Generating and teleporting entanglement for quantum networks

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Sagnac

23.05.2024, Ljubljana, Slovenia

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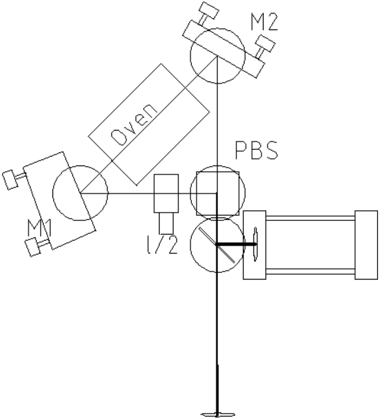
SiQUID
Slovenian Quantum Communication Infrastructure Demonstration

Contents and introduction

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



An example of a Sagnac Interferometer.

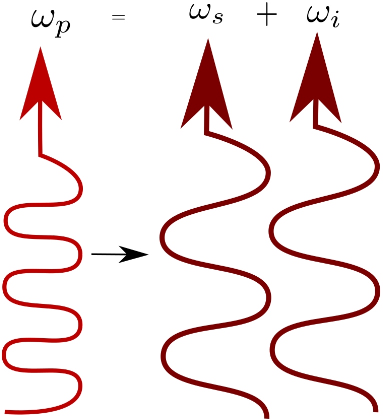
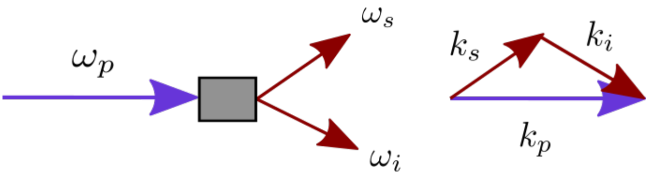


Illustration of SPDC

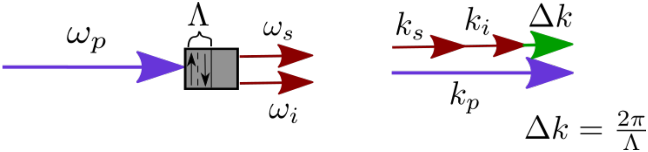
- Degenerate $\omega_i = \omega_s$
- Non-degenerate $\omega_i \neq \omega_s$

What is Phase Matching?

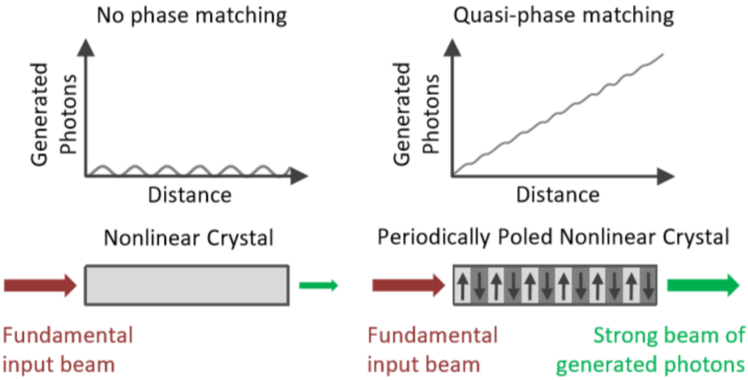
Illustration of Birifringent Phase Matching $k_p - k_i - k_s = 0$ and



