Generating and teleporting entanglement for quantum networks

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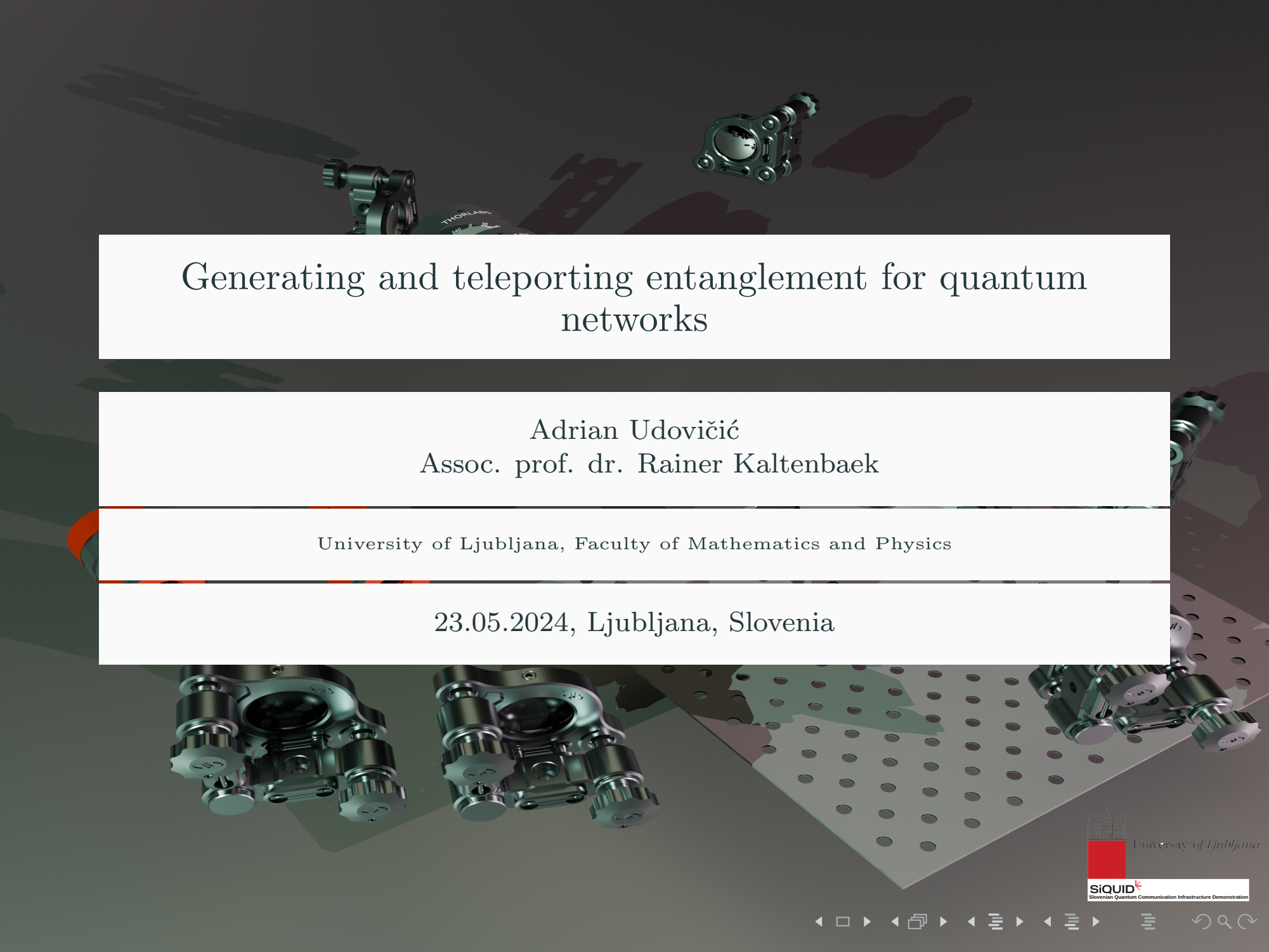
23.05.2024, Ljubljana, Slovenia



Contents and introduction

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SiQUID
Slovenian Quantum Communication Infrastructure Demonstration

Motivation

- Bright source of entanglement

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Motivation

- Bright source of entanglement
- Training in quantum technologies in Slovenia

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Motivation

- Bright source of entanglement
- Training in quantum technologies in Slovenia
- Quantum Network for Slovenia

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Motivation

- Bright source of entanglement
- Training in quantum technologies in Slovenia
- Quantum Network for Slovenia
- Testbed for industrialized version

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Theory

1. SPDC
2. Entanglement swapping

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- Spontaneous Parametric Downconversion

