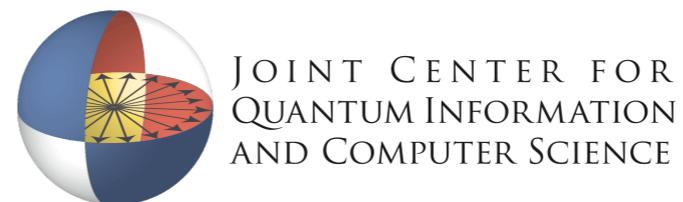


Unforgeable quantum encryption

Christian Majenz

Joint work with Gorjan Alagic and Tommaso Gagliardoni



IBM **Research** | Zurich



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Authenticated Encryption! (Using AES with 128 bit block size in Galois Counter Mode and SHA2)



Technical Details

Connection Encrypted (TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256 128 bit keys, TLS 1.2)

The page you are viewing was encrypted before being transmitted over the internet.

Encryption makes it difficult for unauthorized people to view information traveling between computers. It is therefore unlikely that anyone read this page as it traveled across the network.



Taxonomy of security

Authenticated encryption

authenticity,
Integrity

secrecy

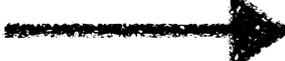
Definition

Integrity of ciphertexts
(INT-CTXT)
(\approx EUF-CMA for encryption
schemes)

Indistinguishability of ciphertexts
under adaptive chosen ciphertext attacks
(IND-CCA2)

Indistinguishability of ciphertexts
under nonadaptive chosen ciphertext attacks
(IND-CCA1)

Indistinguishability of ciphertexts
under chosen plaintext attacks
(IND-CPA)

 = implication

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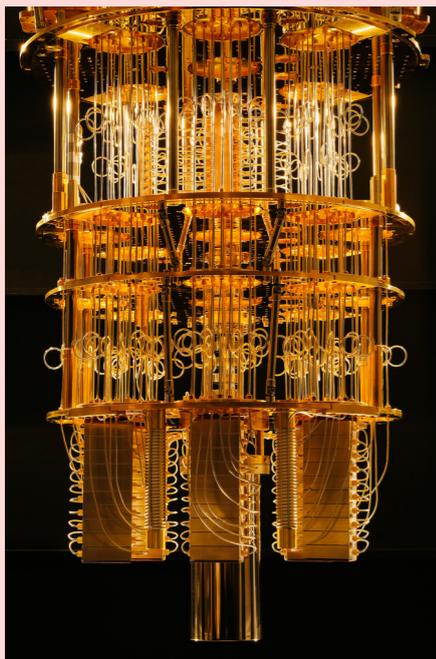
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Broadbent and Jeffery, Crypto 2015
Alagic et al., ICITS 2016



Taxonomy of security

Authenticated encryption

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No quantum version!!!
Why not, what is the difficulty?

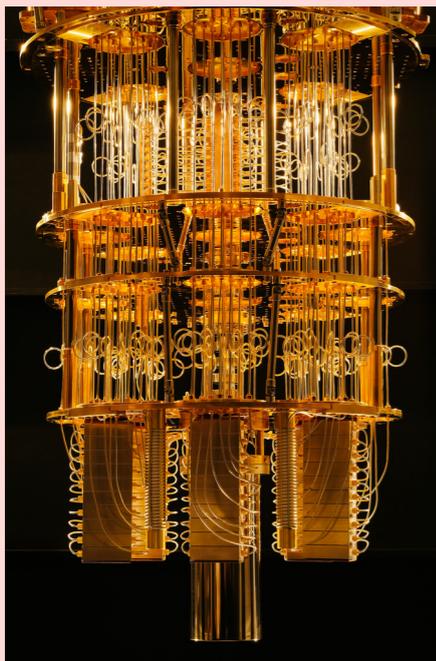
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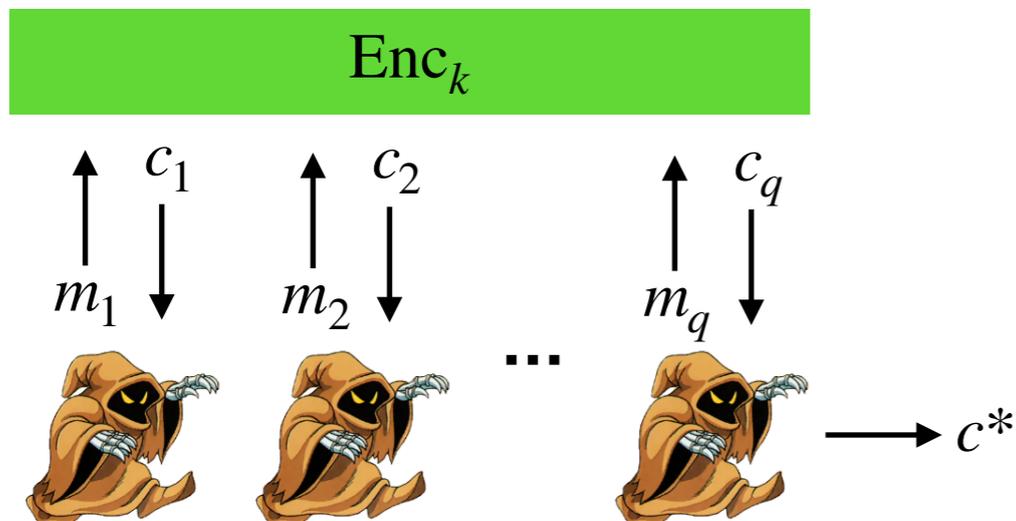
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Broadbent and Jeffery, Crypto 2015
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Integrity of ciphertexts

