Peaked Boson Sampling: towards efficiently verifiable and NISQ-able quantum advantage

Michelle Ding
College of Natural Sciences, The University of Texas

The University of Texas at Austin
College of Natural Sciences

CNS Award for Excellence in
Computer Science & Computer Engineering

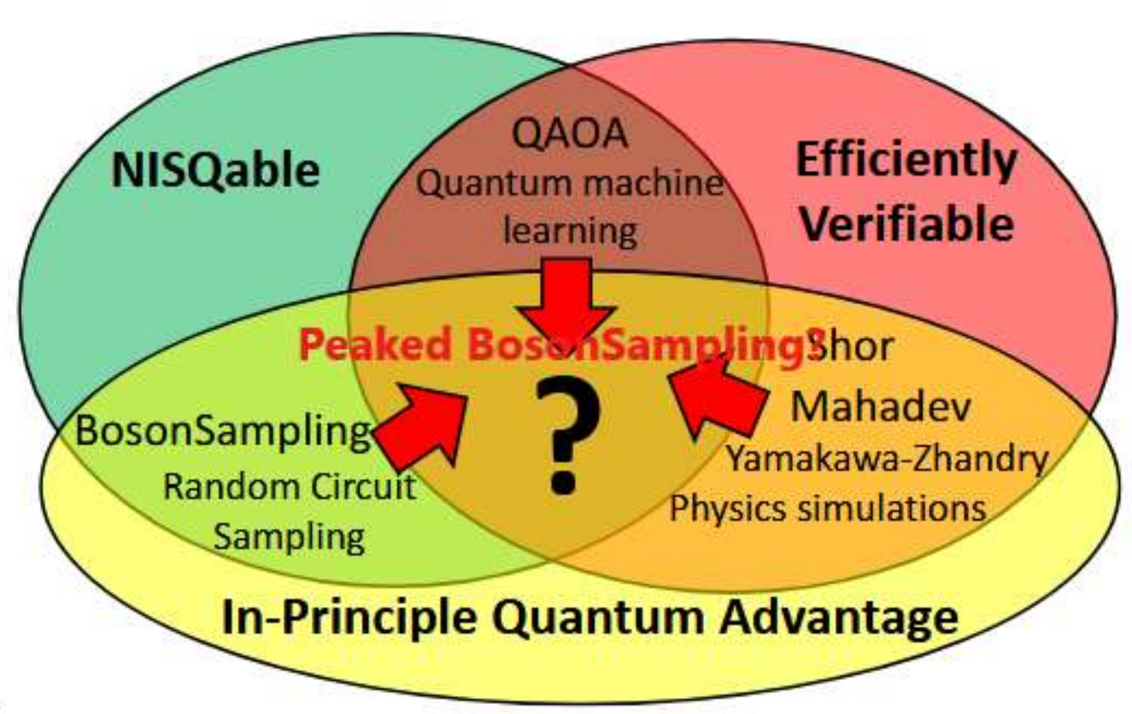
Introduction

The use of randomness in quantum circuits is an intrinsically interesting property due to the model's convergence to the hard-to-simulate Haar measure. While random circuit sampling is both promising for quantum advantage and realistically implementable on a NISQ device, it is not yet efficiently verifiable. Previous work in studying peaked random circuit sampling models has shown optimism for a potentially viable model [1]. In this paper, we extend those observations by studying a simpler, alternative model to quantum computation involving beamsplitter networks. We present numerical and theoretical findings on the structure of peaked beamsplitter networks and evaluate their potential as a candidate for quantum advantage experiments.

Research Goal

I analyze the distributions of both numerically-optimized peaking networks and post selected beamsplitter networks to determine if peaked circuits truly exhibit pseudorandom behavior, and how to efficiently generate them. Although a complete answer remains out of reach within the limited duration of this work, our findings provide a foundation for further investigation.

