Generating and teleporting entanglement for quantum networks

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SiQUID
Slovenian Quantum Communication Infrastructure Demonstration

Contents and introduction

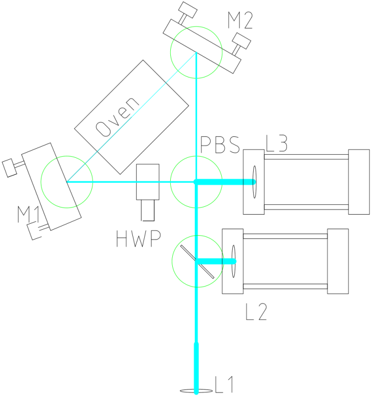
Motivation

- SiQUID
  0. Proof of concept
  1. Entanglement distribution
  2. Entanglement based Quantum Key Distribution (QKD)
  3. Training in quantum technologies in Slovenia
  4. Testbed for industrialized version

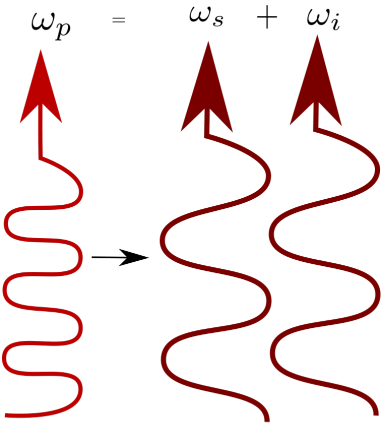
Example of Slovenian Quantum Network.

Motivation

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



An example of a Sagnac Interferometer.



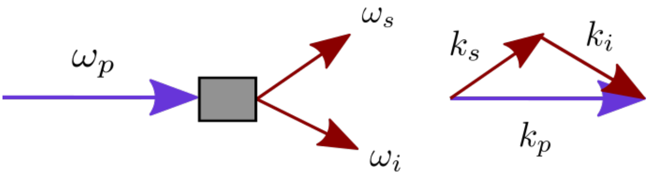
$\Delta\omega = \omega_p - \omega_s - \omega_i$

Illustration of SPDC

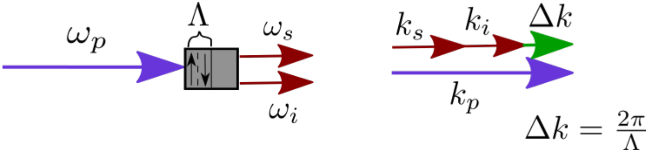
- Degenerate $\omega_i = \omega_s$
- Non-degenerate $\omega_i \neq \omega_s$

What is Phase Matching?

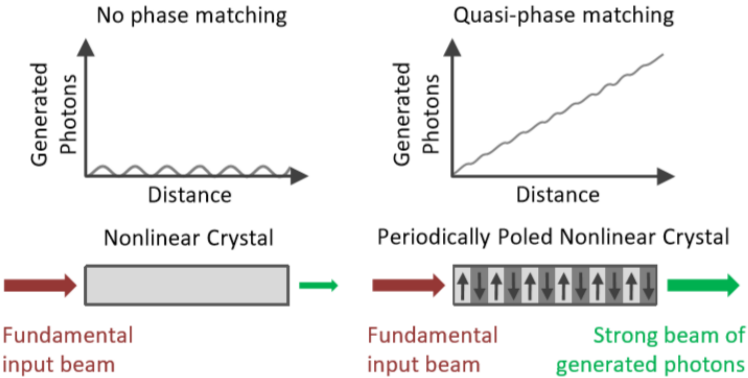
Illustration of Birifringent Phase Matching $k_p - k_i - k_s = 0$ and



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



Difference in photon generation between a unpoled and poled crystal.
Source: Covesion.



- Type-0 : o → o + o
- Type-I : o → e + e
- Type-II : e → e + o

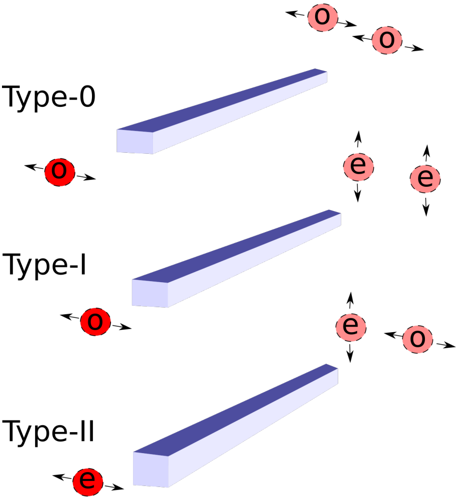
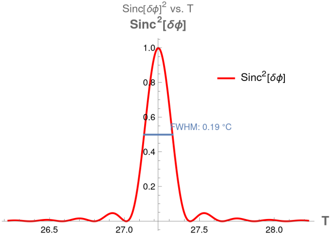
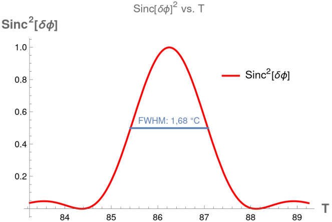


Illustration of different types of polarization conversions.

