# PWFA Plans at SLAC

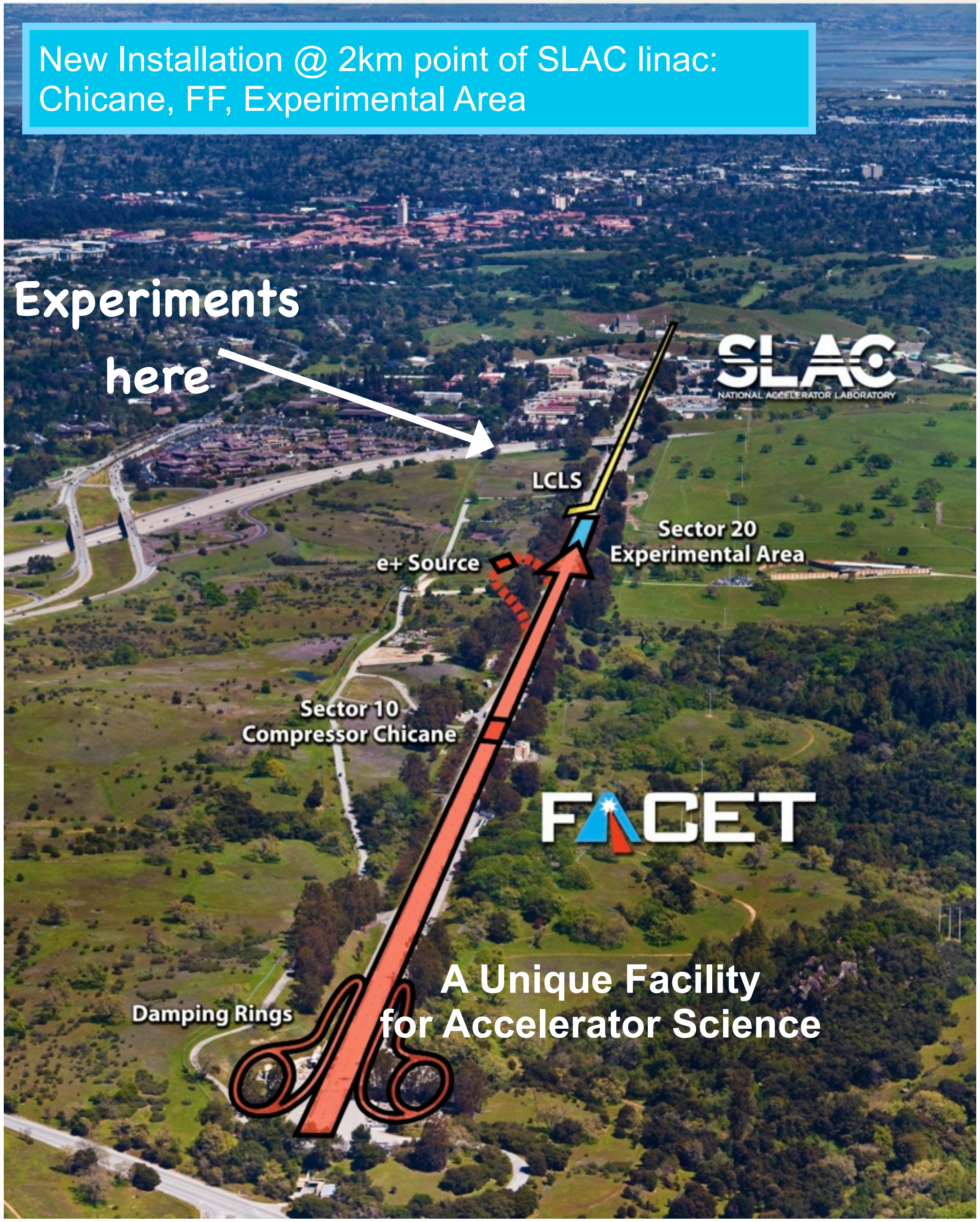
## Helmholtz VI Kickoff Meeting

Mark Hogan October 8, 2012

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

# FACET:
# Facility for Advanced Accelerator Experimental Tests




**Multi-GeV meter-scale plasma cells require:**

- High-density plasmas – gradient
- High-energy beams – stored energy
- Tightly focussed – match to plasma focusing channel
- High peak-current – large wake amplitude

| Parameter | Design | Sep. 2011 | Jun. 2012 best | Jun. 2012 “typical” |
|---|---|---|---|---|
| Energy | 23 GeV | 19.65 GeV (20.8 demo.) | 21.1 GeV | 20.35 GeV |
| Charge/pulse | 3.2 nC | 3.2 nC | 3.2 nC | 2.5…2.9 nC |
| IP spot size | < 20 μm × 20 μm | <30 μm x 50 μm | 20 μm × 23 μm | 35 μm x 35 μm |
| Bunch length | < 20 μm | < 30 μm | 16…25 μm | 16…25 μm |
| Rep. rate | 30 | 10 (ALARA) | 10 (ALARA) | 10 (ALARA) |

***The most important capability is the beam!***

- FACET is first hard push since the end of FFTB/PEP-II programs in 2006/2007
- Much progress, but still work to do (parameters, stability)

