Triple-Modular Redundancy Deployment Optimization in the Sensor Readout System of the CBM Micro Vertex Detector

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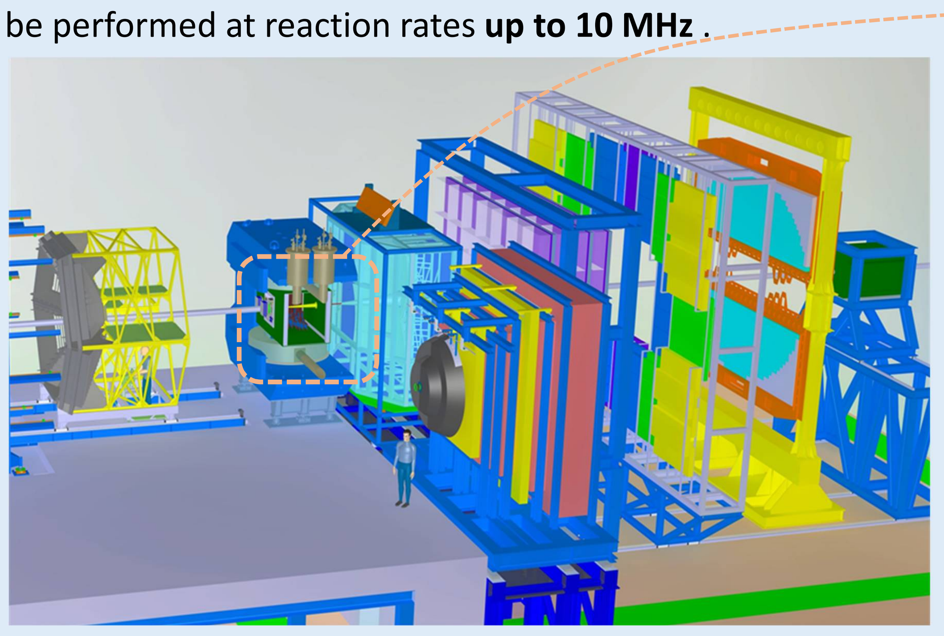
ABSTRACT

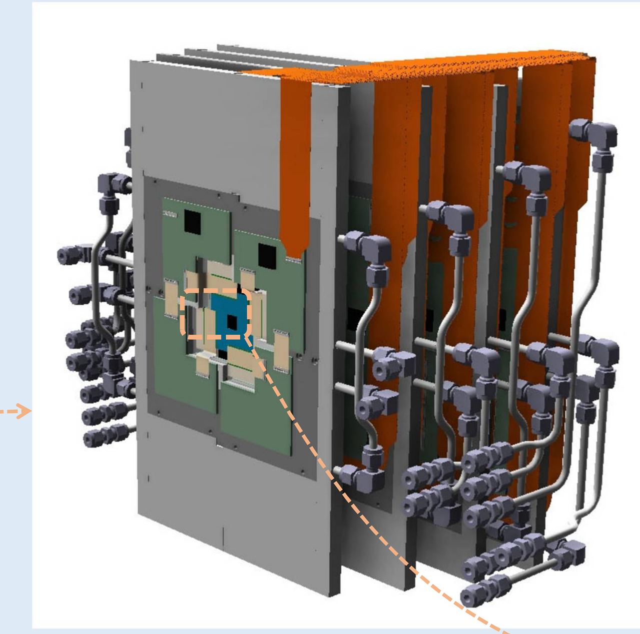
This poster presents the deployment and optimization process of triple-module redundancy (TMR) under high design constraints against single-event upset (SEU) and single-event transient (SET). It includes modeling of single-event effects (SEE) pulses with TCAD mesh model, TMR deployment strategies, and verification methods. The simulation result shows that the prototype with optimized TMR deployment has high reliability with respect to design requirements. The system can run for more than 5 years without crucial errors. And the equivalent error rate in the working environment is lower than 10^{-9}.

