Time-stamping photons with sub-nanosecond resolution for quantum-enhanced imaging and telescopy

19.11.2024

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PIXEL 2024

18 - 22 NOV

STRASBOURG
Collège Doctoral Européen

11th International Workshop on Semiconductor Pixel Detectors for Particles and Imaging

Topics

Abstract submission until July 5
Registration until September 30

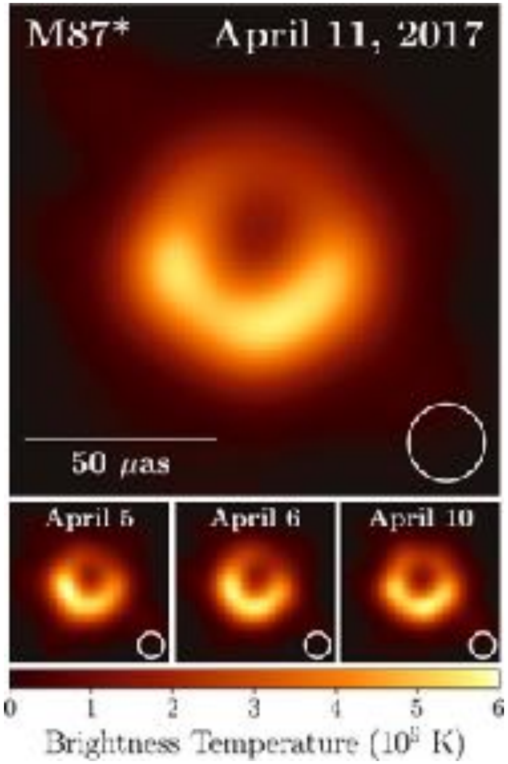
outline

- Motivation for fast imaging (= fast pixels with data-driven time-stamping)
  - Astrophysics &
  - Quantum &
  - Quantum- enhanced telescopy

- Results with existing fast imagers for
  - Quantum-assisted interferometry
  - Quantum optics
  - “Quantum” x-rays

- Ideas for future development

Astronomy picture of the decade



2019 ApJL 875

Black hole in the center of M87 imaged at 1.3mm

sensitive to features
on angular scale

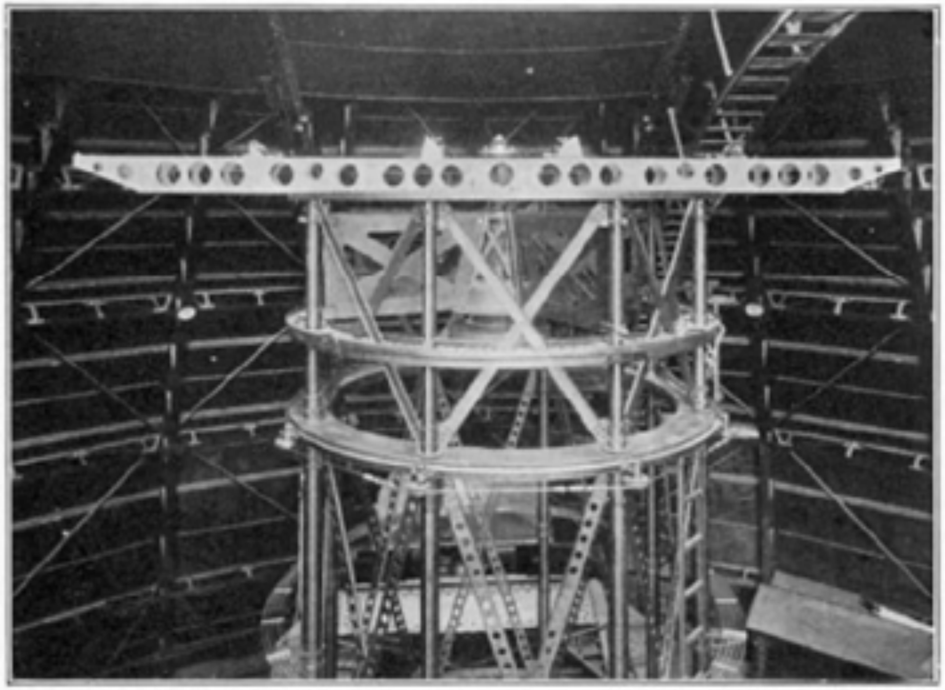
$$\Delta \theta \sim \frac{\lambda}{b}$$

dime at Moon: 5 arcsec

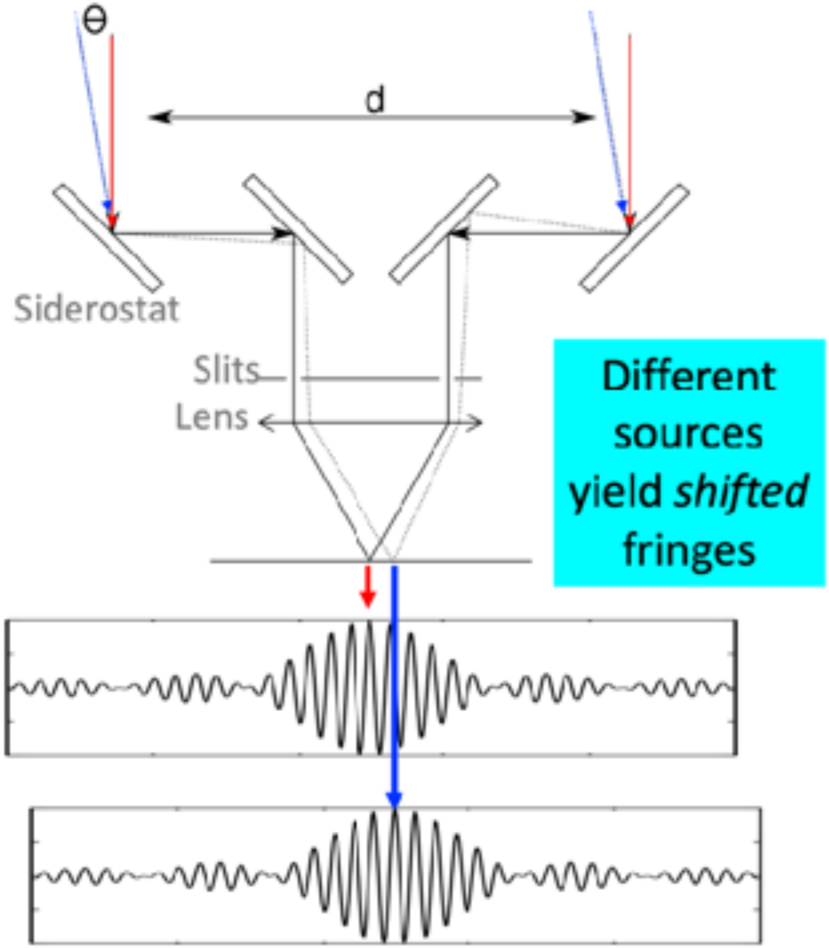
Achieved by radio interferometry with ~10000 km baselines

Classical interferometery

In classical times



Michelson Stellar Interferometer at Mt. Wilson c. 1920, after original idea by Michelson & Fizeau c. 1890

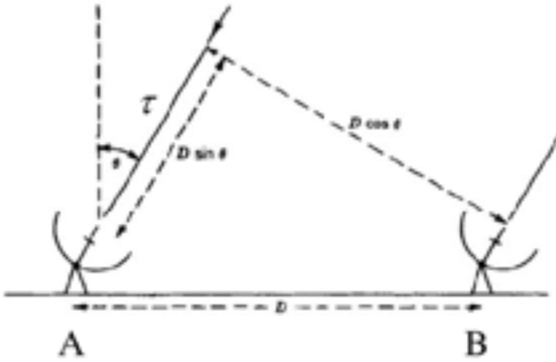


Different sources yield *shifted* fringes

Radio

$\bar{n} \gg 1$

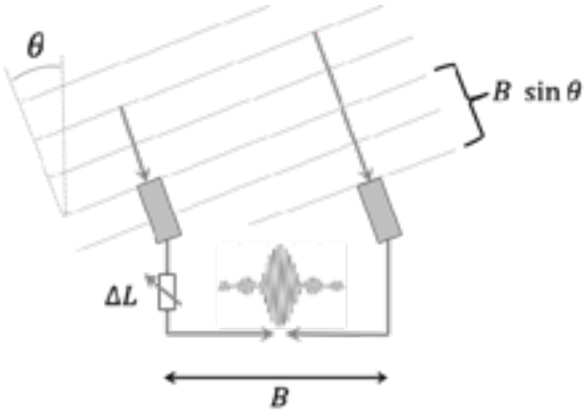
mode population



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

Optical

$\bar{n} \ll 1$ mode population



One photon at a time! Need to bring paths to common point in real time

Need path length *compensated* to better than c/bandwidth

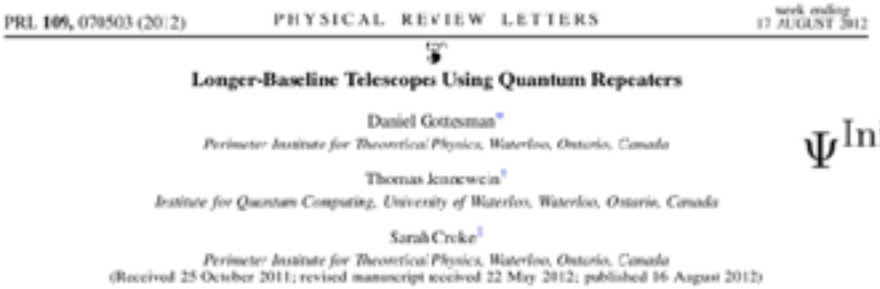
Need path length *stabilized* to better than λ

Accuracy ~ 1 mas

Max baselines to ~ 100 m

Two-photon techniques

Second photon for quantum assist

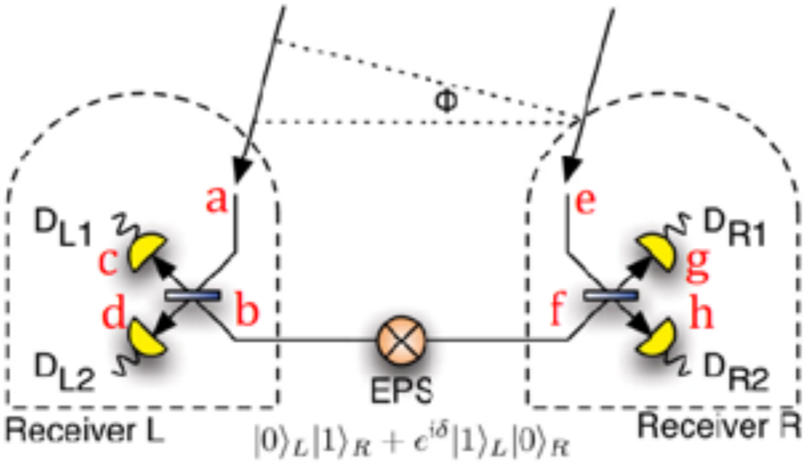


PRL 109, 070503 (2012) PHYSICAL REVIEW LETTERS week ending 17 AUGUST 2012

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)

$$\Psi^{\text{Initial}} = \psi_1\psi_2 = \frac{1}{2}\underbrace{(\hat{a}^\dagger + e^{i\delta_1}\hat{e}^\dagger)}_{\text{Sky photon}}\underbrace{(\hat{b}^\dagger + e^{i\delta_2}\hat{f}^\dagger)}_{\text{Ground photon}}$$



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

Beam Splitters

$$\boxed{\begin{array}{ll} \hat{a}^\dagger \to (\hat{c}^\dagger + \hat{d}^\dagger)/\sqrt{2} & \hat{b}^\dagger \to (\hat{c}^\dagger - \hat{d}^\dagger)/\sqrt{2} \\ \hat{e}^\dagger \to (\hat{g}^\dagger + \hat{h}^\dagger)/\sqrt{2} & \hat{f}^\dagger \to (\hat{g}^\dagger - \hat{h}^\dagger)/\sqrt{2} \end{array}}$$

$$\boxed{\begin{aligned} \Psi^{\text{Output}} \;=\;& (1/4)(\hat{c}^\dagger\hat{c}^\dagger - \hat{d}^\dagger\hat{d}^\dagger + e^{i(\delta_1+\delta_2)}(\hat{g}^\dagger\hat{g}^\dagger - \hat{h}^\dagger\hat{h}^\dagger) + \\ & (e^{i\delta_1} + e^{i\delta_2})(\hat{c}^\dagger\hat{g}^\dagger - \hat{d}^\dagger\hat{h}^\dagger) + (e^{i\delta_1} - e^{i\delta_2})(\hat{c}^\dagger\hat{h}^\dagger + \hat{d}^\dagger\hat{g}^\dagger)) \end{aligned}}$$

$$\boxed{\begin{aligned} P(c^2) = P(d^2) = P(g^2) = P(h^2) &= 1/8 \\ P(cg) = P(dh) &= (1/8)(1 + \cos(\delta_1 - \delta_2)) \\ P(ch) = P(dg) &= (1/8)(1 - \cos(\delta_1 - \delta_2)) \end{aligned}}$$

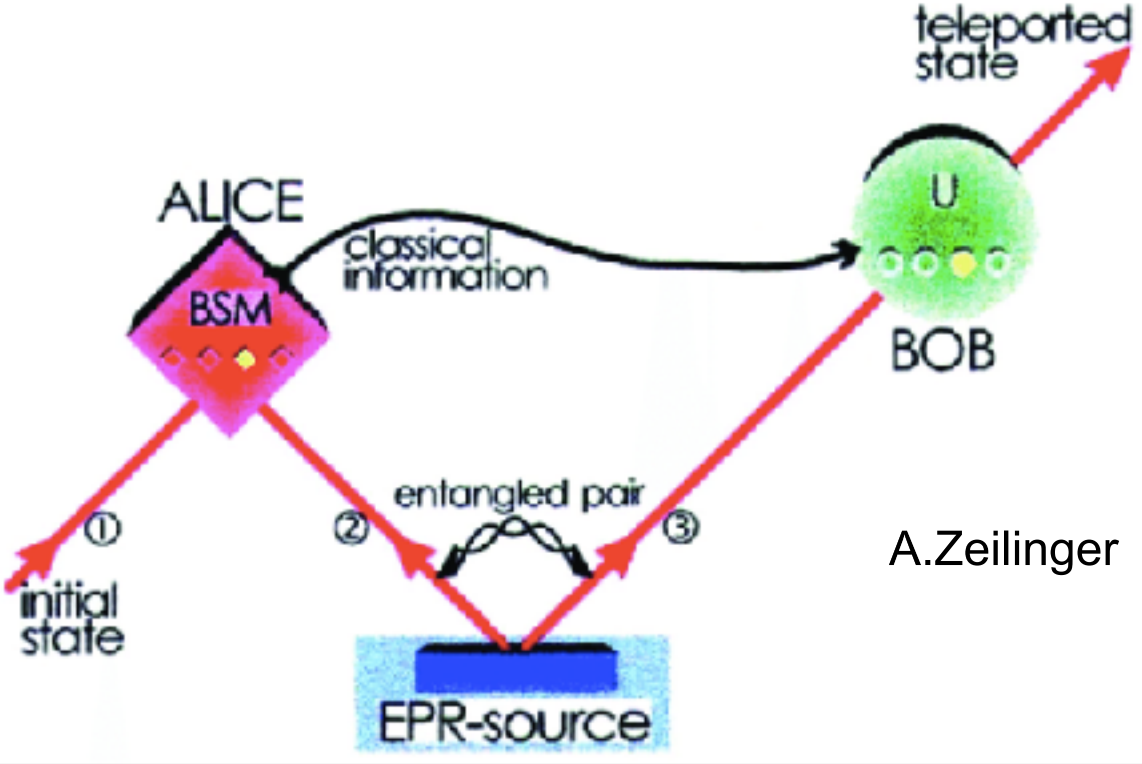
- Measure photon quantum state at one station → teleport the sky photon to 2nd station
- Correlation of counters are sensitive to sky photon phase → direction
- Need to transfer the photon quantum state → can use quantum networks, this will allow long distances

- Verified experimentally in quantum optics settings: M Brown et al, PRL 131, 210801 (2023)

Quantum Network

- Attenuation in fibers → need quantum repeater to reproduce qubits
  - Simple amplification will not conserve the quantum state

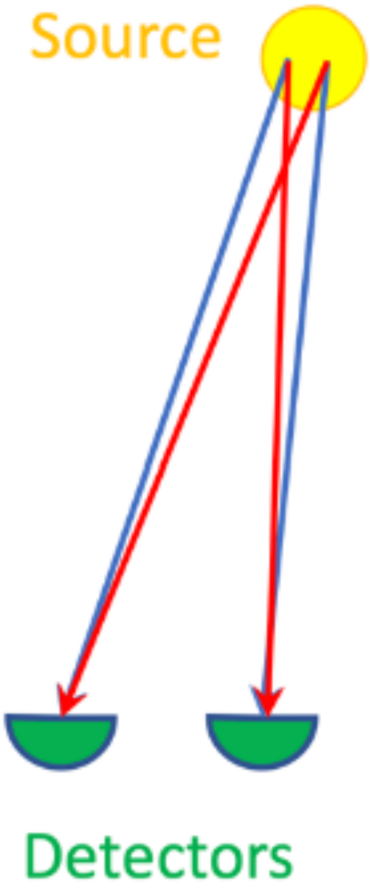
- Qubit teleportation: produce entangled photons and send them to two locations
- Bell State Measurement (BSM) on one photon will collapse the wave function of the other one (or swap entanglement, or teleport photon)



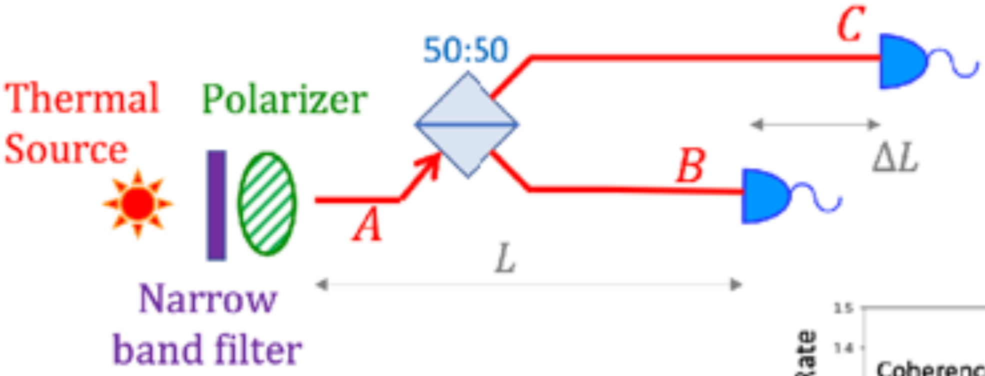
A.Zeilinger

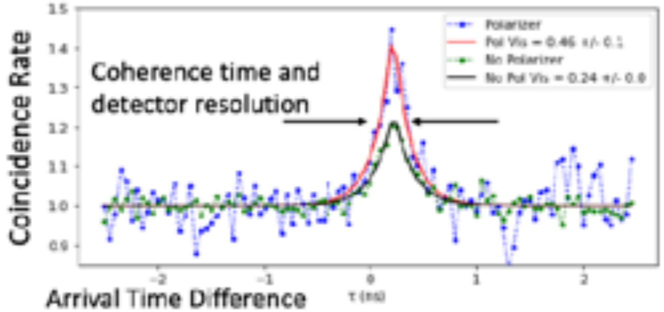
Hanbury Brown - Twiss effect

If points are close enough two options of photons paths are coherent = photon phases not so different and they interfere

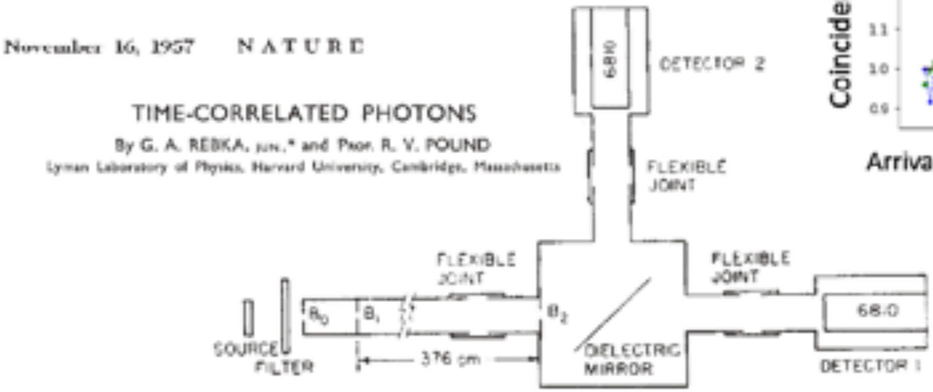


Interference produces photon bunching or HBT effect





visibility = S/B = 46%



November 16, 1957 NATURE

TIME-CORRELATED PHOTONS

By G. A. REBKA, jun.* and Prof. R. V. POUND

Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts

Robert Hanbury Brown
radio-astronomer
1920 – 2002

Richard Q. Twiss
applied mathematician
1920 – 2005

1952: First application of this idea to **radio astronomy**

[Hanbury Brown, Jennison & Das Gupta, *Nature* **170**, 1061 (1952)].

