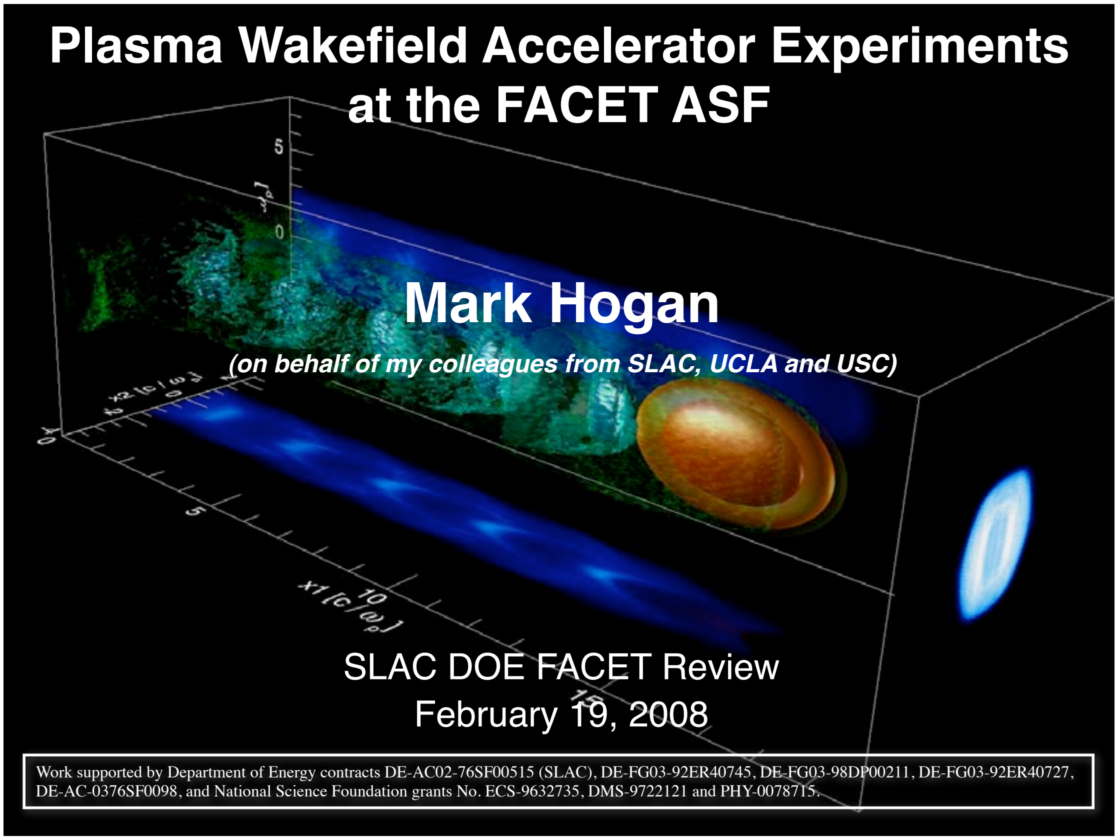


Plasma Wakefield Accelerator Experiments at the FACET ASF

Mark Hogan

(on behalf of my colleagues from SLAC, UCLA and USC)

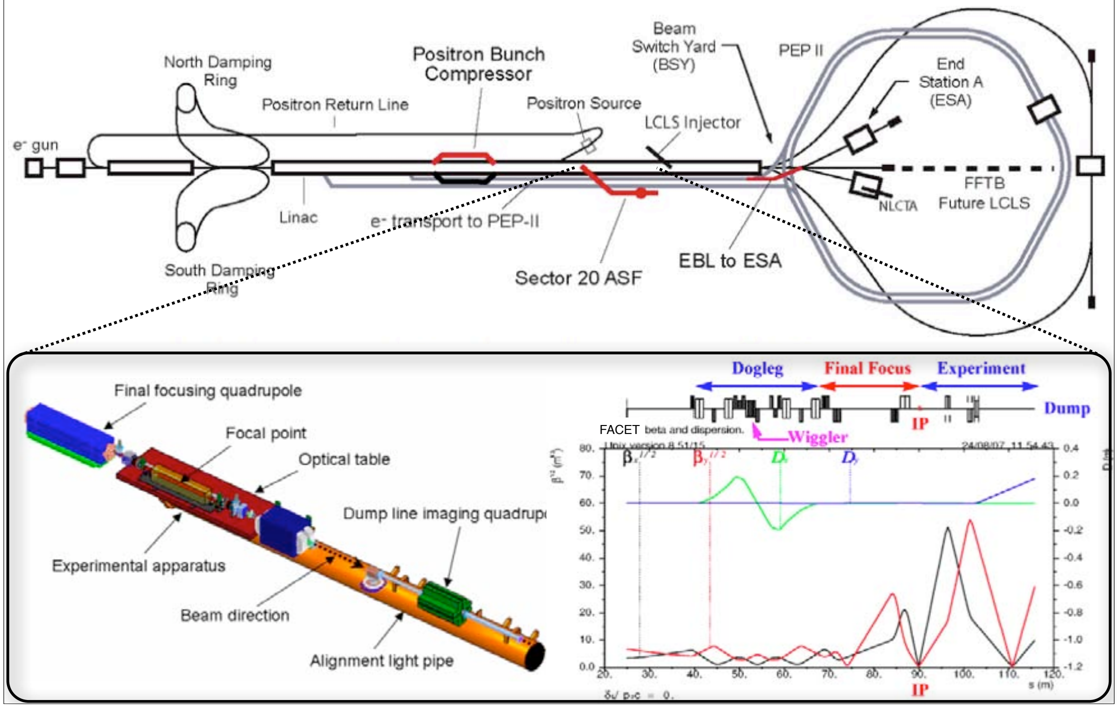
SLAC DOE FACET Review
February 19, 2008

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.

