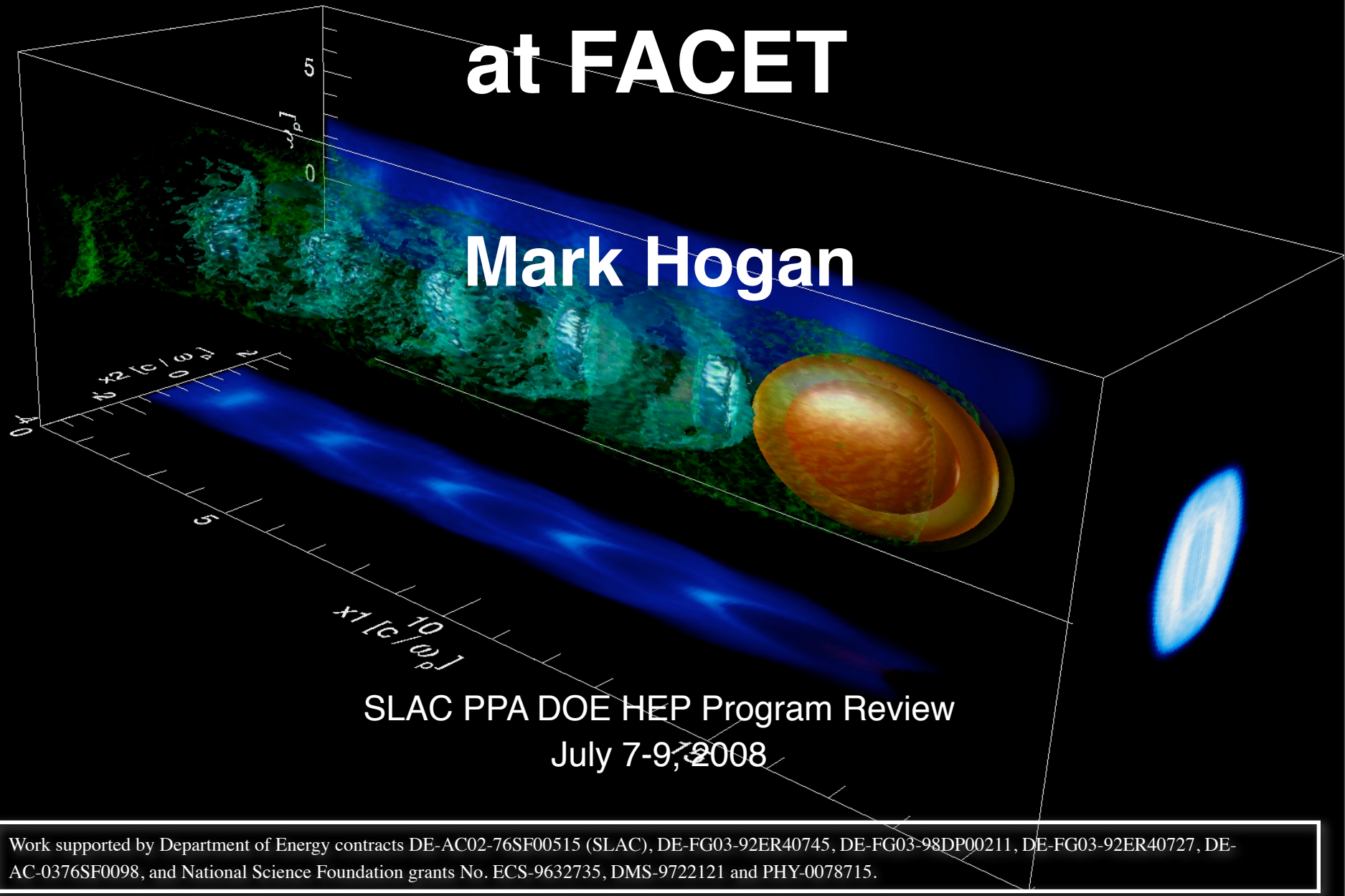
Plasma Acceleration Research at FACET

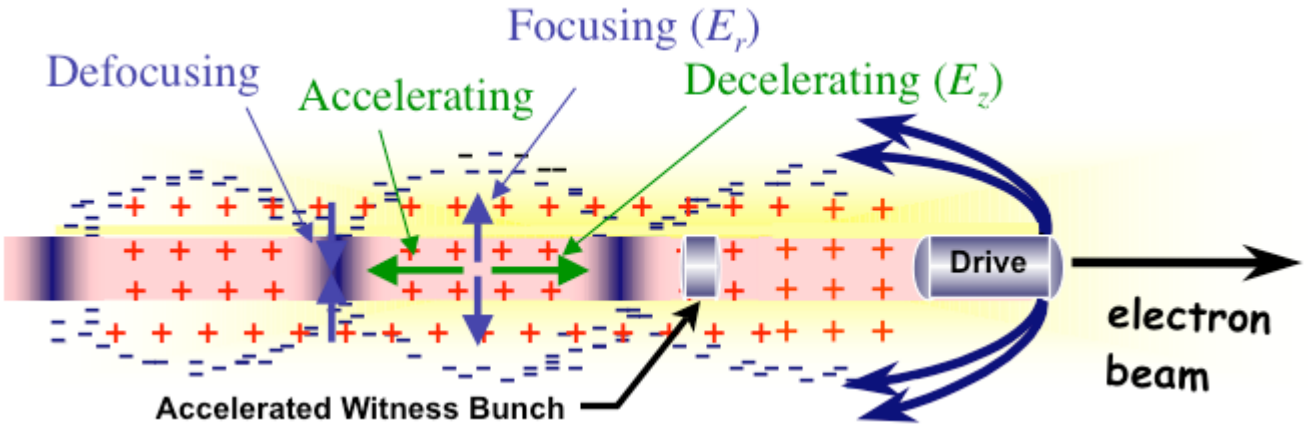


Mark Hogan

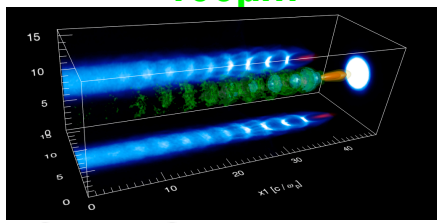
SLAC PPA DOE HEP Program Review
July 7-9, 2008

Work supported by Department of Energy contracts DE-AC02-76SF00515 (SLAC), DE-FG03-92ER40745, DE-FG03-98DP00211, DE-FG03-92ER40727, DE-AC-0376SF0098, and National Science Foundation grants No. ECS-9632735, DMS-9722121 and PHY-0078715.

The Beam Driven Plasma Wakefield Accelerator



~1m
~100μm

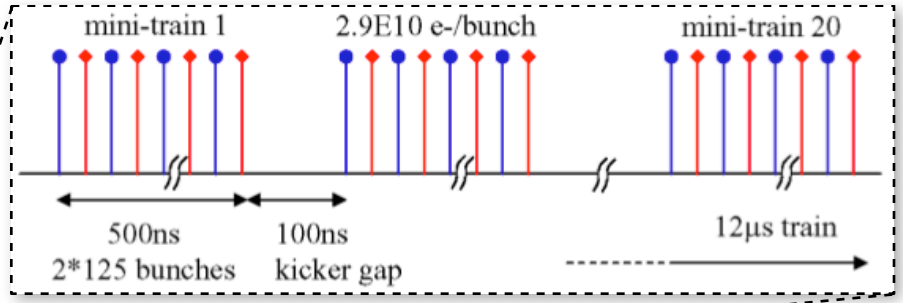


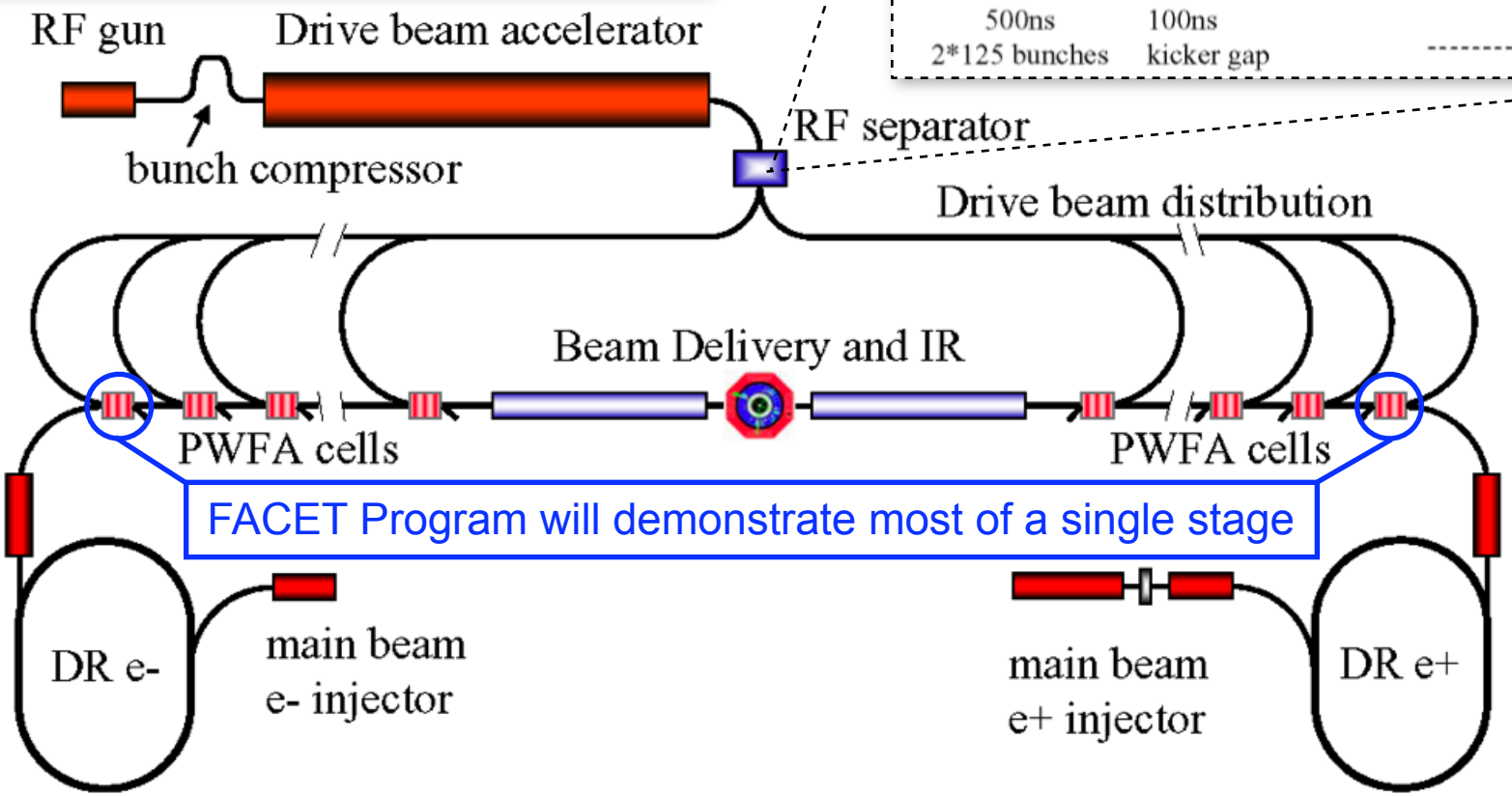
- Plasma wave/wake excited by a relativistic particle bunch
- Plasma e⁻ expelled by space charge forces => energy loss
  (ion channel formation $r_c \approx (n_b/n_e)^{1/2}\sigma_r$ + focusing (>MT/m)
- Plasma e⁻ rush back on axis => energy gain (>GeV/m)
- Linear scaling: $E_{acc} \cong 110(MeV/m)\dfrac{N/2\times10^{10}}{(\sigma_z/0.6mm)^2}$ $1/\sigma_z^2$