1954: The theory behind it [Hanbury Brown & Twiss, *Phil. Mag*. **45**, 663 (1954)].

1956: Lab experiment with **light** [Hanbury Brown & Twiss, *Nature* **177**, 27 (Jan. 1956)].

1956: Measurements on a **star** [Hanbury Brown & Twiss, *Nature* **178**, 1046 (Nov. 1956)].

1961: Interpretation in term of interference between paths of indistinguishable particles

[Fano, Am. J. Phys. **29**, 539 (1961)].

Quantum theory : R. Glauber (1963 => Nobel 2005  **)**

Stellar Intensity Interferometry

Stellar intensity interferometer at Narrabri, Australia, 1968

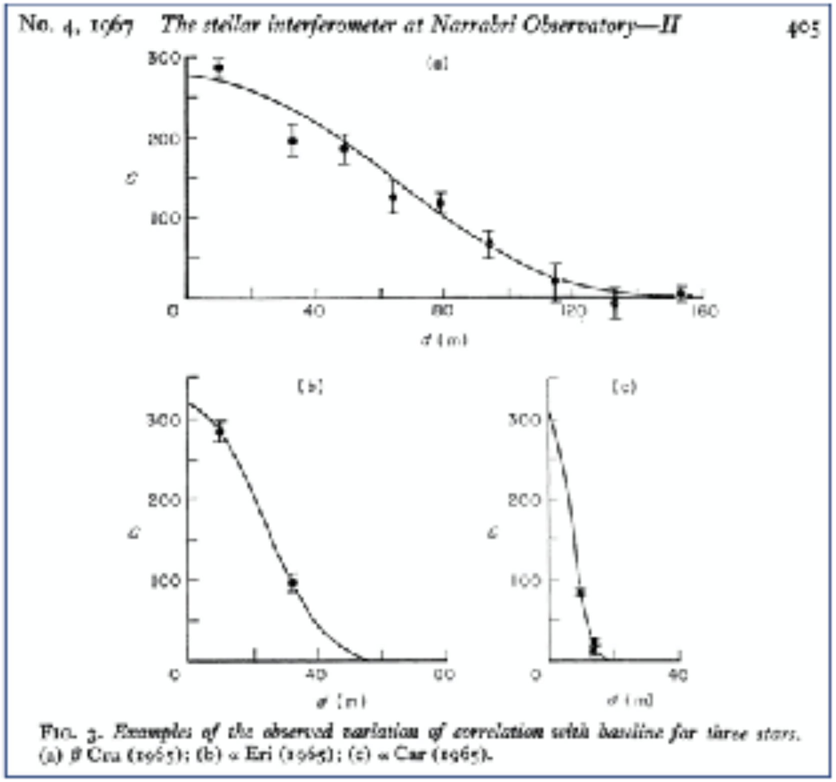
arXiv.org > astro-ph > arXiv:1810.08023

Astrophysics > Instrumentation and Methods for Astrophysics

Intensity Interferometry revival on the Côte d'Azur

Olivier Lai, William Guerin, Farrokh Vakili, Robin Kaiser, Jean Pierre Rivet, Mathilde Fouché, Guillaume Labeyrie, Etienne Samain, David Vernet

(Submitted on 18 Oct 2018)



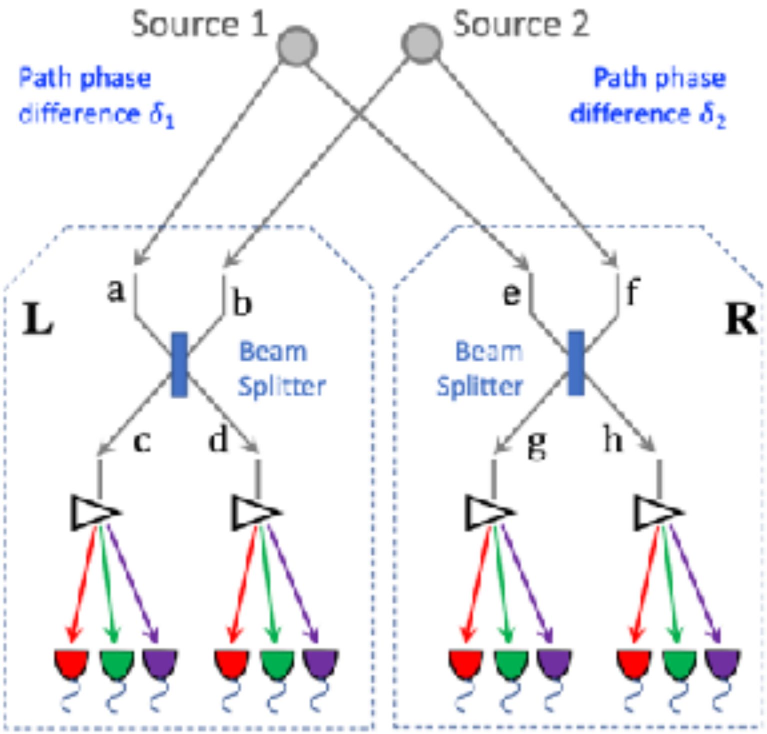
No. 4, 1967 *The stellar interferometer at Narrabri Observatory—II* 405

FIG. 3. *Examples of the observed variation of correlation with baseline for three stars.* (a) β Cru (1965); (b) α Eri (1965); (c) α Car (1965).

Hanbury Brown, Davis, Allen, Rome; MNRAS **137**, (1967) p393-417

renewed interest due to progress in fast detectors!

New ideas extending original proposal



Instrumentation and Methods for Astrophysics

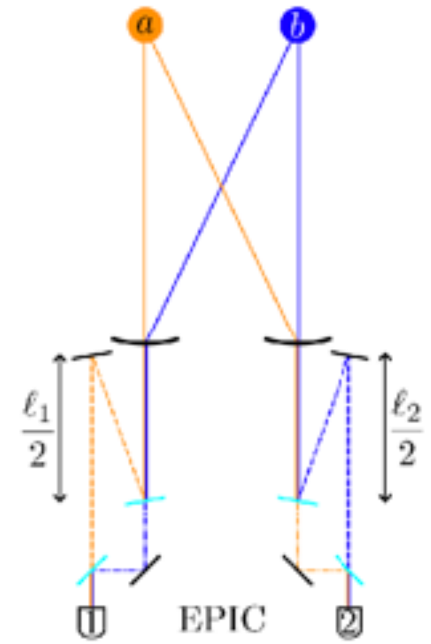
Vol. 5, 2022 · November 01, 2022 IST

Two-photon amplitude interferometry for precision astrometry

Paul Stankus, Andrei Nomerotski, Anže Slosar, Stephen Vintskevich

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

arxiv.org/abs/2010.09100



Astrometry with Extended-Path Intensity Correlation

Ken Van Tilburg,[1, 2, *] Masha Baryakhtar,[3, †] Marios Galanis,[4, ‡] and Neal Weiner[1, §]

[1] Center for Cosmology and Particle Physics, Department of Physics,
New York University, New York, NY 10003, USA
[2] Center for Computational Astrophysics, Flatiron Institute, New York, NY 10010, USA
[3] Department of Physics, University of Washington, Seattle WA 98195, USA
[4] Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada
(Dated: July 10, 2023)

arxiv.org/abs/2307.03221

Extensions of Stellar Intensity Interferometry bridging to quantum-enhanced ideas

Perfect to start exploring this approach

Possible impact on astrophysics and cosmology

https://arxiv.org/abs/2010.09100

offers orders of magnitude better astrometry with major impact

- Parallax: improved distance ladder - sensitive to Dark Energy
- Proper star motions - sensitive to Dark Matter
- Microlensing, see shape changes

- Black hole accretion disk imaging
- Gravitational waves through coherent motions of stars - microHz range
- Exoplanets etc

Requirements for detectors

Photons must be indistinguishable so close enough in frequency and time to interfere → temporal & spectral binning :
need ~ 0.02 nm * 10 ps $\Delta t * \Delta E \geq \hbar/2$

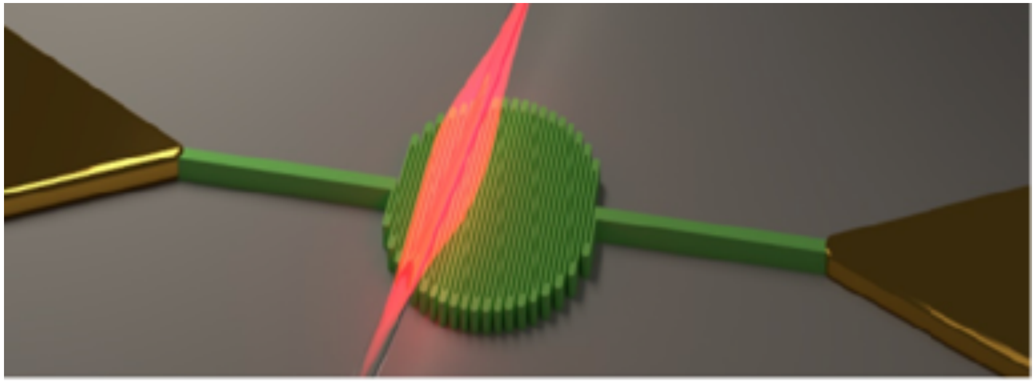
Fast spectrometers at Heisenberg limit

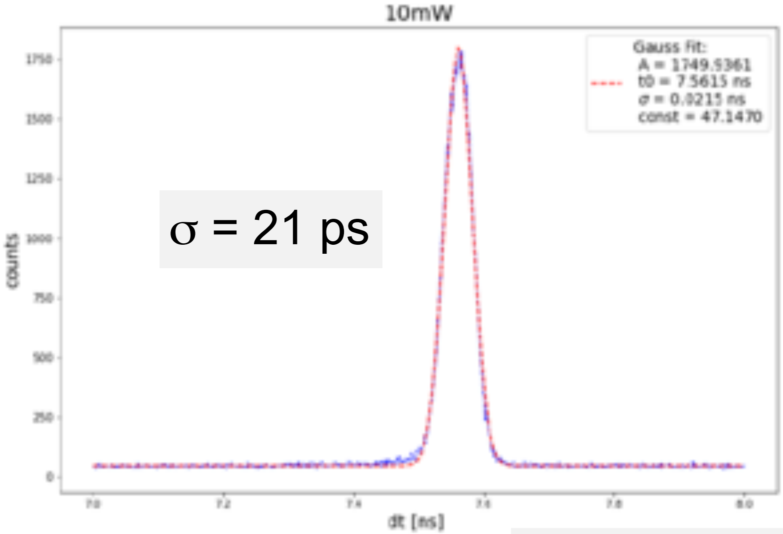
- Fast imaging techniques are the key
  - Promising technologies: **SPADs**, SNSPDs
  - Target 1-100 ps resolution
- Spectral binning: diffraction gratings, echelle spectrometers
- High photon detection efficiency

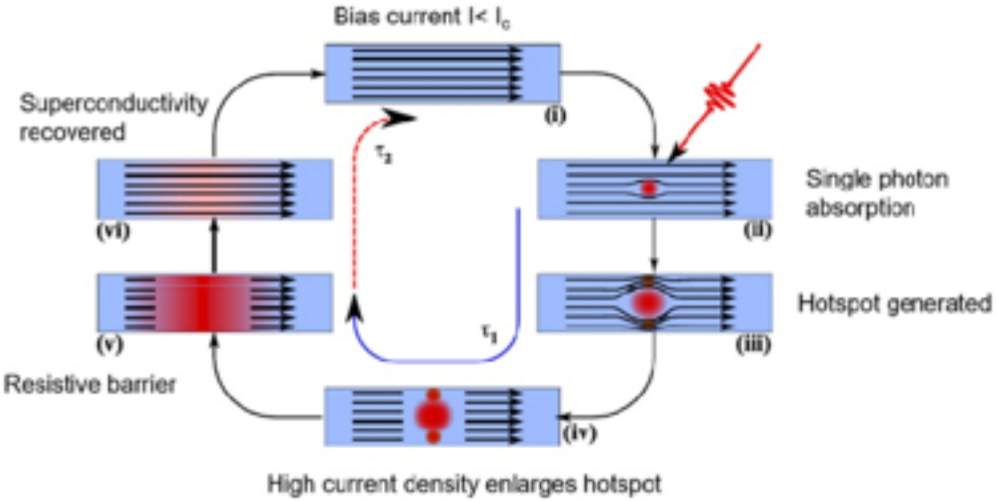
Possible technologies: SNSPD

Superconducting nanowires

- Used Single Quantum SNSPD
- 21 ps resolution for single photons, 3 ps devices reported
- Scaling up is difficult but there are ideas & prototypes





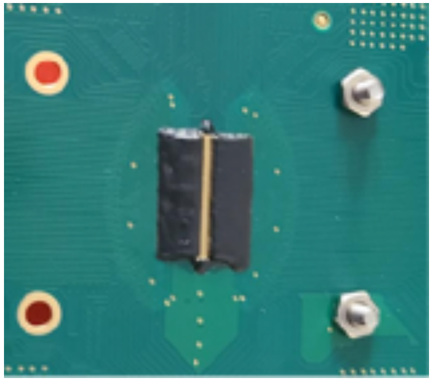


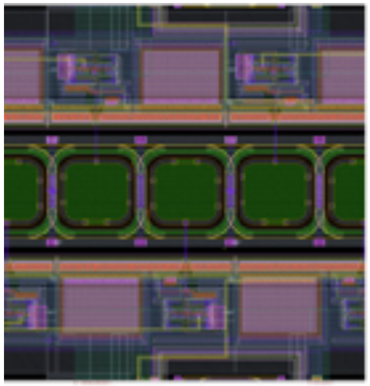
Quantum-Assisted Optical Interferometers: Instrument Requirements; Andrei Nomerotski et al, Proceedings Volume 11446, Optical and Infrared Interferometry and Imaging VII; 1144617 (2020) SPIE Astronomical Telescopes +Instrumentation, https://doi.org/10.1117/12.2560272; arxiv:2012.02812

Possible technologies: SPAD

SPAD = single photon avalanche device
Semiconductor device: p-n junction with amplification

LinoSPAD2



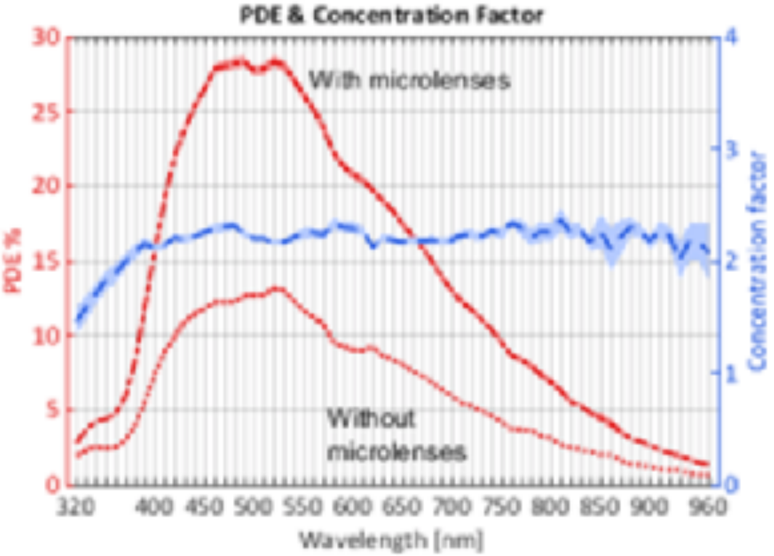


Close-up of SPADs

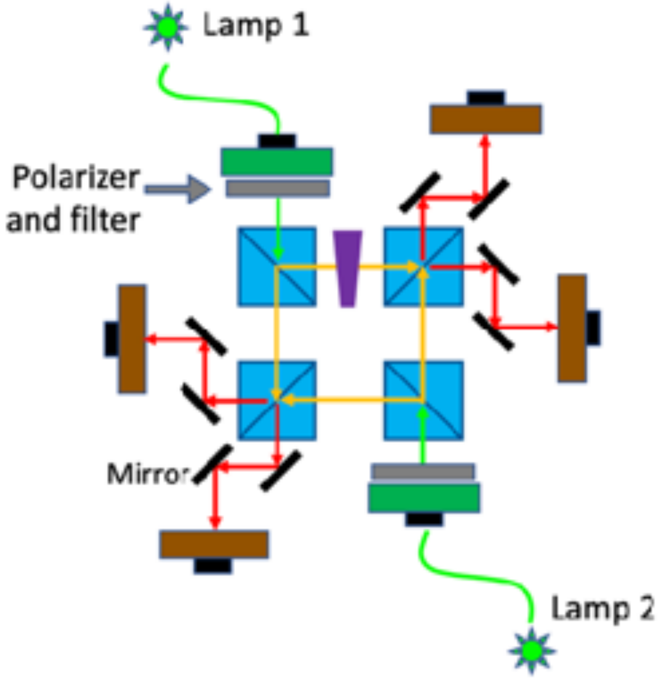
- 512 x 1 pixels
- 24 x 24 micron pixels
- Max PDE (with microlenses) ~ 30%
- 50 ps resolution

Developed in EPFL (Switzerland)
AQUA group (E.Charbon)

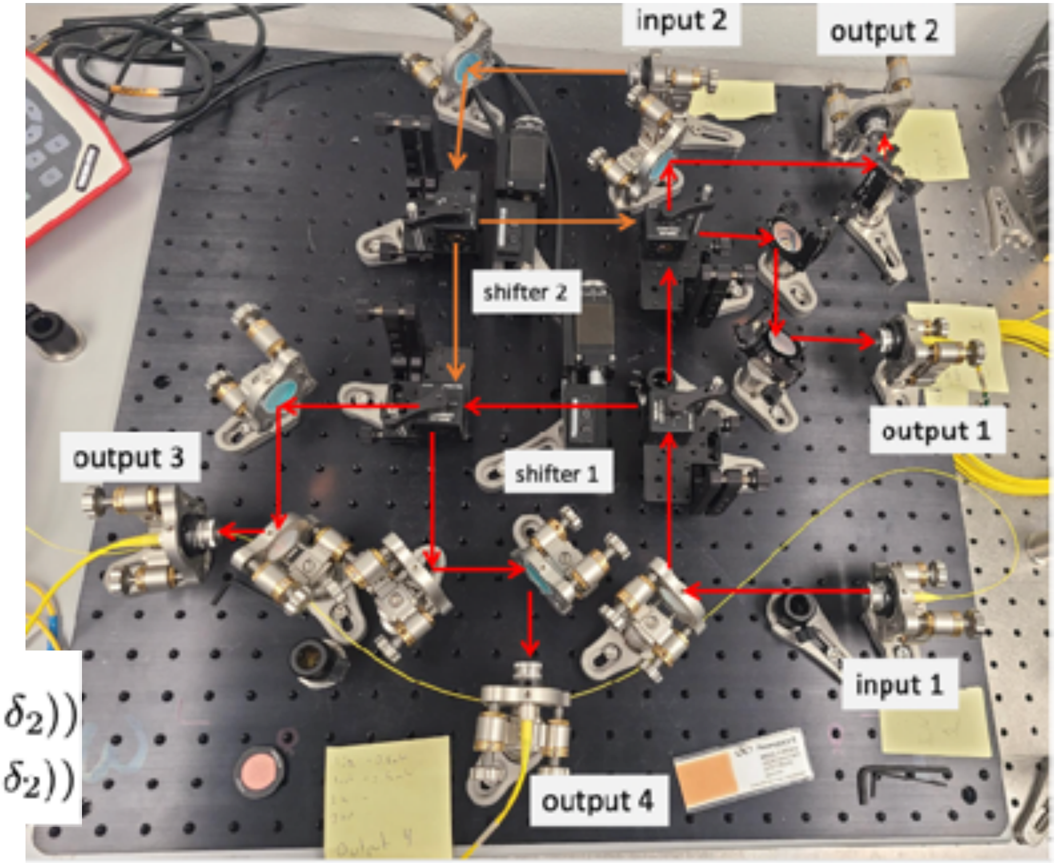
C. Bruschini et al, Linospad2: a 512x1 linear spad camera, in Quantum Sensing and Nano Electronics and Photonics XIX, vol. 12430, pp. 126–135, SPIE, 2023.



