Possible USC Experiments at NML

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PWFA experiments with collider beams

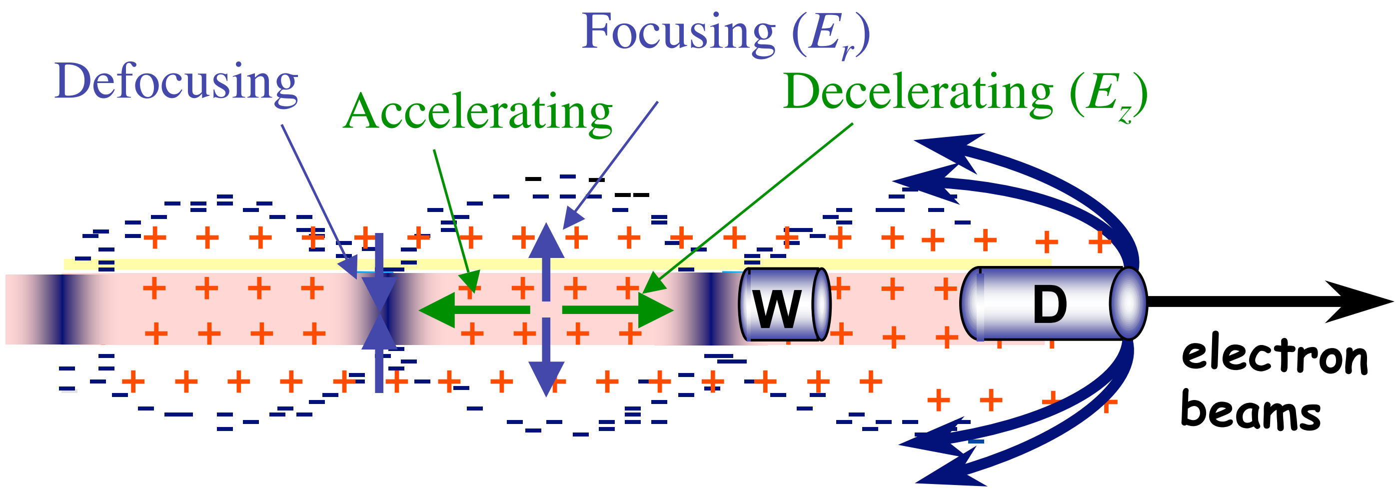
Two important PWFA issues related to PWFA-LC:

1) plasma/gas behavior with large power deposition from the drive beam (P. Muggli)

2) Plasma ion motion due to very dense, low emittance high charge beams (R. Gholizadeh)