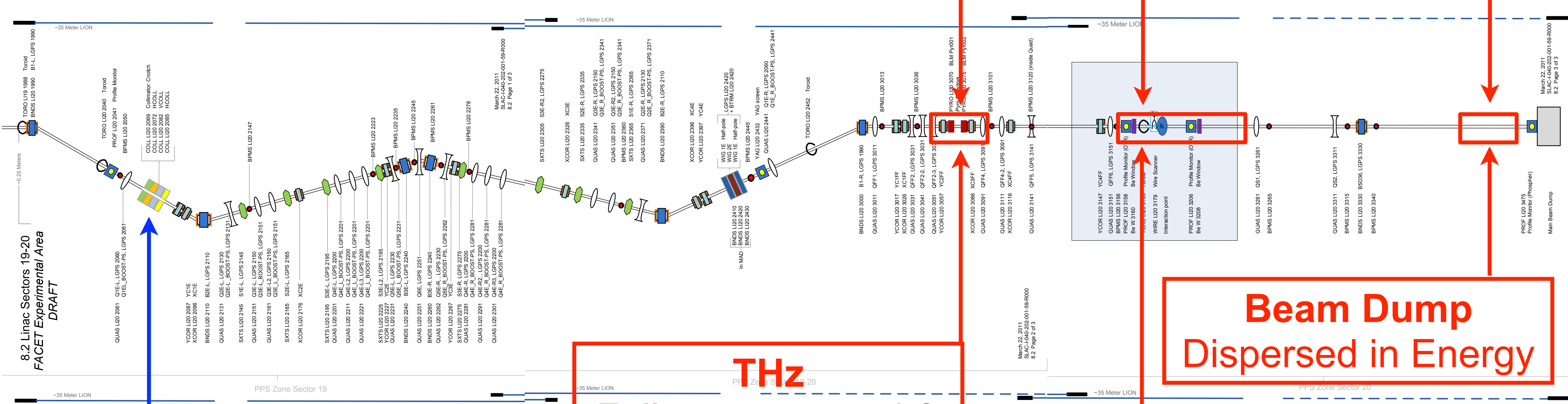
# FACET Sector 20 Beamline

SLAC

## Chicane, Final Focus and Experimental Area

**Beam Direction** →

Three Optical Tables = Experimental Areas



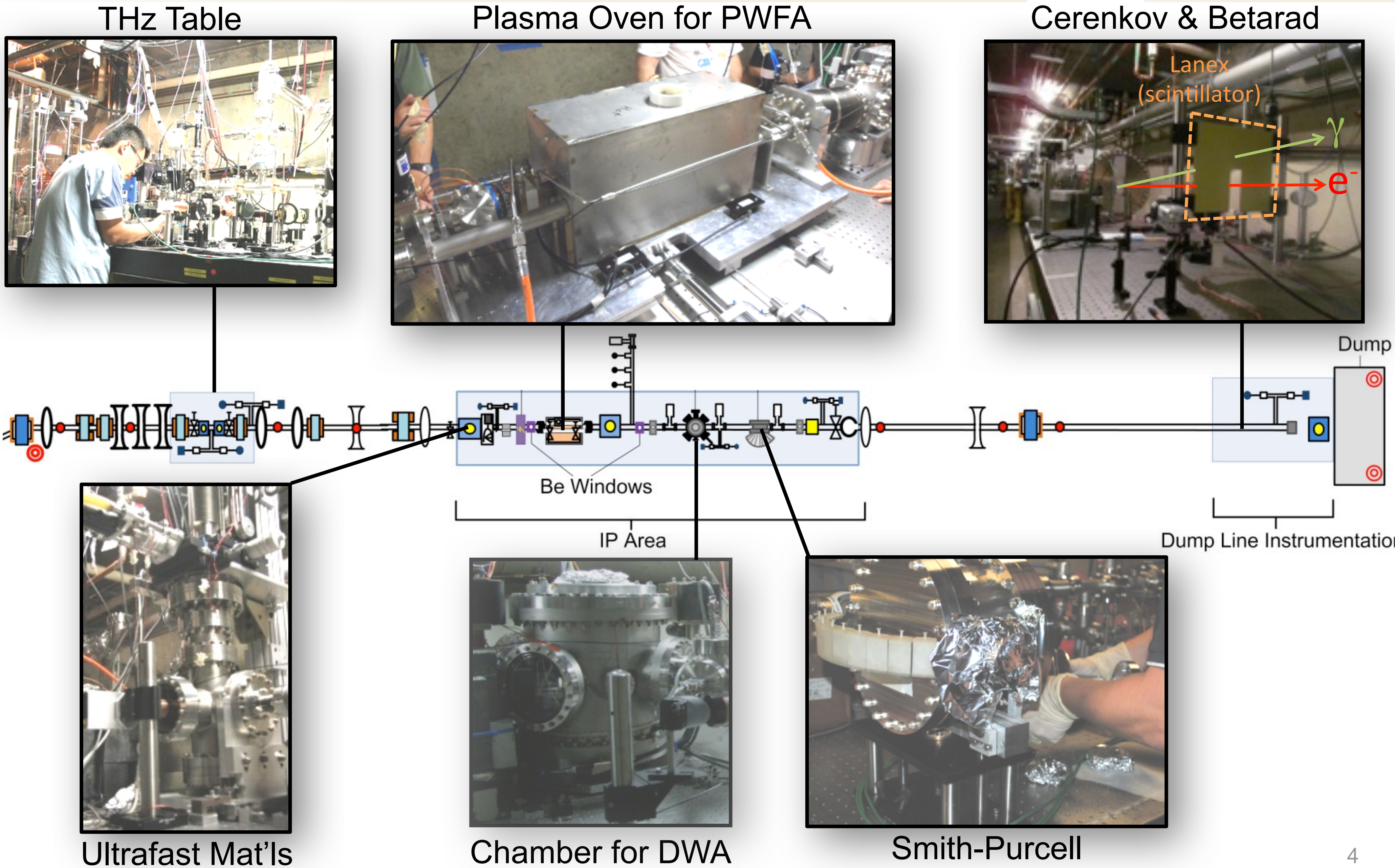

**Beam Dump**
Dispersed in Energy

**THz**
Fully compressed & elliptical beam

**Collimators**
Drive–Witness or Ramped Bunch Production

**IP**
Fully Compressed & Tightest Focus

# Experimental Installation



# Near-Term Goals for FACET Program

- Operate FACET as a premiere facility for advanced accelerator R&D
  - Ultra-High Gradients (Energy Frontier)
  - High-Brightness Beams & Diagnostics (Portal to Other Office of Science Programs)
- Deliver a successful first series of experiments
  - Plasma wakefield acceleration (E200)
  - Dielectric wakefield acceleration (E201)
  - Ultrafast material science (E202, E206)
  - New diagnostics and tuning algorithms (E203, T501)
- Improve operations, stability, user experience
- Increase capabilities with targeted facility enhancements
- Grow user base

# FACET E200 PWFA Program Goals – Next Five Years

Collaboration between SLAC/UCLA/MPI

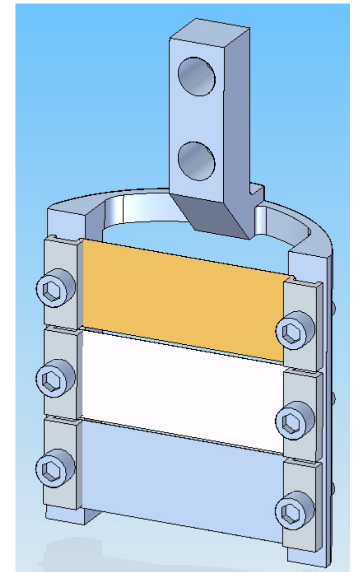
- Demonstrate a single-stage high-energy plasma accelerator for electrons
- Meter scale, high gradient, preserved emittance, low energy spread, and high efficiency
  - Commission beam, diagnostics and plasma source (2012)
    - Physics of processes limiting interaction length
  - Produce independent drive & witness bunch (2012-2013)
    - Create bunch pairs with sub-ps spacing
  - Pre-ionized plasmas and tailored profiles to maximize single stage performance: total energy gain, efficiency (2013-2015)
  - Betatron & Synchrotron radiation, instability studies
- First experiments with compressed positrons
  - Identify optimum technique/regime for positron PWFA (2014-2016)

Want to demonstrate a plasma module with beam parameters and energy gain at the level required for novel radiation sources and Higgs Factory upgrade

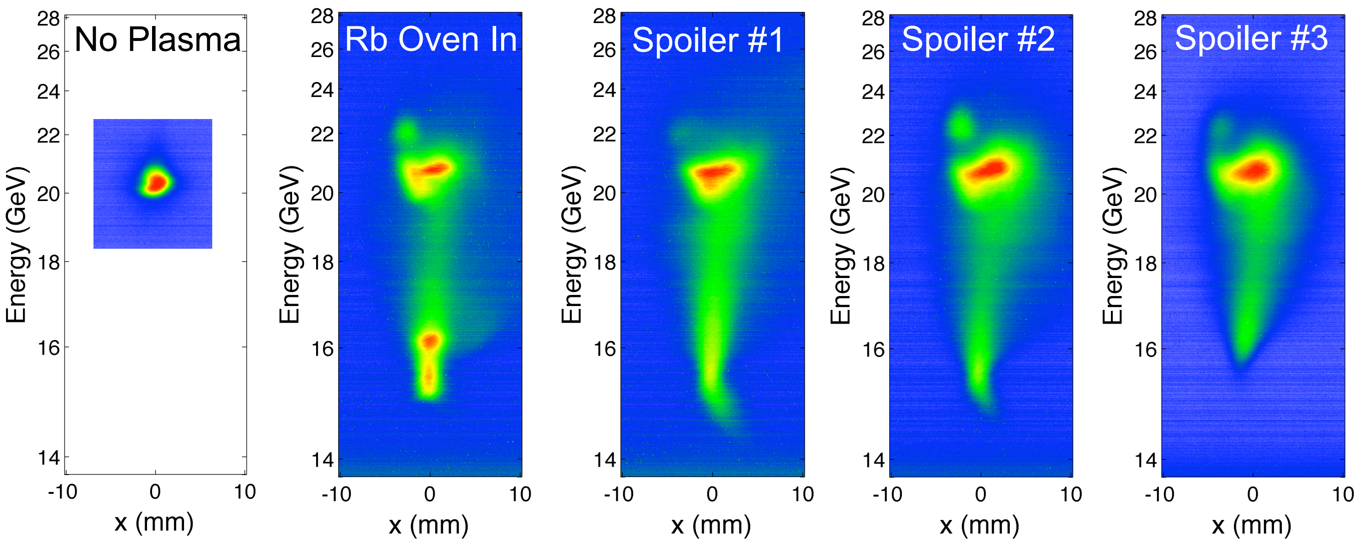
# Progress in 2012: Emittance spoiling, Head Erosion and Dark Current

