Auto/cross-correlation of Green Picosecond Pulses Based on Two-photon Photodiodes

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Outline

- Ultrashort pulses, its measurement and motivation of my project
- Two-photon absorption measurement in UV diodes
- Auto-correlation measurement error quantification

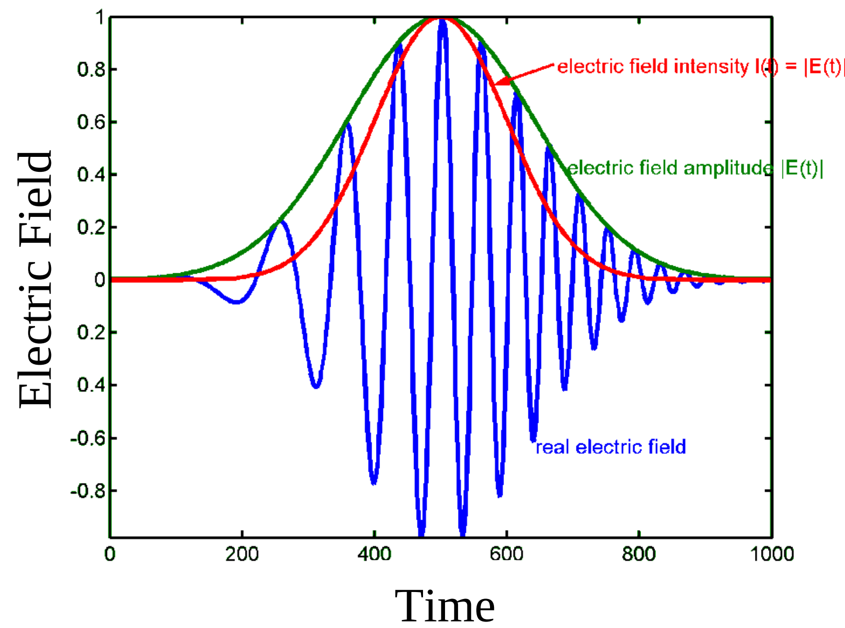
Ultrashort Pulses & Its Measurement

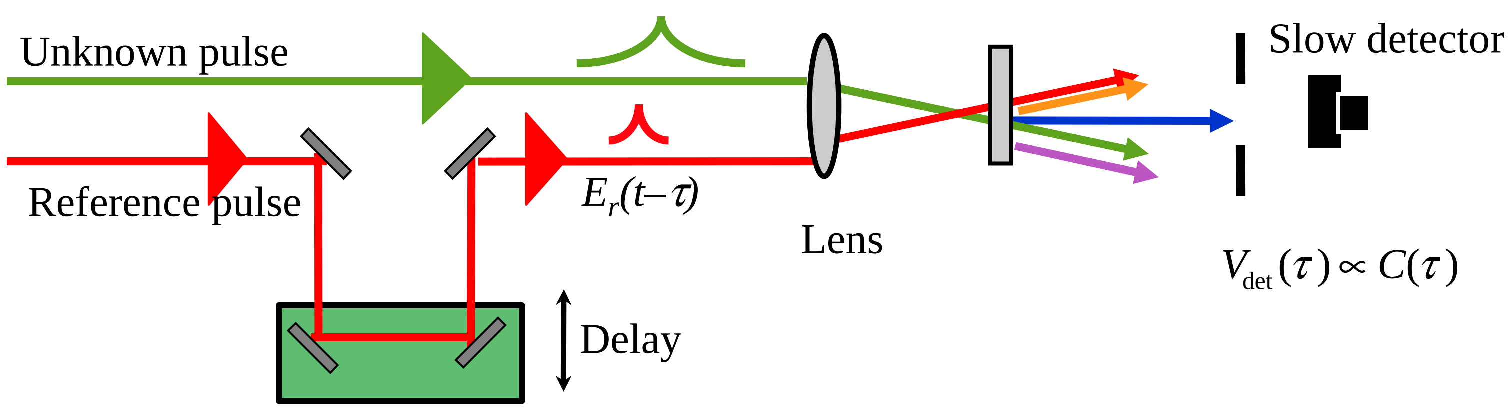
- Electromagnetic Pulses whose time duration is in the femtosecond (fs = 10^{-15} s) to picosecond (ps = 10^{-12} s) range.

- Electronics devices (diodes, oscilloscopes, etc) are not fast enough to allow direct measurement of picosecond and femtosecond pulses.

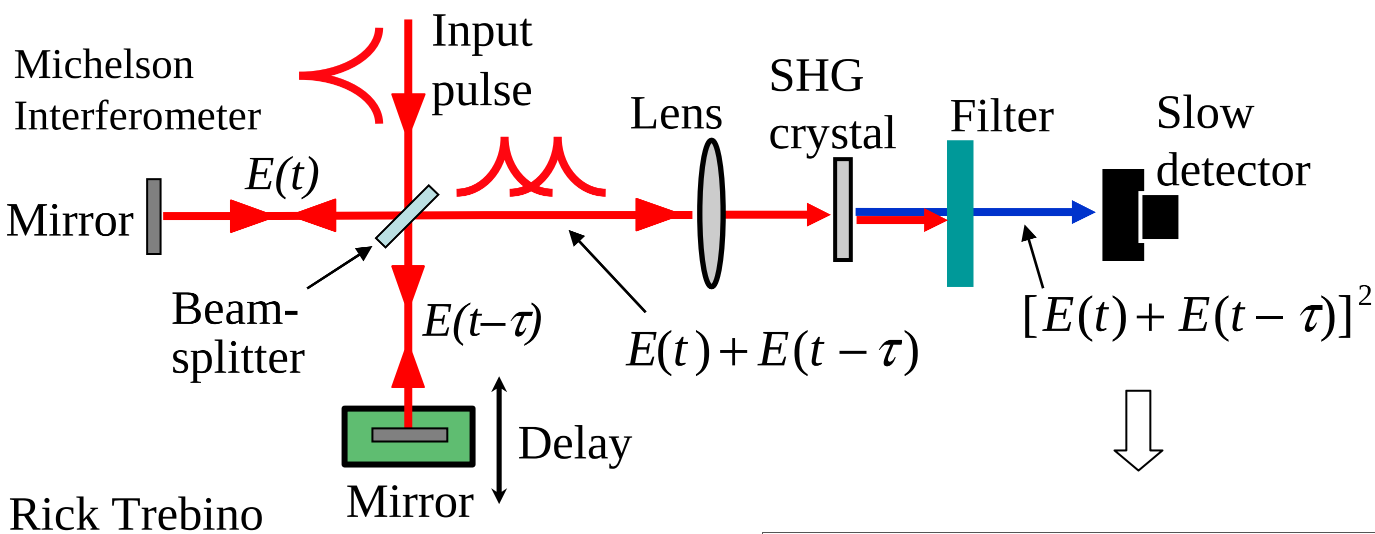
- Intensity Cross-Correlation:

$$A_c(\tau) = \int_{-\infty}^{\infty} I_s(t) I_r(t-\tau)\,dt$$



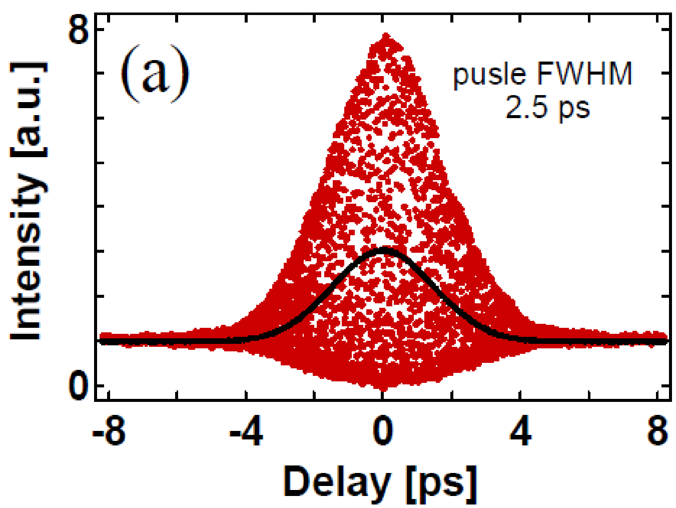


Interferometric Autocorrelation



Rick Trebino

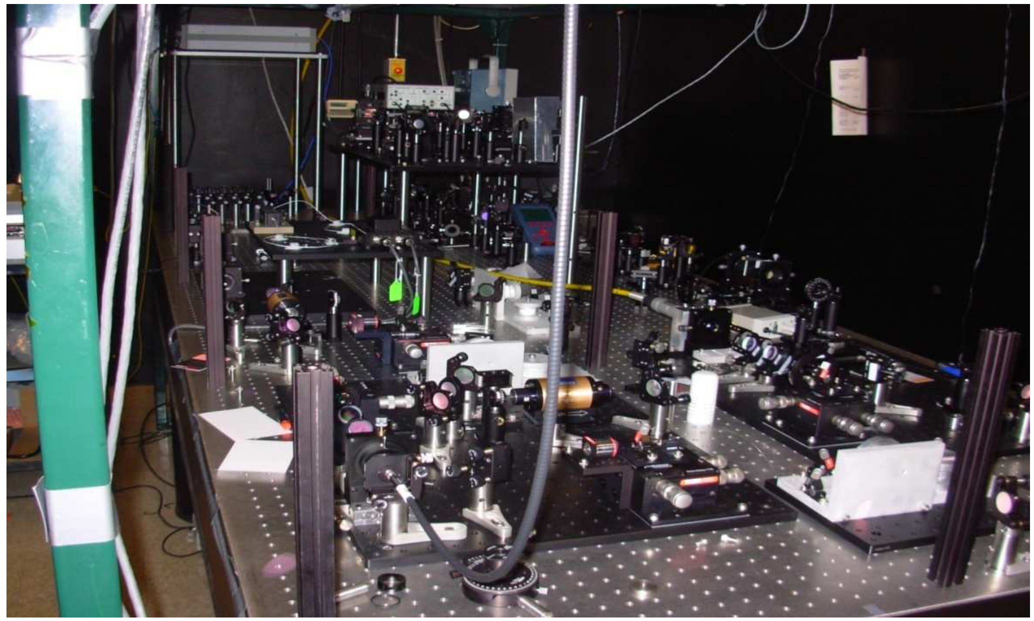
$$G(\tau)=\int_{-\infty}^{\infty}\left|[E(t)+E(t-\tau)]^2\right|^2 dt$$



