

Title: Cluster State Quantum Computing in Optical Fibres

Date: Jun 01, 2007 04:10 PM

URL: <http://pirsa.org/07060006>

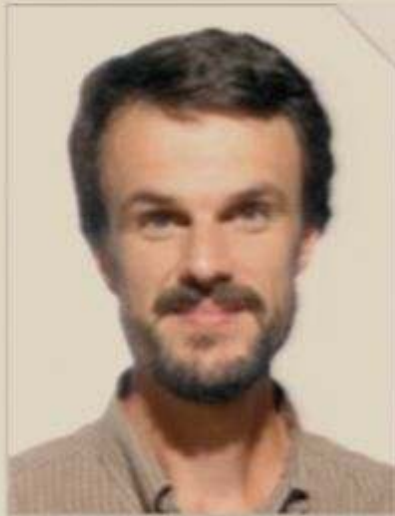
Abstract: In this presentation I will briefly explain the cluster state model of quantum computing. Then will talk about a scheme that uses polarization and time-bin degrees of freedom of photons in optical fibres for the optical realization of this model. We are currently working on the implementation of this scheme in our lab.

Cluster State Quantum Computing in Optical Fibres

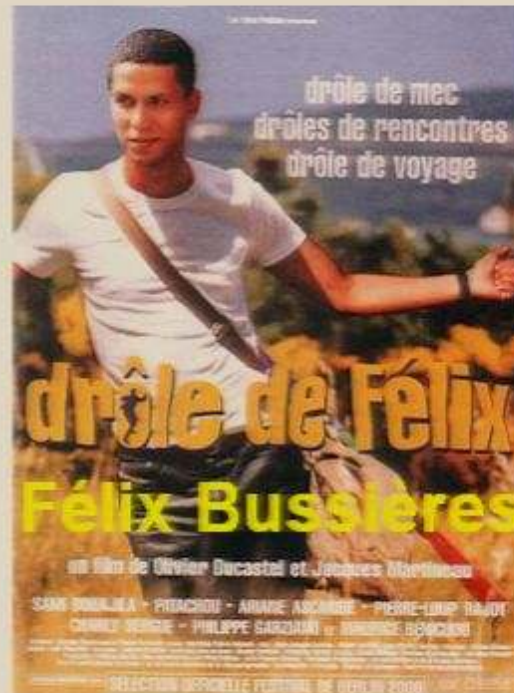
Yasaman Soudagar



Nicolas Godbout



José M. Fernandez

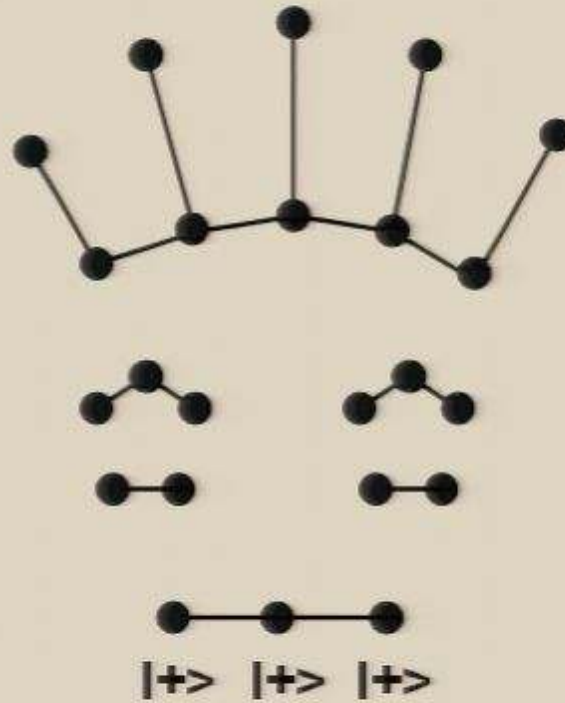


Outline:

- **The Cluster State Model of Quantum Computation**
- **Cluster State Model of QC VS. the Circuit Model in terms of implementation**
- **Our Experimental Method**
- **Immediate Future work!**

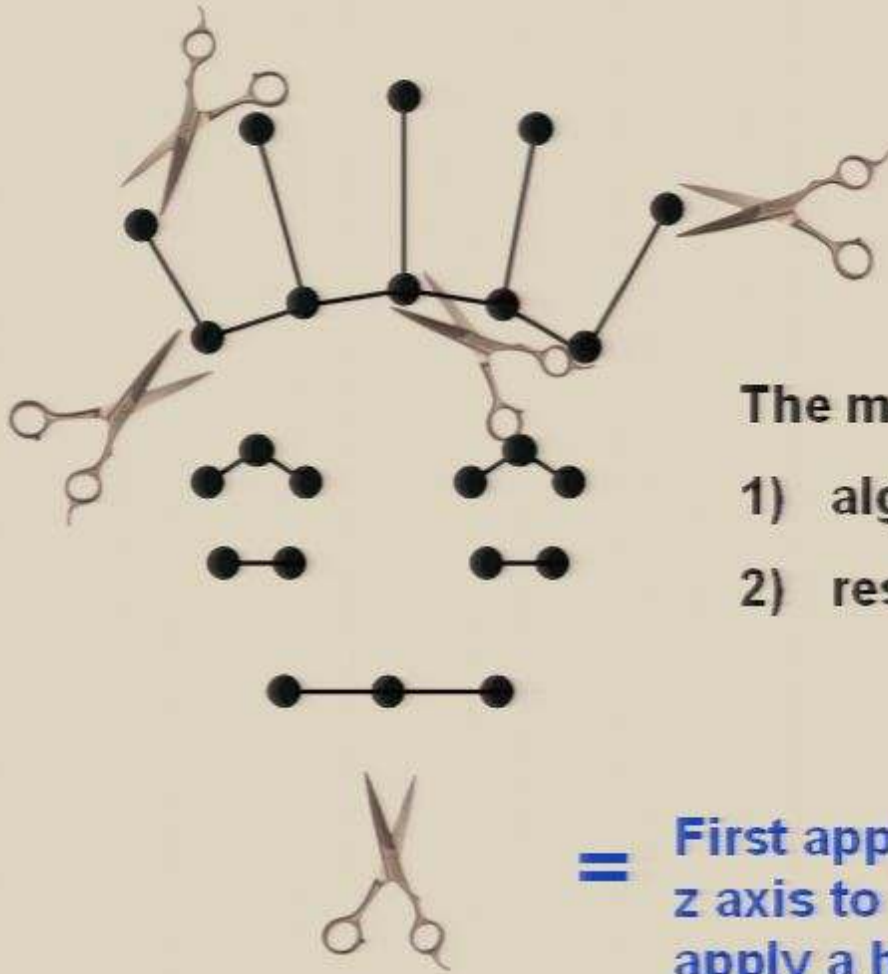
What is a cluster?

What is a cluster?



$$|+\rangle = (|0\rangle + |1\rangle) / \sqrt{2}$$

How to compute with a cluster?



The measurement angles are determined by the:

- 1) algorithm being implemented
- 2) results of the previous measurements

= First apply a rotation by some angle α around the z axis to the qubit that is to be measured, then apply a hadamard on it, and finally detect.

Example

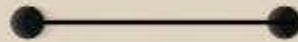
$$\alpha|0\rangle + \beta|1\rangle \quad (|0\rangle + |1\rangle) / \sqrt{2}$$

● ●

$$(\alpha|00\rangle + \alpha|01\rangle + \beta|10\rangle + \beta|11\rangle) / \sqrt{2}$$

Example

$$\alpha|0\rangle + \beta|1\rangle \quad (|0\rangle + |1\rangle) / \sqrt{2}$$



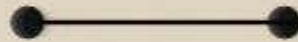
$$(\alpha|00\rangle + \alpha|01\rangle + \beta|10\rangle + \beta|11\rangle) / \sqrt{2}$$

➔ $(\alpha|00\rangle + \alpha|01\rangle + \beta|10\rangle - \beta|11\rangle) / \sqrt{2}$

➔ $|0\rangle \otimes H(\alpha|0\rangle + \beta|1\rangle) + |1\rangle \otimes XH(\alpha|0\rangle + \beta|1\rangle)$

Example

$$\alpha|0\rangle + \beta|1\rangle \quad (|0\rangle + |1\rangle) / \sqrt{2}$$



flow of information



$$(\alpha|00\rangle + \alpha|01\rangle + \beta|10\rangle + \beta|11\rangle) / \sqrt{2}$$

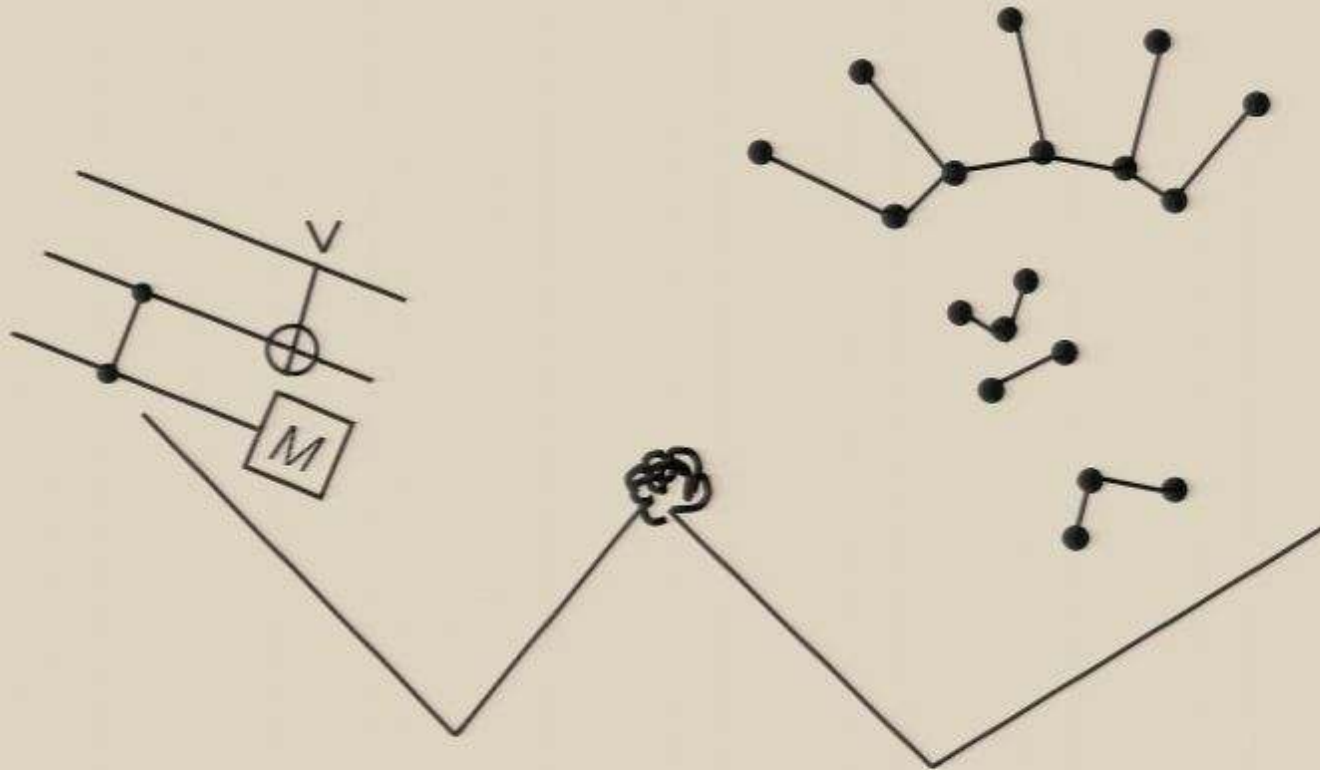


$$(\alpha|00\rangle + \alpha|01\rangle + \beta|10\rangle - \beta|11\rangle) / \sqrt{2}$$

