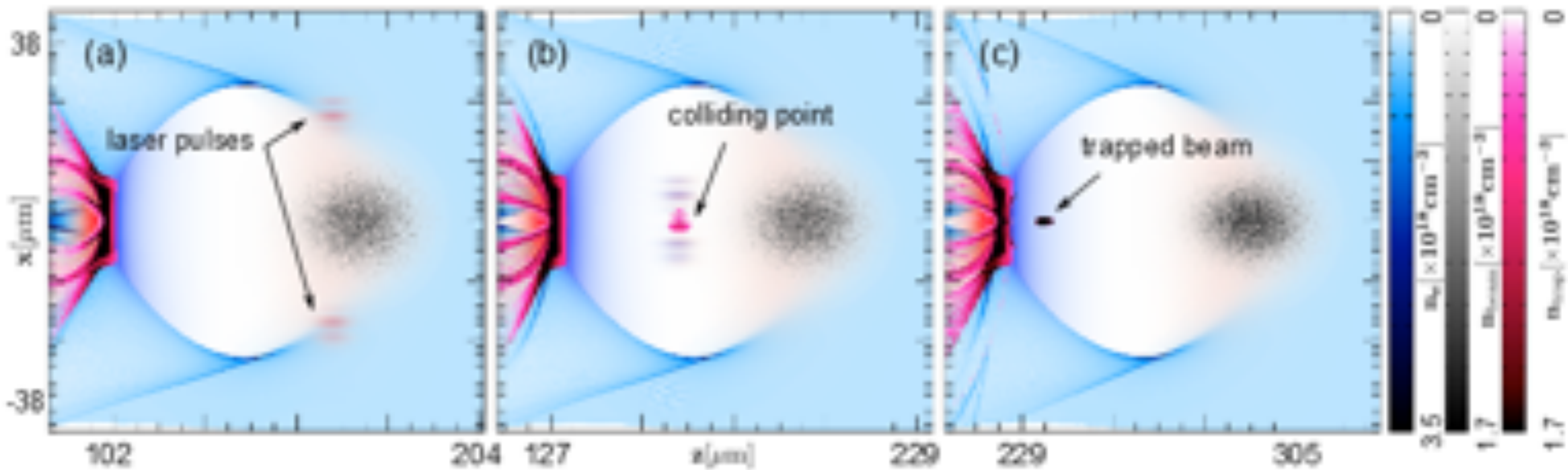
Colliding Beam Injection

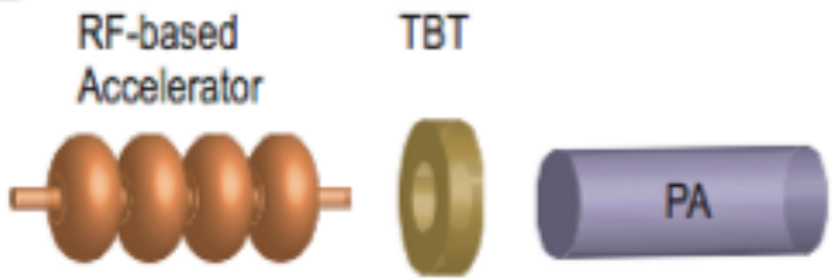


80 fs before | During | 200fs after collision

ε_n = 6nm seen in 3D PIC simulations: Two transversely colliding lasers overlap inside the wake such that the peak intensity just exceeds the ionization threshold

