SSD Controller for Space Applications

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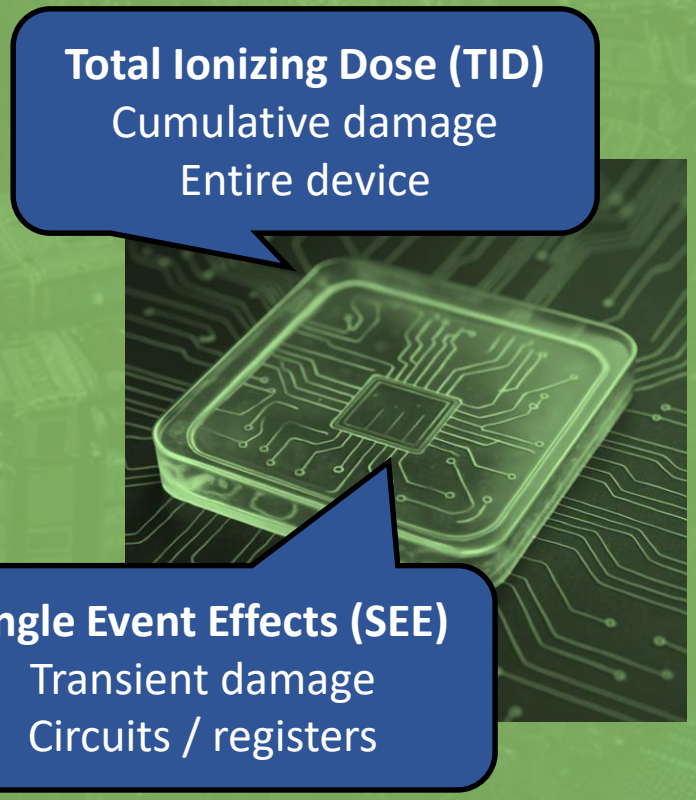
Electronic devices in outer space

1. **Radiation-Hardened (Rad-Hard) hardware**
   - Materials, insulating substrates
   - Redundant circuit
   - Memory ECC
2. **Physical shielding**
3. **Fault Tolerance**
   - Redundant module, data integrity (data path parity).
   - Watchdog timers, self-checking logic.
4. **Software Mitigation**
   - Detect anomalies
   - Reroute HW resources



Challenges of SSD controller in outer space

Controller

1. **Control path fault tolerance**
   - SEU in control logic (especially state machine)
   - FW hanging
2. **Data path fault tolerance**
   - Bit flips during transfer / register
   - Encryption / Scrambler / Encoder
3. **NAND management**
   - FTL / metadata protection
   - Wear out / Retention
   - Power fail

Single event upset (SEU)
Single event transient (SET)
Single event latch-up (SEL)
SEFI
SEB
SEGR