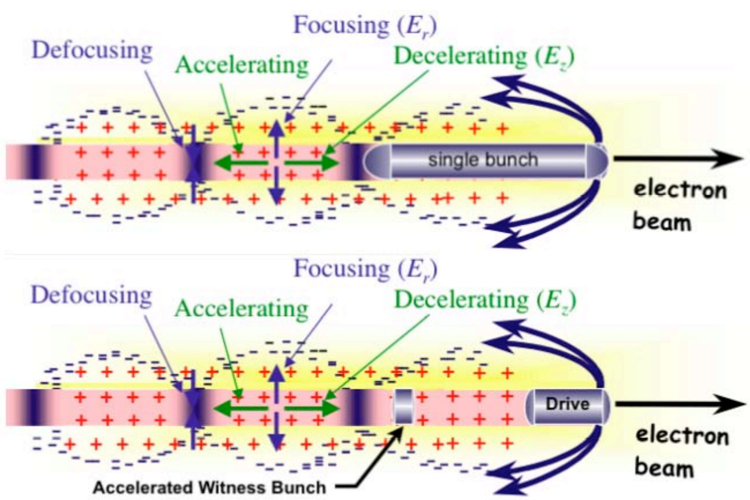
Outline

- The FACET ASF Area
- Two bunch plasma wakefield acceleration
- Positron acceleration
- Trapped particles
- Future possibilities

Plasma Accelerator Experiments will take place in the Sector 20 ASF Area



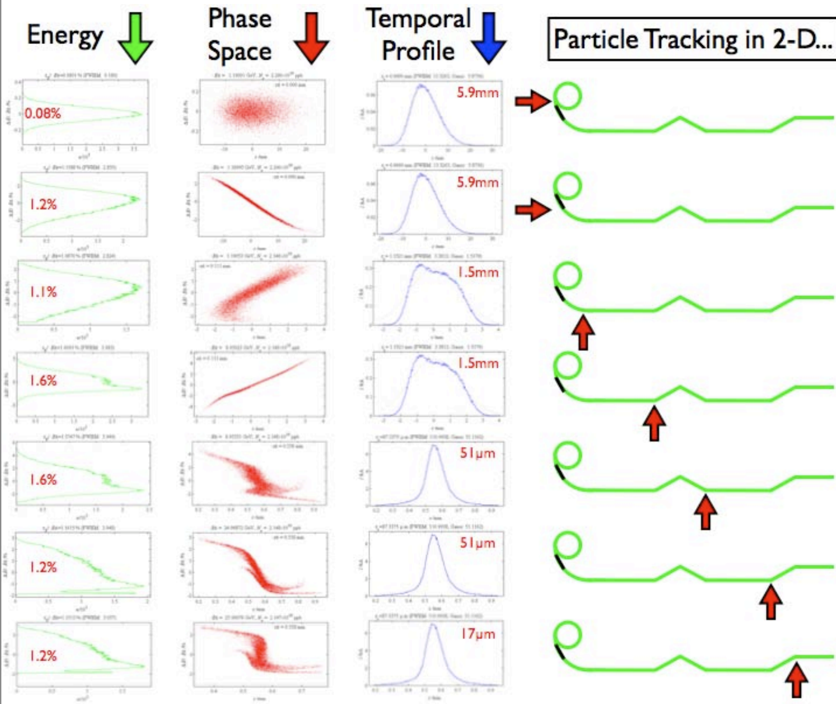
At FACET we will produce and accelerate a discrete bunch – not just a few electrons at all phases



Challenges:

- Drive bunch needs to be substantial enough to both ionize the vapor and drive a large amplitude wake
- Witness bunch needs to be be half-plasma period behind ~ 100μm for 1E17 plasma!

FACET ASF uses a three stage bunch compression process



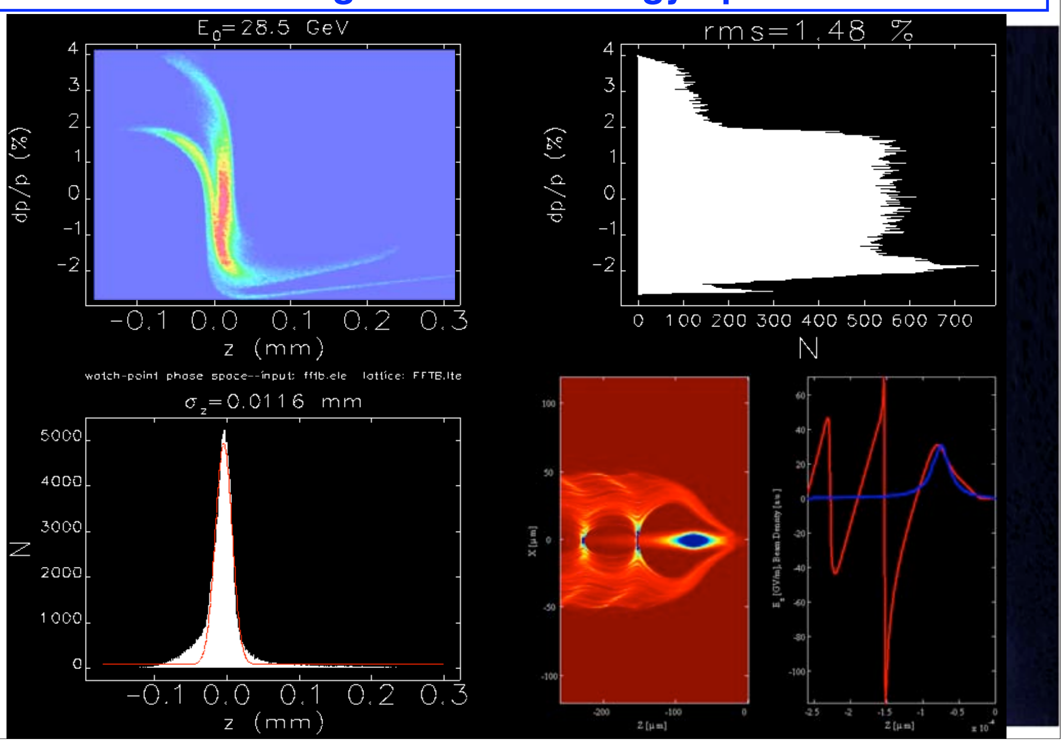
Energy	24 GeV
Charge	3 nC
Sigma z	17 μm
Sigma r	< 10 μm
Peak Current	22 kAmps
Species	e^- & e^+

FACET IP

end of FACET dogleg

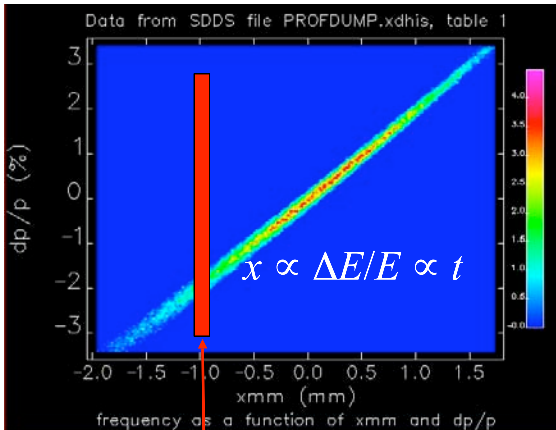
Very similar to FFTB/SPPS operation

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



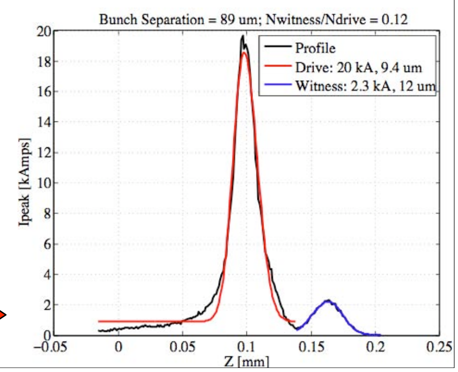
Creating Two Bunches: Use a Notch Collimator