CBM-MVD

Compressed Baryonic Matter (CBM) experiment

The goal is to explore the **strong nuclear interact** in the region of high baryon densities using high-energy nucleus-nucleus collisions. In order to achieve the required precision, the measurements will be performed at reaction rates **up to 10 MHz** .

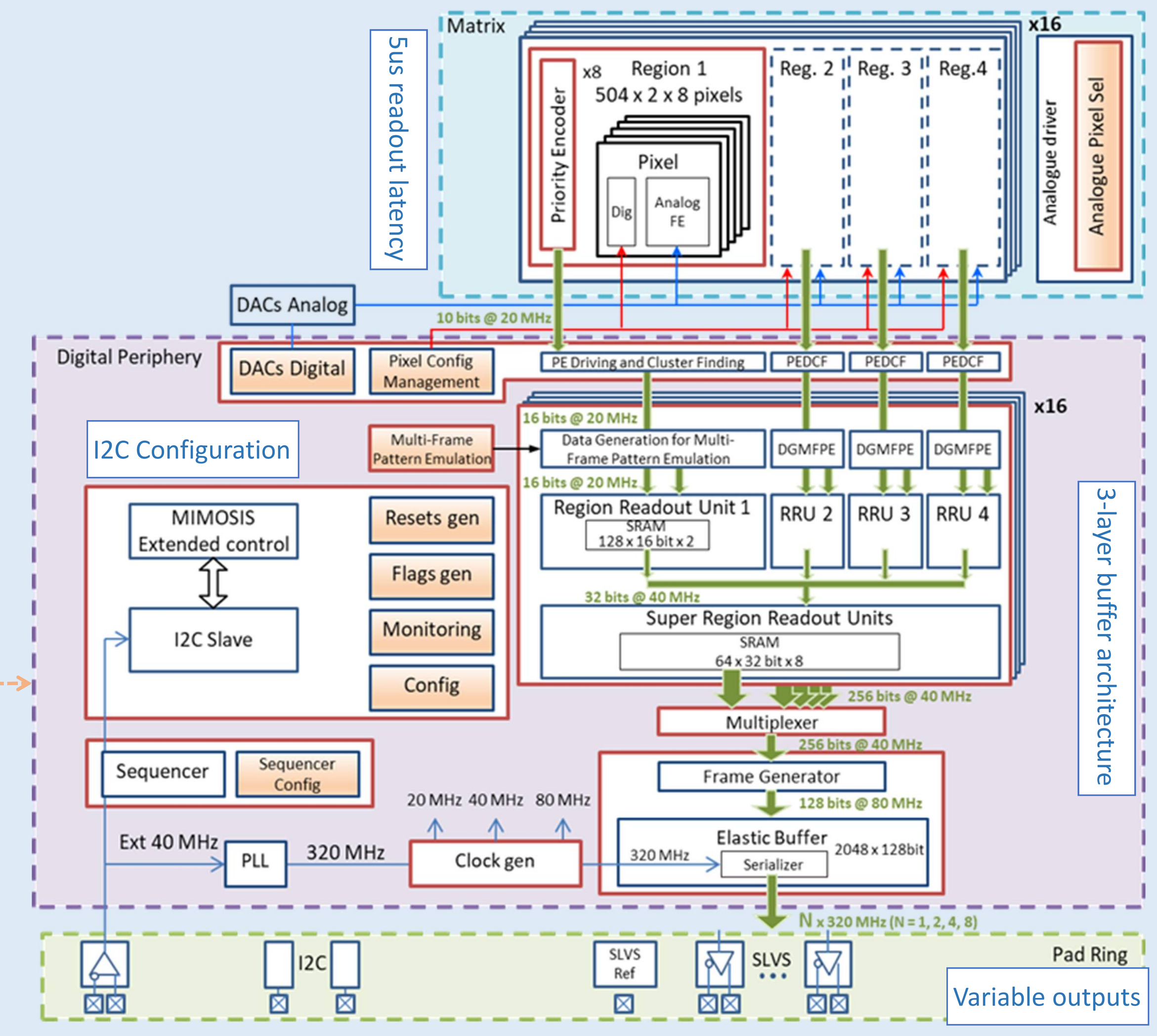




MIMOSIS-1

- MAPS : ~3x2cm^2
  - 80% area = pixel matrix
  - 80% design = digital logic
- 3-layer buffer to reduce the readout data rate
- **Radiation tolerance**
  - **Highly ionizing particles impact**
  - **TMR is good solution**
  - **But it uses too much room to deploy everywhere**

