Generation of three-photon GHZ States with Classical Light

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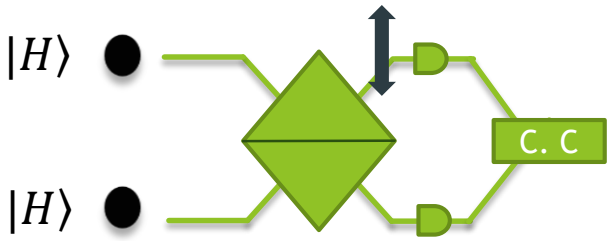
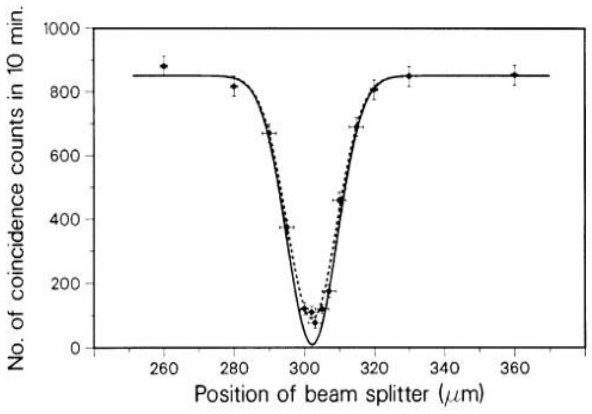
Yoonjeong Shin

Internship at Center for Quantum Information, KIST

Motivation
(1) Ambiguous quantum-ness criteria

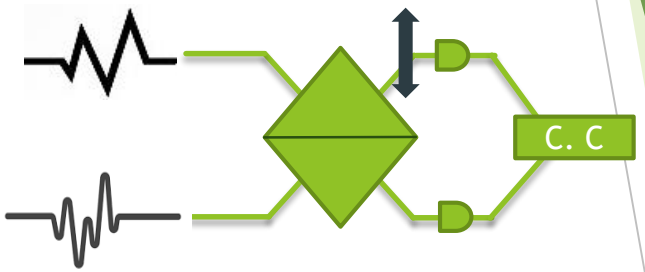
- Phase-incoherent classical lights act like photons
  - Photons

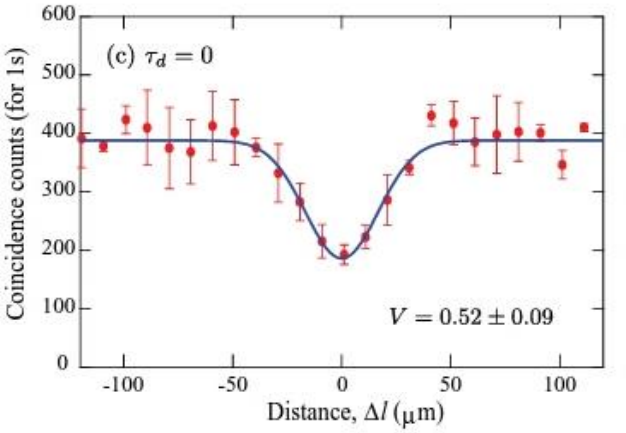




Hong *et al.*, Phys. Rev. L 1987

  - Phase-incoherent Laser pulses

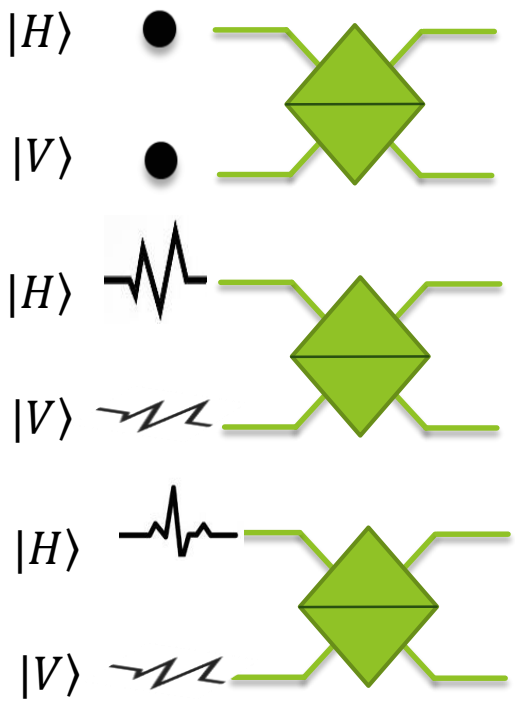




Kim *et al.*, Phys. Rev. A 2013

Motivation
(1) Ambiguous quantum-ness criteria

- Ones with orthogonal polarization..



