Simple and Tight Device-independent Security Proofs

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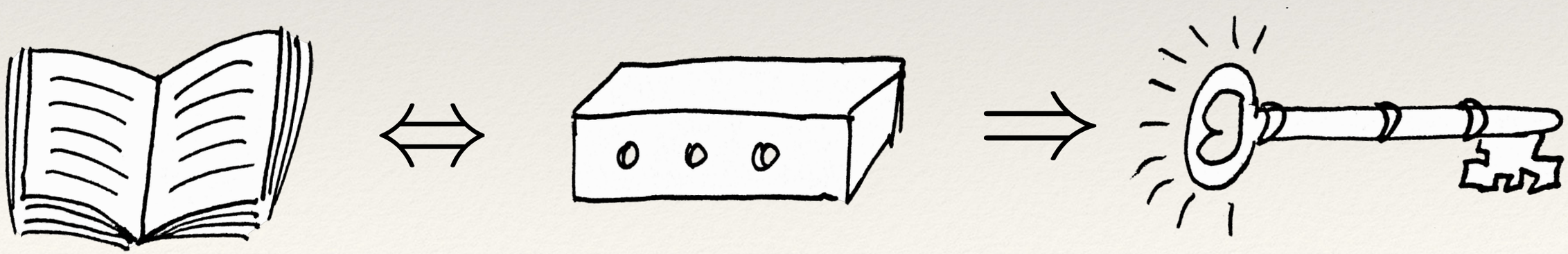
Outline

