UNIVERSIDADE FEDERAL DE MATO GROSSO

INCT-IQ
Instituto Nacional de Ciência e Tecnologia de Informação Quântica

CNPq
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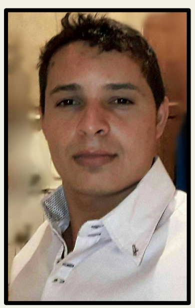
CAPES

Mach-Zehnder interferometer with quantum beamsplitters

XIX Meeting of Physics, Lima – Peru (2020)



Nelson Almeida, *PhD candidate.* (UFMT)

Thiago Werlang, *Prof.* (UFMT)

Daniel Valente, *Prof.* (UFMT)

valente.daniel@gmail.com

Big question: single quanta?

Are There Quantum Jumps? Part II
Author(s): E. Schrödinger
Source: *The British Journal for the Philosophy of Science*, Vol. 3, No. 11 (Nov., 1952), pp. 233-242

registering the fact, that we *never* experiment with just *one* electron or atom or (small) molecule. In thought-experiments we sometimes assume that we do; this invariably entails ridiculous consequences

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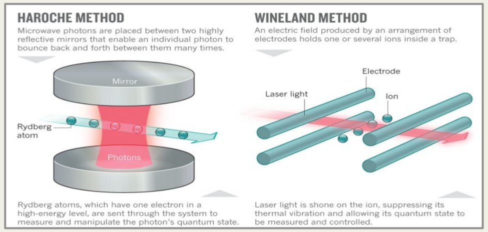
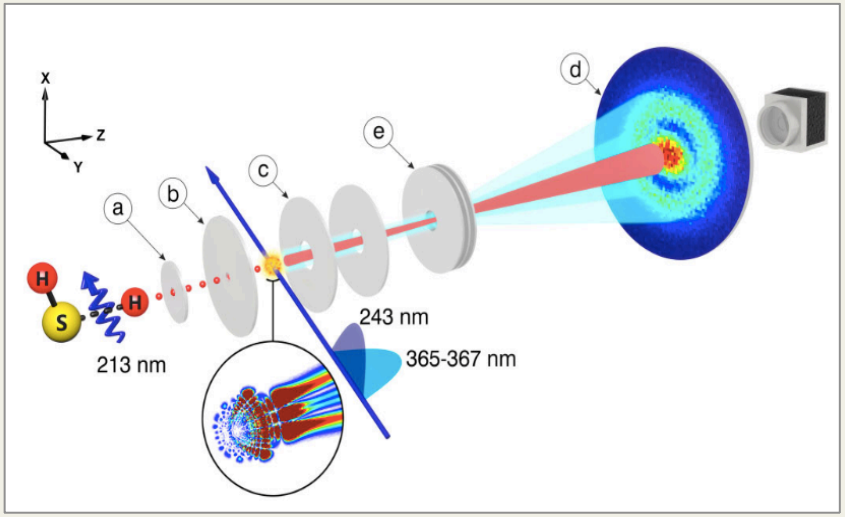


The Nobel Prize in Physics 2012

Serge Haroche | **David J. Wineland**

Prize motivation: "for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems"



Selected for a Viewpoint in *Physics*
PRL **110,** 213001 (2013) PHYSICAL REVIEW LETTERS week ending 24 MAY 2013

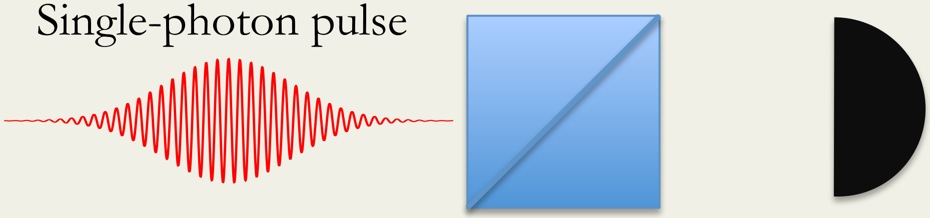
Hydrogen Atoms under Magnification: Direct Observation of the Nodal Structure of Stark States

A. S. Stodolna,[1,*] A. Rouzée,[1,2] F. Lépine,[3] S. Cohen,[4] F. Robicheaux,[5] A. Gijsbertsen,[1] J. H. Jungmann,[1] C. Bordas,[3] and M. J. J. Vrakking[1,2,*]
[1]*FOM Institute AMOLF, Science Park 104, 1098 XG Amsterdam, Netherlands*
[2]*Max-Born-Institut, Max Born Straße 2A, D-12489 Berlin, Germany*
[3]*Institut Lumière Matière, Université Lyon 1, CNRS, UMR 5306, 10 Rue Ada Byron, 69622 Villeurbanne Cedex, France*
[4]*Atomic and Molecular Physics Laboratory, Physics Department, University of Ioannina, 45110 Ioannina, Greece*
[5]*Department of Physics, Auburn University, Auburn, Alabama 36849, USA*