Interferometric Autocorrelation:

- Split the pulse in two with a Michelson Interferometer.
- Overlap them as they recombine.
- Shaker arm creates the delay time.

First Stage of 1.3 GHz System



1.3 GHz oscillator

20 ps
14 mW

Compressor

2 ps
7 mW

SMF pre-amplifier

250 mW

DC-LMA amplifier

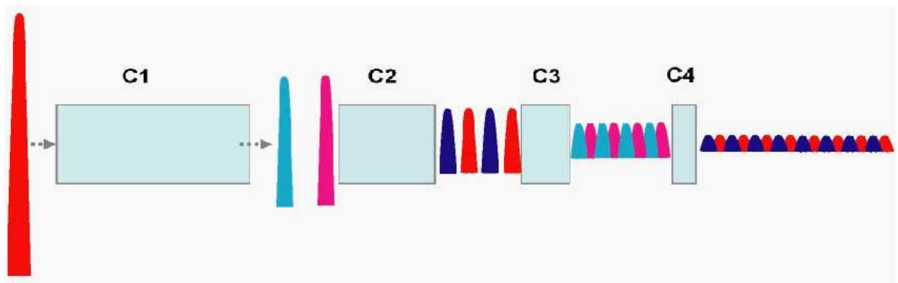
5 watts

SHG

250 mW

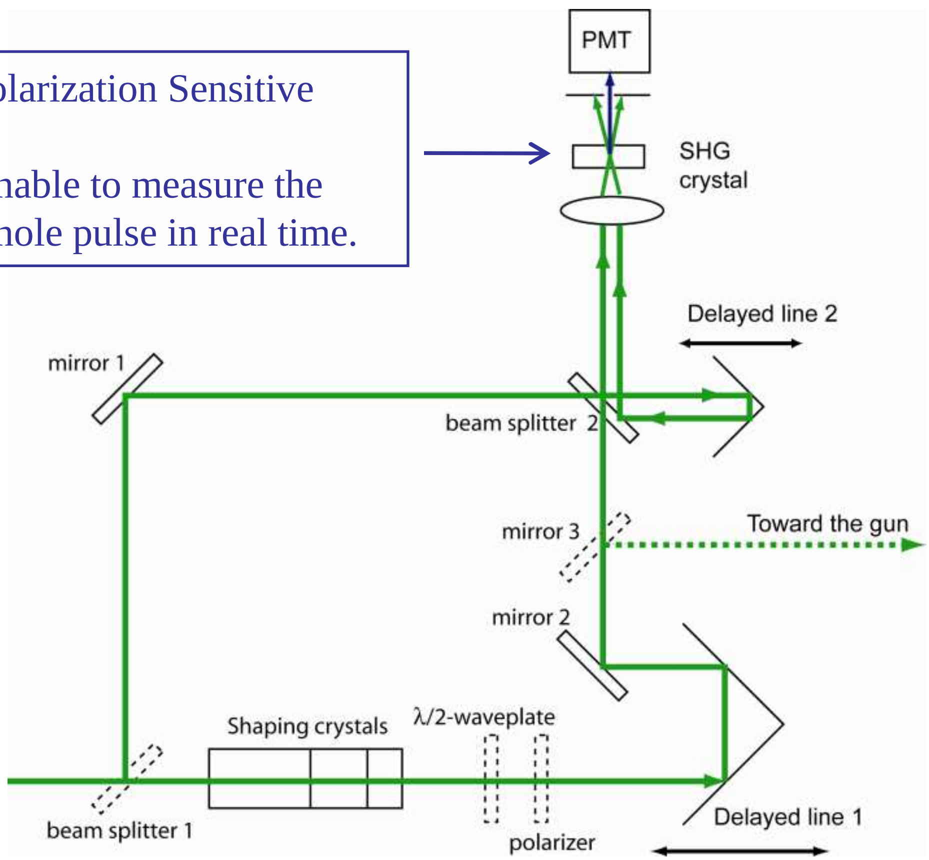
Shaping Crystals

Longitudinal Shaping & SHG Auto-correlator



Polarization Sensitive

Unable to measure the whole pulse in real time.

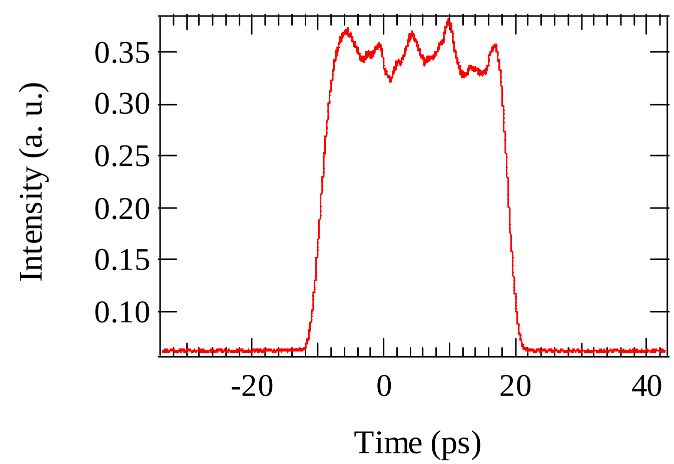


- ERL requires Flat-top pulses.

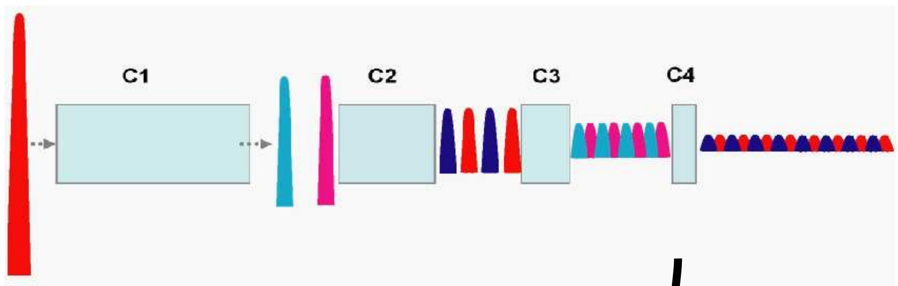
  ⇩

  We stack 2-ps pulses through a sequence of 3 birefringent crystals to produce pulse with nearly flat-top.

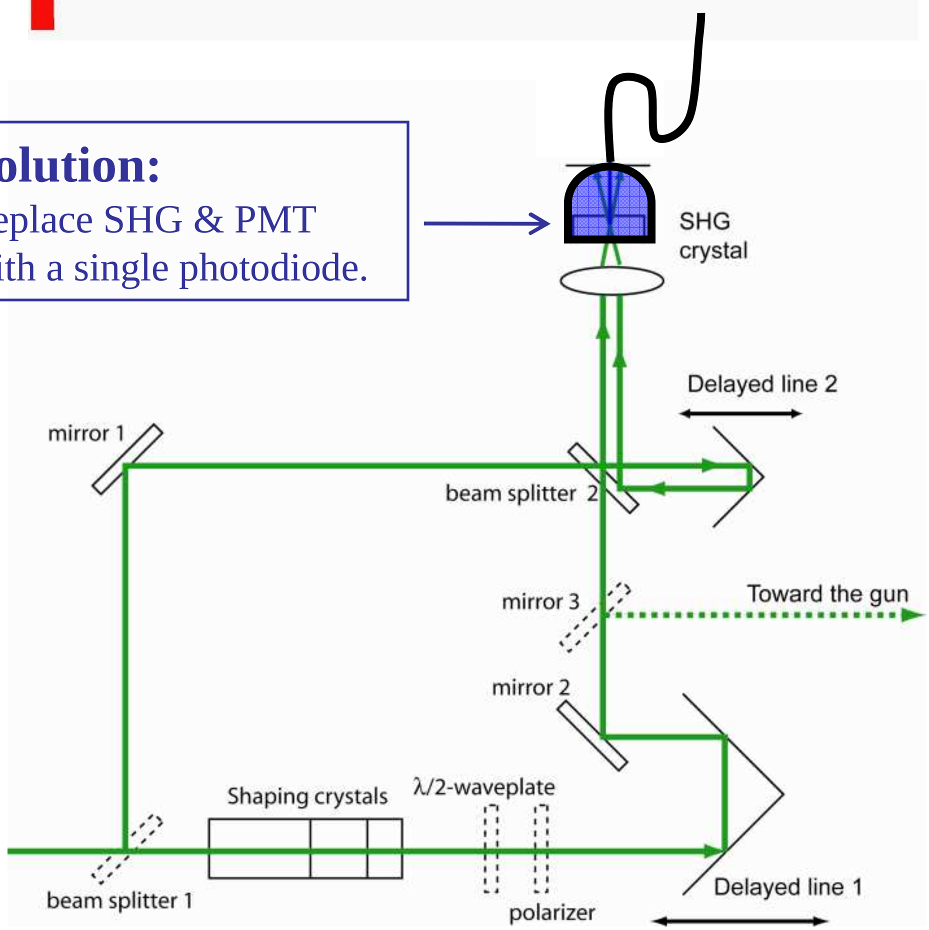
- **Problem**: SHG crystal is polarization sensitive.