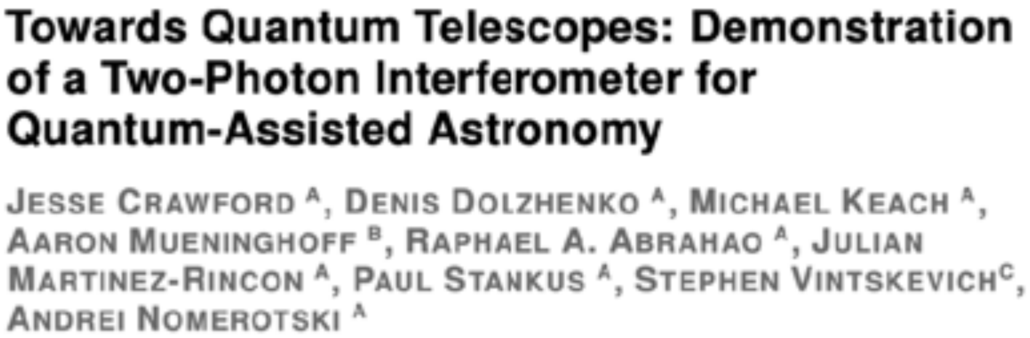
Benchtop Verification



$$
\begin{aligned}
P(cg) &= P(dh) = (1/8)(1+\cos(\delta_1-\delta_2)) \\
P(ch) &= P(dg) = (1/8)(1-\cos(\delta_1-\delta_2))
\end{aligned}
$$



SPAD and SNSPD readout

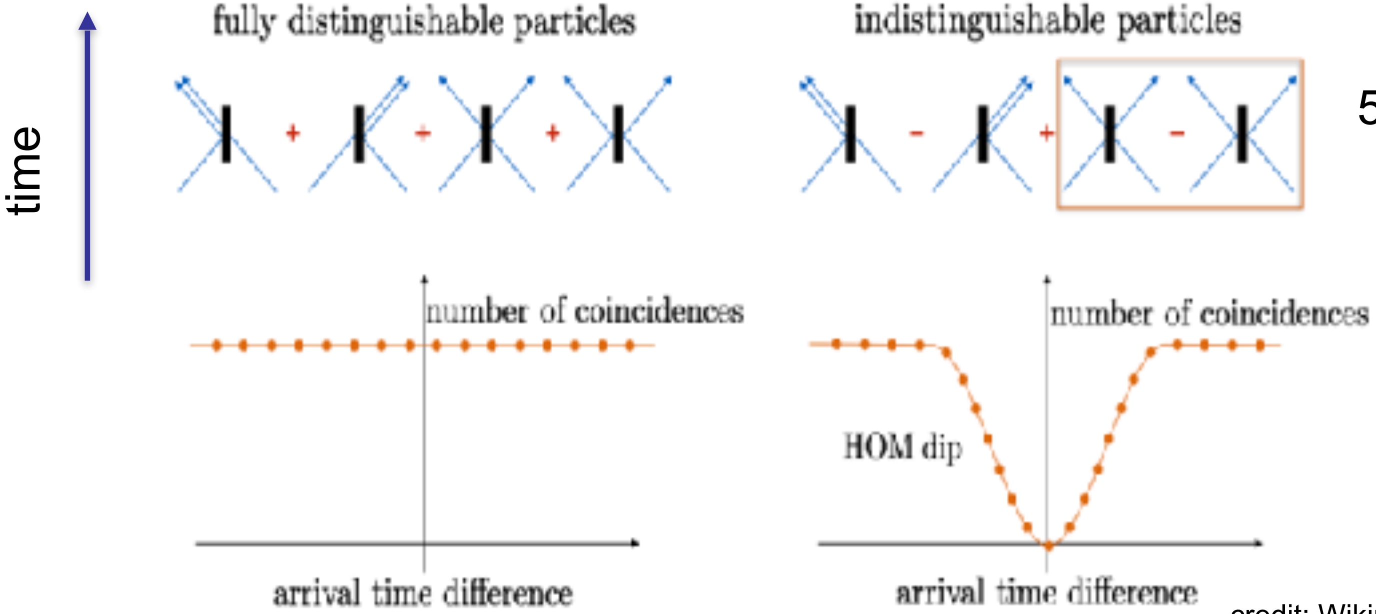


Towards Quantum Telescopes: Demonstration of a Two-Photon Interferometer for Quantum-Assisted Astronomy

Jesse Crawford [A], Denis Dolzhenko [A], Michael Keach [A], Aaron Mueninghoff [B], Raphael A. Abrahao [A], Julian Martinez-Rincon [A], Paul Stankus [A], Stephen Vintskevich[C], Andrei Nomerotski [A]

arxiv.org/abs/2301.07042
published in Optics Express

Hong-Ou-Mandel effect



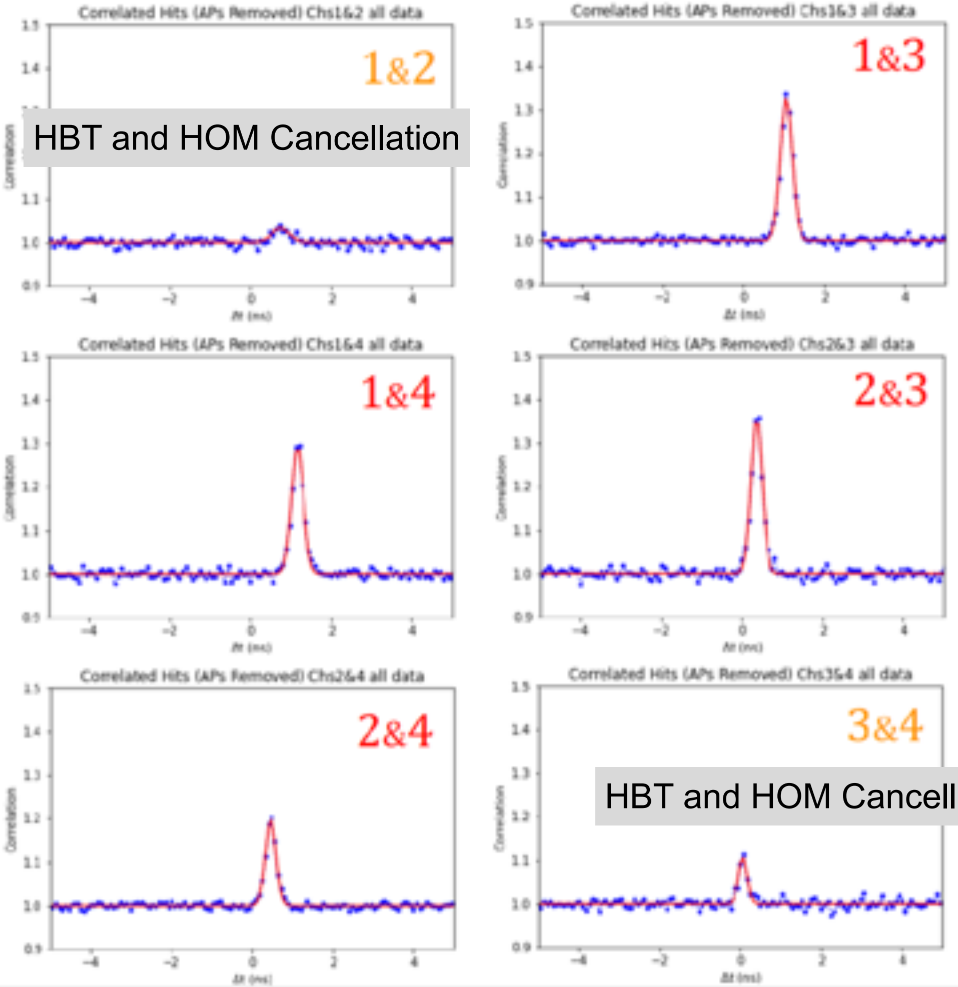
50/50 beam splitter

credit: Wikipedia HOM article

HOM dip for coincidences of two outputs

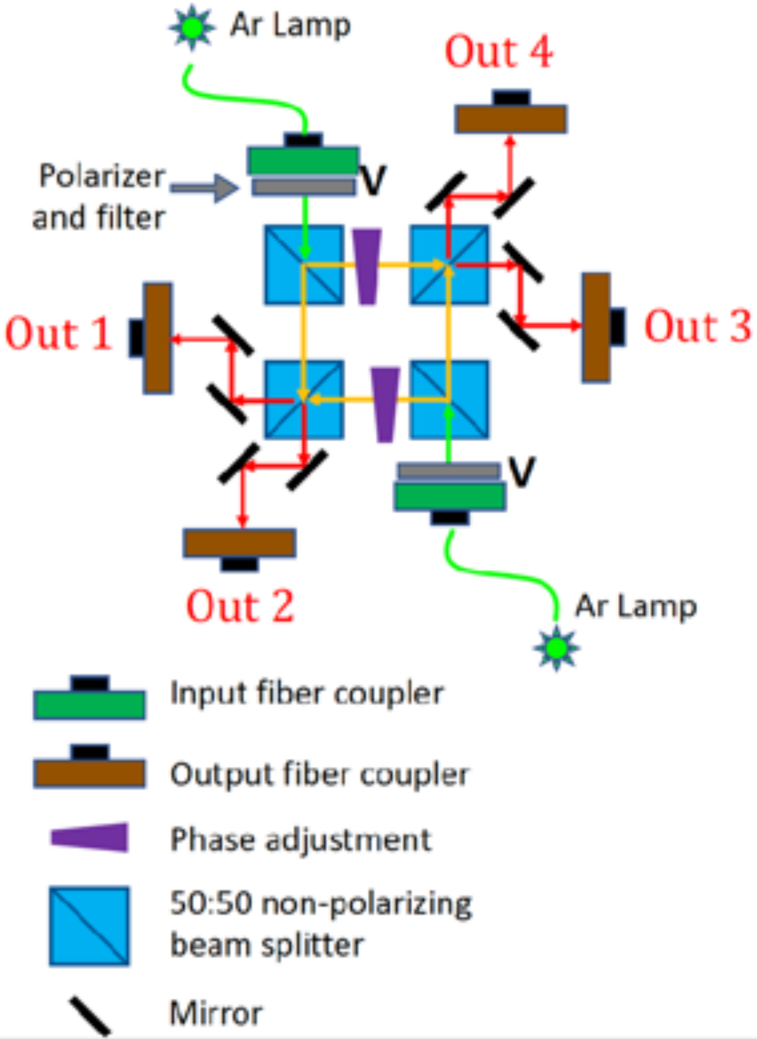
arxiv.org/abs/2301.07042

Polarized – V V



HBT and HOM Cancellation

HBT and HOM Cancellation



🟩 Input fiber coupler

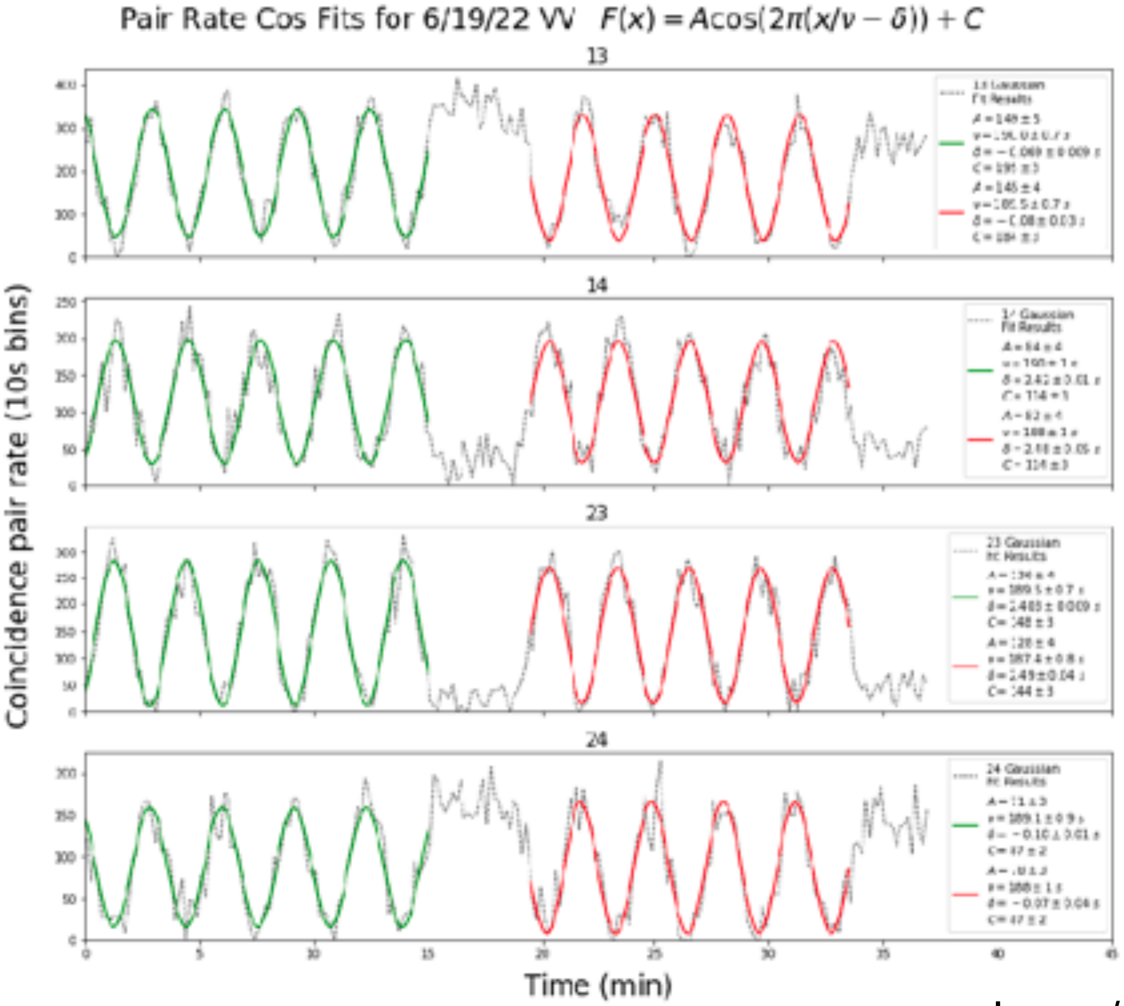
🟫 Output fiber coupler

Phase adjustment

50:50 non-polarizing beam splitter

Mirror

Phase dependence



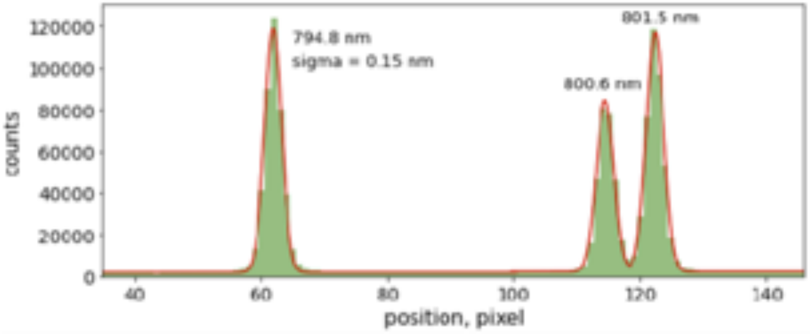
arxiv.org/abs/2301.07042

Population of HBT peaks as function of phase = phase oscillations

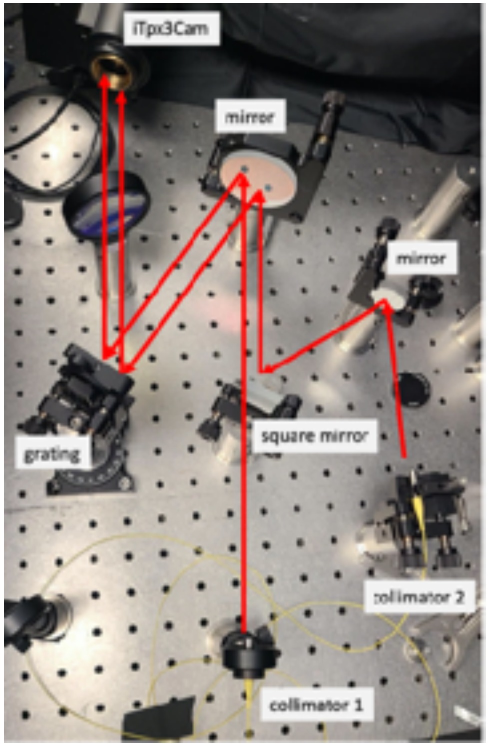
Next step: spectral binning

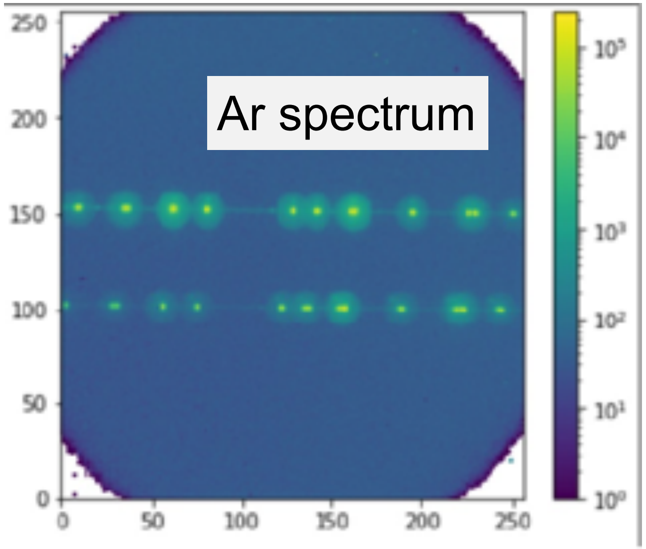
Spectral binning

Two beams of thermal photons → diffraction grating
Based on intensified Tpx3Cam, ns time resolution



