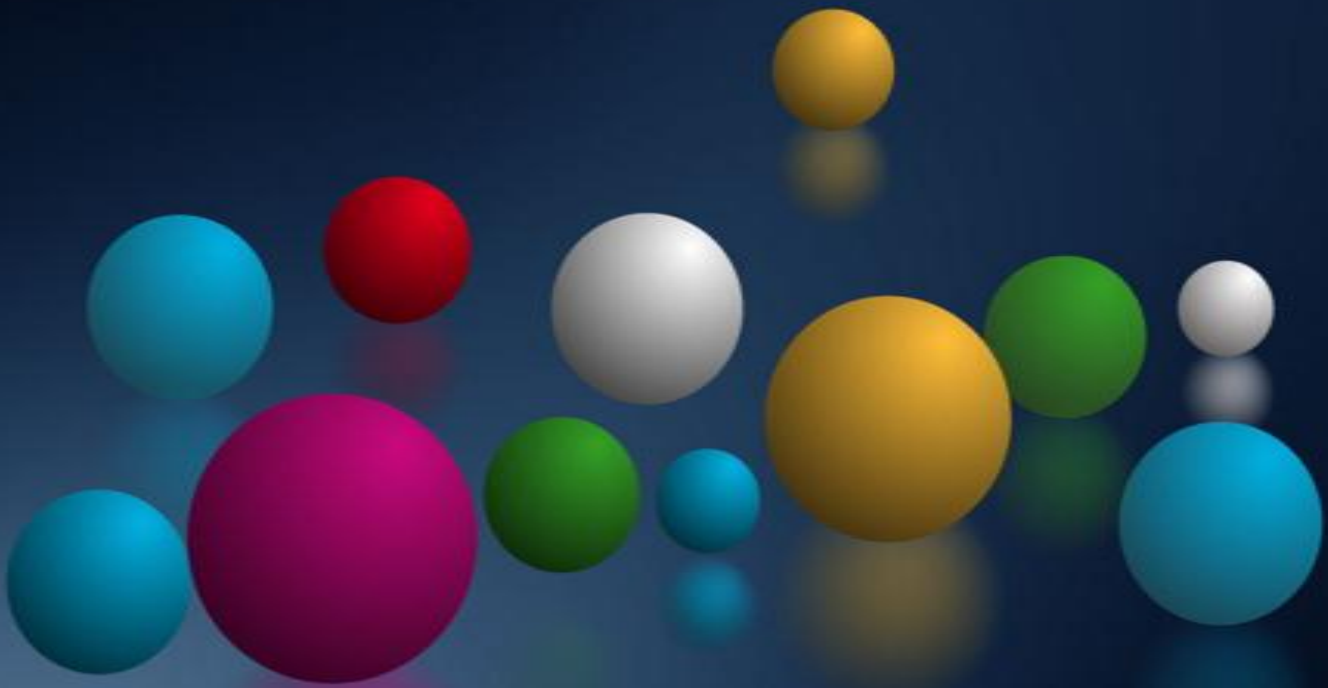
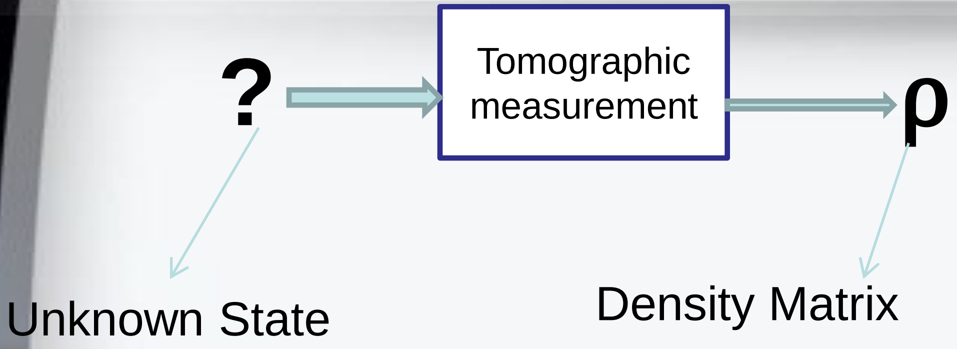
Quantum State Tomography

Ali Akbar



What is quantum tomography?



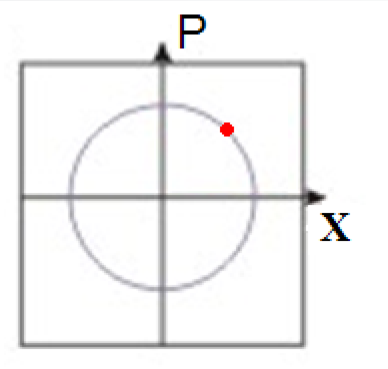
?

