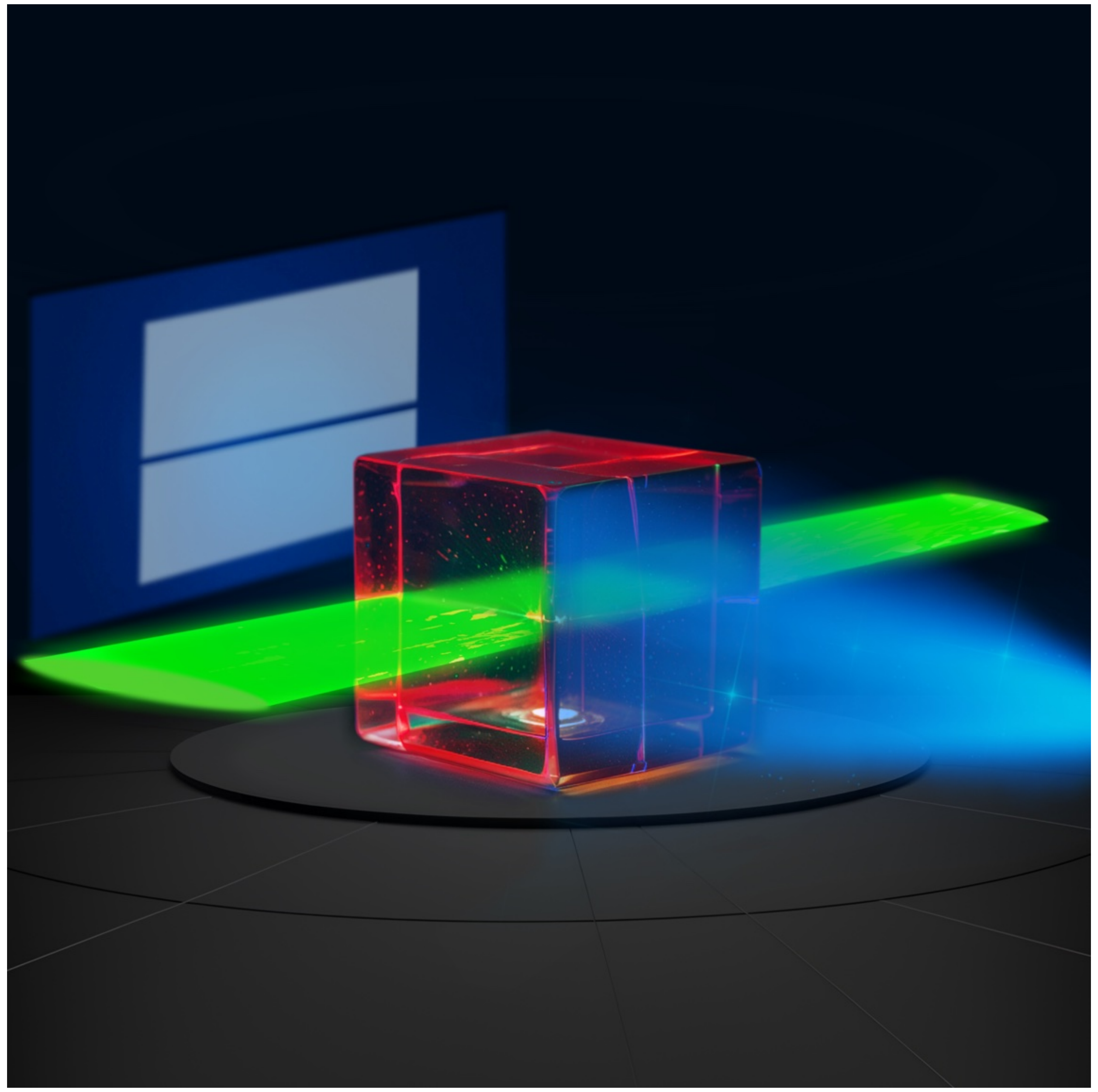


Laser Shadows

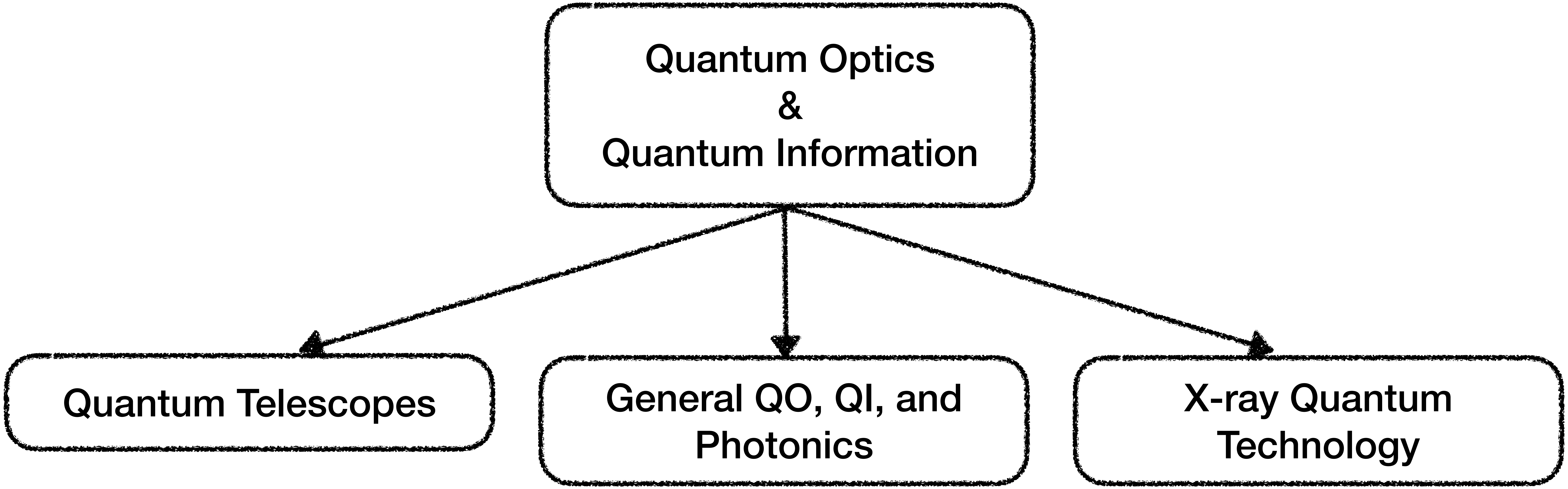
Quantum Telescopes

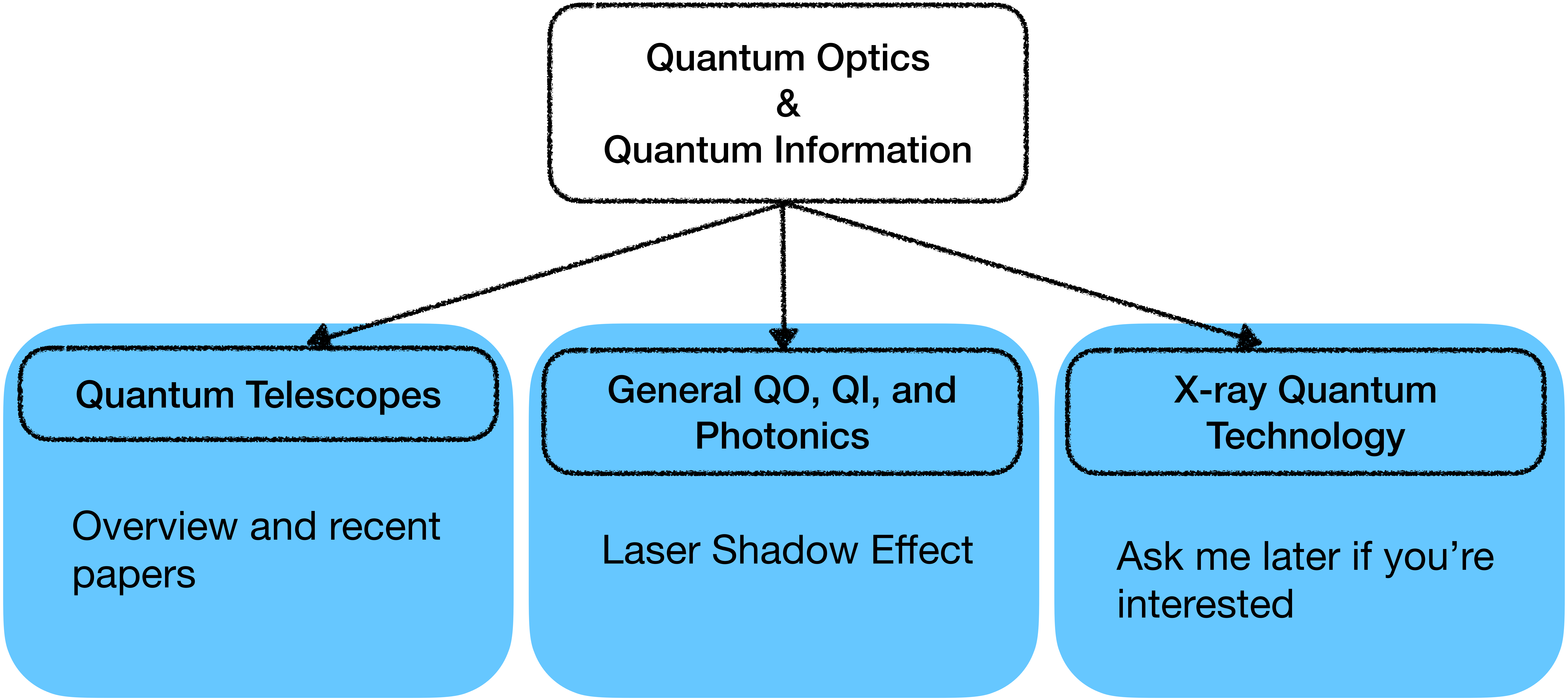
Dr. Raphael Akel Abrahao

July 29 2025

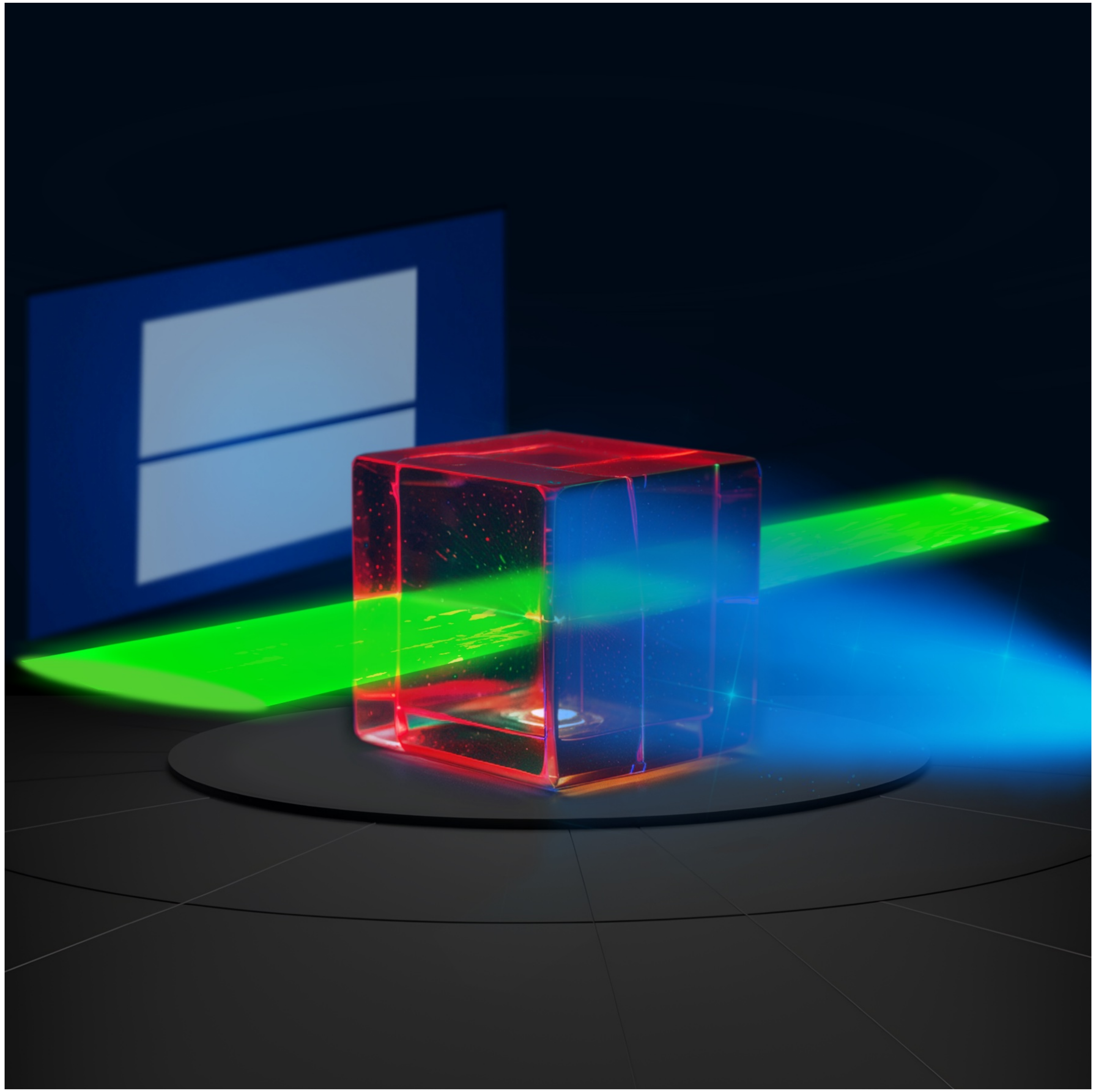
Brookhaven
National Laboratory

Quantum Optics
&
Quantum Information


Quantum Optics
&
Quantum Information
Quantum Telescopes
General QO, QI, and
Photonics
X-ray Quantum
Technology


Quantum Optics
&
Quantum Information
Quantum Telescopes
Overview and recent papers
General QO, QI, and Photonics
Laser Shadow Effect
X-ray Quantum Technology
Ask me later if you’re interested

Have you ever seen the shadow of a laser beam?

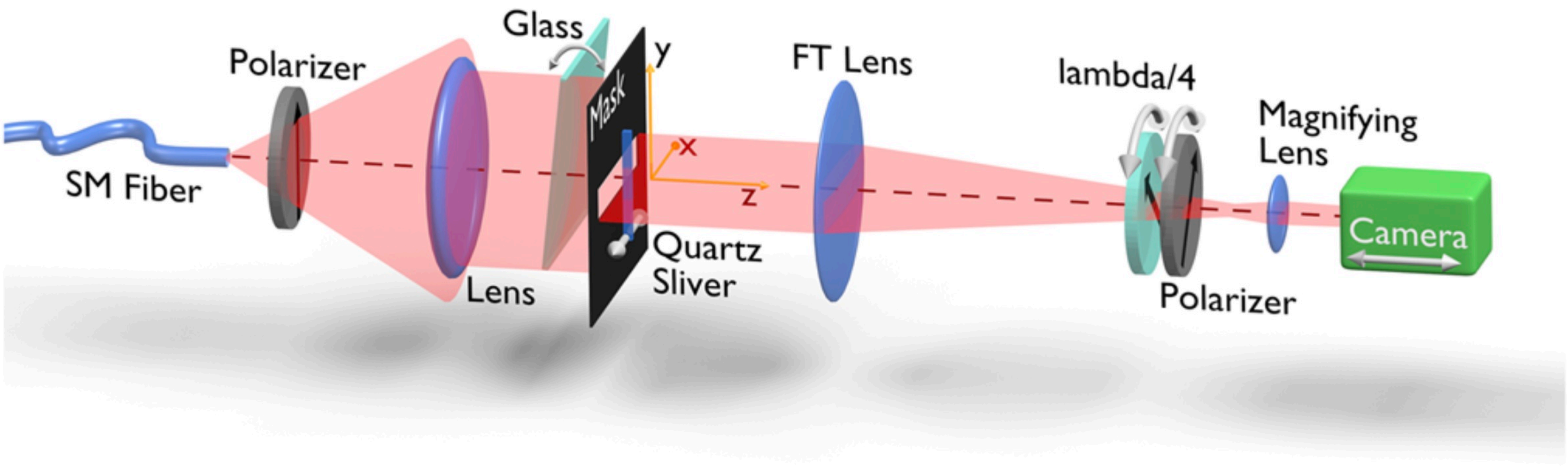


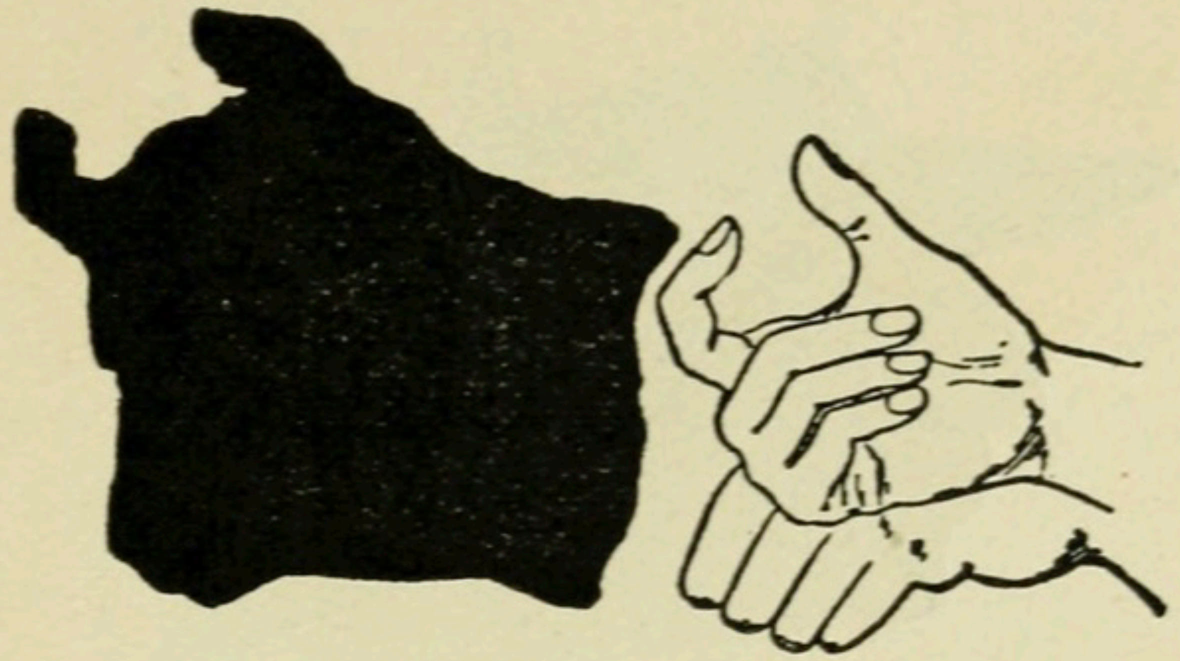
Inspiration

PRL **112,** 070405 (2014) PHYSICAL REVIEW LETTERS week ending 21 FEBRUARY 2014

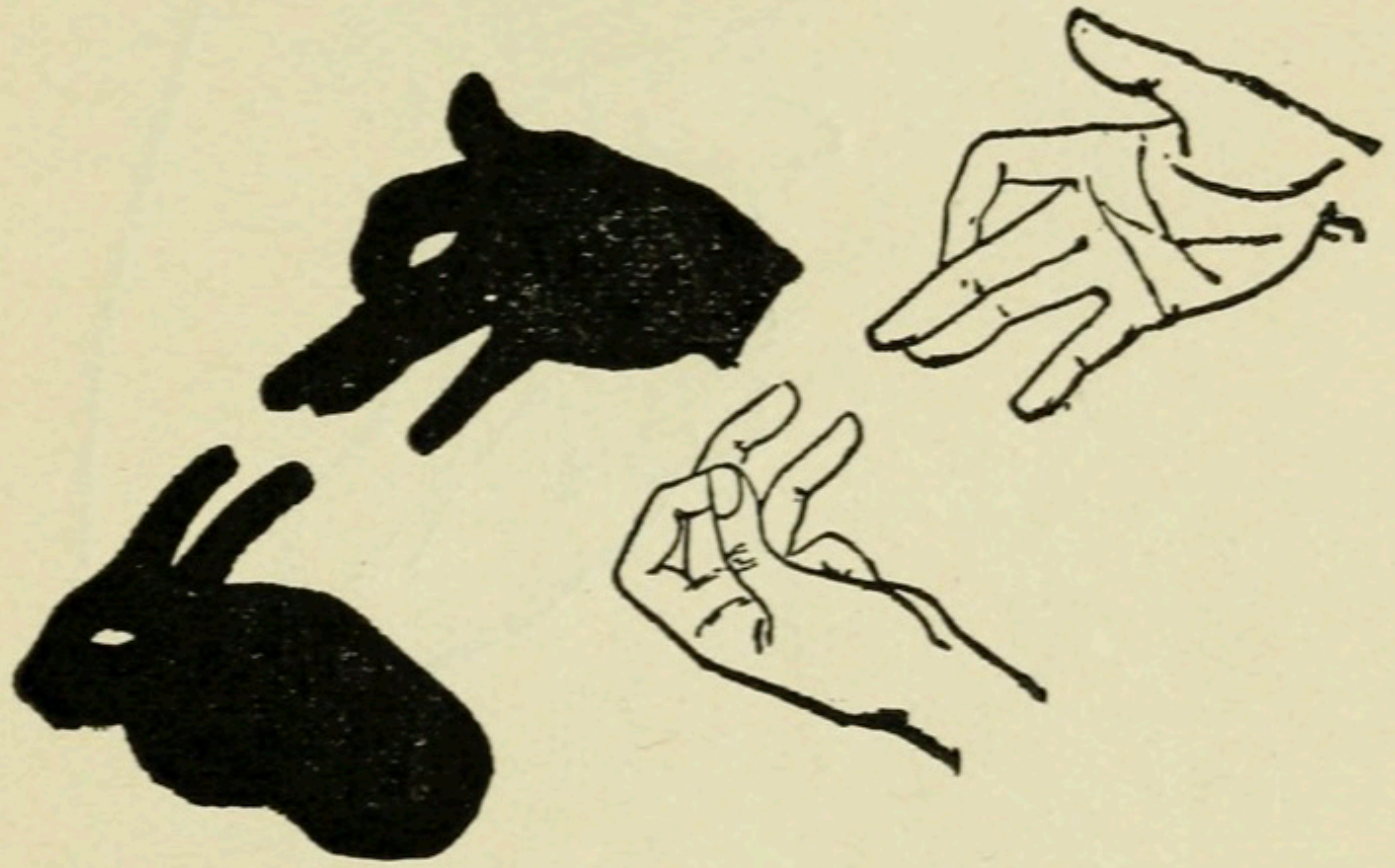
Observing Dirac's Classical Phase Space Analog to the Quantum State

Charles Bamber[1,*] and Jeff S. Lundeen[2,†]

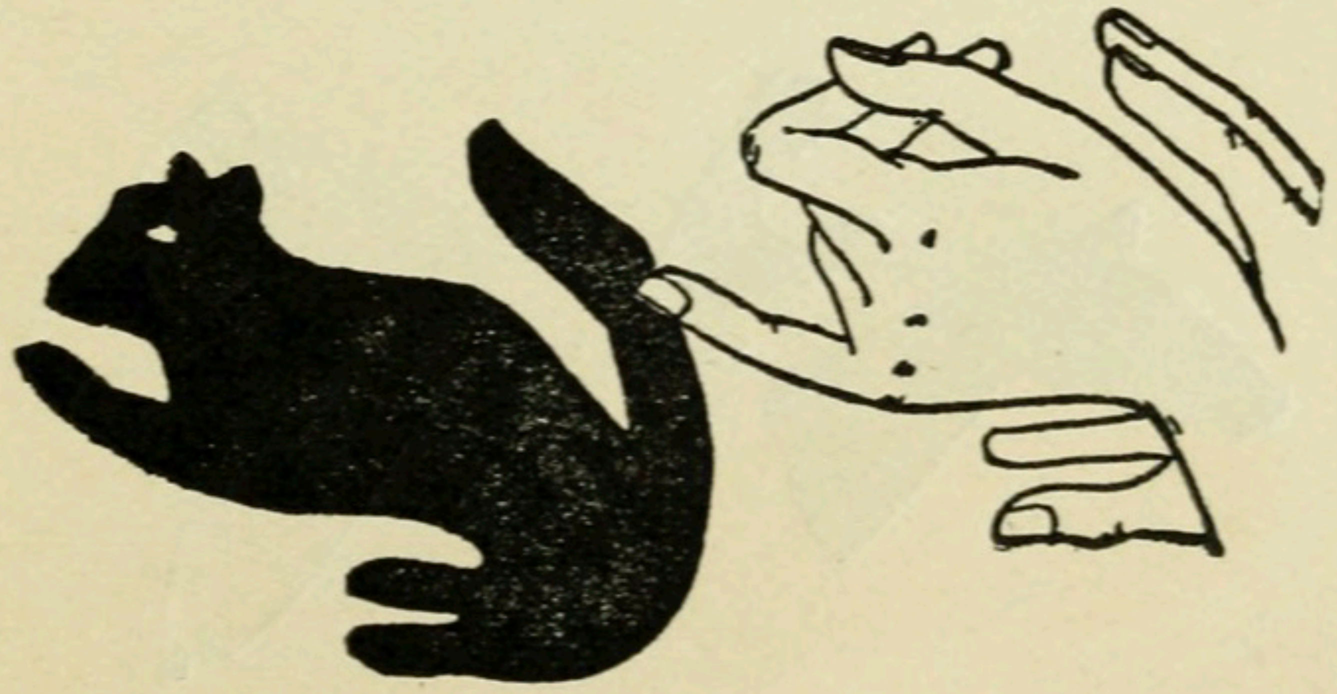




BULL

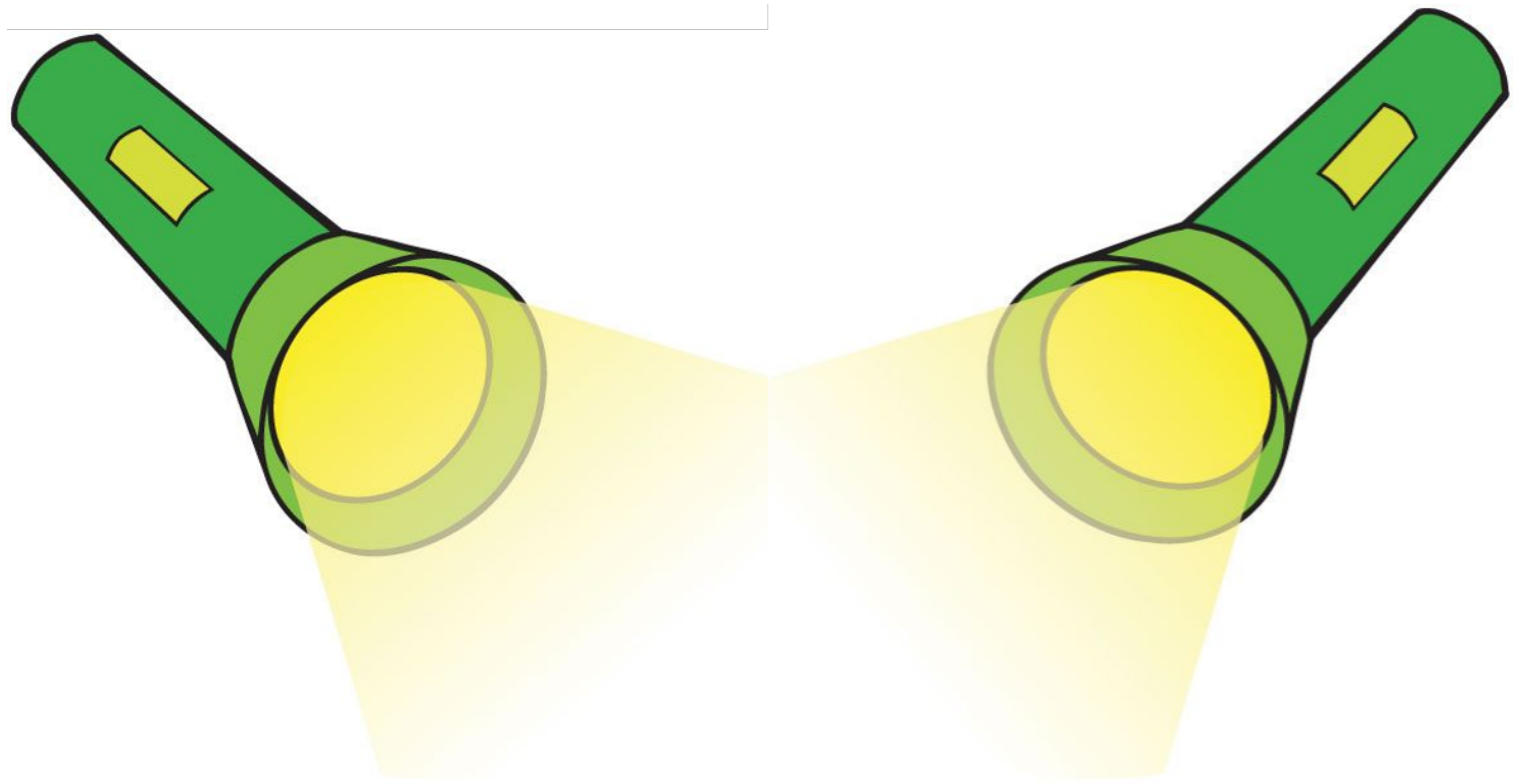


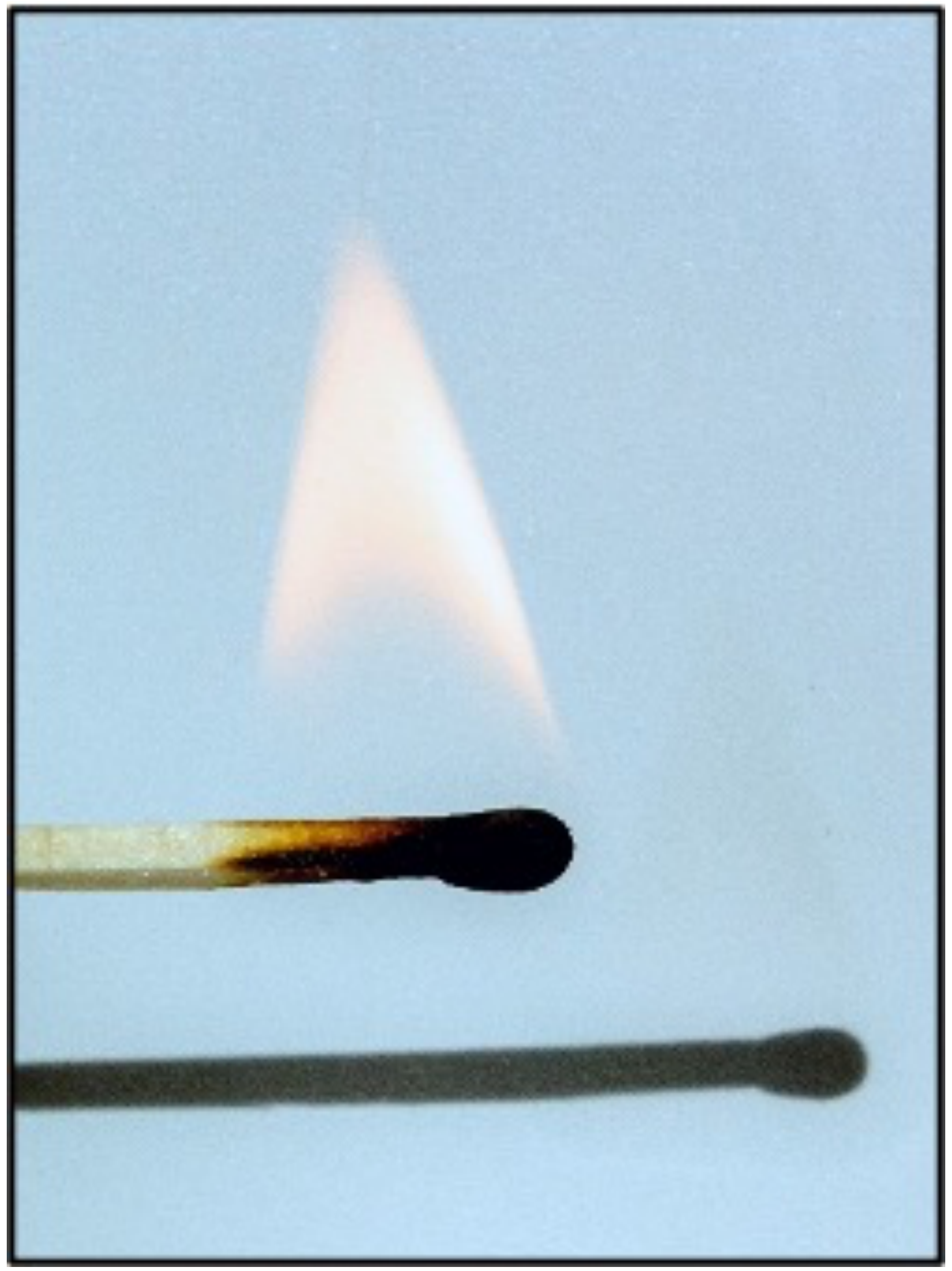
FOX EATING RABBIT



SQUIRREL

Light does not have a shadow





What is a shadow?

Shadow: a dark area on a surface where light has been blocked by an object.

What is a shadow?

Shadow: a dark area on a surface where light has been blocked by an object.

Criteria list:

(i) it is a large-scale effect

(ii) visible by eye on ordinary surfaces

(iii) it is due to the object blocking the illumination light

(iv) it takes the shape of the illuminated object

(v) follows as the object changes position or shape

(vi) the shadow follows the contour of the object it falls on


uOttawa


uOttawa

Most materials becomes more transparent in the presence of a strong laser field.

This would lead to an “anti-shadow” where the shadow location of the laser beam appears brighter than the background.

However, some materials can exhibit an increase in absorption at higher intensities under certain conditions. → reverse saturation of absorption

However, some materials can exhibit an increase in absorption at higher intensities under certain conditions. → reverse saturation of absorption

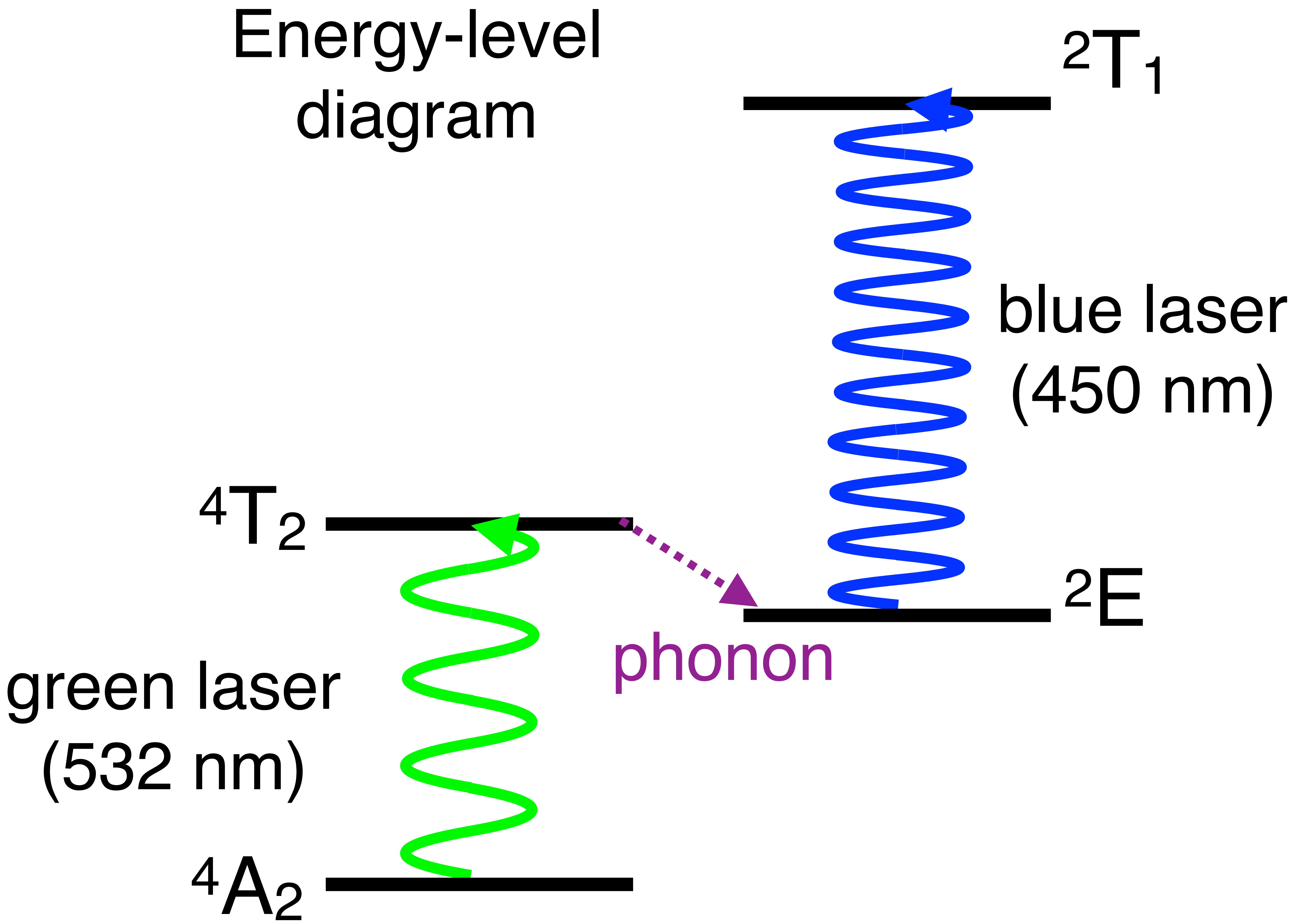
- More than two-level system.
- The excited state must have a larger absorption cross-section than the ground state.
- Neither the first nor the second excited states should decay to other levels that can trap the atomic population.
- The incident light should saturate the first transition only.

