Measurement of 1-Qubit Operations on Single Photons

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http://fc07.deviantart.net/fs70/f/2010/310/b/f/blue_laser_texture_7_by_creepiest-d329eb4.jpg

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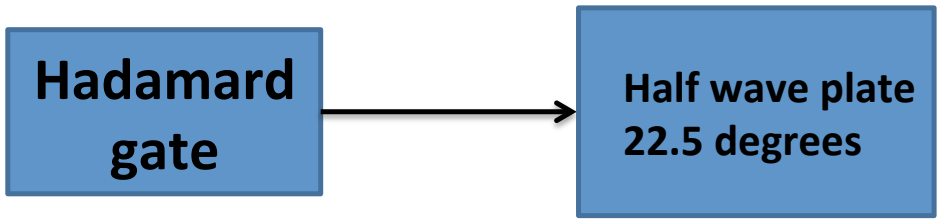
Motivation

- When speaking of quantum information and quantum computing we find serious or gate applications. Now this experiment seeks to move from the theoretical to the experimental, and being an introduction to the properties of the gates experimentally.

- Example



Wave plate

Or retarder is an experimental device with two refractive index difference, which is able to delay a polarization components of incident photons.

Wave Plates

- Quarter wave plate

$$A\downarrow\lambda/4 = [\blacksquare 1 \& 0 @ 0 \& -i\,]$$

$$|\uparrow\rangle = |H\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$|\downarrow\rangle = |V\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$A\downarrow\lambda/4\ (\theta) = \mathrm{R}(\theta) A\downarrow\lambda/4\ R\uparrow -1\ (\theta)$$

$$\hat{A}_{\frac{\lambda}{4}}(\theta) = \begin{bmatrix} \cos^2(\theta) - i\sin^2(\theta) & \cos(\theta)\sin(\theta) + i\cos(\theta)\sin(\theta) \\ \cos(\theta)\sin(\theta) + i\cos(\theta)\sin(\theta) & -i\cos^2(\theta) + \sin^2(\theta) \end{bmatrix}$$

Wave Plates

- Half wave plate

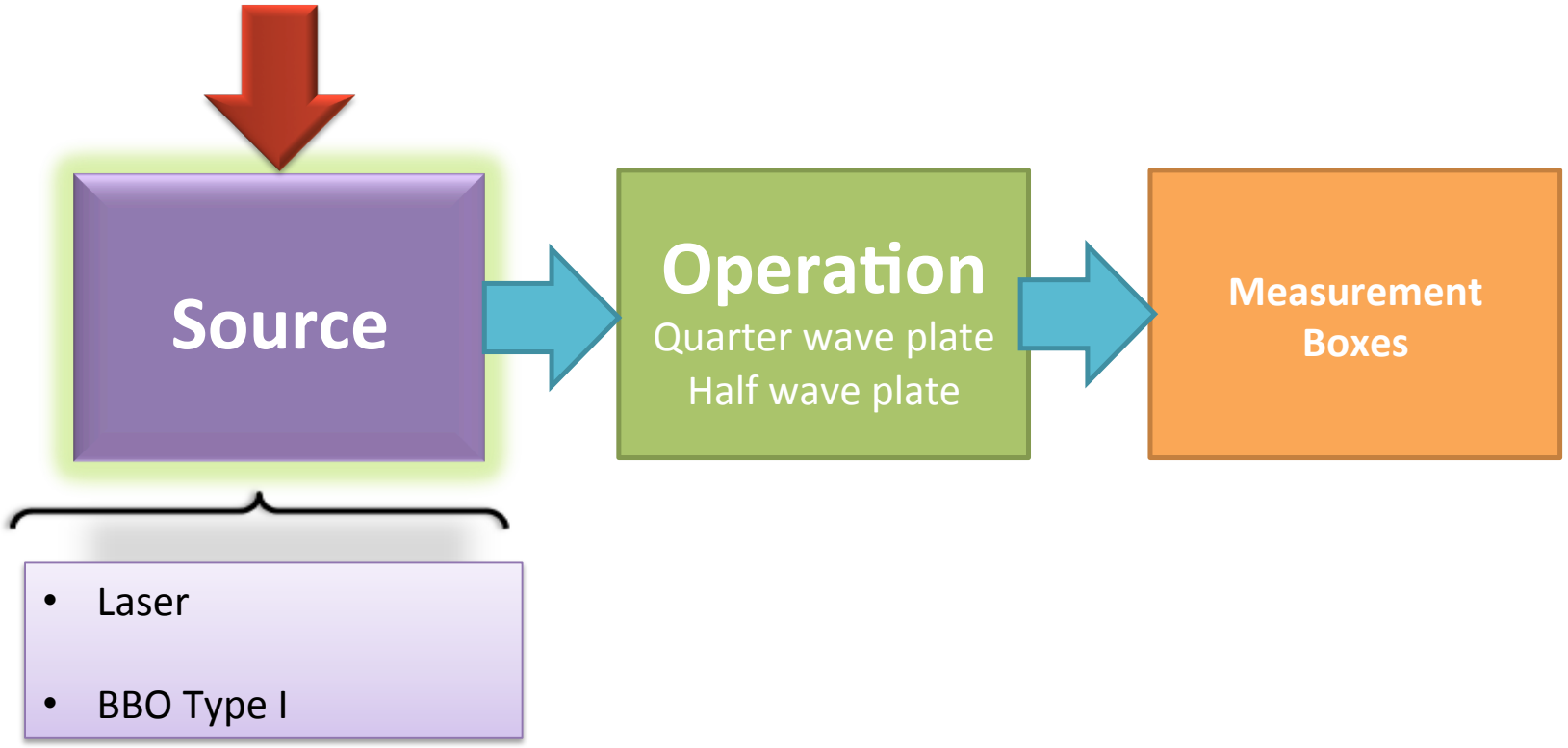
$$A\downarrow\lambda/2 = [\blacksquare 1 \& 0 @ 0 \& -1\ ]$$