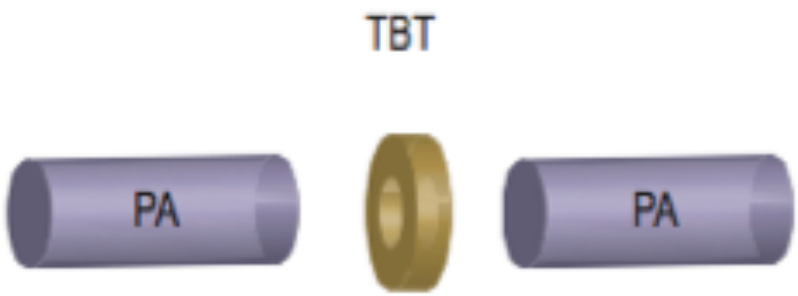
F. Li et al Phys Rev Letts 2013

3) Matching of two stages involving a Plasma Accelerator



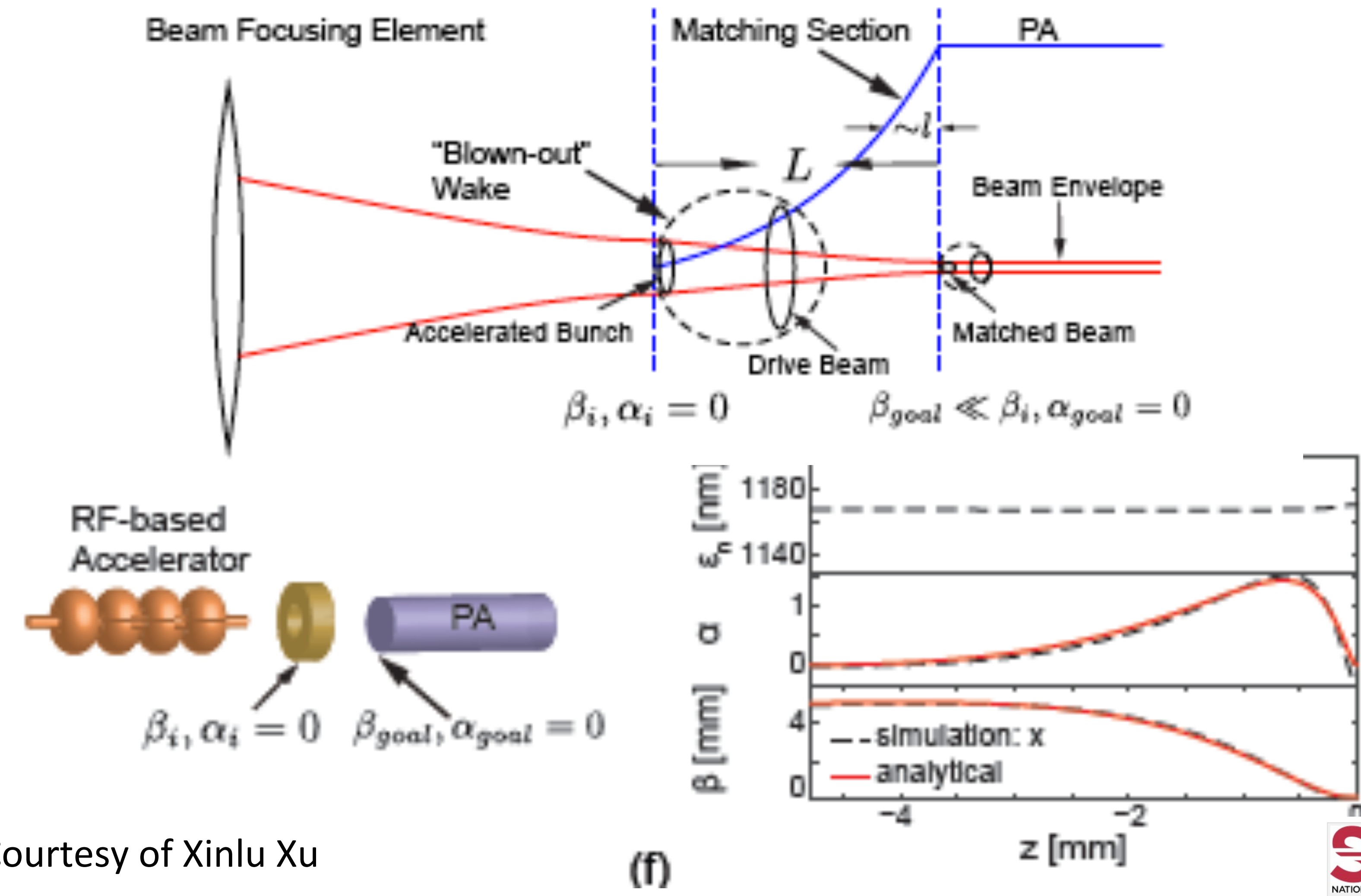
Injection of FACET photoinjector
Bunch into PWFA stage driven
By 10 GeV Bunch

