Continuous-Variable Quantum Computing on Encrypted Data

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Quantum Computing in a Cloud

IBM Quantum Computer in a Cloud

- Security of your data

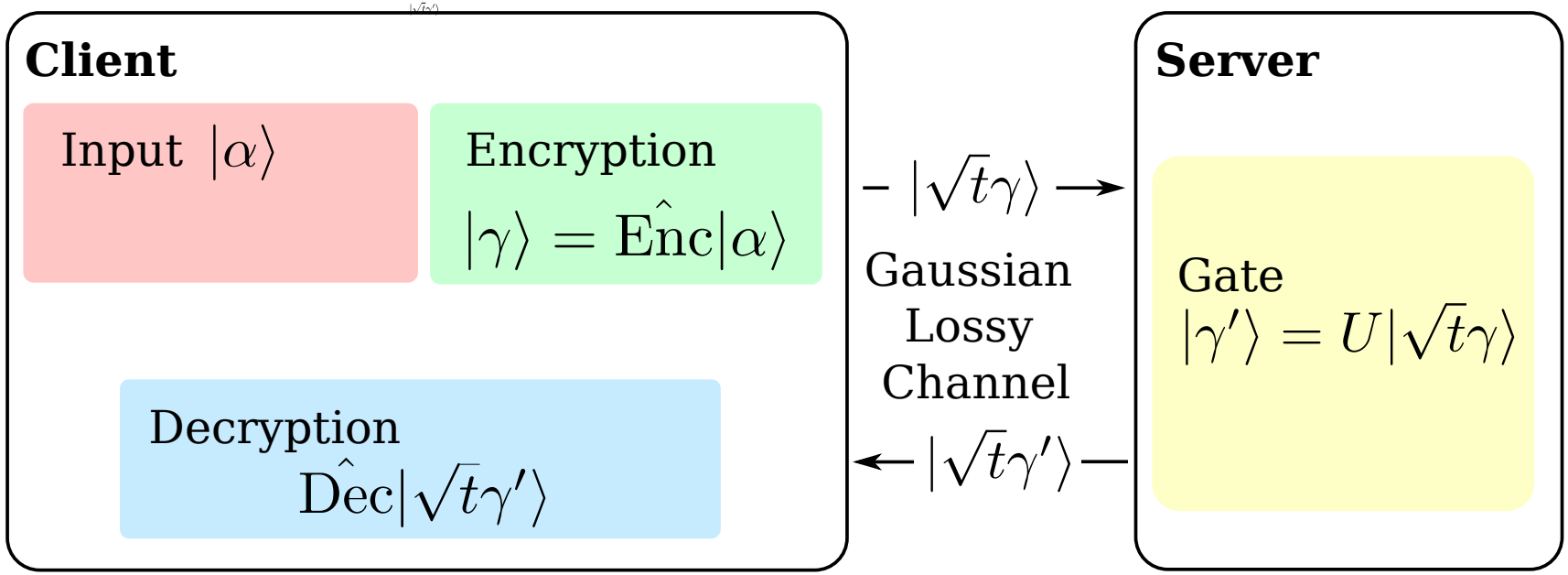
Security in Quantum Cloud Computing

Ideally: Secret input, secret program, secret output, single-round communication, no overhead

Quantum Fully Homomorphic Encryption [1]	Single-round Communication	Secret Program
Blind Quantum Computing [2]	Multi-round Communication	Secret program
Quantum Computing on Encrypted Data	Multi-round Communication	Public program