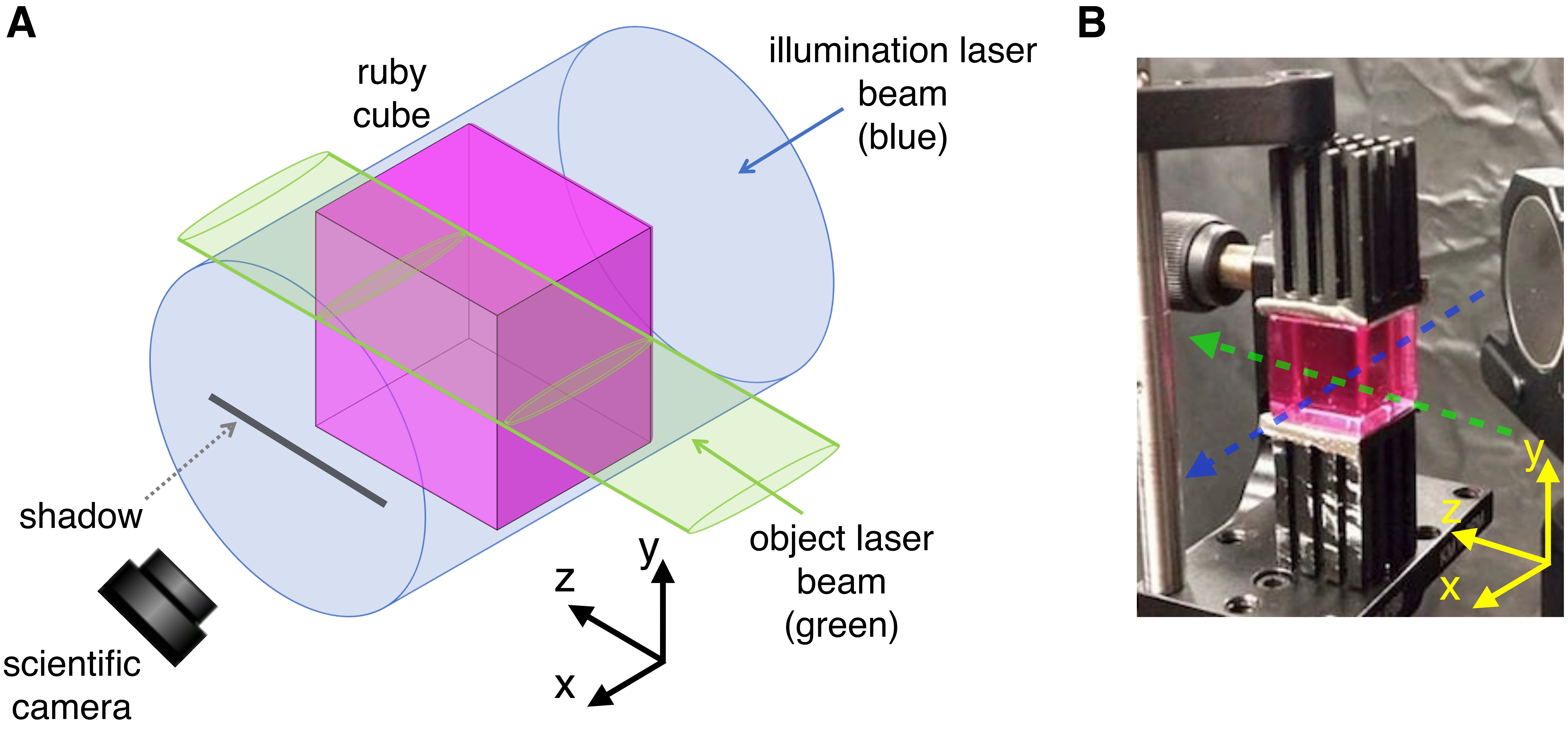
Ruby satisfies all these conditions

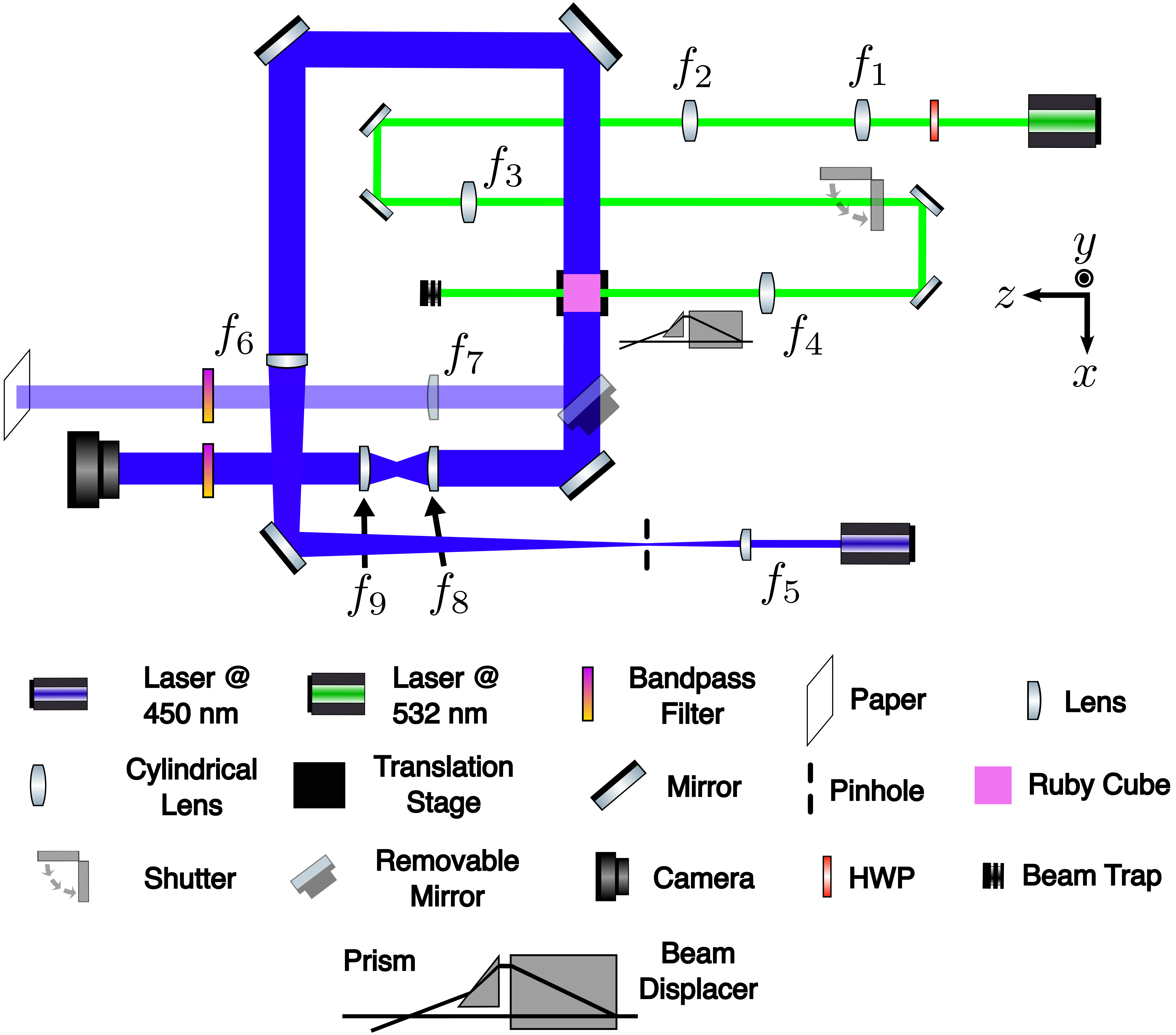
$Al_2O_3:Cr$

Side curiosity

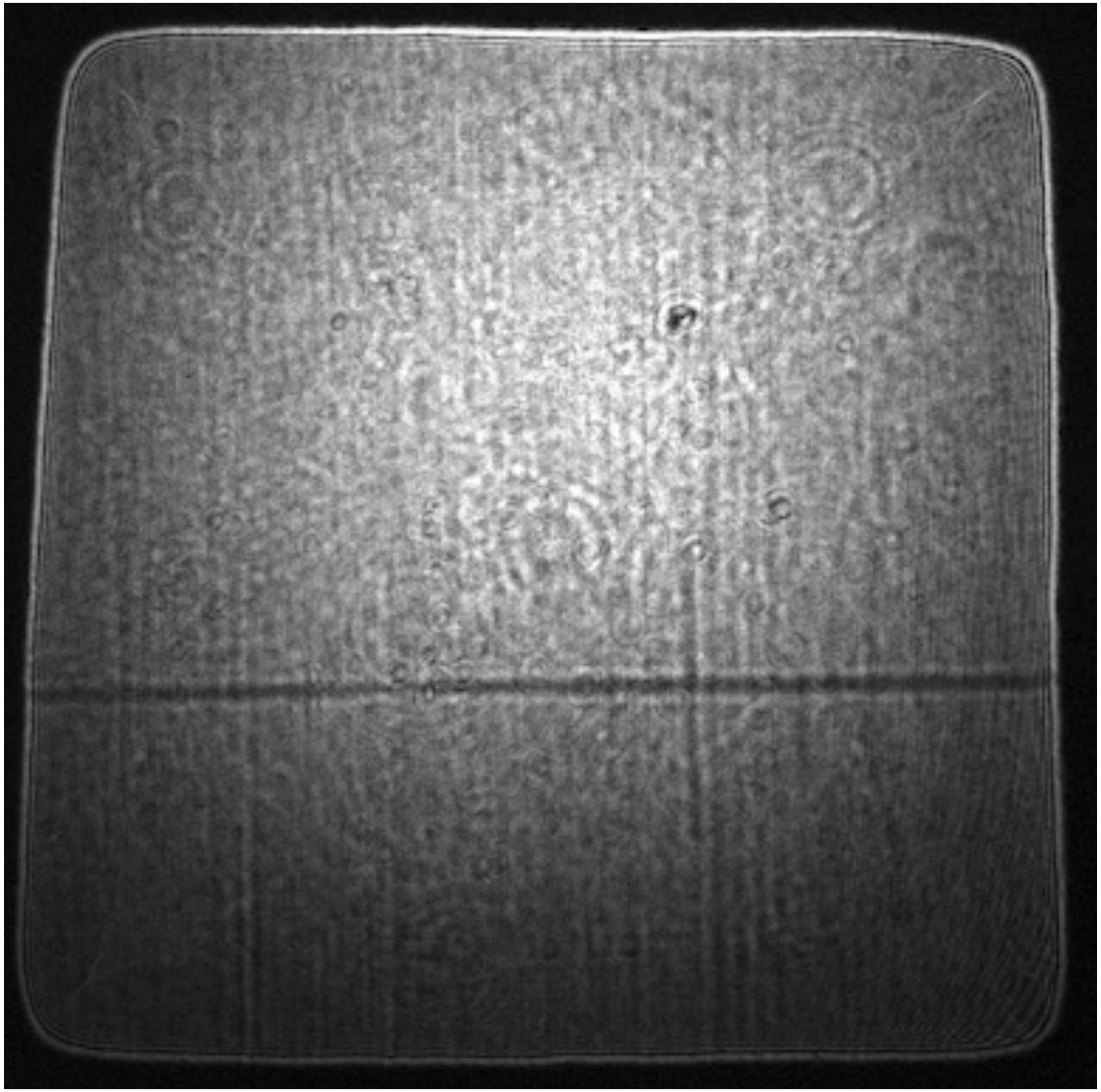
Theodore H. Maiman also used ruby in the first laser.


Energy-level
diagram
$^2T_1$
blue laser
(450 nm)
$^4T_2$
^2E
phonon
green laser
(532 nm)
$^4A_2$

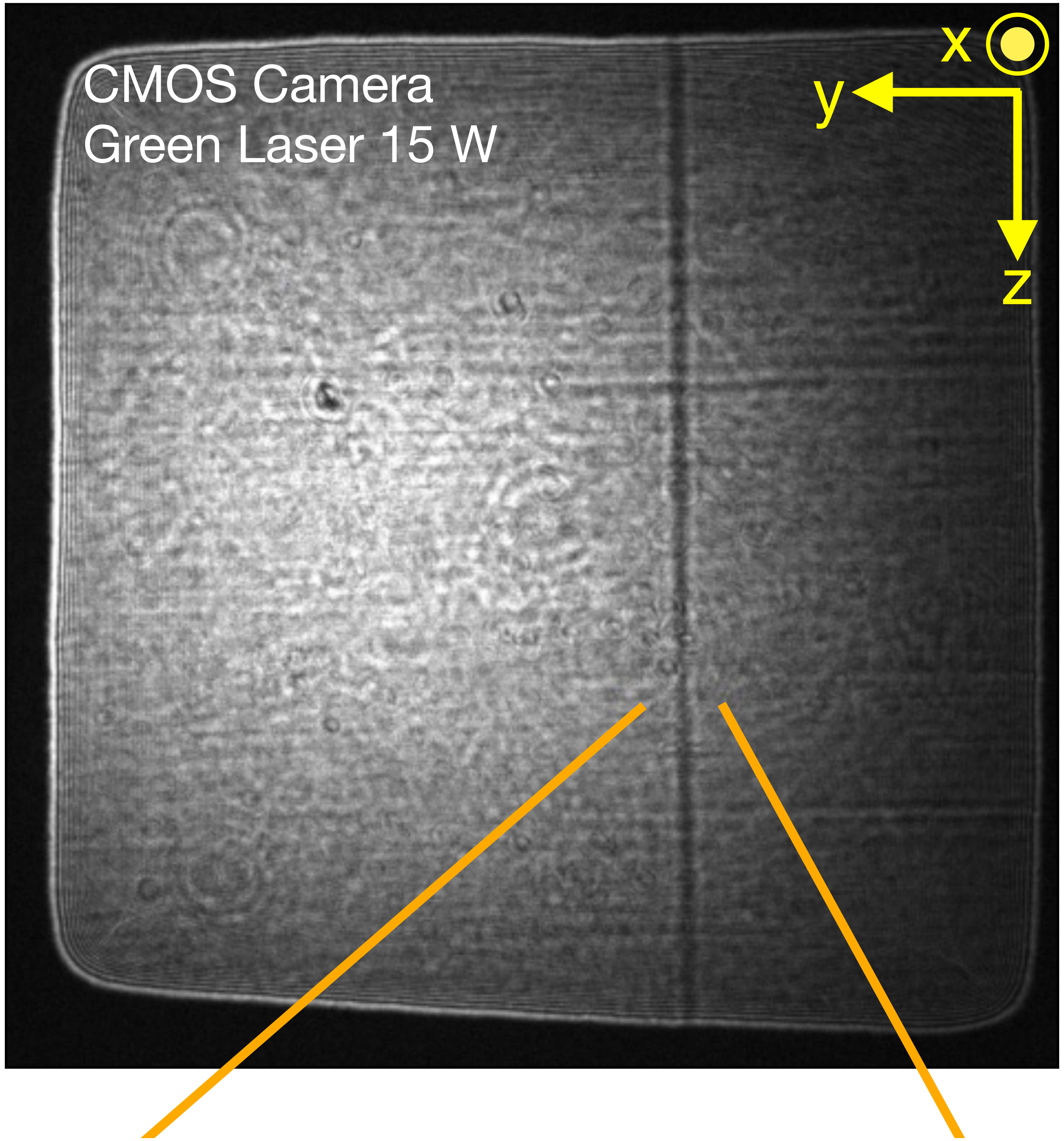

A
ruby cube
illumination laser beam (blue)
shadow
scientific camera
object laser beam (green)
z
y
x
B
y
z
x

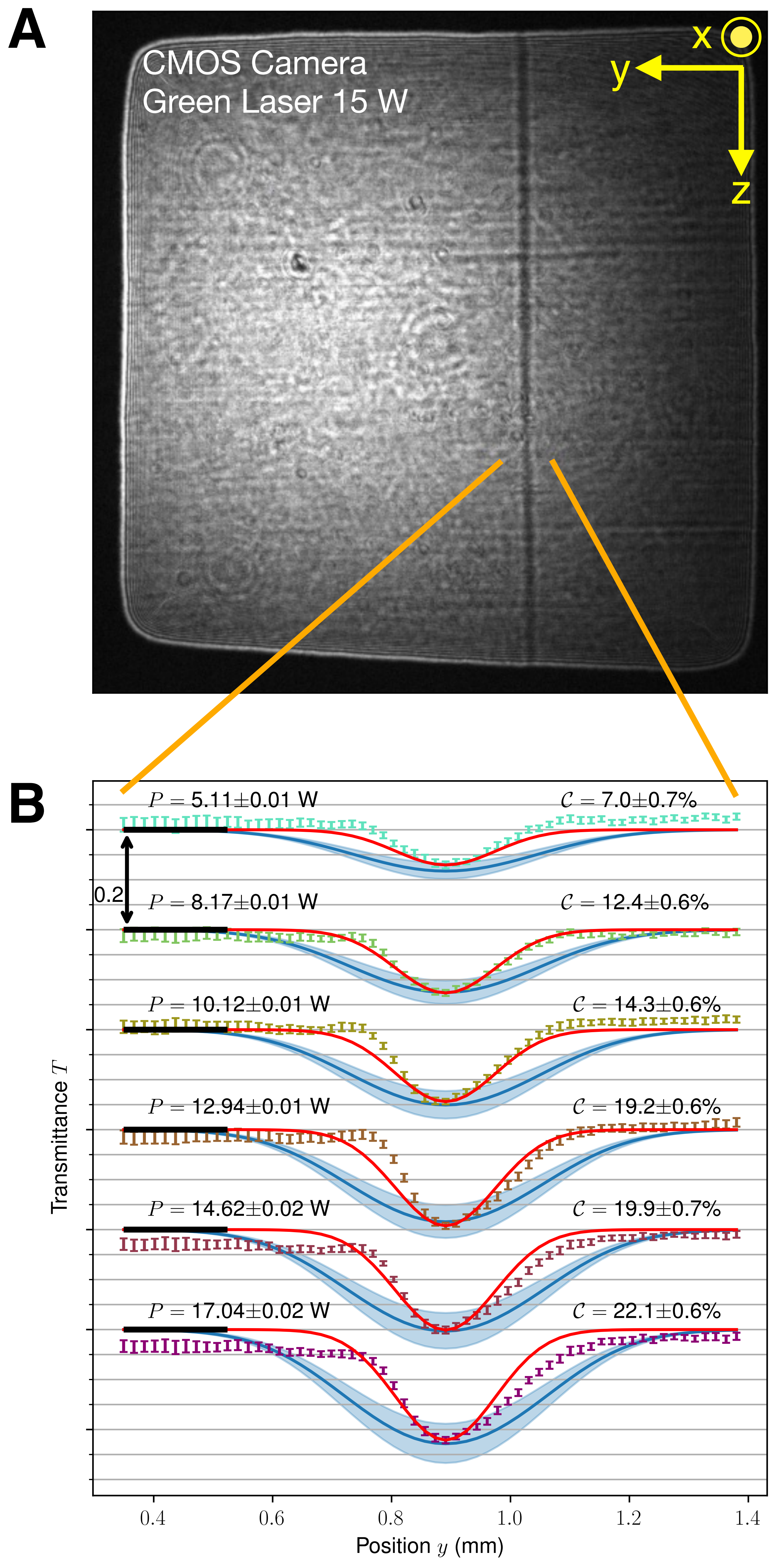


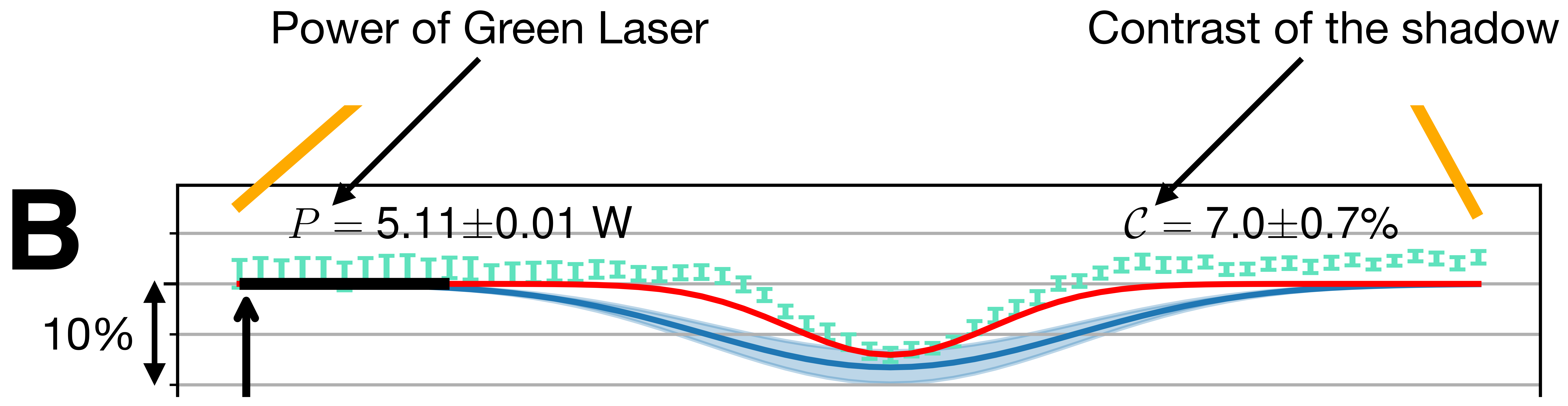
f_1
f_2
f_3
f_4
f_5
f_6
f_7
f_8
f_9
y
z
x
Laser @ 450 nm
Laser @ 532 nm
Bandpass Filter
Paper
Lens
Cylindrical Lens
Translation Stage
Mirror
Pinhole
Ruby Cube
Shutter
Removable Mirror
Camera
HWP
Beam Trap
Prism
Beam Displacer



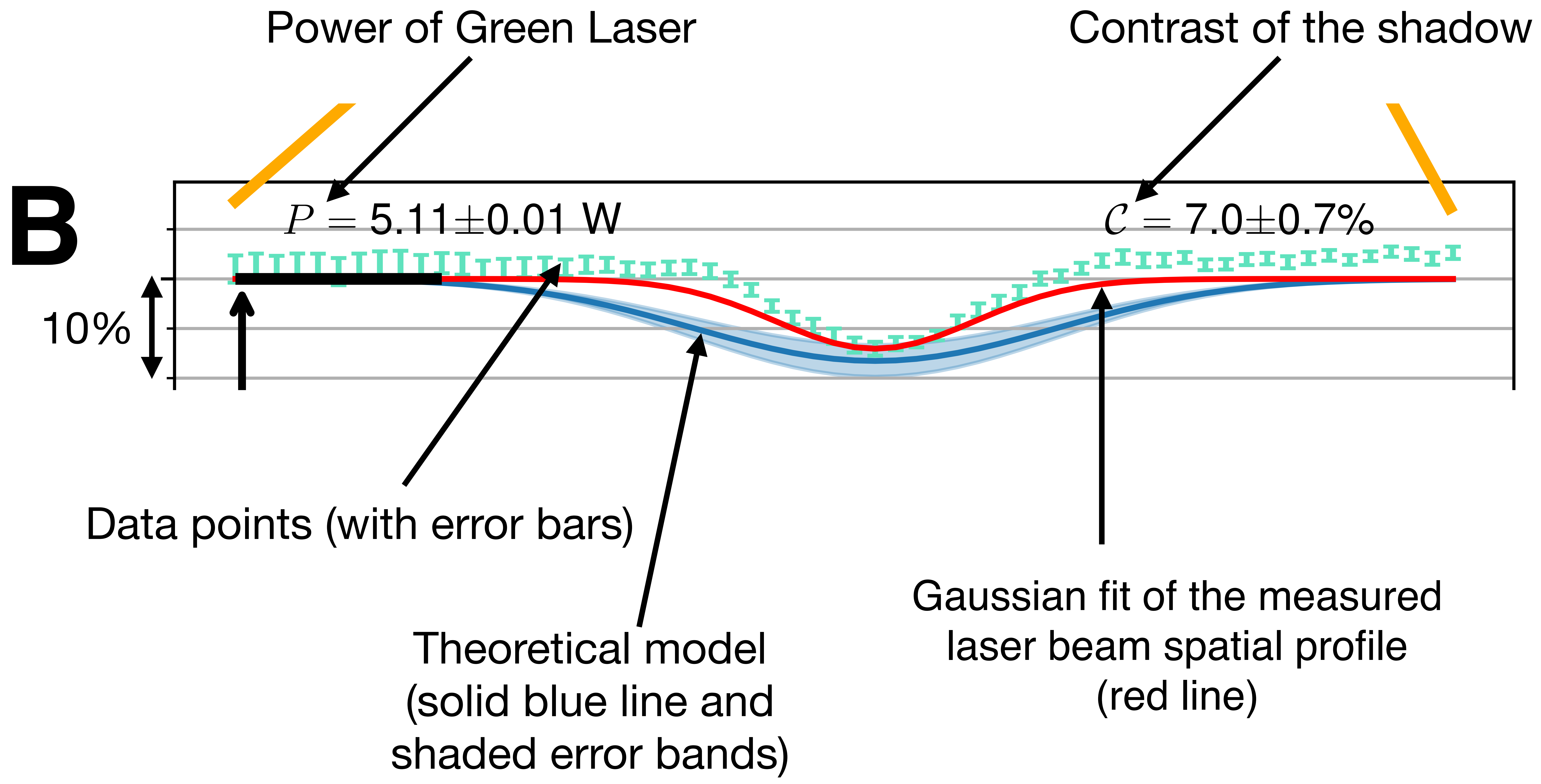
A

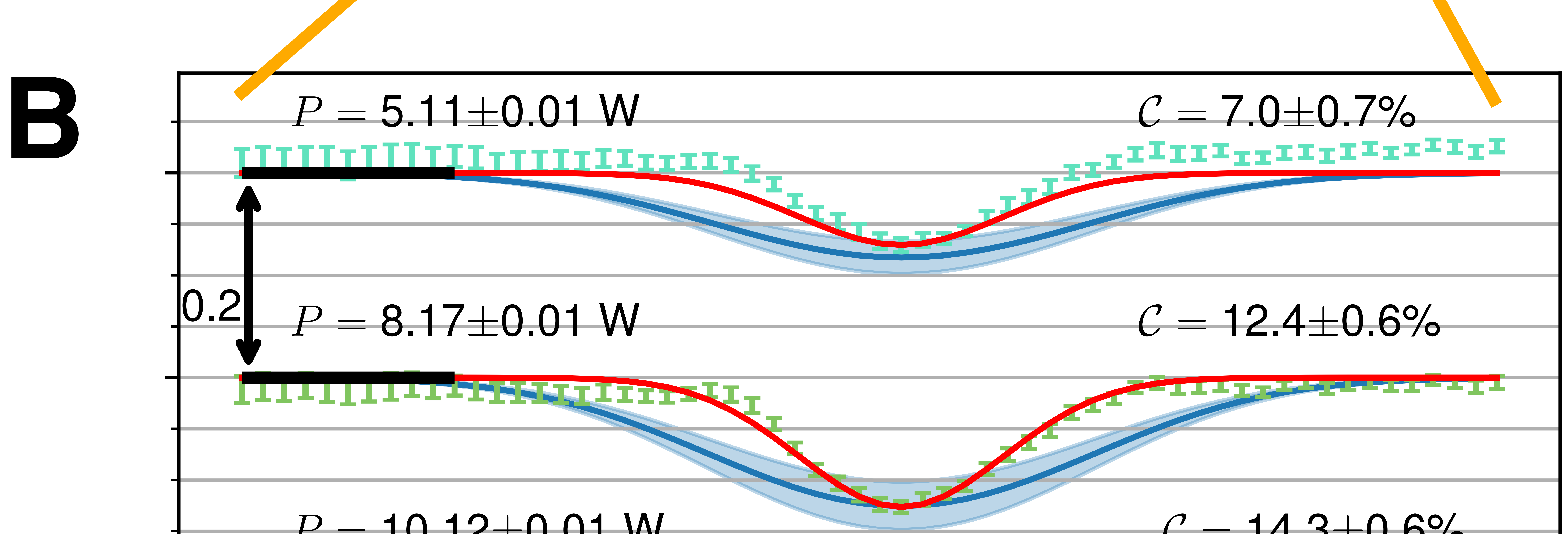


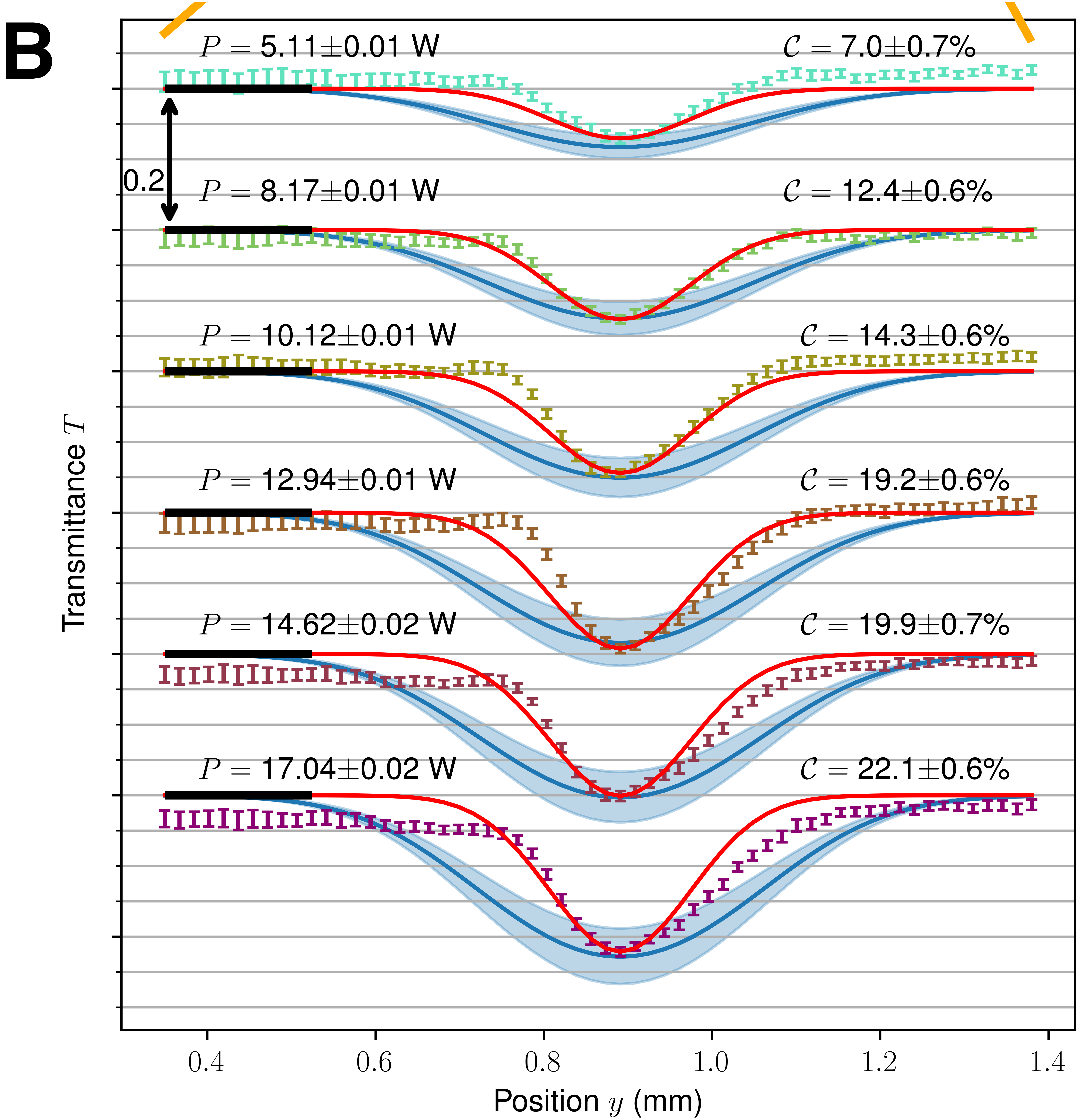

A
CMOS Camera
Green Laser 15 W
x
y
z
B
$P = 5.11\pm0.01$ W
$\mathcal{C} = 7.0\pm0.7\%$
0.2
$P = 8.17\pm0.01$ W
$\mathcal{C} = 12.4\pm0.6\%$
$P = 10.12\pm0.01$ W
$\mathcal{C} = 14.3\pm0.6\%$
$P = 12.94\pm0.01$ W
$\mathcal{C} = 19.2\pm0.6\%$
$P = 14.62\pm0.02$ W
$\mathcal{C} = 19.9\pm0.7\%$
$P = 17.04\pm0.02$ W
$\mathcal{C} = 22.1\pm0.6\%$
Transmittance T
0.4
0.6
0.8
1.0
1.2
1.4
Position y (mm)



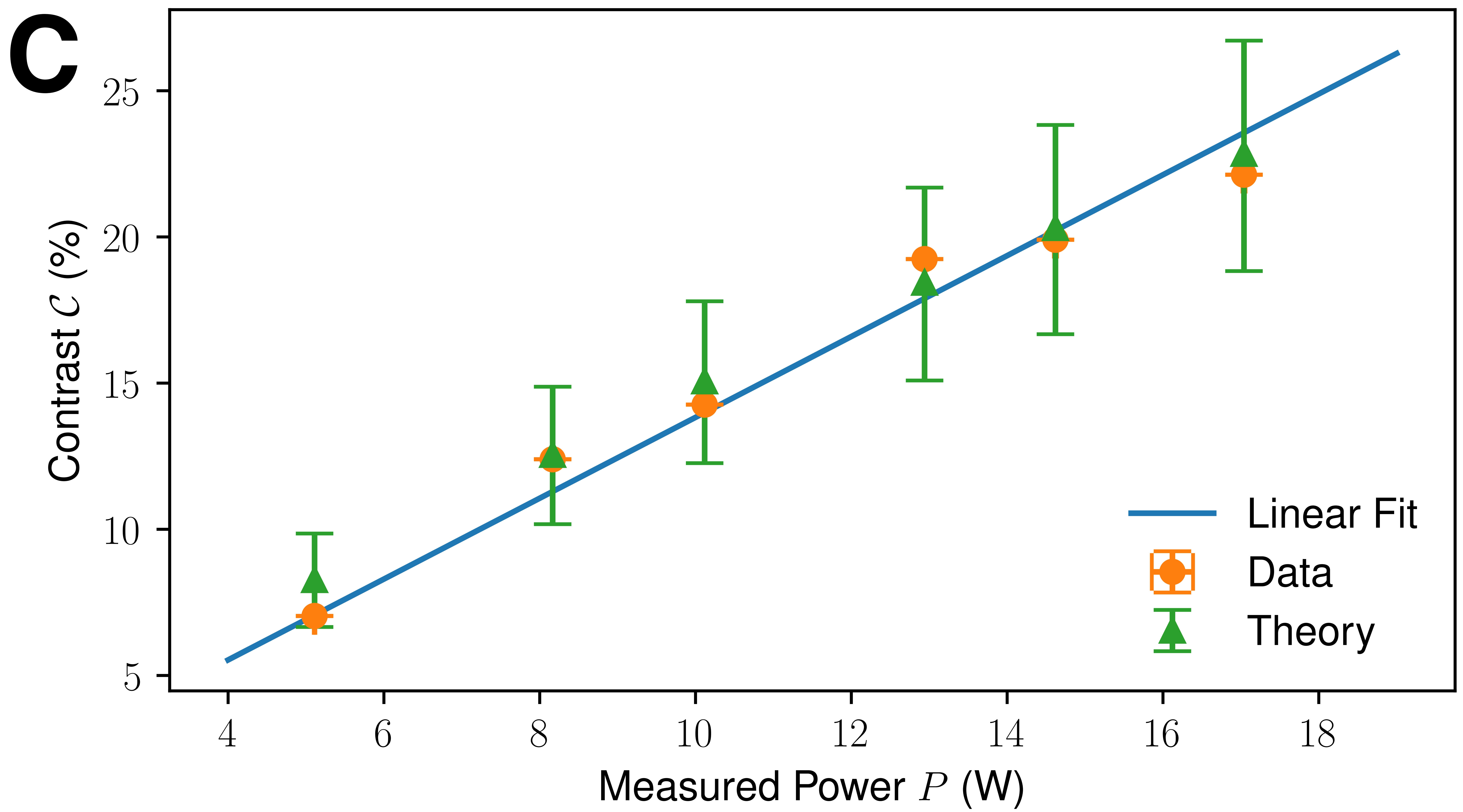
Power of Green Laser
Contrast of the shadow
B
$P = 5.11 \pm 0.01$ W
$\mathcal{C} = 7.0 \pm 0.7\%$
10%


