Diploma Thesis

High Precision Wide Dynamic Range Nonlinear Reflectivity Measurement

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Outline

Motivation
Theory
Setup 1: AOM
Setup 2: Cube
Measurement
Results
Remaining Challenges
Conclusion

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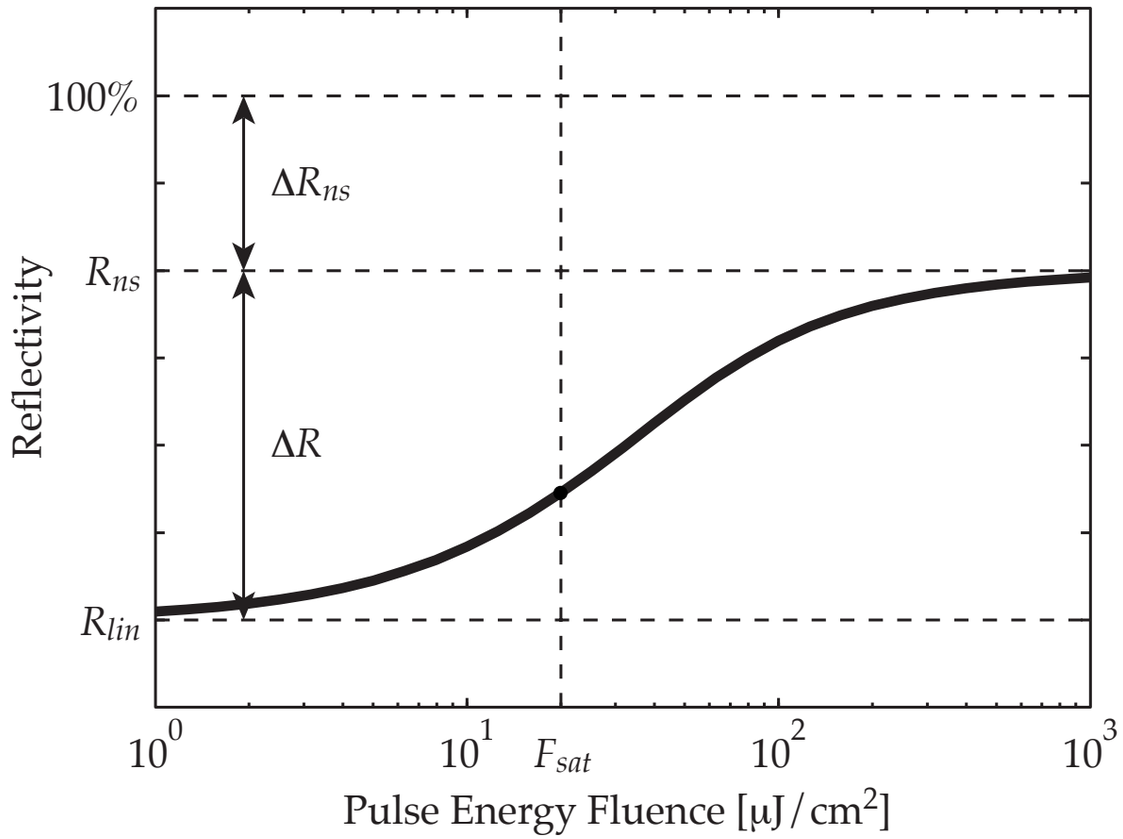
SESAM reflectivity



small modulation depths $\Delta R < 1\%$ are desired

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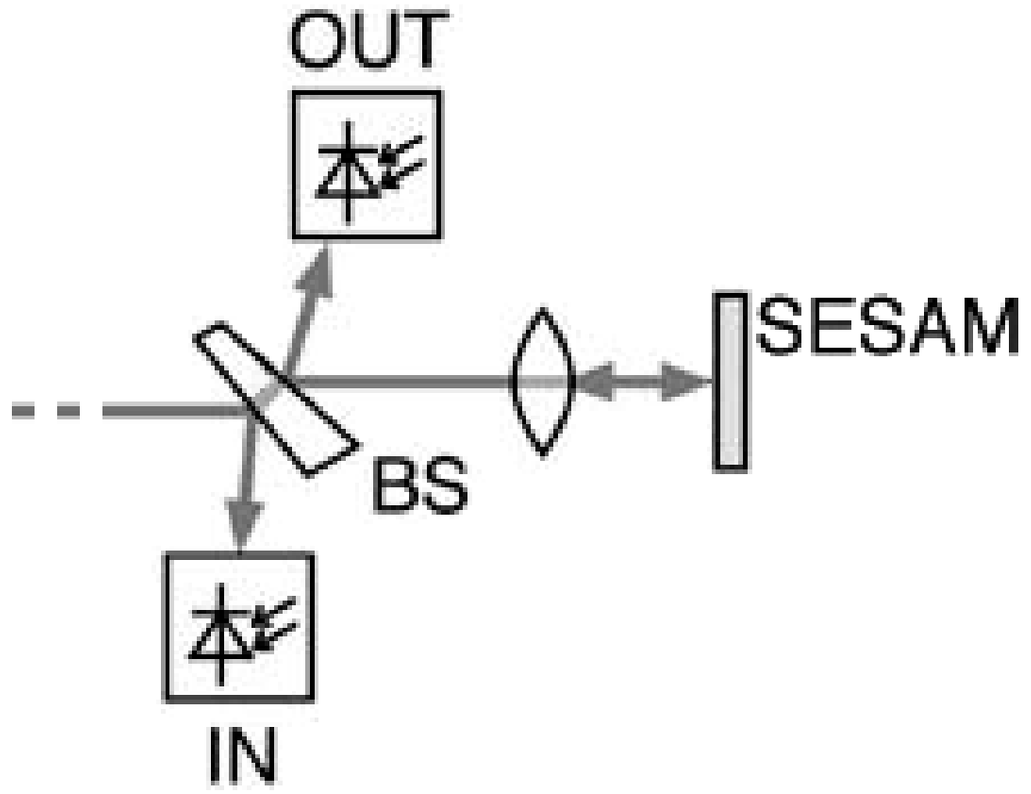
Previous measurement setup



