Unconditionally secure device-independent quantum key distribution with only two devices

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Based on joint work with Jon Barrett and Adrian Kent

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Outline

- Motivation for device-independence
- Brief History
- Recent developments
- Main result
- Remaining problems and open questions

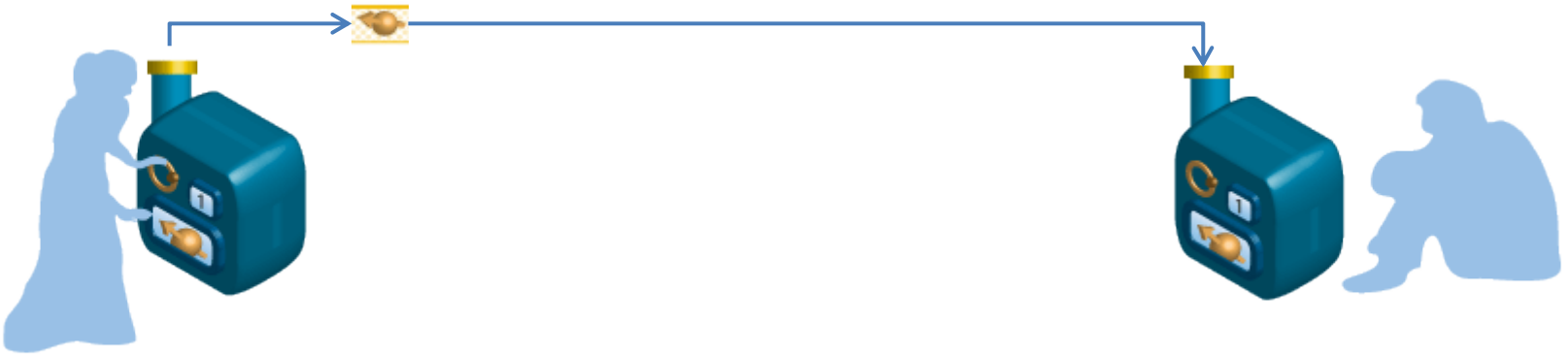
Two sides of cryptography

Theoretical

Start with ‘clean’, well-defined assumptions and try to prove security based on these.

Practical

Try to build devices that satisfy the theoretical assumptions as closely as possible.



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e.g. have a device that emits single photons in a state of my choice and can perform arbitrary measurements with arbitrarily high fidelity.

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Hmm…ok, I have to change my assumptions and work on my proof…

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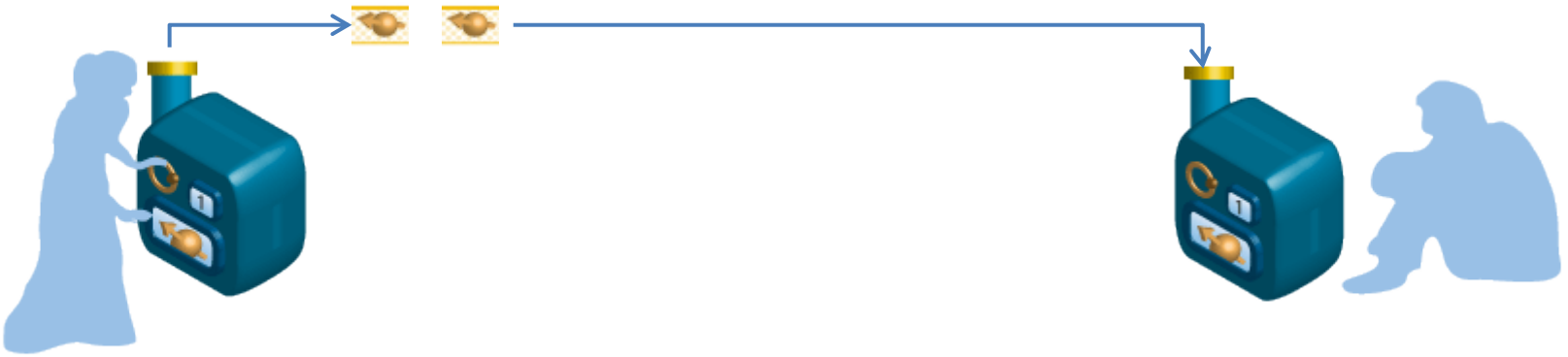
Motivation

