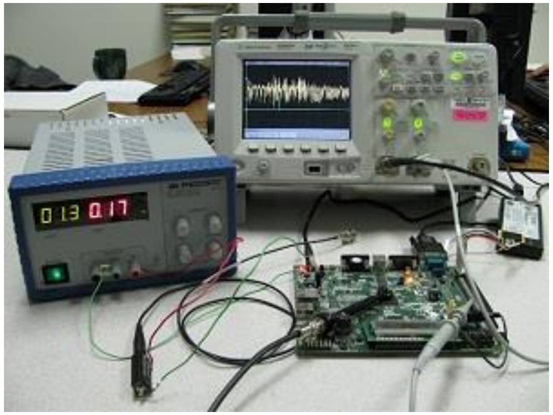
Analysing the Leakage-Resistance of the NIST's Lightweight Crypto Standardization Process Finalists



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NIST Lightweight Crypto Workshop 2022, Virtual

Outline

- Introduction/methodology
- Mode-level analysis of all finalists
- Interest of levelled implementations
- Hardware design space exploration
  - For Ascon, ISAP and Romulus-T only
- Conclusions (take home messages)

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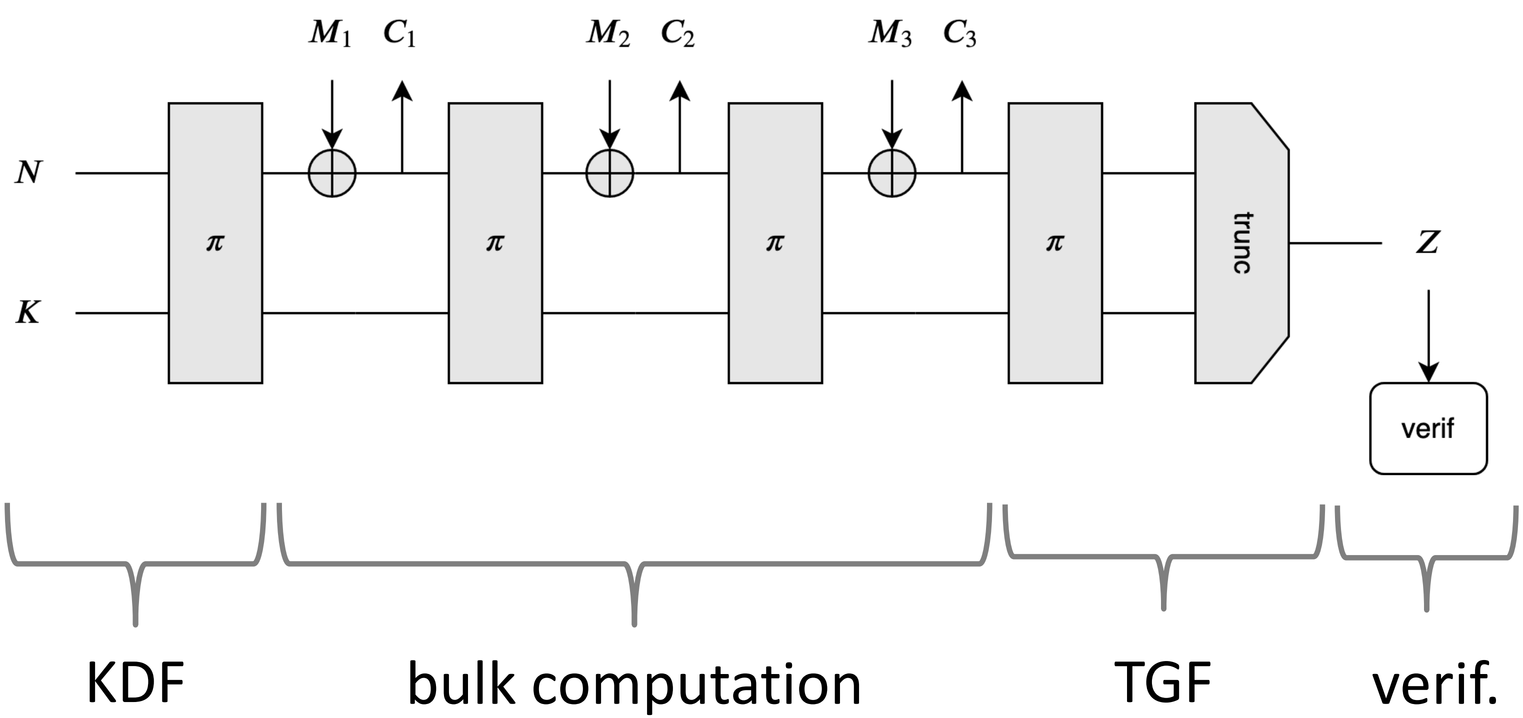
Security targets

- Confidentiality: security against CPA or CCA
- Plaintext Integrity (PI), Ciphertext Integrity (CI)
  - Composite definitions useful: confidentiality & integrity often call for $\neq$ physical assumptions
- Leakage in encryption only (1) or enc./dec. (2)
- Nonce misuse-resistance (M) or resilience (m)
- Leakage-resistance (L) or resilience (l)

$\Rightarrow$ Choice of security target depends on application

Mode analysis (I)

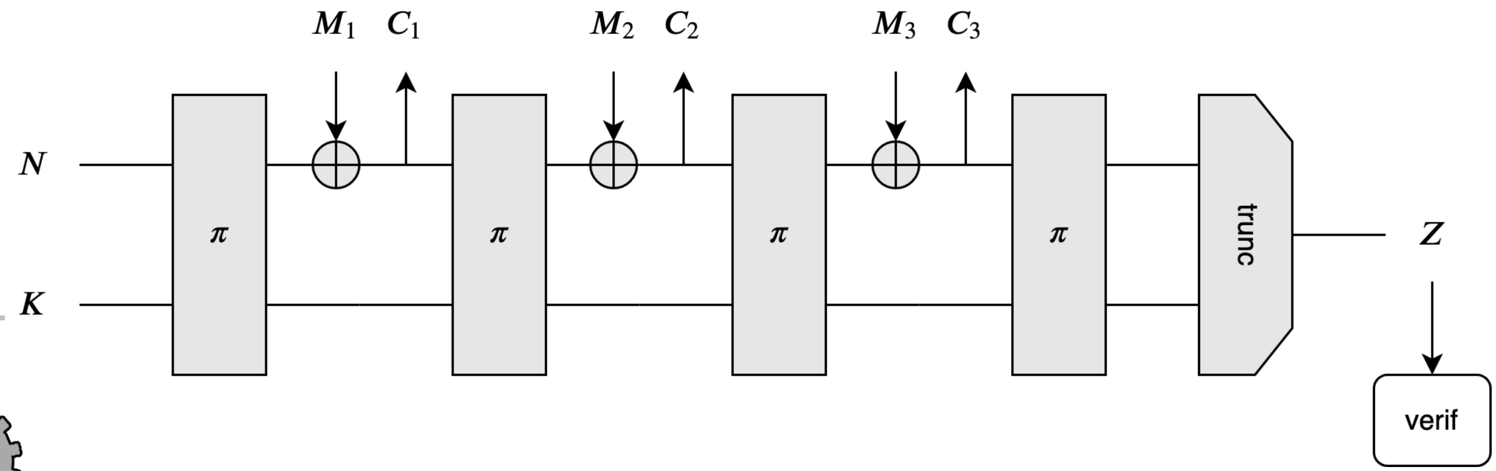
- Identify main steps, e.g., inner keyed sponge

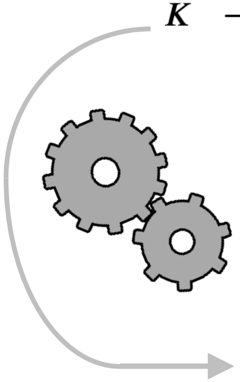


- (Some steps empty for some modes, ignoring AD)

Mode analysis (II)

- Reduce the mode to (weak) assumptions (tightly)





only computation leaks

leak-free components   bounded leakage

strong unpredictability with leakage

simulatable leakages   hard-to-invert leakages

oracle-free leakages   [...]

