Ultrafast Laser Physics

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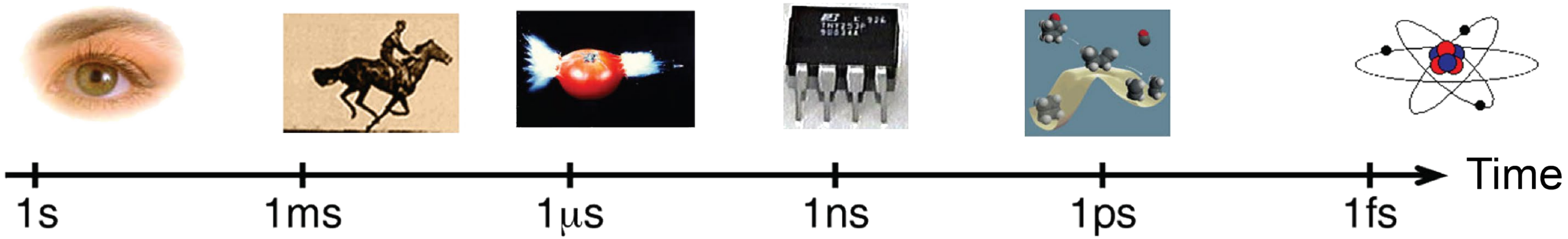
Chapter 10: Ultrafast Measurements

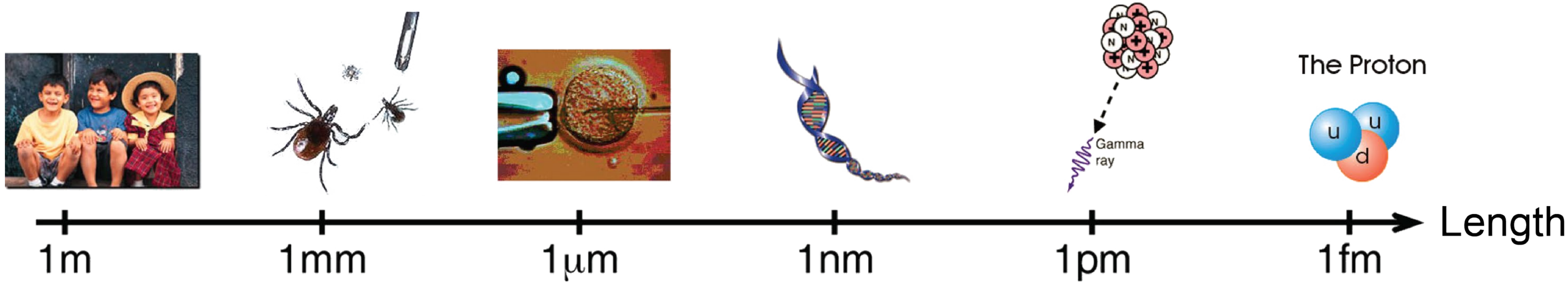
Ultrafast laser physics (ULP)



1 picosecond = 1 ps = 10^{-12} s

1 femtosecond = 1 fs = 10^{-15} s

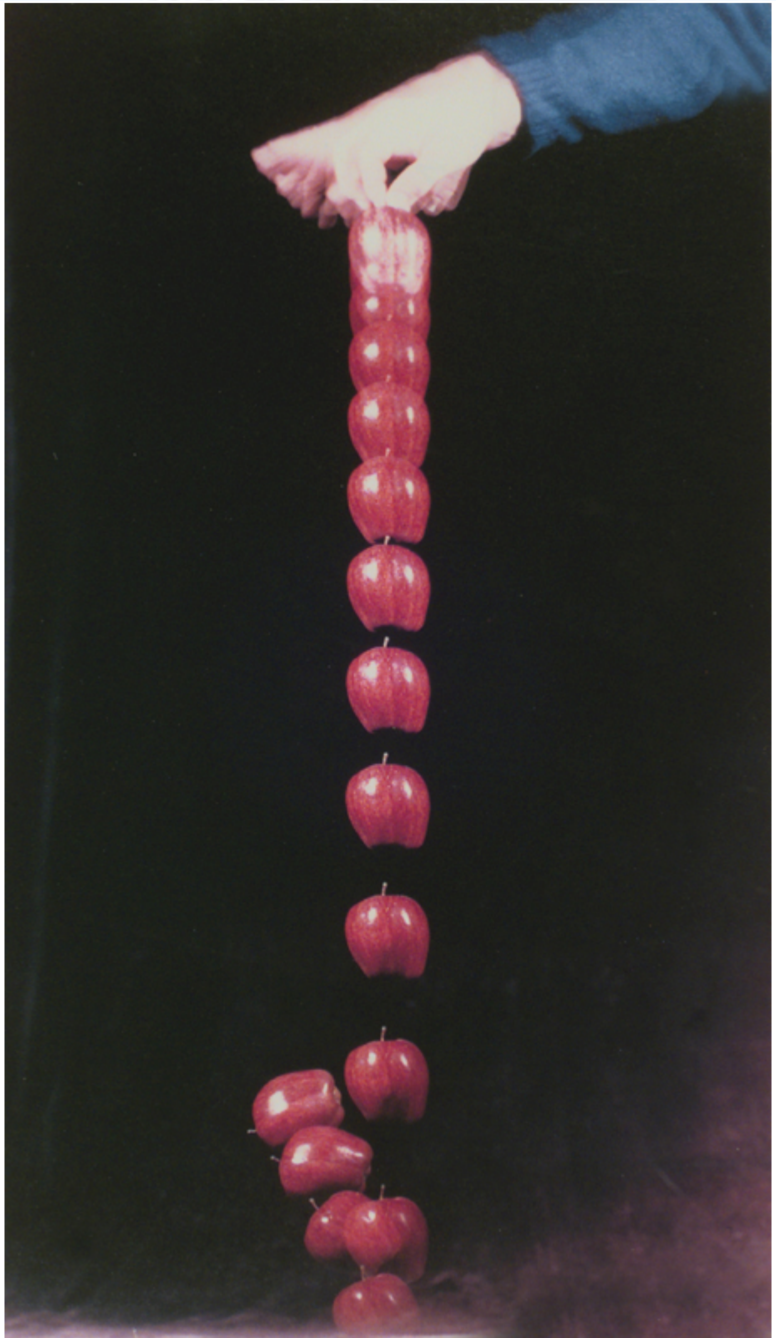
1 attosecond = 1 as = 10^{-18} s



Measurement with μs time resolution

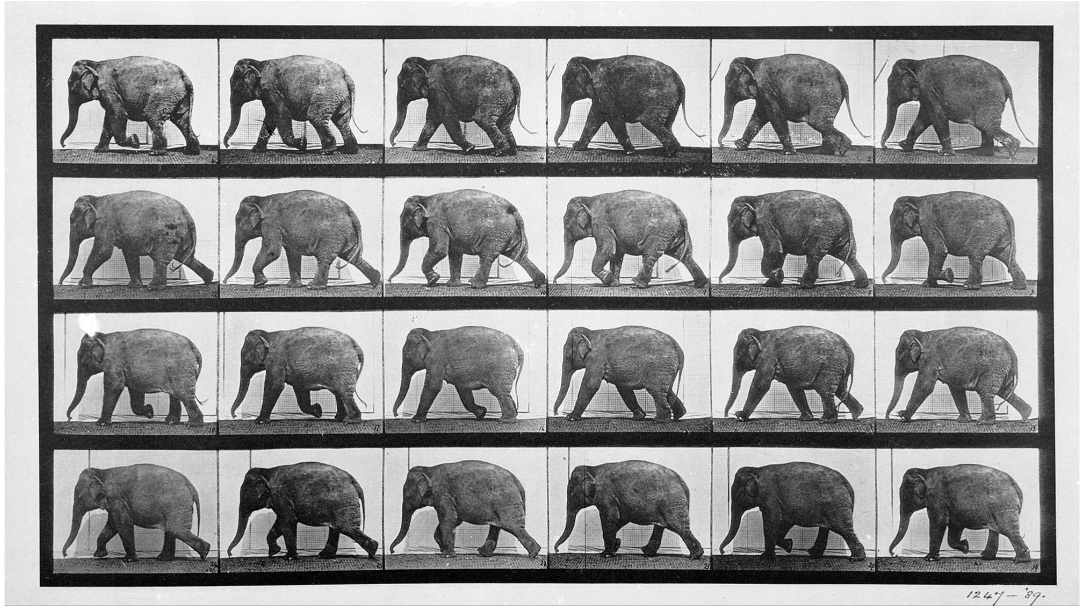
Harold E. Edgerton, MIT
1903-1990

Flash photography:
Flash lights driven by electronics
⇒ triggered flash lights
⇒ ≈ μs time resolution
(already available 1935)
limited by flash duration
(„light pulse duration“)

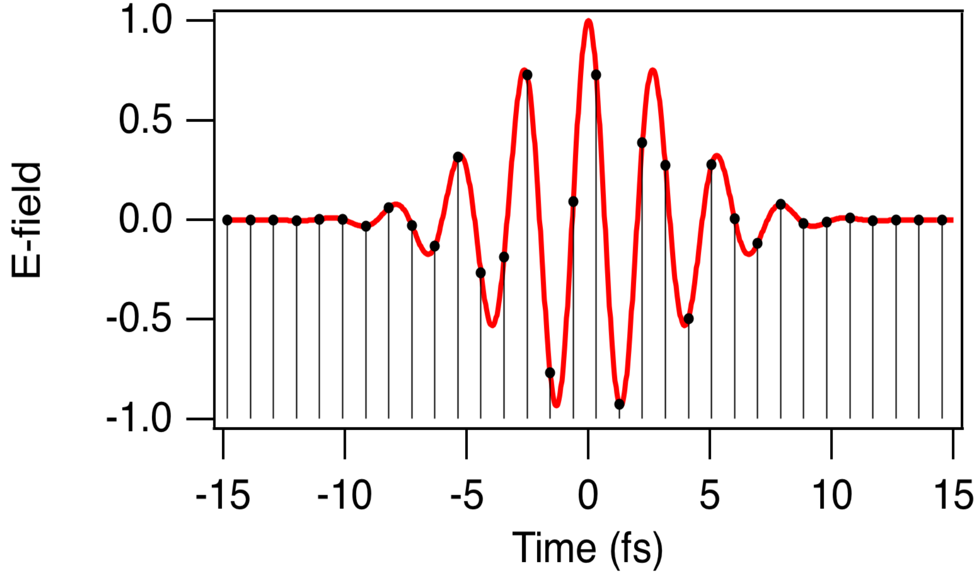


The problem

- Straightforward: Measure slow event with fast event
- However, all detectors are time-integrating on these time scales
- Solution: Map dynamics/time axis to static observable!