Talk by Xinlu Xu



Matching of beam emnating
from one PA into another PA
Talk by Karl

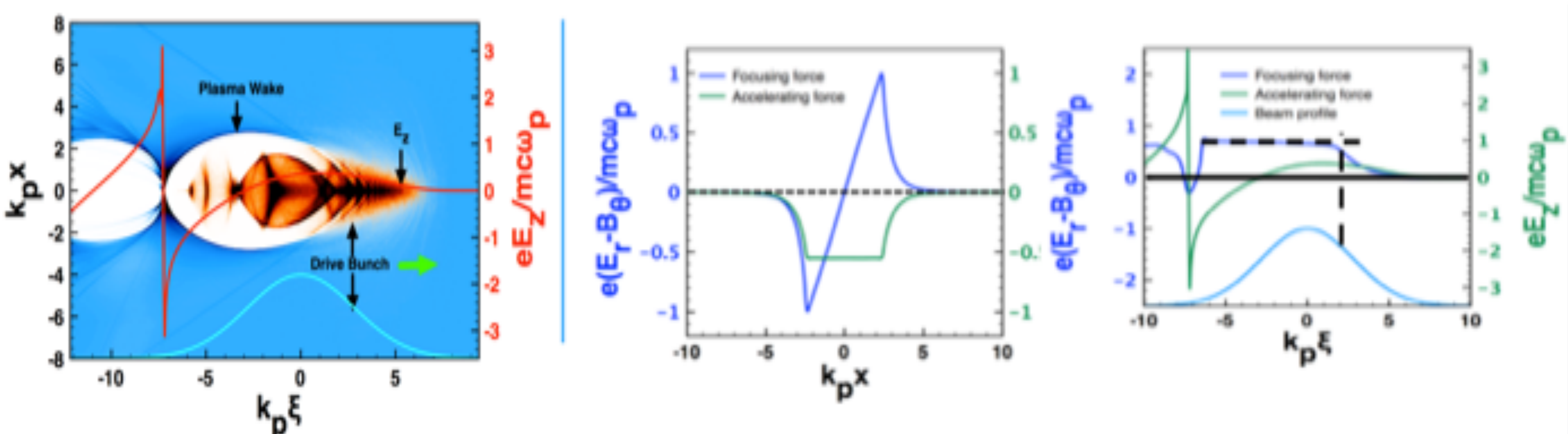
3) Matching of two stages involving a Plasma Accelerator Using Density Ramps: talk by Xinlu Xu



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 effect such as asymmetric beam shape or emittance affect emittance preservation of the beam load?

