Single Photon Image Discrimination and Quantum Steganography

Greg Howland, Curtis Broadbent, John Howell, Peatross Zerom, Heedeuk Shin, and Bob Boyd
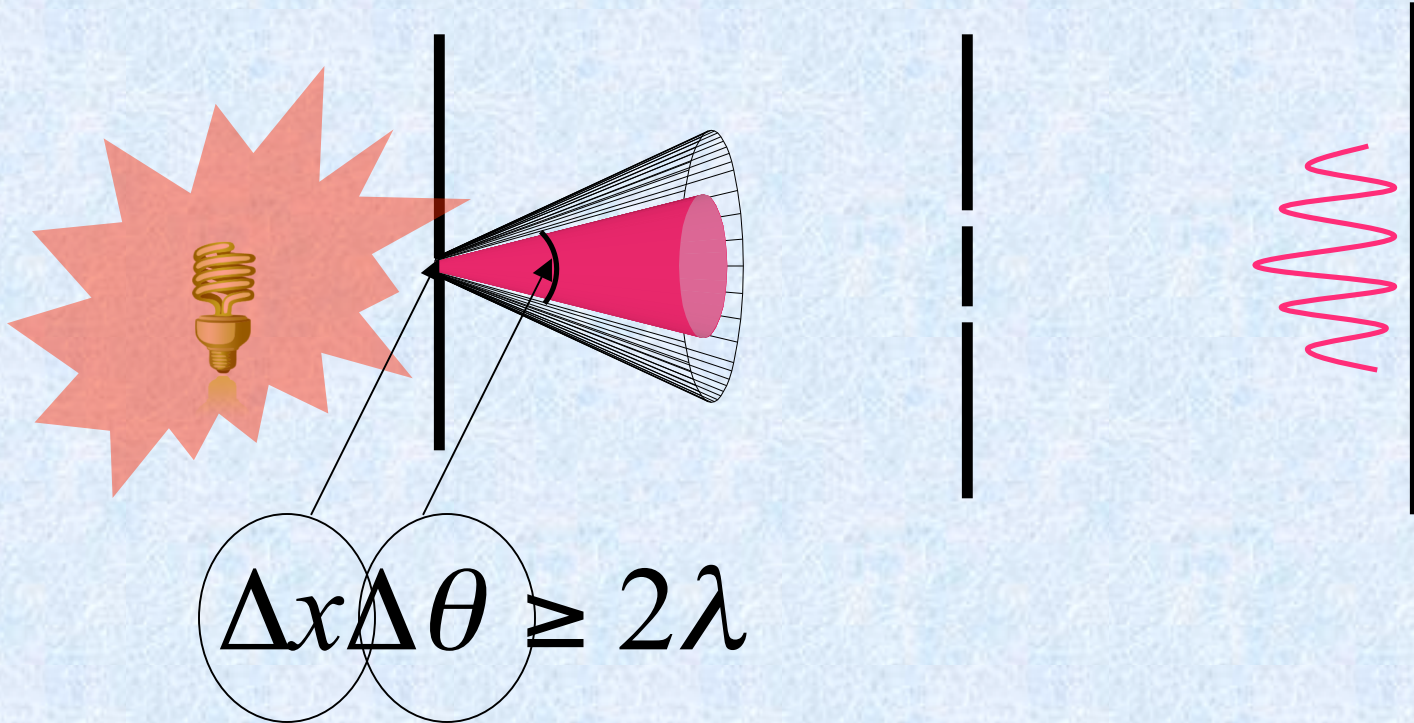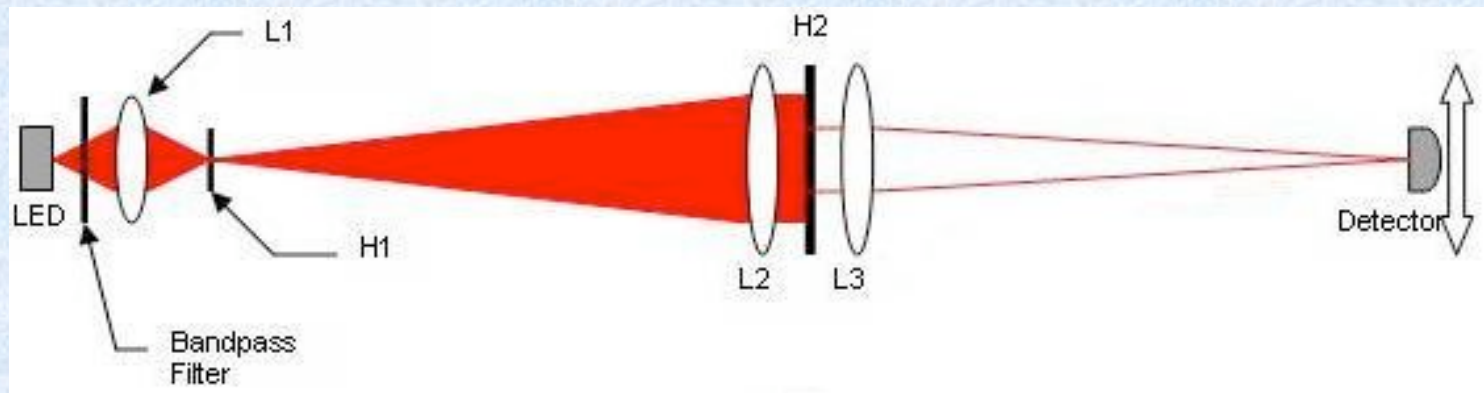
Quantum Imaging MURI

Overview

- **Peter's question**
  - Are there applications in quantum imaging that cannot be done classically?