Recall: single-photon in a Mach-Zehnder interferometer

Probability of click in Detector 1 = **50%**

Single-photon pulse



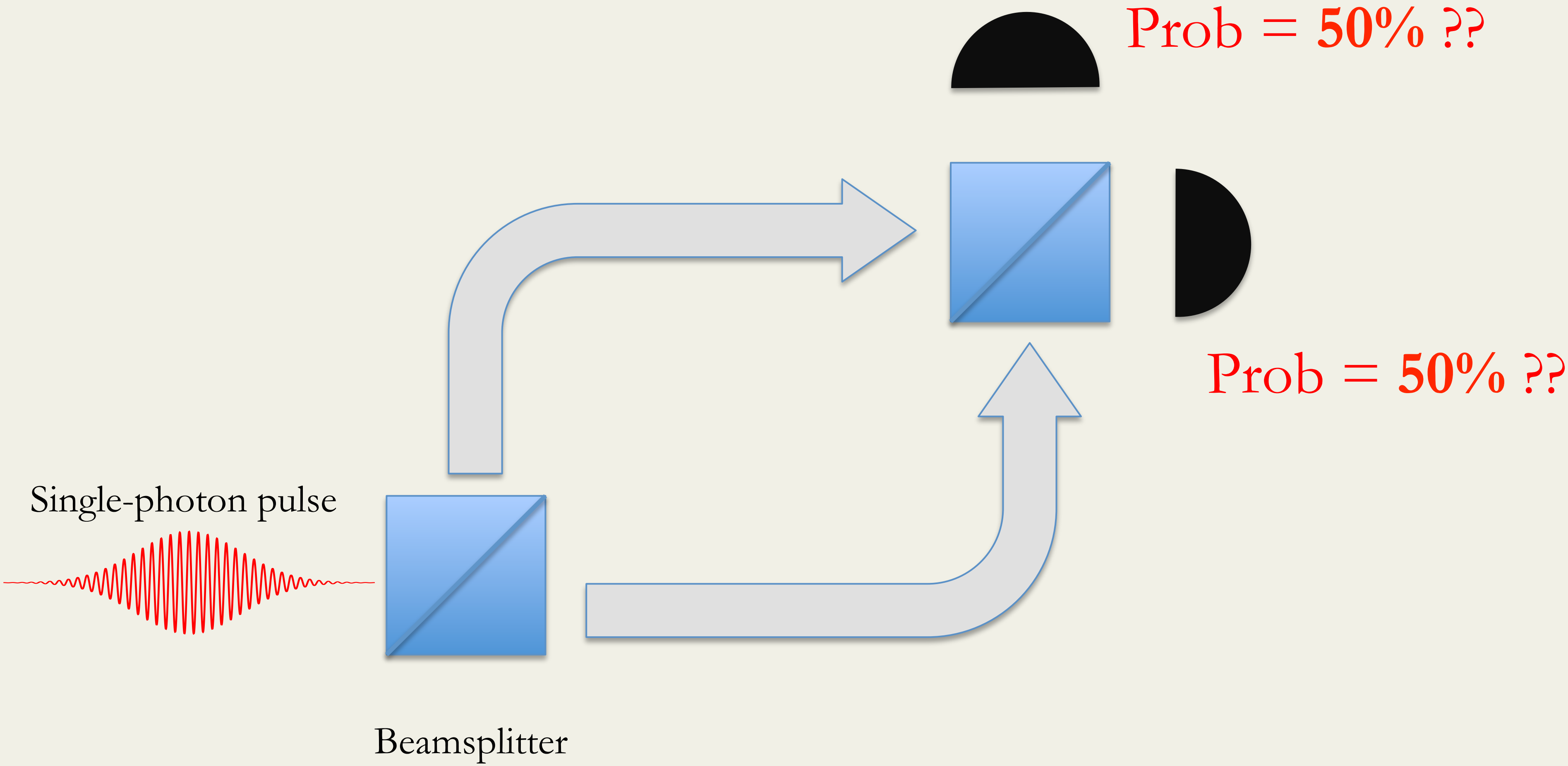
Probability of click in Detector 2 = **50%**