- Things can go wrong



- E.g. Alice's device may start sending multiple states
- If the protocol doesn't check this, then it is quickly rendered insecure
- Attacks exploiting the difference between real devices and how they are modelled are relevant in practice

e.g. Gerhardt et al. N. Comms **2** (2011)

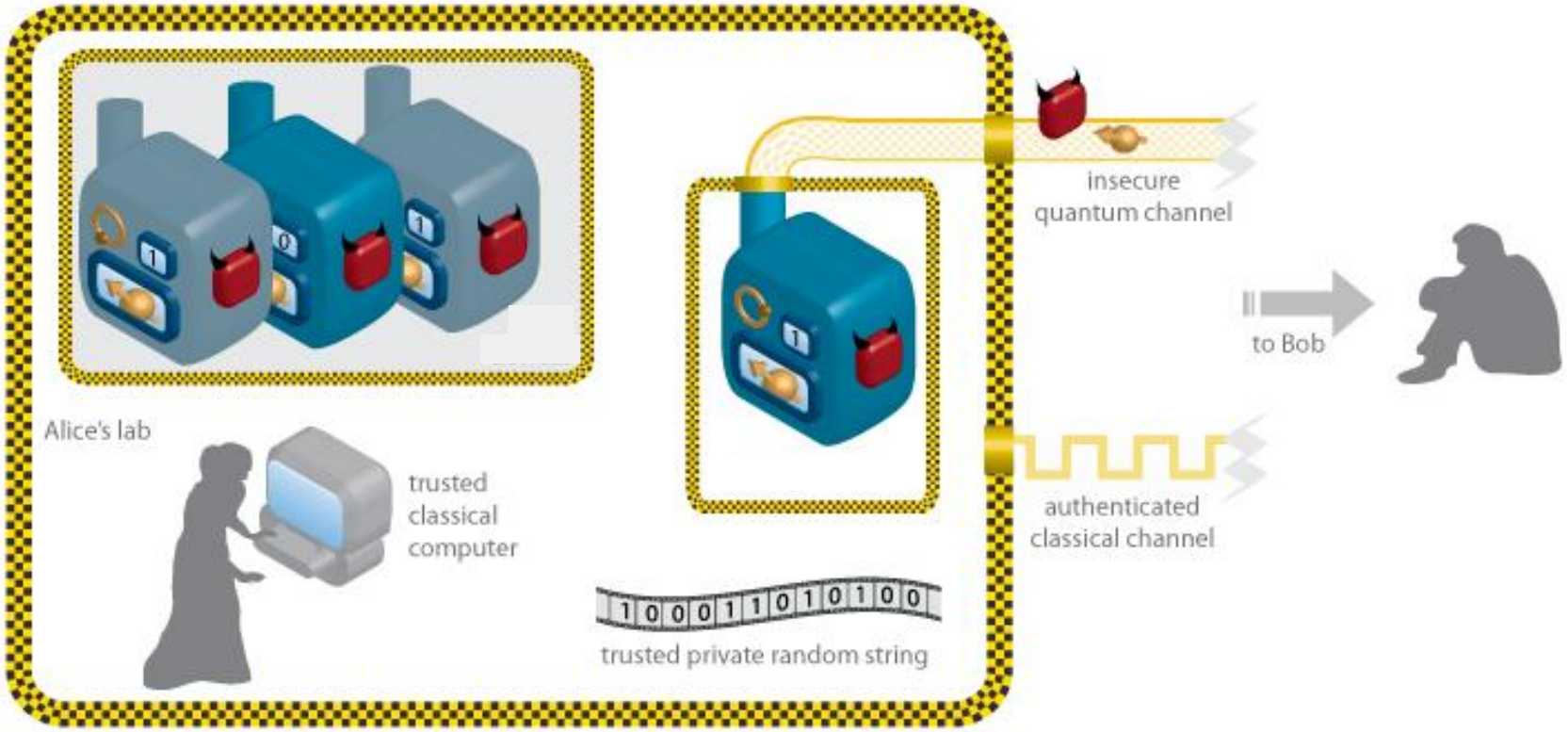
Motivation

- Basing a proof on weaker assumptions makes it easier for a particular implementation to come closer to satisfying the assumptions.
- Motivates **device-independence**, in which one tries to prove security without making any assumptions about the workings of quantum devices.
- Idea first introduced in [Mayers-Yao FOCS 98] and significantly developed in [AGM PRL **97**, 120405 (2006), Scarani et al. PRA **74**, 042339 (2006), …]

