Tighter Security for Generic Authenticated Key Exchange in the QROM

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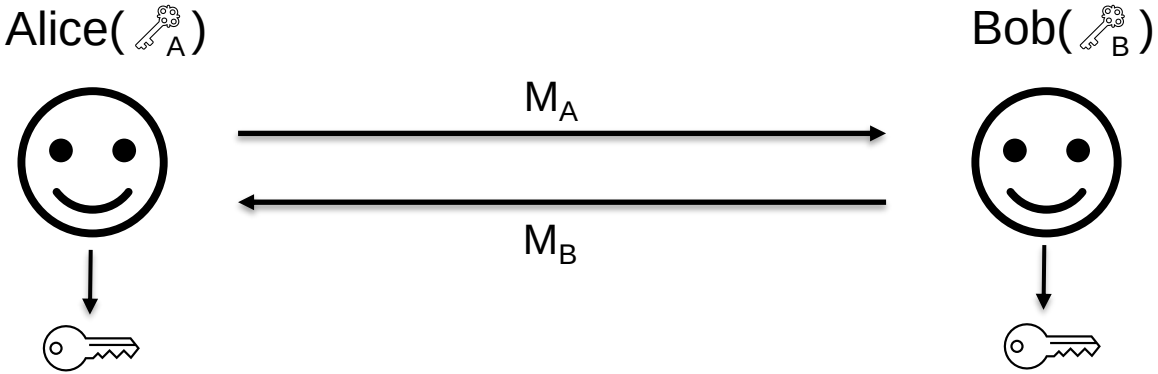
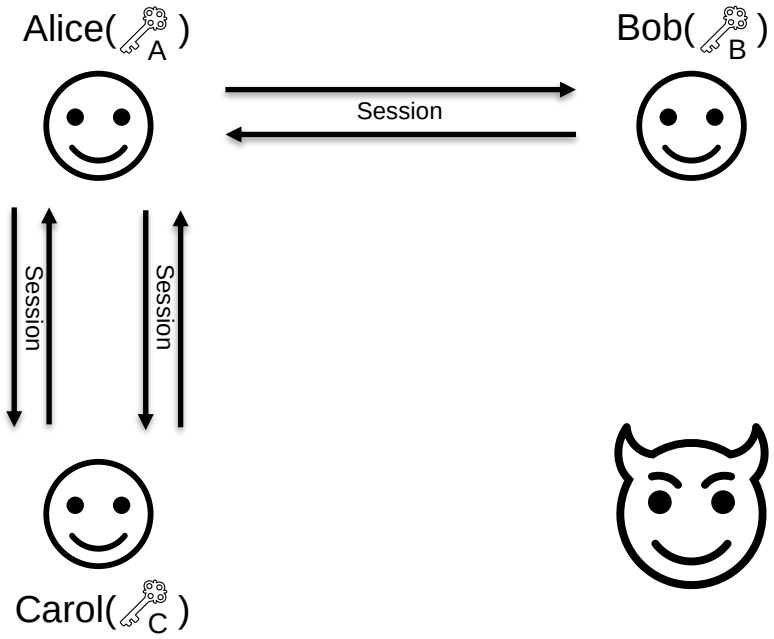
Authenticated Key Exchange

Two-message AKE



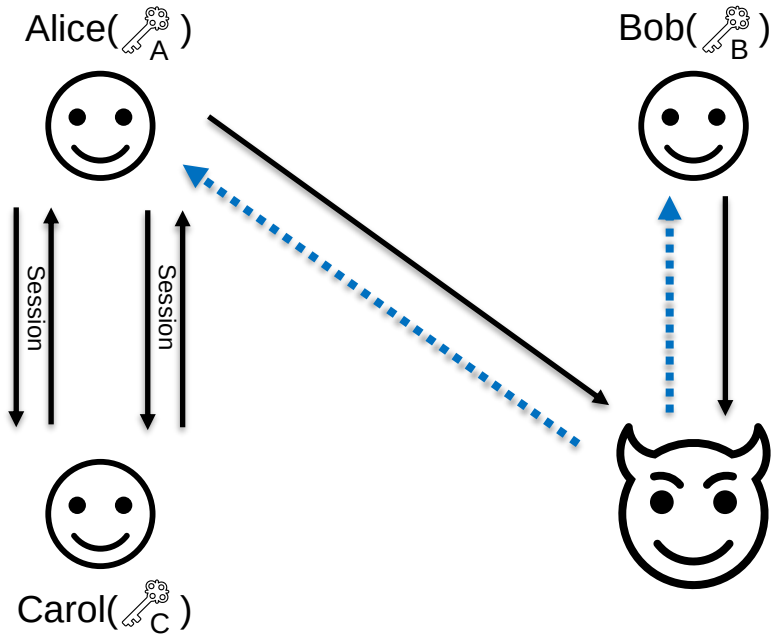
Security of AKE

- Multi-user and Multi-session Settings



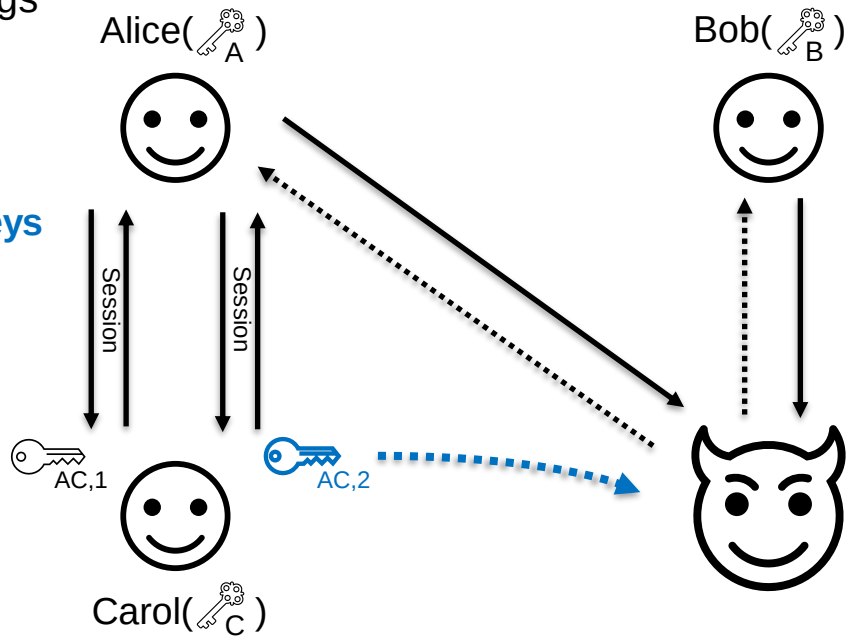
Security of AKE

- Multi-user and Multi-session Settings
- Adversary Capabilities
  - **Control the network**