- **Partial Coherence**

- **Single Photon Image Discrimination**

- **Nonorthogonal image discrimination**

- **Quantum Steganography**
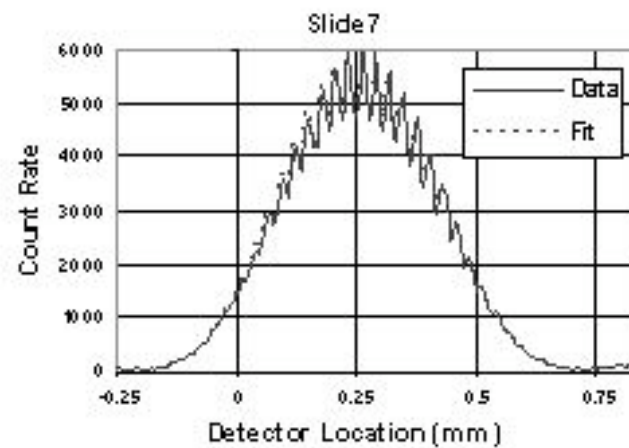 - Hiding images 2nd order, revealed 4th order

Partial Coherence

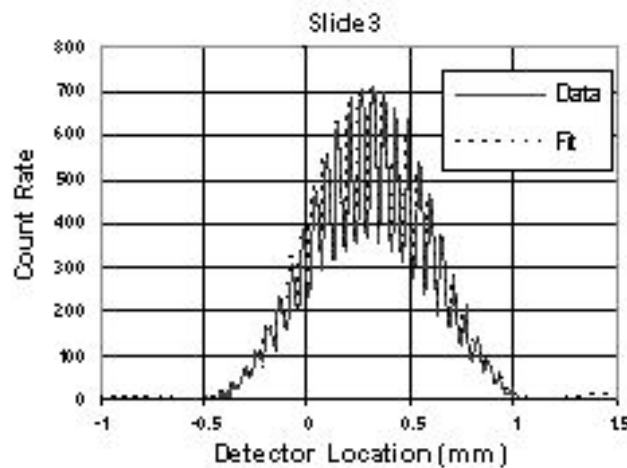

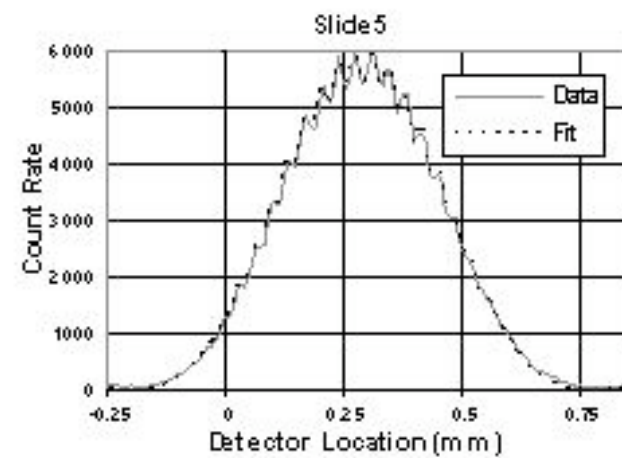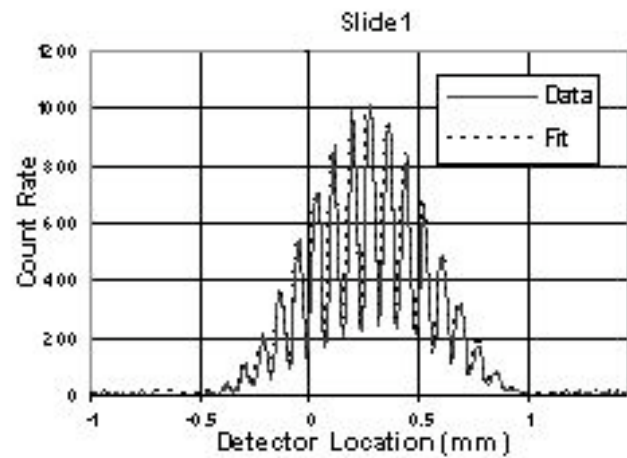$$\Delta x \Delta \theta \geq 2\lambda$$
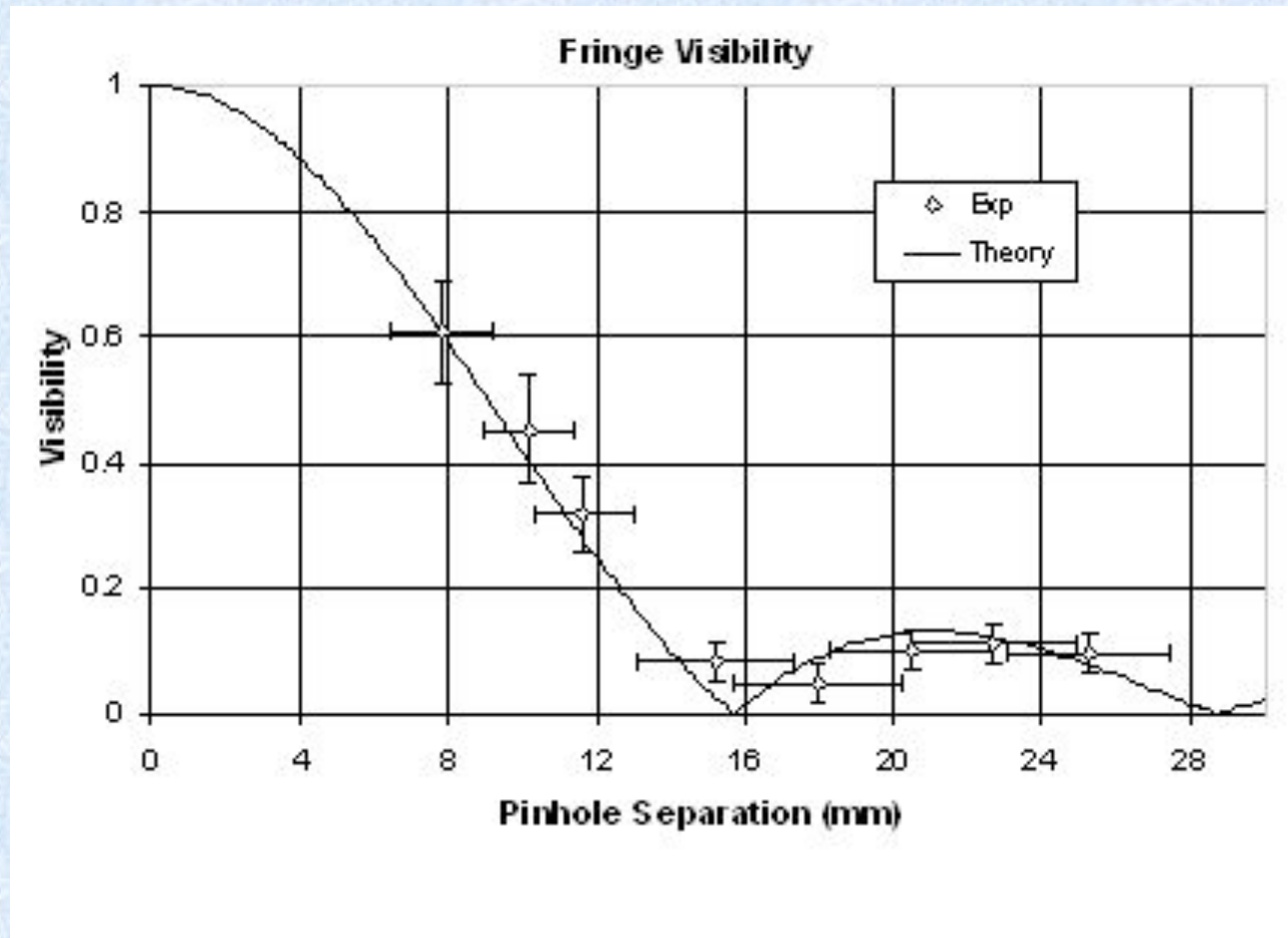
Results with LED

