A Monte Carlo-Based Analysis of Radiation Effects Mechanisms in 3D NAND Memories

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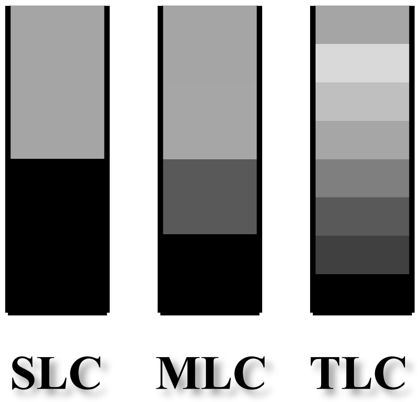
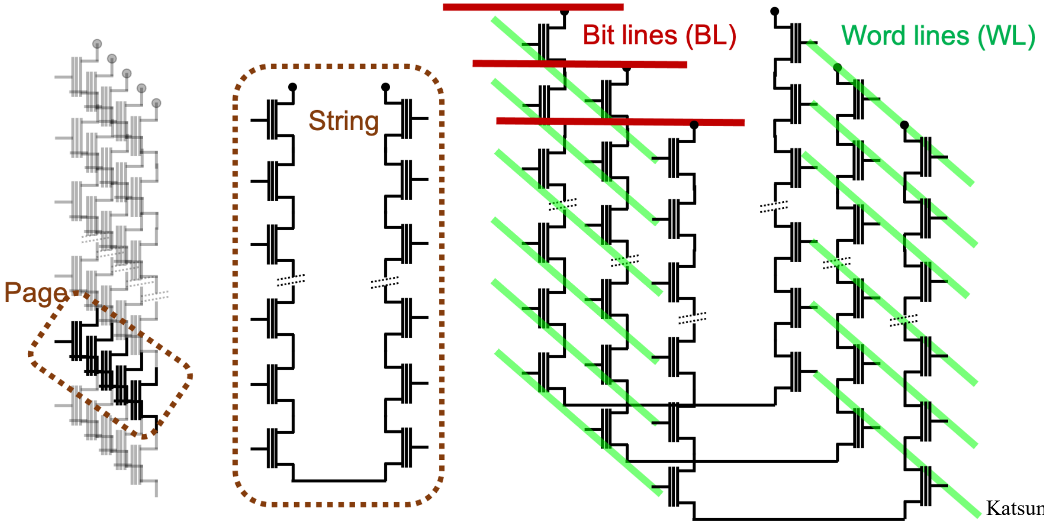
Outline

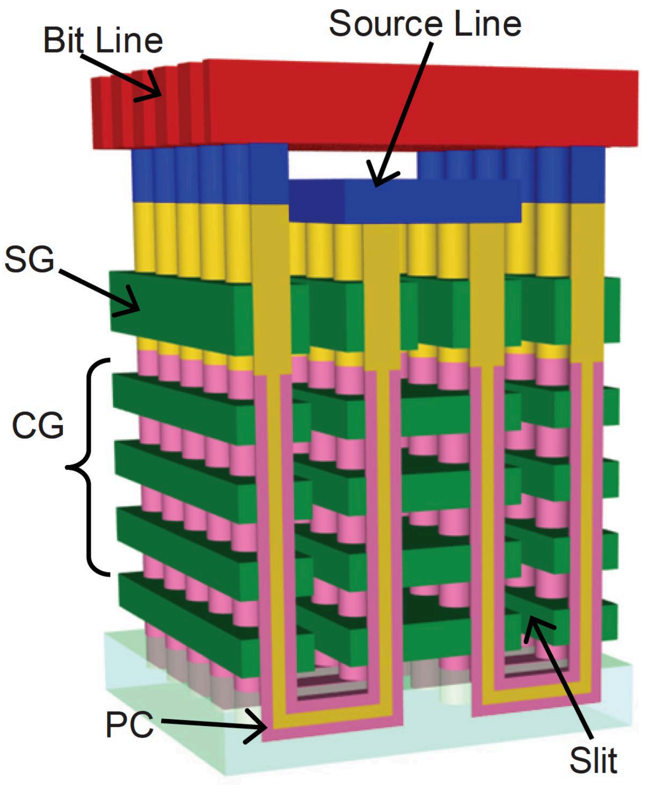
- 3D NAND memories
  - Charge-trap (CT) vs. floating-gate (FG)
- Development of MRED simulations for 3D NAND
  - Simulation vs. experimental results
- Comparison of dose-enhancement effect in FG & CT devices
- Conclusion

3D NAND memory

- 72-layer SK Hynix charge-trap 3D NAND
- p-BiCS structure (“U” shaped string)
- Operational modes trade reliability for density