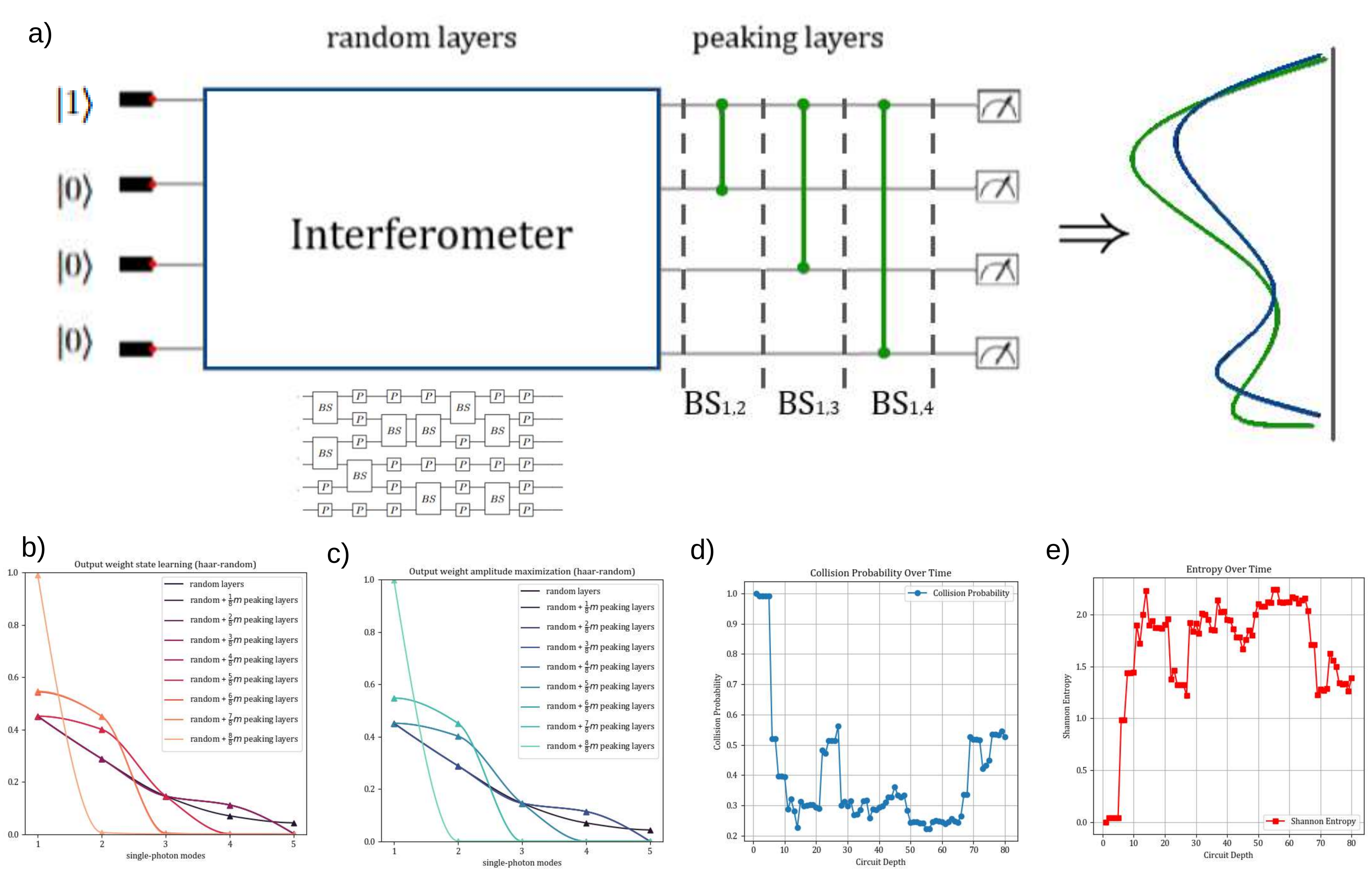
Methods



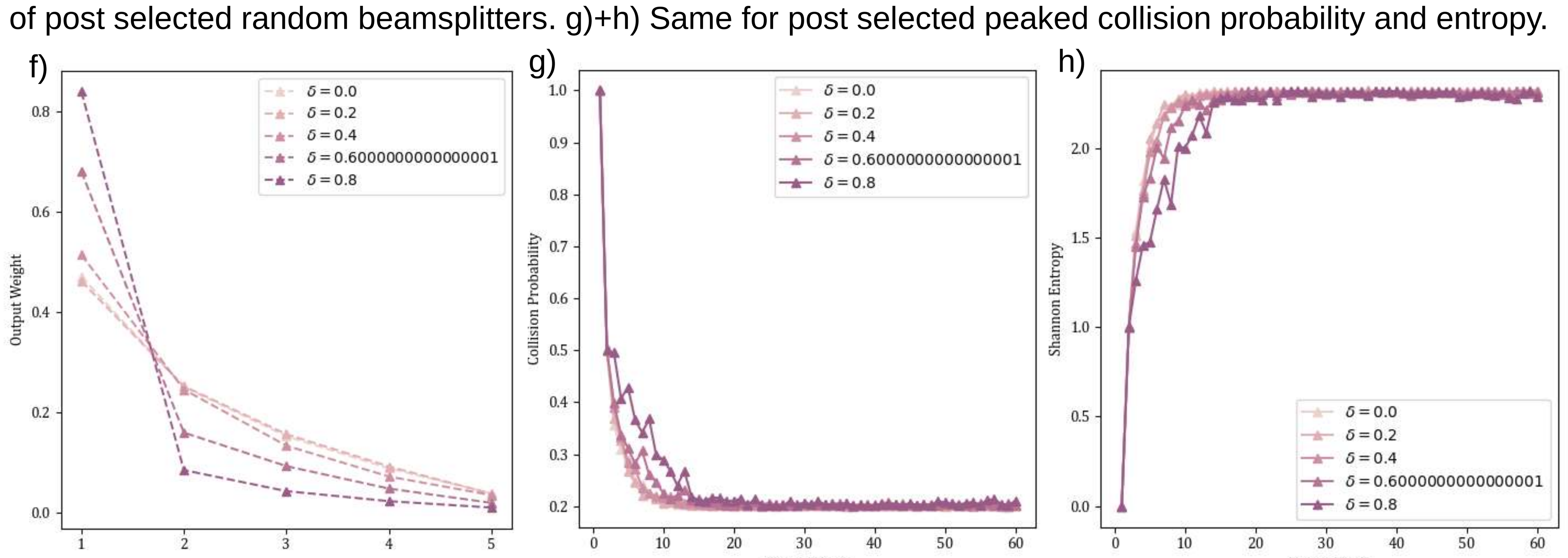
.

Our experiment(s) combine the linear optical setup of Boson Sampling[1] with the efficiently verifiable properties of peaked circuits. We use an interferometer setup to generate random networks. We then use stochastic gradient descent to optimize over the peaking layer of the constructed circuit. Finally, we examine the entropy and collision probability over time of post selected random beamsplitter networks.

