Block Ciphers that are Easier to Mask How Far Can we Go ?

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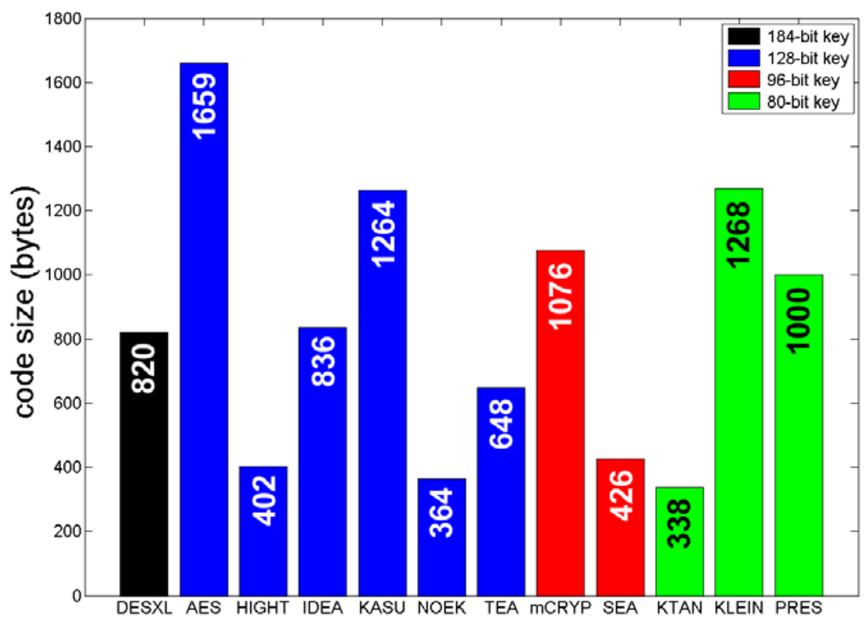
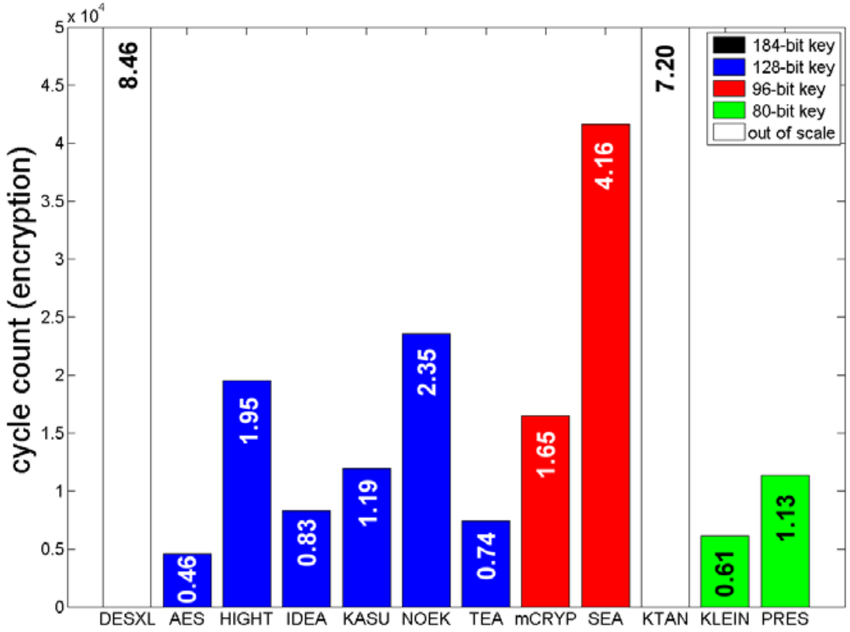
  - Optimized for various performance criteria
    - Code size, throughput, gate count, energy, …