incident and reflected power are measured separately

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Errors

$$OUT = c_1 P R$$

$$IN = c_2 P$$

$$c_1/c_2 R$$

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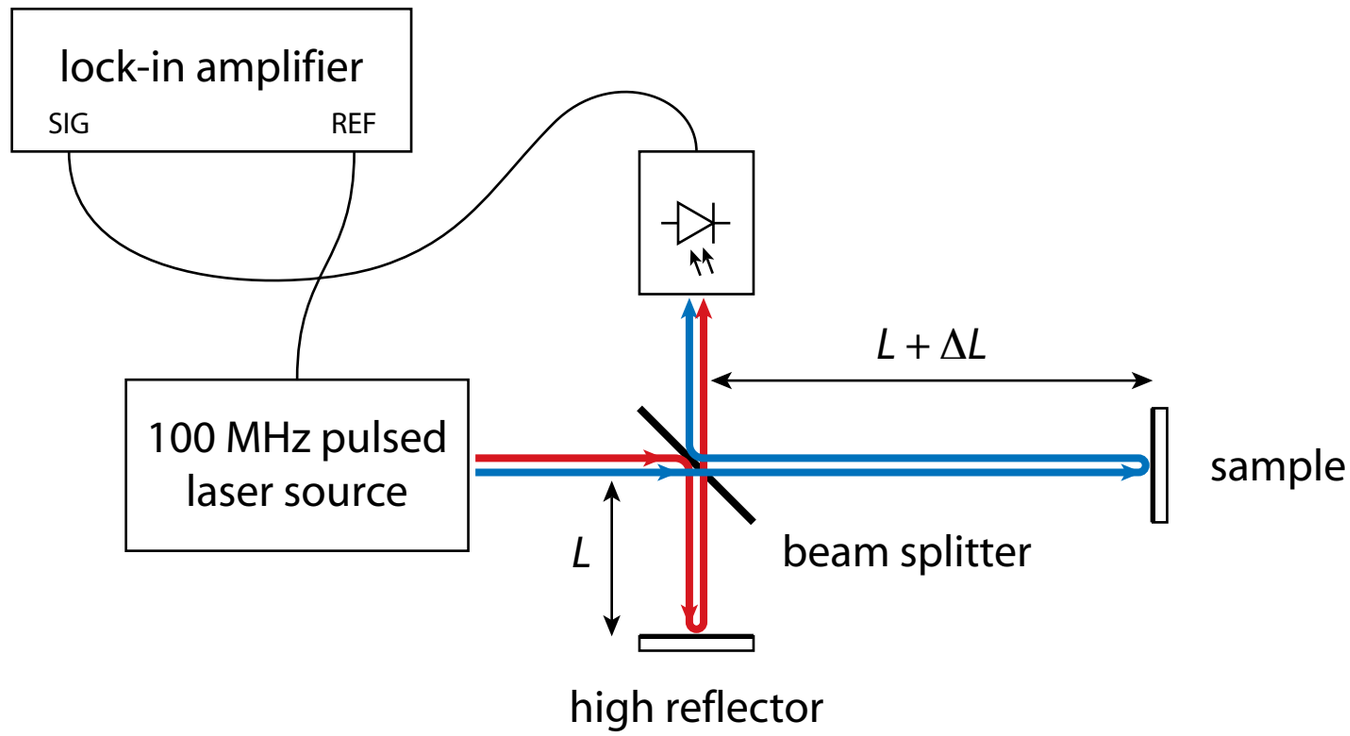
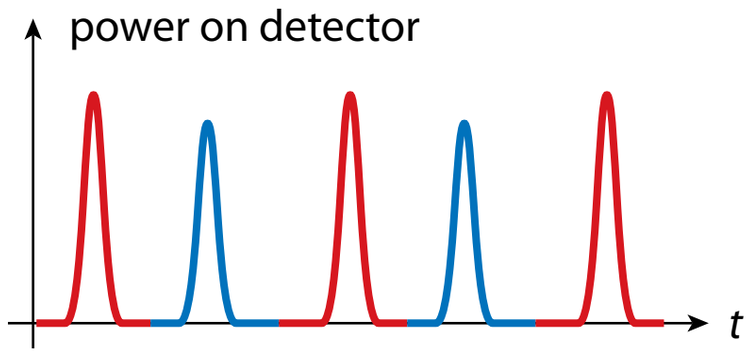
Basic setup





no interference

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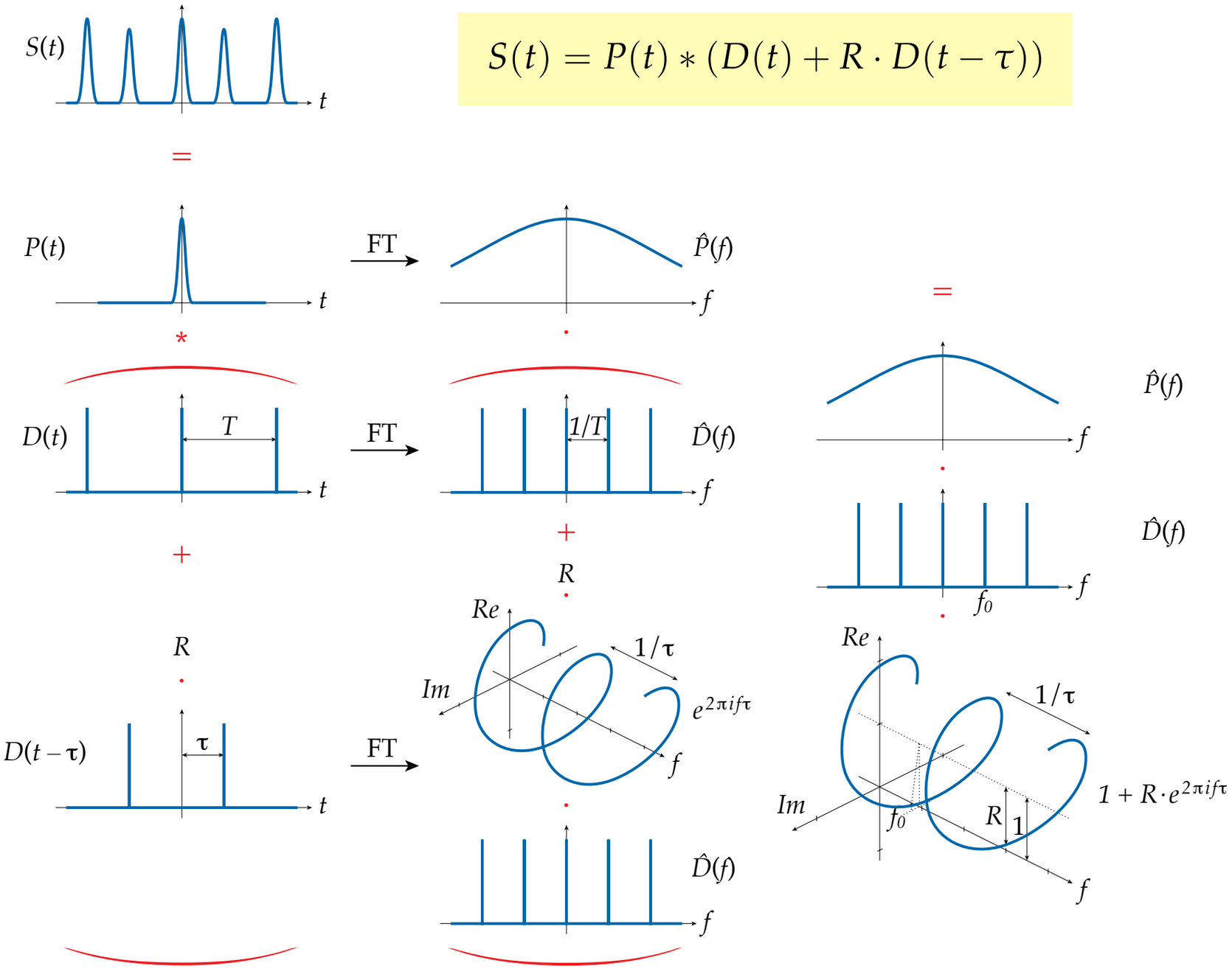
Fourier transform

$$S(t) = P(t) * (D(t) + R \cdot D(t-\tau))$$



$$\hat{S}(f) = \hat{P}(f) \cdot \left(\hat{D}(f) + R \cdot e^{2\pi i f \tau} \cdot \hat{D}(f)\right)$$