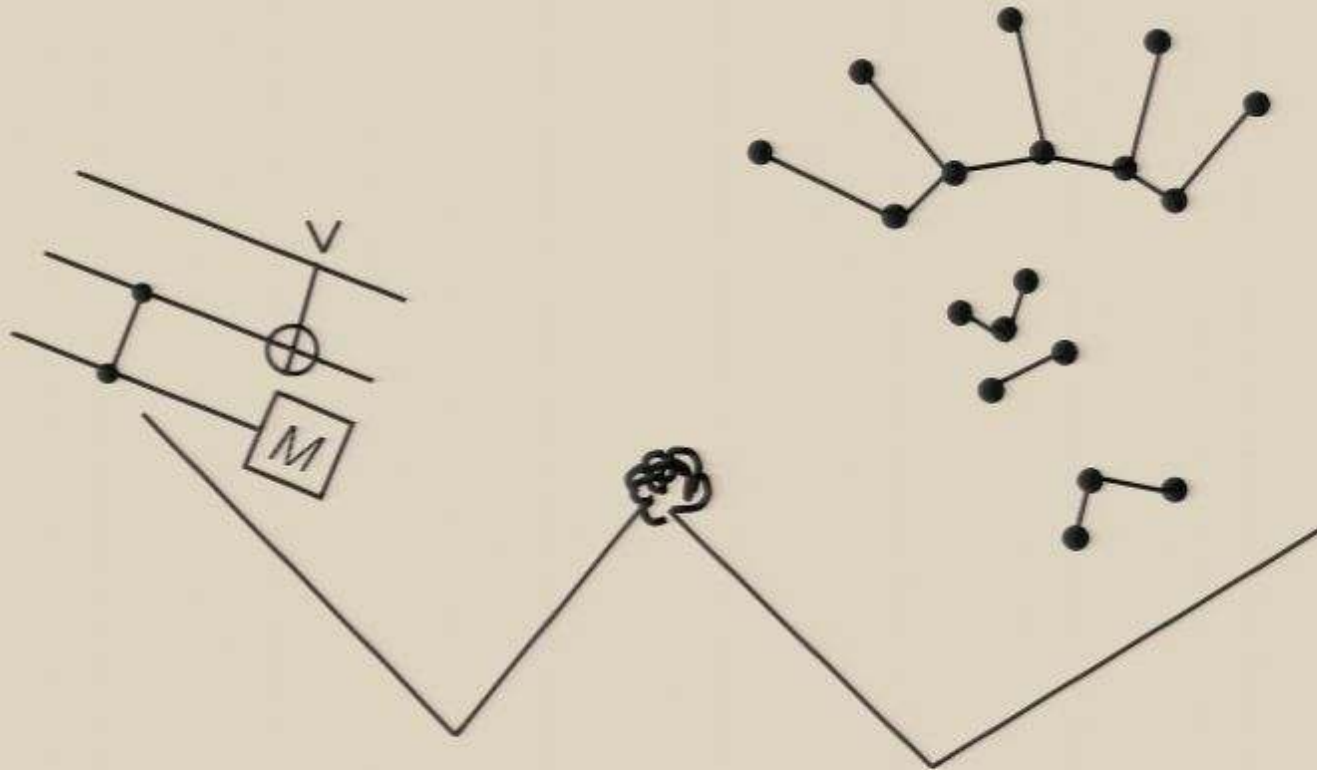


$$|0\rangle \otimes H(\alpha|0\rangle + \beta|1\rangle) + |1\rangle \otimes XH(\alpha|0\rangle + \beta|1\rangle)$$

