Generic Security of the Ascon Mode: On the Power of Key Blinding

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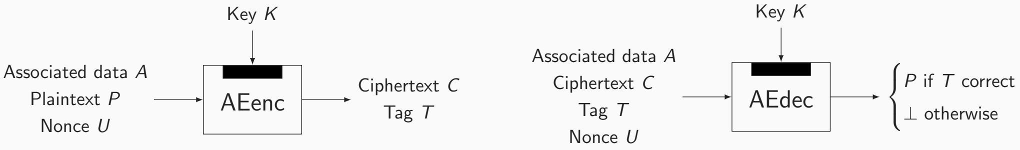
Selected Areas in Cryptography

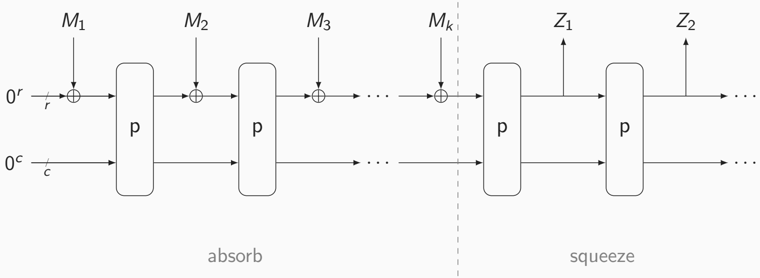
30 August 2024

Authenticated Encryption with Associated Data



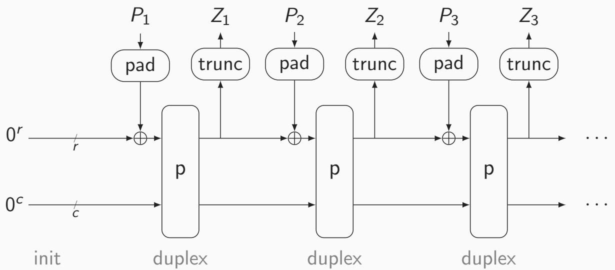
Conventional security: confidentiality (indistinguishability of ciphertexts) and authenticity (unforgeability)

The Sponge Construction [BDPV07]

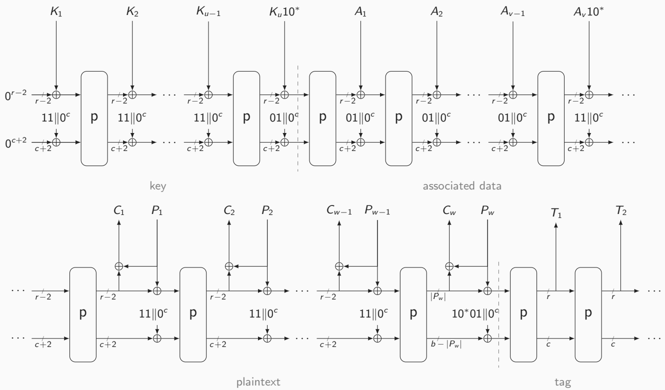


- State of size $b = r + c$
- $M_1 \| \cdots \| M_k$ is the message injectively padded into r-bit blocks

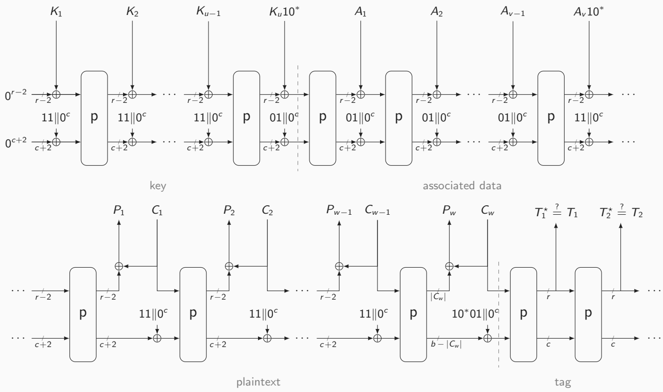
The Duplex Construction [BDPV11]