Exploit Position-Time Correlation on e⁻ bunch to create separate drive and witness bunch

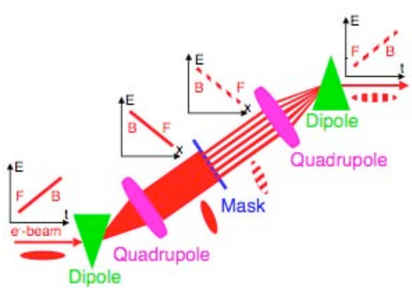


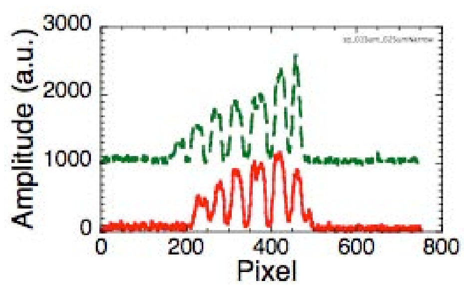
Access to *time* coordinate along bunch

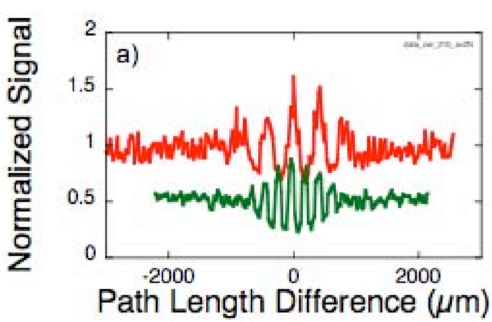
1. Insert tantalum blade as notch collimator
2. Do not compress fully to preserve two bunches separated in time

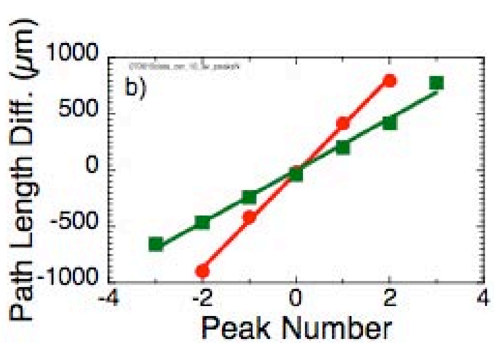


A variation of the notch collimator was recently demonstrated at BNL ATF



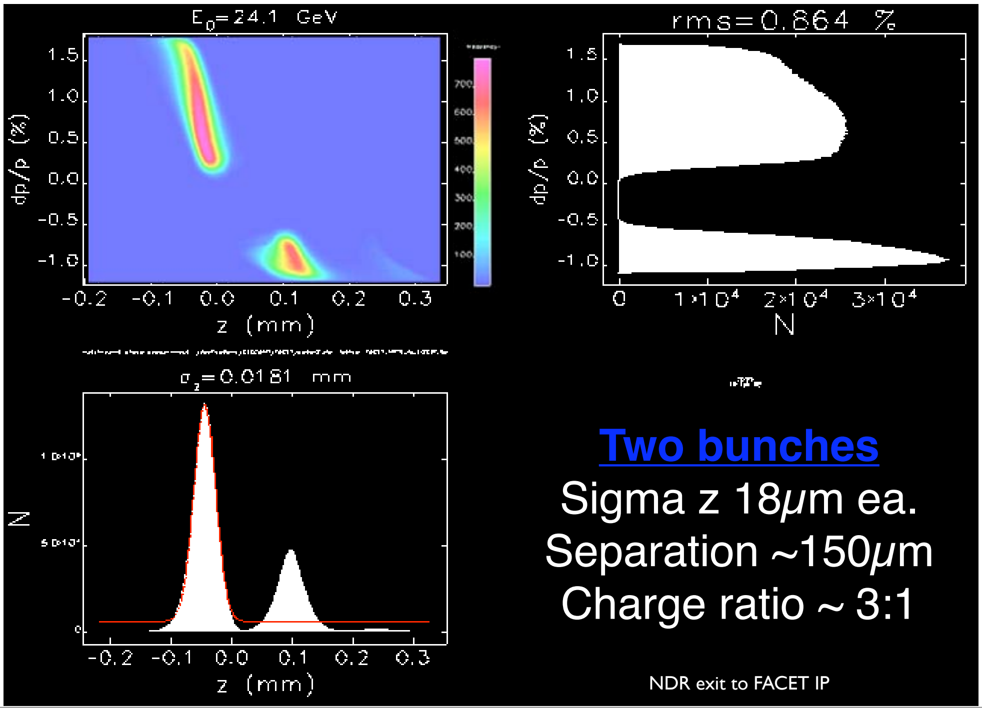




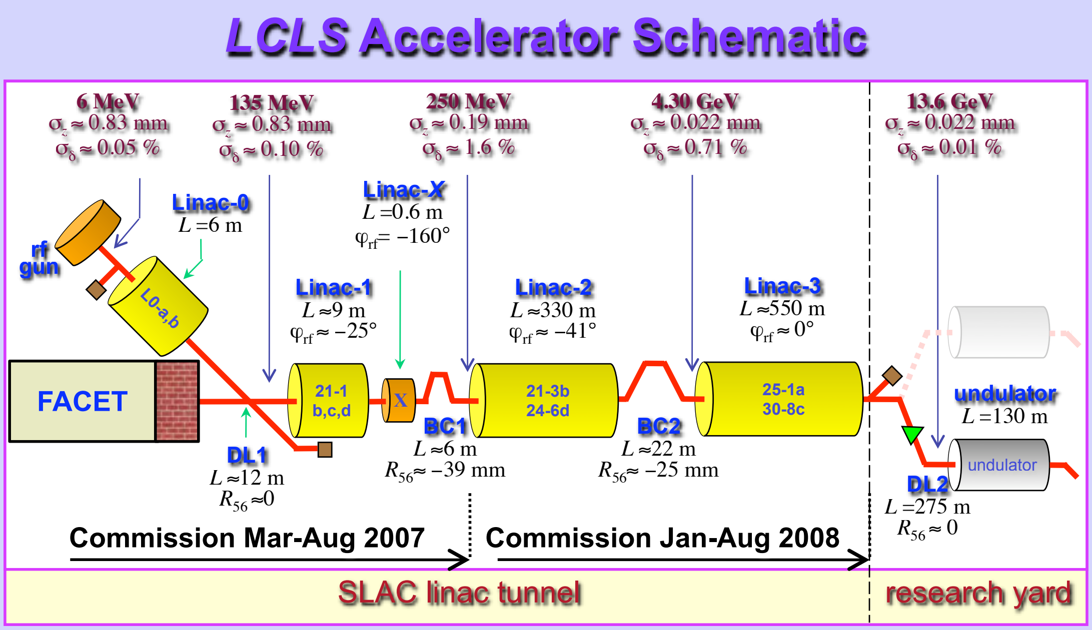


(P. Muggli, V. Yakimenko et al submitted for publication)

