Two-Photon Interferometry of Undulator Radiation

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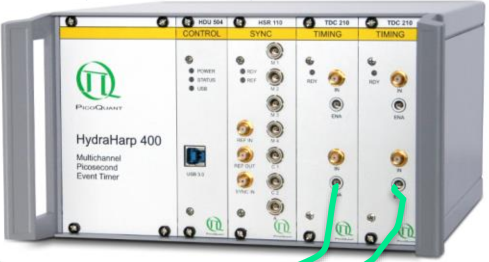
G. Stancari, A. Romanov, I. Lobach + interest from UC Berkeley and others

(project funded by Fermilab LDRD)

Oct. 28, 2021

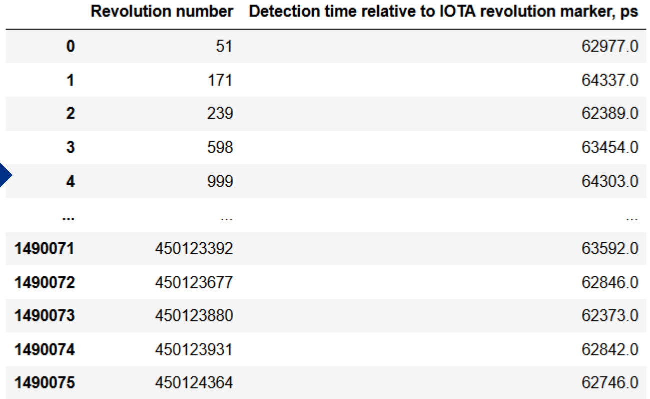
Design of the experiment with a single electron

Picosecond event timer
(dead time < IOTA revolution period)
provided by G. Stancari