$1 - R$

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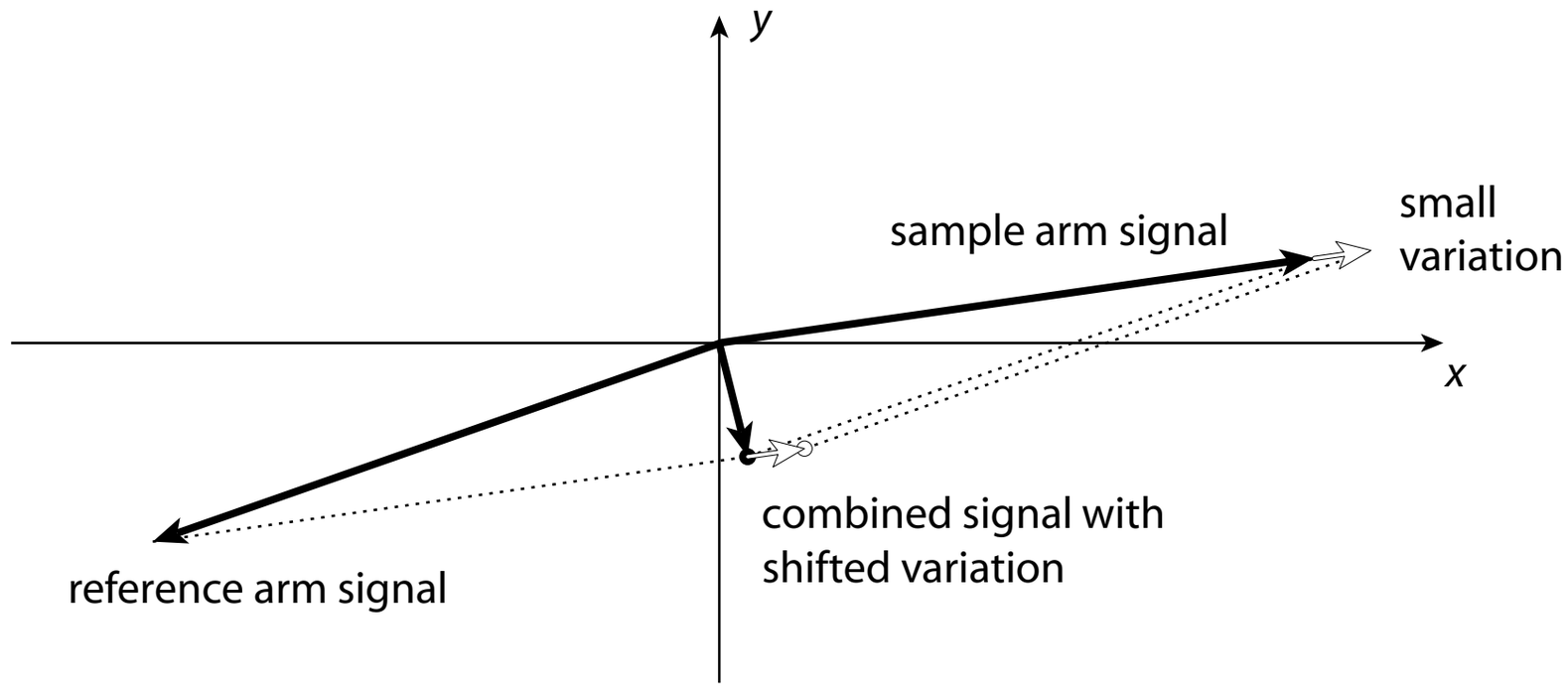
Lock-in amplifier output



power ↔ amplitude scaling

delay ↔ phase rotation

exact adjustment of power ratio and delay is not needed

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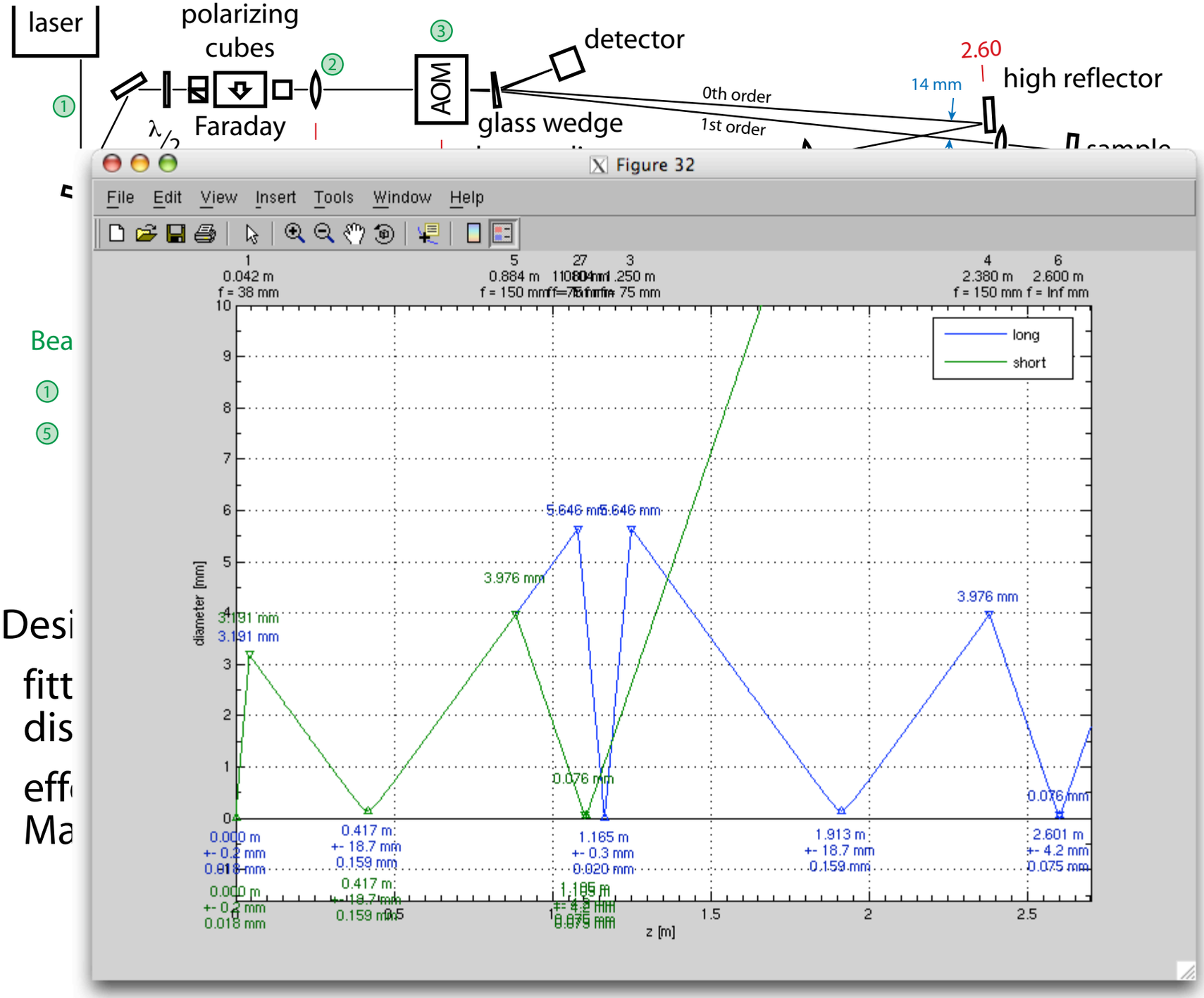
Setup design



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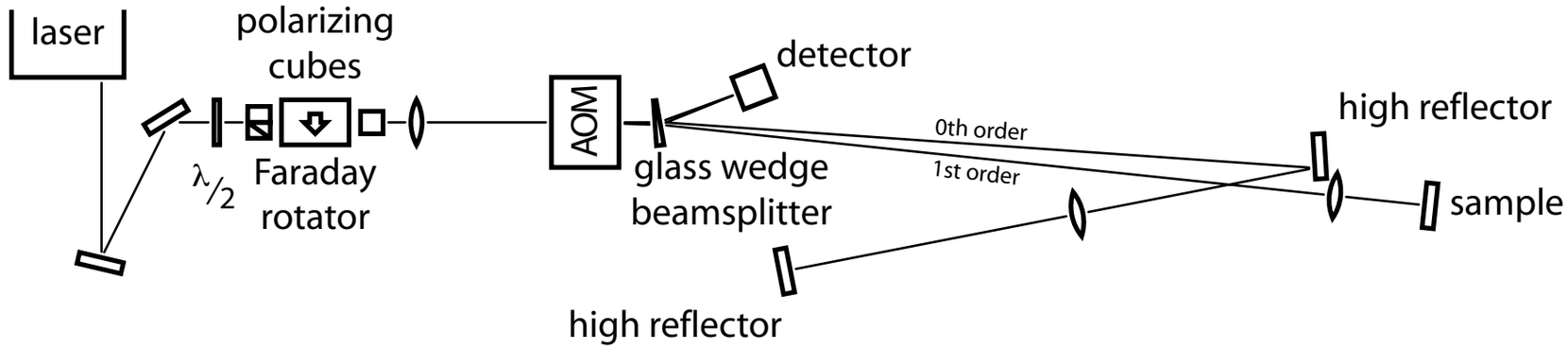
Setup using an AOM



- wide dynamic range attenuation by half wave plate and polarizer
- isolator to prevent destabilizing feedback into the laser
- focus in AOM
- AOM splits beam into 0th and 1st diffraction order
- separation of beams by a mirror
- glass wedge beamsplitter deflects reflected light onto detector

Failure because of

- too wide beam and too small diffraction angle
- 50/50 beam splitting ratio difficult to stabilize