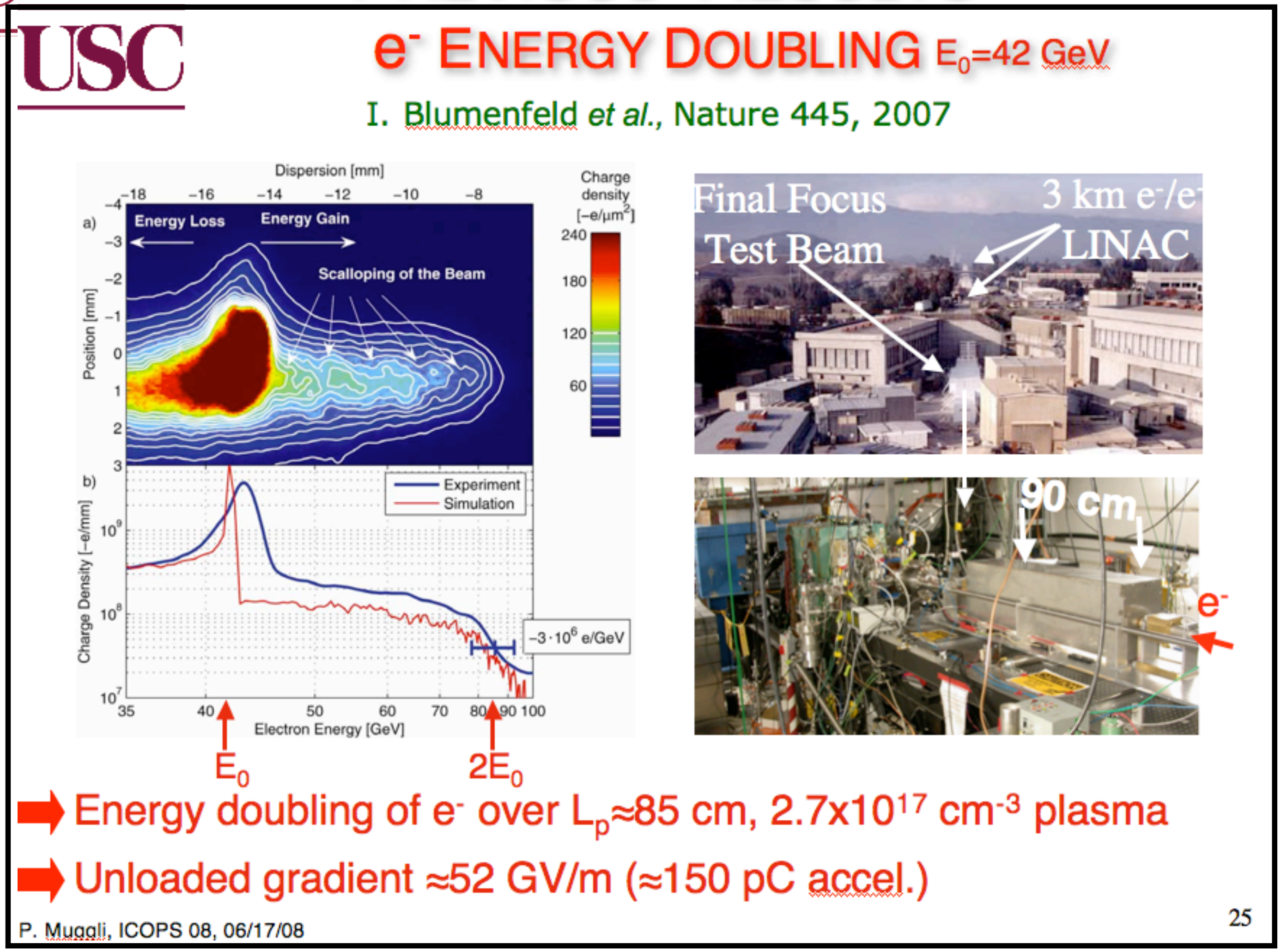
USC PLASMA WAKEFIELD ACCELERATOR* 101

- Two-beam, co-linear, plasma-based accelerator



- Deceleration, acceleration, focusing by plasma
- Accelerating field/gradient scales as N/σ_z^2
- $N=2\times10^{10}$: $\sigma_z=600\ \mu m$, $n_e=2\times10^{14}\ cm^{-3}$, $E_{acc}\sim100$ MV/m, $B_\theta/r=6$ kT/m
  $\sigma_z=20\ \mu m$, $n_e=2\times10^{17}\ cm^{-3}$, $E_{acc}\sim10$ GV/m, $B_\theta/r=6$ MT/m
- Conventional accelerators: $E_{acc}<150$ MV/m, $B_\theta/r<2$ kT/m
- High-gradient, high-efficiency energy transformer

PREVIOUS RESULTS

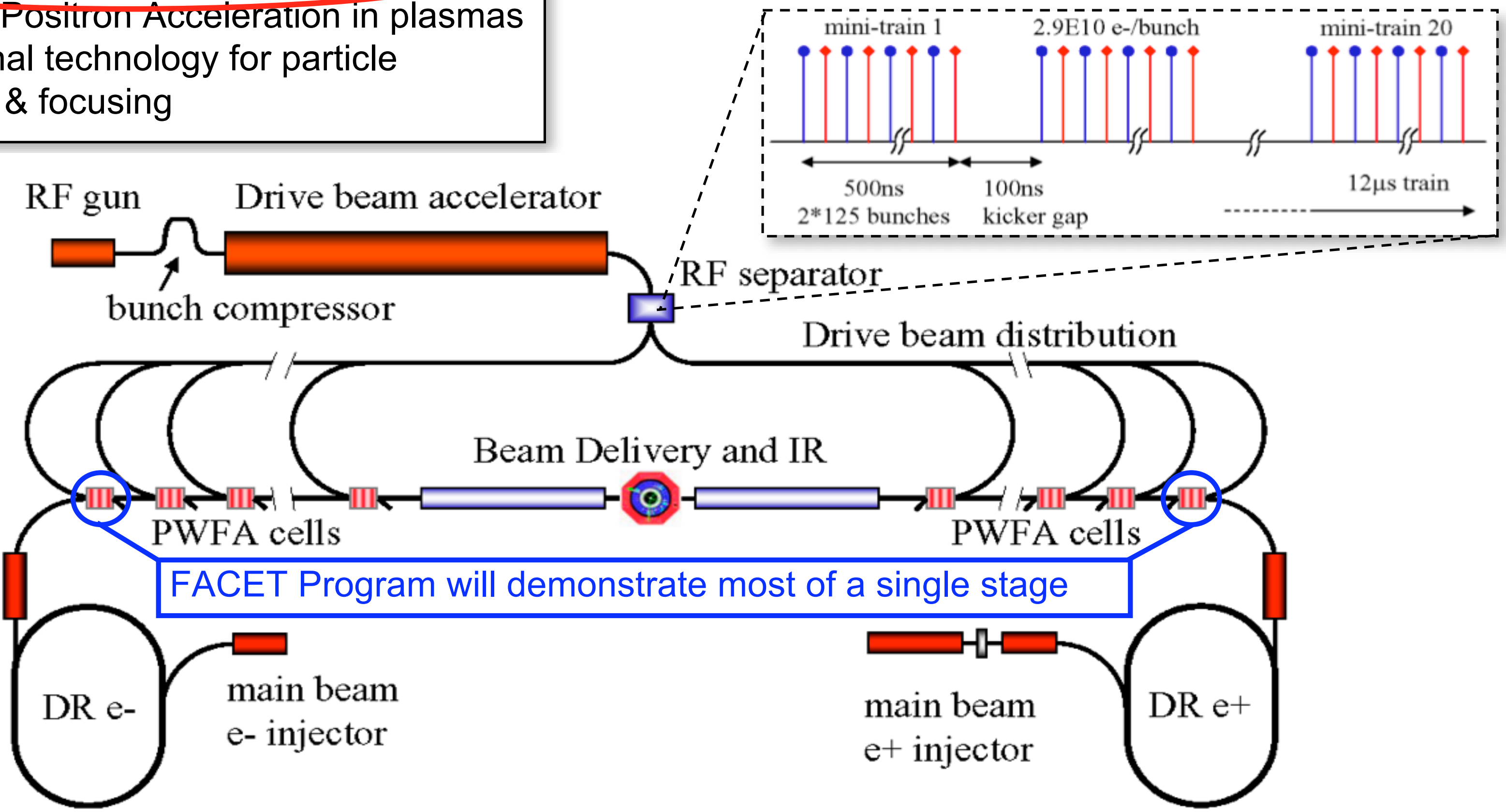


- Tremendous progress with PWFA
- Acceleration, transverse dynamics, positrons, etc.
- “Single bunch” experiments (1Hz)