CLUSTER VS CIRCUIT

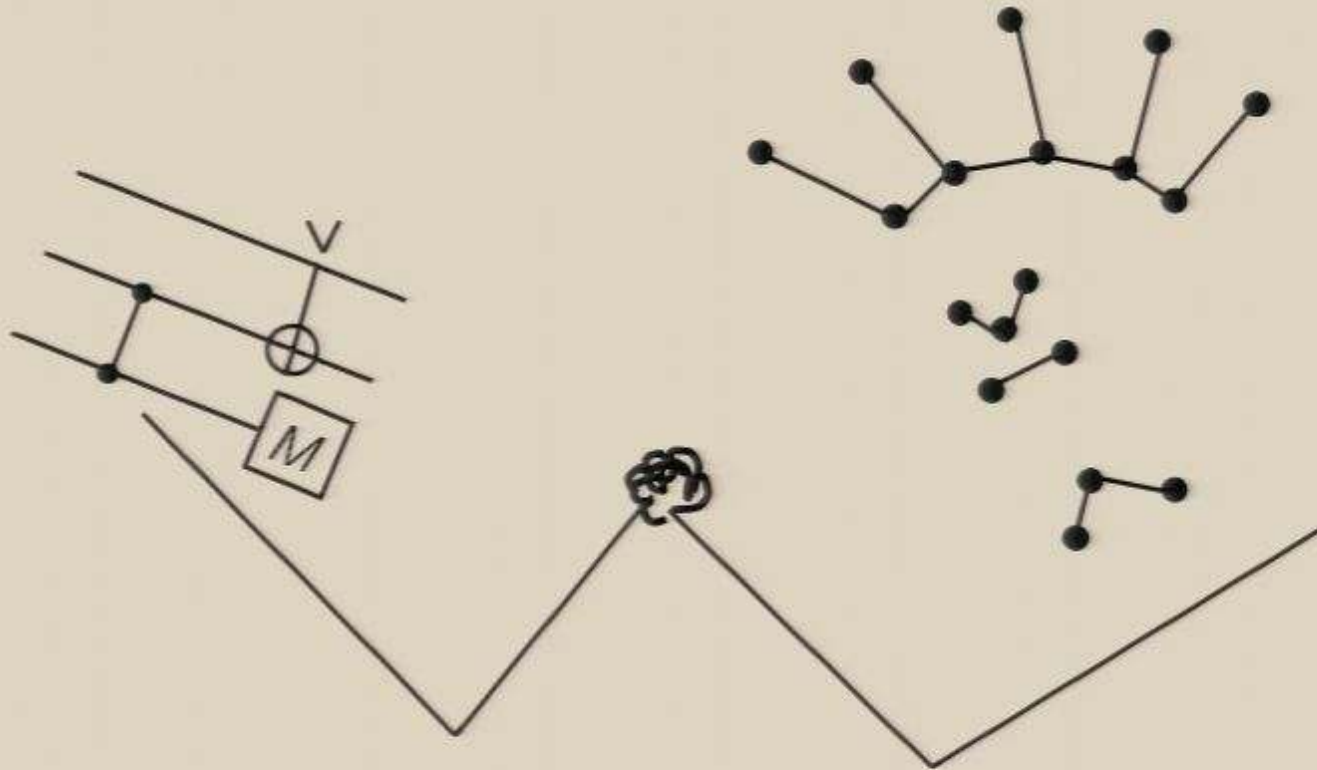


CLUSTER VS CIRCUIT



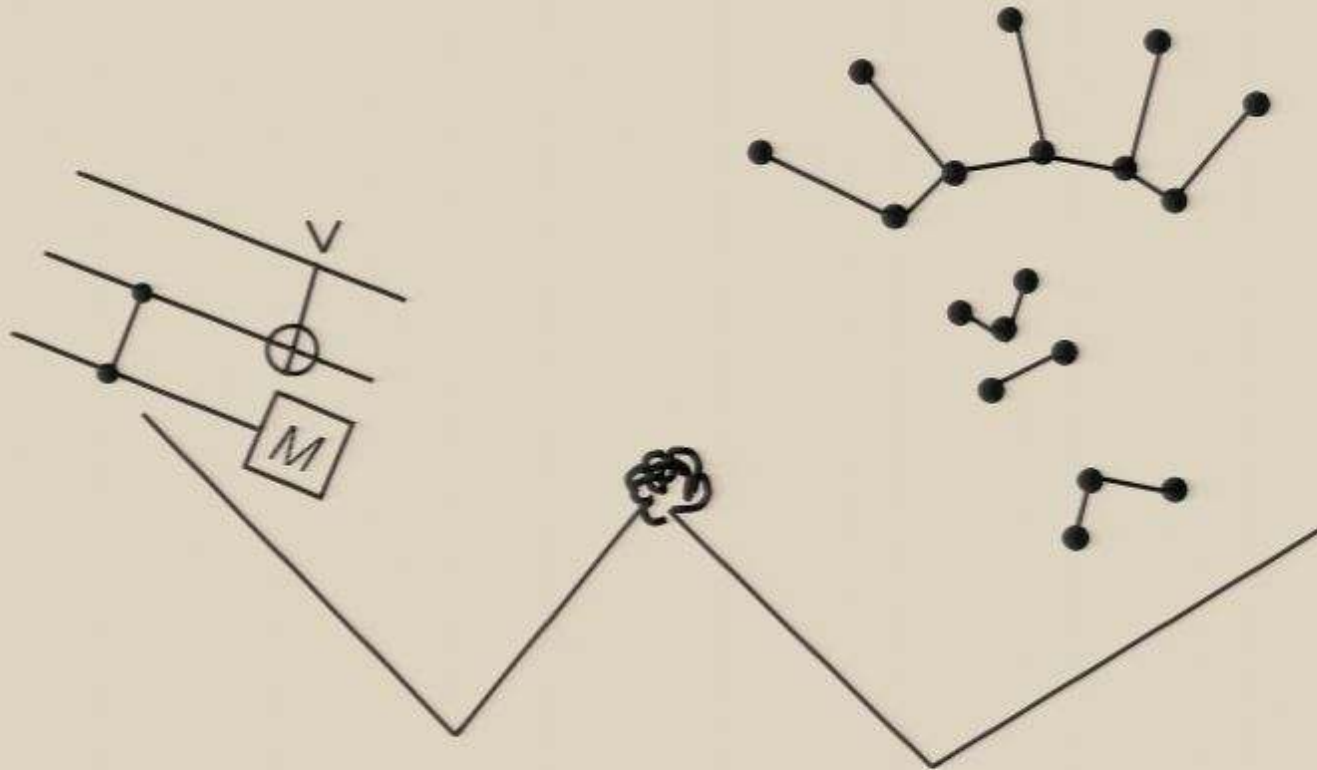
➤ **Input: Single qubit states**

CLUSTER VS CIRCUIT



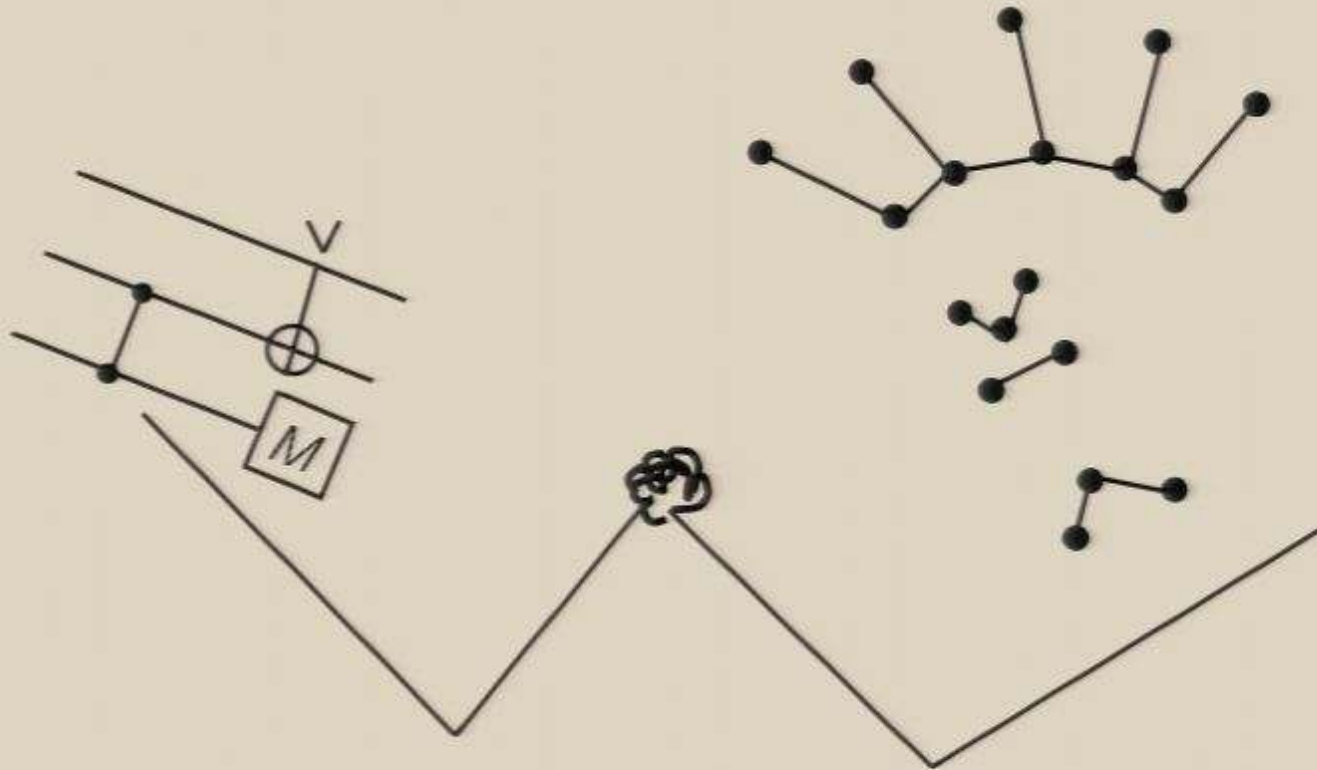
- **Input: Single qubit states**
- **Processing:**
Multi-qubit unitary operations

CLUSTER VS CIRCUIT



- **Input:** Single qubit states
- **Processing:**
Multi-qubit unitary operations
- **Output:** Qubits

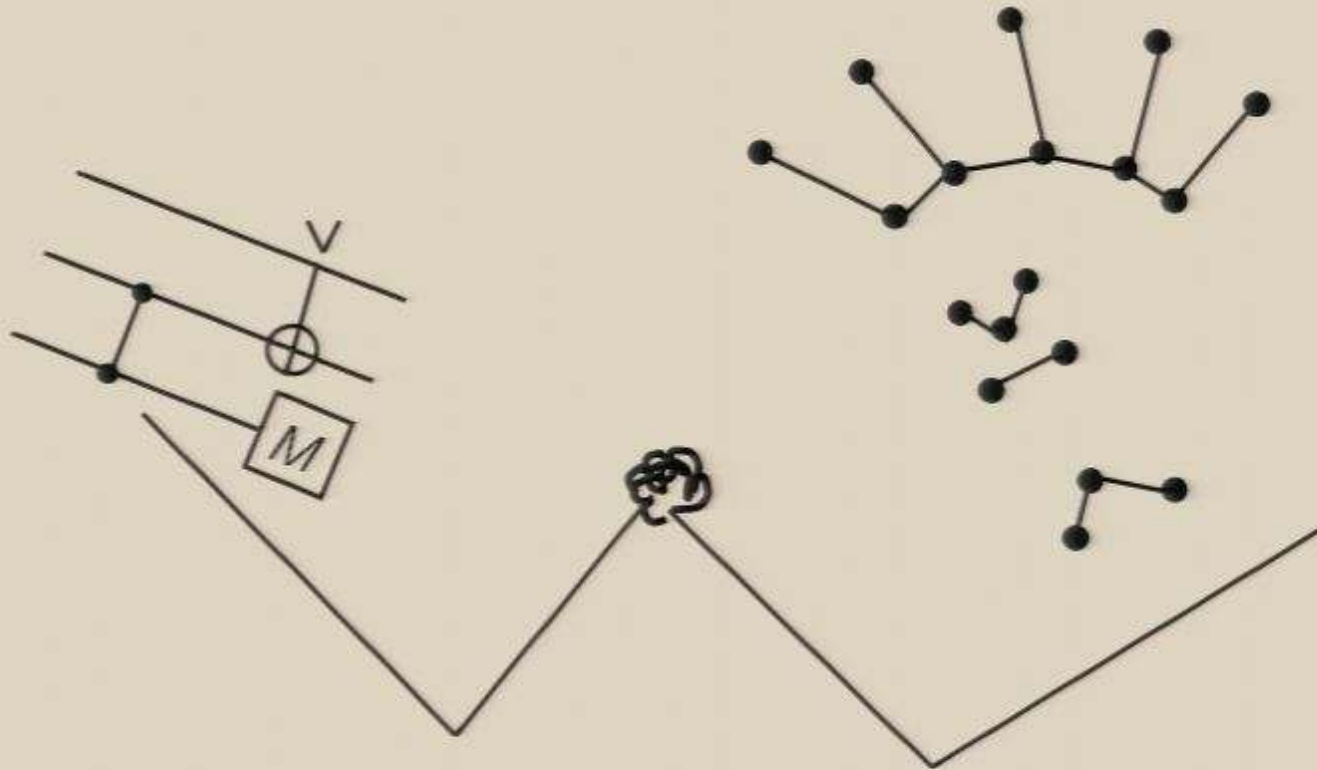
CLUSTER VS CIRCUIT



- **Input:** Single qubit states
- **Processing:**
Multi-qubit unitary operations
- **Output:** Qubits

- **Initial resource:**
Cluster of entangled qubits
- **Computation:**
Single qubit measurements

