Improved Differential Fault Analysis on CLEFIA

Junko Takahashi and Toshinori Fukunaga

NTT Information Sharing Platform Laboratories, JAPAN

FDTC 2008 Washington DC, USA
August 10

Outline

- Background
- Previous Study
  - Structure of CLEFIA
  - General DFA Method
  - Chen’s Attack
- Proposed Attack
  - Attack Method
  - Simulation Results
- Conclusions

Background

- CLEFIA - 128-bit block cipher developed by SONY Corporation in 2007.
  - Small implementation size and high speed utilizing characteristic structure
- Differential fault analysis (DFA) on CLEFIA was first proposed by Chen et al. in 2007.
  - Simply applied attack against DES to CLEFIA
  - 18 pairs needed to obtain 128-bit key

➡ Can we develop more efficient attack using characteristic of CLEFIA structure ?

Background

- CLEFIA - 128-bit block cipher developed by SONY Corporation in 2007.
  - Small implementation size and high speed utilizing characteristic structure
- Differential fault analysis (DFA) on CLEFIA was first proposed by Chen et al. in 2007.
  - Simply applied attack against DES to CLEFIA
  - 18 pairs needed to obtain 128-bit key

⇨ Yes, we can !!

Result

Comparison of attack efficiency for 128-bit key

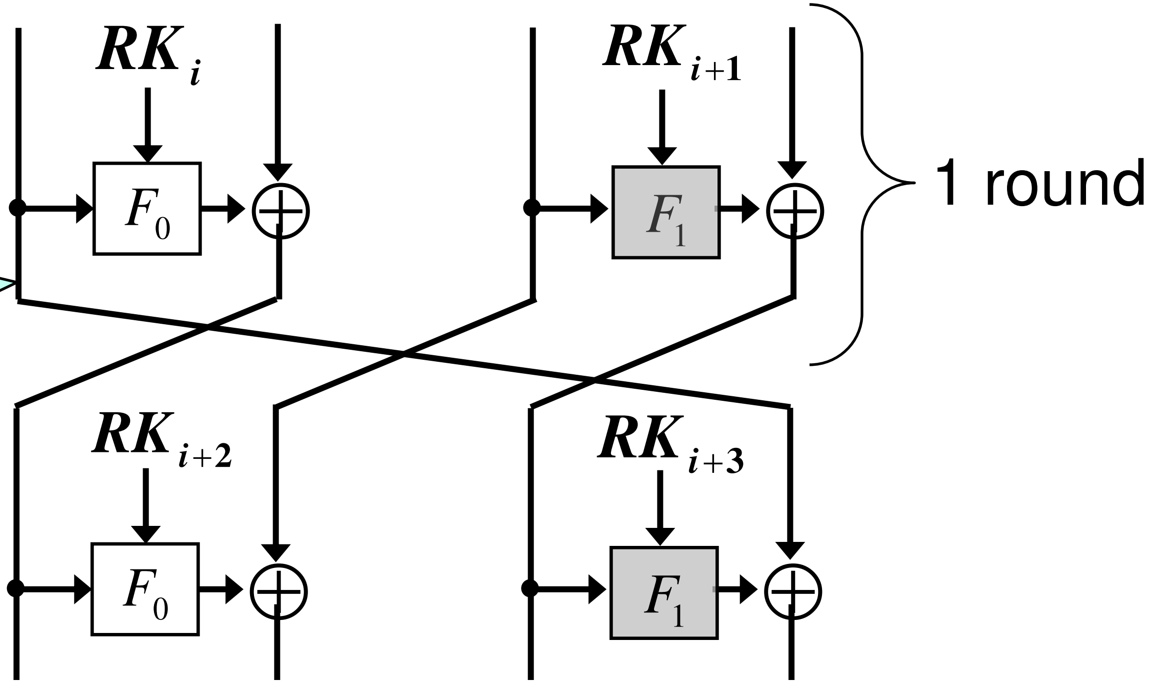
	No. of pairs of correct & faulty ciphertexts	No. of fault injection points	Calculation time on Xeon 3GHz PC
Proposed attack	2	2	average 3 min
Chen's attack (in 2007)	18	6	< 1 sec

- Background
- Previous Study
  - Structure of CLEFIA
  - General DFA Method
  - Chen’s Attack
- Proposed Attack
  - Attack Method
  - Simulation Results
- Conclusions