Device-independence

- No trust at all in any quantum devices used for the protocol.
- With device-independence, it wouldn’t matter if an adversary tampered with or substituted my devices: we would still have security.
- Clean, well-defined assumption
- Tests the devices during the protocol (if critical faults have developed, the protocol aborts)

Device-independence assumptions



Limitations of prior works

- Various protocols have been proven unconditionally secure with no trust on the devices, for example:
  - BHK, PRL **95**, 010503 (2005)
  - Masanes et al., quant-ph/0606049
  - HR, arXiv:1009.1833
  - MPA, N. Comms. **2**, 238 (2011)
- All have the weakness that the security proofs apply only with many separated devices

Recent developments

- 3 recent works show that this limitation can be removed (all at QIP13). Each uses a different technique to achieve security with only two devices.

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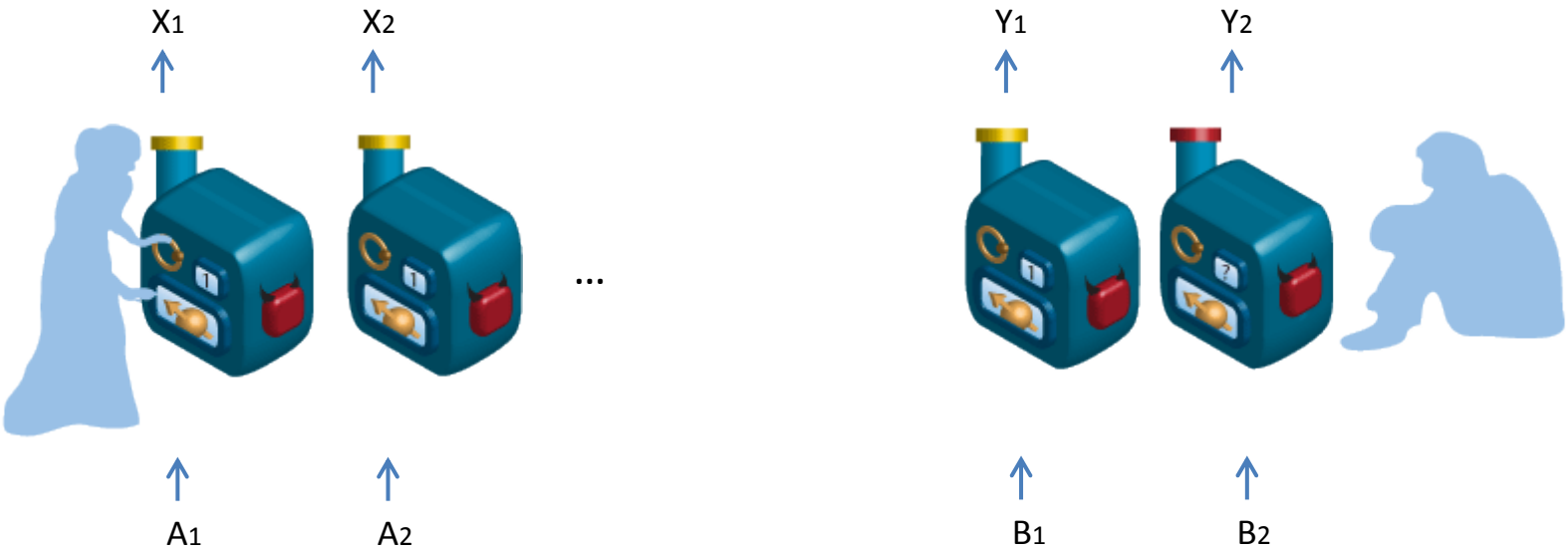

Old proofs

Recent developments

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New proofs

Our technique

- In the spirit of minimizing assumptions, our protocol is secure against a non-signalling (not necessarily quantum) adversary.
- Design the protocol in such a way that the optimal eavesdropping attack is i.i.d.
- Exploit a set of “super-strong” quantum correlations
- Correlations are monogamous in non-signalling sense.

