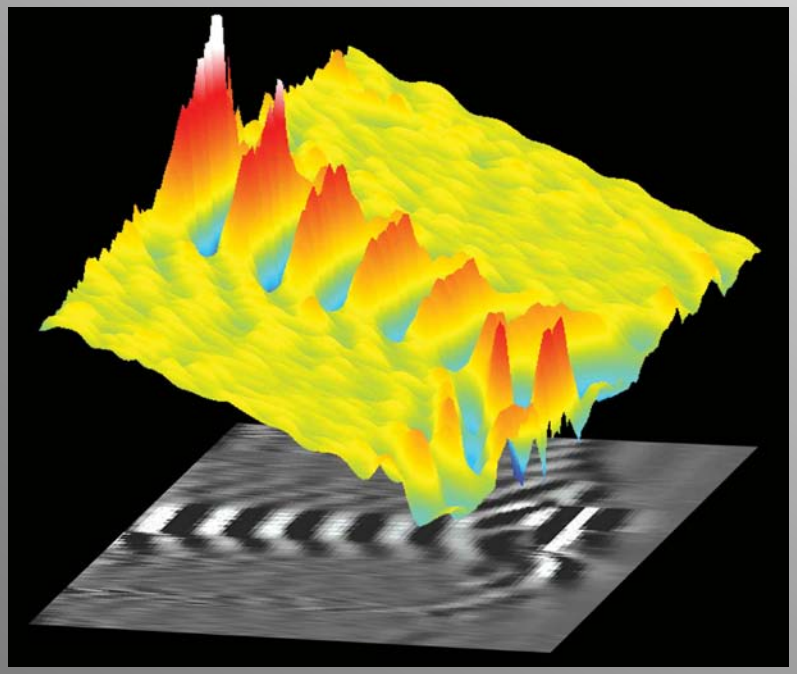
Optical Measurement of Plasma Wave Structure Produced by the Multi-Bunch Driven PWFA.

Rafal Zgadzaj, Austin Yi, Michael C. Downer , Gennady Shvets, *(UT Austin)*
Patrick Muggli *(USC)*
Vitaly Yakimenko, Karl Kusche, Marcus Babzien, Mikhail Fedurin *(BNL/ATF)*

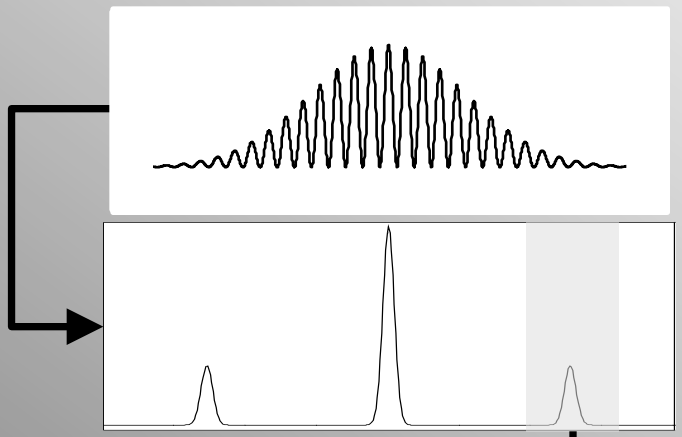
ATF Users Meeting Oct. 6-7, 2010

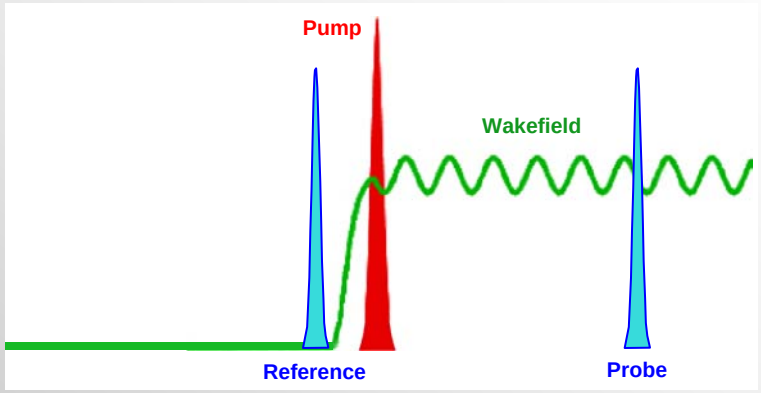


N. H. Matlis, et al., *Nature Physics*, **2**, 749 - 753 (2006)

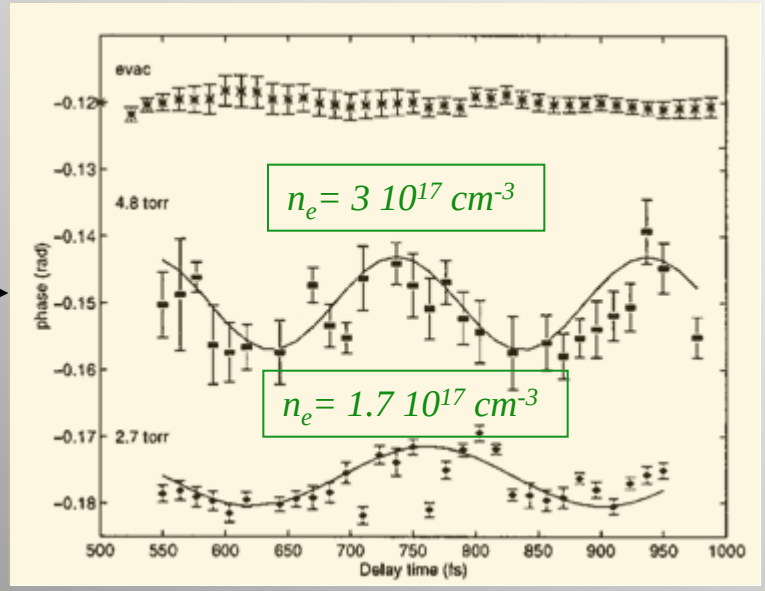
Financial Support: Department of Energy

FDI – Frequency Domain Interferometric reconstruction of laser-driven wakes



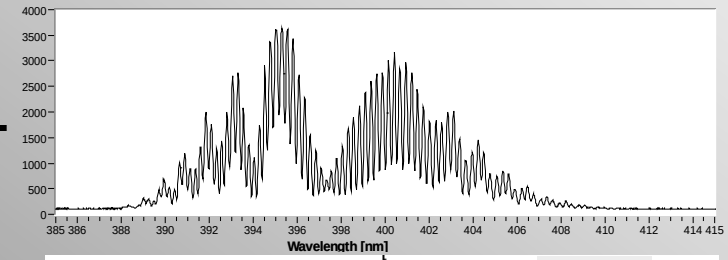


- *Multi shot*
- *Temporal and transverse resolution*
- *Very simple reconstruction*
- *Less sensitive to noise than FDH*
- *Requires good shot to shot repeatability of signal*

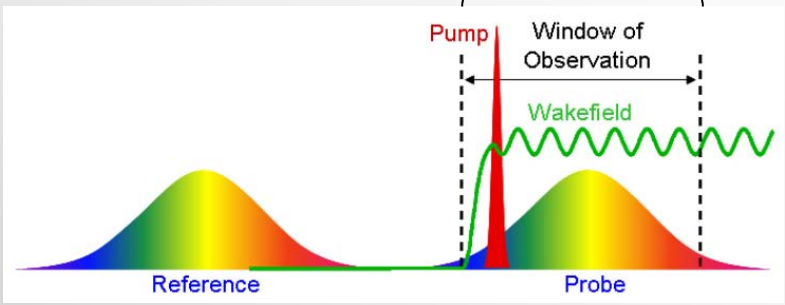


Tokunaga *et al*., Optics Lett. **17**, 1131 (92)
Siders *et al*., PRL **76**, 3570 (96)
Marqués *et al*., PRL **78**, 3463(97)
Kotaki *et al*., Phys. Plasmas **9**, 1392 (02)