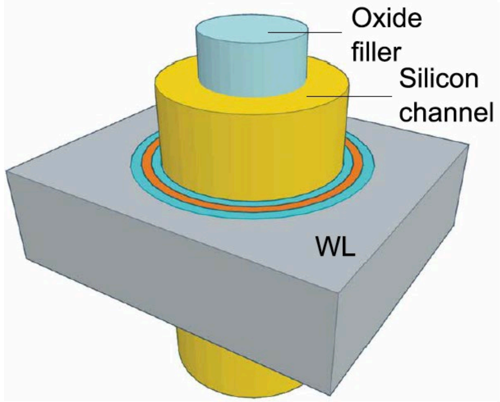




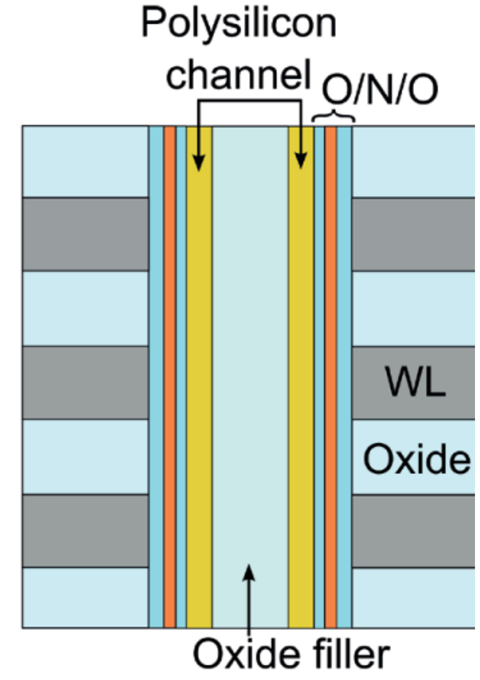
Katsumata et al., “Pipe-shaped BiCS flash memory with 16 stacked layers and multi-level-cell operation for ultra high density storage devices,” *Symp. VLSI Tech.*, pp.136-137, 2009

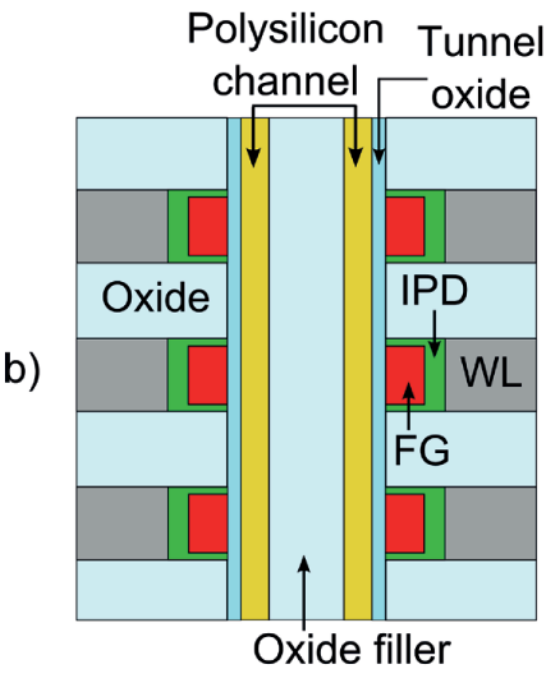
3D NAND – two types

- Charge trap (CT)
  - Gate-last fabrication
  - Uses silicon nitride layer as CT
  - Metal (usually W) word lines
- Floating gate (FG)
  - Gate-first fabrication
  - Polysilicon FG with IPD
  - Polysilicon word lines



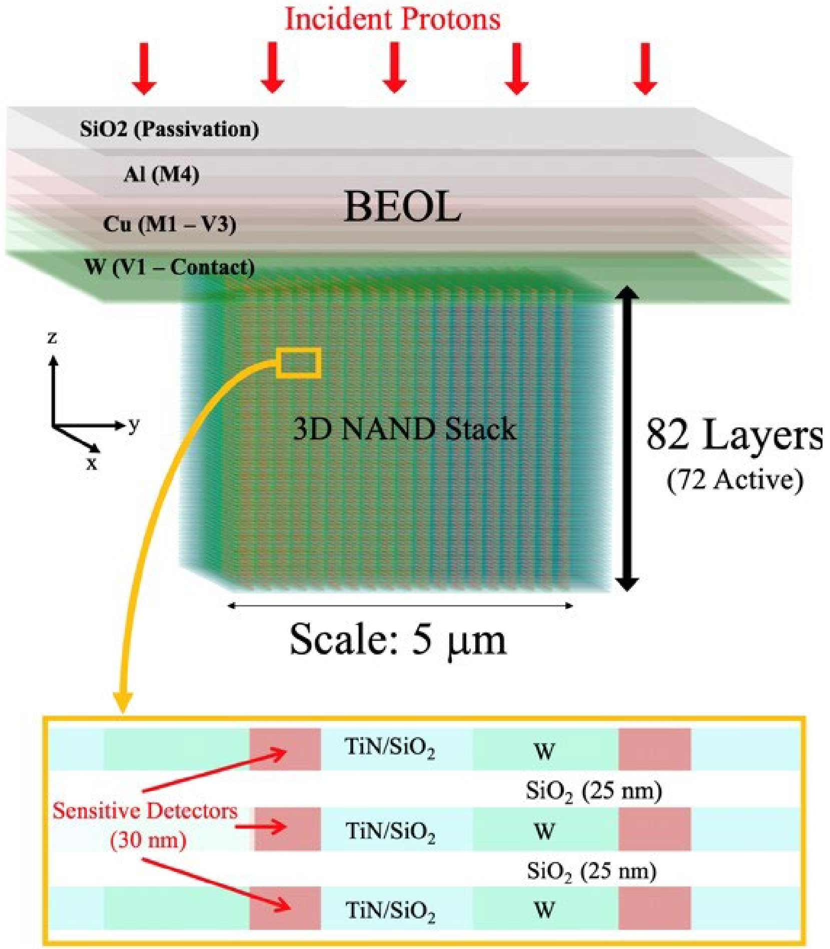
Compagnoni, et al. *Proc. IEEE*, 105(9), 2017