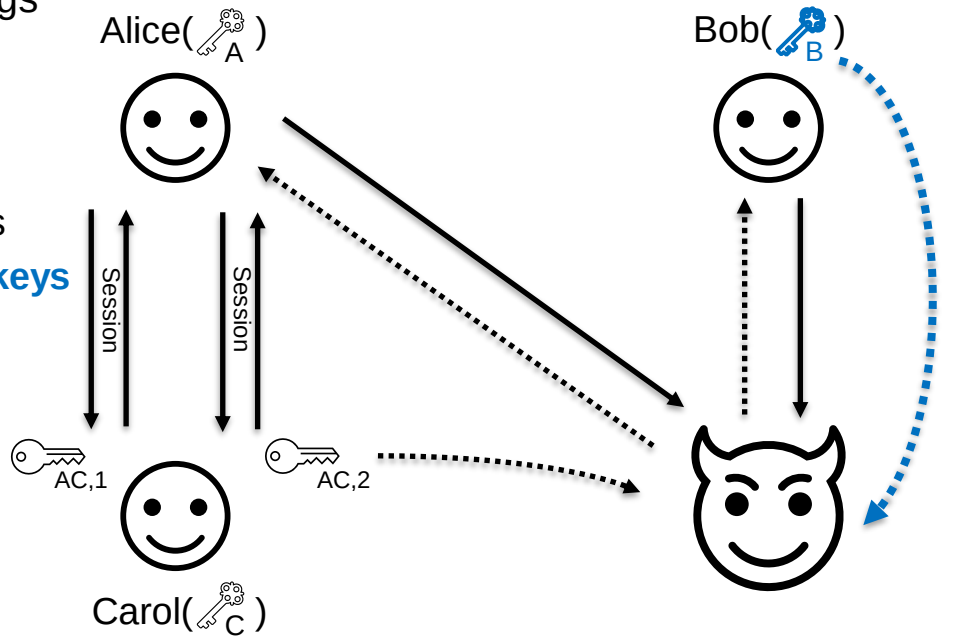
Security of AKE

- Multi-user and Multi-session Settings
- Adversary Capabilities
  - Control the network
  - **Reveal established session keys**



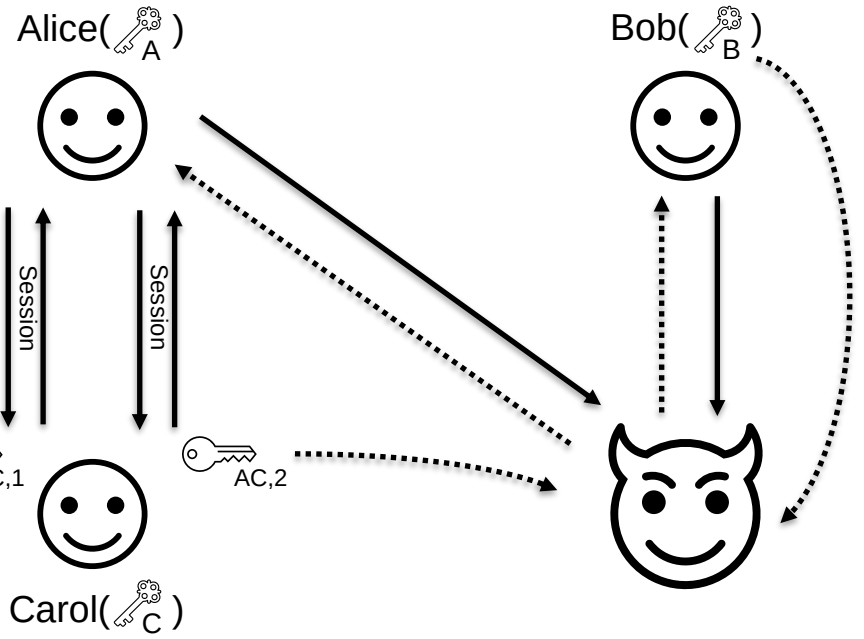
Security of AKE

- Multi-user and Multi-session Settings
- Adversary Capabilities
  - Control the network
  - Reveal established session keys
  - **Adaptively corrupt long-term keys**



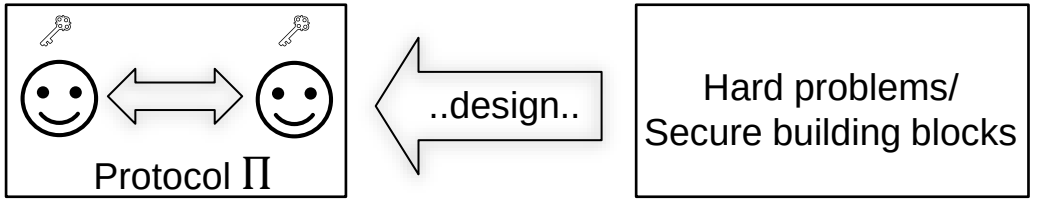
Security of AKE

- Multi-user and Multi-session Settings
- Adversary Capabilities
  - Control the network
  - Reveal established session keys
  - Adaptively corrupt long-term keys
- Security Goals
  - Key Indistinguishability
  - Authentication



