Reliable quantum certification for photonic quantum technologies

Leandro Aolita[1,2], Christian Gogolin[1,3,4], Martin Kliesch[1], and Jens Eisert[1]

[arXiv:1407.4817]

[1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin

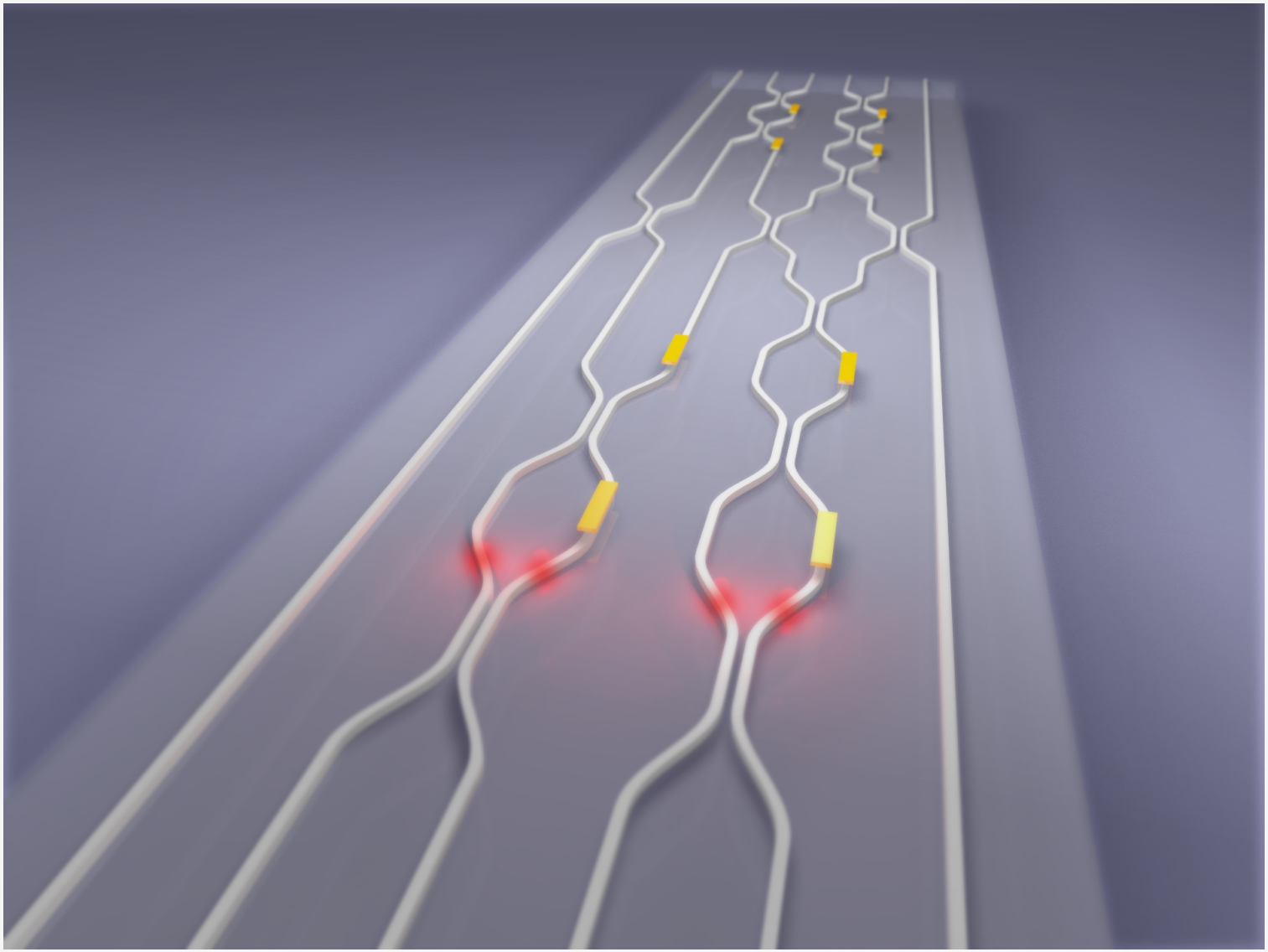
[2]Instituto de Física, Universidade Federal do Rio de Janeiro, Brazil

[3]ICFO - The Institute of Photonic Sciences, Barcelona, Spain

[4]MPQ - Max Planck Institute of Quantum Optics, Garching

DPG Spring Meeting 2015, Heidelberg

Photonic quantum technologies



source http://phys.org/

Example: BosonSampling

Science 339, 798 (2013):