Power of Green Laser
Contrast of the shadow
B
$P = 5.11 \pm 0.01$ W
$\mathcal{C} = 7.0 \pm 0.7\%$
10%
Data points (with error bars)
Theoretical model (solid blue line and shaded error bands)
Gaussian fit of the measured laser beam spatial profile (red line)

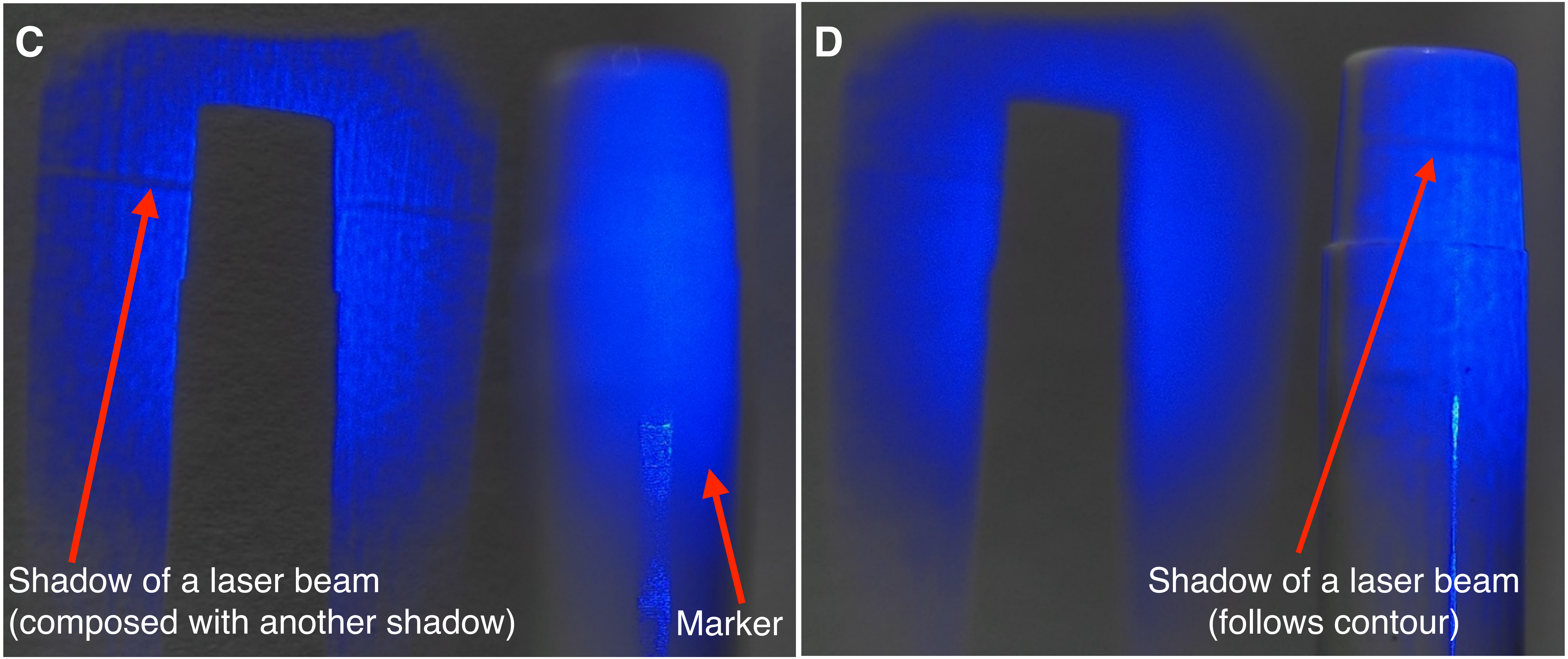

B
$P = 5.11 \pm 0.01$ W
$\mathcal{C} = 7.0 \pm 0.7\%$
0.2
$P = 8.17 \pm 0.01$ W
$\mathcal{C} = 12.4 \pm 0.6\%$



B
P = 5.11±0.01 W
C = 7.0±0.7%
0.2
P = 8.17±0.01 W
C = 12.4±0.6%
P = 10.12±0.01 W
C = 14.3±0.6%
P = 12.94±0.01 W
C = 19.2±0.6%
P = 14.62±0.02 W
C = 19.9±0.7%
P = 17.04±0.02 W
C = 22.1±0.6%
Transmittance T
0.4
0.6
0.8
1.0
1.2
1.4
Position y (mm)


C
Contrast $\mathcal{C}$ (%)
Measured Power P (W)
Linear Fit
Data
Theory
25
20
15
10
5
4
6
8
10
12
14
16
18


A
Shadow of a laser
beam (visible by eye)
zoom in
B
1”
Shadow of a laser
beam (visible by eye)
uOttawa
Table holes distance:
1” = 2.54 cm


C
Shadow of a laser beam
(composed with another shadow)
Marker
D
Shadow of a laser beam
(follows contour)


A
hair shadow
laser shadow
B
shadow of x-shaped
light beam object
C
ruler shadow
laser shadow

Criteria list:

(i) it is a large-scale effect ✓
(ii) visible by eye on ordinary surfaces ✓
(iii) it is due to the object blocking the illumination light ✓
(iv) it takes the shape of the illuminated object ✓
(v) follows as the object changes position or shape ✓
(vi) the shadow follows the contour of the object it falls on ✓

So… what causes the shadow?

Are the photons in the object laser themselves blocking the illuminating light? Or are the atoms in the ruby?

Both! Actually, it is a polariton.

Polariton: a hybrid state between photons and matter.

Polaritons are interesting in their own right and a active area of research in condensed matter.

We intentionally highlighted that in the paper!

"We are in the presence of strong absorption (hence the shadow) and the polaritonic nature of the excitation in the medium, and both concepts are necessary to understand what is happening. Strictly speaking, it is not massless light that is creating the shadow, but it is the material counterpart of the polariton, which has mass, that is casting the shadow.”

Research Article
Vol. 11, No. 11 / November 2024 / *Optica* 1549

Shadow of a laser beam

RAPHAEL A. ABRAHAO,[1,2,*] HENRI P. N. MORIN,[1,3] JORDAN T. R. PAGÉ,[1,4] AKBAR SAFARI,[1,5] ROBERT W. BOYD,[1,4,6] AND JEFF S. LUNDEEN[1,7,8]

PHYS ORG

physicsworld

APS

Physics

NewScientist

GIZMODO
The Future Is Here

OPTICA
OPTICS & PHOTONICS NEWS

OPTICA

EVENTS MEMBERSHIP PUBLICATIONS INDUSTRY RESOURCES COMMUNITY

Home > About > Newsroom > News Releases

Scientists discover laser light can cast a shadow

About Optica

Optica Community

About Our Brand

14 November 2024

Scientists discover laser light can cast a shadow

Surprising finding could lead to new ways of controlling light

Outlook

Other materials

Other wavelengths

Potential new applications

Optical switcher

Control of the intensity of a transmitted laser beam by applying another laser

Quantum telescopes

The Astrophysical Journal Letters, 875:L4 (52pp), 2019 April 10
https://doi.org/10.3847/2041-8213/ab0e85

First M87 Event Horizon Telescope Results. IV. Imaging the Central Supermassive Black Hole

The Event Horizon Telescope Collaboration
(See the end matter for the full list of authors.)

Received 2019 February 11; revised 2019 March 5; accepted 2019 March 6; published 2019 April 10

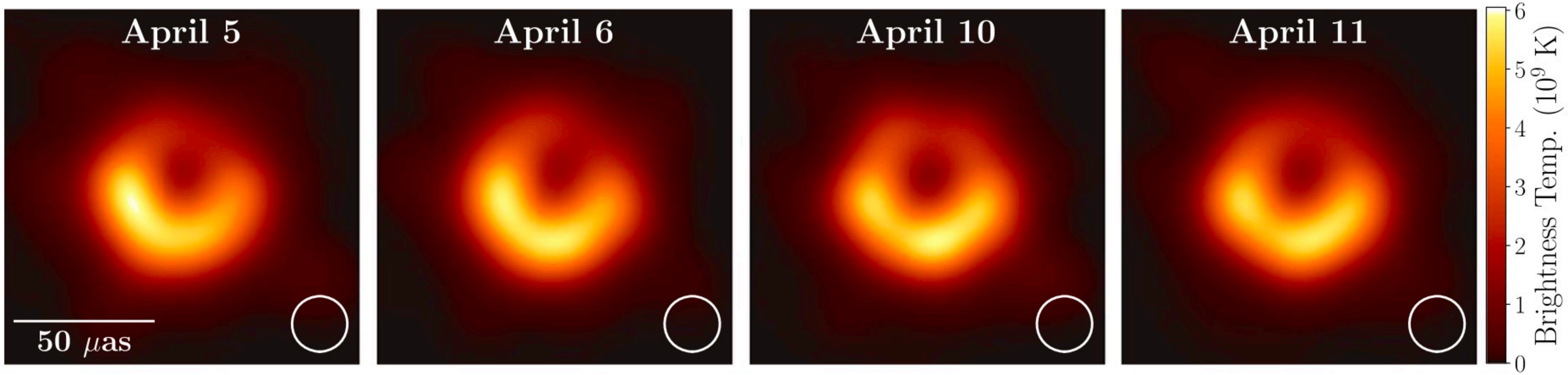


Figure 15. Averages of the three fiducial images of M87 for each of the four observed days after restoring each to an equivalent resolution, as in Figure 14. The indicated beam is 20 μas (i.e., that of DIFMAP, which is always the largest of the three individual beams).

sensitive to features on angular scale

$$\Delta\theta \sim \frac{\lambda}{b}$$

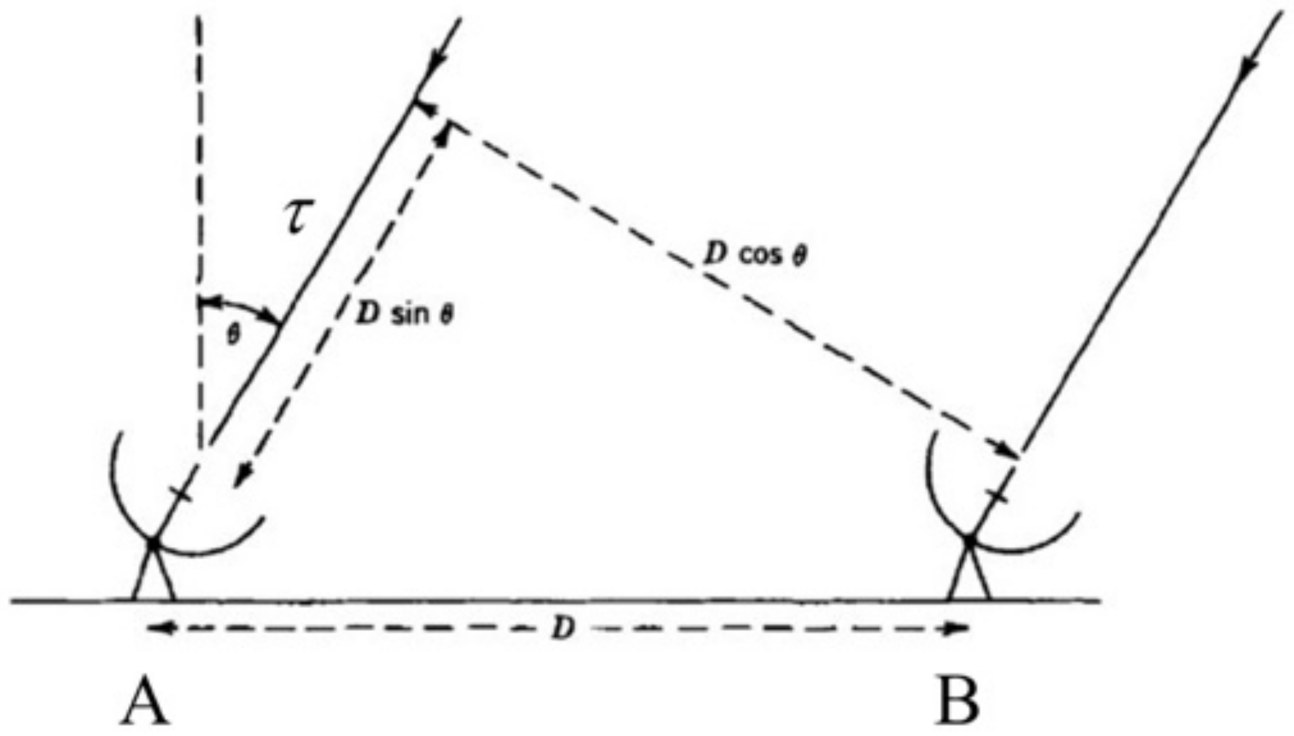
Achieved by radio interferometry

sensitive to features on angular scale

$$\Delta\theta \sim \frac{\lambda}{b}$$

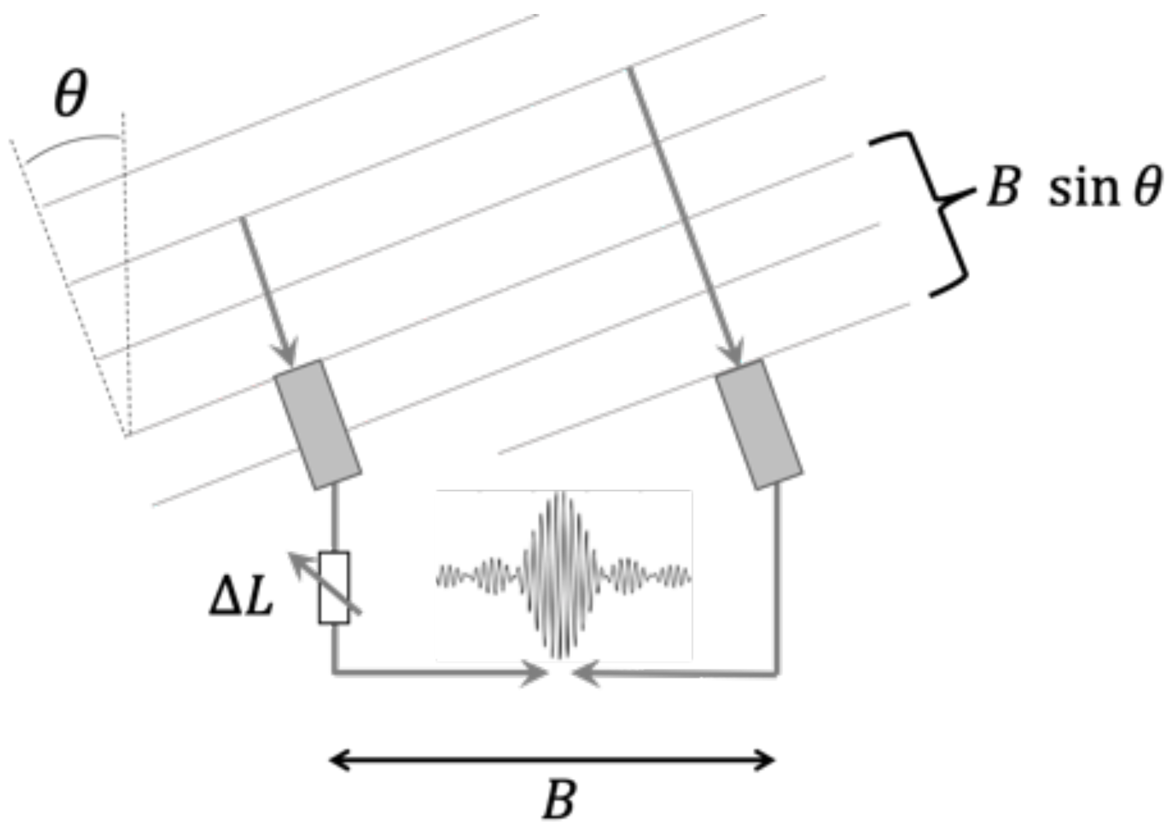
https://iopscience.iop.org/journal/2041-8205/page/Focus_on_EHT

Radio



Can record entire waveform, over some band, separately at each receiver station and interfere later offline

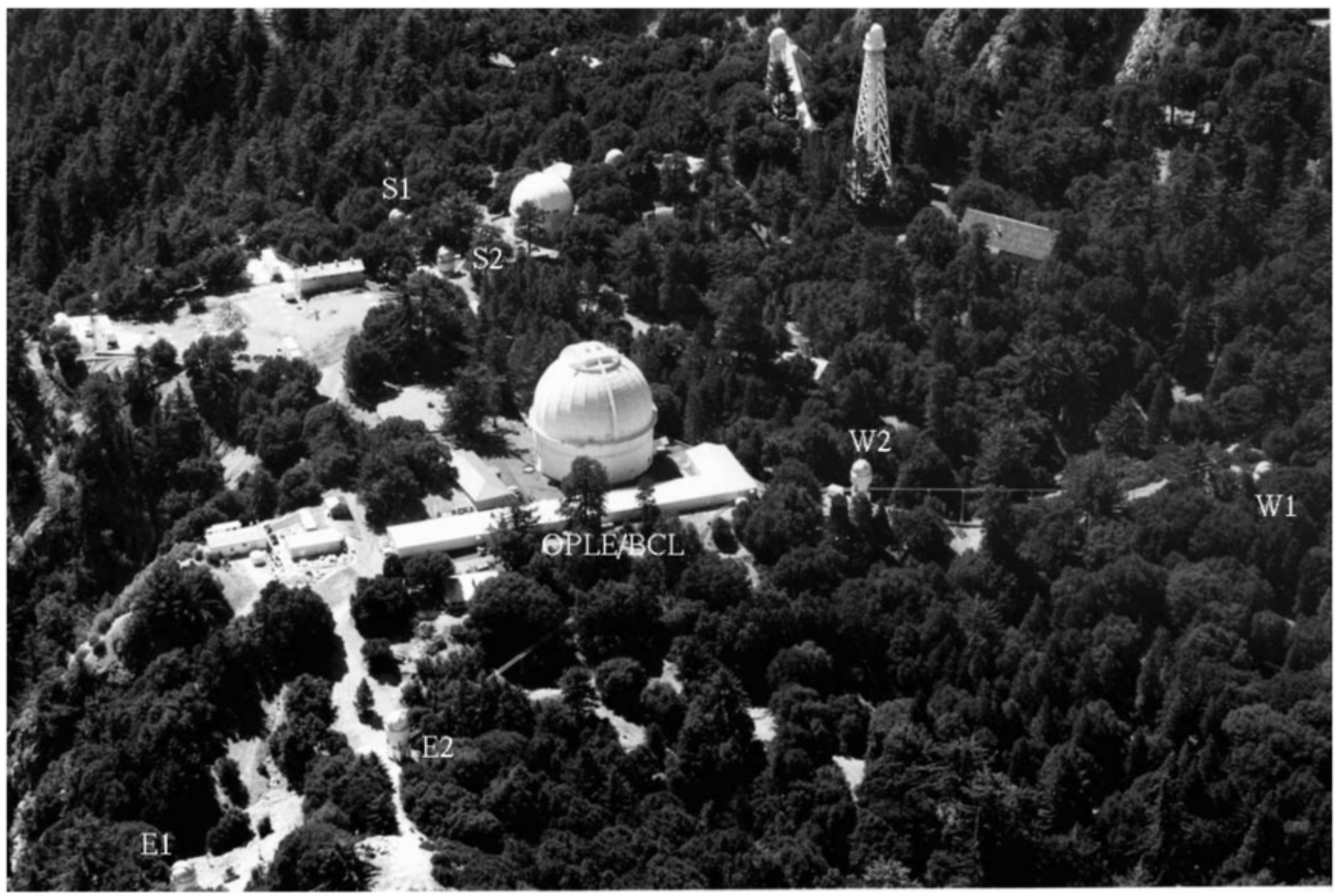
Optical



Need to bring paths to common point in real time
Need path length compensated to better than c/bandwidth
Need path length stabilized to better than λ

CHARA (Center for High Angular Resolution Astronomy) Observatory

baselines up to 330m



Beam line path length control at CHARA

Question: How to get to longer baselines?

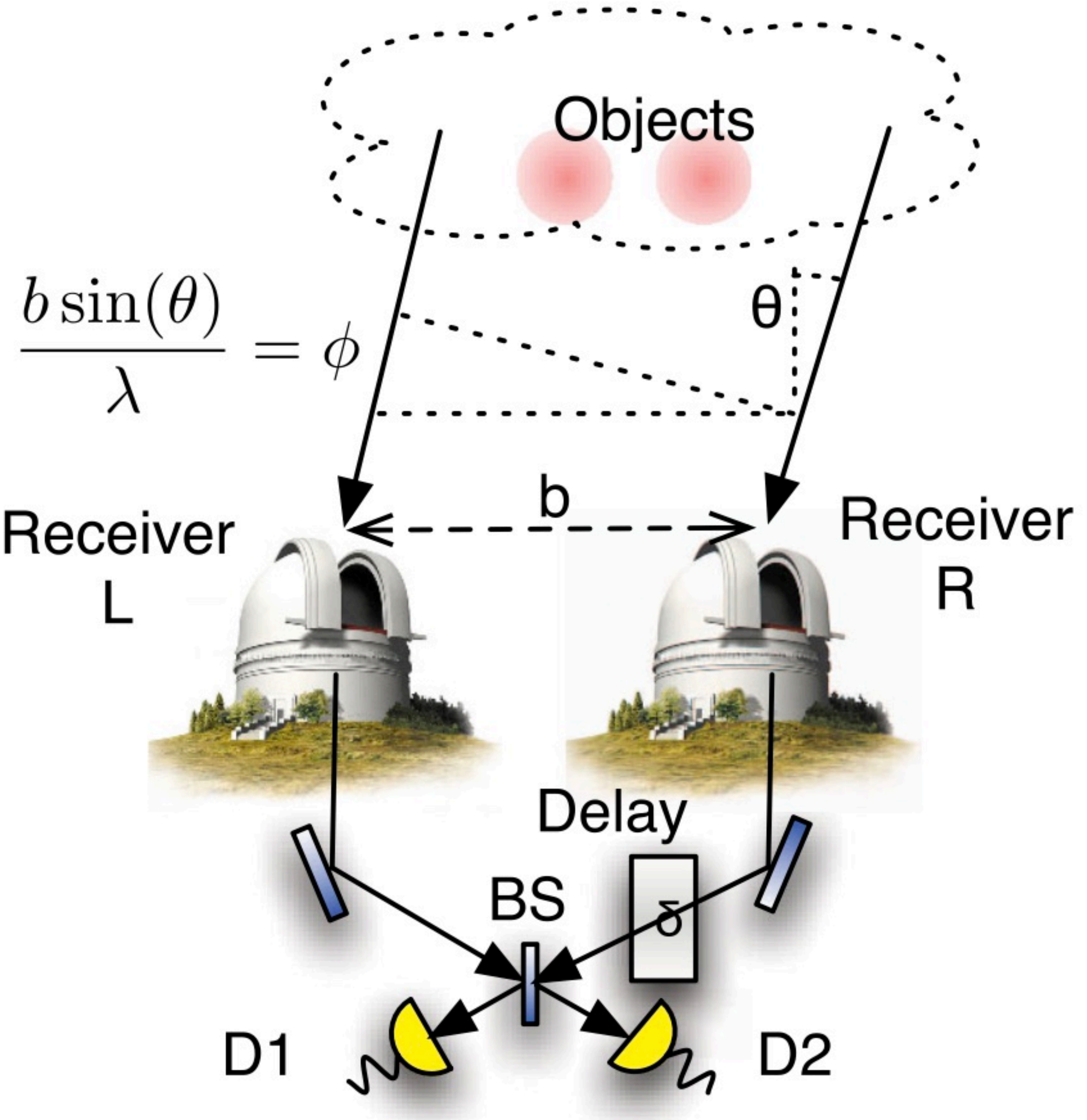
Longer-Baseline Telescopes Using Quantum Repeaters

Daniel Gottesman*
Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada

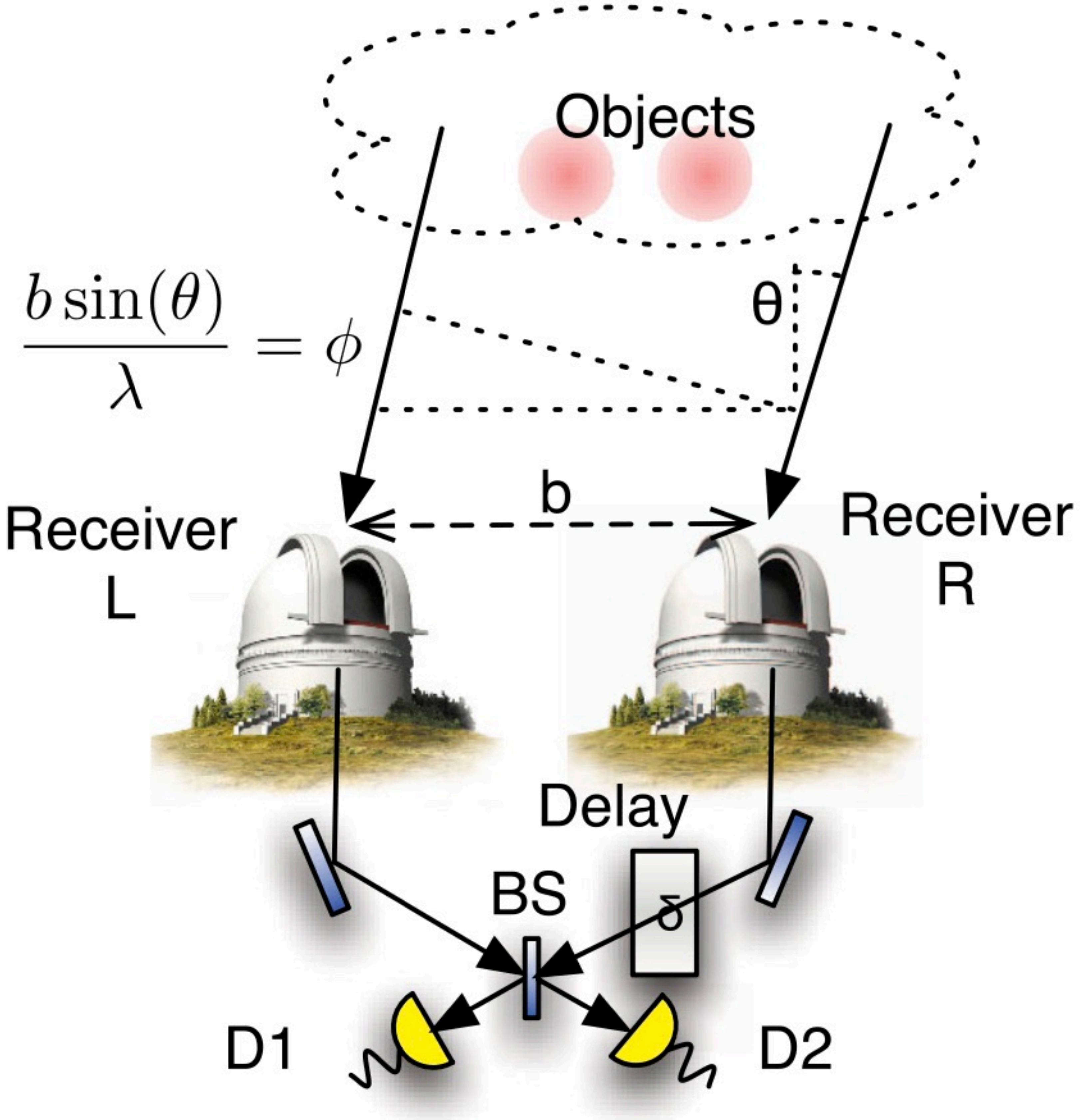
Thomas Jennewein†
Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario, Canada

Sarah Croke‡
Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canada

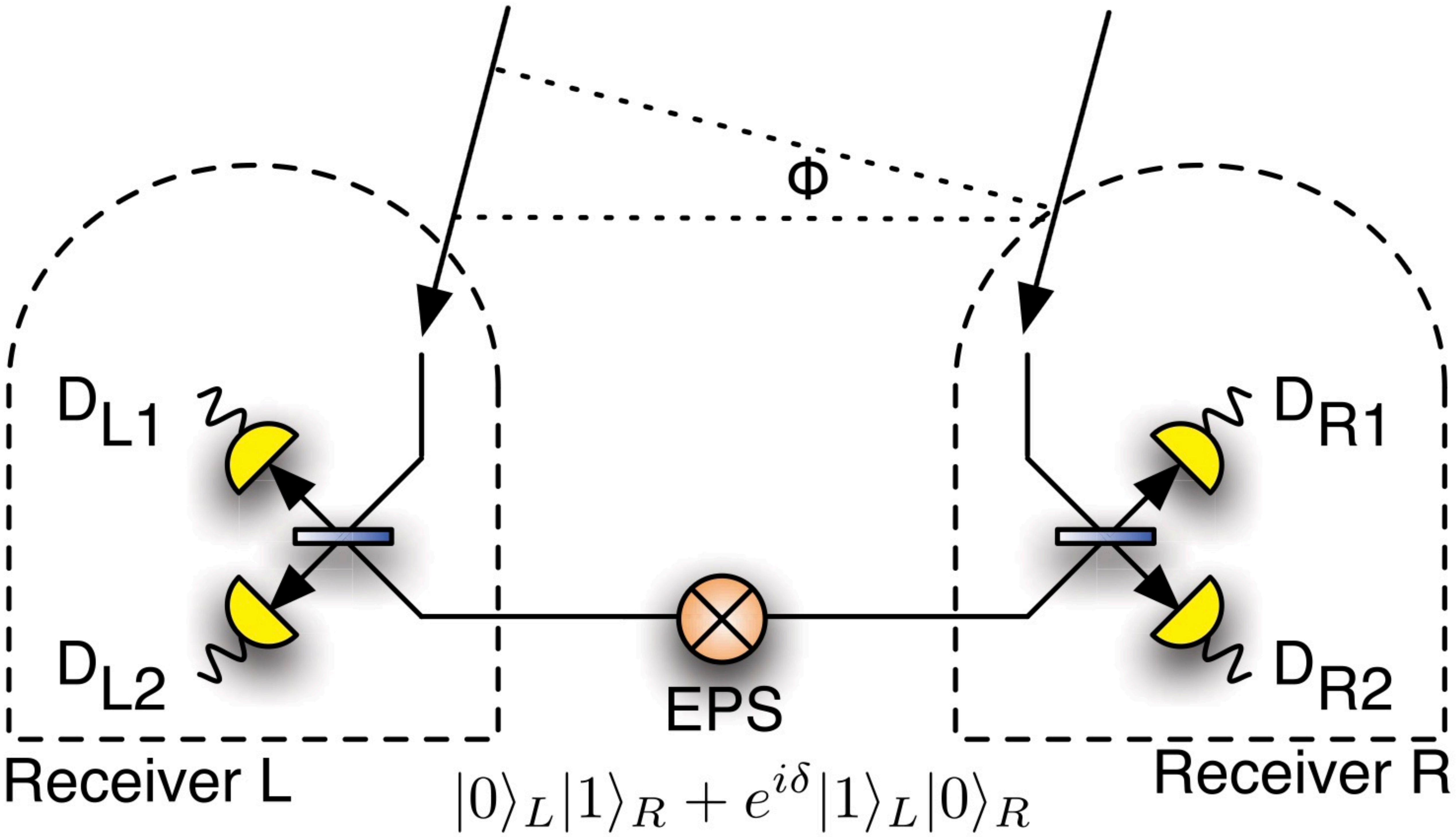
(Received 25 October 2011; revised manuscript received 22 May 2012; published 16 August 2012)



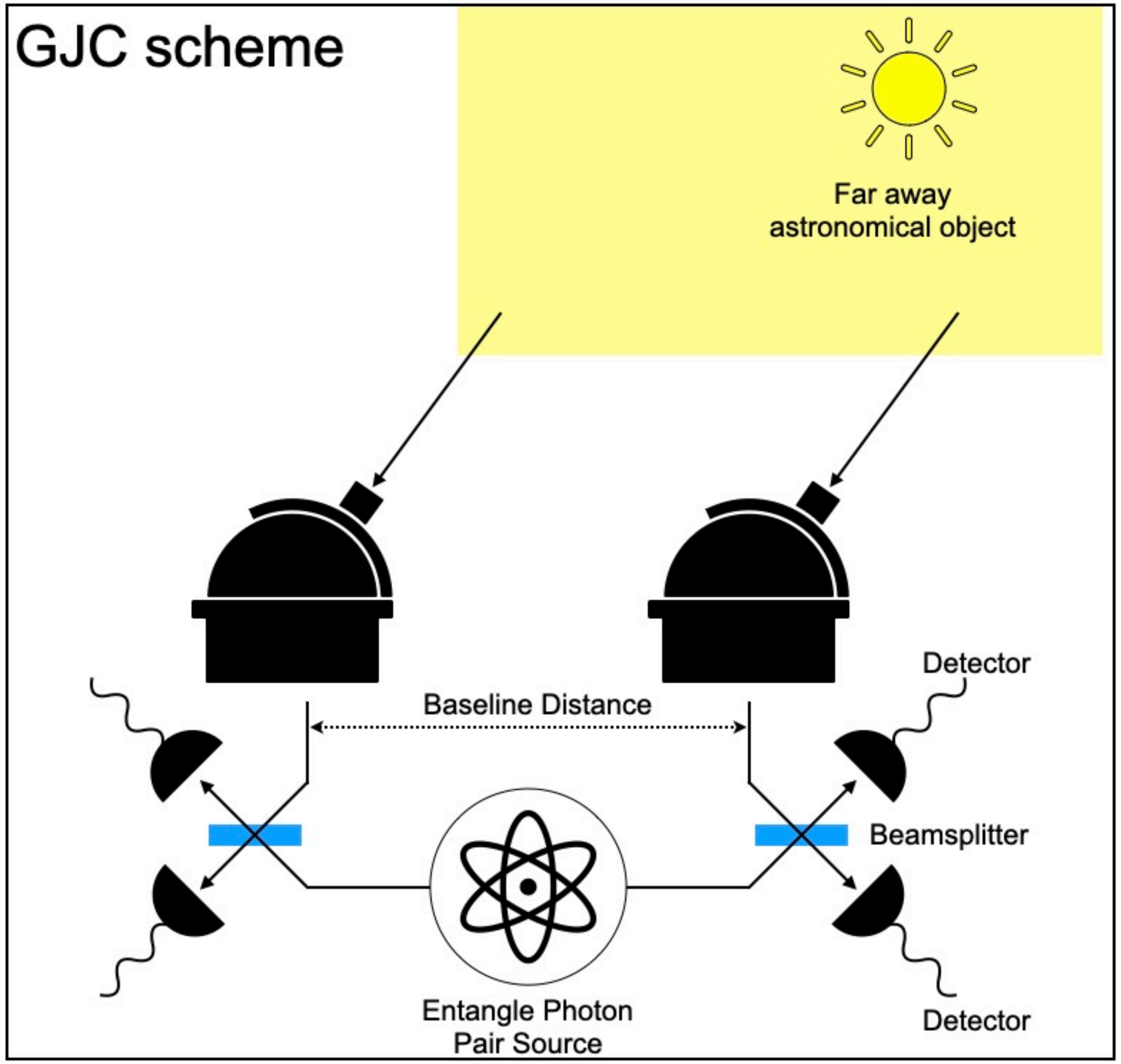
$$|0\rangle_L|1\rangle_R + e^{i\phi}|1\rangle_L|0\rangle_R,$$



Objects
$\frac{b\sin(\theta)}{\lambda} = \phi$
θ
b
Receiver L
Receiver R
Delay
BS
δ
D1
D2



Φ
D_{L1}
D_{L2}
D_{R1}
D_{R2}
EPS
Receiver L
Receiver R
$|0\rangle_L|1\rangle_R + e^{i\delta}|1\rangle_L|0\rangle_R$



Longer-Baseline Telescopes Using Quantum Repeaters

PRL 2012

Seminal work in the field

Very interesting

Not feasible with current quantum technology

Cost? Scale?

Gottesman, D. "Quantum telescopes." Optical and Infrared Interferometry and Imaging VII. Vol. 11446. SPIE, 2020.

There is an alternative!

