Quantum Hacking:
Computer-Simulated Attacks against the BB84 Protocol

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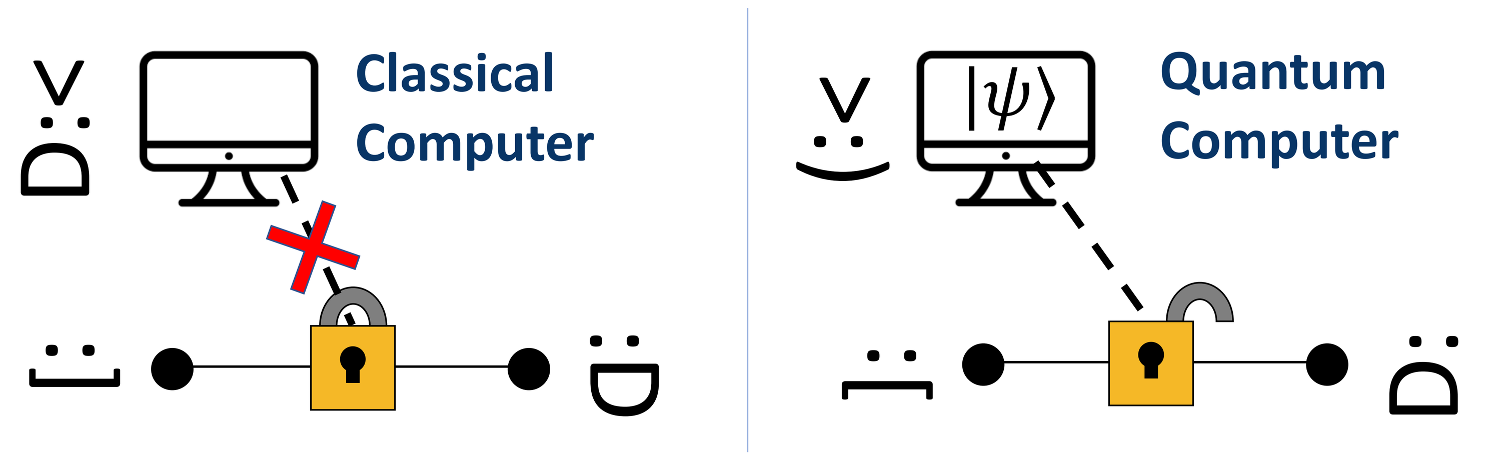
Introduction

The Importance of Quantum Key Distribution

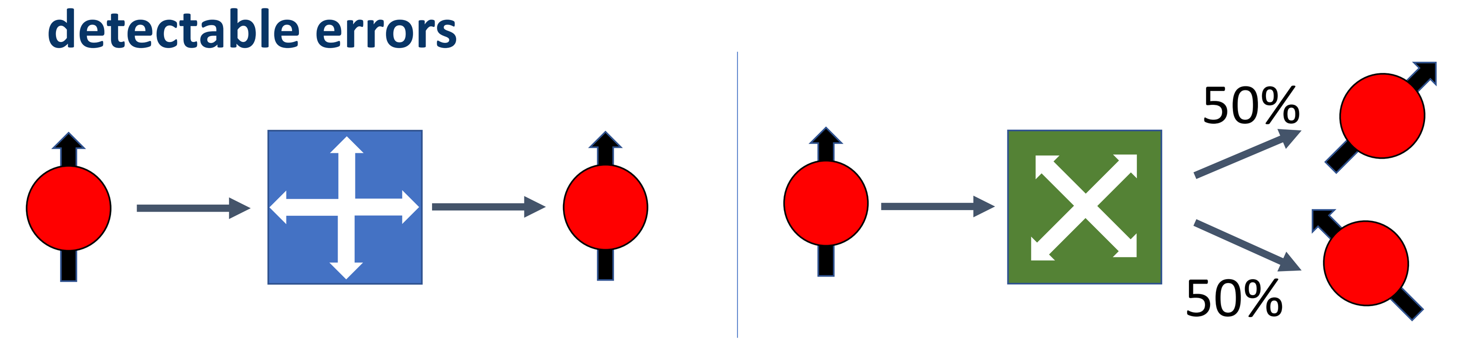
Common encryption protocols are **vulnerable** to quantum computers! (Shor's Algorithm)



Error-free BB84 and other QKD protocols are **secure** against attacks made possible by quantum computers.