$$|\uparrow\rangle = |H\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

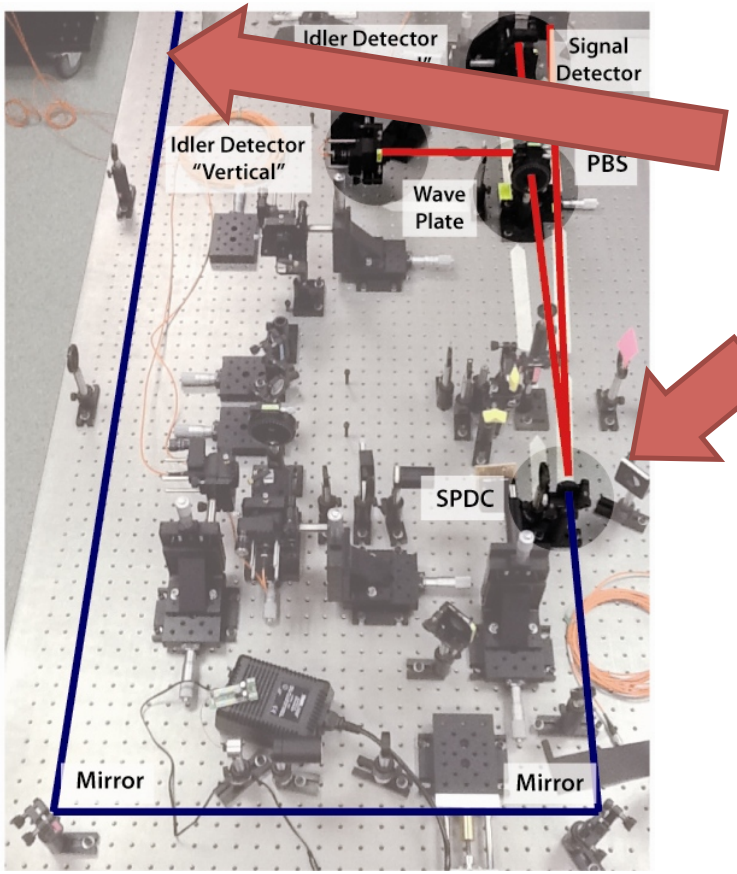
$$|\downarrow\rangle = |V\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

$$\hat{A}_{\frac{\lambda}{2}} = \begin{bmatrix} Cos(2\theta) & Sin(2\theta) \\ Sin(2\theta) & -Cos(2\theta) \end{bmatrix}$$

Experimental Setup



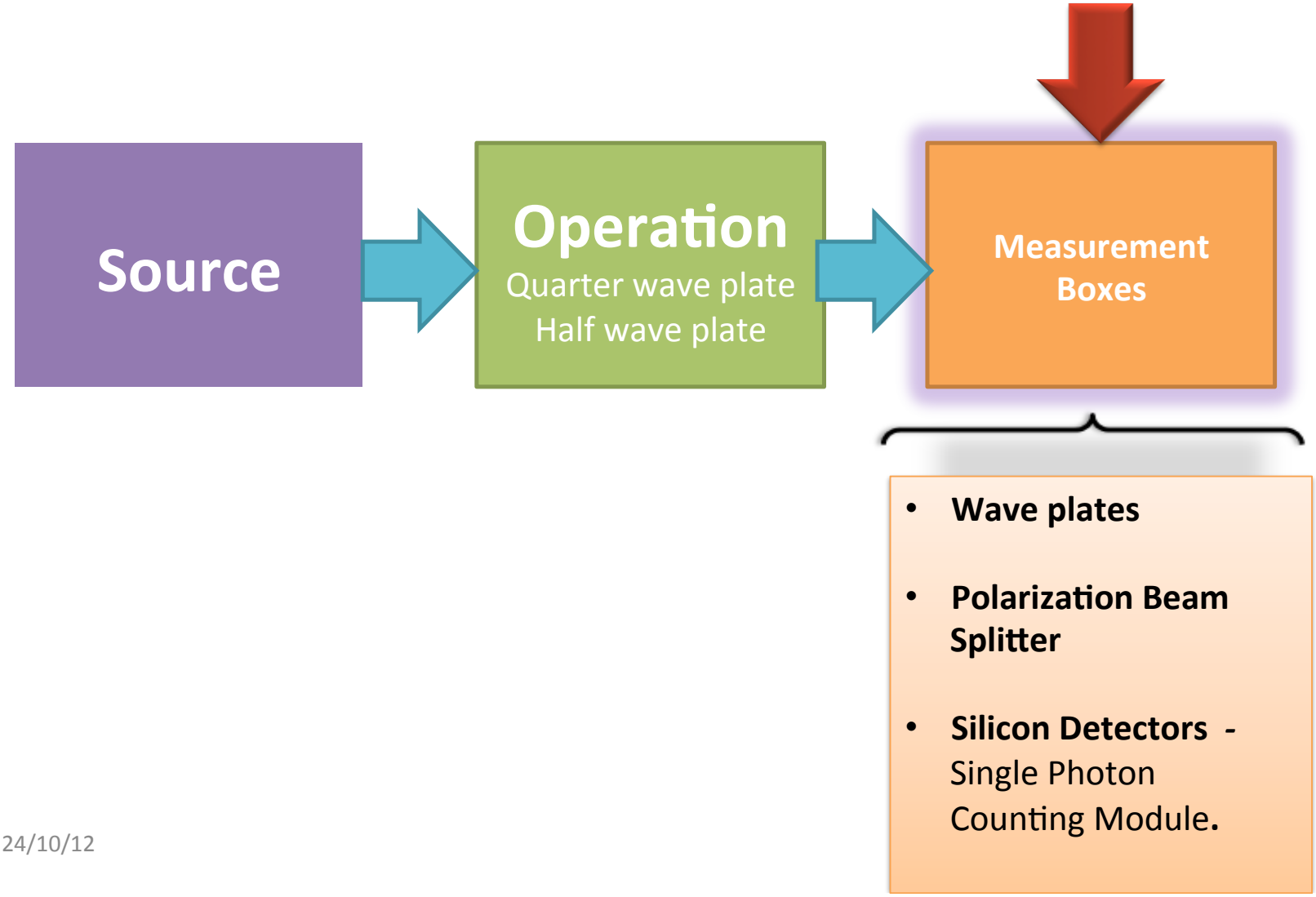
Source



- **Laser 405nm of 50mW**
  $10\uparrow 16$ ***Photons/s***
- **βBO type I.**
  8 x $10\uparrow 4$ ***Photons/s***
  0.6 % are detected at the same time.