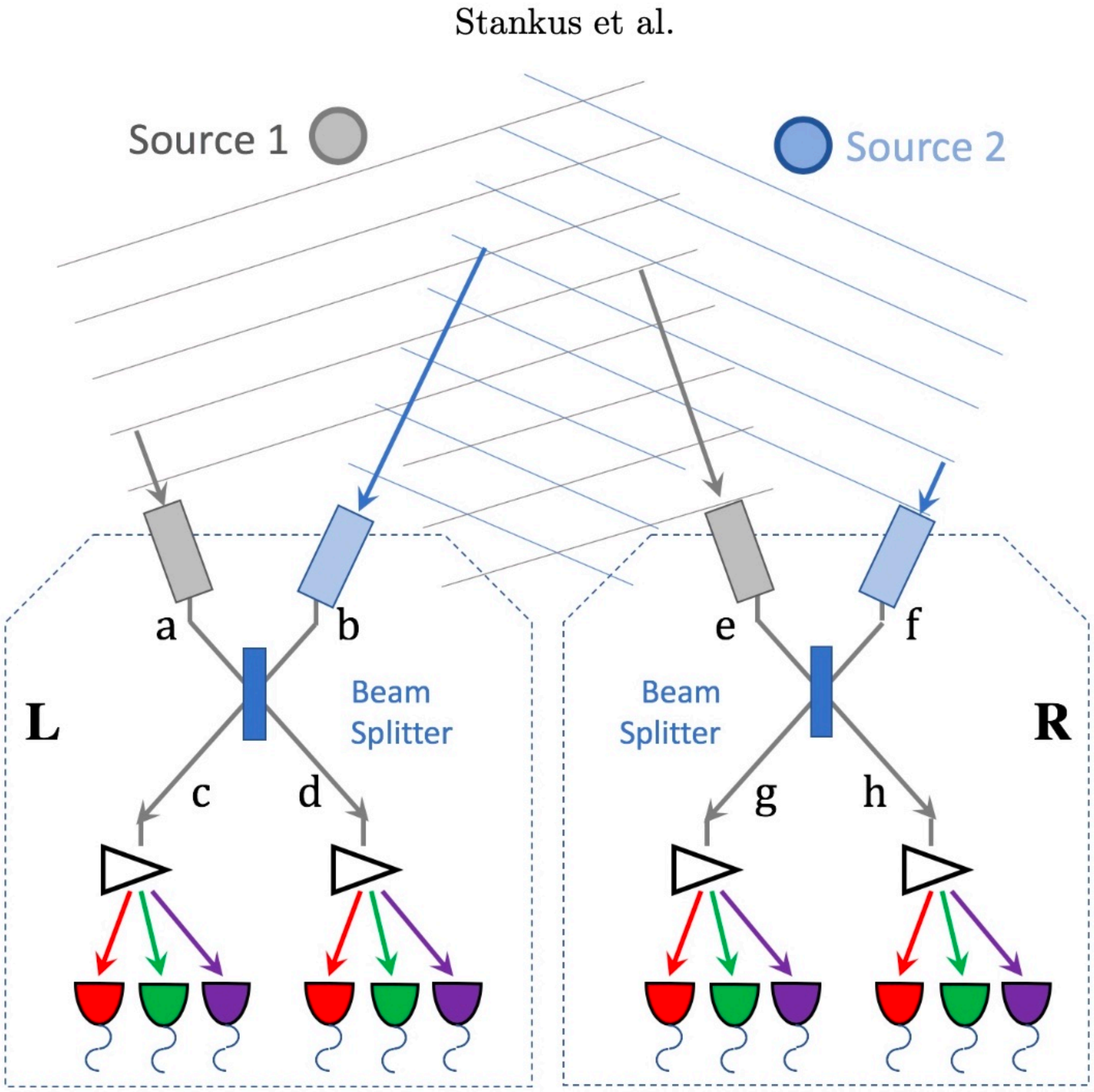
Two-photon amplitude interferometry for precision astrometry

Paul Stankus, Andrei Nomerotski, Anže Slosar, Stephen Vintskevich

https://doi.org/10.21105/astro.2010.09100

Astronomical Instrumentation | Astrometry | Quantum Physics | Inteferometry | Interferometric Correlation

Stankus, Paul, Andrei Nomerotski, Anže Slosar, and Stephen Vintskevich. 2022. "Two-Photon Amplitude Interferometry for Precision Astrometry." *The Open Journal of Astrophysics* 5 (November). https://doi.org/10.21105/astro.2010.09100.



One photon from Source 1 arrives at **a** and **e**

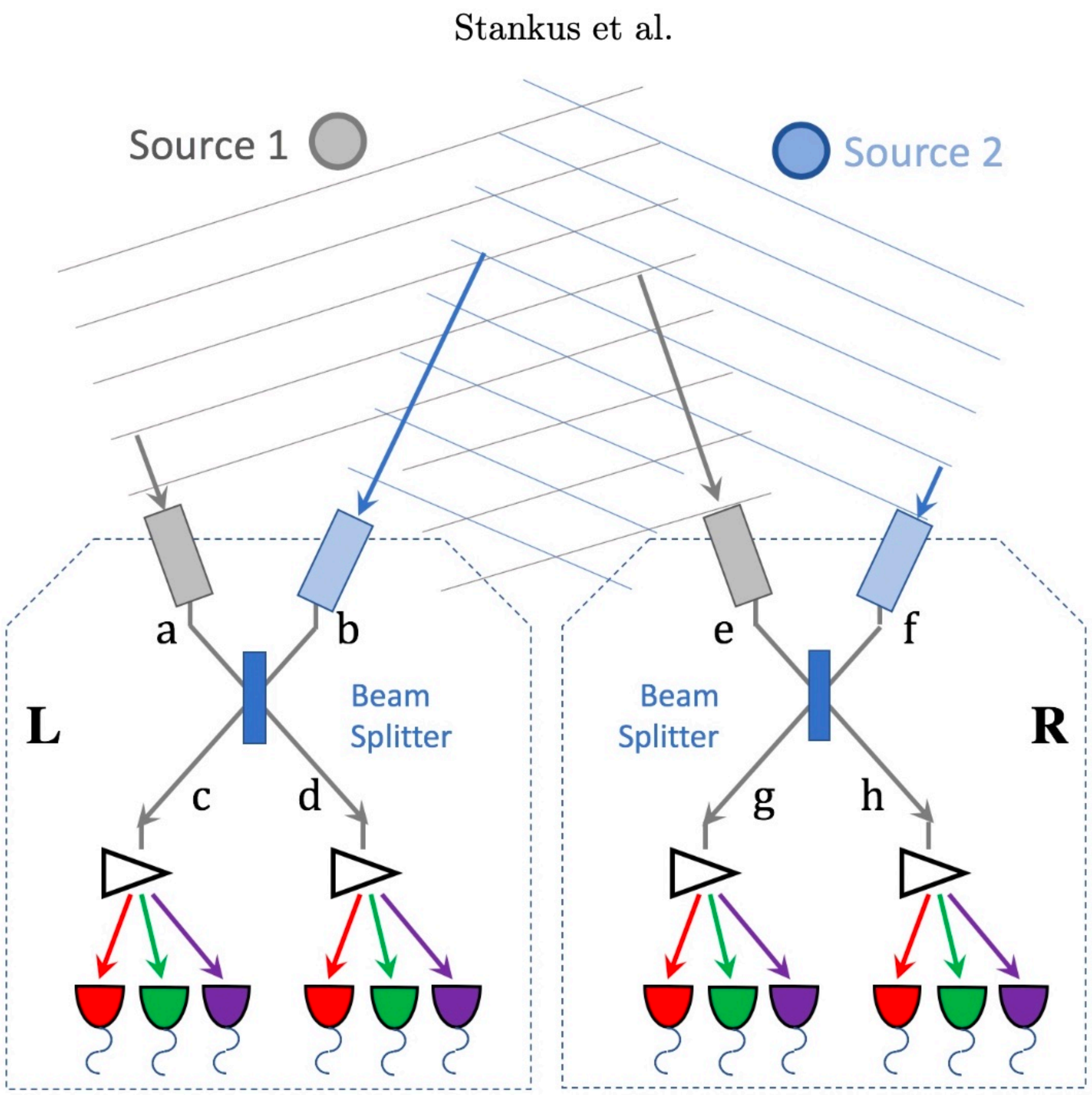
$|0\rangle_L|1\rangle_R + e^{i\delta 1}\,|1\rangle_L|0\rangle_R$

Another photon from Source 2 arrives at **b** and **f**

$|0\rangle_L|1\rangle_R + e^{i\delta 2}\,|1\rangle_L|0\rangle_R$

(path entanglement)

Stankus et al.
Two-photon amplitude interferometry for precision astrometry
The Open Journal of Astrophysics 2022



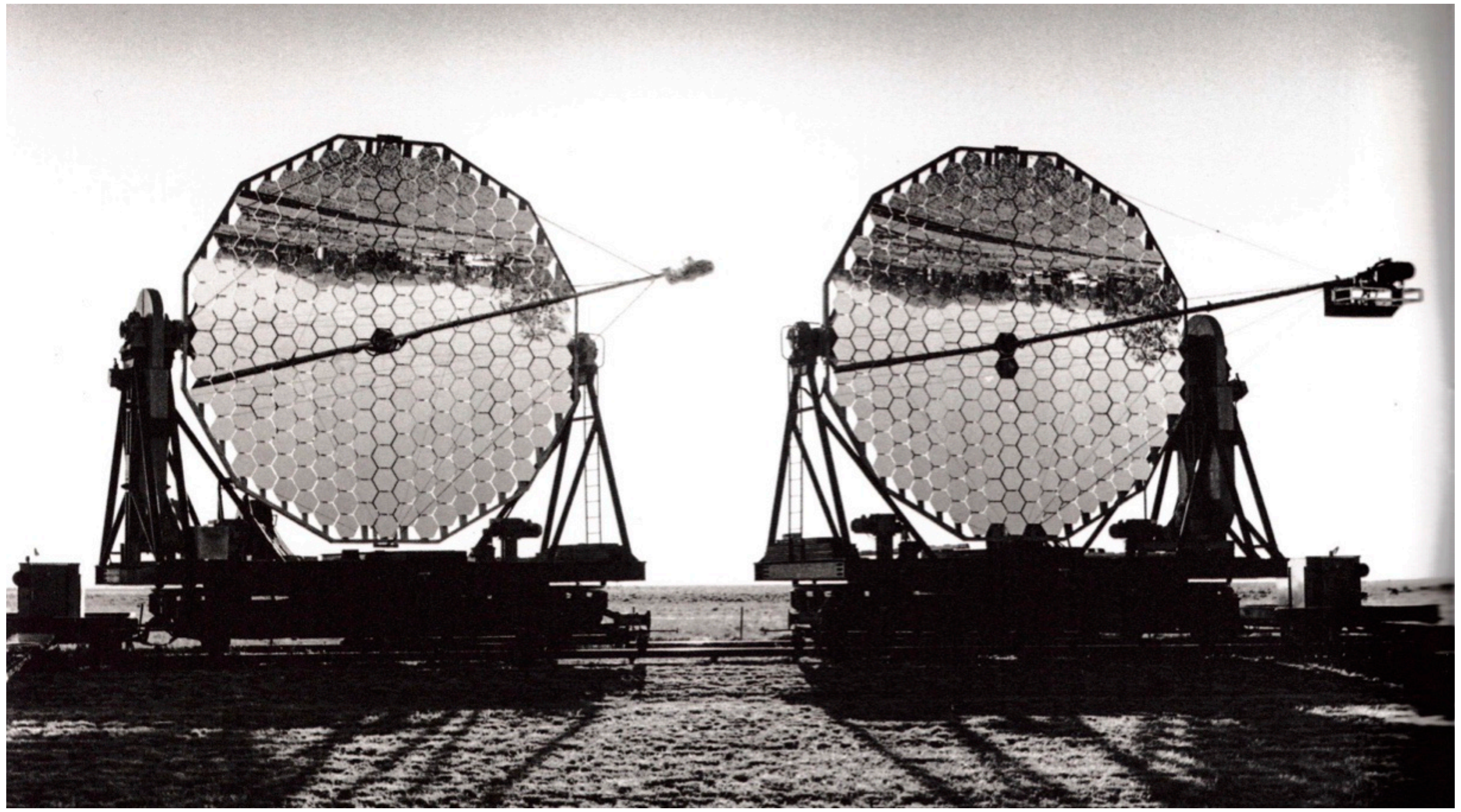
Output

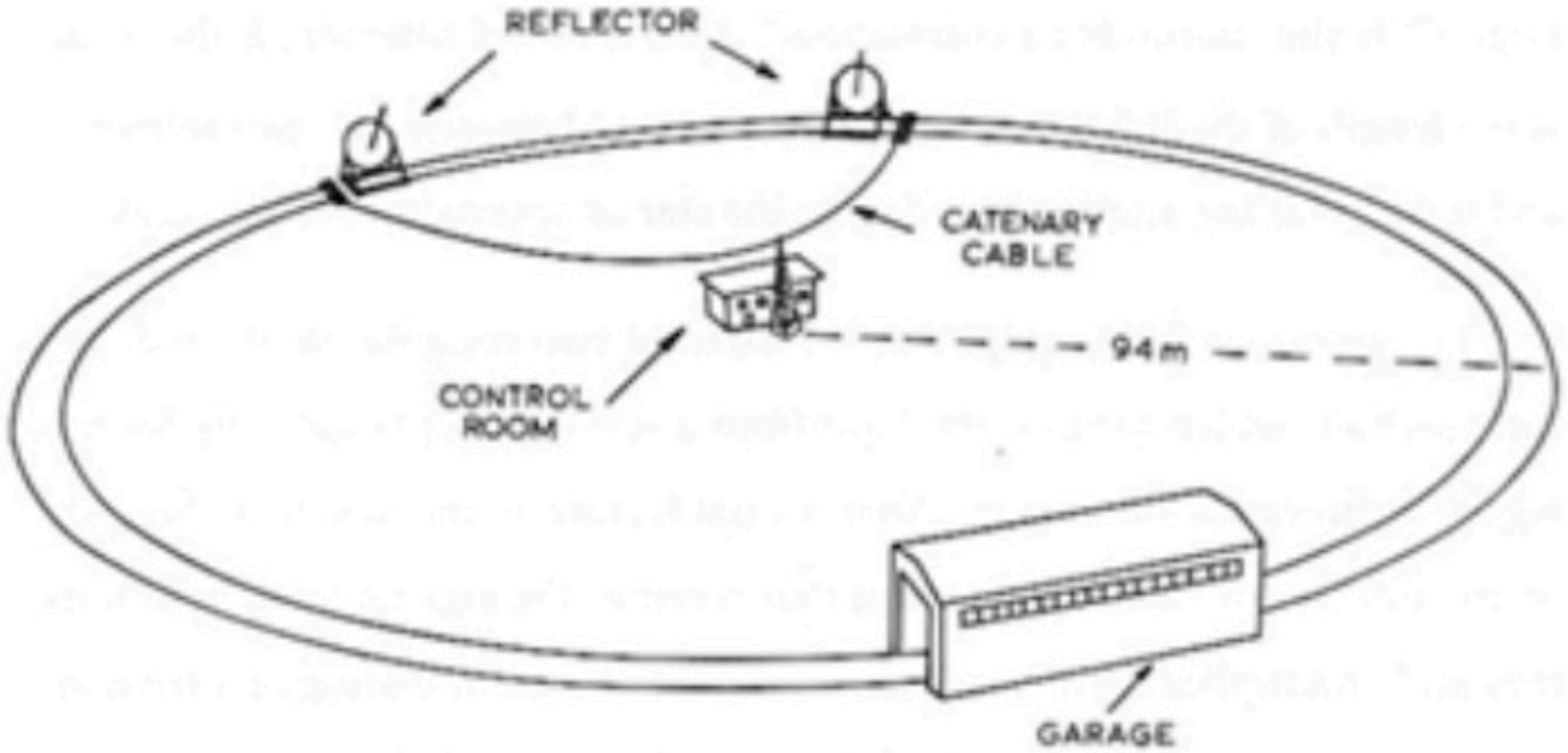
$$P_{12}(cg) = P_{12}(dh) = (1/8)(1 + \cos(\delta_1 - \delta_2))$$
$$P_{12}(ch) = P_{12}(dg) = (1/8)(1 - \cos(\delta_1 - \delta_2))$$

In some cases, we get Hong–Ou–Mandel cancellations.

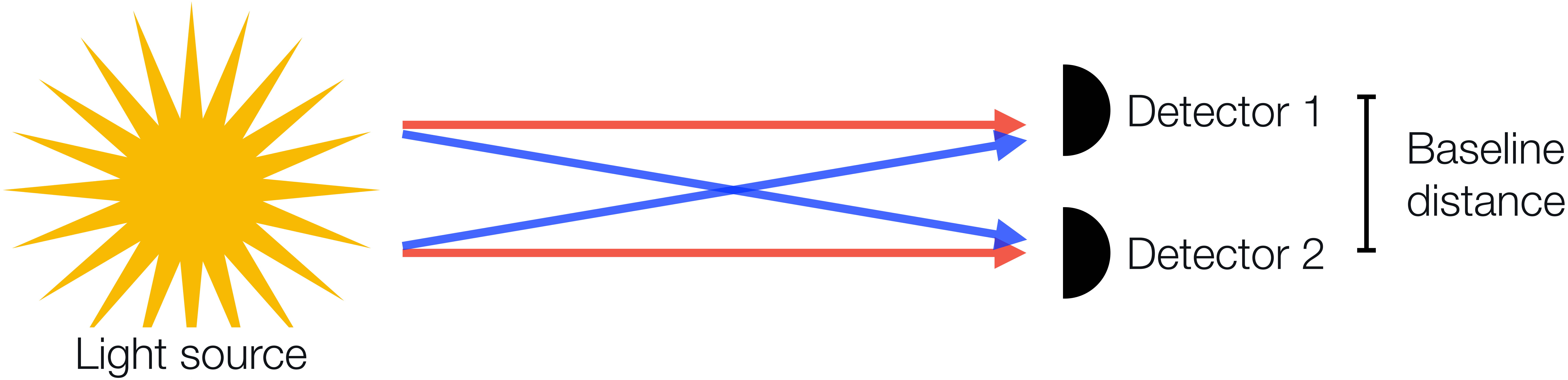
A combination of both the HBT and HOM effects.

Hanbury Brown - Twiss effect

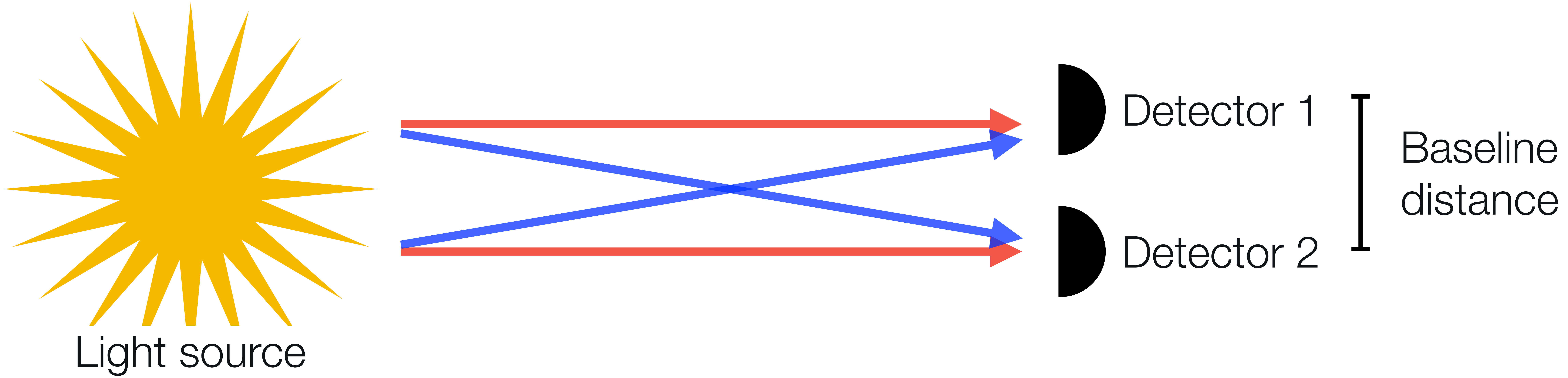




Hanbury Brown - Twiss effect



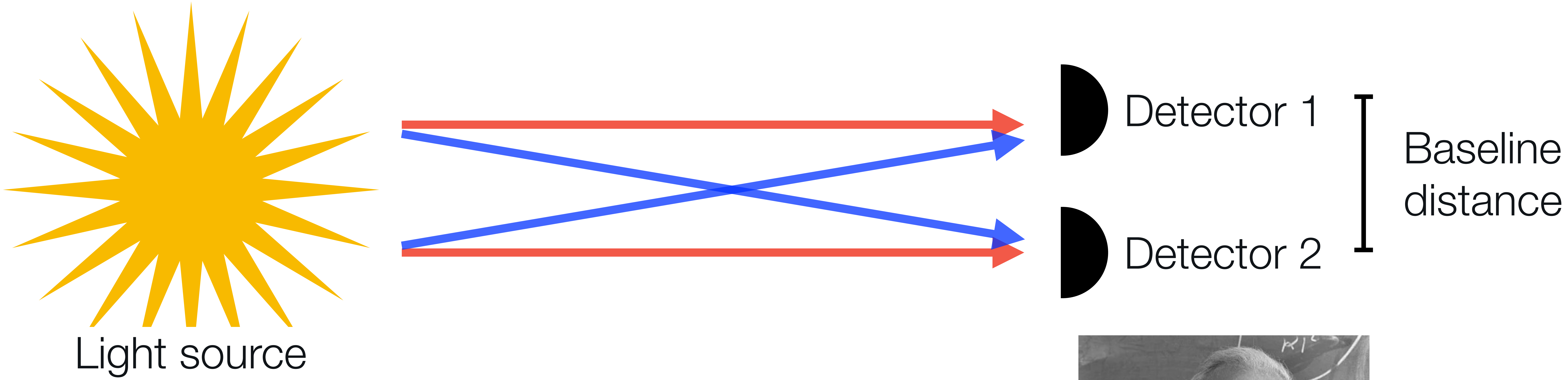
Hanbury Brown - Twiss effect



HBT:

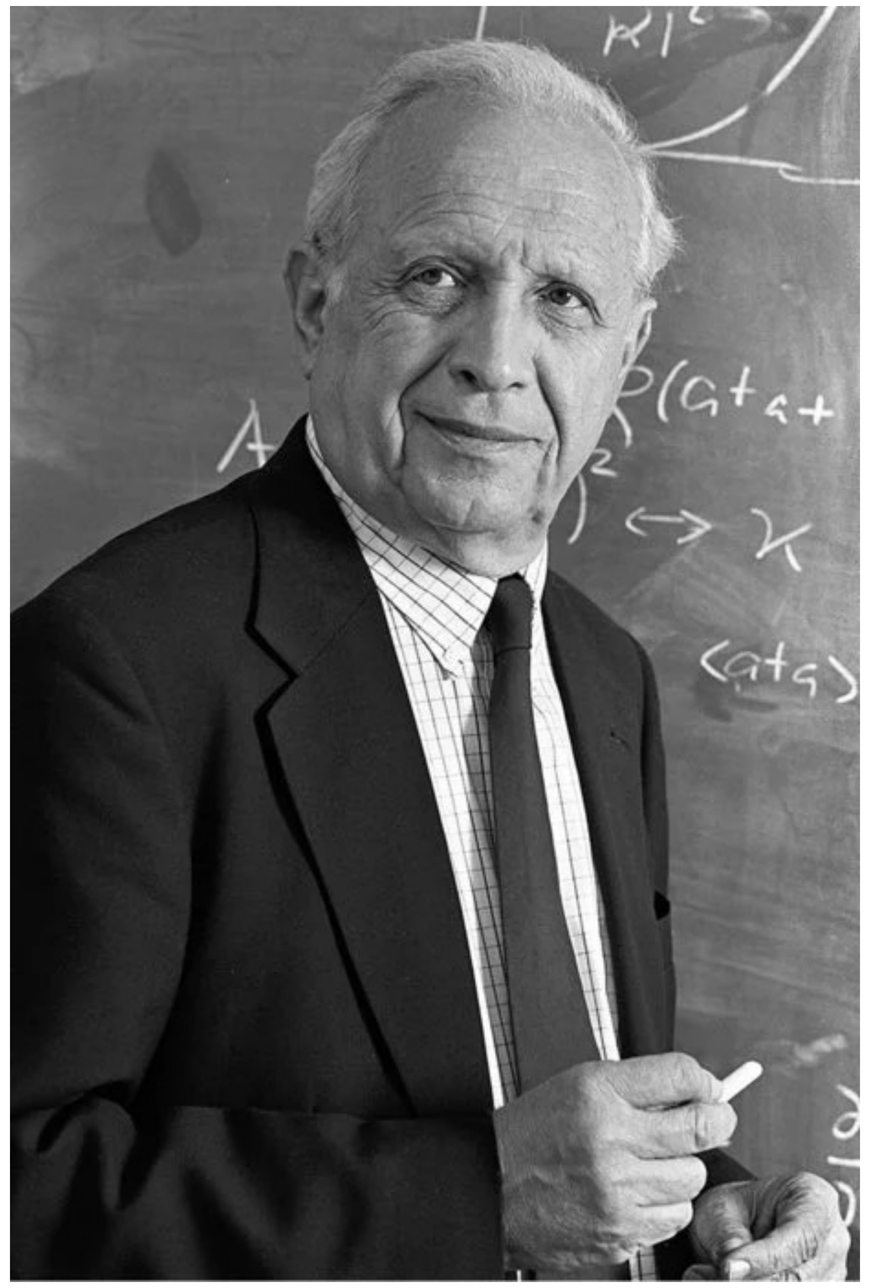
- the bunching of photons coming from a thermal light source
- produces an enhancement in the rate of photon coincidences, creating a peak in the distribution of pair arrival time differences Δt

Hanbury Brown - Twiss effect

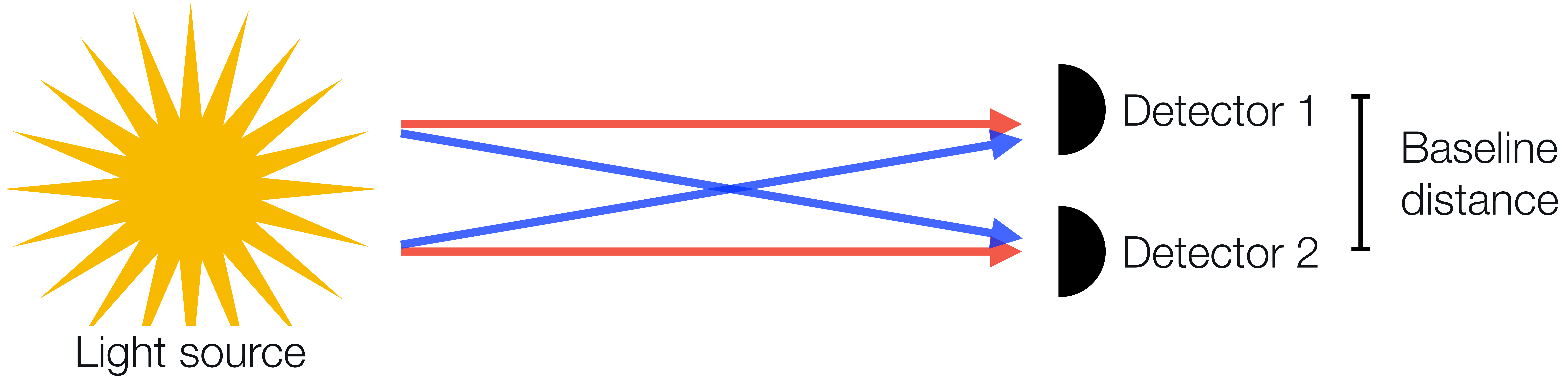


Crucial for the development of Quantum Optics

Roy Glauber (Physics Nobel, 2005)



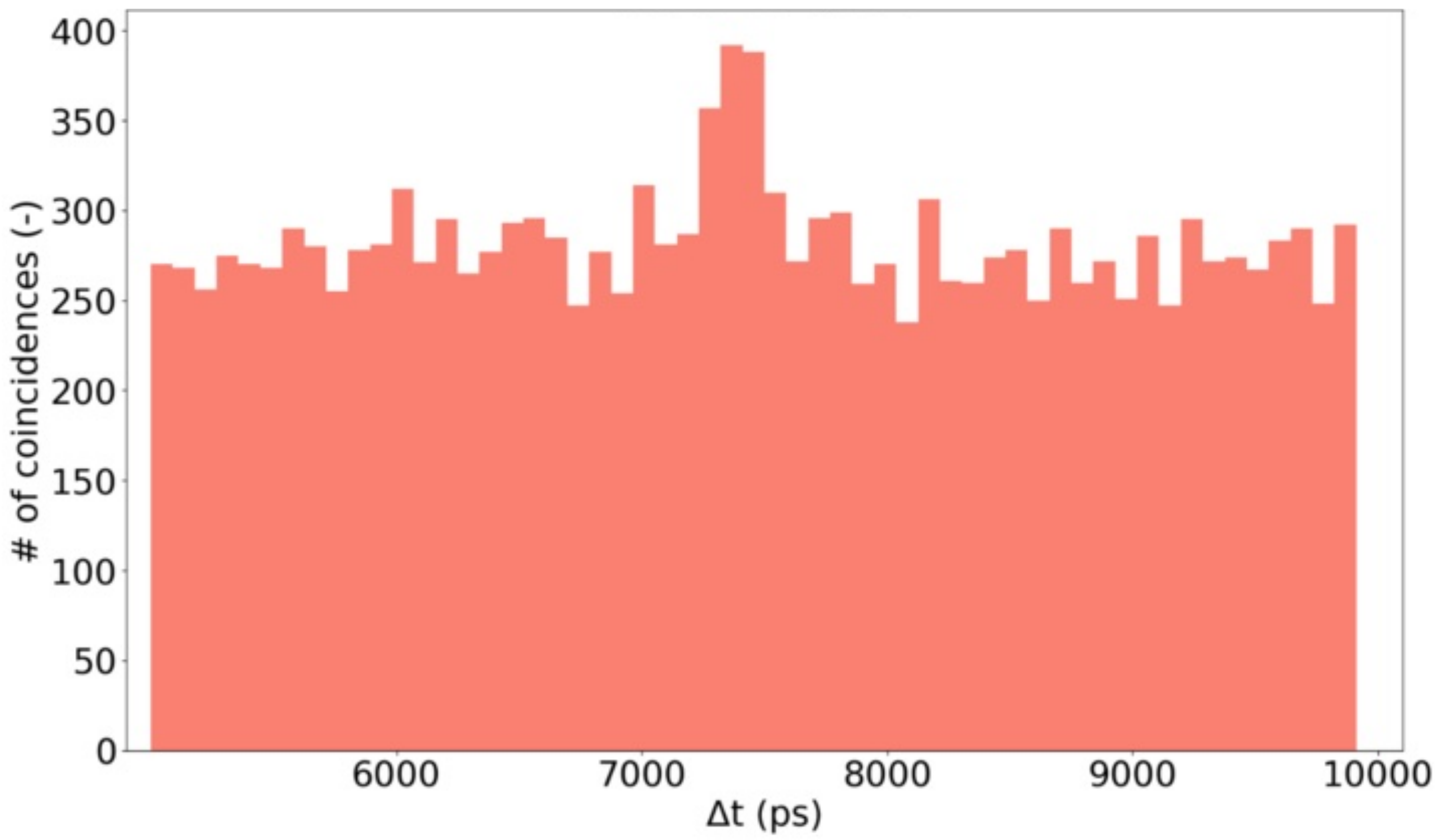
Hanbury Brown - Twiss effect



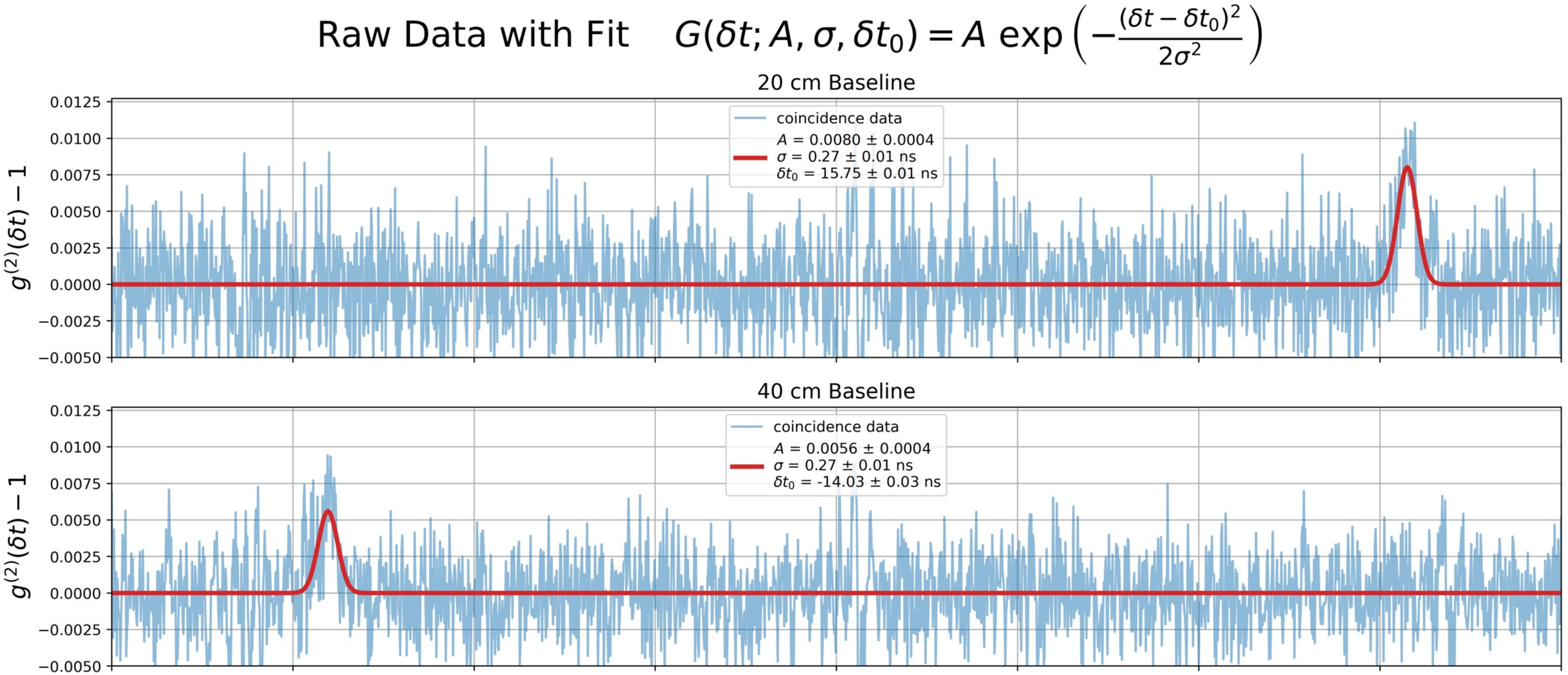
Applications in many areas: nuclear physics

Baym, Gordon. "The physics of Hanbury Brown--Twiss intensity interferometry: from stars to nuclear collisions." *arXiv preprint nucl-th/9804026* (1998).