What is BB84?

- Generate a cryptographic key using polarized quantum particles of light (photons).
- Eavesdropper's (Eve) attempts to learn the key will **induce detectable errors**



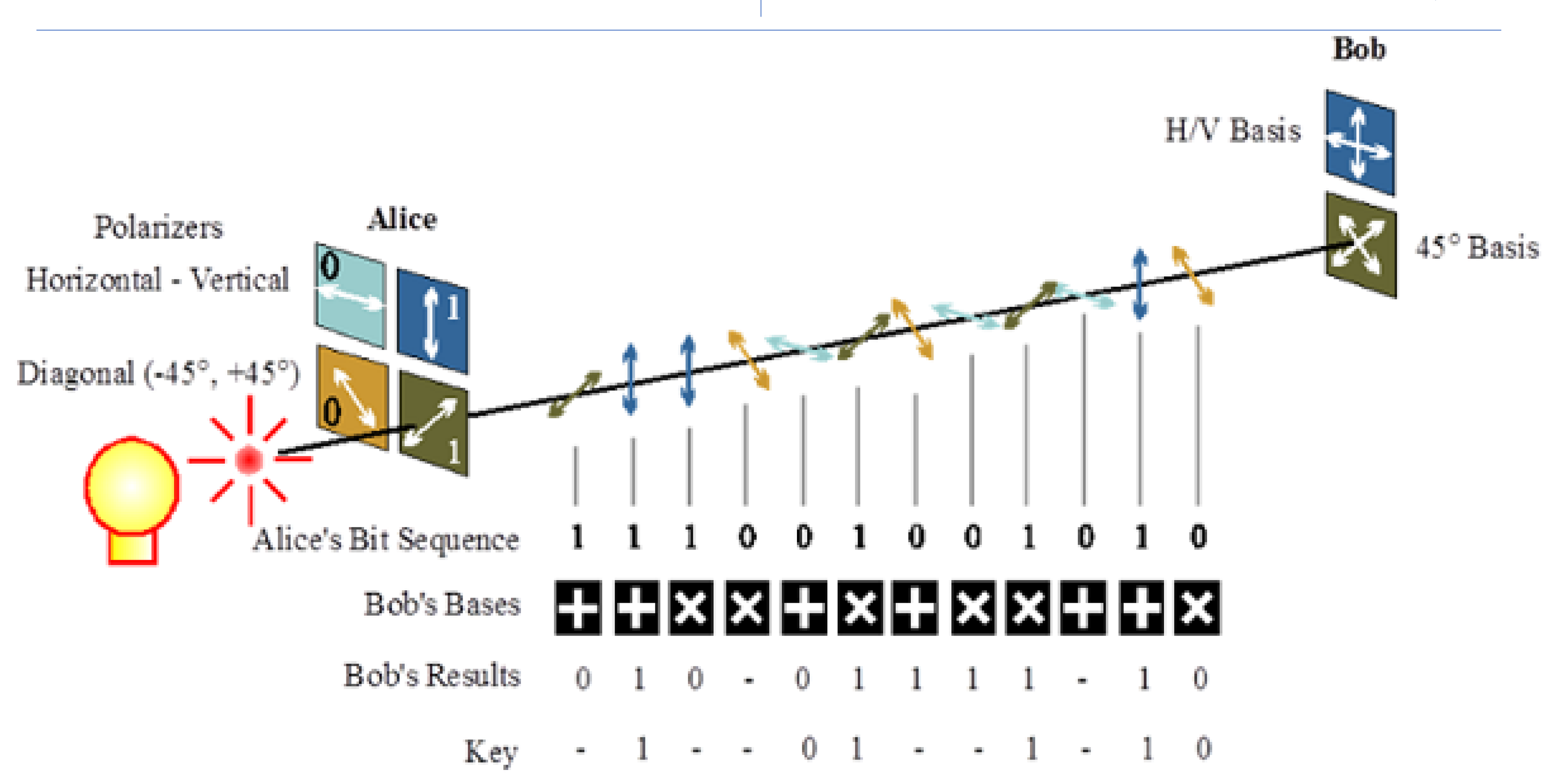
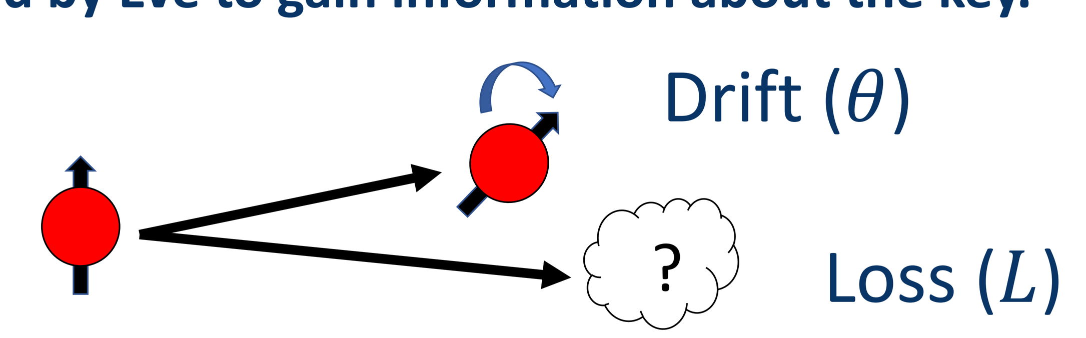


