Quantum-mimetic imaging

DHEERA VENKATRAMAN

29 JANUARY 2015 | THESIS DEFENSE

rLe AT MIT

Massachusetts Institute of Technology

Outline

1. **Overview:** Quantum metrology and quantum-mimetic imaging

2. **Experiment:** PC-OCT

3. **Experiment:** Classical phase-sensitive ghost imaging

4. **Experiment:** First-photon imaging

5. **Conclusions**

1 OVERVIEW

Quantum metrology and quantum-mimetic imaging

What is quantum metrology?

Experiments that use quantum states of light (e.g. entangled states)

Experiments that use quantum detection methods (e.g. HOM dip)

Cannot be explained by semiclassical theory

Example: Q-OCT

Quantum optical coherence tomography

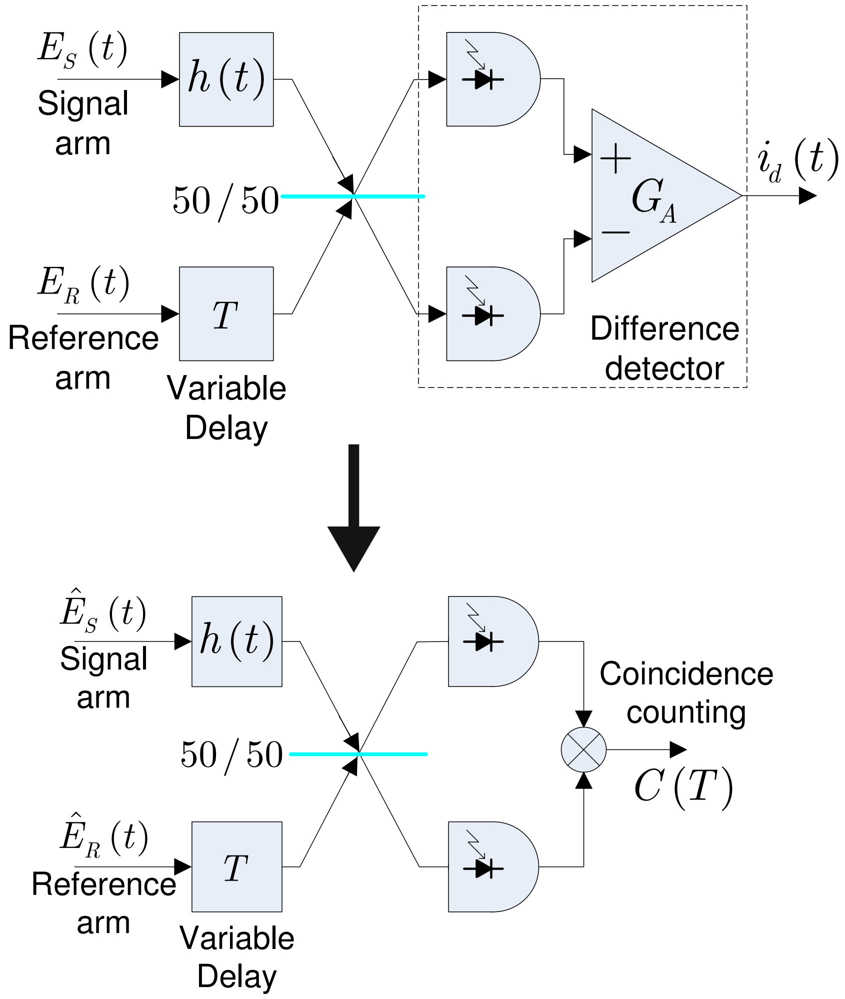