  @ $k_{pe}\sigma_z \approx \sqrt{2}$
- Plasma Wakefield Accelerator (PWFA) = Transformer

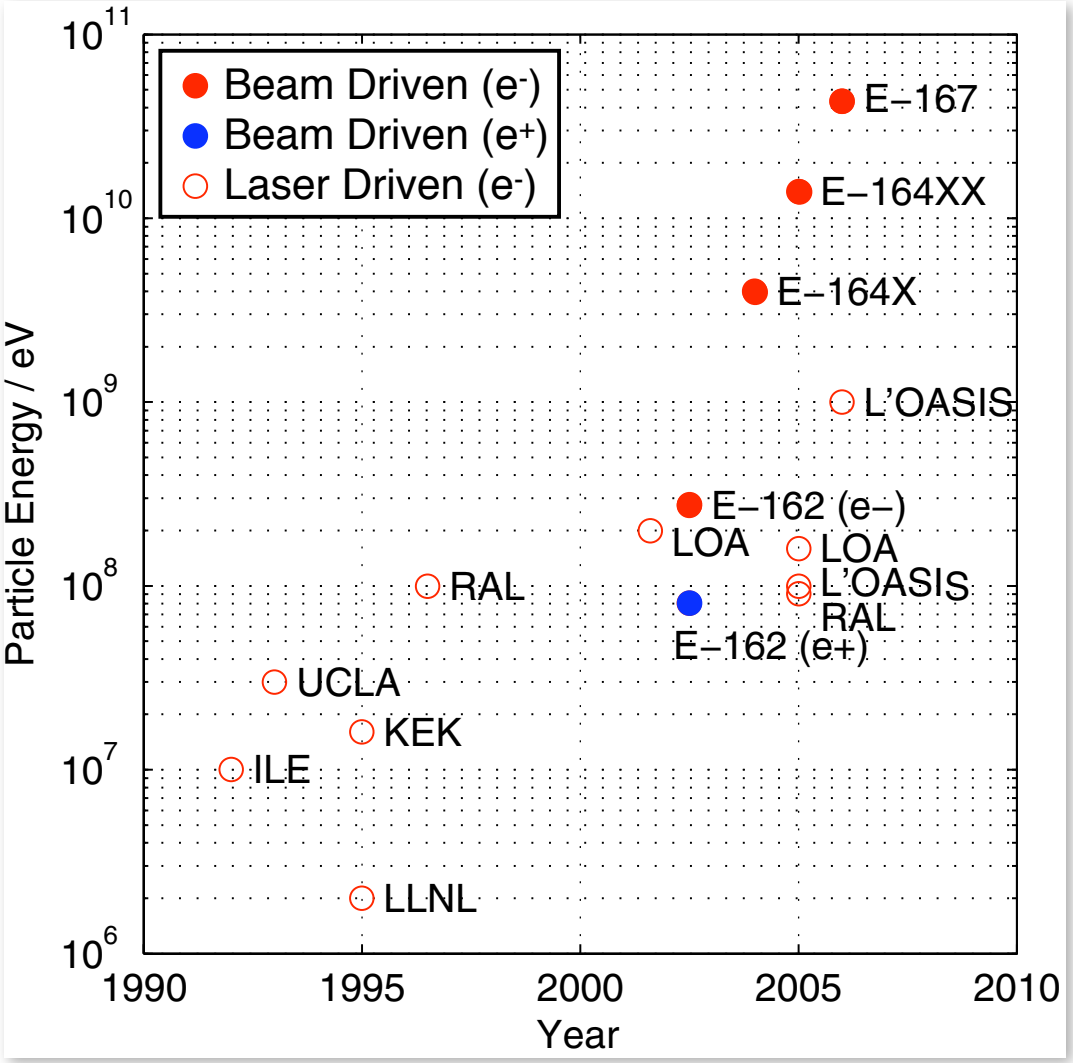
A Concept for a Plasma Wakefield Accelerator Based Linear Collider

- TeV CM Energy
- 10's MW Beam Power for Luminosity
- Positron Acceleration
- Conventional technology for particle generation & focusing





Plasma Acceleration has made tremendous progress in the last two decades



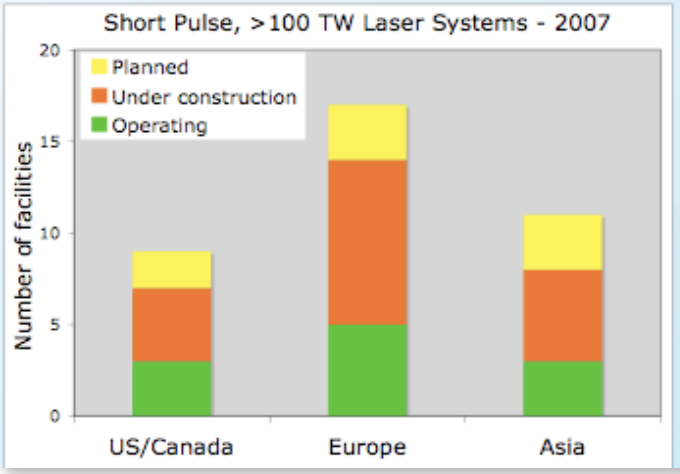
DOE HEP Office Of Science Issued CD-0 for Advanced Plasma Acceleration Facility February 2008

Progress has been enabled by facilities – Many lasers, but only one SLAC...

High power lasers for AA R&D

USA

BNL & UCLA: CO_2, 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

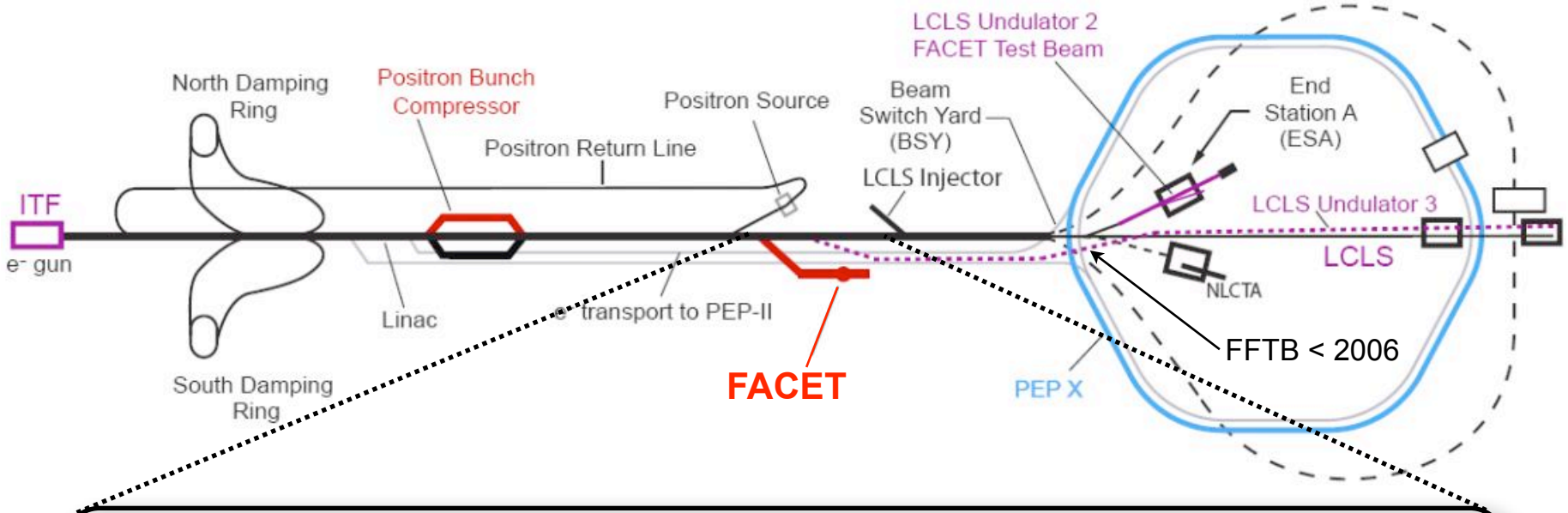
ALLS: 200 TW @ 10 Hz – commercial

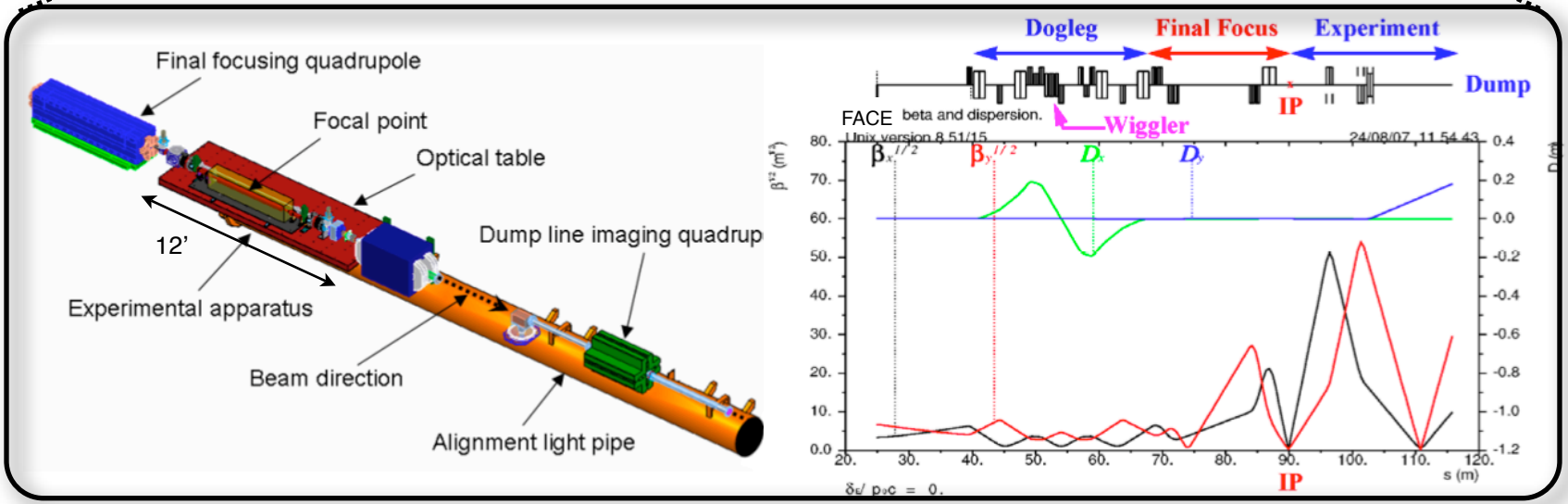
Europe

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

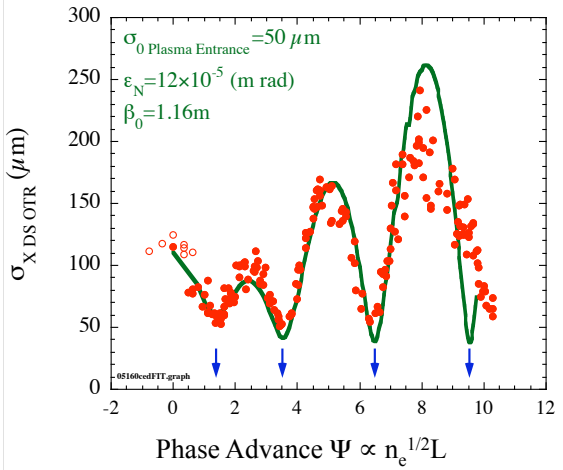
FACET is a new facility to provide high-energy, high peak current e^- & e^+ beams for PWFA experiments





