

Title: TBA

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Abstract:



UNIVERSITY of
ROCHESTER

Weak Values and Precision Measurements

\$Thanks to\$ DARPA, ARO



John Howell

Ben Dixon, David Starling
Praveen Vudya Setu, Curtis
Broadbent, Gerardo Viza,
Julian Martinez-Rincon



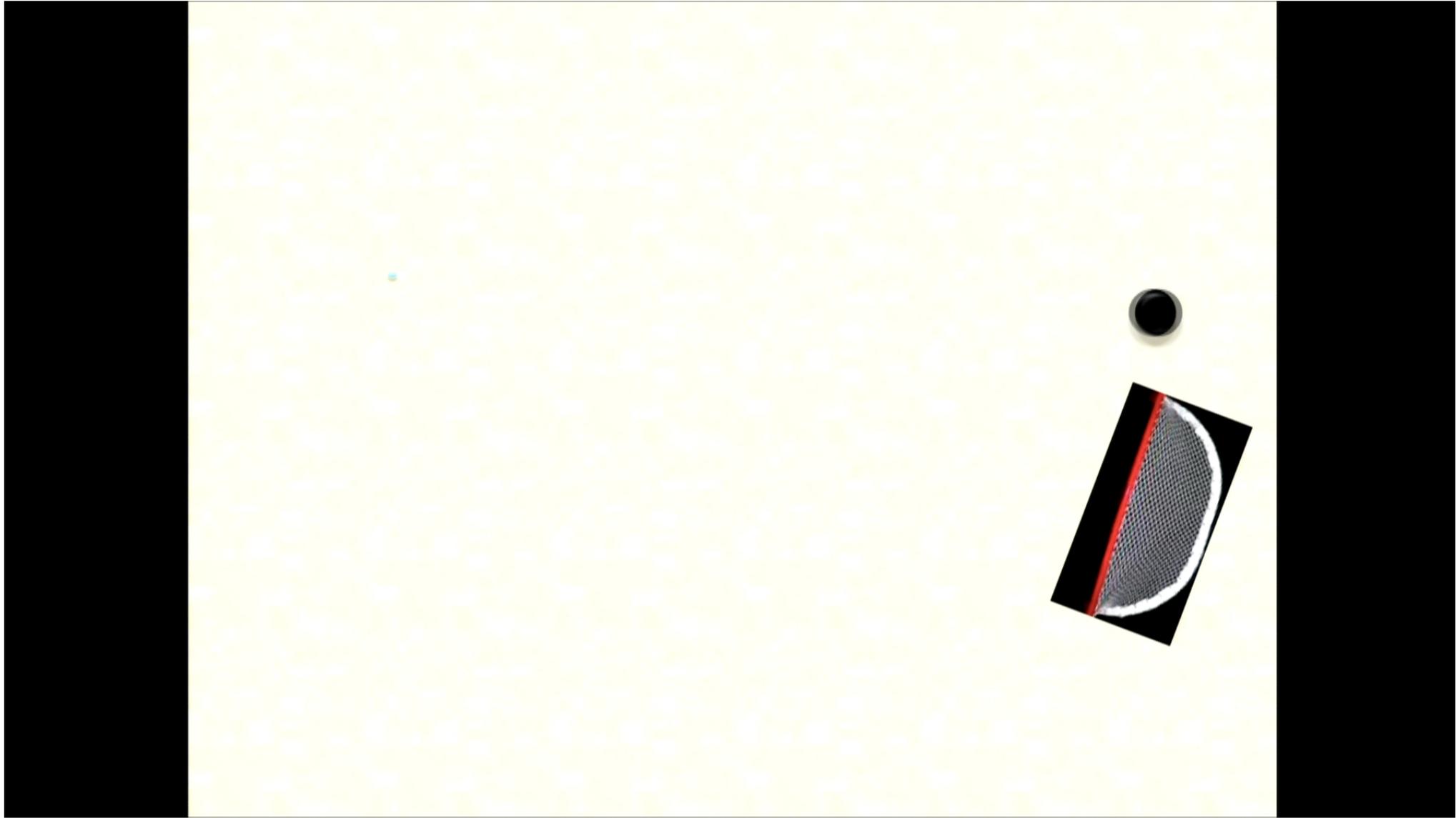
Andrew Jordan

Nathan Williams
Justin Dressel



Overview

- Weak Values
 - Introduction
 - Origins
 - Stern Gerlach
 - Realizations
 - Displacement
 - Deflection
 - SNR and Fisher information
 - Precision phase and gravimetry



Aharonov, Albert and Vaidman

VOLUME 60, NUMBER 14

PHYSICAL REVIEW LETTERS

4 APRIL 1988

How the Result of a Measurement of a Component of the Spin of a Spin- $\frac{1}{2}$ Particle Can Turn Out to be 100

Yakir Aharonov, David Z. Albert, and Lev Vaidman

*Physics Department, University of South Carolina, Columbia, South Carolina 29208, and
School of Physics and Astronomy, Tel-Aviv University, Ramat Aviv 69978, Israel*

(Received 30 June 1987)

Preselection \rightarrow Weak Unitary \rightarrow Postselection

$$\langle \psi_{out} | A | \psi_{in} \rangle$$

$$\langle \psi_{out} || \psi_{in} \rangle$$

← Probability amplitude of measurement

First Weak Value Experiment

PHYSICAL REVIEW LETTERS

VOLUME 66

4 MARCH 1991

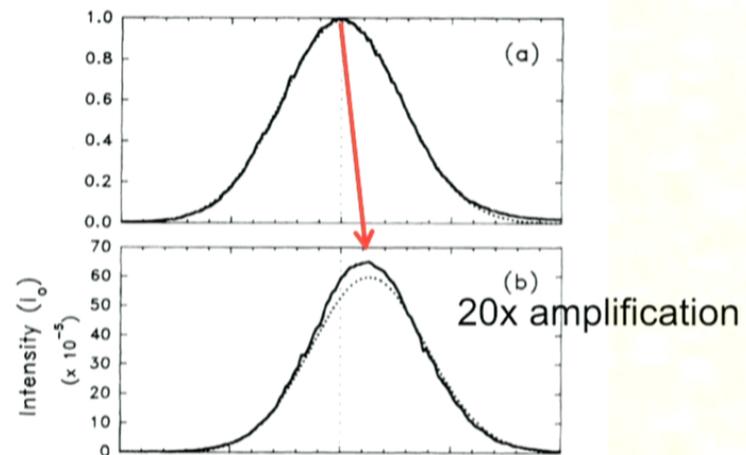
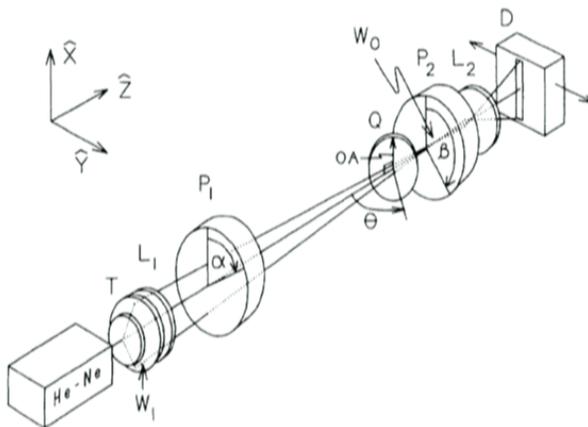
NUMBER 9

Realization of a Measurement of a "Weak Value"

N. W. M. Ritchie, J. G. Story, and Randall G. Hulet

Department of Physics and Rice Quantum Institute, Rice University, Houston, Texas 77251-1892

(Received 7 December 1990)