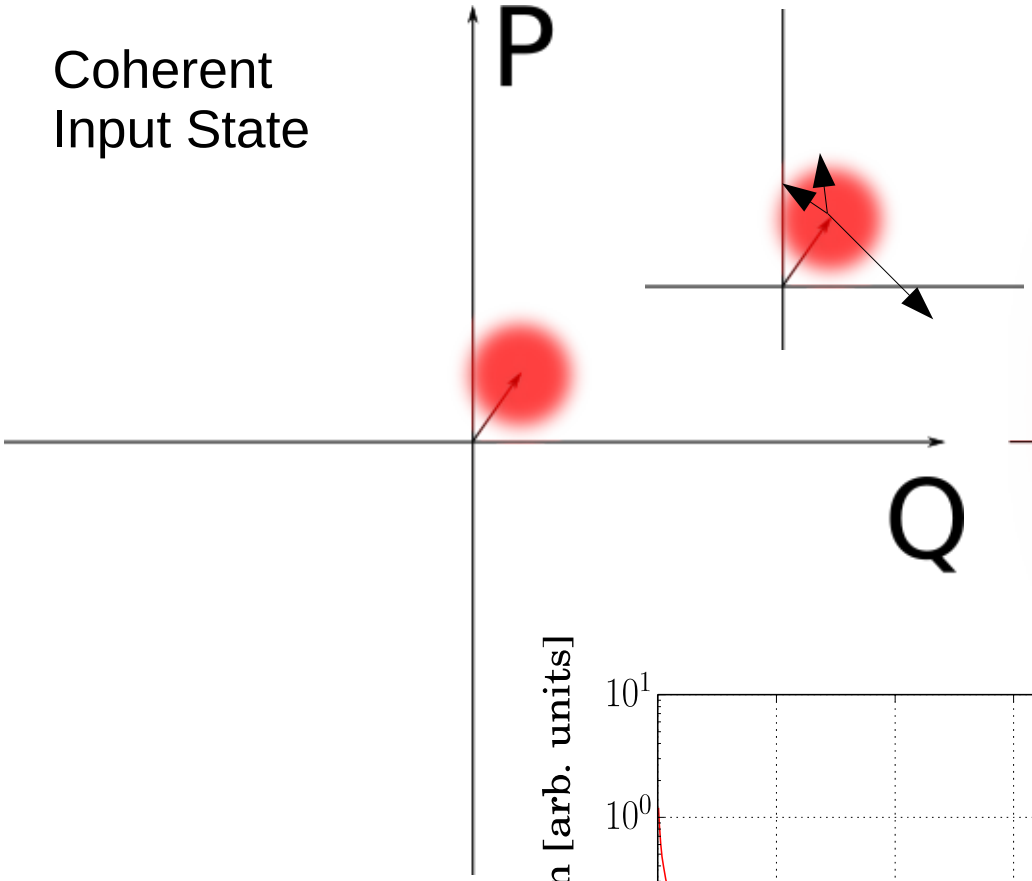
Quantum Computing on Encrypted Data

[1] L. Yu, et al., Phys. Rev. A 90, 050303 (2014)
[2] A. Broadbent, et al., in Foundations of Computer Science, 2009. FOCS '09. 50th Annual IEEE Symposium on (2009), 517, ISSN 0272-5428.