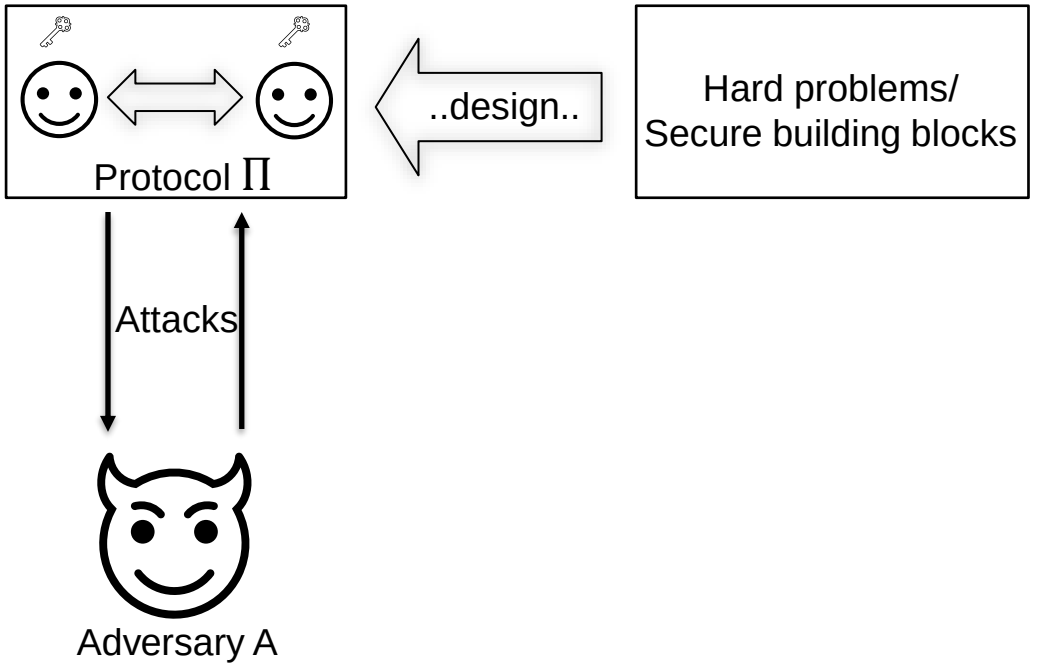
Tightness of Security Reduction

- Security Proof via Reduction



Tightness of Security Reduction

- Security Proof via Reduction
  - A breaks Π



Tightness of Security Reduction

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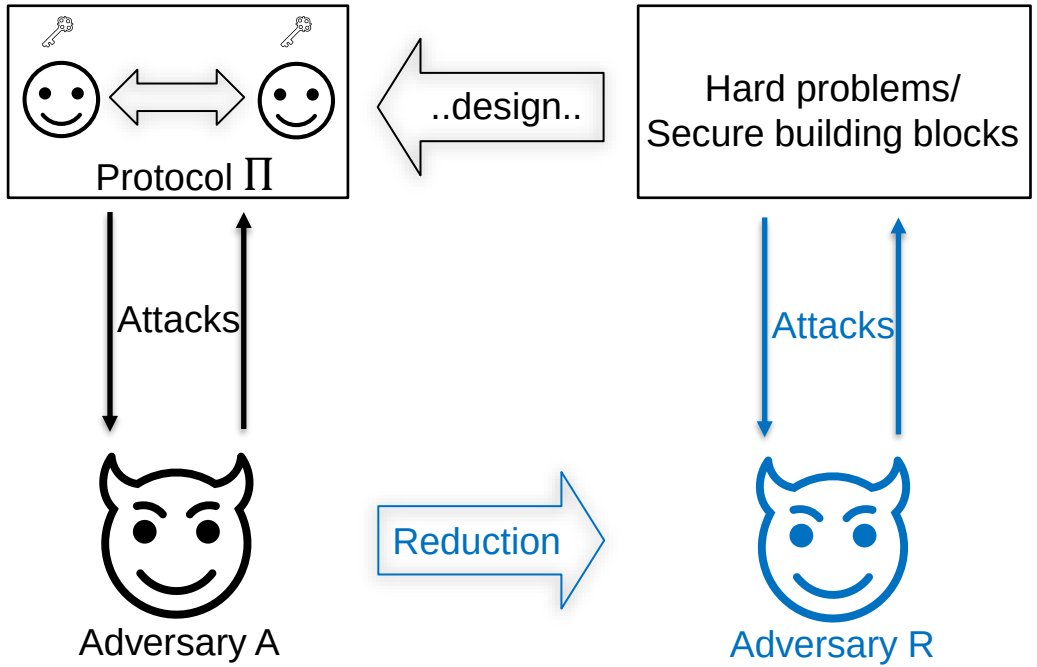
    $\Longrightarrow$ R solves problems



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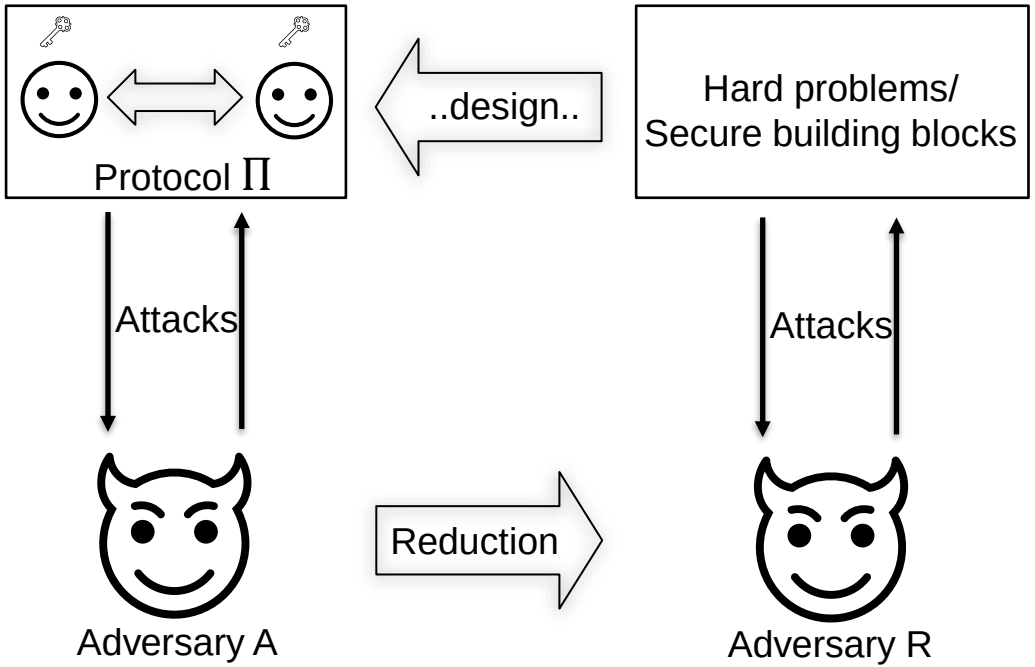
  - $\mathbf{Adv}(\mathrm{R}) \leq L \cdot \mathbf{Adv}(\mathrm{A})$
  - L: Security loss