Practical evaluation (I)

- Translate assumptions into necessary design goals

	KDF/TGF	bulk comp.	tag verif.
conf.	DPA (key recovery)	DPA (key recovery) SPA (key recovery) *1-block conf.*	∅
int.	DPA (key recovery)	DPA (key recovery) SPA (key recovery) unbounded leakages	DPA (tag recovery) unbounded leakages

- Set the target security level (2^m leakages, 2^t time)
- *Evaluate implementation cost & performances*

Practical evaluation (II)

- Approximate performance overheads

	KDF/TGF	bulk comp.	tag verif.
conf.	x 5 – 10 – 100	x 5 – 10 – 100 x 1 – 5 *1-block conf.*	∅
int.	x 5 – 10 – 100	x 5 – 10 – 100 x 1 – 5 x 1	x 5 – 10 – 100 x 1

- DPA security: high-order masking, shuffling, …
- SPA security: parallel implementations, noise, …

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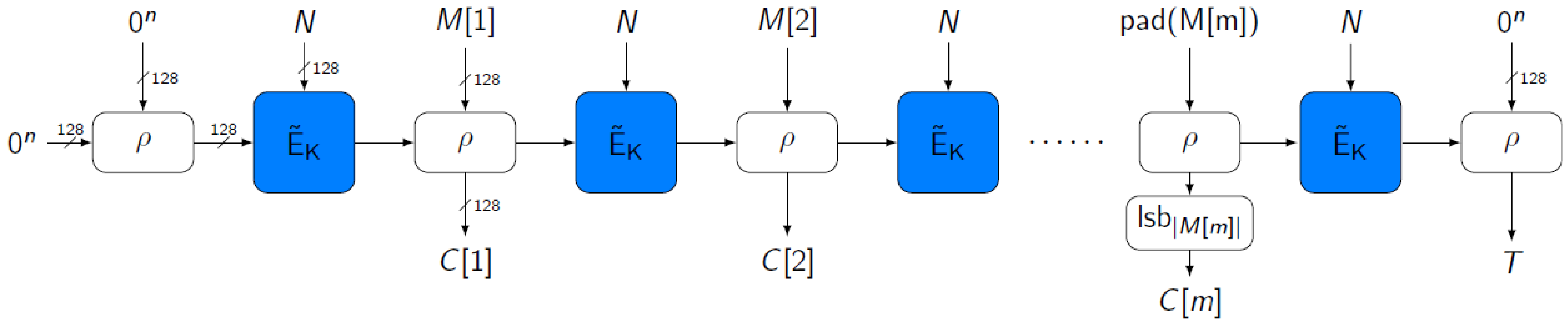
Level-0 (no mode-level resistance)

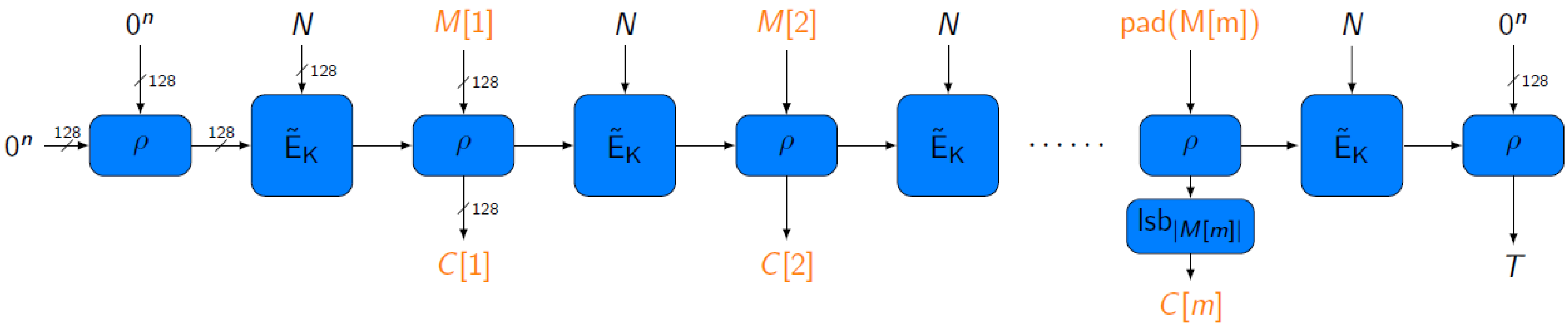
- Example: Romulus-N
  - Integrity: CIL1, CIML1, CIML2



- DPA resistance is needed everywhere, even for the weakest side-channel security target

Level-0 (no mode-level resistance)

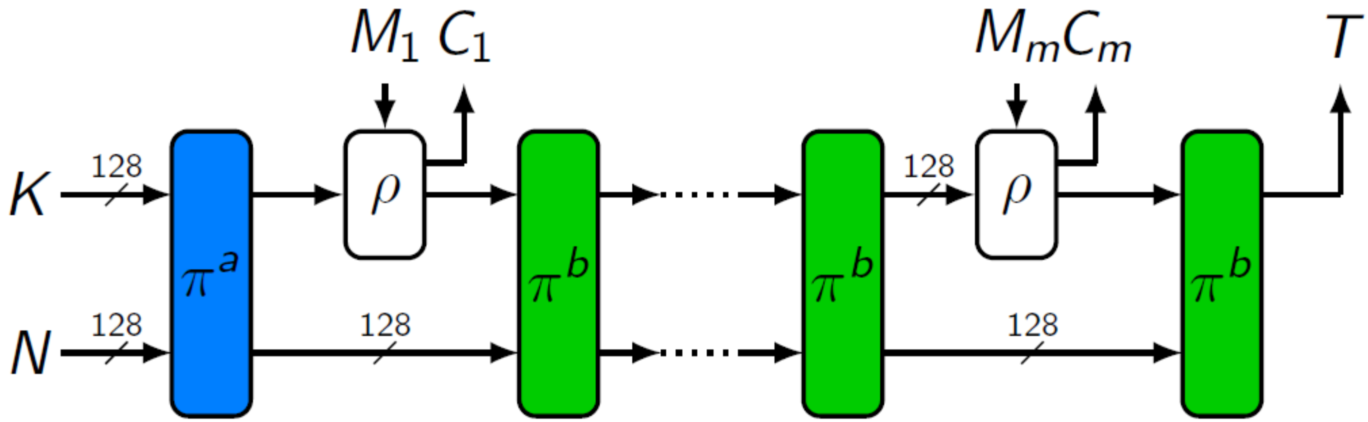
- Example: Romulus-N
  - Confidentiality: CCAL1, CCAmL1, CCAmL2



- DPA resistance is needed everywhere, even for the weakest side-channel security target

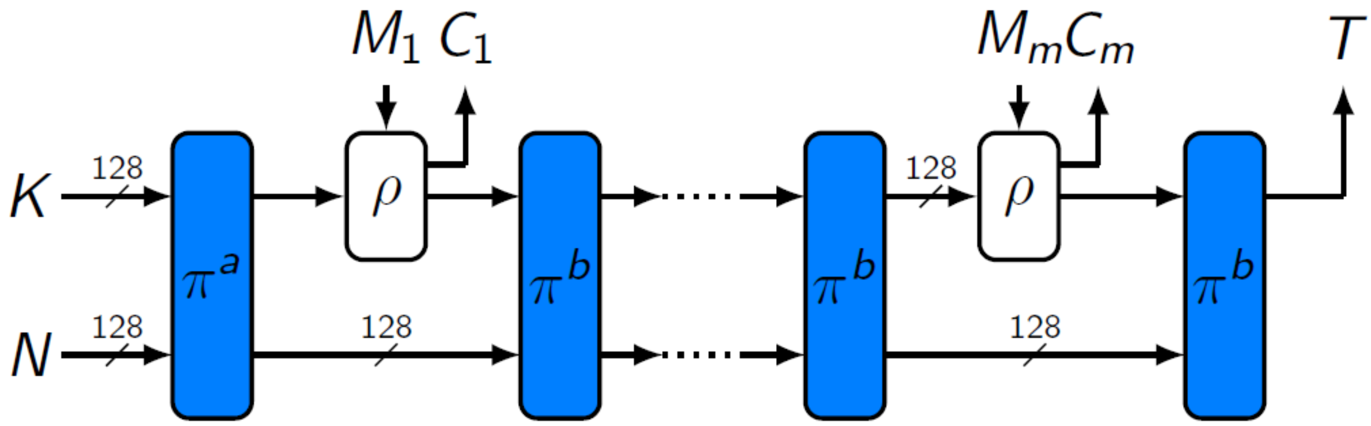
- Similar: Elephant, GIFT-COFB, Tiny-Jambu

