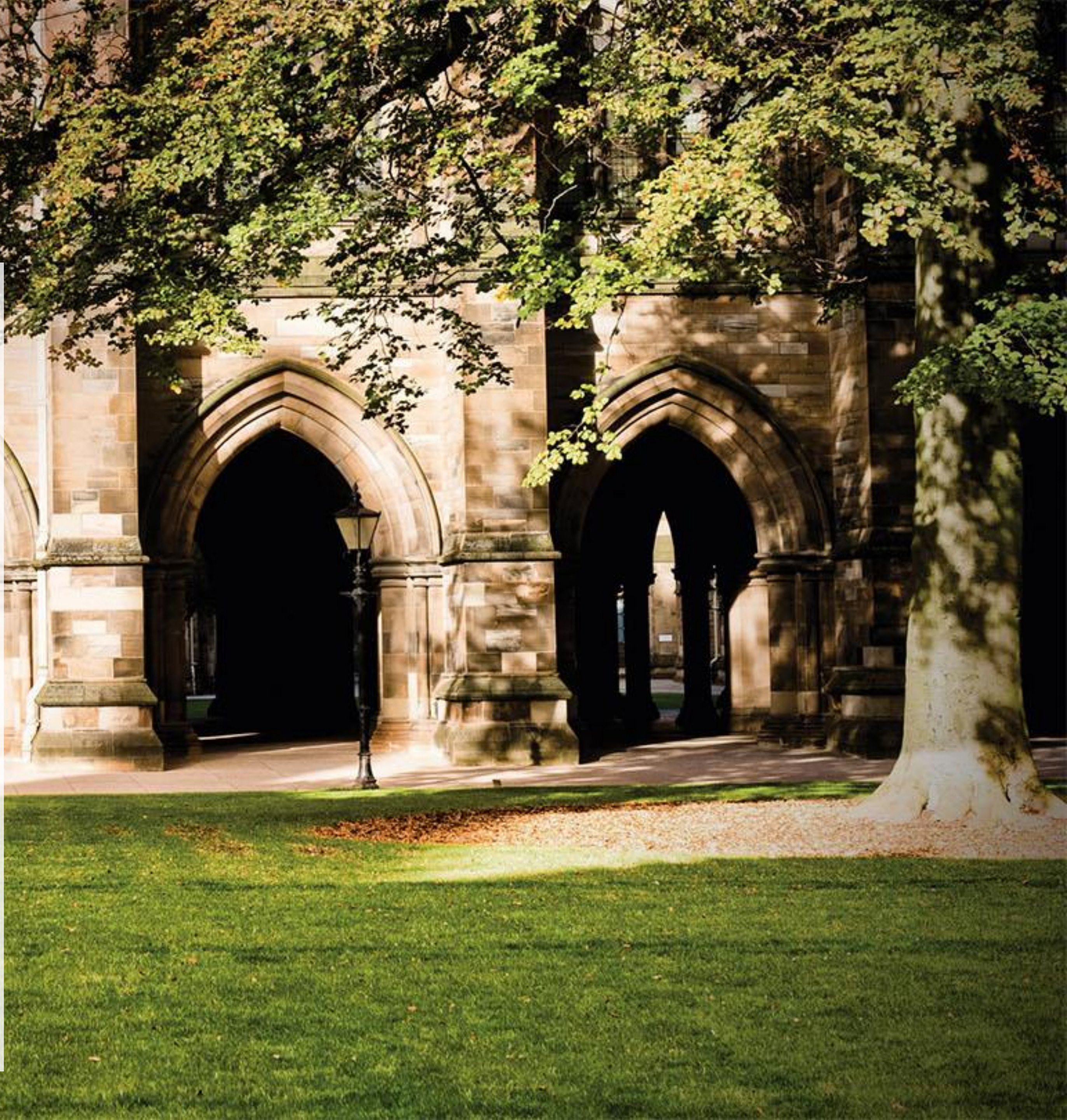
Photon bunching in a rotating reference frame

<u>Sara Restuccia</u>, Marko Toroš, Graham Gibson, Hendrik Ulbricht,
Daniele Faccio, Miles Padgett

INSPIRING PEOPLE

My presentation

- Goals of the experiment and Background information
- Experimental Set-up
- Experiment results and conclusions



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Goal of the Experiment

- **What did we do?**

Constructed a “Quantum Gyroscope”

i.e. HOM interferometer on a rotating platform

- **Why?**

• Interplay quantum mechanics and general relativity

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Physics SYNOPSIS

Playing a Quantum “Oldie” on a Turntable

Published 10 September 2019

A well-known quantum experiment is performed on a rotating lab table—offering a probe of quantum physics in a noninertial reference frame.

See more in *Physics*

PHYSICAL REVIEW LETTERS

Featured in Physics Editors' Suggestion

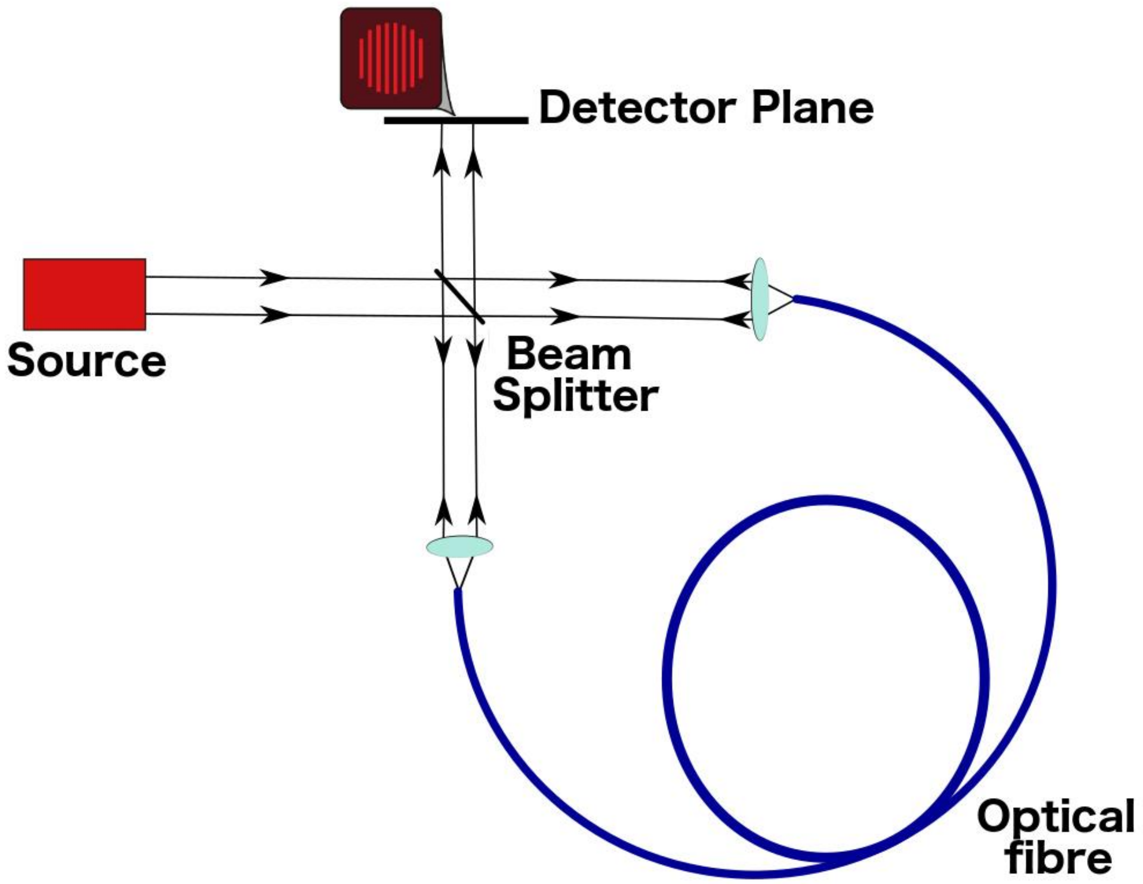
Photon Bunching in a Rotating Reference Frame