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  - $\mathbf{Adv}(\mathrm{R}) \leq L \cdot \mathbf{Adv}(\mathrm{A})$
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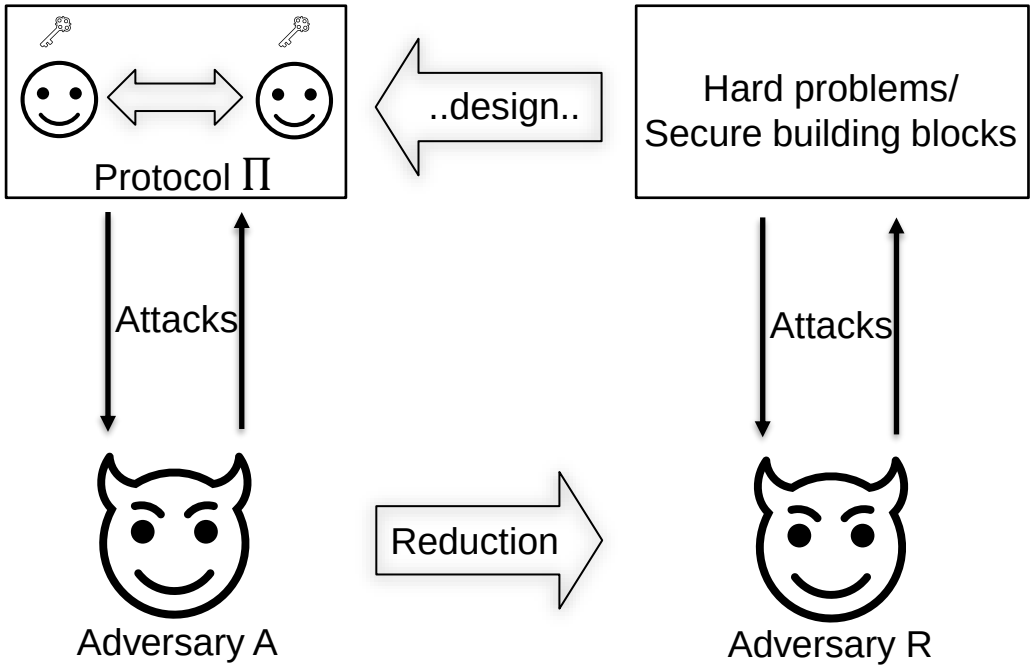
  - L smaller $\Longrightarrow$ tighter



Tightness of Security Reduction

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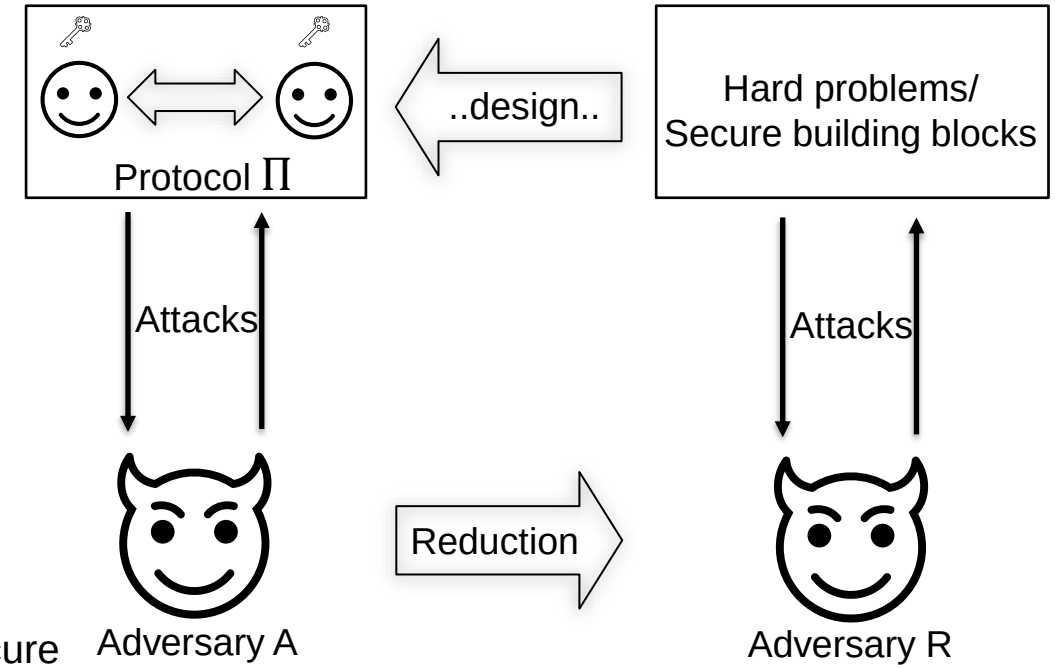
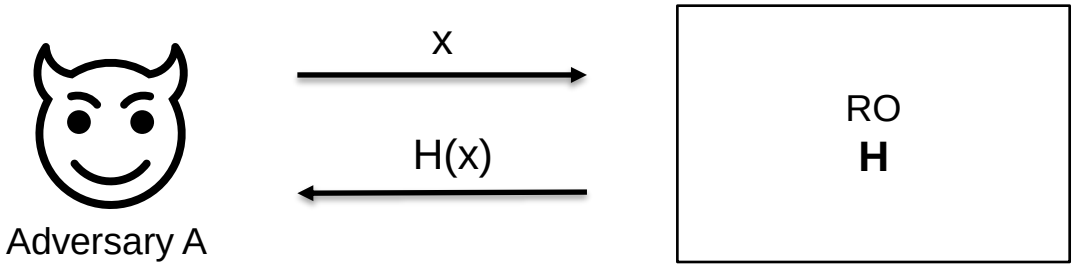
- Tightness of Reduction
  - $\mathbf{Adv}(\mathrm{R}) \leq L \cdot \mathbf{Adv}(\mathrm{A})$
  - L: Security loss
  - L smaller $\Longrightarrow$ tighter
- Relevance: Parameter selection
  - L is large $\Longrightarrow$ inefficient or insecure