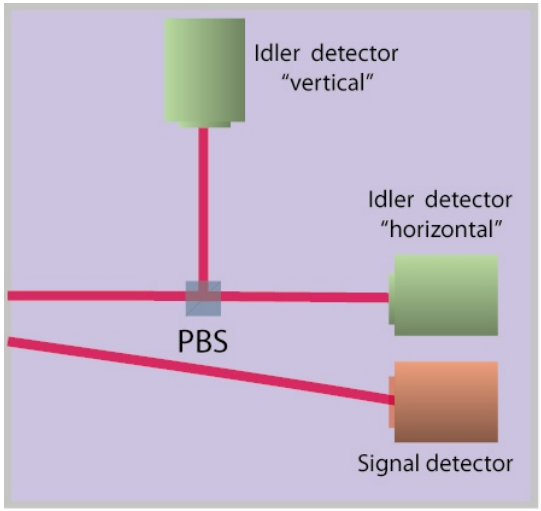
• Produced photons: horizontally polarized
• Signal photon announces existence of idler photon (heralded single photon source)

Experimental Setup



Measurement Boxes

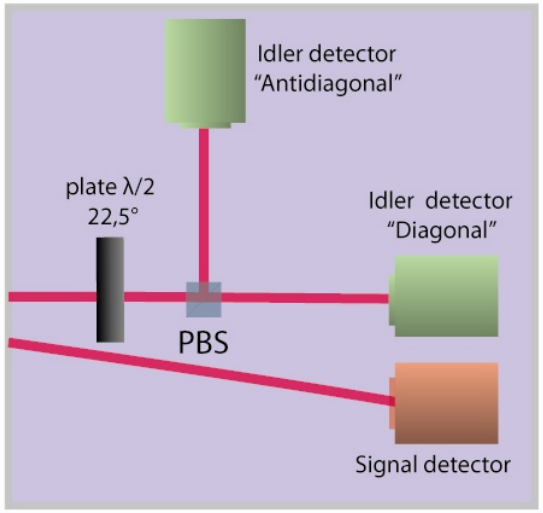
Horizontal / vertical basis



$$|\uparrow\rangle = |H\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$|\downarrow\rangle = |V\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