NAND

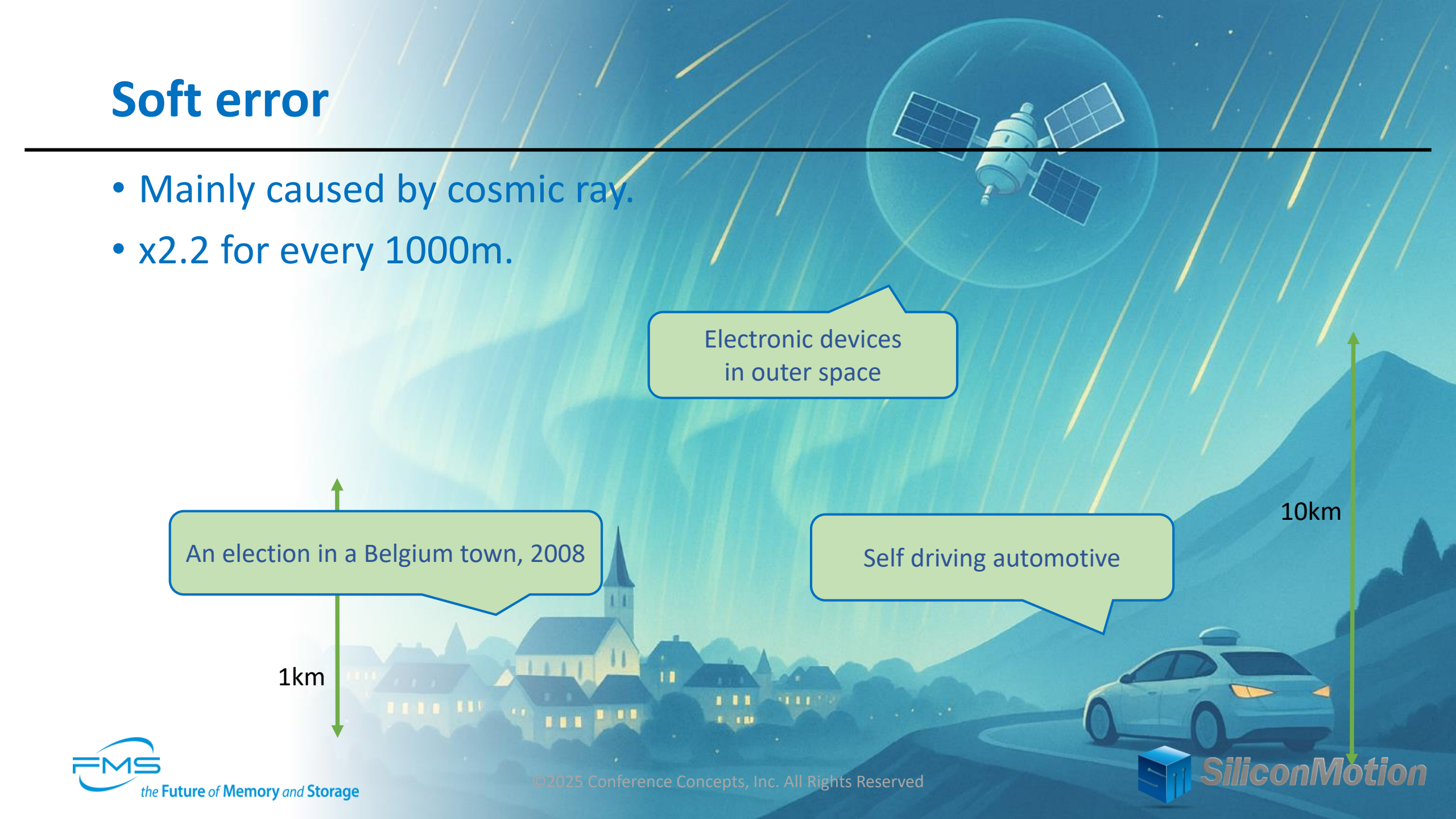
TID
Thermal range

Relatively immune to SEE.

- Passive storage mechanism.
- High threshold to change the amount of charge
- LDPC

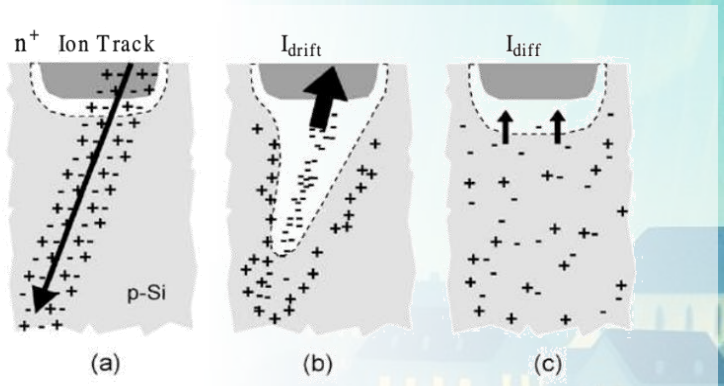
Soft error

- Mainly caused by cosmic ray.
- x2.2 for every 1000m.



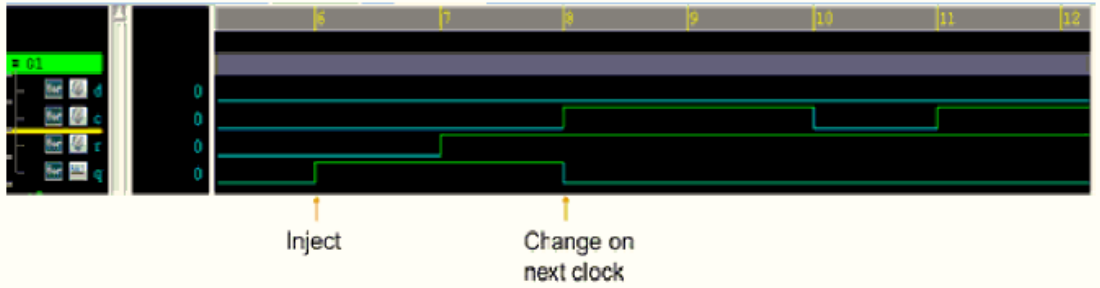
Soft error types

- Single event upset (SEU)
  - Memory or flip-flops
  - Bit flip
- Single event transient (SET)
  - Combinational circuits
  - A voltage spike in circuits