- Spontaneous Parametric Downconversion

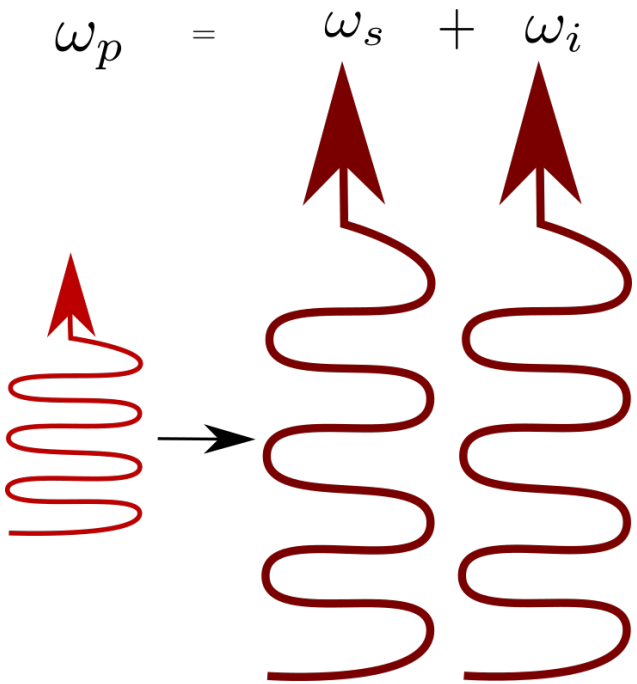

Illustration of SPDC

- Spontaneous Parametric Downconversion

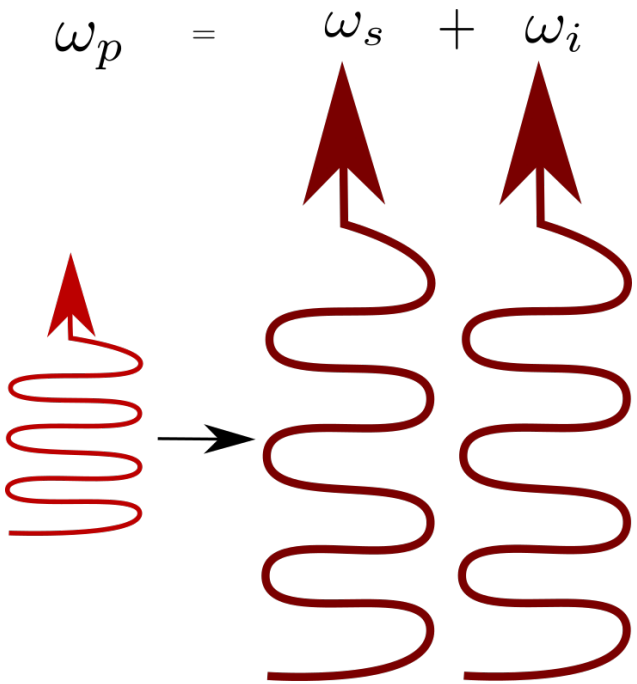

Illustration of SPDC

- Degenerate $\omega_i = \omega_s$

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- Spontaneous Parametric Downconversion

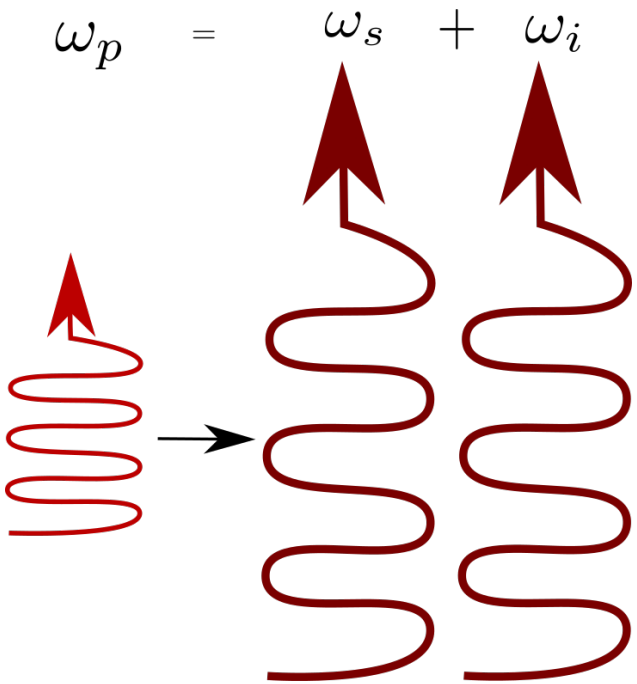

Illustration of SPDC

- Degenerate $\omega_i = \omega_s$
- Non-degenerate $\omega_i \neq \omega_s$

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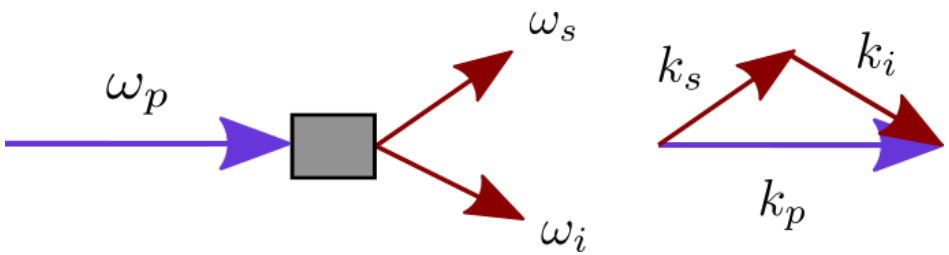
Comparison of different sources

Who When	[1] 2022	[2] 2010	[3] 2007	[4] 2006	[5] 2012
Type	0	II	II	II	0
Brightness/ $\frac{pairs}{smWnm}$	$2{,}5\times10^6$	$87{,}5\times10^3$	273×10^3	5×10^3	278×10^3
Bandwidth/nm	106	0,3	0,3	1	2,3

- Birifringent Phase Matching, Quasi Phase Matching

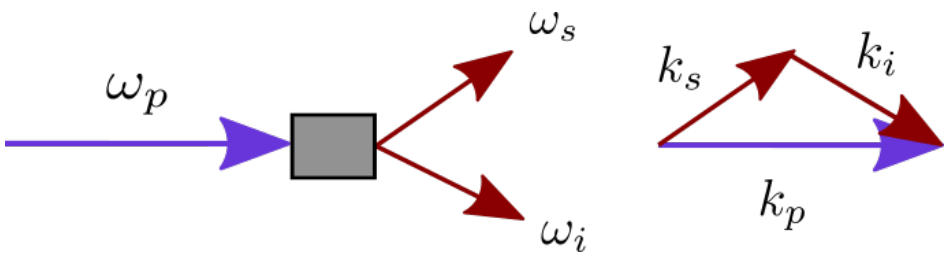
Illustration of a) Birifringent Phase Matching $k_p = k_i + k_s$ and



(a)

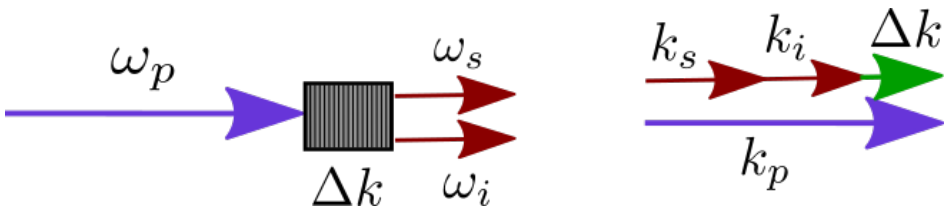
- Birifringent Phase Matching, Quasi Phase Matching

Illustration of a) Birifringent Phase Matching $k_p = k_i + k_s$ and



(a)

b) Quasi Phase Matching $k_p - k_i - k_s - \Delta k = 0$.