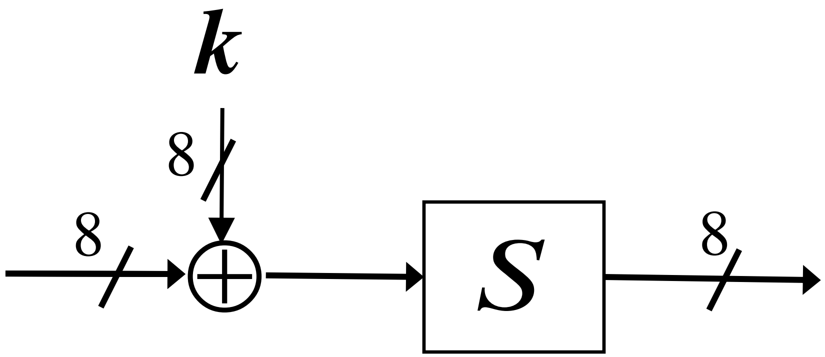
Structure of CLEFIA

- 4-branch generalized Feistel network
- 18 rounds for 128-bit key

Each data line is 32 bits



General DFA on a S-box



Case #0 a $S[k \oplus a]$

Case #1 b $\oplus)\ S[k \oplus b]$

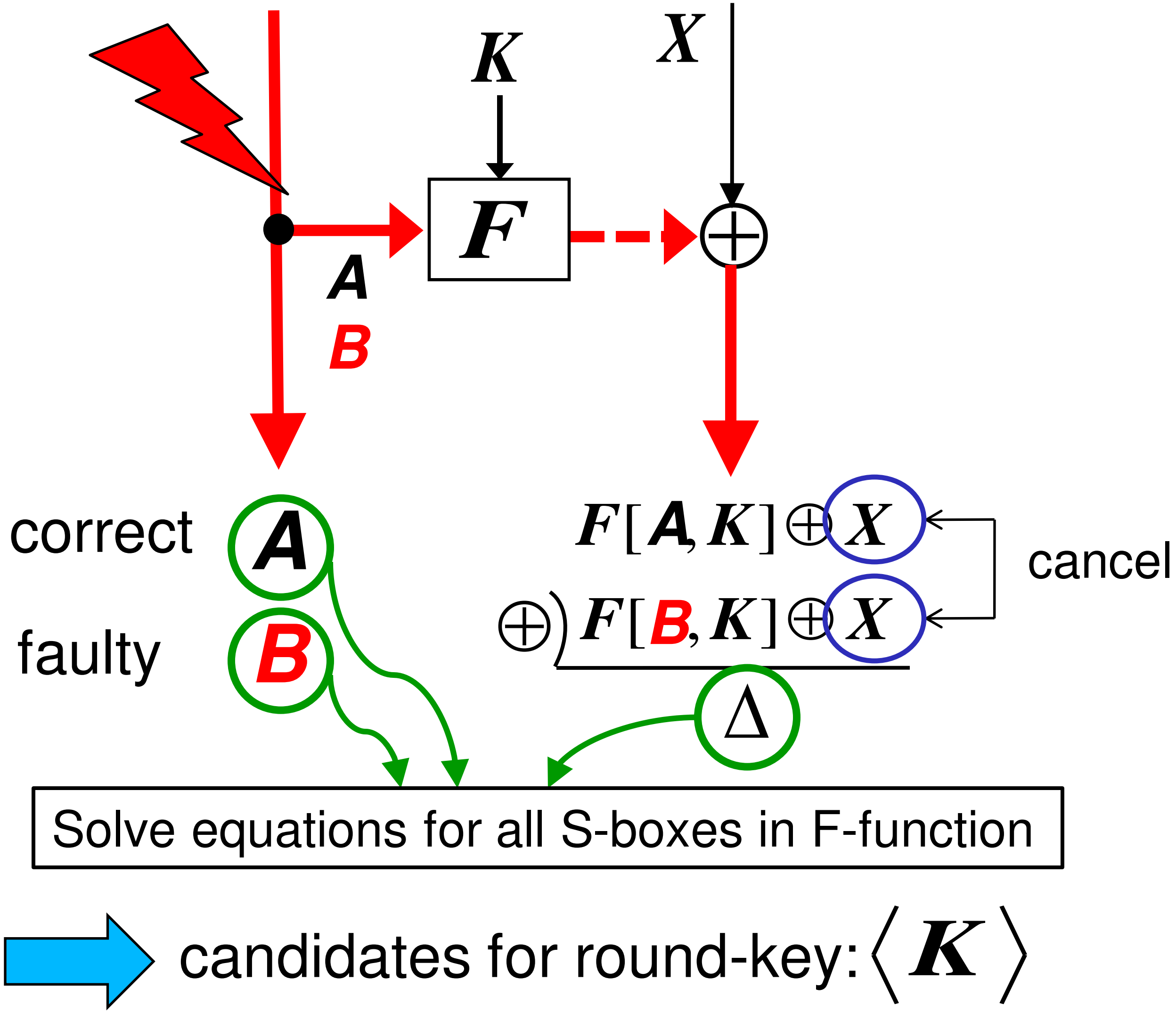
δ

$$S[k \oplus a] \oplus S[k \oplus b] = \delta$$

Solve equation for a S-box

⇨ candidates for key: $\langle k \rangle$

General DFA on Feistel Structure



$$F[A,K]\oplus X$$

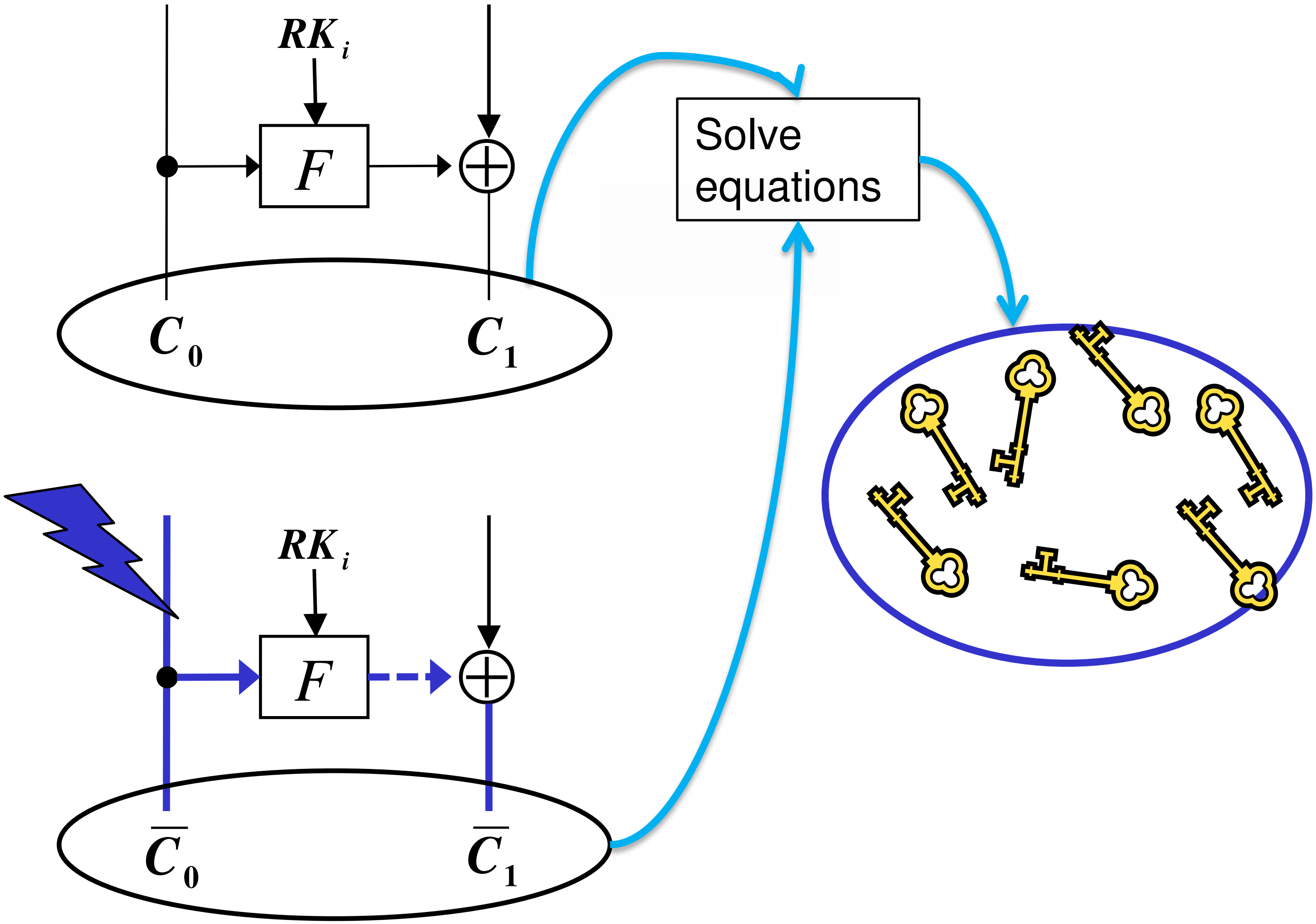
$$\oplus)\ F[B,K]\oplus X$$

$$\Delta$$

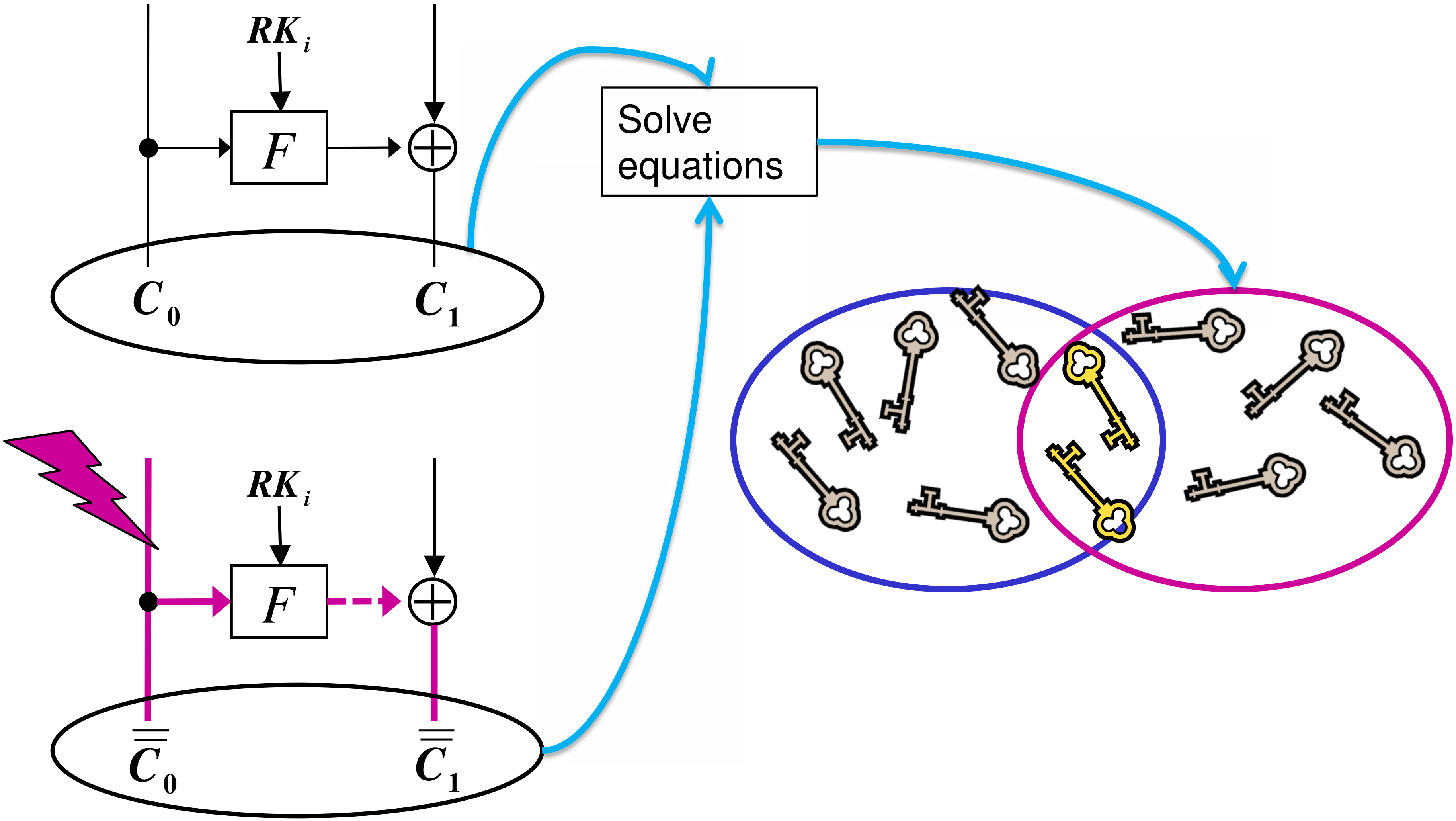
Solve equations for all S-boxes in F-function

candidates for round-key: $\langle K \rangle$

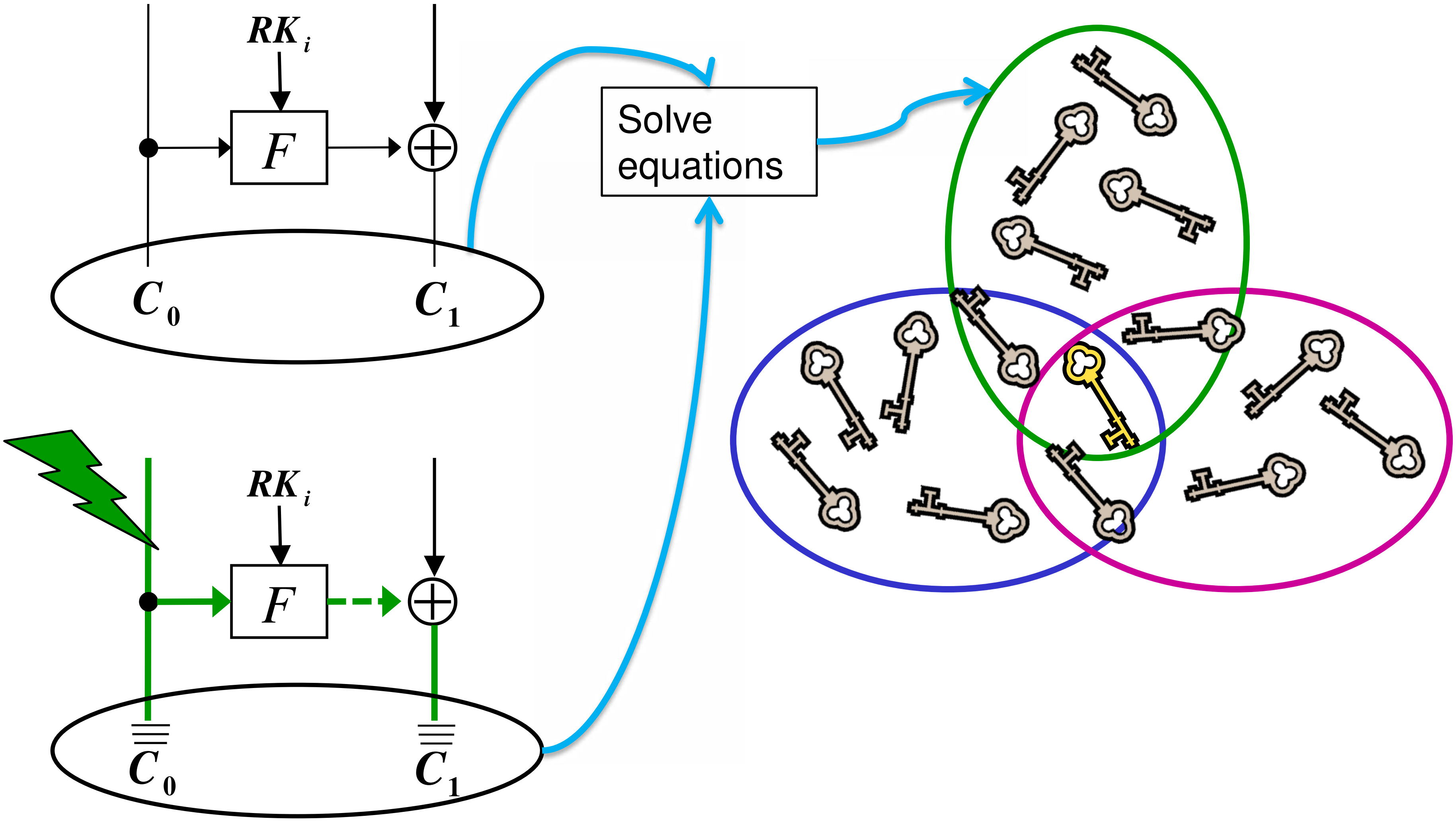
Chen’s Attack (2007)