Beamsplitter

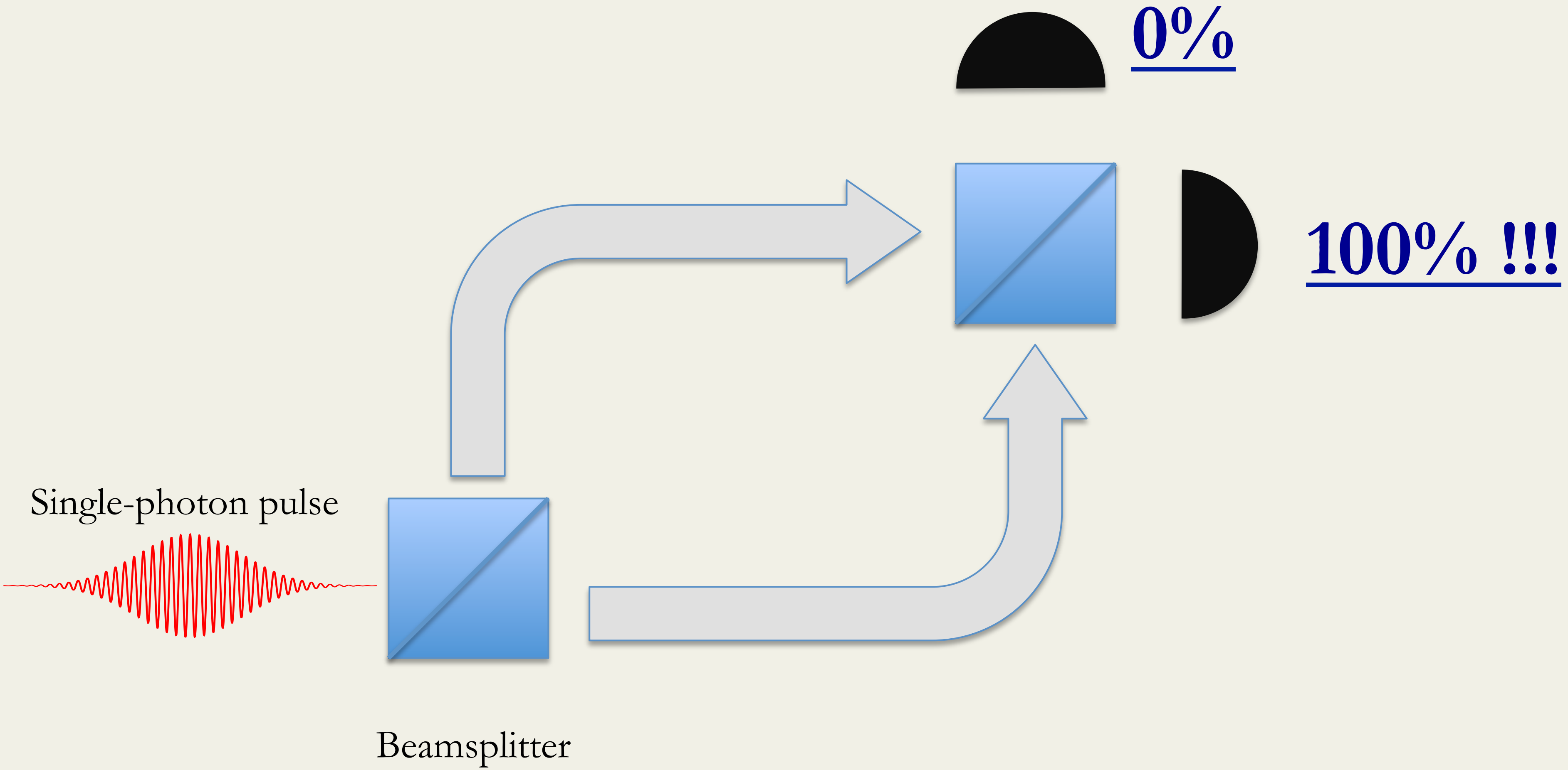
S. Haroche, J. M. Raimond, **Exploring the Quantum** (Oxford Grad. Studies), **Cap. 3**

$$U|1,0\rangle = (|1,0\rangle + i|0,1\rangle)/\sqrt{2}$$

Recall: single-photon in a Mach-Zehnder interferometer



Recall: single-photon in a Mach-Zehnder interferometer

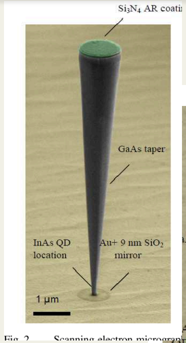


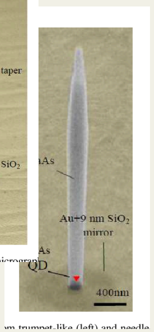
S. Haroche, J. M. Raimond, **Exploring the Quantum** (Oxford Grad. Studies), **Cap. 3**