(a)

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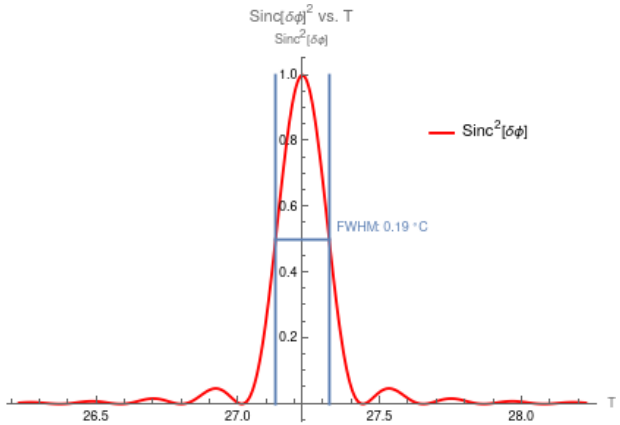
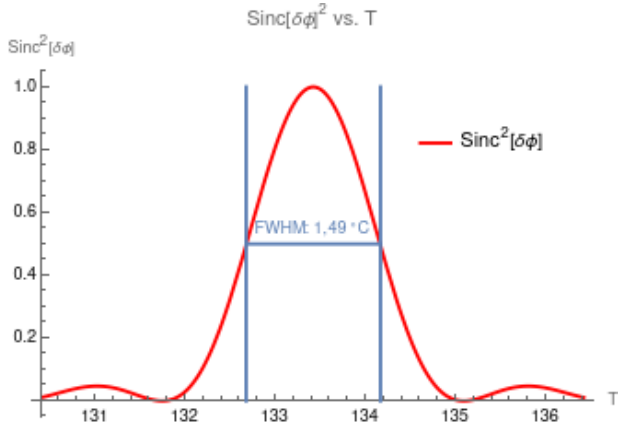
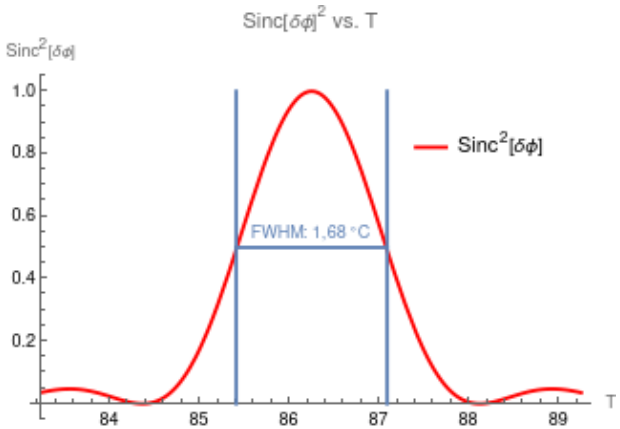
Phase Matching Temperature calculatios for a) Type-2 crystal of 9,12 μm polling period, b) Type-0, 19,25 μm, c) Type-0, 19,45 μm, d), Type-0 19,65 μm



(a)



(b)



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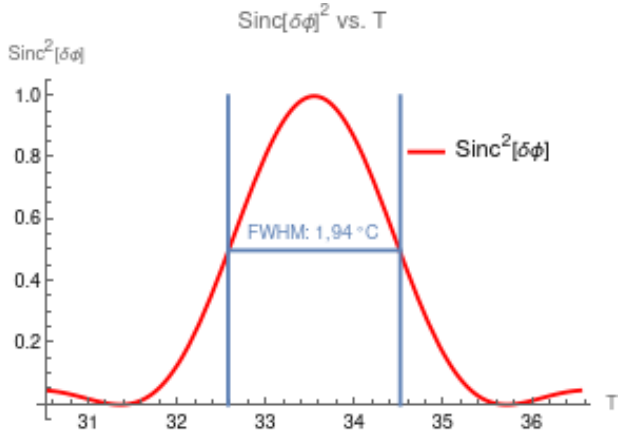

(d)

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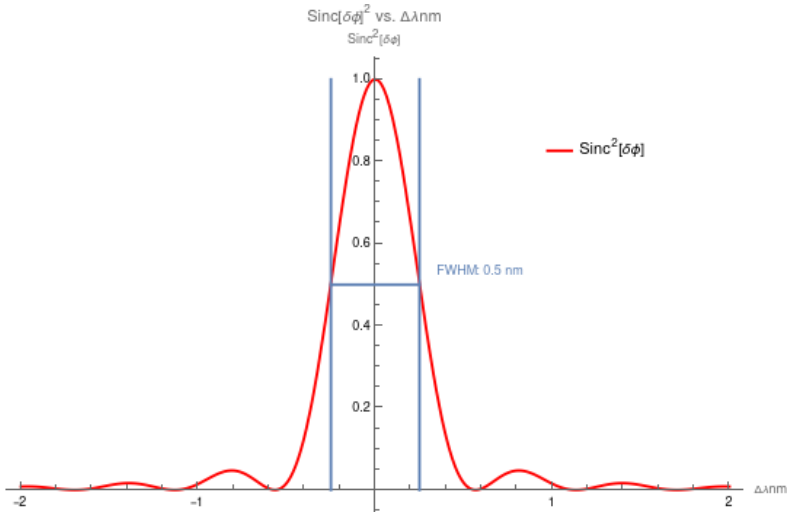
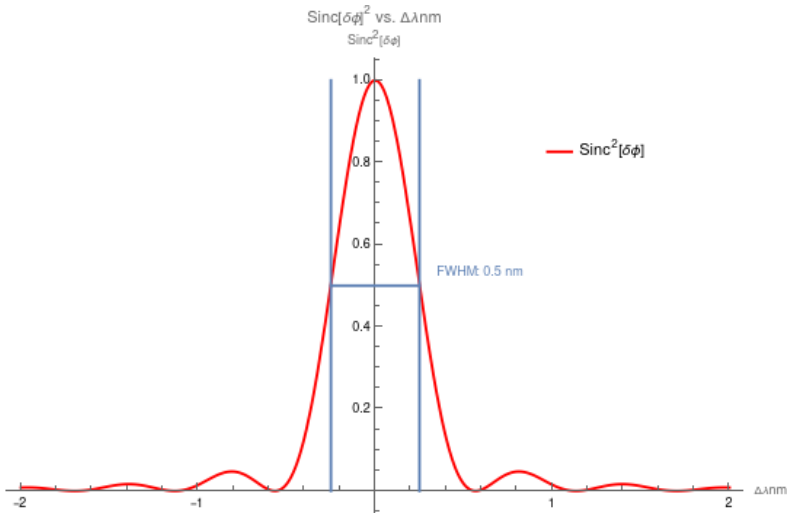
Wavelength bandwidth of a) Type-2 crystal with a polling period of 9,12 μm
b) Type-0 crystals with polling periods of 19,25 μm