FACET program builds on FFTB work
Studied all aspects of beam-plasma interaction

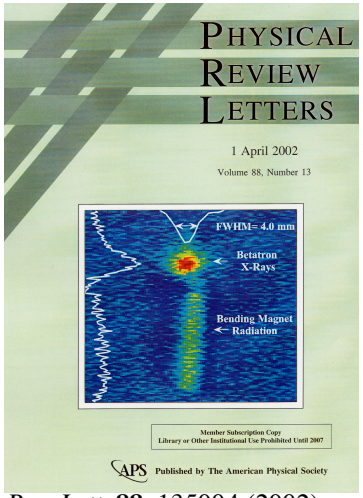
Focusing e-



Phase Advance $\Psi \propto n_e^{1/2}L$

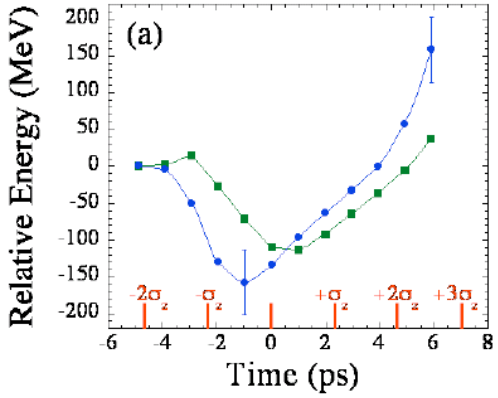
Phys. Rev. Lett. **88**, 154801 (2002)

X-ray Generation



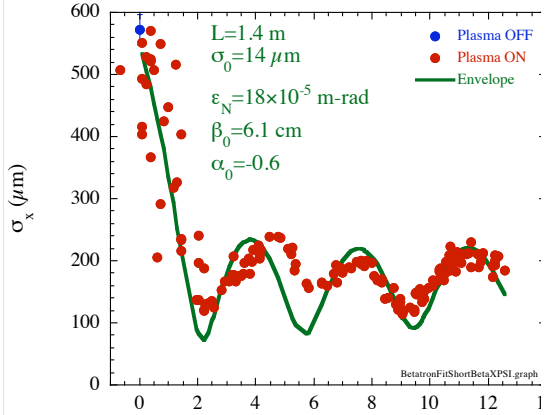
Phys. Rev. Lett. **88**, 135004 (2002)

Wakefield Acceleration e-



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

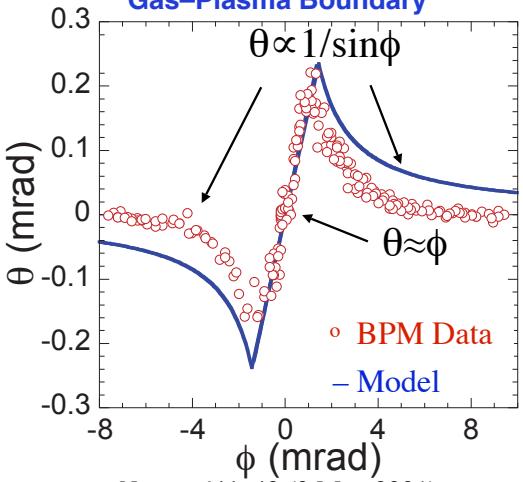
Matching e-



Phase Advance $\Psi \propto n_e^{1/2}L$

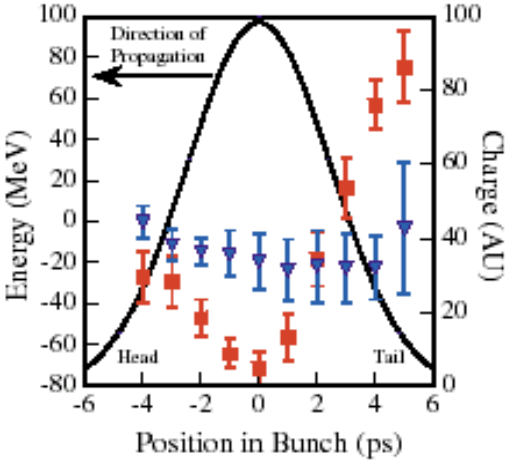
Phys. Rev. Lett. **93**, 014802 (2004)

Electron Beam Refraction at the Gas–Plasma Boundary



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

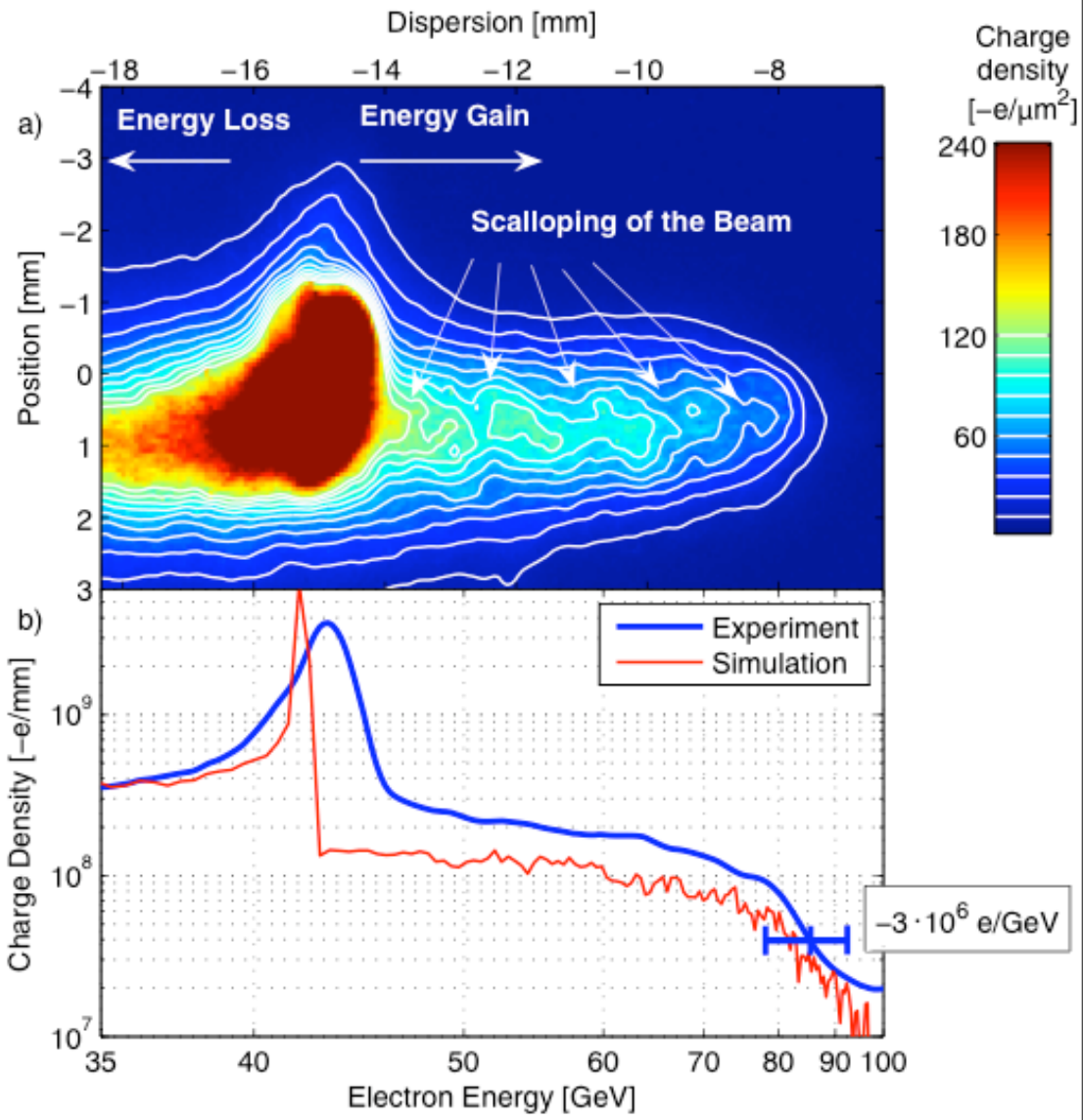
Wakefield Acceleration e+



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

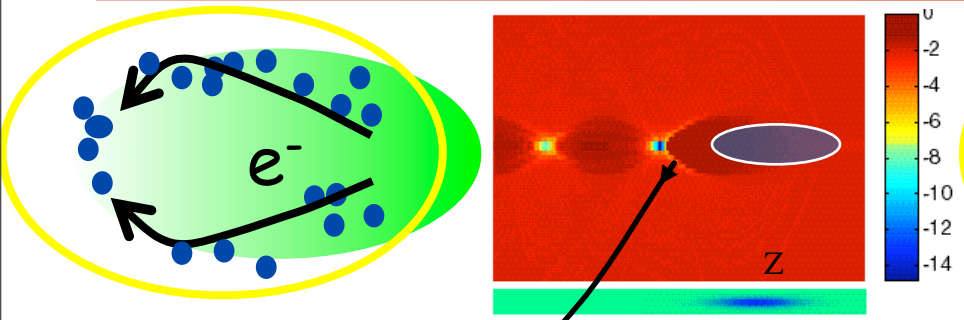
E-167: Energy Doubling with a Plasma Wakefield Accelerator in the FFTB (April 2006)