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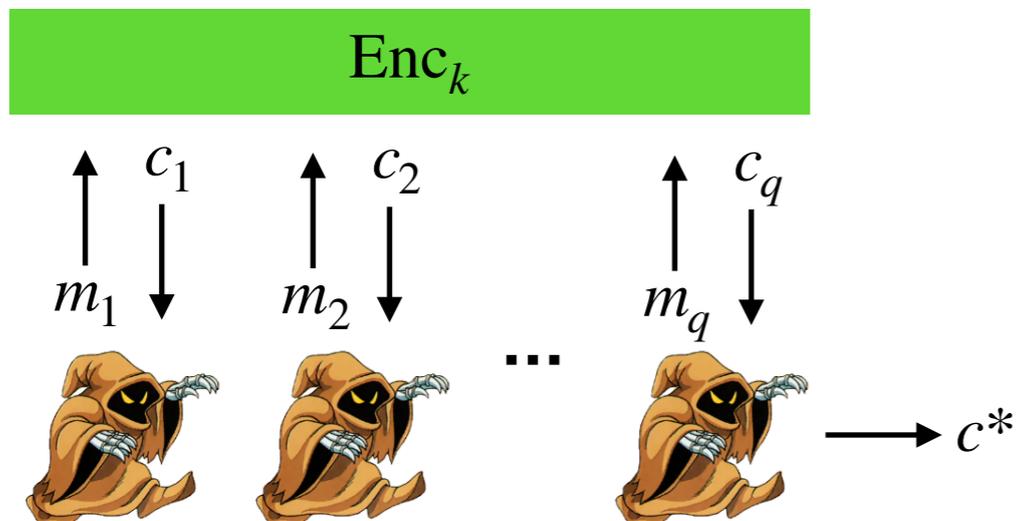


Success:
i) $c^* \neq c_i$ for all $i = 1, \dots, q$
ii) $Dec_k(c^*) \neq \perp$

What about encryption of quantum data?

Quantum Integrity of ciphertexts (attempt)

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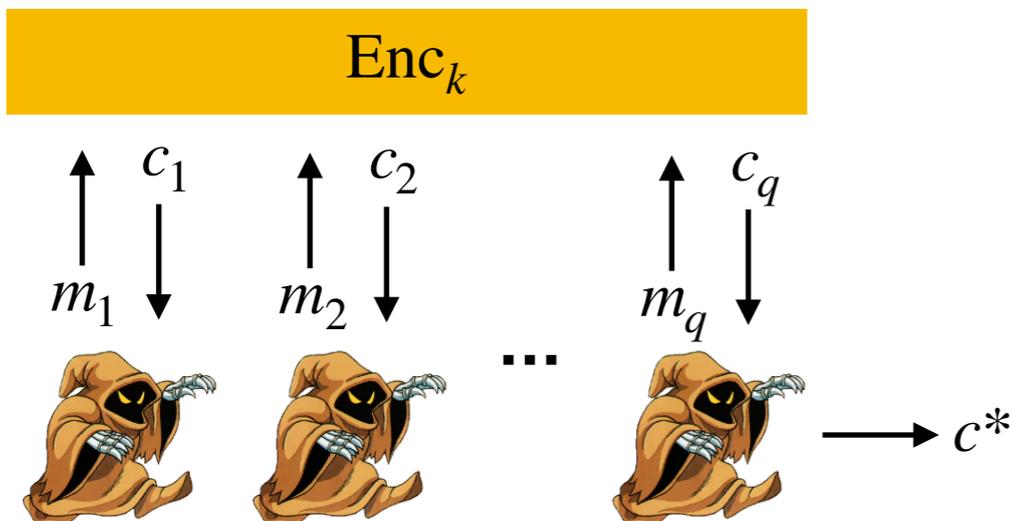
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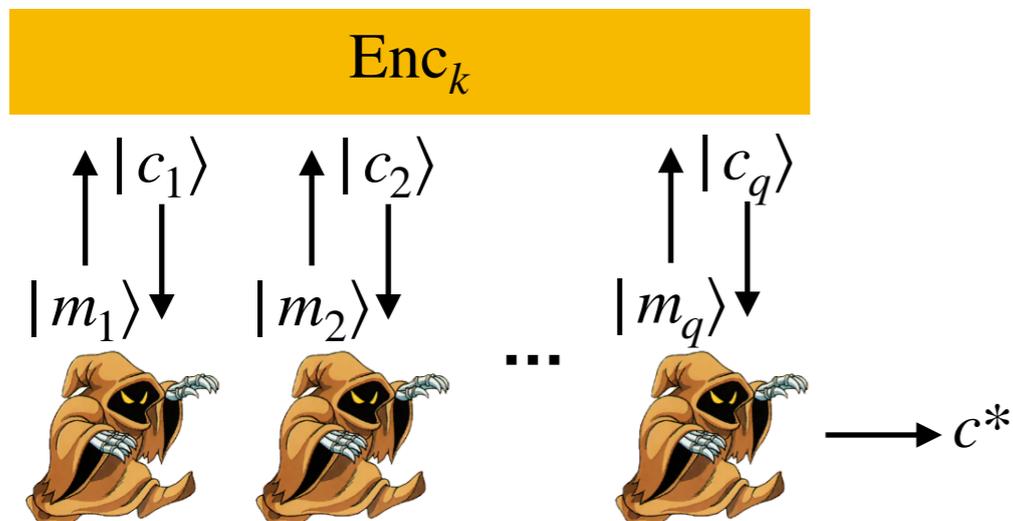
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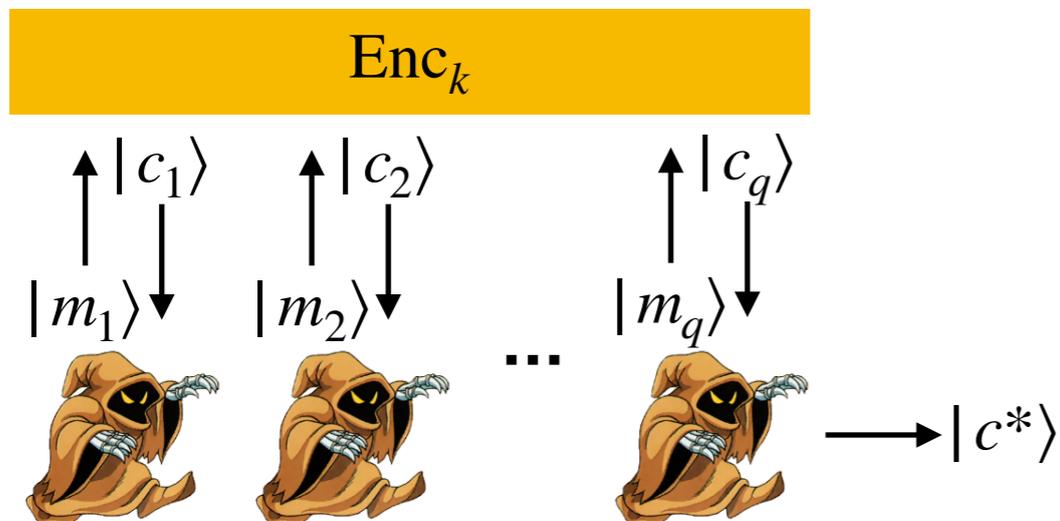
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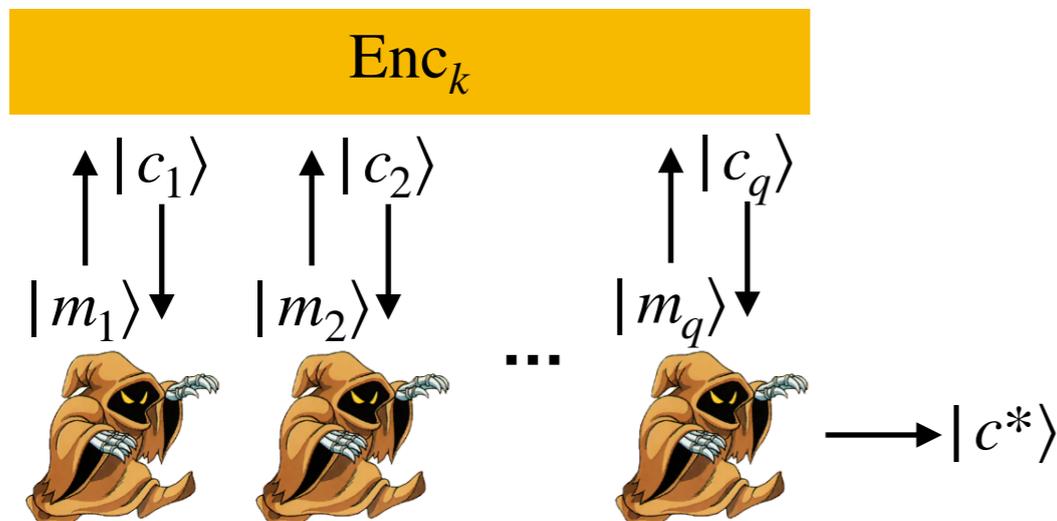
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An encryption scheme (KeyGen, Enc, Dec) has integrity of ciphertexts, if no successful ciphertext-forging adversary exists:



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What about encryption of quantum data?

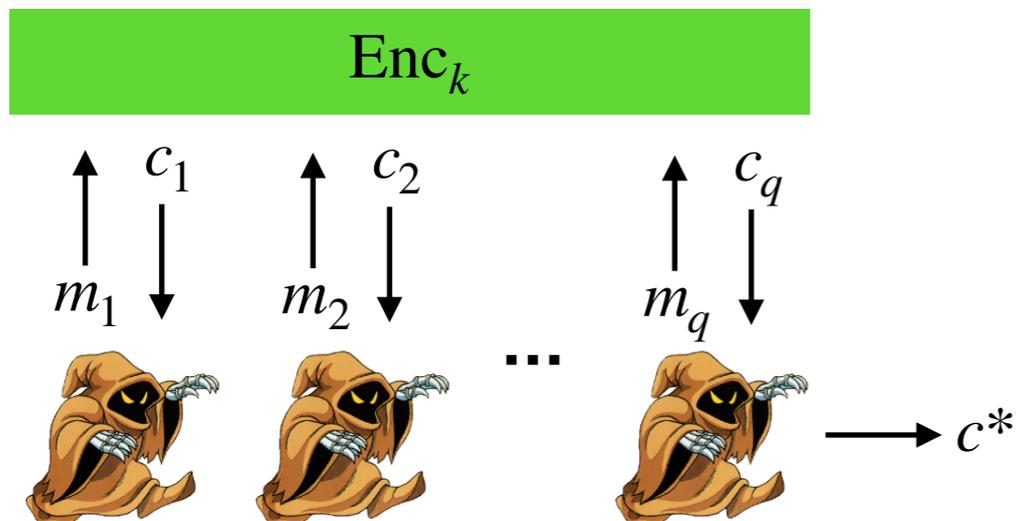
Unsurmountable problems arise:

- no-cloning: can't copy $|c_i\rangle$ for later comparison with $|c^*\rangle$
- destructive nature of quantum measurement: even assuming we had coexisting copies of $|c_i\rangle$ and $|c^*\rangle$, can't compare them without destroying $|c^*\rangle$.

