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ENGINEERING
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WP2300 Radiation Damage: TGF Effects on Electronic Components

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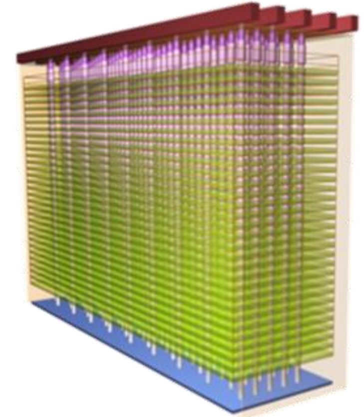
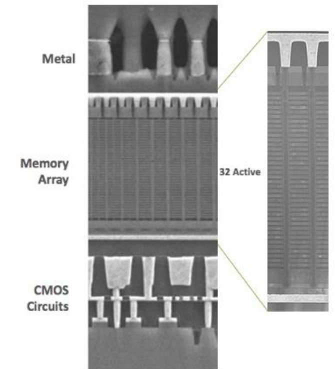
Activities carried out by UniPD

- Selection of an electronic component to be used as a benchmark to evaluate the effects of TGF on electronic equipment
- Design and manufacture of a test board for the benchmark component
- Experimental campaign to collect neutron sensitivity data on the selected component
- Simulation of the interactions between the neutrons generated by TGF and the selected component

3D NAND Flash Memories

- Flash memories are by far the most common type of memory in terms of installed bits
  - They can be found everywhere from smartphone to solid state drives
  - Excellent benchmark
- The semiconductor industry moved away from planar Flash memories to 3D devices, due to the impossibility of scaling the feature size below 10 nm in Floating Gate cells
  - Cells were running out of electrons
  - Too many disturbs and reliability issues
- This change of architecture offers interesting opportunities
  - Cells are physically bigger than before (but the memories are more dense due to vertical integration) ⇒ less sensitivity to heavy ions
  - The errors in the 3D structure can be used to track particles





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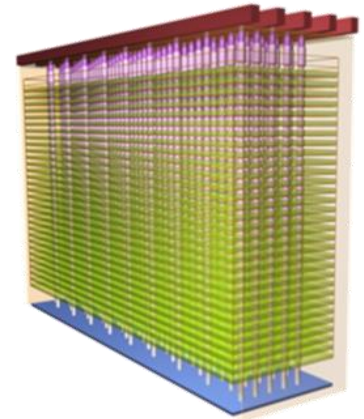
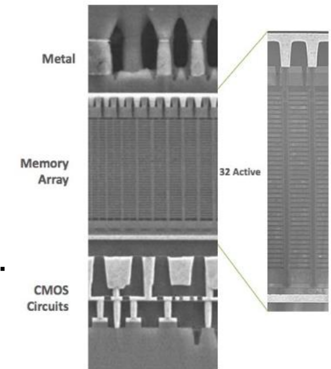
- Ionizing radiation causes a loss of electrons in FG cells, which gives rise to a threshold voltage shift (ΔV_{th}) that can be exploited to realize a particle detector
- 3D NAND offers many advantages as an ionizing particle detector, compared to other memories
  - ΔV_{th} can be extracted, in addition to the number of errors
  - Non volatility: low power, no data loss with SEFIs, passive detectors, ..
  - 3D structure: particles can be tracked in 3D, higher precision in determining the beam features, discrimination of errors due to radiation from other errors
- Some downsides
  - Errors not related to radiation
  - Huge size
  - Complex architecture with multiple bits per cell, different read retry modes, …
- Excellent candidate for this study!