- Example: PHOTON-Beetle
  - Integrity: CIL1



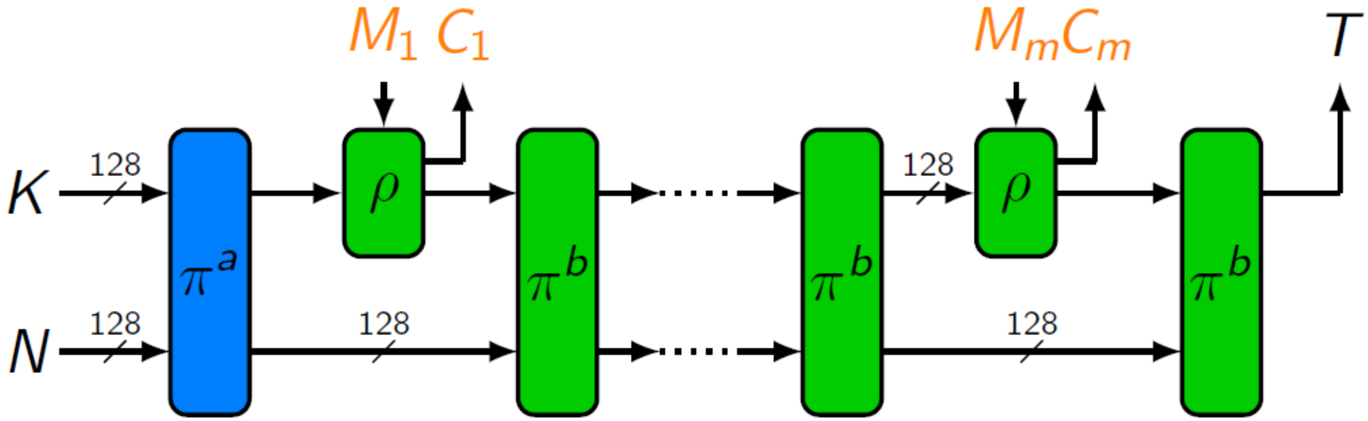
Level-1 (internal re-keying)

- Example: PHOTON-Beetle
  - Integrity: CIML1, CIML2



- DPA resistance is needed everywhere if misuse or leakage in decryption are exploitable

- Example: PHOTON-Beetle
  - Confidentiality: CCAL1



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- Example: PHOTON-Beetle
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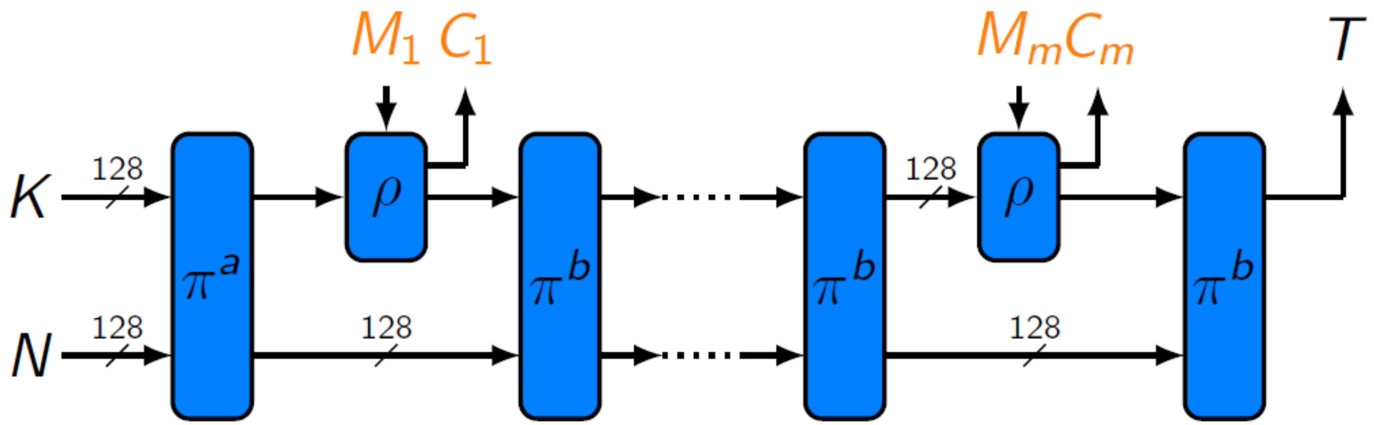
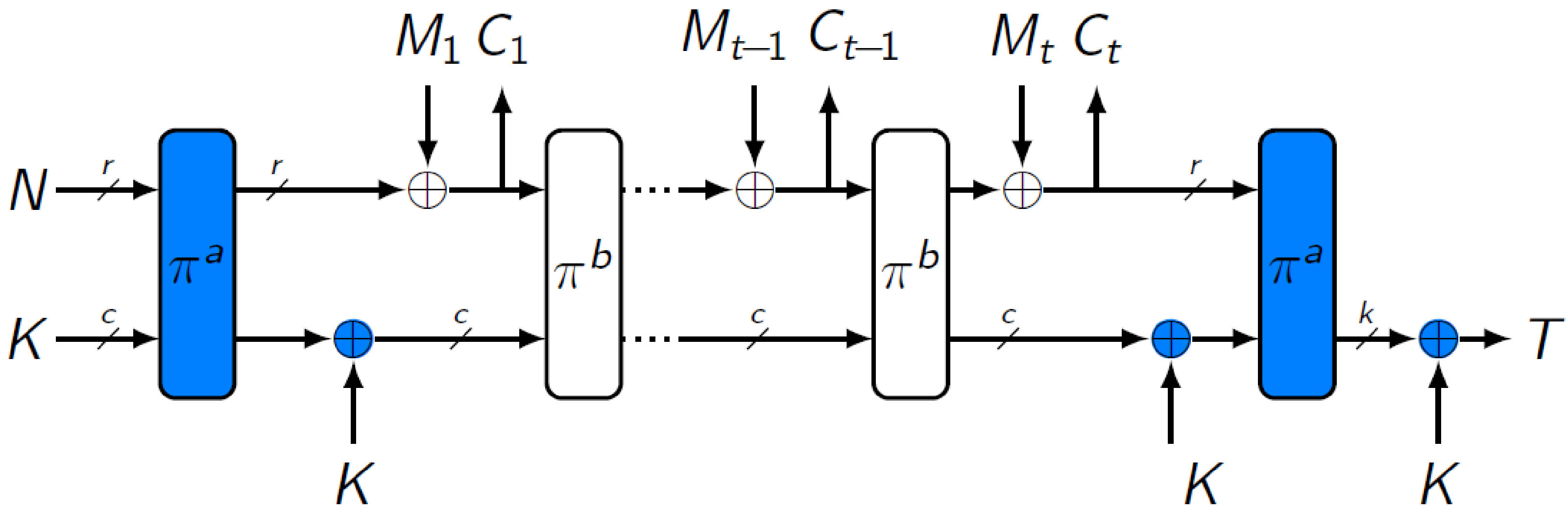


- DPA resistance is needed everywhere if misuse or leakage in decryption are exploitable