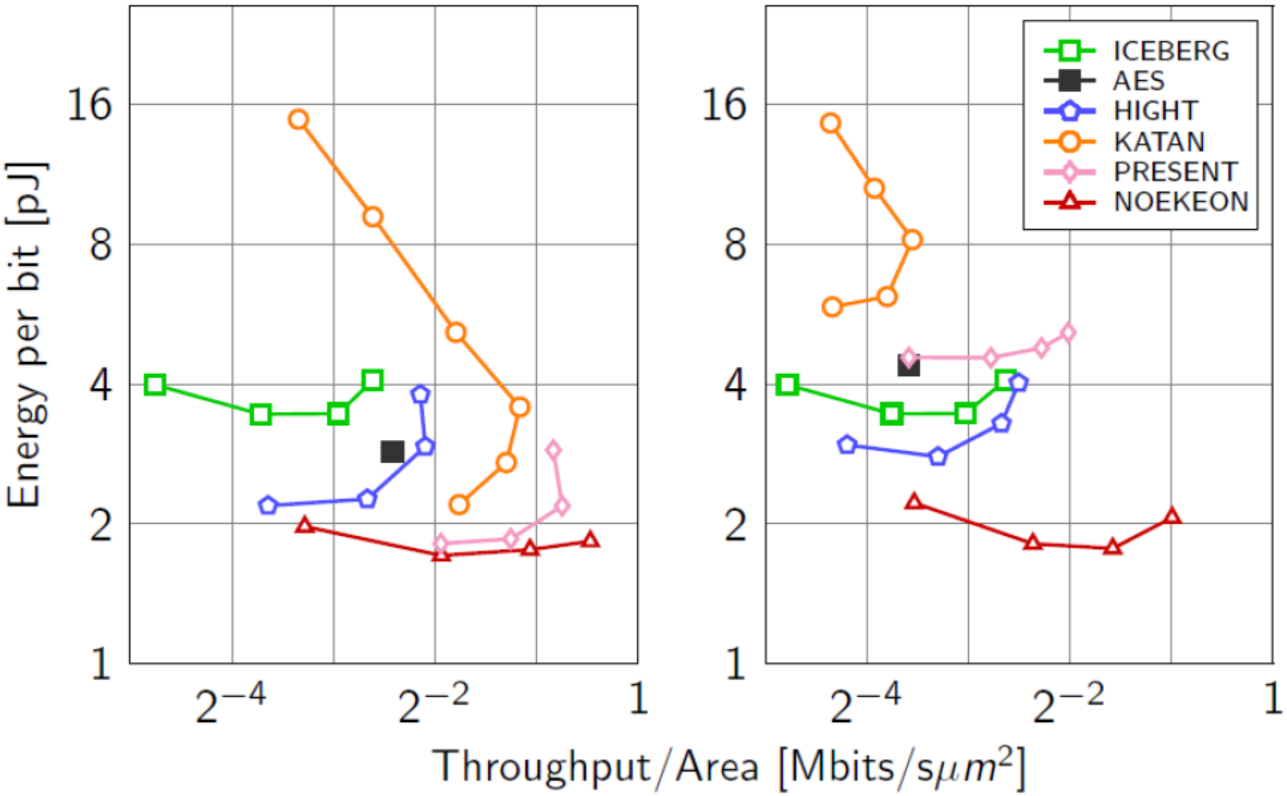
Lessons learned (Atmel AVR case)





- Different designs ≈ different tradeoffs

Lessons learned (ASIC case)



- Different designs ≈ different tradeoffs
- Similar design principles (e.g. wide-trail strategy) lead to similar “efficiencies” (security is the limit)

Masking

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  - Most investigated countermeasure against SCAs
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- If perfect implementation, the data complexity to break masking is proportional to $(\sigma_n^2)^r$
  - Perfect ~ if the smallest-order key-dependent moment in the leakage distribution is *r*
  - Essentially depends on physical assumptions
    - Difficult in hardware (glitches, …)
    - Easier in software (time separation)