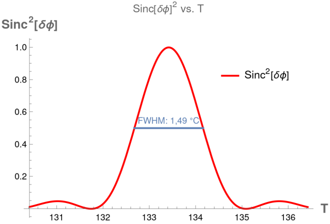
Phase Matching Temperature for Type-II crystal of 9,12 μm poling period, $\delta\phi = \frac{L\Delta k}{2}$

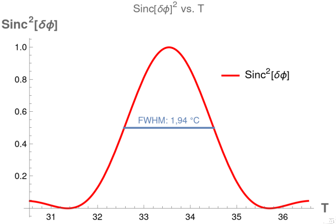




19,45 μm,

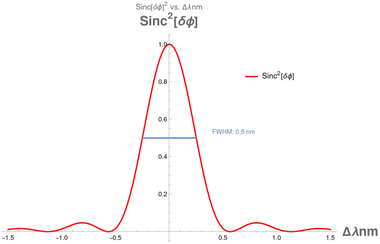
Type-0, 19,25 μm,



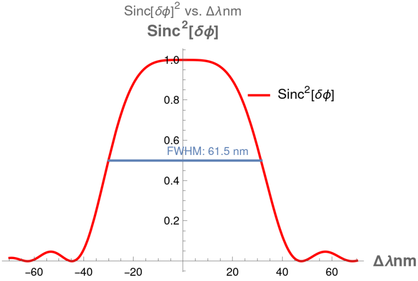


19,65 μm.

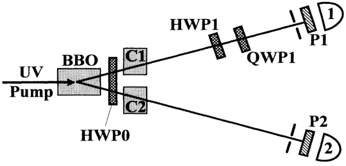
Wavelength bandwidth of a) Type-2 crystal with a poling period of 9,12 μm
b) Type-0 crystals with poling periods of 19,25 μm



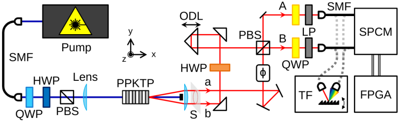
(a)



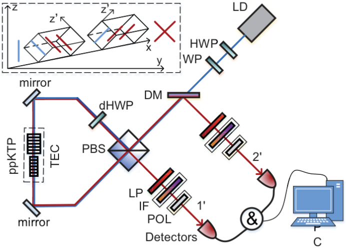
(b)



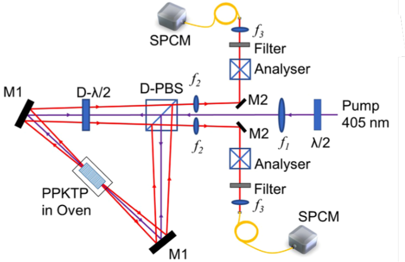
Phys. Rev. Lett. 75, 4337 [1].



Opt. Express 24, 2941-2953 (2016) [3].



Phys. Rev. Lett. 121, 200502 [2].



Sci Rep 7, 12613 (2017) [4].

$$|\Psi_{\text{Type-2}}\rangle = \frac{1}{\sqrt{2}}(a^\dagger_H(\omega_s)a^\dagger_V(\omega_i) + a^\dagger_V(\omega_i)a^\dagger_H(\omega_s))\,|0\rangle$$

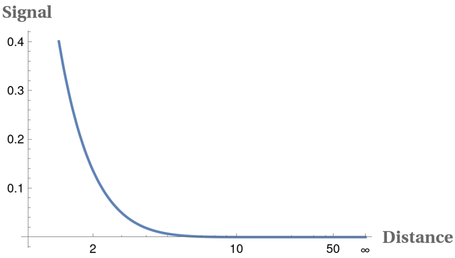
$$|\Psi_{\text{Type-0}}\rangle = \frac{1}{\sqrt{2}}(a^\dagger_H(\omega_s)a^\dagger_H(\omega_i) + a^\dagger_V(\omega_i)a^\dagger_V(\omega_s))\,|0\rangle$$

- FMF/IJS
- Nodes in Ljubljana

- Entanglement source applications:
    1. Distributed Quantum Computation,
    2. Quantum Sensing,
    3. Single Photon Source - Calibration
- Loss in fiber → Entanglement swapping!