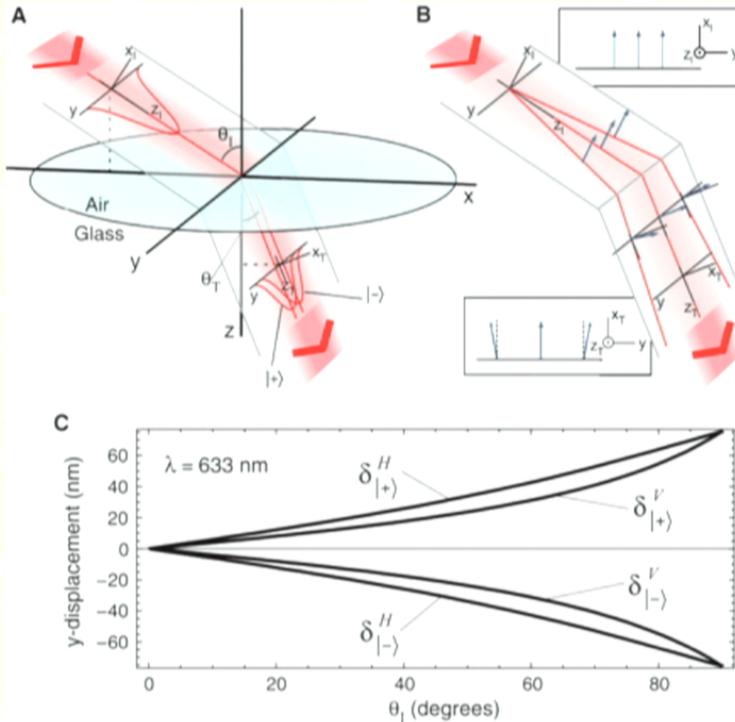
Weak Value Enhanced Deflections

- Y. Aharonov, D. Z. Albert, and L. Vaidman, Phys. Rev. Lett. 60, 1351 (1988).
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- I. M. Duck, P. M. Stevenson, and E. C. G. Sudarshan, Phys. Rev. D 40, 2112 (1989).
- G. J. Pryde, J. L. O'Brien, A. G. White, T. C. Ralph, and H. M. Wiseman, Phys. Rev. Lett. 94, 220405 (2005).
- N. W. M. Ritchie, J. G. Story, and R. G. Hulet, Phys. Rev. Lett. 66, 1107 (1991).
- N. S. Williams and A. N. Jordan, Phys. Rev. Lett. 100, 026804 (2008).
- O. Hosten and P. Kwiat, Science 319, 787 (2008)

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Weak Value Enhanced Deflections



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Stern-Gerlach Experiment

Otto Stern

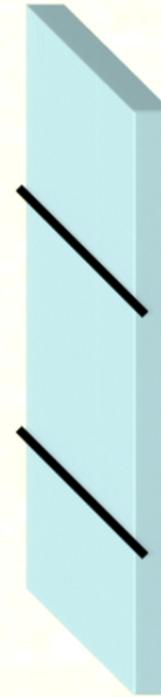
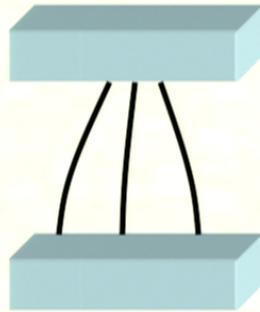
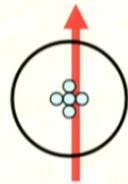


Walter Gerlach

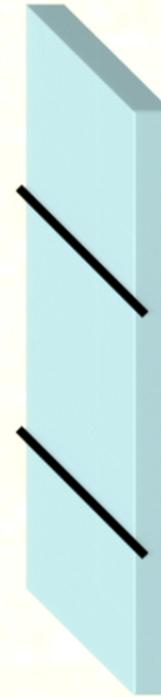
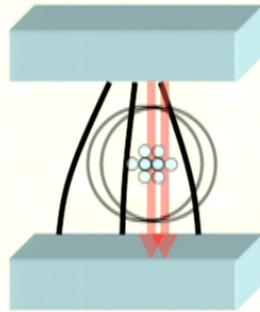


- Performed in 1922 to test quantized orbital angular momentum predicted by Bohr and Sommerfeld, but actually measured spin orbital angular momentum.
- One of THE most important quantum signatures.
- Unlocked intrinsic angular momentum (Spin).
- Reveals spectroscopic structure of the atom.

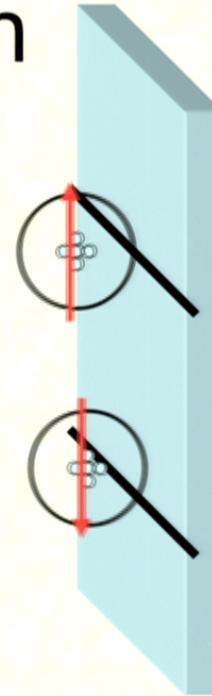
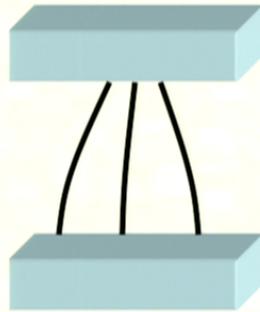
Stern-Gerlach



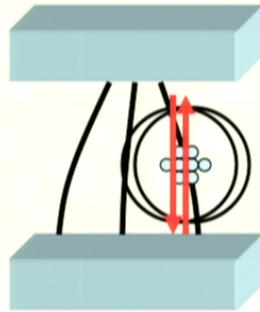
Stern-Gerlach



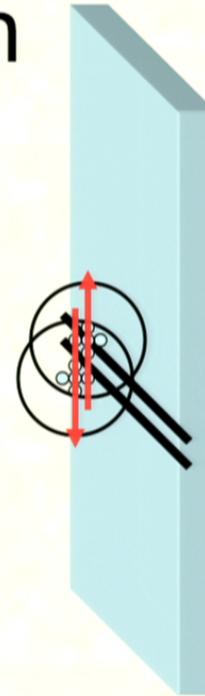
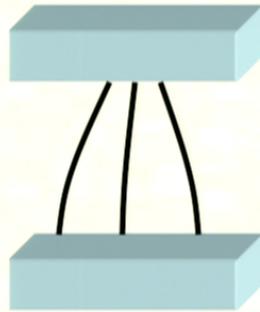
Stern-Gerlach