- Dramatically attenuated LED (low light level thermal source -- photon counting)
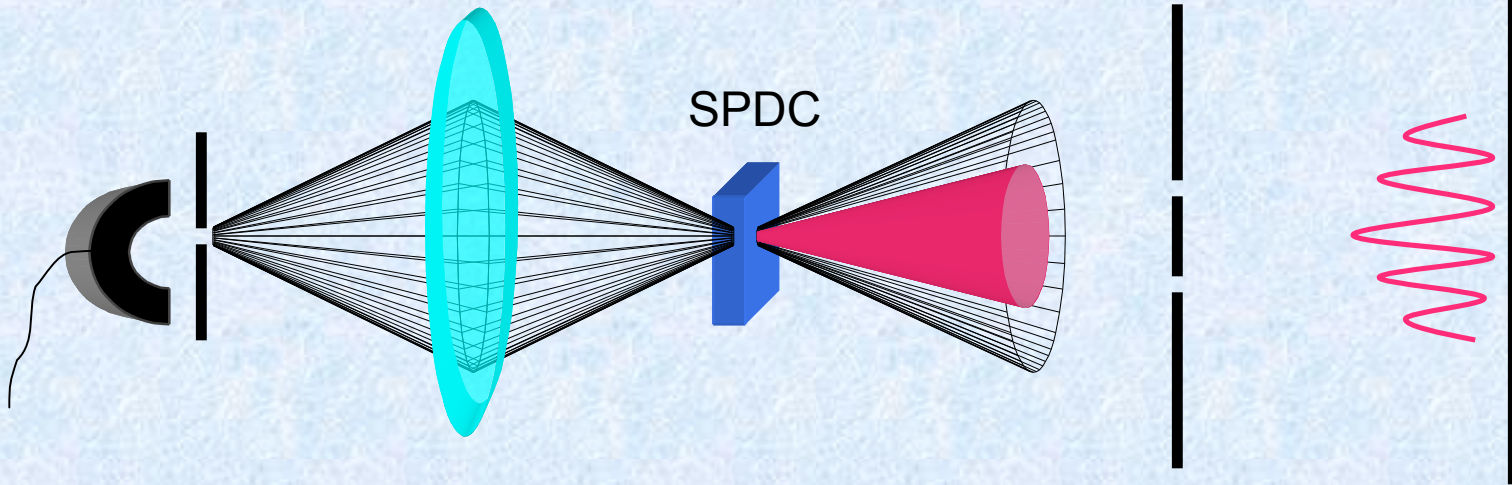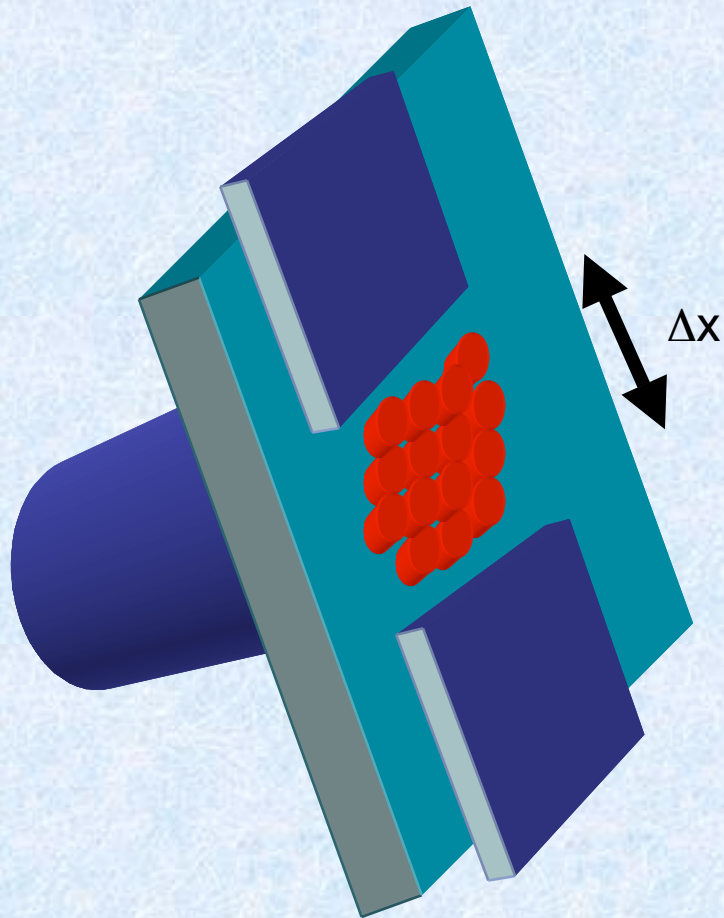
LED Fringes

