Single-photon Detector Overview

- Key metrics
- PMTs
- APDs
- Superconducting
  - TES
  - Nanowire

Key Metrics

- efficiency – how likely to detect a photon
- dark counts – how much noise in the absence of light
- deadtime – how long after detection before ready
- afterpulsing – how often is there a secondary signal
- jitter – what time resolution does a detection have
- latency – how long to get a signal out
- photon-number resolving?
- operating temperature
- $$$

Invited Review Article: Single-photon sources and detectors

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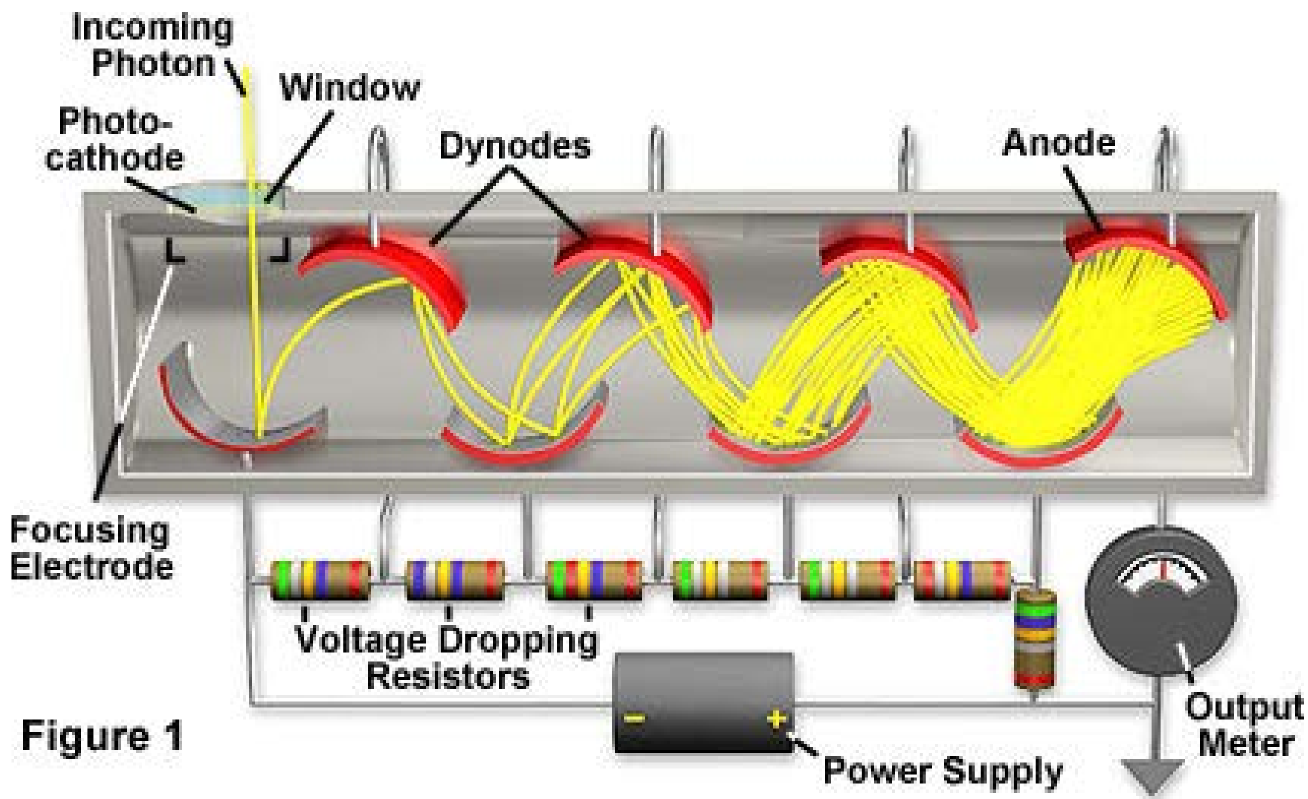
(Received 14 December 2010; accepted 7 June 2011; published online 27 July 2011)

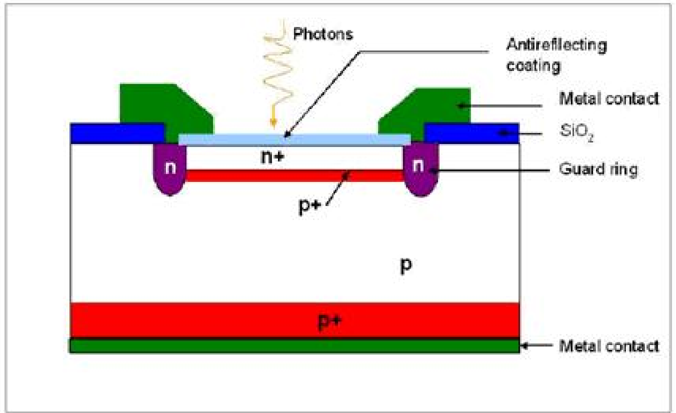
We review the current status of single-photon-source and single-photon-detector technologies operating at wavelengths from the ultraviolet to the infrared. We discuss applications of these technologies to quantum communication, a field currently driving much of the development of single-photon sources and detectors. [doi:10.1063/1.3610677]

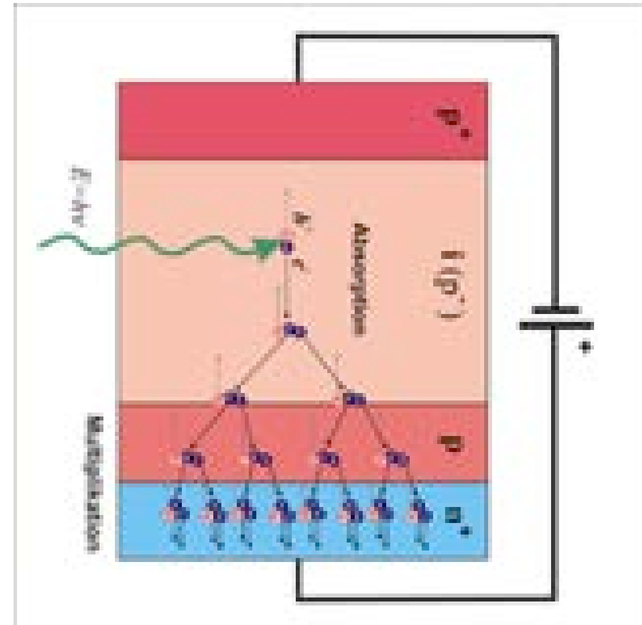
Photomultiplier Tube



Detector type	Operation temperature (K)	Detection efficiency, wavelength η(%), λ (nm)	Timing jitter, δt(ns) (FWHM)	Dark-count rate, D (ungated) (1/s)	Max. count rate ($10^6/s$)	PNR capability
PMT (visible–near-infrared)	300	40 @ 500	0.3	100	10	Some
PMT (infrared)	200	2 @ 1550	0.3	200 000	10	Some

Avalanche Photodiode

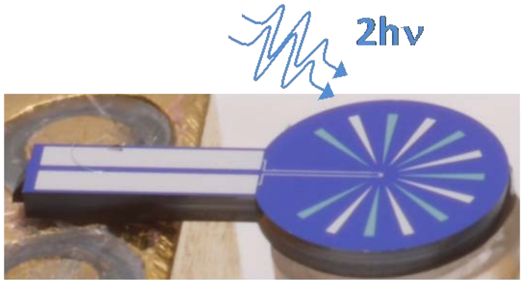




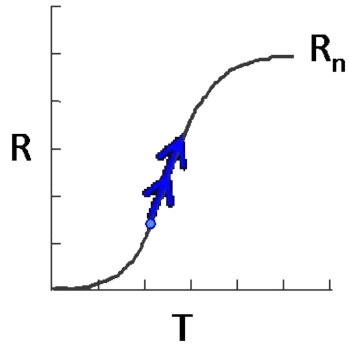
Detector type	Operation temperature (K)	Detection efficiency, wavelength $\eta(\%)$, λ (nm)	Timing jitter, δt(ns) (FWHM)	Dark-count rate, D (ungated) (1/s)	Max. count rate $(10^6/s)$	PNR capability
Si SPAD (thick junction)	250	65 @ 650	0.4	25	10	None
Si SPAD (shallow junction)	250	49 @ 550	0.035	25	10	None
InGaAs SPAD (gated)	200	10 @ 1550	0.370	91	0.01	None
InGaAs SPAD (self-differencing)	240	10 @ 1550	0.055	16 000	100	None