$$U\sigma_x U|1,0\rangle = |1,0\rangle$$

The quantum beamsplitter in waveguide QED

J. M. Gerard
(CEA | FR)

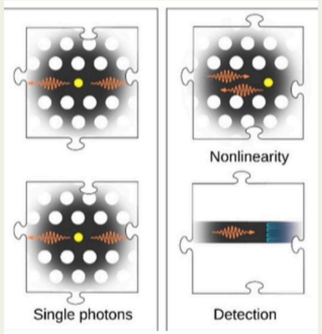




Photonic Nanowires (2010)

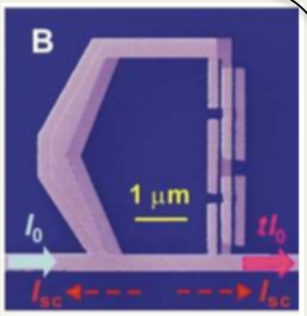
P. Lodahl
(Niels Bohr | DK)

J. Vuckovic
(Stanford | USA)



Photonic Crystal Waveguides (2005)

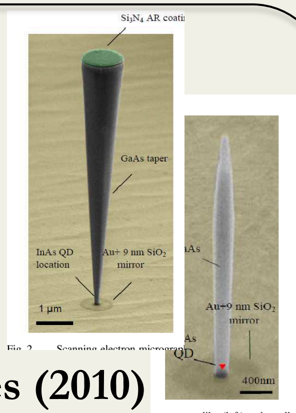
J. S. Tsai
(RIKEN | JP)



Superconducting Waveguides (2010)

The quantum beamsplitter in waveguide QED

J. M. Gerard
(CEA | FR)



Photonic Nanowires (2010)

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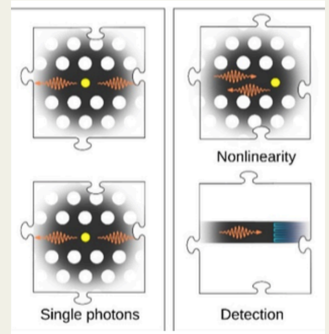

Photonic Crystal Waveguides (2005)

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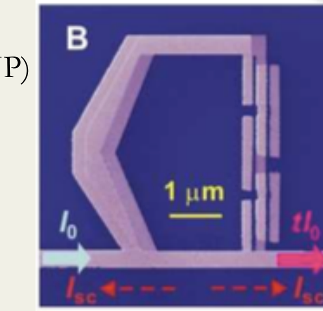
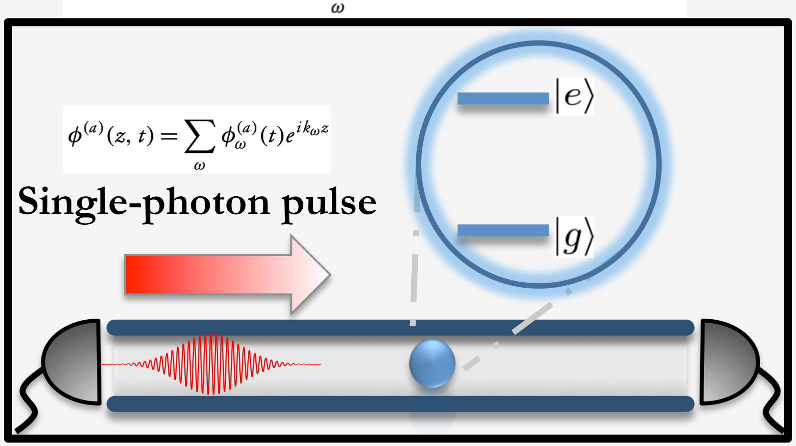


Superconducting Waveguides (2010)

$$|\xi(t)\rangle = \psi(t)|e,0\rangle + \sum_{\omega}[\phi_{\omega}^{(a)}(t)a_{\omega}^{\dagger} + \phi_{\omega}^{(b)}(t)b_{\omega}^{\dagger}]|g,0\rangle$$

$$\phi^{(a)}(z,t) = \sum_{\omega}\phi_{\omega}^{(a)}(t)e^{ik_{\omega}z}$$

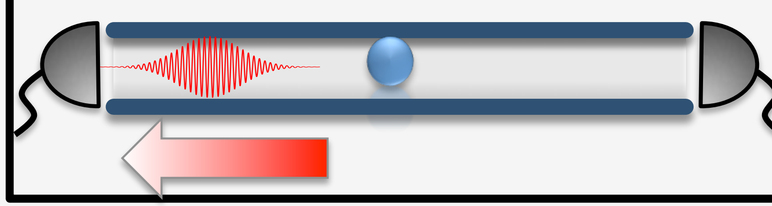
Single-photon pulse



$$H_{\text{int}} = \sum_{\omega} -i\hbar g[\sigma_{+}(a_{\omega}e^{+ik_{\omega}z_s} + b_{\omega}e^{-ik_{\omega}z_s}) - \text{H.c.}]$$