Quantum Random Oracle Model



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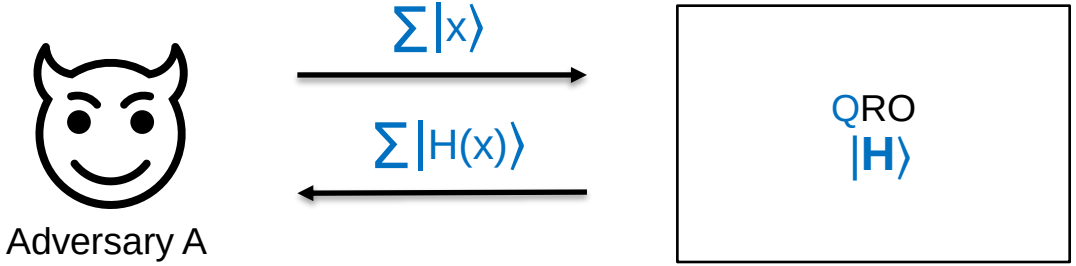

AKE in the (Q)ROM

Scheme	Construction	Assumption	Security Loss	Model
JKRS21	KEM	DDH	$\Theta(1)$	ROM
PWZ23	KEM	LWE	$\Theta(\lambda)$	ROM
HKSU20	PKE/KEM	LWE	$\Theta(N \cdot \boldsymbol{S} \cdot \sqrt{\boldsymbol{\epsilon^{-1}}})$	QROM
XAYLJ20	2KEM	Isogeny	$\Theta(N \cdot \boldsymbol{S} \cdot \sqrt{\boldsymbol{\epsilon^{-1}}})$	QROM

λ: Security parameter
N: Number of user;
$\boldsymbol{S}$**: Number of session**;
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Our Goal	KEM	Post-Quantum	Tight, or tighter?	QROM

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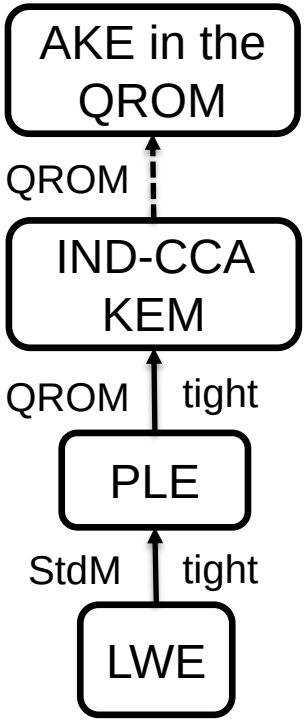
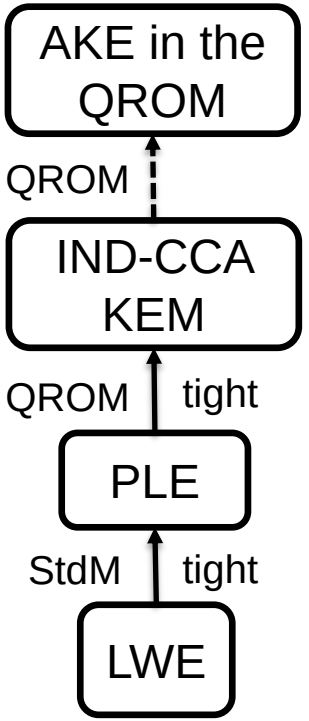
Our Contributions



Our Contributions

- LWE-based AKE with **Tighter** Security in the QROM
  - **Session-tight** and **without square-root loss**
  - Via multi-user-challenge(MUC)-IND-CCA secure KEM



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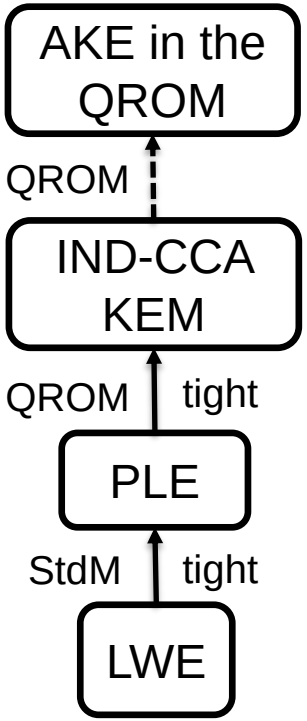
- Parameter-lossy Encryption (PLE)
  - Used to construct **tightly MUC-IND-CCA secure KEM**
  - (Almost-)Tight construction from LWE



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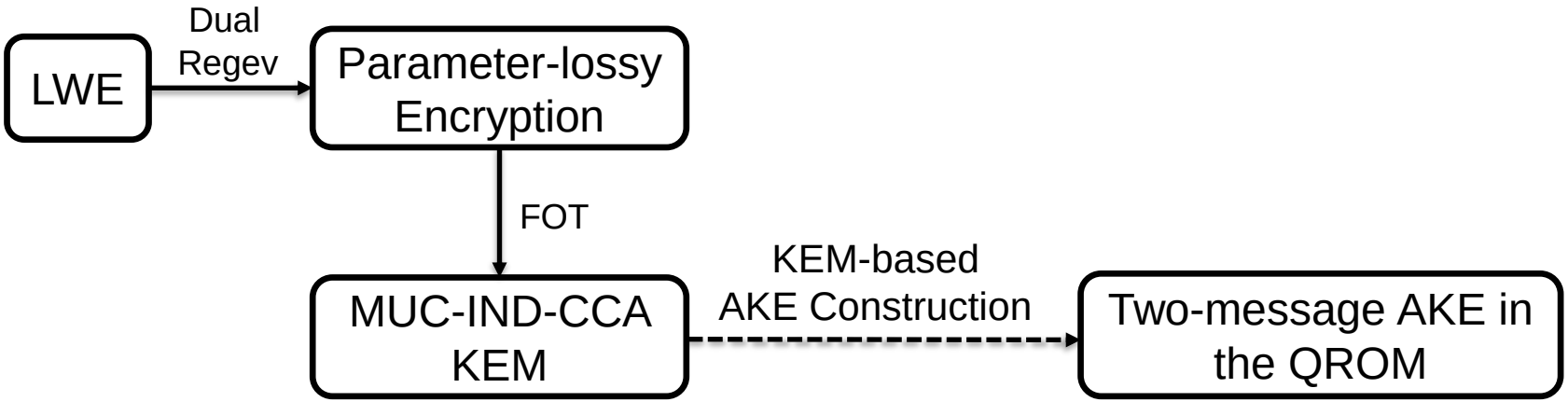
Session-tight and **without square-root loss**