1. Introduction
2. The difficulty of proving security
3. Contribution and results
4. Proof technique
5. Outlook

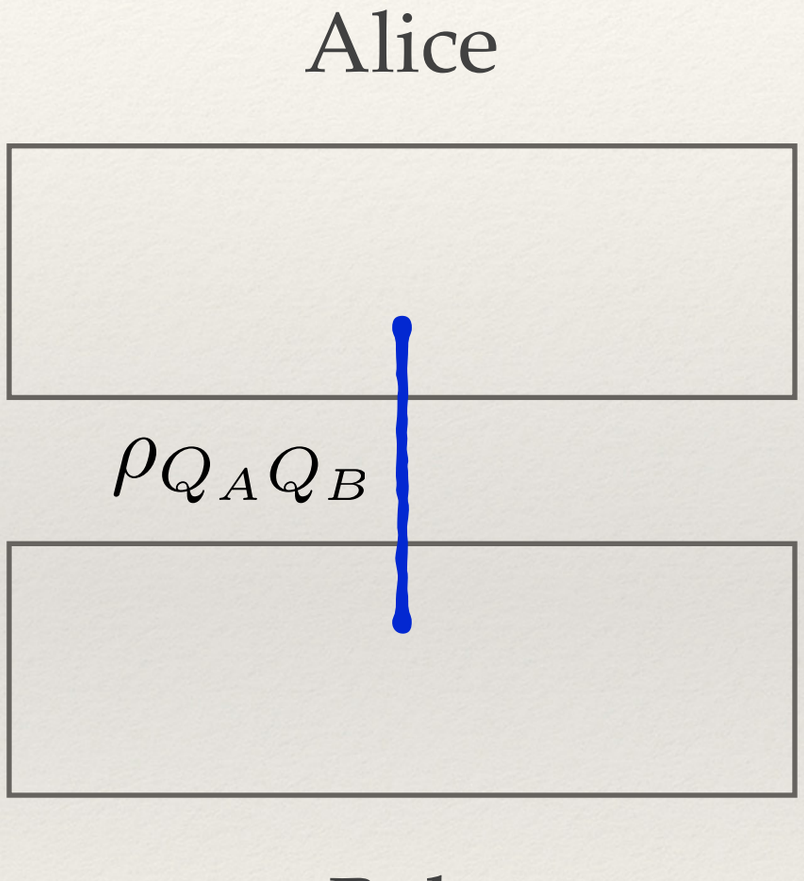
The concept of device independence

The concept of DI

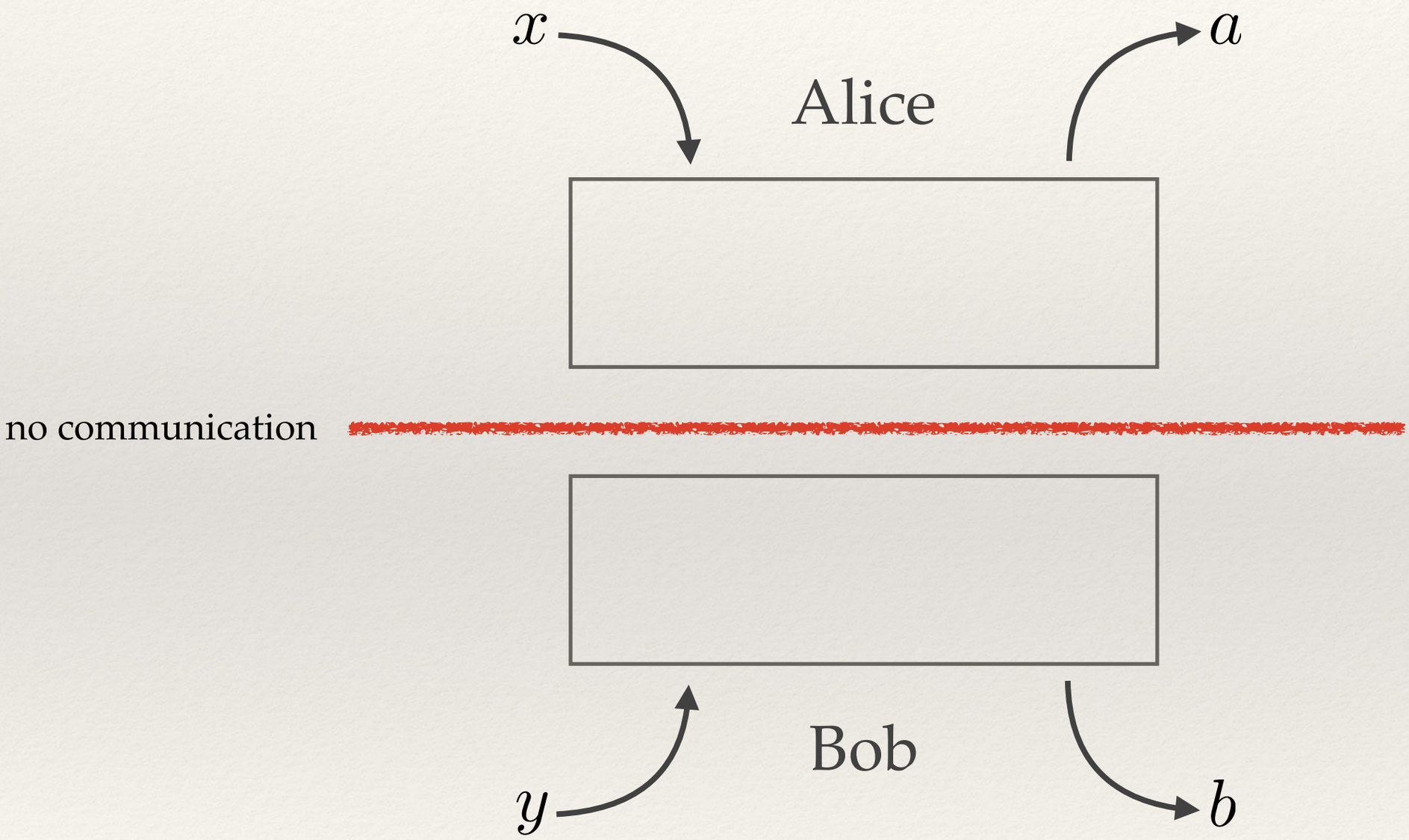
- Alice and Bob share an uncharacterised device
- They interact with it according to some known protocol (e.g., DI quantum key distribution protocol)
- They either abort or accomplish their task (e.g., output a good key)



Bell inequality / game



Bell inequality / game



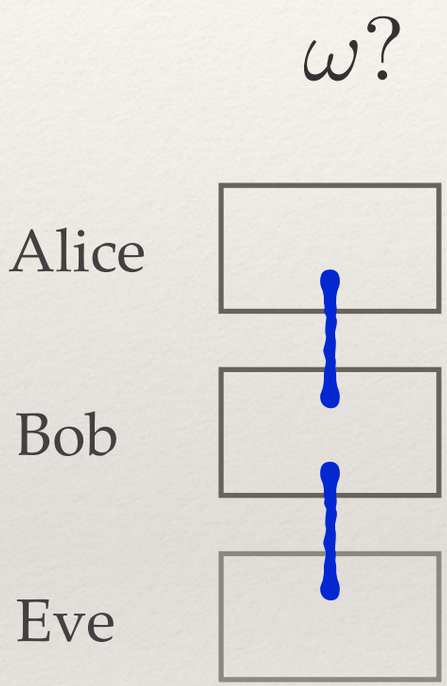
Winning condition: $w(a, b, x, y) \in \{0, 1\}$