Boson Sampling on a Photonic Chip

Justin B. Spring,[1]* Benjamin J. Metcalf,[1] Peter C. Humphreys,[1] W. Steven Kolthammer,[1] Xian-Min Jin,[1,2] Marco Barbieri,[1] Animesh Datta,[1] Nicholas Thomas-Peter,[1] Nathan K. Langford,[1,3] Dmytro Kundys,[4] James C. Gates,[4] Brian J. Smith,[1] Peter G. R. Smith,[4] Ian A. Walmsley[1]*

quantum computers ideally solve problems such as factoring integers

nature photonics
LETTERS
PUBLISHED ONLINE: 26 MAY 2013 | DOI: 10.1038/NPHOTON.2013.112

Integrated multimode interferometers with arbitrary designs for photonic boson sampling

Andrea Crespi[1,2], Roberto Osellame[1,2]*, Roberta Ramponi[1,2], Daniel J. Brod[3], Ernesto F. Galvão[3]*, Nicolò Spagnolo[4], Chiara Vitelli[4,5], Enrico Maiorino[4], Paolo Mataloni[4] and Fabio Sciarrino[4]*

The evolution of bosons undergoing arbi

nature photonics
LETTERS
PUBLISHED ONLINE: 12 MAY 2013 | DOI: 10.1038/NPHOTON.2013.102

Experimental boson sampling

Max Tillmann[1,2]*, Borivoje Dakić[1], René Heilmann[3], Stefan Nolte[3], Alexander Szameit[3] and Philip Walther[1,2]*

dramatic increase in photons. Randomly chosen instances of this problem are strongly classical means. Instances of boson

Science 339, 794 (2013):

Photonic Boson Sampling in a Tunable Circuit

Matthew A. Broome,[1,2]* Alessandro Fedrizzi,[1,2] Saleh Rahimi-Keshari,[2] Justin Dove,[3] Scott Aaronson,[3] Timothy C. Ralph,[2] Andrew G. White[1,2]

Efficient experimental validation of photonic boson sampling against the uniform distribution

Nicolò Spagnolo,[1] Chiara Vitelli,[1,2] Marco Bentivegna,[1] Daniel J. Brod,[3] Andrea Crespi,[4,5] Fulvio Flamini,[1] Sandro Giacomini,[1] Giorgio Milani,[1] Roberta Ramponi,[4,5] Paolo Mataloni,[1,6] Roberto Osellame,[4,5,*] Ernesto F. Galvão,[3,†] and Fabio Sciarrino[1,6,‡]

[1] *Dipartimento di Fisica, Sapienza Università di Roma, Piazzale Aldo Moro 5, I-00185 Roma, Italy*
[2] *Center of Life NanoScience @ La Sapienza, Istituto Italiano di Tecnologia, Viale Regina Elena, 255, I-00185 Roma, Ita*
[3] *Instituto de Físic*
Av. Gal. Milton Tavares
[4] *Istituto di Fotonica e Nanotecnol*
Piazza Leonardo
[5] *Dipartimento di Fisica, Politecnico di M*
[6] *Istituto Nazionale di Ottica (IN*

A boson sampling device is a specialised
um computer that solves a problem wh
strongly believed to be computationally
or classical computers [1]. Recently a
ber of small-scale implementations have be
ported [2–5], all based on multi-photon int

BosonSampling with Controllable Distinguishability

Max Tillmann[1], Si-Hui Tan[2], Sarah E. Stoeckl[1], Barry C. Sanders[3], Hubert de Guise[4], René Heilmann[5], Stefan Nolte[5], Alexander Szameit[5], Philip Walther[1]

[1] *Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria*
[2] *Singapore University of Technology and Design, 20 Dover Drive, 138682 Singapore*
[3] *Institute for Quantum Science and Technology, University of Calgary, Alberta, Canada T2N 1N4*
[4] *Department of Physics, Lakehead University, Thunder Bay, Ontario, P7B 5E1, Canada and*
[5] *Institute of Applied Physics, Abbe Center of Photonics,*
Germany

nature photonics
ARTICLES
PUBLISHED ONLINE: 20 JULY 2014 | DOI: 10.1038/NPHOTON.2014.152