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

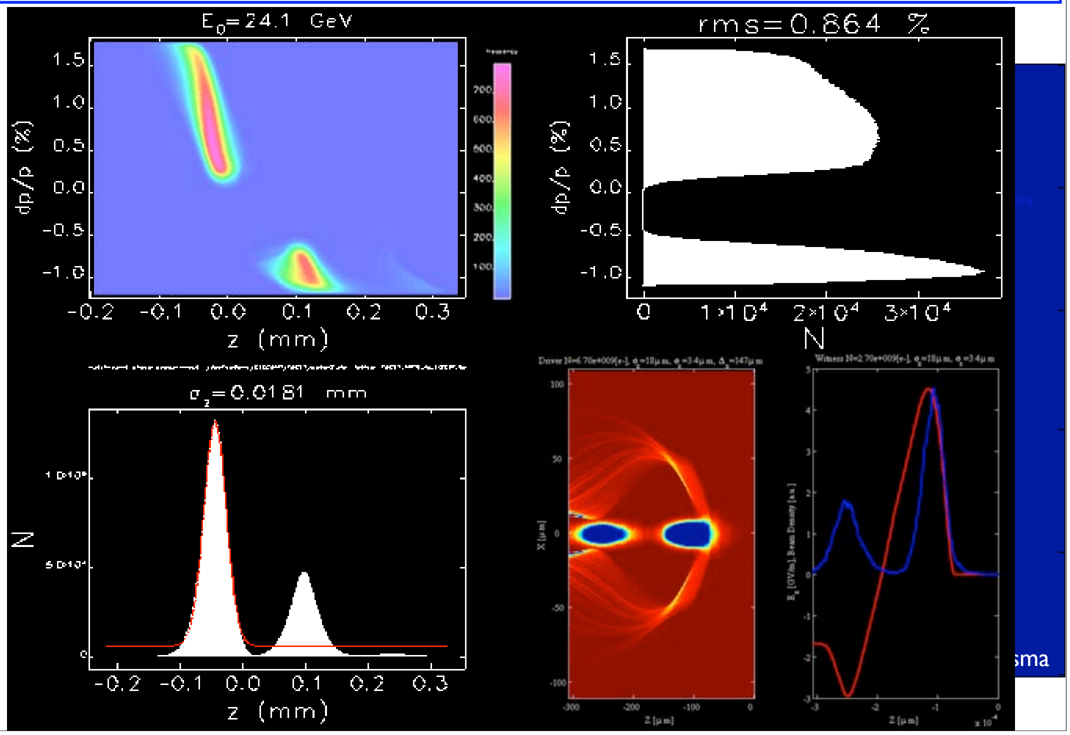


FACET Notch Collimator drive bunch comparable to state of the art

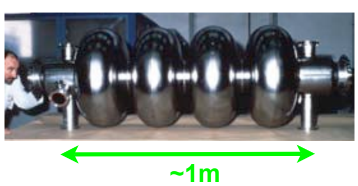


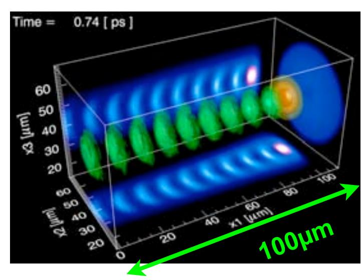
Courtesy of Paul Emma

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

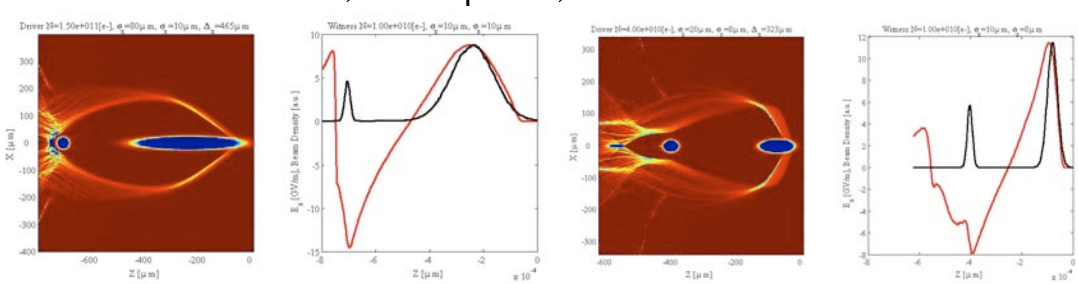


Plasma Accelerators are not just very-high frequency structures



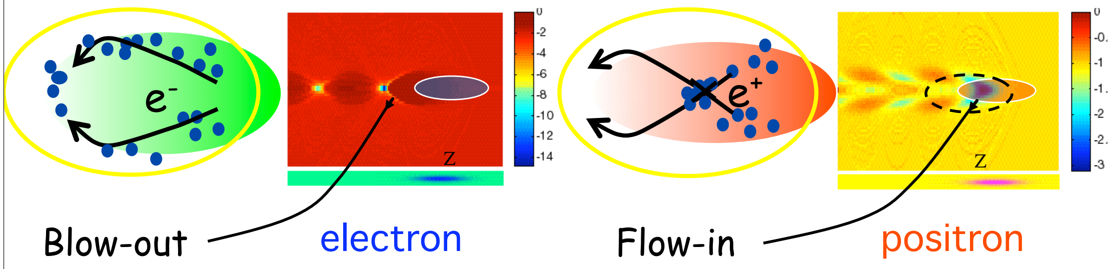


Incoming beam properties partly define the structure:
dimensions, field amplitude, transformer ratio...