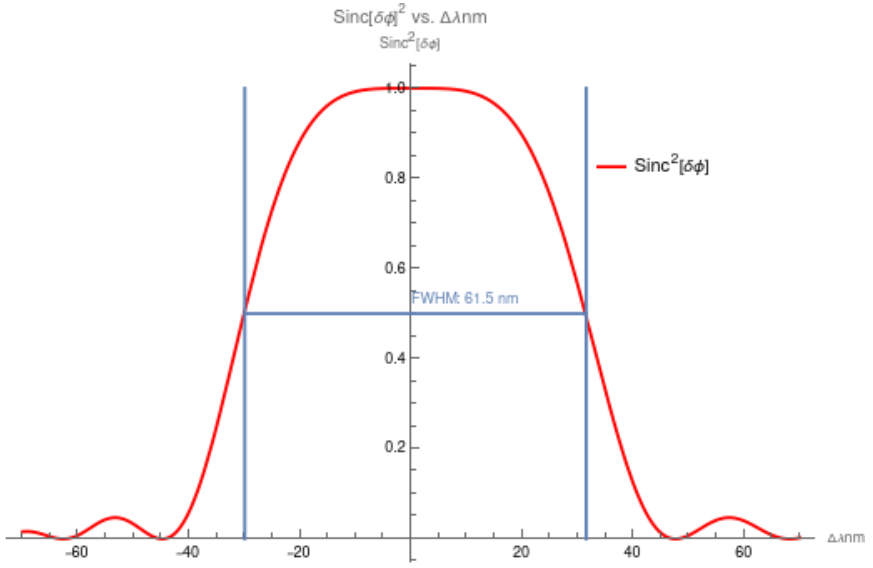


(a)

Wavelength bandwidth of a) Type-2 crystal with a polling period of 9,12 μm
b) Type-0 crystals with polling periods of 19,25 μm



(a)

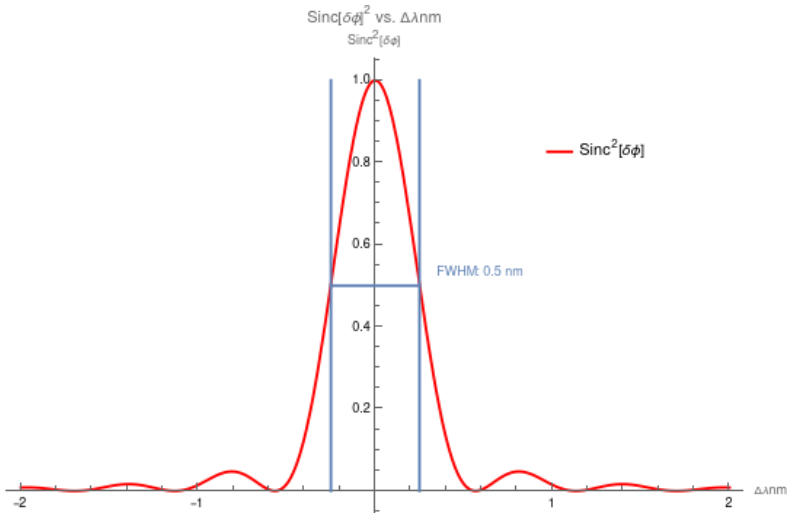


(b)

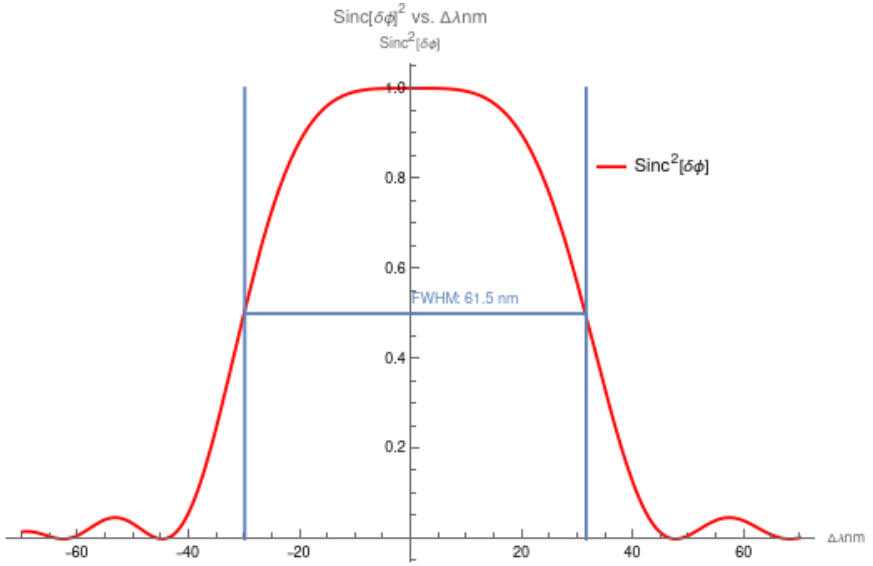
Type-II vs Type-0

Bandwidth

Wavelength bandwidth of a) Type-2 crystal with a polling period of 9,12 μm
b) Type-0 crystals with polling periods of 19,25 μm



(a)



