Evaluating SEE Rate Prediction Methods for Complex Devices

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Motivation

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- **Evaluate single event reliability of complex devices**
  - Complex device – *collection of circuits that consists of more than one basic repeated structure or demonstrates dynamic behavior*
- **Single event analysis increasingly needed**
  - Test considerations covered in JPL Pubs 08-13, 18-2
  - How do we make use of the data? New tools? Guidelines?
- **Complex systems invoke unique *challenges* for rate predictions**
  - How many sensitive volumes?
  - What technology?
  - How much derating/masking?
  - Error latency? Observability?
  - Fluence dependencies?

Survey of Literature

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- **Single event effects reported in FPGA, DDR-II, PWM, rad-hard microprocessor, angular position sensor, video codec, analog switch, resolver-to-digital converter, technology comparison of flip-flop chains**
- **Experiments produce macroscopic cross section curves (cm^2/device) for output errors, functional interrupts**
- **Authors have taken different approaches to predicting component level ion-induced errors (e.g. SEFI)**
  - CREME96 on saturated or normalized cross sections
  - Effective flux approach
  - Undocumented

RPP Approach

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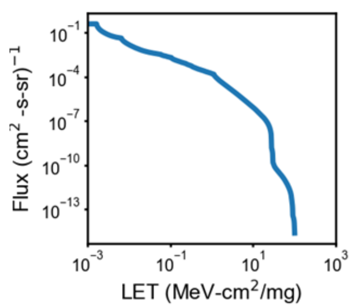
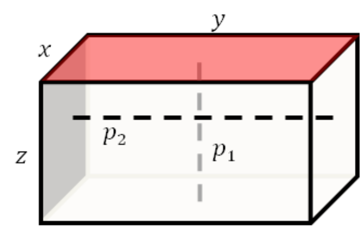
- **RPP model for device SEE cross sections implies a large-area, contiguous sensitive volume**
  - Depth usually assumed to be known
  - Assumes macroscopic sensitive volume represents aggregate contribution of individual sensitive volumes
  - Modifies limit of integration and path-length distribution





$$Qcrit = \frac{z \cdot LET_{th}}{22.5}$$

$$A = xy = \sigma_{bit}$$

$$\lambda_{ion} = 22.5 \cdot Qcrit \cdot \pi \cdot A \int_{22.5 \cdot Qcrit/pmax}^{Lmax} D[p(L)] \cdot \phi(L)/L^2 dL$$

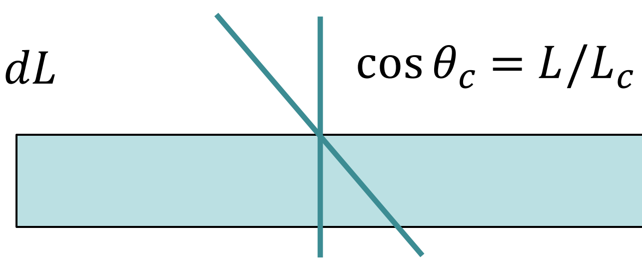
Effective Flux Approach

- **Binder's effective flux approach implemented**
  - Replaces complicated chord distributions
  - Eliminates need for sensitive volume dimensions
  - Calculates normal-incident flux of ions Φ_{eff} with effective LET above LET threshold, L_c
- **Ion-induced SEE rate, λ, depends on L_c and cross section σ**
  - Can be integrated over cross LET curve
- **Intriguing for complex devices**

$$\phi_{eff}(L_c) = \frac{1}{2}\int_{L_{min}}^{L_c} \phi(L)(L/L_c)^2 dL + \frac{1}{2}\int_{L_c}^{L_{max}} \phi(L) dL$$

$$\lambda_{ion} = \phi_{eff}(Lc) \cdot \sigma$$

$$\cos\theta_c = L/L_c$$



D. Binder, "Analytic SEU Rate Calculation Compared to Space Data," *IEEE Trans. Nucl. Sci.*, vol. 35, no. 6, pg. 1570, Dec. 1988.