FDH – Frequency Domain Holographic reconstruction of laser-driven wakes

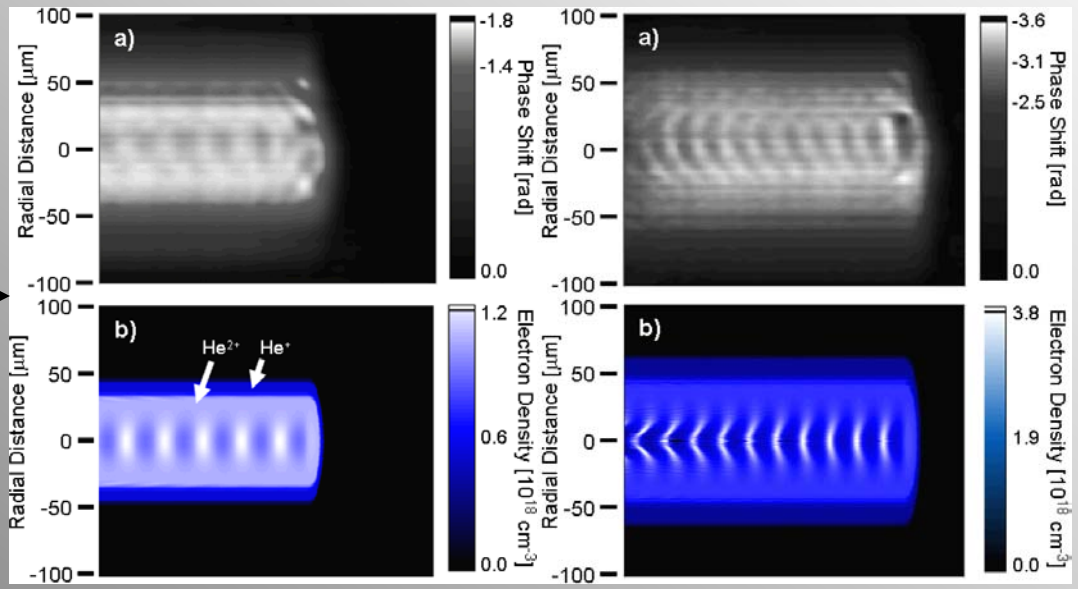


$\Delta t_{probe} \sim 1ps$



$n_e = 10^{18} - 10^{19}\ cm^{-3}$

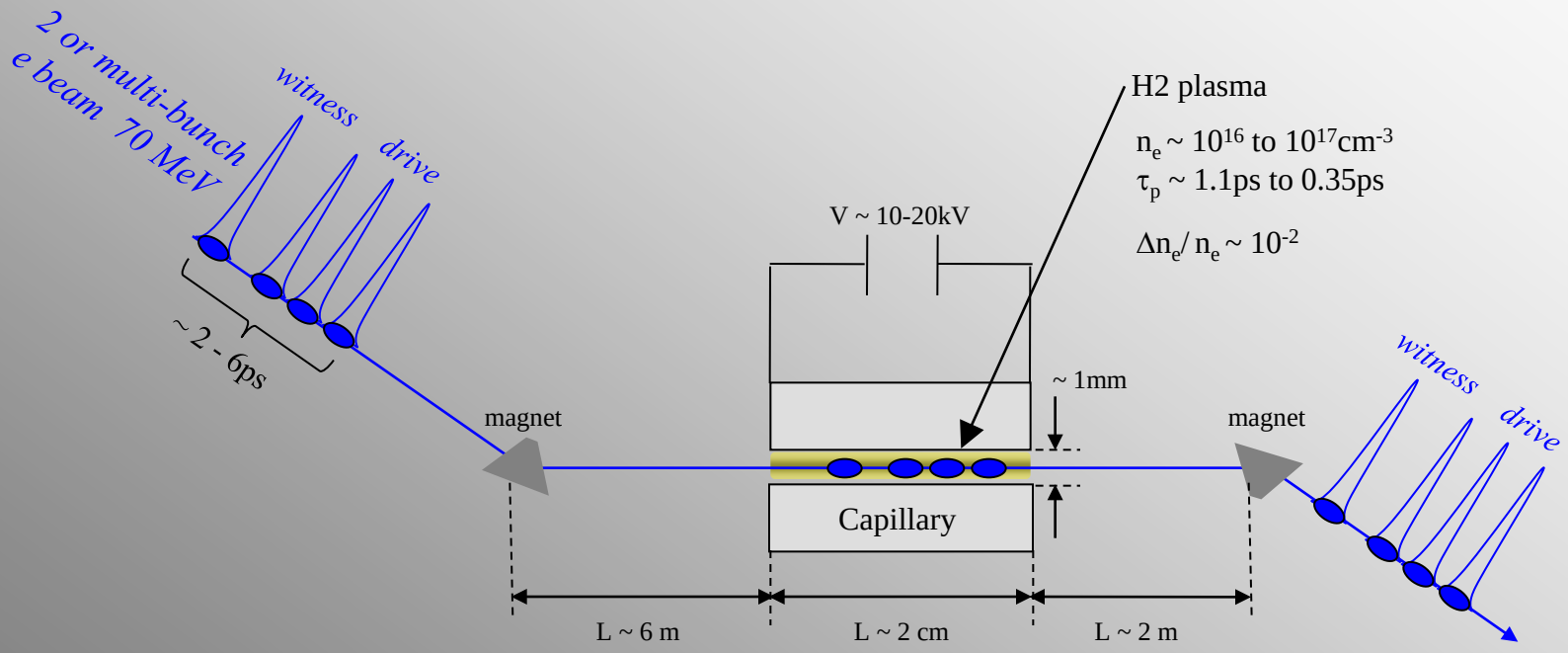
- *Single shot*
- *Temporal and transverse resolution*
- *Signal to noise good for large n_e*
- *Prone to artifacts for low signal levels*
  - *Ionization front*
  - *Continuum generation*
  - *Second harmonic*
  - *Pixelation*
  - *Etc.*

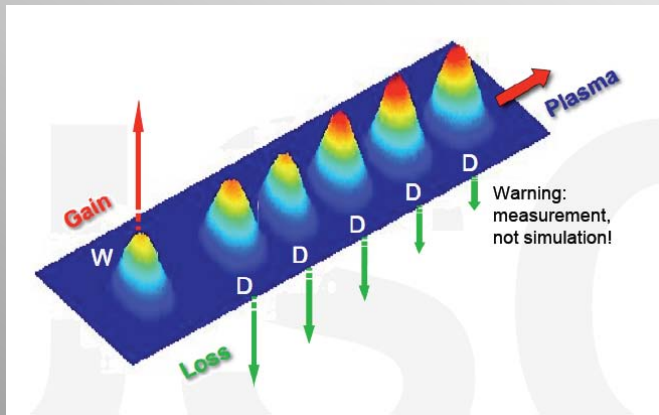


N. H. Matlis, et al., "Snapshots of laser wakefields", *Nature Physics*, **2**, 749 - 753 (2006)

Parameters of BNL ATF experiment

Patric Muggli, Resonant excitation of plasma wakefields, WG4, AAC 2010

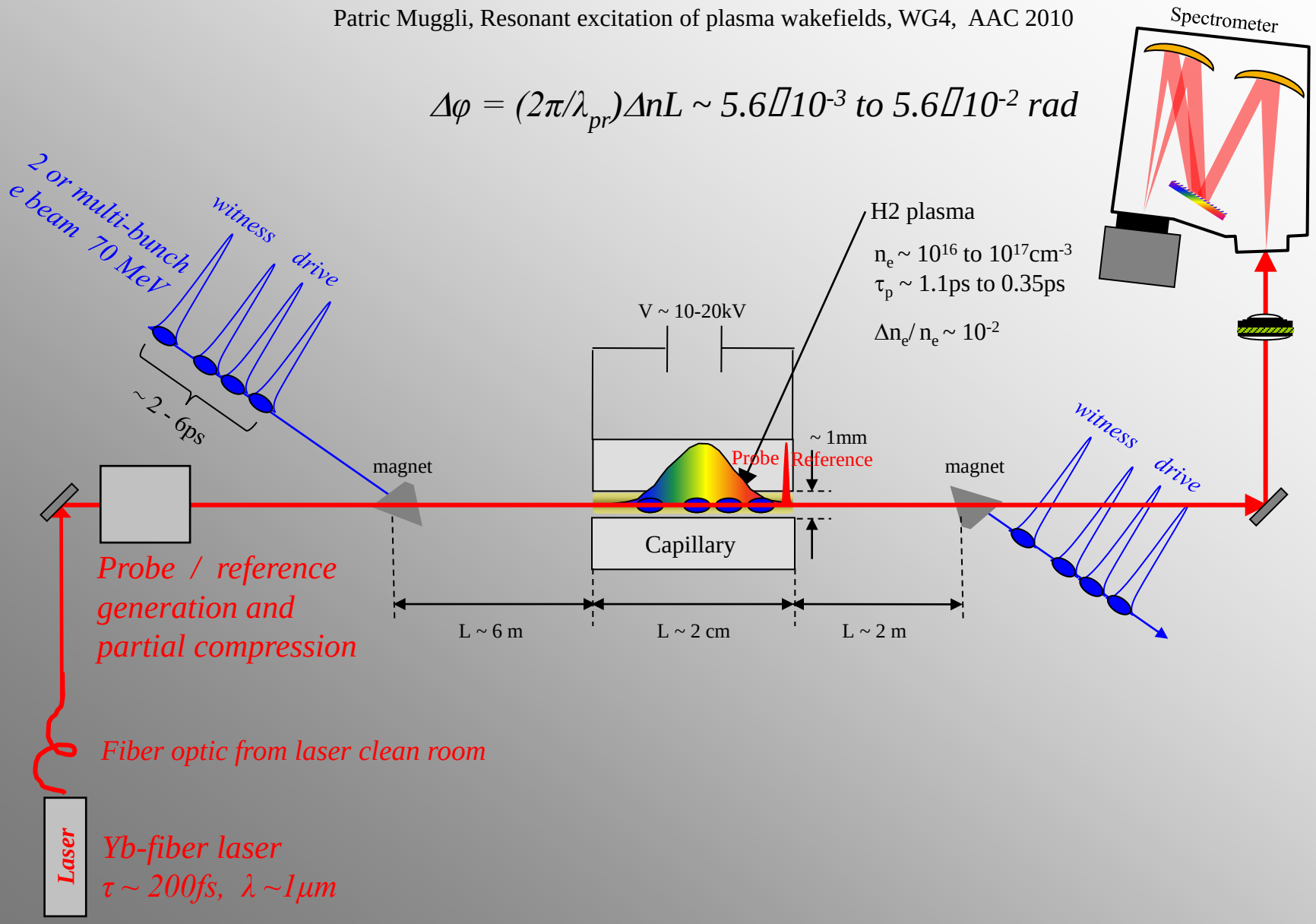




BNL ATF experiment with FDH diagnostic

Patric Muggli, Resonant excitation of plasma wakefields, WG4, AAC 2010

$$\Delta\varphi = (2\pi/\lambda_{pr})\Delta nL \sim 5.6\cdot10^{-3} \text{ to } 5.6\cdot10^{-2} \text{ rad}$$

