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Snapshotting Quantum Dynamics at Multiple Time Points

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Outline

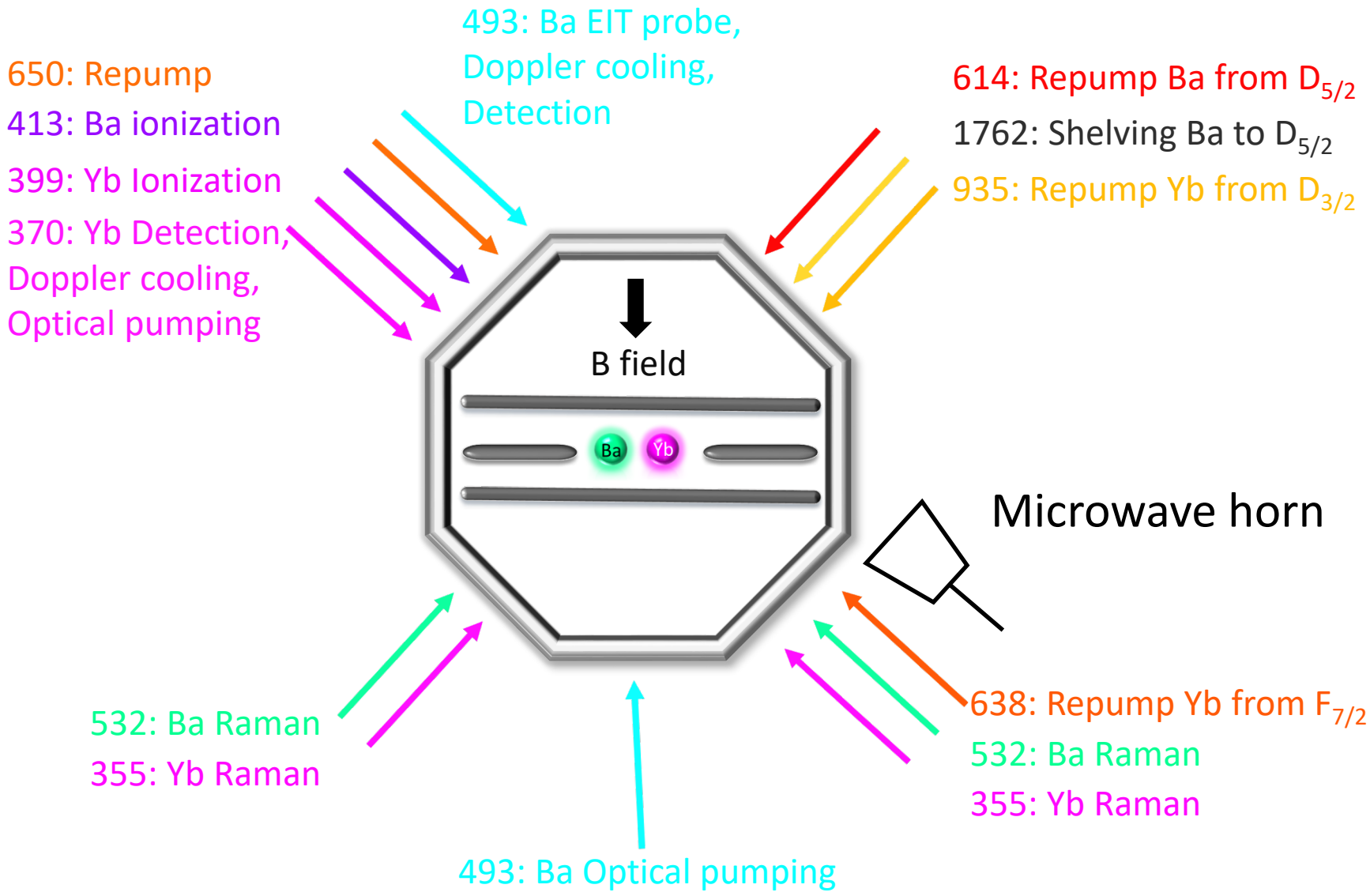
1. $^{171}Yb^{+}$-$^{138}Ba^{+}$ Ion trap system