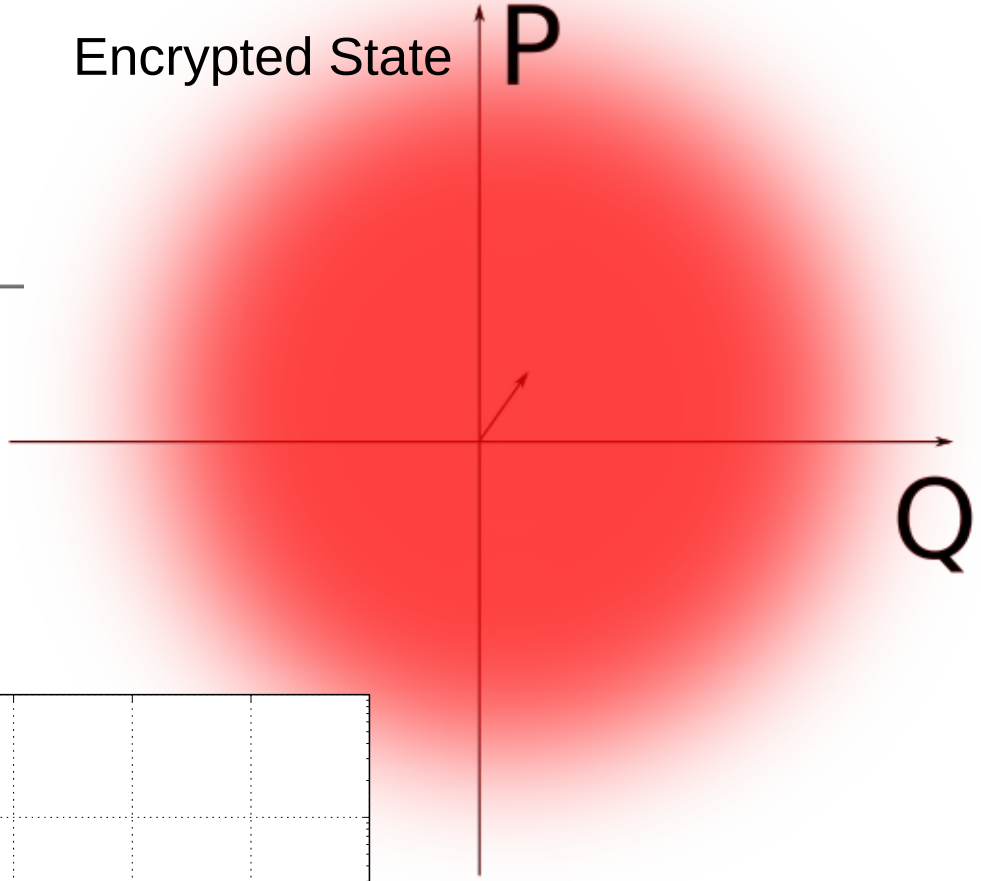


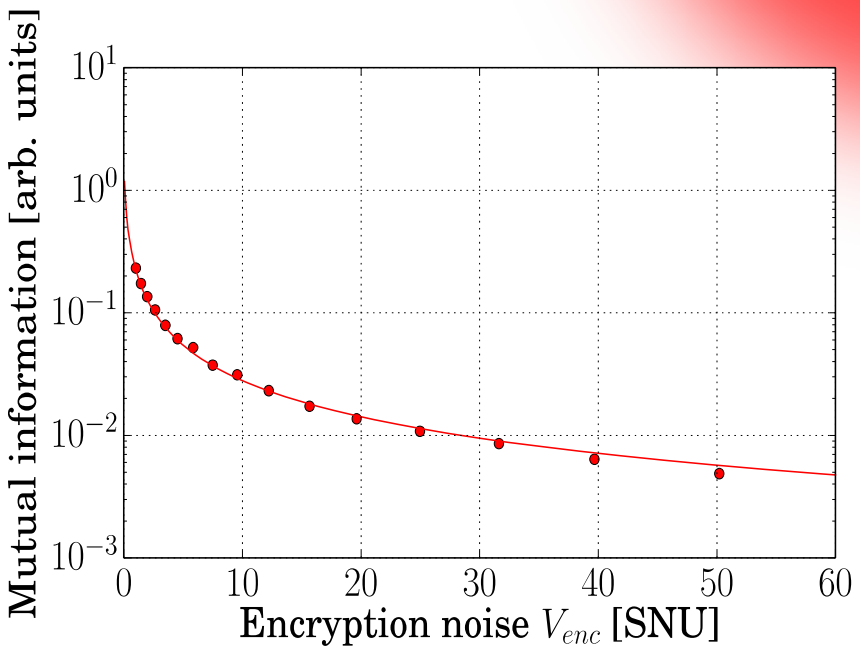
Encryption

Coherent
Input State



Encrypted State





A Continuous-Variable Universal Quantum Computer

Set of gates necessary for continuous-variable universal computing:

Displacement gates	Z(T), X(T)
“Squeezing” gate	$U_2(T)$
Cubic phase gate (“non-gaussian”)	$U_3(T)$
Fourier gate	F
Controlled-not gate	C_Z

