Downloading many-body continuous variable entanglement to qubits

Zhihua Han, Kero Lau

Simon Fraser University
Imagine I have some qubits:

\[ | + \rangle \]
and now I entangle the edges with the CZ gate.
The quantum state specified by $G$ is called a **qubit cluster state**.

$$Qubit\ cluster\ state$$

$$|G\rangle = \prod_{i,j \in E} \hat{C}_Z^{ij} |+\rangle^\otimes N$$
Why we need qubit cluster state

Qubit cluster state + Single qubit measurements

Fault tolerant universal quantum computation

A One-Way Quantum Computer

Robert Raussendorf and Hans J. Briegel
Theoretische Physik, Ludwig-Maximilians-Universität München, Germany
(Received 25 October 2000)

We present a scheme of quantum computation that consists entirely of one-qubit measurements on a particular class of entangled states, the cluster states. The measurements are used to imprint a quantum logic circuit on the state, thereby destroying its entanglement at the same time. Cluster states are thus one-way quantum computers and the measurements form the program.

DOI: 10.1103/PhysRevLett.86.5188 PACS numbers: 03.67.Lx, 03.65.Ud

(Raussendorf 2001)
Qubit cluster state

Goal: Make many body entanglement in physical qubits
How do we make scalable qubit cluster states?

Continuous variable (CV) cluster state

"Downloading entanglement from a CV cluster state"
How do we make scalable qubit cluster states?

Continuous variable (CV) cluster state

$|0, \sigma_p \rangle_p$

Qubit cluster state

Entanglement Transfer Protocol
Now if I have some bosons:

$$|0, \sigma_p\rangle_p$$
and entangle them with CV CZ gate:

\[ \left| 0, \sigma_p \right>_p \]

\[ \hat{C}_Z^{CV} = e^{i\hat{q}_1 \hat{q}_2} \]
We say it is a **CV cluster state**.

\[
|0, \sigma_p\rangle_p = C_V^Z e^{i\hat{q}_1 \hat{q}_2} = |G\rangle_{CV} = \prod_{i,j \in E} \hat{C}^C_V |0, \sigma_p\rangle_p^\otimes N
\]
$\sigma_p$ represents the variance of the squeezed state.

When $\sigma_p \to 0$, the CV cluster state is an **ideal** CV cluster state.
\( \sigma_p \) represents the variance of the squeezed state.

When \( \sigma_p \rightarrow 0 \), the CV cluster state is an **ideal CV cluster state**.
Ultra-large-scale continuous-variable cluster states multiplexed in the time domain

Shota Yokoyama¹, Ryuji Ukai¹, Seiji C. Armstrong¹,², Chanond Sornphiphatphong¹, Toshiyuki Kaji¹, Shigenari Suzuki¹, Jun-ichi Yoshikawa¹, Hidehiro Yonezawa¹, Nicolas C. Menicucci³ and Akira Furusawa¹*

10000 modes! 1D, (Furusawa 2013)
How to make CV cluster state

Invited Article: Generation of one-million-mode continuous-variable cluster state by unlimited time-domain multiplexing

Jun-ichi Yoshikawa; Shota Yokoyama; Toshiyuki Kaji; Chanond Sormpiphatphong; Yu Shiozawa; Kenzo Makino; Akira Furusawa

1 million modes, 1D, 2016

Setup:

Resulting graph:

-1
-1/2
-1/4
1/2
1/4

Squeezed states
EPR states
1D cluster state

2D cluster state
How to make CV cluster state

5x1240 modes, 2D, (Furusawa 2019)

QUANTUM COMPUTING
Generation of time-domain-multiplexed two-dimensional cluster state

Warit Asavanant1, Yu Shiozawa1, Shota Yokoyama1, Baramee Charoonsombutamon1, Hiroki Emura1, Rafael N. Alexander2, Shuntaro Takeda2,4, Jun-Ichi Yoshikawa1, Nicolas C. Menicucci2, Hidehiro Yonezawa2, Akira Furusawa4*

Entanglement is the key resource for measurement-based quantum computing. It is stored in quantum states known as cluster states, which are prepared offline and enable quantum computing by means of purely local measurements. Universal quantum computing requires cluster states that are both large and possess (at least) a two-dimensional topology. Continuous-variable cluster states—based on bosonic modes rather than qubits—have previously been generated on a scale exceeding one million modes, but only in one dimension. Here, we report generation of a large-scale two-dimensional continuous-variable cluster state. Its structure consists of a 5- by 1240-site square lattice that was tailored to our highly scalable time-multiplexed experimental platform. It is compatible with Bosonic error-correcting codes that, with higher squeezing, enable fault-tolerant quantum computation.