(b)

$$|\Psi_p\rangle = \frac{1}{\sqrt{2}}(\sin(\alpha)a_H^\dagger + \cos(\alpha)a_V^\dagger)\,|0\rangle$$

$$|\Psi_{\text{Type-2}}\rangle = \frac{1}{\sqrt{2}}(\sin(\alpha)a_H^\dagger(\omega_s)a_V^\dagger(\omega_i) + \cos(\alpha)a_V^\dagger(\omega_i)a_H^\dagger(\omega_s))\,|0\rangle \quad (1)$$

$$|\Psi_{\text{Type-0}}\rangle = \frac{1}{\sqrt{2}}(\sin(\alpha)a_H^\dagger(\omega_s)a_H^\dagger(\omega_i) + \cos(\alpha)a_V^\dagger(\omega_i)a_V^\dagger(\omega_s))\,|0\rangle$$

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Brightness comparison

$Hz/mW/nm$

FMF		**IJS**
Type-II	**Type-0**	**Type-II**
7,8 $\times 10^6$	2,6 $\times 10^7$	0,05 $\times 10^6$
Bandwidth/nm		
0,68	0,68	0,68

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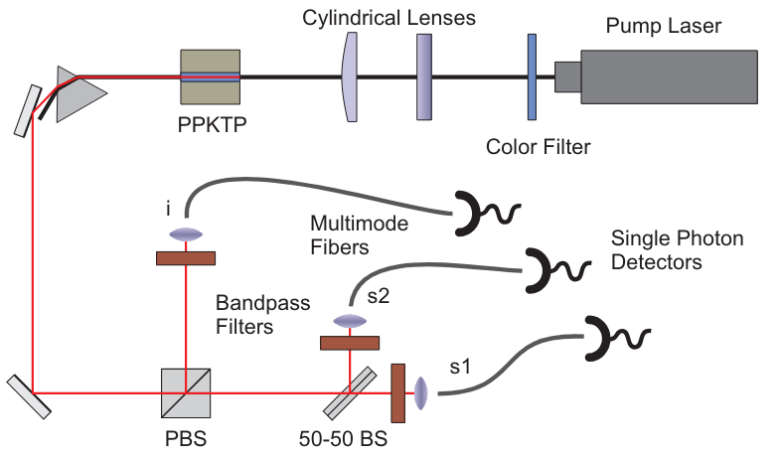
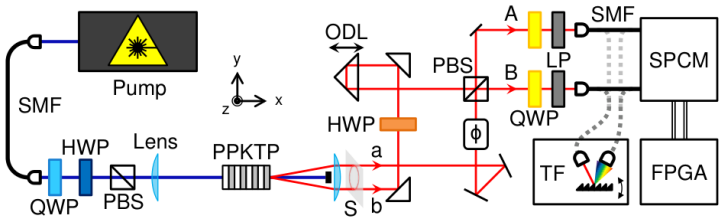
Different Designs

Different design ideas from other groups. a) [6], b) [7], c) [8], d) [9]



(a)



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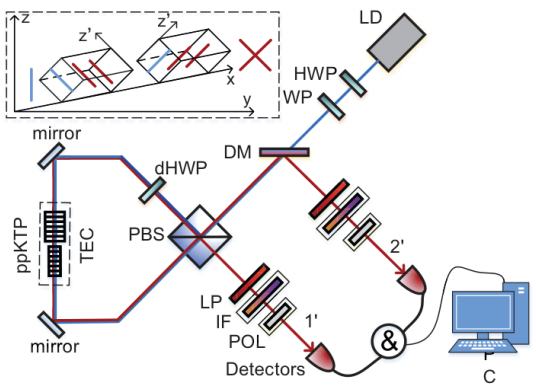

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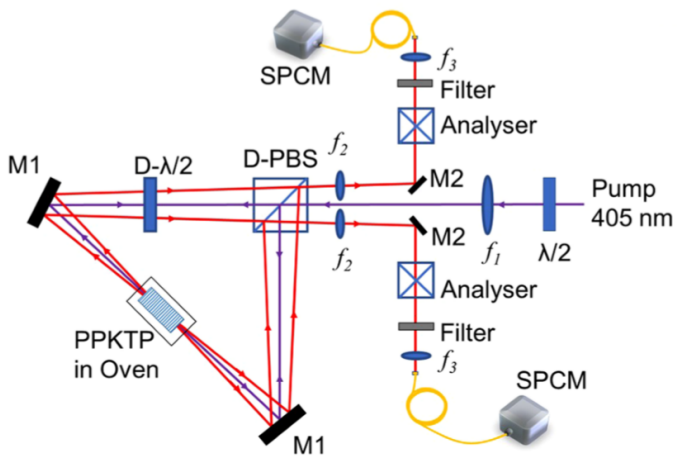

(d)

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- No specific form required - arbitrary states can be teleported
  1. Bell State Measurements
  2. Will try to use Quantum Memory from IJS group
- FMF/IJS

Illustration of Entanglement Teleportation.