Simulation details for 3D NAND

- 72-layer CT 3D NAND (Hynix)
- Incident protons from 500 keV to 1.2 MeV
- Assumptions
    - Block sensitive detectors
    - Monolithic BEOL
    - No voids in stack
    - Simplified materials
    - Not p-BiCS (WL placement)

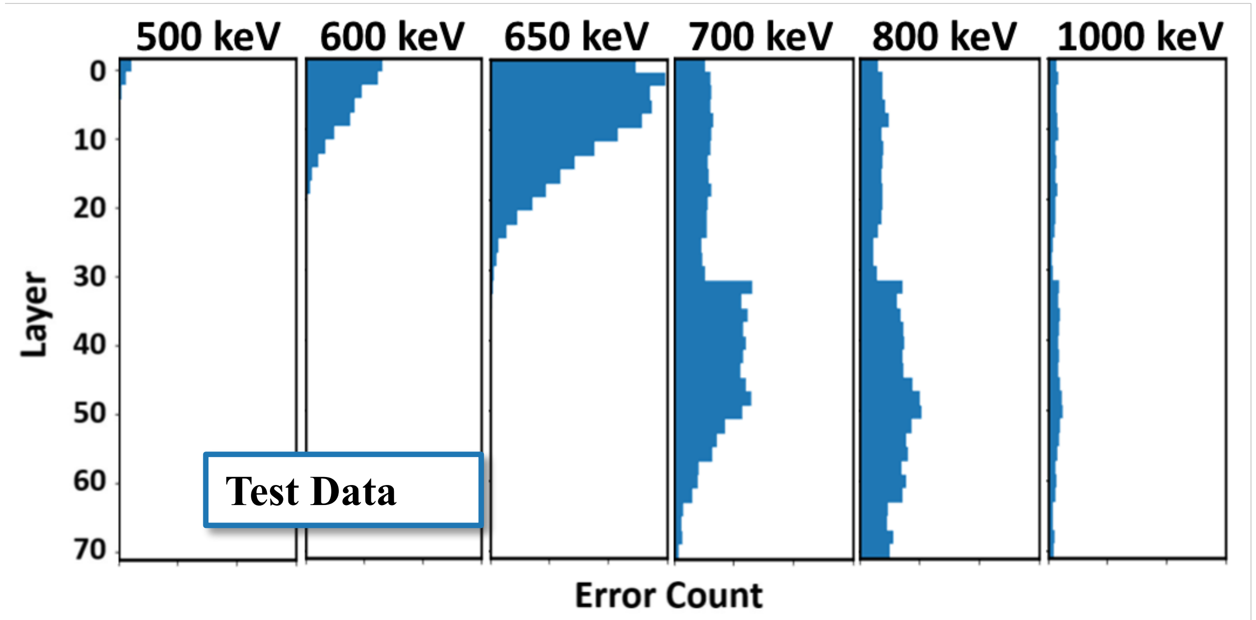


Wilcox, Breeding, et al.
IEEE TNS, 68(5), 2021

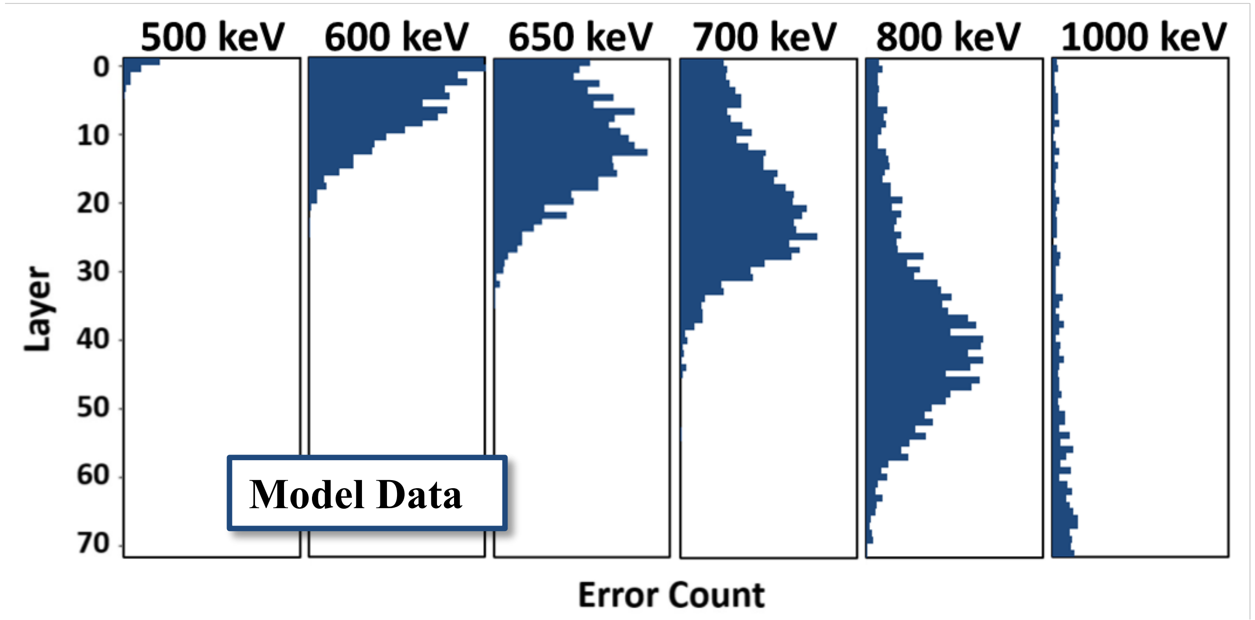
Summary of previous results

Wilcox, Breeding, et al. *IEEE TNS,* 68(5), 2021

- Proton-induced SEU observed in 72-layer SK Hynix 3D NAND (CT)
- Heavy-ion irradiations for top die



