Quantum Optical Coherence Tomography

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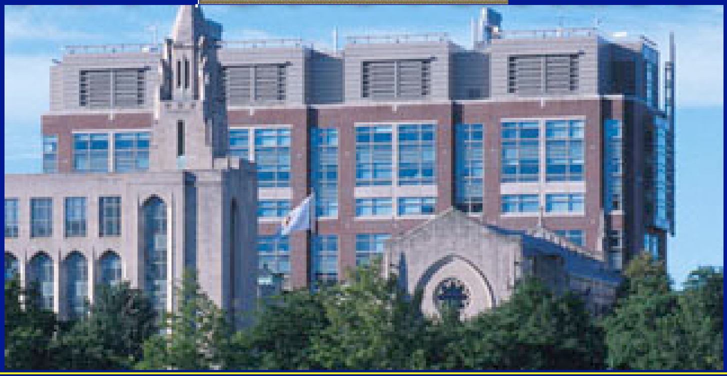


http://www.bu.edu/qil/

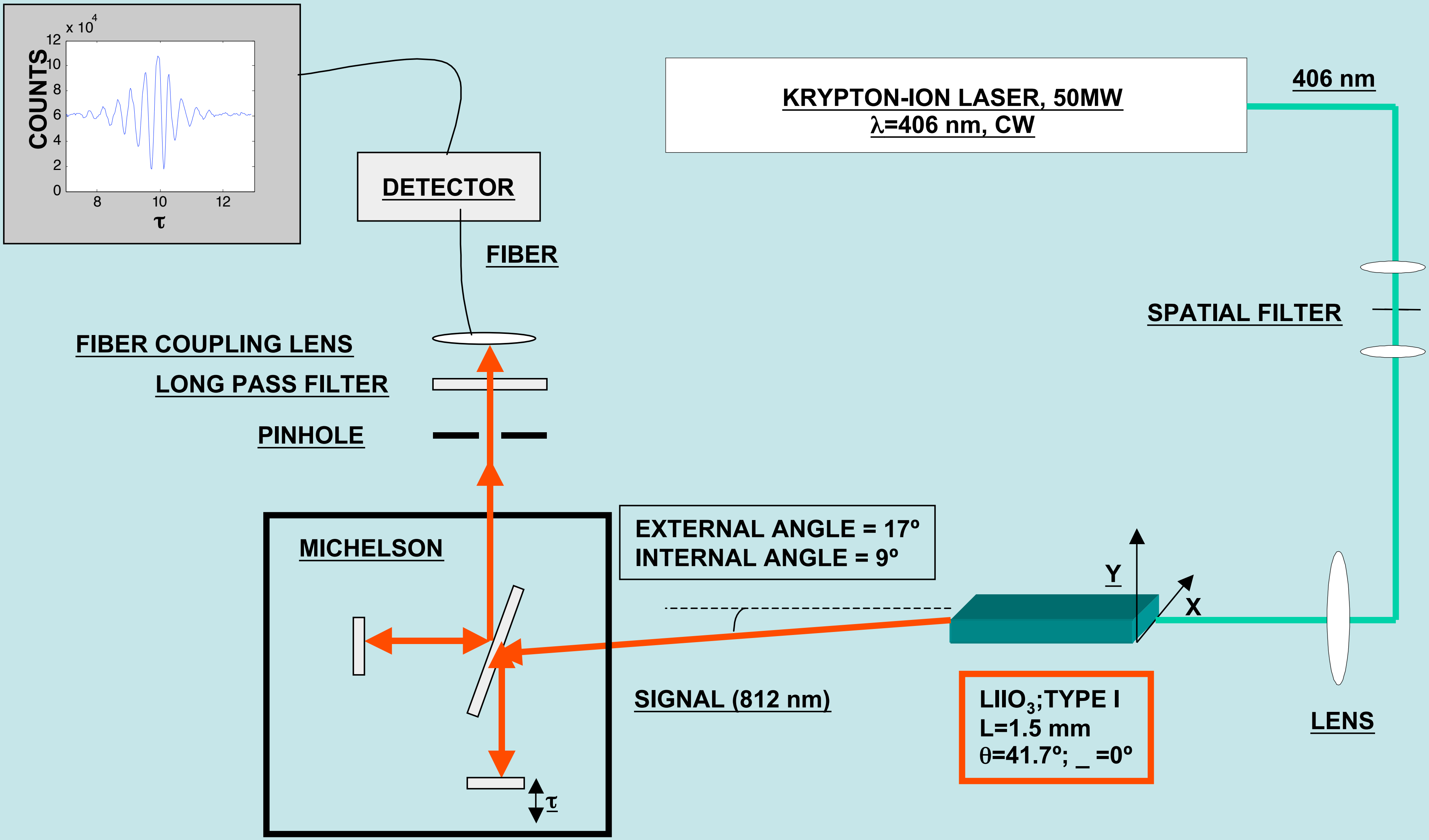
Outline

1. High-resolution QOCT
2. Engineered sources of broadband entanglement

   a) non-collinear SPDC

   b) periodically-polled chirped nonlinear structures
3. Broadband single-photon detectors

Spectral control using spatial modulation



S. Carrasco, A. V. Sergienko, B. E. A. Saleh, M. Teich, J. P. Torres and L. Torner "Spectral engineering of entangled two-photon states", *Physical Review A*, **v. 73**, 063802 (2006).

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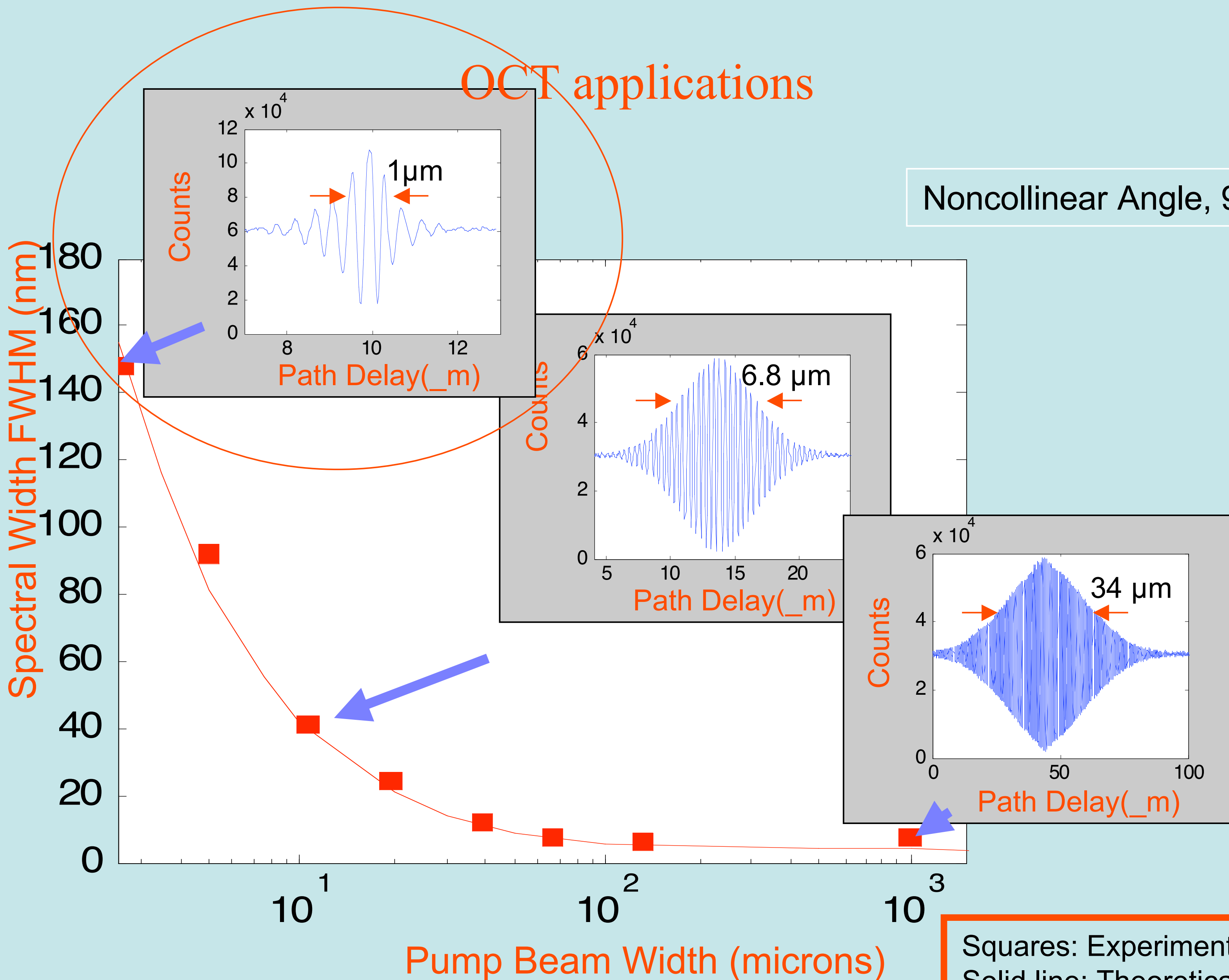
Experimental results: Spectral Width Control