QUANTUM COMPUTING
Deterministic generation of a two-dimensional cluster state

Mikkel V. Larsen1, Xueshi Guo, Casper R. Breum, Jonas S. Neergaard-Nielsen, Ulrik L. Andersen3

Measurement-based quantum computation offers exponential computational speed-up through simple measurements on a large entangled cluster state. We propose and demonstrate a scalable scheme for the generation of photonic cluster states suitable for universal measurement-based quantum computation. We exploit temporal multiplexing of squeezed light modes, delay loops, and beam-splitter transformations to deterministically generate a cylindrical cluster state with a two-dimensional (2D) topological structure as required for universal quantum information processing. The generated state consists of more than 30,000 entangled modes arranged in a cylindrical lattice with 24 modes on the circumference, defining the input register, and a length of 1250 modes, defining the computation depth. Our demonstrated source of two-dimensional cluster states can be combined with quantum error correction to enable fault-tolerant quantum computation.

24x1250, 2D (Andersen 2019)
Continuous variable (CV)

Cluster state

$|0\rangle_p$

How to perform entanglement transfer?

$\hat{C}_Z^{CV} = e^{i\hat{q}_1\hat{q}_2}$

$\hat{C}_Z = \text{diag}(1, 1, 1, -1)$

Entanglement transfer protocol
How to perform entanglement transfer?

Continuous variable (CV) cluster state

$$|0\rangle_p$$

Qubit cluster state

$$\hat{C}^{CV}_Z = e^{i\hat{q}_1\hat{q}_2}$$

Entanglement transfer protocol

$$\hat{C}_Z = \text{diag}(1, 1, 1, -1)$$
Entanglement transfer protocol

How to perform entanglement transfer?

We need:

- A CV cluster state
- $\hat{q}$ quadrature homodyne detection
- Conditional displacement gate $\hat{C}_D$

$$\hat{C}_D = |0\rangle\langle 0|\hat{I} + |1\rangle\langle 1|\hat{D}_q(\sqrt{\pi})$$
Displacement gate of strength $a$ shifts the state.

$$\hat{D}_q(a) |x\rangle := |x + a\rangle$$
Displacement gate of strength $a$ shifts the state.

$$\hat{D}_q(a) |x\rangle := |x + a\rangle$$
Displacement gate of strength $a$ shifts the state.

\[ \hat{D}_q(a)|x\rangle := |x + a\rangle \]
1. Initialize all qubits to $|+\rangle$. 

\[ |+\rangle \]
Step 2: Get a CV cluster state.

$|0\rangle_p$

$\hat{C}^{CV}_Z$
Step 3. Apply conditional displacement to each pair:

$$\hat{C}_D = |0\rangle\langle 0| \hat{I} + |1\rangle\langle 1| \hat{D}_q(\sqrt{\pi})$$
Step 3. Apply conditional displacement to each pair:
\[ \hat{C}_D = |0\rangle\langle 0|\hat{I} + |1\rangle\langle 1|\hat{D}_q(\sqrt{\pi}) \]
Step 4. Measure $q$ quadrature.
You now have a qubit cluster state!

But why does it work?
We show there is a hidden qubit cluster state inside a CV cluster state!
$$|0\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} |2n\sqrt{\pi}\rangle_q$$

Gottesman-Kitaev-Preskill (GKP state)
\[ |1\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} (2n + 1) \sqrt{\pi} |q\rangle \]

\[ \hat{X}^{\text{GKP}} = e^{-i\sqrt{\pi} \hat{p}} = \hat{D}_q(\sqrt{\pi}) \]
\[ |0\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} |2n\sqrt{\pi}\rangle_q \]
\[ |1\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} |(2n + 1)\sqrt{\pi}\rangle_q \]
$$|+\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} |n\sqrt{\pi}\rangle_q = \frac{1}{\sqrt{2}} (|0\rangle_{\text{GKP}} + |1\rangle_{\text{GKP}})$$
Node of ideal CV cluster

\[ |0\rangle_p \]
Node of ideal CV cluster
Node of ideal CV cluster

\[ |0\rangle_p \quad |+\rangle_{\text{GKP}} \quad q \]