On the experimental verification of quantum complexity in linear optics

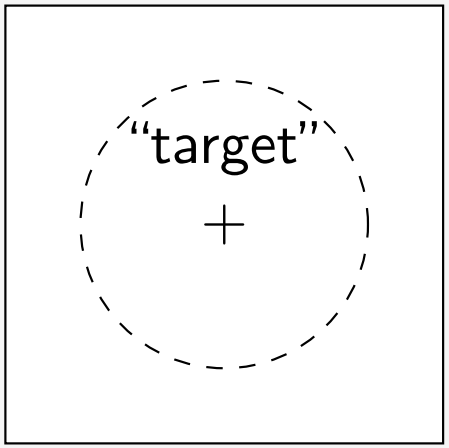
J. Shadbolt[1], Nicholas J. Russell[1], Nur Ismail[2], pson[1], Jeremy L. O'Brien[1],

at are forever intractable to classical computers. The first of
d to their own particular physical capabilities. Sampling the
um-mechanically is conjectured to be intractable to a classical
r, the complexity of this type of problem means its solution is
successful operation becomes one of gathering sufficiently
develop scalable methods to experimentally establish correct
for three, four and five photons in integrated optical circuits,
oad approach is practical for all quantum computational
algorithms are either intractable or unknown.

The problem of certification

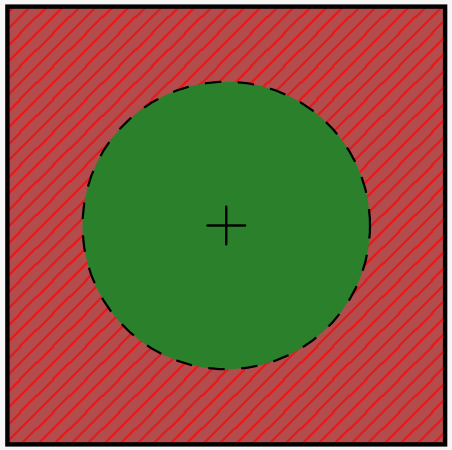
How do you know the device works?

What is certification?



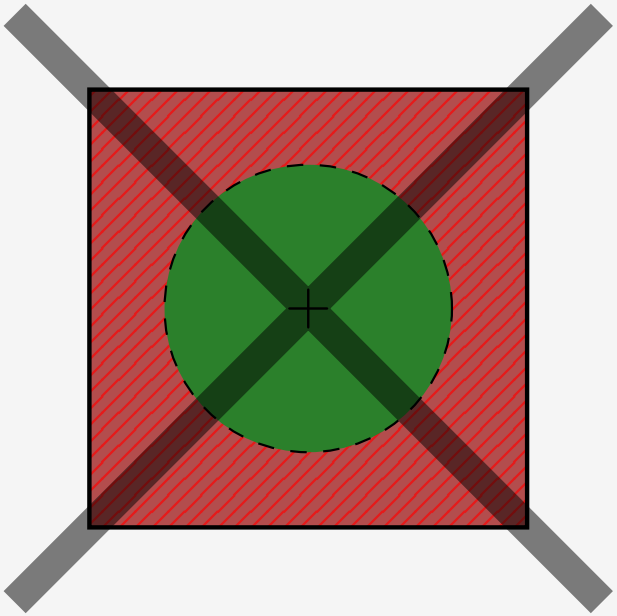
What is certification?

naive



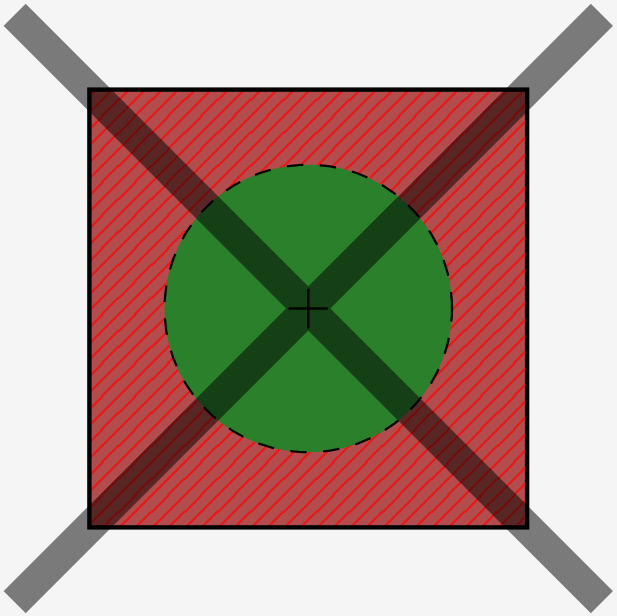
What is certification?