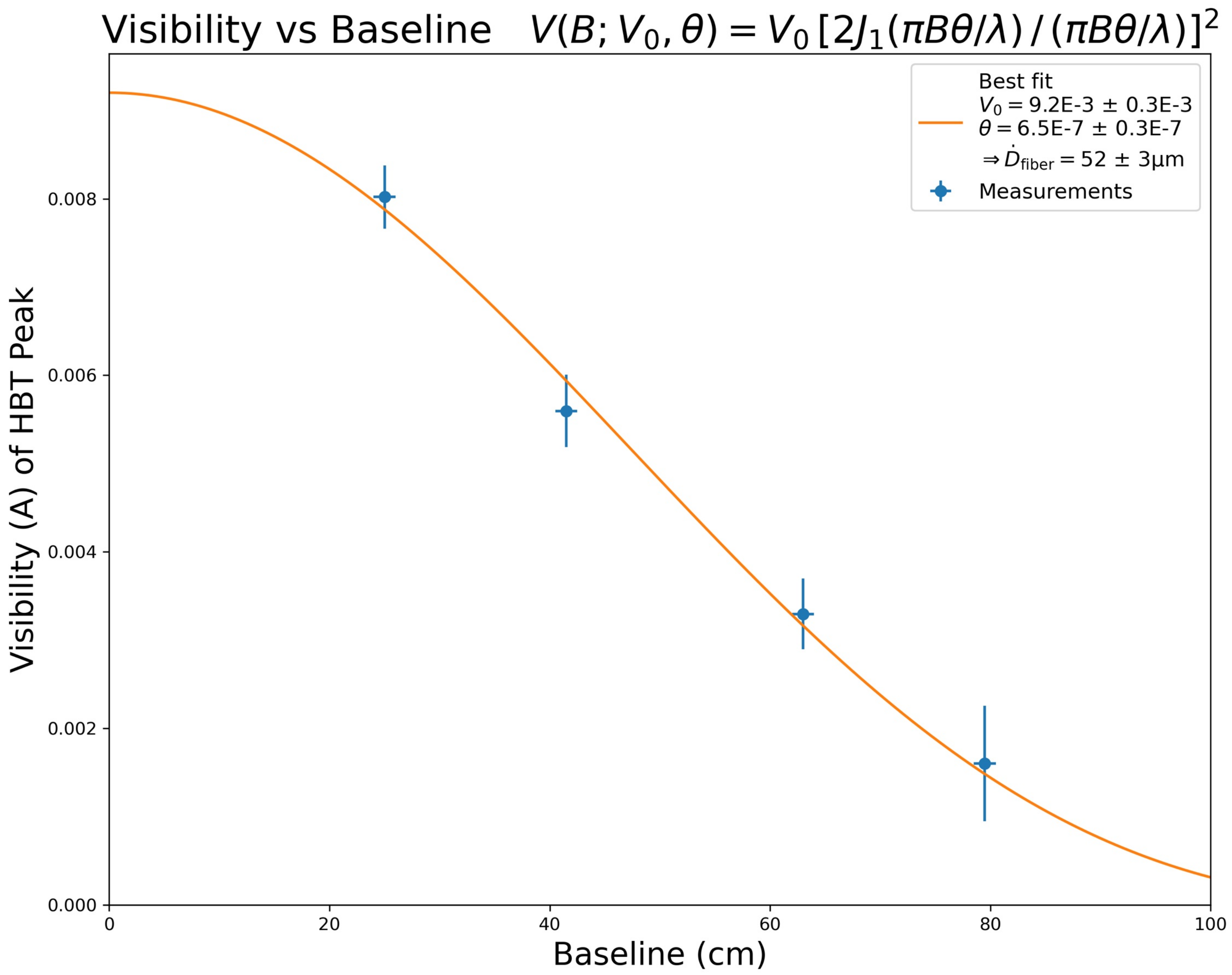
Hanbury Brown - Twiss effect



Hanbury Brown - Twiss effect



Hanbury Brown - Twiss effect



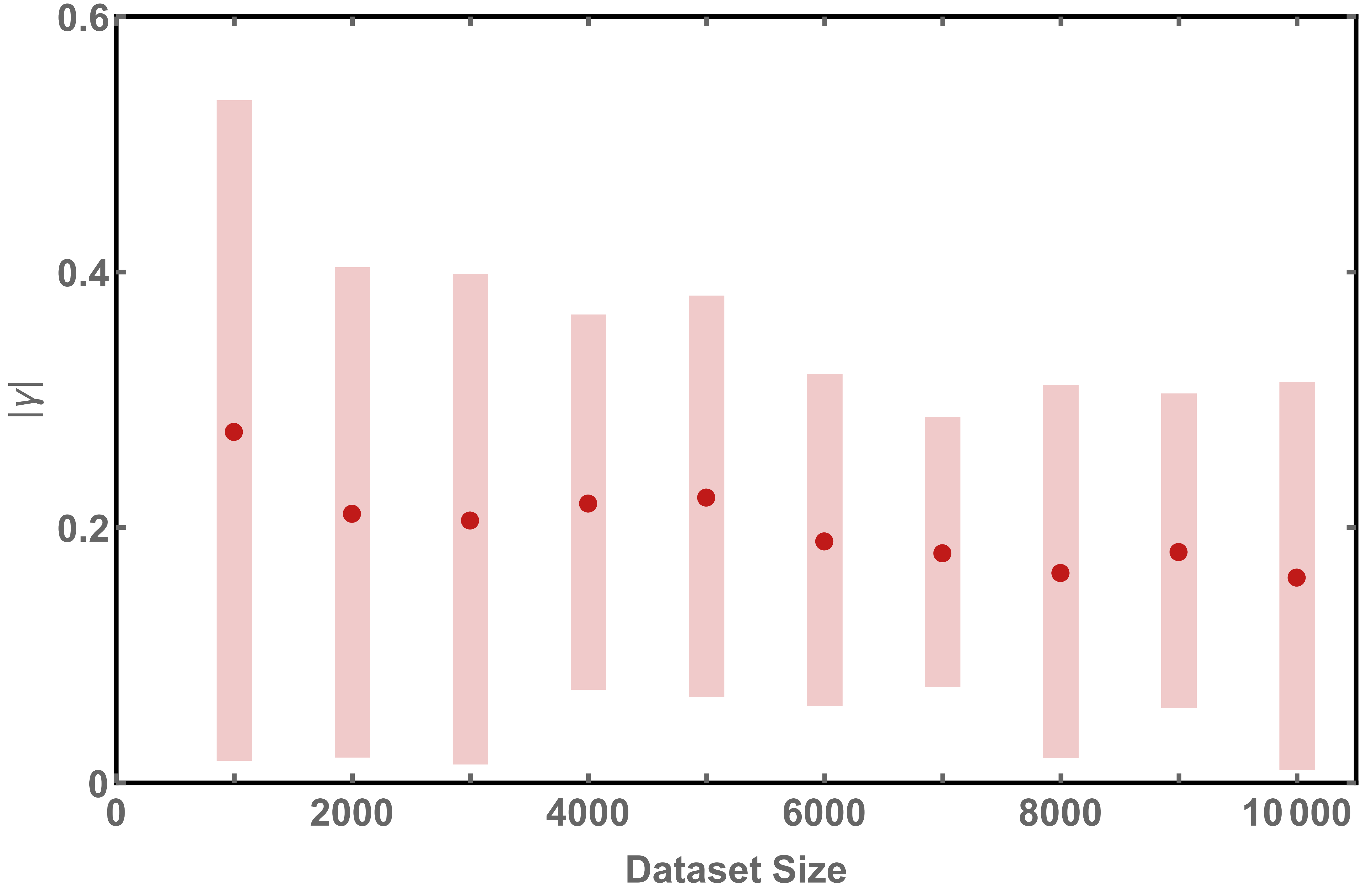
A side note …

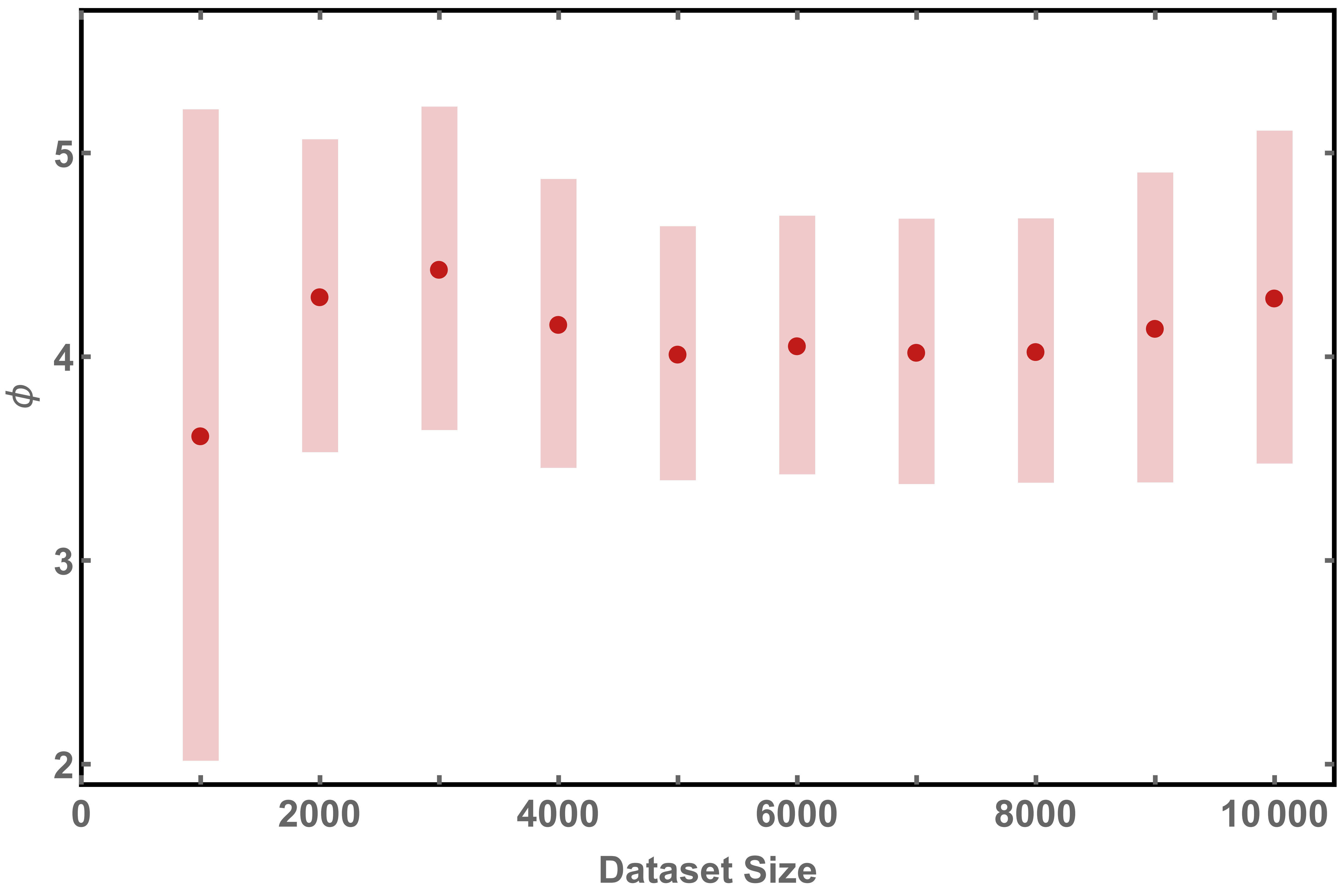
PHYSICAL REVIEW LETTERS **123,** 143604 (2019)

Optimal Imaging of Remote Bodies Using Quantum Detectors

L. A. Howard,[1] G. G. Gillett,[1] M. E. Pearce,[2] R. A. Abrahao,[1] T. J. Weinhold,[1] P. Kok,[2] and A. G. White[1]
[1]*Centre for Engineered Quantum Systems, School of Mathematics and Physics, University of Queensland, 4072 Brisbane, Australia*
[2]*Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, United Kingdom*

Incoherent source: traditonal scheme

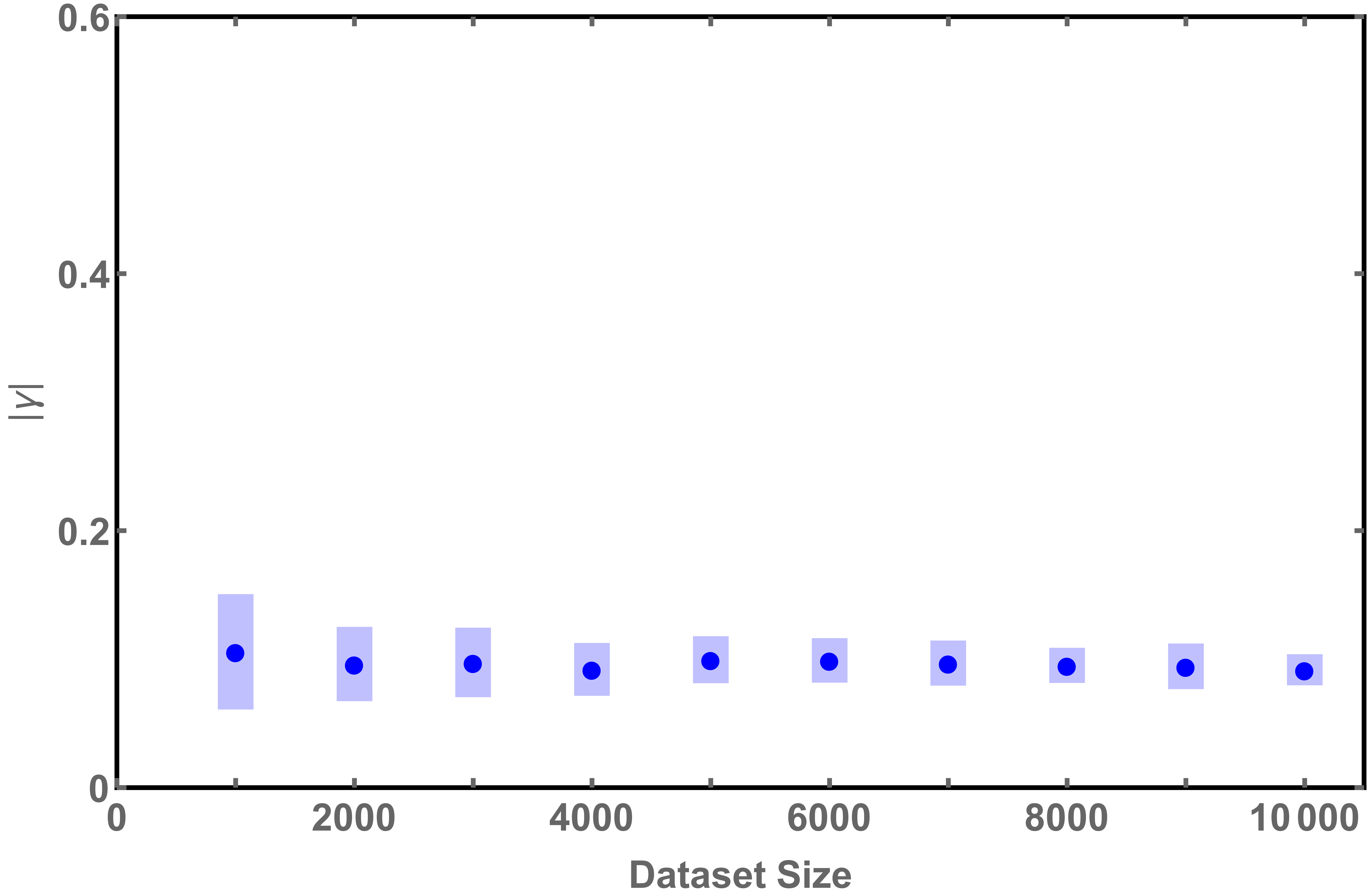


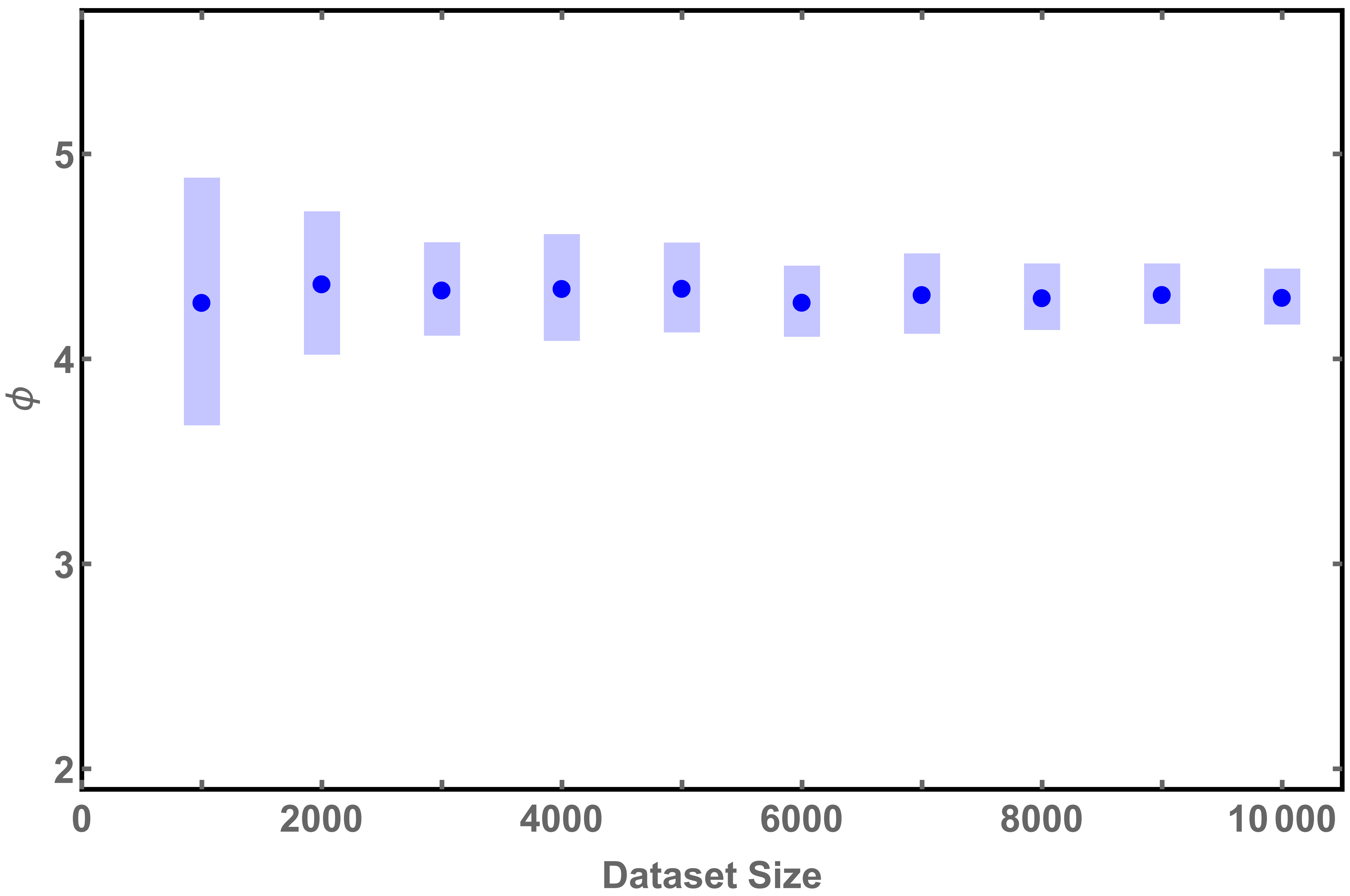


$\gamma = 0.20 \pm 0.16$

$\varphi = 4.50 \pm 1.0$

Incoherent source: count scheme





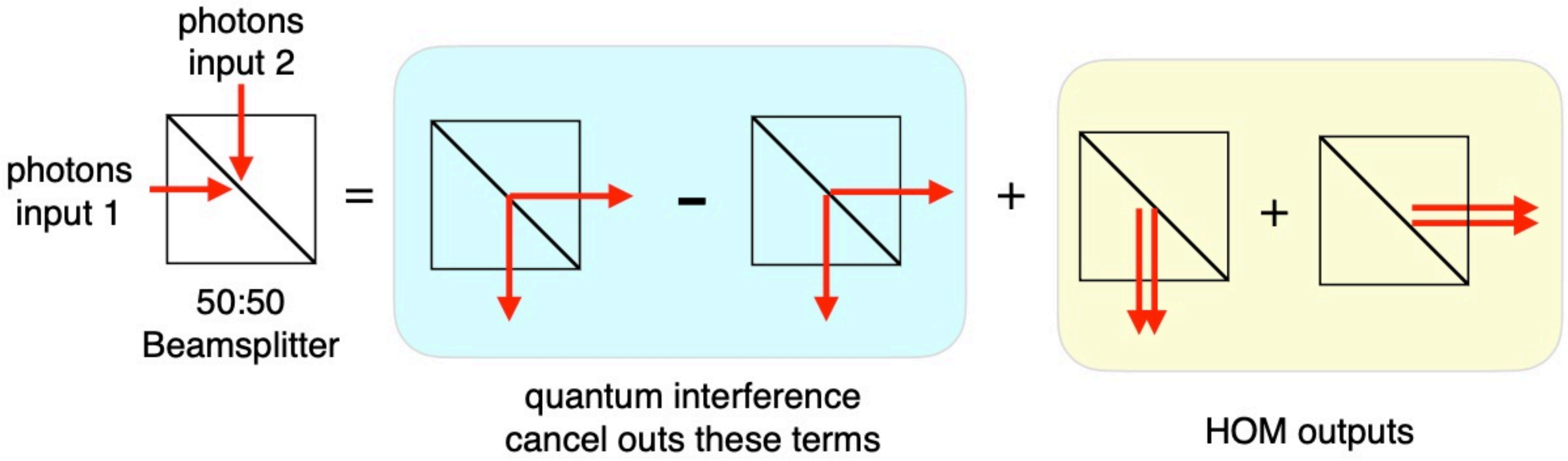
$\gamma = 0.20 \pm 0.16$

$\gamma = 0.096 \pm 0.022$

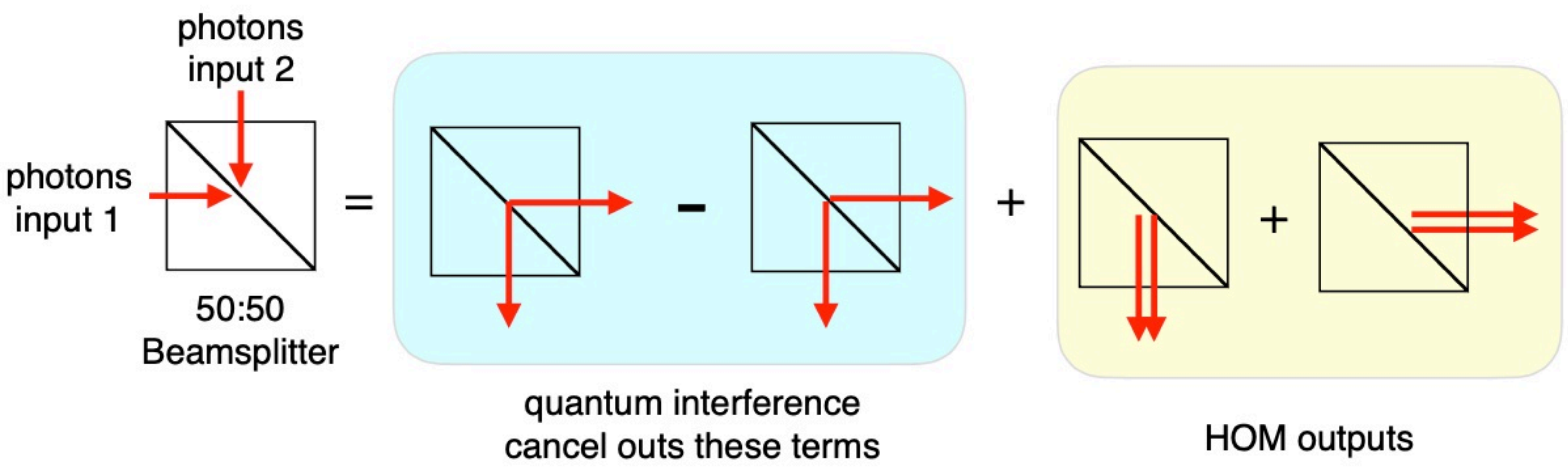
$\varphi = 4.50 \pm 1.0$

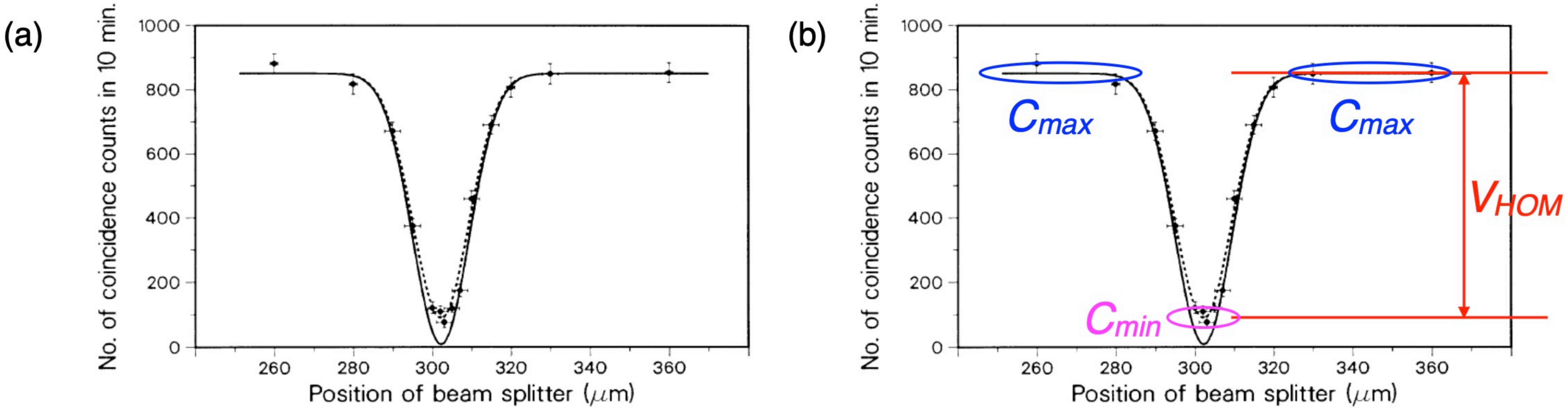
$\varphi = 4.32 \pm 0.25$

Hong-Ou-Mandel Effect



Hong-Ou-Mandel Effect





C.-K. Hong, Z.-Y. Ou, and L. Mandel, "Measurement of subpicosecond time intervals between two photons by interference," Physical Review Letters, vol. 59, no. 18, p. 2044, 1987.

Another side note …

PHYSICAL REVIEW A **106**, 063715 (2022)

Quantum metrology timing limits of the Hong-Ou-Mandel interferometer and of general two-photon measurements

Kyle M. Jordan,[1,*] Raphael A. Abrahao,[1,2] and Jeff S. Lundeen[1,3]

[1] *Department of Physics and Center for Research in Photonics, University of Ottawa, 25 Templeton Street, Ottawa, Ontario, Canada K1N 6N5*

[2] *Brookhaven National Laboratory, Upton, New York 11973, USA*

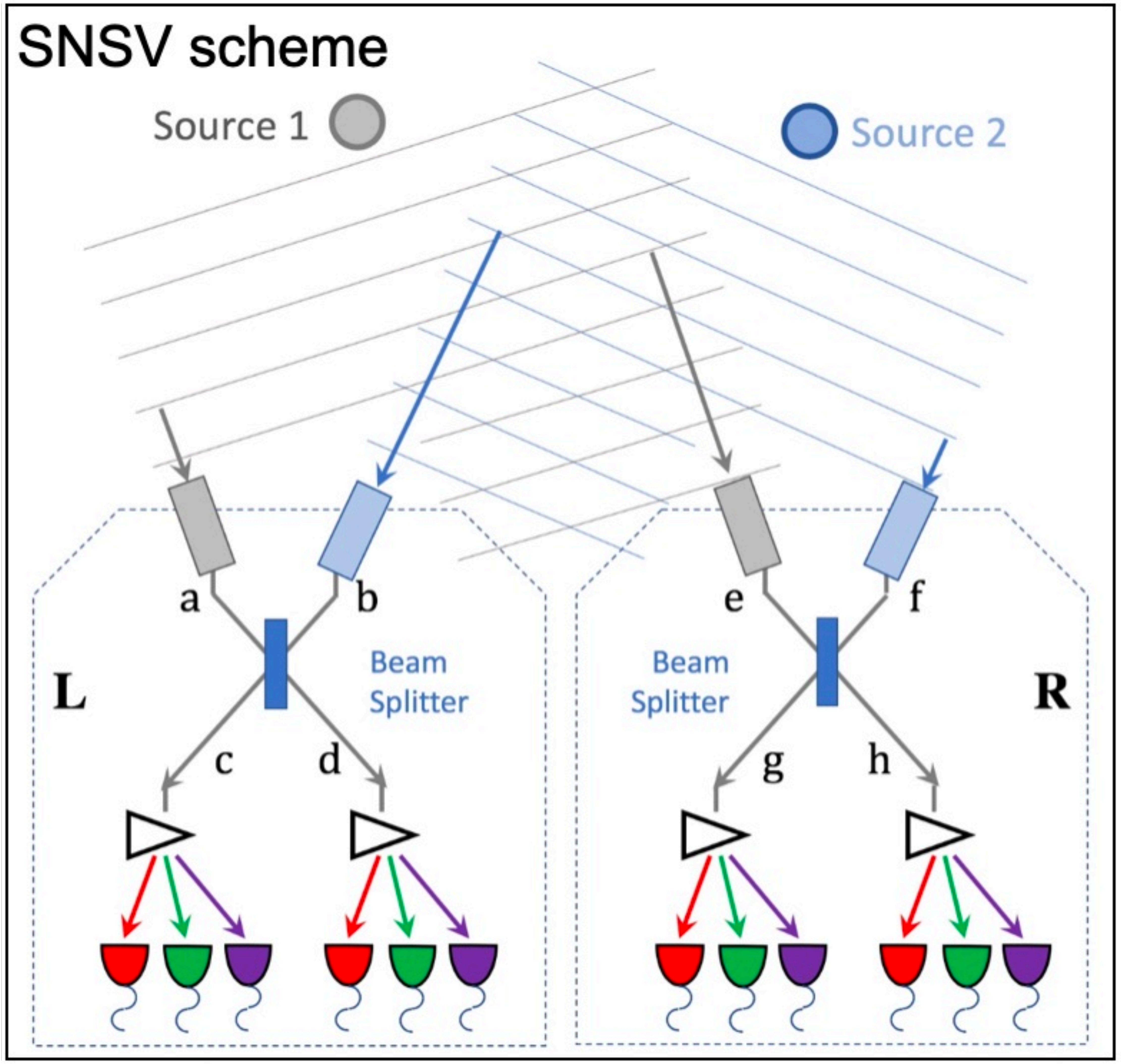
[3] *Joint Center for Extreme Photonics, University of Ottawa and National Research Council of Canada, 100 Sussex Drive, Ottawa, Ontario, Canada K1A 0R6*

(Received 4 July 2022; accepted 2 December 2022; published 22 December 2022)

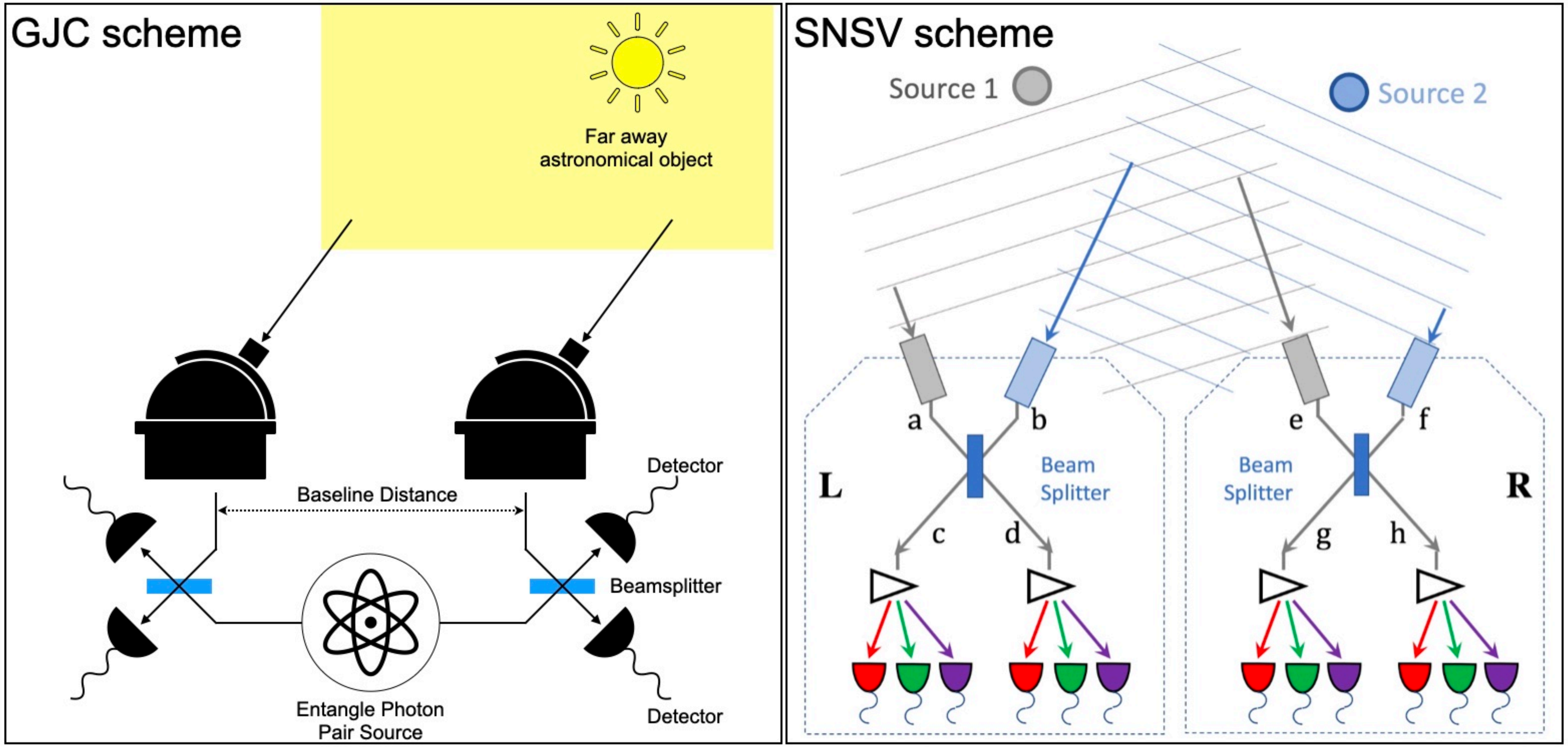
No need for optical connection between base stations

Enable long distance baseline

Requires 2 photons → brighter objects



Two-photon amplitude interferometry for precision astrometry
The Open Journal of Astrophysics 2022



Many great applications in
Astrophysics and Cosmology

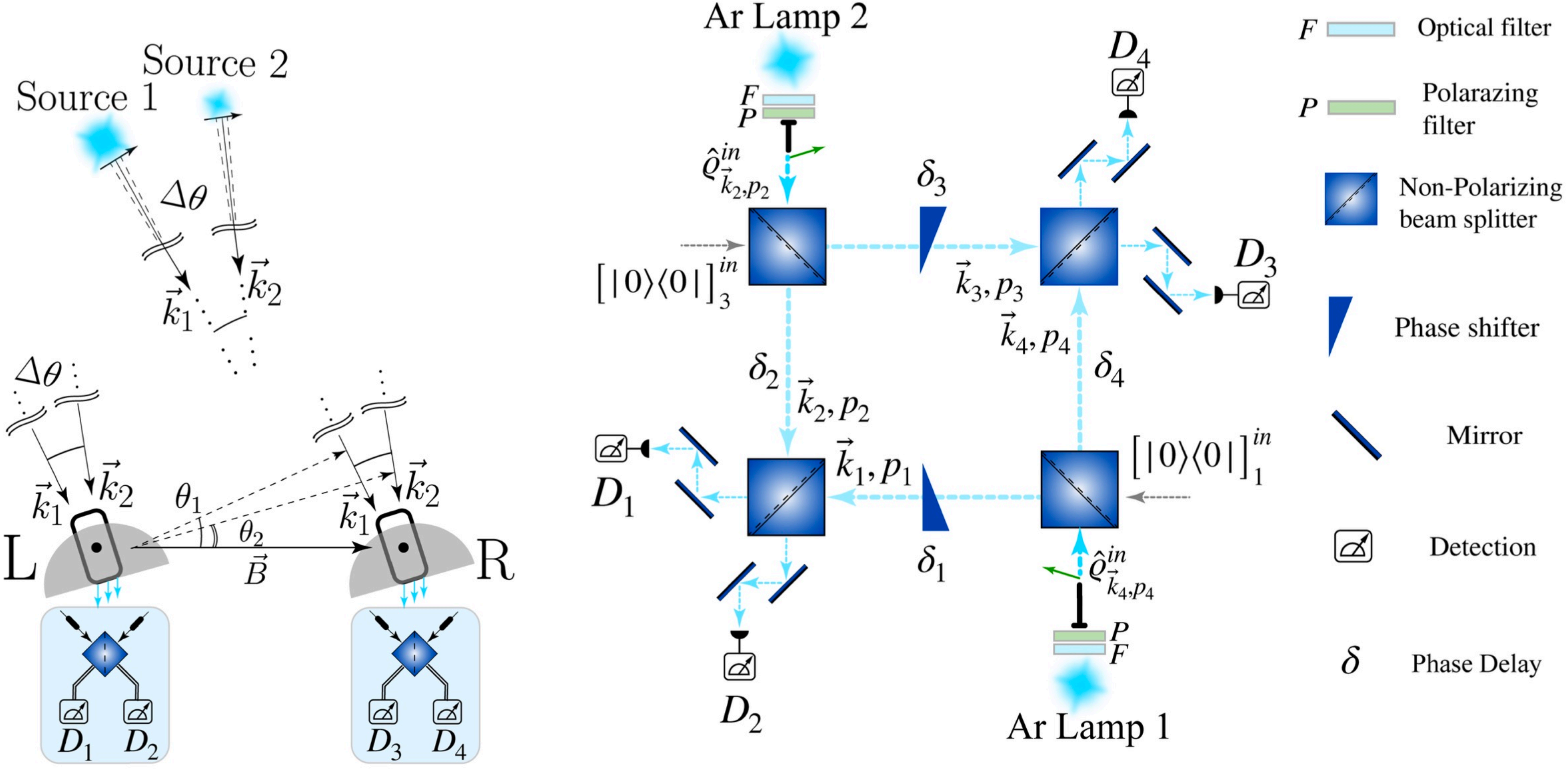
Research Article Vol. 31, No. 26 / 18 Dec 2023 / *Optics Express* 44246