➔ Need Optimization

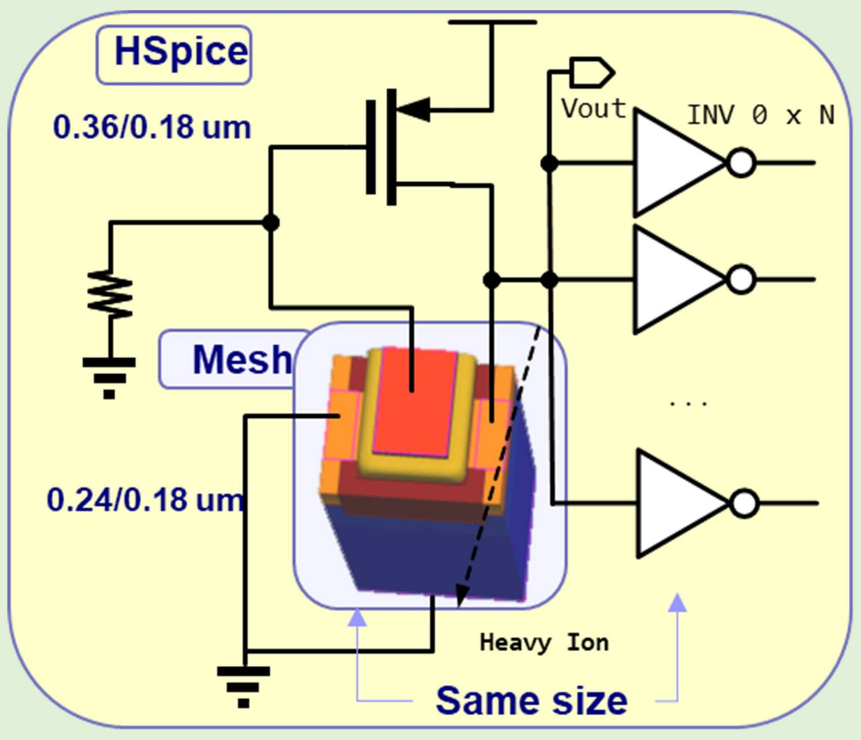


Micro-Vertex-Detector (MVD)

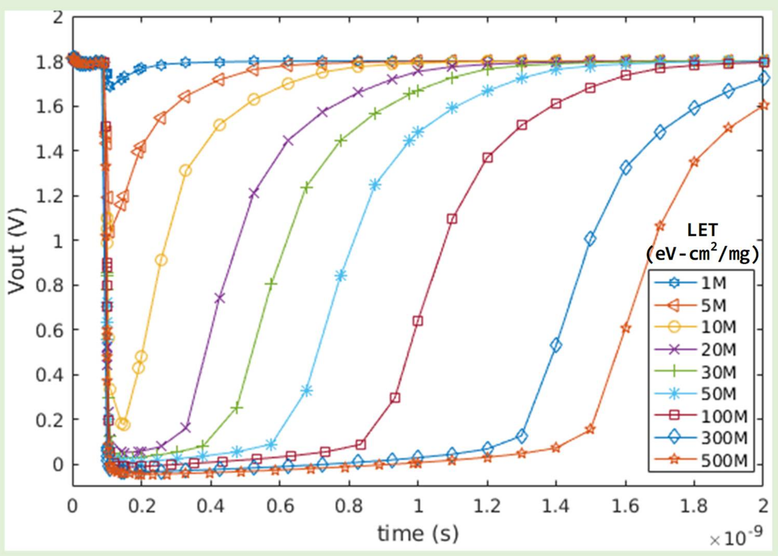
- The MVD is situated in the target spectrometer and is **the closest detector part** with respect to the primary interaction vertex.
- The MVD is a **tracking device** for charged particles and thus essential for a very precise determination of secondary decay vertices of **short-lived particles** such as hyperons or mesons with charm or strangeness content.
- The MVD is exposed to the environment of **highly ionizing particles**. There is an urgent need for protections to ensure the correct operation of the MVD.