Bell inequality / game

- Winning prob. of the device: $\omega \in [0, 1]$
- Bell inequality: $\forall \omega_c \;\; \omega_c \leq I$
- Quantum advantage (violation): $\exists \omega_q \;\; \omega_q > I$
- $\Longrightarrow$ some secret randomness in the outputs with respect to an adversary holding a purification of $\rho_{Q_A Q_B}$

The difficulty of proving security

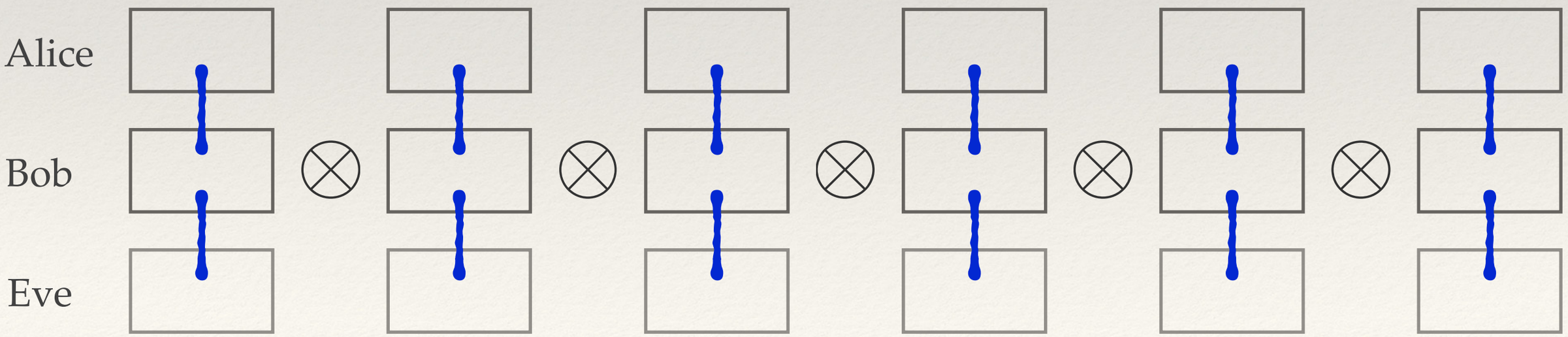
The difficulty of proving security



The IID assumption

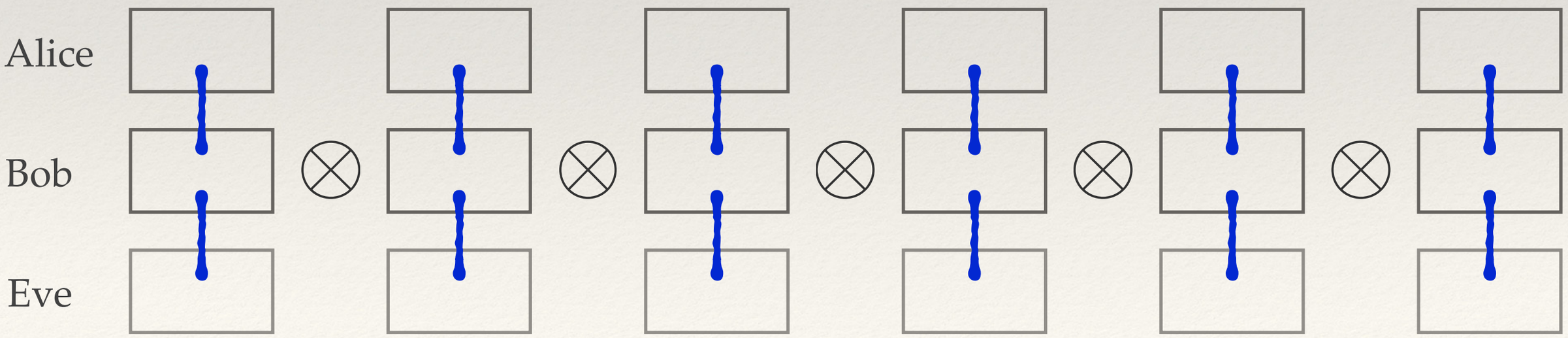
- Play the game many times in an independent and identical way
- Estimate the winning probability in one device
- The total amount of entropy is *roughly* the number of games $\times$ entropy in one game