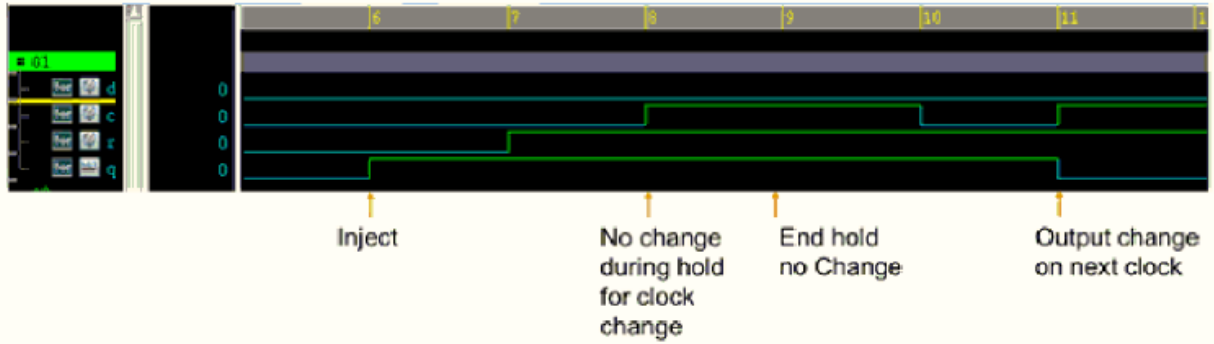
Transient SEU

Example: NA ~ (6) {PORT "test.d1.q"}



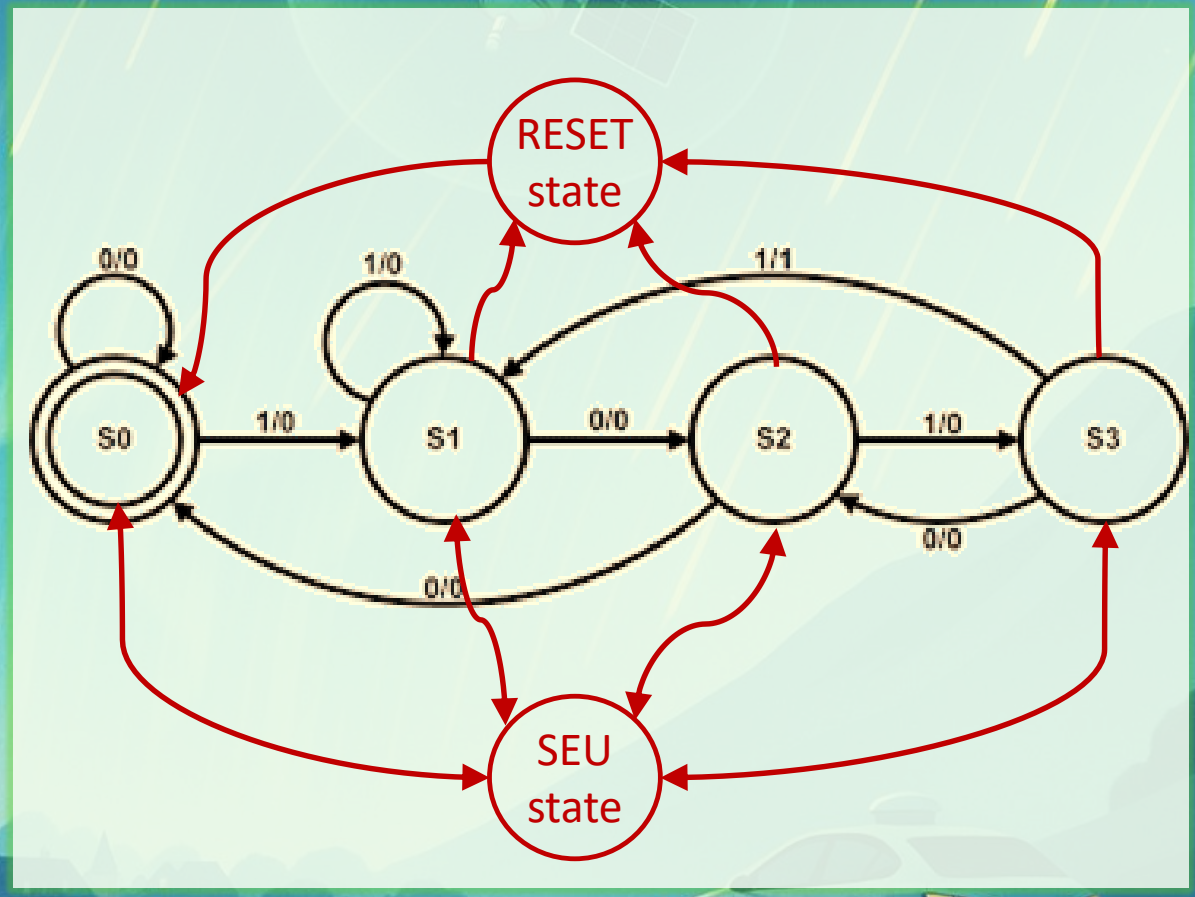
Transient Hold

Example: NA ~ ([6^9]) {PORT "test.d1.q"}



Control path soft error

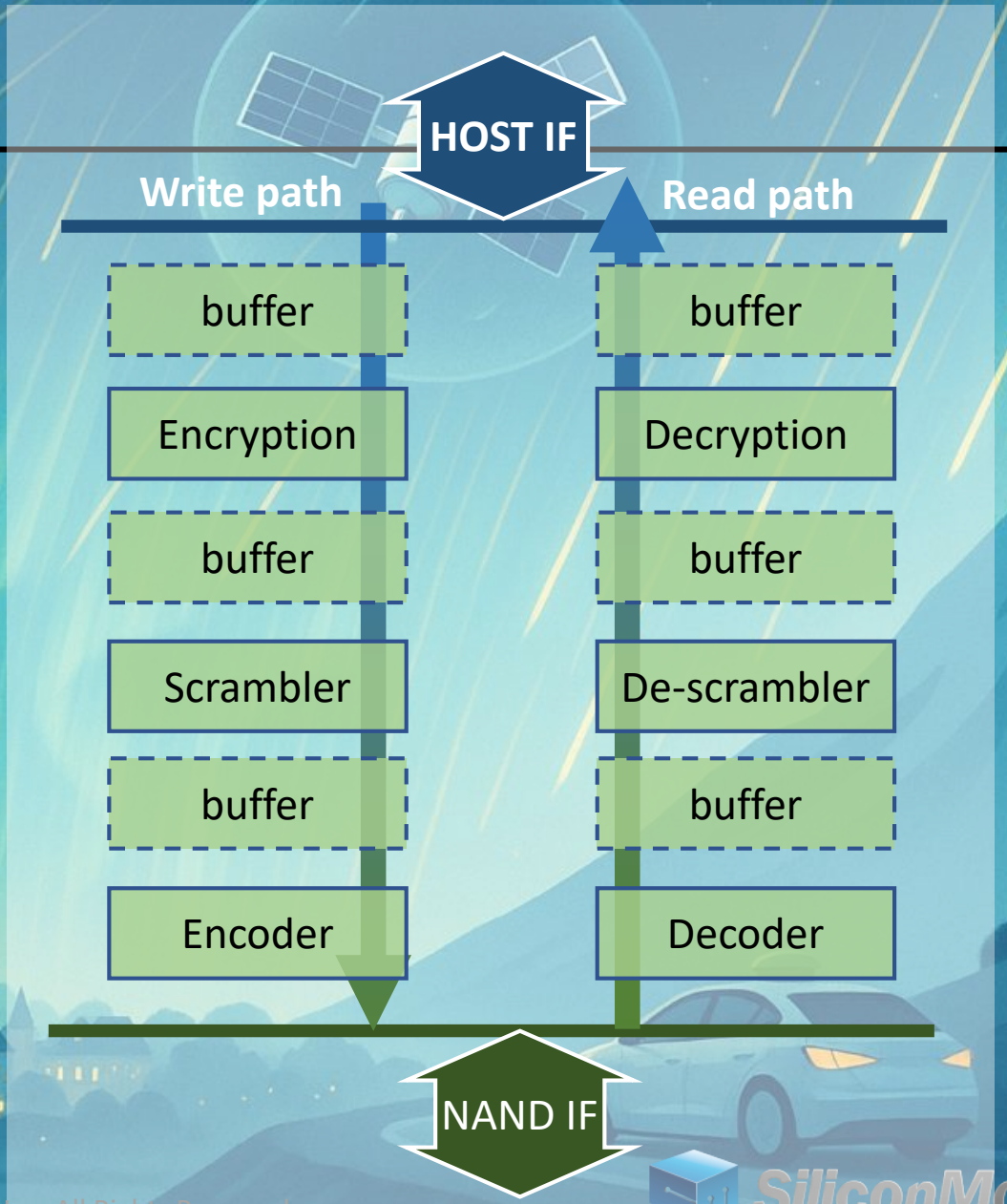
- State registers against SEU
  - ECC for state registers
    - Ex. One-hot states + Hamming code
    - Validate state registers
    - Detection and recovery
    - Correction to original state
- State transition signals against SET
  - Validate state transition signals
    - Time and space redundancy.
    - Hand shake.
    - Use levels instead of pulses.
- Design with atomicity principle