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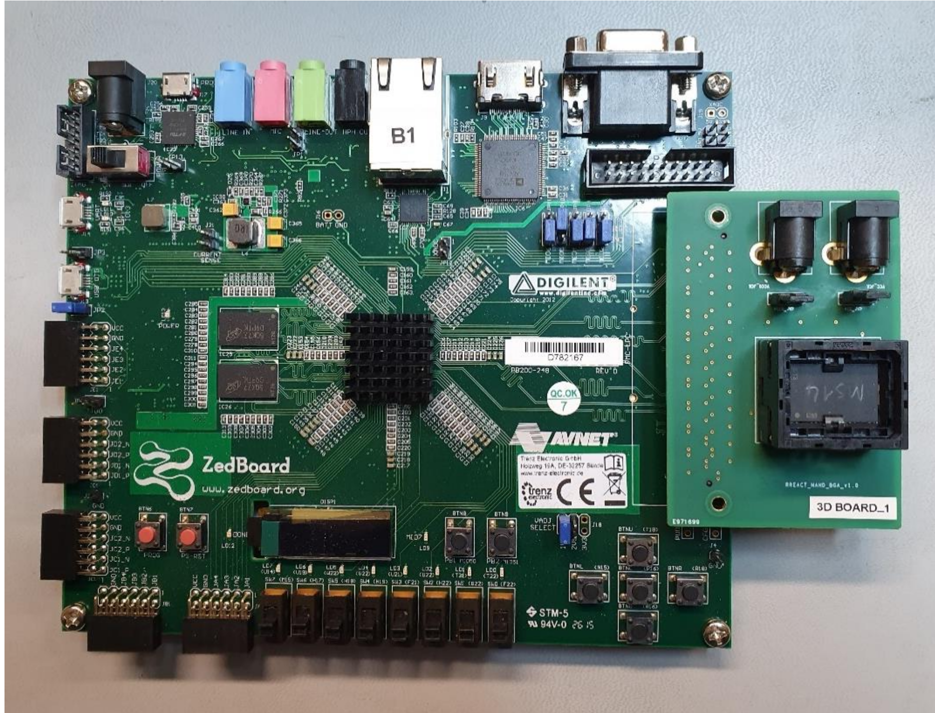
Selected Benchmark Memory

- **3D NAND Flash memories with vertical channel** manufactured by Micron Technology
  - Triple-Level Cells (3 bits per cell), 384-Gbit
  - Equivalent 13-nm feature size (in terms of bit area occupancy)
  - 50 MHz asynchronous interface, 266 MHz DDR2 interface

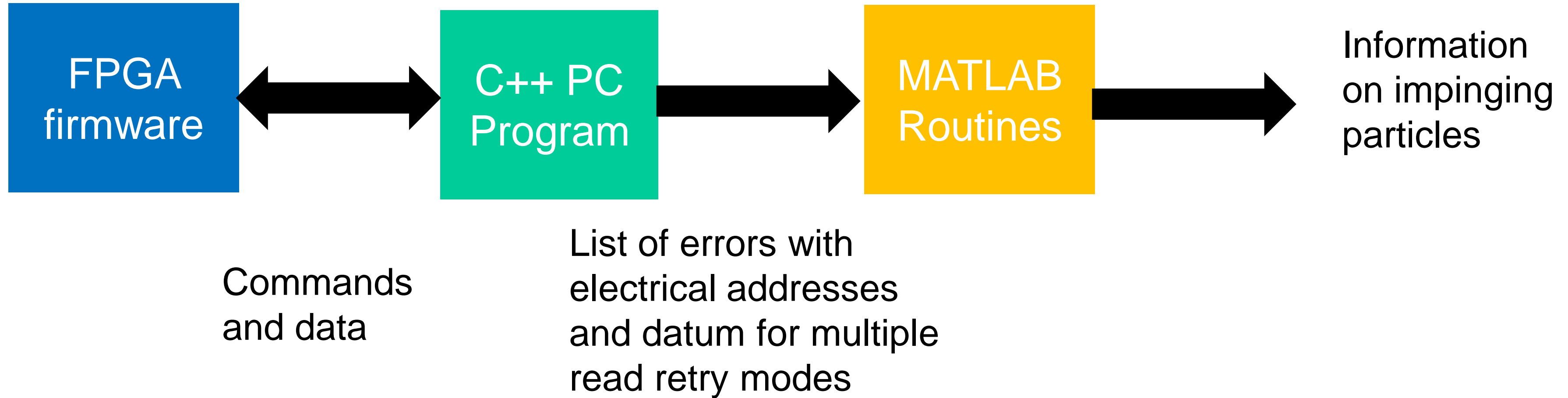
Part number	MT29F384G08EBCBB
Supply voltages	V_{CC}: 2.7–3.6V $V_{CC,Q}$: 1.7–1.95V
Density	384 Gbit, Triple Level Cell
Minimum required ECC	ECC to correct 1e-2 raw bit error rate
Package	132-ball BGA
Operating temperature	0°C to +70°C
Storage temperature	-65°C to +150°C
Endurance specification	1500 program/erase cycles
Package markings	ICT3, QR code