$(entanglement) \neq 0$

$(entanglement) = 0 \;\; (discord) = 0$

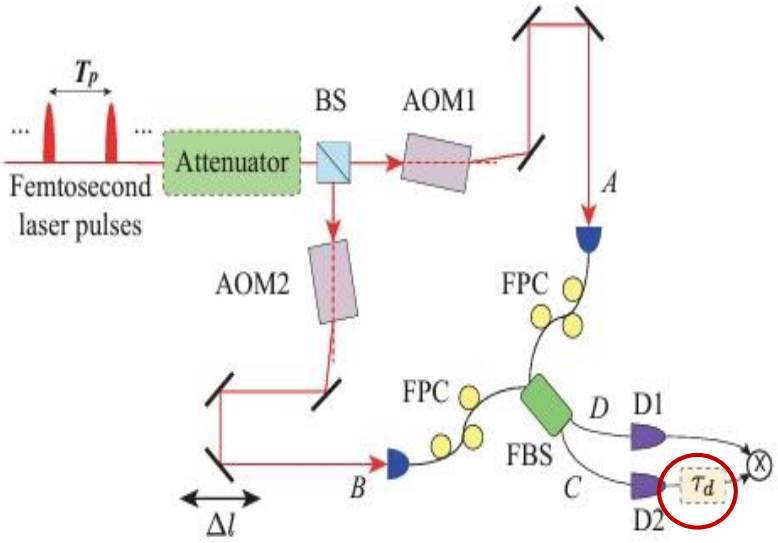
$(entanglement) = 0 \;\; (discord) \neq 0$

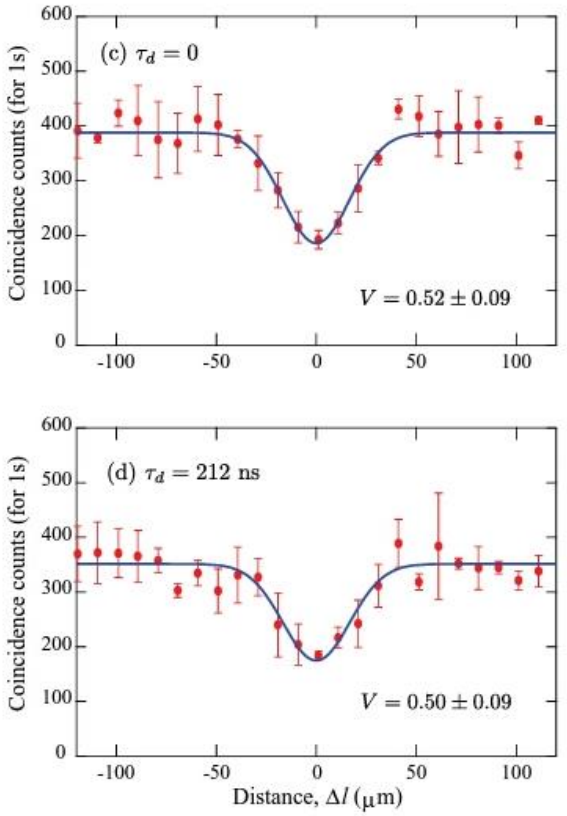
Classical interference → quantum correlation

Kim *et al.*, Opt. Ex 2017

Motivation
(1) Ambiguous quantum-ness criteria

- Interference between probability amplitudes
- Temporal overlapping of inputs is not required