Uses an entangled biphoton source

Advantages

Factor-of-2 resolution improvement

and even-order dispersion cancellation

Advantages initially attributed to quantum physics



Example: Ghost imaging

Ghost imaging

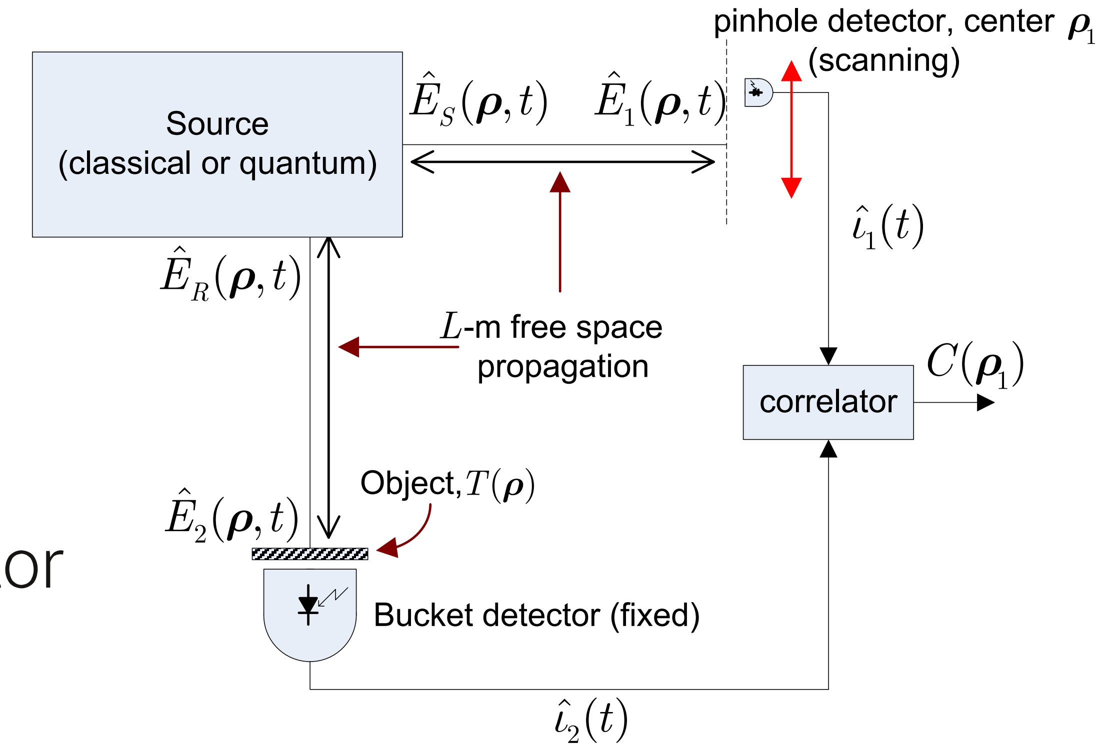
Uses an entangled biphoton source

Advantages

Images at wavelengths without CCDs

Signal arm only requires a single detector

Initially thought to be uniquely quantum



Quantum-mimetic imaging

Quantum imaging experiments are explained by quantum theories, but their claimed advantages may not necessarily be uniquely quantum.

Quantum-mimetic imaging experiments use non-traditional, classical setups to achieve results similar to their quantum counterparts.