Solution



Solution:
Replace SHG & PMT with a single photodiode.



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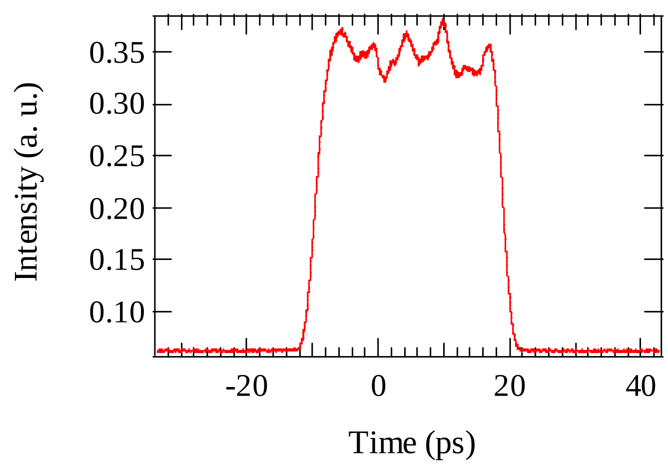
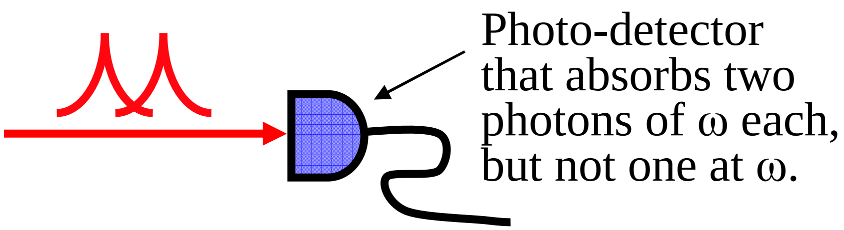
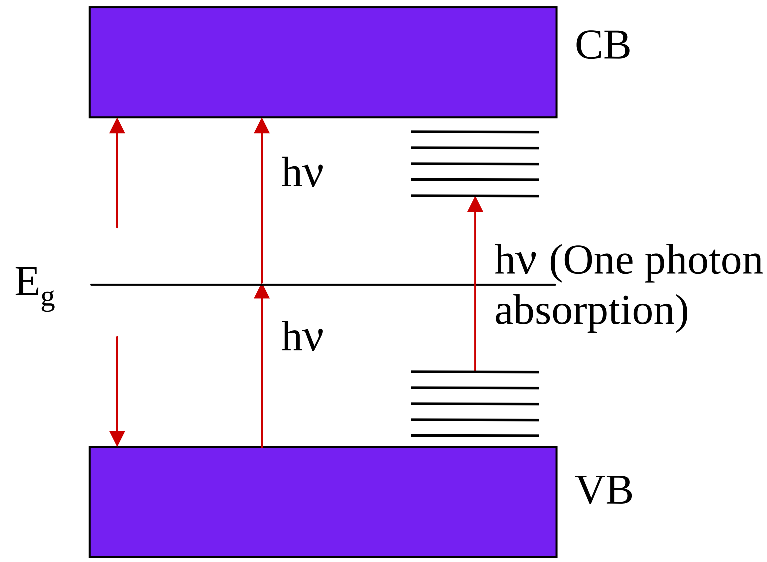


Two-photon Photo-diode

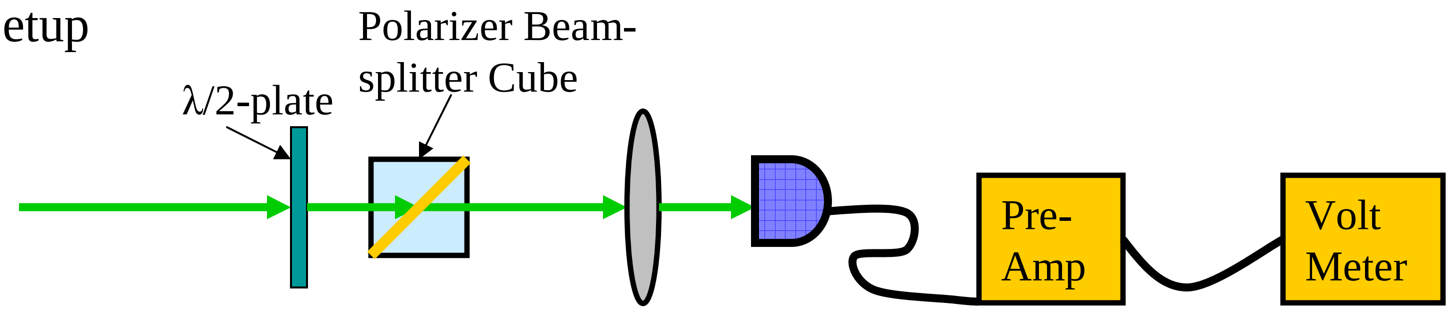




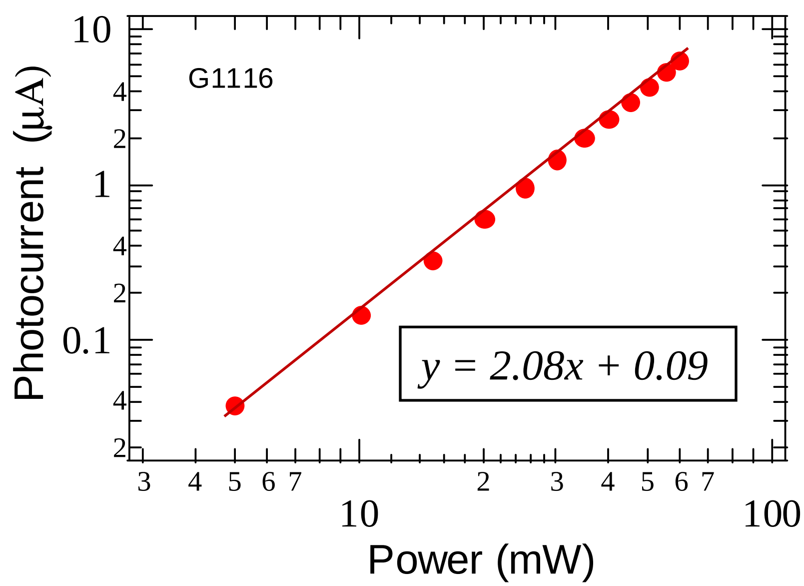
- $h\nu < E_g < 2h\nu$
- Two-photon induced photocurrent: signal is a *quadratic function* of power ~ I^2
- **Problem**: Impurity$\longrightarrow$ linear absorption signal$\longrightarrow$ obscure quadratic signal
- **Solution?** ~ Find one that works!

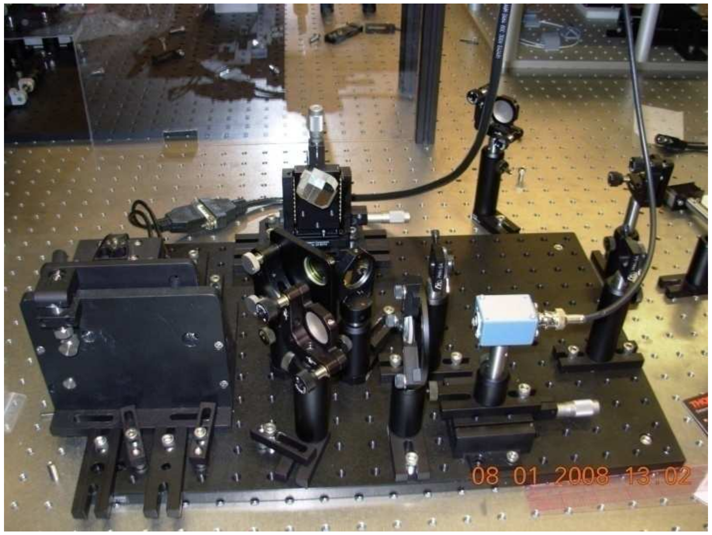
Two-photon Absorption Experiment

- Measurement: photo-current as a function of the laser beam power.
- Setup



- **Trial Experiment:** Diode = G1116, λ = 1μm, I_{peak} ~ 10^7 W/cm^2, w ~ 15 μm
- Result: nice quadratic response (as expected)