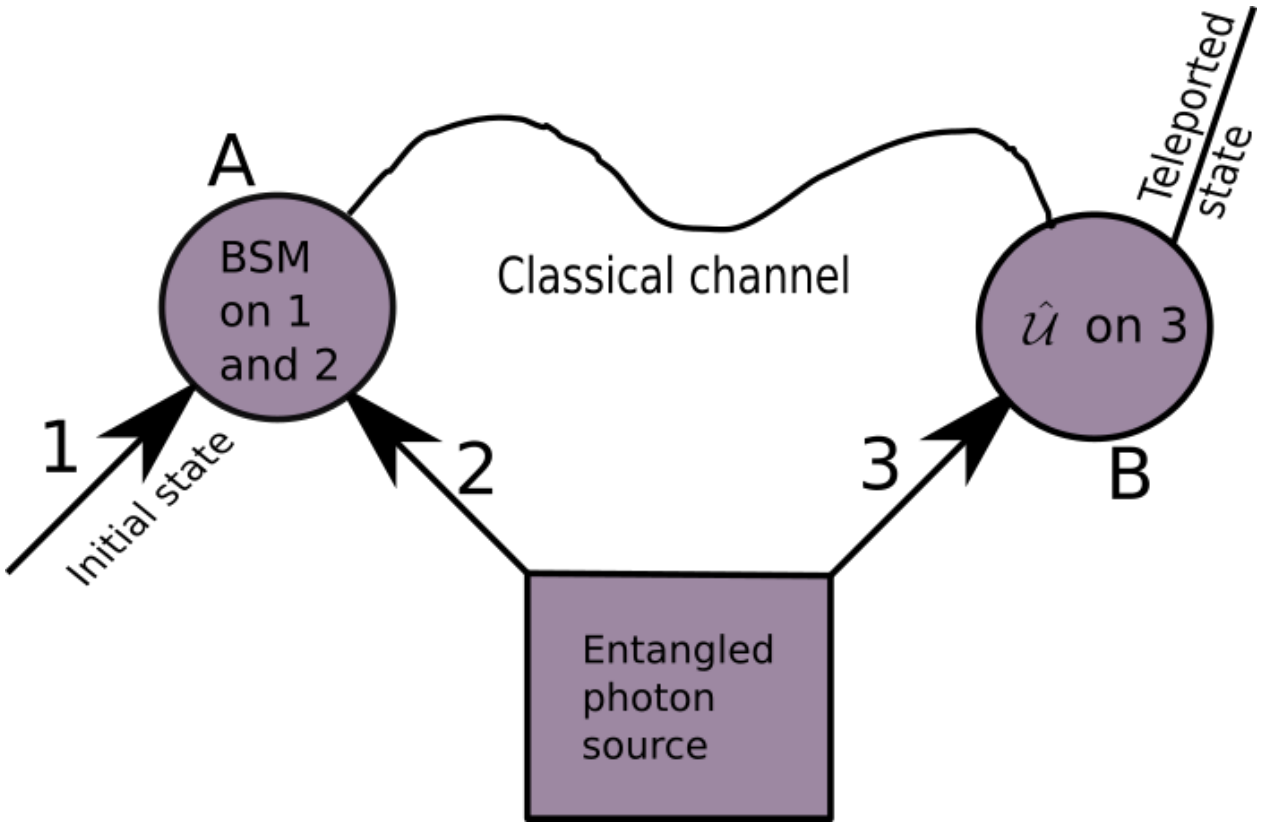
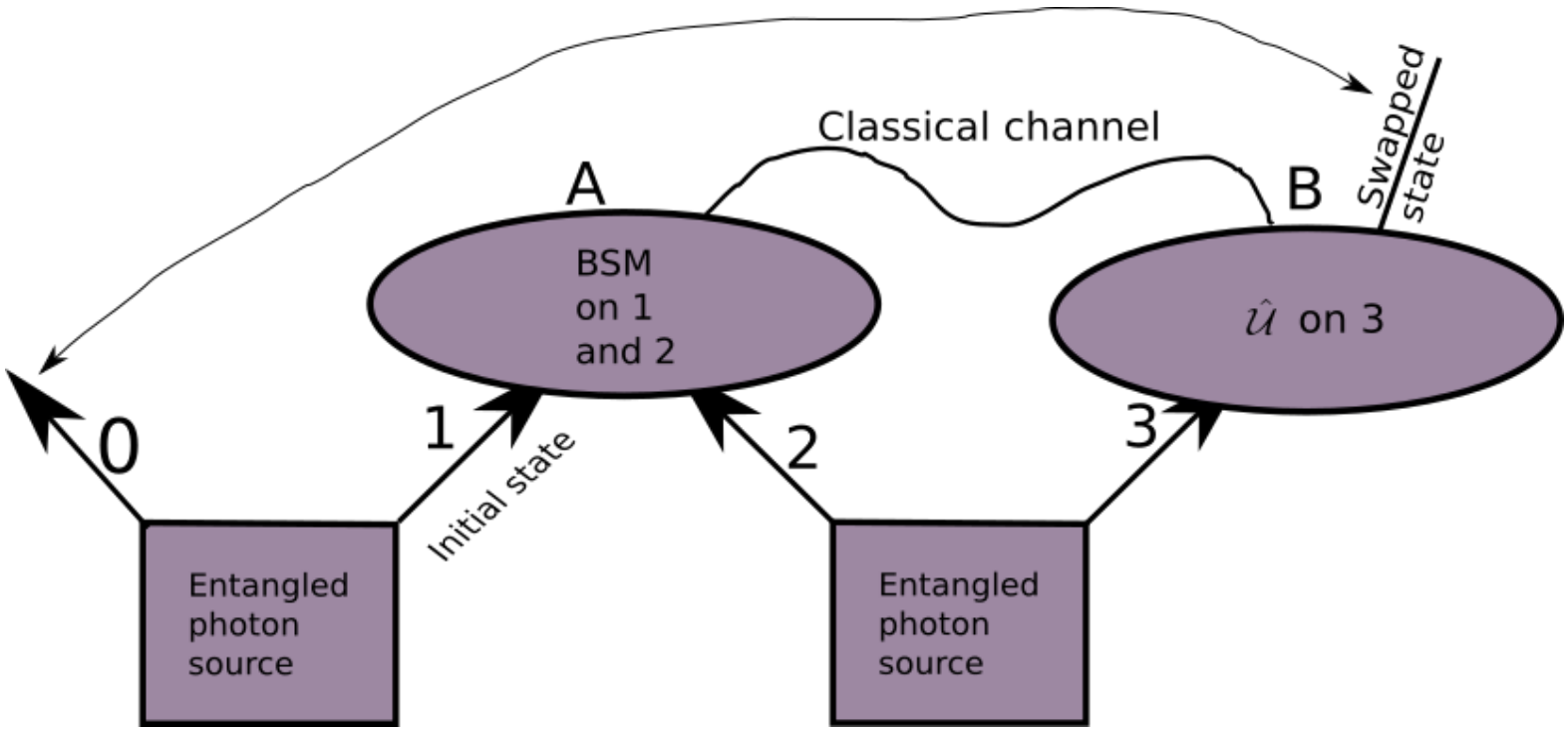


Illustration of Entanglement Swapping.