Results with LED
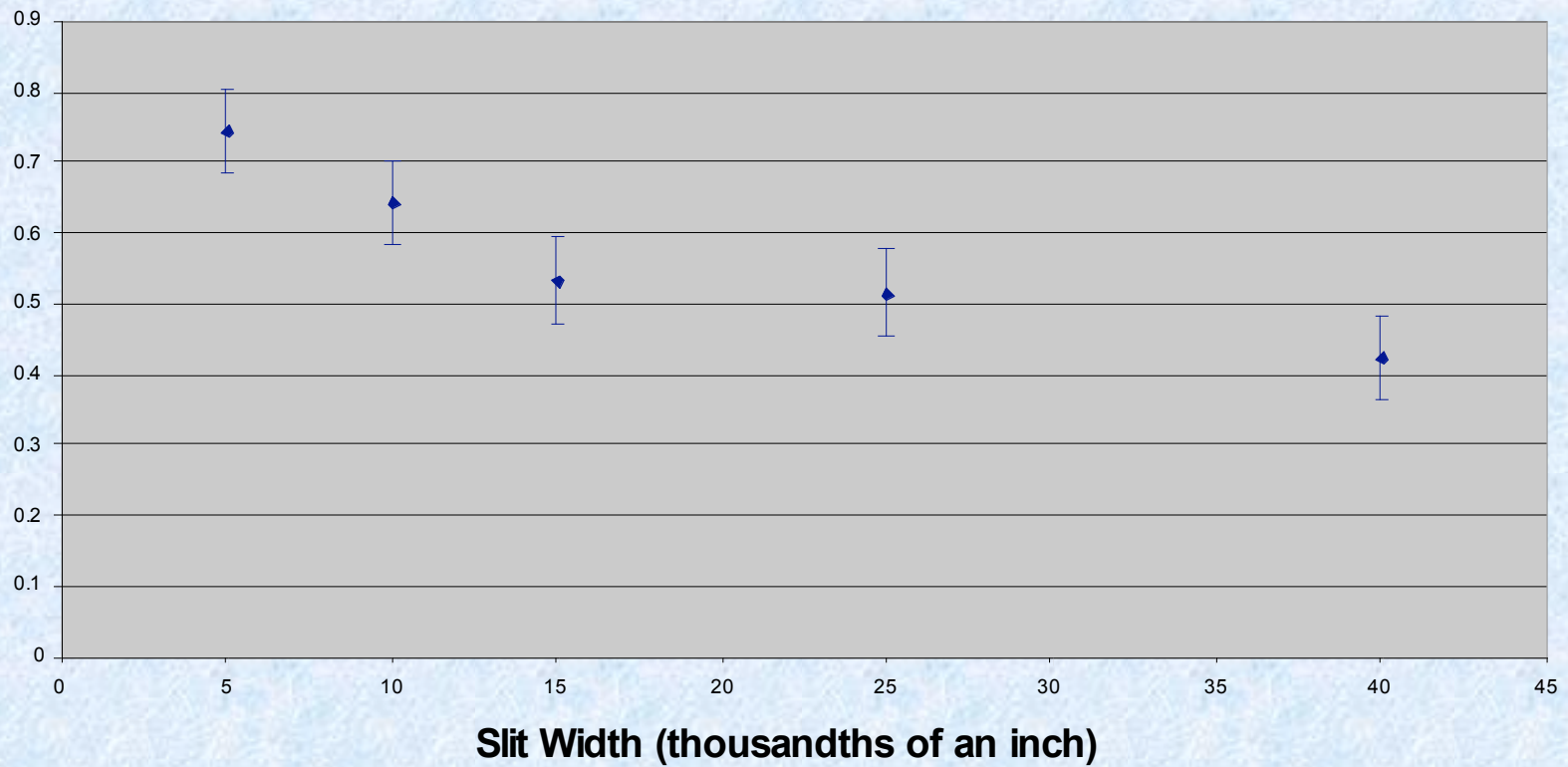
Single Photon Partial Coherence

Biphoton Birthplace and Partial Coherence

- Transverse Δx modified projectively by measuring the twin
- Slit width constrained by twin

Results Single Photon Partial Coherence

Fringe Visibility vs Slit Width

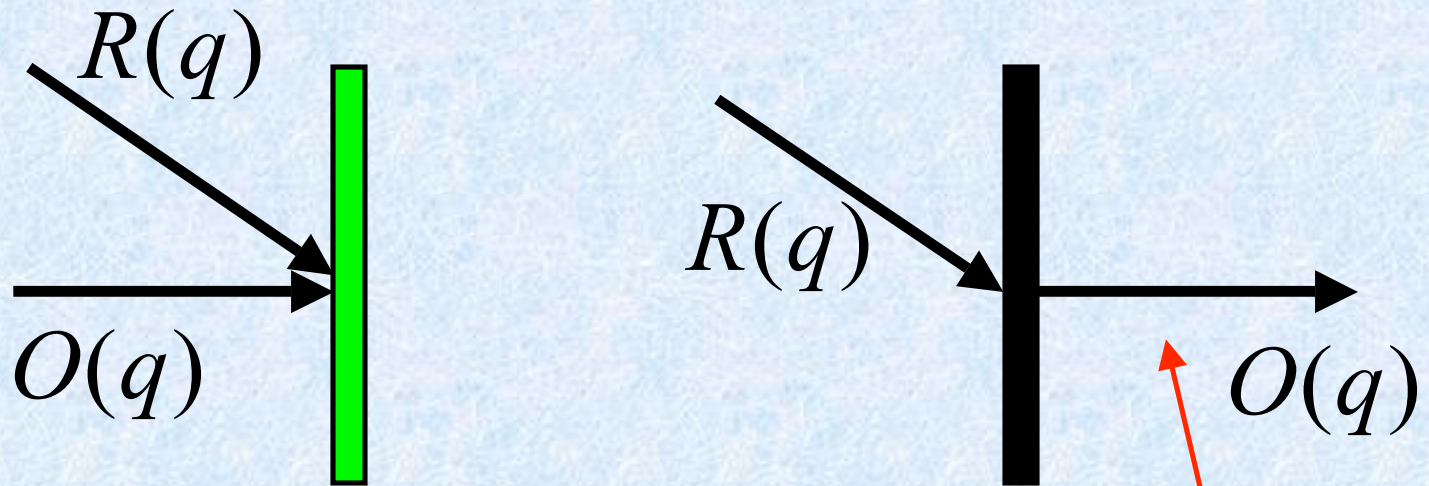

Slit Width (thousandths of an inch)