spectral resolution for Ar lines ~0.15 nm

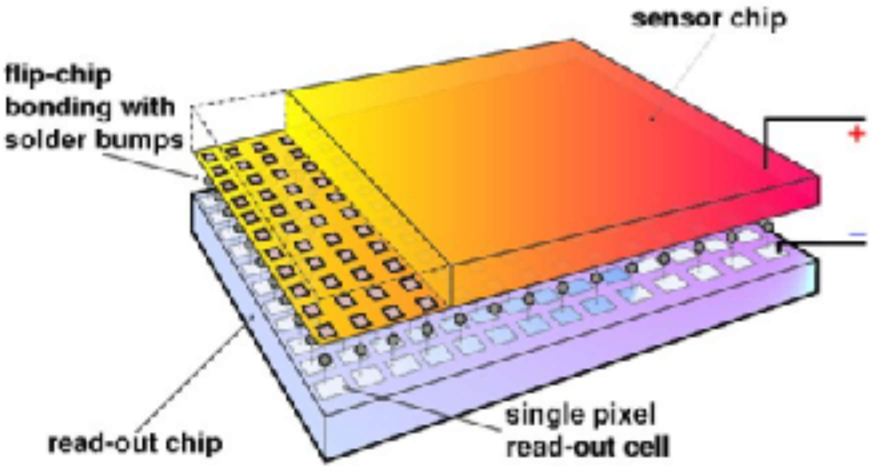



Ar spectrum

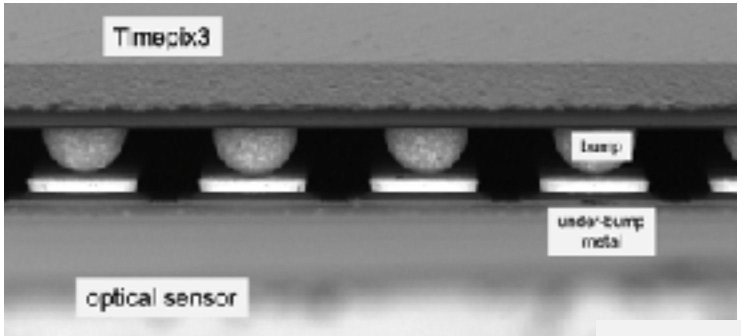
A.Nomerotski et al. Intensified Tpx3Cam, a fast data-driven optical camera with nanosecond timing resolution for single photon detection in quantum applications, arxiv.org/abs/2210.13713, published in JINST

Hybrid pixel detectors

Have roots in R&D for LEP/LHC vertex detectors



Lukas Tlustos and Erik H. M. Heijne, Performance and limitations of high granularity single photon processing X-ray imaging detectors, in CERN proceedings (2005)



credit: IZM

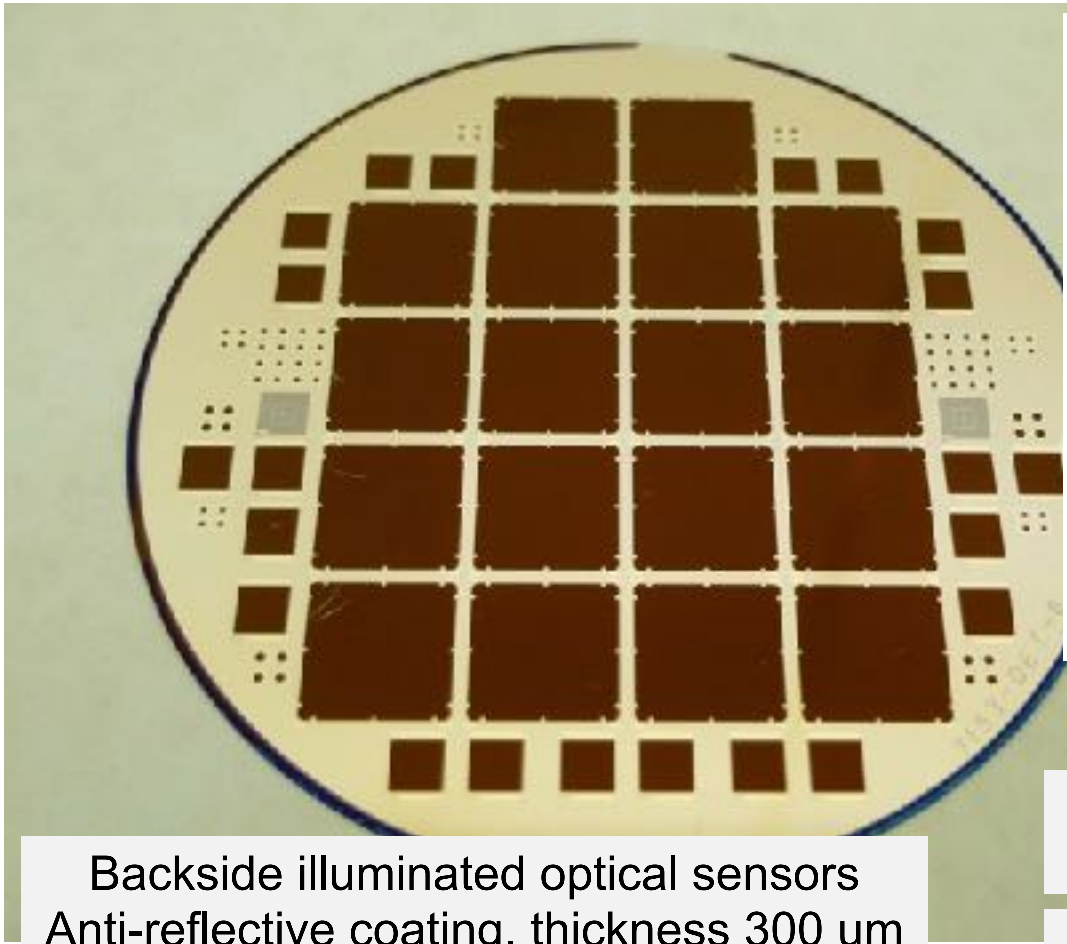
Decouple readout chip and sensor

- optimize technologies for chip and sensor separately

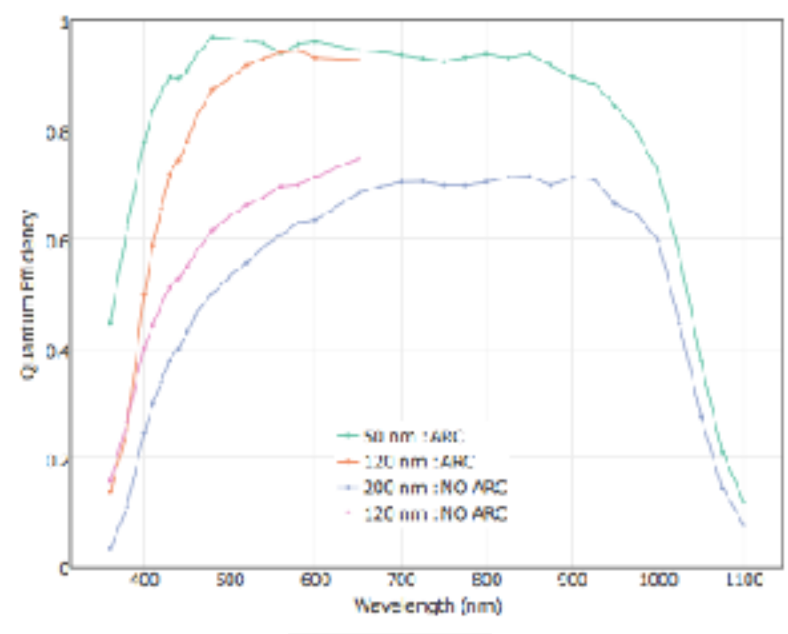
Use different sensors with same readout, versatile approach for x-rays (Si, CZT)

→ we will use **OPTICAL** sensors

Thin window optical sensors



Backside illuminated optical sensors
Anti-reflective coating, thickness 300 um



High QE

M. Fisher-Levine, A. Nomerotski, Timepixcam: a fast optical imager with time-stamping,
Journal of Instrumentation 11 (03) (2016) C03016.

Nomerotski et al, Characterization of TimepixCam, a fast imager for the time- stamping of optical photons,
Journal of Instrumentation 12 (01) (2017) C01017.

Developed at BNL, first produced at CNM (Barcelona) in 2015
Surface preparation is very important, inspired by astronomical CCDs (LSST)

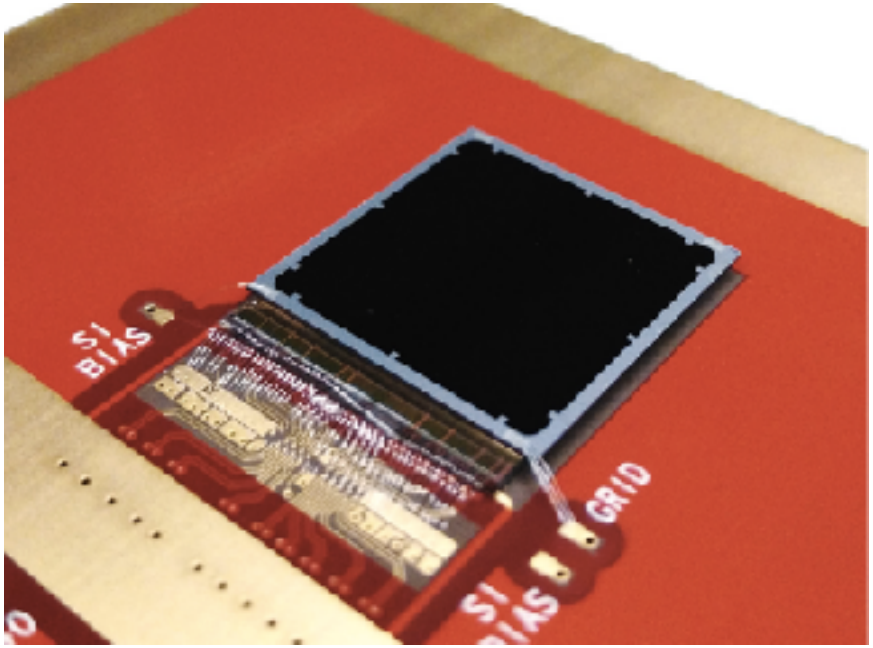
Timepix3 Camera → Tpx3Cam

Camera = sensor + ASIC + readout

Timepix3 ASIC:

- 256 x 256 array, 55 x 55 micron pixel
  - 14 mm x 14 mm active area
- 1.56 ns timing resolution
- Data-driven readout, 600 e min threshold, 80 Mpix/sec, no deadtime
- each pixel measures time and flux, ~1μs pixel deadtime when hit

T. Poikela et al, Timepix3: a 65k channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout, Journal of Instrumentation 9 (05) (2014) C05013.

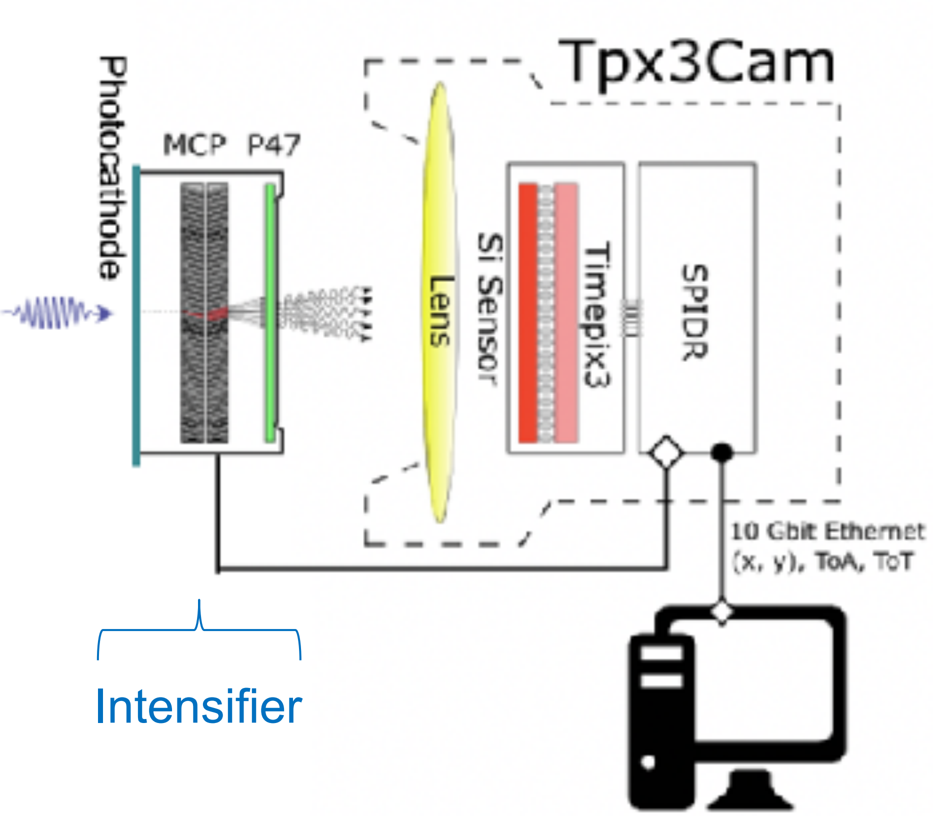


Sensor is bump-bonded to chip

Use existing x-ray readouts:
SPIDR (Nikhef & ASI)
www.amscins.com

Zhao et al, Coincidence velocity map imaging using Tpx3Cam, a time stamping optical camera with 1.5 ns timing resolution, Review of Scientific Instruments 88 (11) (2017) 113104.

Intensified camera: use off-the-shelf image intensifier



Intensifier

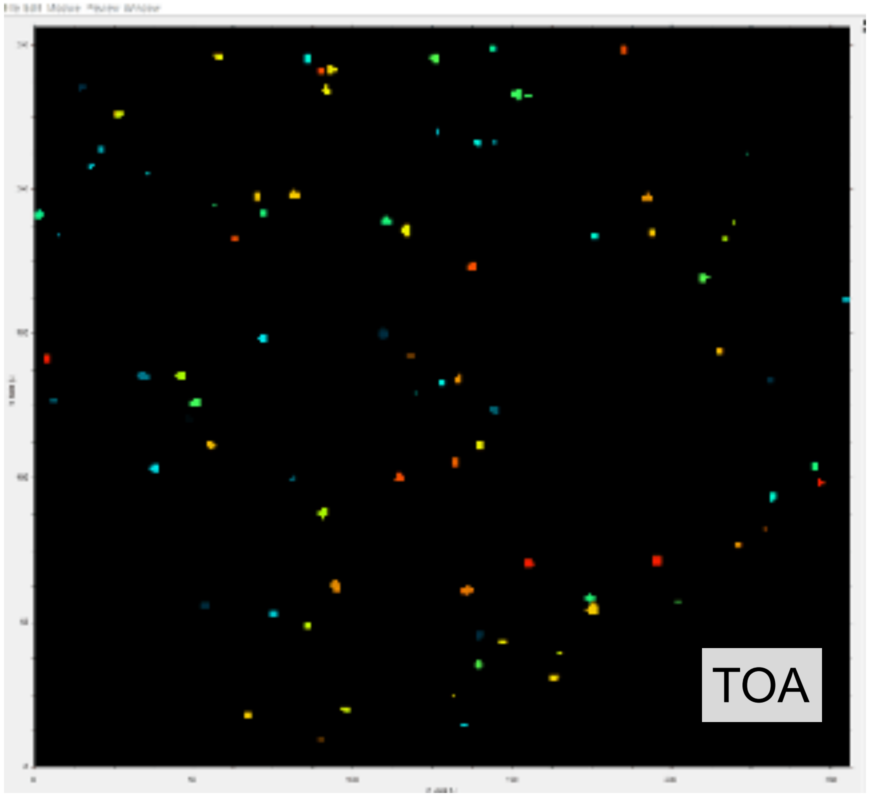
Intensified cameras are common:
- iCCD
- iCMOS cameras

Image intensifier (Photonis PP0360EG)

