Hybrid quantum repeater with encoding

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Optical quantum information theory
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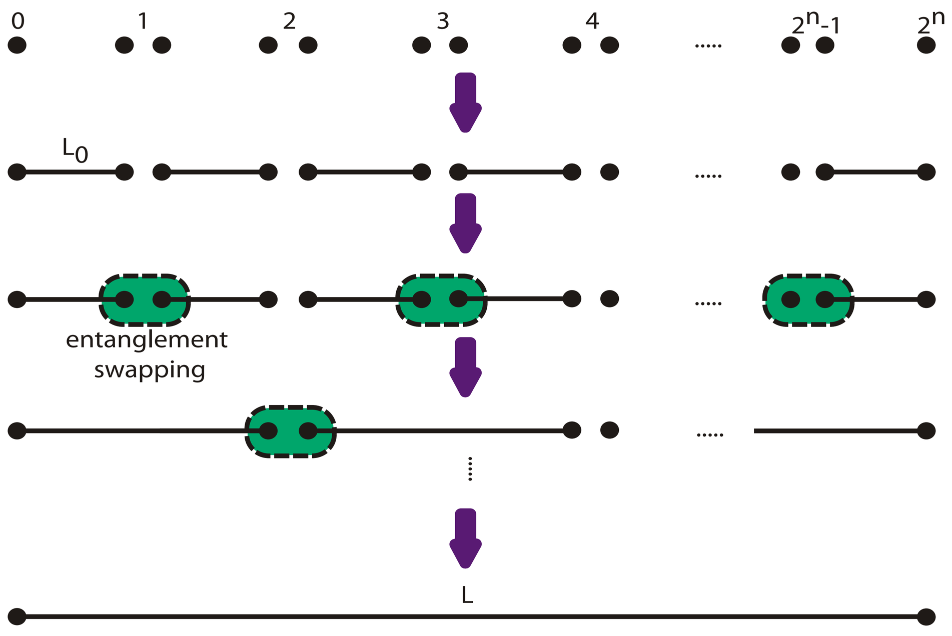
Hybrid Quantum Repeater

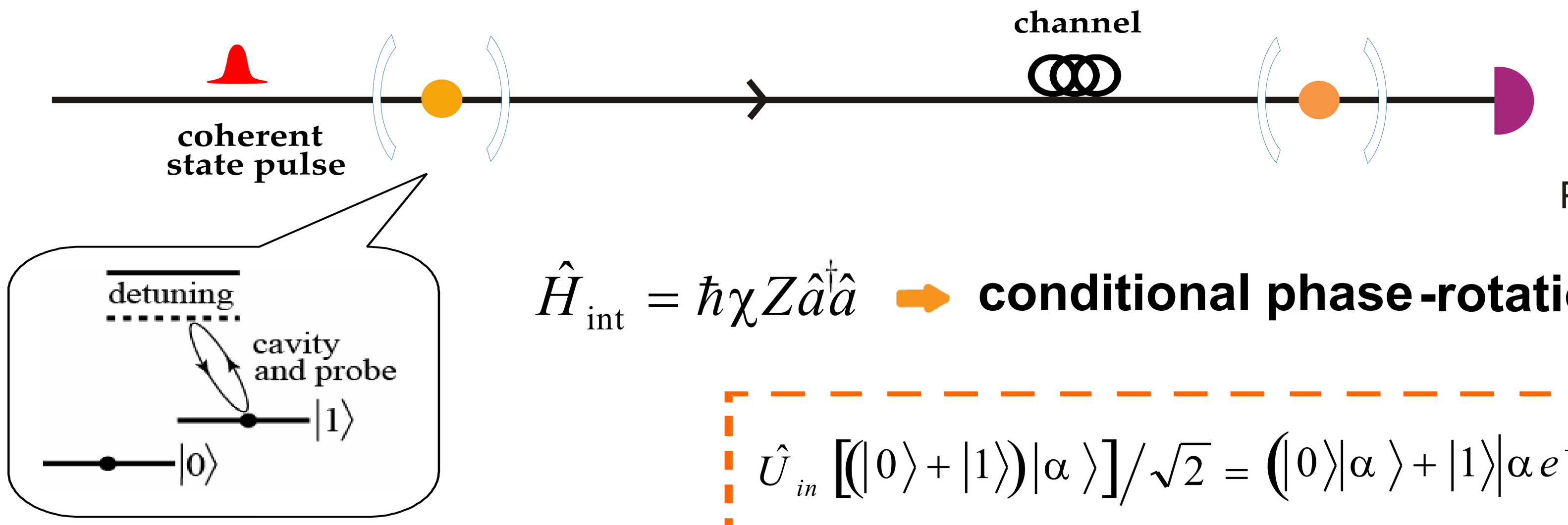
Entanglement is the universal resource for Quantum Information processing. Via a quantum repeater is possible to create long-distance entanglement.