Data path soft error

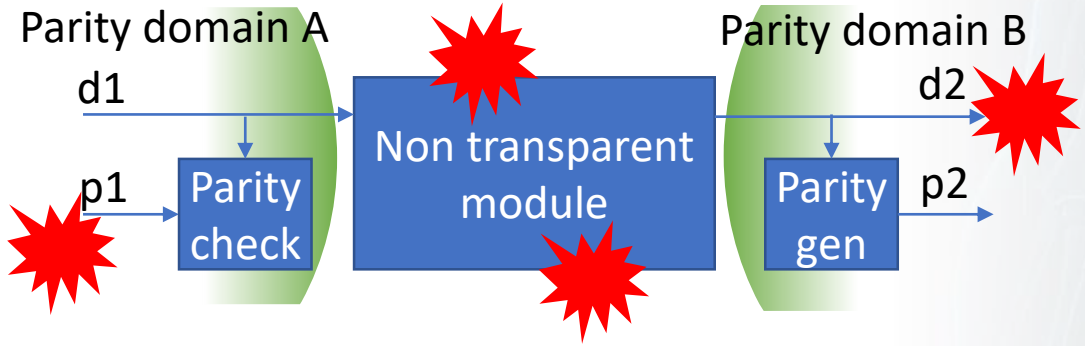
- Host E2E / data parity
  - Check the entire path
- Memory scrubbing
  - Protect buffers
- Encryption /decryption
- Scrambler
- LDPC