* 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



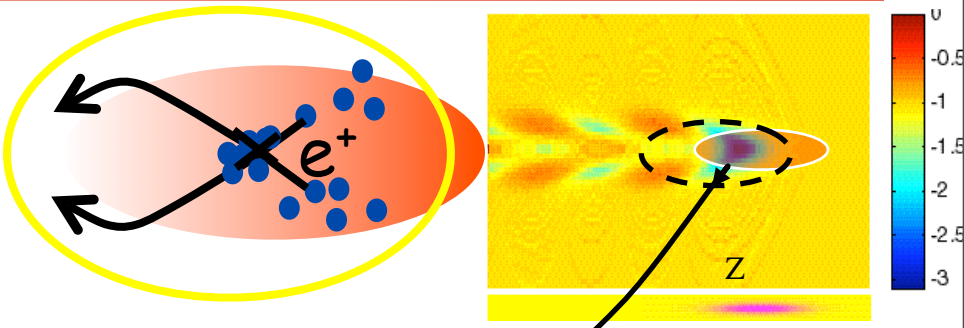
Nature 445 741 15-Feb-2007

PWFA Mechanism is Different for a Positron Beam



Blow-out

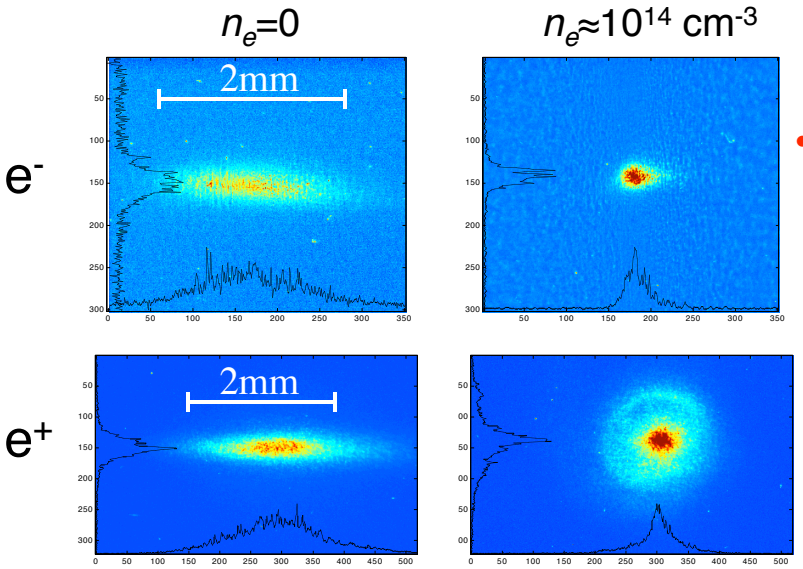
electron



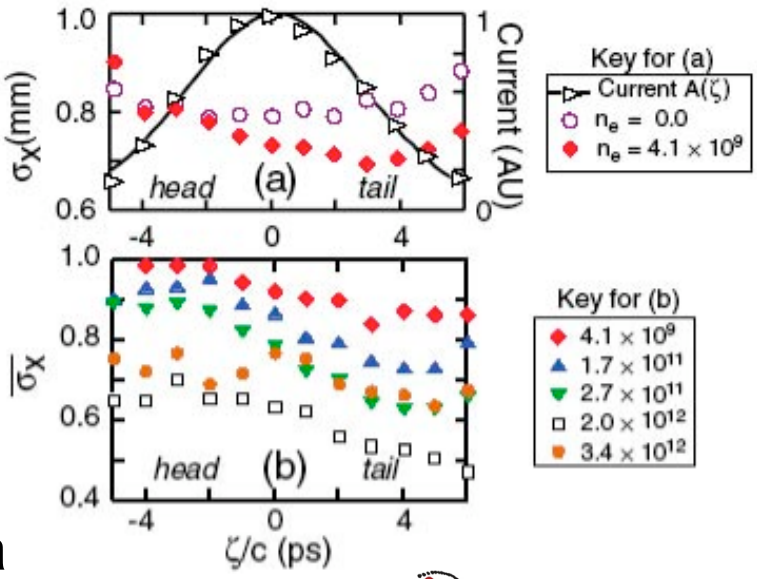
Flow-in

positron

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)

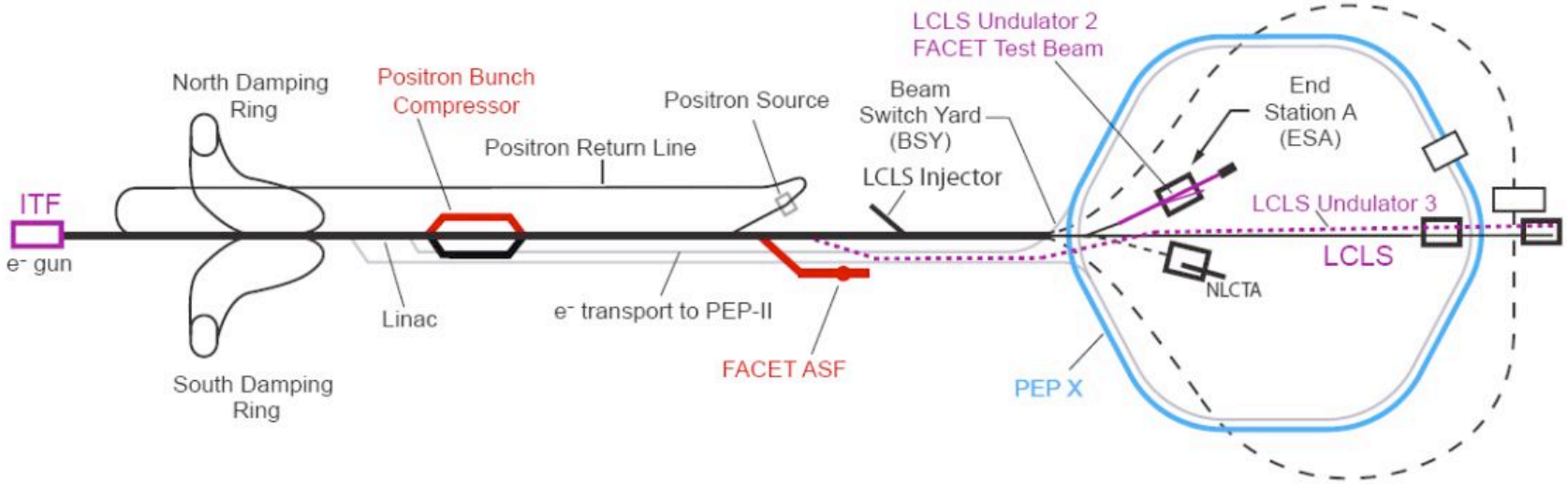
* Strong educational component:
  - 3 MS (UCLA)
  - 13 PhD: USC (3), UCLA (6), Stanford (4)

* FACET will be similar

FACET Facility Provides New Capabilities to Build On Research Started in the FFTB

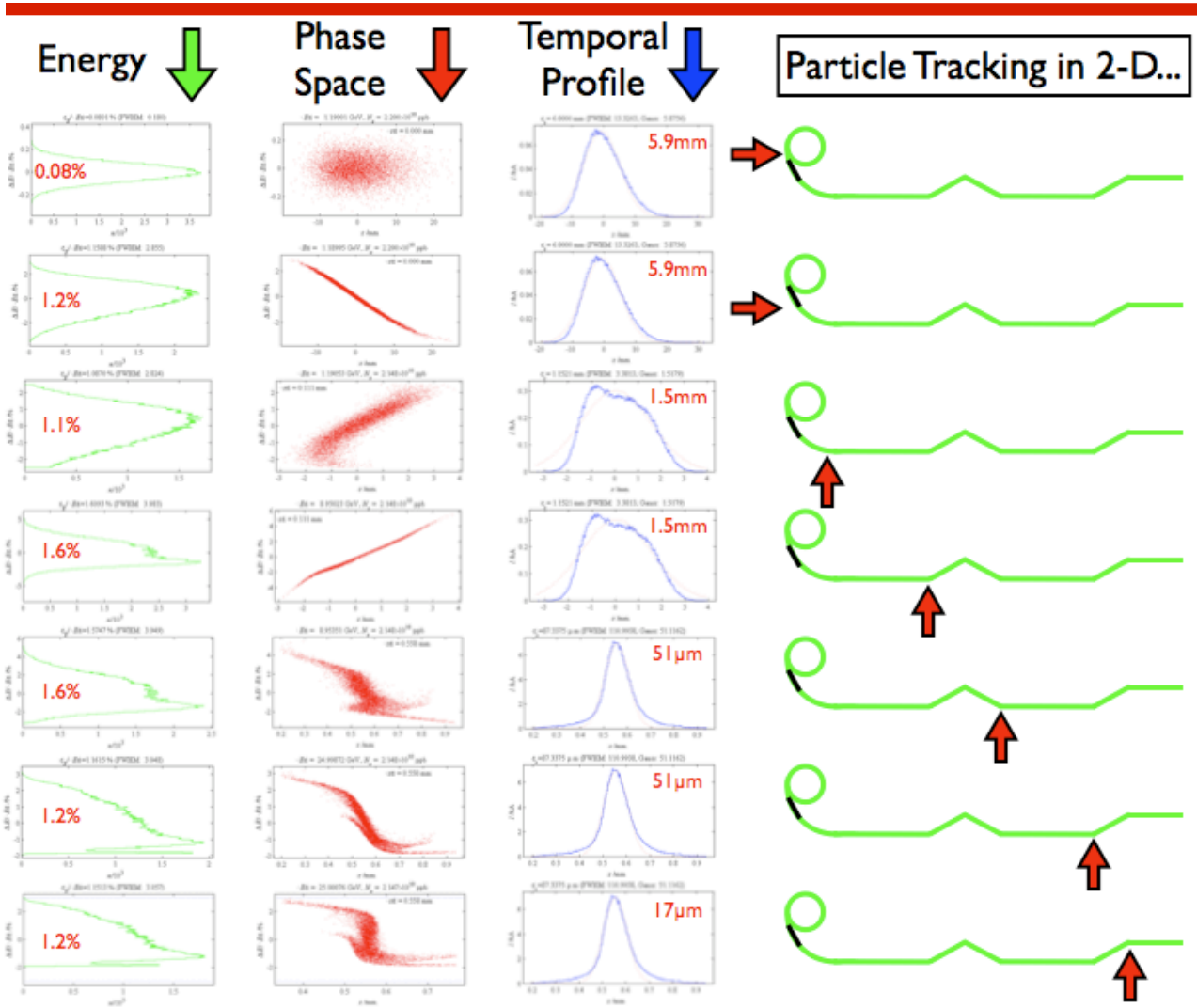
The PWFA-LC concept illustrates the key questions that must be answered:

* 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.



