A Graphical User Interface to Replicate Realistic Simulations of Quantum Optics Experiments

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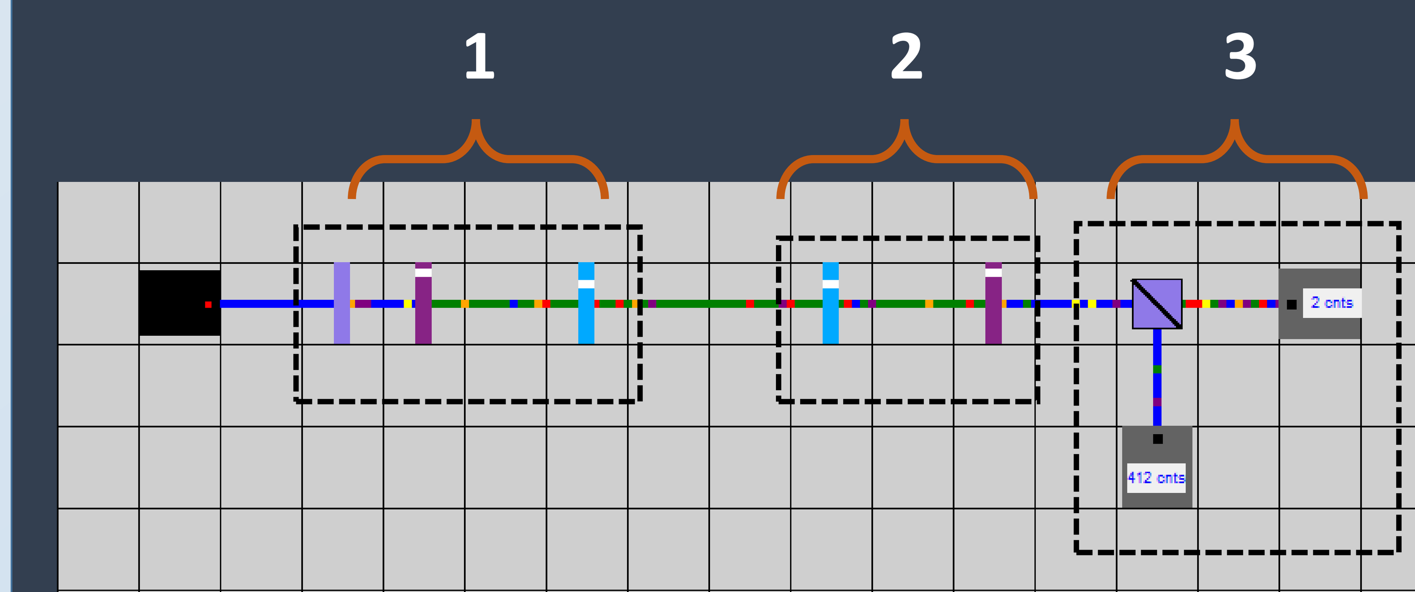
Purpose

- To present a realistic model of quantum optical experiments
- To better understand quantum communications and quantum phenomena
- To expand educational efforts at ARL in the domain of quantum physics

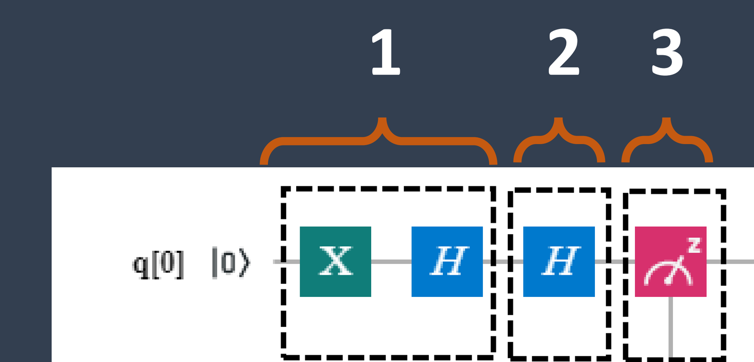
Approach

- Model quantum optics as classical optics with real, stochastic vacuum fields
- Treat measurement outcomes as deterministic threshold-crossing events
- Post-select results to consider only valid measurement outcomes