Difficult!
Especially for the write path

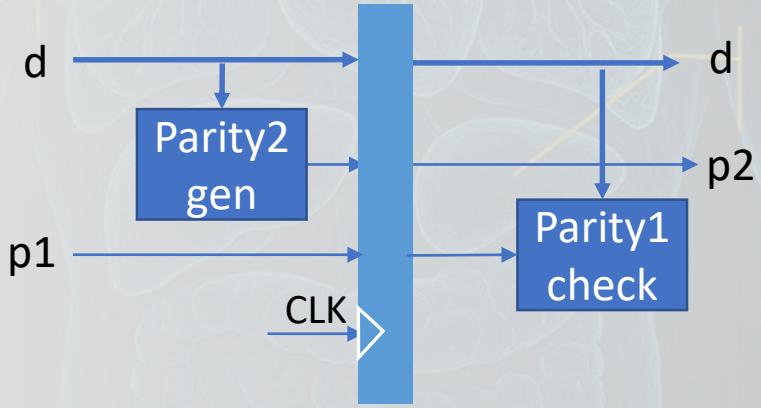


Non-transparent modules

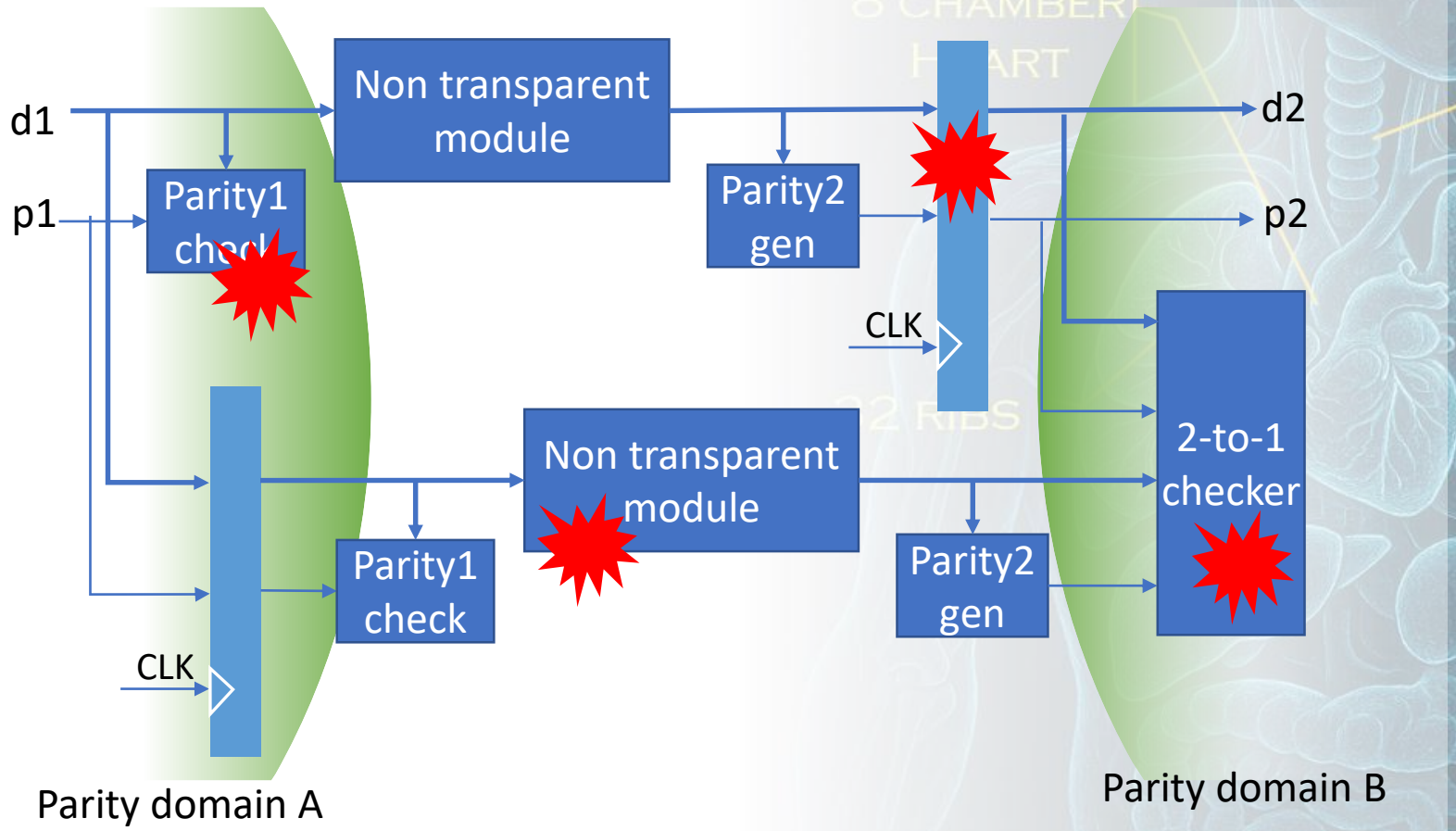
- Encryption, Compression, Scrambler, Encoding … etc
- Invalidate existing parity or ECC
  - Data is modified intentionally.
- Isolate parity domain