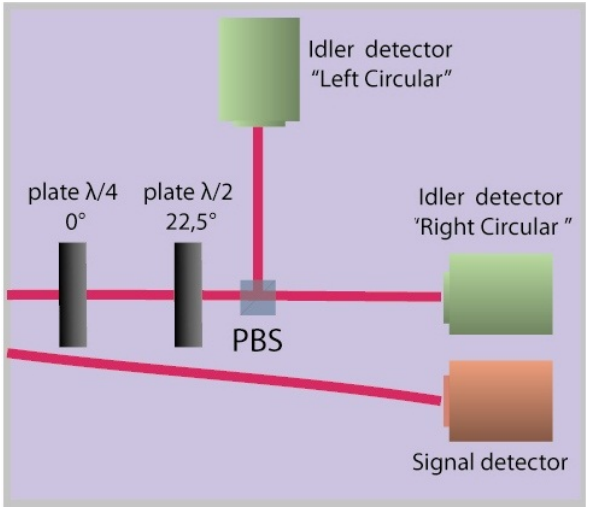
Diagonal / anti diagonal basis



$$|\nearrow\rangle = \frac{|\uparrow\rangle + |\downarrow\rangle}{\sqrt{2}}$$

$$|\searrow\rangle = \frac{|\uparrow\rangle - |\downarrow\rangle}{\sqrt{2}}$$

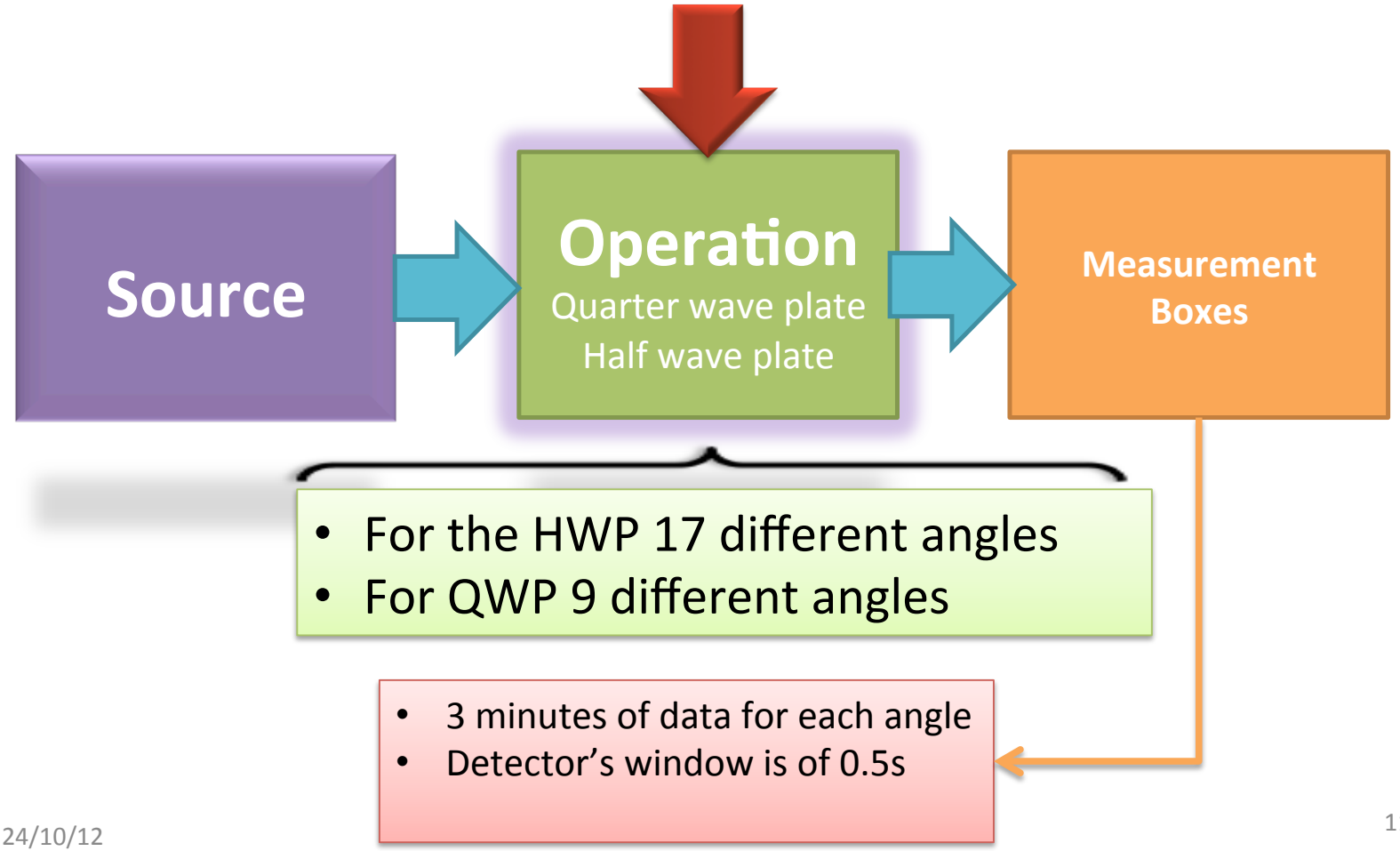
Right circular / left circular basis



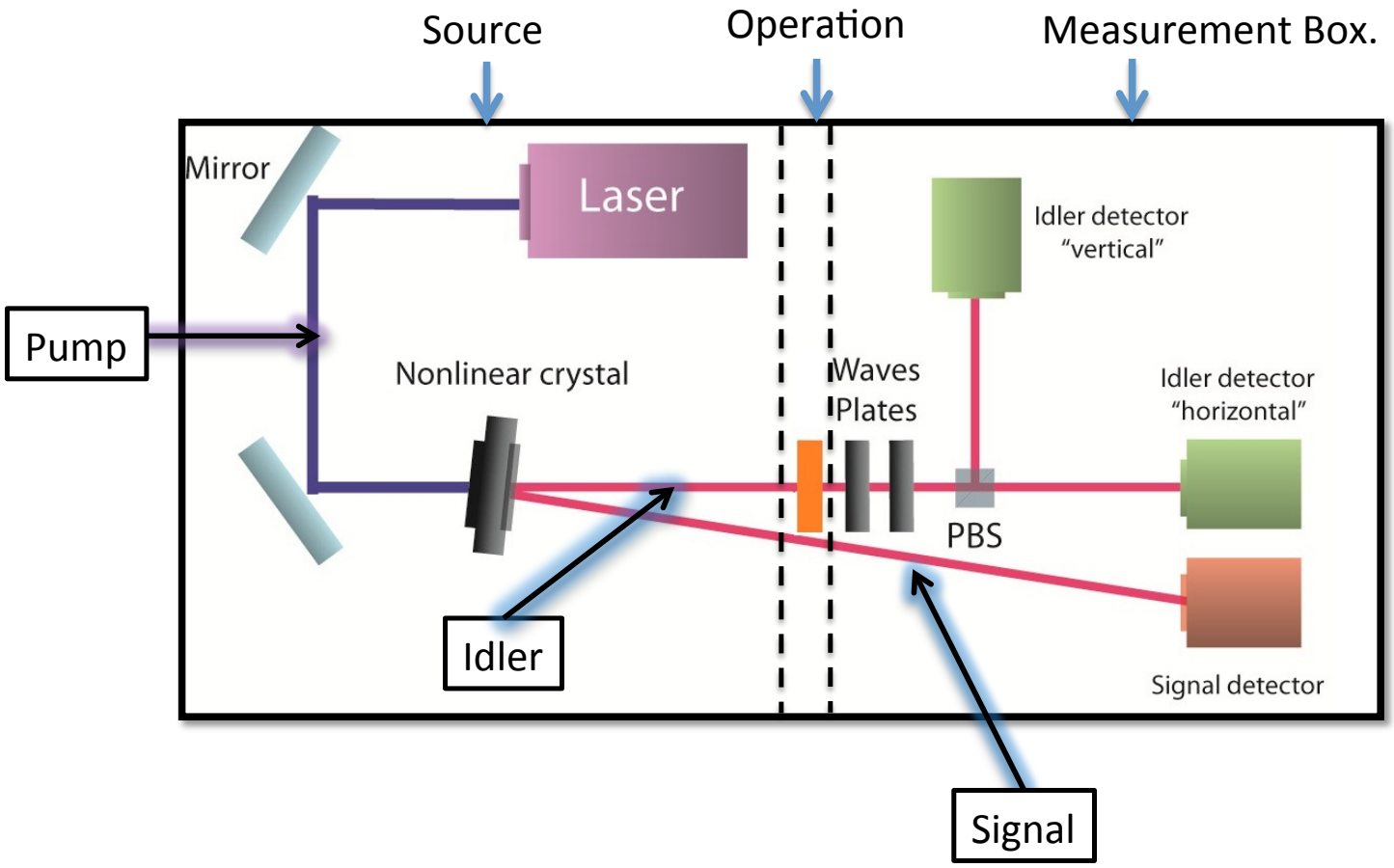
$$|\circlearrowleft\rangle = \frac{|\uparrow\rangle - i|\downarrow\rangle}{\sqrt{2}}$$

$$|\circlearrowright\rangle = \frac{|\uparrow\rangle + i|\downarrow\rangle}{\sqrt{2}}$$