Interleaved absorption and squeezing phases



- Key, associated data, plaintext fed into duplex with domain separators
- Encryption: outer parts used as one-time pad



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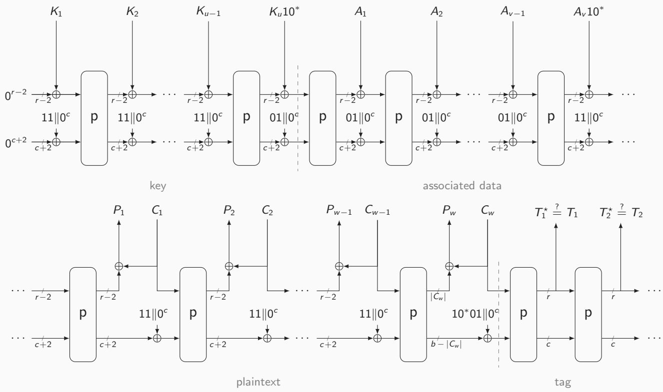
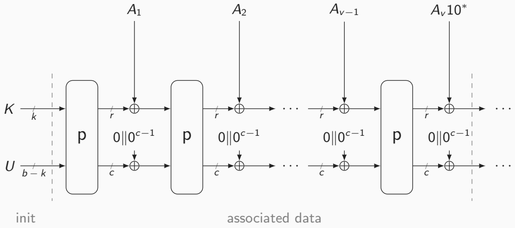
- Encryption: outer parts used as one-time pad
- Decryption: ciphertext overwrites outer part of the state

Application: SpongeWrap [BDPV11]

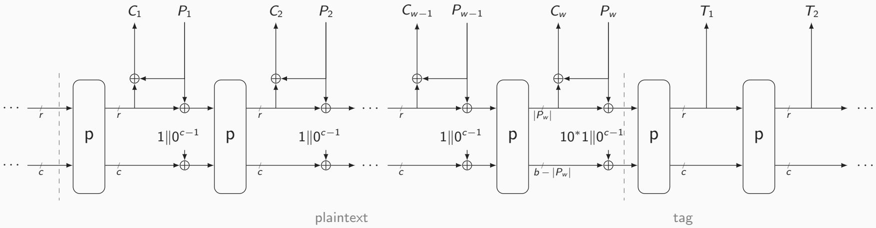


- Key, associated data, plaintext fed into duplex with domain separators
- Encryption: outer parts used as one-time pad
- Decryption: ciphertext overwrites outer part of the state
- Security derived from the indifferentiability of the sponge [BDPV08]

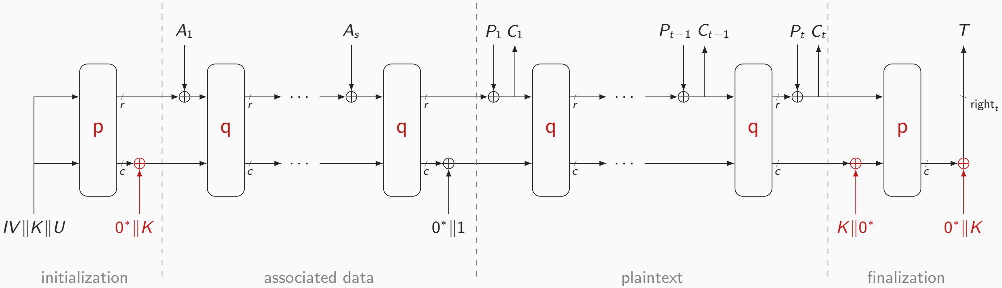
Application: MonkeySpongeWrap [Men23]



- Closer to modern duplex-based AEADs
- State initialized with key and nonce
- Security follows from a generic analysis done in [DMV17]



Ascon-AEAD Mode



- Additional key blindings at initialization and finalization
- Outer and inner permutations p and q differ

Security of Ascon-AEAD Mode

- Generic results on the duplex [DMV17] do not cover Ascon-AEAD mode

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This Work

- Multi-user analysis of confidentiality of Ascon-AEAD mode
- Multi-user analysis of authenticity of Ascon-AEAD mode:
  - Nonce-respecting setting
  - Nonce-misuse setting