Related Work

- ## Geraldo Barbosa

  - "Quantum images in double-slit experiments with Spontaneous down-conversion light" PRA **54**, 4473 (1996)
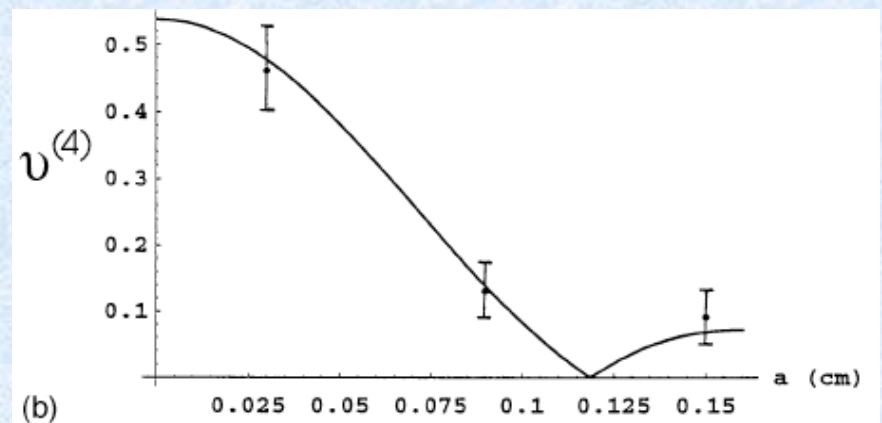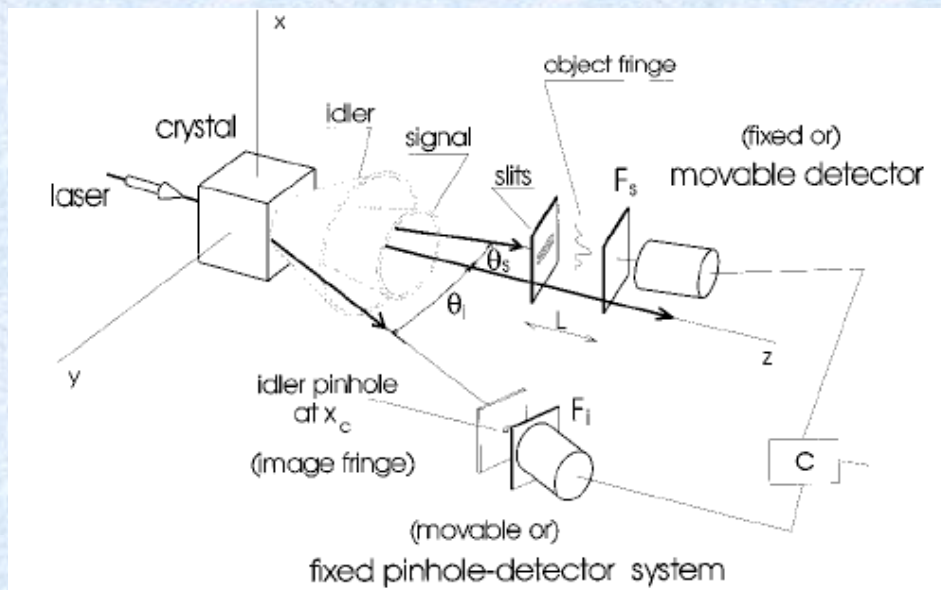
Hologram as image memory

$$t \propto t_0 + \left| R(q) + O(q) \right|^2$$

$R(q)$

$O(q)$

$R(q)$

$O(q)$

$$R(q)\left(\left| R(q) \right|^2 + \left| O(q) \right|^2 + R(q)O^*(q) + R^*(q)O(q) \right)$$

Hologram as discriminator

$$t \propto t_0 + \left| R(q) + O(q) \right|^2$$

$R(q)$

$O(q)$

$O(q)$

$\left| O(q) \right|^2$
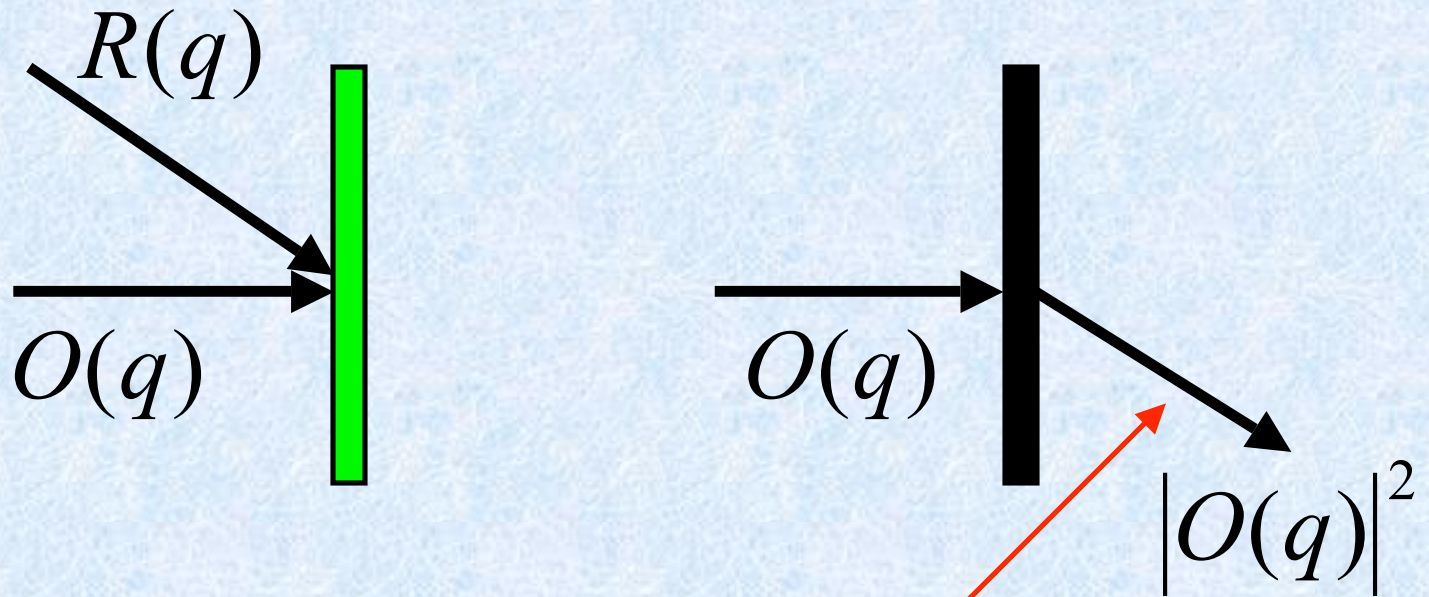
$$O(q)\left(\left| R(q) \right|^2 + \left| O(q) \right|^2 + R(q)O^*(q) + R^*(q)O(q) \right)$$