PWFA-LC Concept (an example)

July 7, 2008

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



- ♦ FACET*@SLAC: single, 1m-long, +25 GeV stage, e^- and e^+
- ♦ 1-10 Hz rep. rate ("single shot")

*Facilities for Accelerator Science and Experimental Test Beams

High average drive beam power, finite transfer efficiency

Questions:

What happens to the plasma and gas?

Does the plasma recombines slowly because of high T_e?

Does heat deposition create shock wave in the plasma and gas?

Does the gas expand radially and does it have a lower density for the next bunch?

Can a favorable equilibrium be reached over the bunch train?

How to reach the equilibrium?

Assumed parameters:

- L-band RF photoinjector source
- 40 MeV low energy injector energy; up to 1.5 GeV high energy beam
- Capable of ILC-like beam parameters:
  - 3.2 nC/bunch; 3 MHz bunch rate; 1 ms long bunch train; 300 mm RMS bunch length; 5 Hz operation
- normalized transverse emittance ~5 µm
- Higher bunch rates for Project X cryomodule testing possible
- Peak currents 10 – 15 kA possible
- single bunch intensity over 10 nC possible

The beam can be compressed and focused to $(20\text{x}20\text{x}20)\mu m^3$ (similar to SLAC beam at FFTB!)

Largest energy loss is 1.5GeV in 10GeV/m plasma with $n_e=10^{17}cm^{-3}$

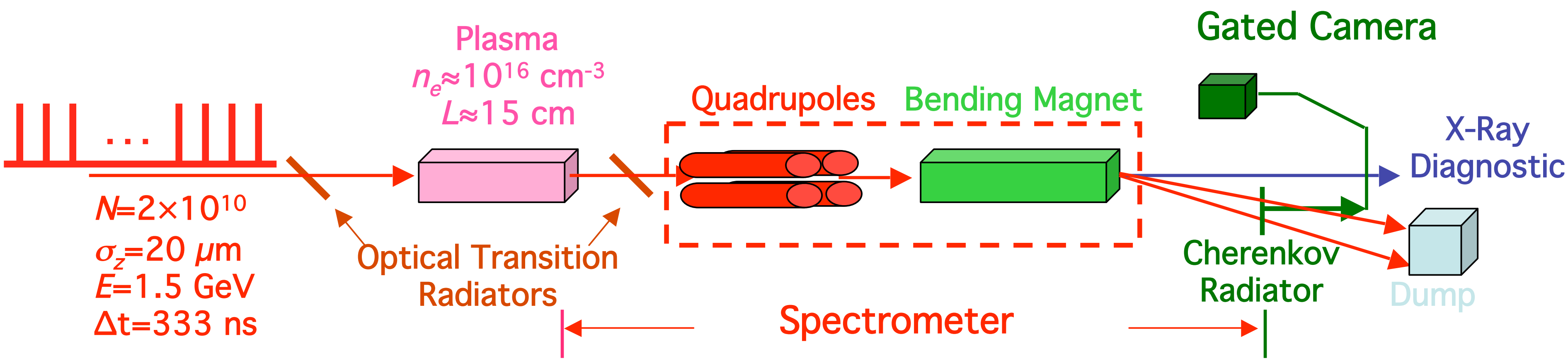
Half the beam energy (2.5J) is deposited in a gas/plasma 1.5GeV/10GeV/m=15cm long and c/ω_p (17µm) in radius ($0.14mm^3$)

$\Delta T=Q/mC=4272^{o}C$ for liquid water

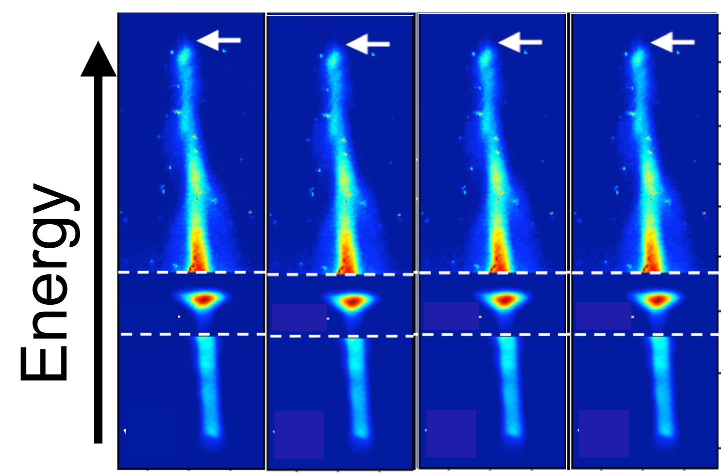
This repeats 3000 times, every 333ns, at 5Hz

Proposed experiments:

1) Measure the energy spectrum of successive bunches in the train using a gated camera and prompt radiation (Cherenhov?)
2) Measure focusing …



