

Implementation of “mobile” polarization-entangled photon source

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Introduction

“God doesn’t play a dice”, said one of most famous physicist Albert Einstein. He suspected quantum-mechanical description of physical reality was complete. He proposed hidden variable theory where any particles have hidden variable in itself *a priori*, and that decide results of any measurements.

The suggestion [1] gave strong impact on physicists around the world. Niels Bohr submitted his paper with his opinion [2]. Another pretty famous physicist, Ervin Schrödinger did, too [3]. 30 years after, in 1965, a paper by J. S. Bell was published where the elegant discriminant (Bell’s inequality) was proposed, which has put the guideline to solve the controversial issue [4]. If the inequality satisfies, then it is proof that Einstein’s opinion is true. If not, it means his opinion is wrong. Here we implemented “mobile” polarization-entangled photon source. Both photon-pair generation system and projective measurement system were implemented on an optical surface plate whose size is even smaller than A2 paper. This system marked fidelity of 82% and we confirmed the violation of Bell’s inequality with this prepared photon pairs.

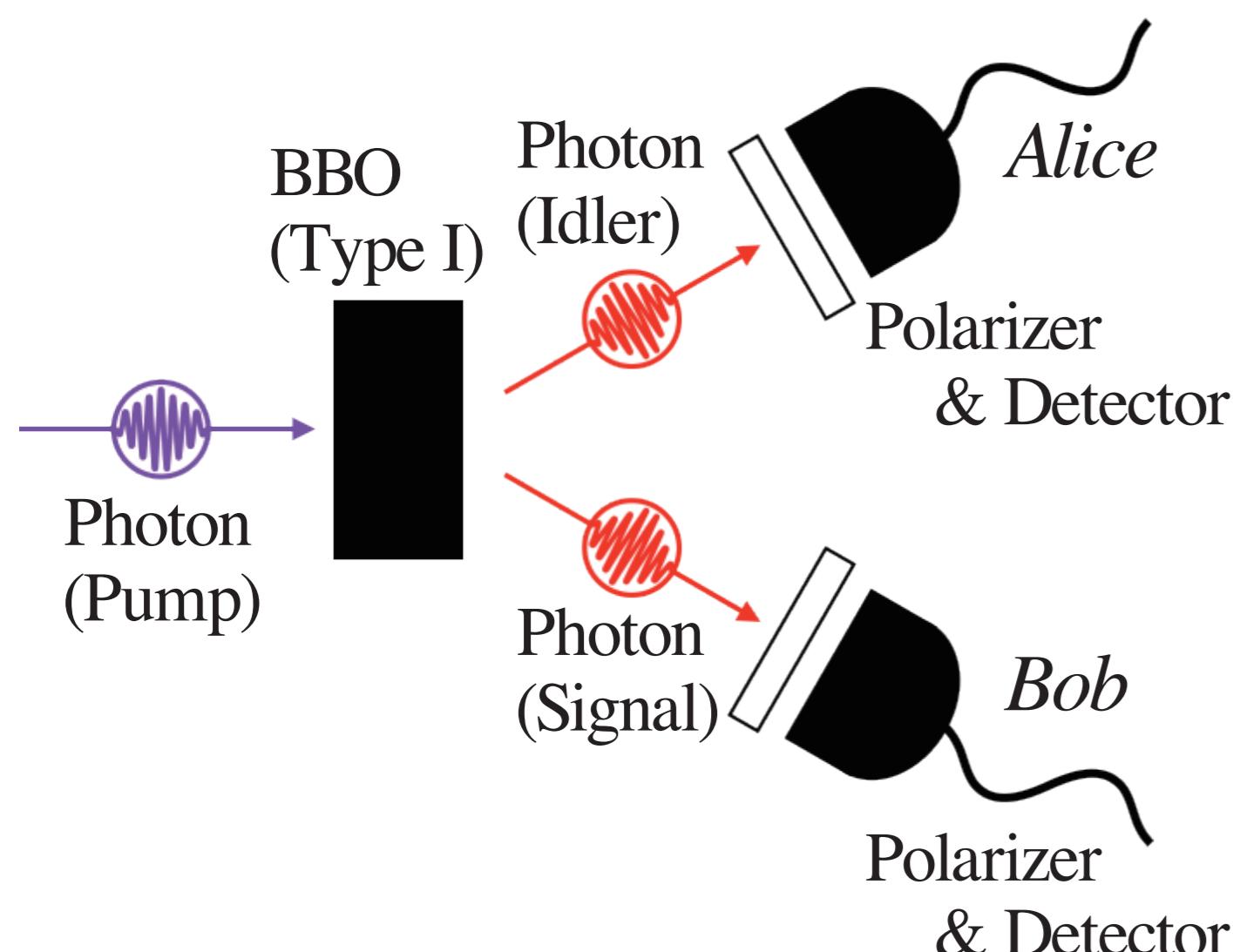
Bell’s Inequality (CHSH version)

This equation (1) is CHSH version of Bell’s inequality.

(There are some versions about Bell’s inequality.)

$$-2 \leq -\langle X_A X_B \rangle + \langle X_A Y_B \rangle + \langle Y_A X_B \rangle + \langle Y_A Y_B \rangle \leq 2 \quad (1)$$

X_A , Y_A , X_B , and Y_B result from polarization measurements by *Alice* and *Bob* shown in FIG. 1. Triangle bracket means the correlation of two components. The inequality is derived without quantum theory, but with simple math.

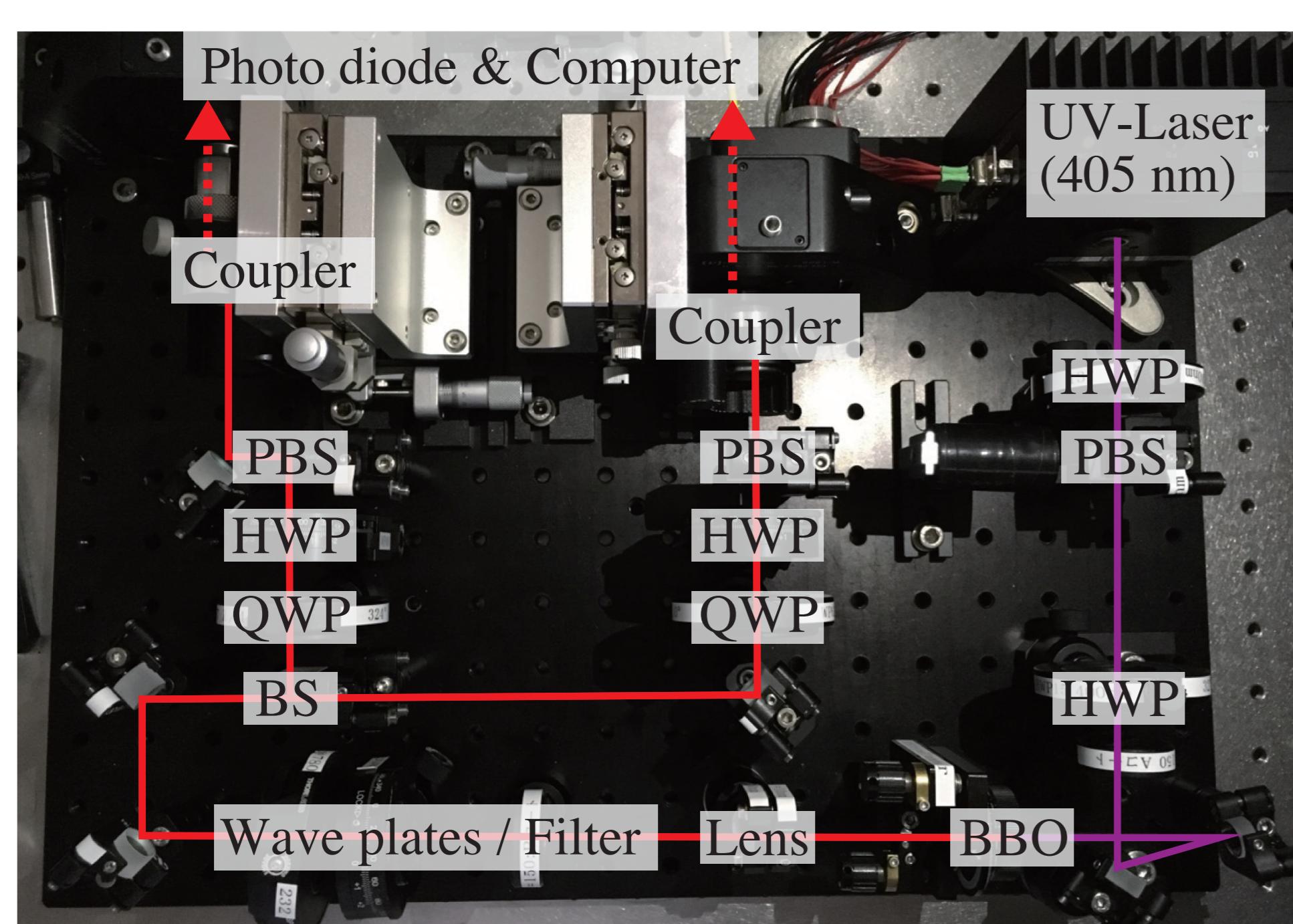


◀ FIG. 1
Alice and Bob measure polarization of each photon. For example, when Alice detects θ_A [deg]- linear polarization, X_A is 1. Other cases are shown in the list below.

$X_A : \theta_A \Rightarrow 1$	/	$\theta_A + 90^\circ \Rightarrow -1$
$X_B : \theta_B \Rightarrow 1$	/	$\theta_B + 90^\circ \Rightarrow -1$
$Y_A : \phi_A \Rightarrow 1$	/	$\phi_A + 90^\circ \Rightarrow -1$
$Y_B : \phi_B \Rightarrow 1$	/	$\phi_B + 90^\circ \Rightarrow -1$

Preparation of Entangled Photon Pair

We generate polarization-entangled photons and measured the states by reconstruction of density matrix tomography [5].

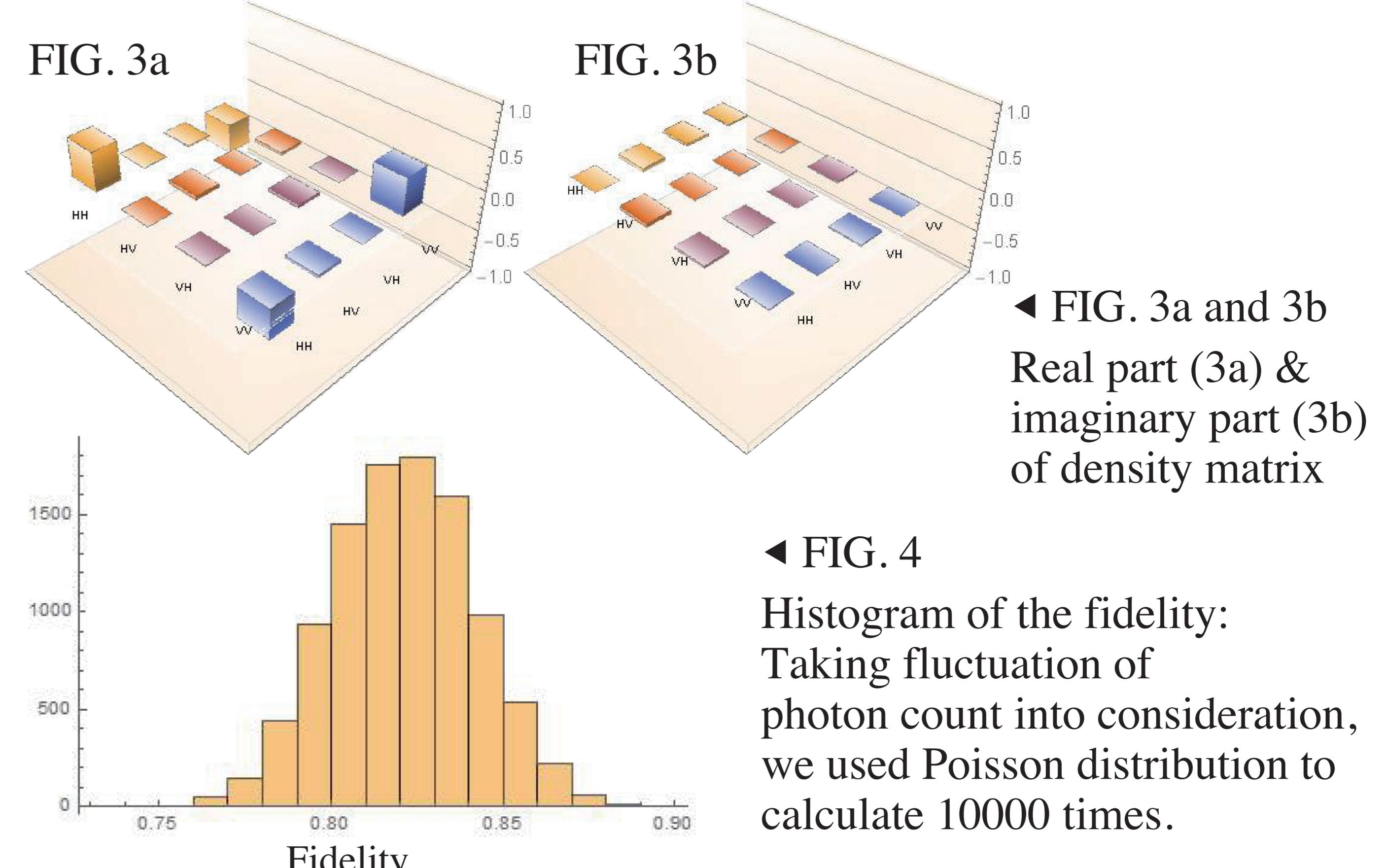


◀ FIG. 2
Experimental Setup:
We adjust intensity by HWP & PBS,
make diagonal polarization and generate
two photons by BBO.
They are split into
two path and detected
as coincidence count
at computer.

References:

- [1] A. Einstein *et. al.*, *Phys. Rev.* **47**, 10, 777 (1935).
- [2] N. Bohr, *Phys. Rev.* **48**, 8, 696 (1935).
- [3] E. Schrödinger, *Naturwissenschaften* **23**, 49, 823-828 (1935).
- [4] J. S. Bell, *Naturwissenschaften* **23**, 49, 823-828 (1935).

In FIG. 3a and 3b, we show density matrix of the prepared states. From this density matrix, fidelity is calculated 0.821 (FIG. 4).

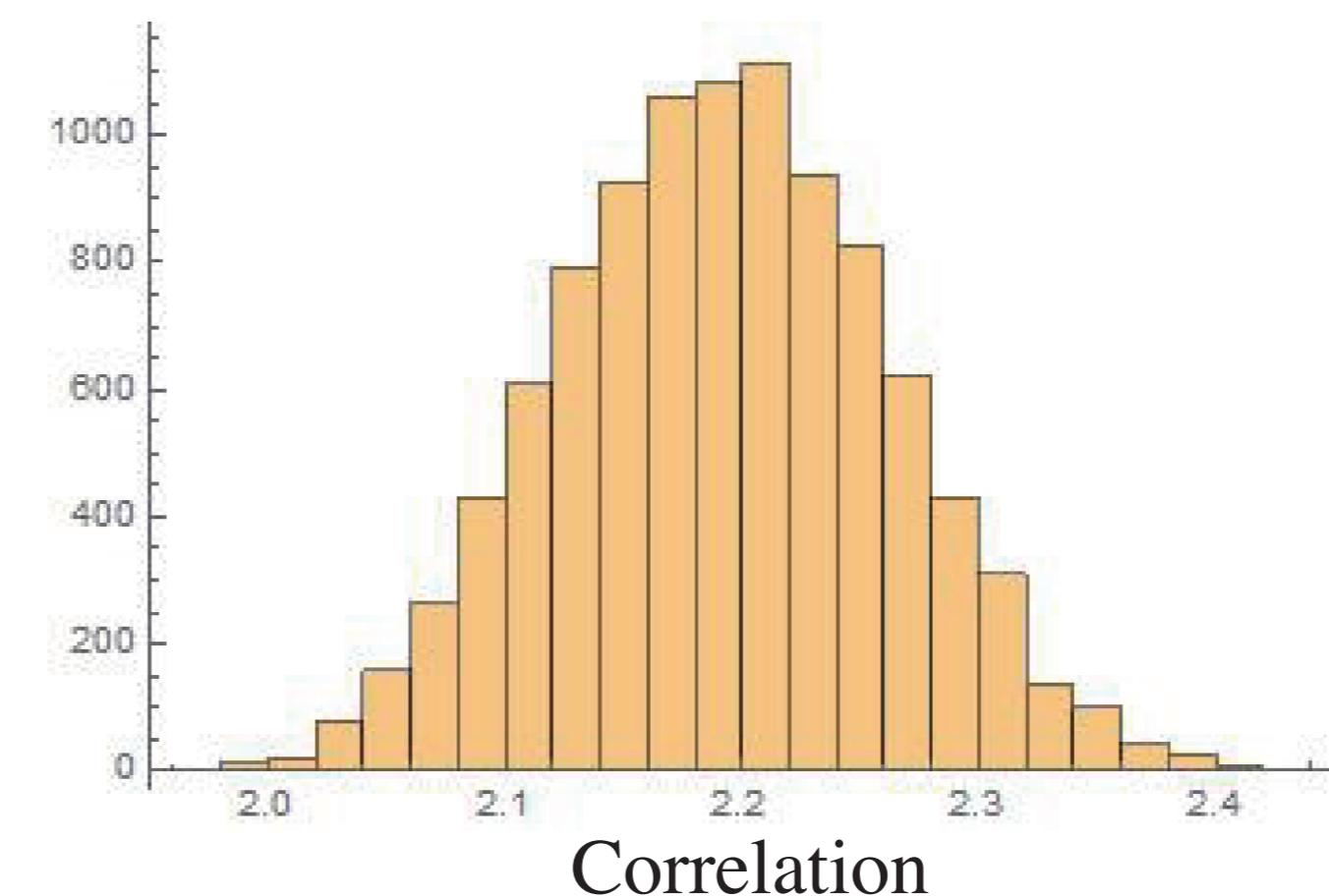


Violation of Bell’s Inequality

By using prepared entangled states, the correlations are calculated in the condition of the following parameters.

$$(\theta_A, \theta_B, \phi_A, \phi_B) = (0^\circ, 22.5^\circ, 45^\circ, 67.5^\circ) \quad (2)$$

Just like the case of fidelity, we used Poisson distribution (FIG. 5).



◀ FIG. 5
Histogram of the calculation
results: 99.6% of the correla-
tions larger than 2.
Standard deviation can be
calculated from this histogram.

Then, we obtained the violation of Bell’s inequality.

$$-\langle X_A X_B \rangle + \langle X_A Y_B \rangle + \langle Y_A X_B \rangle + \langle Y_A Y_B \rangle = 2.19 \pm 0.07 > 2 \quad (3)$$

Then, we also conducted actual *Alice-Bob measurement*, and confirmed the medium side of Bell’s inequality was 2.44. This value causes violation □

- [5] D. F. V. James *et. al.*, *Phys. Rev. A*, **64**, 052312 (2001).
- [6] N. Imoto, 数理科学 **49**, 7, 40-45 (2011).
- [7] M. Genovese, *Phys. Repts.* **413**, 6, 319-396 (2005).