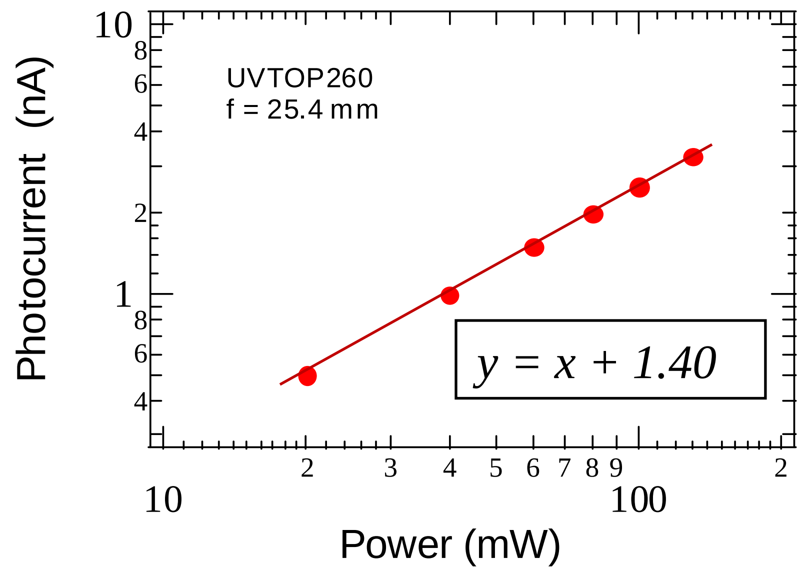
Experiment With Green (λ = 520nm) Laser

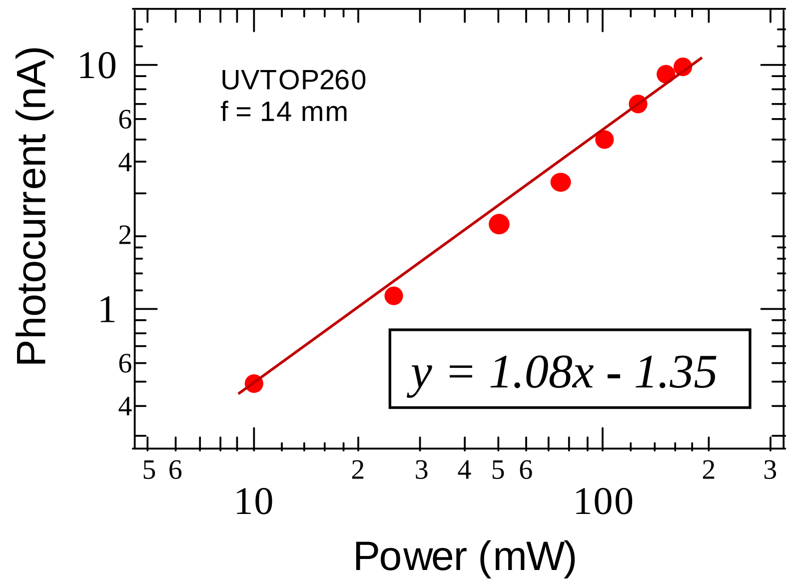
- Diode = UVTOP260
  f_{lens} = 1 inch = 25.4 mm
  w ~ 8 μm
  $I_{peak} \sim 1.8\times10^7$ W/cm^2

Reduce spot size, *w*, of the focused beam, hence, increase I_{peak}

Increase the two-photon absorption rate

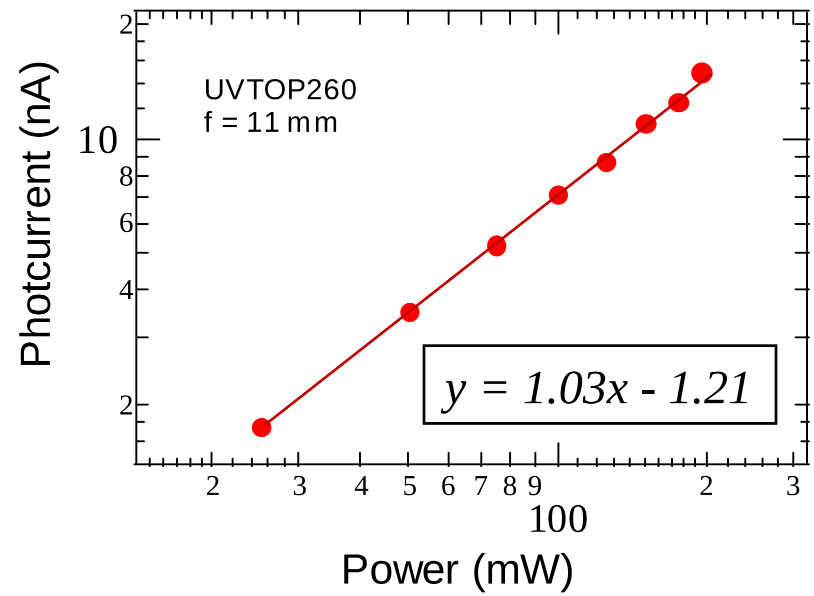
- Diode = UVTOP260
  f_{lens} = 14 mm
  w ~ 4.6 μm
  $I_{peak} \sim 6\times10^8$ W/cm^2



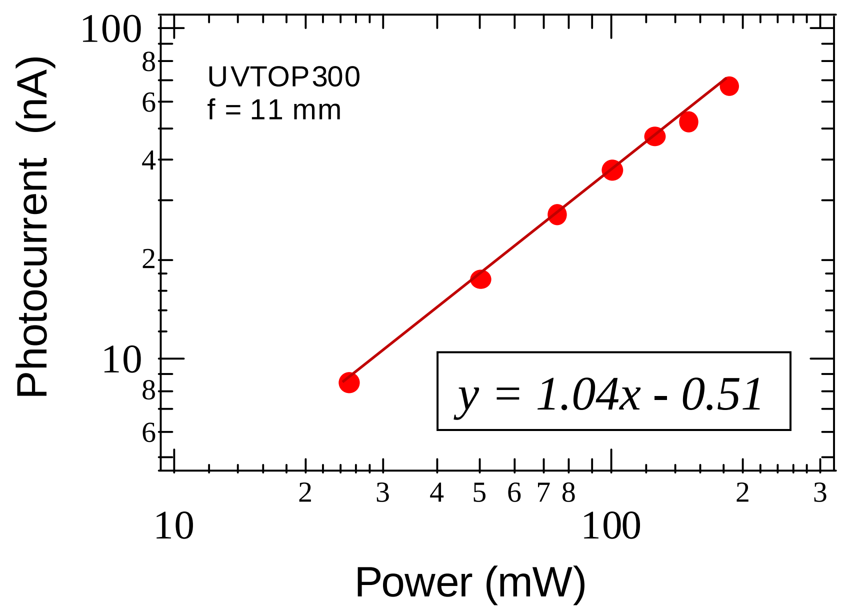


Experiment With Green (λ = 520nm) Laser (2)

- Diode = UVTOP260
  f_{lens} = 11 mm
  w ~ 4 µm
  I_{peak} ~ 9.8×10^8 W/cm^2



- Diode = UVTOP300
  f_{lens} = 11 mm
  w ~ 4 µm
  I_{peak} ~ 9.8×10^8 W/cm^2



Unfortunately, None Works

Errors in Auto-correlation Measurement

- Two major sources of error associated with

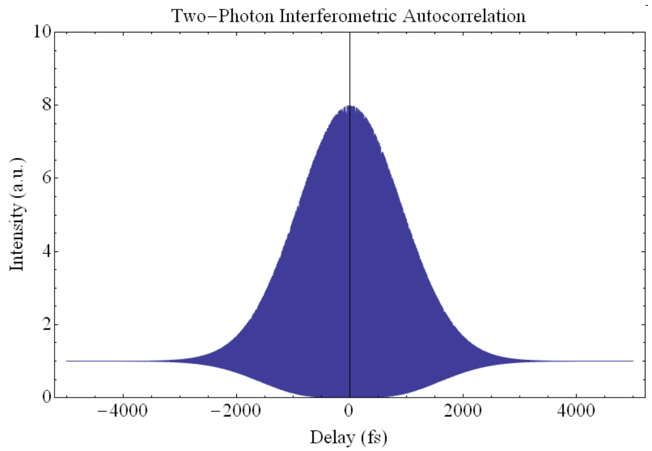
  our measurement:

  - Linear absorption signal distortion

  - Misalignment while scanning the delay

Linear Absorption Distortion

- Linear absorption signal can distort the shape of the pulse.
- **Simulation:** assume pulse FWHM = 2 ps, two-photon signal = linear signal