2 EXPERIMENT

Phase-conjugate optical coherence tomography

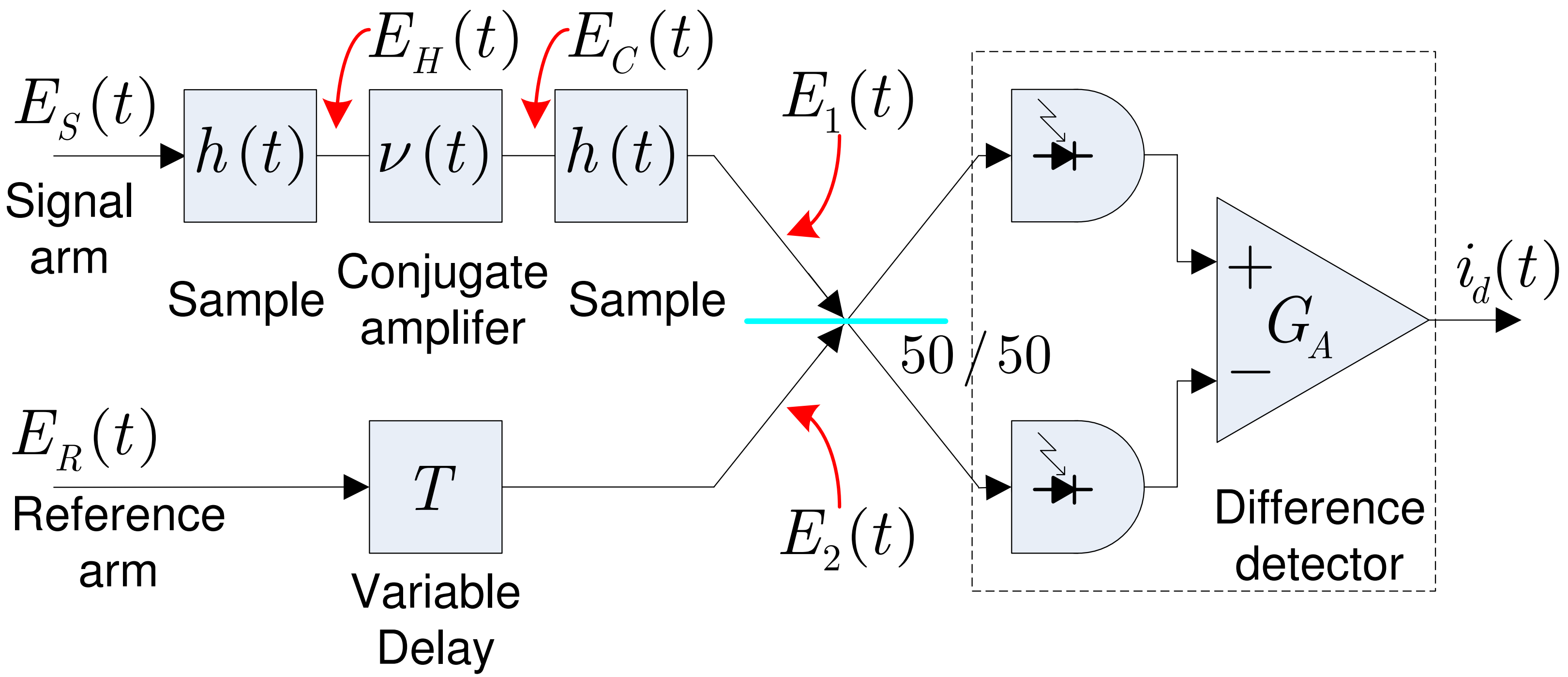
Motivation

Q-OCT advantages (even-order dispersion cancellation, factor-of-2 resolution improvement) shown to originate from phase-sensitive cross-correlations between signal and idler and **not entanglement**

PC-OCT employs a classical phase-sensitive source which is **maximally correlated in the classical sens**

Schematic

PC-OCT uses classical phase-sensitive light and a double-pass configuration to obtain similar advantages to Q-OCT



Comparison of interference signatures

C-OCT signature

$$\langle i_d(t)\rangle = 2q\eta G_A\,\mathrm{Re}\left(\int_{-\infty}^{\infty}\frac{d\Omega}{2\pi}H^*(-\Omega)S(\Omega)e^{-i(\Omega-\omega_0)T}\right)$$

Q-OCT signature

$$\langle C(T)\rangle = \frac{q^2\eta^2}{2}\left[\int_{-\infty}^{\infty}\frac{d\Omega}{2\pi}|H(\Omega)|^2S(\Omega) - \mathrm{Re}\left(\int_{-\infty}^{\infty}\frac{d\Omega}{2\pi}H^*(-\Omega)H(\Omega)S(\Omega)e^{-2i\Omega T}\right)\right]$$