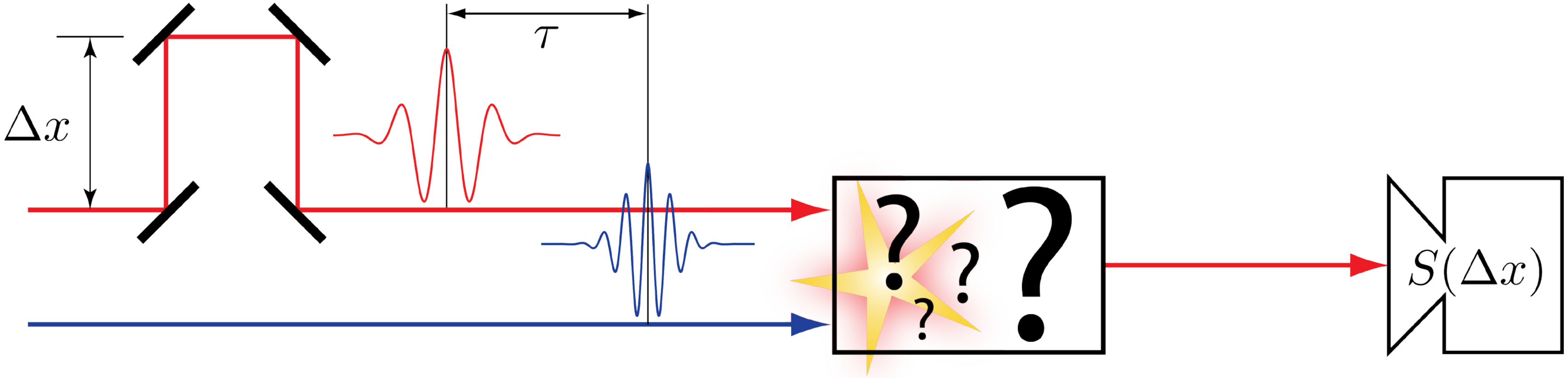


E. Muybridge: Animal Locomotion (1887)



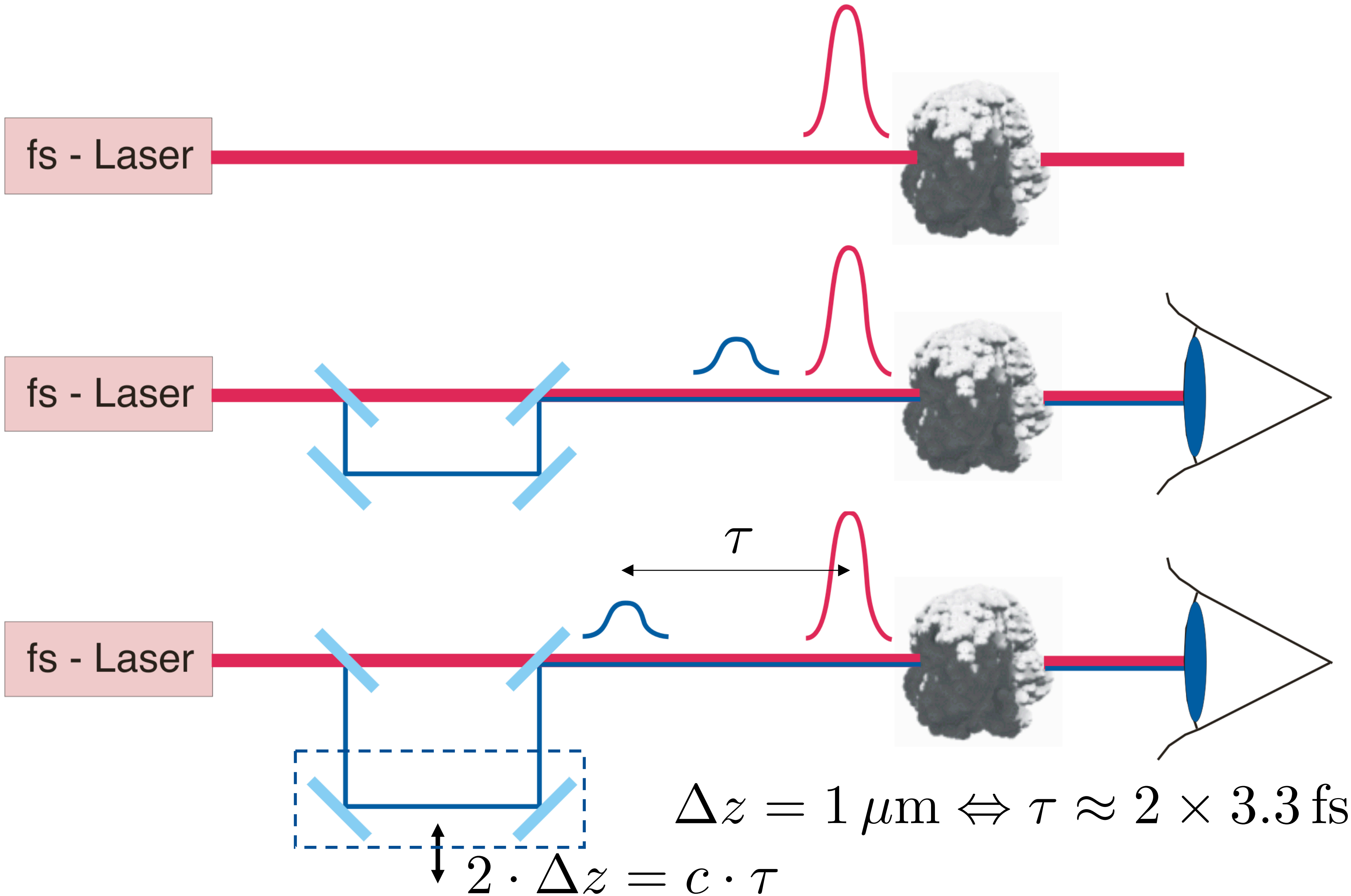
The solution

- The classical pump-probe approach:

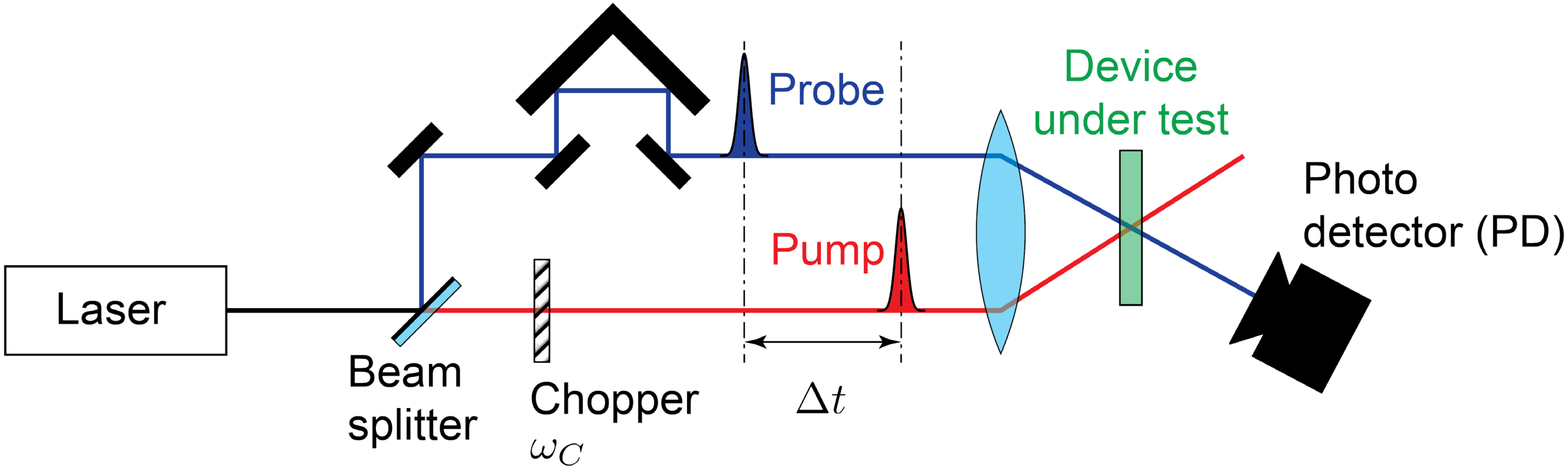


- Map time to translation in space: $\tau = \dfrac{2\Delta x}{c} \propto \Delta x$
- Therefore $S(\Delta x) \Leftrightarrow S(\tau)$
- 1 nm resolution in Δx yields 7 as resolution in τ
- Delay is equivalent to real time if duration of probe pulse is negligible and process is perfectly reproducible
- This idea can be generalized to other mappings of time to time-independent quantities