Sample gas/plasma state at bunches interval of 333 ns with bunches



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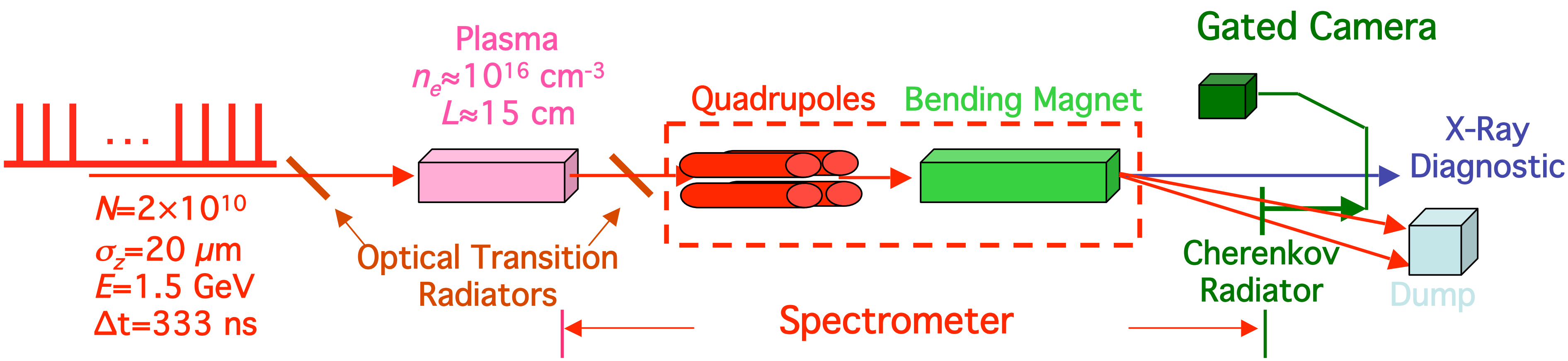

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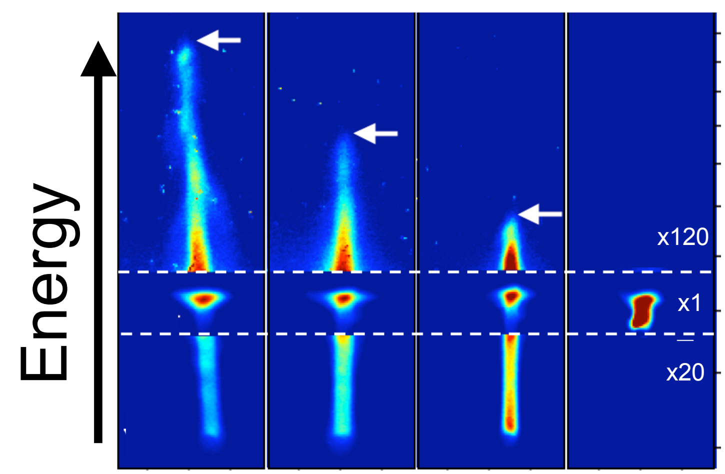
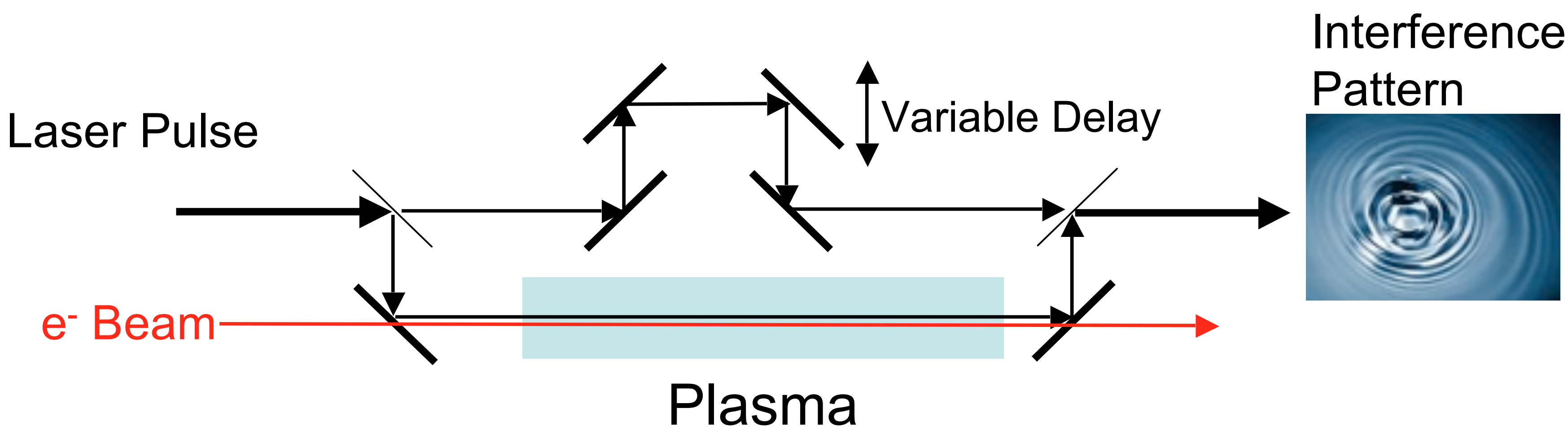


USC

3) Interferometry along the plasma



Delay laser pulse wrt e^- beam for evolution at <333ns scale after each bunch

Phase shift due to plasma and gas density variations (recombination, thermal expansions, etc.)