2. Snapshotting quantum dynamics at multiple time points

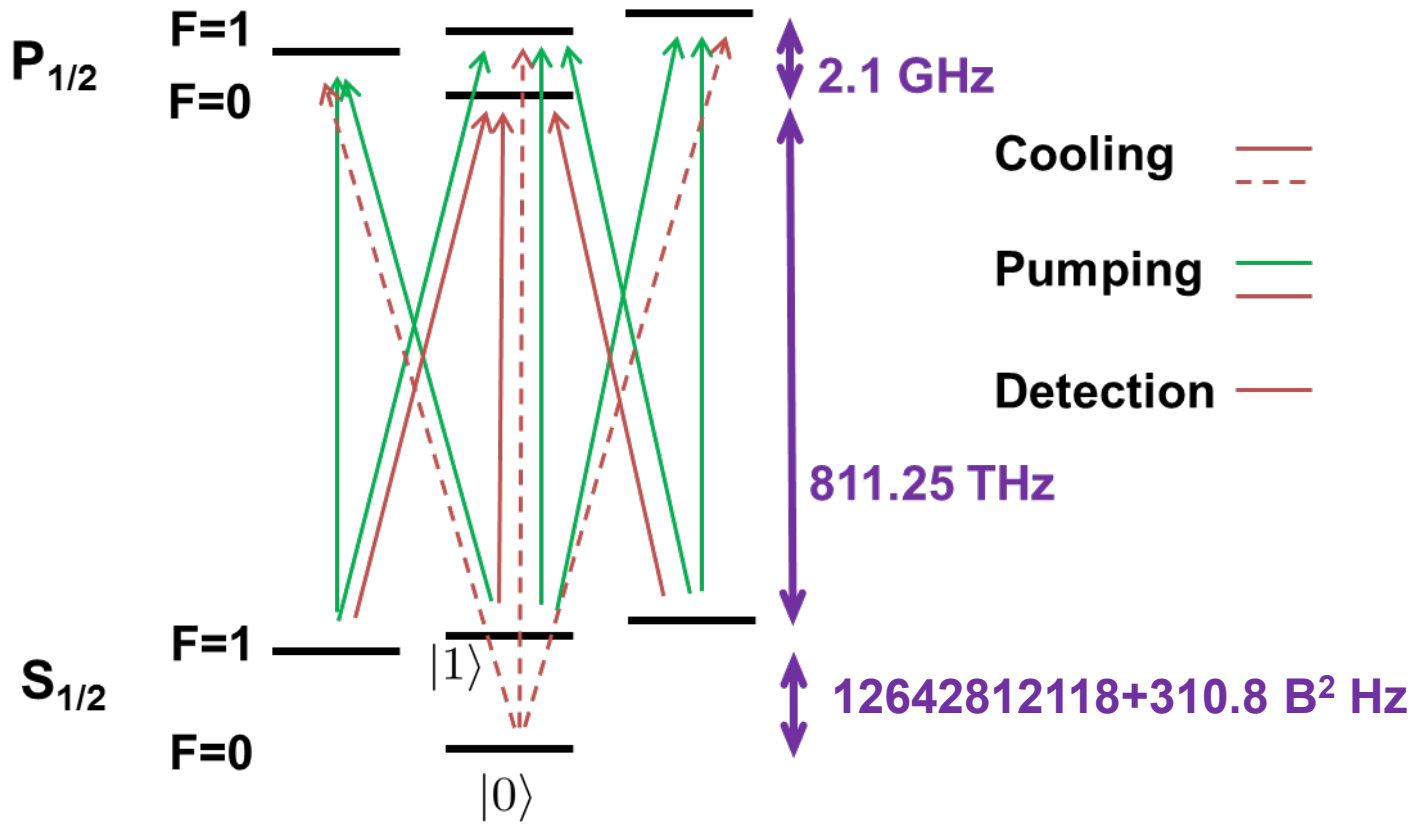
3. Summary

$^{171}Yb^{+}$-$^{138}Ba^{+}$ ion trap system

$^{171}Yb^{+}$-$^{138}Ba^{+}$ Ion trap system

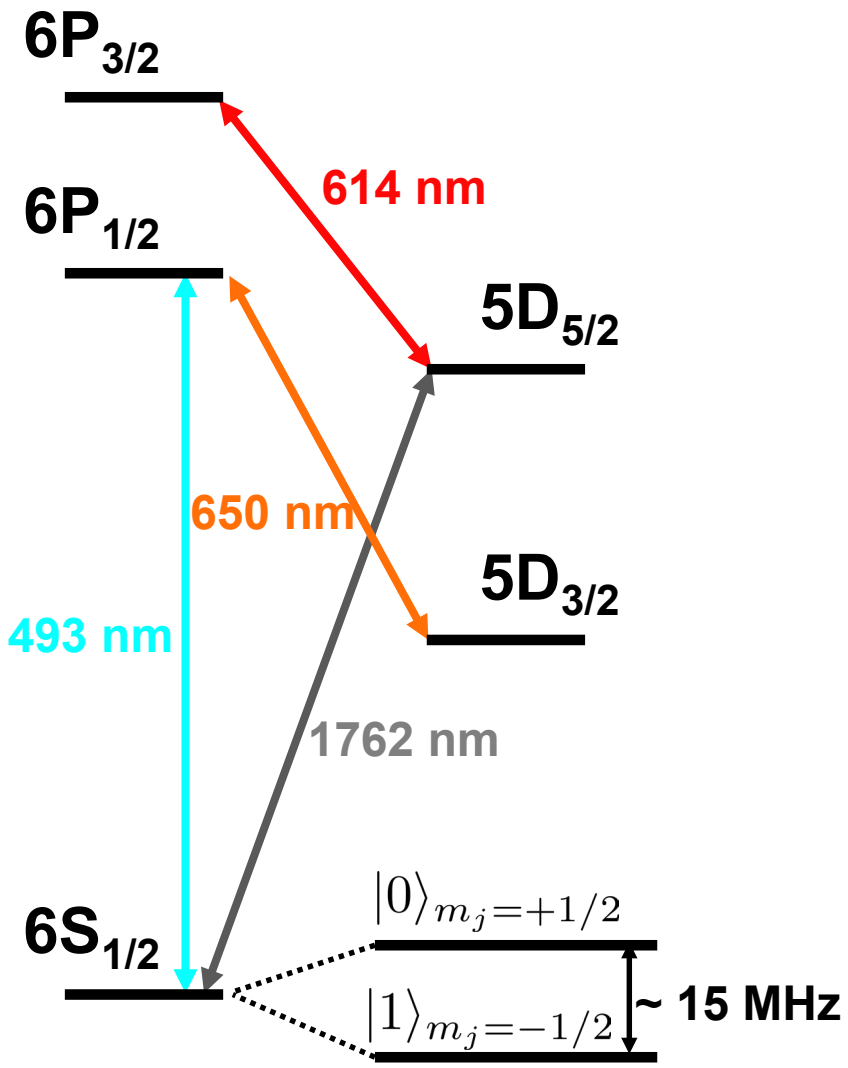


$^{171}Yb^{+}$ ion

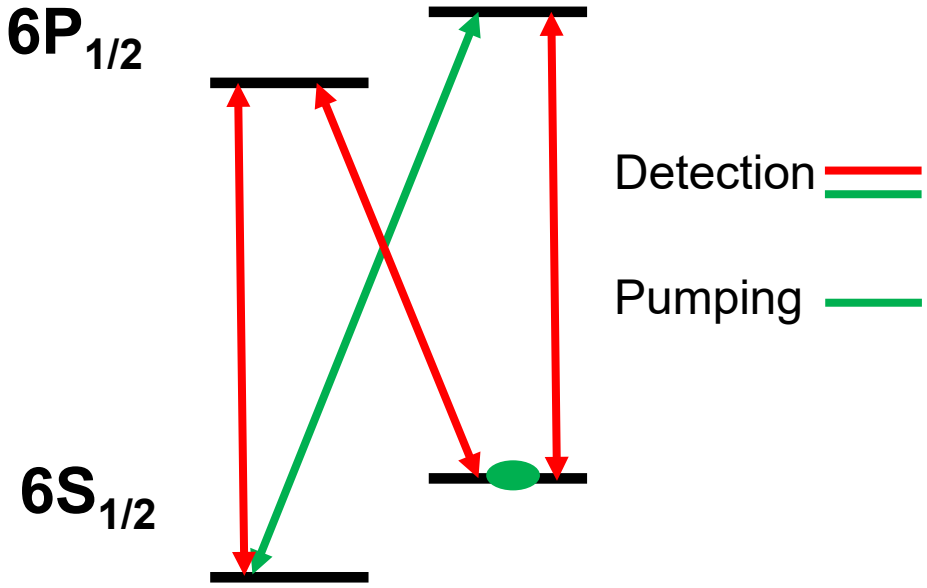


$^{171}Yb^{+}$ Energy levels

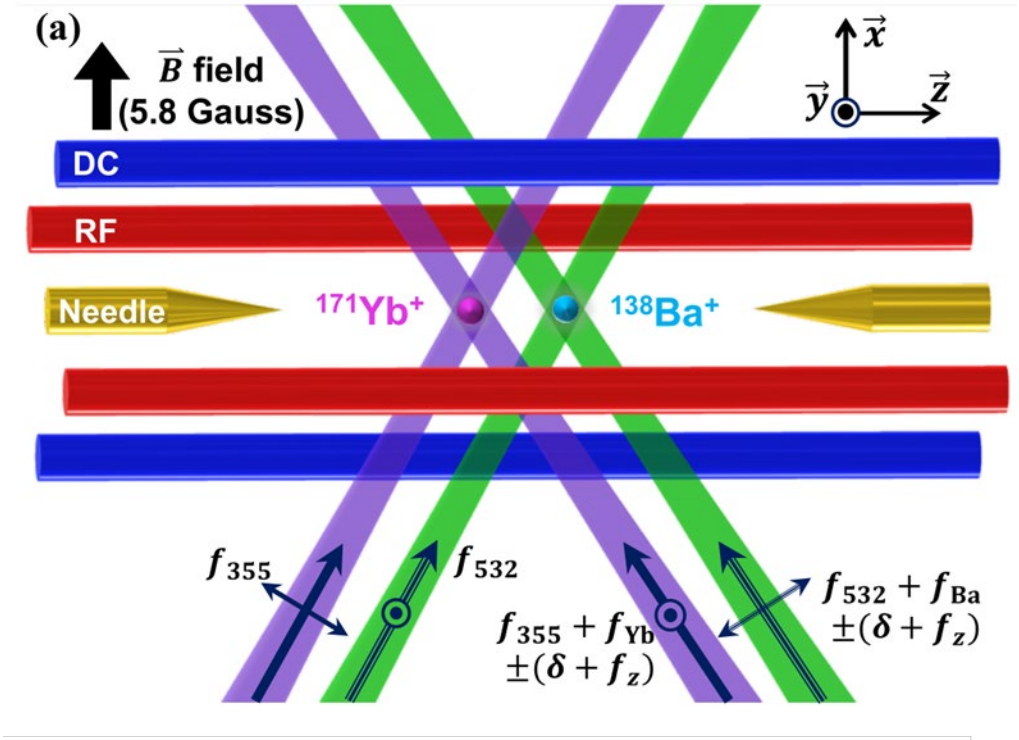
$^{138}Ba^{+}$ ion

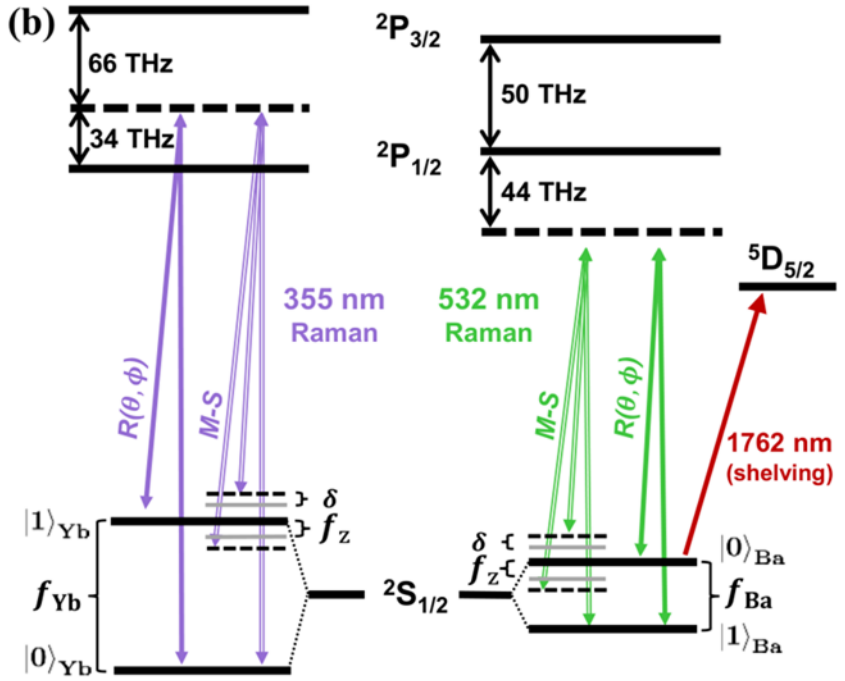


$^{138}Ba^{+}$ Energy levels



Raman lasers





Snapshotting Quantum Dynamics at Multiple Time Points

Pengfei Wang, Kihwan Kim, et al. arXiv:2207.06106.

Why quantum statistic at multiple time points important?

1、Describe system properties beyond the weak perturbation with linear approximation [1]

2、Difference between classical and quantum statistics[2]

Bell inequality and Leggett-Garg inequality all related to quantum statistics