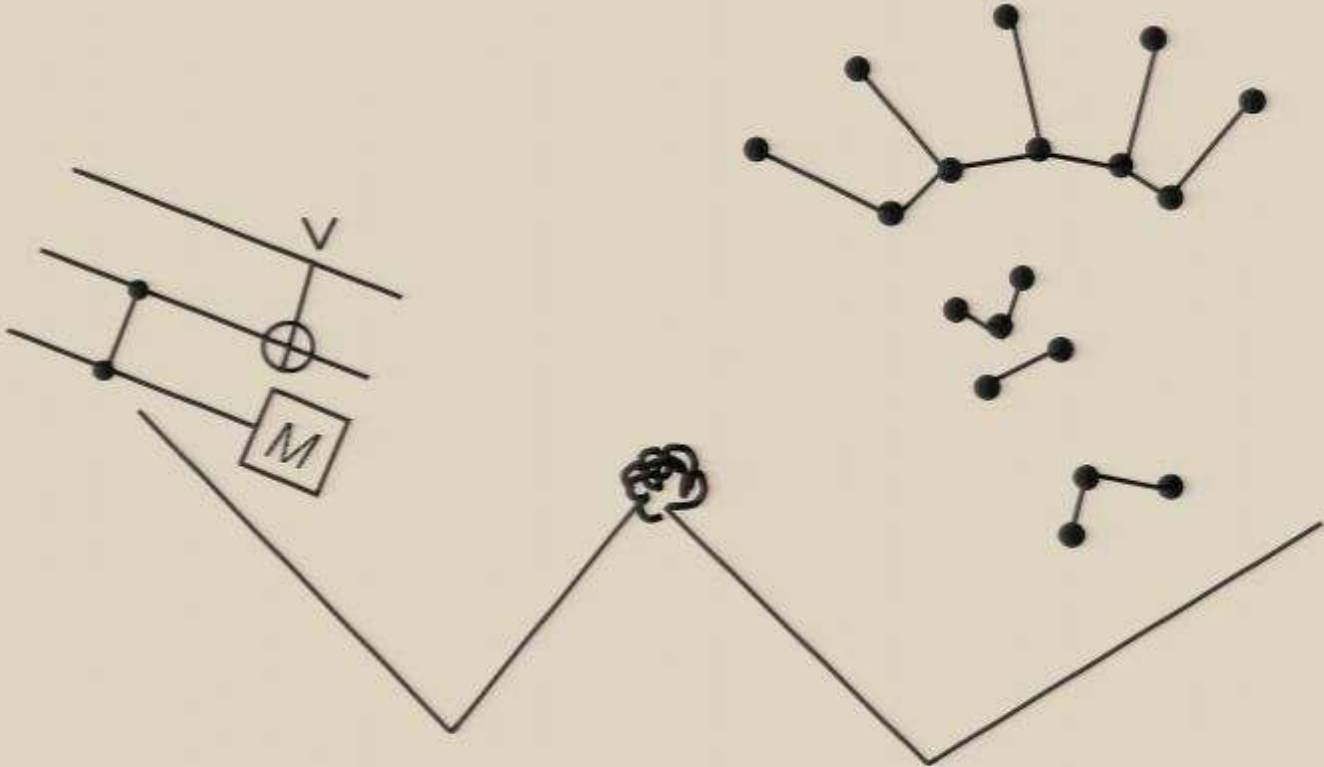
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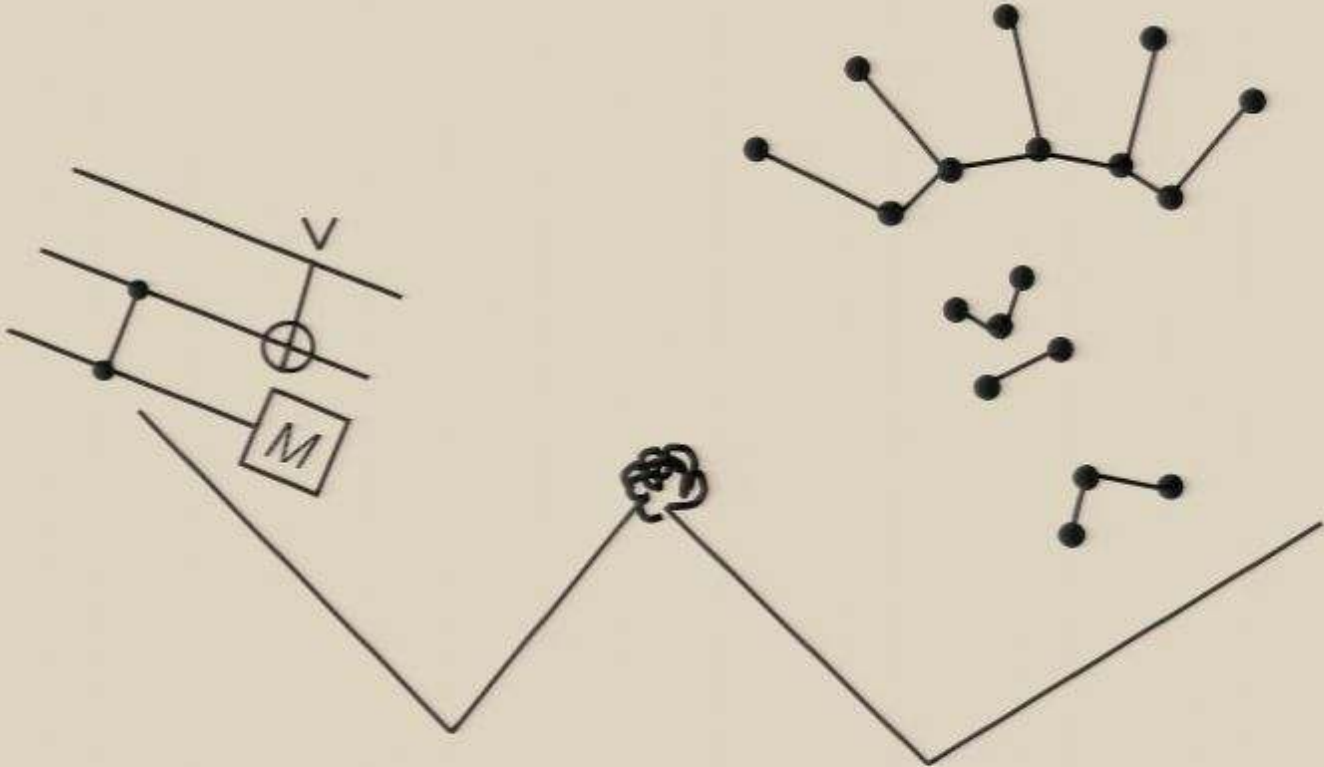
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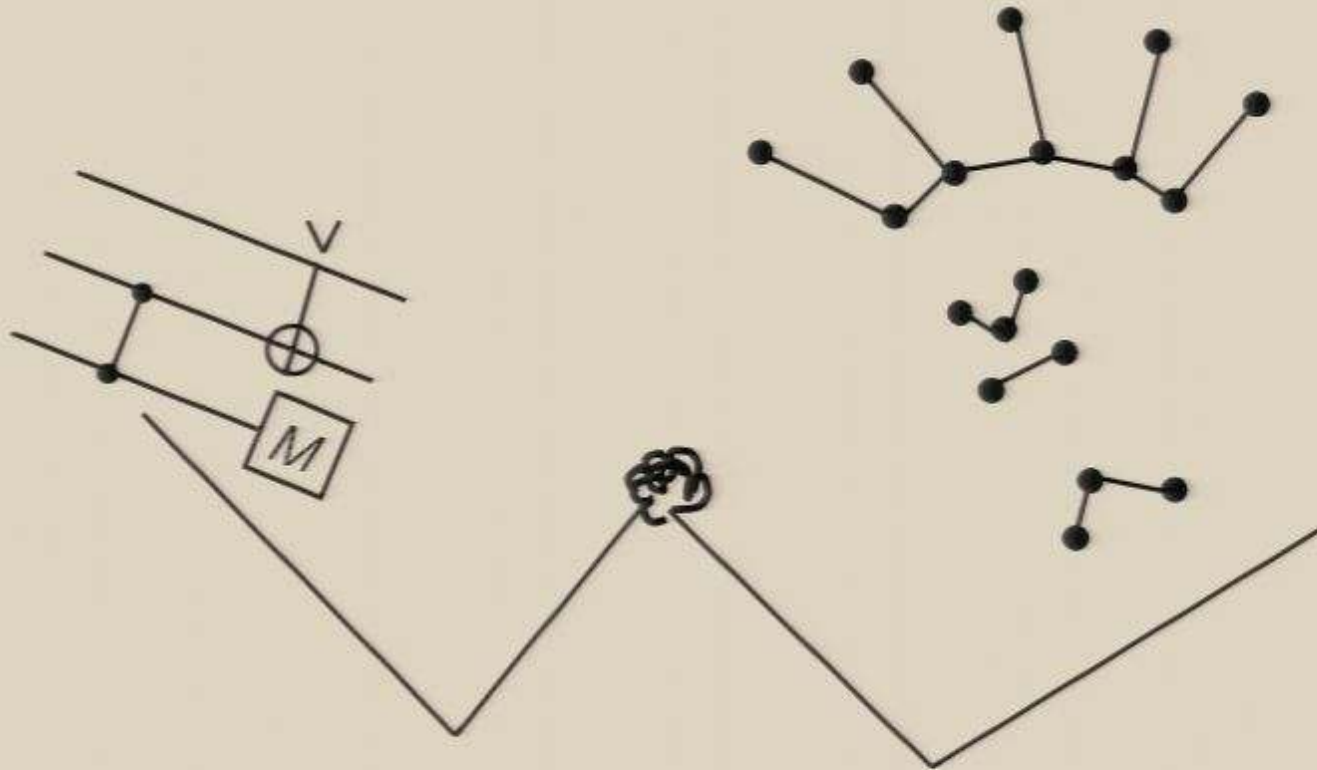
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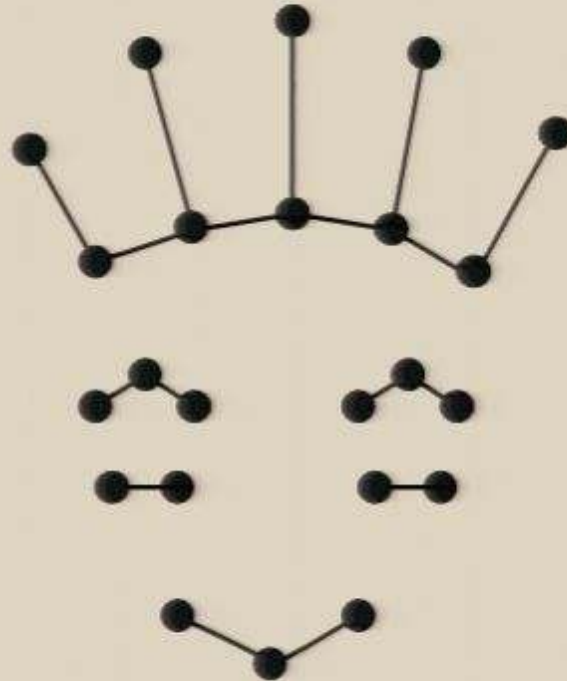
CLUSTER VS CIRCUIT



- Input: Single qubit states
- Processing: Multi-qubit unitary operations
- Output: Qubits

- Initial resource: Cluster of entangled qubits
- Computation: Single qubit measurements

the WINNER is



THE CLUSTER

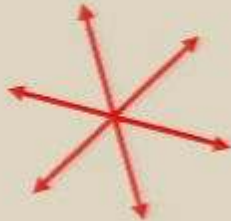
LET THE REAL FUN BEGIN!

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HOW DO WE DO IT IN OUR LAB?

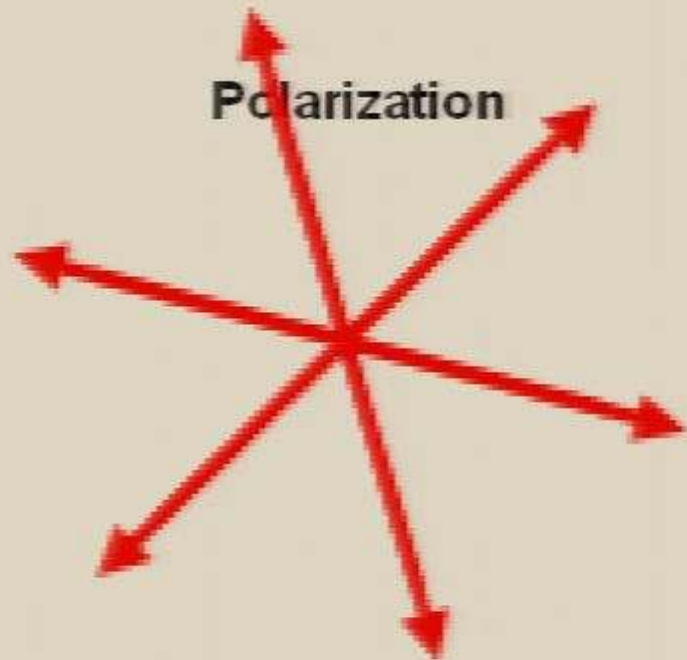
LET THE REAL FUN BEGIN!