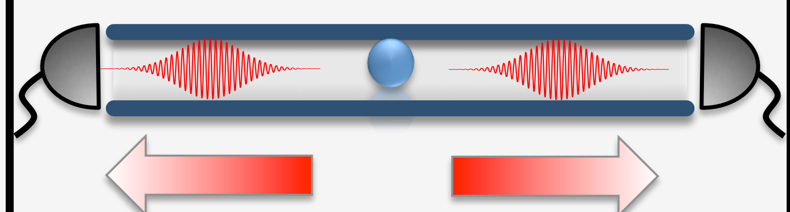
AT resonance

Single-atom mirror



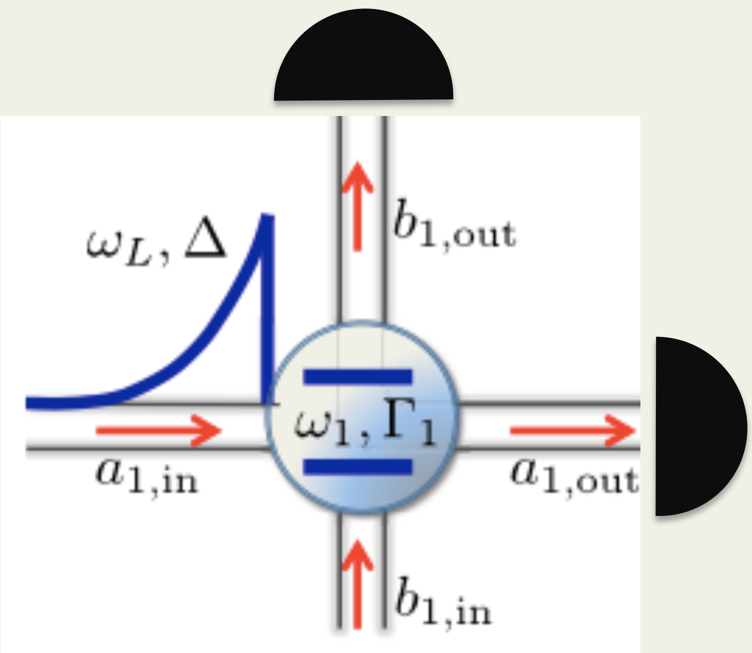
OFF resonance

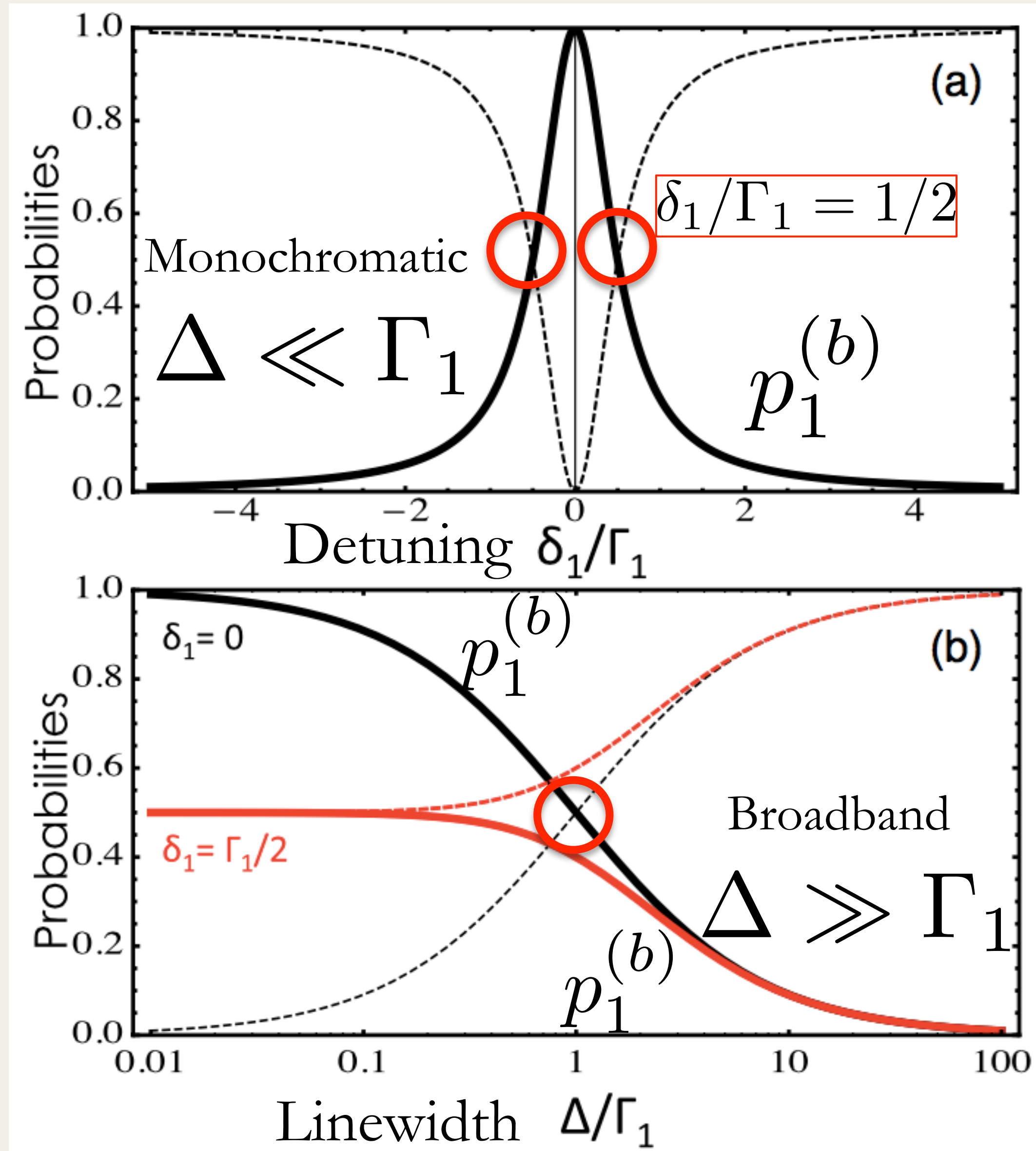
Single-atom beamsplitter



Quantum beamsplitter: **two** ways of getting 50-50%

$$p_1^{(a)} = p_1^{(b)} = 1/2,$$





Key parameters:

detuning δ_L

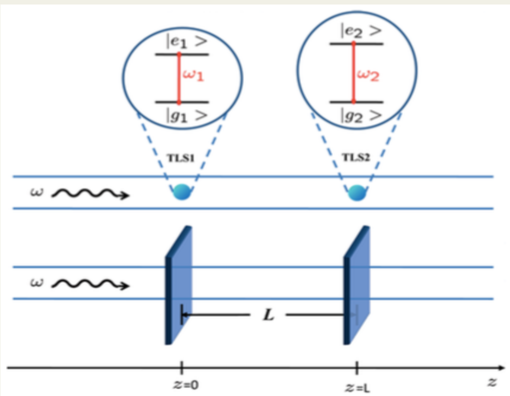
linewidth Δ

Interferometers with quantum beamsplitters?