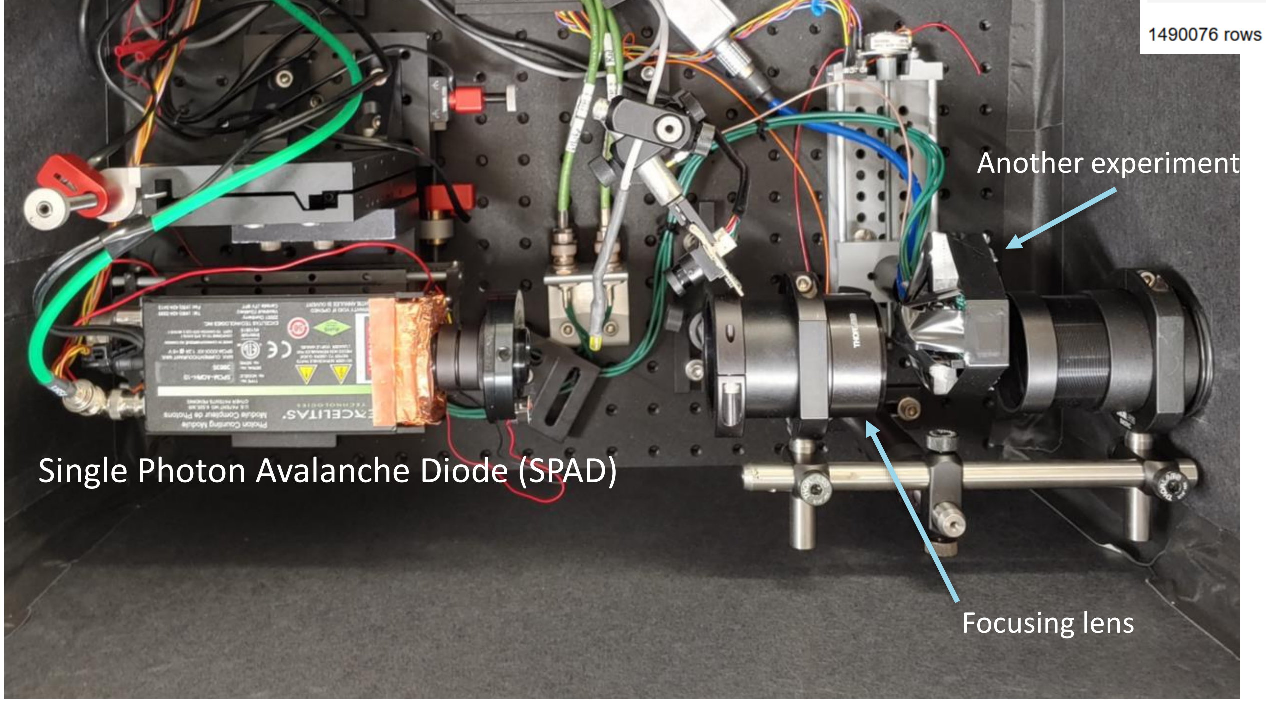
IOTA revolution marker

Record all events for 20 sec – 2 min



	Revolution number	Detection time relative to IOTA revolution marker, ps
0	51	62977.0
1	171	64337.0
2	239	62389.0
3	598	63454.0
4	999	64303.0
...	...	...
1490071	450123392	63592.0
1490072	450123677	62846.0
1490073	450123880	62373.0
1490074	450123931	62842.0
1490075	450124364	62746.0

1490076 rows × 2 columns



Undulator radiation

Single Photon Avalanche Diode (SPAD) detector (two in hand)

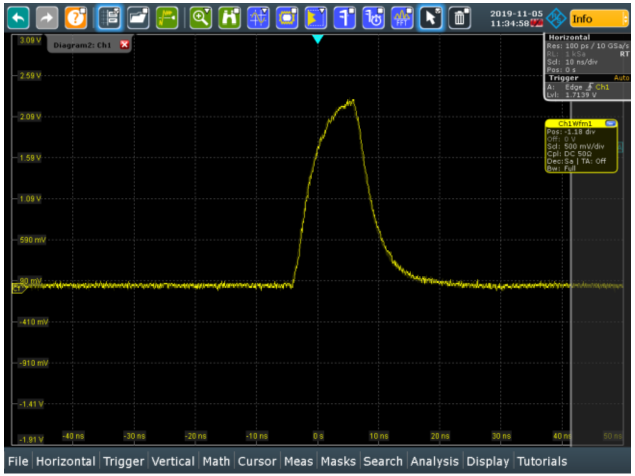
Excelitas SPCM-AQRH-10

Active area (diameter)	**180** μm
Detector efficiency at 650 nm	65%
Dark count	~100 Hz
Dead time	22 ns
Pulse height	2 V
Pulse length	10 ns
Transit time spread (TTS)	0.35 ns

*with gating <10 Hz

*IOTA period is 133 ns

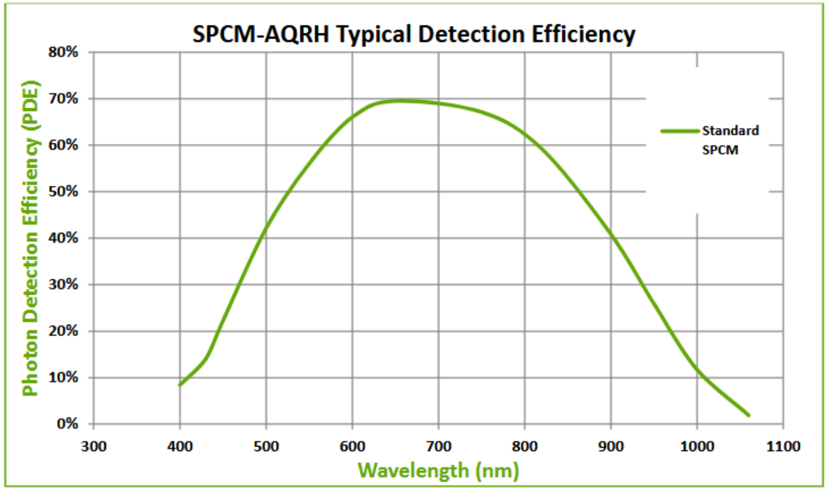
<u>Each detection event creates a pulse of the same height and width:</u>