Plasma Acceleration Research Program at FACET will focus on the first three

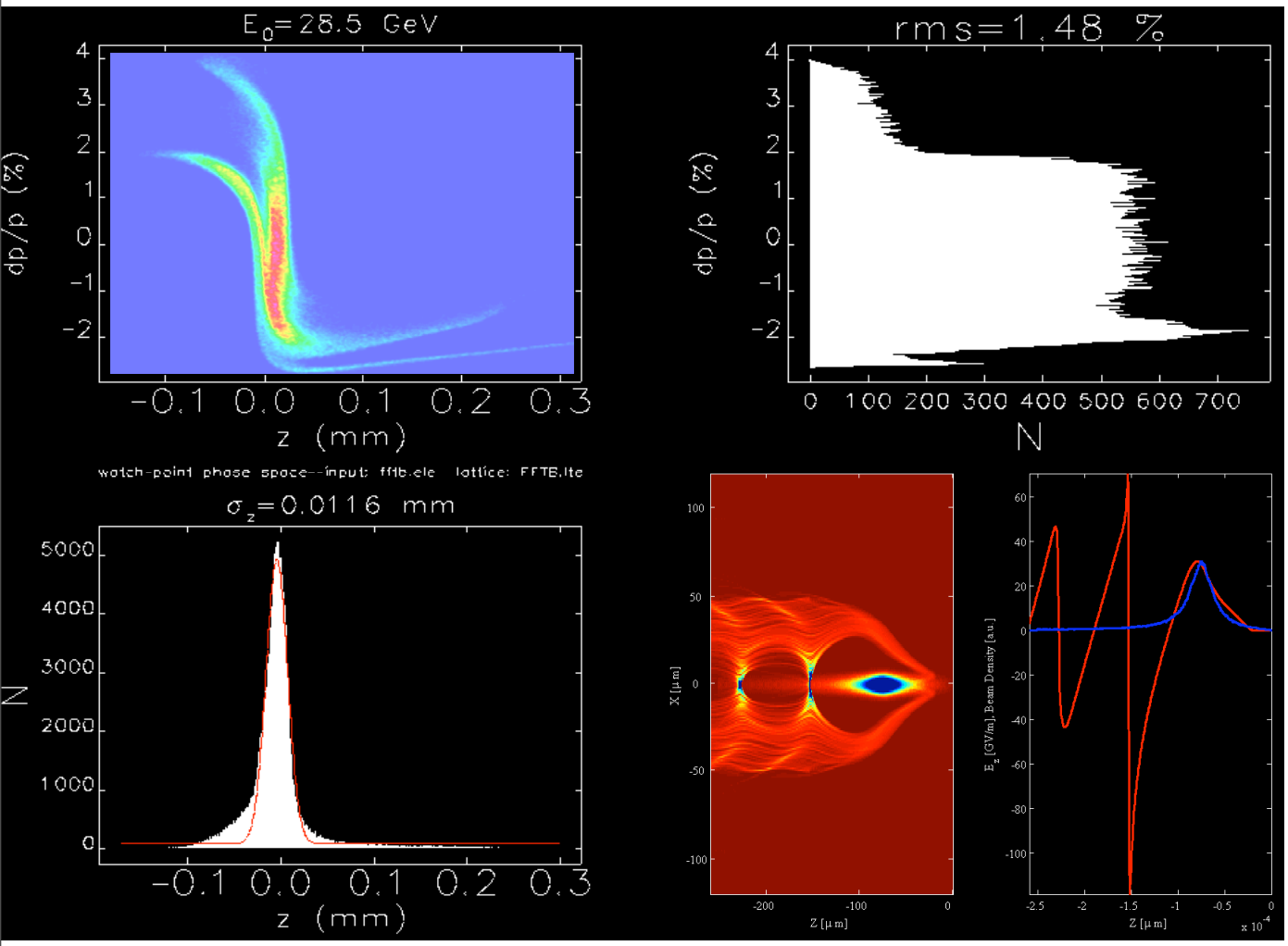
FACET Beam Properties Are Unique In The World

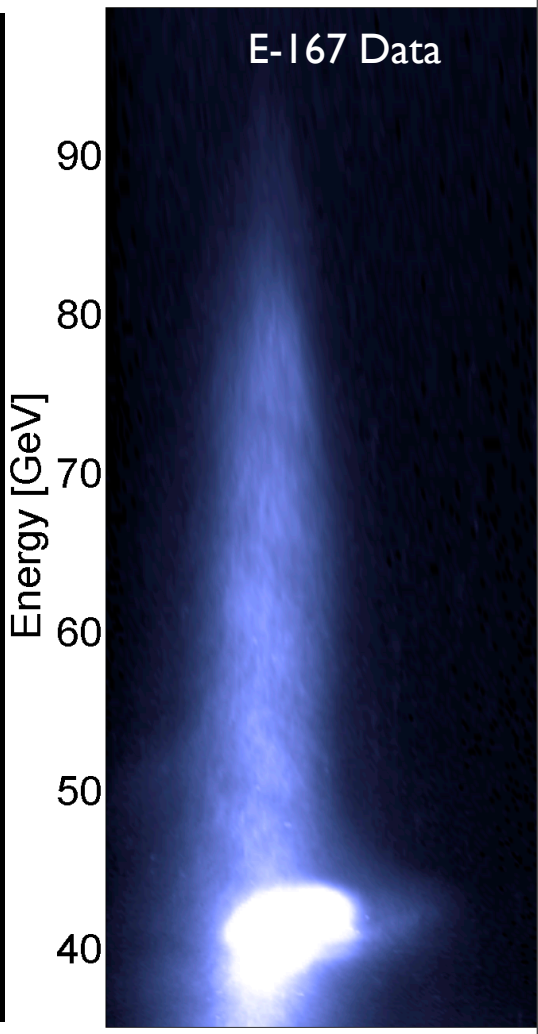


Energy	24 GeV
Charge	3 nC
Sigma z	17 μm
Sigma r	< 10 μm
Peak Current	22 kAmps
Species	e^- & e^+

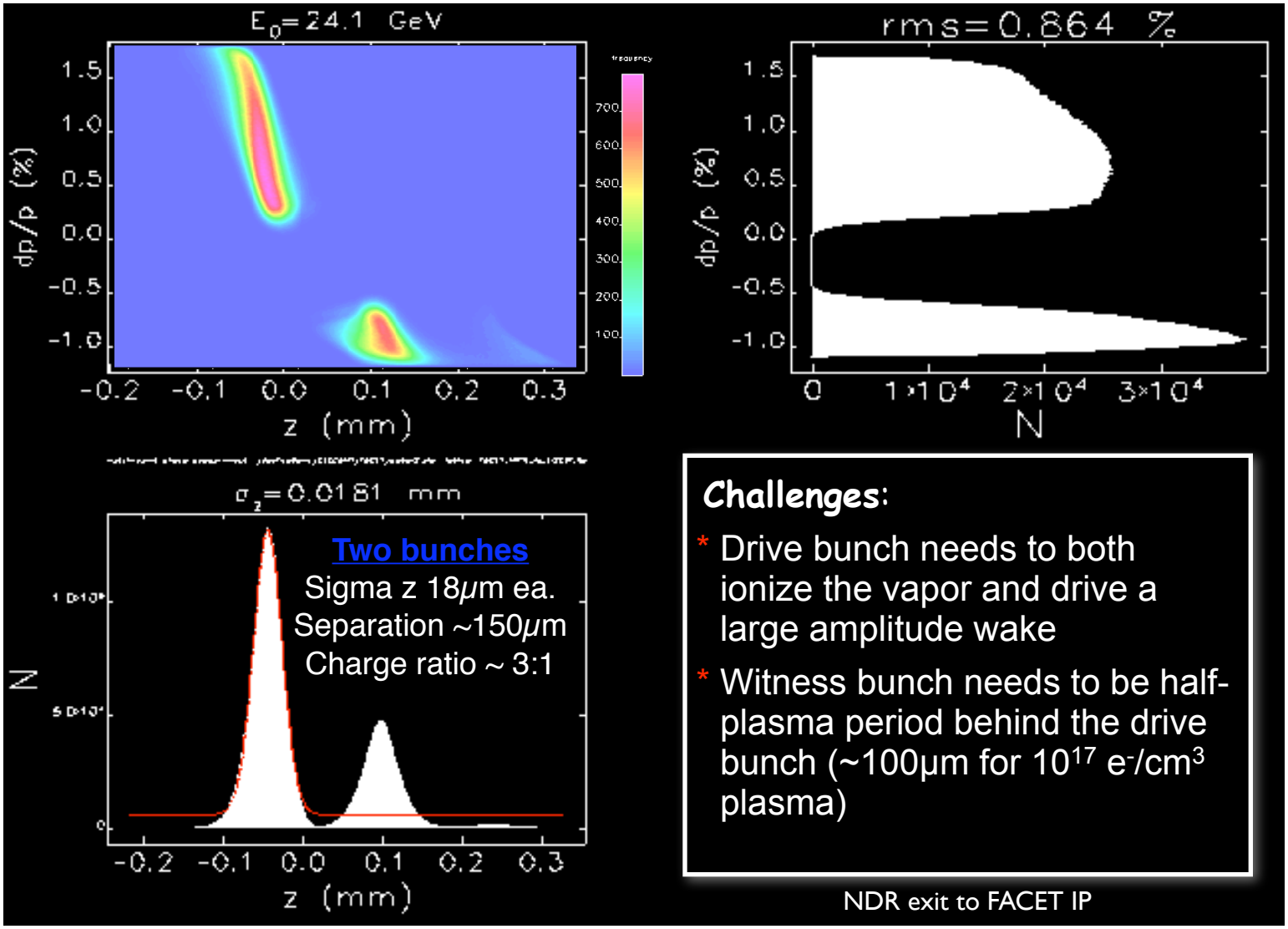
Very similar to FFTB/SPPS operation

Single FFTB Bunch Sampled All Phases of the Wake Resulting in ~ 200% Energy Spread

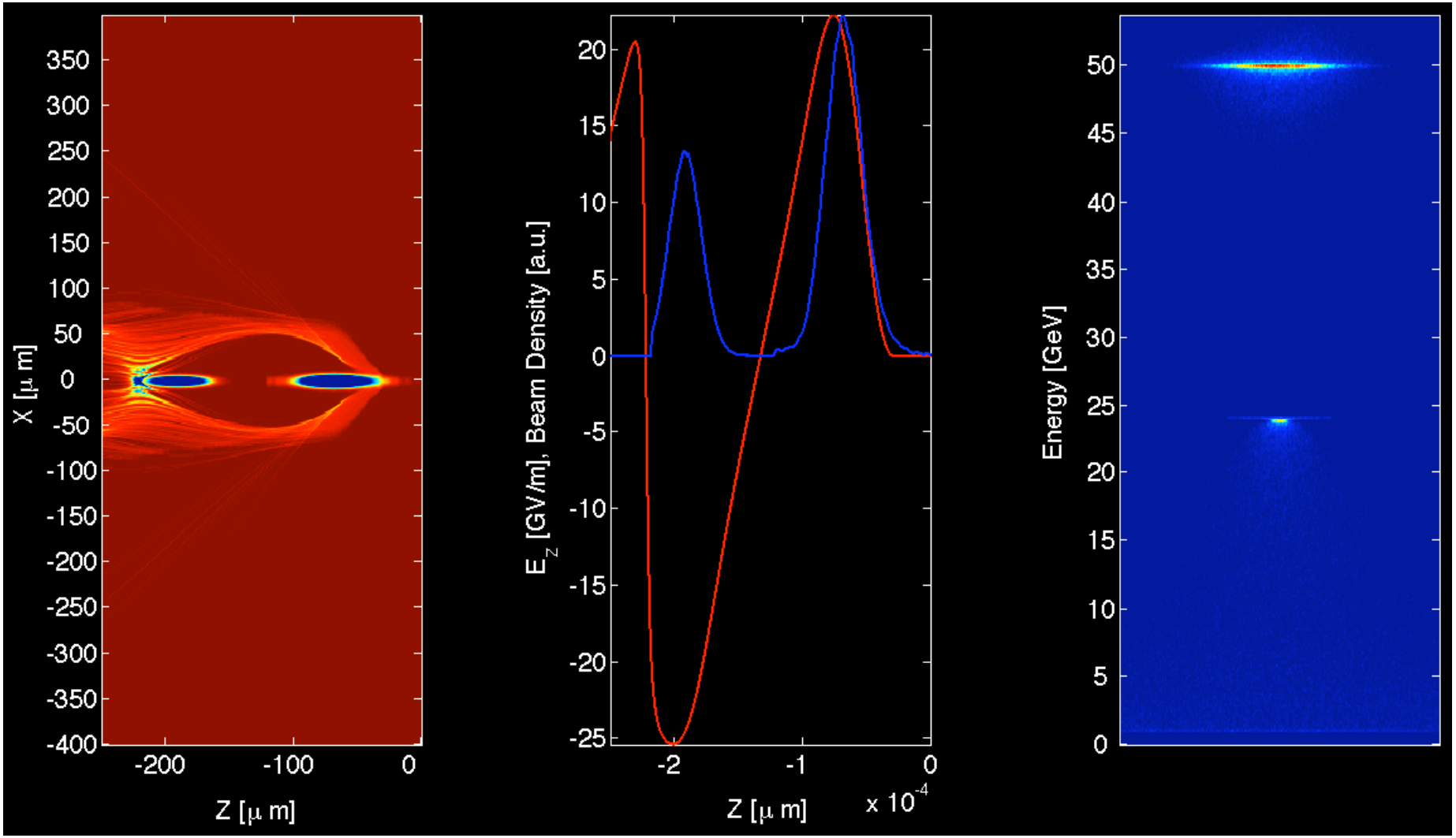




Use a combination of 6D particle tracking in ELEGANT combined with EGS4 to simulate the collimator(s)