- Head erosion limits single stage performance in PWFA

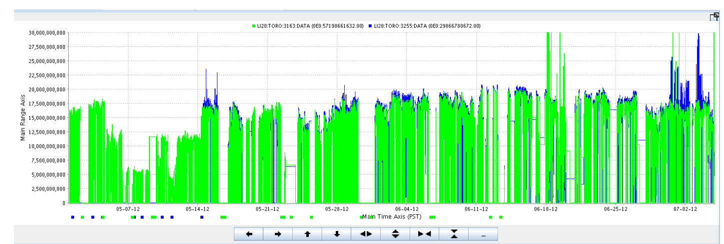
$$V[\mu m/m] = (3.6617\cdot 10^4)\epsilon_i^{1.73}[eV]\frac{\epsilon_N[mm\cdot mRad]}{\gamma}\frac{1}{I^{3/2}[kA]}$$



- Studied energy gain and loss as a function of:
  - Ionization potential (Li, **Rb**)
  - Beam emittance (spoiler foils)
  - Peak current (different levels of bunch compression)



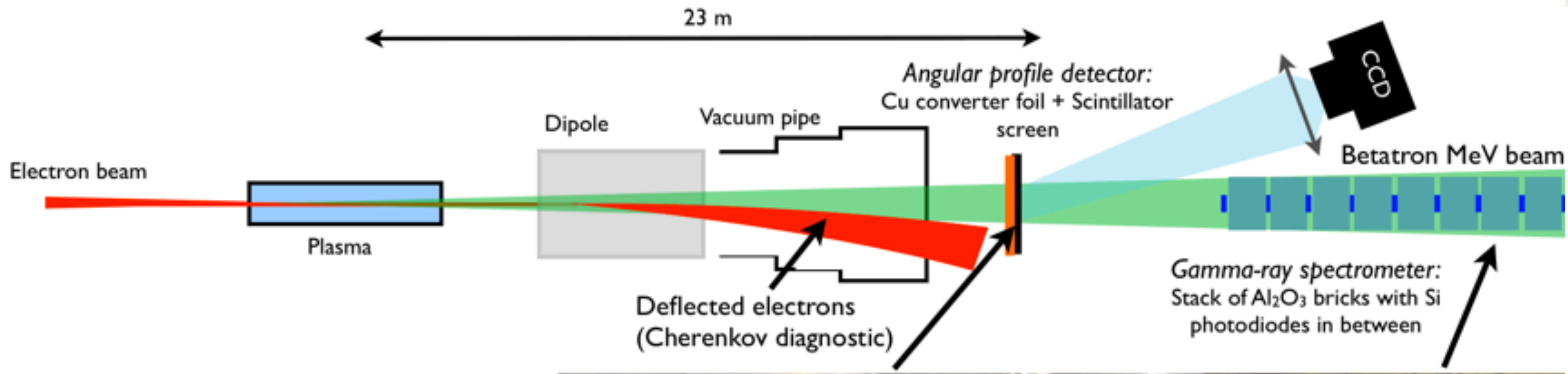

...but plasma dark current



...and fluorescence in Ar

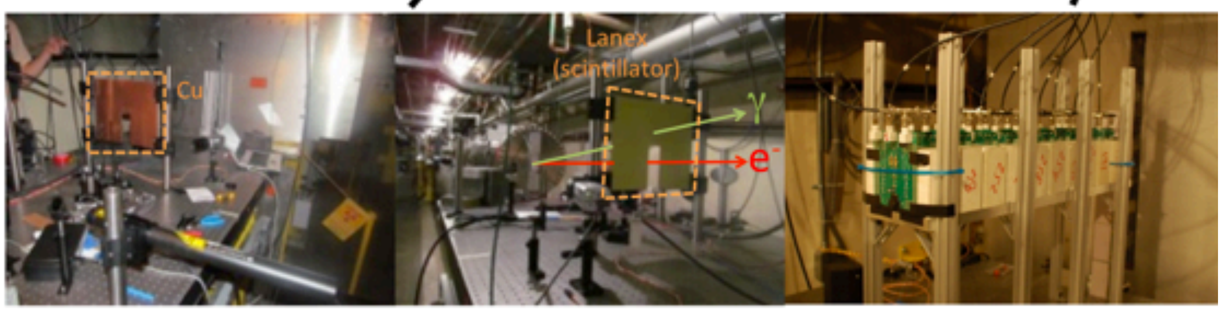
**Analysis of 2012 run data yielding important new science on track for publication**

# Progress in 2012:
# New Diagnostics for Beam Matching and Radiation Generation

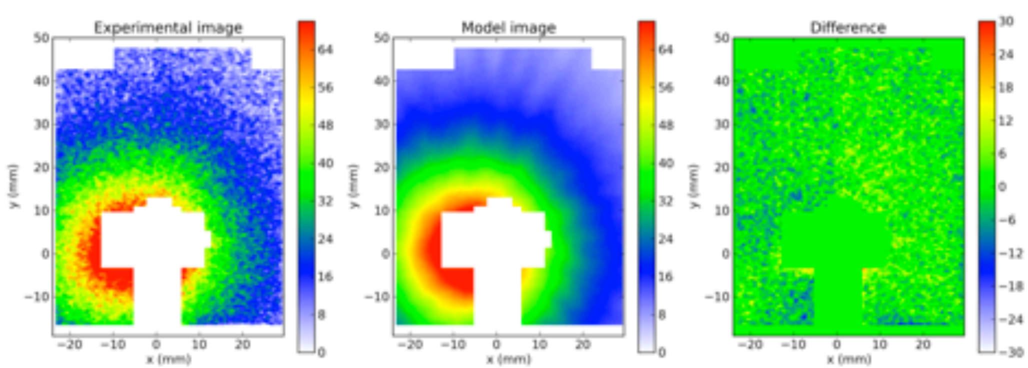



***Measuring gamma-ray radiation reveals important information on the beam dynamics in the plasma.***

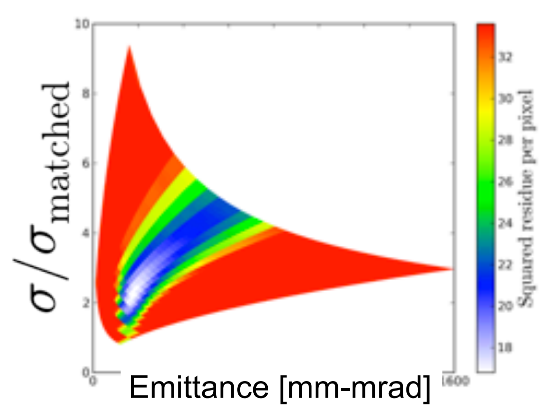
***---> Assessing the matching of the beam in the plasma cavity.***