PC-OCT signature

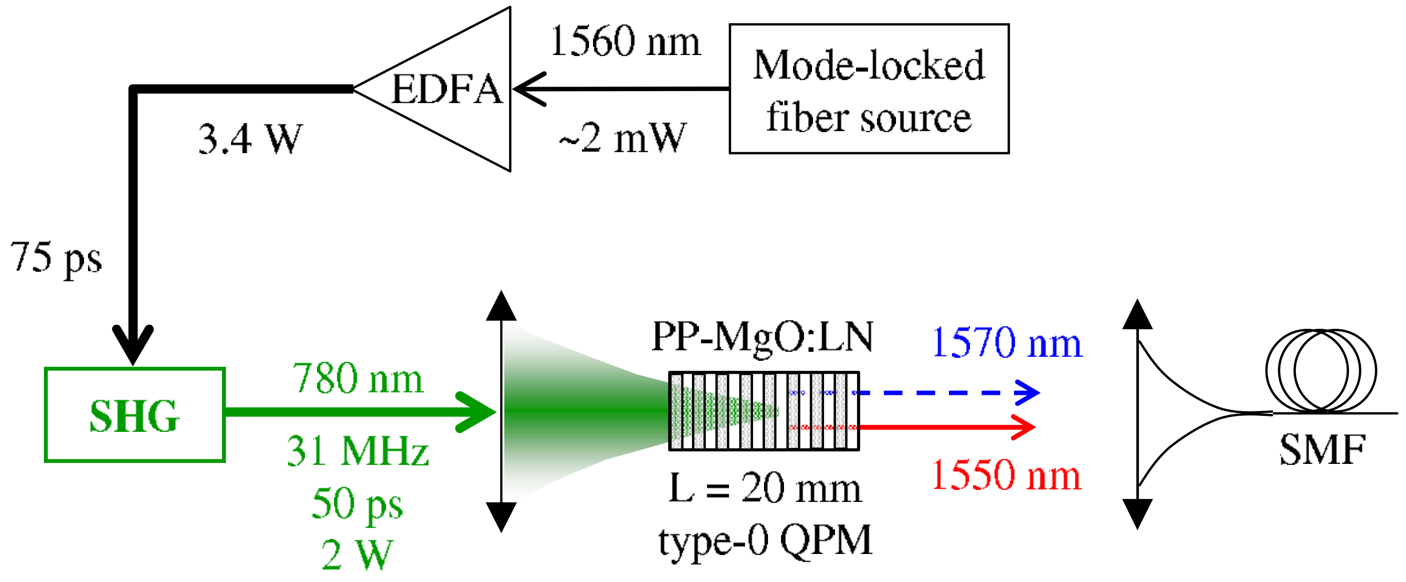
$$\langle i_d(t)\rangle = 2q\eta G_A\,\mathrm{Re}\left(\int_{-\infty}^{\infty}\frac{d\Omega}{2\pi}H^*(-\Omega)H(\Omega)\times V^*(-\Omega)S(\Omega)e^{-i(\Omega-\omega_0)T}\right)$$

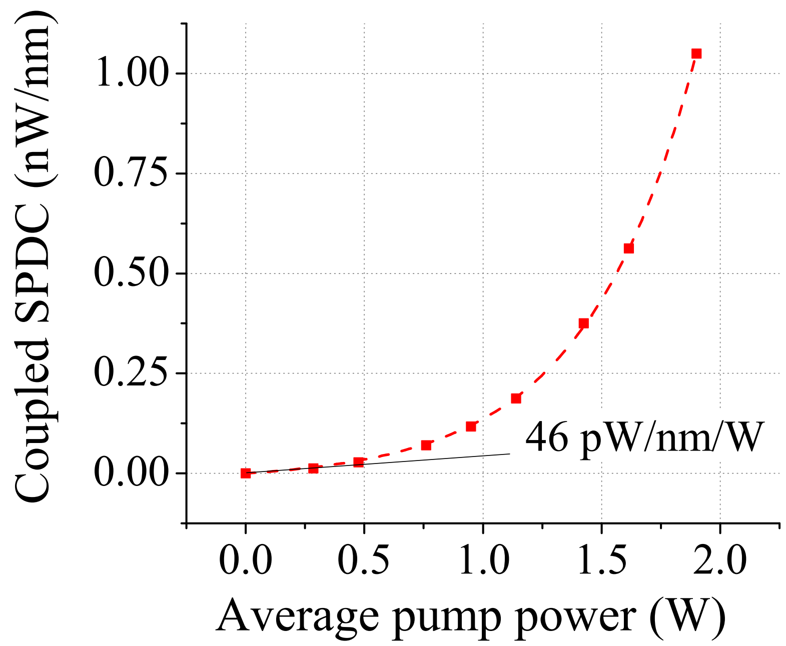
"Quantum-mimetic"