Pump-probe measurement



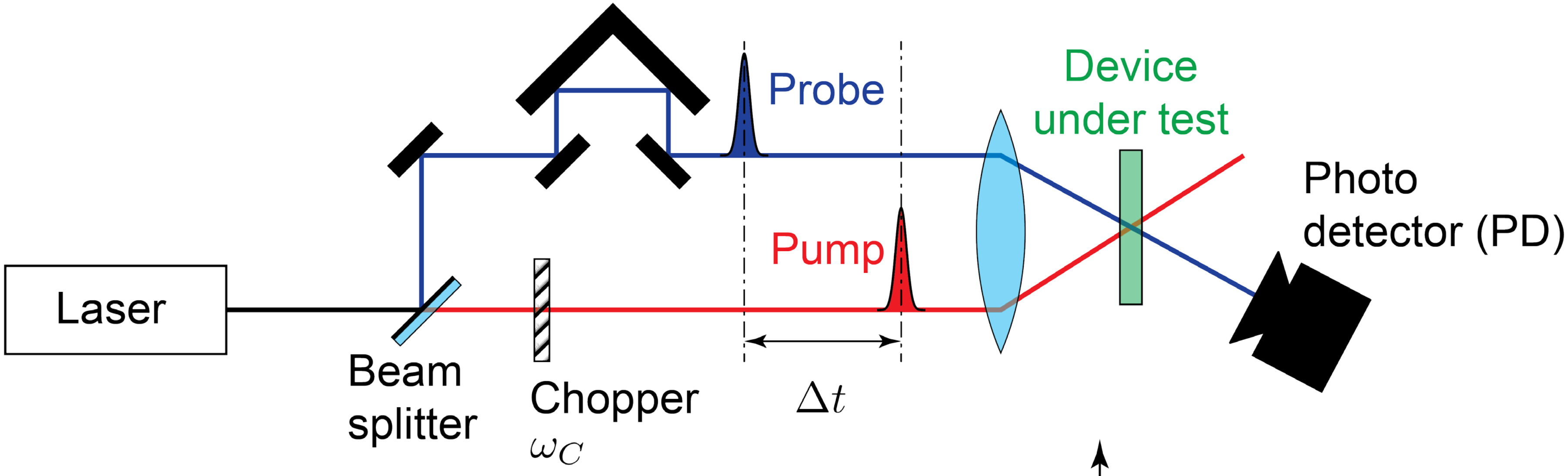
Differential transmission spectroscopy



- Why a chopper?
- Why not the chopper in the probe pulse?
- Why do you use a lock-in amplifier?

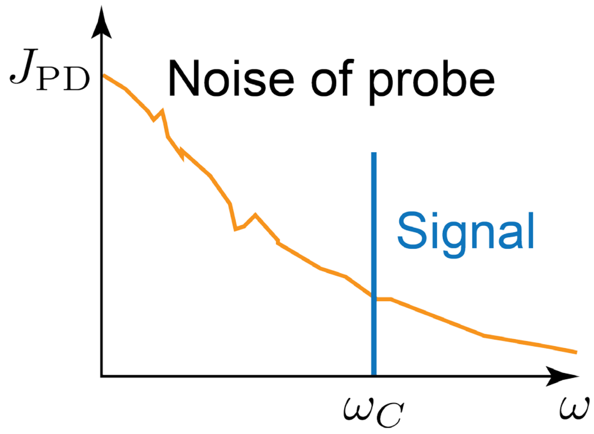
Ultrafast pump-probe techniques

Differential transmission spectroscopy



$$\text{signal} = \Big[\underbrace{T(\Delta t, I_{\text{pump}})} - \underbrace{T(I_{\text{pump}} = 0)}\Big] I_{\text{probe}}$$

Transmission of device under test with
pump on — pump off

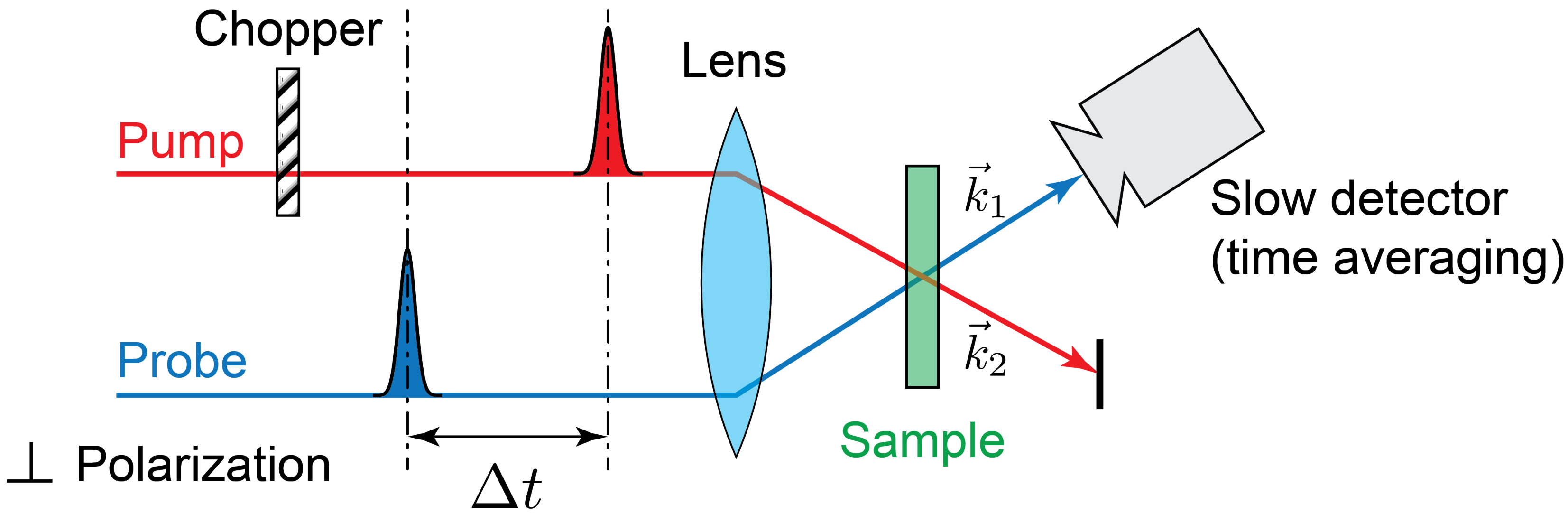


Ultrafast measurements need some kind of nonlinearities in the measurement system (i.e. intensity dependent transmission)

Different arrangements

- Noncollinear degenerate pump-probe measurements
- Collinear degenerate pump-probe measurements

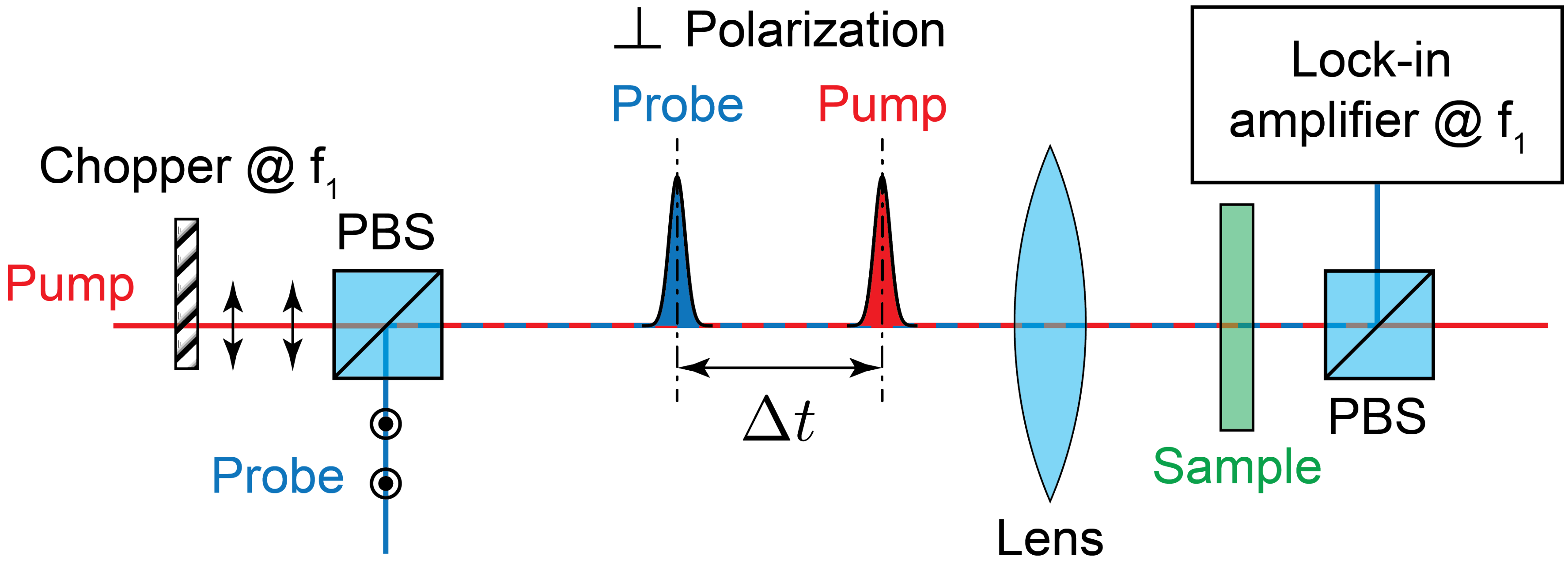
Noncollinear degenerate pump-probe



Noncollinear: pump and probe beam **not** collinear
good for signal-to-noise because pump power is not on detector

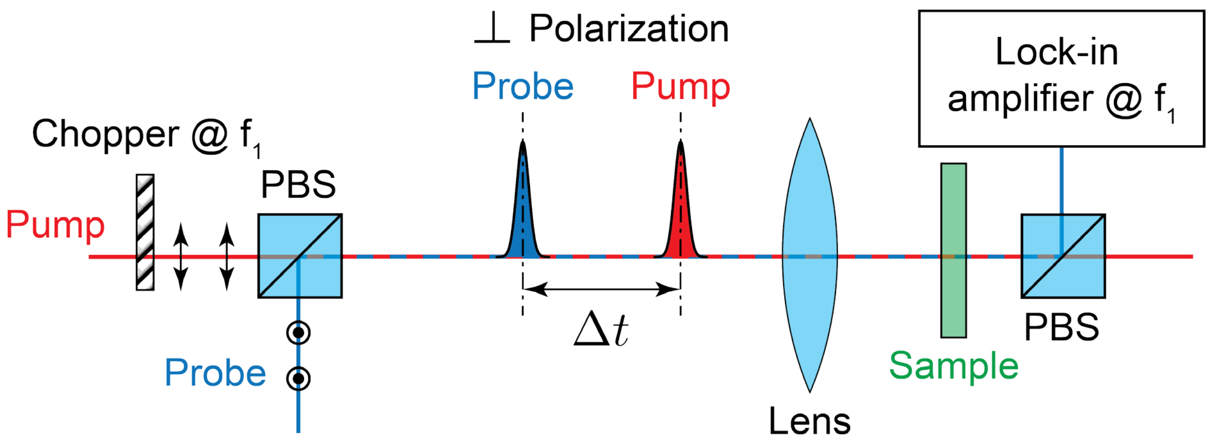
Degenerate: pump and probe pulse have the same central wavelength

