

Systems-Focused Analyses of Flash Memory Data Loss Mechanisms

Ted Wilcox

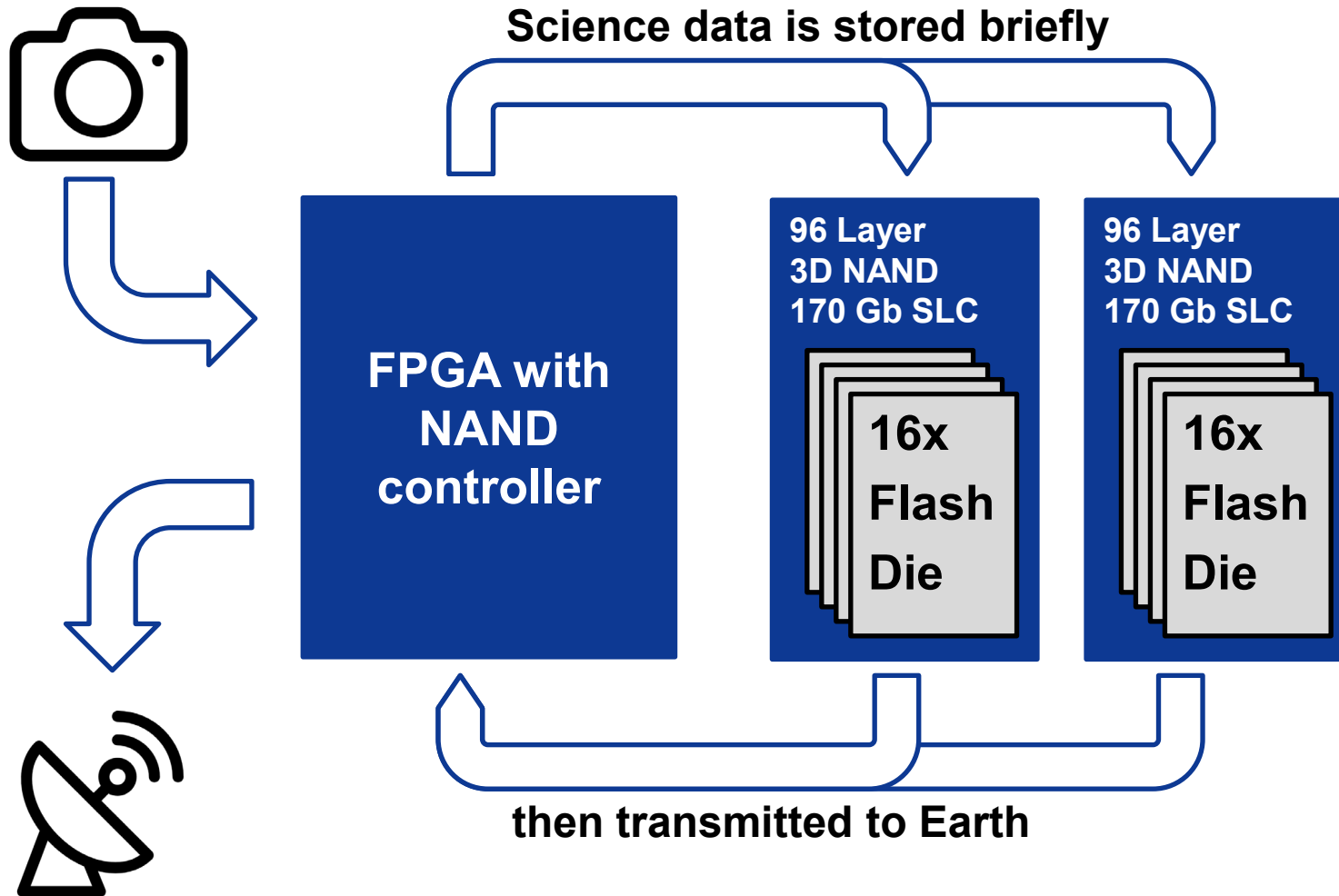
NASA Goddard Space Flight Center



The road here...

- **SEEMAPLD 2022:** “Risk-Driven and Mitigation-Focused SEFI Testing of NAND Flash Devices”
- **ETW 2022:** “Focusing on NAND Flash SEFI Susceptibilities”
- **RADECS 2022:** “Risk-Driven and Mitigation-Focused Single-Event Functional Interrupt Testing”
- **SEEMAPLD 2023:** “Applied SEE Test Data: Modern NAND Flash”

Recent system case study (SEEMAPLD '23)



Radiation Questions Arise:
Is the system sufficiently radiation tolerant?

Threats addressed:
SEU / SEFI / SEL

But, radiation isn't the only threat to the system.

Let's think a little more broadly when producing radiation analyses.