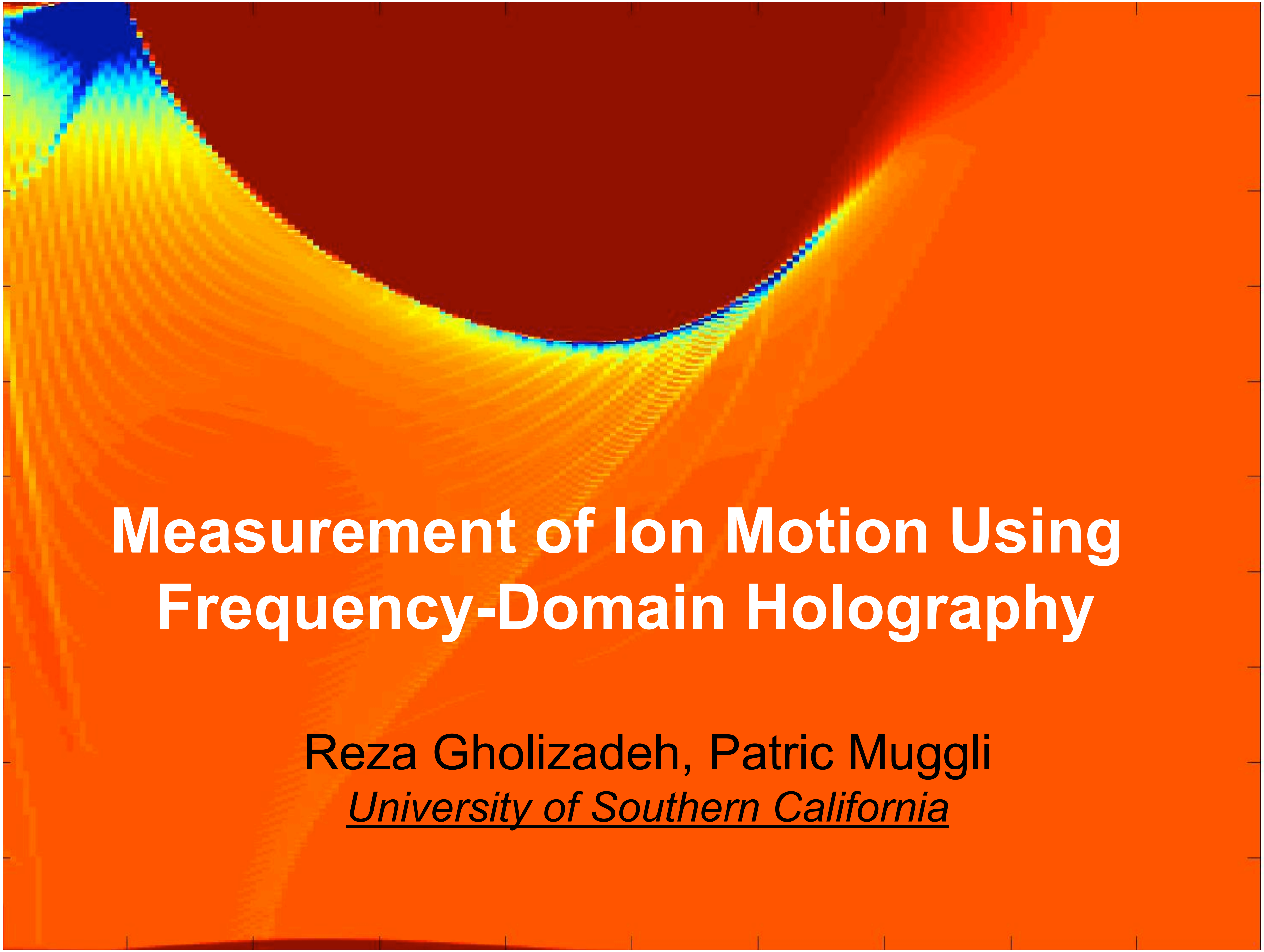
Use Li plasma source

Field ionization for plasma creation

Standard diagnostics for beam size and shape: OTR

Standard diagnostics for beam energy: imaging spectrometer with Cherenkov radiator