***Example of measured gamma-ray beam profile***

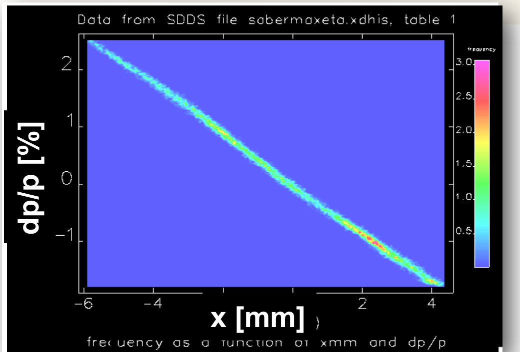



***Deduced beam parameters***




***---> Best fit for a 10 um beam size and 150 mm.mrad emittance (BMAG = 2.6)***

# Full Compression with Nominal Optics

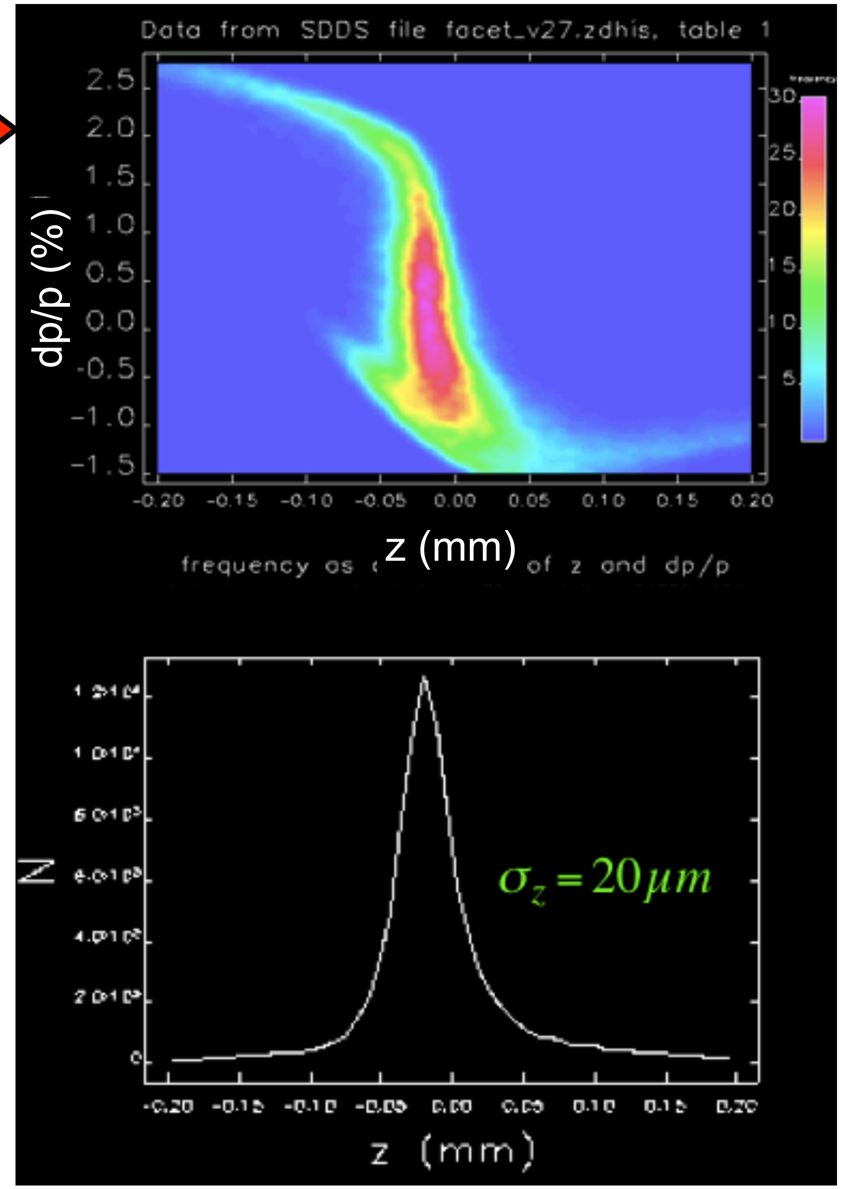


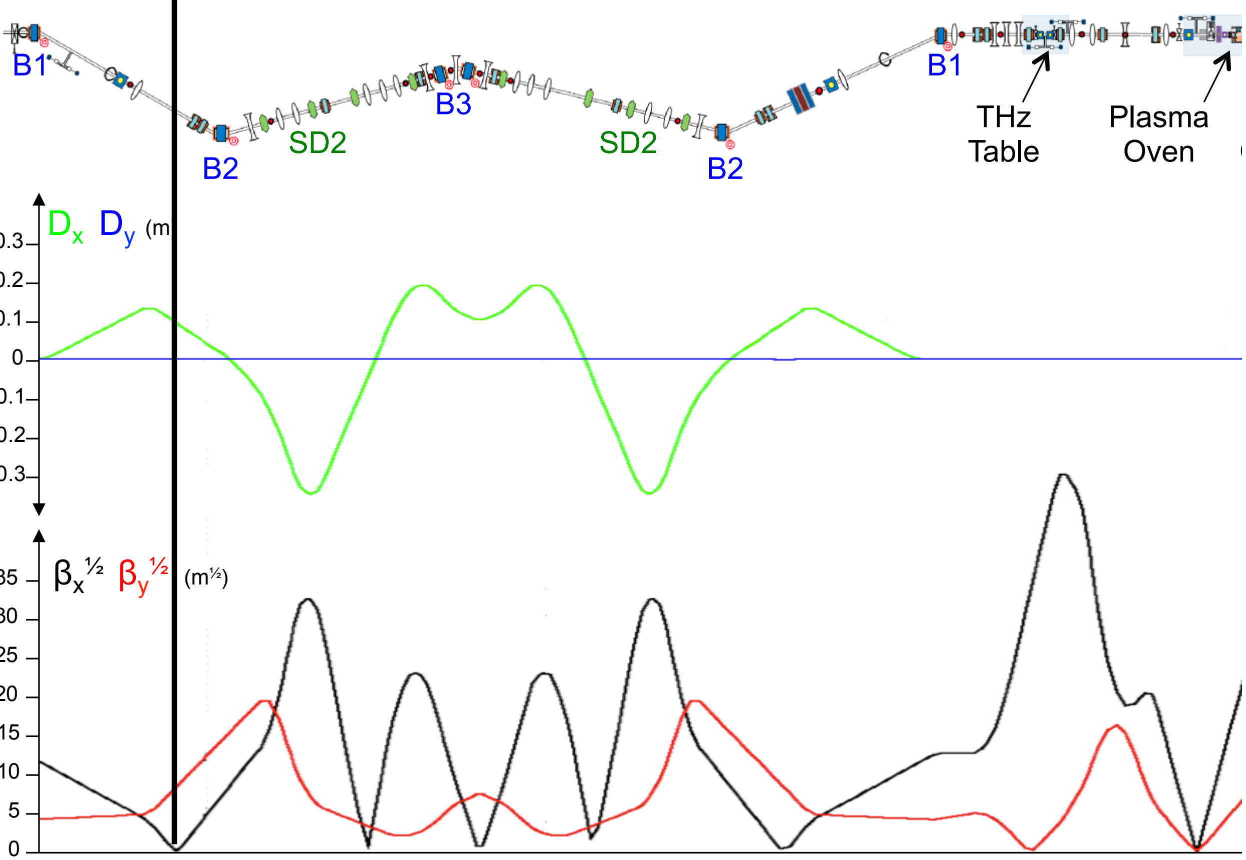

E-Chirp from S10-19 Wake

$x \propto \Delta E/E \propto t$

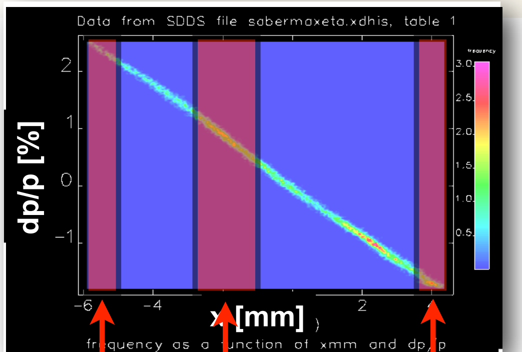
'Optimal Compression'