PRL **113**, 243601 (2014) PHYSICAL REVIEW LETTERS

Fabry-Perot Interferometer with Quantum Mirrors: Nonlinear Light Transport and Rectification

F. Fratini,[1,2,3,4,*] E. Mascarenhas,[1] L. Safari,[4,5] J-Ph. Poizat,[2,3] D. Valente,[6] A. Auffèves,[2,3] D. Gerace,[7] and M. F. Santos[1]



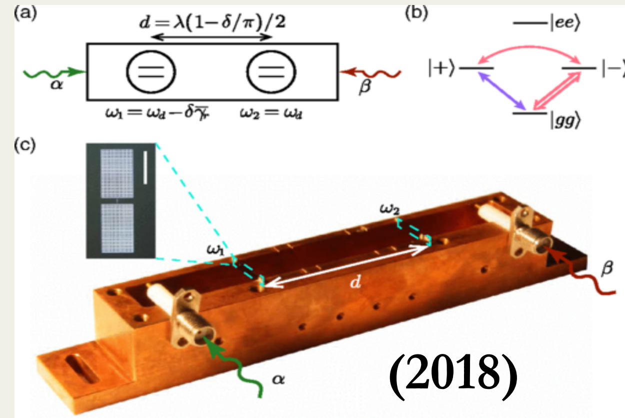
(2014)

Theory

PHYSICAL REVIEW LETTERS **121**, 123601 (2018)