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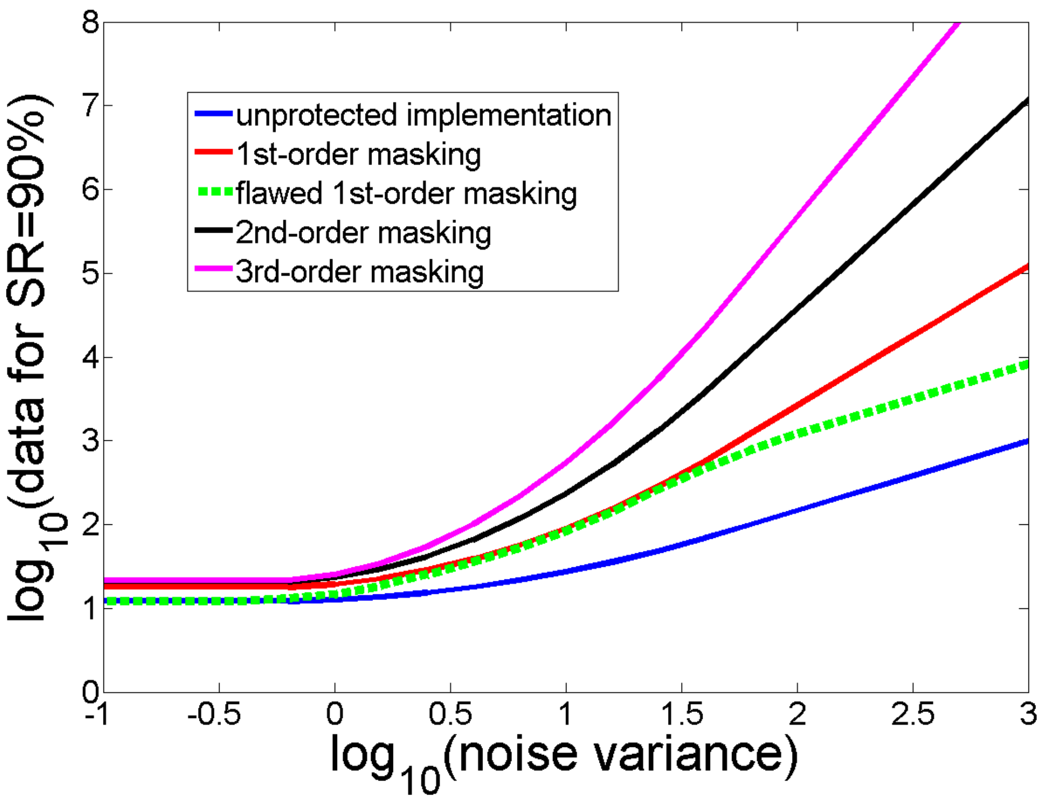

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- Goals are similar to (but not the same as) MPC
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- Given a block cipher (e.g. the AES), it is usually possible to implement masking “quite” efficiently
  - *By finding the best representation*
    - e.g. [RP10,PR11]: AES S-box ≈ 4 multiplications

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- Interesting approach but…
  - Non-bijective S-boxes are bad choice for SCA-resistance (because they allow generic attacks)

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- Reducing the total number of S-boxes
  - Taking advantage of strong diffusion
- Excluding related keys for now
  - As most lightweight ciphers

Outline: the cipher Zorro

1. Which S-boxes?
2. How many S-boxes?
3. Key scheduling
4. Putting things together

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- Goal: reduce the number of multiplications (keeping decent linear/differential/algebraic properties)
  - AES S-box: 4 multiplications, max(WS)=32, max(DS) = 4, algebraic degree = 7