Light is the ideal medium for communication. On the other hand, atoms are perfect for storage and processing.

Optical quantum information processing via the hybrid approach: utilize both discrete and continuous variables, Gaussian and non-Gaussian resources, "best of both worlds".



+ memory and purification!



P. van Loock *et al.*, PRL **96**, 240501 (2006).

$\hat H_{int} = \hbar\chi Z\hat a^\dagger \hat a$ ➡ **conditional phase-rotation!**

$$\hat U_{int}\left[(|0\rangle+|1\rangle)|\alpha\rangle\right]/\sqrt2 = \left(|0\rangle|\alpha\rangle+|1\rangle|\alpha e^{-i\theta}\rangle\right)/\sqrt2$$

$$|\psi\rangle = \left(\sqrt2|\phi^+\rangle|\alpha\rangle + |01\rangle|\alpha e^{i\theta}\rangle + |10\rangle|\alpha e^{-i\theta}\rangle\right)/\sqrt2$$

Error Models

1.Imperfect *generation* of the entangled state

$$F|\phi^+\rangle\langle\phi^+| + (1-F)|\phi^-\rangle\langle\phi^-|$$

$$P_0 = 1-(2F-1)^{\eta/(1-\eta)}$$ **(Upper bound!)**

$$\eta = e^{-l/L_{att}}$$

2. Errors in the *CNOT gates*

$$U_{ij}\rho U_{ij} = \rho' \rightarrow$$

$$(1-q_g)^2\rho' + q_g(1-q_g)(Z_i\rho' Z_i + X_j\rho' X_j) + q_g^2 Z_i X_j\rho' X_j Z_i$$

3.Imperfect *memories*

$$|\phi^\pm\rangle\langle\phi^\pm| \rightarrow (1-q_m(t))|\phi^\pm\rangle\langle\phi^\pm| + q_m(t)|\phi^\mp\rangle\langle\phi^\mp|$$ with $q_m(t) = \frac{1-e^{-t/\tau}}{2}$

Rate Analysis

Assumptions:

- unlimited initial resources
- optimal probabilistic entanglement generation
- deterministic swapping

Errors and error suppression:

- imperfect generation of the entangled state
- local gate error
- imperfect memories
- purification and quantum error correction

➡ Rate to successfully generate an entangled pair per memory using an [n,k,d] code:

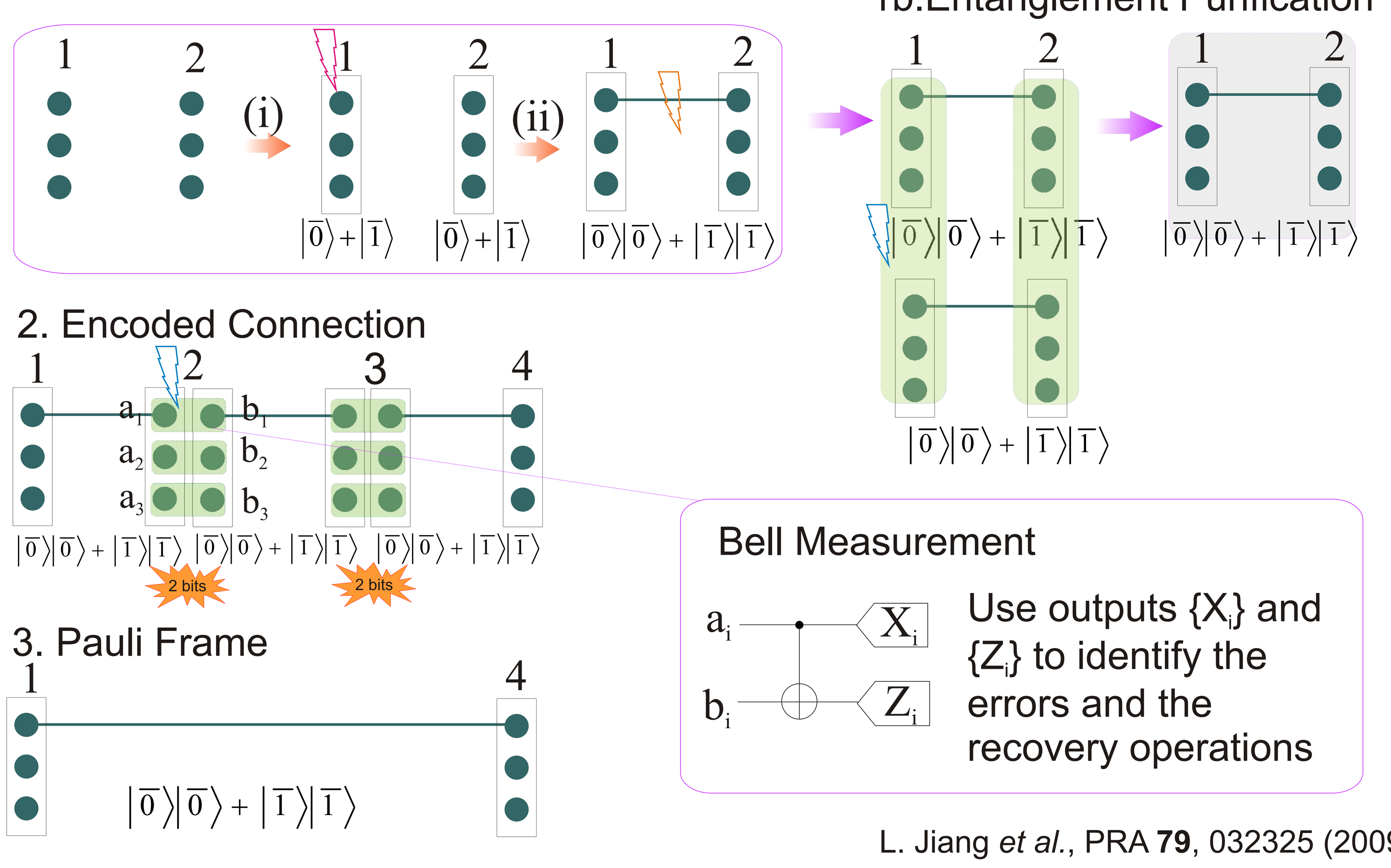
Without purification:

$$R = \frac{P_0}{nT_0}$$

With *r* rounds of purification:

$$R_{pur,n} = \frac{P_0 P_r}{n2^r(r/2+1)T_0}$$

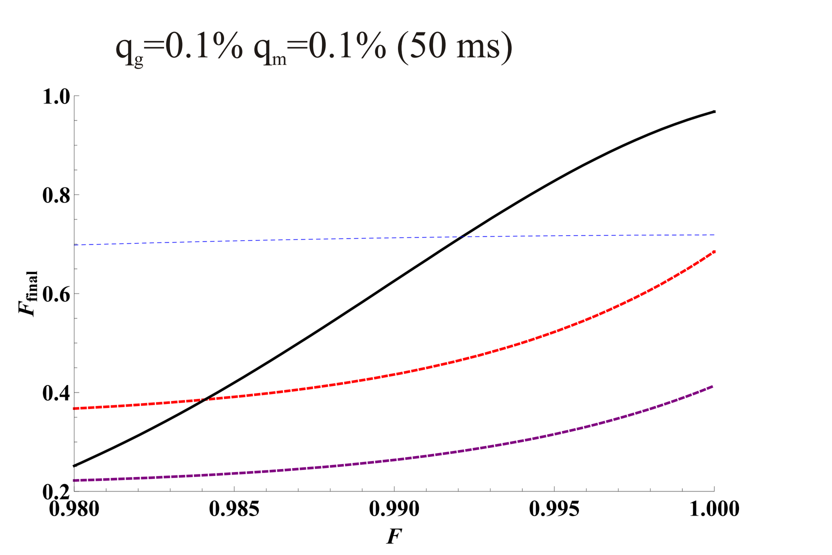
Quantum Error Correction

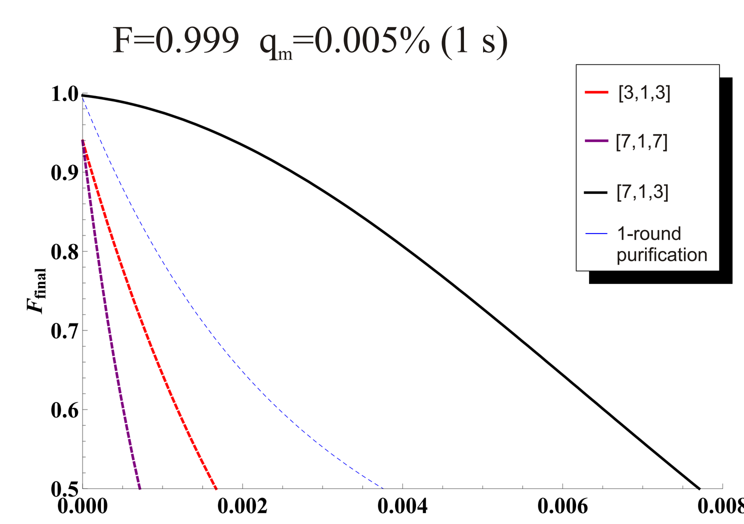


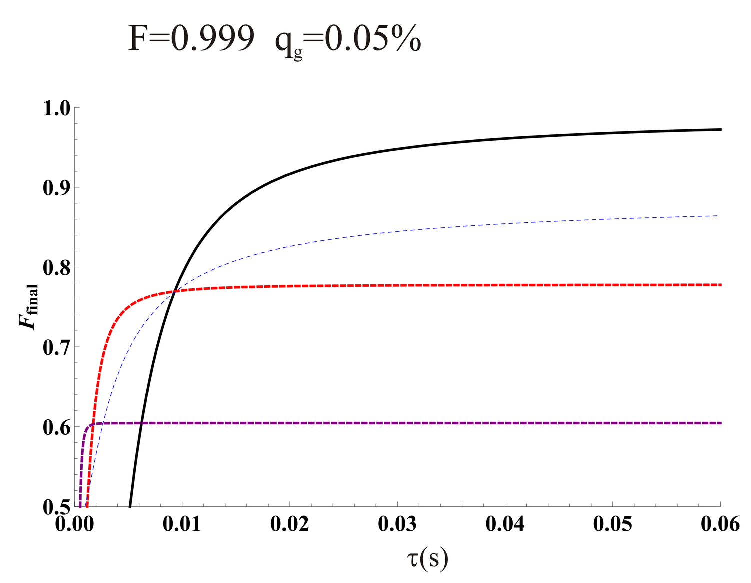
L. Jiang *et al.*, PRA **79**, 032325 (2009)

Results

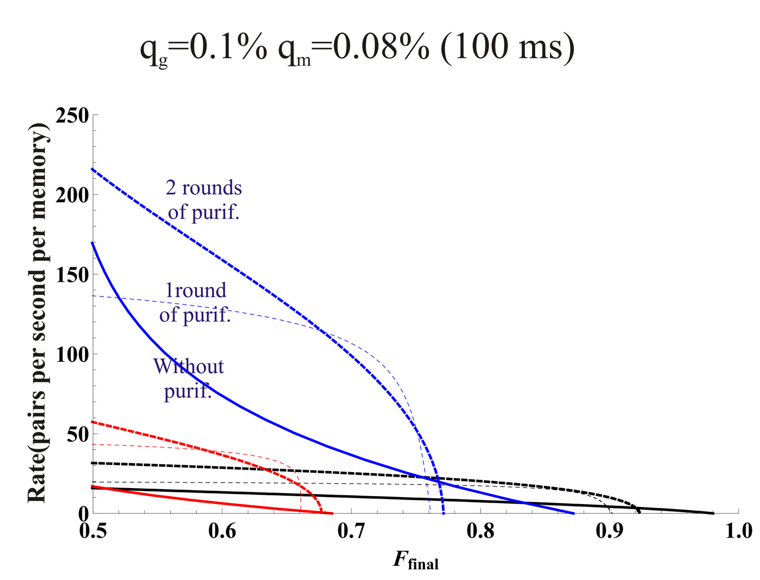
Encoding versus Purification

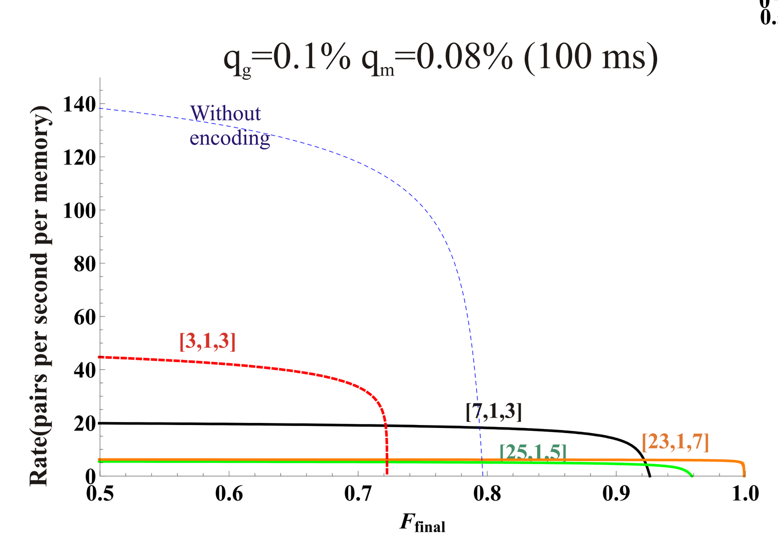