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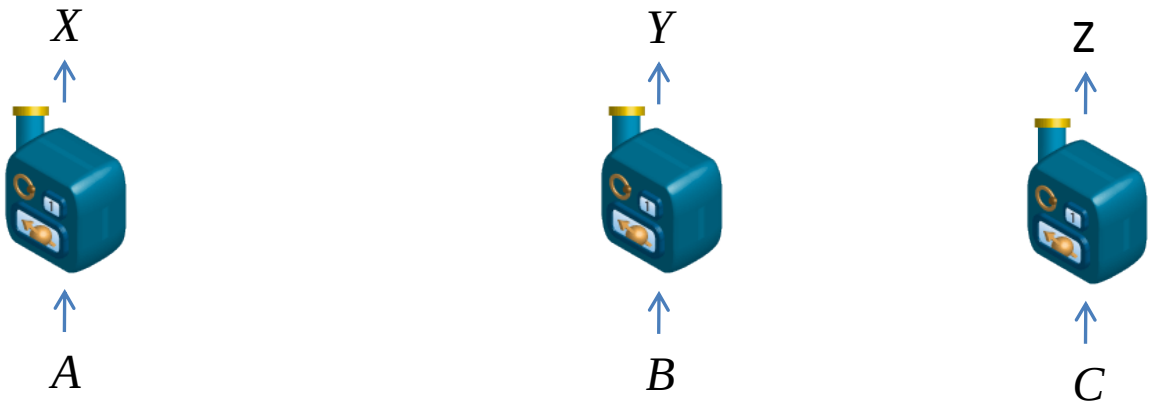

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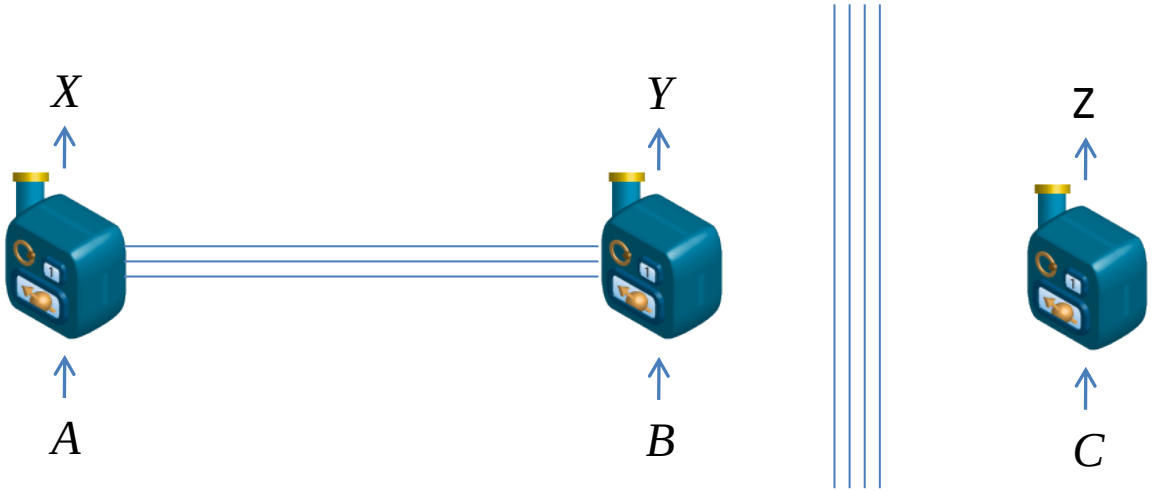