impossible

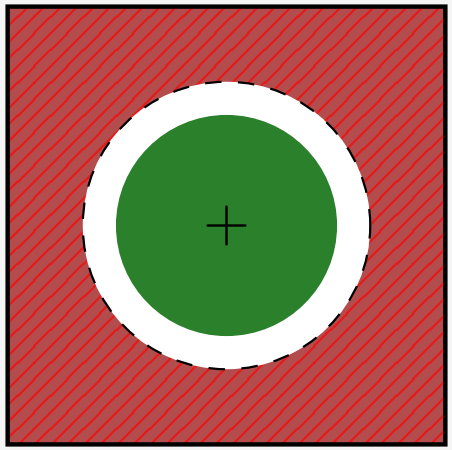


What is certification?

impossible

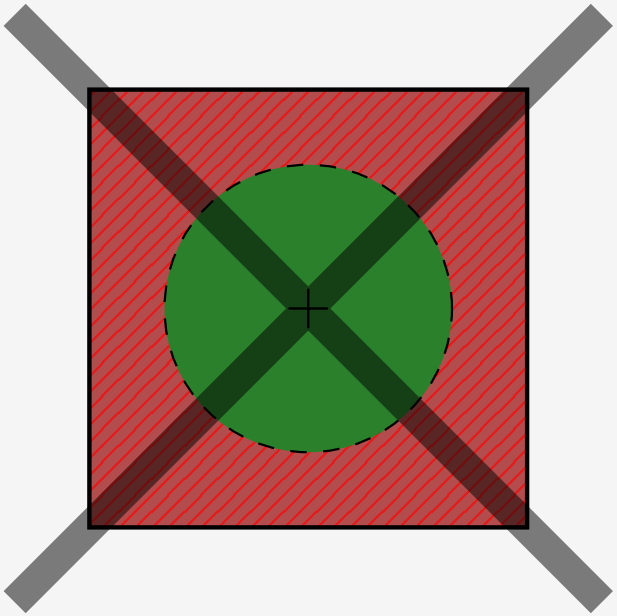


robust

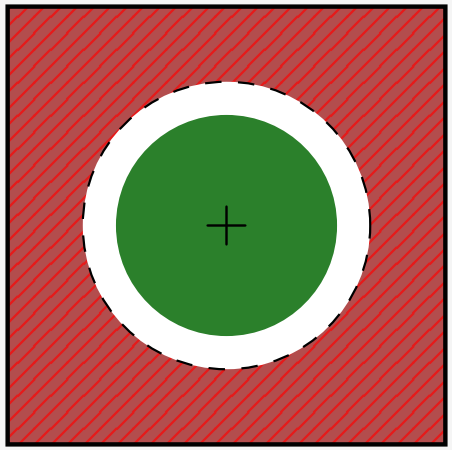


What is certification?

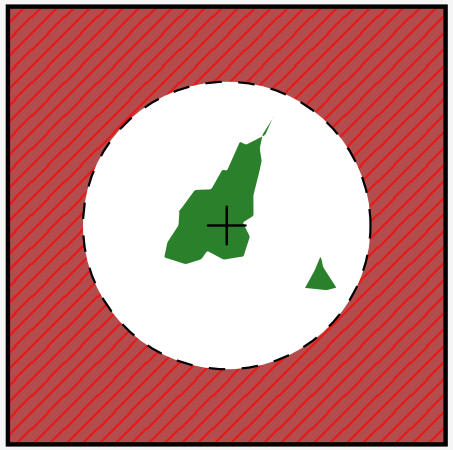
impossible



robust



good enough



Certification as a game

Prover

claims has quantum device

Verifier

only limited measurements

Certification as a game

Prover

claims has quantum device

Verifier

only limited measurements

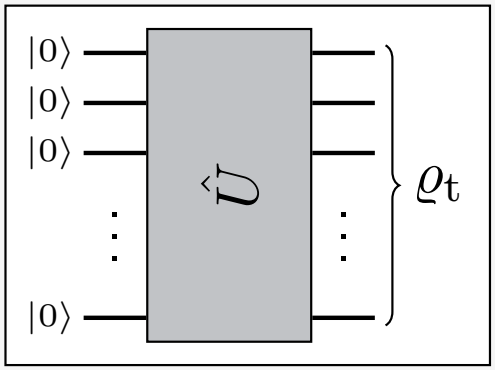
request target state ϱ_{t}

Certification as a game

Prover

claims has quantum device

claims to do:



Verifier

only limited measurements

request target state ϱ_{t}

Certification as a game

Prover

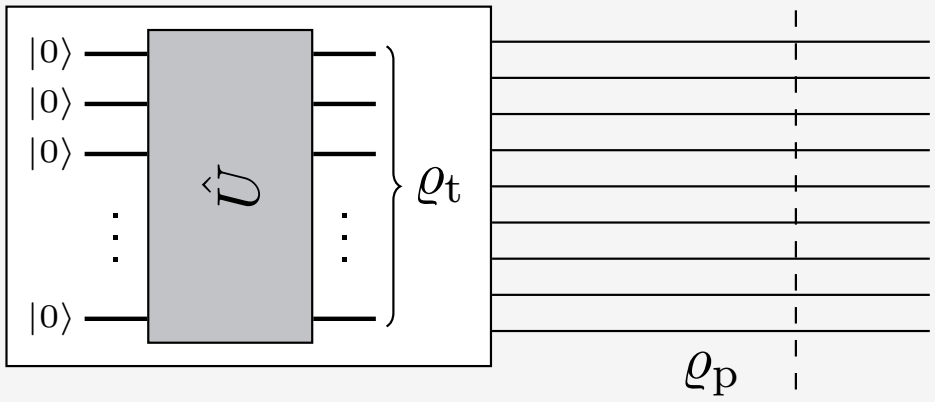
claims has quantum device

Verifier

only limited measurements

request target state ϱ_{t}

claims to do:

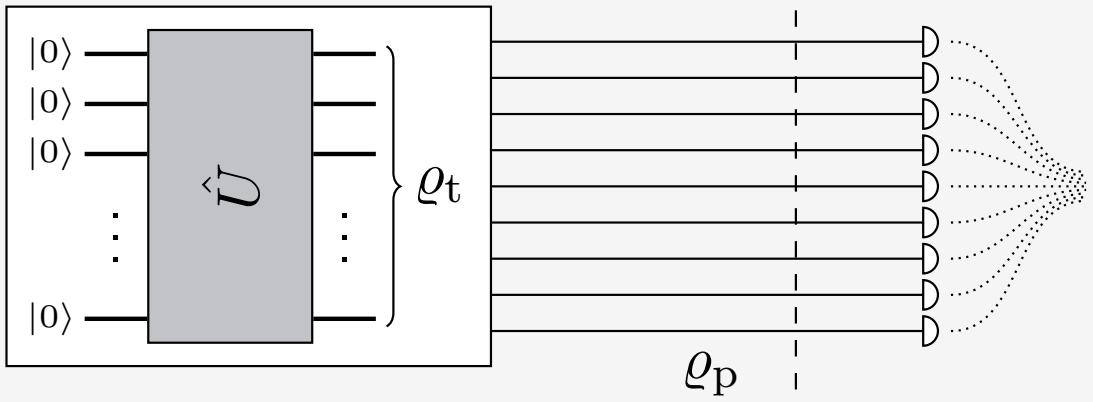


Certification as a game

Prover

claims has quantum device

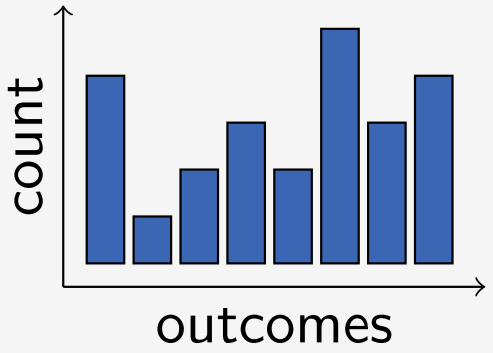
claims to do:



Verifier

only limited measurements

request target state ϱ_{t}

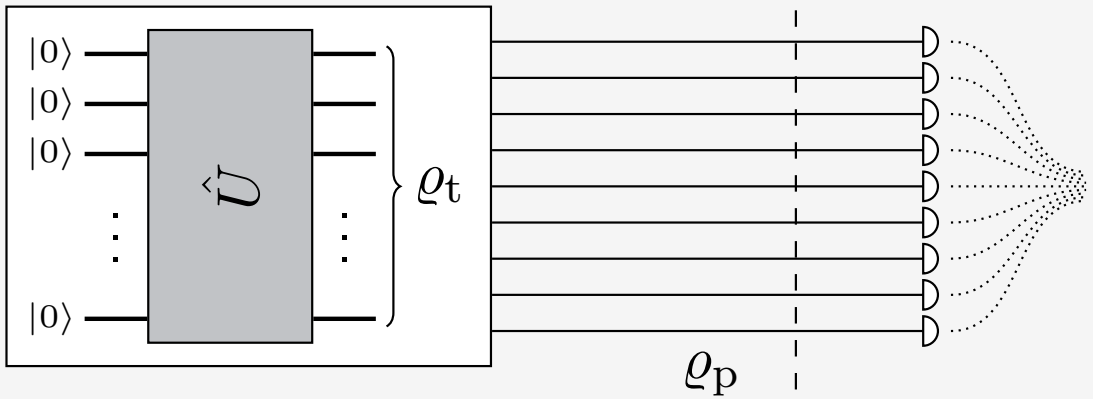


Certification as a game

Prover

claims has quantum device

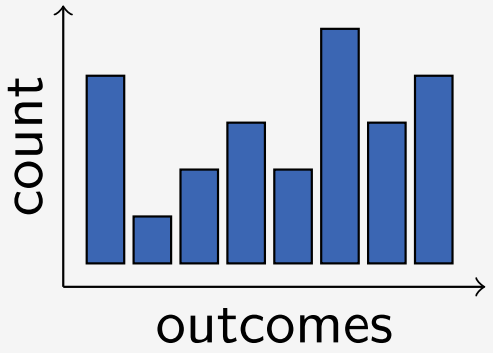
claims to do:



Verifier

only limited measurements

request target state ϱ_{t}



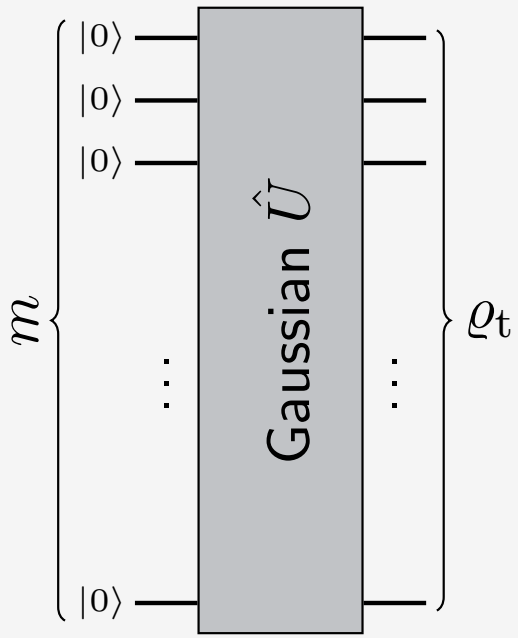
Is $\varrho_{\mathrm{p}} \approx \varrho_{\mathrm{t}}$?

Number of preparations?

The settings

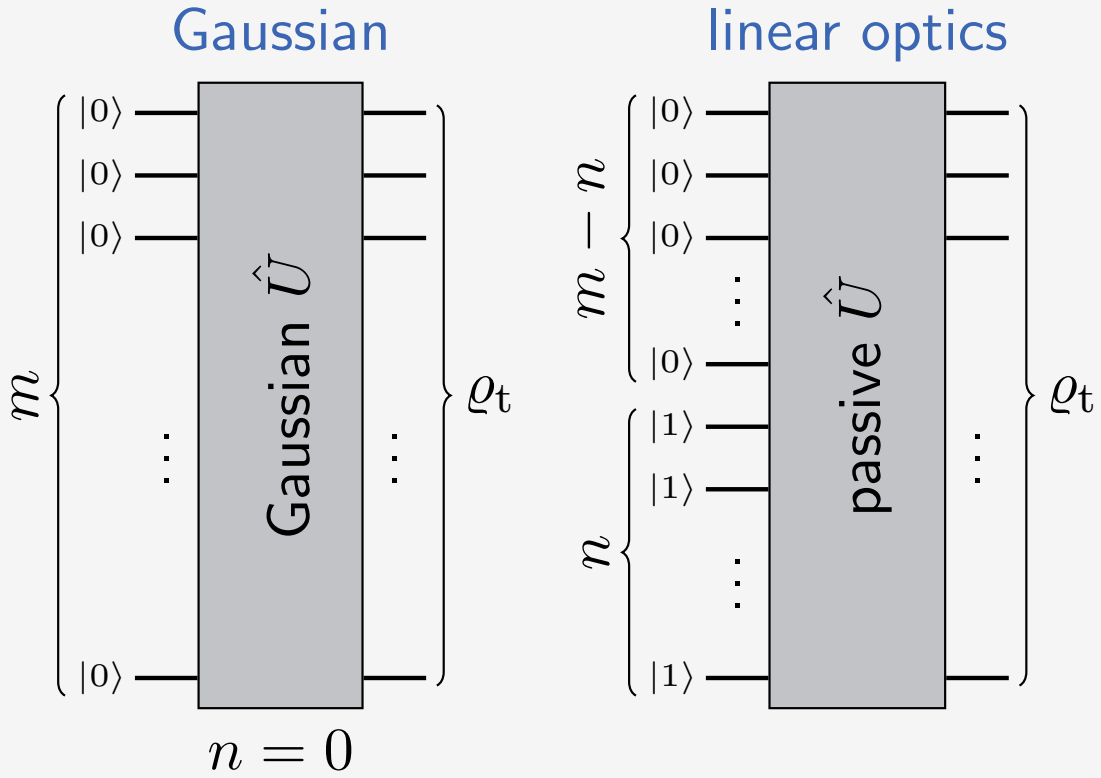
Three classes of target states:

Gaussian



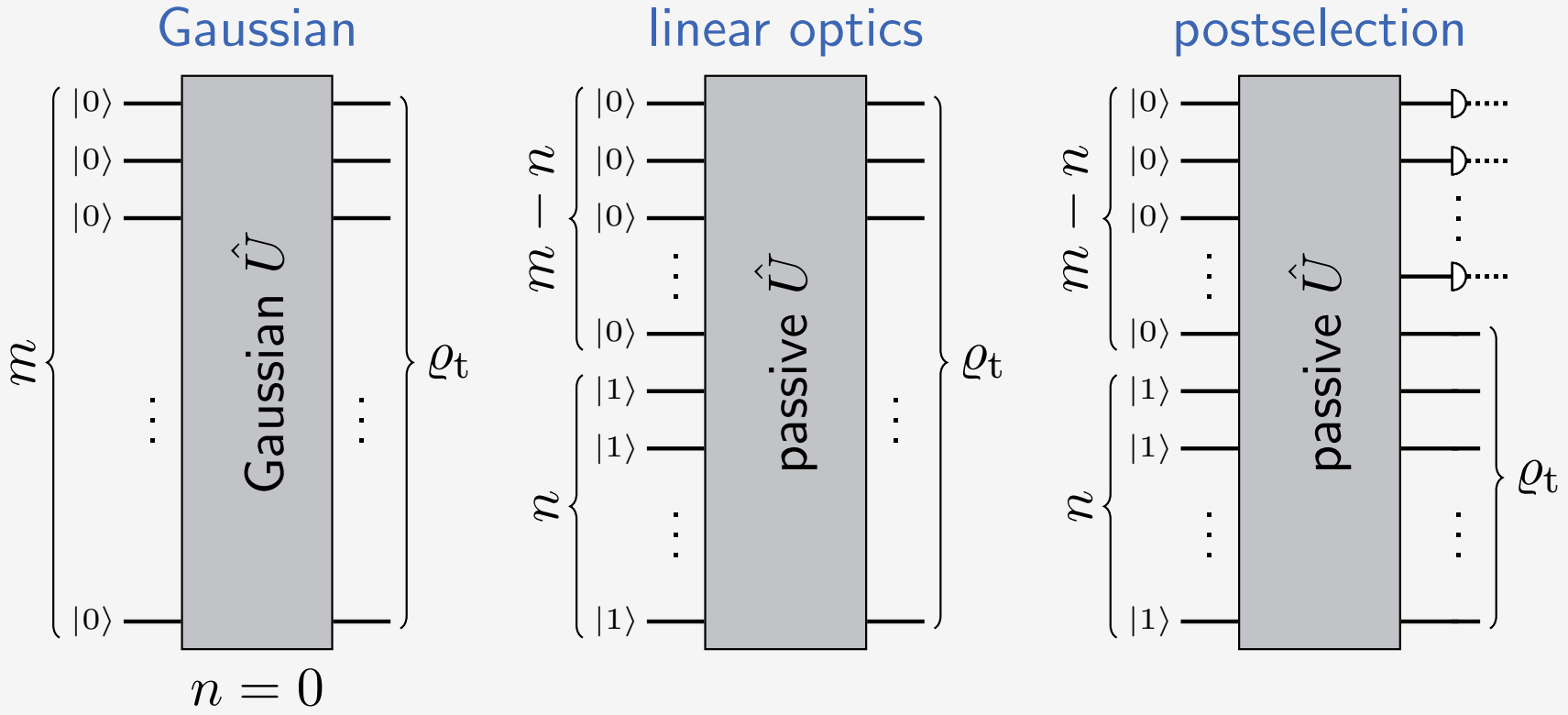
The settings

Three classes of target states:



The settings

Three classes of target states:



Results

Certification test for n initial photons in m modes

1. Choose your target state ϱ_{t}, fix a threshold fidelity F_T, failure probability α, and an estimators error $\epsilon \leq (1 - F_T)/2$.