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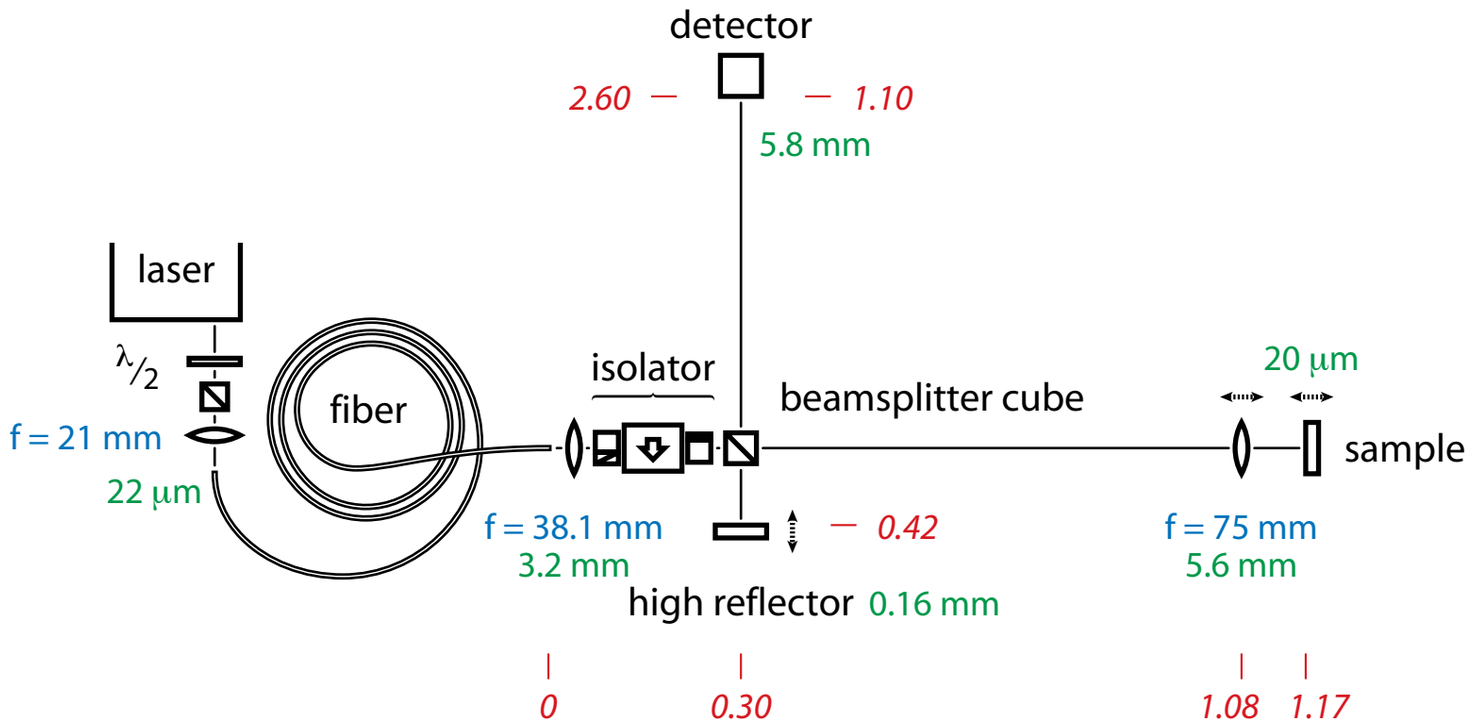
Setup using a cube beamsplitter



- large mode area holey fiber (single-mode) for beam cleaning
- fiber acts as λ/5 plate because of bend-induced birefringence
- cube beamsplitter, in contrast to coated glass plate beamsplitter, is completely symmetric for accurate 50/50 beam splitting
- lens creates focus on reference arm mirror
- wide beam on detector makes additional attenuation unnecessary
- move sample and focusing lens to adjust arm length difference
- move high reflector to adjust power ratio on detector surface by changing beam diameter

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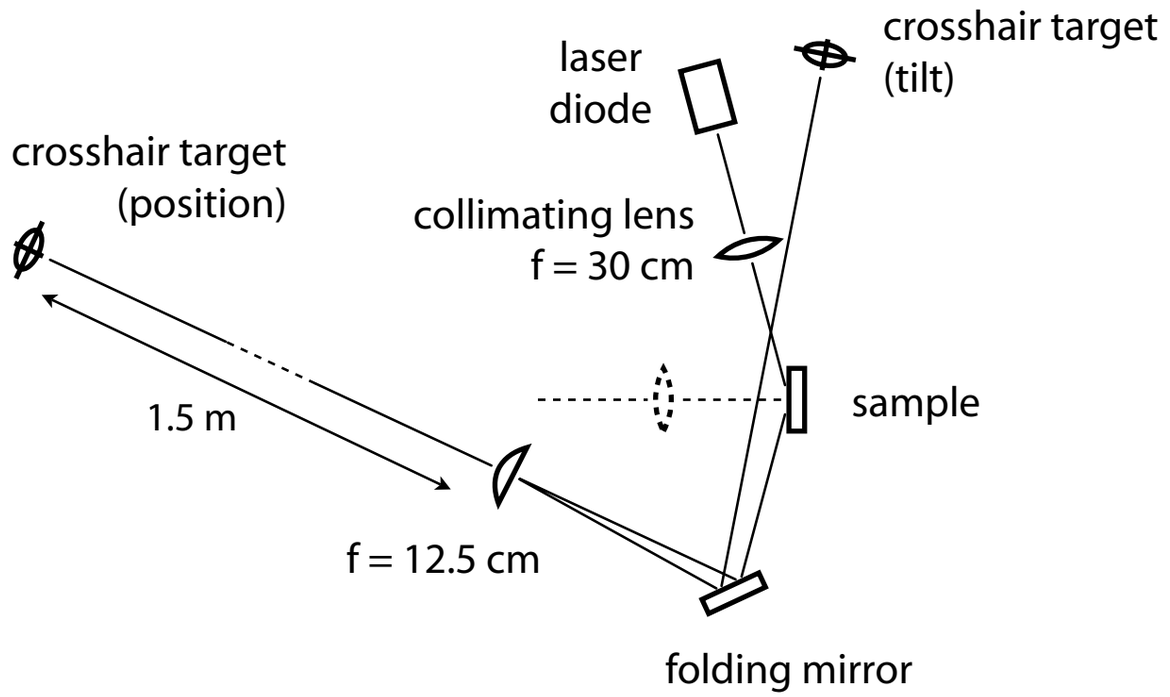
Reproducing sample position



- lateral movement of the beam (≈ sample displacement) is converted to angular movement by lens, which can be amplified by distance
- reflex off the lens enables tilt control
- not independent, but still uniquely identify sample orientation
- collimating lens controls spot size

→ positional reproduction accuracy of 20 µm
(Rayleigh range: 300 µm)