Nonreciprocity Realized with Quantum Nonlinearity

Andrés Rosario Hamann,[1,*] Clemens Müller,[1,2] Markus Jerger,[1] Maximilian Zanner,[3] Joshua Combes,[1] Mikhail Pletyukhov,[4] Martin Weides,[3,5] Thomas M. Stace,[1] and Arkady Fedorov[1,†]



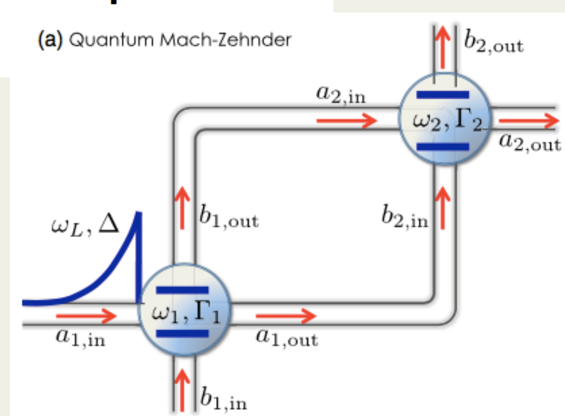
(2018)

Experiment

Journal of the Optical Society of America B
OPTICAL PHYSICS

Mach–Zehnder interferometer with quantum beamsplitters

N. Almeida, T. Werlang, and D. Valente*



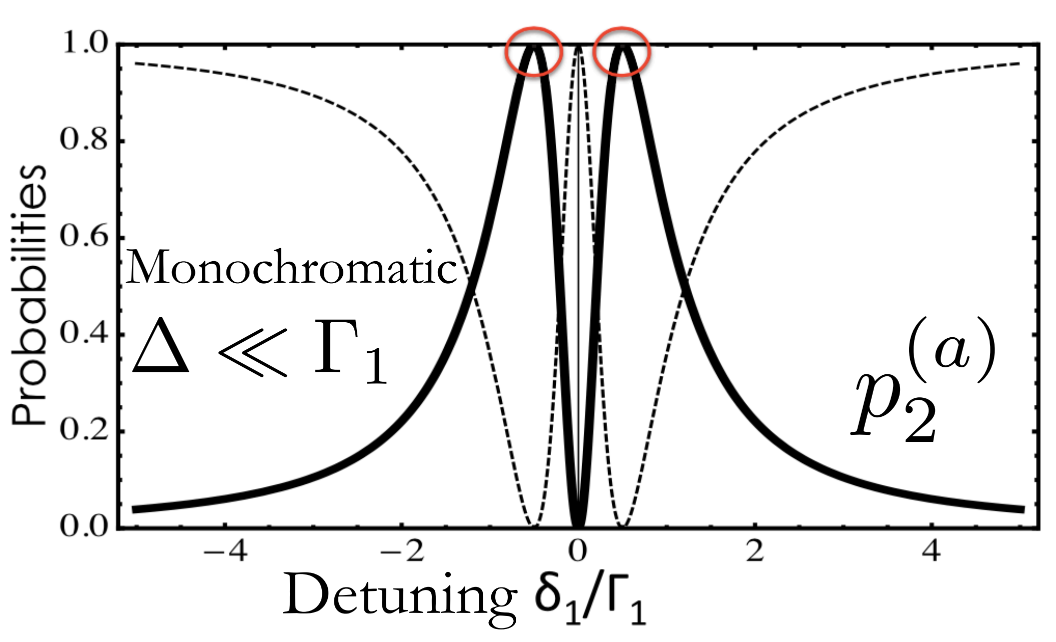
(2019)