- Similar: Sparkle, Xoodyak

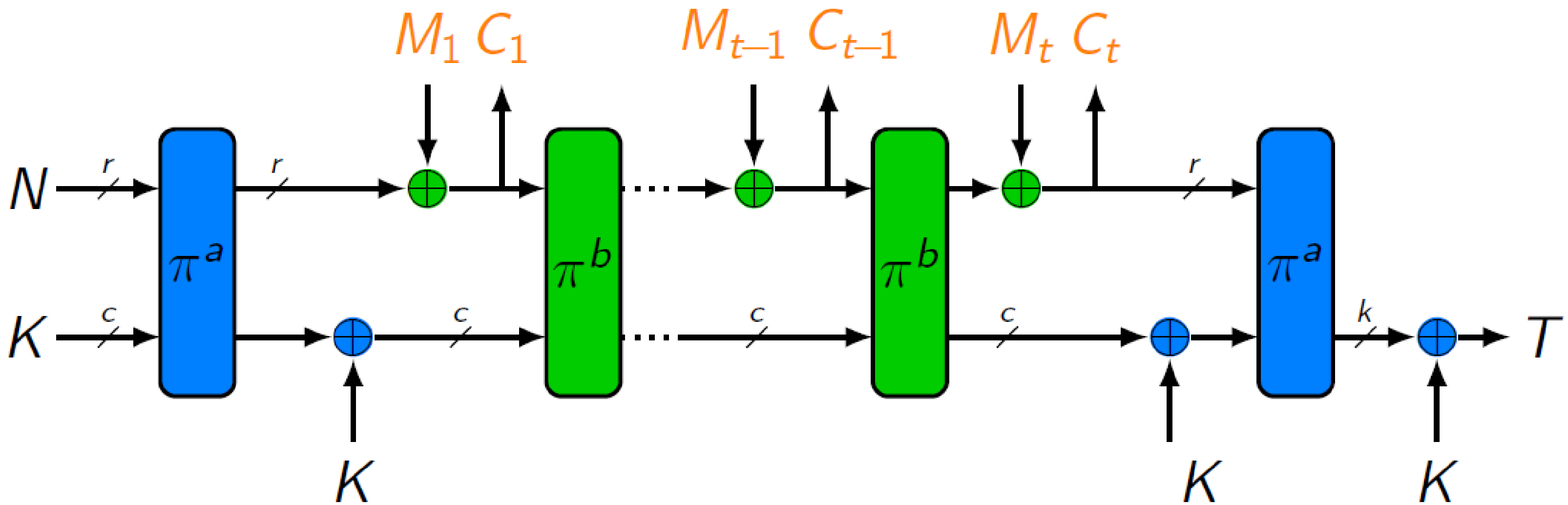
Level-2 (L1 + strengthened KDF/TGF)

- Example: Ascon
  - Integrity: CIL1, CIML2, CIML2



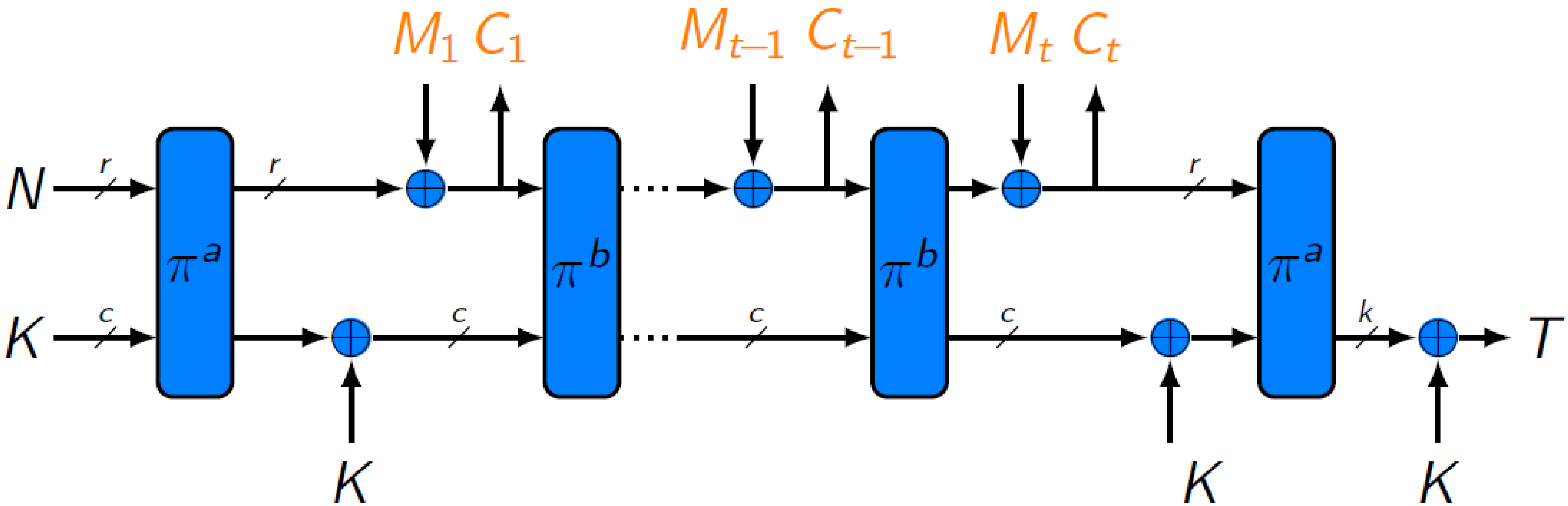
  - Top of the hierarchy (for mode-level protections)

- Example: Ascon
  - Confidentiality: CCAL1, CCAmL1



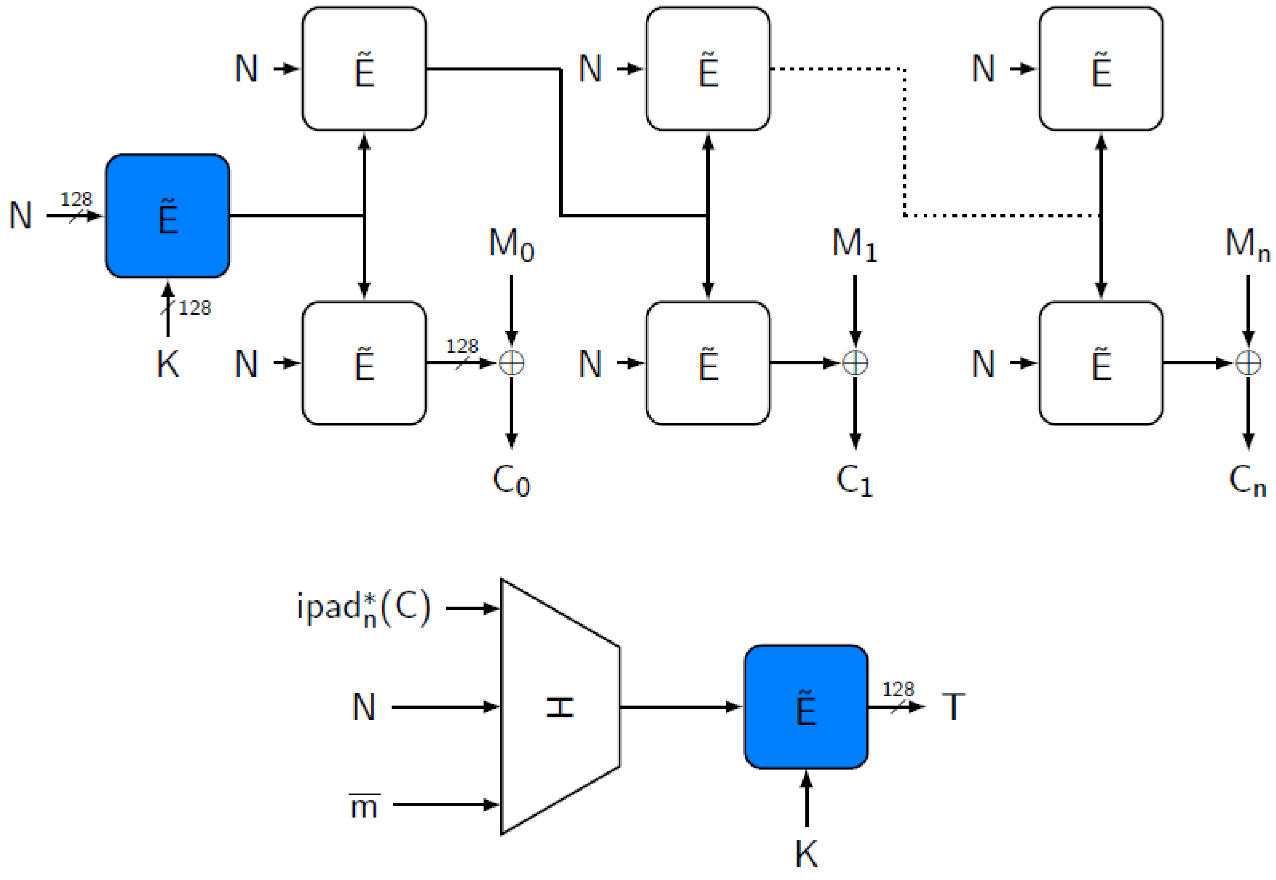
Level-2 (L1 + strengthened KDF/TGF)