IND-CCA2: Adversary gets decryption oracle after the challenge phase, but can't decrypt the challenge. \implies Similar problem

Quantum (plaintext) unforgeability – Setup

For simplicity of exposition, let's try to generalize plaintext unforgeability to quantum

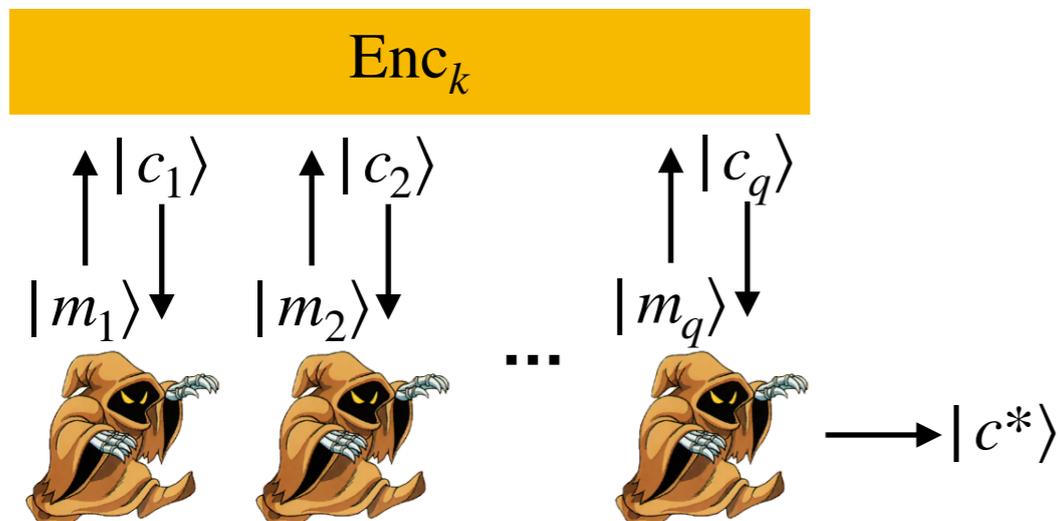


Success:

- i) $m^* := \text{Dec}_k(c^*) \neq m_i$ for all $i = 1, \dots, q$
- ii) $\text{Dec}_k(c^*) \neq \perp$

Quantum (plaintext) unforgeability – Setup

For simplicity of exposition, let's try to generalize plaintext unforgeability to quantum

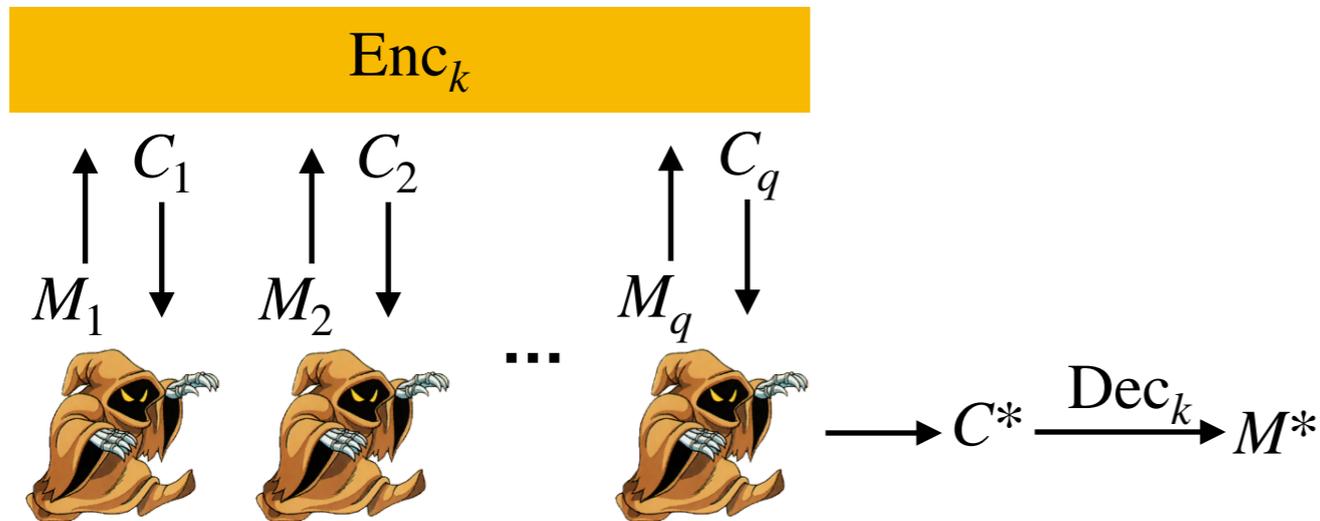


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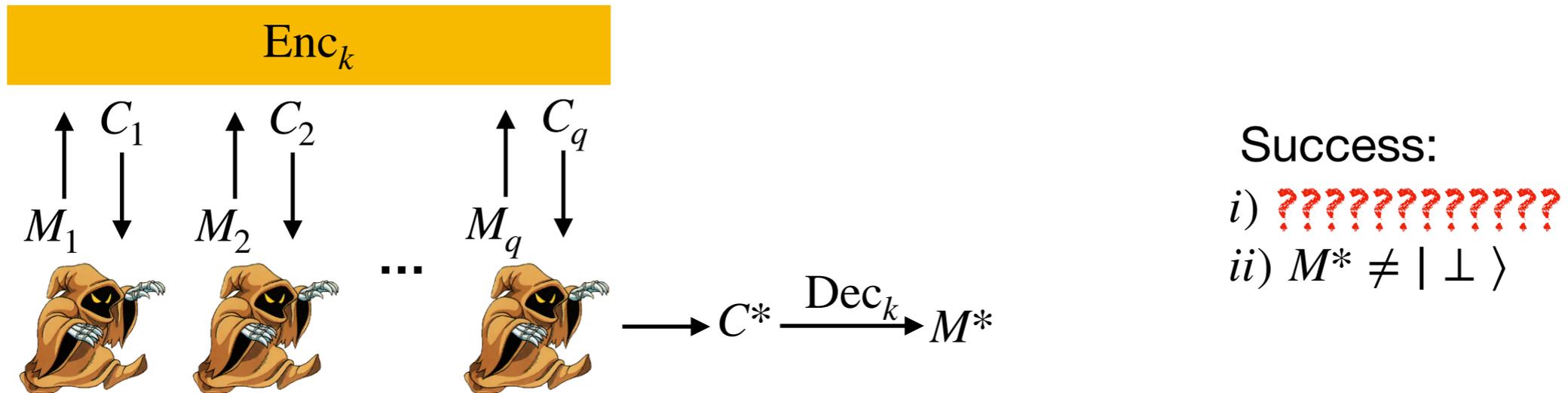