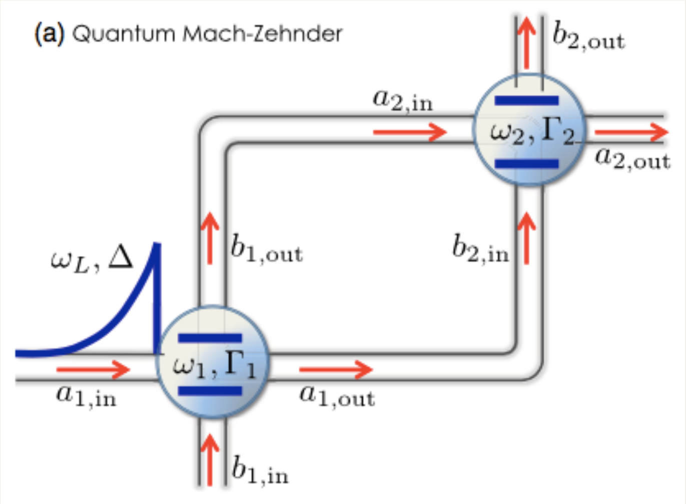
Theory

Results: **ideal** Quantum Mach-Zehnder

$$p_2^{(a)} = 1 \text{ and } p_2^{(b)} = 0,$$

$$p_1^{(a)} = p_1^{(b)} = 1/2,$$



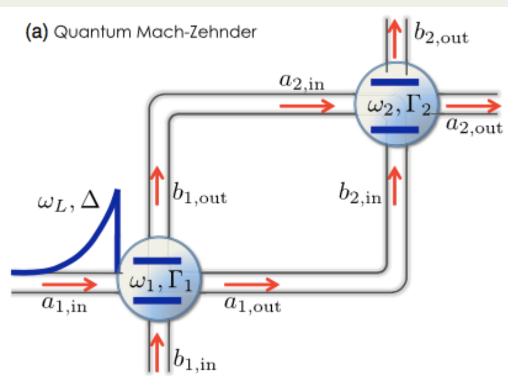


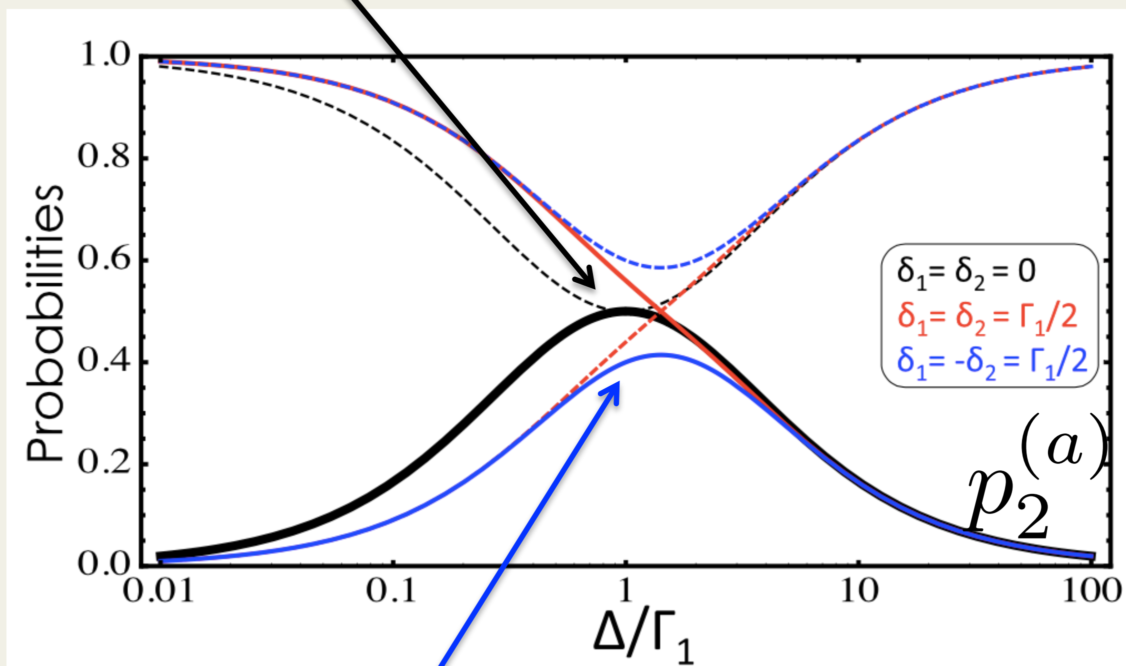
$$\delta_1/\Gamma_1 = \delta_2/\Gamma_1 = 1/2$$

Results: **non-ideal** Quantum Mach-Zehnder

Identical resonant quantum beamsplitters are **unable to preserve** broadband photon interference

$$p_2^{(a)} = p_2^{(b)} = 1/2$$





Oppositely detuned quantum beamsplitters always **preserve** some degree of interference

$$p_2^{(a)} < p_2^{(b)}$$

Summary

✓ **Quantum Mechanics with single particles**: experimental reality;

✓ **Waveguide QED**: interferometers with quantum beamsplitters;

○ **Perspectives**: quantum technologies (see reviews below).

NATURE|Vol 453|19 June 2008|**doi:10.1038/nature07127**

The quantum internet

H. J. Kimble[1]

REVIEWS OF MODERN PHYSICS, VOLUME 87, APRIL–JUNE 2015

Interfacing single photons and single quantum dots with photonic nanostructures

Peter Lodahl,* Sahand Mahmoodian, and Søren Stobbe

Thank you for your time!

valente.daniel@gmail.com