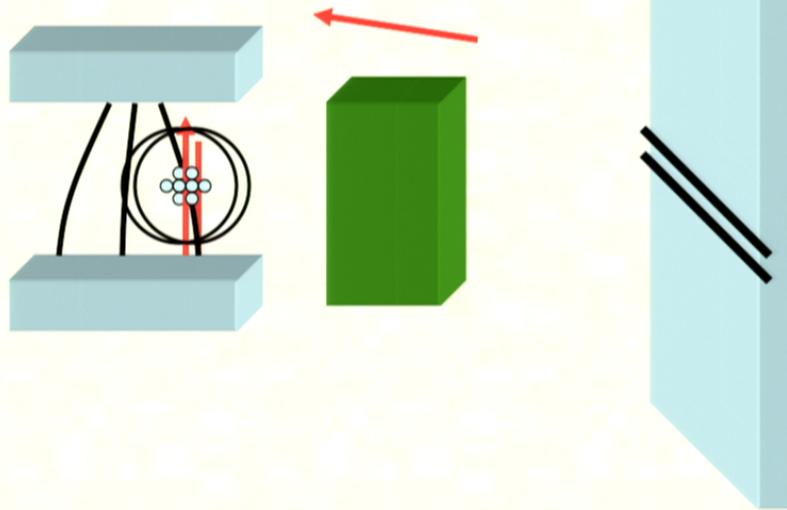
Stern-Gerlach



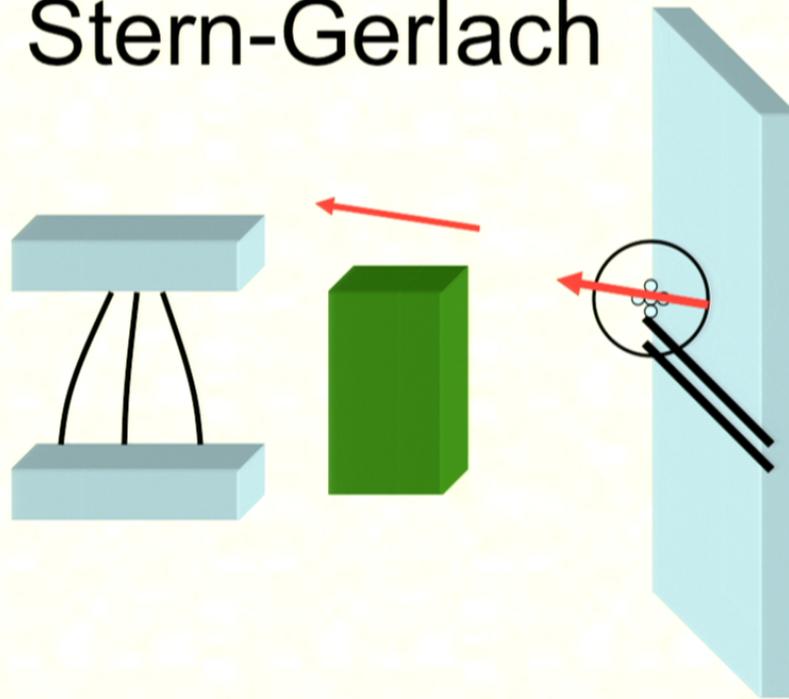
Stern-Gerlach



Stern-Gerlach

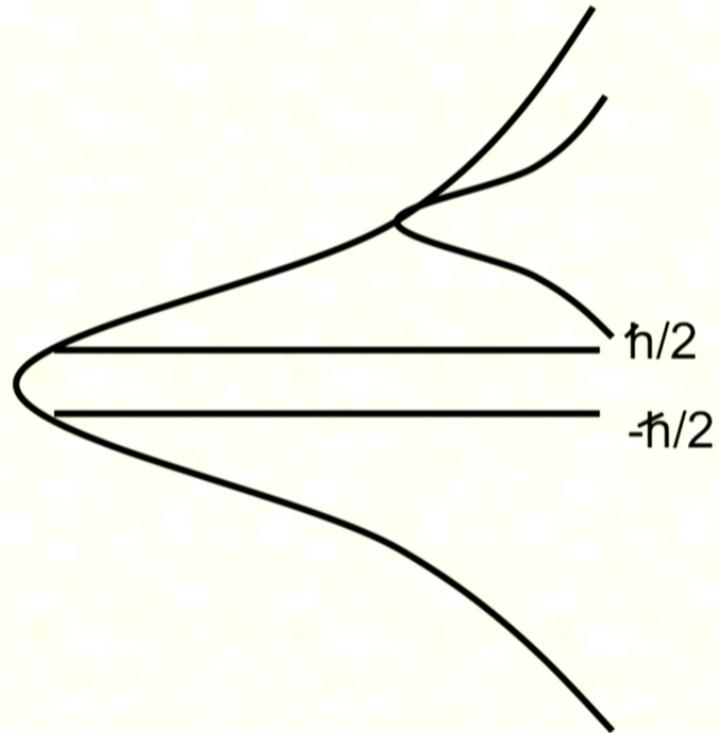


Stern-Gerlach

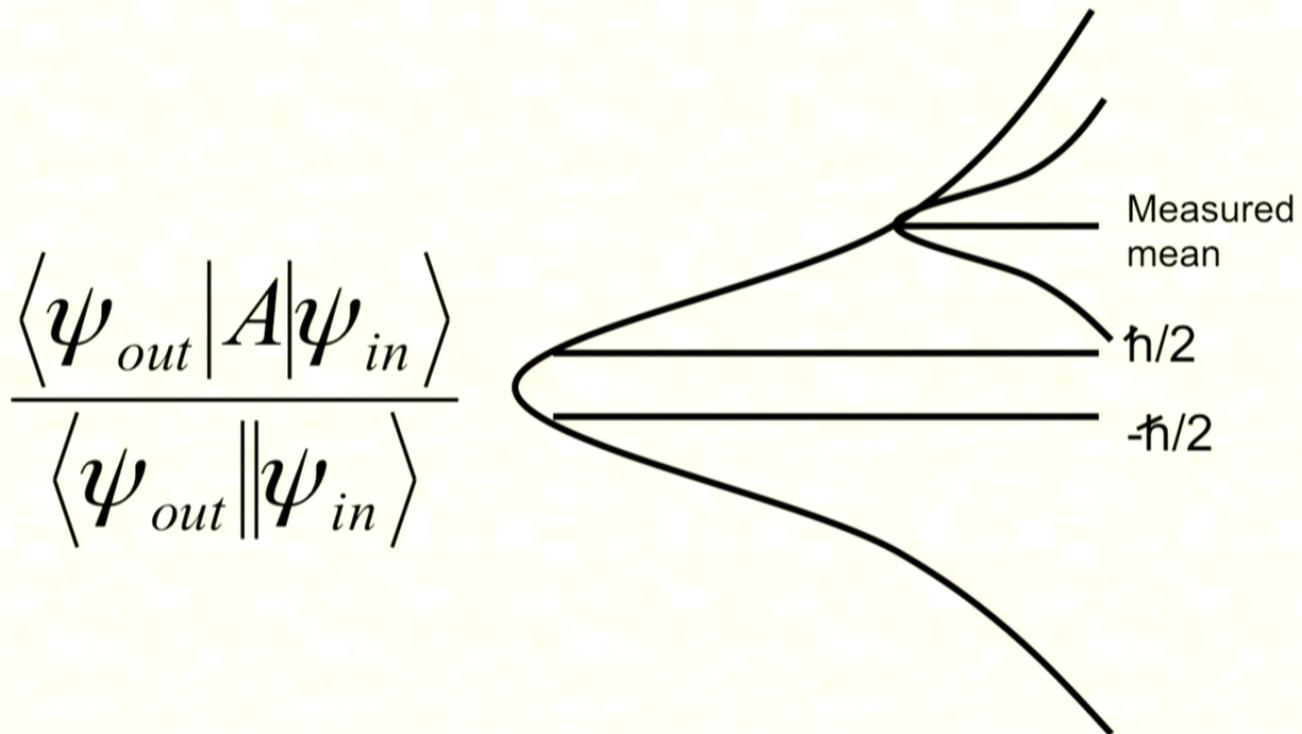


After Postselection

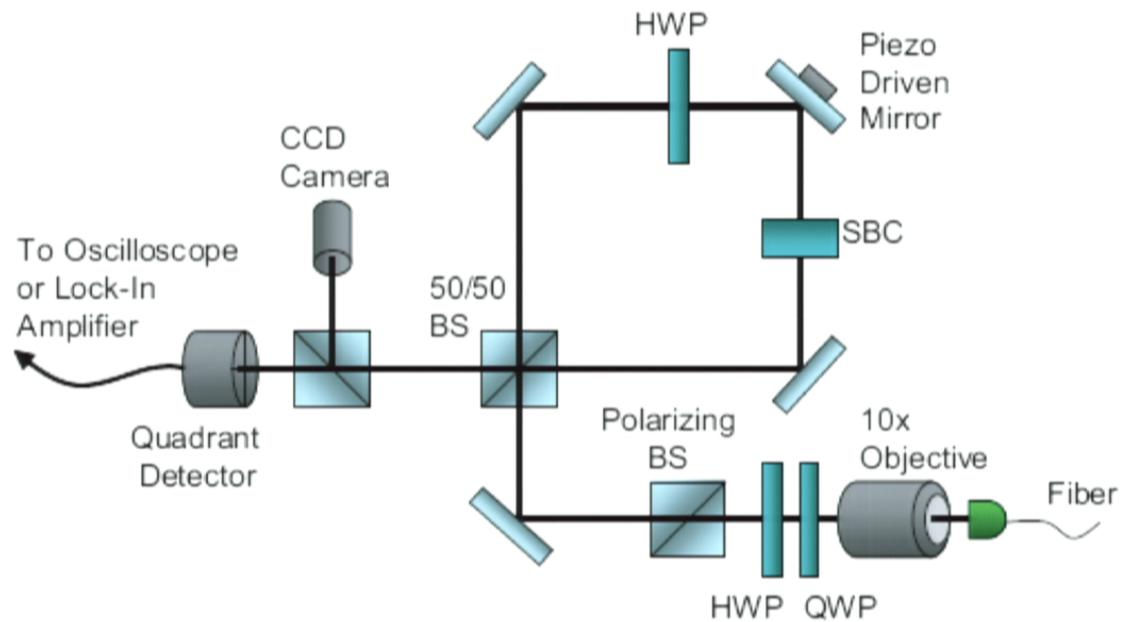
$$\frac{\langle \psi_{out} | A | \psi_{in} \rangle}{\langle \psi_{out} || \psi_{in} \rangle}$$