HOW DO WE DO IT IN OUR LAB?

Polarization



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HOW DO WE DO IT IN OUR LAB?



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Polarization



$$|H\rangle = |0\rangle$$



$$|V\rangle = |1\rangle$$

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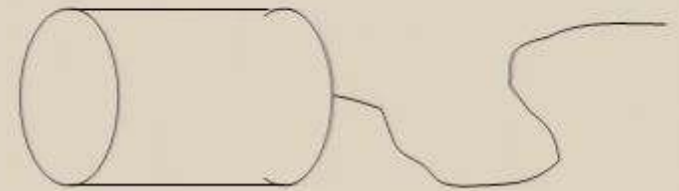


$$|H\rangle = |0\rangle$$



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Time-bin



LET THE REAL FUN BEGIN!

HOW DO WE DO IT IN OUR LAB?

Polarization

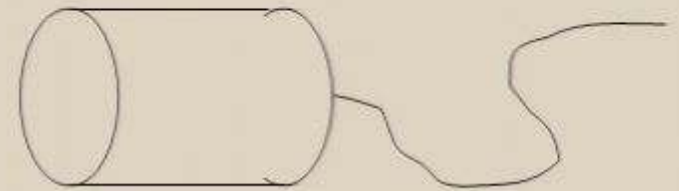


$$|H\rangle = |0\rangle$$



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Time-bin



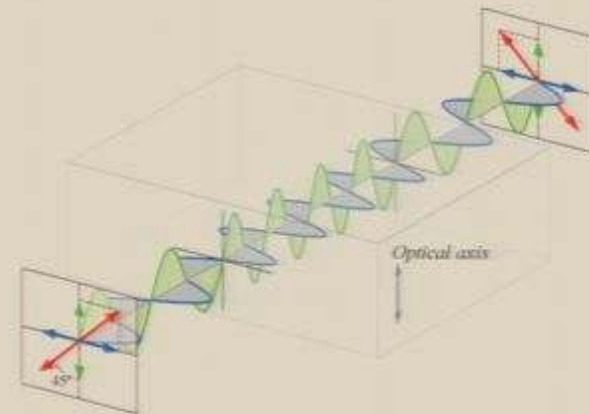
$$|s\rangle = |0\rangle$$

$$|f\rangle = |1\rangle$$

How to create arbitrary qubits?

Half-Wave Plate

$$\alpha|H\rangle + \beta|V\rangle$$

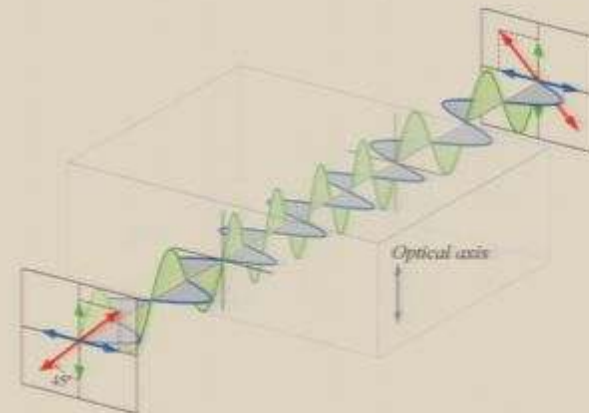


Linearly polarized light entering a wave plate can be resolved into two waves, parallel (shown as green) and perpendicular (blue) to the optical axis of the wave plate. In the plate, the parallel wave propagates slightly slower than the perpendicular one. At the far side of the plate, the parallel wave is exactly half of a wavelength delayed relative to the perpendicular wave, and the resulting combination (red) is orthogonally polarized compared to its entrance state.

How to create arbitrary qubits?

Half-Wave Plate

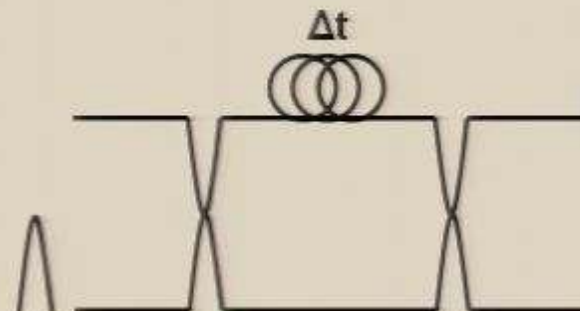
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Interferometer with different arm lengths

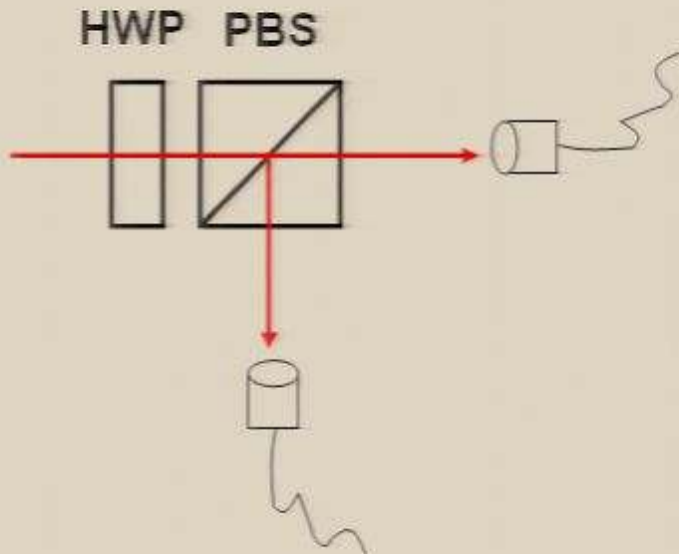
$$\alpha|S\rangle + \beta|L\rangle$$



$$|+\rangle = (|S\rangle + |L\rangle) / \sqrt{2}$$

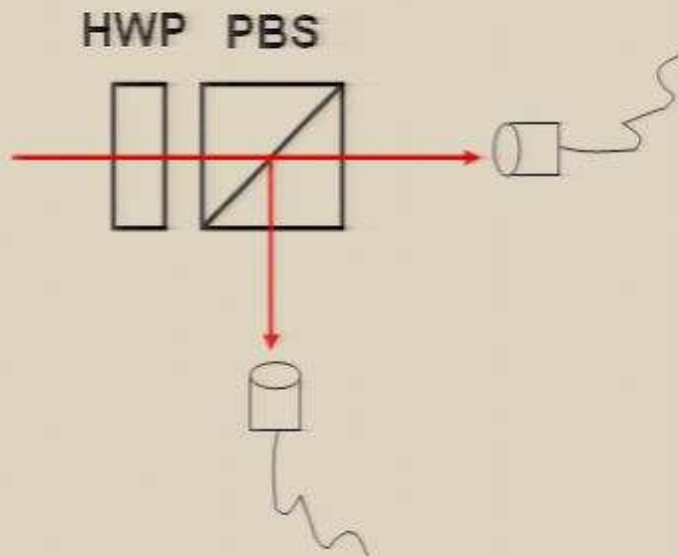
How to measure in different basis angles?

Polarization

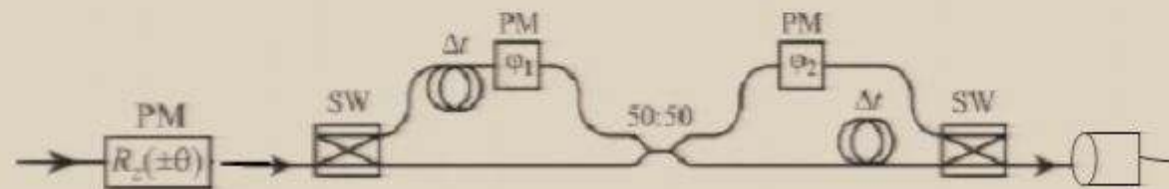


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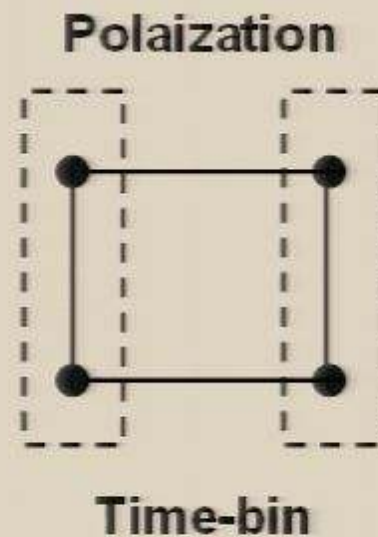
Polarization



Time-bin

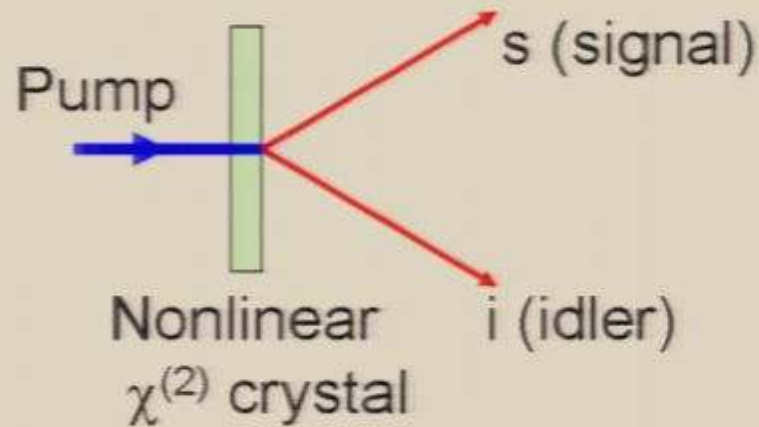


How to create a square cluster using time-bin and polarization degrees of freedom?