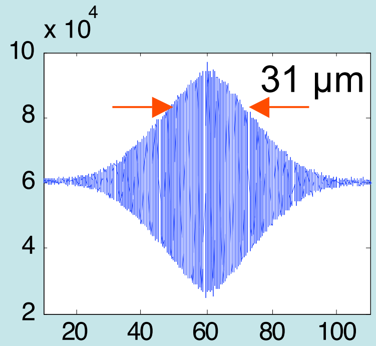
Squares: Experimental results
Solid line: Theoretical results

Experimental results: Submicron Resolution OCT

Not Focused Pump

Narrow spectrum of the state function

Broad interference pattern

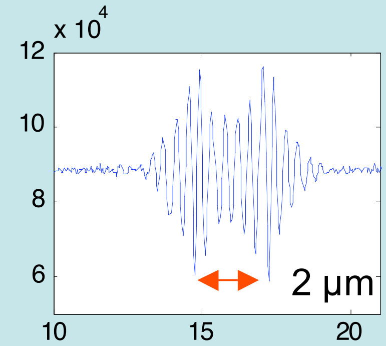


Not able to resolve the 2 micron pellicle

Tightly Focused Pump

Broad spectrum of the state function

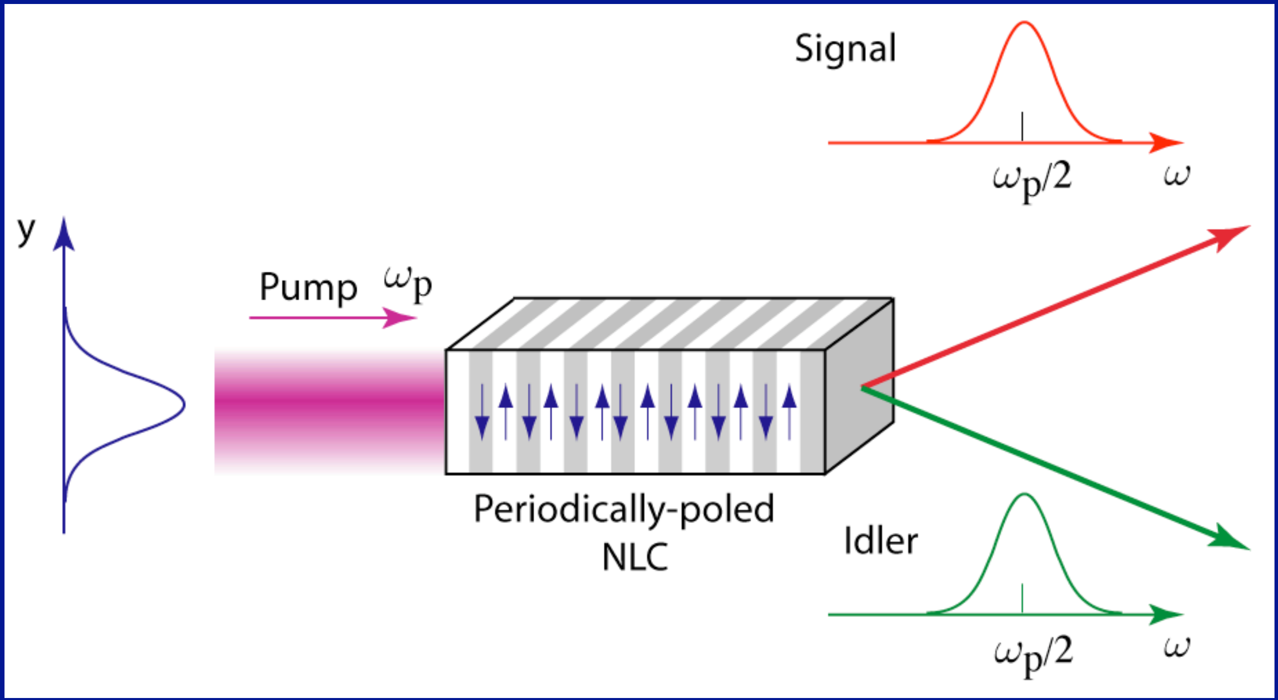
Narrow Interference pattern



2 micron pellicle resolved

QOCT with QPM Crystal

Non-collinear SPDC + Spatial pump shape



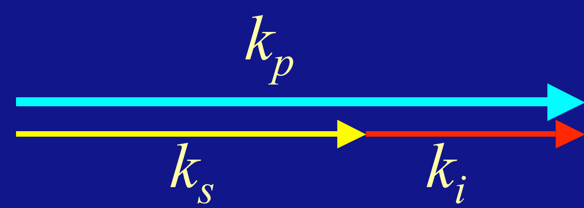
After Carrasco *et al*., *Opt. Lett.* **29**, 2429-2431 (2004)

INTEGRATED COMPACT PPLN ENTAGLED-PHOTONS SOURCE

♦ In-house manufacturing of periodically-poled nonlinear crystals (PPLN) for miniaturization of entangled-photon sources. Design of compact sources of sophisticated entanglement at telecommunication wavelength. Further miniaturization and integration.

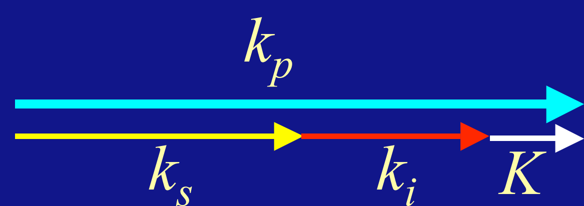
Lithium niobate : - strong second order non-linearity, d_{33}= -27 pm/V (BBO : d_{eff}=2.4 pm/V)
- transparent on a wide frequency range (350 nm to 5μm)

Birefringent phase-matching :



$$k_p = k_s + k_i$$

Periodical poling :



$$k_p = k_s + k_i + K$$

- quasi-phase matching by modulating $\chi^{(2)}(z)=\chi^{(2)} e^{iKz}$
- highest non-linear coefficient