Figure 1: BB84 implementation using polarized photons

The Problem

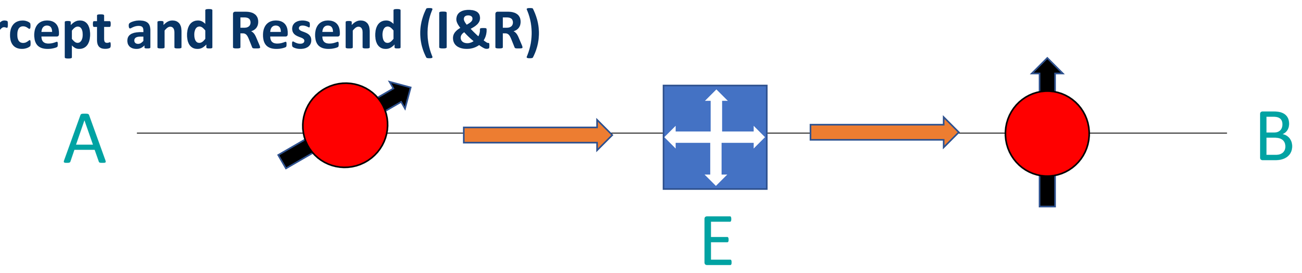
Practical implementation is prone to natural errors which can be **exploited by Eve to gain information about the key.**