Experimental Setup

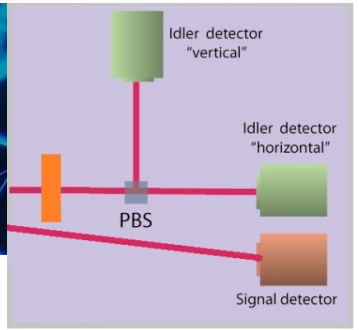


Process

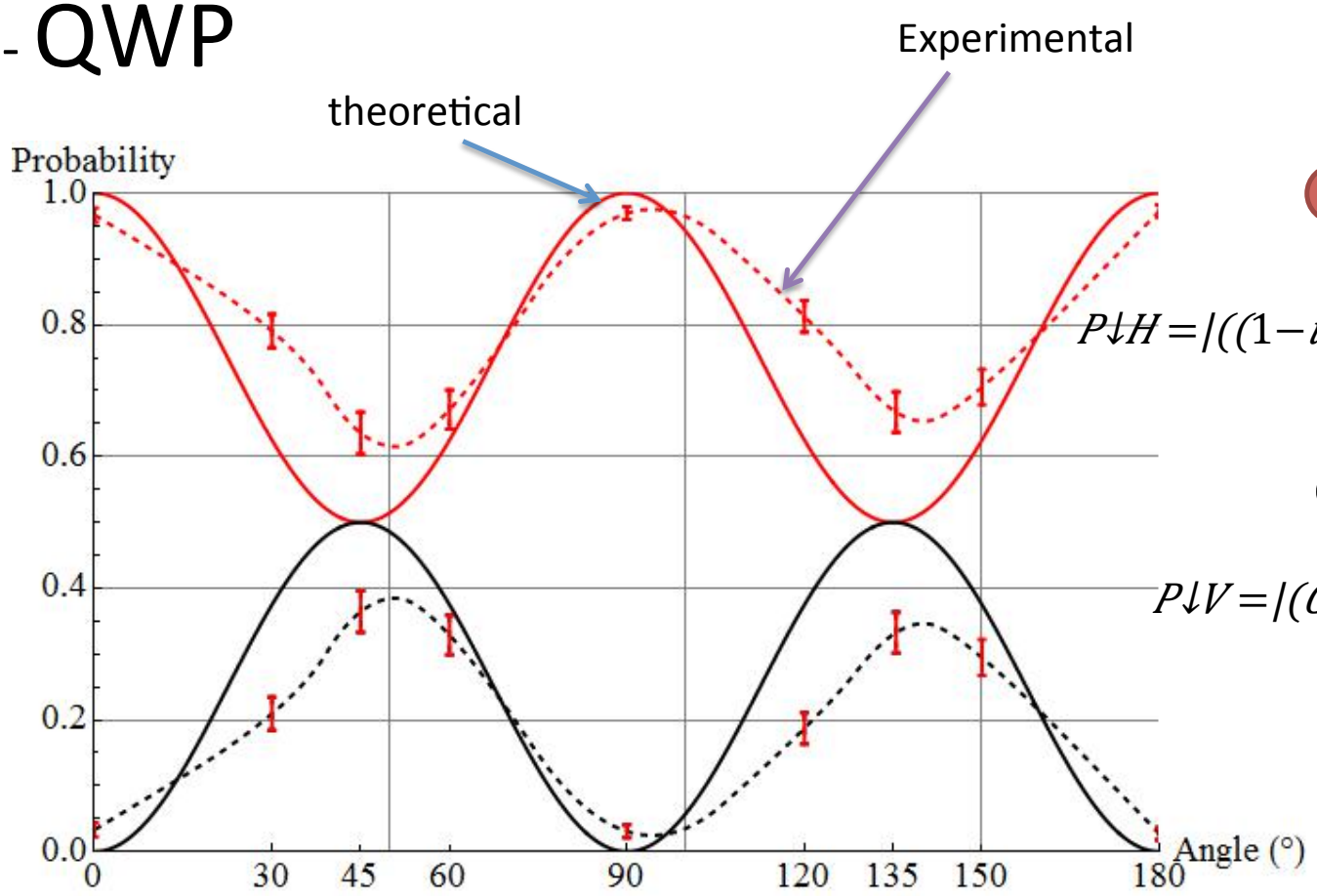

Source
Operation
Measurement Box.
Mirror
Laser
Idler detector
"vertical"
Pump
Nonlinear crystal
Waves
Plates
Idler detector
"horizontal"
PBS
Idler
Signal detector
Signal

Results

Horizontal / vertical basis



- QWP



Horizontal

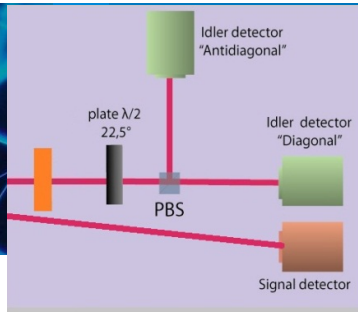
$P\downarrow H = |((1-i)Cos\hat{}\uparrow 2\downarrow(\theta)\ Sin\ \hat{}\uparrow 2\downarrow($

Vertical

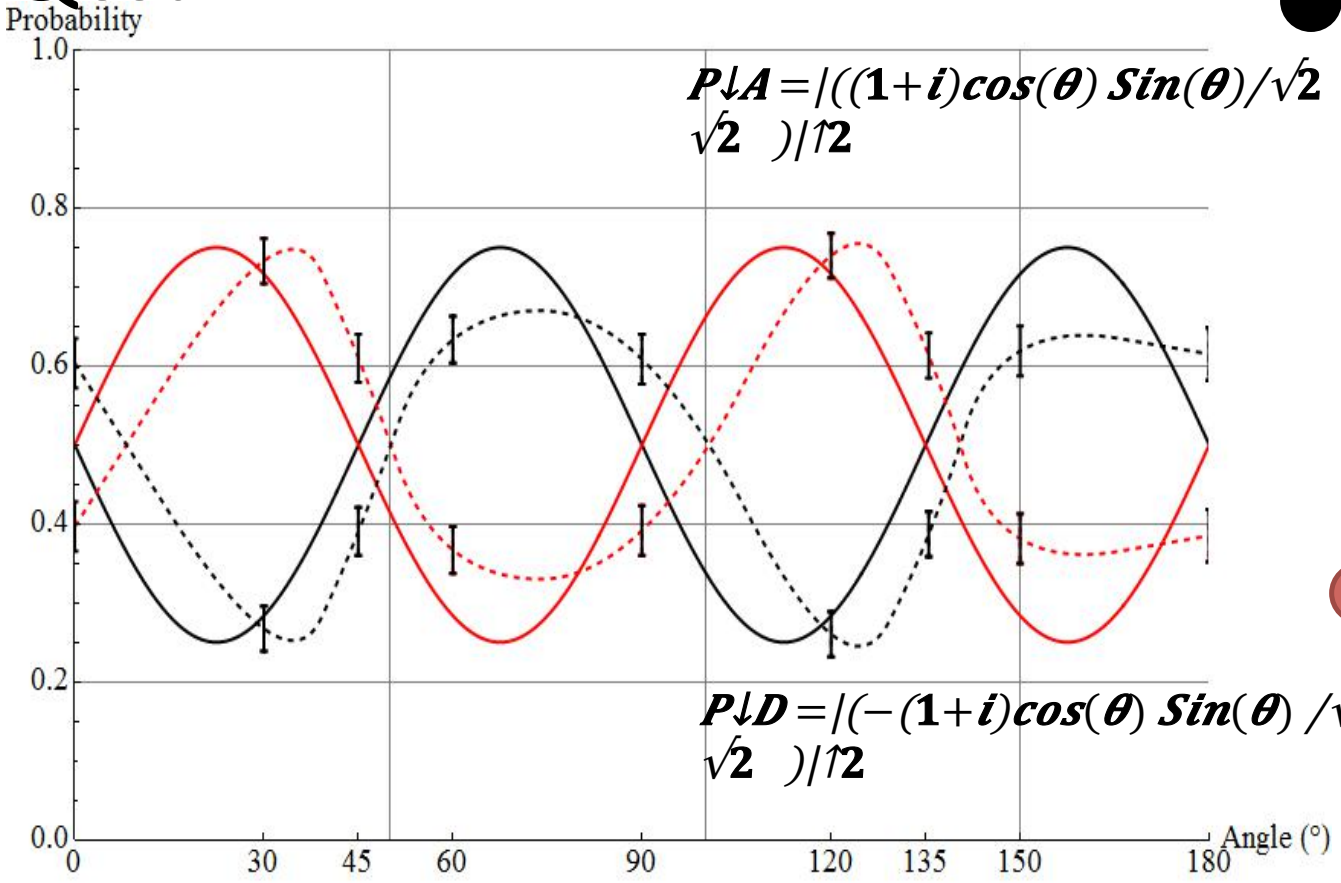
$P\downarrow V = |(Cos\hat{}\uparrow 2\downarrow(\theta)+i\ Sin\ \hat{}\uparrow 2\downarrow$