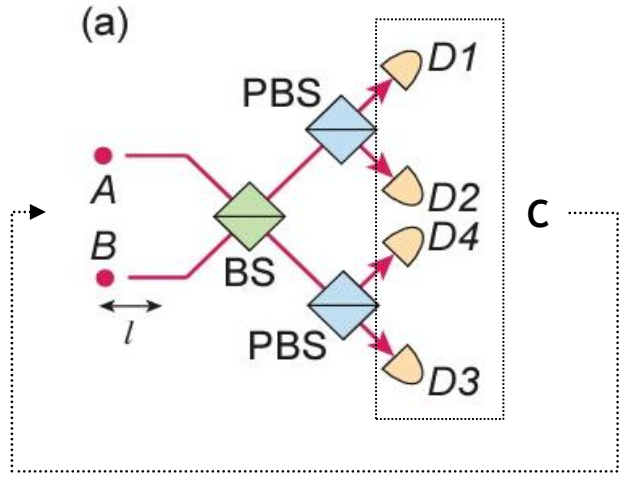


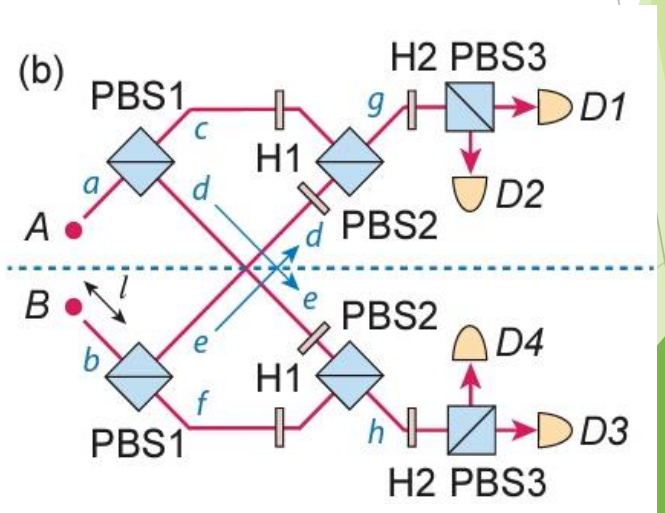


Kim *et al.*, Phys. Rev. A 2013

Motivation
(2) Informationally Symmetric BSM

- Standard BSM
  - Two photons overlapping at BS
  - A third party perfoms BSM
  - Never know if C is trustworthy
- Symmetric BSM
  - BS-free
  - participants perform BSM in tandem
  - Guarantee security
  - Remote communication

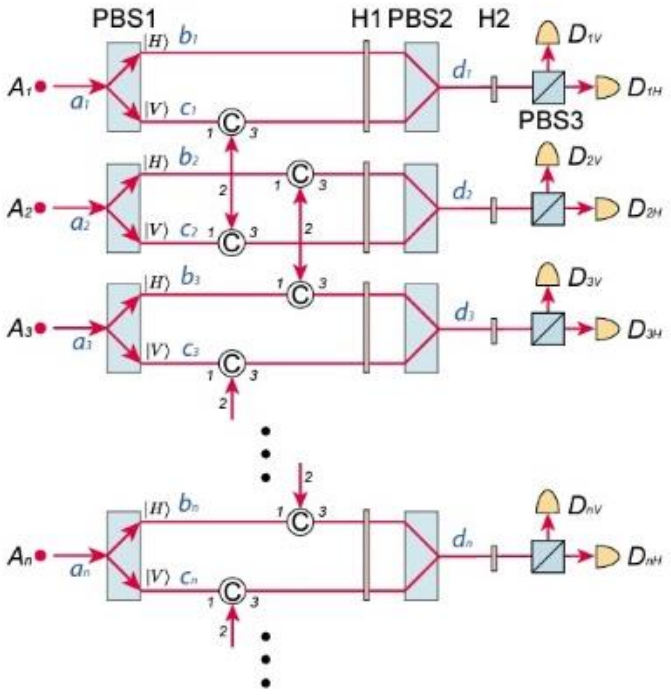




Kim *et al.*, Opt. Ex 2018

Motivation
(2) Informationally Symmetric BSM

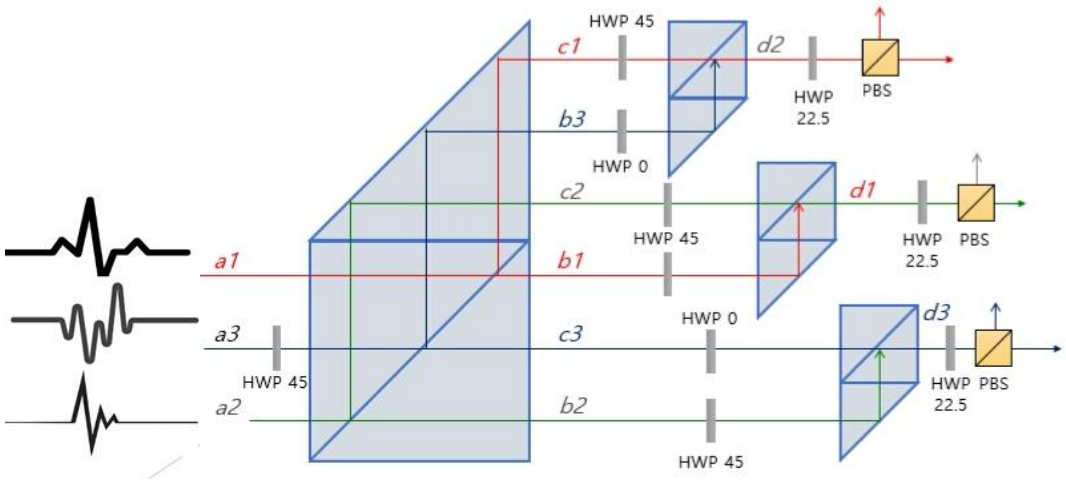
- Generalizable to N-photon GHZ states generation/measurement
  - $|\mathrm{GHZ}_N\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle^{\otimes N} + |1\rangle^{\otimes N}\right)$
  - By adding the scheme in parallel