Interferometry requires laser synchronized with e^- beam, ns time scale

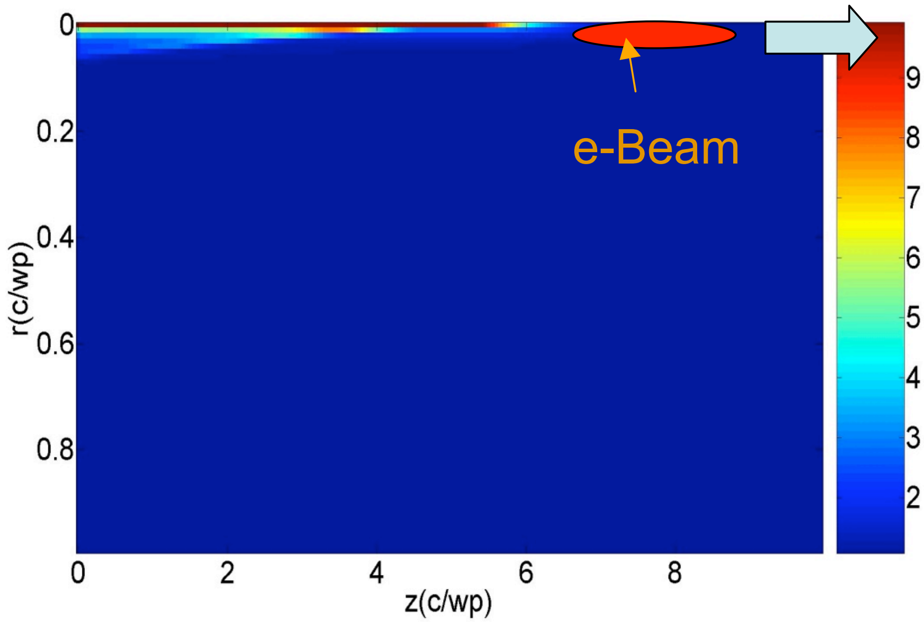


Measurement of Ion Motion Using Frequency-Domain Holography

Reza Gholizadeh, Patric Muggli

University of Southern California

Ion Motion in the presence of a beam



Hydrogen :

$n_o = 10^{16} cm^{-3}$

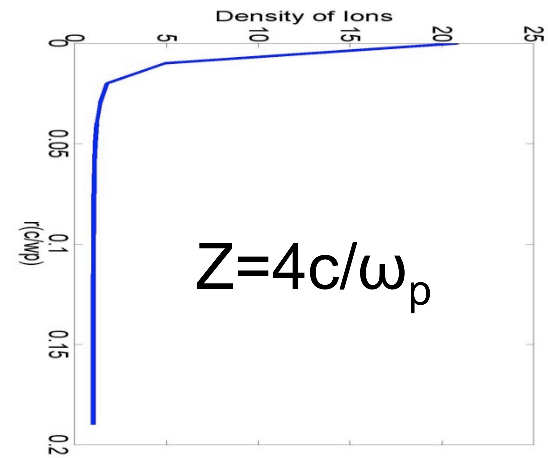
Beam :