3、Witness of nonclassicality[3]:
Negativity in Quasi-probability distribution (QPD)

[1] M. S. Green, J. Chem. Phys. 22, 398 (1954).
[2] A. J. Leggett and A. Garg, Phys. Rev. Lett. 54, 857 (1985).
[3] R. W. Spekkens, Phys. Rev. Lett. 101, 020401 (2008).

How to measure MTP quantum statistic?

1、Sequential projective measurement:

destroy the coherence

2、Weak measurement:

information gain VS disturbance[1]

Measurement back-action

[1] T. A. Brun, Am. J. Phys. 70, 719 (2002).

Our solution:

Ancilla-assisted measurement
&
post processing

- Back-action can be canceled
- Independent of the system's dynamics
- Simultaneously extract exponentially many quantum statistic.

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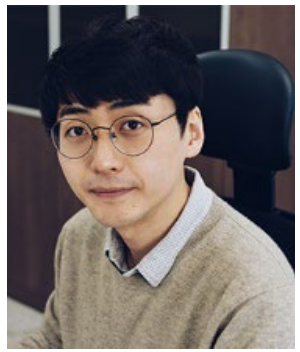
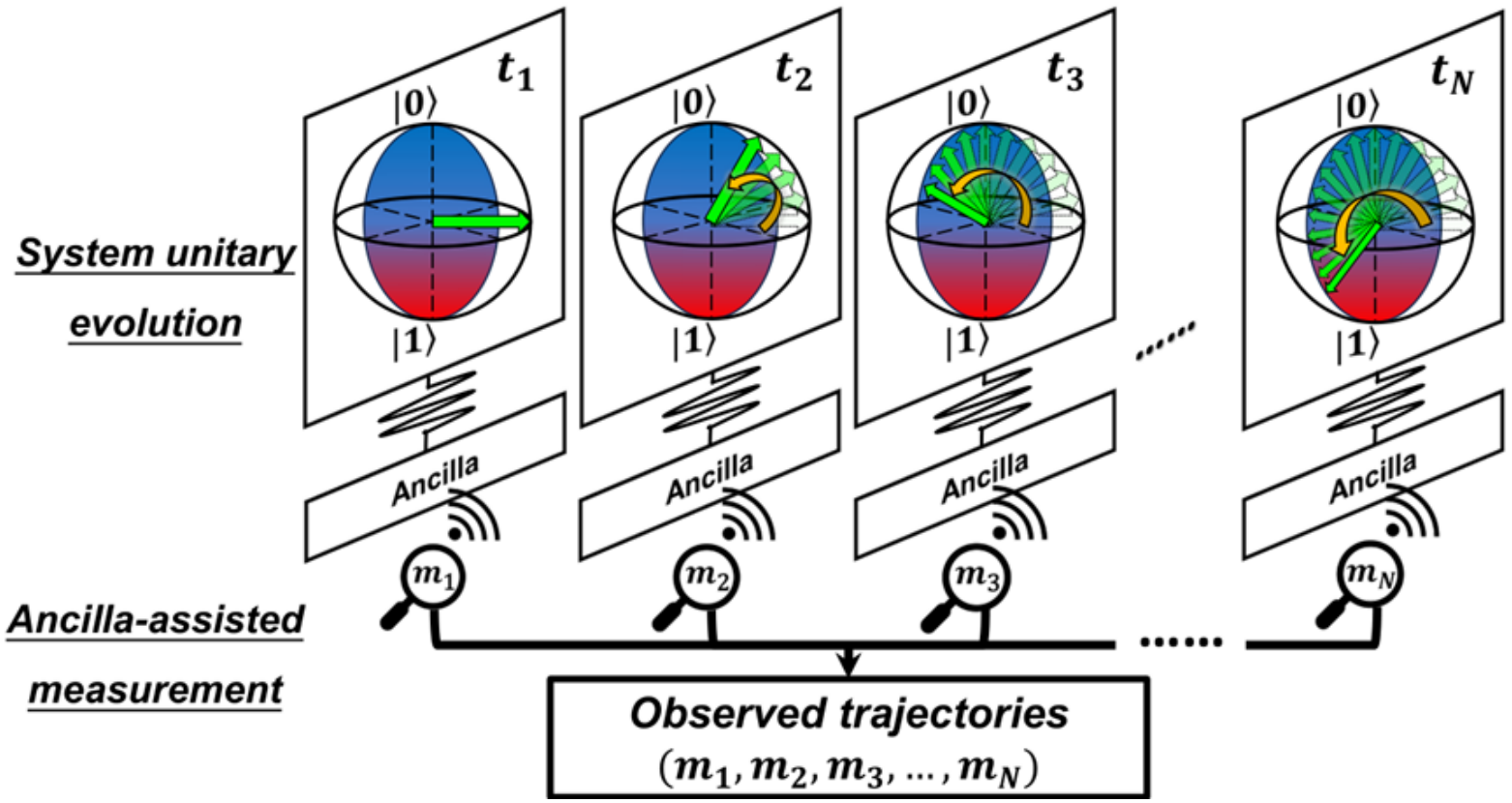
Imperial College London