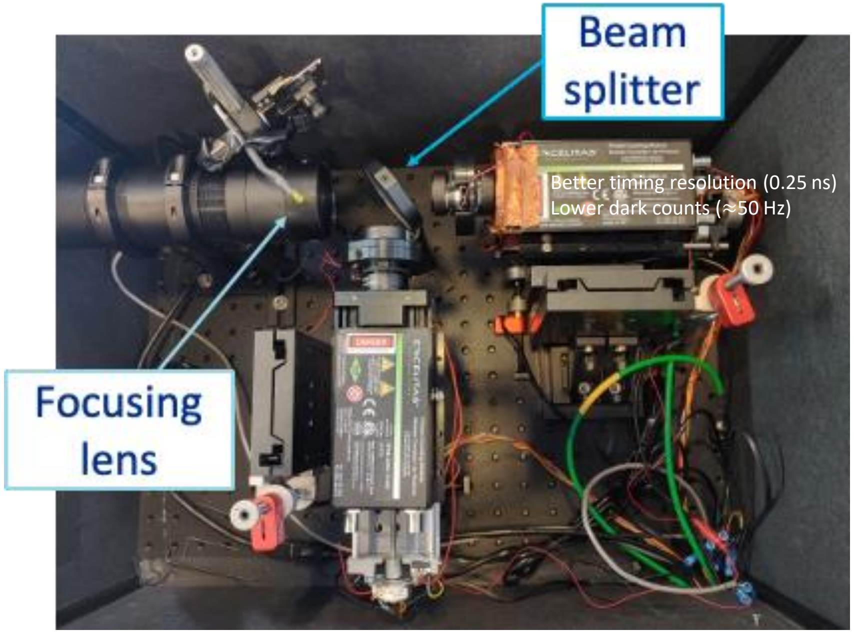
Horizontal
Res: 100 ps / 10 GSa/s
RL: 1 kSa RT
Scl: 10 ns/div
Pos: 0 s
Trigger Auto
A: Edge Ch1
Lvl: 1.7139 V

Ch1Wfm1
Pos: -1.18 div
Off: 0 V
Scl: 500 mV/div
Cpl: DC 50Ω
Dec: Sa | TA: Off
Bw: Full

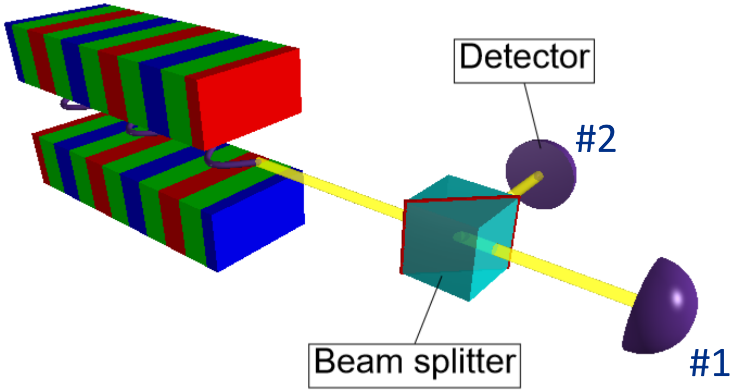
Typical Photon Detection Efficiency (PDE) vs. Wavelength


SPCM-AQRH Typical Detection Efficiency

Two SPAD detectors (June 2021) at 100 MeV



Better timing resolution (0.25 ns)
Lower dark counts (≈50 Hz)



Collected data (up to 5-minutes-long):

0000010000011000000000002000100000011200000000...