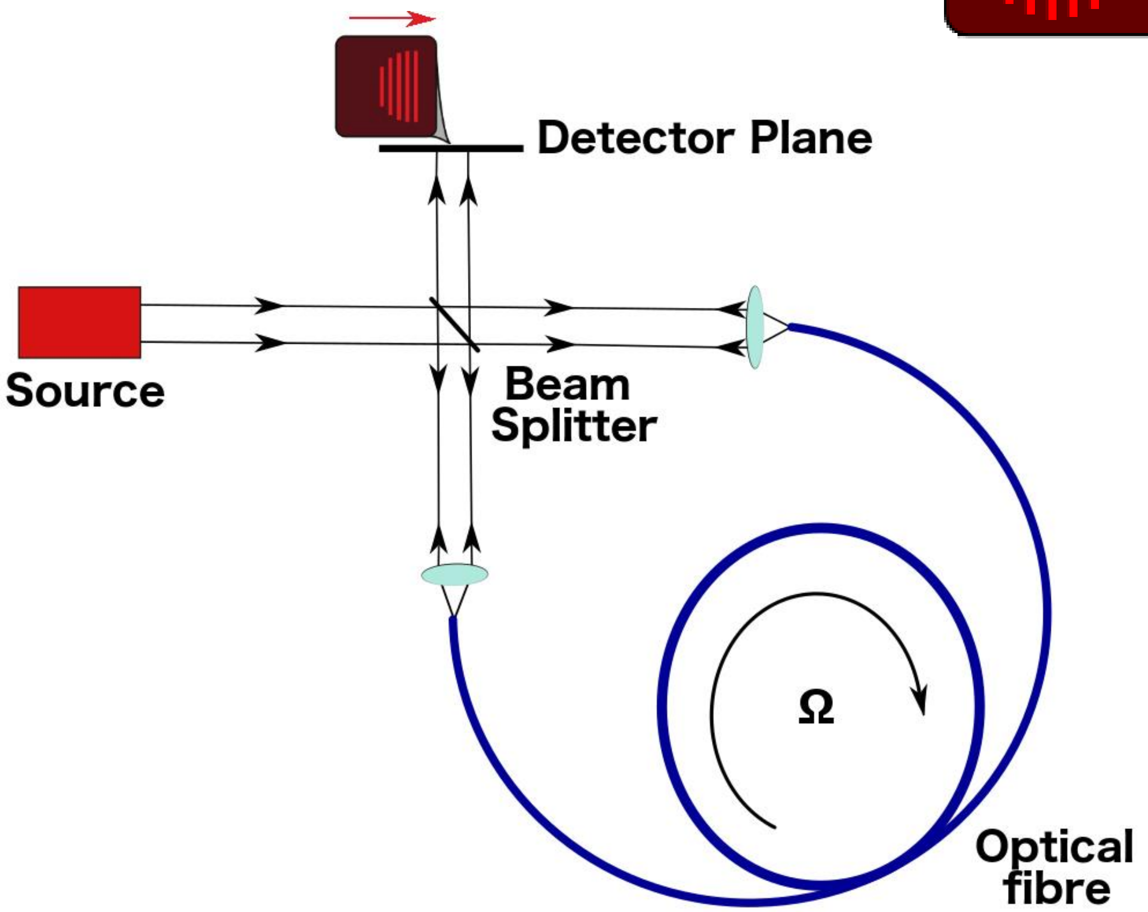
Sara Restuccia, Marko Toroš, Graham M. Gibson, Hendrik Ulbricht, Daniele Faccio, and Miles J. Padgett

Phys. Rev. Lett. **123**, 110401 – Published 10 September 2019

Physics See Synopsis: Playing a Quantum “Oldie” on a Turntable

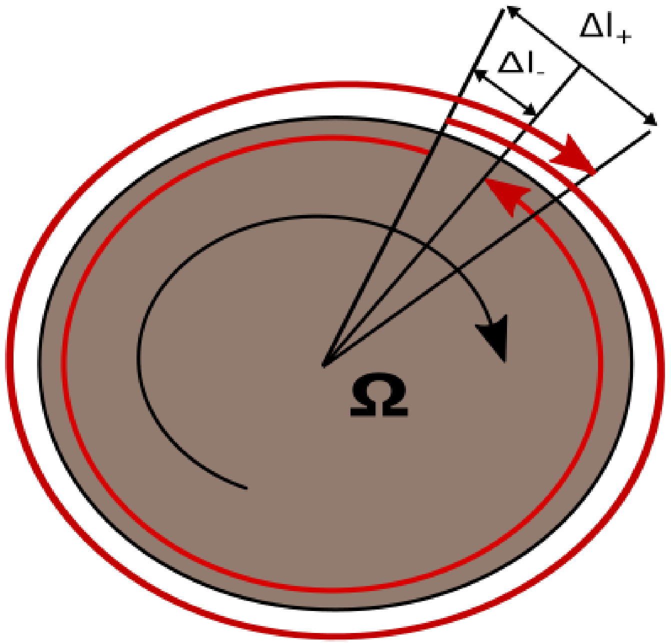
Sagnac Effect in a Fibre Gyroscope





B Culshaw and I P Giles. Fibre optic gyroscopes. Journal of Physics E: Scientific Instruments, 16(1):5–15, jan 1983.