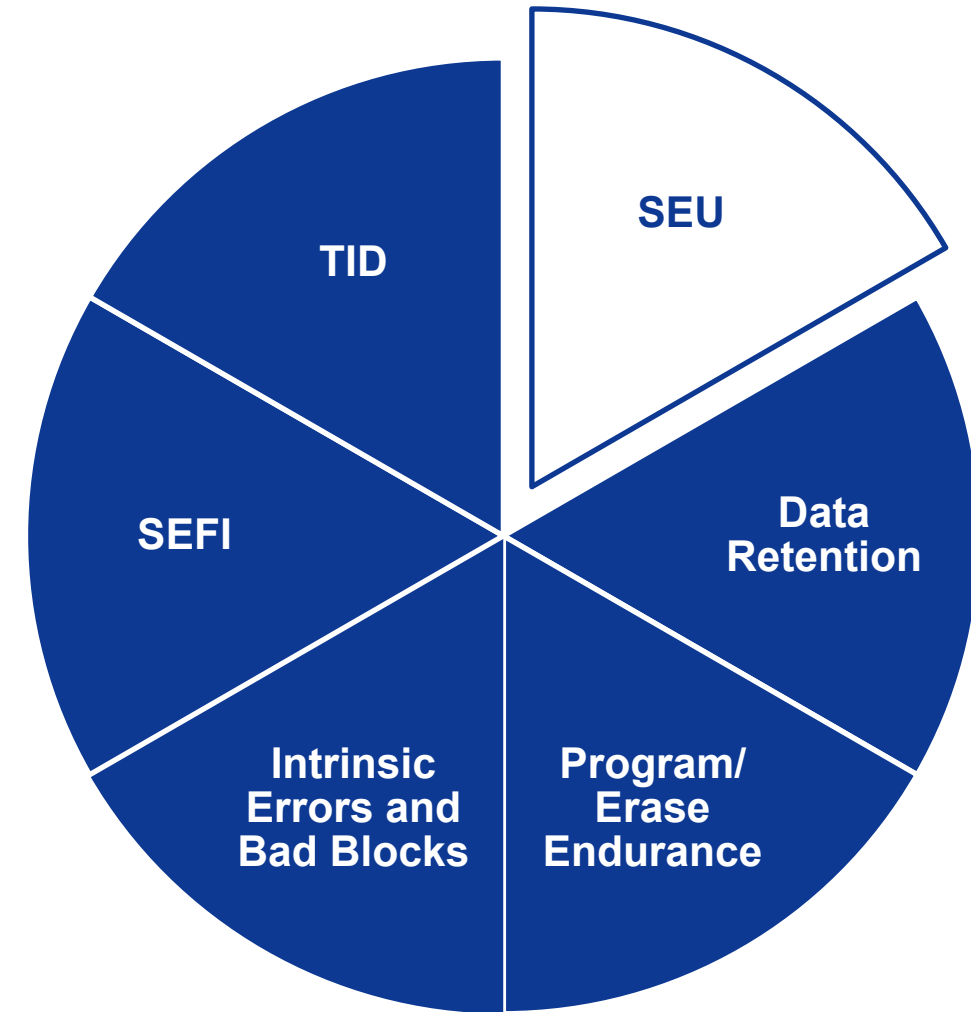
The bigger picture

SEU don't occur in a vacuum.

- What else is happening in my system?

Multiple effects contributing to:

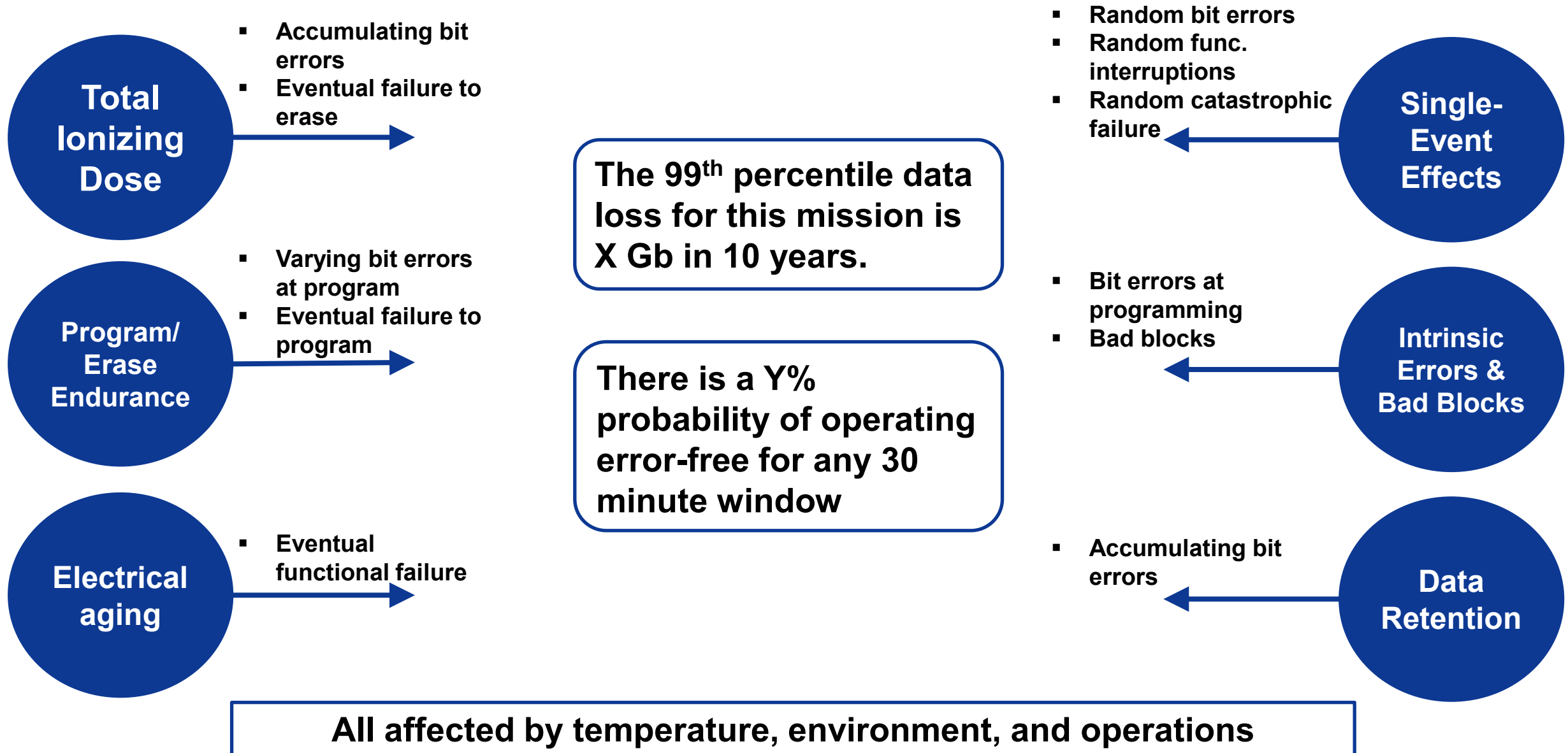
- Random errors
- Accumulating errors
- Functional failures
- Catastrophic failure



System effects of radiation require knowledge beyond radiation rate predictions.



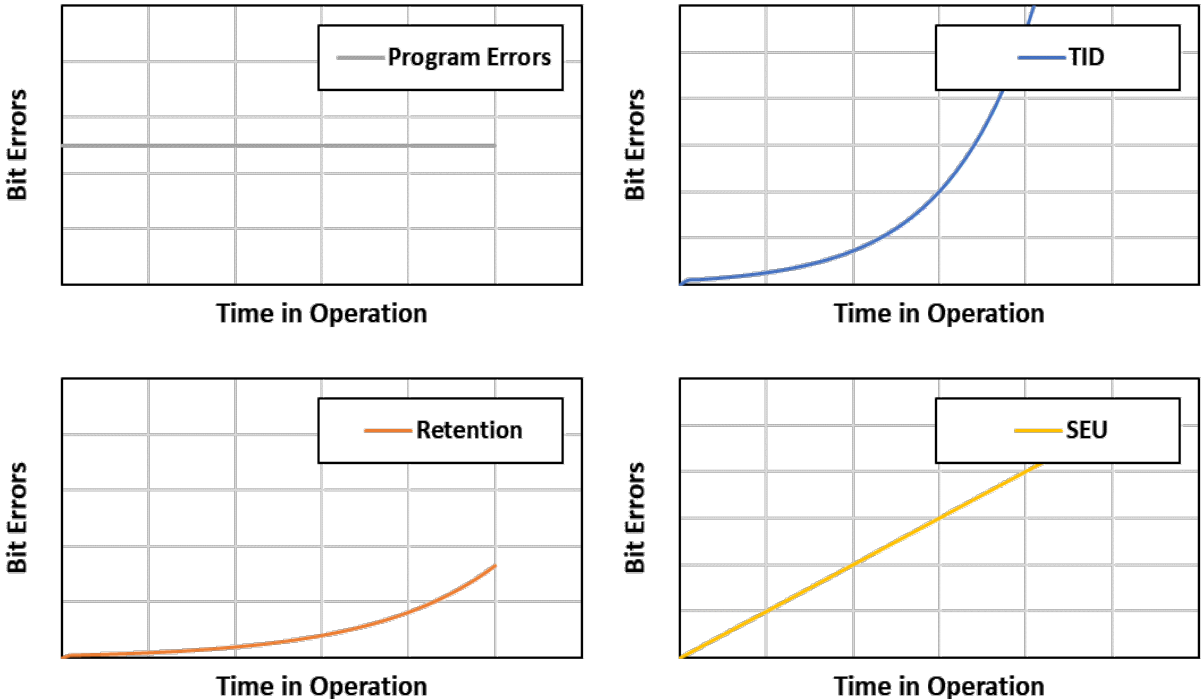
Individual threat analyses are related



Summation of individual (data loss) effects



Individual sources of error react to time, temperature, and environmental conditions differently