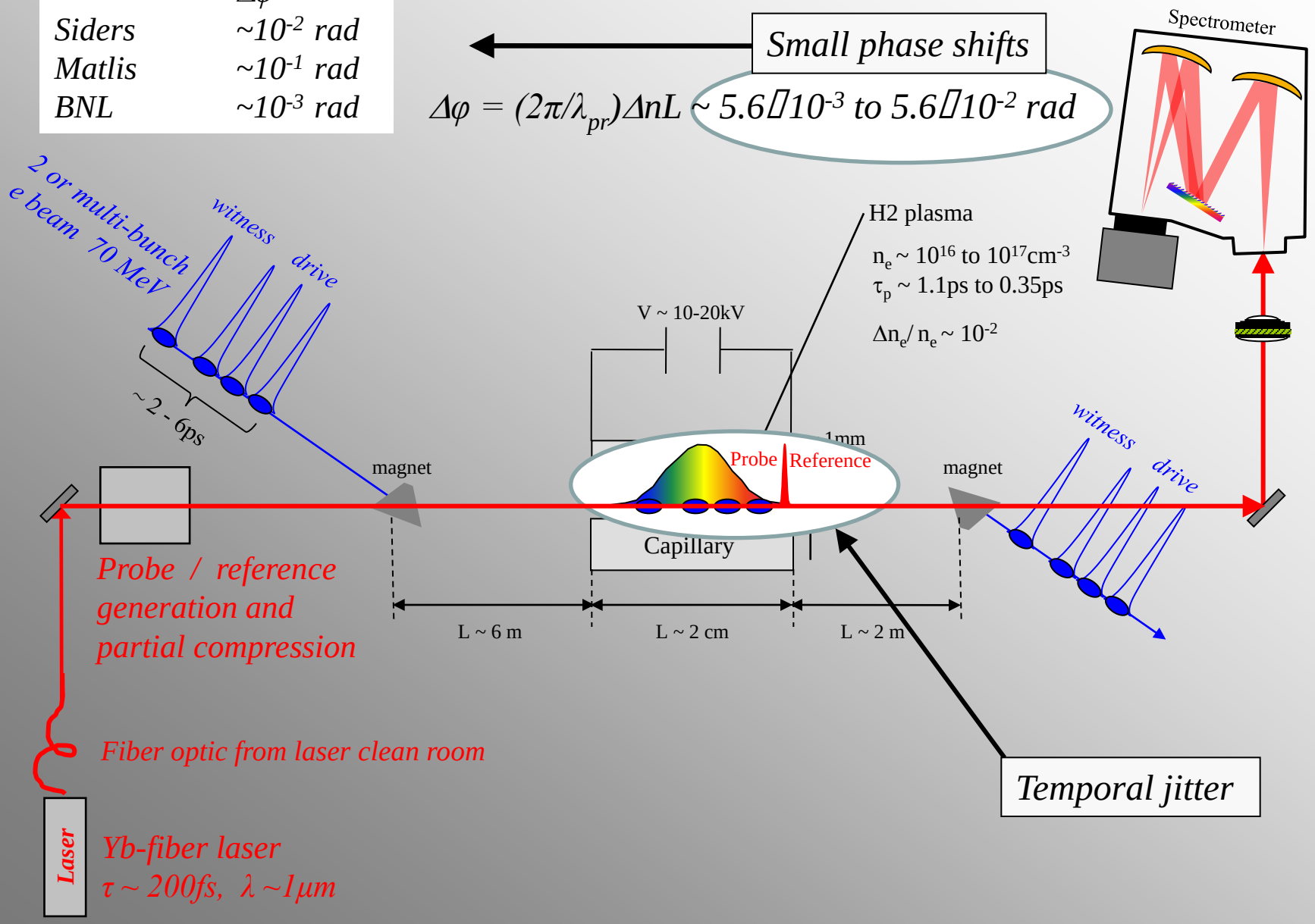


Possible issues

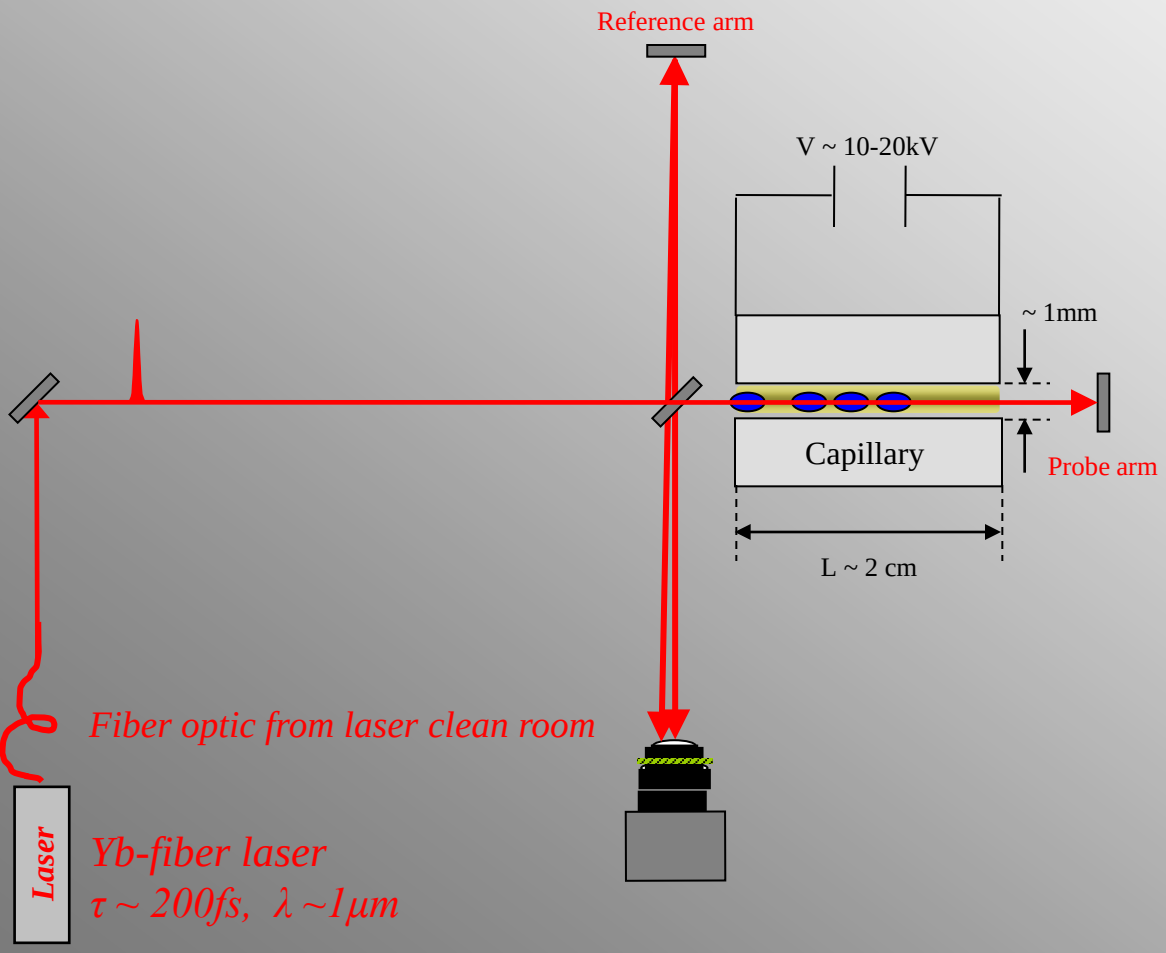
	$\Delta\varphi$
Siders	$\sim 10^{-2}$ rad
Matlis	$\sim 10^{-1}$ rad
BNL	$\sim 10^{-3}$ rad