Test Data



Model Data

Updated simulation structure – fixing assumptions

Block sensitive detectors → GAA geometry

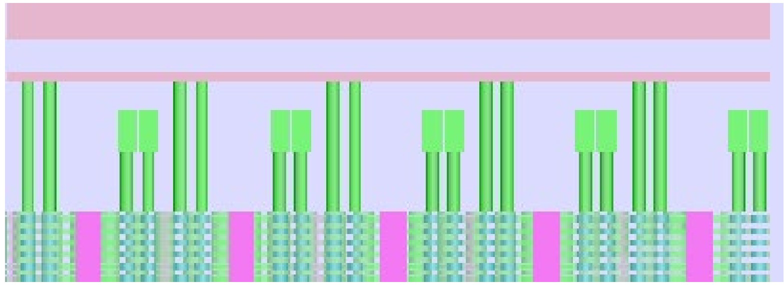
Monolithic BEOL → Detailed BEOL

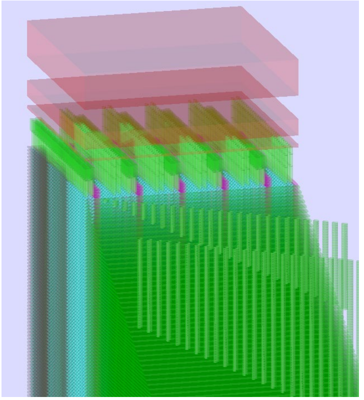
No voids in stack → Air gap voids included

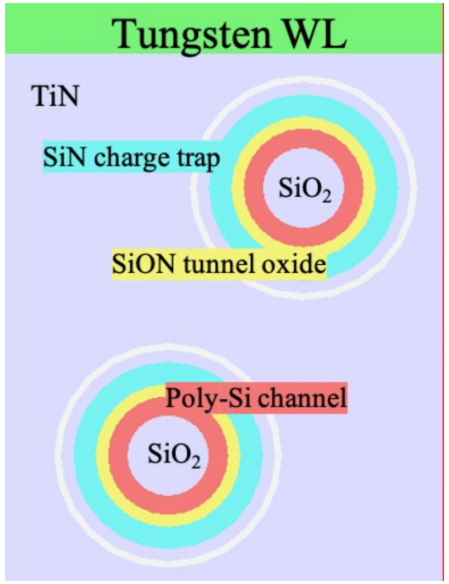
Simplified materials → Full materials used