Simple! ✔



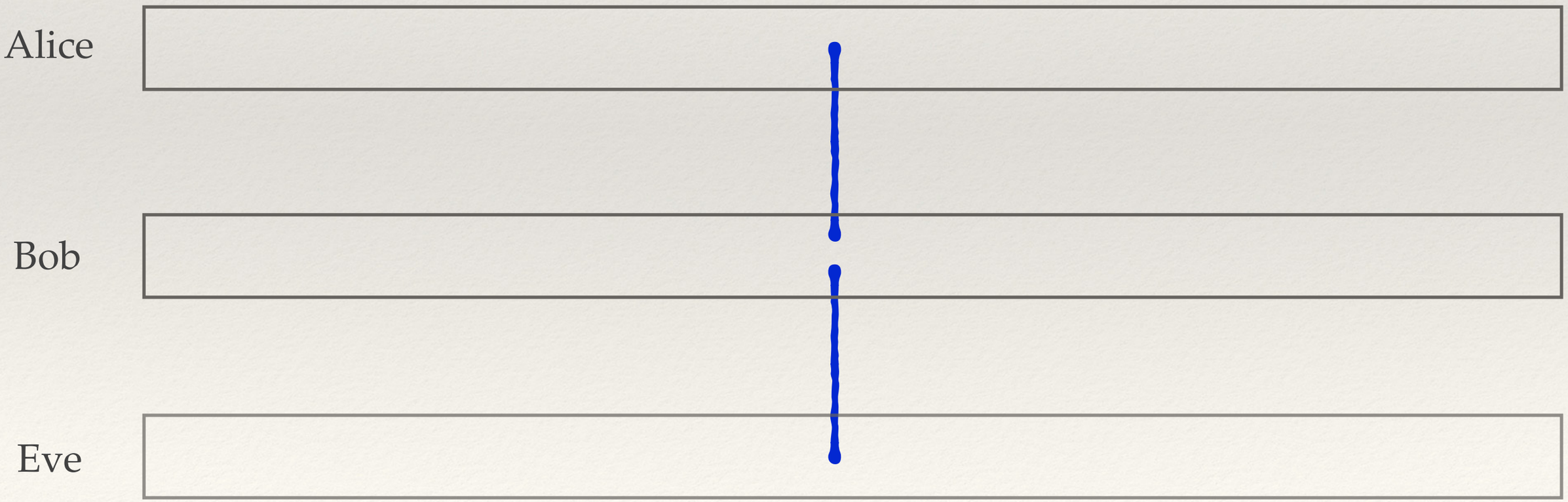
The IID assumption

- But….
- IID is a strong assumption! (e.g., no memory at all)
- Cannot use de Finetti theorems (in contrast to standard QKD)