Success:

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Quantum (plaintext) unforgeability – Setup

For simplicity of exposition, let's try to generalize plaintext unforgeability to quantum



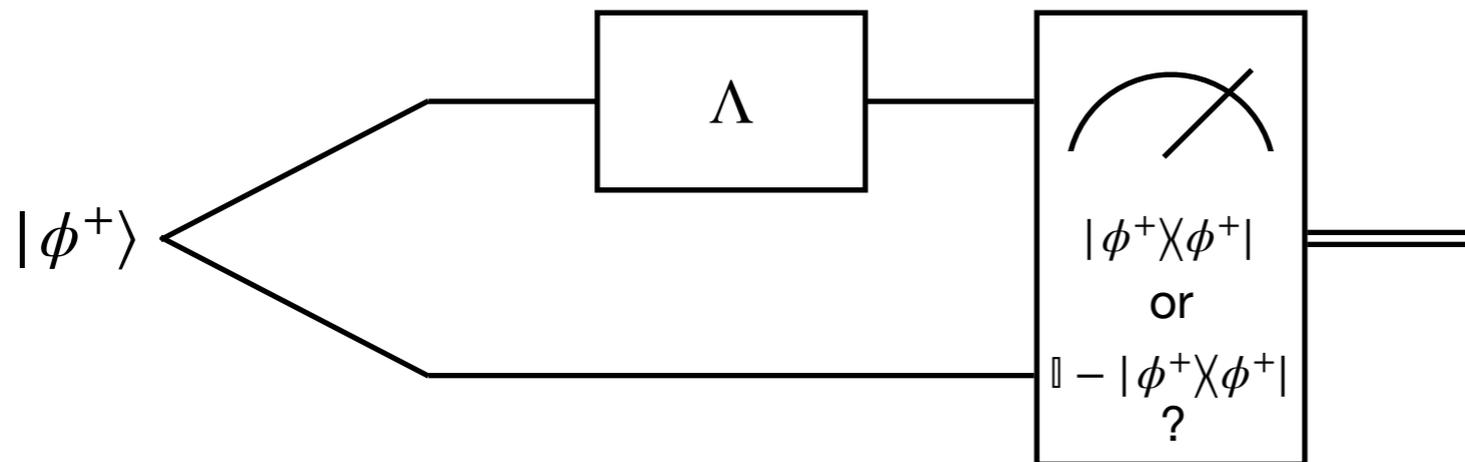
Problem: M_i and M^* don't coexist. Ideas

- look at the channels with input M_i and output M^*
- compare two games, one testing whether any of these channels is the identity, one testing validity of output
- efficiency needed for reduction proofs

Identity test

How do we test whether a quantum channel is the identity?

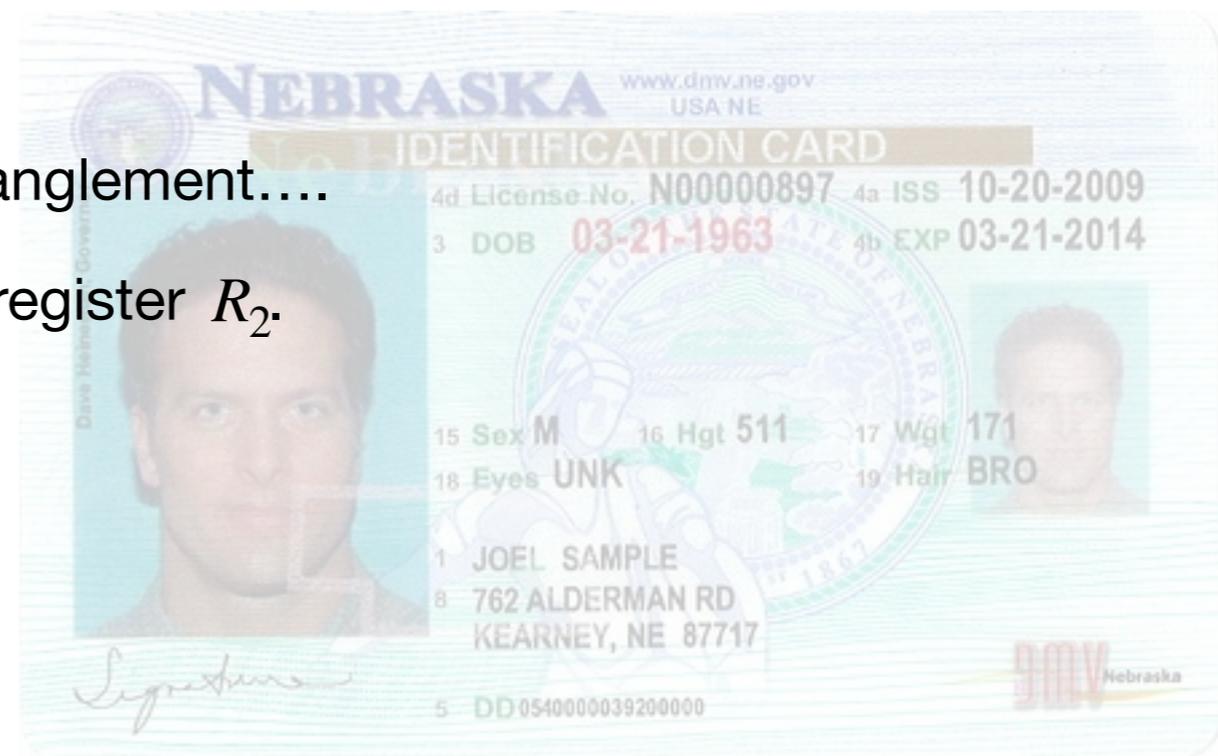
one efficient solution (Broadbent & Waynewright ICITS 2016):