After Postselection

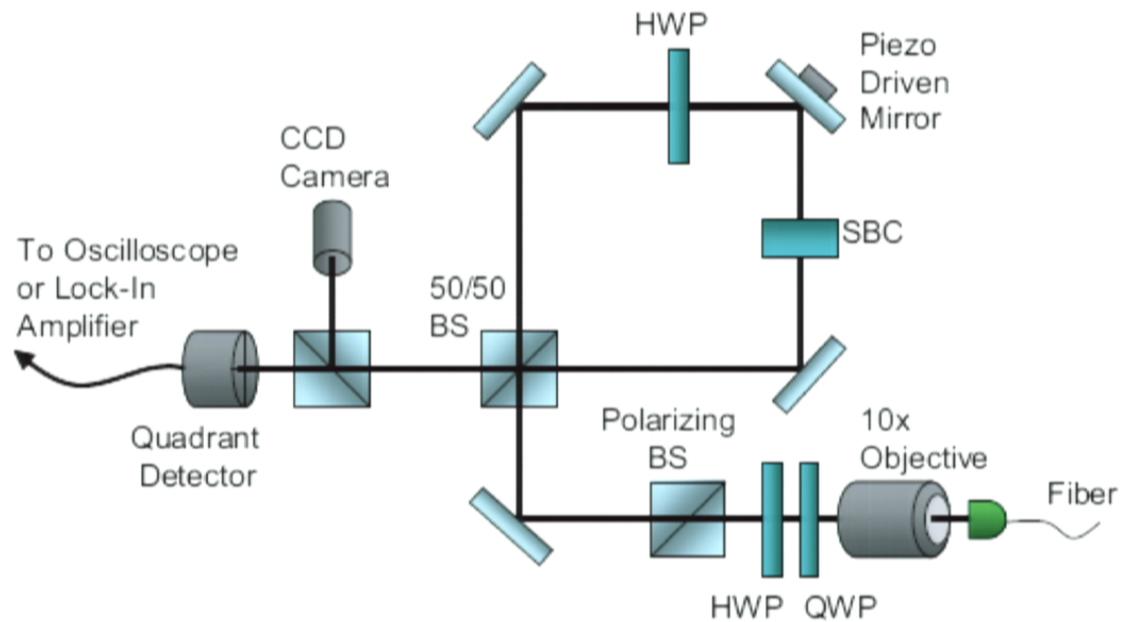


Weak Values Experiment



P. Ben Dixon, David J. Starling, Andrew N. Jordan, and John C. Howell
Phys. Rev. Lett. **102**, 173601 (2009)

Weak Values Experiment

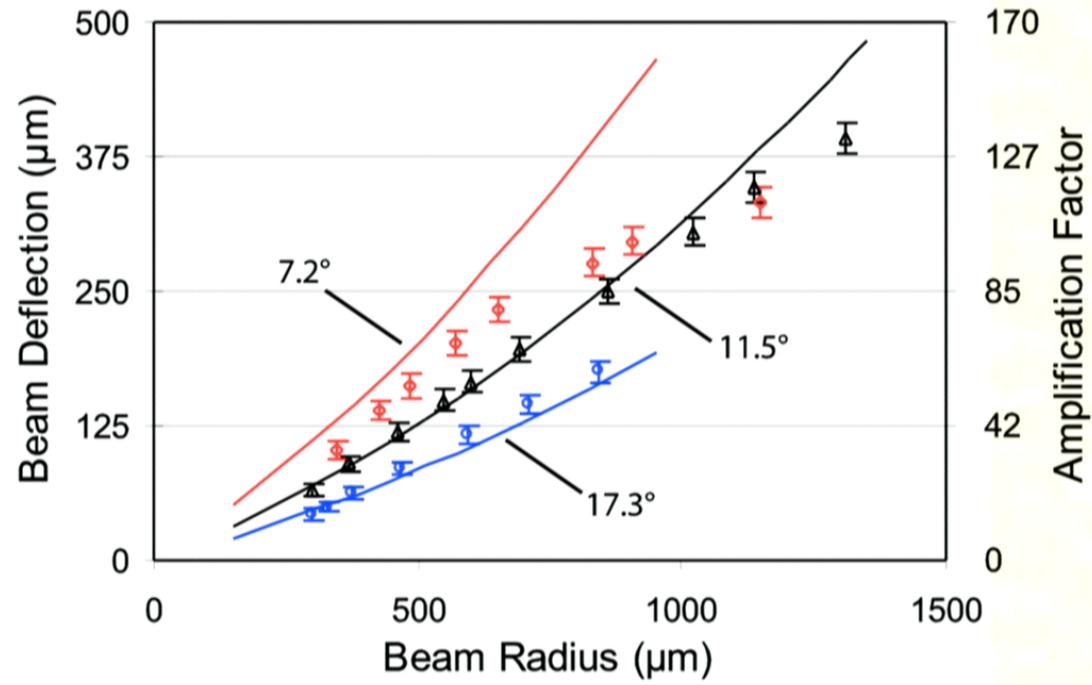


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Phys. Rev. Lett. **102**, 173601 (2009)