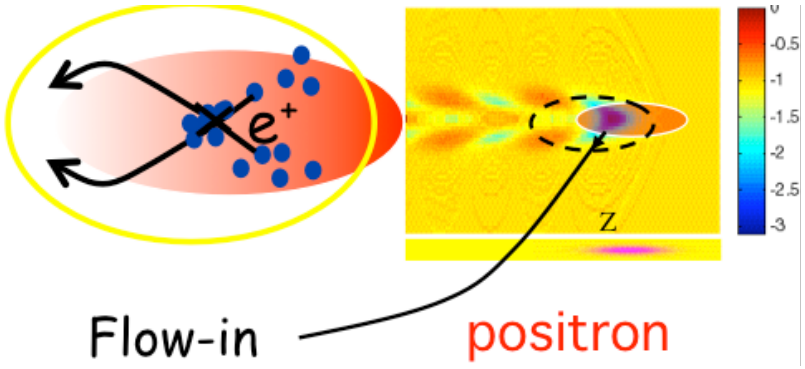


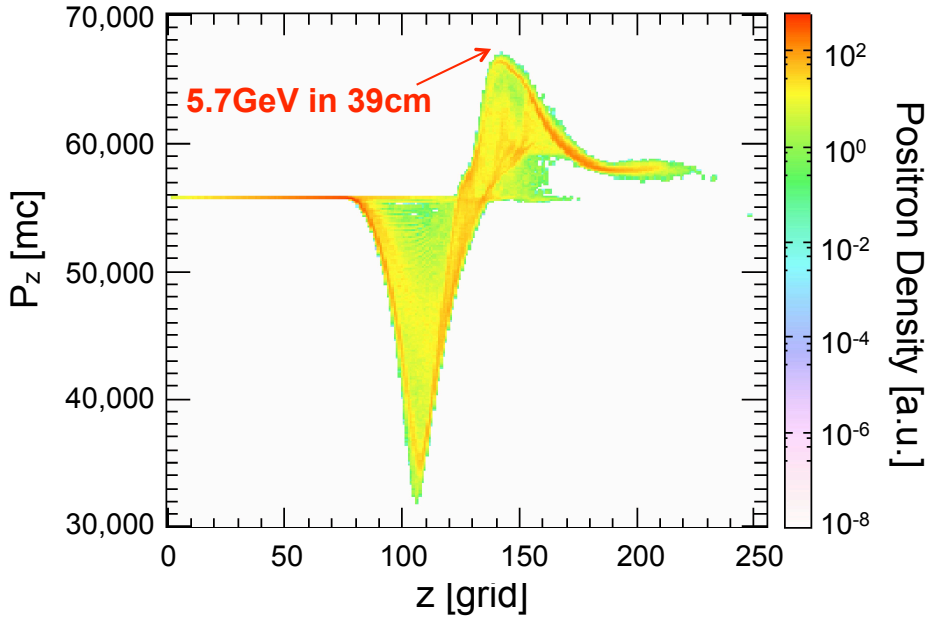
FACET Experiments will accelerate a discrete bunch of particles with narrow energy spread



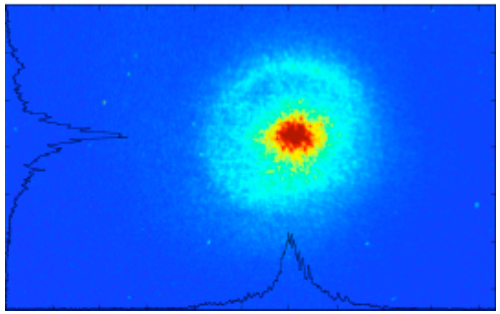
High Gradient Positron Acceleration

* 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:

STI OPTRONICS

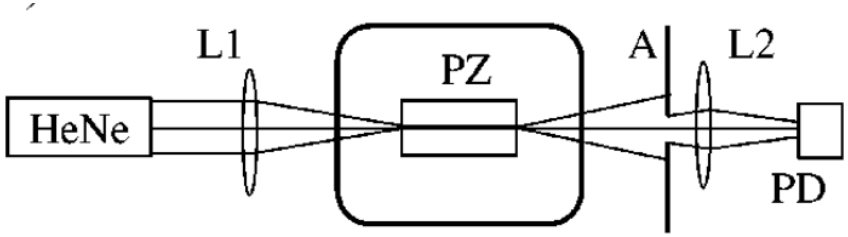
HOLLOW PLASMA CHANNELS FOR POSITRON PLASMA WAKEFIELD ACCELERATION

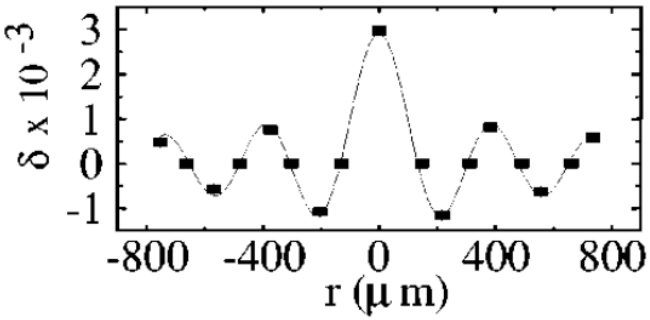
STI Optronics, Inc.
2755 Northup Way
Bellevue, Washington 98004-1495

Principal Investigator: Dr. Wayne D. Kimura

Guiding characteristics of an acoustic standing wave in a piezoelectric tube

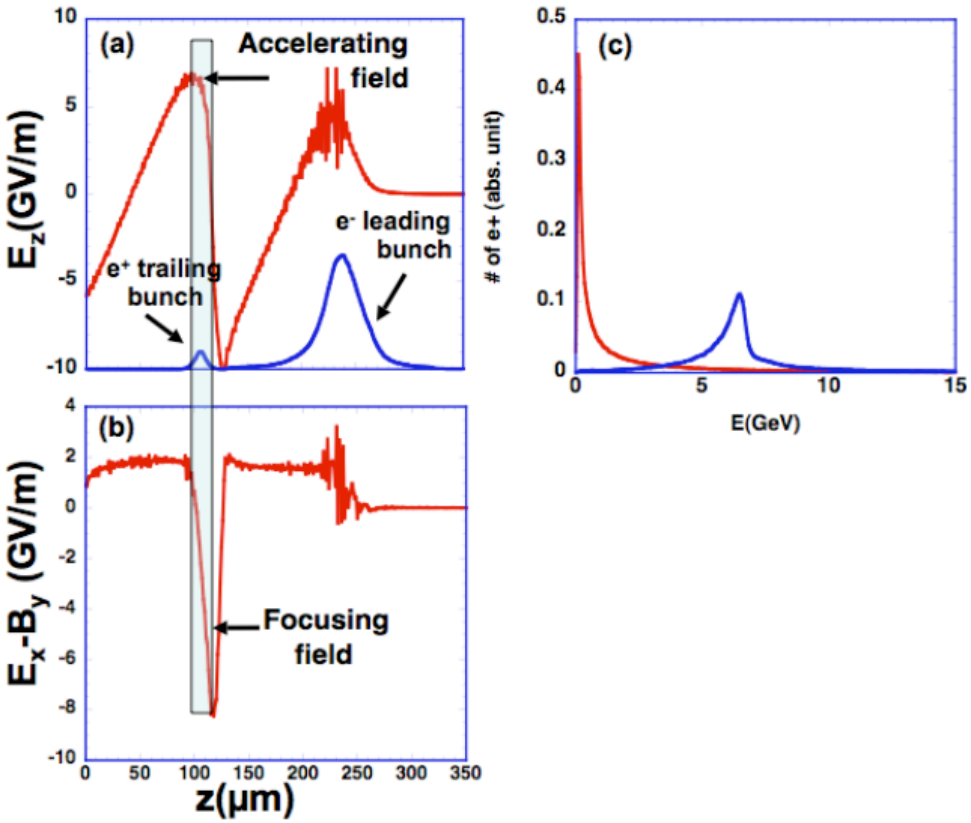
C. M. Fauser, E. W. Gaul, S. P. Le Blanc, and M. C. Downer[a)]
University of Texas at Austin, Department of Physics, Austin, Texas 78712

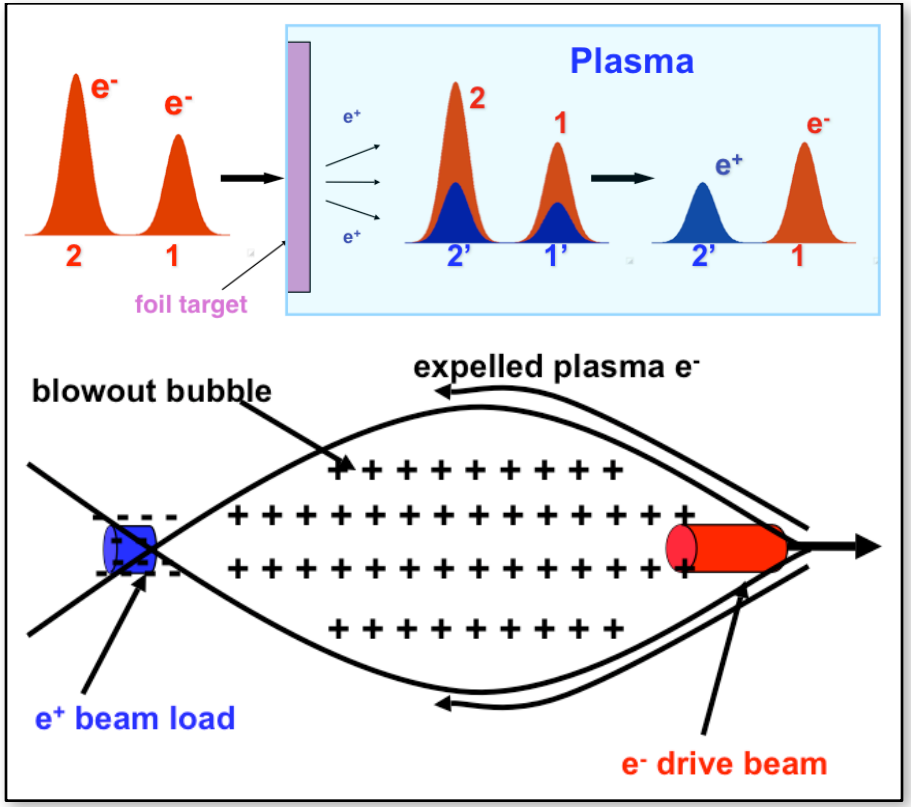




Appl. Phys. Lett., Vol. 73, No. 20, 16 November 1998

Positron Acceleration in Electron Beam Driven Wakes is possible in the weakly non-linear regime