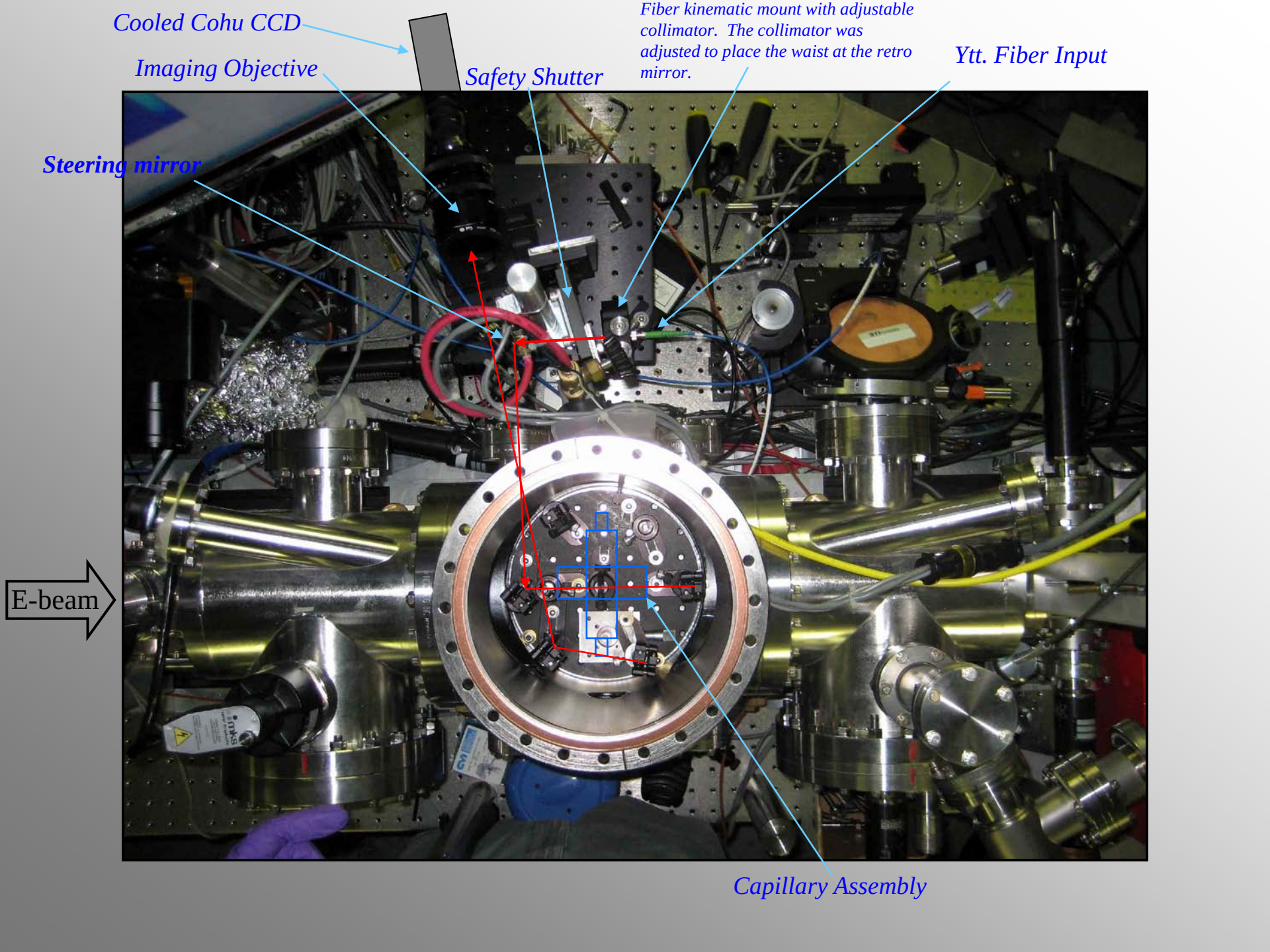
Small phase shifts

$\Delta\varphi = (2\pi/\lambda_{pr})\Delta nL \sim 5.6 \times 10^{-3}$ to 5.6×10^{-2} rad

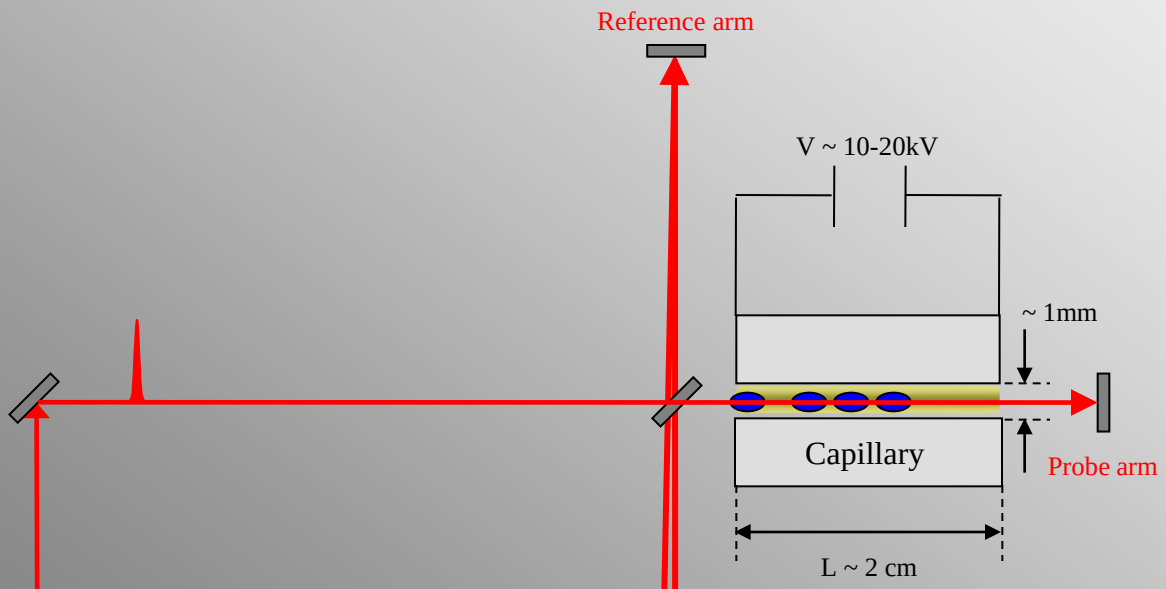


Capillary H2 pressure and plasma density




Cooled Cohu CCD
Imaging Objective
Safety Shutter
Fiber kinematic mount with adjustable collimator. The collimator was adjusted to place the waist at the retro mirror.
Ytt. Fiber Input
Steering mirror
E-beam
Capillary Assembly