SEE Pulse Characteristics

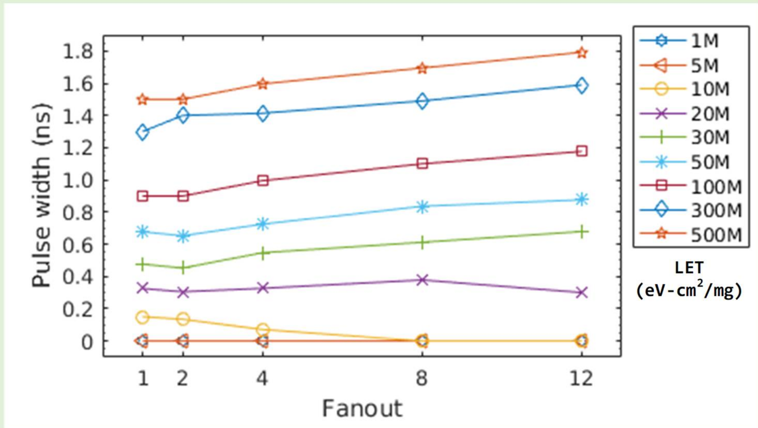
- Identity the type and energy of impact particles
- Simulate the LET range of the particles
- Simulate circuits response in TCAD



TCAD Simulation Input

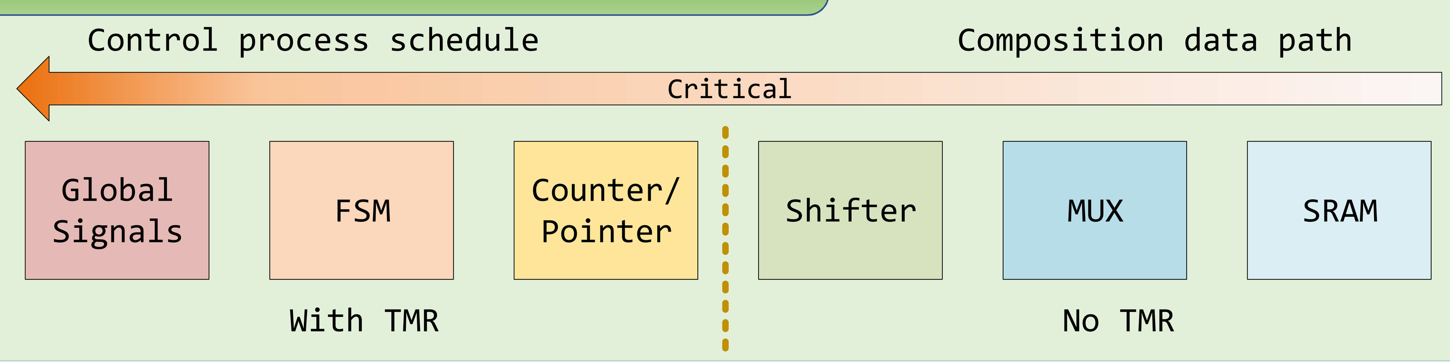


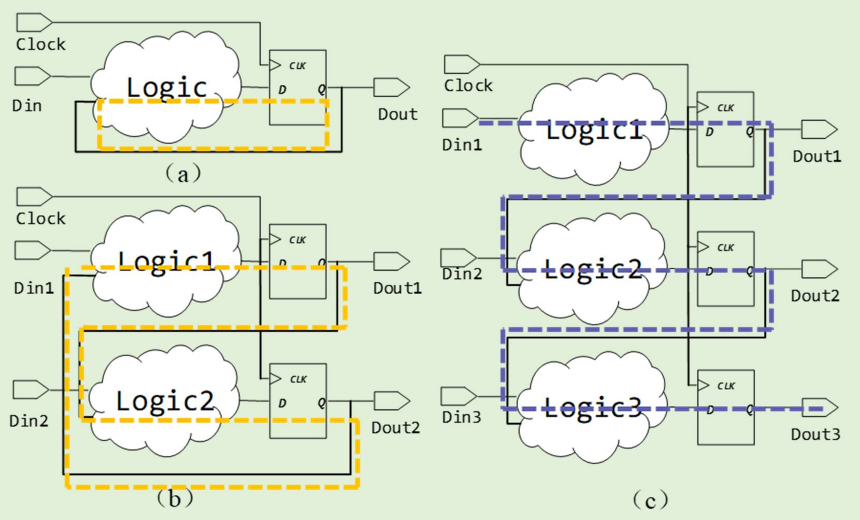
Voltage shift VS time under different LET (Fanout = 1)