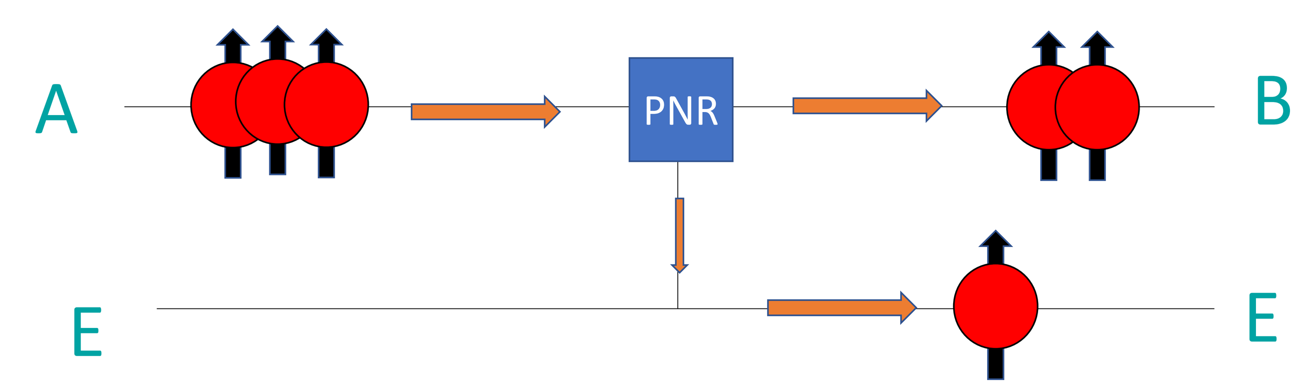
Methods

Attacks

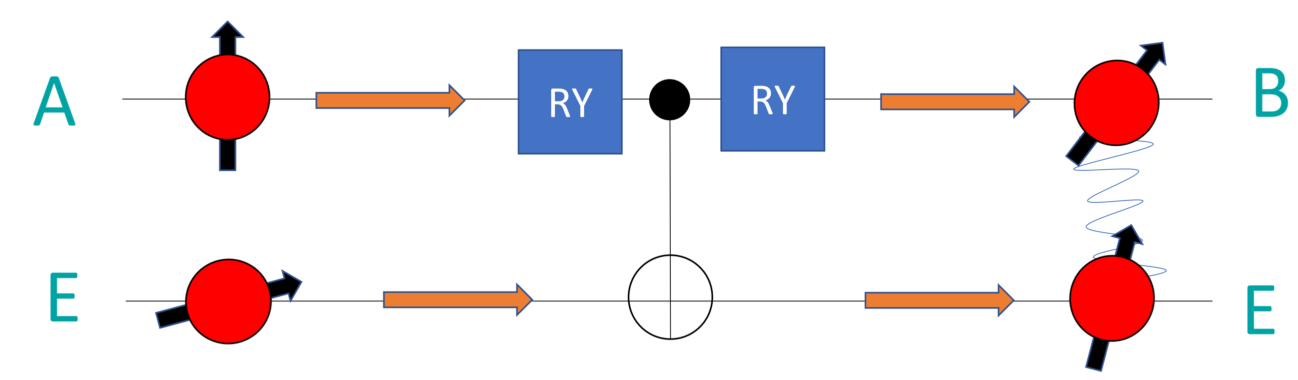
Intercept and Resend (I&R)



Photon-Number Splitting (PNS)



Slutsky-Brandt (SB)

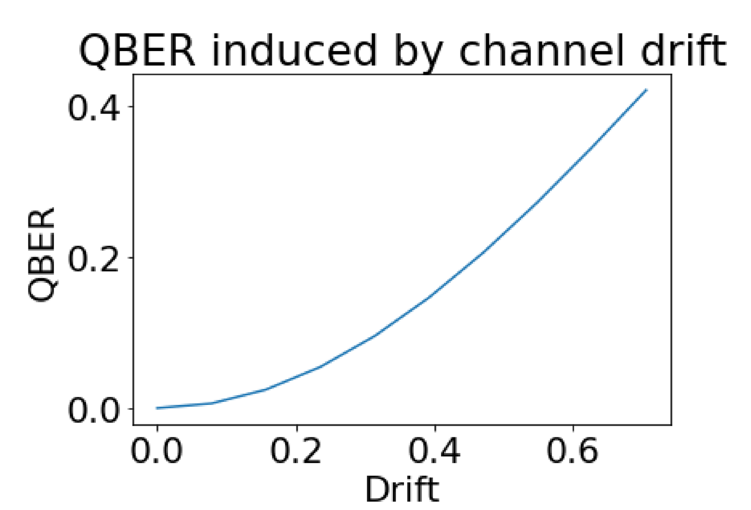


Strategy

Eve tries to gain as much information as possible while inducing **exactly** the expected $QBER$ and L to go undetected.