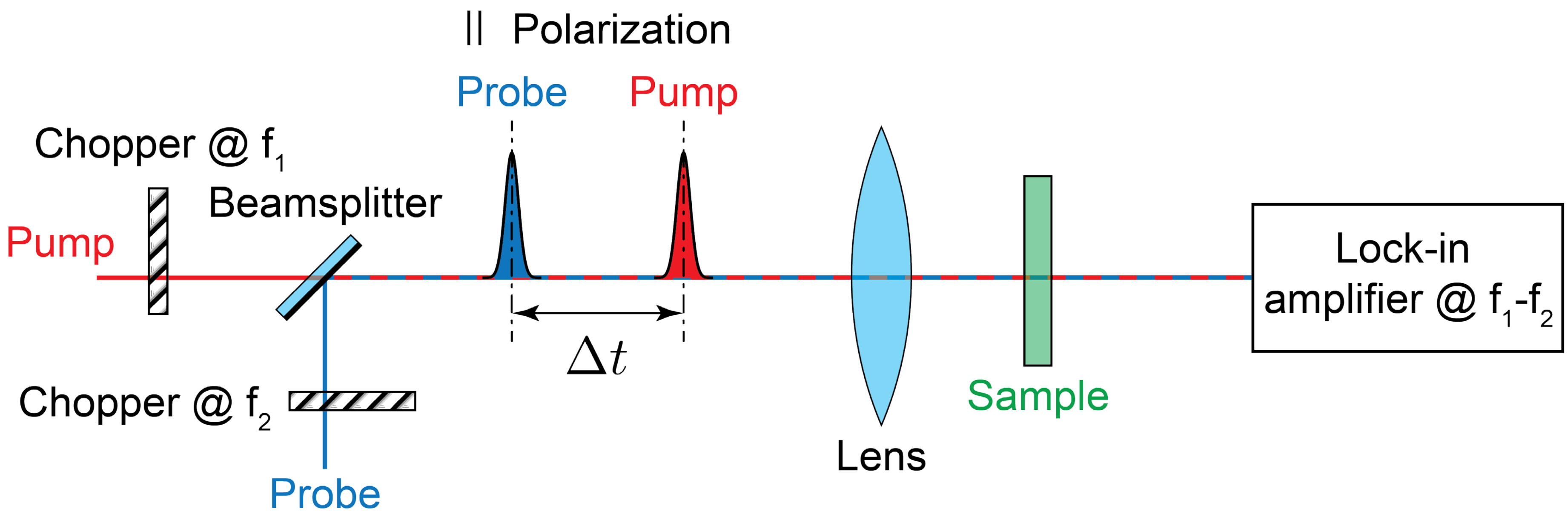
Collinear degenerate pump-probe



What is the reason for the PBS (polarizing beam splitters) in the set-up?

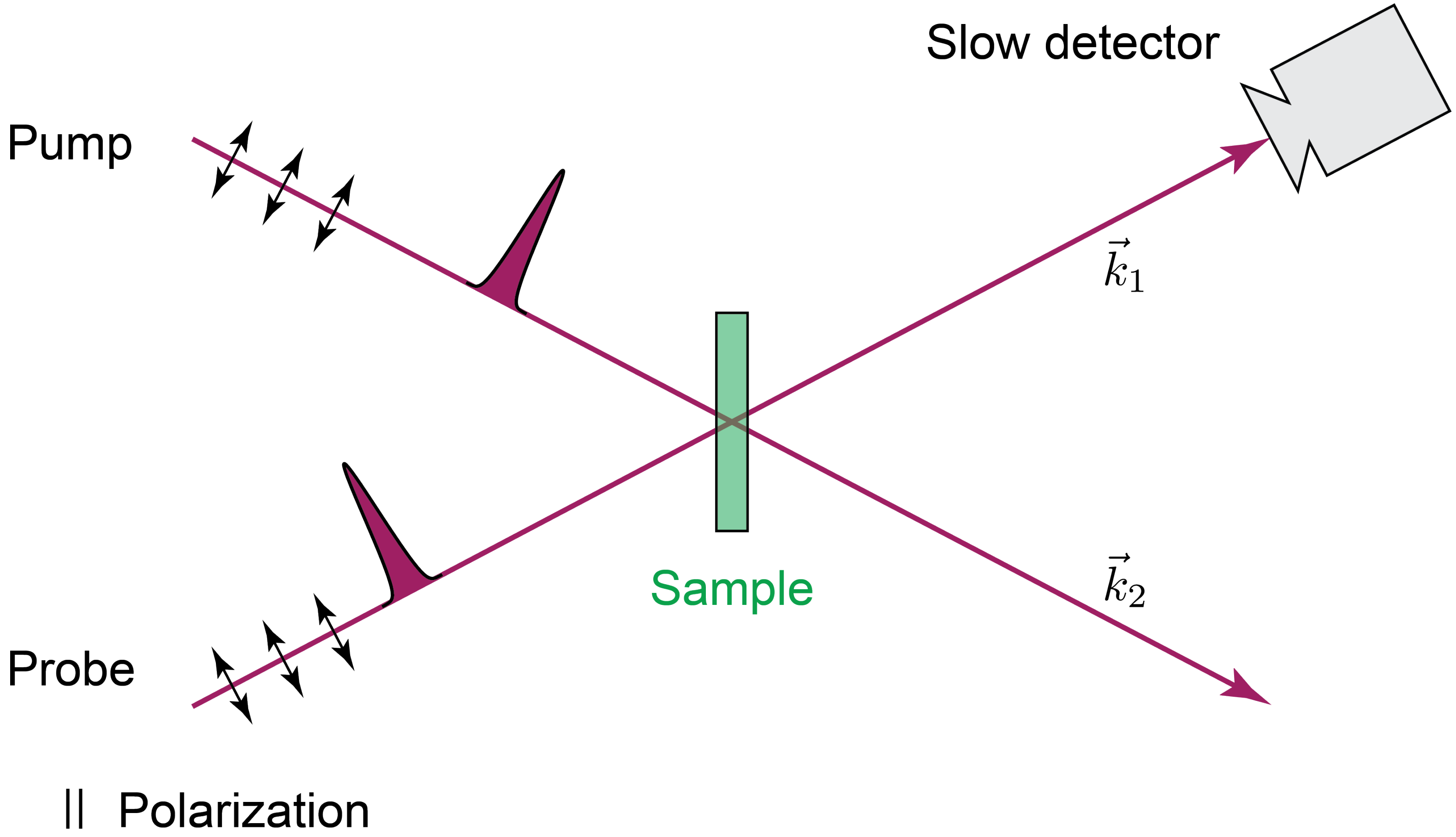
Collinear degenerate pump-probe





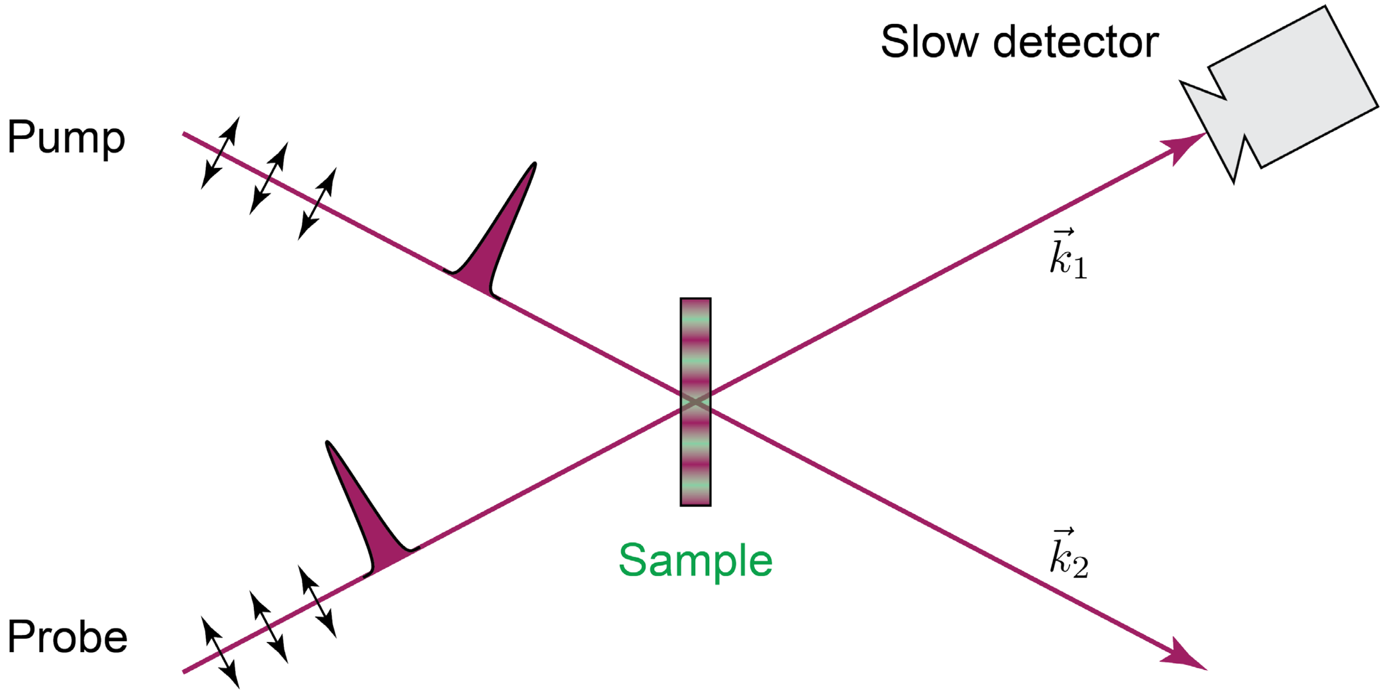
Potential problem? Detector can be saturated by strong pump beam.

Degenerate four-wave mixing



Why is this set-up a degenerate four-wave mixing experiment?