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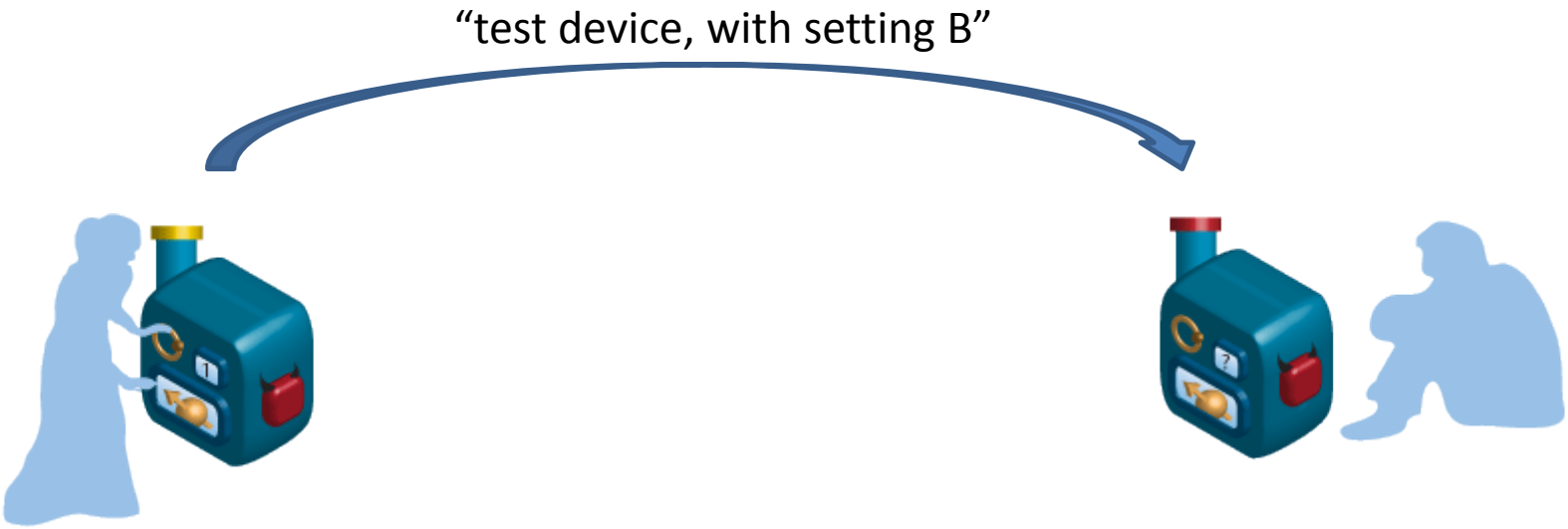