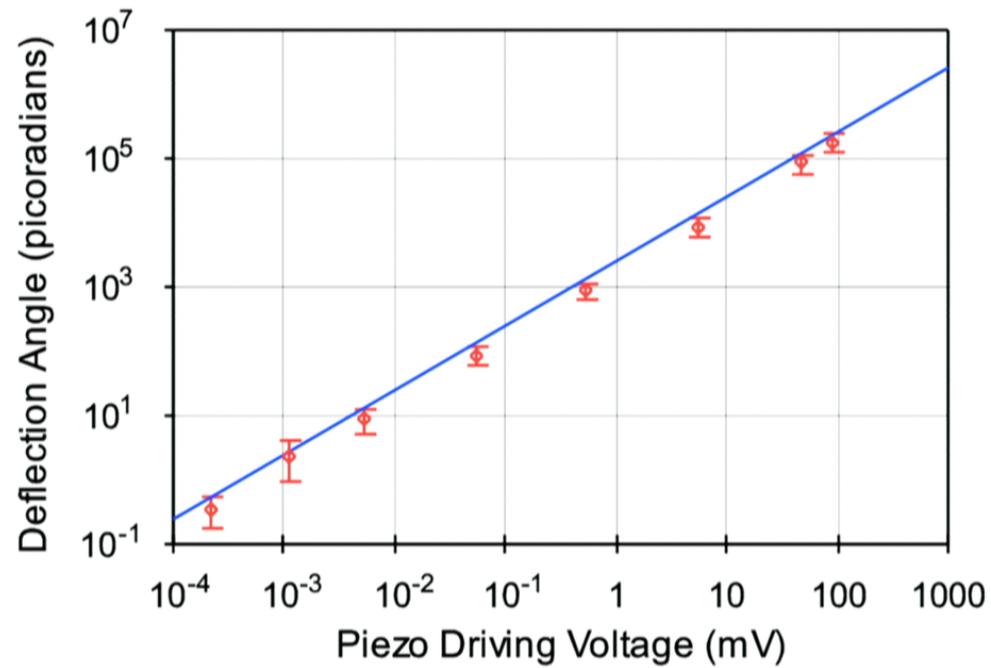
Analogies

- Stern-Gerlach
- Spin
- Fringing field
- Transverse probability distribution
- Deflection of atom
- Interferometer
- Which path
- Mirror deflection
- Transverse spatial mode distribution
- Deflection of beam

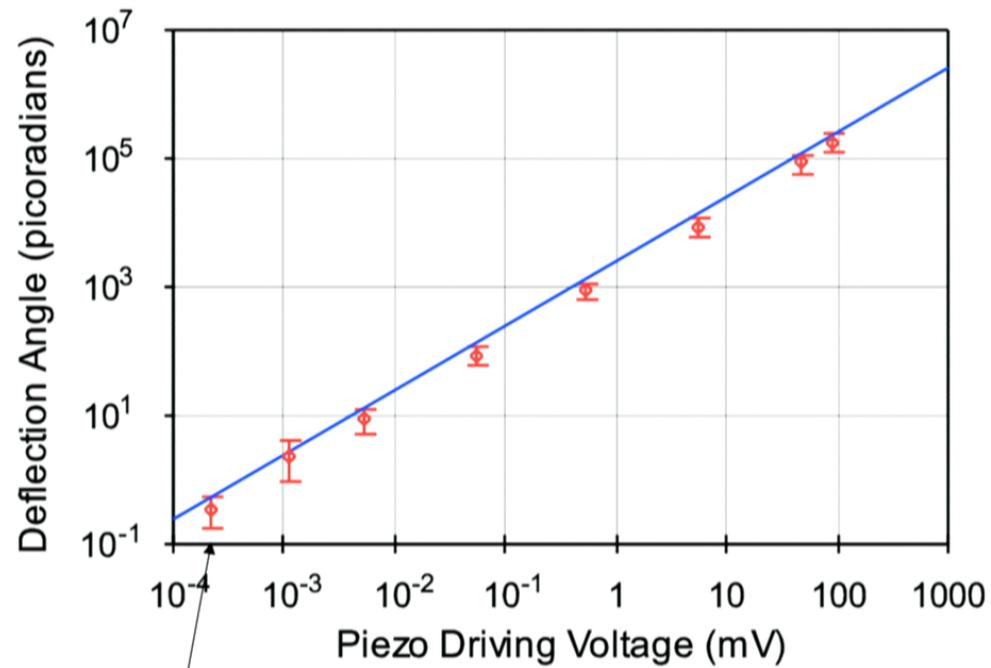
Results



Precision Beam Deflection



Precision Beam Deflection



560 femto radians

Deflection

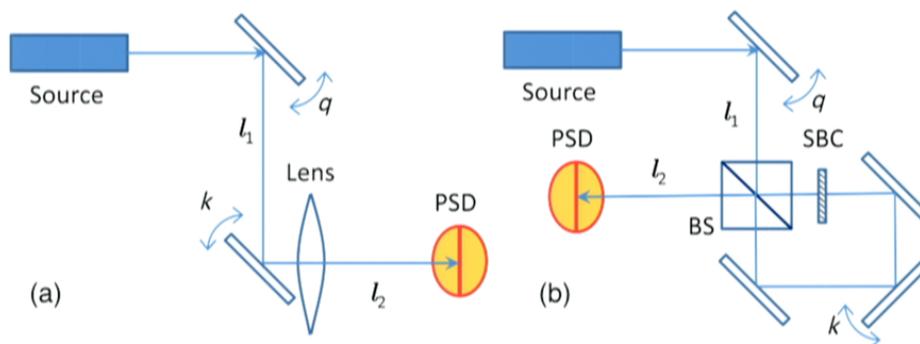


Technical Advantages for Weak-Value Amplification: When Less Is More

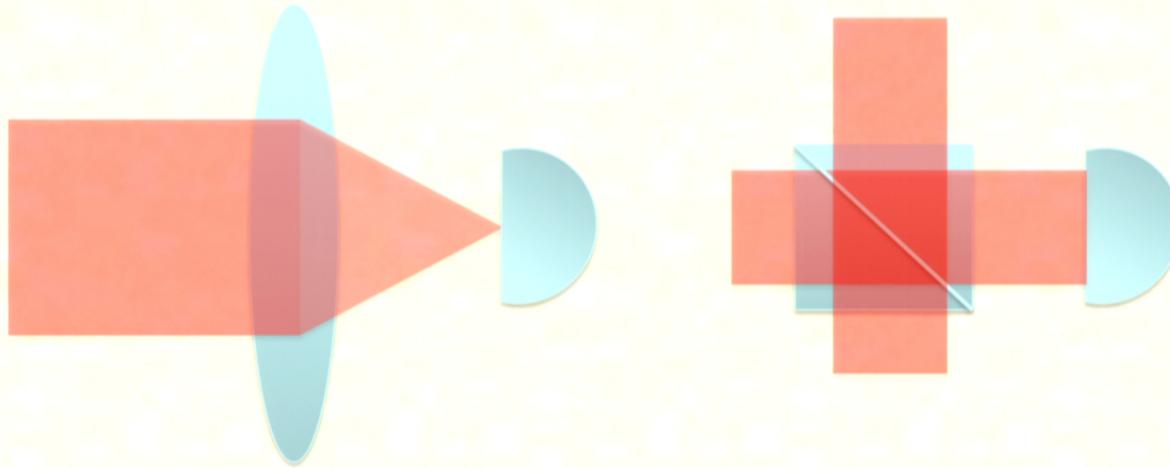
Andrew N. Jordan,^{1,2} Julián Martínez-Rincón,¹ and John C. Howell¹

¹*Department of Physics and Astronomy and The Center for Coherence and Quantum Optics,
University of Rochester, Rochester, New York 14627, USA*

²*Institute for Quantum Studies, Chapman University, 1 University Drive, Orange, California 92866, USA*
(Received 19 September 2013; published 6 March 2014)