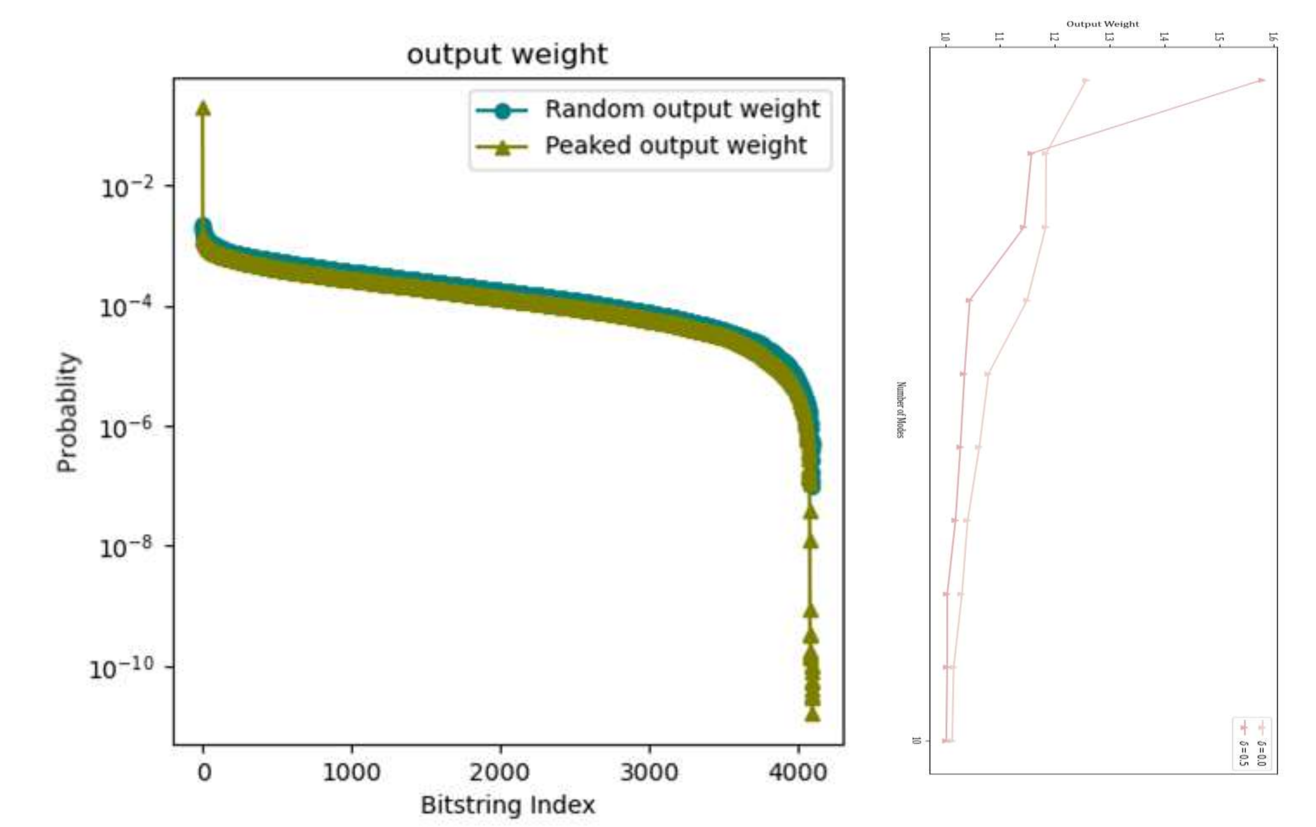
Figures and Results



(TOP) Explicit constructions of peaking circuits. a) An interferometer composed of beamsplitter and phaseshifter gates is followed by $O(m)$ peaked nonlocal beamsplitter gates optimized using a numerical solver. $O(t)$ gates act nonlocally on mode 1 and mode $i \in [2, n]$ to transfer amplitude from the bottom $t - 1$ modes to mode 1.
(MIDDLE) A numerical solver is optimized to learn the output state. b). Various peaking depths are documented over a single-photon experiment with $m = 5$; at around $\frac{1}{2}m$ depth inversions begin to take effect. c) Same as before, but now the objective is to directly maximize the amplitude on the first mode $\min ||\langle 1_n|U|1_n\rangle|^2 - 1|$ rather than the state overlap. d)+e) Circuit evolution of post selected peaked collision probability and entropy.
(BOTTOM) Post selected peaked circuits do not scramble as quickly. f) Distribution for various delta-thresholds of post selected random beamsplitters. g)+h) Same for post selected peaked collision probability and entropy.



Conclusion



Over the past few months, I learned and conducted experiments on the alternative linear optical model of QC and successfully replicated graphs from the standard random circuit model[2] (above). These studies lay the foundation for further experiments on peaked optics models and indicate that there are still nontrivial properties of peaked optics to be explored given their behavior on single-photon modes.
A copy of the classical simulations for this project can be found here: https://github.com/michelled01/Peaked-circuits

Acknowledgments

I would like to thank Scott Aaronson and Nick Hunter-Jones (UT faculty) for their invaluable advice in the duration of this project. I would also like to thank Yuxuan Zhang (UT alumni) for his feedback on the experimental feasibility of my simulations as well as willingness to share ideas from a previously related project.

References

1. Scott Aaronson and Alex Arkhipov. The computational complexity of linear optics. 2010.
2. Scott Aaronson and Yuxuan Zhang. On verifiable quantum advantage with peaked circuit sampling, 2024.