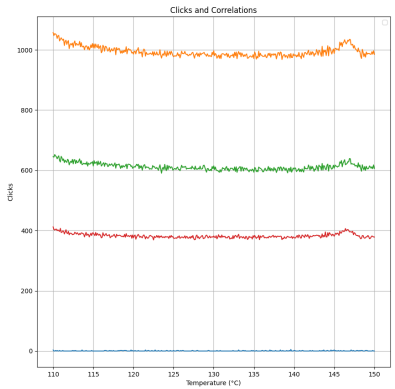
- Focusing parameters [10]

$$\xi = \frac{L}{kw^2} \tag{2}$$

- Heralding

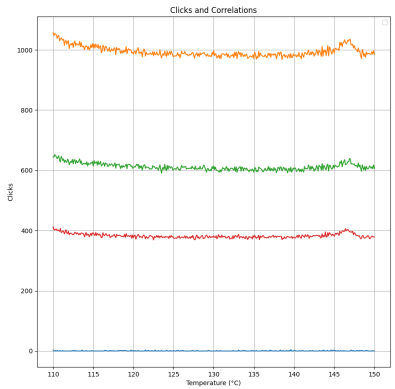
Temperature scans of Type-0 crystals with different polling periods, a) misaligned 19,25 μm, b) 19,25 μm, c) 19,45 μm, d) 19,65 μm

Temperature scans of Type-0 crystals with different polling periods, a) misaligned 19,25 μm, b) 19,25 μm, c) 19,45 μm, d) 19,65 μm

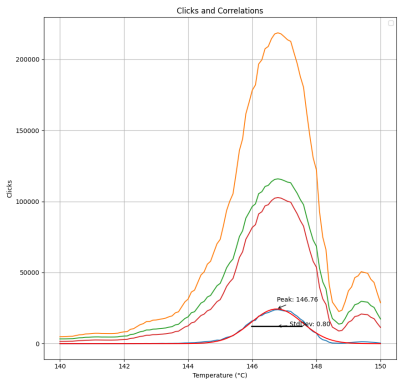


(a)

Temperature scans of Type-0 crystals with different polling periods, a) misaligned 19,25 μm, b) 19,25 μm, c) 19,45 μm, d) 19,65 μm



(a)



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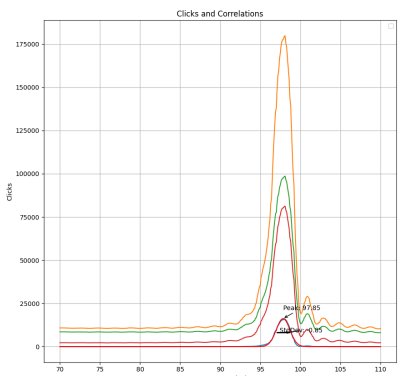

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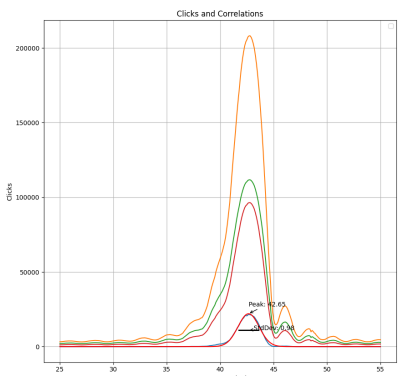
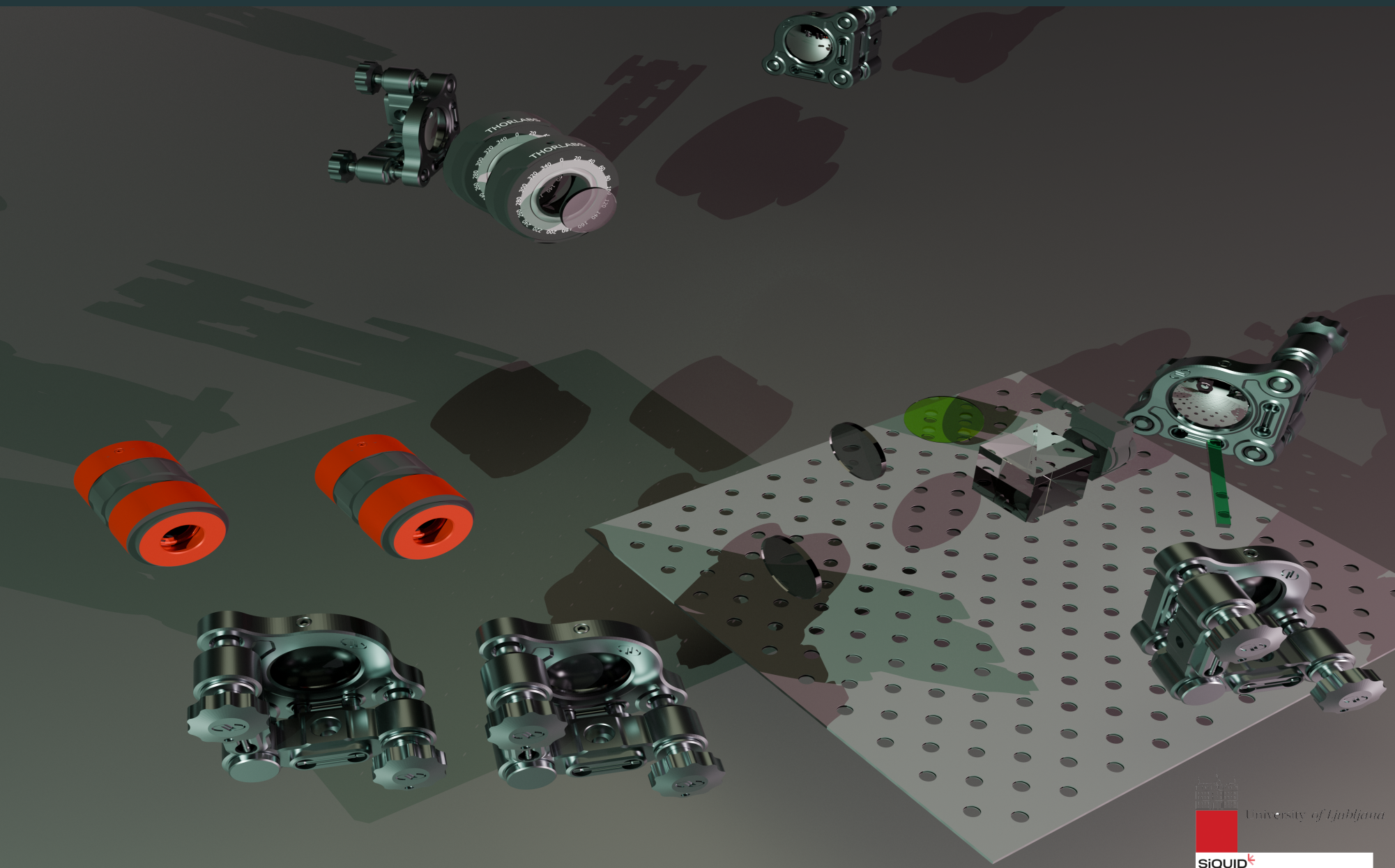