R56 = 4mm



# Notch Collimator for Two Bunches



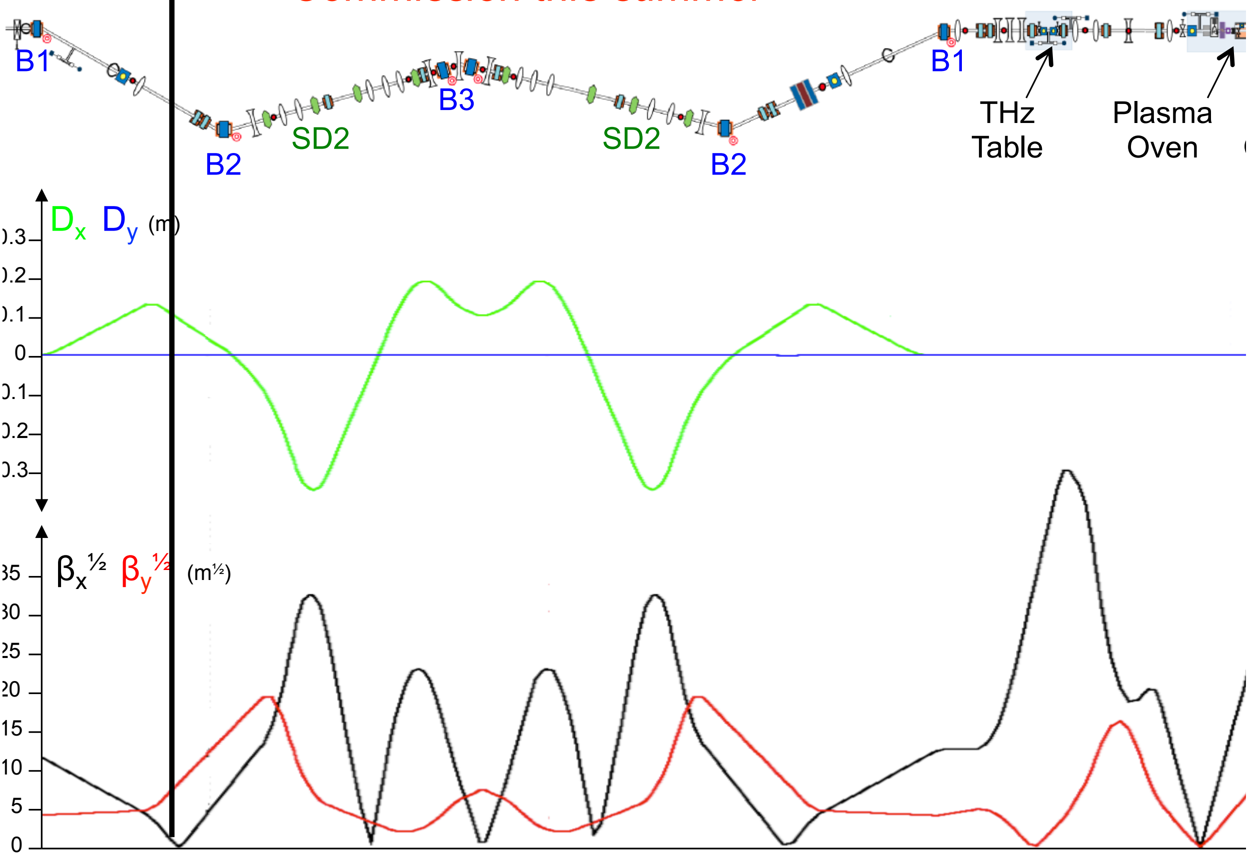

R56 = 10mm

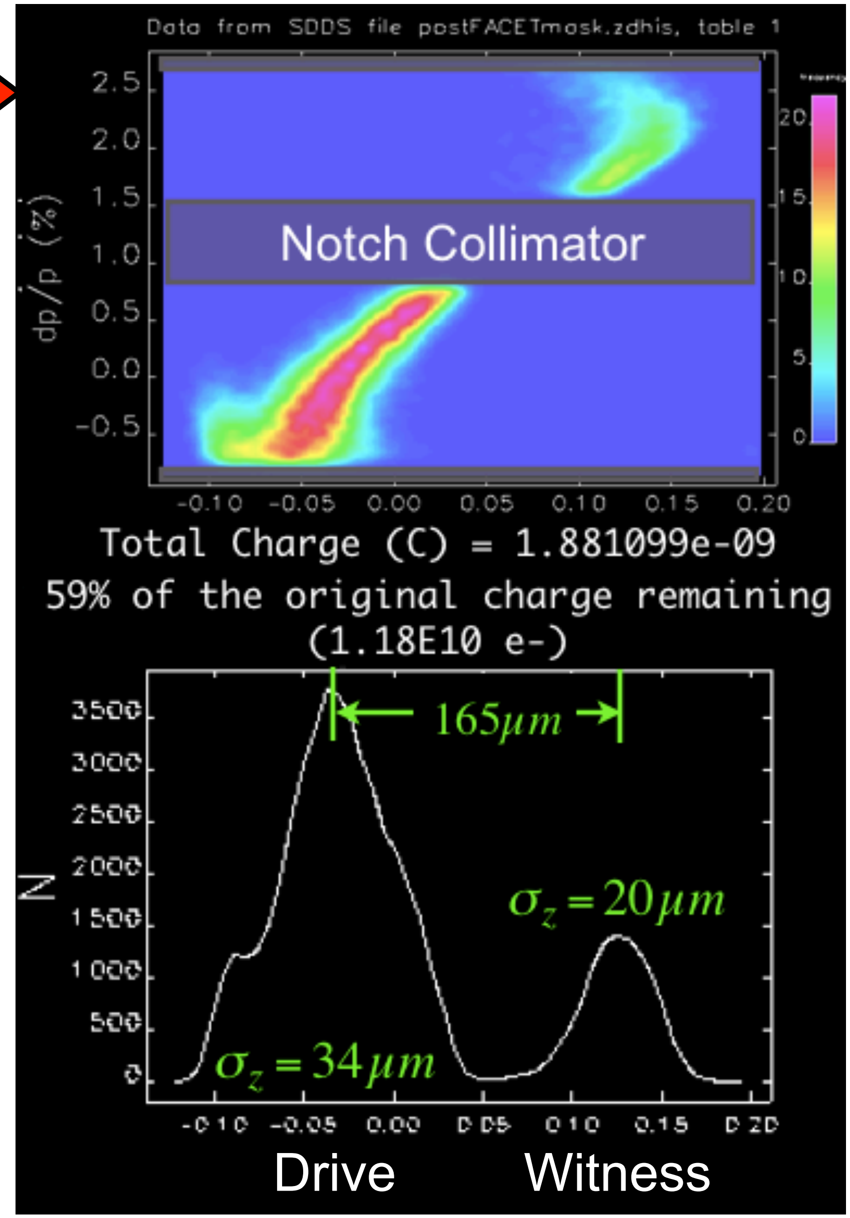
$$x \propto \Delta E/E \propto t$$

'Over-compressed'