- Example: Ascon
  - Confidentiality: CCAmL2



- Message decrypted before verification
  Recovering the ephemeral key with DPA allows an adversary to recover the message in full

- Example I: Romulus-T
  - Integrity: CIL1, CIML1, CIML2



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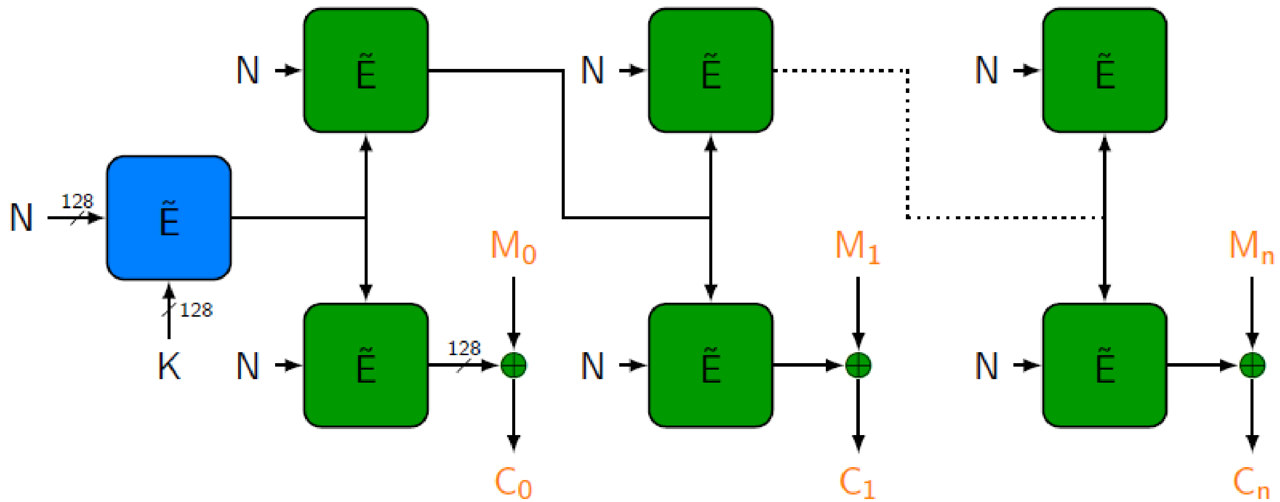
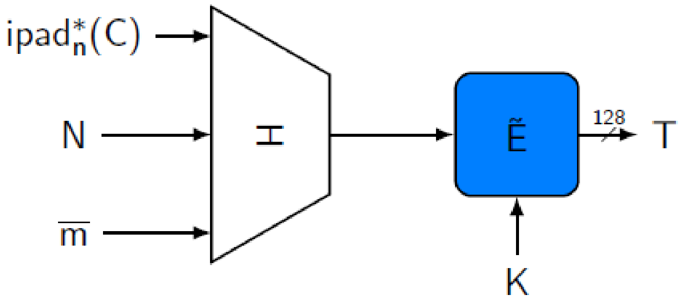
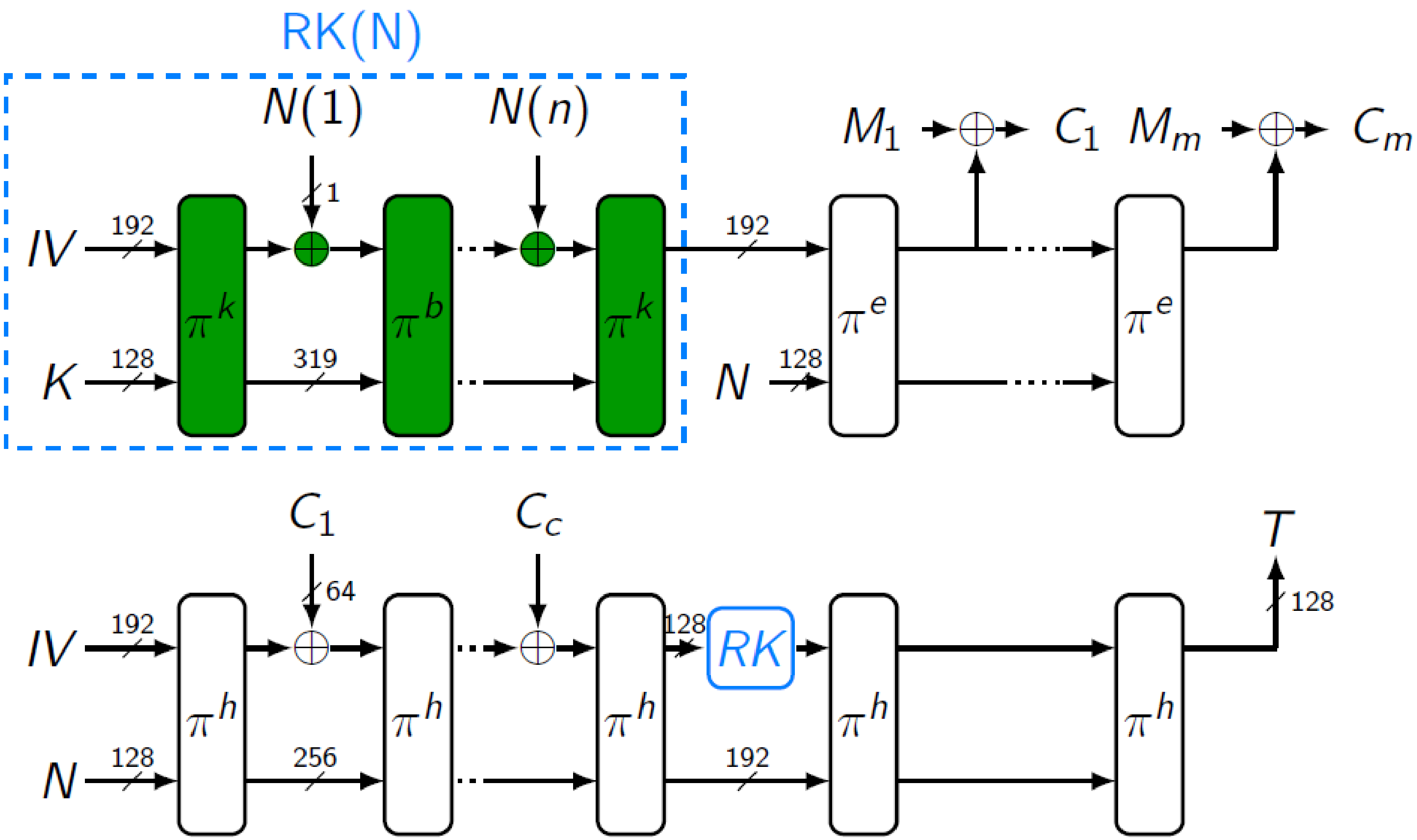




Note: SPA without averaging for CCAL1 & CCAmL1 with averaging for CCAmL2

Level-3 (L2 + two passes)