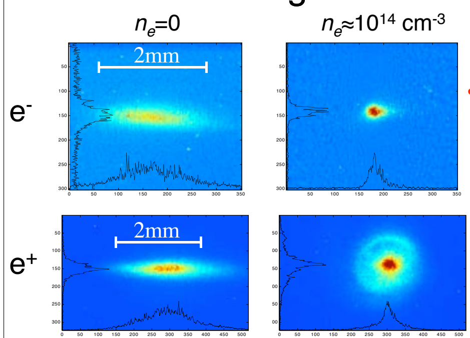


Full understanding requires experimentation, observation and simulation

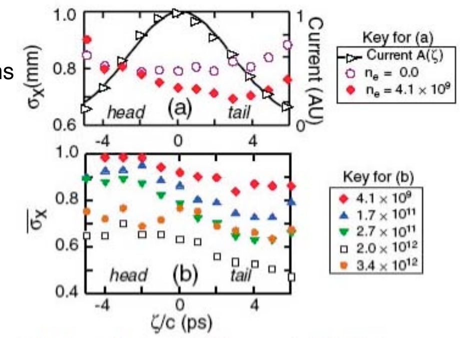
PWFA Mechanism Different For A Positron Beam



Positron Focusing varies with radius and position along the bunch



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

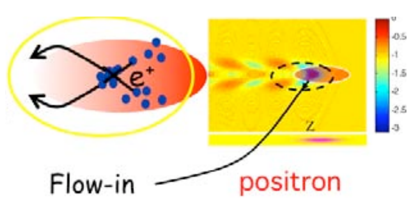


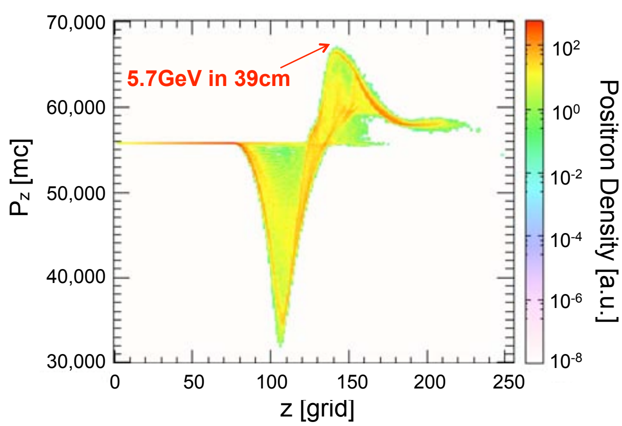
E-162 Data

(M.J. Hogan *et al.*, PRL 2003)

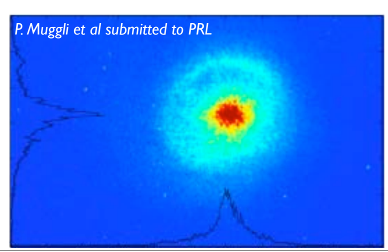
High Gradient Positron Acceleration

- First experiments will attempt to repeat E-167 with positrons
  - Not trivial when consider difference in plasma electron response:





- Second phase will use two bunches (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

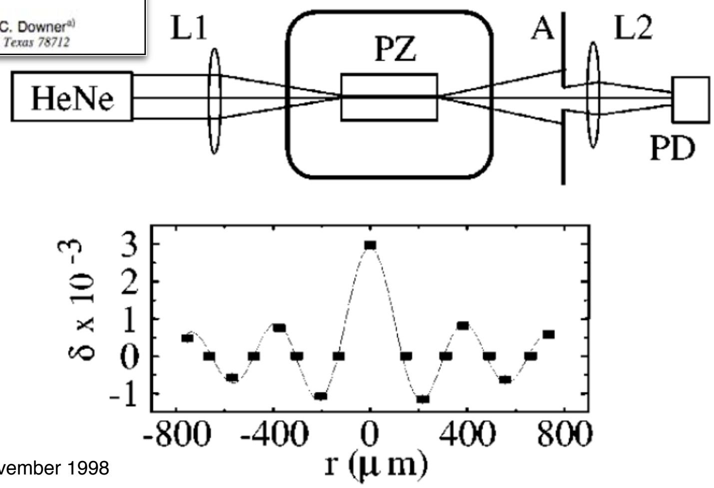


Hollow Channel Plasmas may offer better accelerating wakes and reduce emittance growth

- 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:

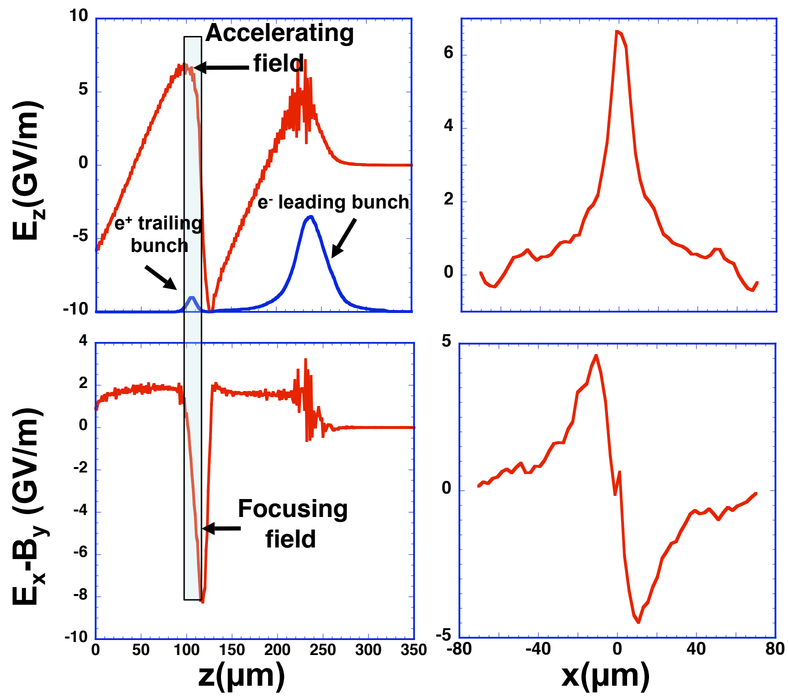

Guiding characteristics of an acoustic standing wave in a piezoelectric tube

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

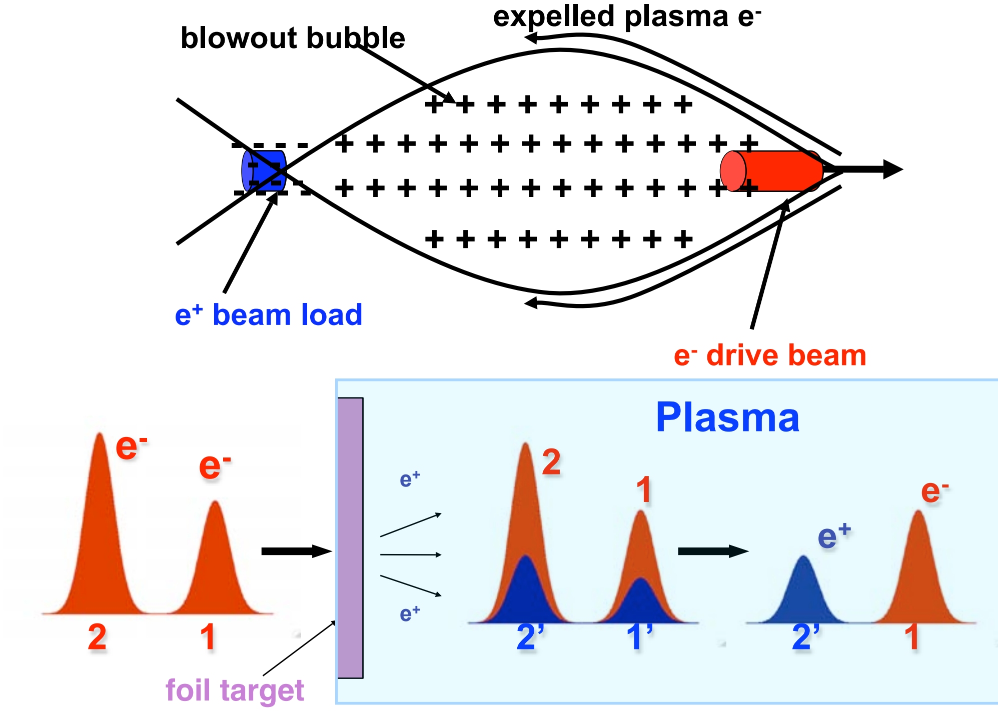


Appl. Phys. Lett., Vol. 73, No. 20, 16 November 1998

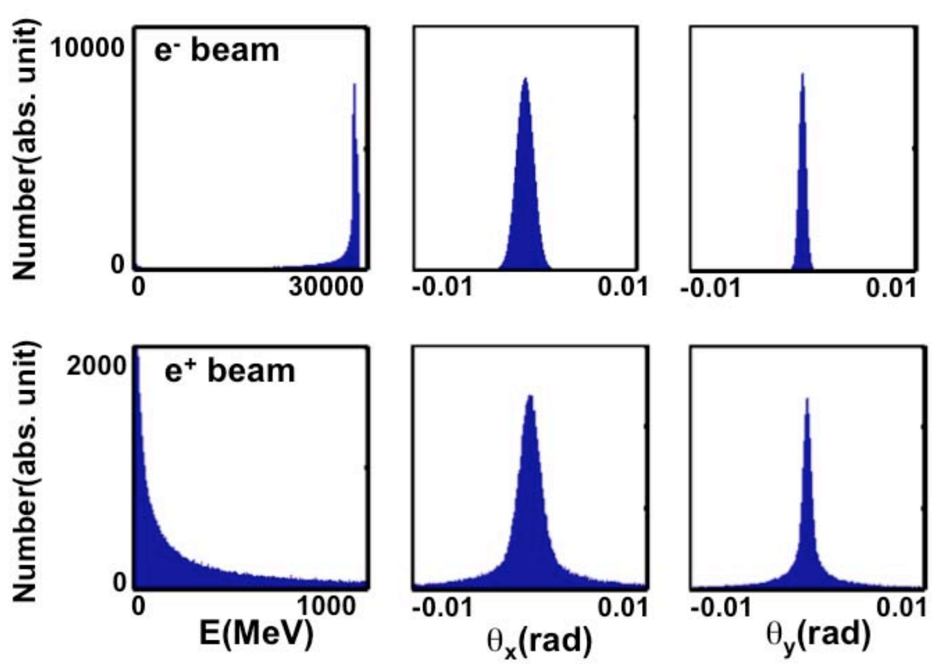
Positron Acceleration in Electron Beam Driven Wakes is possible in the weakly non-linear regime



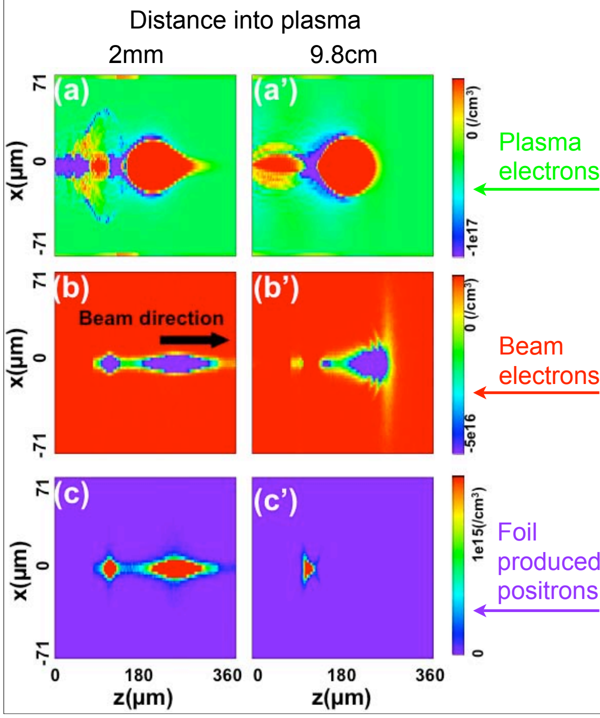
Generating closely-spaced mixed-species bunches is simplified by creating the positrons in the plasma

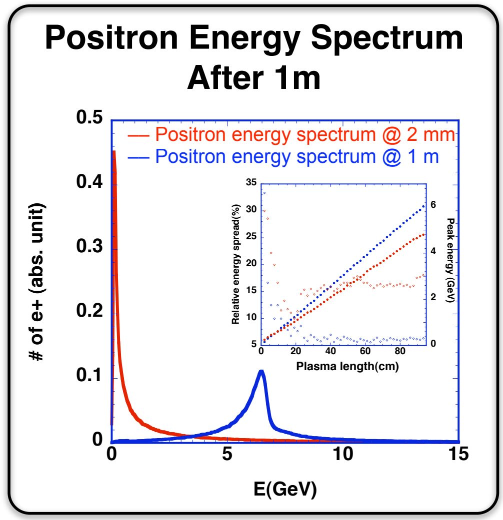


EGS5 Simulation of electron and positron energy spectra and phase space after 0.5mm tantalum target



Wakefield structure naturally selects the positrons with appropriate phase space and accelerates them to high energy