Results

Diagonal / anti diagonal basis



- QWP



Anti-diagonal

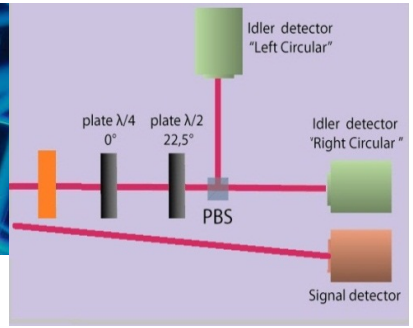
$$P\downarrow A = |((1+i)\cos(\theta)\,Sin(\theta)/\sqrt{2} + Cos\uparrow 2\,(\theta) - iSin\uparrow 2\,(\theta)/\sqrt{2})|\uparrow 2$$

Diagonal

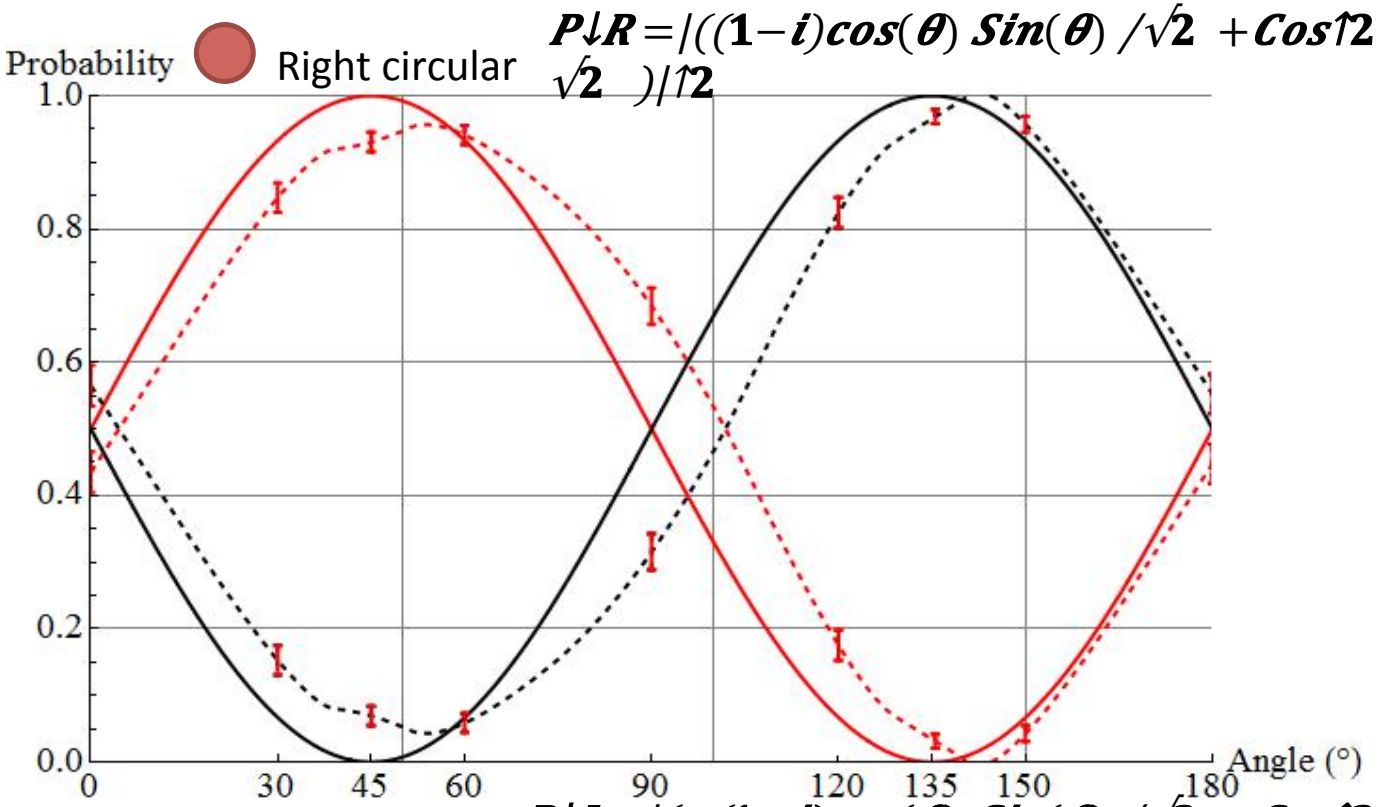
$$P\downarrow D = |(-(1+i)\cos(\theta)\,Sin(\theta)/\sqrt{2} + Cos\uparrow 2\,(\theta) - iSin\uparrow 2\,(\theta)/\sqrt{2})|\uparrow 2$$

Results

Circular basis



QWP

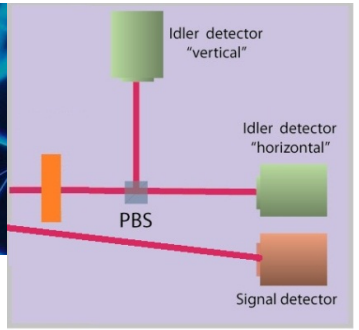


$$P_R = |((1-i)\cos(\theta)\,\mathrm{Sin}(\theta)/\sqrt{2} + \mathrm{Cos}^2(\theta) - i\mathrm{Sin}^2(\theta)/\sqrt{2})|^2$$