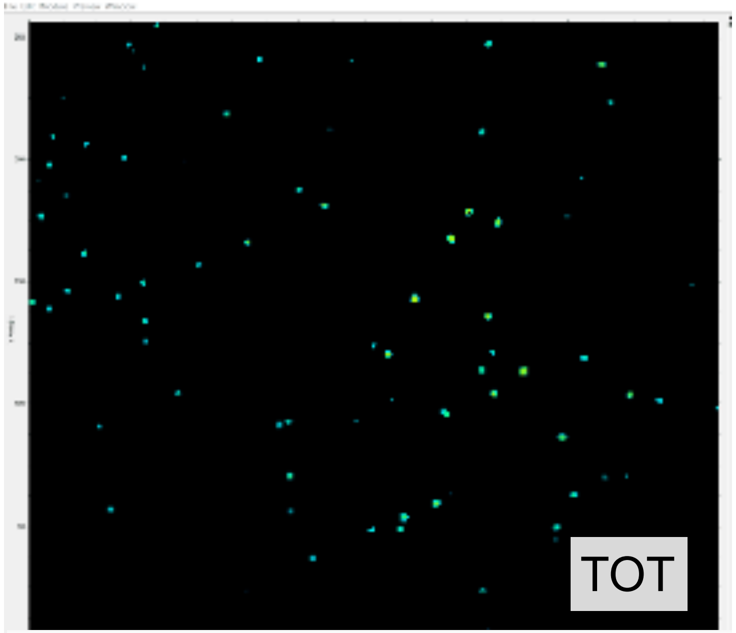
Cricket@

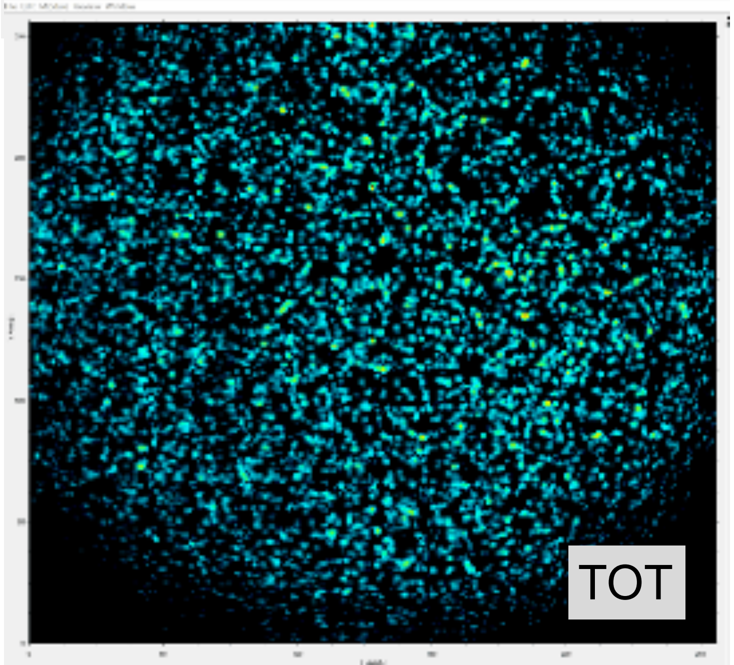
Single Photons in Tpx3Cam

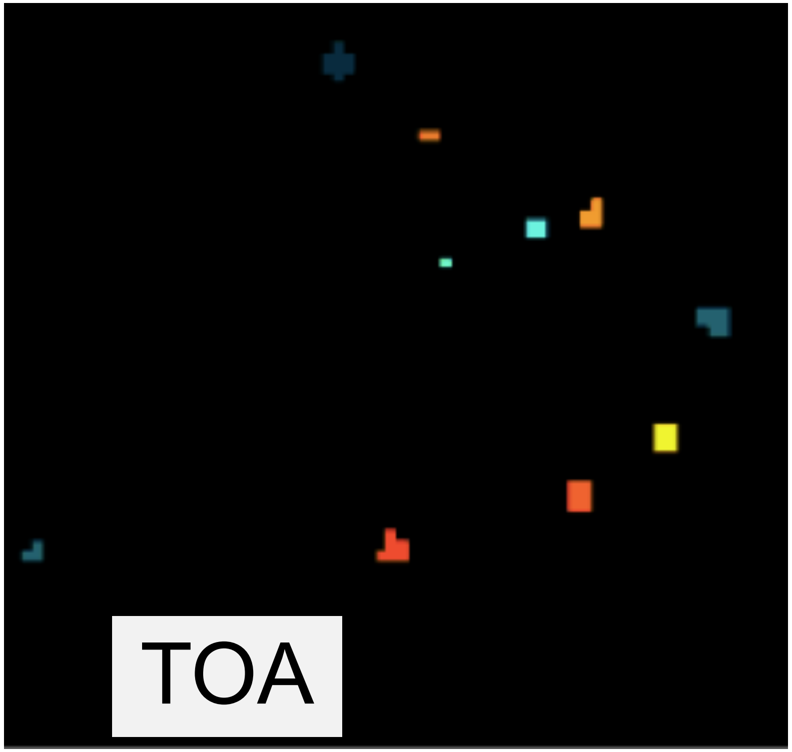
1 ms slice of data
1.5ns time-stamping

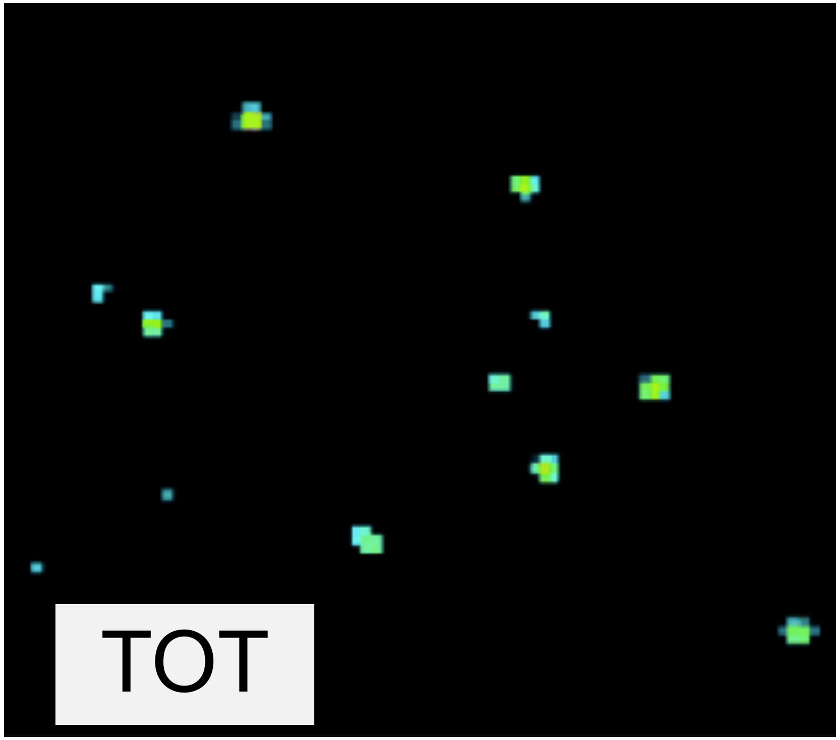


Tpx3Cam + intensifier by Photonis







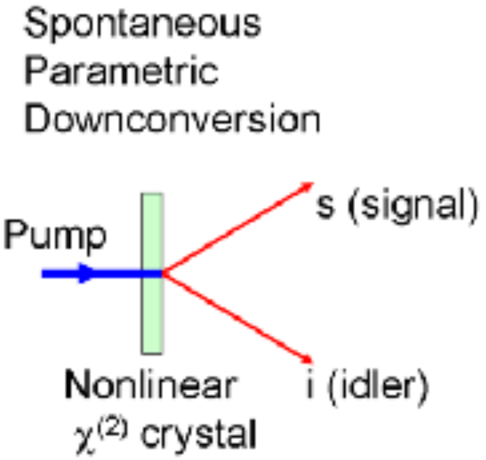


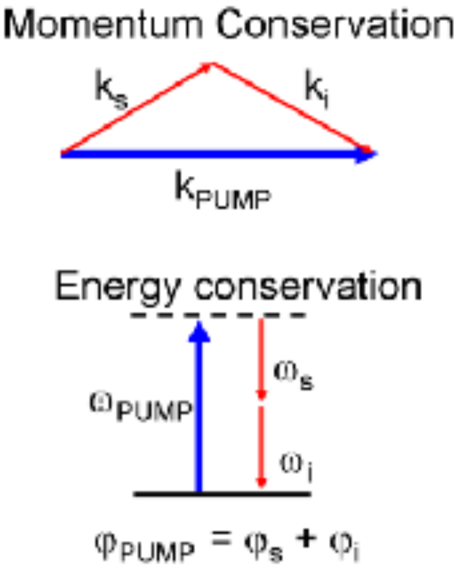
Each photon is a cluster of pixels
à 3D (x,y,t) centoiding

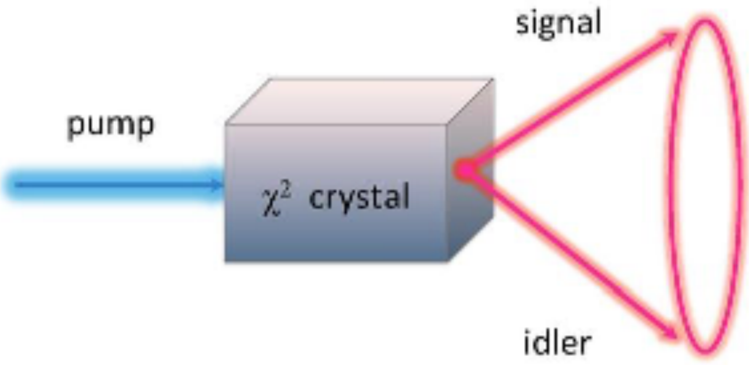
Spatial resolution: 0.1 pixel / photon

Time resolution: < 1 ns / photon

Quantum photon sources - spontaneous parametric down-conversion (SPDC) sources





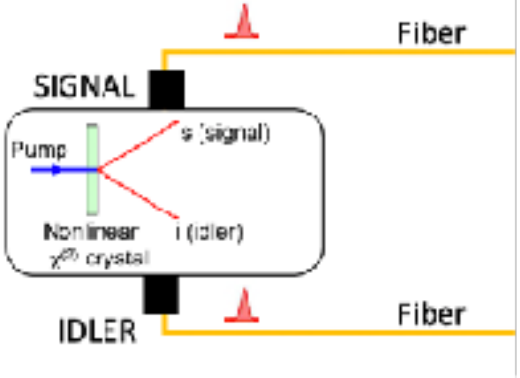


Produce two photons correlated (sometimes entangled) in

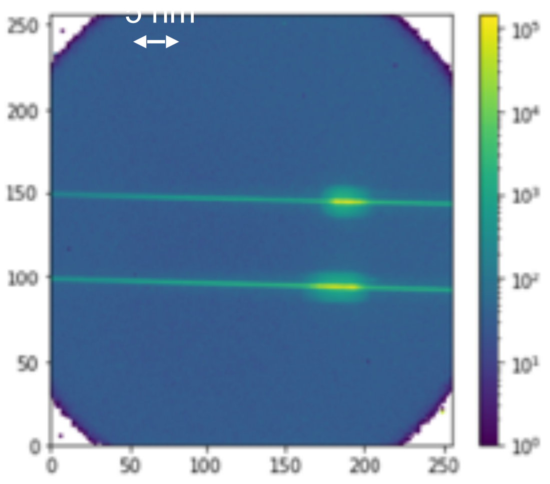
1. Time
2. Position
3. Energy

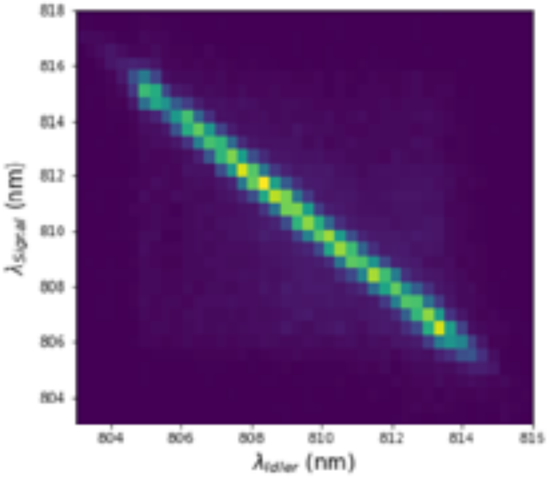
SPDC source in spectrometer

- 810 nm idler and signal
- no filter

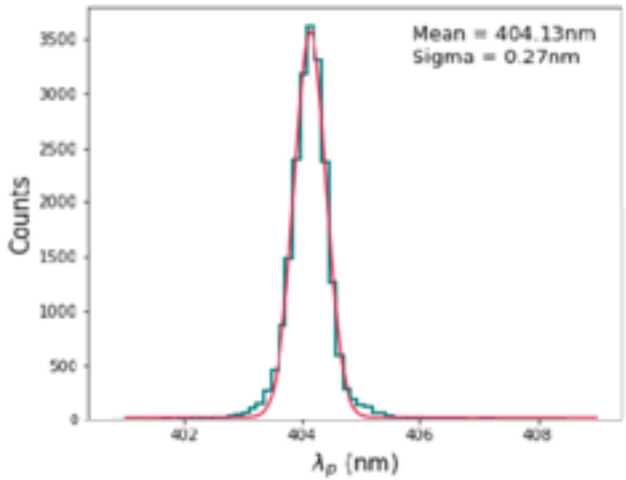


signal & idler in spectrometer

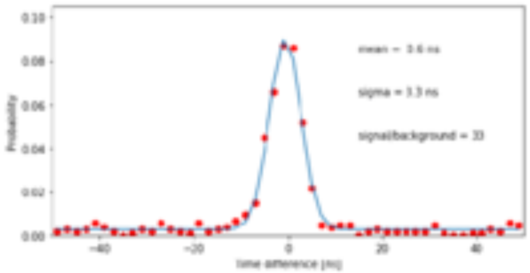




wavelength anti-correlation for photon pairs



pump wavelength



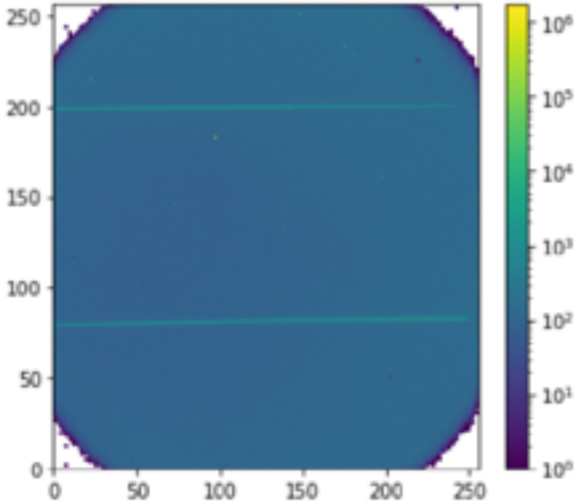
time coincidences

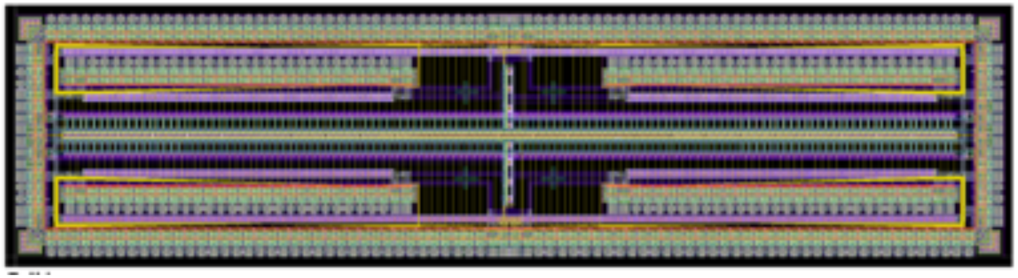
B Farella, G Medwig, R A Abrahao, A Nomerotski, *AIP Advances* 14, 045034 (2024)

arxiv.org/abs/2307.06843

Next steps: spectrometer based on LinoSPAD2

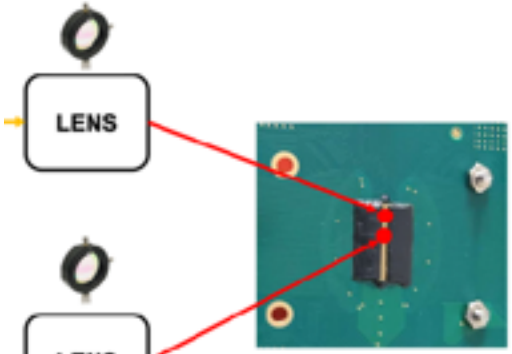
Diffracted photon stripe projected on to linear array



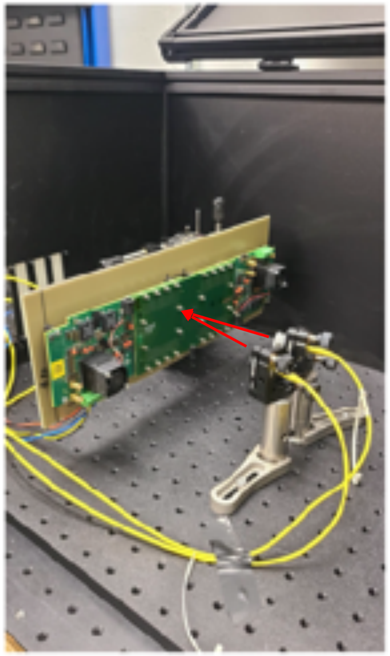


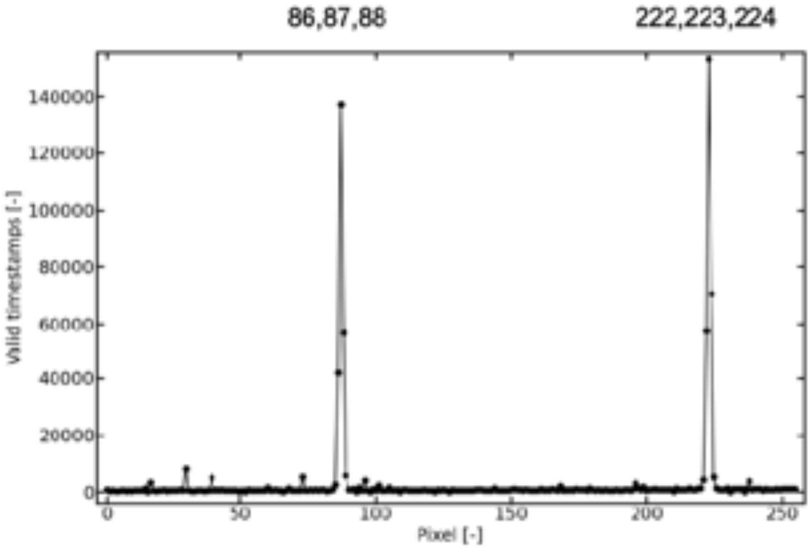
Spectrometer time resolution: 5 ns →100 ps

SPAD arrays with 50 ps resolution

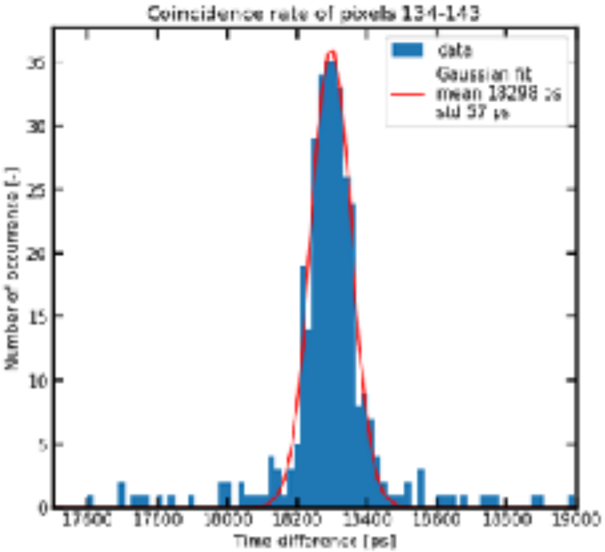


LinoSPAD
512 x 1 pixels – using only half 256
24 x 24 micron pixels





240k photons per peak

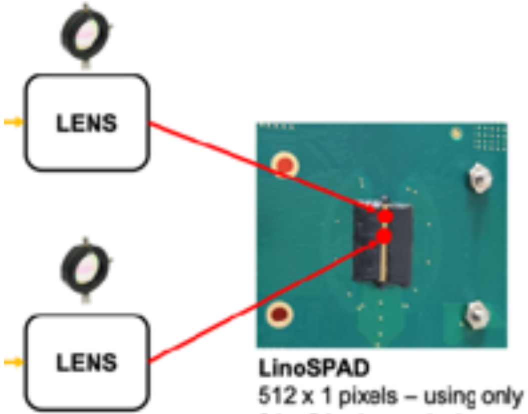


Two beams from SPDC source
Coincidence of two single photons

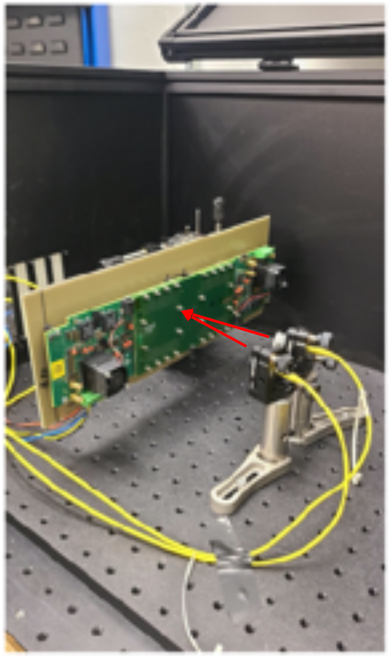
time difference, σ=57 ps

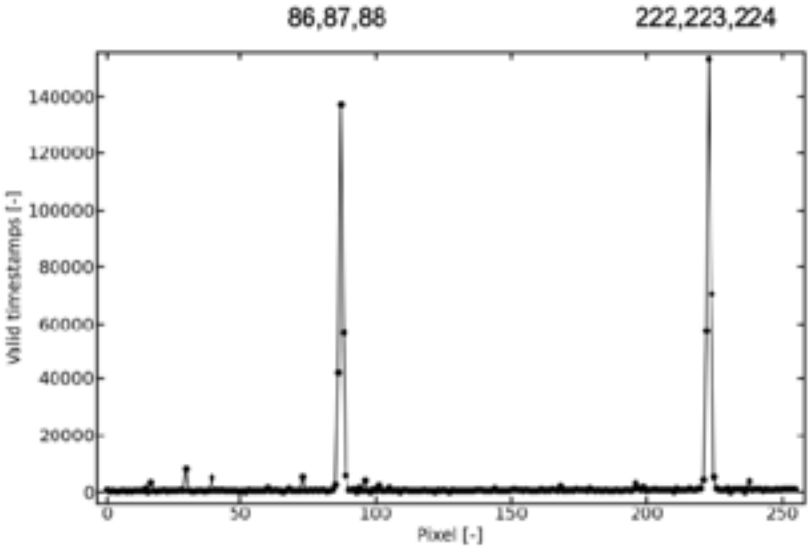
arxiv.org/abs/2304.11999

SPAD arrays with 50 ps resolution



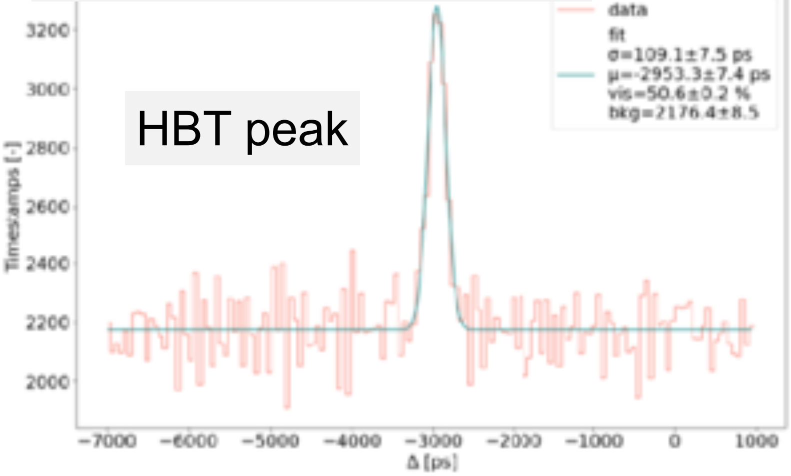
LinoSPAD
512 x 1 pixels – using only half 256
24 x 24 micron pixels