Not p-BiCS (grid) → p-BiCS cell configuration

NVM stack only → TSV fanout included

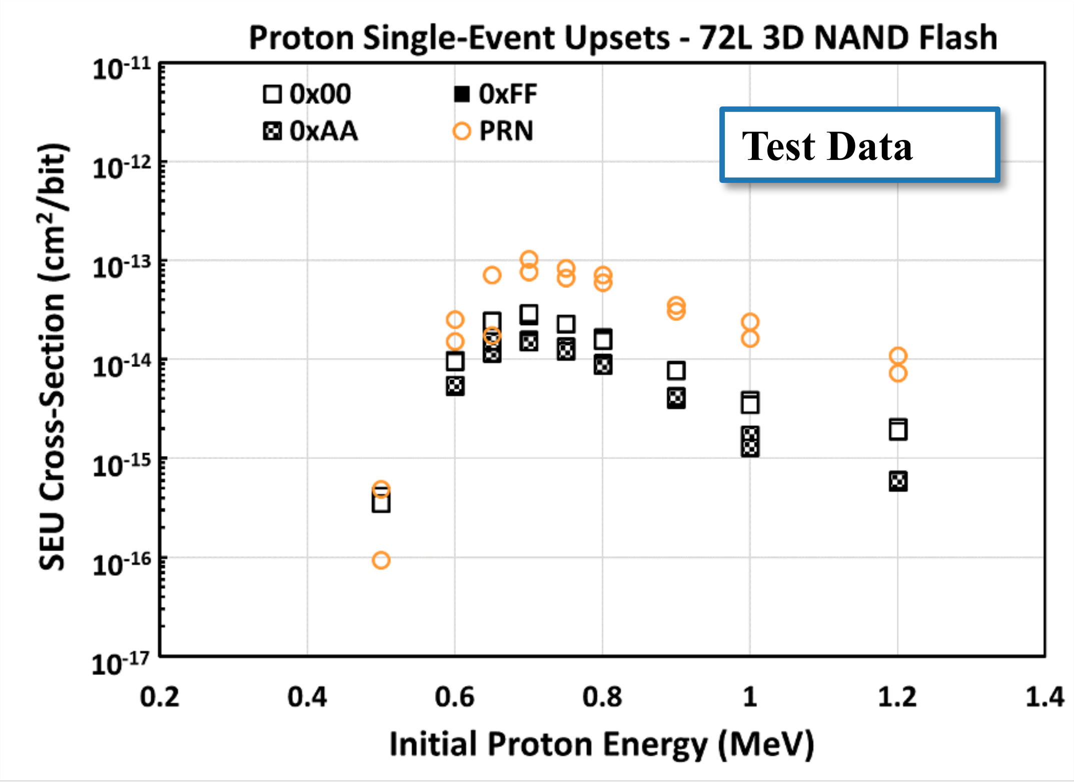


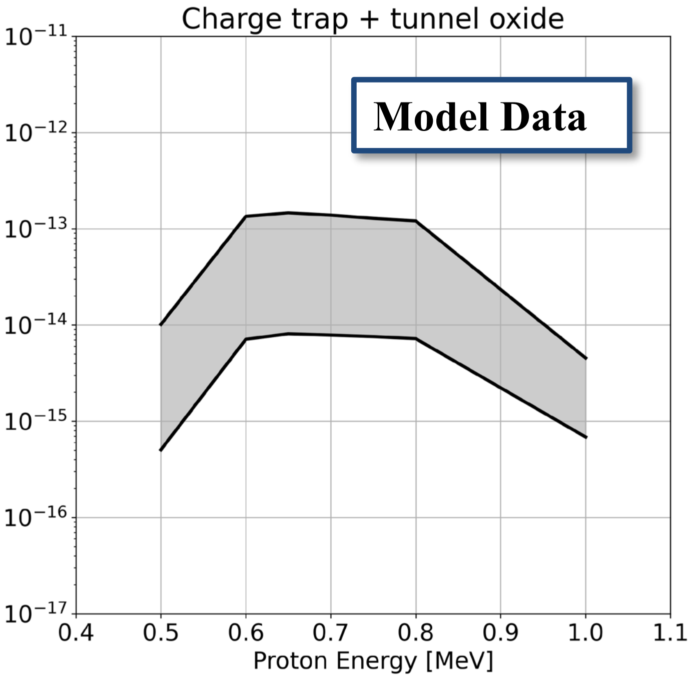




Comparison with MRED model – protons

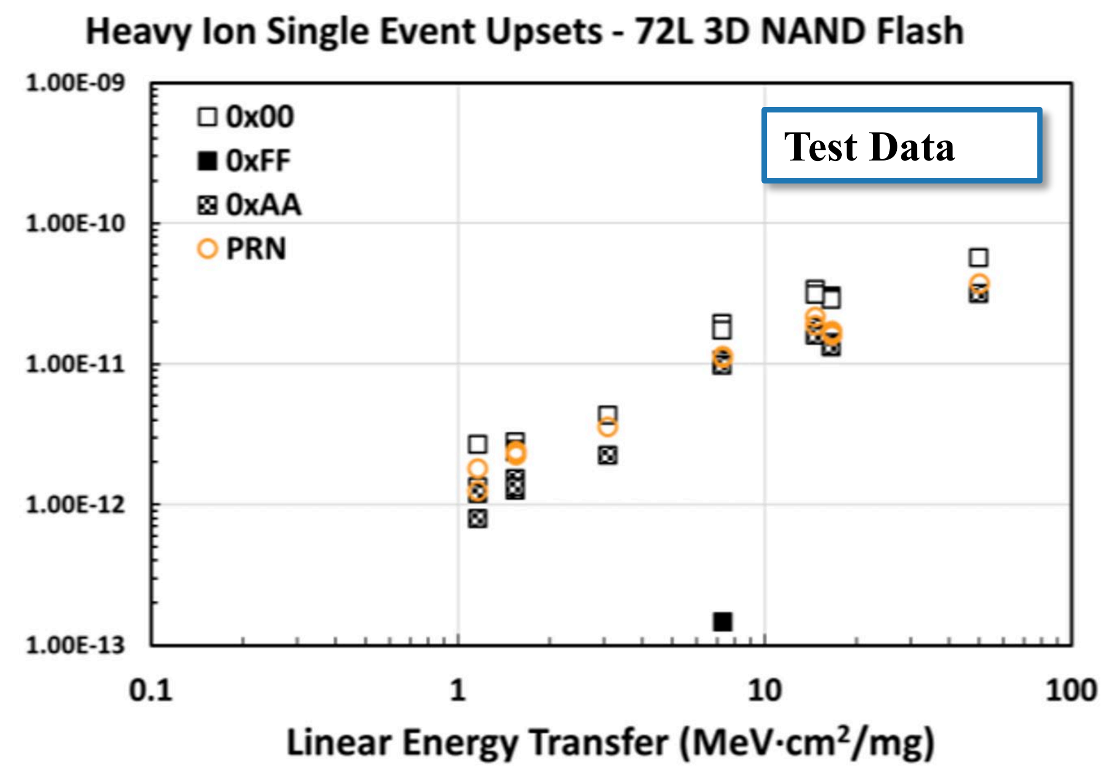
- Proton-induced SEU observed in 72-layer SK Hynix 3D NAND