GKP state
\[ |+_{\mu_q,0}\rangle_{\text{GKP}} \equiv \hat{D}_q(\mu_q)|+\rangle_{\text{GKP}} \]

\[ |0\rangle_p \]

\[ \mu_q \in \left[-\frac{\sqrt{\pi}}{2}, -\frac{\sqrt{\pi}}{2}\right) \]

Displaced GKP state

(Glancy 2006)
Node of ideal CV cluster is superposition of displaced GKP

\[ |+\mu_q,0\rangle_{GKP} \equiv \hat{D}_q(\mu_q) |+\rangle_{GKP} \]

So if we integrate over \( \mu_q \), we should form an ideal \( |0\rangle_p \) state.
Node of ideal CV cluster is superposition of displaced GKP
Edges of ideal CV cluster

\[ |0\rangle_p \quad \hat{C}^{CV}_Z \quad |0\rangle_p \]
$|0\rangle_p$  

$q$  

$\hat{C}_Z^{CV} = \int \int d\mu_{q_1} d\mu_{q_2}$  

$|0\rangle_p$  

$q$  

Edges of ideal CV cluster
\[ |0\rangle_p \quad \hat{C}_Z^{CV} \quad = \quad \int \int d\mu_{q_1} d\mu_{q_2} \quad \hat{C}_Z^{CV} \quad + \quad \hat{C}_Z^{CV} \quad + \quad \hat{C}_Z^{CV} \quad + \quad \hat{C}_Z^{CV} \quad + \quad \hat{C}_Z^{CV} \quad + \quad \hat{C}_Z^{CV} \quad + \quad \hat{C}_Z^{CV} \quad + \quad \hat{C}_Z^{CV} \]

Edges of ideal CV cluster
Nodes of a ideal CV cluster state is a superposition of displaced GKP states

Node of ideal CV cluster is displaced GKP

Nodes of ideal CV cluster state

Displaced GKP states

$\hat{C}_Z^{CV}$

$|0\rangle_p$

$|+\mu_q,0\rangle_{GKP}$
Edge of ideal CV cluster is GKP CZ

The edges of the CV cluster state?

GKP CZ gate
\( \hat{C}_{Z}^{\text{CV}} = e^{i\hat{q}_1 \hat{q}_2} \)

\( |+\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} |n\sqrt{\pi}\rangle_q \)

\( \hat{C}_{Z}^{\text{CV}} |++\rangle_{\text{GKP}} = ? \)

Substitute definition
\[ \hat{C}_Z^{CV} = e^{i\hat{q}_1\hat{q}_2} \]

\[ |+\rangle_{GKP} = \sum_{n=-\infty}^{\infty} |n\sqrt{\pi}\rangle_q \]

\[ e^{i\hat{q}_1\hat{q}_2} \sum_{n_1,n_2} |n_1\sqrt{\pi}\rangle_q |n_2\sqrt{\pi}\rangle_q = ? \]

Apply \( \hat{q} \)
\[ \hat{C}_Z^{CV} = e^{i\hat{q}_1 \hat{q}_2} \]

\[ |+\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} |n\sqrt{\pi}\rangle_q \]

\[ e^{i\pi n_1 n_2} \sum_{n_1, n_2} |n_1\sqrt{\pi}\rangle_q |n_2\sqrt{\pi}\rangle_q = ? \]