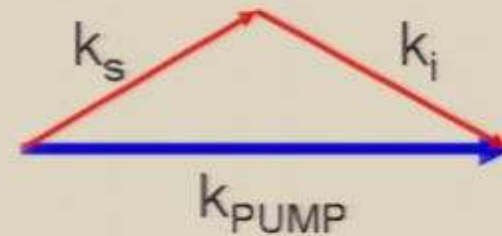


Spontaneous Parametric Down Conversion

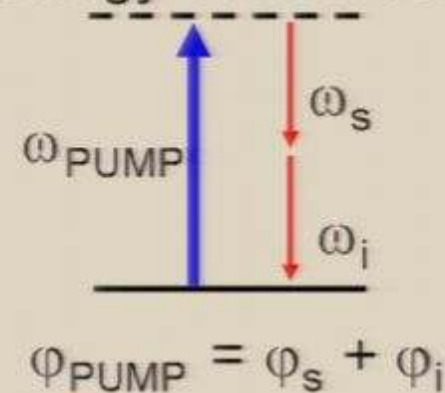
Spontaneous
Parametric
Downconversion



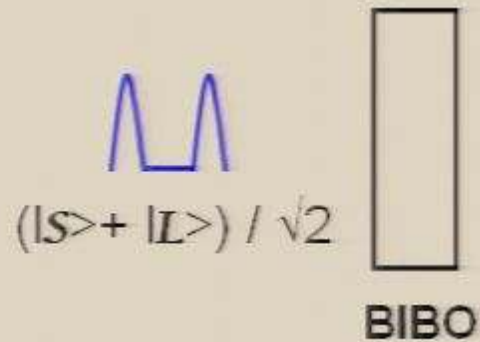
Momentum Conservation



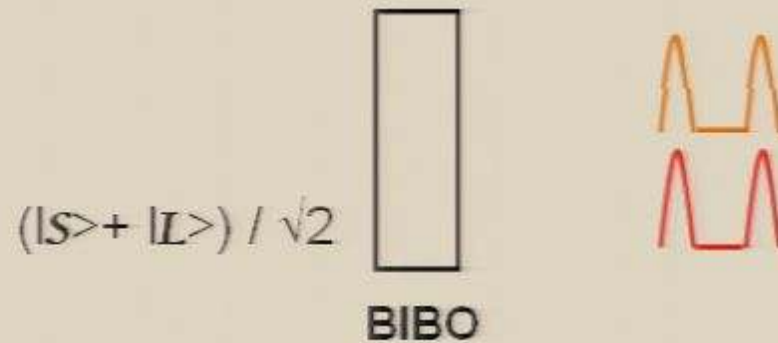
Energy conservation



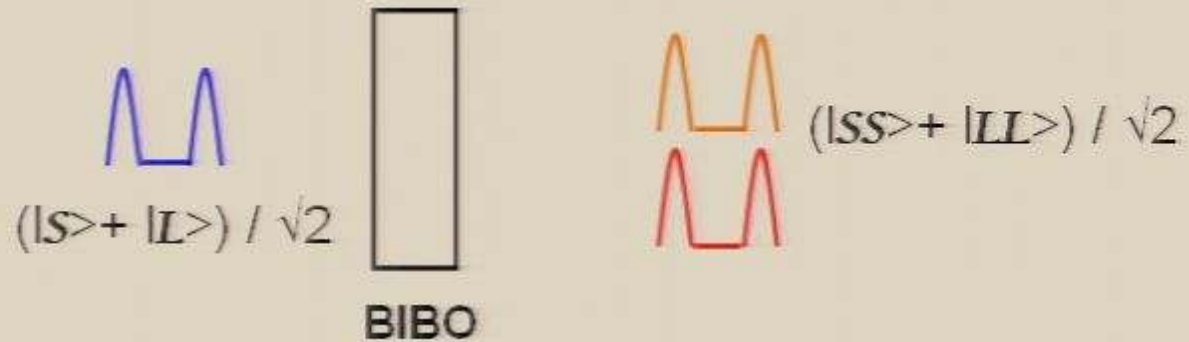
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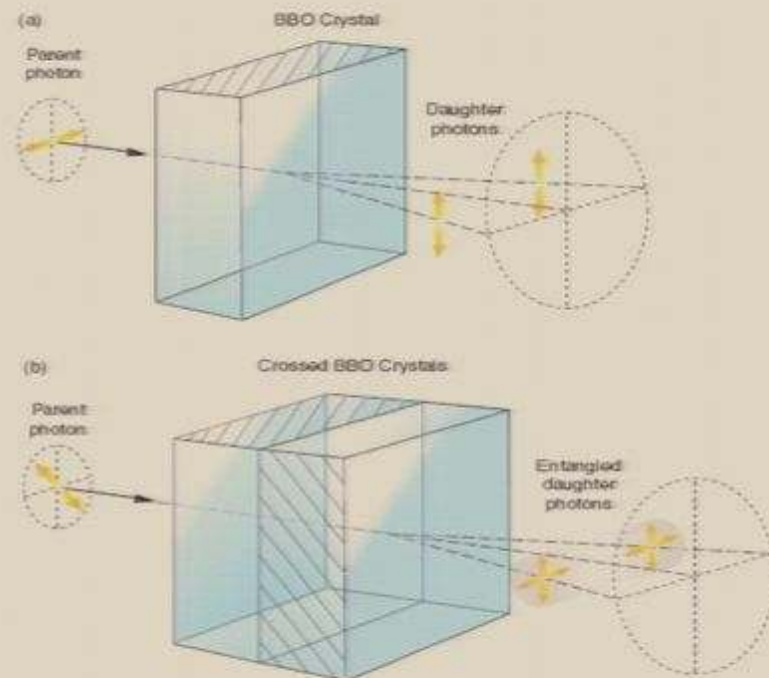
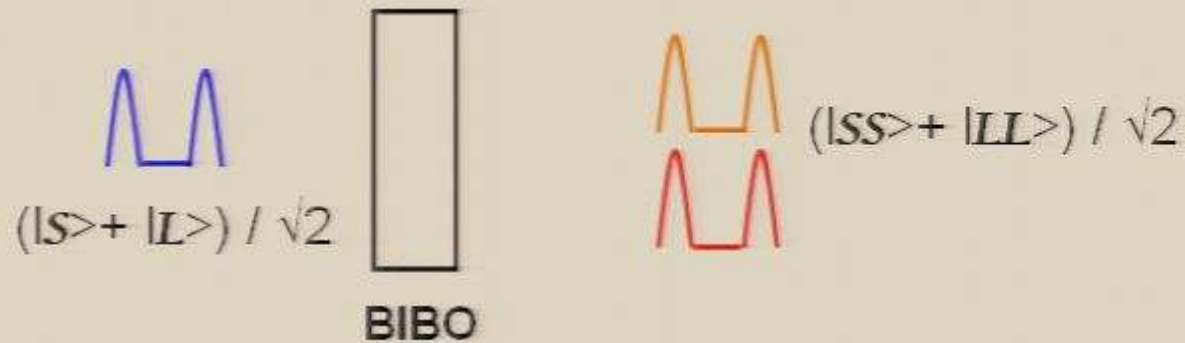
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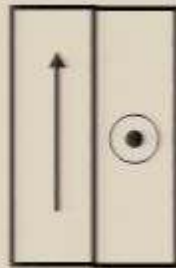
How to create a square cluster using time-bin and polarization degrees of freedom?



$$(|HH\rangle + |VV\rangle) / \sqrt{2}$$

How to create ...


$$(|S\rangle + |L\rangle) / \sqrt{2}$$

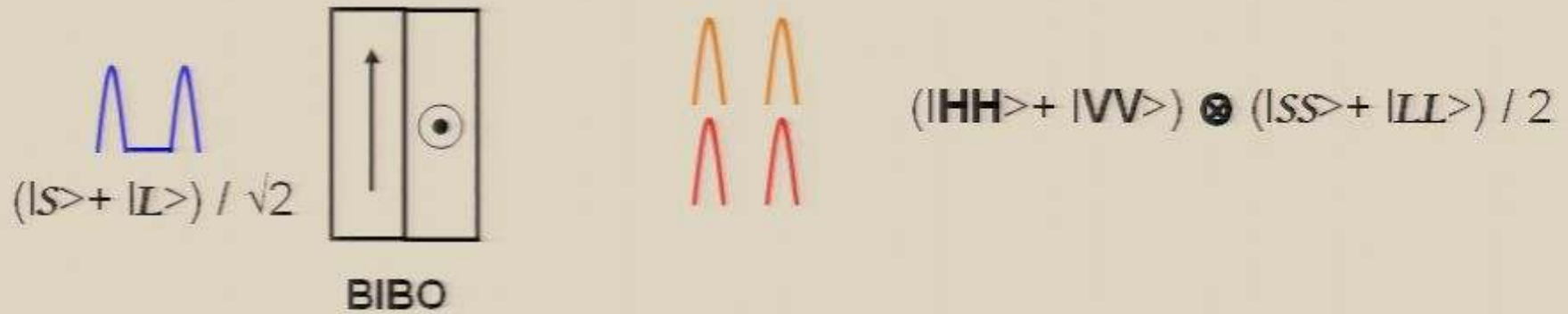


BIBO



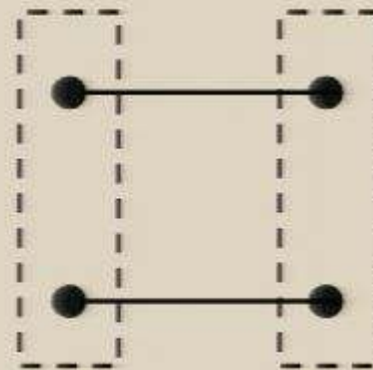
$$(|HH\rangle + |VV\rangle) \otimes (|SS\rangle + |LL\rangle) / 2$$

How to create ...



$(|HH\rangle + |VV\rangle) / \sqrt{2}$

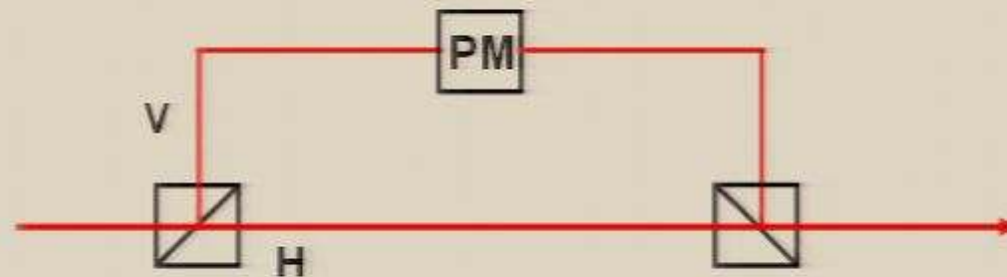
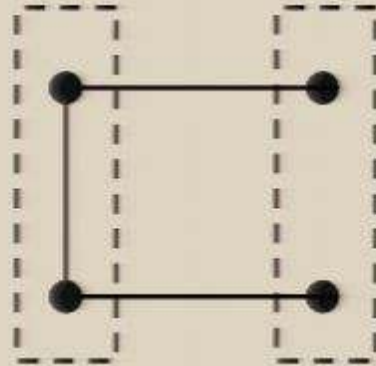
$(|SS\rangle + |LL\rangle) / \sqrt{2}$



How to create ...