Degenerate four-wave mixing



|| Polarization ⇒ diffraction grating

Parallel polarization creates a transient diffraction grating inside the sample.

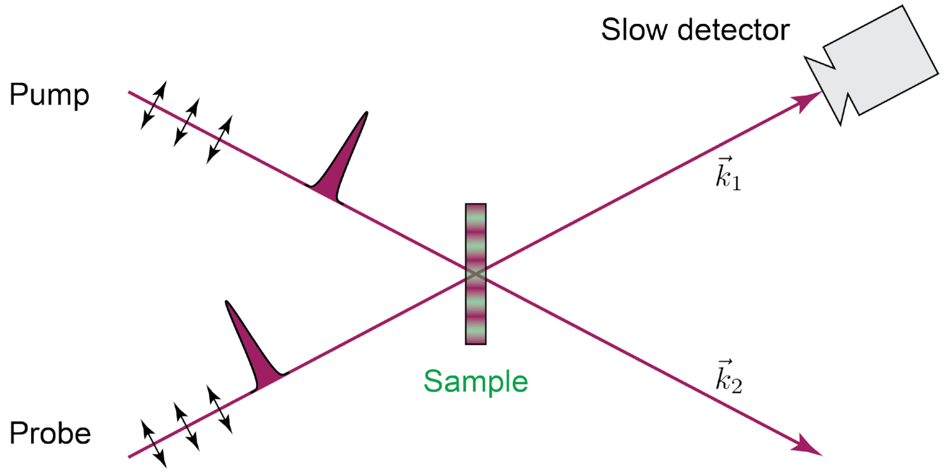
This grating exists as long as there is a coherent excitation (i.e. within the dephasing time)

Review articles: K.-H. Pantke und J. M. Hvam, "Nonlinear quantum beat spectroscopy in semiconductors," *Int. J. of Modern Physics B*, 8, 73-120, 1994

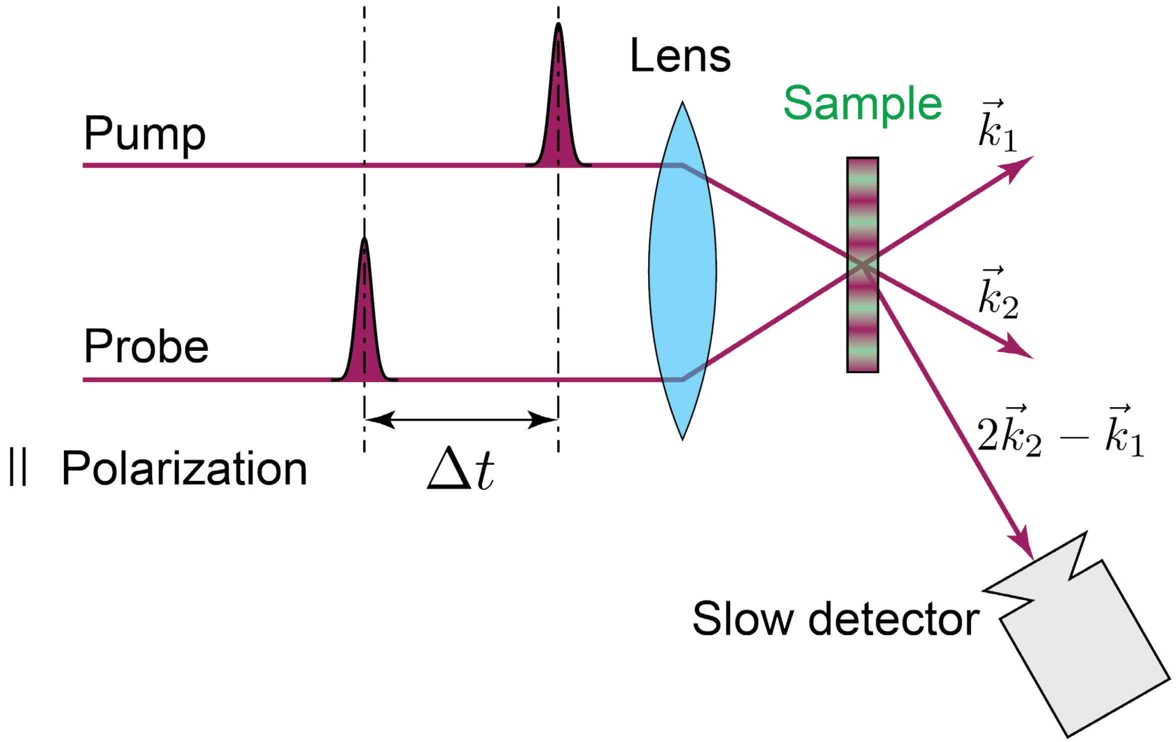
E. O. Göbel, "Ultrafast Spectroscopy of Semiconductors," *Festkörperprobleme, Advances in Solid State Physics,* 30, S. 269-294, 1990