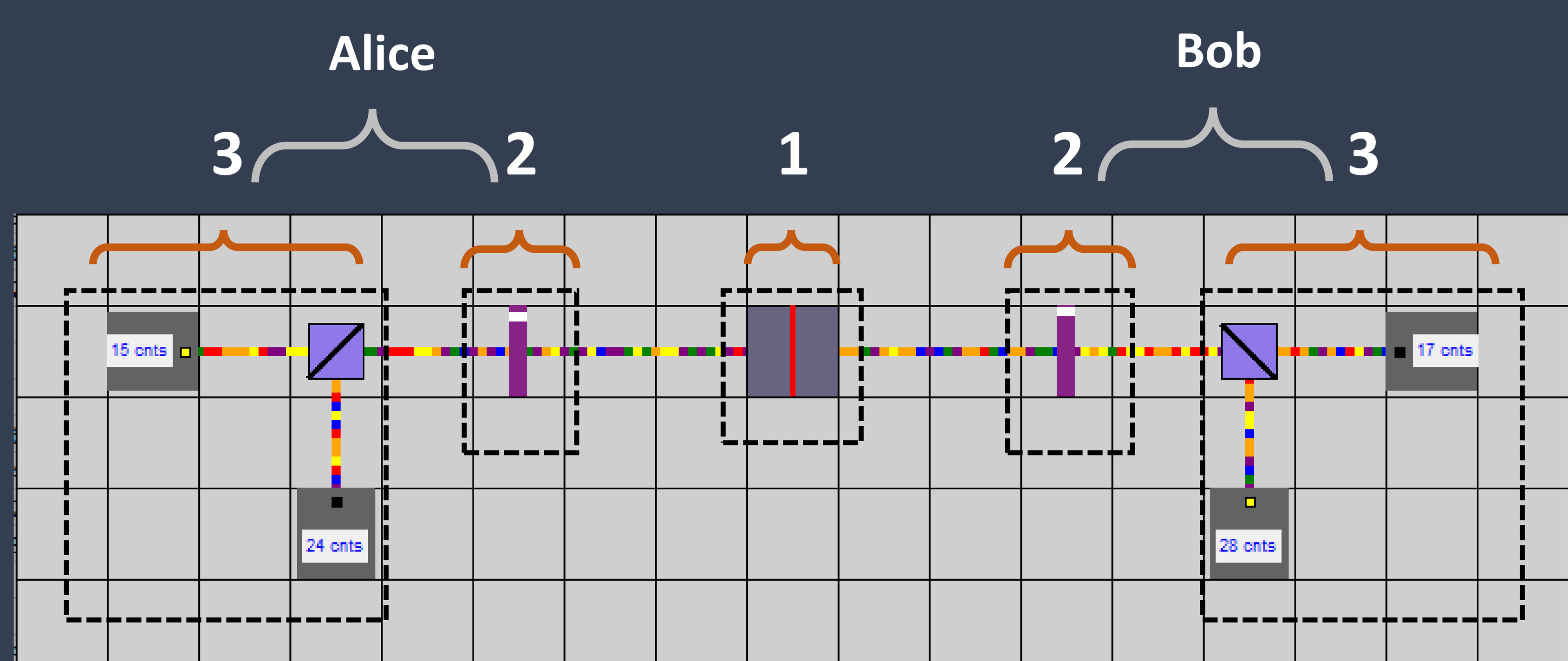
Quantum Key Distribution

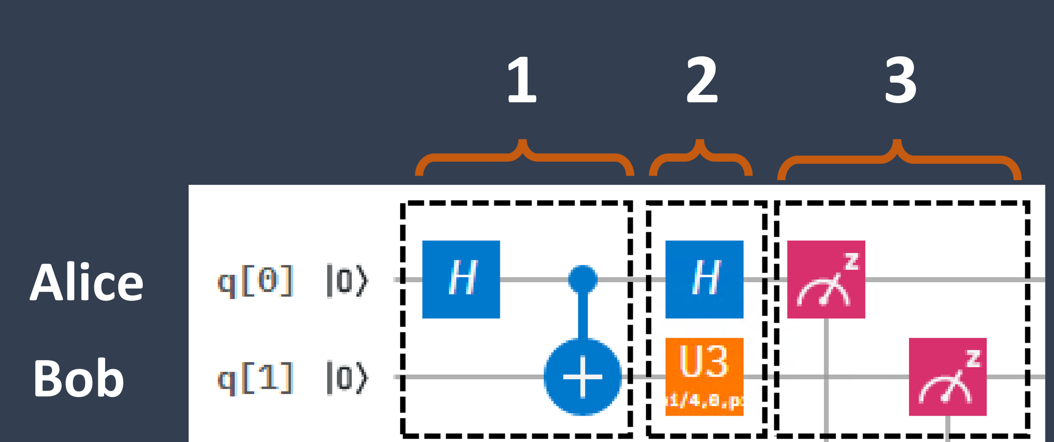


1. Alice prepares an anti-diagonal state
2. Bob chooses a measurement basis
3. Bob measures the state of the qubit



Violating Bell's Inequality





1. A $\frac{|01\rangle - |10\rangle}{\sqrt{2}}$ state is created and sent to Bob and Alice.
2. Bob and Alice choose which of their two observables to measure.
3. Bob and Alice measure the state of their qubits.

The four observables are $A = Z$, $A' = X$, $B = \frac{X+Z}{\sqrt{2}}$, and $B' = \frac{X-Z}{\sqrt{2}}$. Quantum mechanics predicts that $|\langle A \otimes B\rangle + \langle A \otimes B'\rangle| + |\langle A' \otimes B\rangle - \langle A' \otimes B'\rangle| = 2\sqrt{2} \approx 2.828$

Valid coincidence counts occur when both of the detectors paired to the counter have a count specified at a certain time interval and no other detectors have a count.

Coincidences

	AB	AB'	A'B	A'B'
HH	582	505	545	1588
HV	3481	3087	3362	252
VH	3567	3148	3380	280
VV	582	475	555	1570
Totals	8212	7215	7842	3690

Observed Frequencies

	AB	AB'	A'B	A'B'
HH	0.071	0.070	0.069	0.430
HV	0.424	0.428	0.429	0.068
VH	0.434	0.436	0.431	0.076
VV	0.071	0.066	0.071	0.425

Expected Probabilities

	AB	AB'	A'B	A'B'
HH	0.073	0.073	0.073	0.427
HV	0.427	0.427	0.427	0.073