Tomographic measurement

ρ

Unknown State

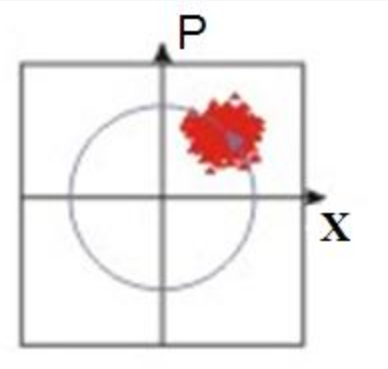
Density Matrix



Harmonic Oscillator

Classical Analogy

Consider a classical harmonic oscillator whose motion can be specified by phase space

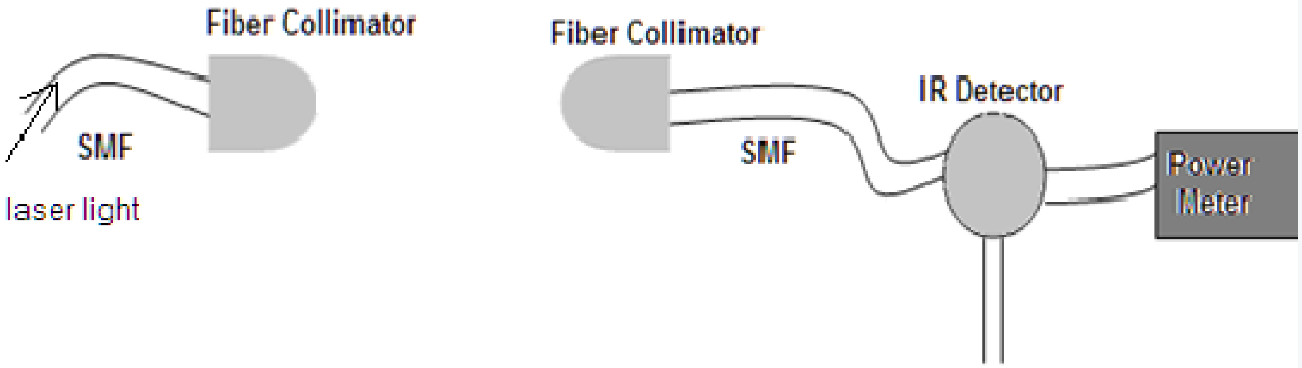


Outlines

- Coupling of light from single moded fiber to SMF through air as a medium between them.
- Polarization control of light
- Generation of entangled photons
- Hong Ou mandel Interference
- Two Qubit tomography

To achieve more than 80% coupling efficiency using fiber laser $\lambda = 1584\mathrm{nm}$

- $\eta = P_{out}/P_{in} = 90\%$
- There is a loss of 4% from air to fiber or fiber to air.

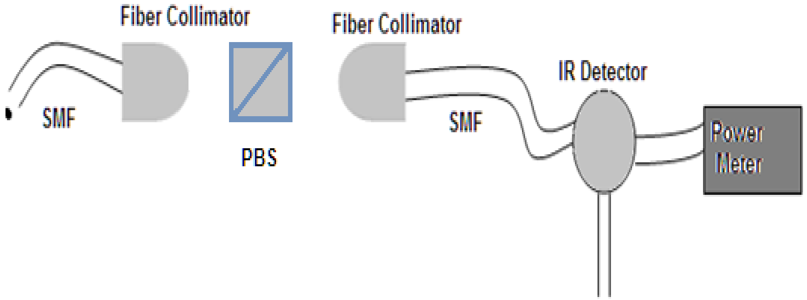


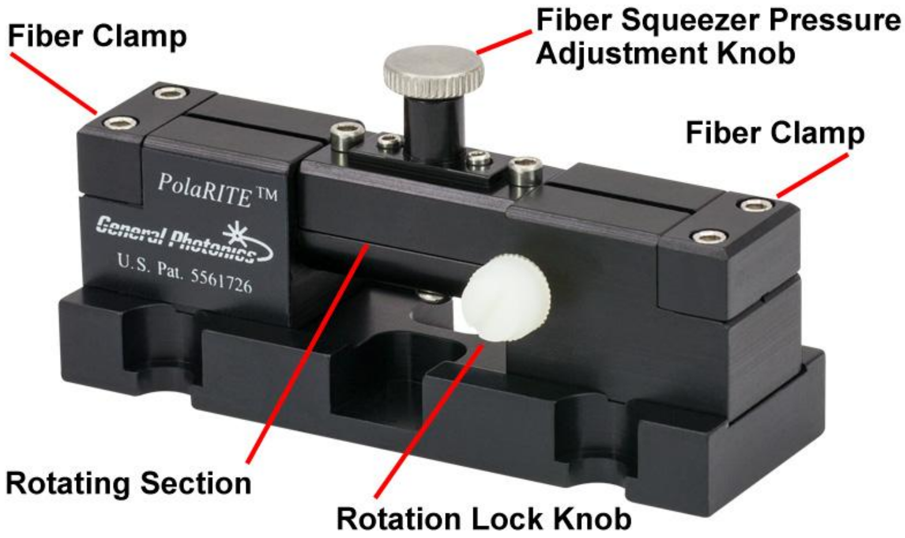
Coupling scheme for laser light From SMF to SMF.