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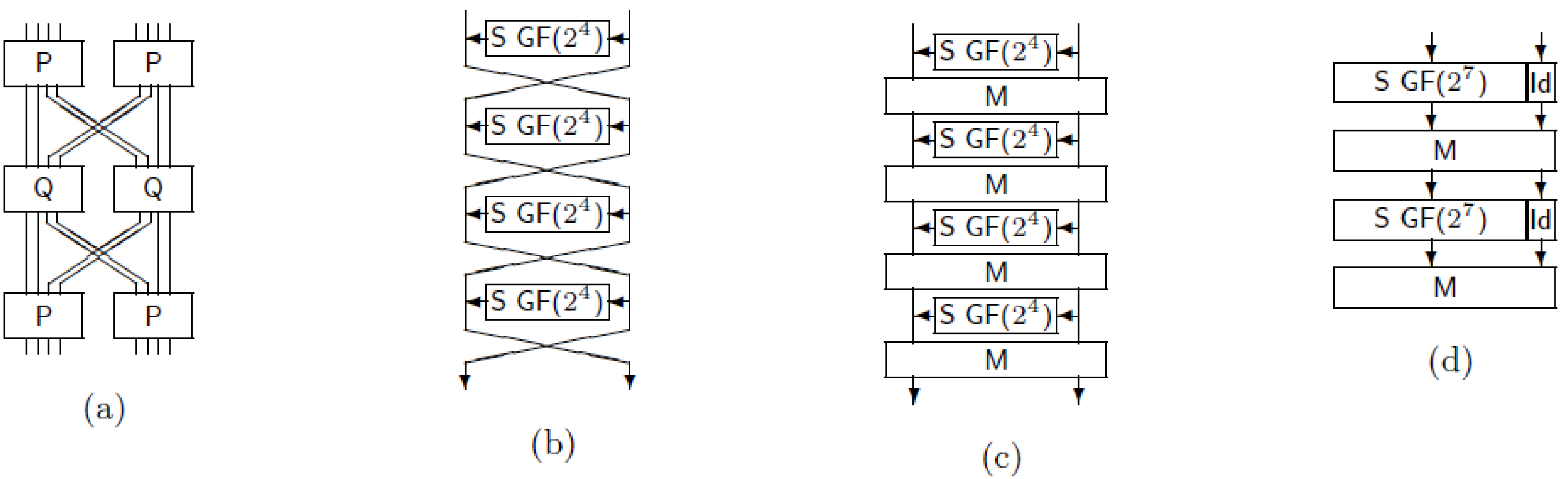
- Monomials/binomials in GF(2^8): exhaustive search
- Others S-boxes: “informed search”, e.g.



Results

	required randomness (bit)			# sec. mult.	additional operations	security properties		
	$d = 1$	$d = 2$	d			$deg(S)$	$\max \Delta_S$	$\max \Omega_S$
AES [33]	48	128	$16d^2 + 32d$	4 (GF(2^8))	7 squ. + 1 Diff. matrix	7	4	32
AES [19]	32	84	$10d^2 + 22d$	5 (GF(2^4))	3 squ. + 5 Diff. matrix	7	4	32
PICARO	16	48	$8d^2 + 8d$	4 (GF(2^4))	2 squ.	4	4	68
X^7	24	64	$8d^2 + 16d$	2 (GF(2^8))	2 squ. + 1 Diff. matrix	3	6	64
X^{29}	32	88	$12d^2 + 20d$	3 (GF(2^8))	4 squ. + 1 Diff. matrix	4	10	64
X^{37}	24	64	$8d^2 + 16d$	2 (GF(2^8))	5 squ. + 1 Diff. matrix	3	6	64
$8X^{97} + X^{12}$	32	80	$8d^2 + 24d$	2 (GF(2^8))	6 squ. + 1 Diff. matrix	3	6	48
$155X^7 + X^{92}$	40	104	$12d^2 + 28d$	3 (GF(2^8))	8 squ. + 1 Diff. matrix	4	6	48
Ex. 1	32	80	$8d^2 + 24d$	4 (GF(2^4))	4 squ. + 4 Diff. matrix	7	10	64
Ex. 2	48	112	$8d^2 + 40d$	4 (GF(2^4))	28 squ. + 4 Diff. matrix	6	8	64
Ex. 3	28	70	$7d^2 + 21d$	2 (GF(2^7))	2 squ. + 2 Diff. matrix	4	10	64