inner product in the Choi-Jamiołkowski picture

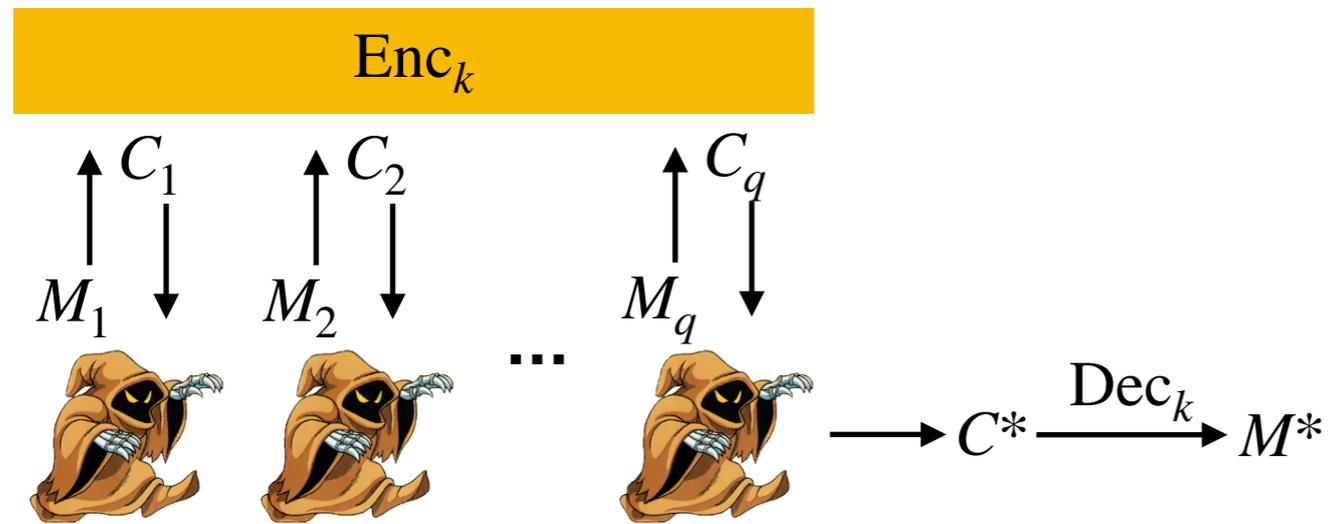
other identity tests possible that don't need entanglement....

Let $\text{Id}_{R_1 R_2}$ be the identity test from register R_1 to register R_2 .



Two games

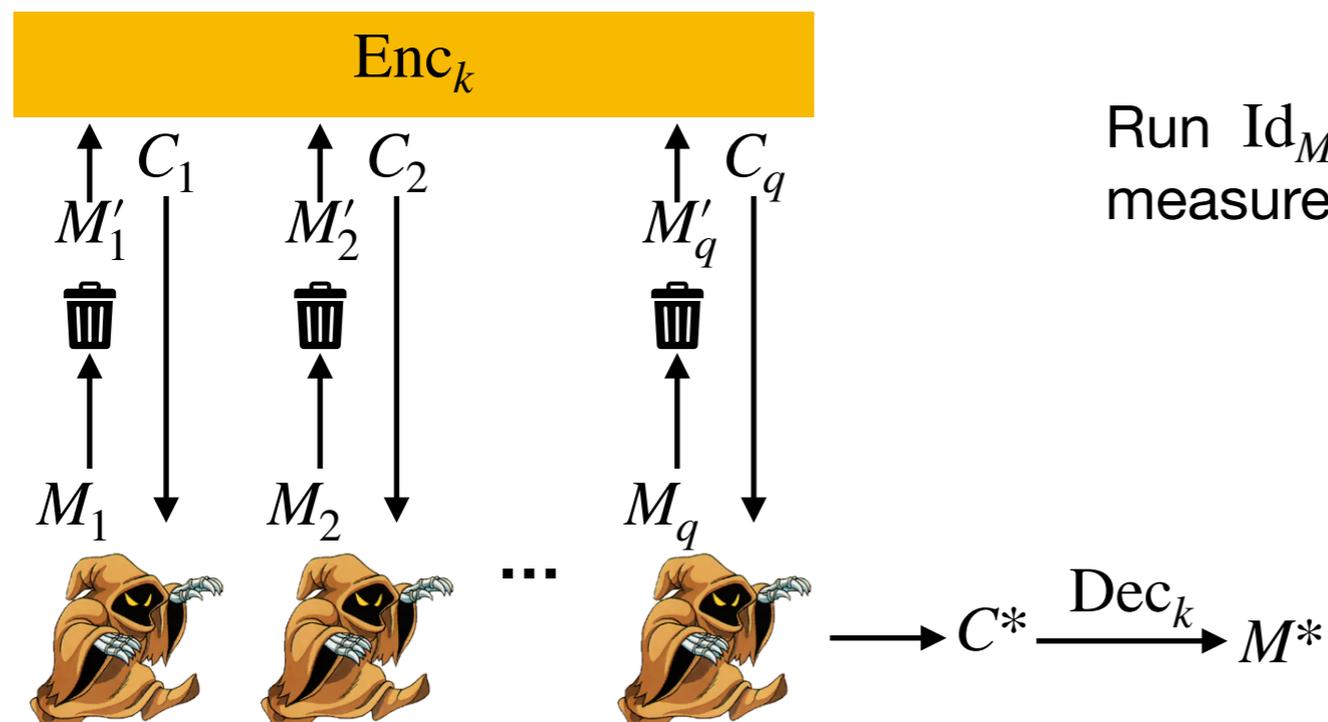
QUF-Forge game



Success:

- i) \emptyset
- ii) $M^* \neq |\perp\rangle$

QUF-Test game



Run $Id_{M'_i M^*}$ For all i . (Ok by gentle measurement lemma)

Cheat (=“Success”):

- i) $Id_{M'_i M^*}$ succeeds for at least one i
- ii) \emptyset

Quantum (plaintext) unforgeability – Definition

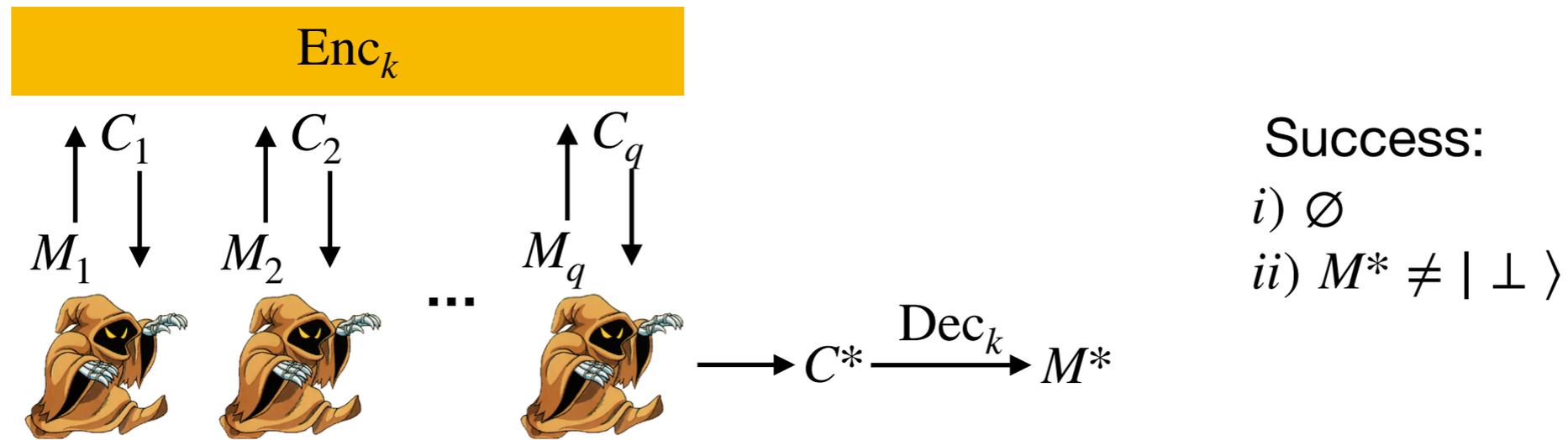
Definition (Quantum plaintext unforgeability):

A quantum encryption scheme $(\text{KeyGen}, \text{Enc}, \text{Dec})$ has unforgeable plaintexts, if for all QPT adversaries \mathcal{A} it holds that

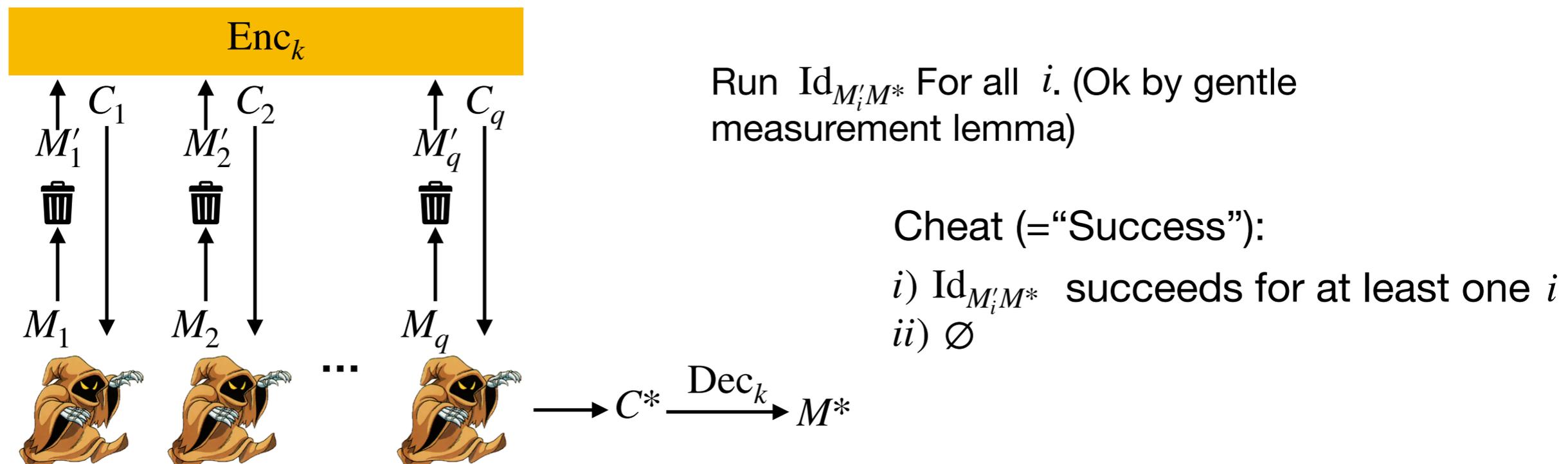
$$\left| \mathbb{P} [\mathcal{A} \text{ wins QUF} - \text{forge}] - \mathbb{P} [\mathcal{A} \text{ wins QUF} - \text{test}] \right| \leq \text{negl}(n)$$