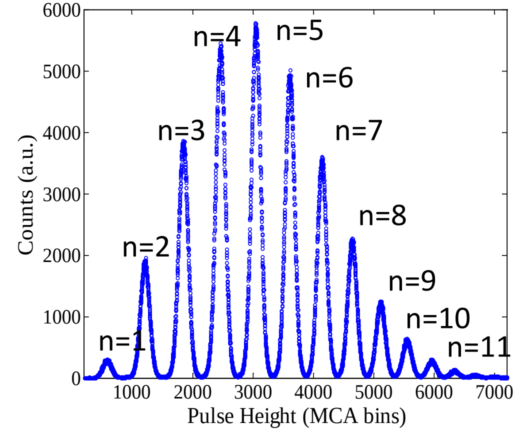
Superconducting Transition Edge Sensor (TES)

Calorimetric detection of UV/optical/IR photons

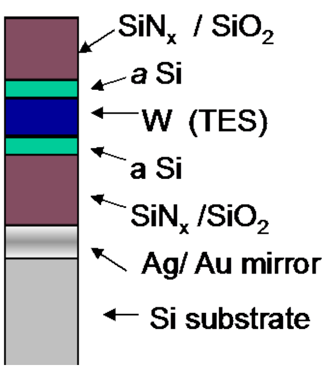


e.g., Tungsten

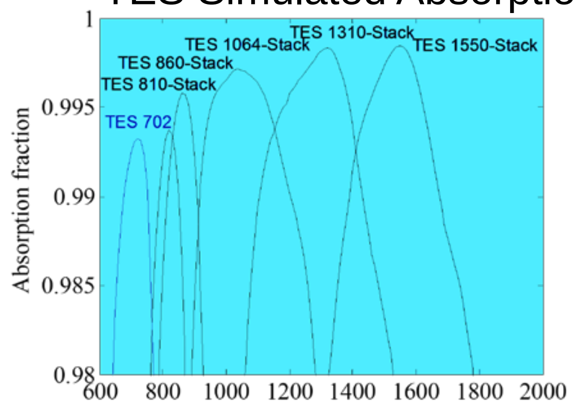




Optical stack



TES Simulated Absorption



Fiber coupled self-aligned TES
< 1% coupling loss

A. E. Lita *et al.*, Opt. Exp. **16**, 3032 (2008)

Detector type	Operation temperature (K)	Detection efficiency, wavelength $\eta(\%)$, λ (nm)	Timing jitter, δt(ns) (FWHM)	Dark-count rate, D (ungated) (1/s)	Max. count rate $(10^6/s)$	PNR capability
TES(W)	0.1	50 @ 1550	100	3	0.1	Full
TES(W)	0.1	95 @ 1556	100	...	0.1	Full
TES(Ha)	0.1	85 @ 850	100	...	0.1	Full
TES (Ti)	0.1	81–98 @ 850	100	...	1	Full

Superconducting Nanowire Single-photon Detectors (SNSPDs)

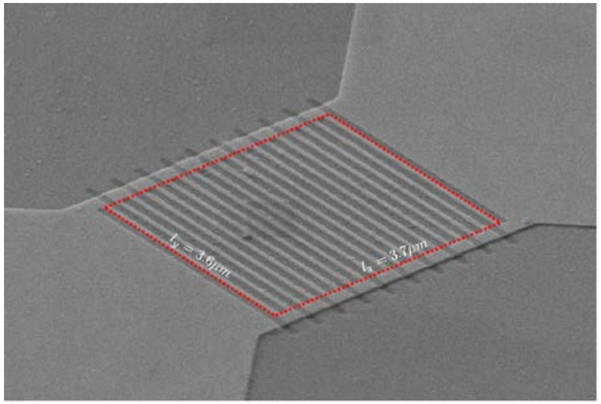
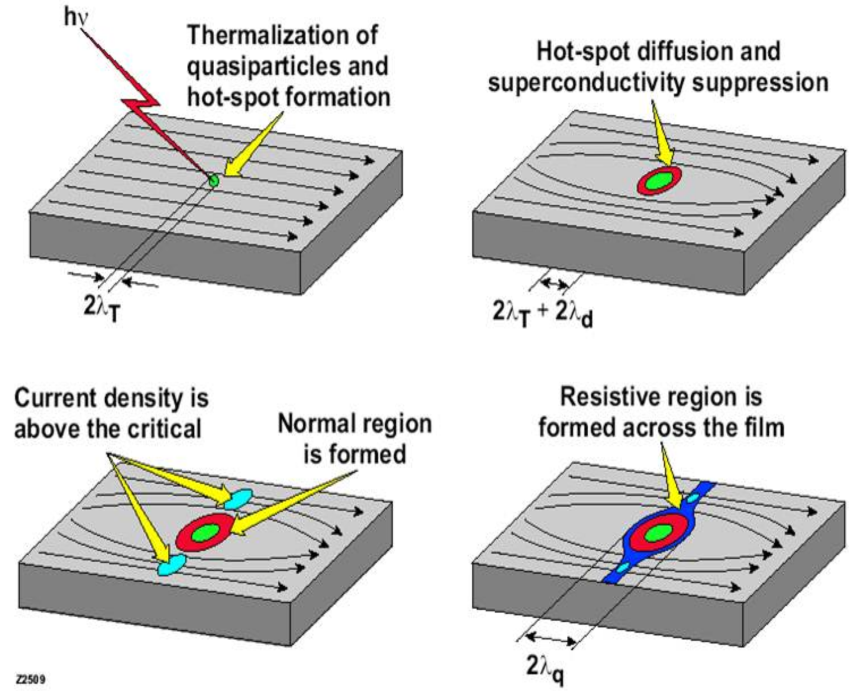
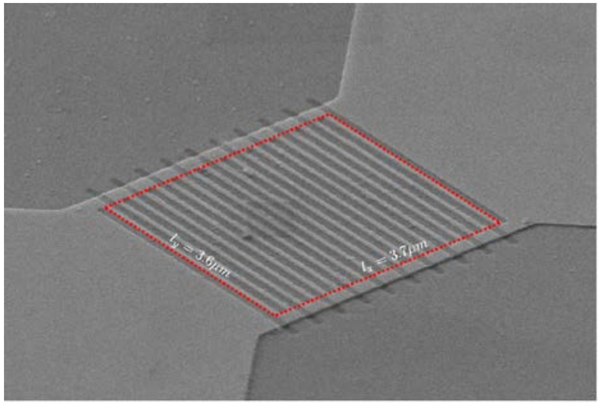


Figure 2.1.: *Scanning Electron Microscope (SEM)* image of a detector. The highlighted region is what we expect to be the active area for photon detection. The image was supplied by K. Ilin from the *Institut für Mikro- und Nanoelektronische Systeme*



Detector type	Operation temperature (K)	Detection efficiency, wavelength η(%), λ (nm)	Timing jitter, δt(ns) (FWHM)	Dark-count rate, D (ungated) (1/s)	Max. count rate ($10^6/s$)	PNR capability
SNSPD	3	0.7 @ 1550	0.06	10	100	None
SNSPD (in cavity)	1.5	57 @ 1550	0.03	...	1000	None

Superconducting Nanowire Single-photon Detectors (SNSPDs)



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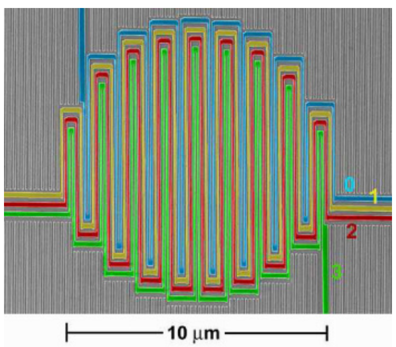
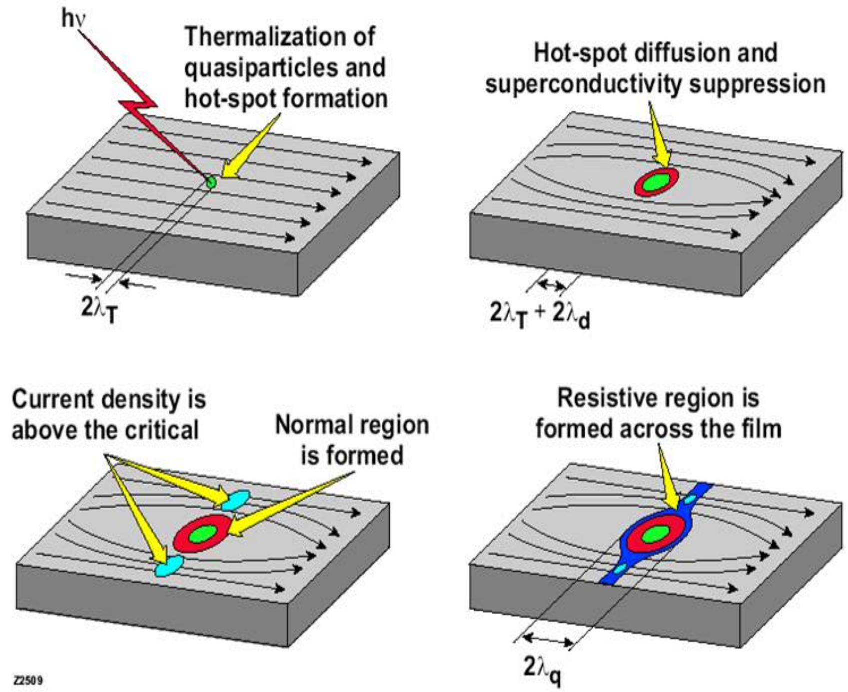