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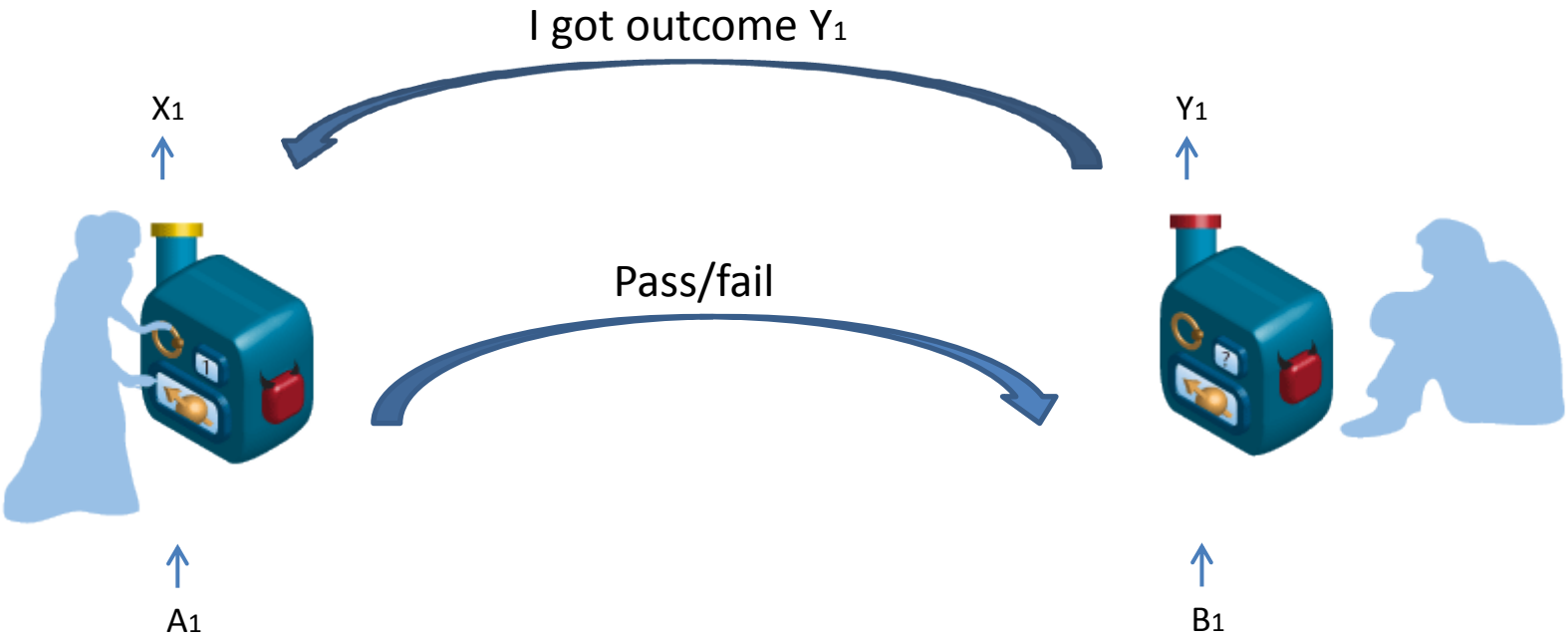


Our technique

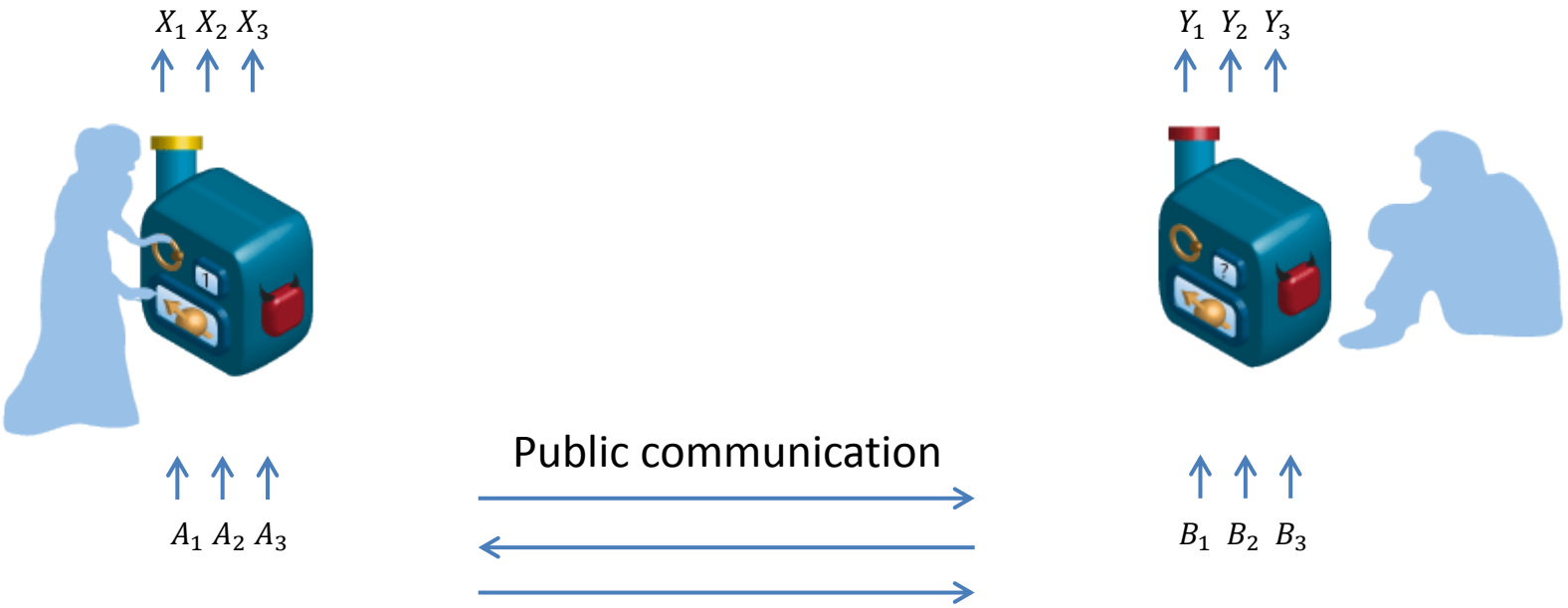
- If the test passes, the whole protocol repeats.
- We can strengthen Eve by giving the devices back to her before repeating the protocol
- Eventually, Alice will randomly choose to generate key, in which case, Alice and Bob both make measurements and take their outcomes to be key bits
- (Note that our protocol does not need privacy amplification).