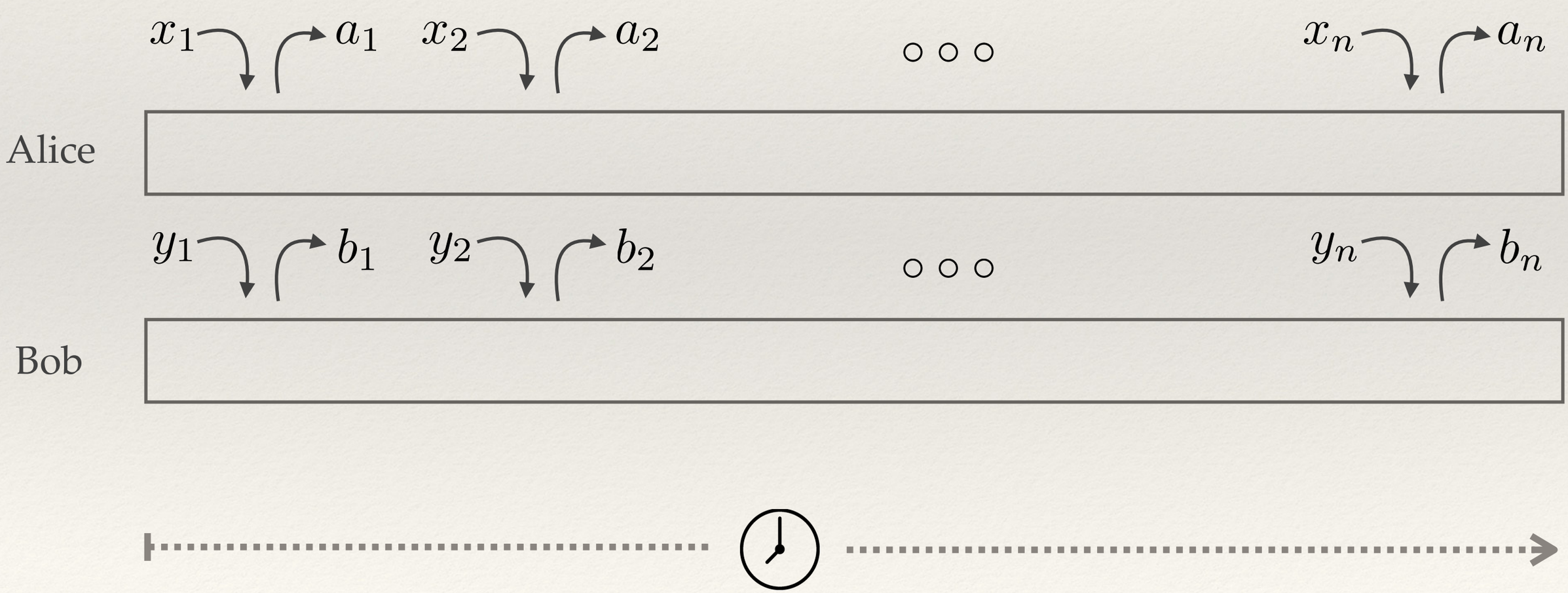
The general case

- One component to each party



The general case

- One component to each party
- Sequential interaction with Alice and Bob's components



Previous DIQKD works

[Ekert, 91]
[Mayers and Yao, 98]

[Barrett, Hardy, and Kent, 05]
Proof of concept

[Pironio, Acìn, Brunner *et al.*, 09]
IID + asymptotic
Optimal rates! ✔

General security
[Reichardt, Unger, and Vazirani, 13]
[Vidick and Vazirani, 14]
[Miller and Shi, 14]