Capillary H2 pressure and plasma density



Fiber optic from laser clean room

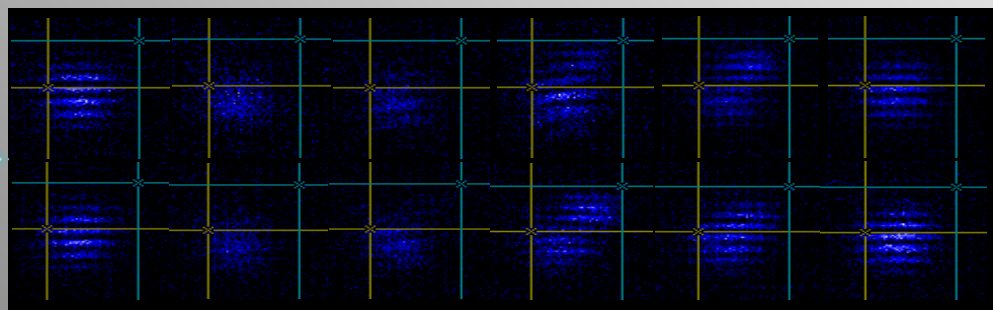
Laser

Yb-fiber laser
τ ~ 200fs, λ ~1μm

15kV

10kV

-0.5μs *-0.1μs* *0.5μs* *0.95μs* *1.2μs* *1.9μs*



Capillary H2 pressure and plasma density

	$\Delta\varphi$
Siders	$\sim 10^{-2}$ rad
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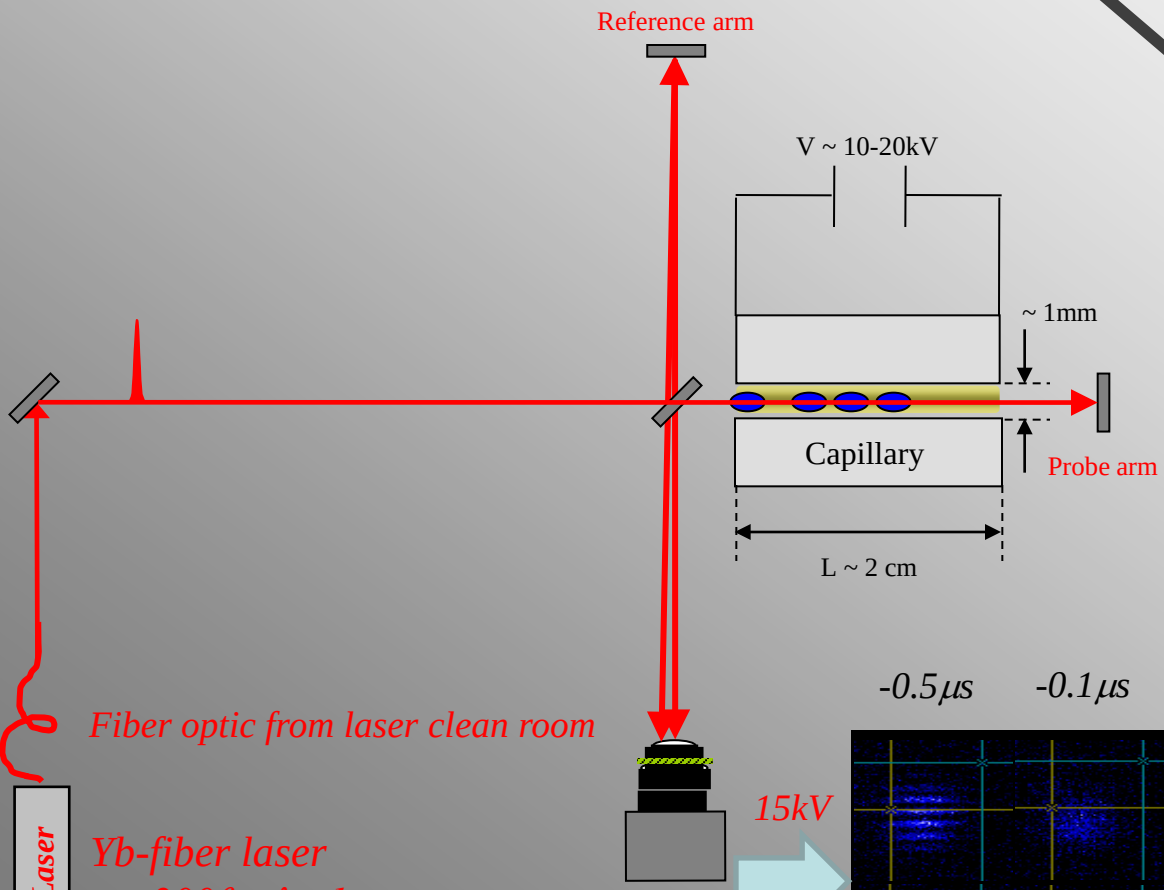
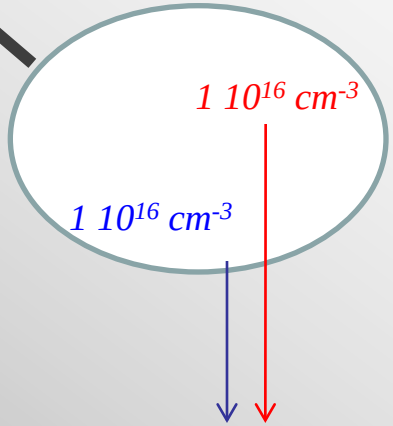
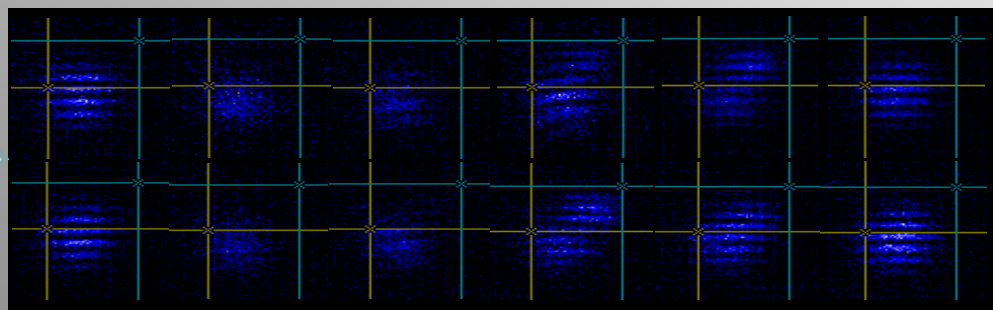
Small phase shifts

$\Delta\varphi = (2\pi/\lambda_{pr})\Delta nL \sim 5.6\times10^{-3}$ to 5.6×10^{-2} rad