Considerable Success in mapping the Field Structure of the wake

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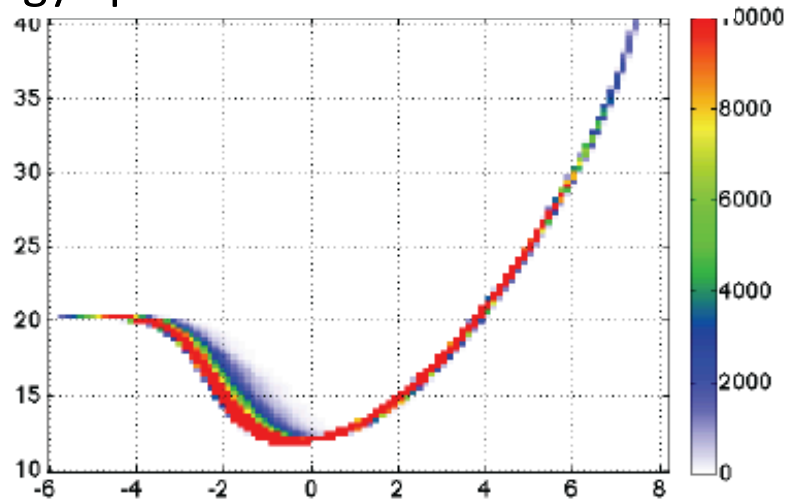
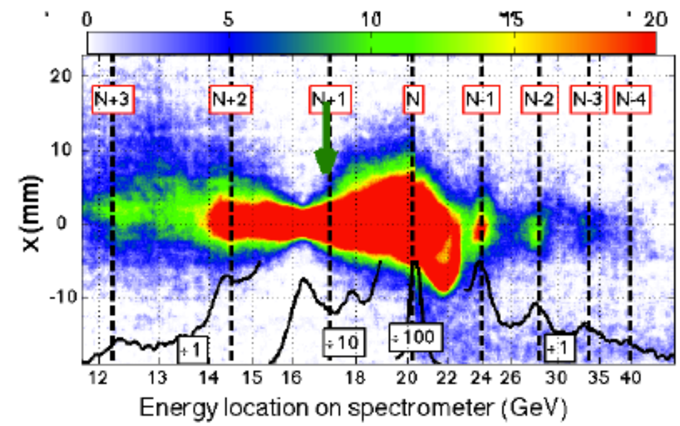
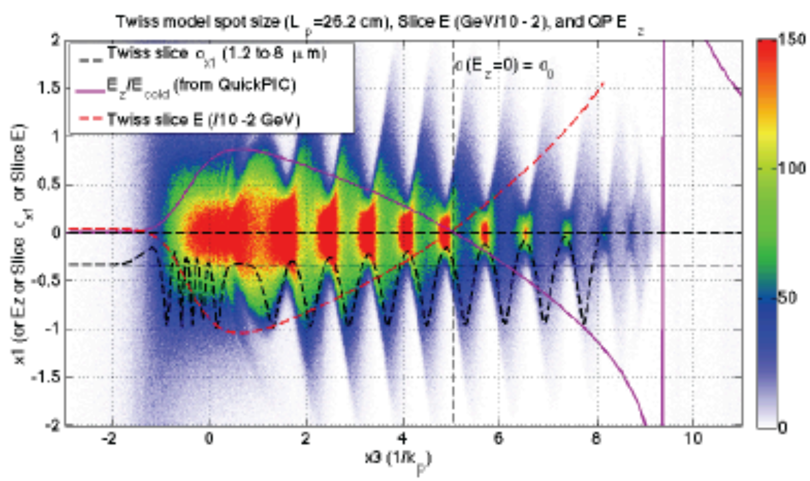
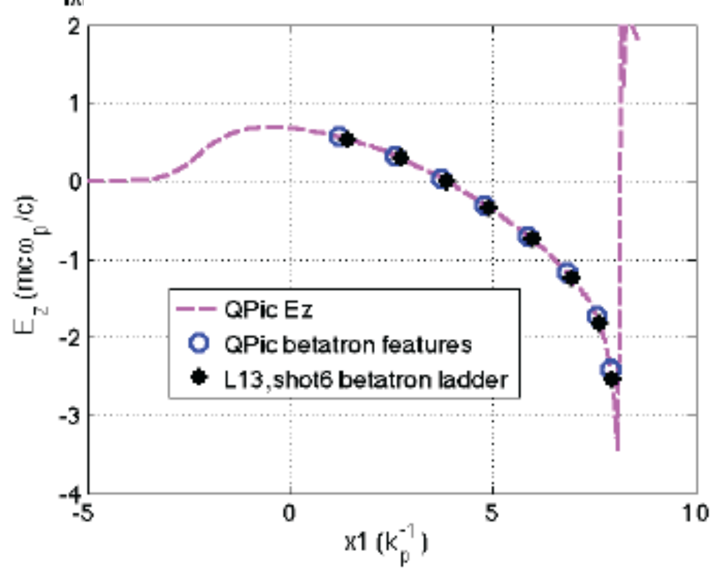
Energy Spectrum of the Drive Bunch