J. Shah, "Ultrafast Spectroscopy of Semiconductors," Springer-Verlag

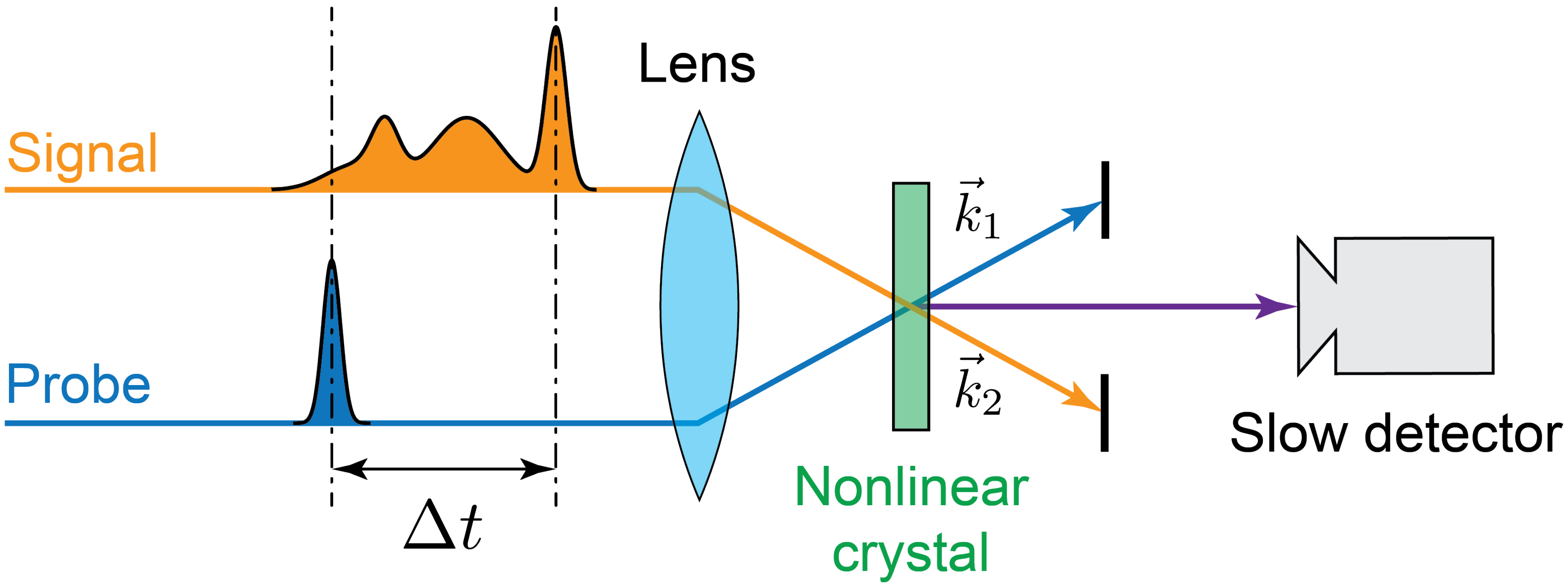
Degenerate four-wave mixing



|| Polarization ⇒ diffraction grating



Optical gating

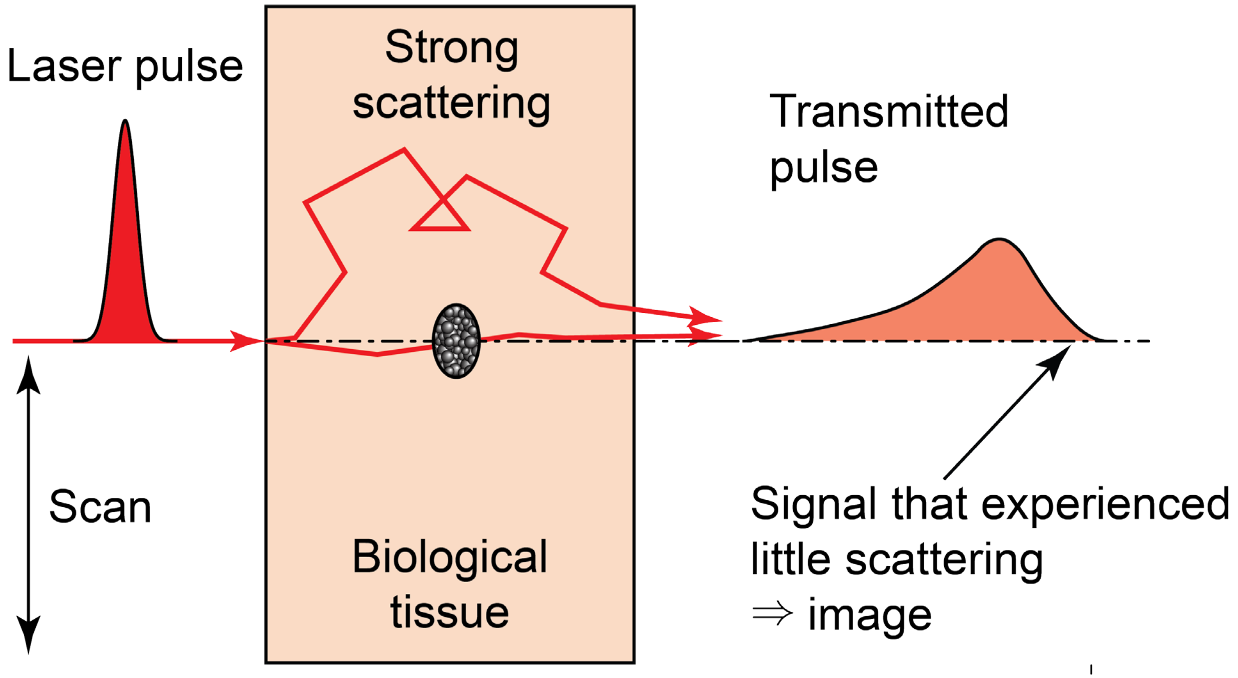


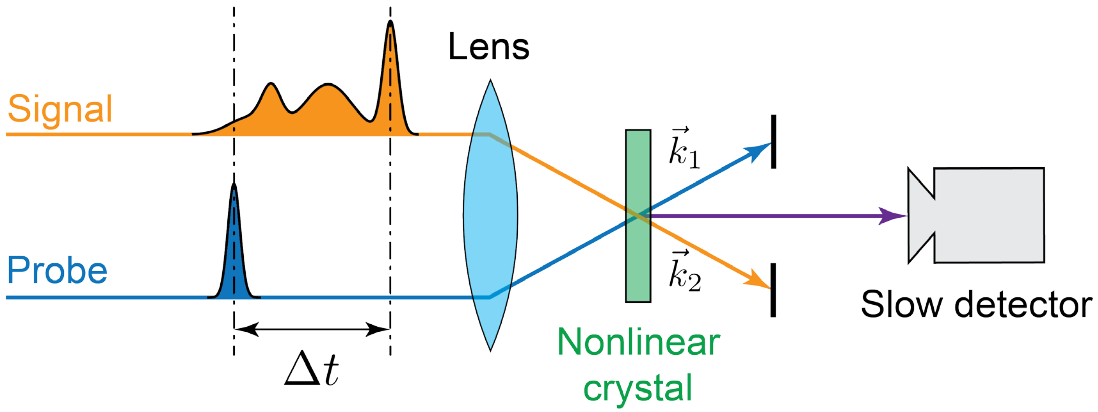
Application: time resolved femtosecond luminescence measurement

T. C. Damen and J. Shah, "Femtosecond luminescence spectroscopy with 60 fs compressed pulses," *Applied Phys. Lett.* **52**, 1291, 1988

J. Shah, "Ultrafast Luminescence Spectroscopy using sum frequency generation," *IEEE JQE*, **24**, 276-288, 1988

Optical gating: time-of-flight imaging

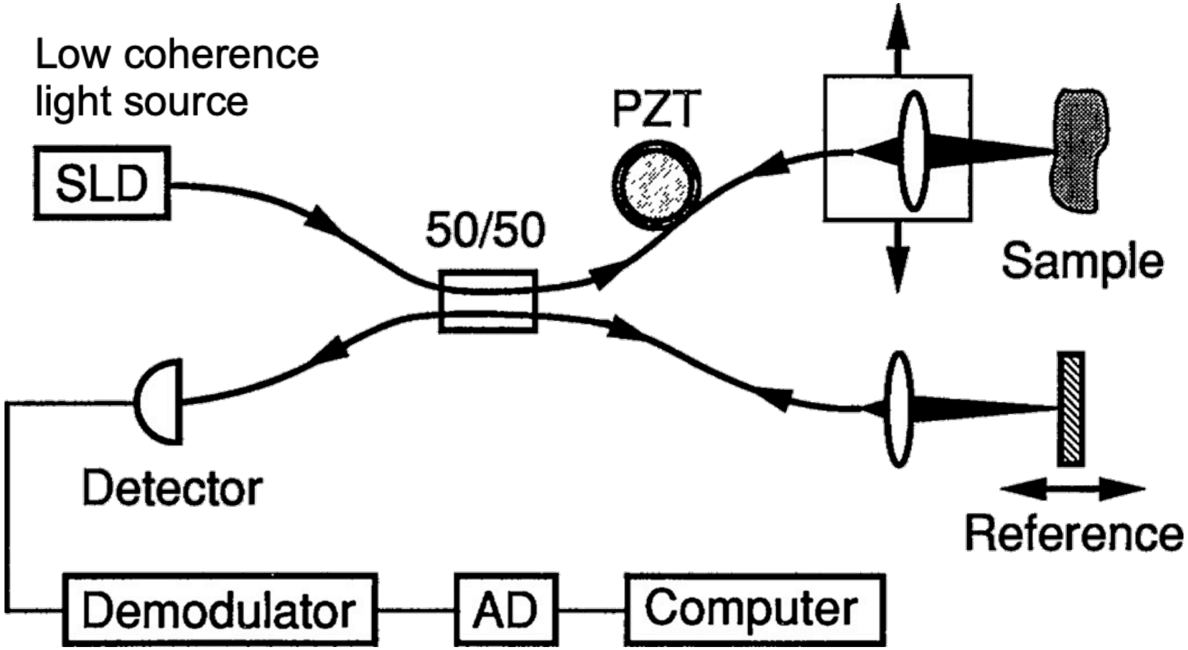




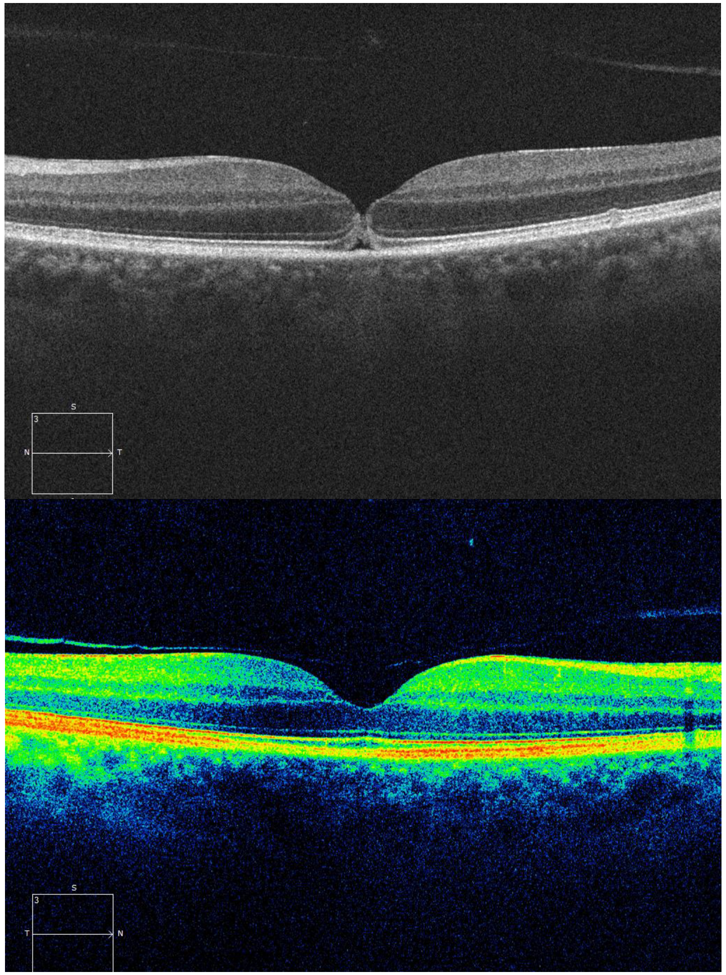
Application of optical gating for “time-of-flight” imaging

M. R. Hee, J. A. Izatt, J. M. Jacobson, J. G. Fujimoto, "Femtosecond transillumination optical coherence tomography," *Optics Lett.*, vol. 18, pp. 950-952, 1993

Optical coherence tomography (OCT)

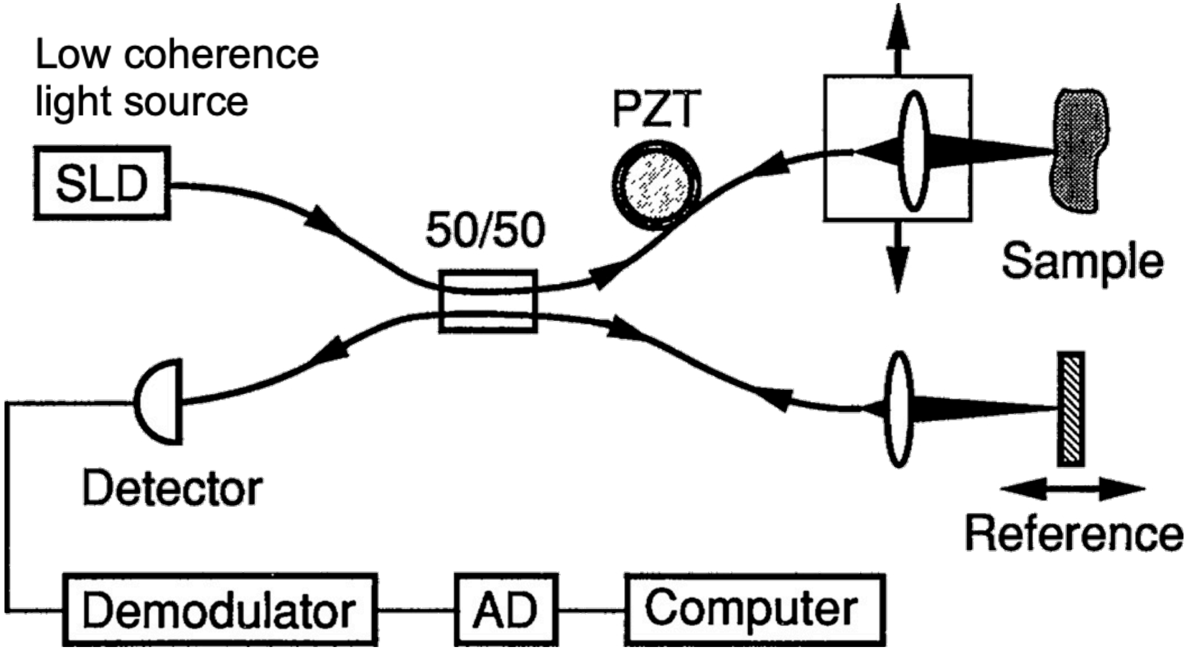


Science **254**, 1178 (1991)