Detector type	Operation temperature (K)	Detection efficiency, wavelength η(%), λ (nm)	Timing jitter, δt(ns) (FWHM)	Dark-count rate, D (ungated) (1/s)	Max. count rate ($10^6/s$)	PNR capability
SNSPD	3	0.7 @ 1550	0.06	10	100	None
SNSPD (in cavity)	1.5	57 @ 1550	0.03	...	1000	None
Parallel SNSPD	2	2 @ 1300	0.05	0.15	1000	Some

optica

Multi-photon detection using a conventional superconducting nanowire single-photon detector

CLINTON CAHALL,[1,*] KATHRYN L. NICOLICH,[2] NURUL T. ISLAM,[3] GREGORY P. LAFYATIS,[2] AARON J. MILLER,[4] DANIEL J. GAUTHIER,[2] AND JUNGSANG KIM[1,5]

We present the first evidence of multi-photon detection using a conventional superconducting nanowire single-photon detector, indicating number resolution up to four photons. The observed multi-photon detection statistics are consistent with the predictions of our model.

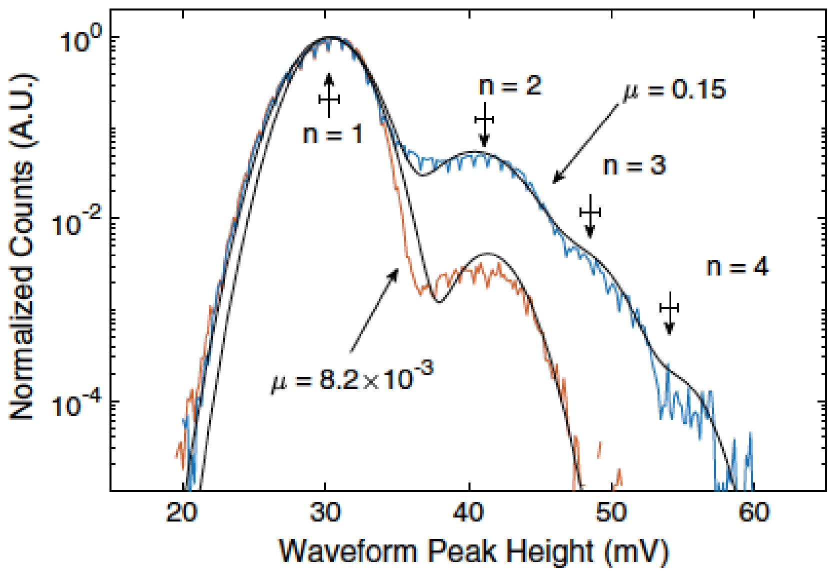
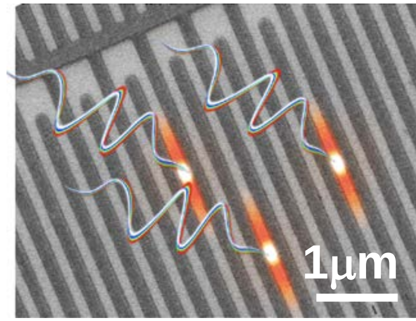
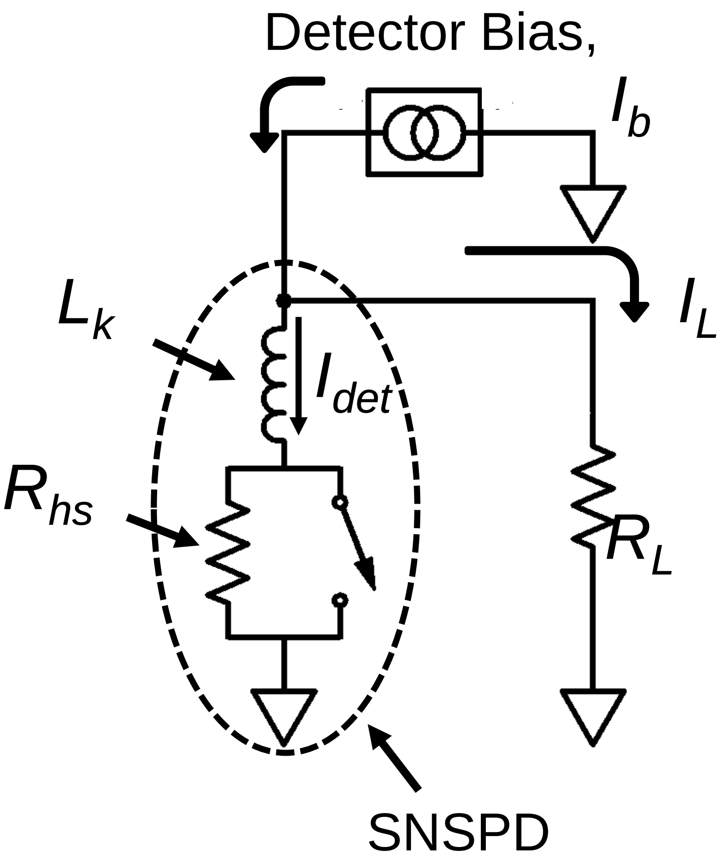


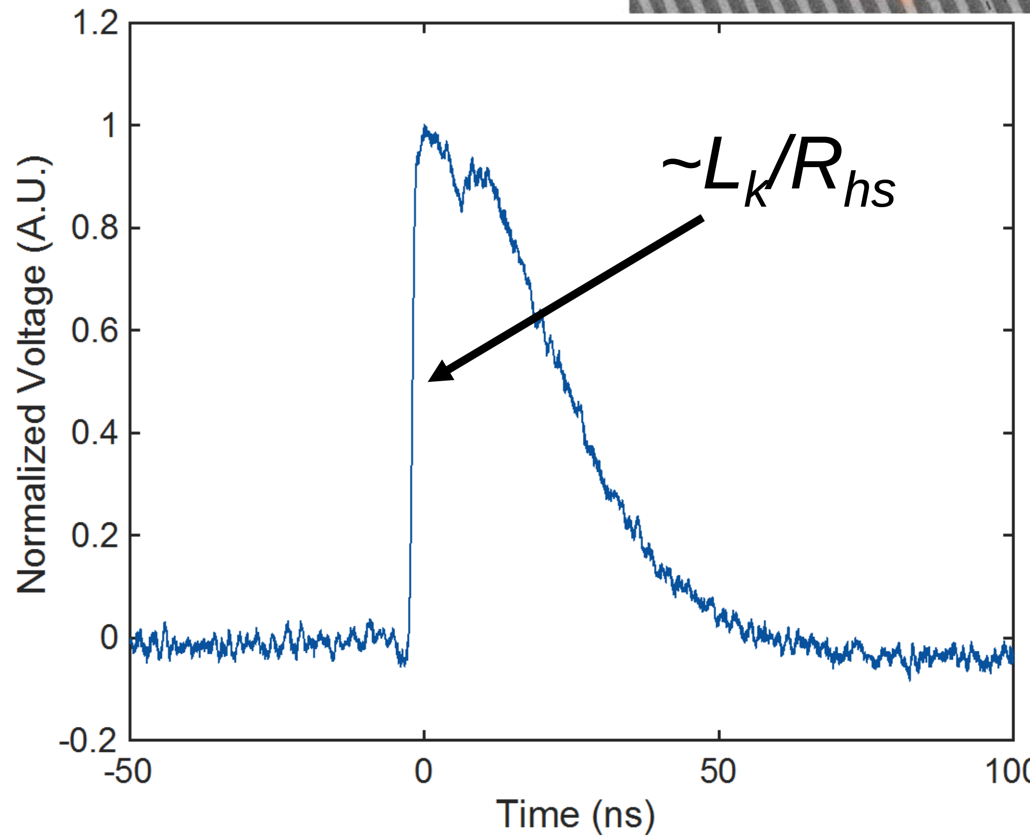
Fig. 2. Histograms of the peak height of differentiated detection waveforms. Each data set is fit with a sum of Gaussian functions, where the integral of each peak is constrained to follow the expected Poisson statistics. The arrows with corresponding error bars show predicted values of the peaks from the electro-thermal model and finite-bandwidth amplifiers.