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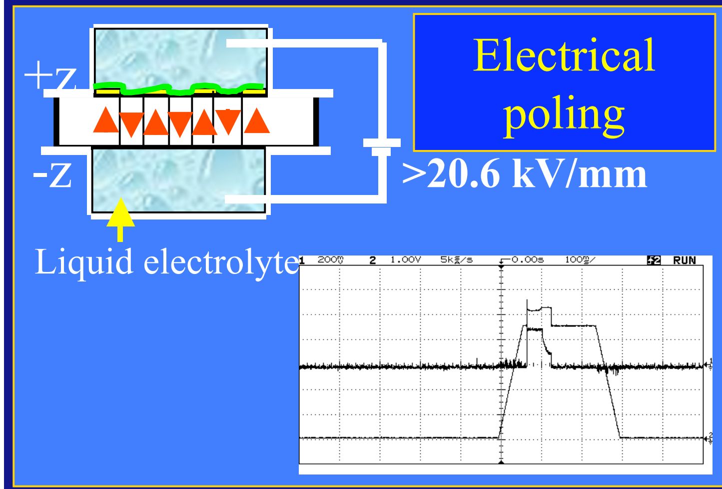
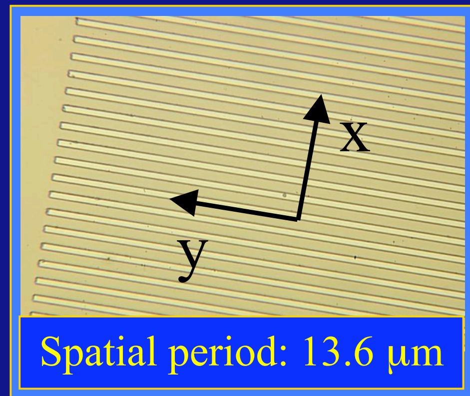
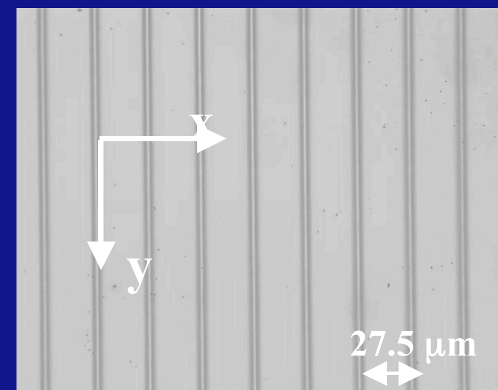
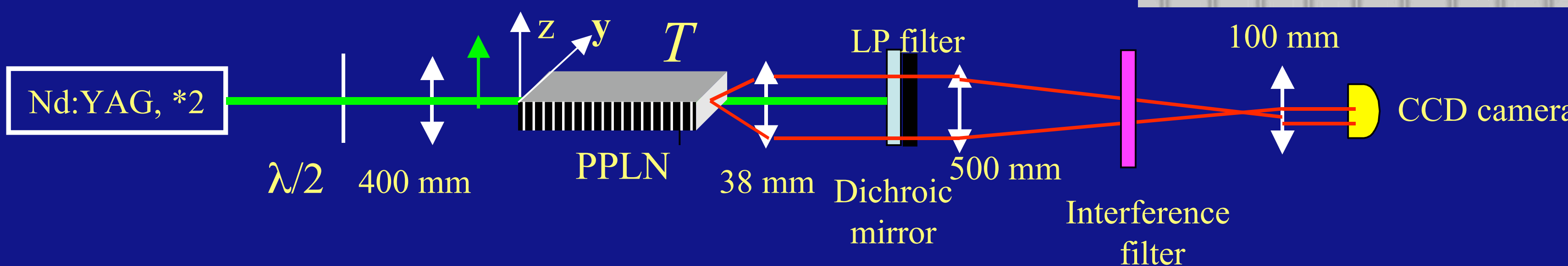
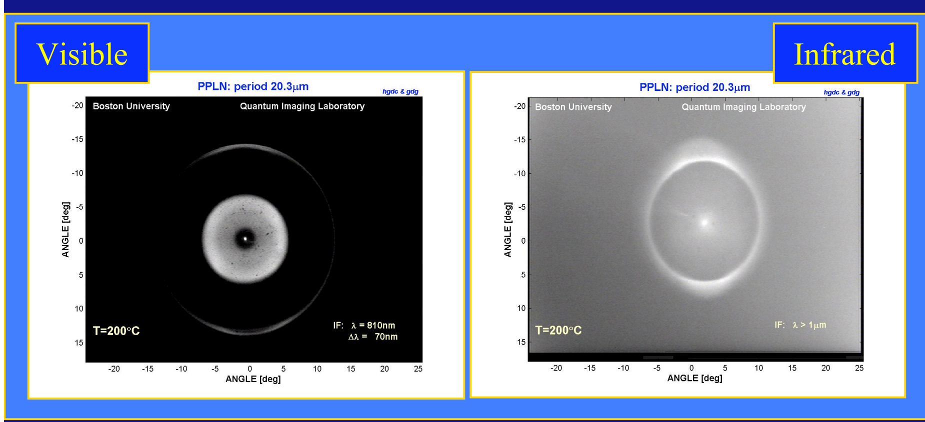
In-House Fabrication of PPLN











H. Guillet de Chatellus, G. Di Giuseppe, A. V. Sergienko, B. E. A. Saleh, and M. C. Teich, "Non-collinear and Non-degenerate Polarization-Entangled Photon Generation via Concurrent Type-I Parametric Downconversion in PPLN", *Optics Express,* **v. 14,** 10060-10072 (2006).

Chirped QPM as source of photon pairs

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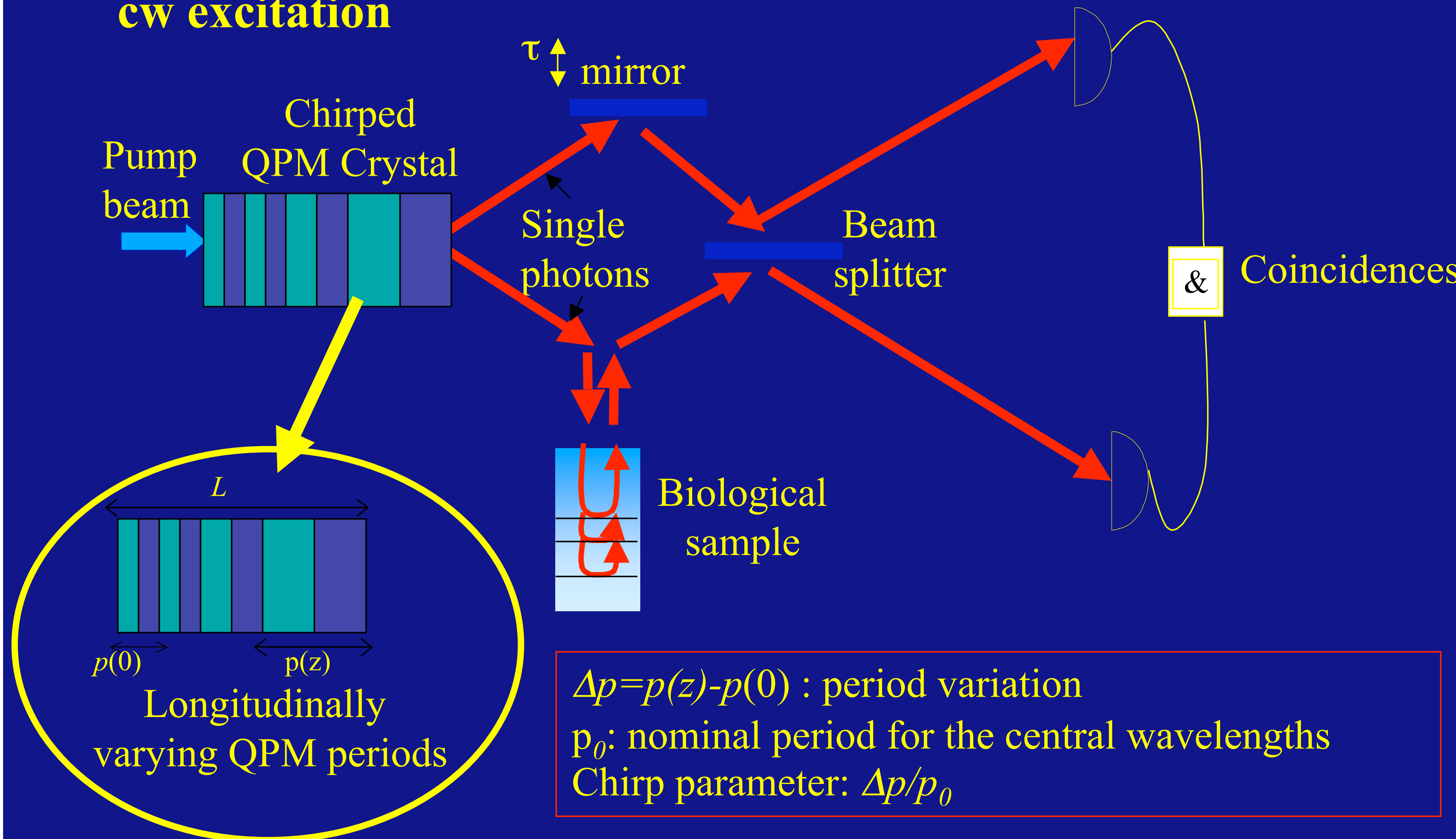
cw excitation