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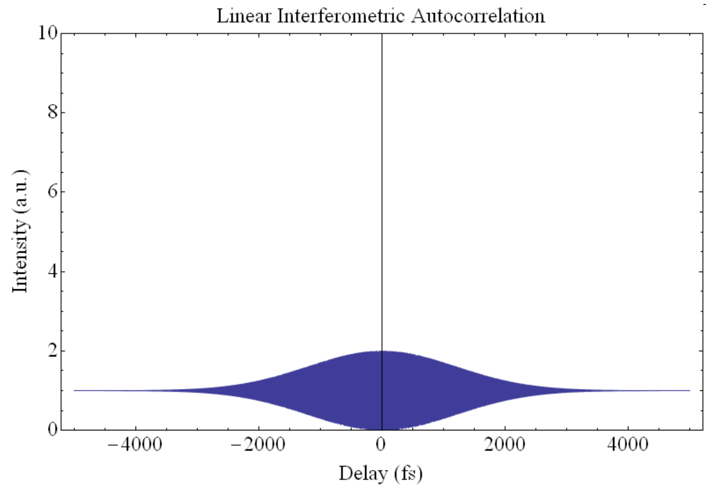

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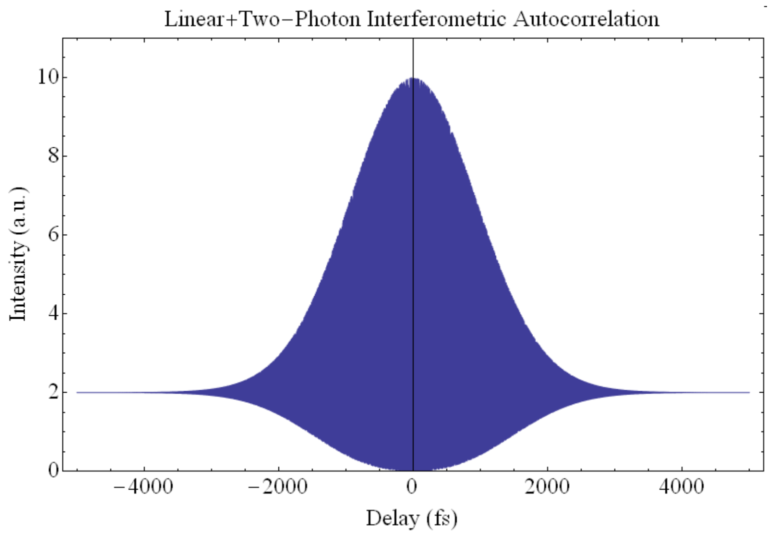
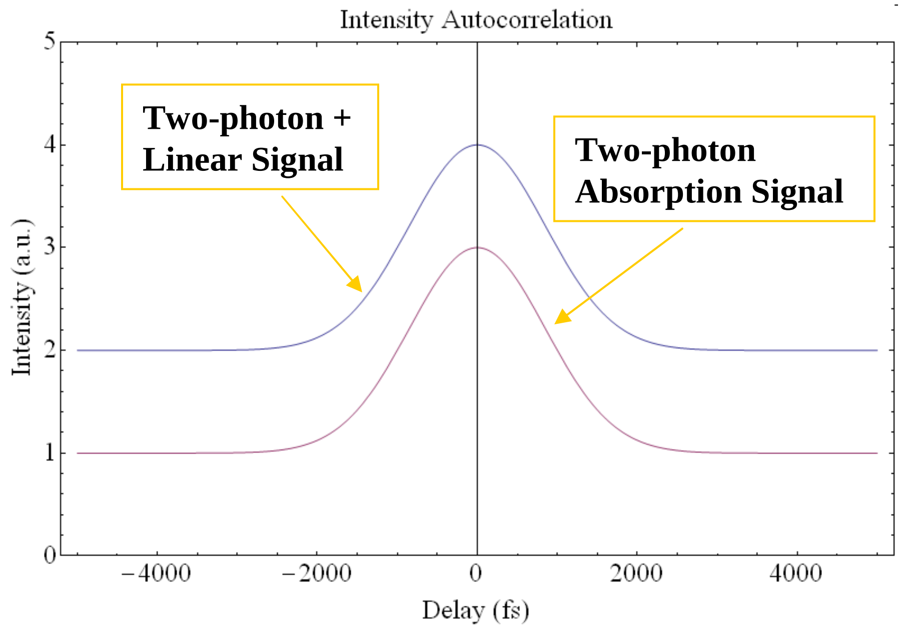
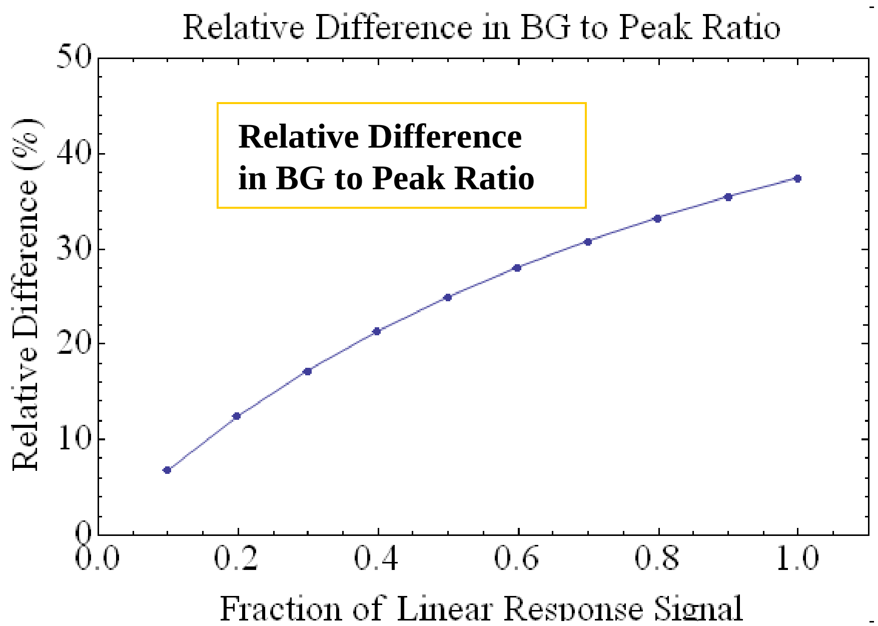
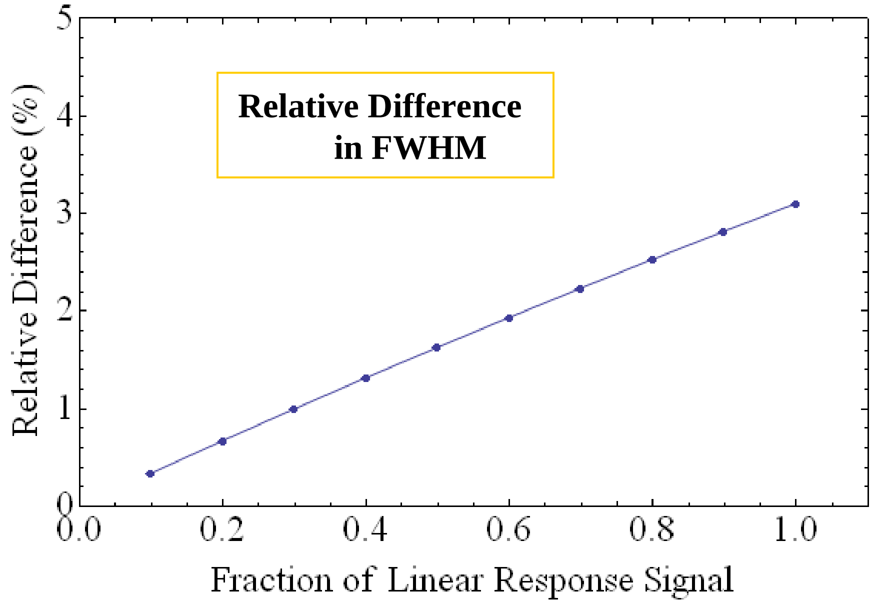


- **The background to peak ratio is distorted.**
- **The FWHM measured is slightly greater than the correct one.**

Linear Absorption Distortion (2)







- Intensity Autocorrelation: The background to peak ratio is also distorted.
- Linear signal = c · two-photon signal ($0 \leq c \leq 1$)
- Background to peak ratio distortion ↓ , as c↓ .
- Difference in FWHM also ↓ . Max discrepancy (c = 1) ~ 3%