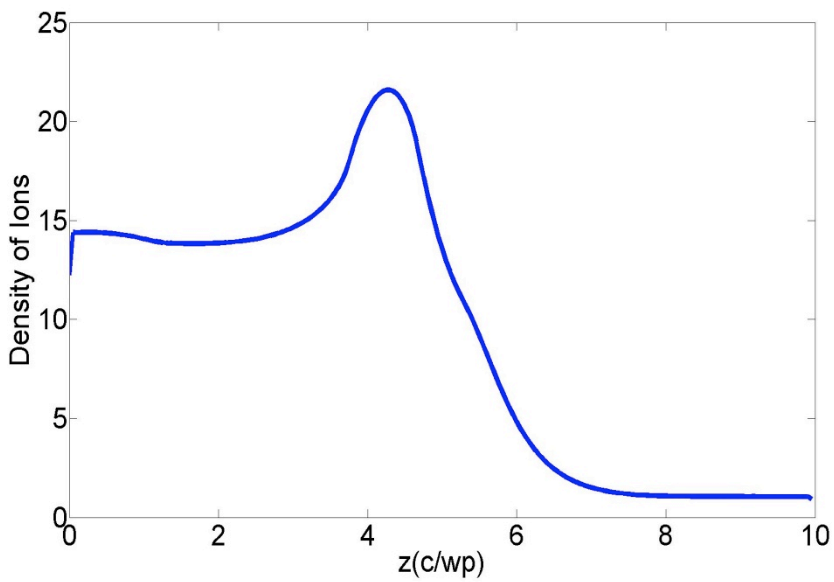
$\sigma_r = 13 \mu m$

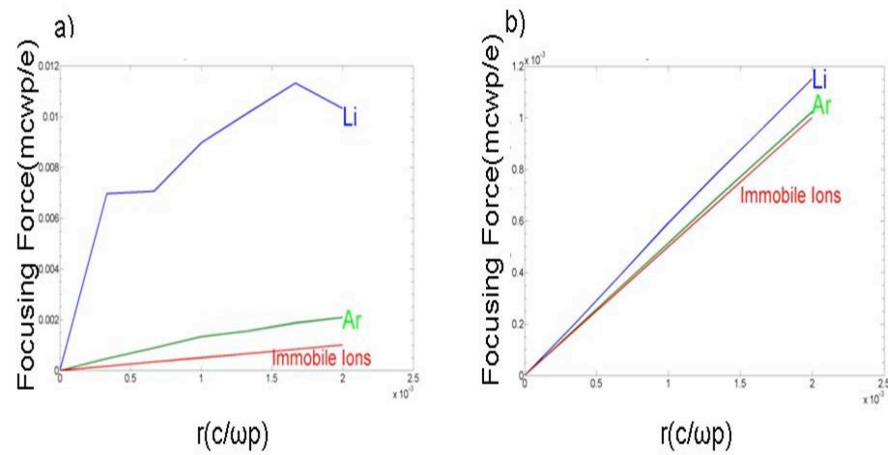
$\sigma_z = 35 \mu m$

$N_b = 1.5 \times 10^{10}$

250GeV



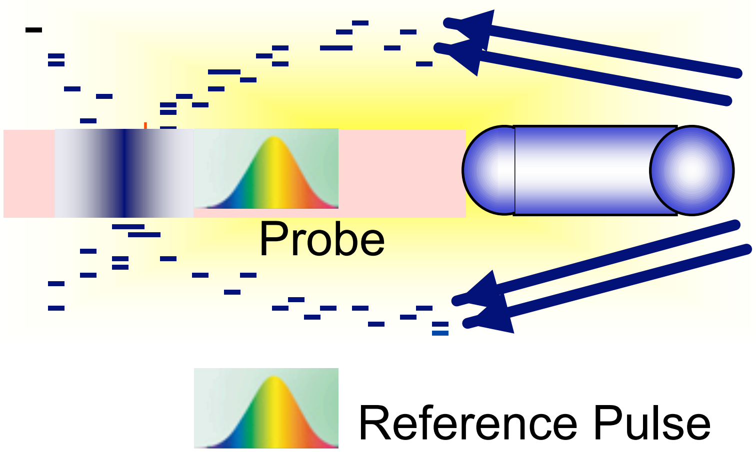


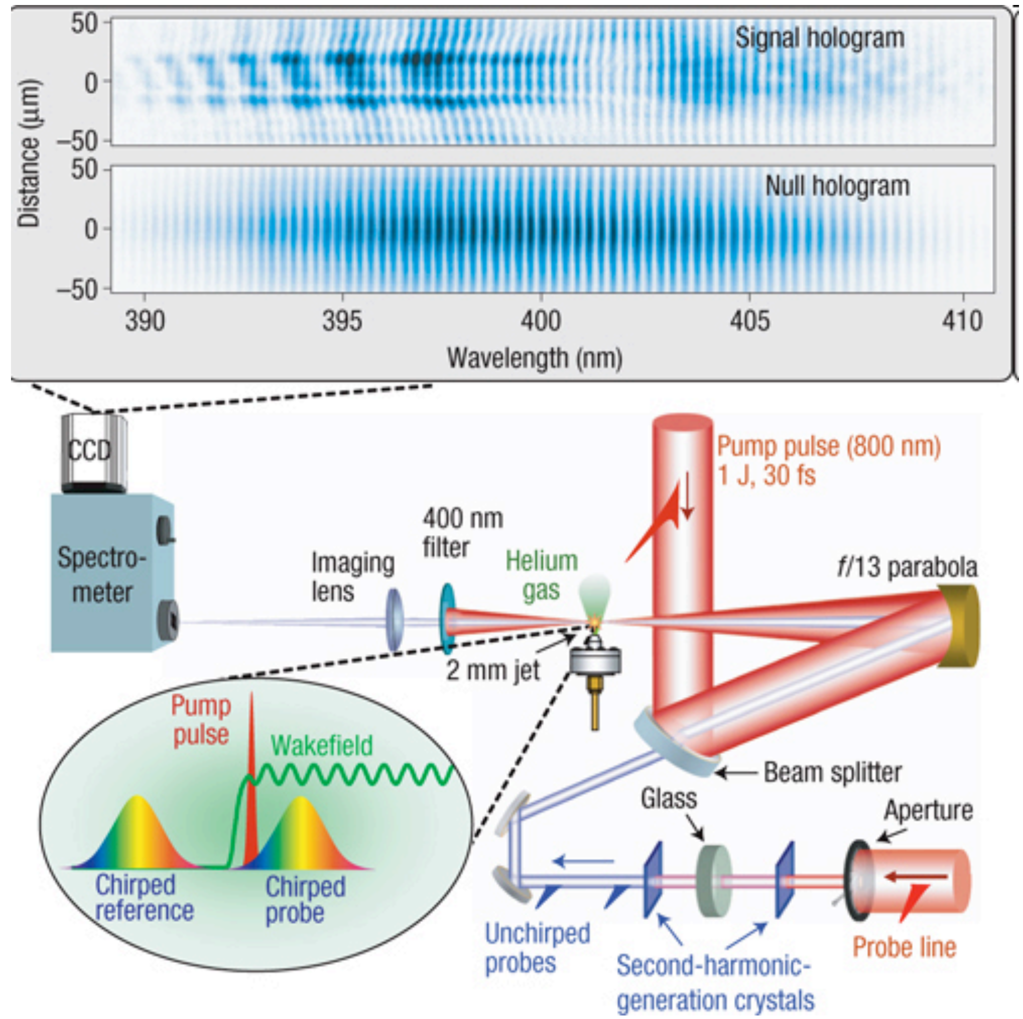


Tail

Head

Frequency-Domain Holography (FDH)





- **Phase Shift Δφ is measured by comparing Probe phase with Reference phase**
- **Phase Shift Δφ depends on the index of refraction**
- **Probe pulse is chirped to extract the information on longitudinal position**
- **The entire 3D image can be made in a single shot by using a chirped wave plane.**

N. H. Matlis et al., “Snapshots of Laser Wakefields”, Nature Physics 2, 749 - 753 (2006)

Calculations

$$\varphi_{ref} = k_0 L$$

$$\varphi_{probe} = n k_0 L = \sqrt{\varepsilon} k_0 L$$

$$\sqrt{\varepsilon} = \left(1 - \frac{\omega_{pe}^2 + \omega_{pi}^2}{\omega_0^2}\right)^{1/2} \approx 1 - \frac{\omega_{pe}^2 + \omega_{pi}^2}{2\omega_0^2}$$

$$\Rightarrow \Delta\varphi = -\frac{\omega_{pe}^2 + \omega_{pi}^2}{2\omega_0^2} k_0 L$$

$\omega_{pe}^2 \sim n_e/m_e$

$\omega_{pi}^2 \sim n_i/M_i$ No Ion Motion: $n_i = n_e = n_0$ $\Delta\varphi = -(\omega_{pe}^2/2\omega_0^2) K_0 L$