Optics EXPRESS

Towards quantum telescopes: demonstration of a two-photon interferometer for precision astrometry

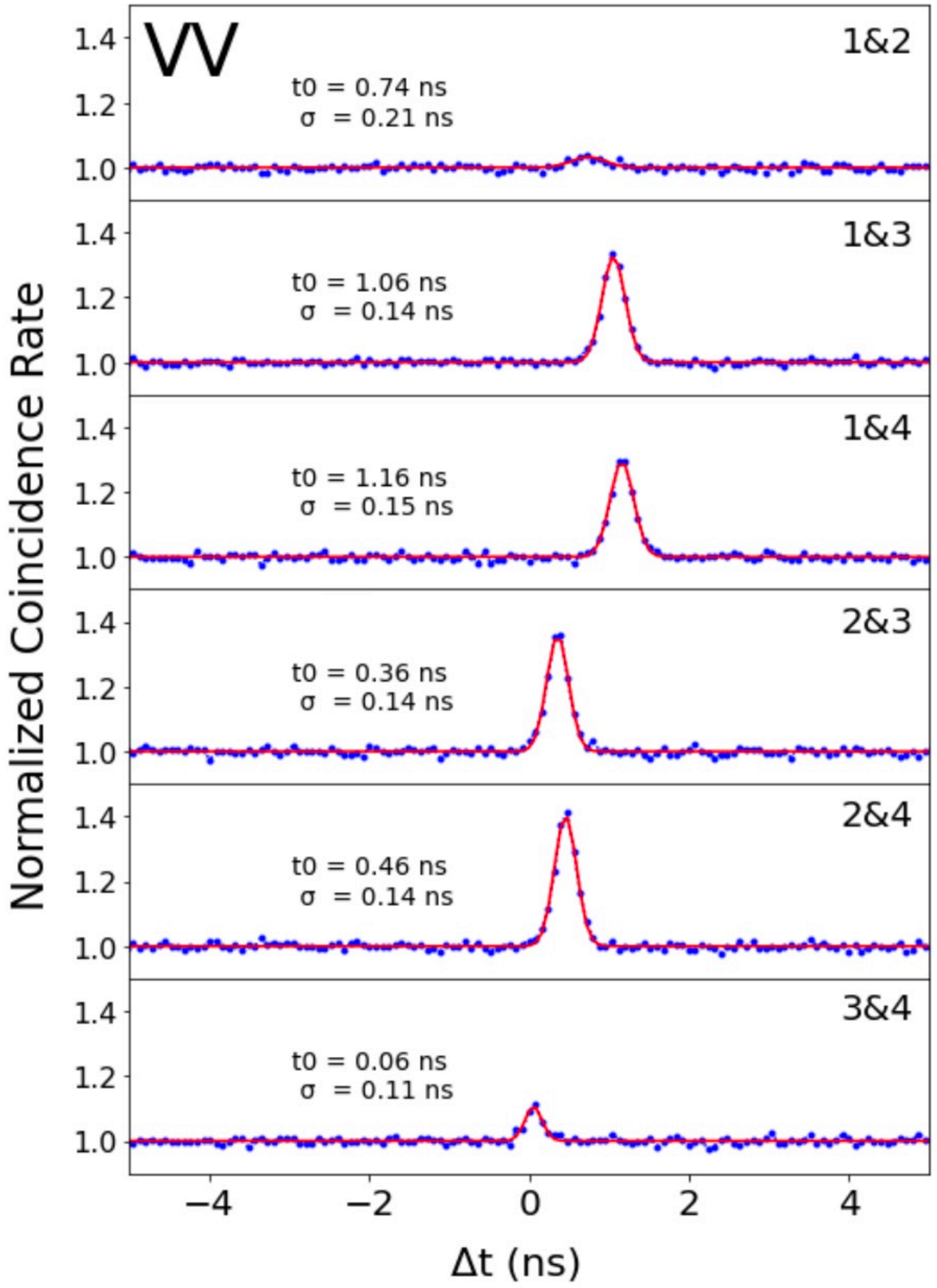
JESSE CRAWFORD,[1] DENIS DOLZHENKO,[1] MICHAEL KEACH,[1] AARON MUENINGHOFF,[2] RAPHAEL A. ABRAHAO,[1] JULIAN MARTINEZ-RINCON,[1] PAUL STANKUS,[1] STEPHEN VINTSKEVICH,[3] AND ANDREI NOMEROTSKI[2,*]

Proof-of-principle tabletop experiment

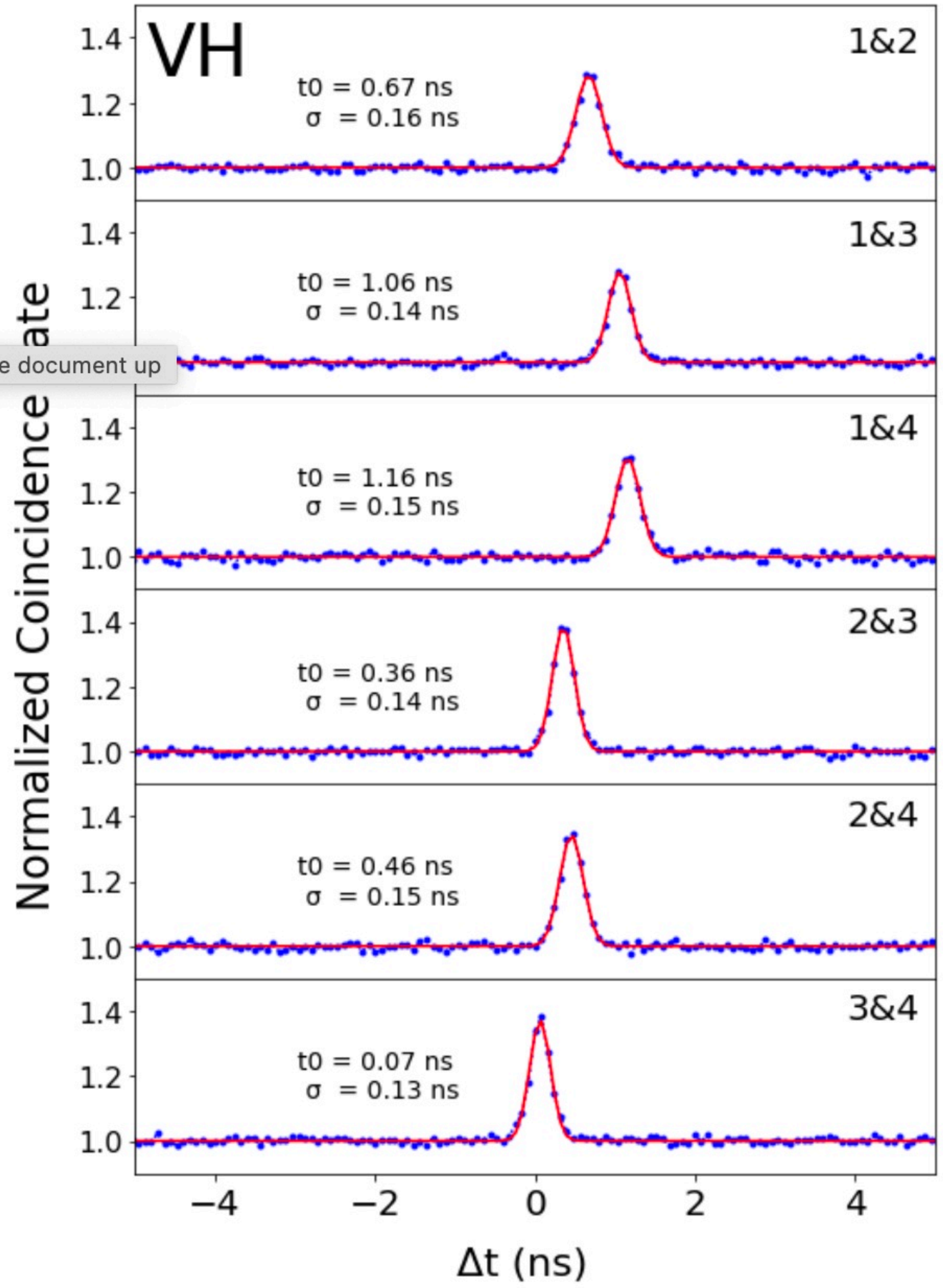


(a) SNSV scheme

(b) Tabletop implementation

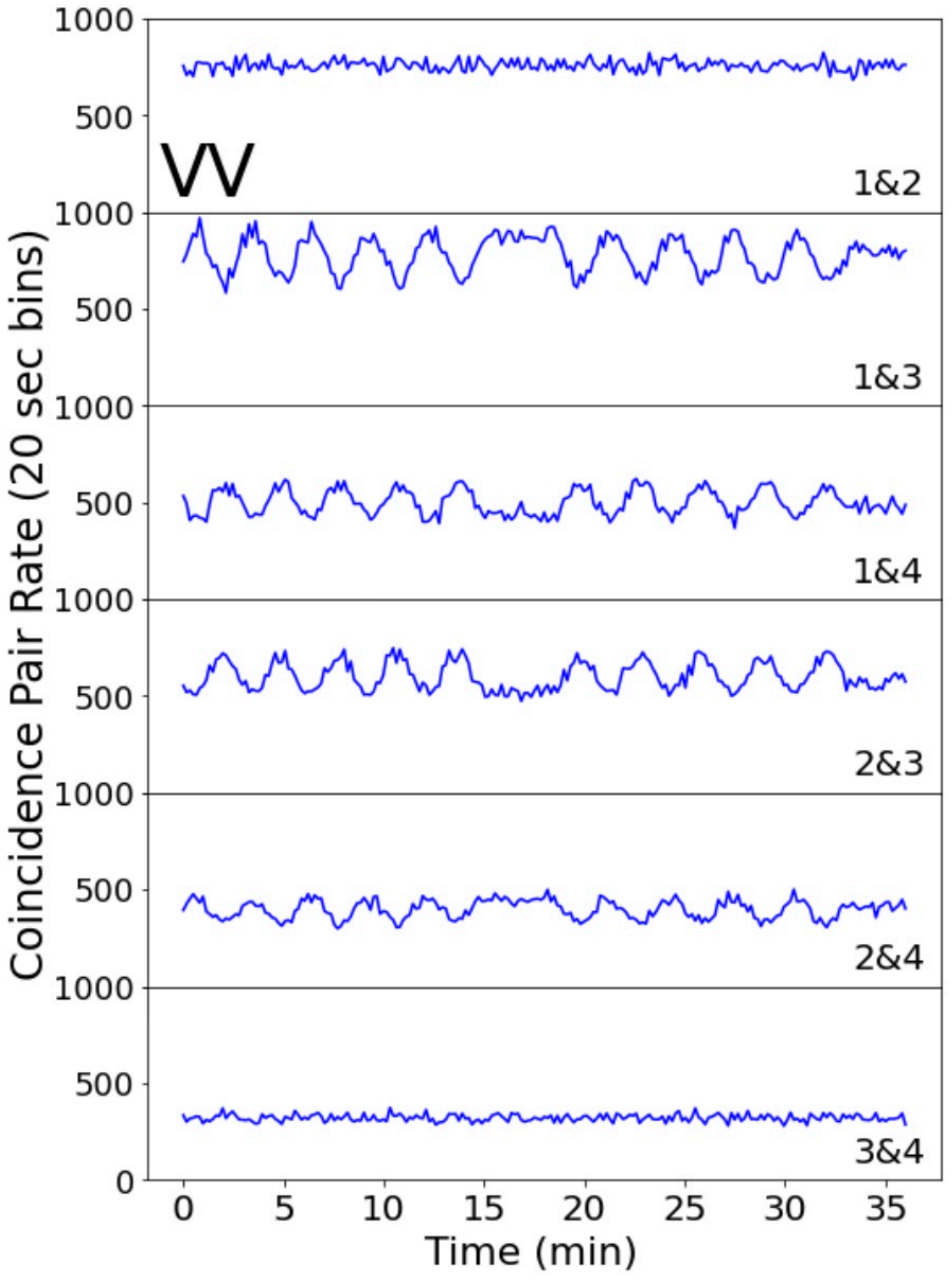


(a) VV

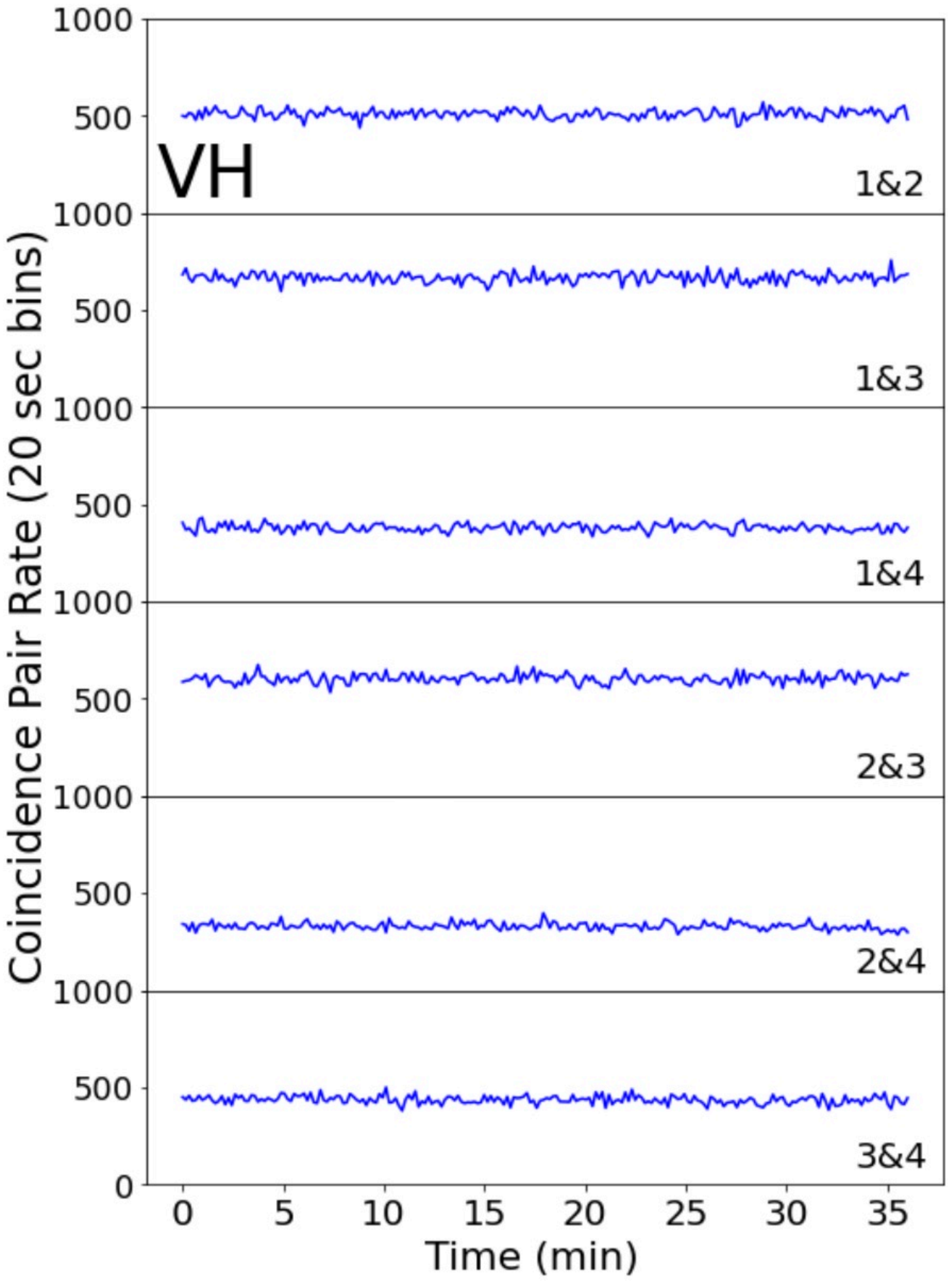


(b) VH

HBT peaks ✓


VV
1000
500
0
1&2
1&3
1&4
2&3
2&4
3&4
Coincidence Pair Rate (20 sec bins)
0
5
10
15
20
25
30
35
Time (min)

(a) VV


VH
1000
500
0
1&2
1&3
1&4
2&3
2&4
3&4
Coincidence Pair Rate (20 sec bins)
0
5
10
15
20
25
30
35
Time (min)

(b) VH

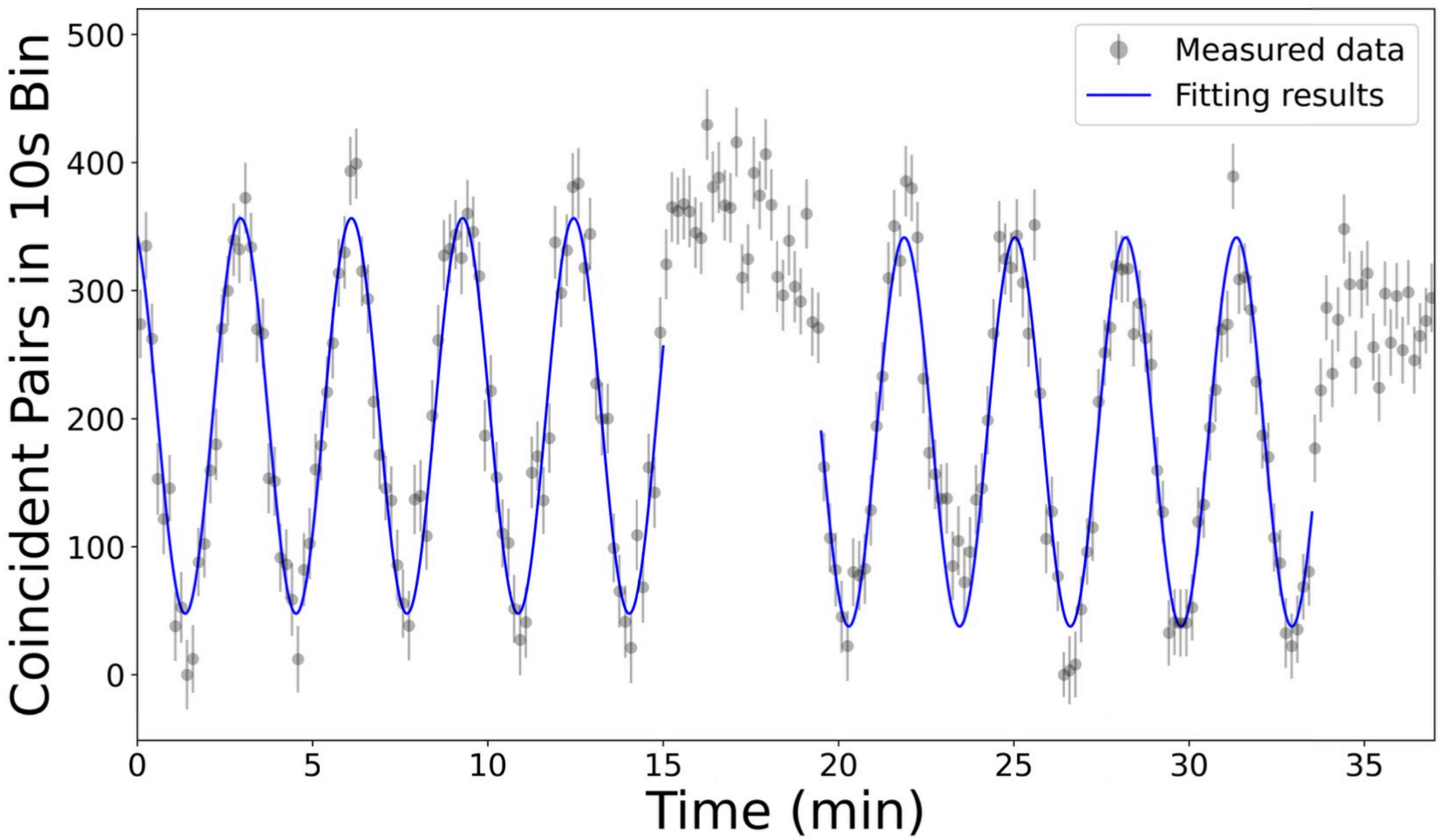
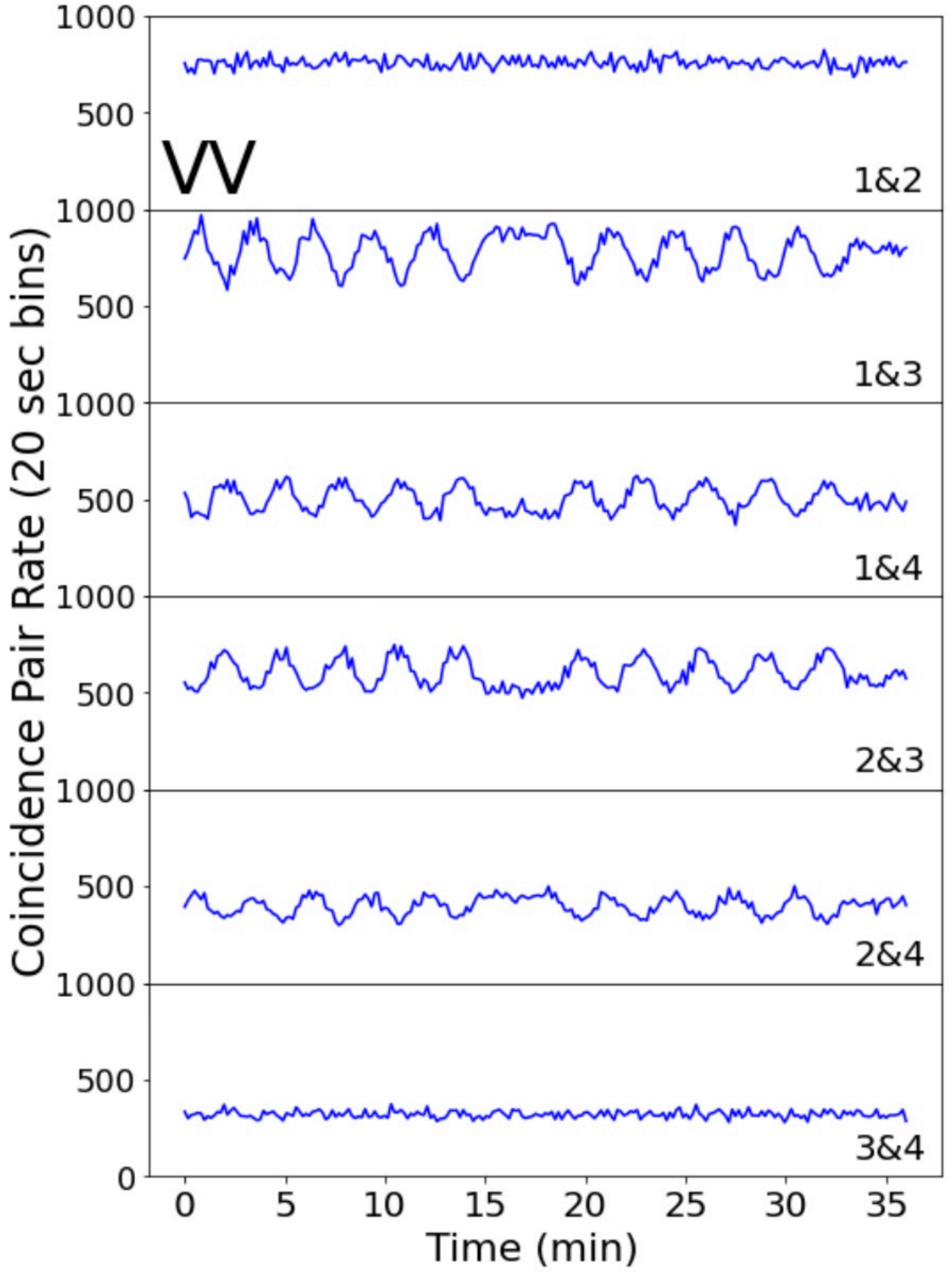
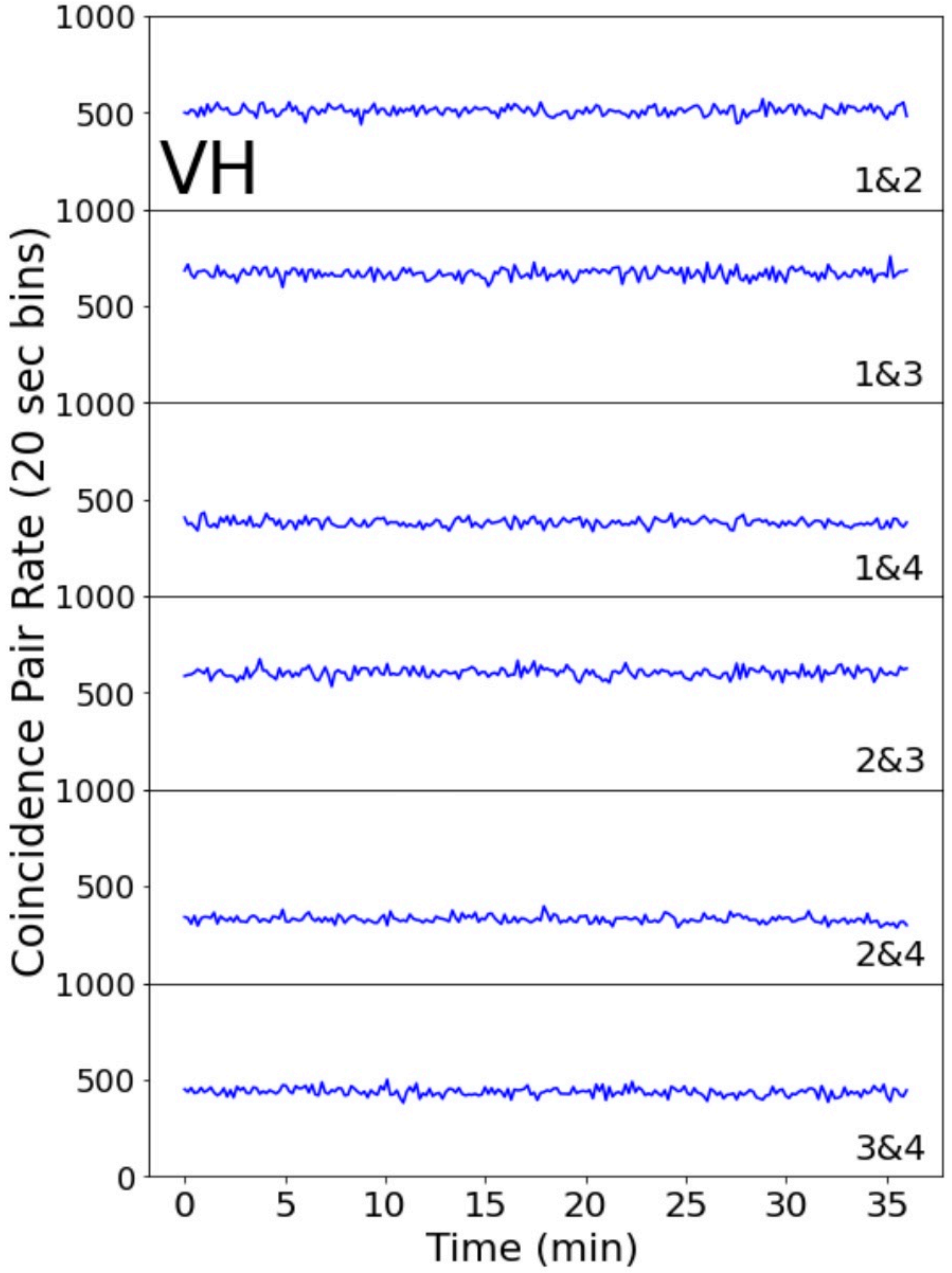


Fig. 4. Two-photon coincidences count rates for the oscillations for detectors 1&3 in the SNSPD data set with VV polarization fit to Eq. (3). The coincidences rates were determined by fitting a Gaussian peak in each 10-second time bin. Data points are presented together with one standard deviation error bars.



(a) VV



(b) VH

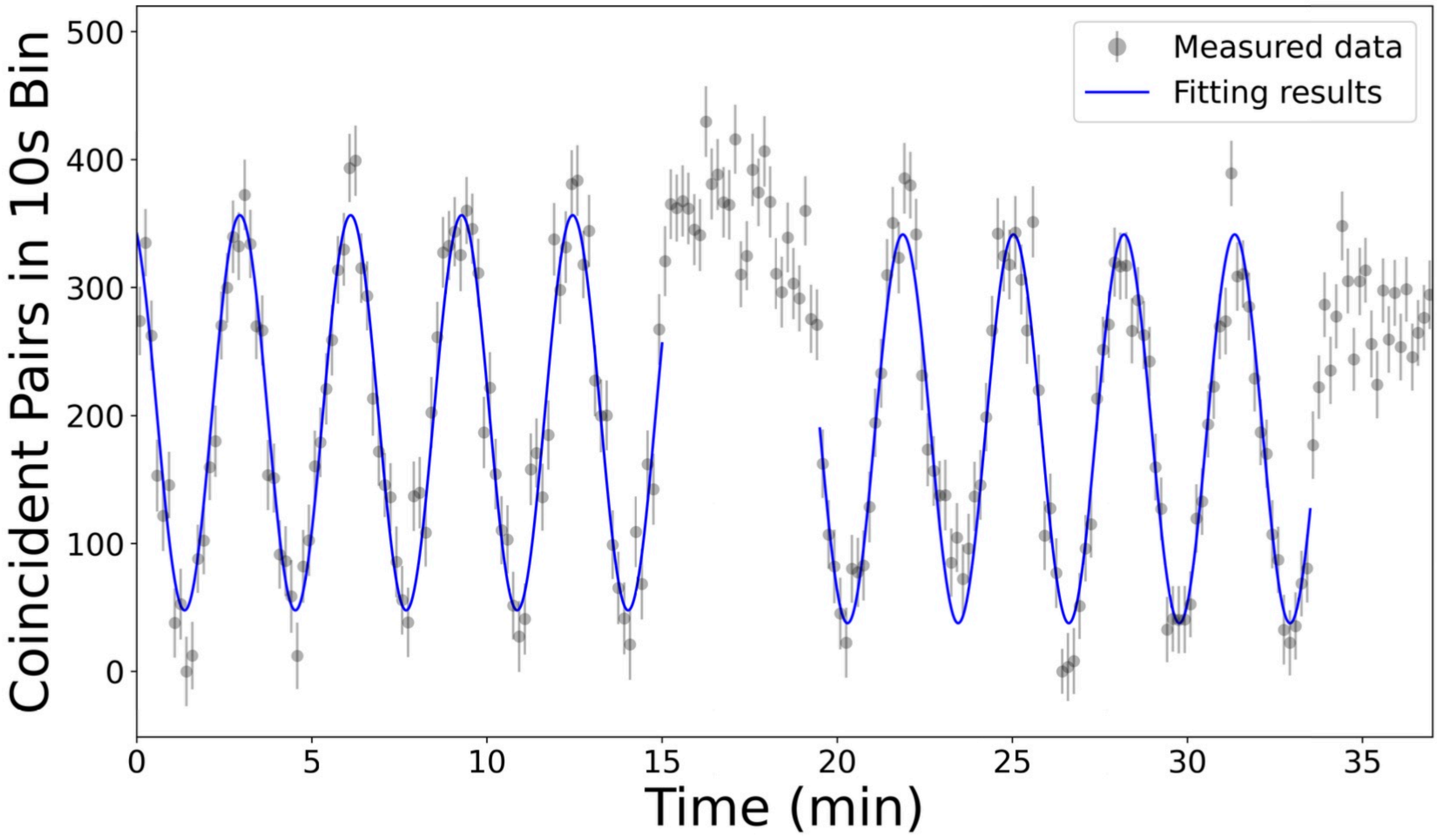
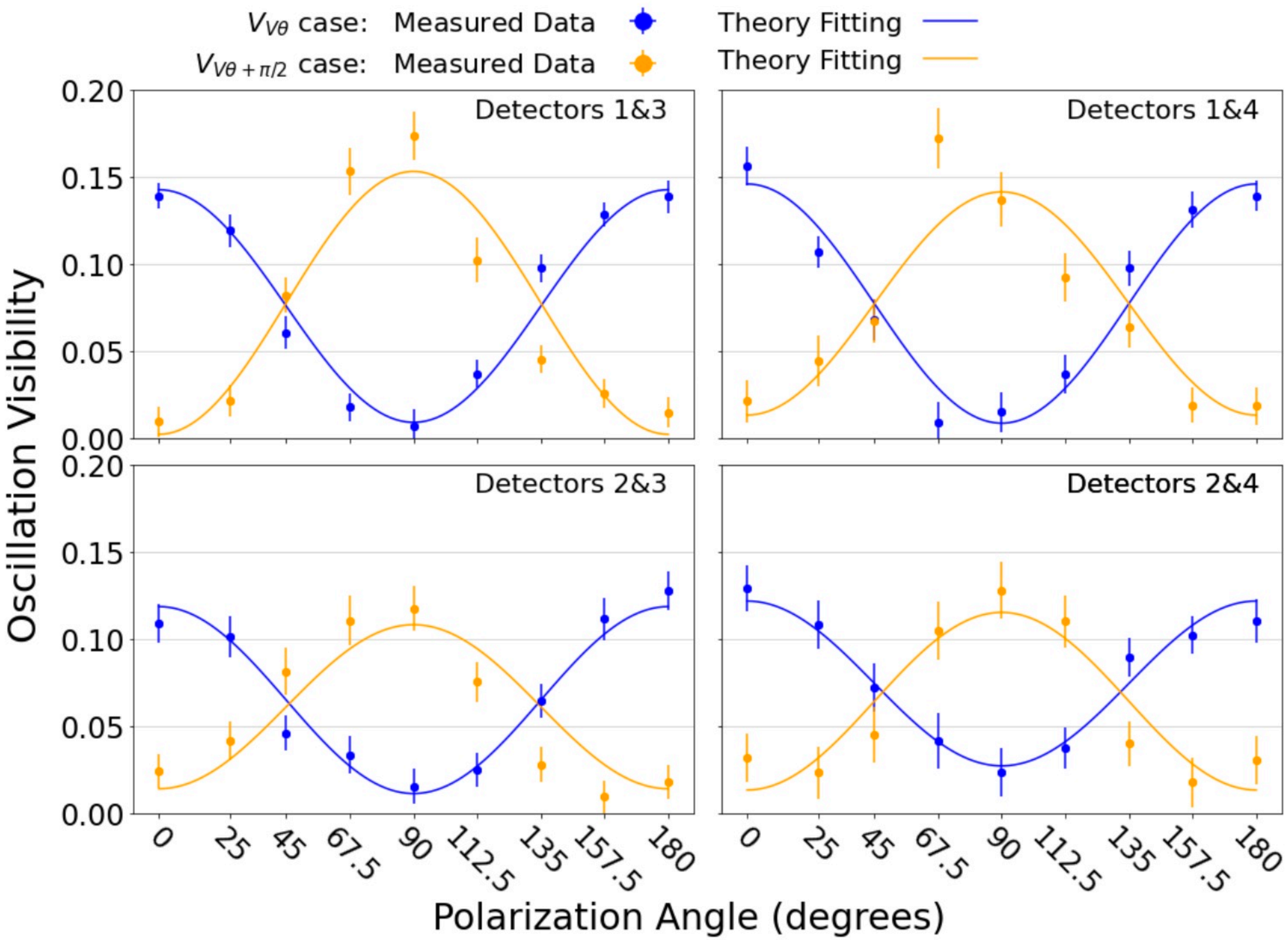


Fig. 4. Two-photon coincidences count rates for the oscillations for detectors 1&3 in the SNSPD data set with VV polarization fit to Eq. (3). The coincidences rates were determined by fitting a Gaussian peak in each 10-second time bin. Data points are presented together with one standard deviation error bars.