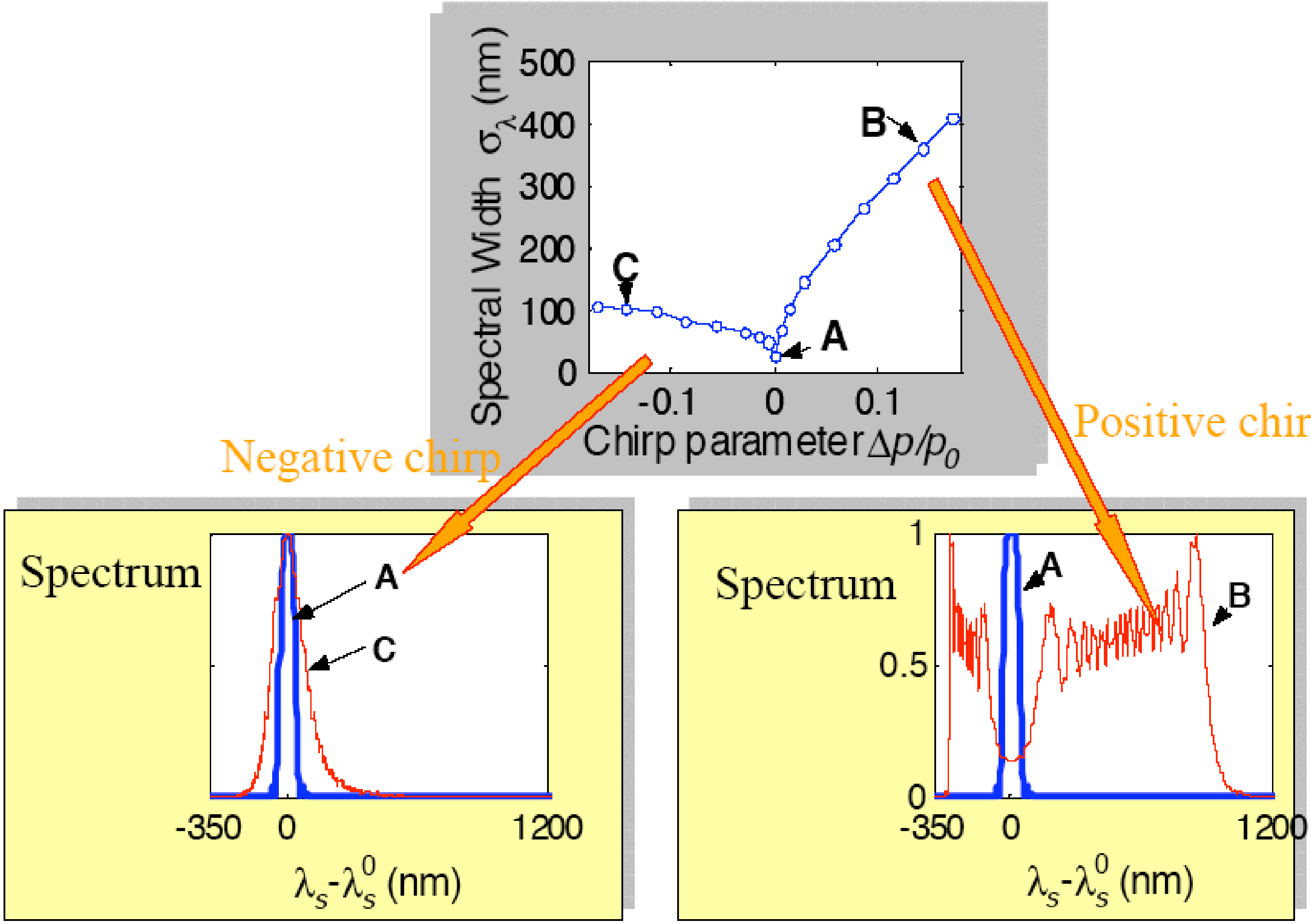


$\Delta p = p(z) - p(0)$: period variation

p_0: nominal period for the central wavelengths

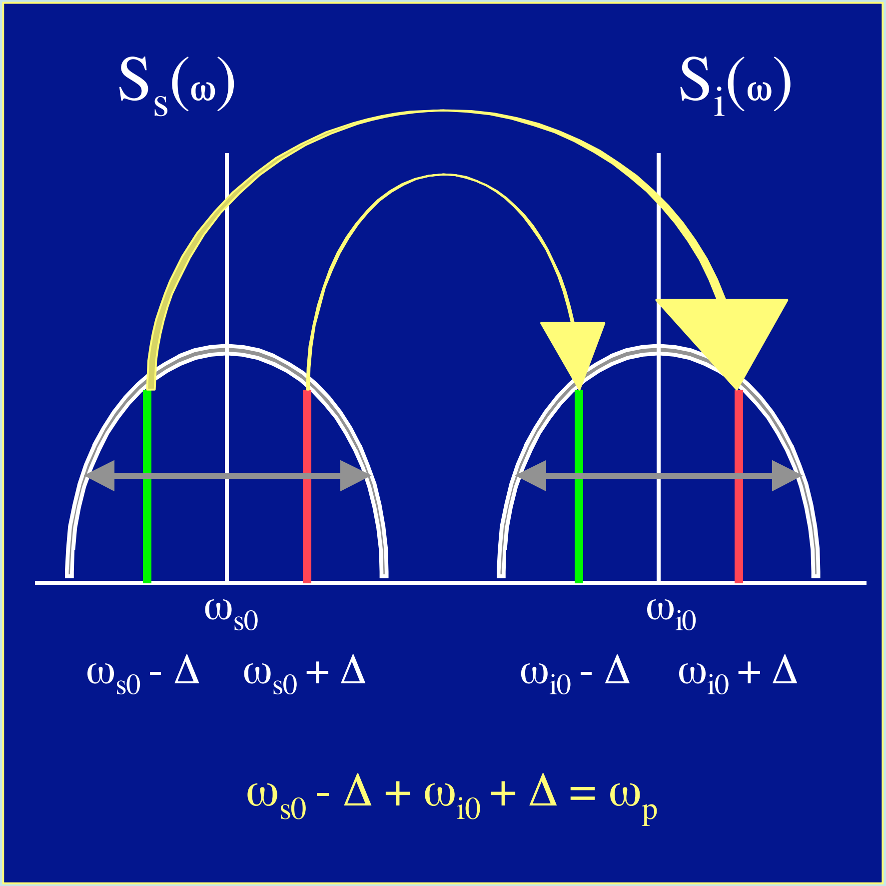
Chirp parameter: $\Delta p / p_0$

Spectral widening

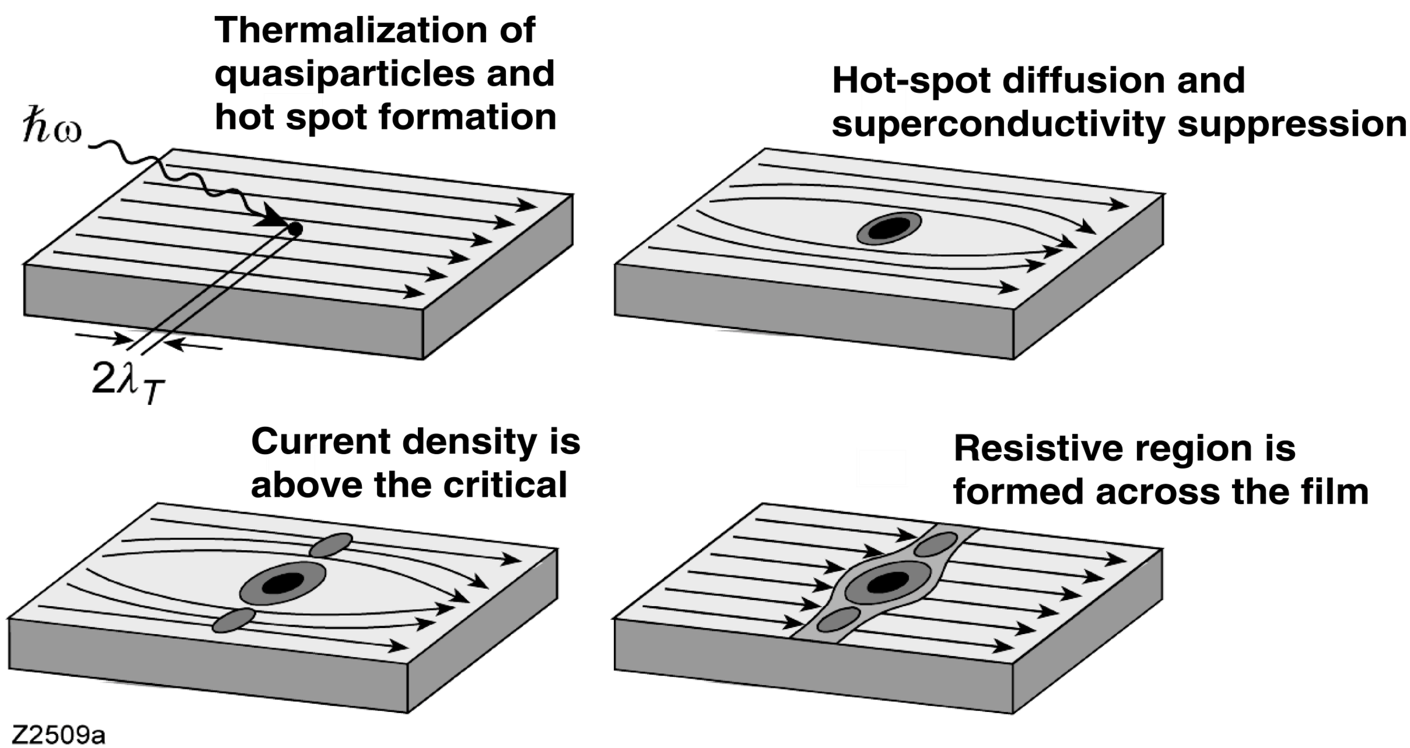


Silvia Carrasco, Juan P. Torres, and Lluis Torner, Alexander Sergienko, Bahaa E. A. Saleh, and Malvin C. Teich, *Optics Letters*, **v. 29**, 2429-2431 (2004).

Spectral entanglement in SPDC and coincidence detection

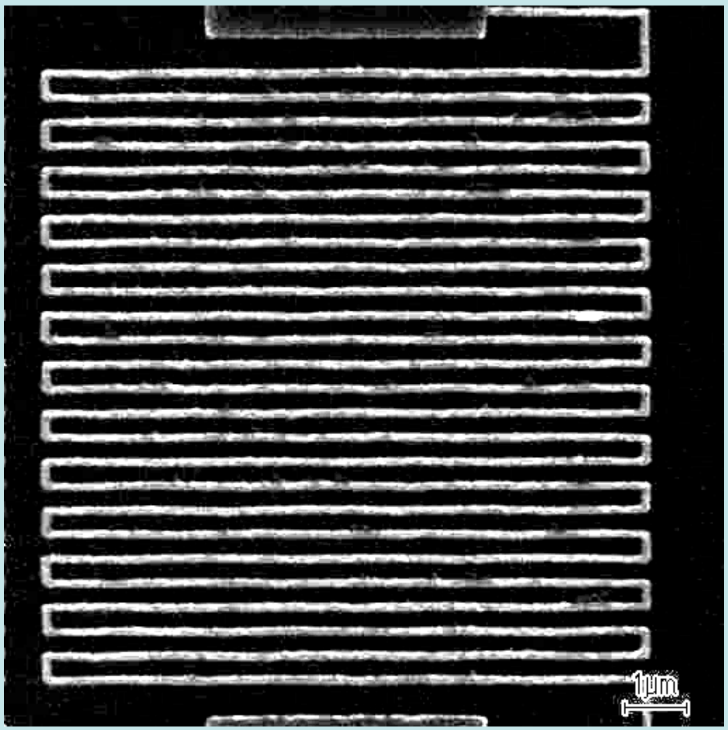


Superconducting Single-Photon Detector (SSPD)Technology



Superconducting Single-Photon Detector (SSPD)Technology