Multi-Photon Detection with SNSPDs

- Photon absorption creates a resistive ‘hot-spot’
- Bias current is diverted to a parallel load resistor
- Rise time of the pulse depends on hot-spot resistance
- Multi-photon events leads to faster rise times

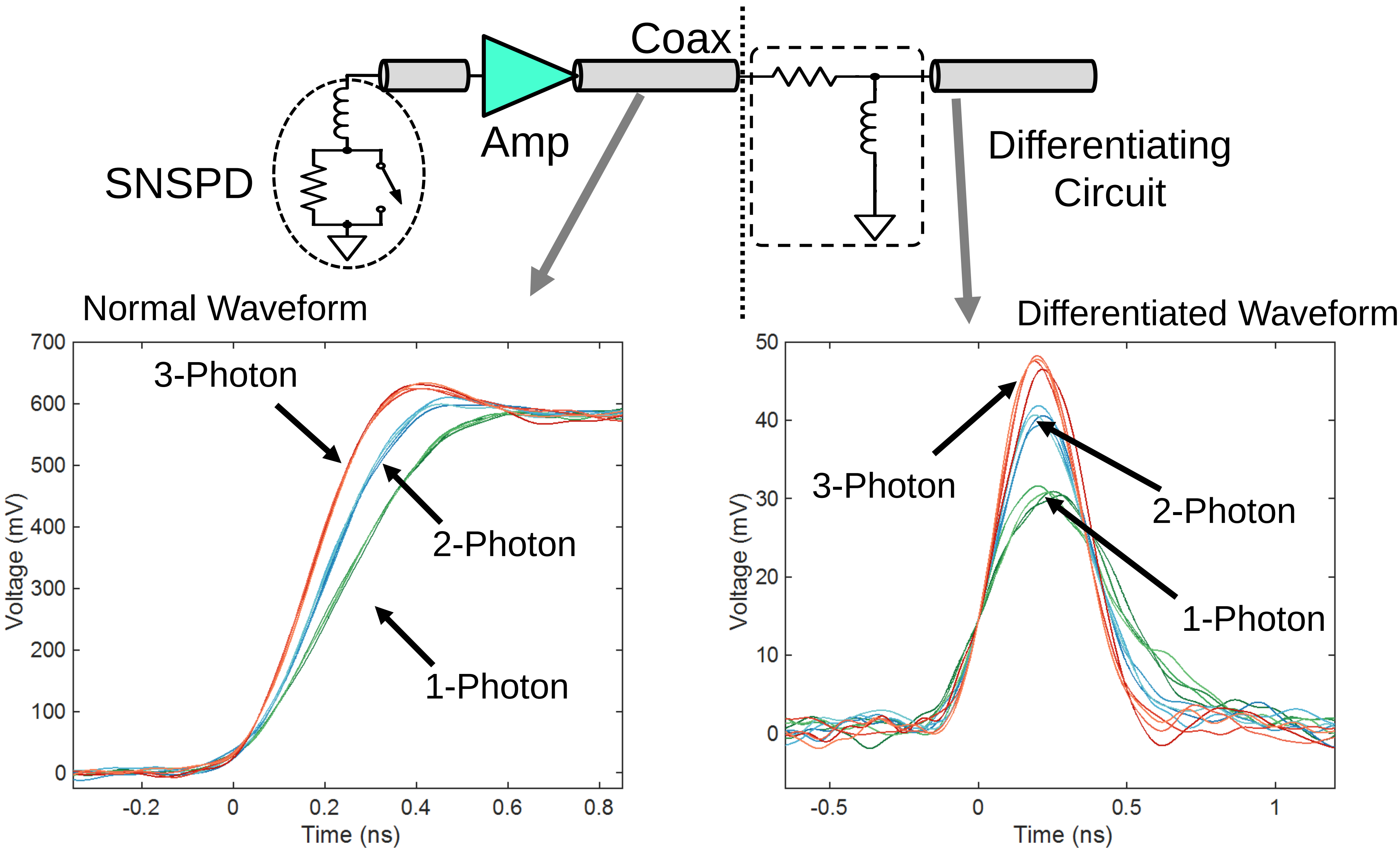






Duke UNIVERSITY

Readout Circuit and Output Waveforms



Single-photon Vision

- Can you SEE single photons?
- At this moment you are detecting ~10^{16} photons every second. But could you see just one?
- No one knows. Past experiments suggested a minimum threshold as high as 8, as low as 1 or 2.
- Now we can give a definitive answer…

PGK, Anthony Leggett
Ranxiao Frances Wang (UIUC Psychology)

Michelle Victora, Julia Spina (GS)

Recordings from single rods

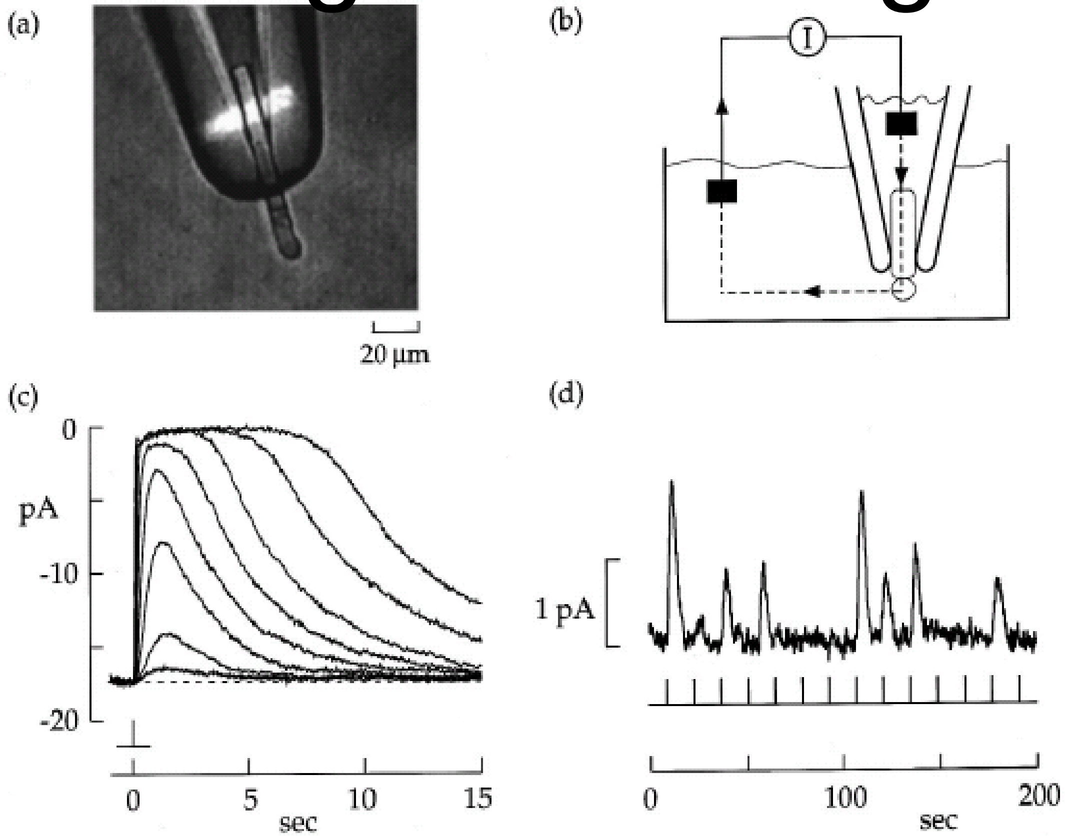
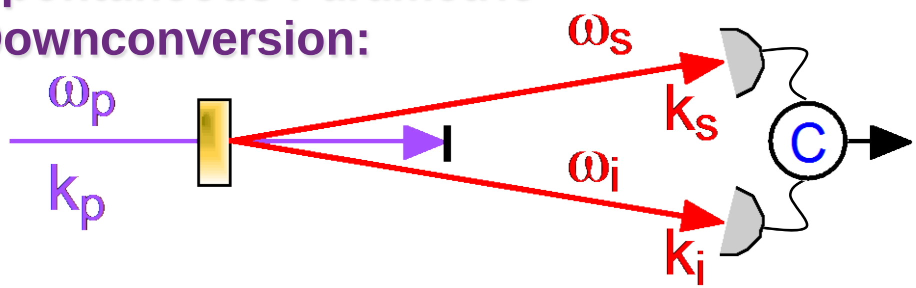
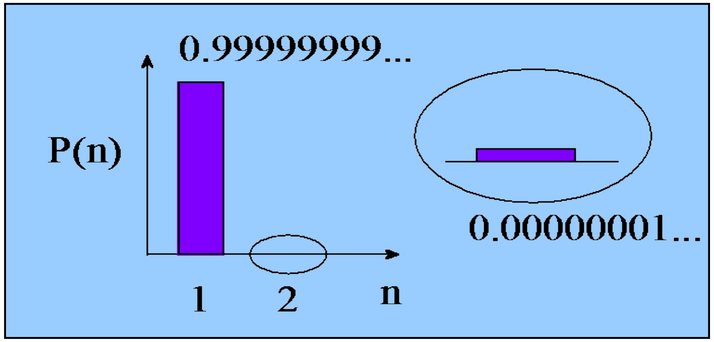