Image Discrimination

(a) exposure 1 — reference (plane wave), object A, holographic plate

(b) exposure 2 — object B, reference (plane wave), holographic plate

(c) single-photon readout — single photon, object A or B, unknown image, hologram, output wave (if image is B), output wave (if image is A)
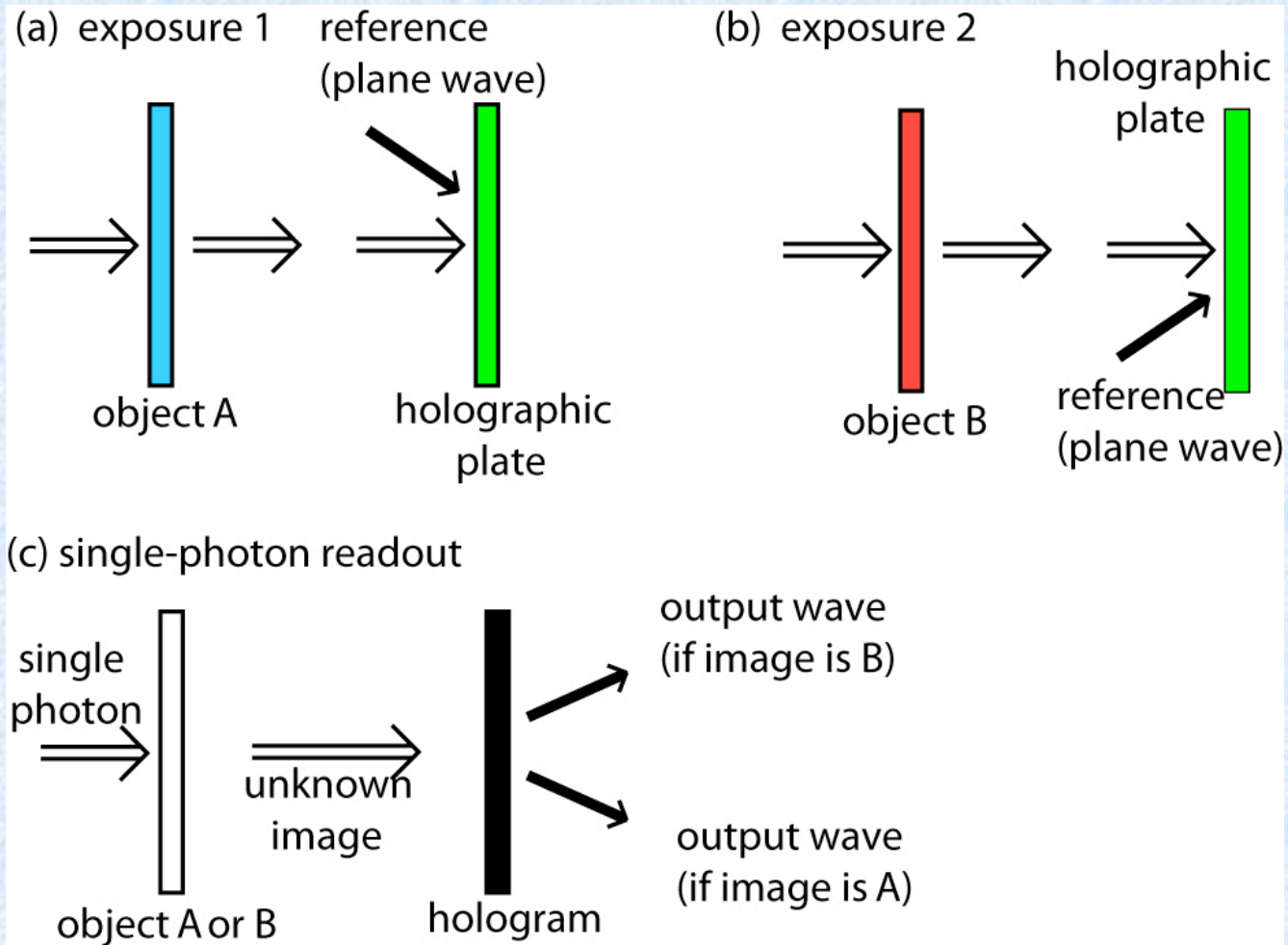
Experimental Setup
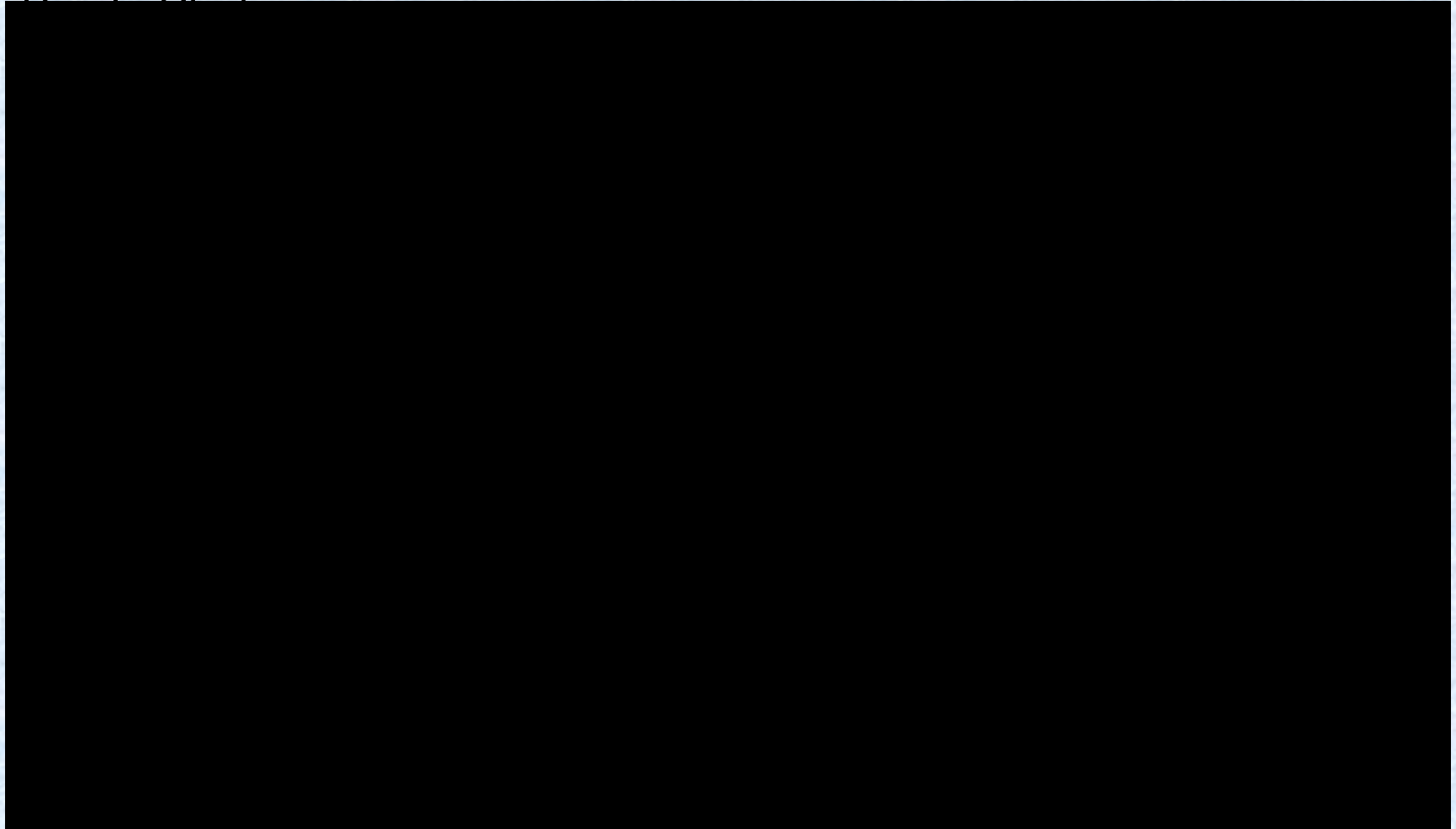
Image Reconstruction
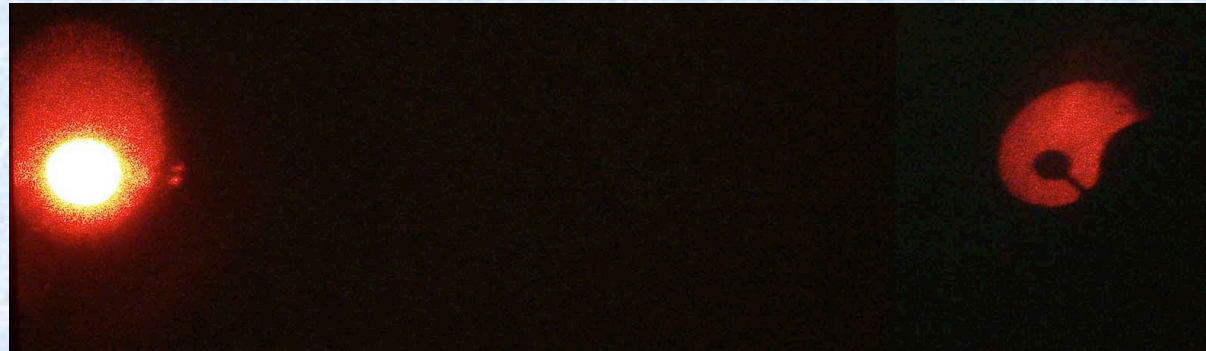
Hologram diffraction efficiencies:

A → 24%
B → 19%
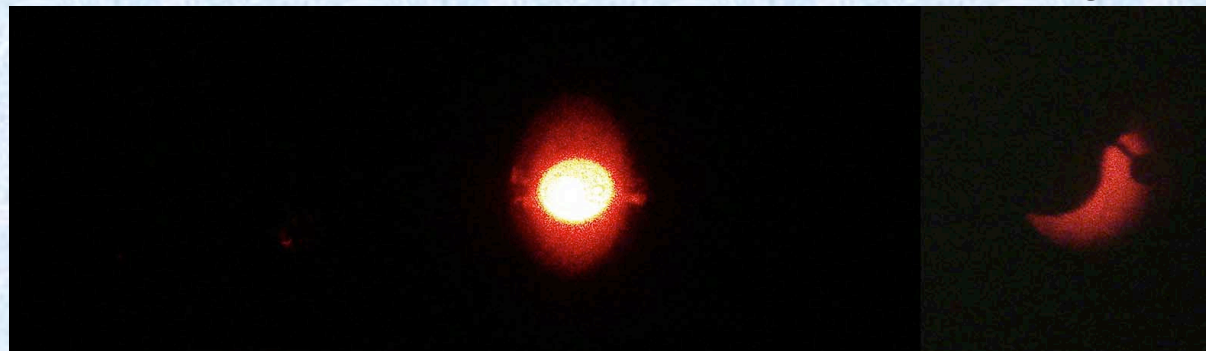
Both references used
→ Both images
   reconstructed

Ref. A   Ref. B   Recons. image A

Ref. A   Ref. B   Recons. image B

Image Discrimination

Negligible crosstalk!