Expand into even and odd sums
\[ e^{i \pi n_1 n_2} \sum_{n_1, n_2} |n_1 \sqrt{\pi}\rangle_q |n_2 \sqrt{\pi}\rangle_q \]

\[ = \]

\[ n_1 \text{ or } n_2 \text{ even} \implies n_1 n_2 \text{ is even} \]

\[ \sum_{n_1 \text{ or } n_2 \text{ even}} |n_1 \sqrt{\pi}\rangle_q |n_2 \sqrt{\pi}\rangle_q = |00\rangle_{\text{GKP}} + |01\rangle_{\text{GKP}} + |10\rangle_{\text{GKP}} \]
Edge of ideal CV cluster is logical CZ

\[ \hat{C}^{CV}_Z |++\rangle_{GKP} \]

\[ = \sum_{n_1, n_2} e^{i\pi n_1 n_2} |n_1 \sqrt{\pi}\rangle_q |n_2 \sqrt{\pi}\rangle_q \]

\[ = \frac{1}{2} (|00\rangle_{GKP} + |01\rangle_{GKP} + |10\rangle_{GKP} - |11\rangle_{GKP}) \]

\[ \equiv \hat{C}^{GKP}_Z |++\rangle_{GKP} \]

Logical qubit CZ gate on GKP states!
Edge of ideal CV cluster is logical CZ

What about CV CZ on a displaced GKP state?
Edge of ideal CV cluster is logical CZ

\[ \hat{C}^{CV}_Z \]

\[ \begin{pmatrix} \mu_{q_1} \\ \mu_{q_2} \\ \mu_{p_1} \\ \mu_{p_2} \end{pmatrix} \]

\[ \hat{C}^{GKP}_Z \]

\[ \begin{pmatrix} \mu_{q_1} \\ \mu_{q_2} \\ \mu_{p_1} + \mu_{q_2} \\ \mu_{p_2} + \mu_{q_1} \end{pmatrix} \]

CV CZ gate on displaced GKP state = GKP CZ on displaced GKP state.
Displaced GKP cluster inside a CV cluster

\[ \hat{C}_Z^{\text{CV}} |0\rangle_p \]
Displaced GKP cluster inside a CV cluster
Homodyne detection collapses the GKP cluster

\[ q = (2n + L)\sqrt{\pi} + \mu_q \]

\[ \left| 0 \right\rangle_p = \int \ldots \]
Displaced GKP cluster inside a CV cluster... How to get the entanglement out?

Displaced GKP cluster state inside a CV cluster...
Interpret the GKP cluster as a qubit cluster.

We perform qubit-qubit quantum teleportation.
Interpret the GKP cluster as a qubit cluster.
We perform qubit-qubit quantum teleportation.

\[
\hat{C}^\text{GKP}_Z = \text{diag}(1, 1, 1, -1)
\]

\[
\hat{C}_Z = \text{diag}(1, 1, 1, -1)
\]

Displaced GKP cluster to qubit cluster
One bit teleportation
One bit teleportation

qubit \ket{\psi} \xrightarrow{X} \xrightarrow{\text{cnot}} qubit

qubit \ket{+} \xrightarrow{X} qubit
GKP-qubit one bit teleportation

GKP (logical qubit)

\[ |\psi_{\mu_q, \mu_p}\rangle_{\text{GKP}} \]

Teleportation by products
GKP-qubit one bit teleportation: X gate

$$\left| 0 \right\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} \left| 2n\sqrt{\pi} \right\rangle_q$$

Gottesman-Kitaev-Preskill (GKP state)
GKP-qubit one bit teleportation: X gate

\[ |1\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} (2n + 1)\sqrt{\pi} |q\rangle \]

\[ \hat{X}^{\text{GKP}} = e^{-i\sqrt{\pi}\hat{p}} = \hat{D}_q(\sqrt{\pi}) \]
GKP-qubit one bit teleportation: $\mu_q, \mu_p$

$$|0\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} |2n\sqrt{\pi}\rangle_q$$

Gottesman-Kitaev-Preskill (GKP state)
\[ |1\rangle_{\text{GKP}} = \sum_{n=-\infty}^{\infty} (2n + 1) \sqrt{\pi} |q\rangle \]

\[ |2n\sqrt{\pi} + \mu_q\rangle \]

\[ \mu_q, \mu_p \text{ as rotational X, Z} \]

\[ q = 0, \sqrt{\pi}, 2\sqrt{\pi}, 3\sqrt{\pi}, 4\sqrt{\pi}, 5\sqrt{\pi}, 6\sqrt{\pi} \]

\[ \mu_q \text{: Rotational X gate} \]

\[ \mu_p \text{: Rotational Z gate} \]
GKP-qubit one bit teleportation

GKP (logical qubit)
\[ |\psi_{\mu_q, \mu_p}\rangle_{GKP} \]

teleportation by products
GKP-qubit one bit teleportation: $X$ gate

GKP X gate

$|\psi\rangle$ qubit

$|+\rangle$ qubit

$|\psi\rangle$ qubit

GKP (logical qubit)