...selectively collimate

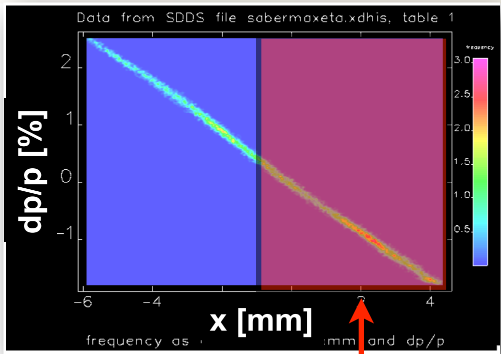
*Commission this summer*



# ...or Ramped Bunch Profiles for High Transformer Ratio

SLAC

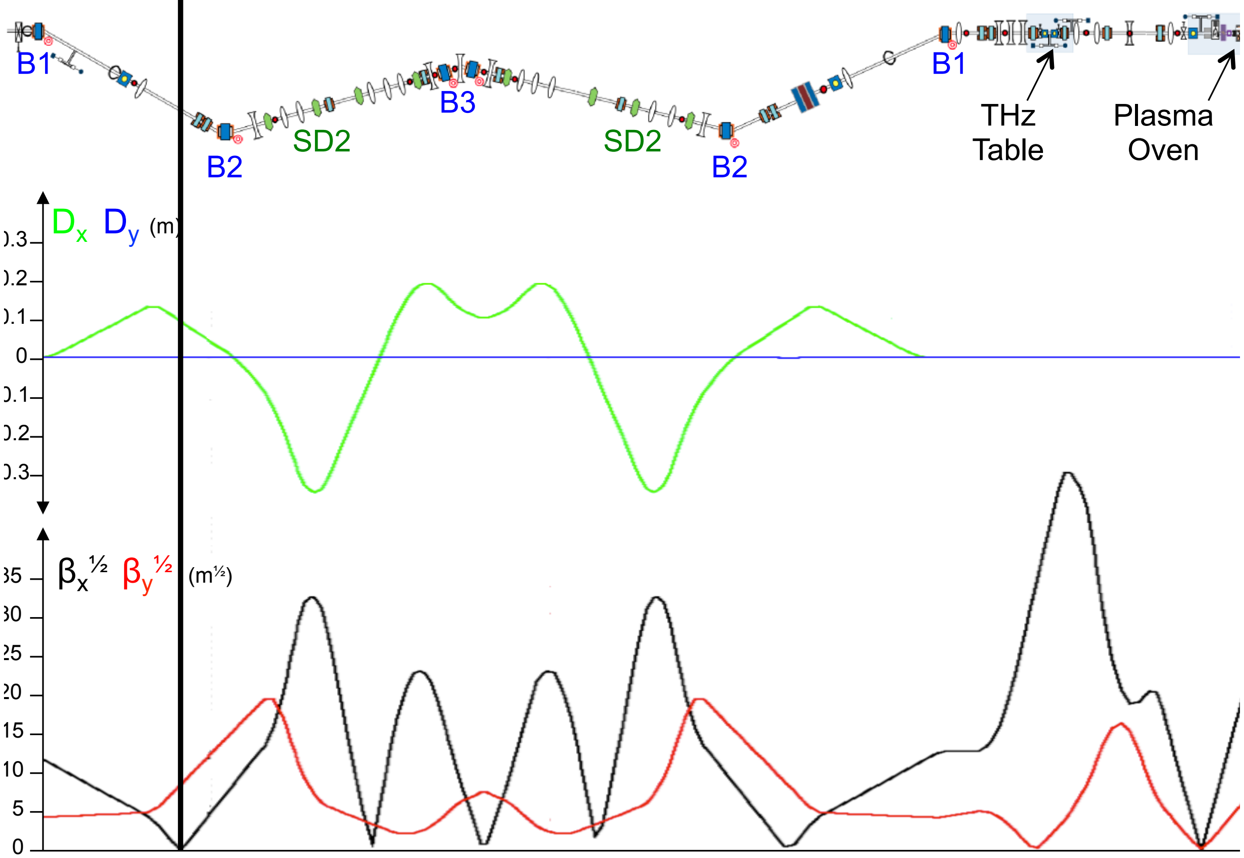


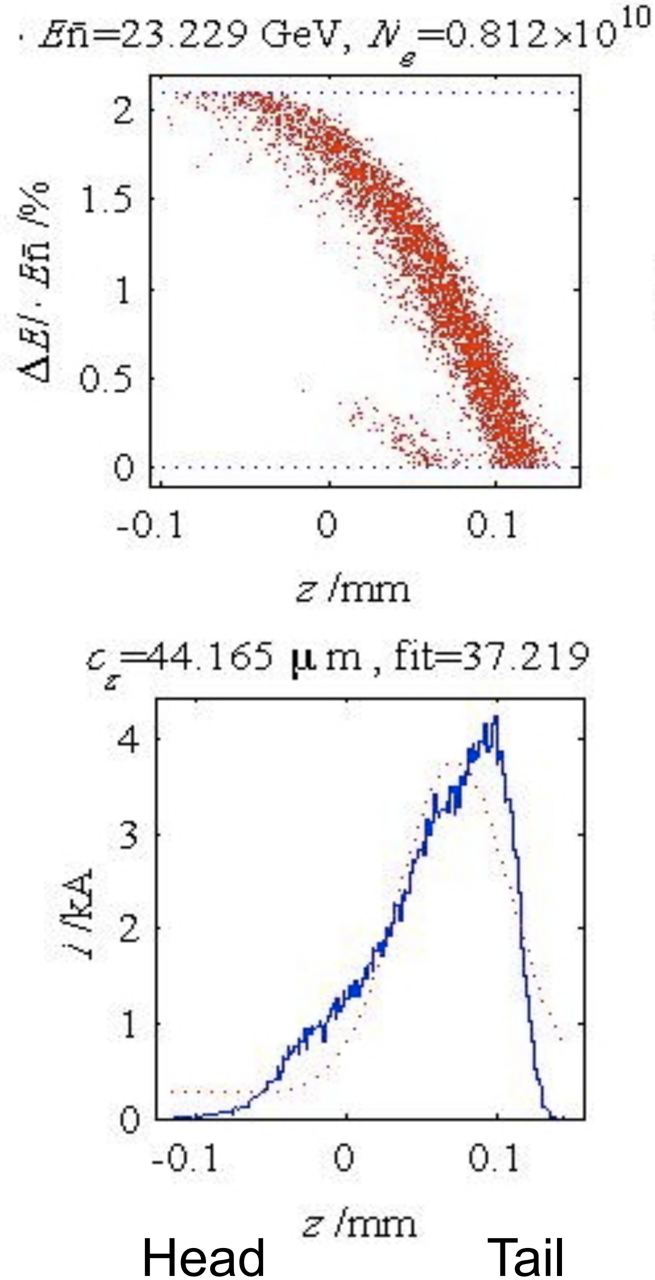

R56 = 0mm

$$x \propto \Delta E/E \propto t$$

'Under-compressed'

...selectively collimate

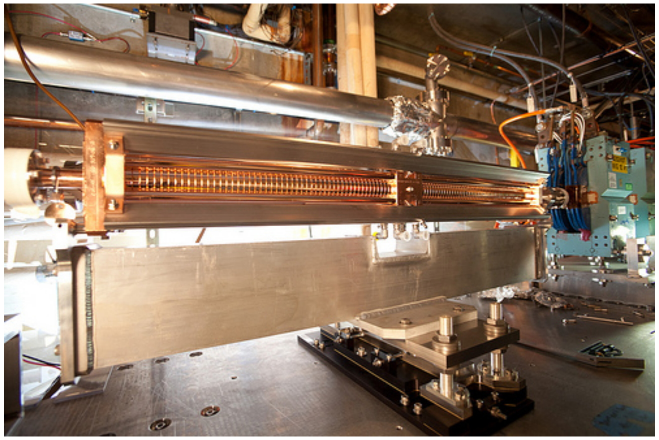


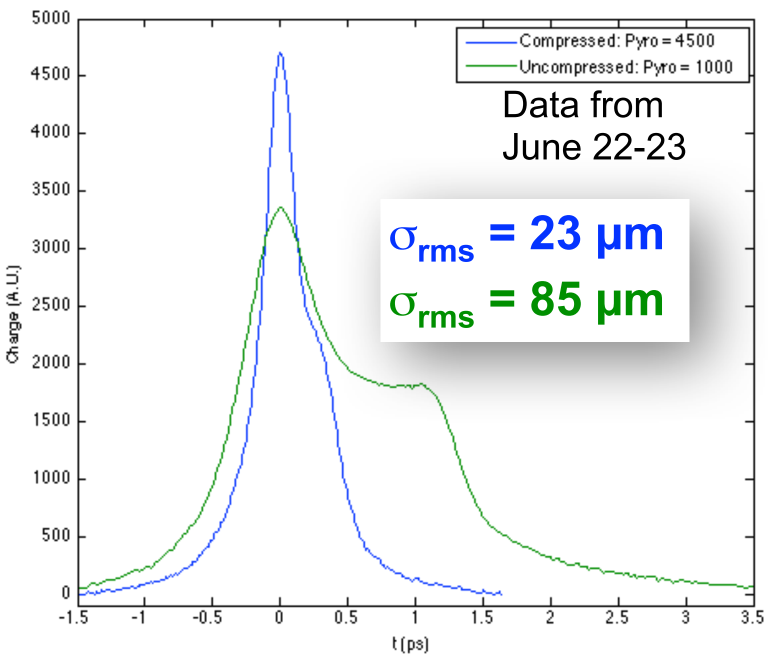
# Progress in 2012:
# Installation and Operation of FACET X-TCAV & Notch Collimator

