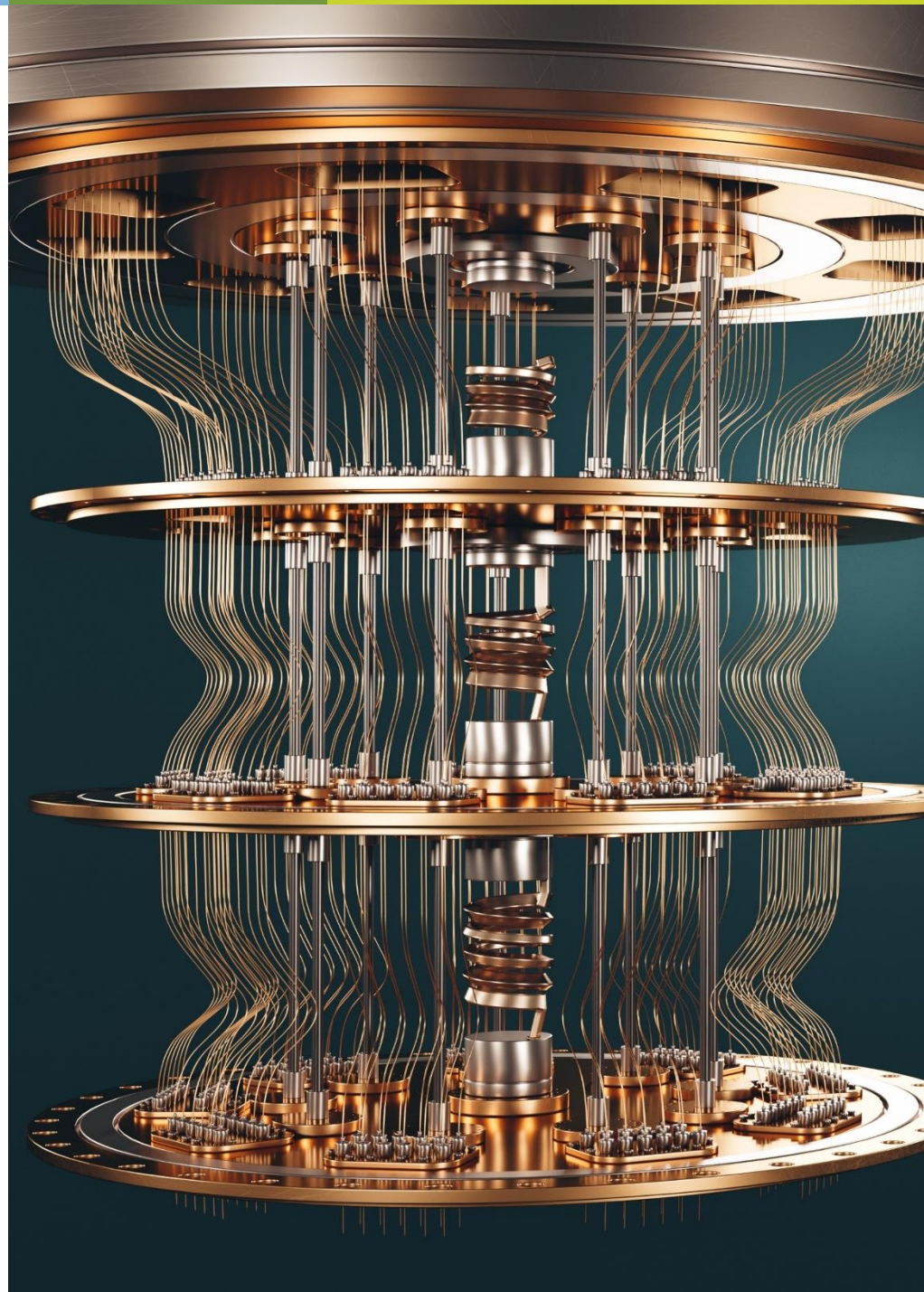
Lessons Learned from Protecting CRYSTALS-DILITHIUM

Melissa Azouaoui, Joppe Bos, Olivier Bronchain, Joost Renes, Markus Schönauer, **Tobias Schneider**, and Christine van Vredendaal

contact: pqc@nxp.com

RWC 2023
March 27, 2023



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PUBLIC

WHY DO WE WANT TO PROTECT DILITHIUM?

NIST chooses **Dilithium** as primary digital signature algorithm.

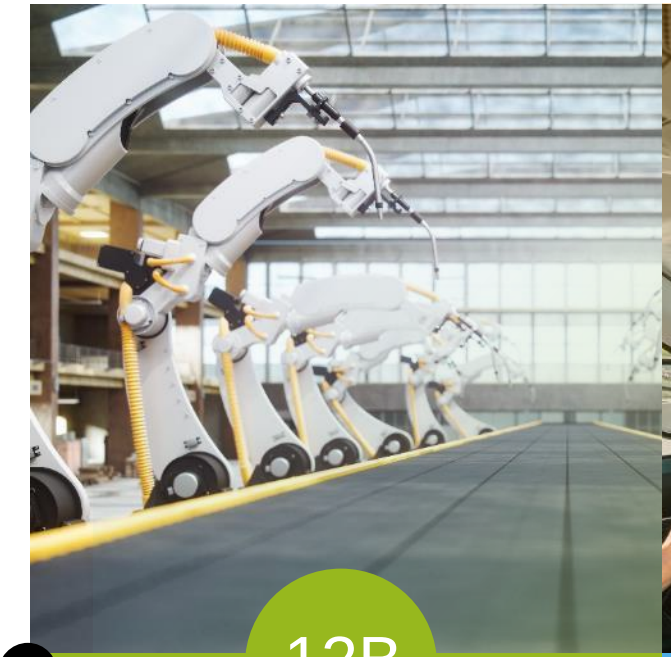
Transition

2022

2024

NIST publishes **standardization documents**.

INDUSTRIAL & IOT



12B

IoT Edge & end nodes from **6B units** in 2021 to **12B units** in **2025**

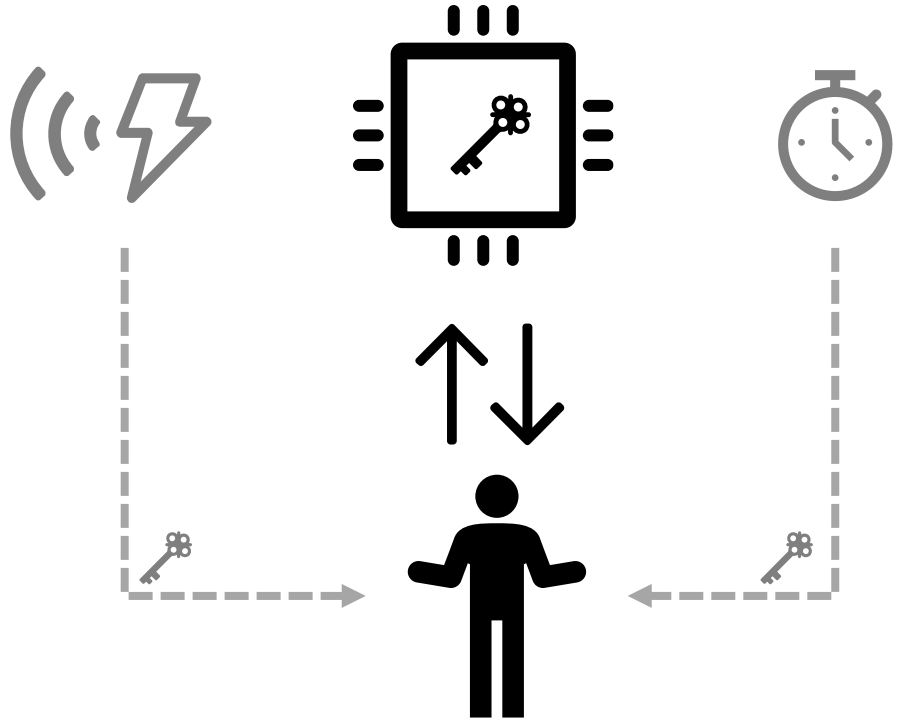
AUTOMOTIVE

70%

70% connected cars by 2025

WHY DO WE WANT TO PROTECT DILITHIUM?

Embedded devices are vulnerable to **physical attacks.**



Protection could require **significant effort**.

Potential to **delay** deployment of **secure PQC**.

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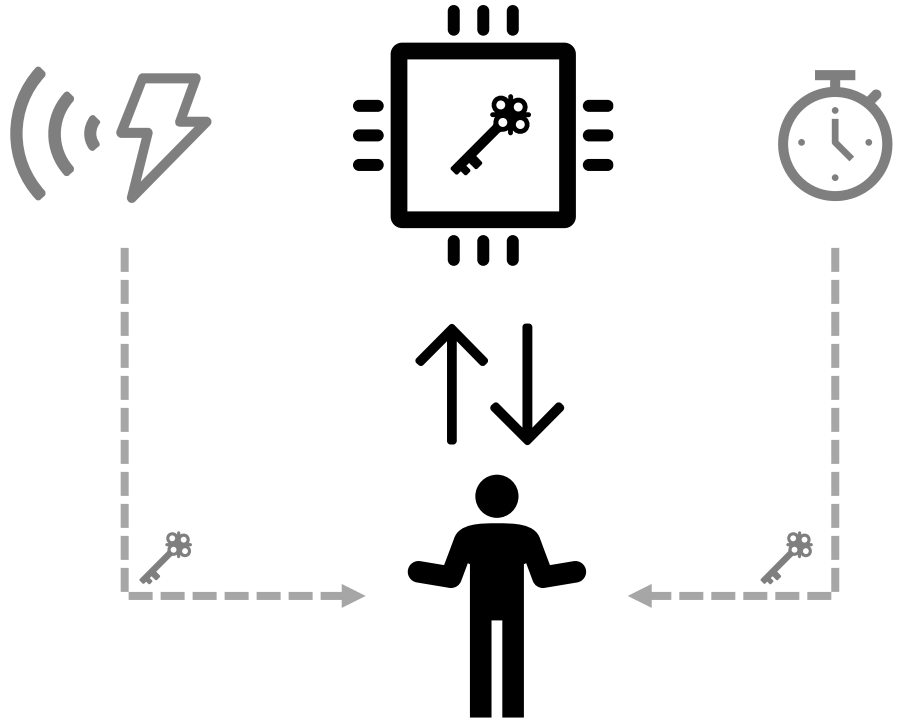

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Found to be extremely vulnerable.