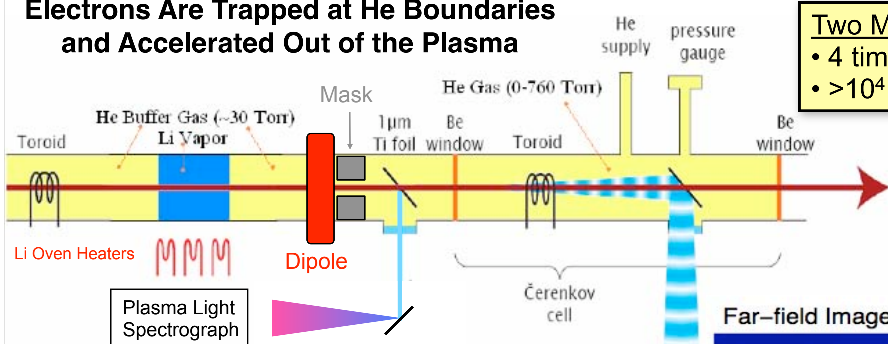


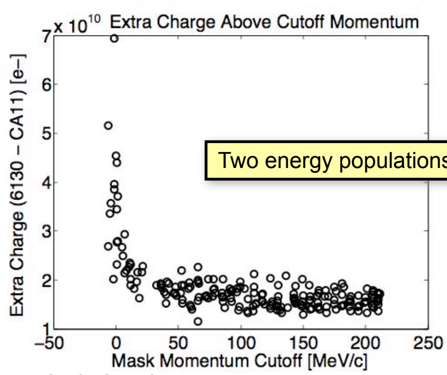


New Phenomena: Trapped Particles

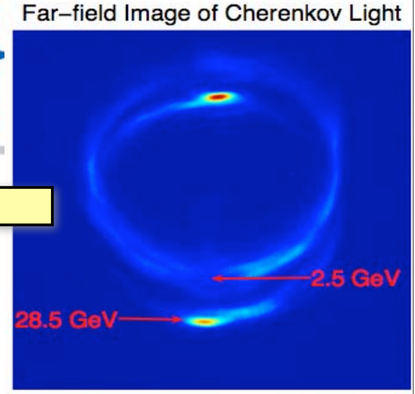
Electrons Are Trapped at He Boundaries and Accelerated Out of the Plasma

Two Main Features
- 4 times more charge
- $>10^4$ more light!





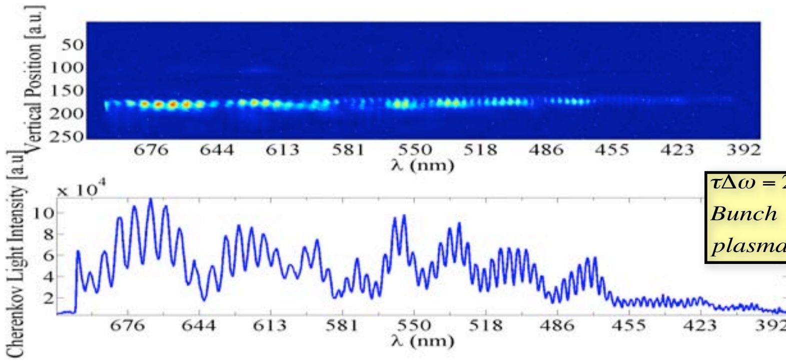
Far–field Image of Cherenkov Light



Note: Primary beam is also radiating!

Trapped Particles Have Short Time Structure

Visible Light Spectrum Indicates Time Structure of Trapped Electrons

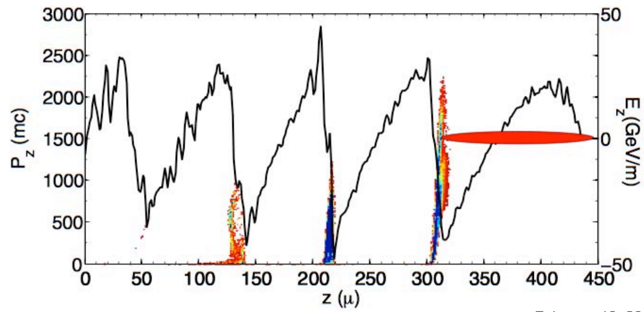


$\tau\Delta\omega = 2\pi$

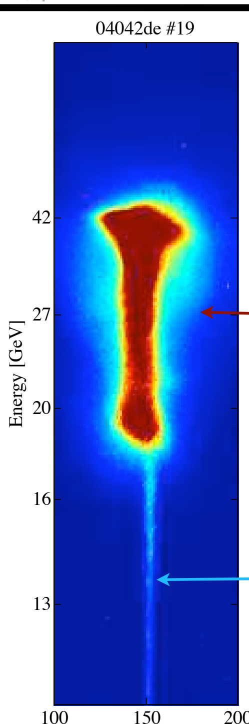
$Bunch\ Spacing = c\tau \approx 70\ \mu,$

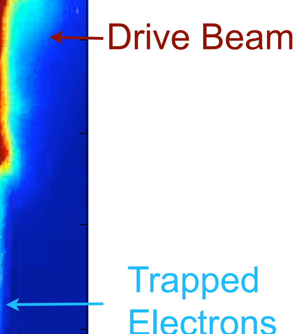
$plasma\ wavelength, \lambda_p = 64\ \mu.$

OSIRIS Simulations:
- He electrons in several buckets
- Spaced at plasma wavelength
- Bunch length ~fs