SSPD detector structure



- SSPD is usually 3-10 nm thick Niobium Nitride (NbN) meandering microstripe sputtered on Sapphire substrate
- E-beam lithography is used to define the device structure
- Detector area is 10 x 10 μm
- Fill factor is ~ 50%
- Operating temperature < 4 °K
- Photons are detected from VIS to IR

MSPU

G.N. Gol'tsman et al. Fabrication of Nanostructured Superconducting Single-Photon Detectors
IEEE Transactions on Applied Superconductivity
VOL. 13, NO. 2, JUNE 2003

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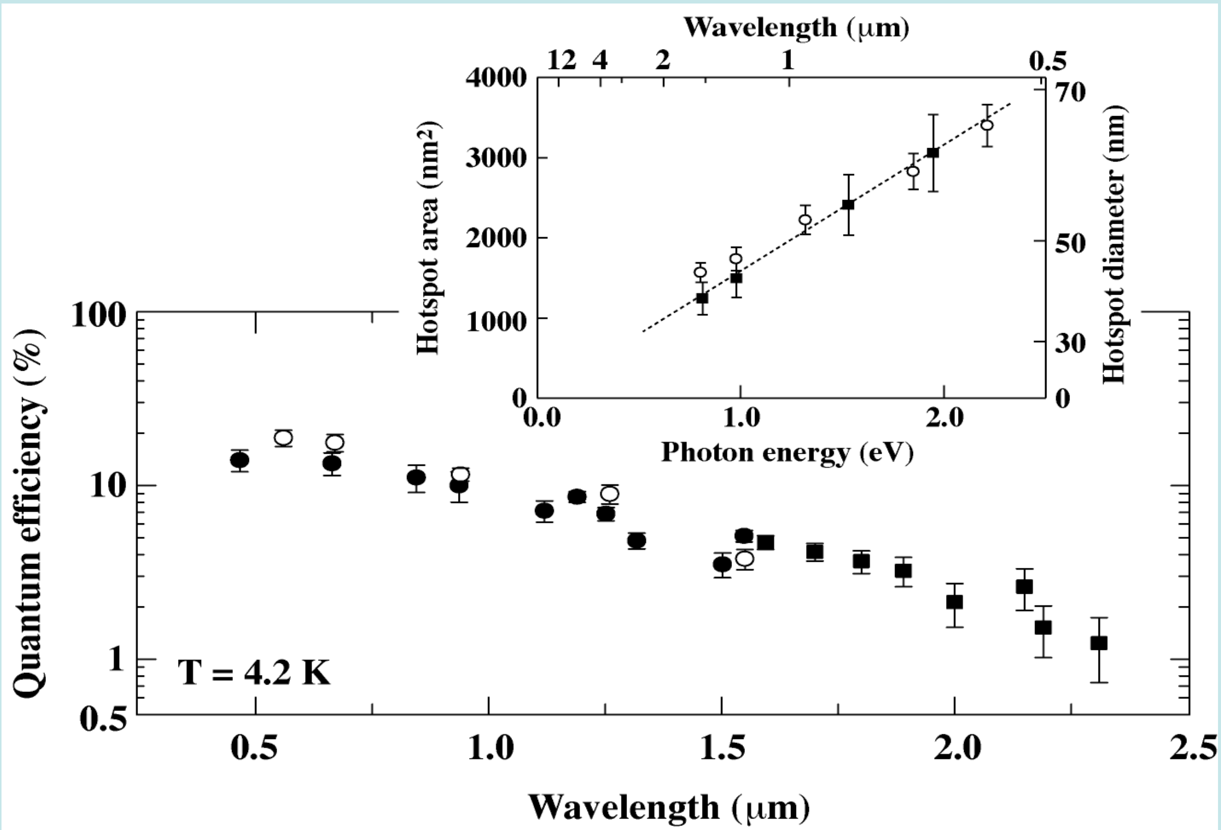
Superconducting Photon-Counting Detectors: NbN SSPD