Kim *et al.*, Opt. Ex 2018

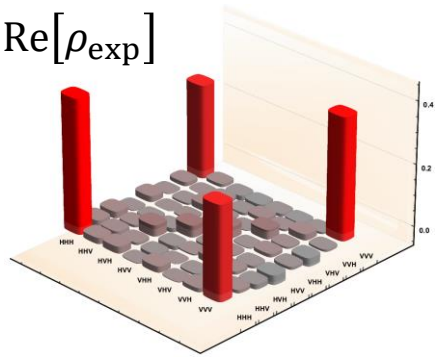
Motivation
(2) Informationally Symmetric BSM

- Created three-photon GHZ states using photons

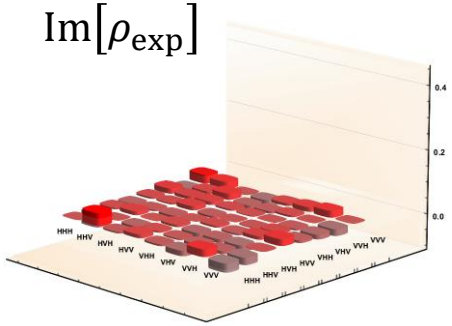


$|DDD\rangle$ input → GHZ output : $|GHZ^{\pm}> = {}^{1}/_{\sqrt{2}}(|HHH> \pm |VVV>)$

$\mathrm{Re}[\rho_{\mathrm{exp}}]$



$\mathrm{Im}[\rho_{\mathrm{exp}}]$



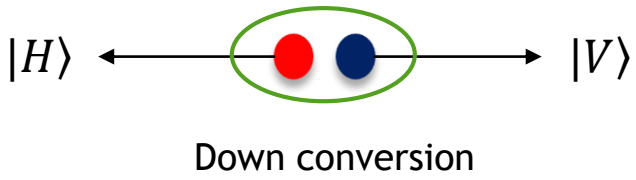
- $\mathrm{P} = 0.53 \pm 0.03$
- $\mathrm{F} = 0.69 \pm 0.03 > 0.5$

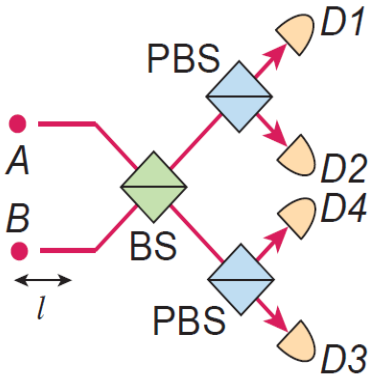
  : Genuine entanglement

Motivation
(3) MDI Quantum Communication

- "Measurement-Device-Independent"
  - M : complete detection efficiency
  - D : knowledge of how devices work

- A way to share entanglement
  - Entangled-based protocol
  - MDI protocol





"Post-select"