Technical Outline

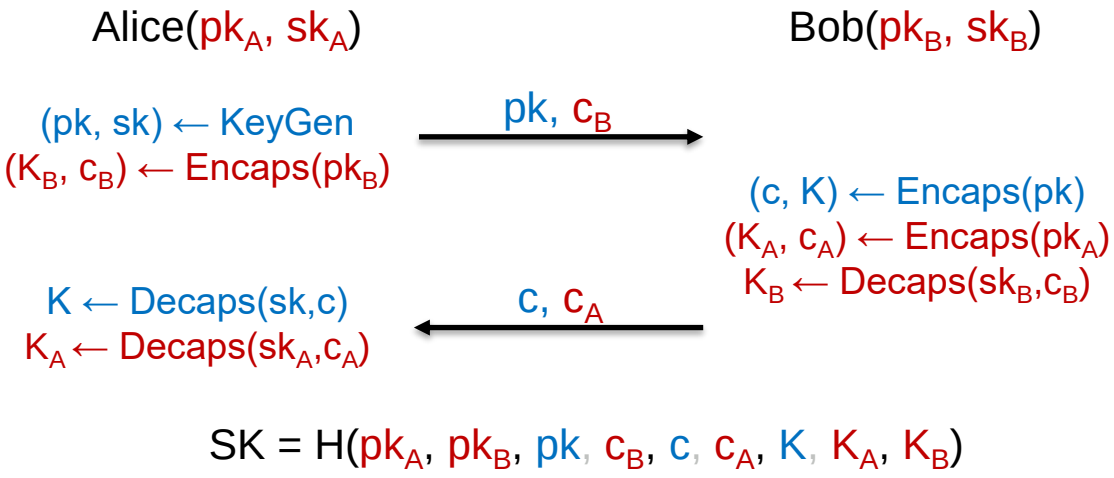


: (almost-)tightly

: non-tightly

AKE from KEM

- Construction [JKRS21, PWZ23]: Static KEM + Ephemeral KEM



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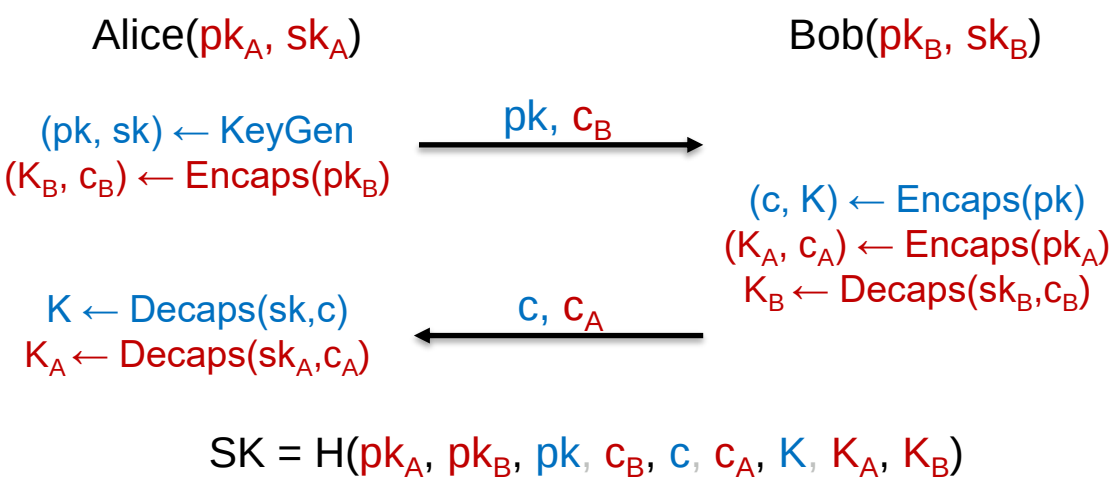

- Ephemeral KEM should have MUC-IND-CCA security
- Static KEM should have MUC-IND-CCA security with strong corruptions [JKRS21, PWZ23]

AKE from KEM

- Construction [JKRS21, PWZ23]: Static KEM + Ephemeral KEM (in the QROM)

- To have tight security in the QROM:
  - Ephemeral KEM should have MUC-IND-CCA security in the QROM
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- Both are unknown how to construct from LWE...
  - Cannot use the re-randomization technique
  - Unknown how to construct such Static KEM from LWE in the QROM

AKE from KEM

- Construction [JKRS21, PWZ23]: Static KEM + Ephemeral KEM (in the QROM)
- To have tight security in the QROM:
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  - Static KEM should have MUC-IND-CCA security with strong corruptions in the QROM
- Both are unknown how to construct from LWE...
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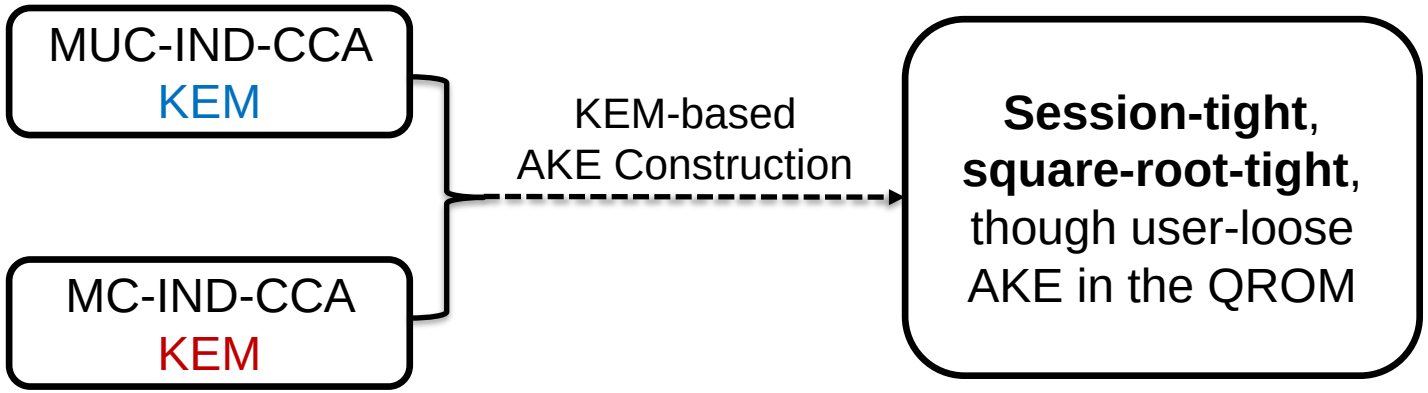
  - Unknown how to construct such Static KEM from LWE in the QROM
- If we have ***MC-IND-CCA*** Static KEM + ***MUC-IND-CCA*** Ephemeral KEM...