Classical phase-sensitive light source

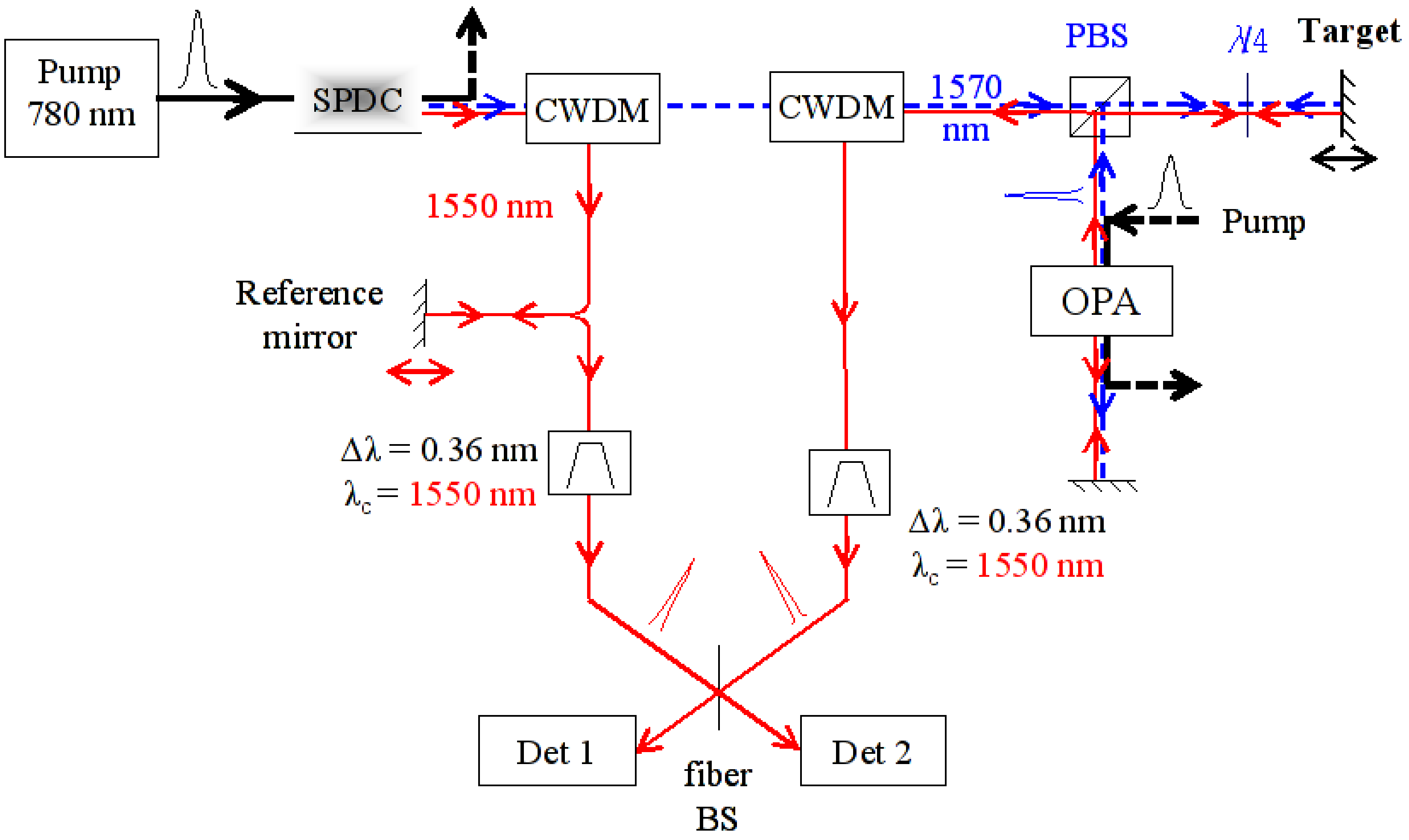
Amplified SPDC used to signal and idler beams

Entanglement-breaking; maximally classically correlated





PC-OCT setup



Pump
780 nm
SPDC
CWDM
CWDM
1570
nm
PBS
λ/4
Target
1550 nm
Pump
OPA
Reference
mirror
Δλ = 0.36 nm
λc = 1550 nm
Δλ = 0.36 nm
λc = 1550 nm
Det 1
fiber
BS
Det 2