Implementation of U_3 gate remains a challenge

Decryption

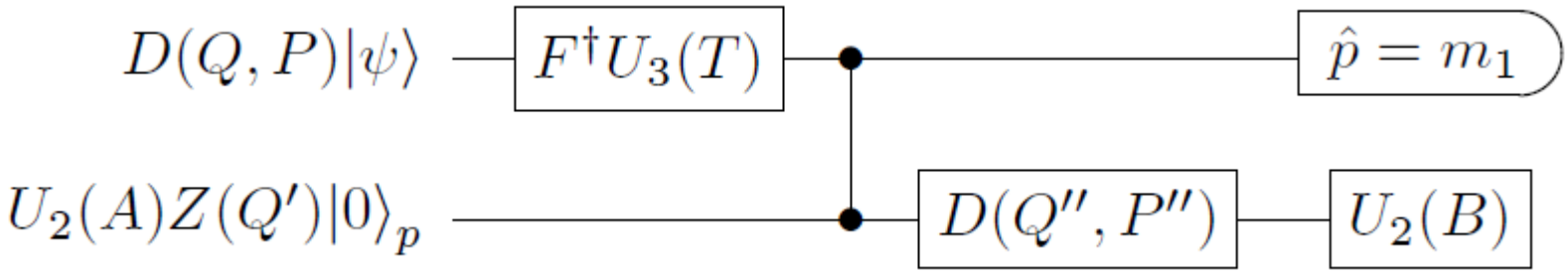
Decryption operation

Gate	Decryption Operation
Z(T)	X(-Q)Z(-P)
X(T)	X(-Q)Z(-P)
$U_2(T)$	X(-Q)Z(-2QT-P)
$U_3(T)$	$X(-Q)Z(3Q^2T-P)U_2(-3QT)$
F	X(P)Z(-Q)
C_Z	$X_1(-Q_1)Z_1(-Q_2-P_1) \otimes X_2(-Q_2)Z_2(-Q_1-P_2)$

For all Gaussian gates it is sufficient to use displacement operations to decrypt

The U_3 gate

Server implementation



A and Q' are randomly chosen by client
B depends on A and Q

Communication from Client to Server:

- Value of B

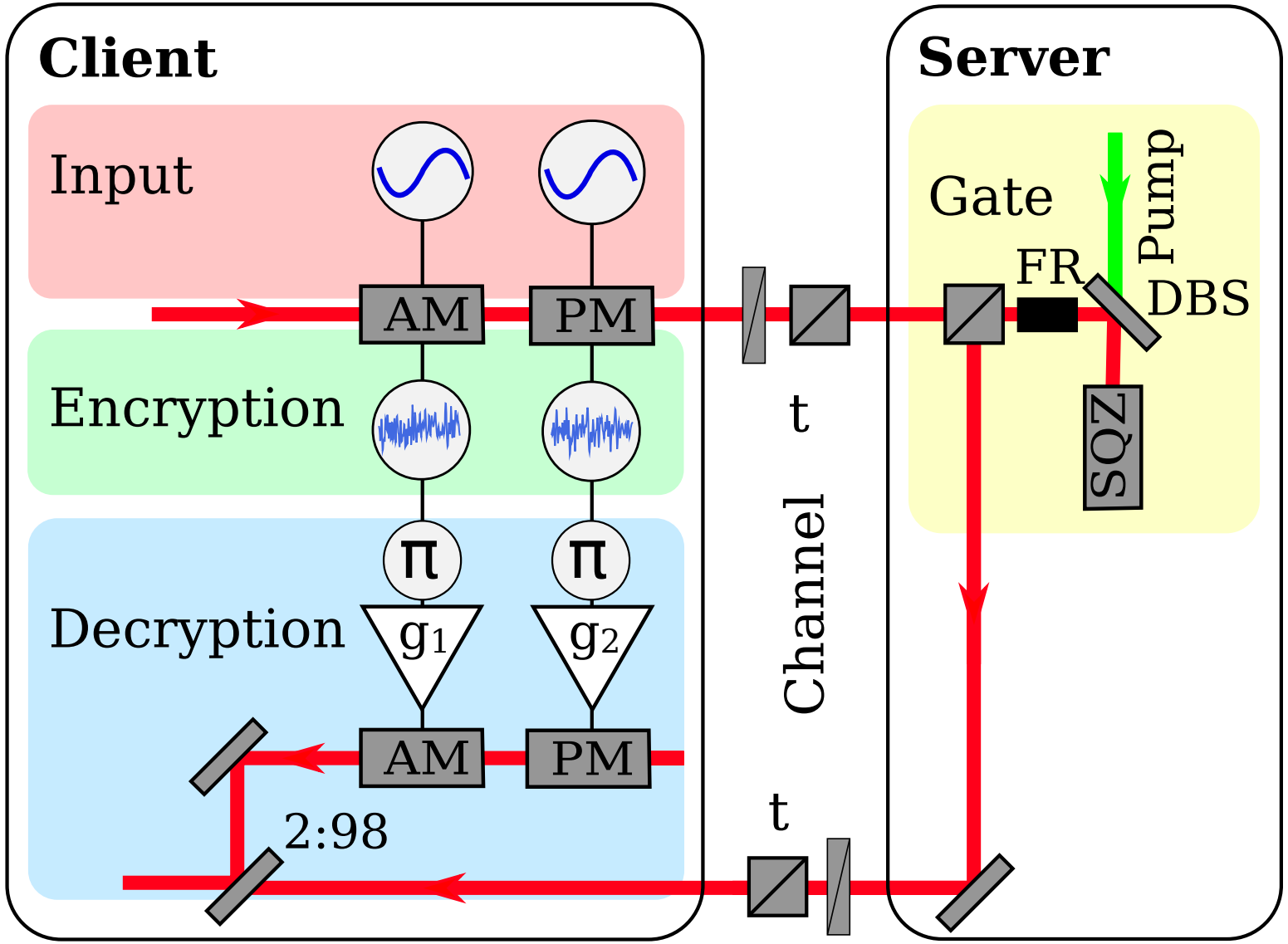
Communication from Server to Client:

- Value of m_1

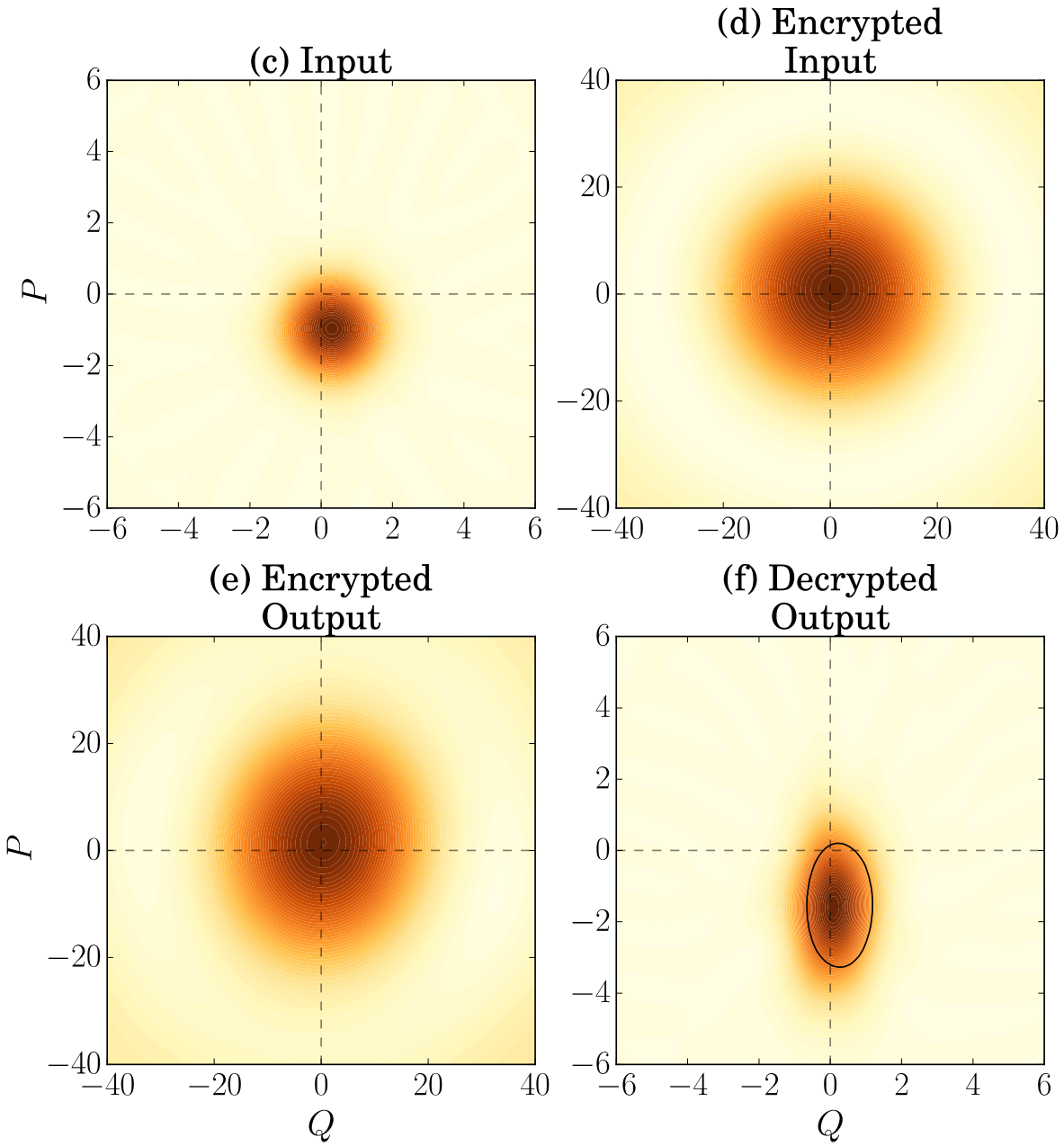
One round of classical communication needed for U_3 gate implementation