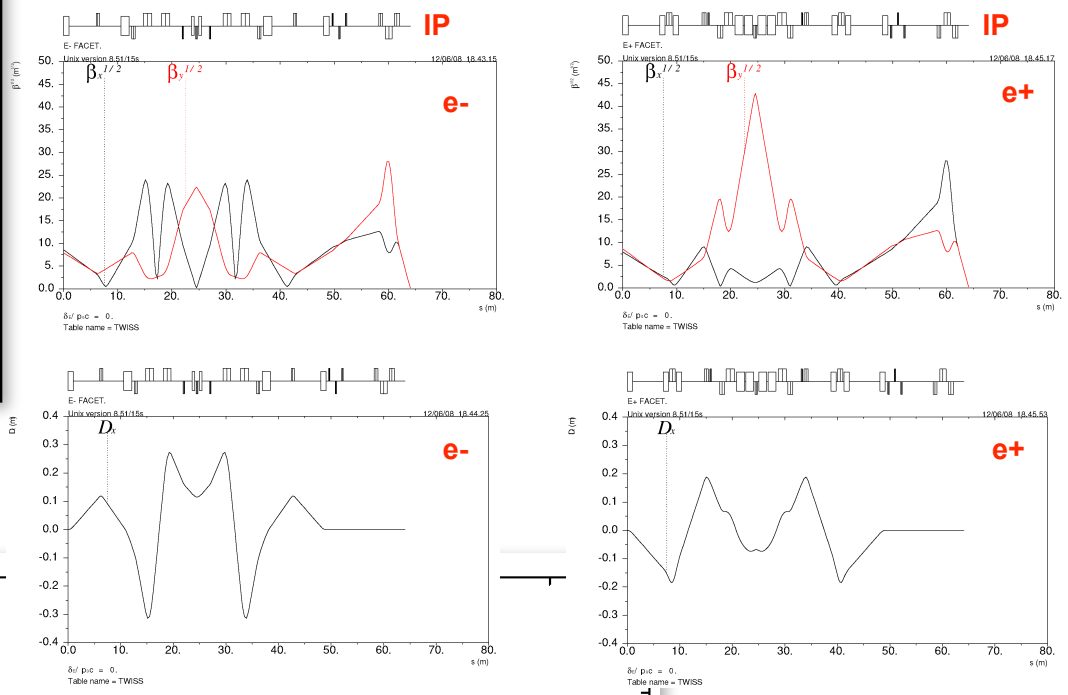


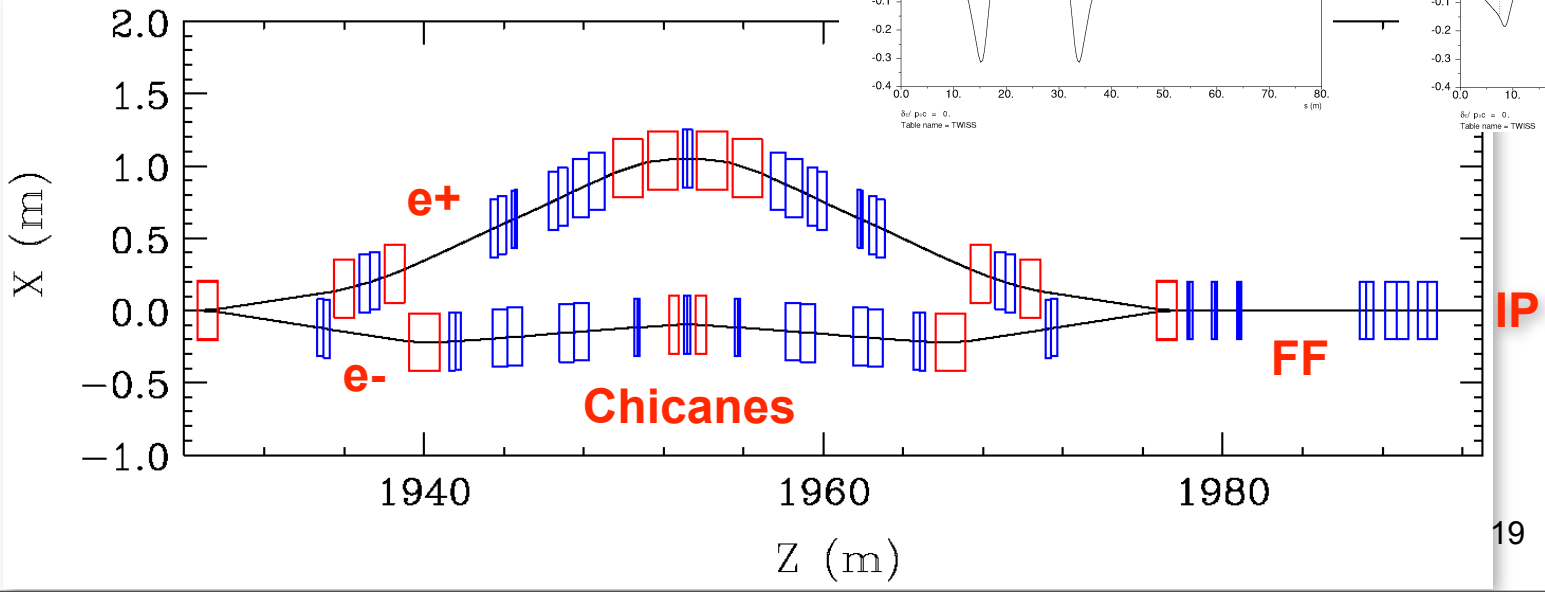
Generating closely-spaced mixed-species bunches is simplified by creating the positrons in the plasma

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 100μm at entrance to plasma

Beta functions and dispersion in chicanes and FF



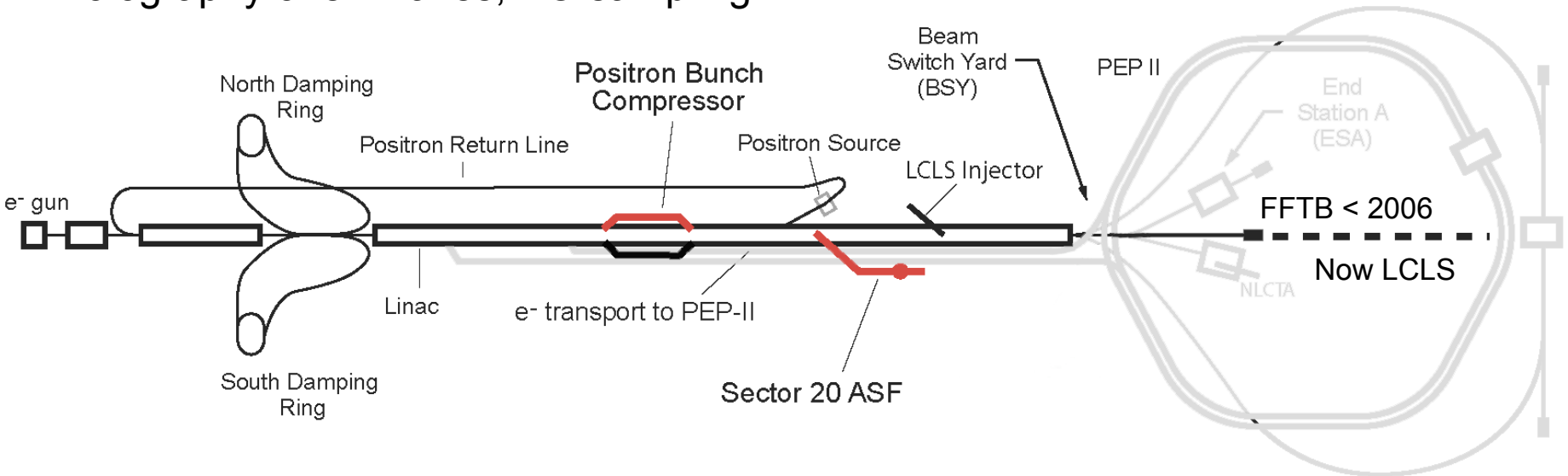


PPA Particle Physics & Astrophysics

Future upgrades will be guided by results

Possibilities:

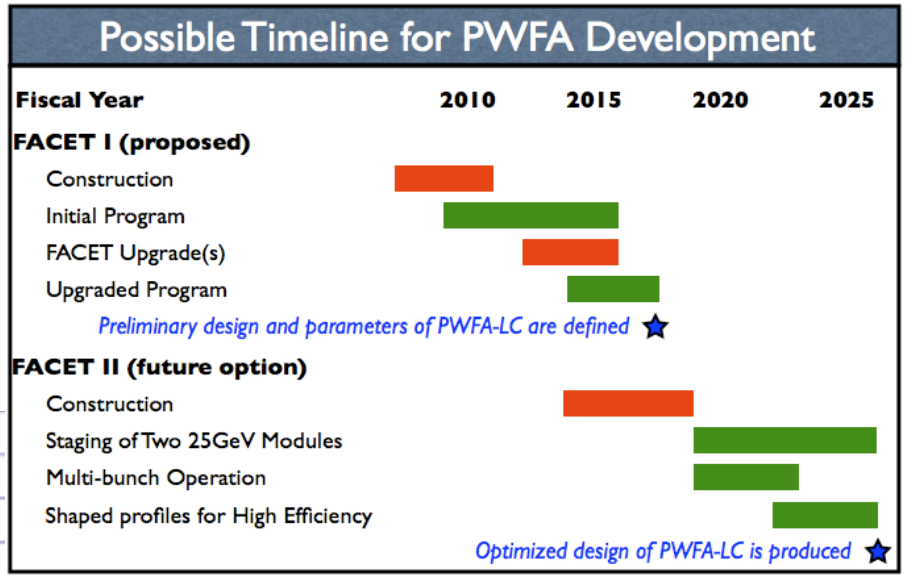
- Sailboat Chicane
  - Positron acceleration in electron wakes with 'real beam' of positrons
- Lower damping ring energy
  - Better compression, higher peak current
- Enhanced LCLS style photoinjector
  - Multiple bunches, bunch trains, shaped pulses with added flexibility
- NLC/ILC style FF
  - Sub-micron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