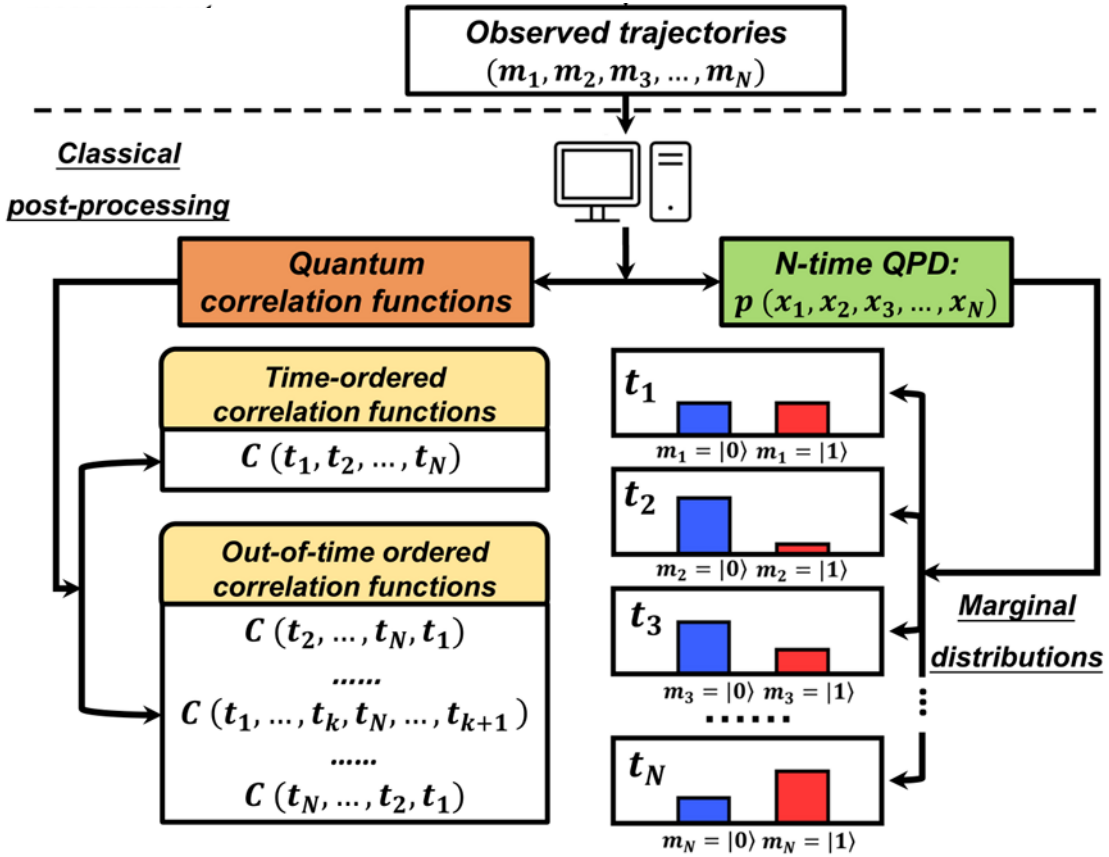


Hyukjoon Kwon
KIAS

Protocol


System unitary evolution
Ancilla-assisted measurement
t_1
t_2
t_3
t_N
$|0\rangle$
$|1\rangle$
Ancilla
m_1
m_2
m_3
m_N
Observed trajectories
$(m_1, m_2, m_3, \ldots, m_N)$

Protocol



MTP quantum correlation function:

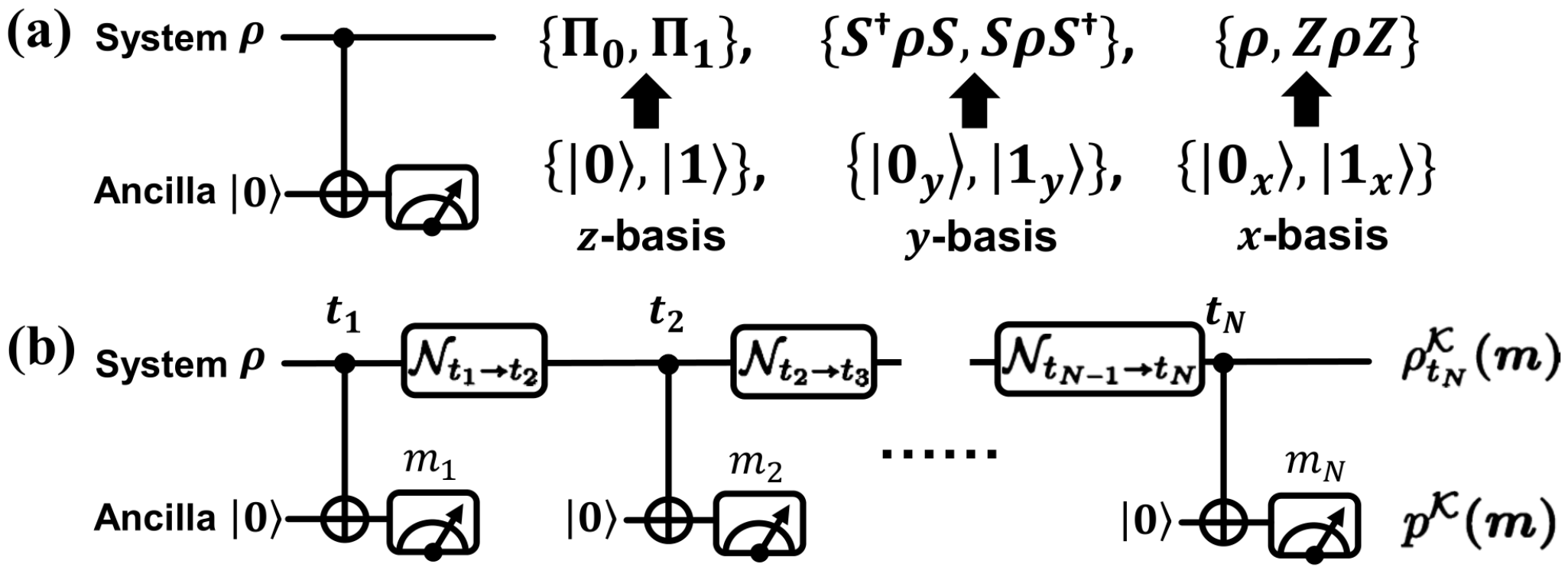
$$C_A(t) := \mathrm{Tr}[\rho A^{(0)}(t_0) A^{(1)}(t_1) \cdots A^{(N)}(t_N)].$$