Pulse width VS fanout under different LET

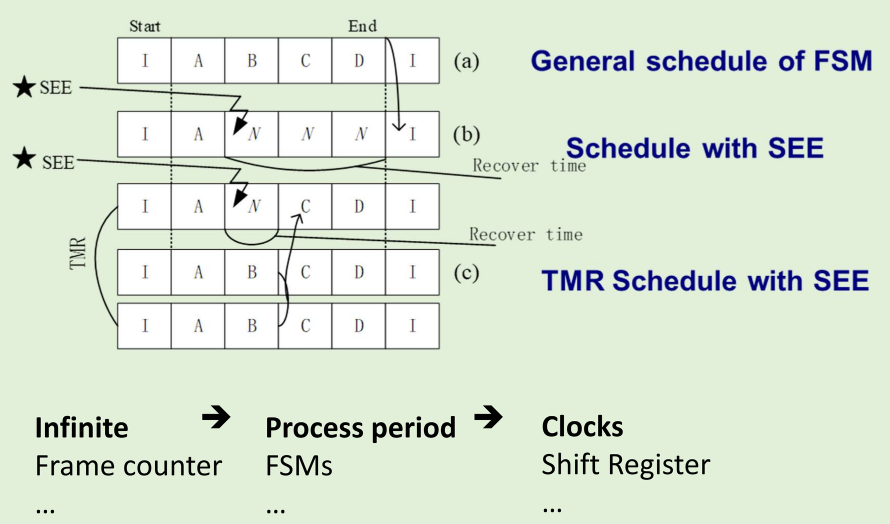
TMR Deployment Strategy