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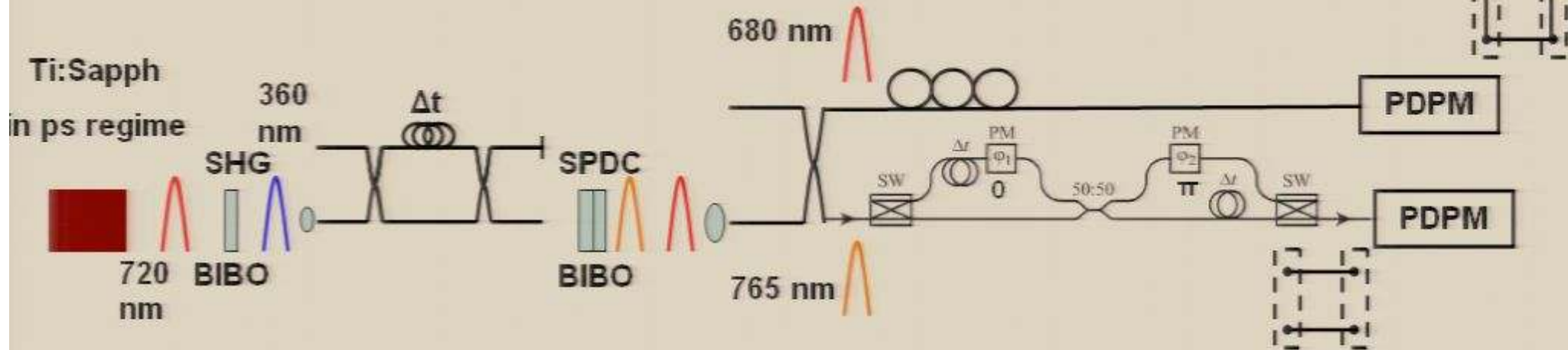
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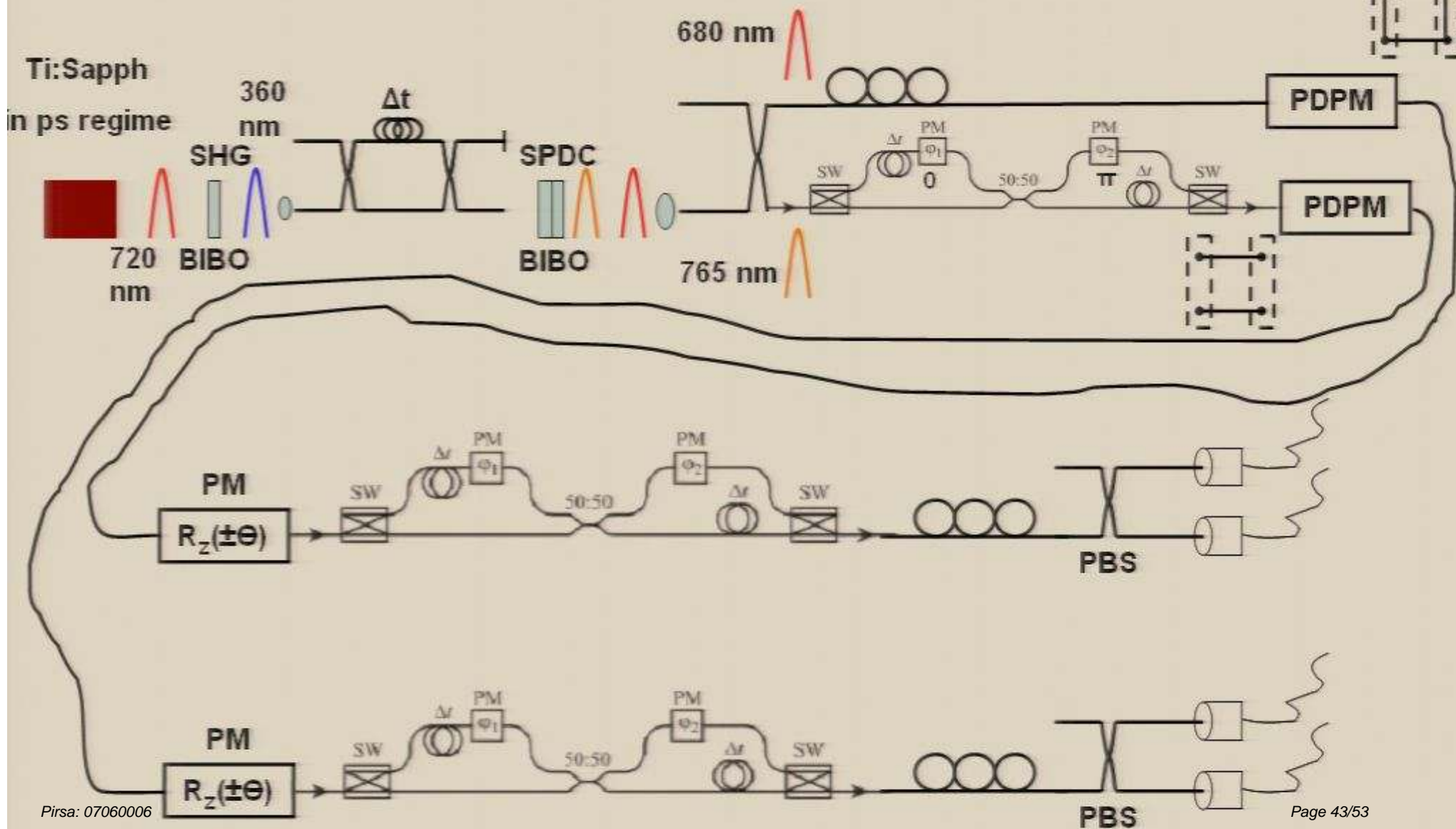
Polarization Dependent Phase Modulator