RWC 2022: FO-CALYPSE

RWC 2023: Breaking 5th order masking

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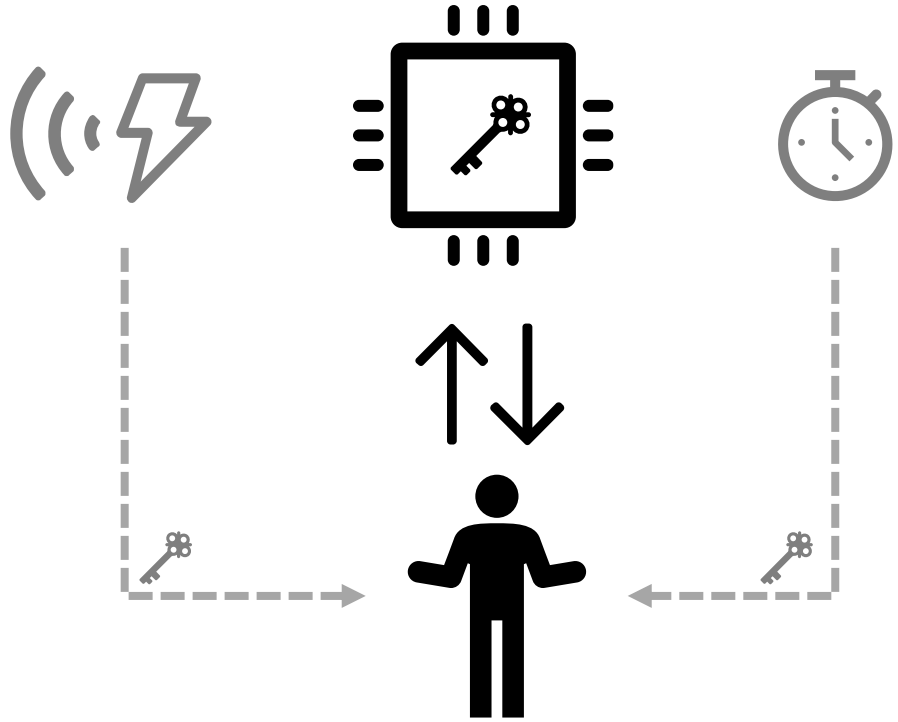

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RWC 2022: FO-CALYPSE

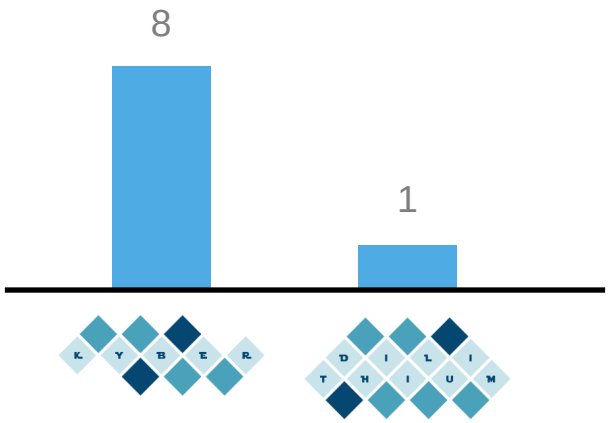
RWC 2023: Breaking 5th order masking

Less investigated**.**

RWC 2023: Lessons learned

DO WE KNOW HOW TO PROTECT DILITHIUM?

Masking Publications until October'22



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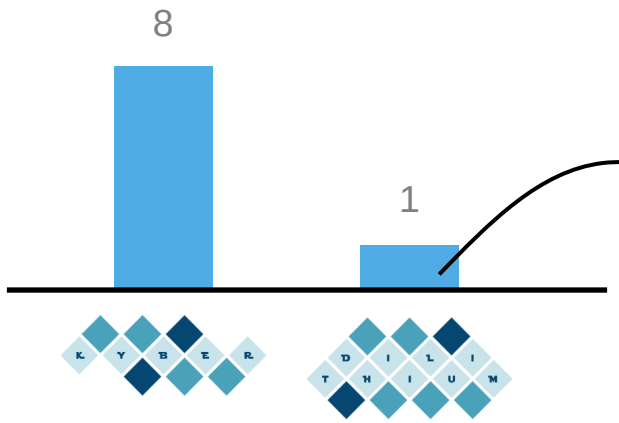

Prior Work [MGTF19]

Masking Dilithium: Efficient Implementation and Side-Channel Evaluation

Vincent Migliore[1], Benoit Gérard[23], Mehdi Tibouchi[4] and Pierre-Alain Fouque[2]

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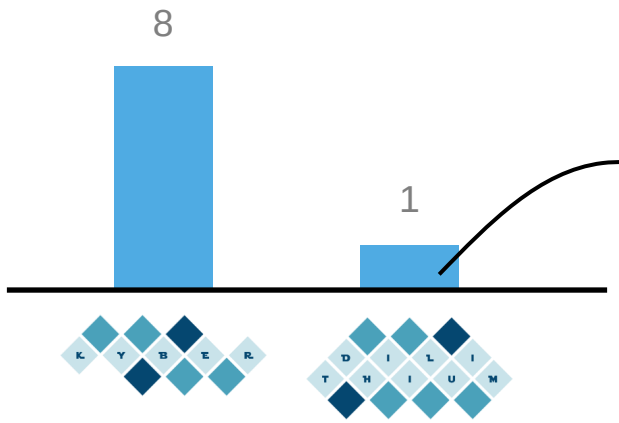

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ePrint 2022/1406

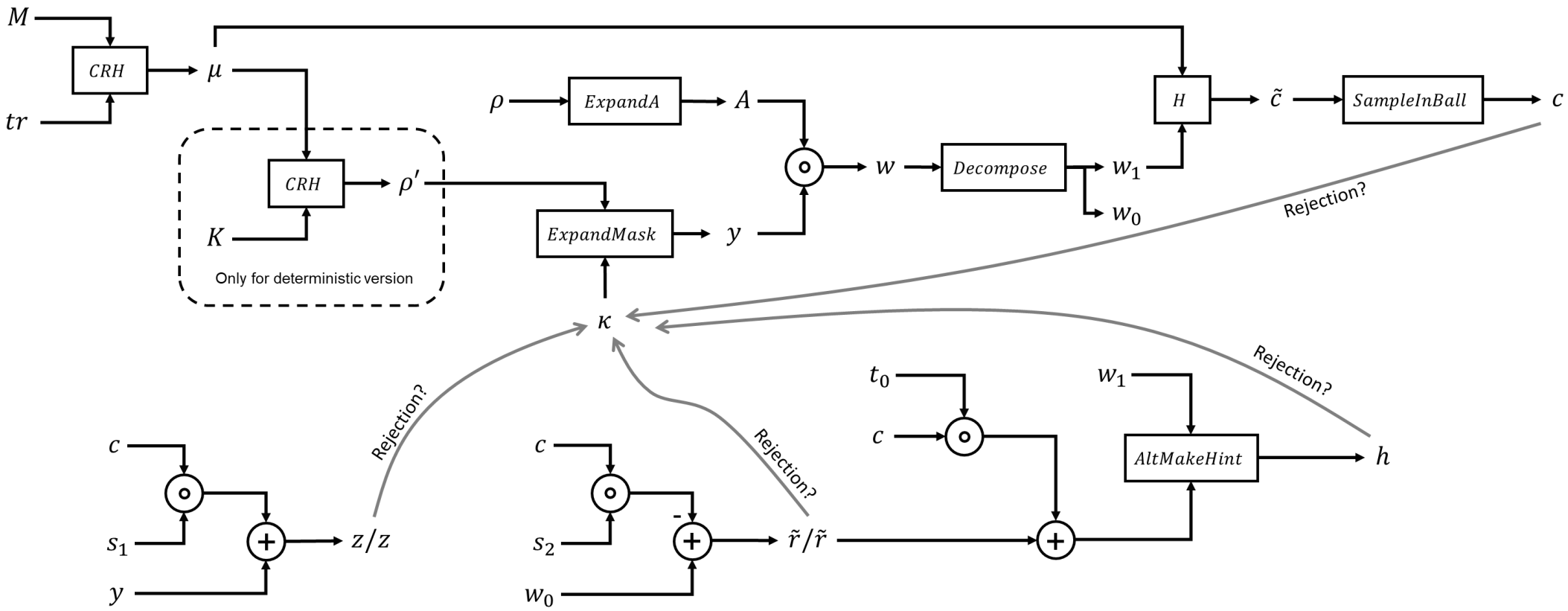
Leveling Dilithium against Leakage

Revisited Sensitivity Analysis and Improved Implementations

Melissa Azouaoui[1], Olivier Bronchain[1,2], Gaëtan Cassiers[2,3,4], Clément Hoffmann[2], Yulia Kuzovkova[1], Joost Renes[1], Tobias Schneider[1], Markus Schönauer[1], François-Xavier Standaert[2] and Christine van Vredendaal[1]