Drawbacks of our protocol

- Inefficient and has low tolerance to noise (in contrast to previous talk)
- Although it allows device reuse within the same protocol, devices cannot be reused in future protocols
  - If the same (untrusted) devices are reused in future protocols, this can compromise previously generated keys [BCK PRL **110**, 010503 (2013)]

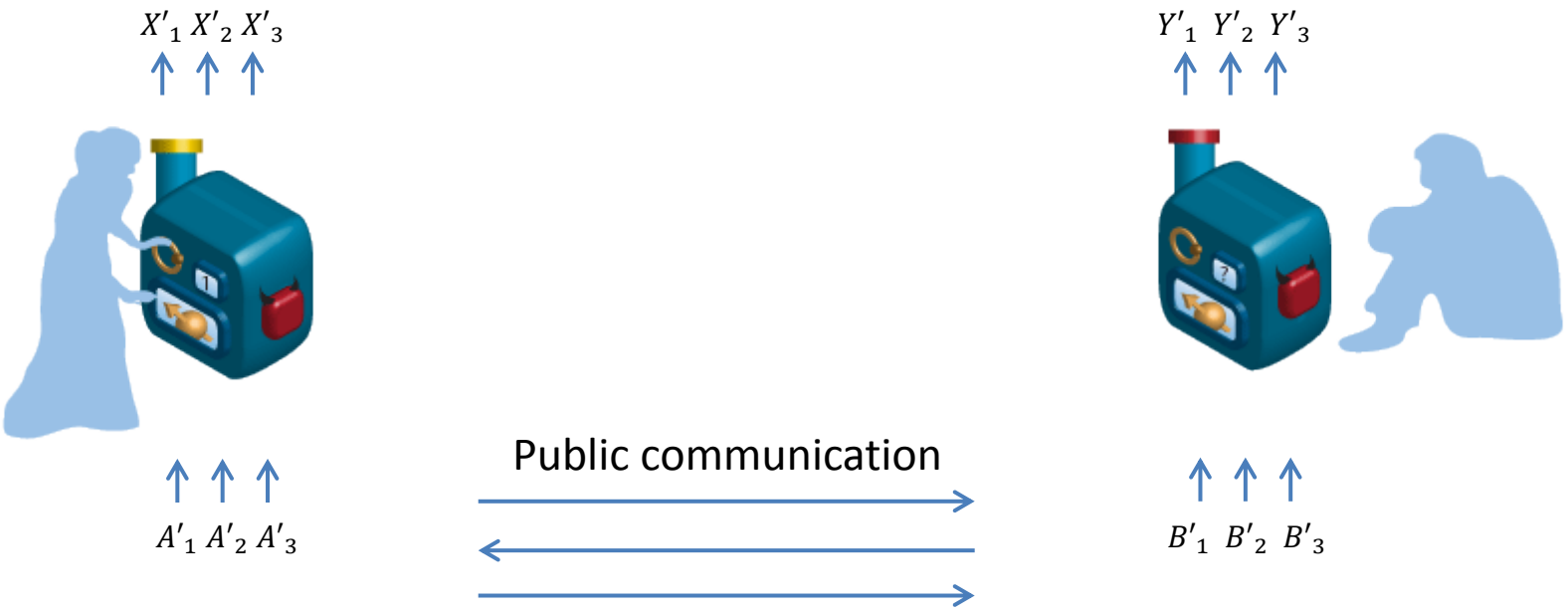
Device-reuse problem

- Consider a malicious device with memory and using it to generate a secure key



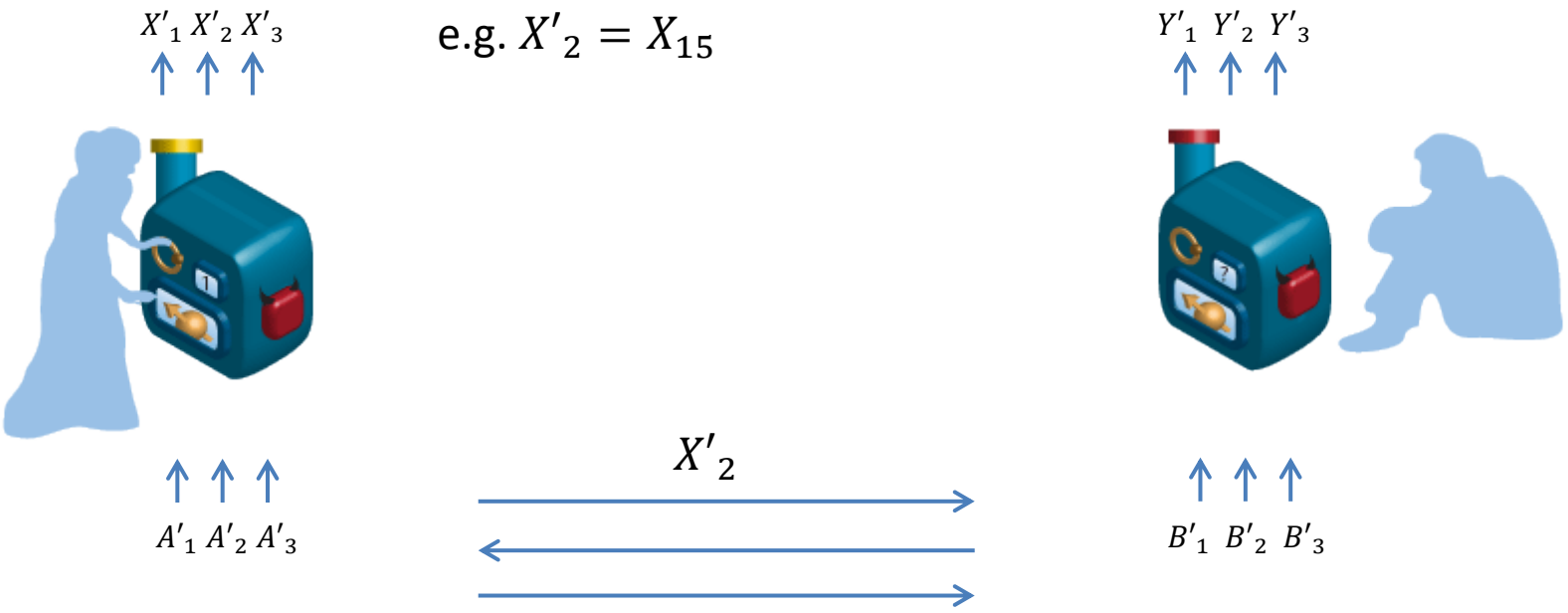
Device-reuse problem

- Reuse it to generate second key



Device-reuse problem

- Device with memory can re-output previous bits via a pre-agreed strategy



Device-reuse problem

- If a malicious device with memory is used to generate a secure key, it can leak data relevant to the first key and potentially compromise it

- This problem is present in all existing protocols

Open questions

- Prove security of a protocol that solves the problem of reusing untrusted devices in multiple protocols
- Need for new security notion
  - Universal device-reuse (reuse of untrusted devices in an arbitrary future application) is not possible
  - However, we think restricted device reuse is possible (reuse the devices only in certain ways)
- Are there efficient and noise tolerant protocols secure against non-signalling adversaries?