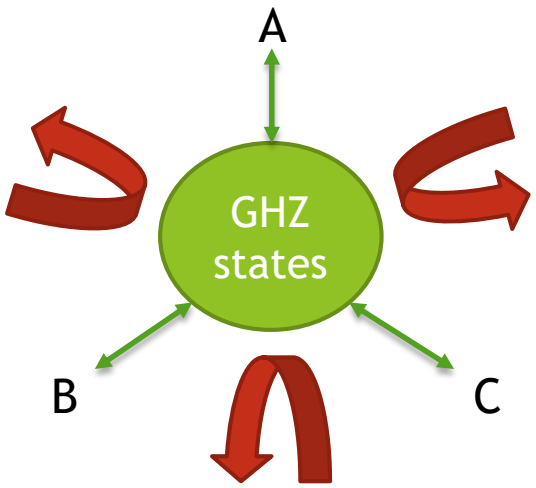
$|\psi^+>$: D12, D34

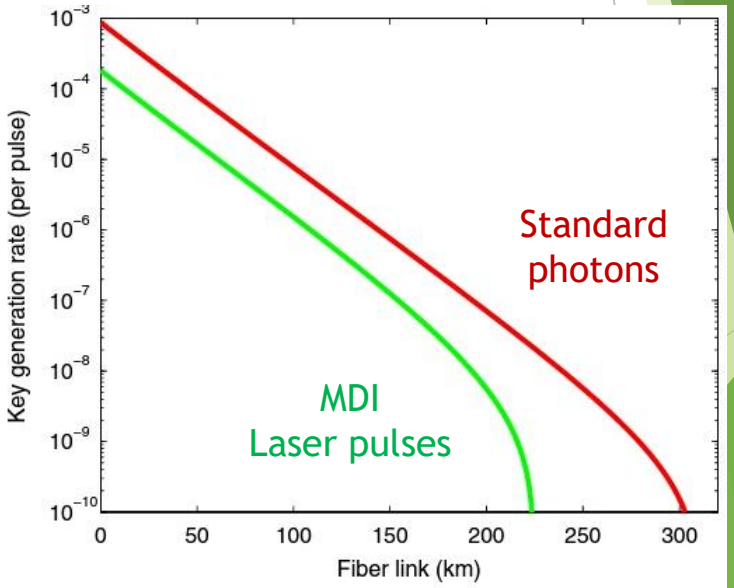
$|\psi^->$: D14, D23

Kim *et al.*, Opt. Ex 2018

Motivation
(3) MDI Quantum Communication

- Feasible
  - Immune to side attacks
  - Ensure long distance key distribution

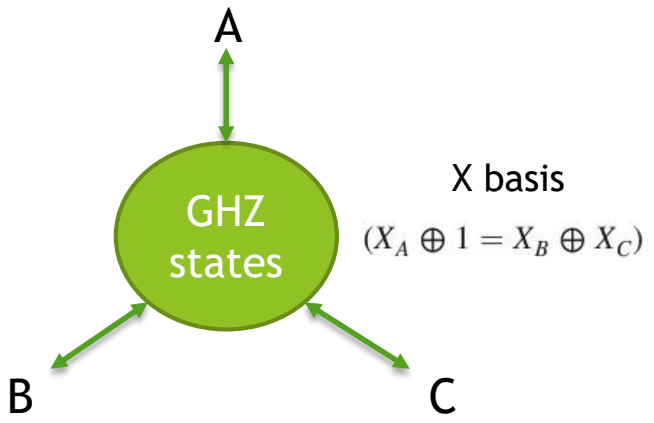


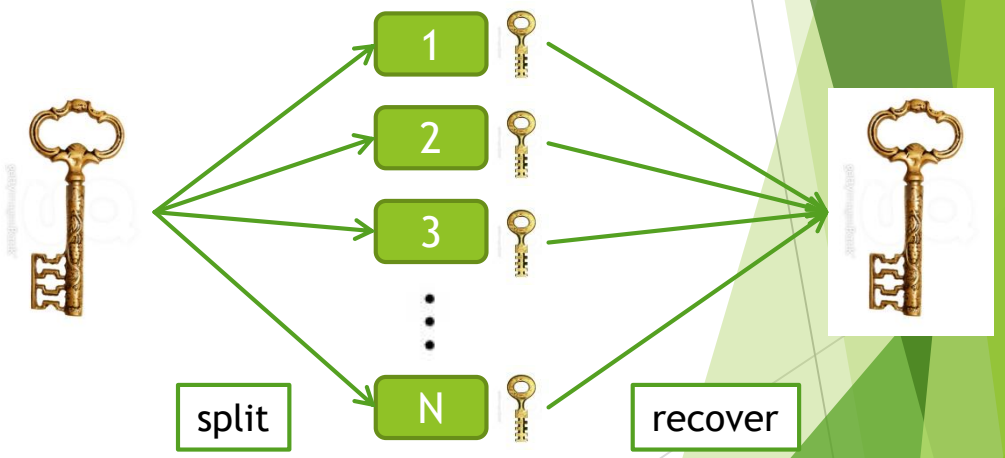


H-K Lo *et al.*, Phys. Rev. L 2012

Motivation
(3) MDI Quantum Communication

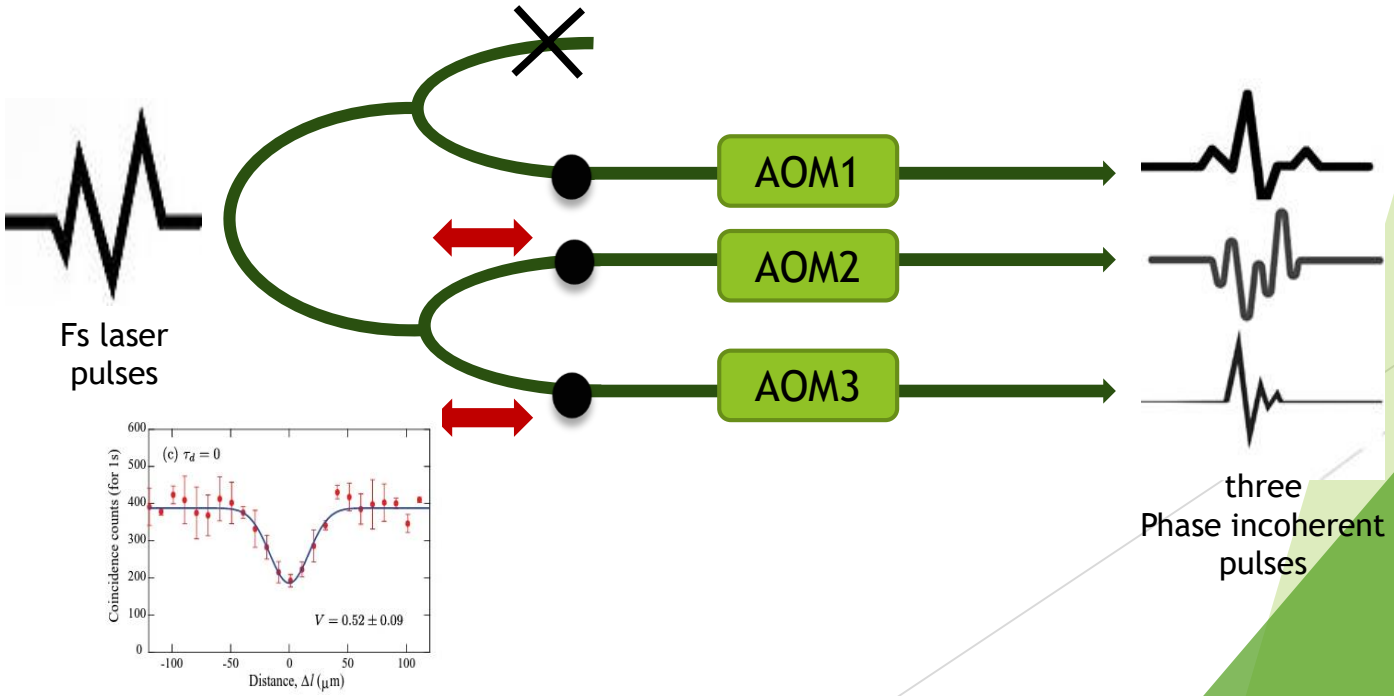
- Practical applications for MDI multi-parity communication
  - QSS : Quantum Secret Sharing
  - Having some important decisions (ex. launching a nuclear missile)





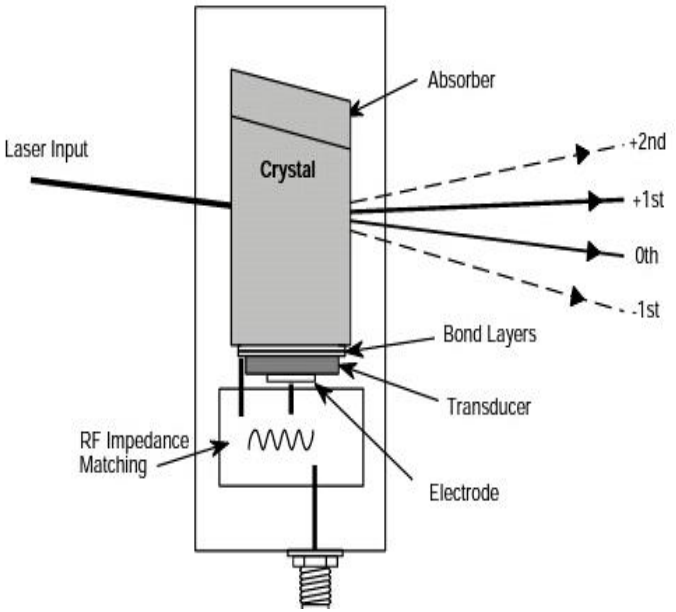
Research Procedure
(1) three incoherent input pulses

1. Split a fs laser into three pulses
2. Go through each AOMs → phase-incoherent
3. Find out where the 2nd order interferences take place → HOM dips

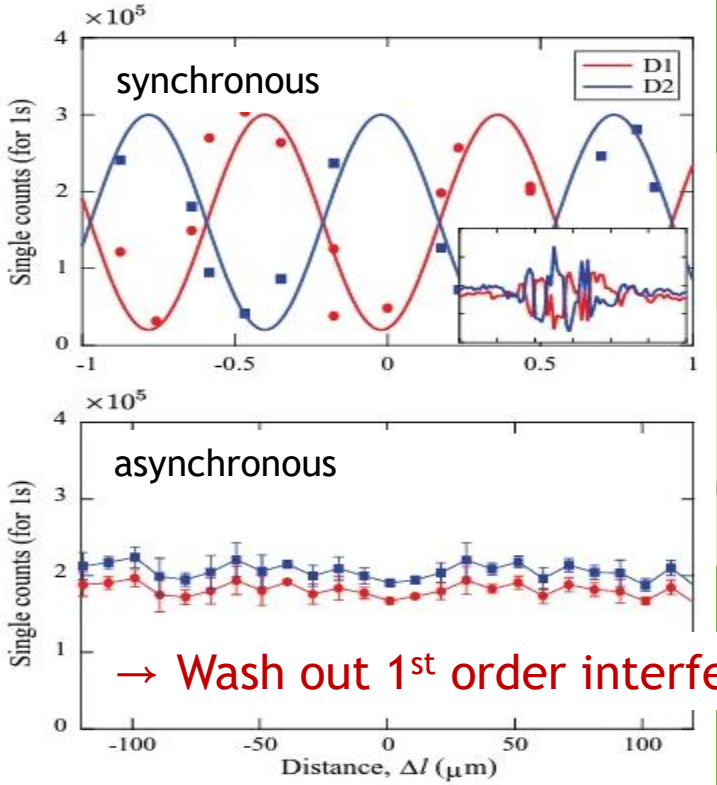


Research Procedure
(1) three incoherent input pulses

- A kind of diffraction grating
- Asynchronous AOMs (Acousto-Optic Modulators)



RF driver
Adds additional phase

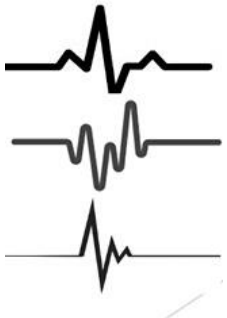


→ Wash out 1st order interference !

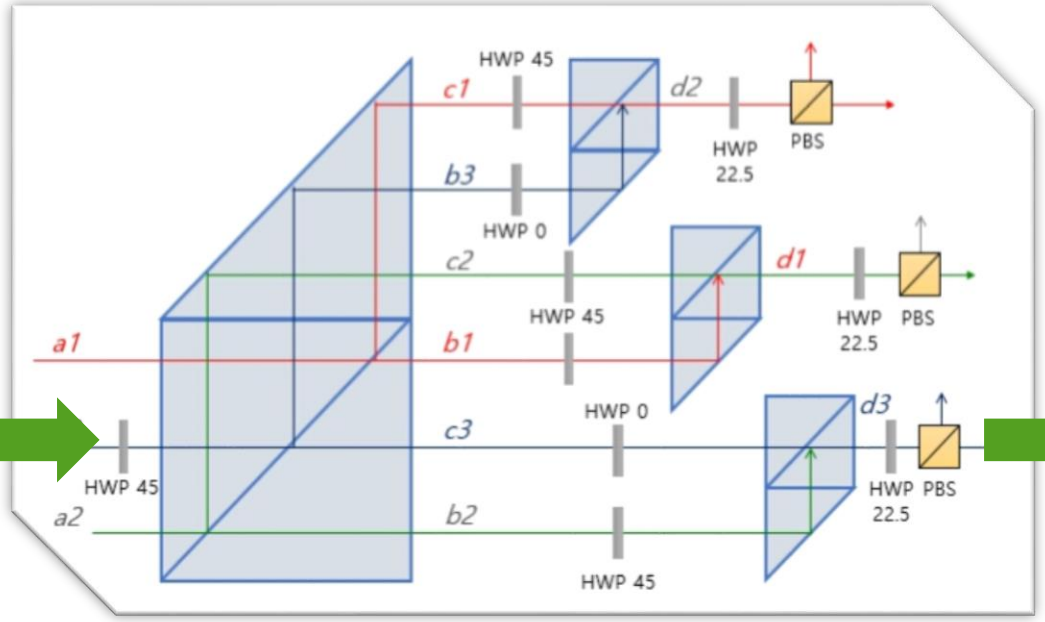
Kim *et al.*, Phys. Rev. A 2013

Research Procedure
(2) three-photon GHZ-like States

- 3rd order interference
- What they actually look like?



incoherent pulses



GHZ states generator

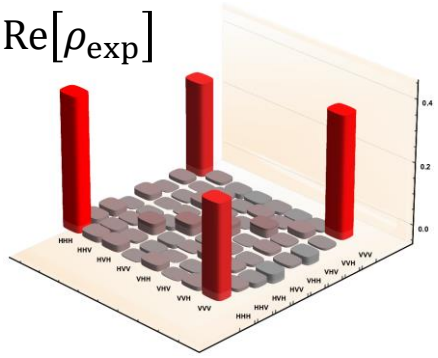
Output states

Research Procedure
(3) Analysis of GHZ-like States

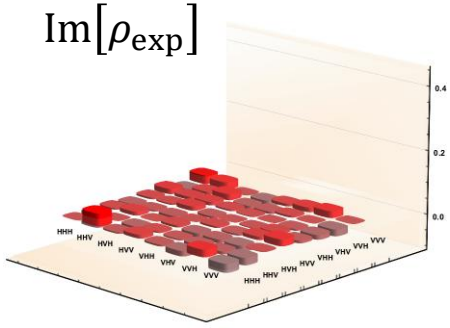
1. Quantum state tomography
   - Obtain fidelity, entanglement, and discord
   - Be compared to the theoretical figures and the results from photons

● : $|DDD\rangle$ input → GHZ output

$\mathrm{Re}[\rho_{\mathrm{exp}}]$



$\mathrm{Im}[\rho_{\mathrm{exp}}]$



- $\mathrm{P} = 0.53 \pm 0.03$
- $\mathrm{F} = 0.69 \pm 0.03 > 0.5$

  : Genuine entanglement

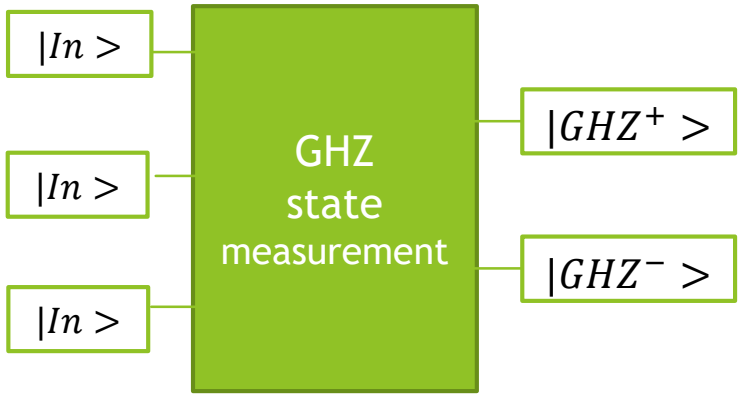
: $|DDD\rangle$ input → GHZ output ?

Research Procedure
(3) Analysis of GHZ-like States

2. GHZ state measurement
   - With two sets of input states

     : $|HHH>, |HHV>, \cdots, |VVV>$ and $|DDD>, |DDA>, \cdots, |AAA>$
   - Calculate error rates

$$|GHZ^{\pm}> = {}^{1}/_{\sqrt{2}}(|HHH> \pm |VVV>)$$



	$\|HHH>$	$\|HHV>$	$\cdots$	$\|VVV>$
$\|GHZ^{+}>$	${}^{1}/_{2}$	0	0	${}^{1}/_{2}$
$\|GHZ^{-}>$	${}^{1}/_{2}$	0	0	${}^{1}/_{2}$

	$\|DDD>$	$\|DDA>$	$\cdots$	$\|AAA>$
$\|GHZ^{+}>$	?	?	?	?
$\|GHZ^{-}>$	?	?	?	?

Summary

- classical lights act like photons
- identify the probability of QC with classical lights
- GHZ states → MDI QC
- more practical and related to the realization of QC in common use

THANK YOU !

"Generation of three-photon GHZ States with Classical Light"

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