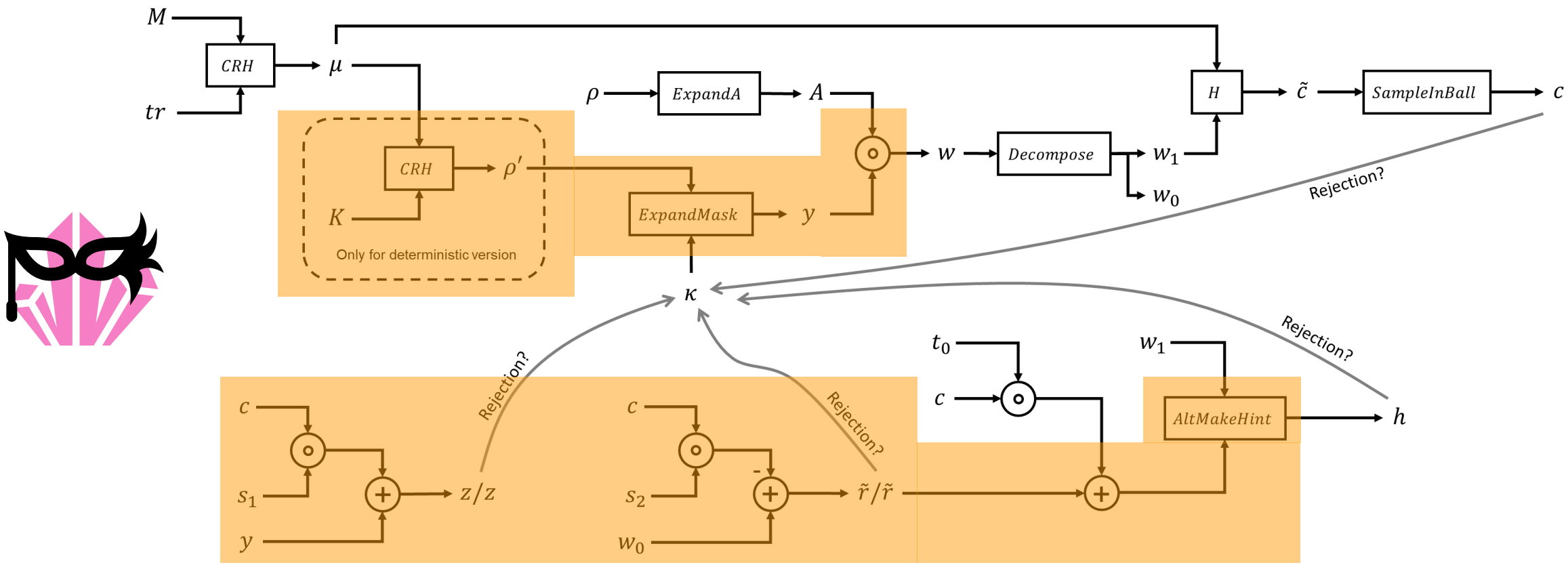
What needs to be protected?
How should it be protected?
What are the bottlenecks?
How can it be fixed?

WHAT NEEDS TO BE PROTECTED?



Signature Generation

PRIOR WORK [MGTF19]

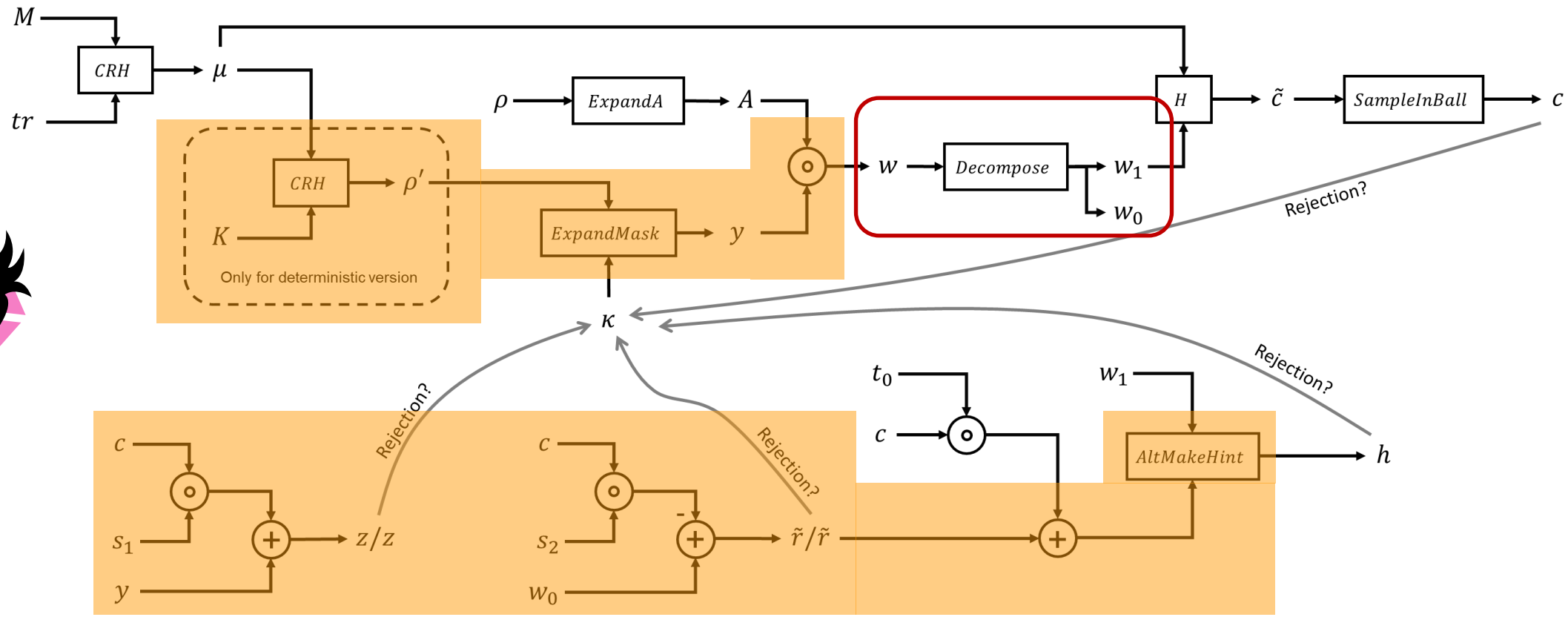


Signature Generation

PRIOR WORK [MGTF19]

Protecting **w**

$\mathbf{w} = \mathbf{A} \cdot \mathbf{y} \Rightarrow \mathbf{y}$ can be computed from **w**



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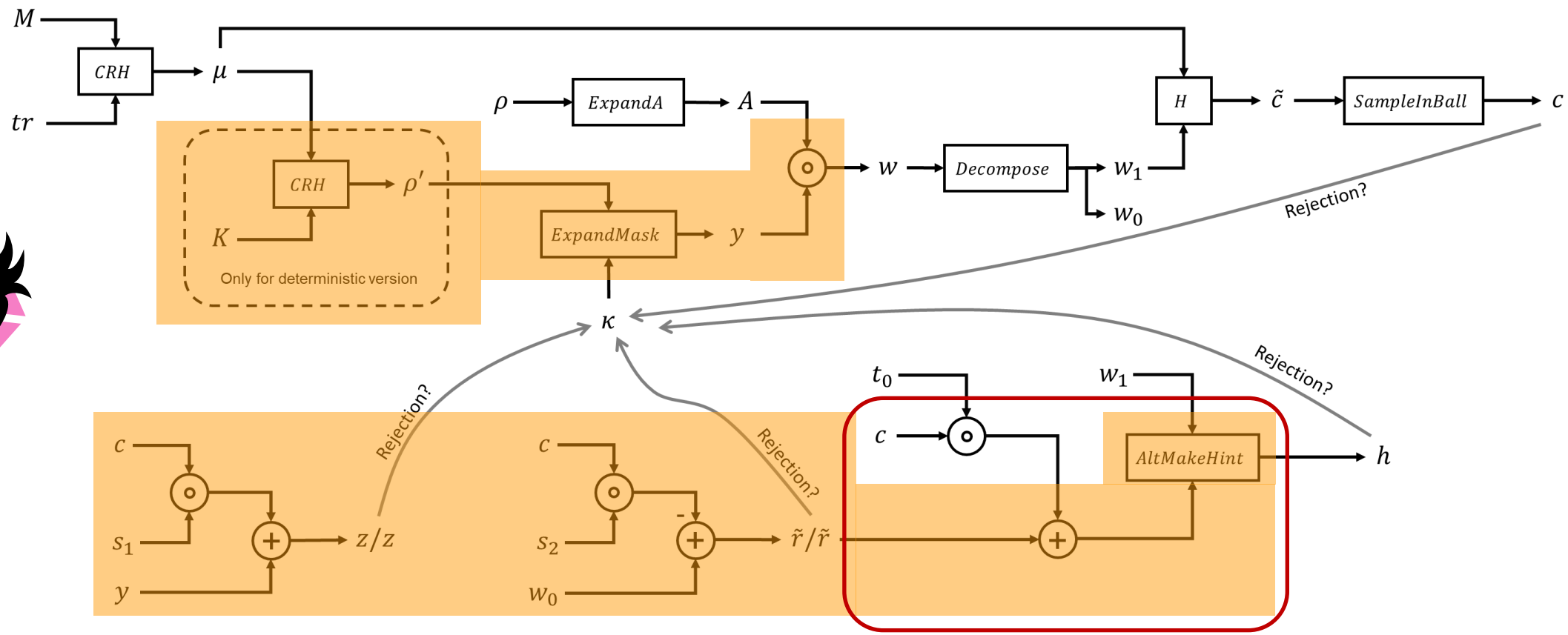