Standard Technique vs WV Detector Jitter



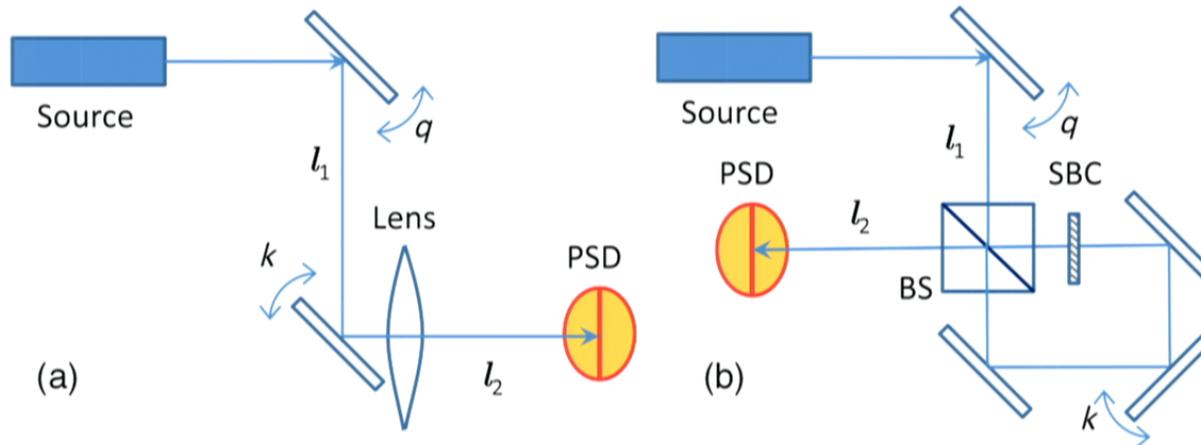
Fisher Information

$$\begin{aligned}\mathcal{I}(d) &= \langle S^2 \rangle = \int dx p(x|d) [\partial_d \log p(x|d)]^2 \\ &= - \int dx p(x|d) \partial_d^2 \log p(x|d).\end{aligned}$$

For Gaussian Distribution of N independent measurements

$$P_G(\{x_i\}|d) = \prod_{i=1}^N \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x_i - d)^2}{2\sigma^2}\right).$$

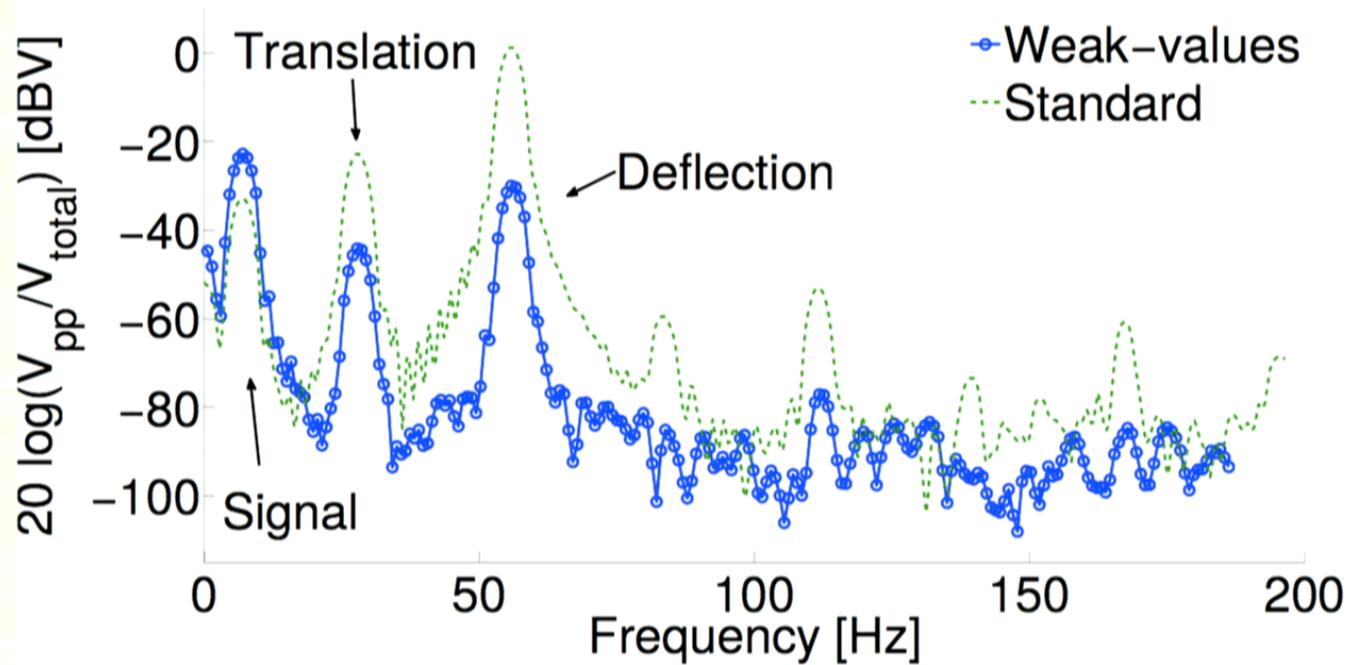
Beam Jitter



$$\mathcal{I}_d = \frac{4N\sigma^2}{1 + (2\sigma Q)^2}.$$

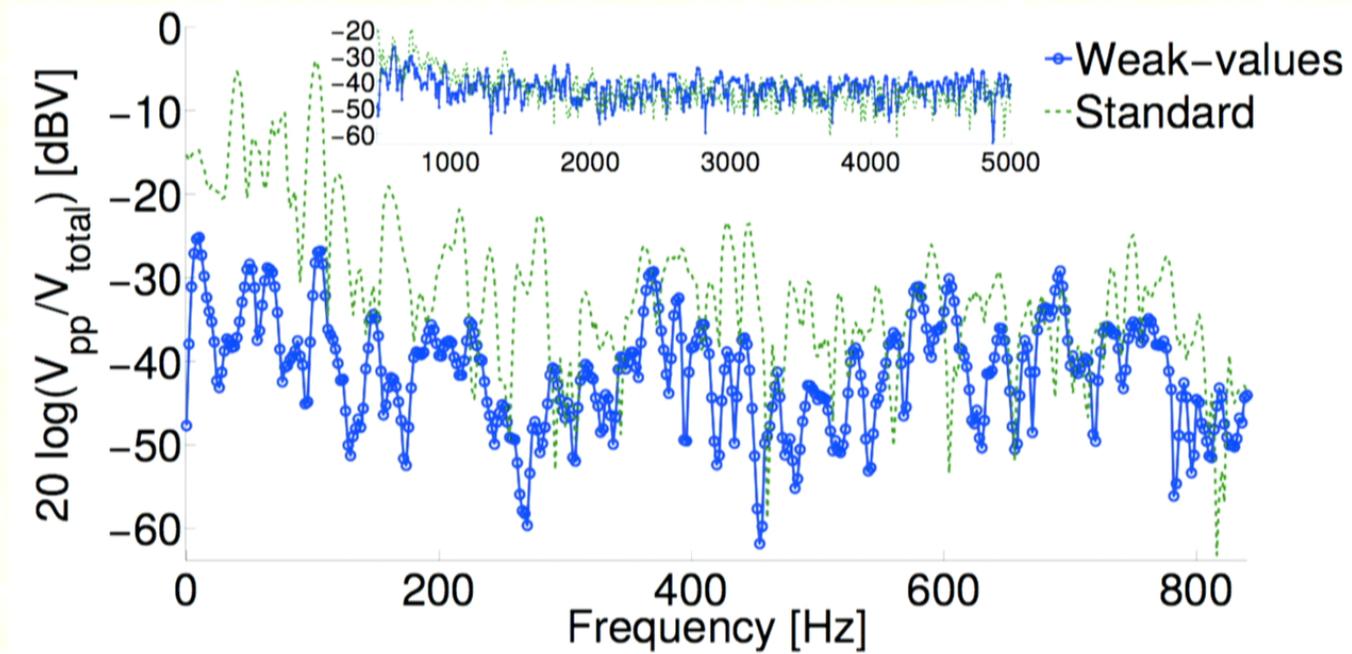
$$\mathcal{I}_{wv} = \frac{4N\sigma^2}{1 + \left(\frac{l_1+l_2}{2k_0\sigma^2}\right)^2 [1 + (2\sigma Q)^2]}.$$

External Jitter (Mirror and Detector)