Polarization control of Light

Any arbitrary input polarization state to be converted to any desired output polarization state.

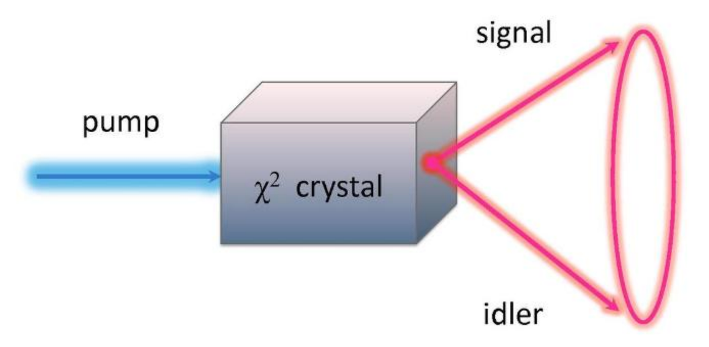
It creates stress-induced birefringence within the fiber by mechanically compressing a cross-sectional axis of the fiber. This creates a variable, rotatable wave plate





Generation of Entangled Photons by SPDC

Spontaneous parametric down conversion is a non linear optical process.



SPDC is in accordance with

Law of conservation of energy and

momentum

$$\omega_p = \omega_s + \omega_i$$

Phase matching condition; $k_p = k_s + k_i$

Type-I parallel Polarization

Type-II Orthogonal polarization

Type-II SPDC

- PPKTP-
- periodically poled potassium titanyl phosphate
- Biaxial crystal; two extraordinary axis
- Ti:sapphire Mode Lock Laser

Pump beam λ=(792nm ± 0.200)nm

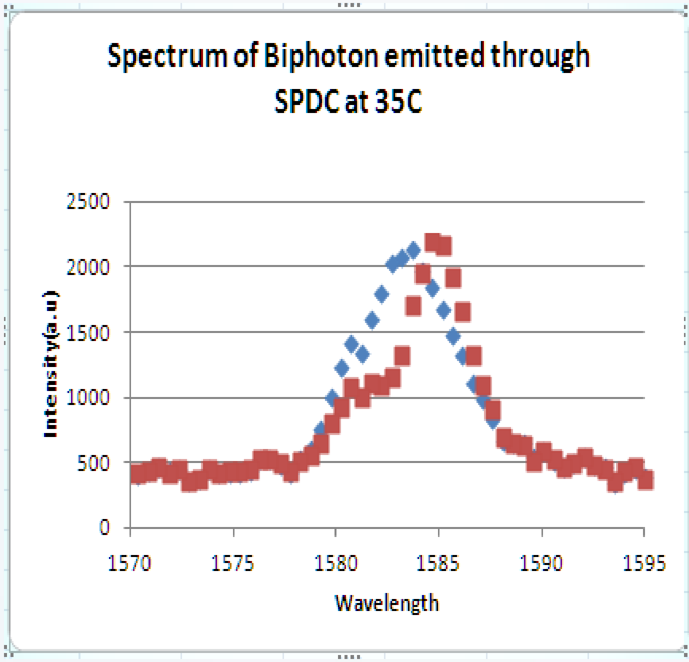
pump beam Power = 200mW

Generated collinear frequency entangled photons by extended phase matching condition

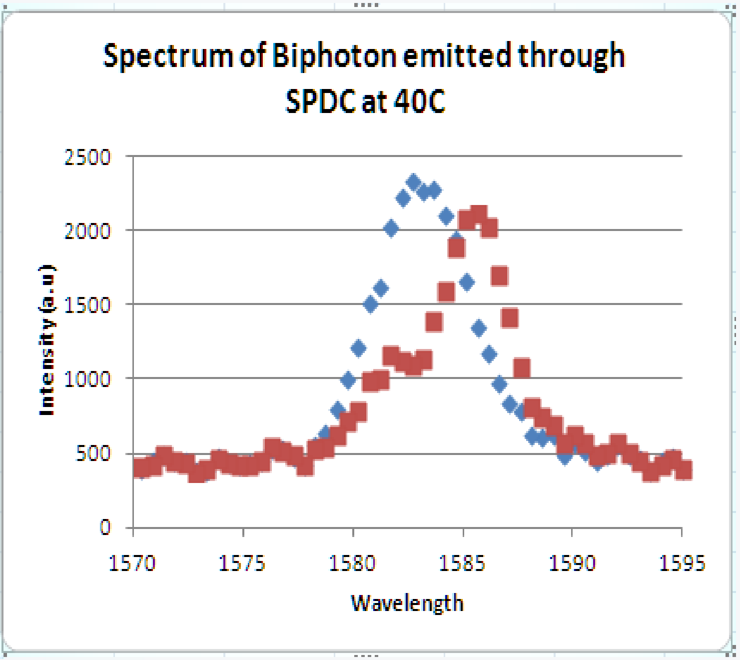
$$k'_p(\omega_p) = \frac{k'_s(\frac{\omega_p}{2}) + k'_i(\frac{\omega_p}{2})}{2}$$