- So far, no deviations from our expectations

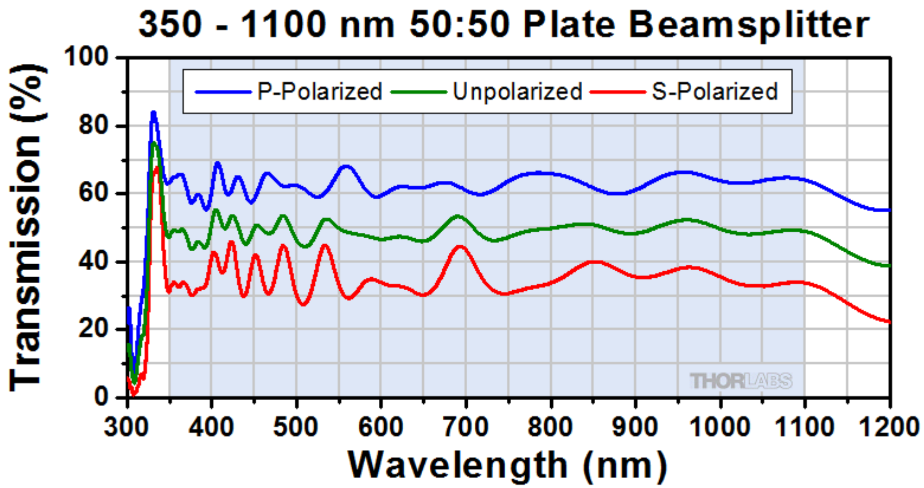
Detector #1: ~30 kHz

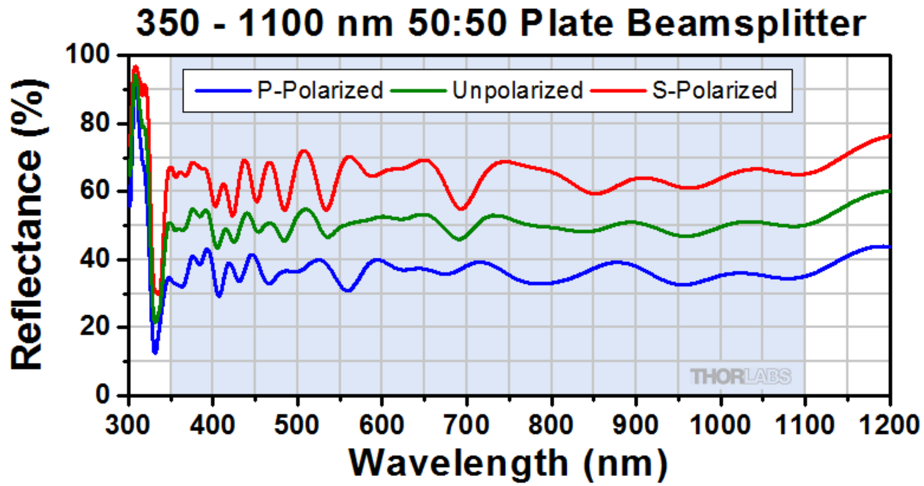
Detector #2: ~15 kHz

Detector #1 & Detector #2: ~70 Hz

Beamsplitter specifications

BSW27 - Ø2" 50:50 UVFS Plate Beamsplitter, Coating: 350 - 1100 nm, t = 8.0 mm





Detector #1: ~30 kHz
Detector #2: ~15 kHz
Detector #1 & Detector #2: ~70 Hz

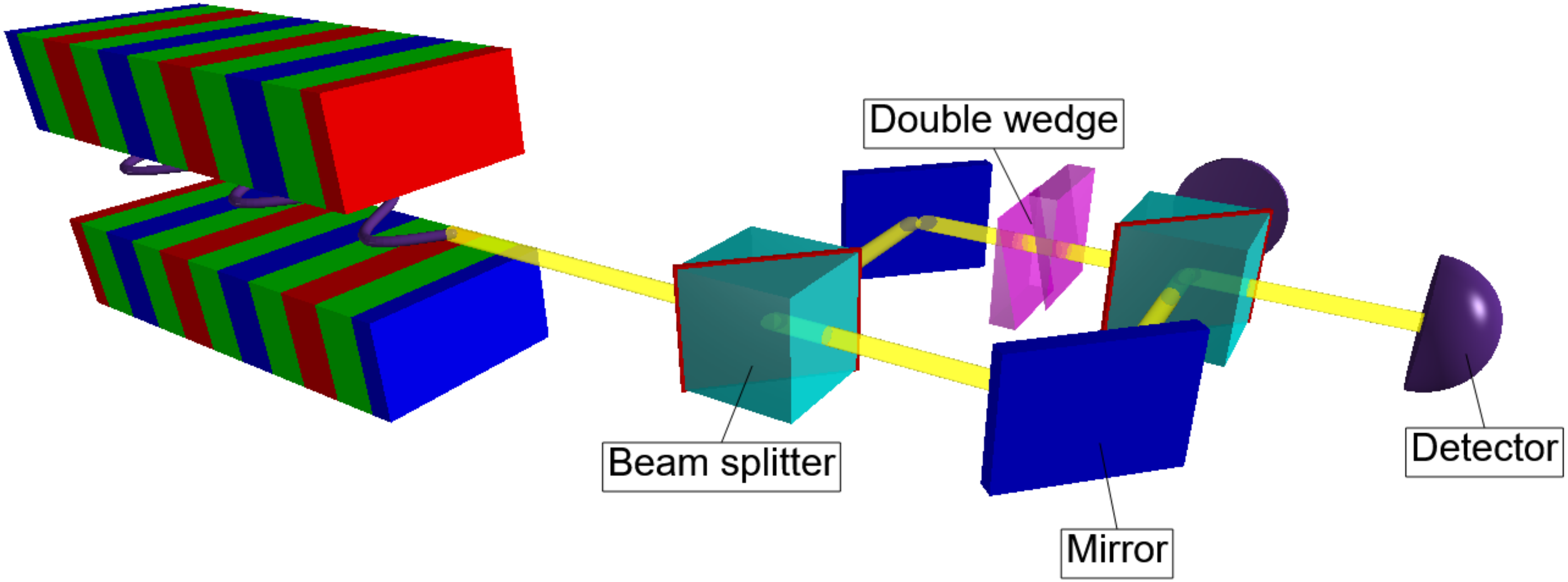
150-MeV beam tests

- The fundamental shifted from 1160 nm to 480 nm
- One SPAD configuration: 27 kHz
- Two-SPAD configuration:
  Detector #1: 8.9 kHz
  Detector #2: 4.6 kHz

- We prefer to operate at the fundamental of undulator radiation in order to have non-zero intensity at zero-angle

Mach-Zehnder interferometry of undulator radiation

- Interference of the photons in emitted photon pairs with two detectors
- IOTA Run 4 proposal