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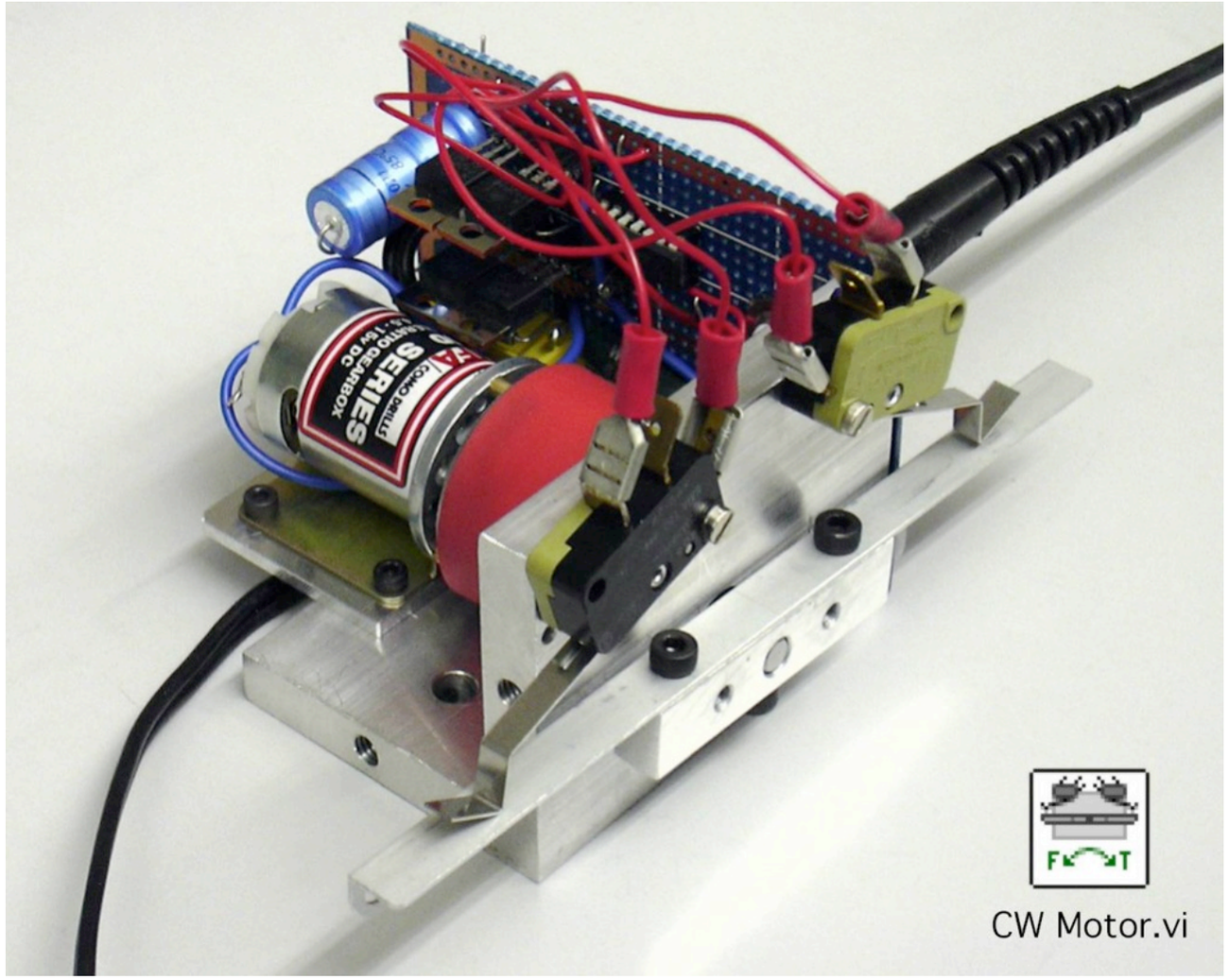
Lock-in amplifier coherent pickup

- small part of reference signal is picked up at measurement input and added to the measured signal
- not constant, has to be measured for every point
- computer-controllable motorized beam blocker needed
- no unused motor controller available – build our own, controlled by the lock-in amplifier's auxiliary output



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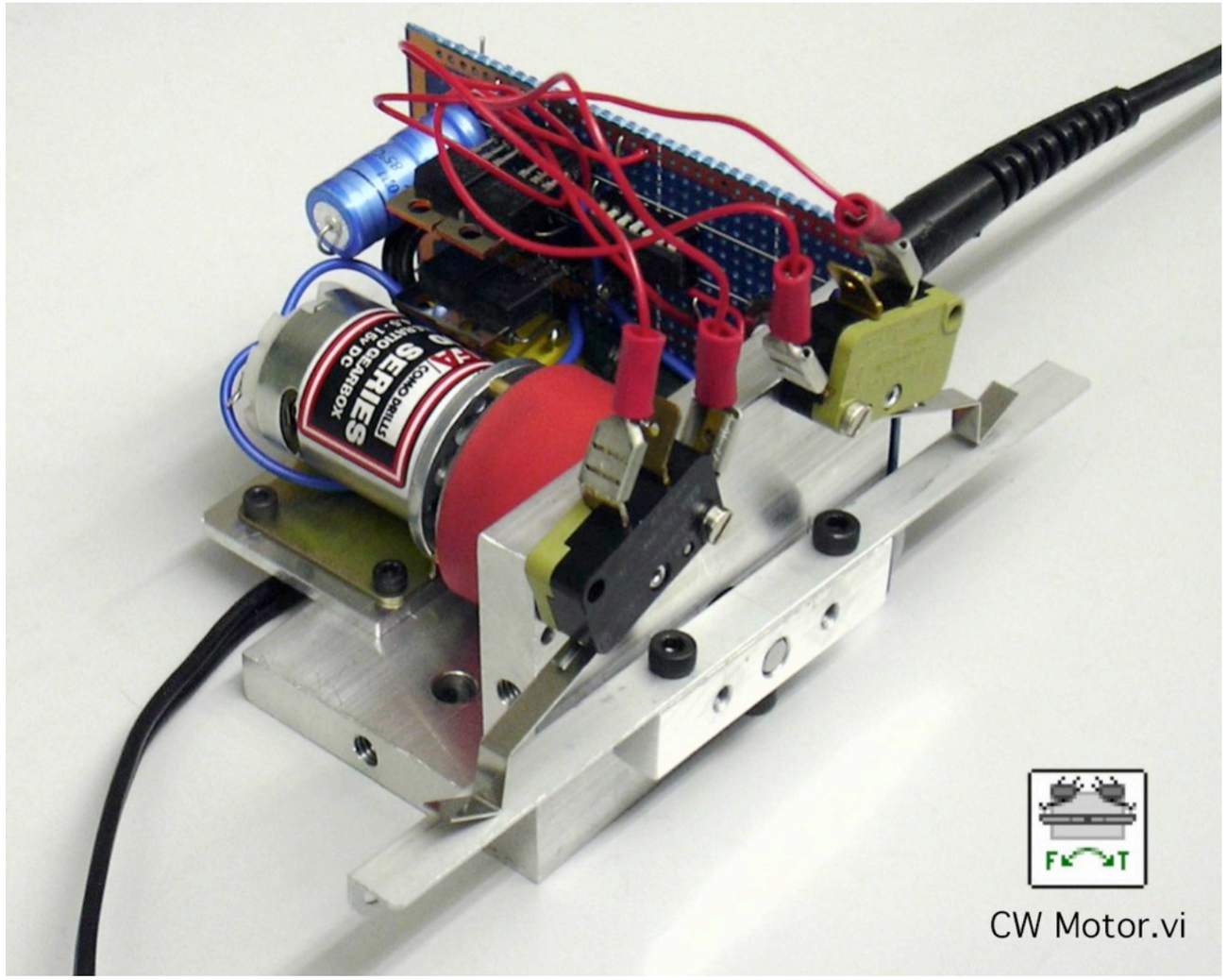
Beam blocker motor

Implementation problems:

- current through relay affected lock-in amplifier measurement
- moving away did not help
- transistors were damaged by induction voltage