3.5-nm-thick devices with 0.5 filling factor. Meander-type structures with the active area 10 x 10 mm.^{2}



QE ~20 - 10%
for visible-light photons

QE ~9 - 6%
for 1.3 - 1.55 μm radiation

MSPU

Gol'tsman *et al.* IEEE Trans. Appl. Supercon., 13, 192 (2003)

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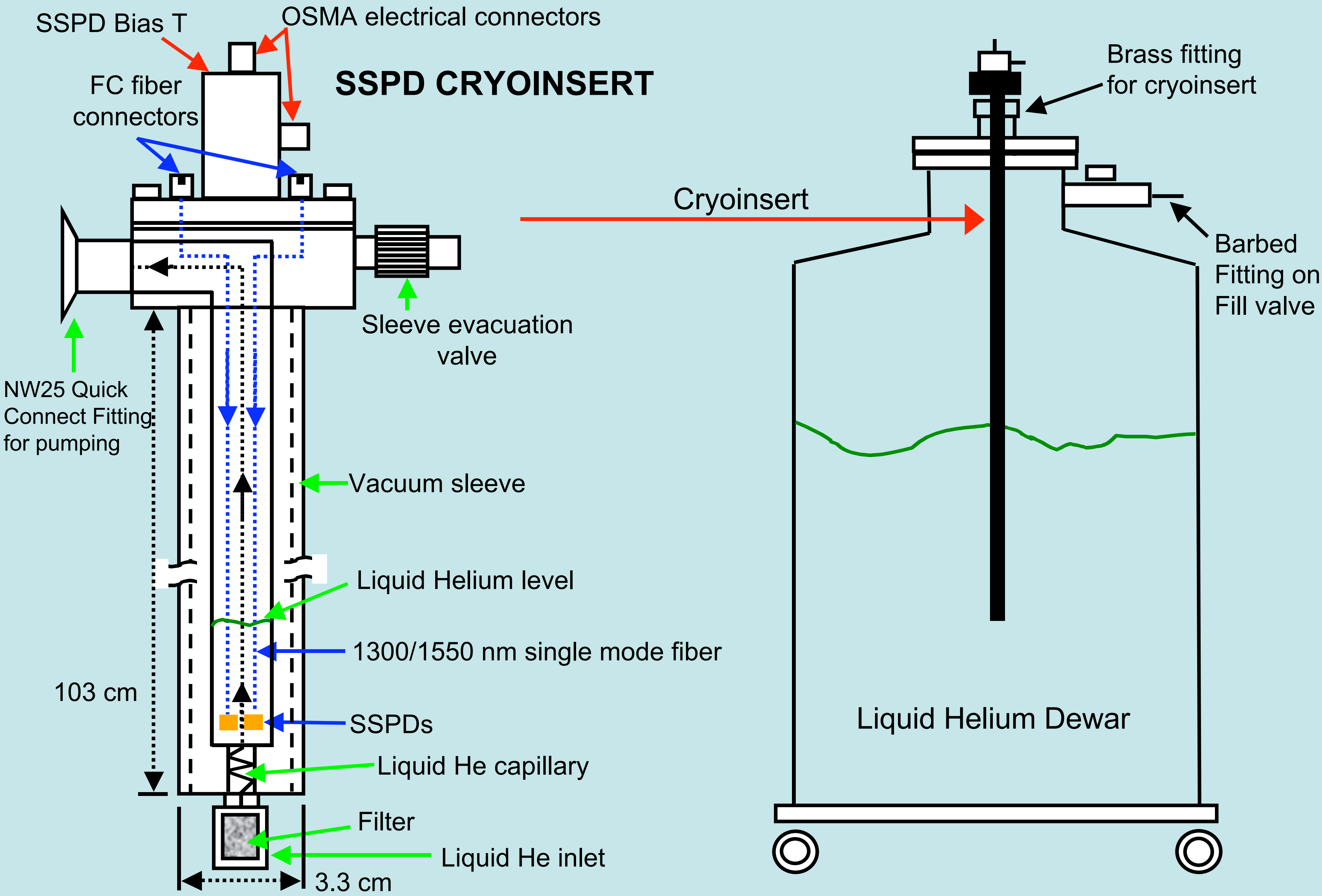
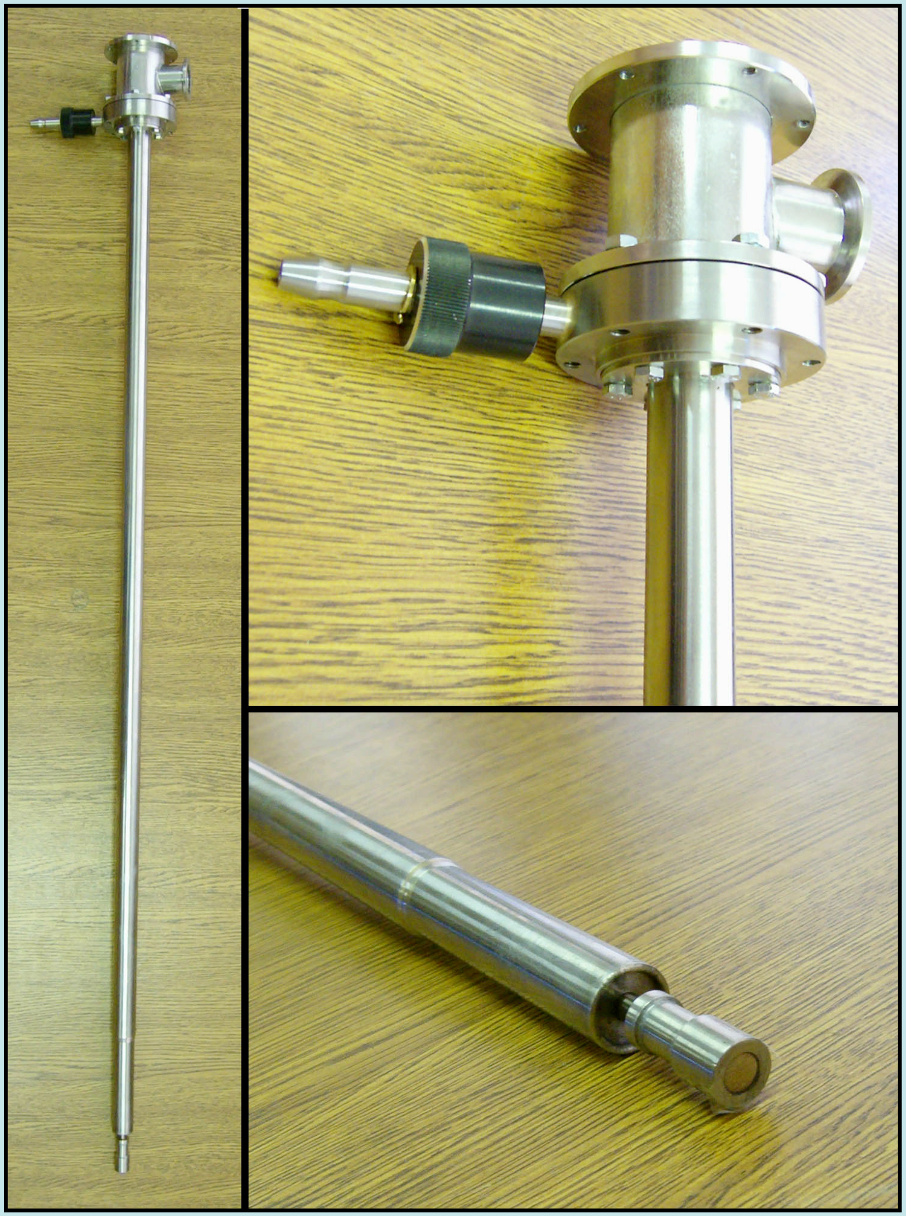
SSPD Hardware