Misalignment

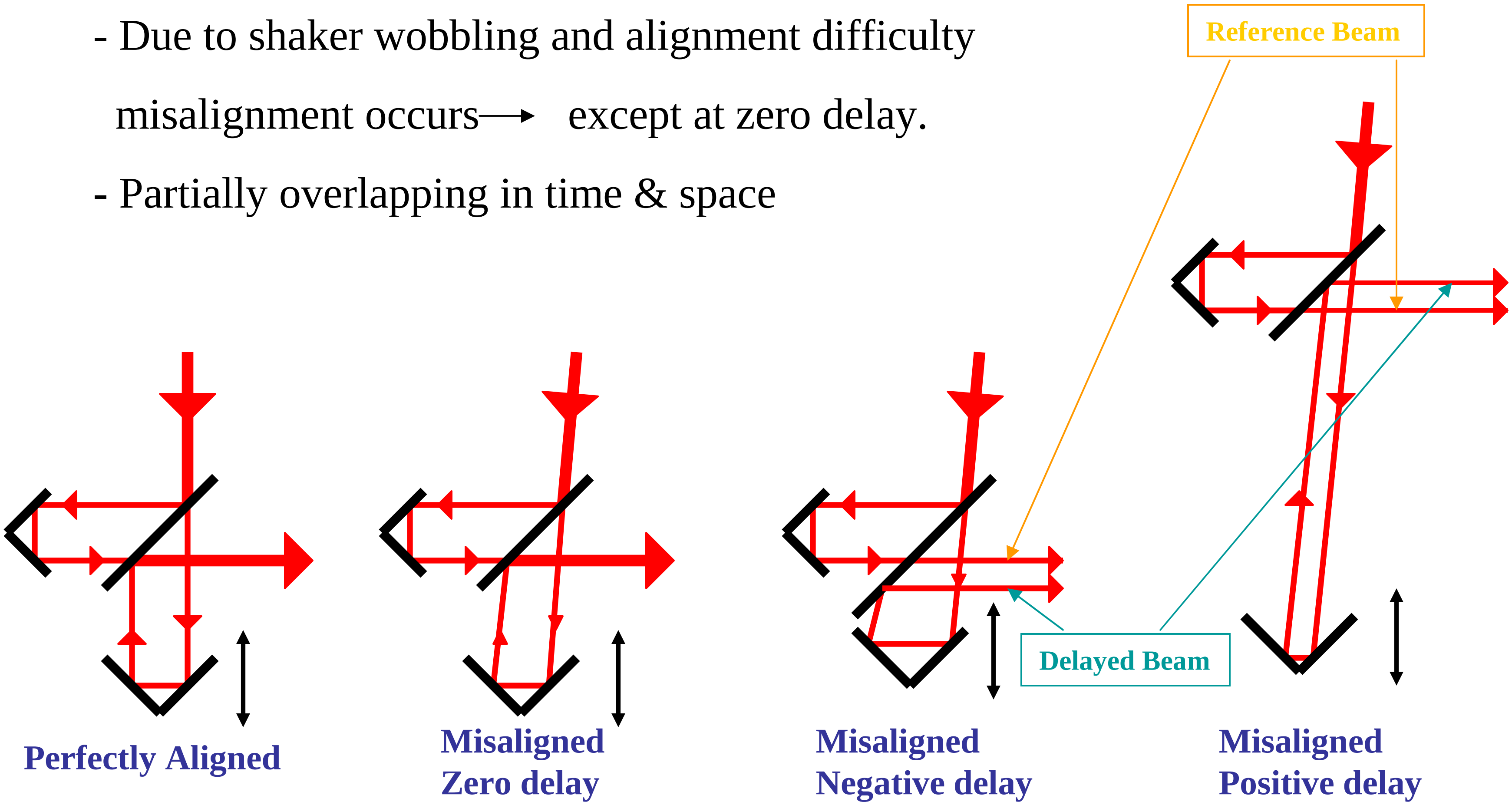
- **Misalignment Error**

  - Align at zero delay

  - Due to shaker wobbling and alignment difficulty

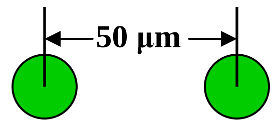
    misalignment occurs ⟶ except at zero delay.

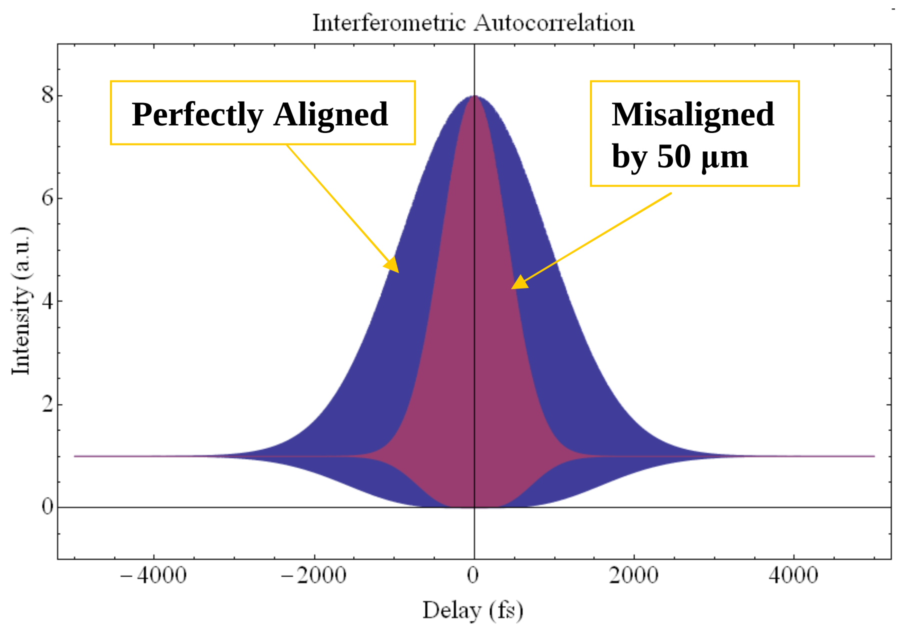
  - Partially overlapping in time & space

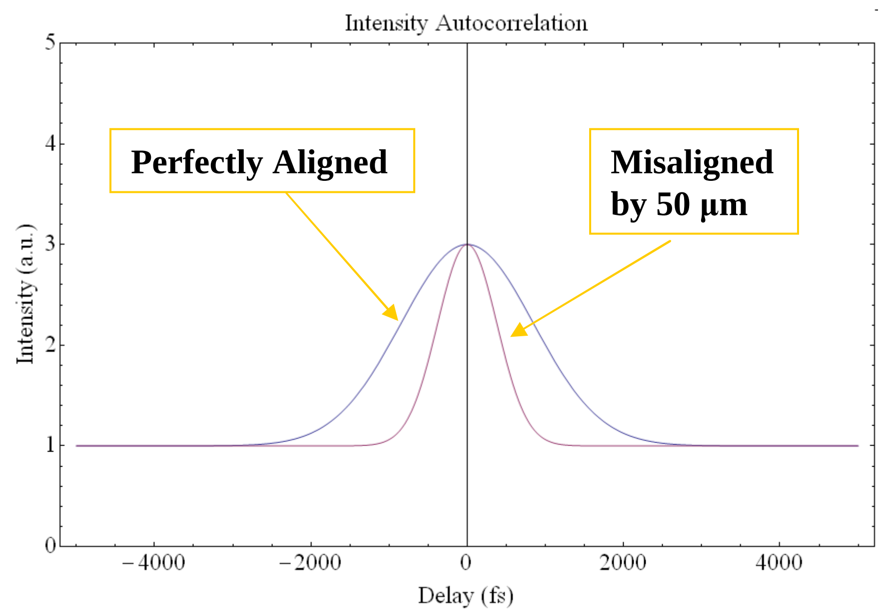


Misalignment Error Simulation

- Assume: D_{beam} = 20 µm, pulse FWHM = 2 ps
- Misalignment:





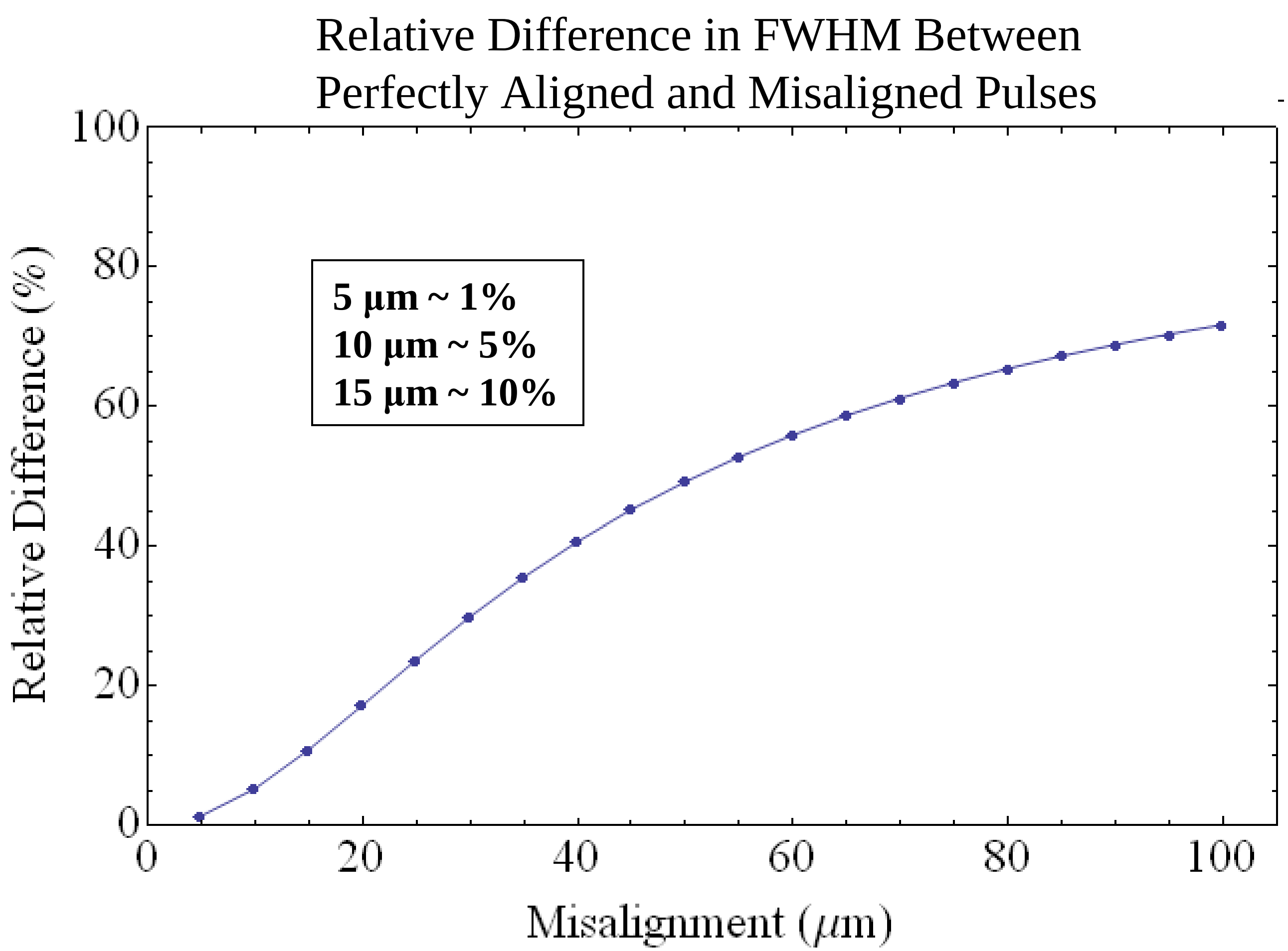


- **Simulation shows:**

  Artificially shortened pulses are measured due to misalignment.

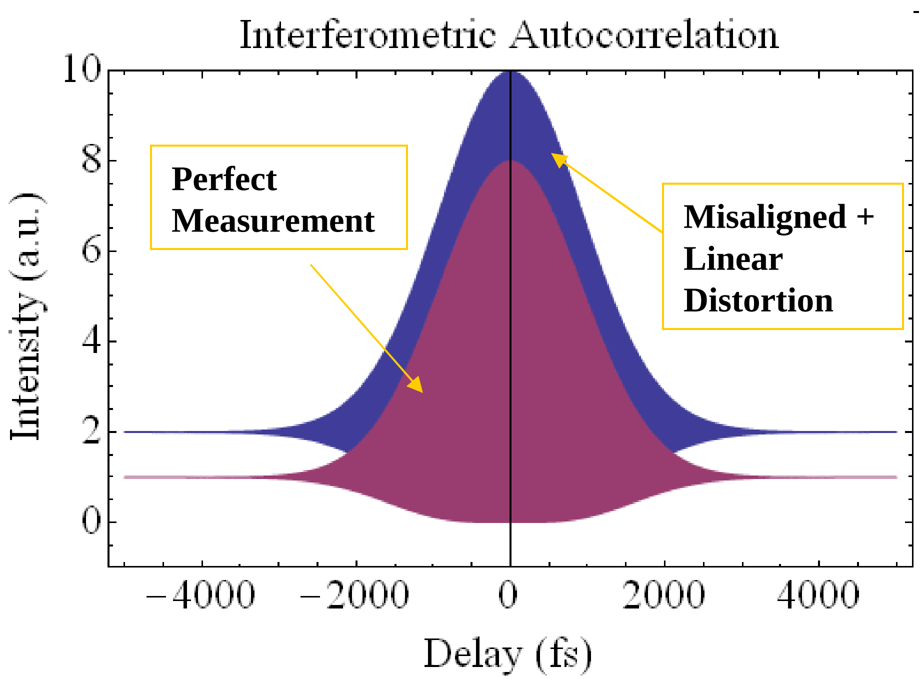
Misalignment Error Simulation (2)

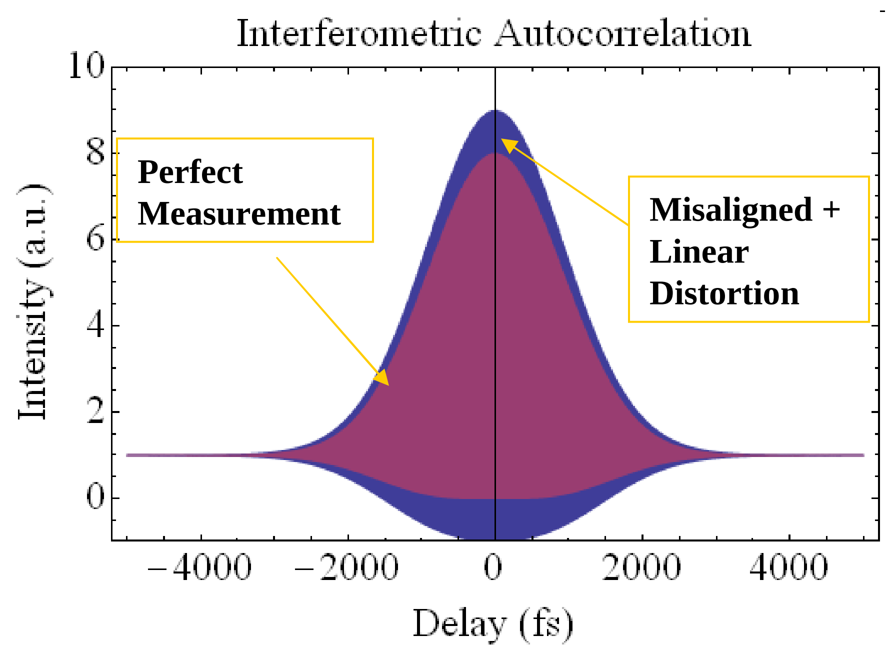
- Under normal conditions ⟶ error within < 10%.



Misalignment + Linear Distortion

- Misalignment ~ 5μm, linear signal = two-photon signal

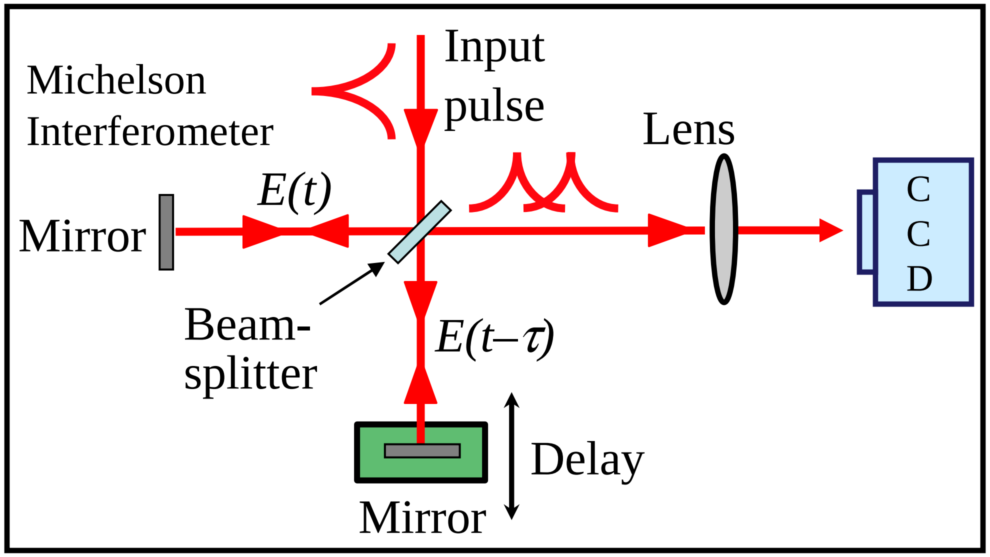




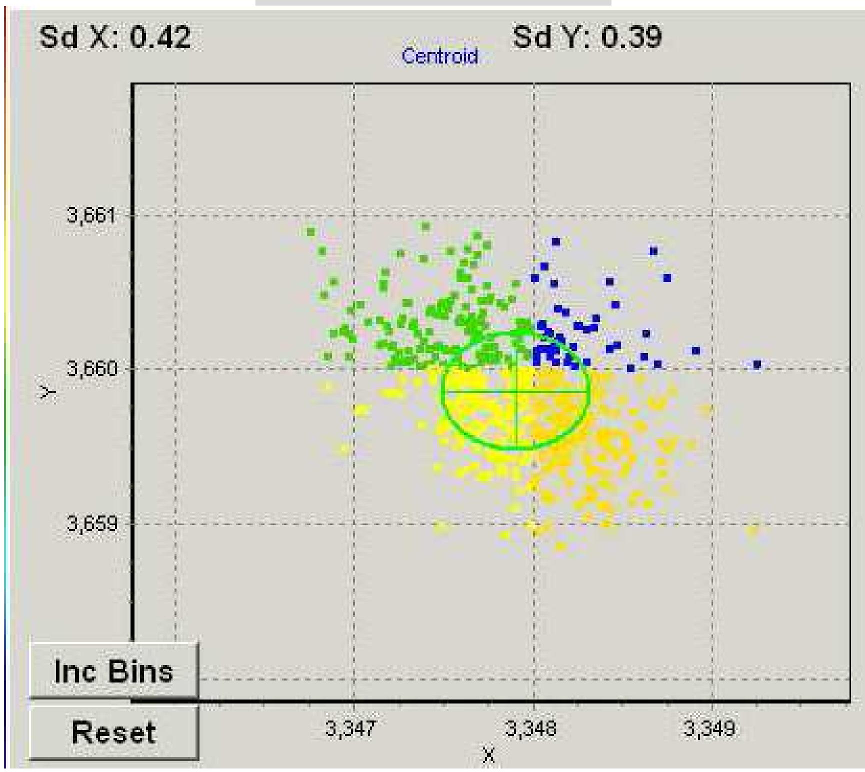
* These plots are intended to show what happens. Under normal conditions, the difference may not be so obvious.