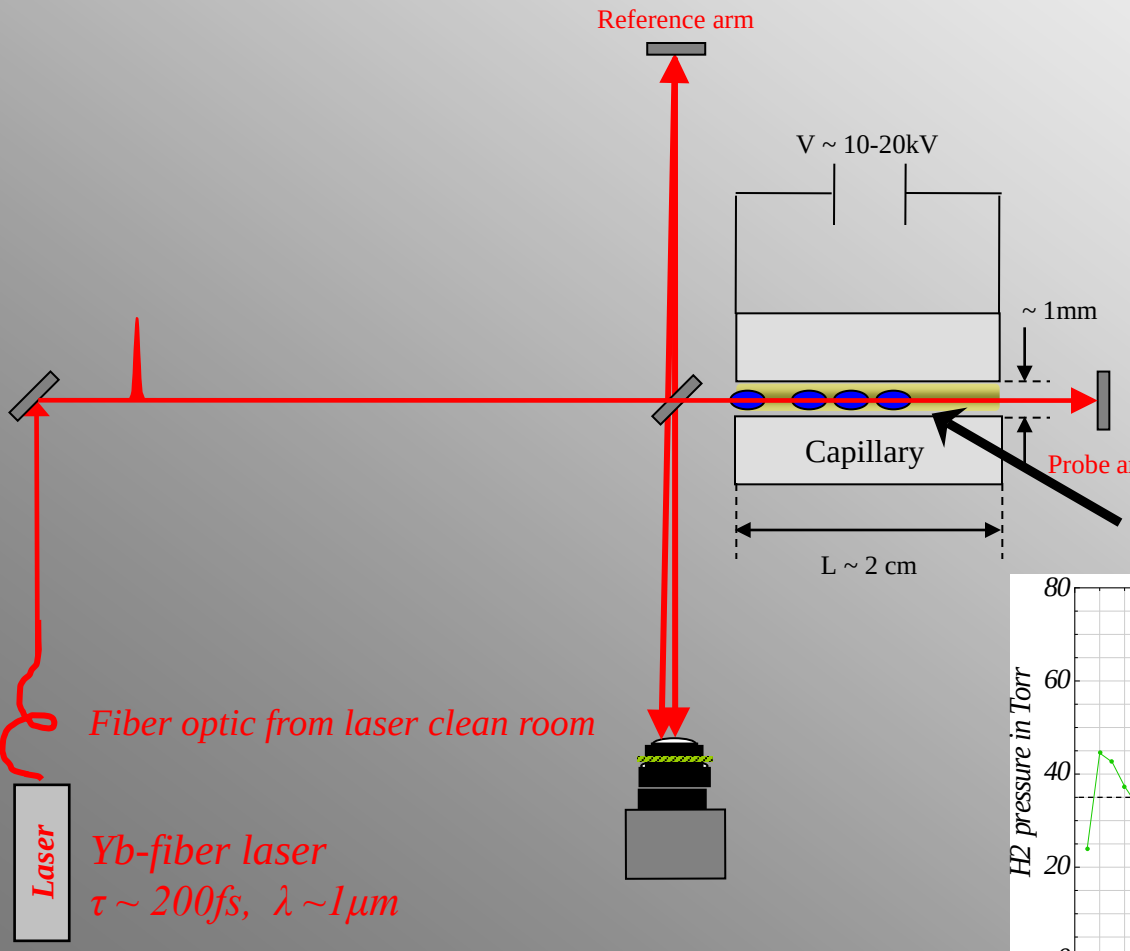


-0.5μs -0.1μs 0.5μs 0.95μs 1.2μs 1.9μs

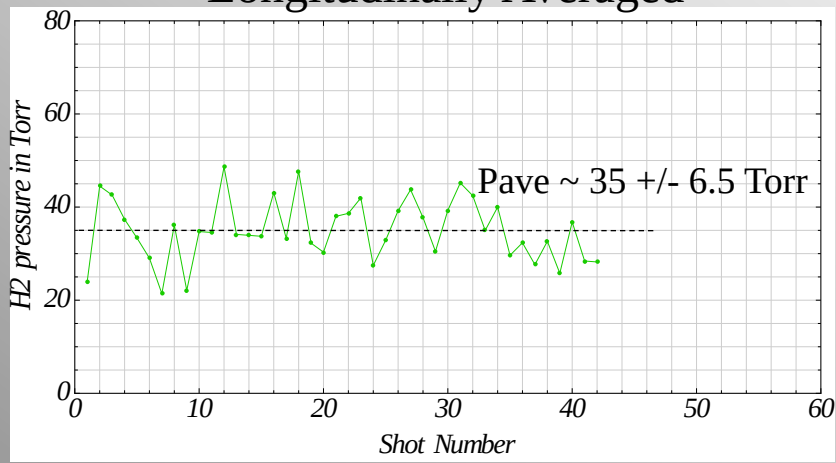


Capillary H2 pressure and plasma density

Patric Muggli, Resonant excitation of plasma wakefields, WG4, AAC 2010

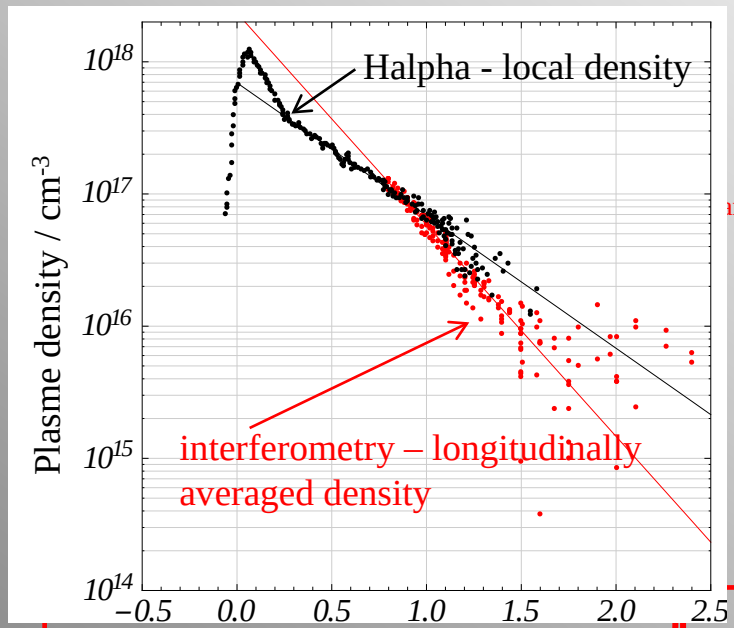


Hydrogen Pressure in Capillary
Longitudinally Averaged

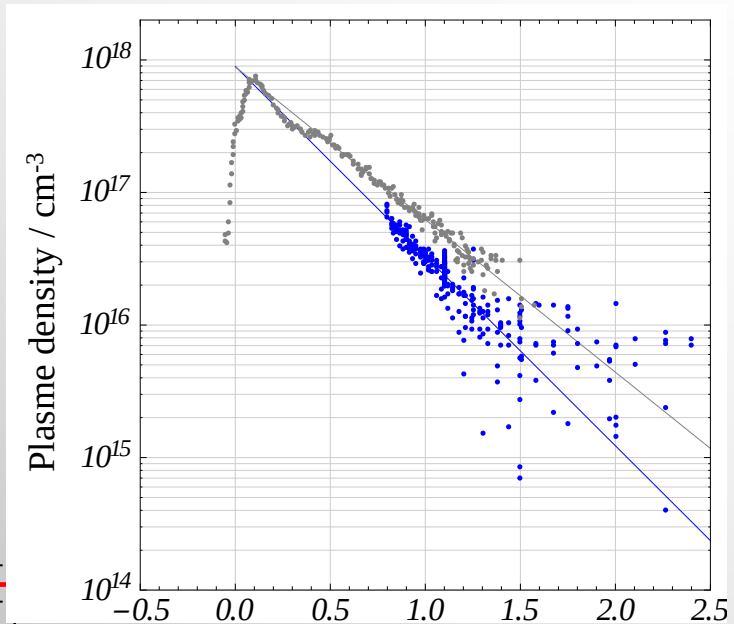


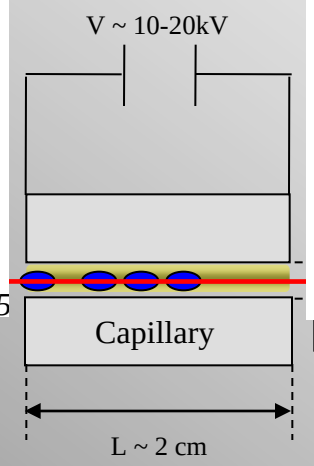
Capillary H2 pressure and plasma density