Contribution and Results

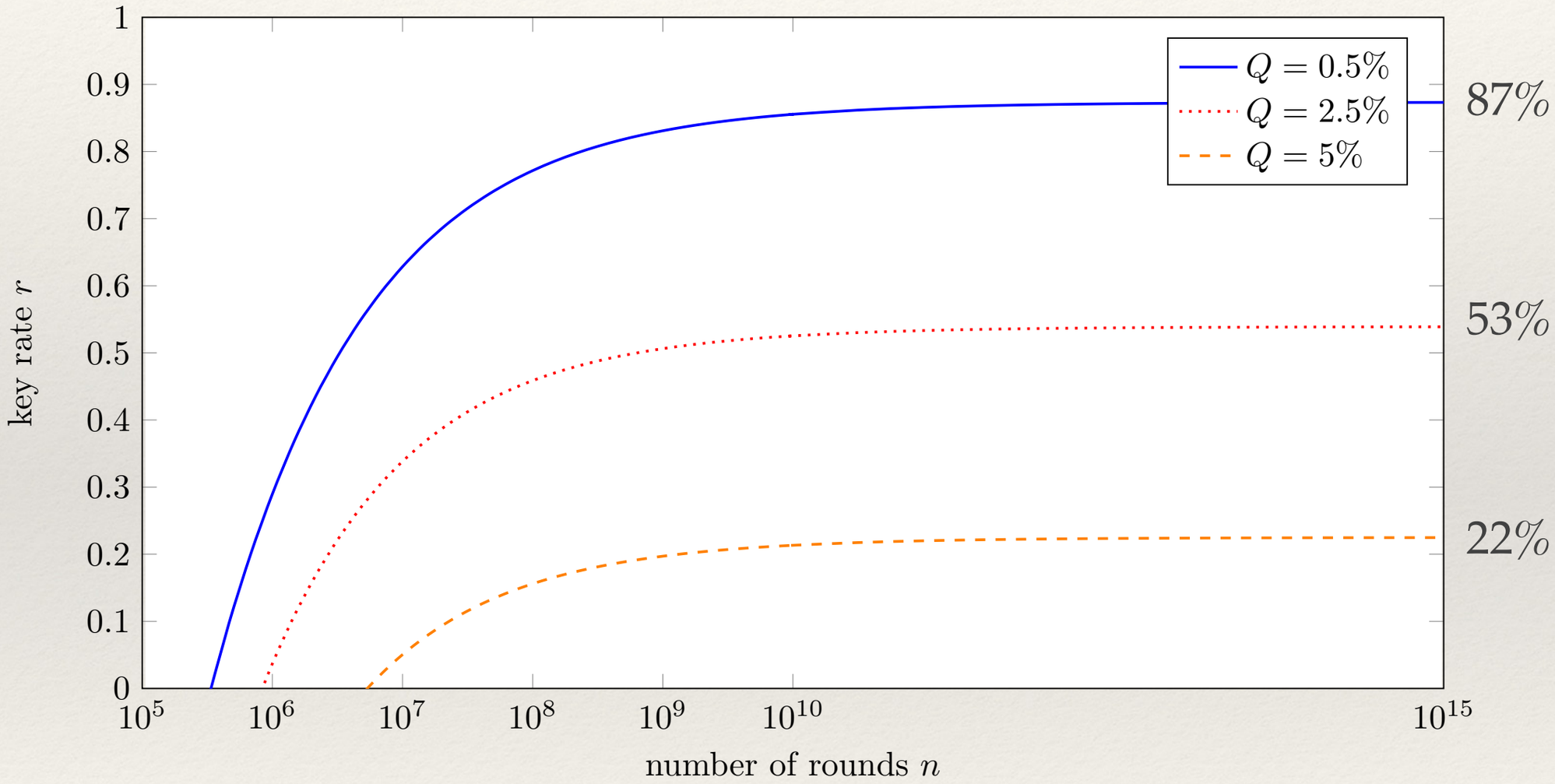
The setting

- Standard assumptions:
  - Alice and Bob's physical locations are secure (unwanted information cannot leak outside to Eve or between their devices)
  - Trusted random number generator
  - Trusted classical post-processing units
  - Authenticated, but public, classical channel
  - Quantum physics is correct (and complete)
- Communication is allowed between Alice and Bob, and from Eve to Alice and Bob, between the rounds of the game (can create "entanglement on the fly")

Contribution

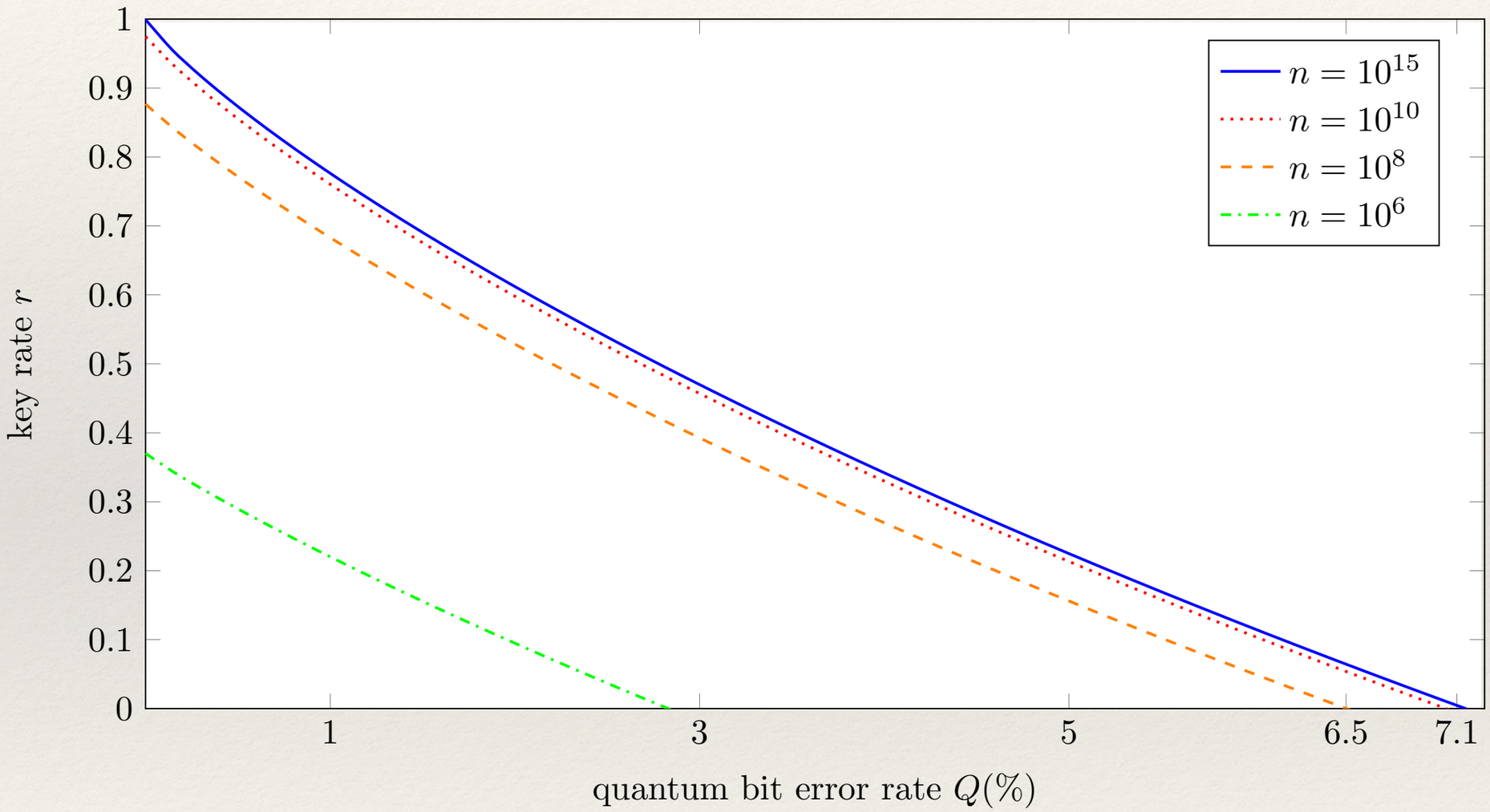
- General framework (flexible protocol + analysis) to prove security of a broad range of DI protocols
- In essence, the proof technique is a reduction to the IID case — sufficient to understand the case of just one game Simple! ✔
- This reduction is virtually lossless in terms of parameters (e.g., key rate vs. noise tradeoff) Tight! ✔