Sagnac Effect in a Fibre Gyroscope



$$\Delta l = \Delta l_{+} + \Delta l_{-} = 2\Delta l = \frac{2\Omega RL}{c}$$

$$\Delta\varphi = \frac{4\pi\Omega RL}{\lambda c}$$

Ω=*angular velocity (rad/s)*

R=*radius of table*

L=length of fibre

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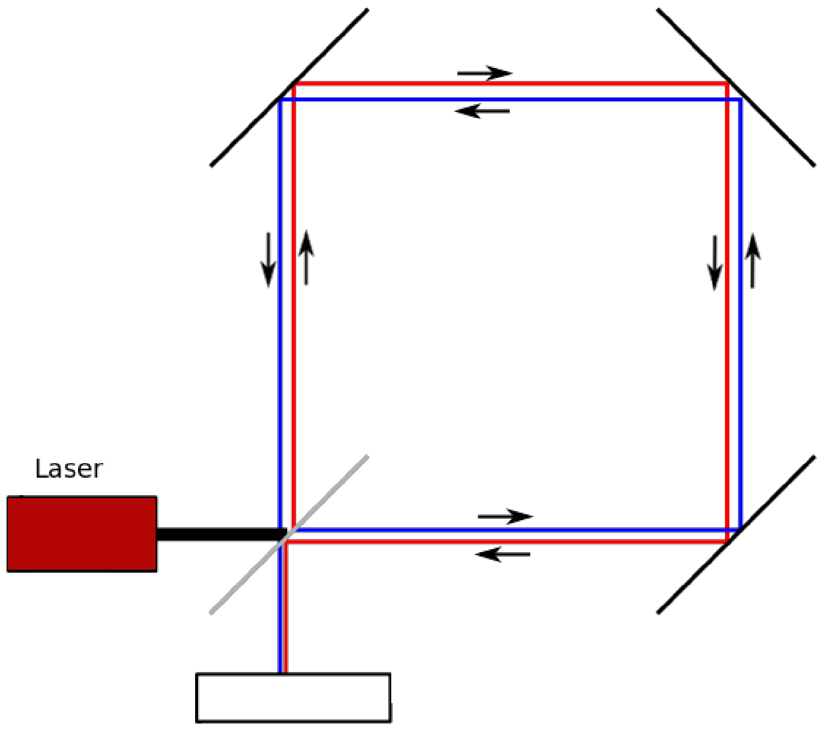
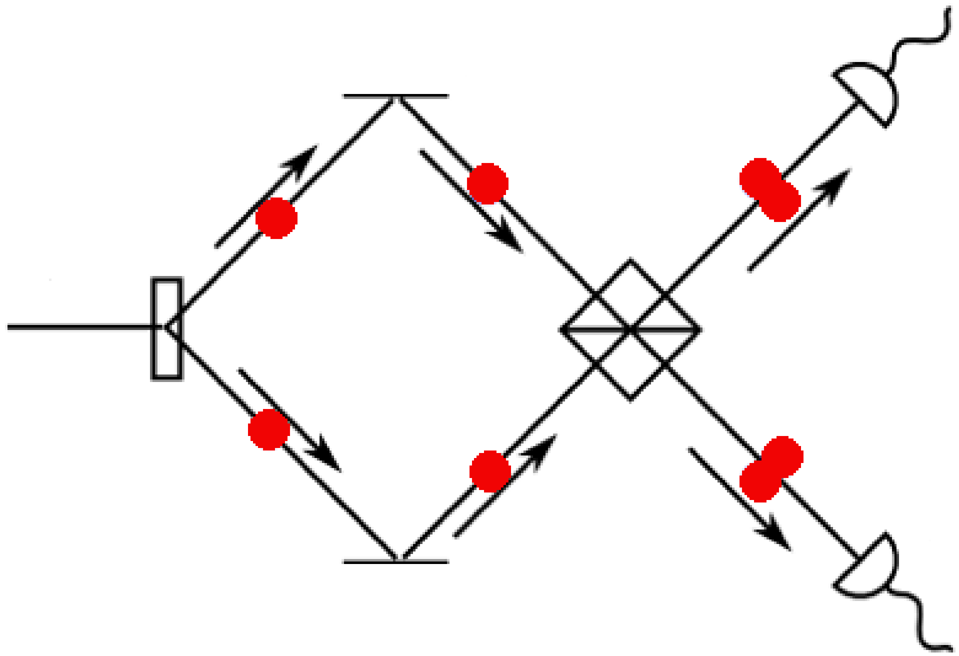
Quantum Equivalent to Sagnac interferometer?

Sagnac



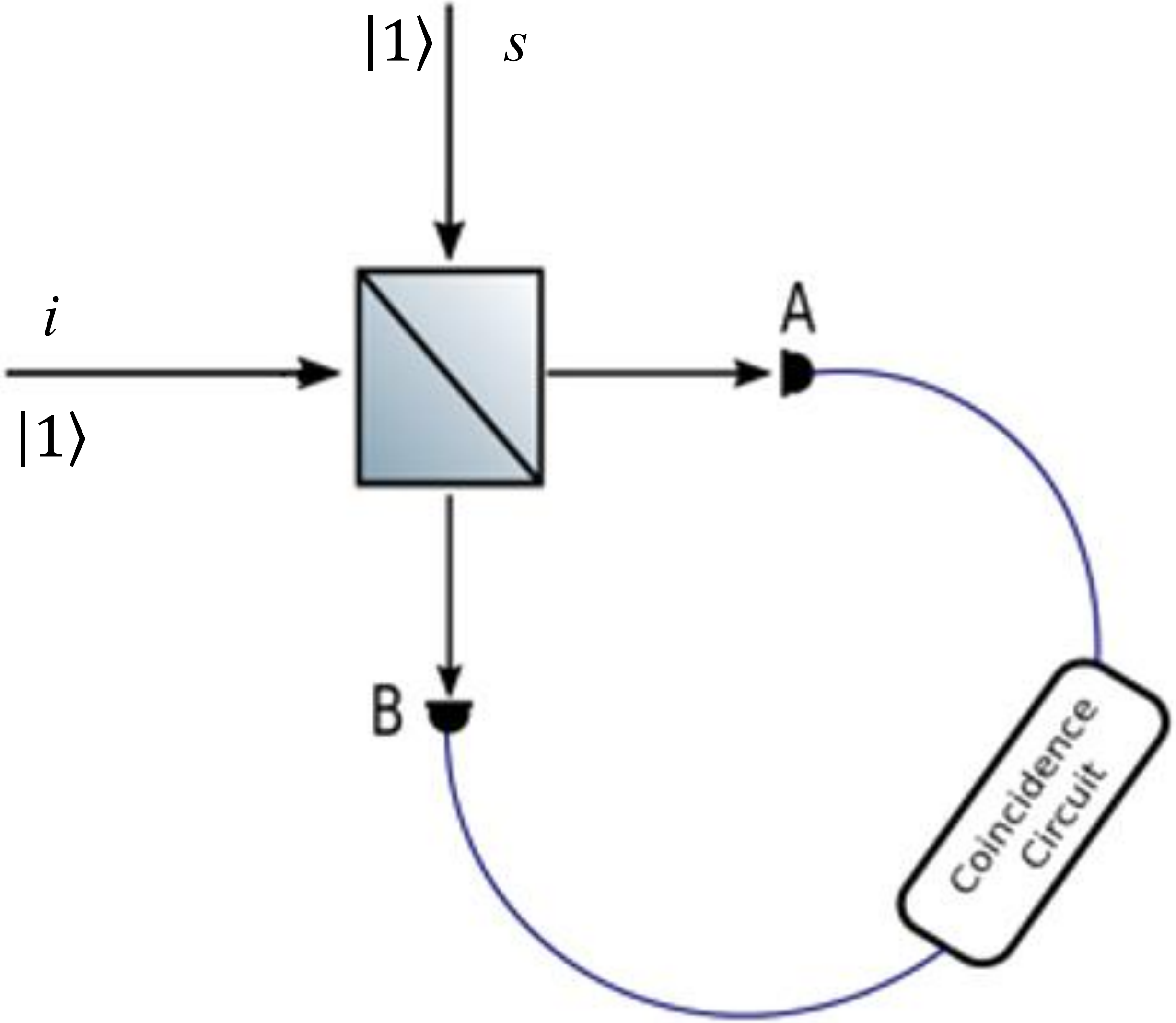
HOM



Hong-Ou-Mandel interferometer:

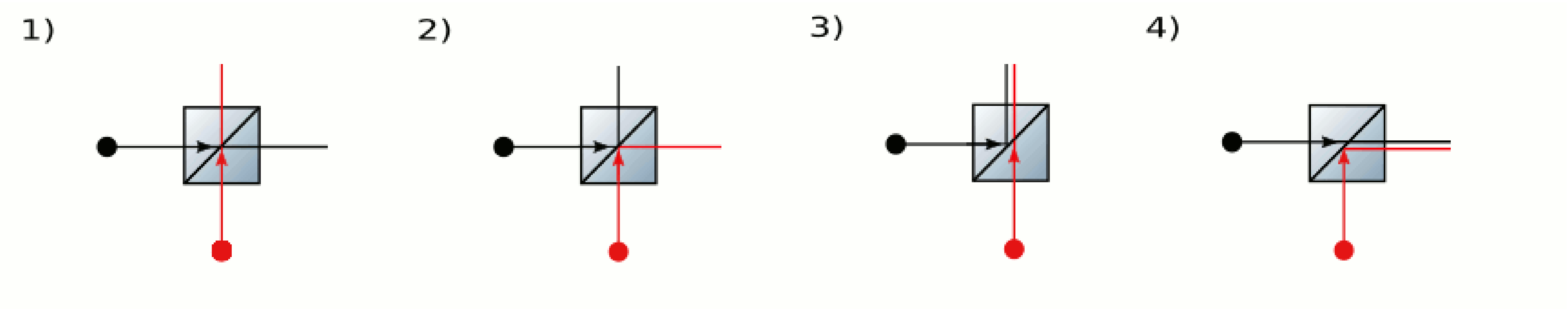
Nonclassical two-photon interference:

Hong-Ou-Mandel



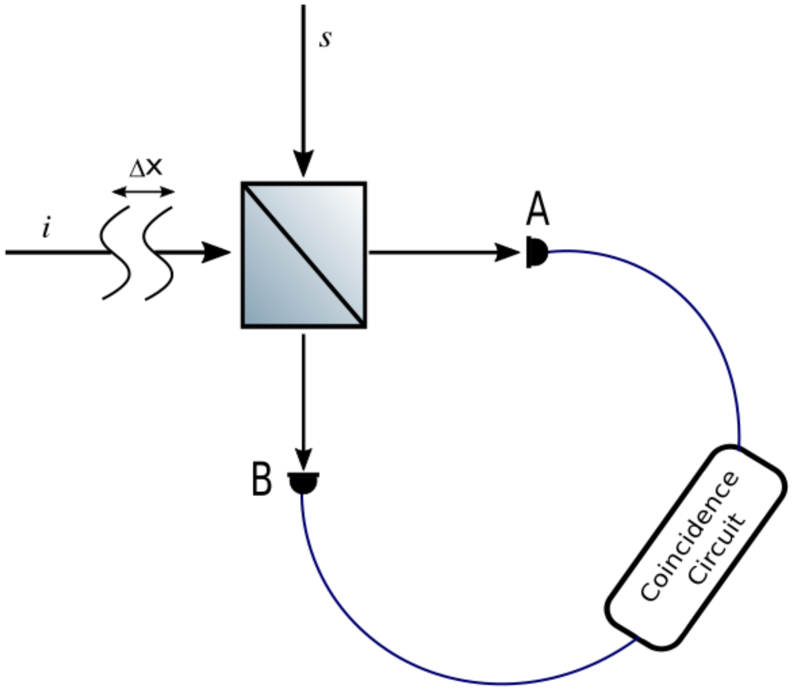
C. Hong, Z. Ou & L. Mandel, Phys. Rev. Lett. **59**, 2044 (1987)

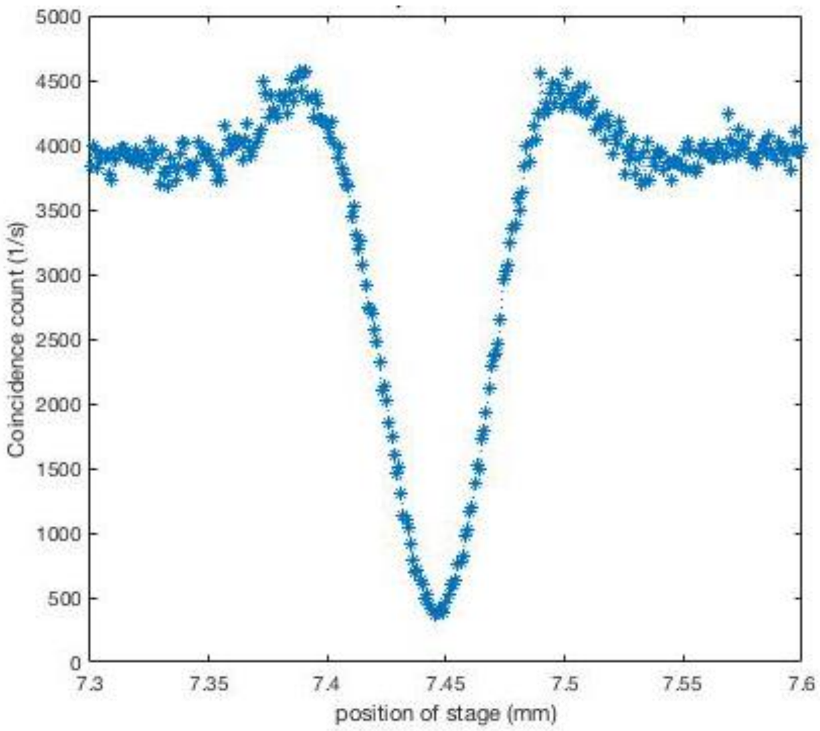
Hong-Ou-Mandel interferometer:



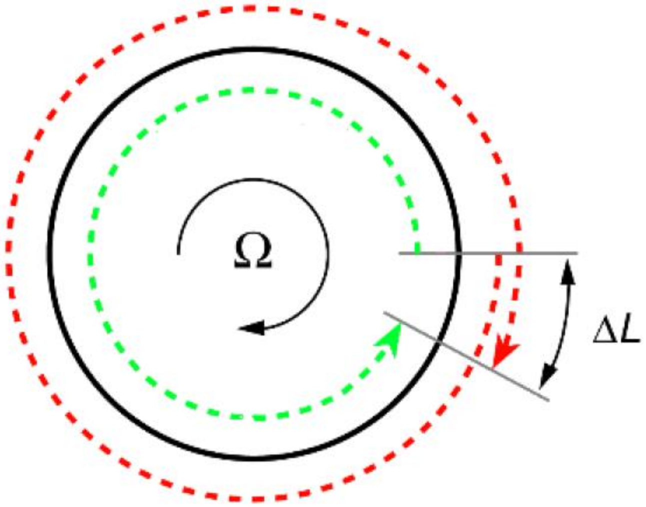
$|1,1\rangle$ $|1,1\rangle$ $|2,0\rangle$ $|0,2\rangle$

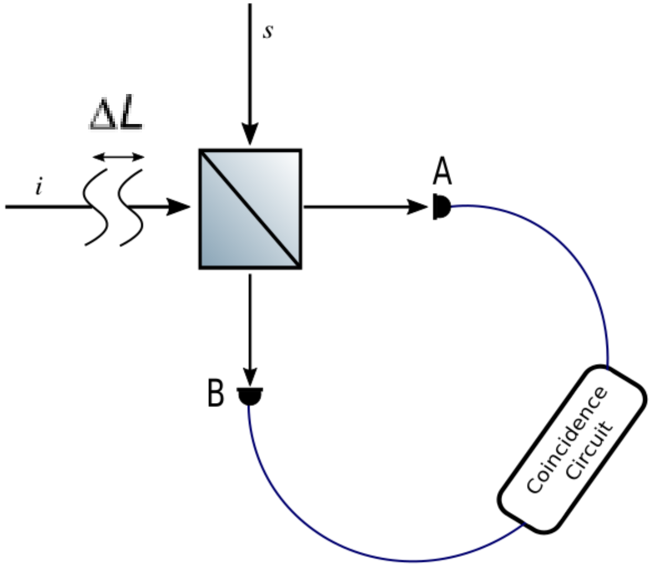
Hong-Ou-Mandel interferometer:

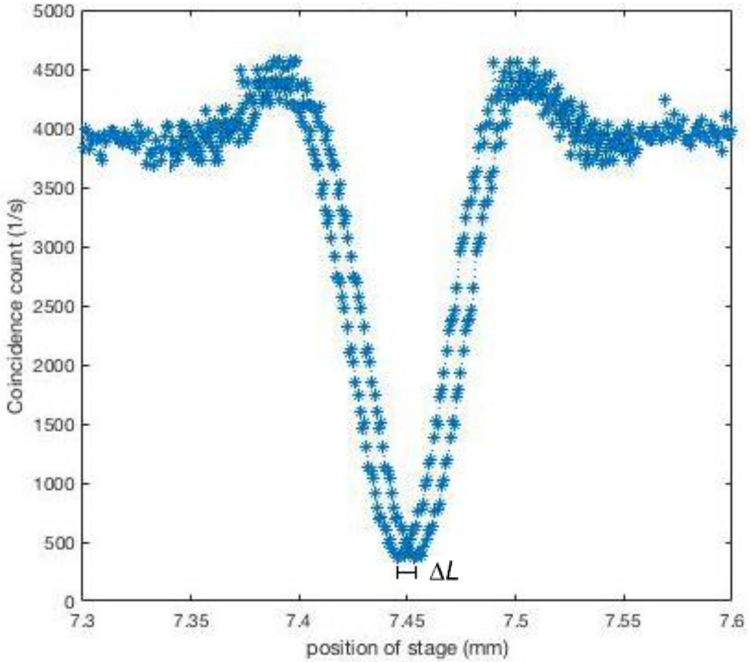




Can we measure the Sagnac effect?

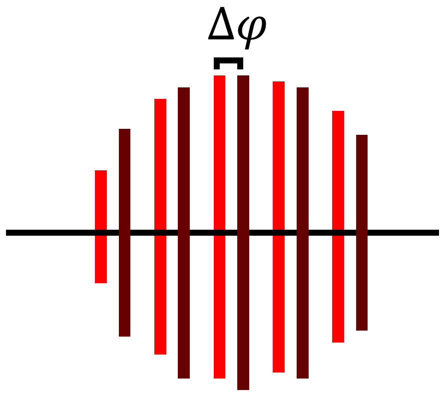






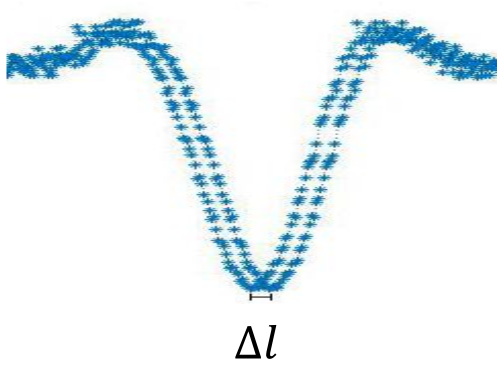
Phase vs Group Velocity?

Sagnac



- has a wavelength (λ) dependency
- Independent of photon drag

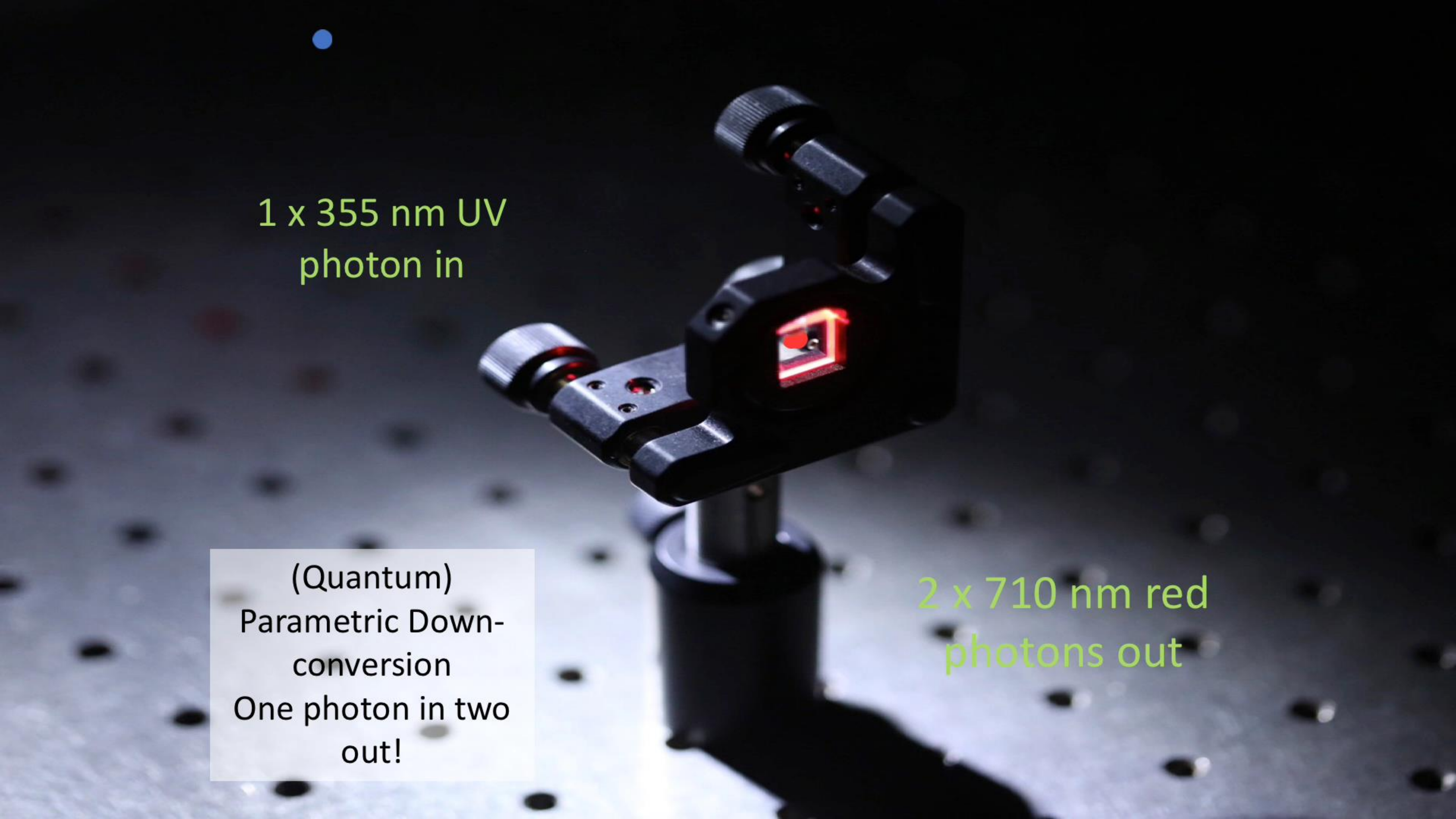
HOM



$$\Delta l \overset{?}{\leftrightarrow} \frac{\lambda}{2\pi}\Delta\varphi$$

- Is Δl effected by photon drag when n>1?