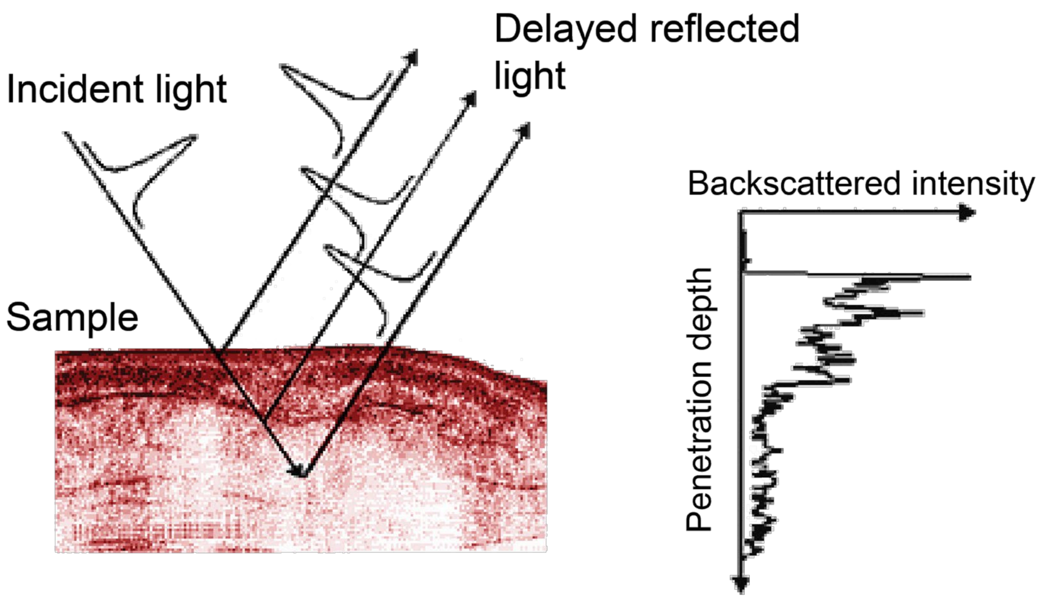
How does this work?

Optical coherence tomography (OCT)



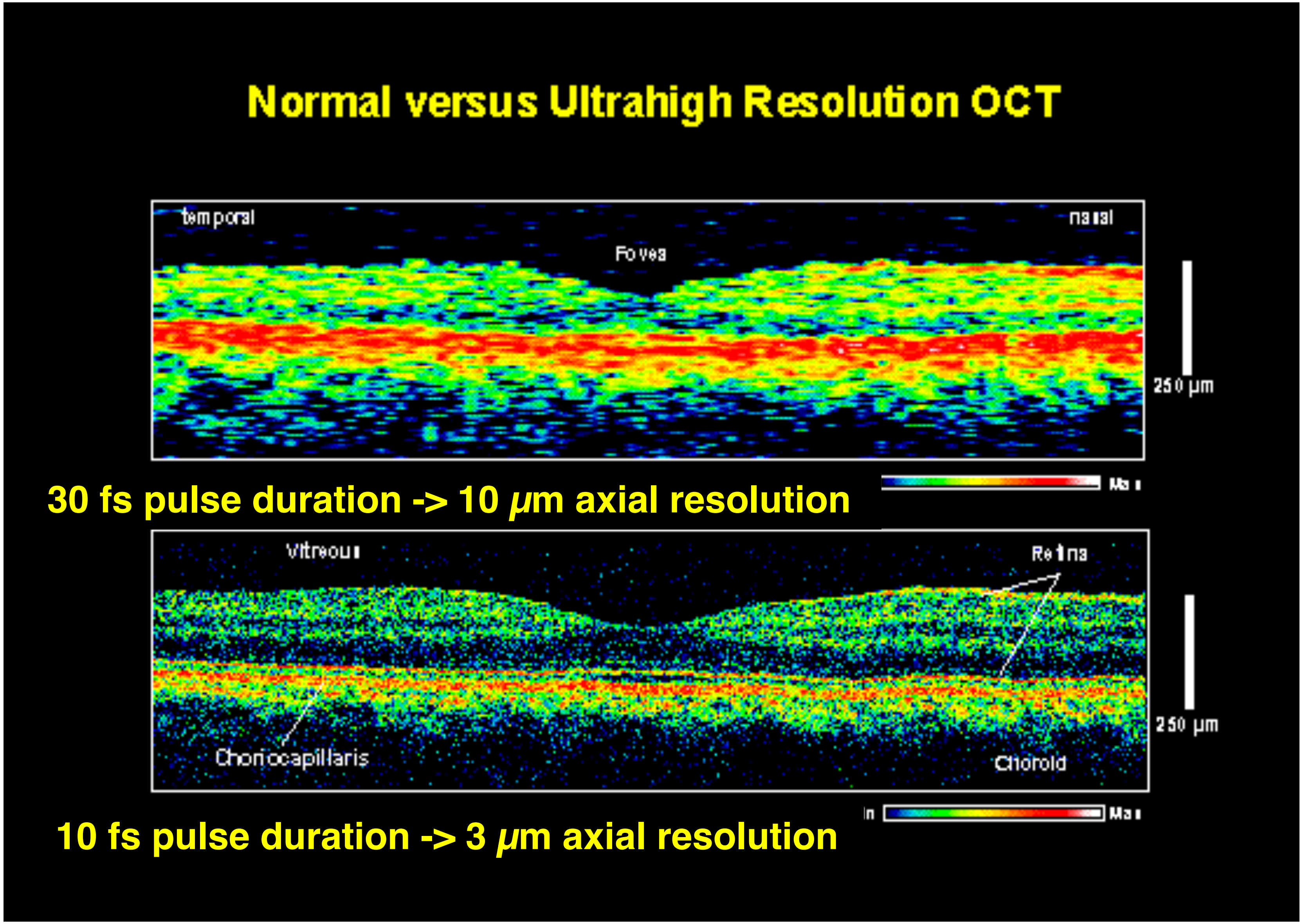
Michelson Interferometer

Interference only within coherence length



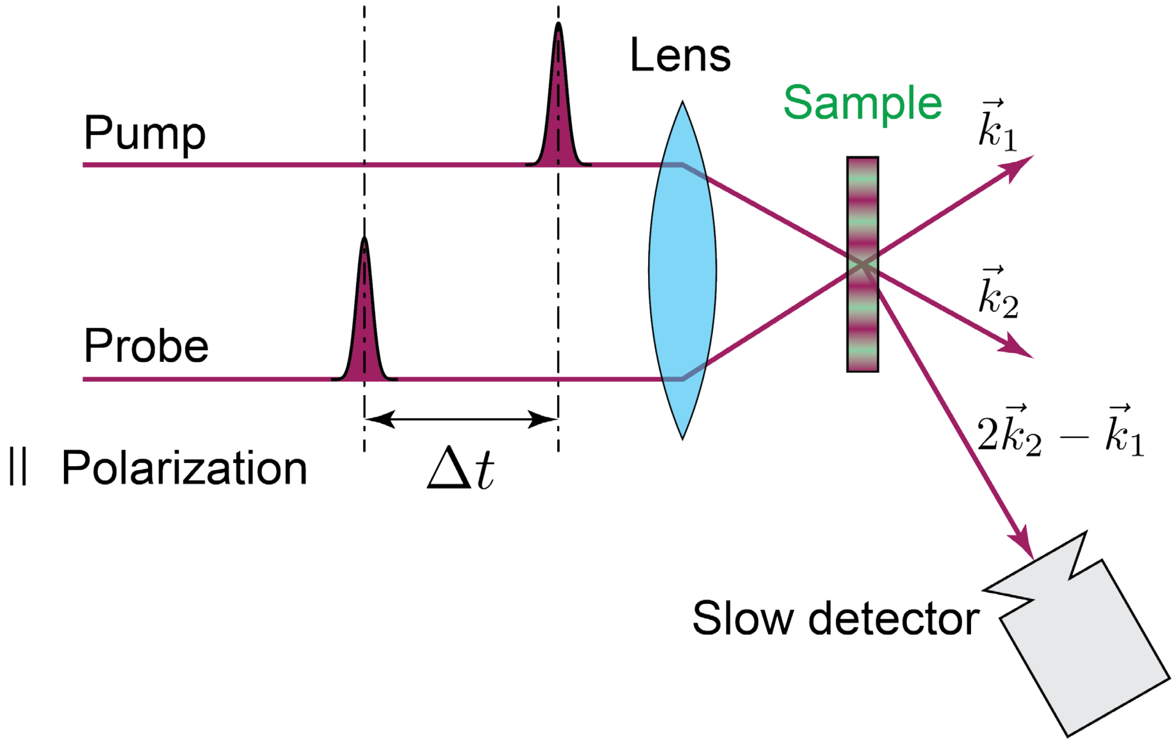
Science **254**, 1178 (1991)

Optical coherence tomography (OCT)