Generated Photon Spectra with crystal temperature

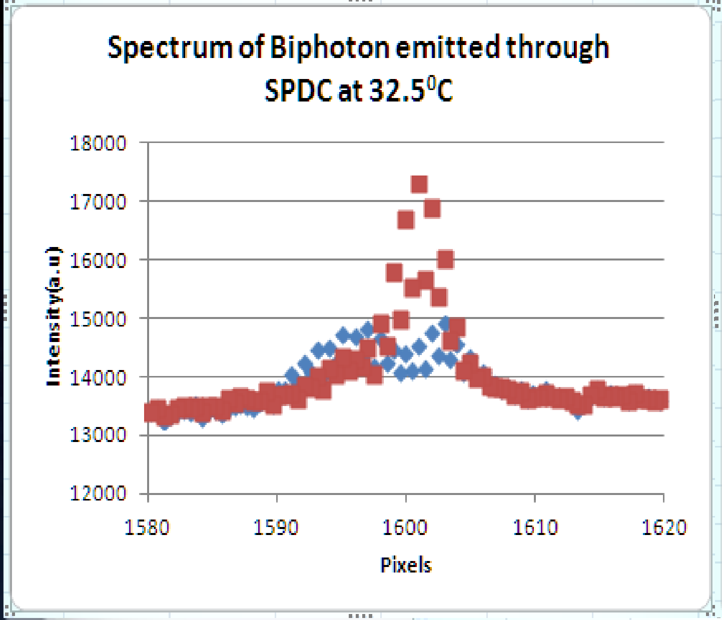
- The degeneracy of generated photon spectrum is very sensitive to crystal temperature.
- Spectral distinguishability between the constituent photons results in the degradation of entanglement.