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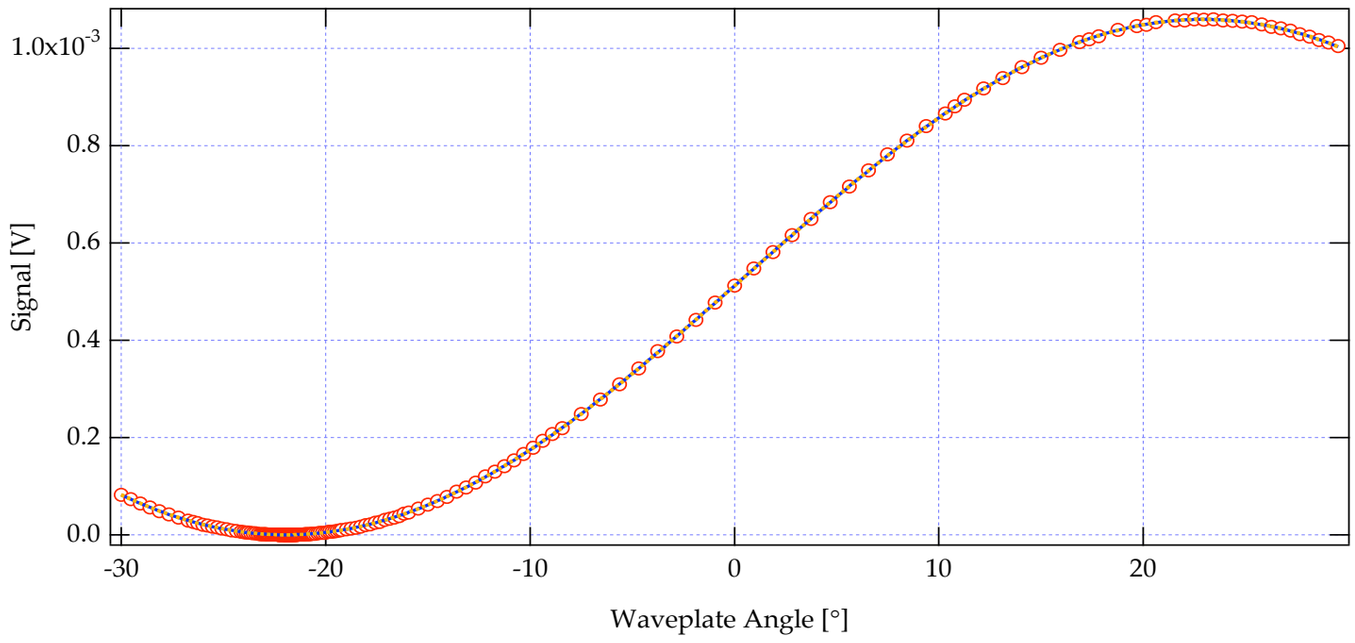
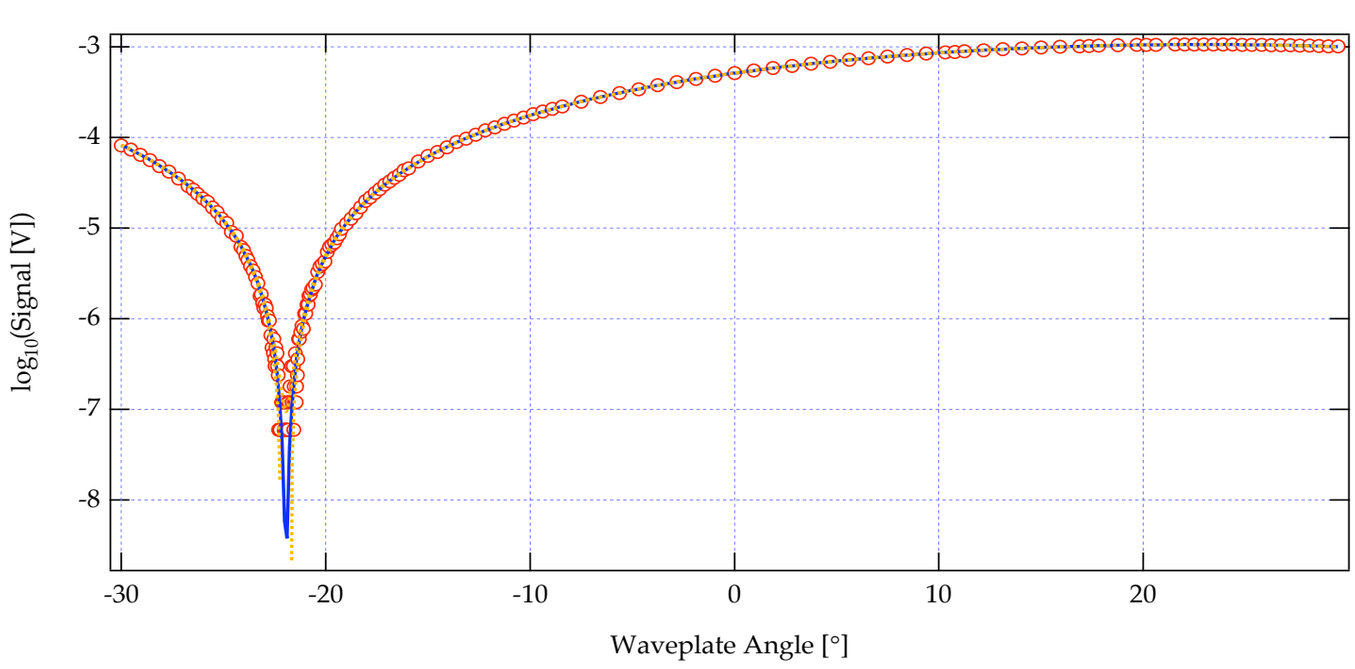
Attenuation calibration





- attenuation to zero is not possible
- measurement by adaptive algorithm
- fit to model function

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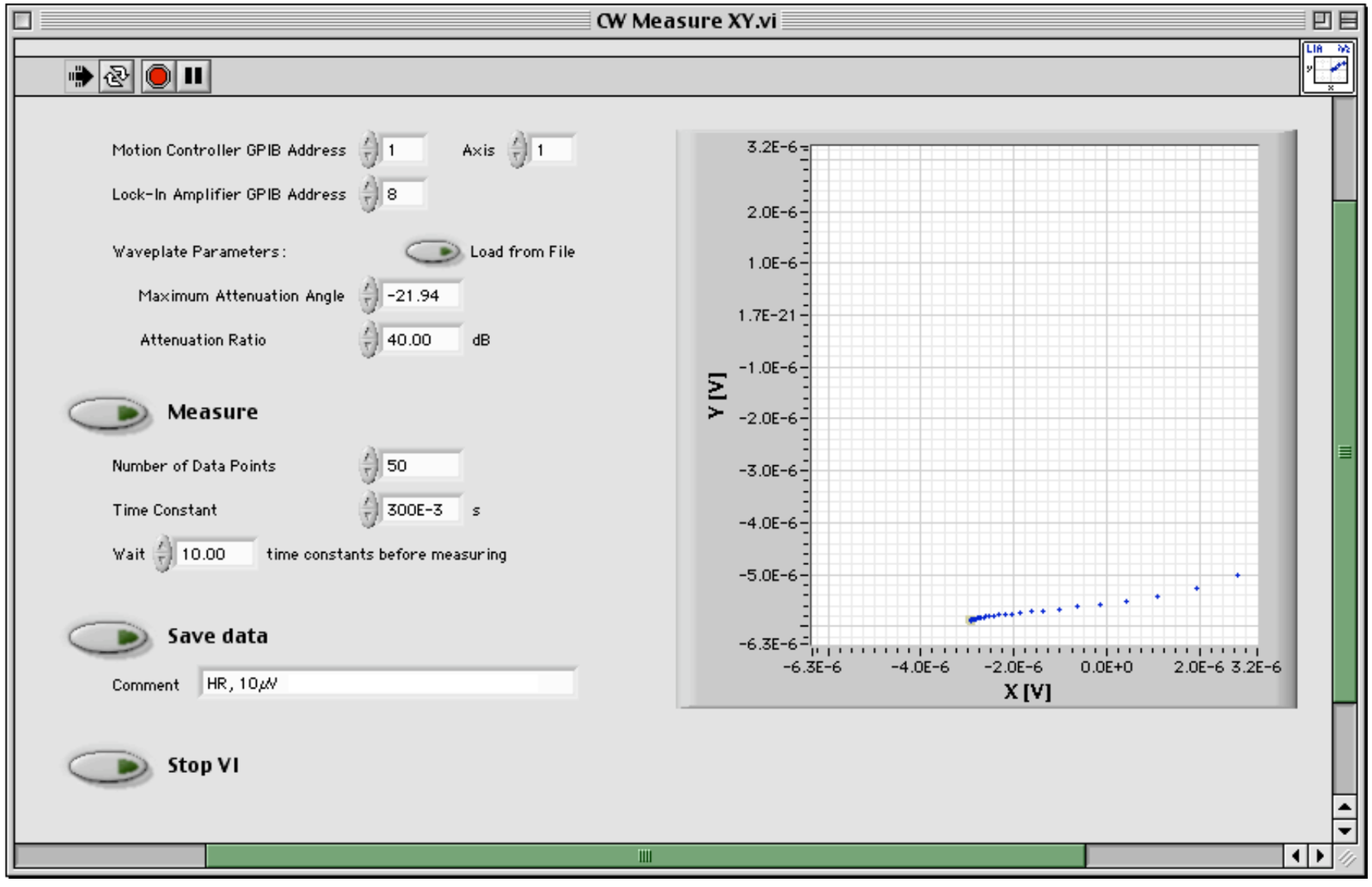
Measurement