Parity overlapping

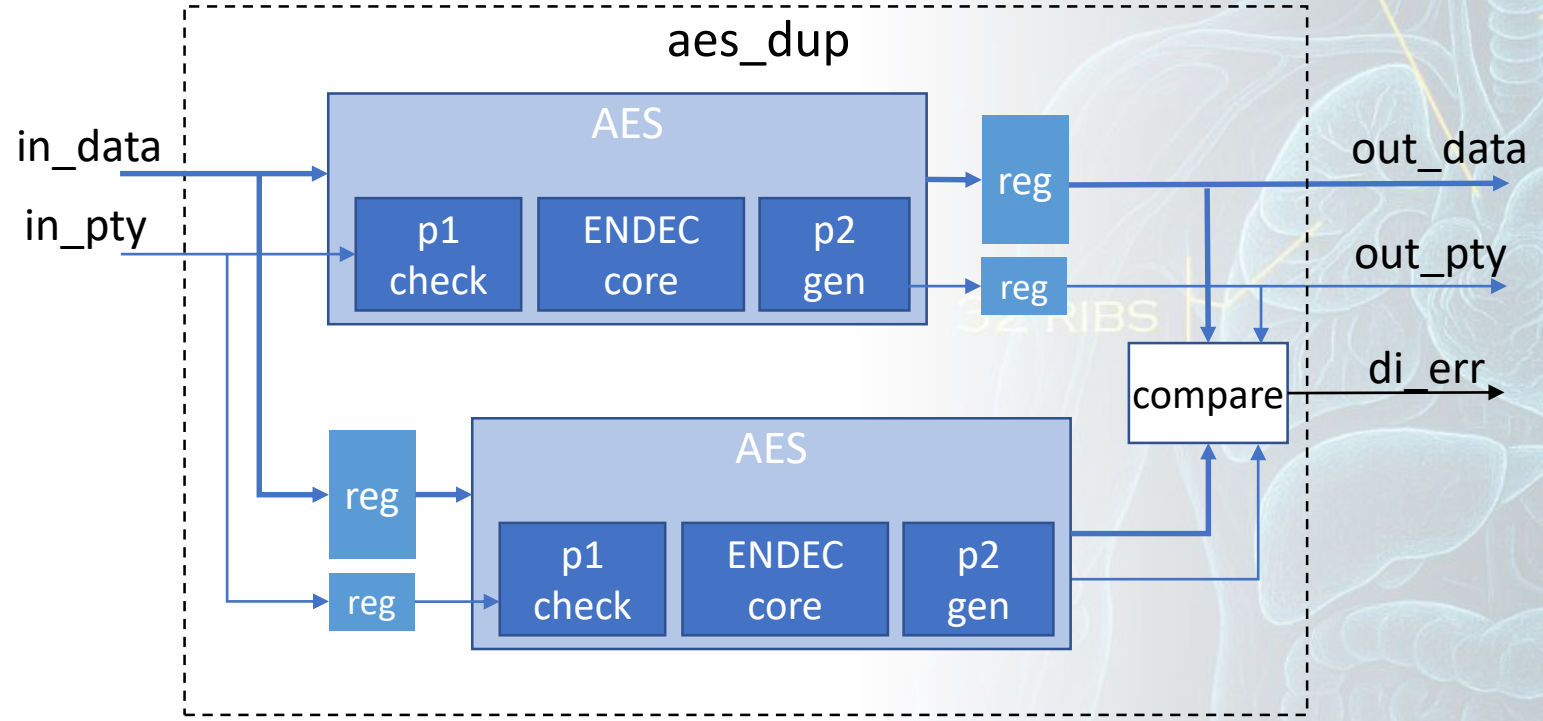


Non-transparent modules

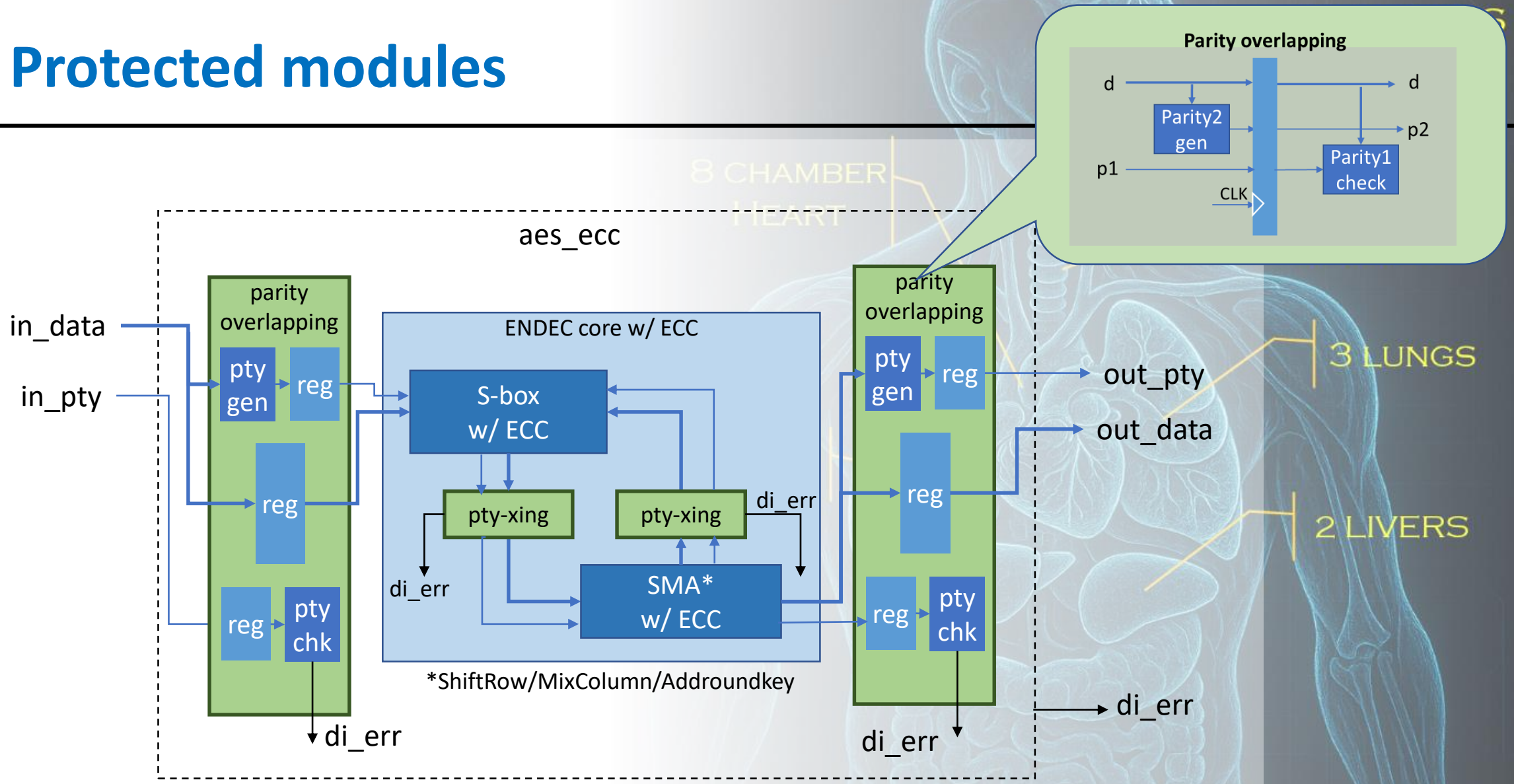


Duplicated modules

- How about huge module like AES?



Protected modules



Comparison

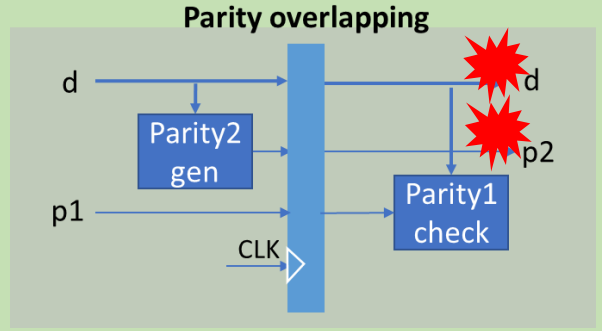
HW results

AES endec	area	Average power	Peak power
Duplication	149k	16.5	21.1
ECC Protection	120k	12.1	15.2
	80.53%	73.3%	72.04%

Fault simulation

AES endec	Total injected fault	Non detection rate
Duplication	39489252	0.48%
ECC Protection		0.89%

Fault at output interface, will be detected at the next stage.



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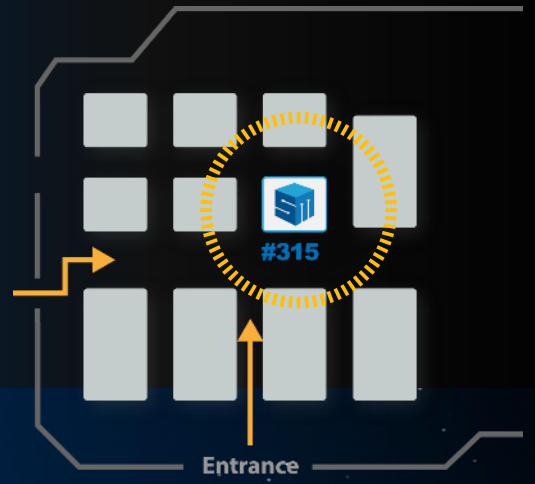

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