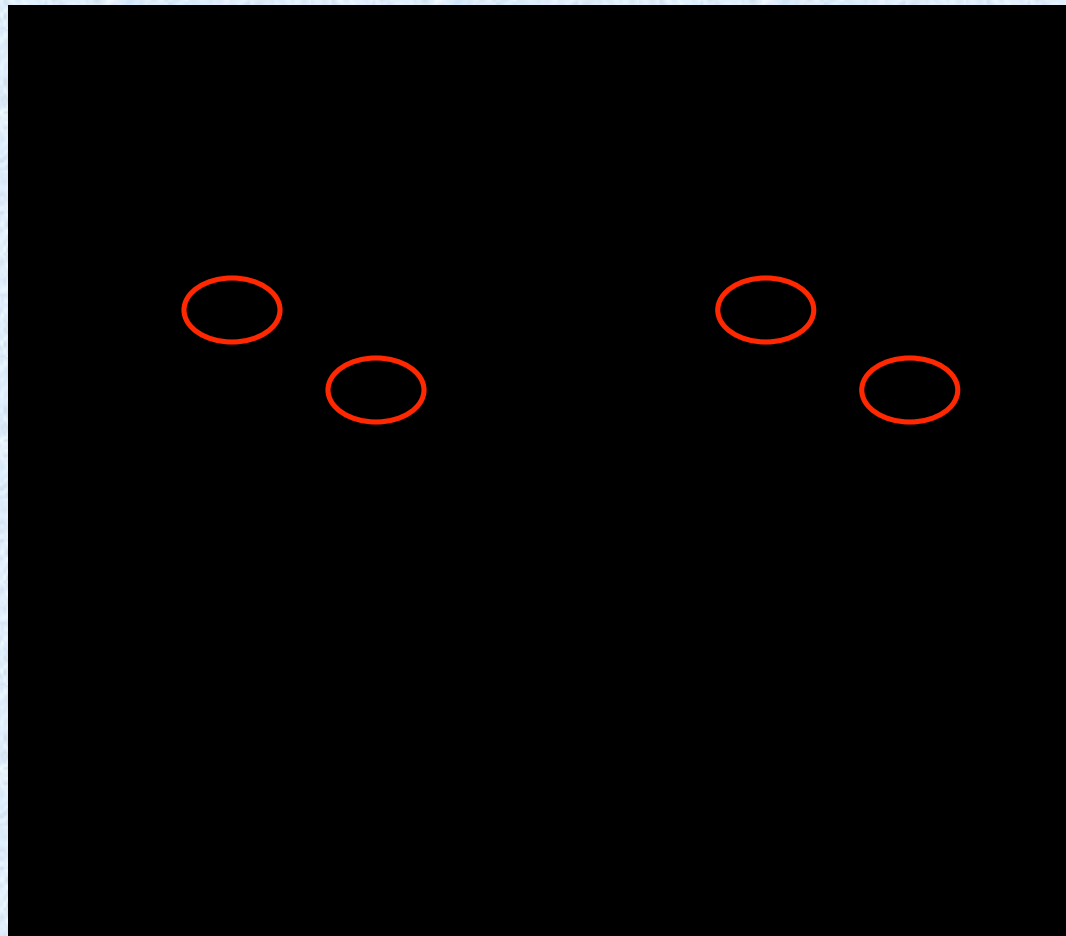Det. A   Det. B   Obj. A

Det. A   Det. B   Obj. B
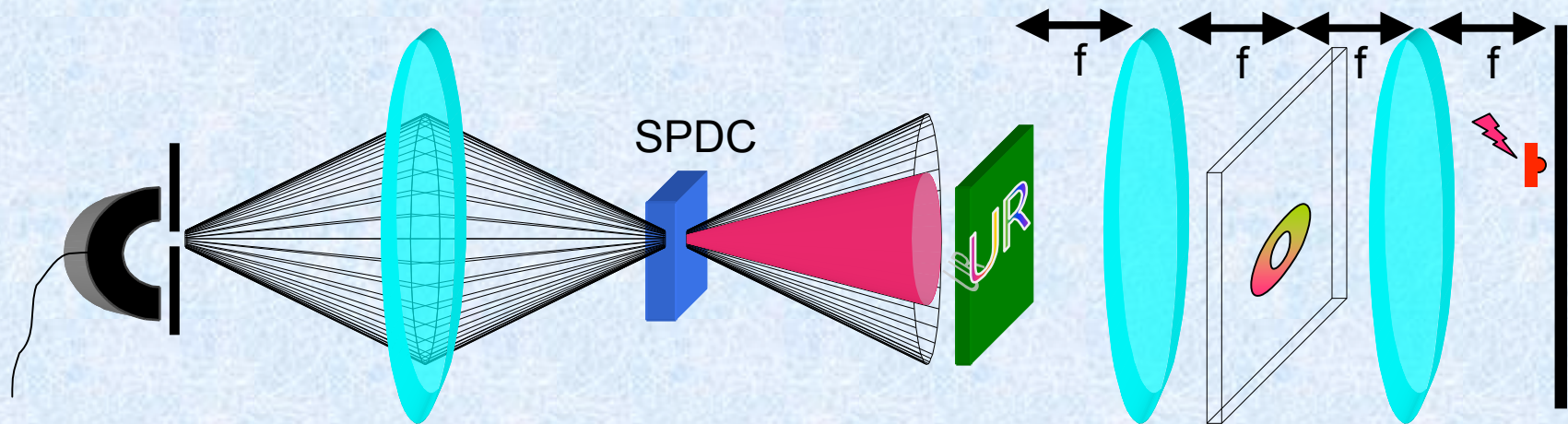
Single Photon Disc. Results

onfidence
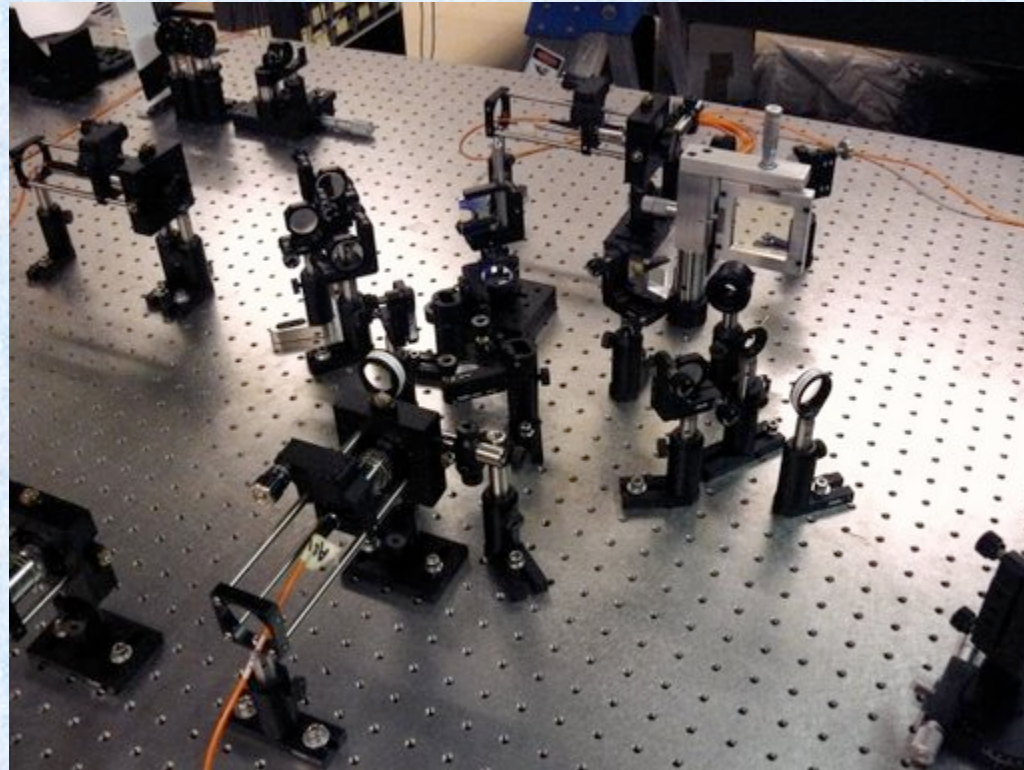
t – 96.8%

t – 93.4%

Quantum Steganography

- Combine
  - Controllable 4th order partial transverse coherence
  - Holographic Image Discrimination

Quantum Steganography Setup

- High Pass Vanderlugt Filter (Nonorthogonal Images)
- 2nd Order Low Coherence (Trace over transverse momentum)
- 4th order High Coherence G:\._Shapiro.ppt
- Multiplexed Holograms

Apparatus

Steganography Agenda

- Phase 1: Partial coherence and Vanderlugt Filter

- Phase 2: Partial Coherence, Vanderlugt Filter, Multiplexed Holograms

- Phase 3: Quantum Steganography Applications