240k photons per peak

time difference, σ=110 ps
visibility = 50%



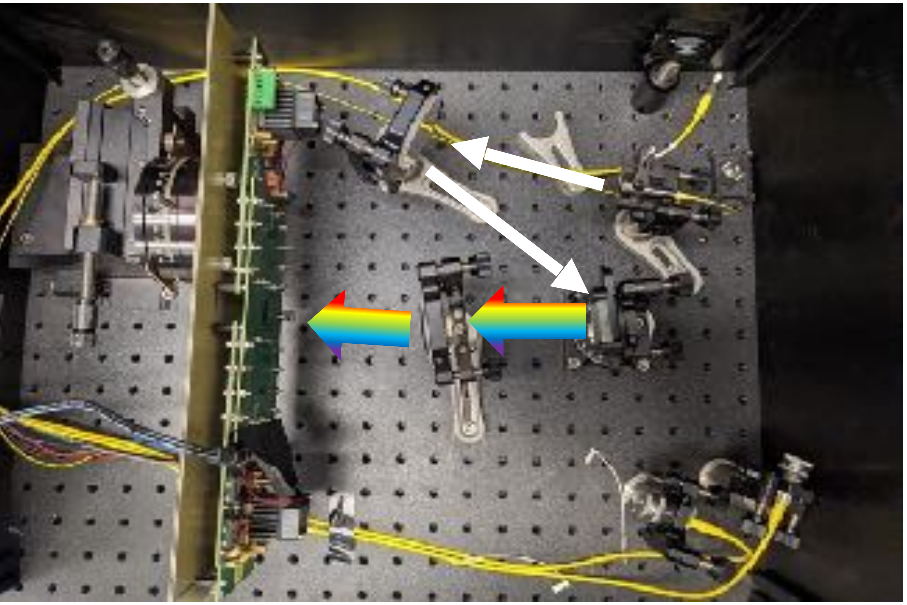
Two beams from Ar lamp + polarizer after beamsplitter

arxiv.org/abs/2406.15323
arxiv.org/abs/2406.13959

Next step: HBT in spectral bins for broadband light

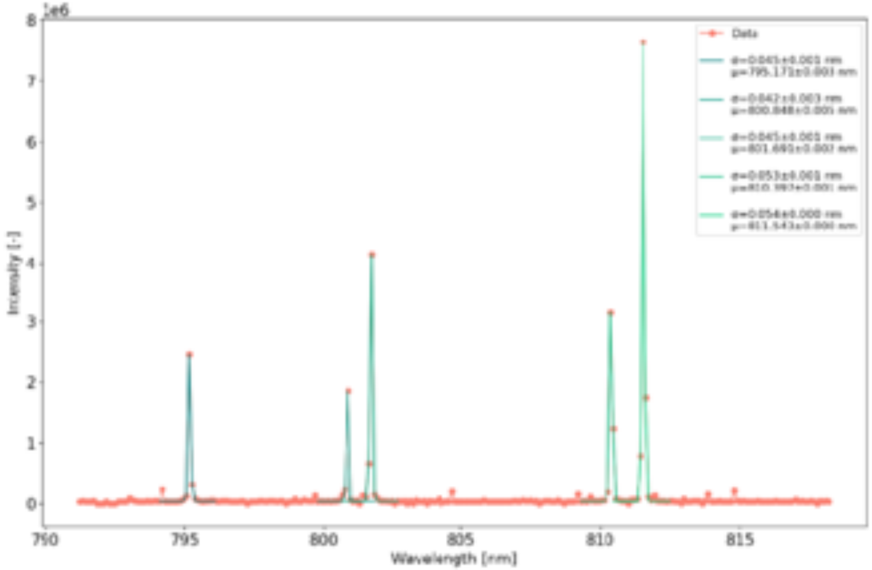
Spectrometer with LinoSPAD2

Used Ar lamp coupled to SM fiber



arxiv.org/abs/2304.11999

Ar spectral lines



spectral resolution 0.04 nm

arxiv.org/abs/2304.11999

Achieved 0.04 nm spectral and 40 ps timing resolution

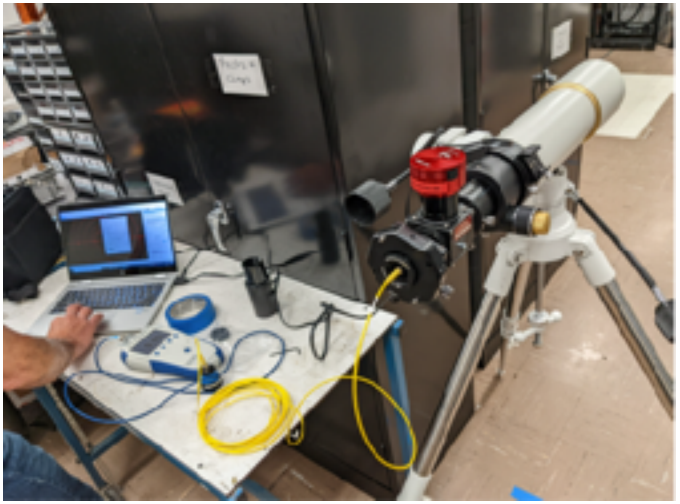
only x10 more than $\Delta t * \Delta E \geq \hbar/2$

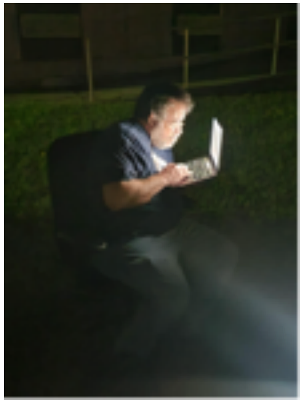
telescopes

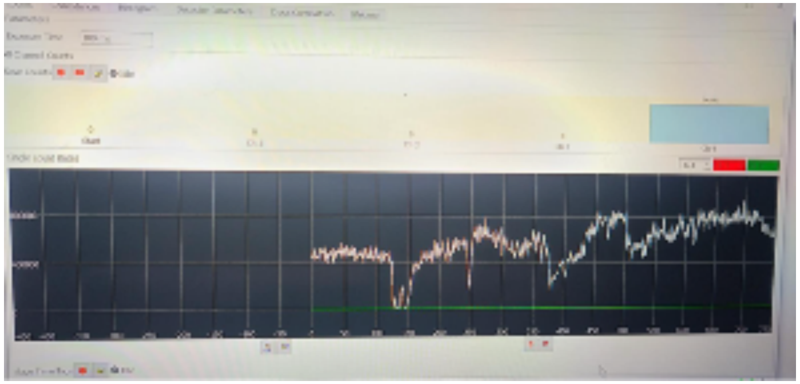
On-sky measurements

- Need to couple to single mode fiber
- Need adaptive optics

Both are difficult tasks



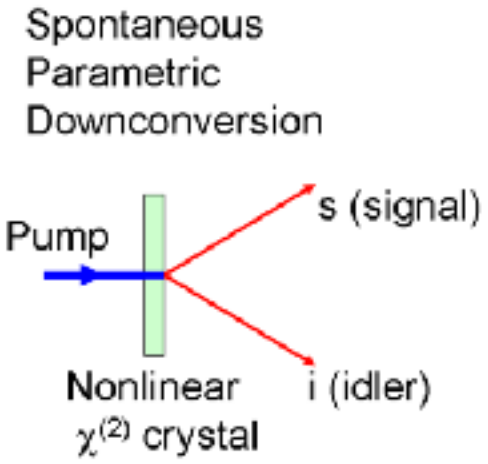


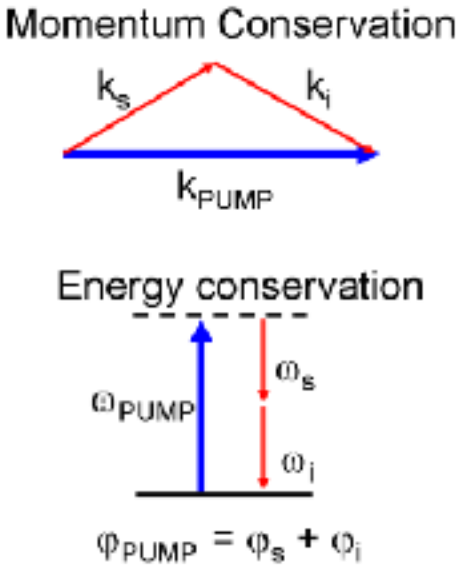


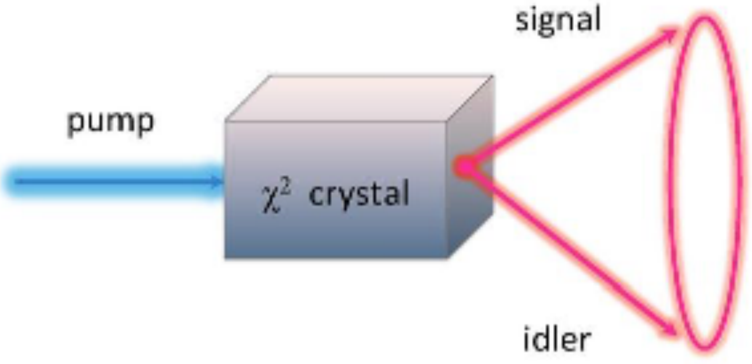
Quantum Optics applications with time stamping of single photons

Some examples how nanosecond scale resolution is used in Quantum Optics

Quantum photon sources - spontaneous parametric down-conversion (SPDC) sources





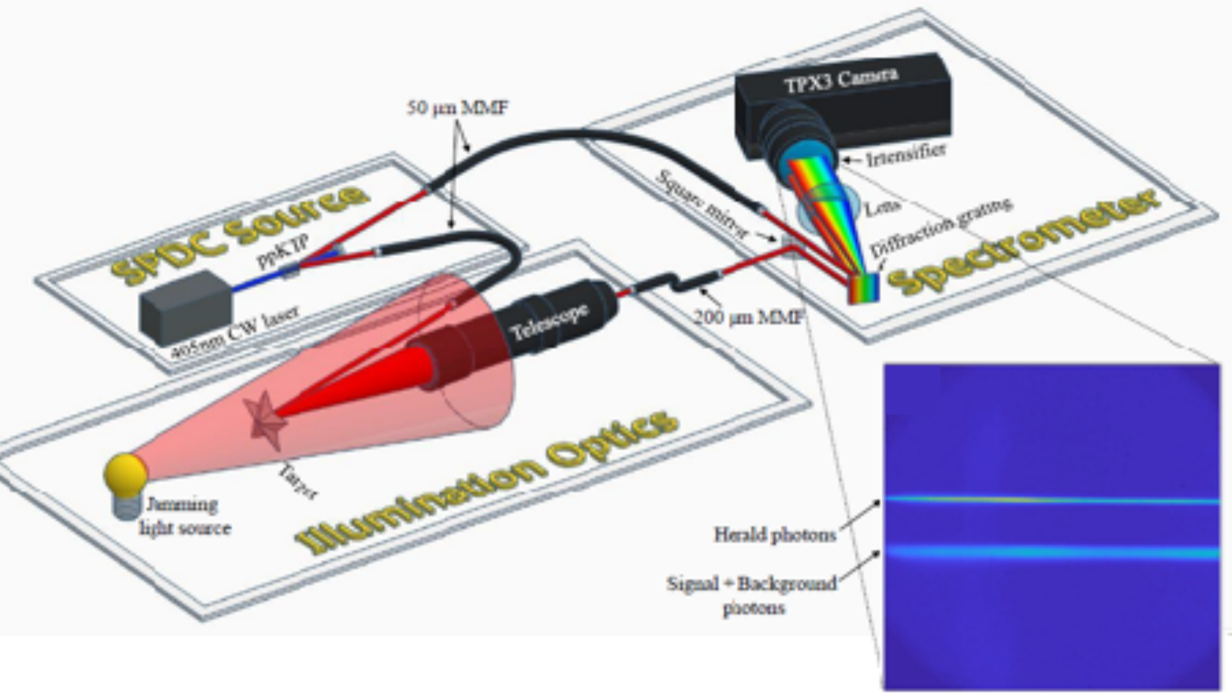


Produce two photons correlated (sometimes entangled) in

1. Time
2. Position
3. Energy

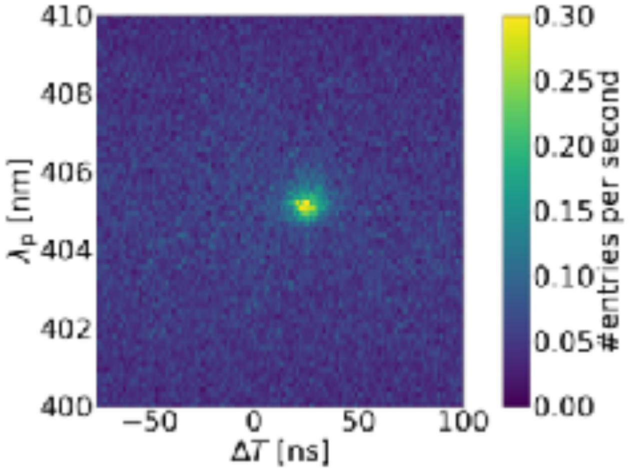
Multidimensional Quantum Illumination

In collaboration with NRC (Ottawa) D.England, Y.Zhang et al



Y Zhang, D England, A Nomerotski, P Svihra et al, Multidimensional quantum-enhanced target detection via spectrotemporal-correlation measurements, Physical Review A 101 (5), 053808

$\delta\lambda * \delta t$ ~ 5 ns * 0.5 nm

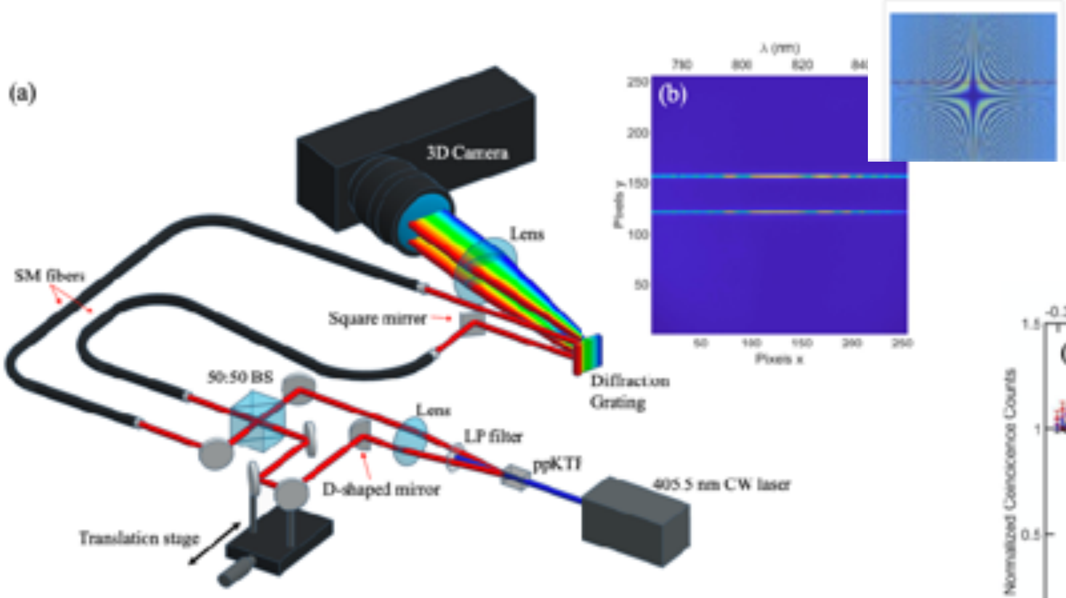


Pump photon wavelength vs time difference

P Svihra et al, Multivariate Discrimination in Quantum Target Detection, Appl. Phys. Lett. **117**, 044001 (2020)

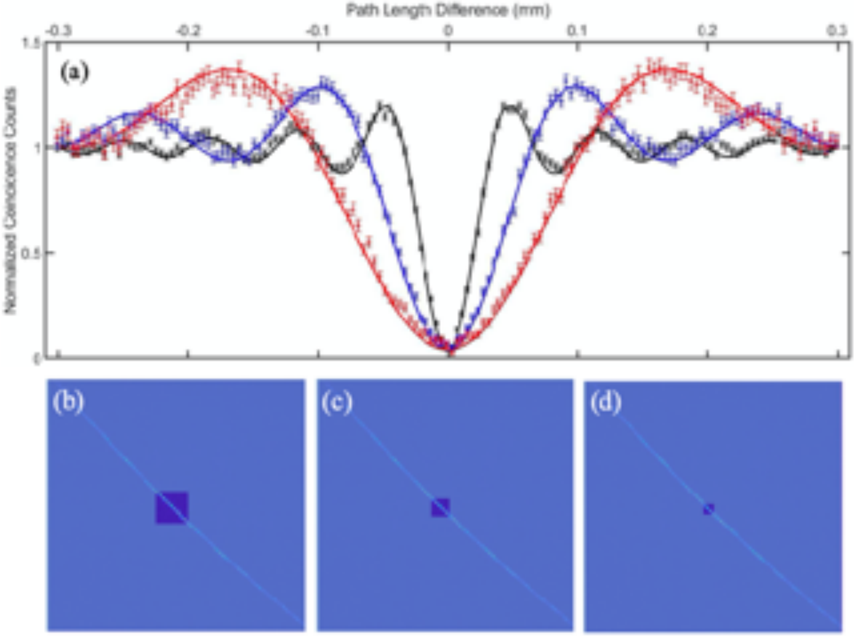
HOM effect with post-selection

Optics Express Vol. 29, Issue 18, pp. 28217-28237 (2021) · https://doi.org/10.1364/OE.432191