SEU Monitor Prototype: Board



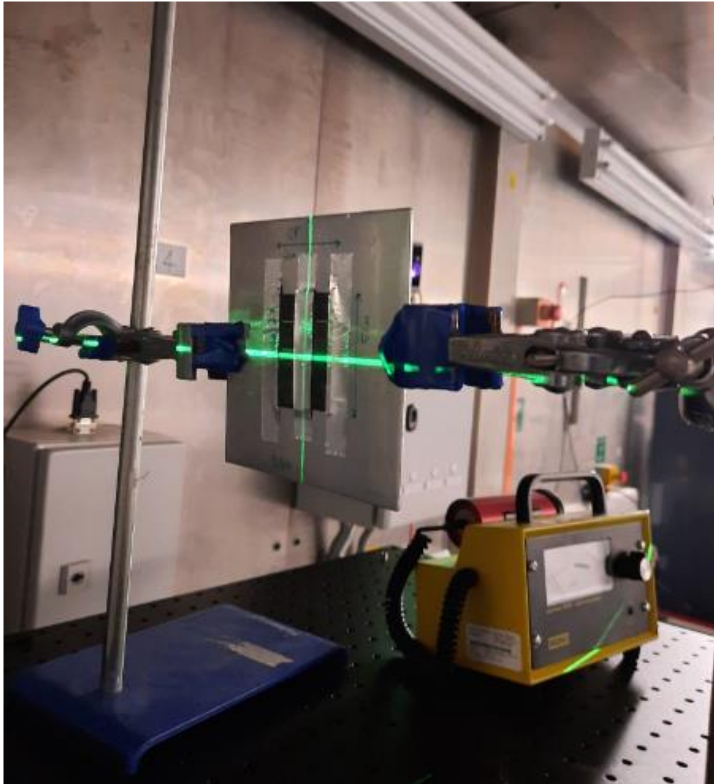
- Commercial SoC Motherboard
  - Custom firmware with asynchronous memory controller
- Custom daughterboard
  - High-speed connector and memory socket
- Software
  - C++ program to control the board
  - MATLAB program to analyze the data and extract the characteristics of the impinging particles

SEU Monitor Prototype: Software



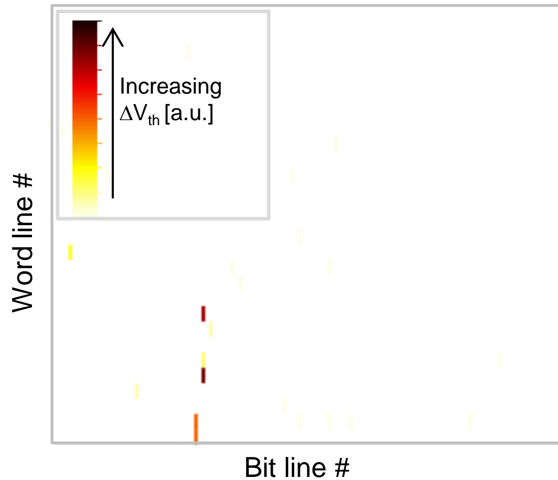
- Read retry: the memory has 8 read modes, corresponding to different placements of the reference voltages. These are meant to “help” ECC
- Randomizer: the memory has a randomizer which prevents the storage of solid patterns. The randomizer has been disabled and cells are programmed to the highest levels before the exposure