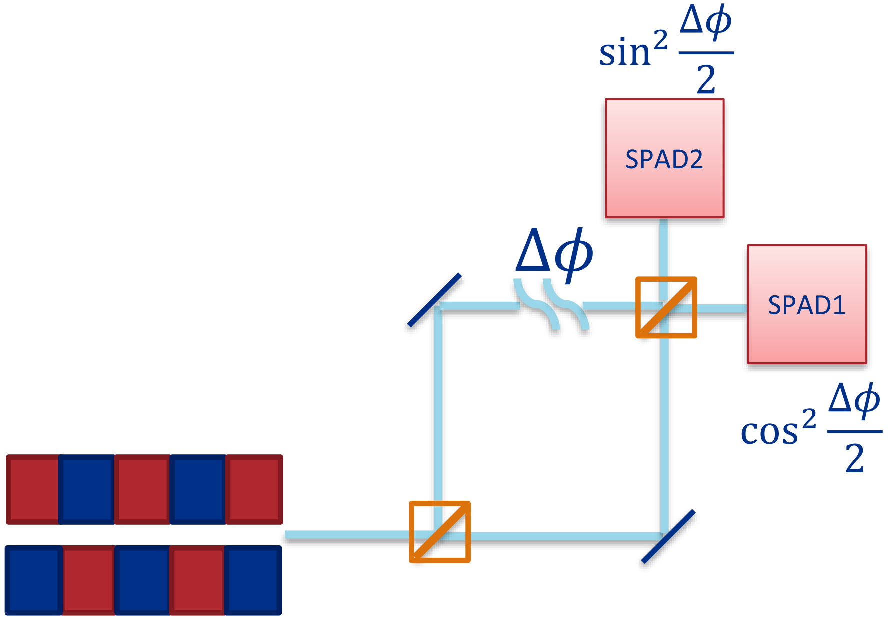


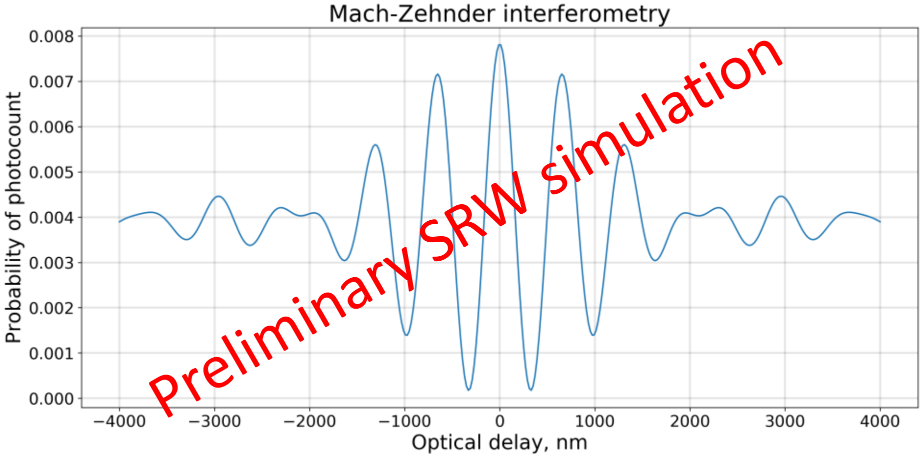
- **Mach–Zehnder interferometer:**
  - **Output 1:** $E(t) - E(t+\delta t)$
  - **Output 2:** $E(t) + E(t+\delta t)$

*light pulse length ≈ 30 fs

Measurement of the light pulse shape in time domain

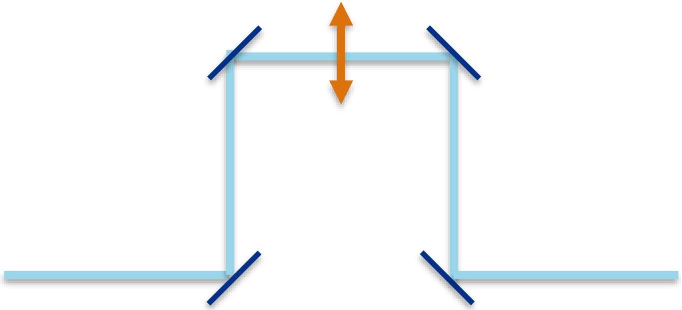
Mach-Zehnder interferometry with a single electron