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Our choice: same # of multiplications as PICARO

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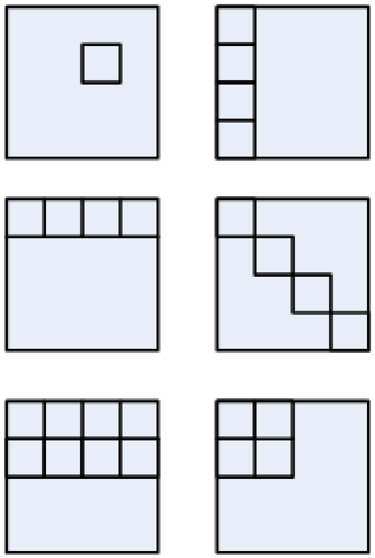
- Informal tests: how many rounds for
  - At least going through one S-box
  - All output bytes having a non-linear term
  - Input diffs. with non-linear effect on output bytes

Testing different configurations

	NrSbox	NrNlin	NrDiff
1 S-box	3	2	4
4 S-boxes, 1 line	2	1	3
8 S-boxes, 2 lines	2	1	3
4 S-boxes, 1 column	3	1	3
4 S-boxes, 1 diagonal	2	2	3
4 S-boxes, 1 per column	2	2	3
4 S-boxes, Square	3	2	4



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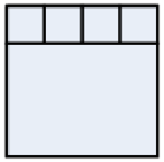

Our choice: 4 S-boxes on the first state line

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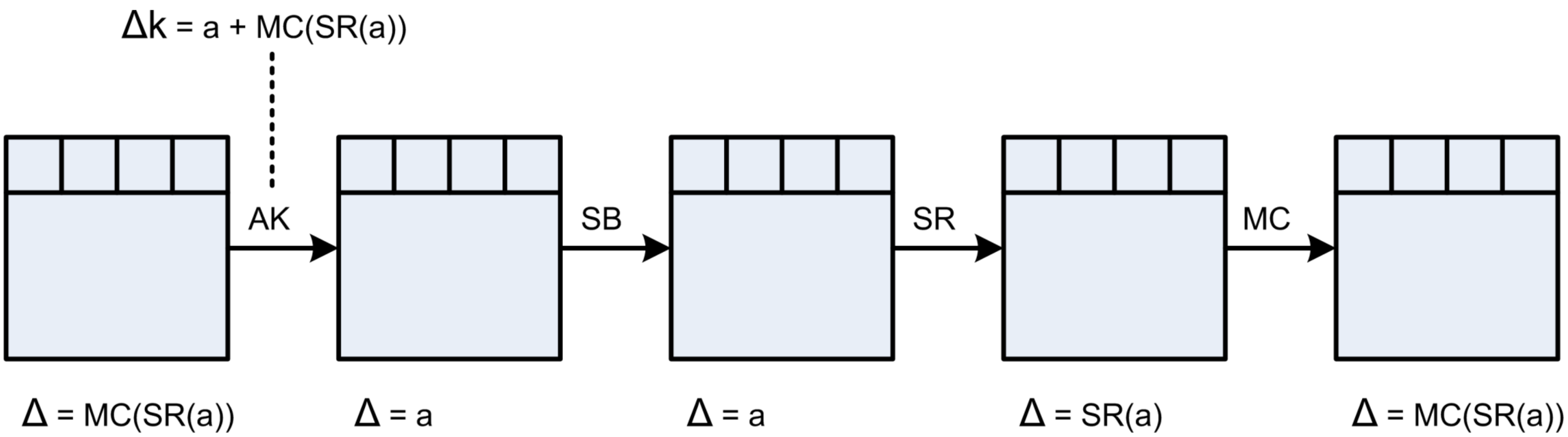
- Example: every single round => related-key issue