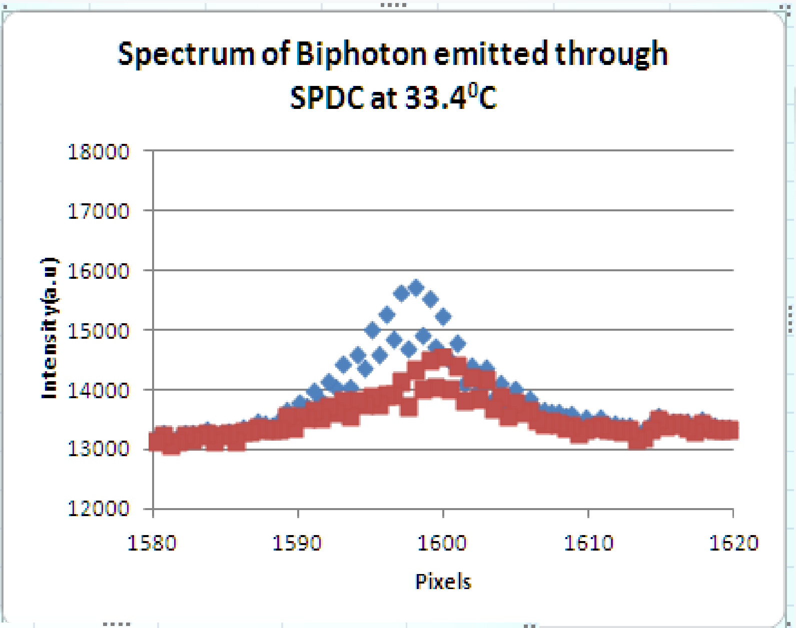


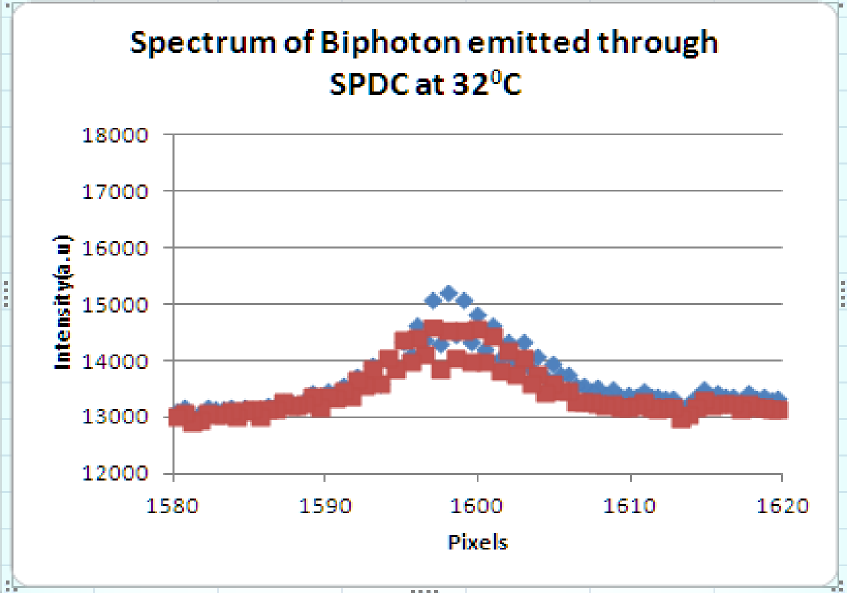
Spectrum of Biphoton emitted through SPDC at 35C