SSPD Hardware



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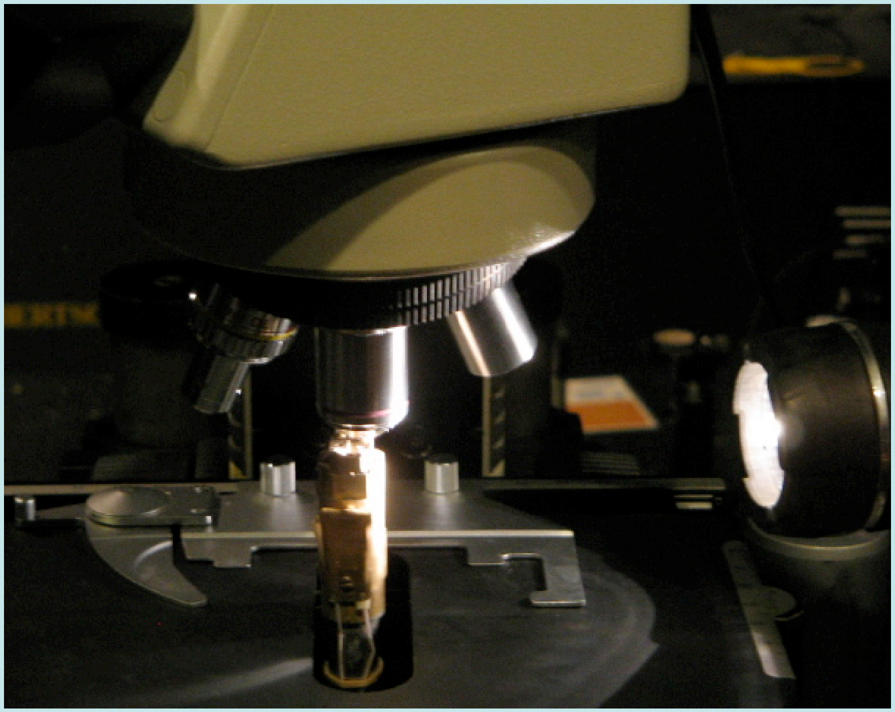
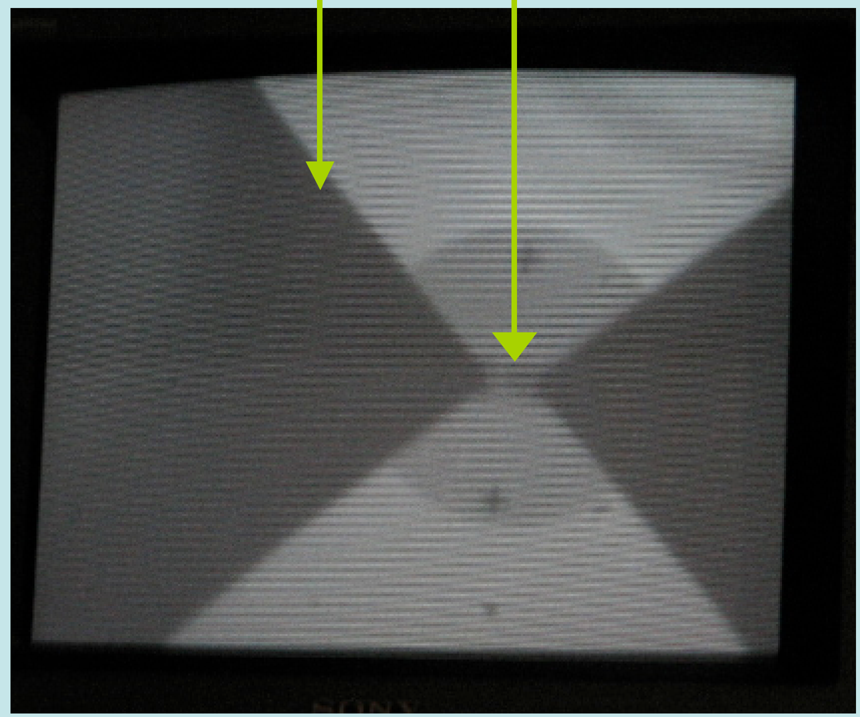
SM Optical Fiber Alignment to SSPD



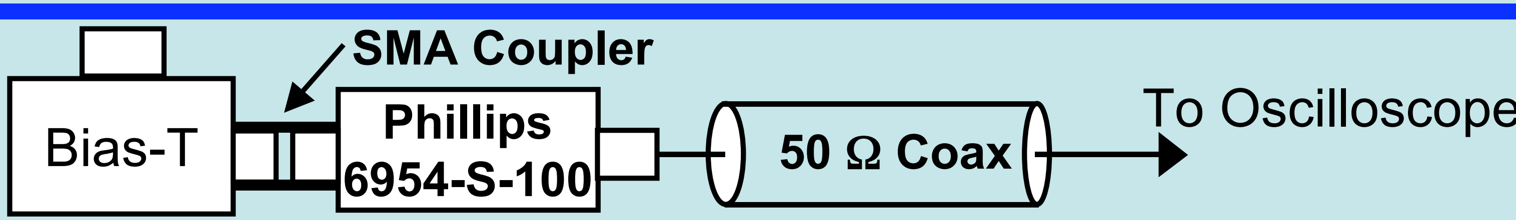
SSPD viewed under Microscope
100 X Magnification