Response of the system incorporates these plus operational and mitigating considerations



Probabilistic System Analysis Tool (Radiation)



Define Mission Parameters

Mission Timeline

5 Years

Steps: 1 day

Error Rates (Any Source)

Background:
Solar Min

Peak:
Worst Day

System Components

(32) Micron 96L Die

Operations

Rewrite every 14 days
and power cycle every
60 days

Setup Analysis

1000 independent Monte
Carlo simulations

Background
Variability:
+/- 3x

Peak Events:
1 per 50
years

Part Response Uncertainty:
+/- 2x

SEU,
SEFI

TID,
Retention

EOL or
Mitigation
Failures

Program
Errors

Iterative Monte Carlo Simulations

Random Errors
Created

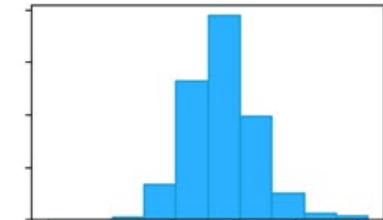
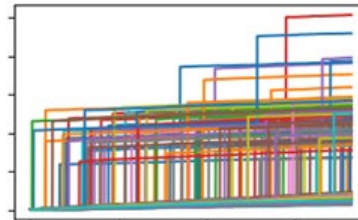
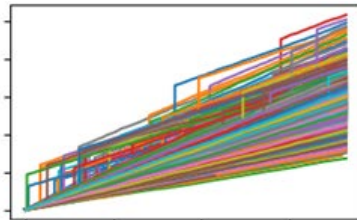
Accumulated Errors
Created