Spectrum of Biphoton emitted through SPDC at 40C

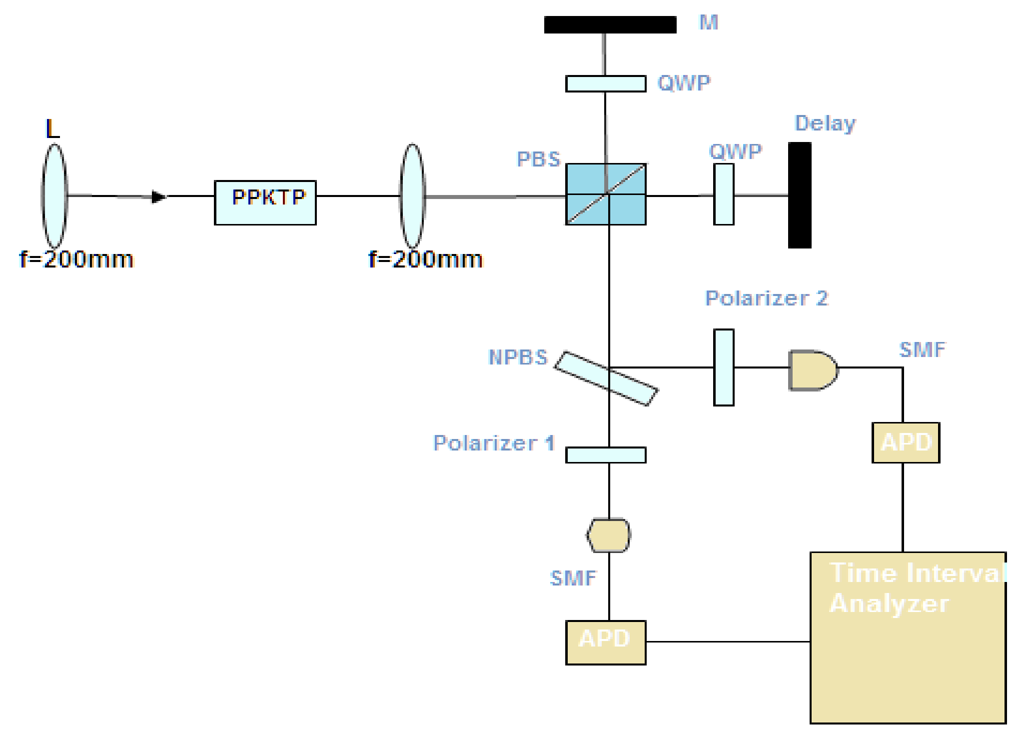

Spectrum of Biphoton emitted through SPDC at 32.5^{0}C


Spectrum of Biphoton emitted through SPDC at 33.4^{0}C

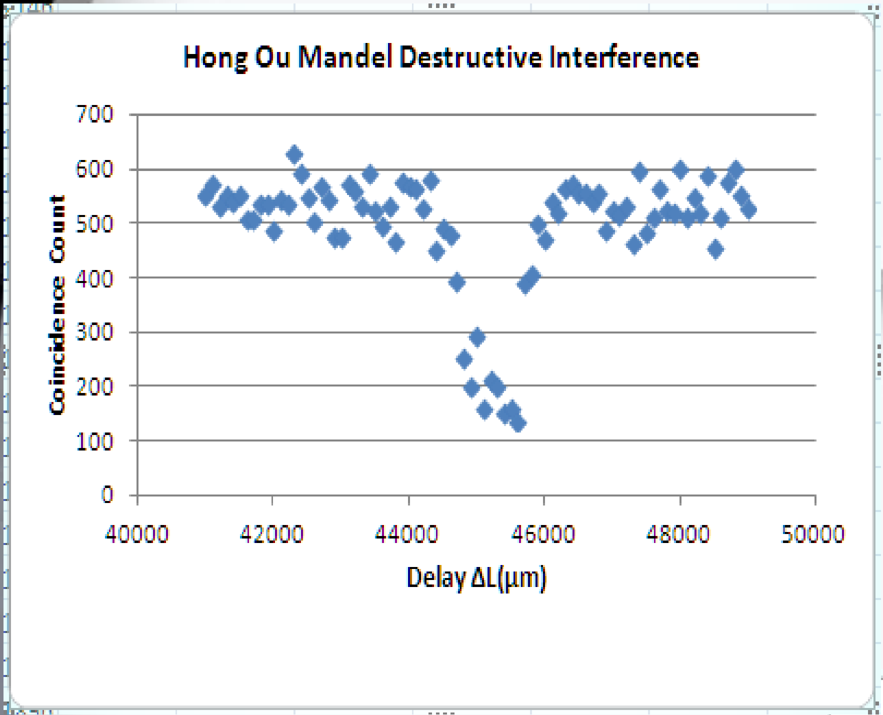

Spectrum of Biphoton emitted through SPDC at 32^{0}C

Hong-Ou Mandel Interference

- The Hong–Ou–Mandel effect can be used to test the degree of indistinguishability of the two incoming photons.
- The coincidence rate of the detectors will drop to zero when the identical input photons overlap perfectly in time.

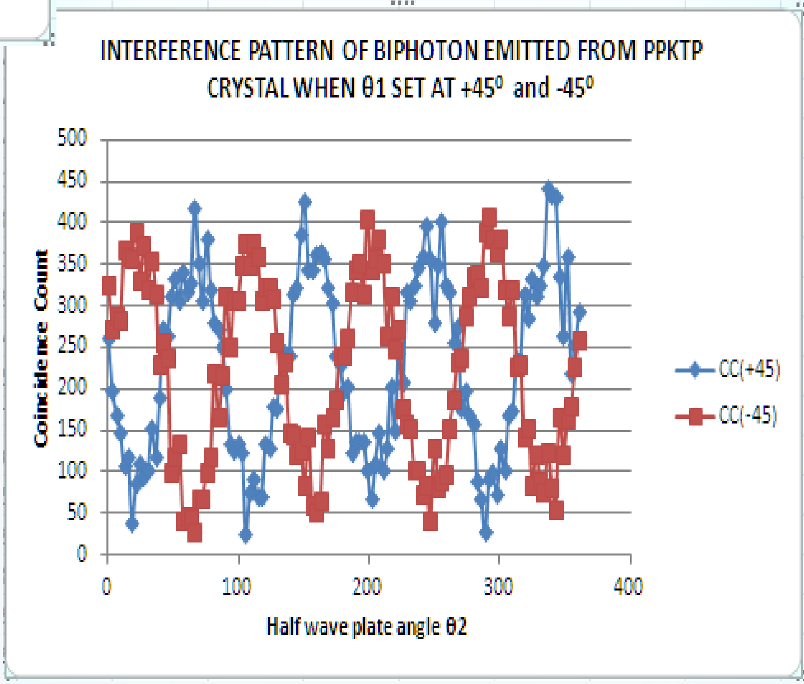


Schematic diagram for observing Hong Ou Mandel interference



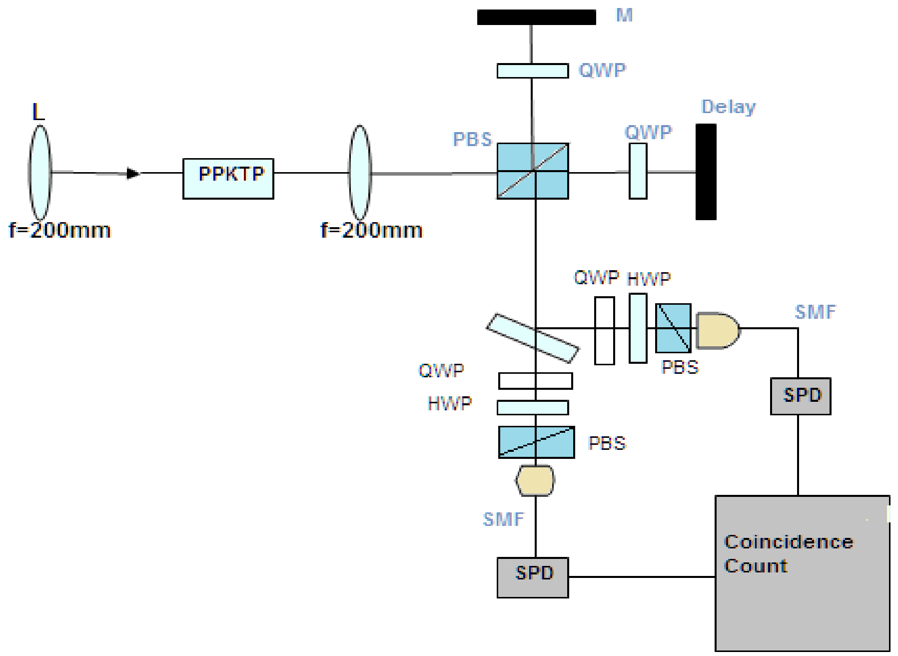
$$\text{Visibility} = \frac{I_{\max} - I_{\min}}{I_{\max}}$$