Minkowski vs Abraham


1 x 355 nm UV
photon in
(Quantum)
Parametric Down-
conversion
One photon in two
out!
2 x 710 nm red
photons out

Experimental set-up:

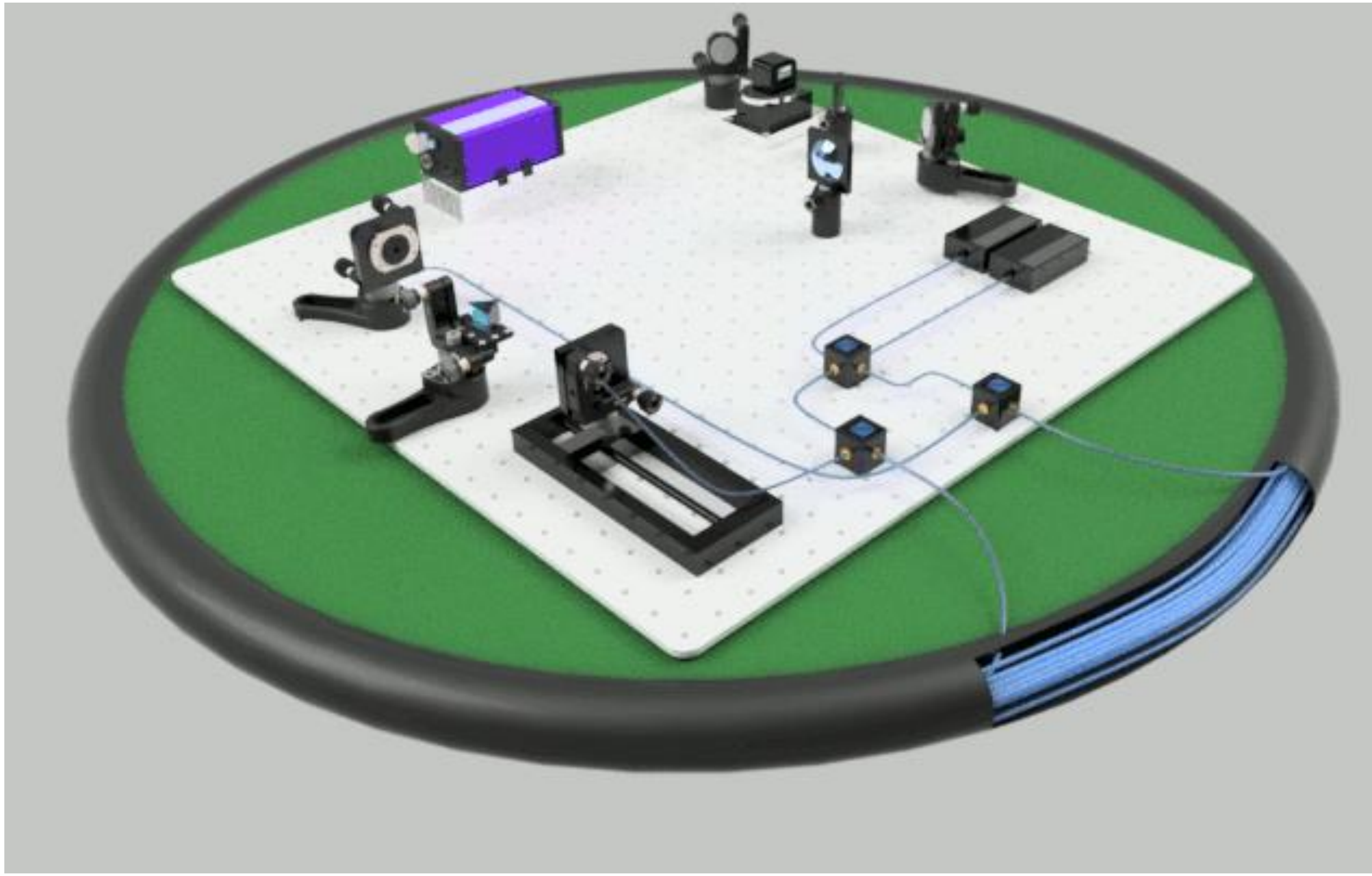
2 down converted photons through SPDC

Coupled into single mode polarization maintaining fibres

Photons travel through a 100m fibre in opposite directions

The photons exit the fibre and interfere at the beam splitter

SPADs are used to count the photons and coincidence counts are measured



Results:

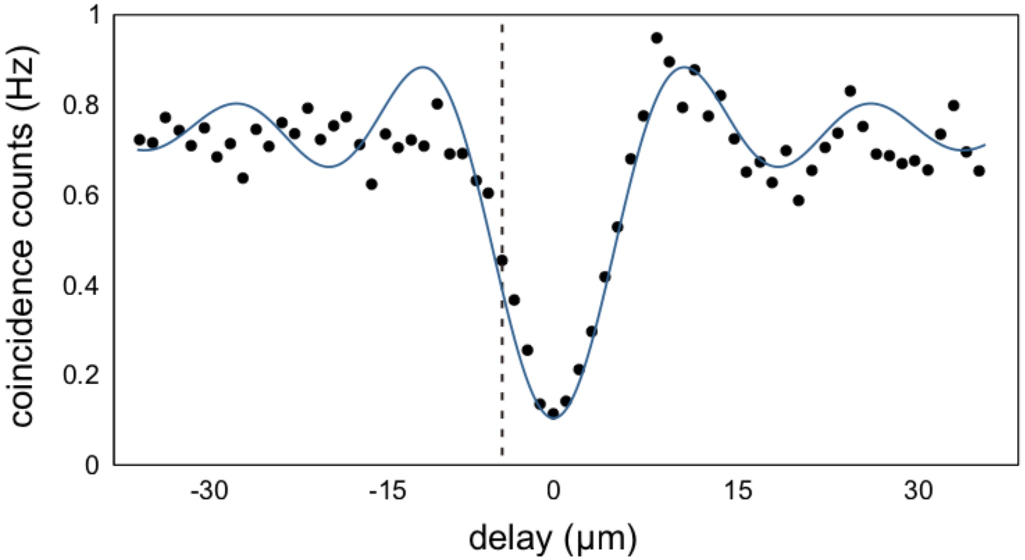
Set-up parameters:

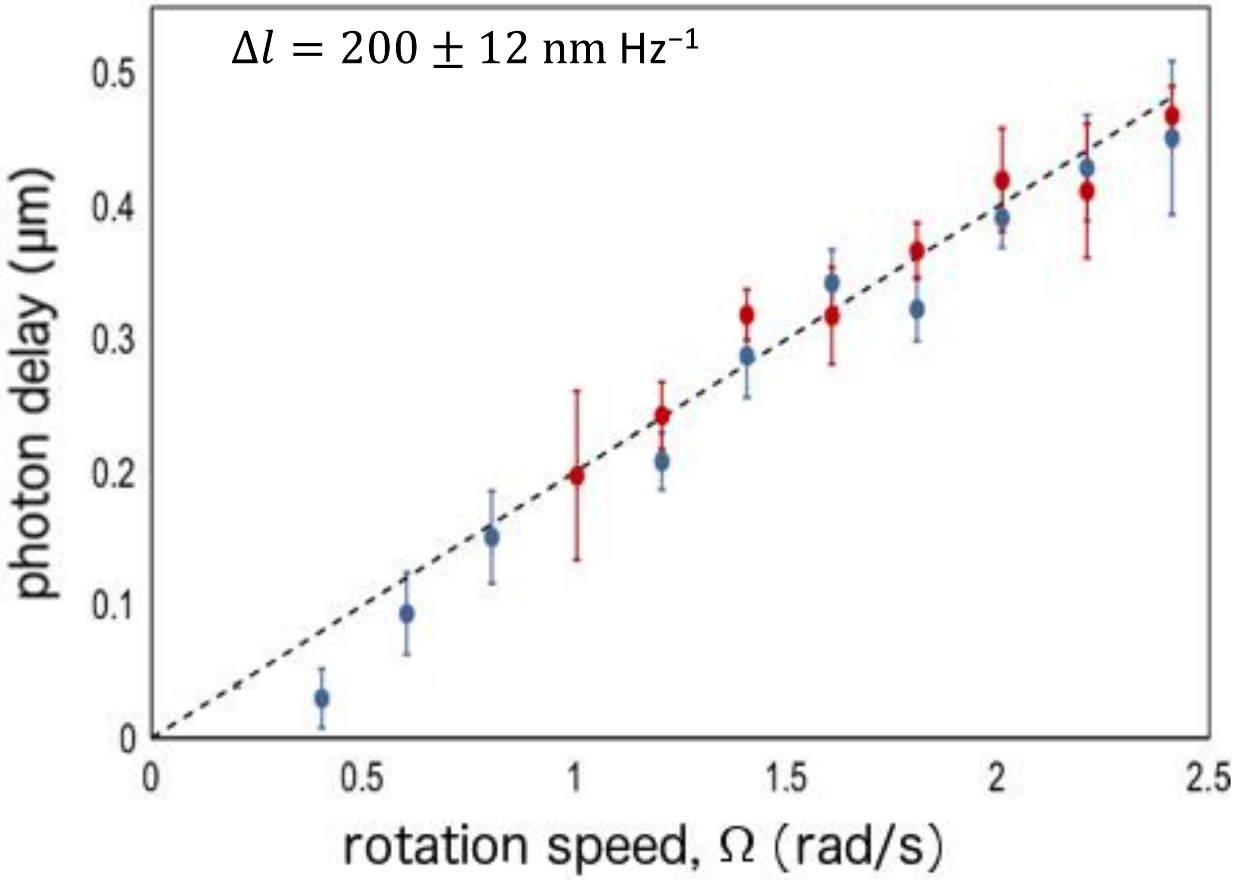
L=100m, R=0.454m, Ω_{max} =2.4 rad/s

Measured delay:

Δl_{max}=0.45μm

Measured HOM, for 40nm bandwidth photons





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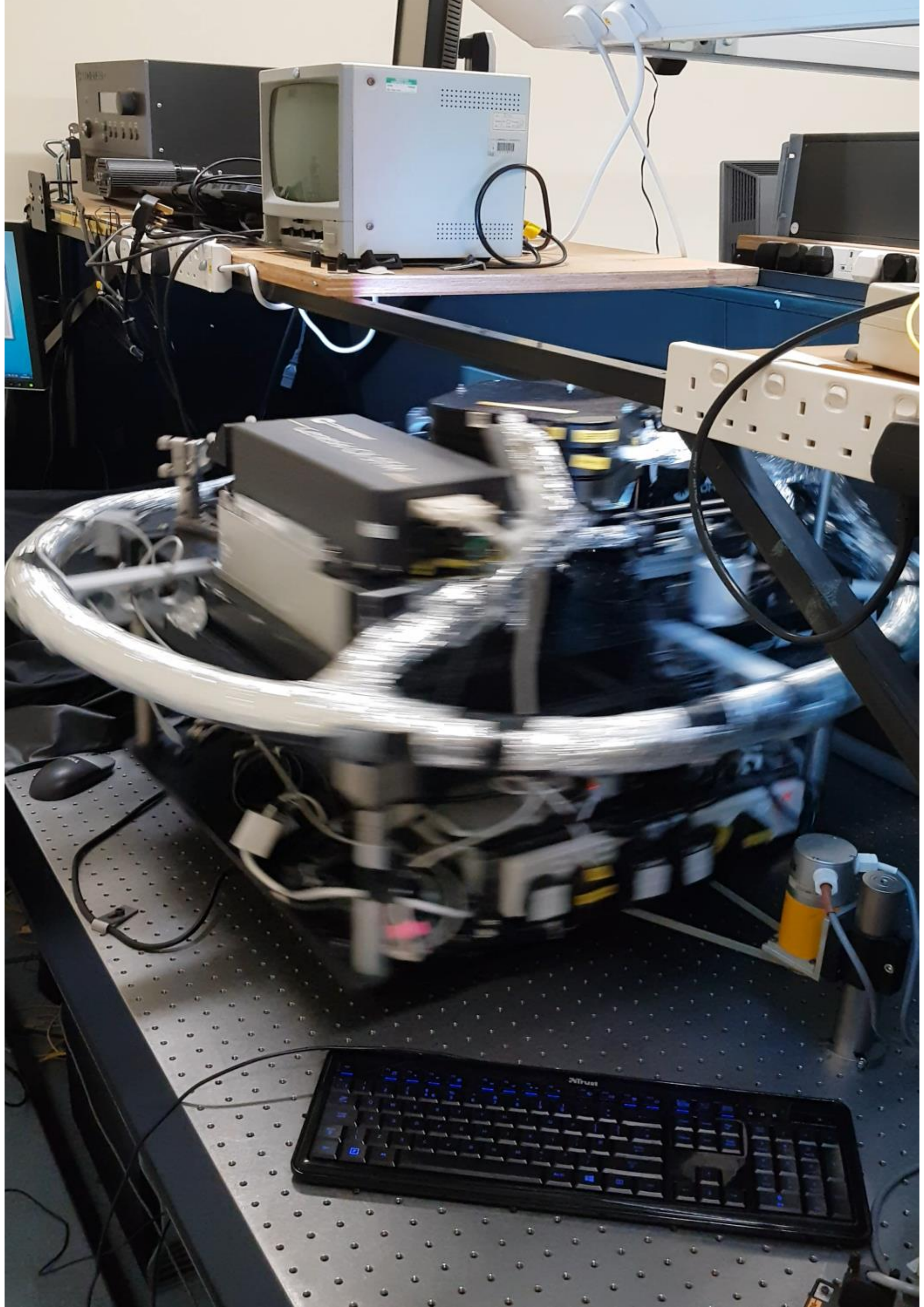
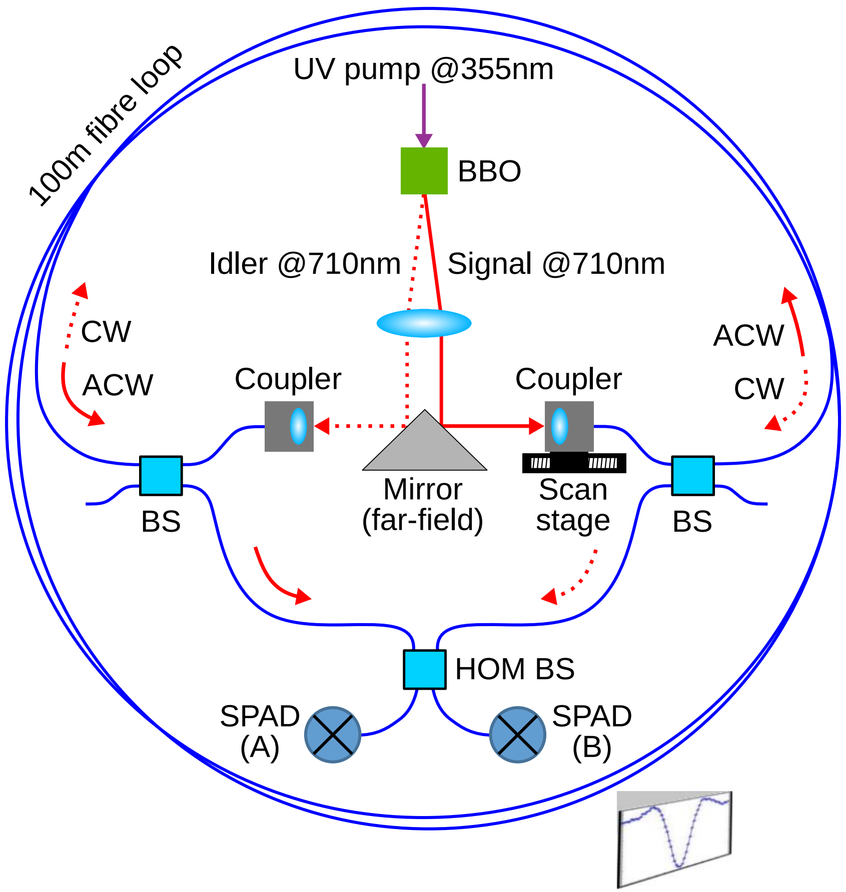
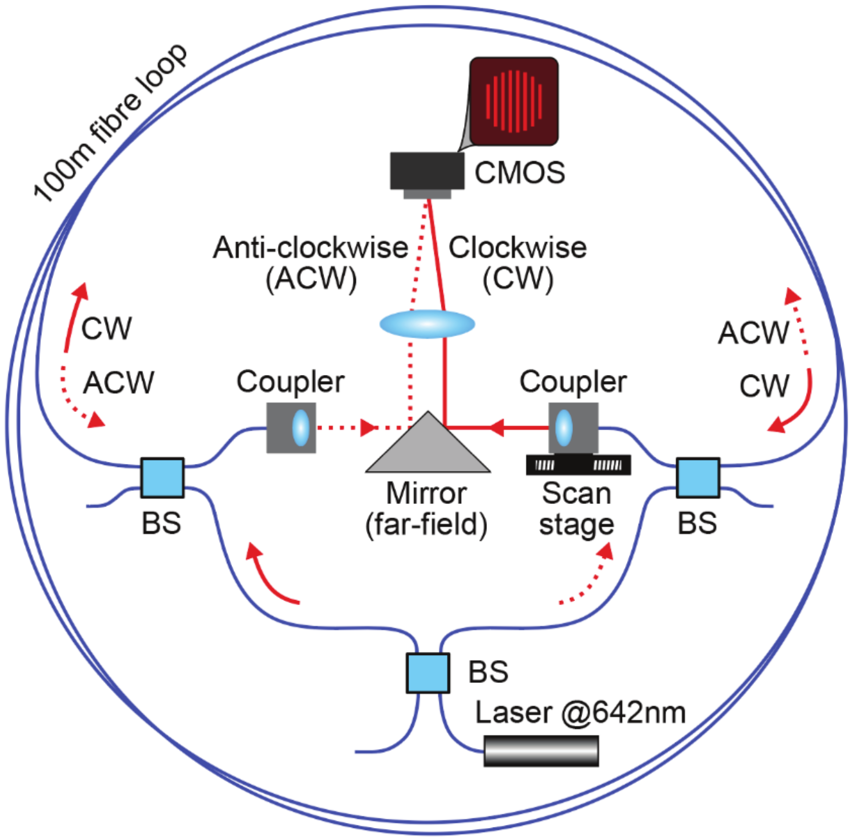