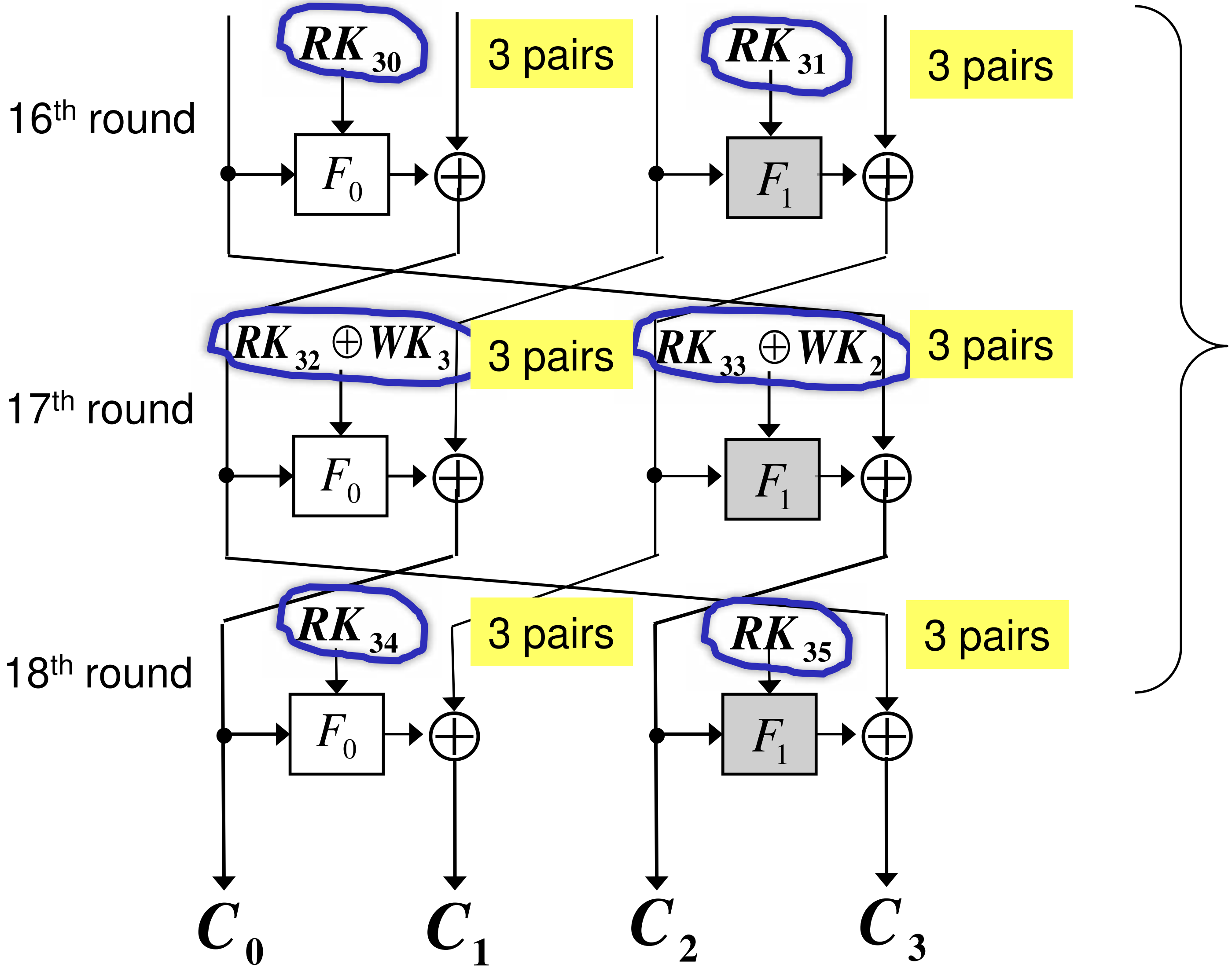
Chen's Attack (2007)



Chen’s Attack (2007)


RK_i
F
C_0
C_1
Solve equations
RK_i
F
$\overline{\overline{\overline{C}}}_0$
$\overline{\overline{\overline{C}}}_1$

Chen’s Attack (2007)



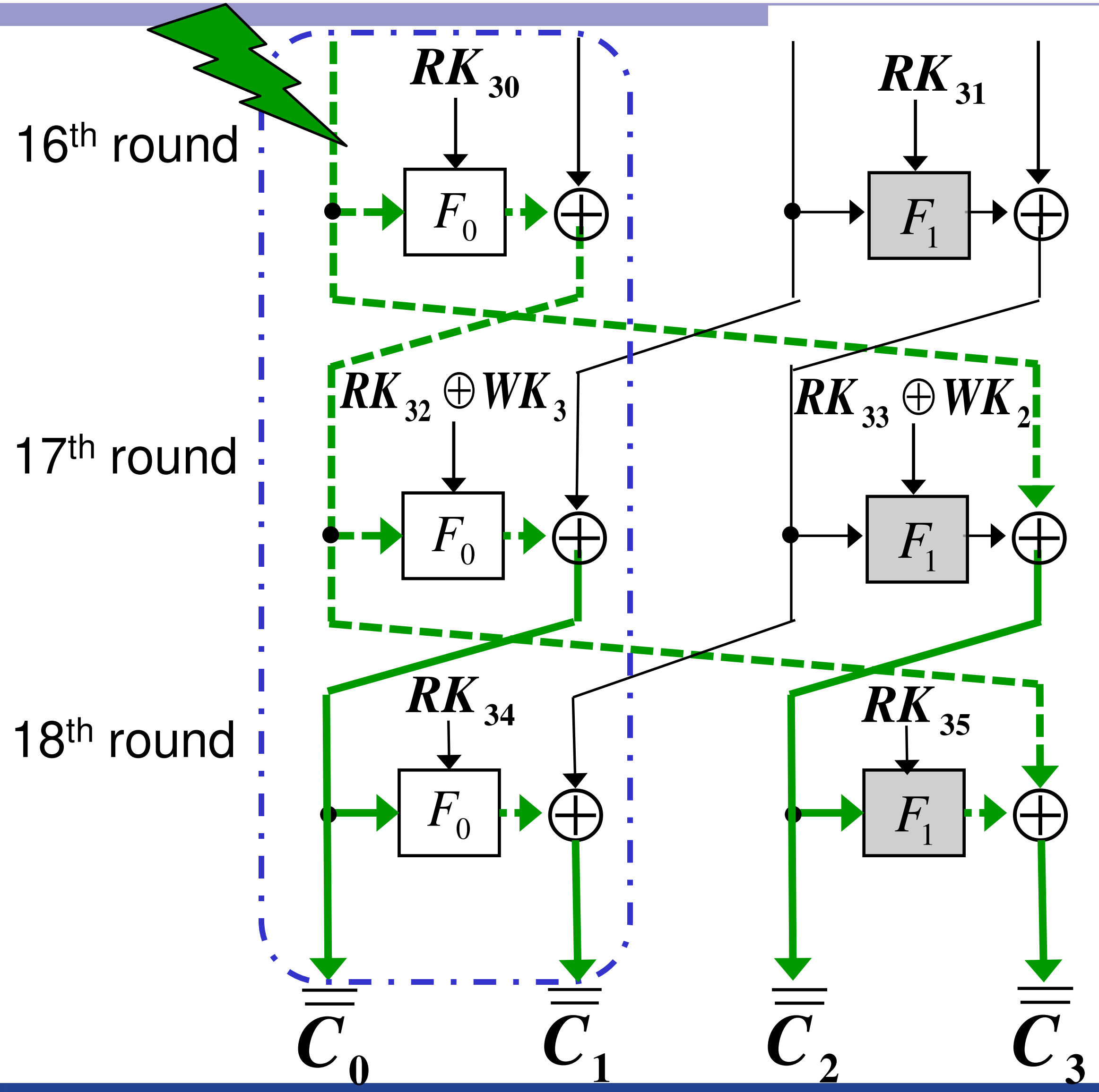
A total of 18 pairs are needed

- Background
- Previous Study
  - Structure of CLEFIA
  - General DFA Method
  - Chen’s Attack
- Proposed Attack
  - Attack Method
  - Simulation Results
- Conclusions