- record lock-in amplifier *x* and *y* signal for a logarithmically spaced set of powers
- 3 measurement runs:
  - SESAM
  - no sample (reference arm only)
  - high reflector

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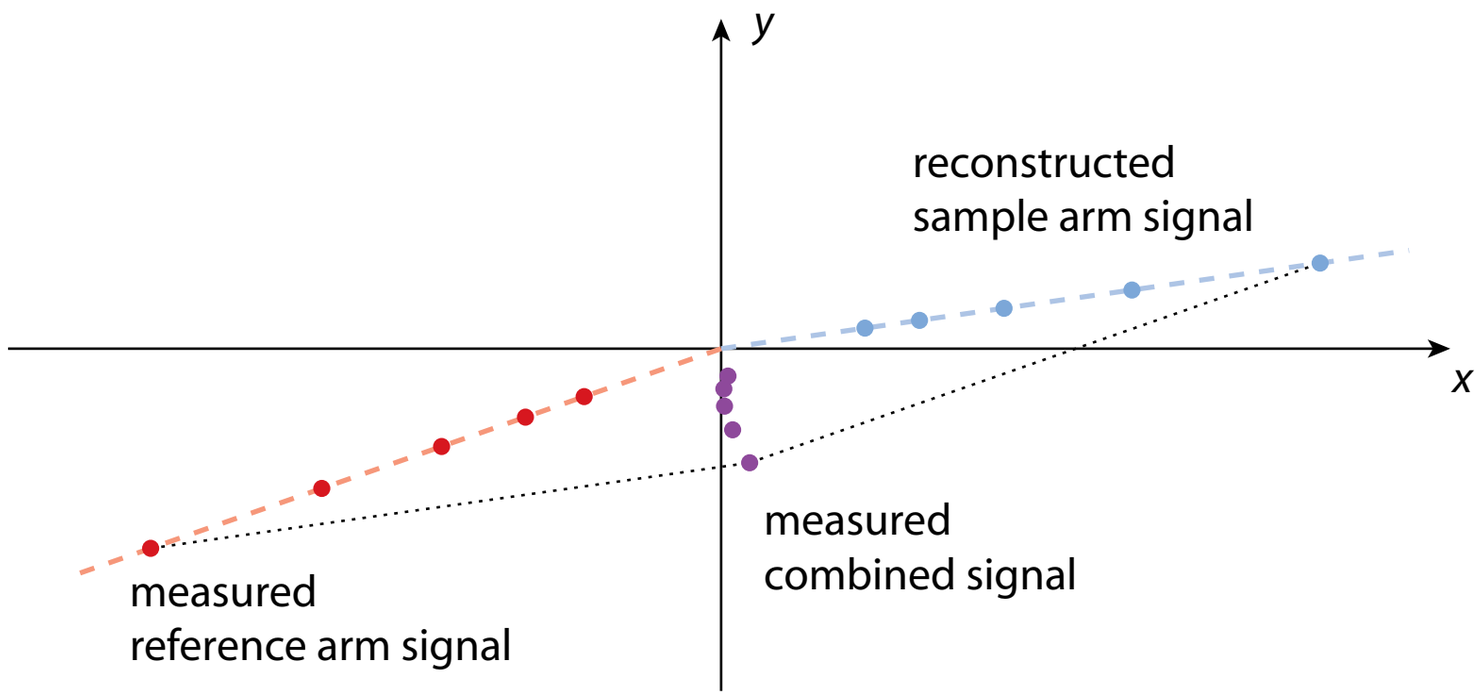
Evaluation



For both SESAM and HR:

- sample arm signal is reconstructed by subtracting reference signal from combined signal
- reference signal and reconstructed sample signal are projected onto their main axes to get scalar values
- division yields values proportional to reflectivity

$$\bullet = c_1 \cdot P \cdot R \qquad \bullet = -c_2 \cdot P$$

$$\frac{c_1}{c_2} R = -\frac{\bullet}{\bullet} = -\frac{\bullet - \bullet}{\bullet} = 1 - \frac{\bullet}{\bullet} \qquad \frac{\bullet}{\bullet} = 1 - \frac{c_1}{\underbrace{c_2}_{\approx 1}} R$$

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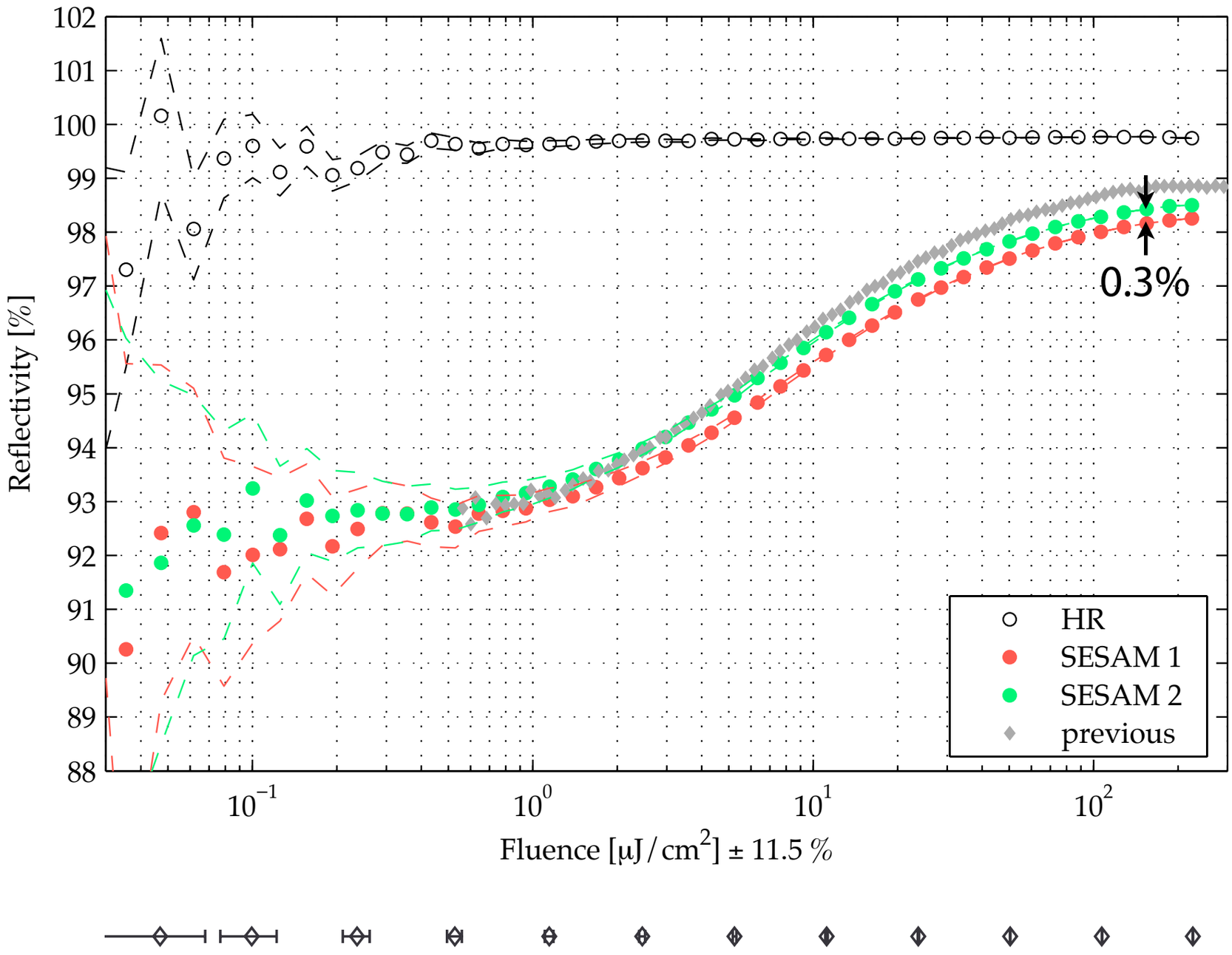
ES134 ($\Delta R = 7\%$)