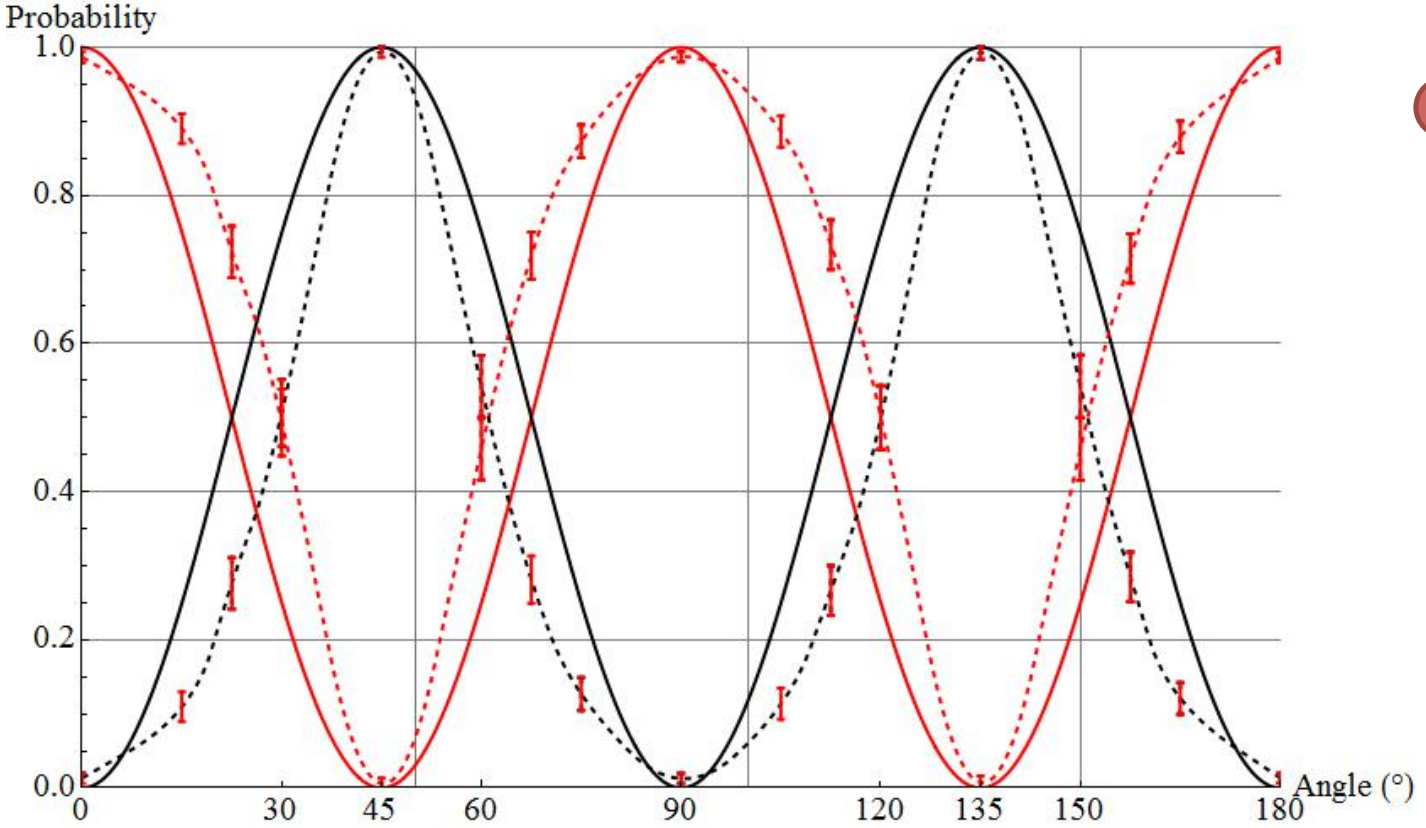
$$P_L = |(-(1-i)\cos(\theta)\,\mathrm{Sin}(\theta)/\sqrt{2} + \mathrm{Cos}^2(\theta) - i\mathrm{Sin}^2(\theta)/\sqrt{2})|^2$$

Results

Horizontal / vertical basis



HWP



Horizontal

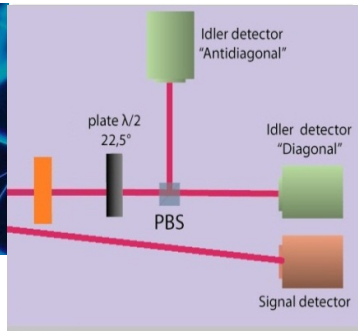
$P\downarrow H = \mathrm{Cos}\hat{}\uparrow 2\downarrow 2\theta$

Vertical

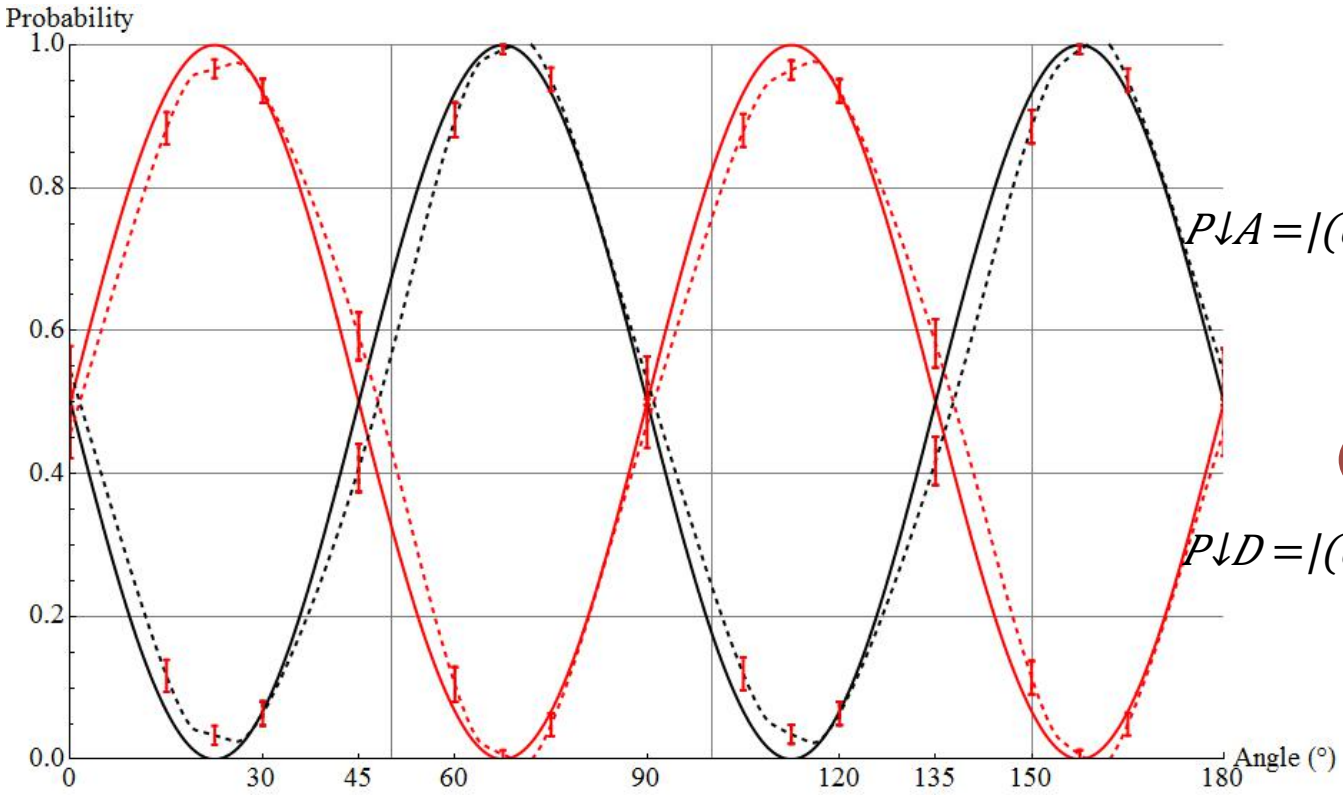
$P\downarrow V = \mathrm{Sin}\hat{}\uparrow 2\downarrow 2\theta$