Comparison of Classical to nonclassical systems





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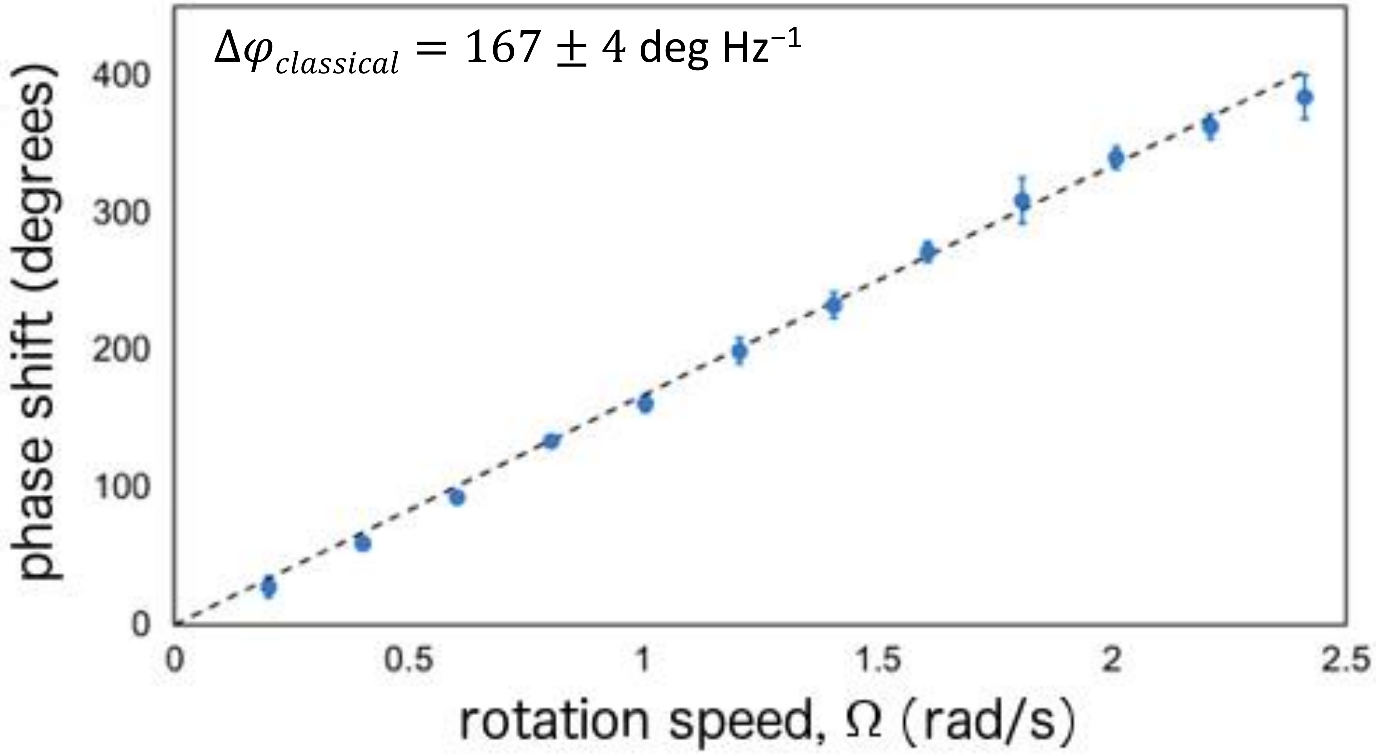
Classical results and comparison:



Where the theoretical estimate is:

$$\Delta\varphi = 170 \text{ deg Hz}^{-1}$$

Comparing the classical and quantum results:

$$\frac{\Delta l_{quantum}}{\Delta\varphi_{classical}} = 1.2 \pm 0.07 \text{ nm deg}^{-1}$$

Where:

$$\frac{\Delta l}{\Delta\varphi} = \frac{\lambda}{2\pi} = 1.8\text{nm deg}^{-1}$$

These results differ by a factor:

1.478 ± 0.09

Where the n of our fiber is:

$n \sim 1.45$

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Conclusions

- In our experiment we where able to measure a shift in position of the HOM dip as a function of the rotation speed of the table.

- We have also shown that this relative delay in the photons arrival is equivalent to the classical Sagnac effect with the sole difference being that while in the classical set-up the rotation motion induces a change in the interference of the two beams, in the quantum set-up the change is in the quantum interference of the two photons.

- This experiment therefore implies that the quantum interference of two photons is affected by non-inertial motion, which opens new pathways to probe the relation between gravity and quantum mechanics.

University of Glasgow

Thank you!

University of Southampton:

Marko Toroš, Hendrik Ulbricht

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Experimental set-up: