Quantum repeaters based on concatenated bosonic and discrete-variable quantum codes

Filip Rozpedek,[1] **Kyungjoo Noh**,[2] **Qian Xu**,[1] **Saikat Guha**,[3] **Liang Jiang**[1]

[1]*Pritzker School of Molecular Engineering, University of Chicago, Chicago, IL 60637, USA*

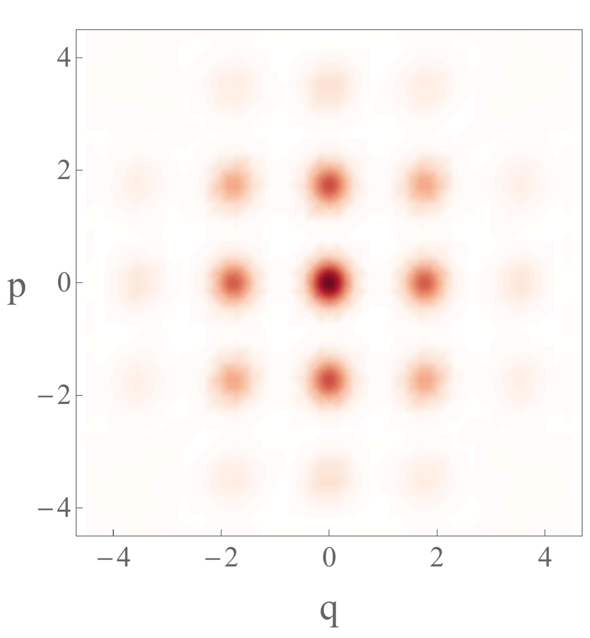
[2]*Department of Physics, Yale University, New Haven, CT, 06520, USA*

[3]*James C. Wyant College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA*

Introduction

We propose a **one-way repeater** architecture based on concatenation of the **bosonic GKP code**[1] with a **multi-qubit code**. The main resource required for our scheme is high degree of **GKP squeezing**, which makes it possible to achieve long distance communication with just a **few optical modes**. This is possible thanks to the additional **analog information**[2] obtained from the GKP syndrome measurement. Additionally, resources can be saved by using **two types of repeaters**.

GKP code



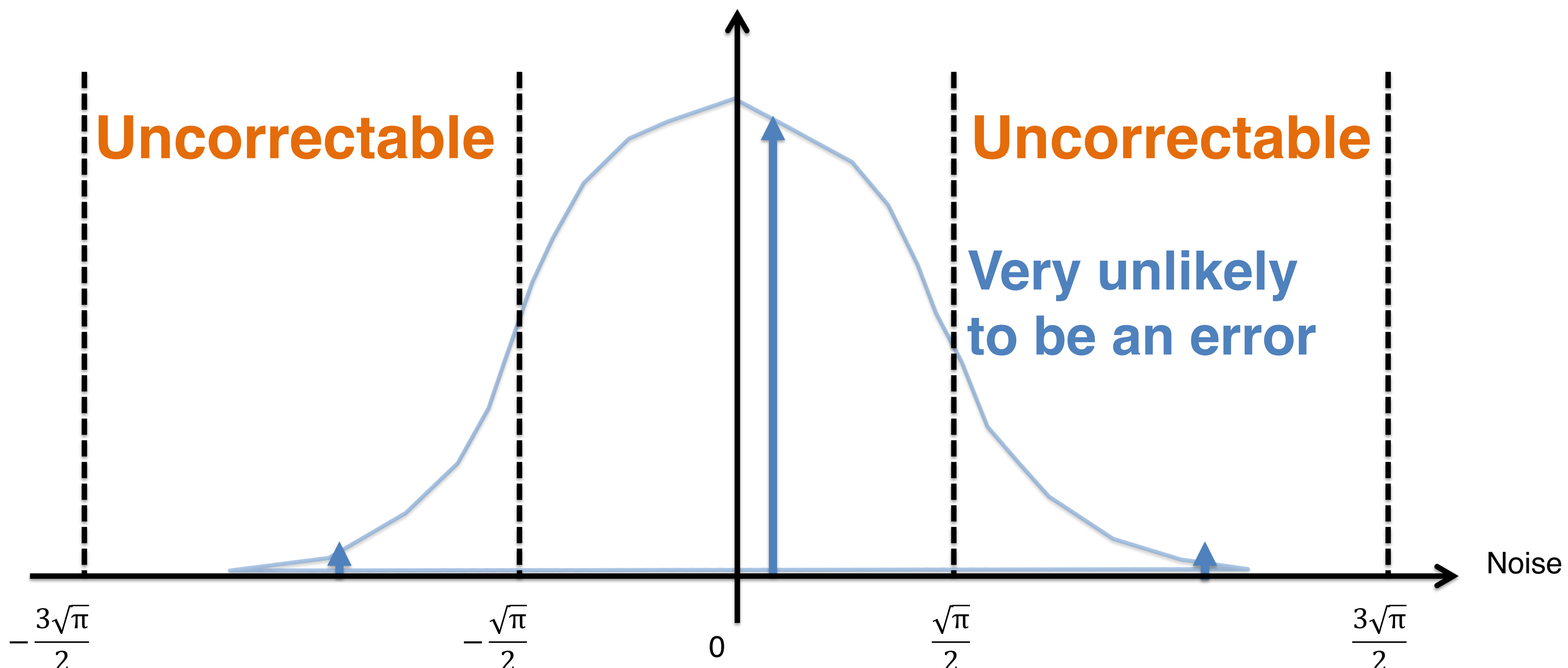
$$\hat{S}_q = e^{i2\sqrt{\pi}\hat{q}} \text{ and } \hat{S}_p = e^{-i2\sqrt{\pi}\hat{p}}$$

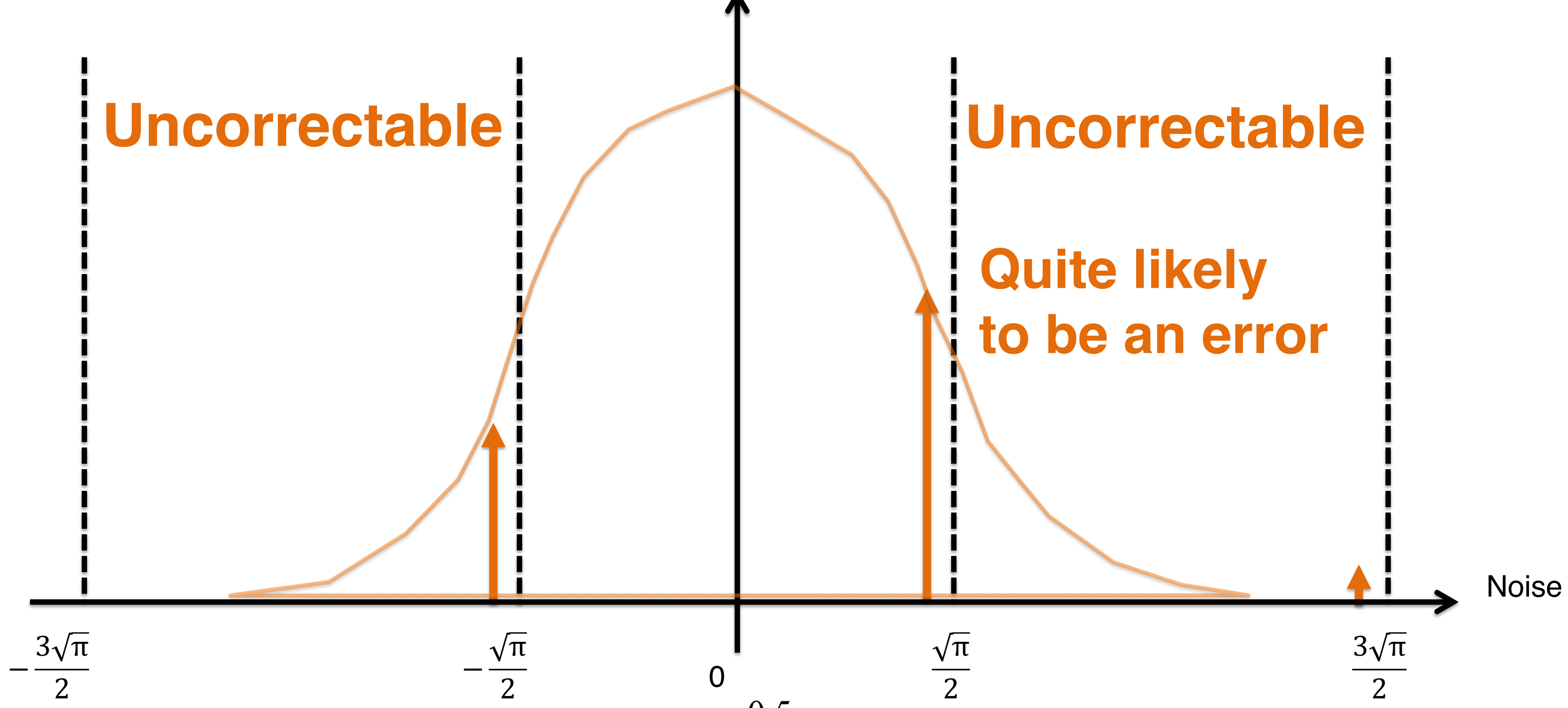
$$|0_{gkp}\rangle \propto \sum_{n\in\mathbb{Z}} |\hat{q} = \sqrt{\pi}(2n)\rangle$$

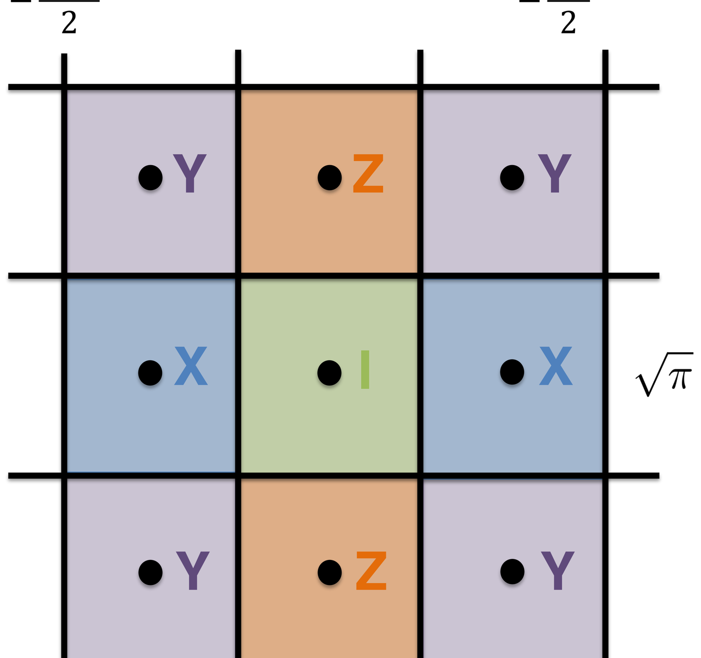
$$|1_{gkp}\rangle \propto \sum_{n\in\mathbb{Z}} |\hat{q} = \sqrt{\pi}(2n+1)\rangle$$

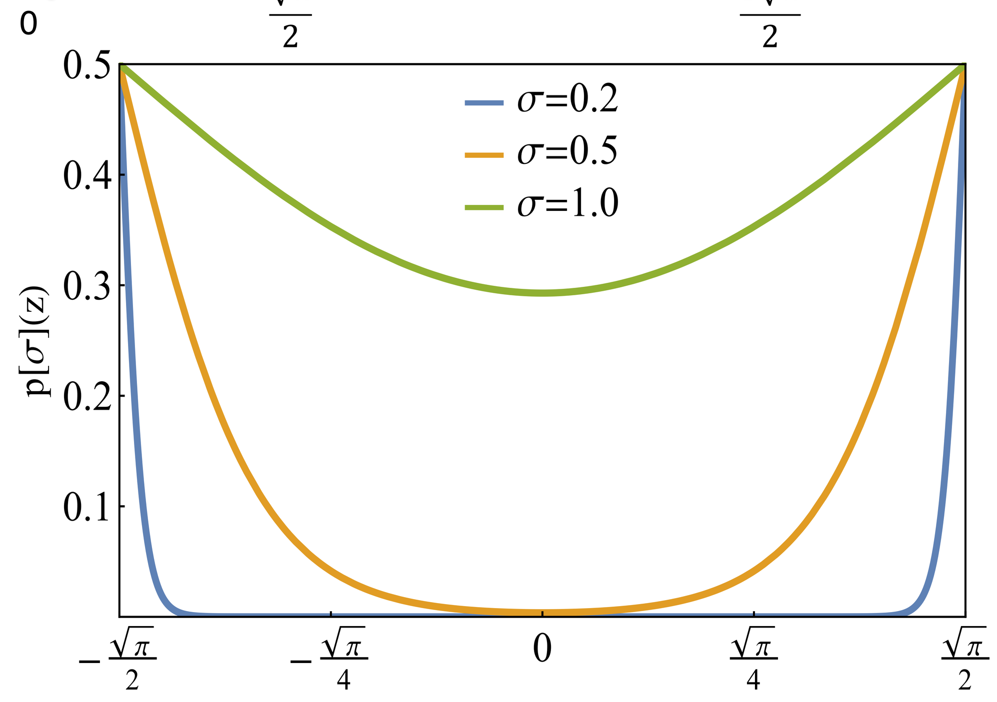
$\hat{q} = \hat{p} = 0 \, mod \sqrt{\pi}$: Can correct shift errors in the phase space

Logical Pauli errors under the action of a Gaussian random displacement channel with standard deviation σ:



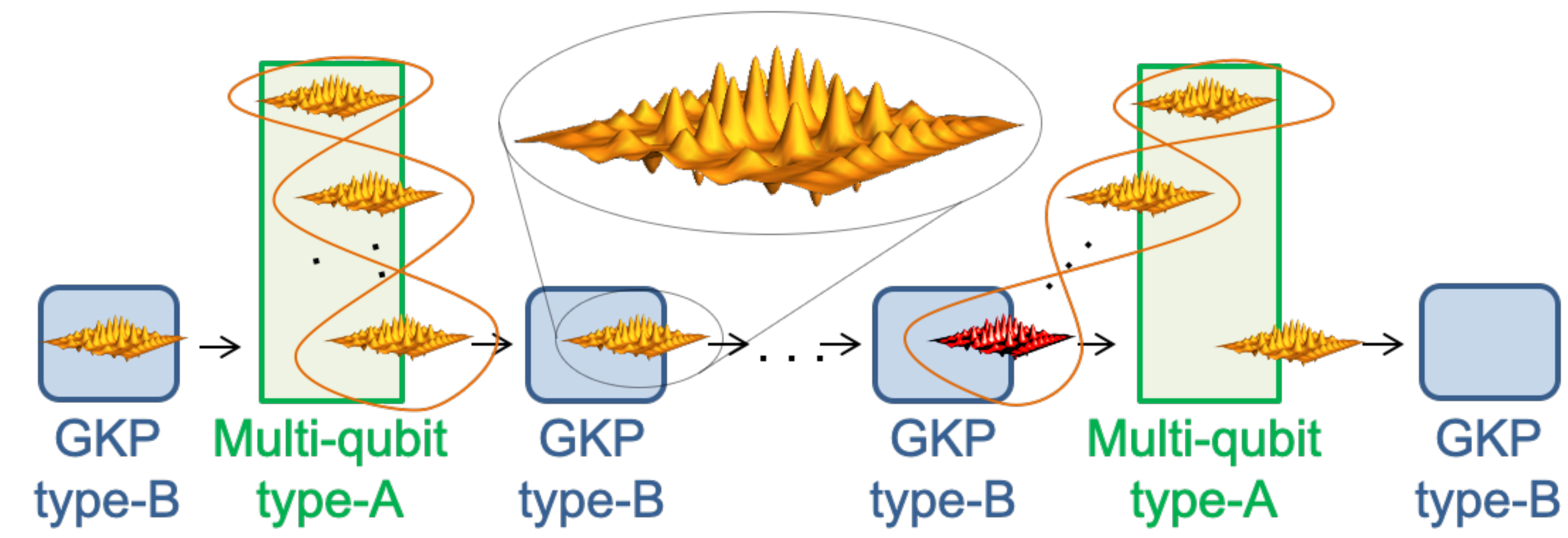






Quantum repeaters

Concatenate GKP code with the [[7,1,3]] Steane code



- Finite GKP squeezing (describes width of GKP peaks):

$$s_{gkp} = 10\log_{10}\left(\frac{1}{2 * \sigma_{gkp}^2}\right)$$

- Photon outcoupling efficiency in repeaters: η_0

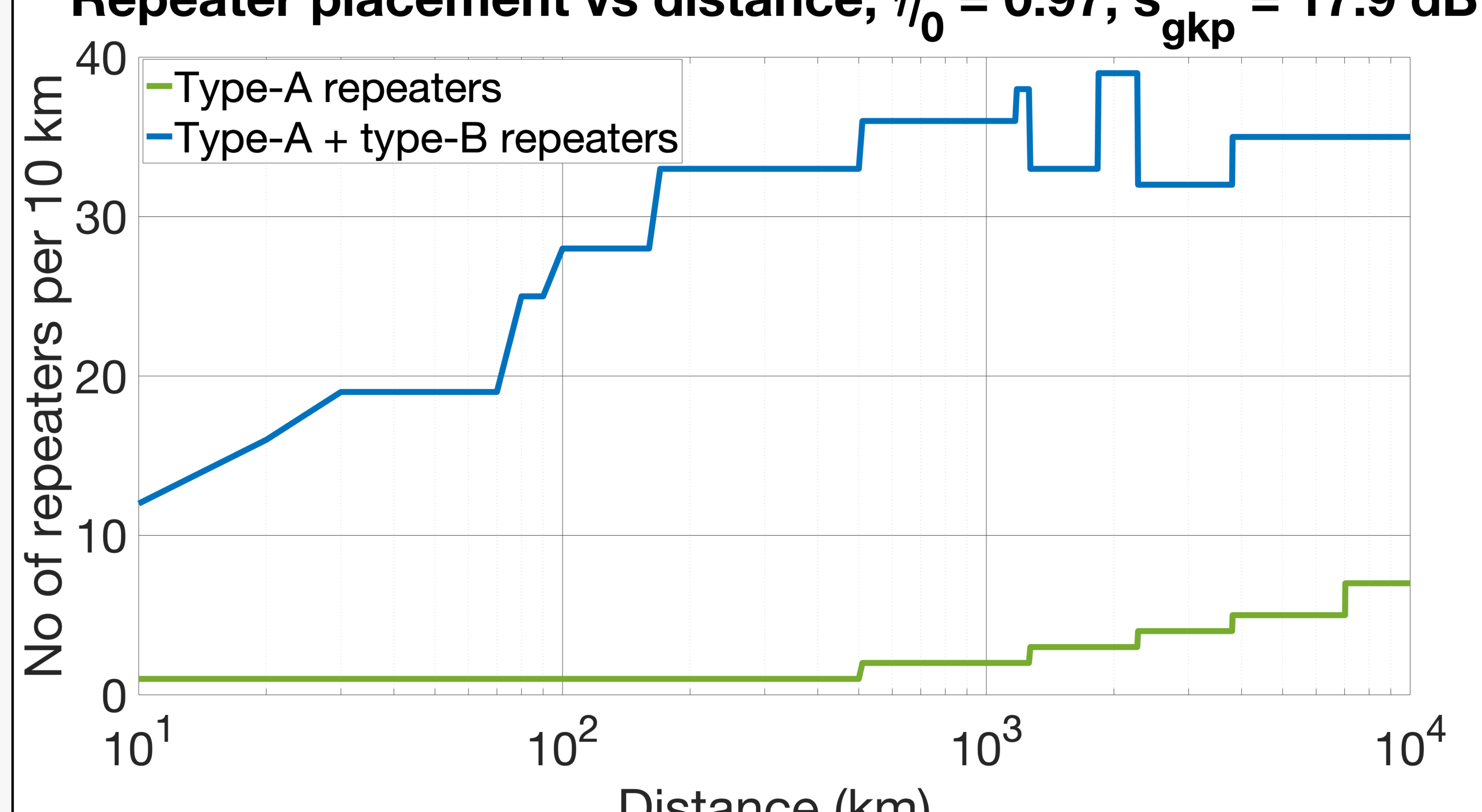
Achievable distances for secret key generation (km)

		η_0		
		0.93	**0.95**	**0.97**
s_{gkp} (dB)	**17.9**	1120	>10000	>10000
	16.2	360	2830	>10000
	14.7	120	310	730

- Optimise resources by minimizing cost function:

$$C = \frac{\#\, storage\ modes \times storage\ time\ inside\ repeaters}{secret\ key}$$

Repeater placement vs distance, η_0 = 0.97, s_{gkp} = 17.9 dB



References

1. Gottesman, D., Kitaev, A., and Preskill, J. Encoding a qubit in an oscillator. *Physical Review A*, 64(1):012310, 2001.
2. Noh, K. and Chamberland, C. Fault-tolerant bosonic quantum error correction with the surface–gottesman-kitaev-preskill code. *Physical Review A*, 101(1):012316, 2020.