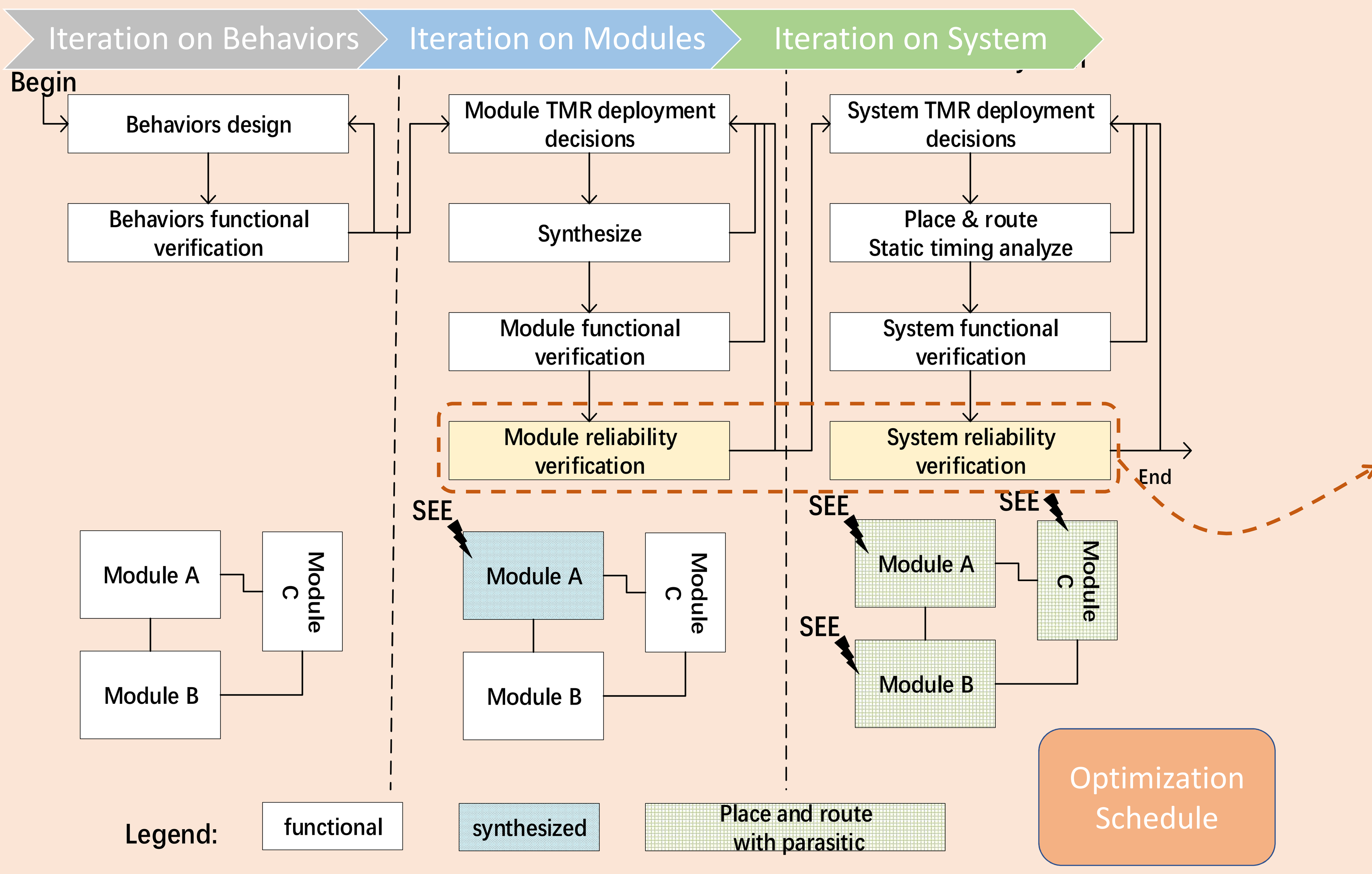
Loop replicates errors — No error replicated