PDPM

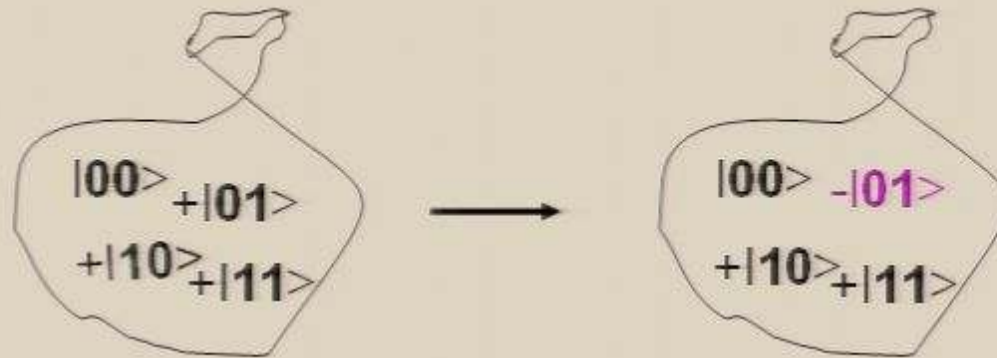
Complete experimental scheme



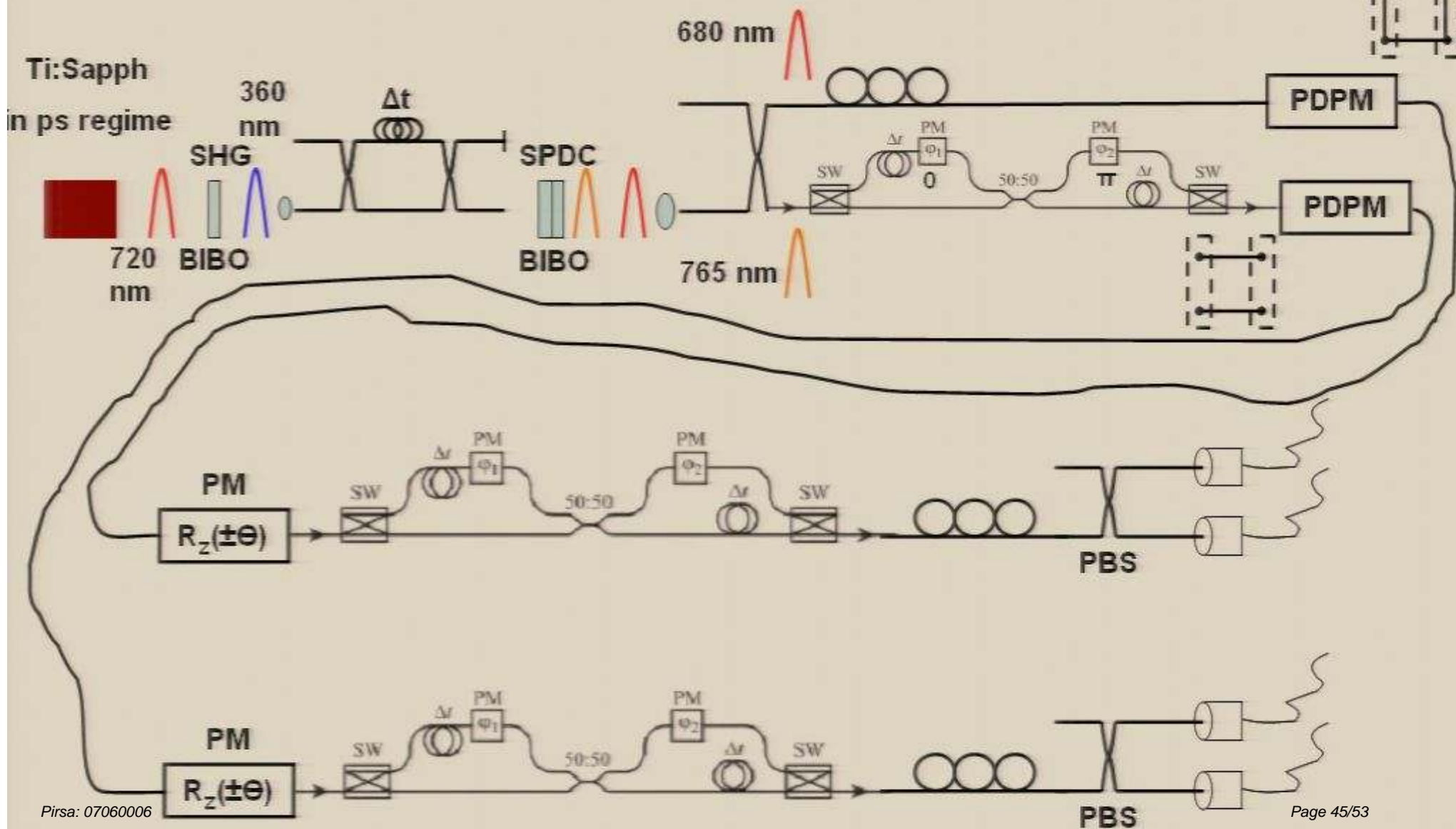
Complete experimental scheme



Grover



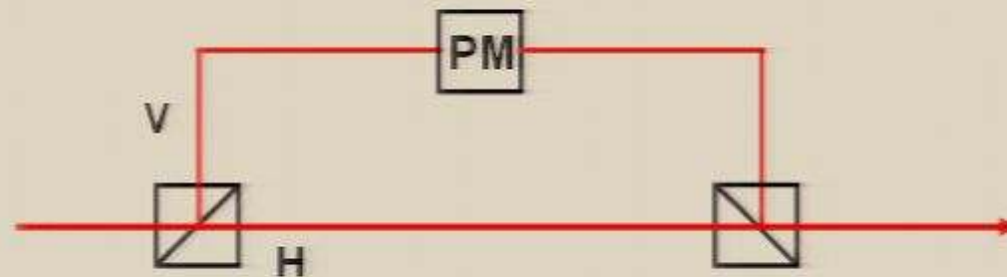
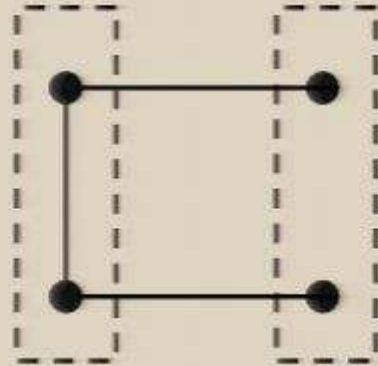
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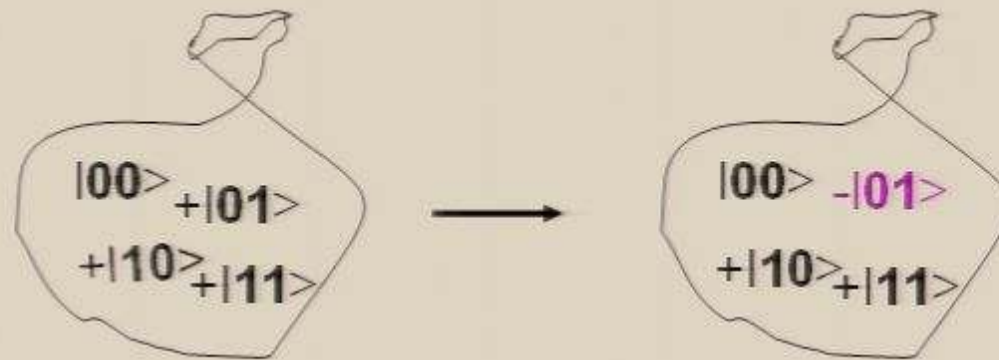
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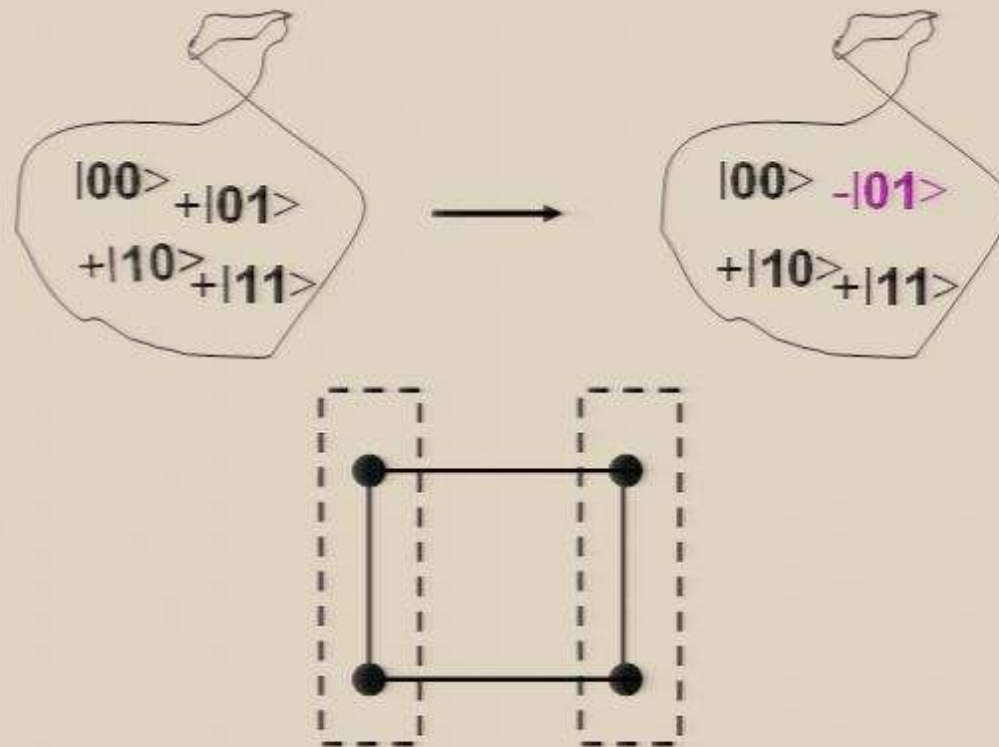
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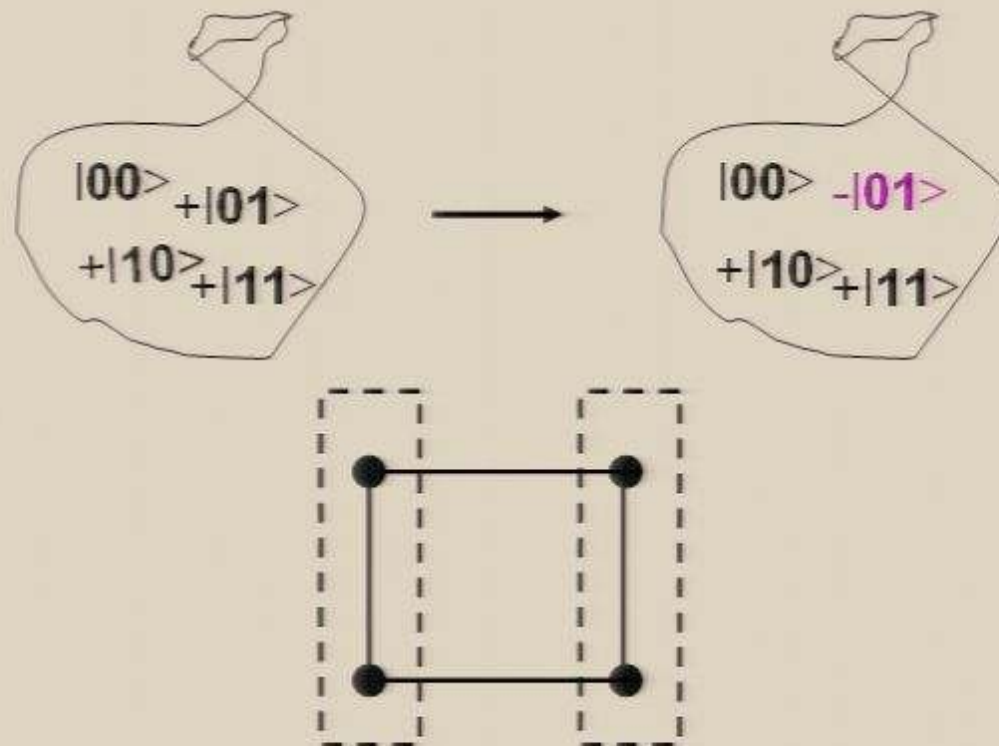
Grover



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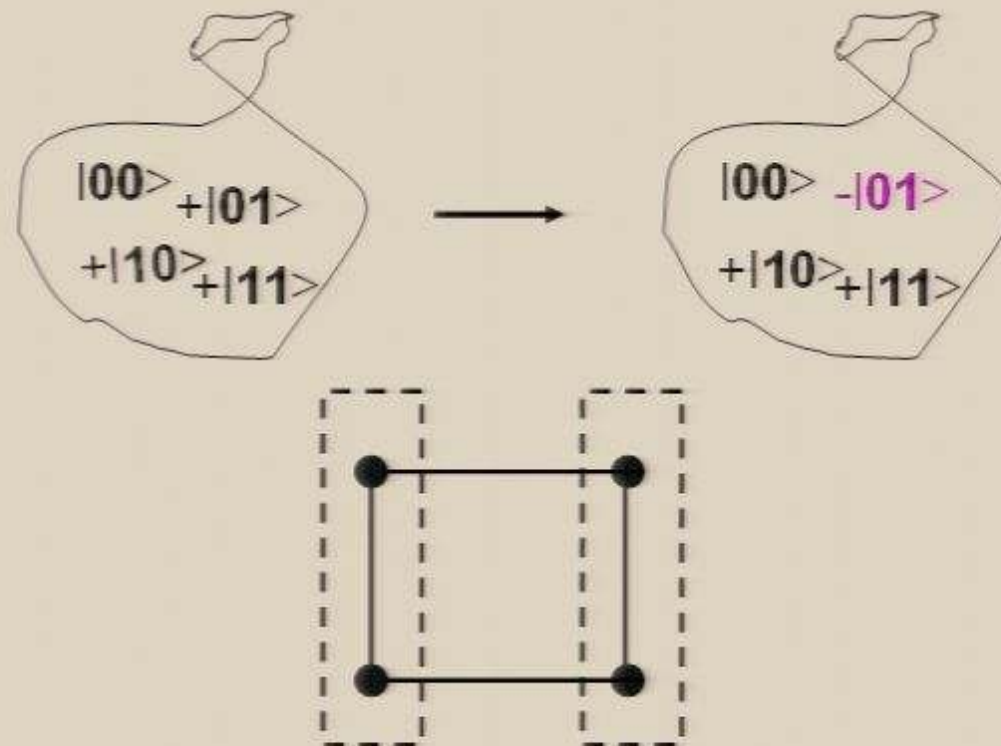


Grover



- ✓ Picks a state, labels it.
- ✓ Then applies a Hadamard, which is a part of the inversion about the average.

Grover



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- ✓ Then applies a Hadamard, which is a part of the inversion about the average.

- ✓ Finishes the inversion about the average
- ✓ Reads out.

Advantage of using more than one degree of freedom

- **Reduces the required amount of resources**
- **Reported more than 95% fidelity for quantum gate output for polarization and spatial degrees of freedom**
- **For our system, using optical fibres to delay photons, we can implement the feed-forward feature of the Cluster State model**

Immediate Future work!

- **Continue building the experimental setup to completion**
- **Study of generation of large clusters using polarization and time-bin degrees of freedom**
- **Study of the types of computations that can be realized when one photon carries more than one qubit**

- Thanks to **Elham Kashefi** for useful discussions on Cluster State model
- Thanks to **you**, I love you all very much. If there is a vote on who gets the iPOD, please vote for me...