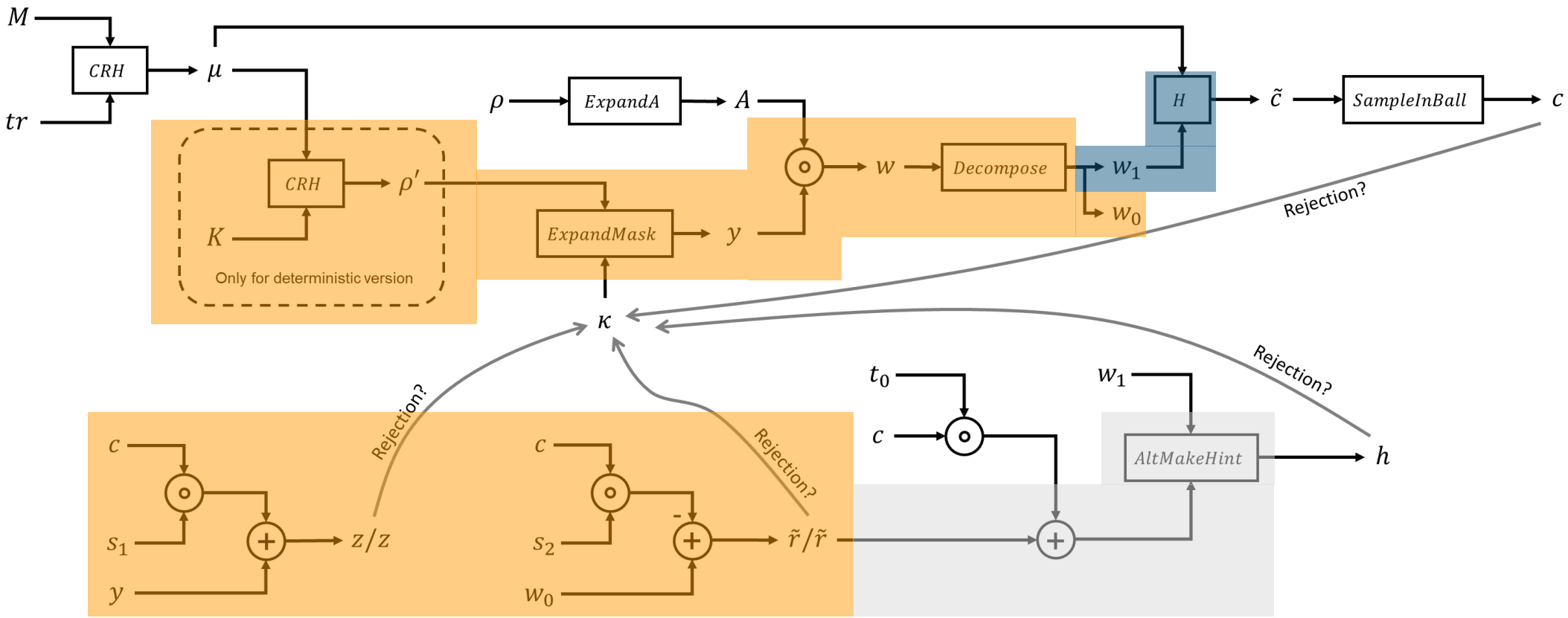
Signature Generation

Unmasking $\tilde{\mathbf{r}}$

$\mathbf{Az} - \mathbf{ct} = \alpha.\mathbf{w_1} + \tilde{\mathbf{r}} \Rightarrow \tilde{\mathbf{r}}$

can be computed from public values only

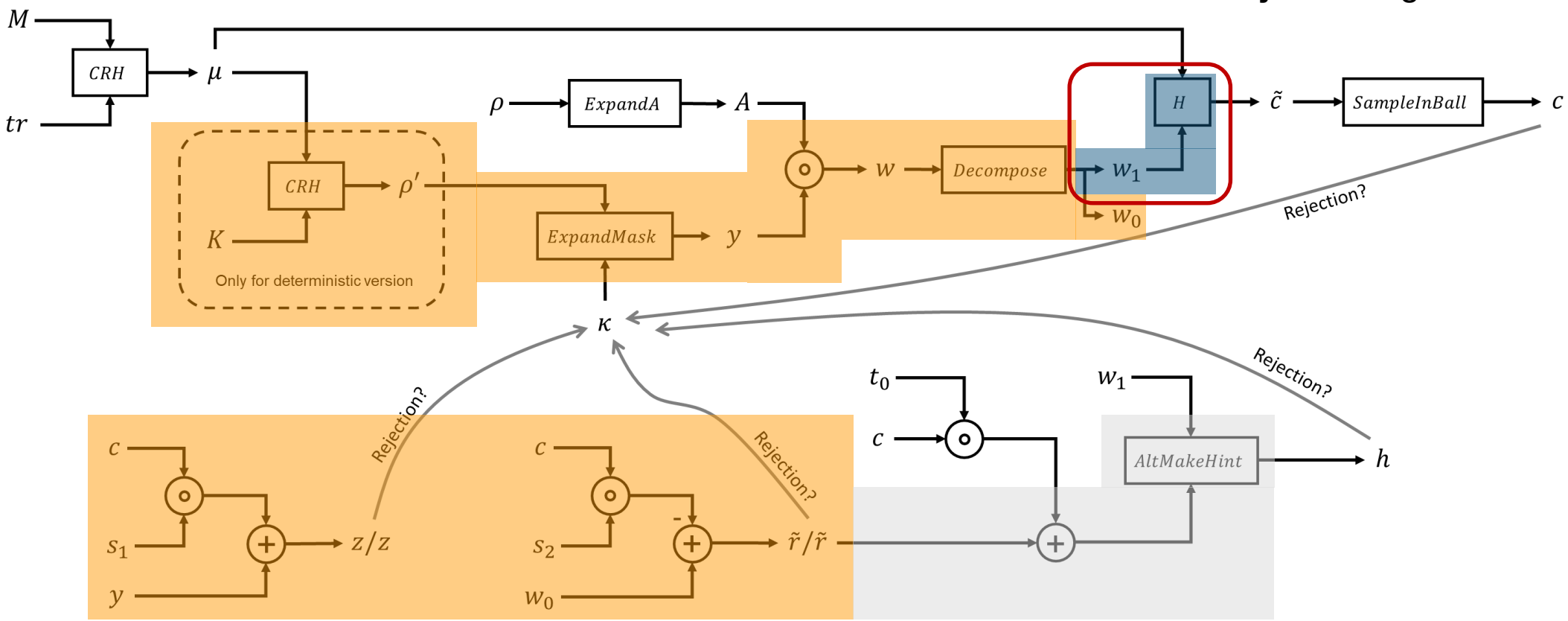
UPDATED SENSITIVITY ANALYSIS



Signature Generation

UPDATED SENSITIVITY ANALYSIS

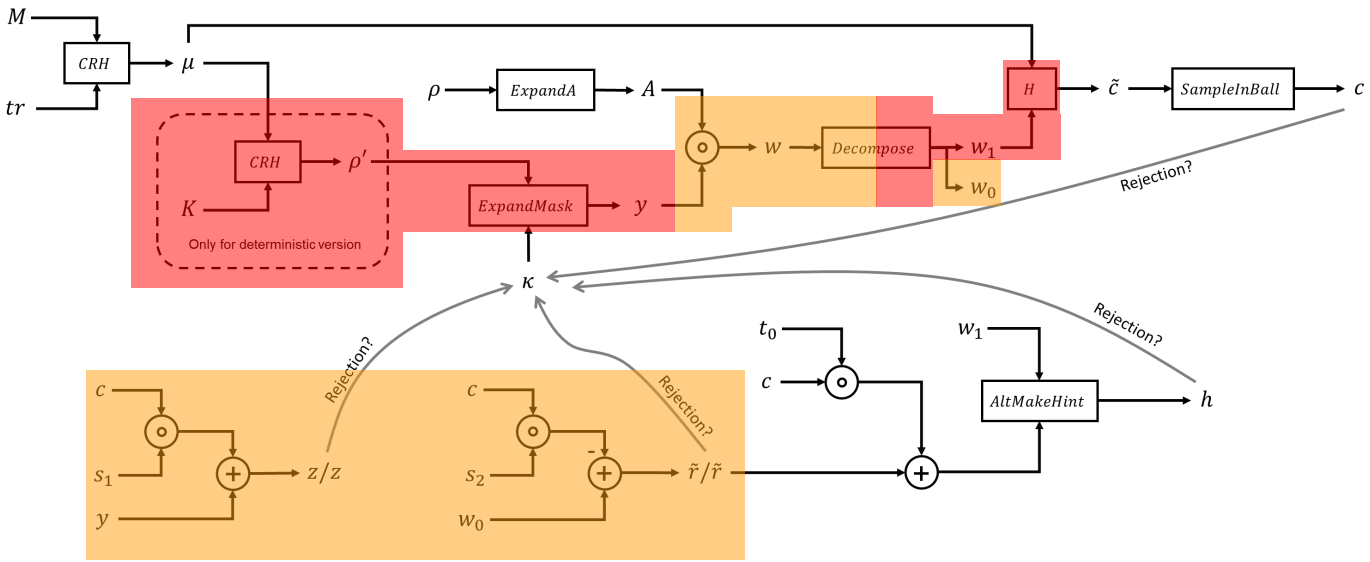
Protecting $\mathbf{w_1}$
Public for **valid** signatures,
unclear for **rejected** signatures



Signature Generation

HOW SHOULD IT BE PROTECTED?

Standard Approach: Masking

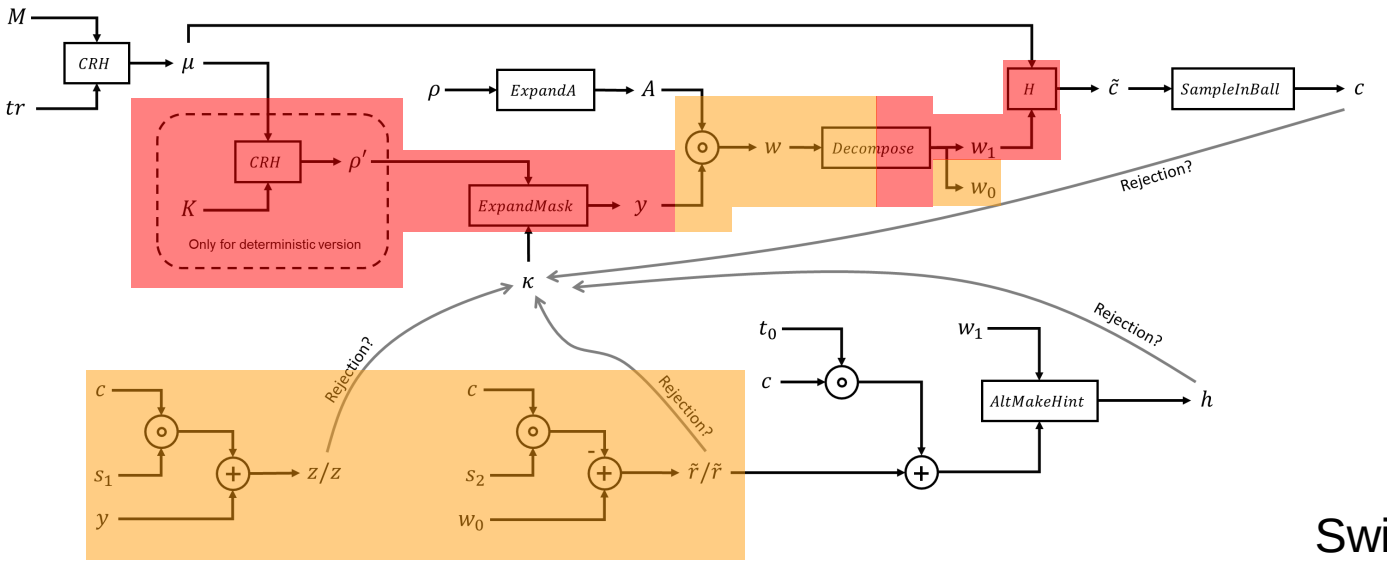


Signature Generation

Observation 1:
Requires a mixture of **Boolean** and **arithmetic** masking with a **prime modulus**

HOW SHOULD IT BE PROTECTED?