VH	0.427	0.427	0.427	0.073
VV	0.073	0.073	0.073	0.427

The correlation between measurements, for example C_{12} between measurements A and B' is computed as follows:

Observed: $C_{12} = (+1)(+1)\frac{505}{7215} + (+1)(-1)\frac{3087}{7215} + (-1)(+1)\frac{3148}{7215} + (-1)(-1)\frac{475}{7215}$

Expected: $C_{12} = (+1)(+1)(.073) + (+1)(-1)(.427) + (-1)(+1)(.427) + (-1)(-1)(.073)$

Correlations

	C_{11}	C_{12}	C_{21}	C_{22}
Observed	-0.716	-0.728	-0.720	0.711
Expected	-0.707	-0.707	-0.707	0.707

Computing the correlation for all four combinations results in the Bell Statistic

Observed: $S = |C_{11} + C_{12}| + |C_{21} - C_{22}| = |-0.716 + -0.728| + |-0.720 - 0.711| = 2.875$

Expected: $S = |C_{11} + C_{12}| + |C_{21} - C_{22}| = |-0.707 + -0.707| + |-0.707 - 0.707| \approx 2.828$

Since the value is greater than 2, satisfying the violation of the classical bound, Bell's inequality has been violated.

Future Motivation

We hope that this tool can be used for further research in the field of quantum physics and quantum optics. Those who are interested in replicating quantum optical setups should find our setup to be accessible and accurate. Moreover, we hope that our tool is used in an educational setting directed towards beginners and prospective students of quantum physics.

User Interface