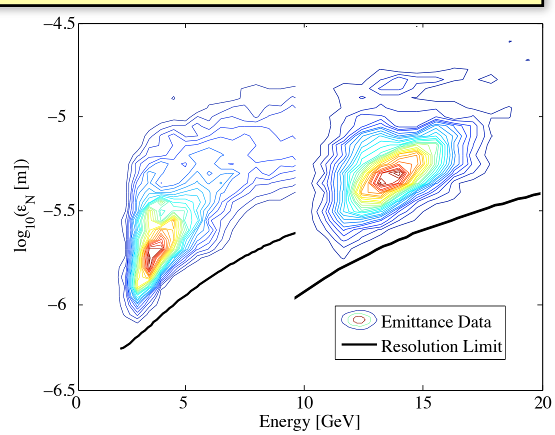


Trapped Particles



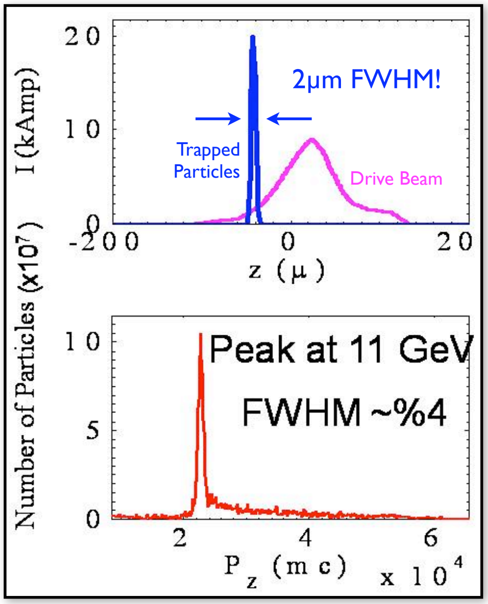


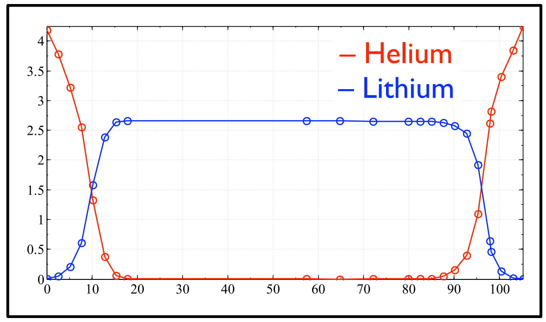
High Brightness Electron Source?
- Multi-GeV Energy
- fs pulse length
- Normalized Emittance 10 smaller than the drive beam



Designing next generation experiments to better understand and produce more of them!

OSIRIS Simulations indicate the high-quality trapped particle bunches are destroying themselves trying to get out





Ionization level	Ionization He	Energy Li	(eV) Ar
1st	24.587	5.392	15.759
2nd	54.416	75.638	27.629
3rd		122.451	40.74

Can Be Optimized by Varying Beam and Plasma Parameters

5 Year FACET Program

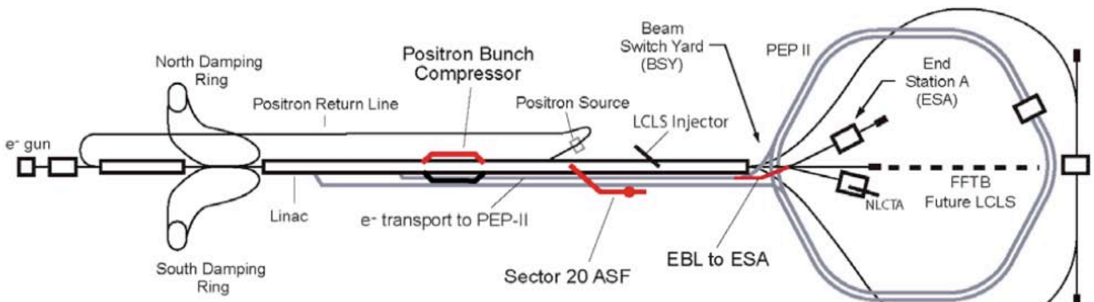
Run	Plasma Wakefield Accelerator Program	
	Program	**Description**
	Electrons	
FY10	Commissioning	Commission profile monitors, bunch length diagnostics and energy spectrometers. Initiate first experiments.
FY11	Acceleration of witness bunch with narrow energy spread	Demonstrate creation of two bunches with notch collimator then accelerate a witness bunch with narrow energy spread.
FY12	Quantify efficiency & optimization	Optimize notch collimator & plasma density to quantify tradeoff between final energy spread and efficiency.
FY13	Quantify efficiency & optimization	Continuing from FY12.
FY14	Plasma lens	Demonstrate high demagnification plasma lens with sub-micron spot size.
FY15	Emittance preservation & Ion motion	Vary ratio of the beam/plasma density to quantify emittance growth due to ion motion.
	Positrons	
FY10		
FY11	High Gradient Acceleration	Study wake amplitude for single, short positron bunches in a field ionized plasma for the first time.
FY12	High Gradient Acceleration	Continuing from FY11.
FY13	Hollow Channel Plasmas	Use plasma sources with a hollow channel, density minimum on axis, to increase wake amplitude and minimize emittance growth.
FY14	Positrons in electron beam driven wakes	Create positrons within the electron wake using a conversion target within the plasma source.
FY15	Positrons in electron beam driven wakes	Re-configure ASF beamline to combine electrons & positrons from the main linac.

Results of this program will guide future facility upgrades...

Future upgrades will be guided by results

Possibilities:

- Lower damping ring energy
  - Better compression, higher peak current
- Enhanced LCLS style photoinjector
  - Multiple bunches, bunch trains, shaped pulses with added flexibility
- ASSET type experiment with e-e+, 5cm dz @ Li09 chicane, coast to FACET IP
  - Positron acceleration in electron wakes with ‘real beam’ of positrons
- NLC/ILC style FF
  - Sub-micron spots @ IP for ion motion studies
- Holography of e+ wakes, EO sampling

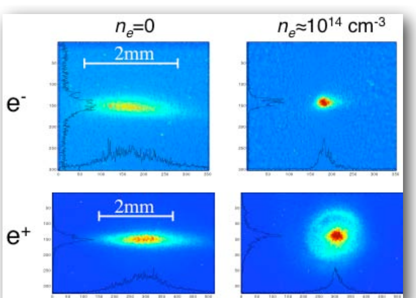


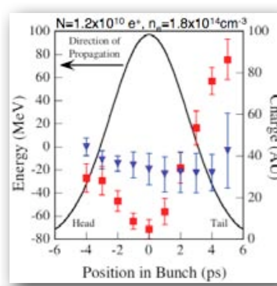
Plasma Wakefield Accelerator Research Summary

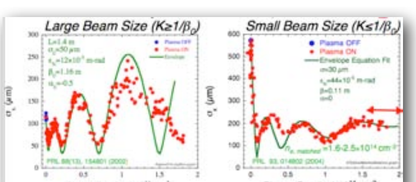
From the FFTB Program

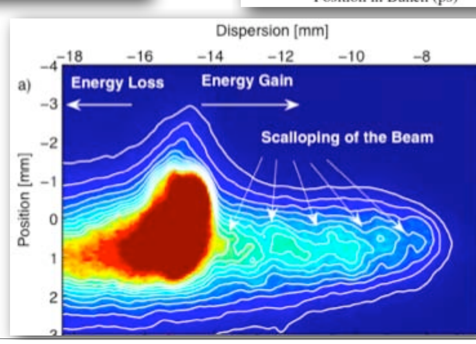
Over 25 Peer reviewed publications *covering all aspects of beam plasma interactions:* Focusing (e^- & e^+), Transport, Refraction, Radiation Production, Acceleration (e^- & e^+)

Major Accomplishments









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