The Misalignment Experiment

- Setup →



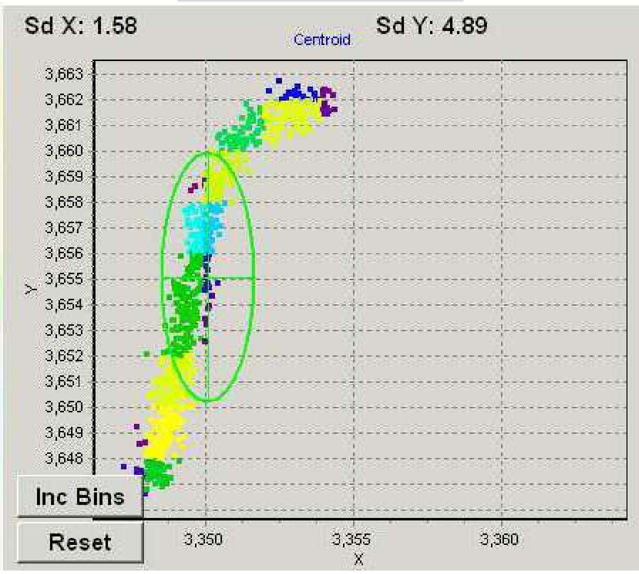
Reference Arm



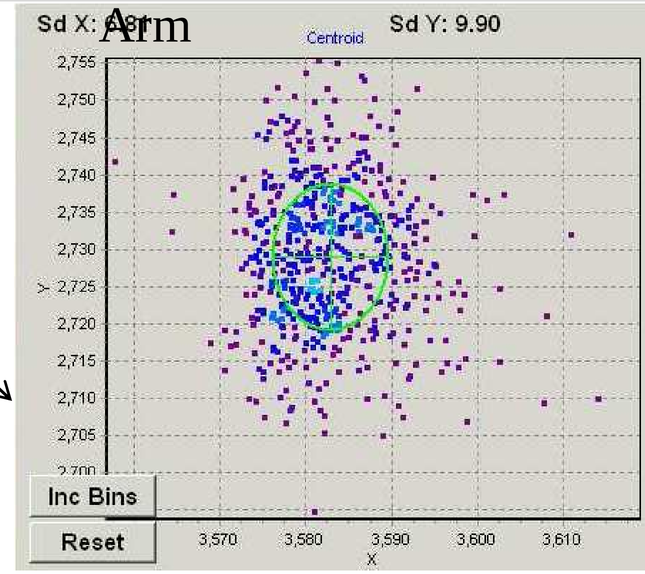
- Standard Deviation, σ, shows how stable the beam is.
- Reference Arm: σ ~ 0.6 μm

The Misalignment Experiment (2)

Shaker Arm

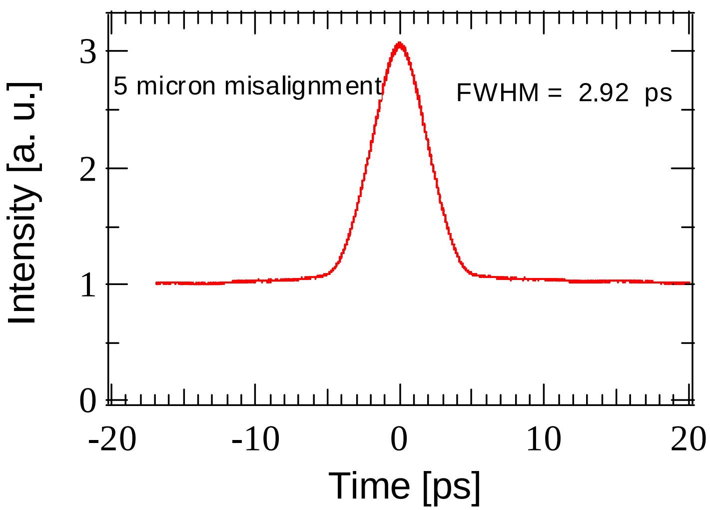


Further Misaligned Shaker Arm

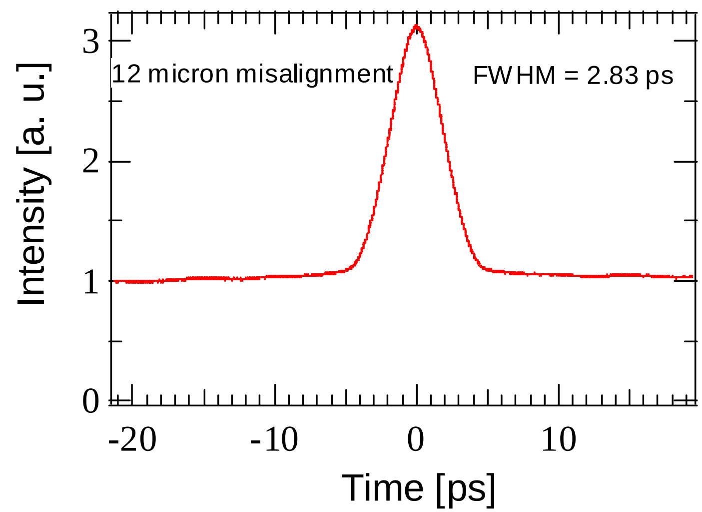


σ ~ 5 μm

σ ~ 12 μm
Wobbling effect increases substantially

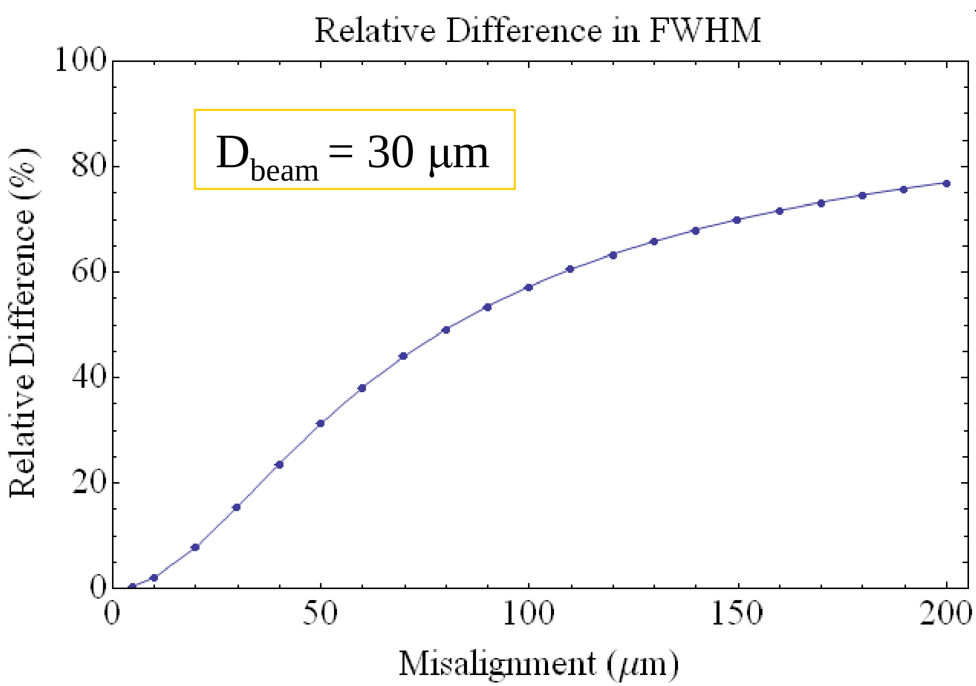


Replace CCD with photo-diode and measure the traces.



Experimental Results VS Theoretical Results

- **Experimental** Results: $$\frac{FWHM_{5\mu m} - FWHM_{12\mu m}}{FWHM_{5\mu m}} \approx 3\%$$
- **Theoretical** Results: $$\frac{FWHM_{5\mu m} - FWHM_{12\mu m}}{FWHM_{5\mu m}} \approx 1.6\%$$



- **Discrepancy** arises due to the non-negligible wobbling effect of the shaking mirror.

Conclusion

1. None of the photo-diode exhibits quadratic response signal at the current power level. We will continue to search for more suitable diodes.
2. However, it is likely that these diodes we tested will work at higher beam power, which will happen once the second stage amplifier is in operation.
3. Computer simulation shows that **linear absorption** signal can
   - distort the background to peak ratio of both the interferometric and intensity autocorrelation measurement.
   - artificially lengthen the pulse. (< 5%)
4. Computer simulation also shows **misalignment** between the reference and shaker arm will yield artificially shortened pulses.

   There is about a factor of 2 discrepancy between the experimental and theoretical results. One of the main reason for such discrepancy is due to the increasing wobbling effect of the shaker mirror when it is misaligned purposely.

Acknowledgement

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