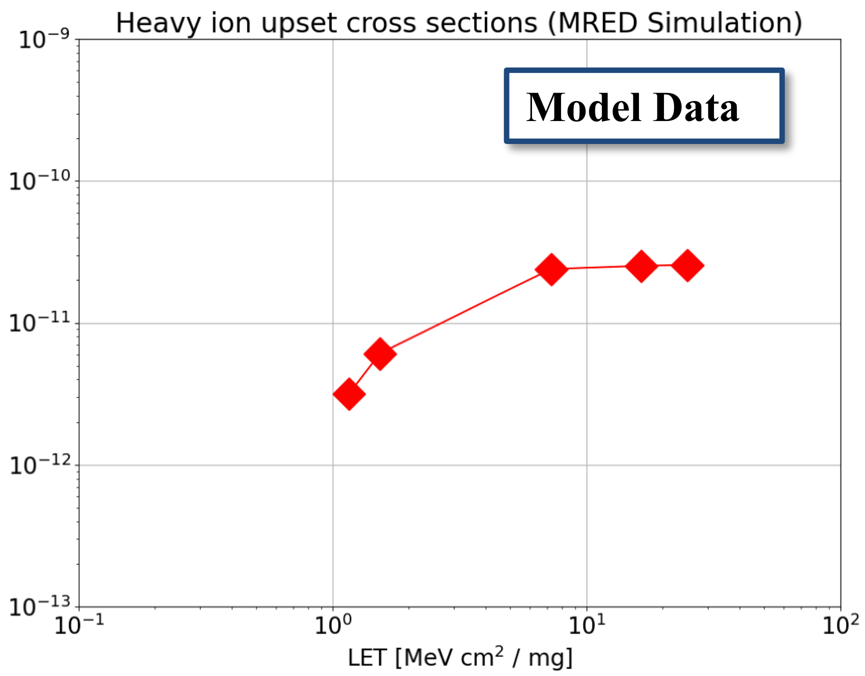




Comparison with MRED model – heavy ions

- Heavy-ion SEU observed in 72-layer SK Hynix 3D NAND





TID in 3D NAND – dose enhancement

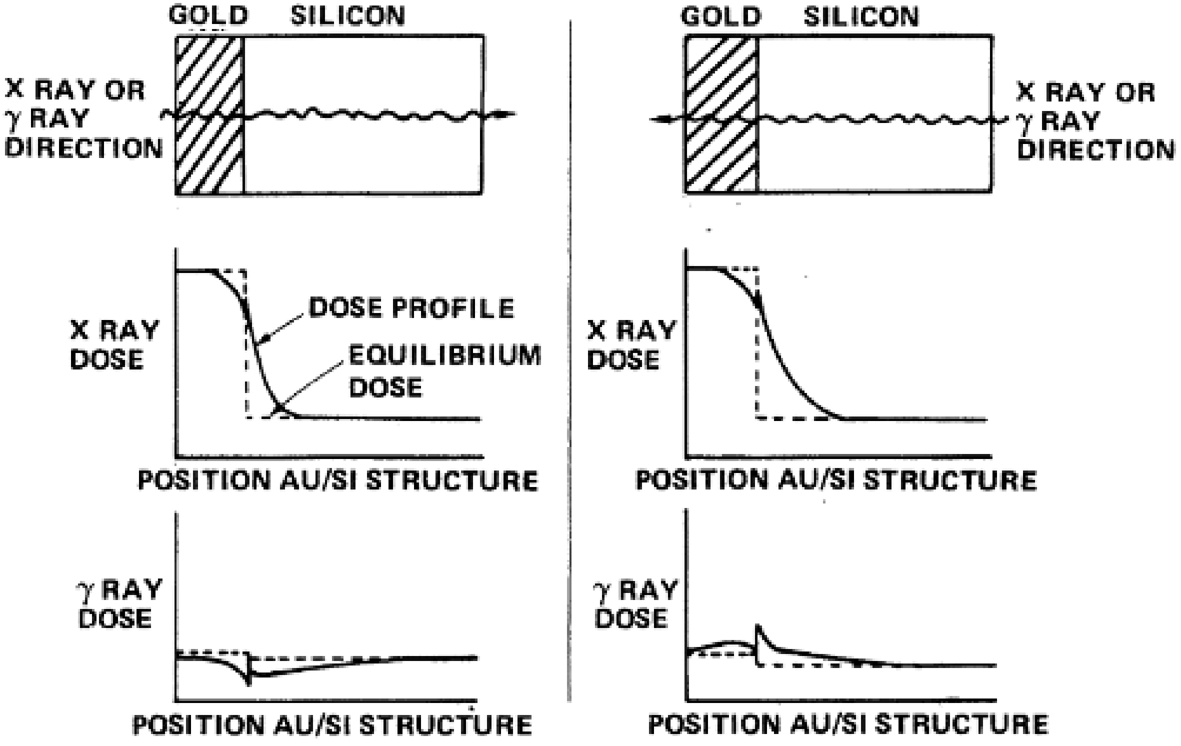
CT NAND
Hynix
Tungsten WLs

FG NAND
Micron
poly WLs

Do the tungsten WLs in CT NAND lead to significant dose enhancement?

Choe, “Comparison of Current 3D NAND chip and cell architecture,” *Flash Memory Summit,* 2009