Standard Approach: Masking



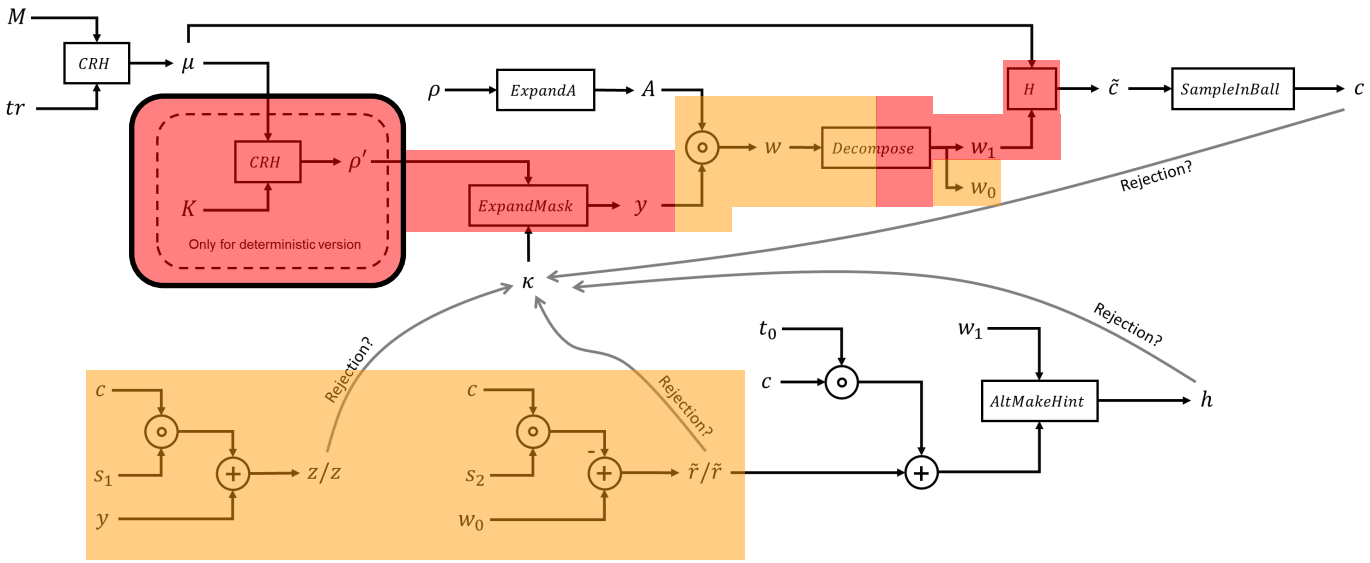
Signature Generation

Observation 1:
Requires a mixture of **Boolean** and **arithmetic** masking with a **prime modulus**

Proposal from [MGTF19]:
Switch from prime to **power-of-two modulus** results in **7x – 9x speed-up**

HOW SHOULD IT BE PROTECTED?

Standard Approach: Masking



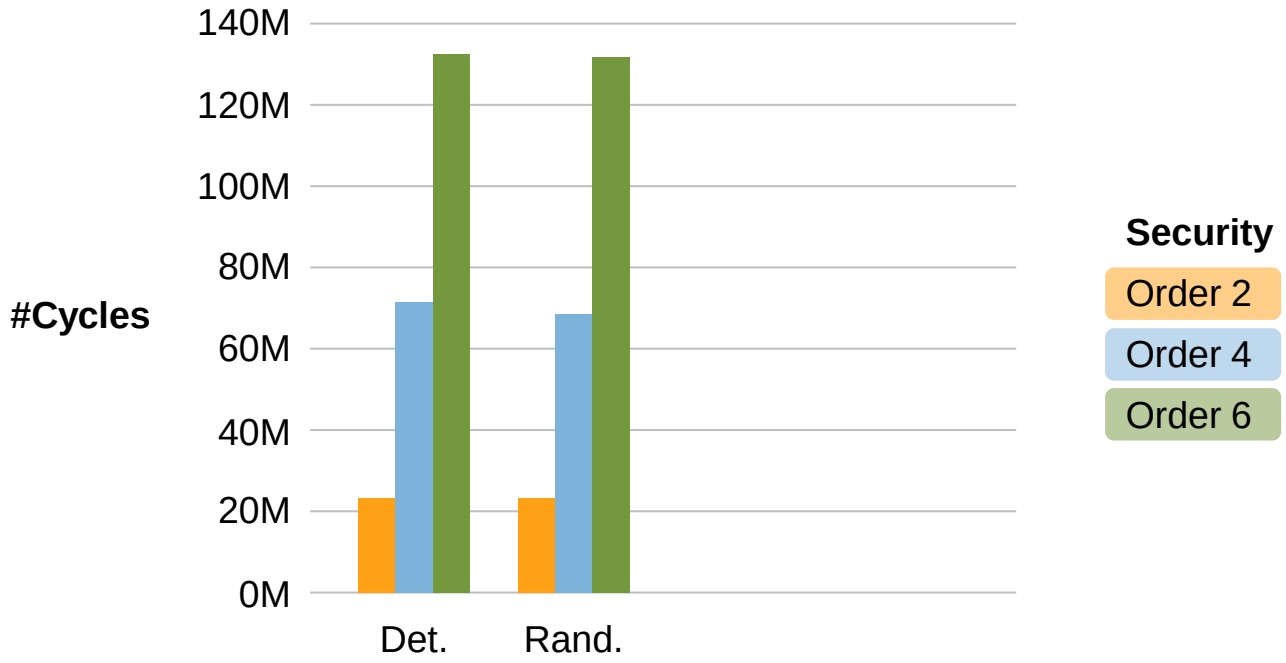
Signature Generation

Observation 2:
Deterministic is much more vulnerable than **randomized** Dilithium.

- Additional long-term secret K
- Measurements can be repeated with same inputs to reduce noise.
- More vulnerable to fault attacks as well.

WHAT ARE THE BOTTLENECKS?

Benchmark Masked Dilithium-3 (M4):



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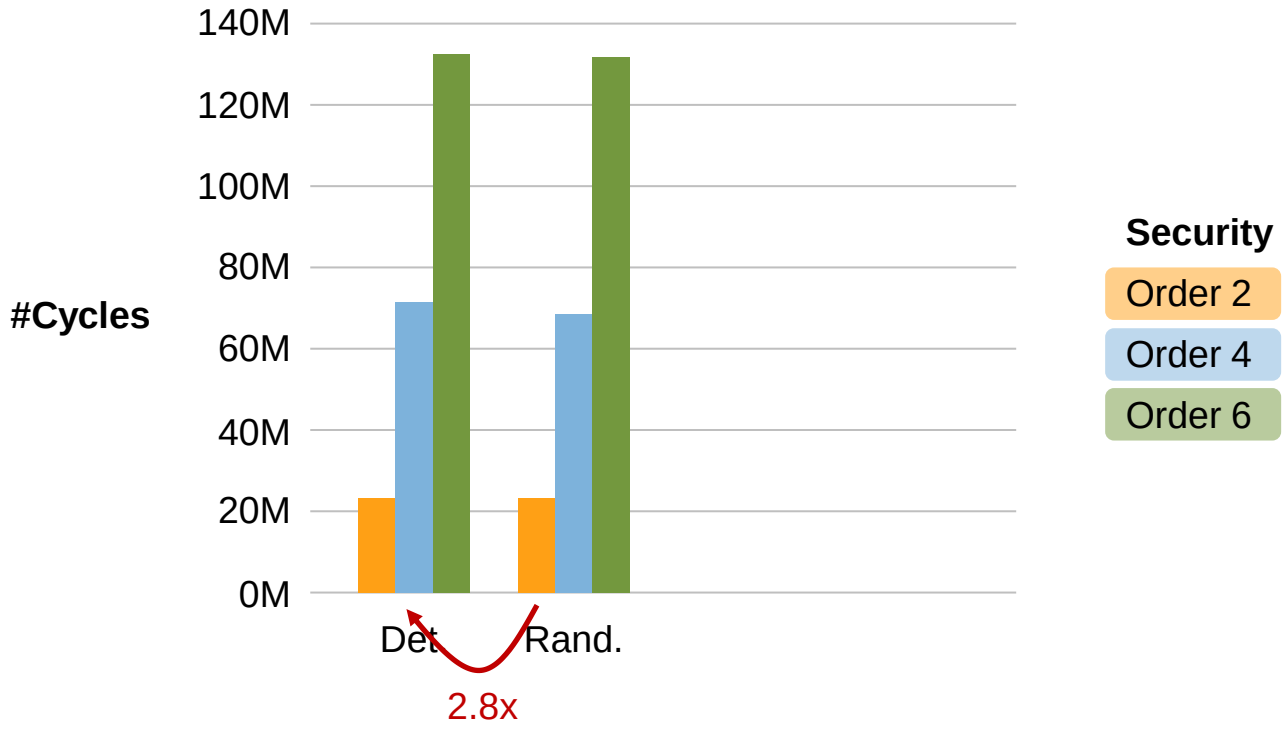
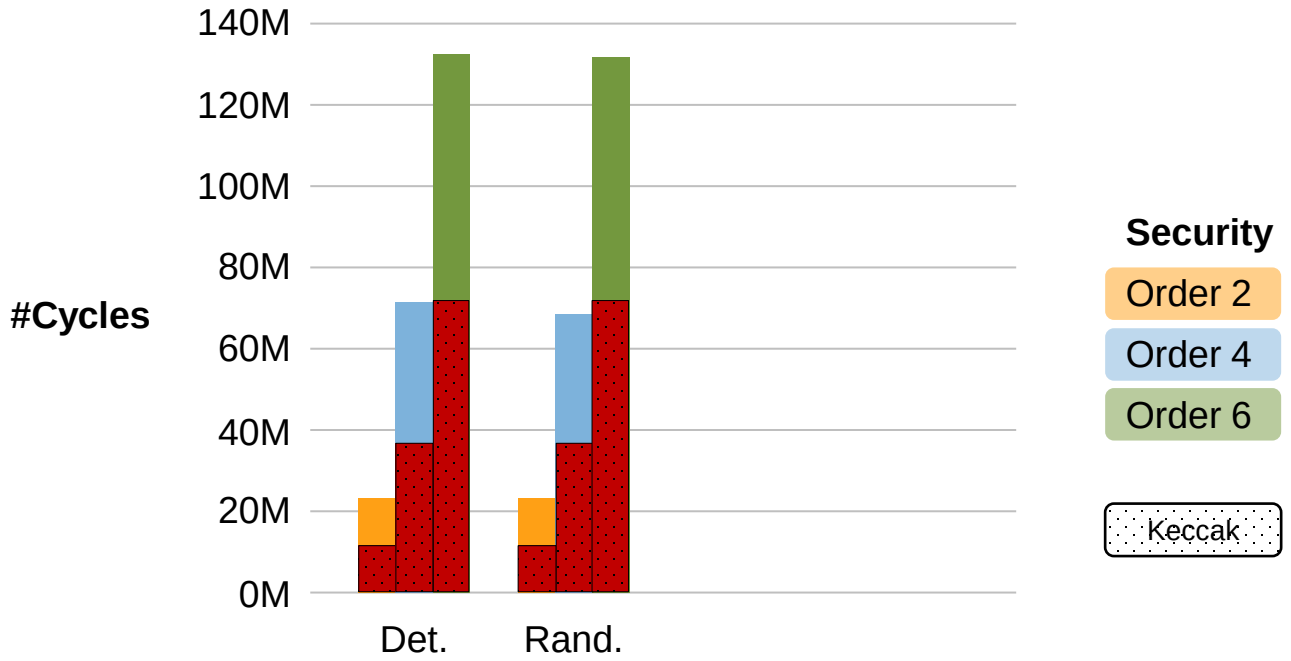