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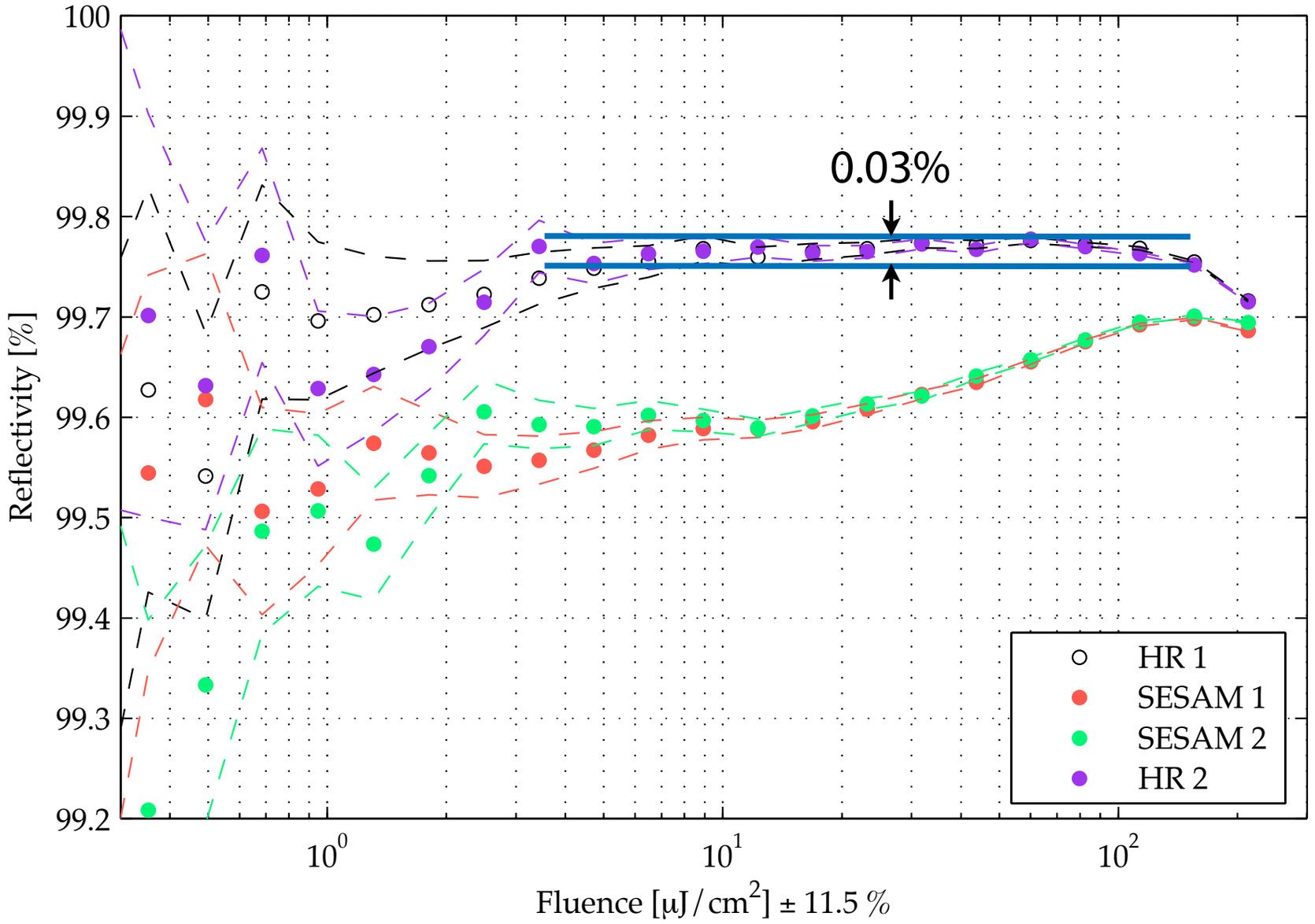
ES160 ($\Delta R = 0.3\%$)



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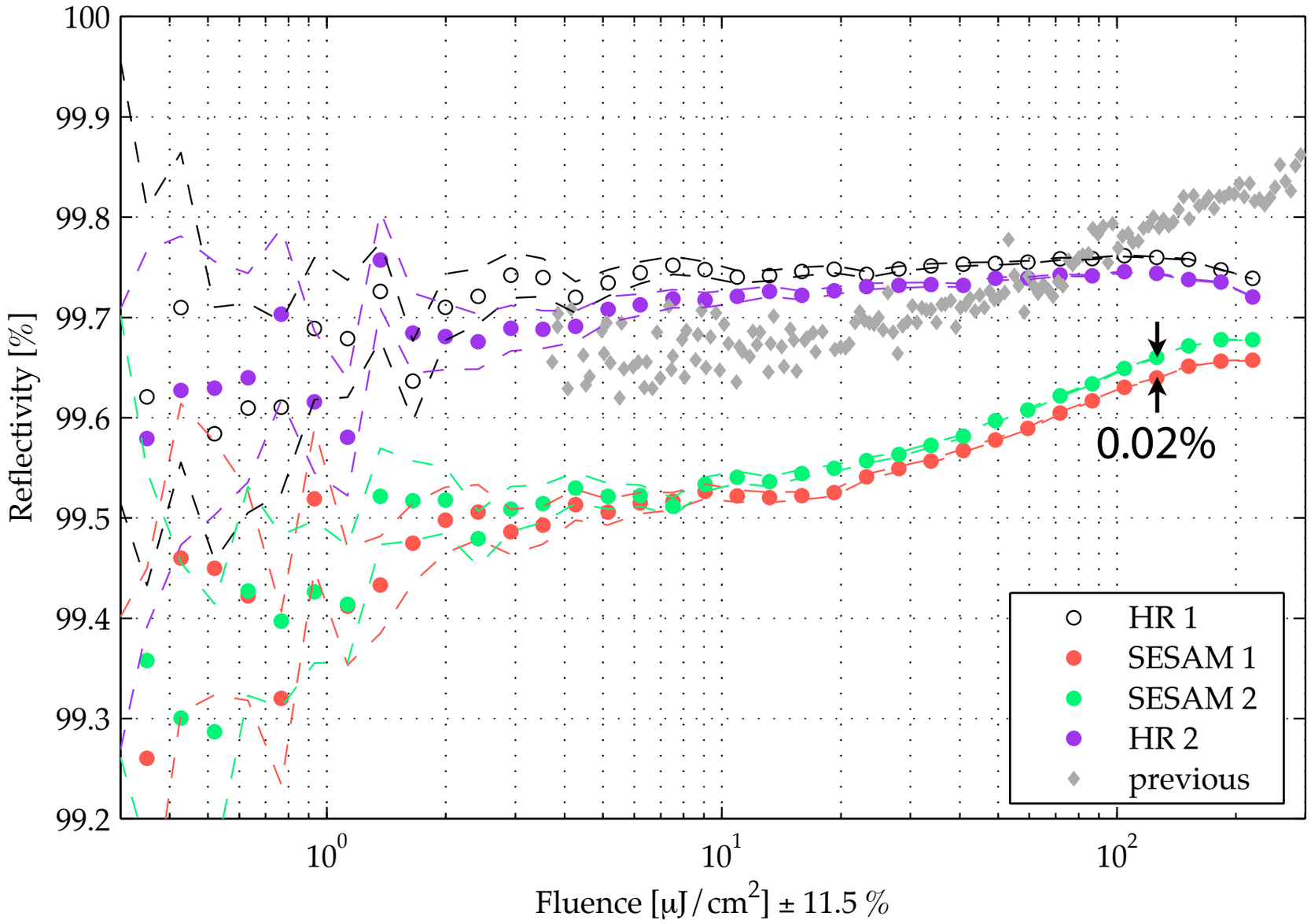
ES160 ($\Delta R = 0.3\%$)



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Remaining challenges

- nonlinearity
  in amplitude and phase
- reproducibility
  only intermittently achieved

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precise SESAM measurements achieved

- dynamic range of 4–5 orders of magnitude
- accuracy below 0.1% over 2–3 orders of magnitude

experimental difficulties overcome

- precise calibration of wide dynamic range attenuation
- beam quality improvement by fiber
- sample positioning reproducibility
- coherent pickup correction by motorized beam blocker