DIQKD key rates



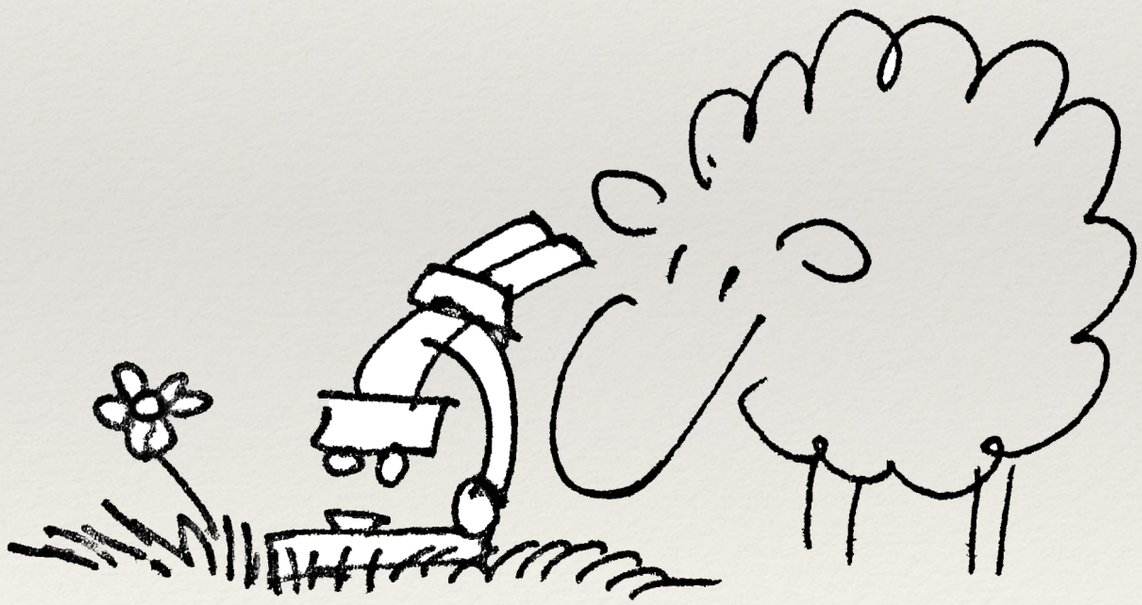
Comparable to the rates achieved in QKD [Scarani and Renner, 08] ✔