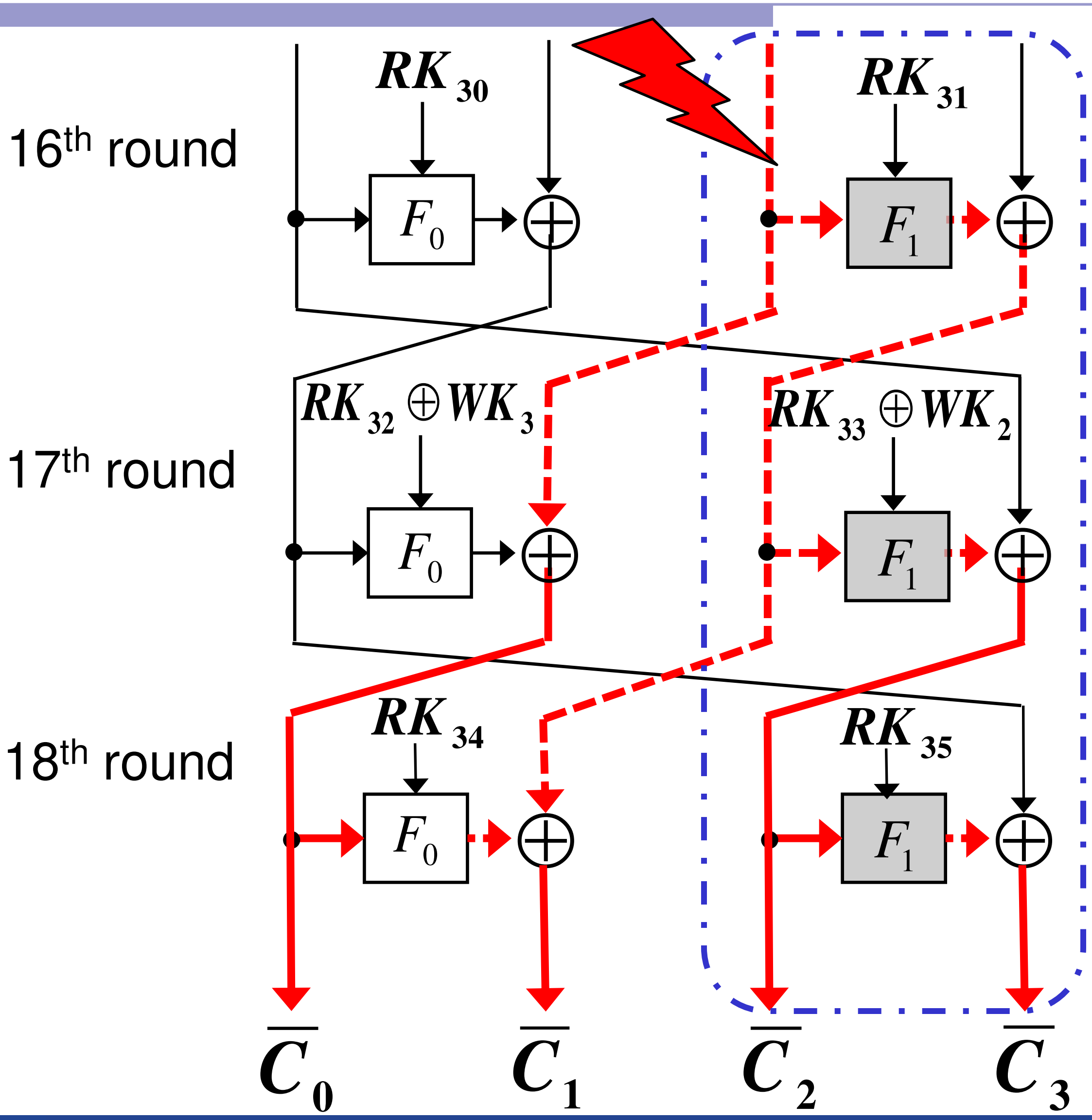
Key Point of Proposed Attack

- Utilize 4-branch structure with 32-bit data lines
  - We can obtain 6 round keys by utilizing the fault propagation of two fault injections.
  - The space of candidates for round key is small and we can obtain a 128-bit key within a practical time.