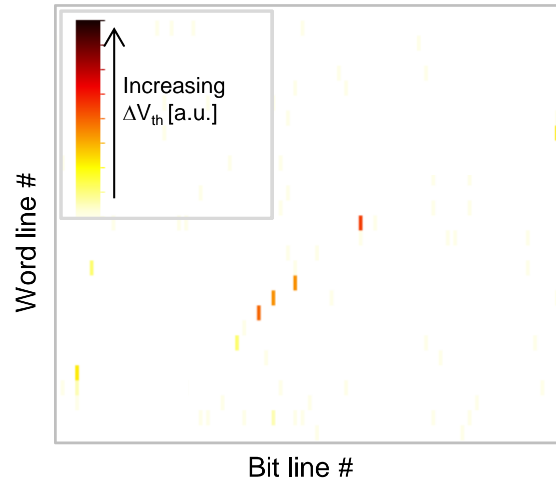
Experimental Campaign at ISIS

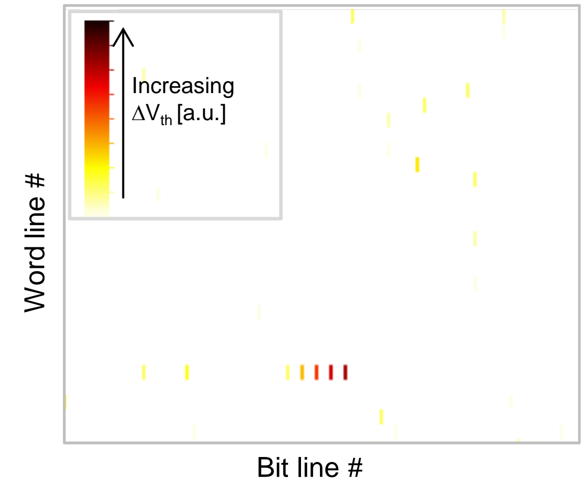


- The selected devices have been irradiated at the ISIS line of the Rutherford Appleton Laboratories in UK with total fluence of 1.57×10^{12} n/cm^2 (Energy >10MeV)
- The irradiation emulates the terrestrial environment with a high acceleration factor (10^9)
- Error log files with raw data are about 35 GB!
  - Lot of events to process and interpret

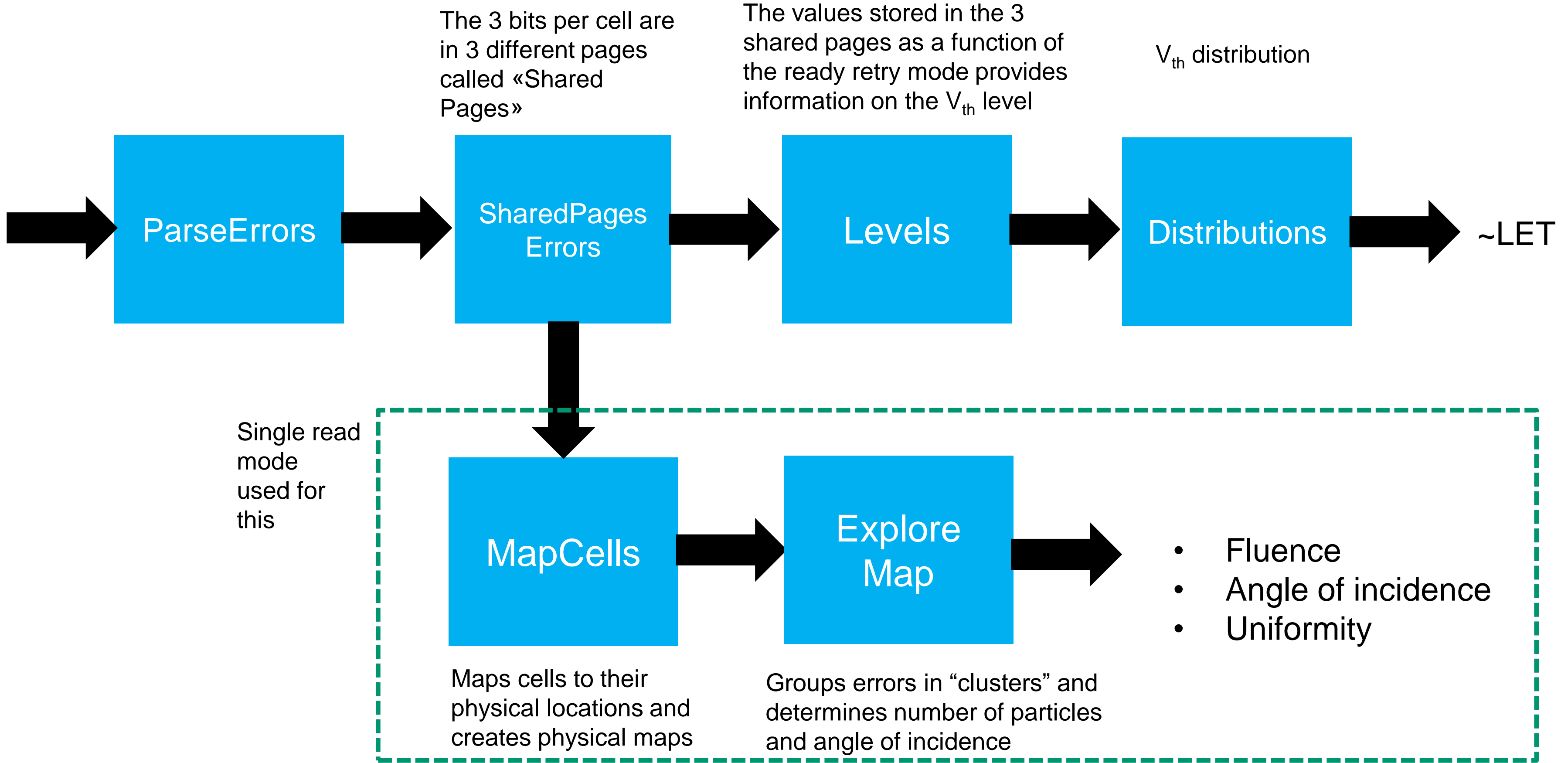
- «Manual» inspection of the log files shows interesting events.
- Ionizing particles create **tracks of cells with shifted V_{th}**