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



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

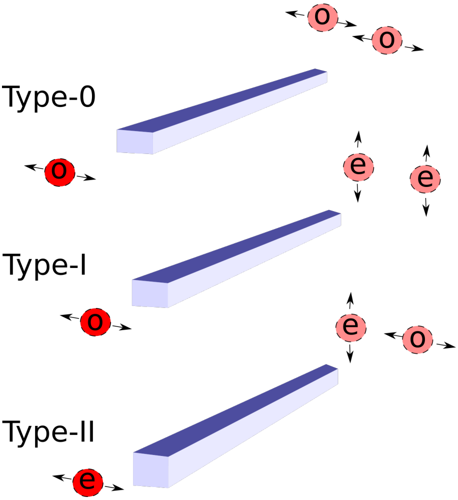
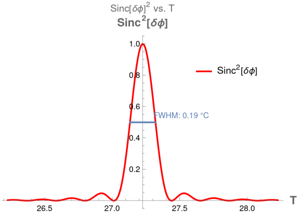
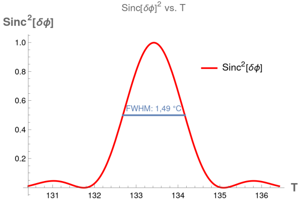


Illustration of different types of polarization conversions.

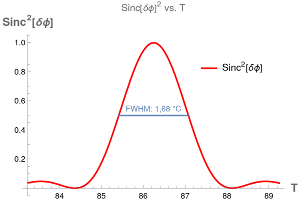
Phase Matching Temperature plots for a) Type-2 crystal of 9,12 μm poling period, b) Type-0, 19,25 μm, c) Type-0, 19,45 μm, d), Type-0 19,65 μm



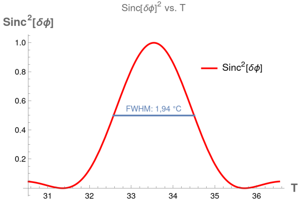
(a)



(b)

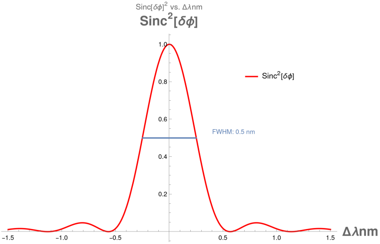


(c)

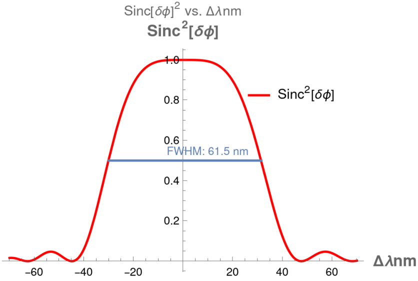


(d)

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)

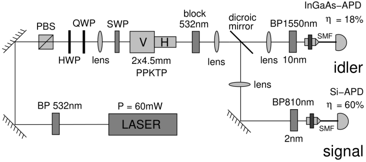


(b)

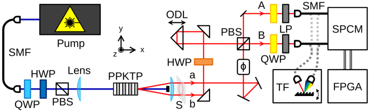
Comparison of different sources

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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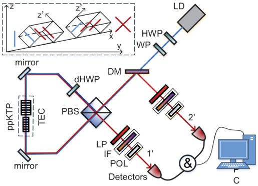
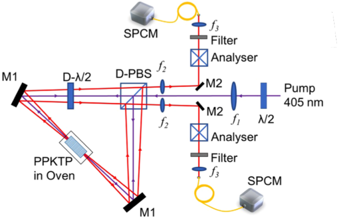


(c)



(d)

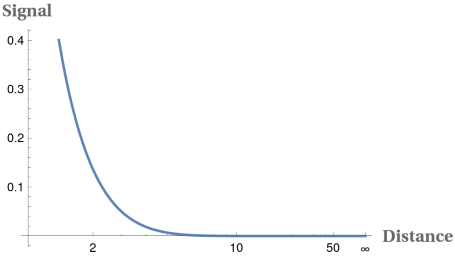
Entanglement

What is it good for?

- Entanglement source applications:
  1. Distributed Quantum Computation - Send a state then receive a result on the entangled pair,
  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.

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

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

- FMF/IJS
- Nodes in Ljubljana

Illustration of Entanglement Teleportation.