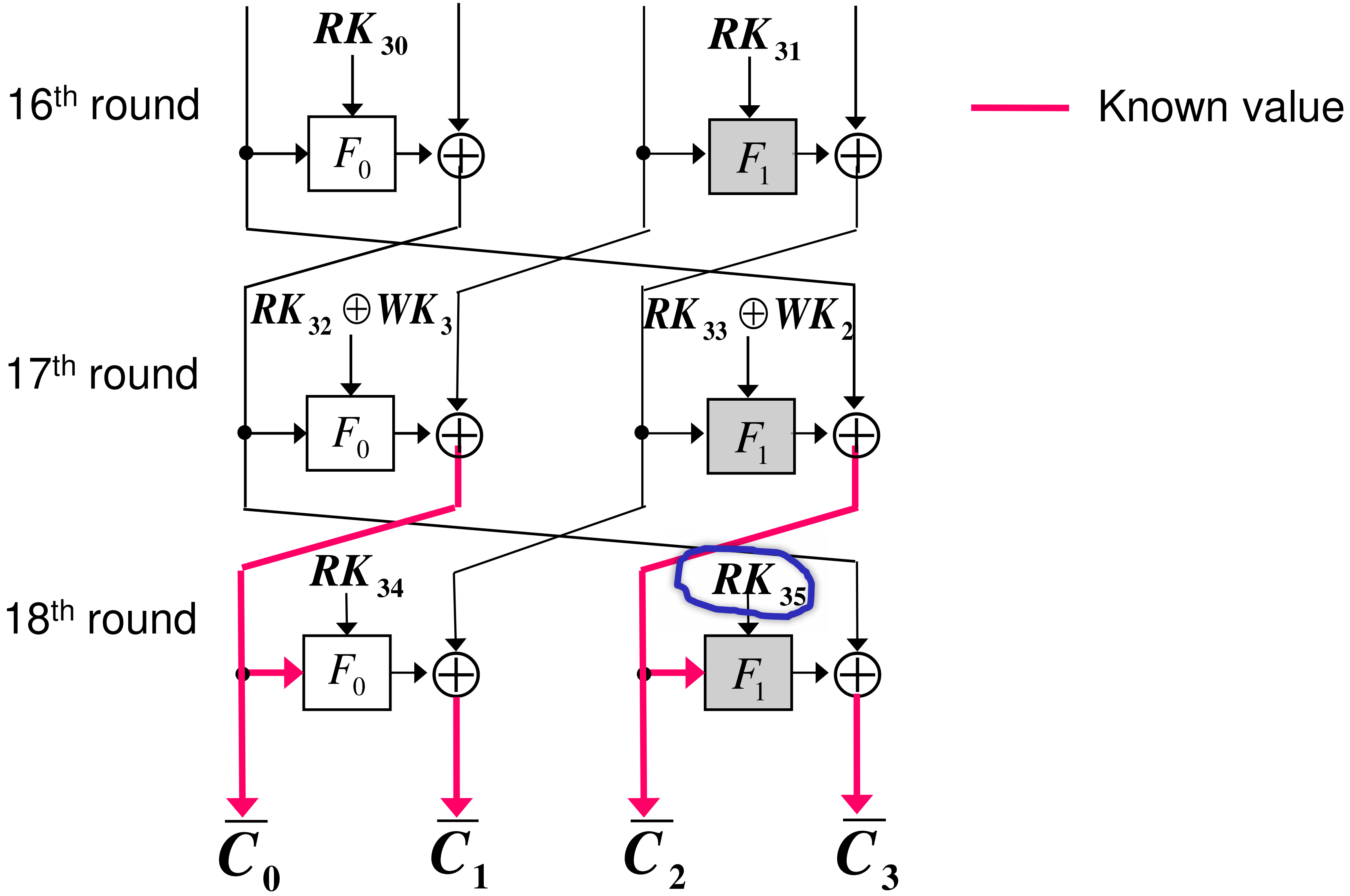
Fault Propagation



Fault Propagation

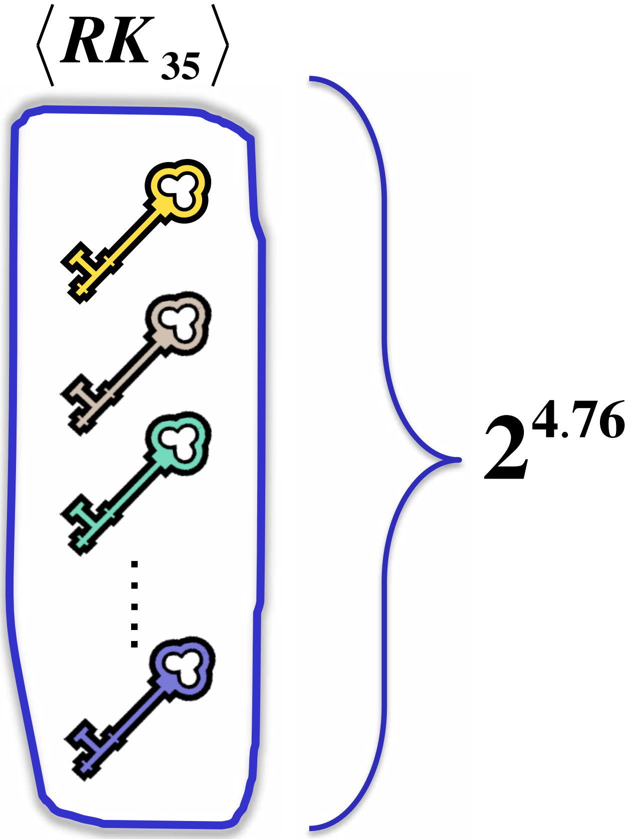


Step1: Obtain <RK_{35}>



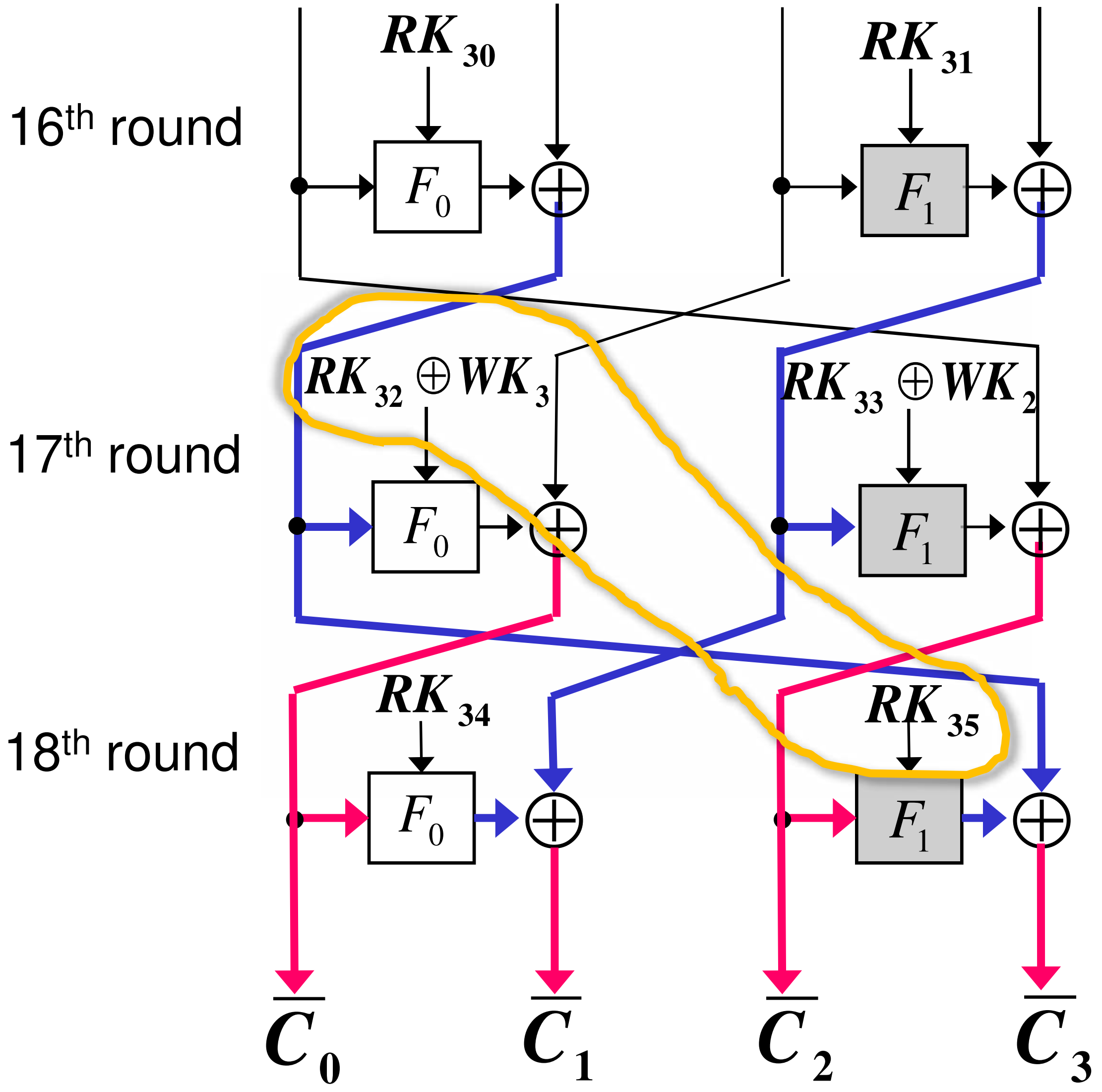
Step1: Obtain <RK$_{35}$> (2)

- Average space of candidate for RK_{35} is $2^{4.76}$



- Also obtain candidates for RK_{34}

Step2: Obtain $\langle RK_{35}, RK_{32} \oplus WK_3 \rangle$



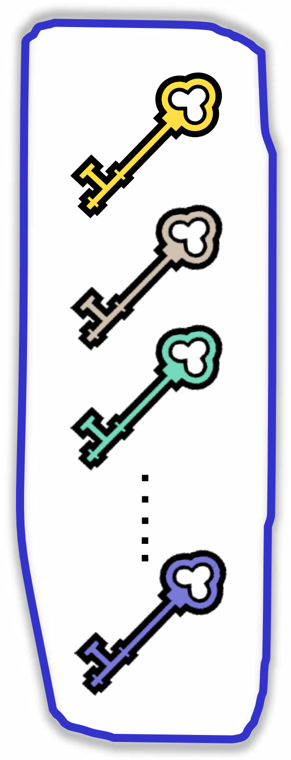
— Known value

— Guessed Value calculated from $\langle RK_{35} \rangle$ and $\langle RK_{34} \rangle$

Step2: Obtain <RK_{35}, $RK_{32} \oplus WK_3$> (2)

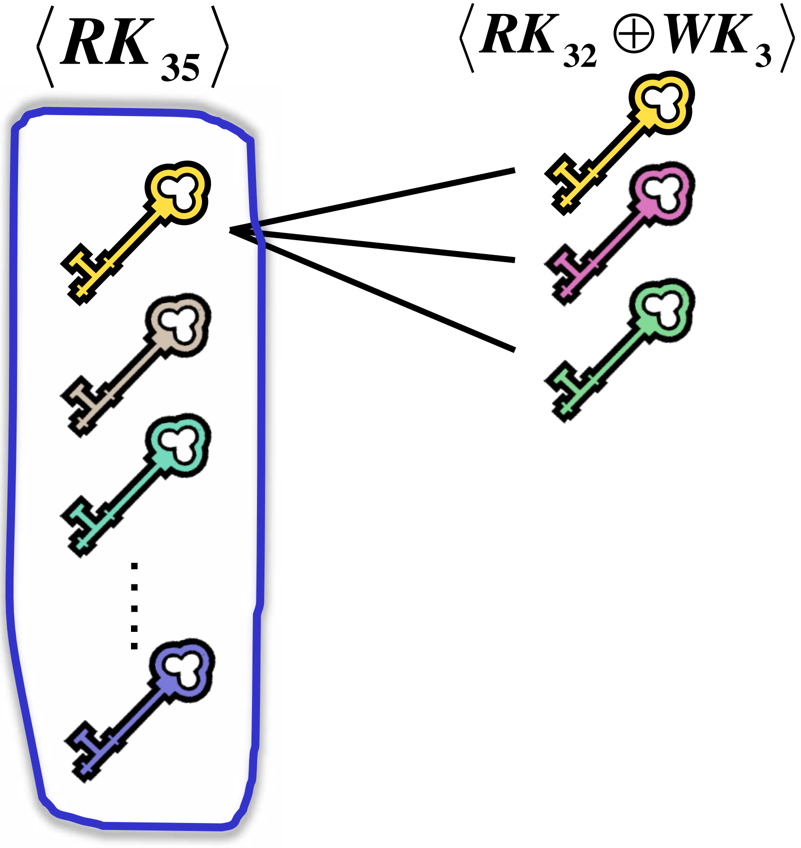
- Solve equation using candidates for RK_{35}

$\langle RK_{35} \rangle$ $\langle RK_{32} \oplus WK_3 \rangle$



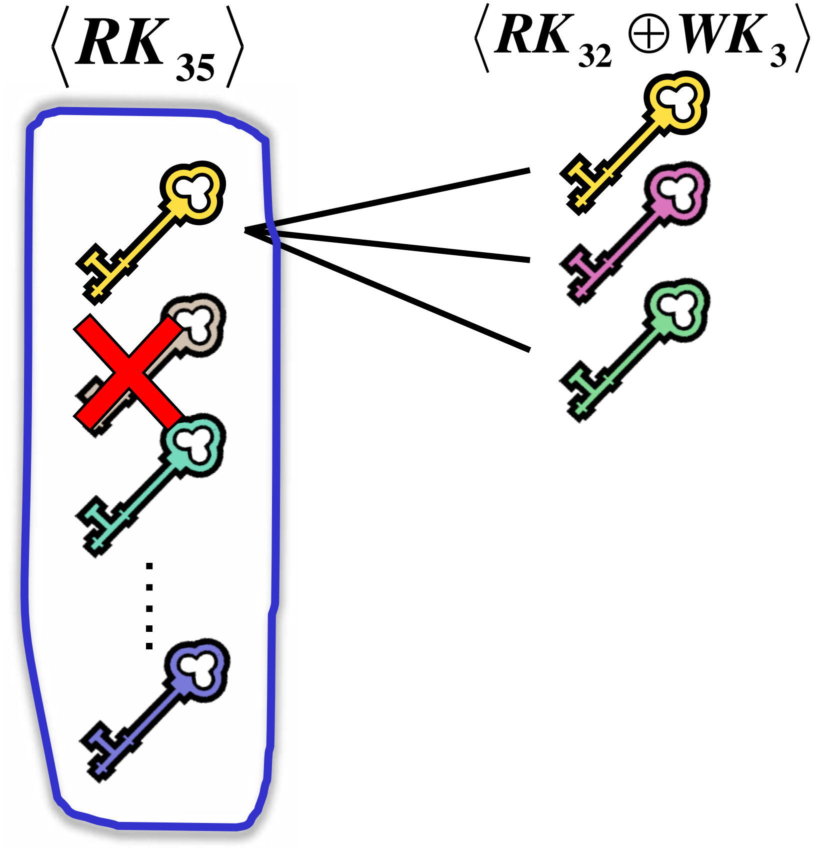
Step2: Obtain <RK_{35}, $RK_{32}\oplus WK_3$> (2)

- Obtain candidates for combination $(RK_{35}, RK_{32}\oplus WK_3)$



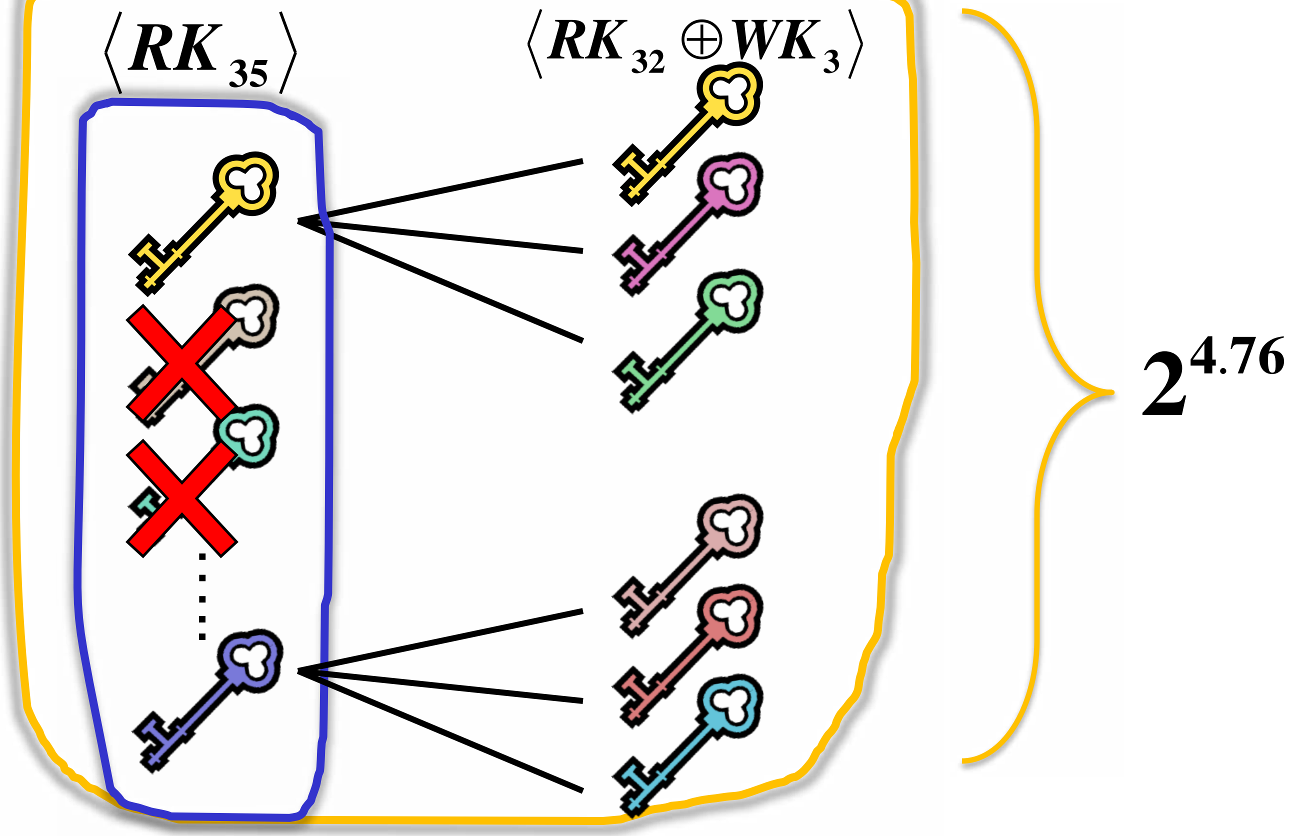
Step2: Obtain <RK_{35}, $RK_{32} \oplus WK_3$> (3)

- Some candidates for RK_{35} is rejected.