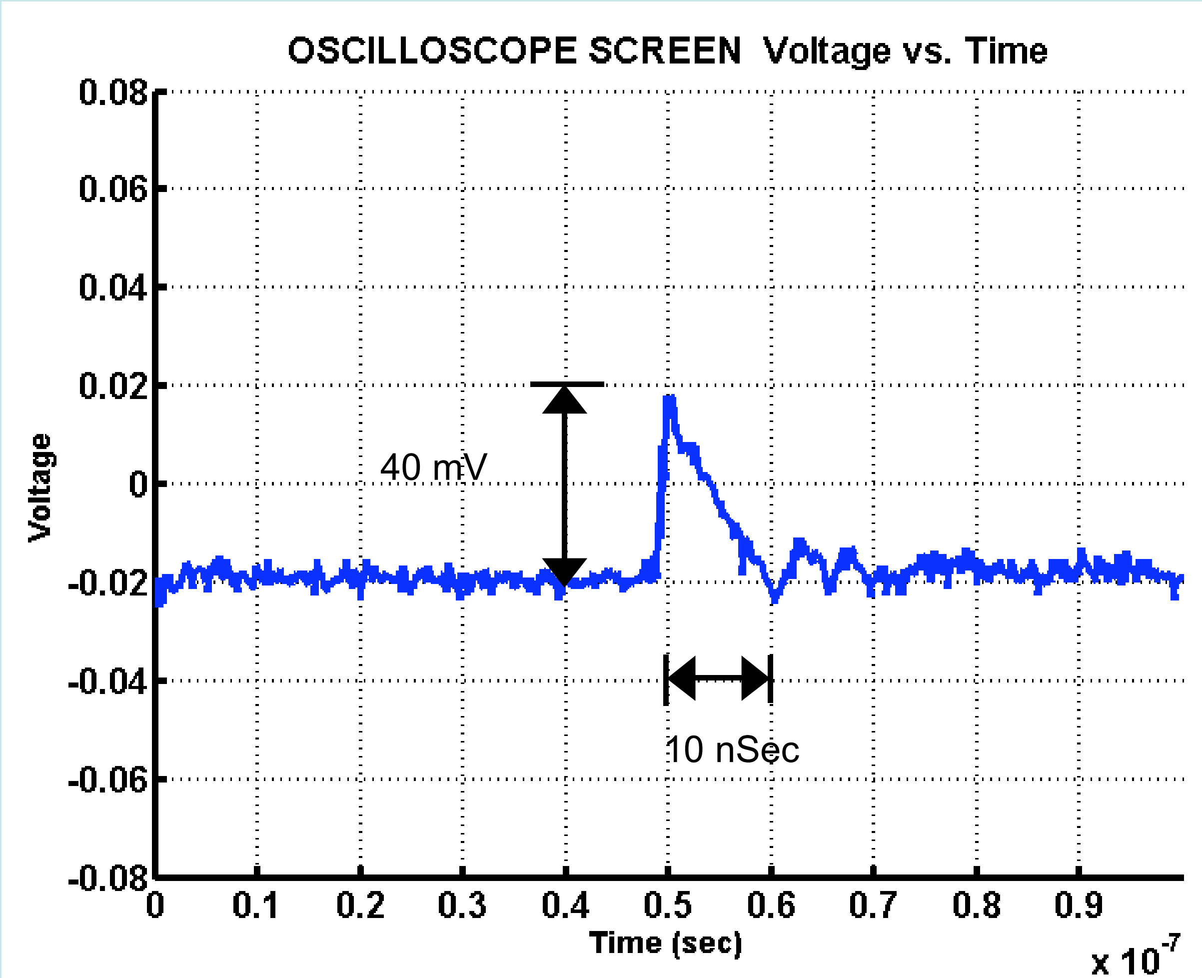


SSPD Meander and Gold contacts
as seen with CCD Camera
(100 X) Maginfication

New SSPD

(Phillips 6954-S-100 amplifier is connected very close to bias-T output
Phillips 6954 Supply Voltage = 20.0V; SSPD Bias Current = 21 uA)





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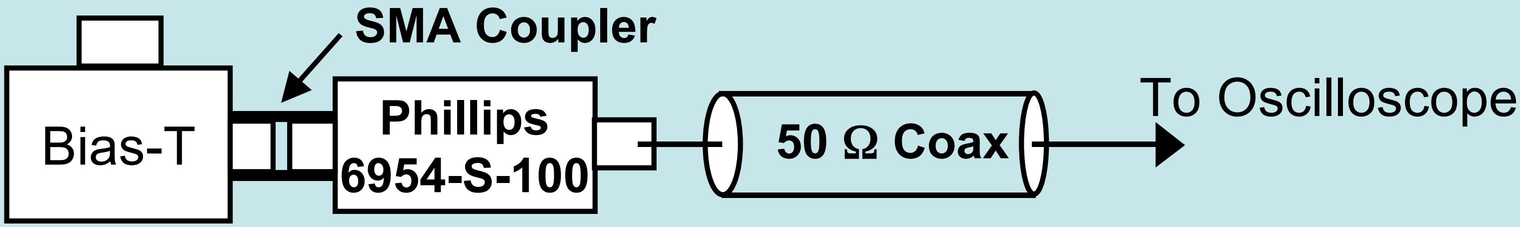
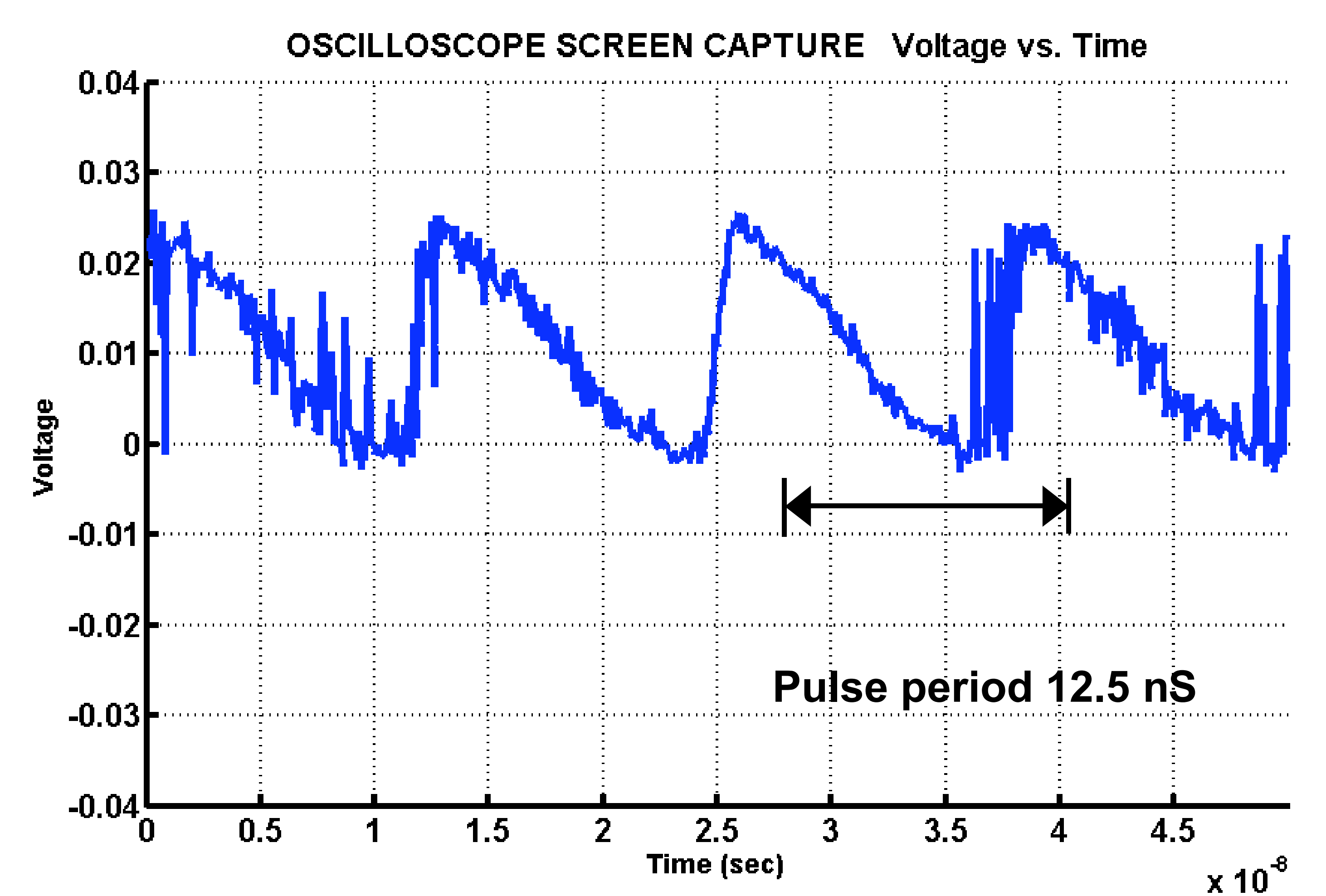
SSPD #1, Counting at 80 MHz rep rate

(800 – 820 nm Picoquant laser coupled into 780 nm SM fiber illuminates the SSPD)





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What's next

1. Correlation (coincidence) measurement of quantum interference with broadband integrated sources of entangled photons (PPLN) and broadband superconducting photon-counting detectors (SSPD) for high-resolution QOCT.

2. Initial laboratory tests with biological samples.