$M_i = 1836 m_e$ With Ion Motion: $n_i \sim 25 n_0$ $\Delta\varphi = -(\omega_{pe}^2 + \omega_{pi}^2 / 2\omega_0^2) K_0 L$

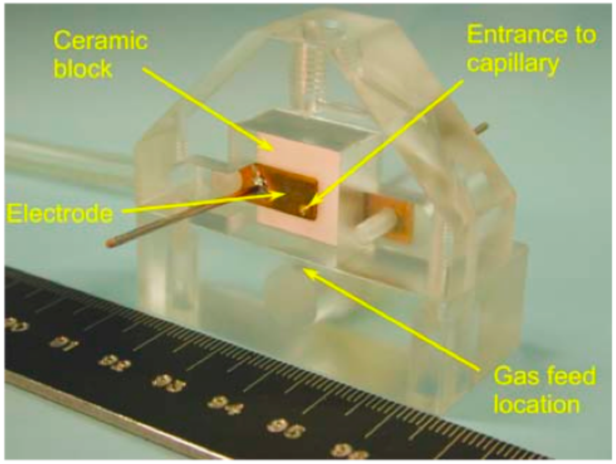
Proposed Experiment:

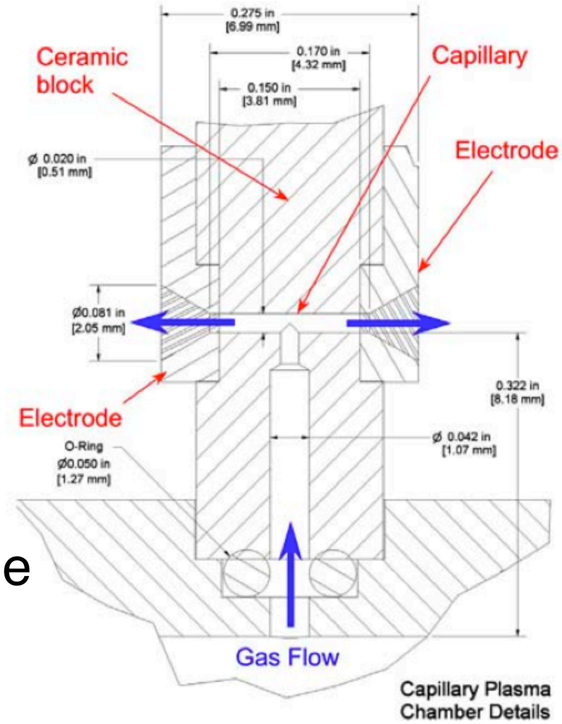
- Inside the bubble, $\omega_{pe}=0$
- Plasma Density= 10^{17} cm^{-3}
- Laser Wavelength λ=500nm
- Capillary Length L=1cm
- Ion Mass=1836 amu (H) (in order to maximize ion motion)

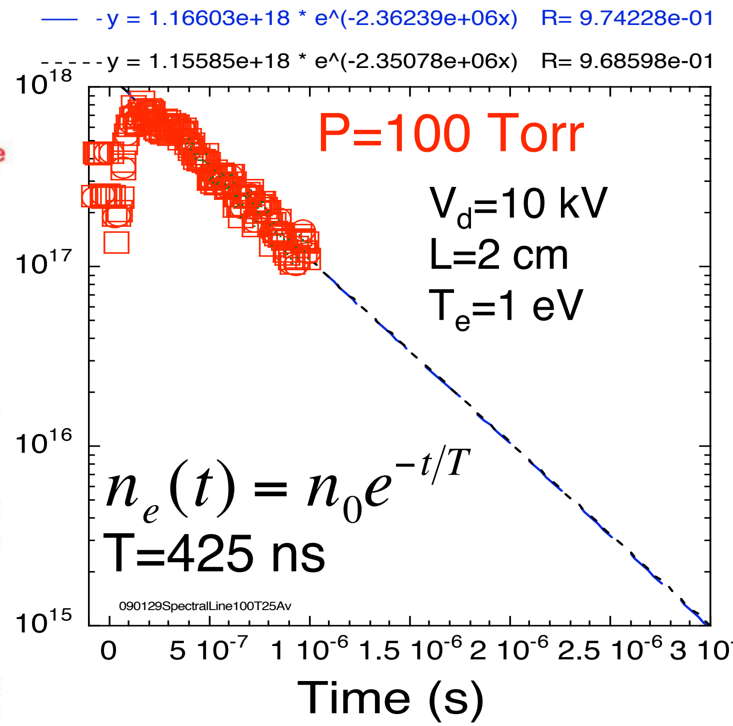
→ $\Delta\varphi \sim \pi/2$

Experimental Expertise on Plasma Sources and FDH

Brookhaven:







H_2-puff Capillary Discharge

- **2 cm long capillary already available**
- **Collaboration with Prof. Downer's group in near future**
- **Experience with FDH**

Take advantage of the unique collider beam format at the ILC Test and AARD Facility at the New Muon Lab (NML) for PWFA experiments

Address PWFA collider issues:

1) Effect of power deposition in the plasma on the acceleration and focusing process

2) Existence of ion motion

Goals:
- complement experiments at SLAC-FACET and BNL-ATF
- use experience acquired at SLAC-FACET and BNL-ATF: plasma source, diagnostics, …
- devise solutions to mitigate these potentially negative effects