$\langle RK_{35} \rangle$
$\langle RK_{32} \oplus WK_3 \rangle$

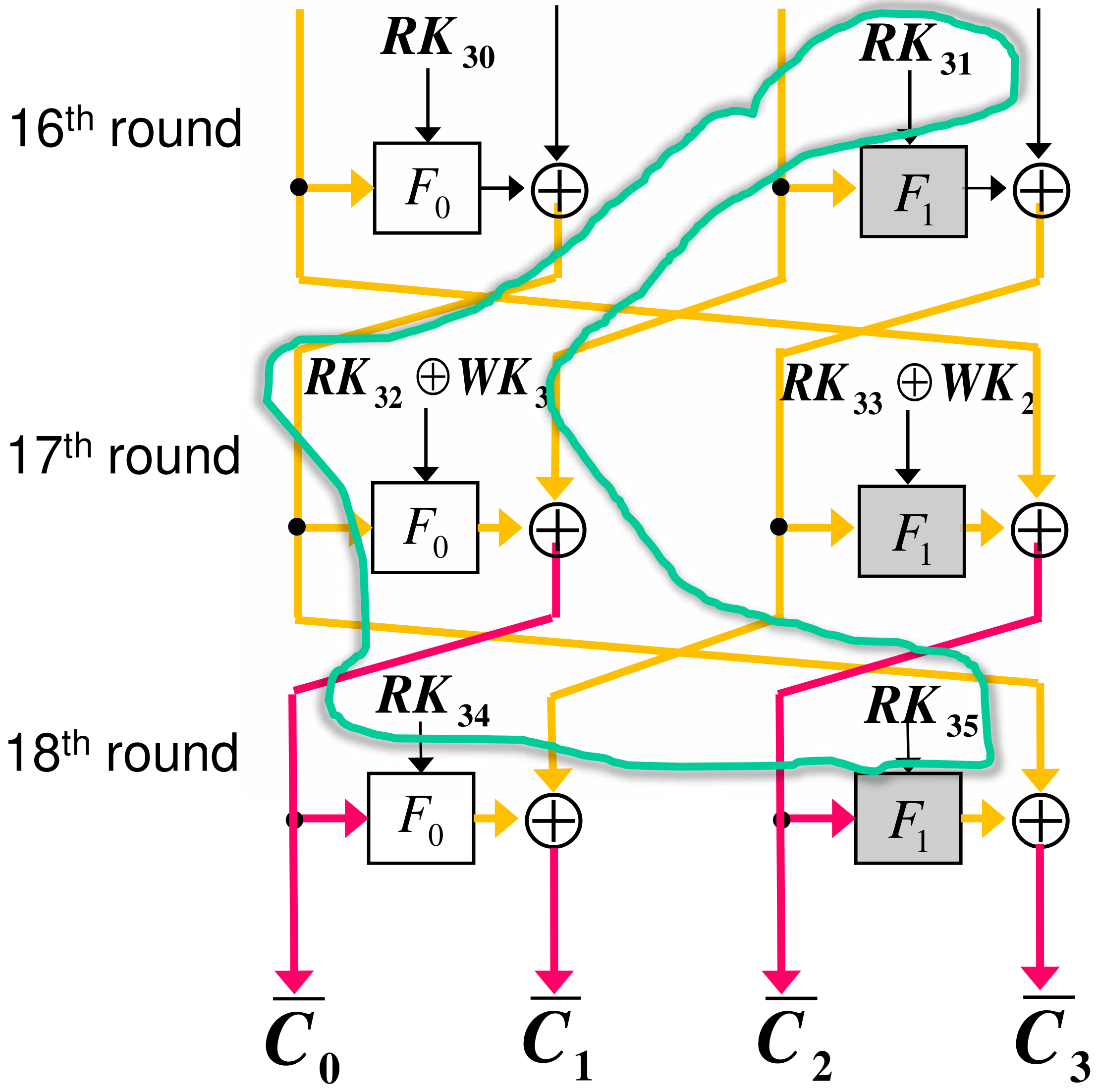
Step2: Obtain <RK_{35}, $RK_{32}\oplus WK_3$> (4)

- Average space of candidates for $(RK_{35}, RK_{32}\oplus WK_3)$ is $2^{4.76}$



- Also obtain candidates for $(RK_{34}, RK_{33}\oplus WK_2)$

Step3: Obtain <RK_{35},RK_{34},$RK_{32} \oplus WK_3$,RK_{31}>

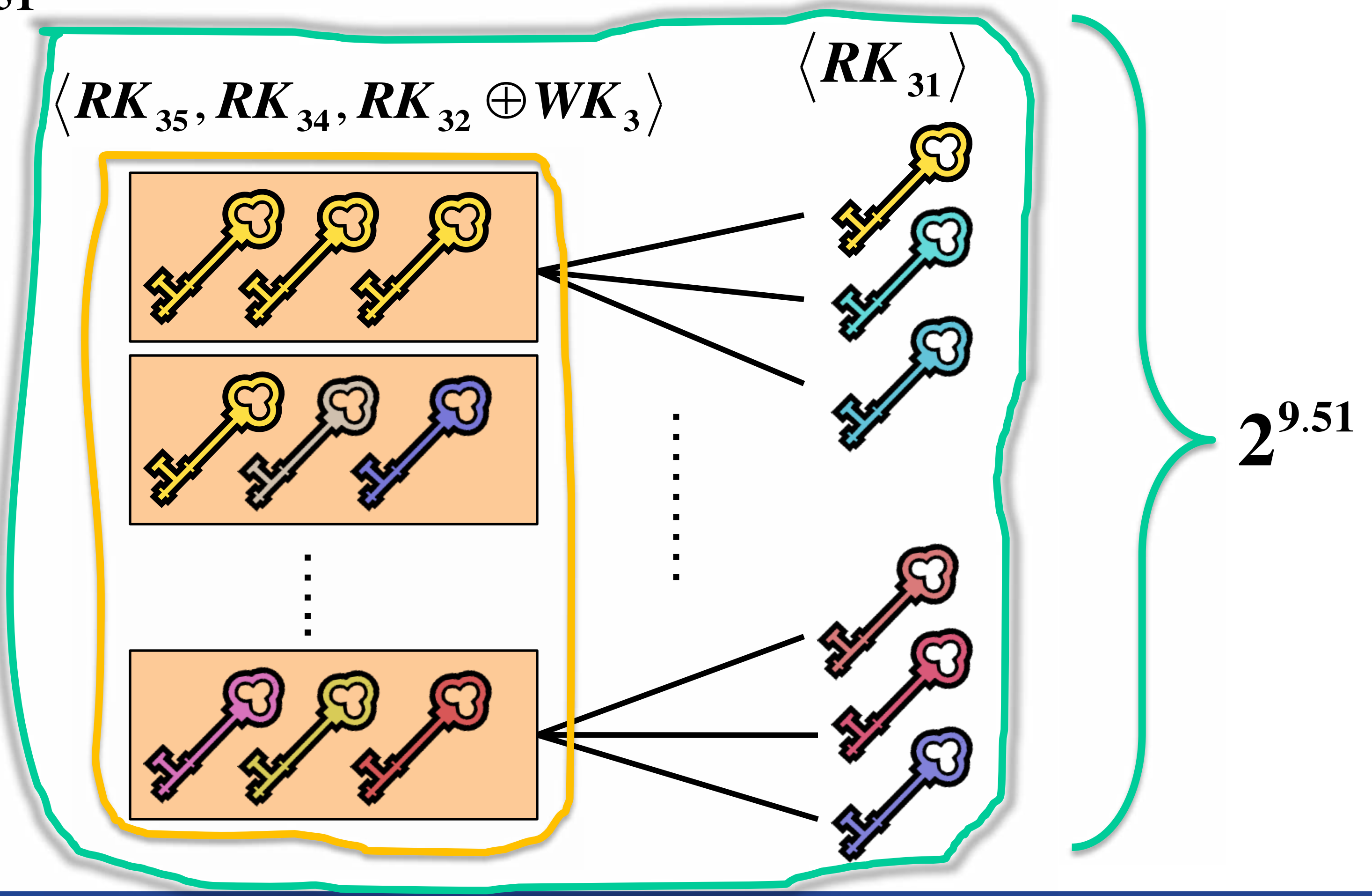


Known value

Guessed values calculated from $\langle RK_{32} \oplus WK_3 \rangle$ and $\langle RK_{33} \oplus WK_2 \rangle$

Step3: Obtain <RK_{35},RK_{34},$RK_{32}\oplus WK_3$,RK_{31}> (2)

- Average candidate space for $(RK_{35}, RK_{34}, RK_{32}\oplus WK_3, RK_{31})$ is $2^{9.51}$