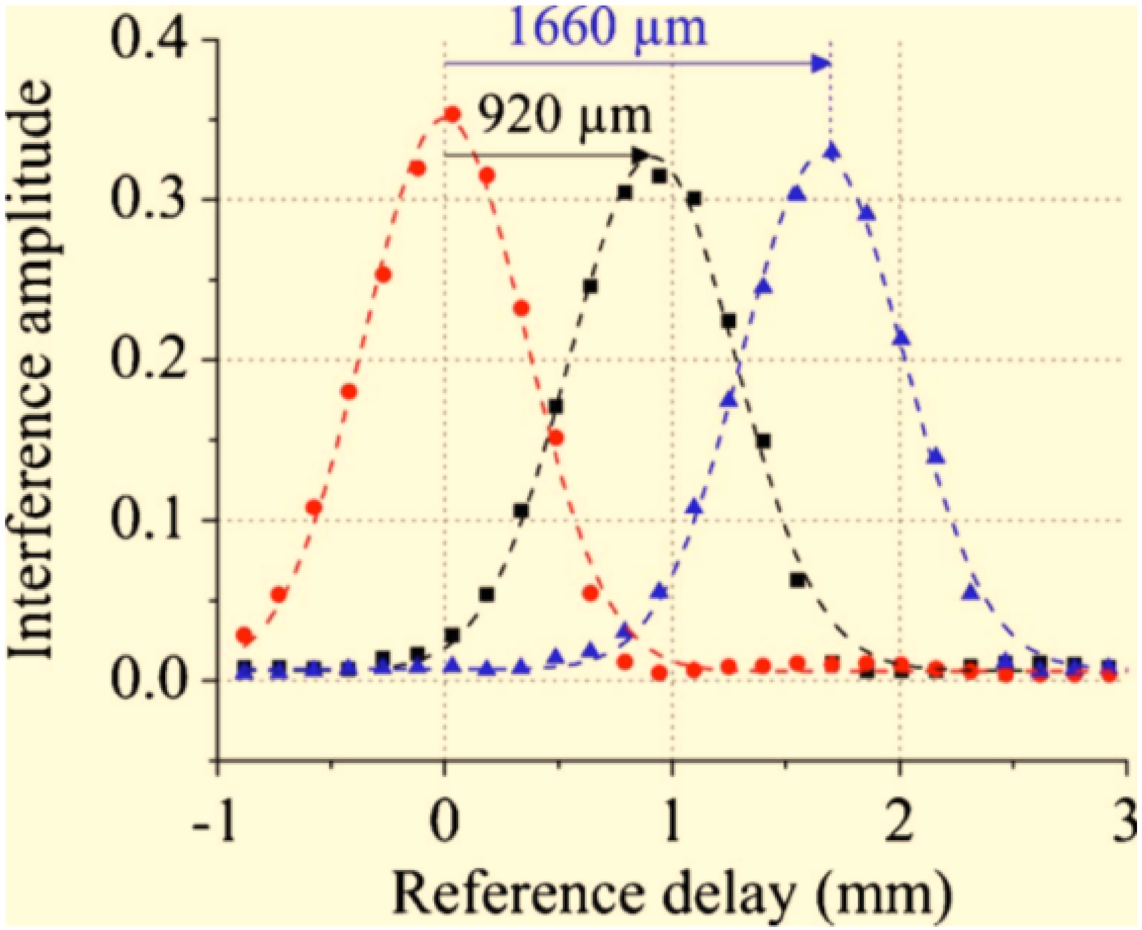
Results

Translation steps of 450 μm

Factor-of-2 resolution improvement visible

Dispersion cancelled almost perfectly

Temperature fluctuations affected long fibers



3 EXPERIMENT

Far-field phase-conjugate ghost imaging

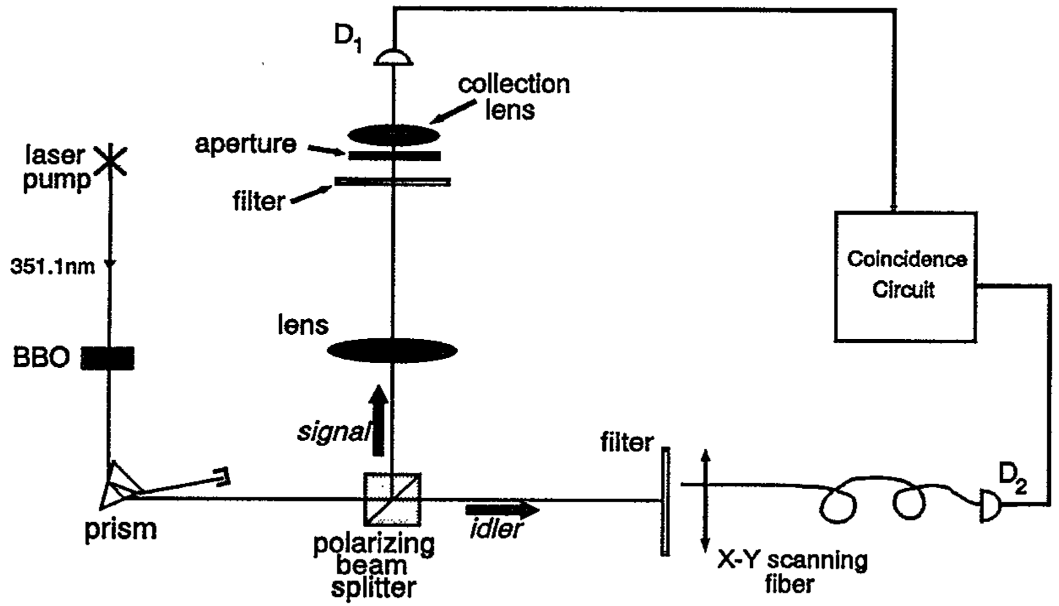
Ghost imaging history

PHYSICAL REVIEW A VOLUME 52, NUMBER 5 NOVEMBER 1995

Optical imaging by means of two-photon quantum entanglement

T. B. Pittman, Y. H. Shih, D. V. Strekalov, and A. V. Sergienko