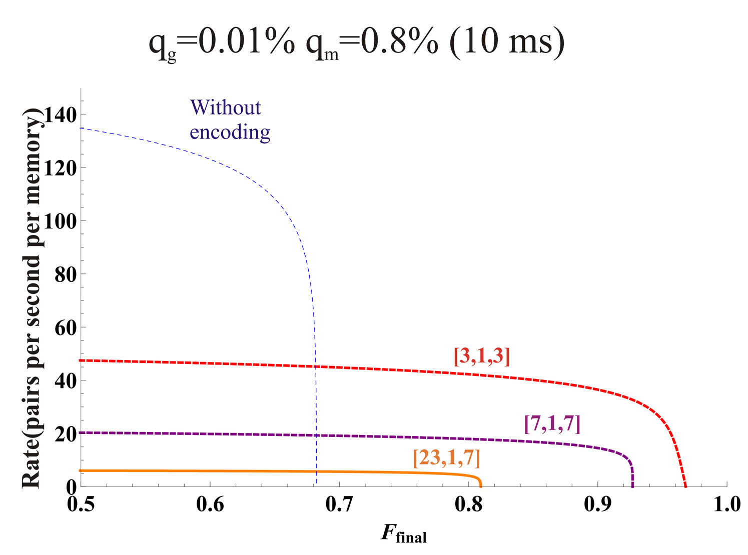




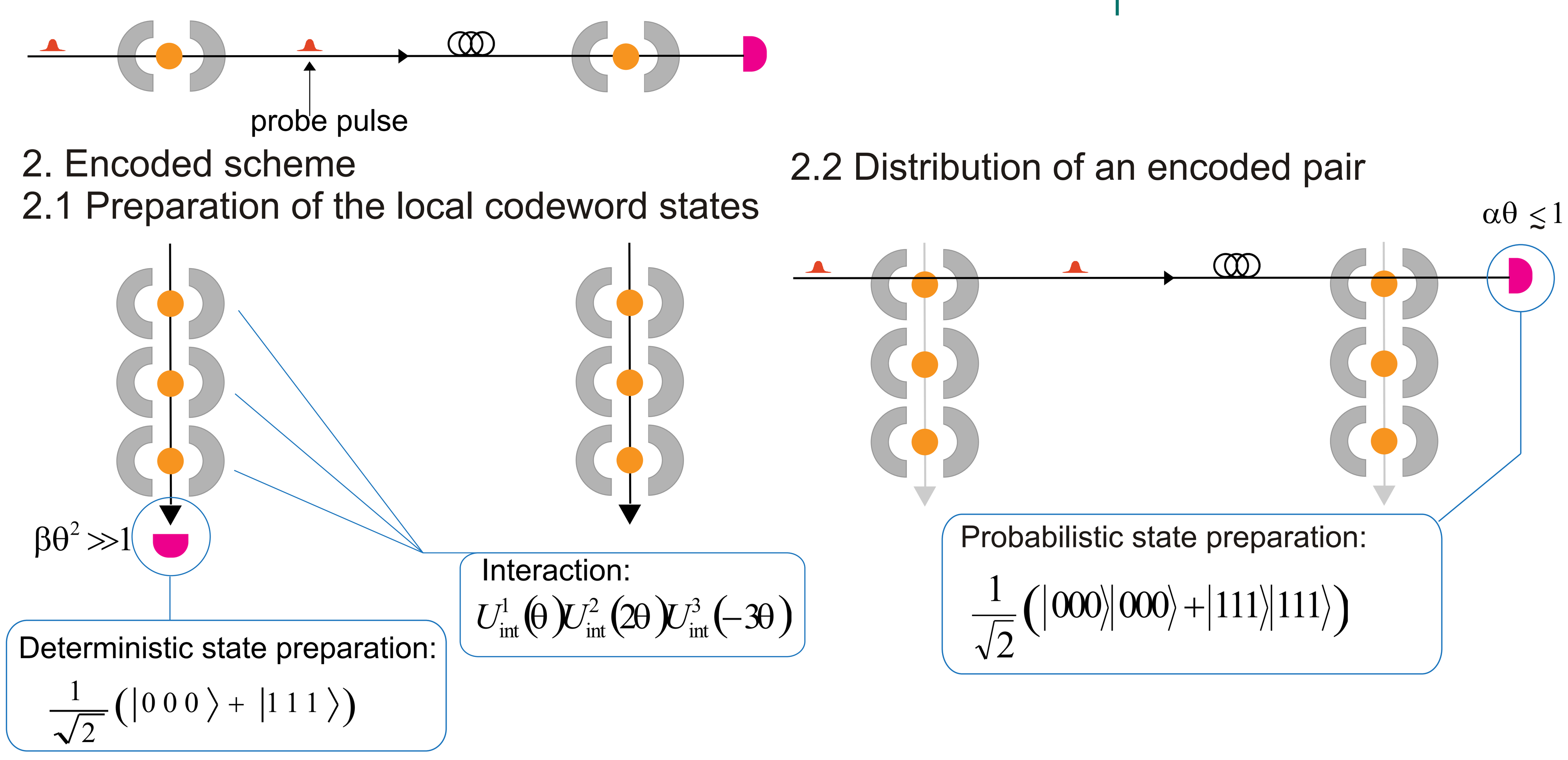
Encoding+Purification







Implementation



arXiv:11053566v2