Observation 1:
Deterministic has comparable performance to randomized for **same** security order.
Deterministic requires increased order.
Note: Impacts memory requirements as well.

WHAT ARE THE BOTTLENECKS?

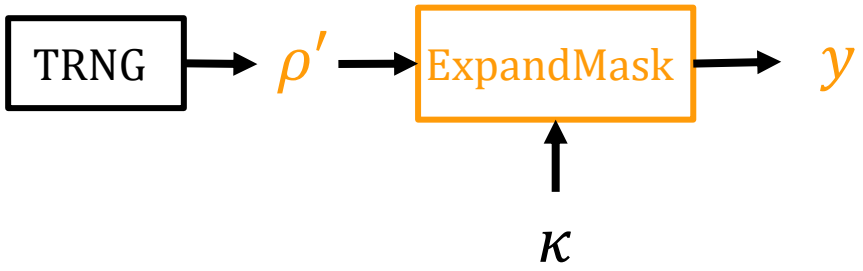
Benchmark Masked Dilithium-3 (M4):



Observation 2:
Protected Keccak for sampling y takes up **50%** of runtime.

HOW COULD IT BE FIXED?

Randomized:



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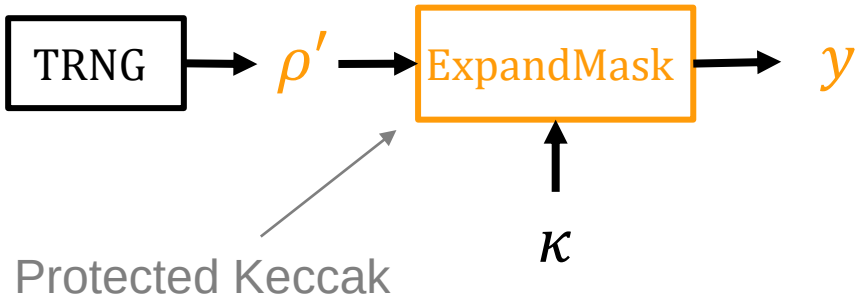

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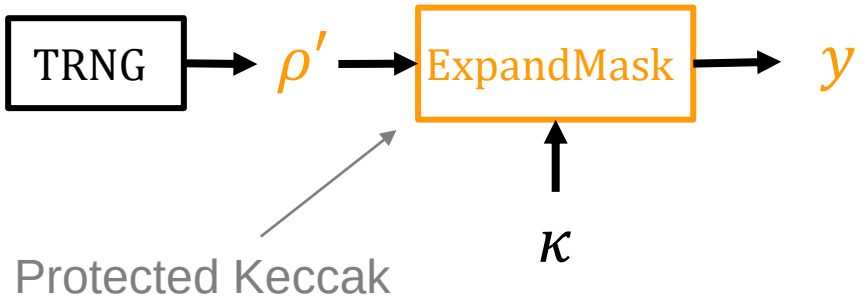
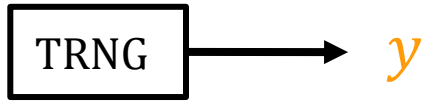


Flexible-Sampling:

- Does not specify how y is sampled
- Option: Generate shares of y via TRNG



Note: Requires proper TRNG or post-processing

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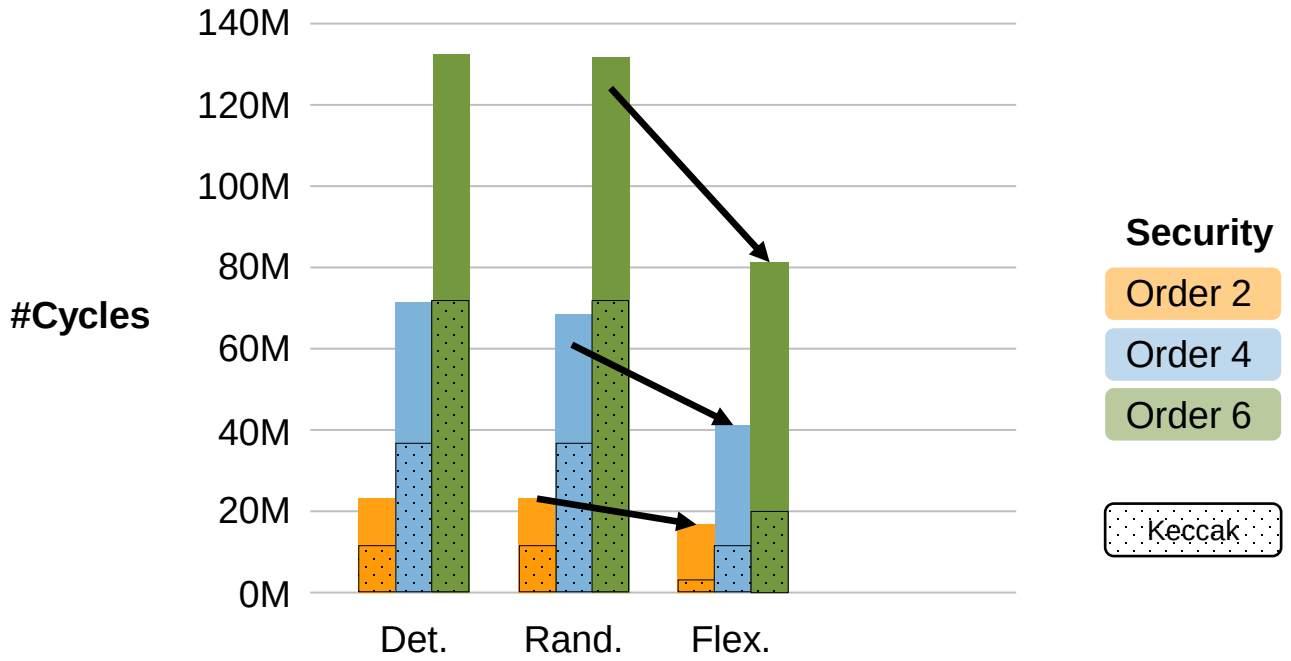
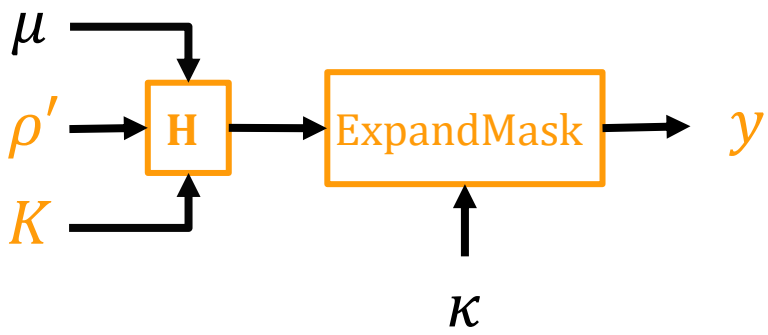


Observation 3:
Flexible-Sampling provides significant speed-up over **randomized**.

WHAT WILL BE DONE?

Hedged:



Combined deterministic and randomized Dilithium into one

$\rho' = random\ string$ if randomized Dilithium

$\rho' =$ "" if deterministic Dilithium

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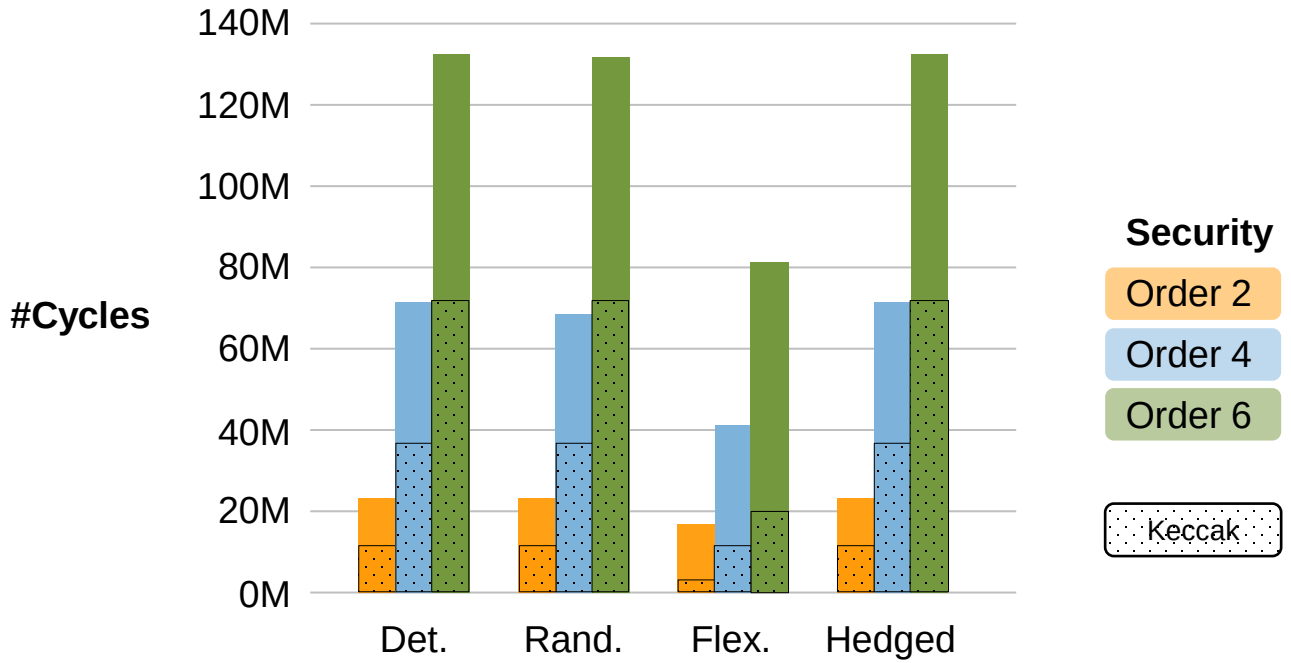
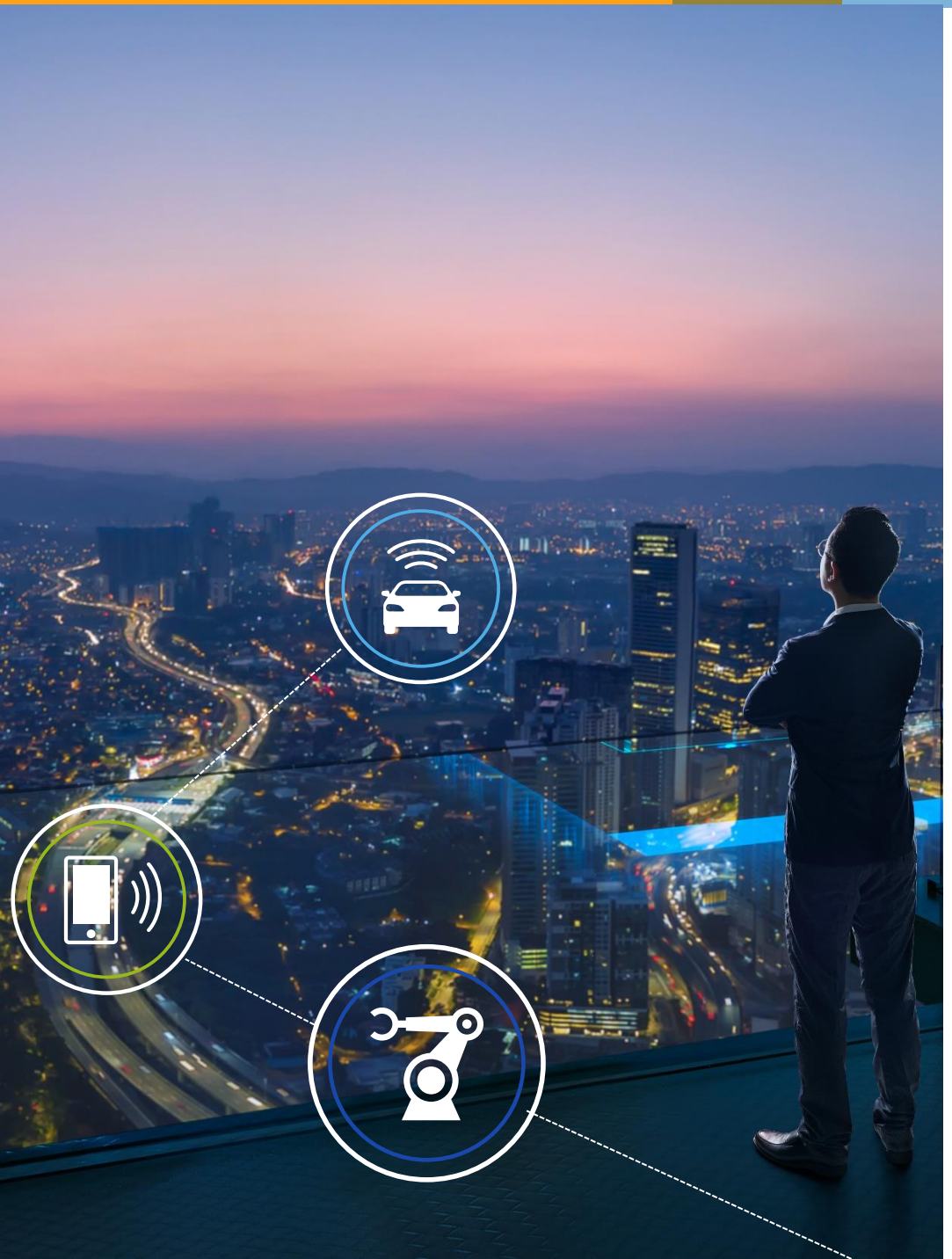
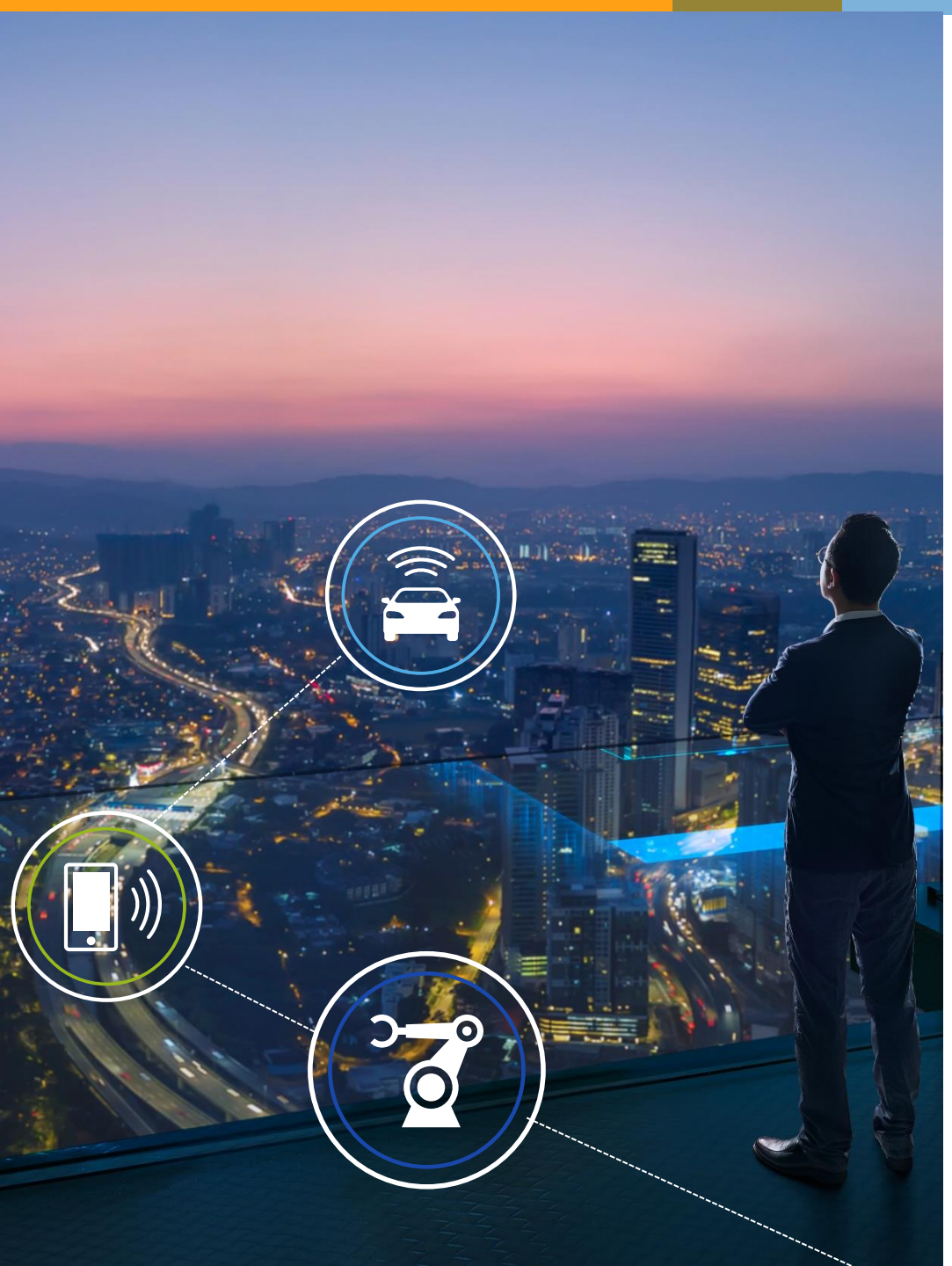


Observation 4:
Hedged (Randomized) provides comparable performance as **randomized.**