$$= 75\%$$



Two qubit tomography

- Quantum tomography is the art of determining a quantum state from making measurements on multiple copies of the state.



(i)PBS; polarizing beam splitter, (ii)SPD; single photon detector (iii) PPKTP crystal for the generation of entagled photon through spontaneous parametric down conversion.

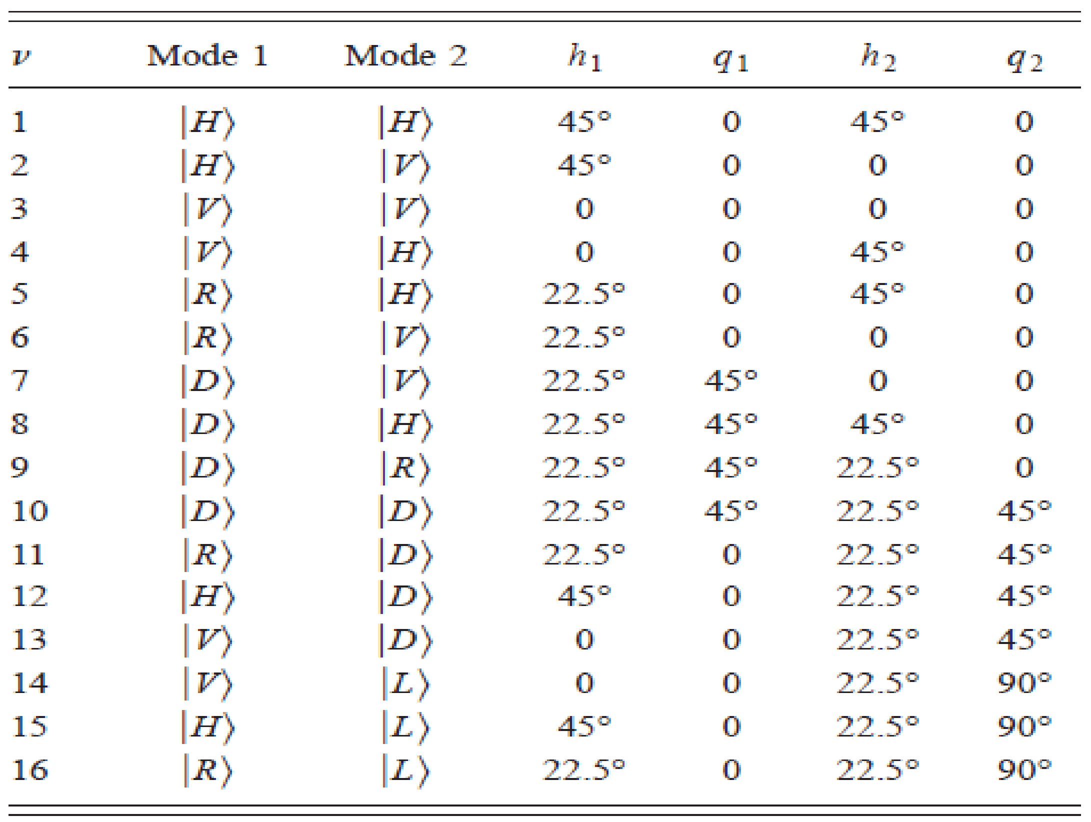
- Our Goal is to construct a physical density matrix from the projection measurement of the system

$$\rho = \sum_i P_i |\Psi\rangle\langle\Psi|$$

Having properties

- ✓Density matrix should be hermitian
- ✓Tr(ρ) = 1
- ✓ρ should have positive semi definiteness.

- For a two qubit system we have to do 16 projection measurement to completely characterize the state of the system.