- Example II: ISAP
  - Integrity: CIL1, CIML1, CIML2



- Example II: ISAP
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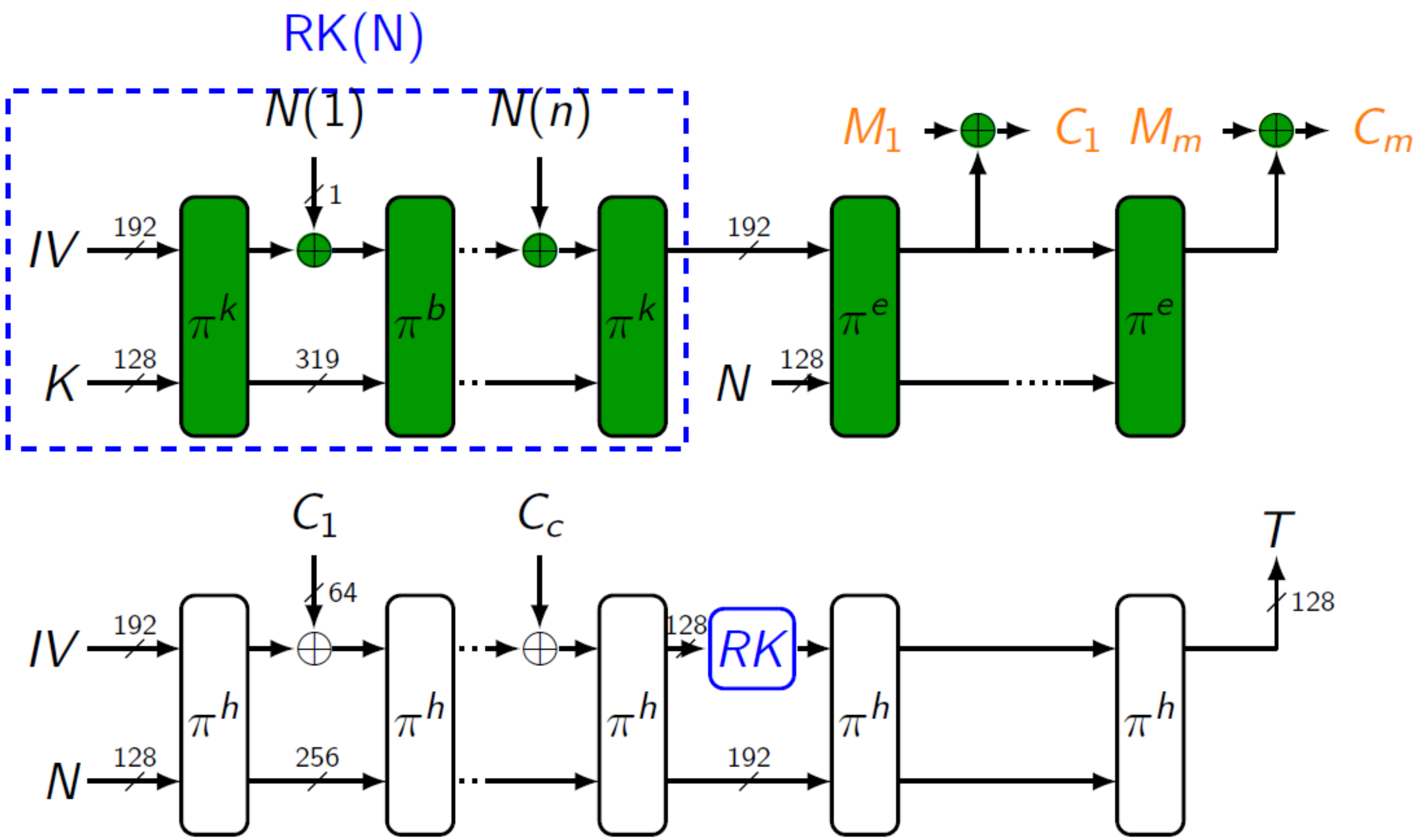

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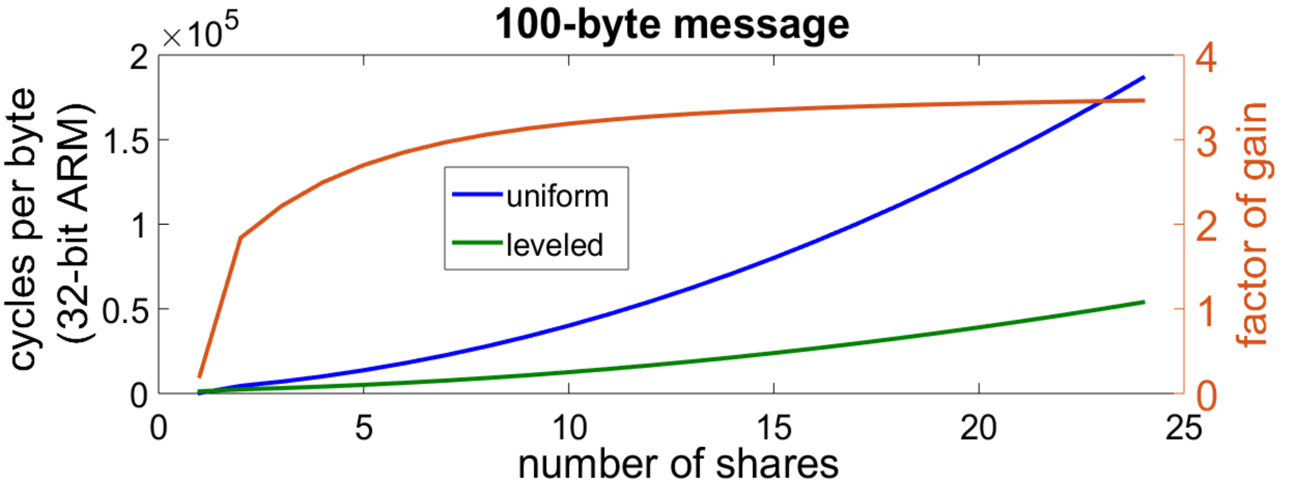
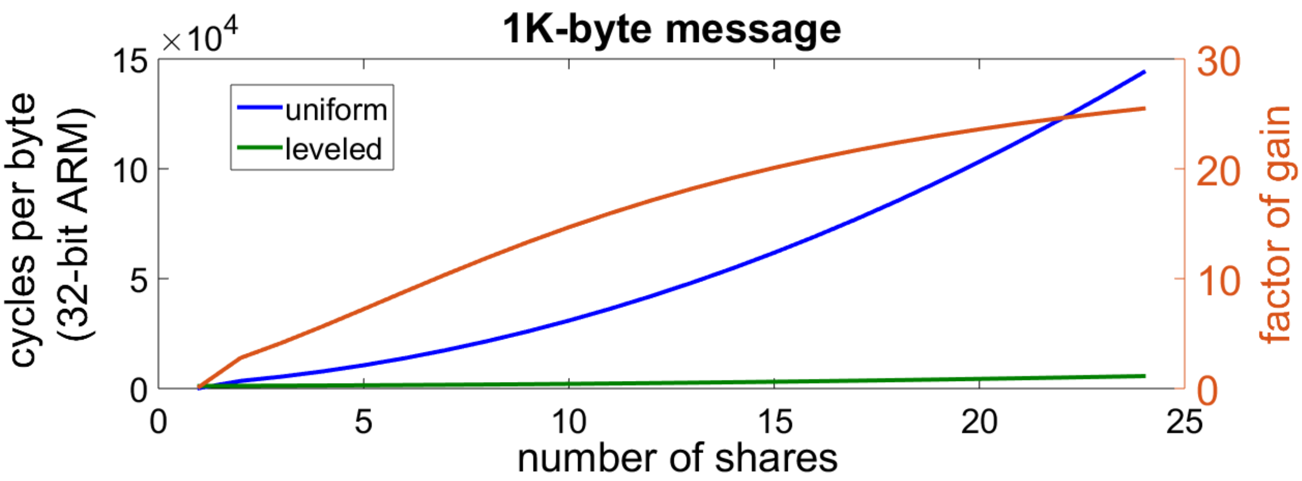
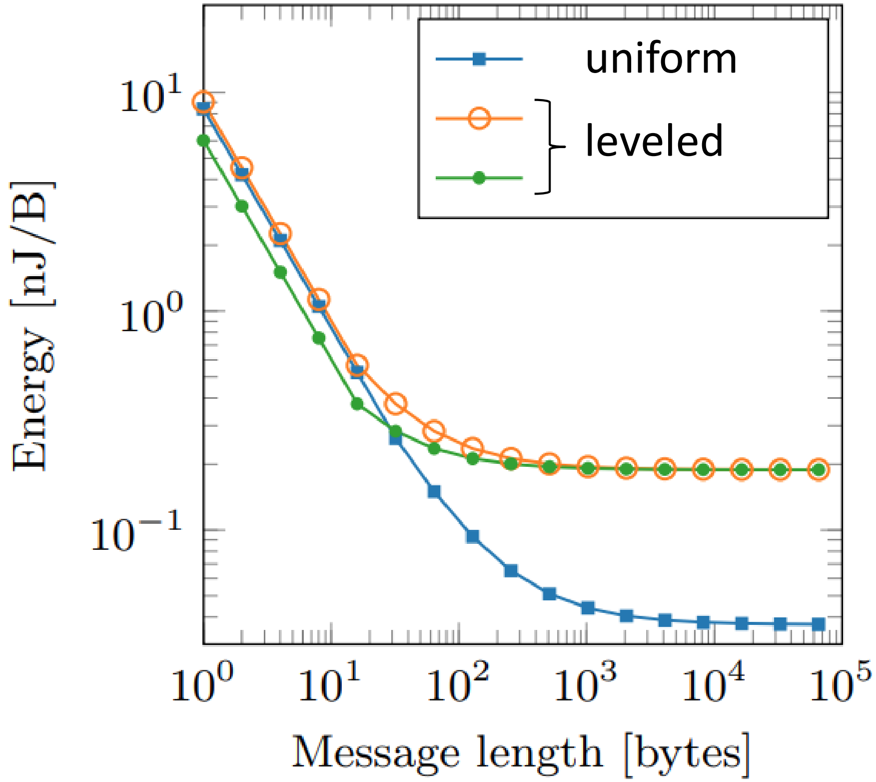
Leveled implementation gains