Experiment: Squeezing Gate

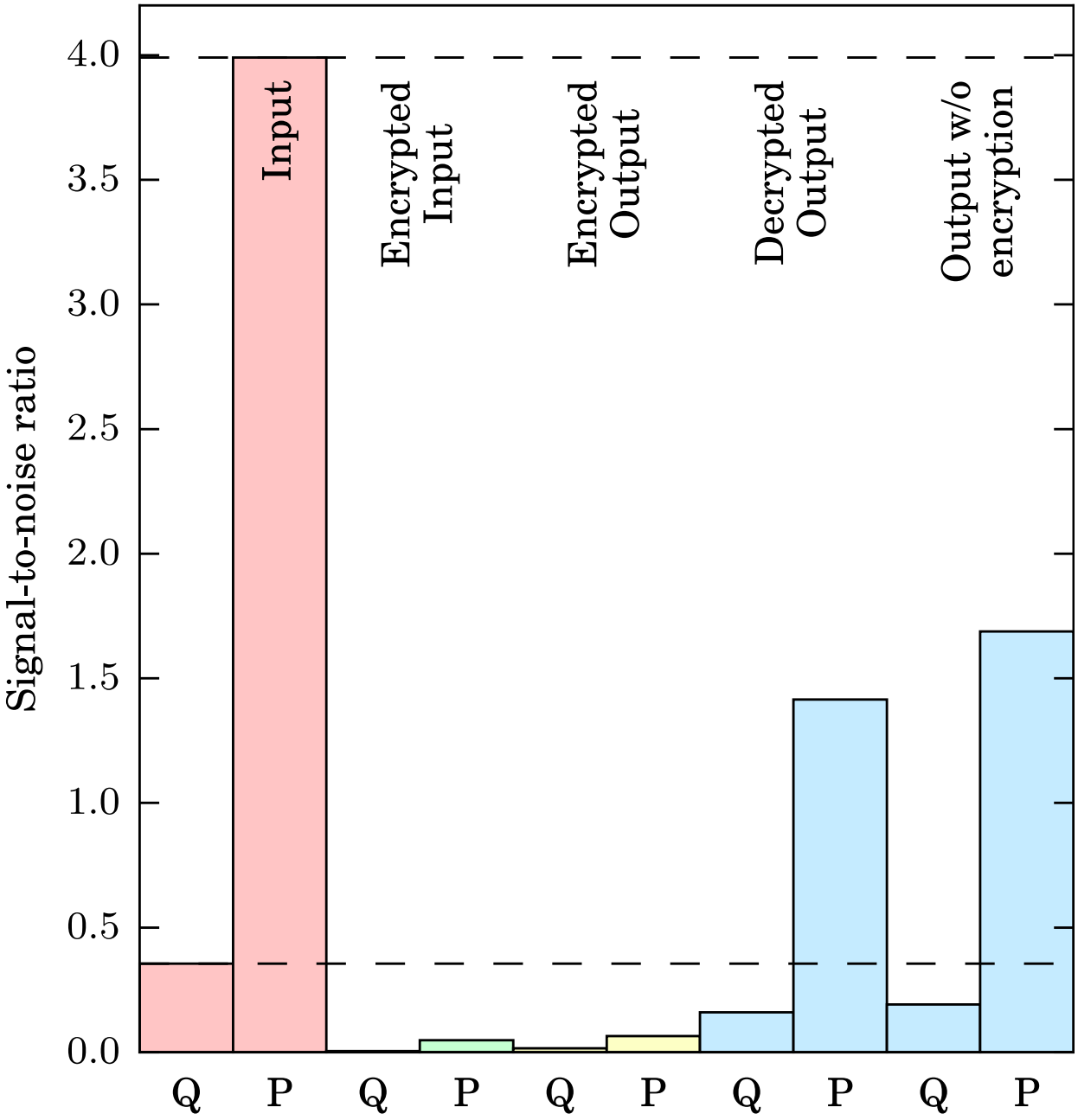
U_2 gate: phase shift, squeezing, phase shift