Challenge: Number of Volumes

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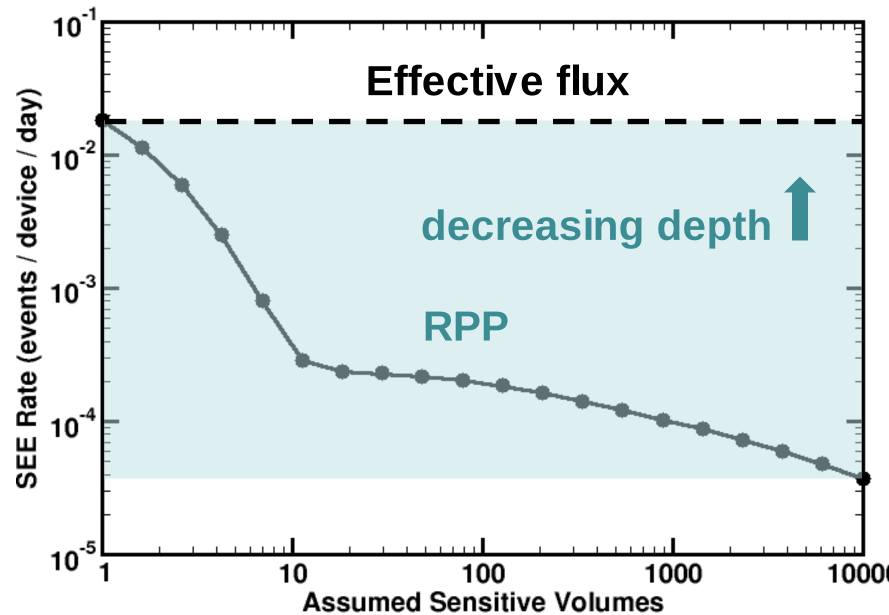
- **Complex ICs typically have an unknown number of sensitive volumes and/or unknown resource utilization**
  - *Is rate conservative and by how much?*
- **Calculated rates for 10,000 1 × 1 × 1 μm sensitive volumes**
- ***RPP approach can be strongly affected by assumed bits, depth***
  - Least amount of information yields largest rates
- ***Effective flux approach unaffected by assumed bits***
  - Proportional to cross section
  - Consistent with single volume, depth → 0



Challenge: Stacked Devices

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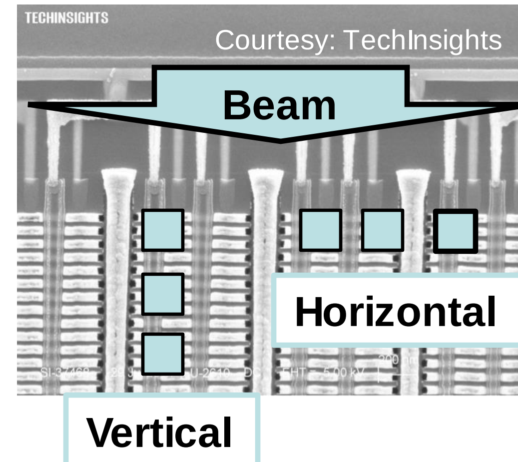
- **Memories, die stacks, integrated processes**
  - *Are cross sections similar for stacked devices?*
- **3 horizontal and 3 vertical volumes irradiated with 100k 10 MeV alphas in CRÈME-MC**
  - 3x fewer events (vert.), events have order of 3

Order	Horizontal		Vertical	
	Count	σ (cm^2)	Count	σ (cm^2)
1	4.99×10^3	1.18×10^{-7}	8.49	2×10^{-10}
2	5.52	1.3×10^{-10}	6.37	1.5×10^{-10}
3	-	-	1.67×10^3	3.94×10^{-8}

- **Event σ differ, but total upset σ remains →** ***both rate predictions unchanged***