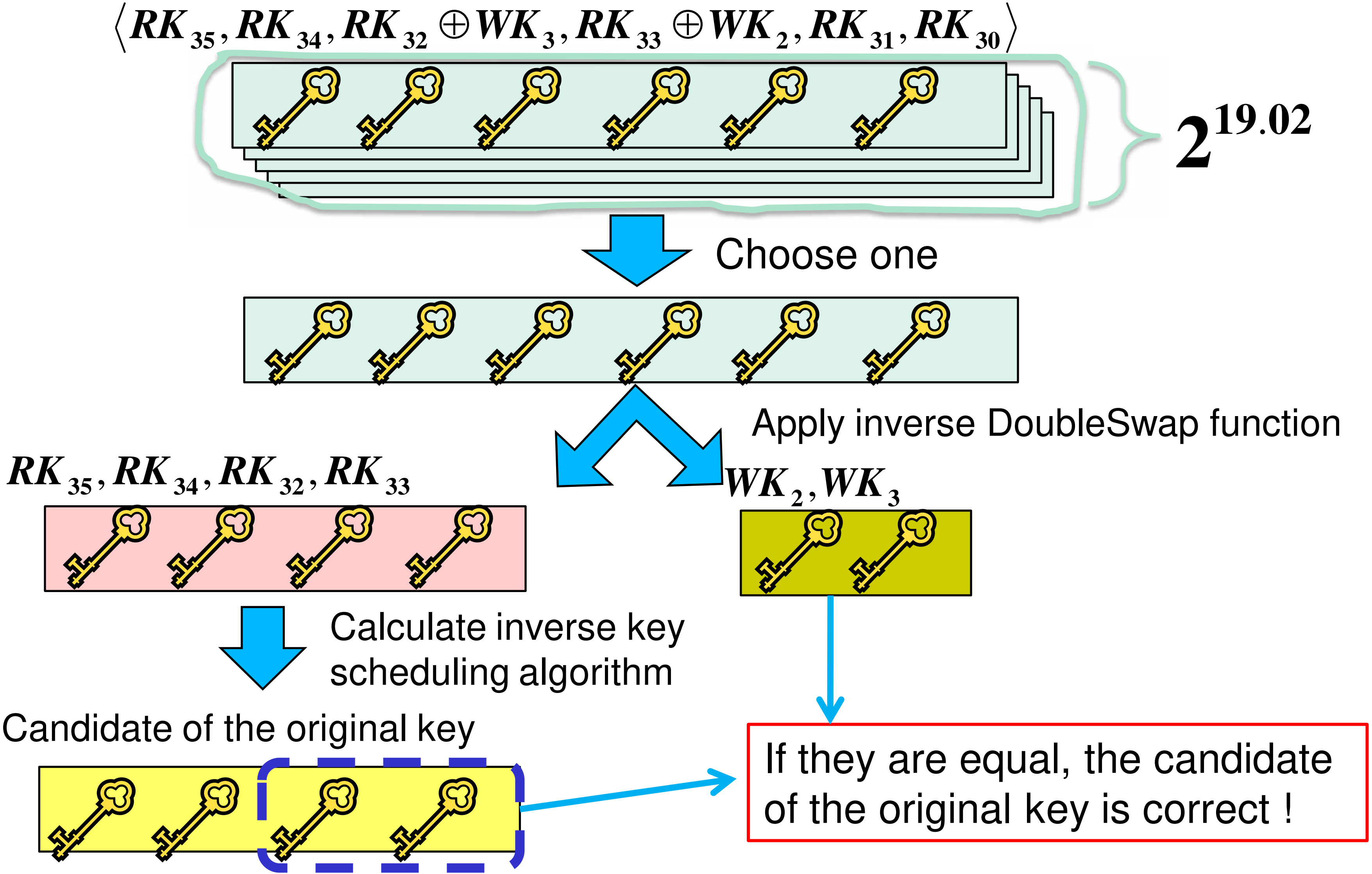


Total Brute-Force Search Space

- Average candidate space for $(RK_{35}, RK_{34}, RK_{32} \oplus WK_3, RK_{31})$ is $2^{9.51}$
- Also, average candidate space for $(RK_{35}, RK_{34}, RK_{33} \oplus WK_2, RK_{30})$ is also $2^{9.51}$
- Therefore, the total average space is $2^{19.02}$

We need average a 19.02-bit brute-force search to obtain 128-bit key !

Step4: Recover Original Key



$\langle RK_{35}, RK_{34}, RK_{32} \oplus WK_3, RK_{33} \oplus WK_2, RK_{31}, RK_{30} \rangle$

$2^{19.02}$

Choose one

Apply inverse DoubleSwap function

$RK_{35}, RK_{34}, RK_{32}, RK_{33}$

WK_2, WK_3

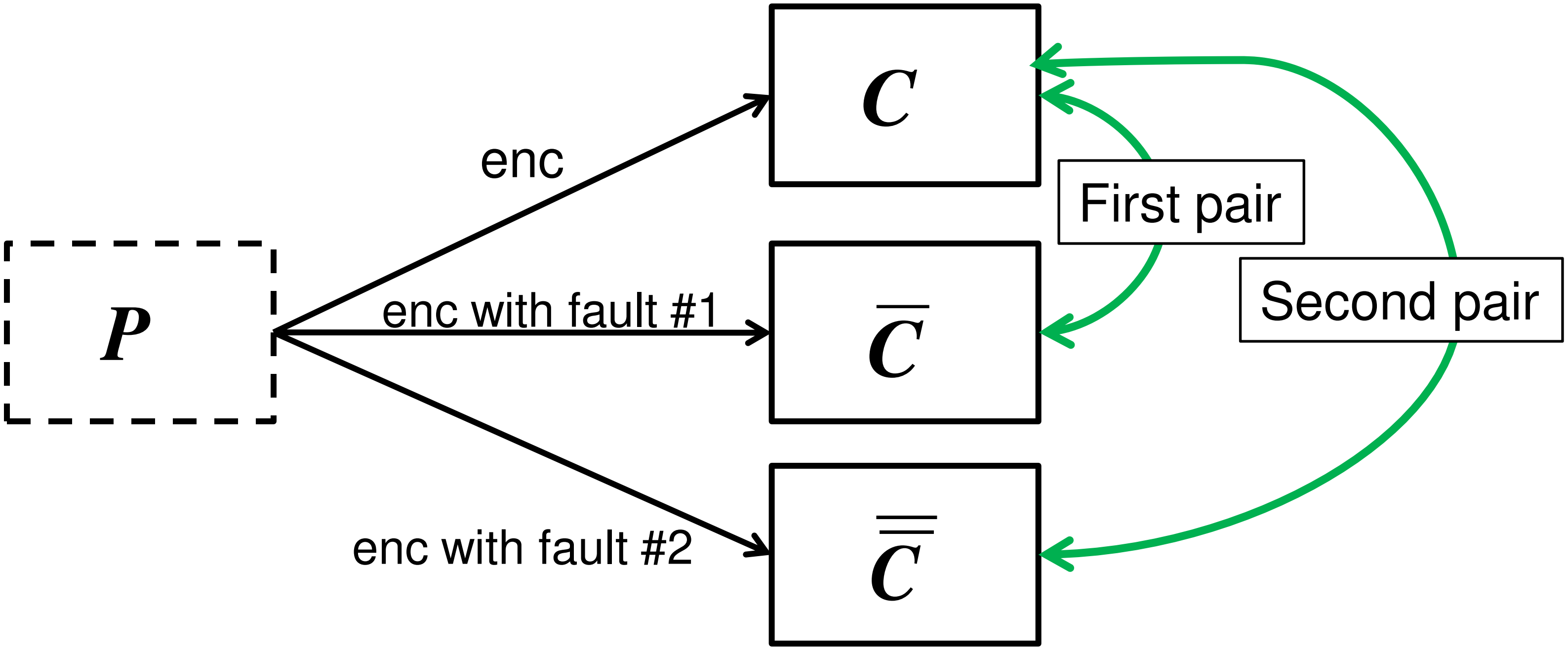
Calculate inverse key scheduling algorithm

Candidate of the original key

If they are equal, the candidate of the original key is correct !

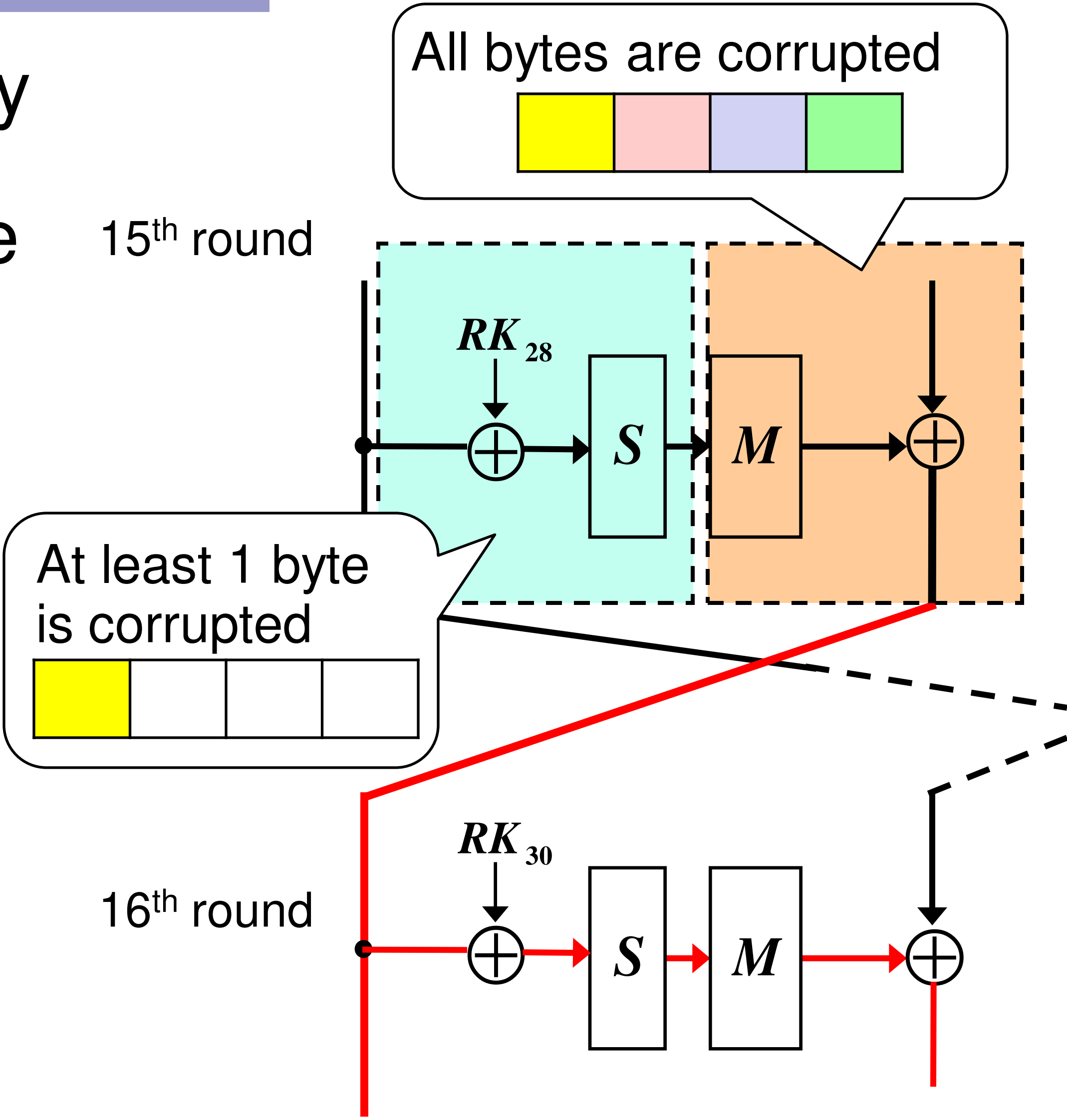
Attack Conditions (1)