Very precise adjustable optical delay

Moved by picomotors: 10 nm step



Nanopositioners

nanopositioning made simple

ECSx3030/Al/NUM/RT

linear bearing based nanopositioner for horizontal motion

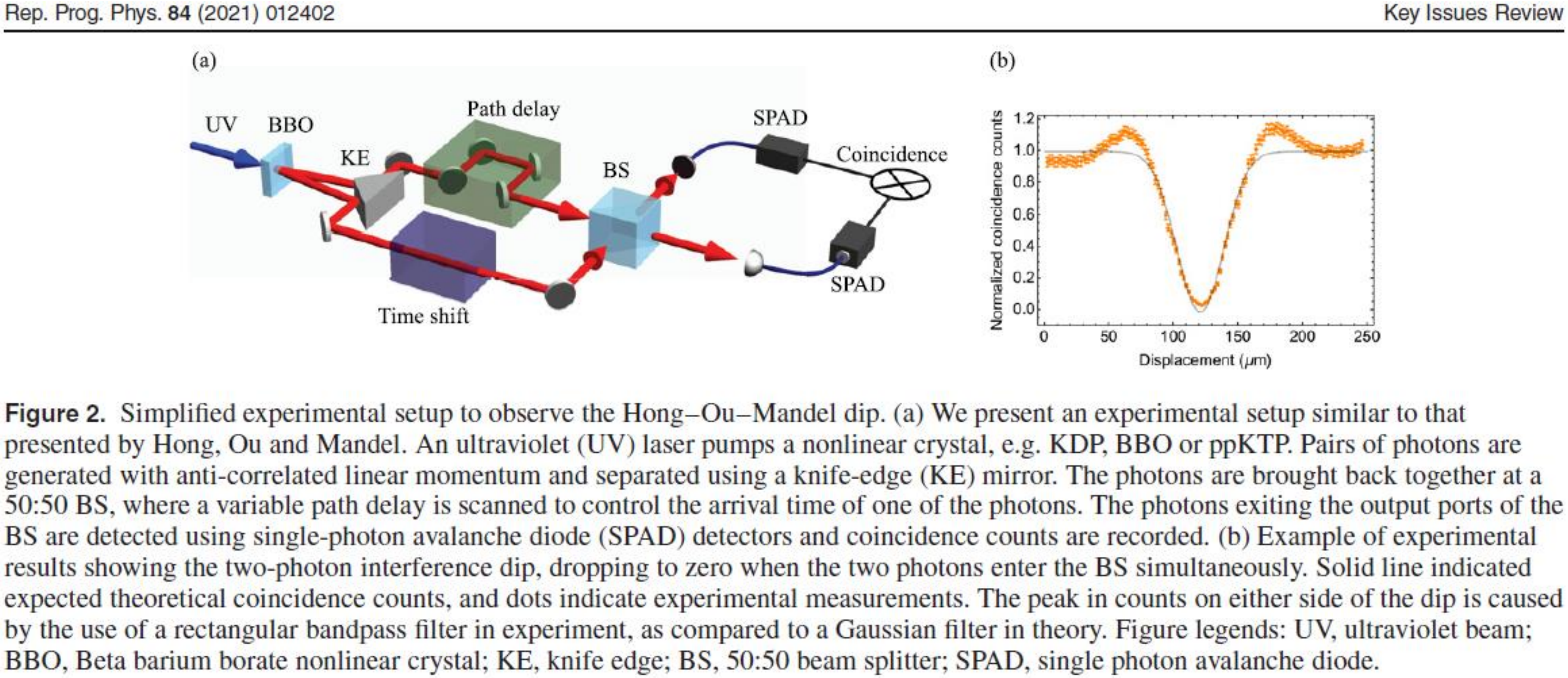

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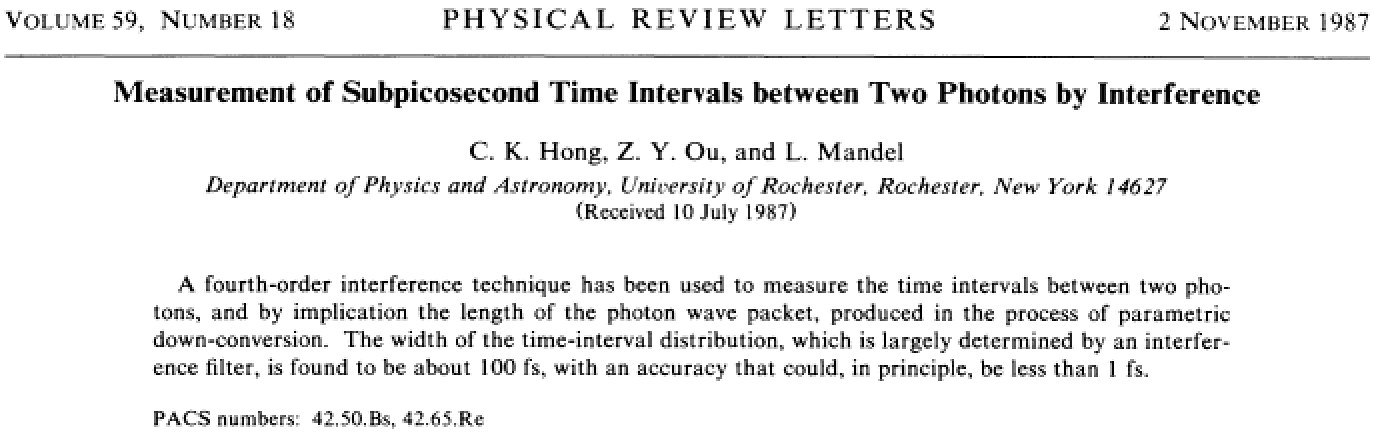
Figure 2. Simplified experimental setup to observe the Hong–Ou–Mandel dip. (a) We present an experimental setup similar to that presented by Hong, Ou and Mandel. An ultraviolet (UV) laser pumps a nonlinear crystal, e.g. KDP, BBO or ppKTP. Pairs of photons are generated with anti-correlated linear momentum and separated using a knife-edge (KE) mirror. The photons are brought back together at a 50:50 BS, where a variable path delay is scanned to control the arrival time of one of the photons. The photons exiting the output ports of the BS are detected using single-photon avalanche diode (SPAD) detectors and coincidence counts are recorded. (b) Example of experimental results showing the two-photon interference dip, dropping to zero when the two photons enter the BS simultaneously. Solid line indicated expected theoretical coincidence counts, and dots indicate experimental measurements. The peak in counts on either side of the dip is caused by the use of a rectangular bandpass filter in experiment, as compared to a Gaussian filter in theory. Figure legends: UV, ultraviolet beam; BBO, Beta barium borate nonlinear crystal; KE, knife edge; BS, 50:50 beam splitter; SPAD, single photon avalanche diode.