Check for
Uncorrectable Errors

Perform Any
Scheduled Tasks

Update
Results

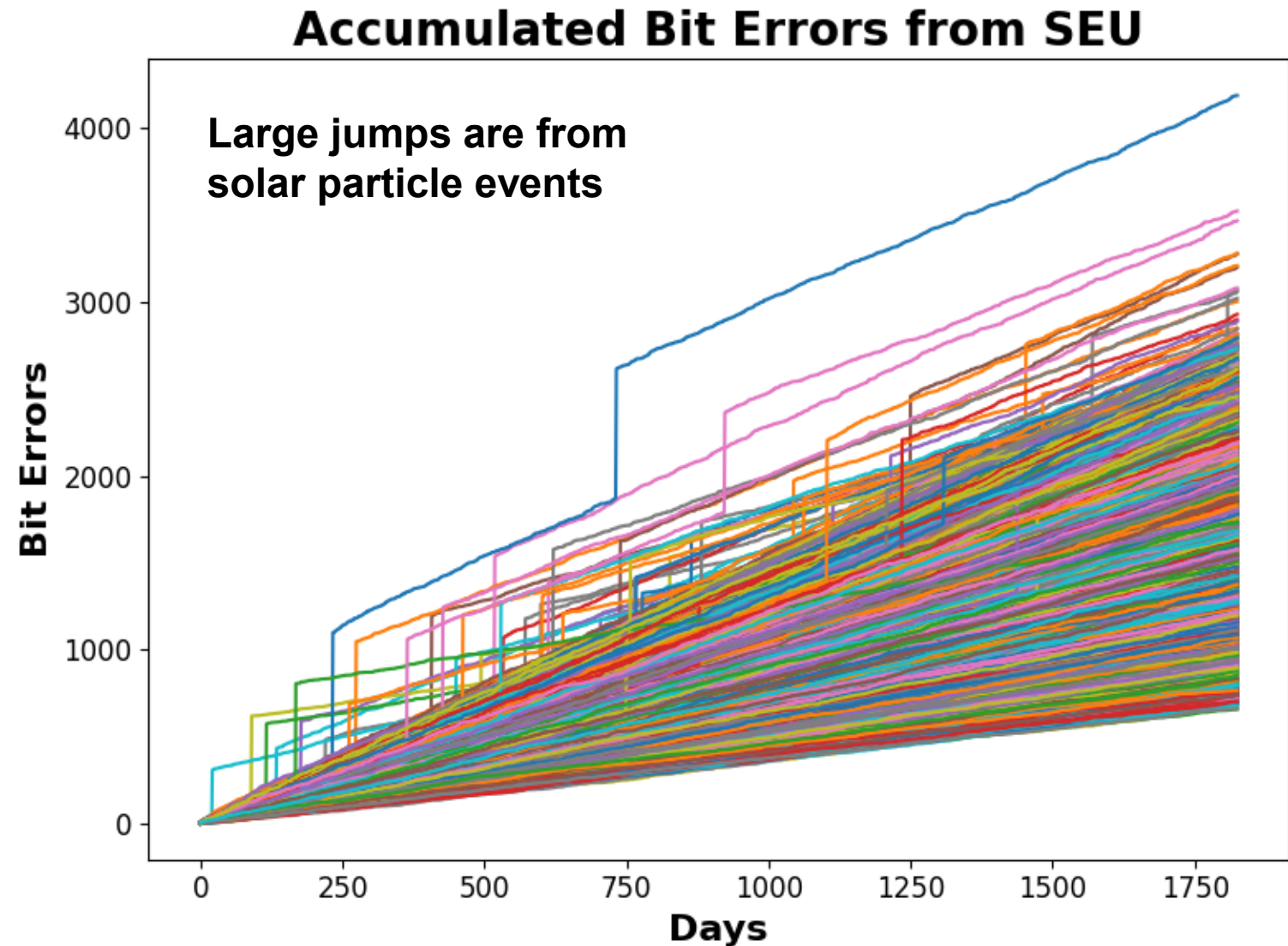
Collect and Summarize Data



Monte Carlo SEE Analysis (Die Level SEU)



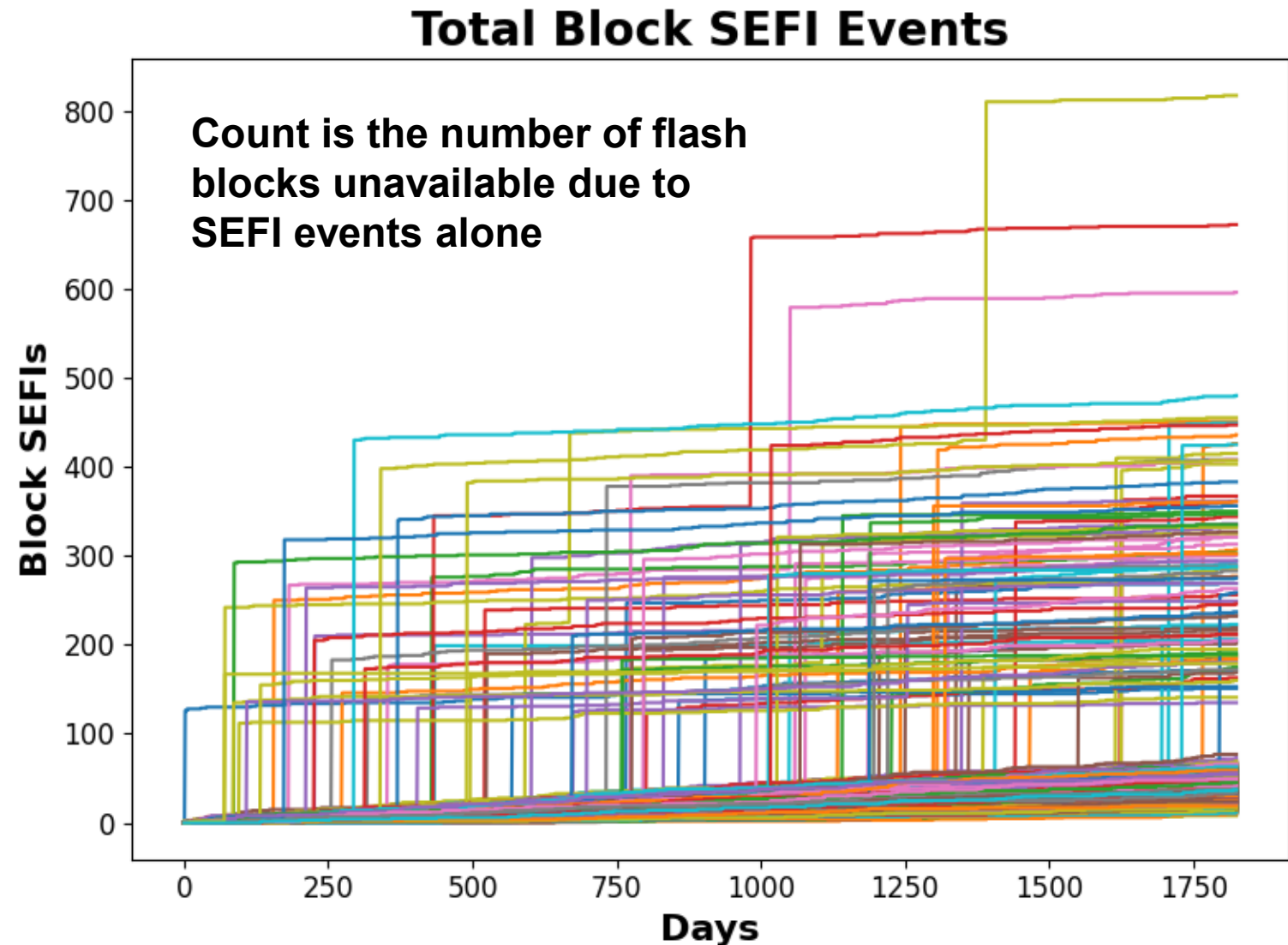
- Die-level SEU
- 1000 Monte Carlo Runs
- Layer In:
 - Rate Uncertainty and Environmental Variation
 - Random SPE