Department of Physics, University of Maryland Baltimore County, Baltimore, Maryland 21228

(Received 22 December 1994)

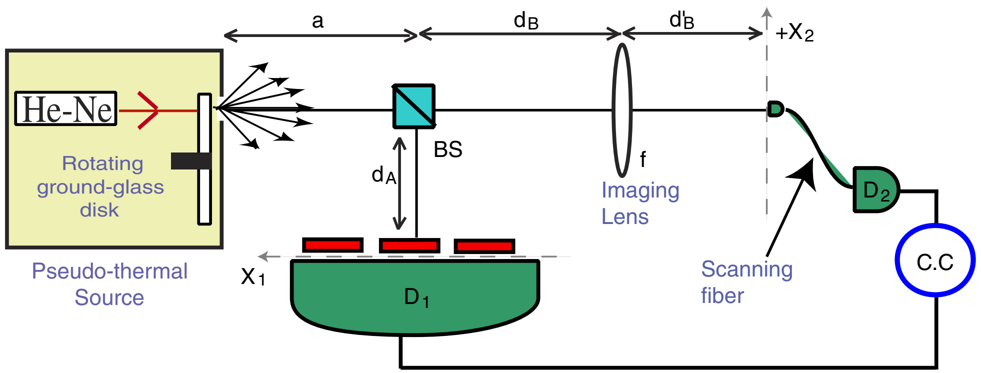


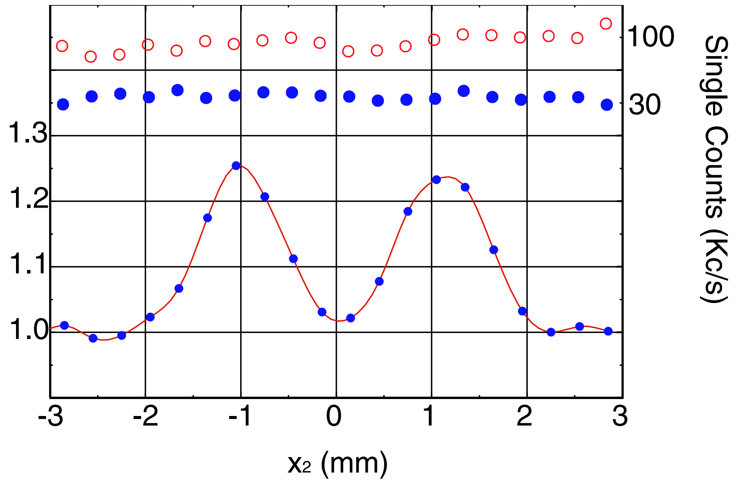
Ghost imaging history

PRL **94,** 063601 (2005) PHYSICAL REVIEW LETTERS week ending 18 FEBRUARY 2005

Two-Photon Imaging with Thermal Light

Alejandra Valencia, Giuliano Scarcelli, Milena D'Angelo, and Yanhua Shih
Department of Physics, University of Maryland, Baltimore County, Baltimore, Maryland 21250, USA
(Received 30 July 2004; published 16 February 2005)