$|\psi_{\mu_q,\mu_p}\rangle_{\text{GKP}}$
GKP-qubit one bit teleportation: $\mu_p$

$$|\psi\rangle \xrightarrow{X} |\psi\rangle$$

GKP (logical qubit)

$$|\psi_{\mu_q, \mu_p}\rangle_{\text{GKP}}$$

displaced GKP interpreted as rotated qubit

$$\hat{R}_Z(\mu_p \sqrt{\pi}) |\psi\rangle$$
GKP-qubit one bit teleportation: $\mu_q$

\[ q = (2n + L)\sqrt{\pi} + \mu_q \]
Homodyne detection roles:
1. Collapsing the superposition into some GKP cluster
2. Quantum teleportation
3. Need $\mu_q$ to correct phase shifts due to CV CZ

$$q = (2n + L)\sqrt{\pi} + \mu_q$$
Entanglement transfer protocol: Recap
Entanglement transfer protocol: Recap

1. Initialize all qubits to $|+\rangle$. 

$|0\rangle_p$ $D_q(\sqrt{\pi})$ $q$ 

$|0\rangle_p$ $D_q(\sqrt{\pi})$ 

$|+\rangle$ $X^L$ 

$|+\rangle$ $X^L$ $R_Z(-\sqrt{\pi} \mu_{q_1})$ $R_Z(-\sqrt{\pi} \mu_{q_2})$
2. Create a CV cluster state.
Step 3. Apply conditional displacement to each pair:
\[
\hat{C}_D = |0\rangle\langle 0|\hat{I} + |1\rangle\langle 1|\hat{D}_q(\sqrt{\pi})
\]
Step 3. Apply conditional displacement to each pair:

\[ \hat{C}_D = |0\rangle\langle 0| I + |1\rangle\langle 1| \hat{D}_q(\sqrt{\pi}) \]
Step 4. Measure the $q$ quadrature.
Entanglement transfer protocol: Recap

Step 5. Correct by products.
Entanglement transfer protocol: Loss

1. Ideal CV cluster → perfect qubit cluster
2. No GKP states in the protocol
Entanglement transfer protocol: Loss
Entanglement transfer protocol: Loss
Entanglement transfer protocol: Loss

$$D_q(\sqrt{\pi})$$

$$X^L$$

$$R_Z(-\sqrt{\pi}\mu_{q_2})$$

$$R_Z(-\sqrt{\pi}\mu_{q_1})$$
Entanglement transfer protocol: Loss

Squeezed thermal state

\[ \rho(\tilde{n}') \rightarrow S(r') \rightarrow D_q(\sqrt{\pi}) \rightarrow q \]

\[ \rho(\tilde{n}') \rightarrow S(r') \rightarrow D_q(\sqrt{\pi}) \rightarrow q \]

\[ |+\rangle \]

\[ |+\rangle \]

\[ \hat{C}_Z |++\rangle \]
Finite squeezing:

$|0, \sigma_p\rangle_p$

Loss: Finite Squeezing
Finite squeezing:

$$|0, \sigma_p\rangle_p$$
After conditional displacement:

\[ |0, \sigma_p \rangle_p |0\rangle^{\text{Qubit}} \quad \hat{D}_q(\sqrt{\pi}) |0, \sigma_p \rangle_p |1\rangle^{\text{Qubit}} \]
Now, the probability of measuring $q$: 

Loss: Finite Squeezing
The displaced GKP state after measuring $q$: 

Loss: Finite Squeezing
The displaced GKP state after measuring $q$:
The displaced GKP state after measuring $q$: 

The qubit is: $|0\rangle + |1\rangle$ 

Amplitude imbalance error
The qubit is: $|0\rangle + |1\rangle$  

Amplitude imbalance error  

We can correct the qubit by performing weak measurement POVMs $M_0, M_1$.  

Loss: Finite Squeezing
The qubit is: $|0\rangle + |1\rangle$

We can correct the qubit by performing weak measurement POVMs $M_0, M_1$.

