Generating and teleporting entanglement for quantum networks

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Contents and introduction

Motivation

- SiQUID
  1. Training in quantum technologies in Slovenia
  2. Entanglement based Quantum Key Distribution (QKD)
- Bright source of entanglement
- Testbed for industrialized version

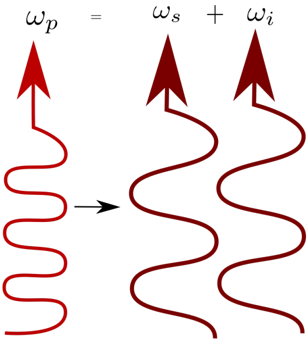
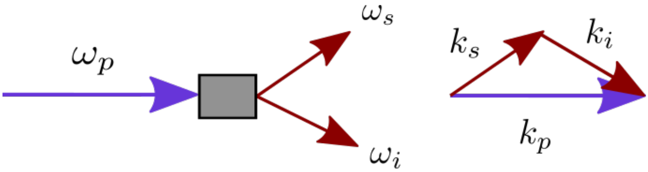


Illustration of SPDC

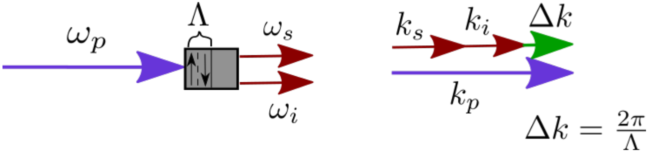
- Degenerate $\omega_i = \omega_s$
- Non-degenerate $\omega_i \neq \omega_s$

What is Phase Matching?

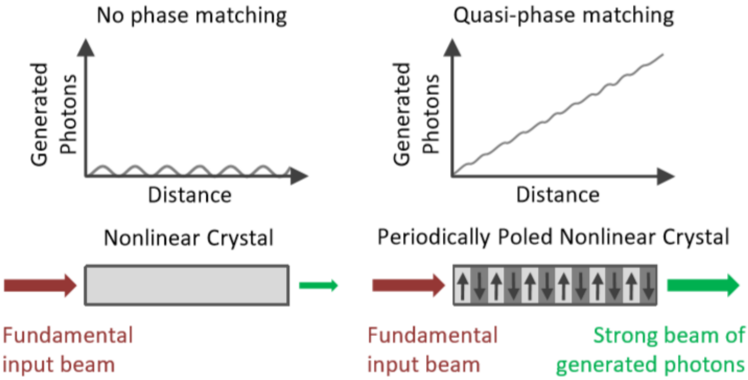
Illustration of Birifringent Phase Matching $k_p - k_i - k_s = 0$ and



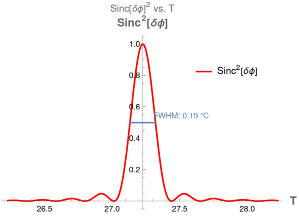
Quasi Phase Matching $k_p - k_i - k_s - \Delta k = 0$.



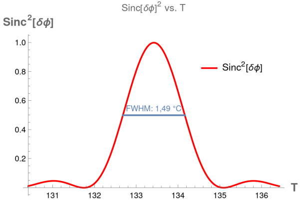
Difference in photon generation between a unpoled and poled crystal.
Source: RP-Photonics



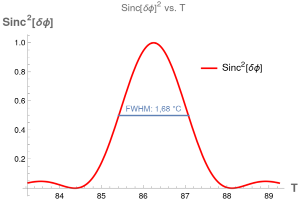
Phase Matching Temperature calculatios for a) Type-2 crystal of 9,12 μm poling period, b) Type-0, 19,25 μm, c) Type-0, 19,45 μm, d), Type-0 19,65 μm



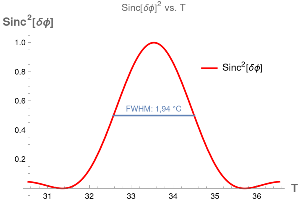
(a)



(b)



(c)



(d)

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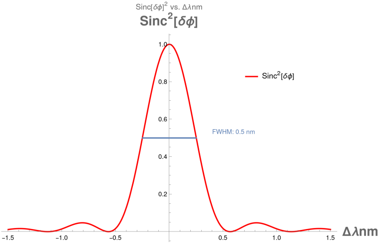
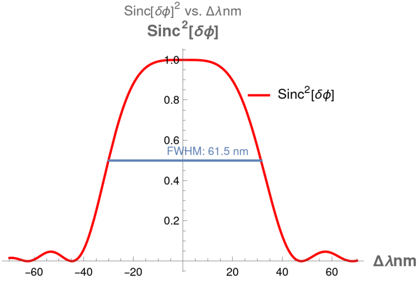
Wavelength bandwidth of a) Type-2 crystal with a poling period of 9,12 μm b) Type-0 crystals with poling periods of 19,25 μm