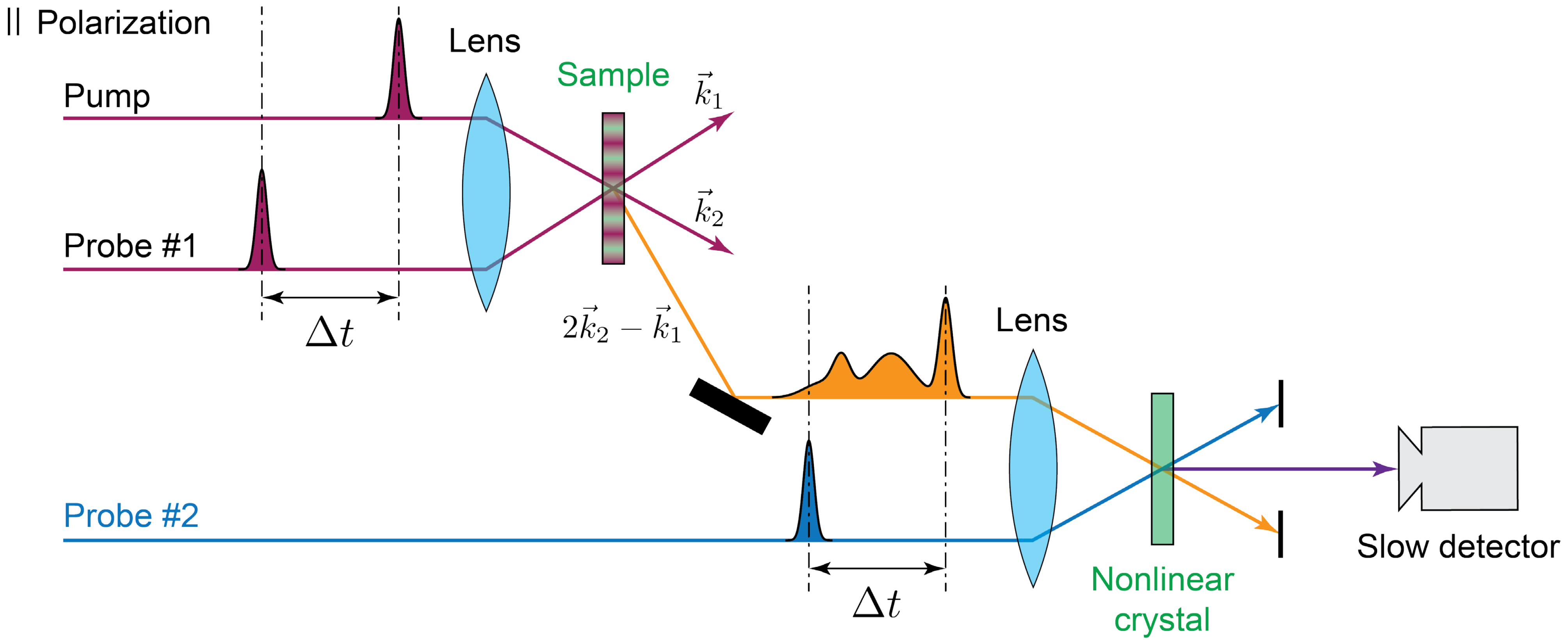
Prof. J. G. Fujimoto, MIT, USA

Time resolved four-wave-mixing

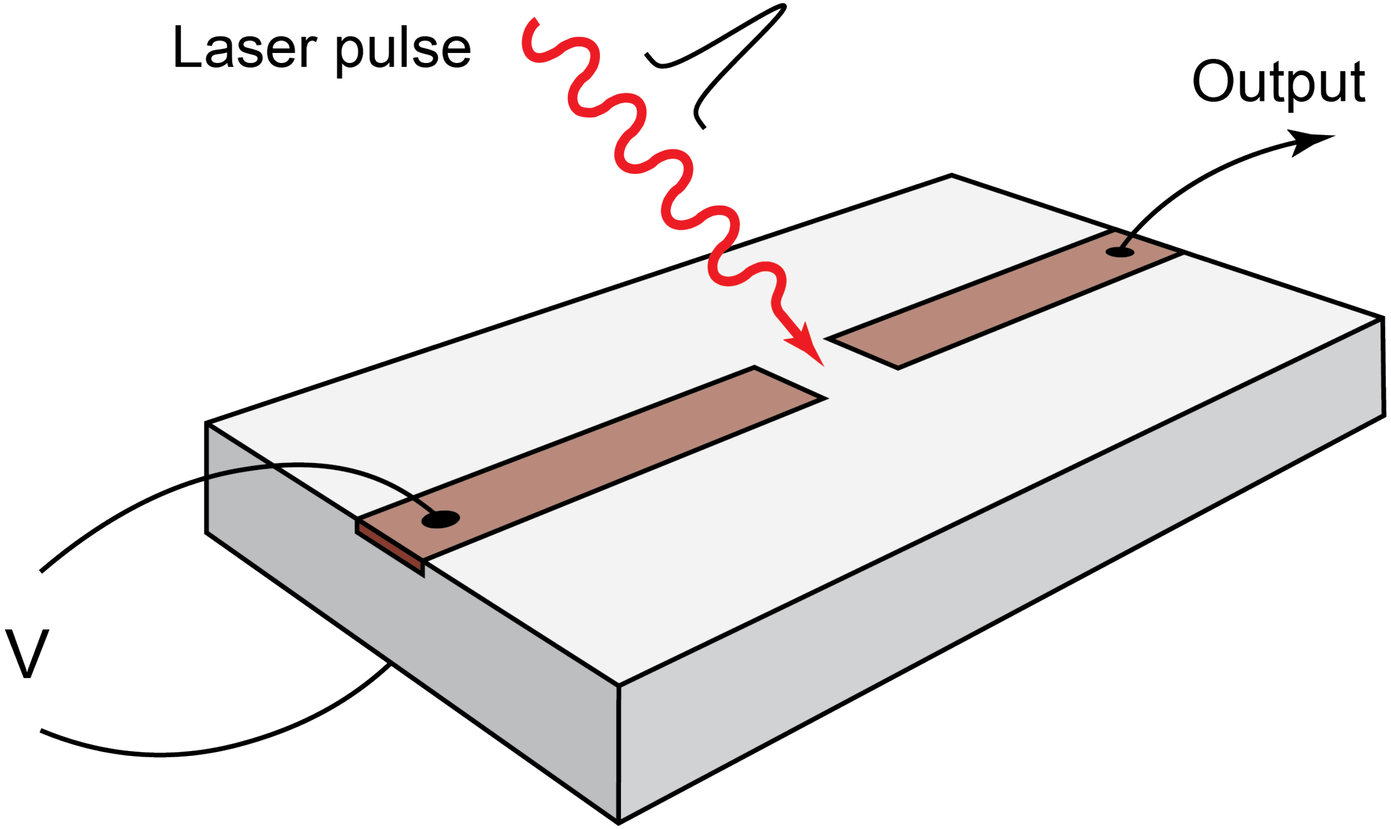


How do you do time resolved four-wave mixing?

Time resolved four-wave-mixing



Photoconductive switching

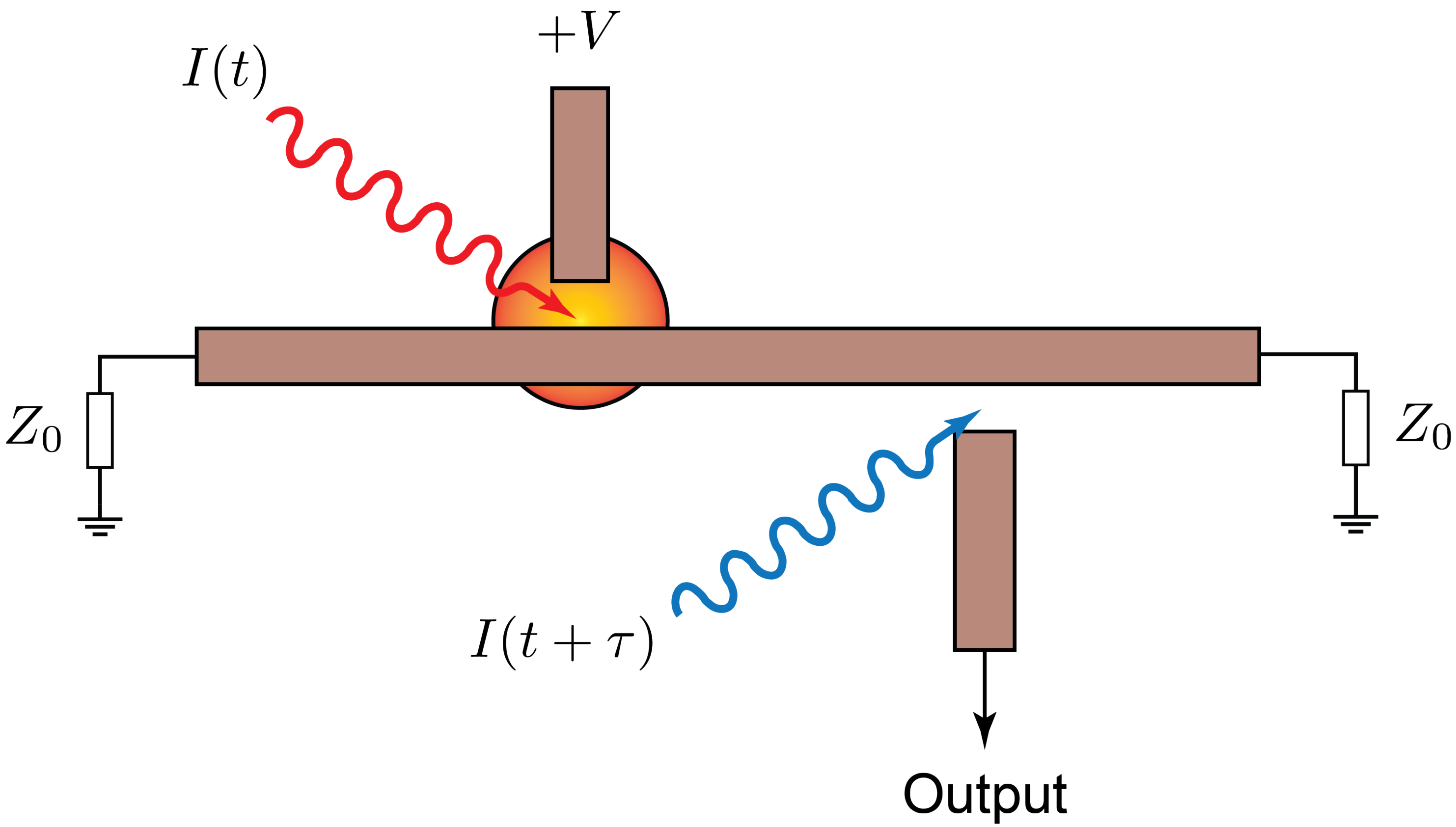


Photoconductive switch or Auston switch:

D. H. Auston, "Picosecond optoelectronic switching and gating in silicon," *Appl. Phys. Lett.* **26**, 101-103 (1975)

D. H. Auston, P. Lavallard, N. Sol, D. Kaplan, "An amorphous silicon photodetector for picosecond pulses," *Appl. Phys. Lett.* **36**, 66-68 (1980)

Photoconductive switching



Photoconductive sampling gate

D. H. Auston, A. M. Johnson, P. R. Smith, J. C. Bean,
"Picosecond optoelectronic detection, sampling, and correlation measurements in amorphous semiconductors"
Appl. Phys. Lett. **37**, 371 (1980)

and much more ….