Success: $1 - p$ $|0\rangle + |1\rangle$

Failure: $p$ $|1\rangle$

Amplitude imbalance error

Loss: Finite Squeezing
Finitely squeezed CV cluster state
Loss: Finite Squeezing

Amplitude imbalance error!
Loss: Finite Squeezing

After weak measurement:
Loss: Finite Squeezing

Can convert initial squeezing error to deletion error!

Failure: $p$
Loss: Finite Squeezing
Loss: Finite Squeezing

After weak measurement:
In order to break entanglement between site 1 and 3 both qubits has to be deleted.
Loss: Finite Squeezing

Dual rail encoding (n=2)

Deletion probability of a site: $p^n$
What happens to the qubit if you send in a squeezed thermal state?

\[ \rho_{\text{thermal}} = \rho \]

Squeezed thermal state

Loss: Channel and detector loss
What happens to the qubit if you send in a squeezed thermal state?

\[ \rho_{\text{thermal}} = \rho \]

Squeezed thermal state

Mixture of squeezed states
What happens to the qubit if you send in a squeezed thermal state?

\[ \rho^{\text{thermal}} \]

\[ \rho |\psi_{\mu_q, \mu_p}\rangle_{\text{GKP}} \]

\[ D_q(\sqrt{\pi}) \]

\[ \hat{R}_Z(\mu_p \sqrt{\pi}) |\psi\rangle \]
What happens to the qubit if you send in a squeezed thermal state?

\[
|0\rangle_p, \sigma_p \rangle_p
\]

\[
\rho^{\text{thermal}}
\]

Loss: Channel and detector loss

Qubit dephases

\[
D_p(p_0) |0, \sigma_p\rangle_p
\]

GKP

\[
|\psi_{\mu_q, \mu_p}\rangle_{\text{GKP}}
\]

\[
\rho
\]

\[
\hat{R}_Z(\mu_p \sqrt{\pi}) |\psi\rangle
\]
Suppose $\hat{C}_D$ is 3 times weaker
Suppose $\hat{C}_D$ is 3 times weaker.
Suppose $\hat{C}_D$ is 3 times weaker
Weak conditional displacement can be cancelled out by performing entanglement transfer more times.

Suppose $\hat{C}_D$ is 3 times weaker.
Weak conditional displacement

Suppose $\hat{C}_D$ is 3 times weaker

Only one round of weak measurement correction.
Possible implementations: Superconducting qubits

CV cluster: Frequency comb in microwave resonator

Transmon

95 correlated modes
(Hernández 2024)

64 correlated modes
(Jolin 2023)
Possible implementations: Superconducting qubits

CV cluster: Frequency comb in microwave resonator

Conditional displacement: ECD gate (A. Eickbusch 2018)
Possible implementations: Superconducting qubits

CV cluster: Frequency comb in microwave resonator

Qubitdyne detection (Strandberg 2023)

Quantum Phase Estimation (Terhal and Weigand 2016)
Possible implementations: Free electron qubits (Reinhardt 2021, Baranes 2024)

CV cluster: Furusawa protocol

CD gate: Photon-induced near-field electron microscopy (Barwick 2009)

Free electron qubits

Homodyne detection
Possible implementations: Summary

<table>
<thead>
<tr>
<th>Superconducting qubit + microwave cavity</th>
<th>Free electron qubits</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV cluster state</td>
<td>Frequency comb in cavity</td>
</tr>
<tr>
<td>Conditional displacement</td>
<td>Echoed conditional displacement gate (ECD gate)</td>
</tr>
<tr>
<td>Homodyne detection</td>
<td>Quantum phase estimation</td>
</tr>
<tr>
<td>Qubit</td>
<td>Transmon</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Downloading many-body continuous variable entanglement to qubits

- We can make many body entanglement in qubits!!
- Entanglement transfer from CV cluster state to qubit cluster state is possible
- Quality of the qubit cluster state depends on the initial state
- Weak measurement protocol and qubit deletion protocol can reduce requirements
- 6dB squeezing for robust quantum memory
- 12dB squeezing for fault tolerant quantum computing
- No GKP states needed in protocol
- arXiv in progress

Zhihua Han: zhi_han@sfu.ca
References

References