Results: Reconstructed Quantum States Step by Step

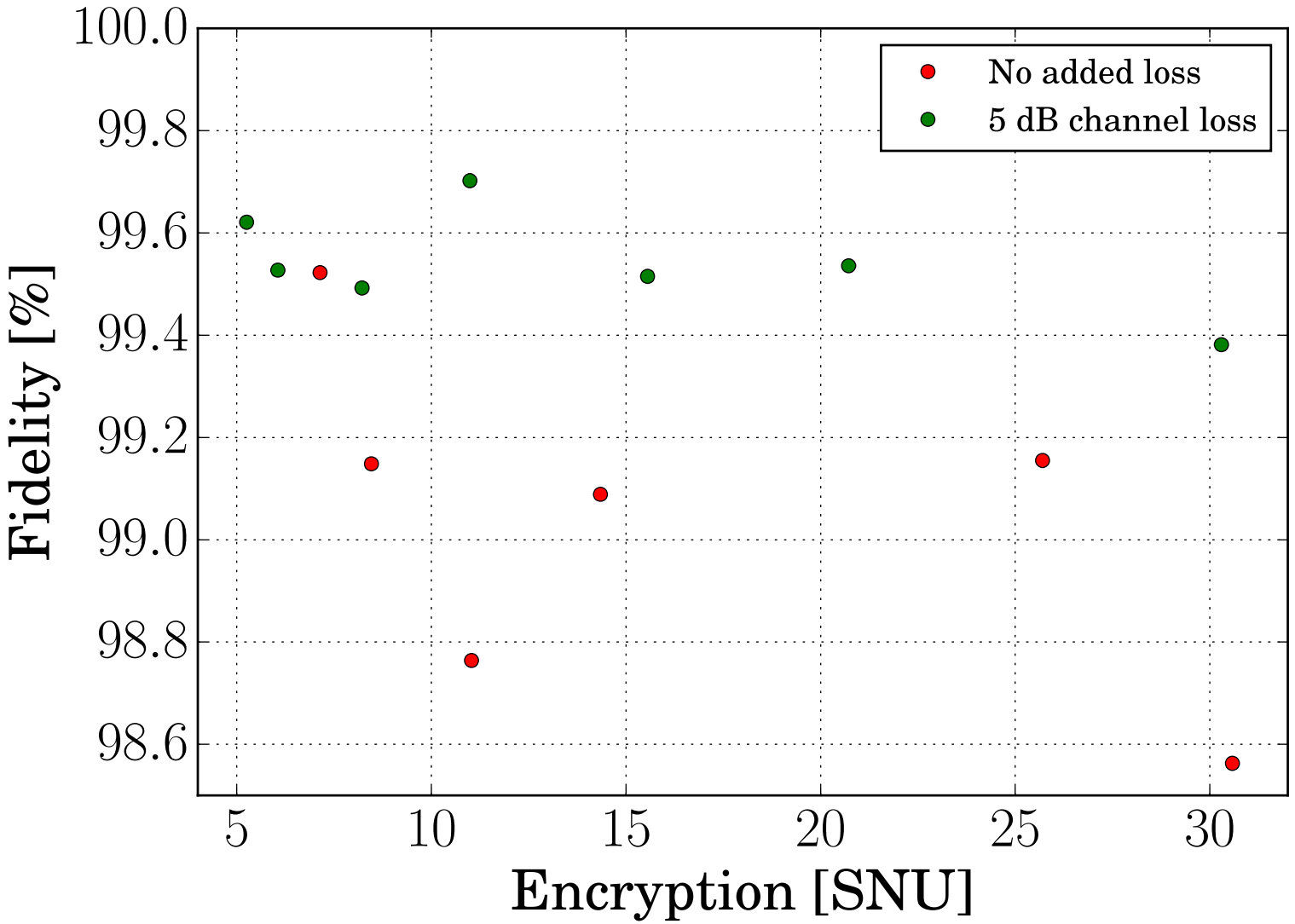


Signal-to-Noise Ratio



Fidelity

Comparion: How good does the encrypted protocol work versus the unencrypted one?



Conclusion & Outlook

Continuous-Variable Quantum Computing on Encrypted Data

- Simple encryption and decryption using displacements and no communication
- Exception: U_3 gate
  - U_3 gate implementation uses extra squeezing
  - One round of classical communication
  - Two modes from client to server

Remaining challenges:

- Formalized security proof (finite encryption variance leaks information)

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