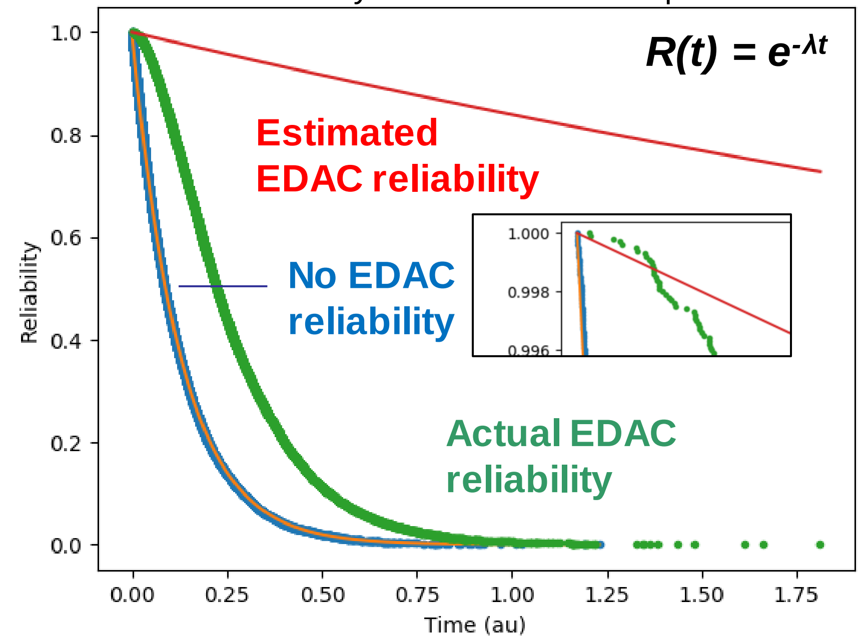
Challenge: Fluence Dependencies

- **Complex systems may include fluence-dependent errors**
  - EDAC (parity) common in cache, processors, …
  - Observable *error* occurs as a result of two or more *upsets*
- **Cannot estimate rates from EDAC cross sections**
  - Error cross section changes over time/fluence (i.e. non-constant rate)
- ***Reliability predictions depend on assumed form***

Simulated Random Upset Times

1.65	**1.24**	**0.51**	**0.07**	**0.40**	**0.26**	**0.33**	**1.47**

Simulated Reliability of 8-bits with λ = 1 upset/bit/time



Challenge: Fluence Dependencies

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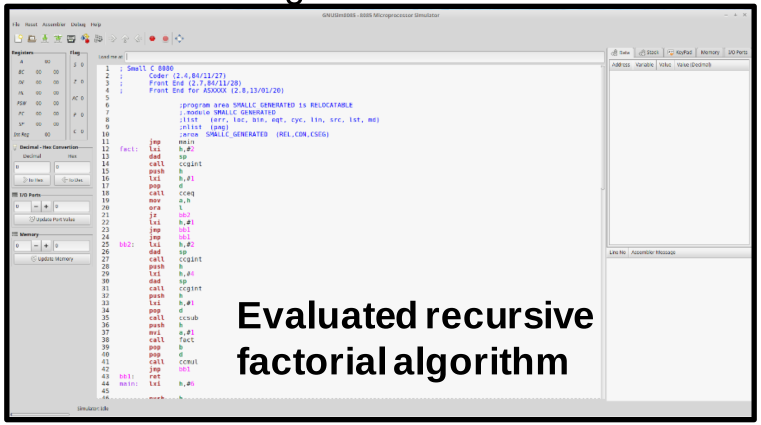
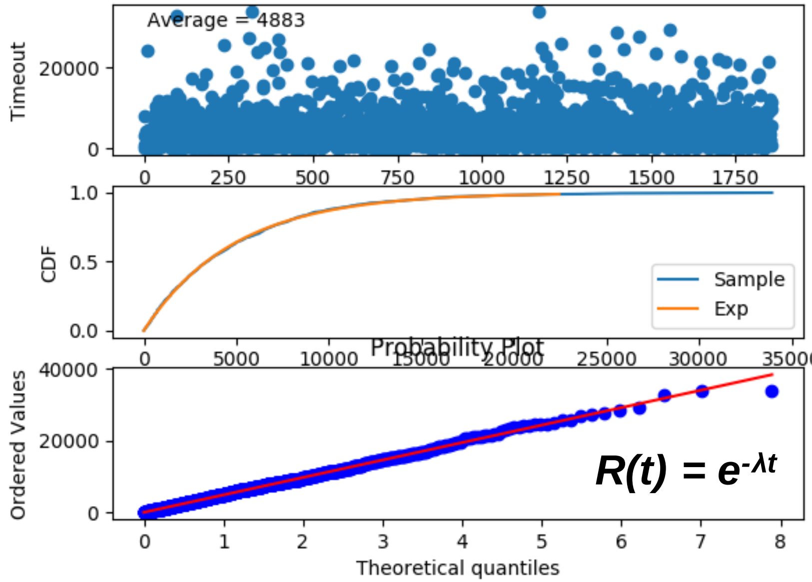
- **Open-source simulator for Intel 8085 microprocessors**
  - Executes assembly code using behavioral model
  - Injects random single event upsets and monitors for faults