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  - Under state recovery with a tailored security model

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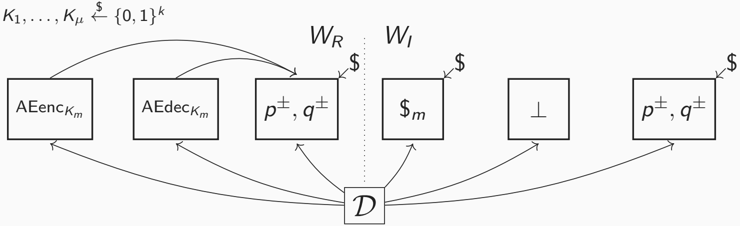
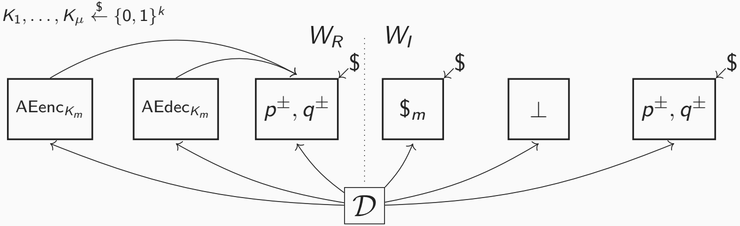
Independent Work

- Chakraborty et al. [CDN23]: tight bound on confidentiality and authenticity in the nonce-respecting case ($p = q$)



- Distinguishing advantage: $\mathbf{Adv}^{\mu\text{-ae}}_{\text{Ascon}}(\mathcal{D})$

Security Model: Nonce-Based AE Security



- Distinguishing advantage: $\mathbf{Adv}^{\mu\text{-ae}}_{\text{Ascon}}(\mathcal{D})$
- Resources of the adversary:
  - Q_E encryption queries with M_E blocks
  - Q_D decryption queries with M_D blocks
  - $M = M_E + M_D$
  - N primitive queries

Security Model: Separation into Confidentiality and Authenticity

- Confidentiality: remove oracle access to $(\mathrm{AEdec}_{K_m})_m / \perp$
- Authenticity: $\mathbf{Pr}\left(\mathcal{D}\left[\left(\mathsf{AEenc}_{K_m}^{p,q}\right)_m, \left(\mathsf{AEdec}_{K_m}^{p,q}\right)_m, (p^{\pm}, q^{\pm})\right] \text{ forges}\right)$

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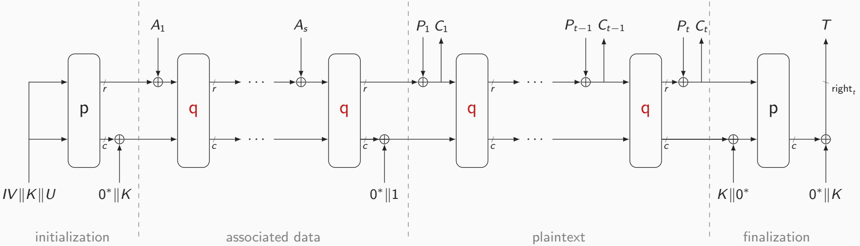
- We have

$$\mathbf{Adv}^{\mu\text{-ae}}_{\mathrm{Ascon}}(\mathcal{D}) \leq \mathbf{Adv}^{\mu\text{-conf}}_{\mathrm{Ascon}}(\mathcal{D}') + \mathbf{Adv}^{\mu\text{-auth}}_{\mathrm{Ascon}}(\mathcal{D}'')$$

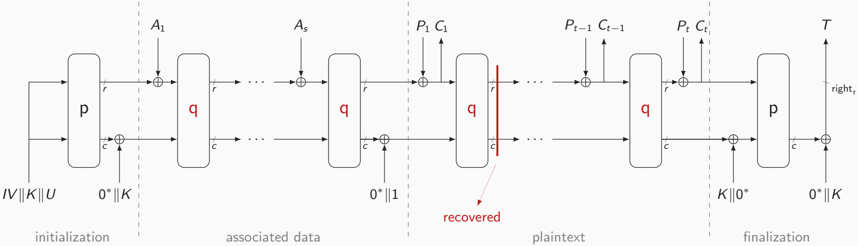
with $\mathcal{D}'$ and $\mathcal{D}''$ having similar complexities than $\mathcal{D}$

Security Model: Authenticity Under State Recovery (1)



Attack Setting

- Adversary may somehow recover any inner state



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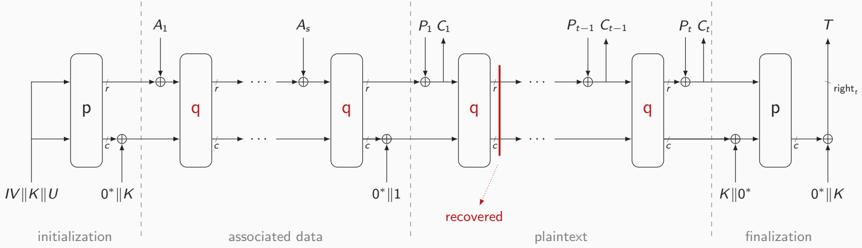
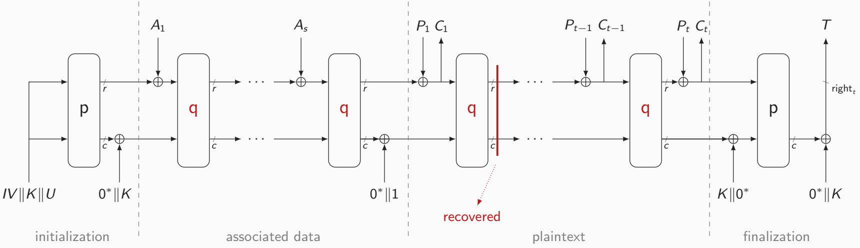


Attack Setting

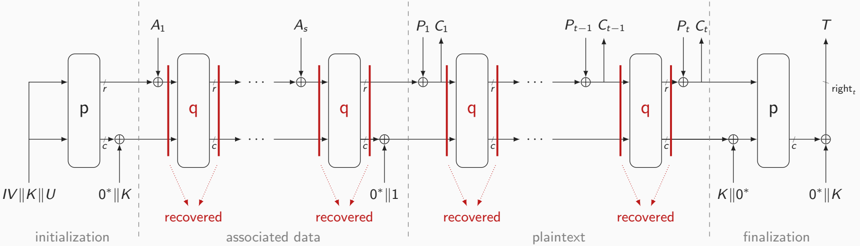
- Adversary may somehow recover any inner state
- Ascon-AEAD designed to still achieve authenticity in this setting

Authenticity Under State Recovery (2)



Model

- Model inspired by permutation-based leakage resilience [DM19a, DM19b]



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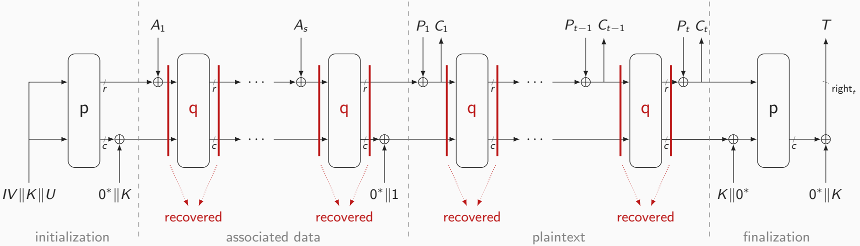

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- Without loss of generality: every encryption/decryption query leaks the entire b-bit state of all evaluations of inner permutation q
- MonkeySpongeWrap-style AEAD does not guarantee security in this setting