Monte Carlo SEE Analysis (Die Level SEFI)



- Die-level SEU
- 1000 Monte Carlo Runs
- Layer In:
 - Rate Uncertainty and Environmental Variation
 - Random SPE
- SEFI



Monte Carlo SEE Analysis (Die Level SEE)

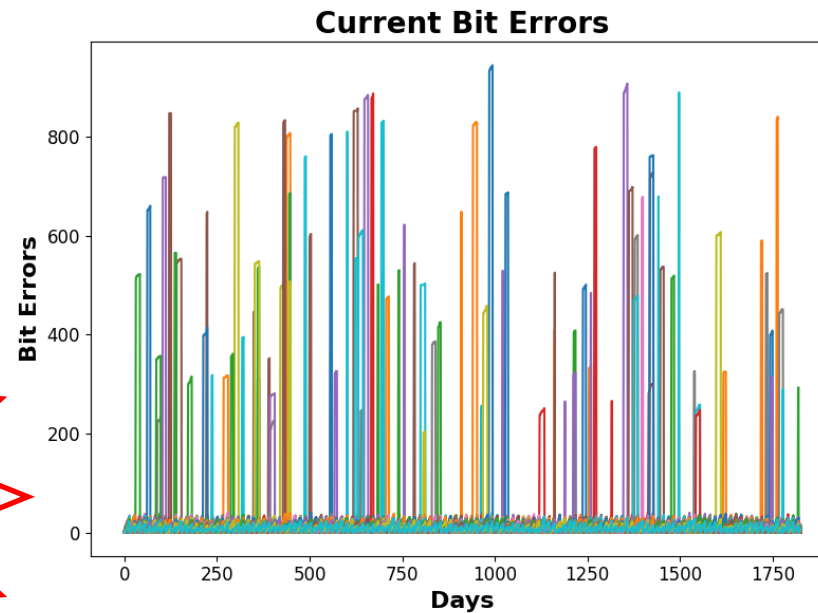


- Die-level SEU
- 100 Monte Carlo Runs
- Layer In:
 - Rate Uncertainty and Environmental Variation
 - Random SPE
- SEFI
- Operational Plans

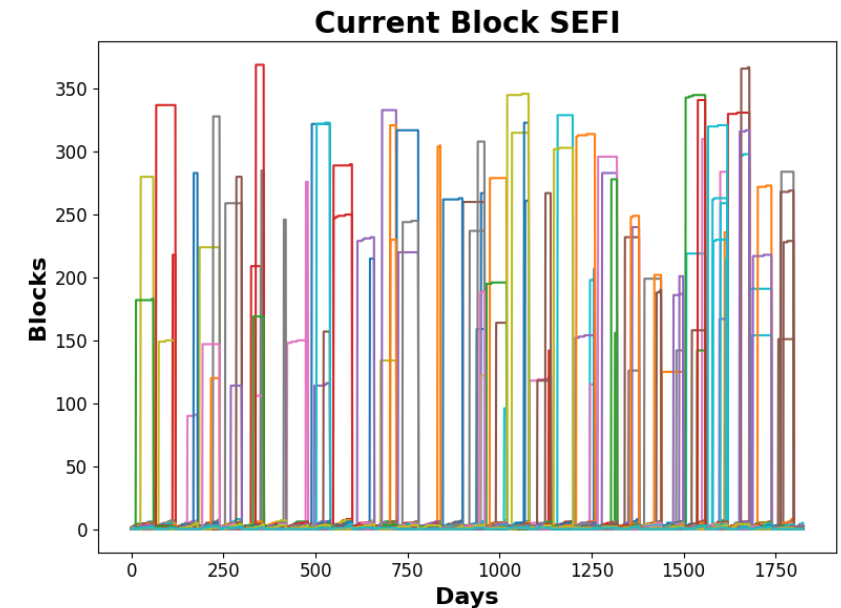
**Still a purely
SEE analysis**

Including mission operations gives us a “telemetry” point-of-view:
How is the system affected *right now*?