Plasma density 15kV discharge



Plasma density 10kV discharge





Probe arm

Fiber optic from laser clean room

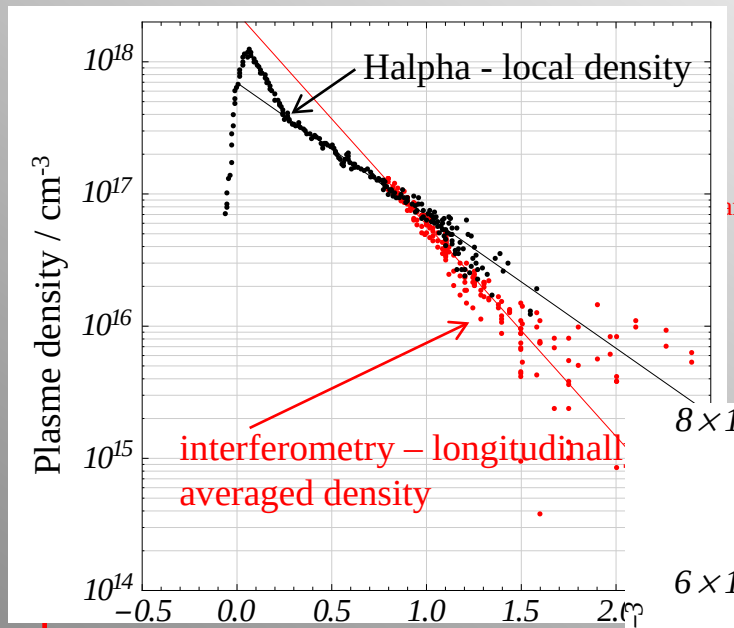
Laser

Yb-fiber laser

τ ~ 200fs, λ ~1µm

Capillary H2 pressure and plasma density

Plasma density 15kV discharge



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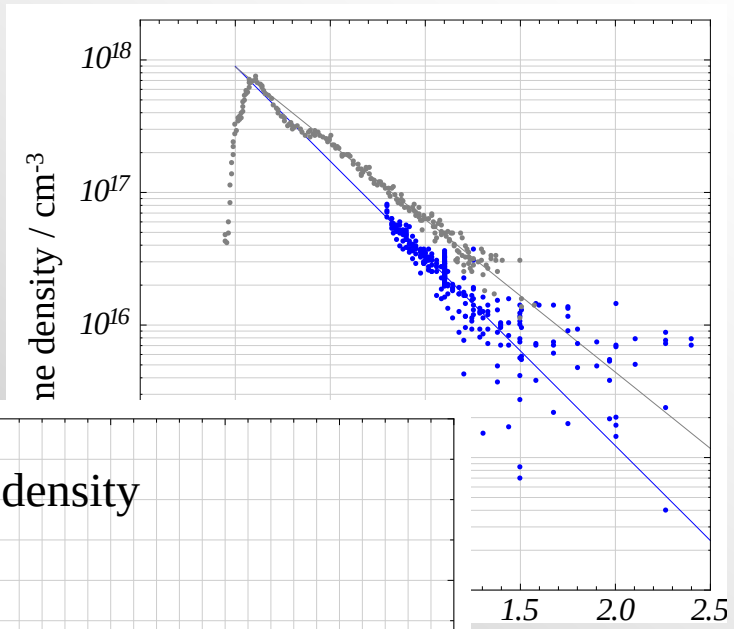
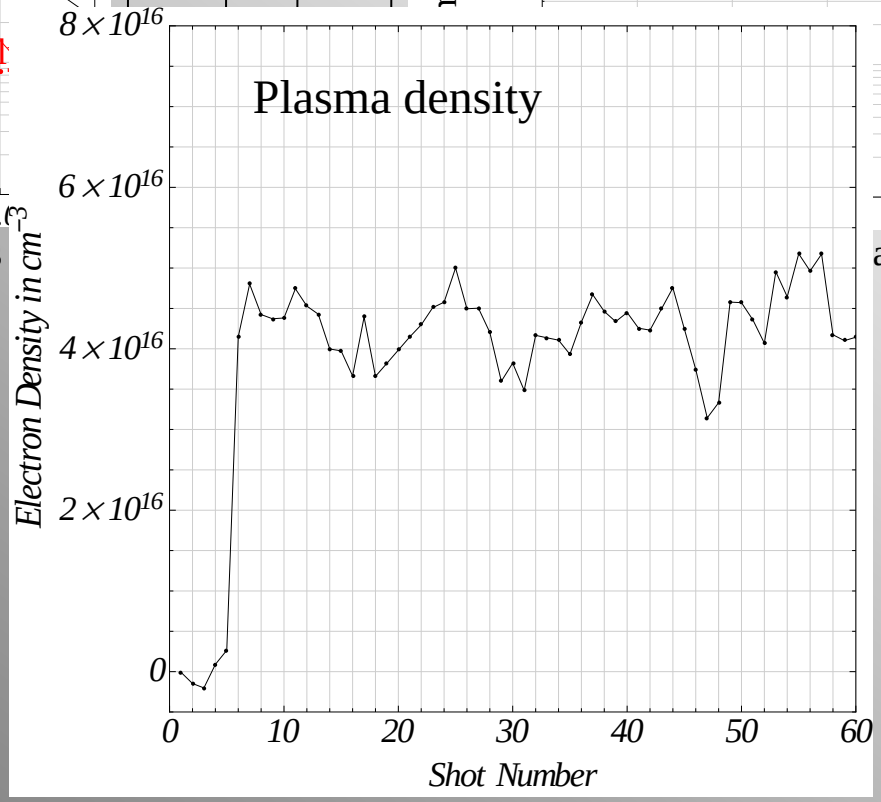
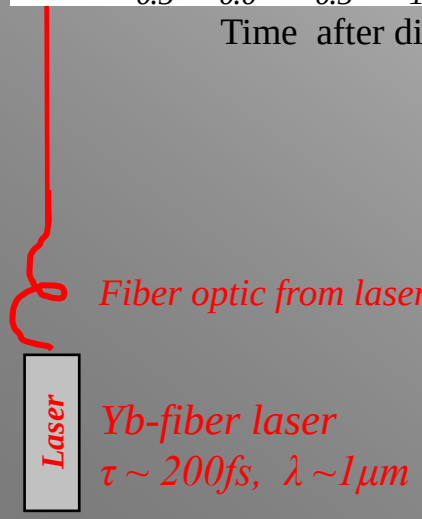
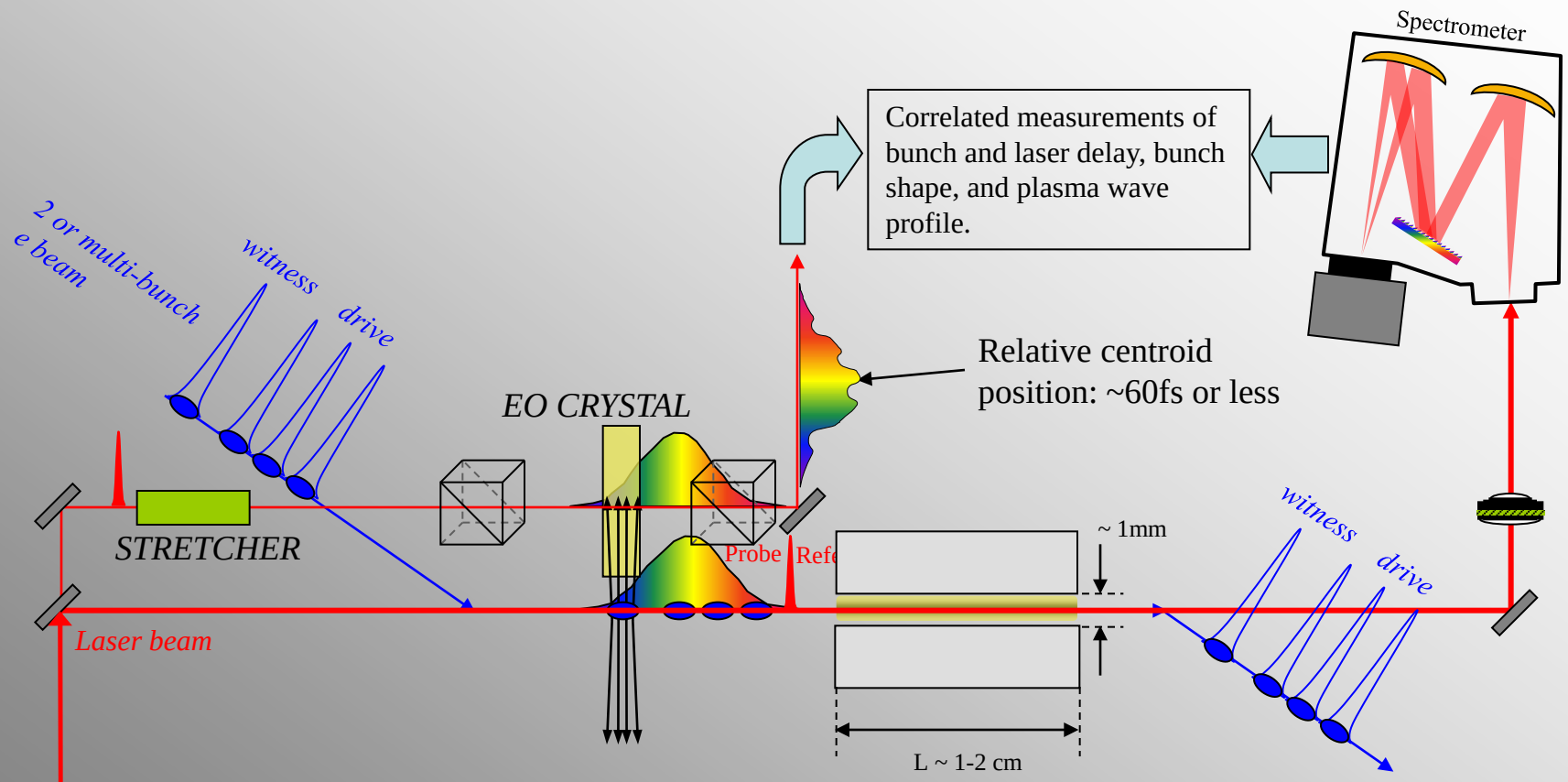






EO time delay and bunch shape measurement



HV Discharge Capillary

$n_e \sim 10^{16}$ to 10^{17}cm^{-3}

$\tau_p \sim 1.1$ps to 0.35ps

$\Delta n_e / n_e \sim 10^{-2}$

Fiber optic from laser clean room

Laser

Yb-fiber laser

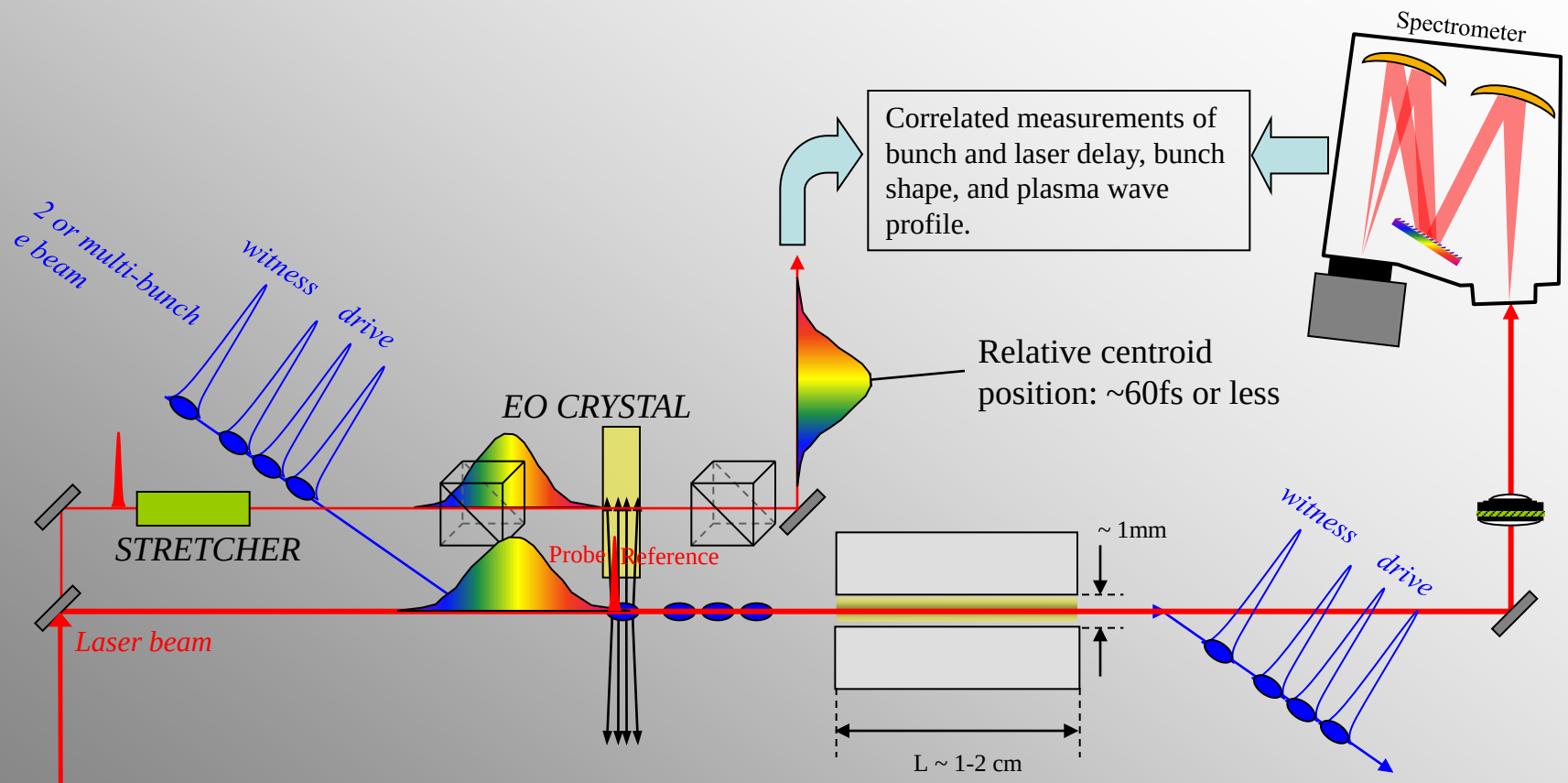
$\tau \sim 200$fs, $\lambda \sim 1\mu$m

Tilborg et al., WG5, AAC 2010

Matlis et al., Plenary, AAC 2010

A. L. Cavalieri, "Clocking Femtosecond X Rays," PRL **94,** 114801 (2005).

EO time delay and bunch shape measurement



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Fiber optic from laser clean room