Quantum (plaintext) unforgeability – Definition

QUF-Forge game



QUF-Test game



Quantum (plaintext) unforgeability – Definition

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A quantum encryption scheme $(\text{KeyGen}, \text{Enc}, \text{Dec})$ has unforgeable plaintexts, if for all QPT adversaries \mathcal{A} it holds that

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- implies IND-CPA, ok because authentication \implies encryption (Barnum et al. 2002).
- classical restriction is equivalent to authenticated encryption
- can be upgraded to quantum ciphertext authentication:
 - * possible via lemma: any quantum encryption function can be implemented by classical sampling and unitary transformation
 - * use identity test for quantum part and save a copy of classical randomness

What I couldn't explain in 17 min...

QIND-CCA2: Use identity test to detect challenge decryption, again by comparing two games

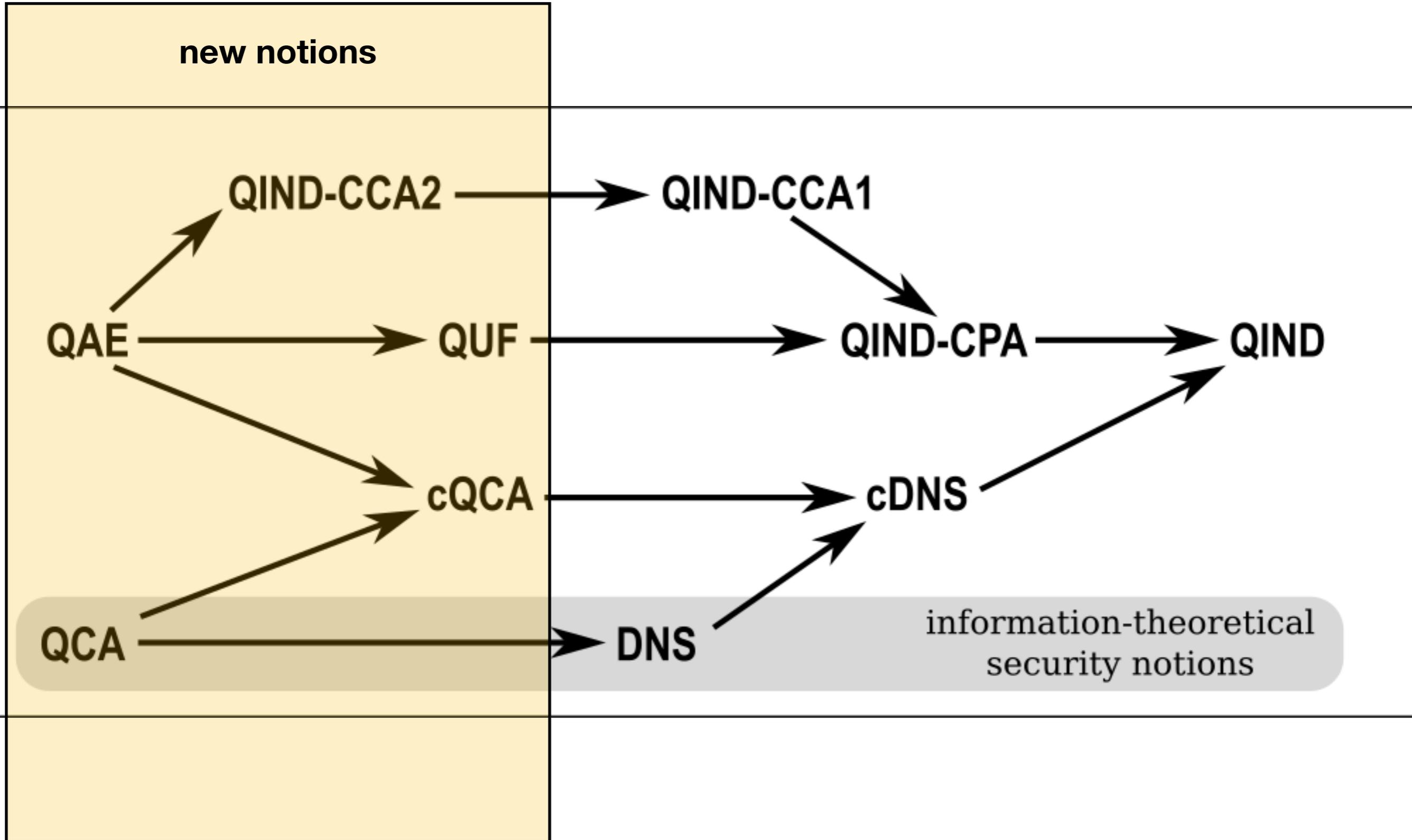
quantum authenticated encryption? Could define as QUF+QIND-CCA2, but...

...alternative real vs. ideal characterization (Shrimpton, 2004) is *made* for the identity testing technique!

⇒ separate definition: QAE

simple construction from pseudorandom functions and unitary 2-designs

Taxonomy of quantum security



Conclusion

- Generalizing authenticity and integrity security notions (and adaptive CCA security) to quantum is complicated by the fact that states from different stages of an algorithm cannot be compared
- Divide and conquer! If it is impossible to check two properties in one game, use two (indistinguishable) games!
- That way we get quantum versions of the integrity notions used in modern crypto.
- They can be fulfilled and have nice relationships.

What's left to do?

- Is $QAE = QUF + QIND-CCA2$?
- Relationship to quantum world notions?