(a)

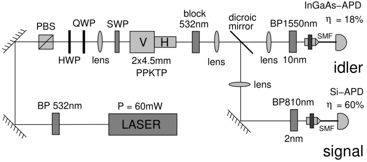


(b)

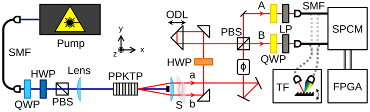
Comparison of different sources

Who When	[1] 2022	[2] 2012	[3] 2007	[4] 2006	[5] 2010
Type	0	0	II	II	II
Brightness [$\frac{\text{Hz}}{\text{mW nm}}$]	$2{,}5\times10^6$	$0{,}278\times10^6$	$0{,}273\times10^6$	0.005×10^6	0.087×10^6
Bandwidth [nm]	106	2,3	0,3	1	0,3

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



(a)



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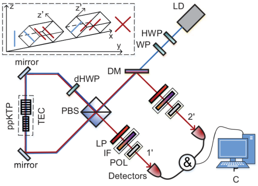

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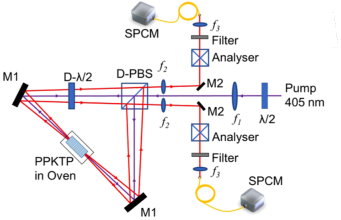


(d)

Why do we care about entanglement?

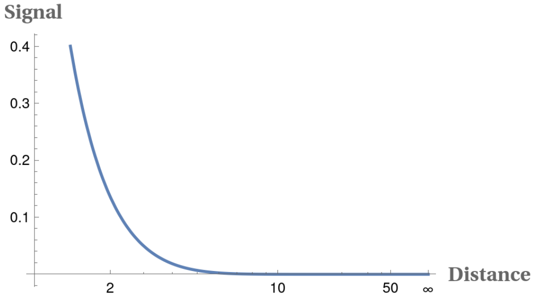
- Entanglement sources by themselves → usless if you can't use them.
- Loss in fiber

Relevant fiber loss.
Source: Thorlabs

λ [nm]	1310	1550
Loss [dB/km]	0.32	0.18

Example: Loss in fiber for 1550/1560 nm

200 km of fiber $\rightarrow 10^4$ loss.



Loss in fiber over distance.

- 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
- Government buildings in Ljubljana

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

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

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

Illustration of Entanglement Teleportation.

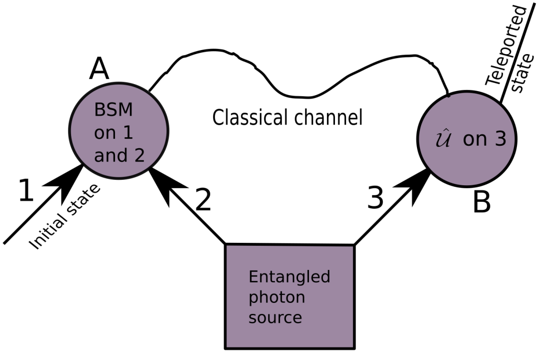
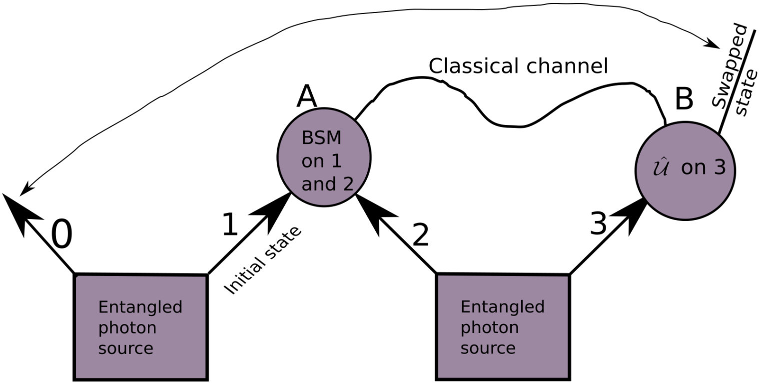


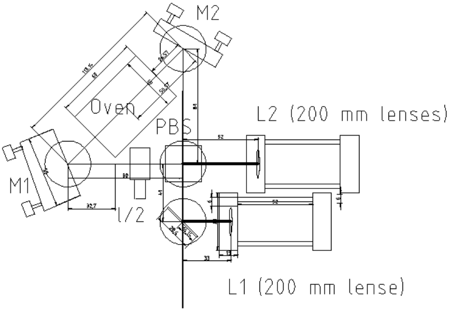
Illustration of Entanglement Swapping.