- In software: reflected in the cycle count

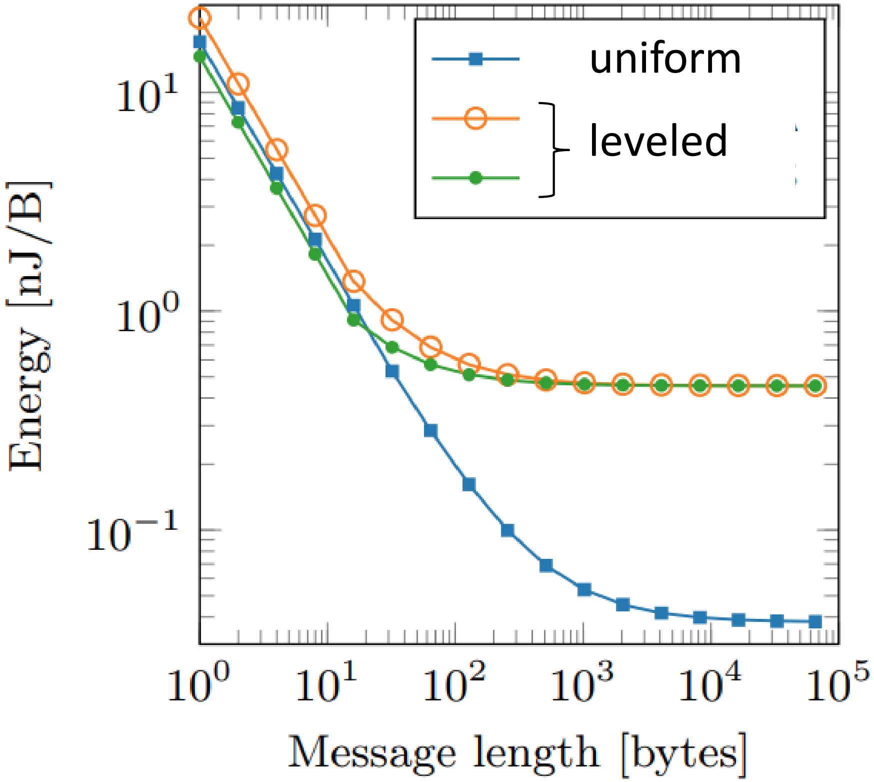




- In hardware: reflected in the energy/byte



d = 2 shares



d = 4 shares

⇒ Gains by factors > 10 for long messages / high security

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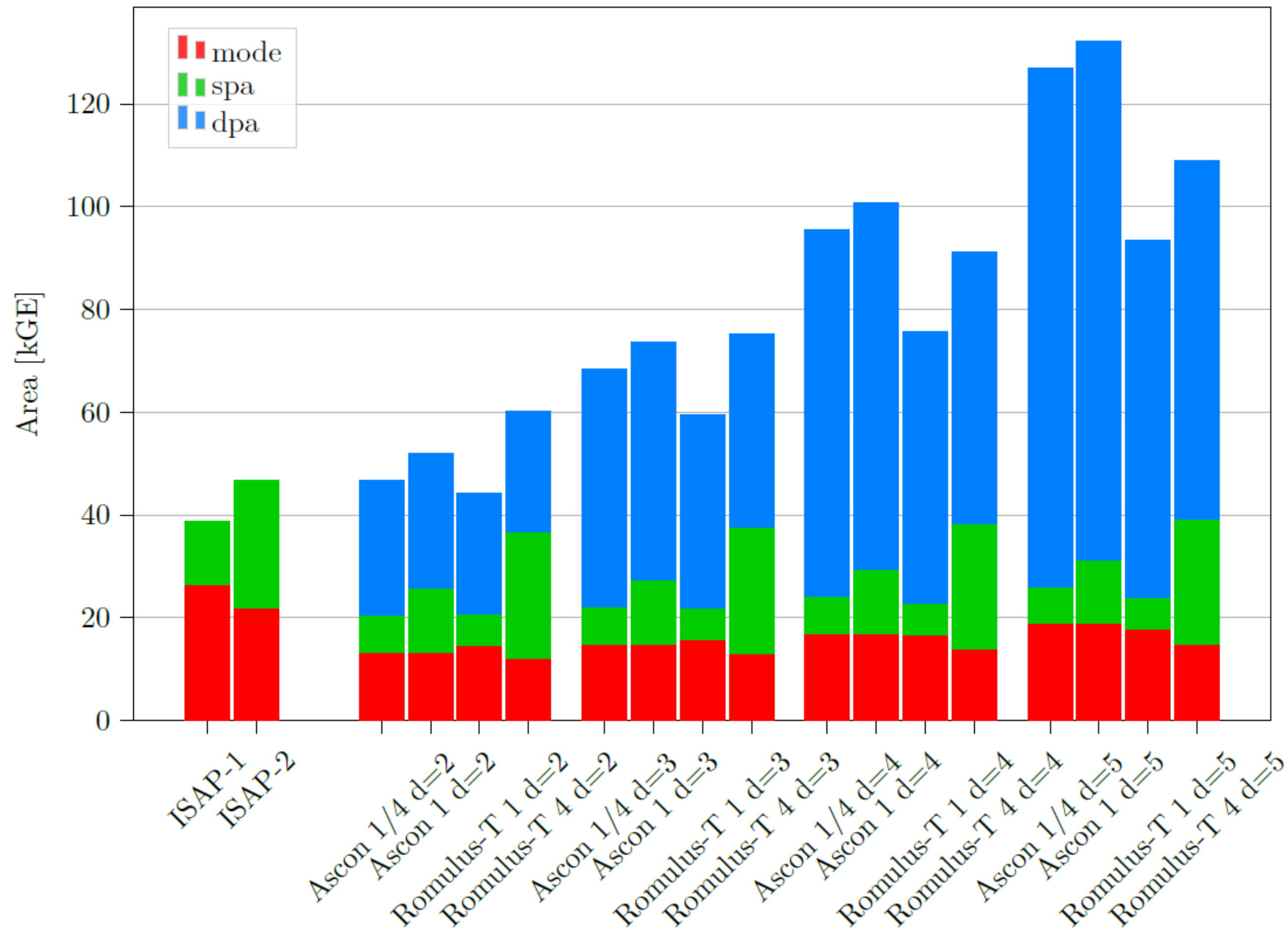
Hardware design space exploration