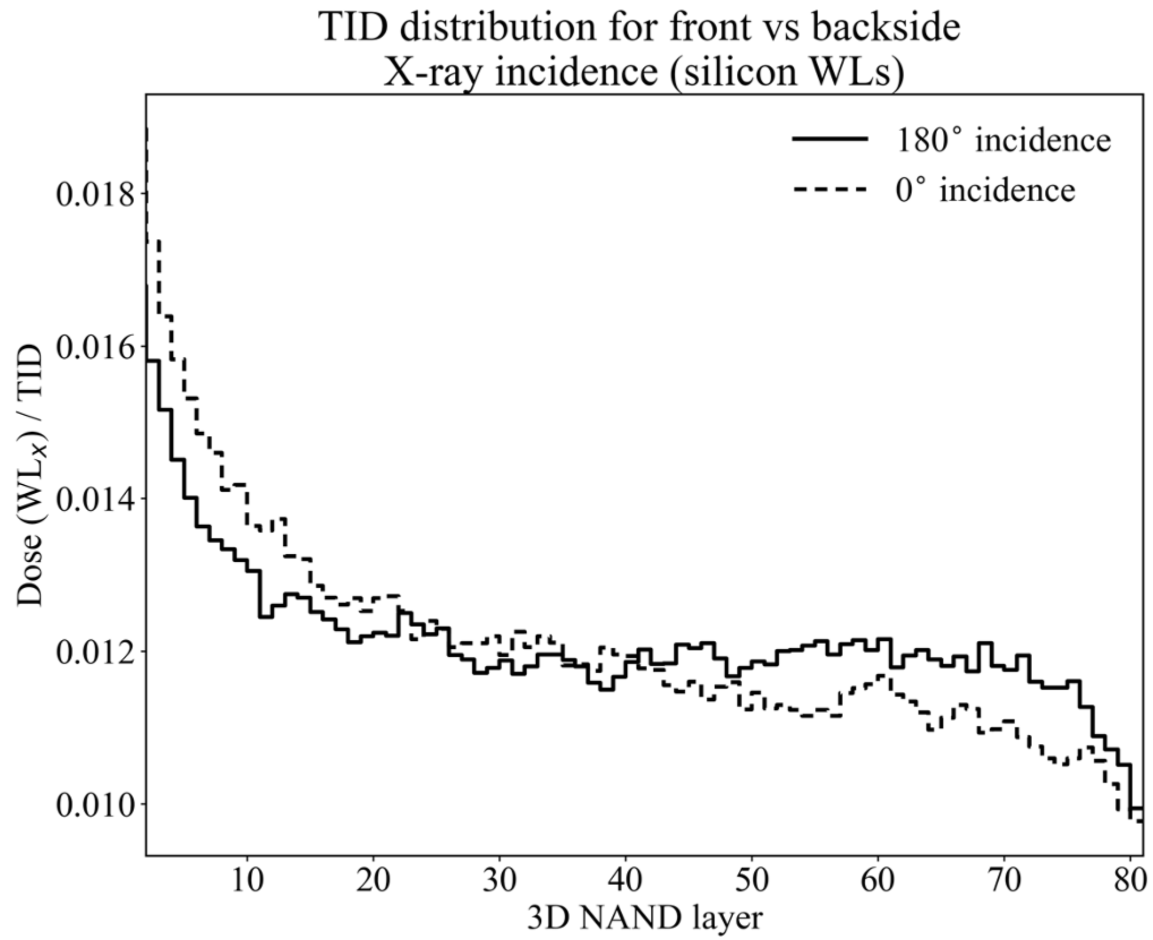
Parat and Dennison, “A floating gate based 3D NAND technology with CMOS under array,” *IEEE IEDM*, 2015