Quasi-probability distribution (QPD):

$$\mathcal{Q}_i(t) := \mathrm{Tr}\left[\rho \Pi^{(0)}_{i_0}(t_0) \Pi^{(1)}_{i_1}(t_1) \cdots \Pi^{(N)}_{i_N}(t_N)\right]$$

$\Pi^{(n)}_{i_n}$ projection operators

Experiment circuit



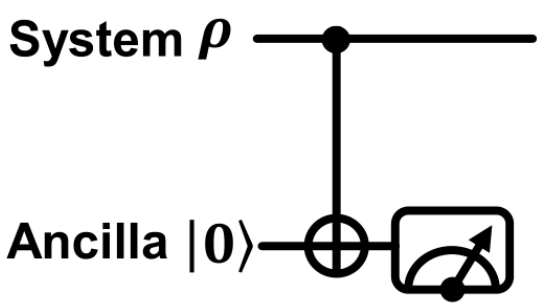
Example of post processing

$$\mathcal{Q}_i(t) := \mathrm{Tr}\left[\rho\Pi_{i_0}^{(0)}(t_0)\Pi_{i_1}^{(1)}(t_1)\cdots\Pi_{i_N}^{(N)}(t_N)\right]$$

$\Pi_{i_n}^{(n)}$ projection operators

Two-point case $\mathrm{Tr}\left[U_{t_1\to t_2}\rho(t_1)\Pi_{i_1}U_{t_1\to t_2}^{\dagger}\Pi_{i_2}\right]$ Heisenberg picture

$$\rho\Pi_x = \frac{\rho - Z\rho Z + \Pi_x\rho\Pi_x - i(-1)^x S\rho S^{\dagger} + i(-1)^x S^{\dagger}\rho S}{4}$$

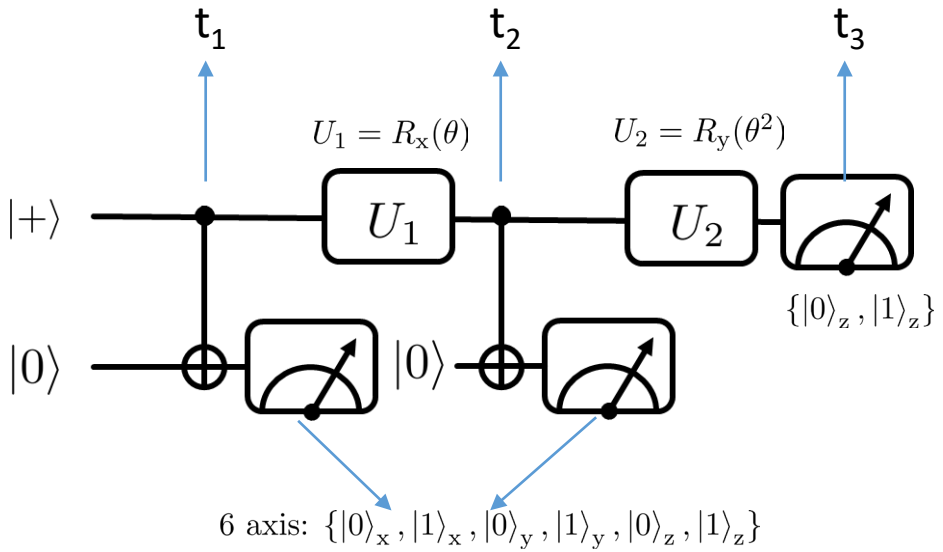


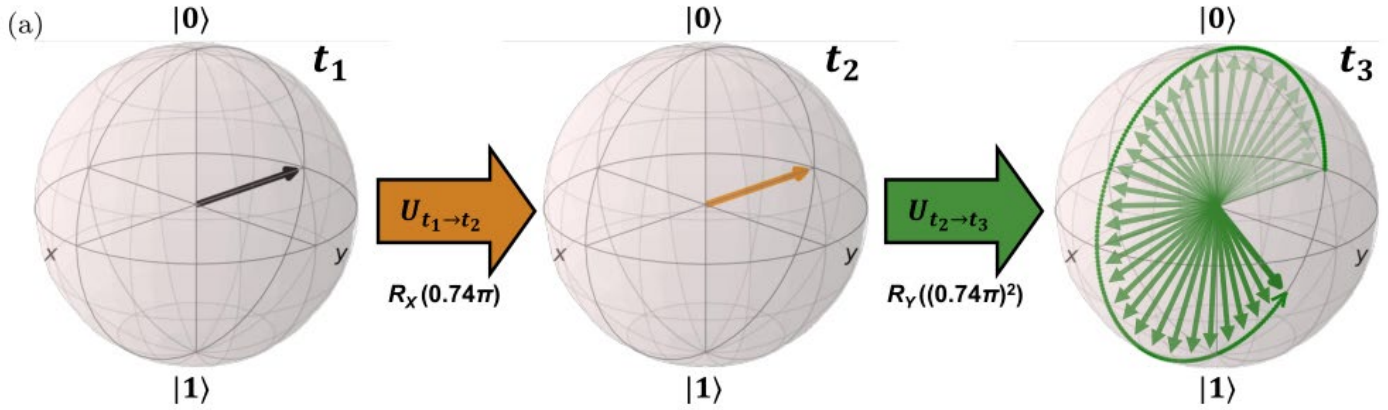
$\{\Pi_0, \Pi_1\}$, $\{|0\rangle, |1\rangle\}$, z-basis