Comparison between Experiment And simulations



Snapshot of two-bunch experiment

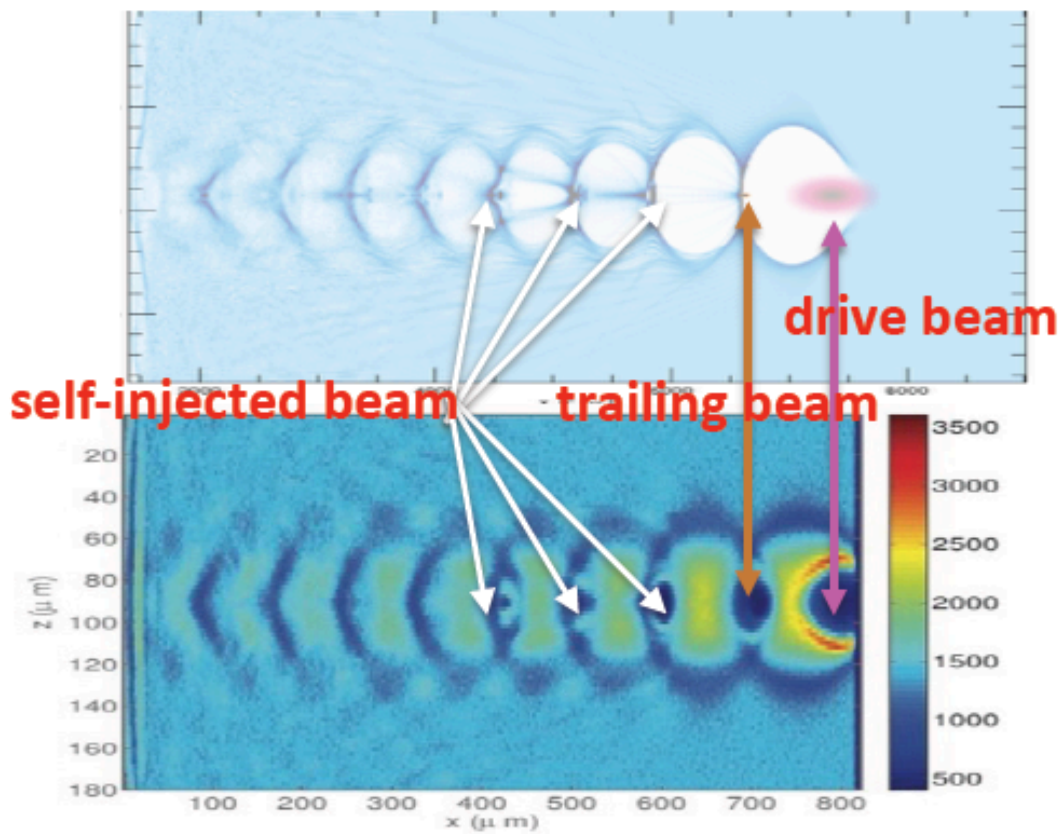
drive beam:
10 GeV, 4 nC
sigma_r = 5 um,
sigma_z = 20 um;

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

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

Probe Parameters

Energy	*200 MeV*
Ene Spread	*20%*
Emittance	*3 mmmrad*
Duration	*35 fs*
Spot size	*1 mm*



Courtesy of Chaojie Zhang

5) Staging Problem

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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.