Hong-Ou-Mandel effect



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Measurement of Subpicosecond Time Intervals between Two Photons by Interference

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(Received 10 July 1987)

A fourth-order interference technique has been used to measure the time intervals between two photons, and by implication the length of the photon wave packet, produced in the process of parametric down-conversion. The width of the time-interval distribution, which is largely determined by an interference filter, is found to be about 100 fs, with an accuracy that could, in principle, be less than 1 fs.

PACS numbers: 42.50.Bs, 42.65.Re

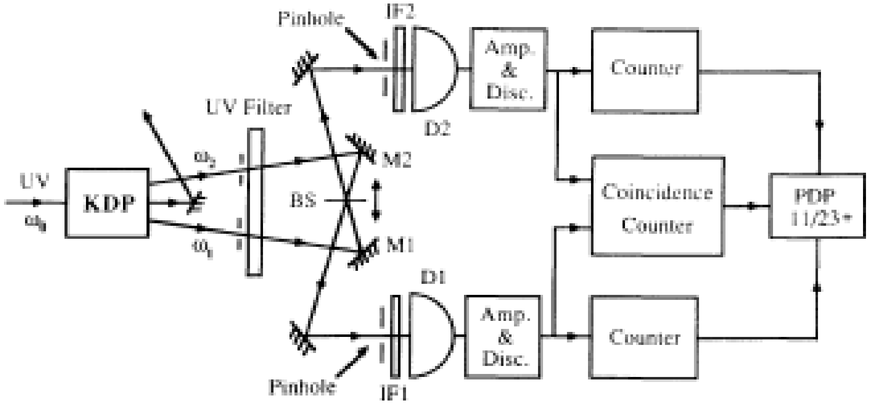

FIG. 1. Outline of the experimental setup.

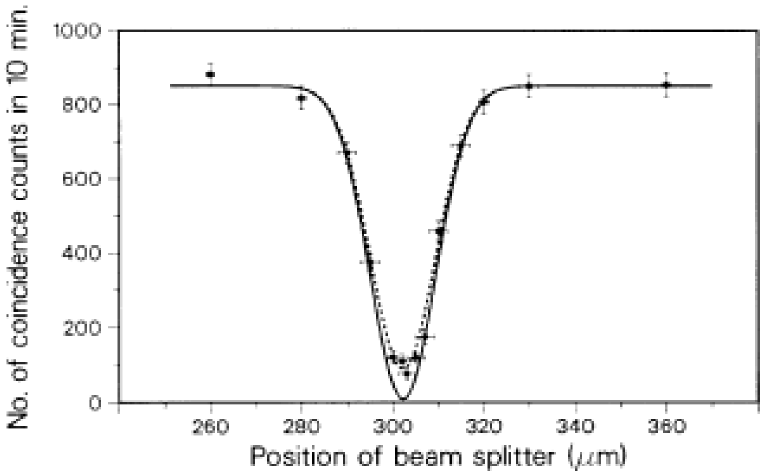

FIG. 2. The measured number of coincidences as a function of beam-splitter displacement $c\,\delta\tau$, superimposed on the solid theoretical curve derived from Eq. (11) with $R/T = 0.95$, $\Delta\omega = 3\times 10^{13}$ rad s^{-1}. For the dashed curve the factor $2RT/(R^2+T^2)$ in Eq. (11) was multiplied by 0.9. The vertical error bars correspond to one standard deviation, whereas horizontal error bars are based on estimates of the measurement accuracy.