Phase Oscillations



$V_{V\theta}$ case: Measured Data
$V_{V\theta+\pi/2}$ case: Measured Data
Theory Fitting
Theory Fitting
Detectors 1&3
Detectors 1&4
Detectors 2&3
Detectors 2&4
Oscillation Visibility
0.00
0.05
0.10
0.15
0.20
0
25
45
67.5
90
112.5
135
157.5
180
Polarization Angle (degrees)

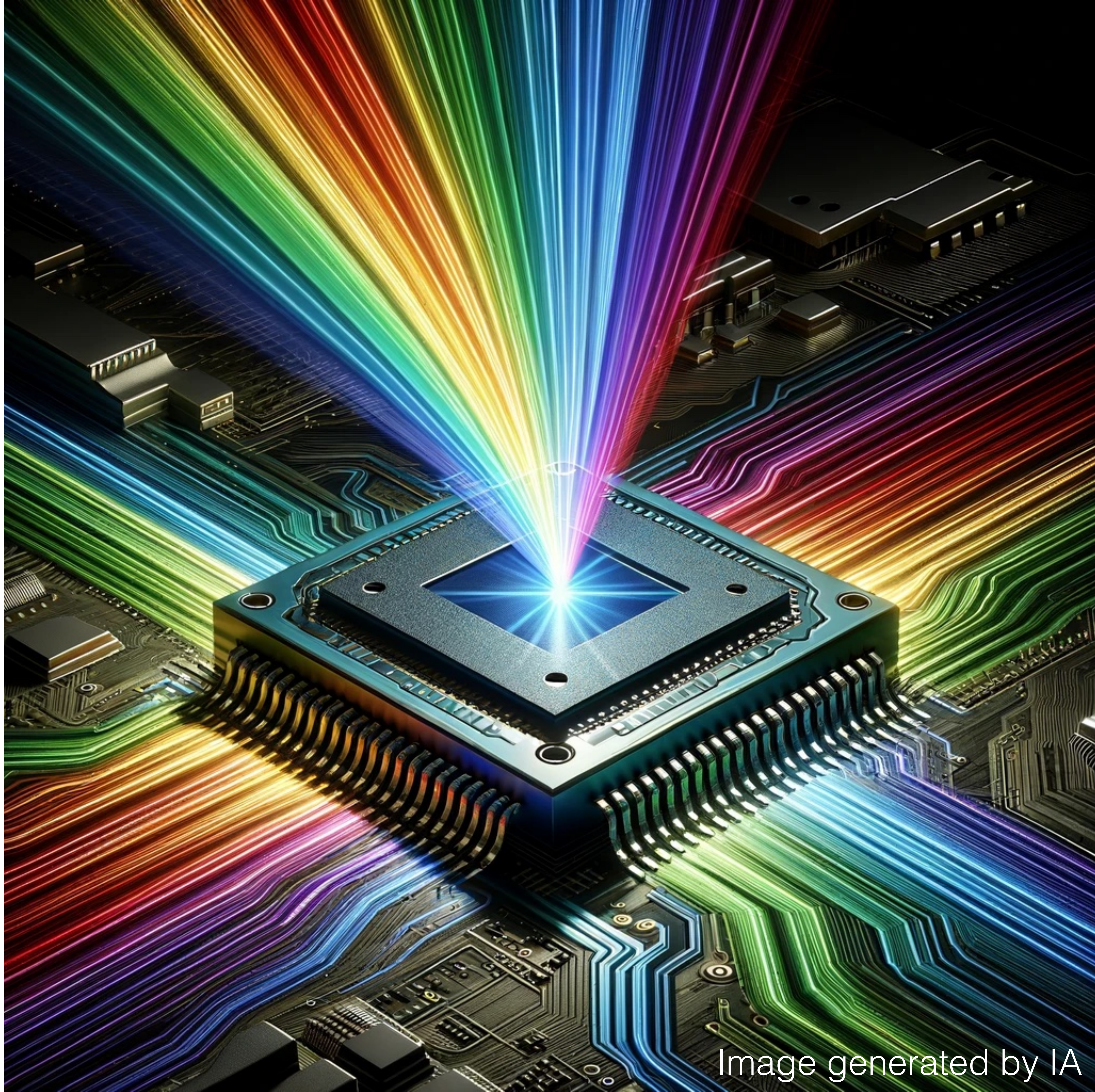
Visibility

Expanding the tool box

+

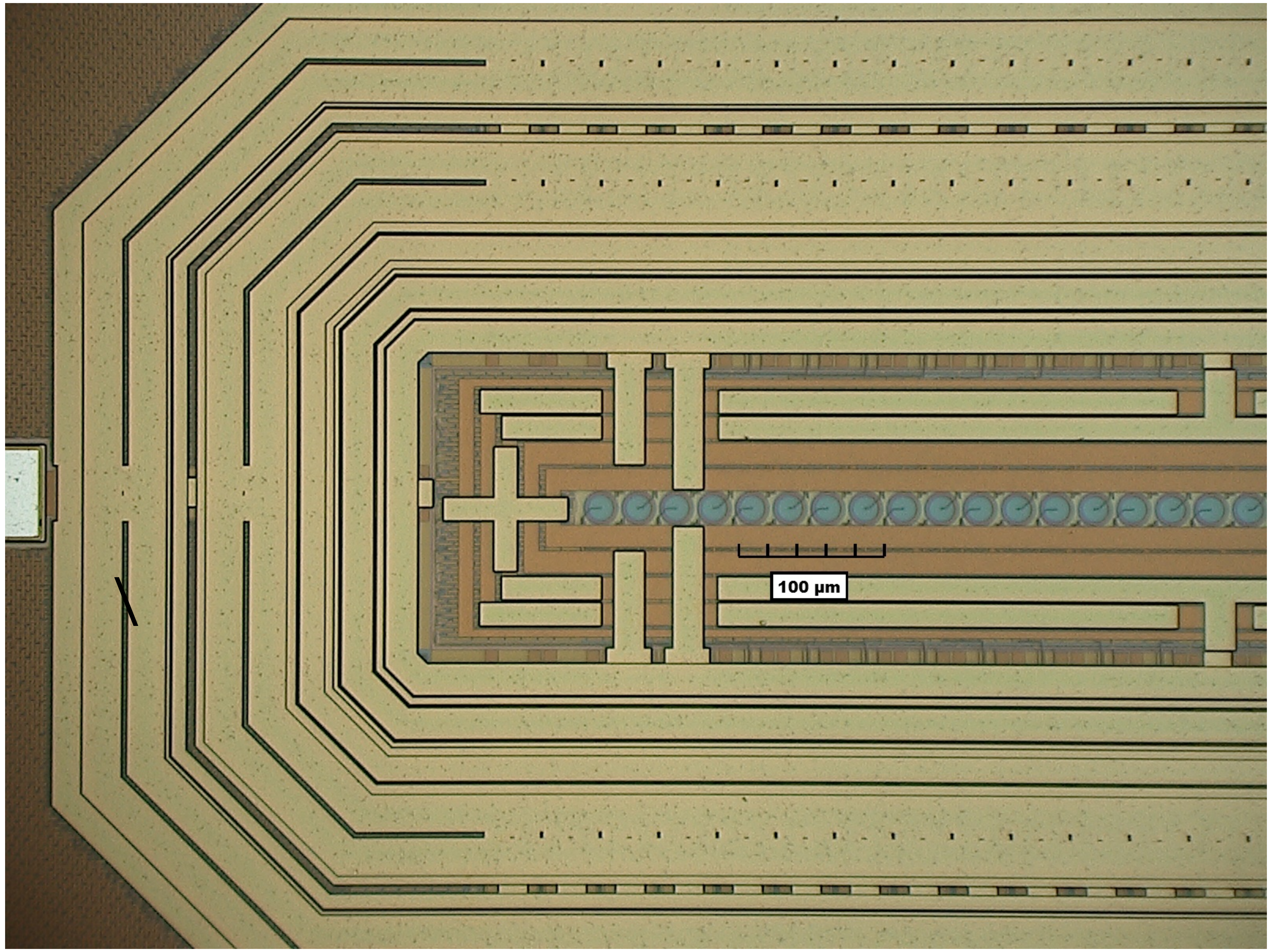
Spectral binning

The spectral binning technique enable us to essentially perform multiple measurements together, because each frequency can be treated as an independent measurement.

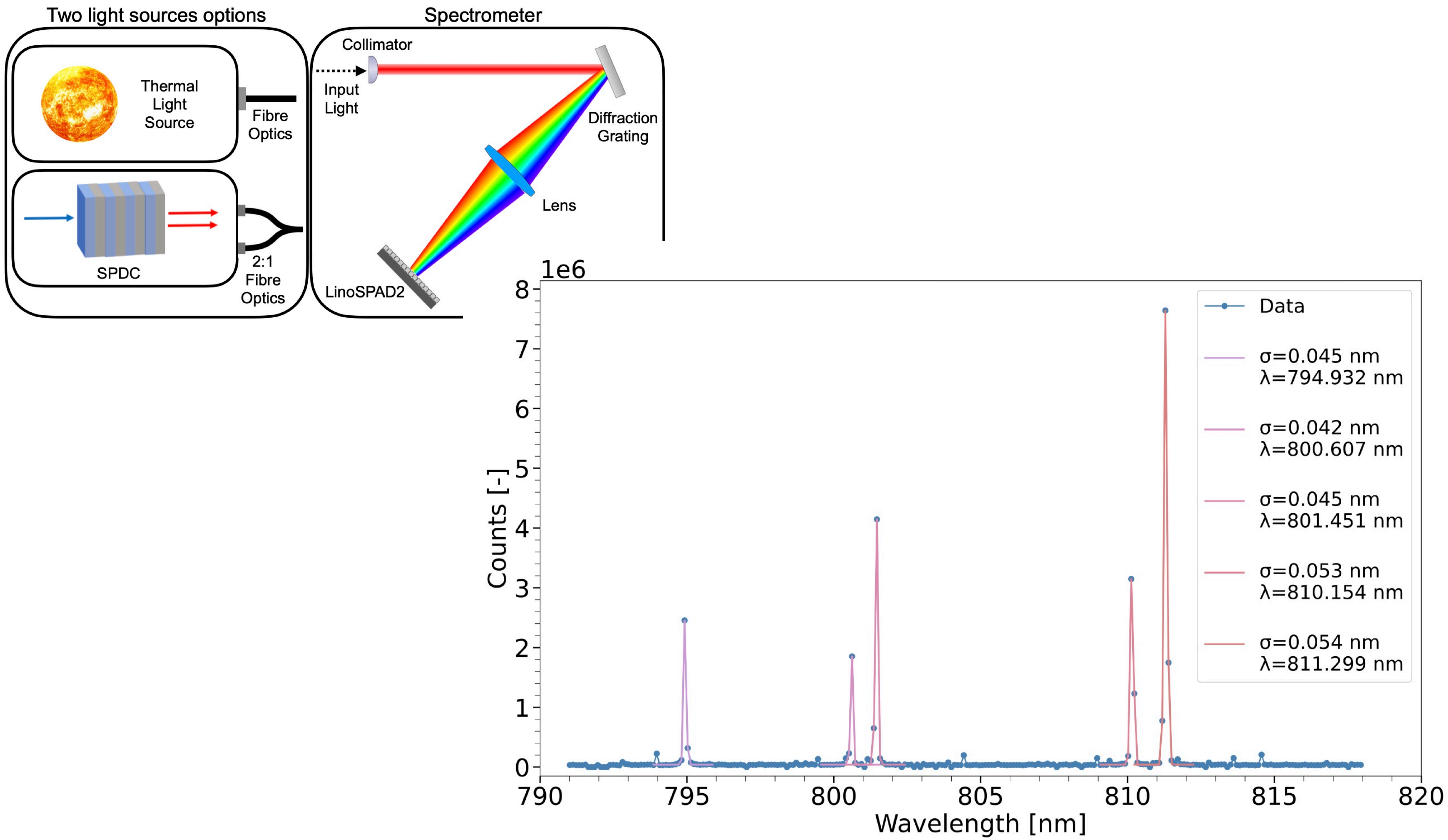


LinoSPAD2

- 512 pixels
- 26.2 μm × 26.2 μm pixel size
- fast data-driven operation

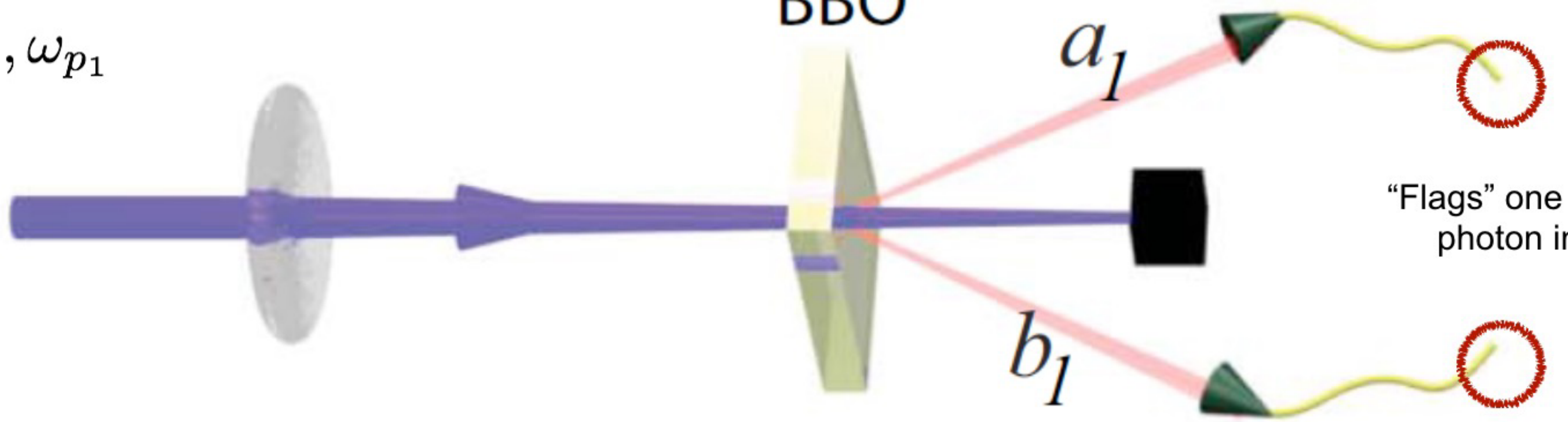


Collaborations:
École Polytechnique Fédérale de Lausanne (EPFL)
AQUA - Advanced Quantum Architecture Laboratory
Czech Technical University in Prague



Two light sources options
Thermal Light Source
Fibre Optics
SPDC
2:1 Fibre Optics
Spectrometer
Collimator
Input Light
Diffraction Grating
Lens
LinoSPAD2
1e6
Counts [-]
Wavelength [nm]
Data
σ=0.045 nm λ=794.932 nm
σ=0.042 nm λ=800.607 nm
σ=0.045 nm λ=801.451 nm
σ=0.053 nm λ=810.154 nm
σ=0.054 nm λ=811.299 nm

SPDC: Spontaneous Parametric Down Conversion



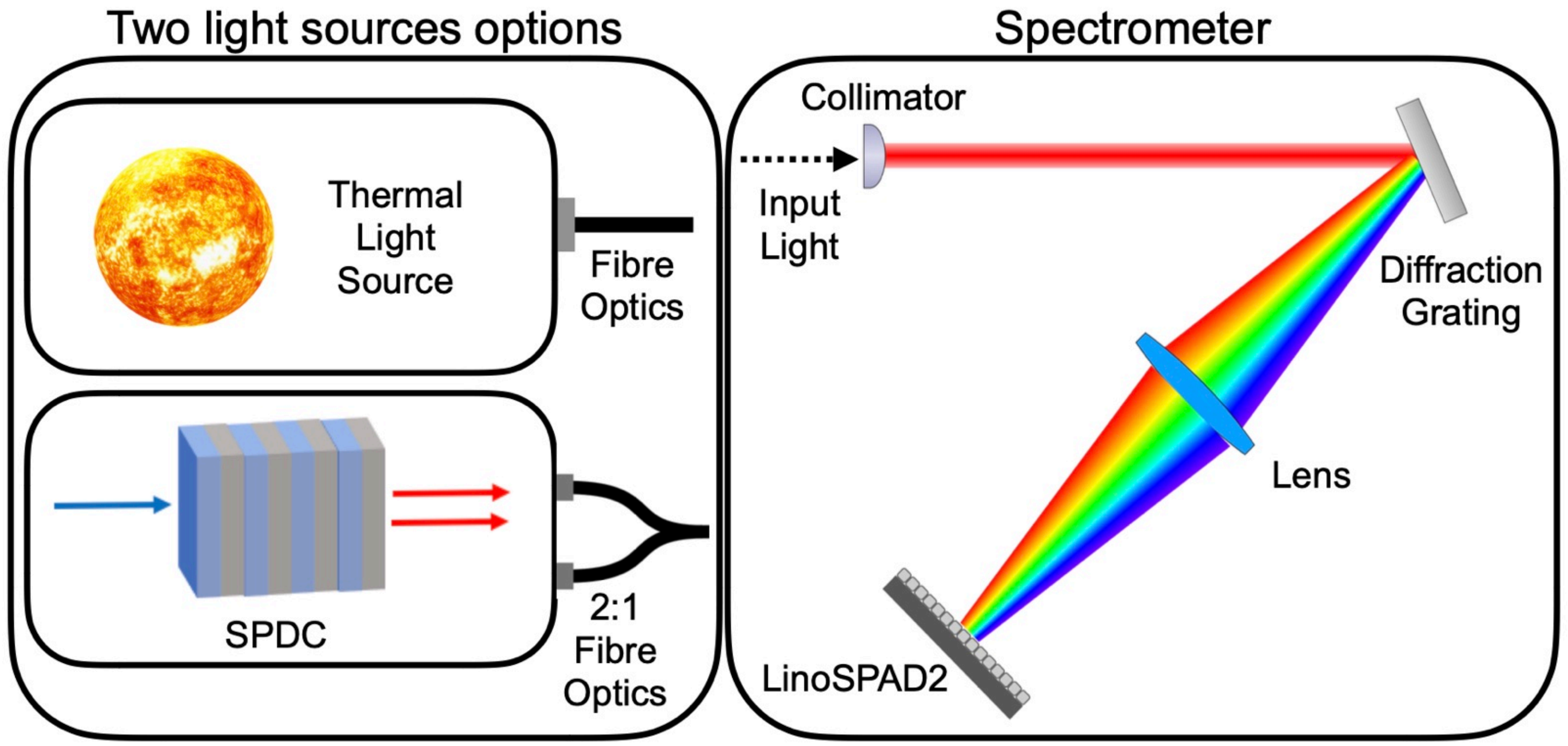
Phase-matching conditions

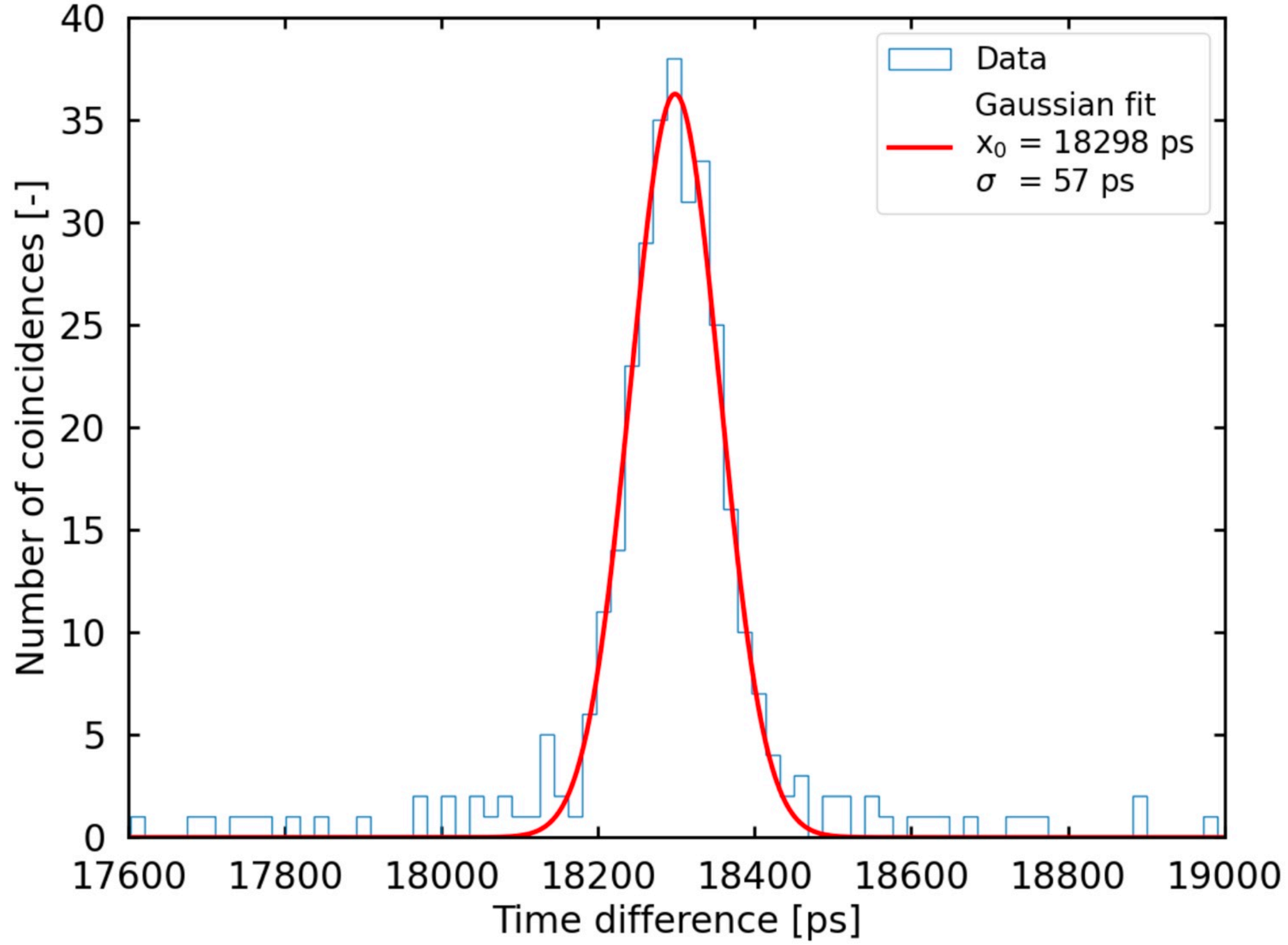
$$\vec{k}_{a_1} + \vec{k}_{b_1} = \vec{k}_{p_1}$$

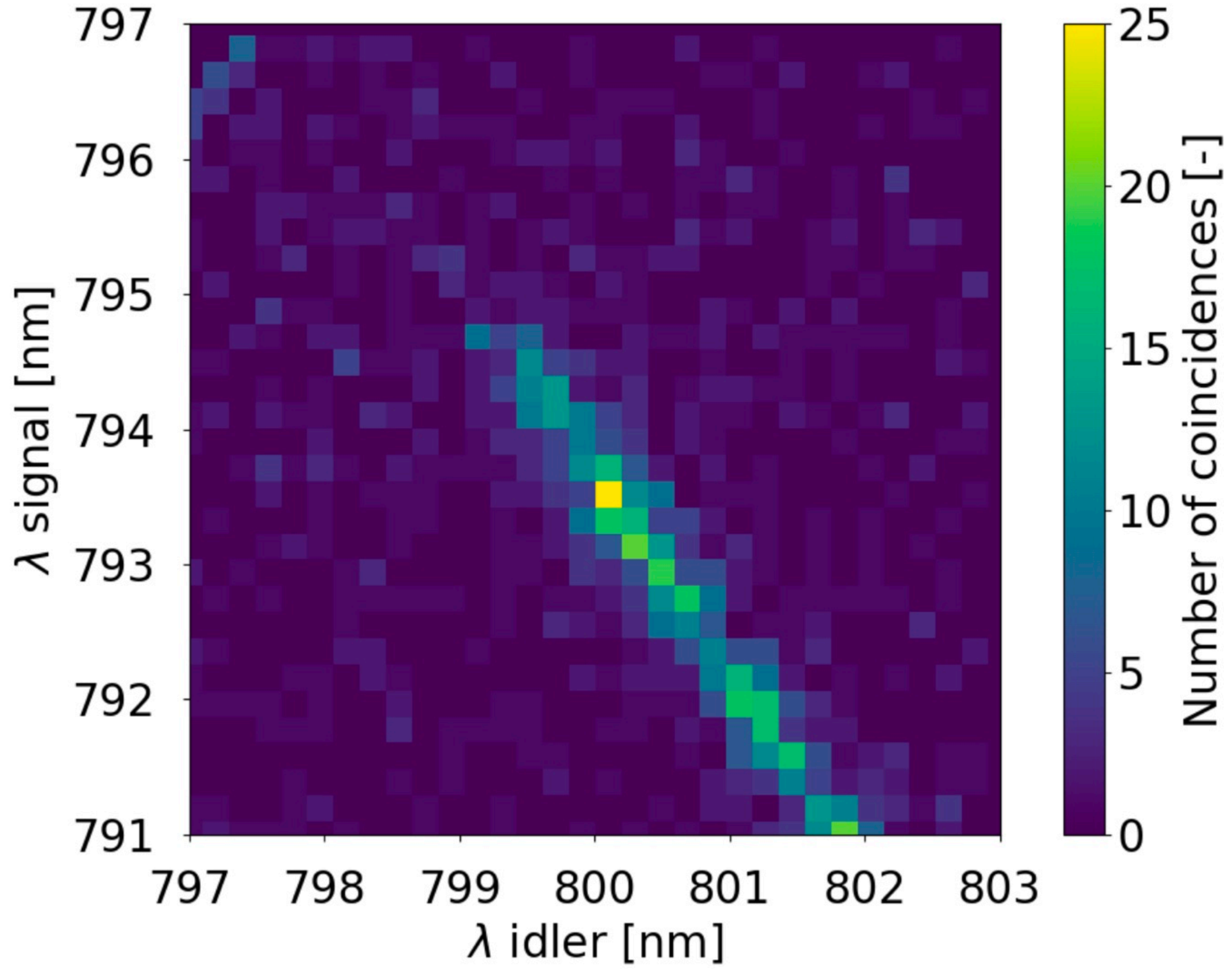
$$\omega_{a_1} + \omega_{b_1} = \omega_{p_1}$$

SPDC
Nonlinear
Probabilistic

Credit Image:
Broome et al., Opt. Express 19, 22698-22708 (2011)


Two light sources options
Spectrometer
Thermal Light Source
Fibre Optics
SPDC
2:1 Fibre Optics
Collimator
Input Light
Diffraction Grating
Lens
LinoSPAD2


Data
Gaussian fit
x_0 = 18298 ps
σ = 57 ps
Number of coincidences [-]
Time difference [ps]


λ signal [nm]
λ idler [nm]
Number of coincidences [-]

Research Article Vol. 33, No. 5 / 10 Mar 2025 / *Optics Express* 9962

Optics EXPRESS

Fast data-driven spectrometer with direct measurement of time and frequency for multiple single photons

JAKUB JIRSA,[1,2] SERGEI KULKOV,[1] RAPHAEL A. ABRAHAO,[3,*] JESSE CRAWFORD,[3] AARON MUENINGHOFF,[4] ERMANNO BERNASCONI,[5] CLAUDIO BRUSCHINI,[5] SAMUEL BURRI,[5] STEPHEN VINTSKEVICH,[6] MICHAL MARCISOVSKY,[1] EDOARDO CHARBON,[5] AND ANDREI NOMEROTSKI[1,7,8]

For multifrequency HBT

We need

- Good spectral resolution
- Good temporal resolution
- Single-photon sensitivity
- Decent detection efficiency

We would like

- Room temperature operation

For multifrequency HBT

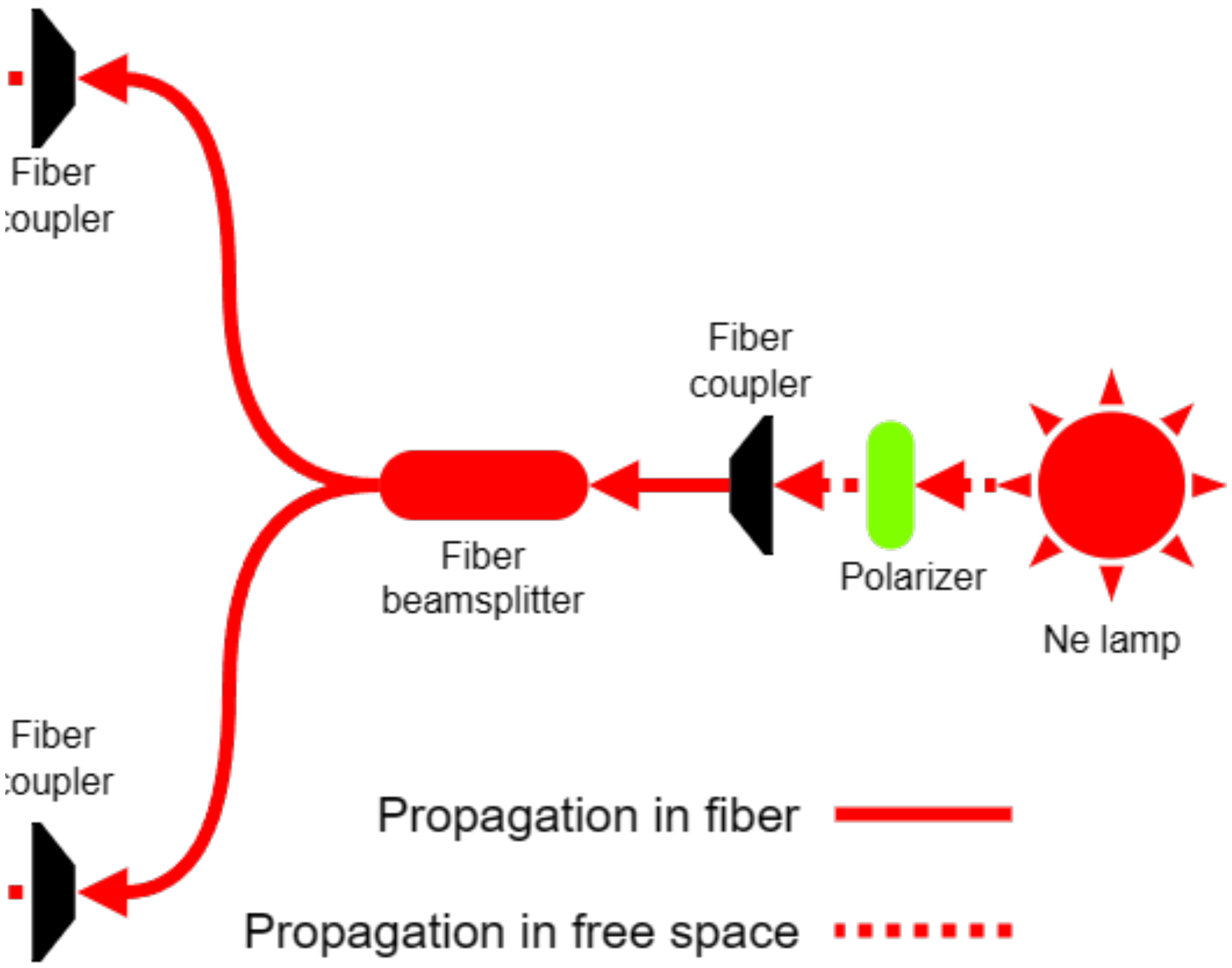
We need

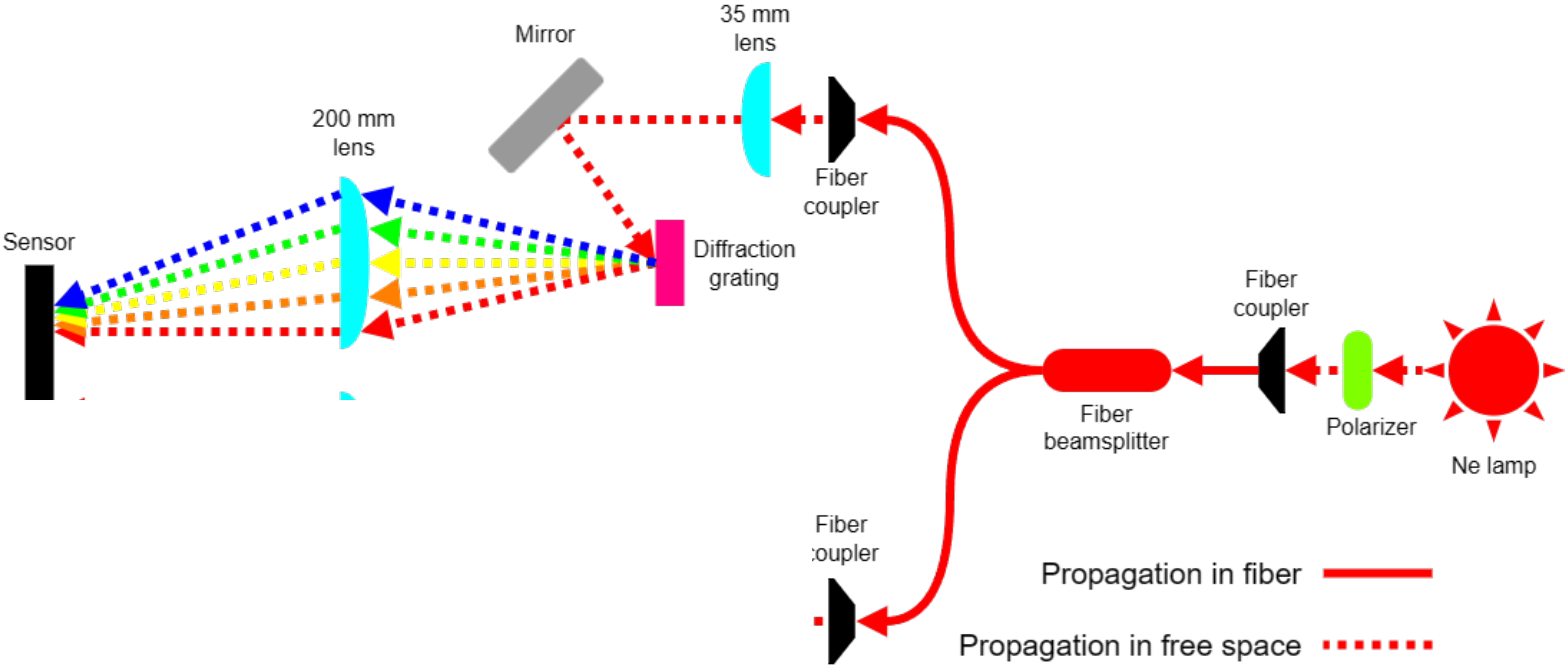
- Good spectral resolution
- Good temporal resolution
- Single-photon sensitivity
- Decent detection efficiency

We would like

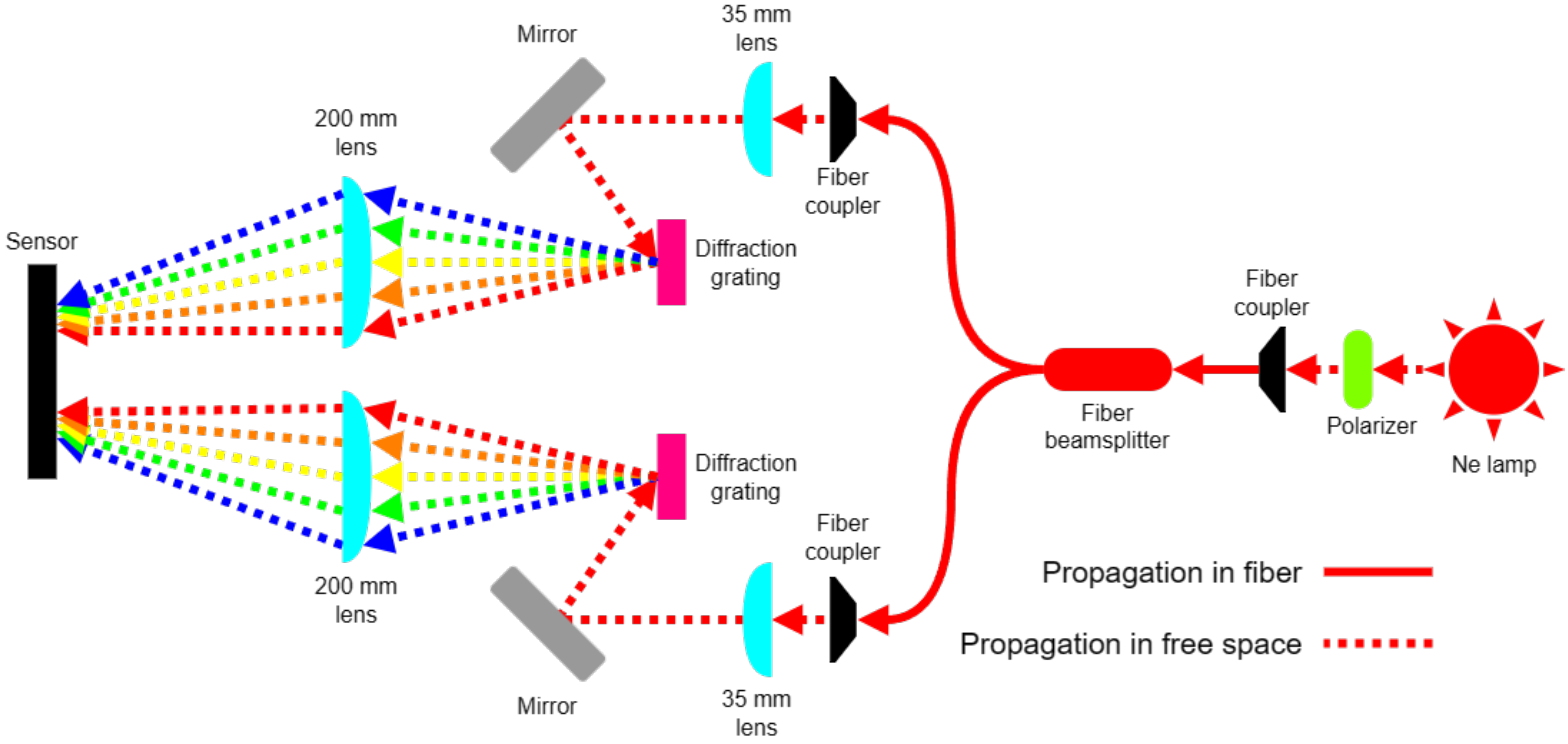
- Room temperature operation

Not an easy list, but we did!