Security Results

Property	Setting	Security bound (simplified)
Confidentiality	nonce-respecting	$\mathcal{O}\left(\frac{\mu(N+\mu)}{2^k} + \frac{N^2}{2^b} + \frac{N}{2^c}\right)$
	nonce-misuse	—
	state recovery	
Authenticity	nonce-respecting	$\mathcal{O}\left(\frac{Q_D}{2^t} + \frac{\mu(N+\mu)}{2^k} + \frac{M_E N}{2^b} + \frac{M_D N}{2^c}\right)$
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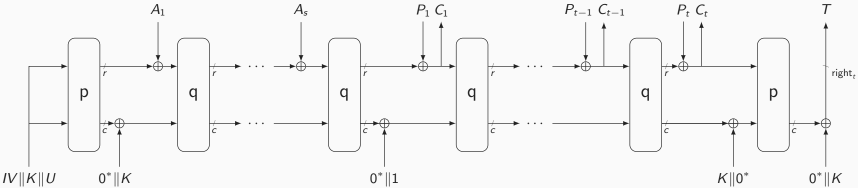
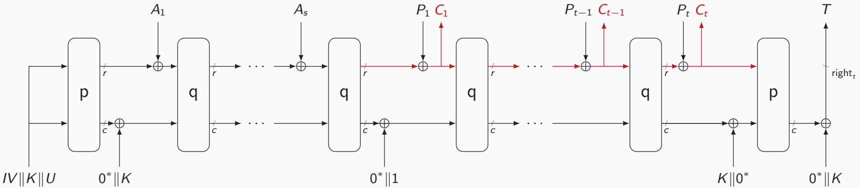
- Nonce-misuse and state recovery authenticity degrade in the last terms
- Improvement from Chakraborty et al. [CDN23] in nonce-based security



Modular Proof

- Some bad events are kept unchanged $\implies \mathcal{O}\left(\frac{Q_D}{2^t} + \frac{\mu(N+\mu)}{2^k}\right)$
- Others are adjusted, depending on the setting:



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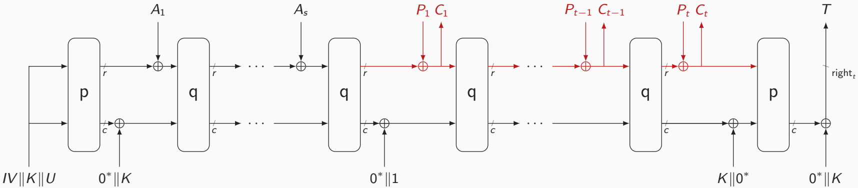

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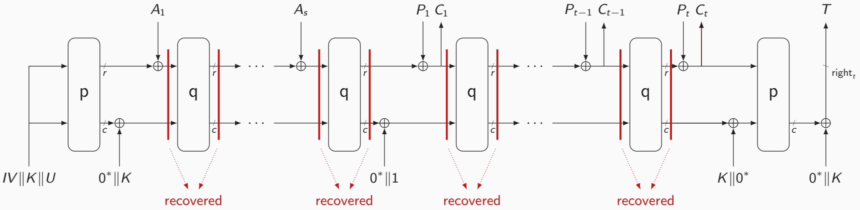

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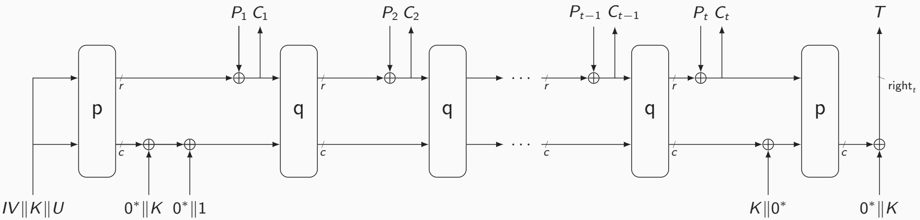
  - State recovery: inner states fully leak, thus permutation queries may correspond later to construction queries $\implies \mathcal{O}\left(\frac{N^2}{2^c}\right)$