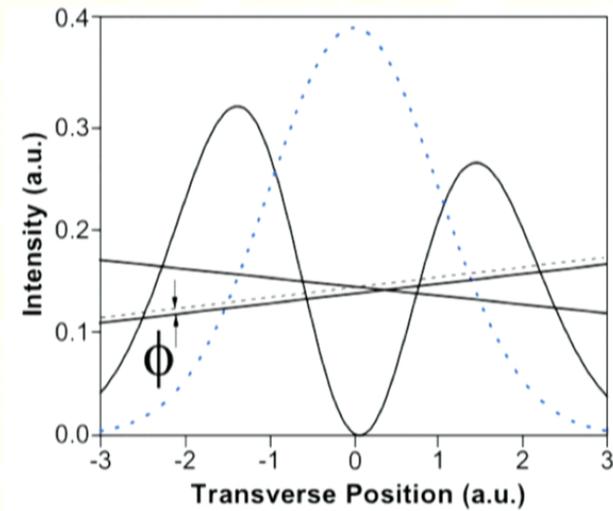
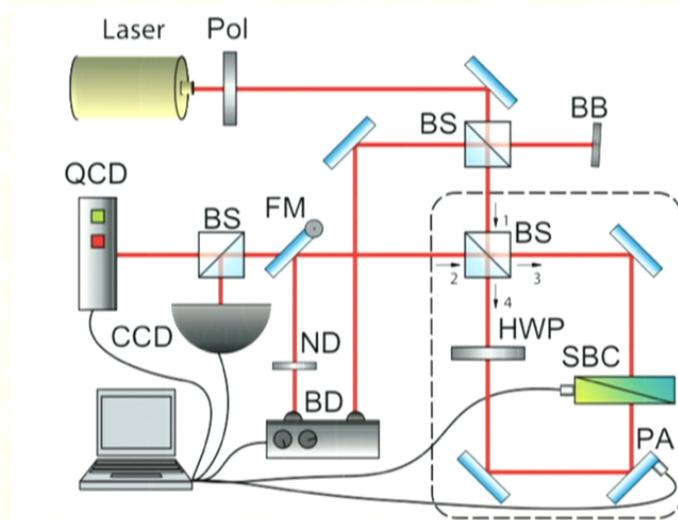


Laser Jitter

“Noise in the wild” Andrew Jordan

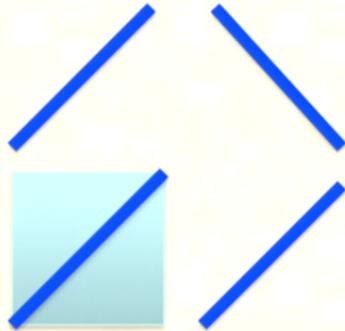


Precision Phase

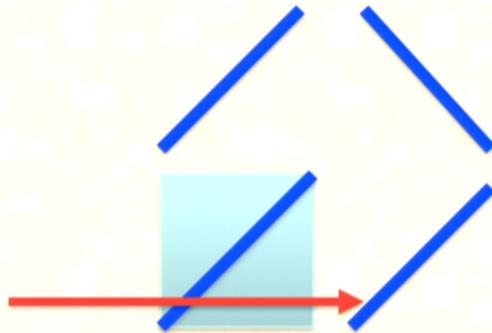


D.J. Starling, P.B. Dixon, N.S. Williams, A.N. Jordan and J.C. Howell
PRA(R) 82, 011802 (2010)