- ISAP-1, ISAP-2
  - RK: round-based Ascon permutation
  - Bulk: 1x or 2x round-based Ascon permutation
- Ascon-1/4, Ascon-1
  - KDF/TGF: 80-bit masked permutation, HPC2 [A]
    - S-box: 5 AND gates in parallel in 2 cycles
  - Bulk: 80-bit or 1-round Ascon permutation
- Romulus-T-1, Romulus-T-4
  - KDF/TGF: 128-bit masked Skinny TBC, HPC2 [A]
    - S-box: 2 AND gates in parallel in 6 cycles
  - Bulk: 1x or 4x round-based Skinny TBC

[A] Gaëtan Cassiers, Benjamin Grégoire, Itamar Levi, François-Xavier Standaert: *Hardware Private Circuits: From Trivial Composition to Full Verification*. IEEE Trans. Computers 70(10): 1677-1690 (2021)

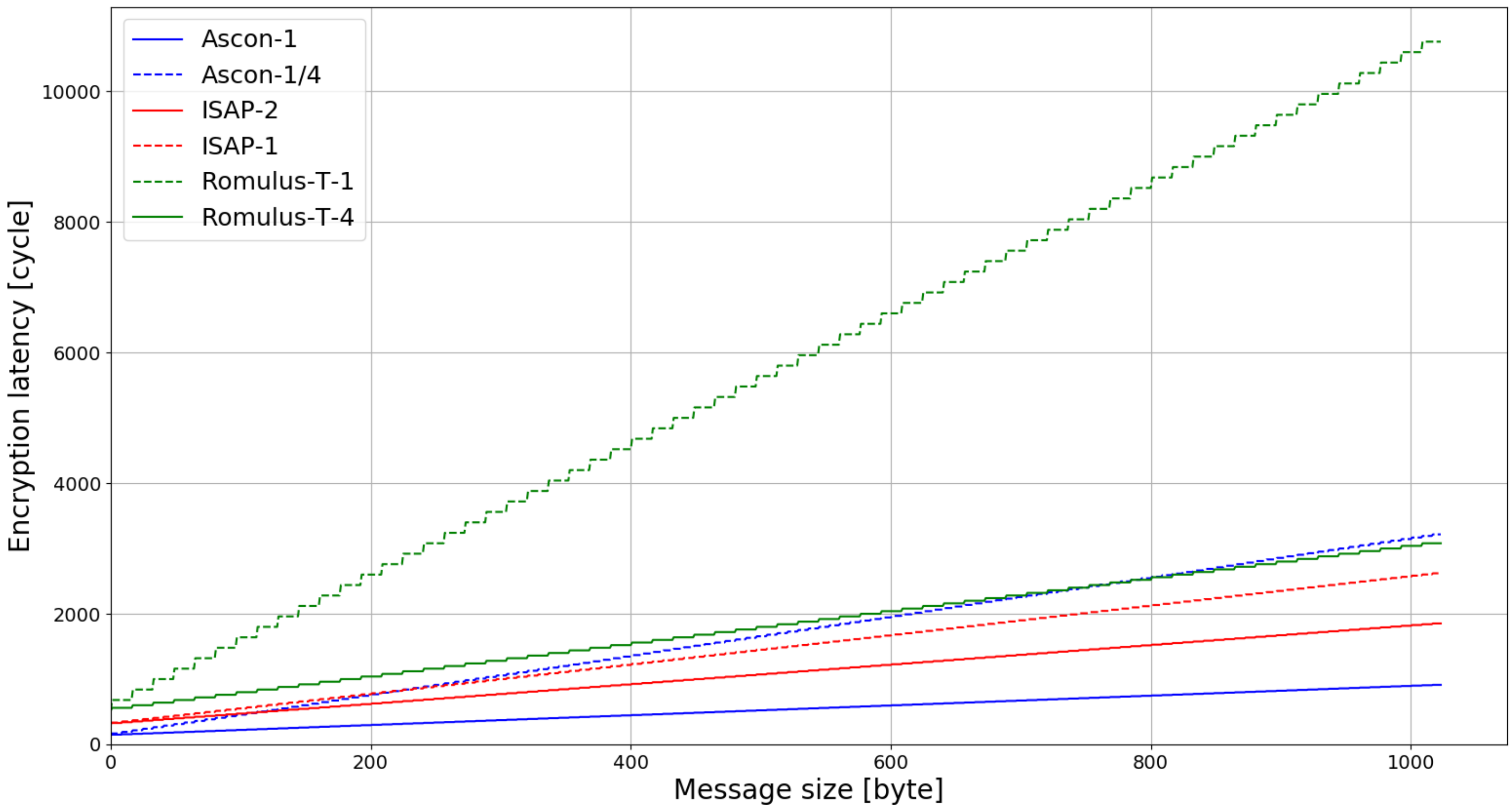
Area comparisons



excluding the randomness cost

- Ascon & Romulus-T area dominated by masked KDF/TGF
- Moderate cost of levelling (mode could be optimized)

Latency comparisons



- As the message size increases, mostly impacted by the unprotected bulk computations & its tradeoffs

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Quantitative

- For similar security, Ascon is more efficient than Romulus-T (at the cost of not providing CCAmL2)
- ISAP security not directly comparable
  - Our guess: hard to attack in parallel hardware
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- 3 efficient designs for side-channel security
- Hardware design choices matters a lot!
  - Leads to stronger differences than the primitives
- Security margins are not the same!
  - E.g., CIML2 for Ascon with $p^b = 6$ rounds

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⇒ Our view: should not drive NIST selection

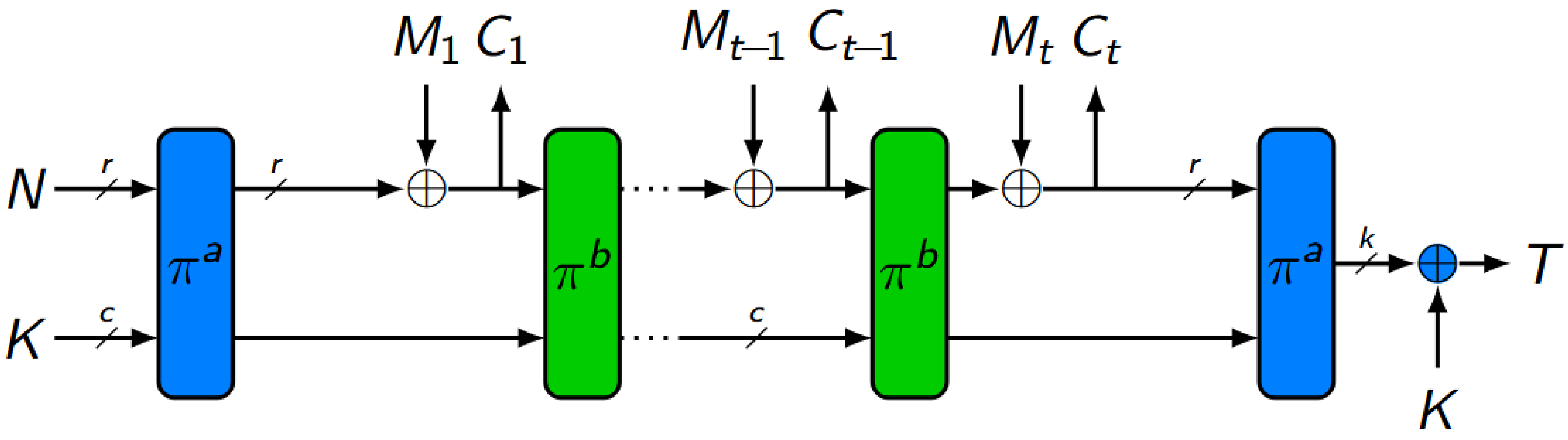
Qualitative

- Willing CCAml2 security in 2 passes (vs. 1-pass)
  - Yes: ISAP or Romulus-T
  - No: Ascon
- Willing flexible overheads (vs. always on)
  - Yes: Ascon or Romulus-T
  - No: ISAP
- Willing a single algorithm (vs. a suite)
  - Yes: Ascon or ISAP
  - No: Romulus

(Note: short messages require separate treatment…)

THANKS!

- SPARKLE:



- Bad TGF (from the leakage viewpoint)
  - Final key addition creates a DPA target