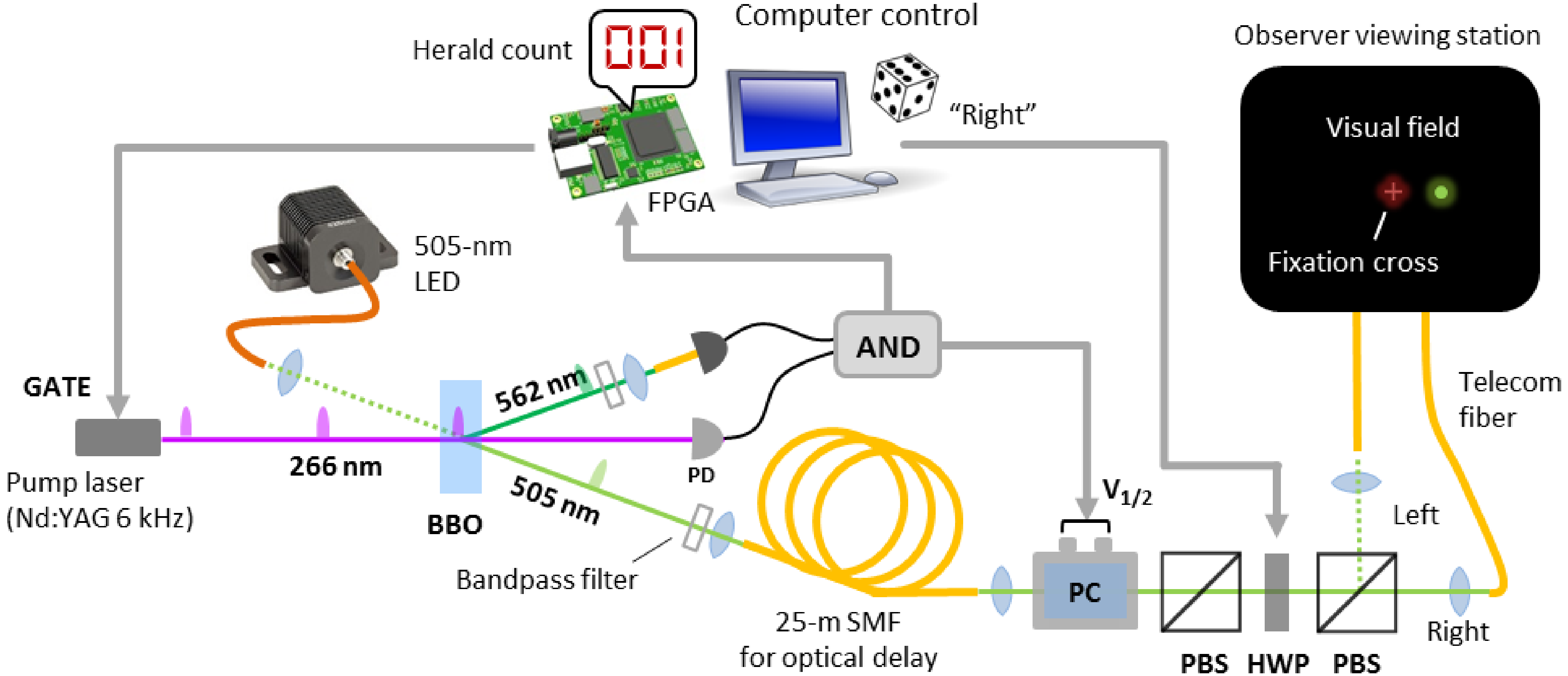
Figure 2: (a) A single rod photoreceptor cell from a toad, in a suction pipette. Viewing is with infrared light, and the bright bar is a stimulus of 500 nm light. (b) Equivalent electrical circuit for recording the current across the cell membrane. (c) Mean current in response to light flashes of varying intensity. Smallest response is to flashes that deliver a mean ~ 4 photons, successive flashes are brighter by factors of 4. (d) Current responses to repeated dim light flashes at times indicated by the tick marks. Note the distinct classes of responses to zero, one or two photons. From [Rieke & Baylor 1998a].

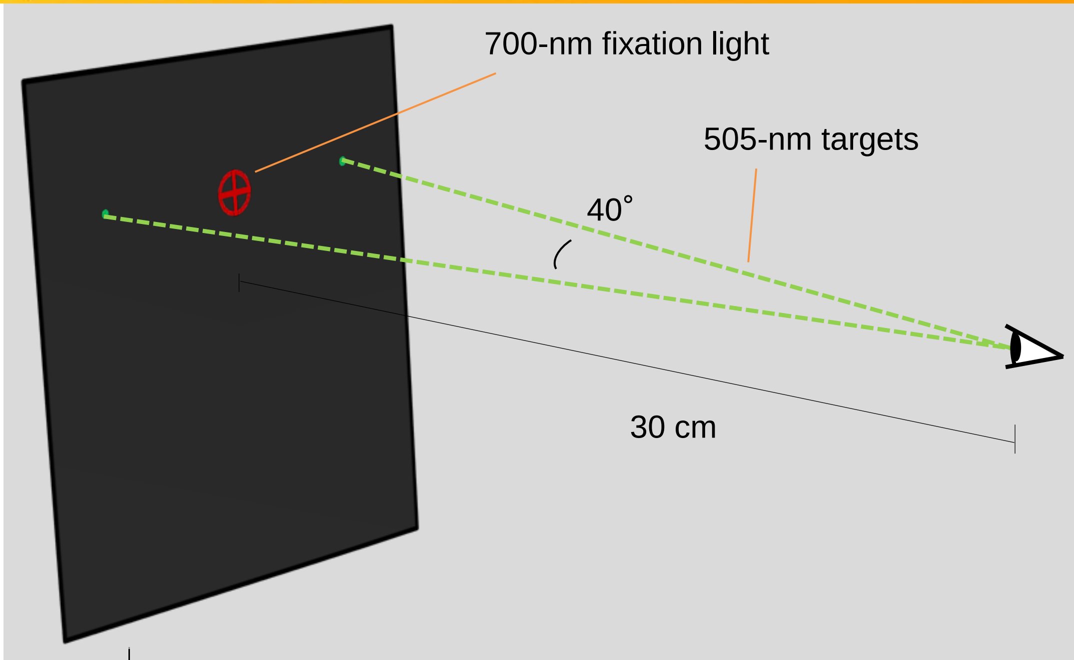
"Heralded" Single-Photon Source

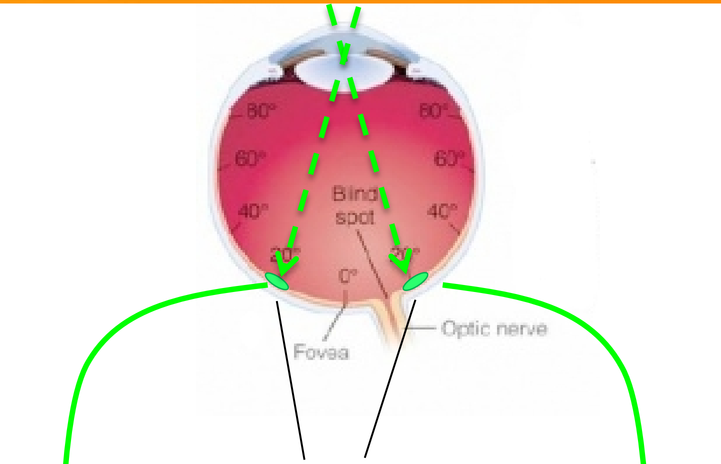
Spontaneous Parametric Downconversion:



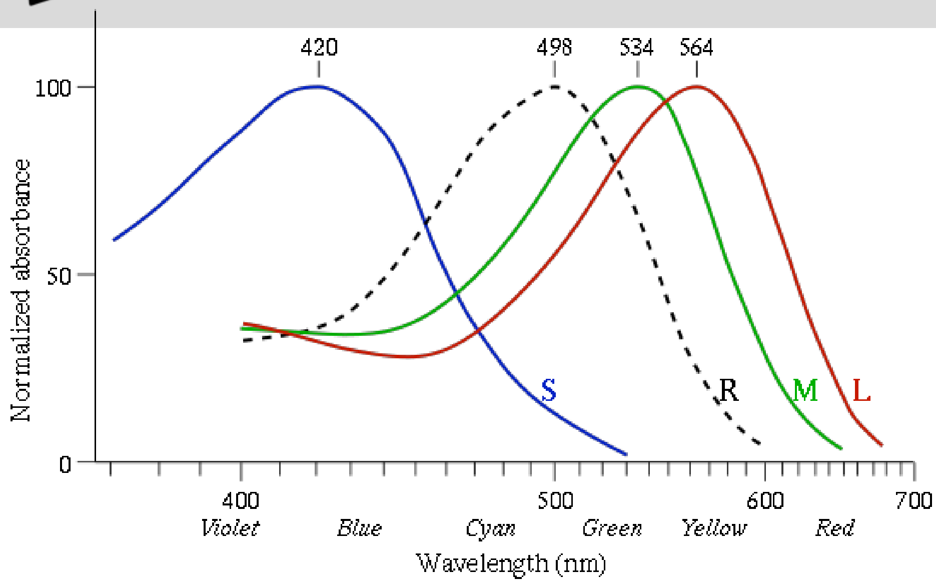


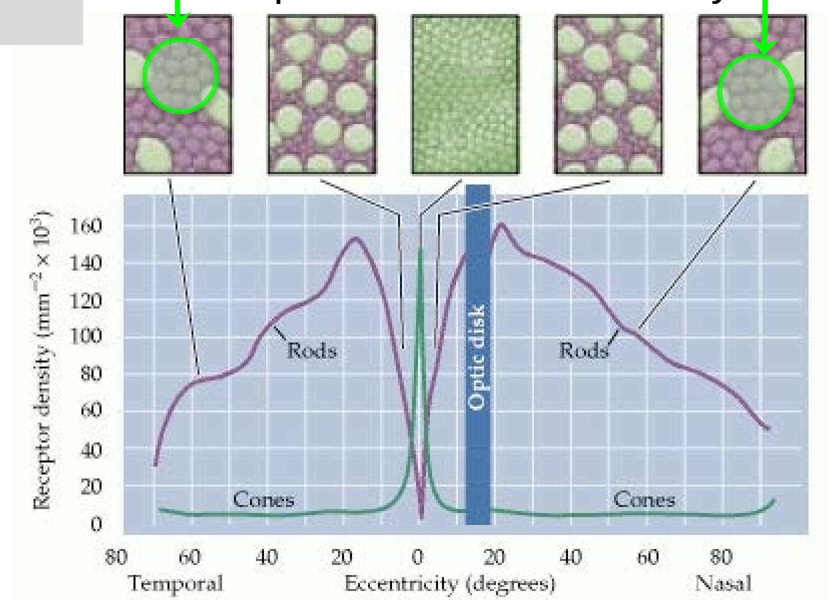




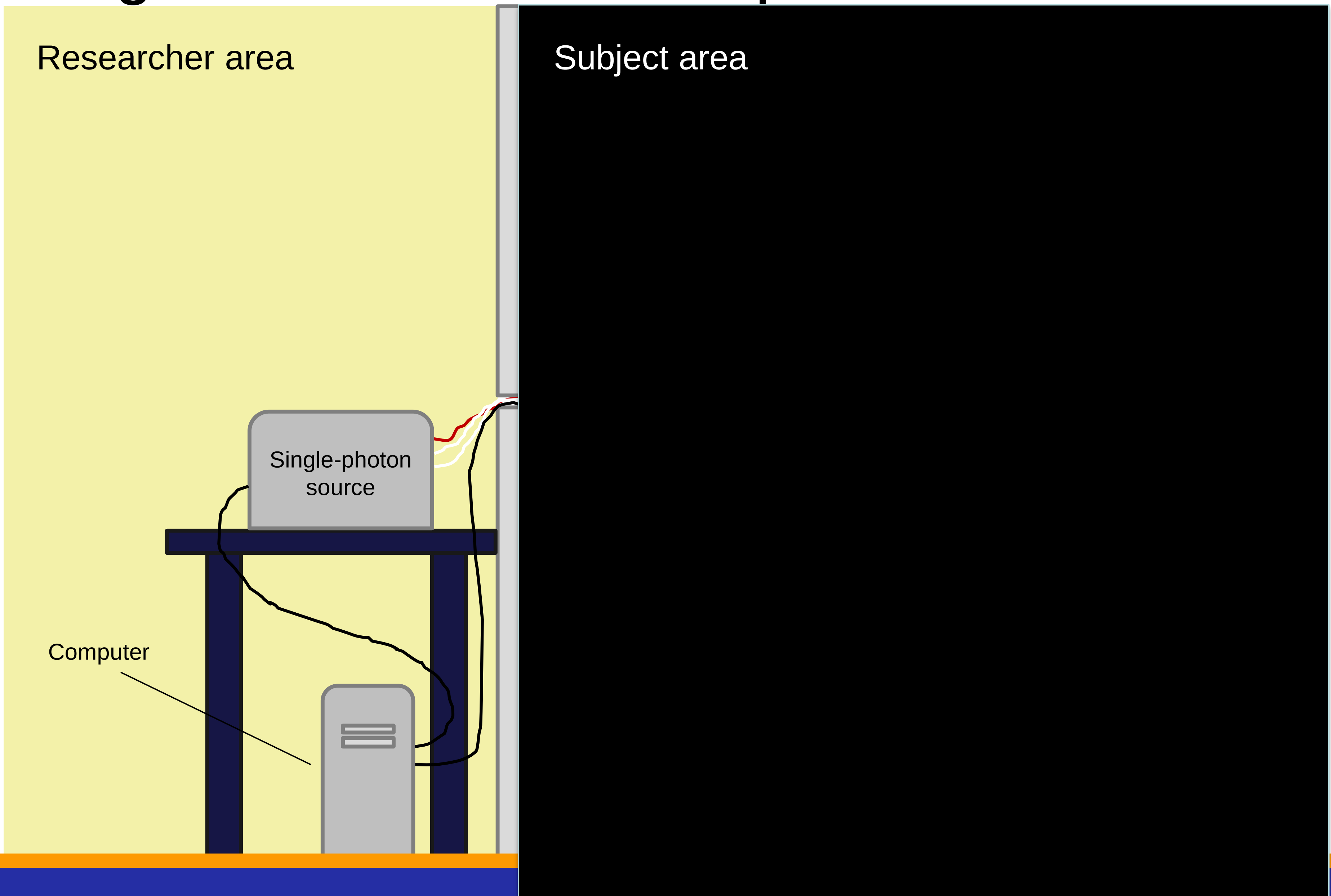


10-µm diameter spots at 20˚ on the nasal and temporal retina of the left eye

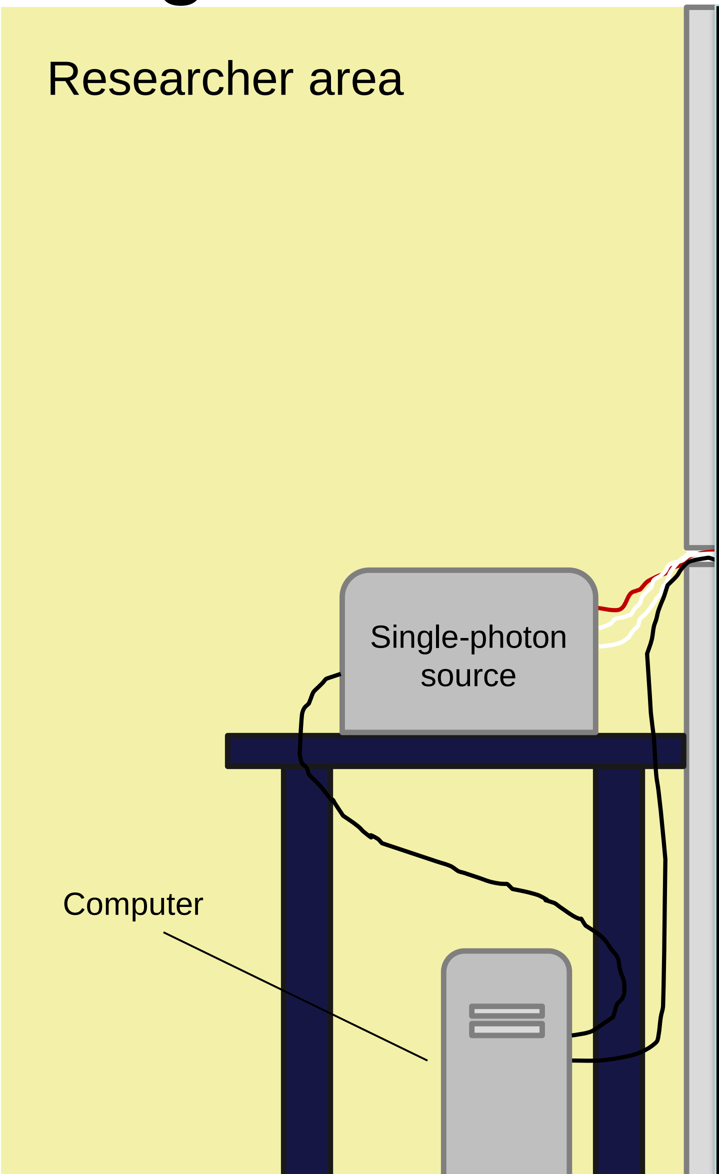




Single-Photon Vision Experiment



Single-Photon Vision Experiment



Subject area

Current Status:
Weak LED and N-photon trials show SOME subjects can reliably detect <30 incident photons (~3 at the retina)

Temporal integration time of the eye longer than expected (~800 ms)

New single-photon trials underway

Can YOU see single photons?
http://research.physics.illinois.edu/QI/Photonics/vision/

“Each photon then interferes only with itself. Interference between two different photons never occurs.”