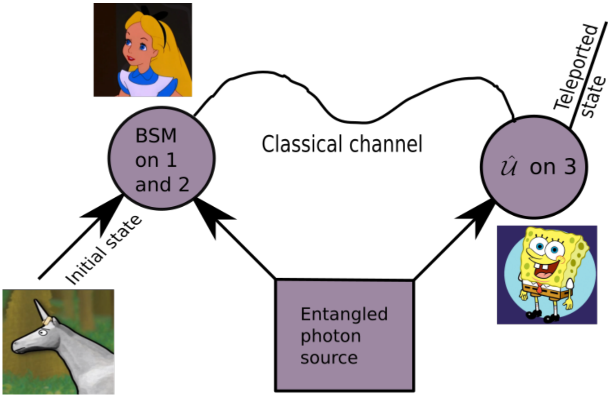
Relevant fiber loss. *Source: Thorlabs*

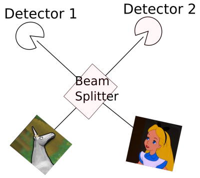
λ [nm]	430	532	780	1310	1550	1900
Loss [dB/km]	50	30	12	0.32	0.18	5



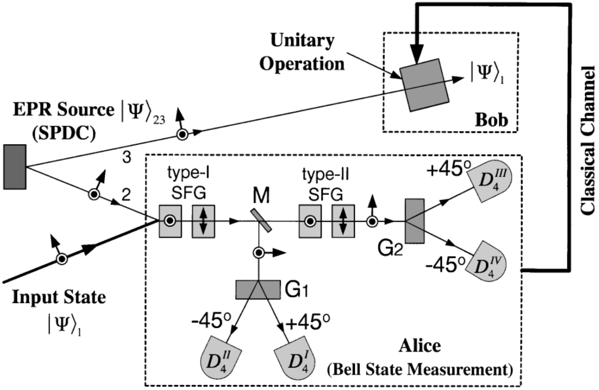
Loss in fiber over distance.

Illustration of Quantum Teleportation: Basis of Entanglement Swapping.





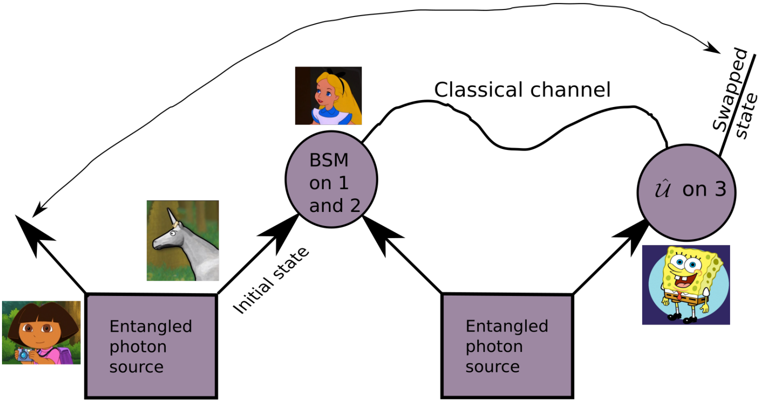
(a)



(b)

The simplest and the complete BSM.

Illustration of Entanglement Swapping: Prerequisite for a Quantum Repeater.



Possible realization of the Slovenian Network

Final user — Relay / Switch (trusted node) — Relay (trusted node - optional) — Quantum ground station

Example of the Slovenian Quantum Network.
Source: https://siquid.fmf.uni-lj.si/.

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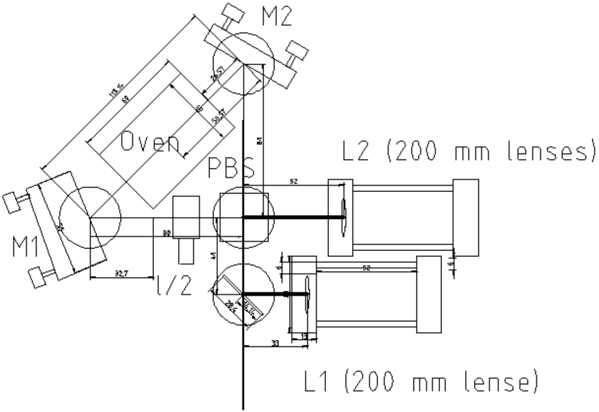
SiQUID
Slovenian Quantum Communication Infrastructure Demonstration

- Focusing parameter [5]

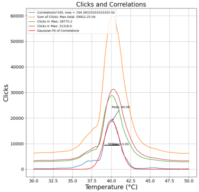
$$\xi = \frac{L}{2z_R} = 2.08$$

- Correct lenses and distances for efficient coupling

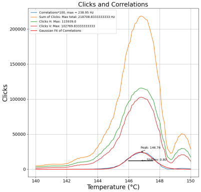


Design of the Sagnac interferometer.