**SEU cleared every 14 days as
data cycles through the system**



**SEFI cleared every 60 days* with
scheduled power cycling**



***or after uncorrectable errors**



Applied SEE Data: Final [SEE] Products

- Probabilistic deliverables to system stakeholders can evaluate multiple system architectures or mitigation schemes.
- SEE assessment from SEEMAPLD 2023 case study was presented as:

Monte Carlo Results	Implementation #1	Implementation #2
Any uncorrectable errors?	100% of missions	25% of missions
99 th Percentile Data Loss	• 21.1 GB (.0024%) Loss • SEFI on 850 of 1824 days • Data lost on 850 days	• 1.12 GB (.00013%) Loss • SEFI on 844 of 1824 days • Data lost on 2 days

- System-level results vary significantly (99th percentile: loss of 25 MB every other day, vs loss of 560 MB twice in five years)
- Time-dependent factors (operations, current state, and environmental conditions) provide context and a means to incorporate many partially-related failure modes that a purely statistical evaluation struggles to incorporate

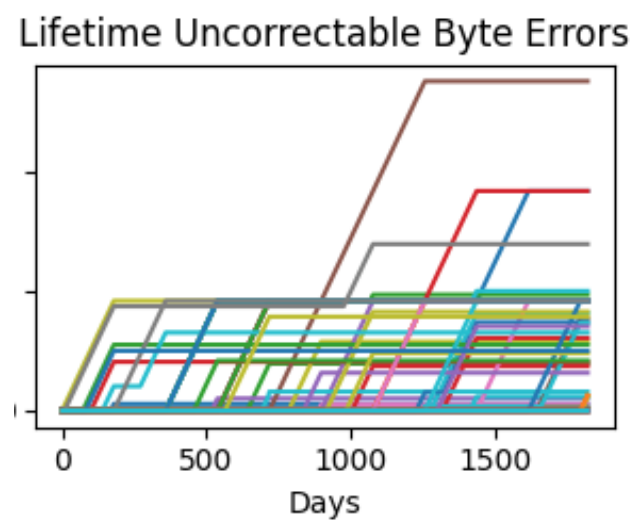
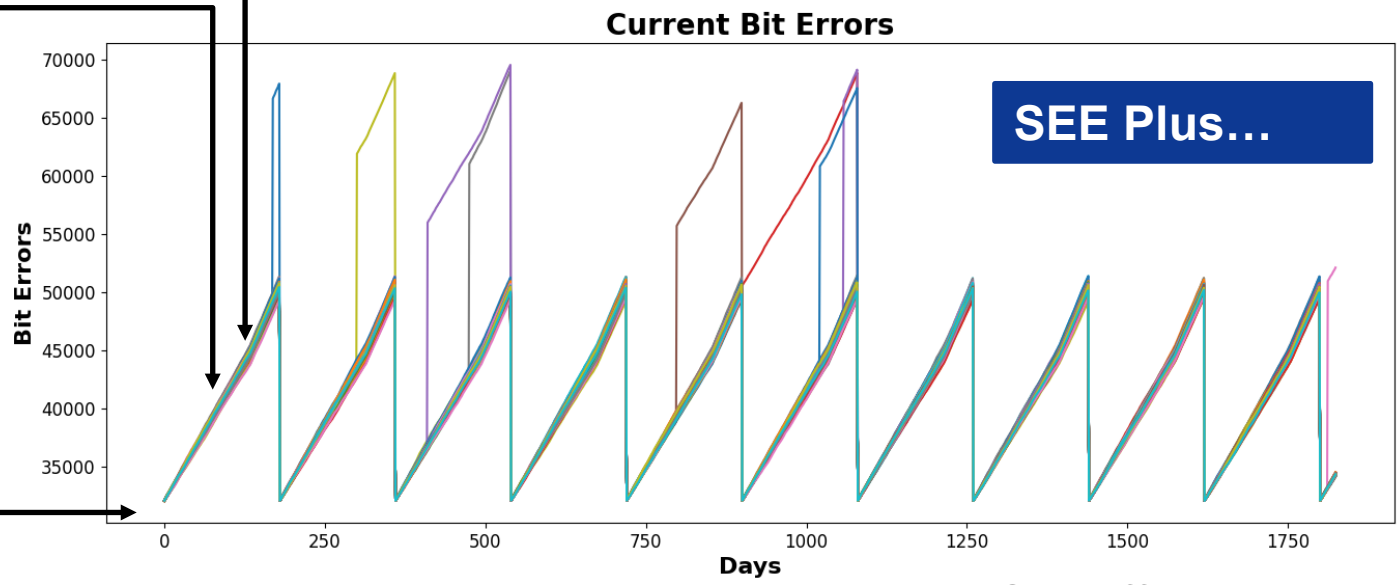
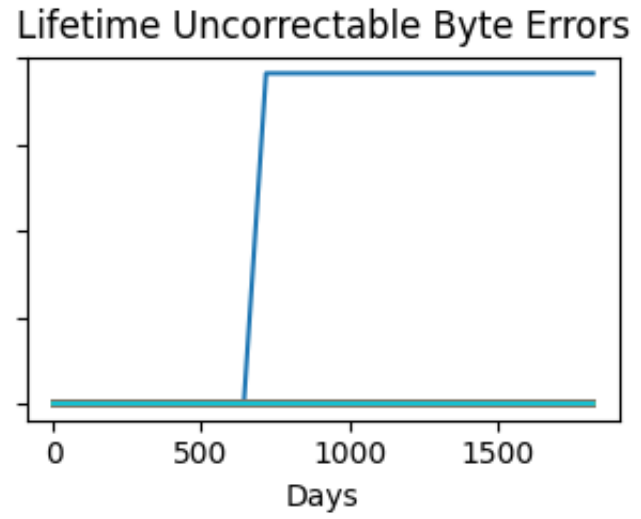
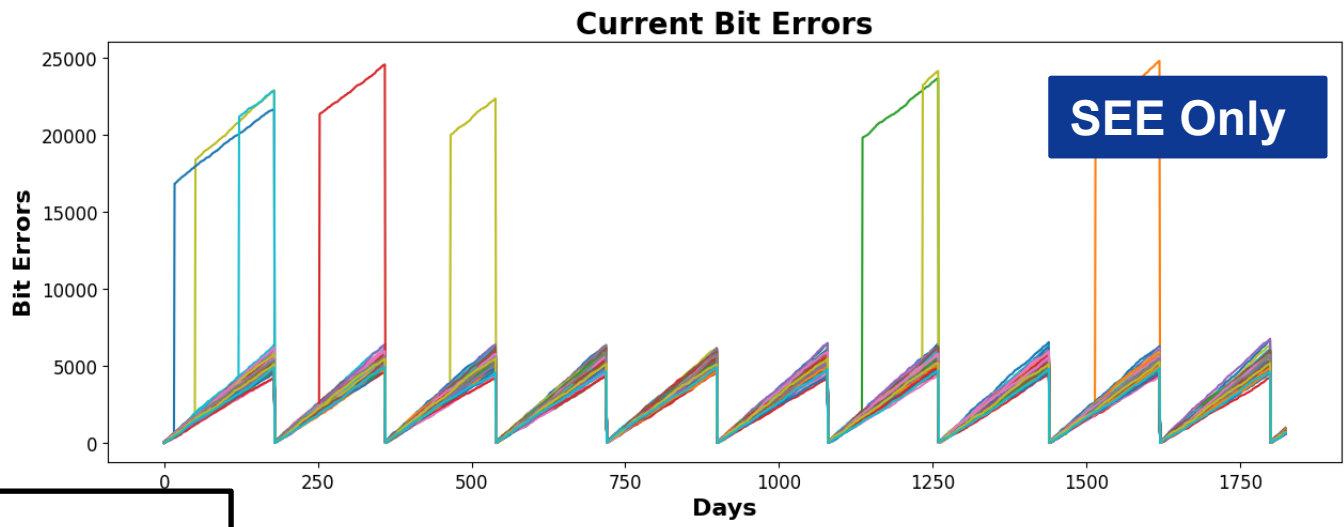


- **Incorporate some awareness of non-radiation factors into analysis where software is already implemented for similar mechanisms**
 - Rather than erasing periodically to a blank slate, add appropriate number of intrinsic programming errors and mark some blocks as unavailable
 - In parallel with random error injection during each time step, add non-linear accumulations of errors to account for TID and data retention
 - When performing scheduled/periodic operations (e.g., power cycling or erasures), add a check for EOL conditions

Preliminary Examples (Combined Effects)



- SEU
- Rate Uncertainty
- Environmental Variation
- Random SPE
- SEFI
- Operational Plans
- TID
- Retention
- Intrinsic Programming Errors



SEU cleared every 180 days as data cycles through the system. Non-SEE effects are not based on accurate part data (yet)

Summary



- Certain parts have SEE response similar to that of other stimuli (temperature, time, total dose, part-to-part variability, etc.)
- Robust system evaluation includes variability, uncertainty, system-level mitigations and operational details to deliver probabilistic analyses
- It is possible to incorporate many of these other effects into existing SEE analyses; the response in some systems may dominate SEE response
- Not strictly applicable to all part/system types, but always relevant to understand interactions of multiple failure modes
- Future work: incorporating application duty cycle and recovery steps