SLAC

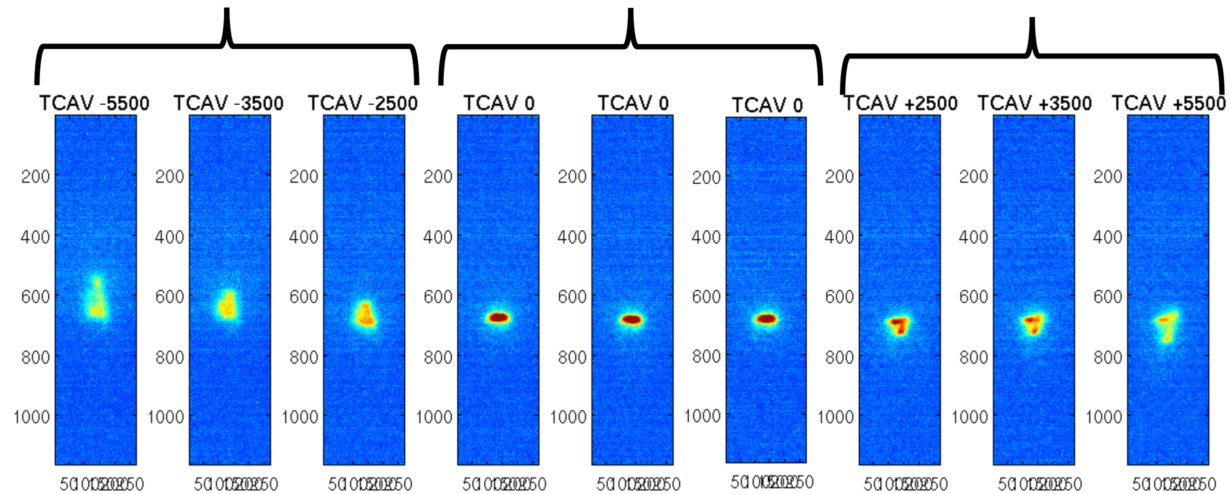
**X-band TCAV installed in Sector 20**

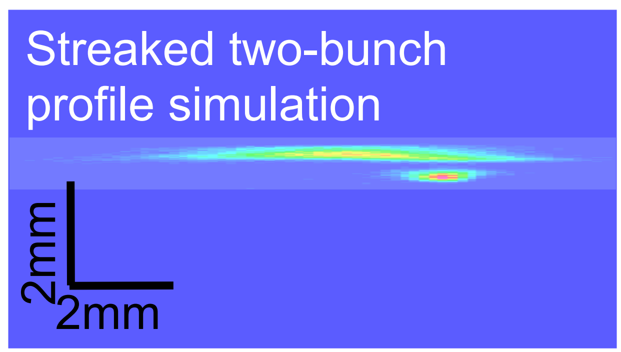


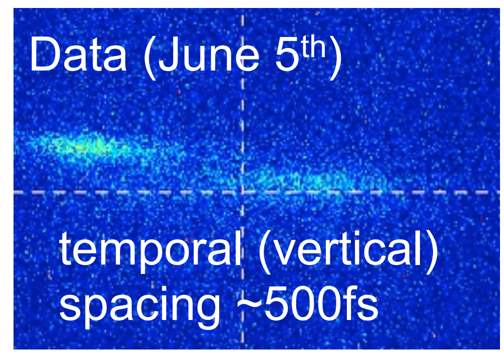
**Measured Temporal Profile**




$\phi$=180˚ TCAV OFF $\phi$=0˚




Now commissioning the tools to make and measure appropriate beams for the two bunch PWFA experiments

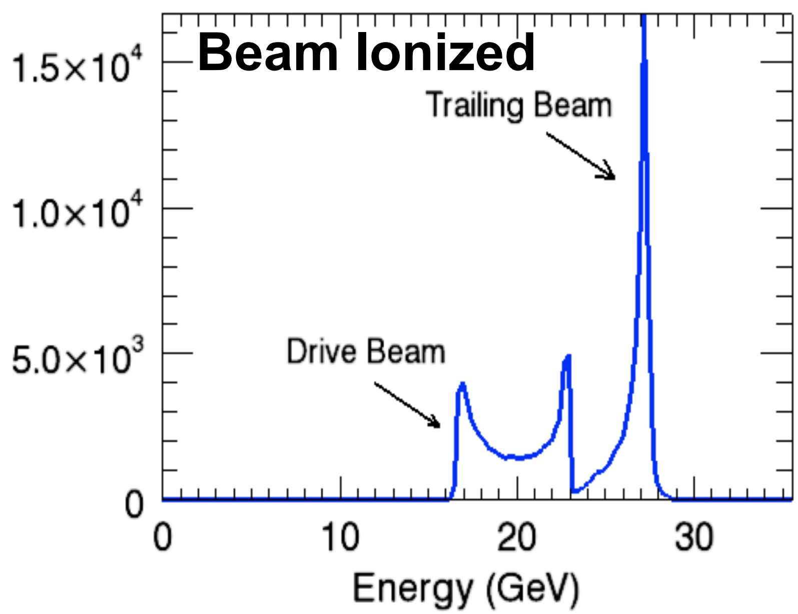
# Plans for 2013:
# Two Bunches with Field Ionized and Pre-ionized plasma

SLAC

**Simulations**

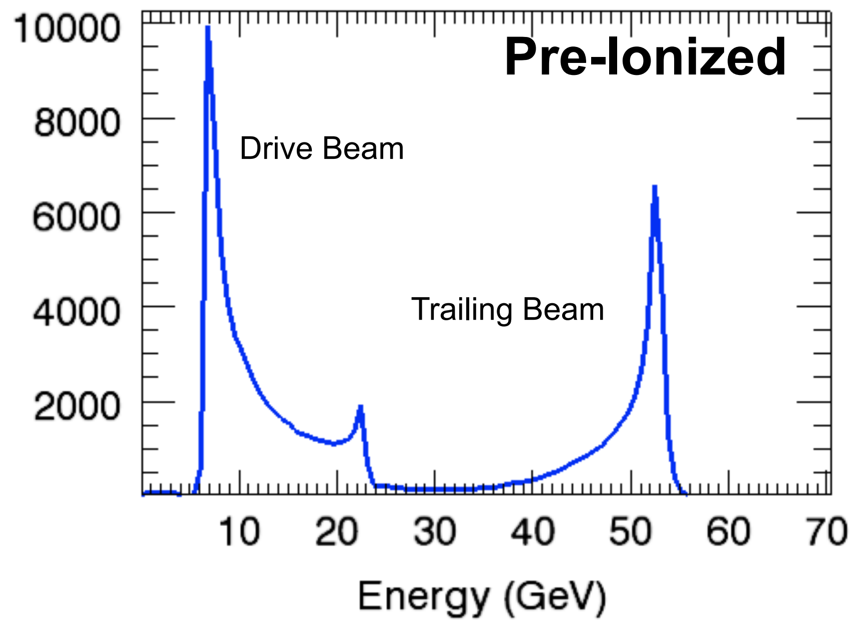
After 88.5 cm of 3.7 x $10^{16}$ plasma

- Energy Gain 5 GeV
- Energy Spread ~ 3%
- Variable with plasma density, beam emittance, ionization potential




After 143 cm of 5 x $10^{16}$ plasma

- Energy Gain 30 GeV
- Energy Spread ~ 5%
- Energy Loss 17 GeV, Beam loading efficiency 64%



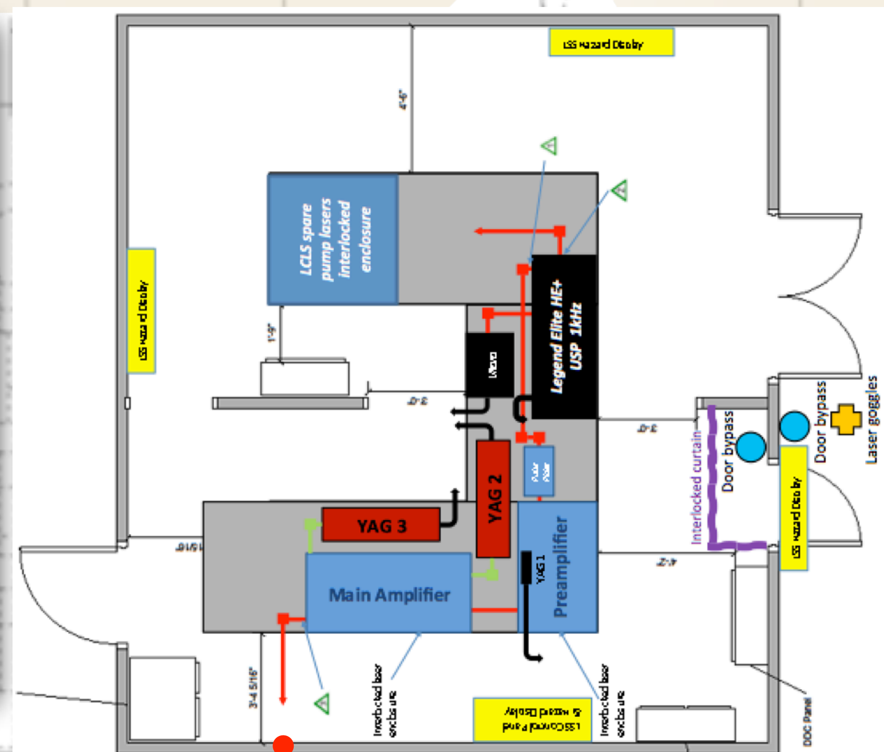

$$V[\mu m/m] = (3.6617 \cdot 10^4)\epsilon_i^{1.73}[eV]\frac{\epsilon_N[mm \cdot mRad]}{\gamma}\frac{1}{I^{3/2}[kA]}$$