Experimental timeline for FACET Program

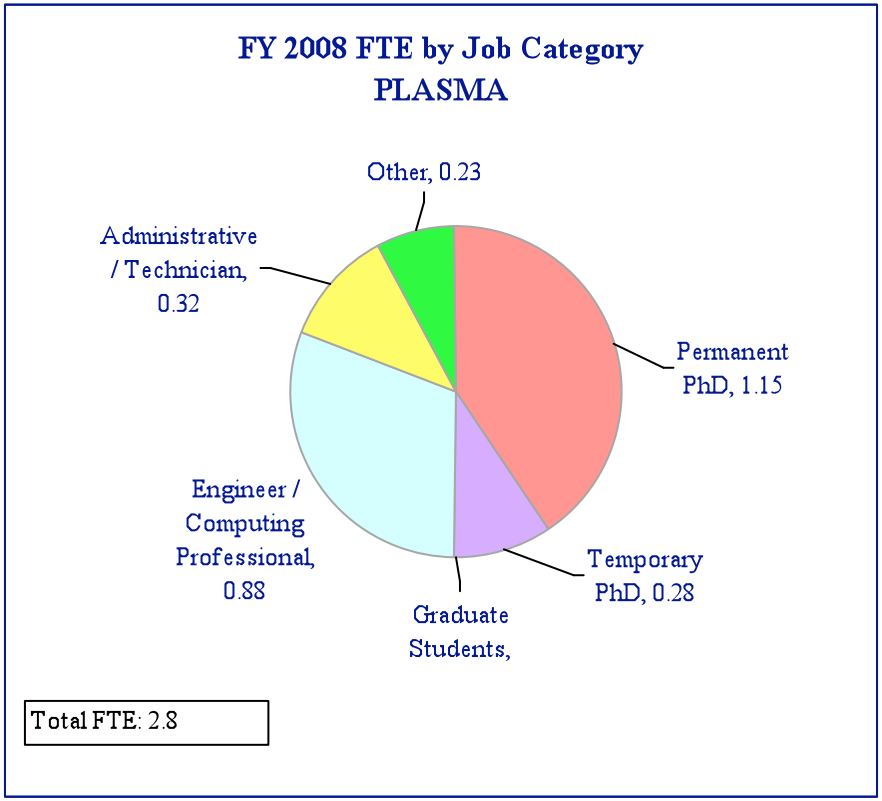
Experimental Tasks and Milestones	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16
Accelerate e- bunch with sufficient charge		FACET	FACET					
Accelerate e- bunch achieving low energy spread			FACET	FACET				
Accelerate e- bunch with high efficiency			FACET	FACET				
Demonstration of electron acceleration: high η, low ΔE ★								
Emittance preservation of e- bunch			FACET	FACET	FACET			
Demonstration of a single stage of an electron PWFA-LC ★								
Acceleration of e+ bunch by e+ drive			FACET	FACET	FACET			
Initial test of e+ acceleration in e- wakes				FACET	FACET			
Emittance preservation of e+ bunch				FACET	FACET		FACET	
Upgrade Sector-20 chicane ●								
Accelerate e+ by e- drive; charge, low dE/E						FACET	FACET	
Accelerate e+ by e-, high efficiency, low emittance						FACET	FACET	
Selection of optimum positron acceleration mechanism for a PWFA-LC ★								
Upgrade injector with rf gun ●								
Plasma cell with jet and power removal	Study	Study	Eng.	Eng.	FACET	FACET	FACET	
Design plasma cell with needed stability and cooling ★								

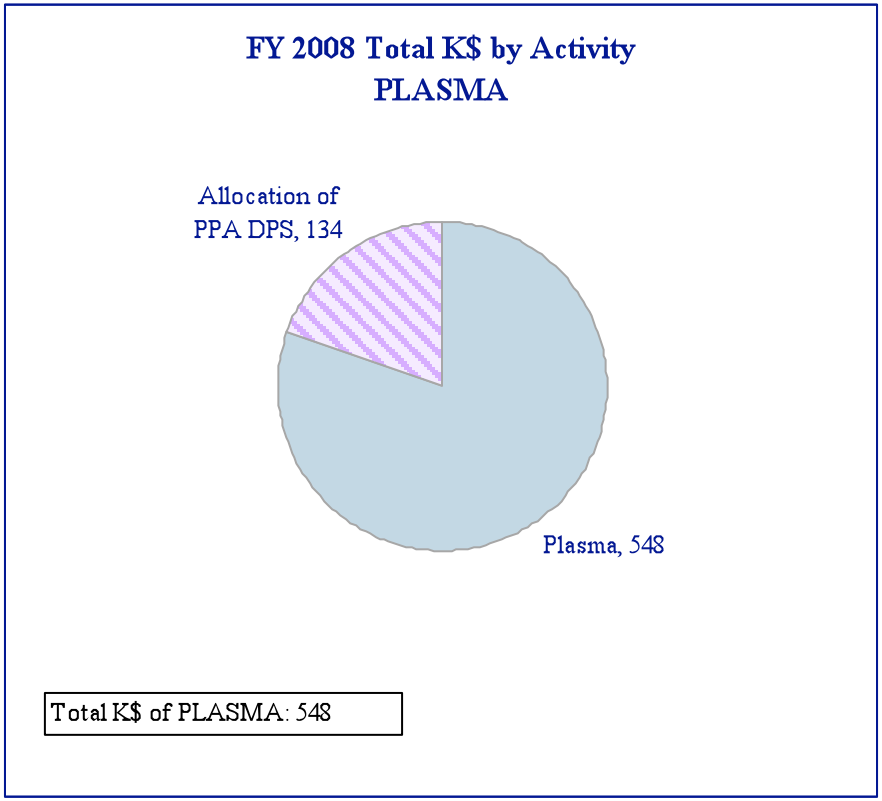
Plasma accelerator research at FACET is in the context of a broader, longer term effort



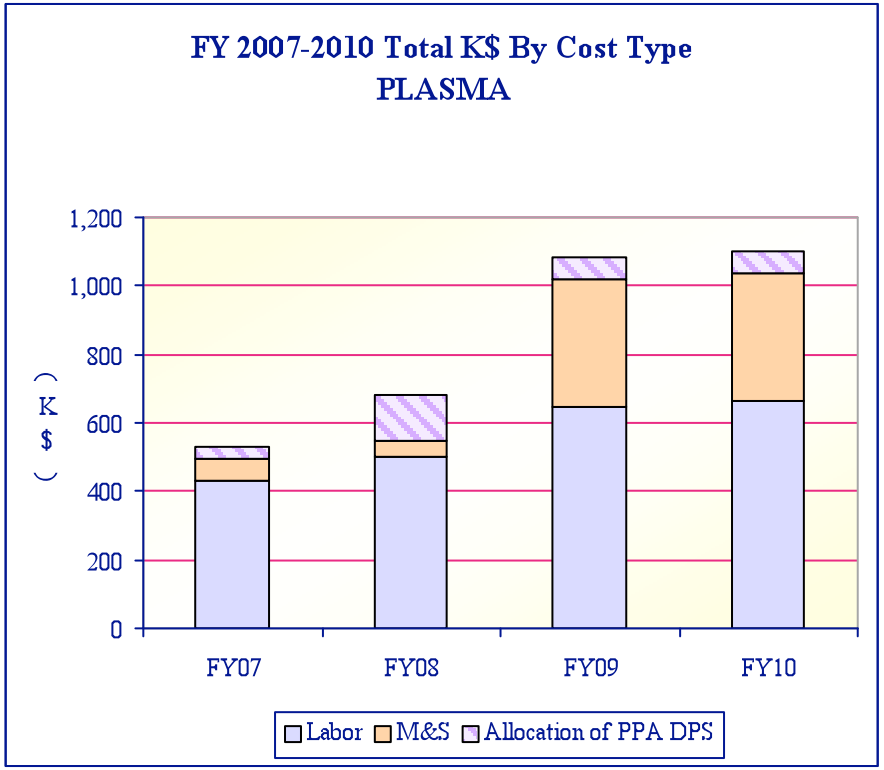
Concurrent Design and Engineering Tasks and Milestones								
Multi-bunch PWFA acceleration	Study	Study	Study					
Initial tolerance studies	Study	Study	Study					
Colinearity of main and drive beams		Study	Study					
Timing offset of main and drive beams		Study	Study					
Drive beam generation, affordable power		Study	Study					
Drive beam utilization		Study	Study					
Combiner recombiner, reasonable footprint		Study	Study					
Shaping the drive bunches for high efficiency			Study	Study				
Main beam injector, compressor & DR			Study	Study				
Final focusing, large energy acceptance				Study	Study			
Cleaning or collimation of the accelerated beam					Study	Study		
Evaluate physics reach of PWFA-LC options					Study	Study	Study	
Detailed design of PWFA-LC subsystems						Study	Study	Study

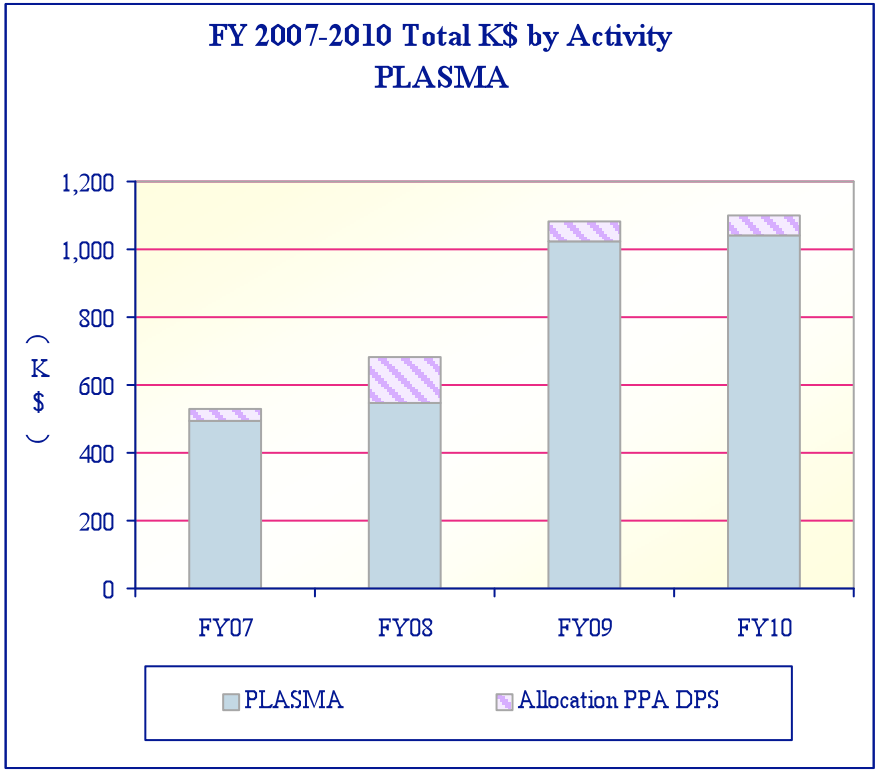
Overview of Financial Data – FY2008





Overview of Financial Data 2007-2010





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