Channel-induced Errors = **Attack-induced Errors**

$$QBER = \sin^2\theta$$

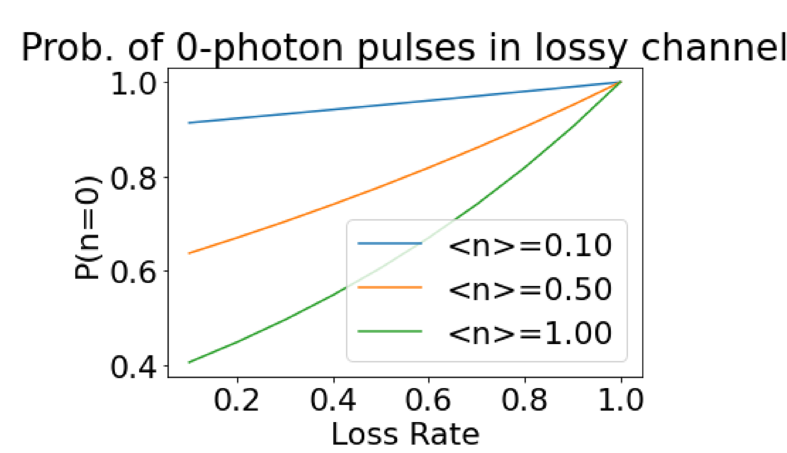


$$QBER_{I\&R} = 0.25$$

$$QBER_{SB} = \frac{S^2}{2}$$

*$|T_{in}\rangle = \frac{\sqrt{1-S^2}+S}{\sqrt{2}}|0\rangle + \frac{\sqrt{1-S^2}-S}{\sqrt{2}}|1\rangle$ is the input state of Eve's entangling probe

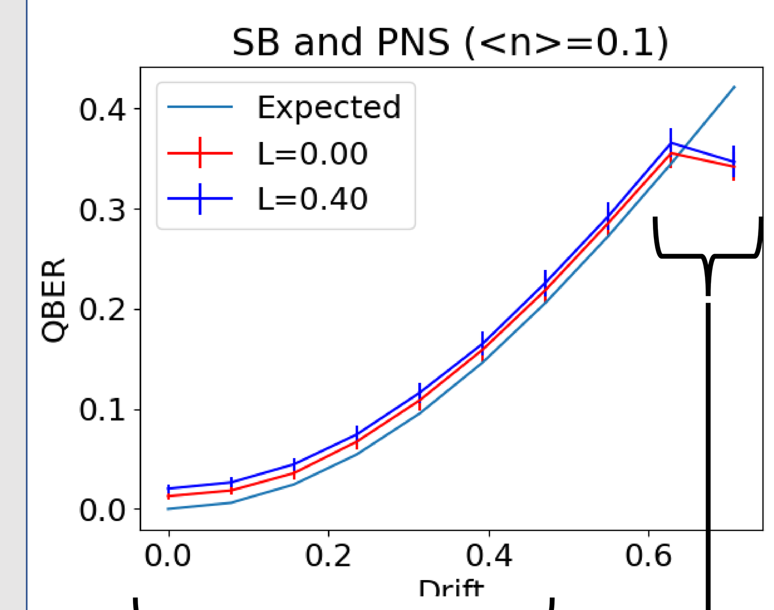
$$P(n=k) = \frac{(1-L)^k e^{-\langle n\rangle(1-L)}\langle n\rangle^k}{k!}$$