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- Property so strong that it leads to non-related-key attacks with 2^64 data and 2^64 time
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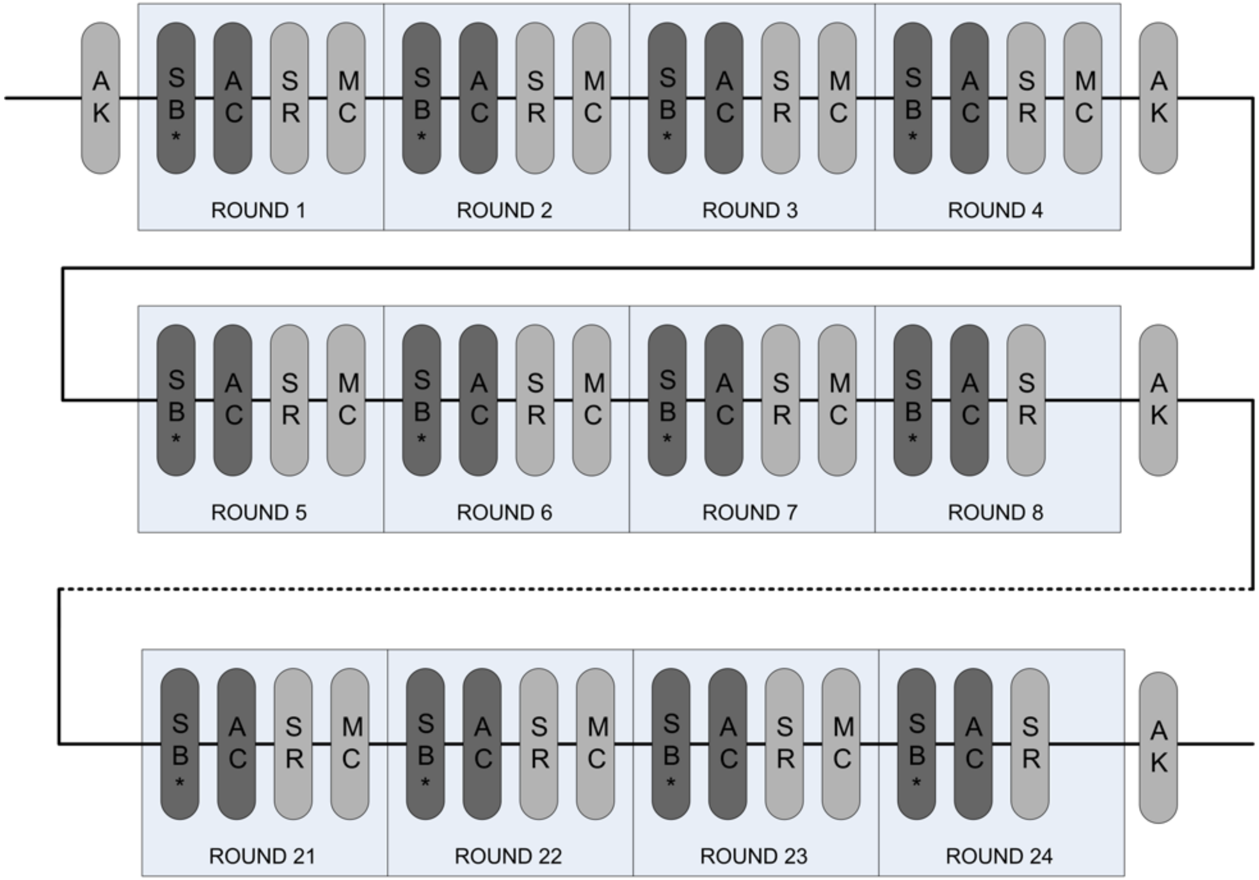
… and a sufficient number of times to avoid generic attacks against Even-Mansour schemes (we choose 7)

- cfr. Asiacrypt 2012 and 2013
  - (*thanks to Orr Dunkelman*!)