Results

Certification test for n initial photons in m modes

1. Choose your target state ϱ_{t}, fix a threshold fidelity F_T, failure probability α, and an estimators error $\epsilon \leq (1 - F_T)/2$.
2. Request N preparations.

Results

Certification test for n initial photons in m modes

1. Choose your target state ϱ_{t}, fix a threshold fidelity F_T, failure probability α, and an estimators error $\epsilon \leq (1 - F_T)/2$.
2. Request N preparations.
3. Estimate correlators: $2\,m$ single mode and $\mathrm{O}(m\,(4\,m^2+1)^n)$ multi mode (needs only $\binom{m}{n}\,2^{n+1}$ single mode homodyne settings)

Results

Certification test for n initial photons in m modes

1. Choose your target state ϱ_{t}, fix a threshold fidelity F_T, failure probability α, and an estimators error $\epsilon \leq (1 - F_T)/2$.
2. Request N preparations.
3. Estimate correlators: $2\,m$ single mode and $\mathrm{O}(m\,(4\,m^2+1)^n)$ multi mode (needs only $\binom{m}{n}\,2^{n+1}$ single mode homodyne settings)
4. Estimate fidelity and if $F^* < F_T + \epsilon$ reject, otherwise accept.

Results

Certification test for n initial photons in m modes

1. Choose your target state ϱ_{t}, fix a threshold fidelity F_T, failure probability α, and an estimators error $\epsilon \leq (1 - F_T)/2$.
2. Request N preparations.
3. Estimate correlators: $2\,m$ single mode and $\mathrm{O}(m\,(4\,m^2+1)^n)$ multi mode (needs only $\binom{m}{n}\,2^{n+1}$ single mode homodyne settings)
4. Estimate fidelity and if $F^* < F_T + \epsilon$ reject, otherwise accept.

Gaussian:

Achieve robust certification for $N \in \mathrm{O}\left(\frac{\mathrm{poly}(m)}{\epsilon^2 \log(\frac{1}{1-\alpha})}\right)$.

Results

Certification test for n initial photons in m modes

1. Choose your target state ϱ_{t}, fix a threshold fidelity F_T, failure probability α, and an estimators error $\epsilon \leq (1 - F_T)/2$.
2. Request N preparations.
3. Estimate correlators: $2\,m$ single mode and $\mathrm{O}(m\,(4\,m^2+1)^n)$ multi mode (needs only $\binom{m}{n}\,2^{n+1}$ single mode homodyne settings)
4. Estimate fidelity and if $F^* < F_T + \epsilon$ reject, otherwise accept.

linear optics:

Achieve robust certification for $N \in \mathrm{O}\left(\frac{m^4(\mathrm{poly}(m)\,n)^n}{\epsilon^2 \log(\frac{1}{1-\alpha})}\right)$.

Results

Certification test for n initial photons in m modes

1. Choose your target state ϱ_{t}, fix a threshold fidelity F_T, failure probability α, and an estimators error $\epsilon \leq (1 - F_T)/2$.
2. Request N preparations.
3. Estimate correlators: $2\,m$ single mode and $\mathrm{O}(m\,(4\,m^2+1)^n)$ multi mode (needs only $\binom{m}{n}\,2^{n+1}$ single mode homodyne settings)
4. Estimate fidelity and if $F^* < F_T + \epsilon$ reject, otherwise accept.

postselection:

Achieve certification for $$N \in \mathrm{O}\left(\frac{m^4(\mathrm{poly}(m)\,n)^n}{P^2\,\epsilon^2\,\log(\frac{1}{1-\alpha})}\right).$$

Conclusions

- In the Gaussian setting efficient ($\mathrm{poly}(m)$ effort) and robust.

Conclusions

- In the Gaussian setting efficient ($\mathrm{poly}(m)$ effort) and robust.
- In the linear optics setting still robust and efficient in m but not in n.

Conclusions

- In the Gaussian setting efficient ($\mathrm{poly}(m)$ effort) and robust.
- In the linear optics setting still robust and efficient in m but not in n.
- For explicit bounds (number of preparations, size of acceptance region, ...) and all the fine print (definition of robust certification, post selection, ...) see [arXiv:1407.4817].

Conclusions

- In the Gaussian setting efficient ($\mathrm{poly}(m)$ effort) and robust.
- In the linear optics setting still robust and efficient in m but not in n.
- For explicit bounds (number of preparations, size of acceptance region, ...) and all the fine print (definition of robust certification, post selection, ...) see [arXiv:1407.4817].

Thank you for your attention!