Authenticity Under State Recovery: Matching Attack



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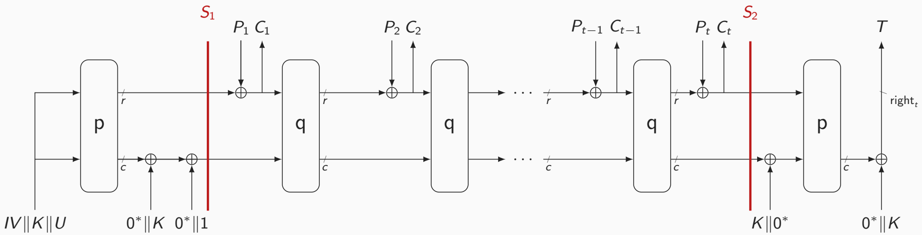

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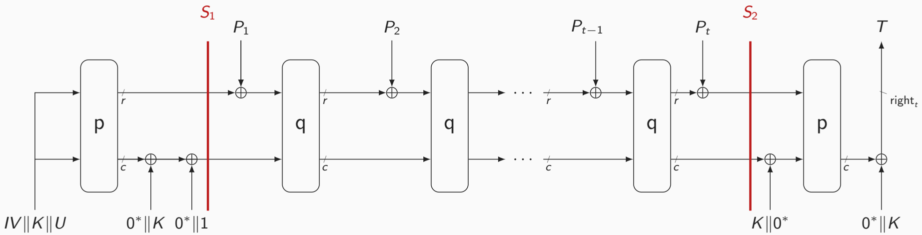

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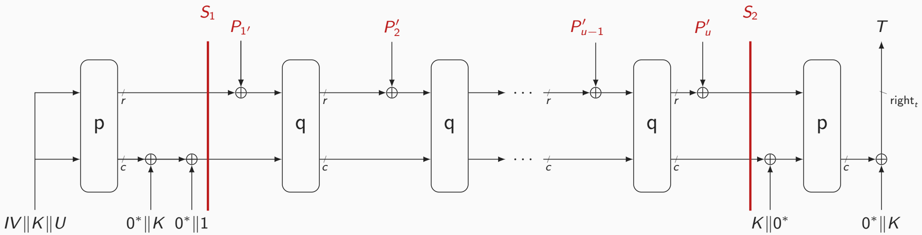

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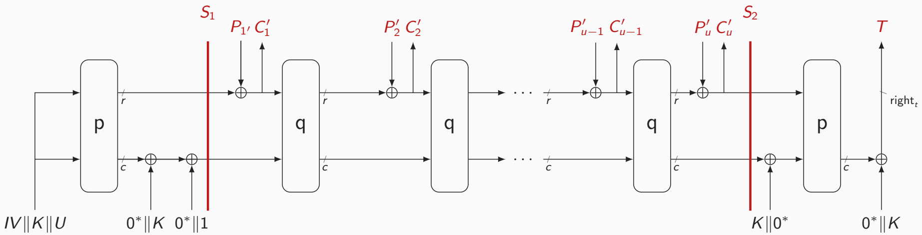

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- Submit a forgery with the associated ciphertext and T

Application to Ascon-AEAD Parameters

- $(k, b, c, r, t) = \begin{cases} (128, 320, 256, 64, 128) \text{ for Ascon-128} \\ (128, 320, 192, 128, 128) \text{ for Ascon-128a} \\ (160, 320, 256, 64, 128) \text{ for Ascon-80pq} \end{cases}$
- Assume number of users $\mu \ll 2^{64}$
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$\Longrightarrow$ Ascon-128: in all cases, generic security as long as $N \ll 2^{128}/\mu$

$\Longrightarrow$ Ascon-80pq: in all cases, generic security as long as $N \ll 2^{160}/\mu$

$\Longrightarrow$ Ascon-128a: nonce-respecting/misusing generic security as long as $N \ll 2^{128}/\mu$, authenticity under state recovery as long as additionally $N \ll 2^{96}$

Conclusion

- General security analysis of Ascon-AEAD mode
- Main focus on role of key blindings
- Caution: the results hold in ideal permutation model (e.g. see [BCP22] for attack in nonce-misuse setting on concrete instantiation)

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Thank you for your attention!

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