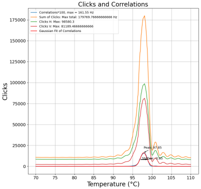
Temperature scans of Type-II and Type-0 crystal with different poling periods, a) Type-II, 9,12 μm, b) 19,25 μm, c) 19,45 μm, d) 19,65 μm



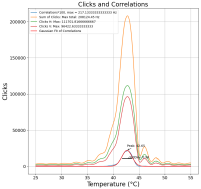
(a)



(b)



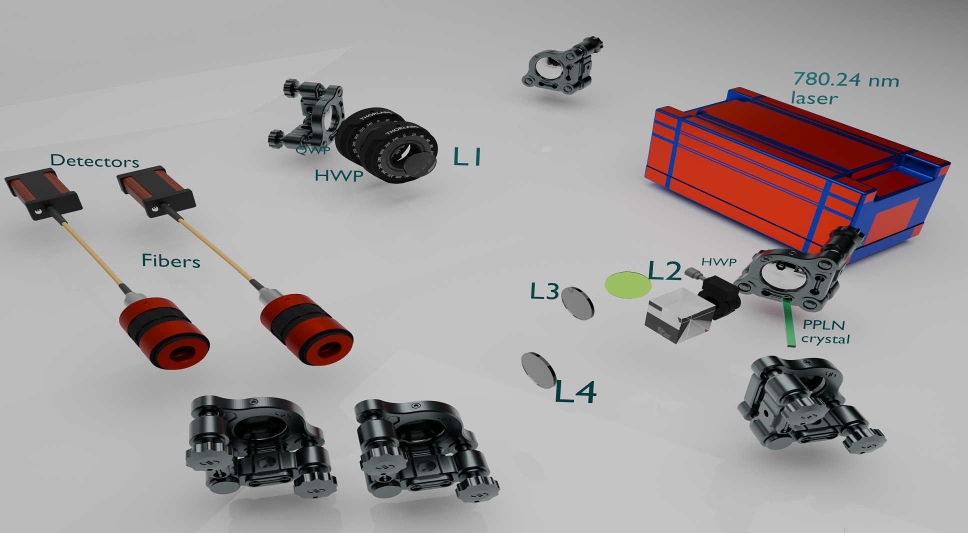
(c)



(d)

Present state

Building a Sagnac Interferometer



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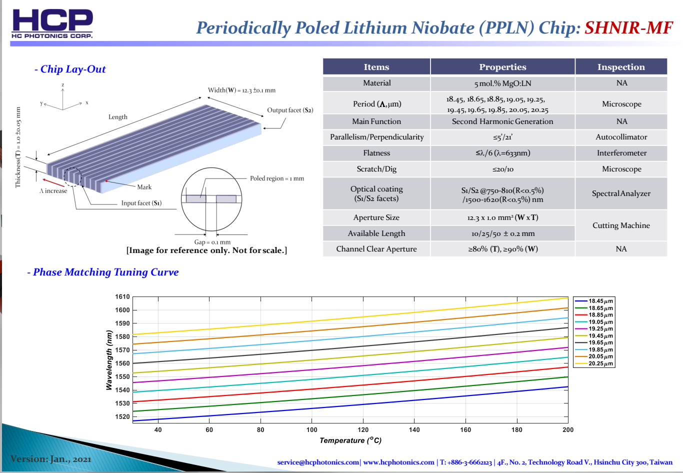

HCP
HC PHOTONICS CORP.

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	Cutting Machine
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.

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SiQUID Slovenian Quantum Communication Infrastructure Demonstration

Outlook

- Complete the source
- Bell State Measurements
- Entanglement swapping between FMF and IJS
- Free space link to IJS
- Fiber link to reactor
- Use Quantum Memory from IJS group
- SiQUID
  - Building quantum network:
    1. Experimental network
    2. Government network

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

FMF		**IJS**
Type-II	**Type-0**	**Type-II**
$7{,}8 \times 10^{6}$ [1]	$2{,}6 \times 10^{7}$ [1]	$0{,}05 \times 10^{6}$ [2]
Bandwidth [nm]		
0,81	0,81	0,81

[1] Linear setup
[2] Sagnac interferometer

Comparison of different sources

Who When	[6] 2022	[7] 2012	[8] 2007	[9] 2006	[10] 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