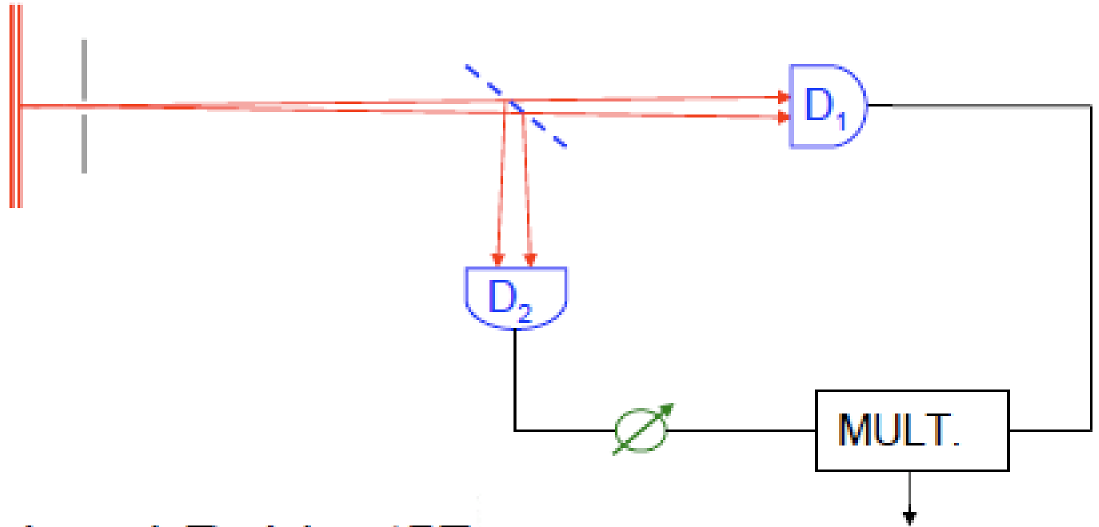
-P.A.M.* Dirac

On Hanbury-Brown Twiss correlations: “…if such a positive correlation did exist, it would call for a major revision of some fundamental concepts in quantum mechanics.”

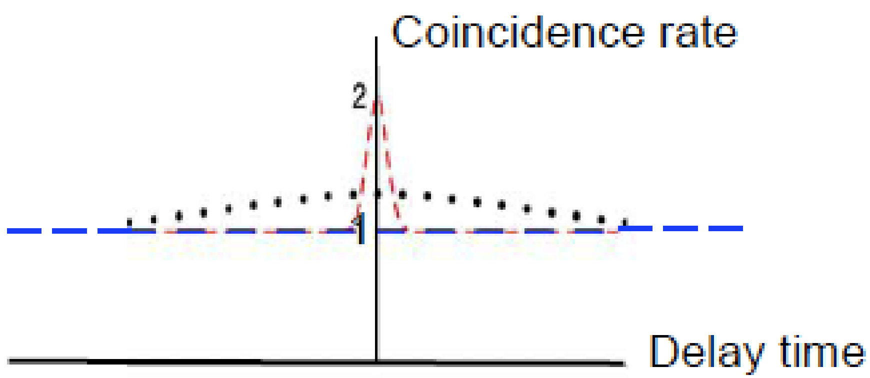
-Brannen and Ferguson

*Paul Adrien Maurice

Hanbury Brown and Twiss '56

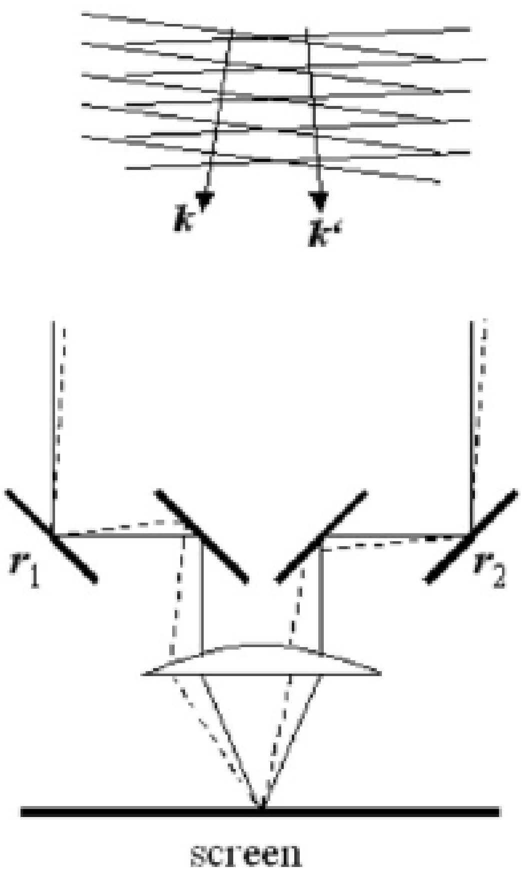


Pound and Rebka '57

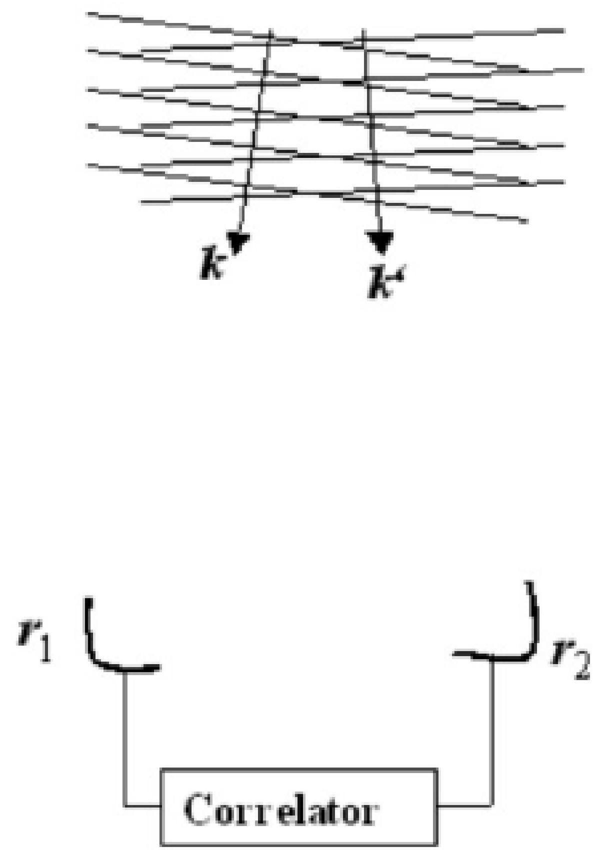


Hanbury-Brown and Twiss

"Michelson Stellar Interferometry" --
Measure field-field correlations



"HBT Interferometry" --
Measure intensity-intensity correlations

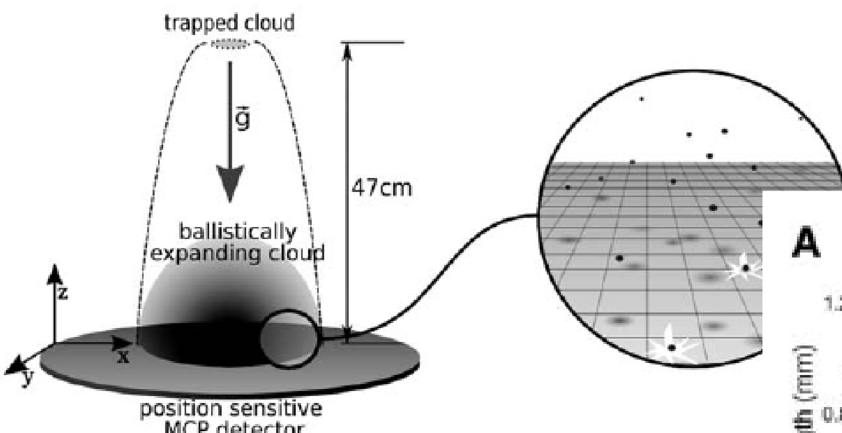


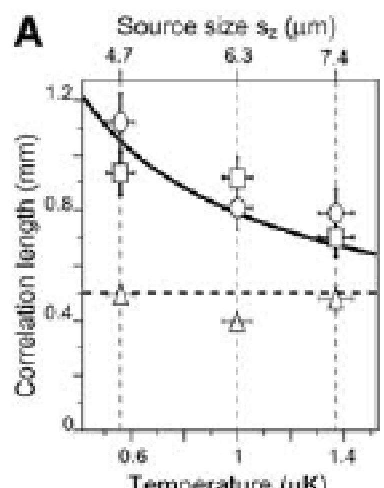
Hanbury Brown Twiss Effect for Ultracold Quantum Gases