- Attacker can obtain two pairs of correct and faulty ciphertexts.
  - He does not need to know the value of the plaintext.



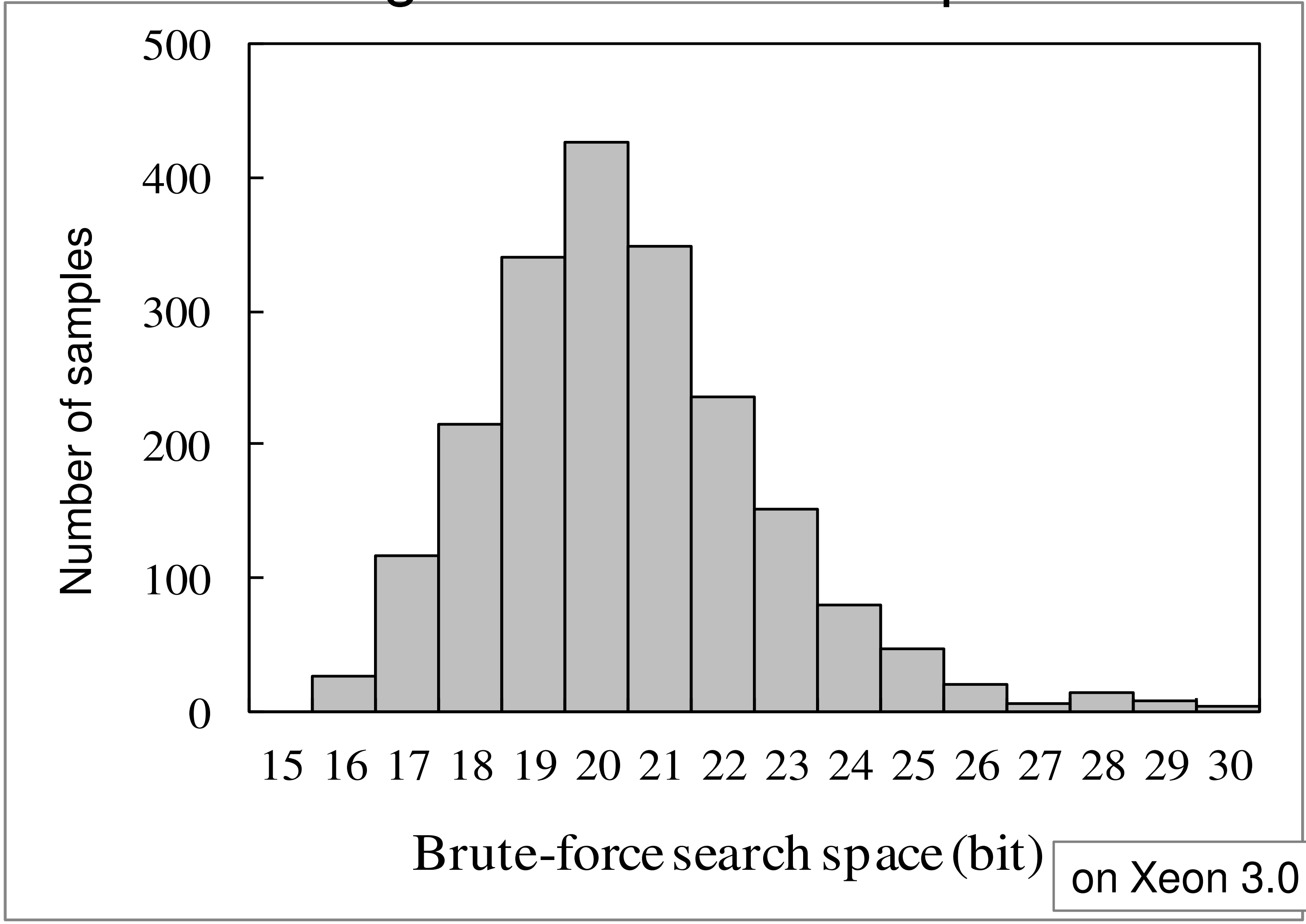
Attack Conditions (2)

- Attacker must randomly corrupt a total of 4-bytes of the input in the 16th round.
  - He does not need to know value of faults.
  - He can choose the convenient ways of fault injection depended on devices.



Simulation Results (B-F Space)

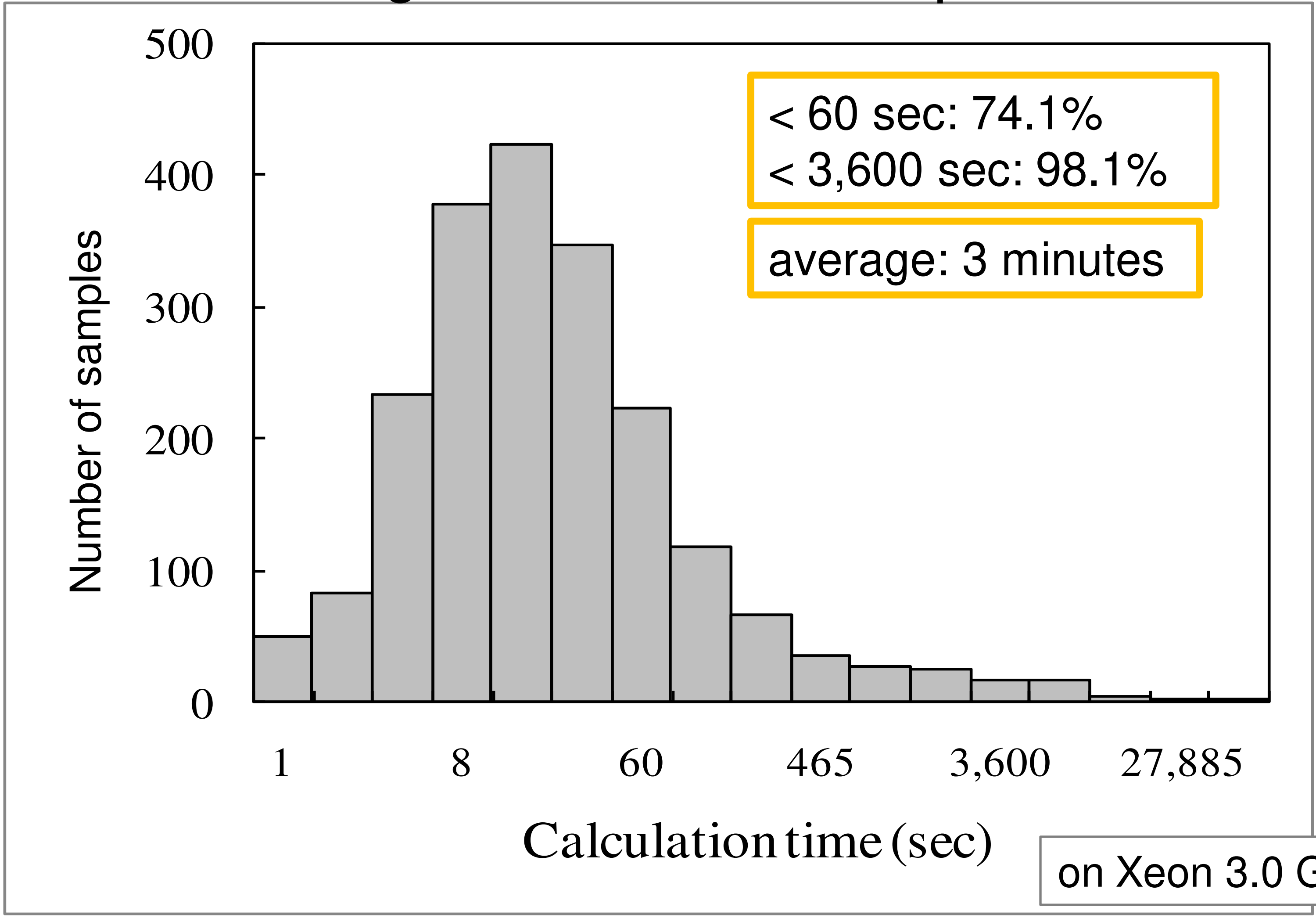
Histogram for 2000 samples



on Xeon 3.0 GHz PC

Simulation Results (Time)

Histogram for 2000 samples



< 60 sec: 74.1%
< 3,600 sec: 98.1%

average: 3 minutes

on Xeon 3.0 GHz PC

- Background
- Previous Study
  - Structure of CLEFIA
  - General DFA Method
  - Chen’s Attack
- Proposed Attack
  - Attack Method
  - Simulation Results
- Conclusions

Conclusion

- Developed efficient DFA on CLEFIA using its 4-branch structure with 32-bit data lines
  - Requires 2 pairs of correct and faulty ciphertexts
  - Average calculation time to obtain 128-bit key is about 3 minutes