Laser

Yb-fiber laser

$\tau \sim 200fs$, $\lambda \sim 1\mu m$

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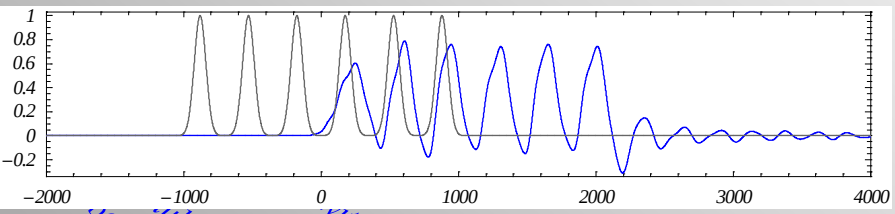

Correlated measurements of bunch and laser delay, bunch shape, and plasma wave profile.

Spectrometer

Relative centroid position: ~60fs or less

multi-bunch beam

witness

drive

EO CRYSTAL

STRETCHER

Probe

Ref

~ 1mm

witness

drive

Laser beam

L ~ 1-2 cm

HV Discharge Capillary

$n_e \sim 10^{16}$ to 10^{17}cm^{-3}

$\tau_p \sim 1.1$ps to 0.35ps

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Fiber optic from laser clean room

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Yb-fiber laser

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Tilborg et al., WG5, AAC 2010

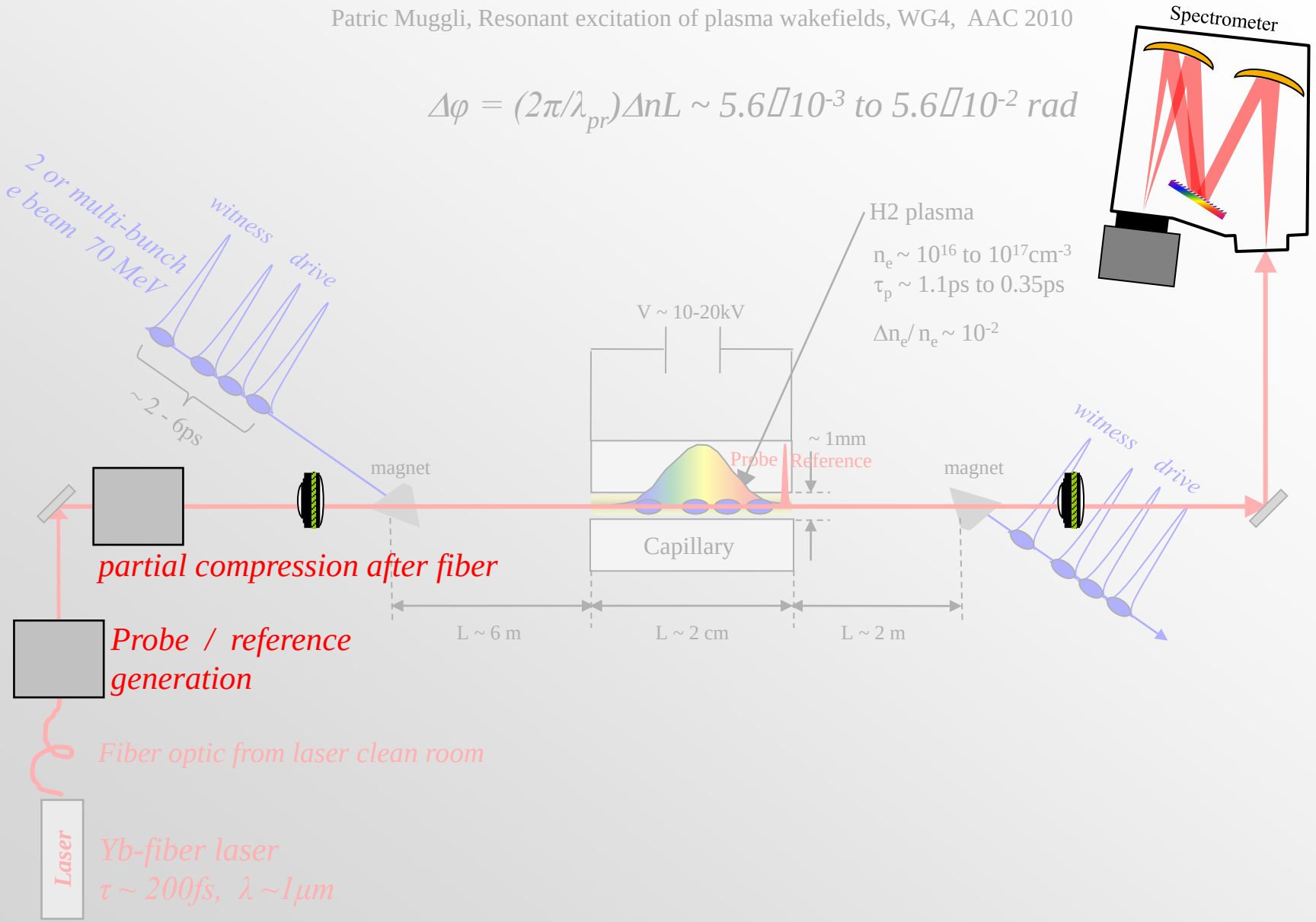
Matlis et al., Plenary, AAC 2010

A. L. Cavalieri, “Clocking Femtosecond X Rays,” PRL **94,** 114801 (2005).

Current Planned FDH setup

Patric Muggli, Resonant excitation of plasma wakefields, WG4, AAC 2010

$$\Delta\varphi = (2\pi/\lambda_{pr})\Delta nL \sim 5.6\,10^{-3} \text{ to } 5.6\,10^{-2} \text{ rad}$$



Conclusion

- *Preliminary interferometric plasma stability and uniformity measurements*
- *FDI measurements unlikely, FDH will probably be necessary*
- *Setup of FDH will begin after this meeting*
- *Austin Yi currently simulating FDH probe propagation with electron bunches - will permit simulation of FDH measurement and determination of resolution and detection limits.*

Ultimate goals:

- *Direct measurement of plasma wave structure*
- *Correlation of local plasma wave and microbunch amplitudes*
- *Direct observation of resonant wake enhancement in the multibunch experiments*
- *Direct observation of different structures of electron and positron driven wakes.*
- *Standard noninvasive diagnostic complementing particle diagnostics in next generation of PWFA experiments.*

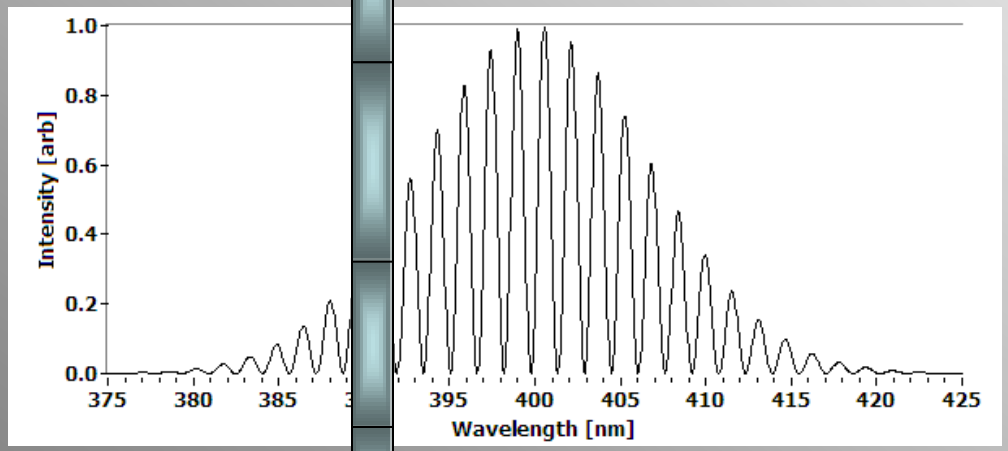
Thank You

Financial Support: Department of Energy

FDI: Temporal Overlap in Spectrometer

Interferogram

Spectrometer
CCD



Spectrometer
Grating

1 ps

Pulse Duration > Pulse Separation

PULSES OVERLAP!