DIQKD key rates



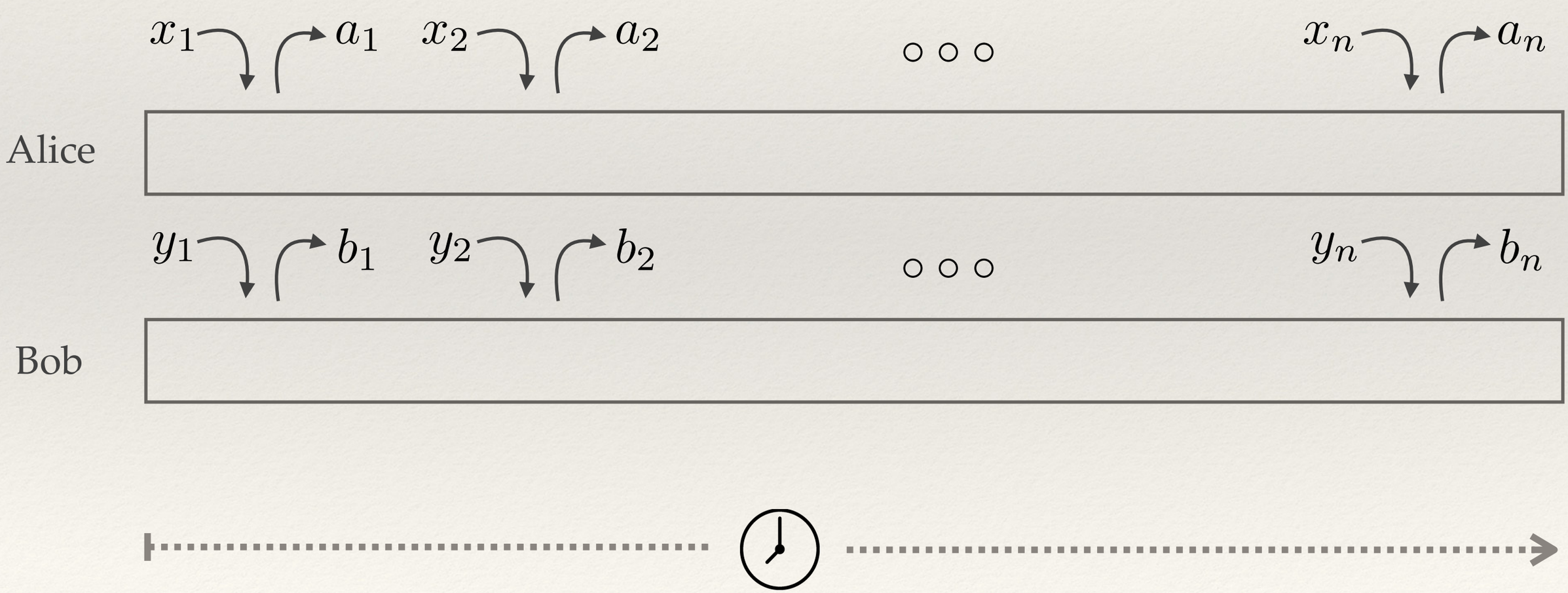
Essentially coincides with the tight bounds achieved in the IID and asymptotic case [PAB+09] for large number of rounds ✔

Proof technique



Proof technique

- Use the sequential structure of the protocol to bound the total conditional smooth min-entropy $H_{\min}^{\varepsilon}(A|E)$



Proof technique

- Use the sequential structure of the protocol to bound the total conditional smooth min-entropy $H_{\min}^{\varepsilon}(A|E)$
- This is done using a new chain rule for entropies — Entropy Accumulation [Dupuis, Fawzi, and Renner, 16]
- The total amount of entropy is *roughly* the number of rounds $\times$ entropy in one game

Simple! ✔

- The relevant one game quantity: $H(A_i|E)$ for all states with a given Bell violation
  - For CHSH a tight bound was shown in [PAB+09]

Outlook

Summary

- General framework to prove security of DI protocols
  - Simple and tight security proofs
    - Concrete examples: DIQKD and randomness expansion based on CHSH
    - (Almost) feasible with today's technology
- In essence, the best adversarial attack is the IID attack also in the DI scenario

What's next?

- Key rates are optimal only with respect to the structure of the considered protocol. Are there better protocols?
  - Different Bell inequalities?
  - Two-way classical post-processing?
- Experiment: detection efficiencies should be relatively high to get a positive key rate
- Is there a general technique to bound the conditional von Neumann entropy $H(A_i|E)$ given the Bell violation?

Thank you!

arXiv:1607.01797 | Simple and tight device-independent security proofs

References

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