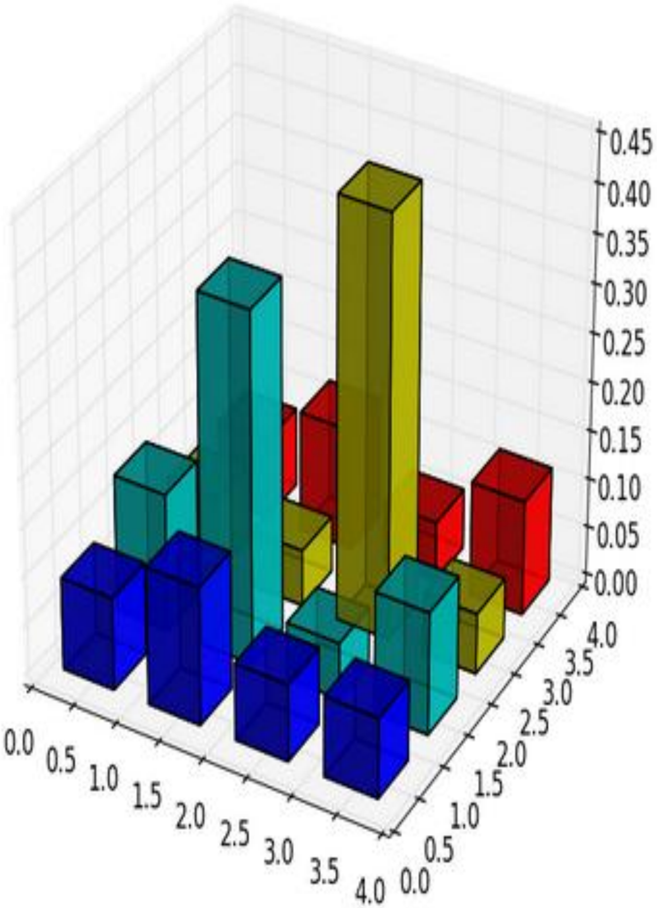
ν	Mode 1	Mode 2	h_1	q_1	h_2	q_2
1	$\|H\rangle$	$\|H\rangle$	45°	0	45°	0
2	$\|H\rangle$	$\|V\rangle$	45°	0	0	0
3	$\|V\rangle$	$\|V\rangle$	0	0	0	0
4	$\|V\rangle$	$\|H\rangle$	0	0	45°	0
5	$\|R\rangle$	$\|H\rangle$	22.5°	0	45°	0
6	$\|R\rangle$	$\|V\rangle$	22.5°	0	0	0
7	$\|D\rangle$	$\|V\rangle$	22.5°	45°	0	0
8	$\|D\rangle$	$\|H\rangle$	22.5°	45°	45°	0
9	$\|D\rangle$	$\|R\rangle$	22.5°	45°	22.5°	0
10	$\|D\rangle$	$\|D\rangle$	22.5°	45°	22.5°	45°
11	$\|R\rangle$	$\|D\rangle$	22.5°	0	22.5°	45°
12	$\|H\rangle$	$\|D\rangle$	45°	0	22.5°	45°
13	$\|V\rangle$	$\|D\rangle$	0	0	22.5°	45°
14	$\|V\rangle$	$\|L\rangle$	0	0	22.5°	90°
15	$\|H\rangle$	$\|L\rangle$	45°	0	22.5°	90°
16	$\|R\rangle$	$\|L\rangle$	22.5°	0	22.5°	90°

Maximum Likelihood Estimation

- Generate a formula for an explicitly physical density matrix which has three properties
- Introduce a likelihood function which quantifies how good the density matrix is in relation to exp. data.
- Using standard numerical optimization techniques, find the optimum set of variables for which likelihood function is maximum.

Density matrix (rho) =

```
(0.09436+0j)        (-0.05915-0.12759j) (0.06302+0.04664j)  (-0.07093+0.04034j)
(-0.05915+0.12759j) (0.35791+0j)        (-0.03743+0.04371j) (-0.07324-0.10095j)
(0.06302-0.04664j)  (-0.03743-0.04371j) (0.42997+0j)        (0.0195+0.05868j)
(-0.07093-0.04034j) (-0.07324+0.10095j) (0.0195-0.05868j)   (0.11777+0j)
```



Properties of rho

Property	*Value*	*Error*
Concurrence	0.14217	+/- 0.0
Tangle	0.02021	+/- 0.0
Entanglement	0.04601	+/- 0.0
Entropy	1.30074	+/- 0.0
Linear Entropy	0.73828	+/- 0.0
Negativity	0.13135	+/- 0.0
Intensity	2092.99671	

Error Estimation Times 1

Summary

- We have generated the entangled photons through type-II SPDC via EPM.
- Spectra of generated photons is fragile as the crystal temperature is changed.
- We observed the Hong-Ou Mandel Interference which used to measure the indistinguishability of entangled photons.
- Performed the two qubit tomographic measurement on photon orthogonal polarization states .
- The quality of tomography results being not good is attributed to misalignment and low visibility of Hong Ou Mandel interference.