AKE from KEM, tighter

- *MC-IND-CCA* Static KEM + *MUC-IND-CCA* Ephemeral KEM



MUC-IND-CCA KEM & Parameter-lossy Encryption

MUC-IND-CCA KEM

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MUC-IND-CCA KEM & Parameter-lossy Encryption

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Parameter-lossy Encryption

- Parameter-lossy Encryption
  - A multi-user version of lossy encryption [BHY09]
  - Lossy public keys & **lossy parameter**

MUC-IND-CCA KEM & Parameter-lossy Encryption

- Lossy Encryption

1. Key indistinguishability:

   real $pk \approx_c$ lossy lpk

2. Lossiness: (Informally) Ciphertexts have statistical indistinguishability under lossy key lpk...

3. $\Longrightarrow$ MC-IND-CPA PKE

MUC-IND-CCA KEM & Parameter-lossy Encryption

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- Parameter-lossy Encryption

1. Parameter-key indistinguishability:

   real $(\boldsymbol{par}, pk_1, \ldots, pk_\mu) \approx_c$ lossy $(\boldsymbol{lpar}, lpk_1, \ldots, lpk_\mu)$

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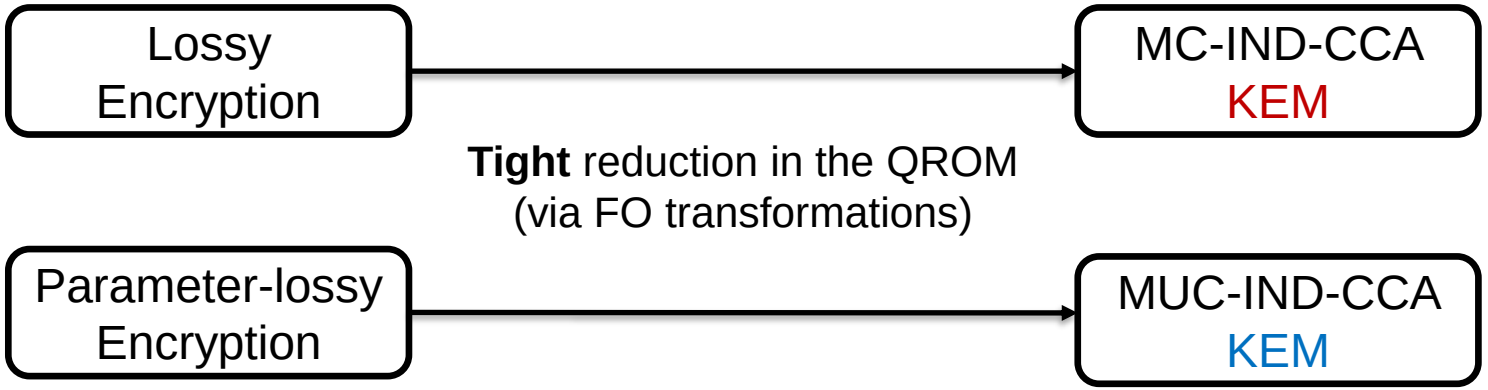
3. $\Longrightarrow$ M**U**C-IND-CPA PKE

MUC-IND-CCA KEM & Parameter-lossy Encryption



Parameter-lossy Encryption from LWE

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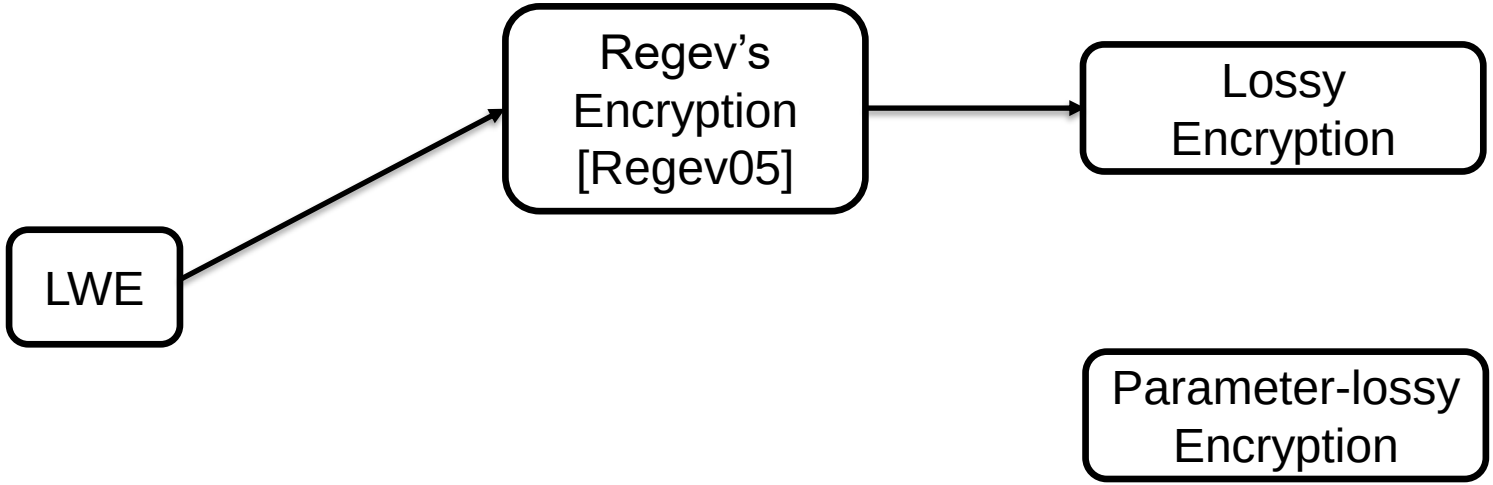