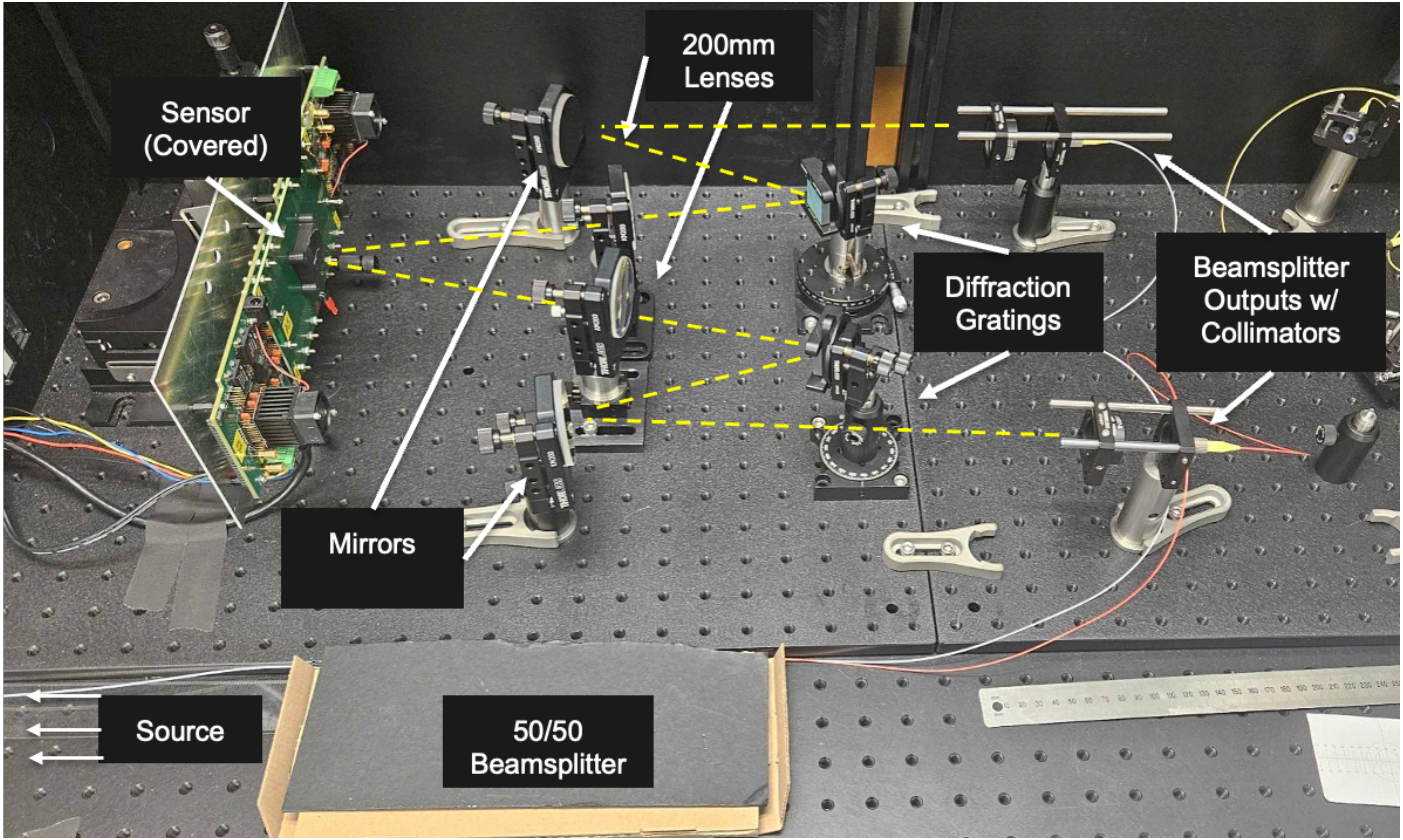

Fiber
coupler
Fiber
coupler
Fiber
coupler
Fiber
beamsplitter
Polarizer
Ne lamp
Propagation in fiber
Propagation in free space



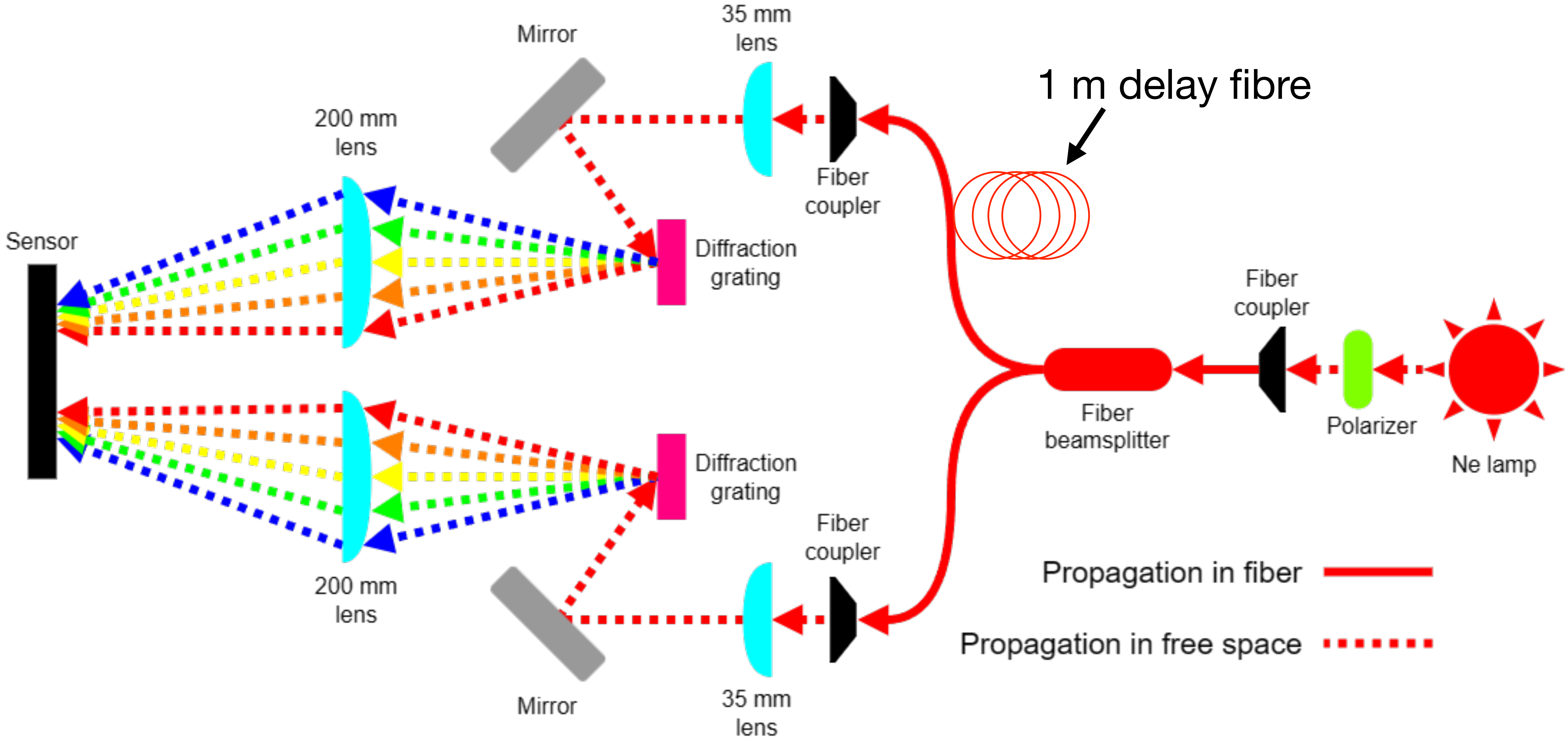
Mirror
35 mm
lens
200 mm
lens
Sensor
Fiber
coupler
Diffraction
grating
Fiber
coupler
Fiber
beamsplitter
Polarizer
Ne lamp
Fiber
coupler
Propagation in fiber
Propagation in free space



Mirror
35 mm
lens
200 mm
lens
Fiber
coupler
Sensor
Diffraction
grating
Fiber
coupler
Fiber
beamsplitter
Polarizer
Ne lamp
Diffraction
grating
Fiber
coupler
200 mm
lens
Propagation in fiber
Propagation in free space
Mirror
35 mm
lens


200mm
Lenses
Sensor
(Covered)
Diffraction
Gratings
Beamsplitter
Outputs w/
Collimators
Mirrors
Source
50/50
Beamsplitter

Undelayed
Delayed
Normalized coincidences [-]
Δt [ns]
1.5
1.0
HBT
5.13 ns
Spect 1 2
Pixel 20 55
λ [nm] 653 653
HBT
5.16 ns
Spect 1 2
Pixel 44 79
λ [nm] 650 650
HBT
5.23 ns
Spect 1 2
Pixel 138 173
λ [nm] 640 640
HBT
5.12 ns
Spect 1 2
Pixel 156 191
λ [nm] 638 638
HBT
5.20 ns
Spect 1 2
Pixel 200 235
λ [nm] 633 633
-5 0 5 10


1 m delay fibre
35 mm lens
Mirror
200 mm lens
Fiber coupler
Sensor
Diffraction grating
Fiber coupler
Polarizer
Ne lamp
Fiber beamsplitter
Diffraction grating
Fiber coupler
200 mm lens
Mirror
35 mm lens
Propagation in fiber
Propagation in free space

Undelayed
Delayed
Normalized coincidences [-]
Δt [ns]
1.0
1.5
-5
0
5
10
HBT
5.13 ns
Spect 1 2
Pixel 20 55
λ [nm] 653 653
CT
Spect 1 2
Pixel 44 55
λ [nm] 650 653
HBT
5.16 ns
Spect 1 2
Pixel 44 79
λ [nm] 650 650
HBT
5.23 ns
Spect 1 2
Pixel 138 173
λ [nm] 640 640
CT
Spect 1 2
Pixel 156 173
λ [nm] 638 640
HBT
5.12 ns
Spect 1 2
Pixel 156 191
λ [nm] 638 638
CT
Spect 1 2
Pixel 200 191
λ [nm] 633 638
HBT
5.20 ns
Spect 1 2
Pixel 200 235
λ [nm] 633 633


Undelayed
Delayed
Normalized coincidences [-]
Δt [ns]
HBT
5.13 ns
CT
HBT
5.16 ns
HBT
5.23 ns
CT
HBT
5.12 ns
CT
HBT
5.20 ns
Spect 1 2
Pixel 20 55
λ [nm] 653 653
Spect 1 2
Pixel 20 79
λ [nm] 653 650
Spect 1 2
Pixel 20 173
λ [nm] 653 640
Spect 1 2
Pixel 20 191
λ [nm] 653 638
Spect 1 2
Pixel 20 235
λ [nm] 653 633
Spect 1 2
Pixel 44 55
λ [nm] 650 653
Spect 1 2
Pixel 44 79
λ [nm] 650 650
Spect 1 2
Pixel 44 173
λ [nm] 650 640
Spect 1 2
Pixel 44 191
λ [nm] 650 638
Spect 1 2
Pixel 44 235
λ [nm] 650 633
Spect 1 2
Pixel 138 55
λ [nm] 640 653
Spect 1 2
Pixel 138 79
λ [nm] 640 650
Spect 1 2
Pixel 138 173
λ [nm] 640 640
Spect 1 2
Pixel 138 191
λ [nm] 640 638
Spect 1 2
Pixel 138 235
λ [nm] 640 633
Spect 1 2
Pixel 156 55
λ [nm] 638 653
Spect 1 2
Pixel 156 79
λ [nm] 638 650
Spect 1 2
Pixel 156 173
λ [nm] 638 640
Spect 1 2
Pixel 156 191
λ [nm] 638 638
Spect 1 2
Pixel 156 235
λ [nm] 638 633
Spect 1 2
Pixel 200 55
λ [nm] 633 653
Spect 1 2
Pixel 200 79
λ [nm] 633 650
Spect 1 2
Pixel 200 173
λ [nm] 633 640
Spect 1 2
Pixel 200 191
λ [nm] 633 638
Spect 1 2
Pixel 200 235
λ [nm] 633 633

We are clearly in the multifrequency regime.

This allows:

- Shorter data taking times
- More information for the same data taking duration

This quantum technology can benefit current classical observatories!

We are clearly in the multifrequency regime.

This allows:

- Shorter data taking times
- More information for the same data taking duration

This quantum technology can benefit current classical observatories!

Spectral binning:

Instead of working with one frequency at a time, we can work with multiple frequencies at the same time.

↳ Can also benefit quantum information

APL Photonics ARTICLE pubs.aip.org/aip/app

Multifrequency-resolved Hanbury Brown–Twiss effect

Cite as: APL Photon. 10, 026113 (2025); doi: 10.1063/5.0226069
Submitted: 28 June 2024 • Accepted: 11 December 2024 •
Published Online: 21 February 2025

View Online Export Citation

Joseph Ferrantini,[1] Jesse Crawford,[1] Sergei Kulkov,[2] Jakub Jirsa,[2,3] Aaron Mueninghoff,[4] Lucas Lawrence,[1] Stephen Vintskevich,[5] Tommaso Milanese,[6] Samuel Burri,[6] Ermanno Bernasconi,[6] Claudio Bruschini,[6] Michal Marcisovsky,[2] Peter Svihra,[2] Andrei Nomerotski,[2,7] Paul Stankus,[1] Edoardo Charbon,[6] and Raphael A. Abrahao[1,a)]

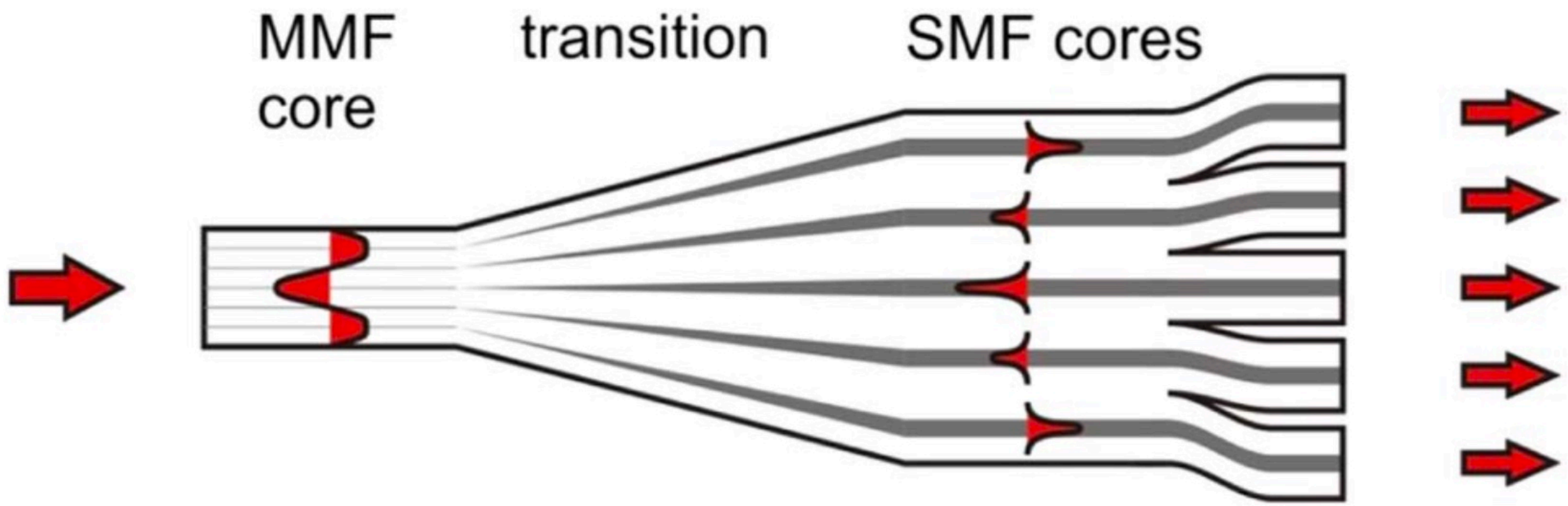
AFFILIATIONS

[1] Brookhaven National Laboratory, Upton, New York 11973, USA
[2] Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University, 115 19 Prague, Czech Republic
[3] Faculty of Electrical Engineering, Czech Technical University, 166 27 Prague, Czech Republic
[4] Stony Brook University, Stony Brook, New York 11794, USA
[5] Technology Innovation Institute, Abu Dhabi, United Arab Emirates
[6] École Polytechnique Fédérale de Lausanne (EPFL), CH-2002 Neuchâtel, Switzerland
[7] Florida International University, Miami, Florida 33199, USA

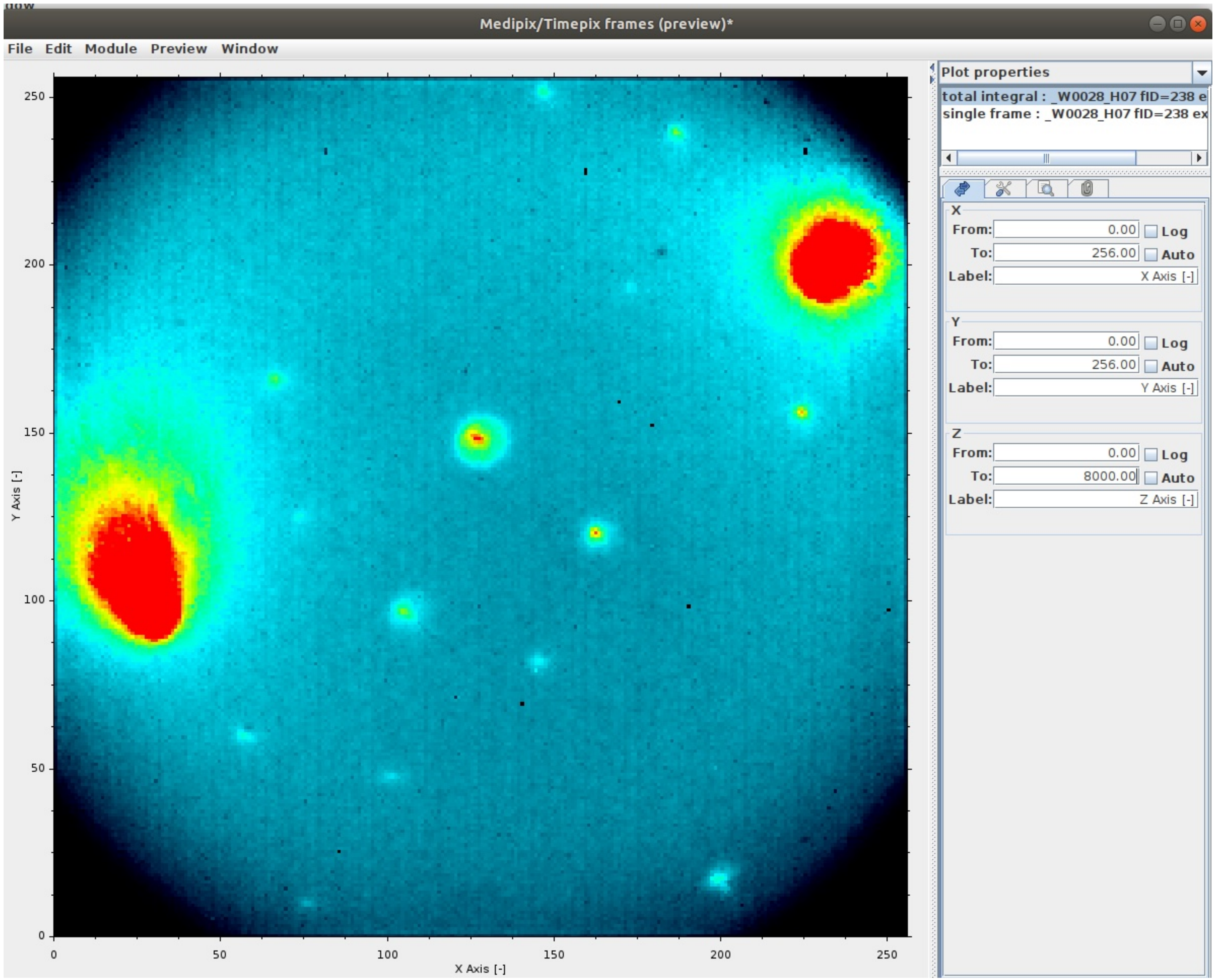
[a)] **Author to whom correspondence should be addressed:** rakelabra@bnl.gov

Technology development

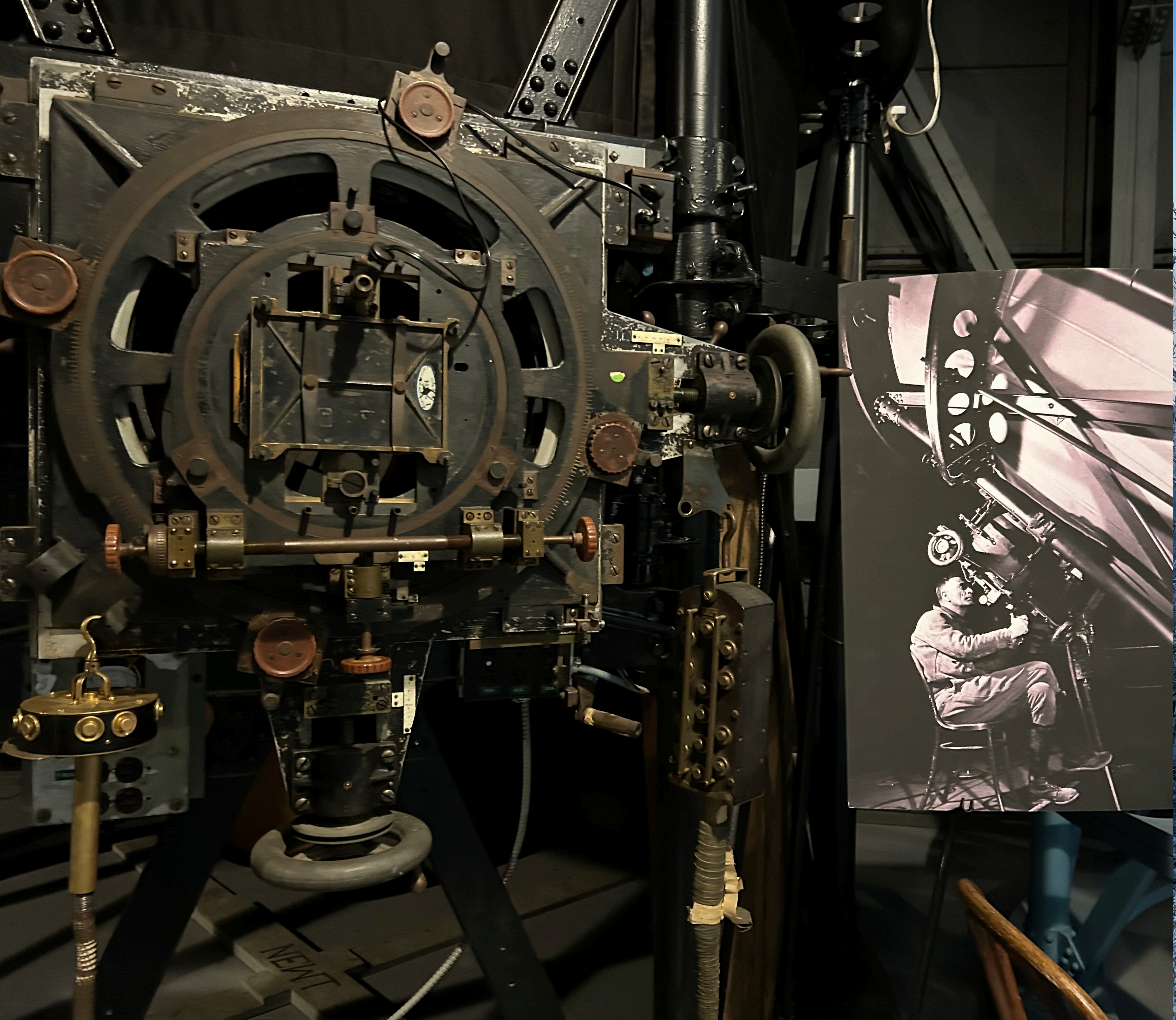
Photonic Lantern - partnership with UCF - Astrophotonics group



T. A. Birks, I. Gris-Sánchez, S. Yerolatsitis, S. G. Leon-Saval, and R. R. Thomson, "The photonic lantern," Adv. Opt. Photon. 7, 107-167 (2015)

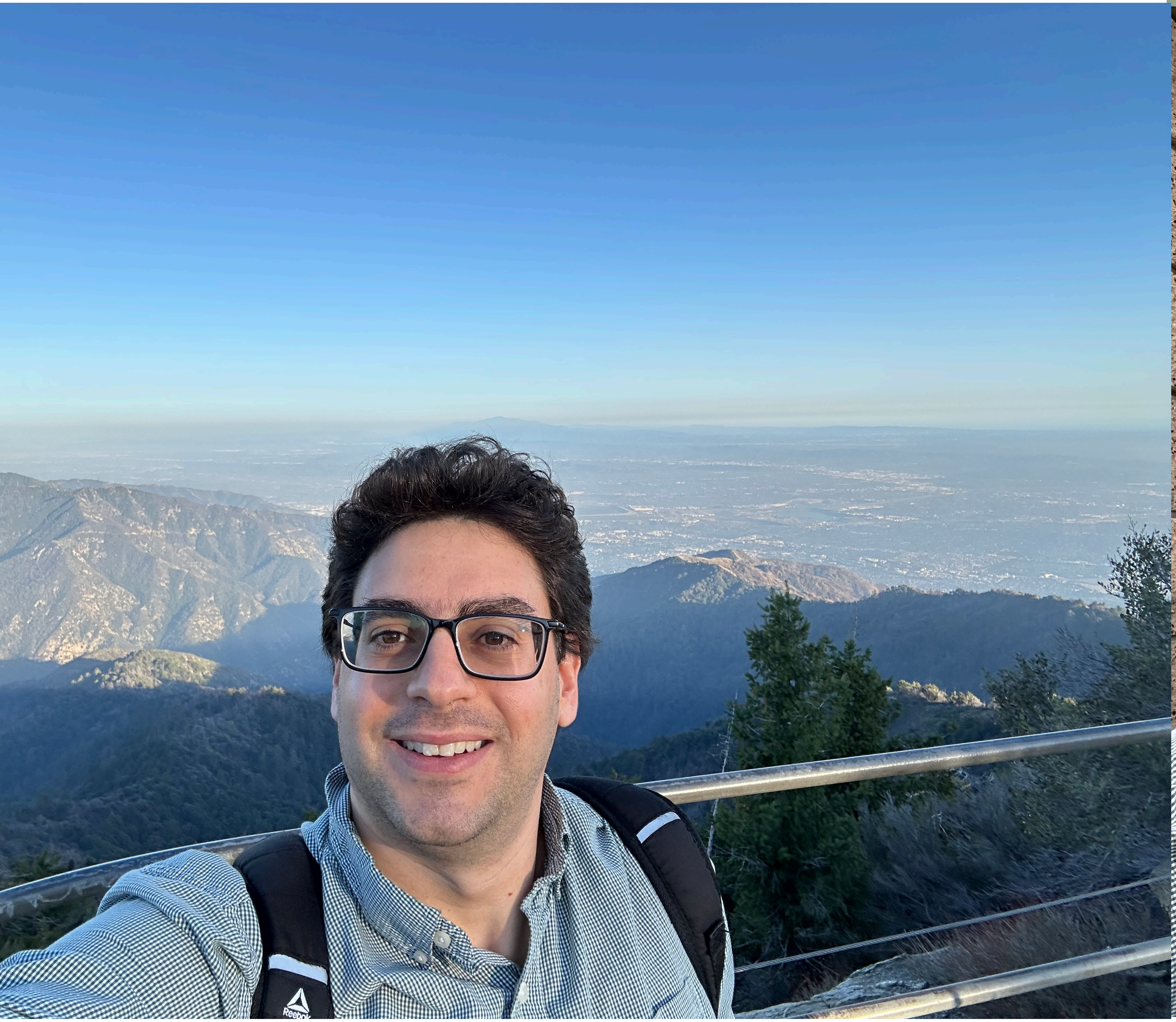

Medipix/Timepix frames (preview)*
File
Edit
Module
Preview
Window
Plot properties
total integral : _W0028_H07 fID=238 e
single frame : _W0028_H07 fID=238 ex
X
From: 0.00
Log
To: 256.00
Auto
Label: X Axis [-]
Y
From: 0.00
Log
To: 256.00
Auto
Label: Y Axis [-]
Z
From: 0.00
Log
To: 8000.00
Auto
Label: Z Axis [-]
Y Axis [-]
X Axis [-]
0
50
100
150
200
250

Collaboration with CHARA

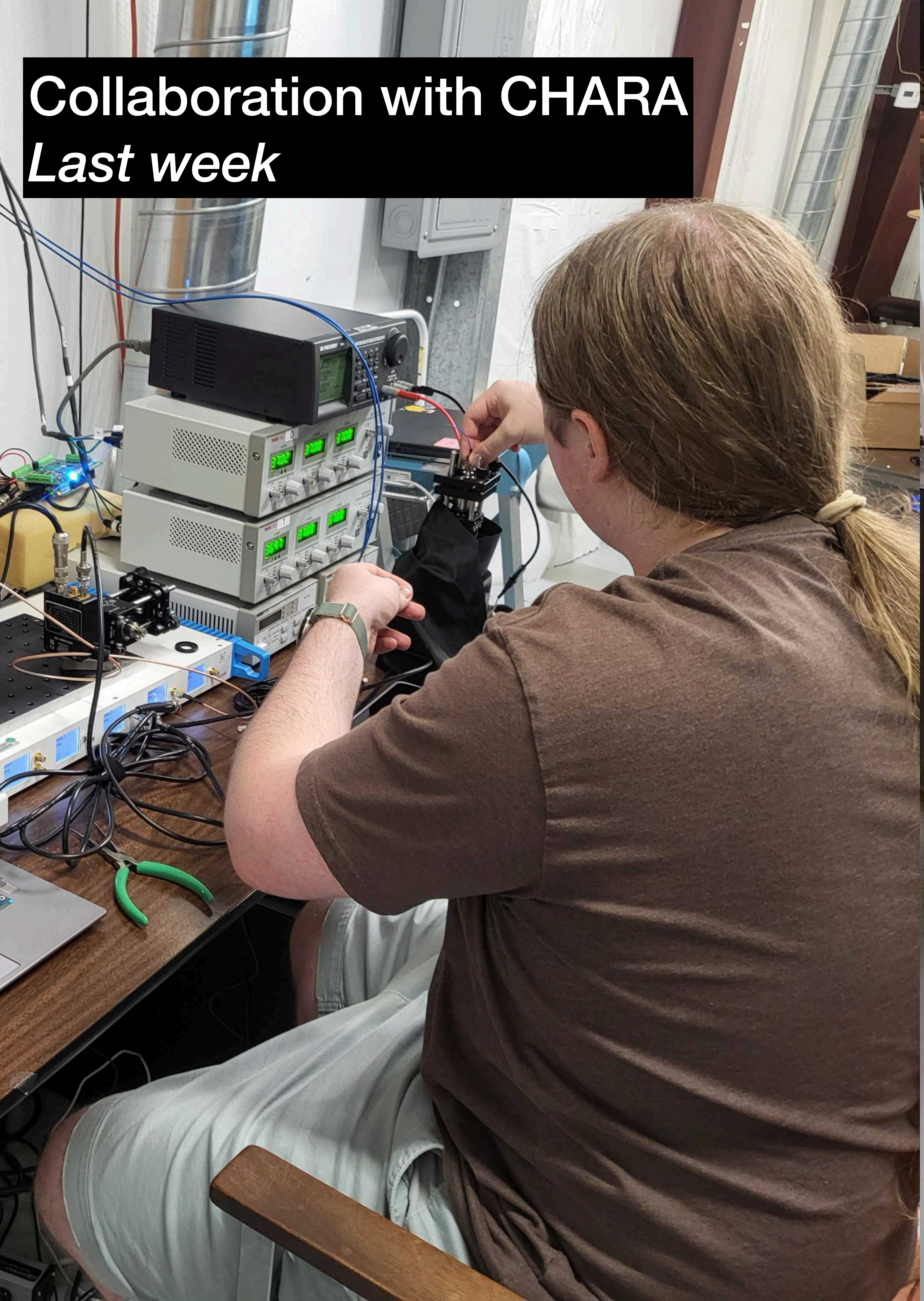


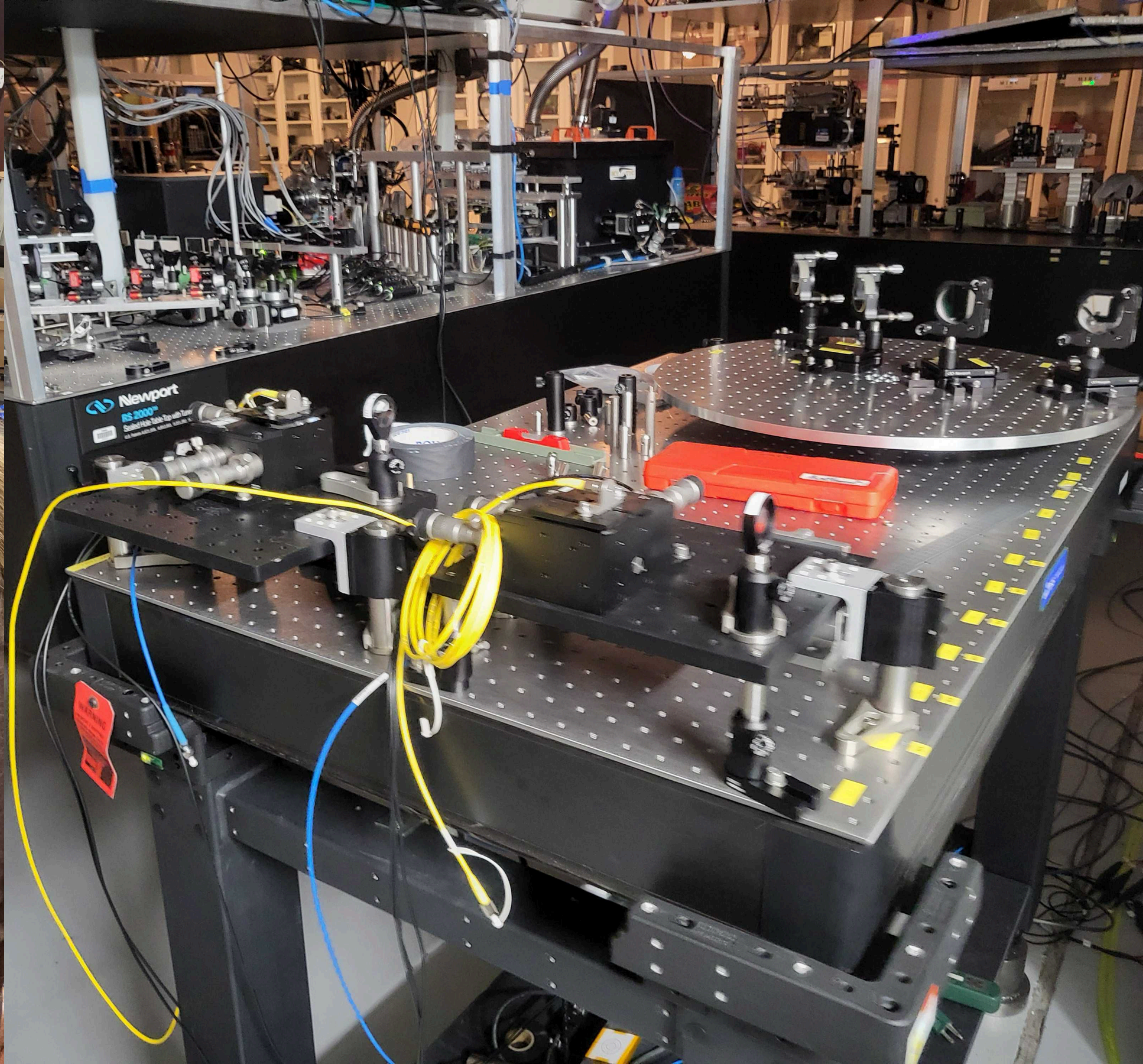

MT WILSON
5,713 FT.
RED JACKET HIKERS.

Collaboration with CHARA



Collaboration with CHARA
Last week





rakelabra@bnl.gov

Raphael Abrahao