Results

Diagonal / anti diagonal basis



HWP



Anti-Diagonal

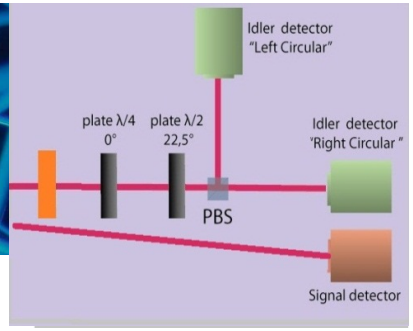
$$P\downarrow A = |(Cos(2\theta)/\sqrt{2} \; -Sin(2\theta),$$

Diagonal

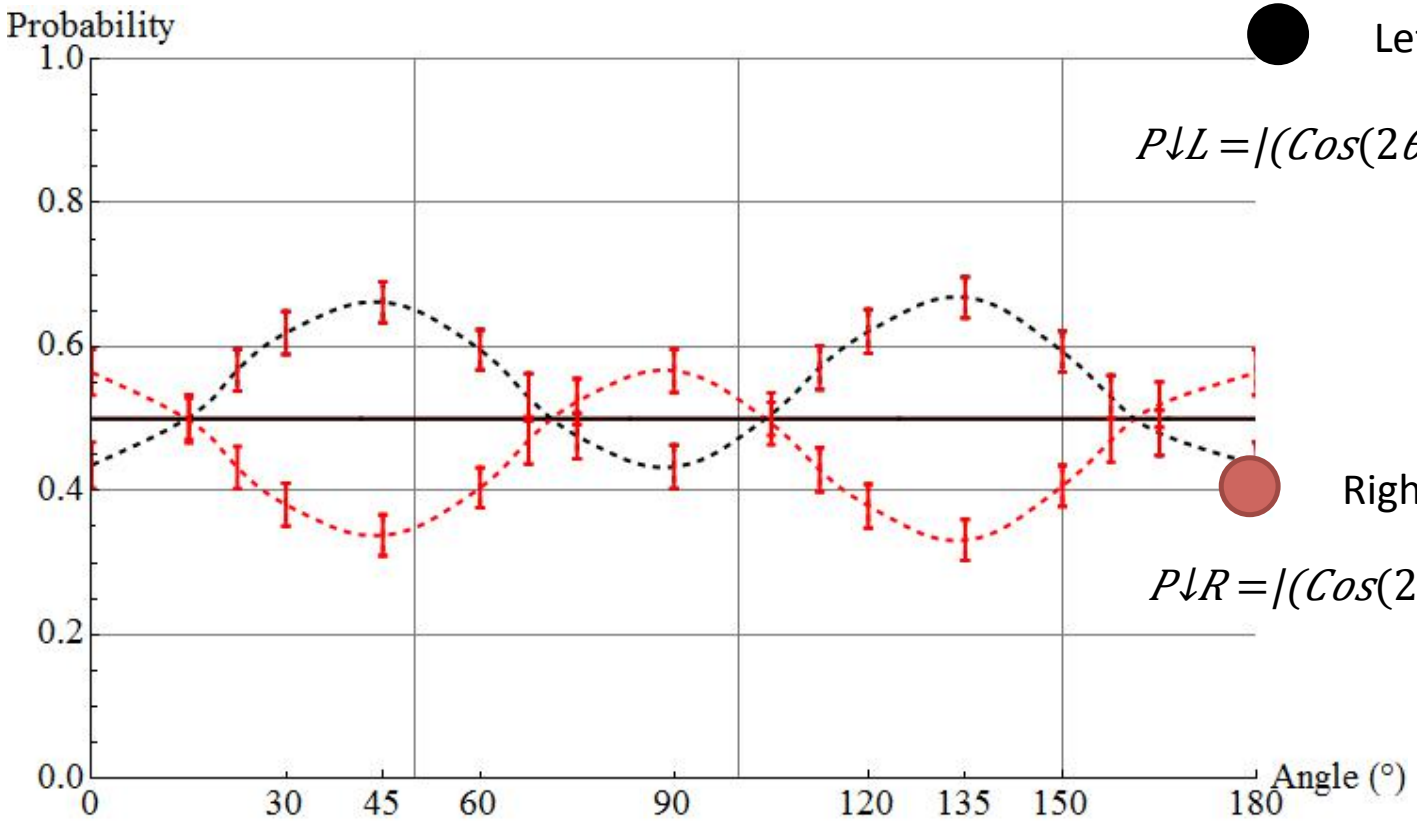
$$P\downarrow D = |(Cos(2\theta)/\sqrt{2} \; +Sin(2\theta),$$

Results

Circular basis



- HWP



Left circular

$$P{\downarrow}L = |(Cos(2\theta)/\sqrt{2} - iSin(2\theta)/$$

Right circular

$$P{\downarrow}R = |(Cos(2\theta)/\sqrt{2} + iSin(2\theta),$$

Conclusions

- The data obtained during the process are theoretically expected which proves operations with qubits in a purely experimental process and shows the characteristics of each operation.

- It serves to understand superposition and normalization concepts on qubits.

- Results show an additional phase compared with theoretical values, due to the alignment of the different wave plates. Therefore it is necessary to improve alignment methods.

- Today this setup is being used by students of a quantum optics course (Universidad de Los Andes), as a regular laboratory session.

Bibliography

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