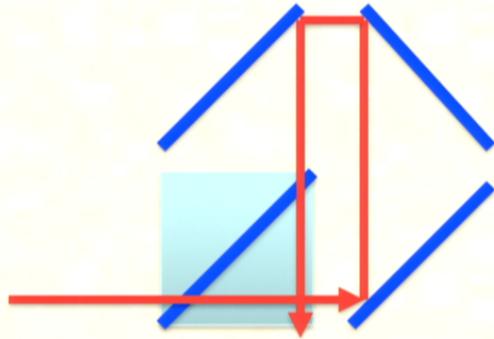
Displaced Sagnac



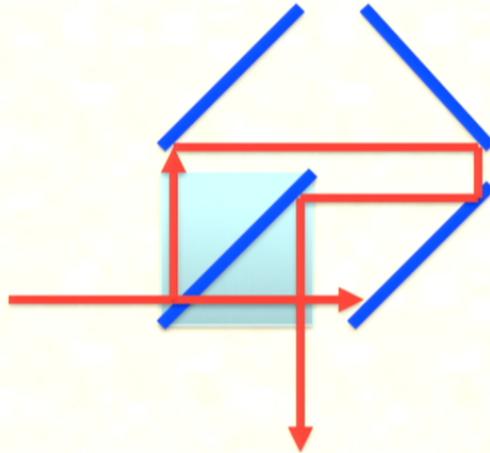
Displaced Sagnac



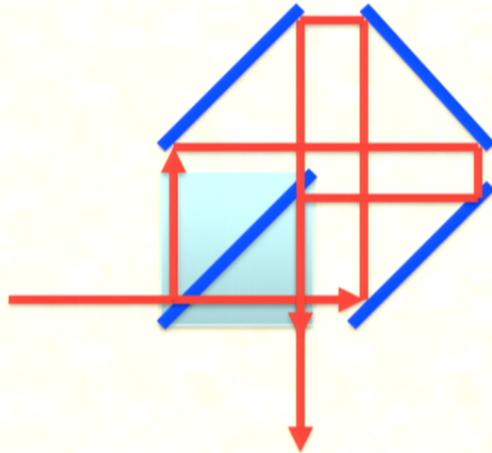
Displaced Sagnac



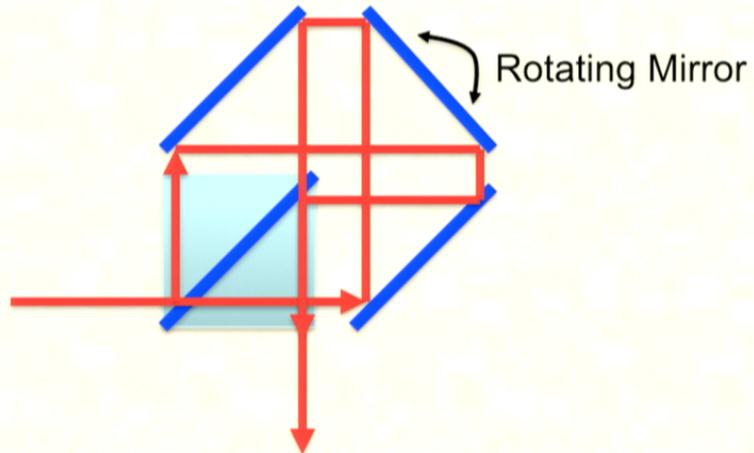
Displaced Sagnac



Displaced Sagnac

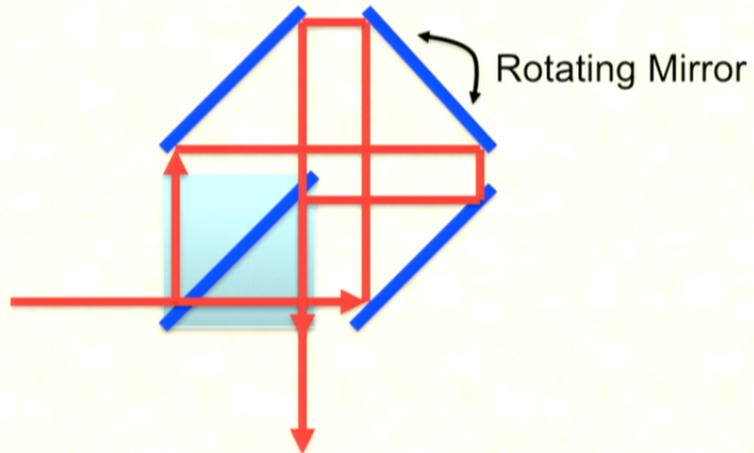


Displaced Sagnac



Displaced Sagnac

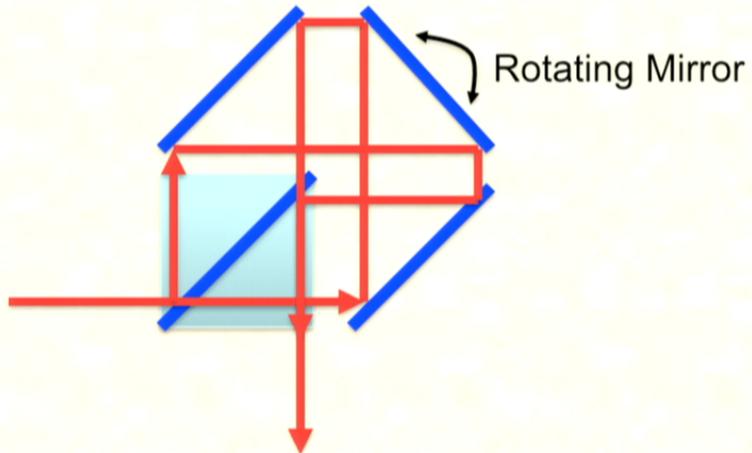
Two Paths Acquire
Different Phase



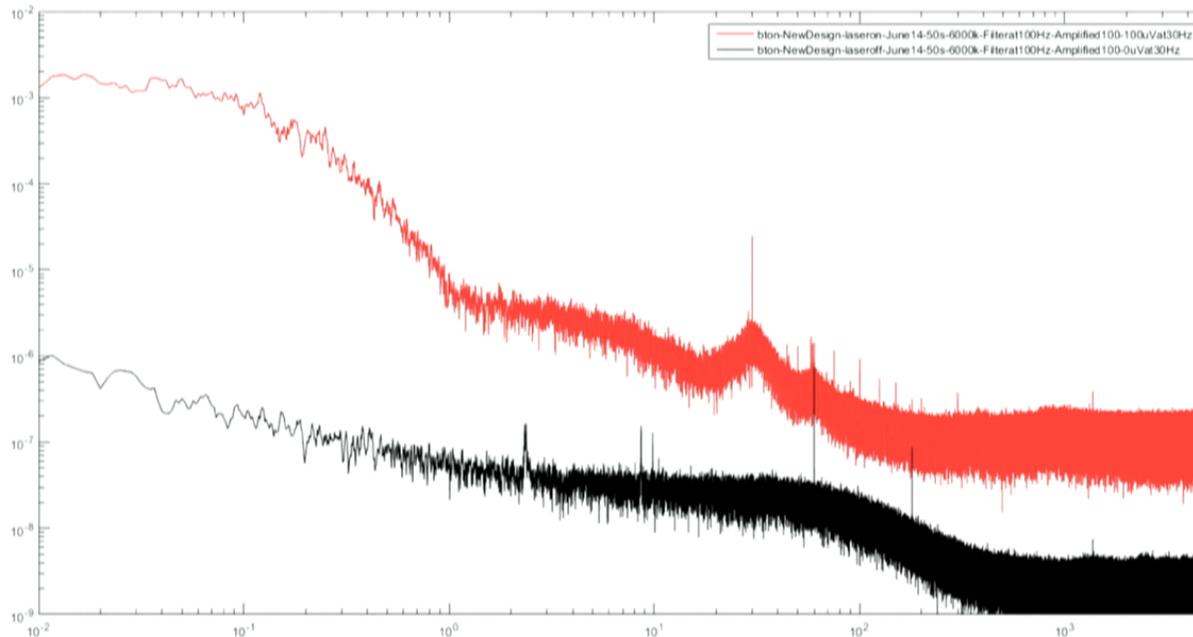
Displaced Sagnac

Two Paths Acquire
Different Phase

$$\Delta\theta \propto \frac{1}{kL\sqrt{N}}$$

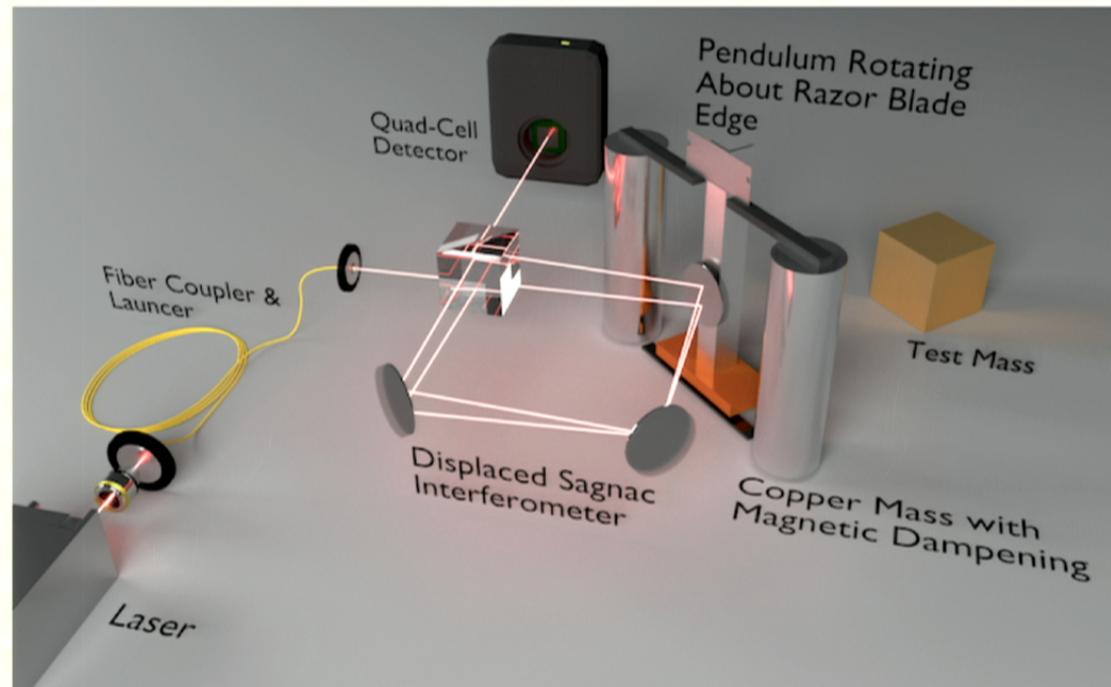


Displaced Sagnac Results



Shot Noise Limit $50 \text{ fRad}/\text{Hz}^{1/2}$
Measured Noise Floor $\sim 1.4 \text{ pRad}/\text{Hz}^{1/2}$

Tilt and Phase Gravimetry



Precision Gravimetry: Quantum Inspired (weak values)

- Shot noise sensitivity: $10 \text{ femto g/Hz}^{1/2}$ with 50ms $1/e$ damping time. (sufficient to detect a human at 100's of meters)
- Other designs: sub atto g SNL resolution with 100 s $1/e$ damping time.
- What if?
 - Noninvasive deep tissue, sub cellular imaging
 - bulk imaging.
- No diffraction limit with gravity!

Intuition

- Beam size is important.
 - Detector jitter important with small beam – standard technique.
- Weak values
 - Interferometer amplifies effect of interest but not pre-interferometer jitter.
 - Standard system treats jitter and signal on same footing.

Weak Values Effective Precision Measurement Paradigm

- Suppresses technical noise.
- More easily measure at shot noise limit.
- Best angular resolution about nanoradian before using weak values.
- Hope to measure very small angular rotations.
- Applies to any weak values type setup, not just interferometer.