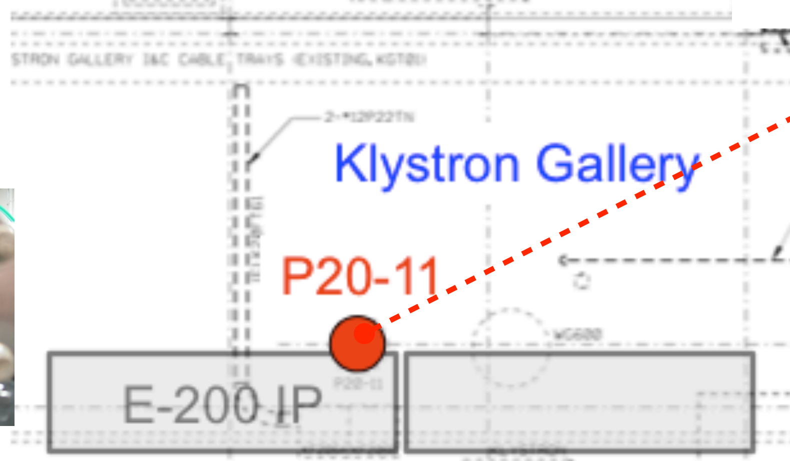
**Need a pre-ionized plasma to maximize single stage performance with two bunches**

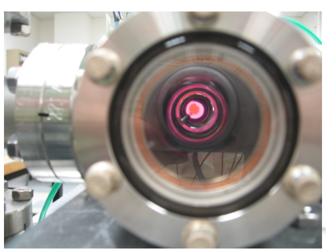
# Plans for 2013:
# Install 10TW Laser System for >1m Pre-ionized Plasma

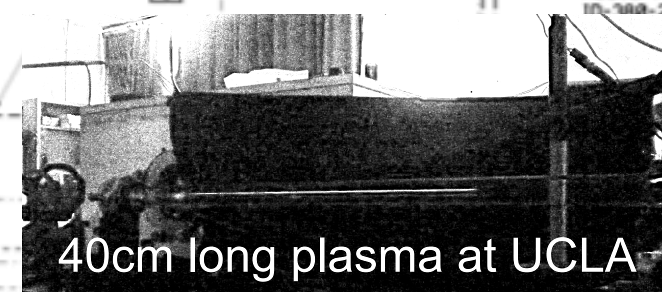
SLAC

- Modifying SW corner of LCLS laser building as we speak
- 10TW laser and transport for production of >1m high-density plasmas
- Opens up many new experimental areas (Trojan Horse, Self-modulation, Plasma holography, THz pump-probe)



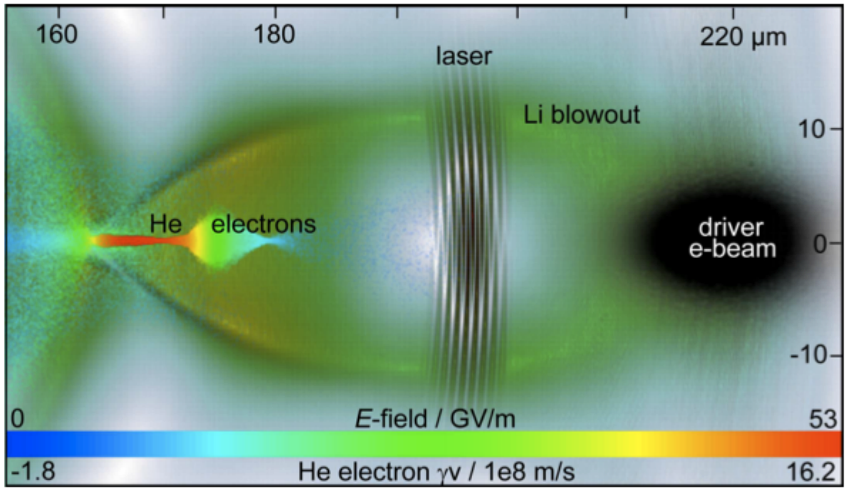






New laser system is essential for the E200 science program

# Expanding Plasma Collaborations and Directions: New Experiments Coming – SAREC October 2012 Meeting

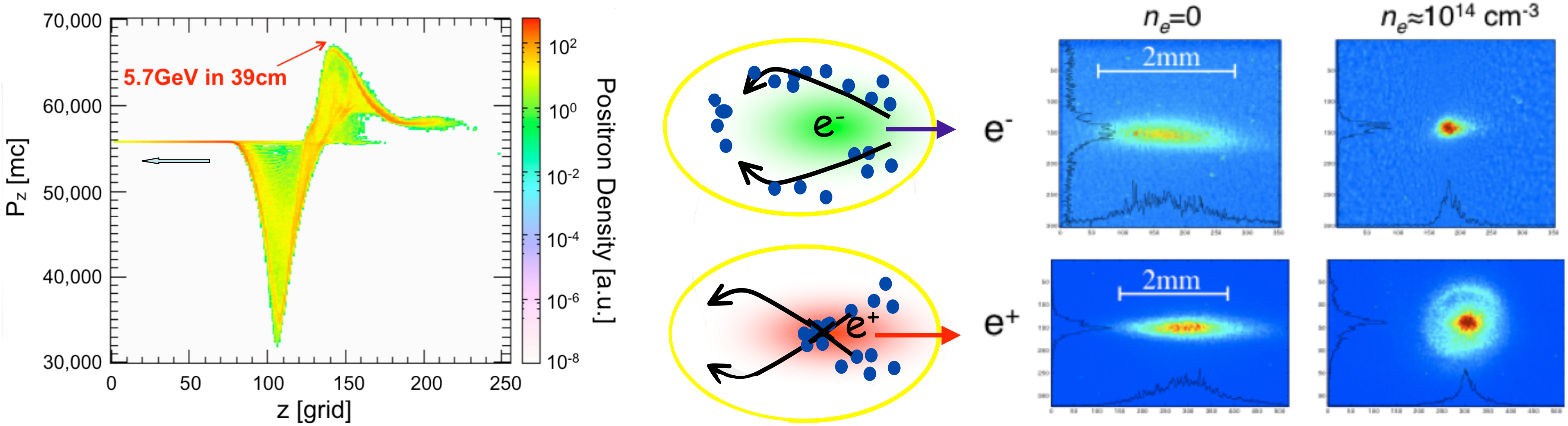
- Trojan Horse Plasma Wakefield Acceleration
  - (UCLA/SLAC/Tech-X/MPI/HHU)
- Study of the Self-Modulation of Long Lepton Bunches in Dense Plasmas and its Application to Advanced Acceleration Techniques
  - (IST/MPI/SLAC)
- Investigation of Hot Plasmas and Fourier Domain Holography of Plasma Wakes
  - (Duke/SLAC/U.T. Austin/UCLA)
- *Others too, but not with plasma*




Facility upgrades like the laser are enabling additional programs that will accelerate progress and increase FACET science output

# 2013-2014:
# PWFA with Compressed Positron Bunches for the First Time

QuickPIC simulation, $\sigma_z$=15µm, N=2x10$^{10}$e$^-$, $\sigma_r$=10µm, n$_e$=2x10$^{17}$cm$^{-3}$, E$_0$=28GeV




*Phys. Rev. Lett.* **101**, 055001 (2008)

- Accelerating gradient ~ 15GeV/m
- Large energy spread
- Emittance growth (transverse, longitudinal field variations)
- Opportunity for new ideas, original solutions...
- Acceleration of e+ on e- driven wake?

# Conclusion

Any Questions?