Long, et al. *IEEE TNS*, 29(6), 1980-1984, 1982

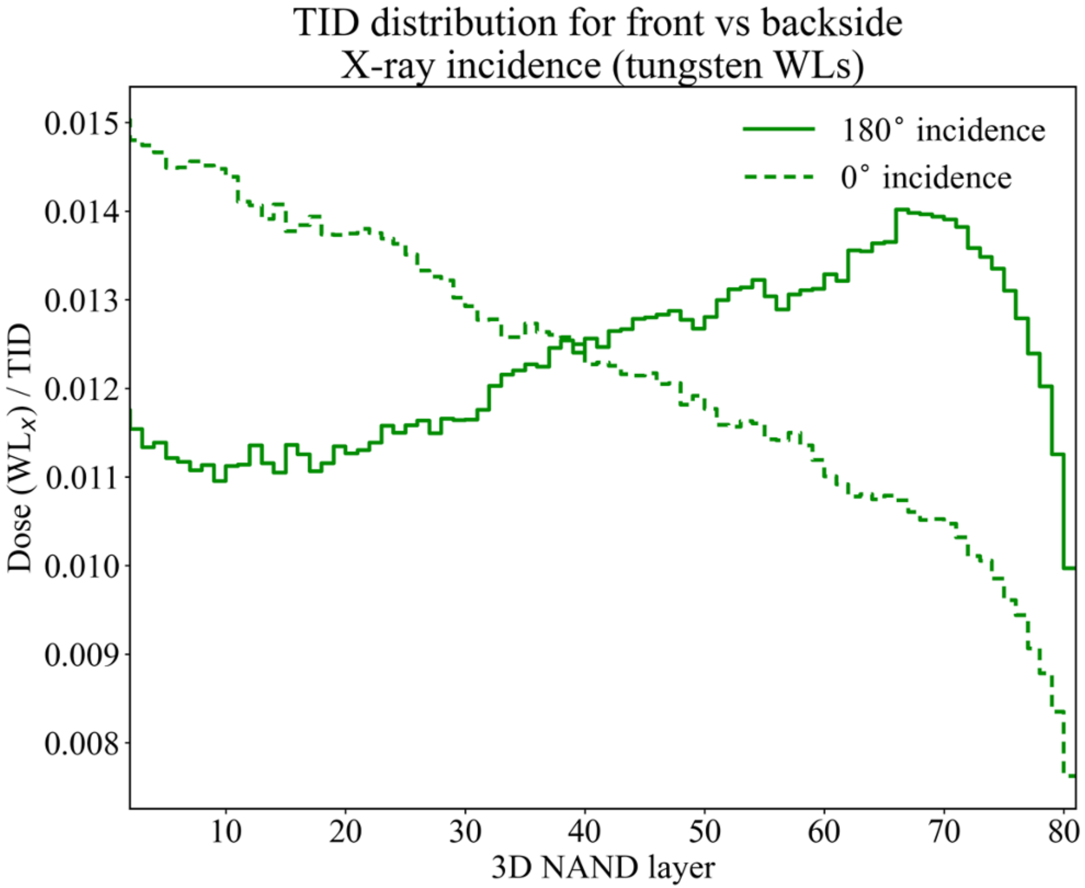
TID in 3D NAND – FG

- Floating gate → polysilicon WL
- Only expect DEF from BEOL metallization
- DEF falls off rapidly
  - ~20 layers → ~1 μm
- X-rays incident from backside have less effect in NAND stack



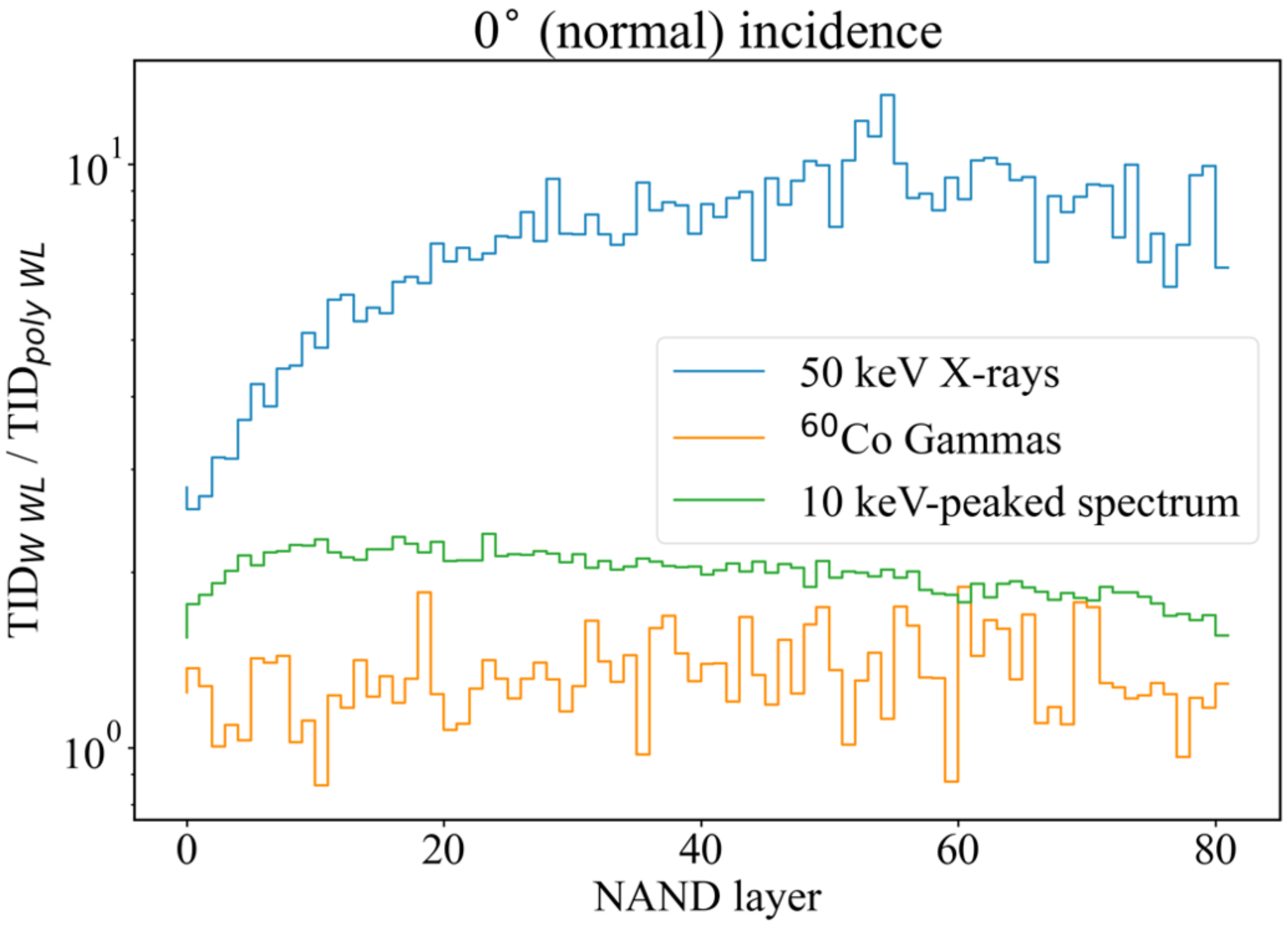
TID in 3D NAND – CT

- Charge trap → tungsten WL
- Expect DEF from BEOL and WLs
- DEF falls off much less rapidly
- X-rays incident from backside have similar effect



TID in 3D NAND – DEF

- Clear dose-enhancement effect
- Function of photon energy
- Poor statistics for gammas



Conclusion

- 3D NAND offers excellent storage capabilities
- Physics-based modelling with MRED is ideal for understanding radiation effects mechanisms in complex devices
- Better to account for full physical features in MRED
- The dose-enhancement effect for CT 3D NAND is significantly greater than in FG 3D NAND due to tungsten WLs
    - Depends on test environment
    - Dose-enhancement effects from BEOL in both cases