4. Putting things together

- Number of rounds: 24 (6 steps of 4 rounds)
  - Roughly divides the total # of multiplications by 4!



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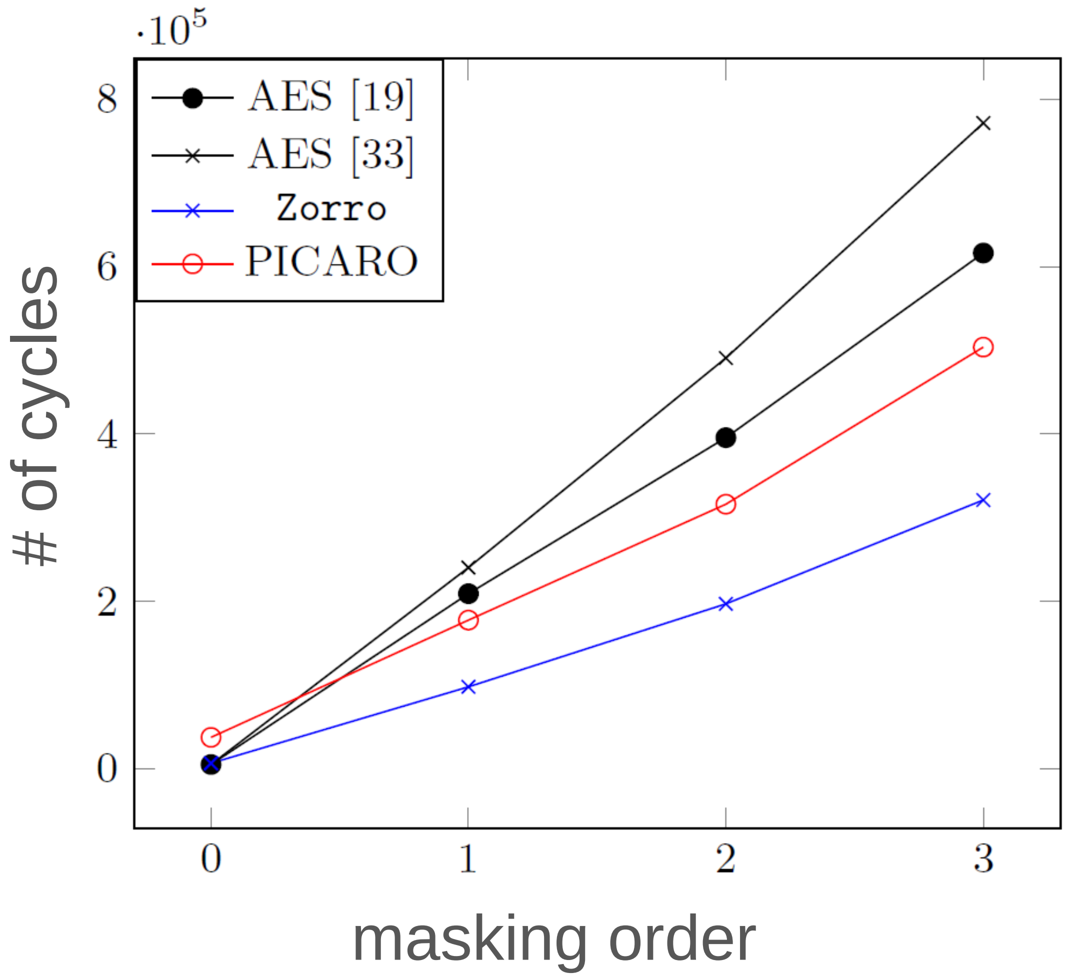
- (+ truncated differential, cube testers, MITM, …)

Performance evaluation

- Case study: Atmel AtMega644p



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  - Stronger diffusion (Khazad-like) or smaller S-boxes (NOEKEON, PRESENT, …)?
- Or specialize to Boolean masking only (=> bitslice)

THANKS

http://perso.uclouvain.be/fstandae/