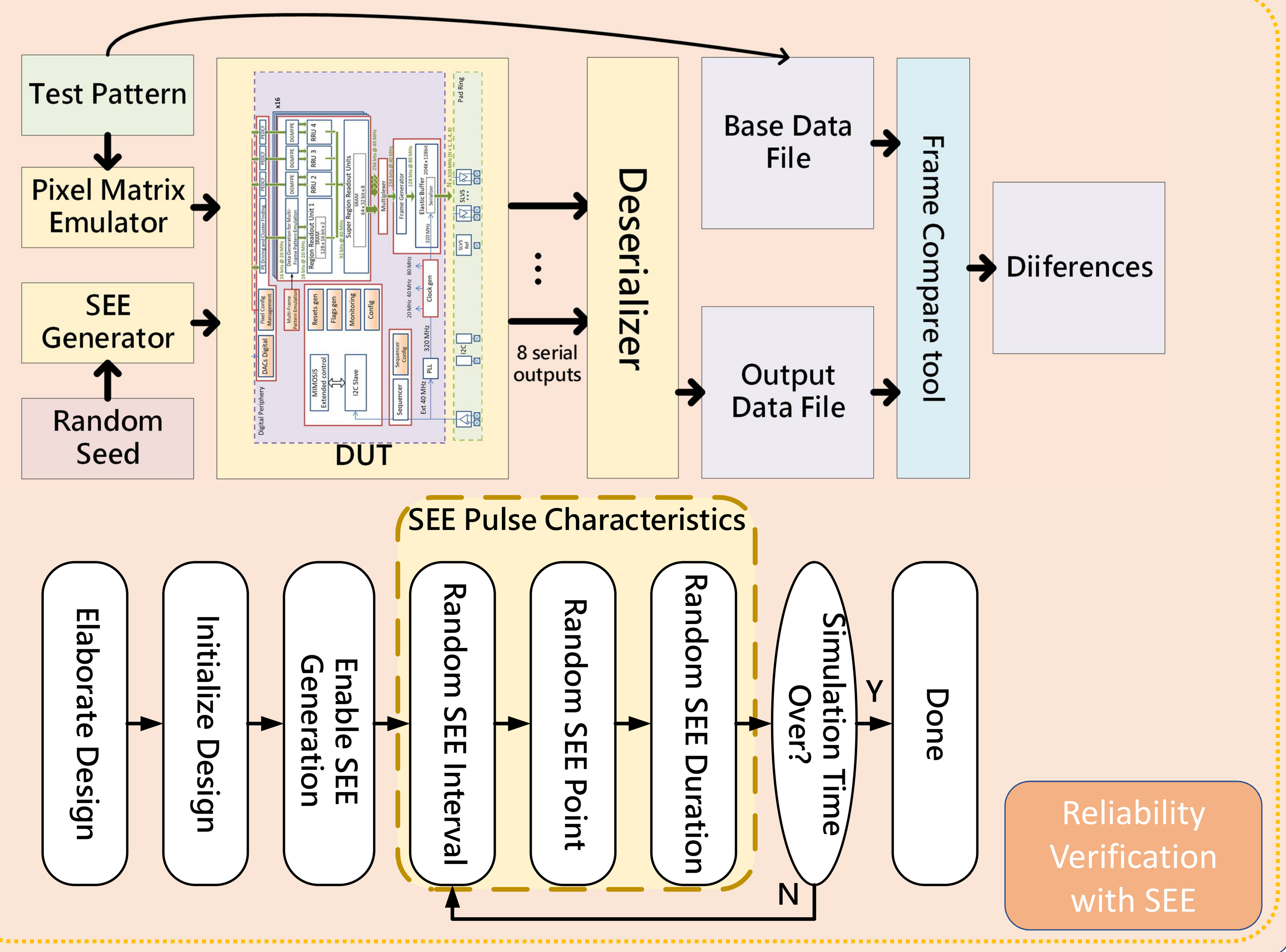
TMR Needed — TMR Not-needed



The recovery time of an FSM is also considered.
➔ TMR helps to guarantee the recovery time of FSM within 1 clock cycle.

Optimization & Verification





Results & Conclusions

- The TMR deployment strategy is a low-cost method to design high reliability circuits.
- The SEE model and verification method guide us to optimize the design with respect to requirements.

	Before	After Optimized TMR
Area (mm^2)	43.47	50.56 (+16%)
Mean time to failures (with SEEs to crucial failure)	< 100	>10^7
	≈ 10min	≈ 5 years
Error rate (data errors/SEE)	>1000	0.135
	Too high to measure	≈10^{-9} in working condition

References

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