LESSONS LEARNED



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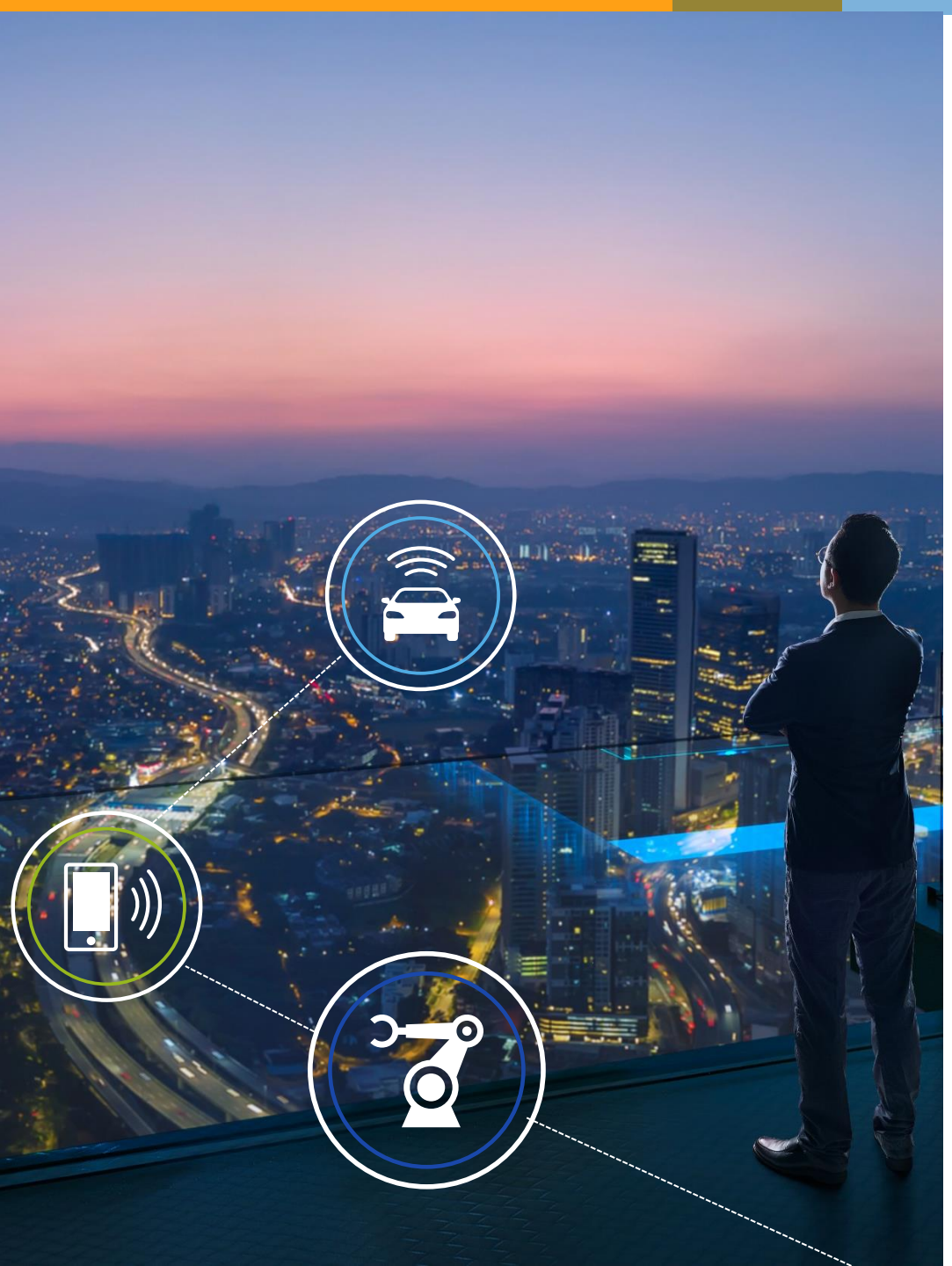
Hedged has negligible impact on runtime.



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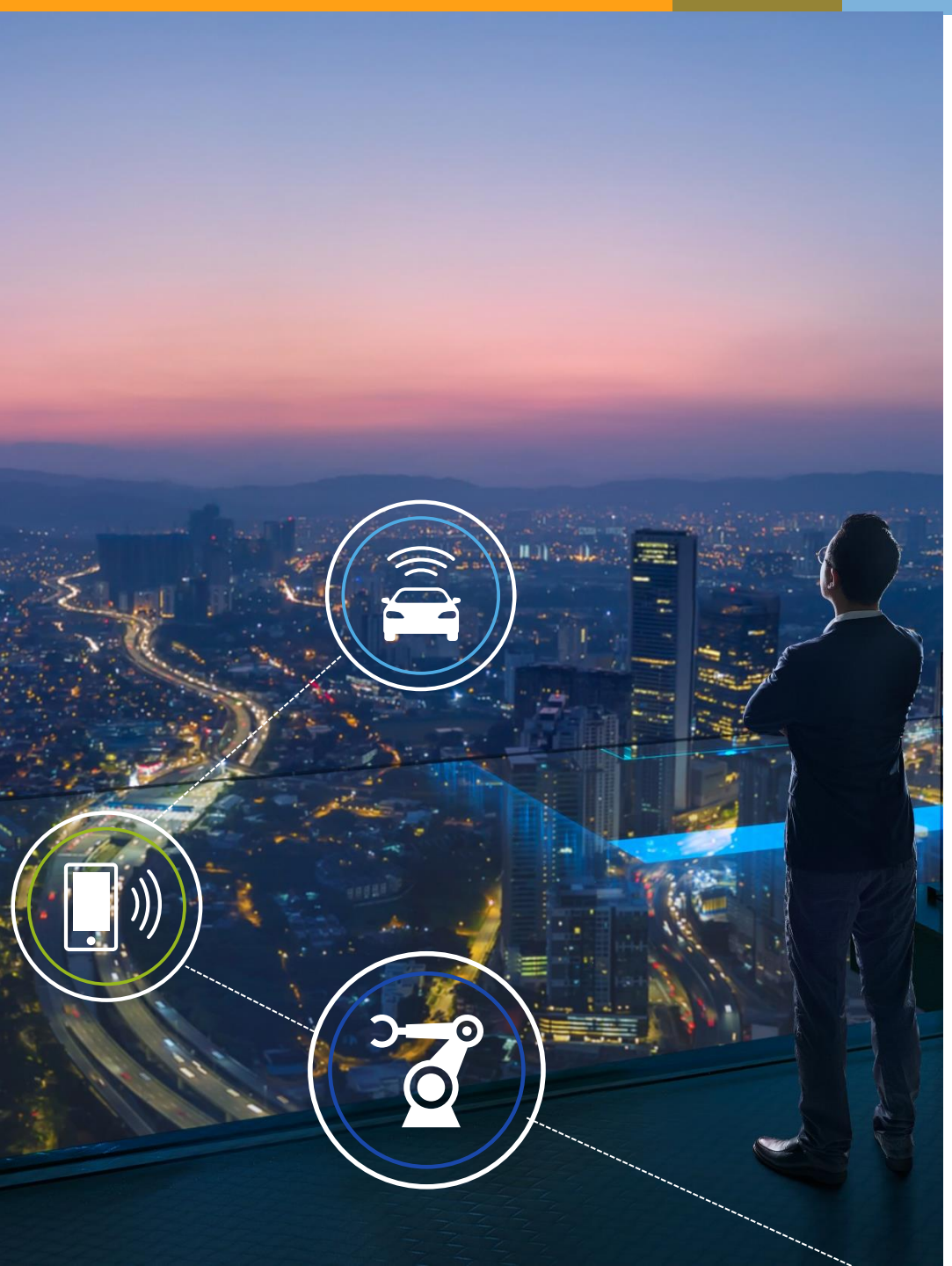

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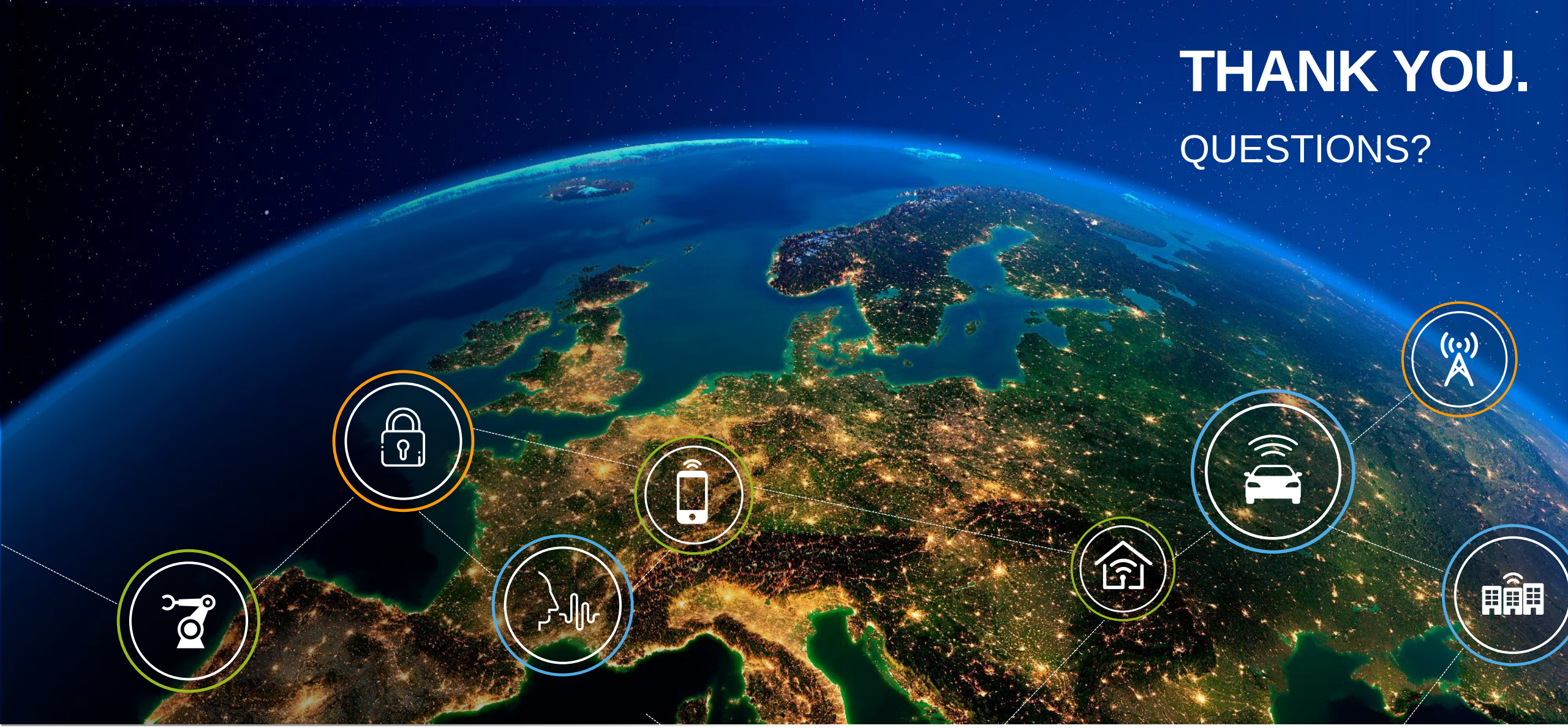
Hardening Dilithium still not mature.

Much less studied than Kyber.

THANK YOU.

QUESTIONS?



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