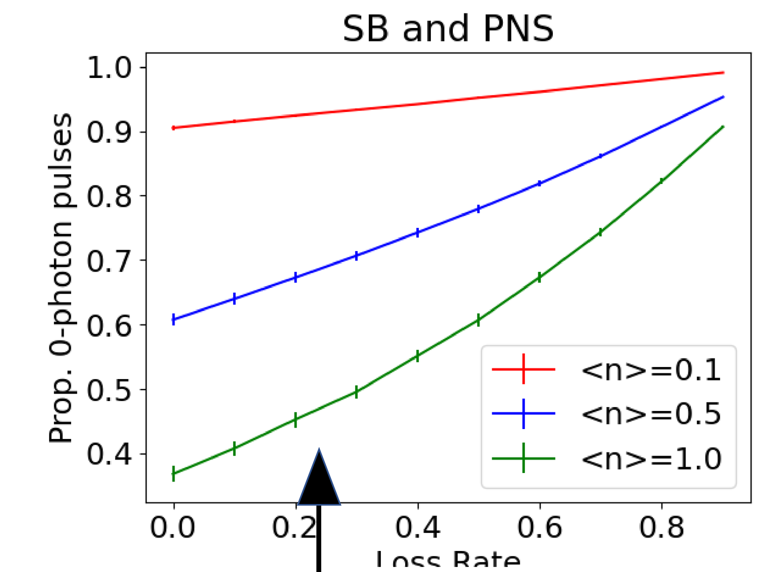


$$L_{PNS} = e^{-\langle n\rangle} + \sum_i P_i \frac{\langle n\rangle^i}{i!} e^{-\langle n\rangle}$$

*P_i =probability that Eve "blocks" a qubit with photon number i.

Results



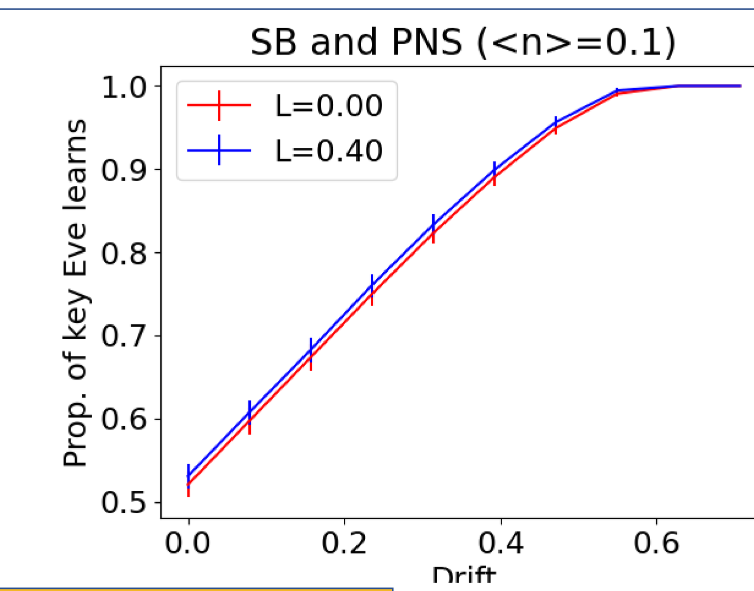


Attack-induced errors **closely match** expected channel errors

Curves match expected loss

Attack-induced errors begin to **deviate** from expected channel errors

Higher drift, loss, and mean photon number ⇒ Eve learns a larger portion of the key.



Conclusion

- Greater errors generally allow Eve to acquire more information.
- Eve's strategy **needs refinement:**
  - Her induced error closely (but not exactly) matches expected error.
  - Quickly diverges beyond $\theta \approx 0.6$
- The security of BB84 is **highly dependent** on the technology used to implement the protocol.
- Imperfect implementation of BB84 must be supplemented with procedures to prevent or detect potential eavesdropping.

References

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