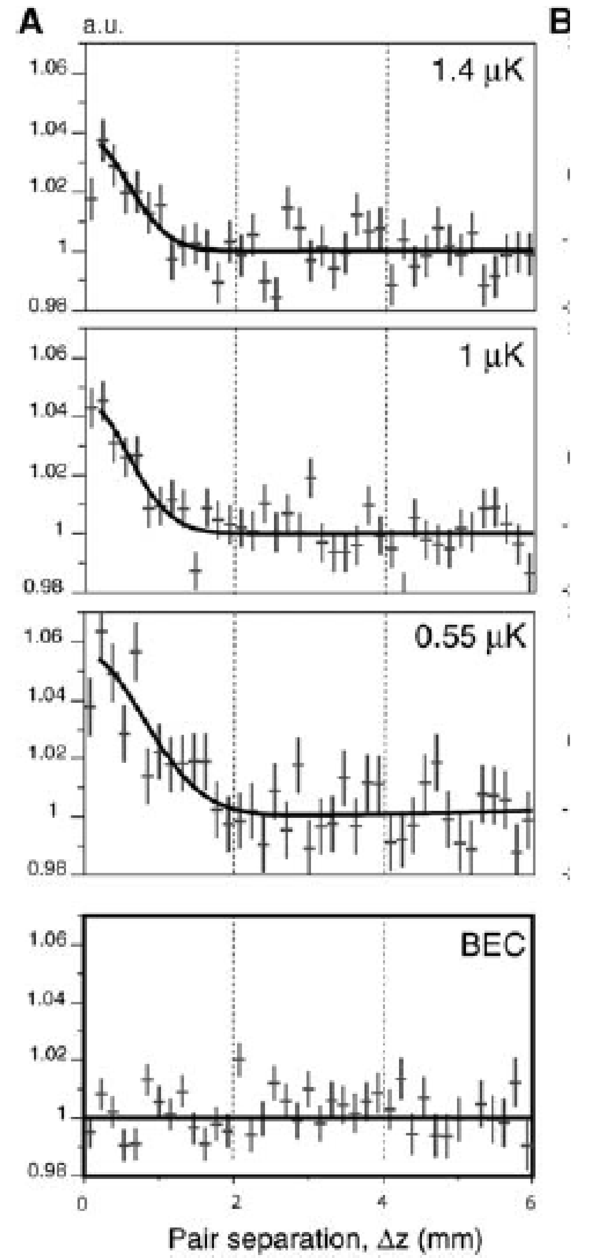
M. Schellekens,[1] R. Hoppeler,[1] A. Perrin,[1] J. Viana Gomes,[1,2]
D. Boiron,[1] A. Aspect,[1] C. I. Westbrook[1*]

We have studied two-body correlations of atoms in an expanding cloud above and below the Bose-Einstein condensation threshold. The observed correlation function for a thermal cloud shows a bunching behavior, whereas the correlation is flat for a coherent sample. These quantum correlations are the atomic analog of the Hanbury Brown Twiss effect. We observed the effect in three dimensions and studied its dependence on cloud size.

648 28 OCTOBER 2005 VOL 310 SCIENCE





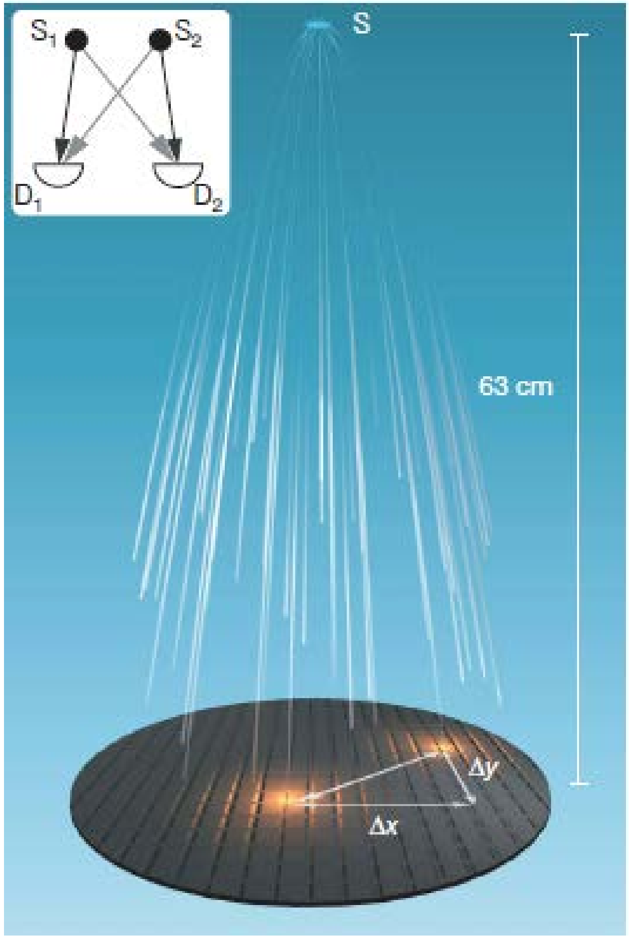


Evaporatively cooled
metastable He
(which one??)

nature Vol 445|25 January 2007|doi:10.1038/nature05513

Comparison of the Hanbury Brown–Twiss effect for bosons and fermions

T. Jeltes[1], J. M. McNamara[1], W. Hogervorst[1], W. Vassen[1], V. Krachmalnicoff[2], M. Schellekens[2], A. Perrin[2], H. Chang[2], D. Boiron[2], A. Aspect[2] & C. I. Westbrook[2]



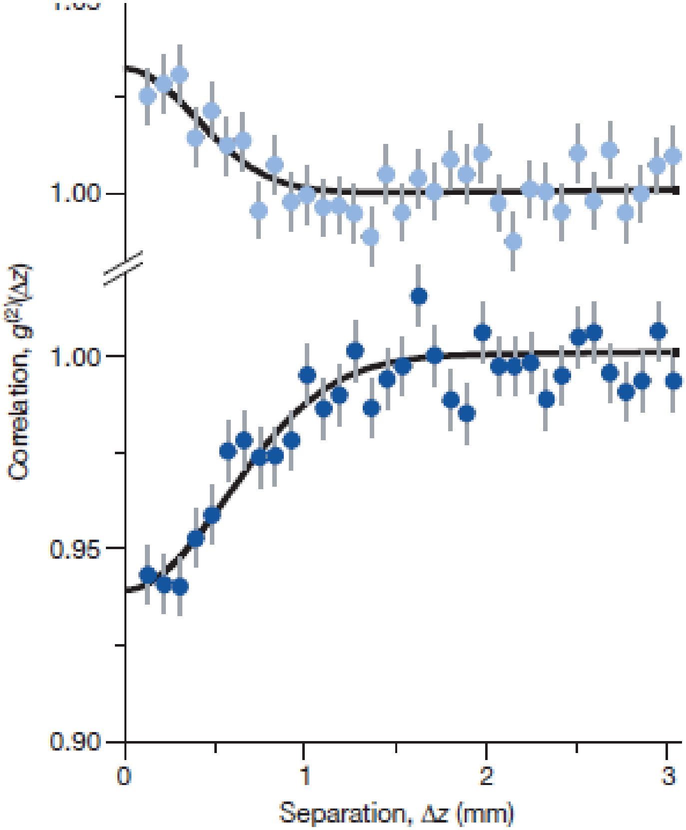


Figure 2 | Normalized correlation functions for ^{4}He* (bosons) in the upper plot, and ^{3}He* (fermions) in the lower plot. Both functions are measured at the same cloud temperature (0.5 μK), and with identical trap parameters. Error bars correspond to the square root of the number of pairs in each bin.