(d)

Present state

Building a Sagnac Interferometer



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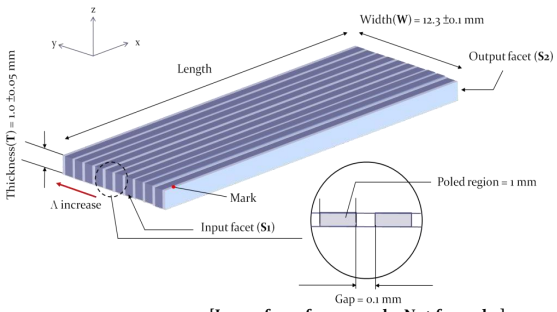
HCP
HC PHOTONICS CORP.

Periodically Poled Lithium Niobate (PPLN) Chip: SHNIR-MF

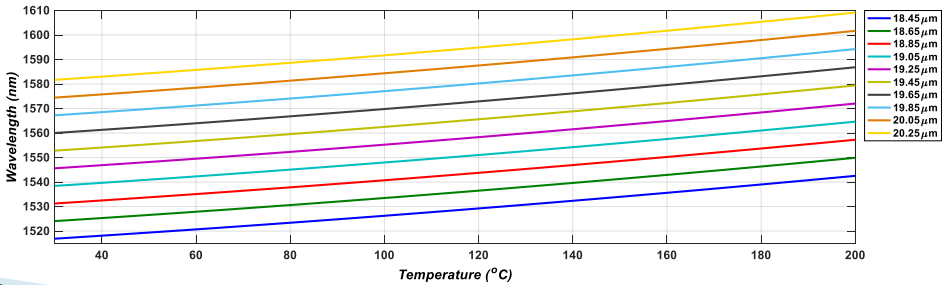
- Chip Lay-Out



[Image for reference only. Not for scale.]

Items	Properties	Inspection
Material	5 mol.% MgO:LN	NA
Period (**Λ**,μm)	18.45, 18.65, 18.85, 19.05, 19.25, 19.45, 19.65, 19.85, 20.05, 20.25	Microscope
Main Function	Second Harmonic Generation	NA
Parallelism/Perpendicularity	≤5'/21'	Autocollimator
Flatness	≤λ/6 (λ=633nm)	Interferometer
Scratch/Dig	≤20/10	Microscope
Optical coating (S1/S2 facets)	S1/S2 @750-810(R<0.5%) /1500-1620(R<0.5%) nm	Spectral Analyzer
Aperture Size	12.3 x 1.0 mm² (**W** x **T**)	Cutting Machine
Available Length	10/25/50 ± 0.2 mm	
Channel Clear Aperture	≥80% (**T**), ≥90% (**W**)	NA

- Phase Matching Tuning Curve



Version: Jan., 2021

service@hcphotonics.com| www.hcphotonics.com | T: +886-3-6662123 | 4F., No. 2, Technology Road V., Hsinchu City 300, Taiwan

Specifications from the crystal manufacturer.

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Outlook

- SiQUID
- Entanglement swapping between FMF and IJS
- Building quantum internet
- Free space link to reactor

Thank you

References


S. P. Neumann, M. Selimovic, M. Bohmann, and R. Ursin, "Experimental entanglement generation for quantum key distribution beyond 1 Gbit/s," *Quantum*, vol. 6, p. 822, Sep. 2022.


H. D. F. A. e. a. Hübel, H., "Direct generation of photon triplets using cascaded photon-pair sources," *Nature 466, 601–603 (2010).*


A. P. T. J. A. Z. A. Fedrizzi, T. Herbst, "A wavelength-tunable fiber-coupled source of narrowband entangled photons," *Opt. Express 15, 15377-15386 (2007).*


M. F. T. Kim and F. N. C. Wong, "Phase-stable source of polarization-entangled photons using a polarization sagnac interferometer," *Optica Publishing Group, (2006), paper JTuH5.*


M. J. H. W. D. P. T. J. R. U. J. R. M. W. M. J. P. T. H. W. V. P. F. Steinlechner, P. Trojek, "A high-brightness source of polarization-entangled photons optimized for applications in free space," *Opt. Express 20, 9640-9649 (2012).*


M. C. Sang Min Lee, Heonoh Kim and H. S. Moon, *Opt. Express 24, 2941-2953 (2016).*


G. K. S. M. V. Jabir, "Robust, high brightness, degenerate entangled photon source at room temperature," *Sci Rep 7, 12613 (2017).*


Y. Chen, S. Ecker, S. Wengerowsky, L. Bulla, S. K. Joshi, F. Steinlechner, and R. Ursin, "Polarization entanglement by time-reversed hong-ou-mandel interference," *Physical Review Letters*, vol. 121, no. 20, Nov. 2018.


E. Bocquillon, C. Couteau, M. Razavi, R. Laflamme, and G. Weihs, "Coherence measures for heralded single-photon sources," *Physical Review A*, vol. 79, no. 3, Mar. 2009.


R. S. Bennink, "Optimal collinear gaussian beams for spontaneous parametric down-conversion," *Phys. rev. A 81, 053805 (2010).*