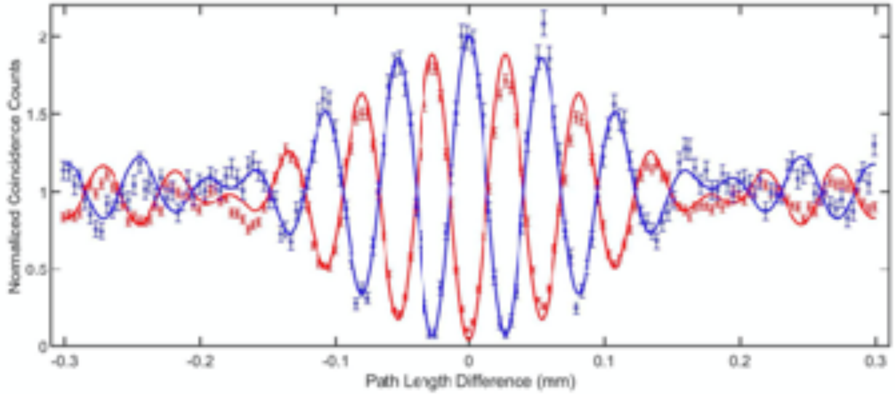


High speed imaging of spectral-temporal correlations in Hong-Ou-Mandel interference

Yingwen Zhang, Duncan England, Andrei Nomerotski, and Benjamin Sussman

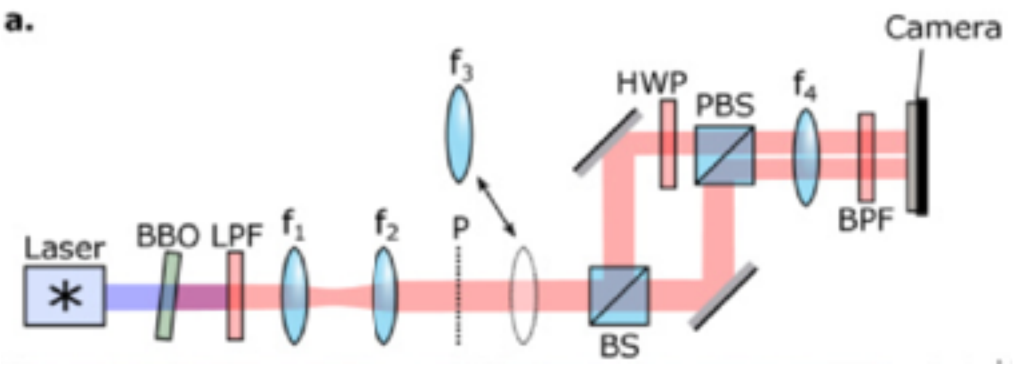


10, 5, 3 nm post-selection filters

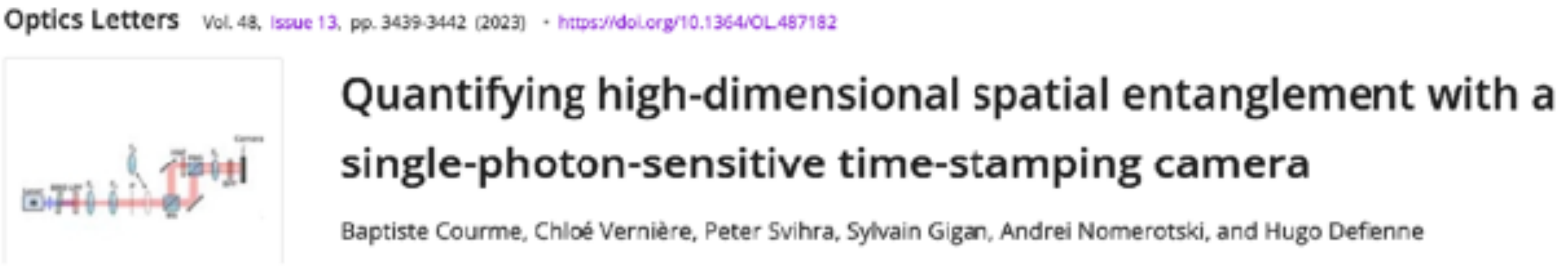


2 nm filters at 805 nm and 817 nm.

Characterizing entanglement



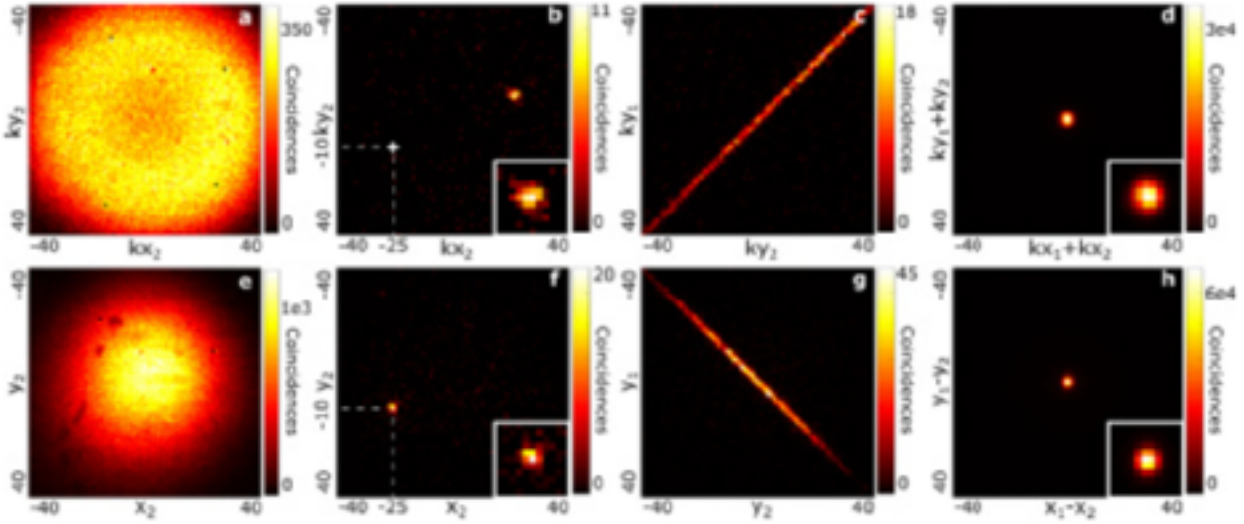
- Image near field and far field
- Study dx*dp correlations to prove they are beyond classical and by how much
- Much faster, more dimensions than with framing cameras where need to subtract background



Optics Letters Vol. 48, Issue 13, pp. 3439-3442 (2023) • https://doi.org/10.1364/OL.487182

Quantifying high-dimensional spatial entanglement with a single-photon-sensitive time-stamping camera

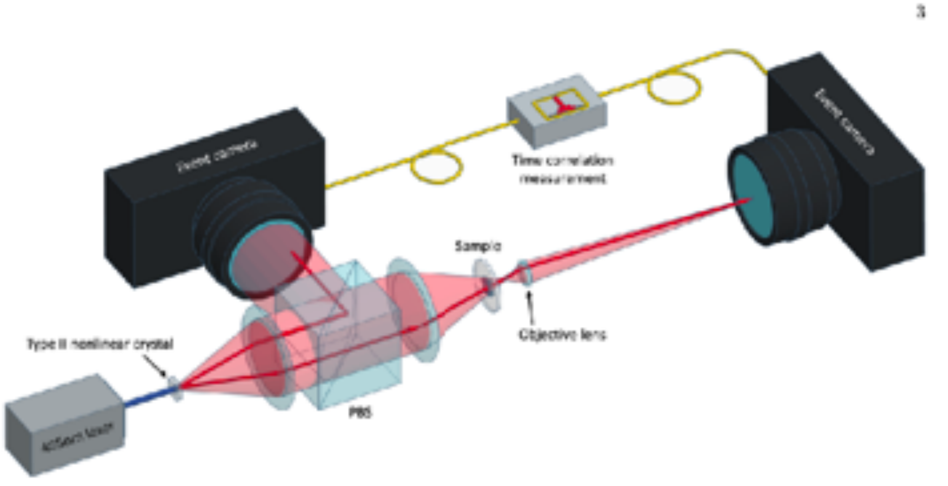
Baptiste Courme, Chloé Vernière, Peter Svihra, Sylvain Gigan, Andrei Nomerotski, and Hugo Defienne

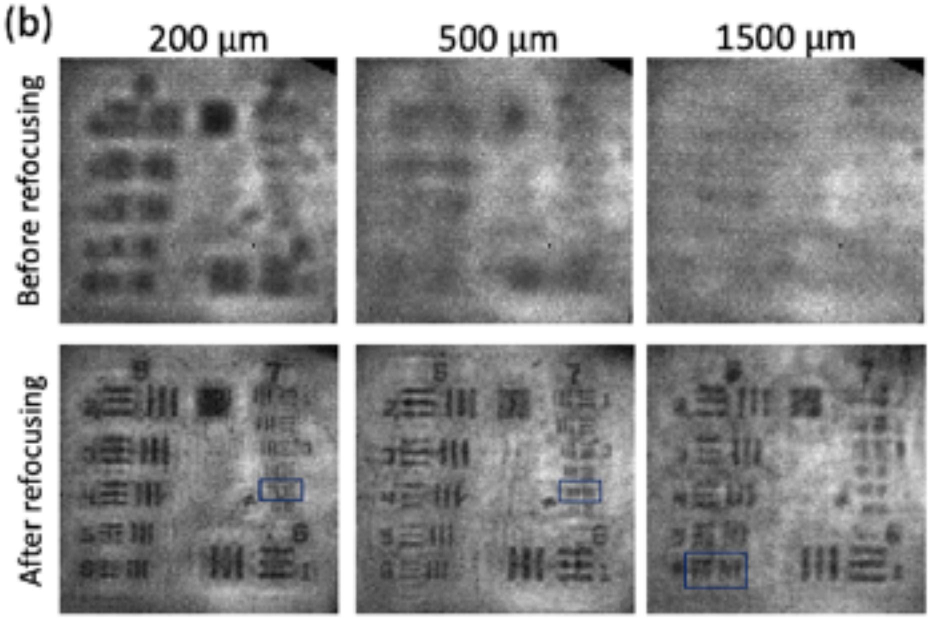


far field

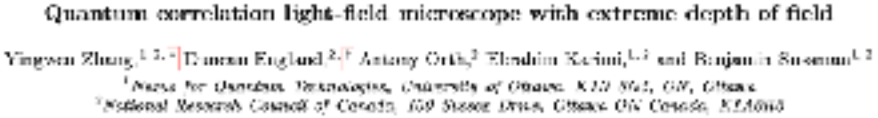
near field

Quantum light-field microscope





- Ottawa NRC group
- Use one photon for position and one photon for angle information
- This allows refocussing at arbitrary distance

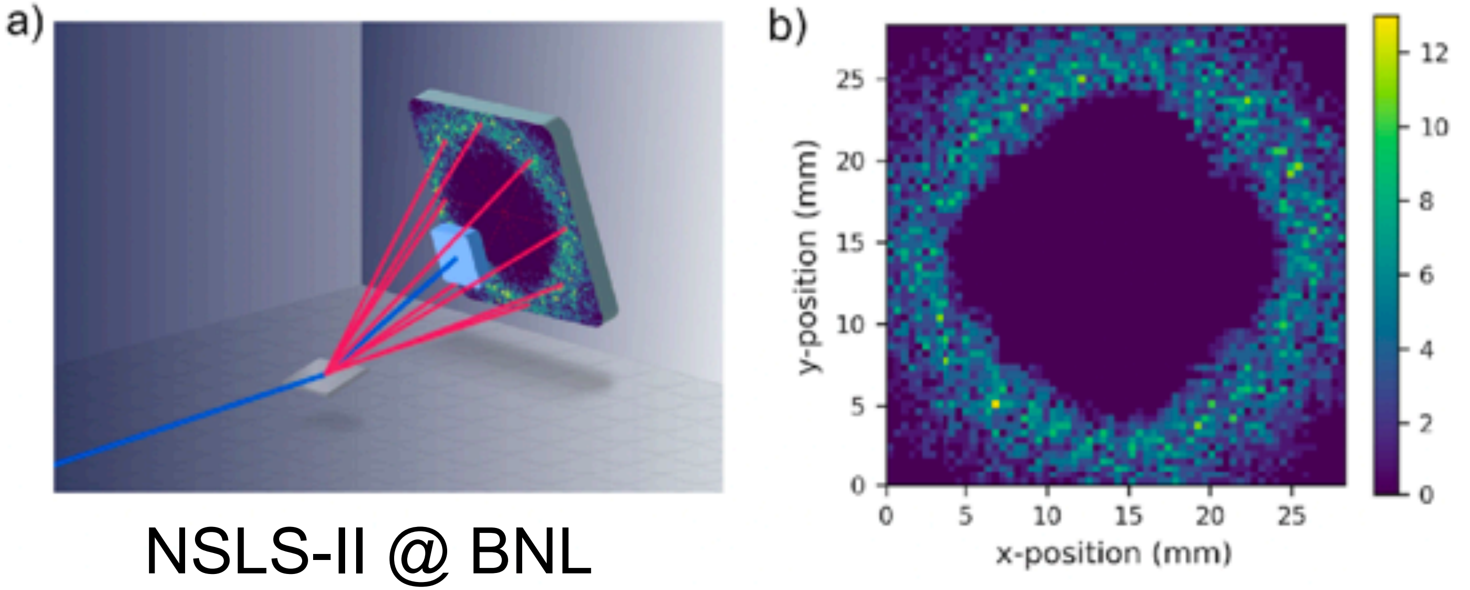


Quantum correlation light-field microscope with extreme depth of field

Yingwen Zhang,[1,2,*] Duncan England,[2,†] Antony Orth,[2] Ebrahim Karimi,[1,2] and Benjamin Sussman[1,2]

[1] Nexus for Quantum Technologies, University of Ottawa, K1N 5N6, ON, Ottawa
[2] National Research Council of Canada, 100 Sussex Drive, Ottawa ON Canada, K1A0R6

Down-conversion of x-rays

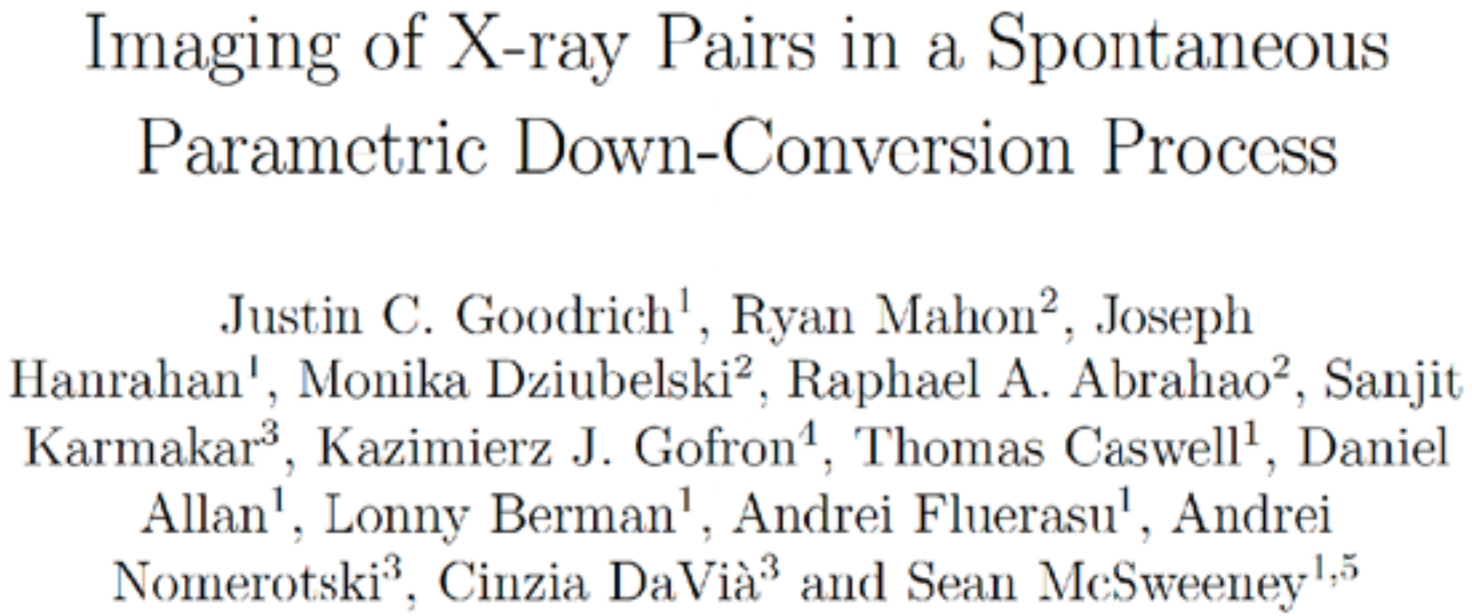


NSLS-II @ BNL

Fig. 1 Conceptual experimental schematic and the final observed SPDC structure. a, A conceptual schematic of the experiment, which shows that the Bragg reflection of a pump incident upon (111) diamond, with a small detuning, can generate down-converted X-ray pairs around the diffracted pump. A tantalum beamstop is played to obscure flooding the detector with diffracted pump photons. **b,** The detected SPDC photons after isolation from background scattering using a robust filtering process. The results are from a one hour exposure at $\Delta\theta = 0.022°$ with a total count of 4,145 photon pairs. Analyses of the spatial and spectral structures follow.