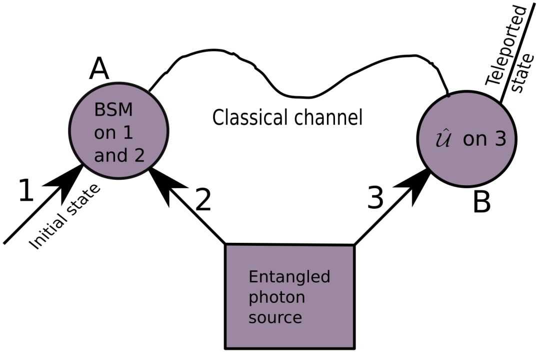
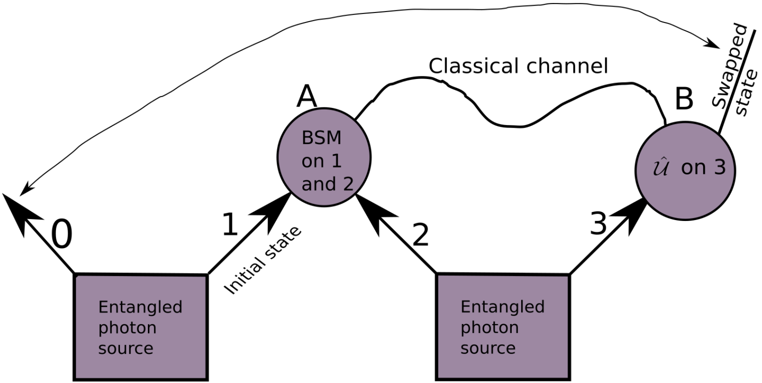


Illustration of Entanglement Swapping: Prerequisite for a Quantum Repeater.



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

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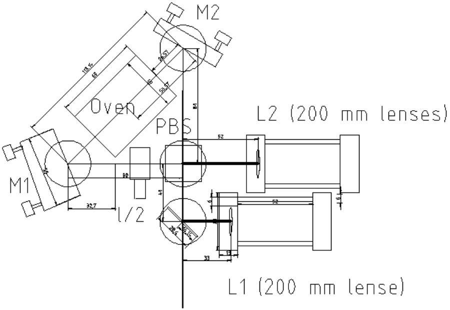
SiQUID
Slovenian Quantum Communication Infrastructure Demonstration

- Focusing parameters [10]

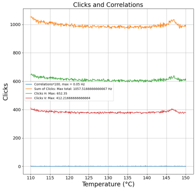
$$\xi = \frac{L}{2z_R} = 2.08$$

- Correct lenses and distances for efficient coupling

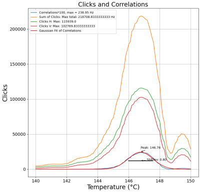


Design of the Sagnac interferometer.

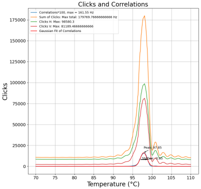
Temperature scans of Type-0 crystals with different poling periods, a) misaligned 19,25 μm, b) 19,25 μm, c) 19,45 μm, d) 19,65 μm



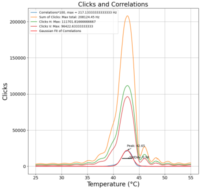
(a)



(b)



(c)



(d)

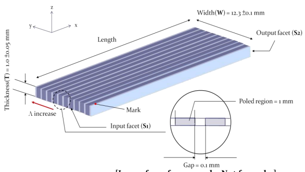
SagnacWithSomeAddedColoursV3.png

SagnacWithSo

HCP
HC PHOTONICS CORP.

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

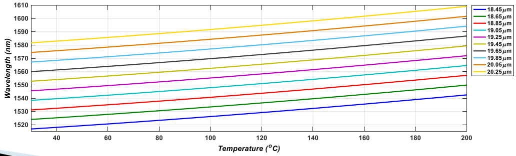
- Chip Lay-Out



[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



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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

Outlook

- Build the source
- Bell State Measurements (CHSH)
- 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 and
    2. Government network

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