- Focusing parameters [10]

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

- Correct lenses and distances for efficient coupling
- Correct size of coupler aperture



Design of the Sagnac interferometer.

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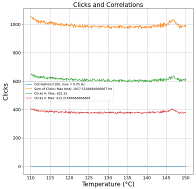
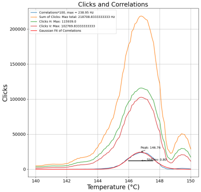
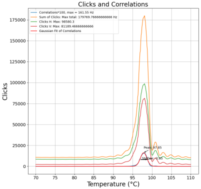
Temperature scans of Type-0 crystals with different poling periods, a) misaligned 19,25 μm, b) 19,25 μm, c) 19,45 μm, d) 19,65 μm



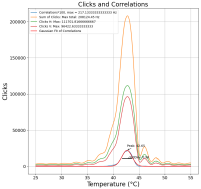
(a)



(b)



(c)



(d)

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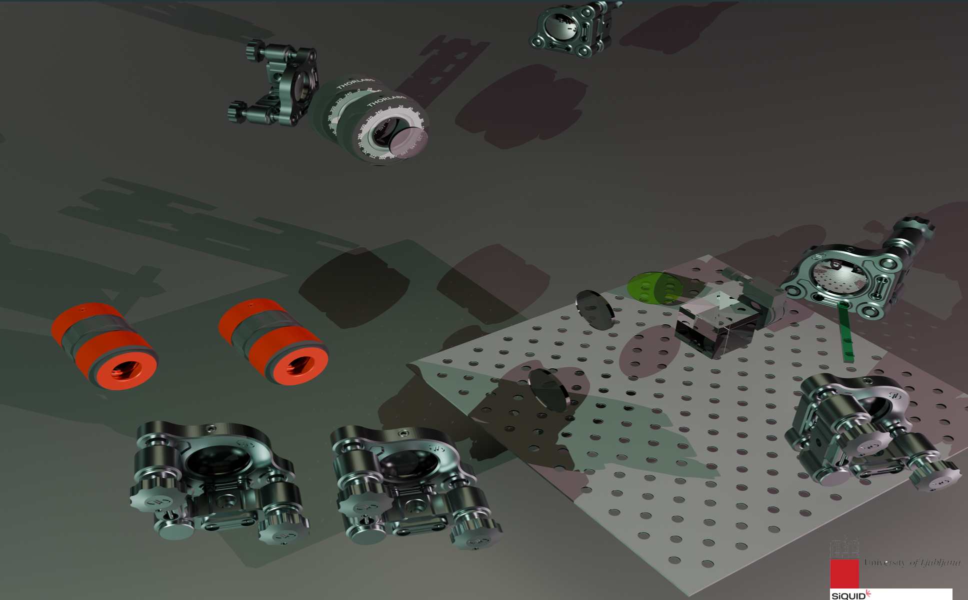
Present state

Building a Sagnac Interferometer



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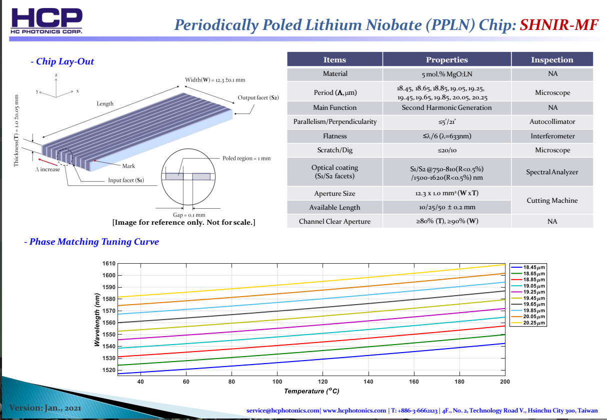

HCP
HC PHOTONICS CORP.

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.
Source: HC Photonics Corp.

Current brightness estimation [$\frac{\text{Hz}}{\text{mWnm}}$]

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]		
0,81	0,81	0,81

Outlook

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

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