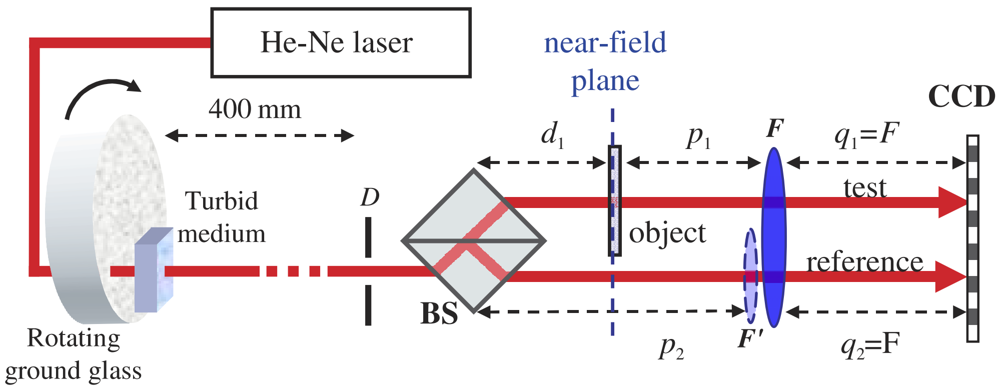


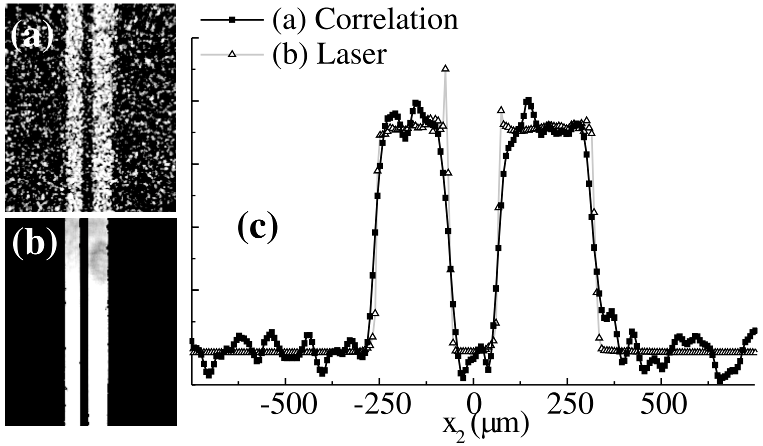
Ghost imaging history

PRL **94,** 183602 (2005) PHYSICAL REVIEW LETTERS week ending 13 MAY 2005

High-Resolution Ghost Image and Ghost Diffraction Experiments with Thermal Light

F. Ferri, D. Magatti, A. Gatti, M. Bache, E. Brambilla, and L. A. Lugiato
INFM, Dipartimento di Fisica e Matematica, Università dell'Insubria, Via Valleggio 11, 22100 Como, Italy
(Received 2 September 2004; published 12 May 2005)





Ghost imaging history

VOLUME 93, NUMBER 9 PHYSICAL REVIEW LETTERS week ending 27 AUGUST 2004

Ghost Imaging with Thermal Light: Comparing Entanglement and Classical Correlation

A. Gatti, E. Brambilla, M. Bache, and L. A. Lugiato

INFM, Dipartimento di Fisica e Matematica, Università dell'Insubria, Via Valleggio 11, 22100 Como, Italy

(Received 25 July 2003; published 26 August 2004)

We consider a scheme for coherent imaging that exploits the classical correlation of two beams obtained by splitting incoherent thermal radiation. This case is analyzed in parallel with the configuration based on two entangled beams produced by parametric down-conversion, and a precise formal analogy is pointed out. This analogy opens the possibility of using classical beams from thermal radiation for ghost imaging schemes in the same way as entangled beams.

DOI: 10.1103/PhysRevLett.93.093602 PACS numbers: 42.50.–p, 42.50.Dv, 42.50.Ar

Ghost imaging history

Unified Theory of Ghost Imaging with Gaussian-State Light

Baris I. Erkmen* and Jeffrey H. Shapiro
Massachusetts Institute of Technology, Research Laboratory of Electronics, Cambridge, Massachusetts 02139, USA
(Dated: February 2, 2008)

The theory of ghost imaging is developed in a Gaussian-state framework that both encompasses prior work—on thermal-state and biphoton-state imagers—and provides a complete understanding of the boundary between classical and quantum behavior in such systems. The core of this analysis is the expression derived for the photocurrent-correlation image obtained using a general Gaussian-state source. This image is expressed in terms of the phase-insensitive and phase-sensitive cross-correlations between the two detected fields, plus a background. Because any pair of cross-correlations is obtainable with classical Gaussian states, the image does not carry a quantum signa-

Erkmen and Shapiro showed

1. Ghost imaging is not unique to quantum light sources
2. **Phase-sensitive ghost imaging** can also be implemented classically

4 EXPERIMENT

Single-photon imaging

5 CONCLUSIONS