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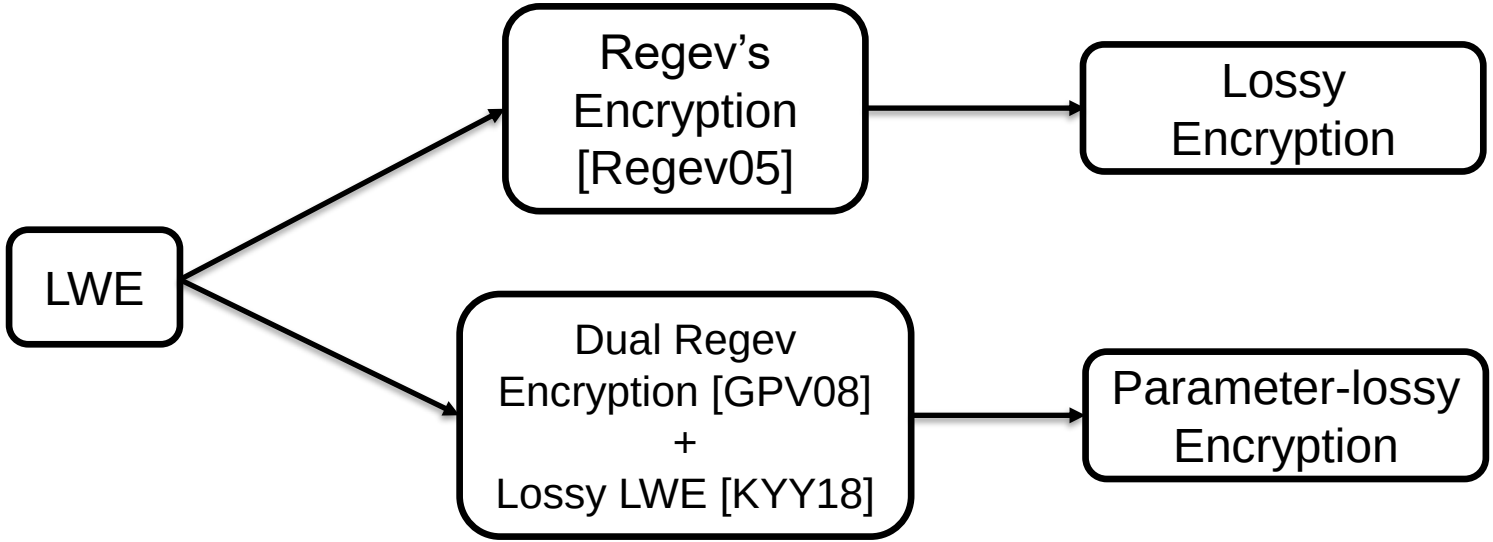
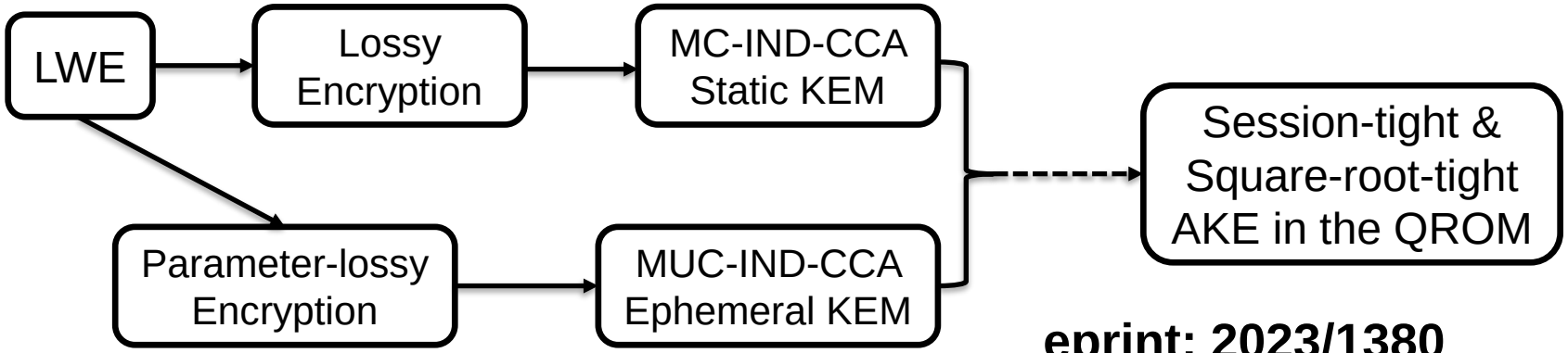


Summary and Open Problems



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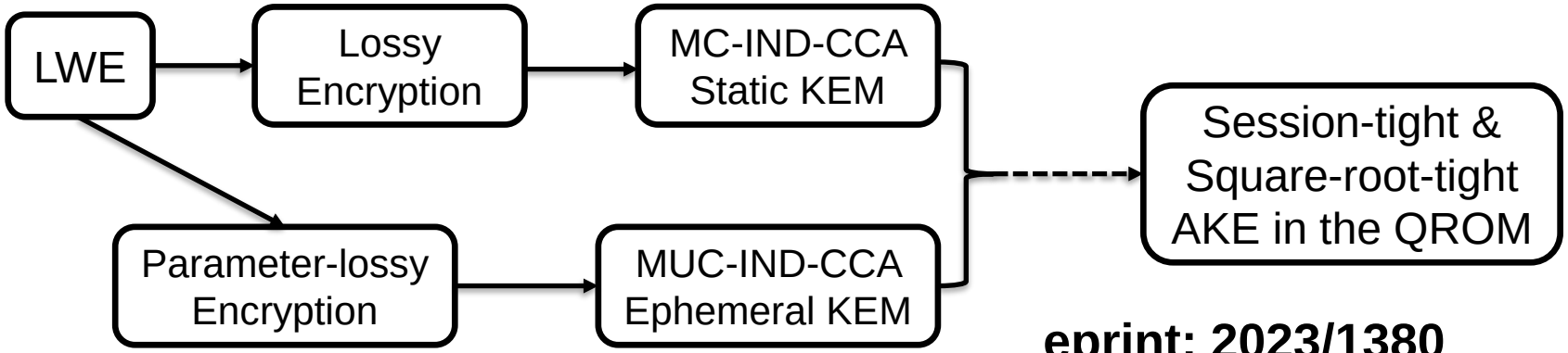

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Also user-tight in the QROM?

References

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