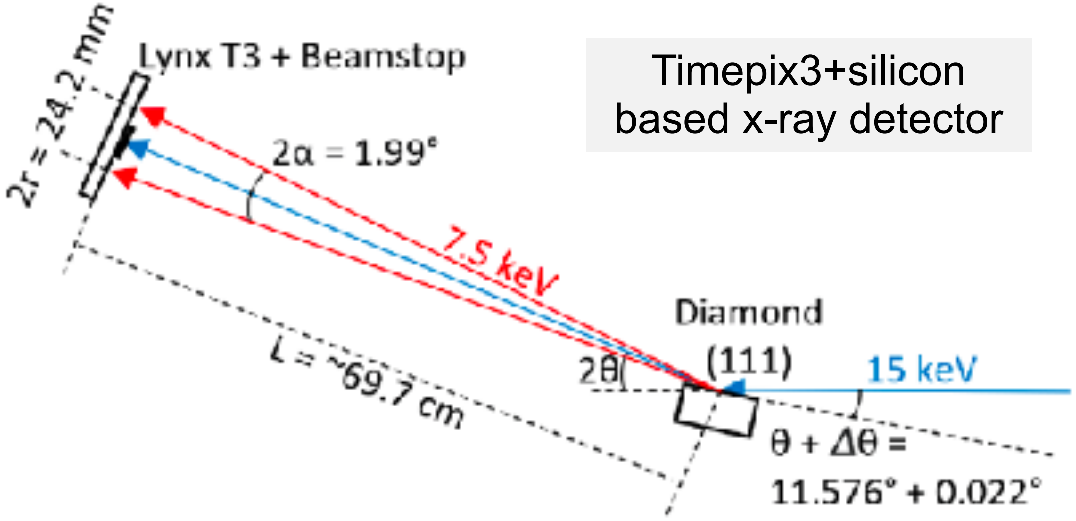
first imaging of x-ray cone
record rate of pair detection ~ few Hz

arxiv.org/abs/2310.13078



Imaging of X-ray Pairs in a Spontaneous Parametric Down-Conversion Process

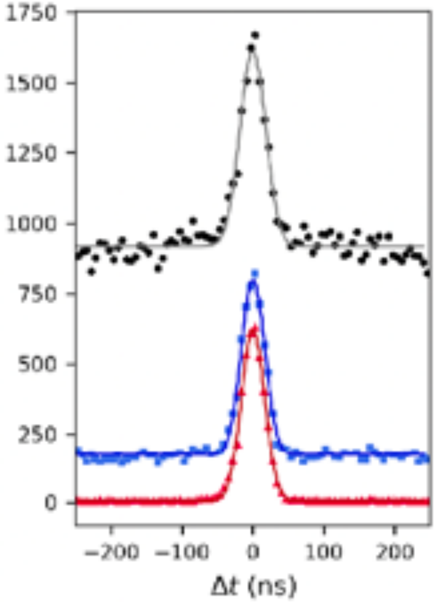
Justin C. Goodrich[1], Ryan Mahon[2], Joseph Hanrahan[1], Monika Dziubelski[2], Raphael A. Abrahao[2], Sanjit Karmakar[3], Kazimierz J. Gofron[4], Thomas Caswell[1], Daniel Allan[1], Lonny Berman[1], Andrei Fluerasu[1], Andrei Nomerotski[3], Cinzia DaVià[3] and Sean McSweeney[1,5]



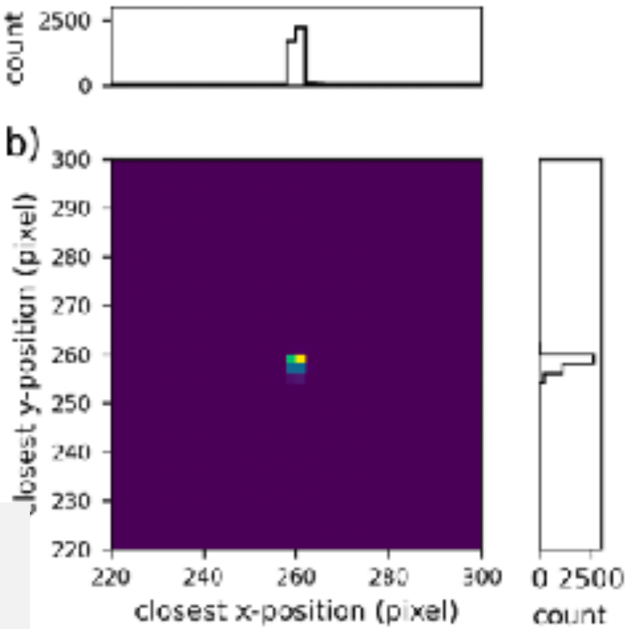
Timepix3+silicon based x-ray detector

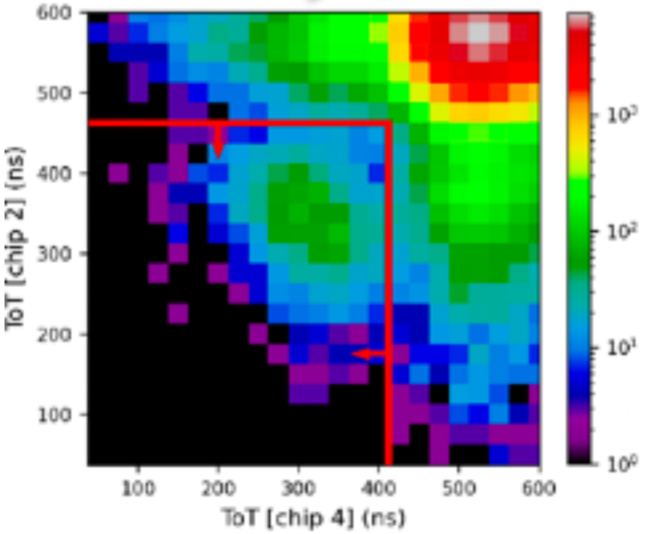
arxiv.org/abs/2310.13078

Detected simultaneously 3 types of correlations: time, spatial & energy



18 ns resolution due to variation of conversion depth





TOT correlation poor resolution

Motivation: x-ray detectors with good timing and energy resolutions

Scope: entanglement studies for x-rays

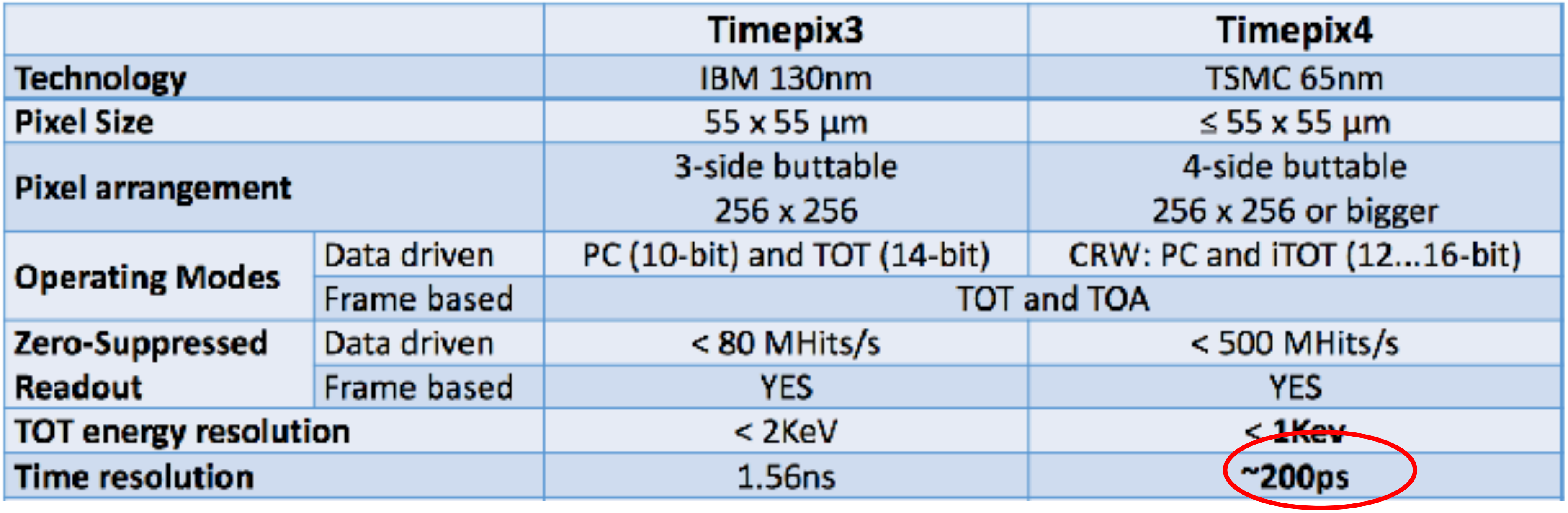
Sensor R&D

Ideas for 2d imaging sensors which can provide 20 ps resolution

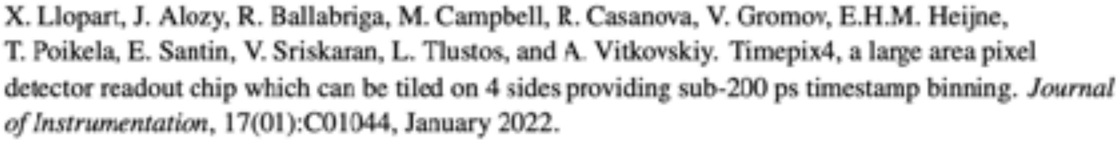
Timepix3 → Timepix4

by Medipix4 collaboration

X. Llopart



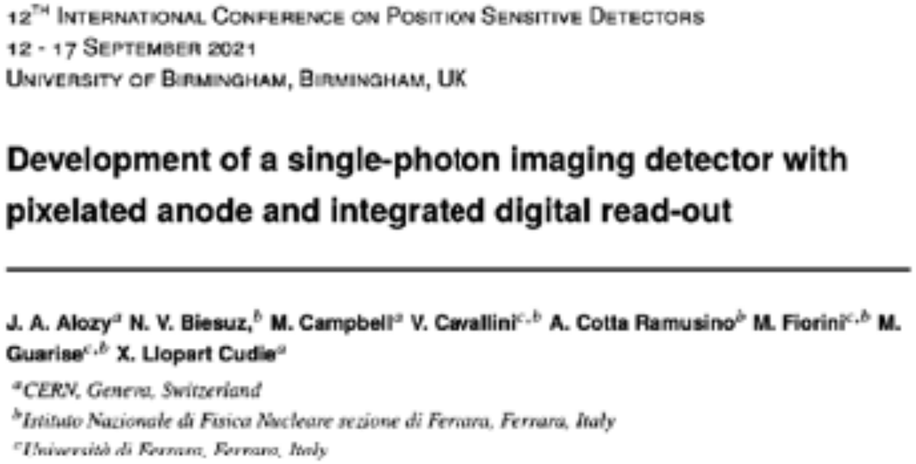
		Timepix3	Timepix4
Technology		IBM 130nm	TSMC 65nm
Pixel Size		55 x 55 µm	≤ 55 x 55 µm
Pixel arrangement		3-side buttable 256 x 256	4-side buttable 256 x 256 or bigger
Operating Modes	Data driven	PC (10-bit) and TOT (14-bit)	CRW: PC and iTOT (12...16-bit)
	Frame based	TOT and TOA	TOT and TOA
Zero-Suppressed Readout	Data driven	< 80 MHits/s	< 500 MHits/s
	Frame based	YES	YES
TOT energy resolution		< 2KeV	< 1Kev
Time resolution		1.56ns	~200ps



X. Llopart, J. Alozy, R. Ballabriga, M. Campbell, R. Casanova, V. Gromov, E.H.M. Heijne, T. Poikela, E. Santin, V. Sriskaran, L. Tlustos, and A. Vitkovskiy. Timepix4, a large area pixel detector readout chip which can be tiled on 4 sides providing sub-200 ps timestamp binning. *Journal of Instrumentation*, 17(01):C01044, January 2022.

External amplification in MCP

Direct detection after MCP in Timepix



12TH INTERNATIONAL CONFERENCE ON POSITION SENSITIVE DETECTORS
12 - 17 SEPTEMBER 2021
UNIVERSITY OF BIRMINGHAM, BIRMINGHAM, UK

Development of a single-photon imaging detector with pixelated anode and integrated digital read-out

---

J. A. Alozy[a] N. V. Biesuz,[b] M. Campbell[a] V. Cavallini[c,b] A. Cotta Ramusino[b] M. Fiorini[c,b] M. Guarise[c,b] X. Llopart Cudie[a]

[a]CERN, Geneva, Switzerland
[b]Istituto Nazionale di Fisica Nucleare sezione di Ferrara, Ferrara, Italy
[c]Università di Ferrara, Ferrara, Italy

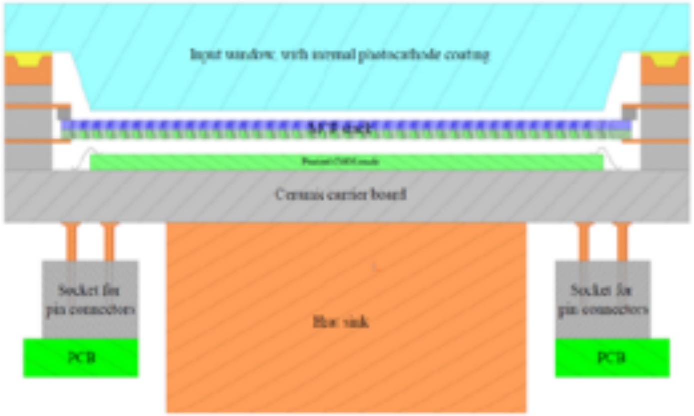


Figure 1. Cutaway schematic view of the detector assembly.

Has been implemented before with Timepix3

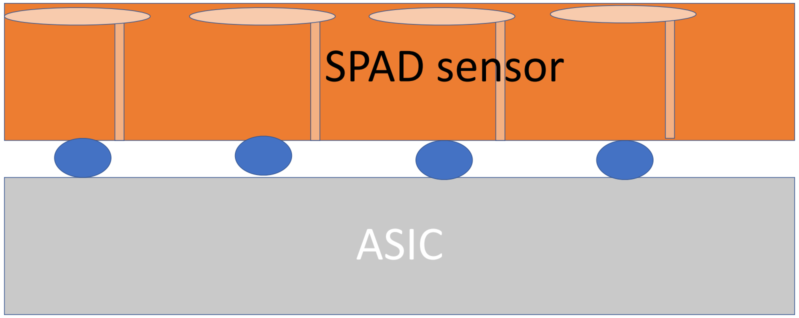
Limitation: photocathode QE ~ 35%

Hybrid SPADs: 20 ps timing

- 20 ps timing is needed for next round of CERN experiments in 10 years, there will be lots of investment in fast ASICs

- example: Timespot1 chip
  - 32 x 32
  - 50 ps
  - 55 micron pitch

- Hybrid detector: SPAD + 20 ps chip



arXiv:2209.13242v1 [physics.ins-det] 27 Sep 2022

Timespot1: A 28 nm CMOS Pixel Read-Out ASIC for 4D Tracking at High Rates

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Sandro Cadeddu,[a,1] Luca Frontini,[b,c] Adriano Lai,[a] Valentino Liberali,[b,c] Lorenzo Piccolo,[d] Angelo Rivetti,[d] Jafar Shojaii,[e] Alberto Stabile[b,c]

[a] *INFN Sezione di Cagliari, 09042 Monserrato, Italy*
[b] *Università degli Studi di Milano, Dipartimento di Fisica, 20133 Milano, Italy*
[c] *INFN Sezione di Milano, 20133 Milano, Italy*
[d] *INFN Sezione di Torino, 10125 Torino, Italy*
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ABSTRACT: We present the first characterization results of Timespot1, an ASIC designed in CMOS 28 nm technology, featuring a 32 × 32 pixel matrix with a pitch of 55 μm. Timespot1 is the first-born small-size prototype, conceived to read-out fine-pitch pixels with single-hit time resolution below 50 ps and input rates of several hundreds of kilohertz per pixel. Such experimental conditions will be typical of the next generation of high-luminosity collider experiments, from the LHC run5 and beyond. Each pixel of the ASIC has been endowed with a charge amplifier, a discriminator, and a Time to Digital Converter with time resolution around 30 ps and maximum read-out rates (per pixel) of 3 MHz. To respect system-level constraints, the timing performance have been obtained keeping the power budget per pixel below 40 μW. The ASIC has been tested and characterised in laboratory concerning its performance in terms of time resolution, power budget and sustainable rates. The ASIC will be hybridized on a matched 32 × 32 pixel sensor matrix and will be tested under laser beam and Minimum Ionizing Particles in the laboratory and at test beams. In this paper we present a description of the ASIC operation and the first results obtained from characterization tests concerning its performance in tracking measurements.

KEYWORDS: Front-end electronics for detector readout, Timing detectors, VLSI circuits

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Main points to take home

- Quantum-assisted two-photon interferometry dramatically enhance astrometric precision with great impact on astro science
- Requires single photon cameras with 10 ps scale resolution

Broad program in quantum-assisted optical interferometry ahead, efforts underway to develop new timing technologies

This will be useful in many fields including the quantum

- Entangled x-rays motivate pixels with ns timing resolution and good energy resolution

“The great advances in science usually result from new tools rather than from new doctrines”

Freeman Dyson (1923-2020)

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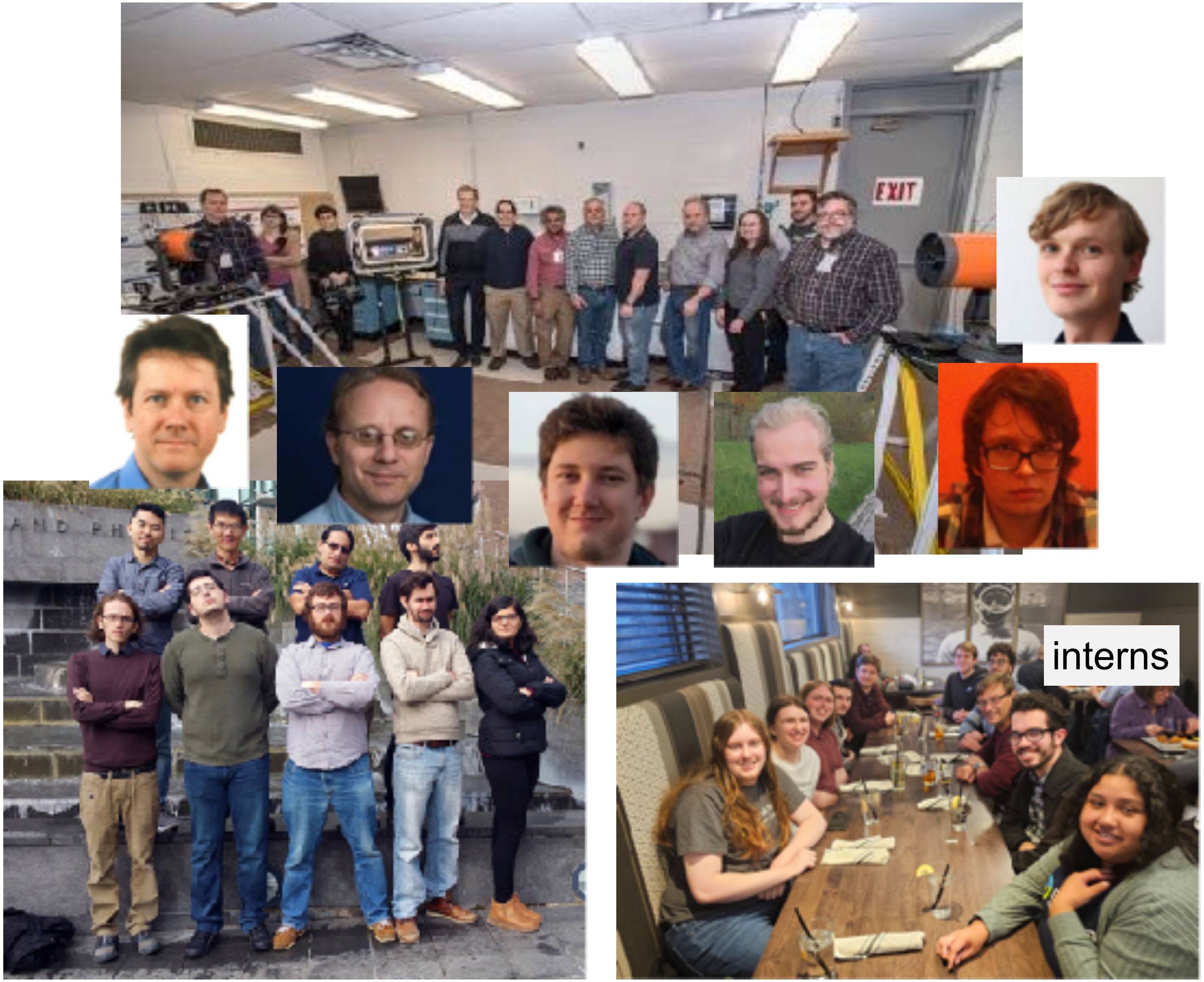

Thank you for your attention!

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