gnusim8085



Evaluated recursive factorial algorithm

- **Routine to extract faults and analyze reliability developed**
- ***Selected algorithm demonstrates no fluence dependence***



$R(t) = e^{-\lambda t}$

Summary

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- **Significant uncertainties can exist in SEE rate predictions for complex devices**
- **Effective fluence approaches require fewer parameters, but can be highly conservative**
  - Some suggestion limits of integration could be defined by process
- **RPP approaches can vary over 100× depending on assumptions**
  - Per bit cross sections only appropriate if mechanism directly associated with each bits
- **Cross sections and rates aren't the whole picture, dependencies affects reliability**
- **Methods and assumptions should be documented!**

Acknowledgments

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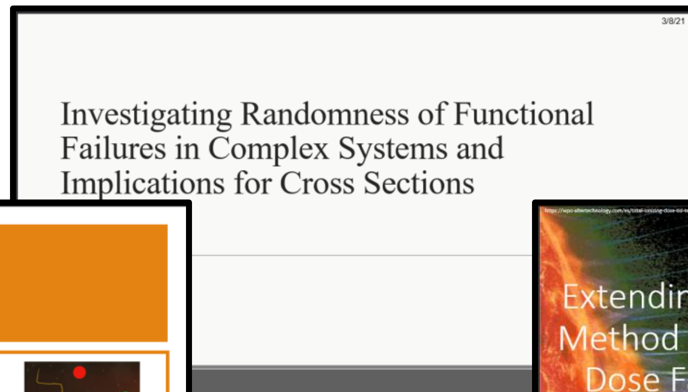
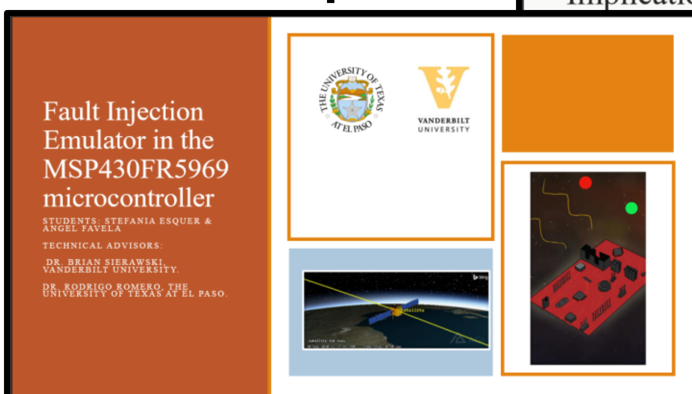
- **SCALE Workforce Development**
  - Undergraduate student participation enriched aspects of this program

David Pauls



Stefania Esquer



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