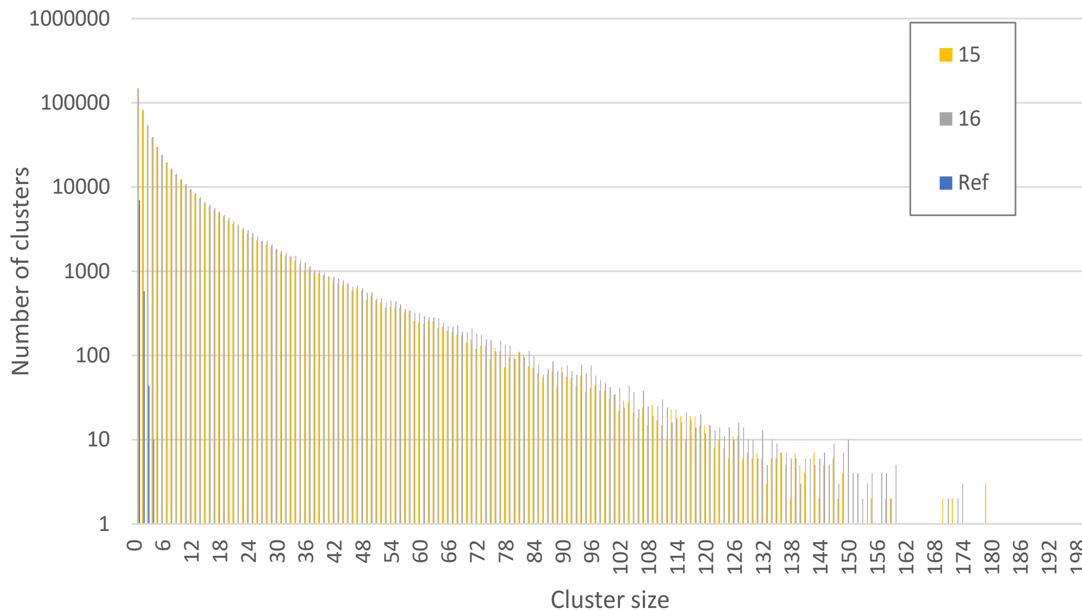


Post-Processing Software: Architecture



RREACT

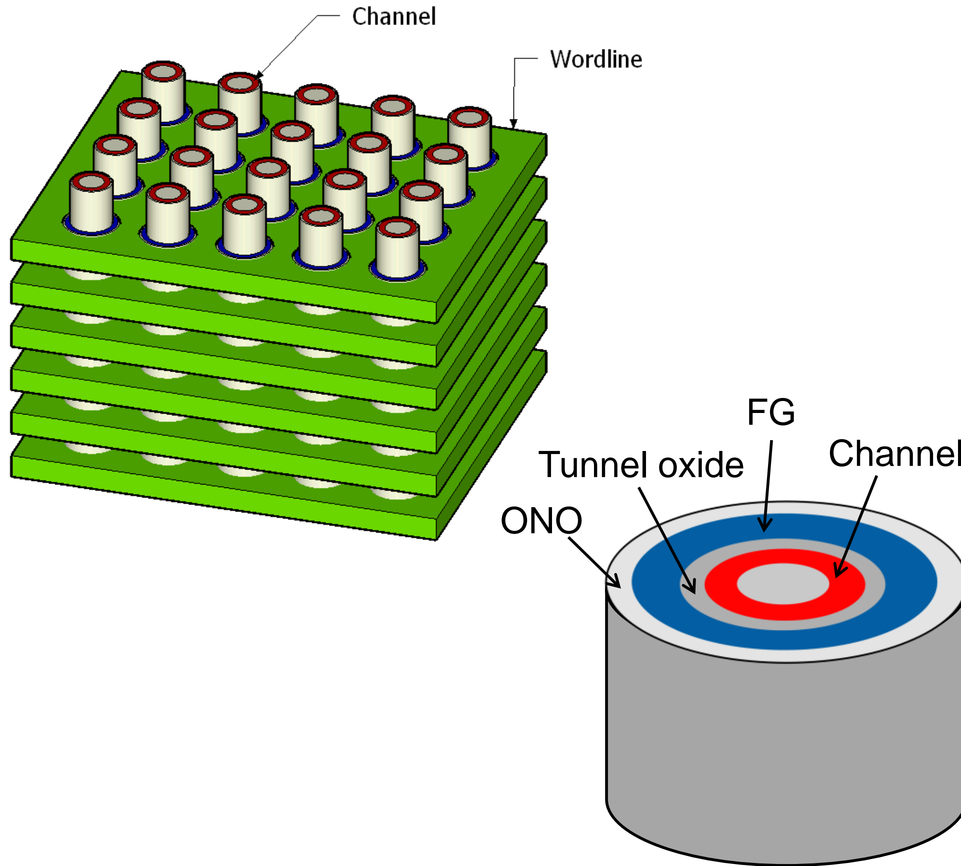
Cluster Size



- Analysis with post-processing software (not yet complete and fully validated),
- Very large cluster of errors
  - Hundreds of cells can be involved
- We aim at studying the secondary energy, angle and LET

Development of Post-processing Software

- Other information about neutron secondaries we expect to extract with post-processing software
  - Range/Energy
  - Angle
  - LET
- We prefer to show the data after the post-processing software is fully validated



- Geant4 based simulations can be performed with different neutron spectra
- Detailed model of the memory with geometry and materials is necessary
- Three sensitive volumes need to be considered
  - Floating gate electrode
  - Tunnel oxide
  - Oxide-Nitride-Oxide (ONO) layer

Geant4-based Simulations: Status

- Geometrical model including all known details is complete
  - We used the Geometry Description Mark-up Language (GDML) which allows quick modifications and parameterization
- Working on speeding up the simulation
  - Investigating bias techniques to emphasize rare nuclear events
- Simulations will be compared to the experiment at ISIS for validation purposes
- The TGF neutron spectrum will be used to understand the effects on electronic devices

Conclusions

- A component of high interest was selected for the study
  - 3D NAND Flash memories used in a wide variety of applications
- An experimental setup has been realized and is almost complete
  - Used for irradiation at ISIS and for Monte Cimone
- An experimental campaign with neutrons has been performed at the ISIS accelerator in UK
  - Error log files are about 35 GB
- A post processing software tool is under development and validation to extract the tracks of the secondaries starting from the errors in the memory
  - Error clustering is key to filter errors not due to radiation
- Monte Carlo simulations
  - Geometrical model is ready
  - Hadronic bias investigation to speed-up the simulations are under way