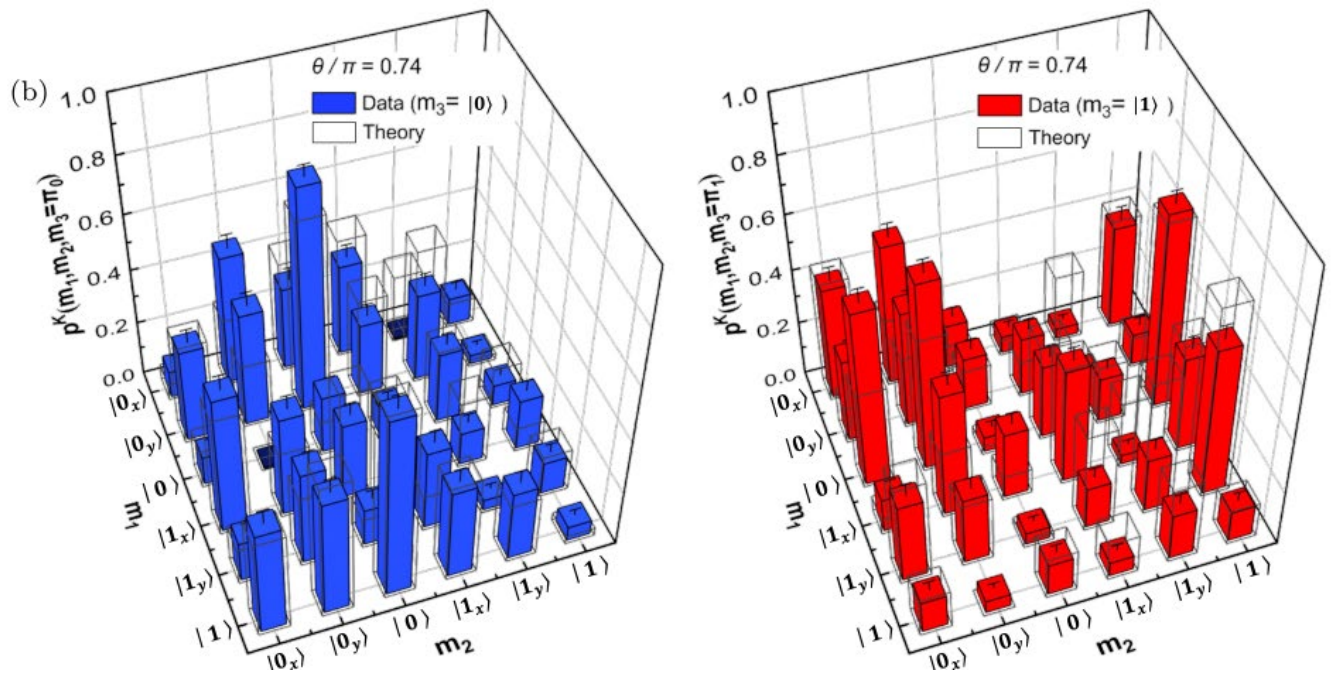
$\{S^{\dagger}\rho S, S\rho S^{\dagger}\}$, $\{|0_y\rangle, |1_y\rangle\}$, y-basis

$\{\rho, Z\rho Z\}$, $\{|0_x\rangle, |1_x\rangle\}$, x-basis

Experiment circuit and raw data

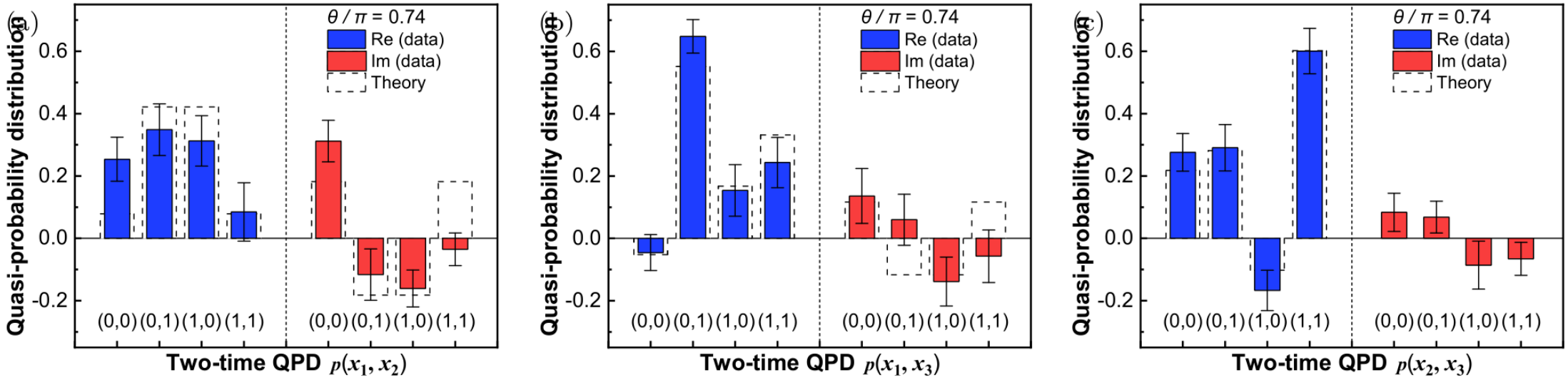




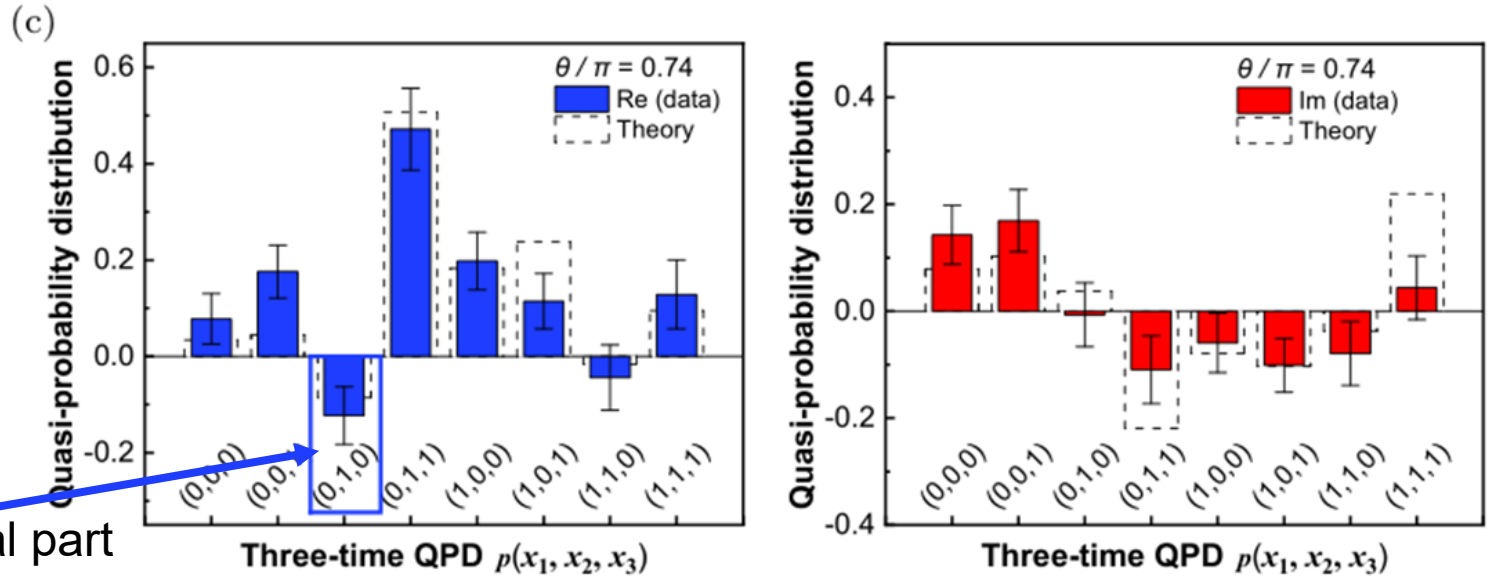


MTP QPD

Two time points:



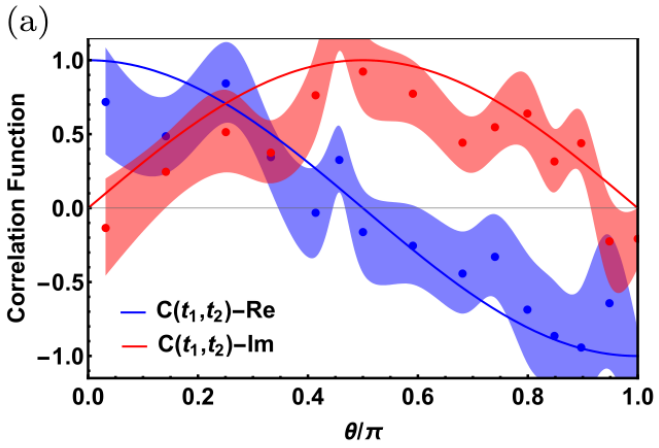
Three time points:

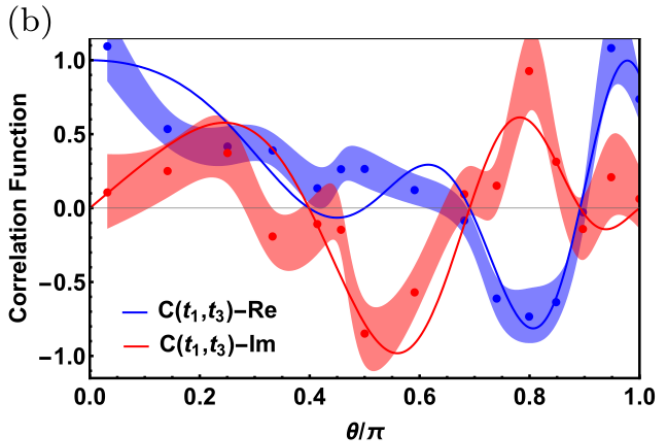


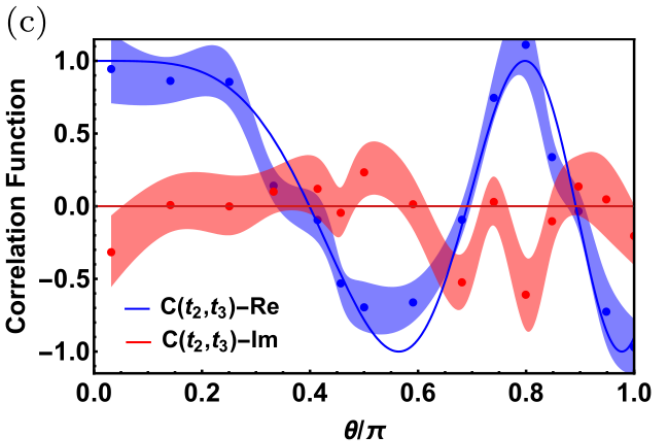
Negativity of real part

MTP Correlation function

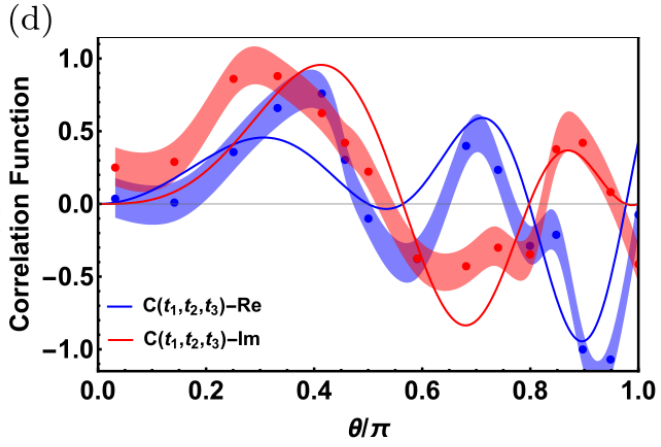
Two time points:

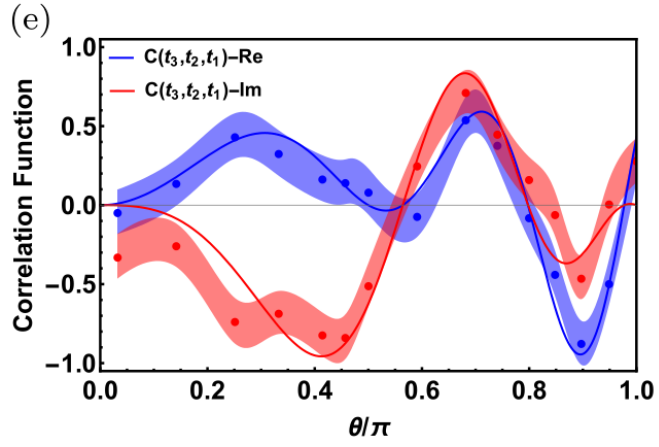


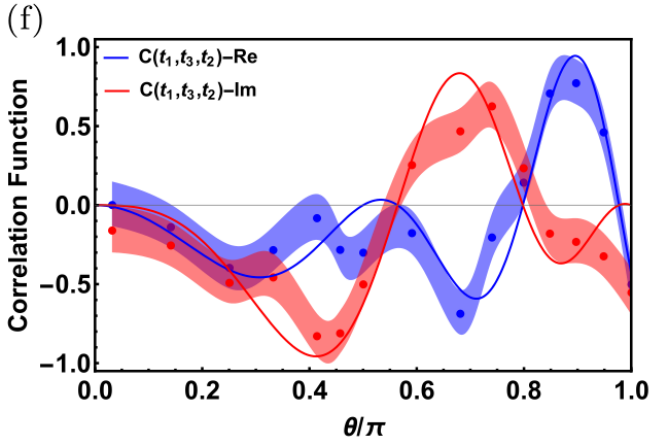




Three time points:

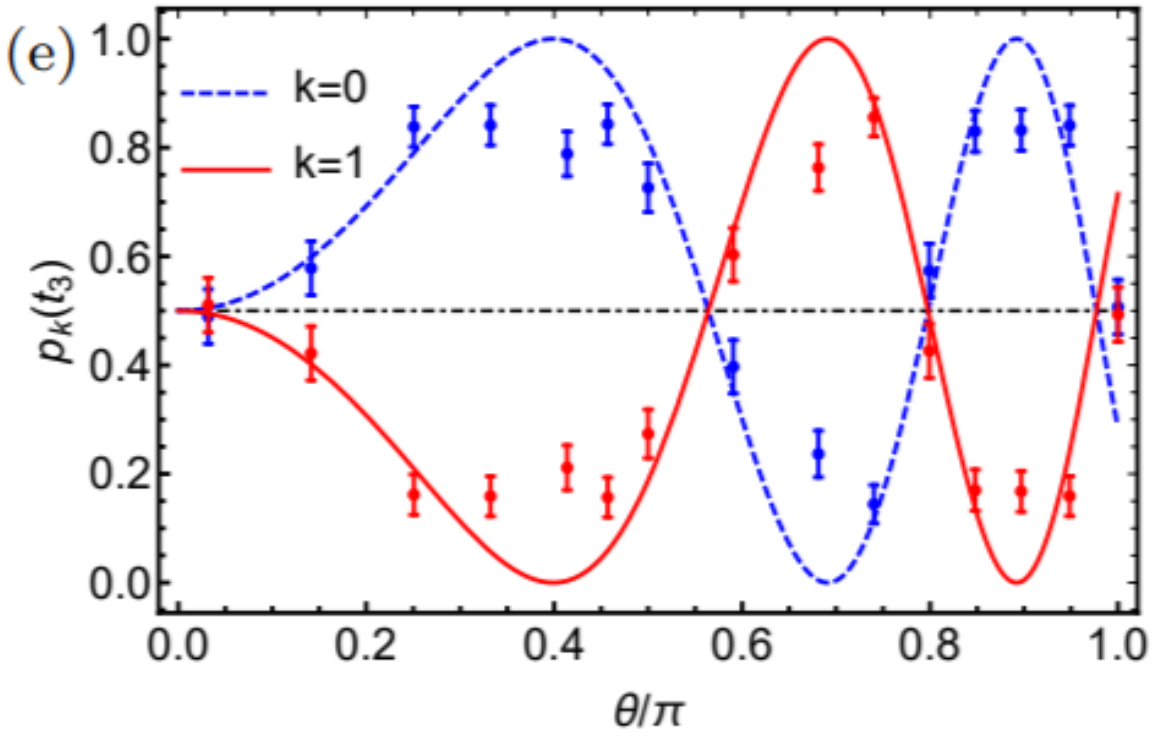


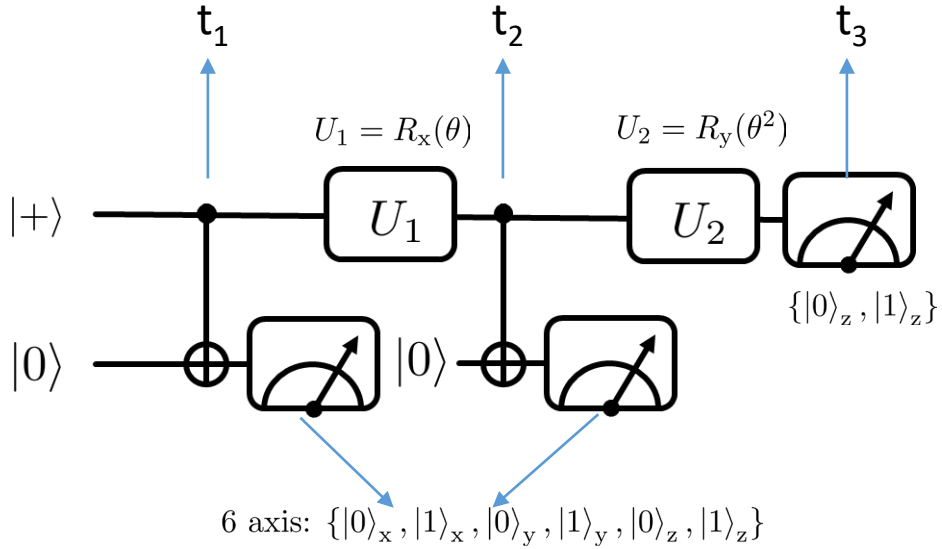




Out-of-time ordered

Marginal distribution at t_3





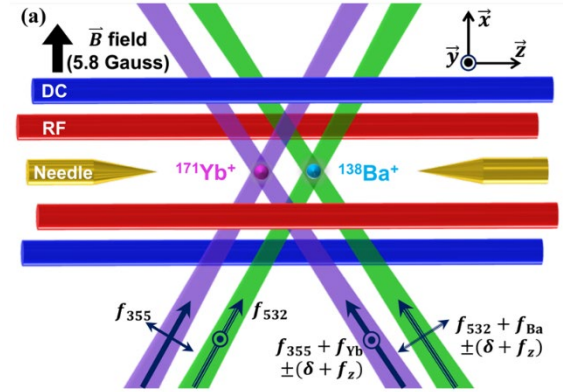
marginal distribution

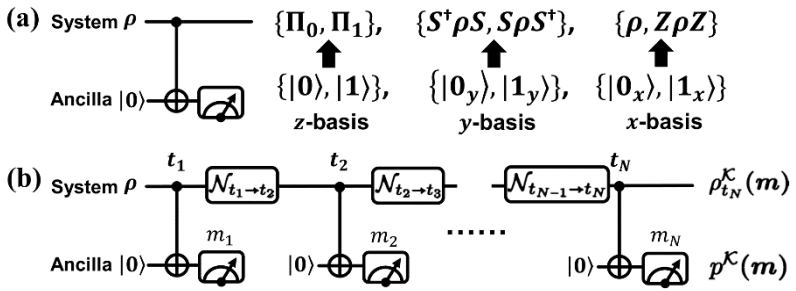
$$\sum_{x_k} p(x_1, \cdots, x_N) = p(x_1, \cdots, x_{k-1}, x_{k+1}, \cdots, x_N)$$

Summary

1、 $^{171}Yb^{+}$-$^{138}Ba^{+}$ hybrid system.

2、Ancilla-assisted measurement & Post processing





Advantage of our method:

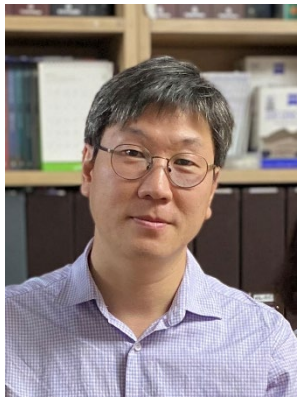
1、 Only need one ancilla qubit for many-time point measurement (reuse).

2、Independent of the system's dynamics, even in the case of an open system.

3、Only need a short-time system-ancilla interaction

4、Simultaneously extract exponentially many correlation functions.

Team leader:



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- Tsinghua University
- Beijing Academy of Quantum Information Sciences

Theory support:

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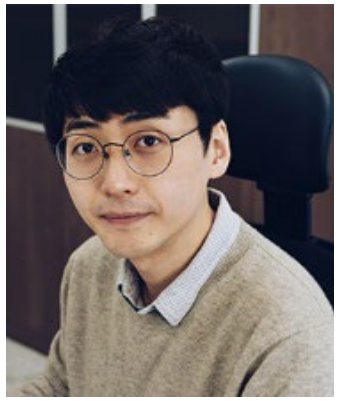
Imperial College London

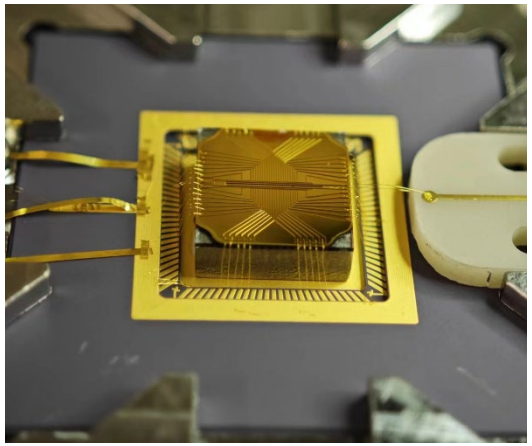


Hyukjoon Kwon
KIAS

Thank you

Surface trap based on fused silica :

- Yb^+-Ba^+ Hybrid system
- QCCD
- Qubit reuse



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